GEM-TPC X-ray Polarimeter onboard GEMS Satellite

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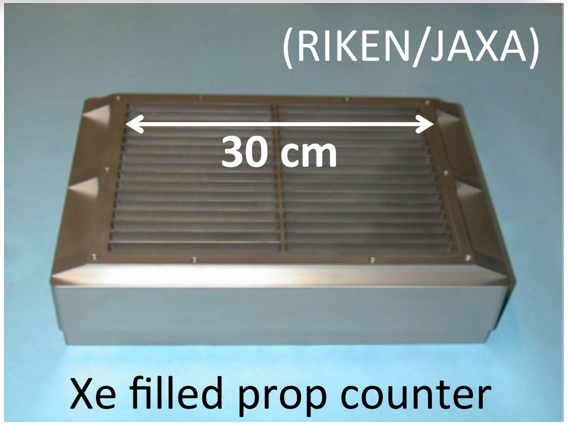
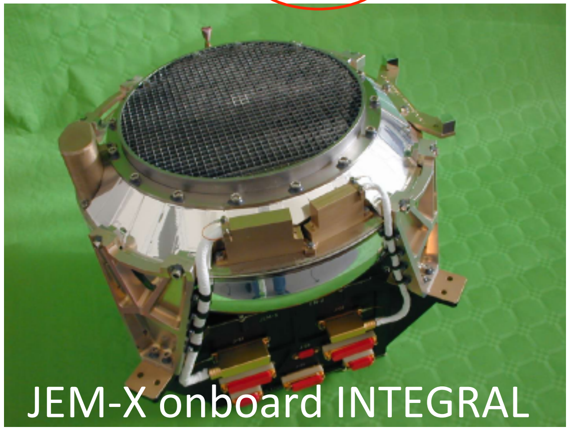
OUTLINE

1. A brief Introduction to polarimetry
2. GEMS mission and GEM-TPC X-ray Polarimeter
3. Performance of the polarimeter
4. Onboard calibration and lifetime estimation
5. Summary and Outlook

1.1 Gas detectors used in space

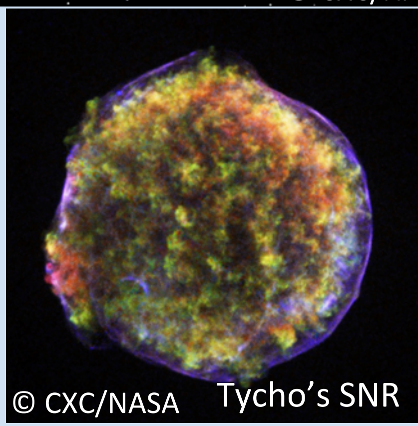
- Gas Detectors
  - key device in X-ray astrophysics for 50 yrs
  - easy to construct large-area counters
  - Ginga, RXTE, MAXI etc.
- Micro Pattern Gas Detectors
  - JEM-X onboard *INTEGRAL*, the first mission employed MSGC
  - Some space applications proposed
- X-ray Polarimeter
  - Ideal application of gas detector (Sakurai+1995)
  - Suitable for MPGD (Costa+2000, Bellazzini+2003, Black+2007, Hayato+2007)



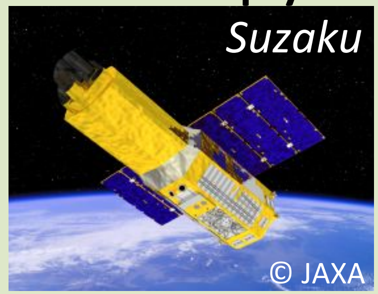


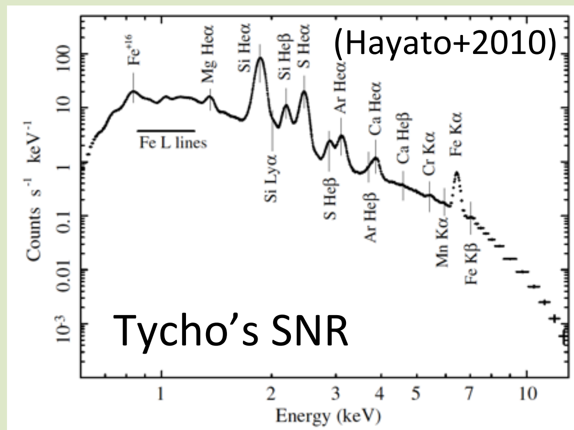
1.2 Open a new field in astrophysics

Imaging

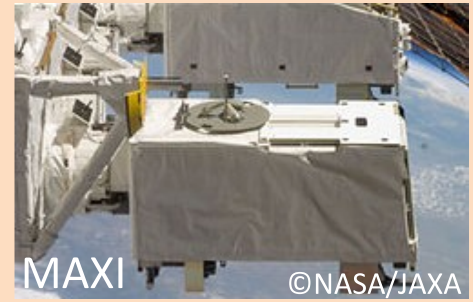


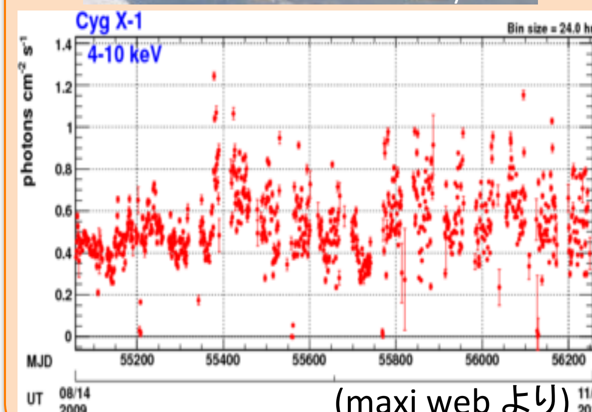
Spectroscopy





Timing

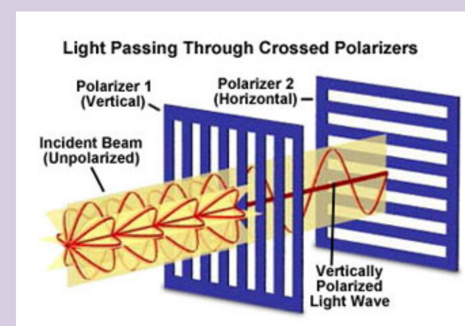




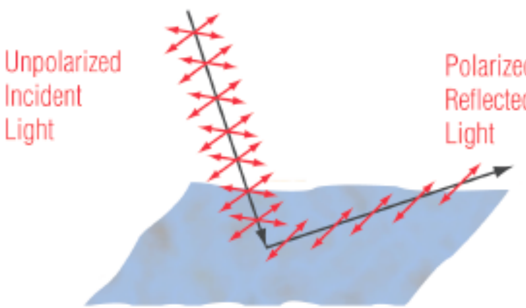
Polarization

- New dimension
- Final frontier in X-ray Astrophysics

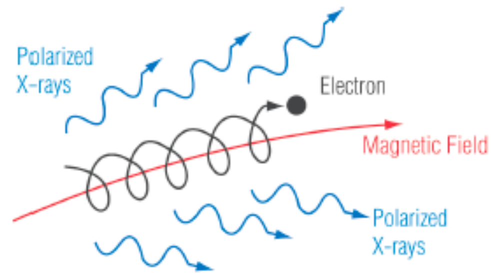
Polarimetry is technically easy in radio and optical, but not in X-ray/gamma-ray. We should know electric vector photon-by-photon.



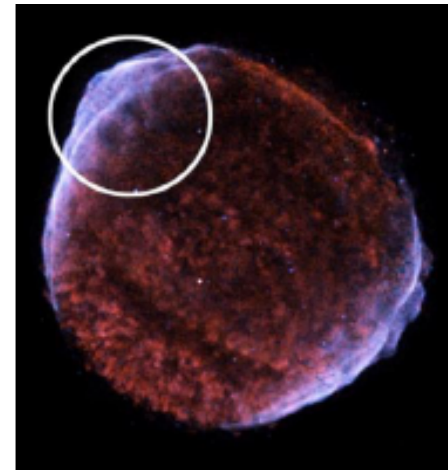
- Explore strong magnetic and gravitational Field
- Geometry of plasma around high energy phenomenon

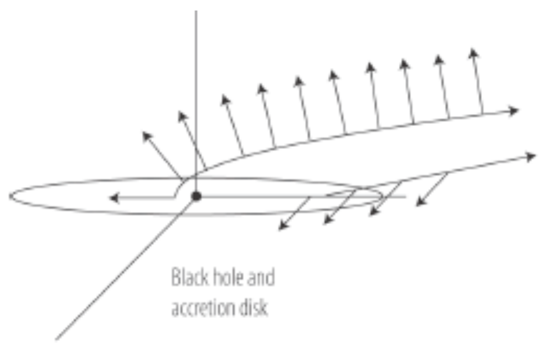


Scattering induces polarization.

