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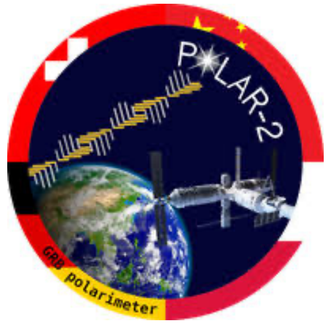


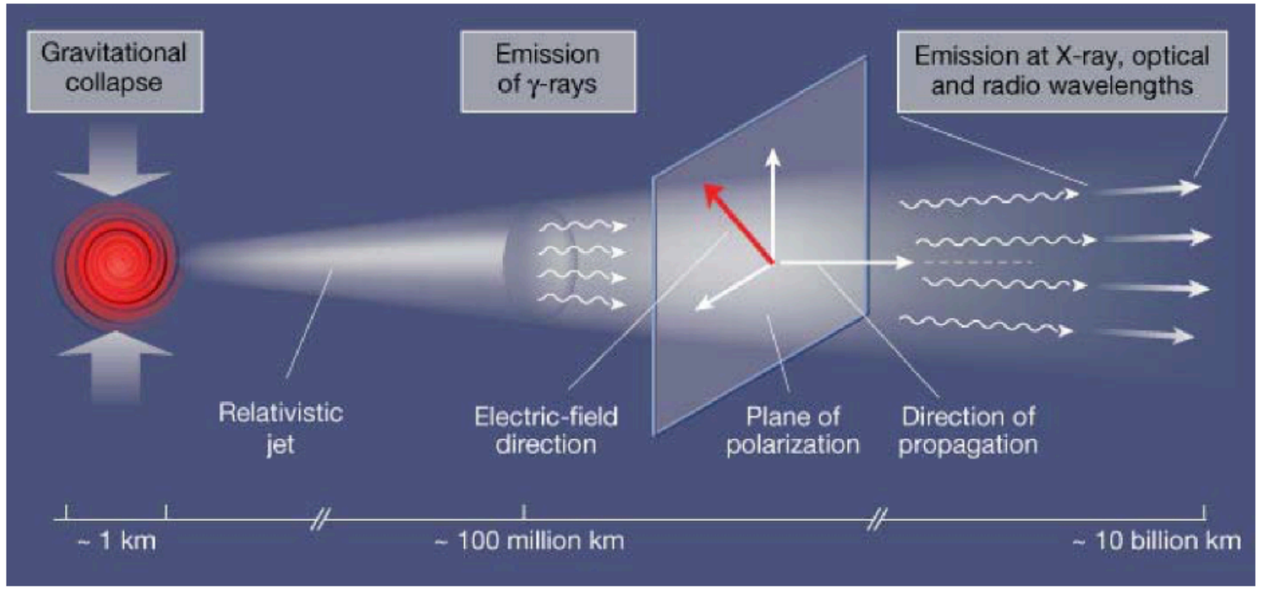
Latest Developments of POLAR-2

Johannes Hulsman
On behalf of the POLAR-2 Collaboration

Contact: johannes.hulsman@unige.ch

Polarization of GRBs

- Extensive analysis on spectral and temporal profile of γ-ray emissions
- Polarization information is a unique probe towards understanding the magnetic fields and emission mechanisms
- Few dedicated instruments measure polarization of these gammas
    - Polarization Degree (PD) and Polarization Angle (PA) very helpful



Waxman, E et. al. Nature (2003) https://doi.org/10.1038/423388a

Polarization of GRBs

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- Polarization information is a unique probe towards understanding the magnetic fields and emission mechanisms
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    - Polarization Degree (PD) and Polarization Angle (PA) very helpful

Ex. Model A:

- synchrotron radiation from large-scale dynamic magnetic fields since beginning of jet
- Linear PD up to 56%

M. Lyutikov *et al* 2003 *ApJ*
https://doi.org/10.1086/378497

Ex. Model B:

- synchrotron radiation from highly ordered magnetic fields
- Linear PD can be 40% for some GRBs

K. Toma *et al 2013 GRB-Symp.*
https://doi.org/10.48550/arXiv.1308.5733

Ex. Model C:

- Photospheric emissions model
- PD about few % above 100keV
- PD about 50% below 1keV

C. Lundman *et al 2016 ApJ*
https://doi.org/10.48550/arXiv.1611.01451

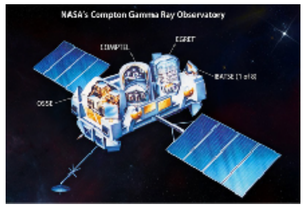
GRB Polarimetry before POLAR

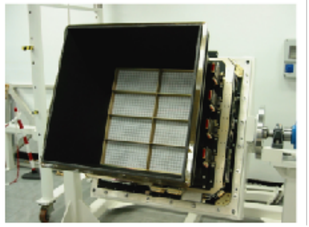
- Inconclusive answers from previous instruments
- Measurements were not dedicated enough for polarization measurements or erroneous

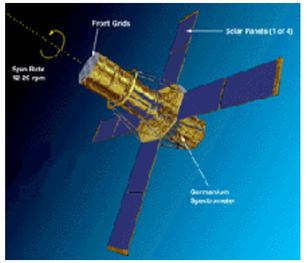
We need:

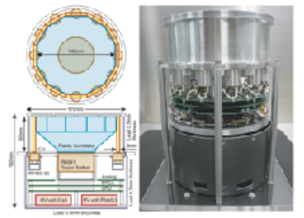
- large sample of GRB measurements
- instrument capable of measuring temporal evolution of linear polarization

GRB	Instrument	PD (%)	Energy (keV)	Note
930131	BATSE/CGRO	>35	20-1000	Not optimized for polarization. Poor sensitivity
960924		>50		
041219A	IBIS/INTEGRAL		100-350; 200-800; 200-800	Large systematic uncertainty
61122		>33	250-800	
140206A			200-400	
21206	RHESSI		150-2000	Large systematic uncertainty
100826A	GAP/IKAROS	27 +/- 11	70-300	
110301A		70 +/- 22		Const. Pol. Angle
110721A		84^{+16}_{-28}		Const. Pol. Angle
160530A	COSI	<46	200-5000	Low statistics







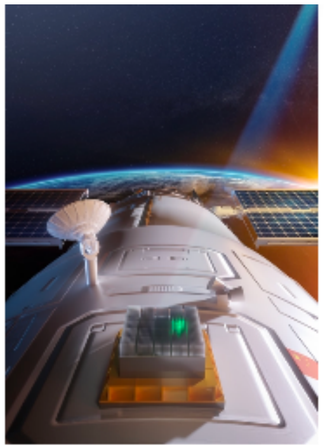


POLAR Instrument

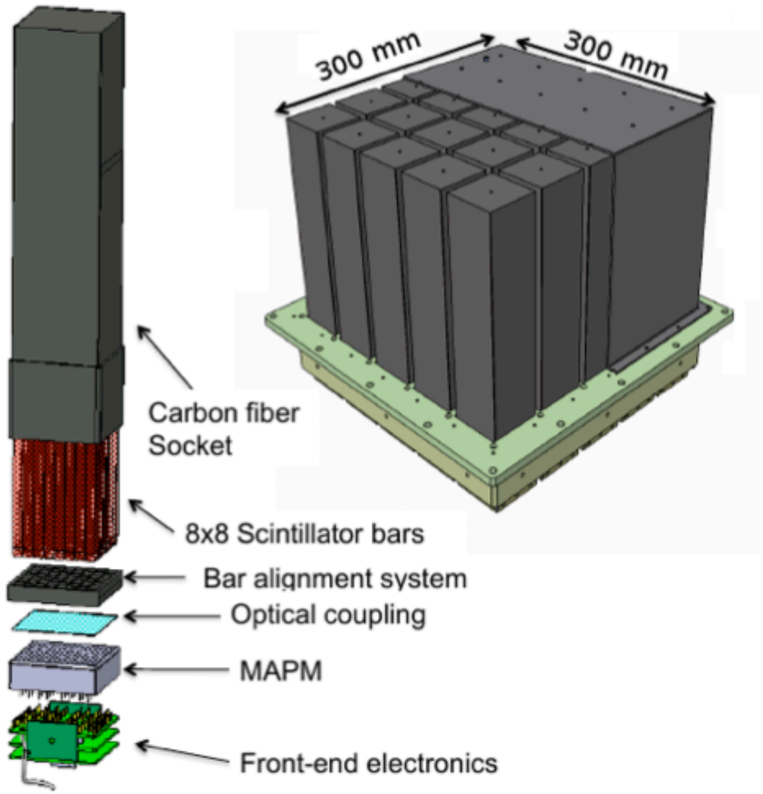
Main Goal: Perform most detailed polarization analysis on GRB prompt emission

- launched in Sep. 2016 on Chinese Space Laboratory Tiangong-2 (TG-2)
- Sensitive in 50-500 keV range
- operational for 6 months
- 55 GRBs detected (14 with good statistics)

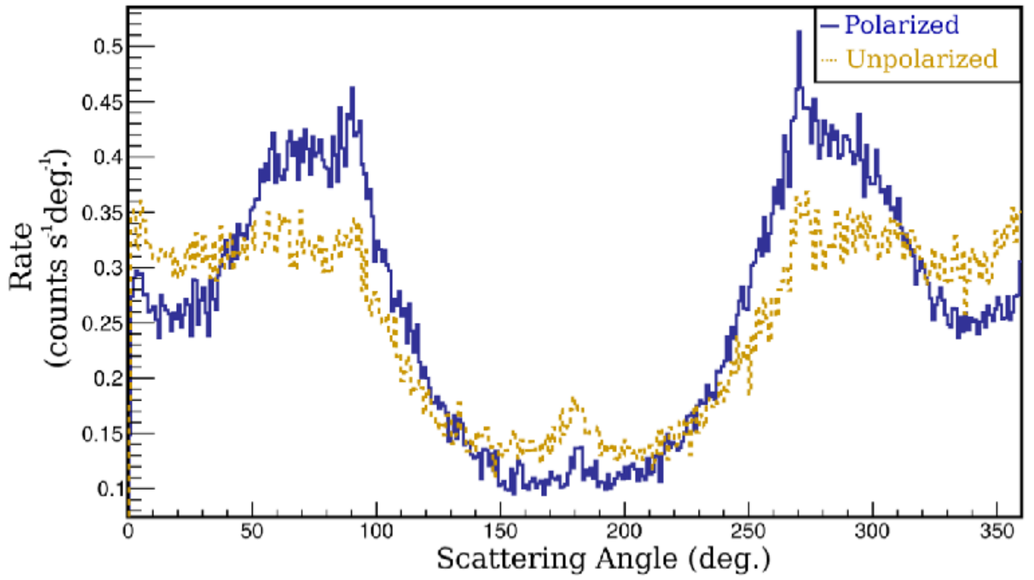


POLAR Instrument



$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\frac{E'^2}{E^2}\left(\frac{E'}{E} + \frac{E}{E'} - 2\sin^2\theta\cos^2\phi\right)$$

