APS-U Beamline Design & Standard Components

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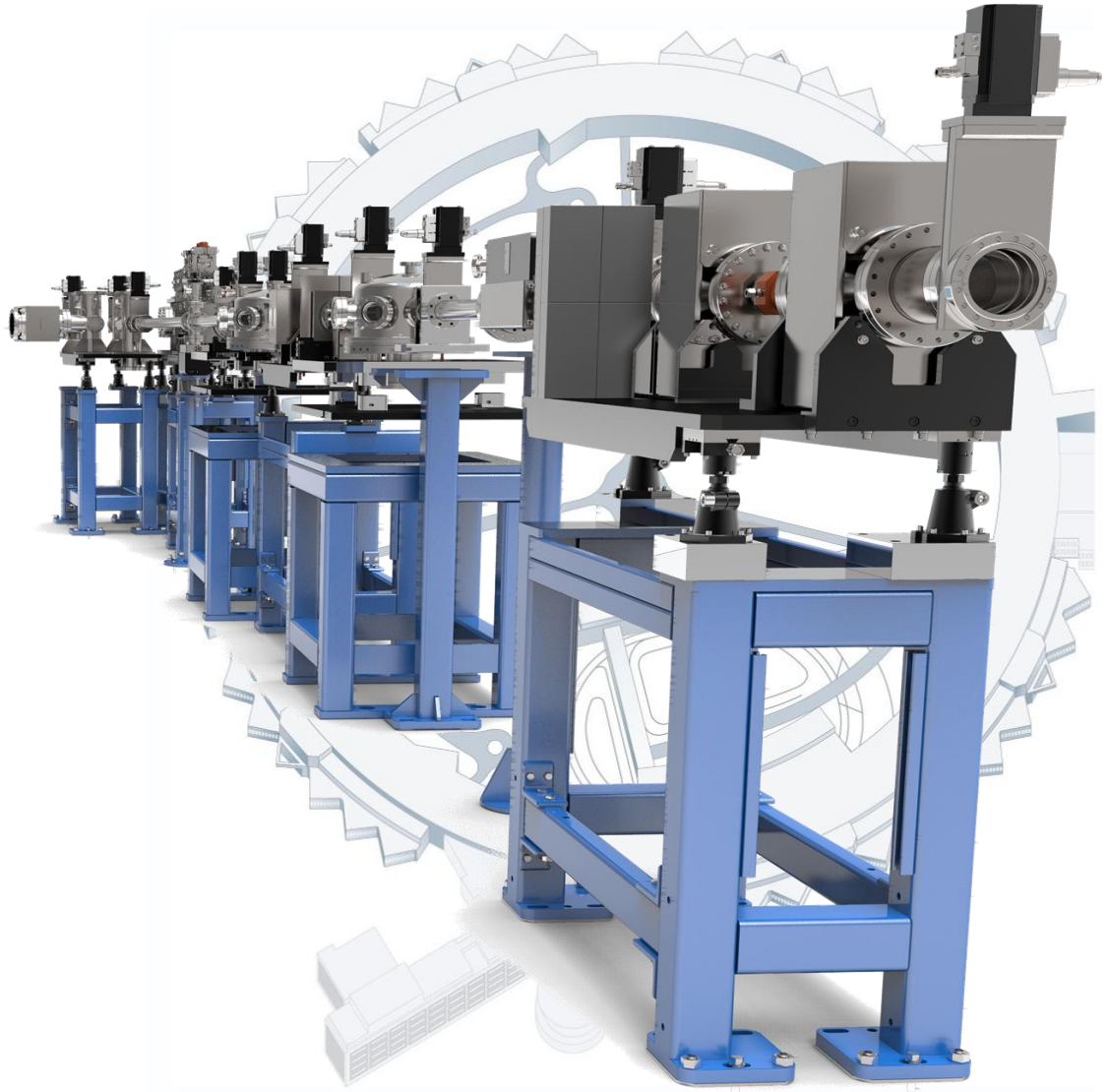
BNL Beamline Engineering Meeting- March 25-26, 2019

APS-U Feature Beamlines

- To take full advantage of the higher brightness and higher energy of the new storage ring, 9 “feature” beamlines have been chosen to showcase these capabilities and deliver world class scientific programs.

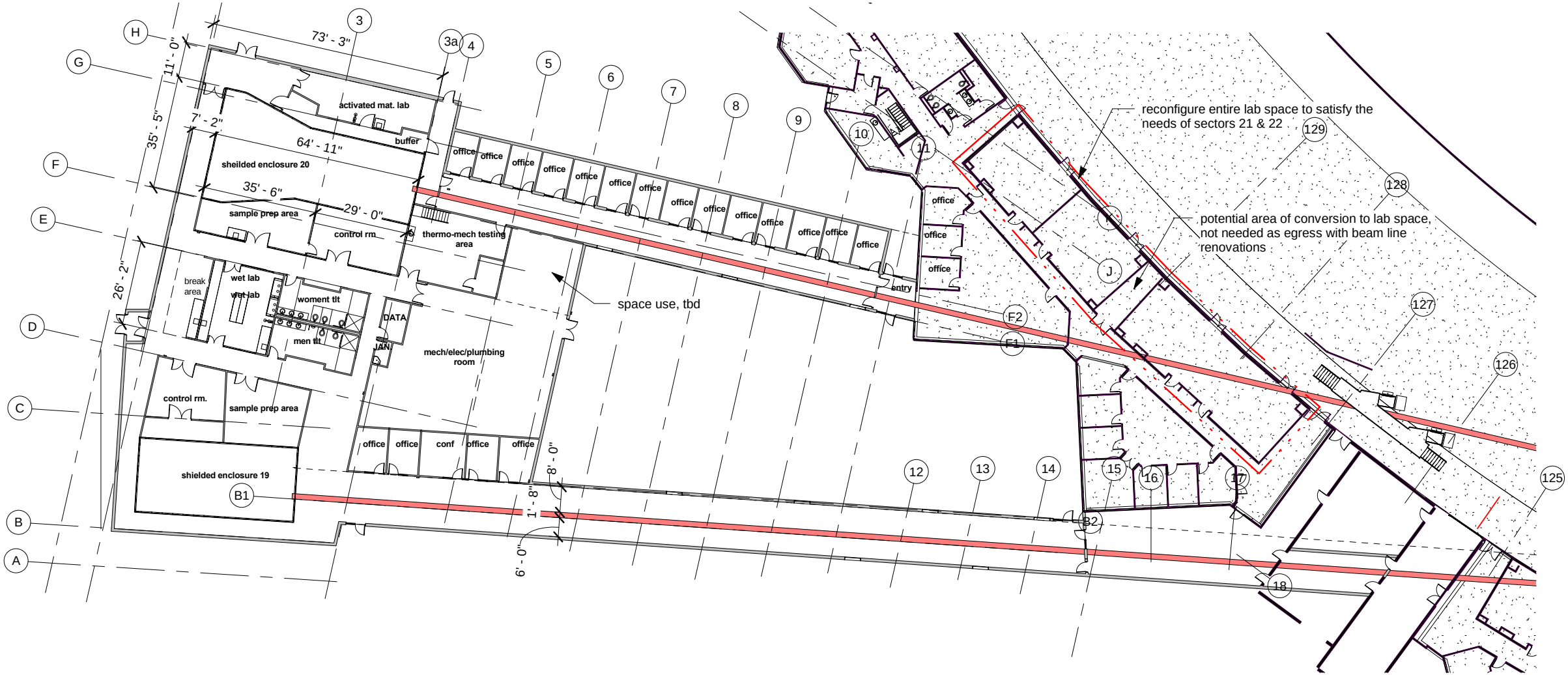
- Beamlines were chosen based on scientific impact, degree of benefit to the general user program, and alignment with upgraded APS capabilities and APS strategic plans (high energy, coherence, etc.)



APS-U Feature Beamlines Scope

Location	Name	Title	Science Lead	Technique
28-ID	CHEX	Coherent High-Energy X-ray Sector for In Situ Science	Robert Winarski Brian Stephenson	*In situ*, surface high-energy coherent scattering
4-ID	Polar	Polarization modulation spectroscopy	Daniel Haskel	Magnetic spectroscopy
20-ID	HEXM	A High-Energy X-ray Microscope	Sarvjit Shastri Jon Almer	High-energy microscopies & CDI
8-ID	XPCS	Development of a Small-Angle X-ray Photon Correlation Spectroscopy Beamline for Studying Dynamics in Soft Matter Wide-Angle X-Ray Photon Correlation Spectroscopy and Time-Resolved Coherent X-Ray Scattering Beamline	Suresh Narayanan Alec Sandy	Small-angle XPCS Wide-angle XPCS
33-ID	Ptycho	PtychoProbe	Volker Rose	Ultimate resolution, forward scattering ptychography/spectromicroscopy
19-ID	ISN	InSitu Nanoprobe Beamline	Jörg Maser	*In-situ*, forward scattering ptychography/spectromicroscopy Long working distances
9-ID	CSSI	Coherent Surface Scattering Imaging Beamline for Unraveling Mesoscopic Spatial-Temporal Correlations	Jin Wang Jiang Zhang	Coherent GISAXS, XPCS
34-ID	ATOMIC 3DMN	Atomic – A beamline for extremely high resolution coherent imaging of atomistic structures 3D Micro & Nano Diffraction	Ross Harder Jon Tischler	Diffraction microscopy & CDI Bragg CDI Upgrade of current 34-ID

Long Beamline Building (LBB)



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SK5c

LBL - CONFIGURATION OPTION 5c

apsu - argonne national laboratory

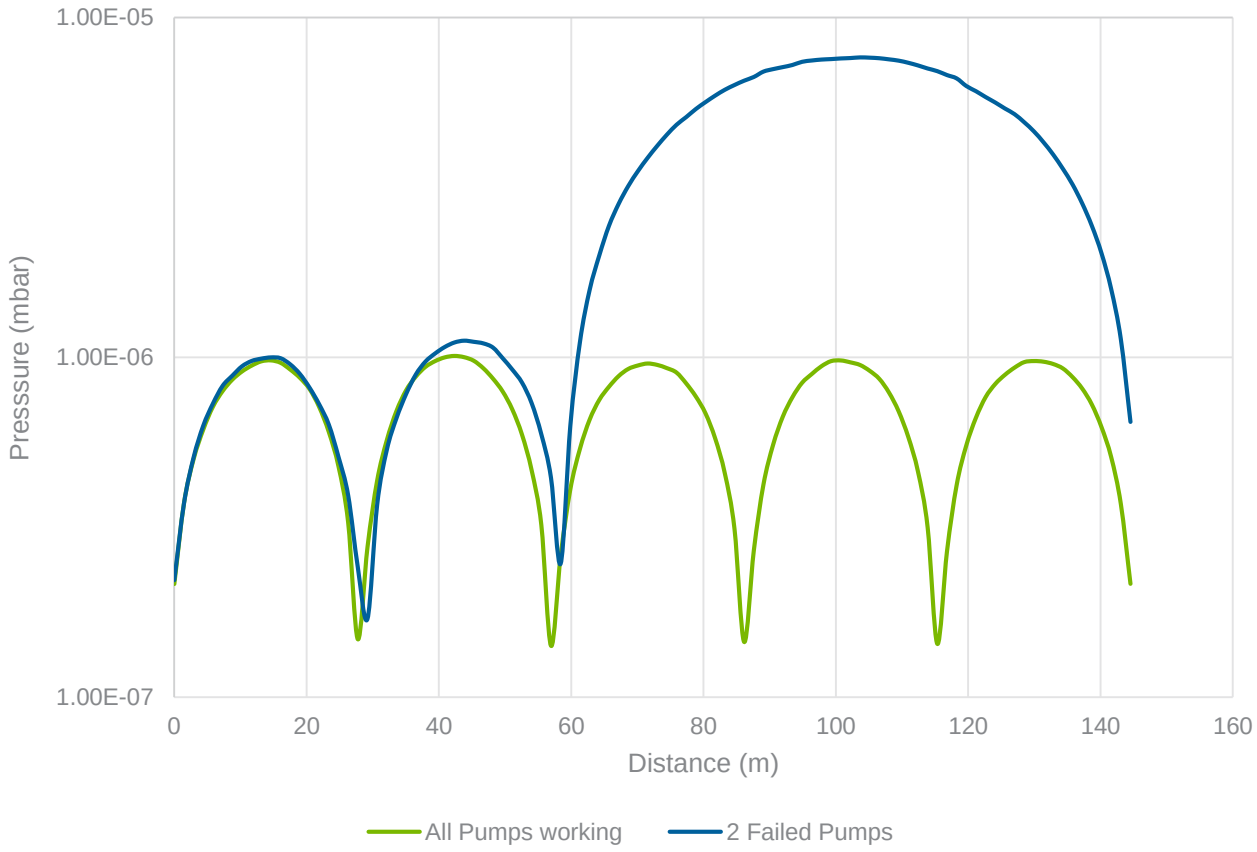
long beam line project

ramp vs walkway study

Long Transport Vacuum Simulation

Vacuum Conductance Analysis run in MolFlo - Tim Clute (AES-MOM Vac)

- ISN Dimensions
  - 146 meters
  - 4 inch inner diameter
- Assumptions:
  - $3x10^{-10}$ mbar*L/s/cm^2 outgassing rate
  - (Conservative for stainless steel)
- Determination:
  - 4x 200 L/s pumps equally spaced along beamline with 100 L/s pumps at either end
- Compared to LCLS - XTOD Tunnel Vacuum Transport System (XVTS) Final Design Report
  - Similar results and assumptions



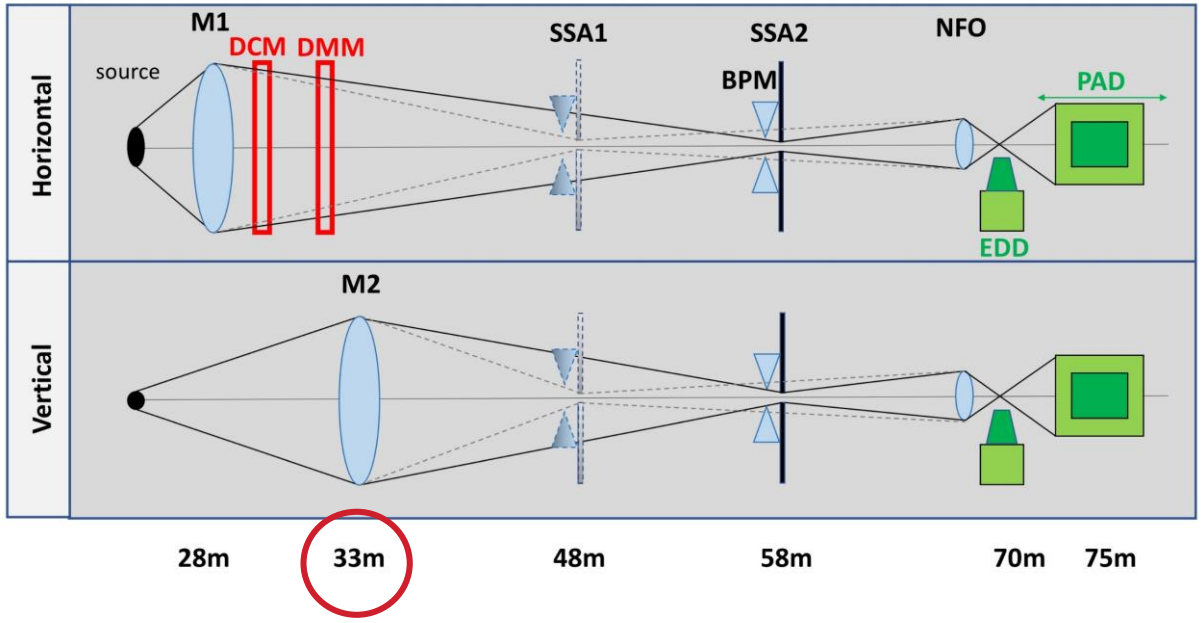
Beamline Design

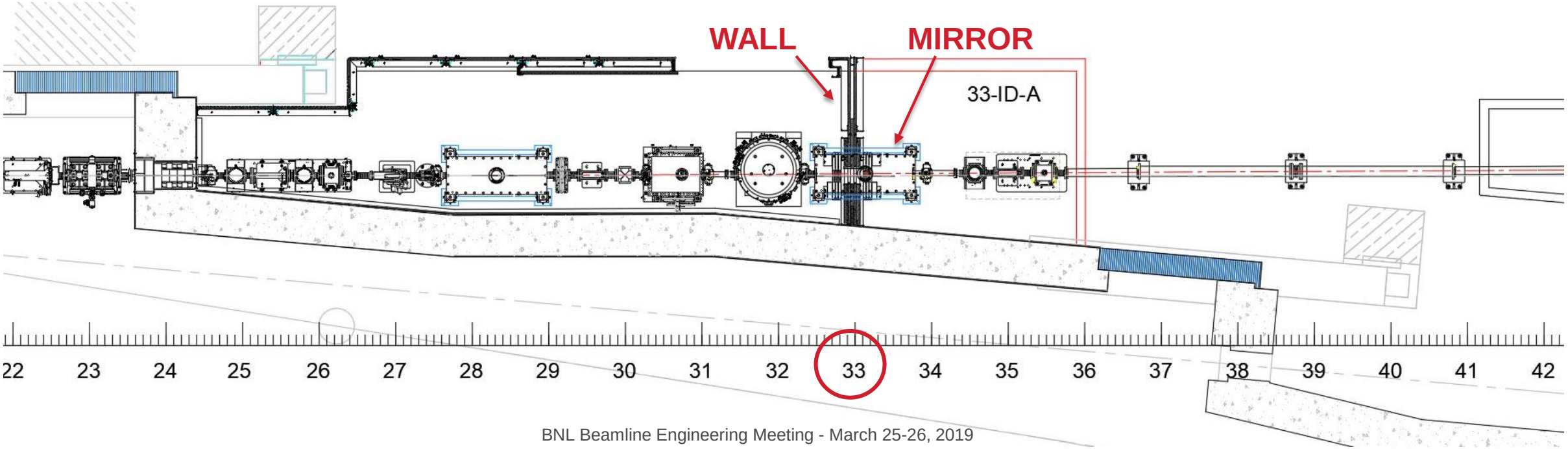
Beamline Design Process

Start with “perfect” optical layout

- Mirror locations
- Focal distances
- Sample positions
- Easy enough!

