A Simple Calculation on the Impact of Space Charge in RHIC μTPC

Here is a simple minded calculation to estimate the impact of positive ion space charge on the drift properties of the RHIC μTPC.

Assuming:

dE/dx for MIP in CH4:	$n = 80$ i.p./cm
Average track length:	$l = 40$ cm
Ion mobility in the gas:	$\mu = 2.26\ cm^2V^{-1}s^{-1}$ (from Nikolai)
Drift field:	$E_d = 1$ kV/cm
Maximum track rate:	$R = 2$ MHz
Ion feedback rate:	$f = 10\%$ @ 1kV/cm drift field. (linear with E_d)
TPC length:	$L = 40$ cm
Effective gas gain:	$G = 2x10^3$
TPC Volume:	$V = 3.7x10^5\ cm^3$

Then

Ion drift speed: $V_d = \mu * E_d = 2260$ cm/s

Ion drift time: $T_i = L/V_d = 40/2260 \sim 17$ ms

Total primary electron/ion rate:

$$R_T = R * l * n = 2x10^6 * 40 * 80 = 6.4x10^9\ s^{-1}$$

Total ion feedback rate:

$$R_i = R_T * G * f = 6.4x10^9 * 2x10^3 * 0.1 = 1.3x10^{12}\ s^{-1}$$

Total ion density in the TPC volume:

$$\rho = Ri * Ti / V = 1.3x10^{12} * 0.017 / 3.7x10^5 \sim 6x10^4\ e/cm^3 \sim 1x10^{-8}\ C/m^3$$

A 3D electrostatic model of the TPC (r_1=25cm, r_2=60cm, L=50cm) is constructed under Maxwell 3D. Assume a uniform space charge density of $10^{-8}\ C/m^3$,

The maximum radial field component is near the middle of the inner cylinder, about 1.7V/cm. Combined with the 1kV/cm nominal drift field, this would result in a change of drift angle for electrons of the order of 1/400th of a radian. For an electron that traverses the entire 40cm length near the inner cylinder, it would be pushed outward by about 0.5mm.

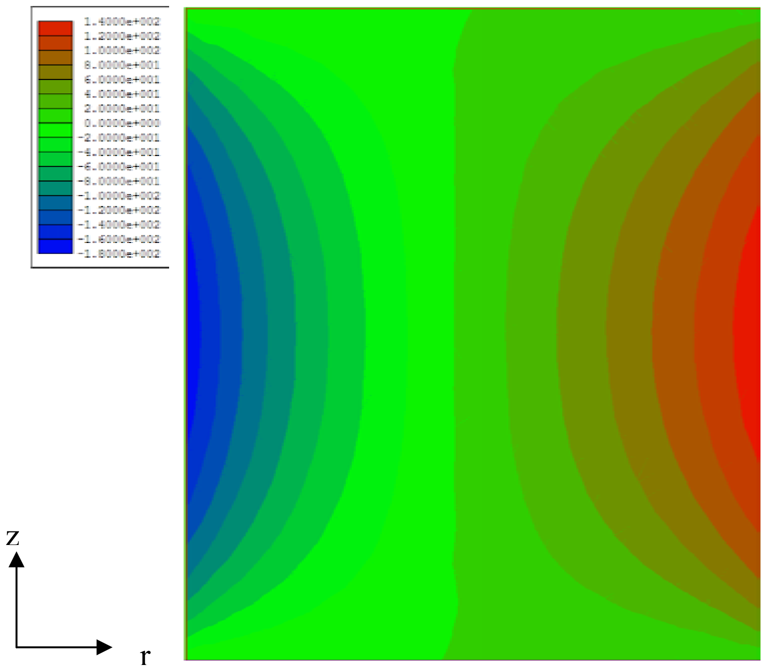


Fig. 1. Contour plot of the radial component of the distortion field in the TPC volume. The maximum radial value is about 1.7V/cm near the inner cylinder surface (on left). All TPC surfaces are considered as grounded conductors.

