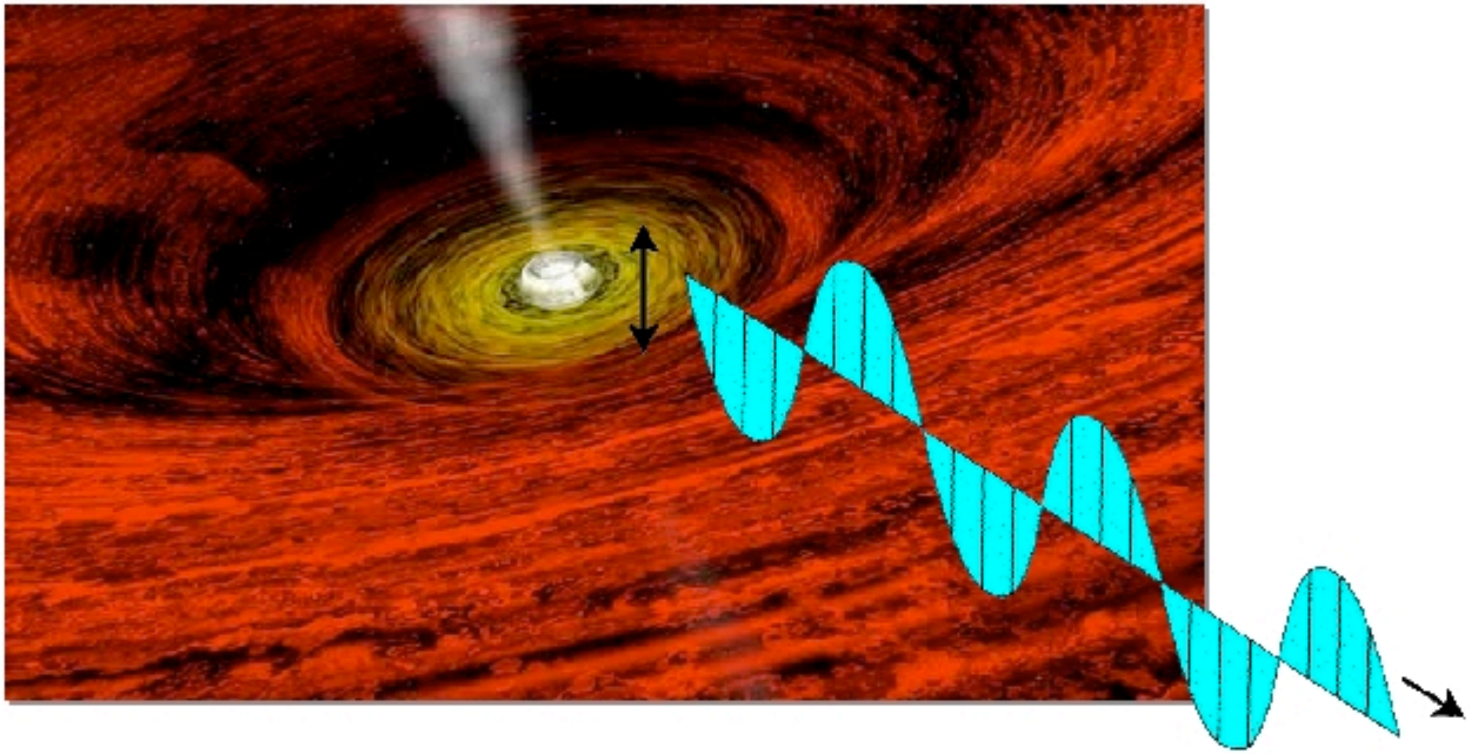
Gravity and Extreme Magnetism SMEX

- Submitted to Small Explorer AO (Jan 2008) (1 of 32)
  - PI: Jean Swank, Deputy PI: Keith Jahoda
- Selected for Phase A study (1 of 6)
  - GEMS (GSFC), Joint Astrophysics Nascent Universe Satellite (PSU), Transiting Exoplanet Survey Satellite (MIT), Coronal Physics Explorer (NRL), Interface Region Imaging Spectrograph (Lockheed), and Neutral Ion Coupling Explorer (UC Berkeley) selected
- Phase A Concept Study reports completed (12/08)
- Site Visit completed (4/09)
- Selections (2) expected (7/09)
- Launch: Dec 2012 or April 2014

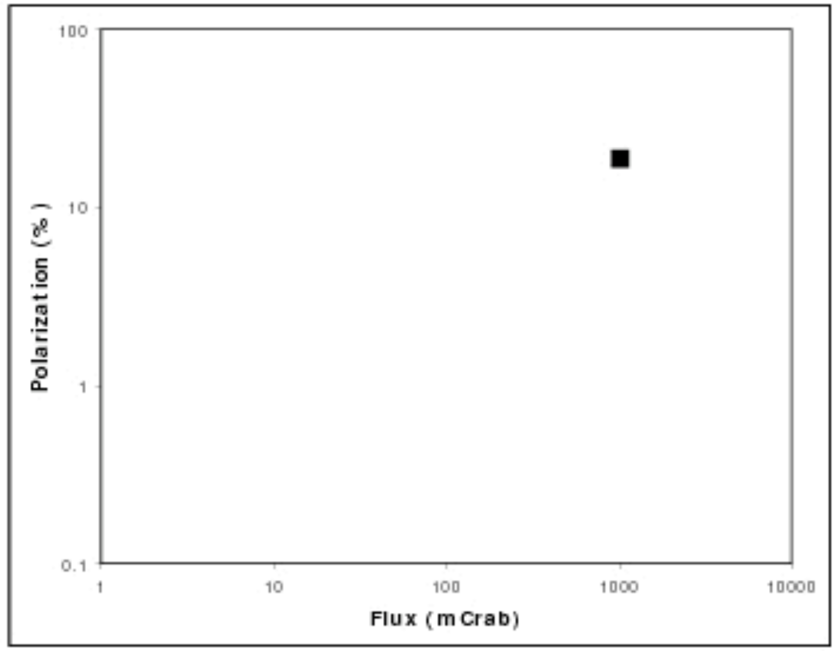
X-ray Polarization Unlocks a Previously Hidden Astrophysical World



- Polarization, the direction of the electric field of electromagnetic waves, encodes information about the structure of cosmic sources.
- Previous X-ray observatories have been insensitive to polarization.
- GEMS will be the **first** observatory to systematically measure X-ray polarization

