



X-Ray Diagnostics for the Levitated Dipole Experiment



J. L. Ellsworth, J. Kesner

MIT Plasma Science and Fusion Center

D.T. Garnier, A.K. Hansen, M.E. Mauel

Columbia University

S. Zweben

Princeton Plasma Physics Laboratory



Presented at

*The APS Division of Plasma Physics Annual Meeting 2003
Albuquerque, New Mexico*

Columbia University



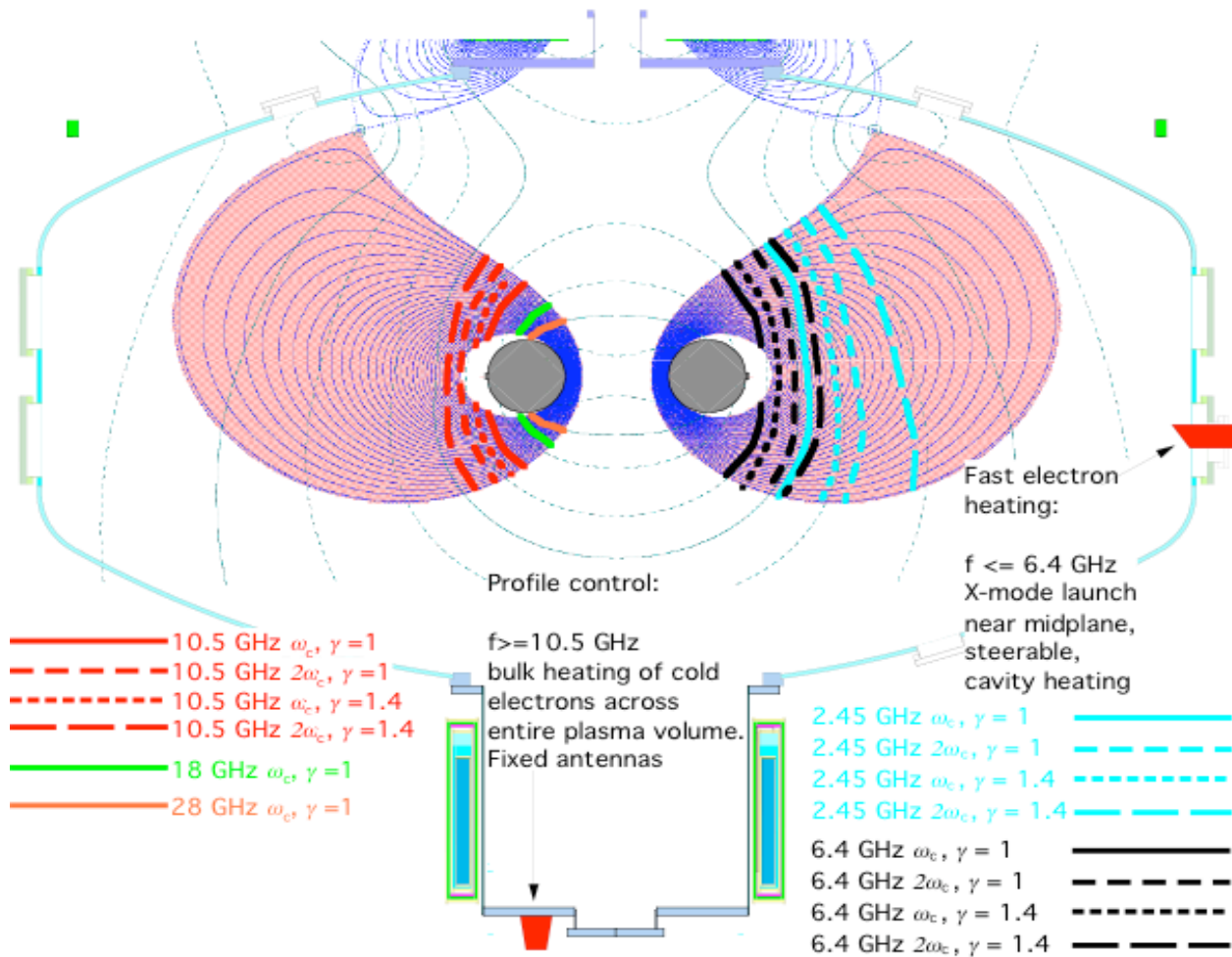
27 October 2003

Abstract

Plasmas in the Levitated Dipole Experiment (LDX) will initially be created using electron cyclotron heating and it is therefore expected that most of the plasma energy will be stored in the fast electrons ($T_e > 100$ KeV). As a consequence of these fast electrons, substantial x-ray flux is expected. In the initial run campaign we plan to utilize two x-ray diagnostics. An x-ray pulse height analyzer will measure the energy spectrum of bremsstrahlung emission at four radially spaced locations. An x-ray camera [1] on loan from PPPL, will view the intensity of bremsstrahlung emission from a portion of the toroidal cross section of the plasma at sixty fields per second. Since the rapid toroidal drift of the hot electrons will symmetrize the hot electron component we expect that an asymmetry in the bremsstrahlung signal will indicate a spatial asymmetry in the ion population. We therefore expect to use the camera to indicate plasma asymmetries, which might indicate the presence of convective cells. The design, construction and calibration of these diagnostics will be discussed.

[1] S. von Goeler et al. *Rev. Sci. Instrum.* **65** (5) 1994, p. 1621

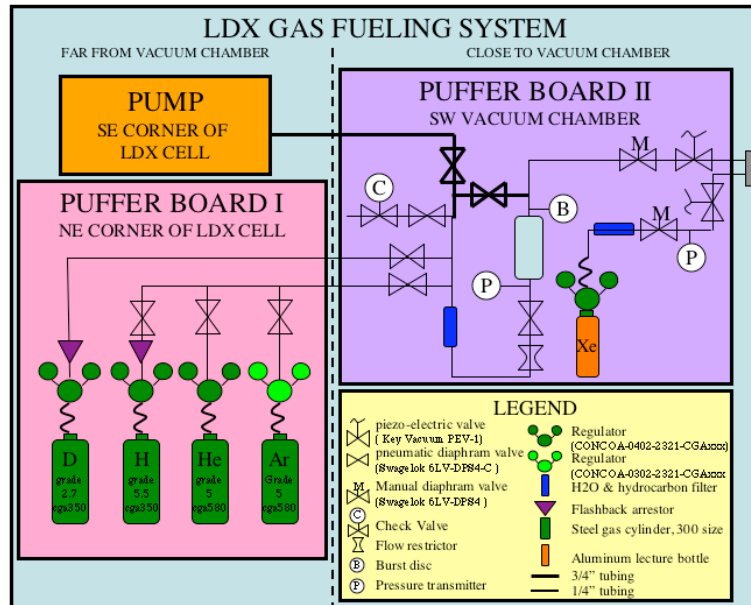
Multifrequency Electron Cyclotron Resonant heating will create a hot electron plasma



- Effective way to create high- β hot electron population.
- Hot electron plasma means that plasma temperature can be diagnosed with bremsstrahlung diagnostics.
- Measure single frequency response.
 - X-ray pulse-height analyzer
 - X-ray camera (collaboration with S. Zweben, PPPL)
- Tailor multi-frequency heating power to produce ideal (stable) pressure profile with maximum peak β .
 - 2.45 and 6.4 GHz form base hot-electron plasma
 - Higher frequencies are used to tailor the profile

Locations of ECRH resonances, for both cold and 200 keV electrons (Diagram from A.K. Hansen)

Gas Puffing Capabilities



CURRENT STATUS OF GAS FUELING SYSTEM

- Plumbing is in place for D,H,He, Ar lines and pneumatic lines.
- Parts for Xe line are on site and need to be assembled.
- System will be leak checked and tested after APS.