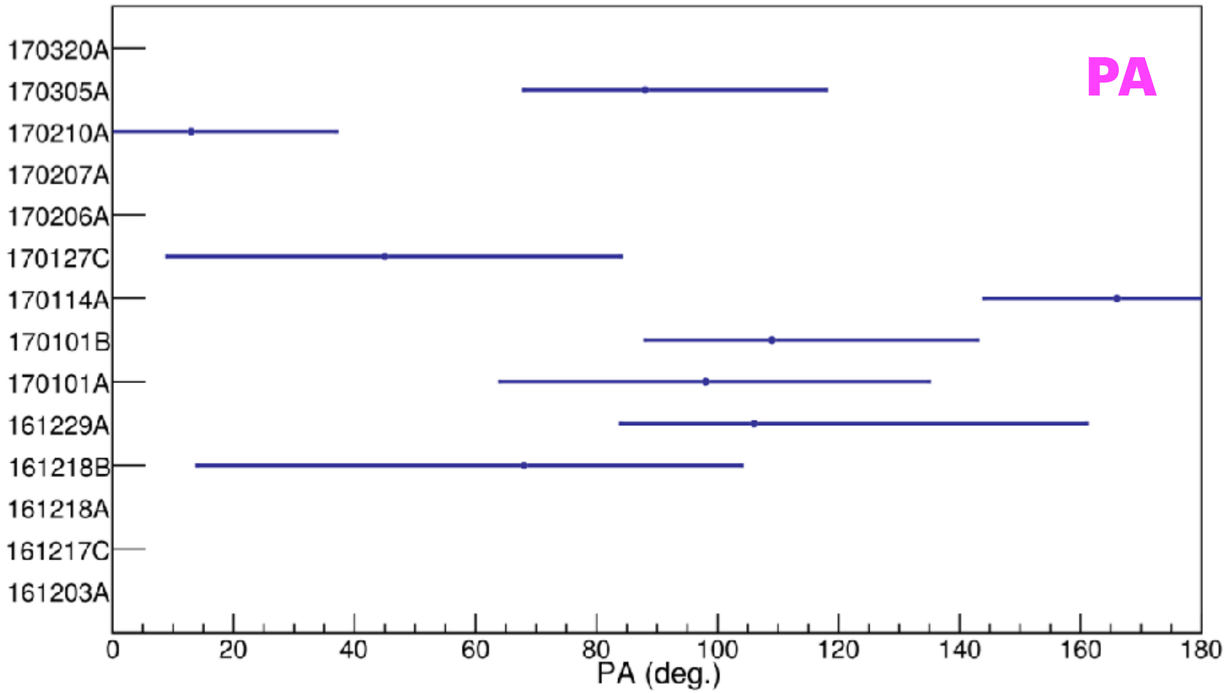


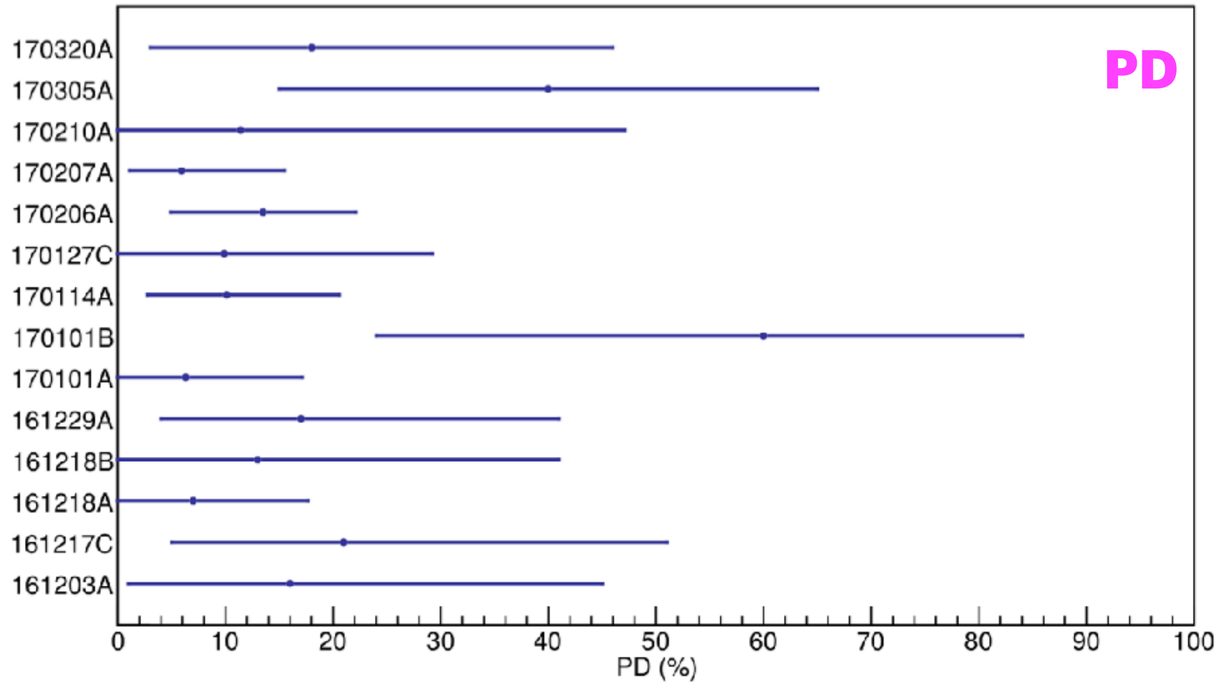
M. Kole *et al., 2016 IEEE (NSS/MIC/RTSD)*
https://doi.org/10.48550/arXiv.1612.04098

M. Kole, et. al A&A, 644 (2020) A124
https://doi.org/10.1051/0004-6361/202037915

POLAR Results - Integrated

M. Kole, et. al A&A, 644 (2020) A124
https://doi.org/10.1051/0004-6361/202037915

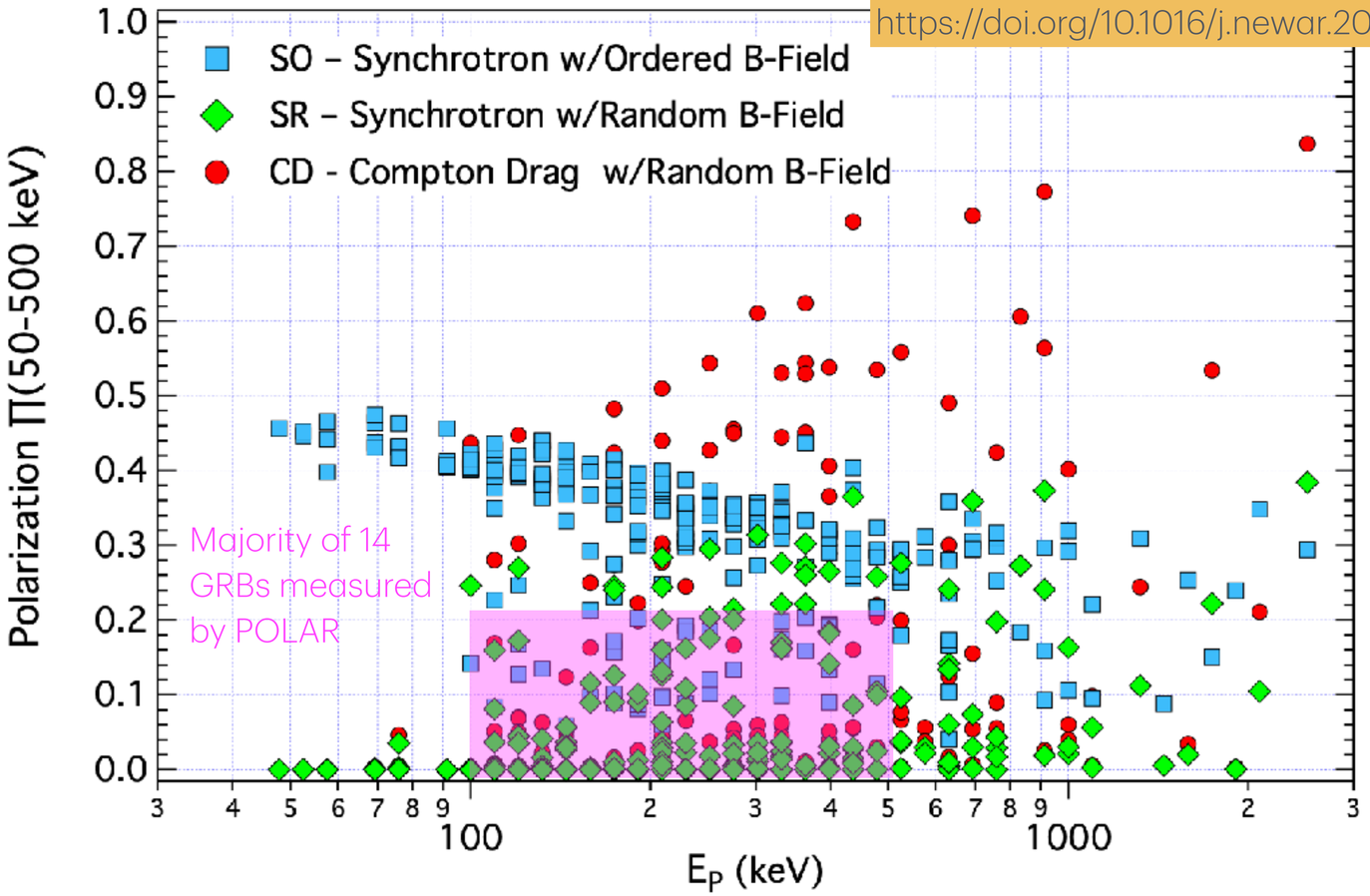




- 14 GRBs studied and catalogued in https://doi.org/10.1051/0004-6361/202037915
- Typically low levels of polarization

