HXMT: the Hard X-ray Modulation Telescope mission
POLAR: the GRB polarimeter onboard China's Tiang-Gong 2 Spacelab

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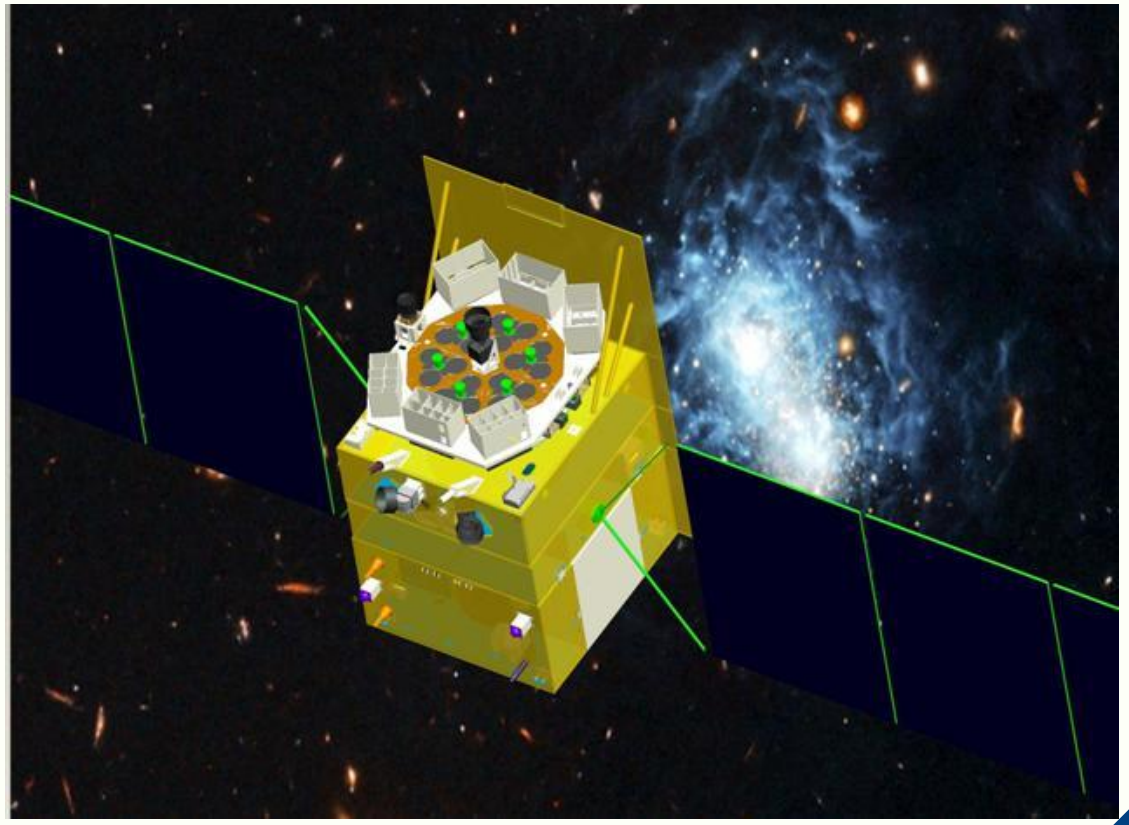
Hard X-ray Modulation Telescope (HXMT) satellite

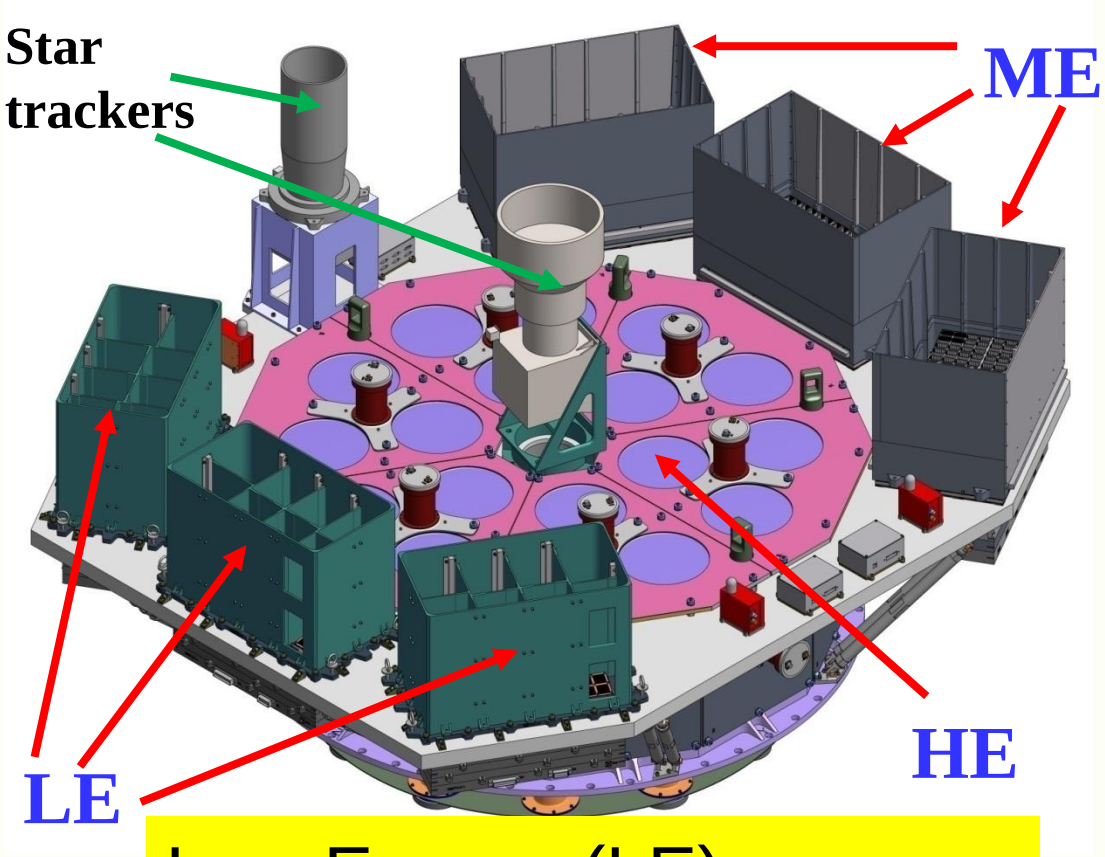
- China's 1st X-ray astronomy satellite
- Selected in 2011
- Total weight ~2500 kg
- Cir. Orbit 550 km, incl. 43°
- Pointed, scanning and GRB modes
- Designed lifetime 4 yrs
- Launch in June 2017



HXMT core sciences

1. Galactic plan scan and monitor survey: finding more weak short transients at hard X-rays
2. Pointed observations: high statistics observations of bright sources and high cadence XRB outbursts
3. GRB observations: up to 3 MeV with large area
4. Multi-wavelength observations

HXMT Payloads



Medium (ME):

Si-PIN,5-30 keV, 952 cm^2

High Energy (HE): Normal Mode

NaI, 20-250 keV, ~5000 cm^2

CsI, 50-700 keV, ~5000 cm^2

High Energy (HE): GRB Mode

NaI, 100-300 keV, 5000 cm^2

CsI, 250-3000 keV, 5000 cm^2

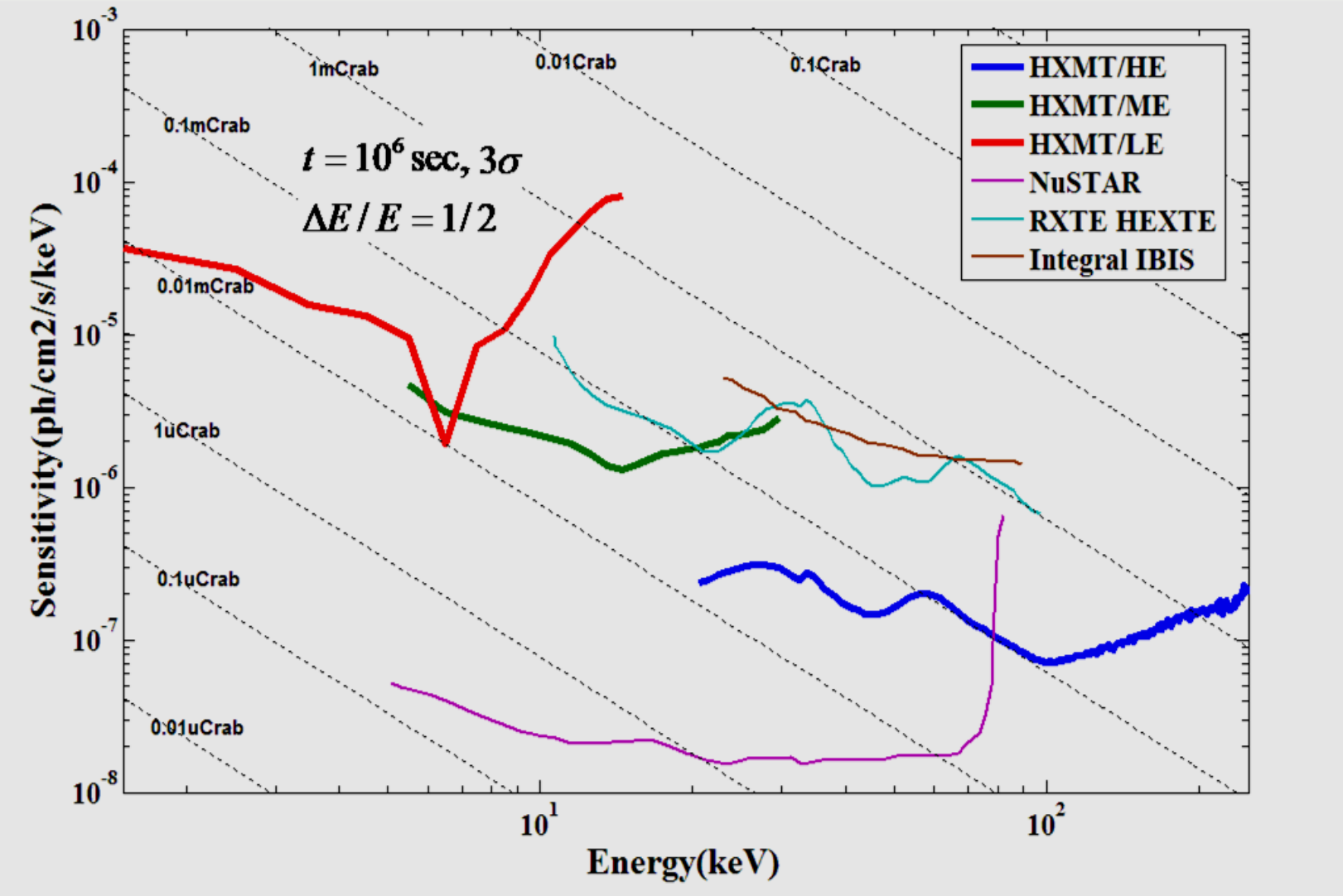
Low Energy (LE):

SCD,1-15 keV, 384 cm^2

Main characteristics of the HXMT Mission

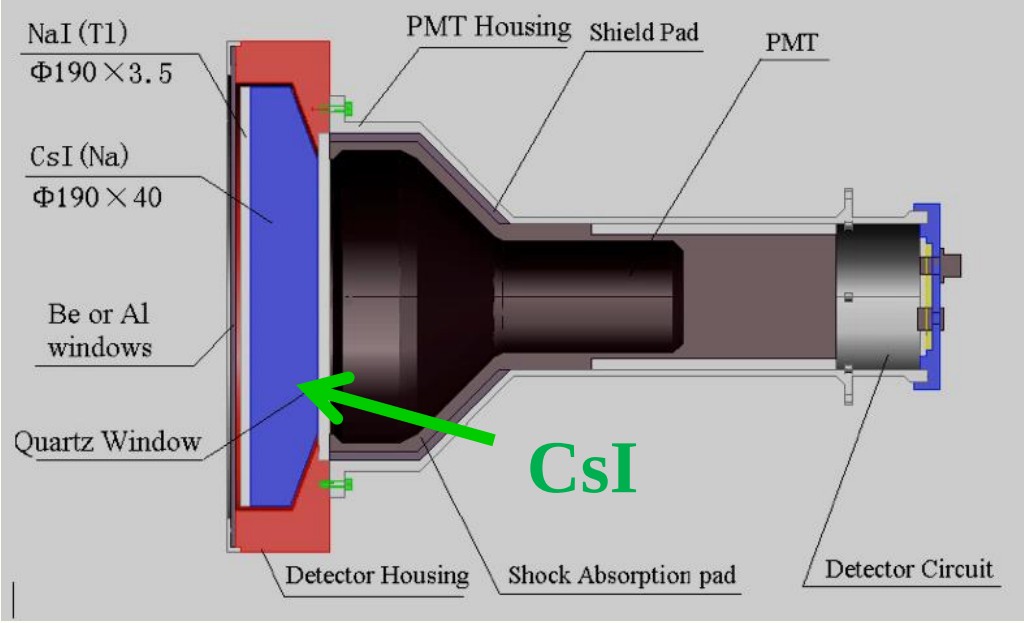
Detectors	LE: SCD, 384 cm^2;ME : Si-PIN, 952 cm^2 HE : NaI/CsI, 5000 cm^2
Energy Range	LE: 1-15 keV;ME: 5-30 keV;HE: 20-250 keV GRB mode：200-3000 keV
Time Resolution	HE: 25μs; ME: 20μs;LE: 1ms
Energy Resolution	LE: 2.5% @ 6 keV ME: 8% @ 17.8 keV HE: 19% @ 60 keV
Field of View of one module	LE: 6° ×1.5° ; 6° ×4° ; 60° ×3° ; blind; ME: 4° ×1° ; 4° ×4° ; blind; HE: 5.7° ×1.1° ; 5.7° ×5.7° ； blind
Source Location	<1' (20σ source)

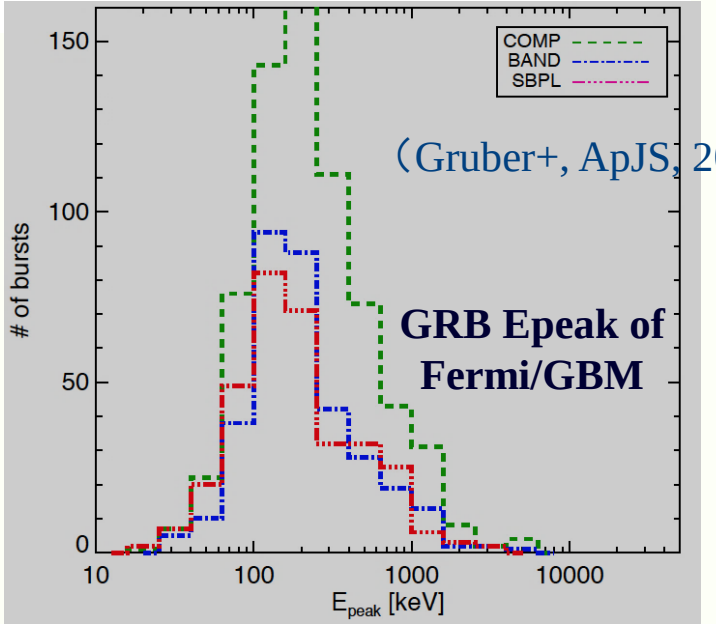
HXMT Sensitivity: pointed observation



Two modes of HXMT/HE

	NaI Energy Range (keV)	CsI Energy Range (keV)	Note
Normal mode	20 – 250	40 – 600	Normal HV
GRB mode	100 – 1250	200 – 3000	Lower HV to reduce gain by 5X And turn-off AGC system



