First OMEGA Laser Facility User's Group Workshop
29 April to 1 May 2009 Rochester, New York

A High Resolution Transmission Crystal Spectrometer for Analyzing the Properties of EP-Generated MeV Electrons

U. Feldman[a], J.F. Seely[b], L.T. Hudson[c] and C.I. Szabo[a]

a) Artep Inc., 2922 Excelsior Spring Circle, Ellicott City, MD 21042
b) *Space Science Division, Naval Research laboratory Washington DC 20375-5352*
c) *National Institute of Standards and Technology, Gaithersburg, MD 20899 USA*

Abstract

- A High Resolution Transmission Crystal Spectrometer has been designed to analyze the generation of electrons and other particles with MeV energies.
- While slowing down in target materials, the energetic electrons generate x-ray line emission by inner-shell ionization and a hard Bremsstrahlung continuum that can potentially be used for Compton scatter radiography of dense and compressed objects in energies of tens to hundreds of keV.
- The MeV electron circulation outside the small ($\geq$10 μm) laser focal spot, with ranges up to 1 mm, can result in unacceptably large source size that can spoil the radiogram's spatial resolution.
- The spectrometer designed for the EP laser (ECS) will utilize a novel method to measure the hard x-ray source size, the source broadening of K-shell x-ray lines with energies up to 115 keV, and will characterize and understand the circulation of energetic electrons outside the focal spot.
- This will be accomplished by using targets configured with a small central heavy metal component for hard x-ray generation while efficiently utilizing the energetic electrons circulating from the surrounding lower atomic number material into the heavy metal component.
- The hard x-ray sensitivity of the spectrometer and the image plate and electronic detectors will be absolutely calibrated.

Transmission Crystal Spectrometers

Hard x-ray spectrometers have been designed and built by the NRL-NIST group:

- **HXS** *High-Energy X-Ray Spectrometer*

  Developed in 1999; fielded at the OMEGA laser in 2000 and 2001.
  One transmission crystal covers 12-60 keV with moderate resolution.

- **HENEX** *High Energy Electronic X-Ray Spectrometer*

  Prototype NIF instrument; fielded at OMEGA in 2003, 2005, and 2006.
  Five crystals (one in transmission) cover 1-40 keV with high resolution.

- **DCS** *Dual Crystal Spectrometer*

  Fielded at OMEGA in 2005, LLNL TITAN ps laser in 2006, at PICO2000 at LULI in 2007 and at OMEGA-EP in January 2009.
  Two transmission crystals cover 11-120 keV with high resolution.

- **LCS** *LULI Crystal Spectrometer*

  Used at LULI PICO2000 and “100 TW” laser in 2008.
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Observed by transmission crystals:

- K-shell lines (22-87 keV) from single shots: Ag, Sn, Sm, Ta, Au, Pb.
- K-shell spectra (95-115 keV), heavy elements up to U fluoresced by a 2 MeV linear accelerator.

Motivation:

- High-energy plasma diagnostics: temperature, density, ionization balance, opacity.
- Hot electron energy distribution, hard x-ray brightness optimization.
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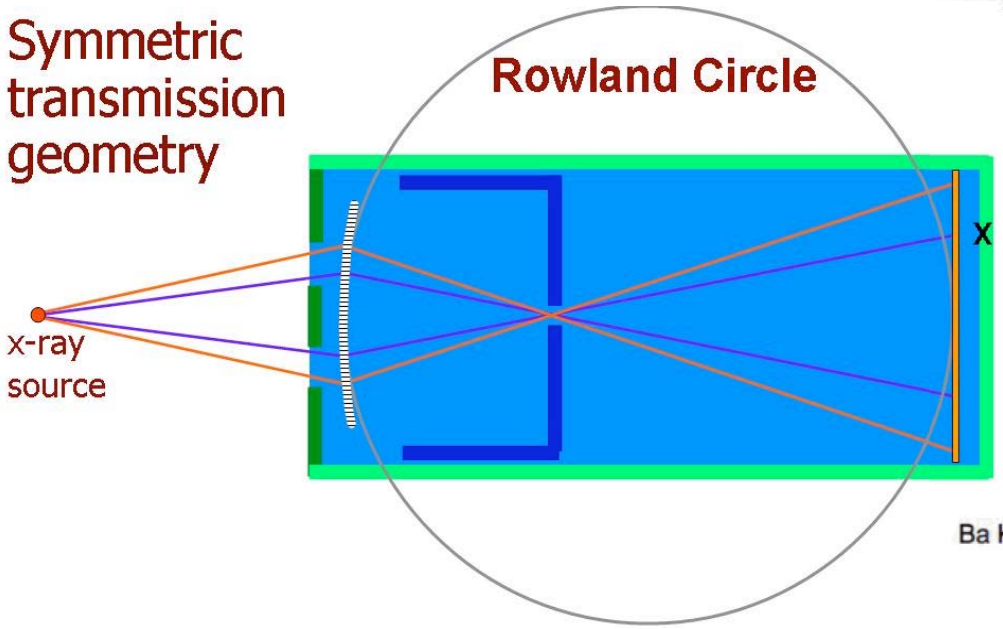
Spectrometer and Spectra

Schematic of the Cauchois type transmission crystal spectrometer



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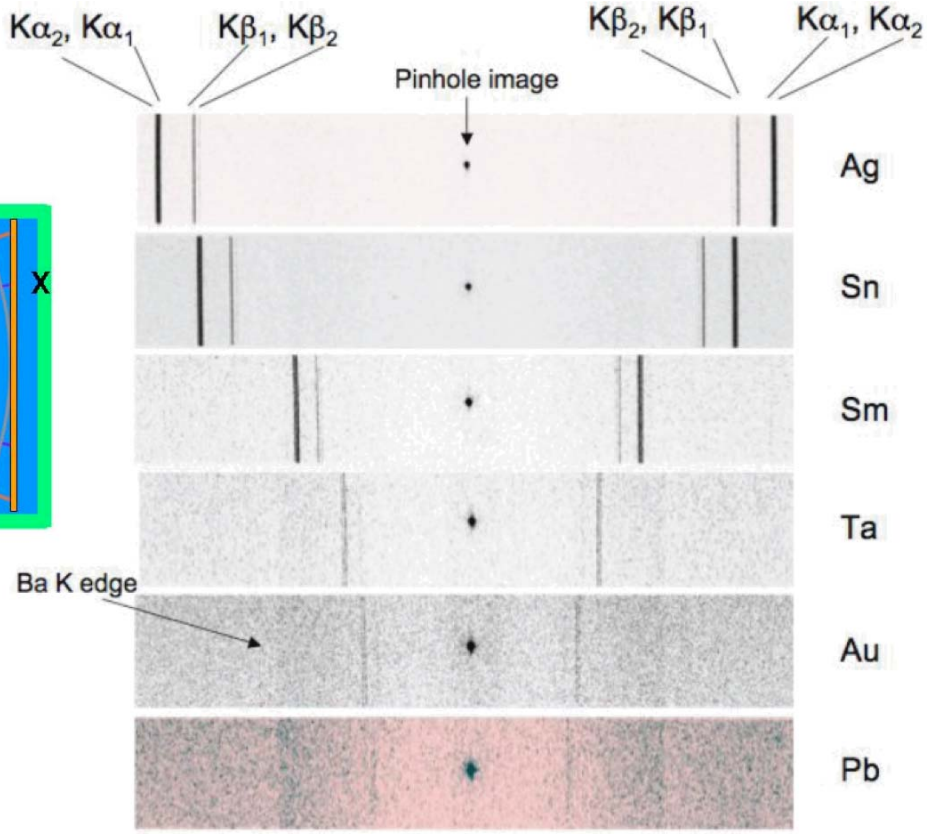

[with R. Tommasini, H-S Park, P. Patel]

- accommodates long stand-off distance & small diffraction angles (high-E's)
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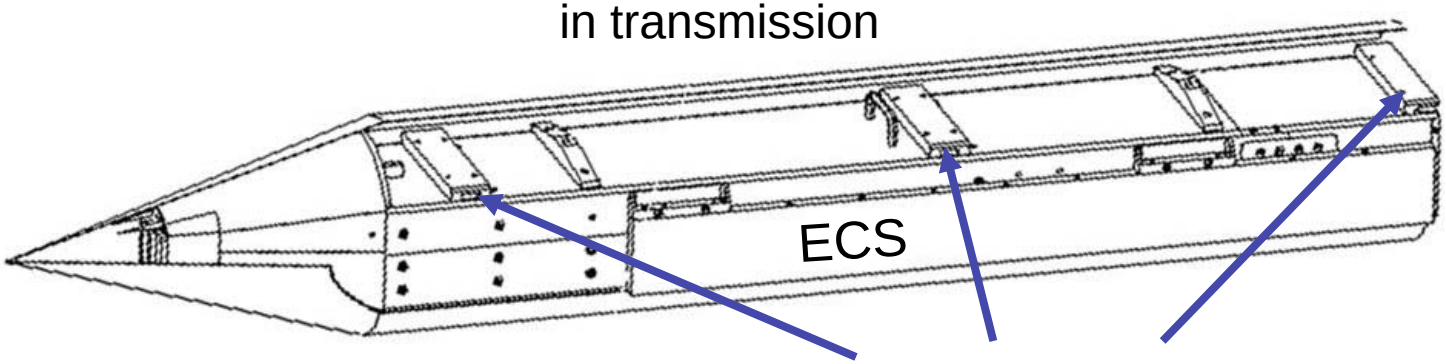
The EP Crystal Spectrometer (ECS)

TIM based x-ray spectrometer with cylindrically bent Quartz (10-11) crystal in transmission



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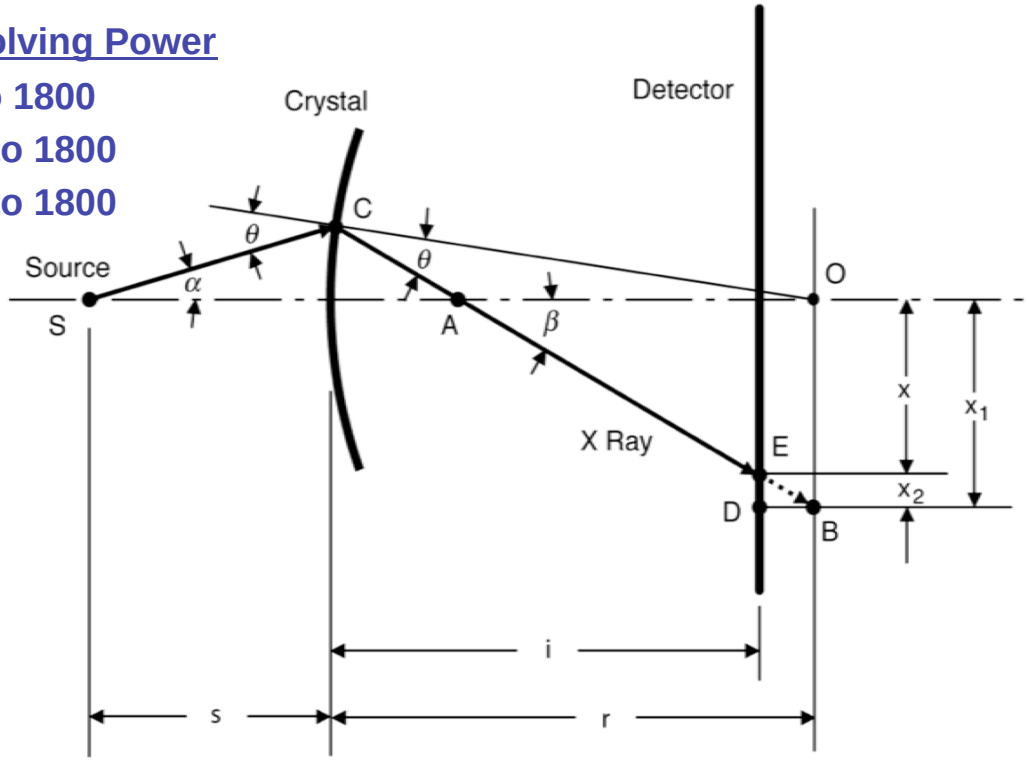