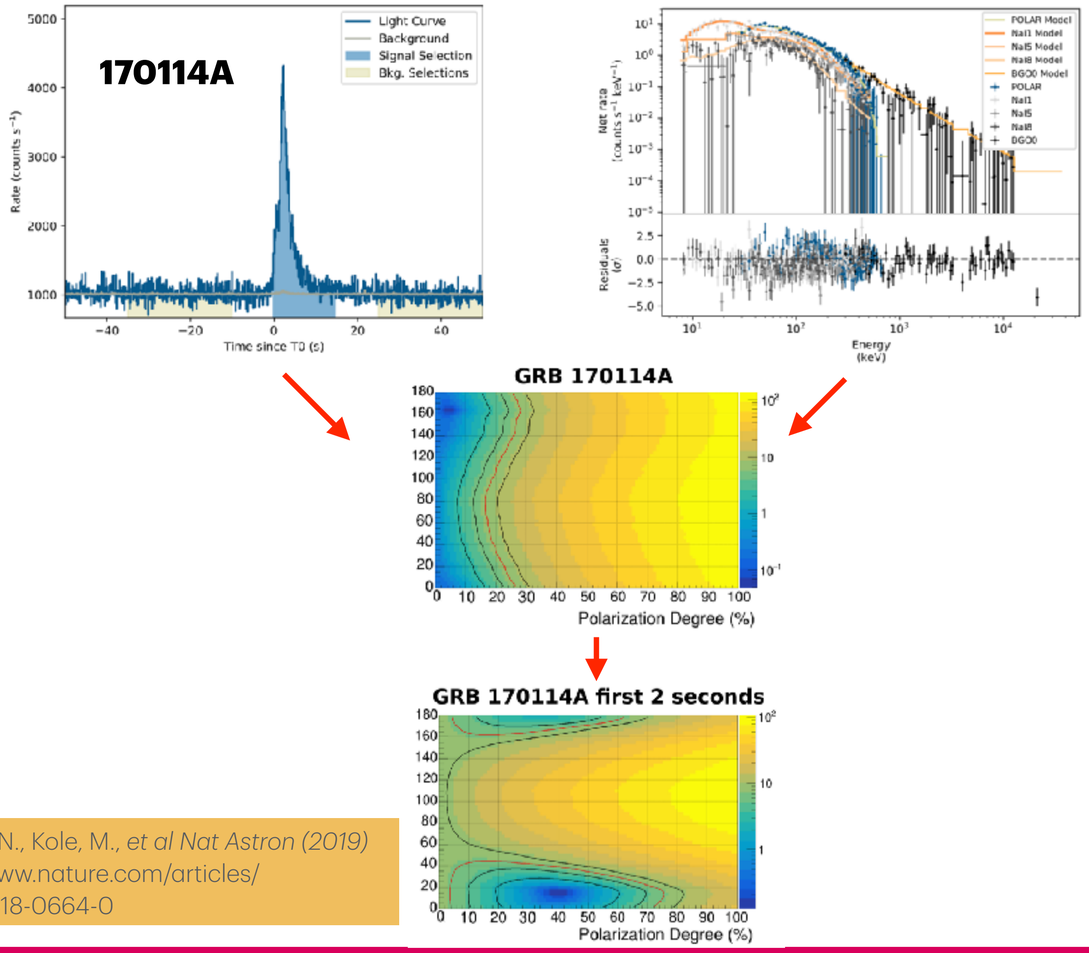
POLAR Results - Integrated

M. McConnel, NAR 2016
https://doi.org/10.1016/j.newar.2016.11.001



- Most precise polarization results in its field
- Results comparable with low level or unpolarized emission
- No tight constraints on PD for several GRBs due to lack of sensitivity

POLAR Results - Time Resolved



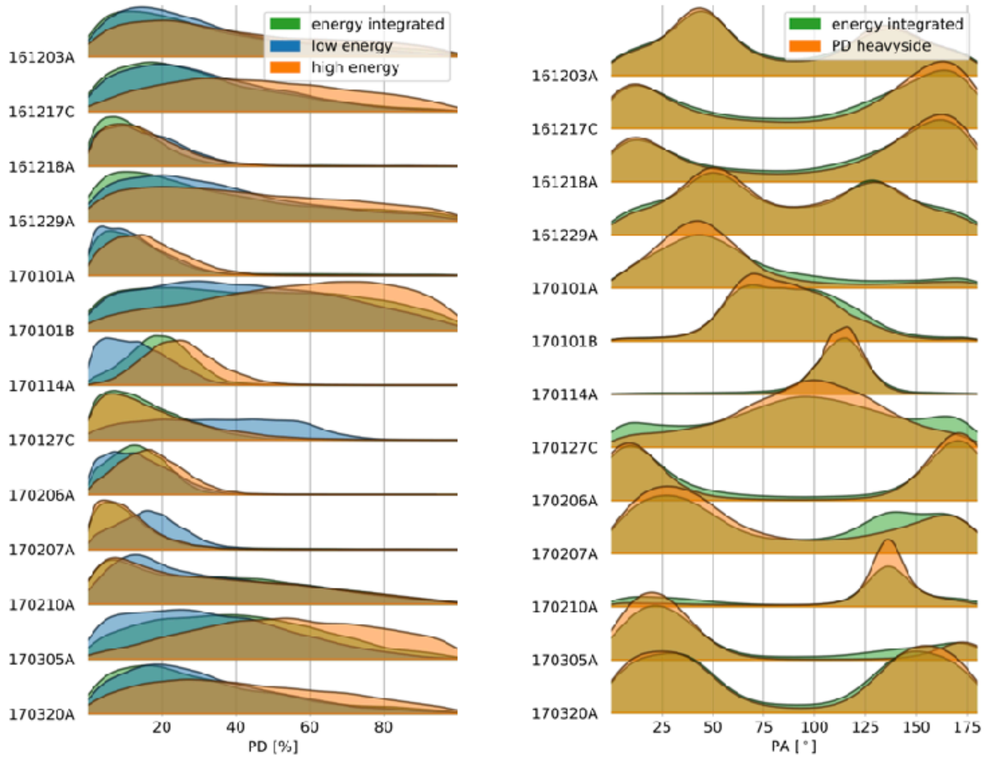
Zhang, SN., Kole, M., *et al Nat Astron (2019)* https://www.nature.com/articles/s41550-018-0664-0

GRB	TIme Bin Division	Note
170101A	Time Bin 1: 0 - .5s Time Bin 2: .5 - 2s	consistent with an unpolarized flux
170114A	0.6s time bins from 0 to 4.8s (larger for later time frames)	slight trend of growing polarization in time reaching values of~ 30% at the temporal peak of the emission
170207A	Time Bin 1: 0 - 10s Time Bin 2: 15 - 25	consistent with an unpolarized flux

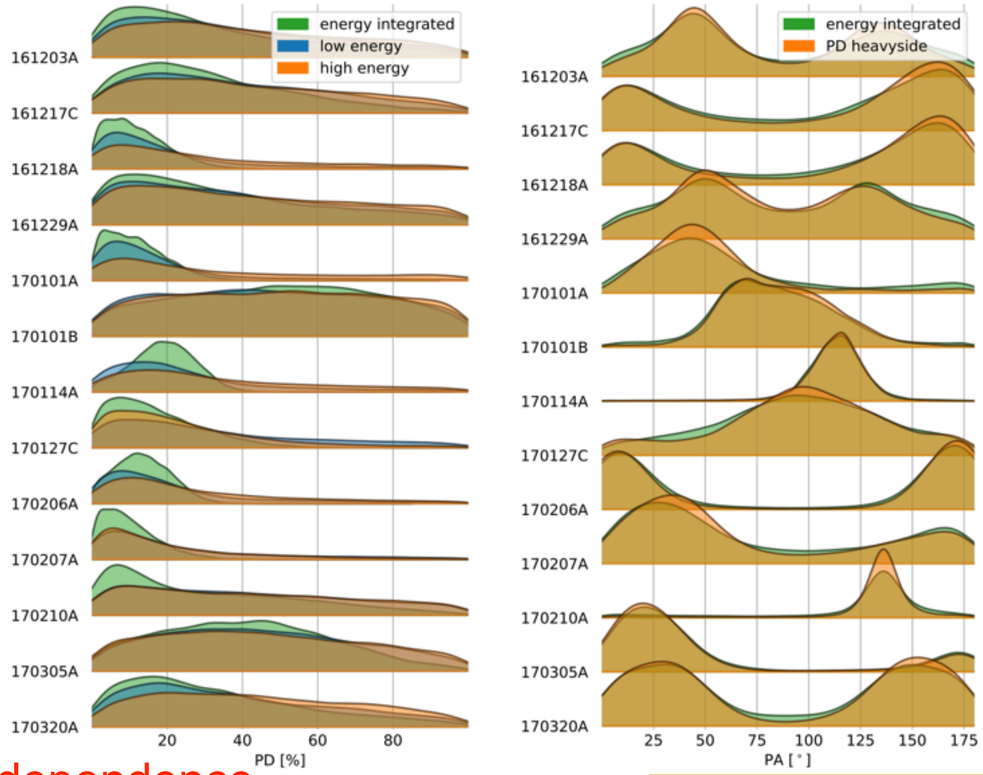
M. Kole, et al A&A, 644 (2020) A124 https://doi.org/10.1051/0004-6361/202037915

