The Requirements for Calibrating an X-ray Polarimeter

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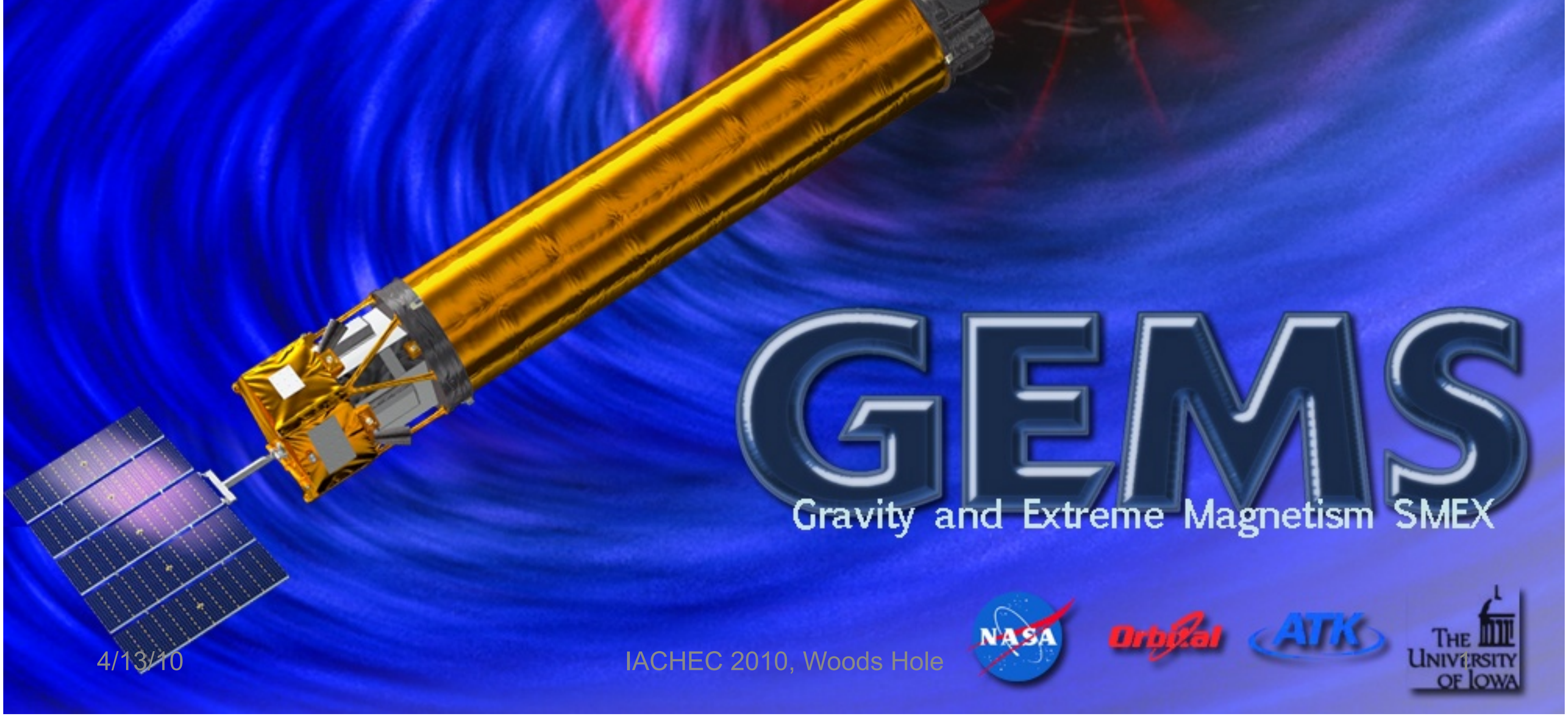
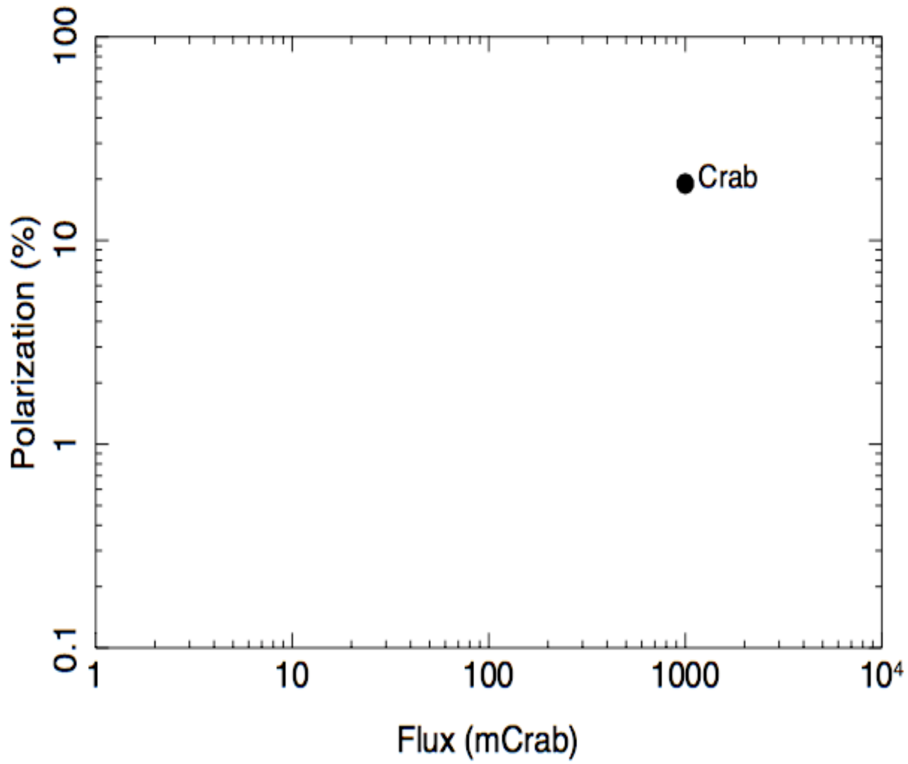
IACHEC 2010 Woods Hole, MA



X-ray Polarimetry

- Observational Status
- Photoelectric polarimetry basics
- Time projection detector concept
- Gravity and Extreme Magnetism Small Explorer mission
  - Expected Sensitivity and Results
    - Demonstrate the wisdom of including Polarimetry on IXO
  - Calibration needs and plans

Status of X-ray Polarimetry



KNOWN SINCE 1978

But interest remains high among theorists and experimentalists:

"X-ray Polarimetry Workshop", Stanford, Feb 9-11, 2004

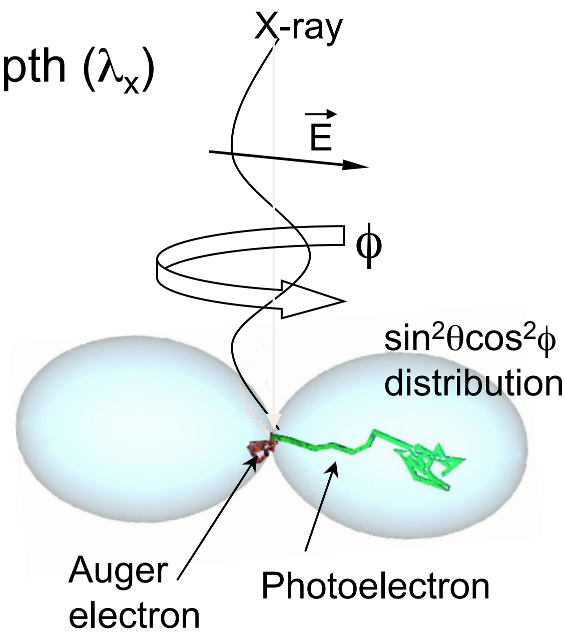
http://www-conf.slac.stanford.edu/xray_polar/talks.htm

"The Coming Age of X-ray Polarimetry", Rome, April 27-30 2009

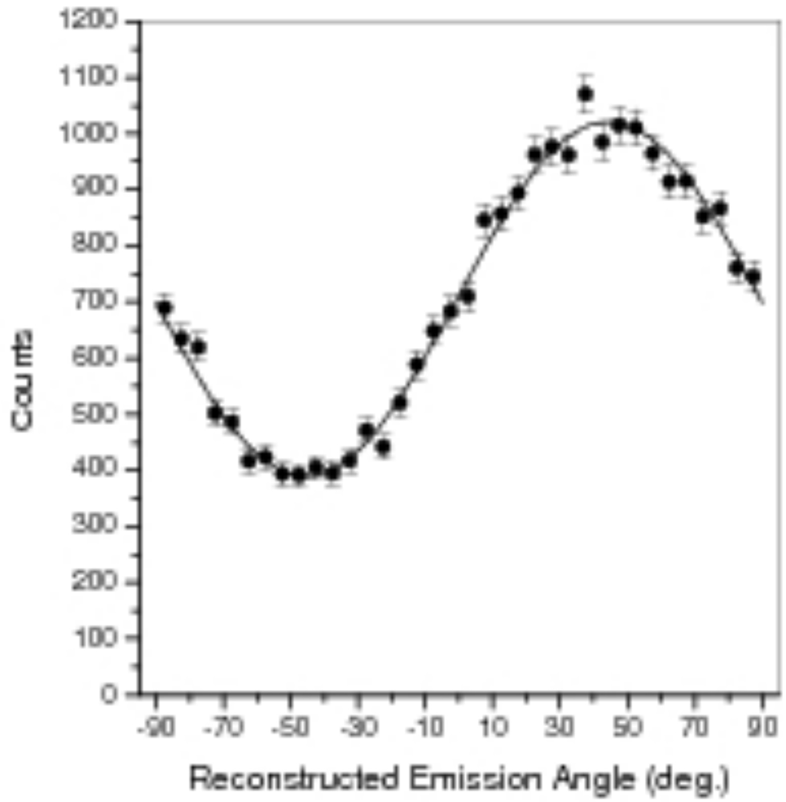
http://projects.iasf-roma.inaf.it/xraypol/xraypol.htm

Photoelectric X-ray Polarimetry

- Exploits: strong correlation between the X-ray electric field vector and the photoelectron emission direction
- Advantages: dominates interaction cross section below 100keV
- Challenge:
  - Photoelectron range < 1% X-ray absorption depth (λ_x)
  - Photoelectron scattering mfp < e^- range
- Requirements:
  - Accurate emission direction measurement
  - Good quantum efficiency
- Ideal polarimeter: 2d imager with:
  - resolution elements $\sigma_{x,y}$ < e^- mfp
  - Active depth ~ λ_x
  - => $\sigma_{x,y}$ < depth/10^3



Modulation - Definitions



In practice, the distribution of estimated track directions, even for purely polarized input, is more complicated than a projection of the $\sin^2\theta\cos^2\phi$ probability distribution.

$$N = A + B \cos^2 (\phi - \phi_0)$$

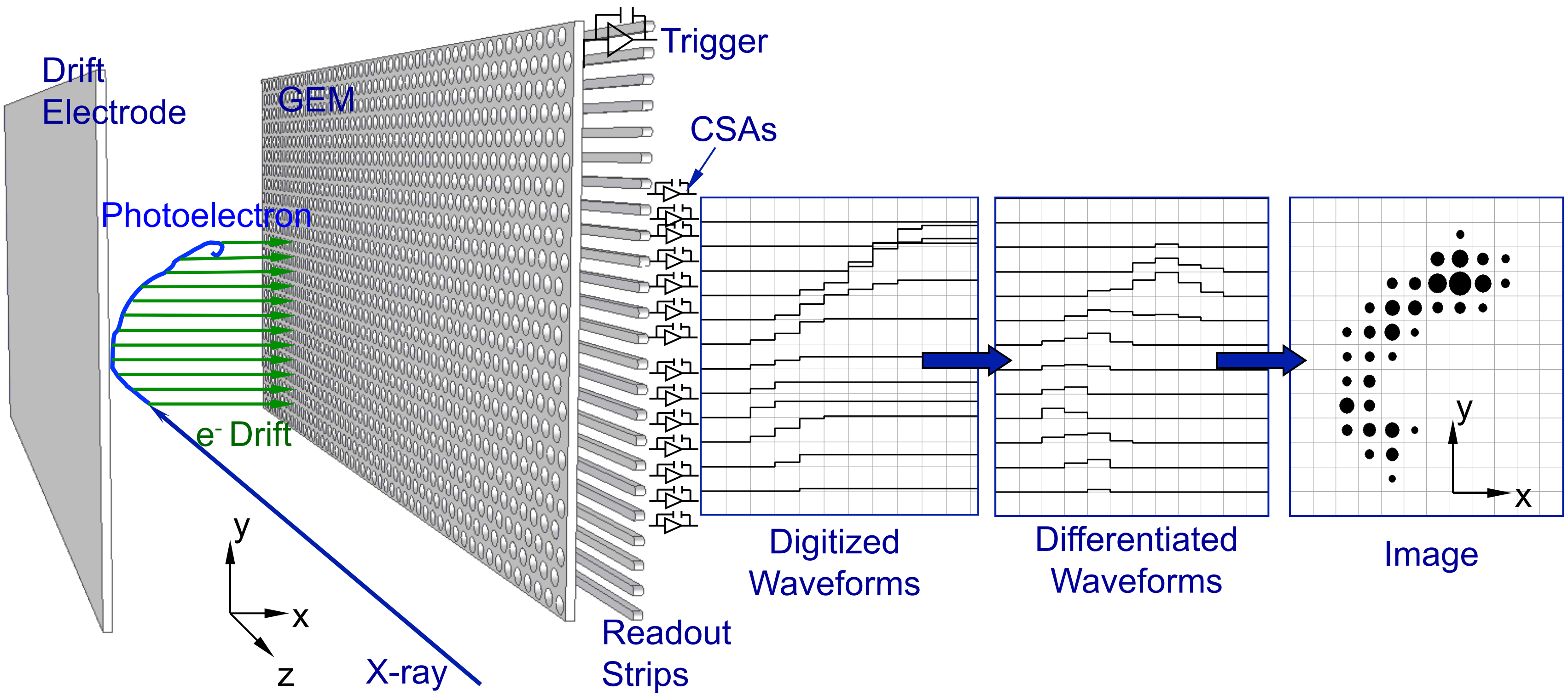
$$\mu = \frac{N_{max} - N_{min}}{N_{max} + N_{min}}$$