- ✓ Hydrogen, deuterium, helium, and argon are available for creating plasmas.
- ✓ Xenon gas is available to enhance the x-ray signal.
- ✓ Remote control of system with PLC unit is possible.
- ✓ This capability allows us to probe x-ray emission at the edge of the plasma by puffing just a little xe into the edge of the plasma;
- ✓ And allows us to view the x-ray energy spectrum for plasmas that are thinner and cooler than expected.

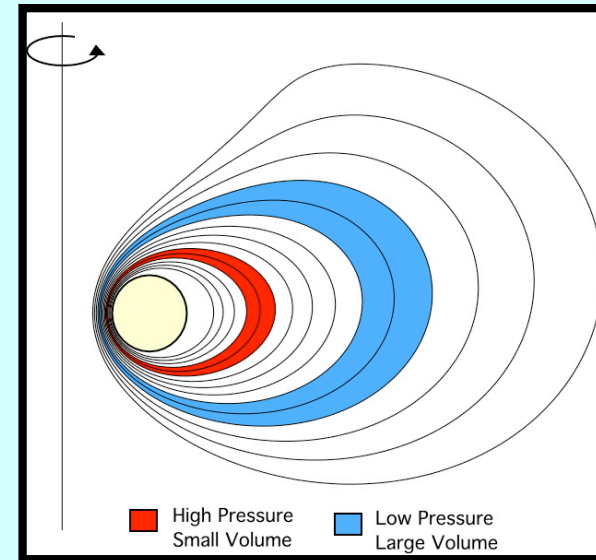
Predicted Bremsstrahlung Emission

PROJECTED LDX PARAMETERS

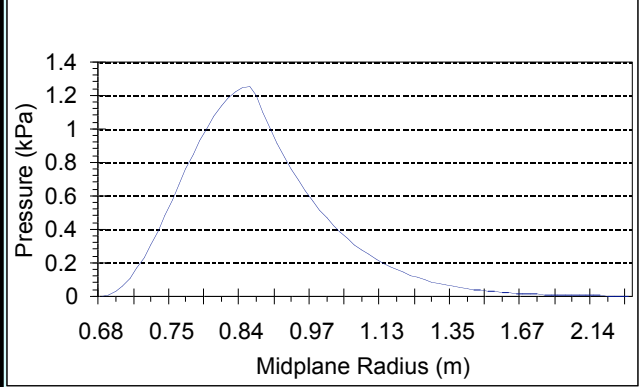
Table 1: Plasma equilibria parameters. (A) diverted, no shaping, (B) diverted, shaped for maximum beta, (C) diverted, shaped for minimum beta, (D) limited plasma.

| | A | B | C | D |
|--|-------|-------|-------|-------|
| S-Coil Currents; I_{s1}, I_{s2} (kA) | 0,0 | 1,12 | 50,50 | 3,12 |
| Plasma Volume (m^3) | 14 | 27 | 1.7 | 24 |
| SOL Pressure (Pa) | 0.25 | 0.25 | 0.25 | 0.1 |
| Max Pressure (Pa) | 136 | 1530 | 45 | 472 |
| Plasma Current (kA) | 3.2 | 16.4 | 0.39 | 5.78 |
| Stored Energy (J) | 316 | 1450 | 27 | 516 |
| $R(P_{max})$ (m) | 0.76 | 0.76 | 0.77 | 0.79 |
| $B(P_{max})$ (T) | 0.088 | 0.088 | 0.088 | 0.088 |
| $\beta(P_{max})$ | 0.08 | 0.55 | 0.015 | 0.15 |

PRESSURE CONTOURS

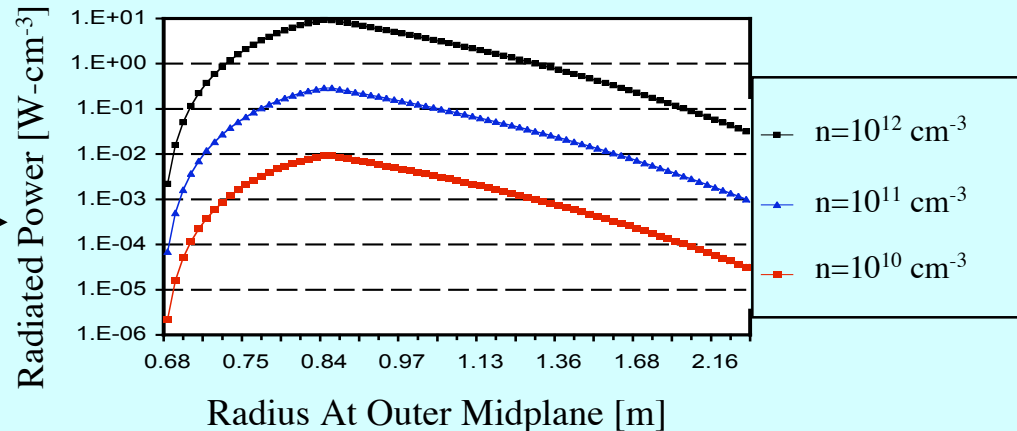


PREDICTED PLASMA PRESSURE PROFILE



$P = nT$

Estimated Bremsstrahlung Power



$$P_B = 1.69 \times 10^{-32} n_{\text{hot}} n_i Z^2 T_e^{1/2} \text{ [W-cm}^{-3}\text{]}$$

