

21-ID (ESM) Endstation Review

Meeting Date: March 13, 2015

The objective of this review is to assess the status of the NEXT endstation final design for the ESM beamline and its readiness to proceed to, or continue with, the construction phase. As of January 2015, most of the major endstation procurements are progressing and are expected to be awarded in the third quarter of FY15 and a number of smaller procurements and in-house design/build components remain to be completed. The review will identify any major residual design risks that must be mitigated prior to the start of full construction. It will also present an opportunity for support groups (Utilities, Safety Systems, Controls, ES&H, QA) to review the endstation designs as a whole and identify potential issues.

ESM (21-ID) Endstation Review Panel Charge Questions

1. Does the endstation's portion of the project performance baseline address the beamline's scientific program objectives? **Yes - Based on the original proposal the endstation meets the performance baseline. Prioritizing is needed to determine what comes first, in regards to establishing the separate components of the endstation matrixed with first light experiment.** Is the endstation final design technically mature, sound, and likely to meet the performance expectations identified in the project performance baseline? **Yes, on the general layer however the goals are aggressive and will require careful engineering and technical commissioning. In addition there are specific comments and feedback listed within the body of this report that should be considered.**

2. What are the major residual technical design risks, and are appropriate steps being taken to manage and mitigate these risks? **A failure analysis of the sample transfer system should be conducted. A clear path for the controls logic should be developed to assist the Controls Group. A mitigation strategy should be considered in the event that the controls system is not completed in time for first light. ESM to work with Controls group to identify resource needs to meet controls requirements.**

An analysis of the vibration issues for the endstation is being investigated such that they can prepare a plan for mitigation. Please see additional comments and details in the comments and feedback section within this report. A vacuum analysis should be conducted to assure required vacuum levels can be achieved.

3. Is the design effort consistent with the planned procurement/fabrication strategy and sufficiently mature to support procurement/fabrication of major components? **Yes – based on the timeline that was presented, procurement of Commercial items, and procurement status of custom equipment.**

4. What ES&H/QA issues and risks remain to be addressed, if any?

Concern with the automation and the leak valve used in the system. Further ESH review is required for the use of the automated leak valve(s) including engineering controls. In the event that an enclosure around the beamline area is to be installed, a design review will need to be conducted. An evaluation needs to be completed to keep personnel and equipment out of the way of moving equipment.

No major QA risks were identified. Refer to comments and feedback section for general QA comments.

5. Have the interfaces between endstation subsystems and Common Systems and Beamline Controls been identified and detailed sufficiently to support successful endstation construction? [Utilities interfaces have been identified and sufficiently supported. The interfaces for PPS were not presented. The interfaces for EPS were not sufficiently identified in the presentation.](#) See further details in the comments and feedback section of this report.

6. After construction and assembly, will this beamline's endstation(s) be able to sustain Instrument Readiness Review and lead to successful operations? [Yes - The instrument design itself. However, ESM needs to assure that all of the appropriate documentation is ready. Refer to comments and feedback section for general QA comments](#)

Comments and Feedback:

In general a number of questions were asked by the review panel and attendees in regards to the design and operational feasibility of the endstation components based on the information provided in the presentation. Andrew provided reasonable answers to show how and why the system will work as intended as well as limitations of the system components. Such questions addressed the vacuum system requirements, LHe, rotation of components including why and limitations, automation of system, assembly of components, ordering of components, and installation of the components. The schedule of the construction was reviewed where the goal is to have the hardware assembly completed by 1/1/2016 to enable testing of the instrument prior to first light. Risk management was discussed where hardware is underway; however there is a risk in completing the software in time.

The reviewers provided additional comments and feedback below in the areas of scientific, engineering, ESH, QA, controls, vacuum, installation, and utilities. The ESM group should consider the feedback provided in the completion of the endstation design.

Scientific:

The ESM team presented a nice suite of end-station capabilities that clearly have some unique, world-leading features. Due to the complexity and multiple sample environments careful planning of first-light experiments is required. The ESM team should start prioritizing what endstation capabilities will be brought up and in what order. Reaching out to the user community for first light experiment ideas would greatly benefit this exercise and should be done to ensure that the demands for high impact science are available as soon as possible after endstation commissioning.

The ESM team should start considering about the use of LHe cryostats in order to minimize the vibrations transmitted to both the sample and endstation optics.

What levels of vibration expected? 200-300nm region as per vendor.

Software development is perhaps the biggest risk for the endstation completion. Considering the proposed level of automation, lack of complete and tested control software may impact instrument readiness for the experiments, as well as cause ES&H issues. Additional resources (i.e. dedicated engineer/programmer, or external vendor) may be necessary to complete project on time. Also, ESM

personnel should consider implementing mitigating procedures, i.e. manual sample handling setup, which would enable to operate the endstation on Day 1, even if the control software is not fully operational.

Engineering:

It would be good to point out what you plan on having on day one and what you plan to have later.

Design is for the best possible temperature that that can achieve. Consider the controls components in your risk management.

Because of vibration issues cannot do manipulation at low temperatures.

Claw is in-house design and is motorized.

Upon completion of the design and analysis of the supporting structure for the analyzer, the engineering design review should include all major components comprising the ARPES endstation and an adequate collision protection system in accordance to the design review procedure for NSLS-II. Identify the design reviews in the timeline to suit the assembly and installation by January 2016 as planned.

The vibration analysis for the KB mirror system and ARPES endstation instruments should include all potential options for minimizing vibration such that a conclusion can be made that would have minimal impact on the facility and surrounding beamlines and meet the cost and schedule of the ESM beamline project. The planned meetings should target the appropriate audience for identifying a solution that meets the needs of the ESM beamline and the facility.

Changing samples in the Low Temperature Chamber requires the removal of the cryostat and small preparation chamber to access the sample-mounting region. The design needs to include the center of mass and locations for lifting the apparatus with assistance from a manual crane. A documented beamline procedure may be useful to the staff for this activity.

Conducting failure modes and effects analysis (FMEA) throughout the automated sample-mounting scheme will identify each potential failure to use as an aide to identify early design challenges with minimal impact on the samples. The areas of concern for potential failure are the impact of the stage during the delivery/retrieval process, potential losses due to misalignment; secure sample detection during transit, and the effects of cold adhesion between materials under low temperature. Identifying early design challenges and creating a simplified recovery plan will improve the survival rate of samples using the automated sample mounting method.

ESH:

The team needs to evaluate the consequences of software and hardware failures for the automated systems, especially the leak valve that may control gas introduction to the sample chamber. Controls need to be in place to mitigate any consequences (i.e. pressure relief, gas monitoring).

The construction of barriers or interlocks to keep personnel away from moving parts needs to be evaluated. If personnel access is needed when the chamber is powered, an interlock such as a light switch could be implemented. If no personnel access is required during operation, a procedure for locking out the device during maintenance needs to be developed.

Personnel egress needs to be considered if partitions are put in place around the experimental area.

QA:

Design review(s) for A1/A2 equipment needs to be completed, documented, and actions closed. A top level traveler that verifies installation/commissioning readiness needsto be developed and executed. Operating procedure/manual needs to be developed and personnel trained on it. The PPS vacuum switch will be included in the Beamline Radiological Interlock Certification Tests. All these items need to be completed prior to an IRR.

Controls:

Clearly mapping out the sequence of events to automate the sample preparation in a logic diagram will aide as a tool for unforeseen events in the process (FMEA) and guide the Controls Engineer in the development of the software. Identifying the resources necessary for the ESM endstation is essential to the successful operation of the endstation for day one operations and first experiments.

0.5 FTE support for controls is provided for beamline. Important that the controls is completed in time in order to use the micro scanning stage. Two switches are being considered for positioning in the event one of the switches fails.

Thermal diodes included as well as thermocouples to help provide temperature control.

Vacuum:

A comprehensive pressure analysis, including the KB mirror, should be generated based on detailed estimates of expected gas loading from discrete components. Where possible, show vacuum performance from similar devices currently in service. Empirical data is valuable to compare against calculated estimates.

The vacuum level of 1×10^{-10} mbar or less may be very difficult to attain based on the provided pumping. While there are a significant number of UHV pumps (i.e. ion pump, TSP pump, NEG pump), they are on the same vacuum conduit and appear conductance limited (choked off). This limits the effective pumping speed at the chamber, resulting in high operational pressure. Consideration should be given to improving the conductance and/or possible distribution of pumps (with consideration to ion pump fringe field) to improve overall effective pump speed. Also affecting ultimate pressure is the manner in which the components are cleaned and prepared. A plan detailing the steps to ensure parts are cleaned (or kept clean) should be generated. If specific materials or components are new and unproven, the outgassing rate should be measured prior to installation in final assembly. Steps to improve vacuum performance should be considered, such as vacuum baking components prior to installation. A high

temperature vacuum bake of 48 hours at 450C should be considered on components where possible and appropriate (i.e. SS chambers, elbows, mu metal (?) etc) to reduce bulk hydrogen and outgassing.

The manner in which the endstation receives a final bakeout should be planned. Custom heat tracing and/or heating jackets should be used and remain installed where possible, so unplanned bakeouts can be repeated efficiently. For best UHV results the bakeout temperature should be as close to 250°C as possible within the constraints of installed devices and should not be limited by improper material selection where possible.

Installation/Utilities:

The review discussed concerns about sources of external vibration. A plan is in place to investigate a suitable mitigation plan. It is recommended that a framed wall be constructed along high-traffic corridors (i.e. between the NSLS-II main entry doors and the end station area). The framed wall itself must be constructed on the outer corridor so that it is also isolated from the experimental floor. This solution will limit foot traffic to the outer corridor. Currently, this solution is being reviewed for funding and ES&H implications.

Secondly, vibrations are caused by foot traffic on the overhead walkway and adjacent lobby balcony. The review proposed a solution of cutting out a section of the experimental floor at the end station. This will most likely involve cutting through the concrete, mesh, and deep into the sand to effectively provide isolation. Calculations are underway to determine if this will be feasible. Potentially, this has many negative implications, the most significant of which is that the cut-out may not sufficiently isolate the end station from vibrations caused by foot traffic on overhead walkway and balcony. It may also introduce new stability issues because it is such a small mass of material. Therefore, it is recommended that less invasive solutions be pursued first. For example, the surface of the overhead walkway and balcony could have dampening material installed and evaluated. This is a relatively easy and inexpensive solution to evaluate before taking more invasive measures. The presentation addressed that the utilities for the endstation are already in place and no further work is needed.

Review Committee members:

Mike Buckley - Chair
Stuart Wilkins (Science)
Jurek Sadowski (Science)
Mary Carlucci-Dayton (Engineering)
Joe Zipper (QA)
Lori Stiegler (ESH)
Rob Todd (Vacuum)
Zhijian Yin (Controls)
Chris Stebbins (Installation/Utilities)

Attendees: M. Buckley, A. Walter, Y. Zhu, L. Lienhard, M. Fukuto, J. Ma, J. Anibal Boscoboinik, J. Adams, V. Bisogni, C. Hetzel, T. Valla, R. Todd, J. Keister, I. Pletikosic, J. Dvorak, C. Mazzoli, I. Jarrige, Z. Yin, J. Sadowski, S. Wilkins, C. Stebbins, J. Zipper, L. Stiegler, M. Carlucci-Dayton, S. Hulbert, N. Simos, E. Vescovo, Y. Zhu

3/31/2015

X



Michael Buckley
Research Operations Support Group Leader
Signed by: Buckley, Michael

Agenda and Charge for ESM (21-ID) Endstation Review

Date: 13th March 2015

Location: Bldg. 745 rm 156

The objective of this review is to assess the status of the NEXT endstation final design for the ESM beamline and its readiness to proceed to, or continue with, the construction phase. As of January 2015, most of the major endstation procurements are progressing and are expected to be awarded in the third quarter of FY15 and a number of smaller procurements and in-house design/build components remain to be completed. The review will identify any major residual design risks that must be mitigated prior to the start of full construction. It will also present an opportunity for support groups (Utilities, Safety Systems, Controls, ES&H, QA) to review the endstation designs as a whole and identify potential issues.

Dec. 13, 2015	ESM (21-ID) Endstation Review	Speaker
8:30-8:45	Executive Session (Committee Members)	
9:00-9:15	Introduction	S. Hulbert
9:15-9:45	ESM overview	E. Vescovo
9:45-10:45	ESM ARPES end-station	A. Walter
10:45-11:00	Break	
11:00-11:30	Sample manipulation	A. Walter
11:30-12:00	Critical Issues	Yi Zhu
12:00-13:00	Executive Session (Committee Members)	
13:00-13:30	Close Out Session (Committee Members and ESM Team)	

Committee Members:

Mike Buckley - Chair
Stuart Wilkins
Jurek Sadowski
Mary Carlucci-Dayton
Joe Zipper
Lori Stiegler
Rob Todd
Zhijian Yin
Chris Stebbins

Following the review, a report will be developed addressing the charge of the committee listed on the following page. The committee chair will organize the preparation of this report. Comments are welcomed by the attendees during the review.

ESM (21-ID) Endstation Review Panel Charge Questions

1. Does the endstation's portion of the project performance baseline address the beamline's scientific program objectives? Is the endstation final design technically mature, sound, and likely to meet the performance expectations identified in the project performance baseline?
2. What are the major residual technical design risks, and are appropriate steps being taken to manage and mitigate these risks?
3. Is the design effort consistent with the planned procurement/fabrication strategy and sufficiently mature to support procurement/fabrication of major components?
4. What ES&H/QA issues and risks remain to be addressed, if any?
5. Have the interfaces between endstation subsystems and Common Systems and Beamline Controls been identified and detailed sufficiently to support successful endstation construction?
6. After construction and assembly, will this beamline's endstation(s) be able to sustain Instrument Readiness Review and lead to successful operations?

The committee is requested to present their findings, comments, and recommendations at the conclusion of the review, and to send a report to the NEXT project director within three weeks of the conclusion of the review.

21-ID (ESM) Endstation Review
Attendance Sheet

Date: March 13, 2015

Name	Title	Department/Division or Company
Michael Buckley	Res. Ops Sup Group Leader	NSLS-II
Andrew Walter	Asst Physicist	NSLS-II
Yi Zhu	Engineer	NSLS-II
Lukas Richard	engineer	NSLS II
Masa Fukuto	Physicist	NSLS II
JUN MA	Engineer	NSLS II
Jorge Anibal Bascoboinik	Chemist	CFN
Julian Adams	Project Manager	NSLS II
Valentina Bisogni	Physicist	NSLS II
CHARLES HETZEL	ENGINEER	NSLS II
TENICA VALLA	PHYSICIST	PM/BNL
ROBERT TODD	ENGINEER	NSLS II VACUUM
Giff KEISTER	Proj Mgr	NSLS-II
IVO PLETIKOSIC	PHYSICIST	CMPMS
Joe Dvorak	Physicist	PS
Claudio Mazzoli	Physicist	PS
Ignace Jarrige	Physicist	PS
Zhijian Yin	Controls Engin	PS
Jurek Sadowski	Mat. Scientist	CFN
STUART WILKINS	Soft X-RAY Program Mgr	PS
Chris Stebbins	Engineer	PS
JOE ZIPPA	QA	PS
Lori Stiegler	ESH	PS
Mary Carlucci-Dayton	BL ENG GROUP LEADER	PSD
Steve Hulbert	NEXT PM	NSLS-II
Nick Simos	Sr. Scientist	NSLS II/NS9T
Elio VESCOVO	Physicist	NSLS II

ESM: Overview

1 of 9



Elio Vescovo
ESM Endstation Review, March 13, 2015

Outline

2 of 9

- Original Scientific Proposal (June 2010)
 - new Science Enabled by μ -ARPES
- ESM beamline performances
- ESM μ -APRES endstation
 - original requirements
 - guiding principles
 - sample measurements positions

Electron-Spectro-Microscopy Facility for Fundamental Studies of the Physics and Chemistry of Materials (ESM)

3 of 9

from BES-DOE Five Grand Scientific Challenges:

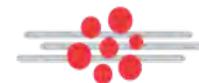
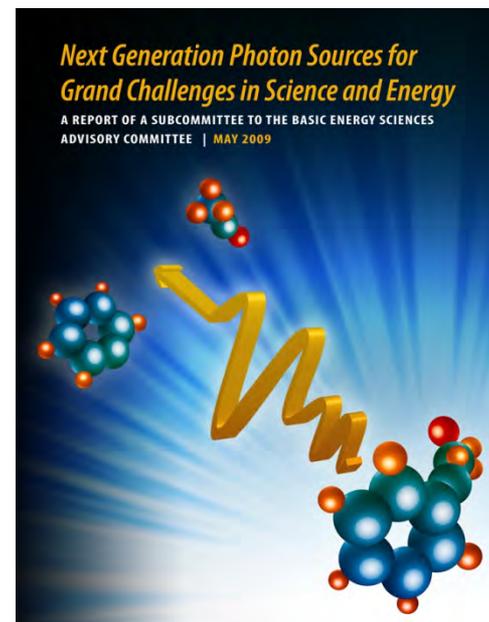
- *controlling material processes at the electronic level*
- *designing synthesis of revolutionary new materials with tailored properties*
- *understanding and controlling the emerging phenomena and the non-equilibria processes and mastering energy and information on the nanoscale*

from Next-Generation Photon Sources for Grand Challenges in Science and Energy:

... sustainable energy technologies will revolve around transformational new materials and chemical processes that convert energy efficiently among photons, electrons and chemical bonds ... that tap sunlight, store electricity or make fuel from splitting water or recycling carbon dioxide ...

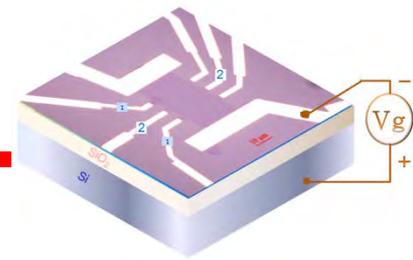
Electron Spectro-Microscopy Facility:

a suite of instruments to probe, characterize and design functional materials from the electronic structure



Center for Functional Nanomaterials
Brookhaven National Laboratory

Overcoming Lateral Averaging: Science @ ESM



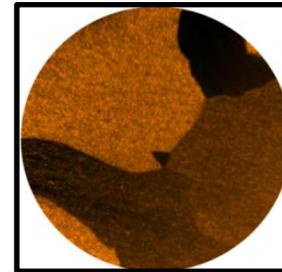
Graphene μ -device

Classes of New Experiments Enabled:

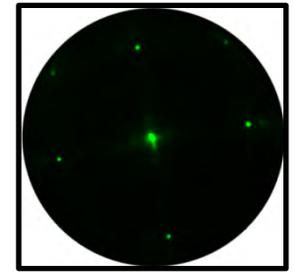
- ARPES from $\sim 1 \mu\text{m}$ samples
(inside polycrystalline grains)
- SP-ARPES from demagnetized samples
(inside single magnetic domain)
- Chemical composition maps ($\sim 500 \text{ nm}$)
- Combinatorial investigation of multi-parameter samples
- measurements from real (micro-)devices
(spintronics, fuel-cells, gas sensors, etc)

polycrystalline sample

PEEM

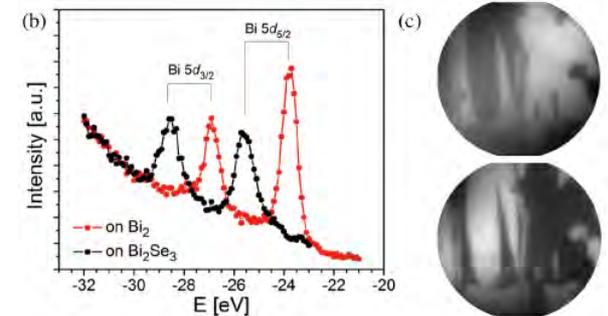


μ -LEED



J. Sadowski: U5UA-PEEM

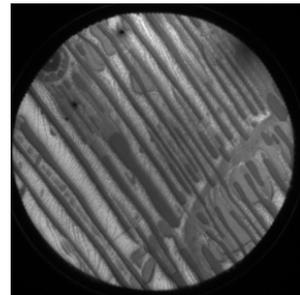
Chemistry maps Bi₄Se₃: Bi₂ + Bi₂Se₃



T. Valla & J. Sadowski: U5UA-PEEM

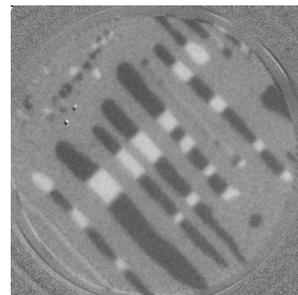
Magnetism Fe – nanowires

LEEM



fov = $10 \mu\text{m}$

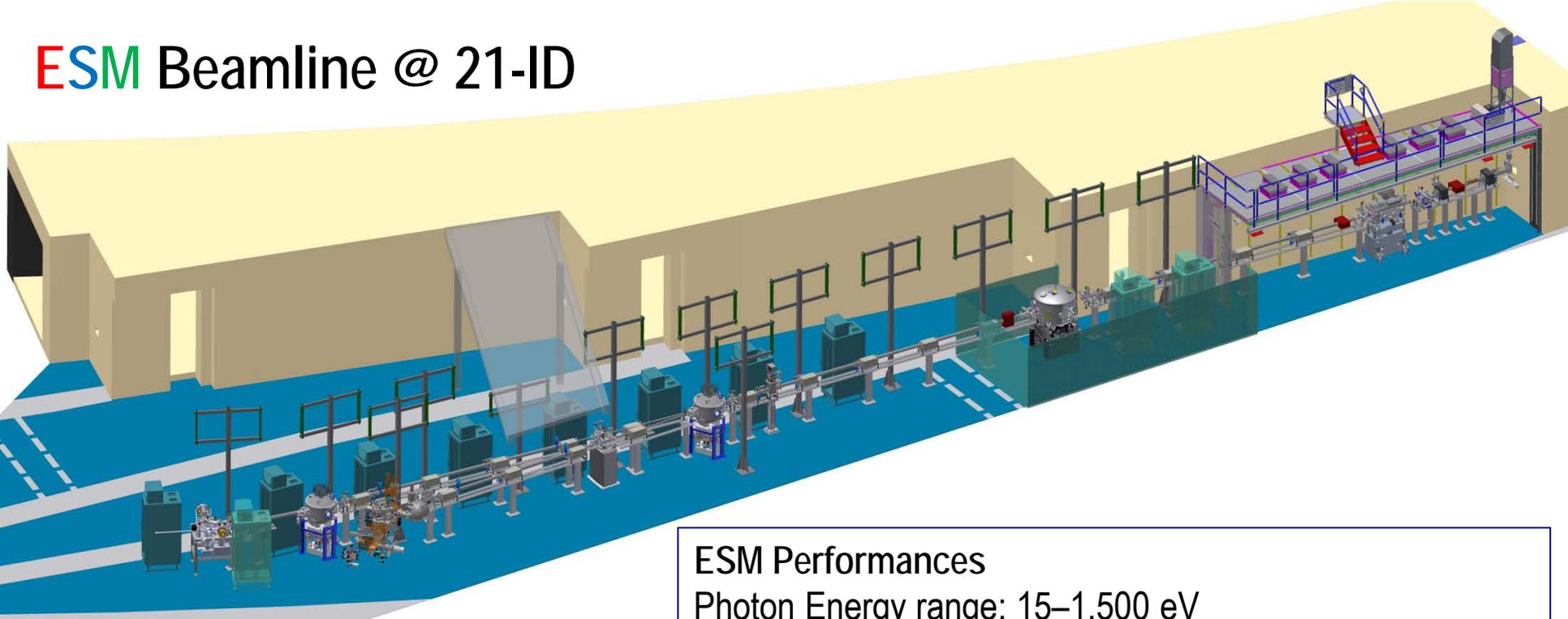
XMCD-PEEM



fov = $4 \mu\text{m}$

E. Vescovo & O. Mentès: ELETTRA-XPEEM

ESM Beamline @ 21-ID



2 scientific programs:

- 1) μ -ARPES
- 2) XPEEM

ESM Performances

Photon Energy range: 15–1,500 eV

(2 *in-line* EPU:QP105, 57)

Light Pol.: linear horizontal,

linear vertical & left/right-circular (>30 eV)

Resol. Power: <1 meV up to 100 eV ($\Delta E/E = 100,000$);

<50 meV up to 1,000 eV ($\Delta E/E = 20,000$)

Flux: ARPES: 10^{10} - 10^{11} ph/s

XPEEM: 10^{11} - 10^{12} ph/s

Spot Size: ARPES $\leq 1 \mu\text{m}$ > 60 eV (diff. Limit.)