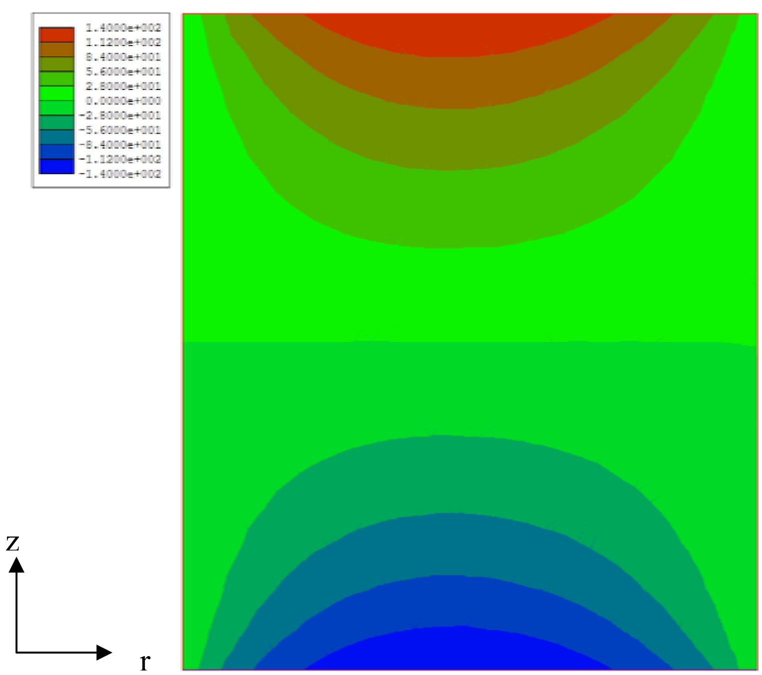
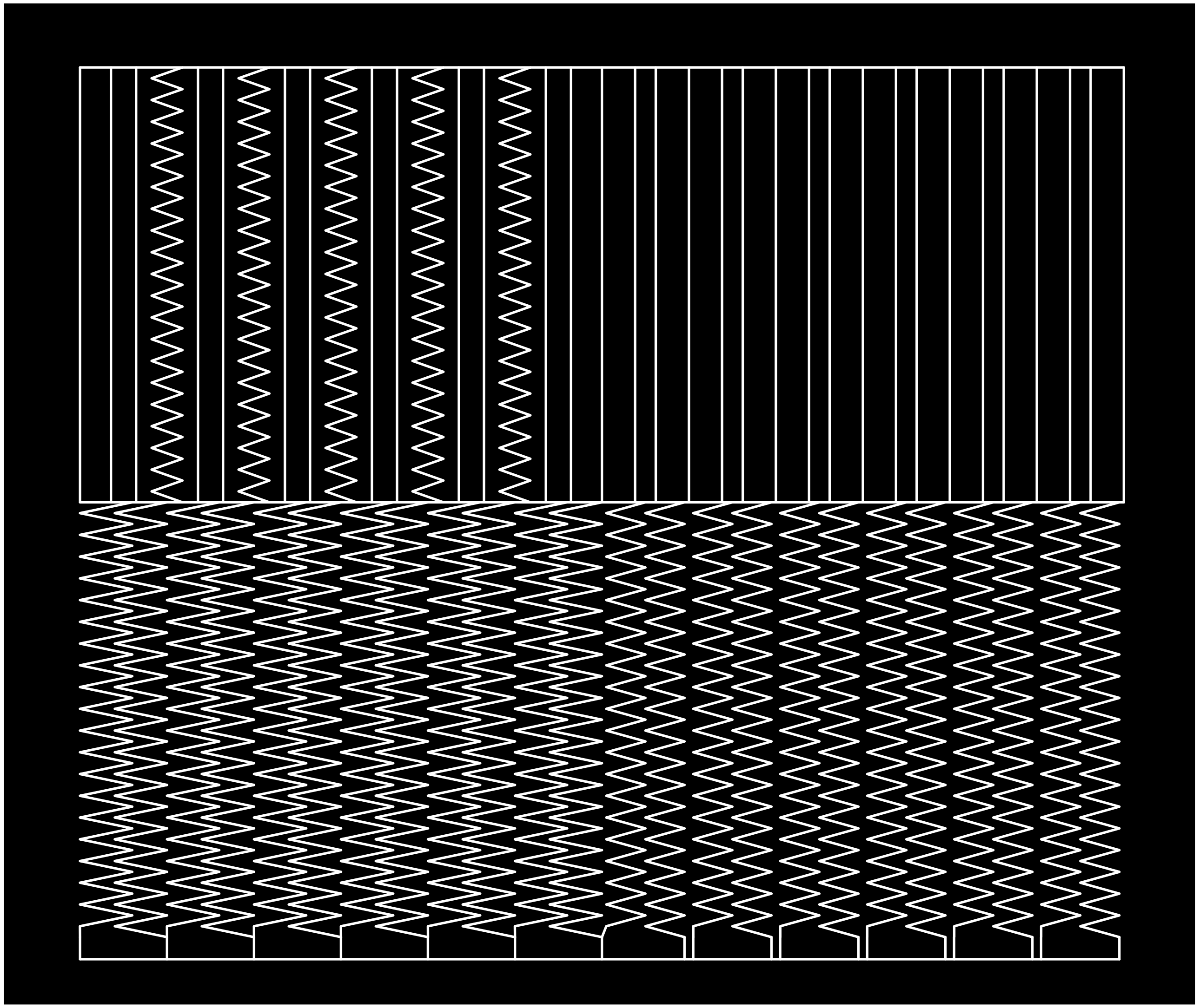


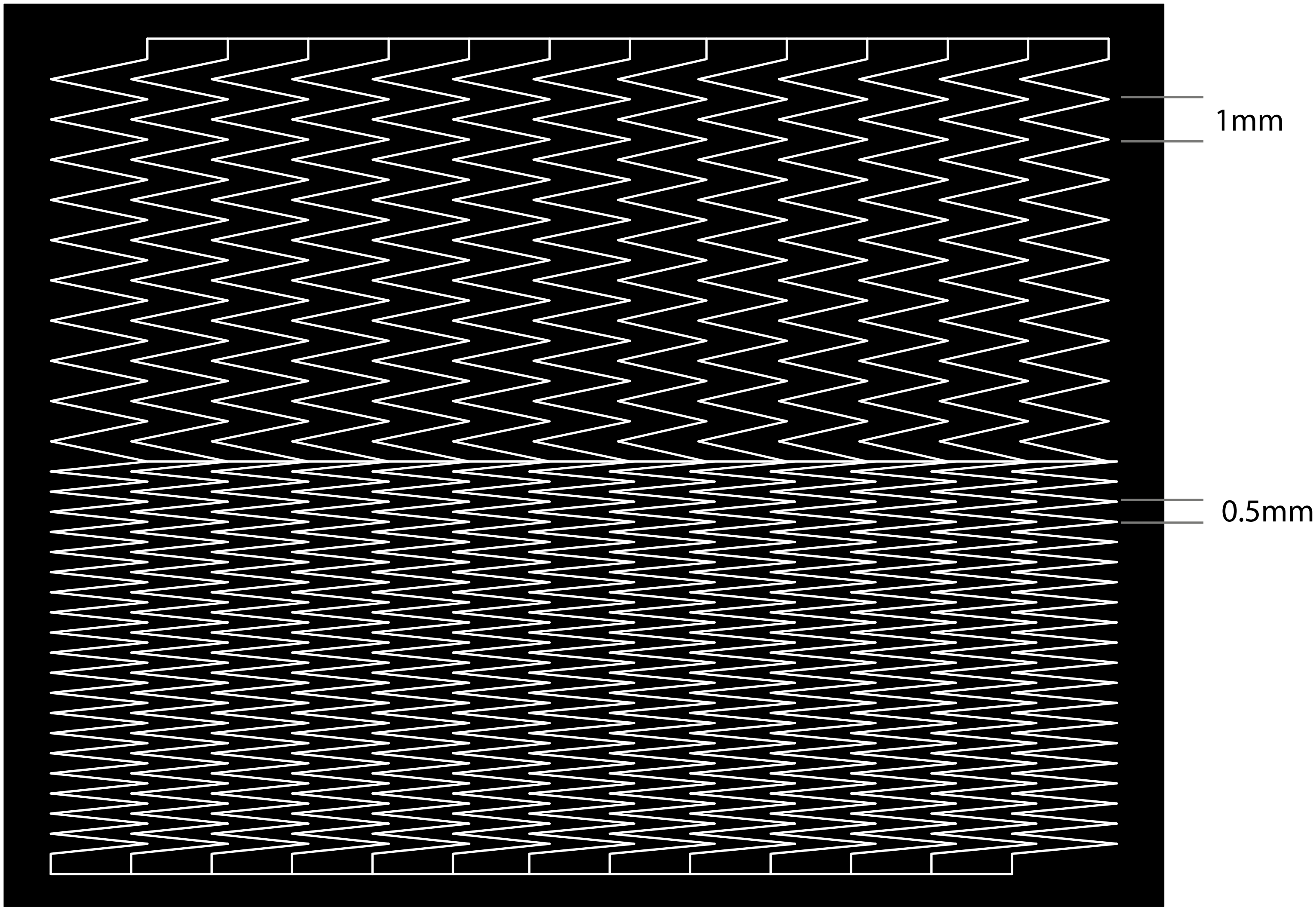
Fig. 2. The Contour plot of the axial component of the distortion field in the TPC volume. The maximum axial field is about 1.4V/cm near each of the end caps.