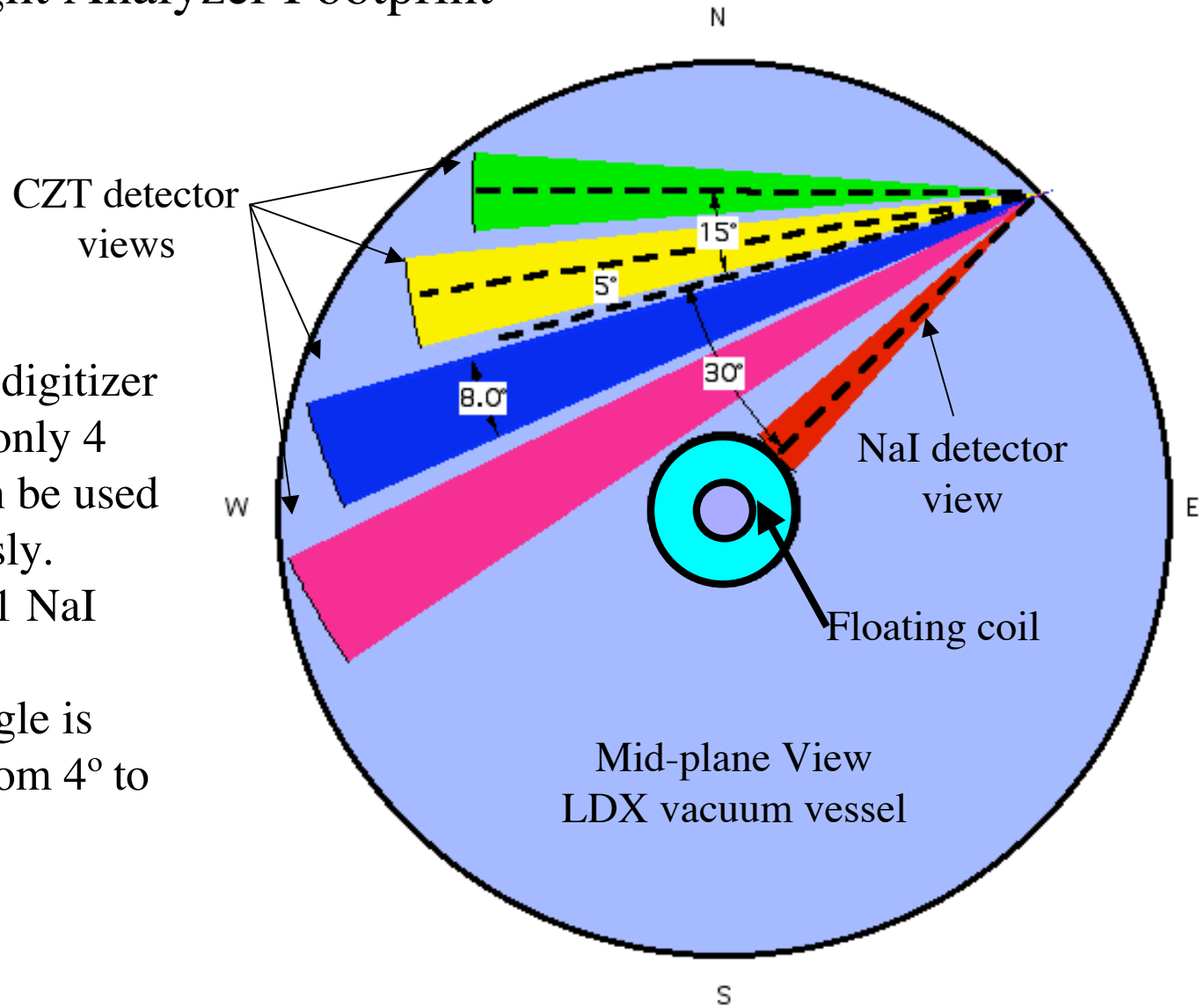
Ref: Chris Jones

X-Ray Pulse Height Analyzer Summary

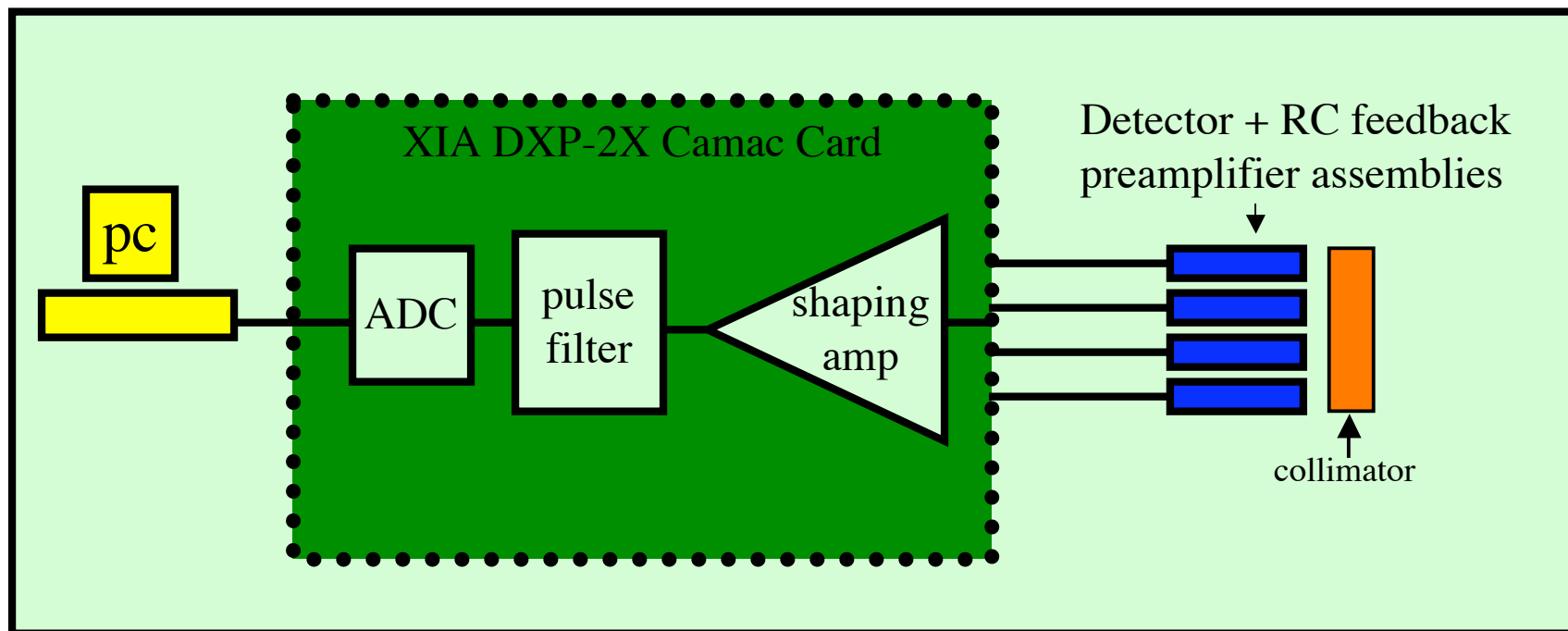
- PHA will provide time resolved profile of hot electrons with an expected resolution of 1 ms,
- And a spatially resolved profile of hot electrons from 4 line integrated chordal measurements
- This energy spectrum will be used to infer the temperature and density of hot electrons in the plasma for monitoring of multi-frequency ECRH.
- Hot electron measurements will indicate our ability to vary the plasma pressure profiles.