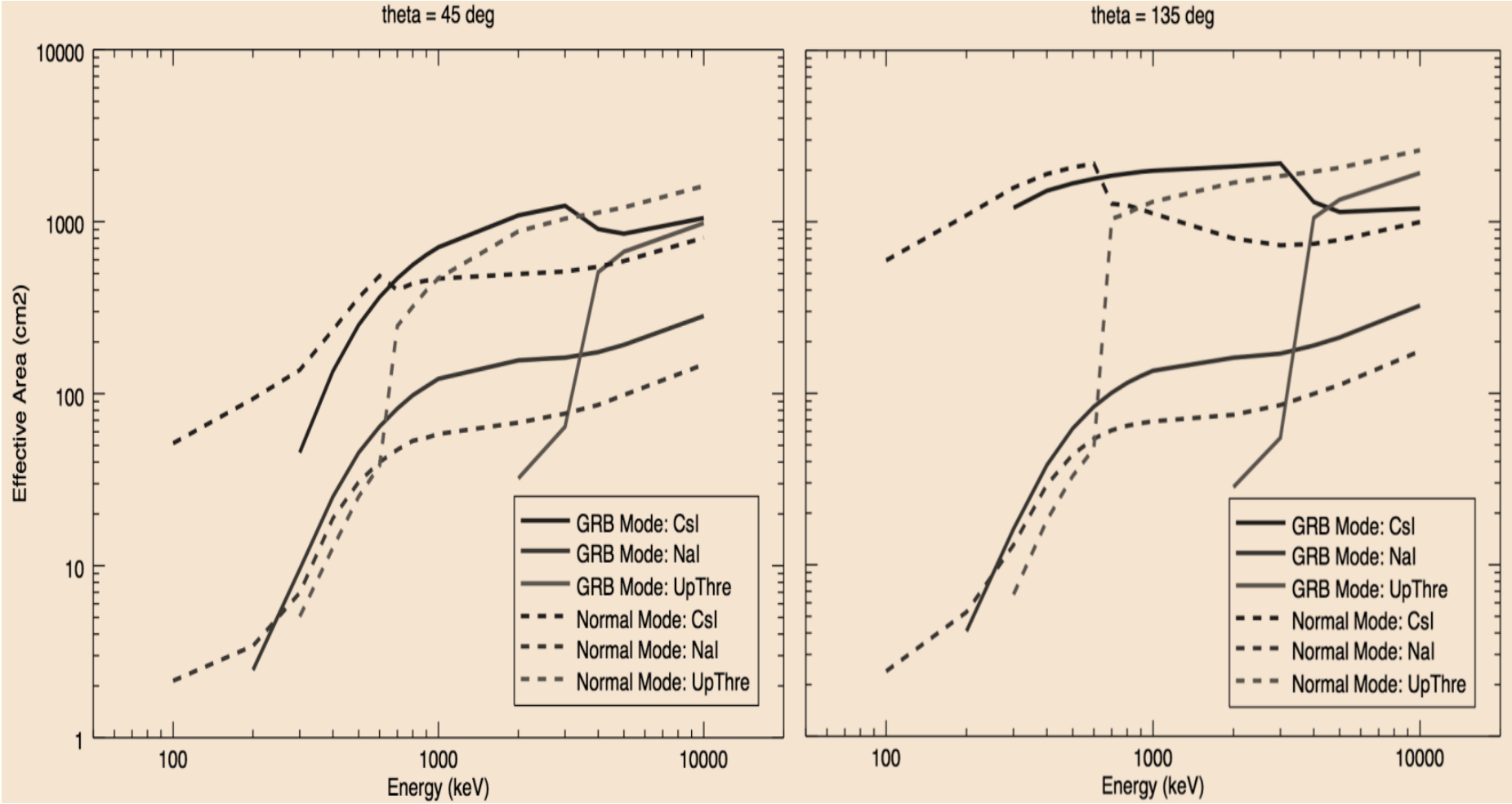


（Gruber+, ApJS, 2014）

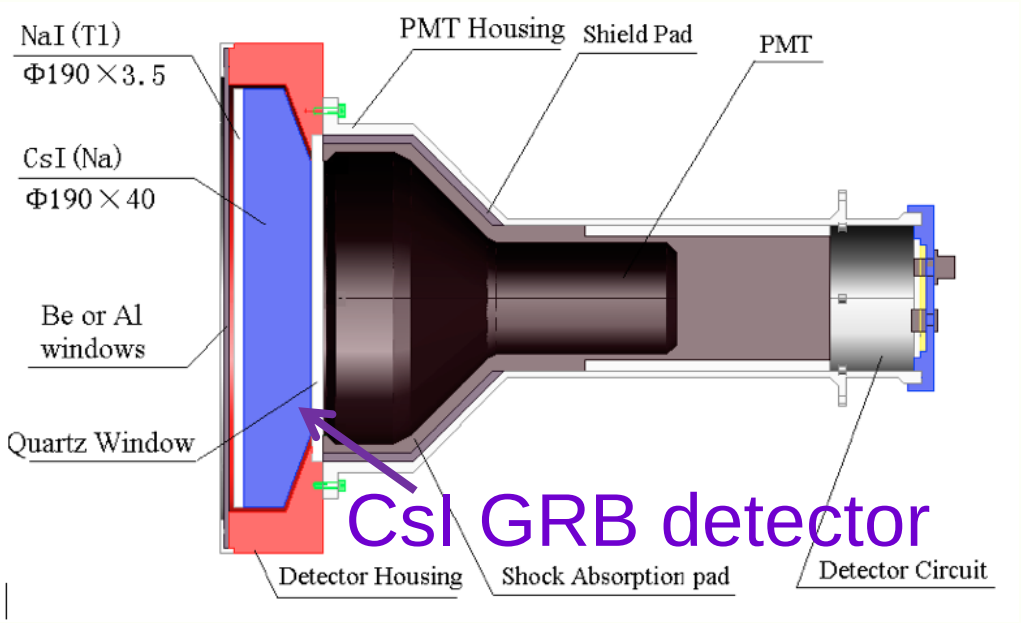
Effective area

Front incident

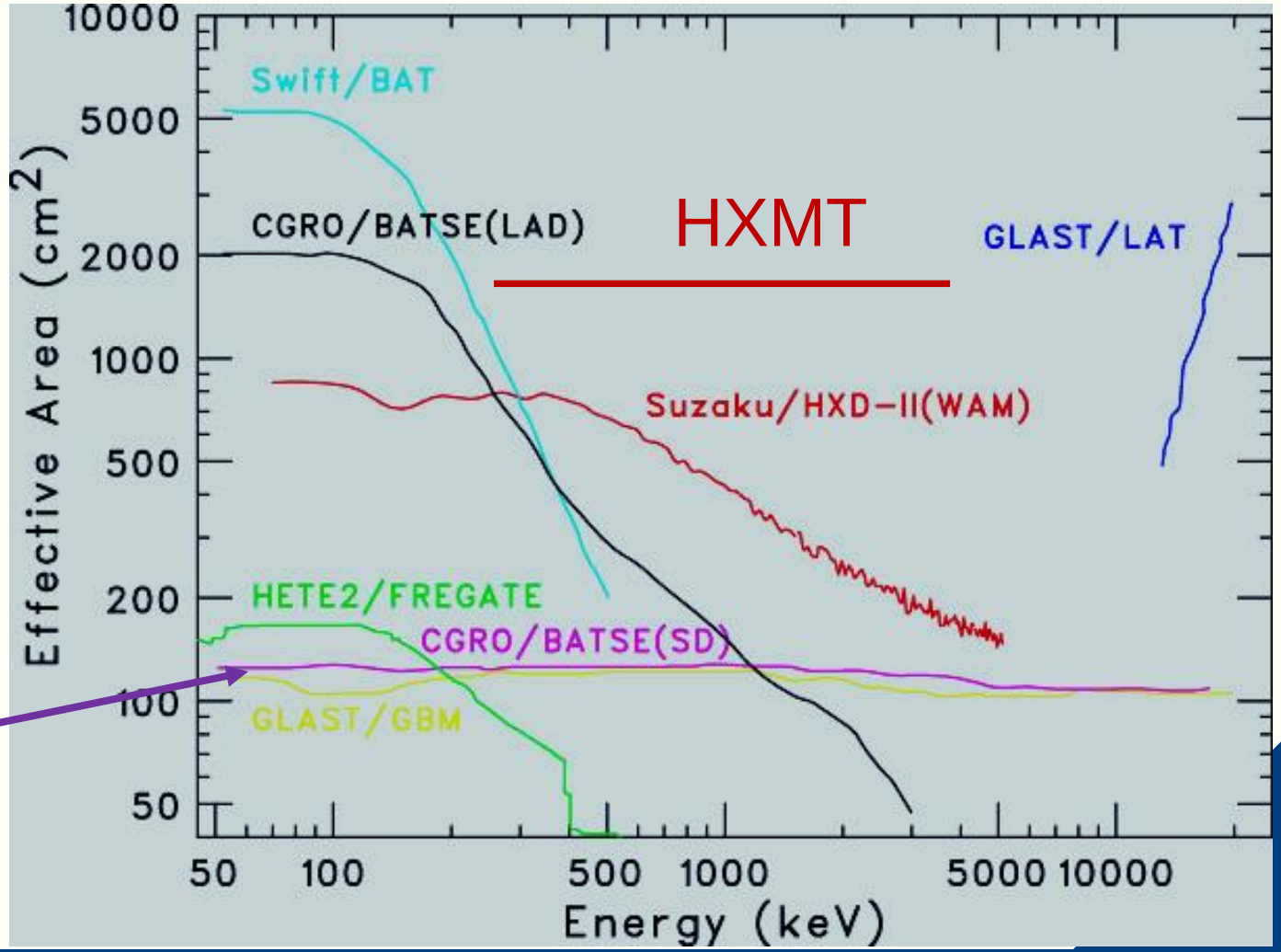
Back incident



HXMT's GRB capability comparison



Quite sensitive in soft gamma-rays (MeV), 10X larger than GBM on-board Fermi satellite.

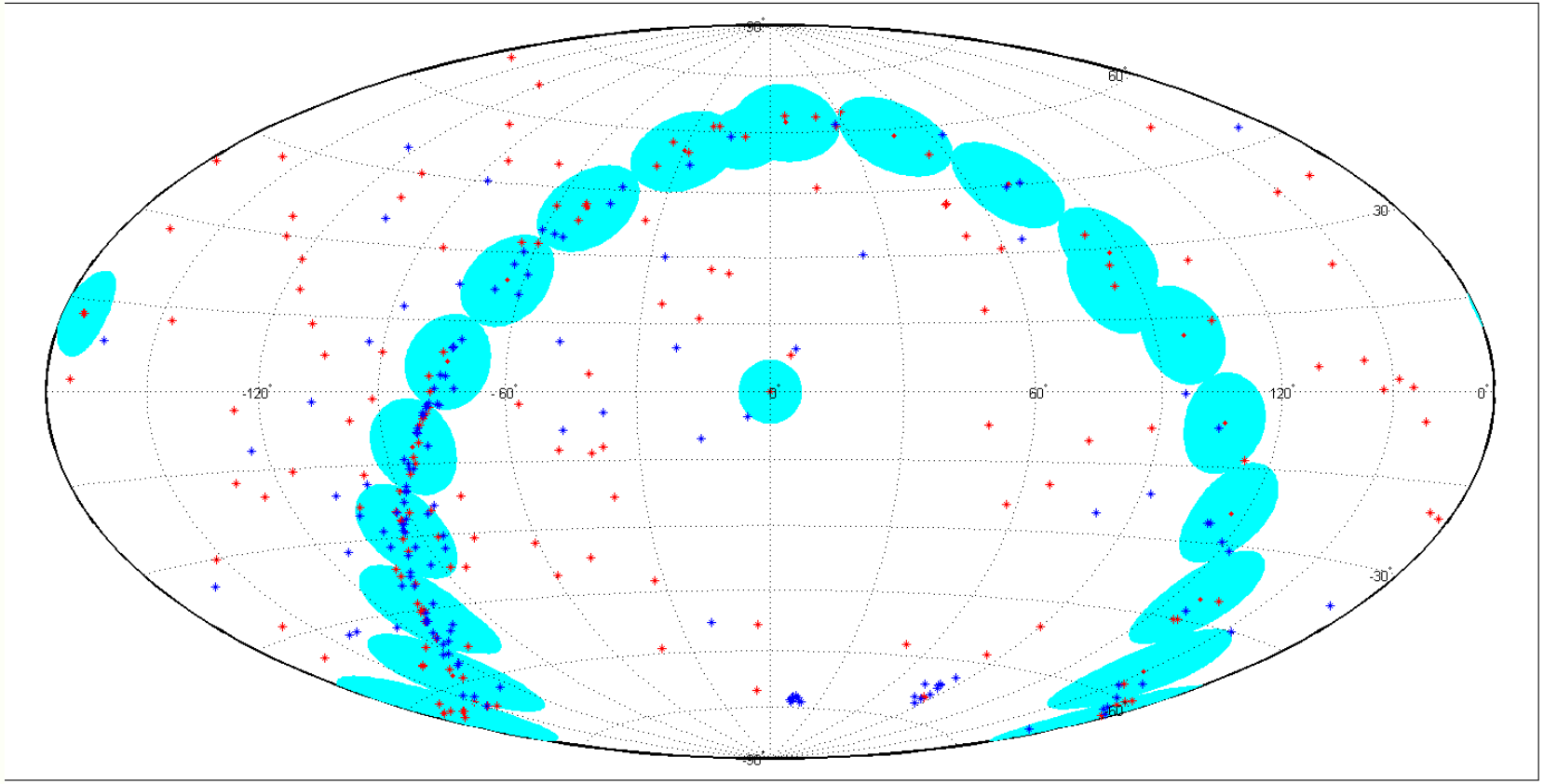


Expected HXMT GRB detection rates

Significance (sigma)	GRB mode (GRBs/year)		Normal mode (GRBs/year)	
	Front	Back	Front	Back
5	70	130	85	145
10	40	110	50	135
20	20	80	25	115

