X-Ray Measurements of the Levitated Dipole Experiment

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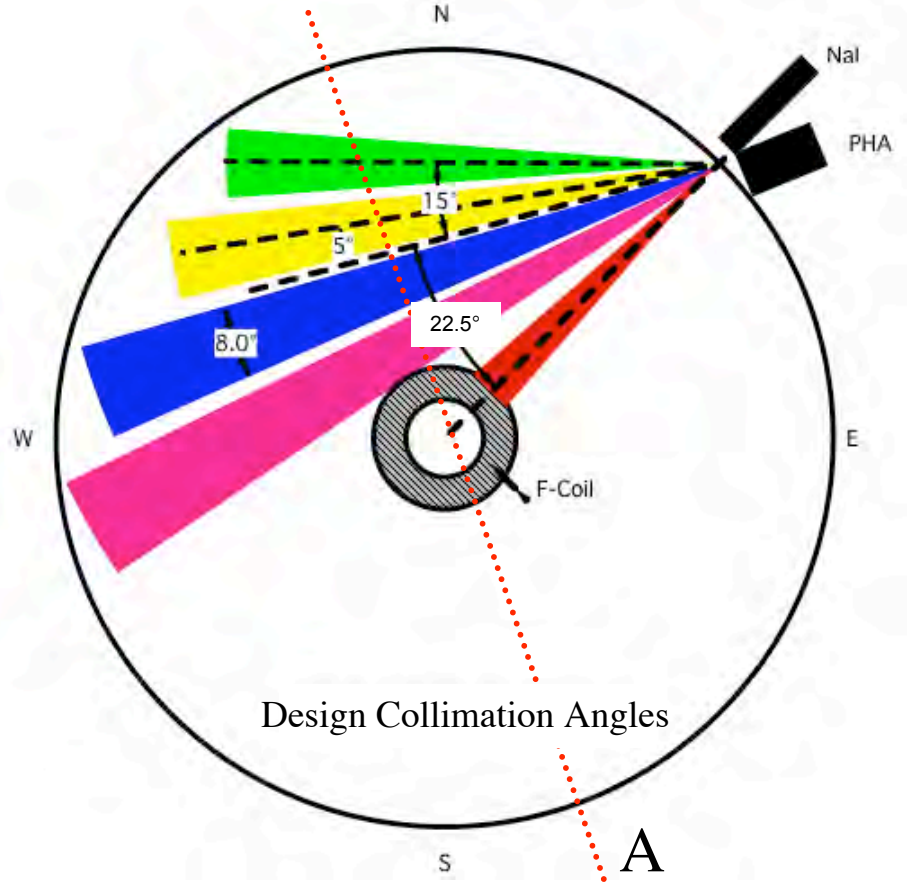
Abstract

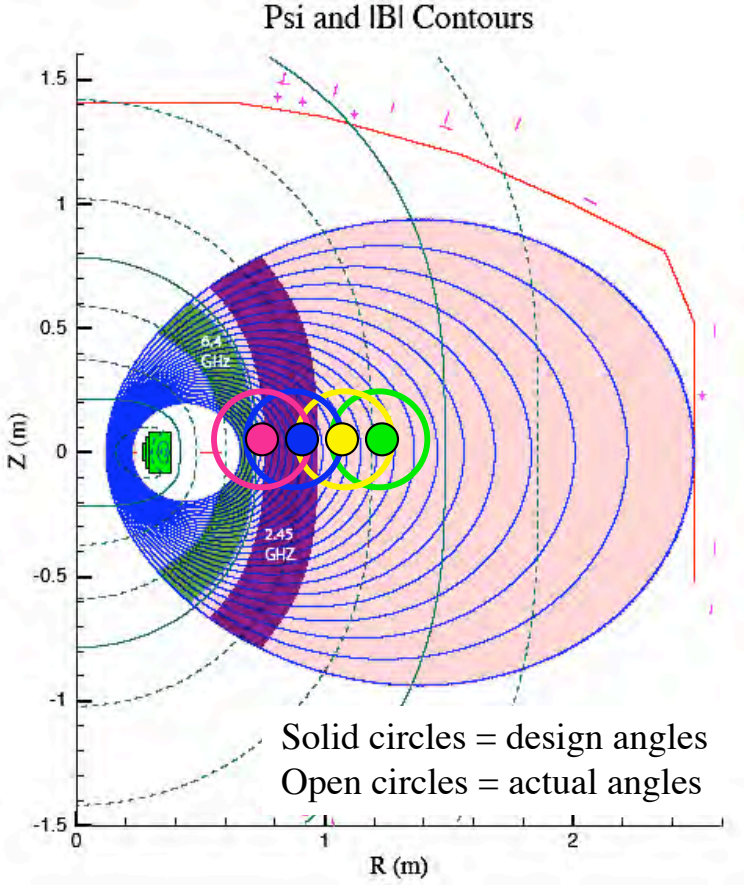
Initial plasma experiments in the Levitated Dipole Experiment focus on producing hot electron, high beta plasmas using a supported dipole configuration. Plasmas are created using multi-frequency ECRH; it is therefore expected that most of the plasma energy will be stored in the fast electrons, $T_e \approx 100$ keV. As a consequence, x-ray flux from bremsstrahlung emission is expected to be easily detectable. The energy spectrum of the x-ray emission below 740 keV is measured by a four channel pulse height analyzer using cadmium zinc telluride detectors. In addition, a single sodium iodide detector which views energies up to 3 MeV will measure the intensity of x-ray emission from the plasma. The electron temperature may be inferred from the x-ray energy. These x-ray spectral measurements can then be combined with the reconstructed plasma equilibria and line-integrated density measurements to give an estimate of the hot electron pressure profile. X-ray measurements will be essential in diagnosing the effectiveness of various ECRH configurations. Initial measurements will be discussed.

*This work supported by USDOE OFES.

