LVP facilities at synchrotrons: design paradigms and future prospects

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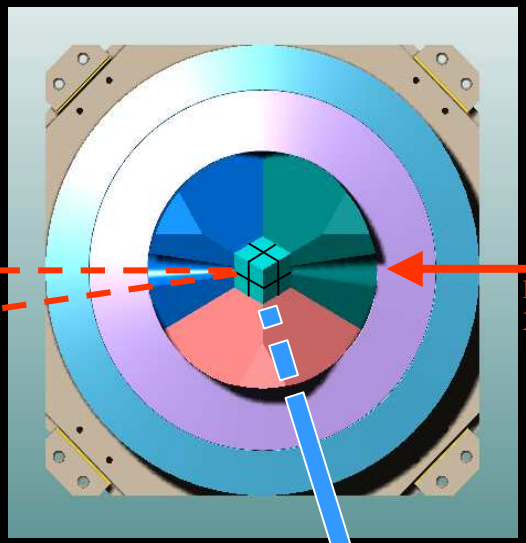
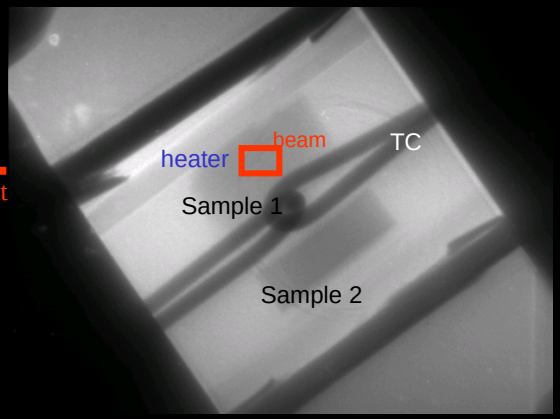
GSECARS, Univ. Chicago

Outline

- LVP techniques: current status and developments
- Existing facilities at 3G synchrotrons
- Beamline considerations
- Upcoming LVP facilities
- “Ideal” LVP beamline

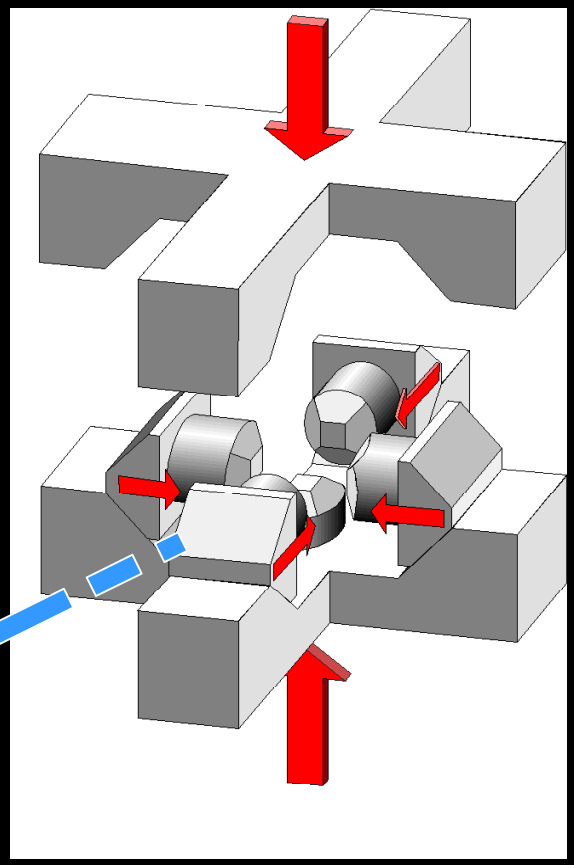
Multianvil modules

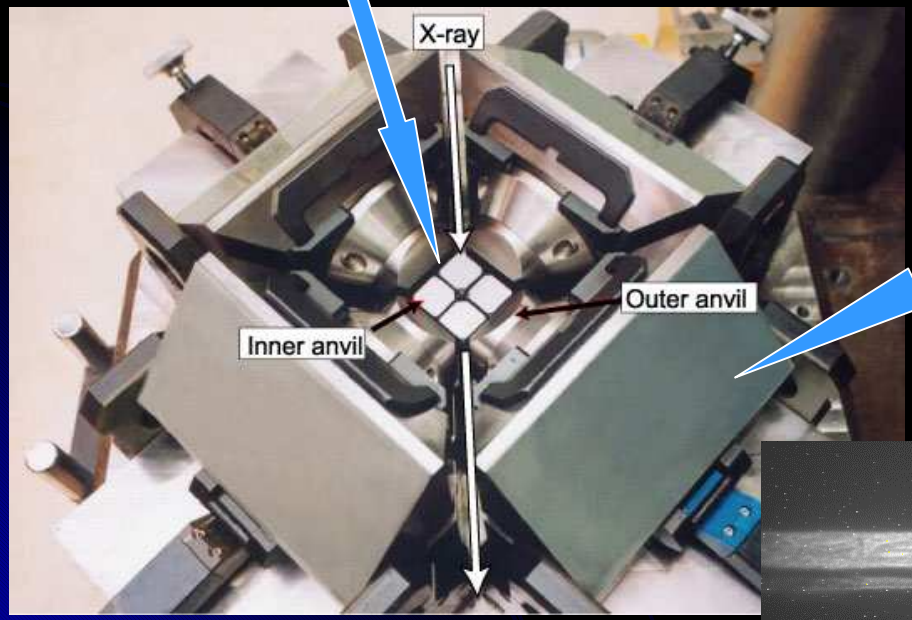


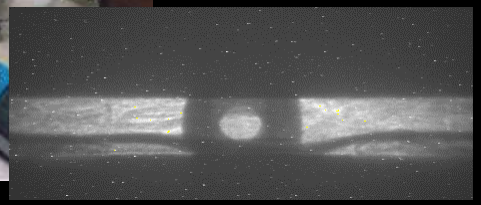


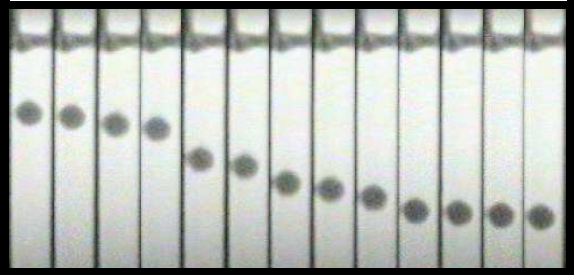
Kawai-type

DIA







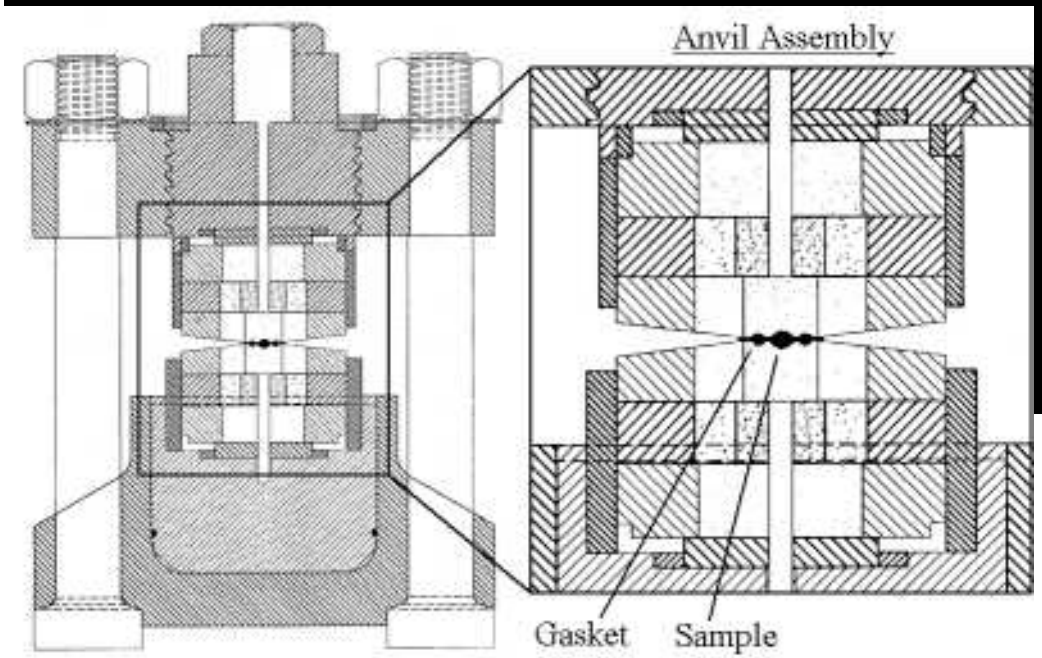


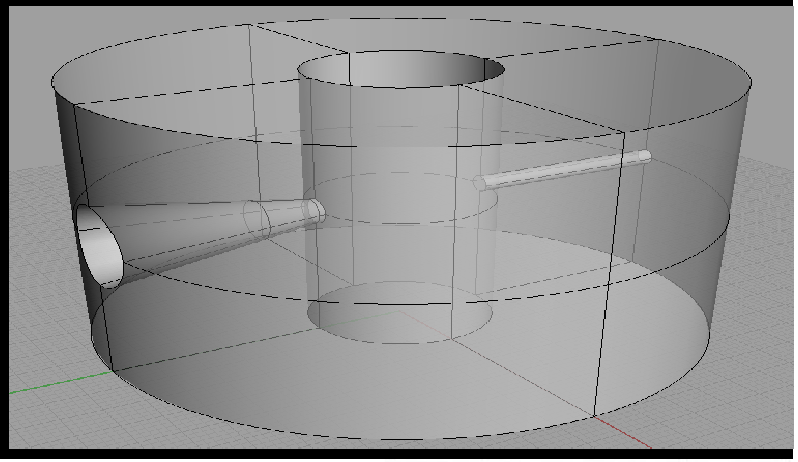
Double-stage

Science in MA

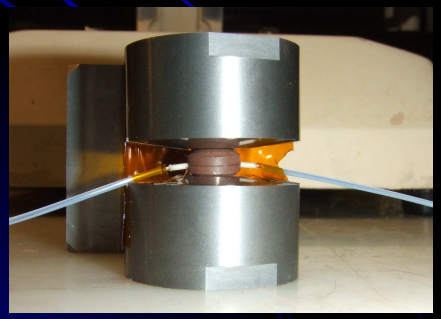
- Single-stage DIA: ~(20 GPa, 2000K), large Q range, EDXD, ADXD (+/- Soller slits)
  - Crystallography
  - Transformation mechanisms (SLIP)
  - Density by absorption
  - EXAFS (high energies)
  - Acoustic velocities
- Single-stage Kawai: ~(30 GPa, 3000K), limited Q, mostly EDXD, offline cells transferable
  - “In situ petrology”
  - P-V-T
  - Kinetics
  - Melting
  - Acoustic velocities
- Double-stage: ~(80 GPa, >2000K), limited Q range, mostly EDXD
  - Lower mantle
  - Potential crystallography (CAESAR diffraction)
  - Acoustic velocities