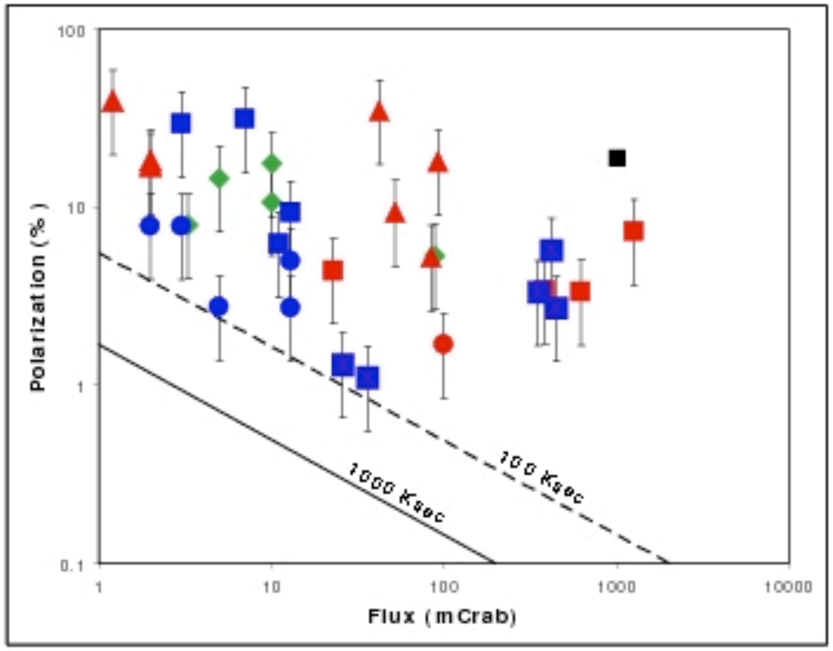
GEMS Opens a New Discovery Space in Astrophysics

- Polarized X-rays have been detected from only one cosmic source



GEMS Opens a New Discovery in Astrophysics

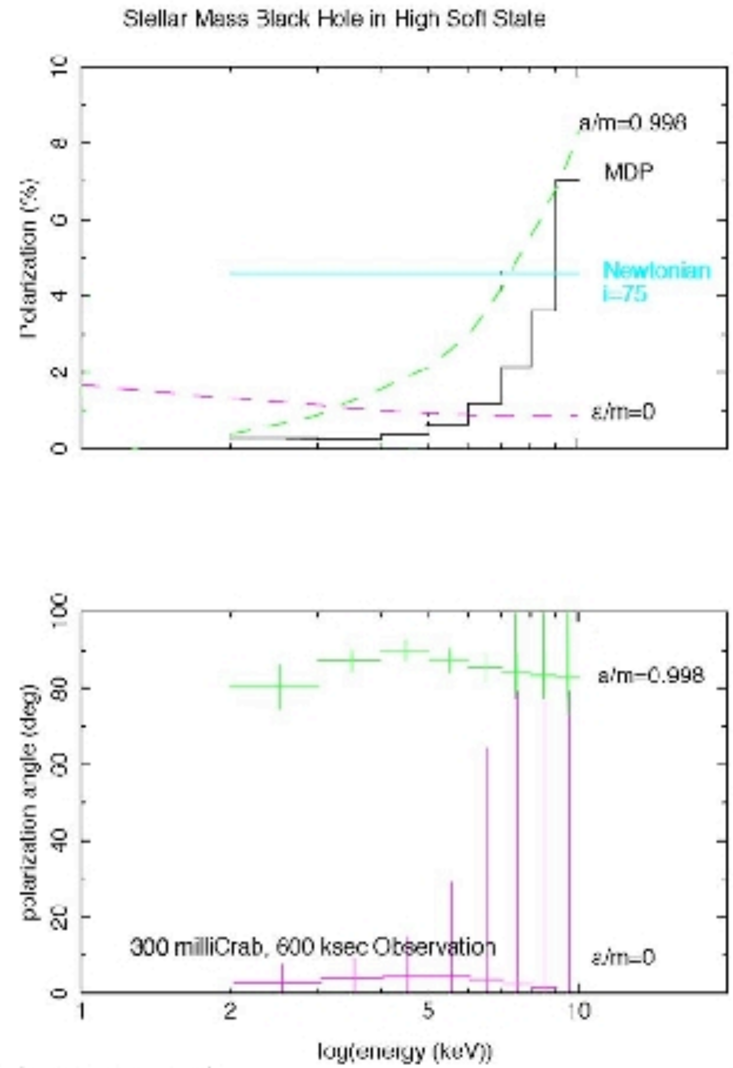
- GEMS will observe:
  - ✓15 black holes
  - ✓11 pulsars and neutron stars
  - ✓6 supernova remnants
- And address questions including:
  - ✓Where is the energy released near black holes?
  - ✓What is the origin of X-ray emission from pulsars?
  - ✓What is the magnetic field structure in high energy nebulae?



GEMS is a pathfinder for much larger future observatories e.g. the International X-ray Observatory (IXO)

How Does Black Hole Spin Warp Space-time?

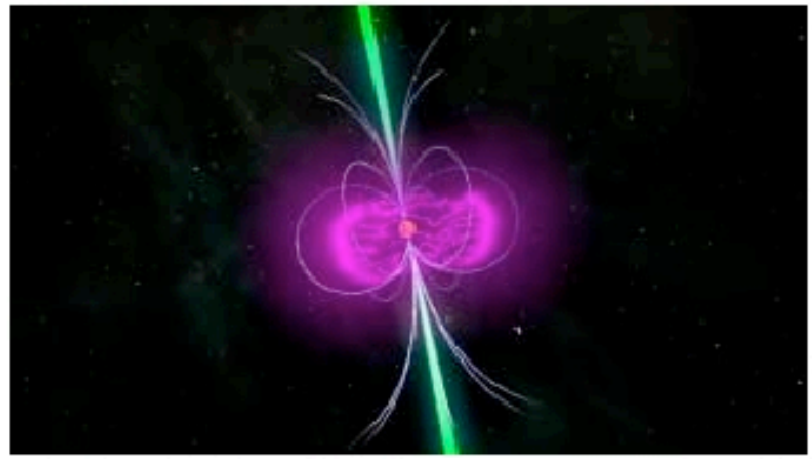
- Black Holes have only two astrophysical properties; Mass, and Spin
- Determining spin is critical for understanding growth of massive black holes
- X-ray polarization will provide a new, unique approach to measure spin
- Strong gravity bends light paths
  - Energy dependent measurements will test for rapid spin vs non-spin



GEMS
Gravity and Extreme Magnetism SMEX

How Do Magnetars Work?