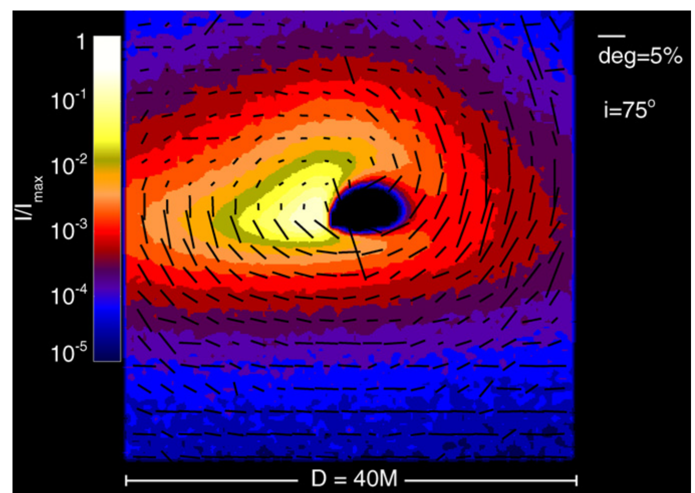


Electrons in strong magnetic field radiate with polarization perpendicular to B.

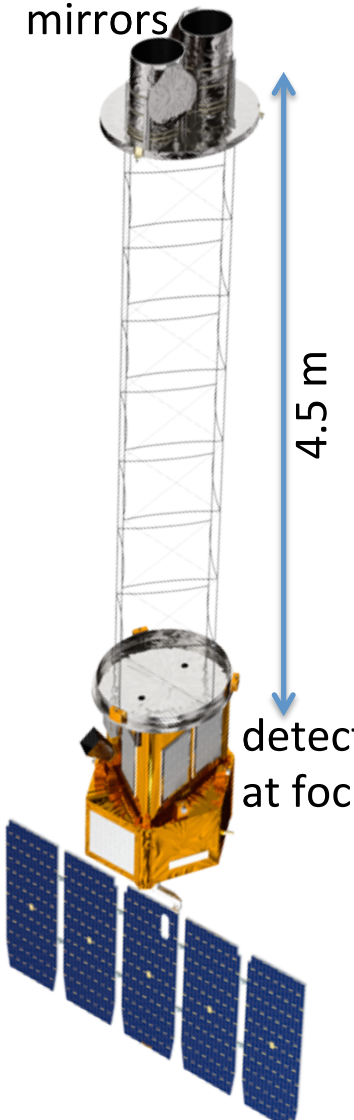




Gravitational distortions of space bend the photon trajectories and rotate polarization.



2.1 GEMS mission overview

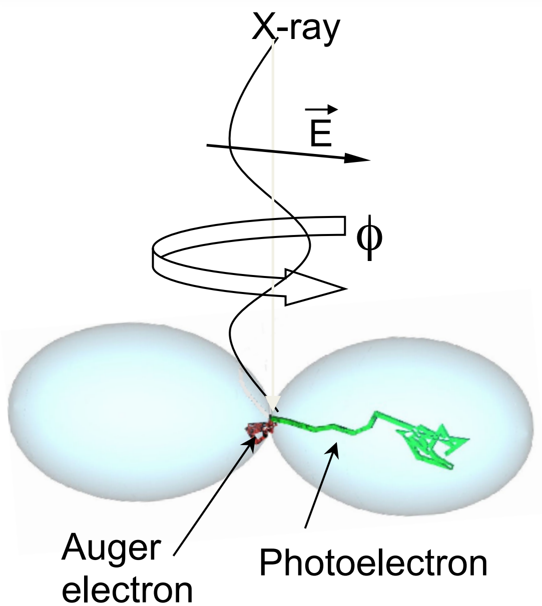


The Gravity and Extreme Magnetism Explorer (GEMS)

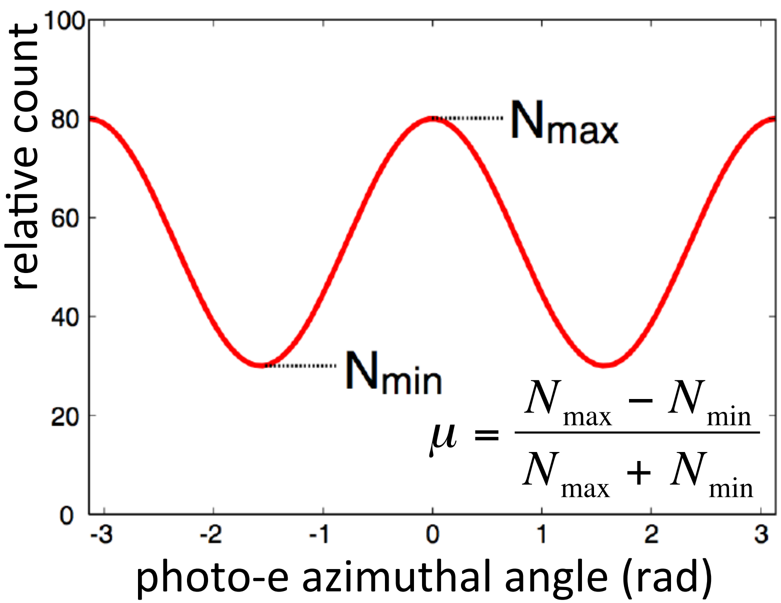
- Selected by NASA in 2009 for launch in 2014 (NASA Small Explorer Mission).
- GEM-TPC polarimeters at the focus of X-ray optics, on the rotating space craft (0.1 rpm).
- Energy Band: 2-10 keV
- Mission Lifetime > 9 months (goal 2 years)
- Low Earth Orbit 565 km, inclination 28.5 deg.
- radiation 3.6 krad over the life of the mission
- Project non-confirmed in 2012 due to cost overrun, but we will propose the mission again in 2014

note: European group are proposing another polarimeter mission XIPE.

2.2 How to measure X-ray polarization



- GEMS polarimeters use the polarization sensitivity of the photoelectric effect.
- As a result of an X-ray interaction, the photoelectron is ejected preferentially in the direction of the electric field.
- differential cross section ∝ $\cos^2\phi$
- quantum efficiency can be $\varepsilon \sim 1$
- Analyzing power μ=1 (intrinsic) but μ<1 (in reality)



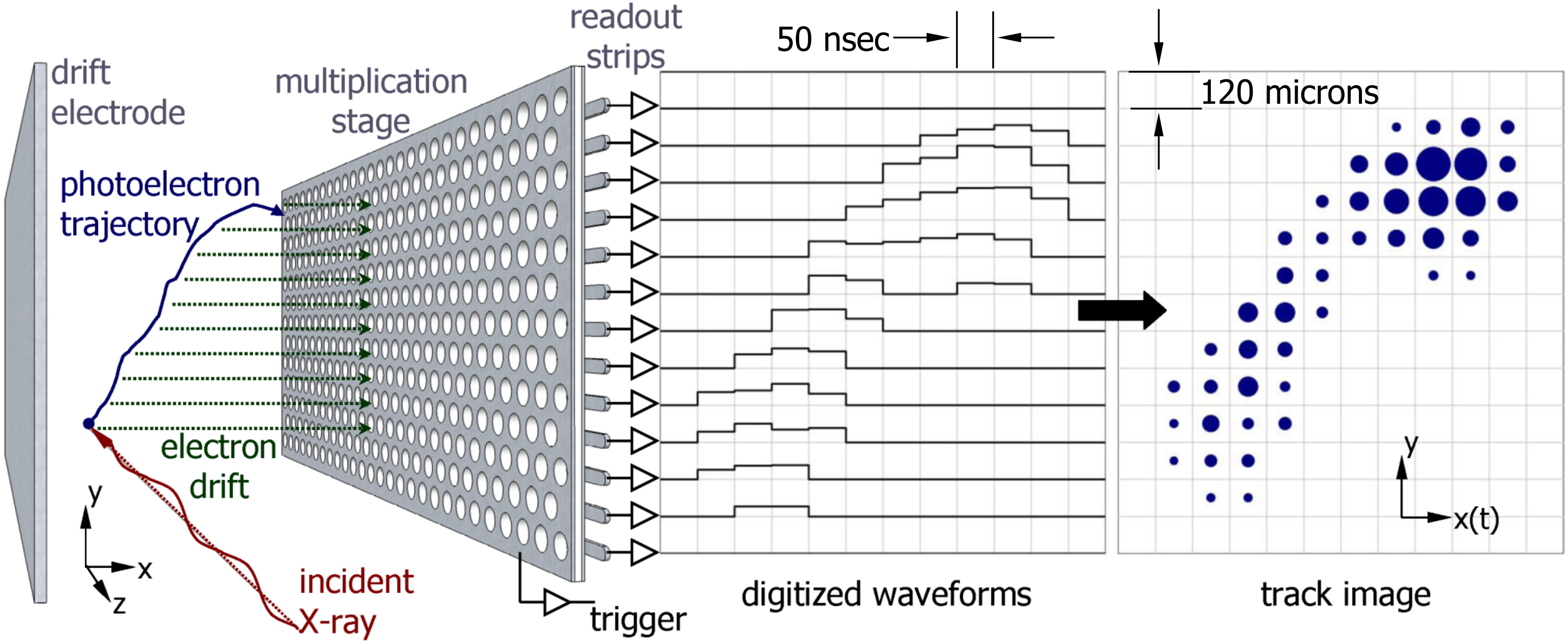
- A gas detector is essential to obtain a longer photoelectron track.
- A micro pattern gas detector is also essential to reconstruct the track.

$$\text{Figure of merit} \propto \mu\sqrt{\epsilon}$$

Optimization is needed.

gas species
pressure
effective volume etc.