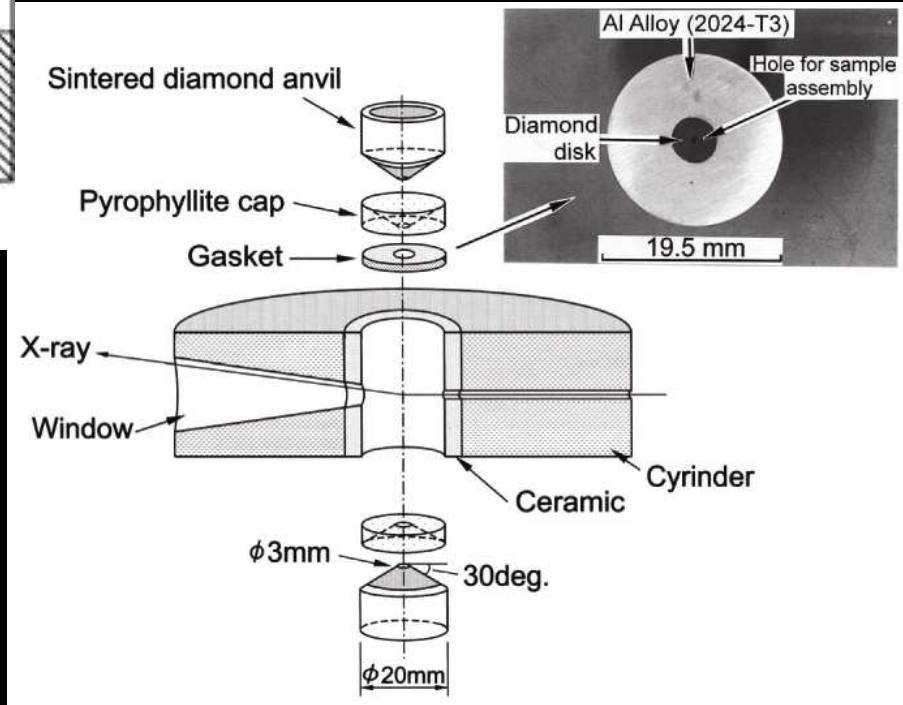
Opposed anvil modules





Toroidal / PE cell Klotz et al., 2004



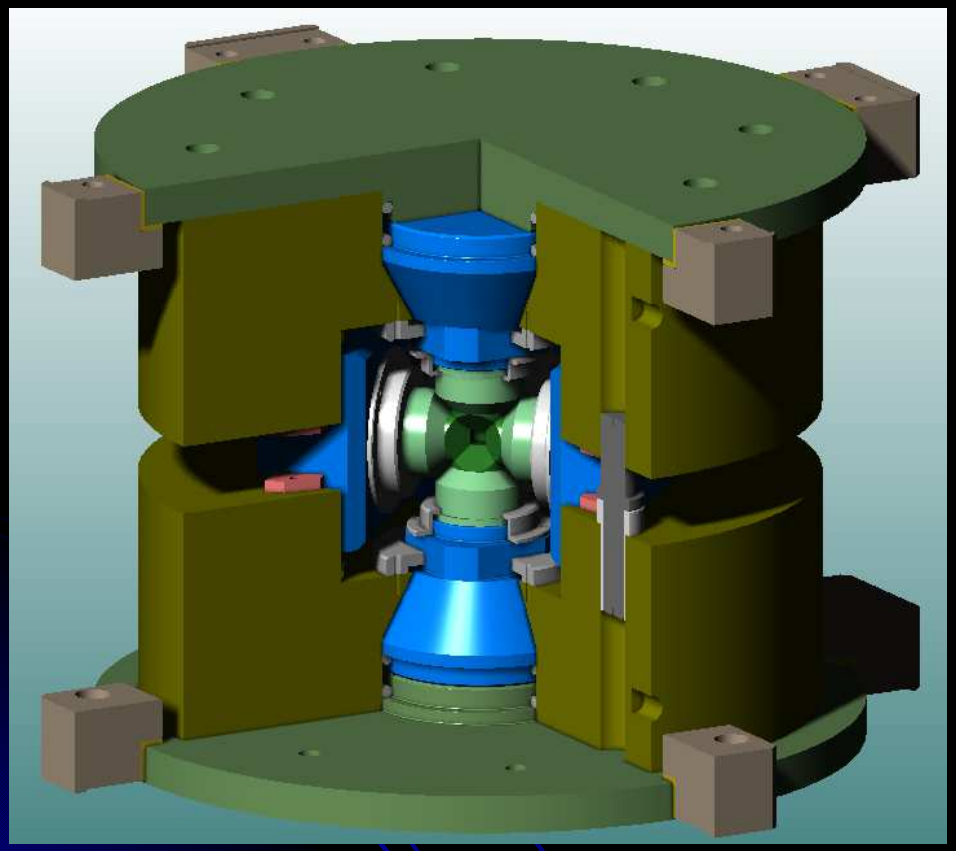


Drickamer Gotoh et al., 2006

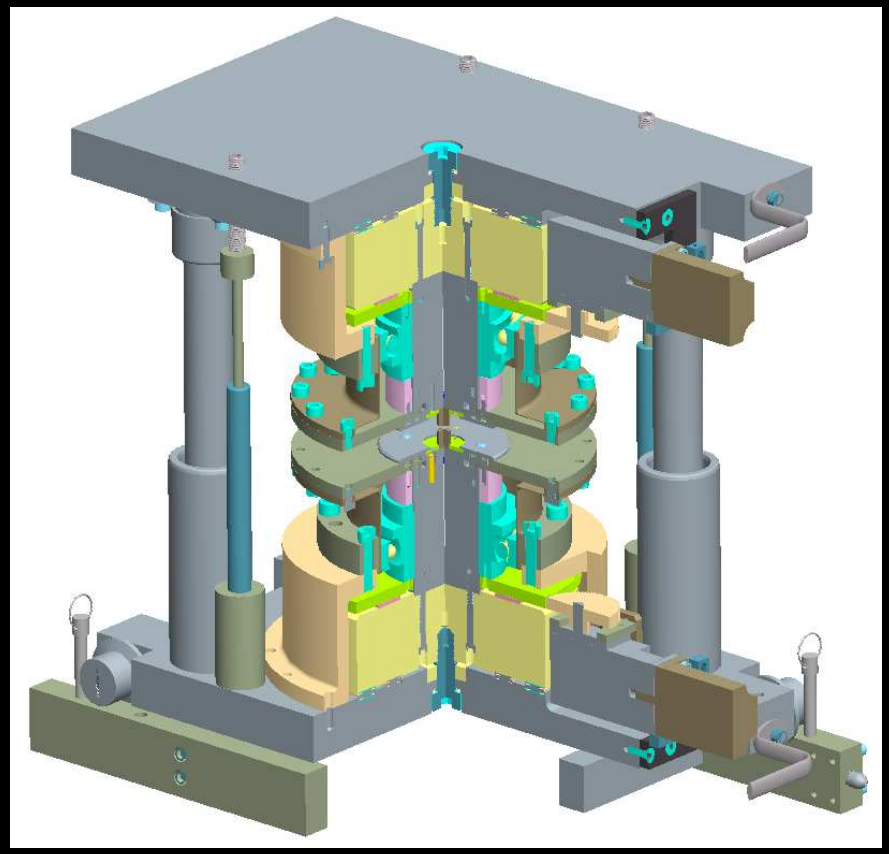
Science in OA

- PE: ~(20 GPa, 2000 K), large Q range, mostly ADXD (w/ Soller slits)
  - Crystallography
  - Melt structure
  - EXAFS
  - Acoustic velocities
- Drickamer: ~(60 GPa, 2500 K), limited Q range, mostly EDXD
  - P-T exploration
  - Potential rheology studies

“Specialty” modules



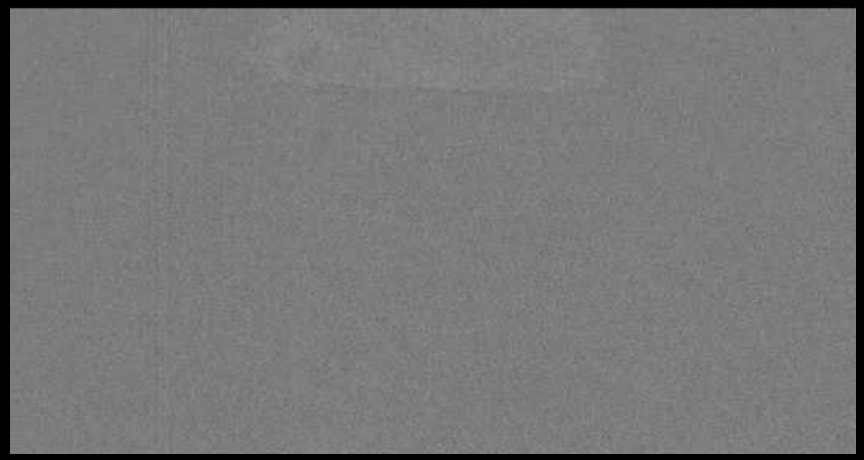
Deformation DIA (D-DIA)
(Wang et al., 2003)



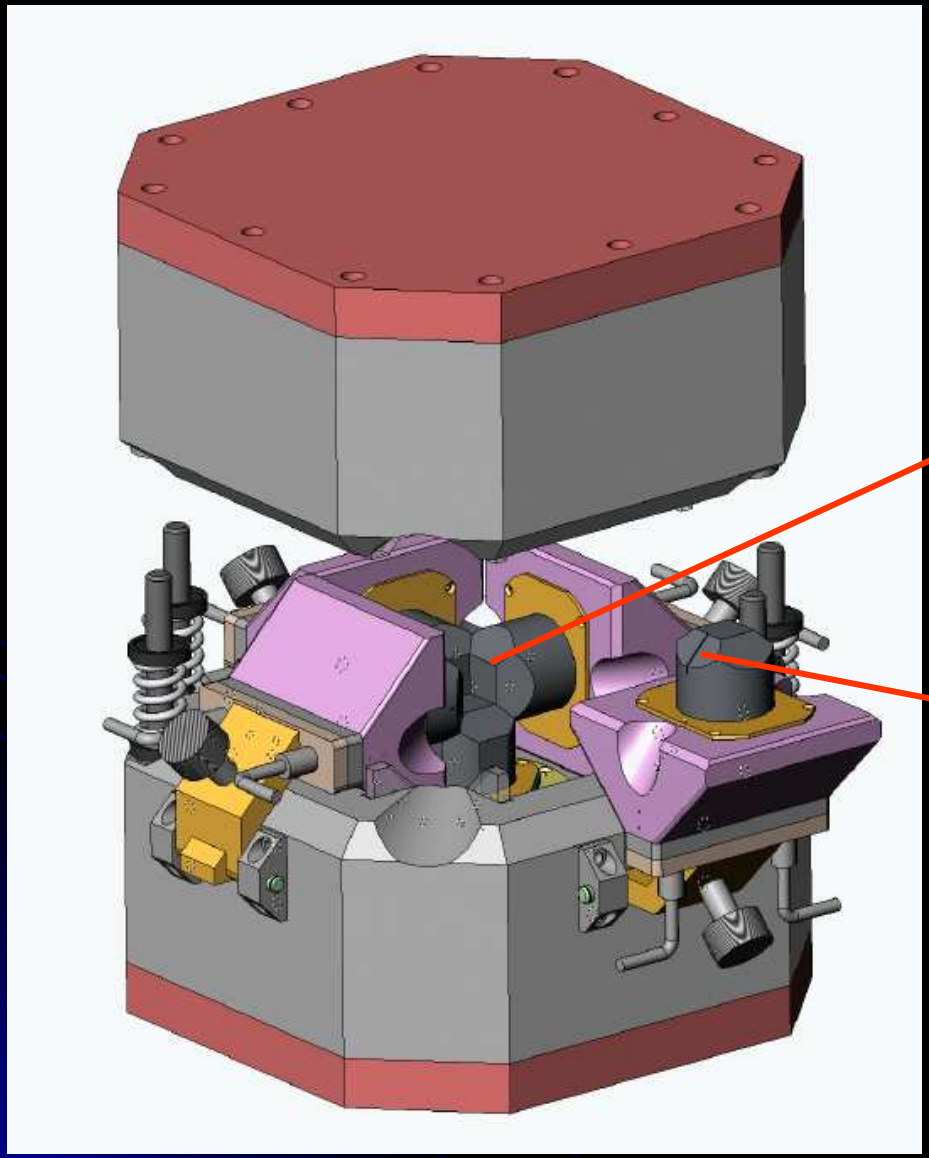
RDA (Yamazaki & Karato, 2001)
High-P tomography (Wang et al., 2005)

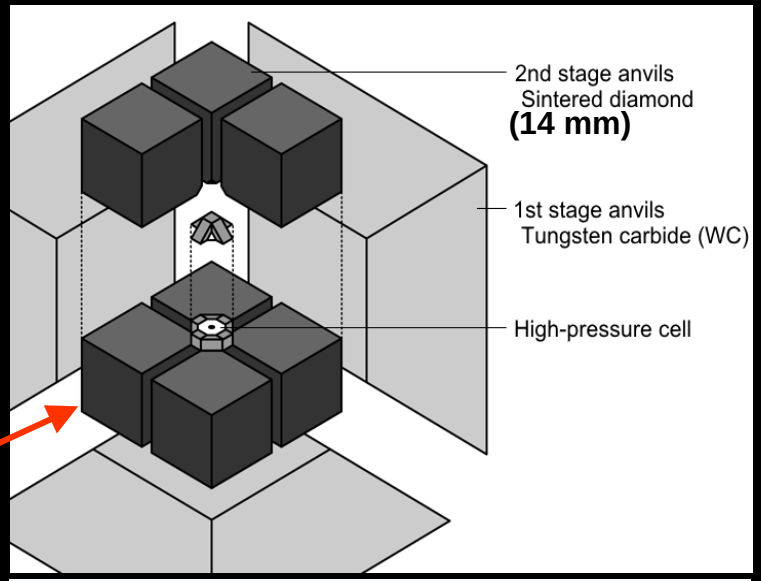
Science in D-DIA and HPXTM

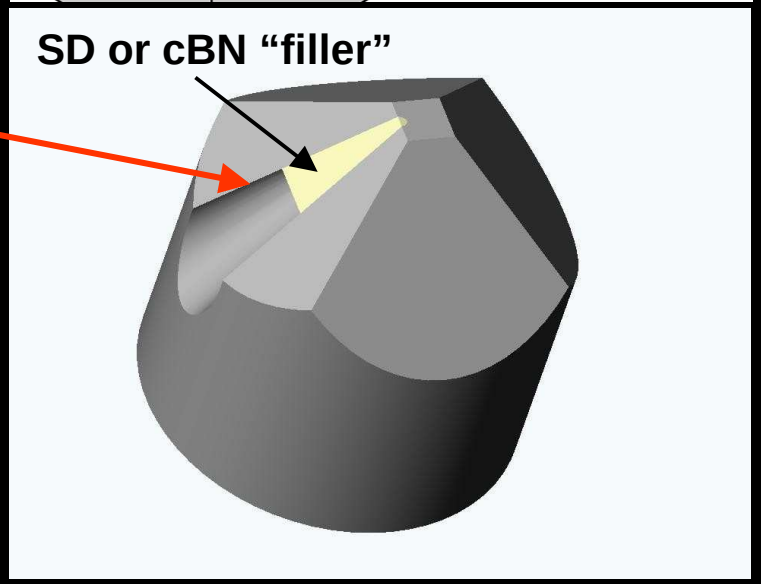
- D-DIA: EDXD & ADXD
  - Rheology of crystalline materials
  - Controlled hydrostatic experiments
  - Acoustic velocities
- HPXTM: mono imaging + EDXD
  - Spatial resolution: currently 4- 5 microns
  - Direct volume imaging on non-crystalline materials (eos)
  - Shear induced texture evolution
    - Partial melting
    - Melt percolation
    - Porosity



New directions: going large



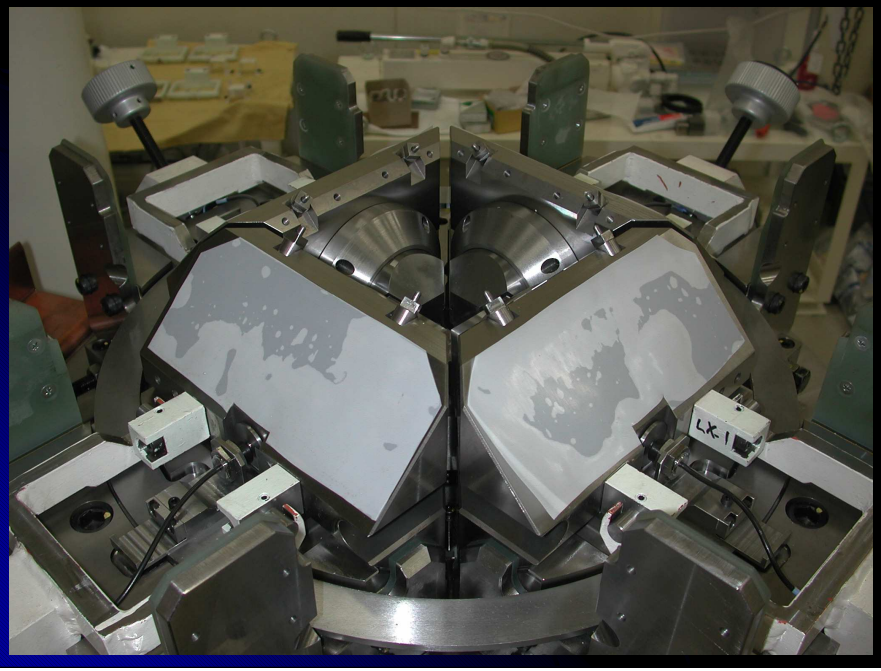




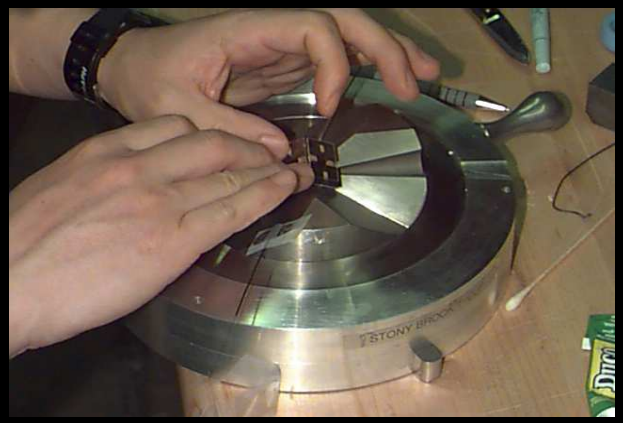
Wang et al., '05 COMPRES Annual meeting

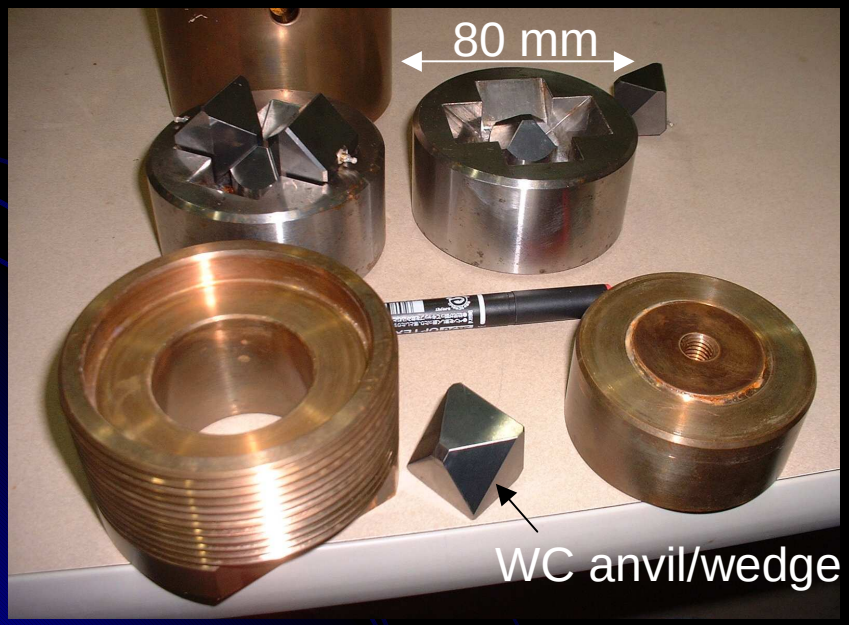
Large D-DIA at GRC

- 1500 t capacity
- ~10 mm diff ram travel
- All anvil displacements encoded
- Servo-control