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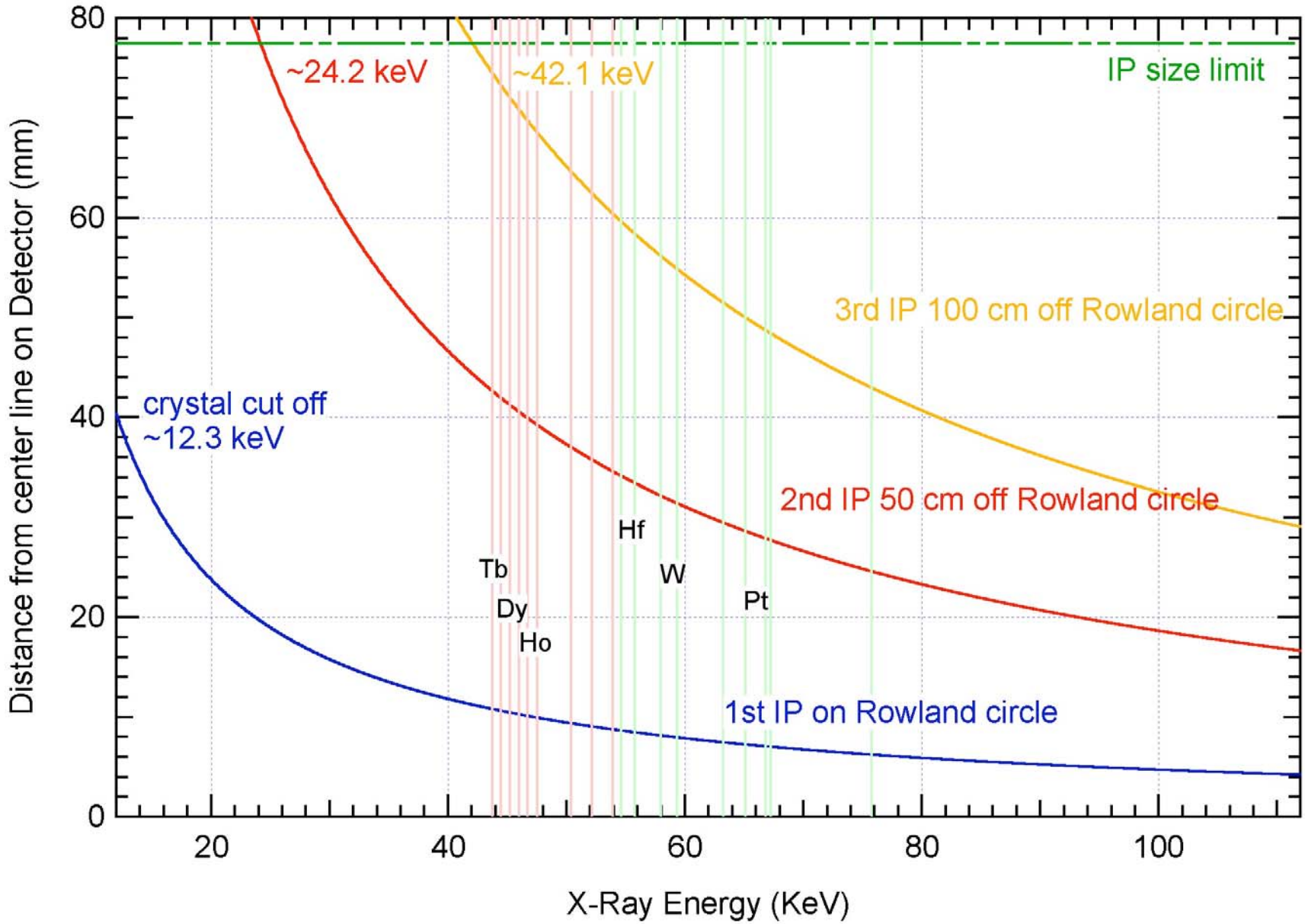

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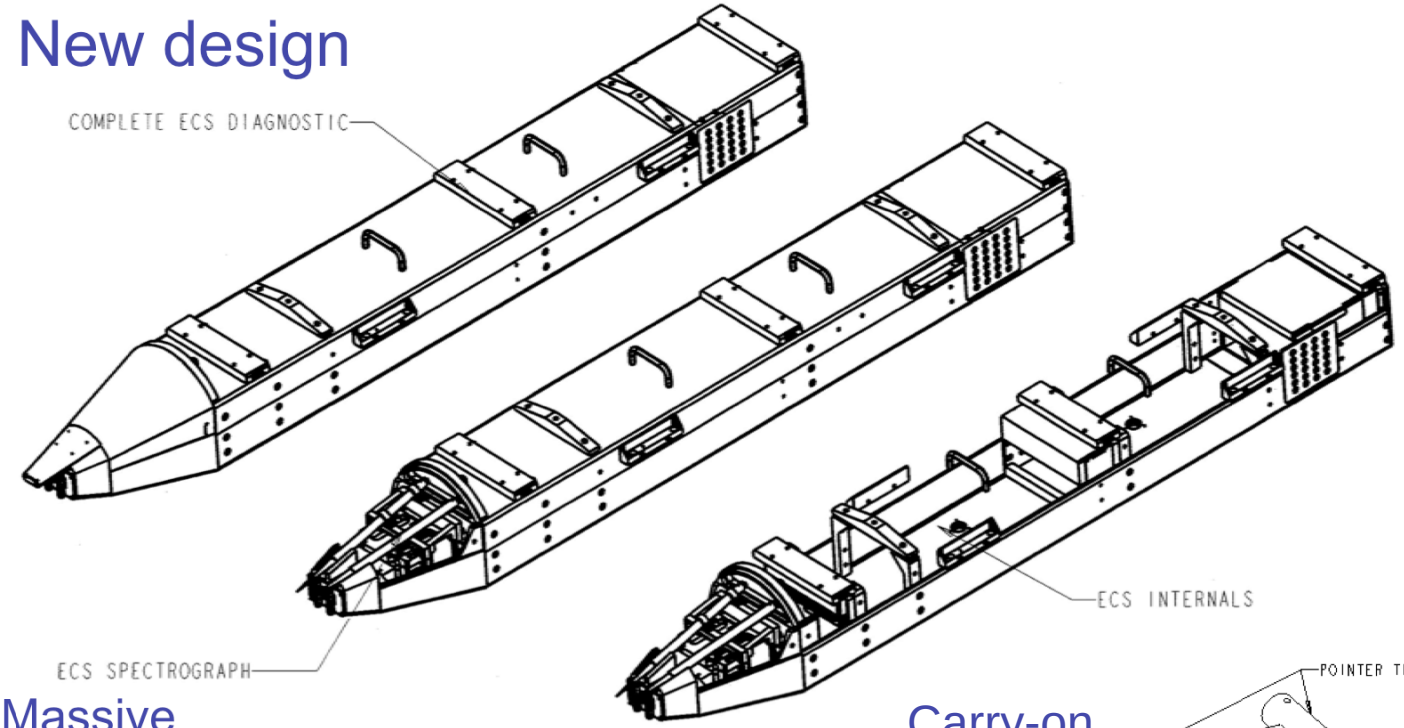

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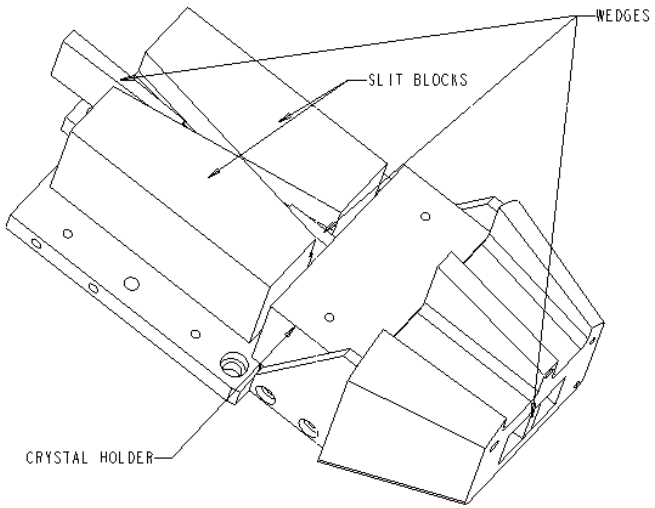

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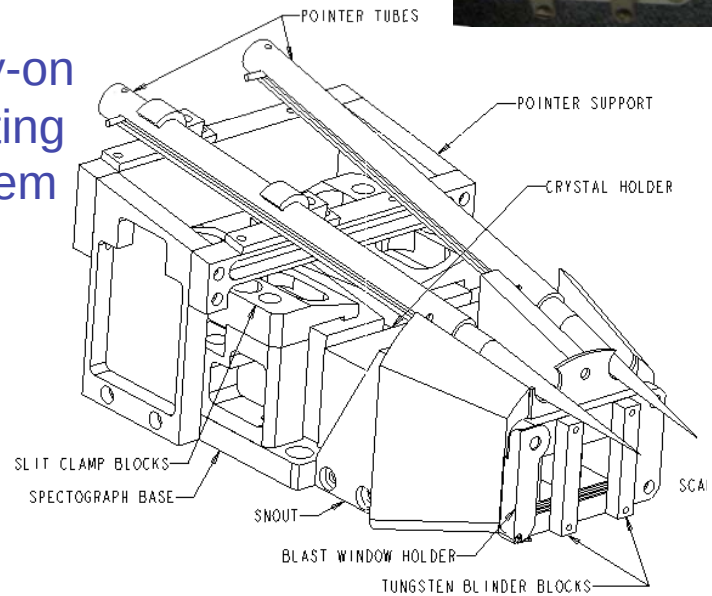

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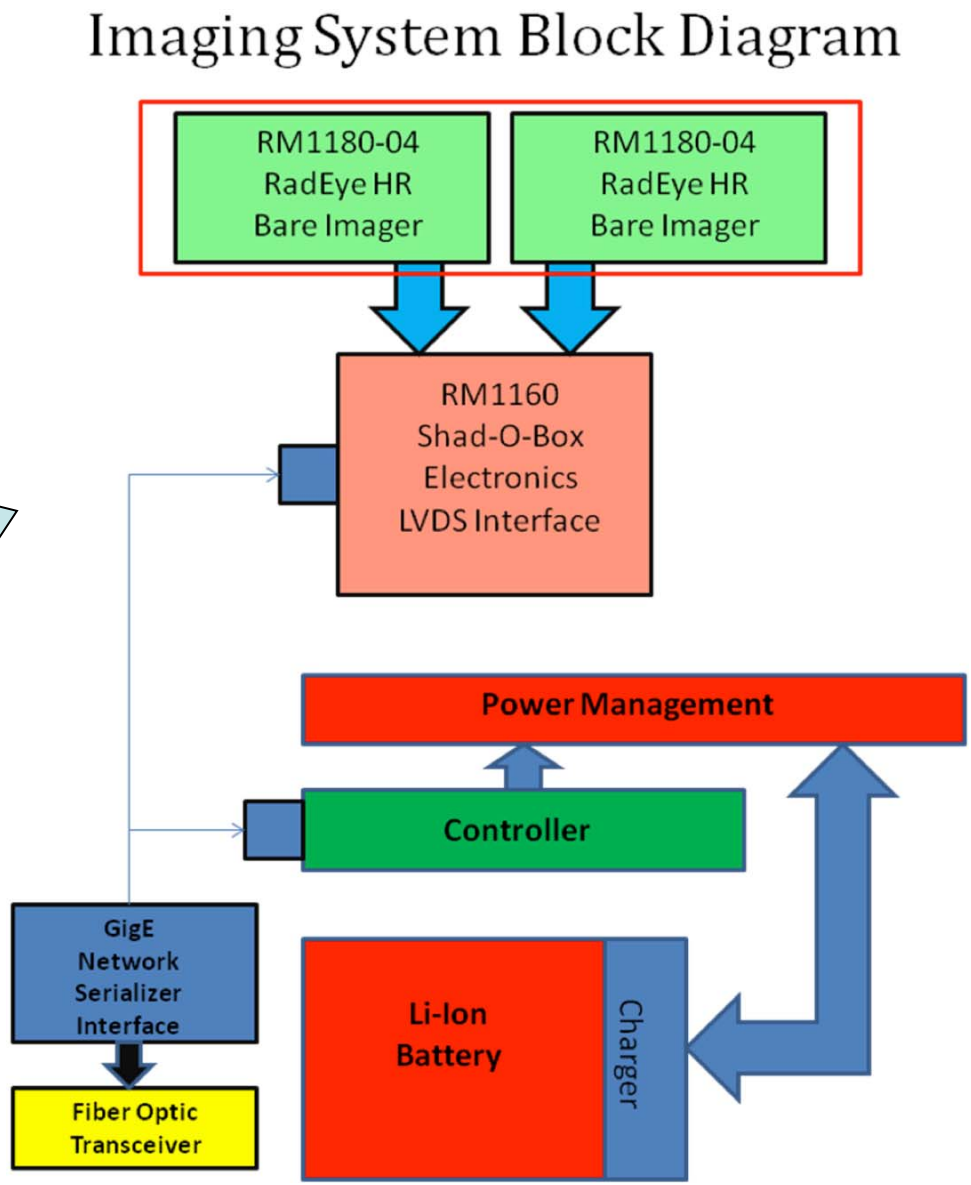