Now we have to make it fit in the real world

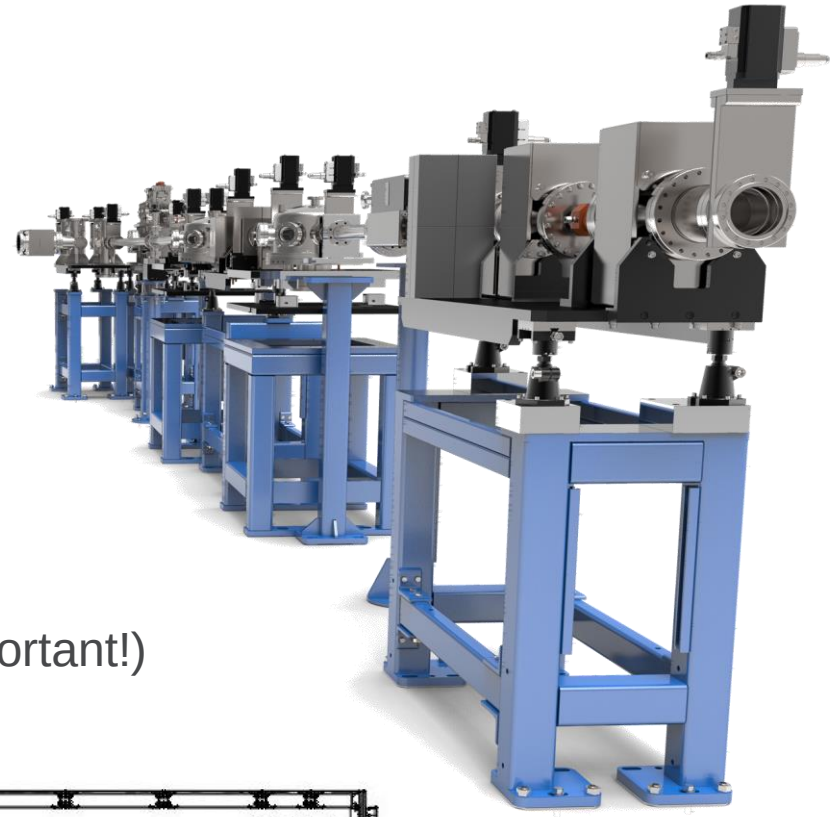


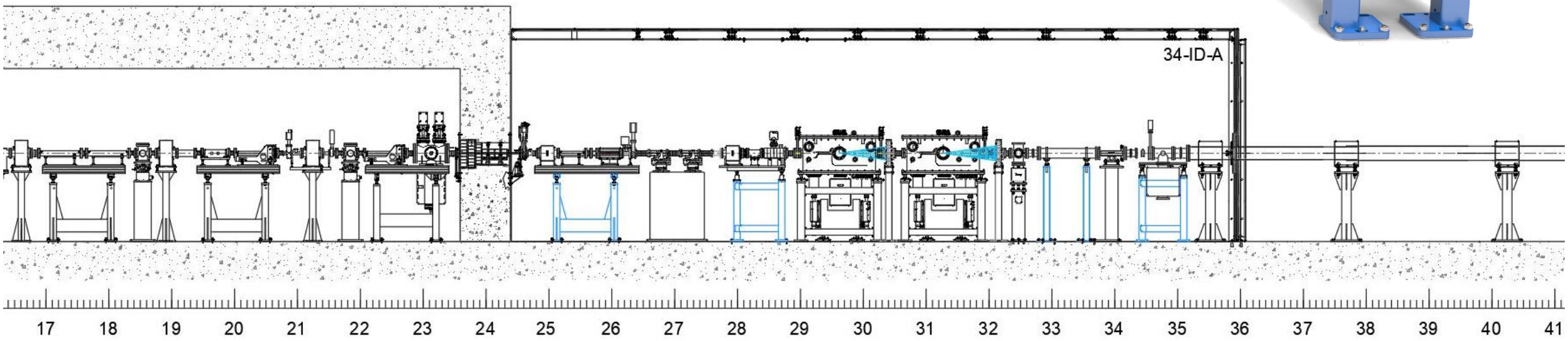


Beamline Design Process

Many factors drive the beamline design process:

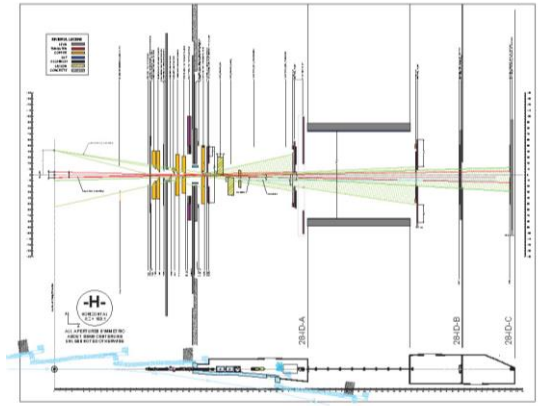
- Physics requirements
- Existing infrastructure
- Shielding requirements
- Size of actual hardware
- Access restrictions
- Vacuum conductance
- Fire code
- Cost
- Schedule
- Thermal stability
- Vibration isolation
- Safety Considerations (most important!)

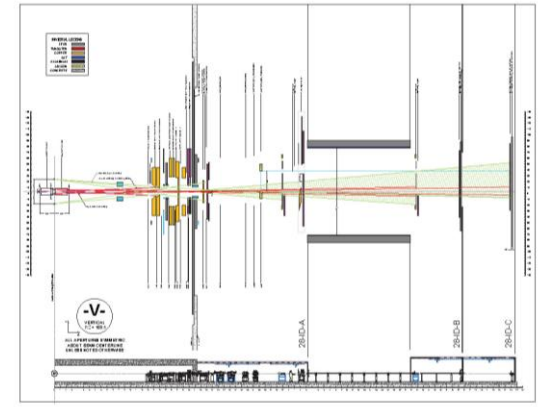


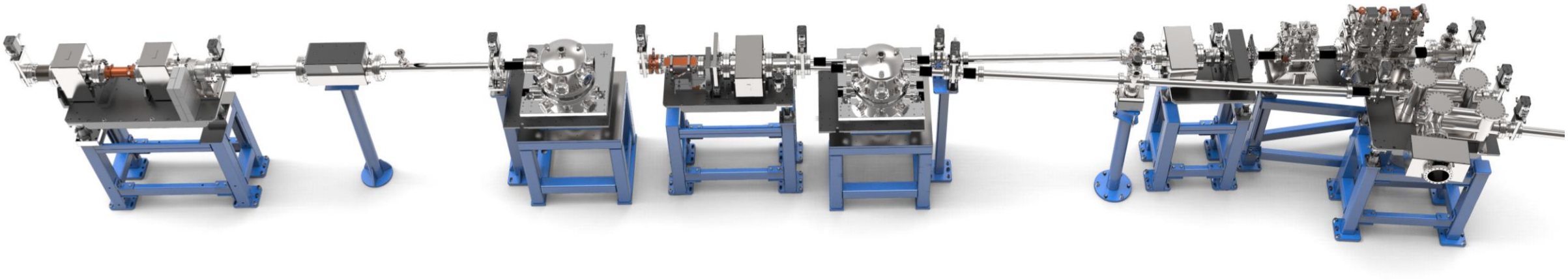


Beamline Design Process

- Optical layouts defined by physics requirements
- Ray tracings and Layouts drawn in AutoCAD to determine component locations and apertures
- Individual component designs and fabrication drawings modeled in PTC/CREO
- Process optimized through experience with past beamline upgrades
- Team based approach, promote commonality across beamlines







Ray Tracing Evolution

- Back in the day……
- As a new facility, there weren't really any standards for ray tracing
- What size are these apertures

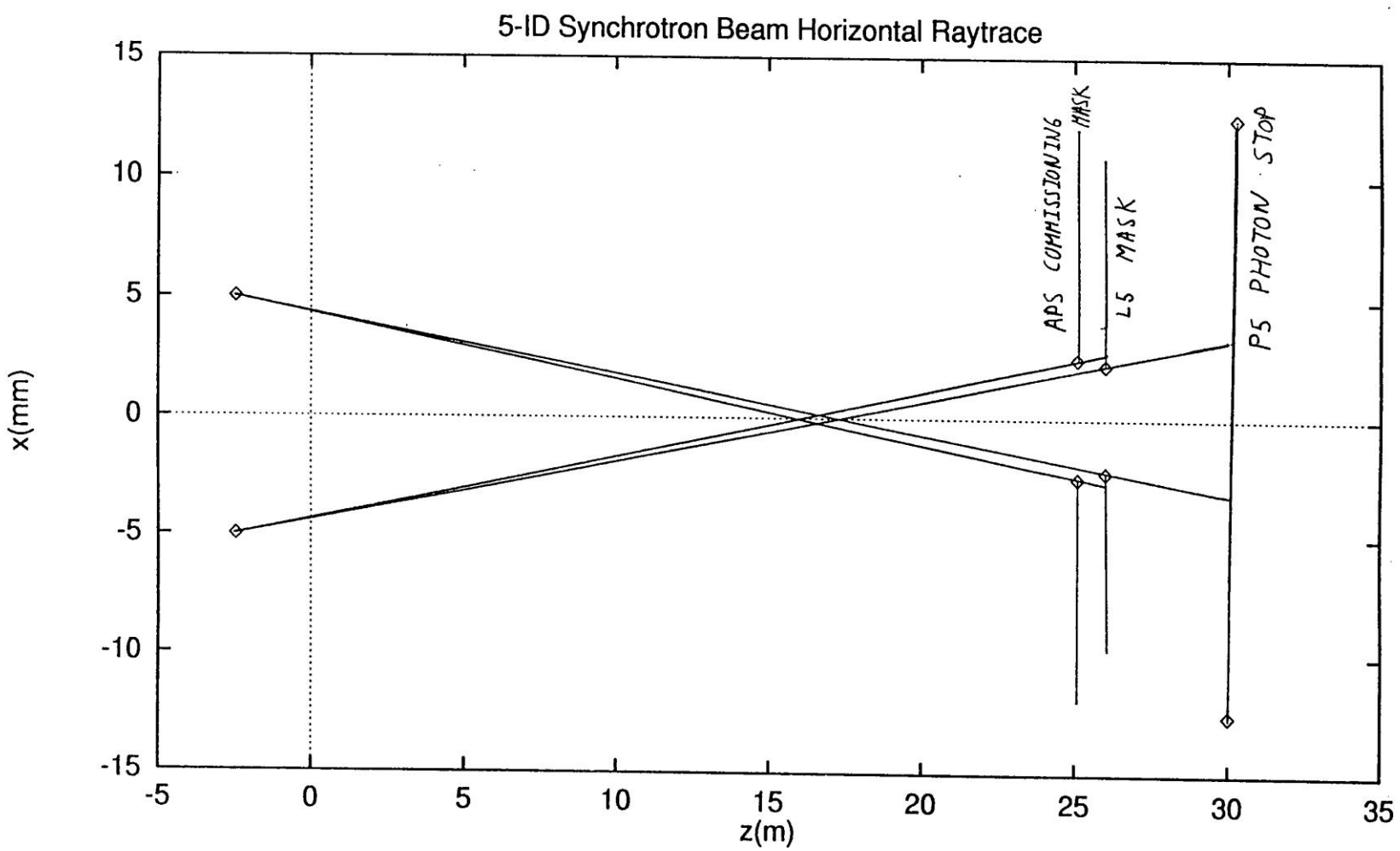
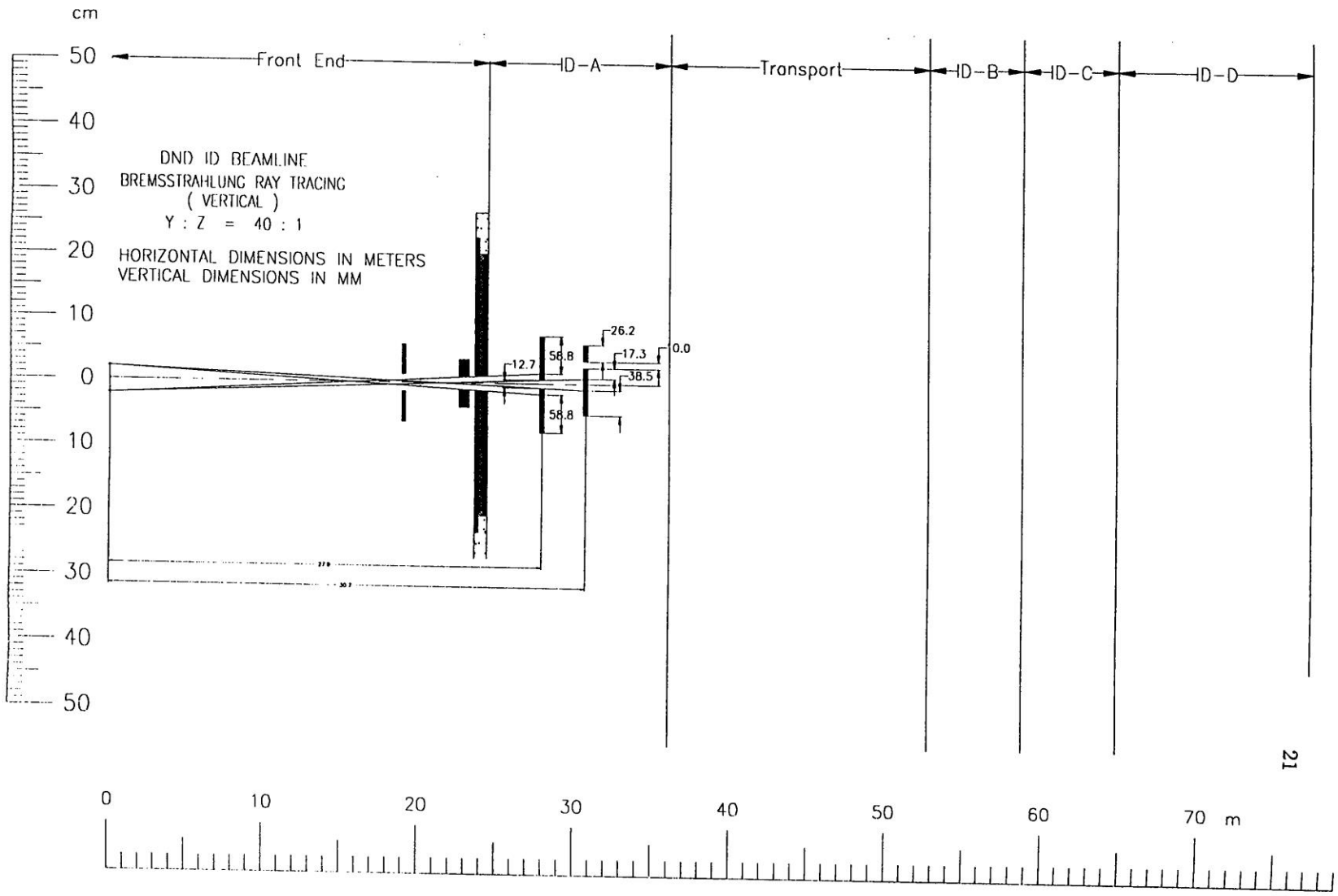


Figure 3: Synchrotron ray tracing for 5-ID [horizontal]

Ray Tracing Evolution

- 40:1
- Left to Right
- What components am I looking at again?
- We know the apertures but what components are these?

Figure 2: Bremsstrahlung ray tracing for 5-ID [vertical]



Ray Tracing Evolution

- Top to Bottom?
- Total Chaos!

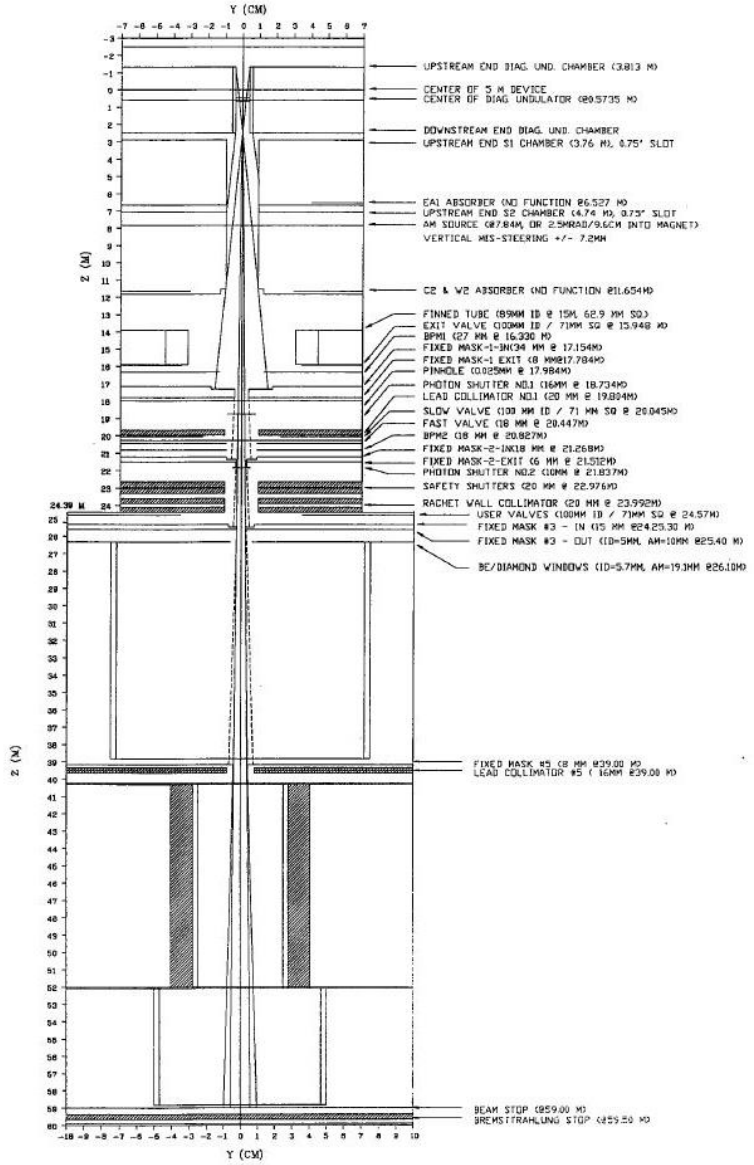


Fig. 35-ID-7 Aperture plan (horizontal) of the AM Beam lines which shows major optical elements and mis-steered beam