New directions: going small

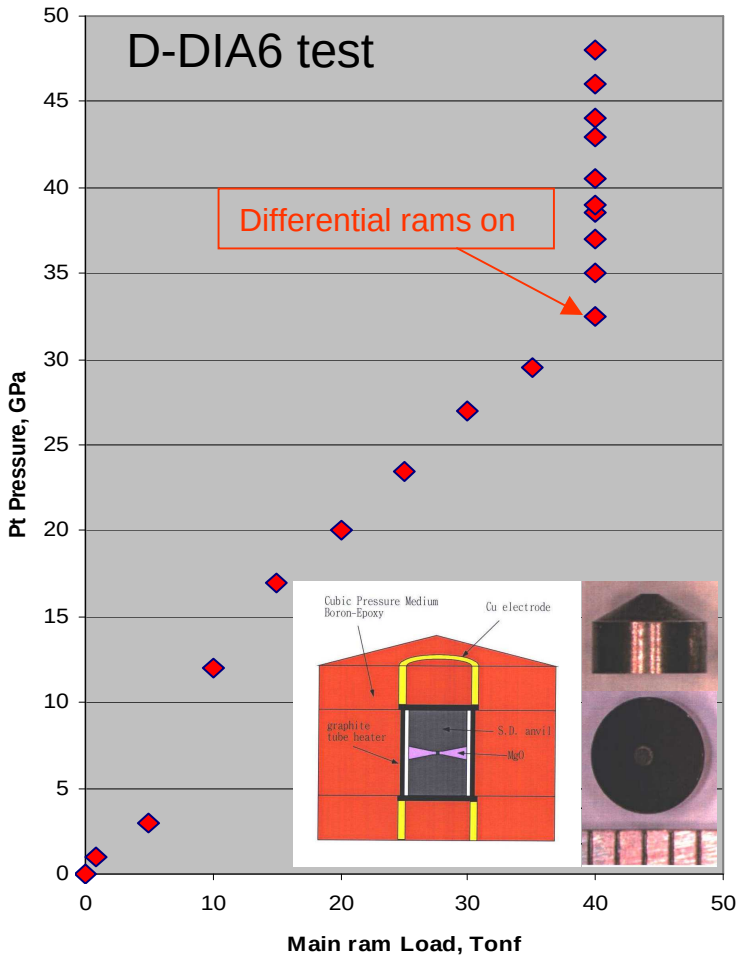




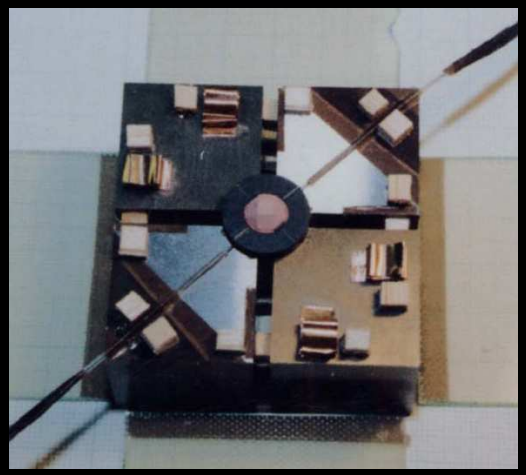
Uwatoko et al., 2007

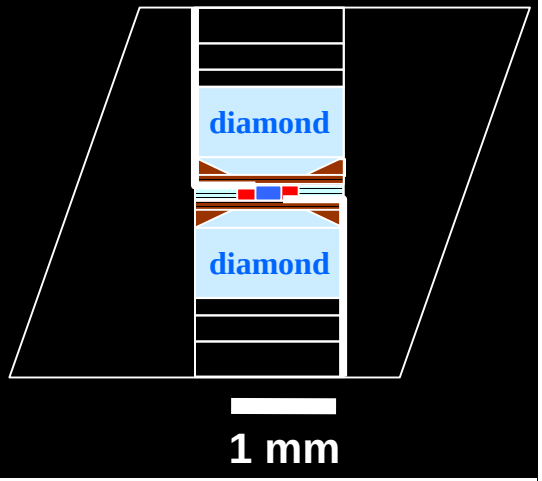
Nishiyama et al., 2007

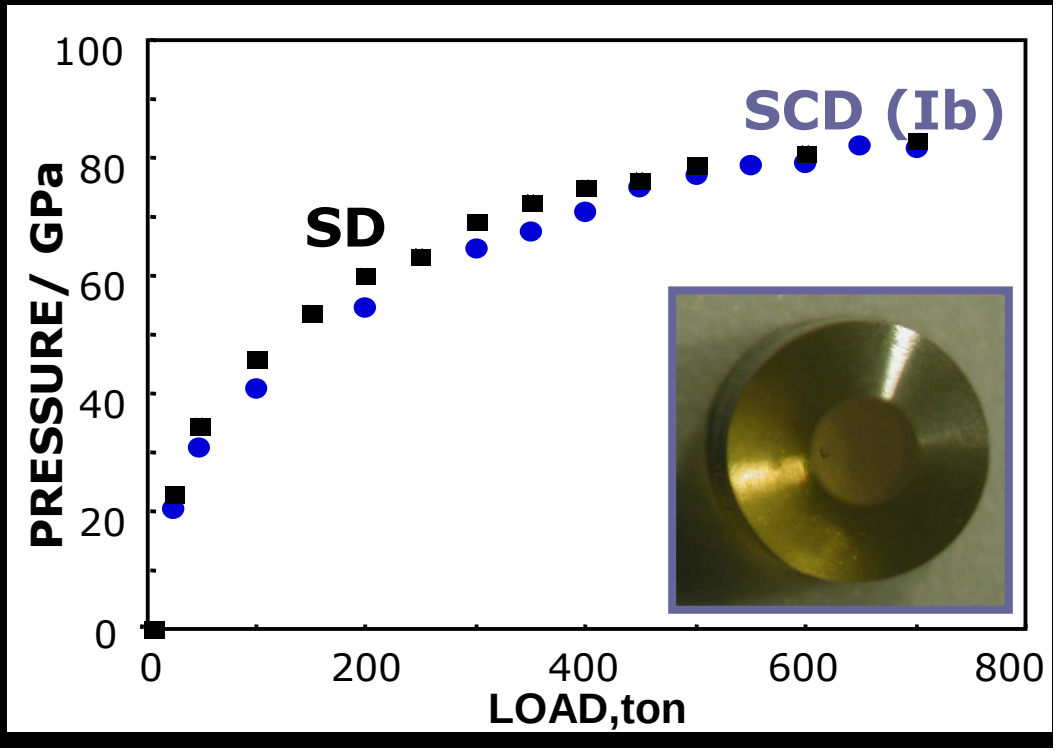
New directions: DAC in LVP



Wang et al., 2005



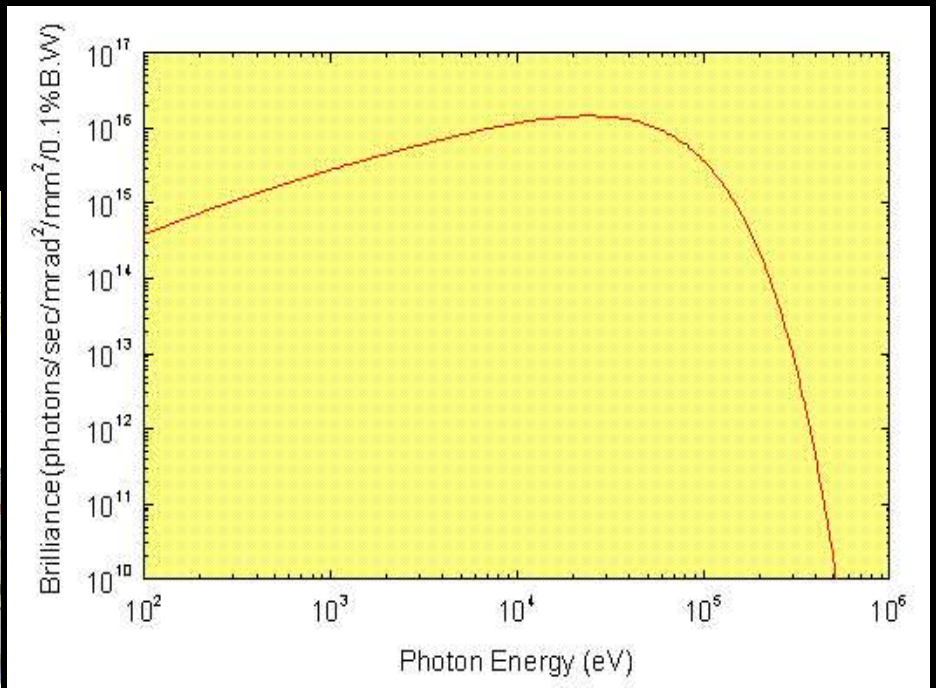




Irifune et al., 2007

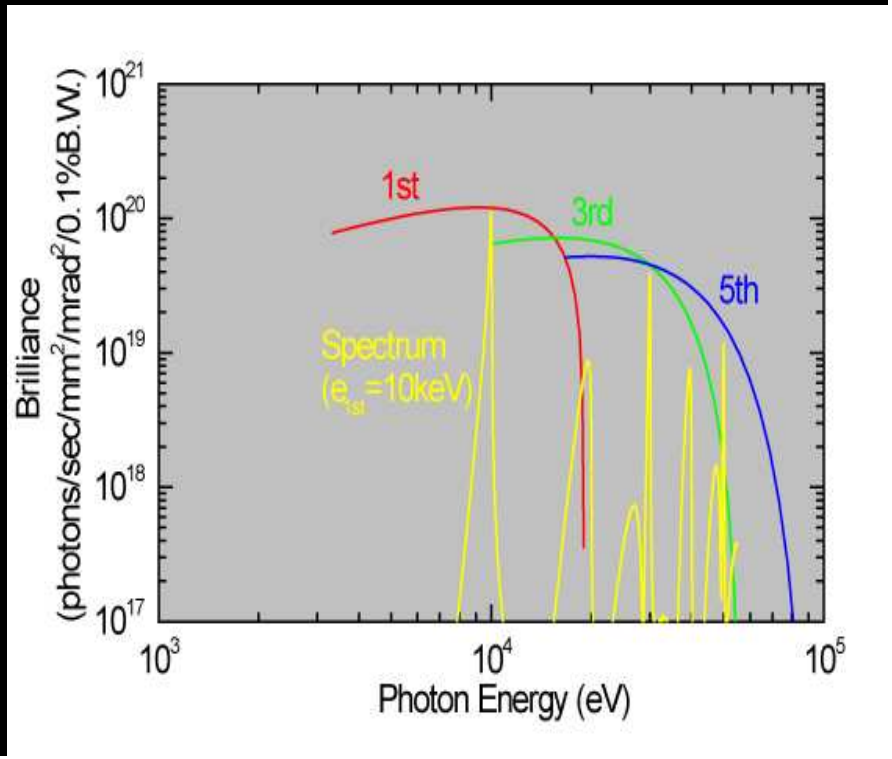
LVP at 3G synchrotrons: SPring-8

- BL04B1: Bending magnet
- Two 1500 t presses, SPEED MK-II has oscillating capability
- Double-stage only
- Full-time operation (2 beamline scientists)
- Exclusively EDXD
- ADXD planned
- Imaging



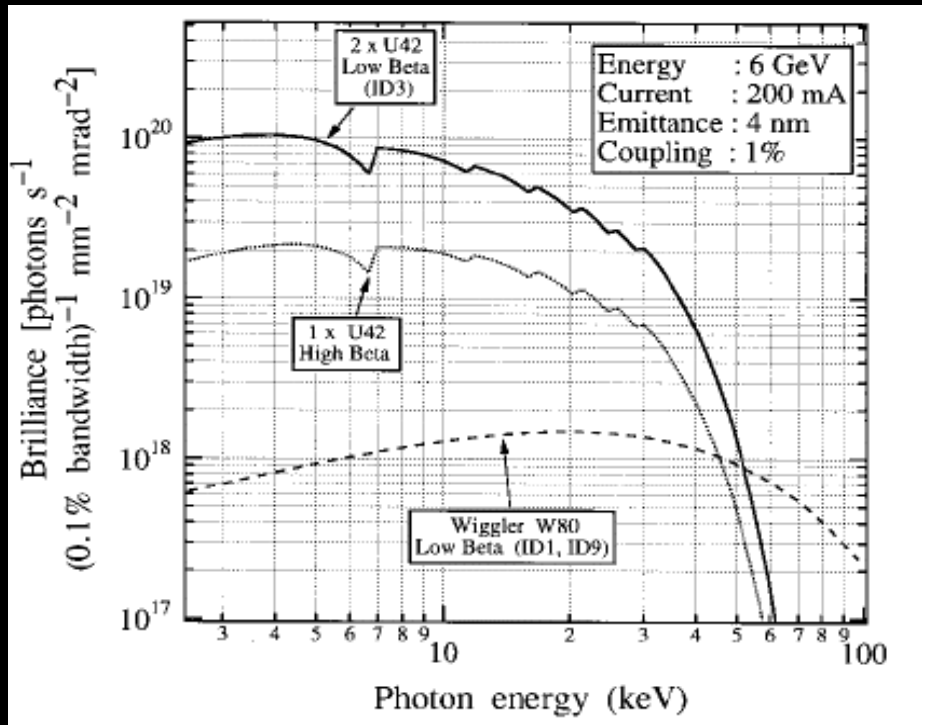
LVP at 3G synchrotrons: Spring-8

- Beamlines BL14B1 and 22XU
- BL22XU Undulator (period 26 mm, length 5 mm, ? T, 18.9 kW)
- Single-stage DIA devices (SMAP)
- PE cell
- EDXD, ADXD, absorption
- “Private” (JAEA)