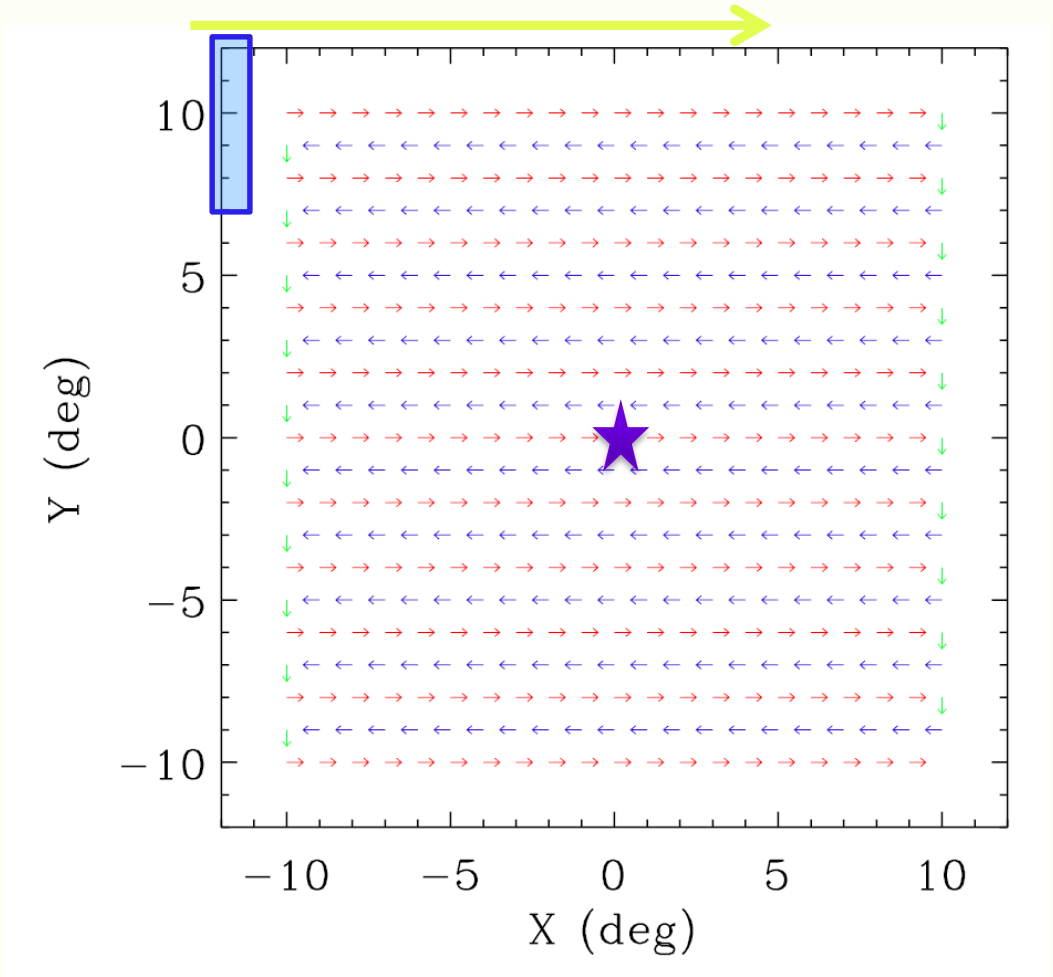
About 200 GRBs per year > 5 sigma

1st yr observation program: July, 2017

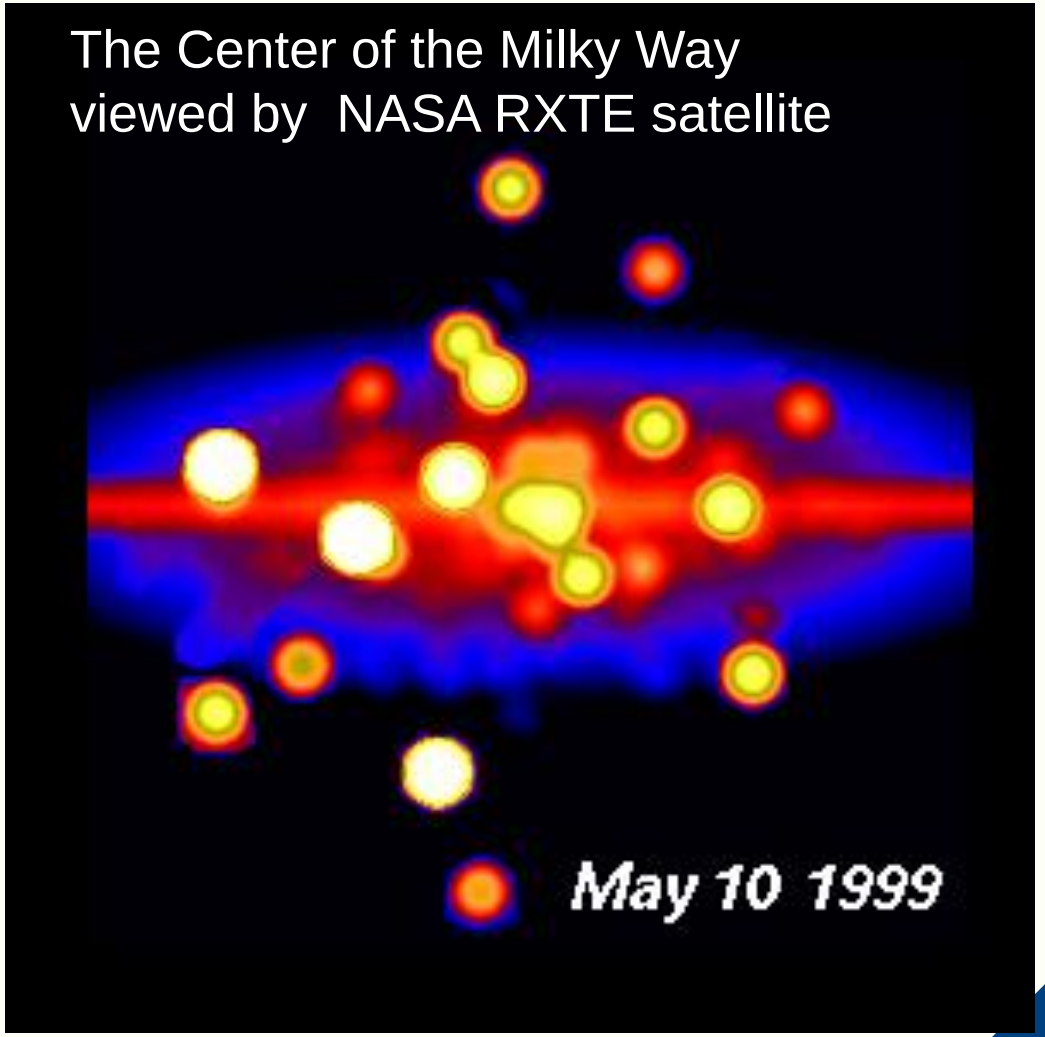


From HXMT AO-1： Regular; ToO; scanning

The Milky Way is highly variable in X-ray eyes!

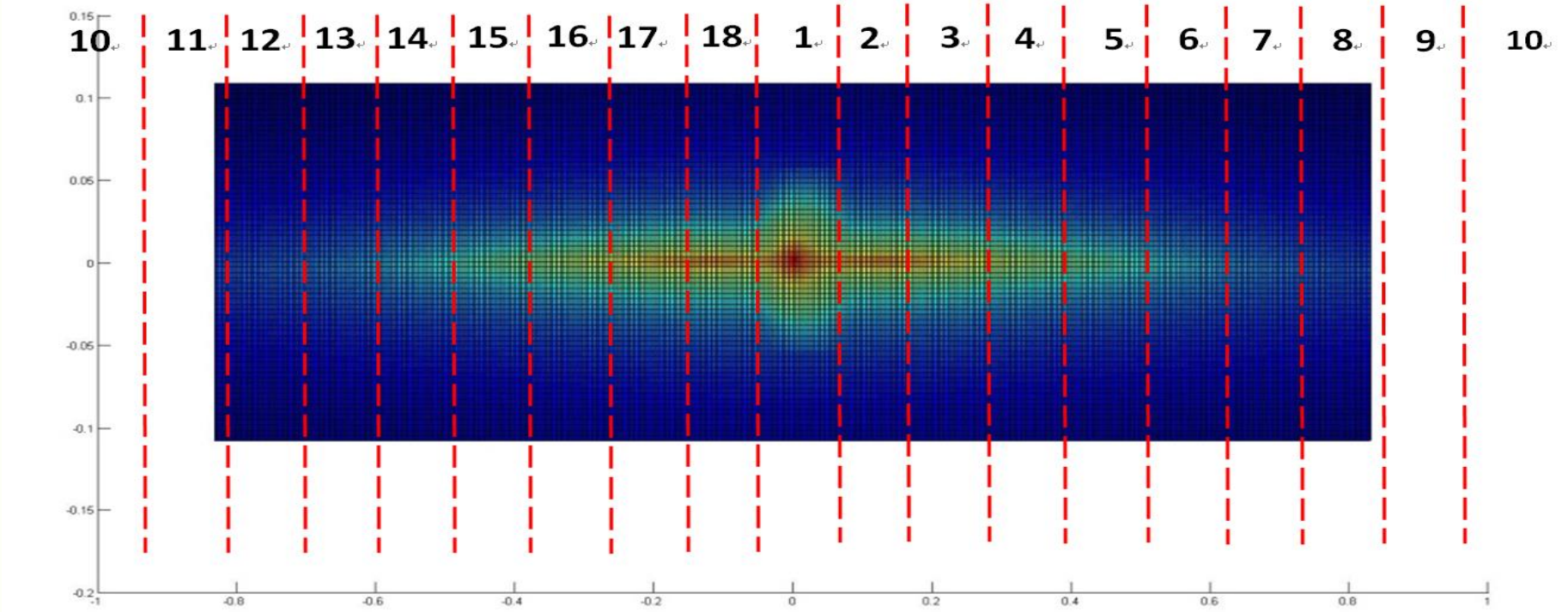


HXMT scan mode



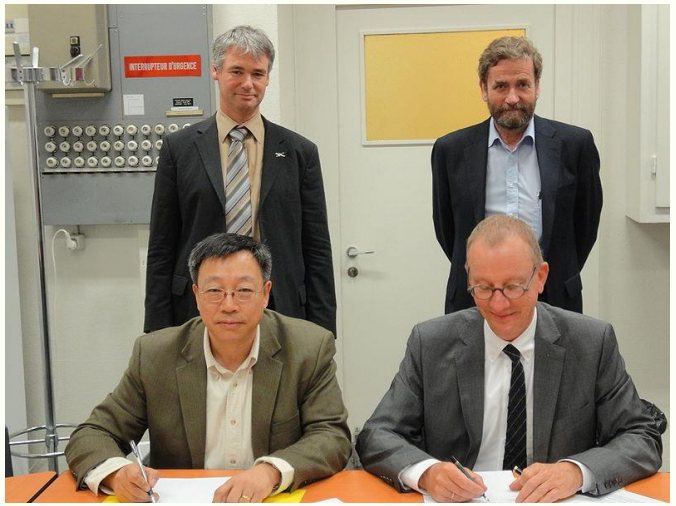
HXMT scanning survey of the Milky Way

- Repeatedly scanning the whole Milky Way, to discover new variable black holes and neutron stars, and monitor activities of the known X-ray sources

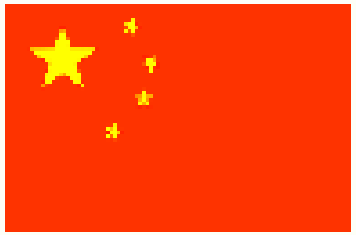


Collaborations of POLAR

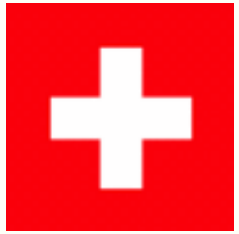
- PIs:
  - Shuang-Nan Zhang
  - Martin Pohl



China



Switzerland



Poland

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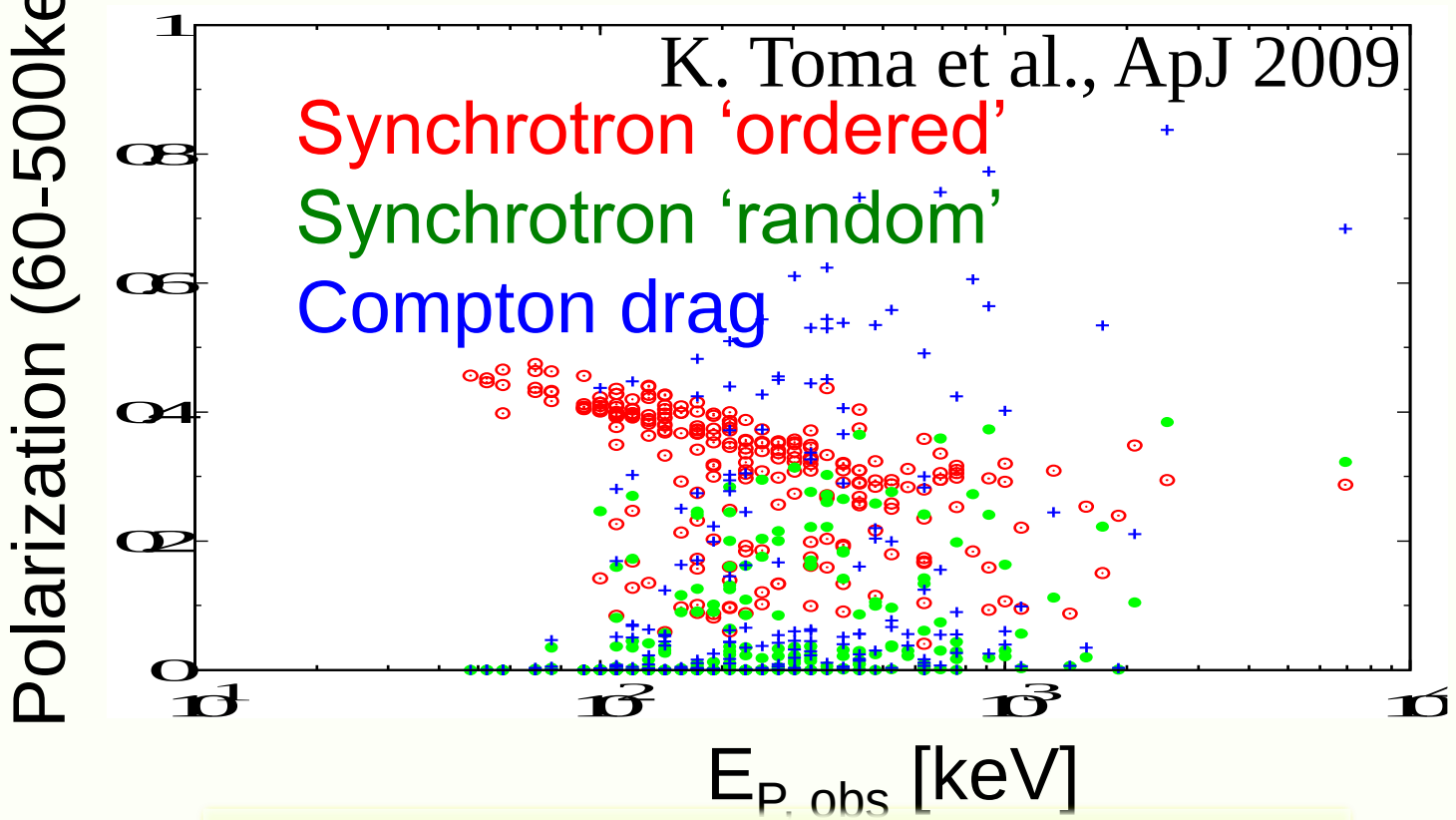
NCBJ

GRB Models and Polarization

The leading models that describe the prompt emission are based on synchrotron emission from relativistic electrons in GRB jets



