Overview of the POLAR mission

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Introduction to POLAR

- Platform: onboard China's space lab "Tiangong-2", launched on 15th Sep., 2016
- Collaborations: China (IHEP), Switzerland (UNIGE, PSI, ISDC), Poland (NCBJ)
- Main goal: Polarization measurement of GRB prompt emissions with high precision
- Extended detection abilities in-orbit: Pulsars, Solar flares, etc.
- R&D phases
  - 2005~2010, concept and prototype
  - 2011~2013, qualification model
  - 2013~2016, flight model
  - 15th Sep. 2016, launch
- Stopped on 1st April, 2017 due to HVPS failure

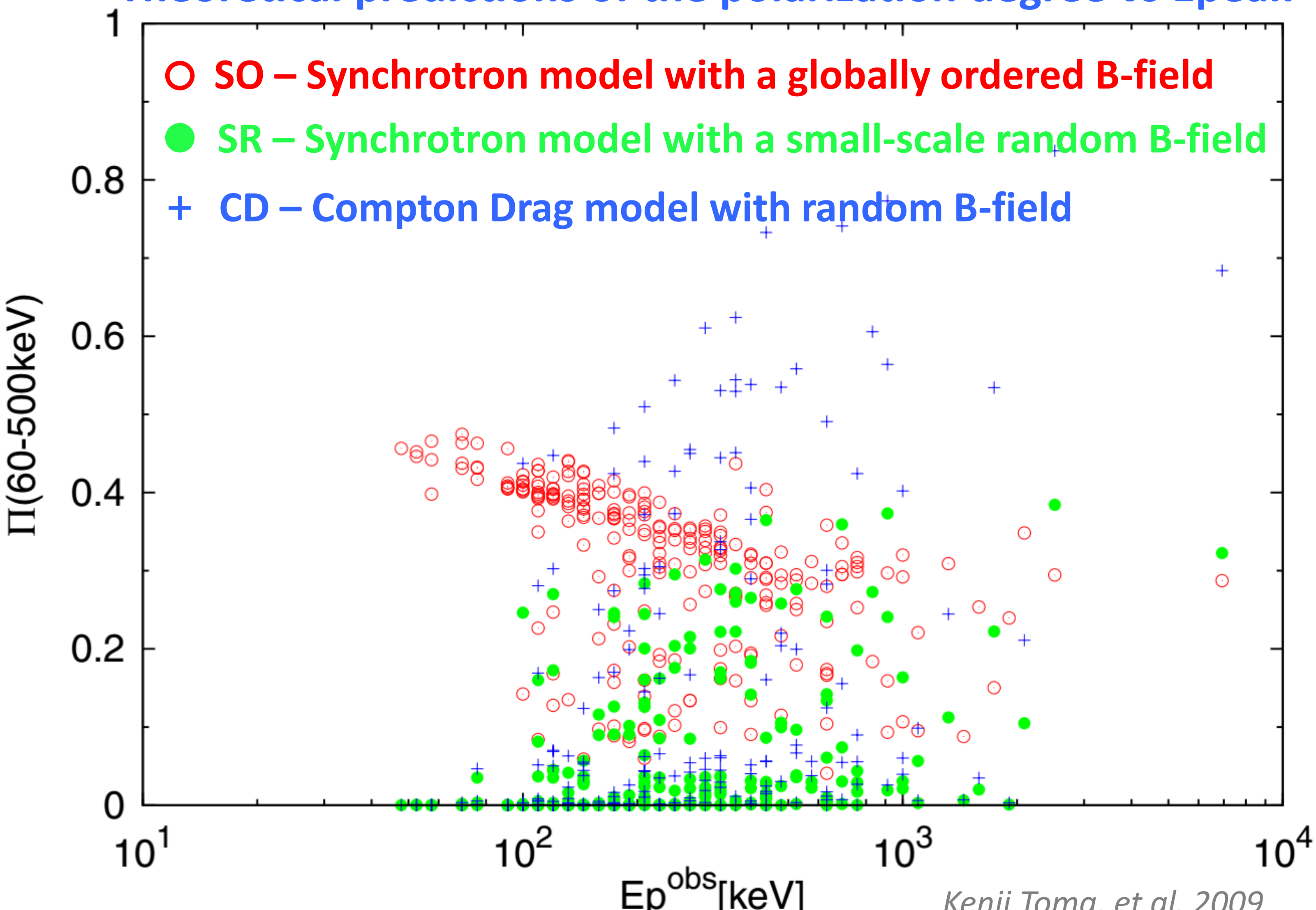
Instrument Characteristics
OBOX size: 462×462×262.5 mm^3 IBOX size: 247×160×85 mm^3 Plastic scintillator bar size: 5.9×5.9×176 mm^3
Mass: OBOX: 28 kg, IBOX: 3.5 kg
Energy range: 50 – 500 keV
FOV: ~±90° ×±90°
Orbit statistics
Orbit: ~400 km
Orbital inclination: ~42.79°, Period: ~ 92 mins

OBOX

IBOX

Motivation of GRB polarization measurement

Theoretical predictions of the polarization degree vs Epeak



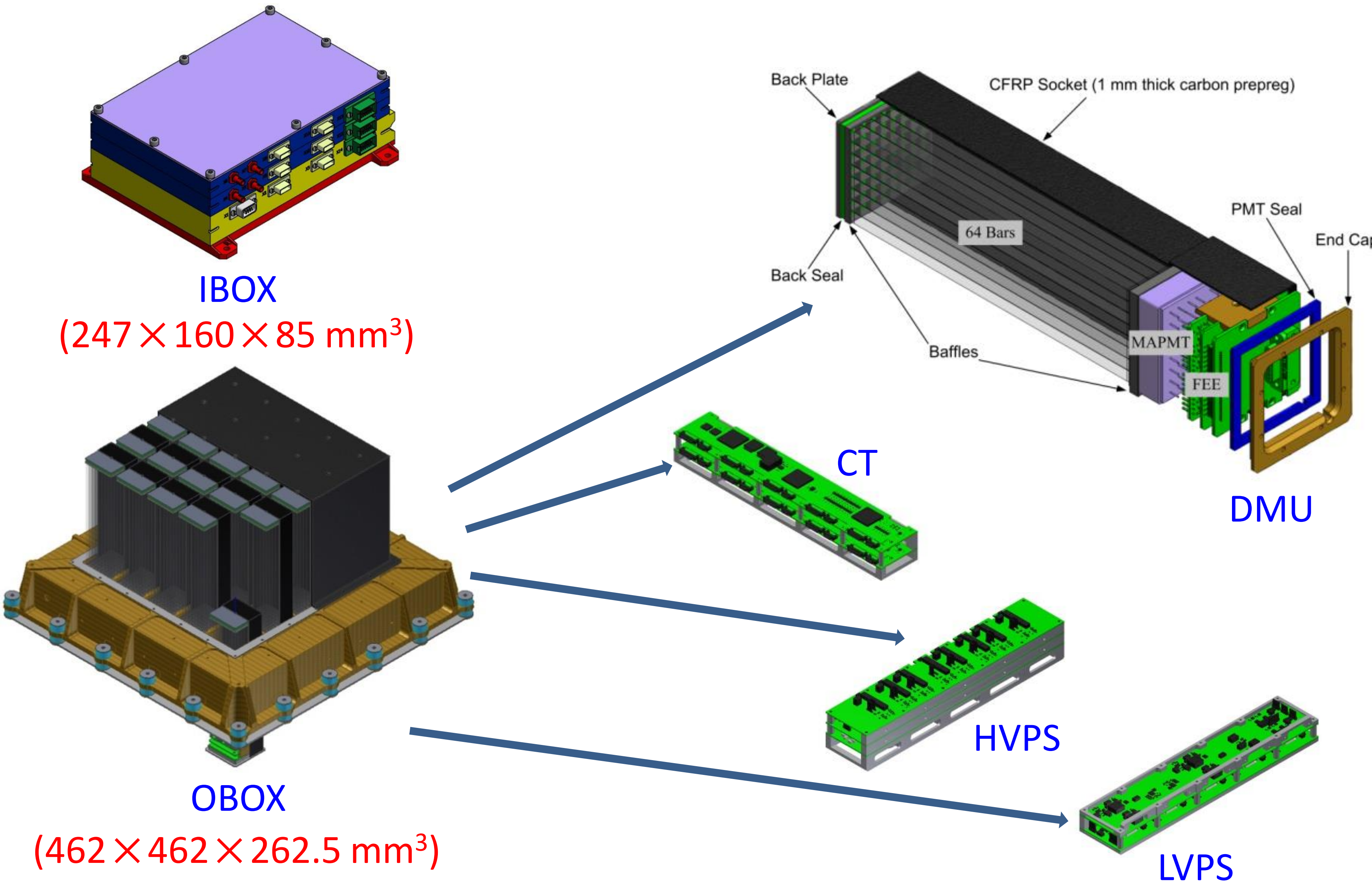
Kenji Toma, et al. 2009

GRB polarization measurements before POLAR

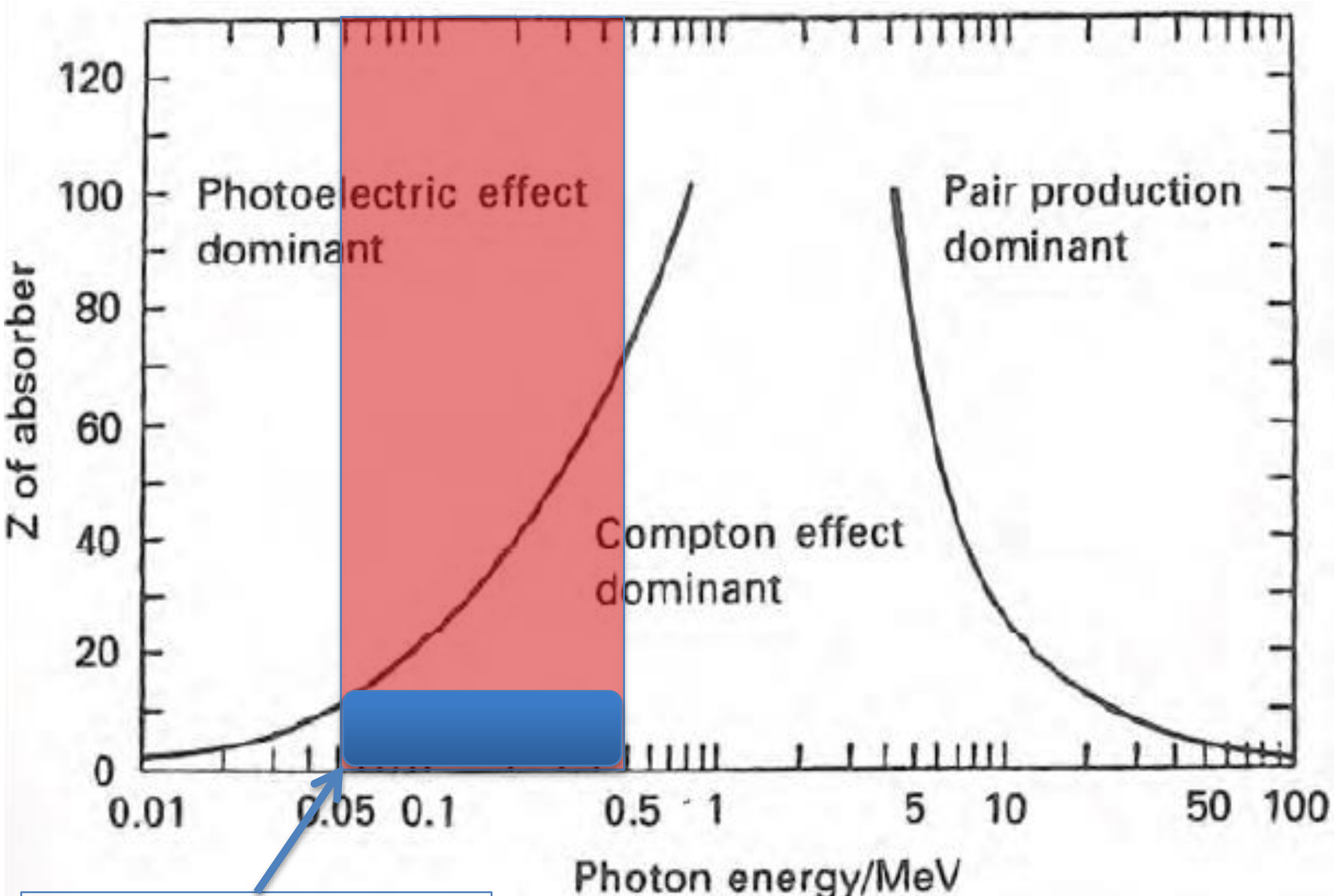
Most of the results suffer from big systematic uncertainties except COSI and GAP

GRB	Instrument/SAT	PD(%)	Erange(keV)	Comments
160530A	COSI	< 46%	200-5000	No evolution
110721A	GAP/IKAROS	84^{+16}_{-28}	70-300	No evolution
110301A	GAP/IKAROS	70 ± 22	70-300	No evolution
100826A	GAP/IKAROS	27 ± 11	70-300	Multi-peaks, PA evolution
021206	RHESSI	80 ± 20; 41^{+57}_{-44}	150-2000	Big systematic uncertainty
140206A	IBIS/INTEGRAL	>28	200-400	Big systematic uncertainty
061122	IBIS/INTEGRAL	>33;	250-800;	
041219A	IBIS/INTEGRAL IBIS/INTEGRAL SPI/INTEGRAL	<4; 43 ± 25; 98 ± 33	200-800; 200-800; 100-350	
960924	BATSE/CGRO	>50	20-1000	
930131	BATSE/CGRO	>35	20-1000	

Composition of POLAR

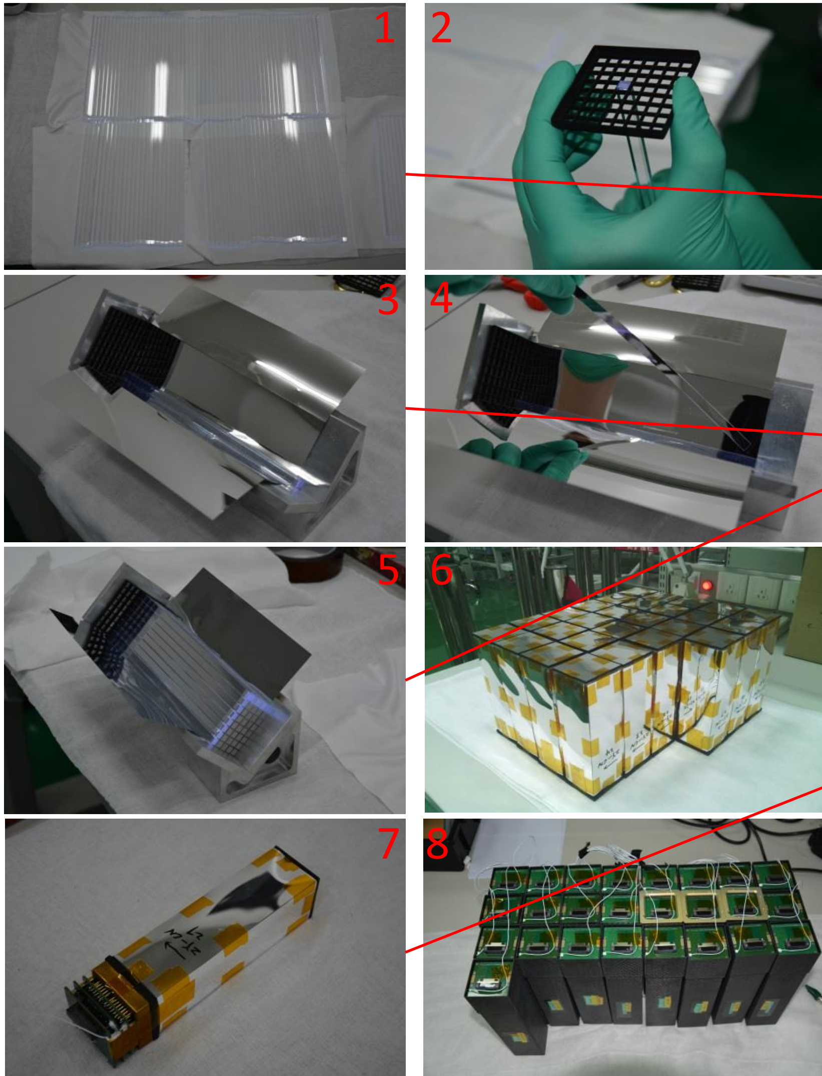


Detection theory



Plastic scintillators
(low Z material)

Construction of the detector modular unit (DMU)



- Main assembly procedure:

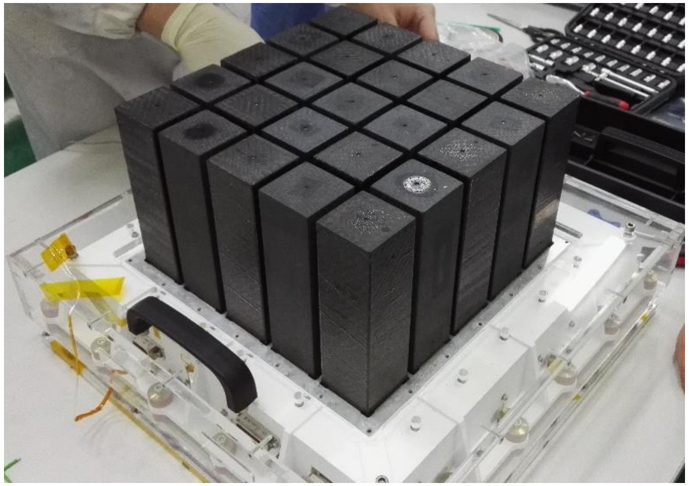
(a) Matching of plastic scintillator (PS) bars and the baffles, making sure the PS bars exceed 0~1mm

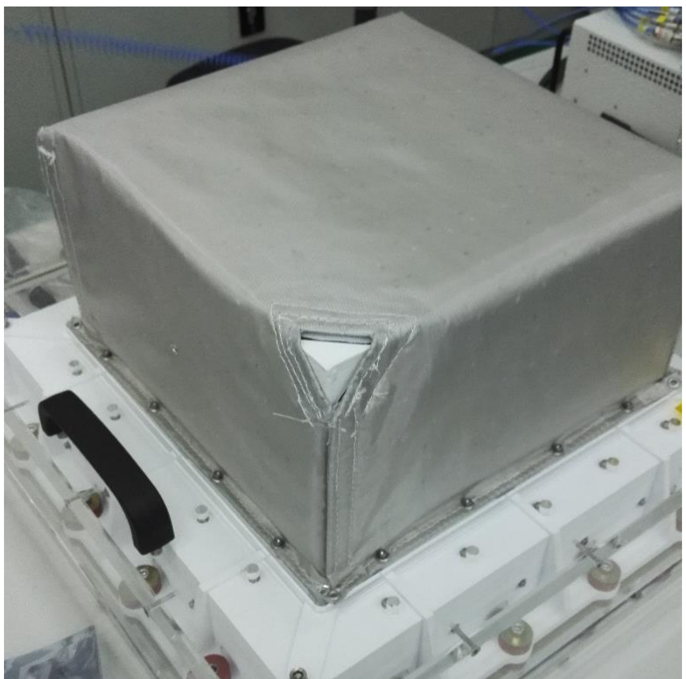
(b) Assembly of the plastic scintillator bars target, insert ESR reflective films between each two bars and exposure surfaces

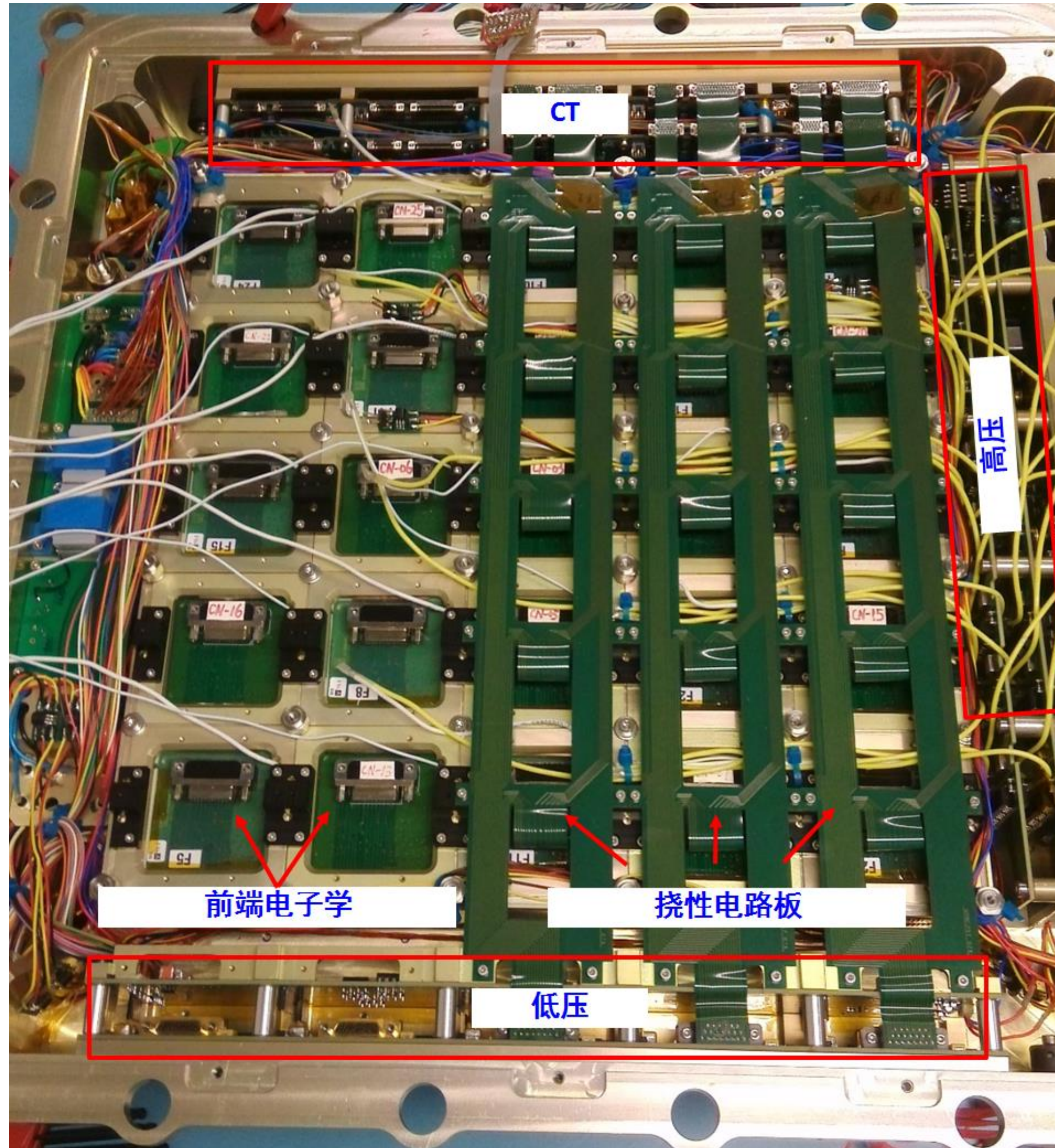
(c) Coupling of the PS target and MAPMT, FEE