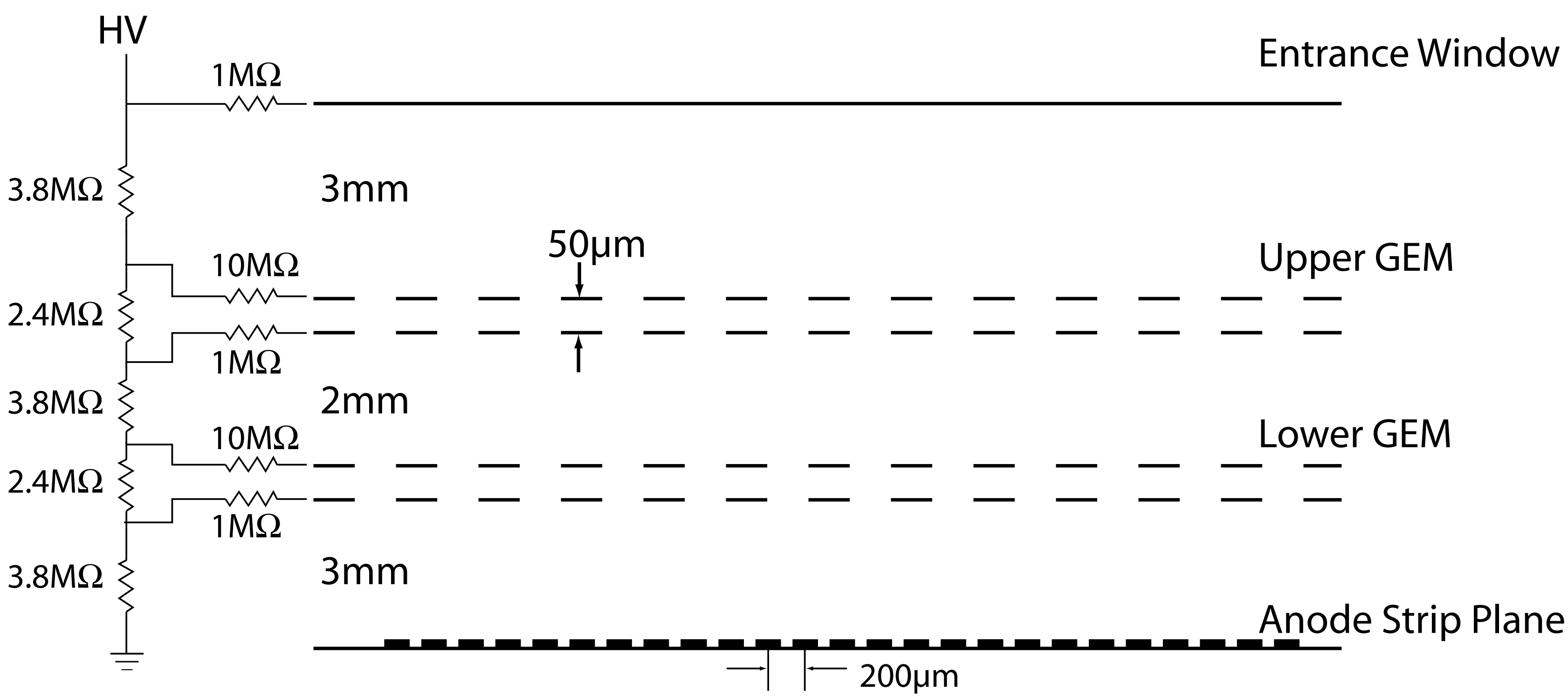
Two Intermediate Strip
(TIS)