X-Ray Intensity Detector and X-Ray Pulse Height Analyzer Views



Top View

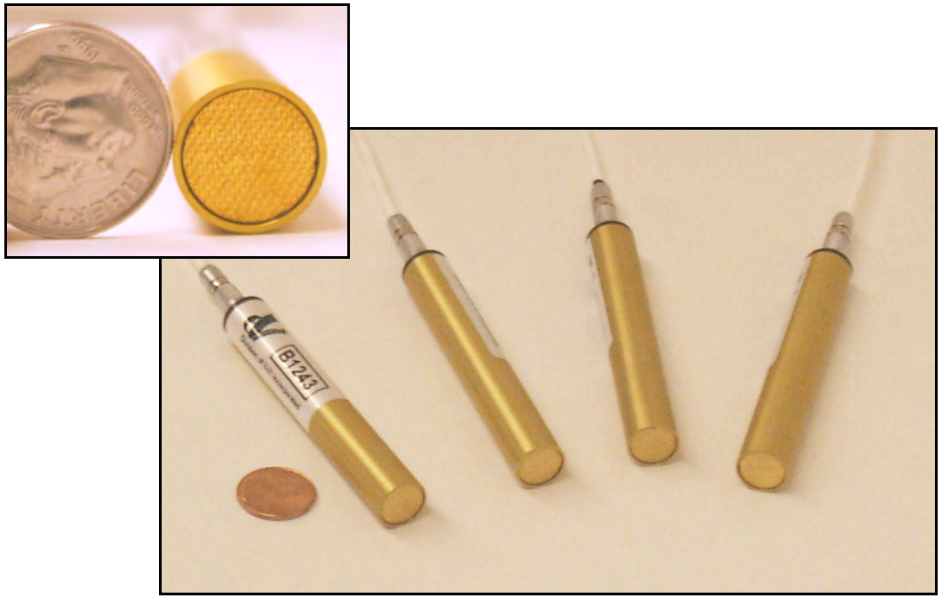


Section View A

Shot 40917-19 t=3.22 s

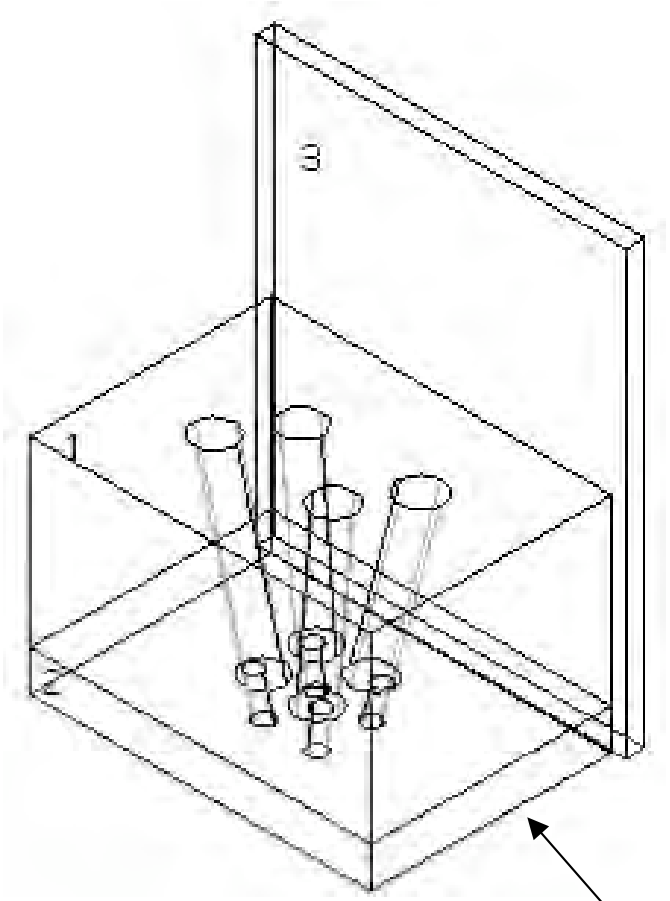
The PHA design views have identical collimation angles, and are symmetric about the 22.5° axis. For August and September runs, the pinhole was not used, so viewing angles(typically 26°) are larger than design angles (8°) and views for adjacent channels overlap.

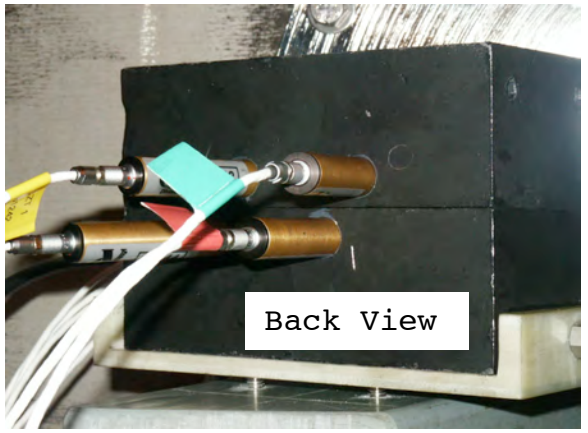
X-Ray Detection

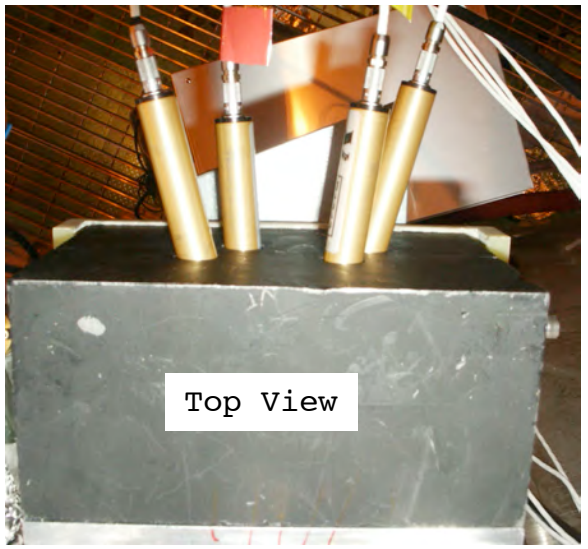


* 4 Cadmium Zinc Telluride (CZT) detectors from eV products with built in preamplifier units.
* Energy range: 10 keV - 670 keV.
* Energy resolution: 4% FWHM at 122 keV.
* Nominal sensitivity: 0.11 mV/keV.
* Rise time at the source: 35 ns.
* RC decay time: 750 μs.

PHA Collimator





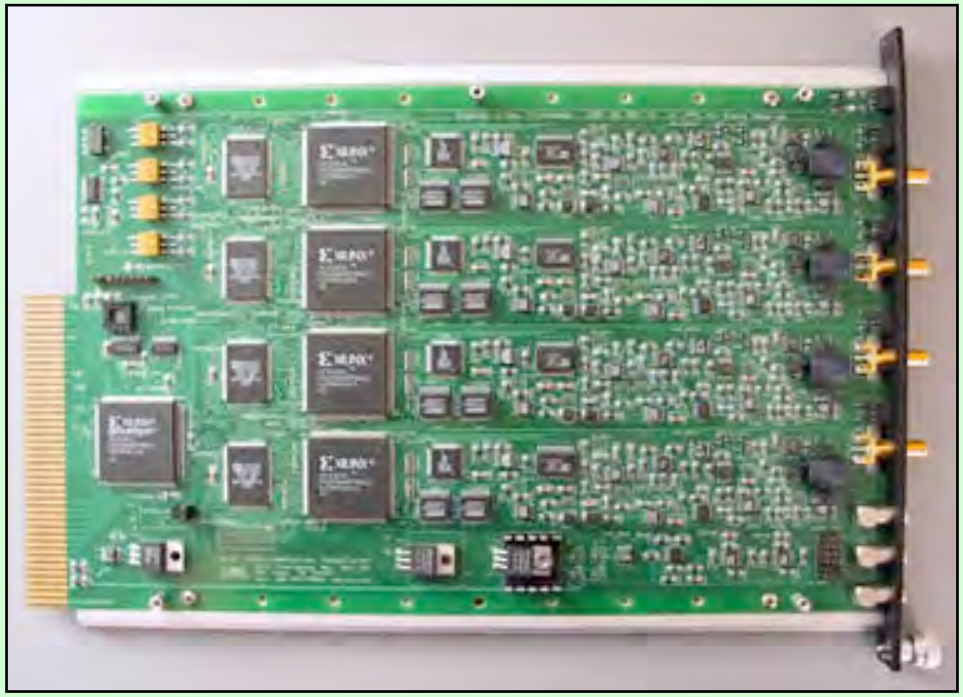


Viewing angles can be adjusted by sliding the detectors further into the lead tubes.