$$\mu = B / (2A + B)$$

$$MDP_{99} = \frac{4.29}{\mu R} \left(\frac{R + B}{T}\right)^{1/2}$$

TPC Polarimeter Concept

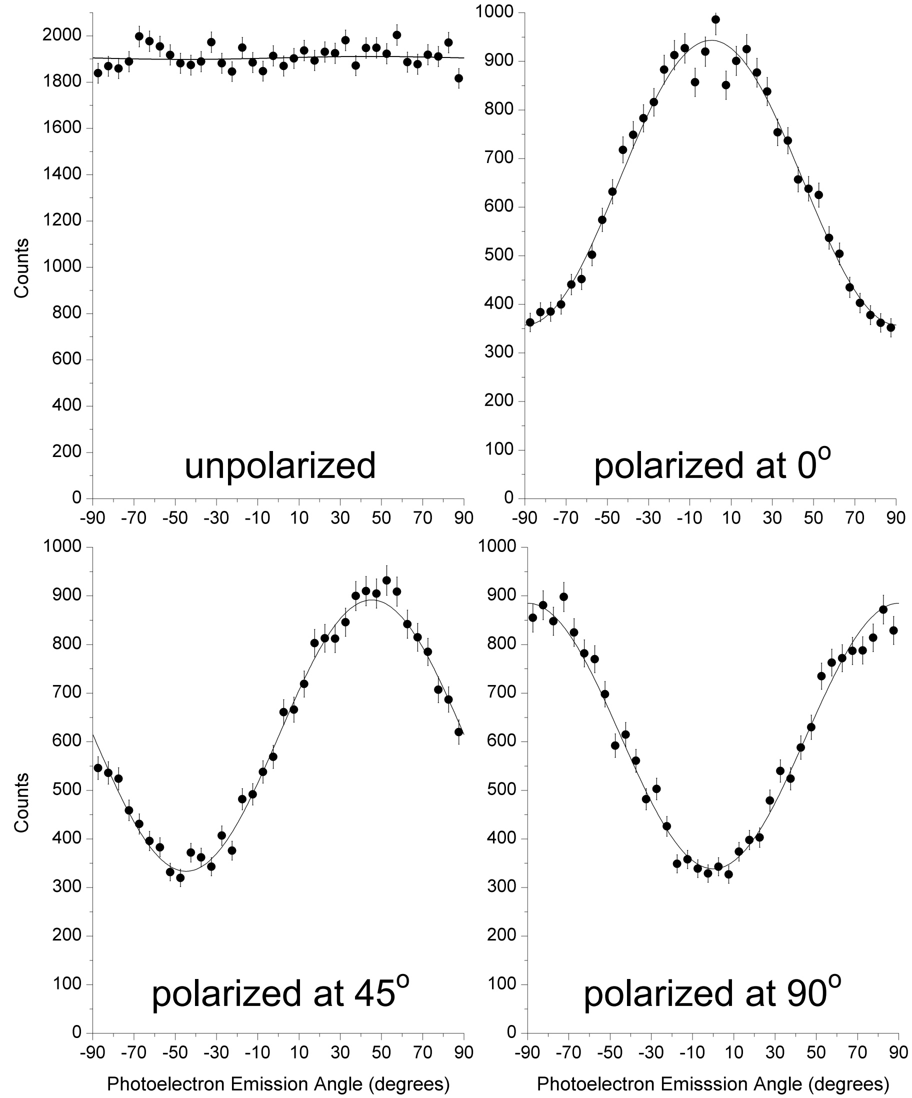
- Drift direction is perpendicular to X-ray propagation so that diffusion is independent of the active depth
- Image in a plane normal to the detector elements using strip readout
- Pixels are formed by time projection, coordinates [arrival time,strip location]
- Drift height determined by collimation of beam



Analysis and Results

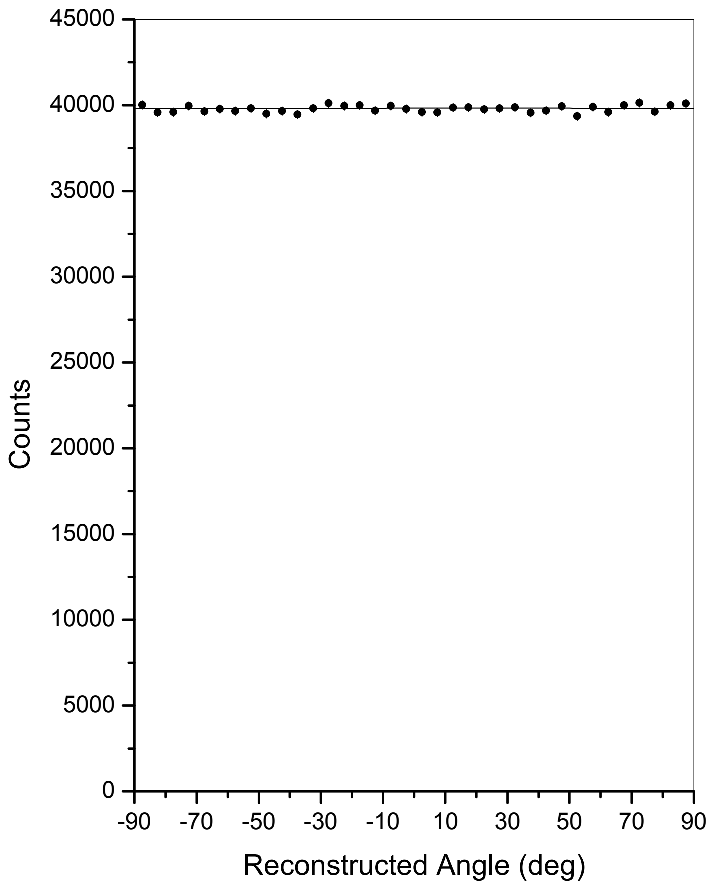
- Histograms of reconstructed angles fit to expected functional form: $N(\phi) = A + B\cos^2(\phi - \phi_0)$ where ϕ_0 is the polarization phase
- The modulation is defined as: $\mu = (N_{max} - N_{min})/(N_{max} + N_{min})$
- Results:
  - It's a polarimeter
  - Uniform response
  - No false modulation
- Black et al. (2007) NIM A, 581, 755