Pulse Height Analyzer Footprint

- There are 4 digitizer channels so only 4 detectors can be used simultaneously.
- 3 CZT and 1 NaI
- Or 4 CZT
- Viewing angle is adjustable from 4° to 45°



PHA Layout



- 4 Channels
- Count rates of 500 kHz per channel are expected
- CZT 5x5x5mm detectors view energy range of 10 keV-720 keV
- NaI 2x2x2" detector views an energy range of 1 keV-3 MeV

Detectors

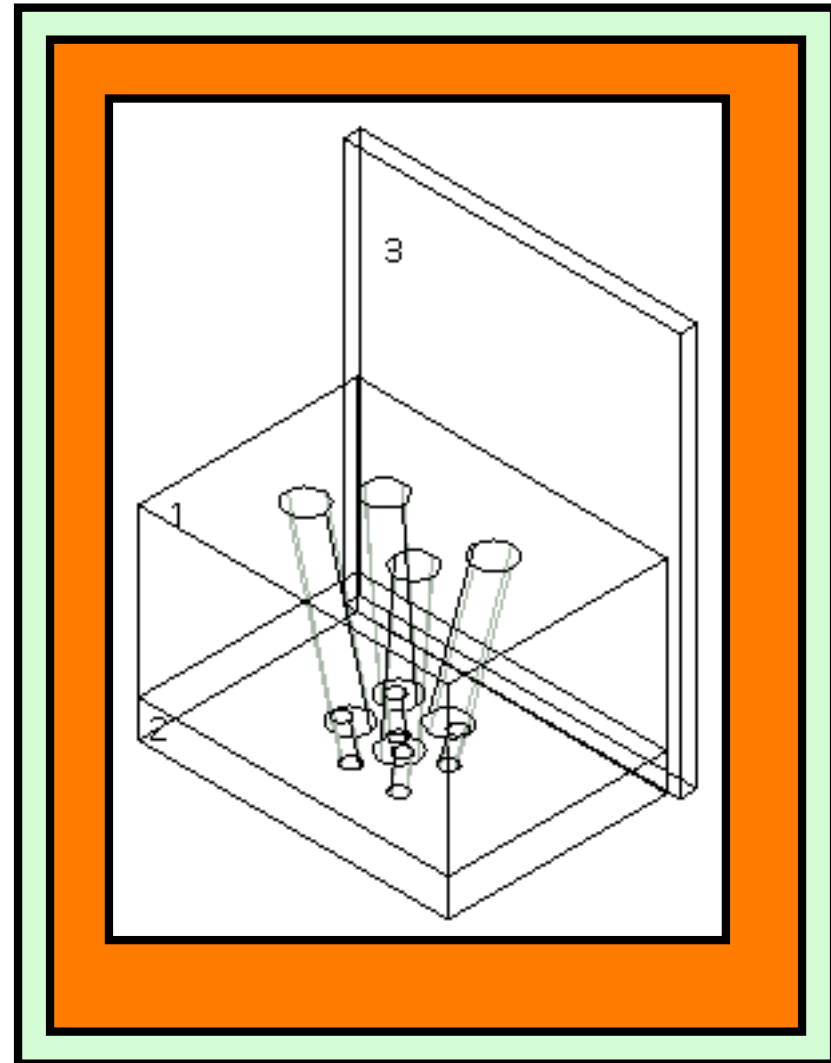


- ✓ 4 CZT detectors
- ✓ Energy Range: 10 – 670 keV
- ✓ Resolution: 4% FWHM at 122keV (STP)
- ✓ Built in RC feedback preamplifier

- ✓ 1 NaI detector
- ✓ Energy Range: 1 – 3000 keV
- ✓ Resolution: 7% at 1.3 MeV
- ✓ RC feedback preamplifier attached

Collimator

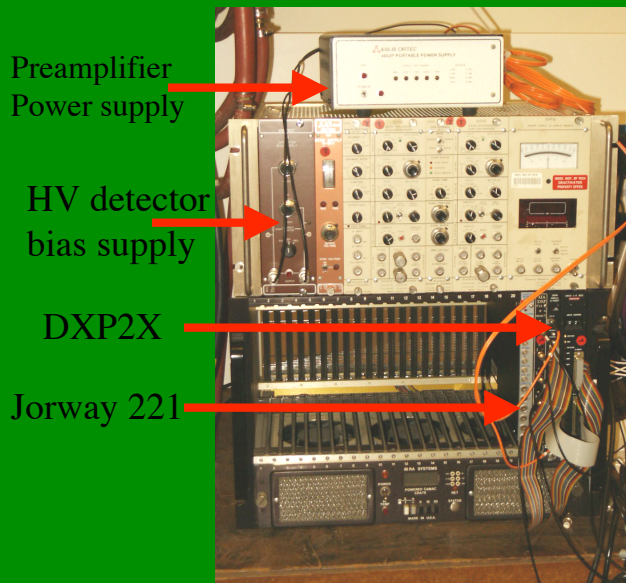
- CZT collimator is designed for an adjustable view angle from 4 degrees to 45°.
- NaI collimator is a 4 degree view angle pinhole.
- Only 4 detectors may be used at a time. Detectors in use will be determined by switching cables.



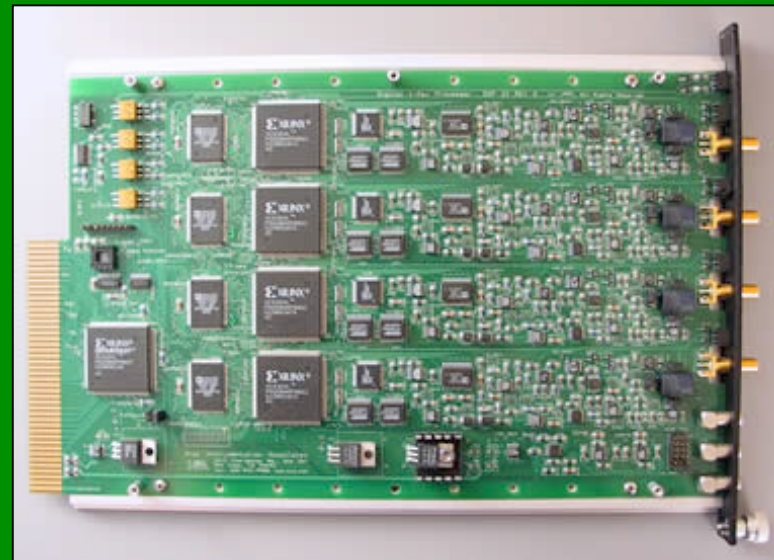
Data Acquisition

- We will use an X-ray Instrumentation Associates DXP-2X Camac module.
- The DXP-2X is a multi-element digital x-ray processor which includes a shaping amplifier and multi channel analyzer.
- Count rates up to 500 kcps.
- 4 independent channels
- Programmable peaking times: 125ns-80 μ s
- 40 dB gain adjustment
- External gate and sync signals to control timing. We will use a Jorway 221 for timing signals.