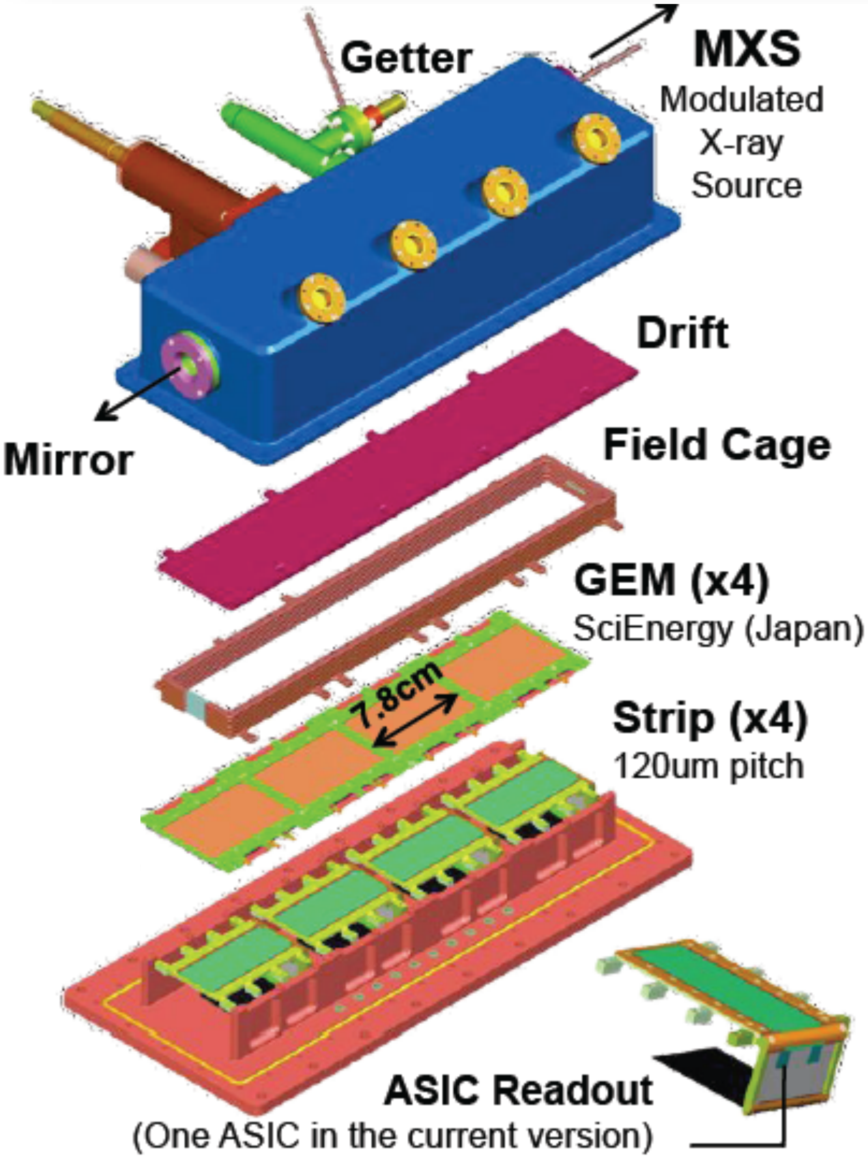
GEM-TPC as a photoelectron track imager (Black+2007)

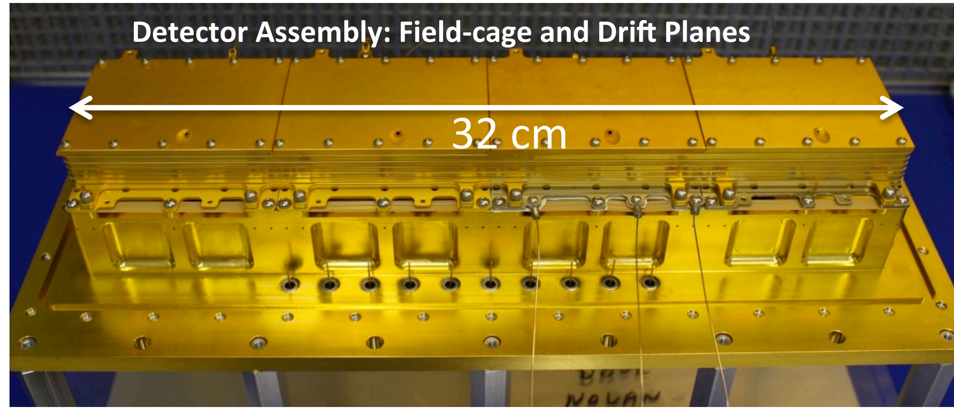


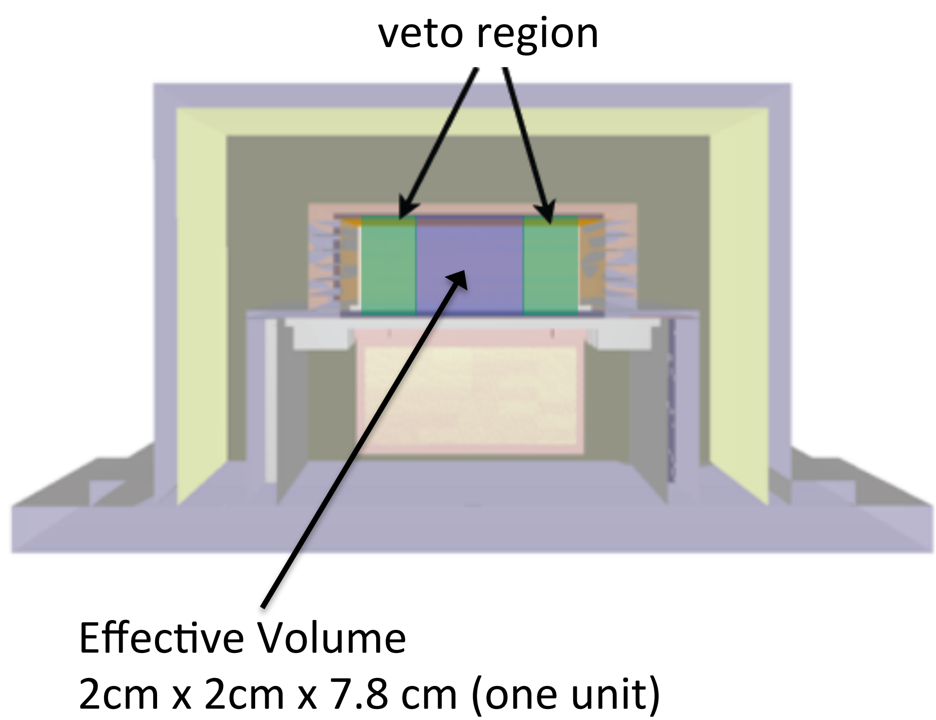
A time-projection technique creates pixel images from a 1D readout.

- Pure DME (C_2H_6O), 190 Torr to obtain longer photoelectron tracks
- Longer (>30cm) effective volume along the optical-axis for good detection efficiency
- Slow drift velocity of DME = spacing of strips (0.25cm/us * 20 MHz = 120 micron)