Spot Size: XPEEM $\leq 40 \mu\text{m}$

μ -ARPES (largely PS-owned; proposed Partner Users: UMKC and BNL CMPMSD)

- ARPES: $\Delta E < 1 \text{ meV}$, $\Delta\Theta < 0.1^\circ$, $\Delta\Theta_{\text{tot}} = 30^\circ$
- Vectorial Mini-Mott Spin Detector
- Sample
 - x-y $\sim 100 \text{ nm}$ accuracy, $\Theta \sim 0.1^\circ$; T $\sim 5 - 1000 \text{ K}$

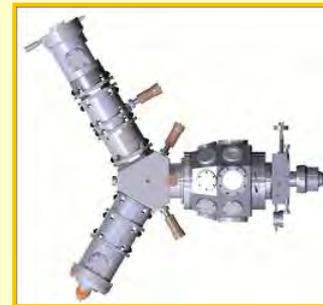


Scienta R4000
mini-Mott

NSF
(NSLS-U5UA)

AC-XPEEM (proposed Partner User: BNL CFN)

- ELMITEC GmbH/SPECS
 - Aberration correction
 - LEEM spatial res'n $< 2 \text{ nm}$ (vs. 7-8 nm uncorrected)
 - PEEM spatial res'n $< 10 \text{ nm}$ (vs. 30-50 nm uncorrected)
- Transm. incr. $\times 8 - 10$



Elmitec LEEM/PEEM

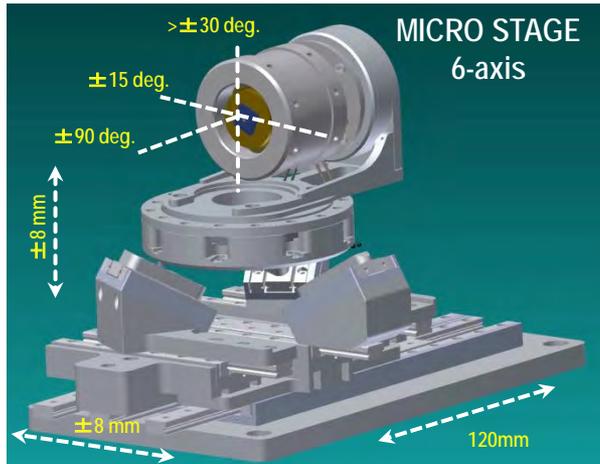
CFN
(NSLS-U5UA)

ESM μ -ARPES Endstation: Main Ideas

7 of 9

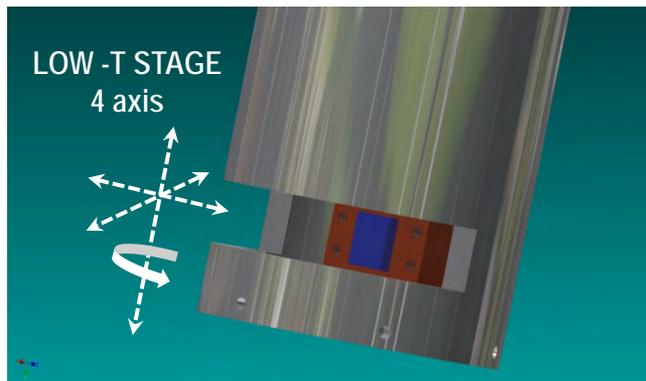
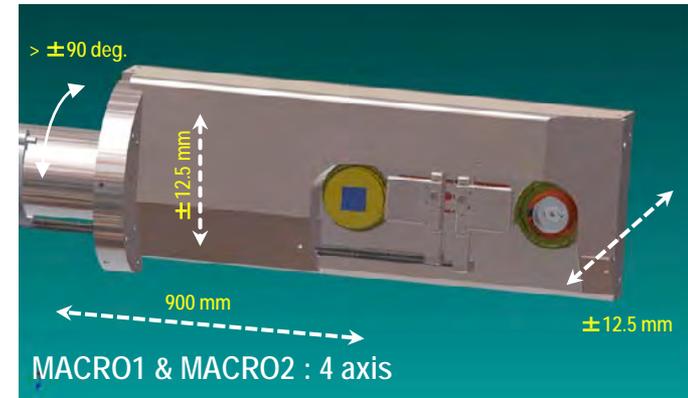
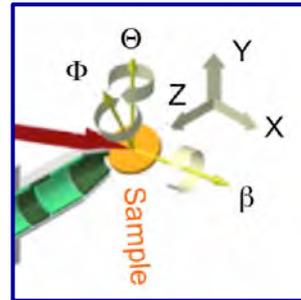
- specialized sample stages
 - for “regular” ARPES (in-situ sample preparation)
 - for microscopy – 1 micron scanning
 - for high resolution – low temp
 - for magnetic samples
- sample “fixed” / movable analyzer or electronic deflection
- robotic sample-transfer & sample-storage
- basic single crystal preparation (automation)
- basic thin film preparation (automation)
- compatibility with:
 - vacuum suitcase
 - MBE/PLD facility

ESM μ -ARPES sample stages capabilities



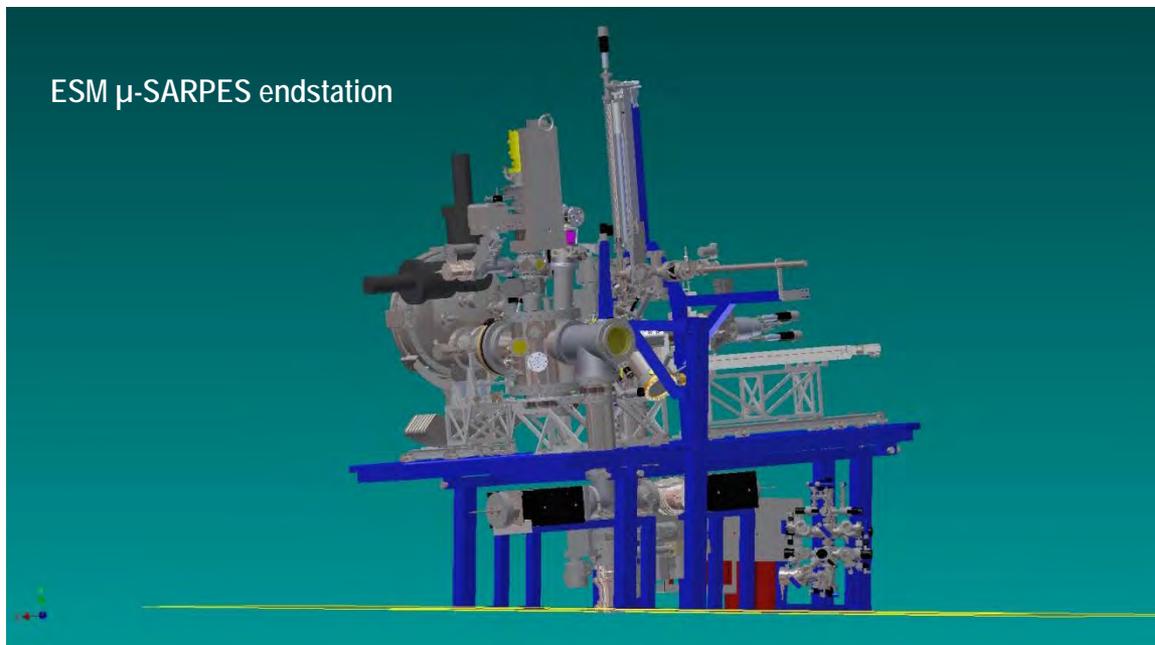
4 measurements positions:

- Micro → 1 μ m scanning micros.
- Macro1 → regular ARPES
- Macro2 → magnetic samples
- Ultra-Low T → high-resolution



- All samples connected to closed cycle LHe cryostats
- sample-puck concept, exchangeable between MICRO and MACRO stages
- low-T stage: sample glued to cryostat tip

ESM next presentations



Dec. 13, 2015	ESM Endstation FDR	Speaker
9:00-9:15		
9:15-9:45		
9:45-10:45	ESM ARPES end-station	A. Walter
10:45-11:00		
11:00-11:30	Sample manipulation	A. Walter
11:30-12:00	Critical Issues	Yi Zhu
12:00-13:00		

ESM (S)ARPES Endstation

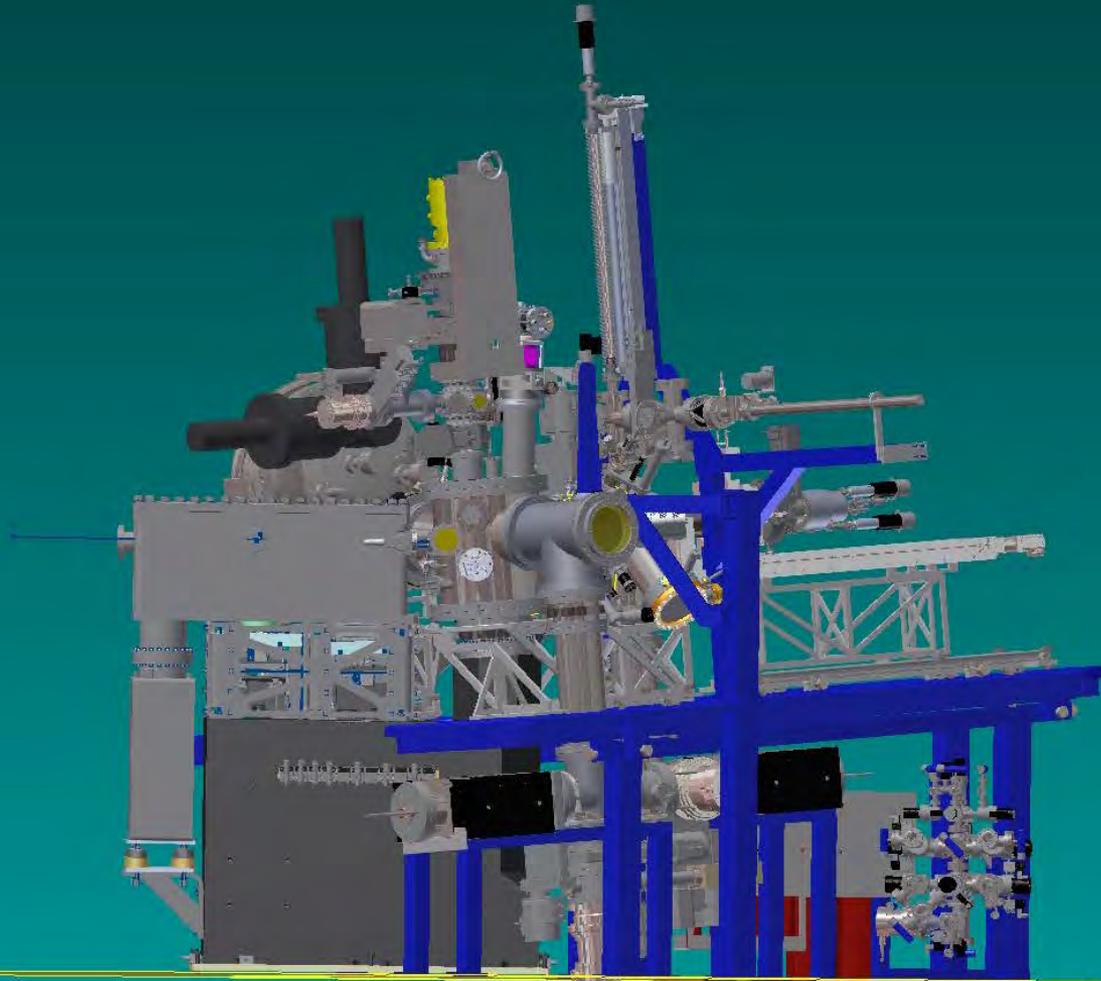


Andrew Walter
Asst. Physicist
NSLS II
03/13/2015
1

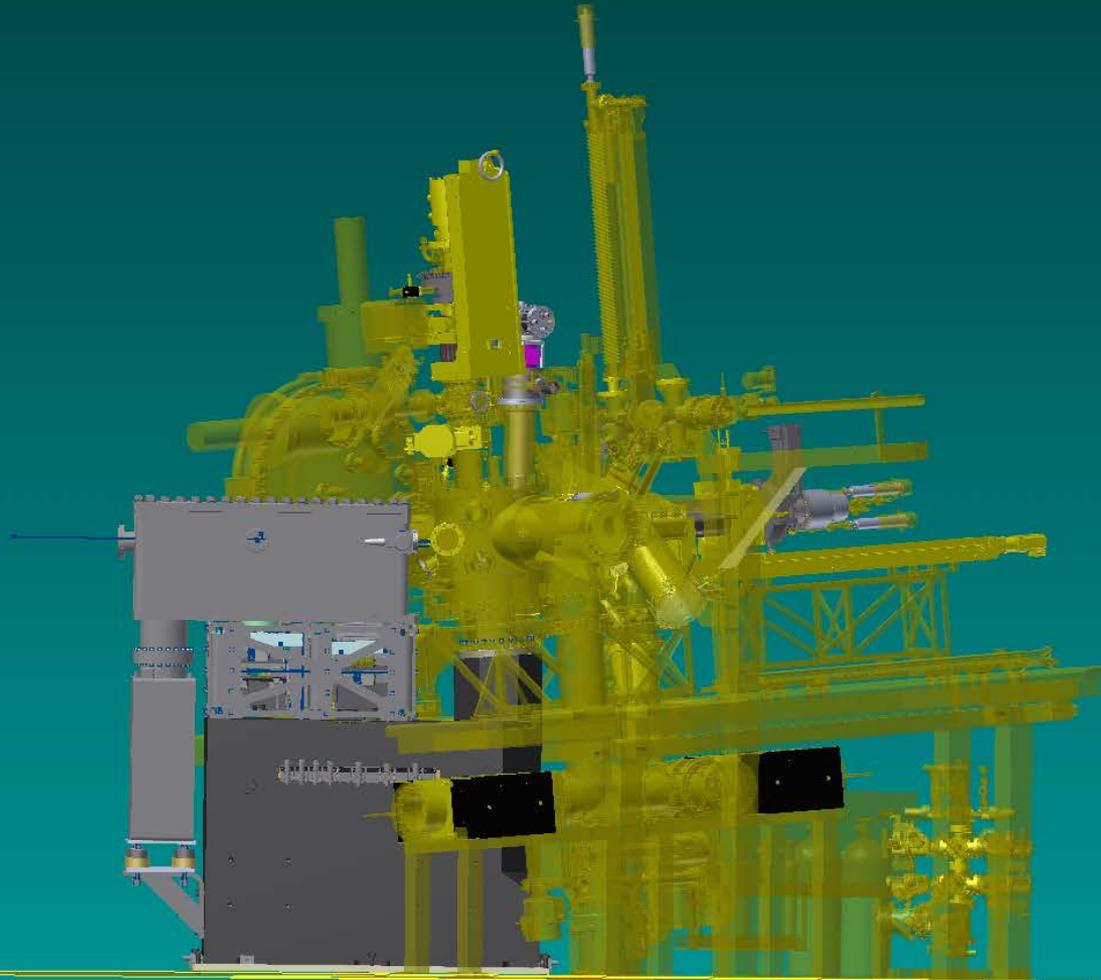
Outline

- Complete system
- Endstation “sections”
 - Analysis chamber
 - Preparation chamber
 - Low temperature chamber
 - Load Lock
 - Support structure
- Overview of capabilities
- Known issues
- Construction timeline

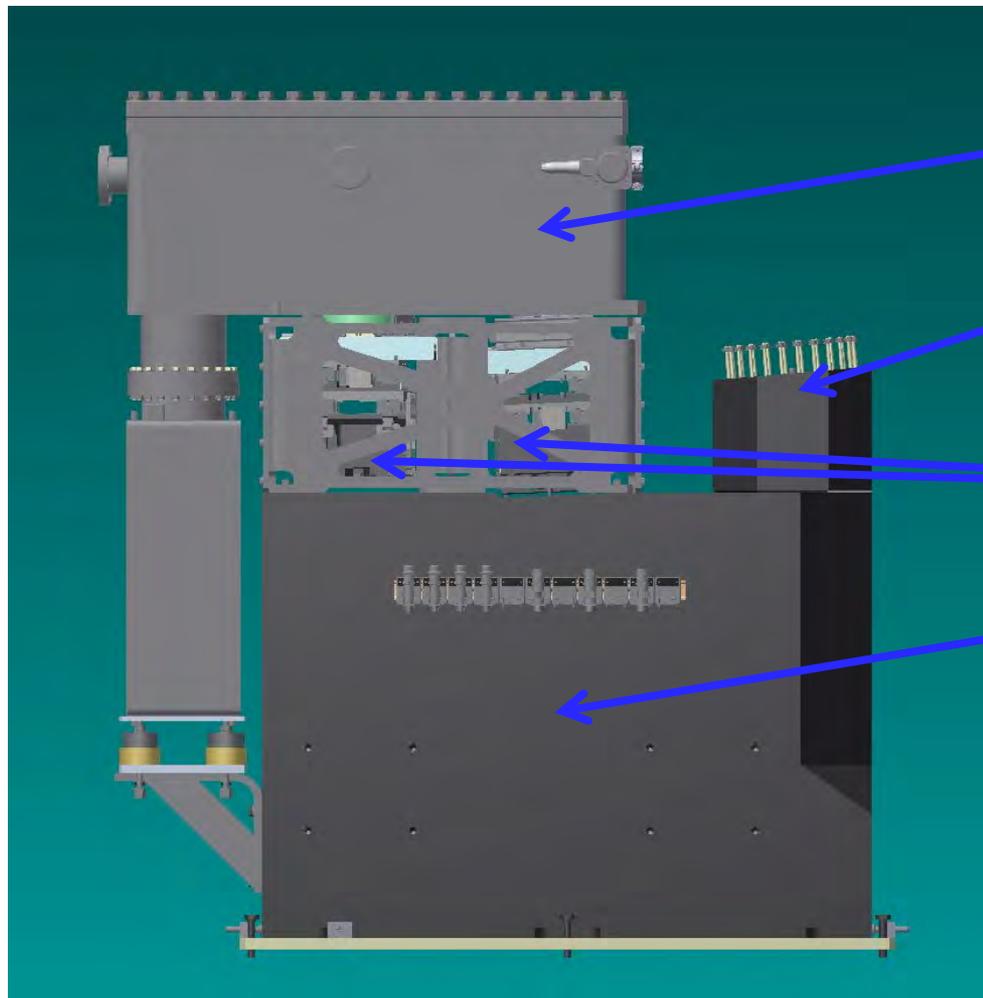
Endstation and KB system



Endstation and KB system



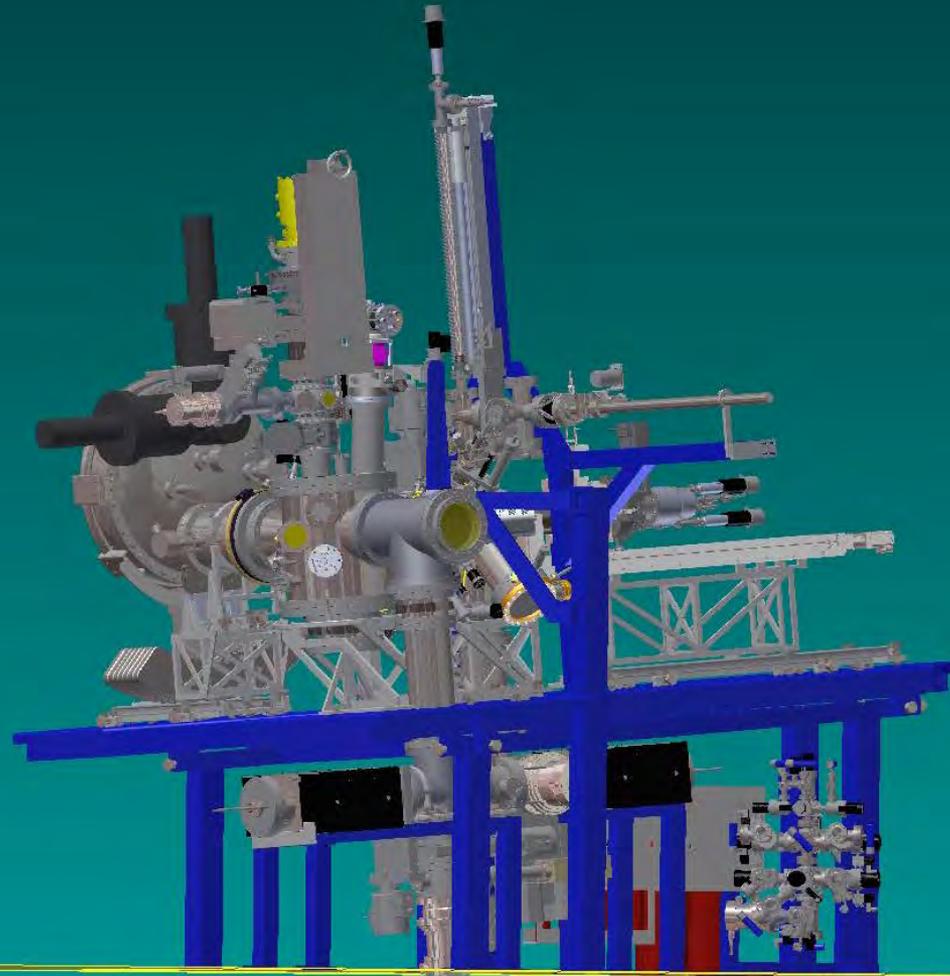
KB system



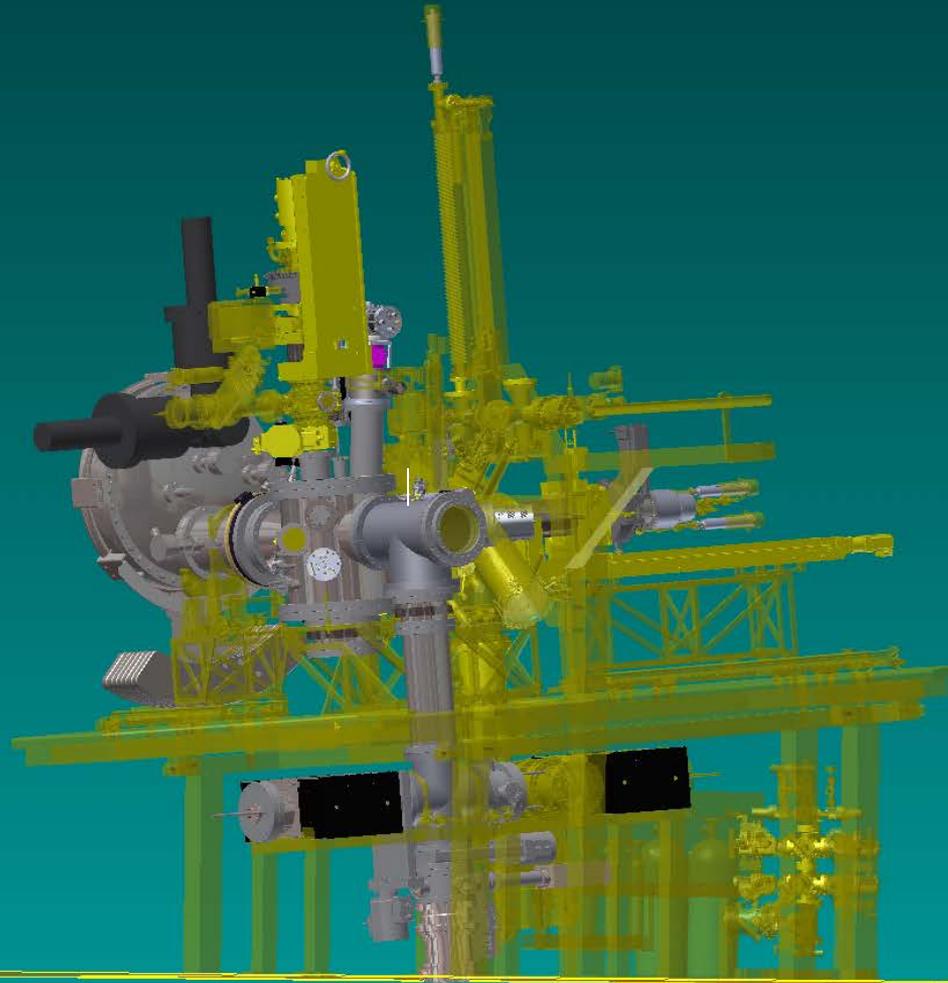
- Main components
 - Mirror chamber
 - Support for Micro-scanning stage
 - Support for mirrors
 - Granite support



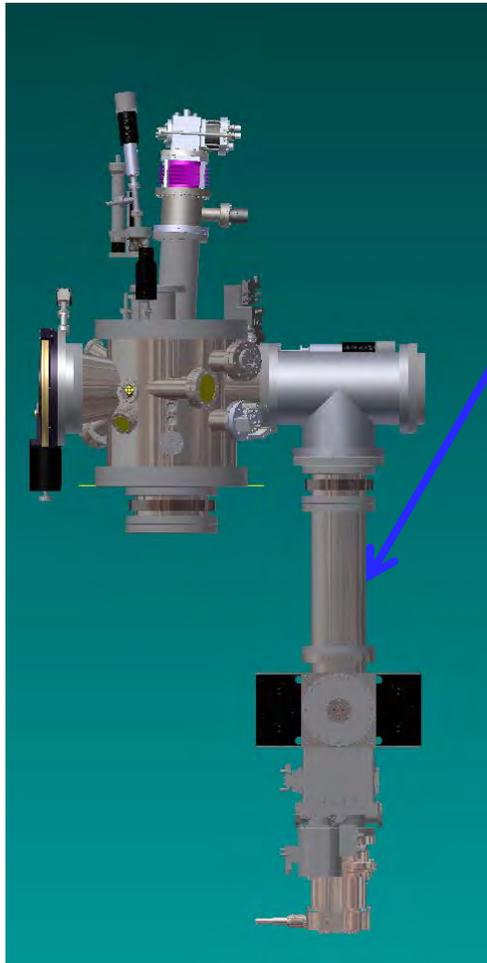
Analysis chamber



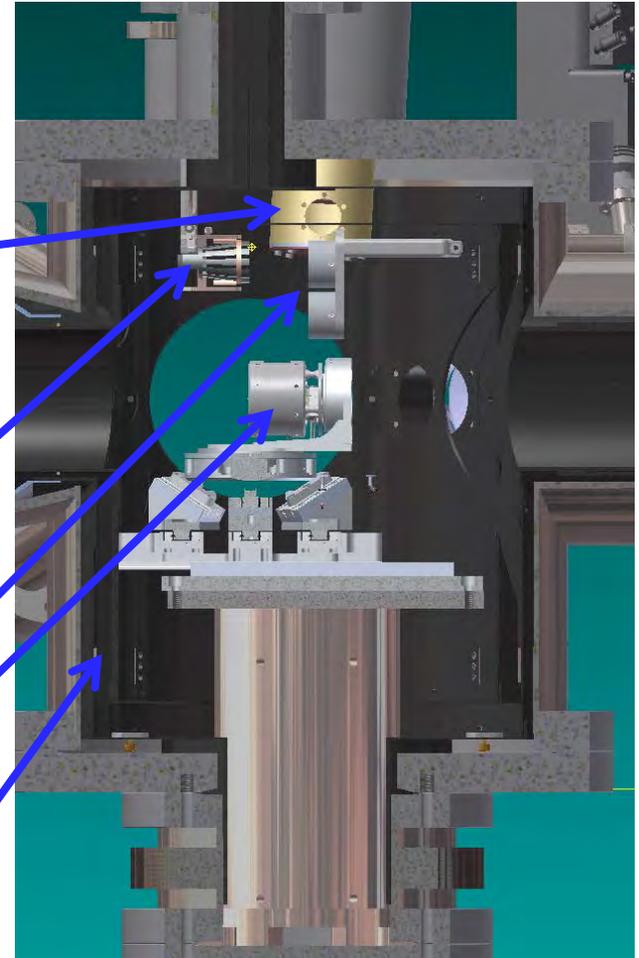
Analysis chamber



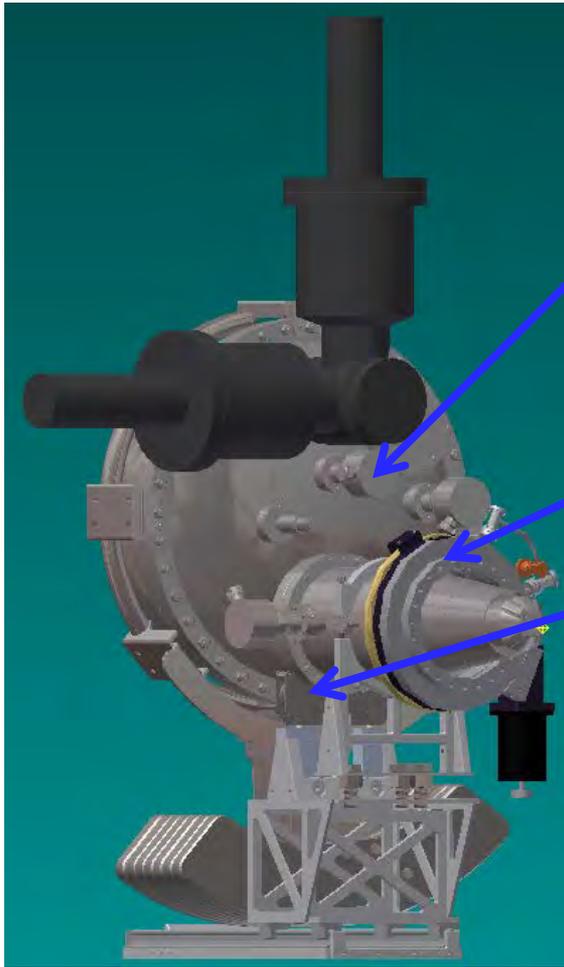
Analysis chamber



- Main components
 - Pumping vibration isolated
 - Micro scanning stage cryostat
 - Sample transfer system
 - Calibration puck sample storage
 - Smaract μ -scanning stage
 - Double mu-metal magnetic shield