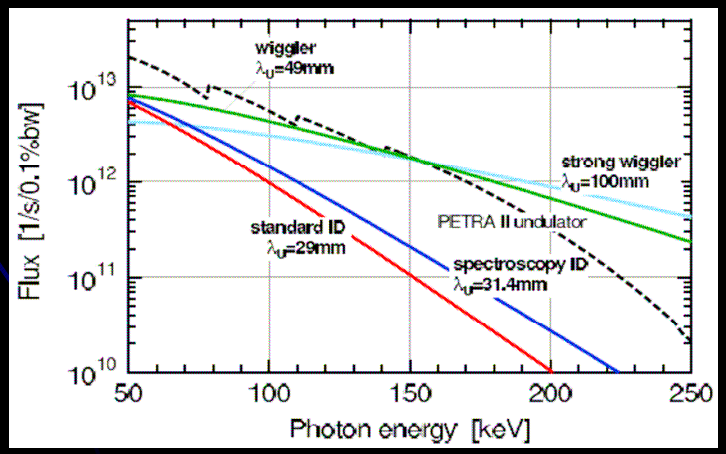
LVP at 3G synchrotrons: ESRF

- ID27: Wiggler (period 70 mm, 1 T, min gap 16 mm) and 2 undulators (periods 40/35 mm, 0.52/0.47 T, min gap 16 mm)
- Two stations, PE and DACs
- ADXD (EDXD phasing out)
- Full-time operation



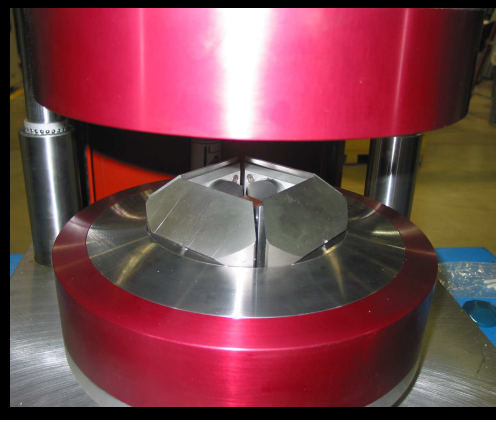
LVP at DESY

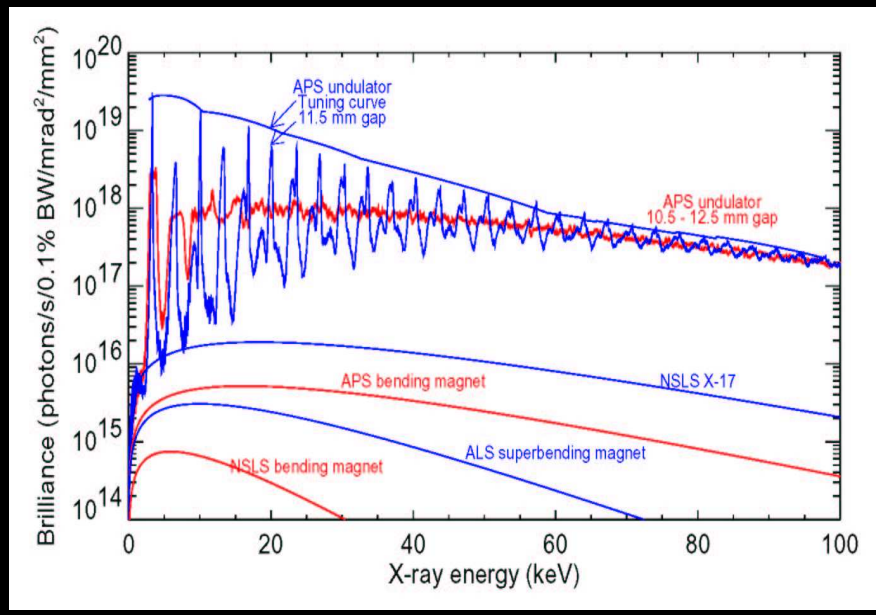
- DORIS-III, Beamline HARWI-II (GFZ)
- “Hard x ray wiggler” (period 110 mm, length 4 m, 1.98 T, 29 kW)
- 1700 t (?) press (MAX200x)
- Double-stage only
- EDXD only
- Imaging

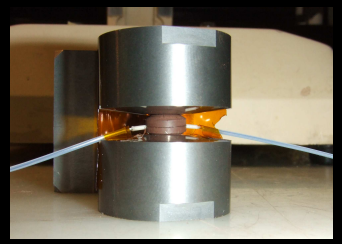


LVP at 3D synchrotrons: APS

- 13-ID-D: APS undulator A (period 33 mm, length 2.4 m, 0.849 T)
- Tapered gap for white beam operation
- 1000 t press, T-25, DIA, toroidal
- Modified cubic anvil module (planned)
- Mostly EDXD
- “CAESAR” diffraction
- Imaging
- Ultrasonics
- Shared w/ DAC

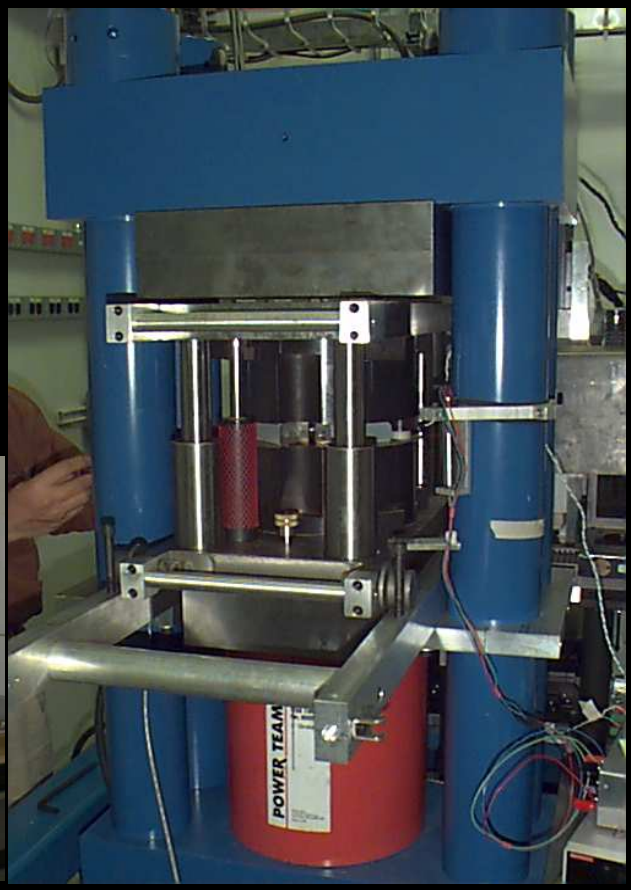






LVP at 3G synchrotrons: APS

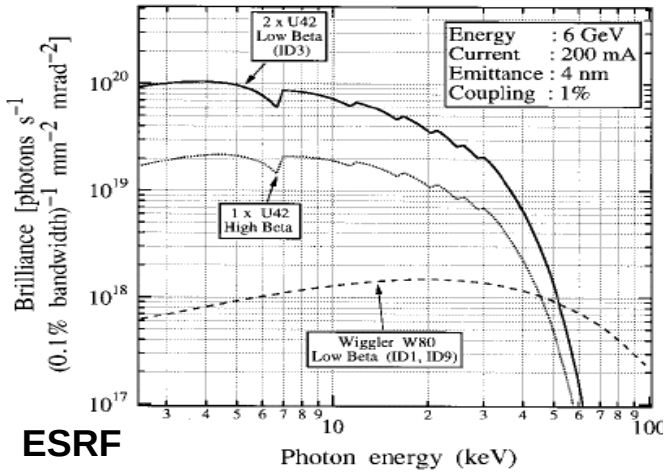
- 13-BM-D: bending magnet
- 250 t press, interchangeable modules
- ADXD, EDXD
- Radiography
- Tomography
- Ultrasonics
- Shared w/ DAC, tomo, EXAFS



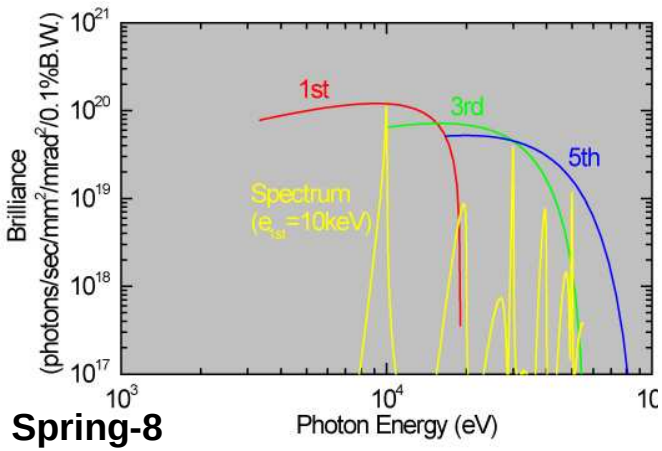
Beamline considerations

- High brilliance at high energies
- Diffraction mode
  - EDXD: “smooth” spectrum
    - Wiggler v. tapered undulator
    - Single- v. multi-element detectors
  - ADXD: tunable in energy
    - Mono: max. energy and resolution
    - Collimation
    - Focusing/defocusing?
- Beam size: imaging requirement
  - Compatibility with diffraction side collimation
- Switching between white and mono mode

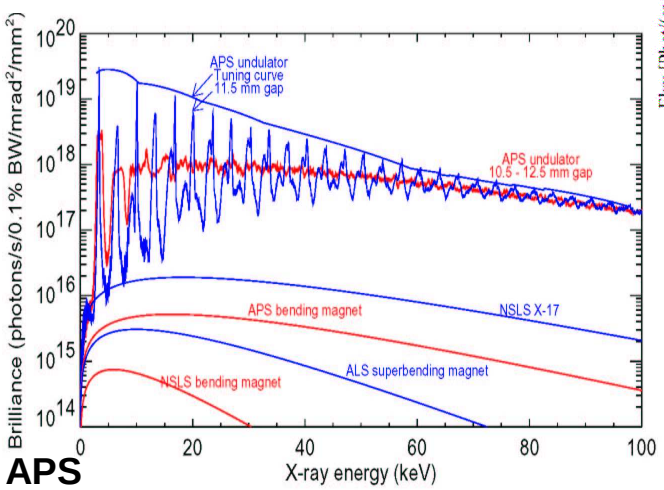
The source



ESRF



Spring-8



APS

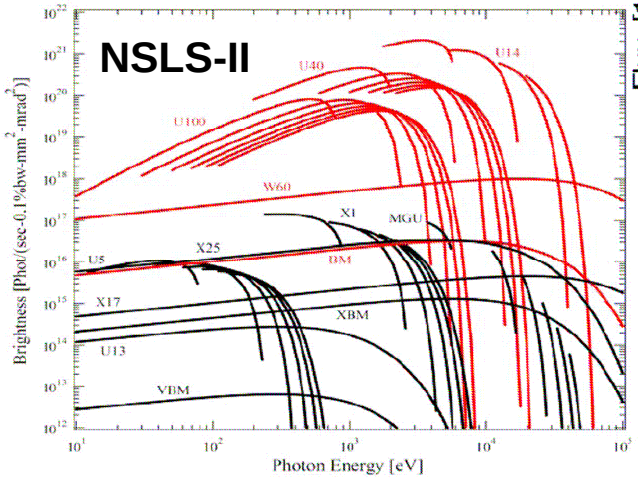


Fig. 1: Brightness tuning curves based on the updated data

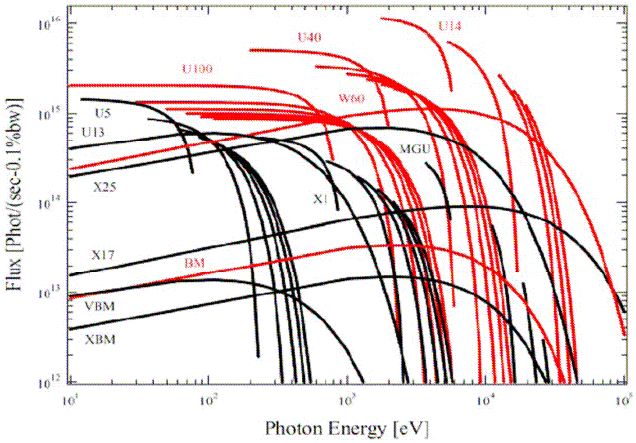
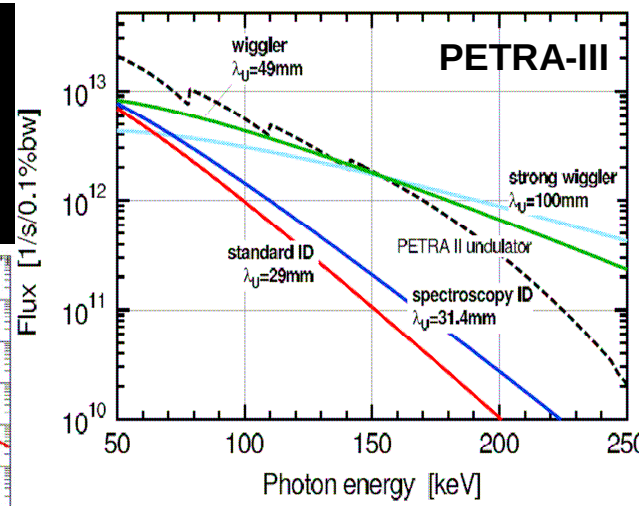
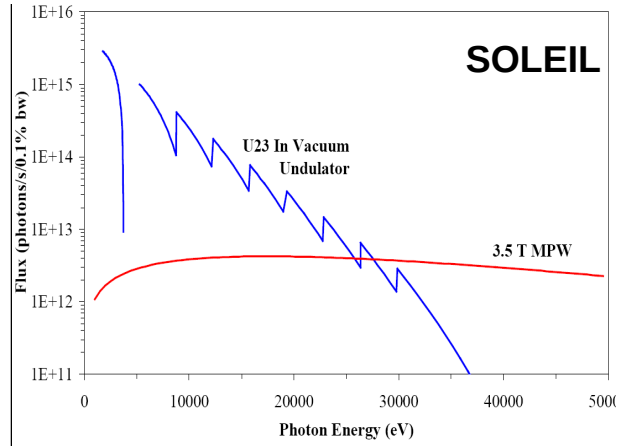
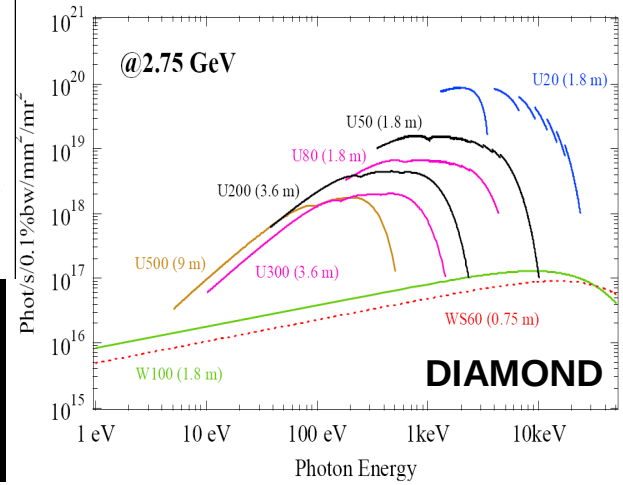