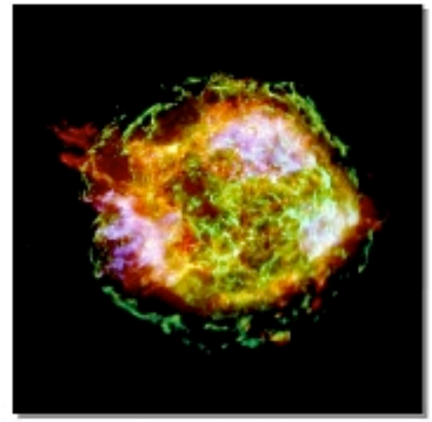
- Magnetars have the strongest magnetic fields in the universe: 10^{13}-10^{15} gauss = 10^{9}-10^{11} tesla
- They are neutron stars which are pulsars and sources of intense X-ray and γ-ray bursts
- Strong intrinsic X-ray polarization is virtually certain
- The polarization will tell the field geometry and the size and location of the emission region
- Observations during outbursts will measure changes in the field geometry
- Polarization is a key test of our model



GEMS will measure the polarization vs pulse phase of magnetars and thereby deduce their magnetic field structure

How Does Cosmic-ray Acceleration Occur in Supernova Remnants?

- X-ray imaging and spectral observations have shown:
  - Supernova remnant shocks are sources of synchrotron radiation from radio through X-rays
    - The shock thickness implies B fields are amplified
  - The shocks are sources of radiation from up to TeV (10^{12} eV) energies
- Questions remain:
  - Do electron-photon interactions or pion decay dominate the high energy γ-ray production?
  - Does this vary from one remnant to another?
  - How are the B fields amplified?
  - Are the B fields tangled or coherent?
- X-ray polarization will tell whether the field is coherent or tangled



Cas A with Chandra

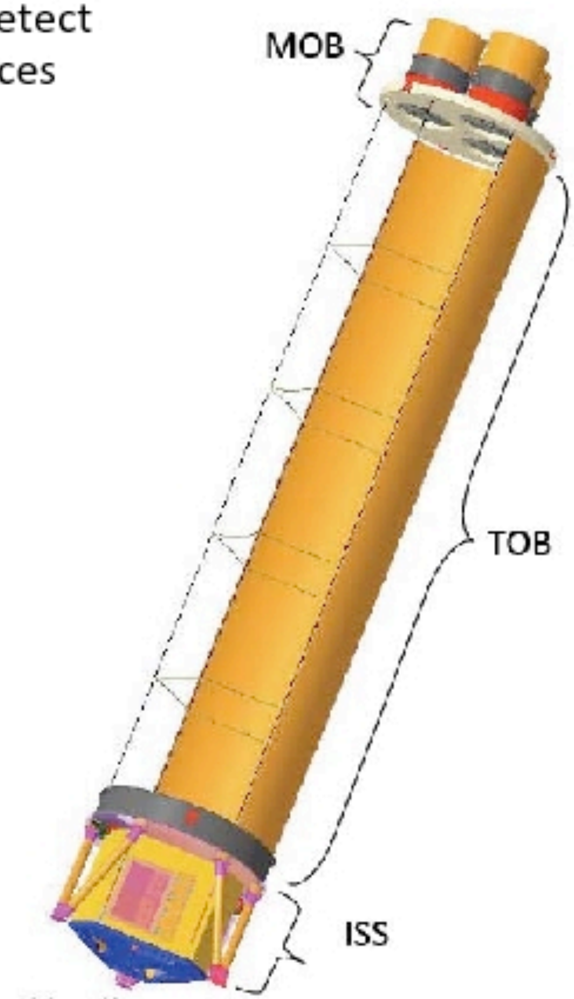
SN1006 with Chandra showing GEMS fov

Instrument Overview

- GEMS Scientific goals require the ability to detect small fractional polarizations from faint sources

- Key elements of the GEMS Instrument are
  - Sensitive and Efficient **TPC Polarimeters**
  - High throughput **Mirrors**
  - **Rotating Platform**

And lots of Instrument, S/C, and Mission Engineering



Photoelectric X-ray Polarimetry

Resolution < electron mean free path and << photon mean free path is required

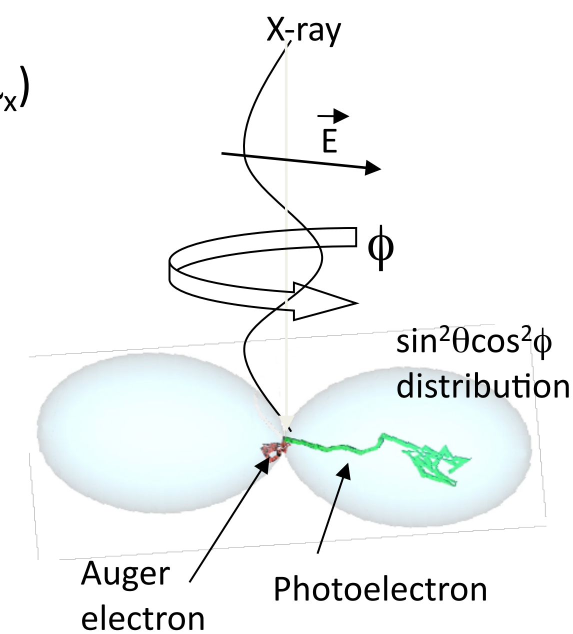
- Exploits: strong correlation between the X-ray electric field vector and the photoelectron emission direction