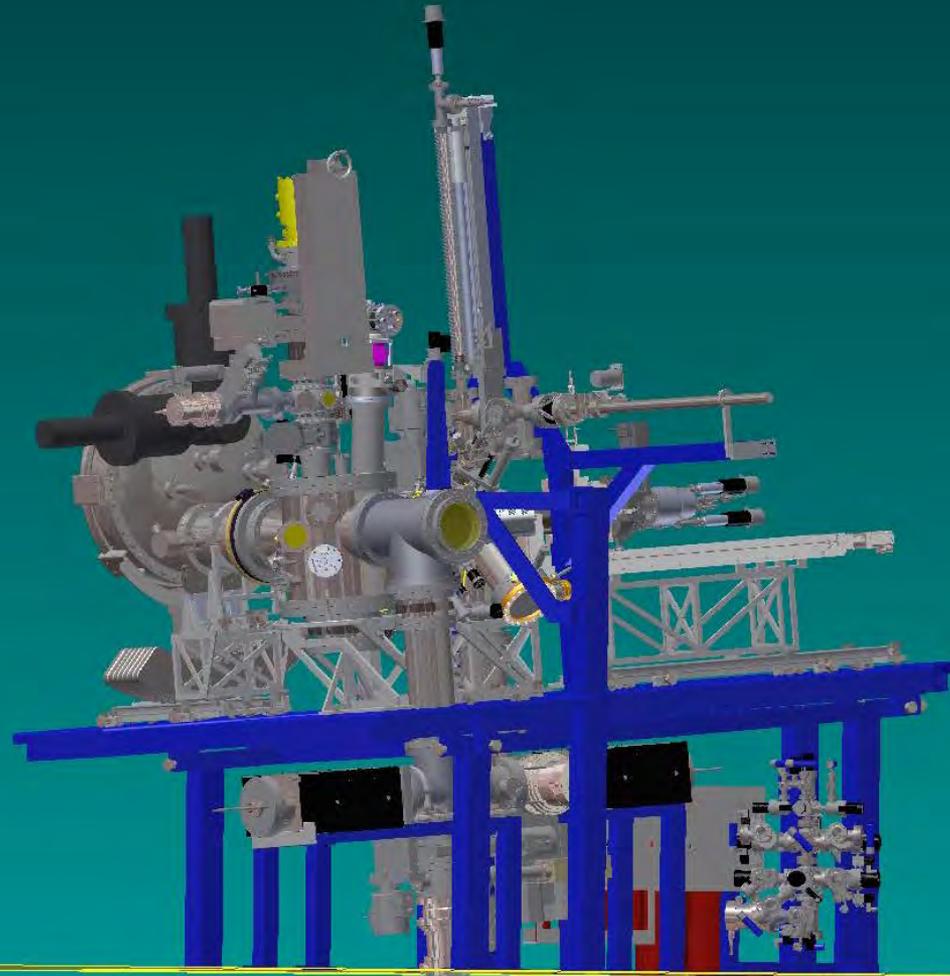
Analyzer and support



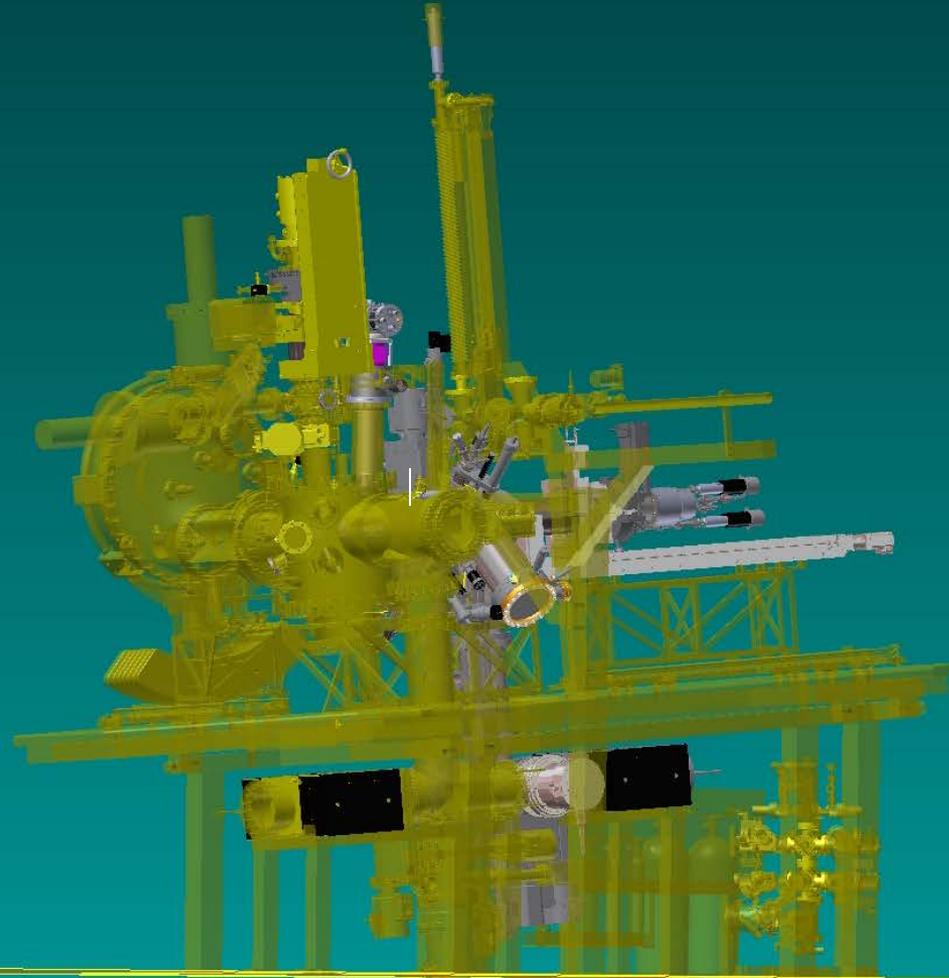
- Main components
 - Scienta DA30 analyzer with angle and spin detectors
 - Differential pumped rotary feedthrough
 - Support bearing
 - Counterweight
 - Linear bearings for installation



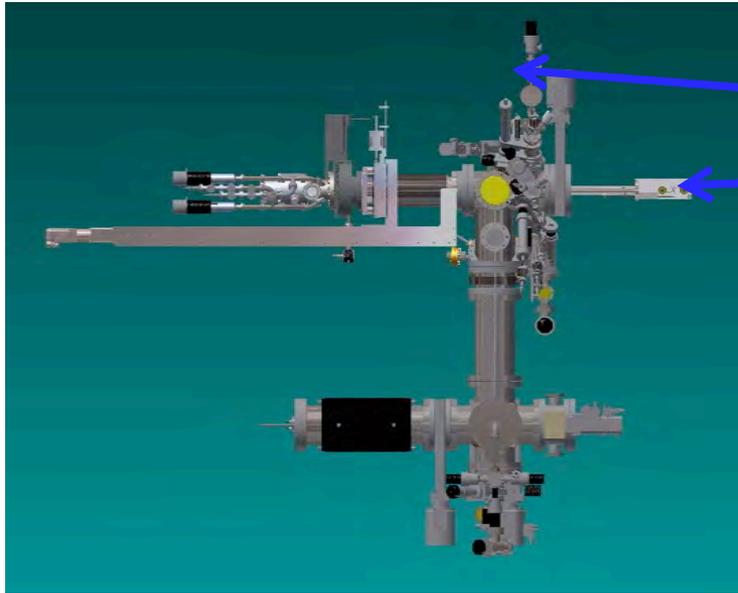
Preparation Chamber



Preparation Chamber



Preparation Chamber

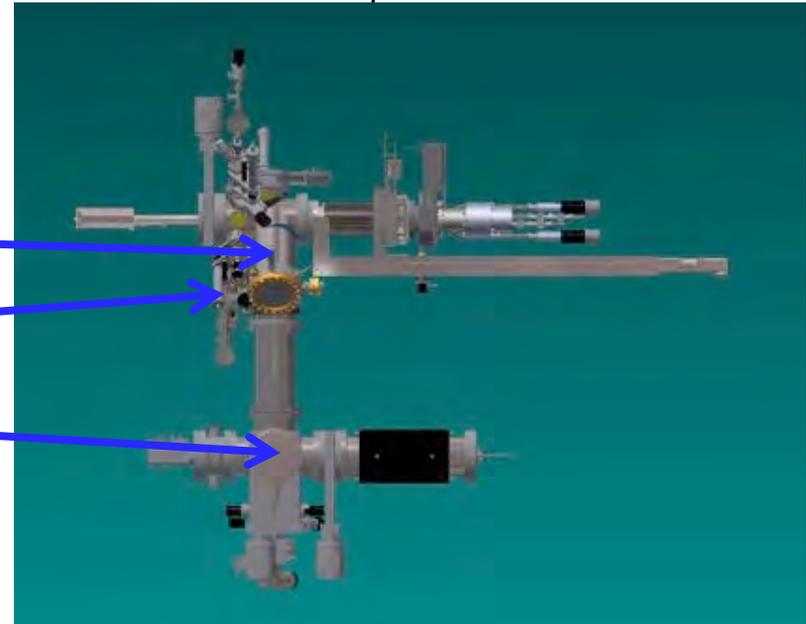


- Main components

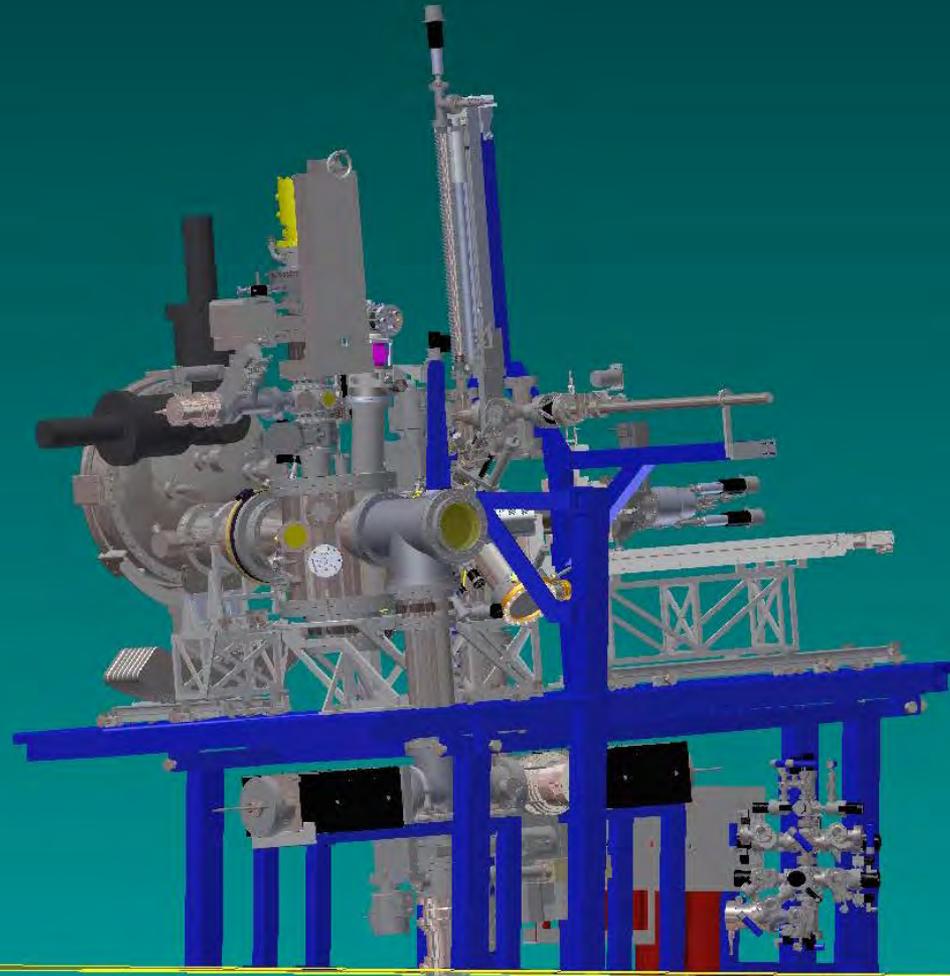
- Sputter gun
- Manipulator with 2 sample locations.
 - electromagnets on 1
 - Movable masks on both
 - E-beam heating on both
 - Can access measurement position

- LEED
- 4 removable evaporator ports
- Automated gas leak valve

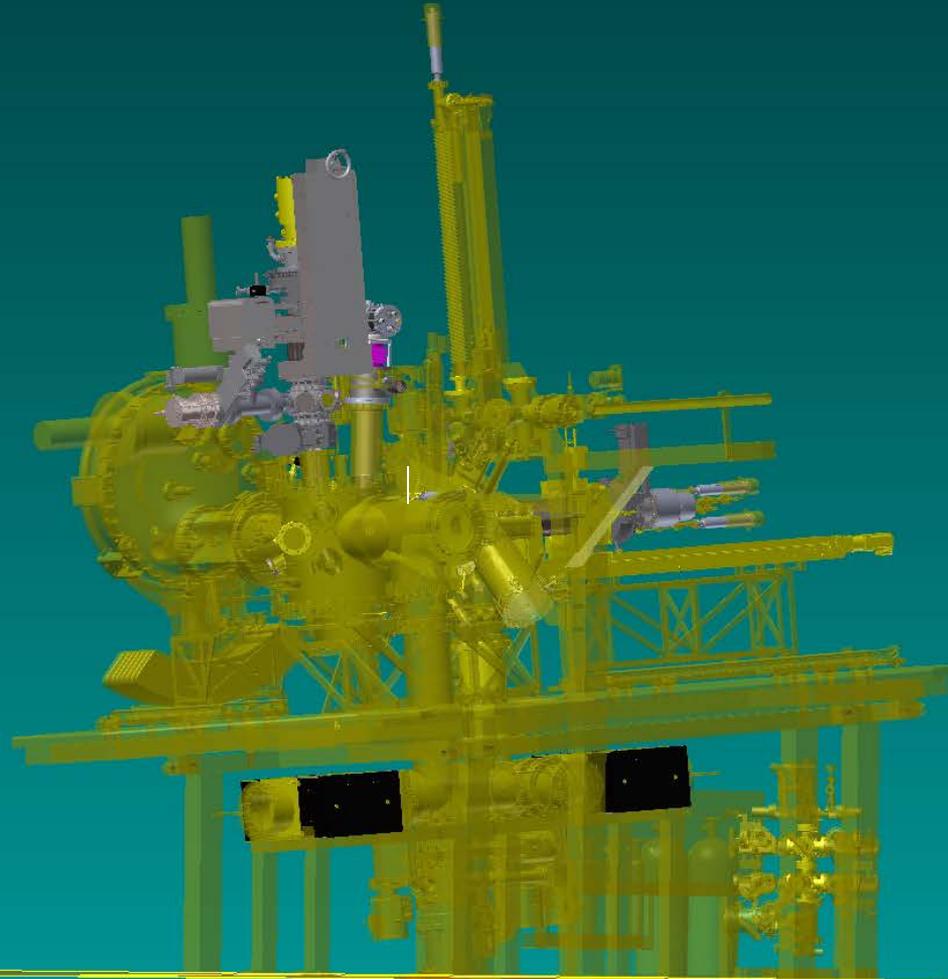
- Aiming for full automation in sample preparation



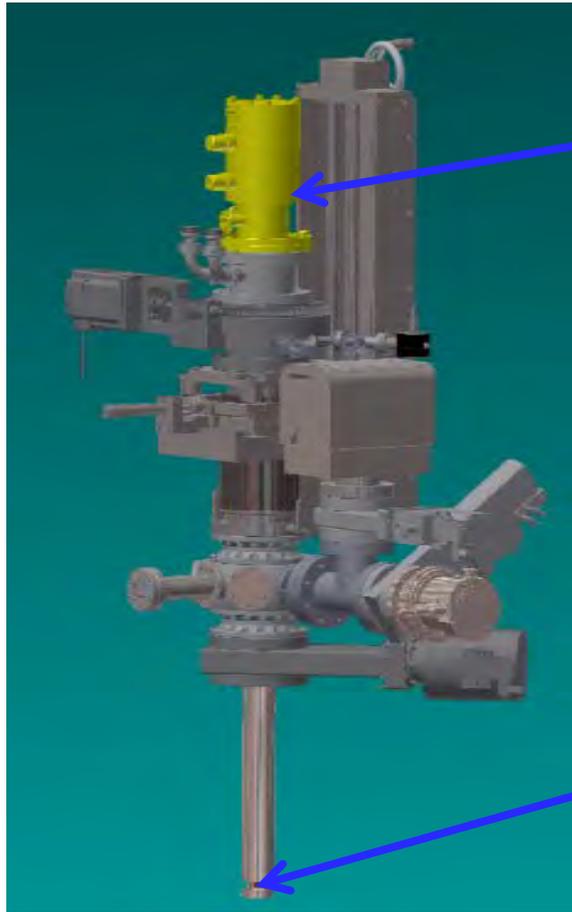
Low Temperature Chamber



Low Temperature Chamber



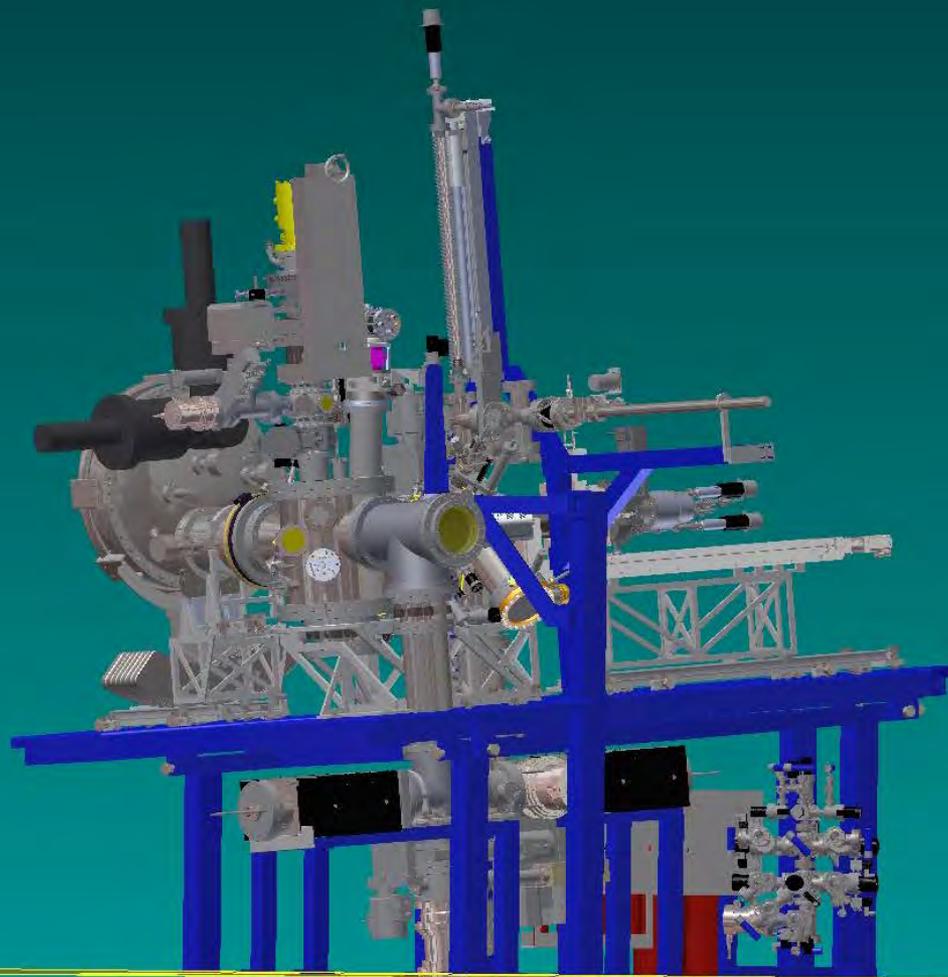
Low Temperature Chamber



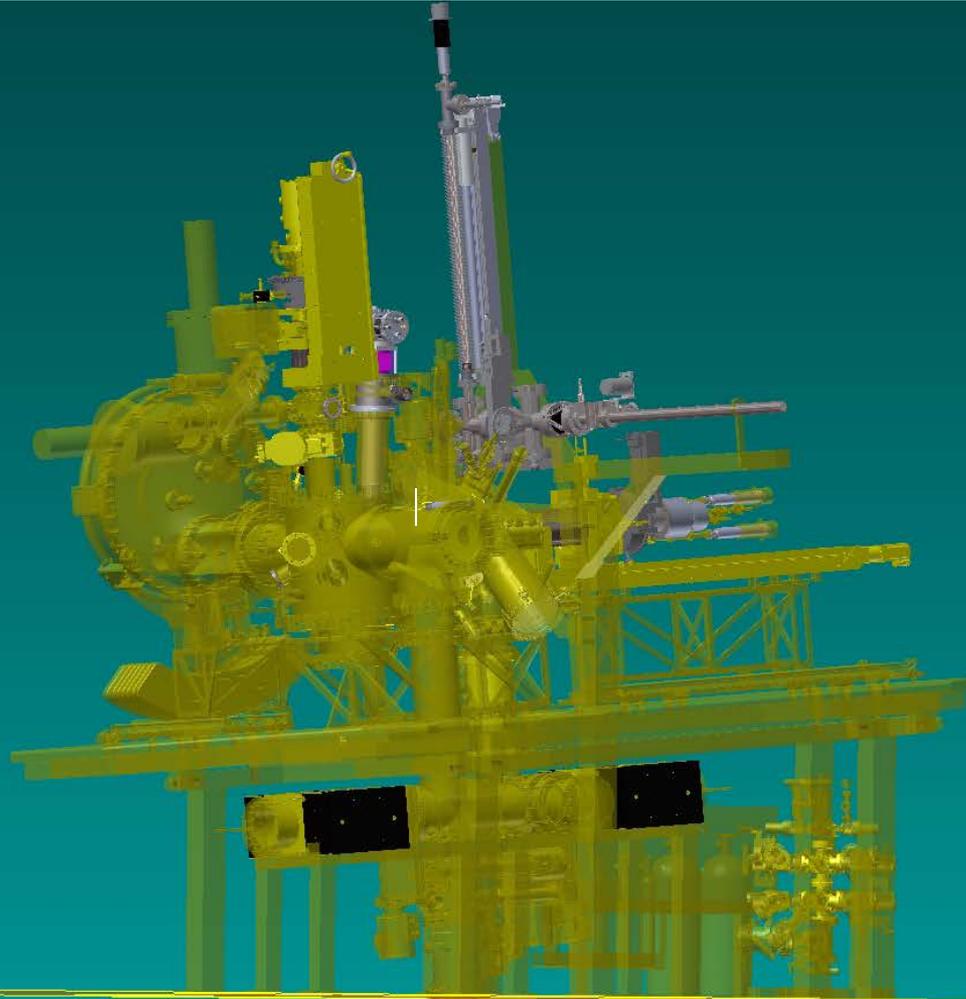
- Main components
 - Single Closed cycle LHe Cryostat
 - Small preparation chamber with some ports
 - sample “glued” to cold tip for ultimate temperature performance



Load Lock Chamber

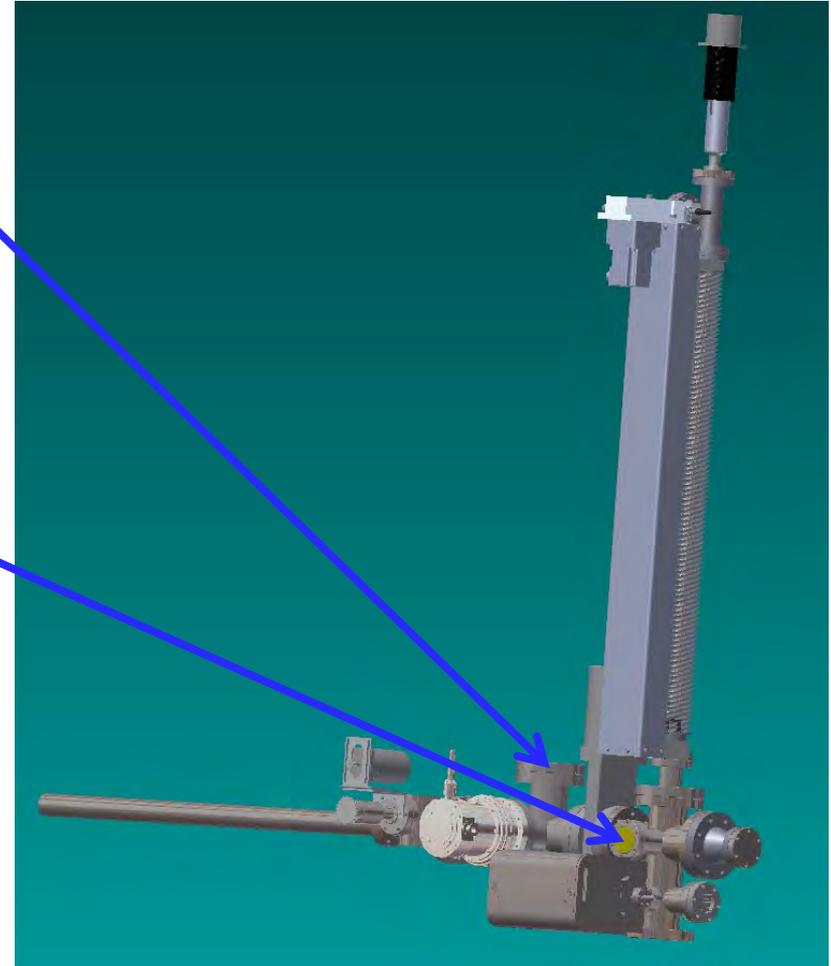


Load Lock Chamber

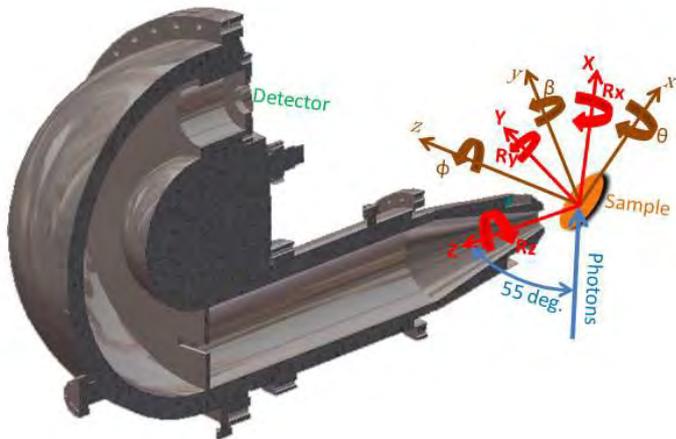


Load Lock Chamber

- Main components
 - Initial chamber, vented to air for sample insertion
 - Ability to insert 4 samples at once
 - Second chamber kept under vacuum ($< 1 \text{ E}7 \text{ mbar}$ at all times, normally $< 5 \text{ E} -9 \text{ mbar}$)
 - Can transfer 1 sample at a time to the preparation chamber
 - All motion is motorized allowing for fully automated sample transfer.
 - Monitoring of vacuum pressures ensures valves are opened only when pressures on both sides are adequate.