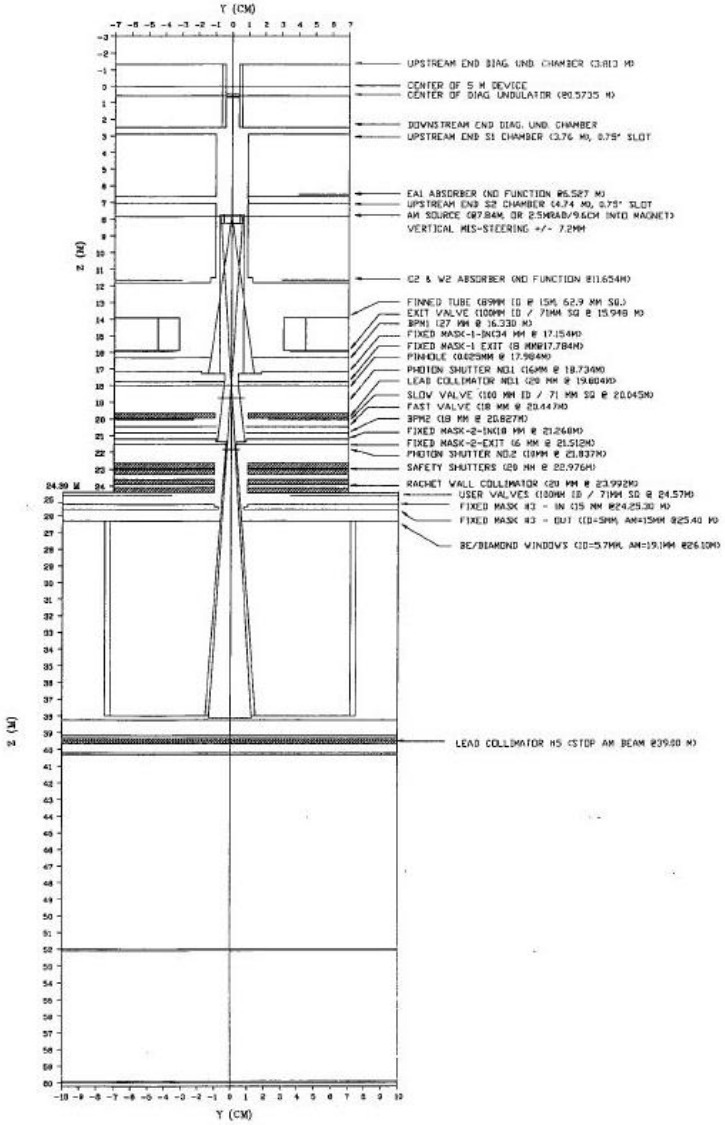
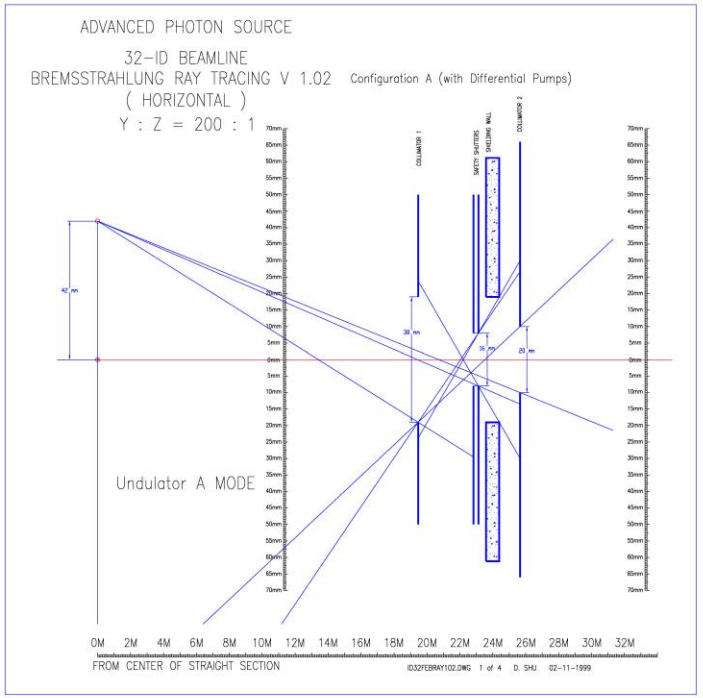
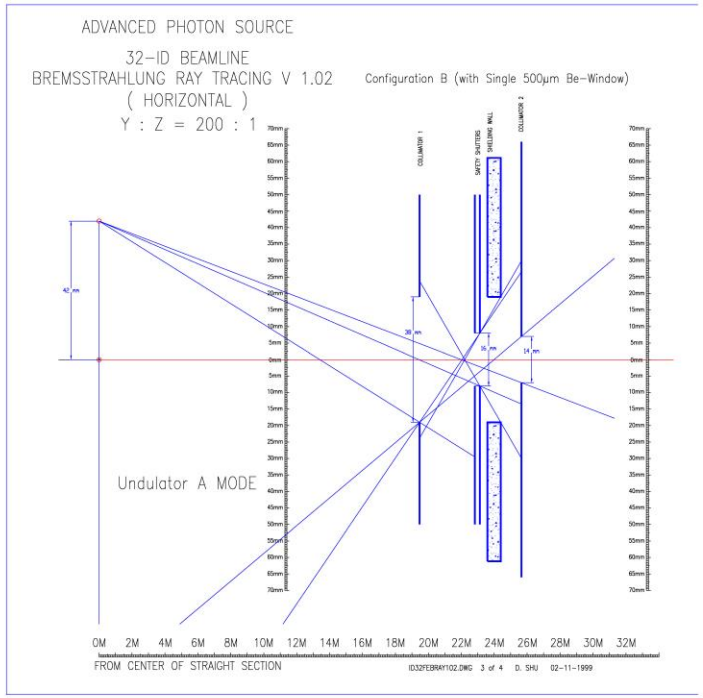


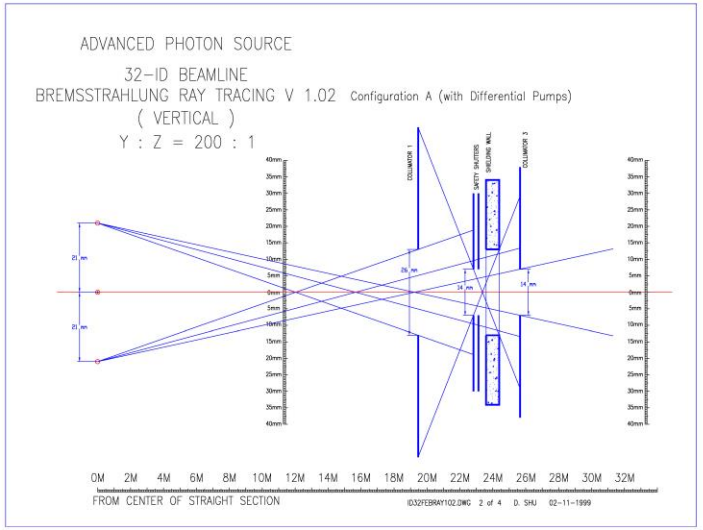
Fig. 35-ID-8 Aperture plan (vertical) of the AM beam line which shows major optical elements and mis-steered beam

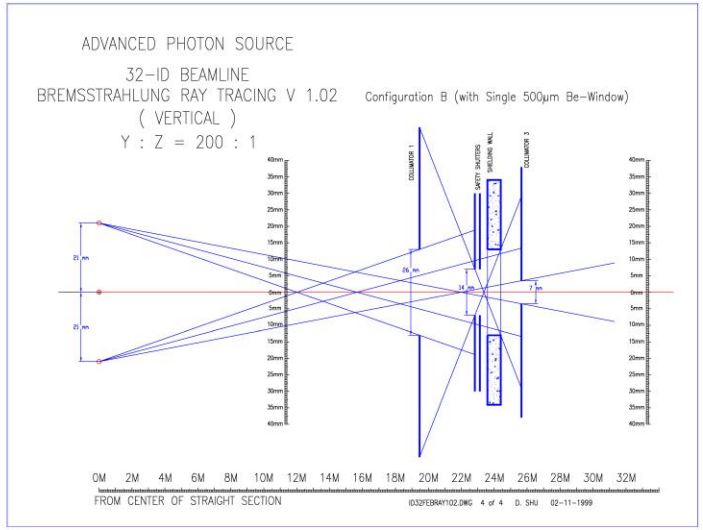
Ray Tracing Evolution

- What's going on here?
- 200:1?
- How do we verify locations shown match beamline layout?



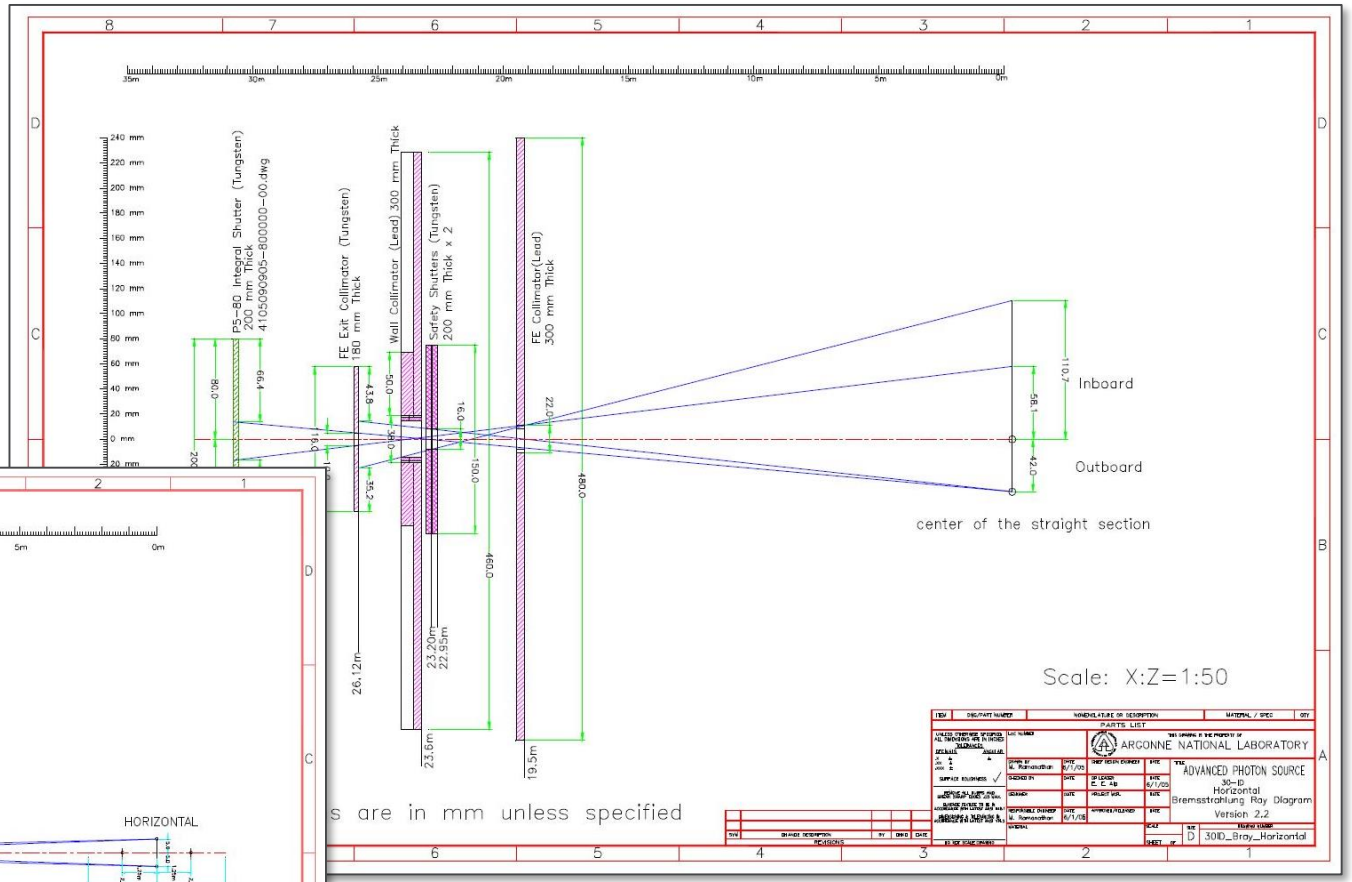


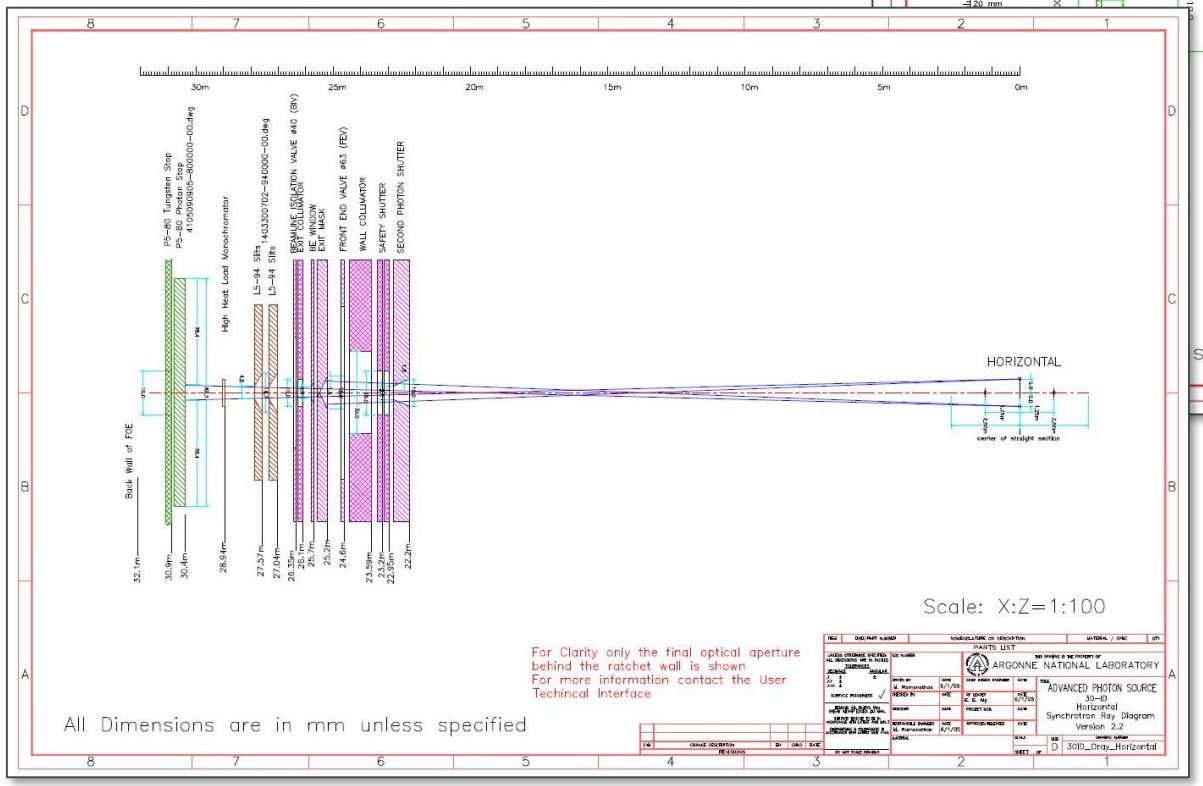




Ray Tracing Evolution

- Right to left?
- 1:50? 1:100?

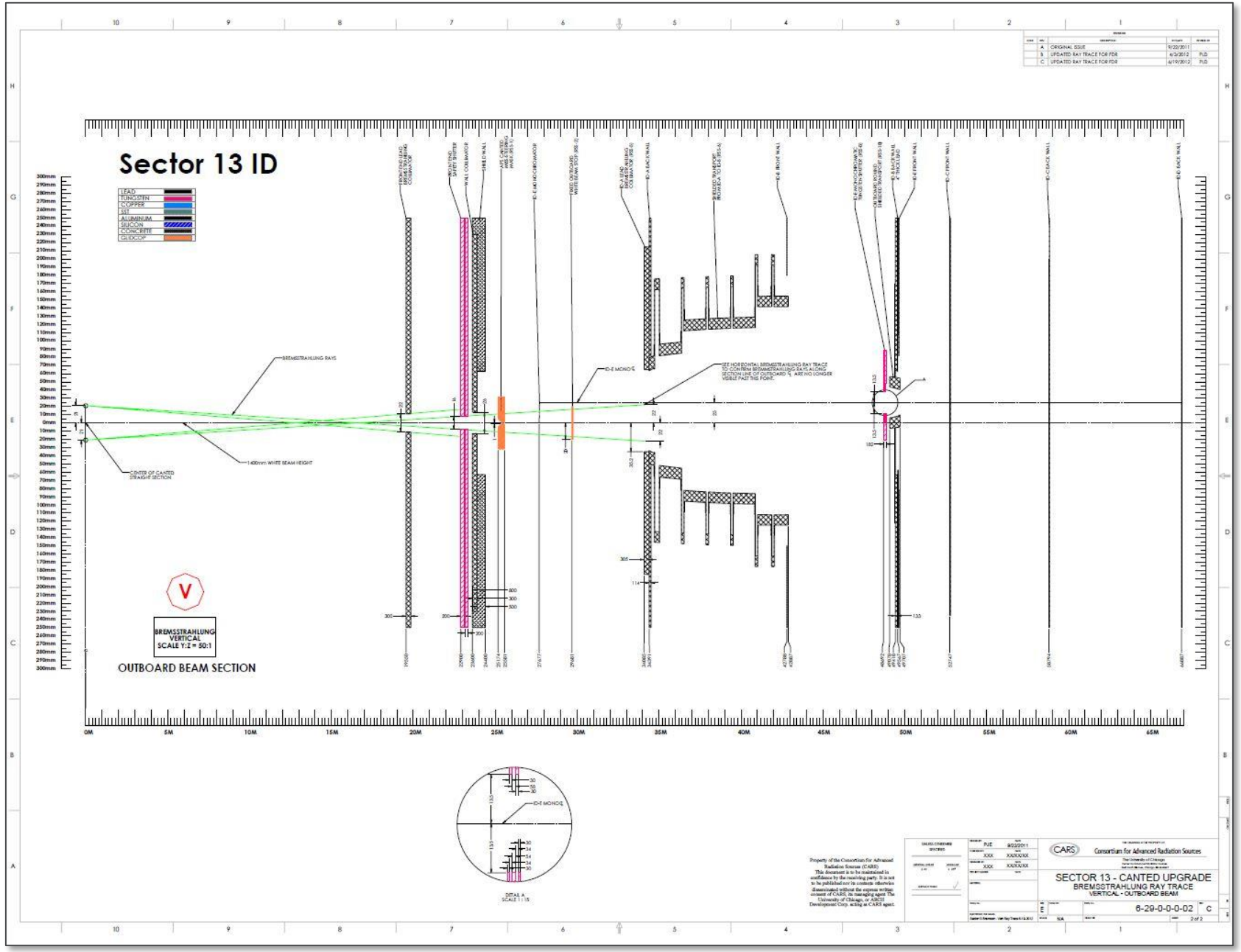




Drawn by Mohan Ramanathan?