Digital X-Ray Processor

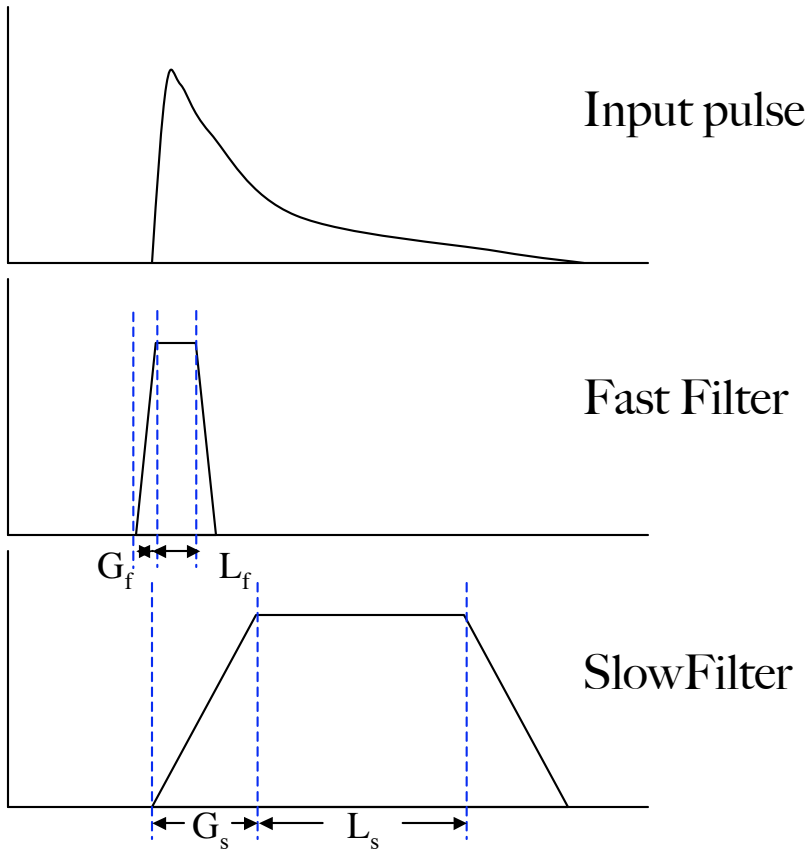
* X-ray Instrumentation Associates DXP-4c2x CAMAC module.
* The DXP is a multi-element digital x-ray processor which includes a shaping amplifier and multi channel analyzer.
* 4 independent channels
* Count rates up to 500 kcps.
* Programmable peaking times: 125ns-80ms
* 40 dB gain adjustment
* External gate and sync inputs allow for timing control.

Photograph of the DXP-2X

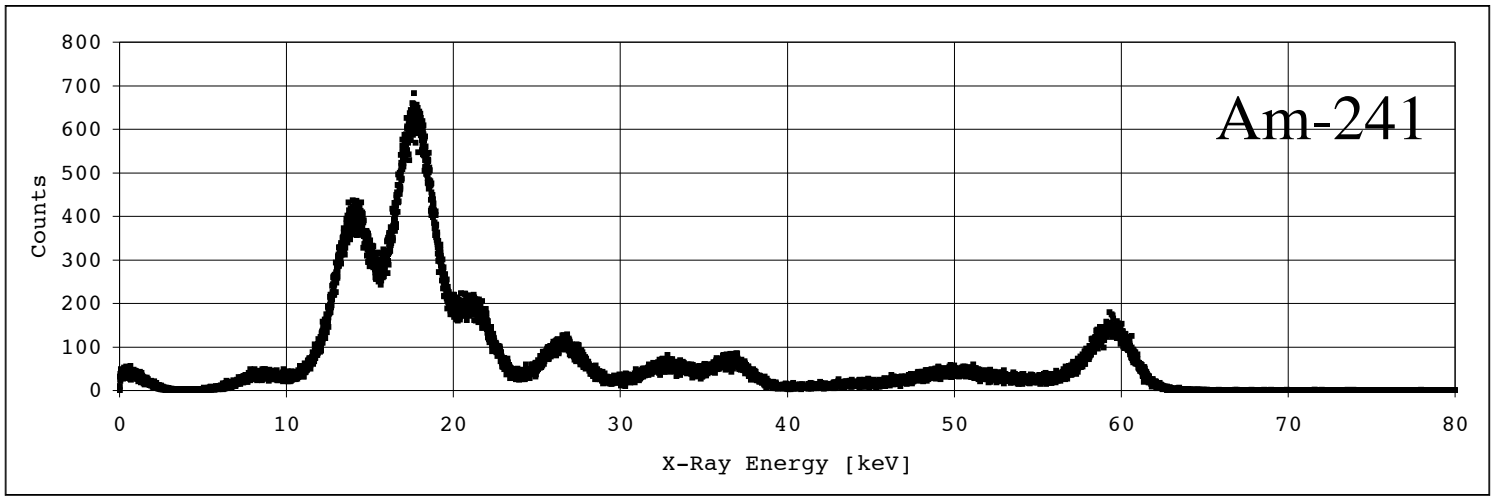


Digital Pulse Filtering

* Digital pulse filtering is similar to analog pulse shaping.
* DXP uses two trapezoidal filters (similar to shaping amplifiers).
  - Slow filter improves energy resolution and reduces pulse pile-up.
  - Fast filter determines pulse arrival time and pulse height.

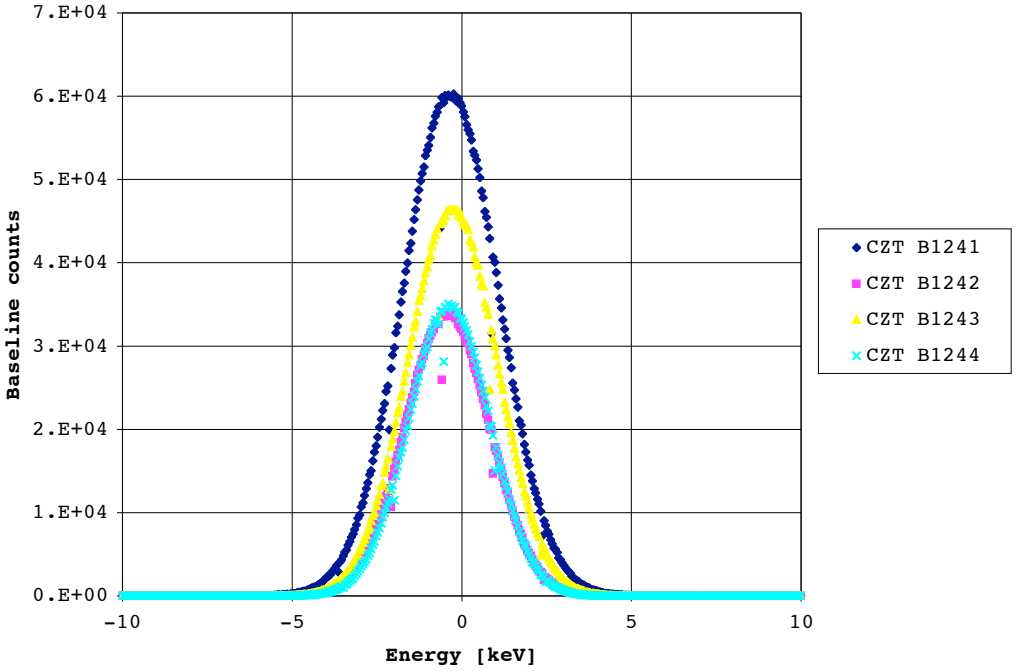


Calibration Data



* Detectors are calibrated using an iterated Gaussian fit to the 59.5 keV of an Am-241 source.
* Calibration routine is built in to the software that accompanies the DXP.
* Zero is determined from baseline measurement.
* Representative spectrum measured with the CZT Spear detectors is shown above.