Overview of directions/angles



Direction label	Conventional label	Description
X	X	Perpendicular to the slits, parallel to the detector
Y	Y	Parallel to the slits, in the plane of the storage ring
Z	Z	Parallel and centered on the analyzer lens axis
Rx	θ	Clockwise rotation about the X axis
Ry	-	Clockwise rotation about the Y axis
Rz	-	Clockwise rotation about the Z axis
X	-	In the plane of the sample surface, equivalent to X for β and $\theta = 0$
Y	-	In the plane of the sample surface, equivalent to Y for β and $\theta = 0$
Z	-	Perpendicular to the sample surface, equivalent to Z for β and $\theta = 0$
θ	-	Clockwise rotation around the X axis
ϕ	ϕ	Clockwise rotation around the Y axis
β	β	Clockwise rotation around the Z axis

Overview of capabilities

Axis (units)	Sample prep. 1 (sp1)			Sample prep. 2 (sp2)			Micro-scan. (ms)			Low temperature (lt)			Scientia Analyzer (sa)		
	max	min	Res.	max	min	Res.	max	min	Res.	max	min	Res.	max	min	Res.
X (mm)	12.5	-12.5	~ 15E-3	12.5	-12.5	~ 15E-3	8.5	-8.5	~ 15E-6	12.5	-12.5	~ 15E-3	--	--	--
Y (mm)	803	-97	~ 15E-3	892	-8	~ 15E-3	55	-8	~ 15E-6	12.5	-12.5	~ 15E-3	--	--	--
Z (mm)	12.5	-12.5	~ 15E-3	12.5	-12.5	~ 15E-3	10	-110	~ 15E-6	488	-12.5	~ 15E-3	--	--	--
Rx (deg.)	--	--	--	--	--	--	24	-24	~ 2E-6	60	-300	~ 1E-1	15	-15	~ ??
Ry (deg.)	300	-60	~ 1E-1	235	-50	~ 1E-1	14.5	-14.5	~ 2E-6	--	--	--	15	-15	~ ??
Rz (deg.)	--	--	--	--	--	--	15.5	-15.5	~ 2E-6	--	--	--	10	-100	~ ??
Φ (deg.)	--	--	--	--	--	--	100	-100	~ 2E-6	--	--	--	--	--	--
θ (deg.)	--	--	--	--	--	--	50	-25	~ 2E-6	--	--	--	--	--	--
Temp. (K)	~ 15	~ 3000	~ 1K	~ 15	~ 3000	~ 1K	~ 15	~ 400	~ 1K	~ 4.5	~ 400	~ 1K	--	--	--
Bx (Gauss)	270	-270	~ 20	--	--	--	--	--	--	--	--	--	--	--	--
By (Gauss)	270	-270	~ 20	--	--	--	--	--	--	--	--	--	--	--	--
Bz (Gauss)	500	-500	~ 20	--	--	--	--	--	--	--	--	--	--	--	--

Note: Numbers in Blue are estimates and are to be confirmed during testing and commissioning. All other numbers are based on 3D models (for clearance limits) and the component specs.

Construction Timeline

- Construction timeline:
 - Aim to have the hardware assembly completed by 01/01/2016 to enable testing of the instrument prior to "first light".

Activity	Feb-2015	Mar-2015	April-2015	May-2015	June-2015	July-2015	Aug-2015	Sept-2015	Oct-2015	Nov-2015	Dec-2015
Assembly of load lock	Active	Active									
measure COM of Scienta		Active	Active								
Assembly of prep manip.				Active	Active	Active					
Assembly of Prep chamber							Active	Active	Active		
Assembly of Analysis chamber							Active	Active	Active		
Assembly of endstation on stand								Active	Active	Active	Active
Assembly of low temp chamber									Active	Active	Active
Installation of Endstation walls						Decision on this req. soon					

Risk management

- Hardware development of the Endstation is underway and can be achieved by the end of the project.
- Software development is the biggest risk to Endstation completion.
 - Software is required for:
 - motion limits (varies depending on position of several variables).
 - Automated motion.
 - Turbo DPRF backing system.
- This software will also be employed by SIX and others
 - Resources for this are still to be found.

ESM (S)ARPES Endstation, critical issues



Yi Zhu/ Andrew Walter
Engineer/ Asst. Physicist
NSLS II
03/13/2015
1

Outline

- Sample transfer system
- Proximity of end-station to front entrance doors/ pedestrian walkway
- Proximity to overhead walkway/ viewing area

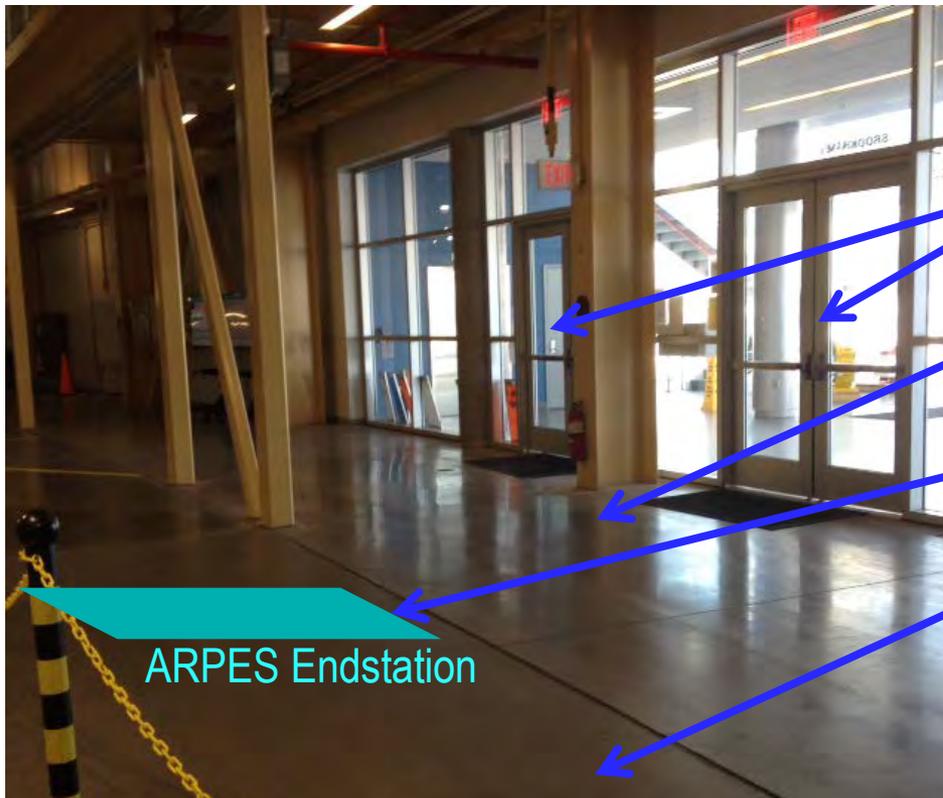
Sample manipulation system

- Complex sample manipulation system.
 - Testing of the system which is already underway.
- Closed cycle LHe cooling.
 - Testing of the cooling system is already underway.
- Hardware component testing is progressing well and progress is being monitored closely.



Proximity to Front entrance doors

- ARPES endstation is located close to the outer walkway right near the main entrance doors
 - Traffic in this area can therefore have an effect on the stability of the experimental end-station environment.



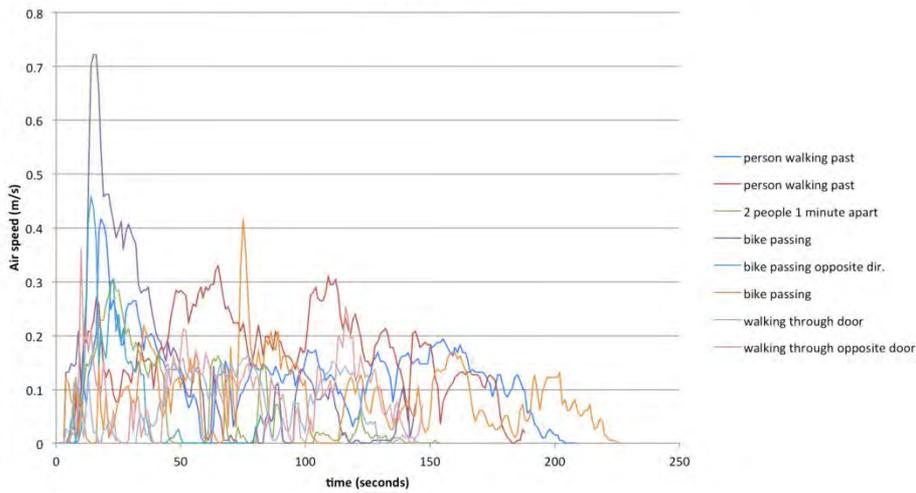
- **Approximate locations**

- Main entrance foyer doors
- Main walkway
- ARPES Endstation location
- Experimental floor

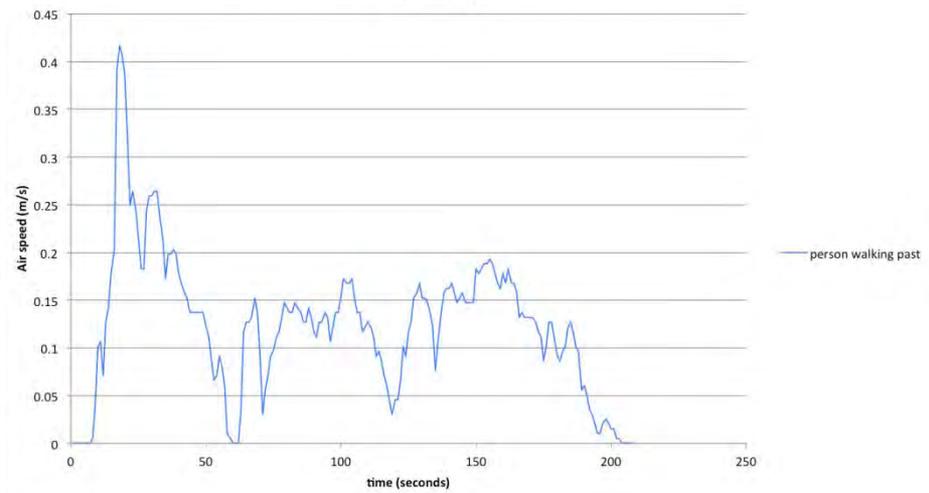
Proximity to Front entrance doors

- Proximity to front entrance doors
 - Air flow disruption at ARPES end-station location due to traffic in walkway and/or opening/closing the Foyer doors.

Air speed at the endstation as a function of time for various "traffic" on the walkway

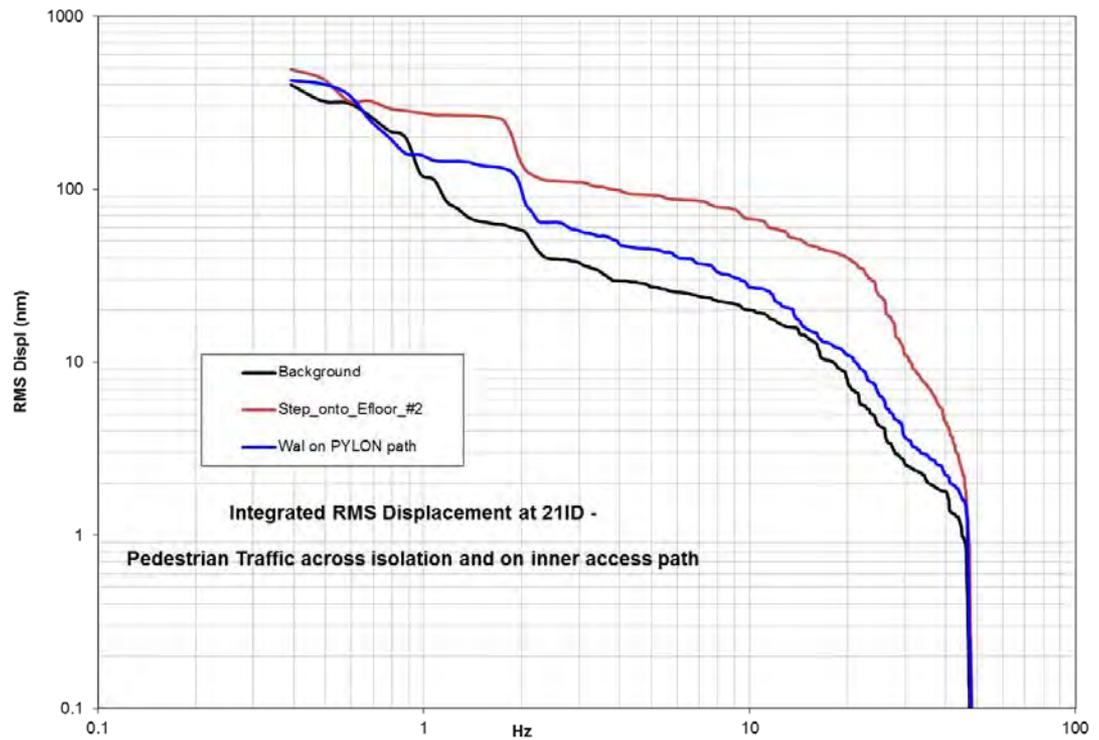


Air speed at the endstation as a function of time for a pedestrian on the walkway



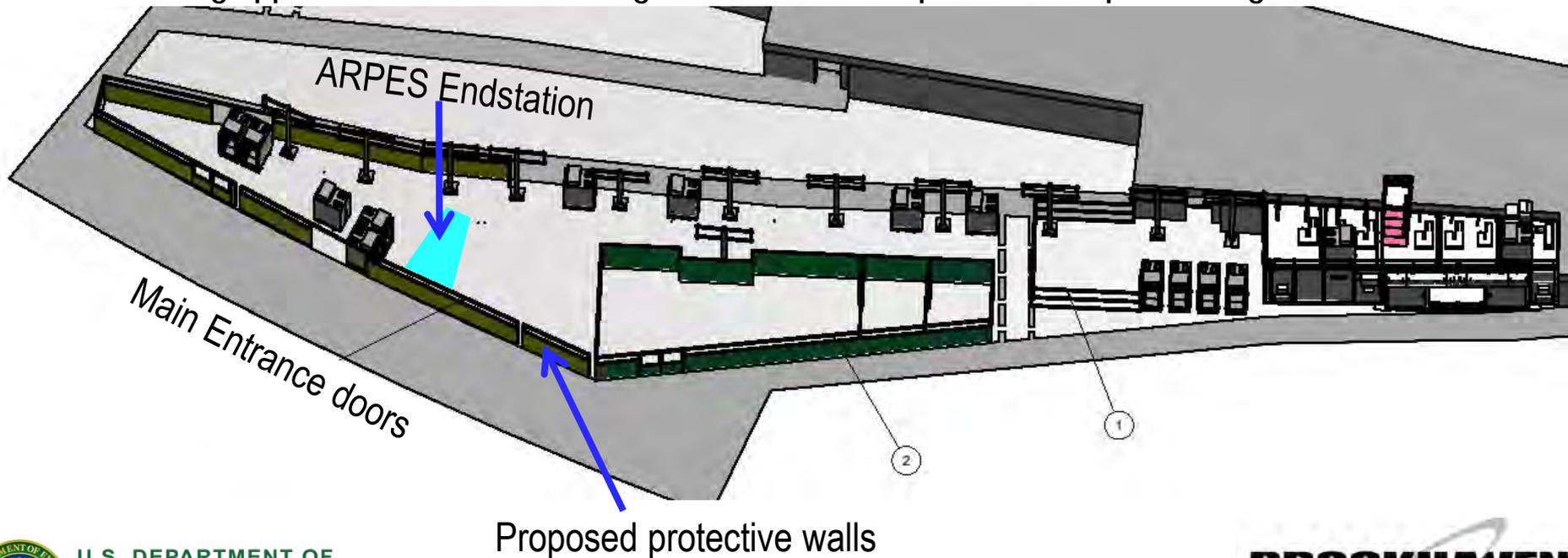
Proximity to Front entrance doors

- Air flow disruption at ARPES end-station location due to traffic in walkway and/or opening/closing the Foyer doors.
- Vibrations caused by pedestrian traffic close to the end-station
- Results of vibration study
 - Traffic stepping across the break from the walkway to the experimental floor (red) causes vibrations above the 100 nm requirement up to ~ 10 Hz
 - Traffic on the axis path between 21-ID and 21-BM (blue) causes vibrations above the 100 nm requirements up to ~ 2 Hz



Proximity to Front entrance doors

- ARPES endstation is located close to the outer walkway right near the main entrance doors
 - Traffic in this area can have an effect on the stability of the experimental end-station environment.
- Proposed solution
 - The proposed solution is to build extruded Al framed walls around the endstation and control areas.
- Status of solution
 - Awaiting approval from NSLS II management, which is required before proceeding.



Proximity to overhead walkway

- ARPES endstation is located close to the overhead walkway and “viewing area”.
 - This is likely to cause vibration issues due to traffic on this bridge.



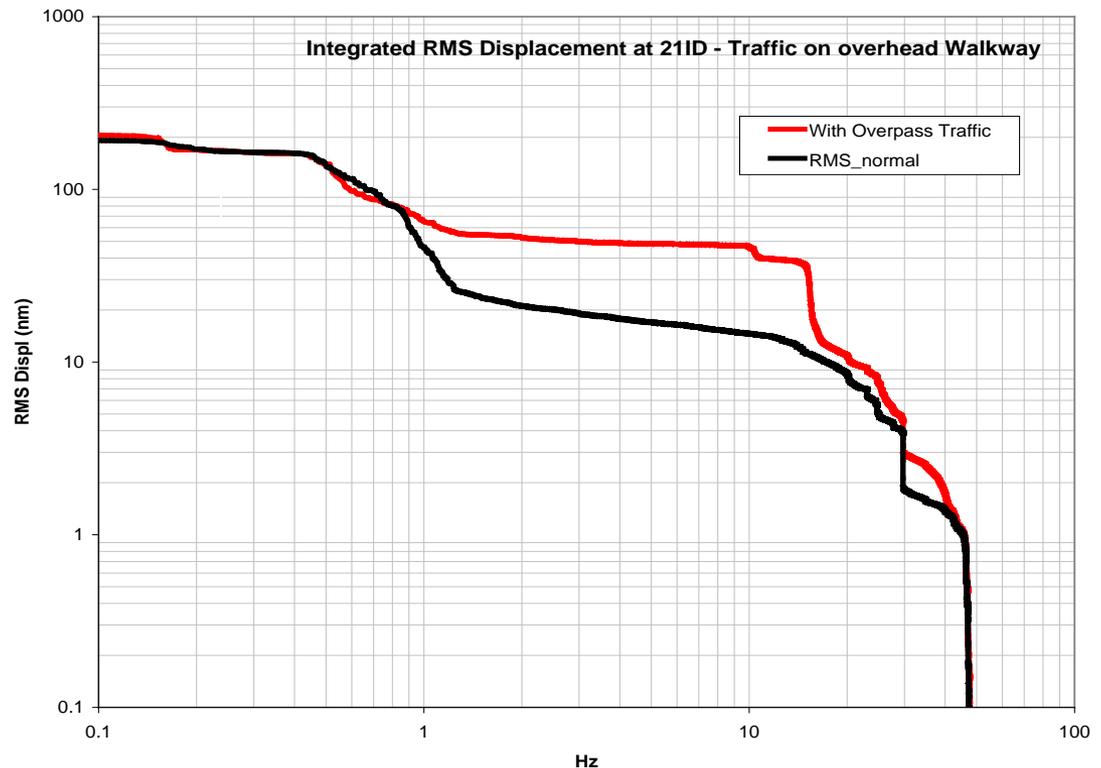
- Approximate locations
 - “Viewing area”
 - Overhead walkway
 - Experimental floor
 - ARPES Endstation location

Proximity to overhead walkway

- The overhead walkway and “viewing area” cross the
- Vibrations caused by pedestrian traffic close to the end-station

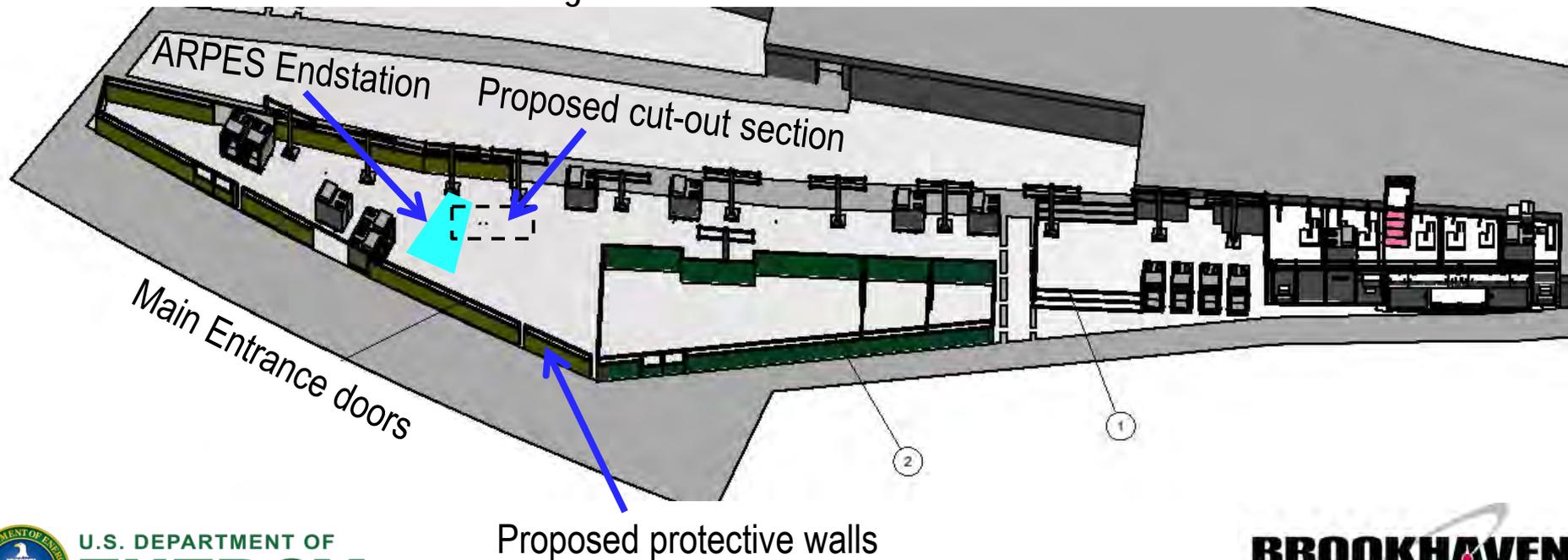
- **Results of vibration study**

- Traffic on the “viewing area” and the overhead walkway (red) causes vibrations above the 100 nm requirement up to ~ 1 Hz
- Traffic on the “viewing area” and the overhead walkway (red) causes vibrations above the 50 nm requirement up to ~ 1 Hz



Proximity to overhead walkway

- ARPES endstation is located close to the overhead walkway and the “viewing area”
 - Traffic in this area can therefore have an effect on the stability of the experimental endstation. Proposed solution
 - The proposed solution is to cut the floor around the KB mirror granite, which will isolate both the KB mirrors and the micro-scanning stage from the vibrations on the experimental floor.
- Status of solution
 - Calculations are continuing to determine if this will adversely affect the vibration level of the “cut-out” floor section and the surroundings.



