Preliminary in-flight performance and calibration status of POLAR

Jianchao SUN

Institute of High Energy Physics, CAS

On behalf of the POLAR collaboration

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Outline

- Introduction to POLAR experiment
- Status of in-orbit operation and tests
- Status of in-flight calibration
- Summary and outlook

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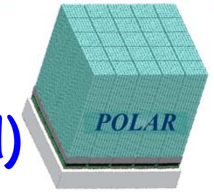
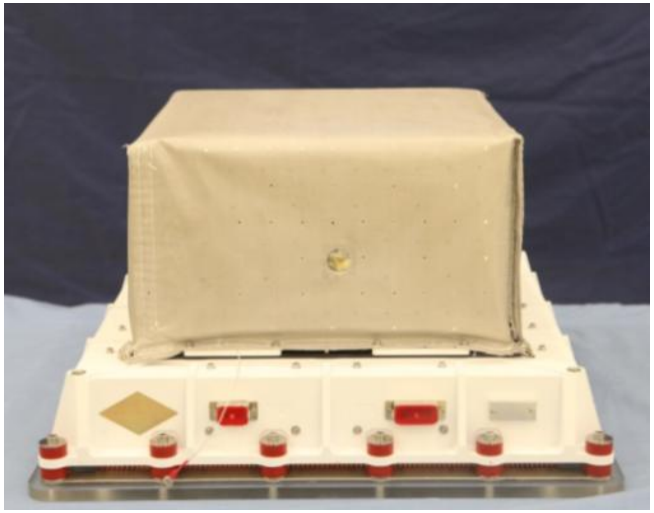
1. Introduction-R&D history and mission goals



Project: aboard TG-2, CN-EU collab (China, Switzerland, Poland)

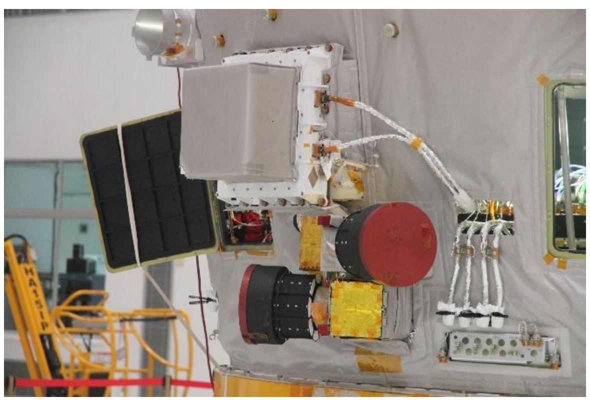
- **R&D history:**
  - 2005~2010, experiment concept and prototype development, Ref.: *N. Produit et al. 2005, NIMA; S. Xiong et al. 2009, NIMA; S. Orsi et al. 2011, NIMA; E. Suarez-Garcia, 2010, PhD thesis*
  - 2011~2013, qualification model, Ref.: *S. Orsi et al. 2014, Proc. of SPIE; J. Sun, 2012, PhD thesis; H. Xiao, 2012, Post-doc report*
  - 2013~2016, flight model, Ref.: *J. Sun et al. 2016, Proc. of SPIE; M. Kole et al. 2016, Proc. of IEEE; H. Xiao, 2016, Astroparticle Physics*
  - Sep. 15th/2016, launch onboard TG-2! Latest Ref.: *X. F. Zhang et al. 2018, NIMA; N. Produit et al. 2018, NIMA; M. Kole et al. 2017, NIMA; 郑世界等, 2017, 中国科学; S. Xiong et al. 2017, Proc. of ICRC; H. Li et al. 2017, Proc. of ICRC; Y. Wang et al. 2017, Proc. of ICRC*
- **Original scientific goal:**
  - Precise polarization (PL&PA) measurement of GRB prompt emissions
- **Extended scientific goals:**
  - Test of pulsar navigation with POLAR data
  - Search of gravitational wave high-energy electromagnetic counterpart
  - Observation of Solar Flare

1. Introduction-instrument, installation, launch



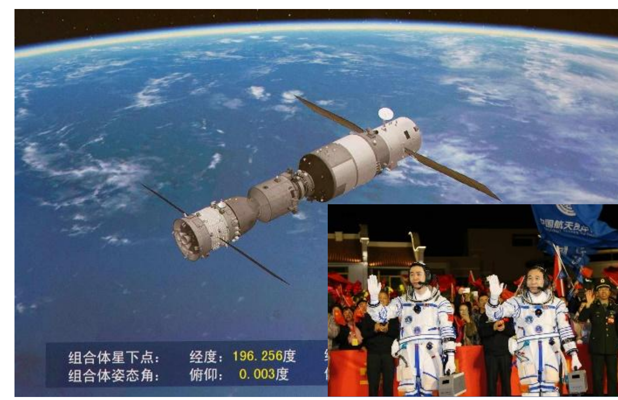
Detector (OBOX)

Electric cabinet (IBOX)