Polarization Phase	Measured Parameters		
	Modulation (%)	Phase (degrees)	χ_ν^2
unpolarized	0.49 ± 0.54	44.6 ± 28.7	1.2
0°	45.0 ± 1.1	0.3 ± 0.6	1.1
45°	45.3 ± 1.1	45.2 ± 0.6	1.0
90°	44.7 ± 1.1	-89.9 ± 0.6	1.4



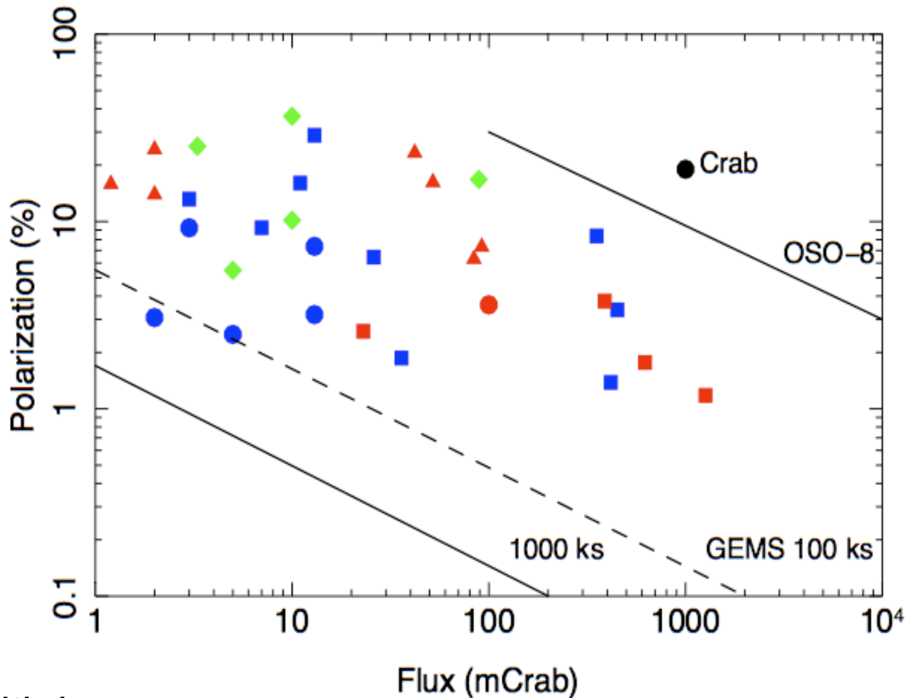
Response to unpolarized X-rays

- Histograms of reconstructed angles for unpolarized data. 1.4 x 10^6 cts over 40 ks
- ~60 "spacecraft rotations"
- measured modulation
  - Amplitude 0.05% +/- 0.12%
  - ϕ_o = 20.9 +/- 73.9 deg
  - χ^2 = 1.05 / dof



Gravity and Extreme Magnetism Small Explorer Concept

- The Time Projection Polarimeter is the heart of the Gravity and Extreme Magnetism Small Explorer
  - Currently in Phase B
  - Launch in 2014
- Rotation of three-axis stabilized spacecraft for low false modulation due to instrumental systematic error
- Full sky visibility; ~300 sources accessible, each for ~ 8 weeks every 6 months
- Straightforward operations concept
- 9 month program of 35 targets
  - Black Holes, Neutron Stars, SNR
- No consumables, lifetime ≥ 2 yr