POLAR Results - Energy Resolved

Energy resolved studies performed by performing with an energy break at 150keV



Energy resolved studies in two energy bins with dynamic energy break

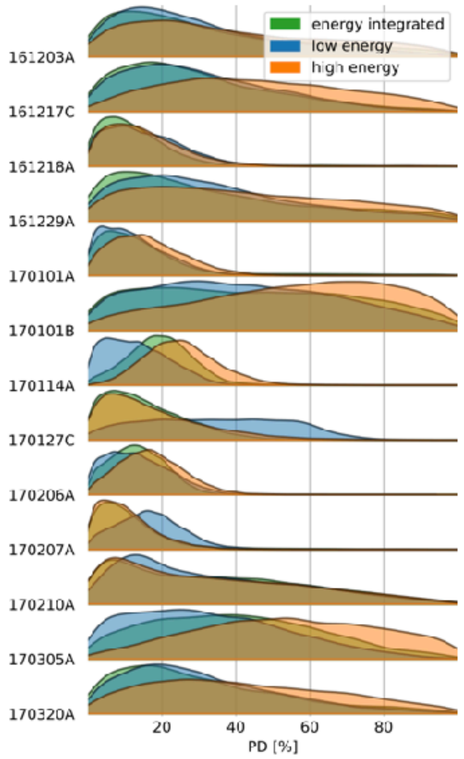


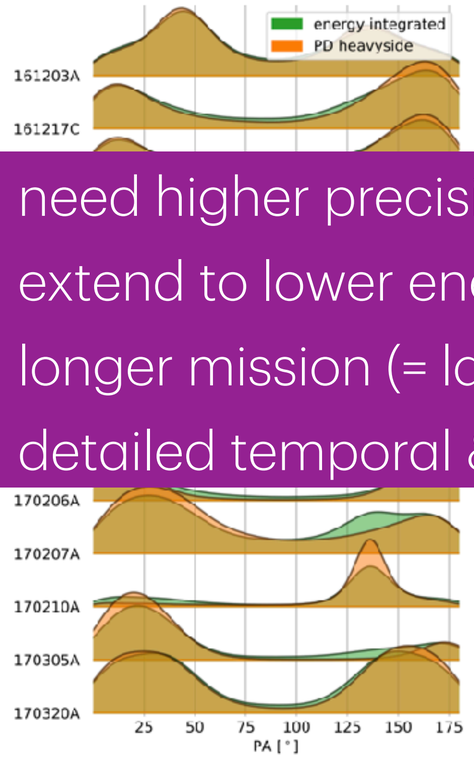
No significant energy dependence
+ need better statistics

N. De Angelis, et al ICRC PoS (2023)
https://doi.org/10.22323/1.444.0619

POLAR Results - Energy Resolved

Energy resolved studies performed by performing with an <u>energy break at 150keV</u>





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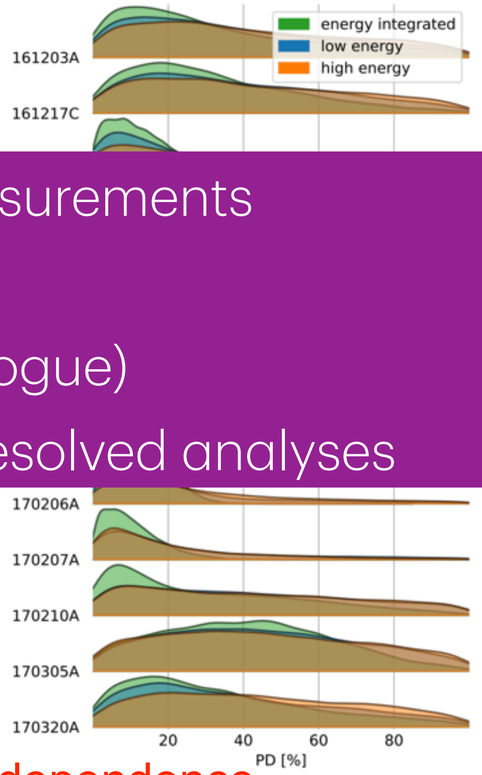

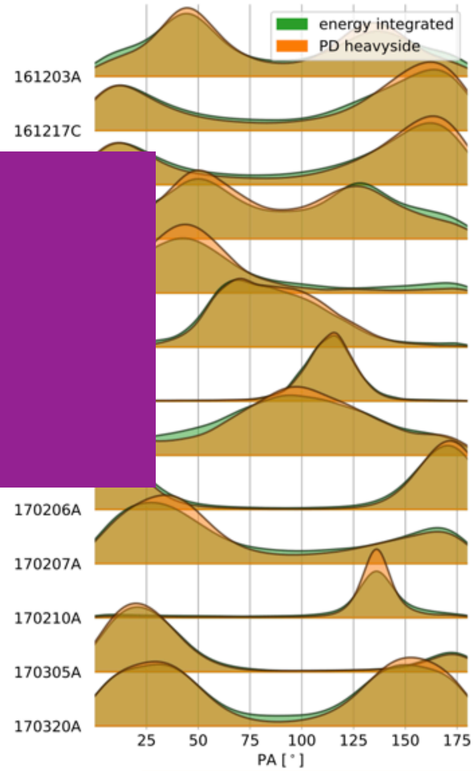

- need higher precision of measurements
- extend to lower energy range
- longer mission (= larger catalogue)
- detailed temporal & energy resolved analyses

No significant energy dependence
+ need better statistics

N. De Angelis, et al ICRC PoS (2023)
https://doi.org/10.22323/1.444.0619

POLAR-2

- successor to POLAR
- manifested for launch in 2027 on the China Space Station (CSS)
- 2 year mission (qualified for 10 years
- 30 - 800keV

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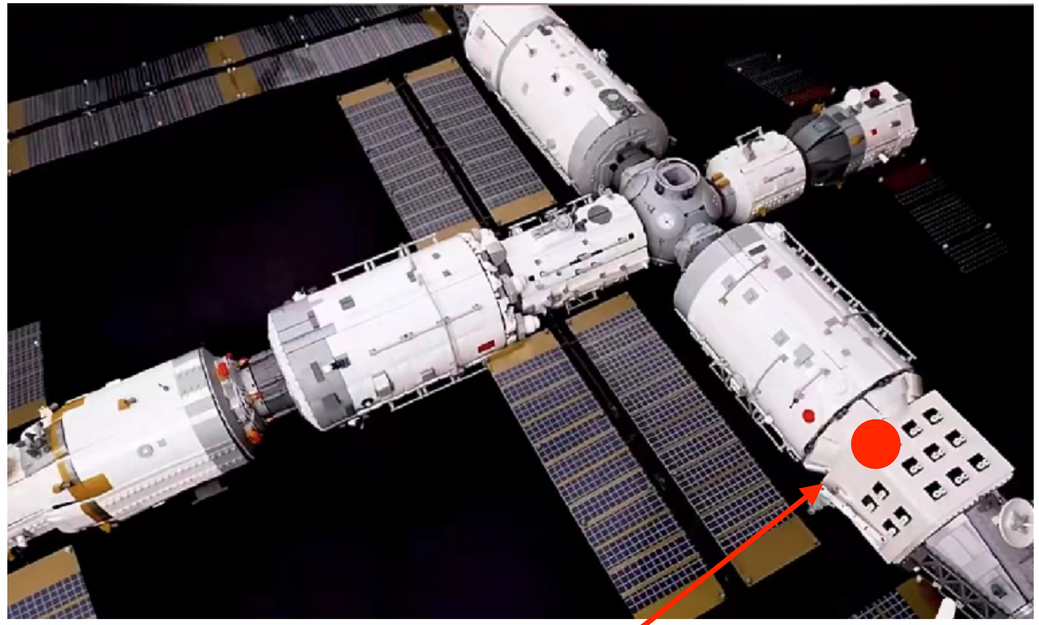
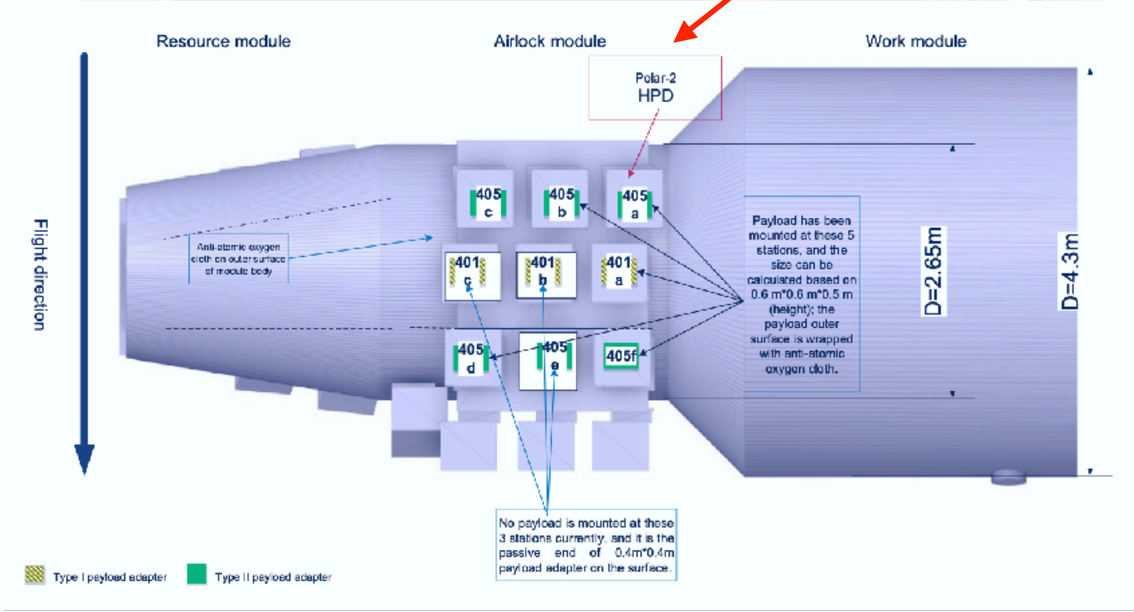
NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