Installation on TG-2

Launch of TG-2

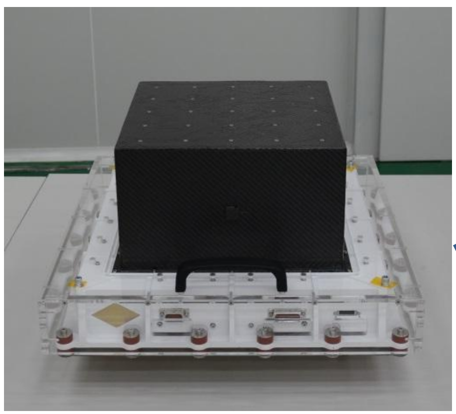


Docking of TG-2 and Shenzhou-11 space ship

1. Introduction-instruments composition

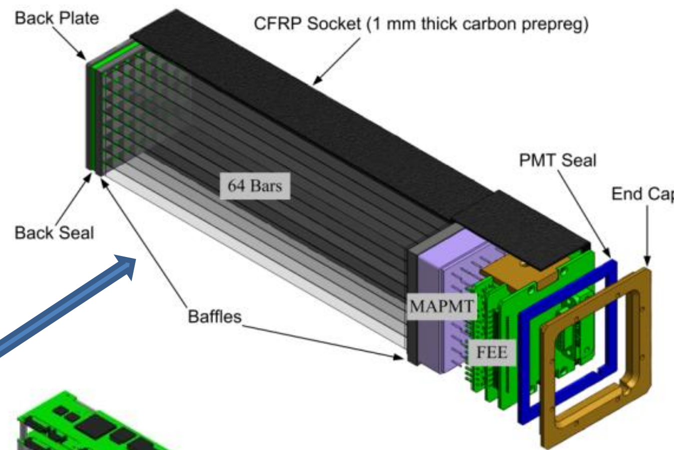
POLAR

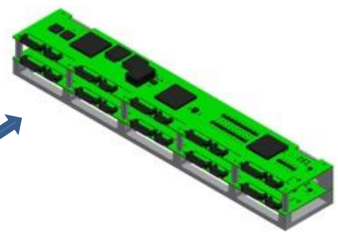
IBOX



OBOX

DMU





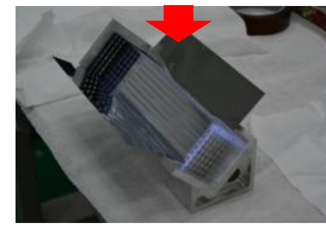
CT

HVPS

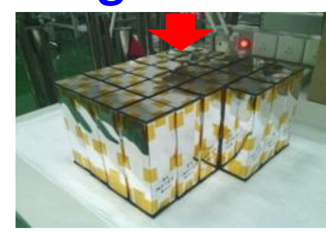
LVPS

DMUs

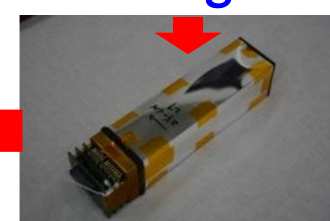
PS bar screen



PS target assembly

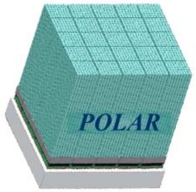


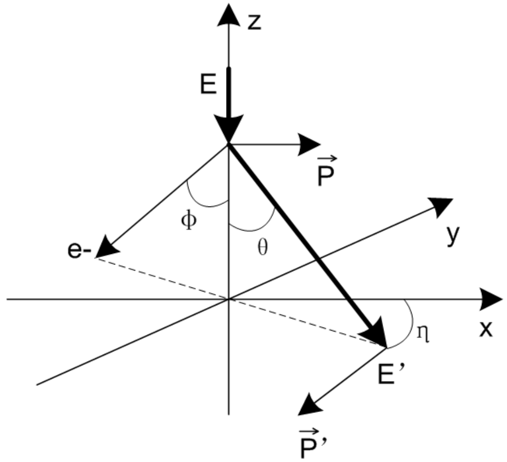
PS targets



Naked DMU

1. Introduction-detection theory

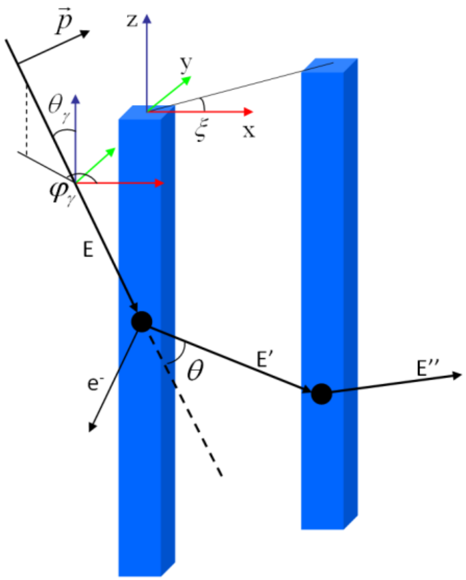




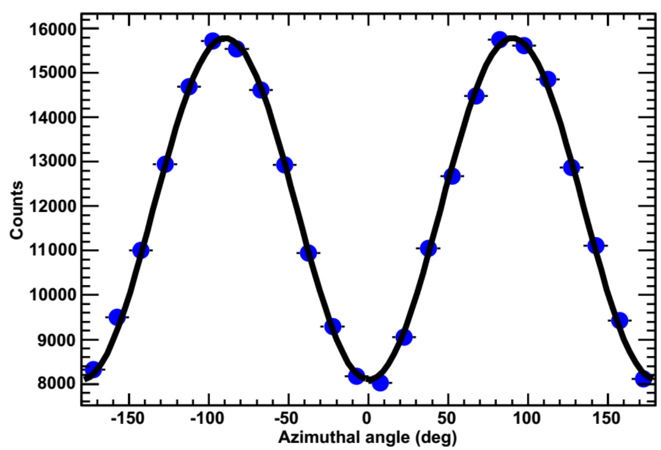
Compton Scattering with polarization

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

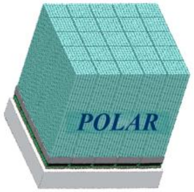
$$C(\xi) = A\cos(2(\xi - \varphi + \frac{\pi}{2})) + B$$

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

Modulation factor

Polarization level

2. In-orbit Operation and Tests



- Sep. 16th/2016, first powering on - IBOX
- Sep. 22nd, powering on of OBOX, start the commissioning phase

Summary of tests during POLAR commissioning phase (until April 1st/2017)