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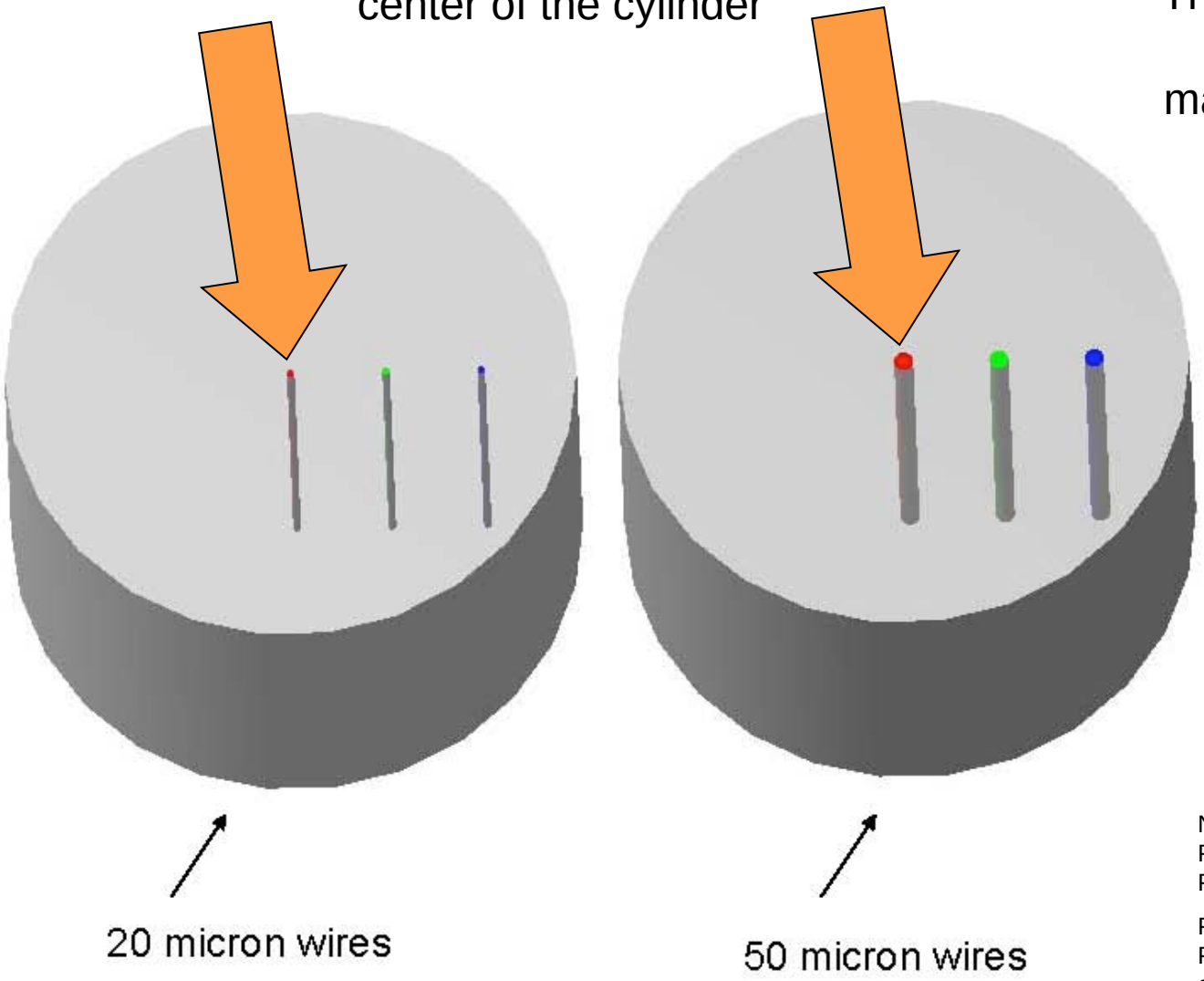

Thin wires embedded in cylinders
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Diameter: 1.5 mm
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Low Z: Ho, Dy, Tb

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NLUF campaign:
PPRad-EP-09A; August 13, 2009
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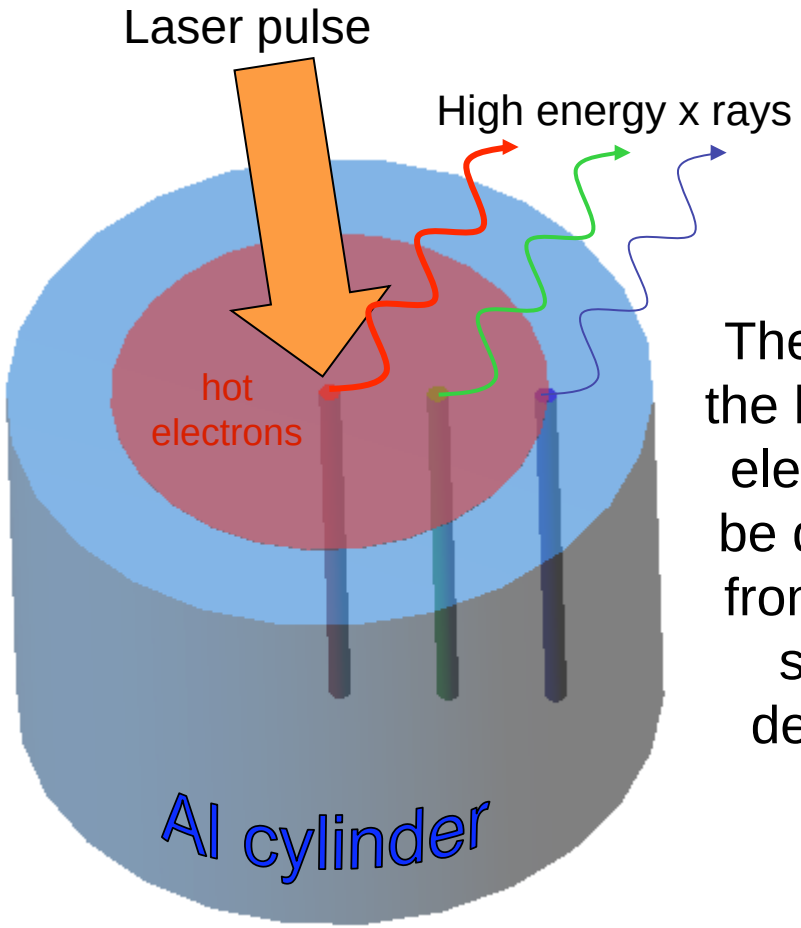

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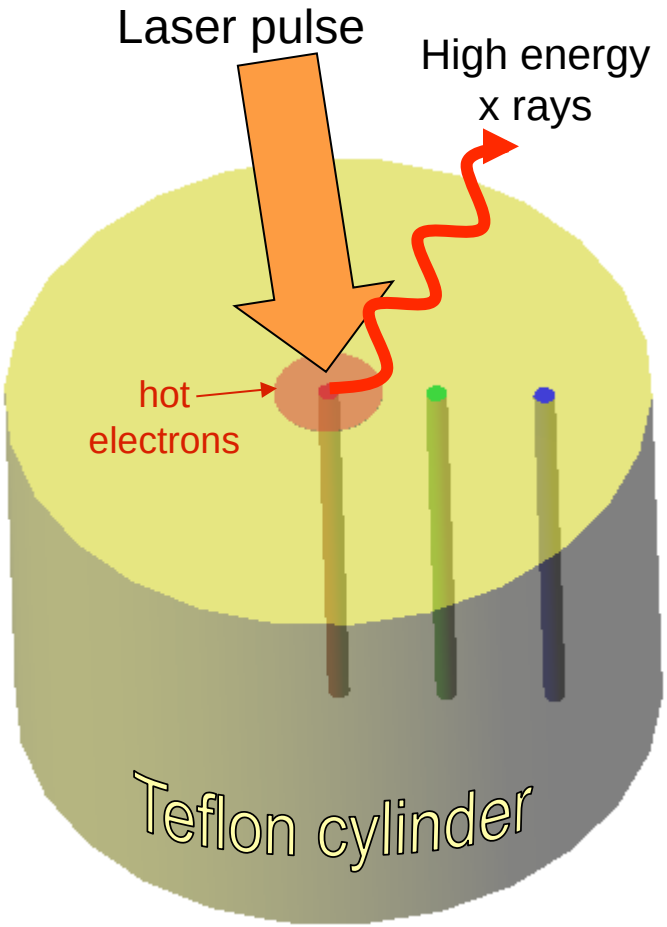

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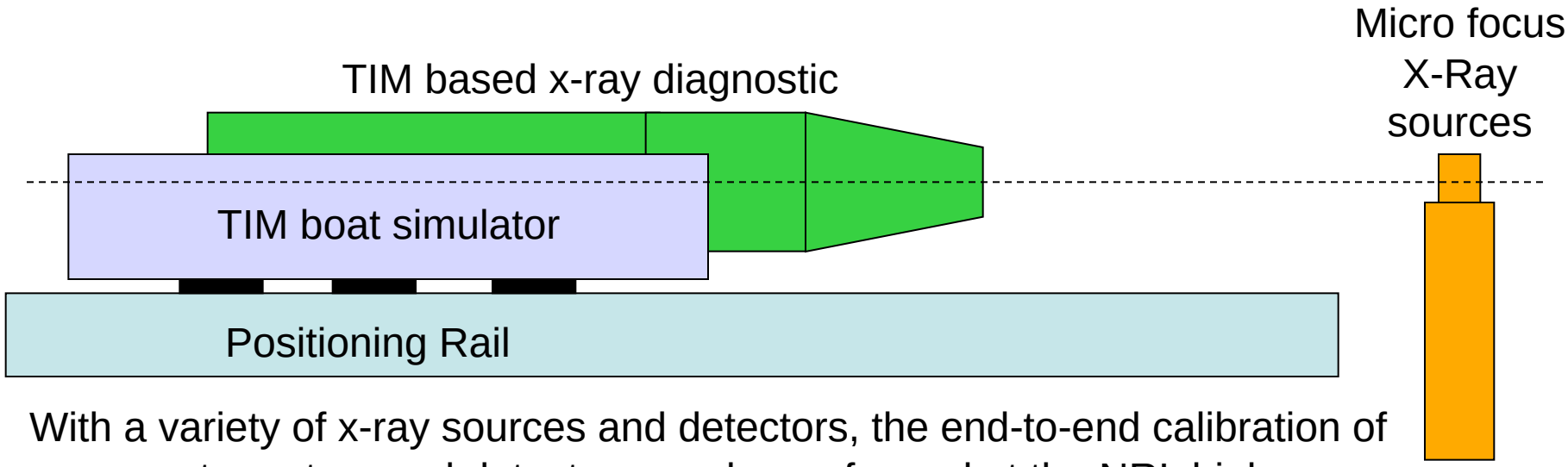

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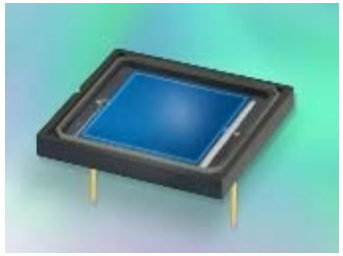

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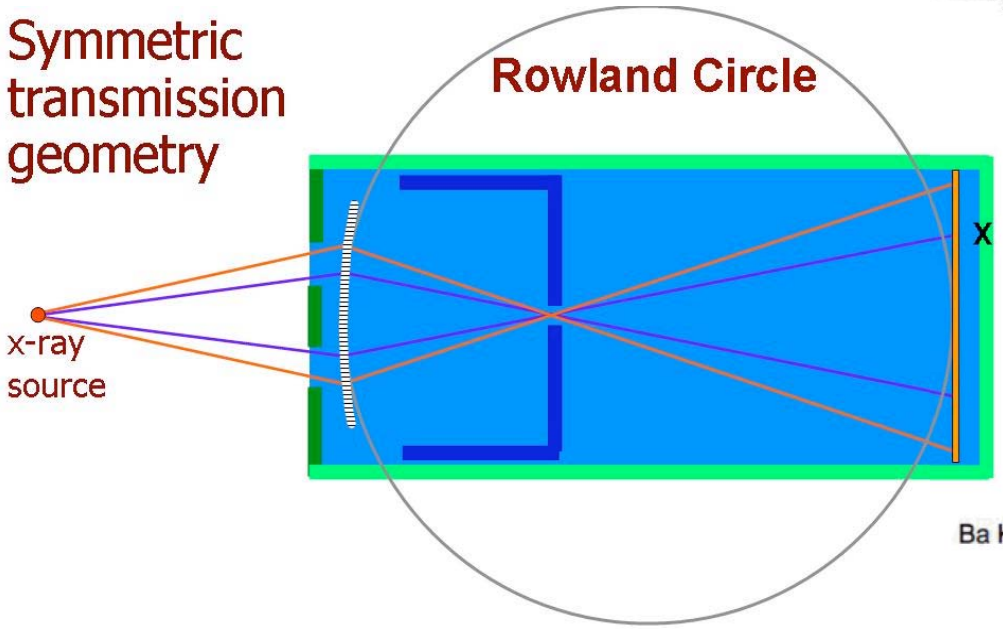

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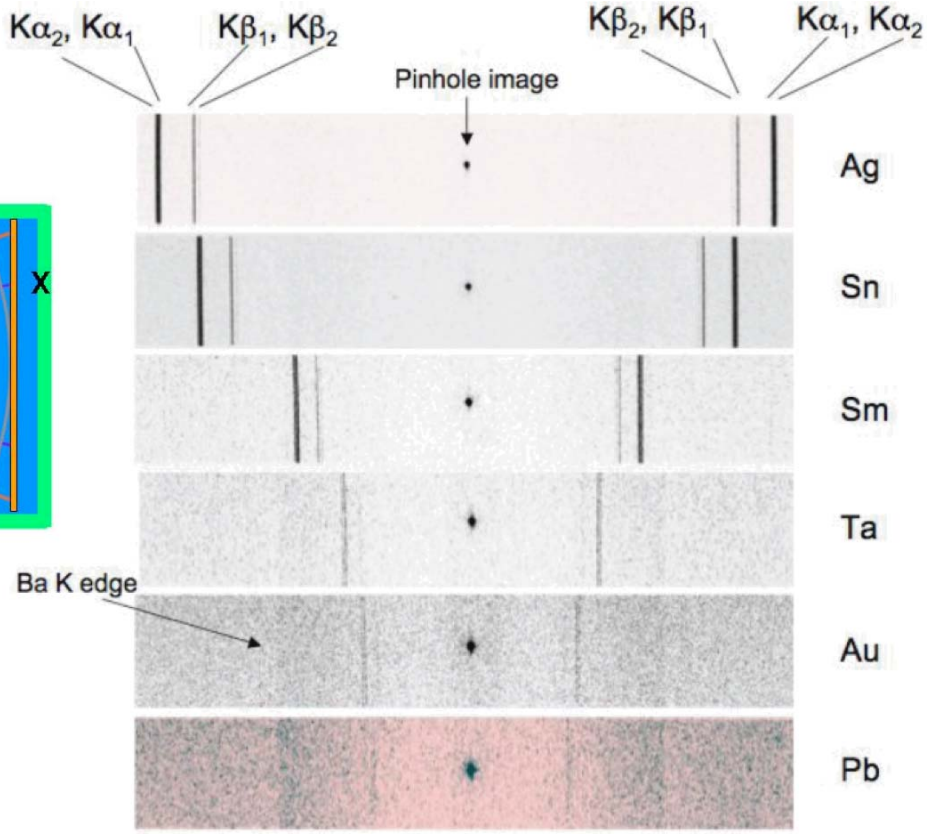