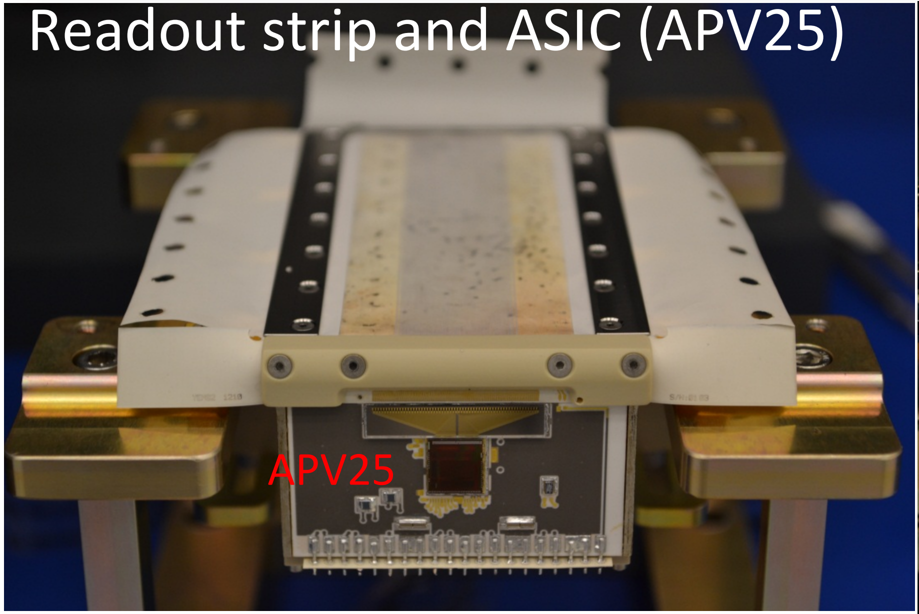
2.4 GEM-TPC Polarimeter

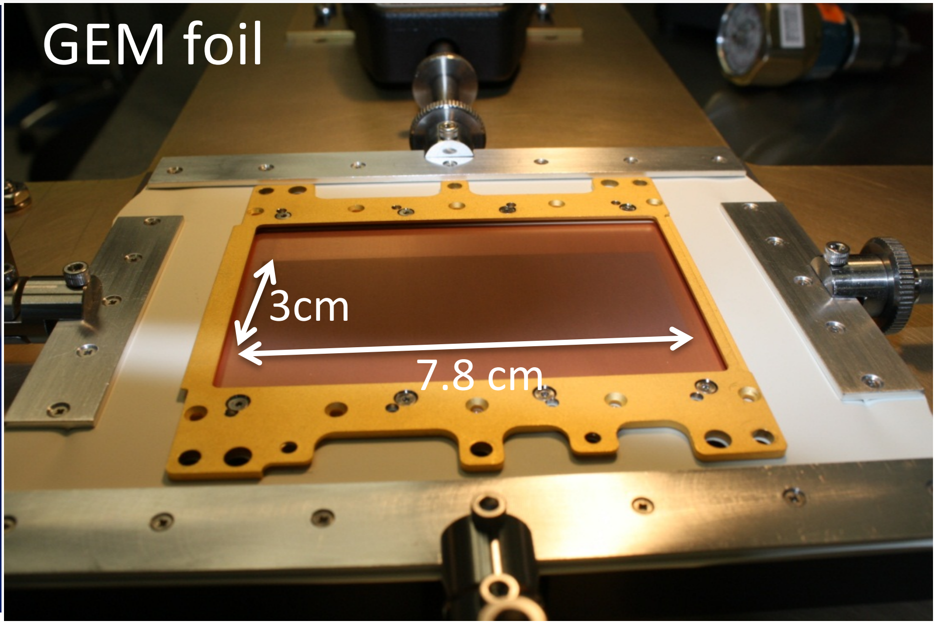






2.5 Readout strip and GEM foils



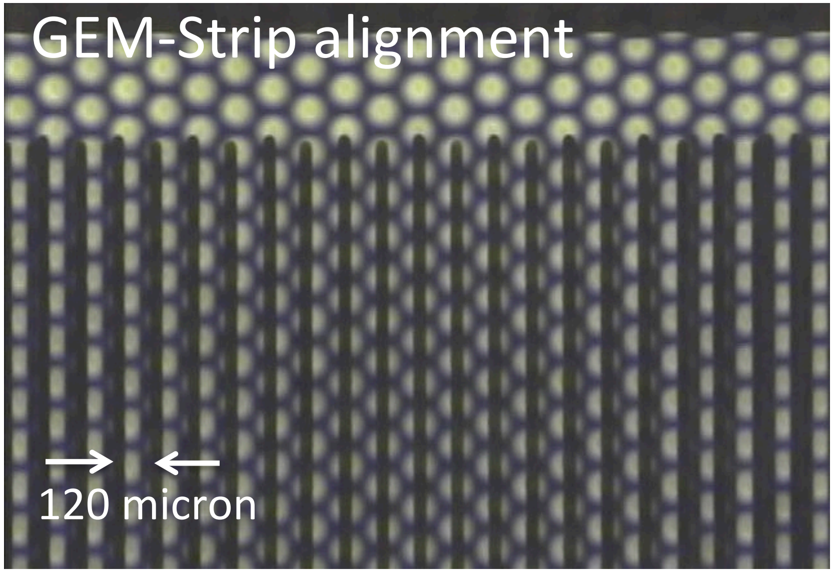


Readout strip

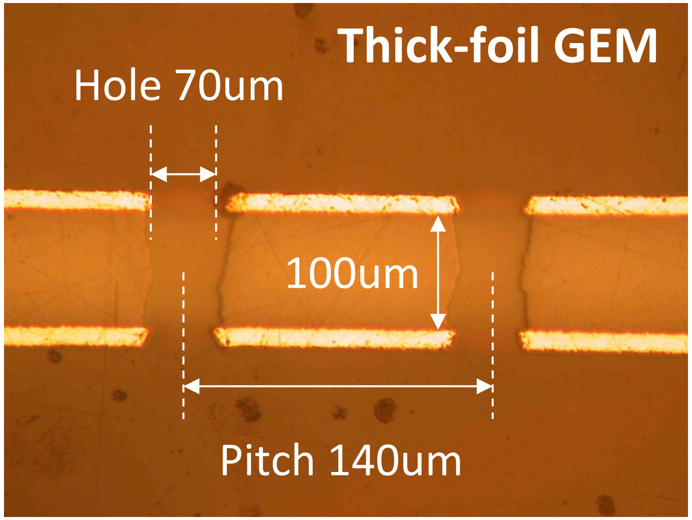
- 128 strips (pitch 120, width 60 micron, 7.8 cm long)
- veto region in both side
- connecting to APV25 (20 MHz clock)

GEM foil

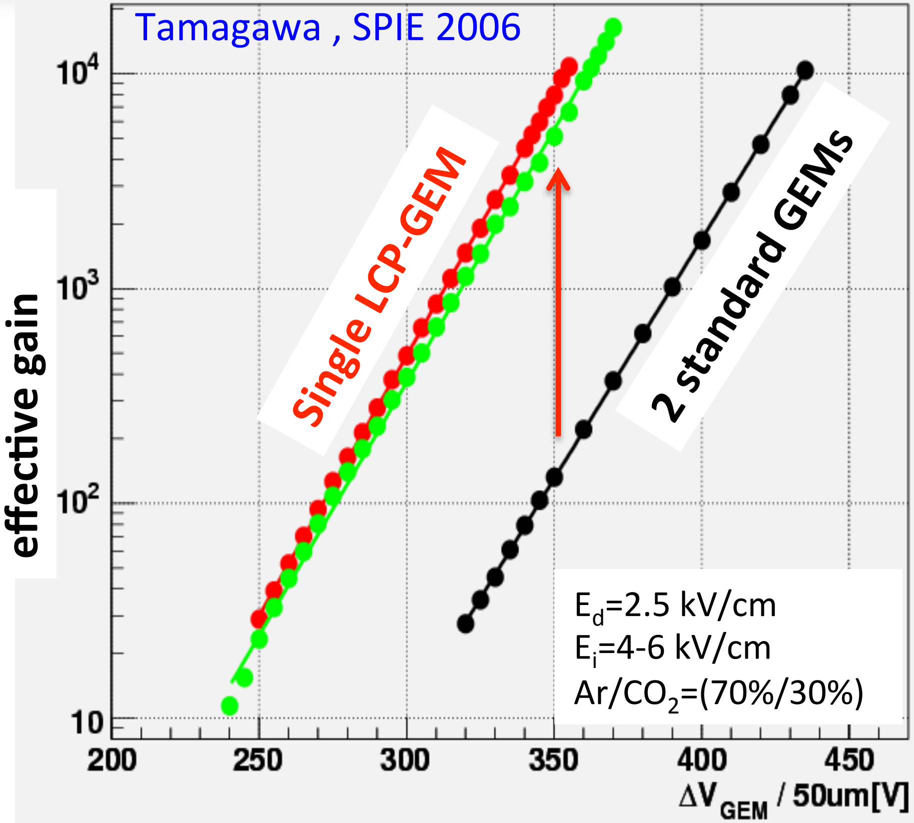
- LCP-GEM
- 140 micron pitch, 70 micron hole
- 100 micron thick



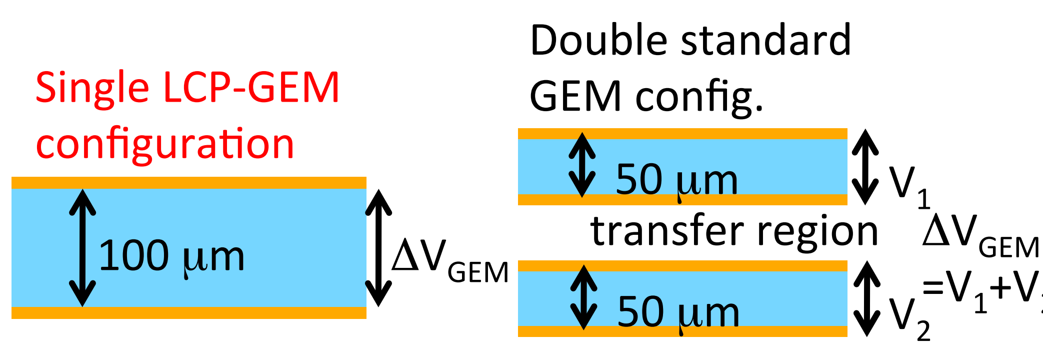
2.6 Thick-foil LCP-GEM



- Laser Drilling (Tamagawa+2006)
- Liquid Crystal Polymer (LCP)
- Two times thicker insulator foil than standard GEM