- Advantages: dominates interaction cross section below 30 keV

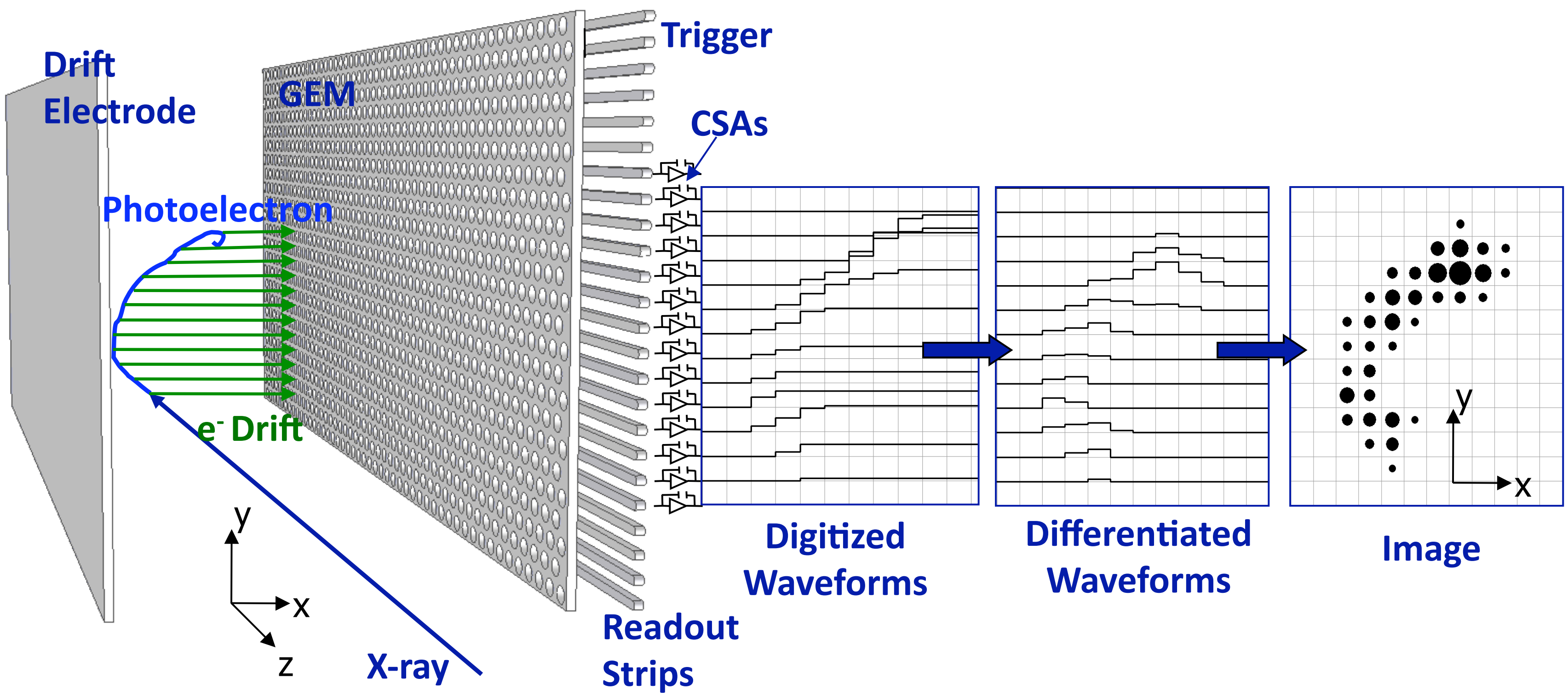
- Challenge:
  - Photoelectron range < 1% X-ray absorption depth (λ_x)
  - Photoelectron scattering mfp < e^- range

- 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



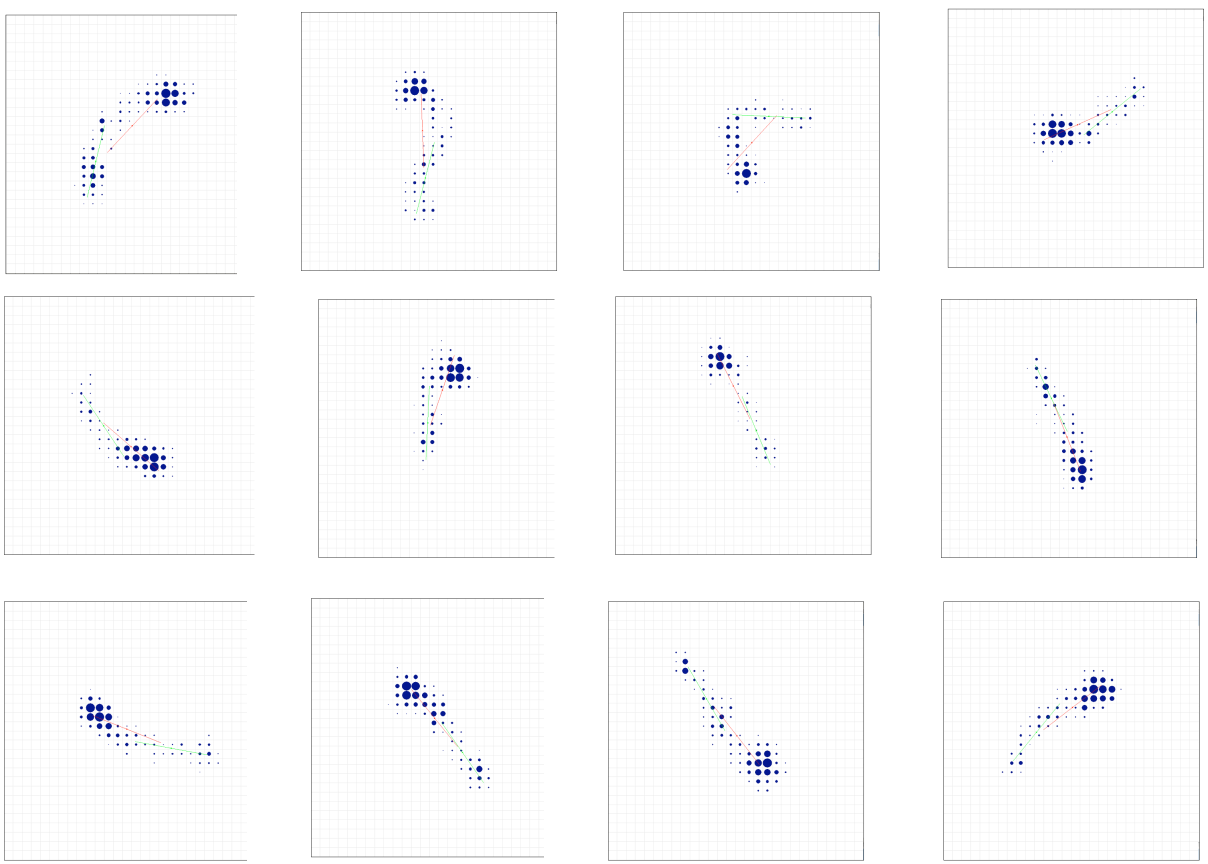
TPC Photoelectric Polarimeter Concept

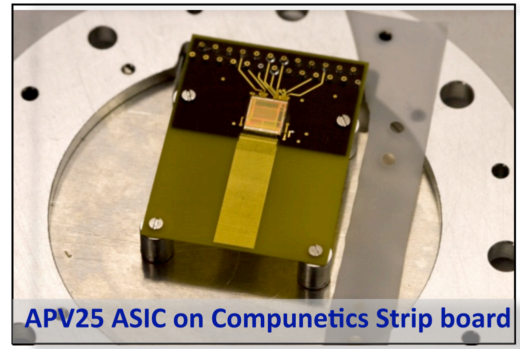


- Image pixels are formed by readout strip pitch (y) and drift velocity/sampling rate (x)
- Quantum efficiency (depth) is perpendicular to readout (drift) direction