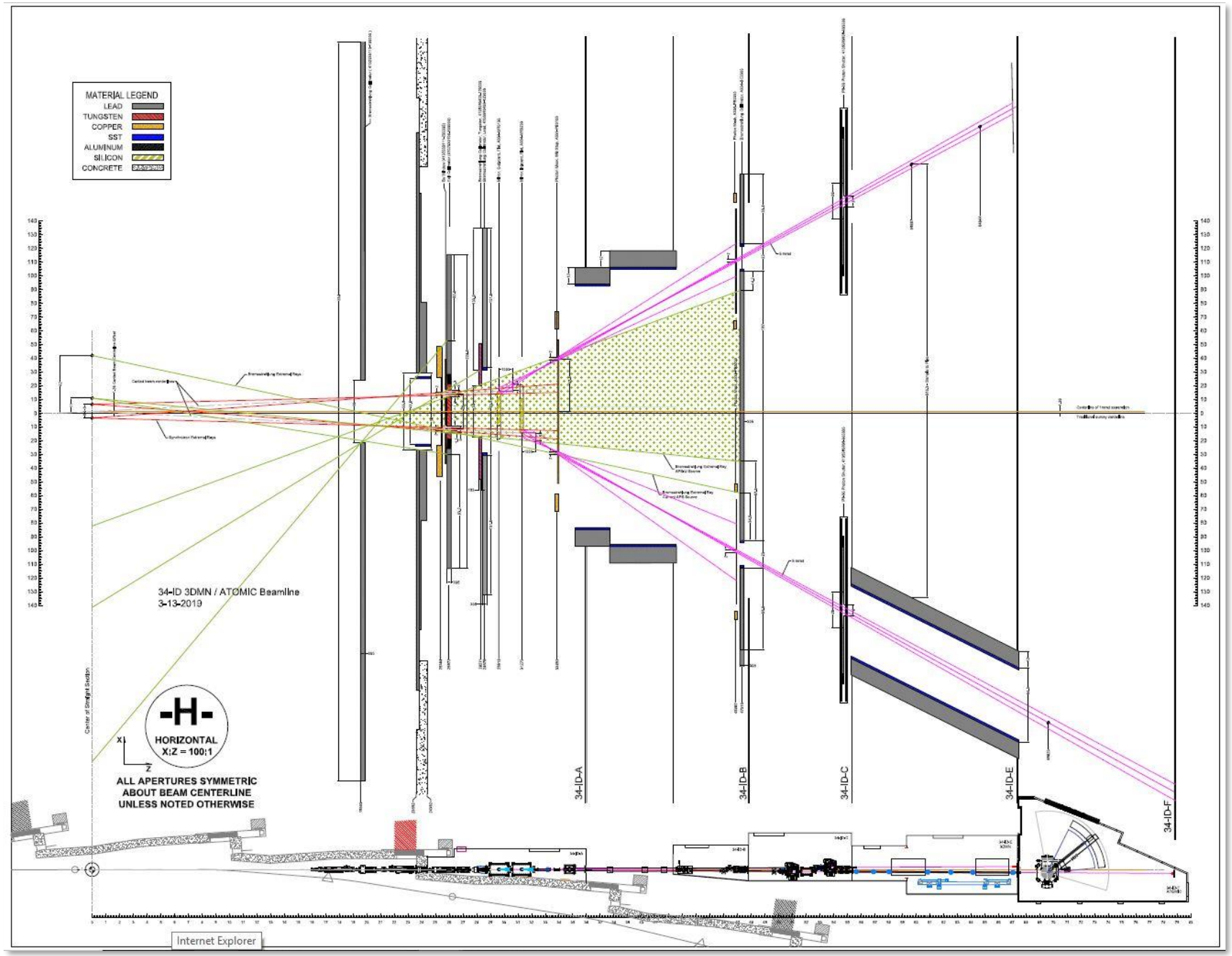
Ray Tracing Evolution

- Getting Better!



Current Ray Tracing

- Current APS raytracing standards have evolved to a very mature and consistent state
- Layout view incorporated into bottom of ray tracing
- Easy to see what's going on here
- Horizontal/Vertical clearly identified
- Standard Template 1:100
- Left to Right!
- Synchrotron and Bremsstrahlung combined in same file clearly shows component / beam interaction



Beamline Ray Tracing - Basics

Extremal Ray [ik-**stree**-m*uh* l]

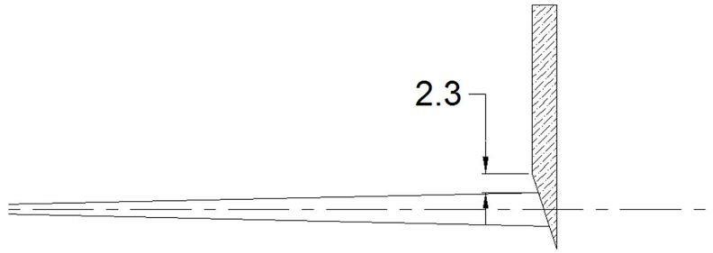


Figure 2. When the distance to the edge of an aperture is less than 3 mm, show the actual distance: in this case 2.3 mm. The distance is measured transverse to the beam direction.

the most divergent propagated ray

- Synchrotron extremal rays are limited by what is transmitted through an aperture in a *mask*,
- Bremsstrahlung extremal rays are limited by passing through the specified thickness of heavy metal in a *collimator*
- The fan of transmitted radiation (synchrotron or bremsstrahlung) is finally terminated in a *stop*.

Guidelines for Beamline and Front-End Radiation Shielding Design at the Advanced Photon Source, P. K. Job (Technical Bulletin ANL/APS/TB-44, rev. 2)

APS_1192967 Standard APS Beamline Ray Trace Drawings

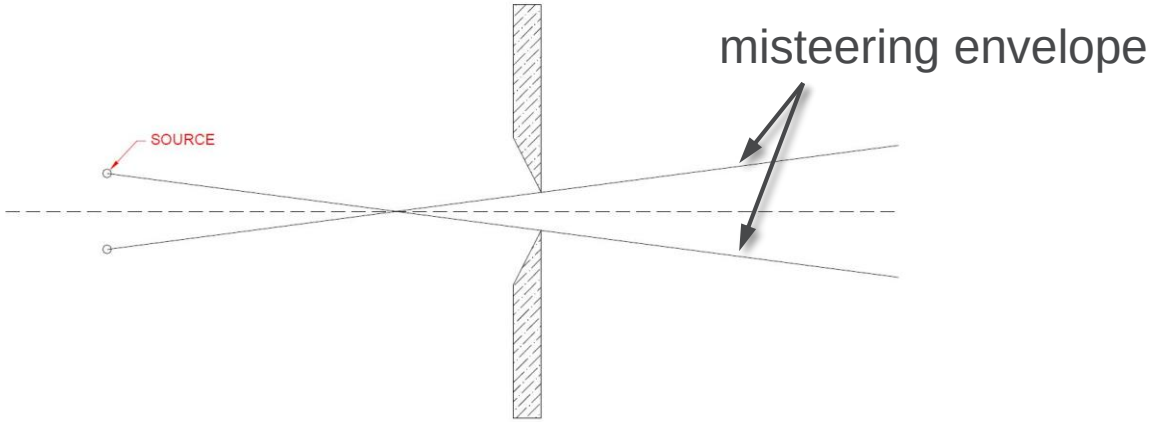


Figure 1. Typical synchrotron extremal rays defined by the FE exit mask.

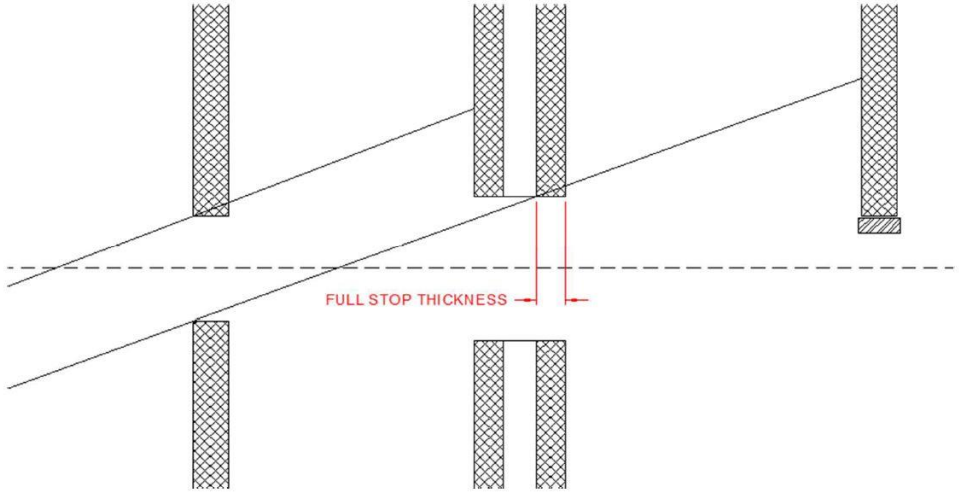
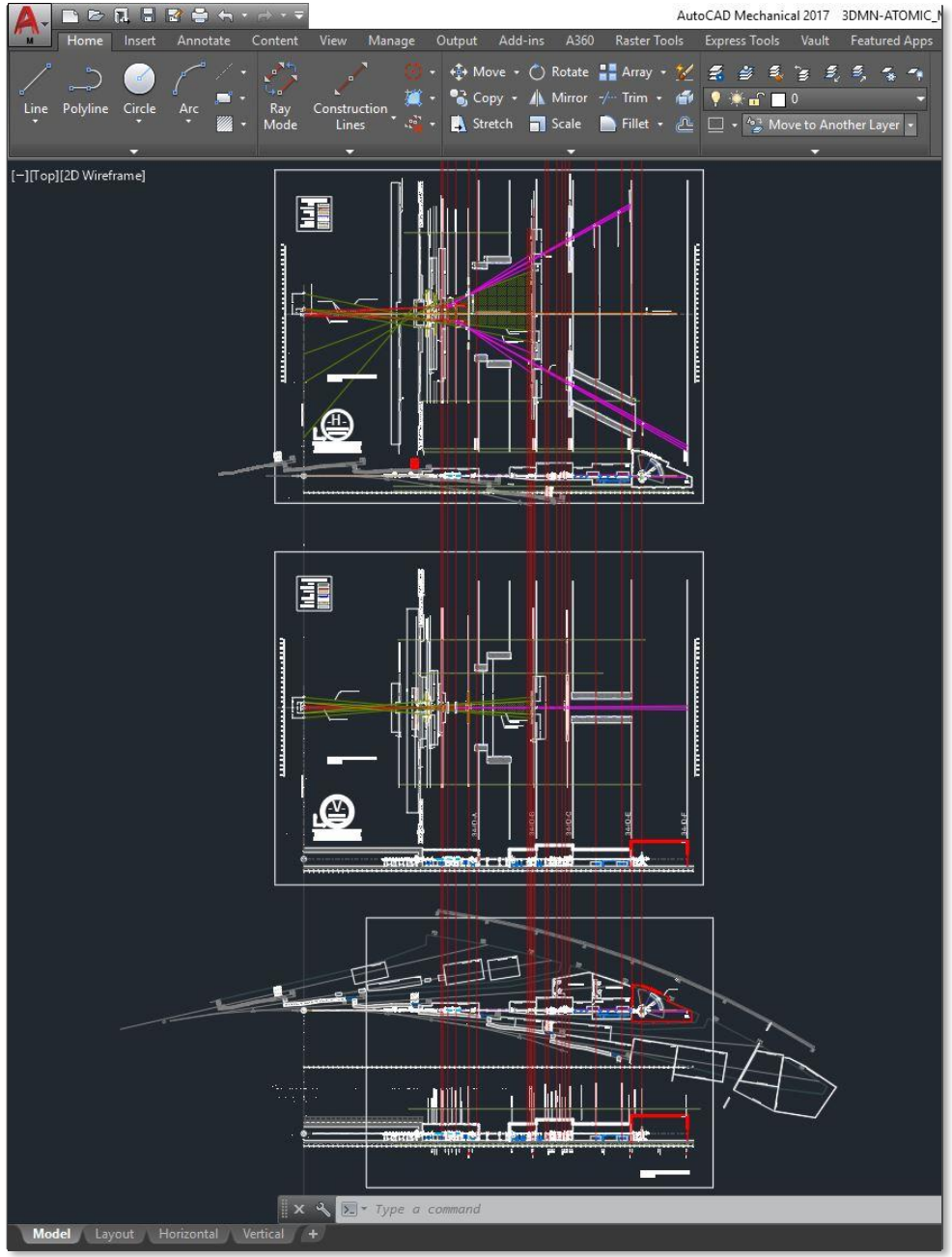


Figure 3. A bremsstrahlung extremal ray passes through a full stop thickness of shielding material before terminating on the next shield.

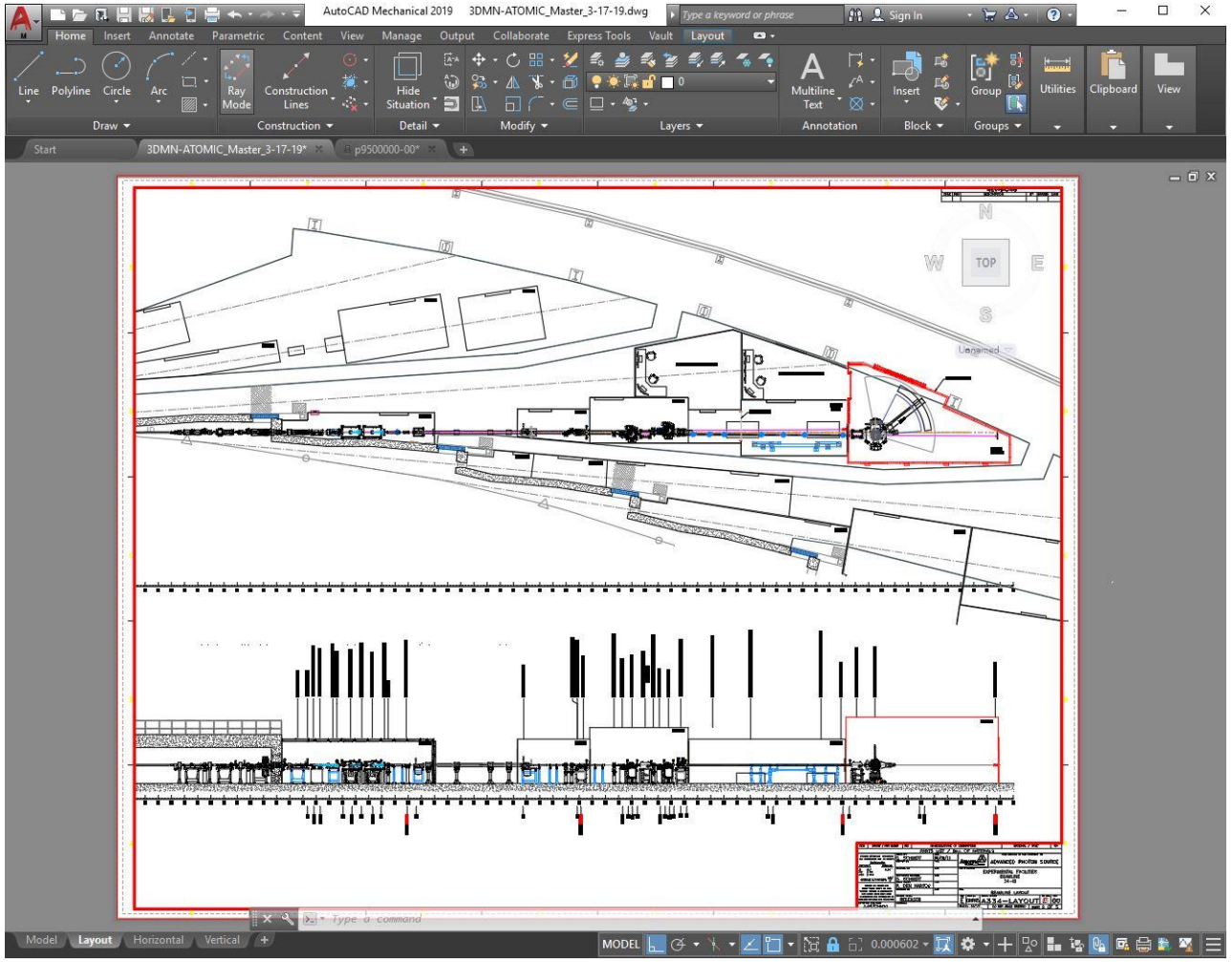
Master Design Template

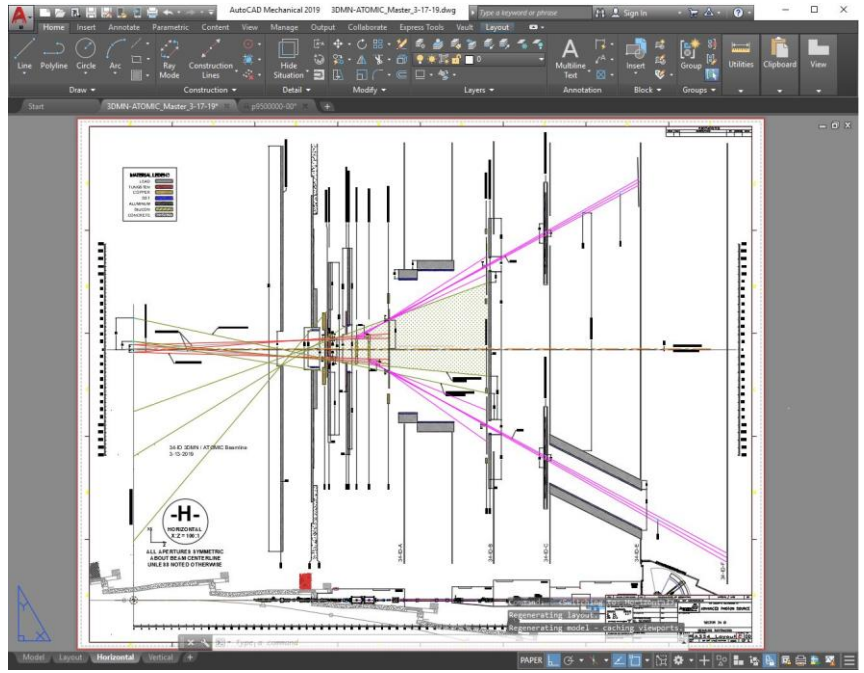
- Master AutoCad design file determines all component locations, apertures, and requirements.
- Layout and raytracing combined in same file to ensure accuracy
- Vertical guide lines ensure precise component location
- Single horizontal and vertical eliminates redundancy
- Iterative Process
- Quickly able to try out different configurations

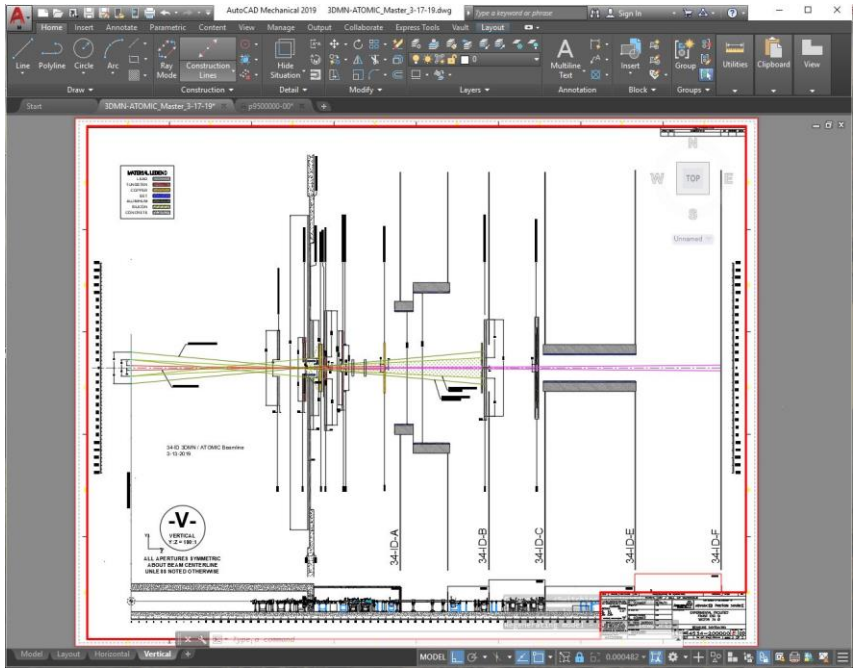


Drawing Formatting

Formatted drawings generated in paper space for review and release







Design Tools

AutoCad

- Overall beamline design and layout
- Component specifications
  - Apertures
  - Locations