ESM (S)ARPES Sample manipulation



Andrew Walter
Asst. Physicist
NSLS II
03/13/2015
1

Outline

- Common components
- Sample preparation manipulator
- Micro-scanning manipulator
- Low temperature manipulator
- Software development

Common components

- Sample puck
 - Allows for samples $\leq \sim 12 \times 12$ mm.
 - Significant flexibility in sample mounting.
 - Mounting face can have holes for screws or for e-beam heating of the back of the sample directly.
 - Cu for Temperatures $\leq \sim 800$ °C, Mo for Temperatures ≥ 800 °C.
 - Engraved “serial no.” on each puck aids in sample identification inside vacuum system.

FRONT



BACK



Common Components

- Sample storage dock
 - Push-on, Pull-off mechanism using stainless steel “leaf springs”.
 - “low cost” design with no heating/cooling capabilities.
 - Shaped leading edge ensures small sample misalignment (~ 2 mm) is



Common Components

- Sample preparation/ measurement dock
 - Push-on, Pull-off mechanism using Mo “leaf springs”.
 - “Commercial” (KJ Lesker) solution reduces manufacturing costs.
 - Mo material allows for temperatures ≤ 2500 °C.
 - Holding force higher than “storage dock” to ensure a better thermal contact for low temp. applications.



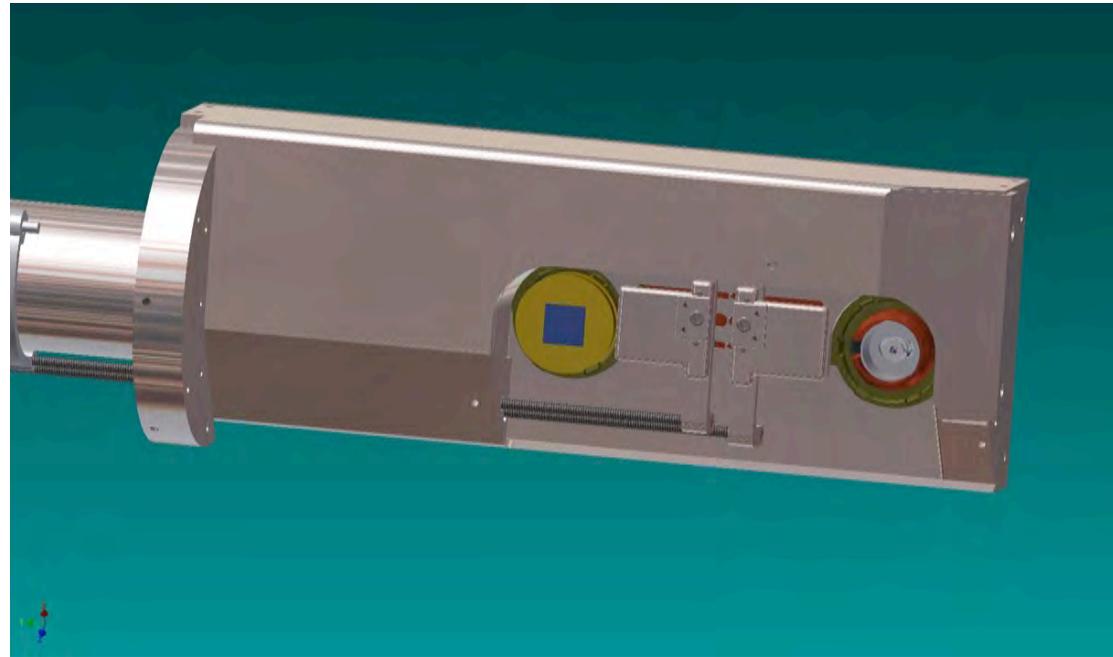
Sample preparation manipulator

- McAllister X,Y,Z, θ Manipulator.
 - X,Y range $25 \pm 15 \times 10^{-3}$ mm; Z range $900 \pm 15 \times 10^{-3}$ mm; θ range $-300 \pm 0.1^\circ$ to $60 \pm 0.1^\circ$.
 - All axes motorized and encoded.
- Coldedge low vibration closed cycle LHe cryostat.
 - Measured temperature at cold-tip extension 7 K, cool down time 133 mins.
 - Expected temperature at sample $\sim 10 - 15$ K.



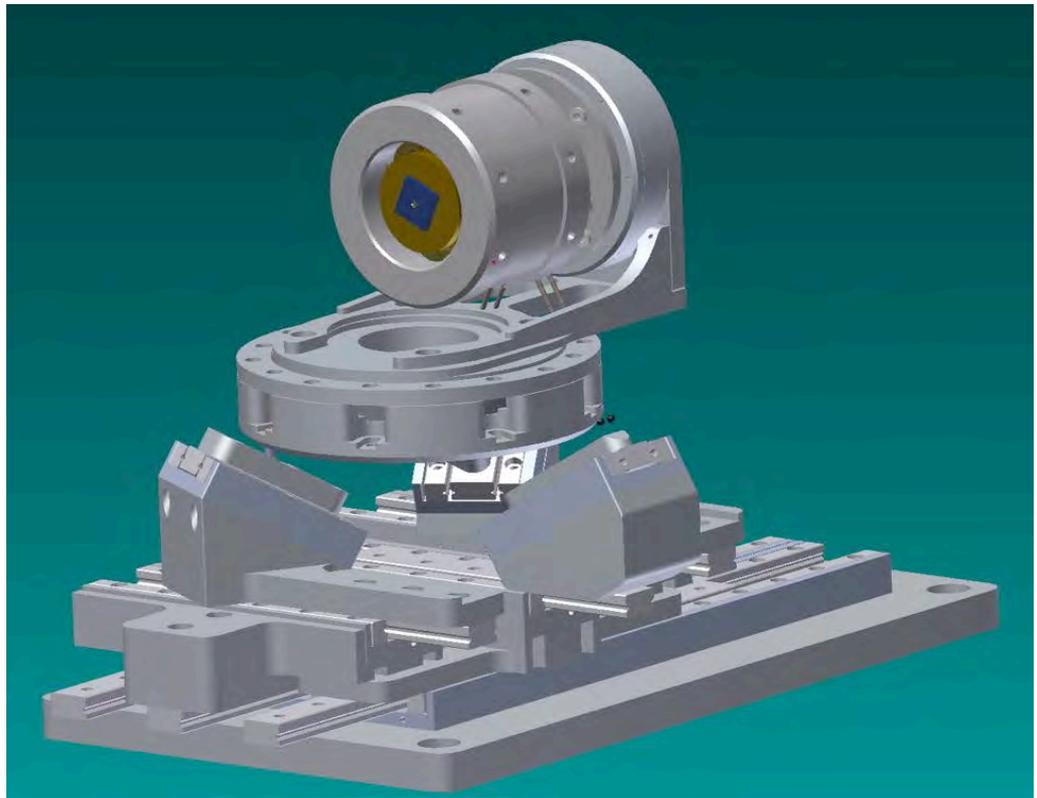
Sample preparation manipulator

- 2 Sample locations.
 - Independent, motorized, masks for wedge growth.
 - Independent e-Beam and diode heating systems
 - Left location has 3 coil magnets for magnetization experiments
 - Both locations can access the Scienta Analyze measurement position.



Micro-scanning manipulator

- Smaract nano-positioning Smarpod
 - Kinematic system gives 6 degrees of freedom, but limited angle ranges
 - Large range (≥ 17 mm) with ~ 5 nm precision
 - Additional rotary stages
 - Normal emission and incidence can be measured
 - 200° in plane rotation
 - $\pm 14^\circ$ “flip” angle.



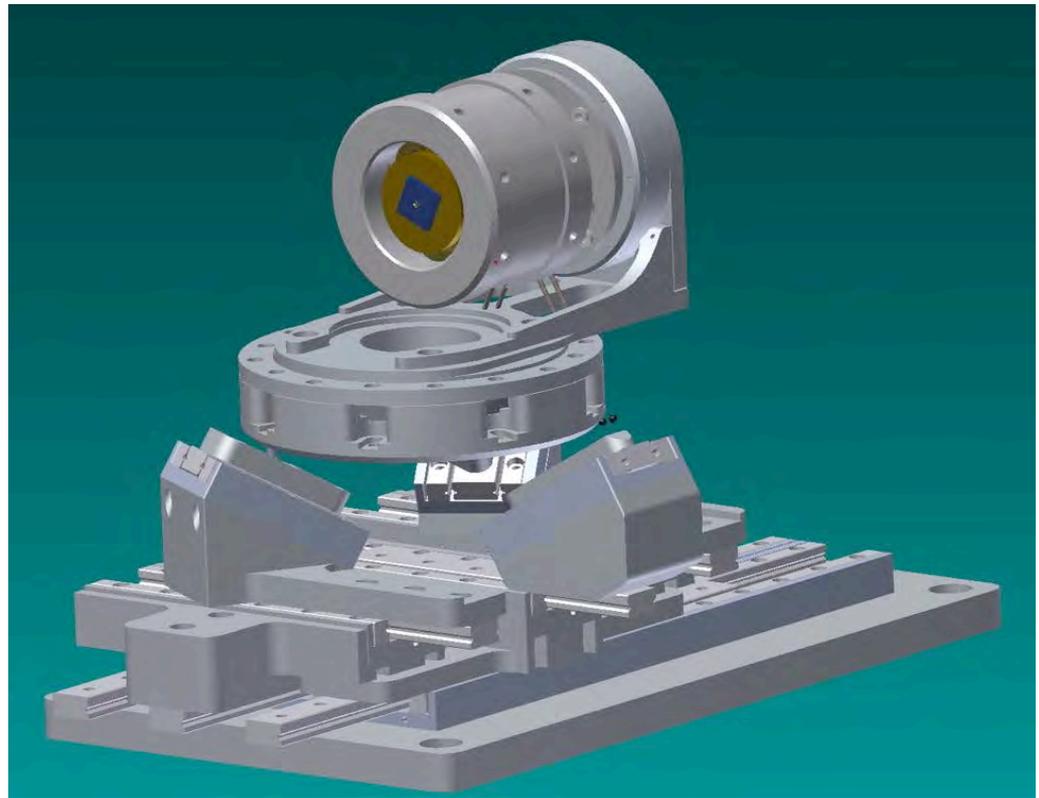
Micro-scanning manipulator

- Coldedge ultra low vibration closed cycle LHe cryostat.
 - Measured temperature at cold-tip extension 4.1 K, cool down time 6 hrs.
 - Expected temperature at sample ~ 10 – 15 K.



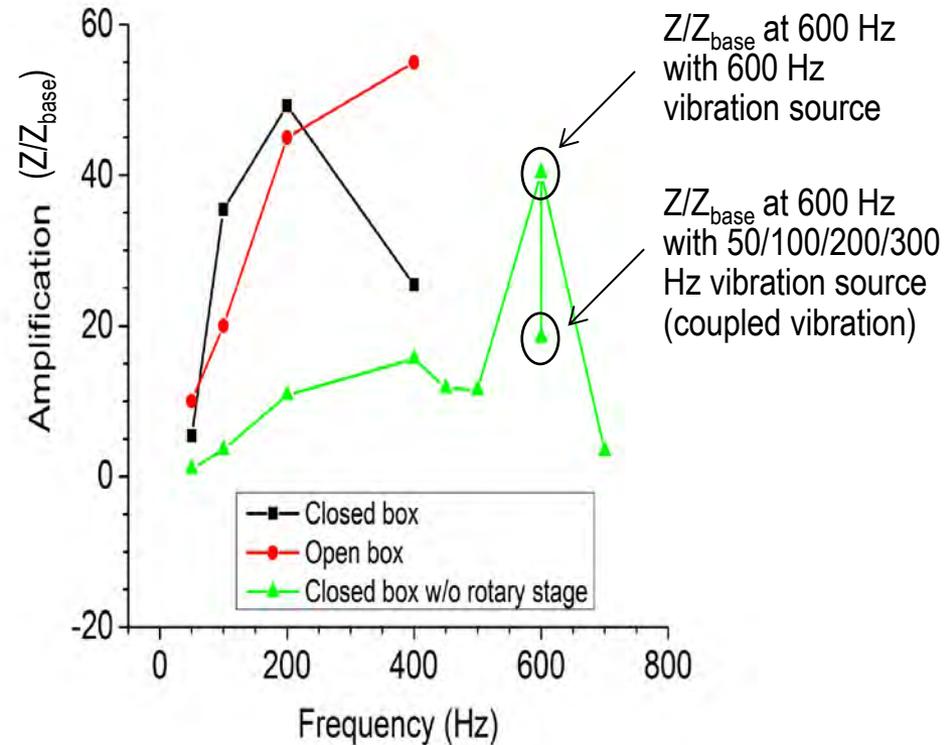
Micro-scanning manipulator

- Sample mounting “head”.
 - Consists of a cryo-shield surrounding the sample, all of which is on top of the motions.
 - Independent e-Beam and diode heating systems
 - E-beam system may be limited to lower temp. to avoid overheating Smaract stages.



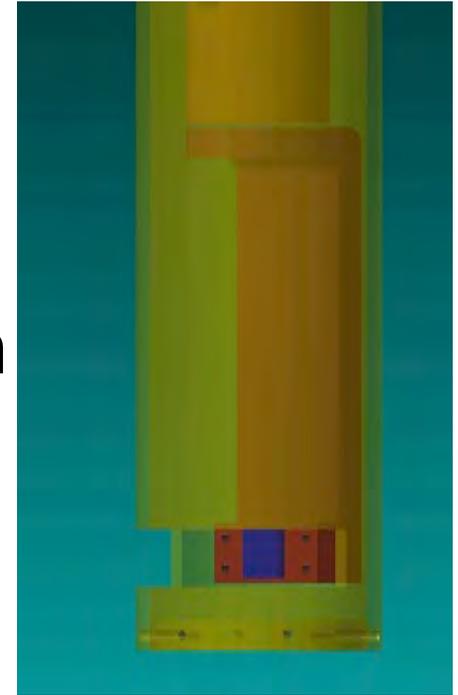
Micro-scanning manipulator

- System stability.
 - Measured linear step accuracy is on the order of 5 nm.
 - Measured vibration amplification across the stage has been measured.
 - Extra in-plane rotation stage increases amplification, investigation into solutions is ongoing.
 - Rotation measurements are in progress.



Low temperature manipulator

- McAllister X,Y,Z, θ Manipulator.
 - X,Y range $25 \pm 15 \times 10^{-3}$ mm; Z range $\sim 600 \pm 15 \times 10^{-3}$ mm; θ range $-300 \pm 0.1^\circ$ to $60 \pm 0.1^\circ$.
 - All axes motorized and encoded.
- Coldedge low vibration closed cycle LHe cryostat.
 - Similar cold-head to micro-scanning stage with sample mounted directly to cold-tip.
 - expected temperature at cold-tip ~ 4.5 K.
 - Expected temperature at sample ~ 4.5 K.



Software development

- Hardware development of the sample manipulation is underway and can be achieved by the end of the project.
- Software development is the biggest risk to sample manipulation problems.
 - The sample manipulation scheme is also being used for SIX and possibly for other beamlines.
 - Solving the resources issue related to software is the biggest risk foreseen at the moment.

ESM ARPES END-STATION MANUAL

Preliminary version

3/3/2015

Authors:

Andrew Walter

Contents

1	Table of Figures.	4
2	Table of Tables.	5
3	General Information.	6
3.1	ARPES Endstation overview.	6
3.2	Definition of sample directions and angles.	7
3.3	Common electrical feedthroughs.	8
3.4	Overview of sample measurement positions.	9
4	Analysis Chamber.	10
4.1	Introduction.	10
4.2	Micro-scanning stage.	11
4.2.1	Stage description.	11
4.2.2	Sample mounting stage.	12
4.2.3	Stage electrical feedthrough descriptions.	13
4.3	Sample Transfer assemblies.	13
4.3.1	Assembly description.	13
4.3.2	Assembly electrical feedthrough description.	14
4.4	Sample view mirror assembly.	14
4.4.1	Assembly description.	14
4.5	Chamber.	15
4.5.1	Description.	15
4.5.2	Chamber port definitions.	16
4.5.3	Mu metal shielding.	17
4.6	Control systems.	18
5	Preparation chamber.	19
5.1	Introduction.	19
5.2	Sample preparation stage.	20
5.2.1	Stage description.	20
5.2.2	Sample preparation 1 (sp1) location.	21
5.2.3	Sample preparation 2 (SP2) location.	21
5.2.4	Stage electrical feedthrough descriptions.	21
5.3	Evaporation equipment.	22

5.3.1	Evaporator exchange system.....	22
5.3.2	Evaporator mask assembly.....	22
5.4	Dropped sample recovery assembly.....	23
5.5	Gas leak valve system and ion sputter gun system.....	23
5.6	Low Energy Electron Diffraction setup.....	24
5.7	Chamber.....	24
5.7.1	Description.....	24
5.7.2	Chamber port definitions.....	25
5.8	Control systems.....	26
6	Low Temperature chamber.....	27
6.1	Introduction.....	27
6.2	Stage Description.....	28
6.3	Chamber.....	28
6.3.1	Description.....	28
6.4	Control systems.....	28
7	Load-Lock chamber.....	29
7.1	Introduction.....	29
7.2	Preparation chamber transfer bar.....	29
7.3	Load lock transfer bar.....	29
7.4	Control systems.....	30
8	Backing system.....	31
8.1	Introduction.....	31
8.2	Control systems.....	32
9	Appendices.....	33
9.1	Appendix 1: Table of abbreviations.....	33

1 Table of Figures.

Figure 3-1. Diagram showing the complete ARPES Endstation, the various chambers have been labeled. 6	6
Figure 3-2 Definition of directions and angles relative to incoming light and the analyzer 7	7
Figure 3-2. 7 pin feedthrough diagram indicating the labels of the pins 8	8
Figure 4-1. Analysis chamber external (A) and internal (B) view with the main components highlighted.10	10
Figure 4-2 Micro-scanning stage made up of Smaract GmbH piezo stages configured to give 3 rotation and 3 linear degrees of motion. The stage (zoom) is shown mounted on its solid support and with the low vibration cryostat located in space relative to the stage. 11	11
Figure 4-3. Sample mounting stage for piezo positioning stages. Complete (A), minus the sample and puck (B), the cryo shield (C), the sample puck mount(D), the smaract stage heating/ cooling shield (D) and a combined side view of D and E..... 12	12
Figure 4-4. View of the electrical feedthroughs for the micro-scanning stage, descriptions of the pin layout for the cryo feedthrough and e-beam feedthrough are given in section 3.2..... 13	13
Figure 4-5. Sample transfer arm, these allow for samples to be transferred to/from the various stages in the analysis chamber..... 13	13
Figure 4-6. Feedthroughs for analysis chamber sample transfer arms. 14	14
Figure 4-7. Sample view mirror assembly external view (A), complete view (B), upstream zoom (C) and downstream zoom (D)..... 14	14
Figure 4-8. Top view of the analysis chamber with the location of the port focal points in the X-Y plane indicated. The xyz co-ordinates are defined in the top right with the origin at the chamber centre (I) and z = 0 at the bottom flange face. Angles for the ports are clockwise given in the X-Y plane with the x axis being zero (γ) and above (+ve) and below (-ve) the X-Y plane (β). 15	15
Figure 4-9. Images of the analysis chamber and mu metal shielding. The mu metal shielding consists of an inner and outer skin with separate port tubes. The port tubes have small sections at the ends that follow the contours of the ID of the outer mu metal shield, these become sandwiched between the inner and outer tubes holding them in place. The port labels are also shown on the chamber. 16	16
Figure 5-1. Diagram showing the preparation chamber with the main components highlighted. 19	19
Figure 5-2. Sample preparation stage overview (A), manipulator head (B), electrical feedthrough labels (C) and the sample locations with (D) and without (E) a mounted sample. 20	20
Figure 5-3. Evaporator exchange assembly..... 22	22
Figure 5-4. Dropped sample recovery assembly. 23	23
Figure 5-5. Gas inlet valve system and ion sputter gun system. 23	23
Figure 5-6. Images of the preparation chamber with the ports numbered. 24	24
Figure 5-7. End view of the preparation chamber with the location of the port focal points in the X-Y plane indicated. The xyz co-ordinates are defined in the top right with the origin at the chamber centre (I) and z = 0 at the bottom flange face. 25	25
Figure 6-1. Low temperature chamber (A), stage (B), zoom of sample with (C) and without (D) cryoshield. 27	27
Figure 7-1. Load-lock chamber (A) with the main features labeled. In addition the sample forks for the prep chamber transfer bar (B) and vacuum transfer bar (C)..... 29	29
Figure 8-1. Backing manifold system..... 31	31

2 Table of Tables.

Table 3-1. Description of axes and directions, for a schematic view see Figure 3-2.....	7
Table 3-2. Pin allocation for the common 7-pin feedthroughs for cryo cooling, sample measurement and sample transfer	8
Table 3-3. Sample motion, temperature and magnetic field range and resolution data for each of the measurement stages.	9
Table 4-1. Description/ location of the analysis chamber focal points of the ports. A top view showing the X-Y plane location is shown in Figure 4-8.....	15
Table 4-2. Port list for the analysis chamber. The beta rotation is defined as above (+ve) and below (-ve) the XY plane while gamma is defined as clockwise around the z axis with zero in the x direction. Flanges 1 and 2 are the top and bottom flanges respectively and port length is from the focal point.	17
Table 4-3. List of control systems in the analysis chamber.	18
Table 5-1. Port list for the preparation chamber. The beta rotation is defined as above (+ve) and below (-ve) the XY plane while gamma is defined as clockwise around the z axis with zero in the x direction. Flanges 1 and 2 are the top and bottom flanges respectively and port length is from the focal point.	25
Table 5-2. List of control systems in the preparation chamber.....	26
Table 6-1. List of control systems in the preparation chamber.....	28
Table 7-1. List of control systems in the load-lock chamber.	30
Table 8-1. Assignment of the ports on the backing manifold, the labels are shown in Figure 8-1 B.	31
Table 8-2. List of control systems in the preparation chamber.....	32

3 General Information.

3.1 ARPES Endstation overview

The preliminary design for the ARPES endstation is shown in Figure 3-1, It consists of a Scienta Analyzer, Analysis chamber, Low Temperature chamber, Preparation chamber and a double stage Load- Lock. The samples can be mounted onto one of four separate sample "locations": sample preparation (sp1), sample preparation (sp2), micro-scanning (ms) and low temperature (lt). The first two are mounted onto the manipulator that also accesses the sample preparation chamber, and provides a 4 axis stage with in-situ magnetization capability (sp1) and a position without magnetic capabilities (sp2), both of which have ~ 15 micron resolution. The micro-scanning stage (ms) is located in the analysis chamber and allows for 8 axis scanning with sub-micron resolution; samples can be transferred from either of the 2 sample preparation locations onto the micro-scanning stage. The final stage is a dedicated low temperature (lt) stage with its own preparation chamber. Here the sample is mounted directly to the end of a LHe cryostat to ensure temperatures <5K are obtained, and is expected to be used for ultra high energy resolution experimental work.

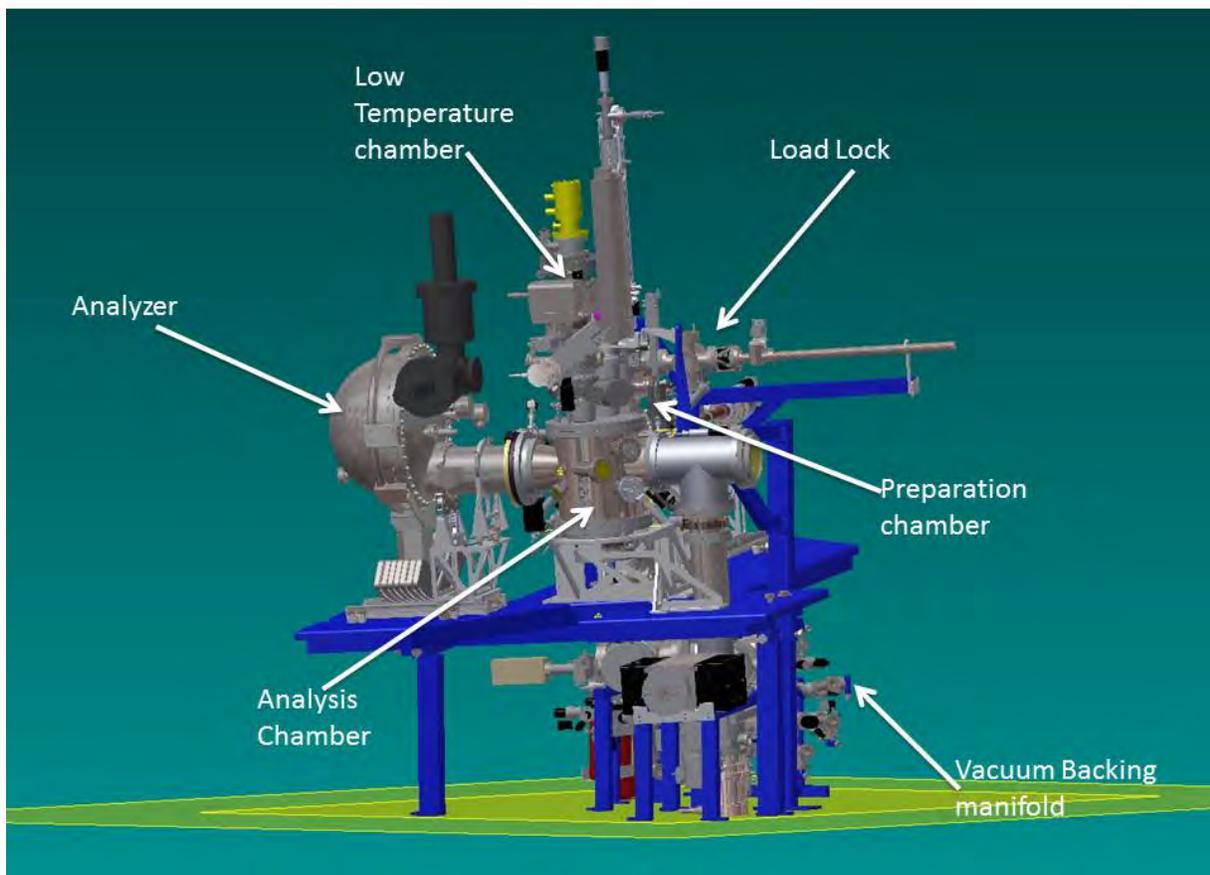


Figure 3-1. Diagram showing the complete ARPES Endstation, the various chambers have been labeled.