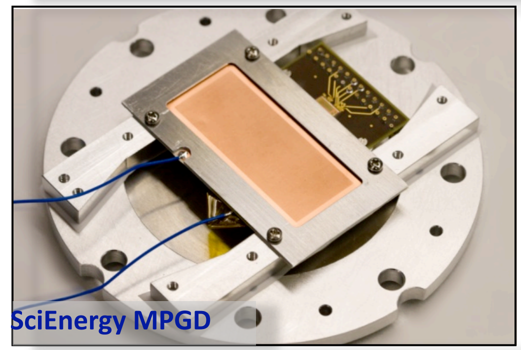
GEMS Electrical EDU

- An Electrical EDU demonstrates the functionality of the APV25 ASIC
- “First Light” - 6 keV tracks

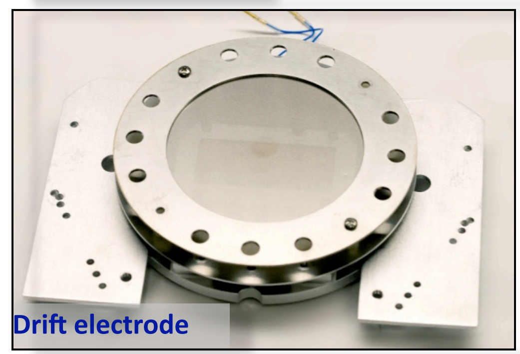




APV25 ASIC on Compunetics Strip board



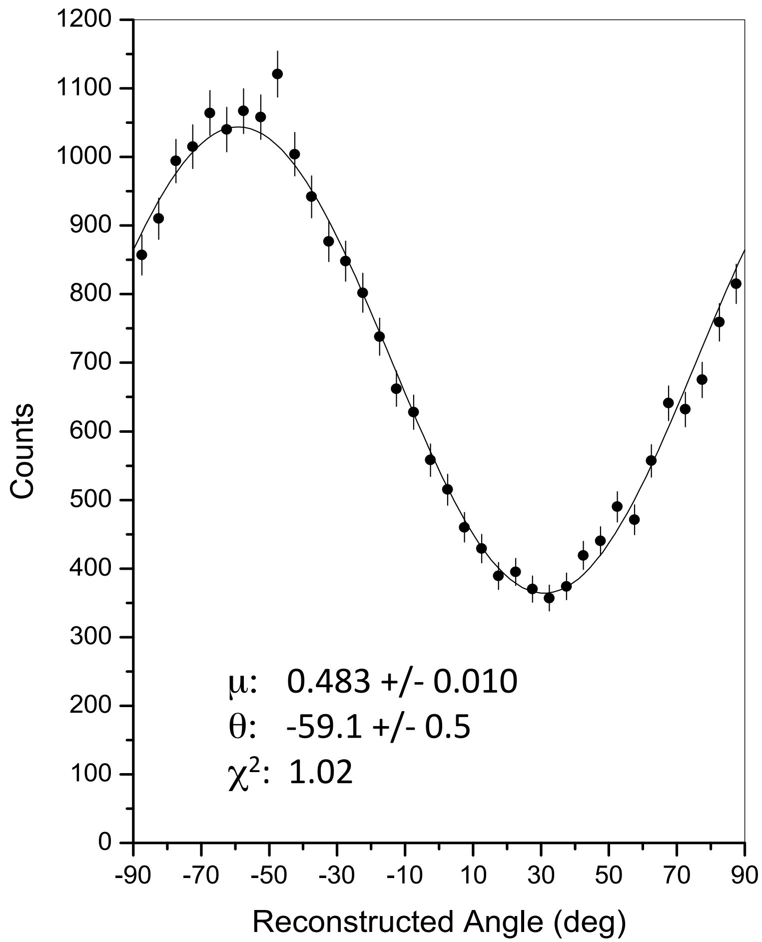
SciEnergy MPGD

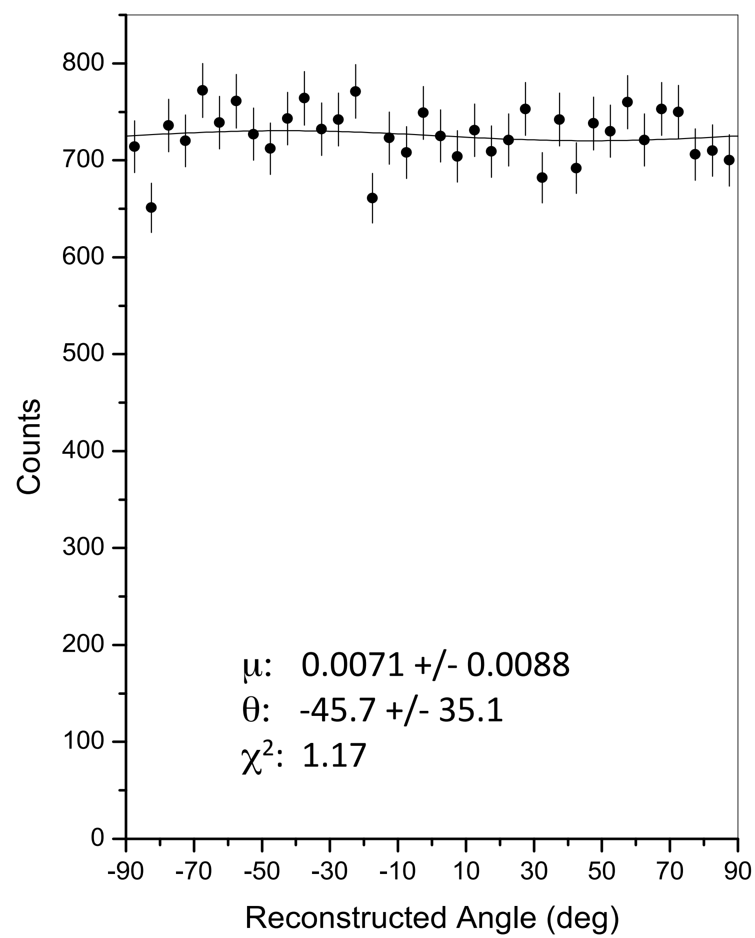


Drift electrode

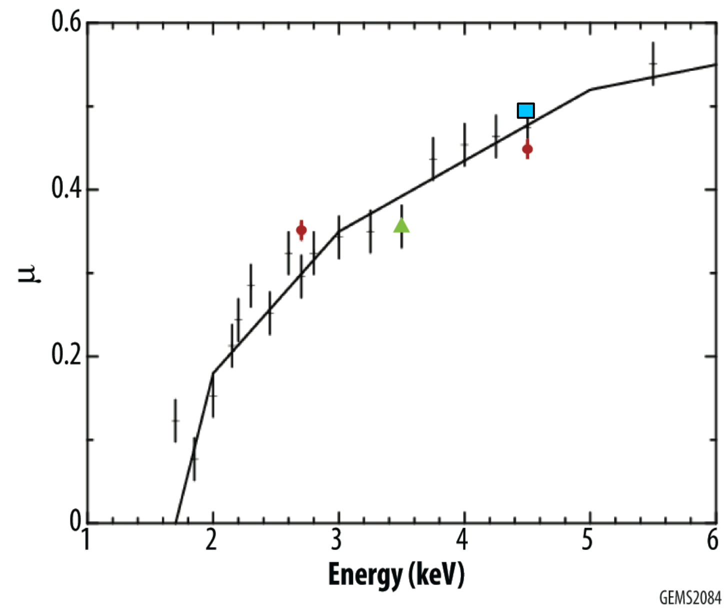
GEMS Electrical EDU

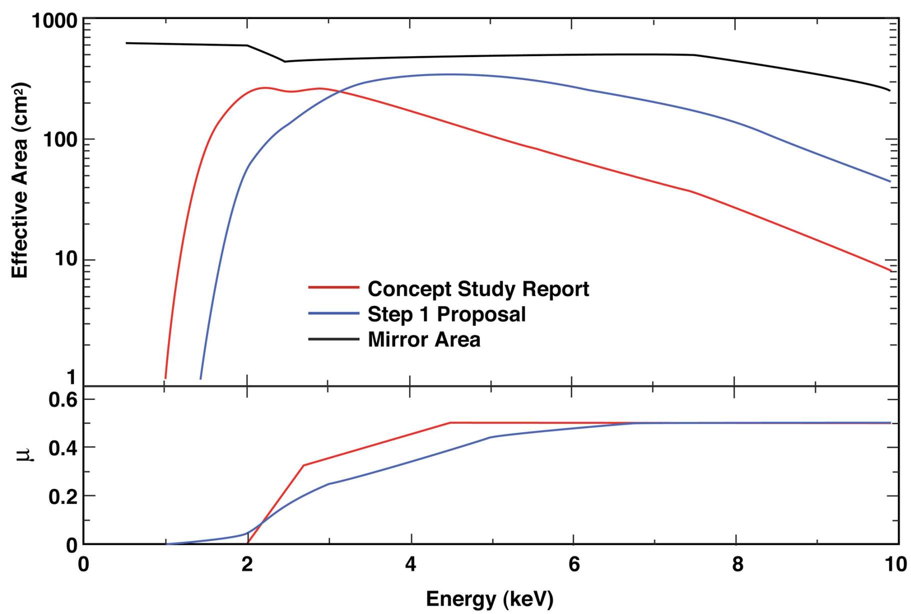
- Modulation at 4.5 keV in flight conditions