PTC Creo

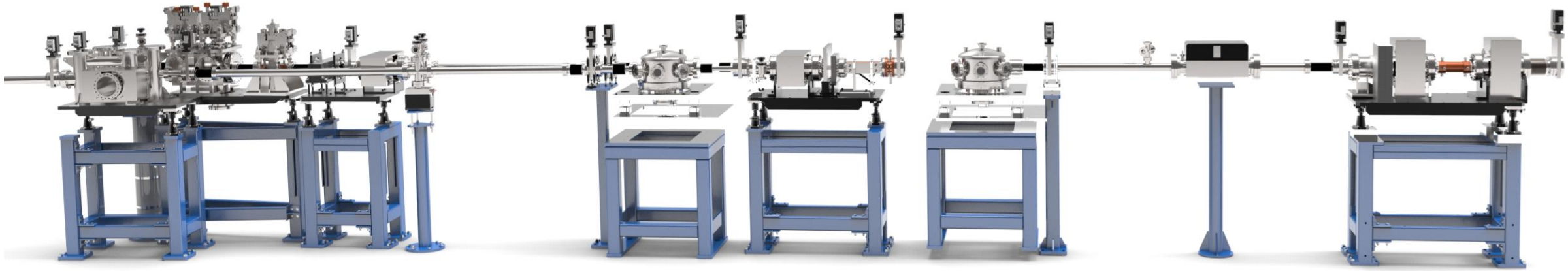
- Detailed component design
- Fabrication drawings
- Models for analysis
- Overall 3D beamline layout

Keyshot

- Fancy Pictures
- Animations
- Integrated into Creo

ANSYS

- Thermal Analysis
- Structural Analysis
- Vibrational Analysis

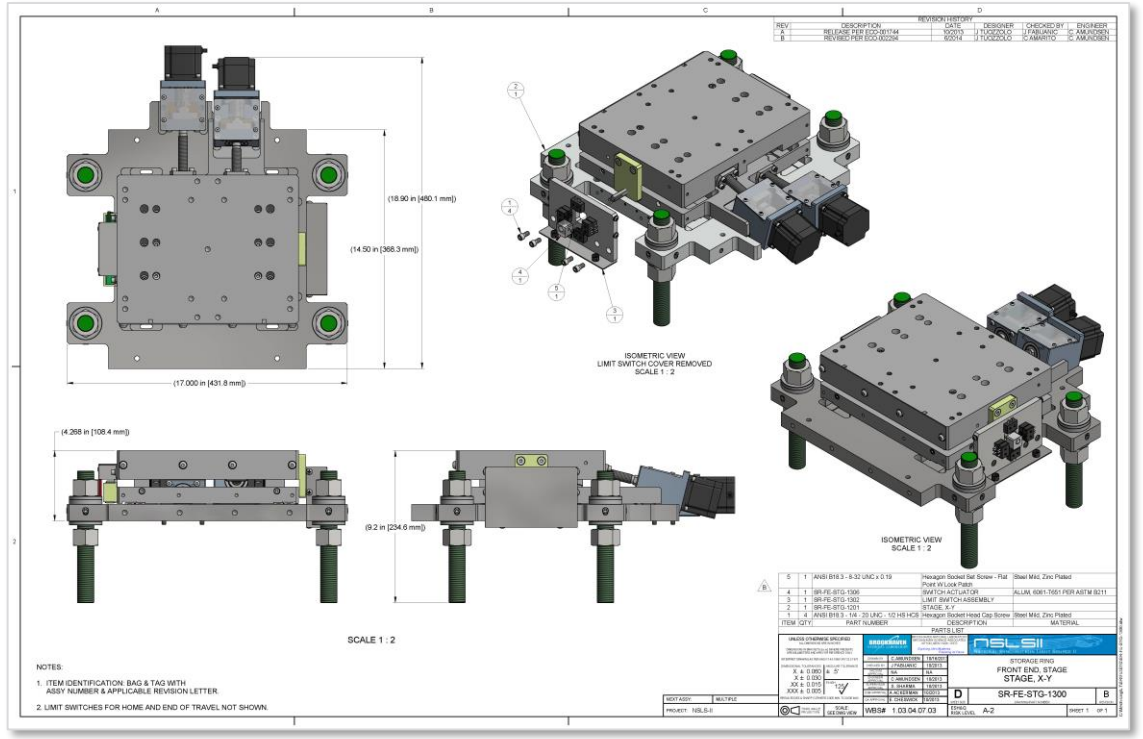


Standard Components

Value Engineering

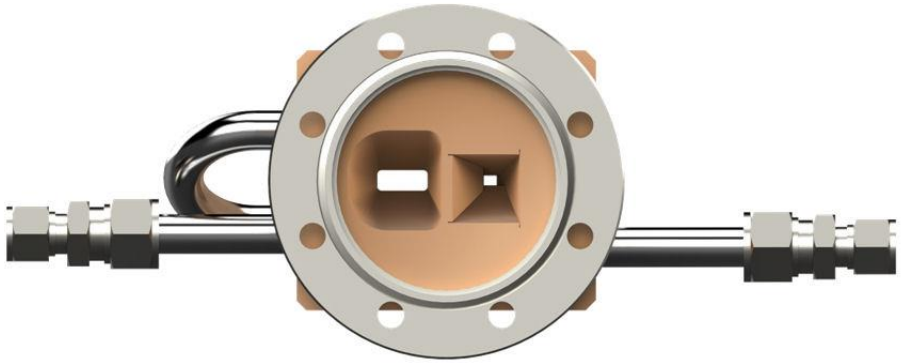
How can we get the most for our money?

- Utilize time tested APS Standard Component designs
  - Photon masks, collimators, tables, shutters, slits, stands, windows, diagnostics, etc…
  - Installation/maintenance experience, technician familiarity
- Vendor supplied components whenever possible
  - Larger design projects; mirrors, monochromators, beamline instrumentation, etc…
  - Ease load on engineering resources
  - Bulk procurements where possible
- Reuse existing infrastructure / components
- Evaluate possible alternative materials
- Leverage designs from other laboratories
  - NSLS-II Precision X-Y Stages
  - Economical Design
  - Many Applications
  - Currently building set for use with white beam slits



White Beam Slits - SL

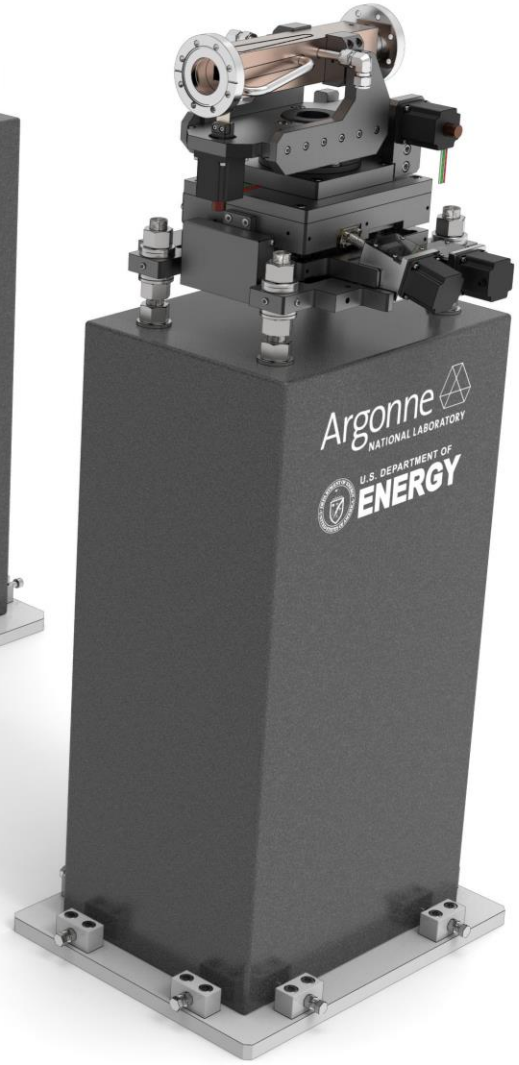
Variable Aperture Photon Absorber



- Pivoting internal edge design
- Single photon absorber can control both vertical and horizontal aperture saving valuable space along beamline
- Canted undulator version in operation since 2010

Canted Undulator Slits

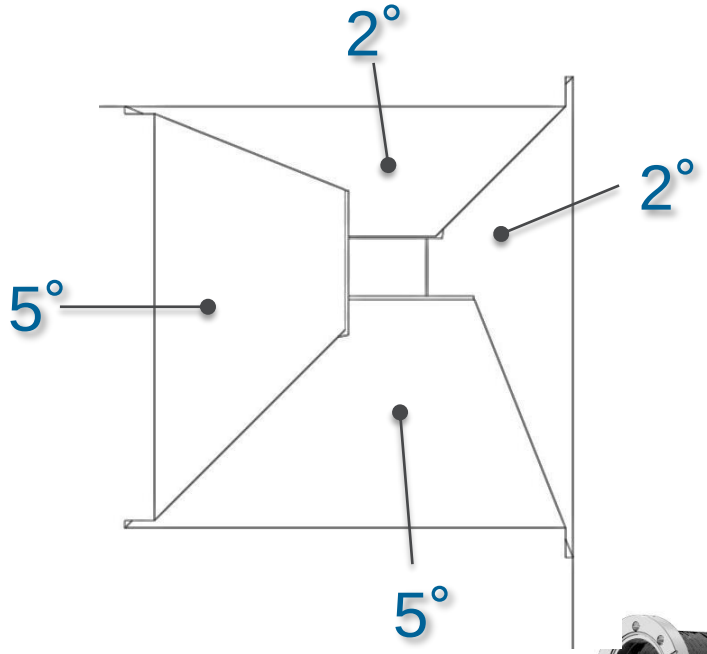
High Heat Load Slits

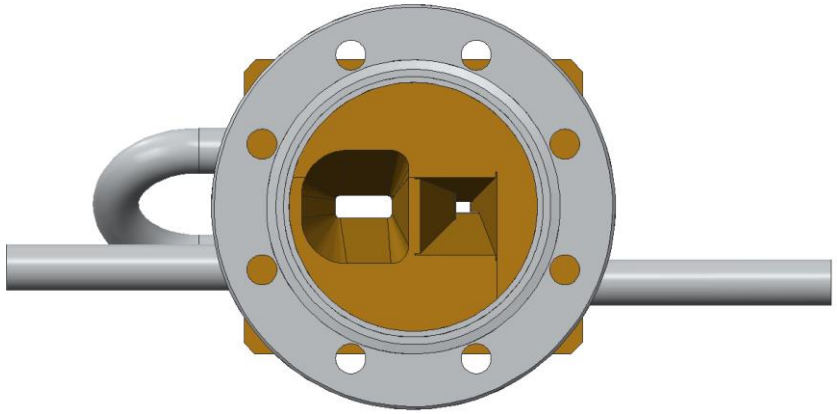


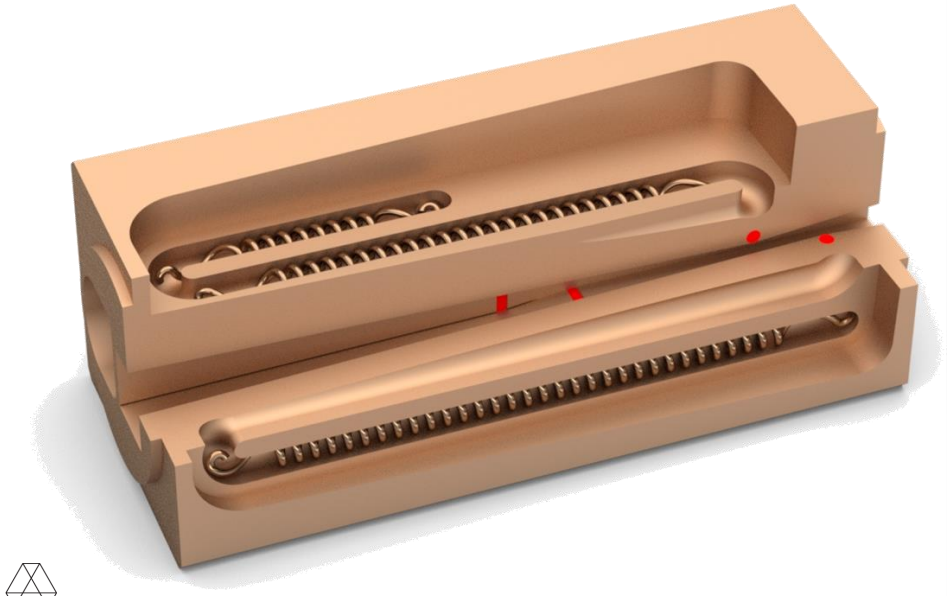
White Beam Slits

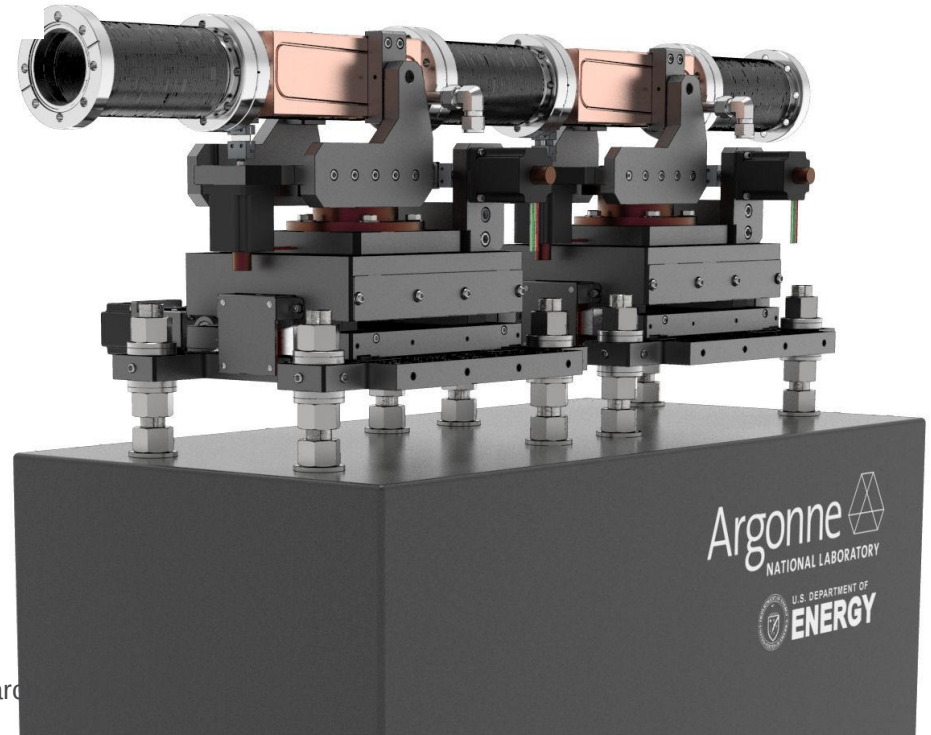
Canted Undulator

- Reliefs cut into corners to eliminate stress
- Edges staggered to cover relief which also creates sharp corners
- Beam absorbing surface angles change from 5° to 2°
- 3° to close





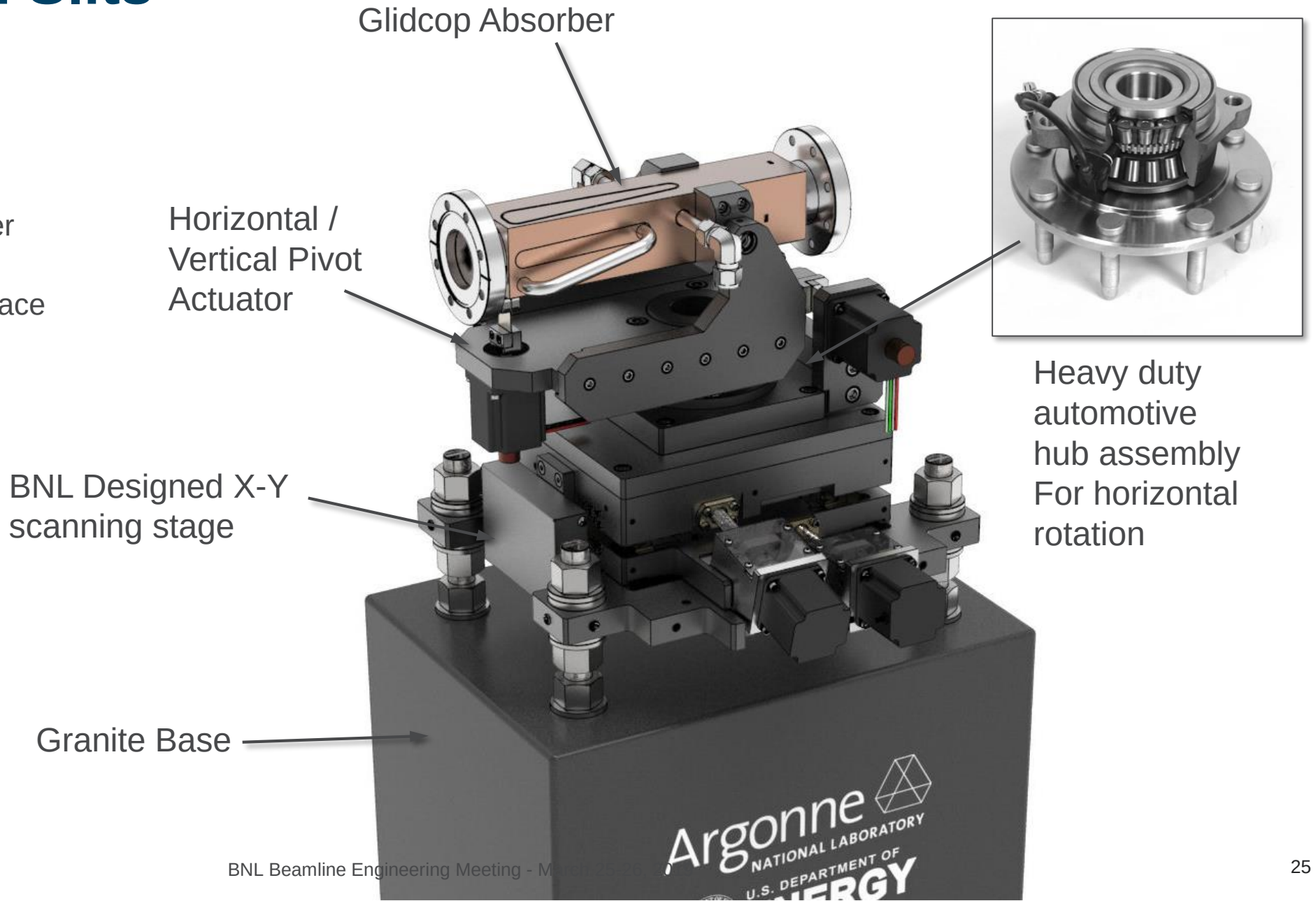




White Beam Slits

High-Heat-Load

- Slightly longer than canted version to accommodate smaller incident angle
- Beam absorbing surface angles change from 3˚ to 2˚
- 1˚ to close