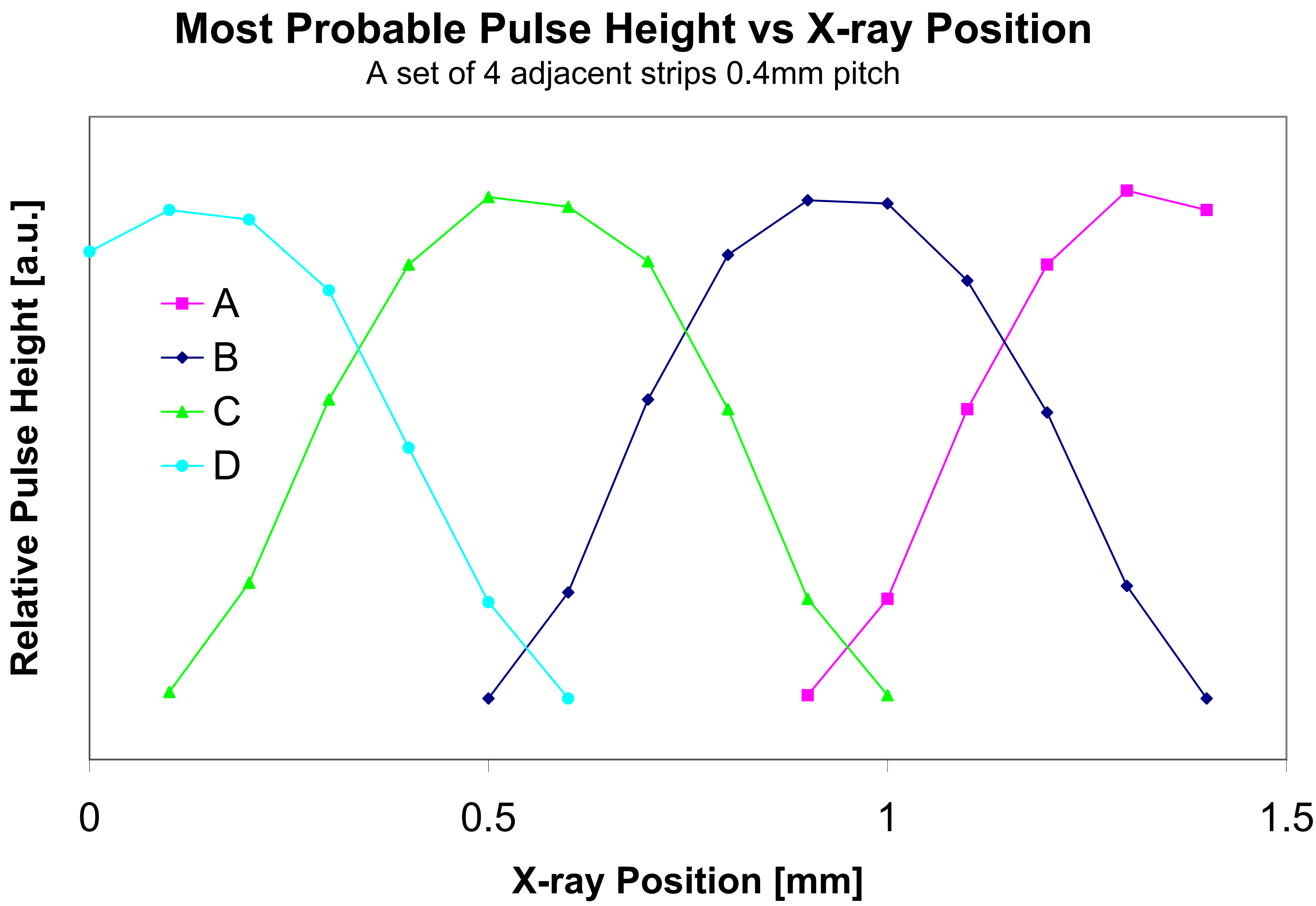
Single Intermediate Strip
(SIS)