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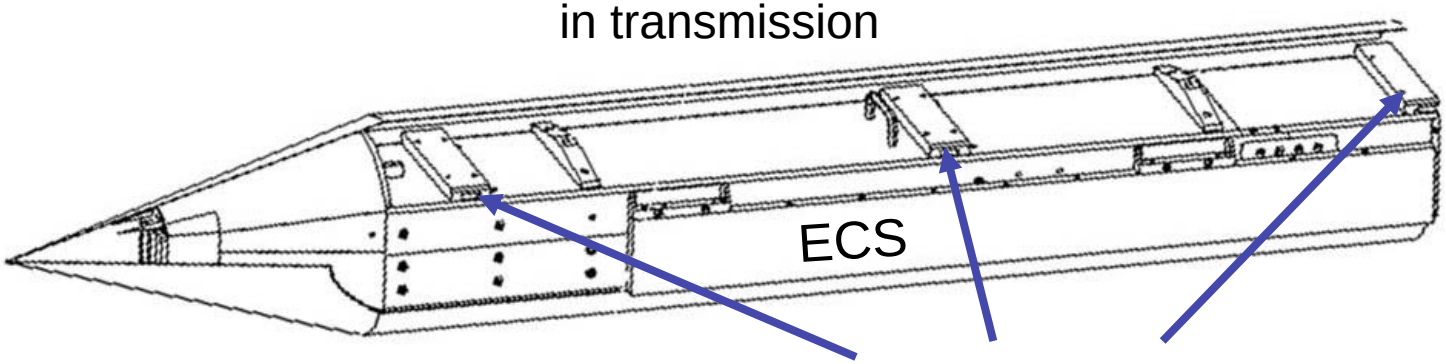

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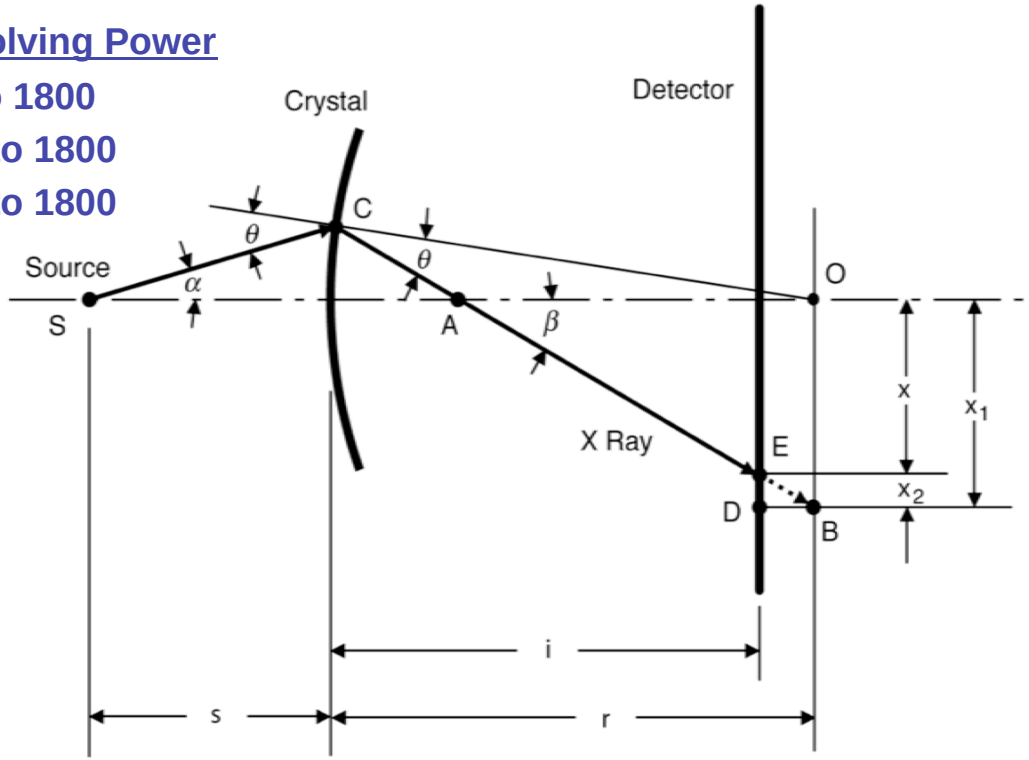

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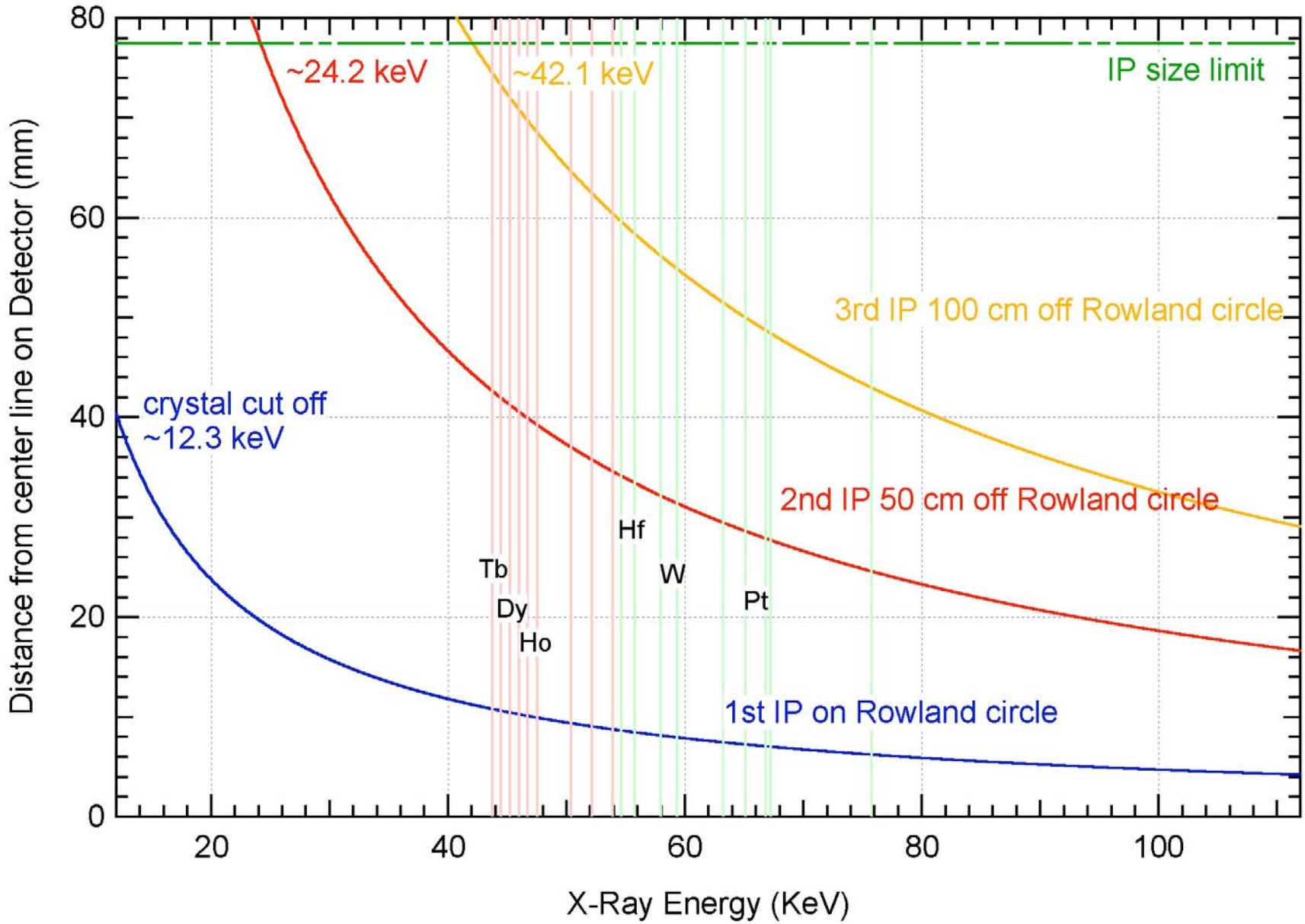

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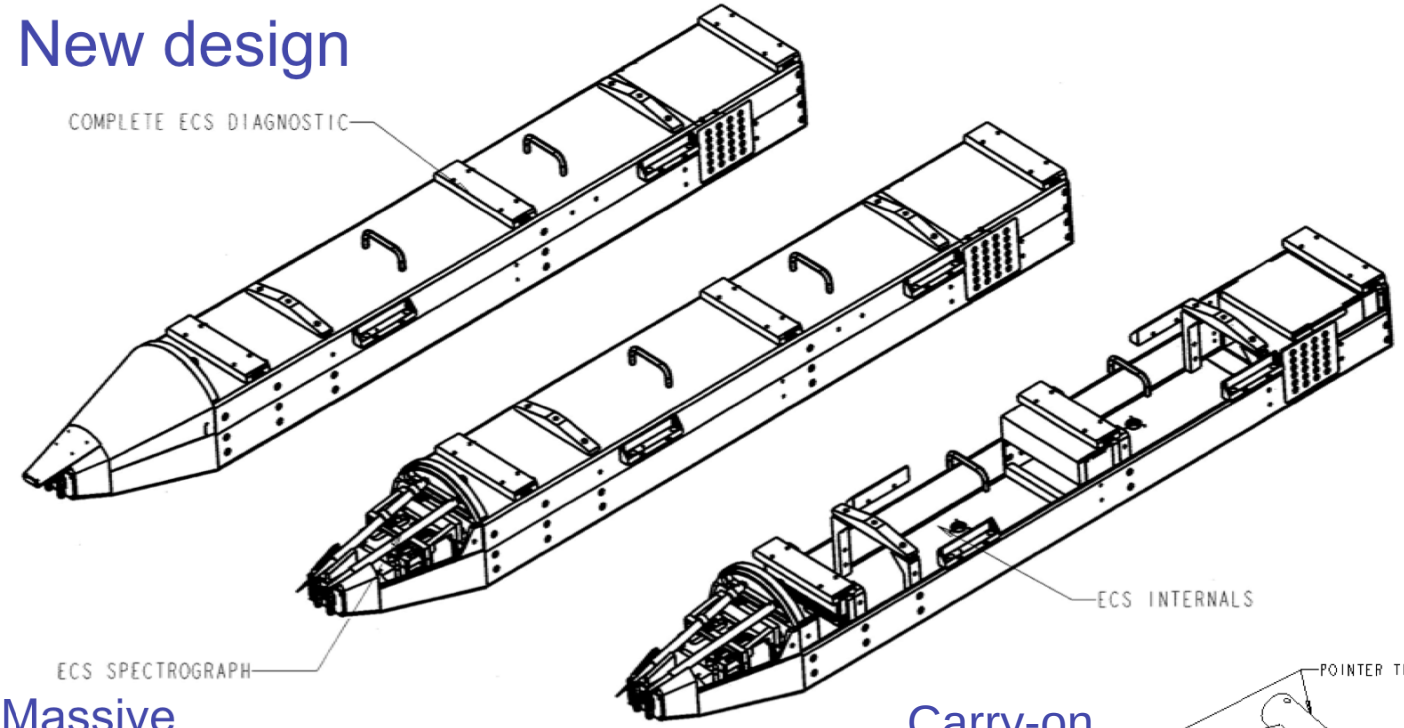

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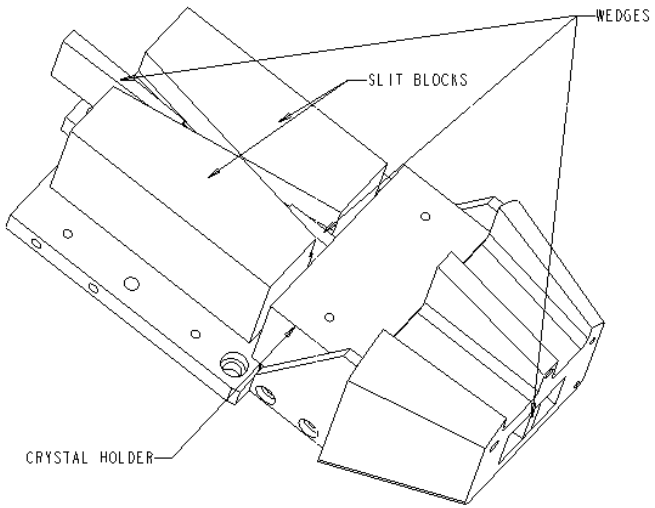