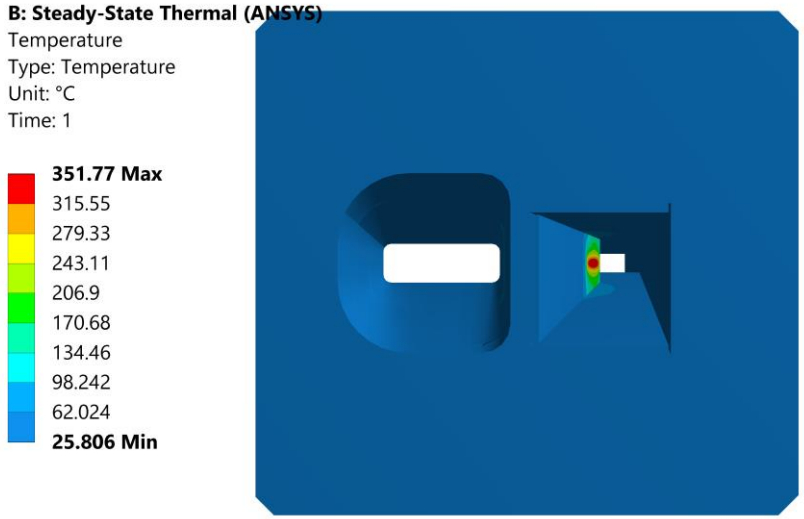


White Beam Slits

Thermal Analysis

Canted Undulator Slits

- Maximum incident angle: 5°
- Total power: 1,406 W
- Peak power density: 359.2 W/mm^2
- Maximum temperature: 352°C

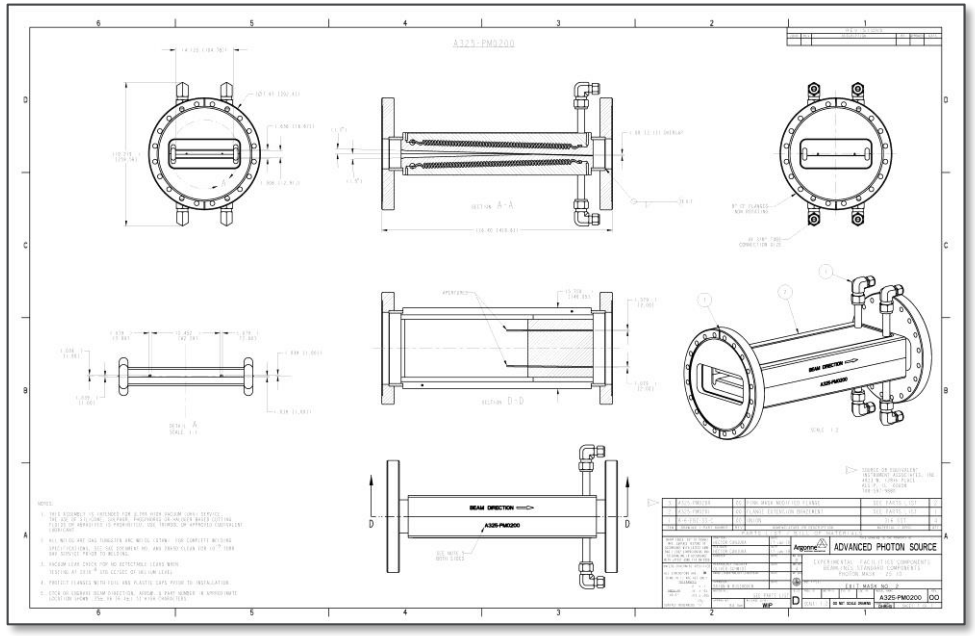


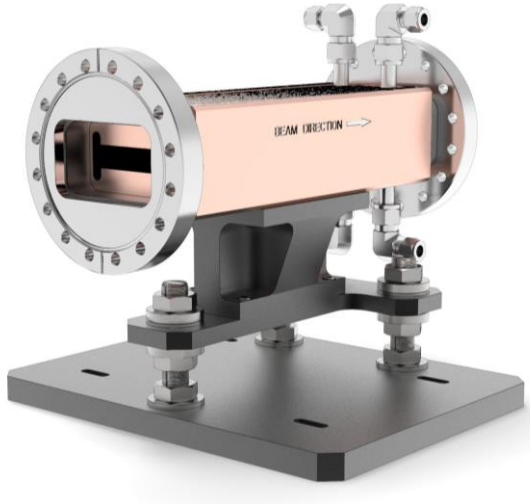
High-Heat-Load Slits

- Maximum incident angle: 3°
- Total power: 3356 W
- Peak power density: 963.4 W/mm^2
- Maximum temperature: 327°C

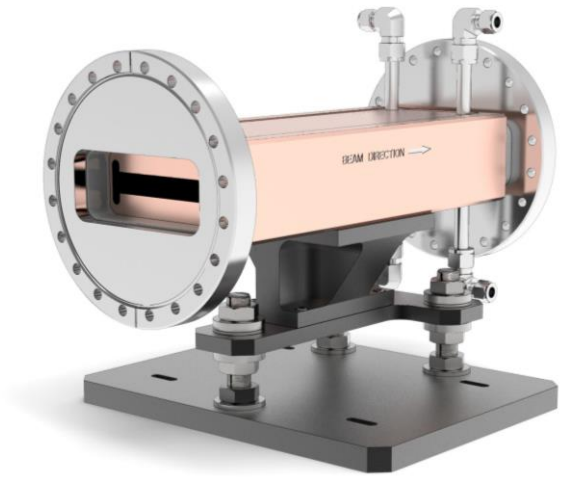
Glidcop Photon Mask

- Brazed Glidcop Body AL-15
- Water Cooled
- Incident angles and apertures customizable to application

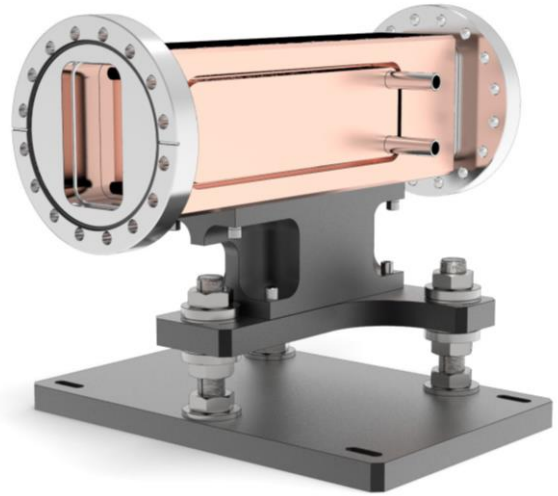




Horizontal



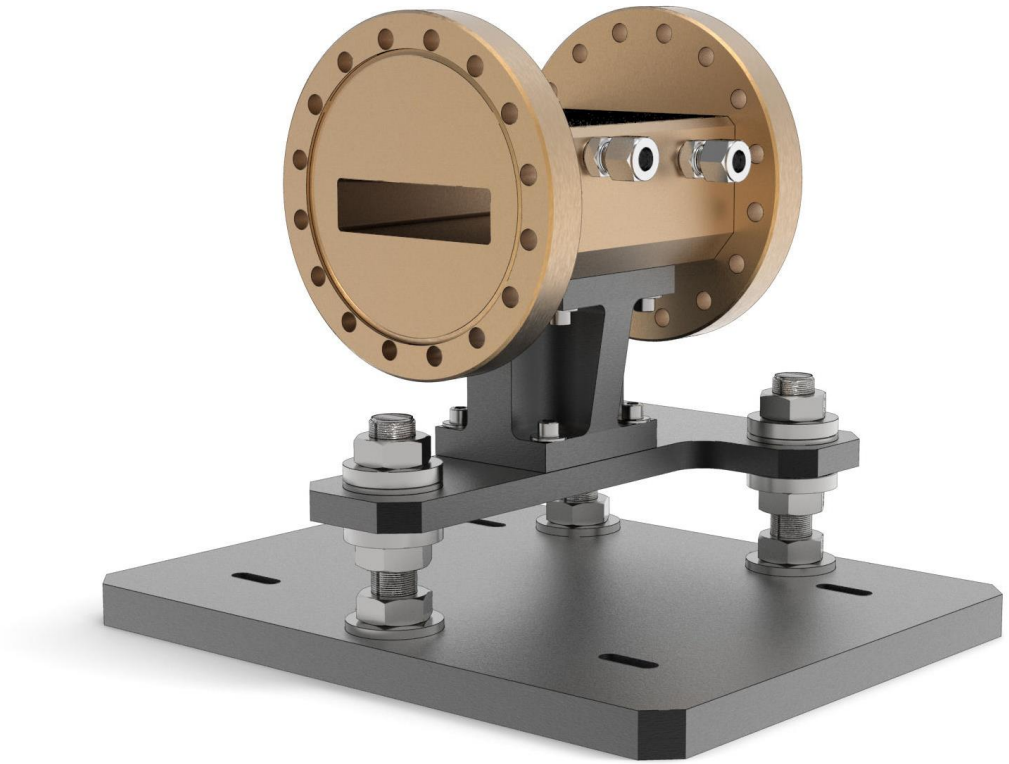
Horizontal (Wide)



Vertical

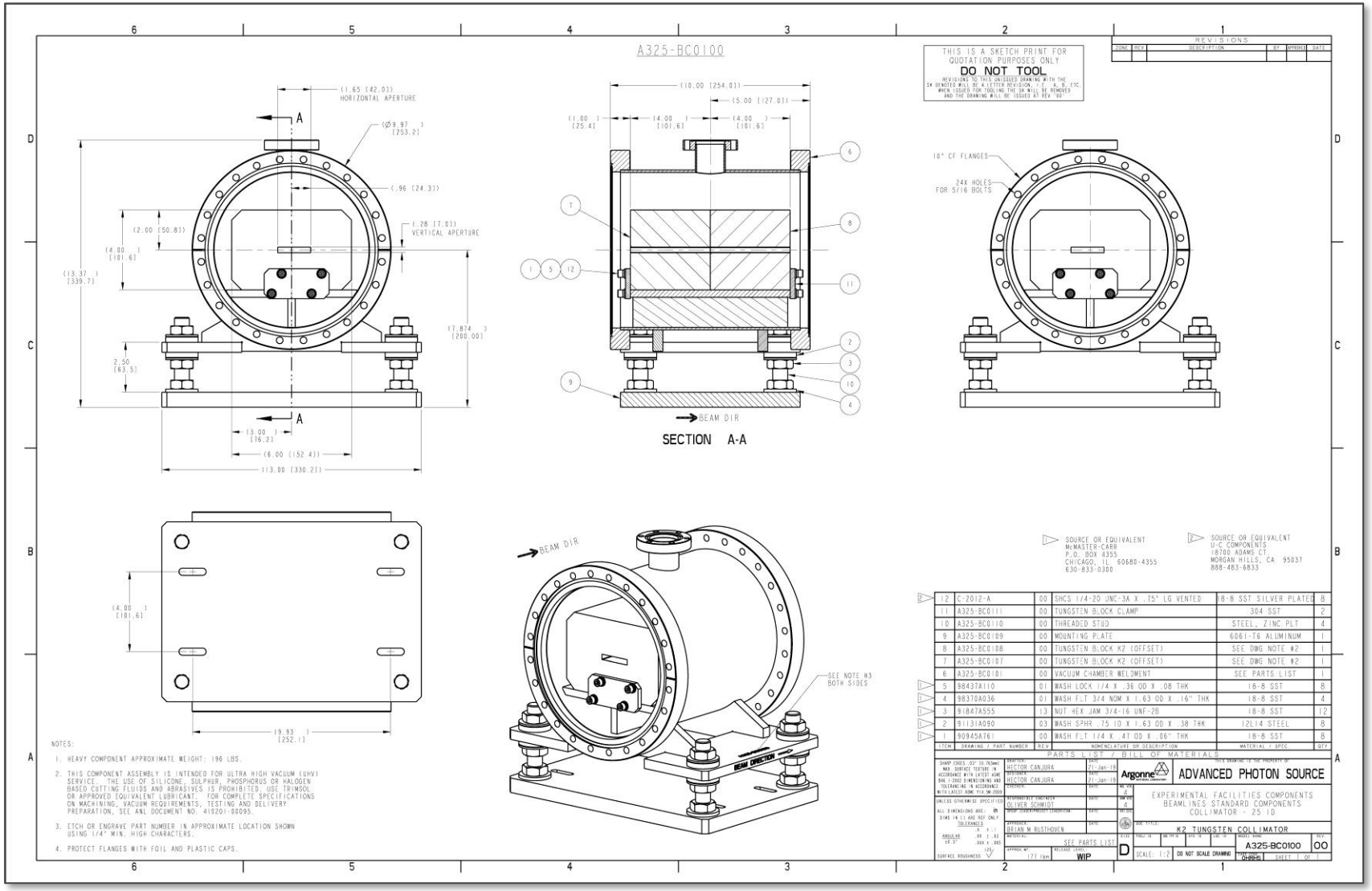
CuCrZr Photon Mask

- We are also beginning to find applications for CuCrZr.
- One Piece Design
- Inexpensive
- Water-cooled
- ConFlat® knife edge integral to mask



Primary Bremsstrahlung Collimator

- Tungsten
  - 180 mm thick
- In-vacuum shielding aperture
- Not conductance limiting



Secondary Bremsstrahlung Collimator

Special attention is given to secondary Bremsstrahlung reflected by white beam mirrors.

- ANL/APS/TB-21 Radiation Shielding of Insertion Device Beamlines Using a Mirror as the First Optical Element
- Works out to roughly 50 mm additional lead covering 8 degrees from center of mirror
- Final aperture to be evaluated for worst case feature beamline application

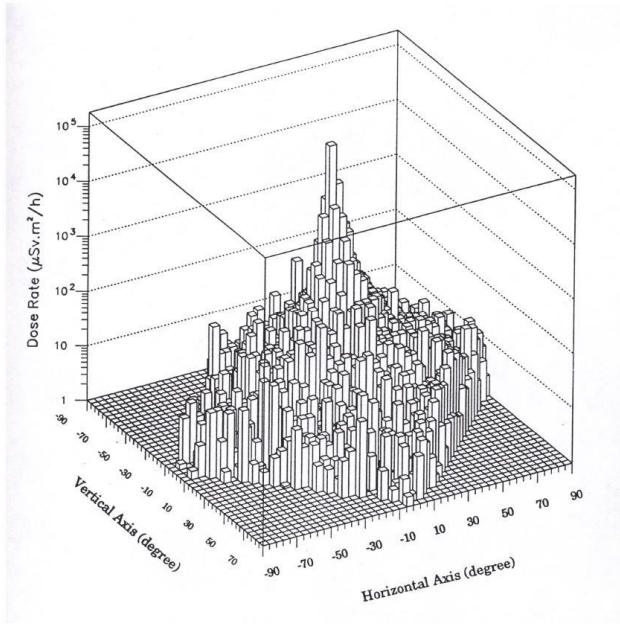
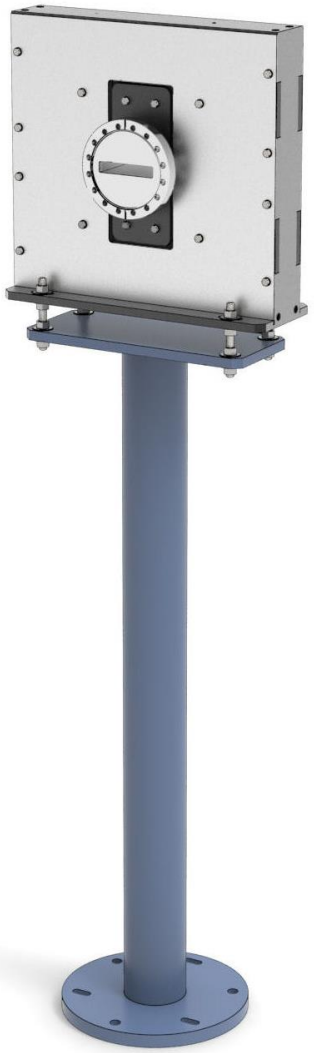
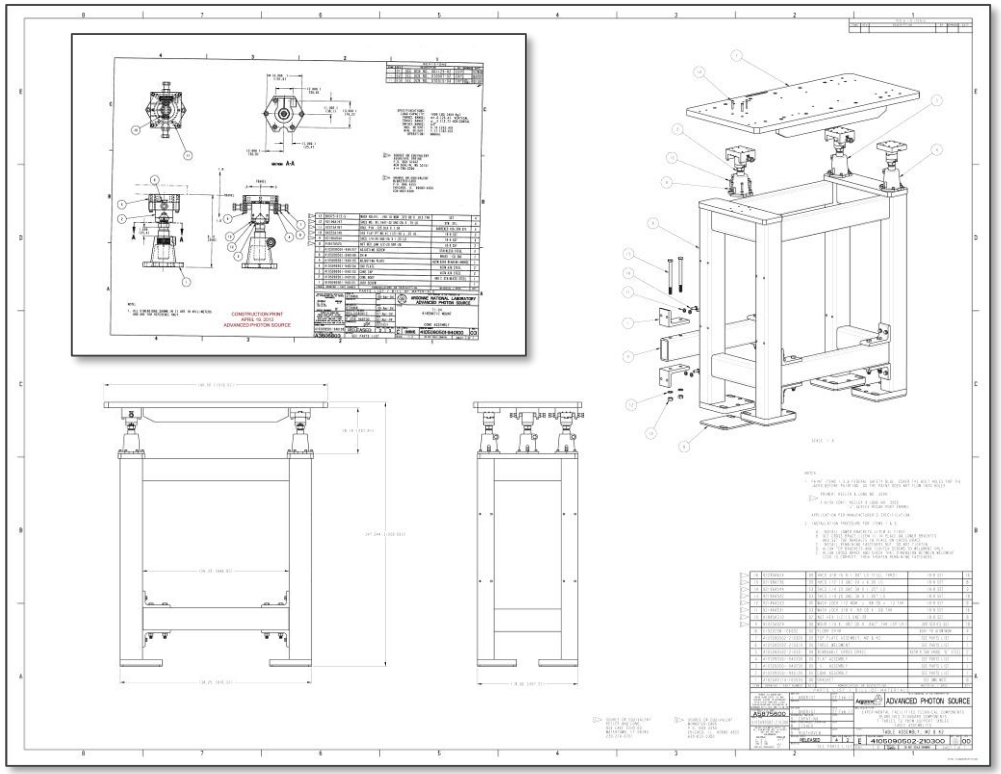