Fig. 2: Flux tuning curves based on the updated data

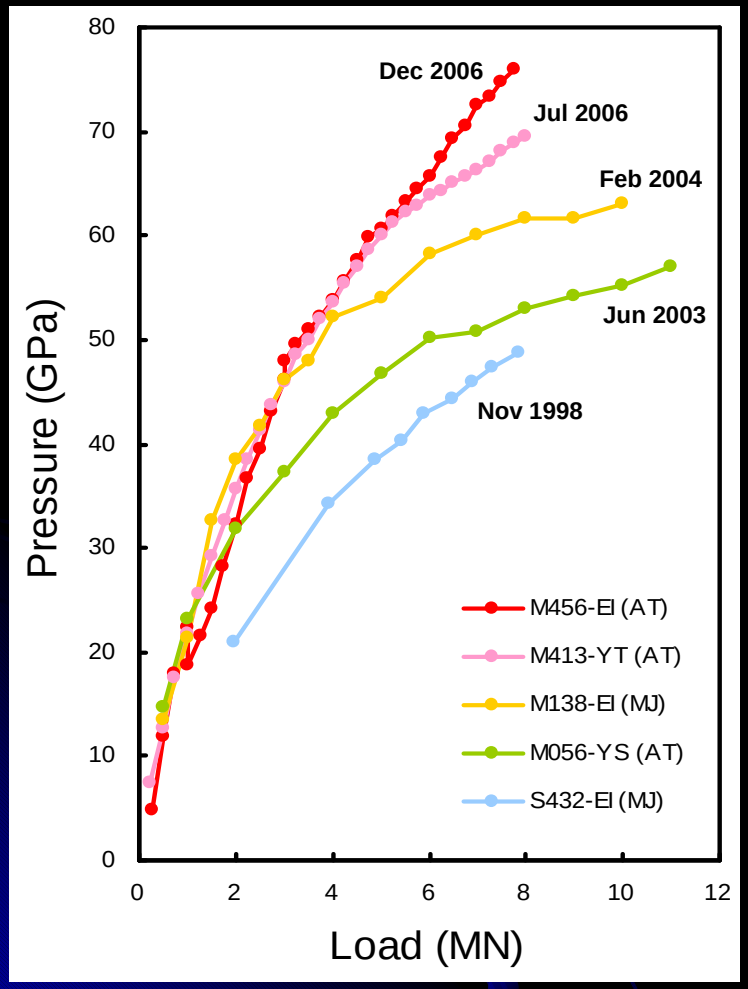
[redacted]







EDXD: toward megabar

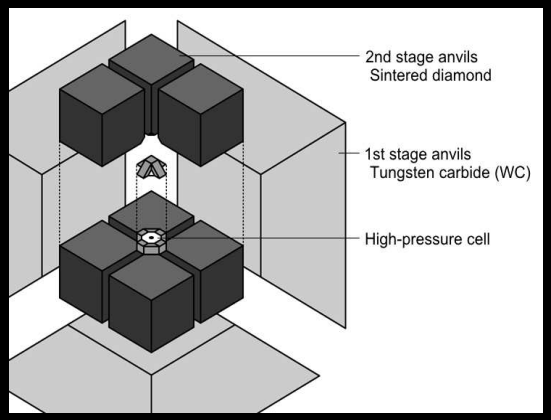


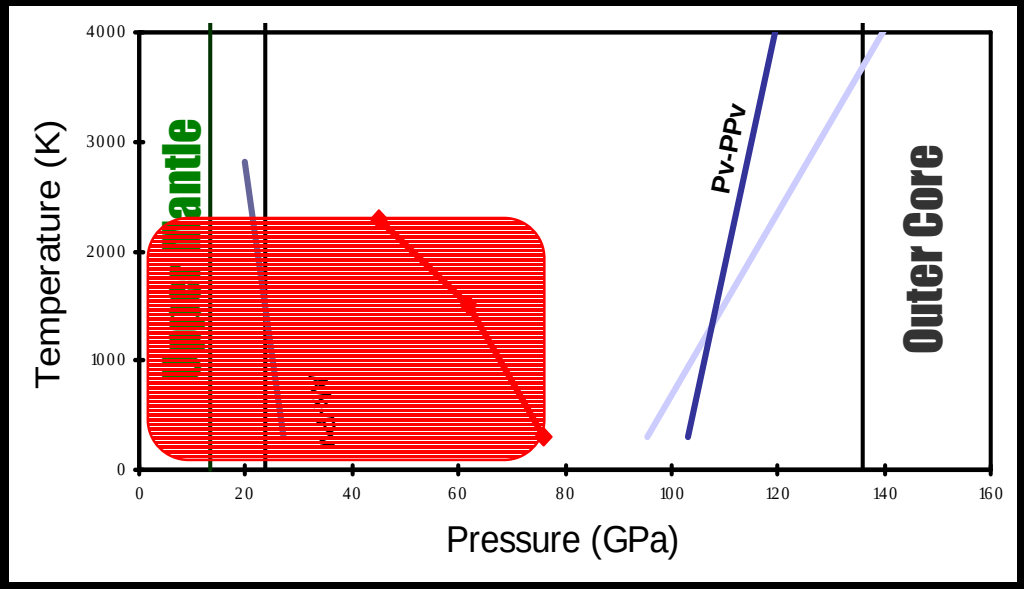
Tange et al., 2007

Room temperature

Sintered diamond anvils
14 mm cube,
TEL = 1.5 mm

MJ: MgO/ Jamieson et al. (1998)
AT: Au/ Tsuchiya (2003)

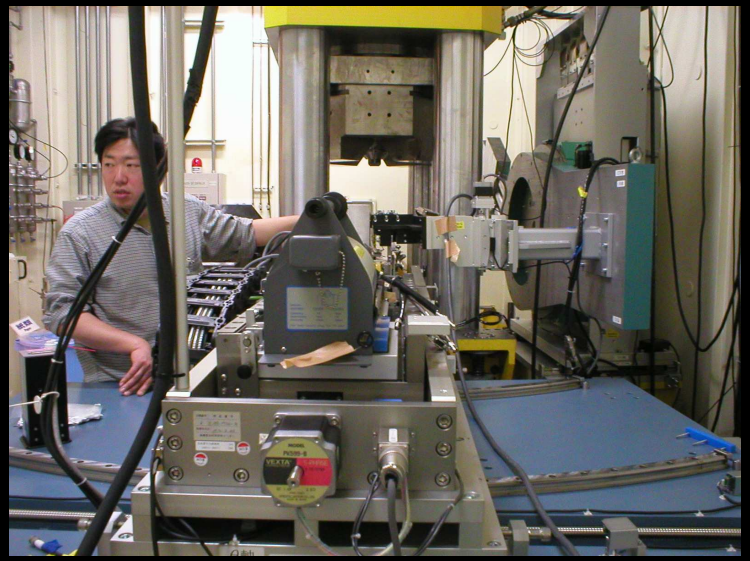


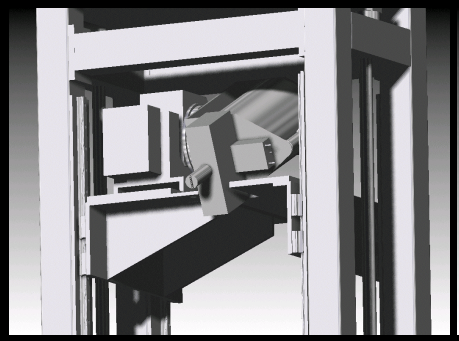


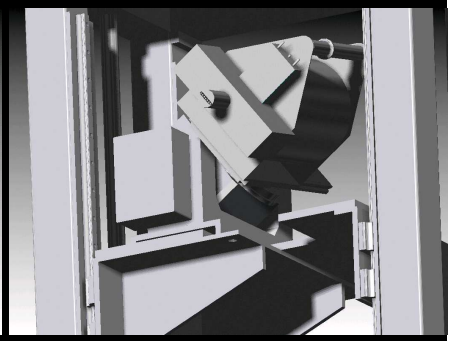
Ak-Pv: Hirose et al. (2001)/ AT
Pv-PPv: Hirose et al. (2006), dark line/ AT; pale line, MgO/ Speziale et al. (2001)

EDXD detectors and control

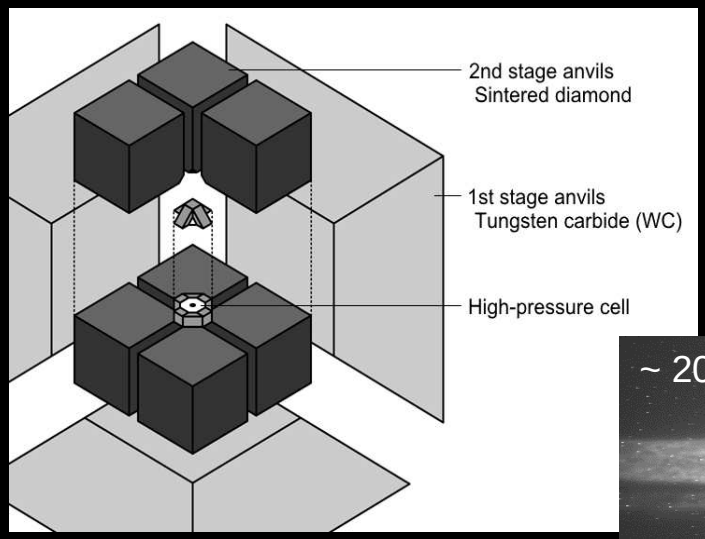
- Solid-state detector:
  - Single- v. multi-element
- Fixed two-theta arms (SPring-8)
  - Vertical (phasing out)
  - Horizontal
  - Centering fixed (curved rails)
- “Virtual goniometer” (GSECARS)
  - Linear stages and rotations
  - Continuous solid-angle coverage
  - “Any” inclination angle
  - Any detector (CCD, IP)
  - Centering variable
  - “CAESAR” scan
- Conical slits w/ multi-element (NSLS)