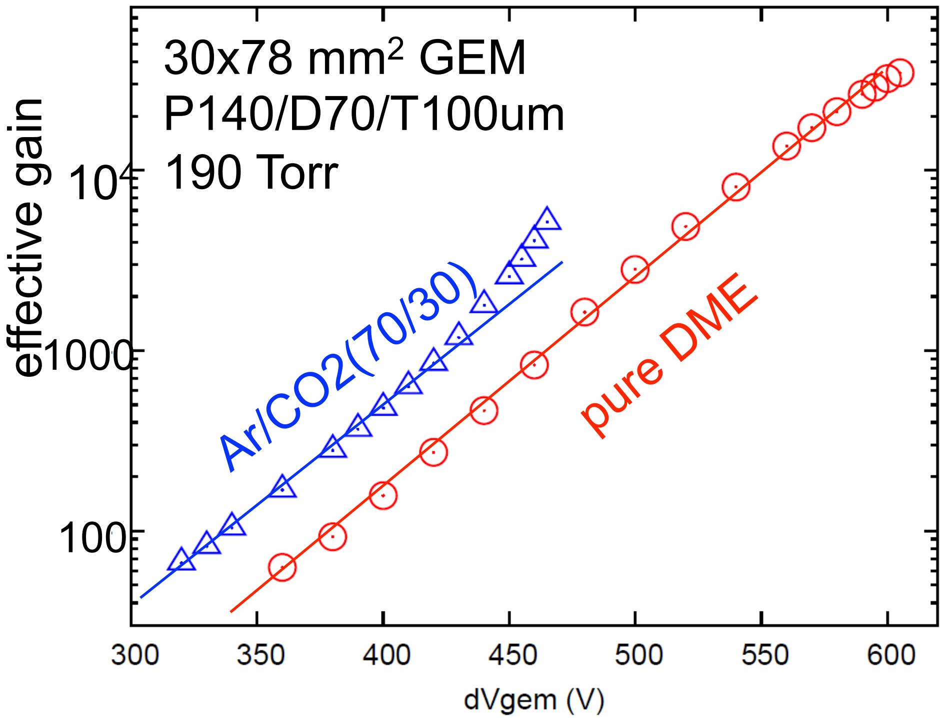


Thick-foil GEM
= efficient way to get
higher gain at lower HV.

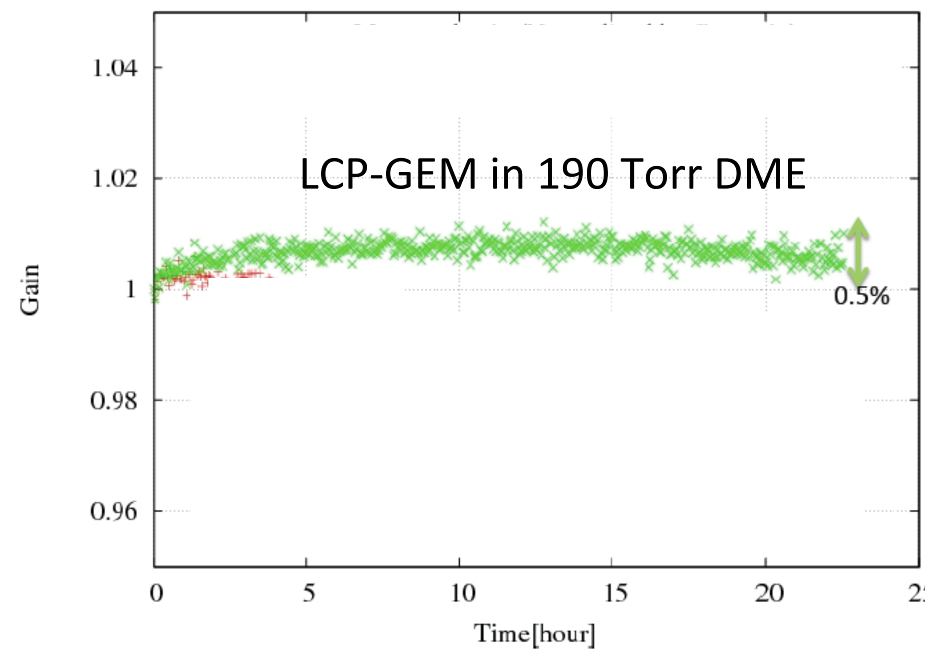


2.7 LCP-GEM operation in DME

Gain curve



Gain stability

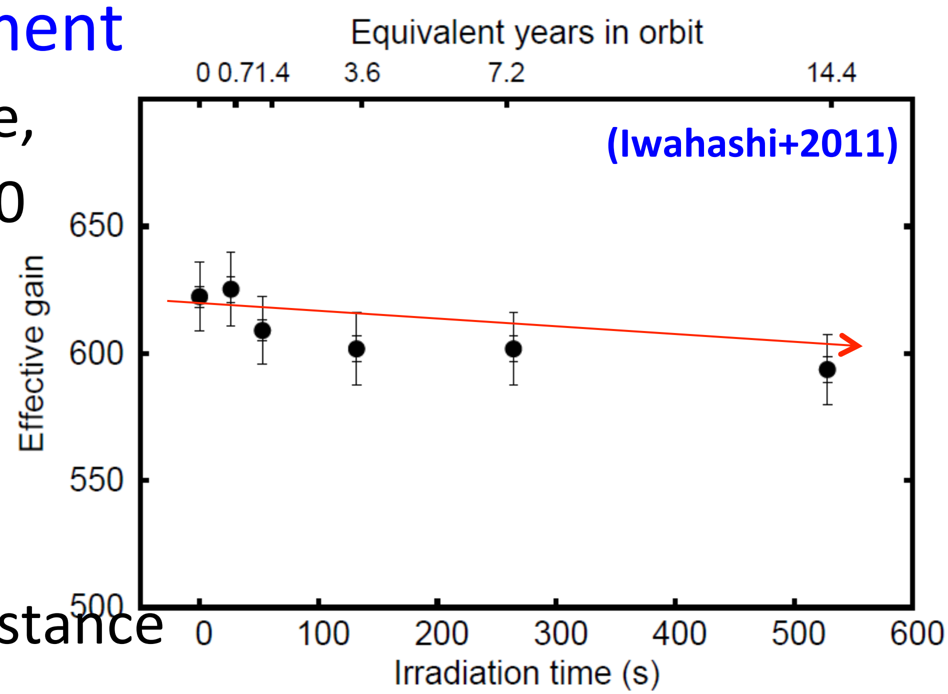


- We can easily achieve gain= 40,000 in pure DME at 190 Torr.
- requirement is around gain=1000-3000

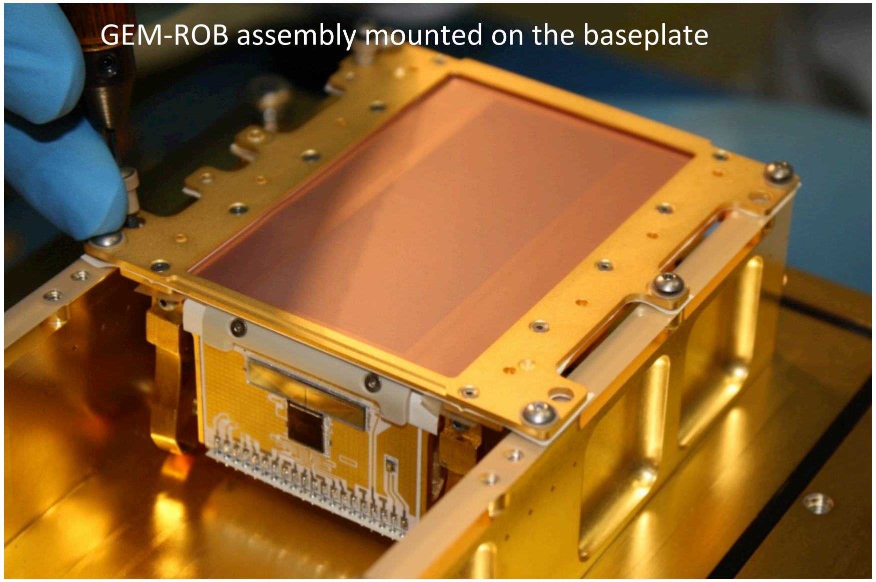
- Gain is stable at the level of 0.5%.