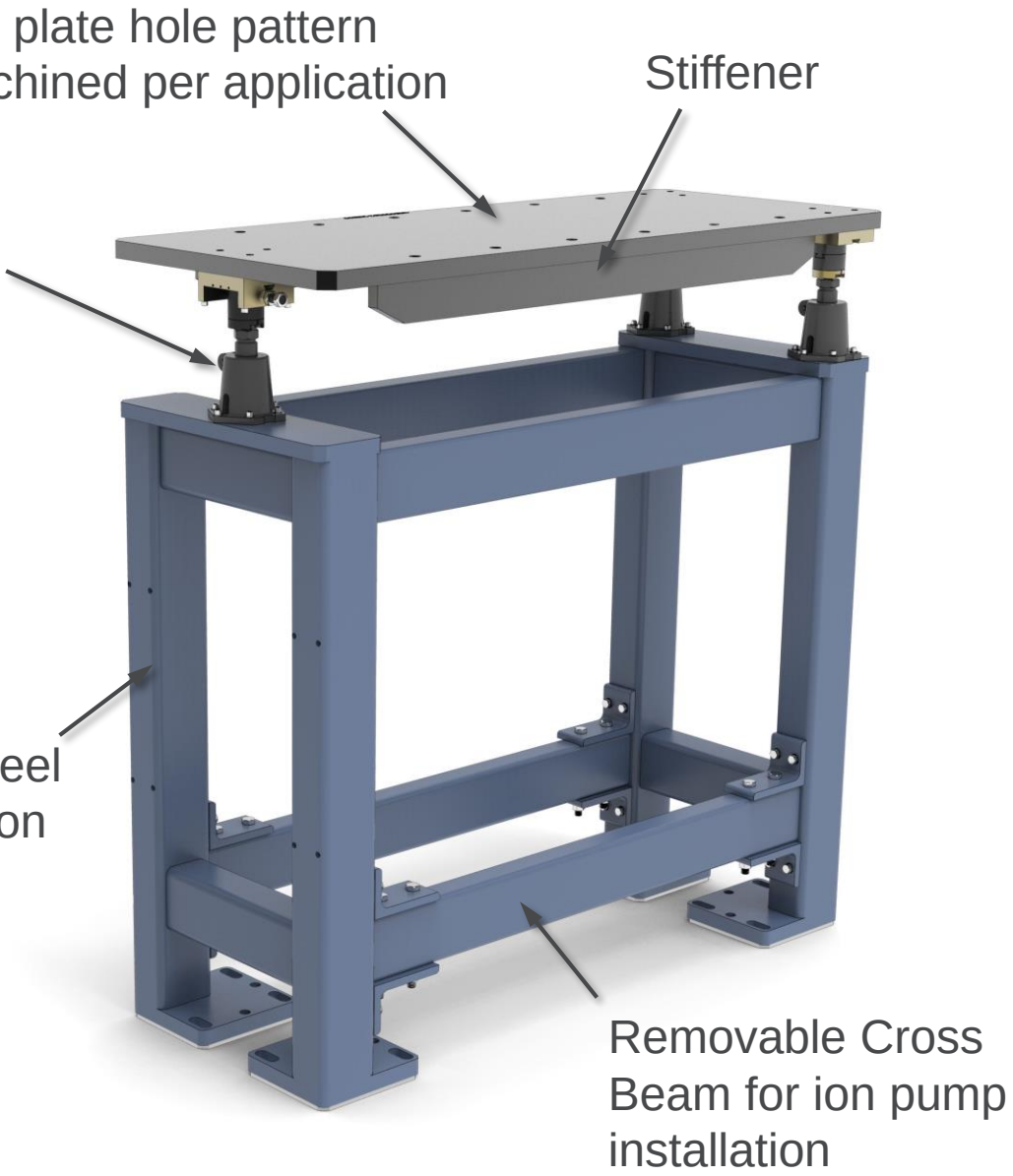
Fig. 6. Angular distribution of the SBR originated from the scattering of BR by the Si mirror.



Support Table

- Classic APS Design
- Perfect for regular components
- Cast aluminum top plate
- Technician familiarity



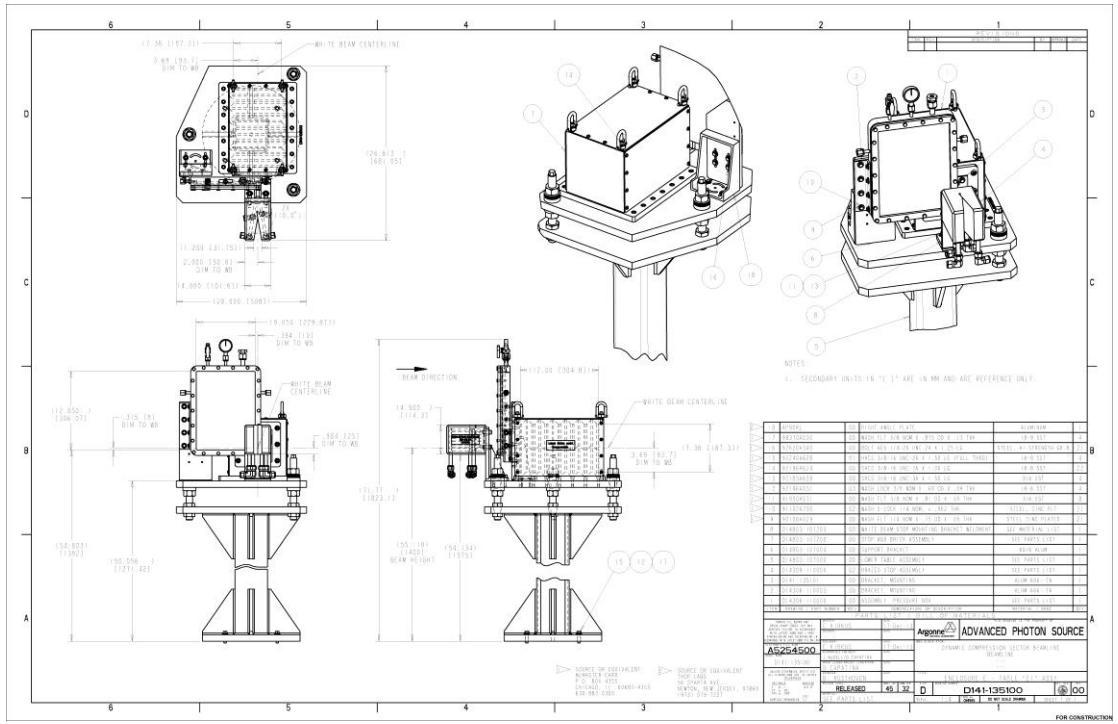


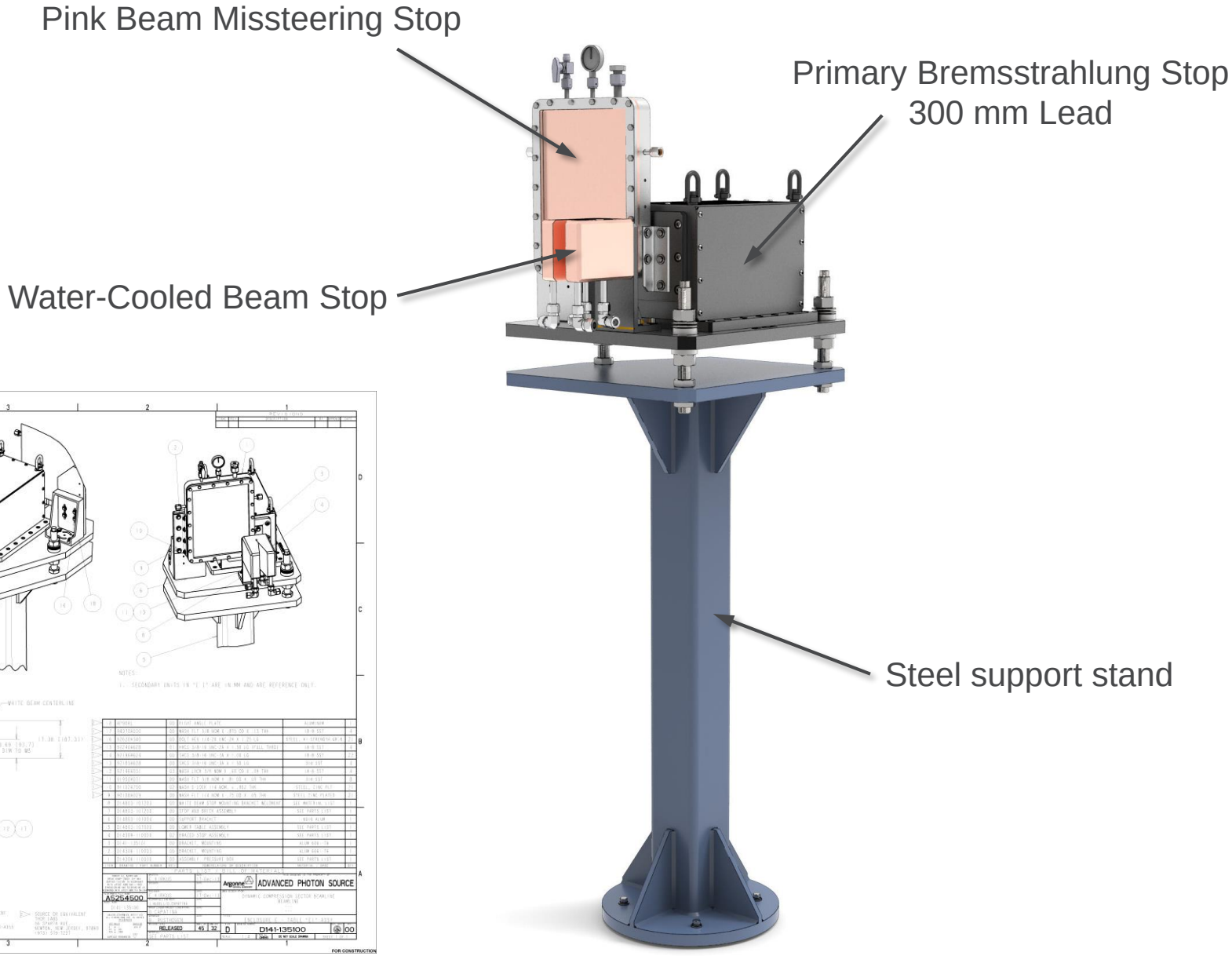
Universal Ion-Pump Stand

- Ion pumps mounted off beam axis
- Standard Pump Size (where possible)
- Minimum footprint along beam axis
- Small pump stand
  - Downstream of WB slits
  - Pump-out
  - RGA
- Large Pump Stand
  - Diagnostics
  - Filters
  - Pump-out