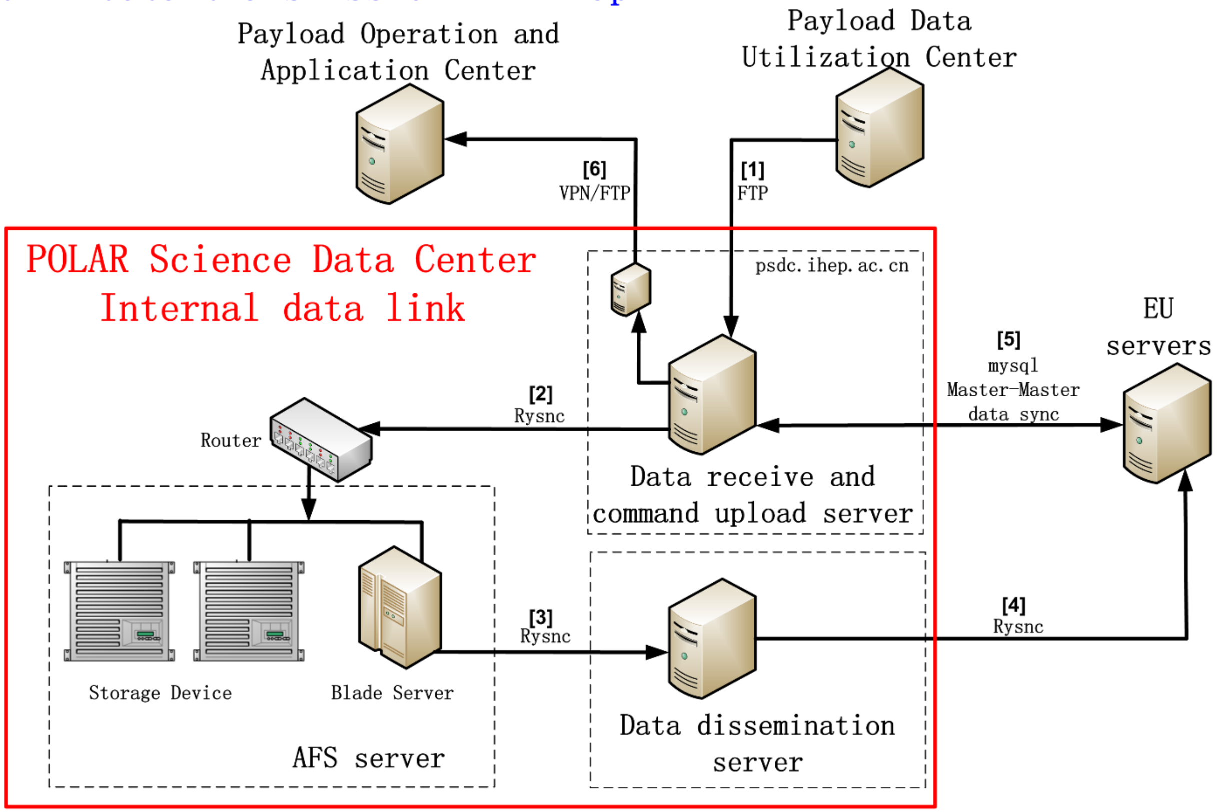
	Summary	Time (hrs)	Comments
	Total time	4567	2016.9.22~2017.4.1
	Time without data	993	Power off or data missing
	Time with data	3574	Obs. time including SAA
Science Obs.	Normal obs. time	1536	Normal mode observation
Science Obs.	Single bar obs. time	1644	Single bar mode observation
Calib.	In-orbit calibration time	394	In-orbit calibration

- In-orbit calib.: response of detector, efficiency, system time precision, etc.
- GRB detection: 55 confirmed GRB, 49 GCN circulars
- Crab pulsar detection: more than 27 million pulsar photons
- Solar Flare detection: ~9 obvious SFL events

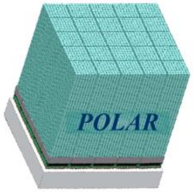
2. In-orbit Operation and Tests

- During the commissioning phase
  - 6.5TB total data size, 5188 data files: 6.4TB 0B data, 99GB 0C data
  - Implemented ~60 times commands upload operation, all succeeded

POLAR data transmission link map



2. In-orbit Operation and Tests



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

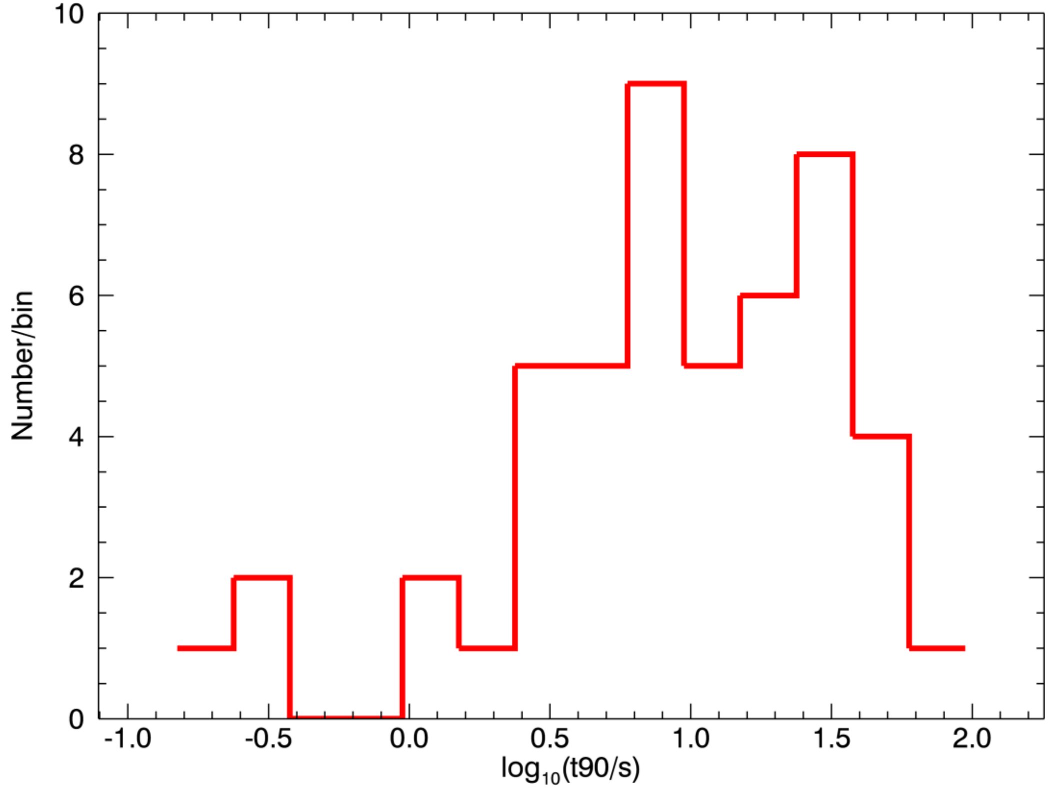
List of GRBs detected by POLAR (confirmed by other instruments)