DAQ hardware in the lab for testing

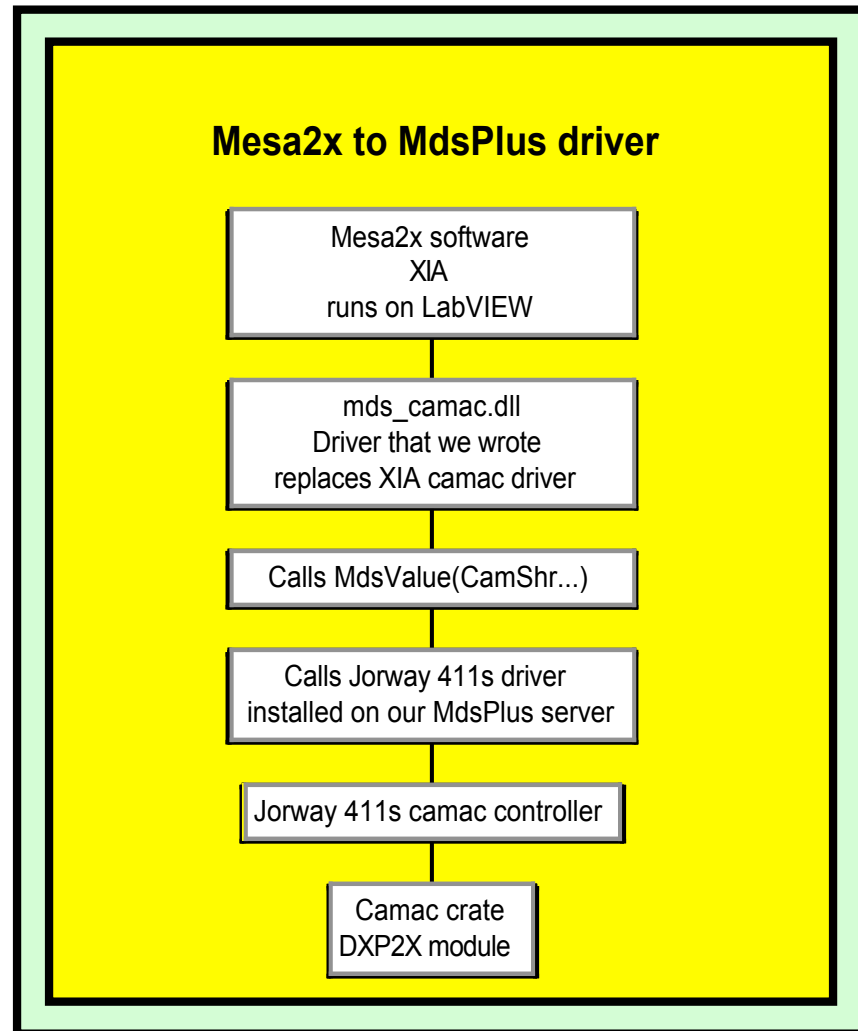


Photograph of DXP2X Camac Module

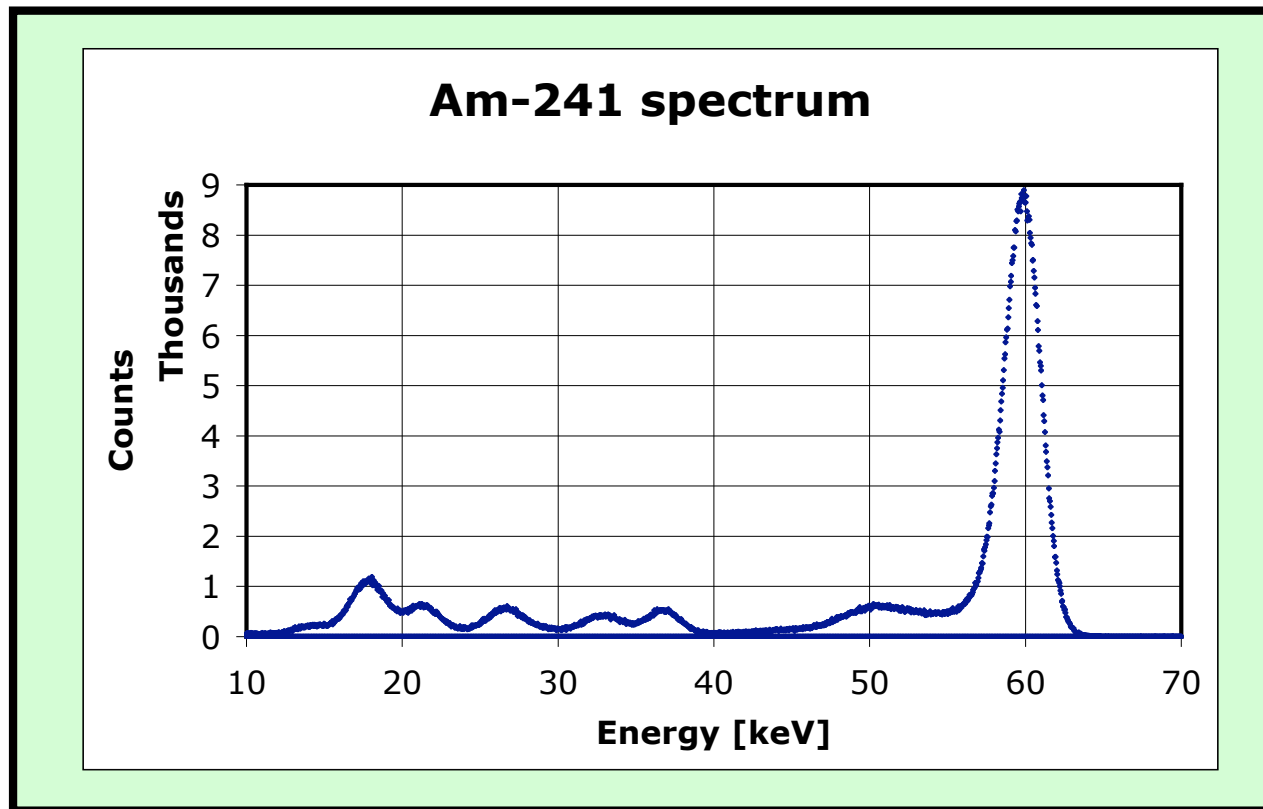


MCA software

A driver has been developed to use the XIA software written for use with DXP2X and MdsPlus data acquisition system. Using this driver, the XIA software executes an MdsValue command, the MdsPlus executes a camac command using the