ZigZag Patterns
2mmx10mm

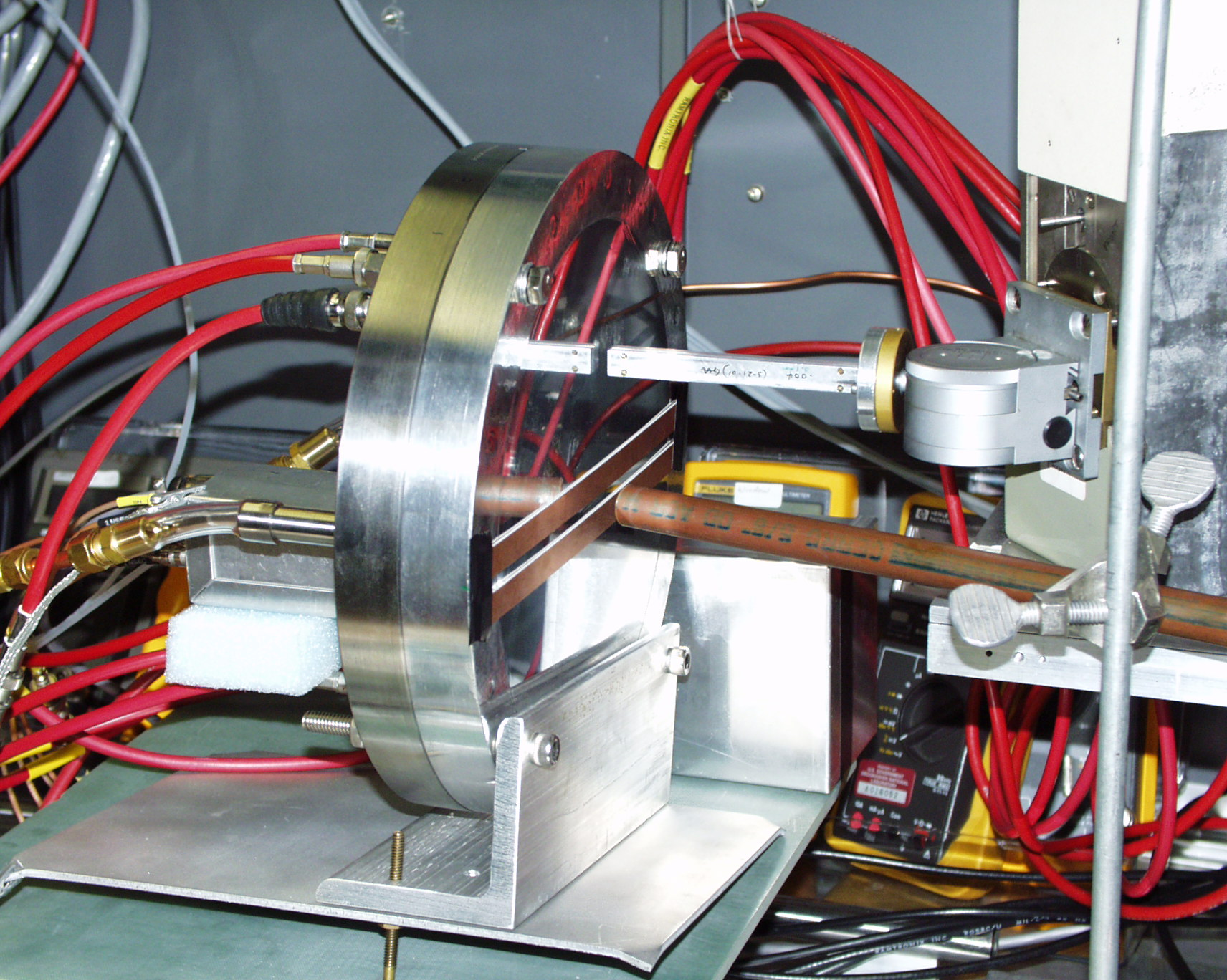


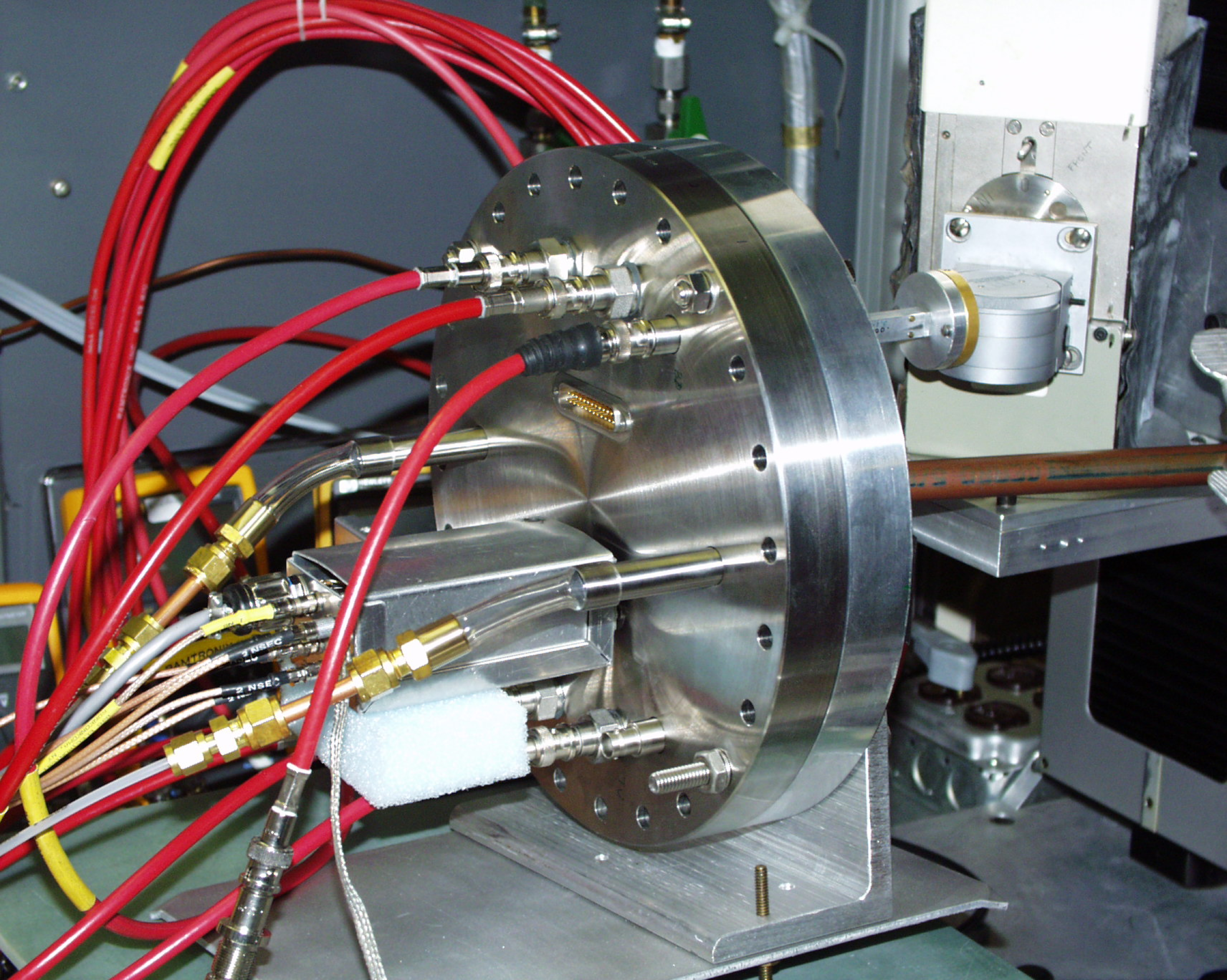
Double GEM Schematic Cross Section



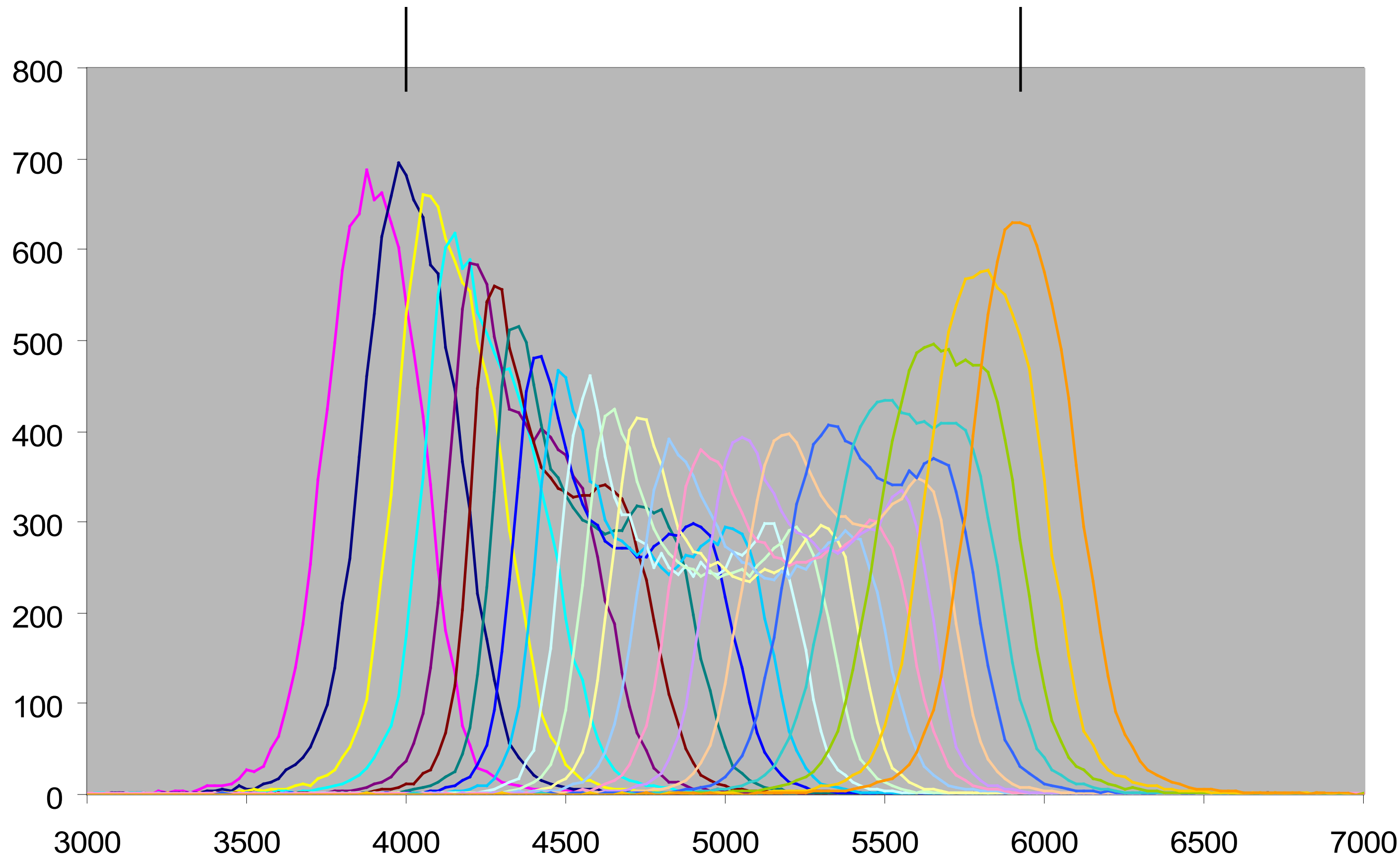


Most Probable Pulse Height vs X-ray Position
A set of 4 adjacent strips 0.4mm pitch