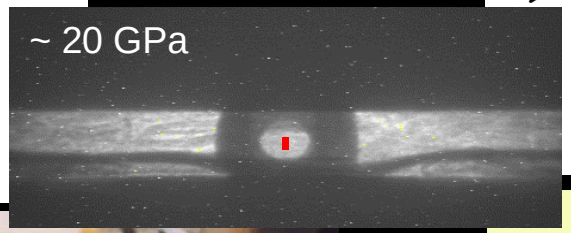


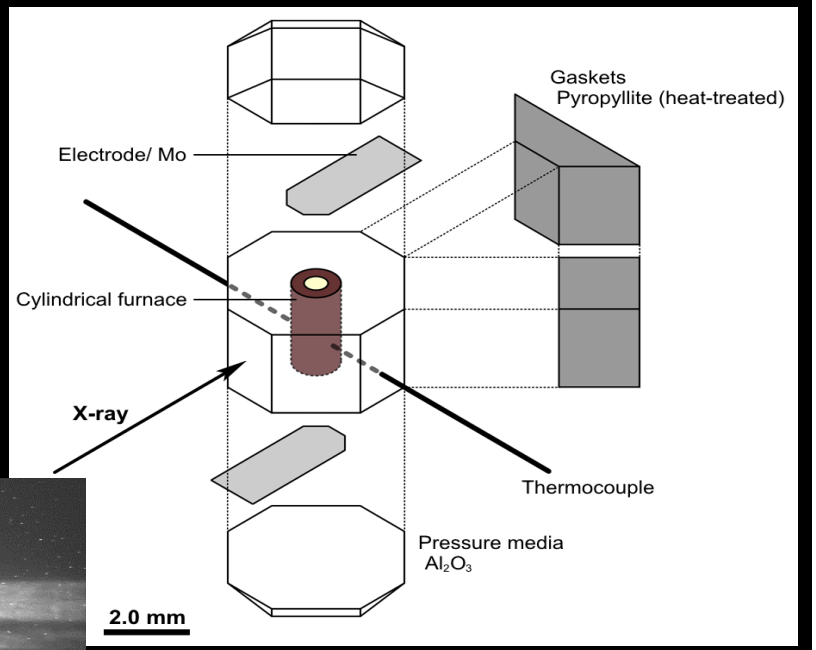


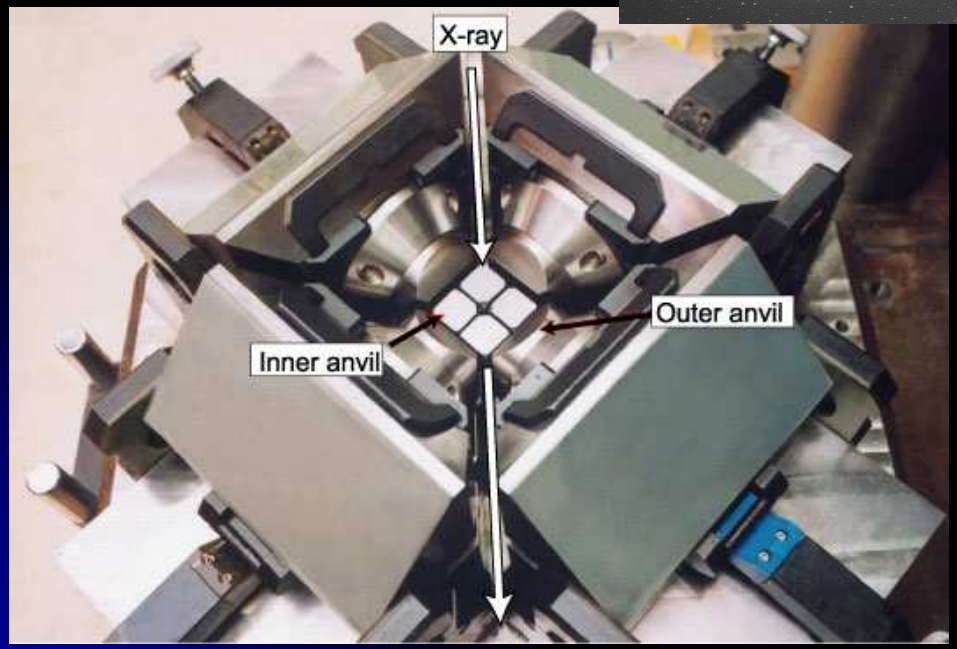


CAESAR: scanning EDXD



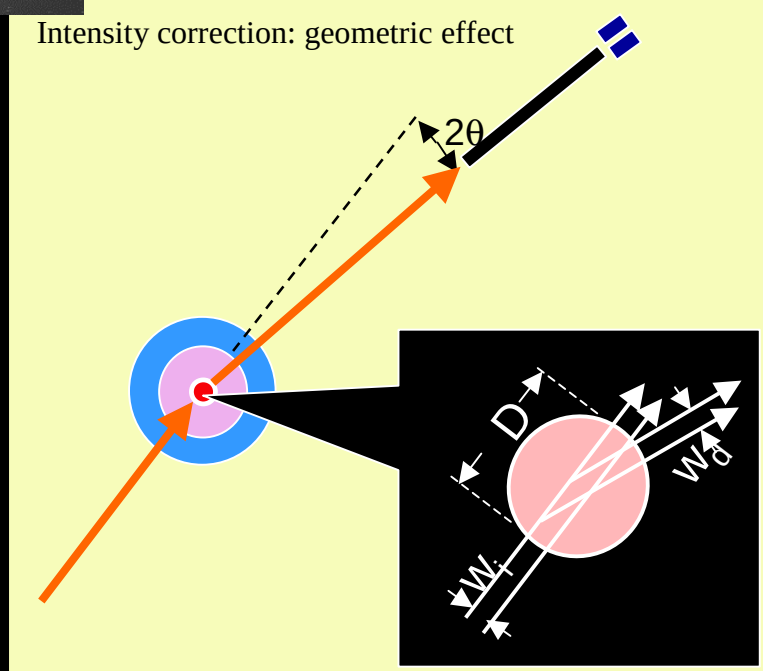




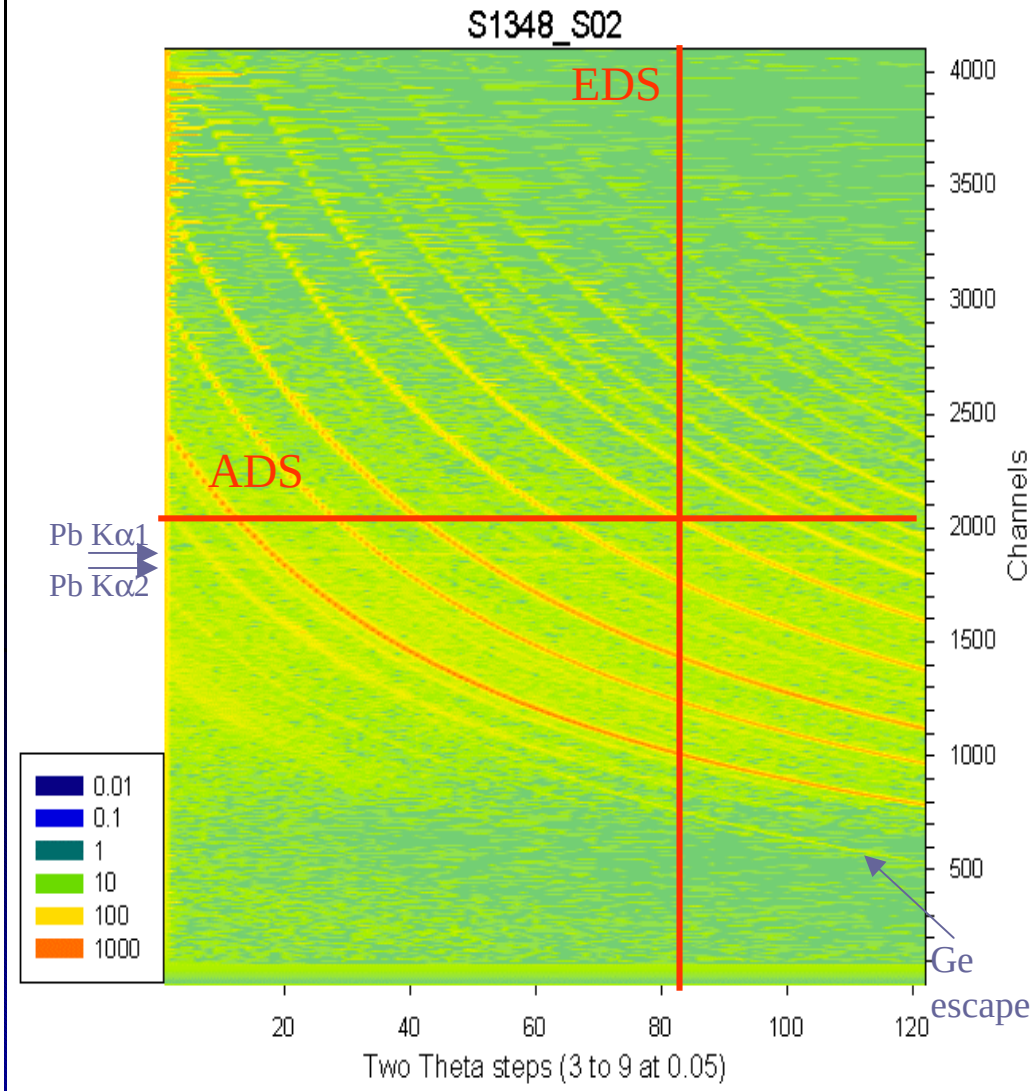


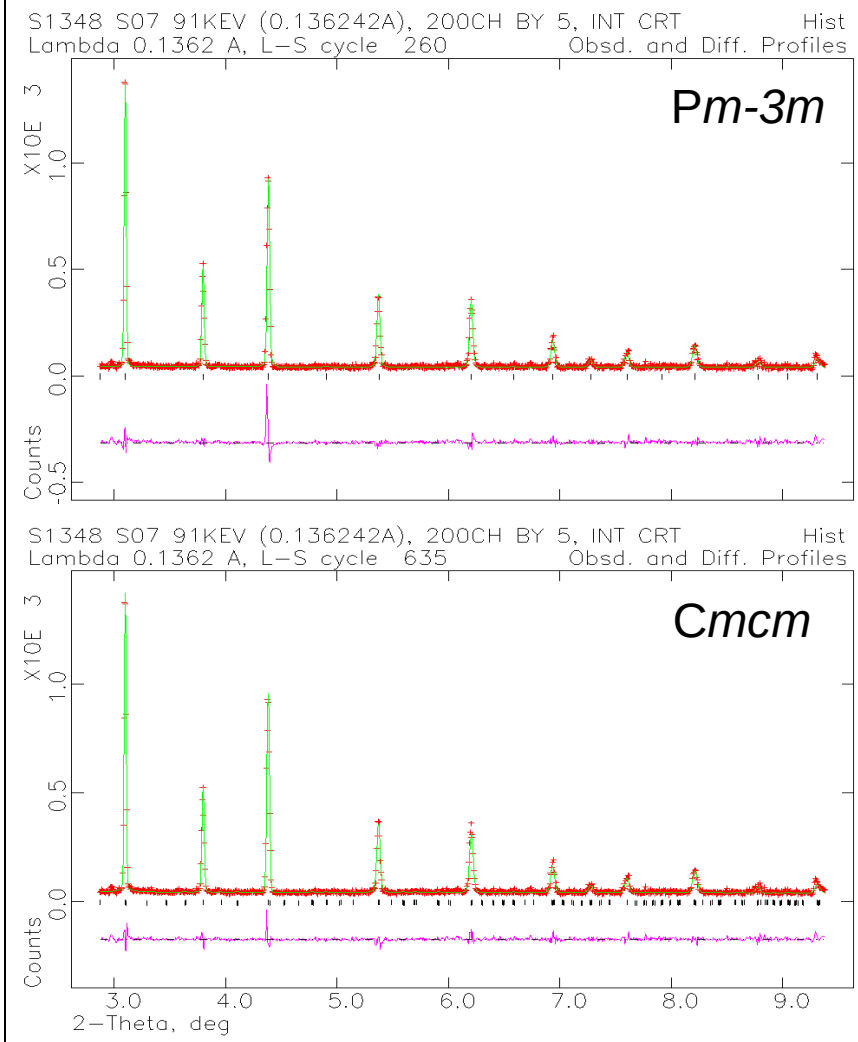
Wang et al., 2004