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

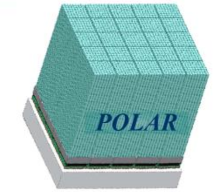
2. In-orbit Operation and Tests

T90 distribution of the 49 GCN circulated GRBs detected by POLAR



S. Xiong report. 2017

2. In-orbit Operation and Tests



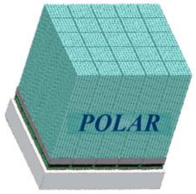
- 10 relatively bright GRBs detected by POLAR

POLAR GRB catalogue – 10 relative bright ones

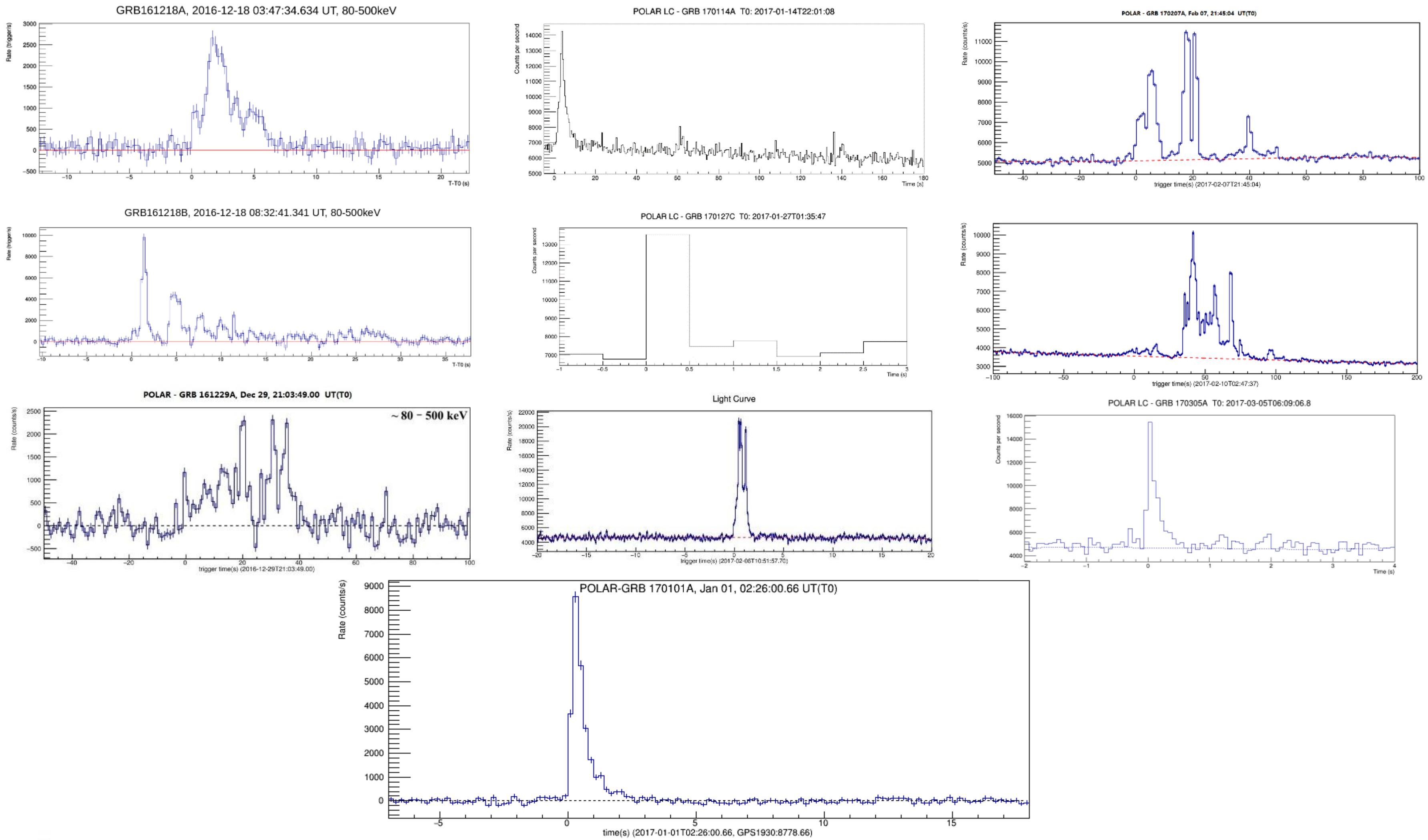
GRB Name	T90 (s)	Total Counts	Theta (deg)	Phi (deg)
GRB 161218A	6.8	6644	24.3	356.6
GRB 161218B	26.3	29340	77.76	252.2
GRB 161229A	35.77	35134	87.6	-103.7
GRB 170101A	2.82	5379	6.04	72.86
GRB 170114A	8.0	26800	26.4	4.9
GRB 170127C	22.0	3600	41.8	157.6
GRB 170206A	1.2	12918	19.5	148.7
GRB 170207A	39.47	63182	70.6	-2.2
GRB 170210A	67.27	106099	80.6	130.9
GRB 170305A	0.3	2400	31.4	239.1