To discriminate between models: $\Pi \sim 10\%$

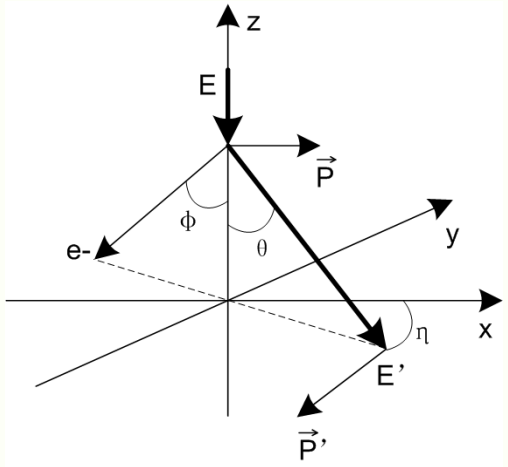
Summary of the current GBR polarization measurements

GRB	Instru/Satellites	Pol degree(%)	Energy range(keV)	Comments
110721A	GAP/IKAROS	84^{+16}_{-28}	70-300	@3.3σ, with constant pol direction
110301A	GAP/IKAROS	70±22	70-300	@3.7σ, with constant pol direction
100826A	GAP/IKAROS	27±11	70-300	@2.9σ, with inconstant pol direction
021206	RHESSI	80±20; 41^{+57}_{-44}	150-2000	With large systematic error
140206A	IBIS/INTEGRAL	>48	200-400	Unable to restrict GRB model
061122	IBIS/INTEGRAL	>60; >65; >52	250-800; 250-350; 350-800	Unable to restrict GRB model
041219A	IBIS/INTEGRAL IBIS/INTEGRAL SPI/INTEGRAL	<4; 43±25; 98±33	200-800; 200-800; 100-350	With variable pol direction
960924	BATSE/CGRO	>50	20-1000	Unable to restrict GRB model
930131	BATSE/CGRO	>35	20-1000	Unable to restrict GRB model

Design of POLAR detector

- Main scientific goals
  - Measure the polarization of the GRB prompt emissions as well as Solar flare emissions, to confirm or restrict the radiation models
  - In 2 years of flight lifetime, be able to measure ~ 100 GRBs, contributing to the largest GRB prompt emission polarization observation database
  - For the GRBs with fluence higher than 10^{-5} erg cm^{-2}, the Minimum Detectable Polarization (MDP) of POLAR can reach down to < 10%

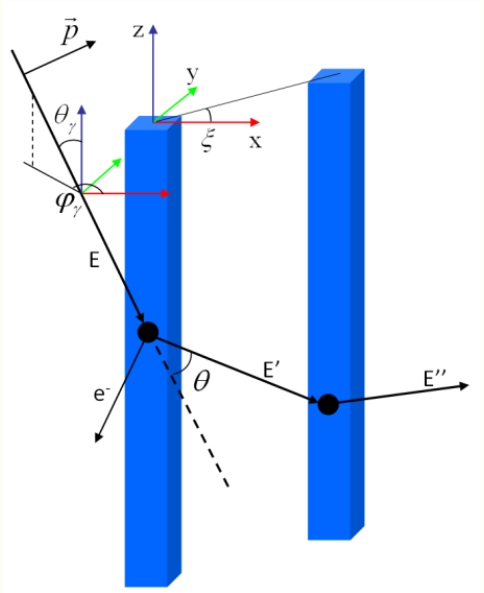
Detection principle of POLAR



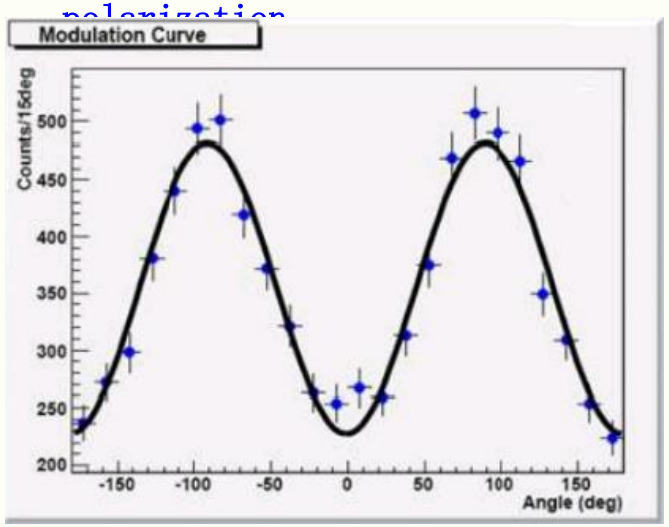
Compton Scattering with polarization

Klein-Nishina equation:

$$\frac{d\sigma_P}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 (\varepsilon + \varepsilon^{-1} - 2\sin^2\theta\cos^2\eta)$$



Detection principle of POLAR



Modulation curve

Distribution function

$$C(\xi) = A\cos(2(\xi - \varphi + \frac{\pi}{2})) + B$$

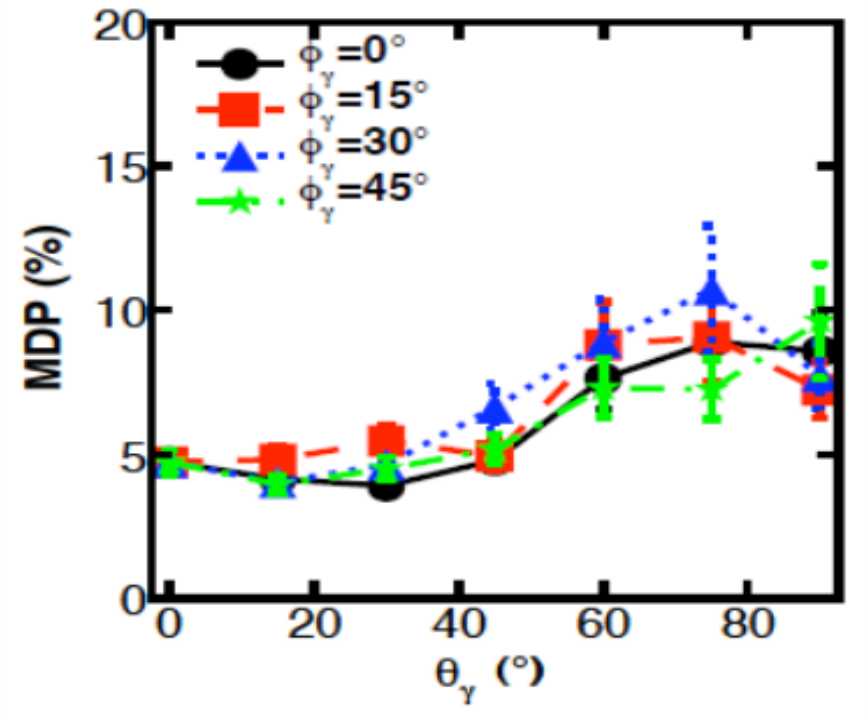
$$\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} \rightarrow P = \frac{\mu}{\mu_{100}}$$

Modulation factor

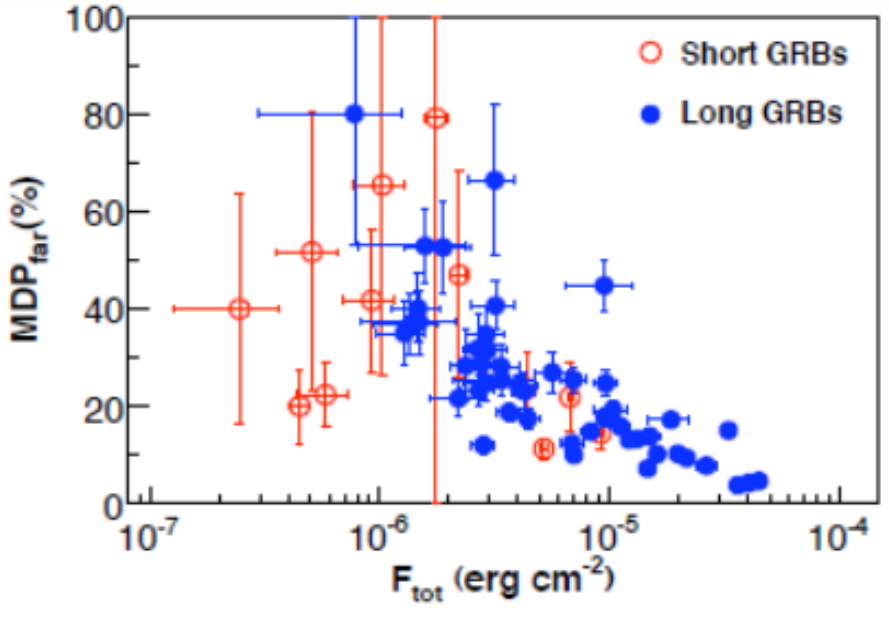
Polarization level

Monte-Carlo Simulations – Minimum detectable polarization

$$MDP = \frac{n_\sigma}{S_F \mu_{100} \varepsilon A} \sqrt{\frac{S_F \varepsilon A + B}{T}}$$



MDP varies with incident direction of the GRB photons. E. S. Garcia, 2010

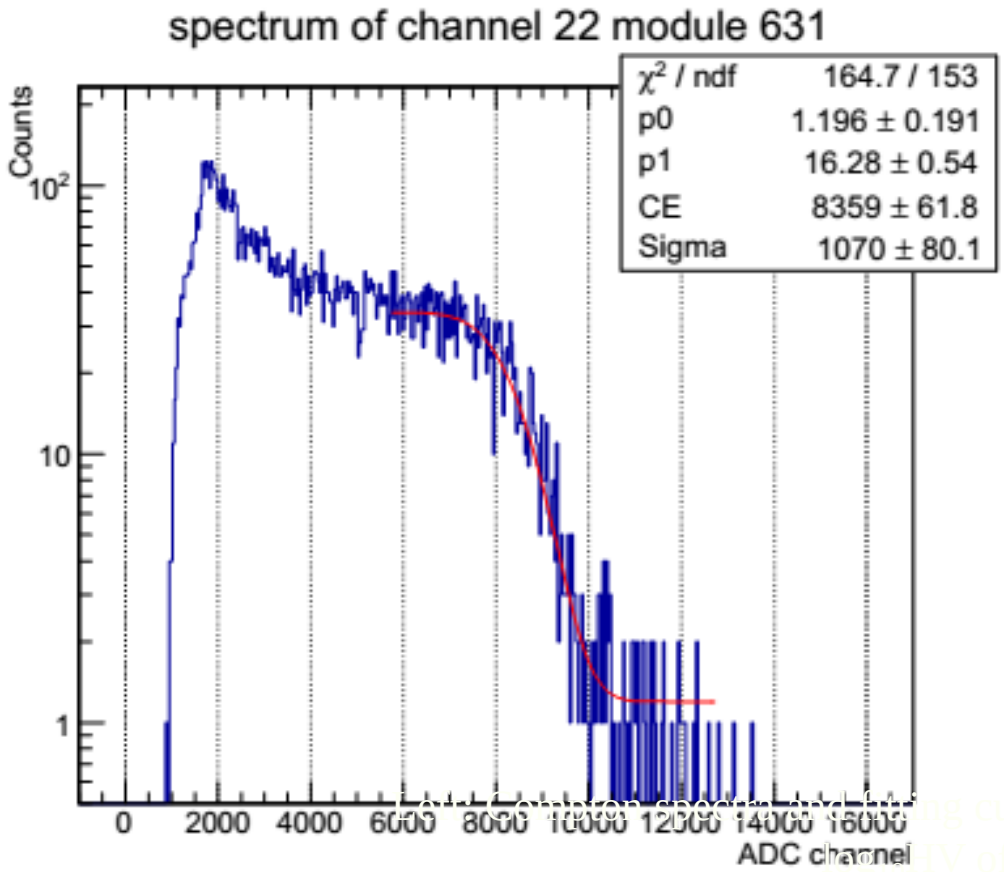


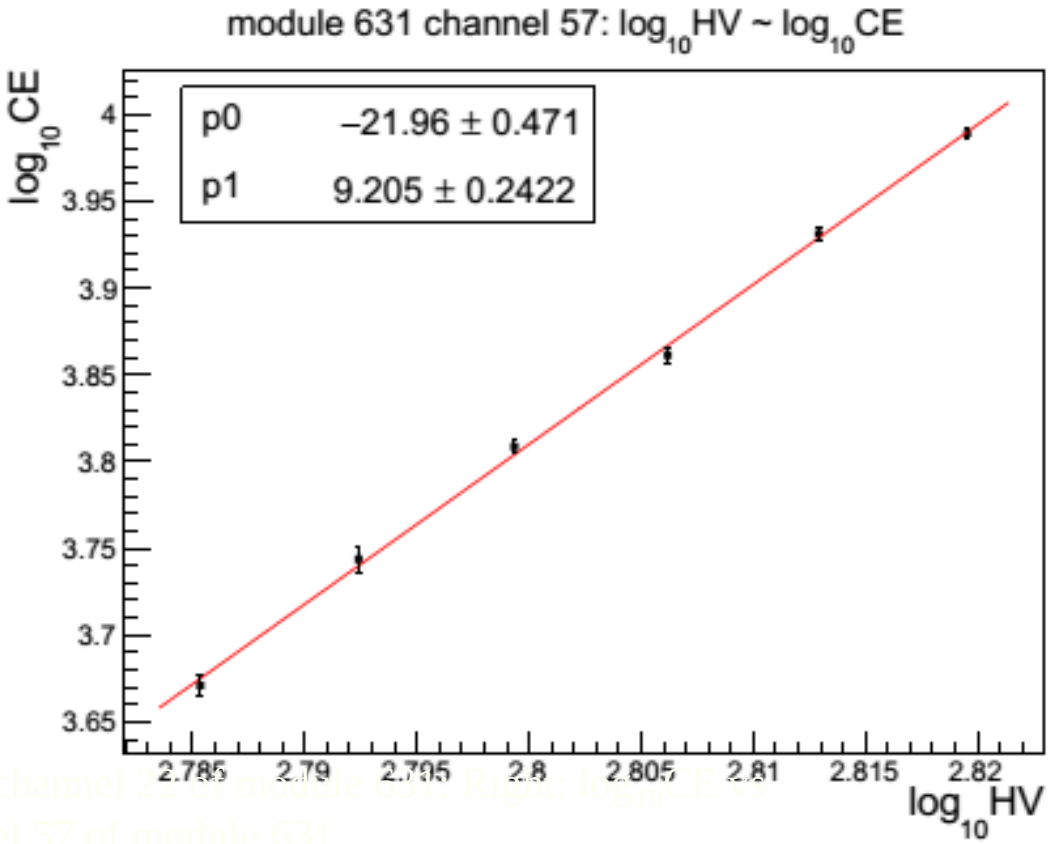
MDP varies with total fluence given in the BATSE catalog for photons with energy above 20 keV. E. S. Garcia, 2010