Intensity correction: geometric effect



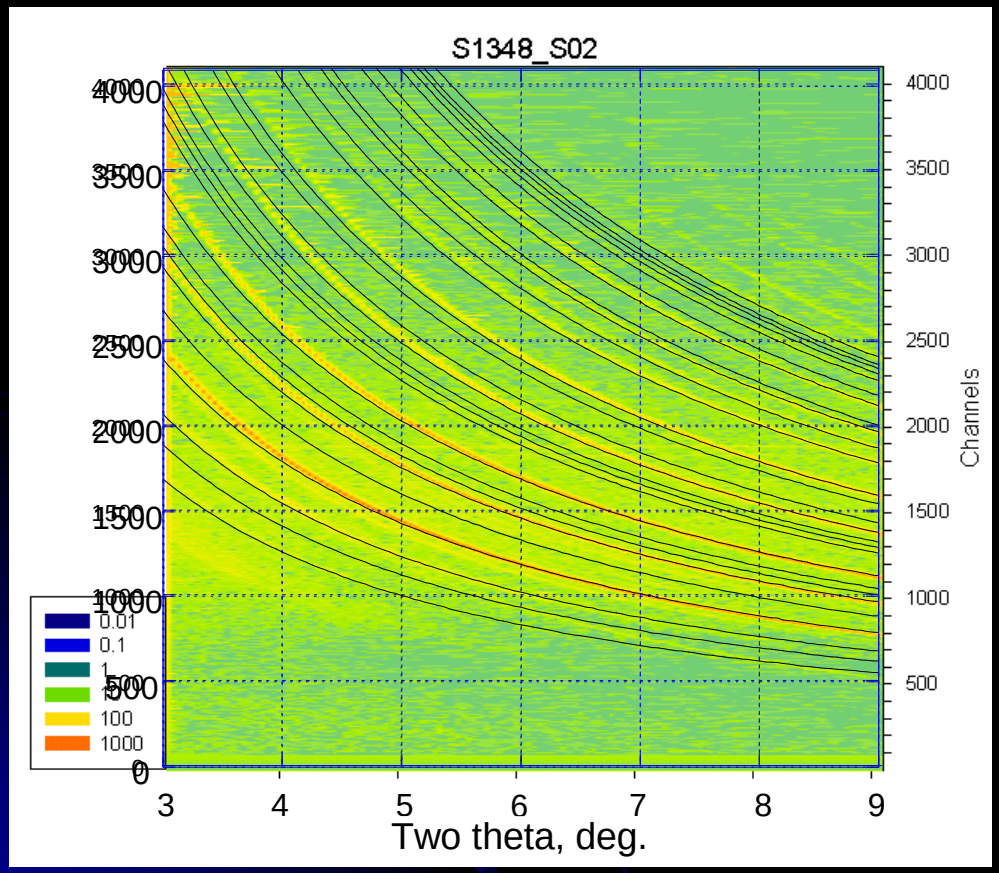
CaSiO3 pv: data and Reitveld refinement

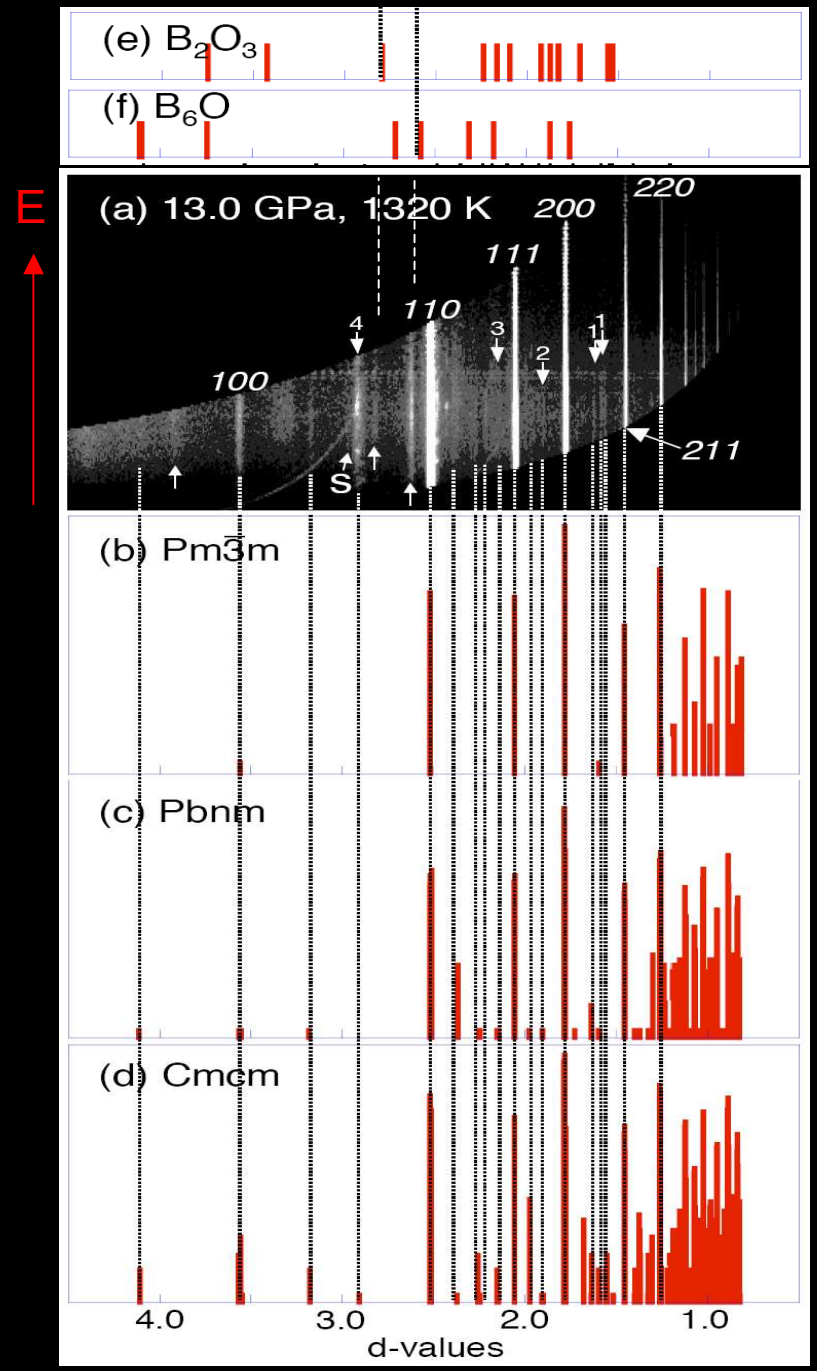




Uchida et al., in prep

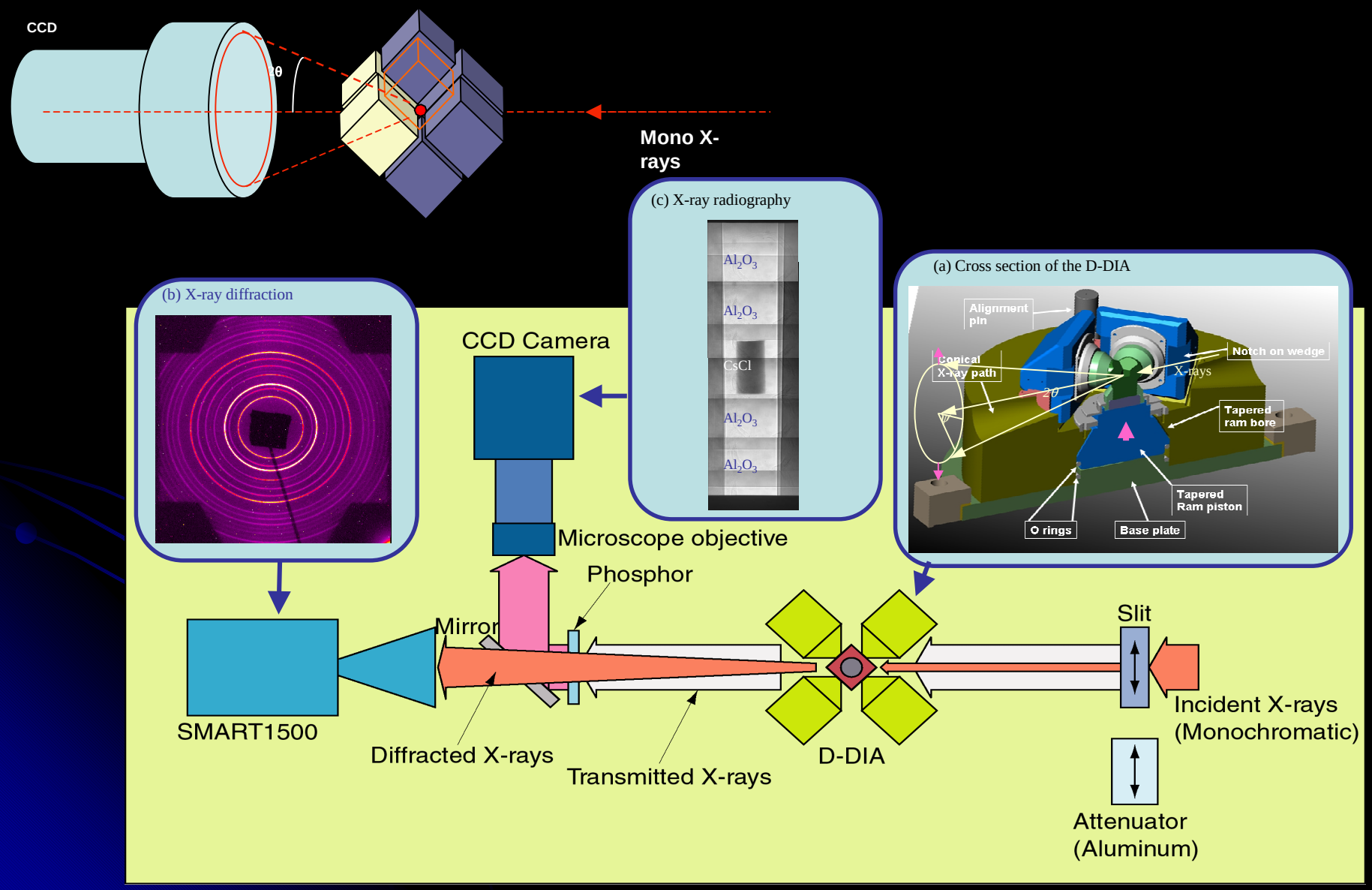
CAESAR: pattern recognition





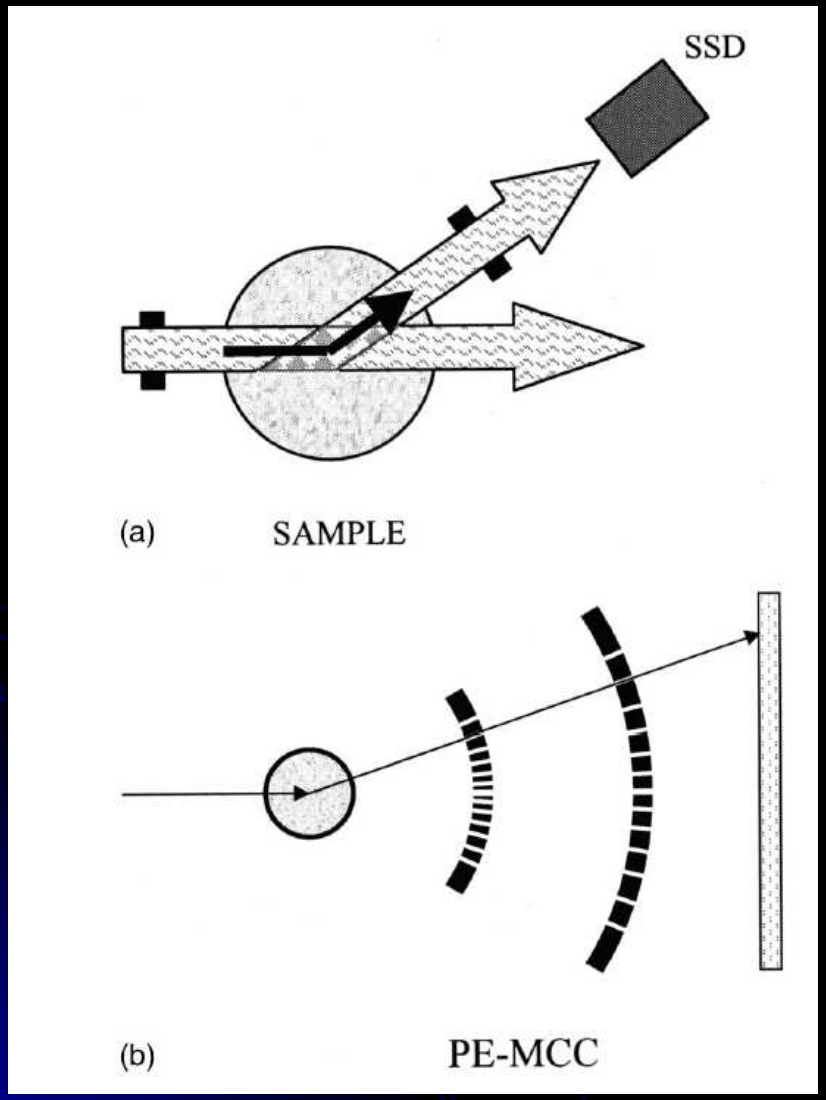
Uchida et al., in prep.