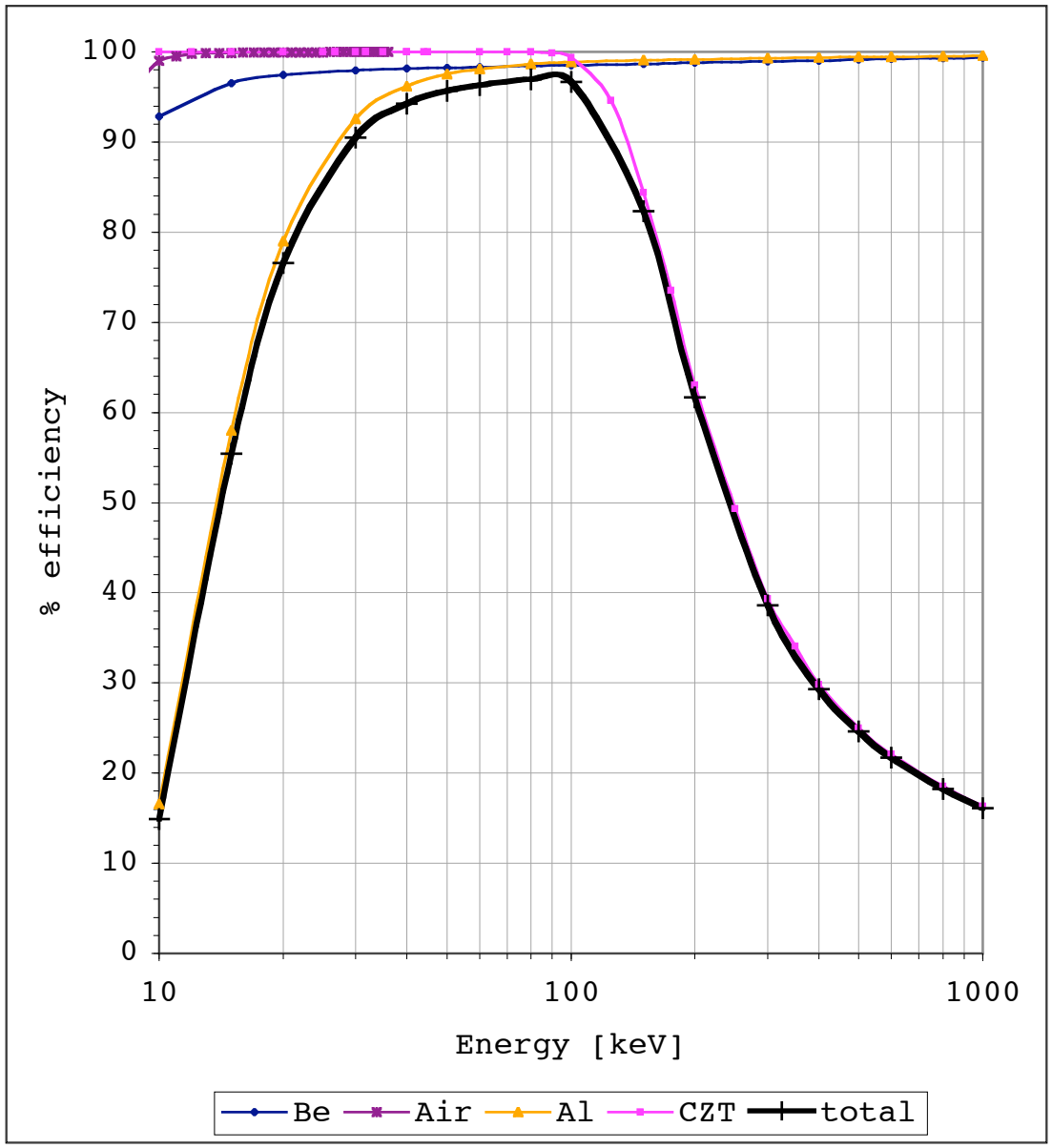
Accuracy and Error



Serial #	mean [keV]	variance [keV]
B1241	0.56	2.05
B1242	0.69	1.75
B1243	0.53	1.85
B1244	0.6	1.75

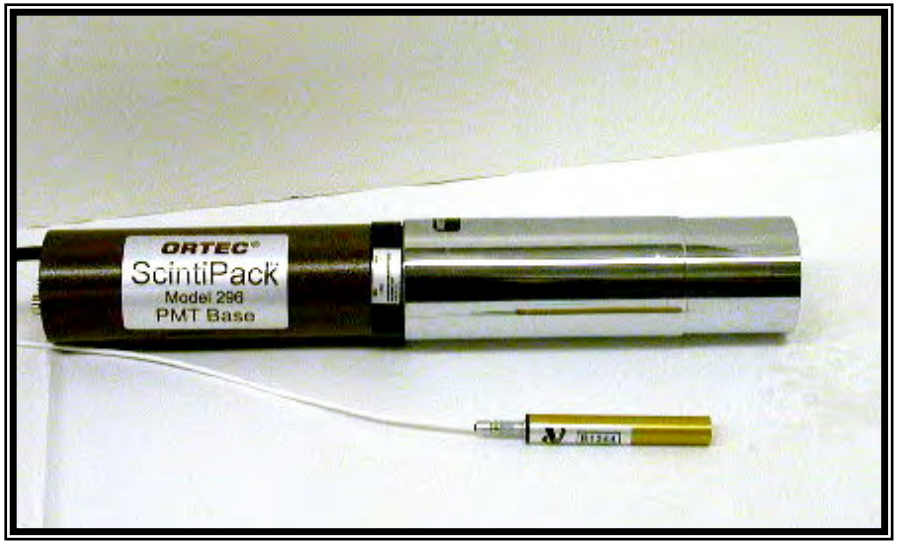
* Baseline measurement: Voltage is sampled when there are no x-ray events to process.
* Mean position of the baseline provides a zero location.
* The width of the spectrum is a measure of the energy resolution of the detector.
* Measurements taken using 8192 bins at 10 eV per bin.

Data Correction

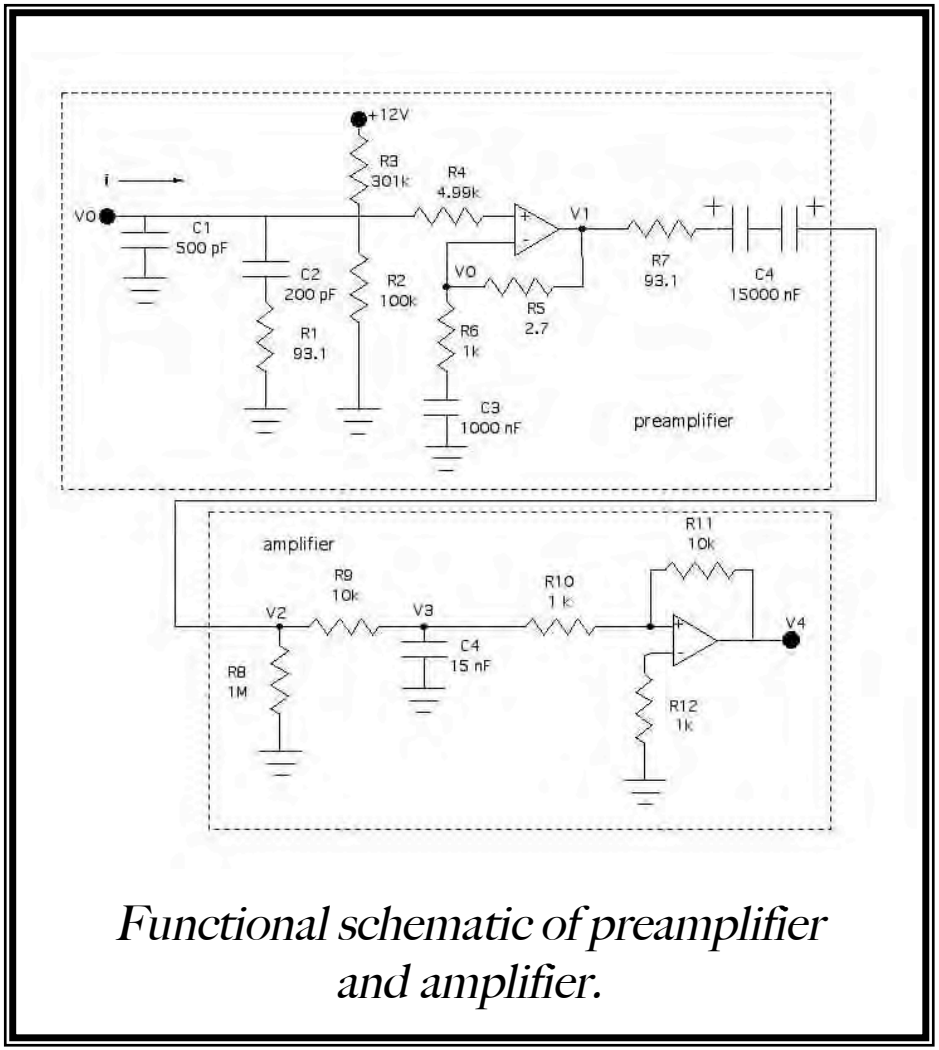


* Raw data must be corrected for losses in Be vacuum window, air, and aluminum detector window as well as for the efficiency of the CZT crystal.
* We assumed each loss was independent and calculated the transmission probability and that all x-rays were incident perpendicular to $\%eff = 100 * exp(-w\mu)$ inverted it to get efficiency.