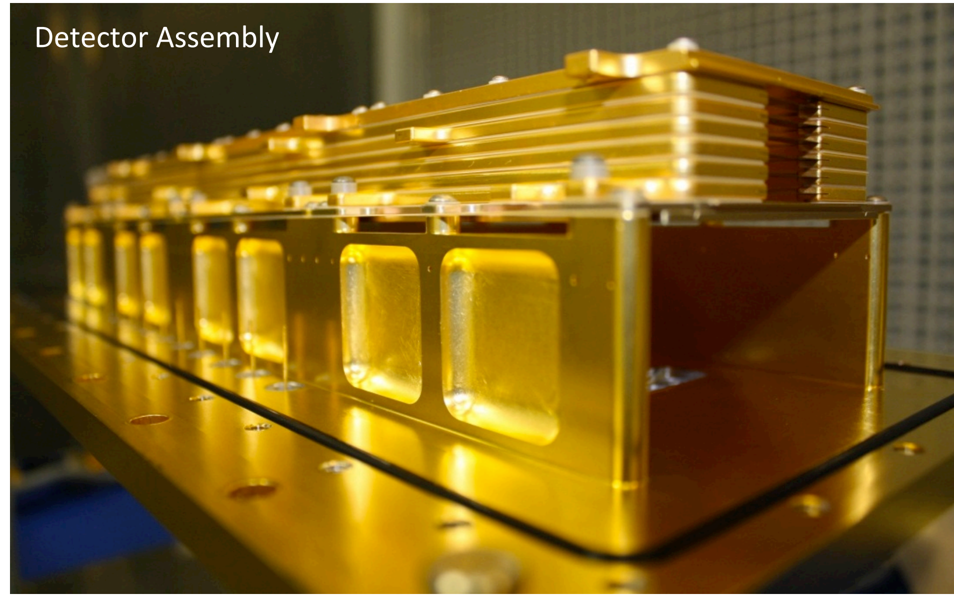
2.8 Radiation Tolerance of LCP-GEM

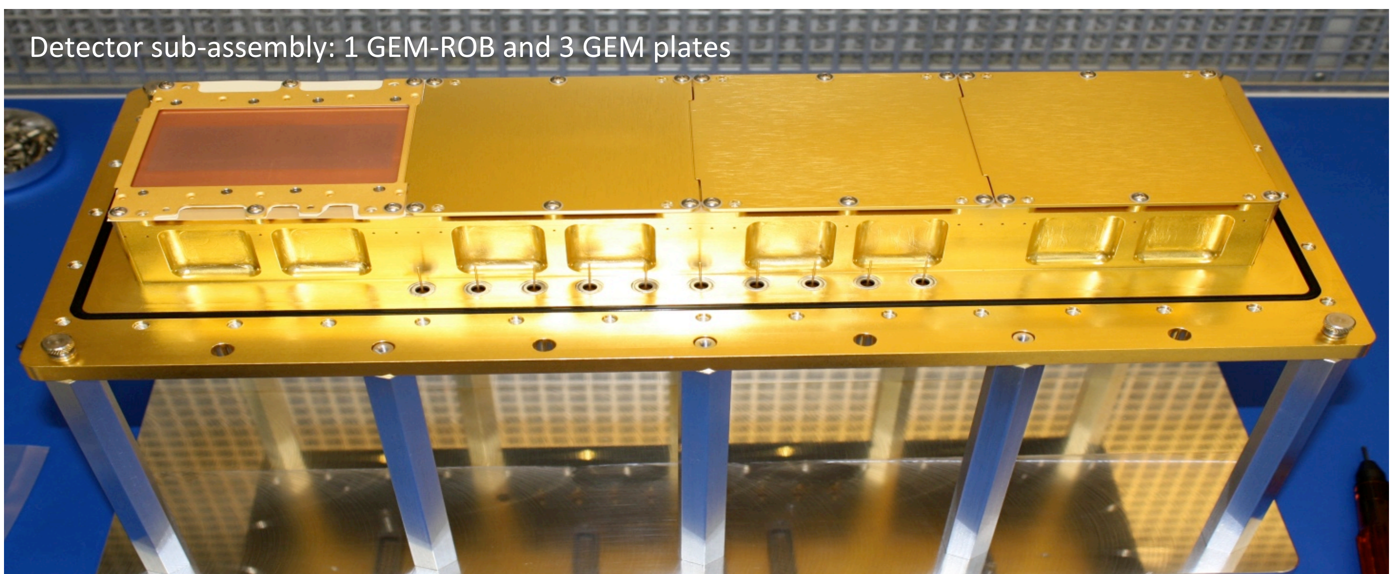
- **High Radiation Environment**
  - LCP is known as a radiation tolerant material.
  - No degradation in withstanding voltage was observed after 5 G rad exposure where Kapton shows 80% degradation of withstanding voltage from initial. (cf. Requirement is less than 10 krad over lifetime.)
- **Cosmic Radiation Environment**
  - We performed heavy ion (Fe, 500 MeV/n) and proton (160 MeV) irradiation tests.
  - For Fe irradiation, 100% of discharge was observed. but safely operate with appropriate protection resistance