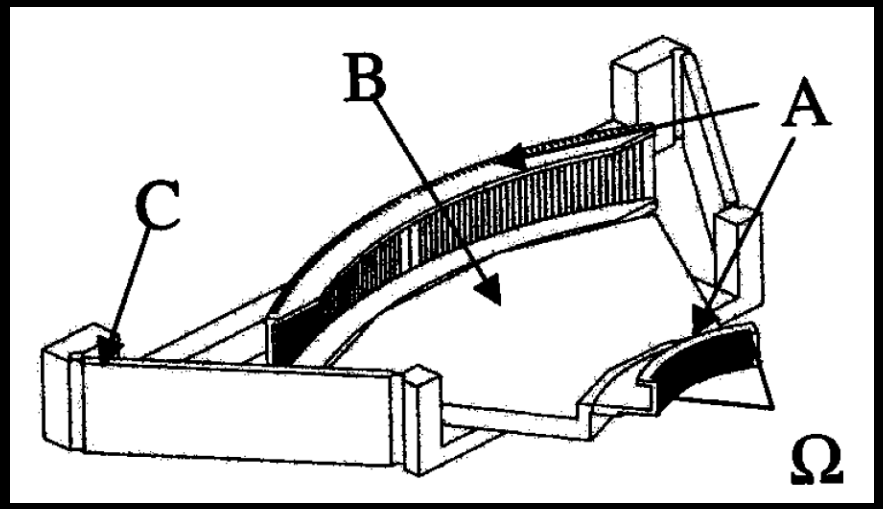
ADXD: w/o diffraction side collimation

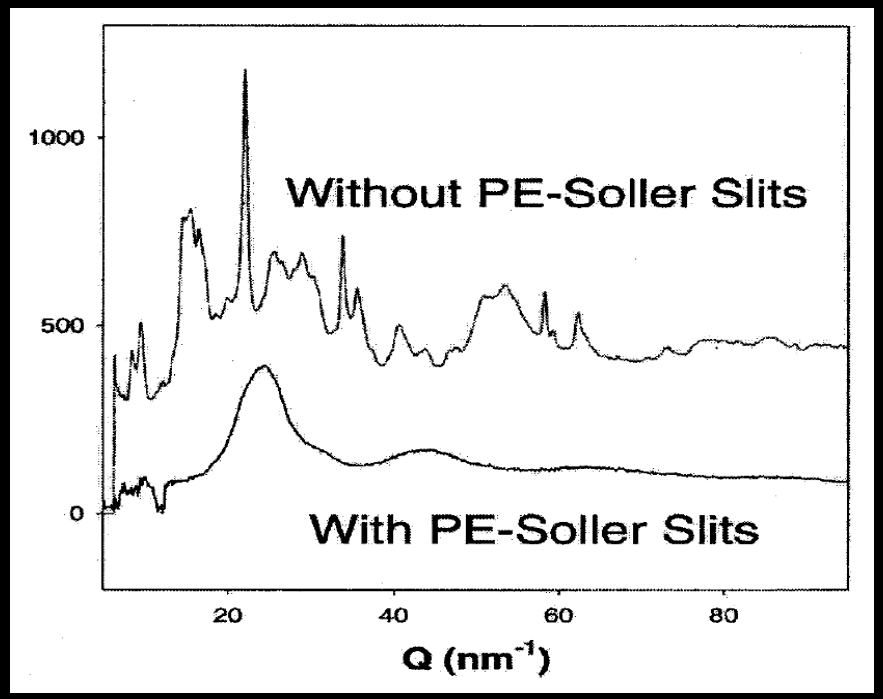


ADXD w/ diffraction side collimation

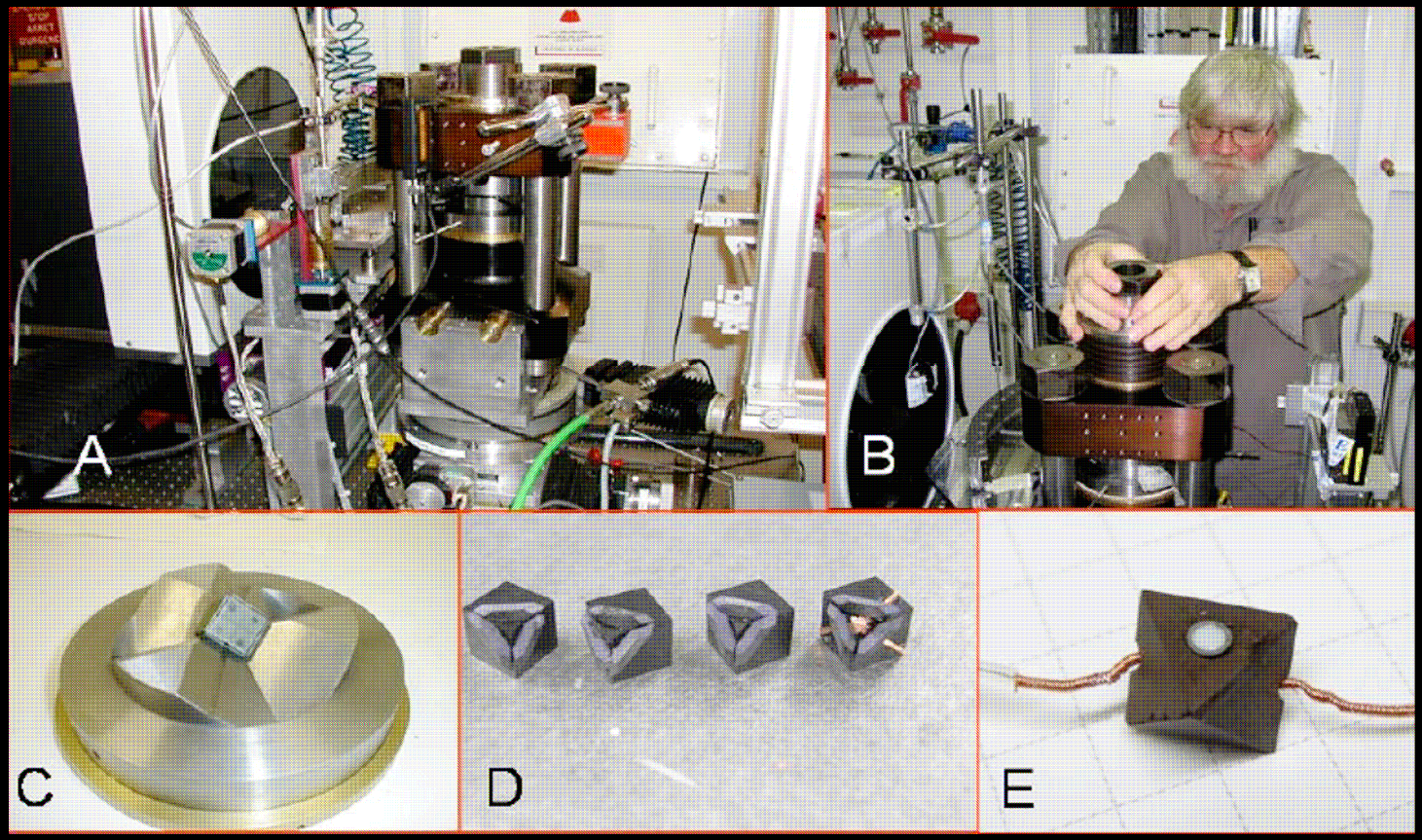
Mostly used for DIA and PE

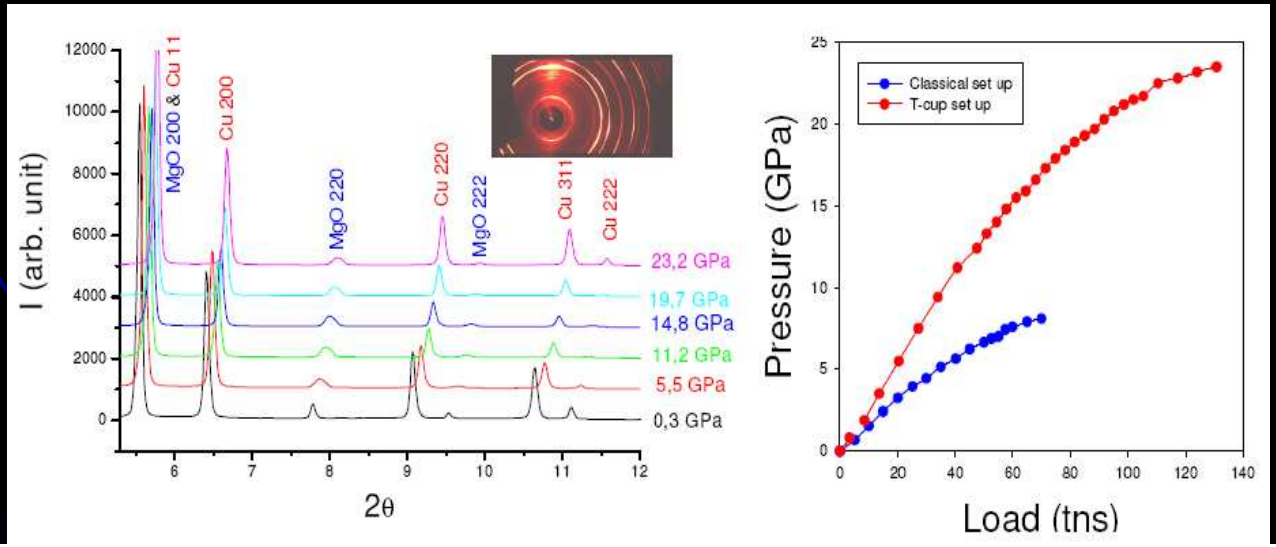






Mesouar et al., 2002



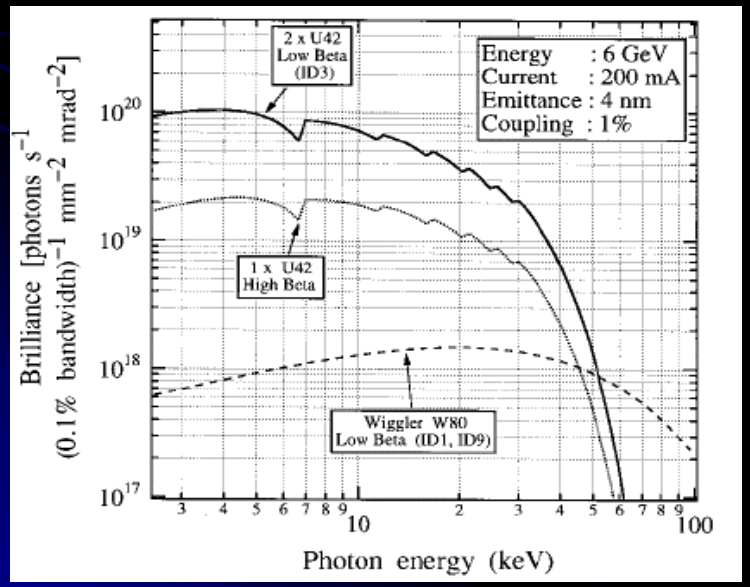


Diffraction through anvils

(Le Godec et al., 2006)

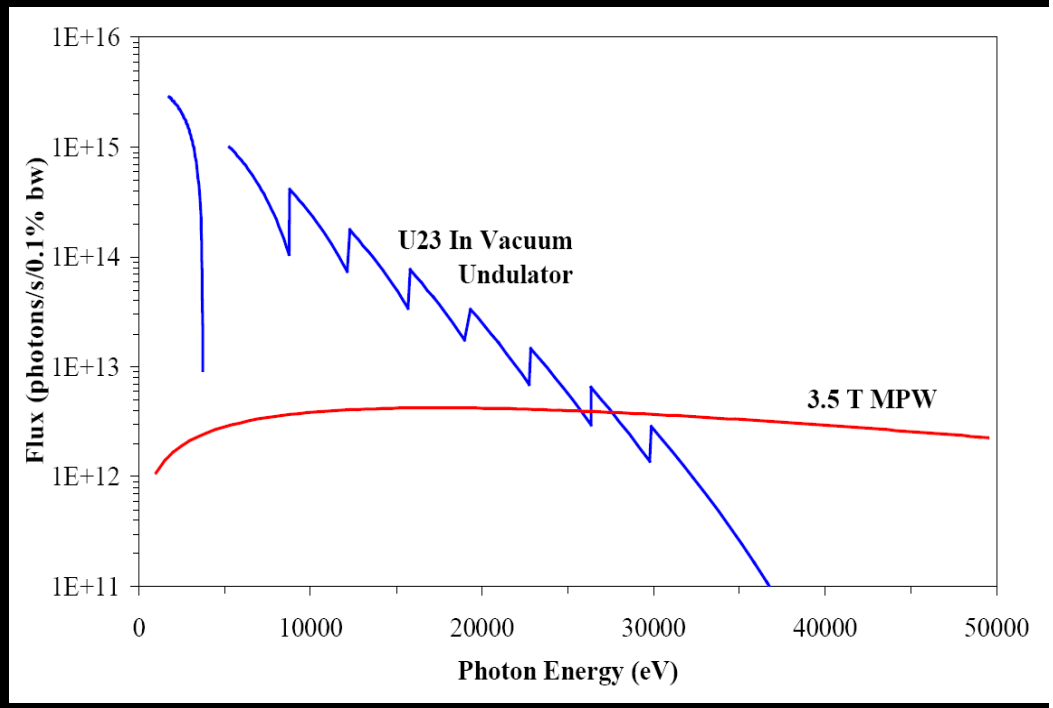
Coming LVP facilities at 3G sources: ESRF

- ID06, under construction
- 2000 t press, large D-DIA module
- Exclusively ADXD
- Shared w/ instrument testing



Coming LVP facilities: Diamond

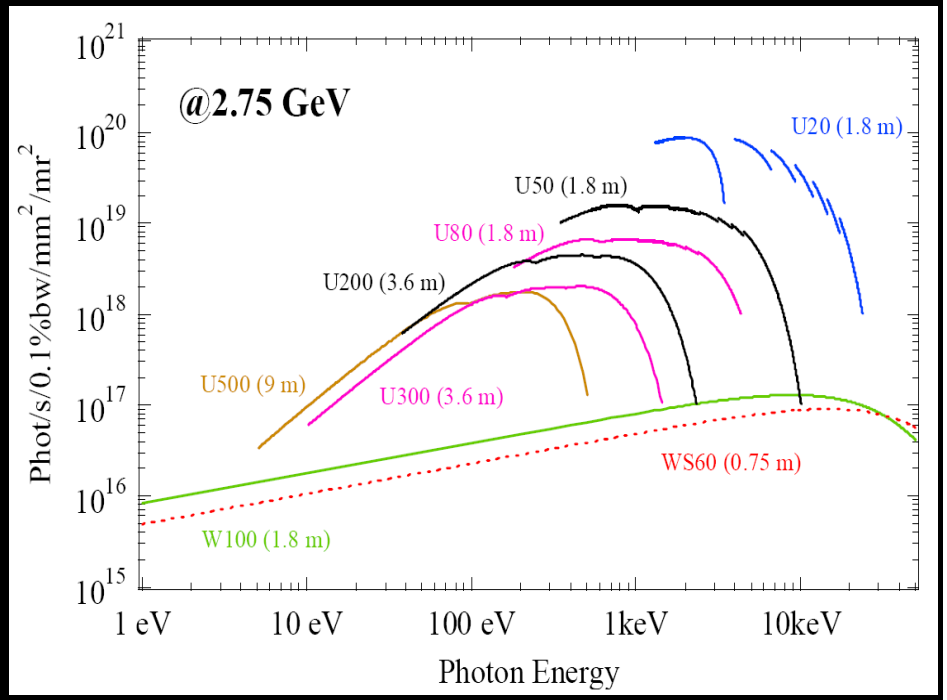
- I15: superconducting multi-pole wiggler (period 60 mm, length 1.5 m, 3.5 T, 29.6 kW)
- Two stations
- PE and DACs
- ADXD and EDXD
- IP, CCD, SSD



Clark et al., 2002

Coming LVP facilities: SOLEIL

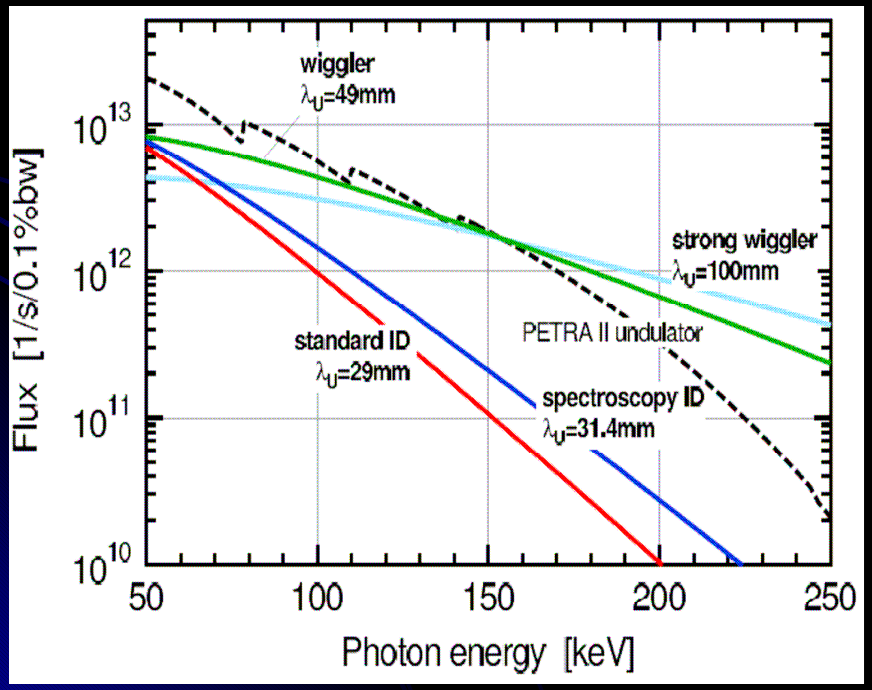
- ID3C: multi-pole superconducting wiggler (period 44 mm, length 1.85 m, 2.6 T, 30 kW)
- White beam hutch
  - PE and MA press (?)
- Mono beam hutch
- Micro-focusing hutch
  - DAC and PE (?)
  - Shared w/ tomography

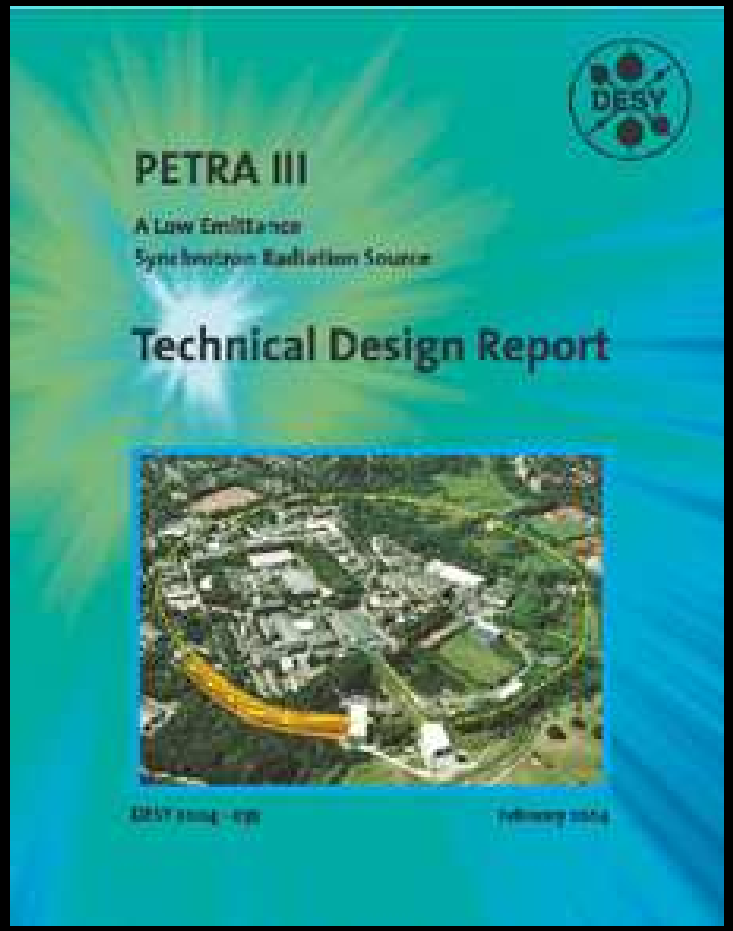


Marcouille et al., 2002

Coming LVP facilities at 3G sources: PETRA-III

- No home beamlines
- Portable only (PE)
- DACs





"Ideal" LVP user facility

- **Can we predict what's needed in 10 yrs?**
- Source: dedicated v. shared
  - Time: BL04B1 (100%), ID06 (~70%), ID27 & X17B2 (LVP-DAC sharing), PETRA-III (no home beamline)
  - Stations: GSECARS (ID, BM), PETRA-III
  - "Dedicated" (2 LVP systems in 2 stations)
- Operation: "designer-driven" v. "user-driven"
  - ID06, BL04B1 v. GSECARS
  - User driven, encourage new techniques
- Pressure modules: "Excalibur" v. "Swiss-army-knife"
  - Reliability v. flexibility
  - Explorative v. refinement
  - Decouple press from modules
  - Kawaii and double-stage
  - Portable devices taking advantages of other beamlines
- Diffraction mode: EDXD v. ADXD
  - BL04B1, ID27&ID06
  - Keep both, switchable, flexible detector support
  - Mono beam energies to 100 keV, with area detectors
  - CAESAR diffraction with Ge "strip" multi-element detectors?

Support labs

- Synthesis facility (environmental control, piston cylinder)
- Micromachining facility
- Sample preparation (sintering, polishing, assembling, etc.)
- Easy access to sample analysis facilities (micro-focus x-ray, microprobe, FIB, S/TEM)