X-Ray Intensity Time Resolved Measurement



The output of a single sodium-iodide PMT tube measures the total x-ray intensity from the plasma.
Energy range: 10 keV - 2 MeV



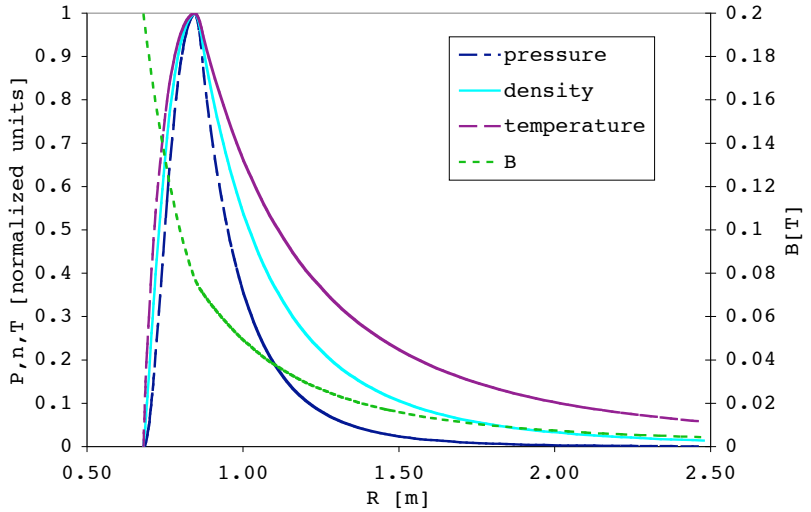
Functional schematic of preamplifier and amplifier.

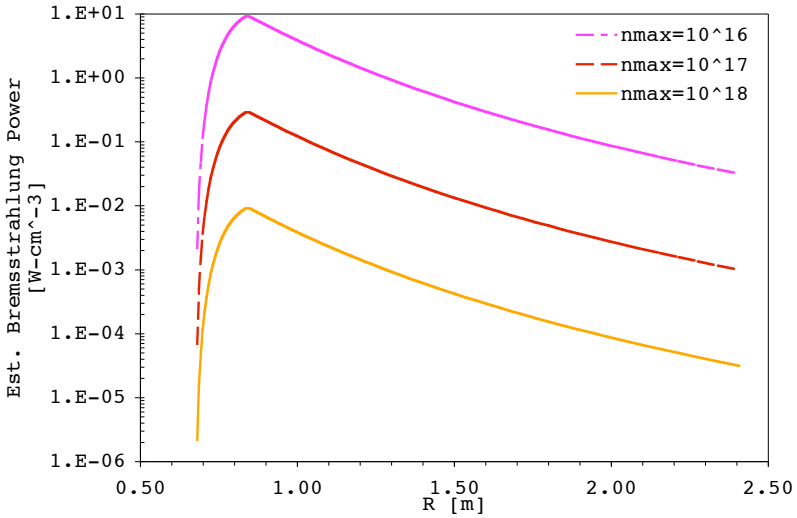
Estimated Parameters and Bremsstrahlung Power

- Estimated pressure and magnetic field were determined from equilibrium simulation, assuming a peak beta of 0.562.
- Density and temperature were determined by assuming $\eta = 2/3$ where, $\eta = \frac{d\ln T}{d\ln n}$.
- Bremsstrahlung power is estimated from

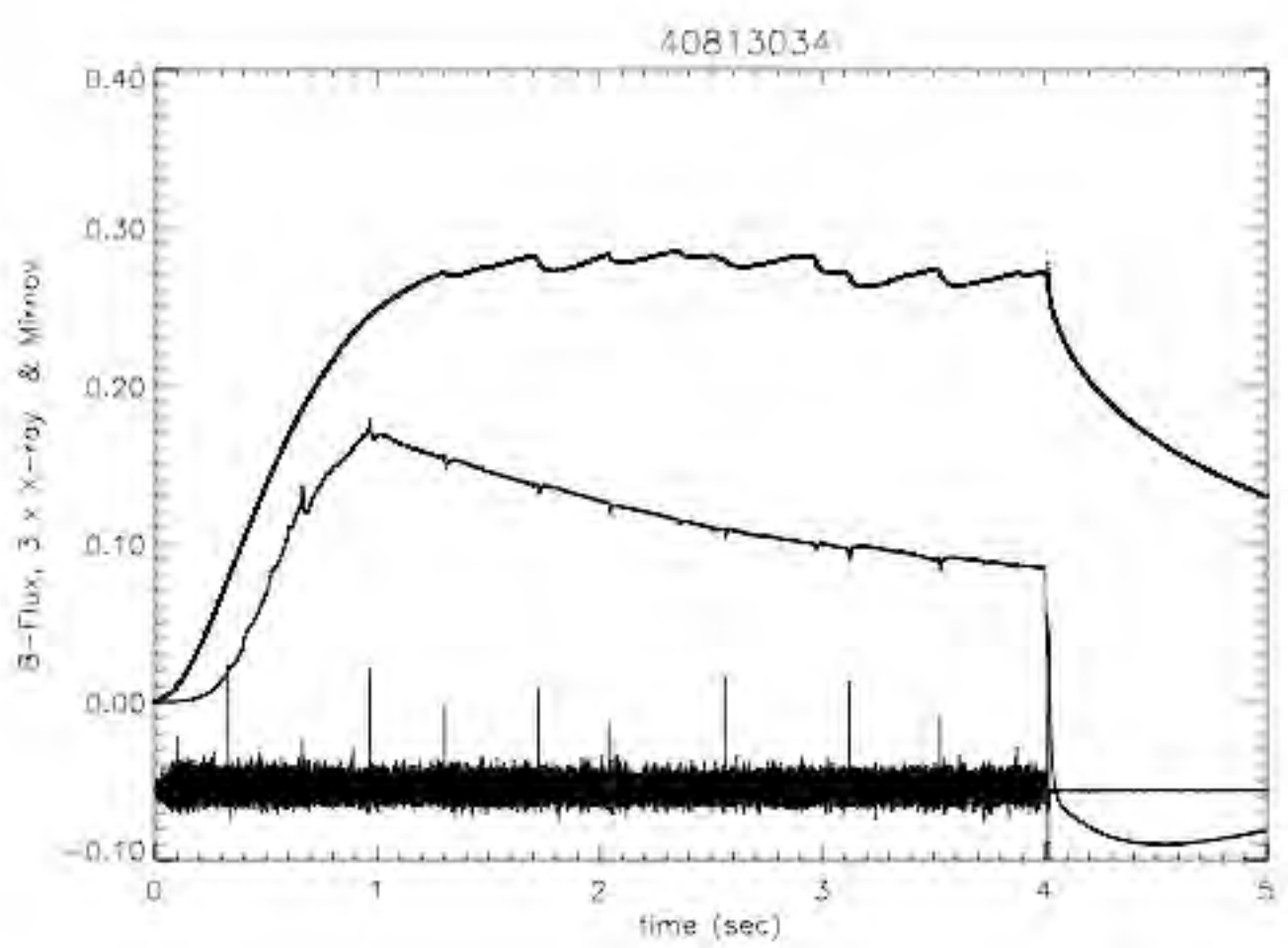
$$dP_b/dV = 1.6910^{-32} n_{eh} n_i \sqrt{T}$$

where we have assumed $Z_{eff} = 1$ and all of the pressure is carried by the hot electrons.