Relative Pulse Height [a.u.]
A
B
C
D
0
0.5
1
1.5
X-ray Position [mm]

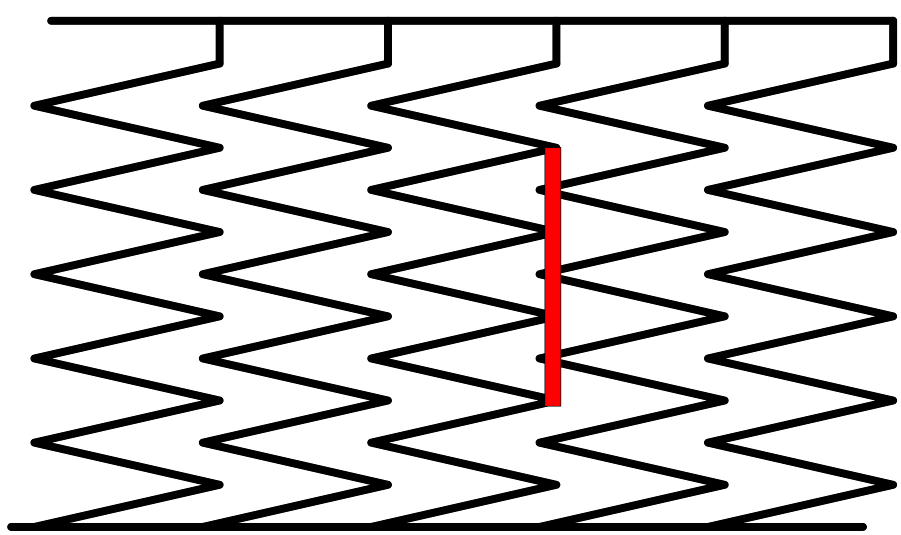

FLUKE


2 NSEC

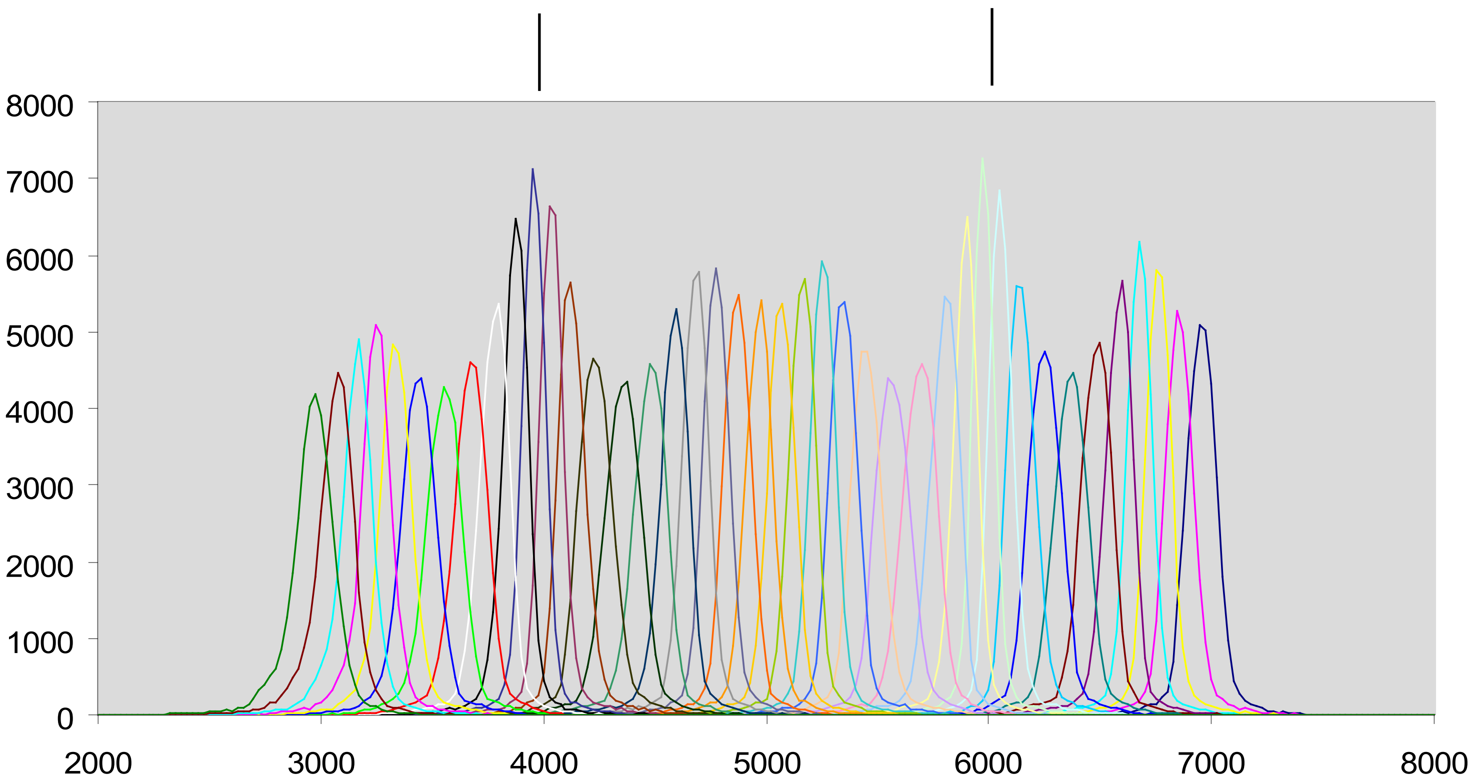
ZigZag (large) Pad Response to 5.4keV X-ray Beam
(Beam size: 100μmx3mm)