3.2 Definition of sample directions and angles.

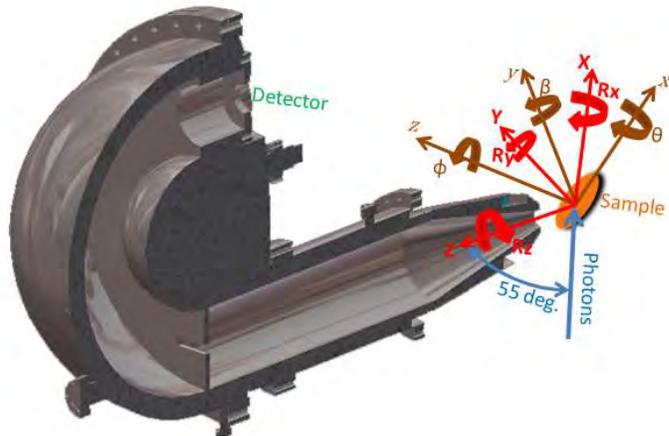


Figure 3-2 Definition of directions and angles relative to incoming light and the analyzer

To define the directions we need to think of two sets of orthogonal axis, one which has the z axis pointing along the analyzer lens axis and a second which moves with the sample surface. These are shown in red and brown respectively in Figure 3-2, and described in Table 3-1. Both sets of axis are defined with the origin at the nominal beam position and with positive z toward the analyzer. Rotations are defined so that positive is clockwise looking along the positive axis direction that the rotation is around. Also included in the table is the labels given to the

various directions for a “conventional 6-axis manipulator” for reference. The convention is to label the axis in the format xx(x)Y(Y), with xx(x) implying the sample location (stage) abbreviation as defined in section 3.1 above. The Y(Y) format above relates to the direction labels shown in Figure 3-2 and Table 3-1. For the sample preparation and low temperature manipulators the standard 4 axis convention is used. For the micro-scanning stage we add Ry, Rz, Φ and θ as rotations. In addition to these degrees of freedom the analyzer itself can rotate around the Z axis (Rz) and includes electrostatic deflection lens to allow for scanning Rx and Ry. Each of these is described in more detail in section 3.4.

Table 3-1. Description of axes and directions, for a schematic view see Figure 3-2.

Direction label	Conventional label	Description
X	X	Perpendicular to the slits, parallel to the detector
Y	Y	Parallel to the slits, in the plane of the storage ring
Z	Z	Parallel and centered on the analyzer lens axis
Rx	θ	Clockwise rotation about the X axis
Ry	-	Clockwise rotation about the Y axis
Rz	-	Clockwise rotation about the Z axis
X	-	In the plane of the sample surface, equivalent to X for β and $\theta = 0$
Y	-	In the plane of the sample surface, equivalent to Y for β and $\theta = 0$
Z	-	Perpendicular to the sample surface, equivalent to Z for β and $\theta = 0$
θ	-	Clockwise rotation around the X axis
Φ	Φ	Clockwise rotation around the Y axis
β	β	Clockwise rotation around the Z axis



Figure 3-3. 7 pin feedthrough diagram indicating the labels of the pins

3.3 Common electrical feedthroughs.

The common electrical feedthroughs are those for the sample measurement (current to ground and sample presence switches), the sample transfer (sample presence and alignment switches), transfer assembly measurement stage (alignment sensors) and the hall probe electrical feedthroughs. These are standardized to ensure that cables can be interchanged for quick and easy diagnosis of electrical issues in the chamber. The pin allocation

for each one is listed in Table 3-2 while the pin labels are shown in Figure 3-2.

Table 3-2. Pin allocation for the common 7-pin feedthroughs for cryo cooling, sample measurement and sample transfer

Feedthrough name	Pin designation	Pin allocation
Sample measurement	A	Sample current
	B	Sample presence switch
	C	Thermocouple1 +ve
	D	Thermocouple1 -ve
	E	Thermocouple2 +ve
	F	Thermocouple2 -ve
	G	Spare
Sample transfer	A	Position 1 Shield proximity switch 1
	B	Position 1 Shield proximity switch 2
	C	Position 1 Sample presence switch
	D	Common wire for switches
	E	Position 2 Shield proximity switch 1
	F	Position 2 Shield proximity switch 2
	G	Position 2 Sample presence switch
Hall probe	A	Axis 1 current +ve
	B	Axis 2 current +ve
	C	Common current -ve
	D	Axis 1 voltage -ve
	E	Axis 1 voltage +ve
	F	Axis 2 voltage -ve
	G	Axis 2 voltage +ve

3.4 Overview of sample measurement positions

The motion, temperature and magnetic field range and resolution for each of the sample measurement locations is presented in Table 3-3. The combination of all four locations provides for a wide range of measurements; including (but not simultaneously) micro-scanning, low temp./ high resolution, magnetic field and coarse scanning. The axis available from the analyzer allows for angular mapping without moving the sample. Additionally rotation of the analyzer and sample simultaneously around Rz (θ for micro-scanning stage) allows for the same area of angular space to be measured for different polarization vectors.

Table 3-3. Sample motion, temperature and magnetic field range and resolution data for each of the measurement stages.

Axis (units)	Sample prep. 1 (sp1)			Sample prep. 2 (sp2)			Micro-scan. (ms)			Low temperature (lt)			Scientia Analyzer (sa)		
	max	min	Res.	max	min	Res.	max	min	Res.	max	min	Res.	max	min	Res.
X (mm)	12.5	-12.5	~ 15E-3	12.5	-12.5	~ 15E-3	8.5	-8.5	~ 15E-3	12.5	-12.5	~ 15E-3	--	--	--
Y (mm)	803	-97	~ 15E-3	892	-8	~ 15E-3	55	-8	~ 15E-3	12.5	-12.5	~ 15E-3	--	--	--
Z (mm)	12.5	-12.5	~ 15E-3	12.5	-12.5	~ 15E-3	5	-115	~ 15E-3	488	-12.5	~ 15E-3	--	--	--
Rx (deg.)	--	--	--	--	--	--	24	-24	~ 2E-6	60	-300	~ 1E-1	15	-15	~ ??
Ry (deg.)	300	-60	~ 1E-1	300	-60	~ 1E-1	14.5	-14.5	~ 2E-6	--	--	--	15	-15	~ ??
Rz (deg.)	--	--	--	--	--	--	15.5	-15.5	~ 2E-6	--	--	--	5	-95	~ ??
Φ (deg.)	--	--	--	--	--	--	100	-100	~ 2E-6	--	--	--	--	--	--
θ (deg.)	--	--	--	--	--	--	50	-25	~ 2E-6	--	--	--	--	--	--
Temp. (K)	~ 15	~ 3000	~ 1K	~ 15	~ 3000	~ 1K	~ 15	~ 400	~ 1K	~ 4.5	~ 400	~ 1K	--	--	--
Bx (Gauss)	270	-270	~ 20	--	--	--	--	--	--	--	--	--	--	--	--
By (Gauss)	270	-270	~ 20	--	--	--	--	--	--	--	--	--	--	--	--
Bz (Gauss)	500	-500	~ 20	--	--	--	--	--	--	--	--	--	--	--	--

4 Analysis Chamber.

4.1 Introduction.

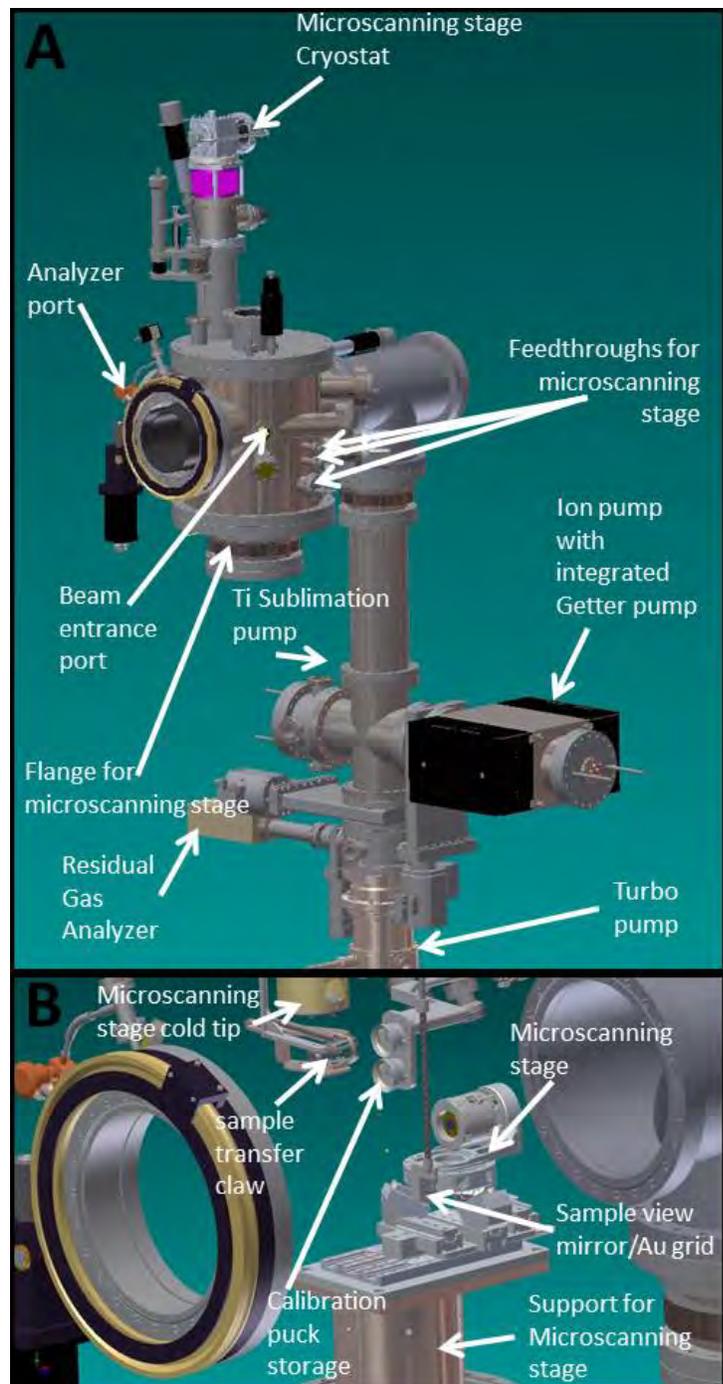


Figure 4-1. Analysis chamber external (A) and internal (B) view with the main components highlighted.

The analysis chamber is shown in Figure 4-1 with the main components highlighted. In addition to the Scienta analyzer the chamber contains: a micro-scanning stage, A sample transfer arm, a dock for holding 2 calibration pucks (one contains a puck with a thermal diode and the second a 3D hall probe permanently mounted), a mirror/ Au grid assembly to allow for a camera to focus on the sample position along the beam direction and a differentially pumped rotary feedthrough (DPRF) to allow the analyzer to rotate around the lens axis. Pumping is performed by a turbo pump, an ion pump, a Ti sublimation pump and a Getter pump. A further small ion pump is used on the two-stage DPRF for the analyzer and the second stage is pumped by the common backing pump manifold. An RGA is used to determine the composition of the residual gases.

Feedthroughs are provided for the micro-scanning stage, sample transfer and sample view mirror/ Au grid. Viewports are included to look at the sample position from above and below the beam entrance, as well as from the internal mirror and from “behind” the analyzer. A further large view port looks at the centre of the chamber facing the back of the sample. Further ports on the back (not shown) make allowances for the wavefront detector (4.5” flange) and the preparation chamber (8 “ flange).

4.2 Micro-scanning stage.

4.2.1 Stage description.



Figure 4-2 Micro-scanning stage made up of Smaract GmbH piezo stages configured to give 3 rotation and 3 linear degrees of motion. The stage (zoom) is shown mounted on its solid support and with the low vibration cryostat located in space relative to the stage.

solid 6" diameter Al mount which is directly mounted to the granite block that also supports the KB optics. This is done to minimize vibrational movement between the sample and the KB optics and hence maintain the spot-sample position as accurately as possible. The motion and temperature limits for the micro-scanning stage are presented in Table 3-3. Definitions of the direction and angles are presented in the preceding section 3.2.

The Micro-scanning stage (Figure 4-2) is constructed from a Smaract GmbH Smarpod 6 axis piezo-driven stage. A further 2 rotation stages are mounted on top of the Smarpod to extend the available ranges for two of the rotations. The directions and rotations are defined in section 3.2. The Smarpod itself consists of 3 "long travel" linear piezo stages at the base. On top of this is a further 3 "medium travel" linear piezo stages mounted at right angles to the first 3. There are 3 short travel linear stages mounted in a circle (60 degrees apart) and in an angle out of the plane of the previous stages. These stages are not moved and used purely as linear bearings. This entire system allows for 6 axis motion, with sub nanometer precision and a 20 micron circle of least confusion when rotating around any point in 3D space. In order to extend the angle of photon incidence and in plane rotation angles a further two rotation stages have been mounted on top of the micro-scanning stage.

Mounted on top of all of these stages is a heating/cooling stage which provides for LHe cryo cooling (Advanced Research Systems, 4K ultra low vibration closed cycle LHe cryostat) in addition to direct current sample heating via a heatwave labs heating unit. This whole stage is mounted on top of a

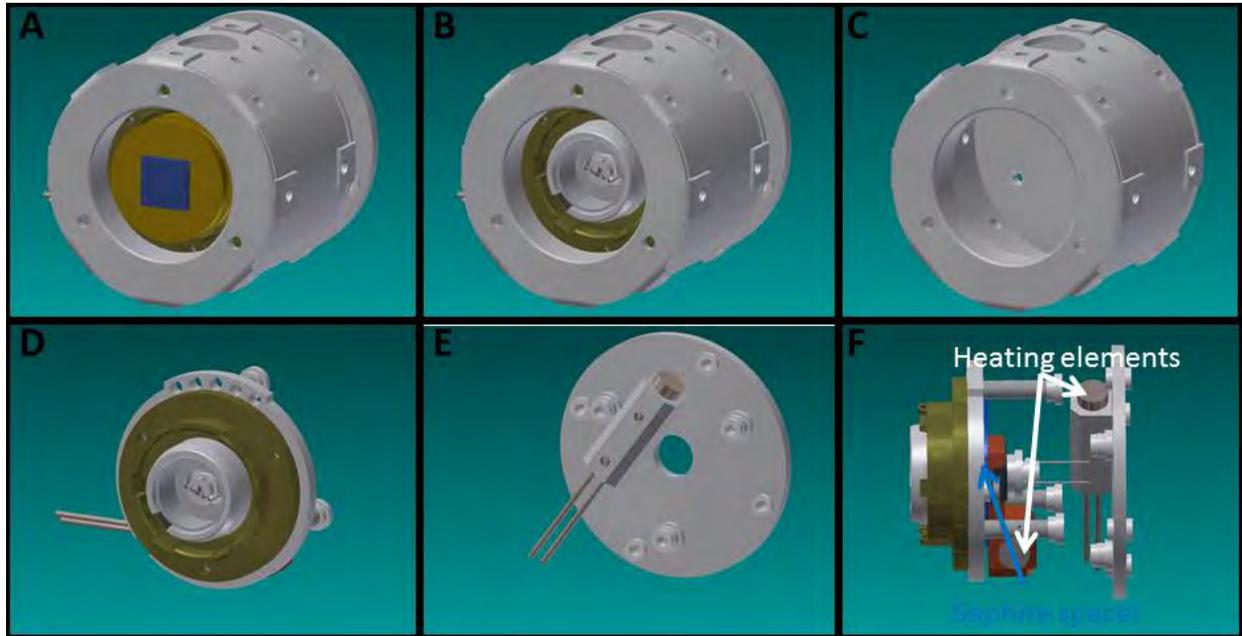


Figure 4-3. Sample mounting stage for piezo positioning stages. Complete (A), minus the sample and puck (B), the cryo shield (C), the sample puck mount(D), the smaract stage heating/ cooling shield (D) and a combined side view of D and E.

4.2.2 Sample mounting stage.

The sample mounting stage, and its components, is shown in Figure 4-3. The samples are mounted on a sample “puck”, made from Cu or Mo. These pucks are designed to “push” on to the sample holder via the radial leaf spring mechanism seen in Figure 4-3 D (commercially available from K. J. Lesker). Located at the bottom left is a small contact switch (black colour in Figure 4-3 D) which acts as a simple I/O switch that indicates the presence, or correct placement, of the puck on the sample holder. The entire sample is surrounded by the “cryo-shield” (Figure 4-3 C), which acts to reduce radiation heat loss. This shield is held at < 100K, while the sample can be held at any temperature in the range indicated in Table 3-3.

In order to prevent the Smaract rotation stage on which it is mounted from cooling to much an independently heated backing plate separates it from the cryo-shield (Figure 4-3 E). The backing plate is heated by a Watlow firerod (# EIA-526) and a thermal diode is mounted to it to allow feedback control. Heating of the sample stage is also via a Watlow firerod (#EIA-526) and controlled using a thermal diode (Figure 4-3 F). Lakeshore temperature controllers will control these heating elements. If higher temperatures can be obtained without overheating the smaract stages (testing necessary) then e-beam heating is also possible. Figure 4-3D shows a filament that sits behind the sample, and a surrounding (electrically isolated) electron shield. For e-beam heating both the electron shield and the filament will be held at high negative voltage while a current is applied through the filament. Electrons emitted from the filament will then be accelerated toward the sample, which is held at ground, and heat the sample. A pyrometer can be used to calibrate the heating, while the sample current to ground and/or a thermocouple will be used to control the heating.

4.2.3 Stage electrical feedthrough descriptions.

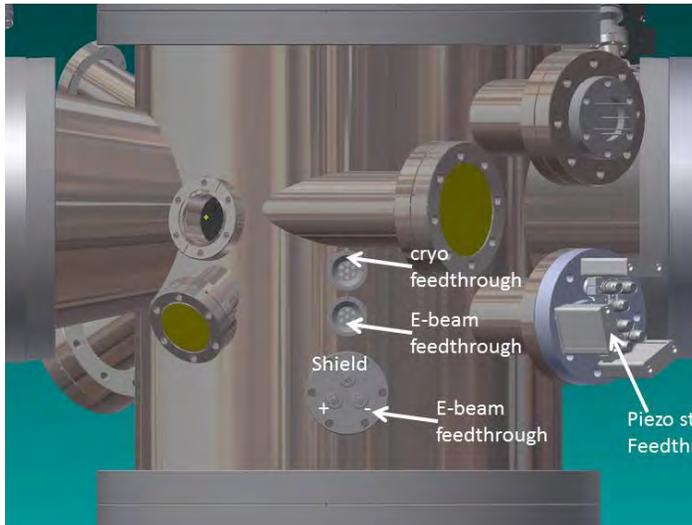


Figure 4-4. View of the electrical feedthroughs for the micro-scanning stage, descriptions of the pin layout for the cryo feedthrough and e-beam feedthrough are given in section 3.3.

The electrical feedthrough locations for the micro-scanning stage are shown in Figure 4-4. The common 7 pin feedthrough pin layouts are described in section 3.3. The layout for the piezo stage and E-beam feedthroughs are shown in Figure 4-4. For the e-beam heating three SHV feedthroughs are supplied, the + and - labels are for the filament while the e-beam shield uses the final feedthrough. The piezo stages use the same feedthrough for each stage; the allocation of a plug to each stage will be labeled in Figure 4-4.

4.3 Sample Transfer assemblies

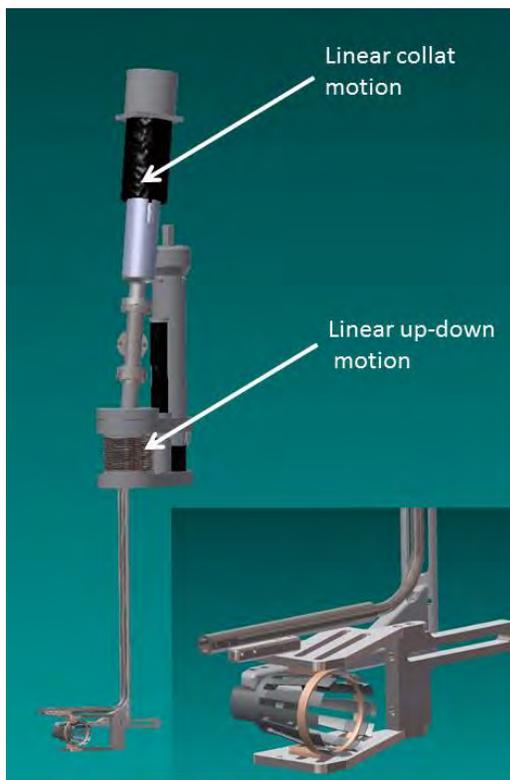


Figure 4-5. Sample transfer arm, these allow for samples to be transferred to/from the various stages in the analysis chamber.

4.3.1 Assembly description.

Transfer from one stage to another in the analysis chamber occurs via a motorized sample transfer “claw” assembly. This allows for transfer to/from the sample preparation manipulator, micro-scanning stage and calibration puck storage locations. Each stage has I/O switches, which indicates that the sample is pushed completely onto the sample stage. These switches, in combination with the sample presence switch on the sample stages, allow for automation of the process of sample transfer.

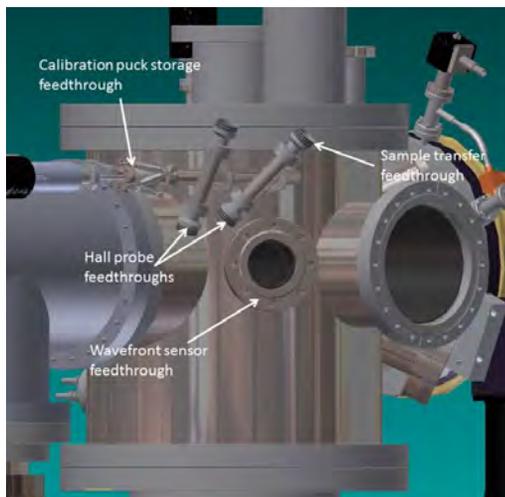


Figure 4-6. Feedthroughs for analysis chamber sample transfer arms.

4.3.2 Assembly electrical feedthrough description.

The sample transfer assemblies require 3 feedthroughs, which are indicated in Figure 4-6. A feedthrough is provided for the location and presence switches on both arms. Finally two feedthroughs are used for the hall probe, each provides connections to 2 single axis, with one set of pins (for one axis) spare. Details on the pin assignments for all of these feedthroughs can be found in section 3.3 and are based on a 7 pin feedthrough.

4.4 Sample view mirror assembly

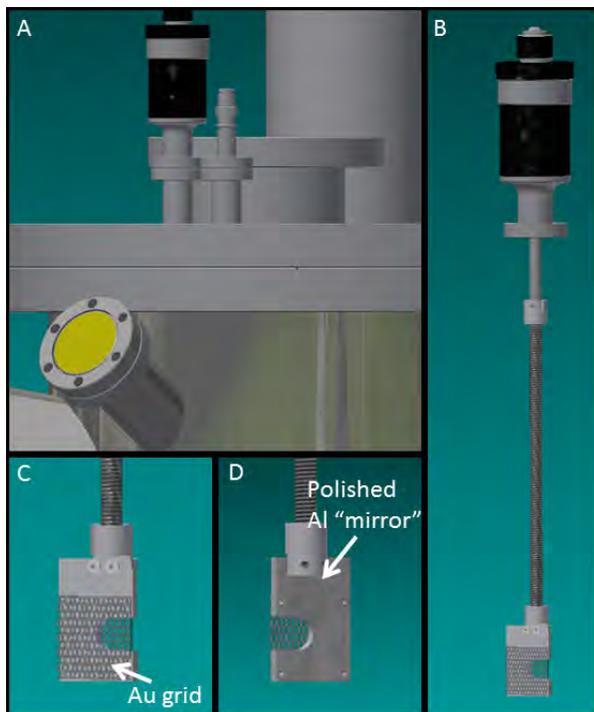


Figure 4-7. Sample view mirror assembly external view (A), complete view (B), upstream zoom (C) and downstream zoom (D).

4.4.1 Assembly description.

In order to be able to view the sample parallel to the beam direction (or very close to it) an in vacuum polished Al mirror is installed between the sample and the beam input port. This mirror is mounted onto a manual rotation/linear drive to allow for alignment, and a microscope lens and camera is installed at 90 degrees to the mirror rotation axis and the beam direction. The mirror is then set at $\sim 45^\circ$ to allow for imaging of the sample. A hole in the mirror is used to allow the light to pass through, while a Au grid covers the hole on the back side of the mirror to allow for measurement of the absorption current. This current can be used for normalizing the data to photon flux. The whole mirror is isolated from the support rod to ensure the current can be measured, while a BNC feedthrough is located next to the rotation positioner for this wire (see Figure 4-7 A).