Calibration Spectrum

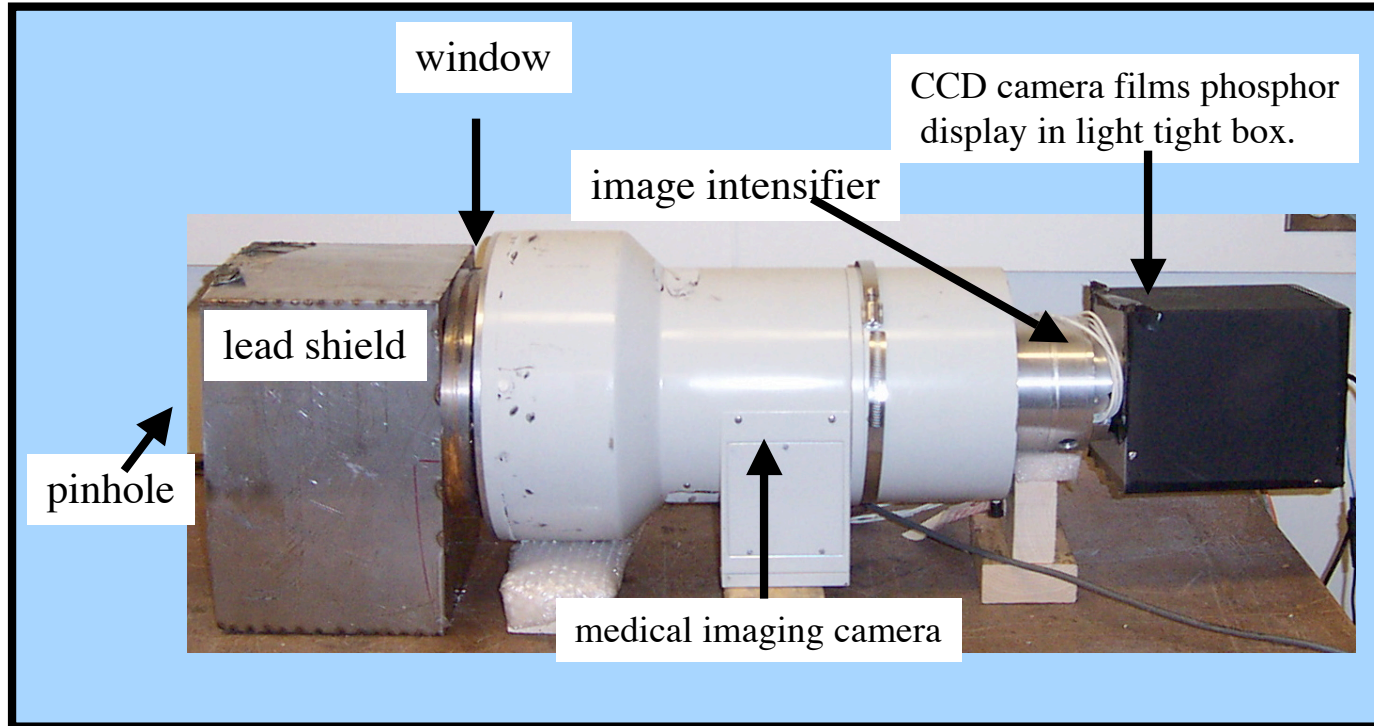


Uncollimated view of Am-241 source with CZT detector.

X-Ray Camera Summary

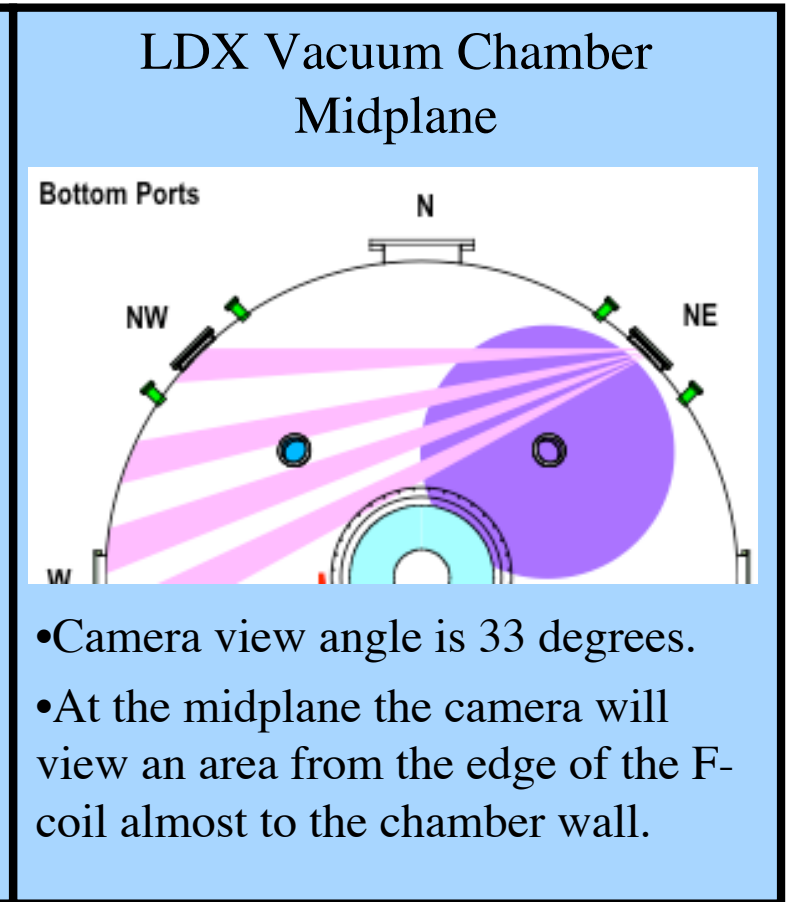
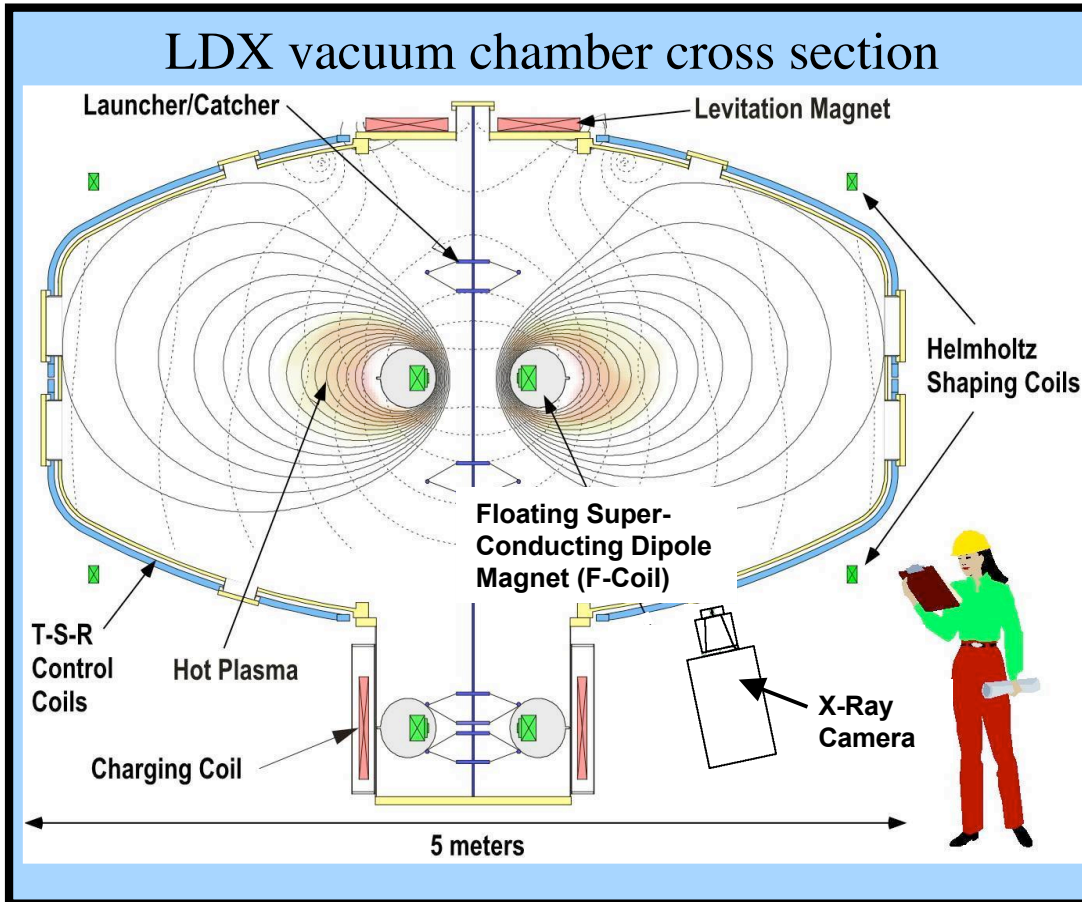
- The X-ray camera (on loan from PPPL) will yield a 2-D image of bremsstrahlung intensity.
- Time resolution is 16 ns.
- A Lead pinhole designed for spatial resolution of 10 μ m at the midplane will be used.
- Potential experiments include a BB experiment where a pellet is dropped through the plasma and the x-ray emission is imaged.
- Also, convective cell formation may be visible as described in the abstract.