KNOWN SINCE 1978

NEW TERRITORY

Targets with known fluxes and polarization estimates

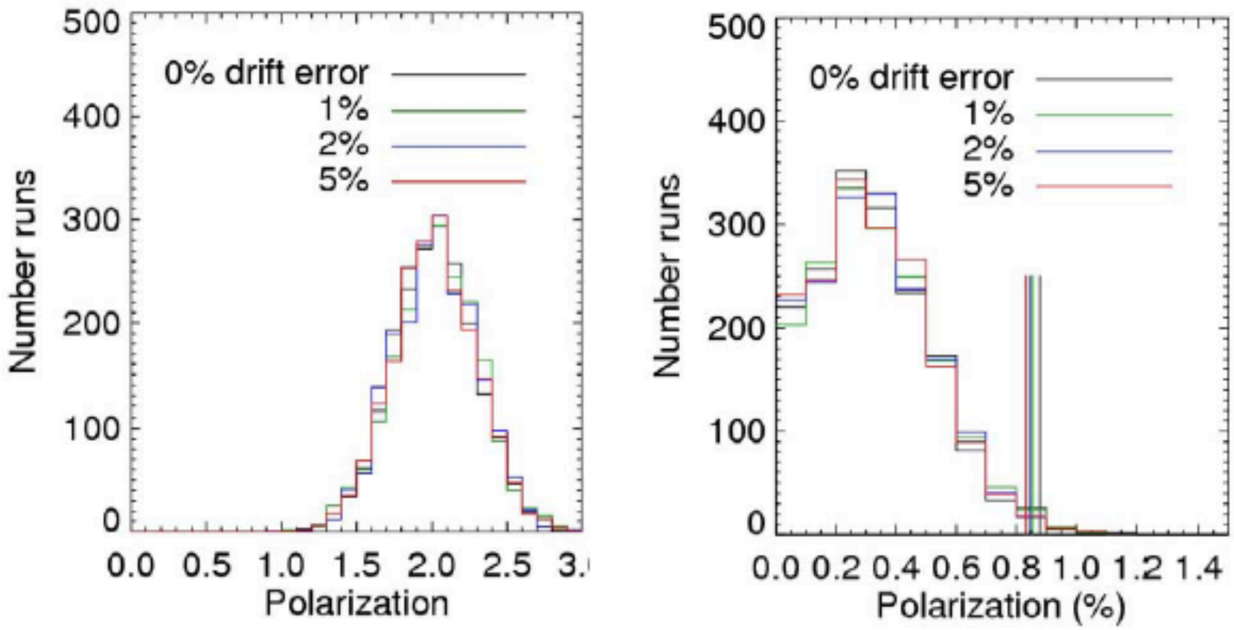
Black holes

Neutron stars

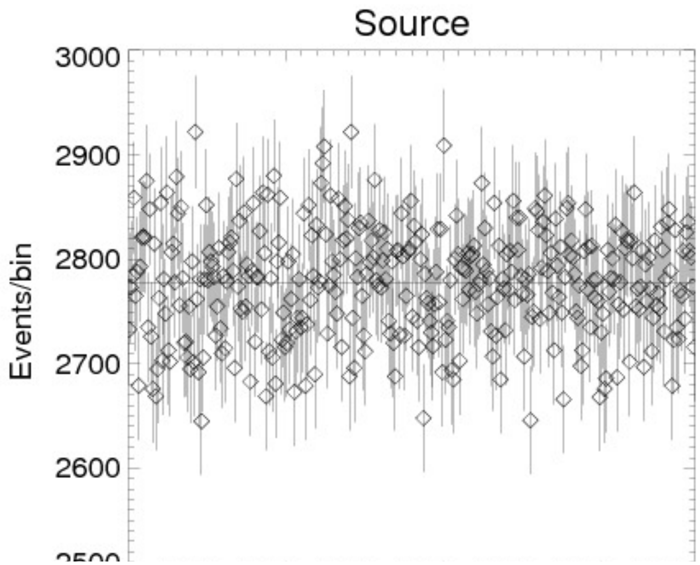
Supernova remnants

Benefits of Rotation

- Simulations with 10^6 photons/run (μ~ 0.5, MDP < 0.01) show the power of spacecraft rotation
- PROCEDURE
  - Generate photons
  - Move photon E-field into detector frame
  - Generate photoelectron direction with $\cos^2(\phi)$ distribution
  - Distort (by stretching) one axis
  - Measure the distorted direction
  - Map the photoelectron direction back onto the sky