MPE

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

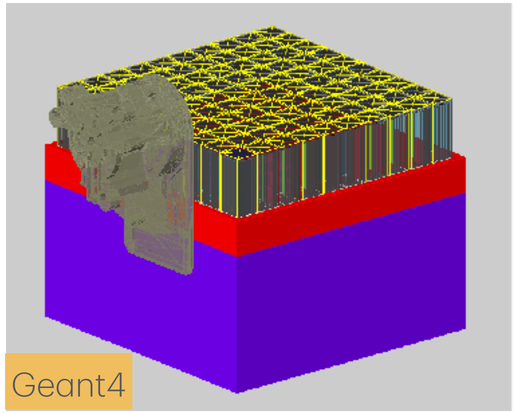


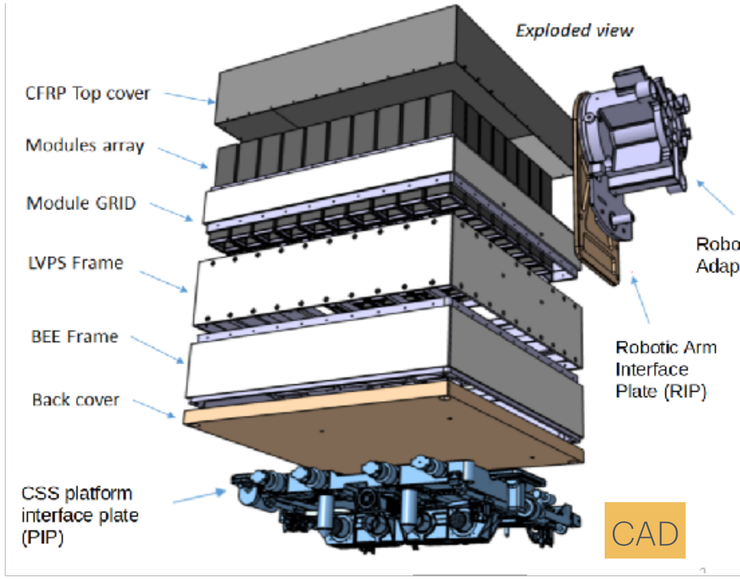


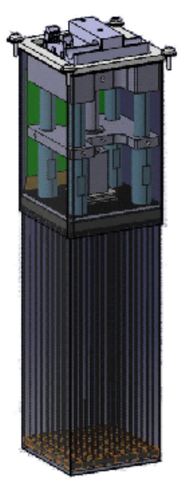
POLAR-2 Instrument Design

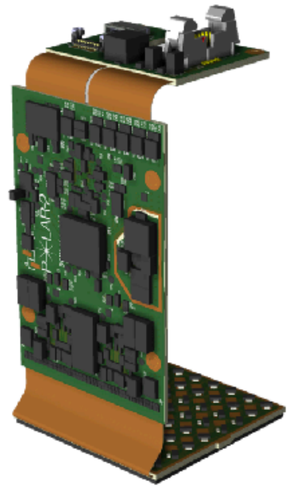
Major Goals:

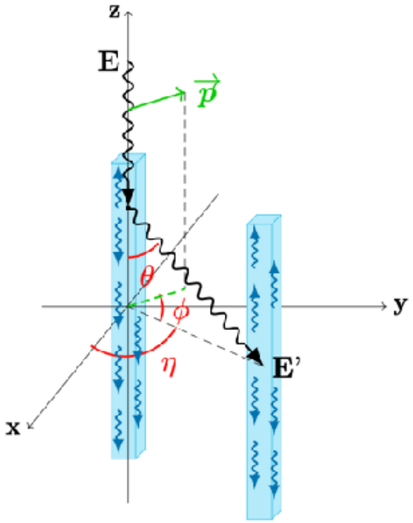
- Apply lessons learned from POLAR
- Perform more precise polarization measurements for time and energy resolved polarization analyses
- Expand GRB polarization catalogue
- Provide rapid alerts through Beidou system







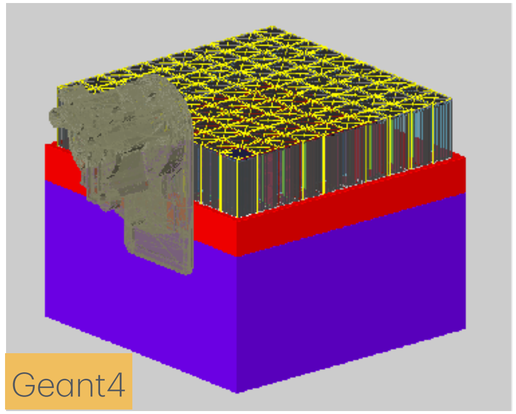


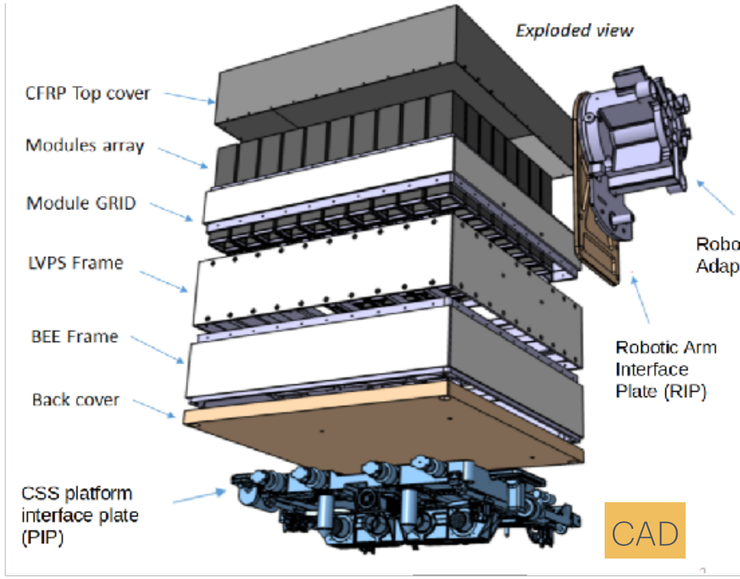


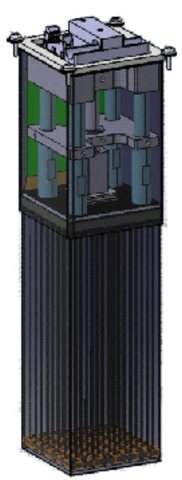
POLAR-2 Instrument Design

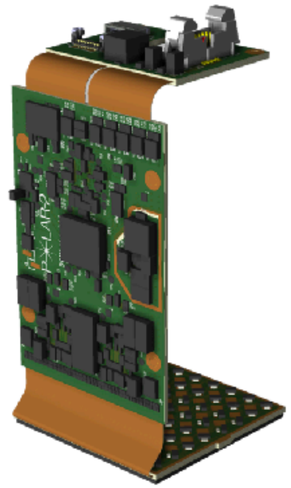
Major Upgrades:

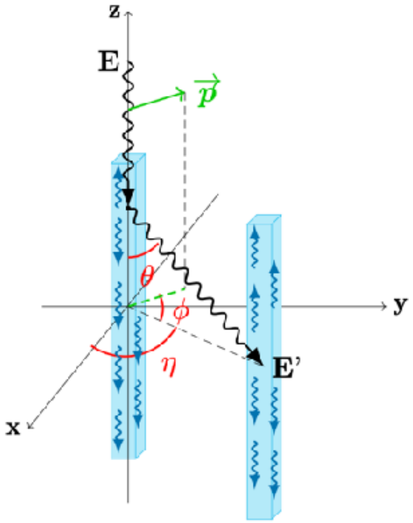
- x100 modules
- MaPMTs -> SiPM (4x16 S13361-6075PE)
- scintillator length optimized (from 200mm to 125mm)
- Add Claryl in addition to Vikuiti reflective strip foils (prevent photon loss along edges)
- scintillators not truncated (bigger surface area & reduce photon loss)



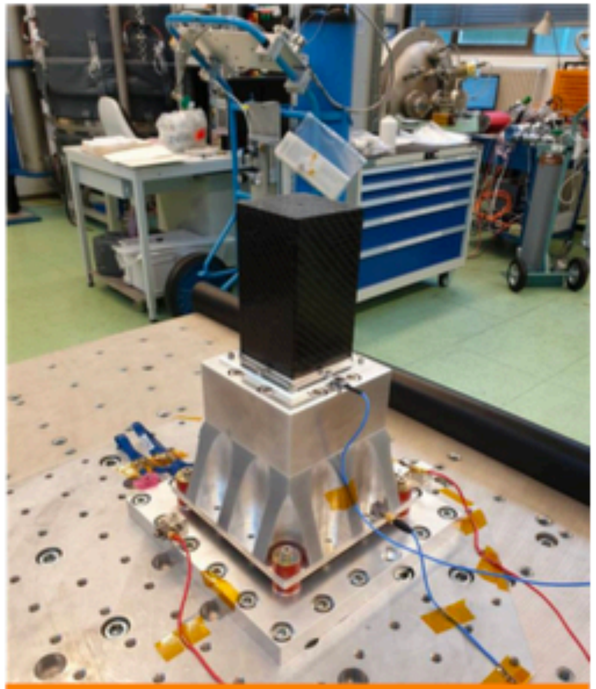








Prototype & Qualification of Key Components

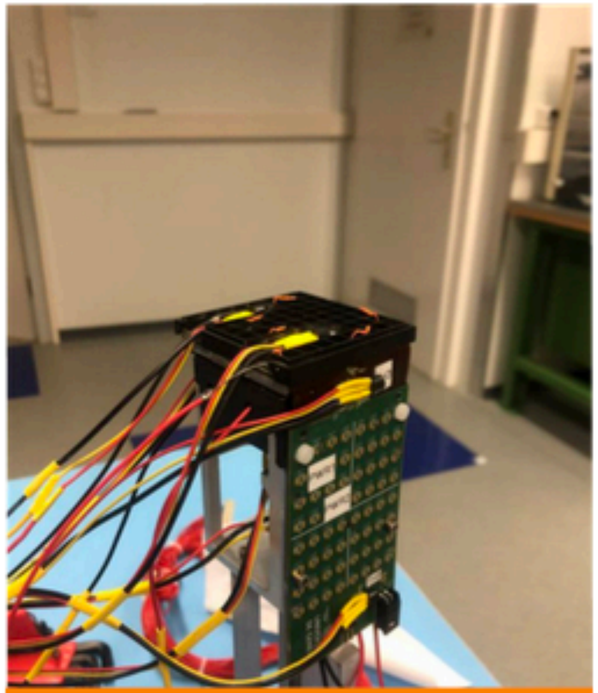


Shock & Vibration

Internal Technical Notes

Radiation

SiPM Radiation: https://doi.org/10.1007/s10686-022-09873-6
SiPM Annealing: https://doi.org/10.1016/j.nima.2022.167934
Scint Radiation: https://doi.org/10.1007/s10686-023-09906-8