2.9 Detector Integration

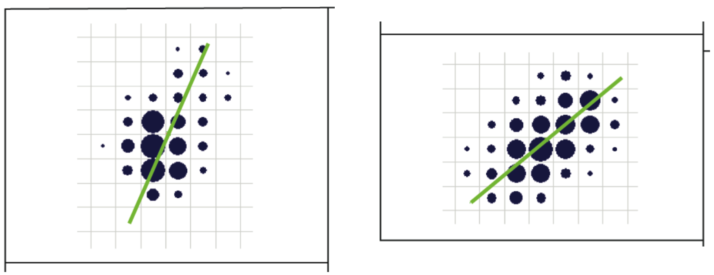

GEM-ROB assembly mounted on the baseplate


Detector Assembly

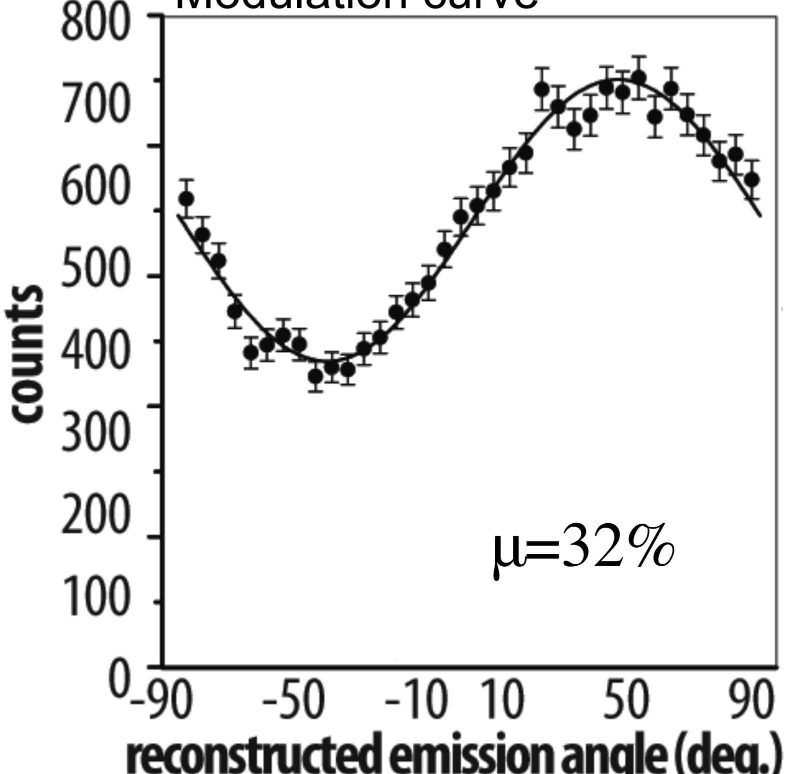

Detector sub-assembly: 1 GEM-ROB and 3 GEM plates

3.1 Track image and modulation curve

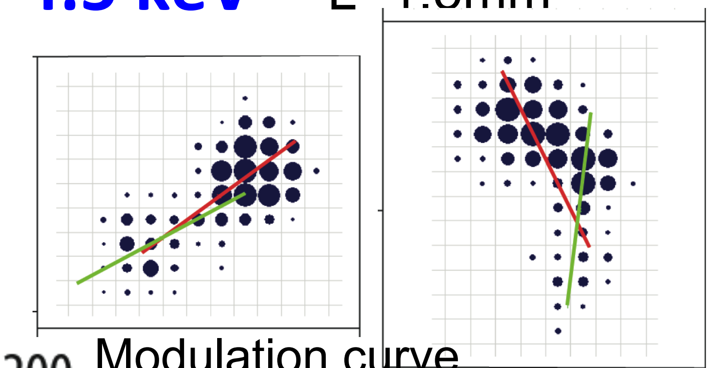
2.7 keV L=600um



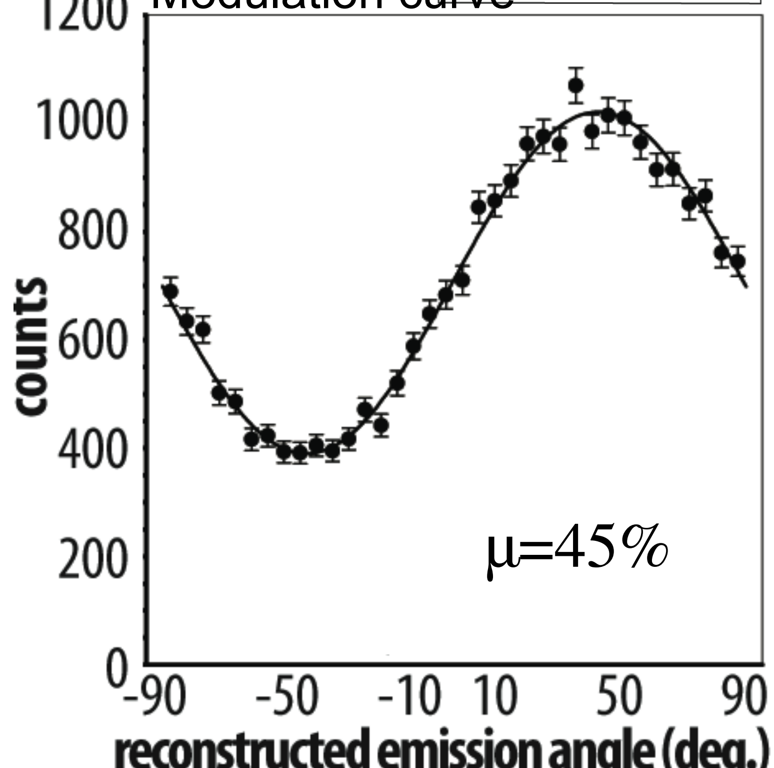
Modulation curve



4.5 keV L=1.5mm



Modulation curve

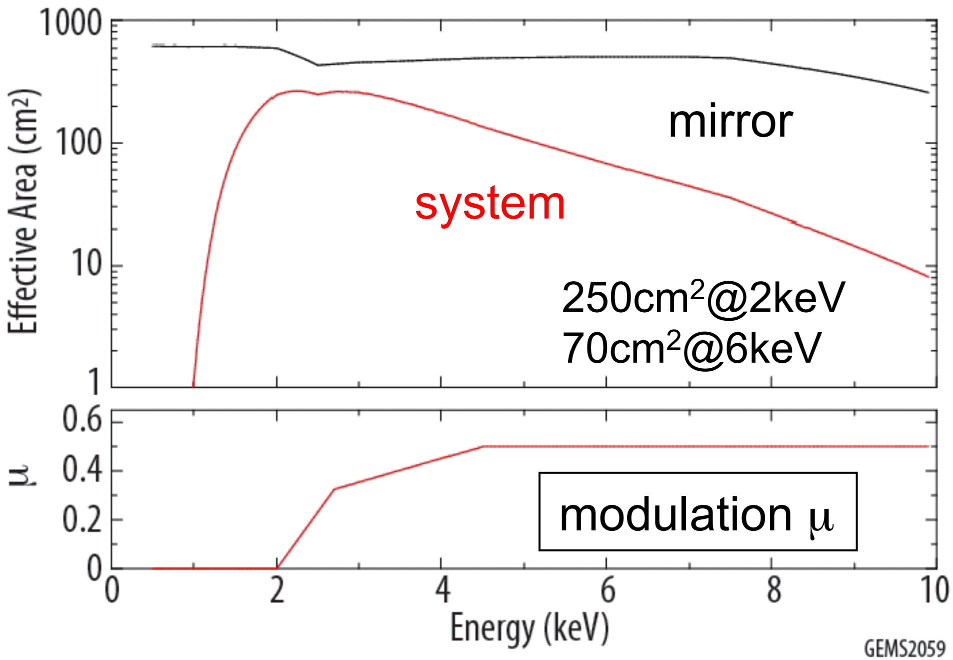


3.2 Sensitivity of polarimeter

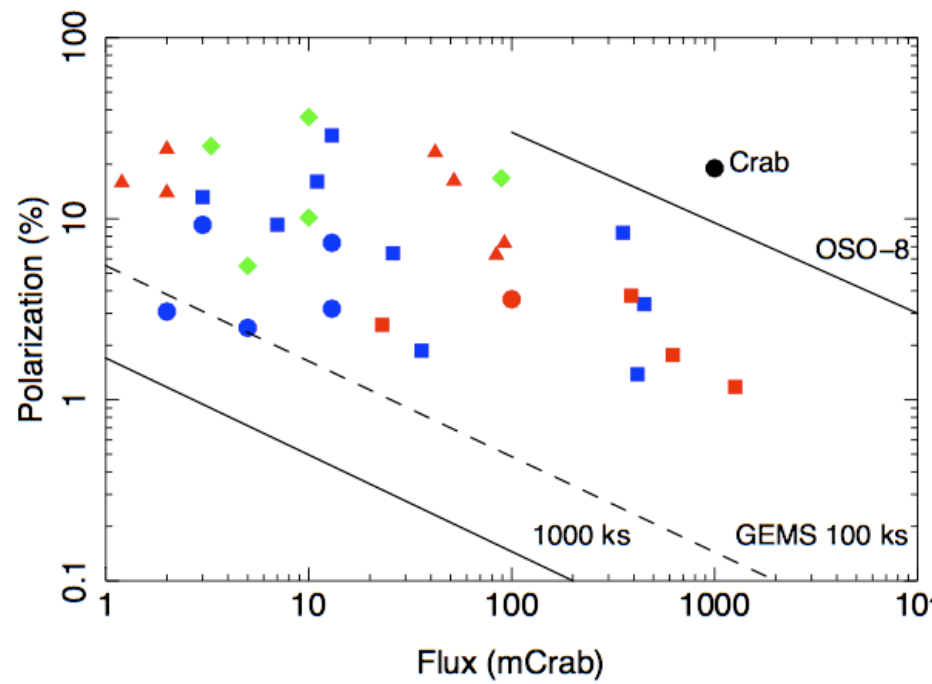
MDP

minimum detectable polarization

$$MDP = \frac{4.29}{\mu \cdot r}\sqrt{\frac{r+b}{T}}$$



sensitivity



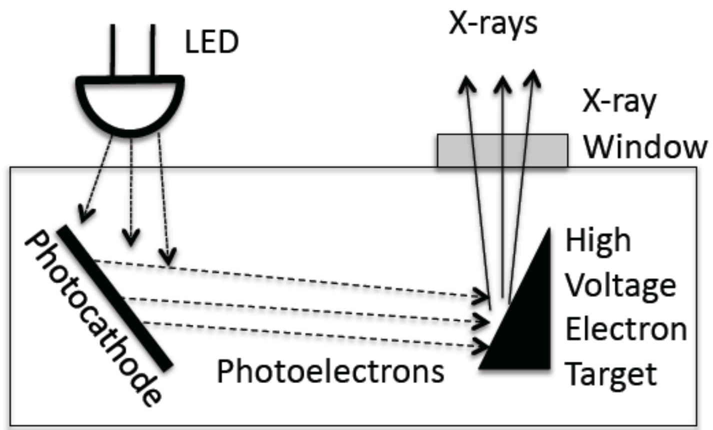
Our GEM-TPC will achieve two order of magnitude higher sensitivity than OSO-8.

4.1 Onboard Calibration

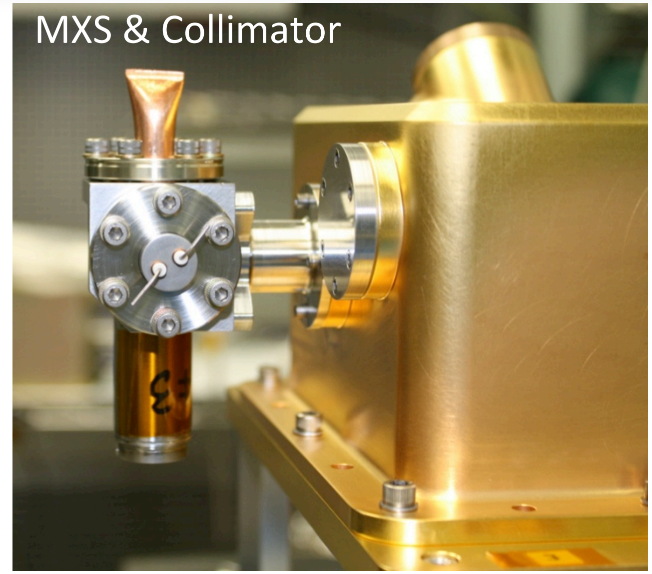
- Onboard calibration is crucial part of the project
  - Energy
  - Drift Velocity