- RESULTS: Spacecraft rotation removes the effects of detector asymmetries

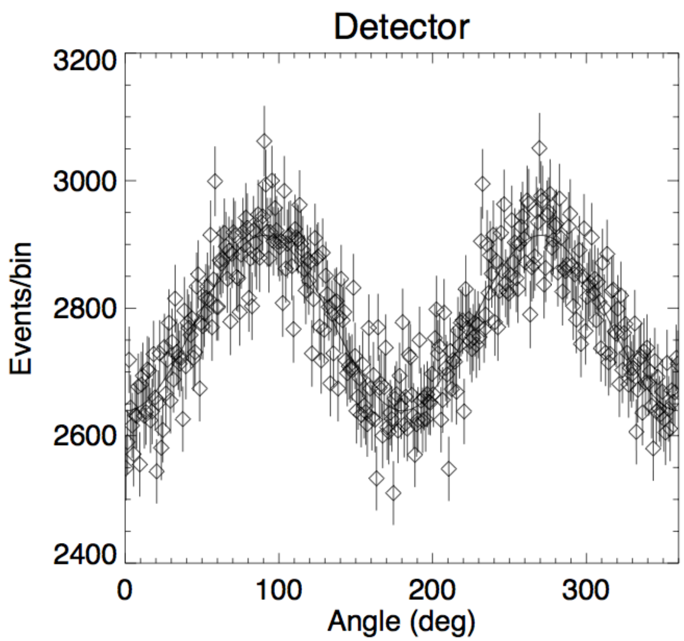


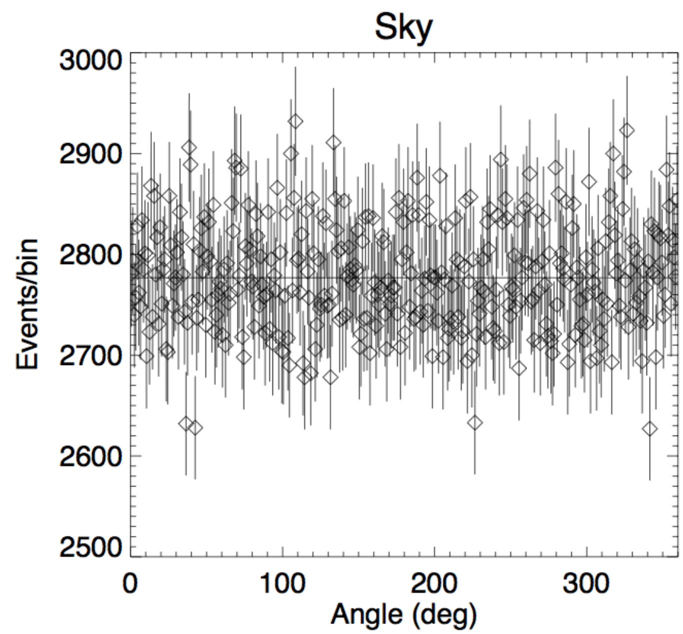
Source is unpolarized

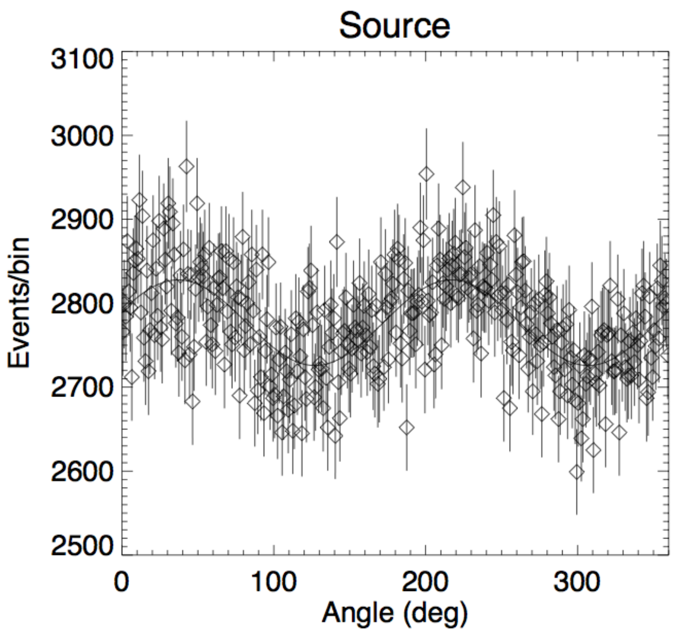
$\mu = 0.5$

$N = 10^6$

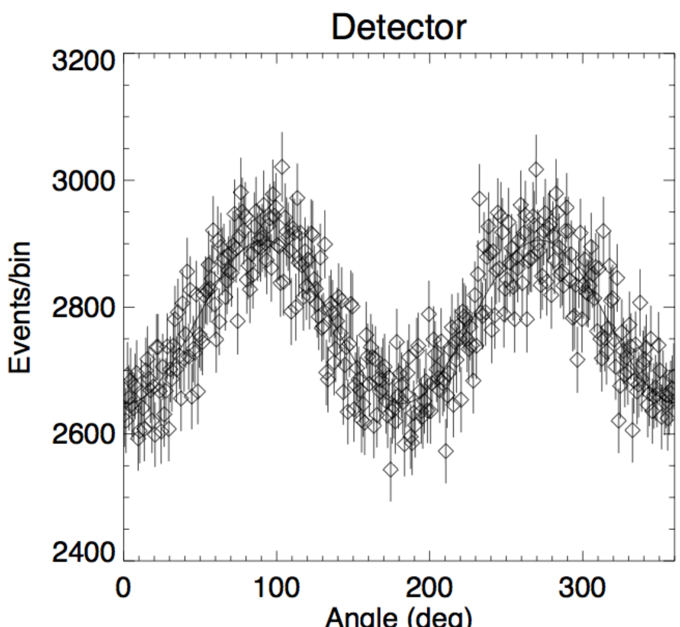
$T = 10^5$ sec (~160 rotations)

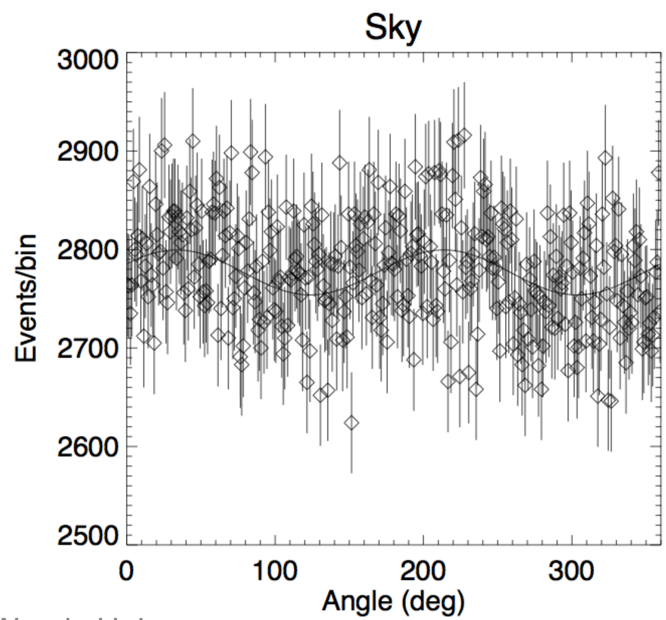






Source has 2% polarization
$\mu = 0.5$
$N = 10^6$
$T = 10^5$ (~160 rotations)

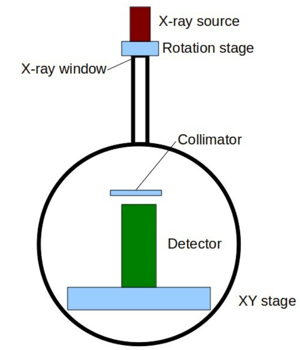




Calibration Needs

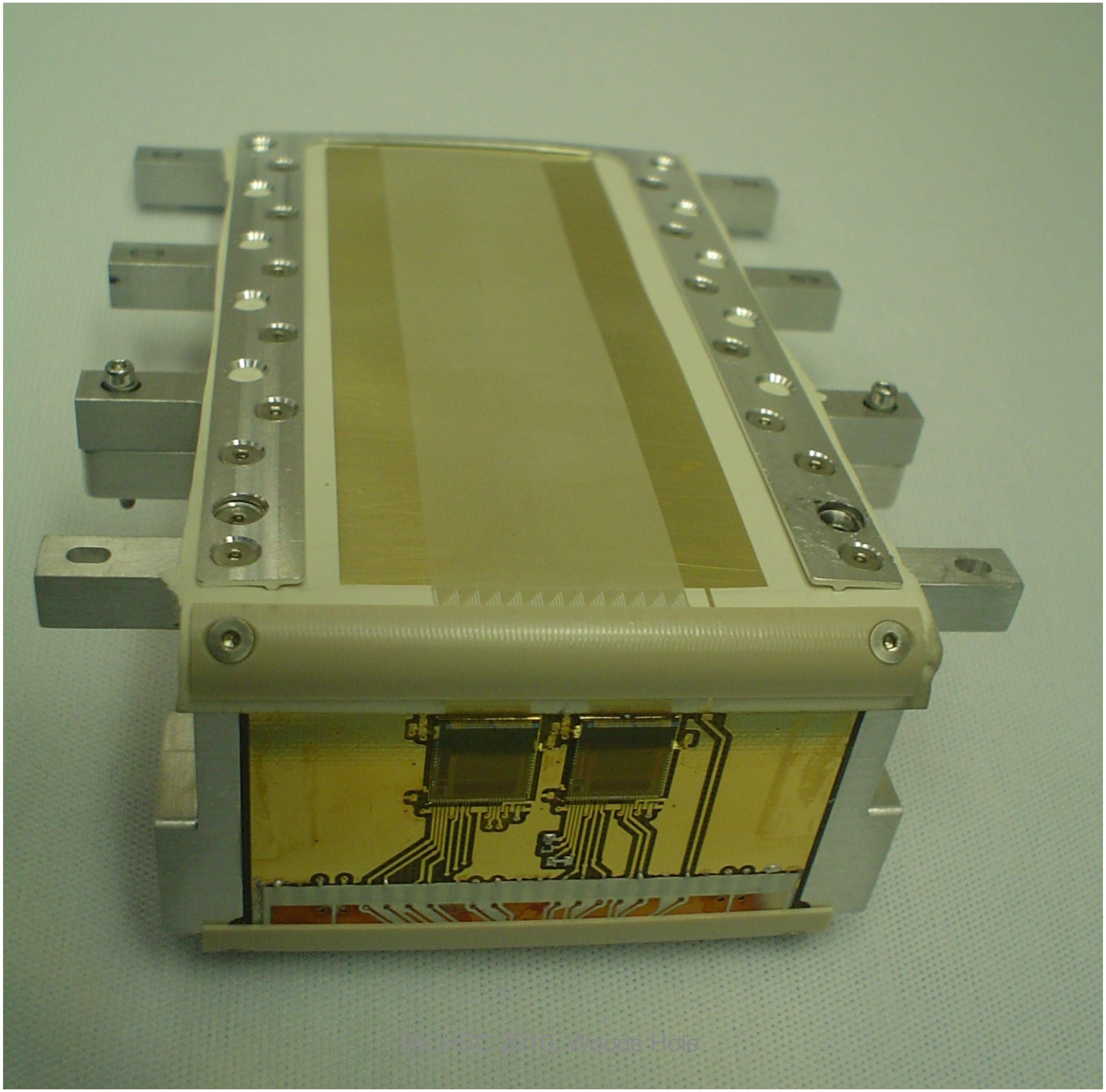
- Verification of Physical and Empirical models for
  - μ_{100} (E, x, y, z) - good precision
  - μ_0 (E, x, y, z) - high precision
  - A_{eff}(E), efficiency (E), redistribution (E)
- Tools
  - At U. Iowa: collimated pencil beams
    - Unpolarized at 2.7 keV, 5-8 keV broad band
    - Polarized at 2.7, 3.7, 4.5, 6.4, 8.0 keV
    - Detector in vacuum
  - At GSFC: collimated and broad band beams
    - 5.9 keV from Fe^{55}
    - 2.7 and 4.5 keV
    - Detector in air
  - At BNL: collimated and polarized beam at "all" energies