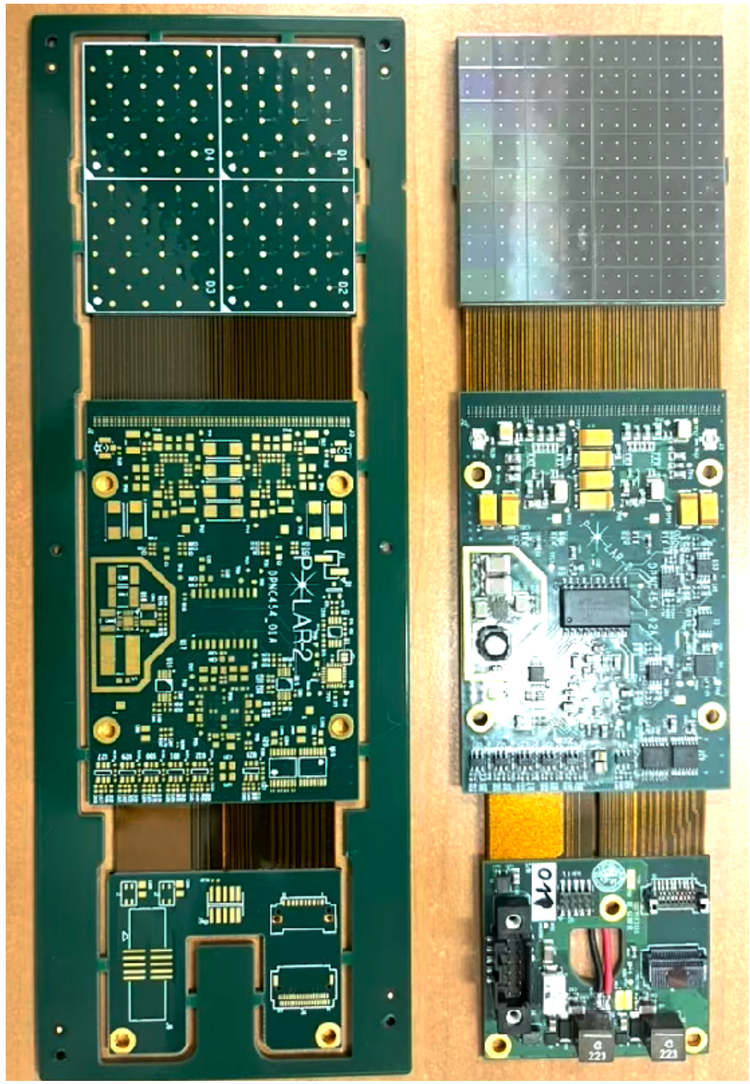
Thermal

Internal Technical Notes

POLAR-2 FEE

- Custom FEE design to read out 64 SiPM channels
  - 2 Citirocs 1A ASICs
  - IGLOO FPGA (by Microsemi)
  - Trigger logic based on charge and timing information
  - 1.7-2W power consumption (depends on config.)
- FEE designed to reduce heat SiPM
- Option to enable SiPM heater for annealing
- Option to enable Peltier for active cooling
- **FEE now being battle-tested for various configurations for any possible issues**

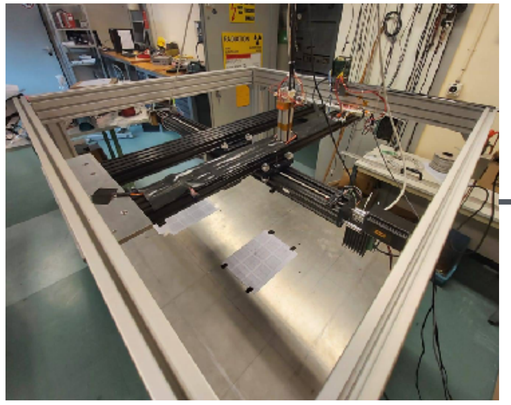
No electronic impact from power sent to heater and Peltier

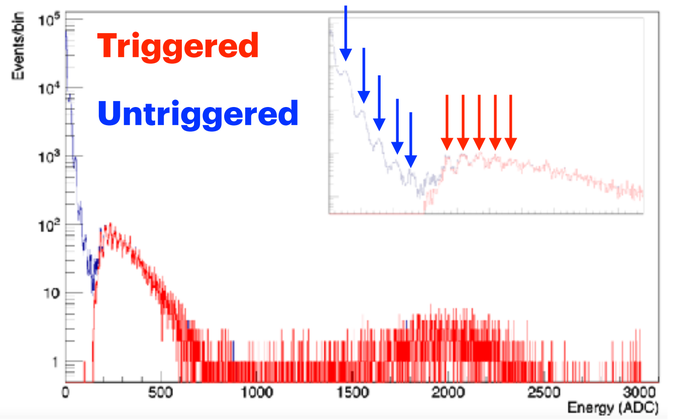


Tell us if you might be interested in the FEE!!

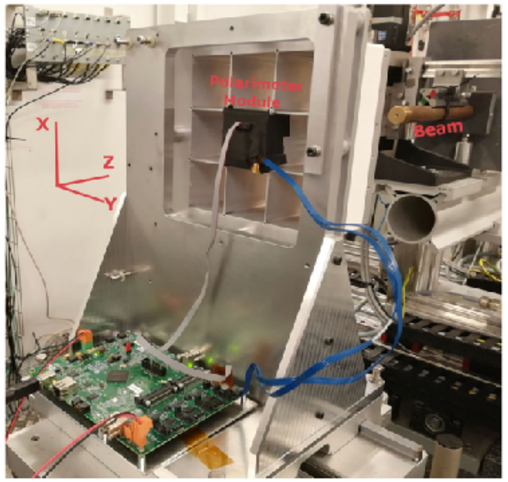
Prototype Design Testing

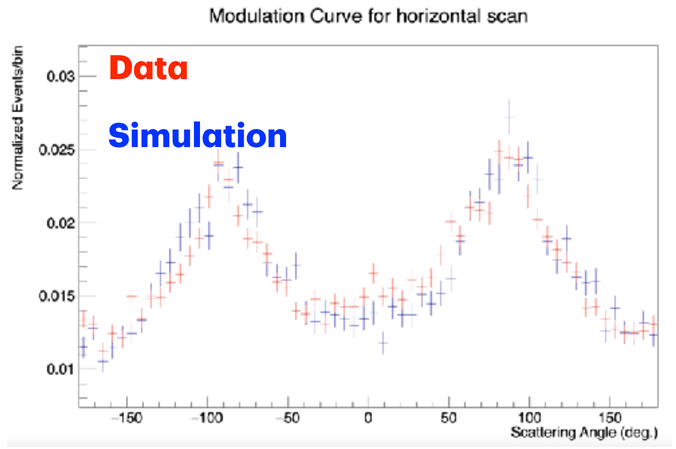
- Lab Measurements with Am-241 to verify single module performance at CERN (CH)





- Measurements at ESRF (FR) to verify module performance with various polarized beams

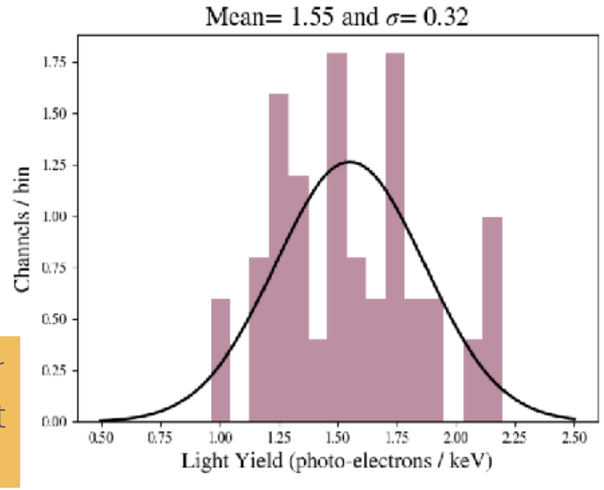




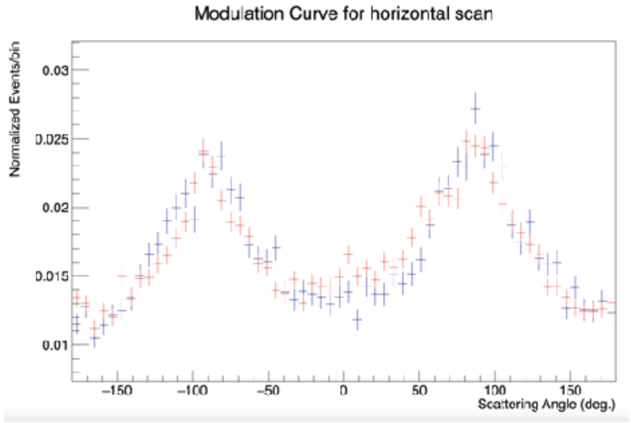
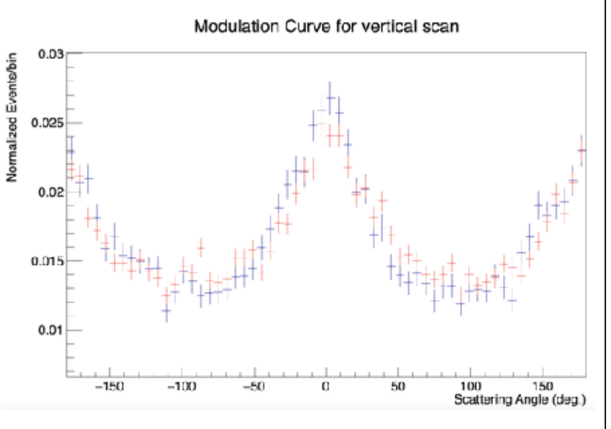
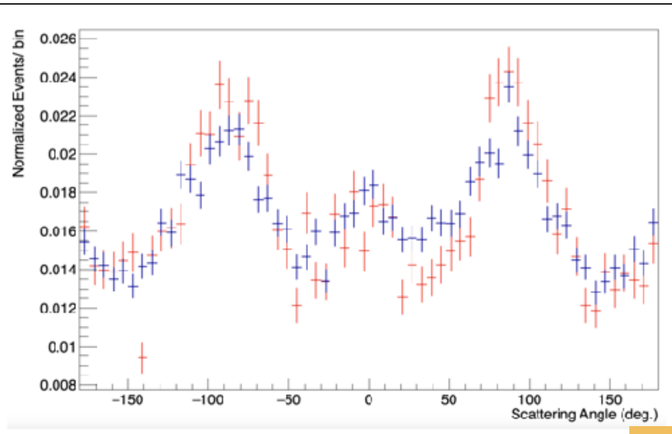
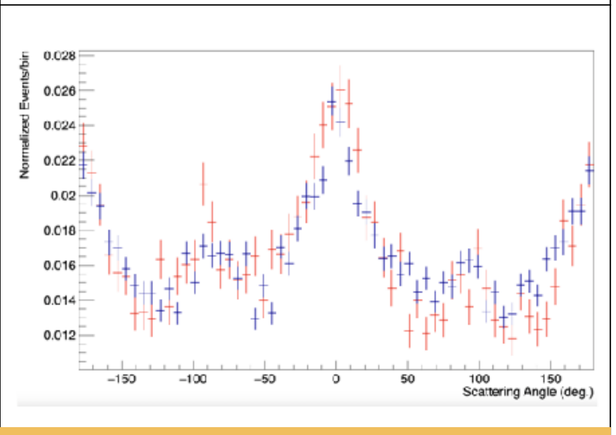
M. Kole, et al JINST (2024)
https://doi.org/10.48550/arXiv.2406.05783