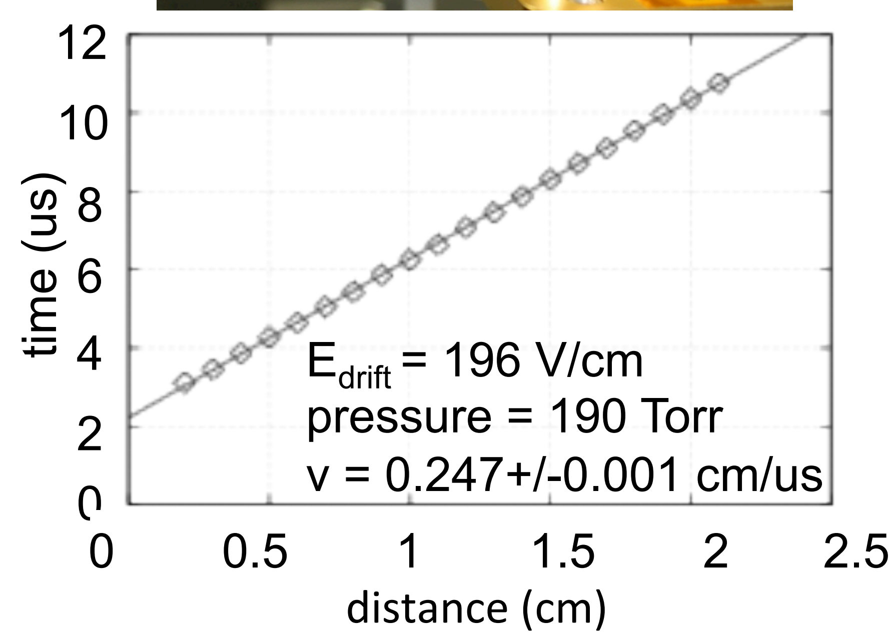
A checking source (e.g. ^{55}Fe) is not appropriate.

- We employ the modulated X-ray source (Gendreau+2010)



- Very good timing ~ nsec
- Emission energy depends on target material Ti (4.5 keV) is suitable.





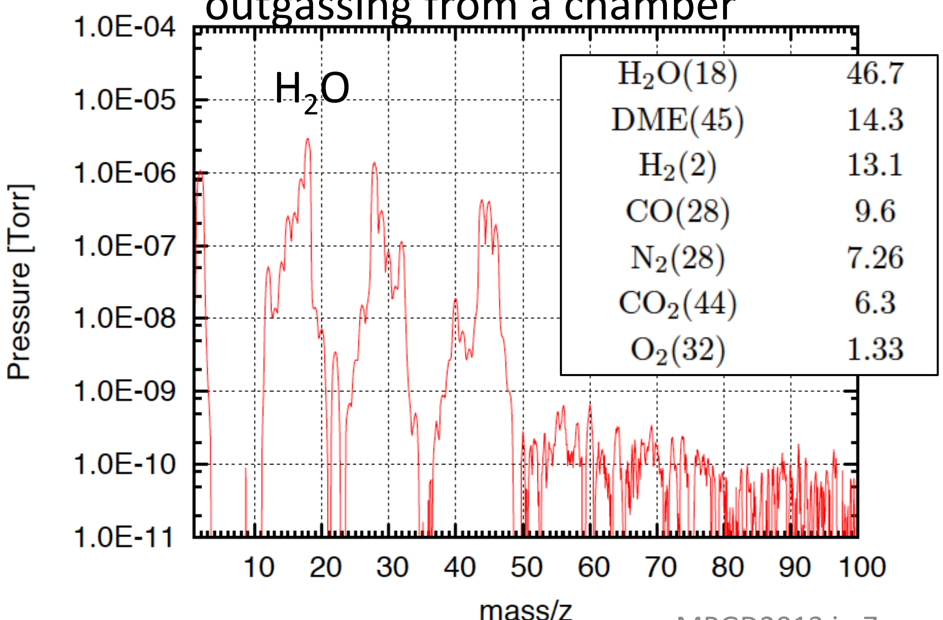
4.2 Lifetime of detector

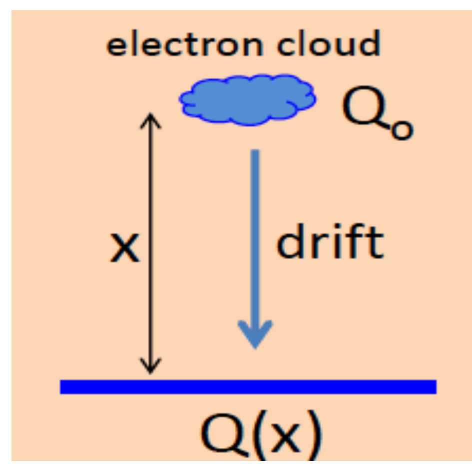
- **Lifetime requirement**
  - 6 months on ground
  - 10 months on orbit
- **Limiter of detector lifetime**
  - Contamination (outgassing)
  - Aging effect

- Variety of materials minimized to reduce number of outgassing species
- Materials carefully selected for DME and high vacuum compatibility
- *PEEK, LCP, Ceramic, Metals*
- bake-outs components
- No epoxies used in assembly

Reduction of outgassing (mostly H_2O) is essential to prevent gas degradation.

outgassing from a chamber





electron attachment coefficient

$$Q(x) = Q_0 \exp(-\alpha \cdot x)$$

keep monitoring α to evaluate gas degradation

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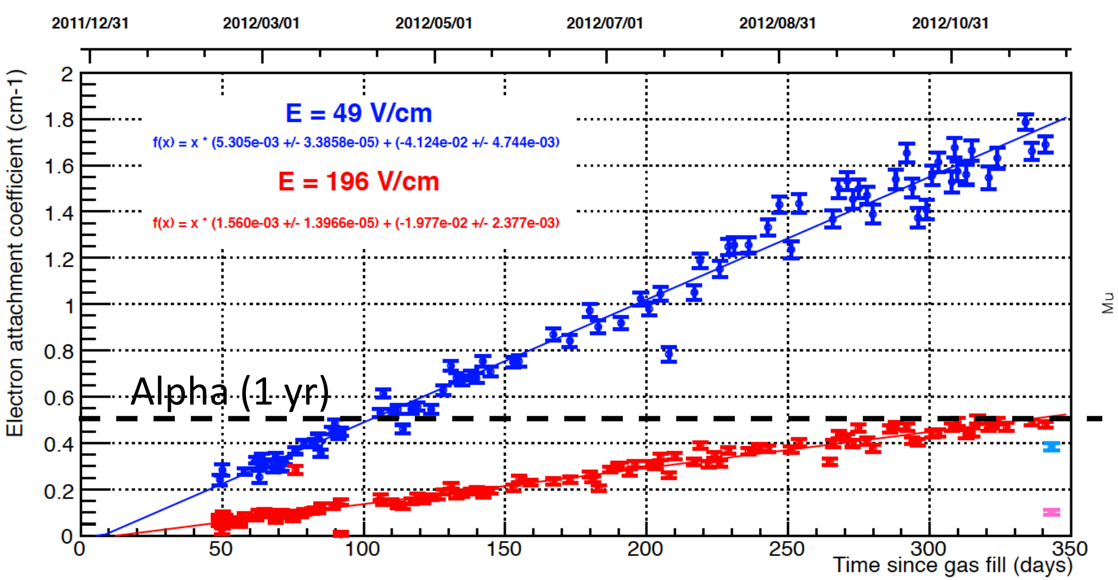

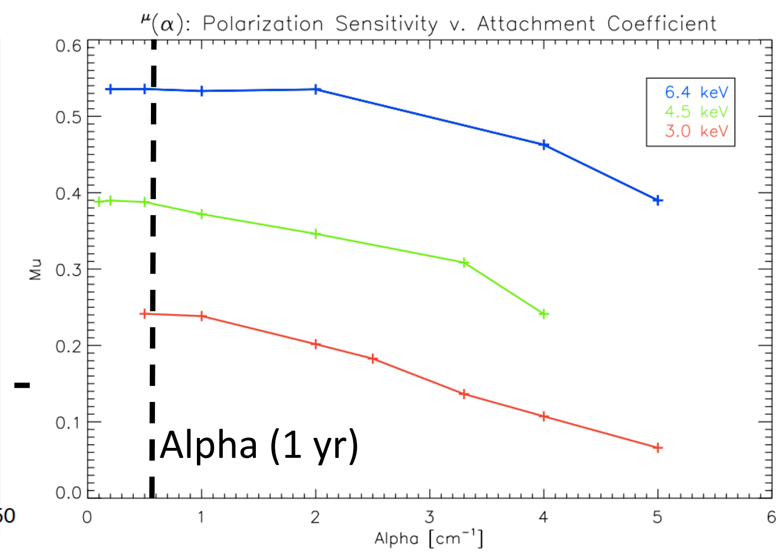

5. Summary and Outlook

- X-ray polarimeter is the best application of MPGD in astrophysics.
- We have fabricated semi-flight detector of GEM-TPC polarimeter for the GEMS mission.
- Operation of LCP-GEM is fine in pure DME at 190 Torr. Electric gain is achieved ~40,000 without any discharges.
- We have the performance which we expected. Detailed performance study is ongoing.
- Lifetime of the detector is mainly limited by outgassing. Current material selection and bake-out protocols have been demonstrated to exceed the lifetime.
- We propose the GEMS mission again in 2014.