(d) Packaging with carbon fiber socket

System integration of POLAR OBOX

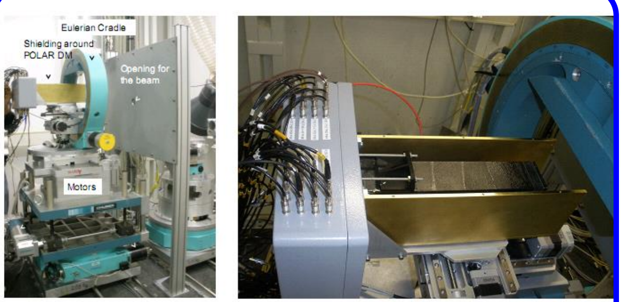






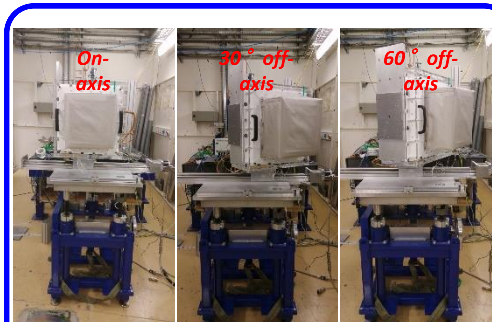
Polarization measurement verification and calibration

- In 2009, verified the detection principle of POLAR with a DMU model at ESRF
- In 2012, performed the polarization measurement calibration of POLAR QM at ESRF, further verified the working principle
- In 2015, accomplished the full polarization measurement calibration with POLAR FM at ESRF
- In 2016, installed the in-orbit calibration ^{22}Na sources in FM, and verified the in-orbit calibration method



Beam test in 2009

Beam test in 2012

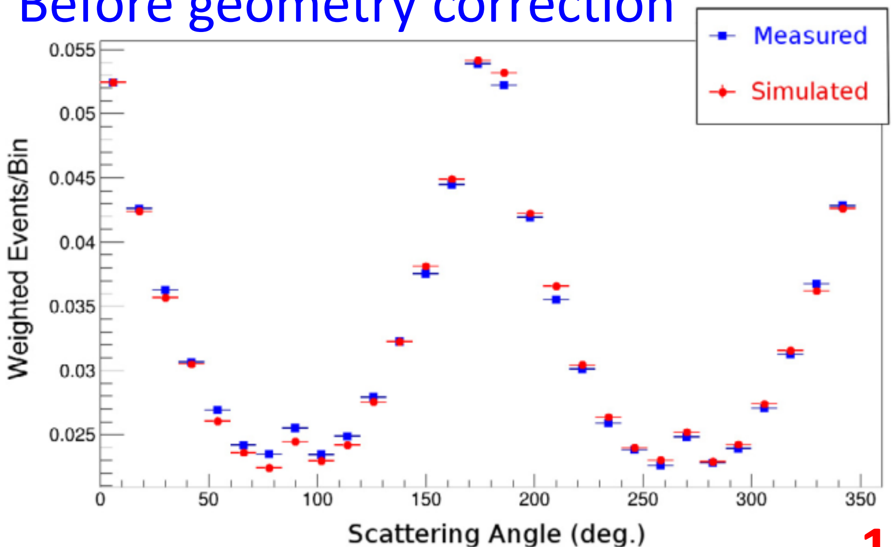


Beam test in 2015

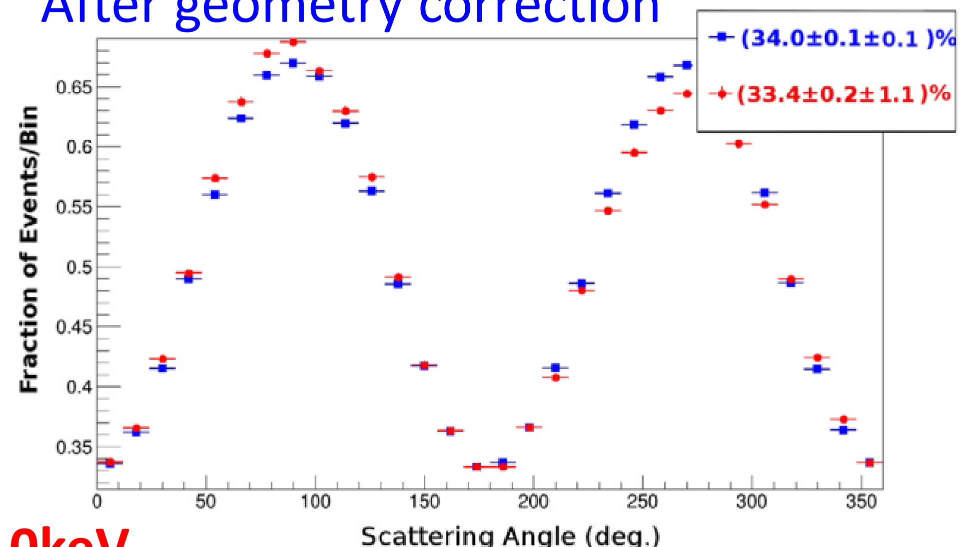
^{22}Na source

Main results of ESRF 100% beam test in 2015

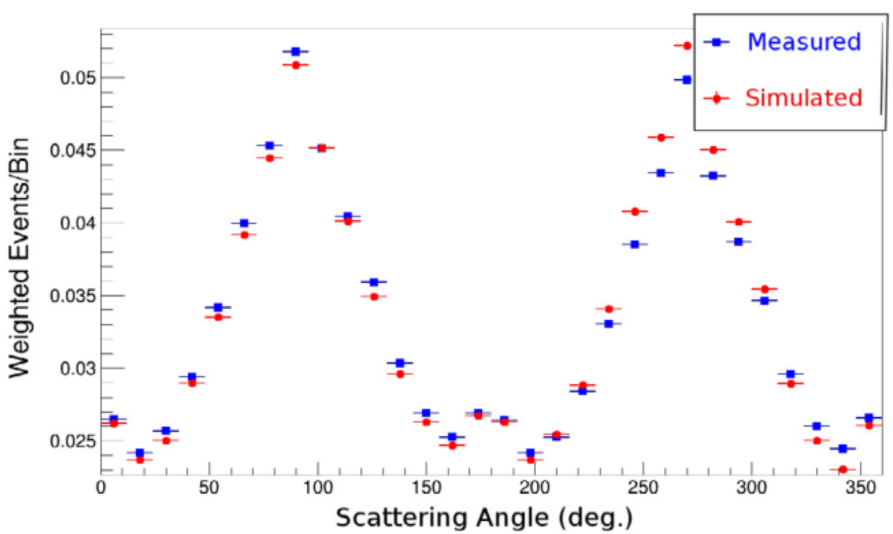
Before geometry correction

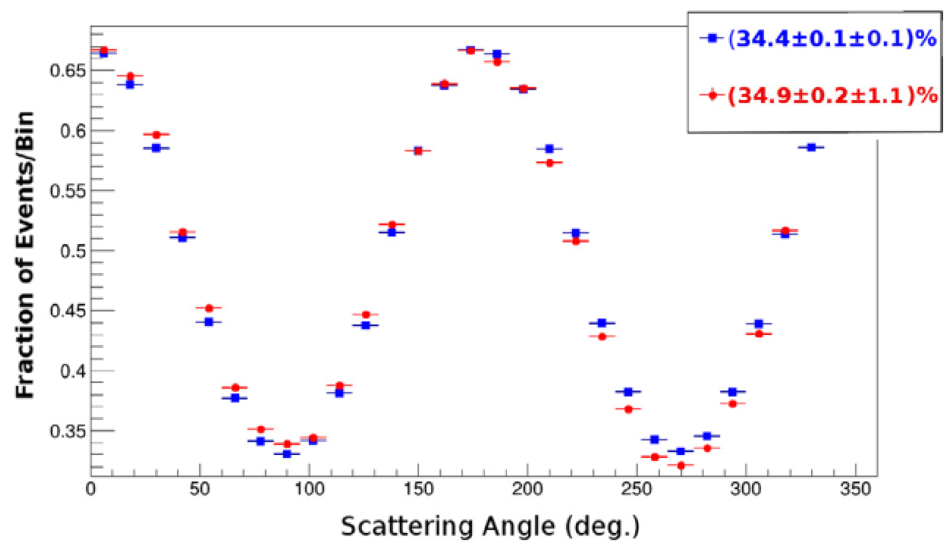


After geometry correction



110keV



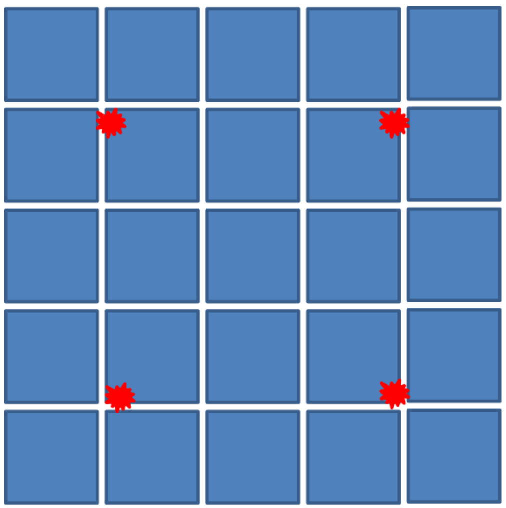


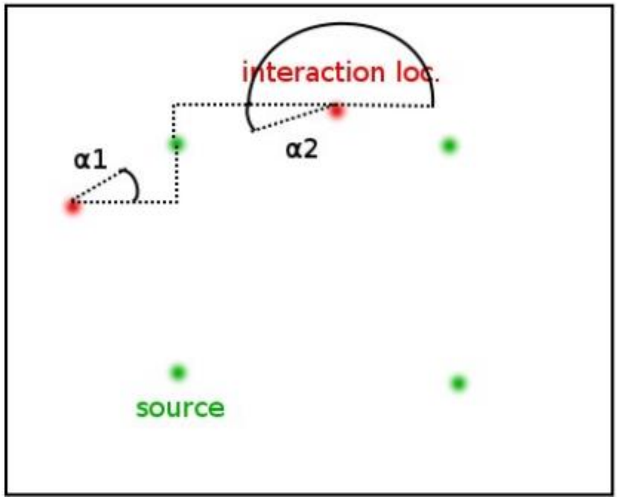
Merlin Kole, et al. NIMA, 2017

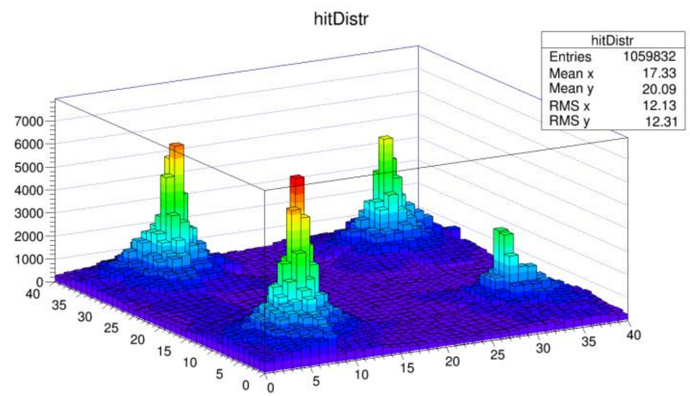
In-orbit calibration method and implementation

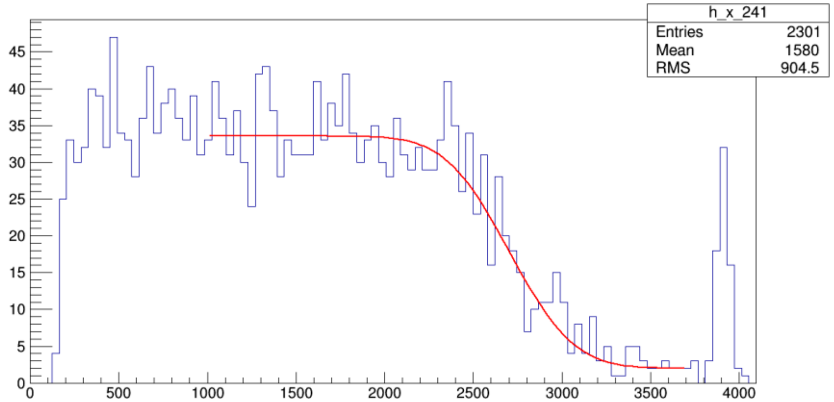
➢ Energy calibration

- Calibration source: 4 ^{22}Na radioactive sources with a total activity ~350 Bq
- Aim: in-orbit energy calibration and long-term performance monitoring



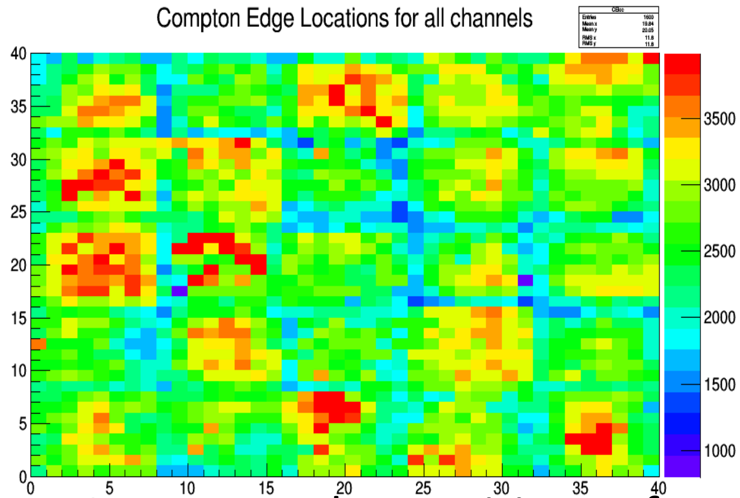




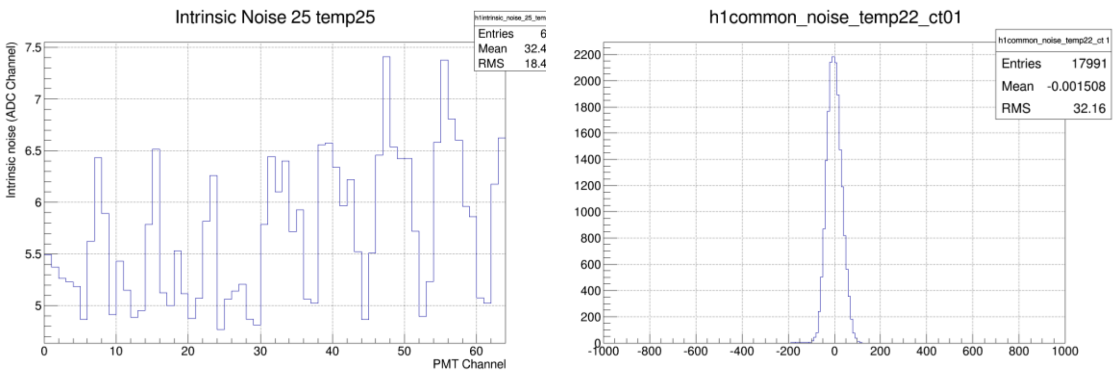


Launch of TG-2

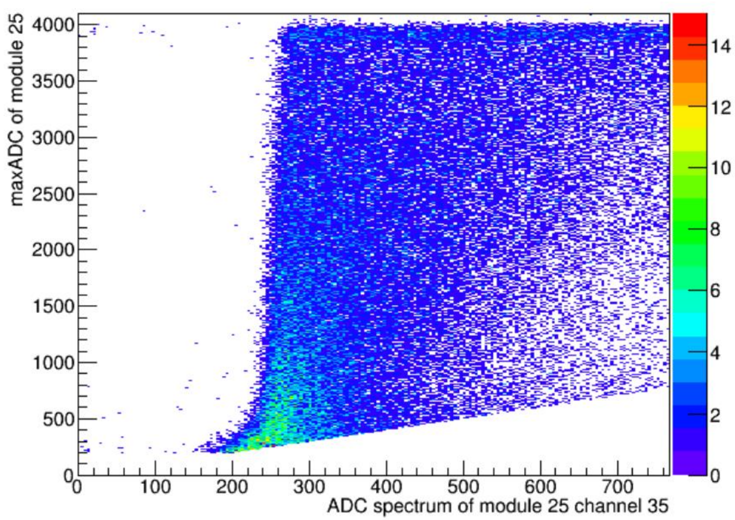
In-orbit calibration and performance study



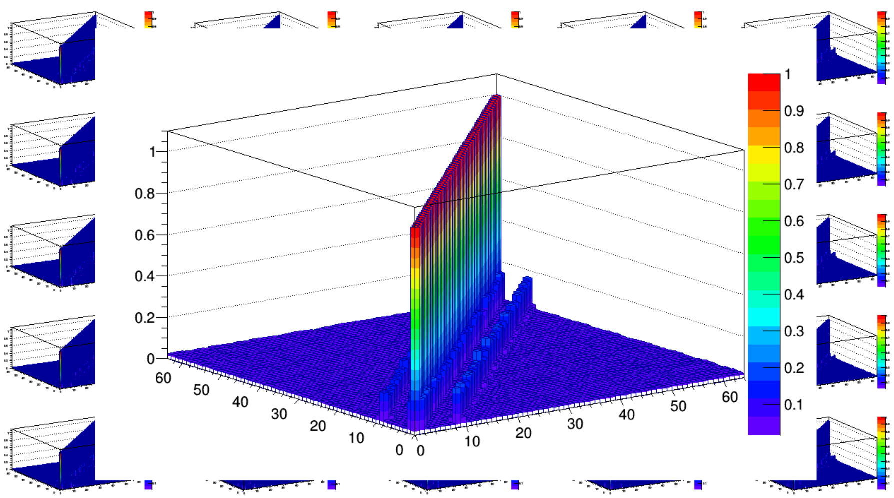
Compton edge positions of 1600 channels



Noise study



Nonlinearity study



Crosstalk signal study

For more details refer to： *Li Zhengheng, et al., NIMA, 2018*

GRB detections by POLAR

- POLAR detected 55 confirmed GRBs, ~132 GRBs per year

List of GRBs detected by POLAR (confirmed by other instruments)

Number	GRB Name	Trigger time (UTC)	Joint observation
1	GRB 160924A	2016-09-24T06:04:09.040	Fermi/GBM, SPI-ACS
2	GRB 160928A	2016-09-28T19:48:05.000	Fermi/GBM, SPI-ACS, KW
3	GRB 161009651	2016-10-09T15:38:07.190	Fermi/GBM
4	GRB 161011217	2016-10-11T05:13:44.420	KW
5	GRB 161012989	2016-10-12T23:45:11.380	KW
6	GRB 161013948	2016-10-13T22:44:40.100	Fermi/GBM
7	GRB 161120401	2016-11-20T09:38:33.520	SPI-ACS
8	GRB 161129A	2016-11-29T07:11:40.000	Swift/BAT, Fermi/GBM, AstroSAT
9	GRB 161203A	2016-12-03T18:41:07.750	KW,SPI-ACS, CALET/CGBM, AstroSAT
10	GRB 161205A	2016-12-05T13:27:18.000	Fermi/GBM
11	GRB 161207A	2016-12-07T20:42:55.000	Fermi/GBM, CALET/CGBM
12	GRB 161207B	2016-12-07T05:22:44.000	Fermi/GBM
13	GRB 161210A	2016-12-10T12:33:54.000	Fermi/GBM
14	GRB 161212A	2016-12-12T15:38:59.000	Fermi/GBM
15	GRB 161213A	2016-12-13T07:05:02.000	Fermi/GBM, SPI-ACS
16	GRB 161217B	2016-12-17T03:03:44.000	Fermi/GBM
17	GRB 161217C	2016-12-17T03:53:15.000	KW
18	GRB 161218A	2016-12-18T03:47:34.634	Swift/BAT
19	GRB 161218B	2016-12-18T08:32:41.341	Fermi/GBM
20	GRB 161219B	2016-12-19T18:48:39.000	Swift/BAT
21	GRB 161228A	2016-12-28T09:43:24.000	Fermi/GBM
22	GRB 161228B	2016-12-28T13:15:40.000	Fermi/GBM, SPI-ACS
23	GRB 161228C	2016-12-28T00:46:20.000	Fermi/GBM
24	GRB 161229A	2016-12-29T21:03:49.000	Fermi/GBM
25	GRB 161230A	2016-12-30T12:16:07.000	Fermi/GBM
26	GRB 170101A	2017-01-01T02:26:00.660	Swift/BAT
27	GRB 170101B	2017-01-01T02:47:18.270	Fermi/GBM
28	GRB 170102A	2017-01-02T02:51:18.000	KW
29	GRB 170105A	2017-01-05T06:14:07.000	SPI-ACS, KW
30	GRB 170109A	2017-01-09T03:17:35.000	Fermi/GBM
31	GRB 170112B	2017-01-12T23:16:09.000	Fermi/GBM
32	GRB 170114A	2017-01-14T22:01:10.000	Fermi/GBM
33	GRB 170114B	2017-01-14T19:59:12.000	Fermi/GBM, KW
34	GRB 170120A	2017-01-20T11:18:30.000	Fermi/GBM
35	GRB 170121A	2017-01-21T01:36:55.200	Fermi/GBM
36	GRB 170124A	2017-01-24T20:58:06.000	Fermi/GBM, KW, CALET/CGBM
37	GRB 170127C	2017-01-27T01:35:49.000	Fermi/GBM, Fermi/LAT, AGILE, AstroSAT
38	GRB 170130A	2017-01-30T07:14:45.000	Fermi/GBM
39	GRB 170131A	2017-01-31T23:14:59.000	Fermi/GBM, Swift, KW
40	GRB 170202B	2017-02-02T07:19:54.000	KW
41	GRB 170206A	2017-02-06T10:51:57.700	Fermi/GBM, Fermi/LAT, SPI-ACS
42	GRB 170206C	2017-02-06T11:40:10.000	SPI-ACS
43	GRB 170207A	2017-02-07T21:45:04.000	Fermi/GBM, IPN, KW
44	GRB 170208C	2017-02-08T13:16:33.000	Fermi/GBM, SPI-ACS
45	GRB 170210A	2017-02-10T02:47:37.000	Fermi/GBM, IPN, KW
46	GRB 170219A	2017-02-19T00:03:07.000	Fermi/GBM, CALET/CGBM, SPI-ACS, KW, IPN
47	GRB 170220A	2017-02-20T18:48:01.000	KW
48	GRB 170228B	2017-02-28T18:32:56.000	Fermi/GBM
49	GRB 170305A	2017-03-05T06:09:06.800	Fermi/GBM, KW, SPI-ACS, Swift/BAT
50	GRB 170306B	2017-03-06T14:07:20.000	Fermi/GBM, Fermi/LAT, SPI-ACS
51	GRB 170309A	2017-03-09T12:26:42.000	CALET/CGBM
52	GRB 170315A	2017-03-15T13:57:53.000	Fermi/GBM
53	GRB 170317A	2017-03-17T09:45:56.000	Swift/BAT
54	GRB 170320A	2017-03-20T03:42:39.000	SPI-ACS, KW
55	GRB 170325B	2017-03-25T21:50:01.000	KW

S. Xiong et al. 2017, Proc. of ICRC

Criteria for polarization analysis sample selection

- 5 GRBs were selected for polarization analysis based on the following criteria for the first paper (S.N. Zhang & M. Kole, et al. Nature Astro. 2019)

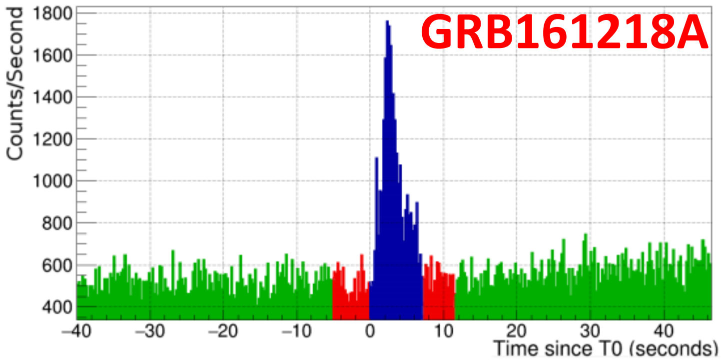
(a) The GRB has been detected by detectors other than POLAR, and good measurement of both the spectrum and location are provided by other instruments

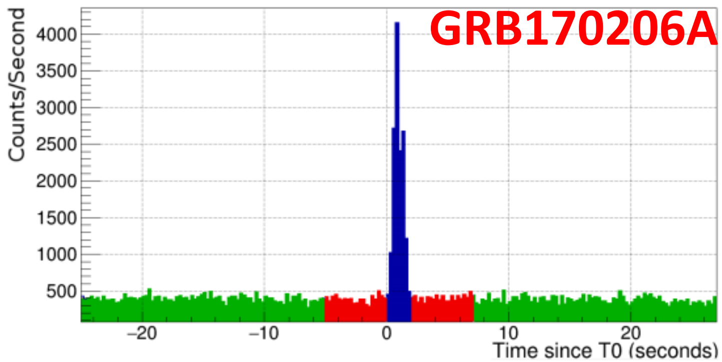
(b) The fluence of the GRB, as provided by other instruments in the 10-1000 keV energy range, exceeds 5×10^{-6} erg cm^{-2}

(c) The incoming angle with respect to the POLAR instrument zenith, θ, is below 45°

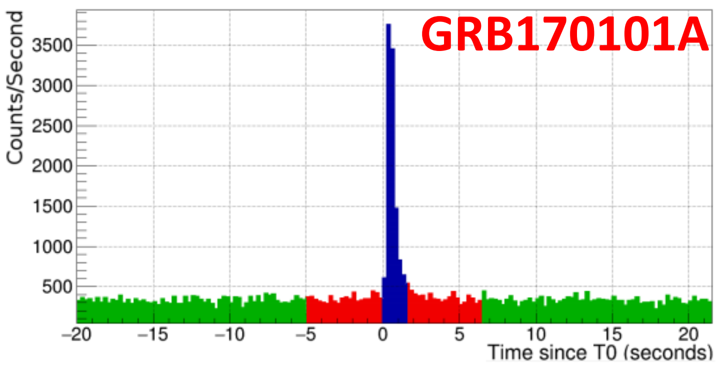
- Criterion (a) minimizes the systematic errors in the polarization results induced by uncertainties in the spectrum and location of the GRB
- Criteria (b) and (c) ensure a large number of events and a large modulation factor and therefore a high statistical significance of the measurement
- Criterion (c) furthermore reduces the influence of photons scattered off the objects in the vicinity of POLAR, thereby removing additional systematic errors

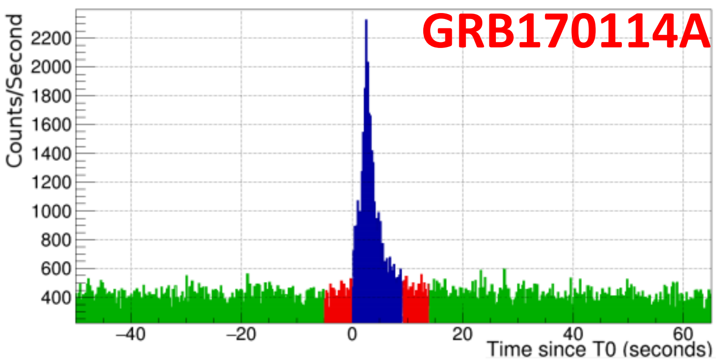
GRB samples selected for polarization study

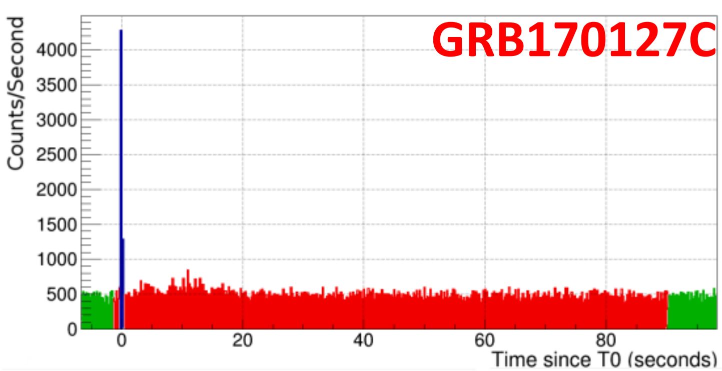


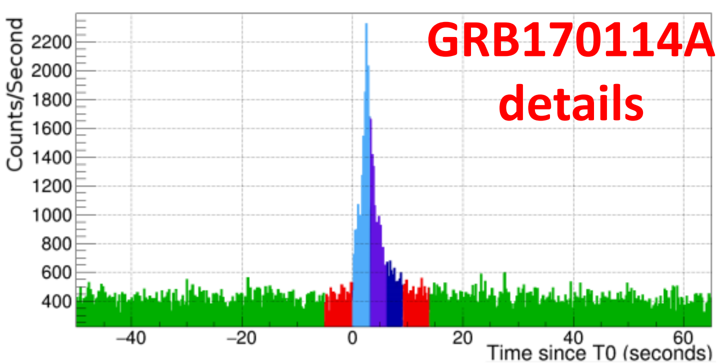


Blue: signal
Green: bkg
Red: non-used









GRB polarization measurement results by POLAR

- Main results

Table 1: Summary of the five GRBs selected (*in units of erg/cm^2 in 10-1000 keV)

GRB	T90 (s)	Fluence*	PD	Prob(PD<2%)	$PD_{up}(99\%)$	PA(deg.)	PA Change
161218A	6.76	1.25×10^{-5}	9%	9%	45%	40	No
170101A	2.82	1.27×10^{-5}	8%	13%	31%	164	No
170127C	0.21	7.4×10^{-6}	11%	5.8%	67%	38	Unknown
170206A	1.2	1.34×10^{-5}	10%	12%	31%	106	No
170114A	8.0	1.93×10^{-5}	4%	14%	28%	164	Yes
170114Ap1	N/A	N/A	15%	8%	43%	122	N/A
170114Ap2	N/A	N/A	41%	0.49%	74%	17	N/A

✓ Largest result sample at a time: in the past decades, ~5 space missions published ~10 GRB measurement results. For POLAR, recently, detailed polarization measurement analysis results of 5 GRBs were published. Besides, more results will be published soon for other GRBs.

✓ High precision: 99% confidence level upper limit is provided for the 5 GRBs

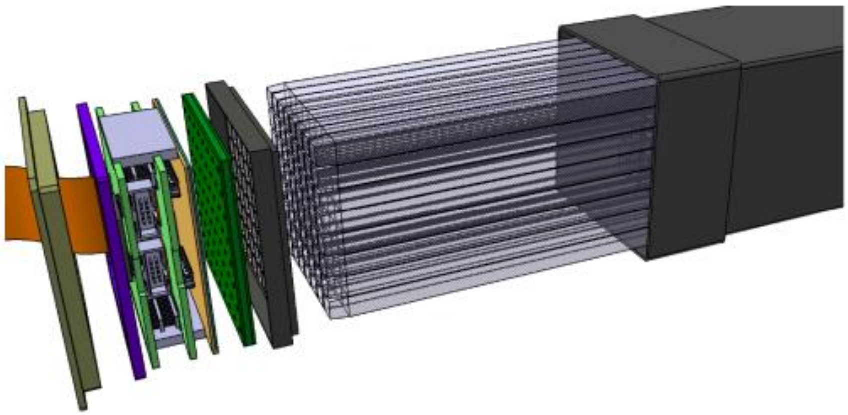
✓ New findings: the average polarization degree for 5 GRBs joint analysis is low (~10%), and clear evolution of the intrapulse polarization angle for GRB170114A

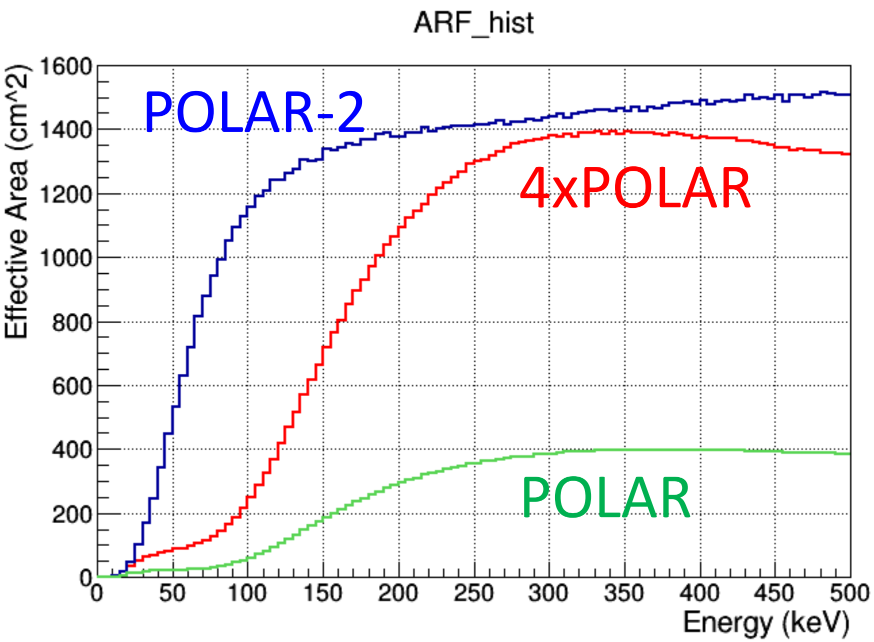
✓ New questions: 1) Polarization evolution of GRB exists commonly or not? 2) And what is the dominant mechanism? 3) Is the global low polarization due to the polarization angle evolution?

More details can be found in: S.N. Zhang & M. Kole, et al. Nature Astro., 2019

Expectations in the future—POLAR-2

- Successor experiment of POLAR: 4 times larger compared to POLAR, detection efficiency increases ~ 2.5 times of POLAR, thus about one order of magnitude of effective area larger than POLAR is expected
- Scientific goal: polarization measurement of GRB prompt emissions with unprecedented sensitivity and significance, thus to answer the questions raised according to POLAR's results
- Scientific capabilities: ~50 measurements of GRB polarization with a precision ≥ the 5 GRBs published by POLAR
- Collaborations: UNIGE, IHEP, MPE, NCBJ
- Current status: officially selected as one of the payloads onboard CSS





For more details see: M. Kole. PS3-249, ICRC2019

Summary

- ~10 years of instrument development: reliable design and on-ground calibration are critical
- In general, POLAR achieved its scientific goal: detected 55 GRBs and published so far the largest data sample for GRB prompt emission polarization measurement at a time, while in the near future more results will be published. Besides, new detection abilities for pulsars and solar flares were developed
- Unfortunately, POLAR stopped working at beginning of April/2017 due to the HVPS failure after ~6 months of operation
- Some new scientific questions raised regarding to POLAR's results: needs more observations and samples, as well as advanced theoretical models to verify and explain

Thank you for your attention!