Technical properties summary of POLAR

1	Detector material	Plastic scintillator (EJ-248M)
2	Yearly detectable GRBs	~50
3	GRB localization accuracy	$\leqslant 5^\circ$ (Fluence $\geqslant 10^{-5}$ erg cm^{-2})
4	Detection energy range	~50—500 keV
5	Field of view	$\pm 90^\circ \times \pm 90^\circ$
6	Modulation factor	40%@200 keV
8	MDP	~10% (Fluence$_{total}$ $\geqslant 3\times10^{-5}$ erg cm^{-2})
9	Detector geometry area	~550 cm^2 (on-axis view)
10	Mass	OBOX: 27.6 kg, IBOX: 3.52 kg
11	Size	OBOX: 462×462×268.5 mm^3 IBOX: 247×160×85 mm^3
12	Maximum power consumption	$\leqslant$80 W
13	Time accuracy(UTC)	$\pm$1 ms
14	Reliability	0.90 (in 2 years lifetime)

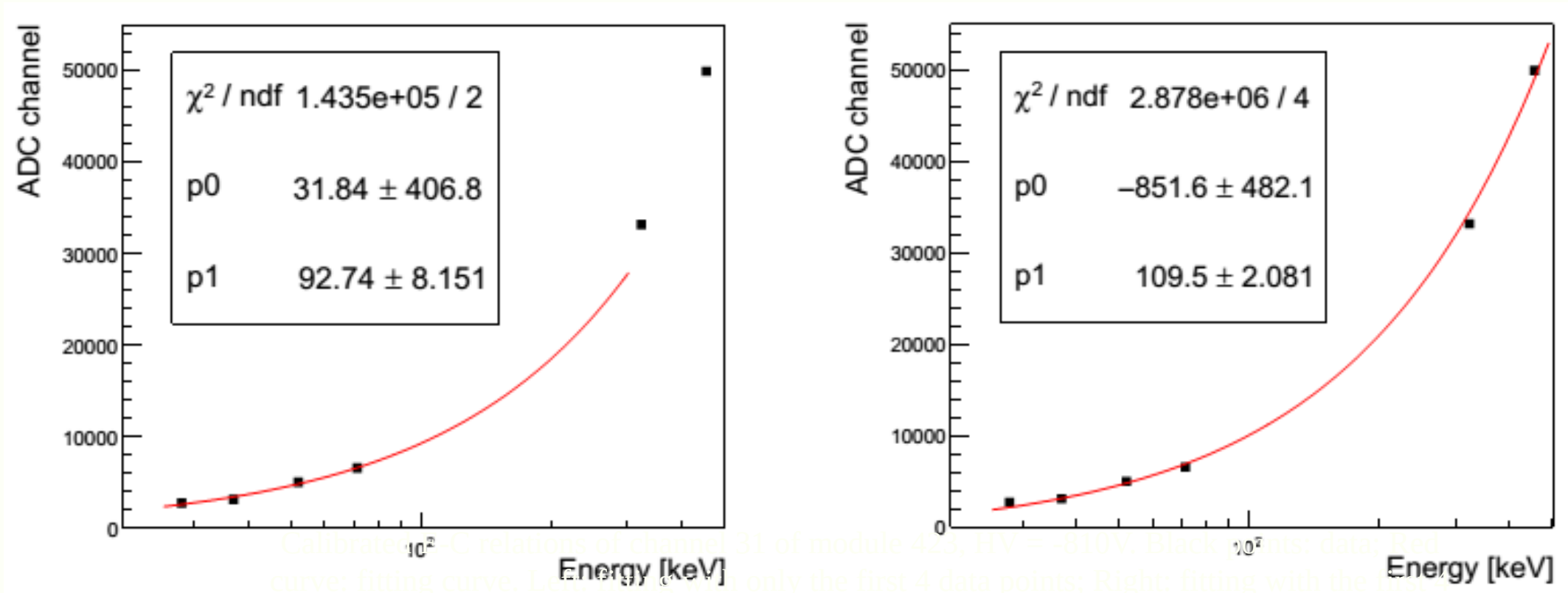
Calibration with radioactive source





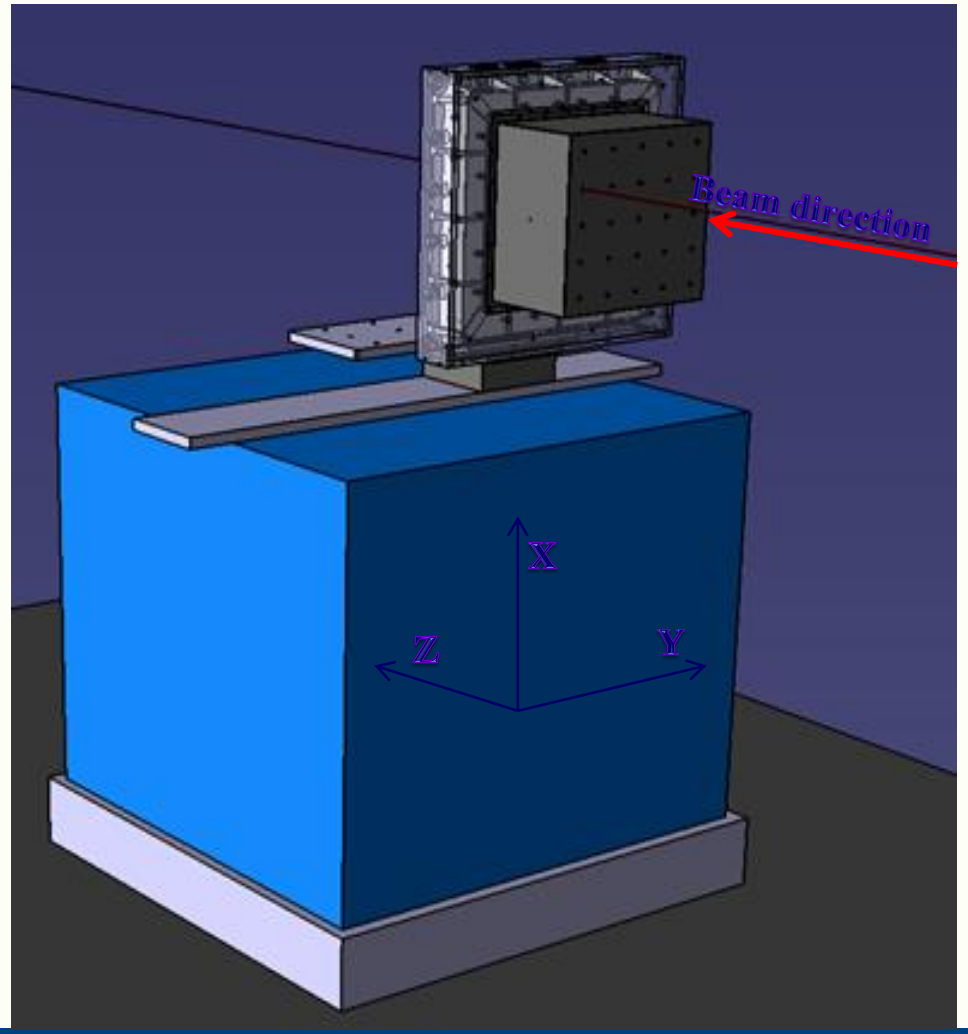
Left: Cobalt spectrum of channel 22 of module 631 Right: Fitting curve of channel 57 of module 631

Calibration with low energy X-ray fluorescence

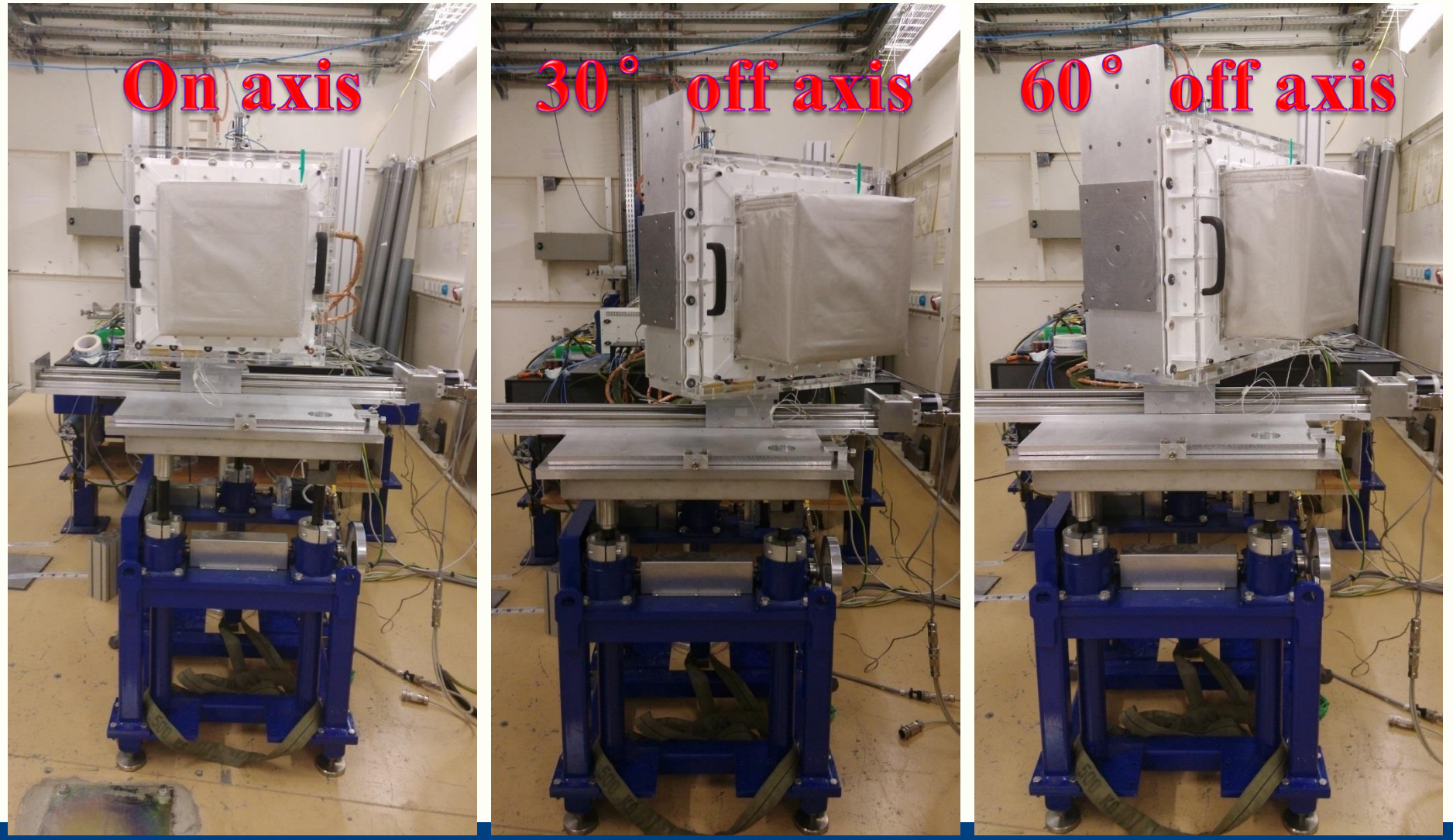


ESRF beam test in 2015 - introduction

- Facility introduction
  - Beamline: ID11
  - Polarization: 100%
  - Pol direction: horizontal
  - Energy range: 35 ~ 140 keV
  - Beam size: minimum (H×V) 0.2×0.07 μm^2, maximum (H×V) 1200×1000 μm^2
  - Initial intensity：~10^7 phs/s