4.5 Chamber.

4.5.1 Description.

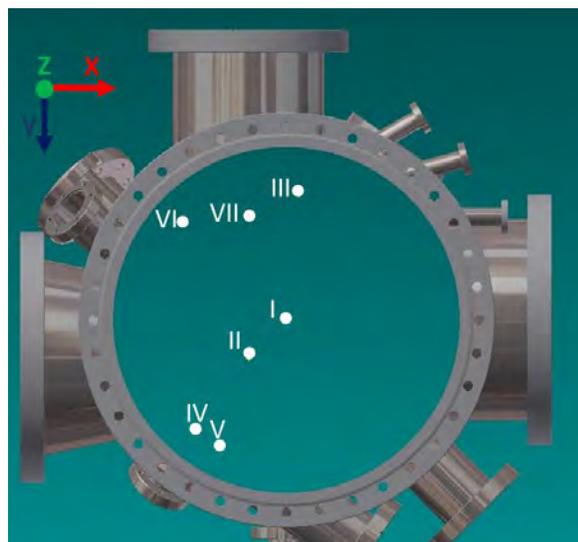


Figure 4-8. Top view of the analysis chamber with the location of the port focal points in the X-Y plane indicated. The xyz co-ordinates are defined in the top right with the origin at the chamber centre (I) and $z = 0$ at the bottom flange face. Angles for the ports are clockwise given in the X-Y plane with the x axis being zero (γ) and above (+ve) and below (-ve) the X-Y plane (β).

The analysis chamber is built around a 10 inch cylinder with 16.5 inch flanges top and bottom. The bottom flange has a 16.5 to 10 inch zero length reducer, and then a 10 inch bellows and a blank flange. The blank flange is fixed to the KB optics granite block and provides a mounting point for the micro-scanning stage; Ensuring vibrational de-coupling from the chamber. The chamber contains a double skin mu-metal magnetic shield inside, with tubes also extending out along each of the larger ports. The inlet port for the incoming beam consists of a welded bellows, which has been welded to the chamber. This is required to de-couple the analysis chamber from the ARPES chamber for alignment and vibrational reasons. The small separation between the analysis chamber and the KB optics chamber requires this flange to be welded to the chamber.

Table 4-1. Description/ location of the analysis chamber focal points of the ports. A top view showing the X-Y plane location is shown in Figure 4-8

Focal point	XY plane label	x position	y position	z position	Focal point description
A	I	0.00	0.00	9.00	Centre of chamber at meas. level
B	I	0.00	0.00	12.00	Ion gauge port
C	I	0.00	0.00	7.00	electrical feedthrough
D	I	0.00	0.00	5.50	Ms- electrical feedthrough
E	I	0.00	0.00	3.00	electrical feedthrough
F	II	-1.50	1.50	9.00	Measurement position
G	III	0.5	-5.00	12.00	ms cryo-stat
H	IV	-3.50	4.40	9.00	Mirror Viewport
I	IV	-2.75	5.50	9.00	mirror motion feedthrough
J	V	-4.90	4.50	9.00	Mirror Electrical feedthrough
K	VI	-3.5	-4.00	9.00	Transfer manipulator
L	VII	-1.50	4.125	13.13	Calibration puck location
M	II	-1.50	-1.50	8.75	Light input port

4.5.2 Chamber port definitions

The focal points for the ports in the main chamber are provided in Table 4-1, and a top view showing their location is shown in Figure 4-8. There are a number of non-critical focal points for the electrical feedthroughs and the LHe cryostat port for the micro-scanning stage. Four critical focal points are also given: measurement position, sample transfer, viewport mirror position and the centre of the chamber at measurement level. A diagram of the chamber, with the ports labeled, is shown in Figure 4-9 along with the mu metal shielding. A port list indicating the angles, focal points, etc. is included in Table 4-2. This completely describes the available ports on the analysis chamber, while the pin layouts of the electrical feedthroughs are described in the sections 4.2, 4.3 and 4.4 for the micro-scanning stage, sample transfer assemblies and sample view mirror assembly respectively.

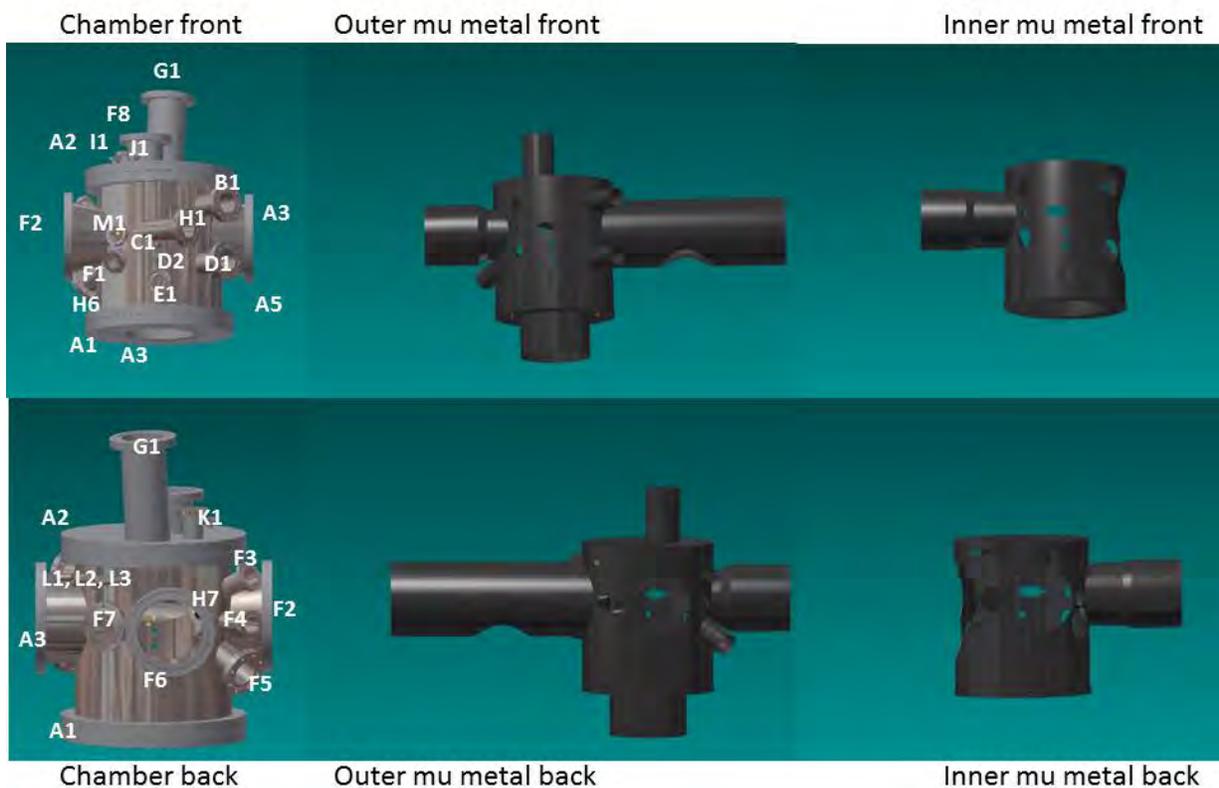


Figure 4-9. Images of the analysis chamber and mu metal shielding. The mu metal shielding consists of an inner and outer skin with separate port tubes. The port tubes have small sections at the ends that follow the contours of the ID of the outer mu metal shield, these become sandwiched between the inner and outer tubes holding them in place. The port labels are also shown on the chamber.

Table 4-2. Port list for the analysis chamber. The beta rotation is defined as above (+ve) and below (-ve) the XY plane while gamma is defined as clockwise around the z axis with zero in the x direction. Flanges 1 and 2 are the top and bottom flanges respectively and port length is from the focal point.

Port no.	Port label	Focal point	β	γ	hole align.	flange size	rot. flange	tapped flange	length	notes
1	A1	A	-90	0	in line	16.5	no	no	9.60	bottom flange
2	A2	A	90	0	in line	16.5	no	no	6.50	top flange
3	A3	A	0	0	in line	10	yes	no	10.5	Pumping unit flange
4	A4	A	-90	0	in line	10	no	yes	10.75	Can be a 16.5" to 10" CF reducer
5	B1	B	0	45	in line	4.5	no	no	10.90	Ion gauge feedthrough
6	C1	C	0	90	in line	1.33	no	Yes	9.00	Electrical feedthrough
7	D1	D	0	45	in line	4.5	no	No	10.90	Scanning stage elec. FT
8	D2	D	0	90	in line	1.33	Yes	yes	9.00	electrical feedthrough
9	E1	E	0	90	in line	2.75	no	yes	9.00	electrical feedthrough
10	F1	F	-30	125	in line	2.75	no	no	8.70	Viewport
11	F2	F	0	180	in line	10	Yes	no	9.00	Conical flange, 6" ID at chamber wall
12	F3	F	25	220	in line	2.75	yes	no	10.00	viewport
13	F4	F	0	225	in line	2.75	yes	no	10.00	Viewport
14	F5	F	-25	225	in line	4.5	Yes	no	10.00	Viewport
15	F6	F	0	270	in line	8	Yes	no	13.00	Prep chamber
16	F7	F	0	305	in line	4.5	Yes	Yes	10.40	Wavefront sensor
17	F8	F	90	0	in line	6	yes	No	11.30	Low temp chamber
18	G1	G	85	305	in line	6	yes	no	10.25	Scanning stage cryo: NB. 4.25OD/4.1 ID tube
19	H1	H	0	35	in line	4.5	yes	Yes	8.30	viewport
20	I1	I	90	0	in line	1.33	No	Yes	8.5	Viewing mirror
21	J1	J	90	0	in line	1.33	no	Yes	8.50	Electrical feedthrough
22	K1	K	90	0	in line	2.75	Yes	No	10.30	Transfer manipulator
23	L1	L	0	0	in line	1.33	yes	no	10.00	Calibration puck dock
24	L2	L	345	0	in line	1.33	yes	No	8.50	Electrical feedthrough
25	L3	L	330	0	in line	1.33	Yes	No	7.5	Electrical feedthrough
26	M1	M	0	125	in line	2.75	No	Yes	5.5	Light input port

4.5.3 Mu metal shielding

The double skin mu metal shielding is shown in Figure 4-9, it is designed with an inner and outer skin and a set of tubes for the ports. The tubes have a flat section, which matches the inner diameter curve of the outer skin. This flat section is screwed to the outer skin to hold it in place. This design allows for the outer skin to be inserted, then each of the tubes placed from the inside and then finally the inner skin is placed inside. This system is necessary, as the double skin mu-metal shield must fit inside taking up very little space. In fact the inner diameter of the inner skin must be > 13.2 inches while the inner diameter of the chamber is 13.75 inches. In addition top and bottom caps are required which also contain some port tubes.

4.6 Control systems

Control systems inside the analysis chamber are used for maintaining and monitoring vacuum, sensing sample position and alignment, moving and transferring samples, heating and cooling samples, viewing samples, measuring experimental variables and characterizing the incoming light beam. The control systems for the analysis chamber are listed in Table 4-3.

Table 4-3. List of control systems in the analysis chamber.

Control type	No.	read	write	Description
Scienta analyzer	1	yes	yes.	Acquires images of emitted electrons.
Wavefront detector	1	yes	yes	Acquires images of the beam wavefront.
Cameras with microscope lens	2	yes	no	Used to image the sample during measurement
Viewing cameras	2	yes	no	Normal cameras for viewing inside the chamber
Stepper motors	3	yes	yes	Used for moving the sample transfer arms and rotating analyzer
Piezo motors	6	yes	yes	6 piezo motor stages for sample positioning (Smaract GmbH)
Pico ammeter	2	yes	no	Reads current to ground from the sample and Au grid
Position sensors	7	yes	no	I/O measurement of sample location/alignment
ARS cryo cooler (lakeshore cont.)	1	yes	yes	Controls the heating and cooling of the sample
Pneumatic gate valves	5	yes	yes	Required for isolating pumps and external chambers
Turbo-molecular pump	2	yes	yes	Controlling the turbo molecular pump
Large ion pump	1	yes	yes	Controlling the large ion pump
Small ion pump	1	yes	yes	Controlling the small ion pump
Ion Gauge	1	yes	yes	Controlling the ion gauge
Ti sublimation pump	1	no	yes	Controlling the Ti sublimation pump
Getter pump	1	no	yes	Controlling the Getter pump
Residual gas analyzer	1	yes	yes	Controlling the residual gas analyzer

5 Preparation chamber

5.1 Introduction

The preparation chamber is shown in Figure 5-1 with the main components highlighted. The chamber is centered around a four axis (X,Y,Z and θ) manipulator from Mcallister Technical Services with a Coldedge 10K LHe closed cycle cryo cooler attached. Mounted on the end of the cryo cooler is a dual sample location mounting stage, labeled the sample preparation stage to distinguish it from the micro-scanning stage in the analysis chamber. The sample preparation stage is designed to allow it to be inserted into the analysis chamber so that measurements can be taken on either of the two sample mounting stage locations. Both locations rely on the out of vacuum motion of the manipulator, but the first has 3 permanent coil magnets allowing for magnetization in any 3D direction. The chamber itself has provision for four evaporators for thin film growth, which can be replaced without breaking the vacuum of the chamber. It also employs a sputter gun, motorized leak valve for controlled gas reactions and a Low Energy Electron Diffraction system for sample cleaning, growth and characterization. The chamber itself has 2 focal points, one for sample cleaning and thin film growth and a second for transfer to/from the loadlock and for LEED measurements. It also employs a Residual Gas Analyzer and has two dropped sample recovery valves, one under each focal point.

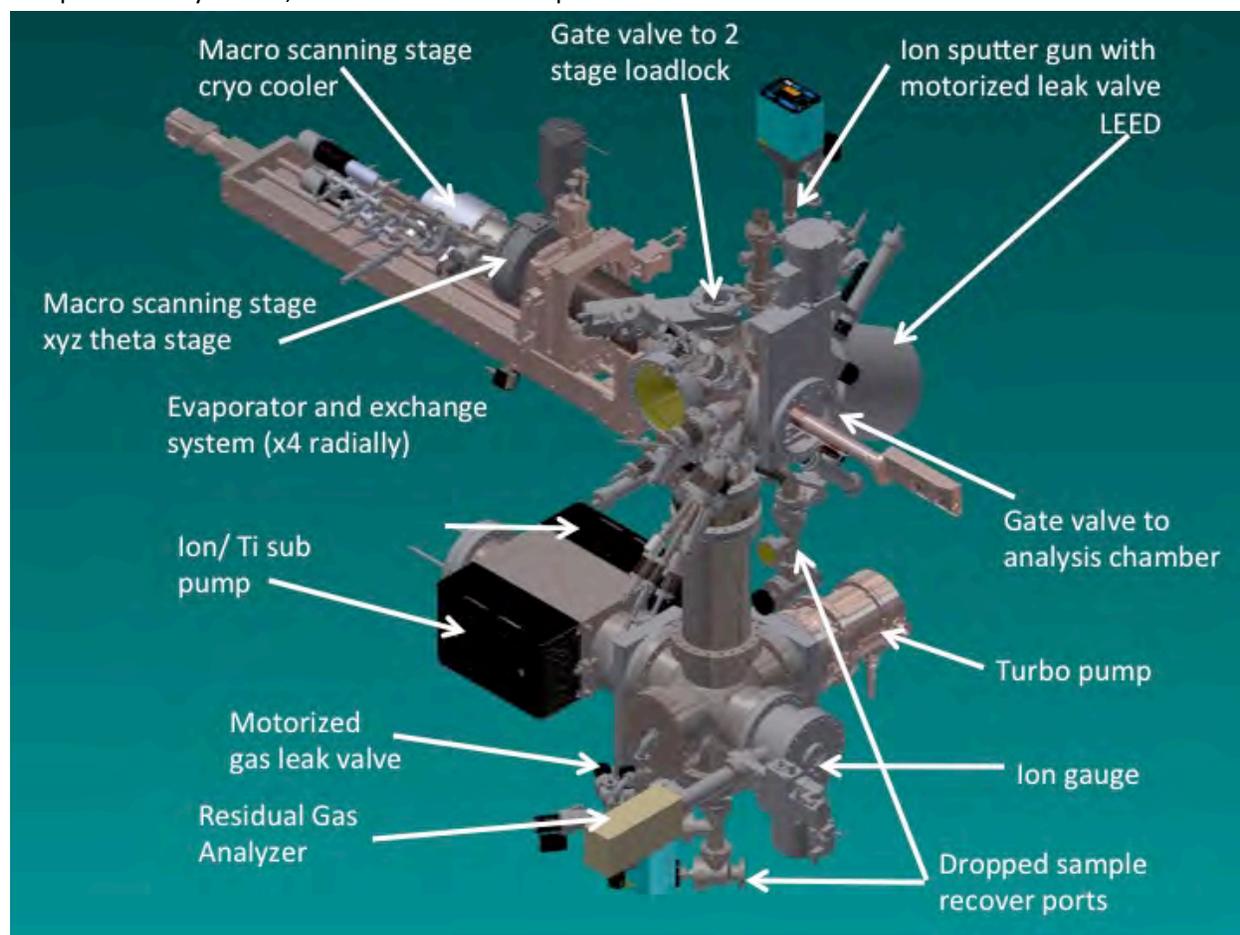


Figure 5-1. Diagram showing the preparation chamber with the main components highlighted.

5.2 Sample preparation stage.

5.2.1 Stage description.

The sample preparation stage (Figure 5-2 A) is designed to be used in both the preparation and analysis chambers, allowing for sample preparation, characterization and ARPES measurements. The main drawback of this system is the reduced scanning resolution and increased vibration level when compared to the micro-scanning stage. It has two sample locations, shown in Figure 5-2 B. The both locations rely entirely on the 4 axis manipulator that the stage is mounted on, however the first location features 3 orthogonal coil magnets allowing for magnetization in any direction. Both stages are equipped with a watlow firerod direct heating element for controlling the sample temperature, in addition an e-beam heating stage is also mounted on each location. Control of the heating is automated to ensure that the sample stages are not overheated at any point.

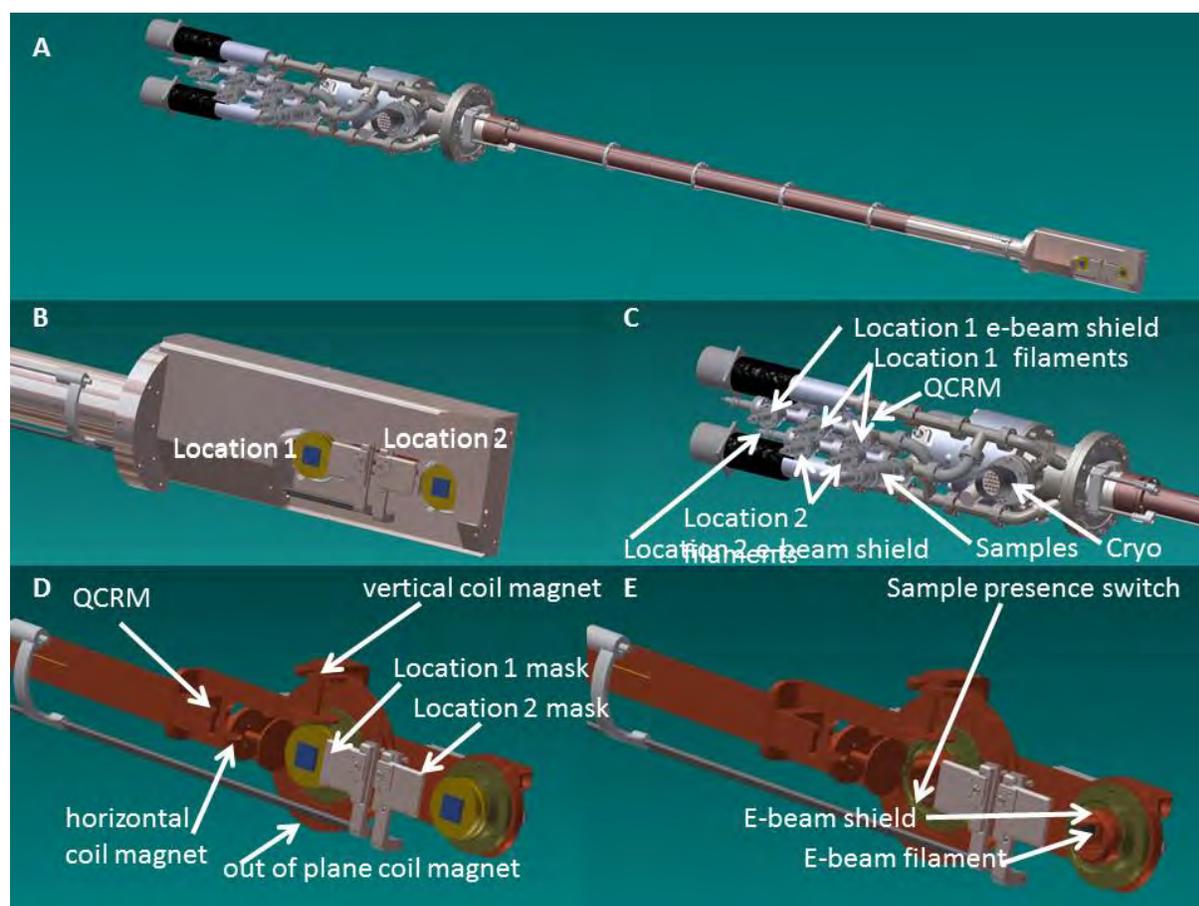


Figure 5-2. Sample preparation stage overview (A), manipulator head (B), electrical feedthrough labels (C) and the sample locations with (D) and without (E) a mounted sample.

5.2.2 Sample preparation 1 (sp1) location.

The sp1 sample location, without the cryo-shield, is shown in Figure 5-2 D (with sample) and E (without sample). The samples are mounted on a sample “puck”, made from Cu or Mo. These pucks are designed to “push” on and “pull” off the sample holder via the radial spring mechanism seen in Figure 5-2 E. Located at the top is a small contact switch which acts as a simple I/O switch that indicates the presence, or correct placement, of the puck on the sample holder. The entire sample is surrounded by the “cryo-shield” (Figure 5-2 B), which acts to reduce radiation heat loss. This shield is held at ~ 100K, while the sample can be held at any temperature in the range indicated in Table 3-3.

The motion and temperature limits for the SP1 sample location are given in Table 3-3. Heating of the stage is via a watlow firerod heating element (#EIA-526) located behind the sample in Figure 5-2 D and E. If higher temperatures are required then e-beam heating is also possible. Figure 5-2 E shows a filament which sits behind the sample, and a surrounding (electrically isolated) electron shield. For e-beam heating both the electron shield and the filament will be held at high negative voltage while a current is applied through the filament. Electrons emitted from the filament will then be accelerated toward the sample (held at ground), which heat the sample. A pyrometer can be used to calibrate the heating, while the sample current to ground and/or a thermo-couple will be used to control the heating. In addition three, orthogonally oriented, coil magnets are placed around the sample allowing for magnetization in any direction. The size of the magnetic field possible is shown in Table 3-3.

5.2.3 Sample preparation 2 (SP2) location.

The SP2 location is shown in Figure 5-2 B and is identical to the SP1 location, without the addition of the magnets. For the position, angle and temperature limits and resolutions for this stage refer to Table 3-3.

5.2.4 Stage electrical feedthrough descriptions.

The electrical feedthroughs for the macro-scanning stage are all located at the top of the manipulator so that any motion of the cables occurs outside vacuum. The feedthroughs are located on a series of mini-conflat T adapters, which allows them to be placed tight to the cryo cooler head. This is essential to allow for as much rotation of the differentially pumped rotary feedthrough (DPRF) as possible without the feedthroughs contacting the backbone of the manipulator. The designation of each of the feedthroughs is shown in Figure 5-2 C, with those with more wires located closer to the manipulator. There is a single 7 pin feedthrough for the sample and cryo connections and SHV feedthroughs for the connections to the e-beam filaments and shield. In addition there is a BNC connector for the quartz crystal rate monitor (QCRM). The in vacuum wires for each of these feedthroughs are coiled around the cryo cooler tube inside the cryo “shield” this has the double benefit of protecting the wires and precooling the wires to prevent heat loss from the sample via conduction through the wires.

5.3 Evaporation equipment.

5.3.1 Evaporator exchange system.

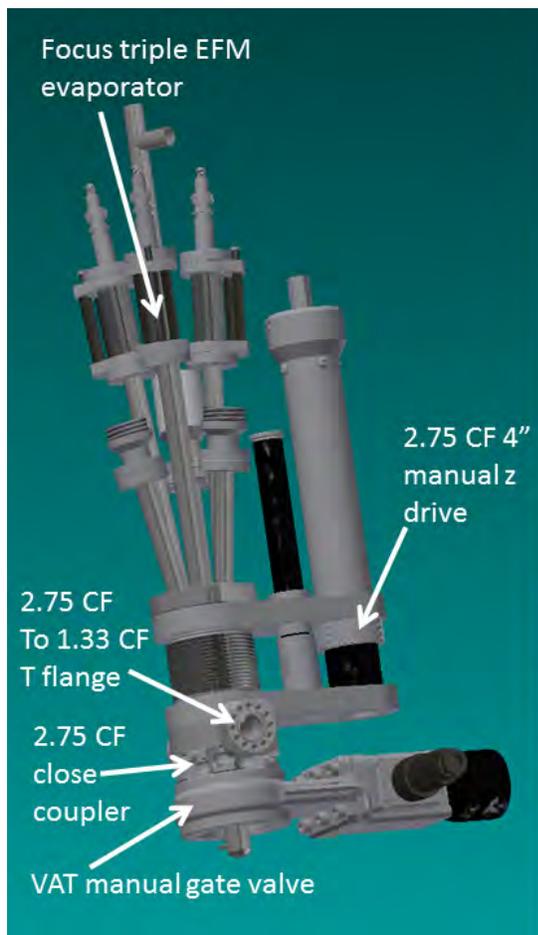


Figure 5-3. Evaporator exchange assembly.