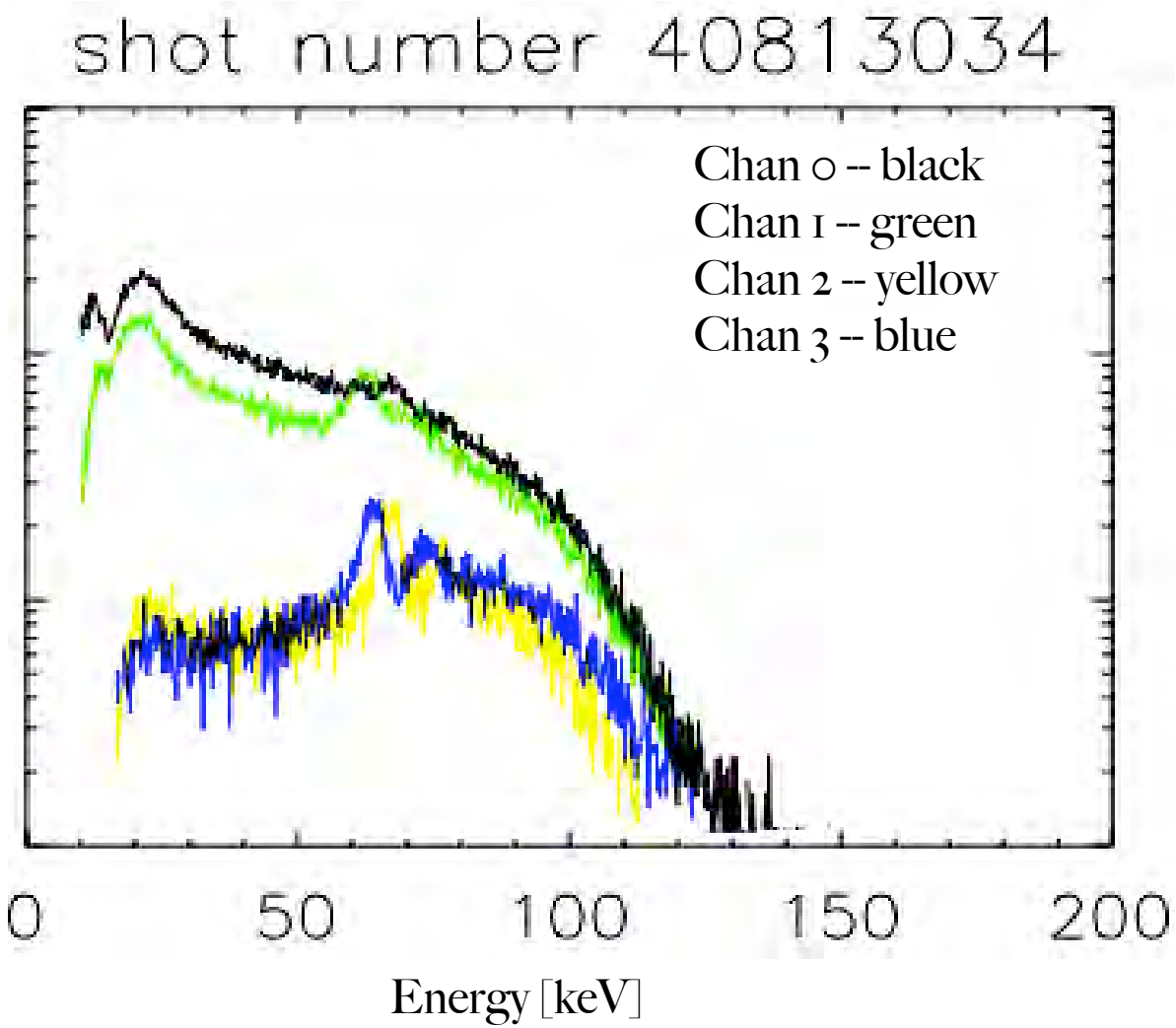




X-Ray Intensity Measurement

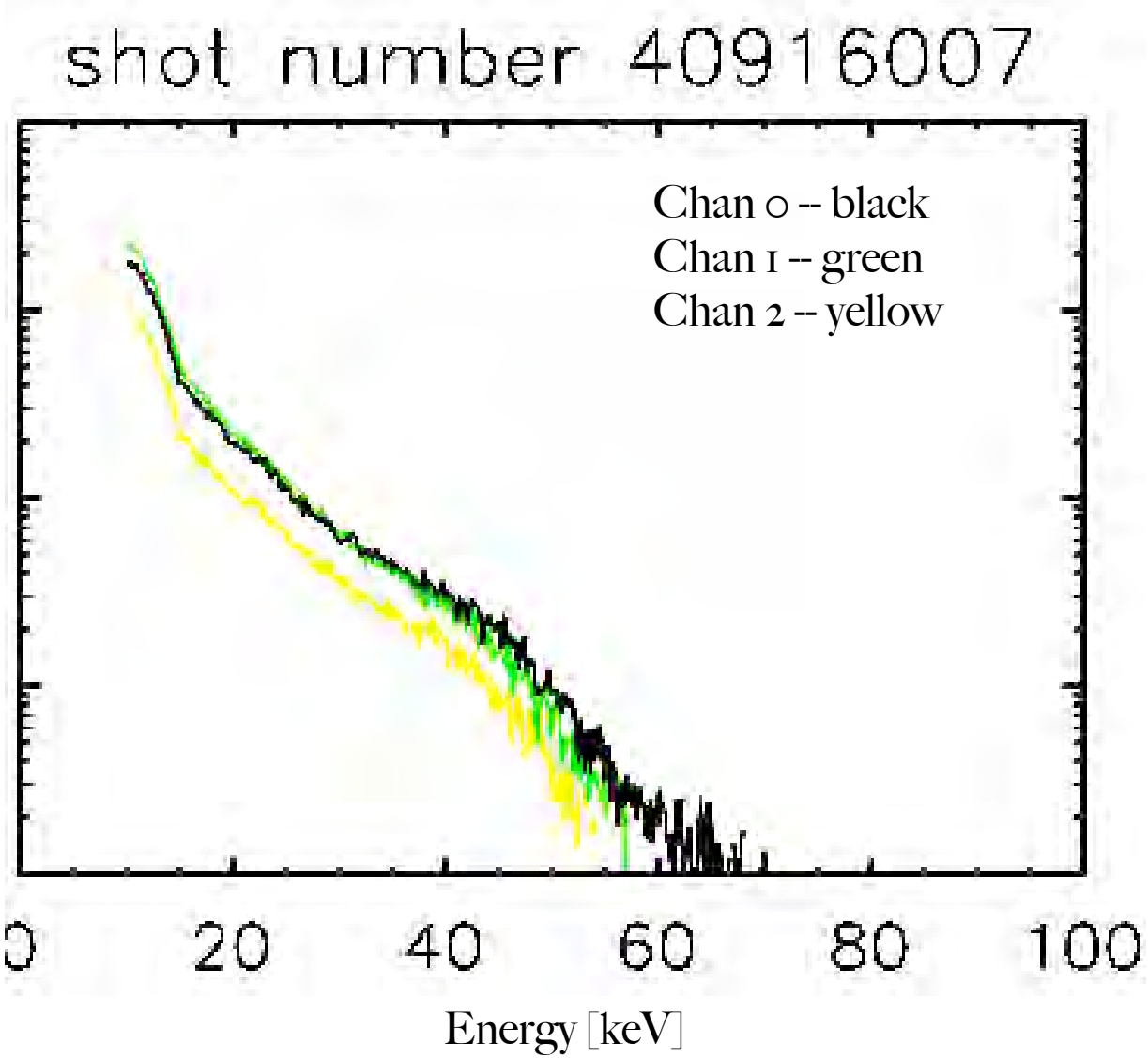


Typical Spectrum from First LDX run



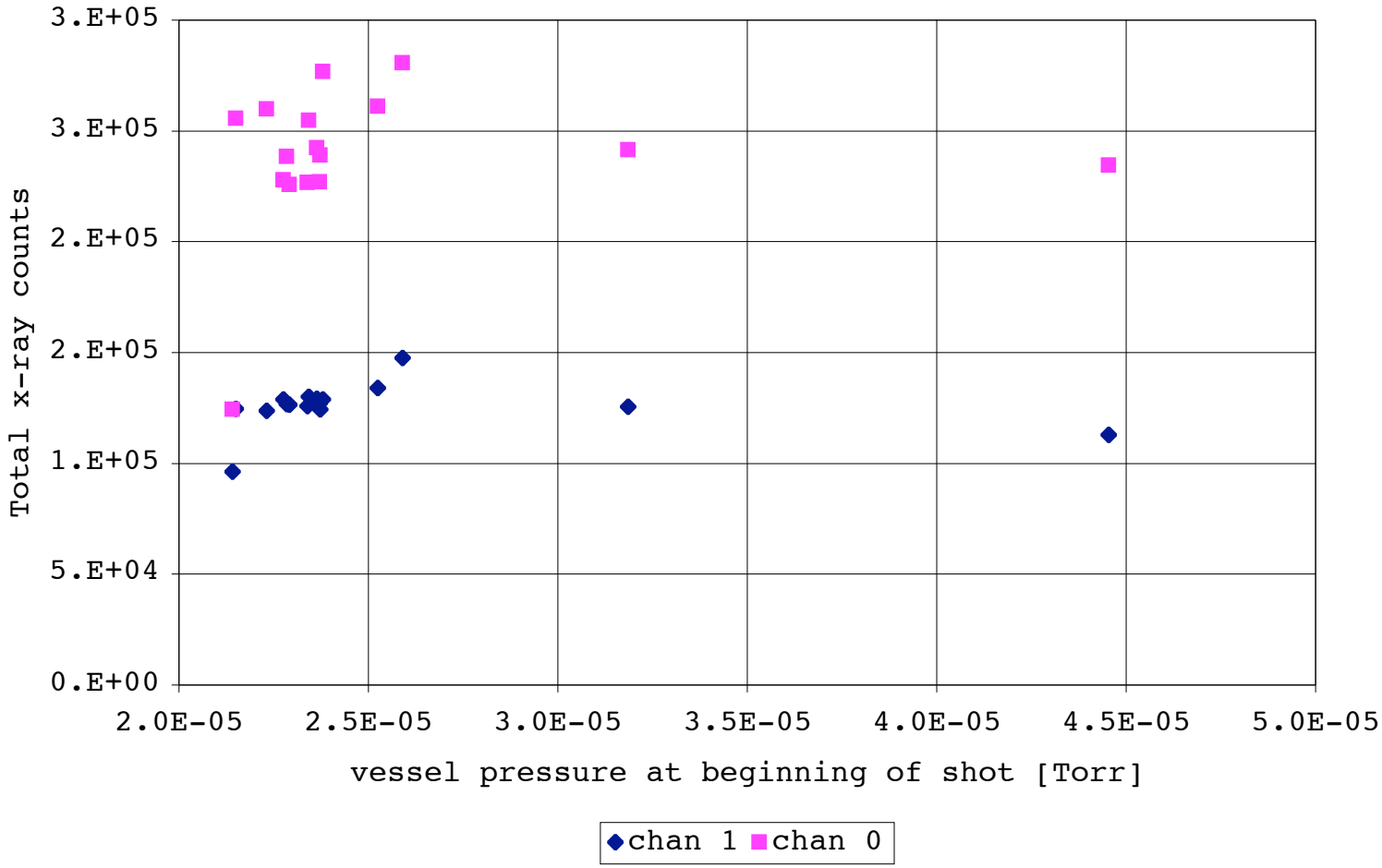
- 6.4 GHz Heating
  - 4 s of heating time
  - 3 kW power
- Spectrum is x-ray emission integrated over entire shot time.