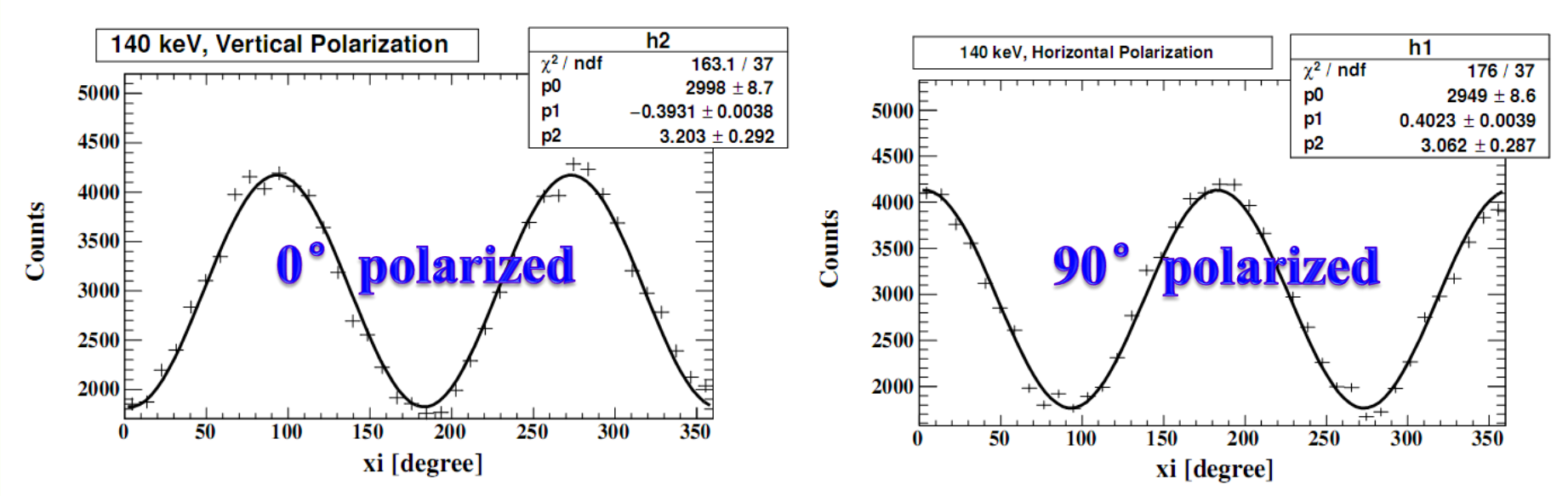


Detector positions for different off-axis



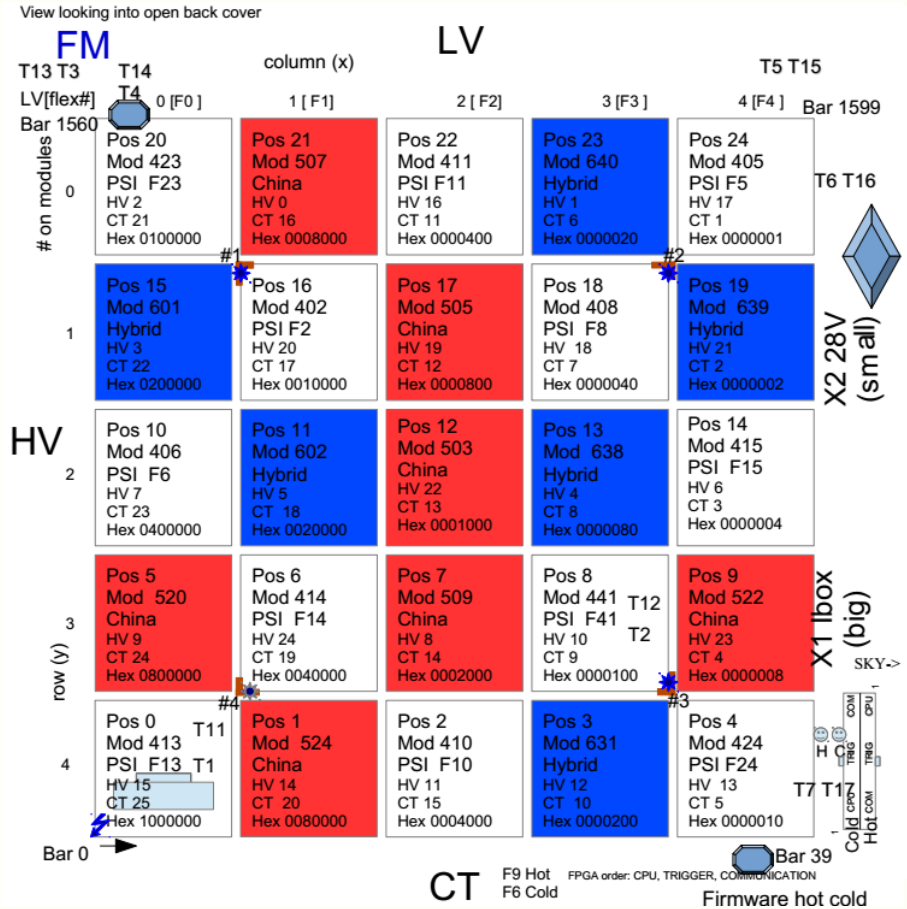
ESRF modulation curve

Modulation curve, 140 keV

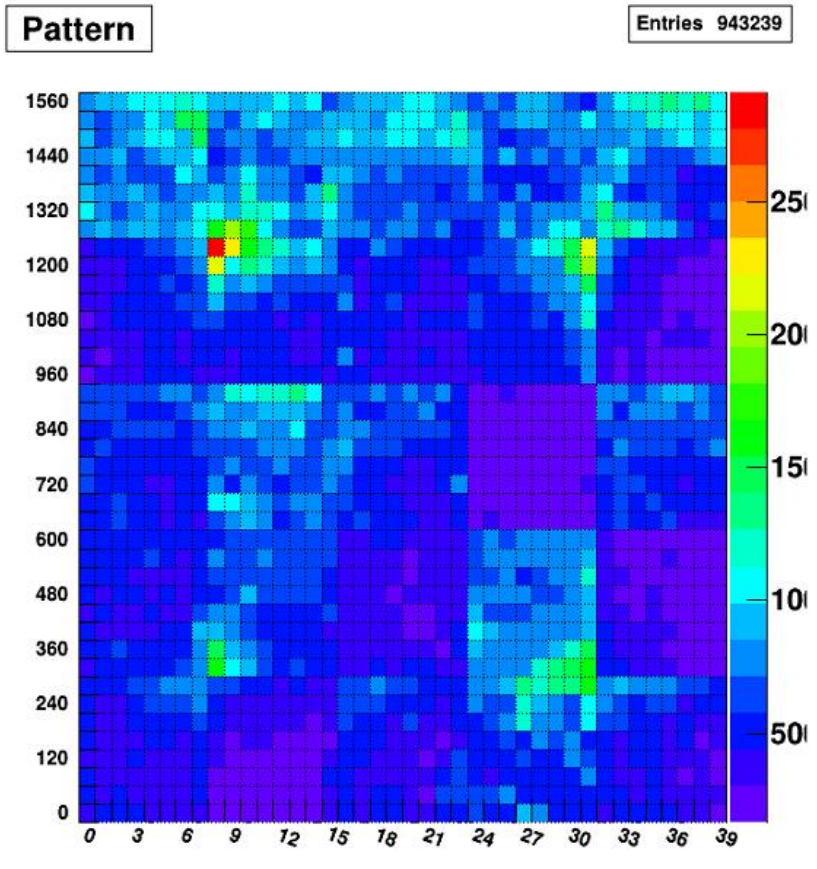


- 140 keV, on-axis measurement
- Modulation factor
  - 0° polarization：39.31%
  - 90° polarization：40.23%
  - Simulated result: ~40%

In-orbit calibration scheme



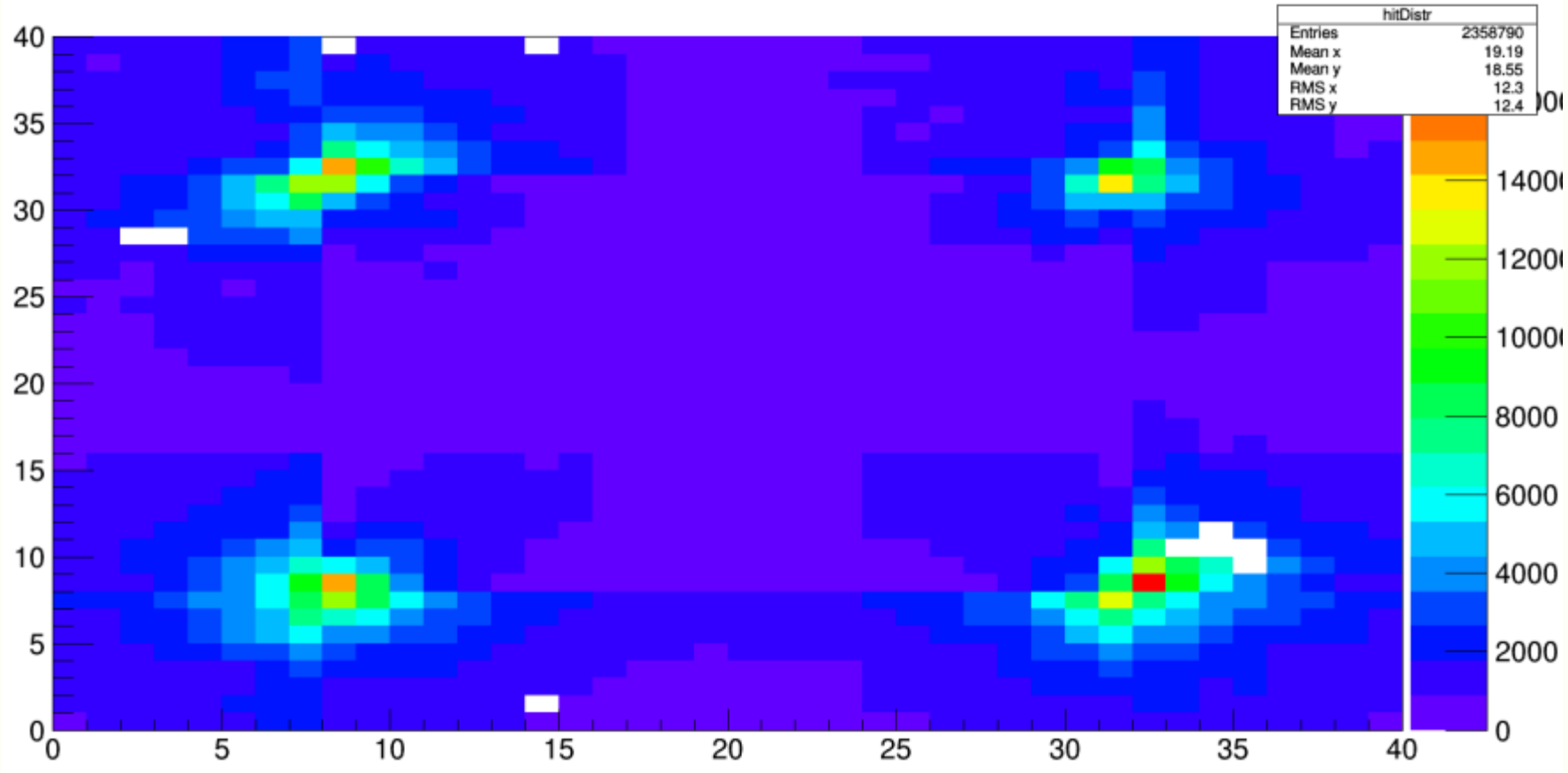
Top view of POLAR: locations of 4 ^{22}Na sources and 25 modules



Triggering pattern of the 1600 channels

In-orbit calibration scheme

Result with event selection criteria

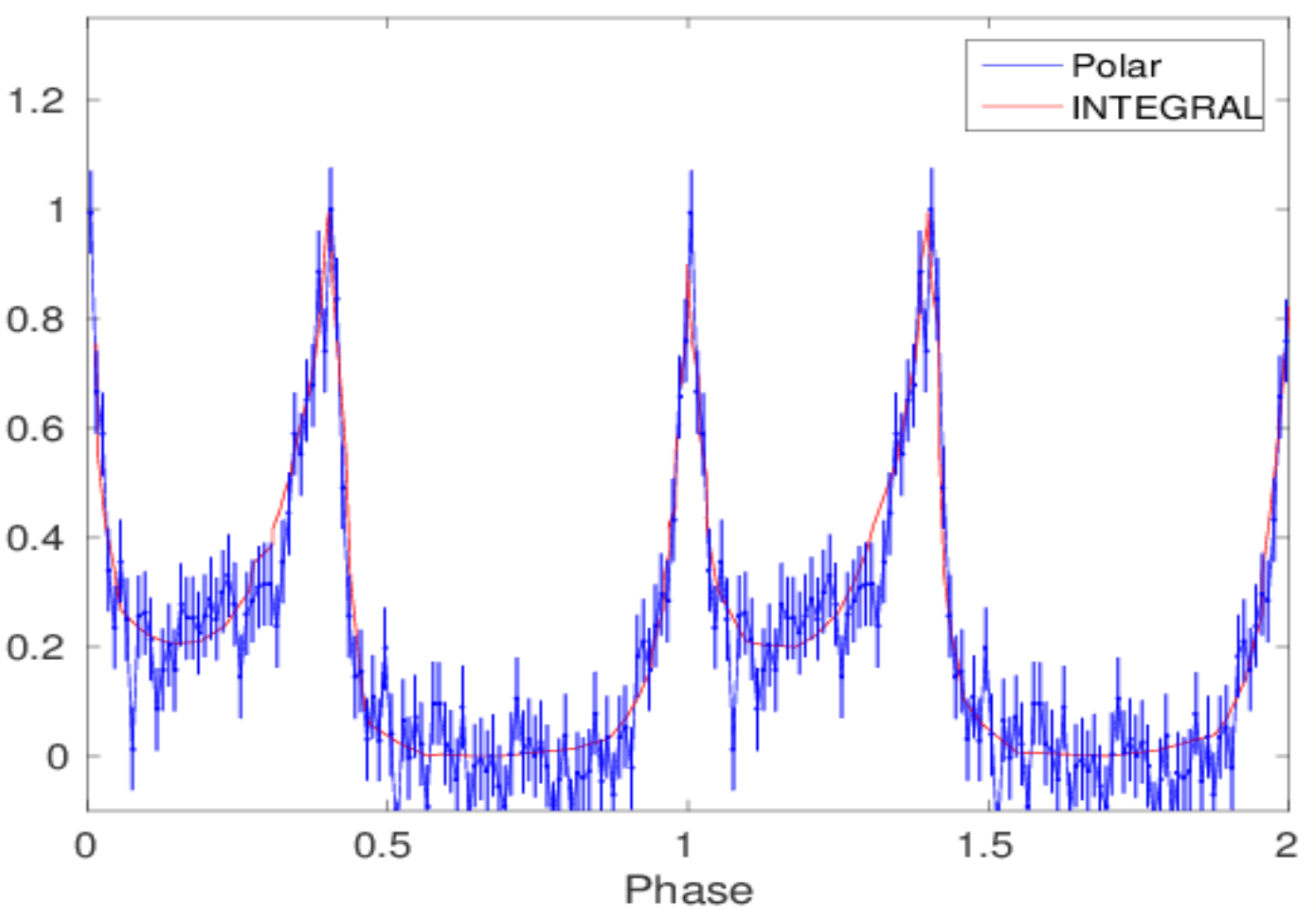


Triggering pattern of the 1600 channels

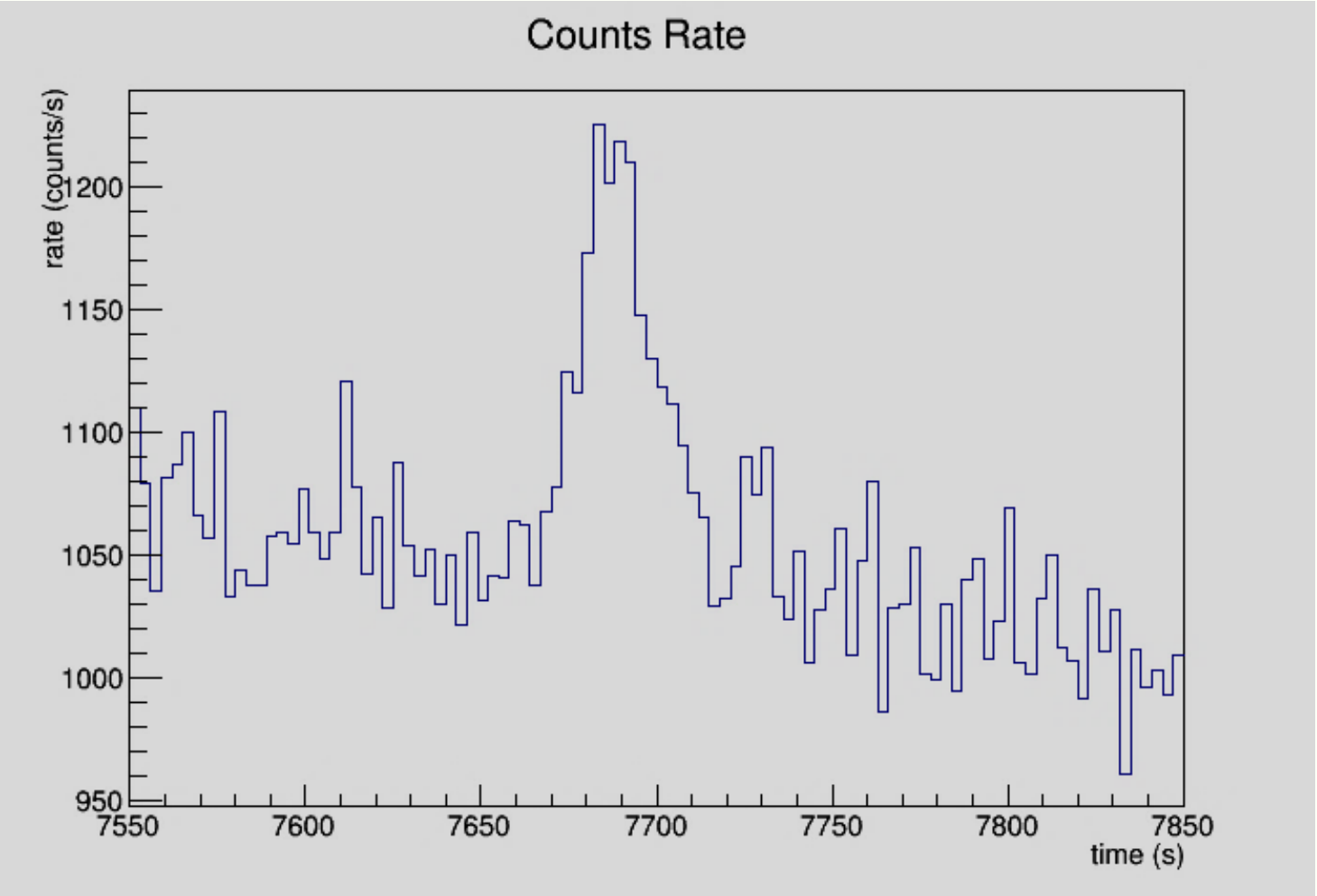
Current status

- ⊙ successfully launched on15th/September
- ⊙ successfully powered-on on 22nd/September
- ⊙ powered-off on 14th/October for docking of TG-2 and Shenzhou-11 spaceship
- ⊙ powered on again on 18th/November…