Calibration beam line

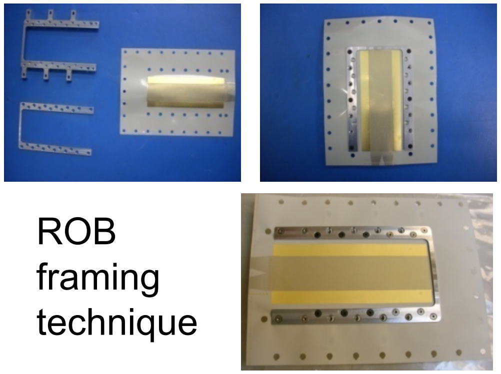


2010 Activities

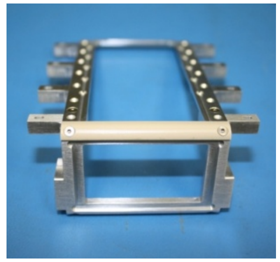
- Construction of Engineering Test Unit
  - Engineering tests
  - Performance tests
    - Uniformity
    - Sensitivity
    - Background rejection
- Construction of U. Iowa calibration beam line
  - ETU performance tests, procedure development
- GEMS SRR
  - Requirements development and documentation



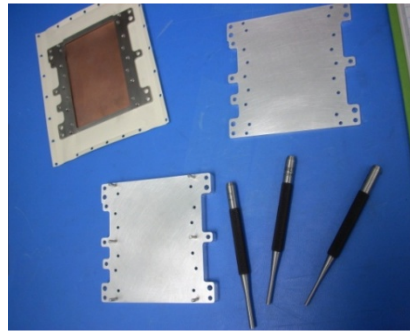
GEM – ROB Hardware



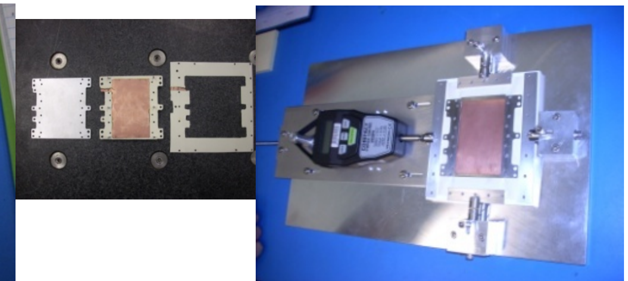
ROB framing technique



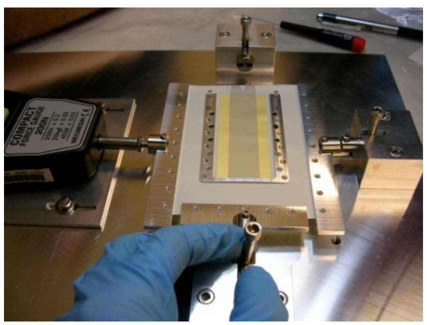
ROB Frame



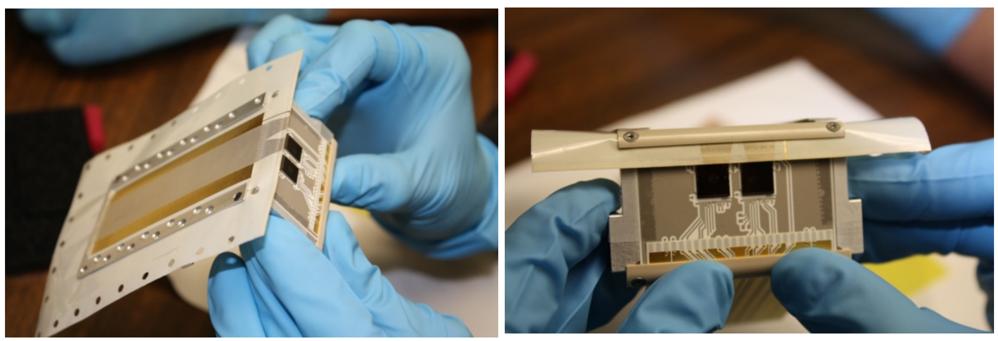
Fixture and Punch Parts



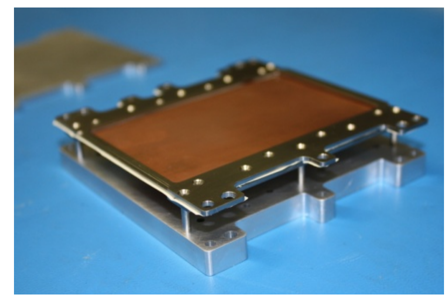
GSE fixture to be used to trim excess LCP from frame after mounting.