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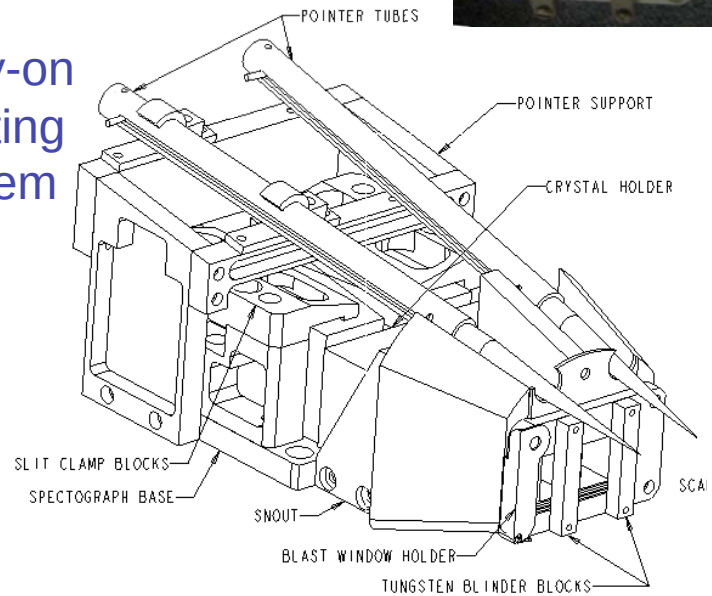

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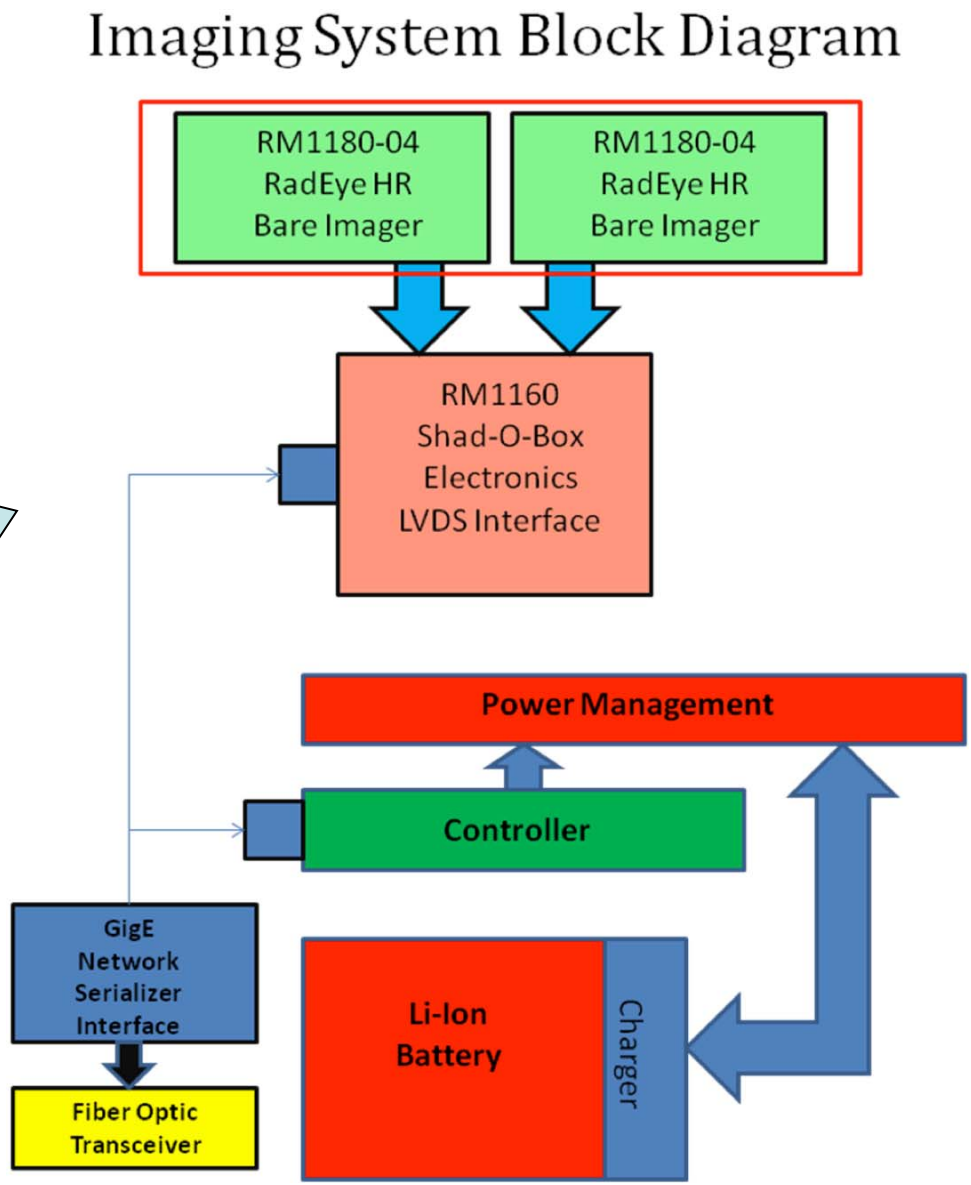

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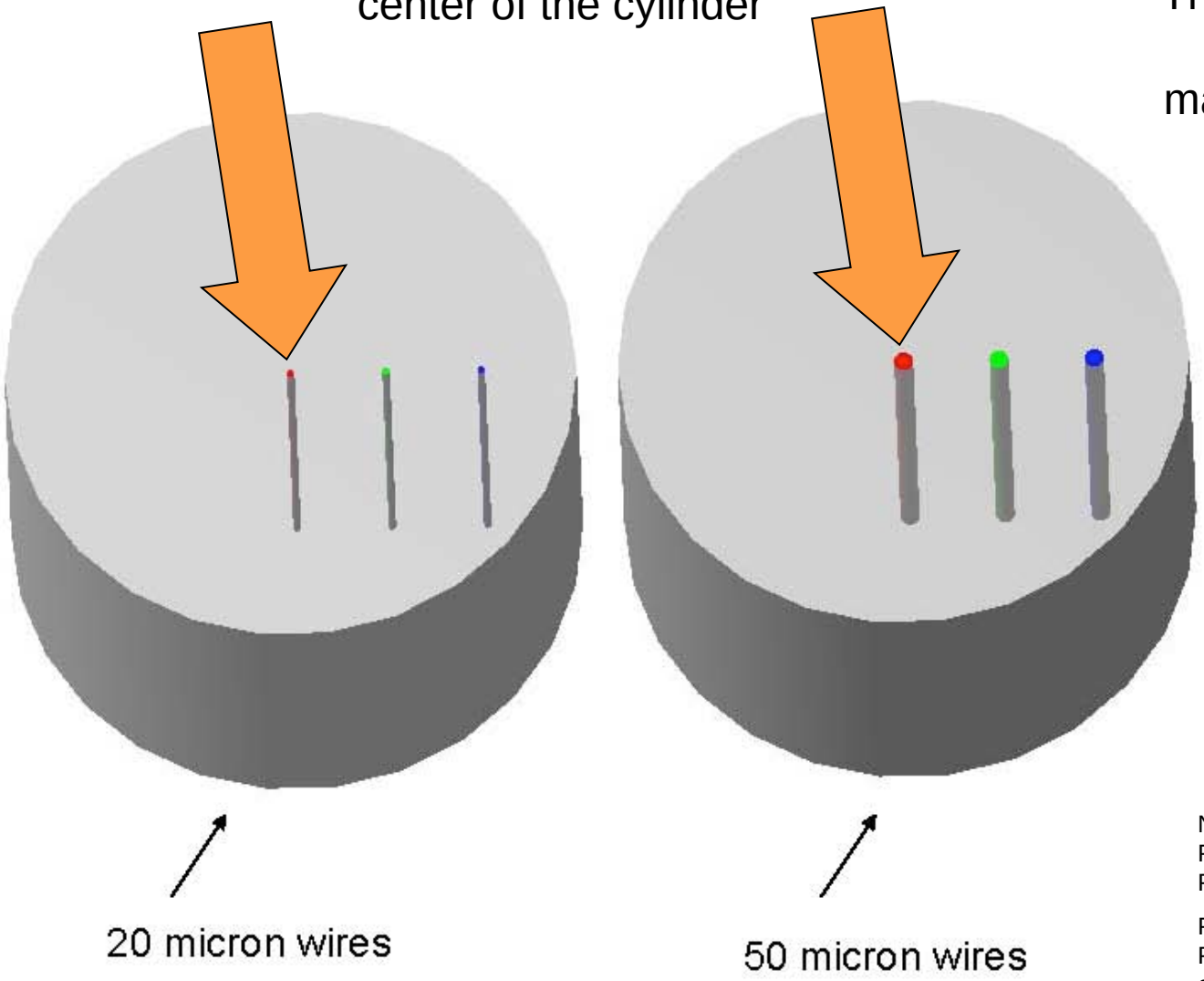

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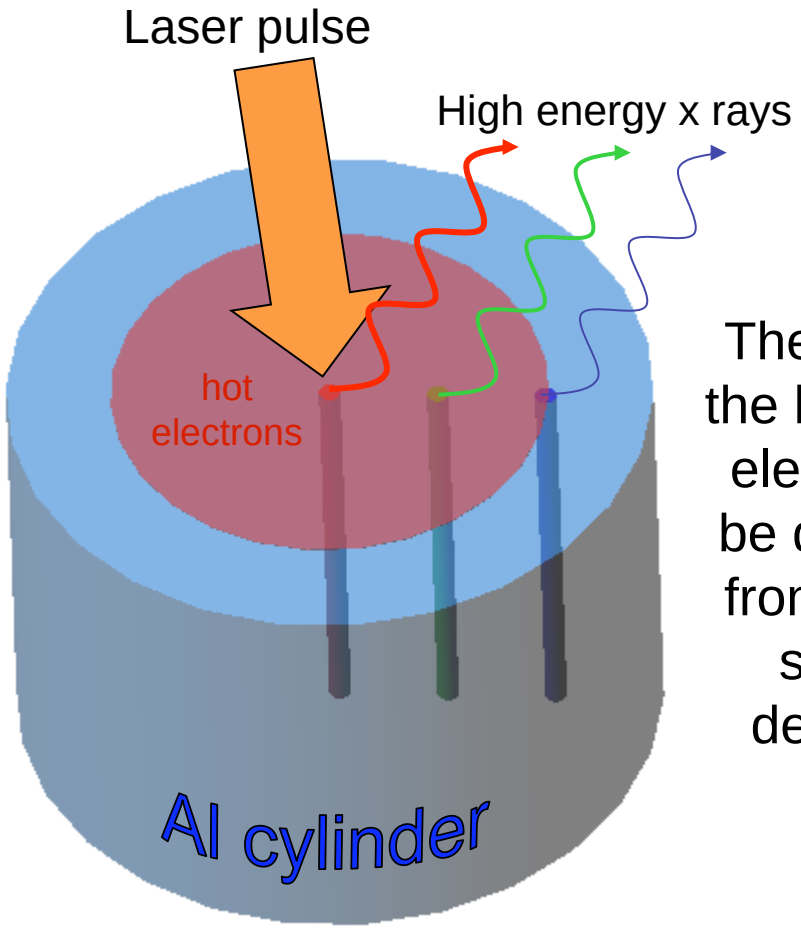

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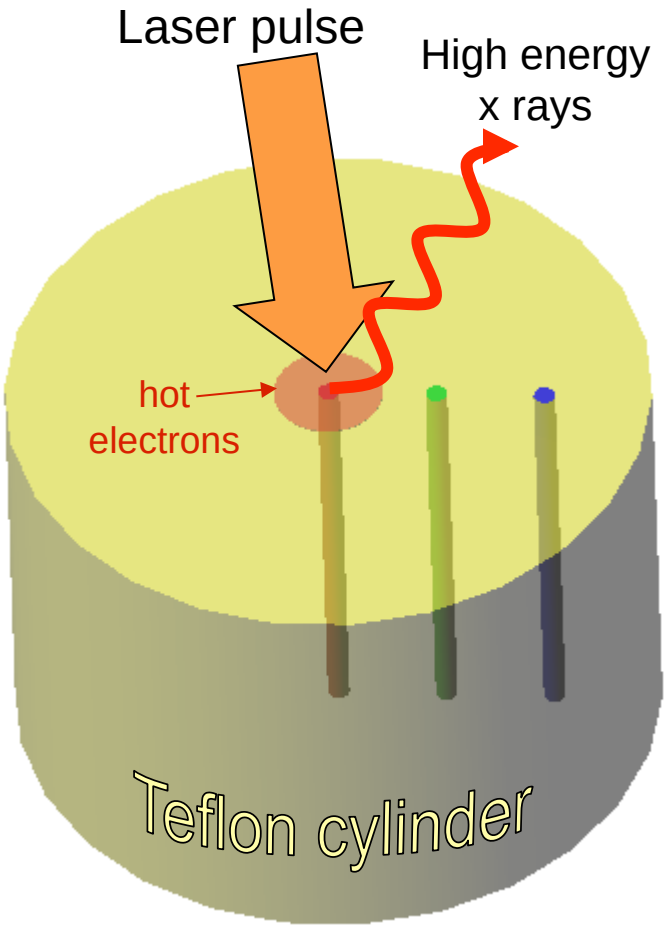