The evaporator exchange assembly, used on each of the four evaporator ports, is shown in Figure 5-3. This system allows for evaporators in each of the four locations to be replaced/ fixed without breaking the vacuum of the preparation chamber. In Figure 5-3 a triple EFM evaporator from Focus is shown, however the system will also work with EFM 3 Focus evaporators and of course homemade evaporators of the correct length. The system consists of a VAT 2.75 CF valve (35 mm width) a close coupler (to allow the valve to be mated to a z translator), a 2.75 to 1.33 CF flange cross and a 4 " z drive. One of the 1.33 CF ports on the flange cross is connected to the backing line system to allow for pump-down of the z drive/ evaporator region. The gate valve allows the z drive/evaporator section to be isolated from the preparation chamber for venting. The z drive allows the evaporator to be moved from the evaporation position to clear the gate valve for venting. For evaporation of multiple atomic species at the same time use the triple evaporator, for other evaporation use the EFM 3 evaporators or a home-made evaporator. For e-beam rod evaporation use the downward facing ports while for crucible evaporation use the upward facing ports.

5.3.2 Evaporator mask assembly.

The mask assembly for evaporation growth is shown in Figure 5-2. These are designed to allow for the growth of thin film wedges. Initially the mask will be placed in front of the sample, the mask is then moved (at the correct rate) during growth ensuring that one side of the sample has a thicker film than the other. The masks z drive is motorized so that the evaporation can be automated and performed remotely; this ensures that the growth is highly reproducible and controlled. In addition the mask can be placed so that it almost touches the sample surface ensuring a sharp edge to the growth pattern. This combined with automation of the evaporators ensures that growth of thin film samples with micron sized features is reproducible and controllable.

5.4 Dropped sample recovery assembly.



Figure 5-4. Dropped sample recovery assembly.

In order to ensure that samples that are “dropped” in the preparation chamber can be removed without venting the chamber underneath each of the sample focal points is a dropped sample recovery port. Attached to these ports is the assembly shown in Figure 5-4. Inside the chamber will be a grid in a “funnel” shape which directs all dropped samples to one of the two ports. The samples will then drop down onto a second metal grid placed in through the window seen in Figure 5-4. At this point the gate valve can be closed, the T section vented and the sample recovered by removing the window. After this has occurred then the angle valve at the bottom is opened to allow for the section to be pumped out, after which it is closed and the gate valve again opened. In order to ensure that samples do not get “caught” on or damage the gate valve it should remained open whenever possible. The angle valve can be connected to the backing system for pumping down. Care must be taken to remove dropped samples ASAP so that they don’t accumulate to the point that the gate valve can no longer be closed.

5.5 Gas leak valve system and ion sputter gun system

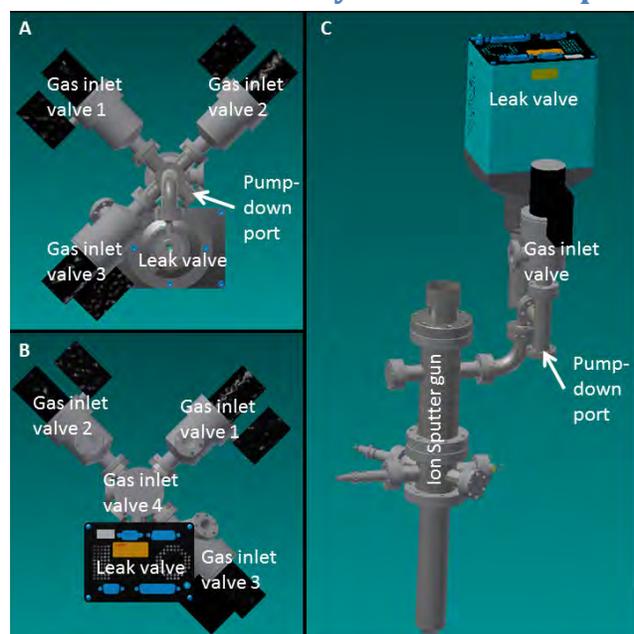


Figure 5-5. Gas inlet valve system and ion sputter gun system.

The preparation chamber has a gas inlet system, for CVD growth or chemical cleaning of samples, and an ion sputter gun, for cleaning of samples. The leak in valves has 4 independent gas inlet valves, a port for pumping down the inlet side of the leak valve and a motorized leak valve for accurate feedback control of the pressure. The ion sputter gun is a Specs GmbH differentially pumped ion sputter source (model IQE 11/35), which ensures that the pressure near the sample surface is kept low. The power supply for the sputter gun (PU-IQE11) has IEC 488 or RS232 control interfaces which will allow for remote and programmable operation. These systems, in addition with the controllable sample growth system, provide a highly repeatable and controllable sample preparation capability.

5.6 Low Energy Electron Diffraction setup

The Low Energy Electron Diffraction (LEED) set up is a Specs ErLEED 150CF system. This system has a beam which is < 1mm and provides a beam current up to 15 μA for beam energies in the range 0-3000V. The LEED system is connected to a low light digital camera, which can be used instead of the analyzer camera in the end-station software. This allows for LEED data to be obtained using the same methods as employed for the ARPES, including in a scanning mode. The power supply unit (ErLEED 3000D) has an RS232 interface to allow for remote and programmable LEED measurements, and the system has the capability to do both LEED and AES spectroscopy.

5.7 Chamber.

5.7.1 Description.

The preparation chamber is built around a 6 inch cylinder with 8 inch flanges at either end. At one end the chamber mounts to a gate valve and then the analysis chamber, at the other end the 4 axis manipulator for the macro-scanning stage is mounted. There are two focal points in the chamber, one for evaporators/sputtering of the sample ($z = 4.2''$ from flange A1) and a second one with a large viewport for transferring to/from the loadlock and for measuring LEED ($z=9.8''$ from flange A1). A third focal point is in the same X-Y plane ($z=9.8''$ from A1) as the LEED/viewport flange but set 7'' (in negative Y direction) below for a vacuum gauge. The chamber also contains an automated system for leaking in various gases for chemical growth and cleaning of samples.



Figure 5-6. Images of the preparation chamber with the ports numbered.

Table 5-1. Port list for the preparation chamber. The beta rotation is defined as above (+ve) and below (-ve) the XY plane while gamma is defined as clockwise around the z axis with zero in the x direction. Flanges 1 and 2 are the top and bottom flanges respectively and port length is from the focal point.

Port no.	Port label	Focal point	β	γ	hole align.	flange size	rot. flange	tapped flange	length	notes
1	A1	A	180	0	in line	8	yes	yes	0.00	Analysis chamber
2	A2	A	0	0	in line	6 (4.25" ID)	no	yes	12.15	manipulator
3	A3	A	90	0	in line	2.75	yes	no	4.70	evaporator
4	A4	A	90	45	in line	2.75	yes	no	4.70	evaporator
5	A5	A	90	90	in line	2.75	yes	no	4.70	evaporator
6	A6	A	90	135	in line	2.75	yes	no	4.70	evaporator
7	A7	A	90	180	in line	2.75	yes	no	4.70	evaporator
8	A8	A	90	225	in line	2.75	yes	no	4.70	evaporator
9	A9	A	90	270	in line	2.75	yes	no	4.70	evaporator
10	A10	A	90	315	in line	2.75	yes	no	4.70	evaporator
11	A11	A	40	45	in line	2.75	yes	no	6.25	viewport
12	B1	B	90	0	in line	4.5	yes	no	4.90	loadlock
13	B2	B	90	135	in line	8	yes	no	12.00	LEED
14	B3	B	90	180	in line	8 (5"OD tube)	no	no	11.50	Pumping section
15	B4	B	90	270	in line	6	yes	no	6.00	viewport
16	C1	C	90	270	in line	4.5	no	no	7.00	Ion gauge

5.7.2 Chamber port definitions

The port focal point for the preparation chamber is shown in Figure 5-7, and the port list is given in Table 5-1. Together these completely describe the preparation chamber.

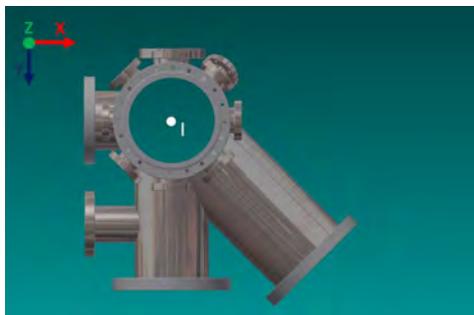


Figure 5-7. End view of the preparation chamber with the location of the port focal points in the X-Y plane indicated. The xyz co-ordinates are defined in the top right with the origin at the chamber centre (I) and z = 0 at the bottom flange face.

5.8 Control systems

Control systems inside the Preparation chamber are used for maintaining and monitoring vacuum, sensing sample position and alignment, moving and transferring samples, heating and cooling samples, viewing samples, cleaning/preparing samples, measuring experimental variables and characterizing the incoming light beam. The control systems for the analysis chamber are listed in Table 5-2.

Table 5-2. List of control systems in the preparation chamber.

Control type	No.	read	write	Description
LEED	1	yes	yes	Used for LEED measurements of the sample
Low light camera	1	yes	no	Used for imaging the LEED pattern.
Viewing cameras	3	yes	no	Normal cameras for viewing inside the chamber
Stepper motors	8	yes	yes	Used for moving the sample and the evaporator masks
Piezo motors	2	yes	yes	2 piezo motor stages for sample positioning (Smaract GmbH)
Pico ammeter	2	yes	no	Reads current to ground from the sample and Au grid
Position sensors	2	yes	no	I/O measurement of sample location/alignment
Gas leak valves	2	no	yes	Used for leaking gas into the chamber (CVD and sputtering)
ARS cryo cooler (lakeshore cont.)	1	yes	yes	Controls the heating and cooling of the sample
Pneumatic gate valves	4	yes	yes	Required for isolating pumps and external chambers
Turbo-molecular pump	1	yes	yes	Controlling the turbo molecular pump
Large ion pump	1	yes	yes	Controlling the large ion pump
Small ion pump	1	yes	yes	Controlling the small ion pump
Ion Gauge	1	yes	yes	Controlling the ion gauge
Ti sublimation pump	1	no	yes	Controlling the Ti sublimation pump
Residual gas analyzer	1	yes	yes	Controlling the residual gas analyzer

6 Low Temperature chamber

6.1 Introduction

In addition to the macro-scanning and micro-scanning stages the end-station also has a low temperature stage. This stage is designed for working in the low temperature region (~ 5 K) which is not accessible on the other two stages. Accessing this low temperature region is essential in order to make use of the sub-millivolt resolution of the beamline as thermal broadening of the data is an issue at such resolutions. In order to ensure that such a low temperature is possible all unnecessary motions/connections are removed and the sample is directly “glued” to a stage which is bolted directly to the LHe cryostat. As the sample cannot be transferred to/from this stage a small preparation chamber is also included. The chamber is shown in Figure 4-9 A, while the stage is shown in B-D. Changing a sample on this stage requires venting the low temperature chamber and re-baking the system. In addition to the lack of in-vacuum motions and sample transfer ability

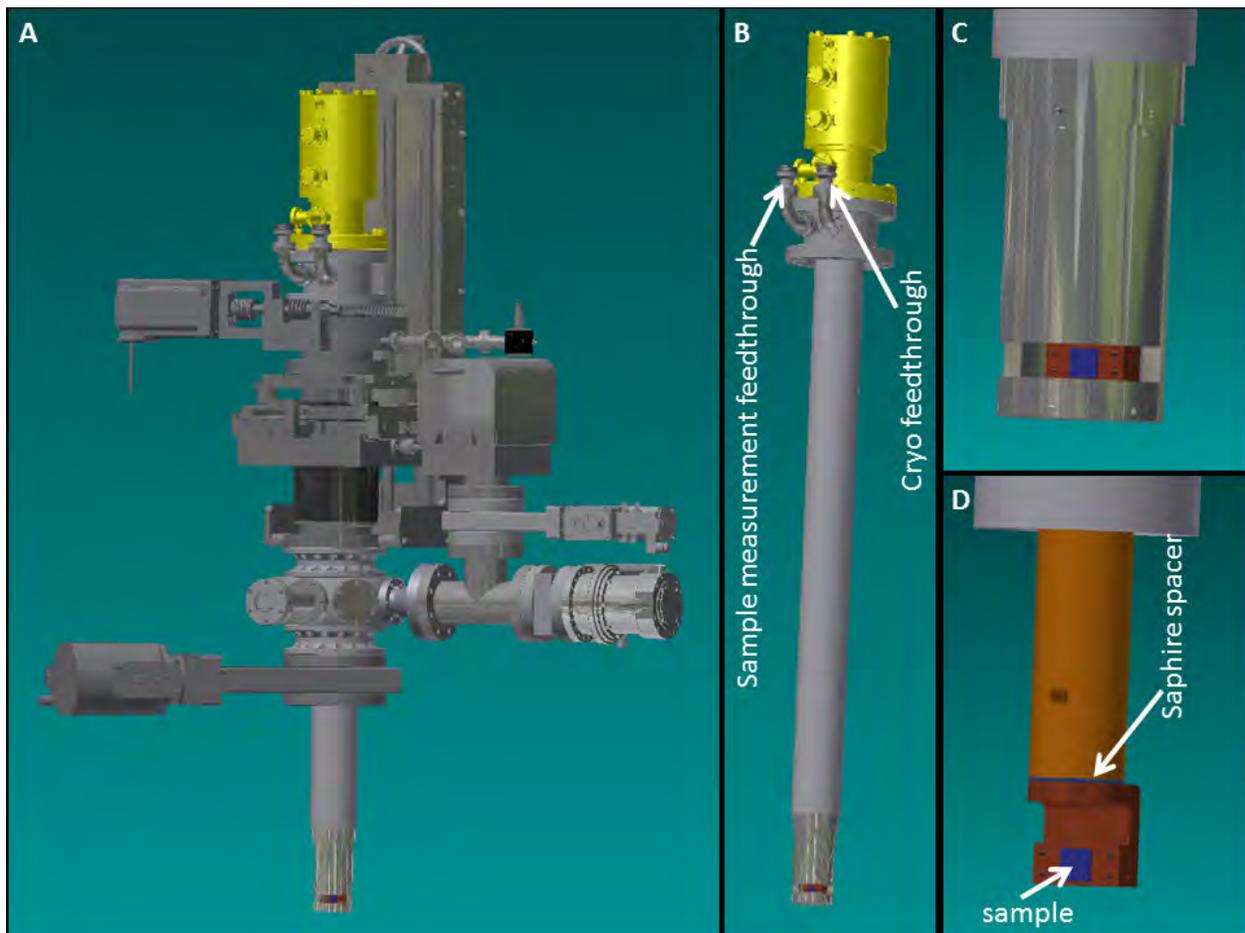


Figure 6-1. Low temperature chamber (A), stage (B), zoom of sample with (C) and without (D) cryoshield.

6.2 Stage Description

The low temperature stage (Figure 6-1) is designed to be used for low temperature/ high resolution ARPES measurements. It consists of a around a four axis (x,y,z and θ) manipulator from Mcallister Technical Services with an Advanced Research Systems 4K LHe closed cycle cryo cooler attached. The cryo-cooler assembly is shown in Figure 6-1 B, the two feedthroughs are described in section 3.3 as they are common sample measurement and cryo feedthroughs. While the feedthroughs are based on the common design in this case only the sample current and a single thermal diode are connected to avoid electrical and thermal noise at the sample. Control of the sample temperature is done via the heater inside the cryo-cooler head which is electrically isolated form the sample via a sapphire spacer. The limits and resolution of motion and temperature is shown in Table 3-3. In order to ensure that the temperature at the sample is as low as possible the sample is “glued” to a small Cu piece that is the only part directly connected to the cryo-head. This ensures minimal heat load on the cryo-stage and the lowest possible sample temperature.

6.3 Chamber.

6.3.1 Description.

The preparation chamber is built around a 6 inch spherical octagon chamber from Kimball Physics, this provides up to 6 2.75” CF ports for evaporators/ sputter guns and other preparation equipment as required, as well as one each for the vacuum pumps and the ion gauge. As the chamber needs to be vented each time a new sample is installed then the complicated evaporator exchange system is not required.

6.4 Control systems

Control systems inside the low temperature chamber are used for maintaining and monitoring vacuum, moving and transferring samples, heating and cooling samples, viewing samples and measuring experimental variables. The control systems for the analysis chamber are listed in Table 6-1.

Table 6-1. List of control systems in the preparation chamber.

Control type	No.	read	write	Description
Viewing cameras	1	yes	no	Normal cameras for viewing inside the chamber
Stepper motors	4	yes	yes	Used for moving the sample and the evaporator masks
Pico ammeter	1	yes	no	Reads current to ground from the sample and Au grid
ARS cryo cooler (lakeshore cont.)	1	yes	yes	Controls the heating and cooling of the sample
Pneumatic gate valves	3	yes	yes	Required for isolating pumps and external chambers
Turbo-molecular pump	1	yes	yes	Controlling the turbo molecular pump
medium ion pump	1	yes	yes	Controlling the medium ion pump
small ion pump	1	yes	yes	Controlling the small ion pump
Ion Gauge	1	yes	no	Controlling the ion gauge

7 Load-Lock chamber

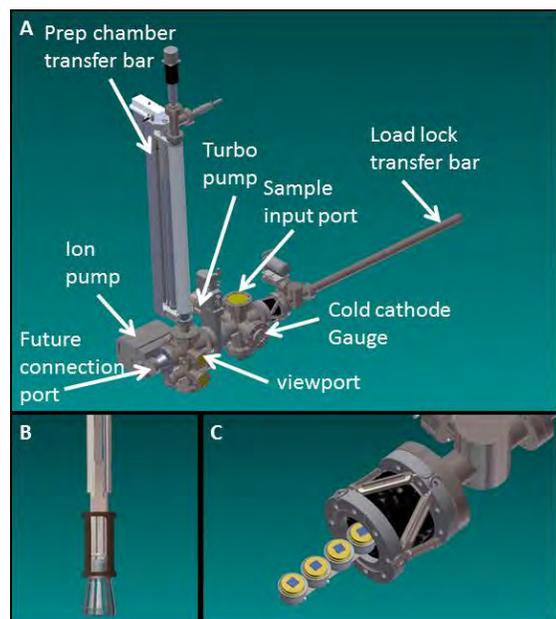


Figure 7-1. Load-lock chamber (A) with the main features labeled. In addition the sample forks for the prep chamber transfer bar (B) and vacuum transfer bar

7.1 Introduction

The load lock chamber is a double stage system for introducing a sample quickly into the preparation chamber without affecting the prep-chamber vacuum. It is shown in Figure 7-1 A. This is achieved by having a second chamber between the load-lock and the preparation chamber. The load-lock is vented to air, and up to four samples can be entered into/removed from the vacuum at a time. This section is then pumped down to the 5×10^{-6} torr range (over \sim an hour), at this point the valve between the input chamber and the transfer chamber can be opened (as the transfer chamber is kept under vacuum, $\sim 5 \times 10^{-9}$ torr level). The sample is then transferred to the transfer chamber, where the pressure is expected to rise into the low 10^{-7} torr range, and then the valve between the two is again closed. After about a further 20 minutes the pressure in the transfer chamber will have recovered to the 5×10^{-9} torr range and then transfer into the preparation chamber can occur without affecting the low 10^{-10} torr pressure.

The valves will be automated and the pressures monitored by a computer program which prevents the valves from being opened if the pressure difference is too large. This will prevent users from opening the valves earlier than necessary to ensure good vacuum. In the preparation chamber the transfer can occur to either one of the sample locations, ensuring that one sample can be entered and one removed into the transfer chamber at a time. It is expected that a future upgrade will add a connection from the transfer chamber to a large sample storage chamber, and extra sample preparation chambers.

7.2 Preparation chamber transfer bar

The preparation chamber transfer bar claw is shown in Figure 7-1 B. The claw has an I/O switch indicator that is used to recognize if a sample is present (and that it is correctly placed on the claw). These systems allow for the transfer to/from the prep chamber transfer bar to be automated. The feedthrough is a standard sample transfer feedthrough described in section 3.3.

7.3 Load lock transfer bar

The load lock transfer bar stage is shown in Figure 7-1 C, and has four sample locations to allow for the input or extraction of four samples at a time. The stage itself consists of four spring loaded “docks” for

the samples to be placed in. An I/O switch indicator is used to recognize if a sample is present in each of the docks (and that it is correctly placed on the dock). The feedthrough is a standard sample transfer feedthrough described in section 3.3.

7.4 Control systems

Control systems inside the load-lock chamber are used for maintaining and monitoring vacuum, sensing sample position and alignment, moving and transferring samples, viewing samples, cleaning/preparing samples. The control systems for the load-lock chamber are listed in Table 7-1.

Table 7-1. List of control systems in the load-lock chamber.

Control type	No.	read	write	Description
Viewing cameras	2	yes	no	Normal cameras for viewing inside the chamber
Stepper motors	3	yes	yes	Used for moving the two transfer bars and opening the claw
Position sensors	6	yes	no	I/O measurement of sample location/alignment
Pneumatic gate valves	1	yes	yes	Required for isolating the load lock from the transfer chamber
Turbo-molecular pump	1	yes	yes	Controlling the turbo molecular pump
medium ion pump	1	yes	yes	Controlling the Medium ion pump
Ion Gauge	1	yes	yes	Controlling the ion gauge

8 Backing system

8.1 Introduction

The backing manifold system ensures that the minimum number of backing pumps are required to back the turbo pumps, Differentially pumped units, gas inlet valves and the removable evaporators. An image of the backing manifold is shown in Figure 8-1 A, As the valves and Gauges complicate the picture a simplified version, showing only the manifold 6 way crosses, is shown in Figure 8-1 B. The ports are numbered in Figure 8-1 B and the port assignments are listed in Table 8-1. The manifold is usually pumped via a turbo with a diaphragm backing pump, and a computer program switches between each of the lines consecutively so that it is only opened to one at a time. When a chamber needs pumping down then the manifold is closed to the turbo and opened to the scroll pump for quick pump down.

This system then ensures that only a single diaphragm pump is required for backing the end-station which reduces cost and noise, it also allows for a quick pump down using a scroll pump without requiring a complicated process of disconnecting backing lines and reconnecting others. The system is automated to allow for one button vent/pump-down routines to be written, this reduces the number of vacuum accidents caused when a valve is left open by accident during a vent/pumpdown.

Table 8-1. Assignment of the ports on the backing manifold, the labels are shown in Figure

No.	name	description
A1	Prep	Prep. chamb. Turbo
A2	recovery	Sample recovery
A3	low temp	Low temp. Turbo
A4	Turbo	Backing Turbo
A5	scroll	Scroll pump
A6	LL	Load-lock Turbo
A7	analysis	Anal. Chamb. Turbo
A8	analyzer	Analyzer Turbo
A9	gauge	Convectron gauge
B1	Sputter 1	Ion gun Diff pump
B2	Sputter 2	Ion gun gas
B3	Evap.	Evaporator exchange
B4	DPRF	DPRF
B5	gas	Gas leak valve

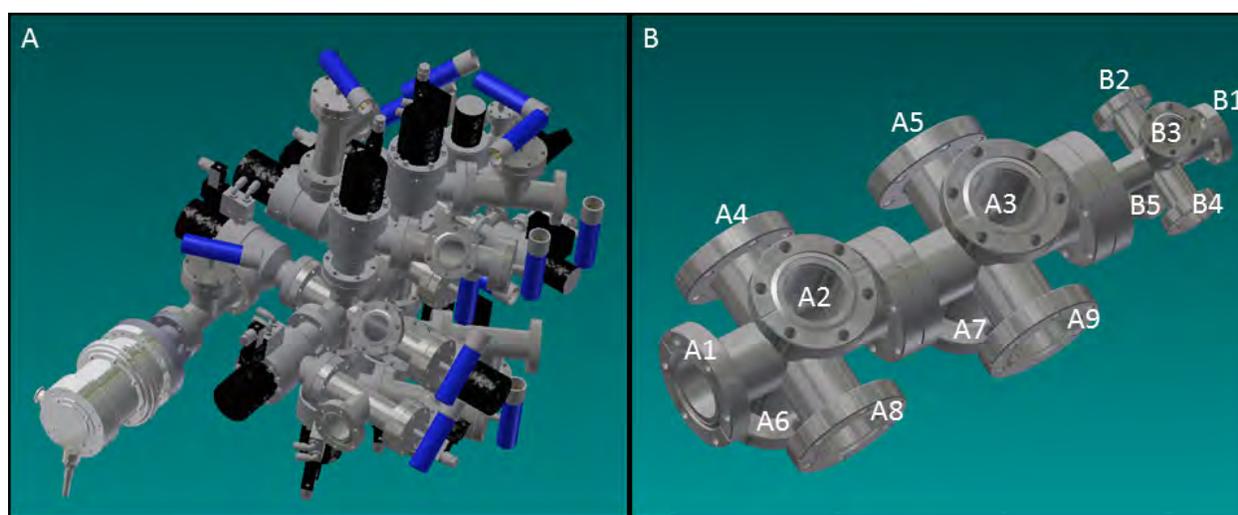


Figure 8-1. Backing manifold system.

8.2 Control systems

Control systems inside the Preparation chamber are used for maintaining and monitoring vacuum, sensing sample position and alignment, moving and transferring samples, heating and cooling samples, viewing samples, cleaning/preparing samples, measuring experimental variables and characterizing the incoming light beam. The control systems for the analysis chamber are listed in Table 5-2.

Table 8-2. List of control systems in the preparation chamber.

Control type	No.	read	write	Description
Angle valves	13	yes	yes	Used for separating the various systems from the backing pump
Turbo-molecular pump	1	yes	yes	Controlling the turbo molecular and diaphragm pump
Scroll pump	1	yes	yes	Controlling the scroll pump
Convectron gauges	15	yes	no	Reading the convectron gauges

9 Appendices

9.1 Appendix 1: Table of abbreviations

Abbreviations	Description
ARPES	Angle Resolved Photoemission Spectroscopy
sp1	Sample preparation manipulator location 1
sp2	Sample preparation manipulator location 2
ms	micro-scanning stage location
lt	low temperature stage location
X, Y, Z, Rx, Ry, Rz	direction labels for analyser lens axis (see Fig. XXX)
X, Y, Z, θ , Φ , β	direction labels for sample surface axis (see Fig. XXX)
sa	Scienta analyzer motion prefix
DPRF	Differentially pumped rotary feedthrough
QCRM	Quartz crystal rate monitor