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

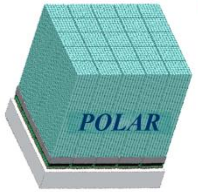
2. In-orbit Operation and Tests



- Light curves of the 10 bright GRBs



3. In-orbit calibration



- POLAR in-orbit calibration requirements:

(1) Performance variation of the detector

- Gain variation due to the shipment, launch and space environment modification
  - Gain of PMT
  - Coupling status between PS target and PMT
- Light output reduction of PS bars due to the irradiation effect in space
  - ~ 5% reduction in 2 years for estimation
- Aging effect
  - PS bars, PMT and electronics

(2) Influence of the performance variation

- Direct influence
  - Pedestal and noise, gain, crosstalk, etc.
- Indirect influence
  - Low threshold, and even polarization measurement error!

- Therefore, we need calibration for POLAR during flight!

3. In-orbit calibration

- POLAR in-orbit calibration includes:

(1) Energy calibration
- Gain vs HV
- Energy vs ADC channel

(2) Systematic effects calibration
- Pedestal and noise, crosstalk, nonlinearity, threshold

(3) Temperature dependence calibration
- Study on the calibration parameters vs temperature in space

(4) Timing calibration
- POLAR instrument system timing calibration with Crab pulsar signals

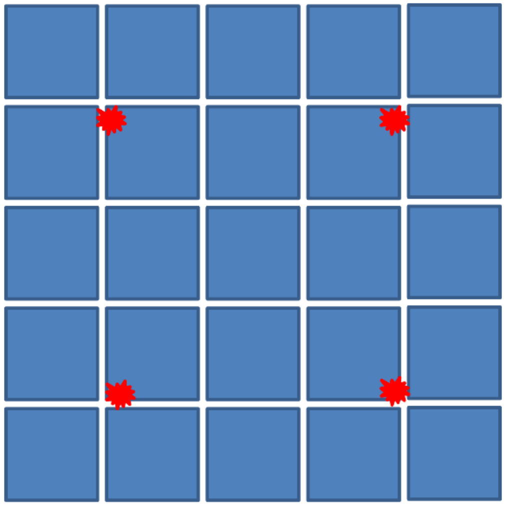
(5) GRB Localization
- Cross check with other satellites

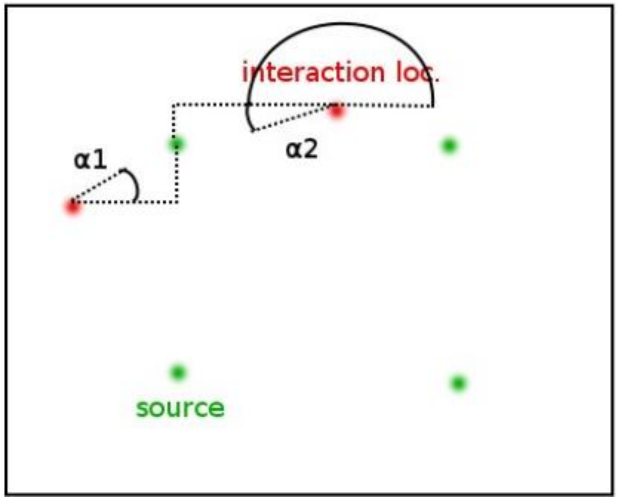
(6) Detection efficiency
- By using the GRB data

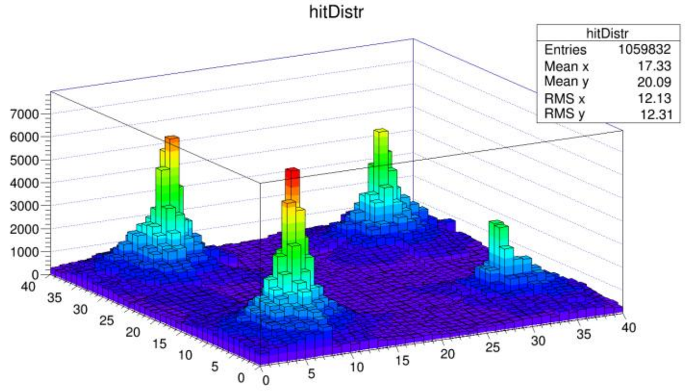
(7) Events filtering
- To exclude the bad or abnormal events

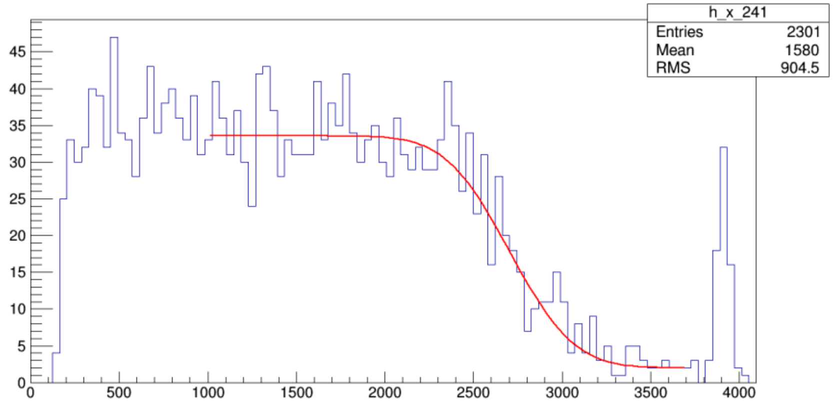
3. In-orbit calibration

- Energy calibration
  - 4 ^{22}Na radioactive devices
  - Total activities ~ 350 Bq