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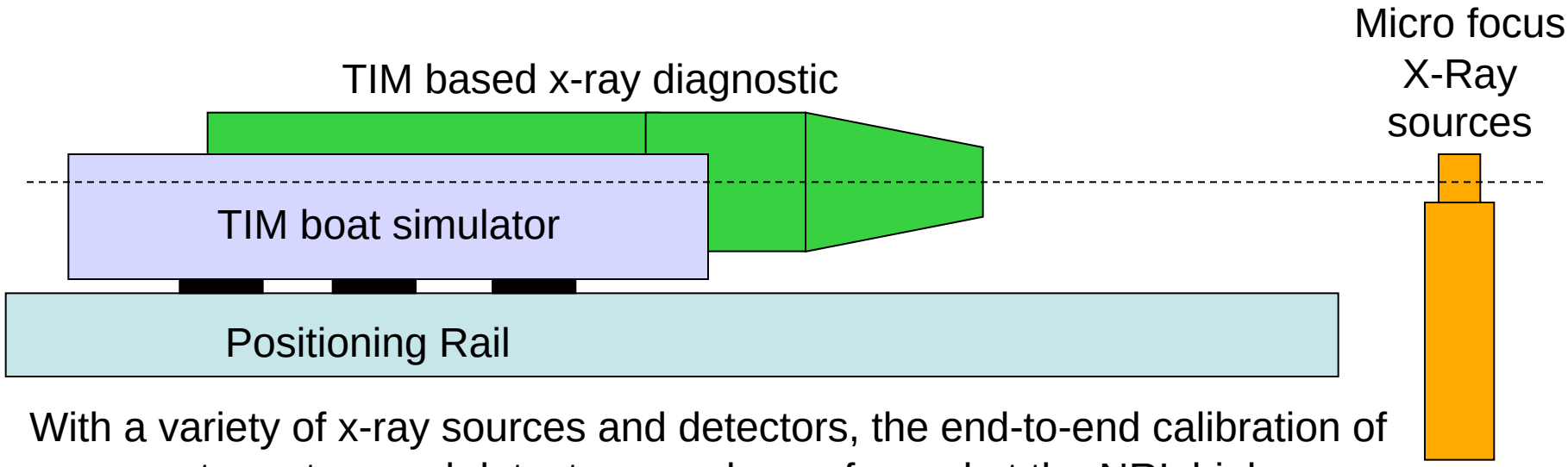

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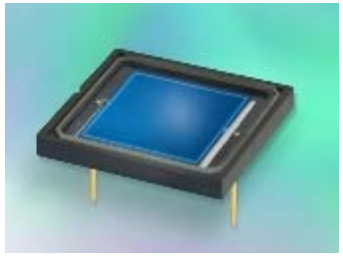

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  Five crystals (one in transmission) cover 1-40 keV with high resolution.

- **DCS** *Dual Crystal Spectrometer*

  Fielded at OMEGA in 2005, LLNL TITAN ps laser in 2006, at PICO2000 at LULI in 2007 and at OMEGA-EP in January 2009.
  Two transmission crystals cover 11-120 keV with high resolution.

- **LCS** *LULI Crystal Spectrometer*

  Used at LULI PICO2000 and “100 TW” laser in 2008.
  One transmission channel 17-120 keV with high resolution

Observed by transmission crystals:

- K-shell lines (22-87 keV) from single shots: Ag, Sn, Sm, Ta, Au, Pb.
- K-shell spectra (95-115 keV), heavy elements up to U fluoresced by a 2 MeV linear accelerator.

Motivation:

- High-energy plasma diagnostics: temperature, density, ionization balance, opacity.
- Hot electron energy distribution, hard x-ray brightness optimization.
- Conversion efficiency to hard x-rays: radiography of dense objects.

Spectrometer and Spectra

Schematic of the Cauchois type transmission crystal spectrometer

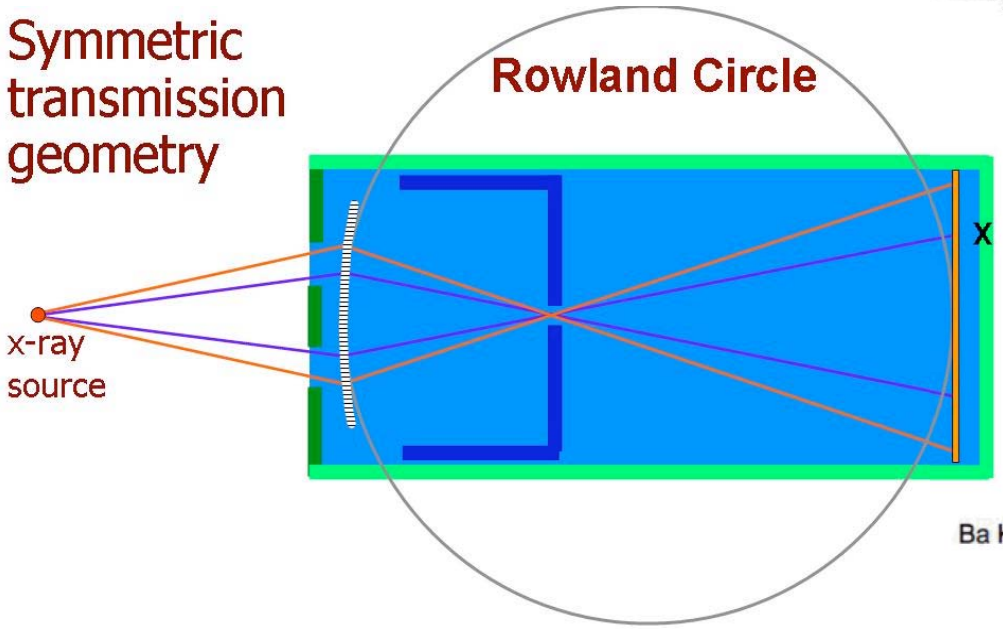
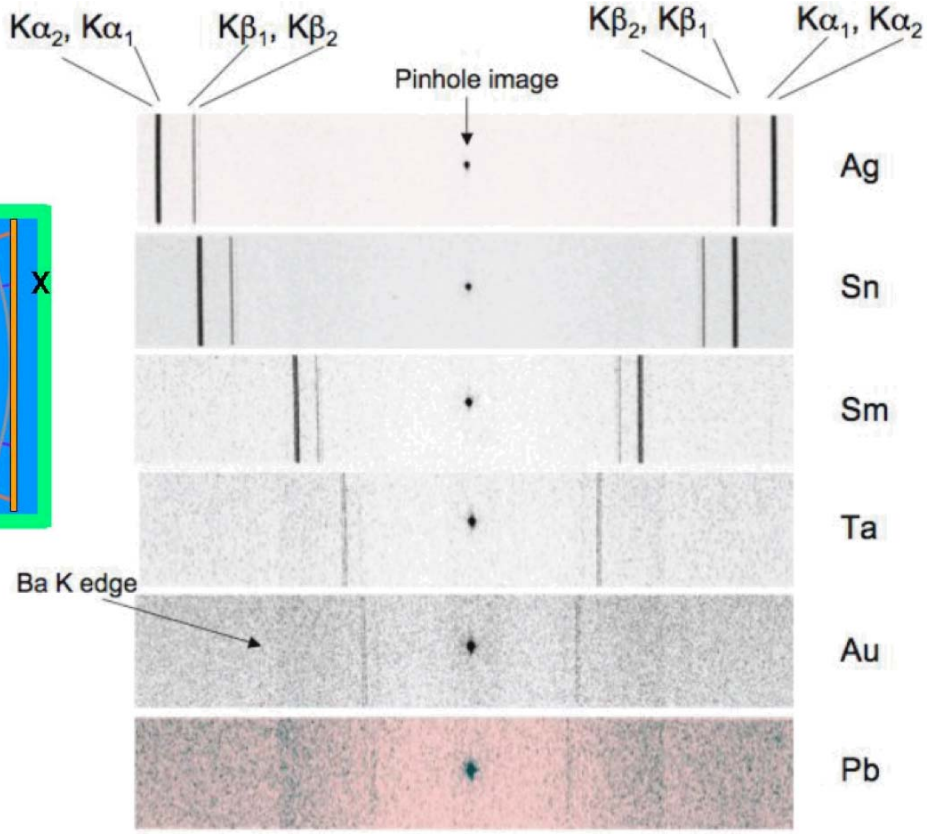


Image spectra with DCS at LLNL Titan ps laser

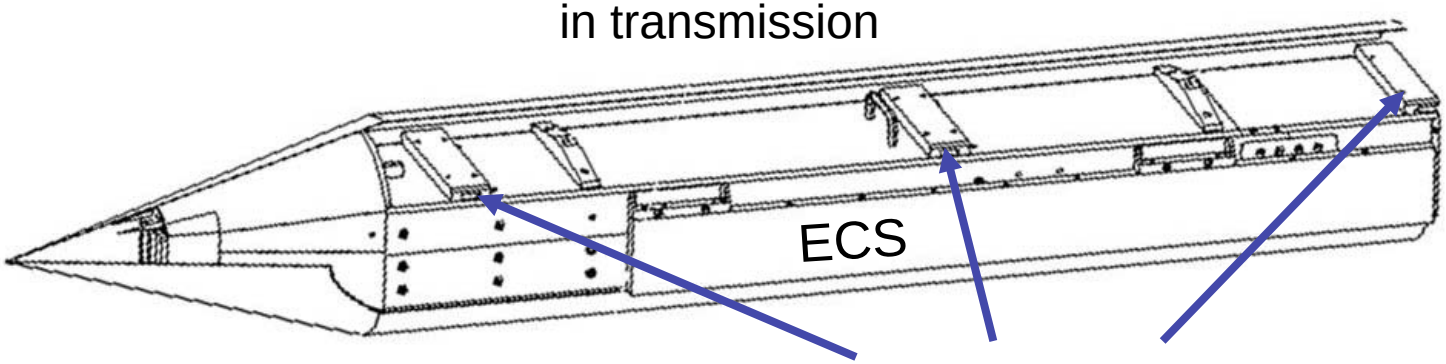


[with R. Tommasini, H-S Park, P. Patel]

- accommodates long stand-off distance & small diffraction angles (high-E's)
- shielded detector (very quiet)
- insertion module appropriate; pinhole image

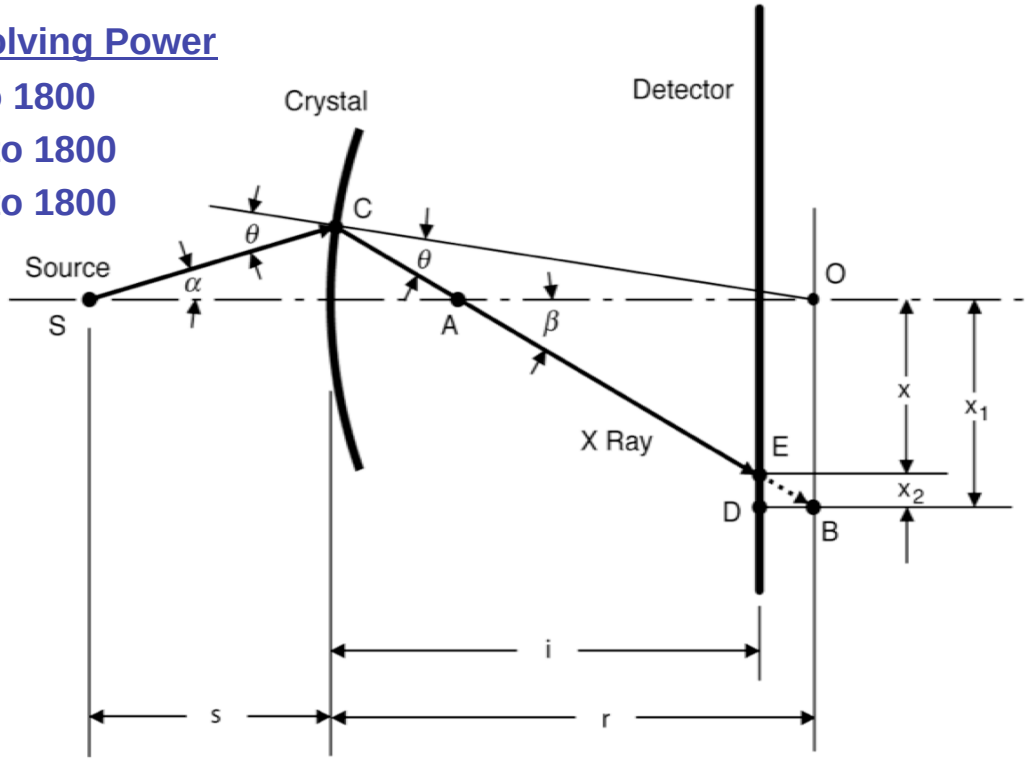
The EP Crystal Spectrometer (ECS)

TIM based x-ray spectrometer with cylindrically bent Quartz (10-11) crystal in transmission



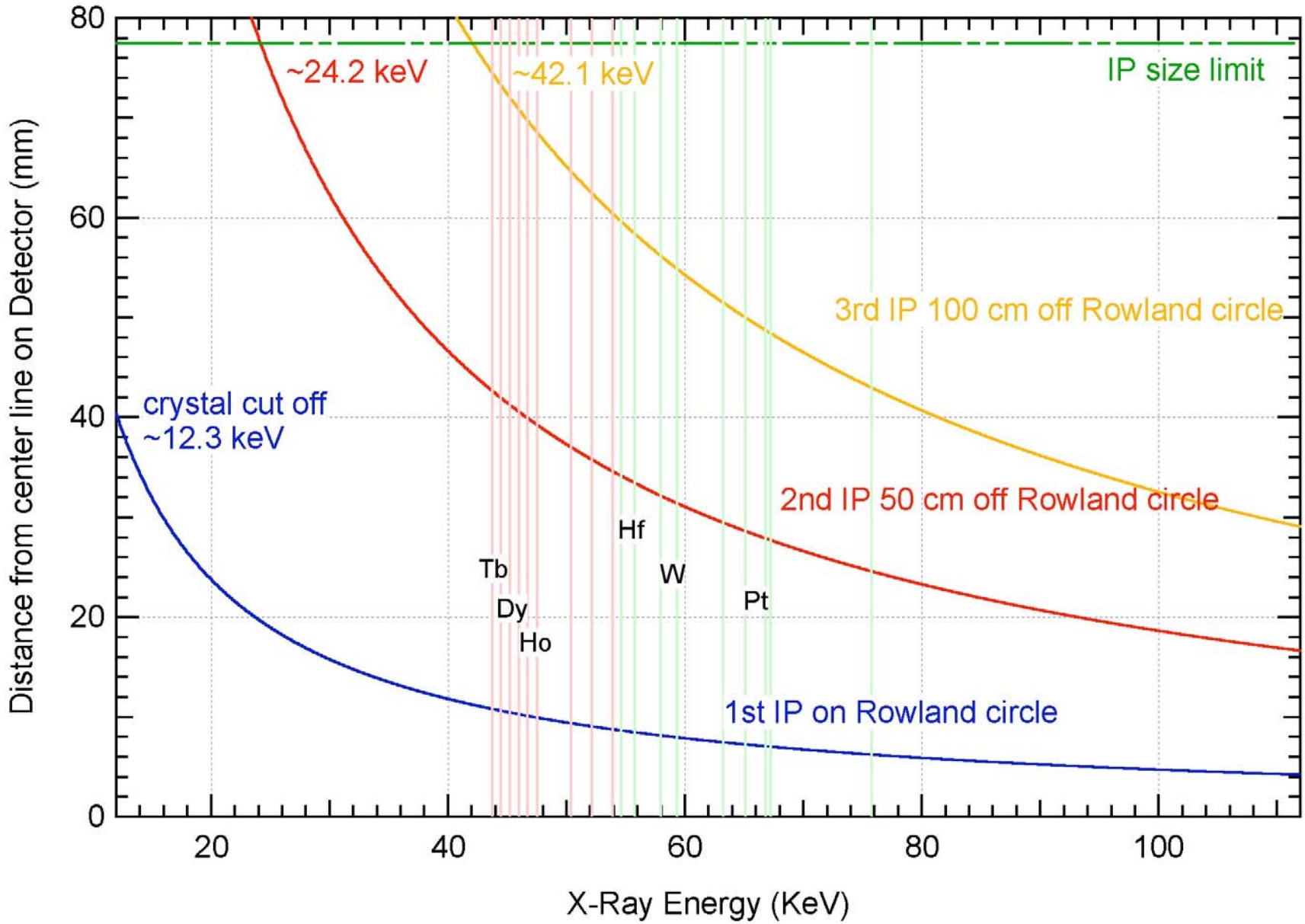
Three detector positions:

Position	Distance	Energy Coverage	Resolving Power
1	0 mm	12 to 115 keV	60 to 1800
2	500 mm	24 to 115 keV	240 to 1800
3	1000 mm	42 to 115 keV	420 to 1800



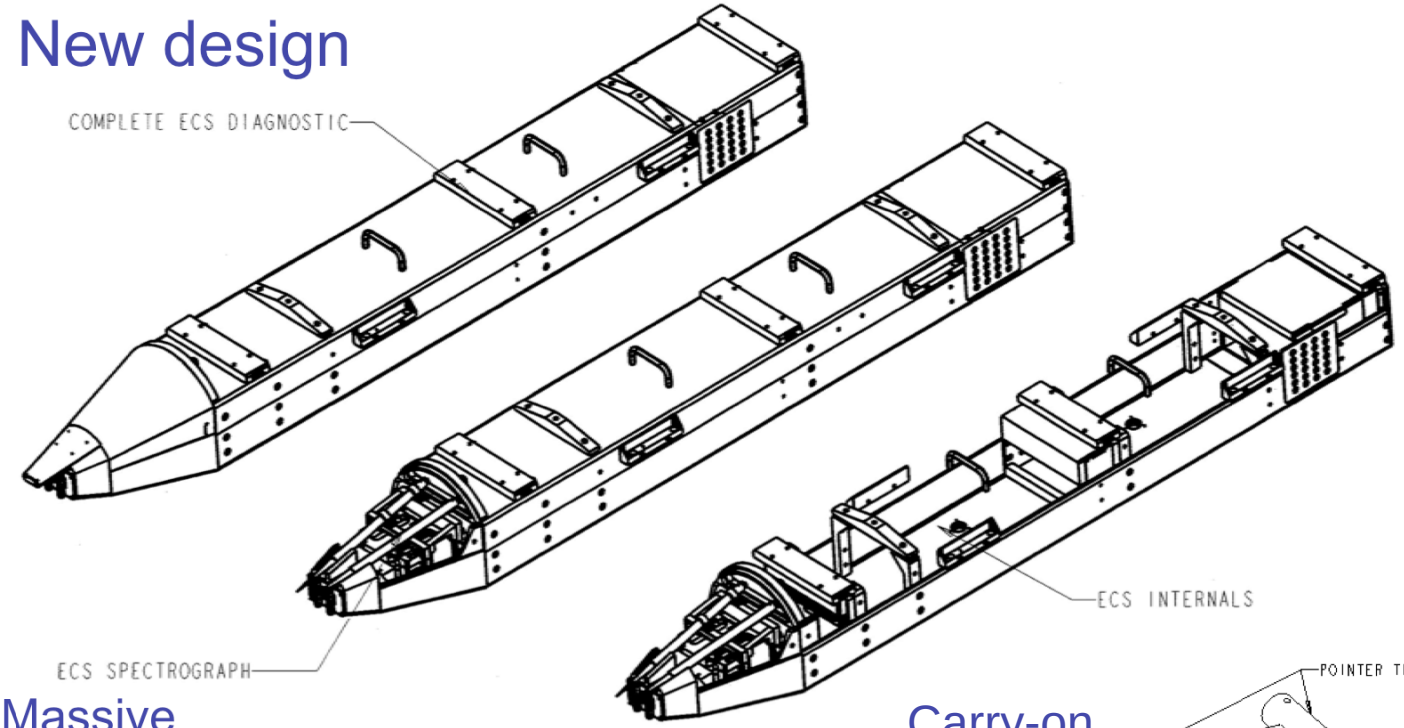
Qz (10-11) 2d 0.6684 nm
Bending radius 254 mm
Standoff 254 mm

Plate Function of ECS at the three detector positions

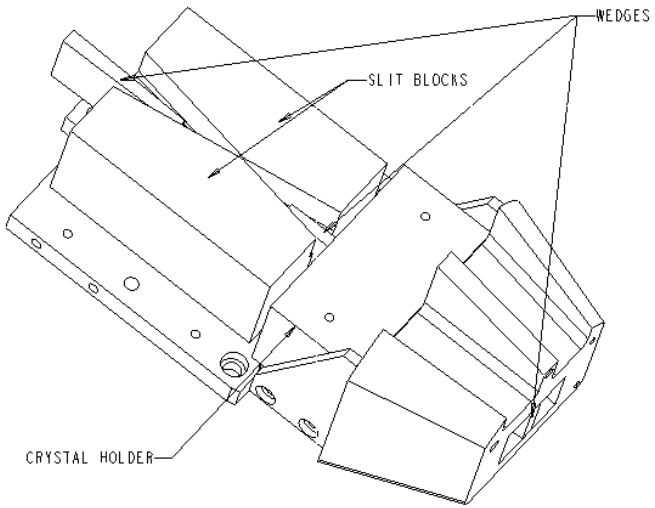


ECS mechanical design

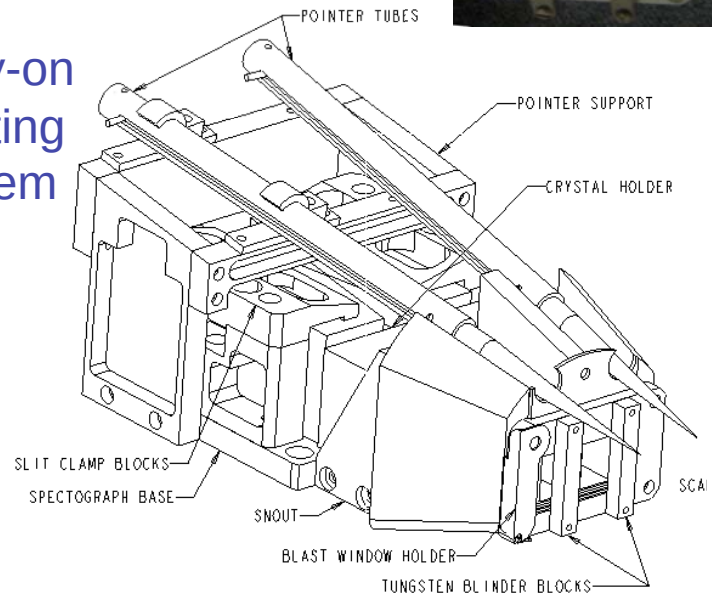
New design



Massive W internal shielding



Carry-on pointing system



The EP Crystal Spectrometer (ECS)

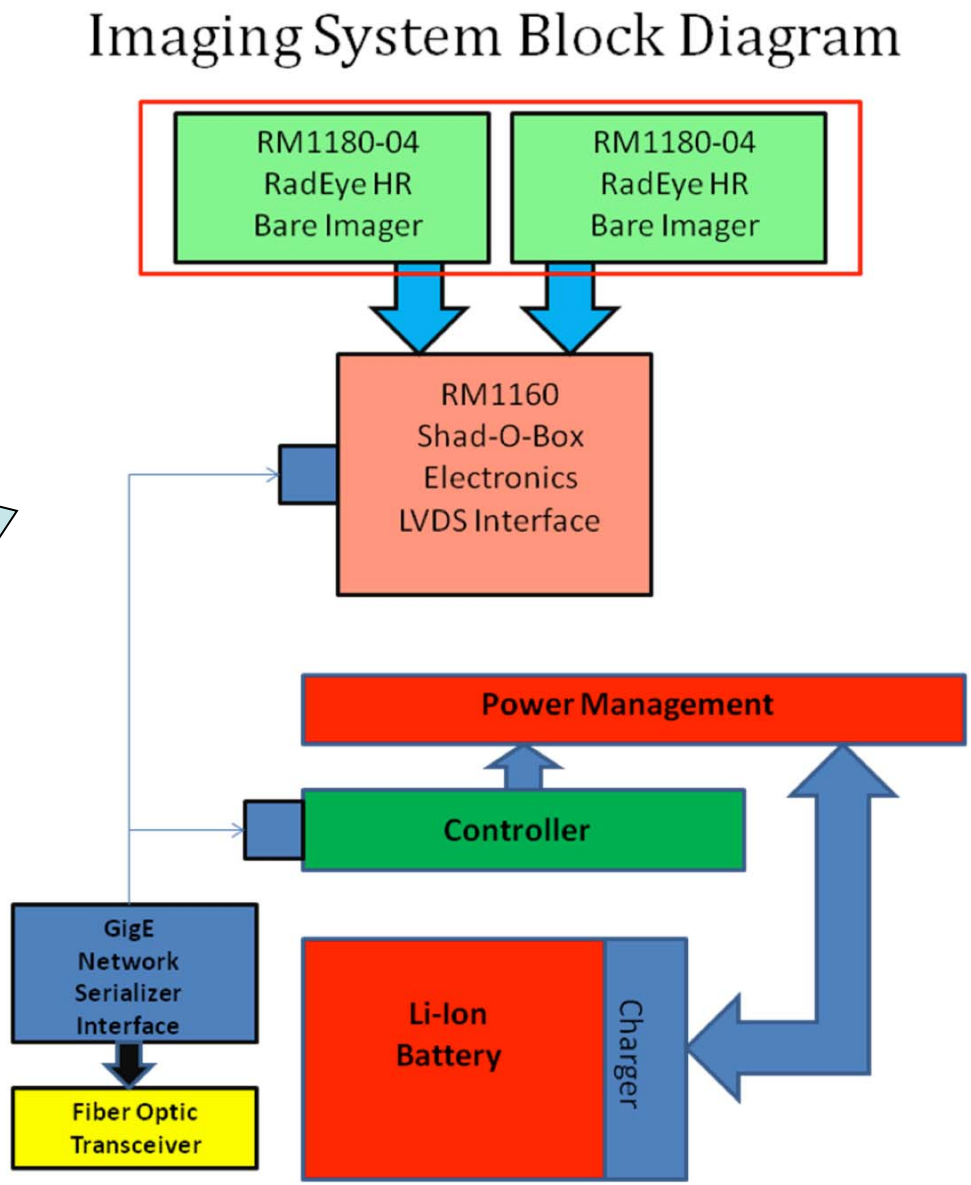
Measure x-ray source size

•Measure hard x-ray source size around OMEGA-EP focal point from broadening of K shell x-ray lines down to 50 μm

•Three detector positions:
1) on the Rowland circle (RC),
2) 20'' off RC
3) 40'' off RC, electronic detection option for maximum resolution