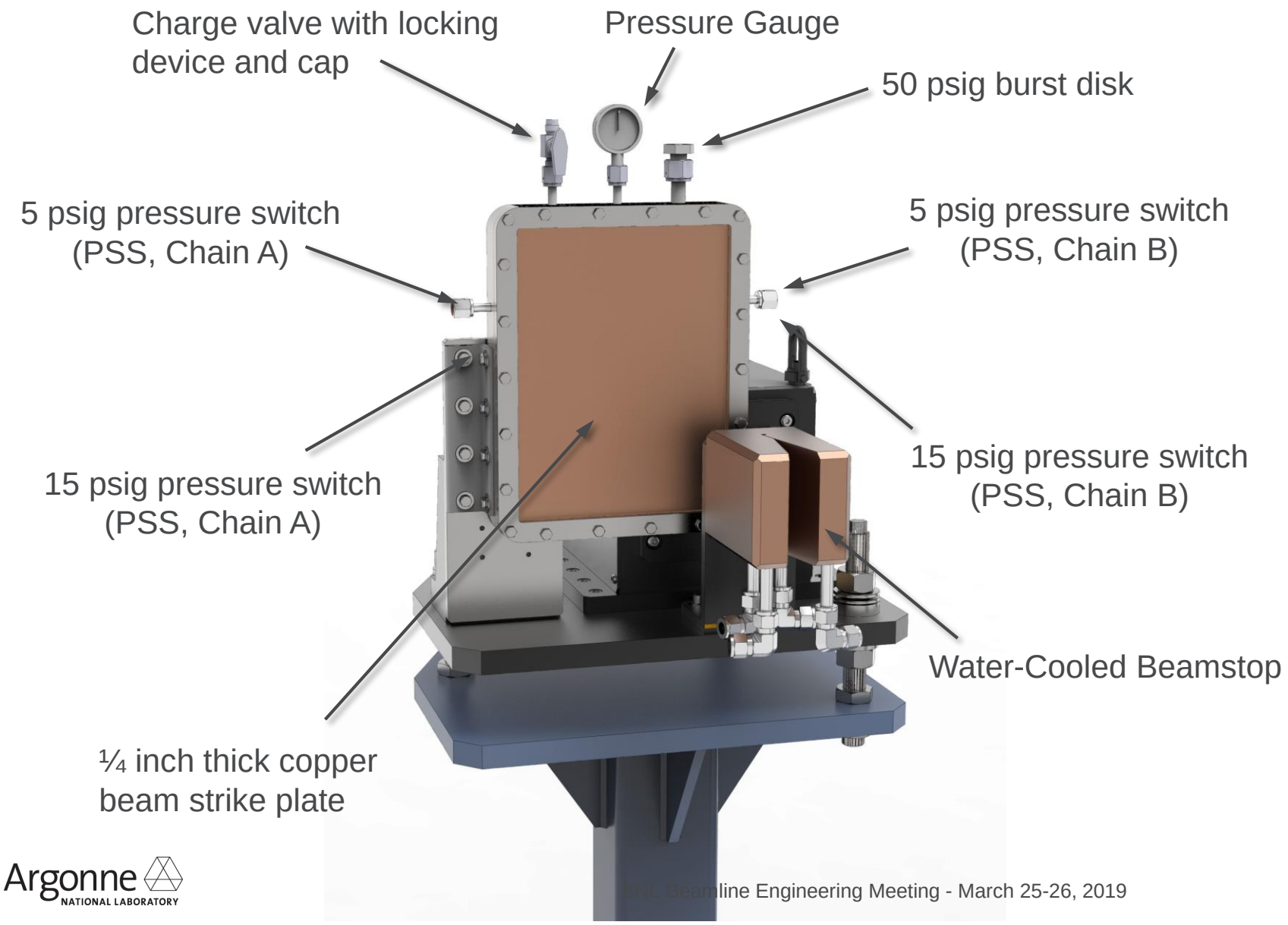
Fixed Beamstop

- Final stop for white beam applications
- Optional pink missteering stop



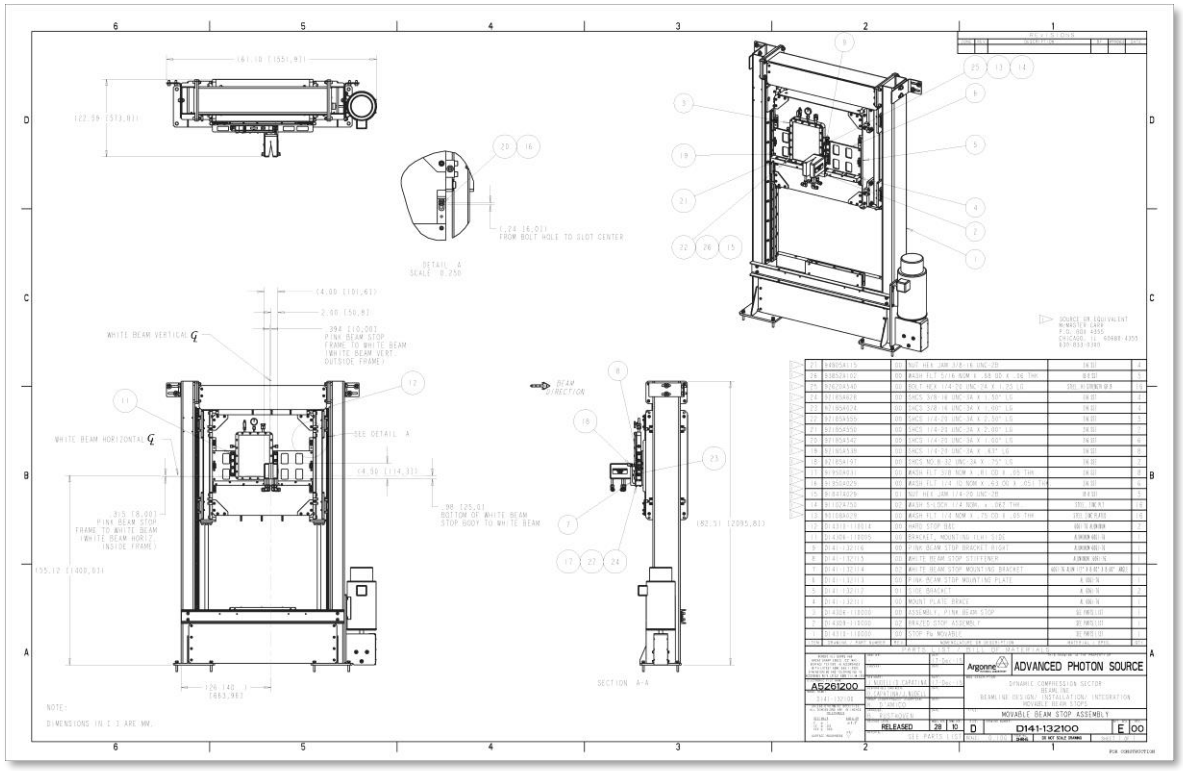


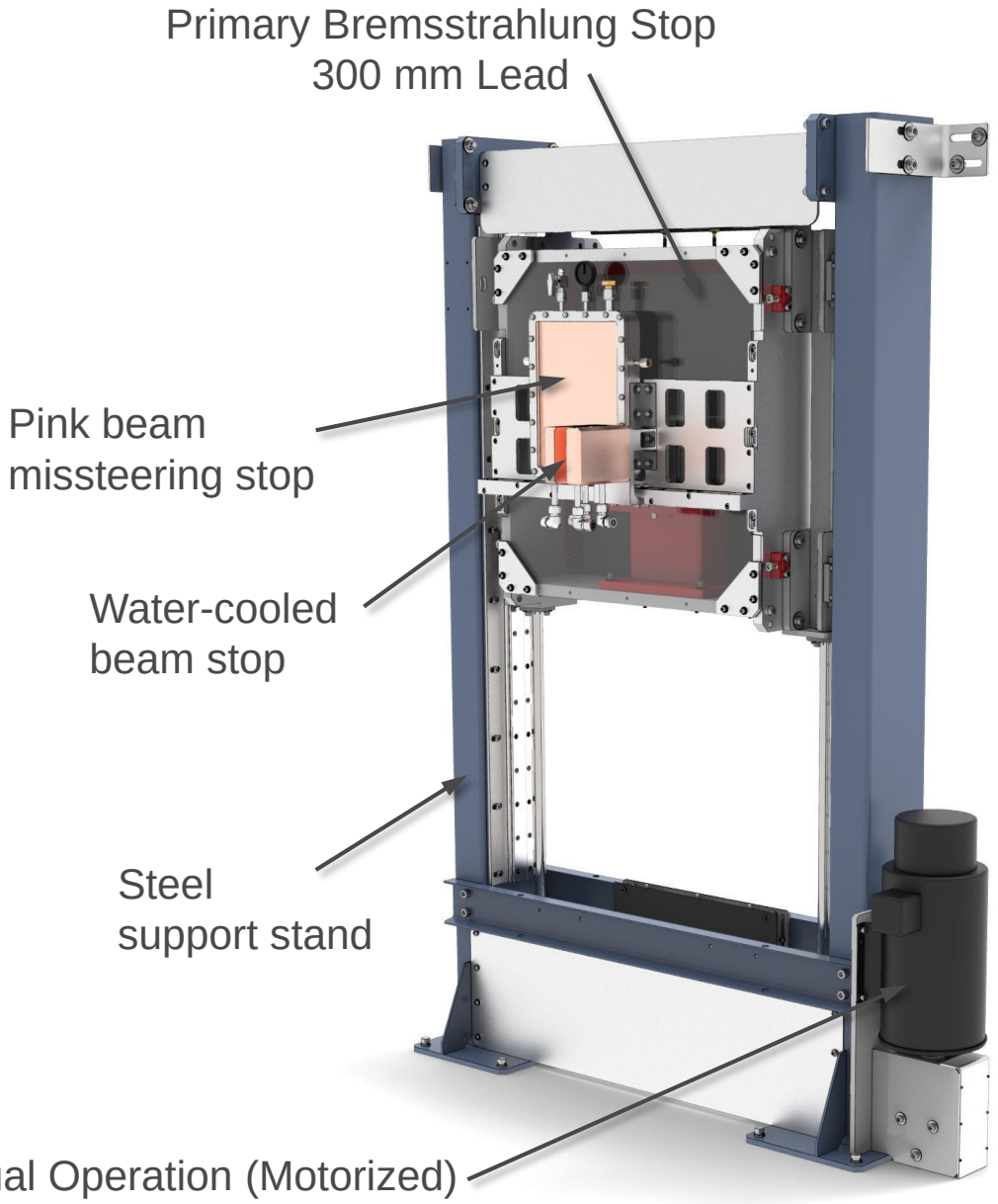
Pink Beam Misteering Stop



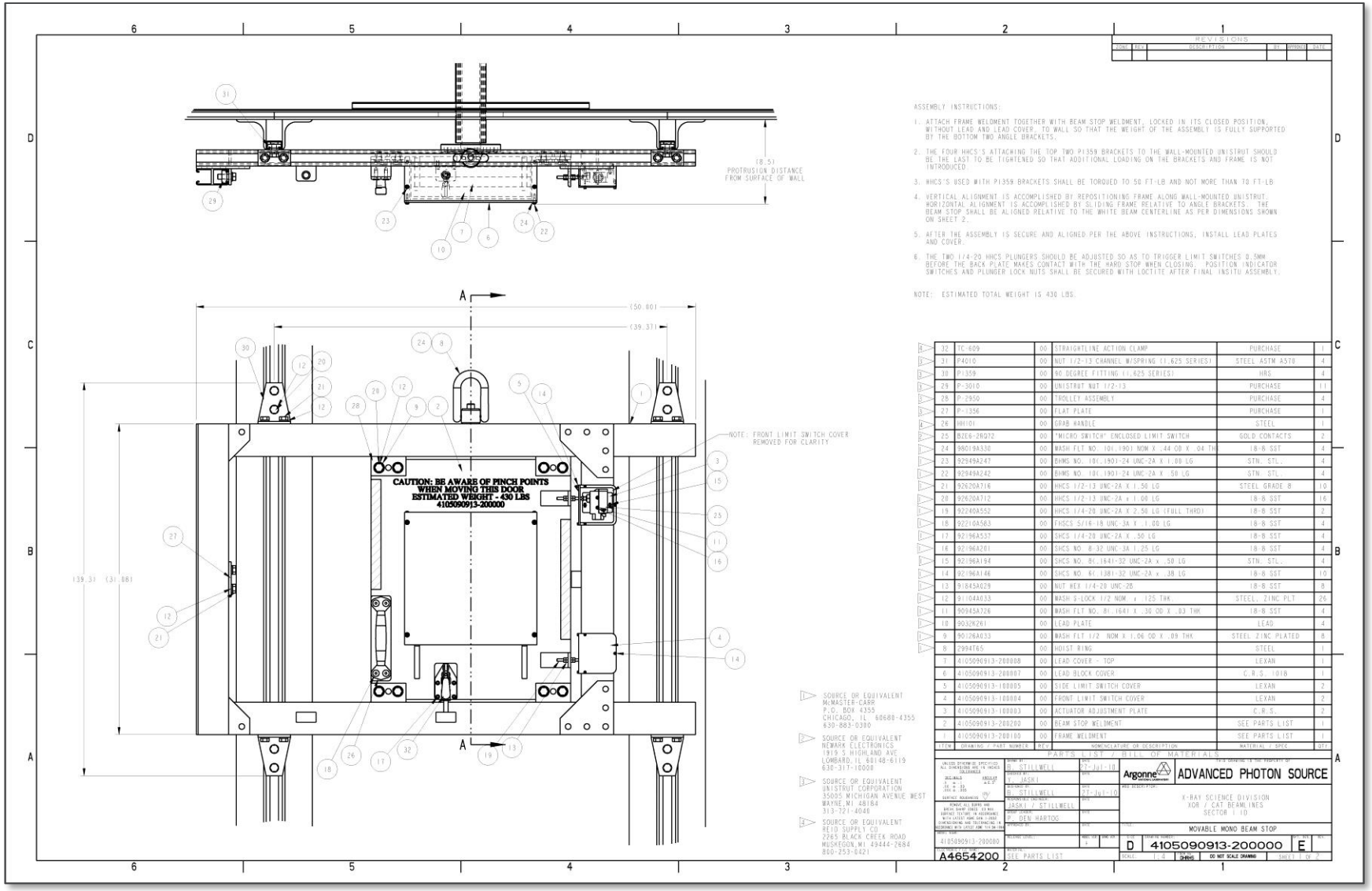
- Pressure-based beam detection over large area (~12 inch x 9 inch)
- Small pressurized sealed gas volume (~1 in^3) for fast response. Gas pressure will increase due to beam heating of the strike plate
- Gas volume charged to 10 psig
- Pressure switches (normally-closed) trigger at set points of 15 psig and 5 psig (2 each, double redundancy)
- A 50 psig burst disk protects the system in the event that the 15 psig pressure switches fail to operate. The 5 psig pressure switches will trigger in this scenario
- Thick copper strike plate can be easily replaced if damaged by the beam

Movable White Beam / Bremsstrahlung Stop



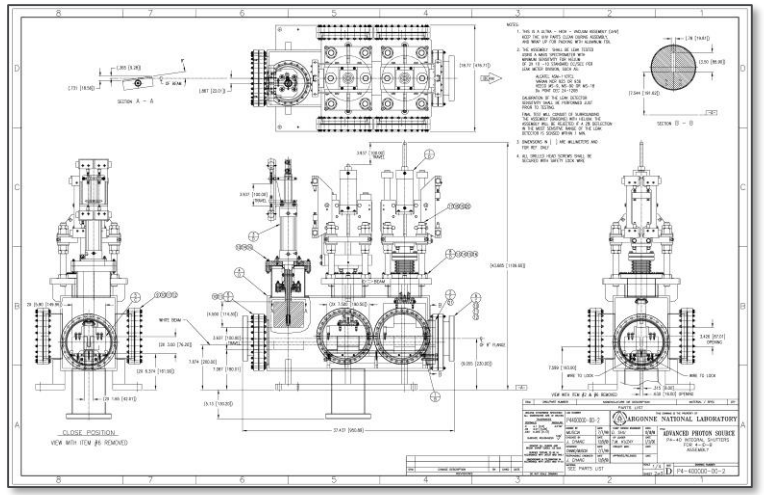


Movable Beamstop (Mono)



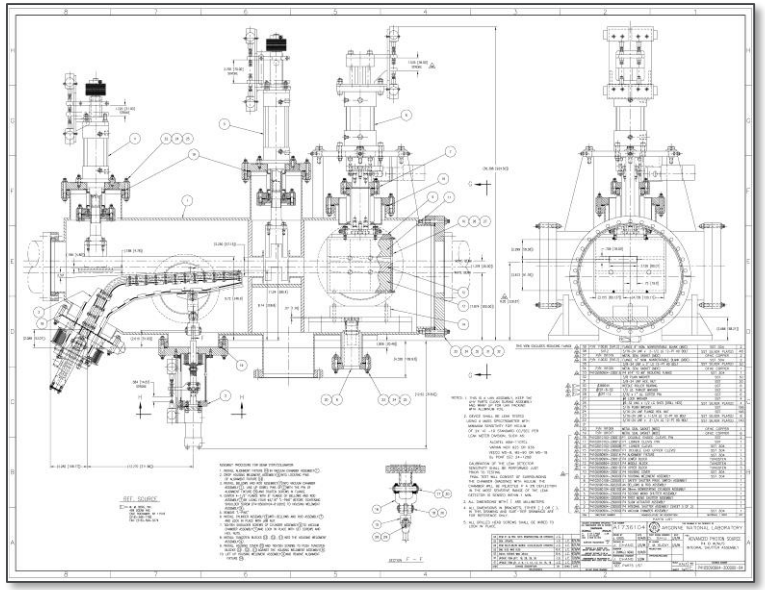
Shutters

We have an arsenal of existing shutter designs at our disposal!

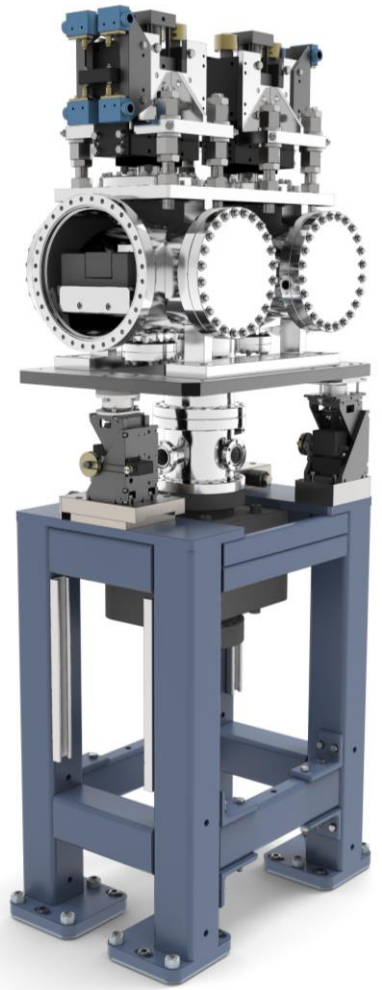


P4-40 White Beam / Bremsstrahlung Shutter

- Many shutters will be reused / repurposed
- White Beam Shutters
- Bremsstrahlung Shutters
- Mono Shutters
- Pink Beam Shutters

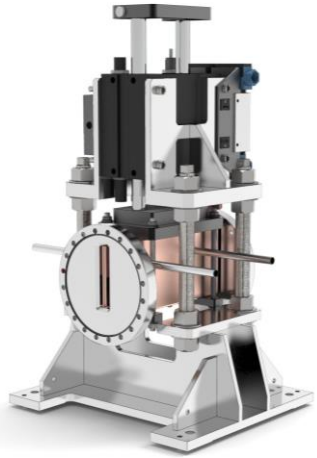


P4-20 Mode Shutter



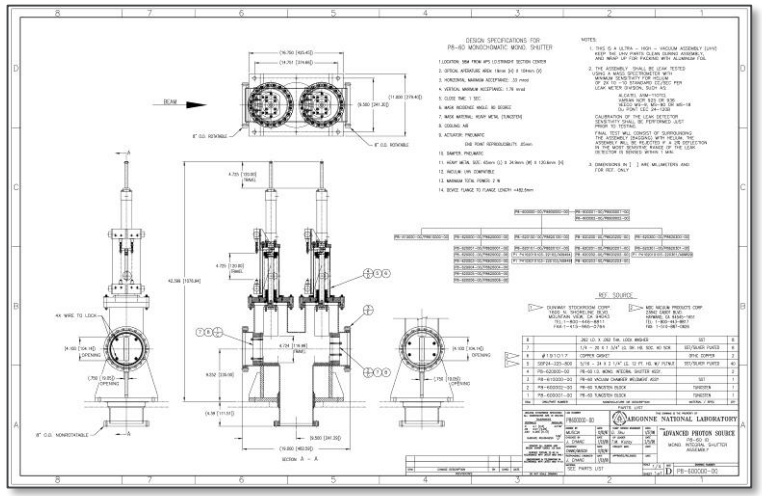
Front-End Safety Shutter

Photon Shutter

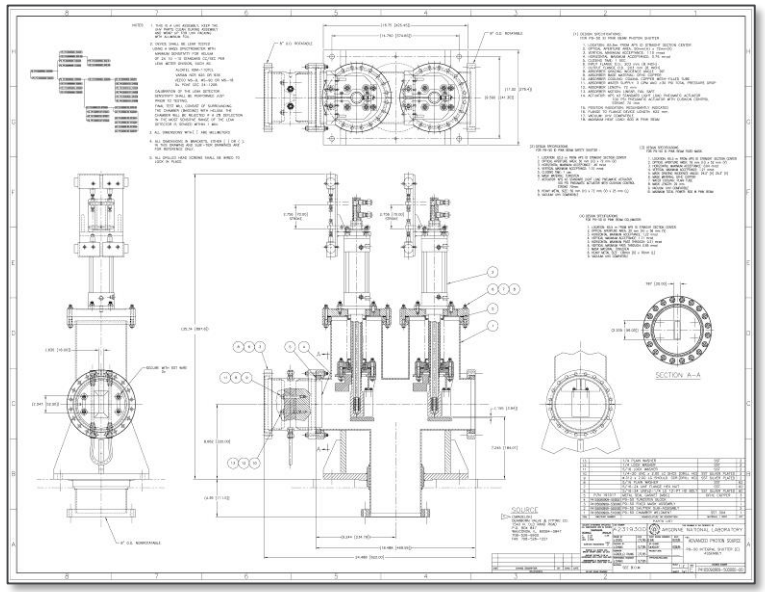


More Shutters!

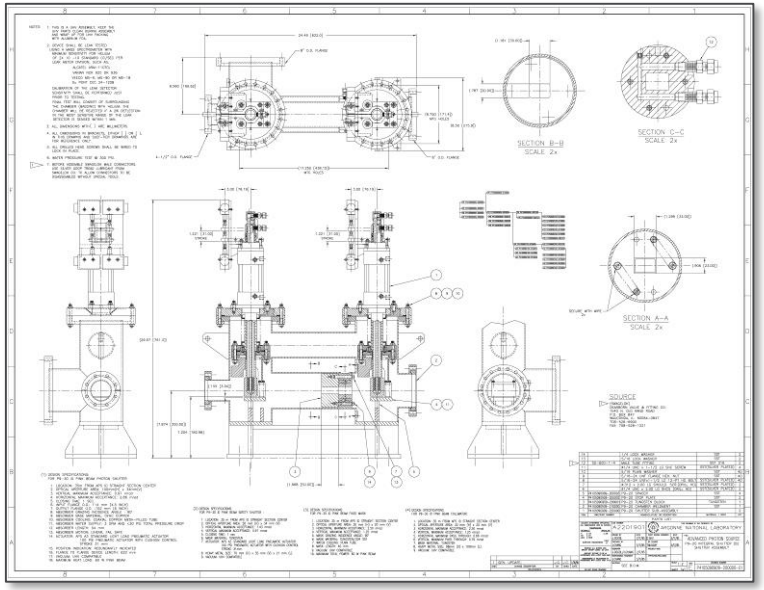
P8-20 Mono Shutter



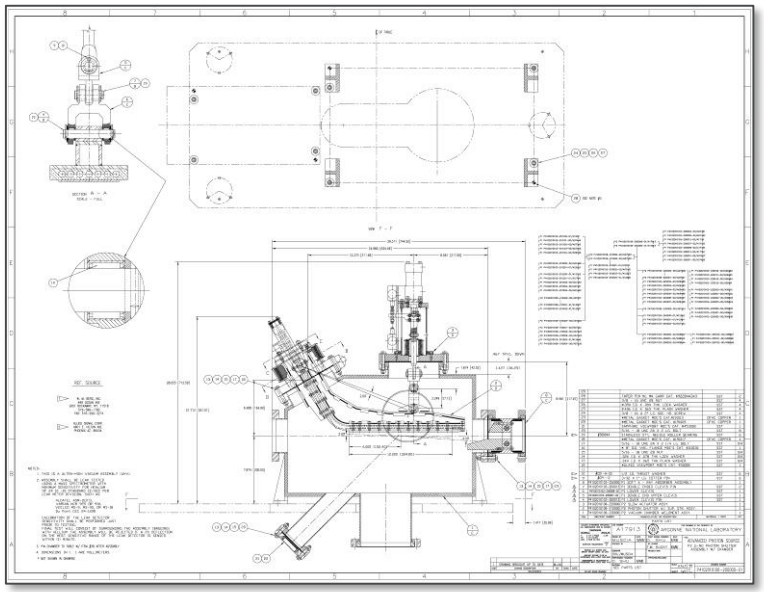
P8-60 Mono Shutter



P9-50 Pink Beam Shutter



P9-30 Pink Beam Shutter



P2-20 White Beam FE Shutter

Normal Incidence Compton XBPM

- CVD diamond blades absorb beam and emit Compton radiation which is then detected using PIN diodes (pyrolytic graphite blades also tested *much cheaper)
- Halo of beam scraped allowing beam center to pass
- Works for white, pink beams
- Vertical and horizontal measurements
- Can be used in canted and high heat load beamlines
- Current setup proven at ~29m from source in 24-ID-A (~20m shows damage in 26-ID-FE)
- Blade geometry can be altered without affecting overall structure of XBPM which allows for optimization for specific placements
- Adjustable spacing between blades allows for optimization at different distances and for different beam sizes from exit mask configurations
- Can use existing XBPM platforms
- RMS resolution ~0.3μm in vertical (horizontal can be refined further with blade geometry)
- Signal to BM background ratio was 30:1 in 26-ID-FE
- Signal up to 1mA with low noise