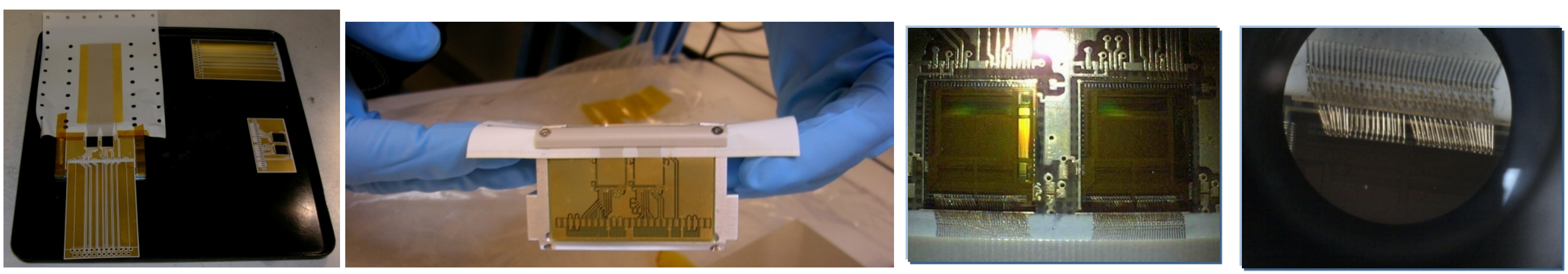
ROB stretching procedure



ROB Prototype Frame and Bracket

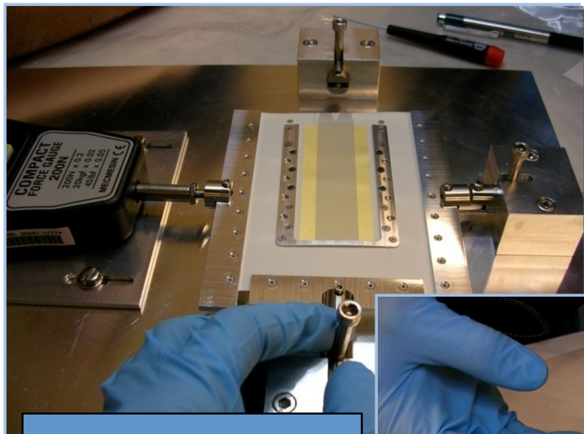


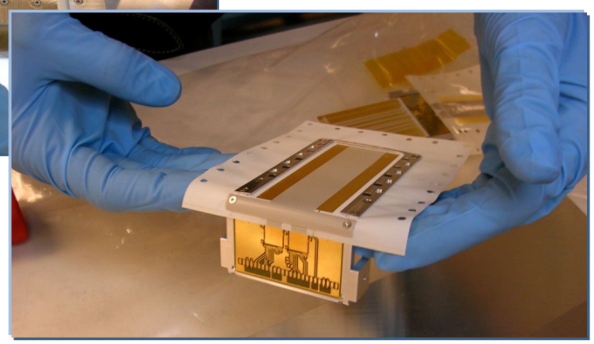
Prototype GEM Assembly



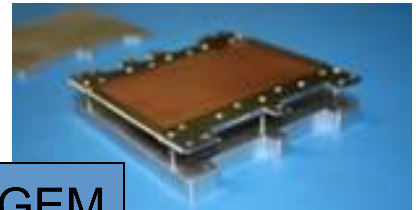
ceramic board with wire bonding

ETU Hardware

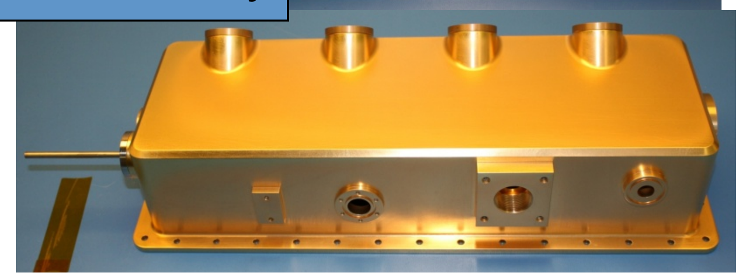




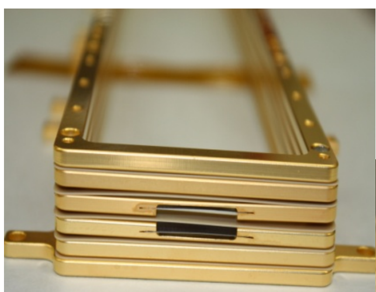
First Level in Assembly

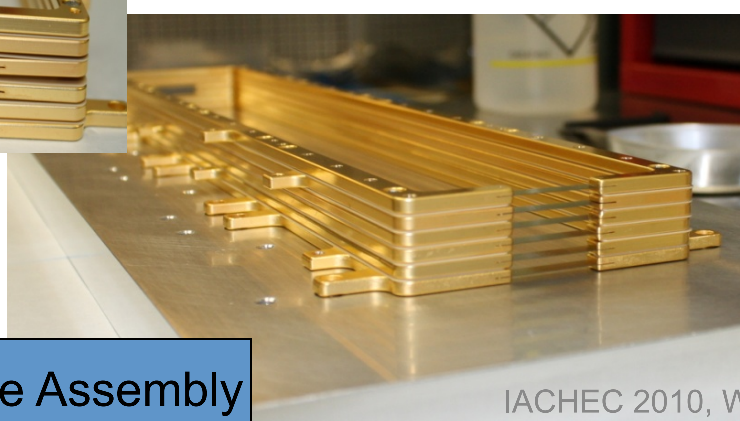


GEM

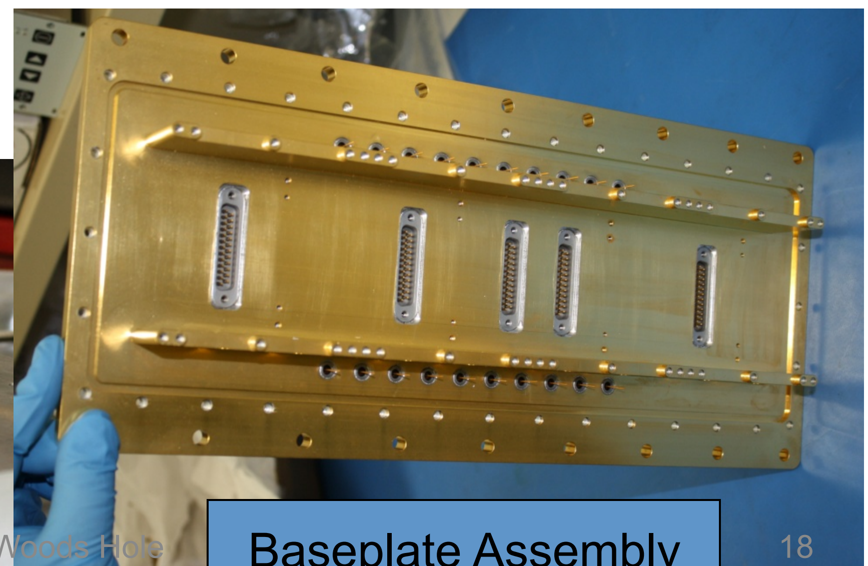


Cover Assembly





Field Cage Assembly



Baseplate Assembly