Preliminary results: Crab pulsar

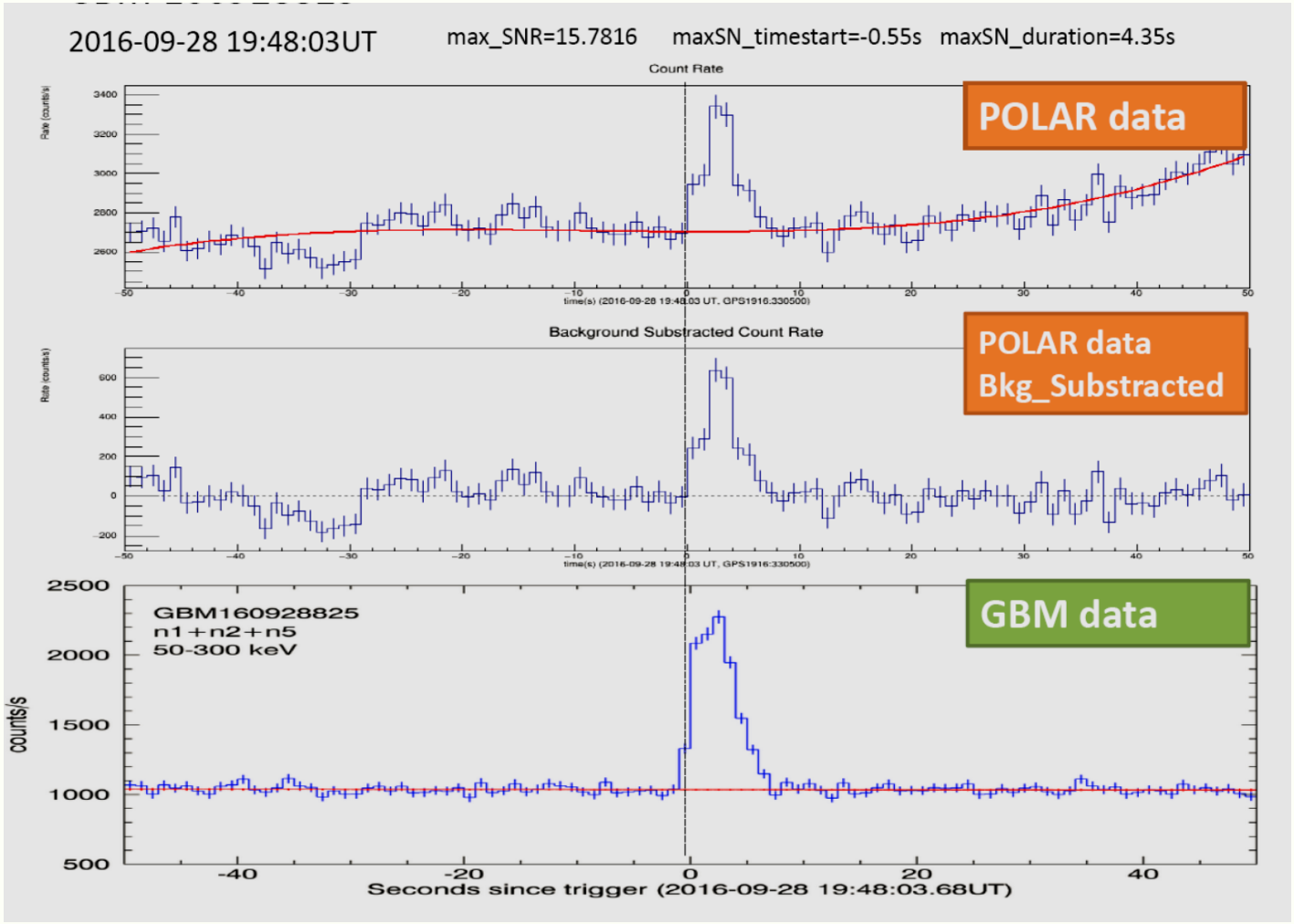


Preliminary results: solar flare



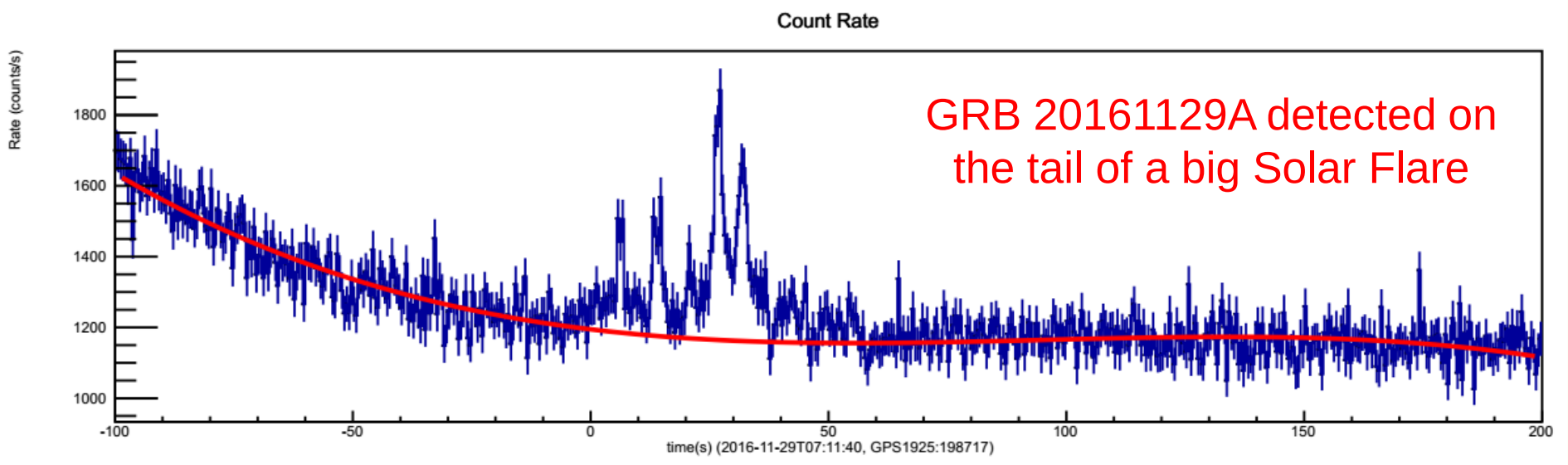
Oct. 12, 2016: consistent with RHESSI results

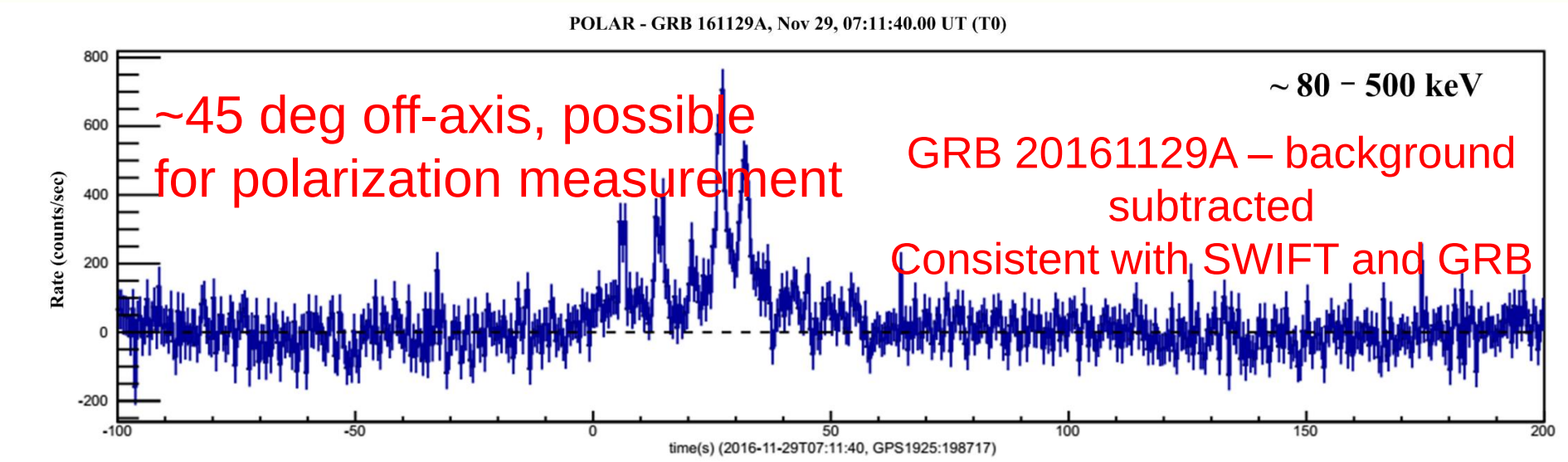
Preliminary results: GRB 20160928A



>90 degree off-axis, not good for polarization

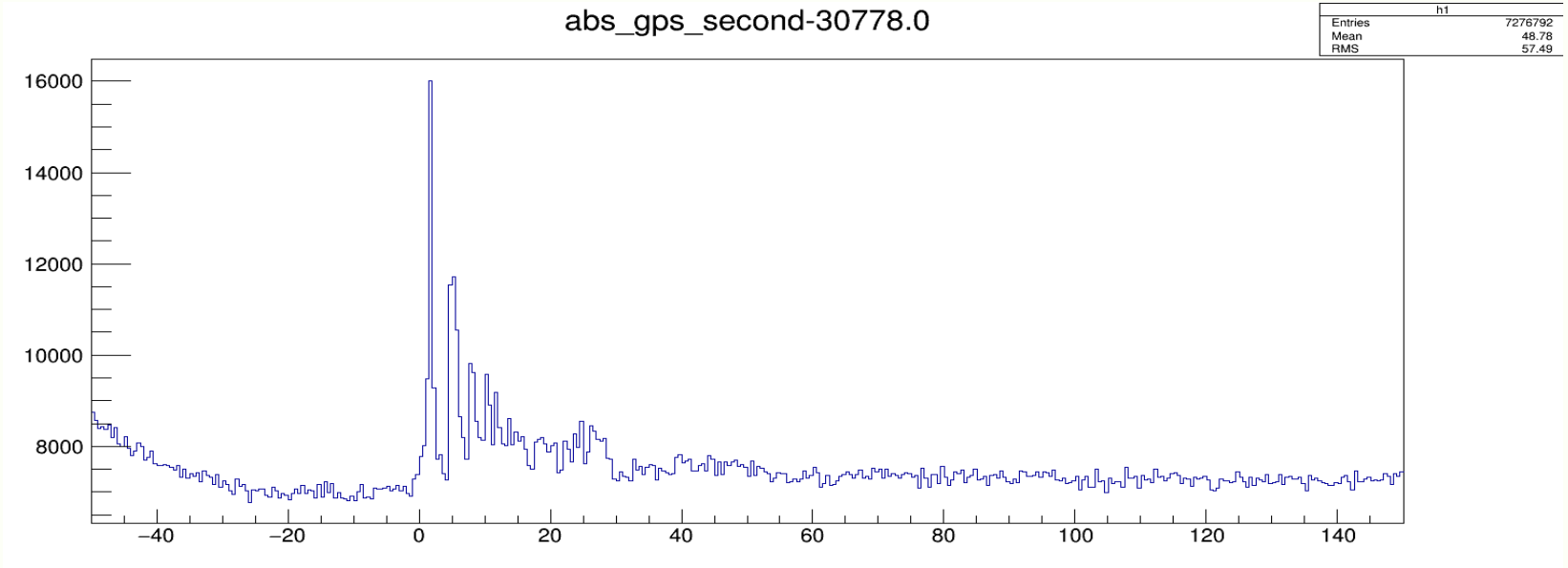
Preliminary results: GRB 20161129A





Preliminary results: GRB161218B

Raw lightcurve：

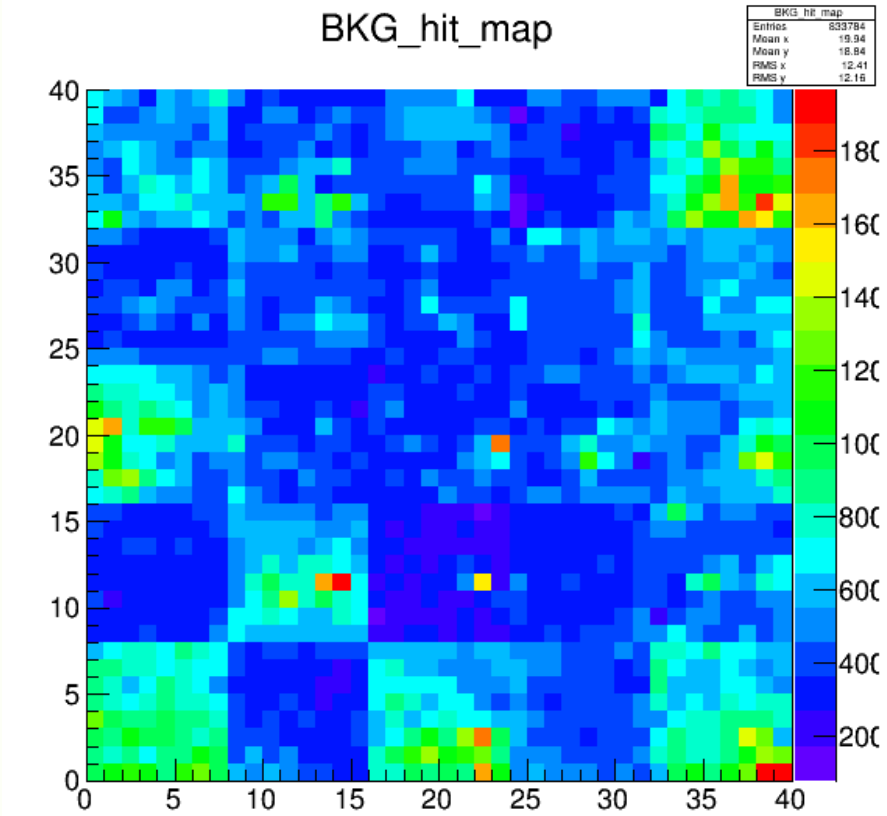


GRB time：GPS 1928:30778.0-1928:30806.8

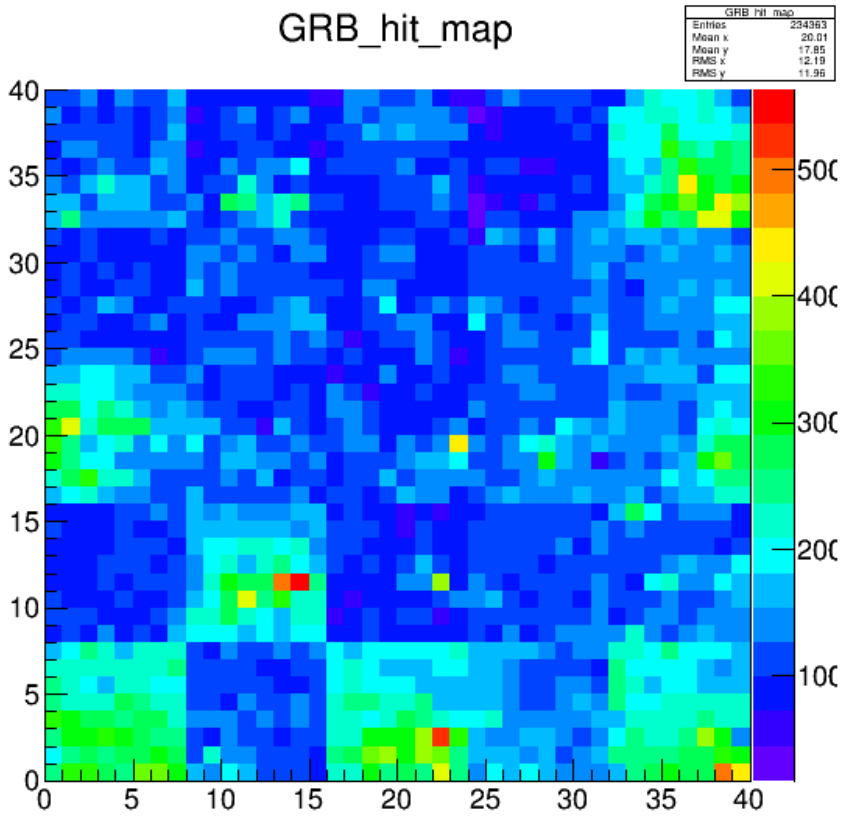
BKG time: GPS 1928:30750-1928:307758:30810-1928:30920

Observation Hit maps

Background off GRB

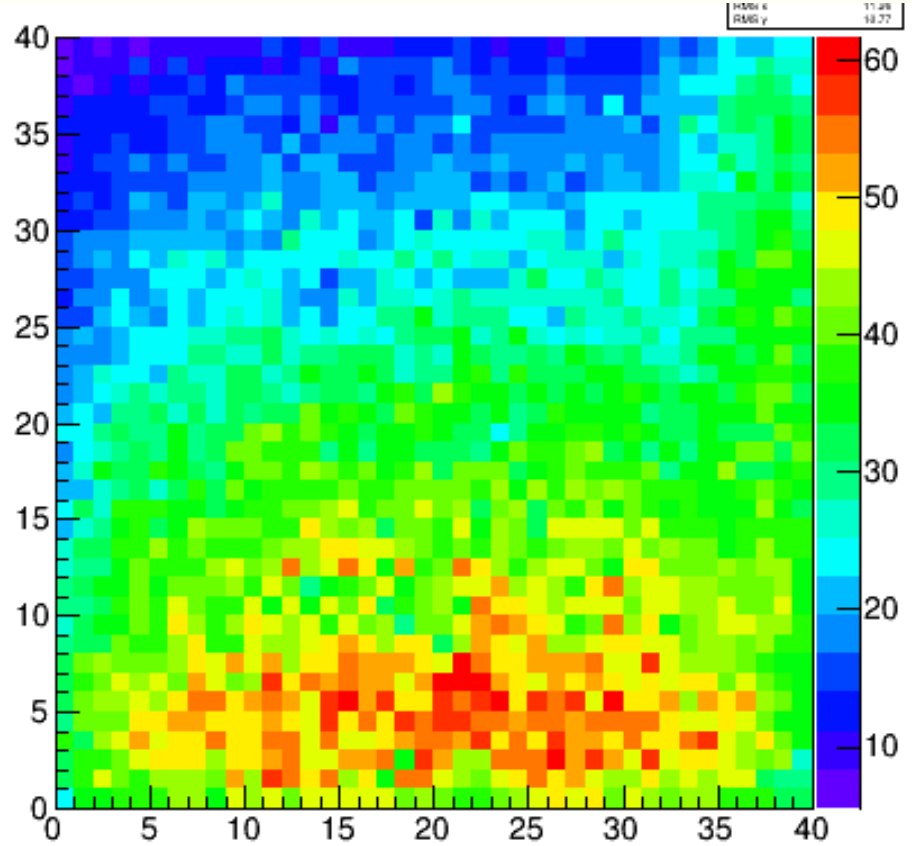


Total during GRB

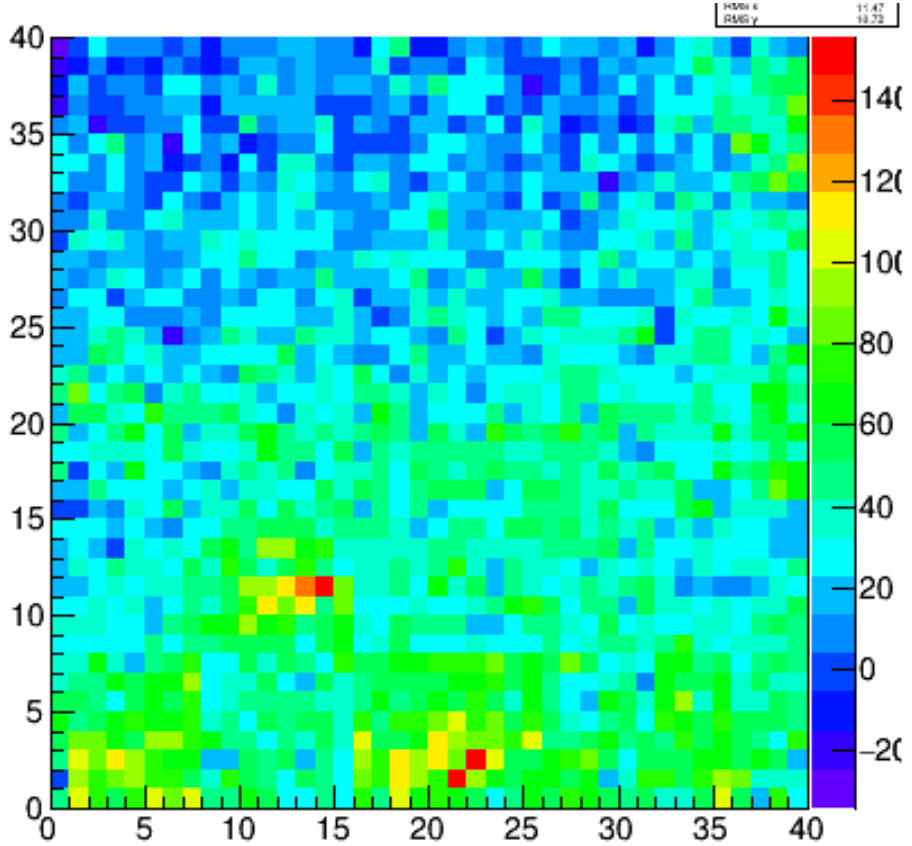


Hit map

Simulated GRB hit map

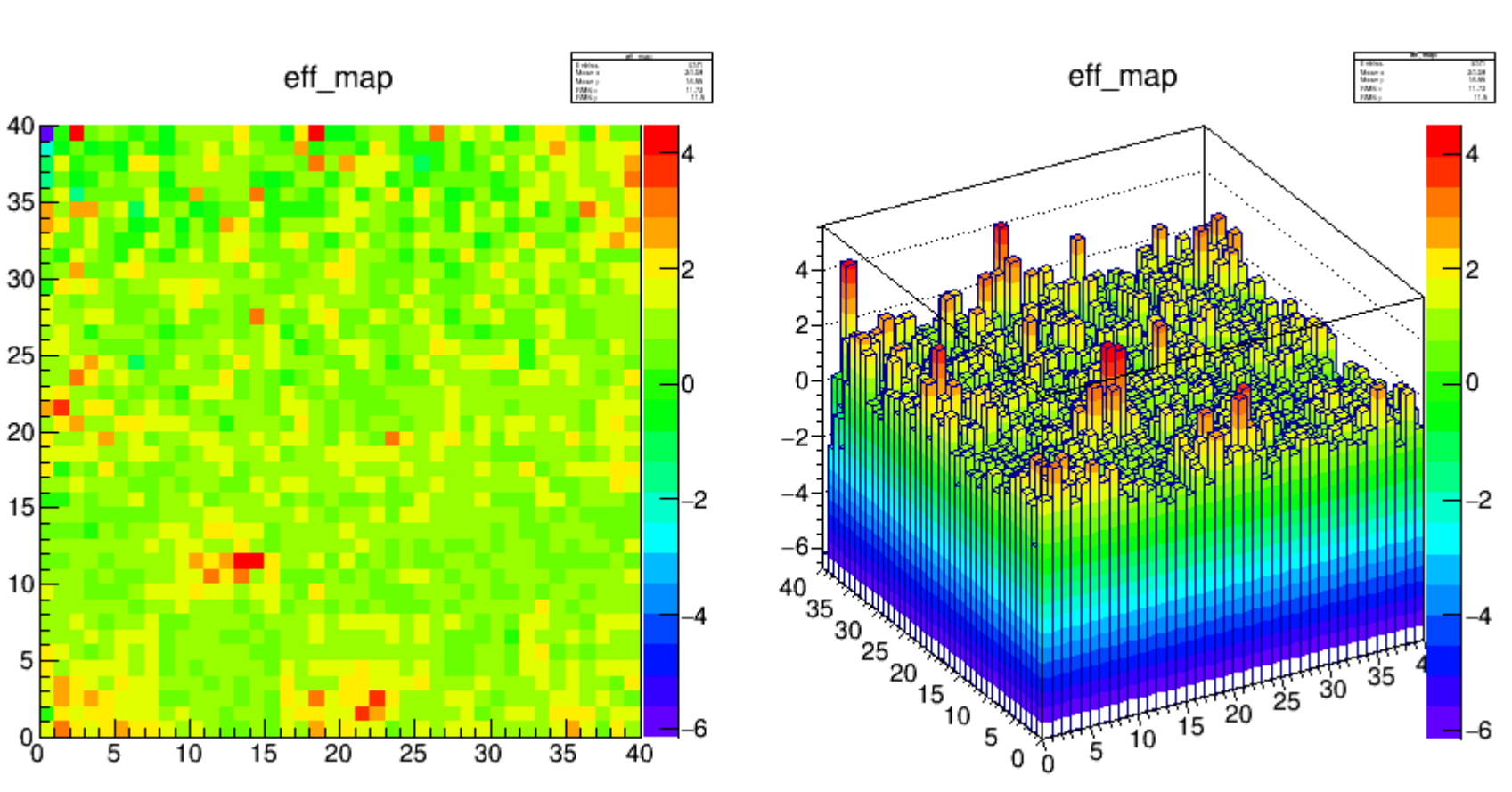


Observed GRB hit map

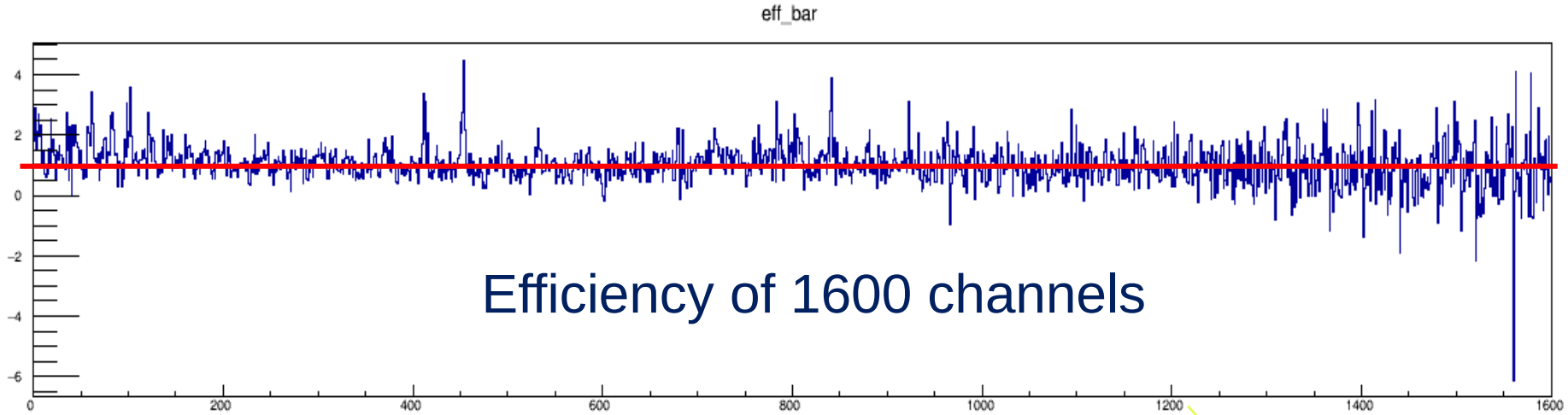


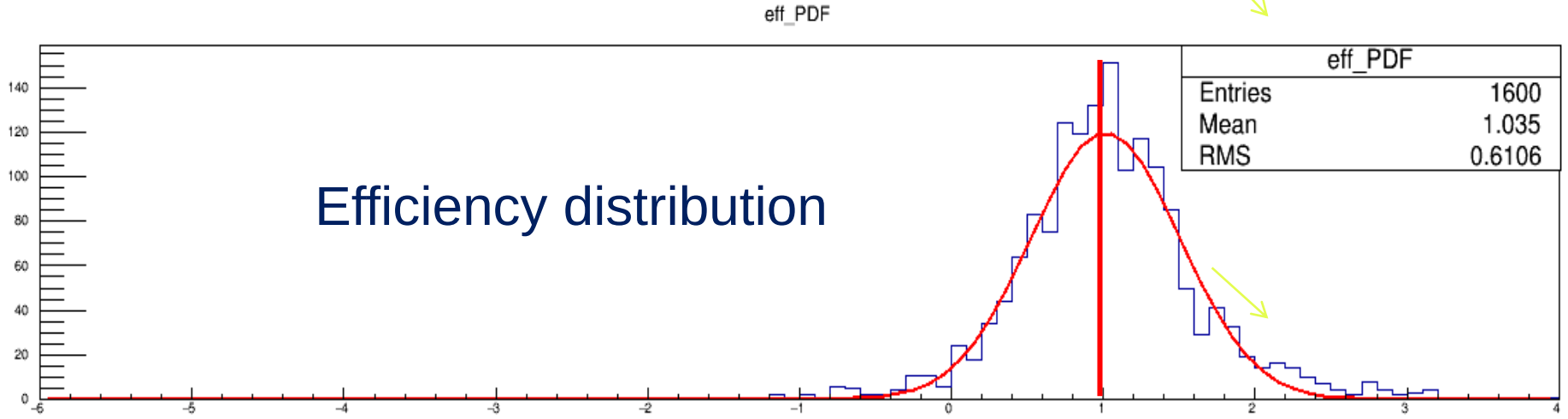
Efficiency map

Observation/ Simulation



Efficiency statistics





Summary and outlook

- HXMT is China's 1st X-ray astronomy satellite: 2017-06.
- HXMT AO-1 → 1st yr observation program available.
  - 1/3 total time in Galactic plane scan and monitoring
  - GRB mode when in Earth shadow or HE not used (~1/2)
  - Will invite ESA, ASI, MPE, etc., for joint studies.
- POLAR, launched on 2016-09-14, is working as expected.
- POLAR has detected the Crab pulsar, solar flares and GRBs.
- In-orbit calibration is on-going: polarization for solar flares and GRBs are expected for bright events.

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