X-Ray Camera



- Tangential viewing pinhole camera.
- Device is a standard medical imaging camera borrowed from PBX-M.
- CCD camera films phosphor display of image intensifier. Data from CCD camera is digitized using video capture card.
- Spatial resolution depends on pinhole size, desired value is 10cm.
- Temporal resolution is set by CCD camera which has standard video output of 30 frames per second.

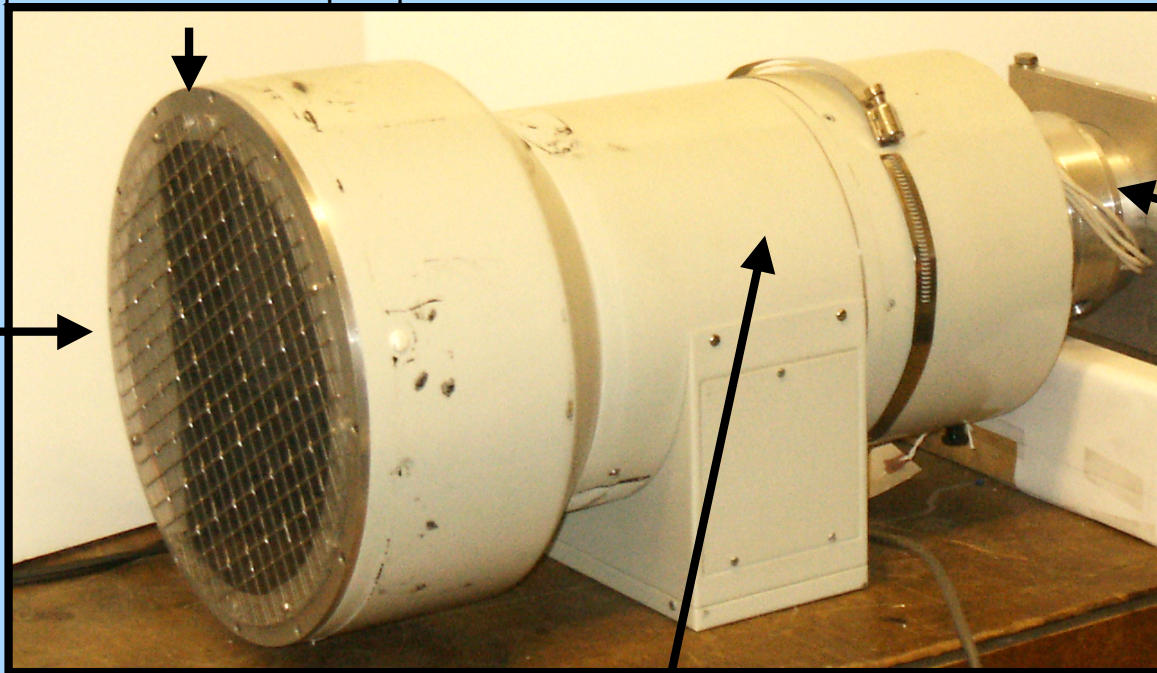
X-Ray Camera Placement



X-ray intensifier function

6" diameter CsI crystal. Inside is coated with a thin layer of phosphor. X-rays are converted to visible light in the CsI crystal. Visible is converted to photoelectrons in the phosphor layer