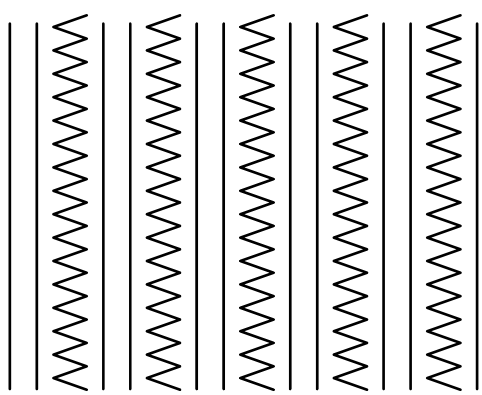


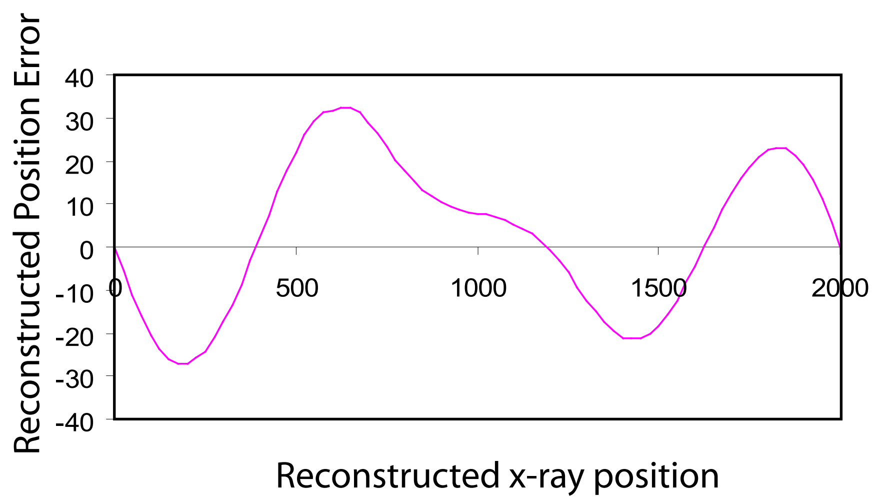
Reconstructed x-ray position



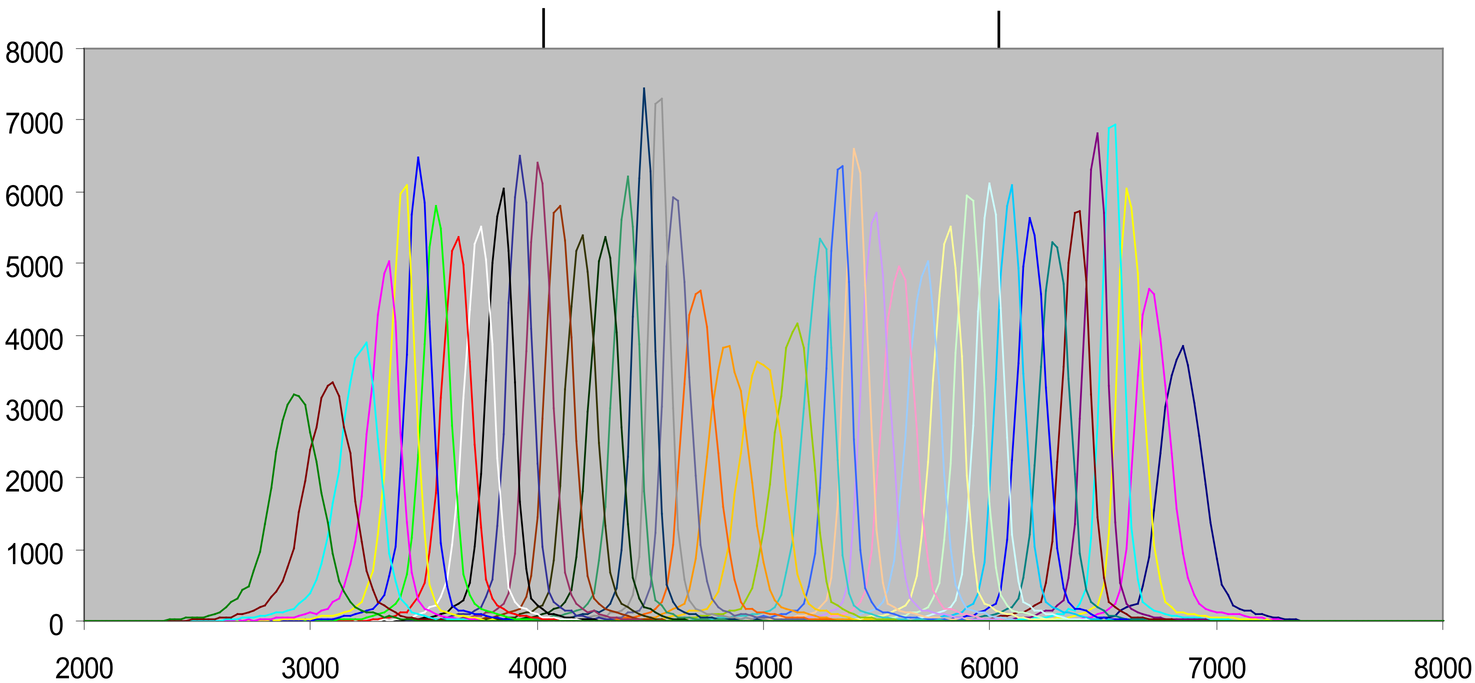
TIS (ZZ) Pad Response to 5.4keV X-ray Beam
(Beam size: 100μmx3mm)