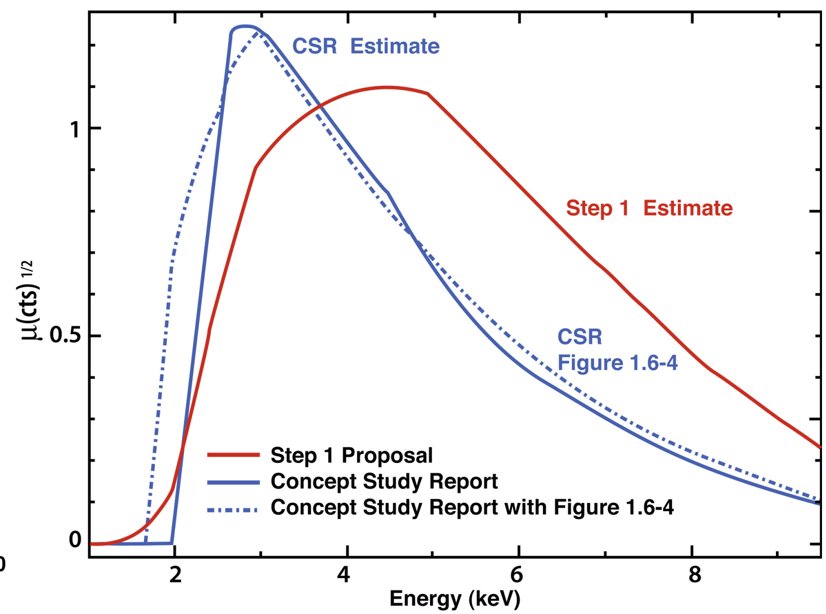




Sensitivity Figures of merit

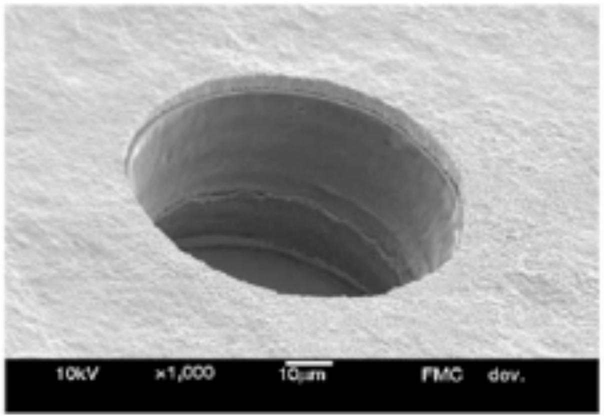


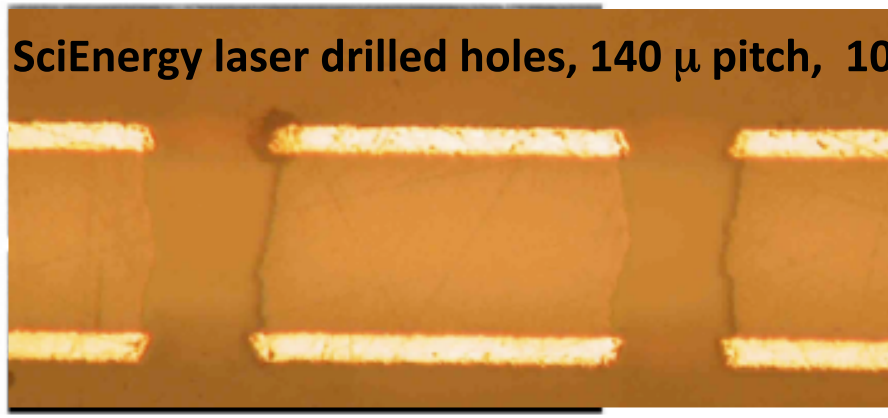




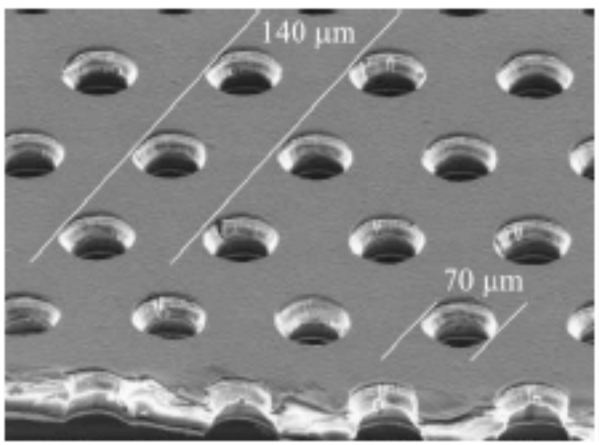
Question 3 – MPGD Performance

Laser drilling leaves very little exposed dielectric penetrated by field lines

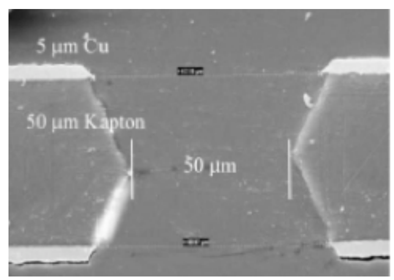


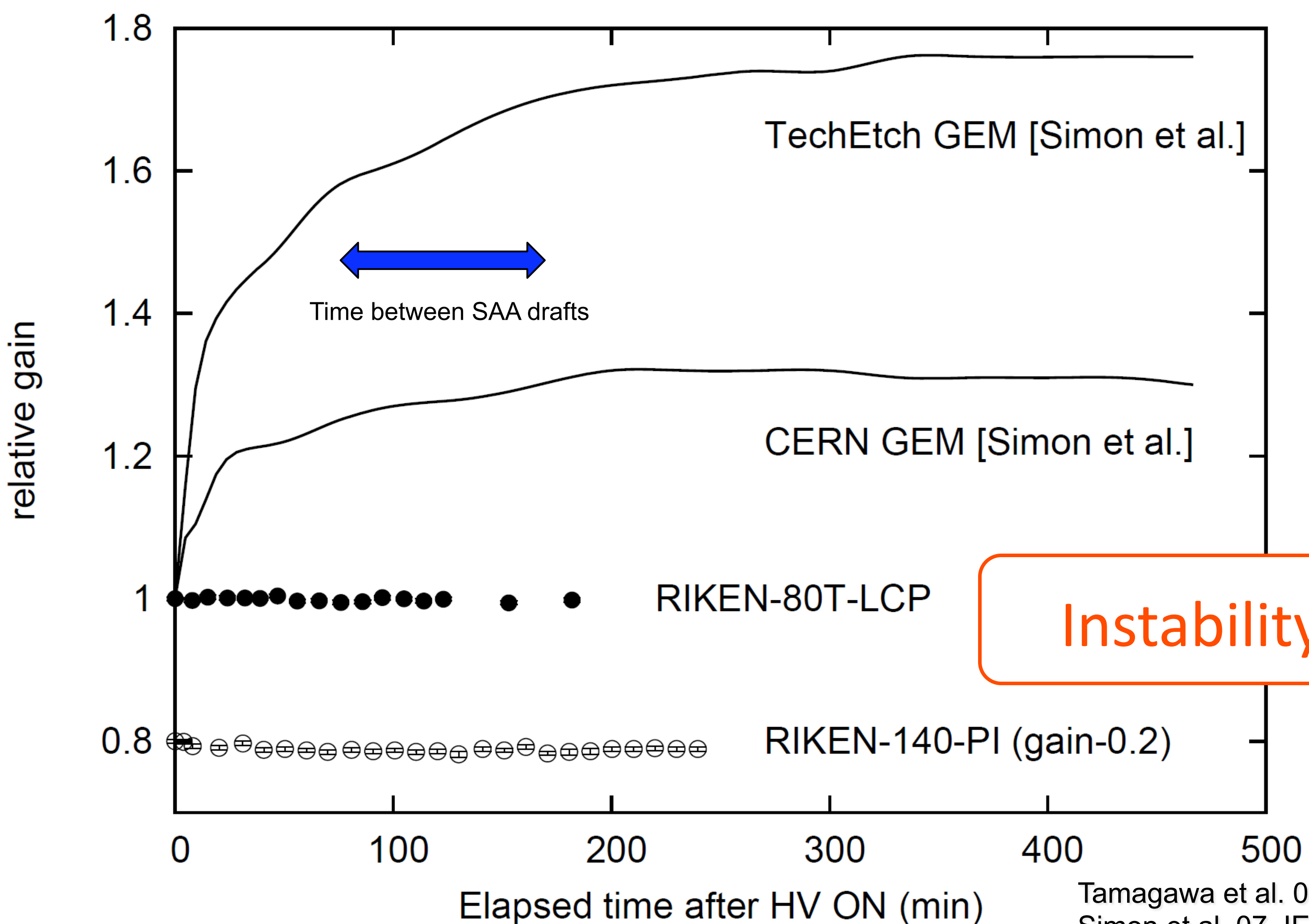


SciEnergy laser drilled holes, 140 μ pitch, 100 μ thick



CERN wet-etched holes, 140 μ pitch, 50 μ thick



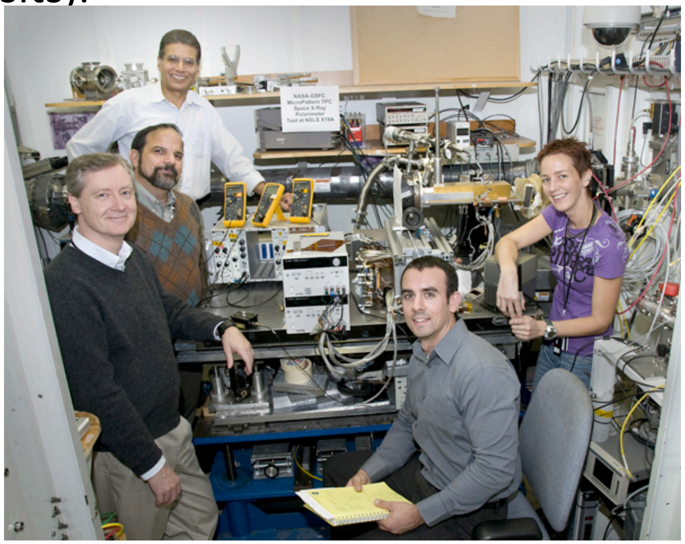


Instability < 1%

Tamagawa et al. 09, NIM A submitted
Simon et al. 07, IEEE-Trans NS 54, 2646

GEMS Ground Calibration

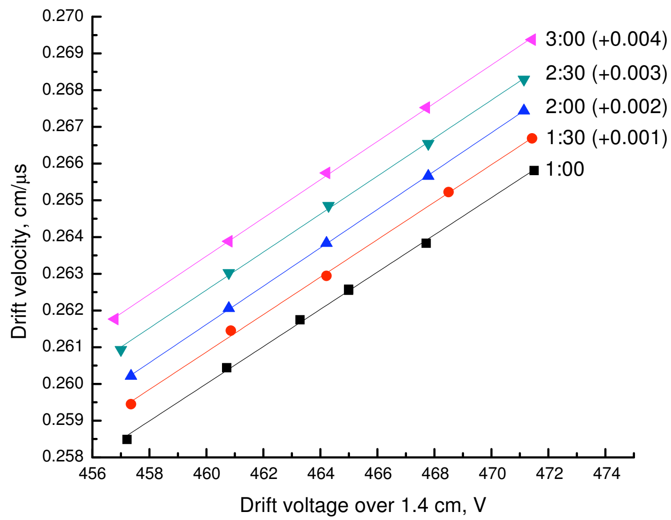
- Approach -
  - Sufficient, well chosen measurements to allow:
    - Construction of a detailed response matrix
    - Parameterized by measurable quantities (in flight or ground calibration)
- Data obtained at GSFC (for each detector):