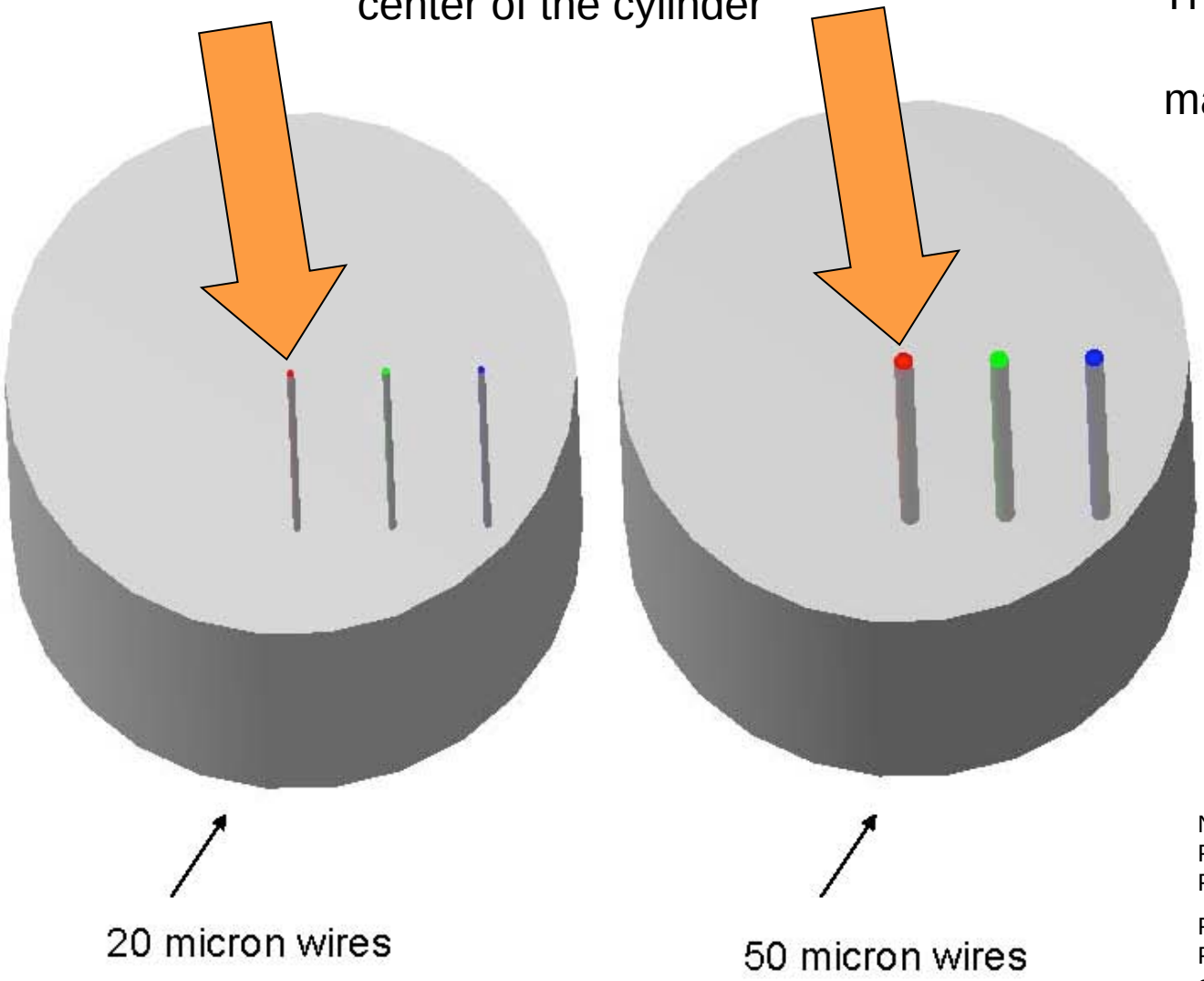
•In the first stage the spectrometer works with image plate detectors. (resolution limited by IP resolution)

•Later electronic detection with ~20 μm pixel size will be added for the high resolution detector position.



The Targets OMEGA-EP experiments

Energetic short pulse beam is focused on the wire in the center of the cylinder



Thin wires embedded in cylinders
made out of Al or Teflon

Diameter: 1.5 mm
height: 1 mm

Wire materials:

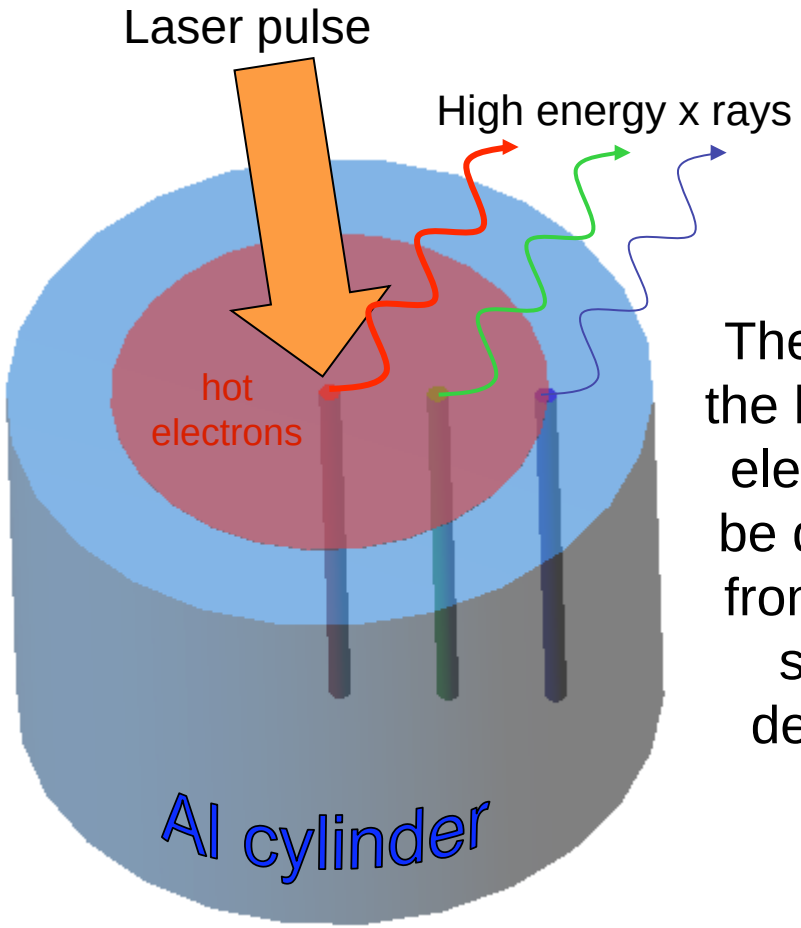
Low Z: Ho, Dy, Tb

High Z: Pt, W, Hf

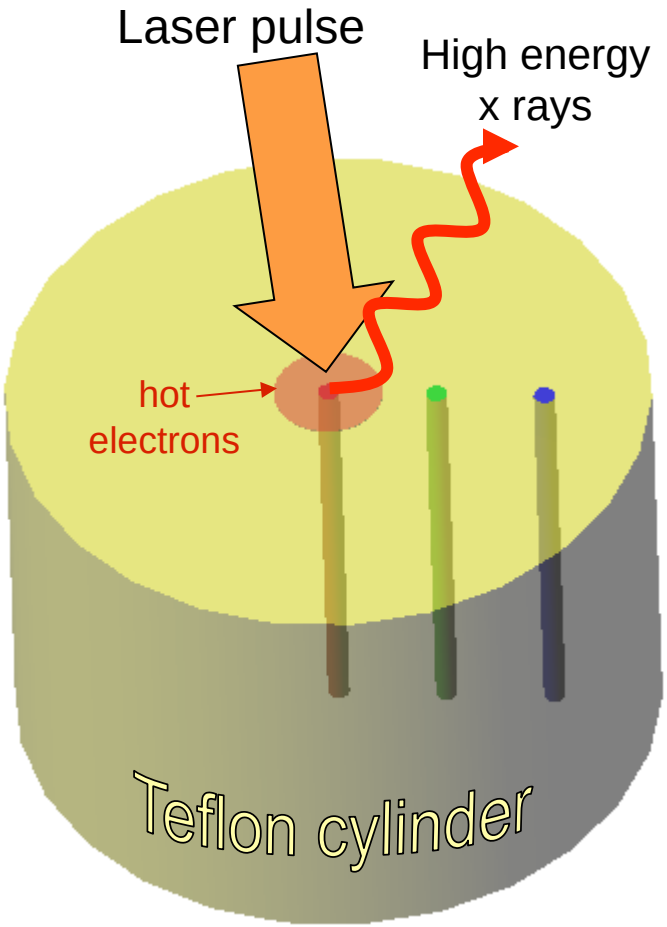
NLUF campaign:
PPRad-EP-09A; August 13, 2009
PPRad-EP-09B; End of September, 2009

PI: Uri Feldman, Artep Inc. (202) 767-3286
PC: Csilla Szabo, Artep Inc. (202) 767-2546
e-mail: cszabo@ssd5.nrl.navy.mil

The Experiment at OMEGA-EP



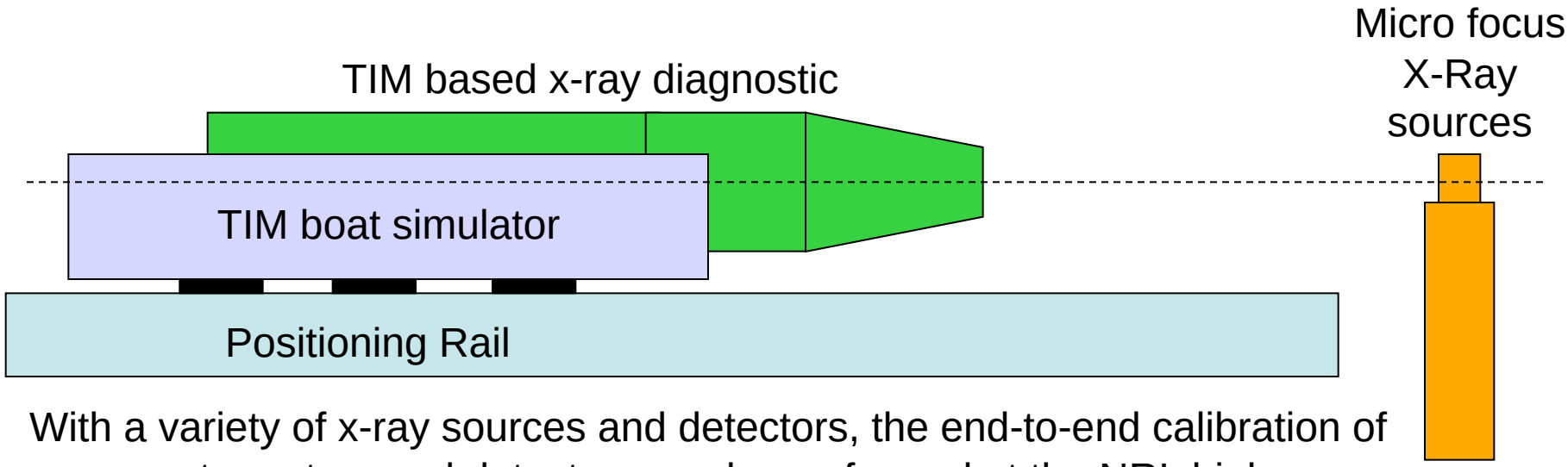
The spread of the high energy electrons can be determined from the x-ray spectrum detected by ECS



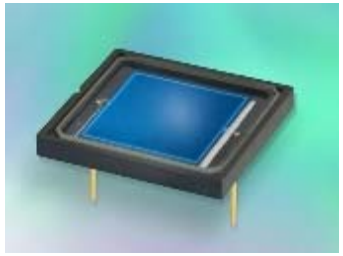
Electrons propagating to large distances due to the presence of return current in conductor

Electrons are recirculated to the irradiated wire if embedded in insulator

Calibration Facility at NRL



With a variety of x-ray sources and detectors, the end-to-end calibration of x-ray spectrometers and detectors can be performed at the NRL high energy x-ray calibration facility



Absolutely calibrated x-ray photo diode

AMPTEK x-ray detector

Multi-function dosimeter

Radio active sources:
Am-242, Cd-109, Co-57

Selected Publications about high energy x-ray spectrometers for use with laser produced plasmas

http://spectroscopy.nrl.navy.mil/

- Seely, JF; Holland, GE; Hudson, LT; et al.
  X-ray modulation transfer functions of photostimulable phosphor image plates and scanners
  APPLIED OPTICS, 47 (31): 5753-5761 NOV 1 2008
- Seely, JF; Hudson, LT; Holland, GE; et al.
  Enhanced x-ray resolving power achieved behind the focal circles of Cauchois spectrometers
  APPLIED OPTICS, 47 (15): 2767-2778 MAY 20 2008
- Hudson, LT; Atkin, R; Back, CA; et al.
  X-ray spectroscopy at next-generation inertial confinement fusion sources: Anticipating needs and challenges
  RADIATION PHYSICS AND CHEMISTRY, 75 (11): 1784-1798 NOV 2006
- Szabo, CI; Hudson, LT; Henins, A; et al.
  Mitigation of fluorescence and scattering in reflection convex-crystal X-ray spectrometers
  RADIATION PHYSICS AND CHEMISTRY, 75 (11): 1824-1829 NOV 2006
- Seely, JF; Back, CA; Constantin, C; et al.
  Krypton K-shell X-ray spectra recorded by the HENEX spectrometer
  JOURNAL OF QUANTITATIVE SPECTROSCOPY & RADIATIVE TRANSFER, 99 (1-3): 572-583 MAY-JUN 2006
- Hudson, LT; Henins, A; Deslattes, RD; et al.
  A high-energy x-ray spectrometer diagnostic for the OMEGA laser
  REVIEW OF SCIENTIFIC INSTRUMENTS, 73 (6): 2270-2275 JUN 2002