First Results of Prototype in Polarized Beam

- 40keV and 60keV polarized and unpolarized beam at ESRF
- **Data** matches well with **simulations**

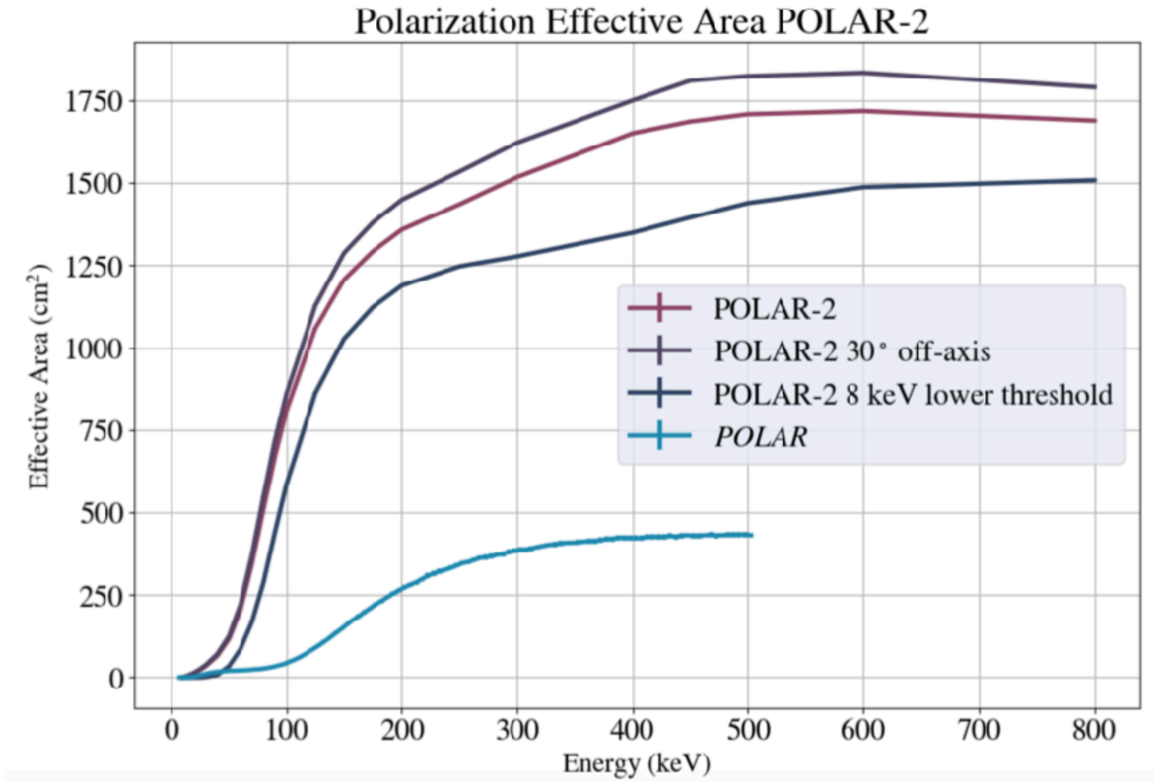


1.55 pe/keV for Module (target is >1.5pe/keV)

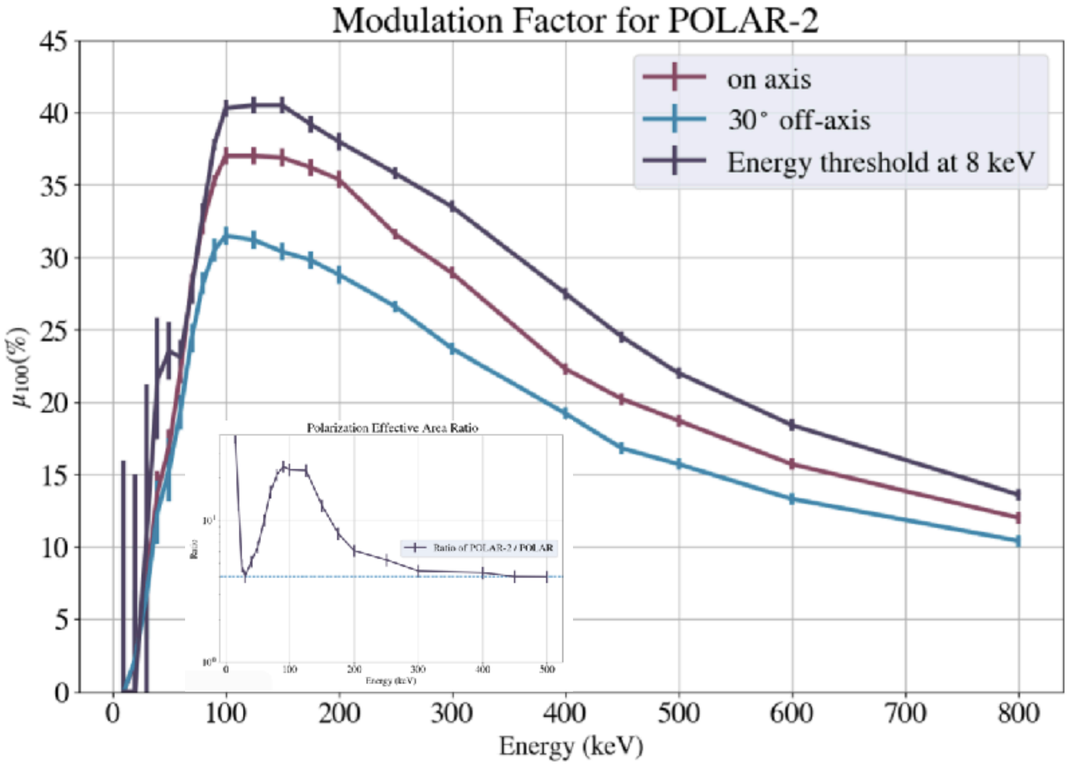
	Horizontal	Vertical
60keV PD=100%		
40keV PD=100%		

M. Kole, et al JINST (2024)
https://doi.org/10.48550/arXiv.2406.05783

Expected Scientific Performance



- x4 larger effective area compared to POLAR (now ~1400cm2)



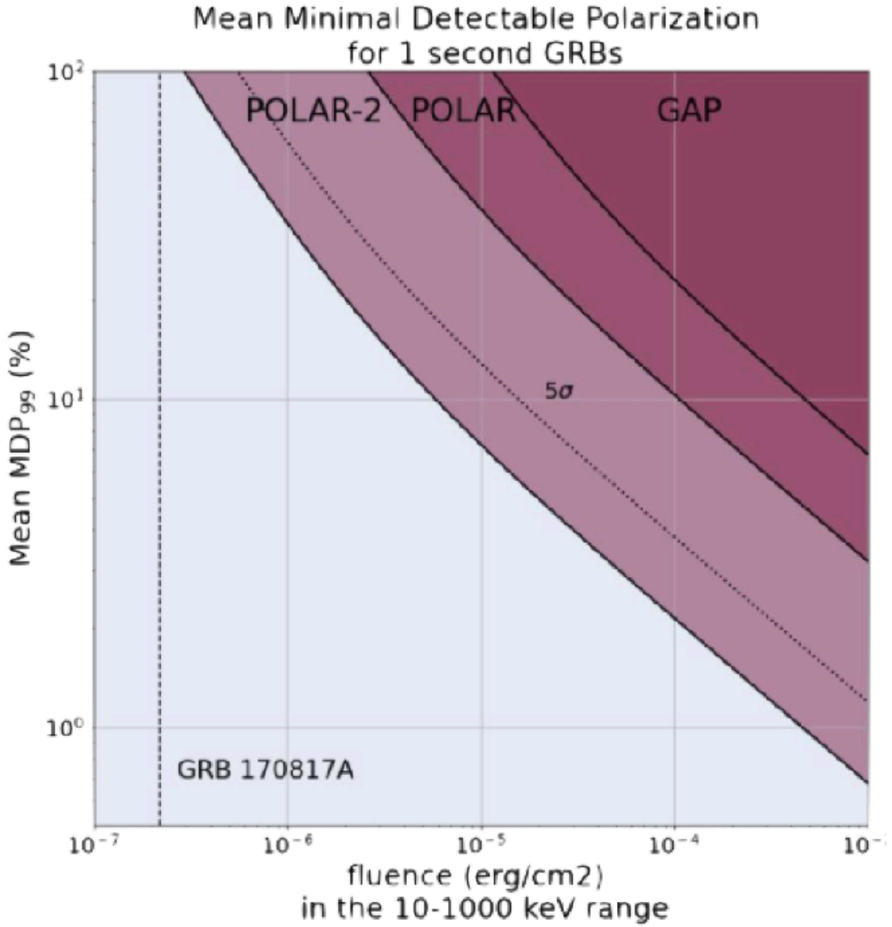
- x10 more sensitive below 150keV compared to POLAR

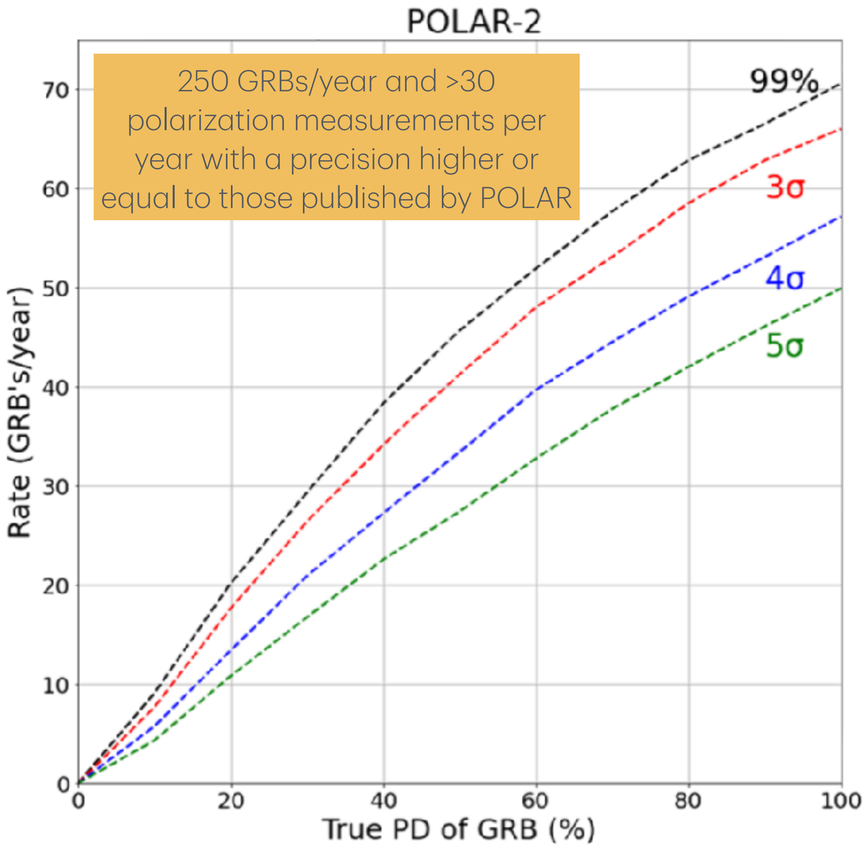
M. Kole, et al JINST (2024)
https://doi.org/10.48550/arXiv.2406.05783