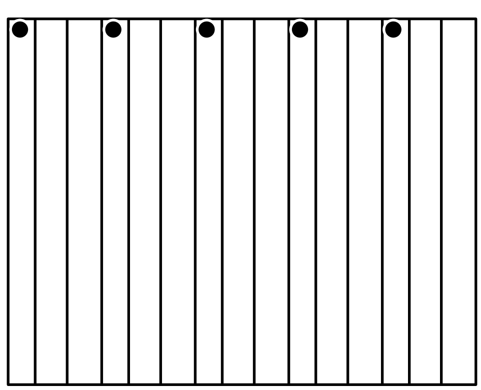




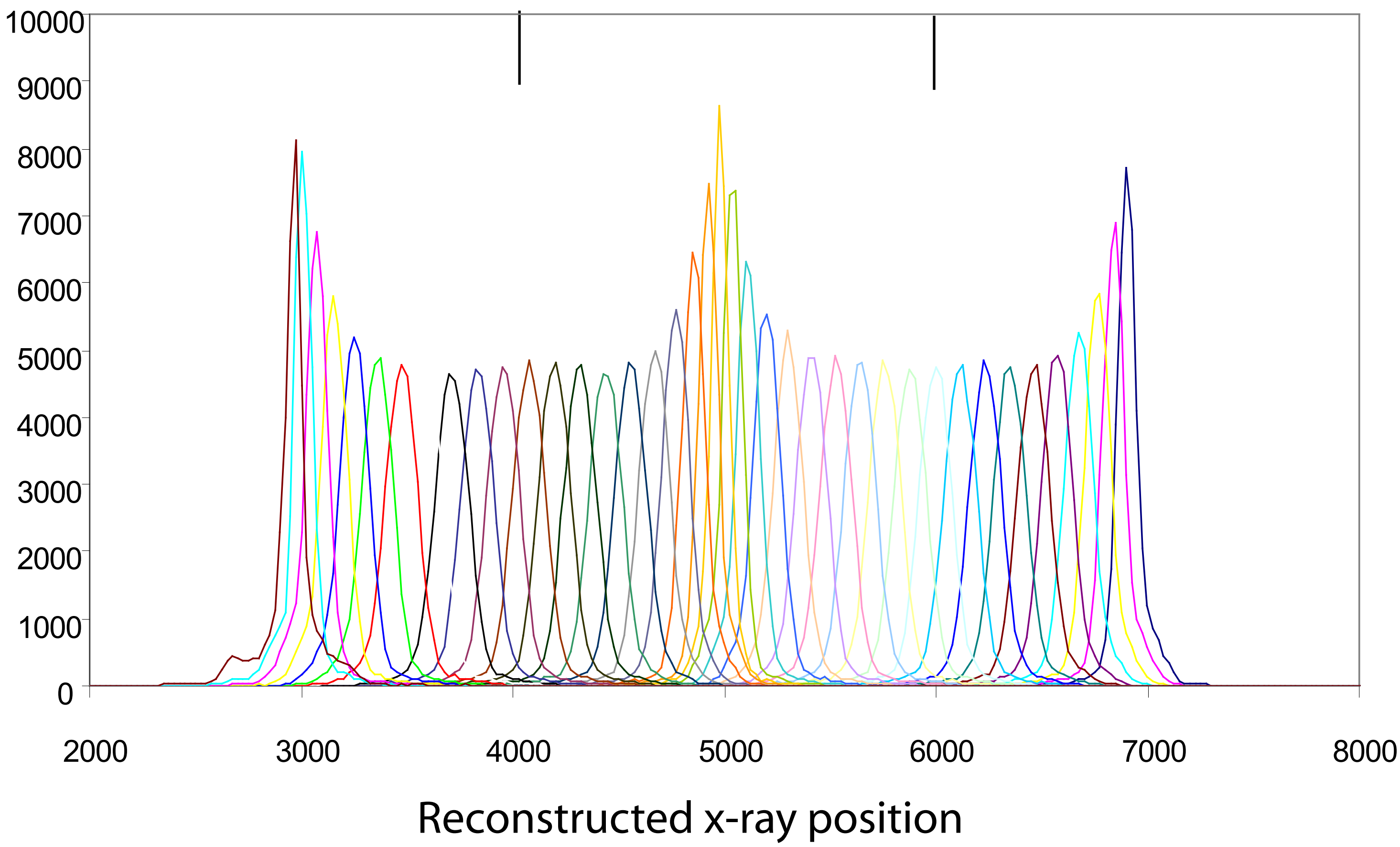
TIS Pad Response to 5.4keV X-ray Beam
(Beam size: 100μmx3mm)



Reconstructed x-ray position



SIS (ZZ) Pad Response to 5.4keV X-ray Beam
(Beam size: 100μmx3mm)



TIS (ZZ) Pad Response to 5.4keV X-ray Beam
(Beam size: 100μmx3mm)