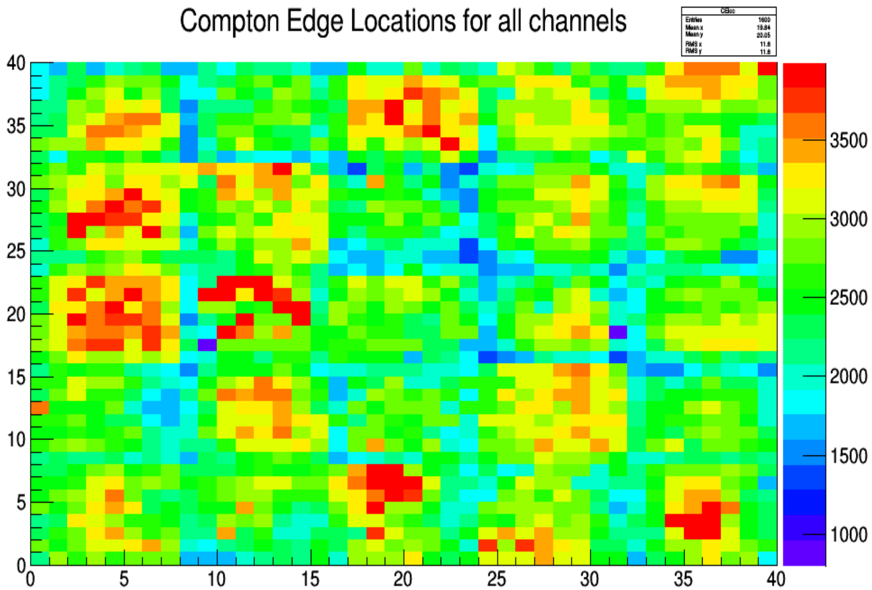




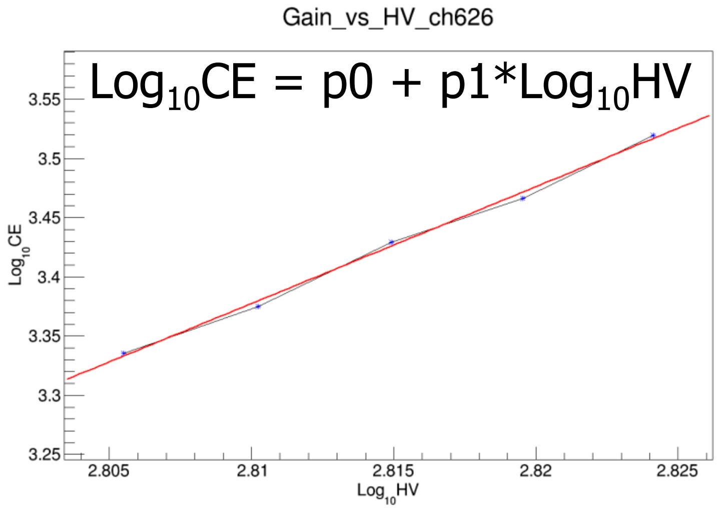


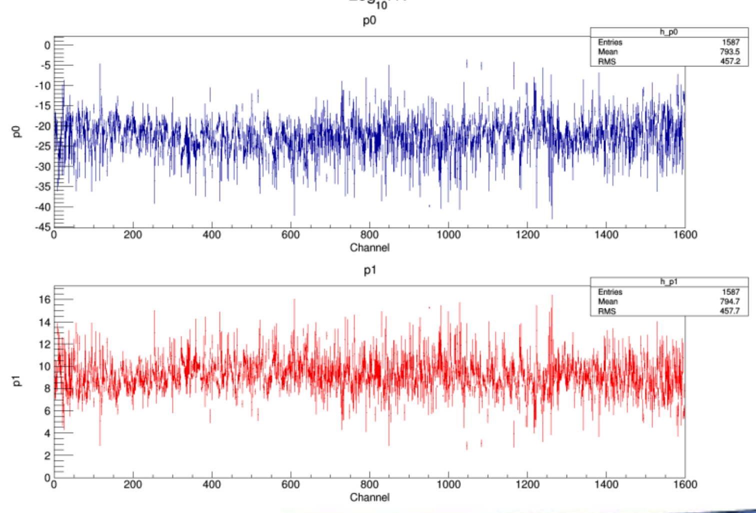
3. In-orbit calibration

- **Energy calibration**
  - Applied 5 different HVs to measure the gain vs HV
  - Application of gain vs HV to normal GRB observation mode



Compton edge positions of 1600 channels





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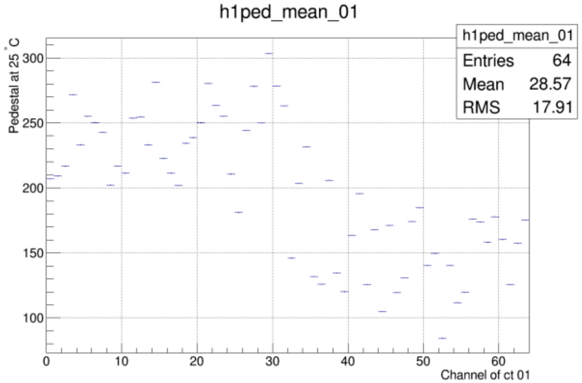
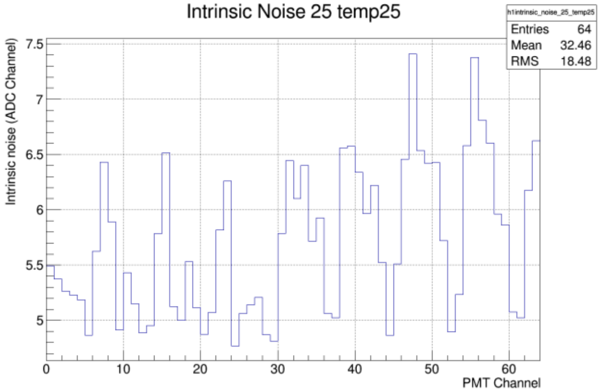
3. In-orbit calibration