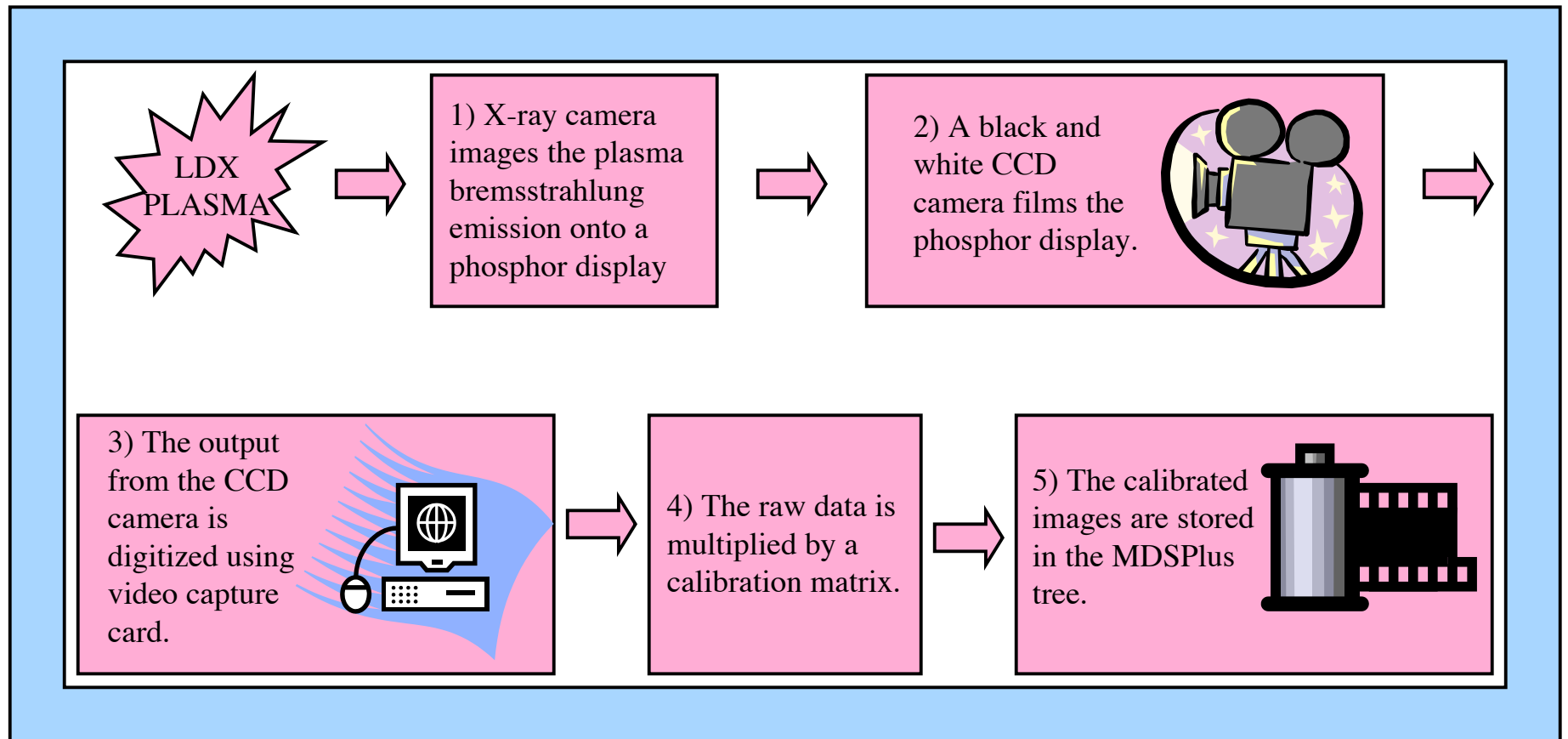
Wire mesh for locating image positions



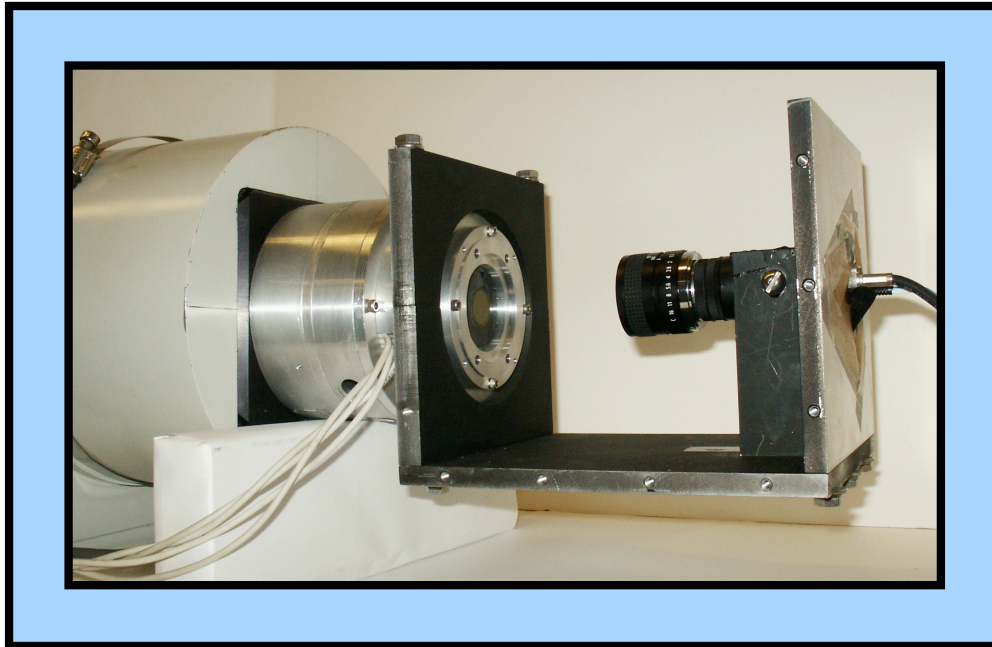
Photoelectrons are converted back to visible light on a second layer of phosphor.

Electrodes focus photoelectrons

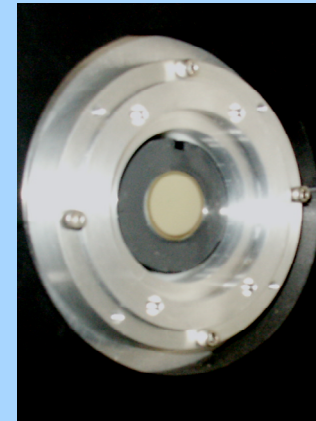
X-Ray Camera Data Acquisition Cartoon



CCD camera setup



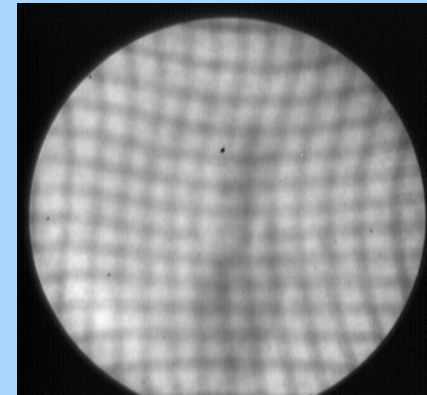
Blowup of phosphor display



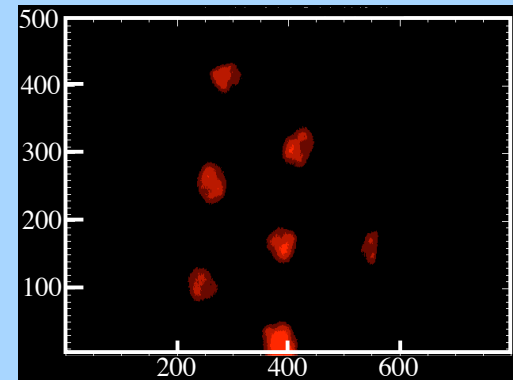
A B&W CCD camera films the phosphor display. A Matrox Meteor video capture card digitized the CCD camera output. Data is acquired using the MdsPlus tree. Currently up to 3s of continuous video can be recorded

X-Ray Camera Calibration

- Crystal absorption is nonuniform so camera must be calibrated.
- An Am-241 radioactive source will be used for the calibration.
- Calibration line of the source is 59.5 keV.
- The source is placed in a fixed position in front of the camera and the signal is integrated for several minutes. Then the procedure is repeated with the source at a different position.
- The intensity measured by the camera is compared to the expected intensity from a disc source.
- The energy spectrum of the source is known from the calibration of NaI and CZT detectors for the PHA.
- Calibration must be done without the pinhole in order to get a map of the entire crystal.



Uncalibrated view of Am241 source. A grid has been placed in front of the x-ray camera.



Superimposed data of Am-241 source intensity with pinhole