  - Polarization at selected energies (matched atomic lines and 45 deg Bragg crystals)
  - "Unpolarized" input at numerous energies
    - Unpolarized data sets can be constructed with any atomic line and rotation
- Data obtained at BNL (one detector, one or more visits):
  - Tunable energies
- Data obtained at U. Iowa (for each detector):
  - Collimated beams, polarized and unpolarized, map uniformity
- Background
  - Response to γ-rays, electrons, protons
  - Rejection efficiency



Black, Martoff, (BNL staff), Dion, Hill at BNL

GEMS In-Orbit Calibration

- X-ray tube periodically illuminates active region
  - Tracks energy scale over orbit scales
  - Tracks polarization sensitivity on observation time scales

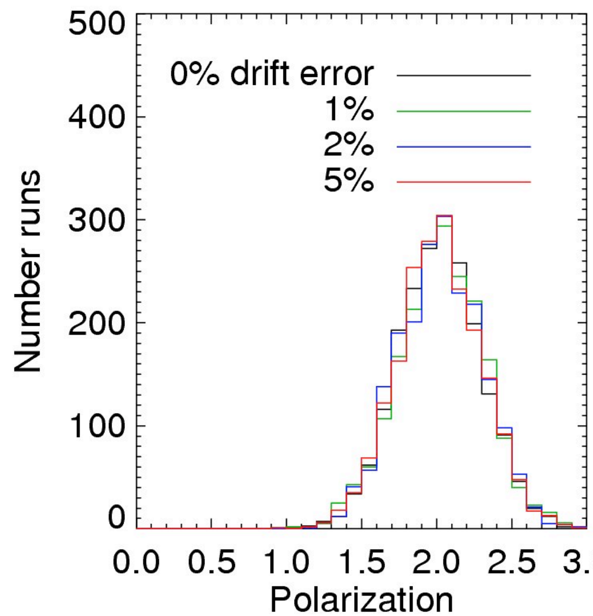


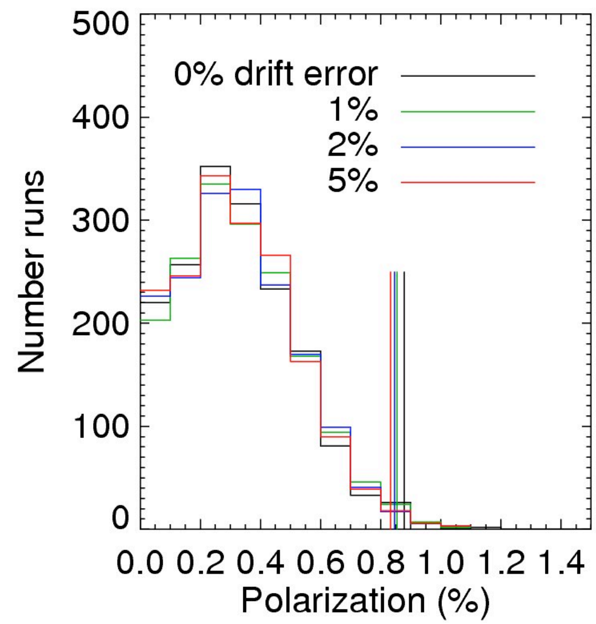
- UV pulser provides sensitive drift velocity calibration on frequent basis

- Spacecraft rotation allows data to be folded against sky angle or detector angle - modulation vs detector angle provides input to response matrix and eliminates sensitivity to residual asymmetries

Identifying and Controlling False Modulation

- Spacecraft rotation mitigates residual asymmetries
- Simulations with 10^6 photons/run ($\mu \sim 0.5$, MDP < 0.01) show the power of spacecraft rotation
  - PROCEEDURE
  - Generate photons
  - Move photon E-field into detector frame
  - Generate photoelectron direction with $\cos^2(f)$ 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

Measuring Background Polarization

- At the faintest fluxes, unrejected background, while small, is no longer negligible
- The average background is predicted to be ~0.15 mCrab
  - 0.09 ct-s^{-1} (sum of all three detectors)
  - scaled from OSO-8 Neon counter (Bunner 1978, Ap.J., 220, 261)
- Background intensity and apparent modulation can be measured from parts of TPC which do not see the source.
-