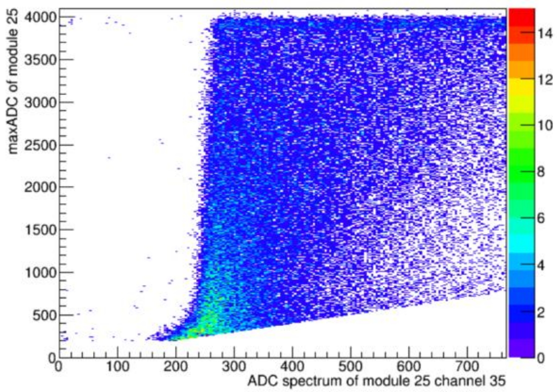
- Systematic effects calibration



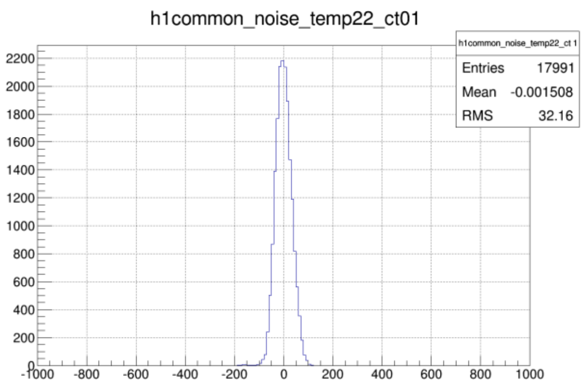
Pedestal



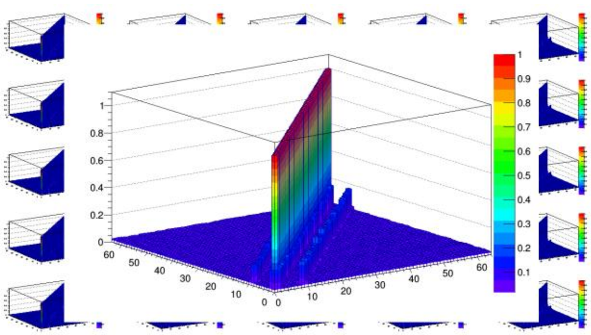
Intrinsic noise



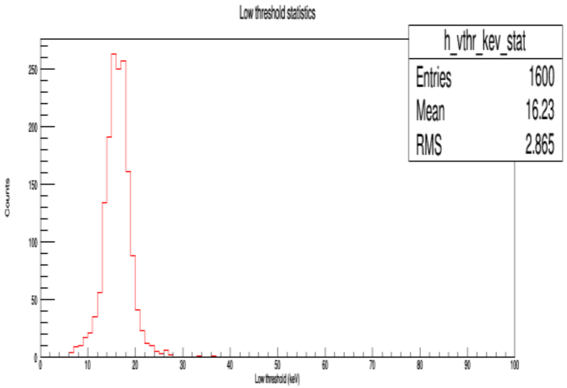
Nonlinearity



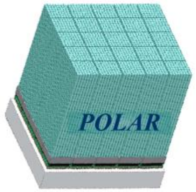
Common noise



Crosstalk matrix

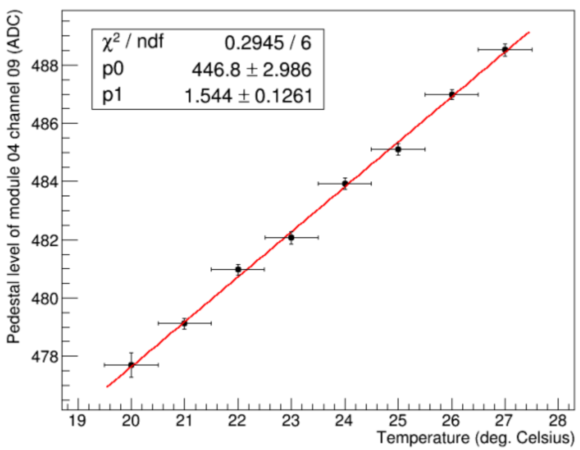


Low threshold

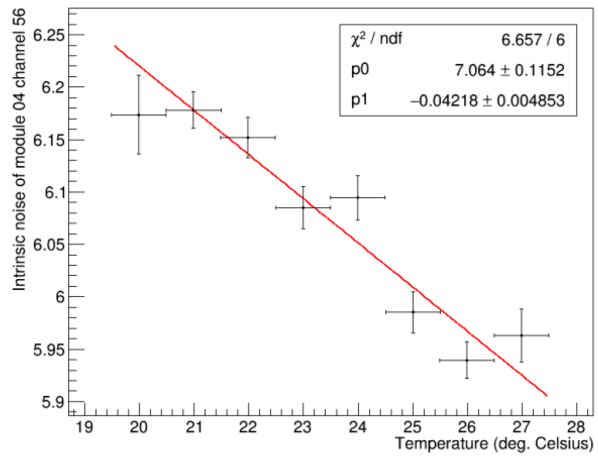


3. In-orbit calibration

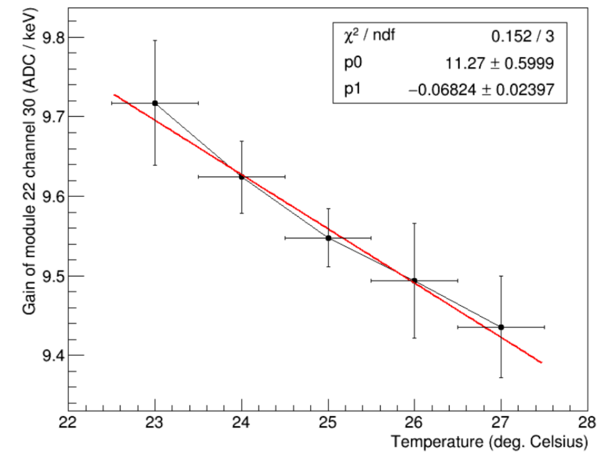
- Temperature dependence calibration



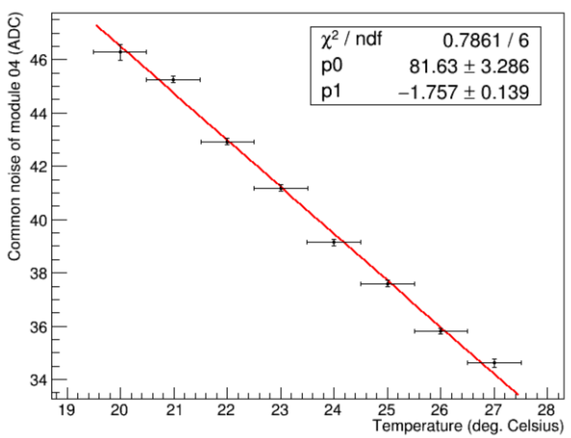
Pedestal vs temp.



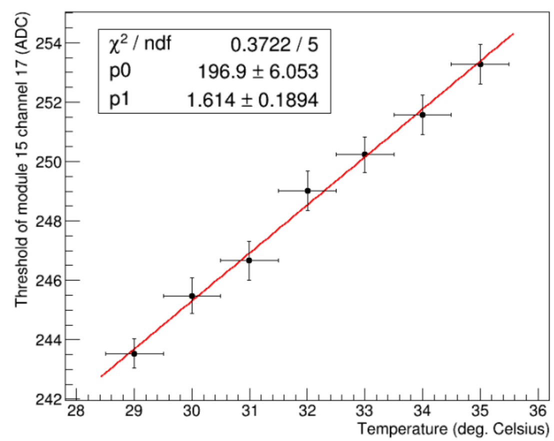
Intrinsic noise vs temp.



Gain vs temp.



Common noise vs temp.



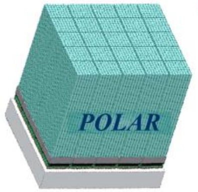
Low threshold vs temp.

Nonlinearity and crosstalk vs temp. can be negligible

Zhengheng Li, et al. 2018, submitted

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

3. In-orbit calibration



- **Timing calibration with Crab pulsar**
  - Precision better than 100 μs

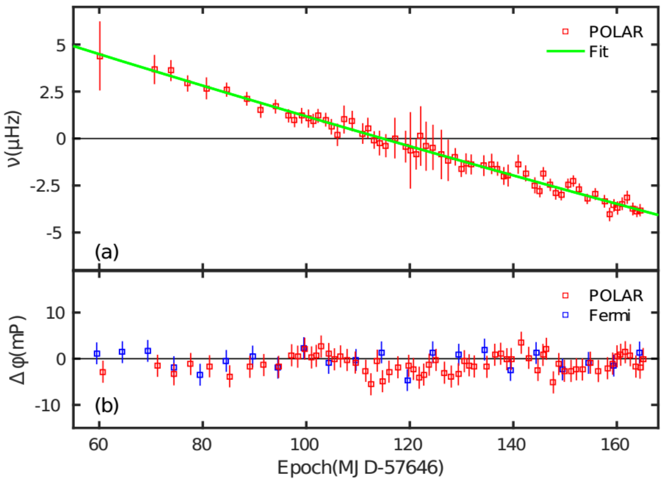
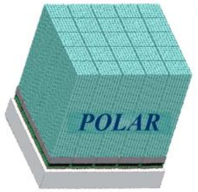