Expected Scientific Performance

- 5σ measurement can be made for a GRB with fluence 10^{-5} erg/cm2 and PD_{true} ~10%

Measurements (#/yr)			
Significance	PD_{true} ~10%	PD_{true} ~20%	PD_{true} ~50%
3σ	10	20	40
5σ	5	10	25

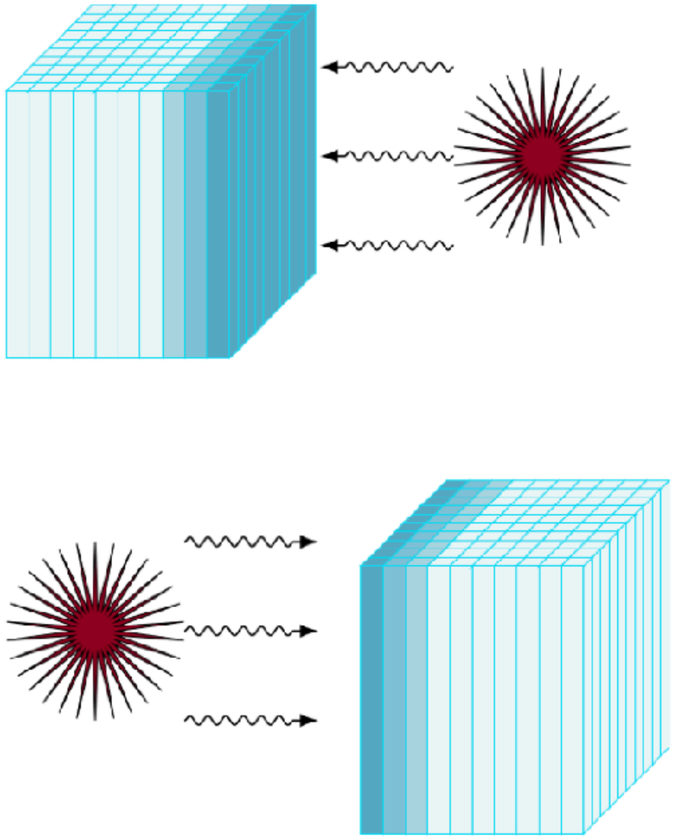




R. Gill, et al Galaxies (2021)
https://doi.org/10.3390/galaxies9040082
https://doi.org/10.22323/1.444.0550

Localization Capabilities

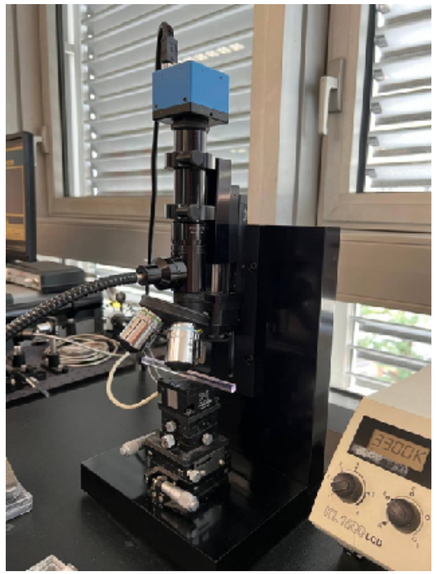
- Localization possible through real-time analysis of angle and spectrum of GRB with a GPU on board of CSS -> HAGRID
- POLAR-2 can provide rapid alerts through Beidou system (exploring to be within ~2min. of onset of GRB)
- Beneficial for Muli-Messenger applications

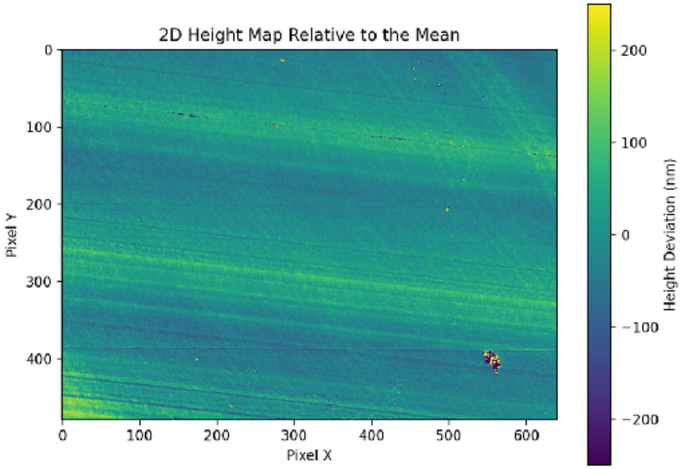


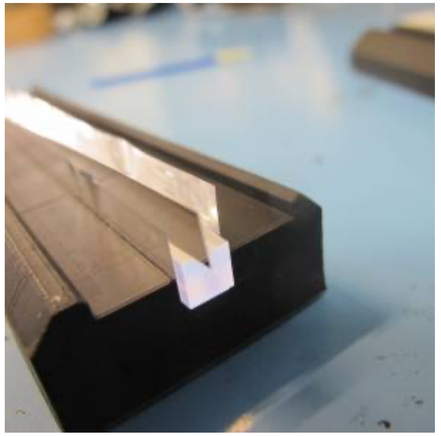
M. Kole, et al ICRC PoS (2023)
https://doi.org/10.22323/1.444.0724

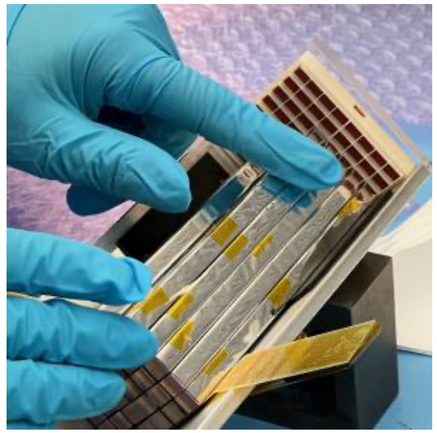
Building POLAR-2

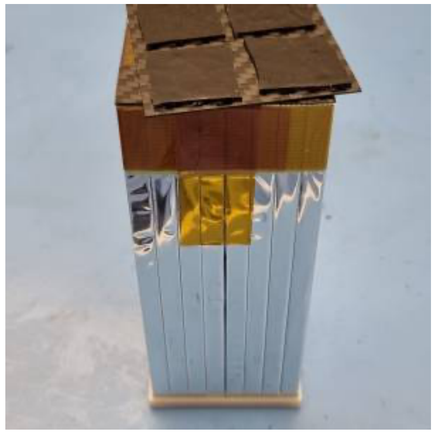
- First components procured (SiPMs, Scintillators, 3D printed cross/grid)
- Performing quality assurance tests

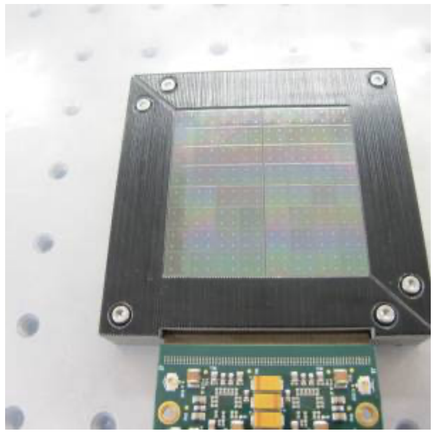


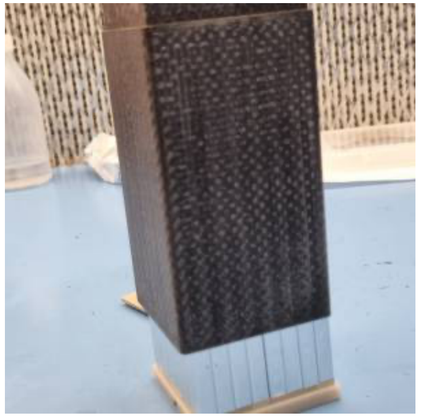












Current POLAR-2 Timeline

2020 - 2024

July 2024 — polarimeter module design completed

Nov 2024 — 1st Scintillator Batch arriving (500/7500 pcs)

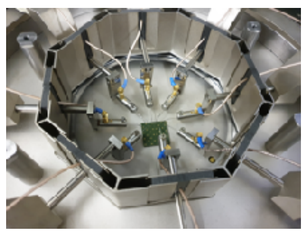
Feb 2025 — 1st SiPM Batch arriving (250/500)

Apr 2025 — 2nd Scintillator Batch arriving (2250/7500)

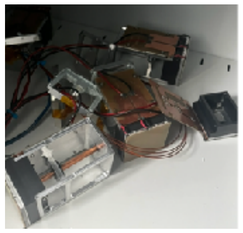
May 2025 — 2nd SiPM Batch arriving (500/500)

EQM Assembly and Testing

Nov 2025 — 3rd Scintillator Batch arriving (4000/7500 pcs)

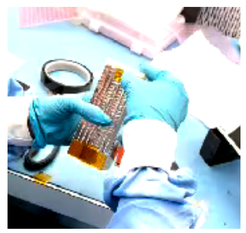


Apr 2026 — 4th Scintillator Batch arriving (5750/7500 pcs)



Final Assembly & FM Tests

Feb 2027 — 5th Scintillator Batch arriving (7500/7500 pcs)



Delivery of FM

May 2027 — Launch to CSS

First Data

The Ball is Rolling!!

Thank you for your attention.