- Peaks are present in the area of 65 keV and 75 keV in many shots during this campaign. – Compton Scattering off lead collimator?
- 250 A/turn in Floating Coil

Typical Spectrum from Second LDX Run

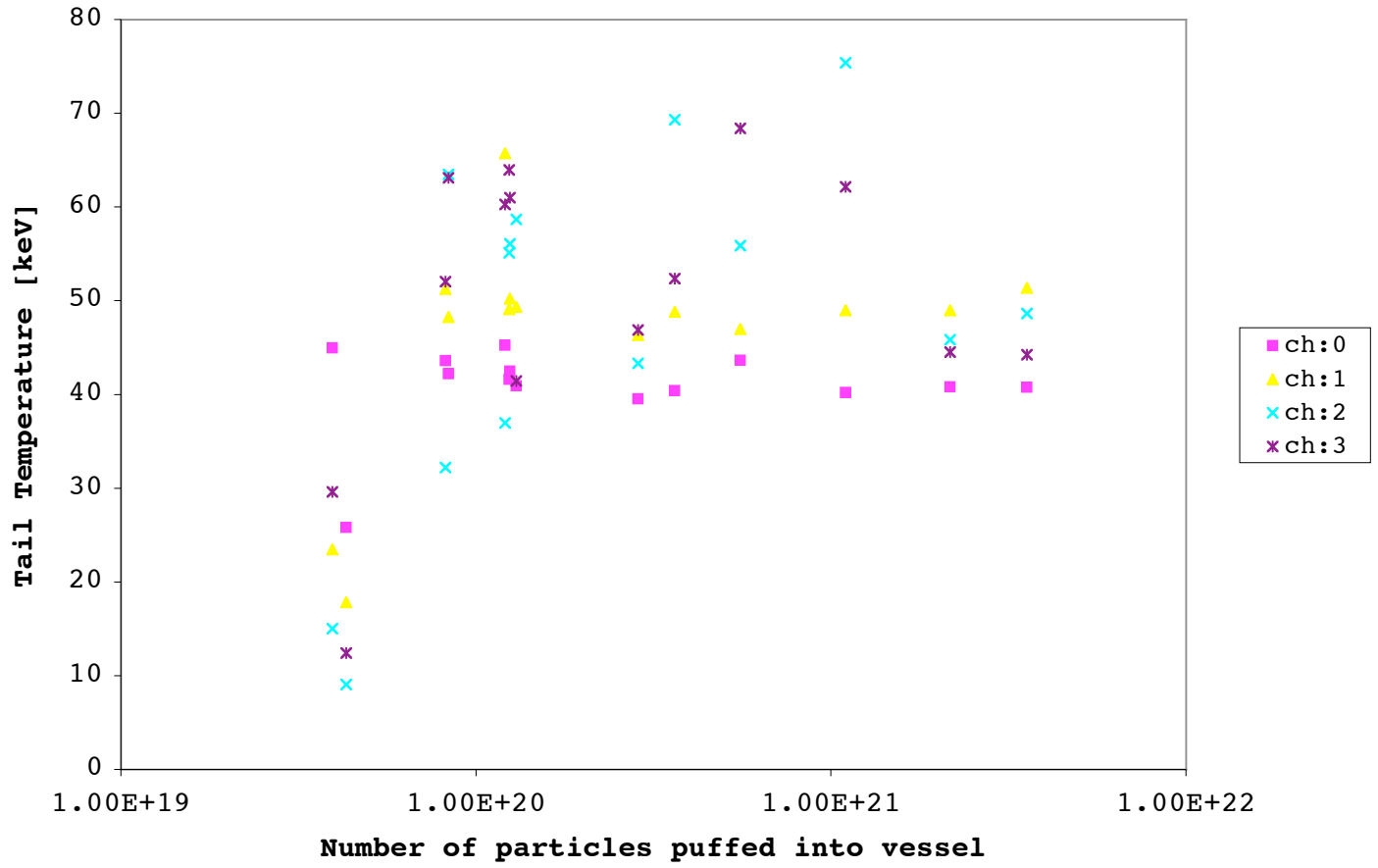


- 6.4 GHz Heating
  - 4 s of heating time
  - 3 kW power
- And 2.45 GHz Heating
  - 3 kW power
- 300 A/turn in Floating Coil.

Gas Scan

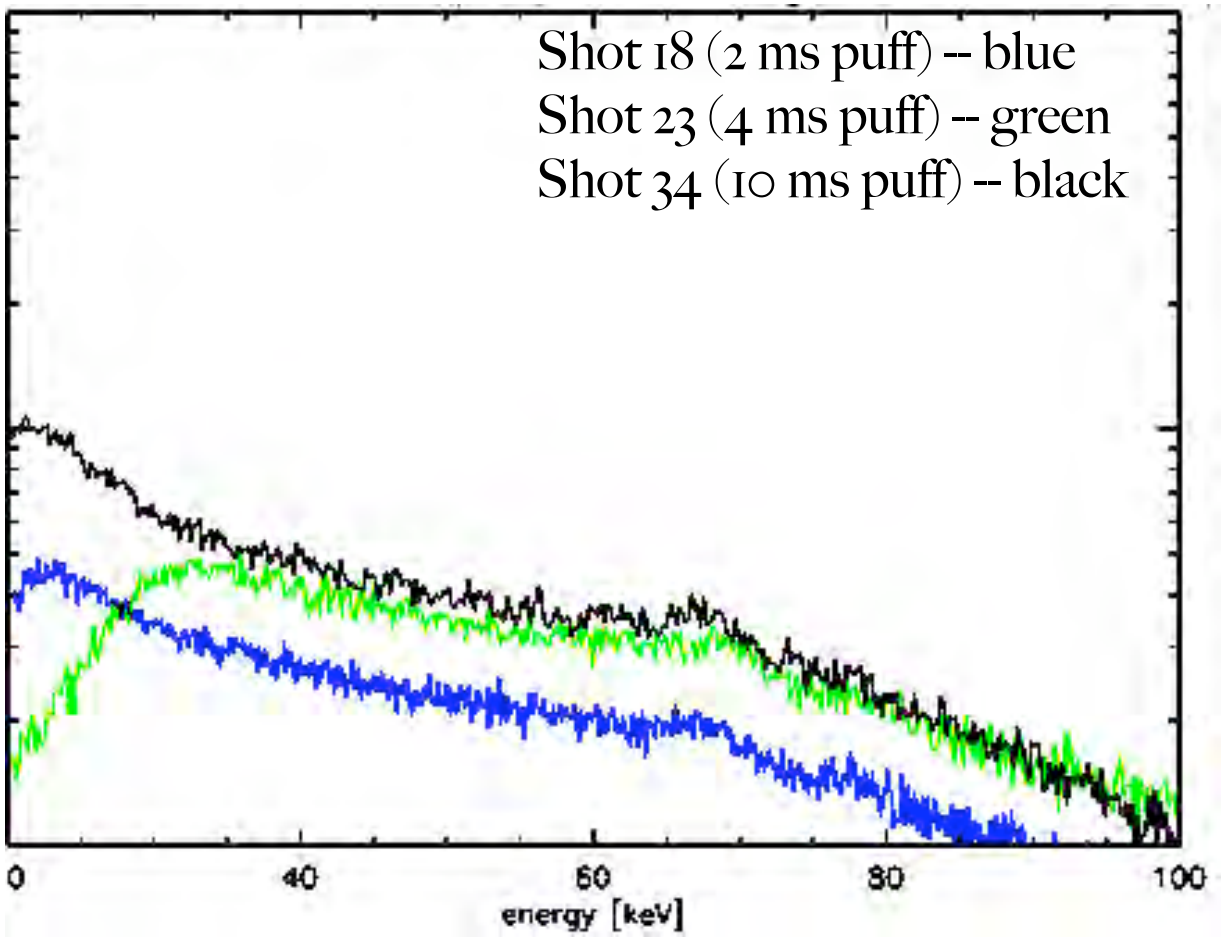

3.E+05
3.E+05
2.E+05
2.E+05
1.E+05
5.E+04
0.E+00
Total x-ray counts
2.0E-05
2.5E-05
3.0E-05
3.5E-05
4.0E-05
4.5E-05
5.0E-05
vessel pressure at beginning of shot [Torr]
chan 1
chan 0

Temperature Response to Vessel Pressure



Tail temperatures were determined by fitting an exponential to the tail of the measured bremsstrahlung spectra for shots with varied fill pressures/puff times. Each shot had a coil current of 250 A/turn and 4s of 6.45 GHz heating with 3kW of heating power.

X-Ray Spectra for Several Gas Pressures



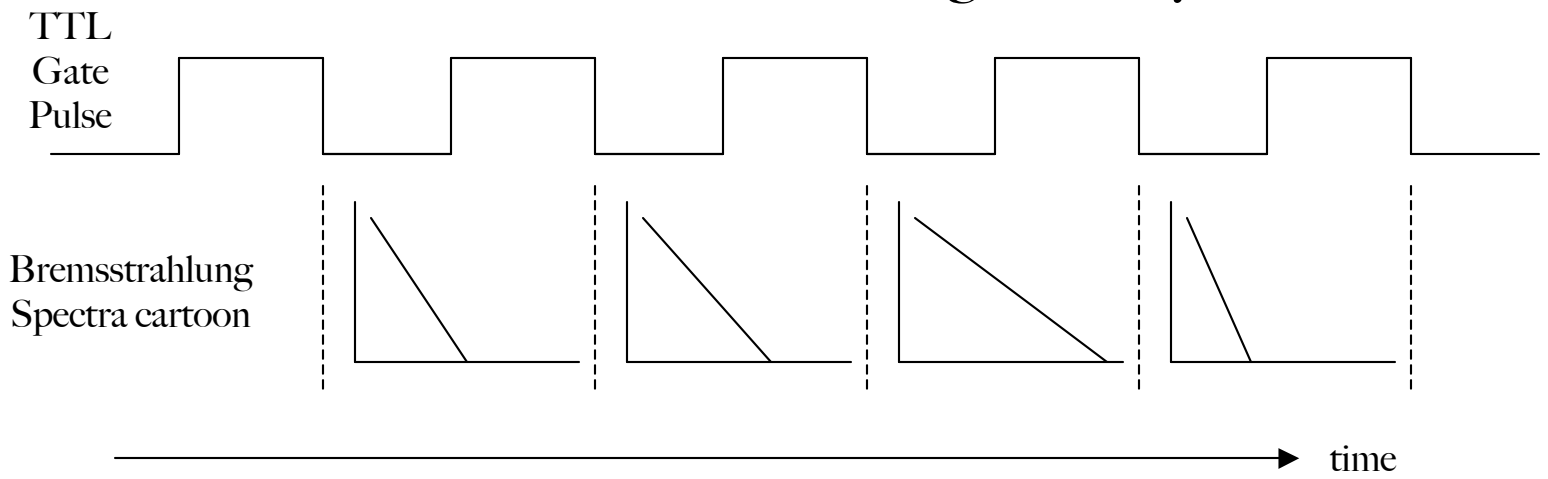
Comparison of three shots for 8/13/04 with different fill pressures. For each of the three shots, the gas was puffed in 1 second before the shot and the plasma was heated for 4 s by 3 kW of 6.45 heating.

Summary

* X-Rays were observed with energies ranging from 10 keV to 250 keV.
* Bursts of X-Rays were observed in a low density regime at the beginning of the shot.
* Big x-ray pulses in short period into afterglow indicate an instability during supported operation.
  - Hot electron interchange instability is followed by x-rays emitted when electrons strike the metal supports.
  - Or microinstability causes losses.
  - Largest emissions come during this time and may dominate the integrated spectrum.

Future Work

Time Resolved Pulse Height Analysis



* Programmable spectra times.
* Continuous data collection. /Gate pulse trailing edge switches to collection of next spectrum only.
* Maximum 64 spectra with 8184 bins.
* Not implemented for August and September runs. Expected to be operational for December run.