Figure 3: Panel (a): the evolution of the spin frequency of the Crab pulsar observed by POLAR. Each data point is subtracted by $(29.648422 - t * 3.68 \times 10^{-10})$ to show the details of its frequency evolution. The green line represents the fitted result. Panel (b): The time residuals of the Crab pulsar observed by Fermi and POLAR, as represented by the blue and red squares respectively.

- **GRB localization**
  - Cross calibration with other instruments in-orbit, precision ~ 5 degrees
- **Events filtering**
  - Cosmic events will be tagged and removed during the data analysis
  - The post cosmic events are mostly abnormal therefore need to be tagged and filtered out also. A method has been developed to filter out more than 95% such events

4. Summary and outlook



- **POLAR has accomplished the commissioning phase tests: has finished the in-flight calibration and data analysis (a paper has been submitted), detected 55 confirmed GRBs, detected the Crab pulsar signals and carried on the preliminary navigation study, detected ~ 9 obvious SFL events**
- **First GRB polarization analysis results are almost ready**
- **Outlook**
  - GRB polarization data analysis and MC simulation
  - Crab pulsar navigation study and polarization analysis
  - SFL data analysis

Fore more info., please refer to and contact
http://polar.ihep.ac.cn
E-mail: wubb@ihep.ac.cn, or sunjc@ihep.ac.cn

Thank you for your attention !

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences