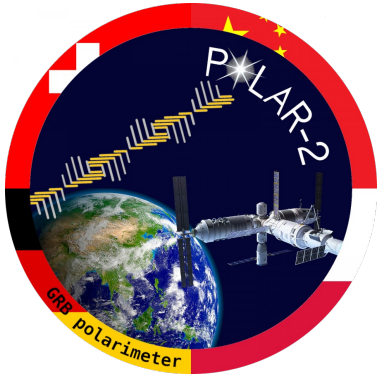
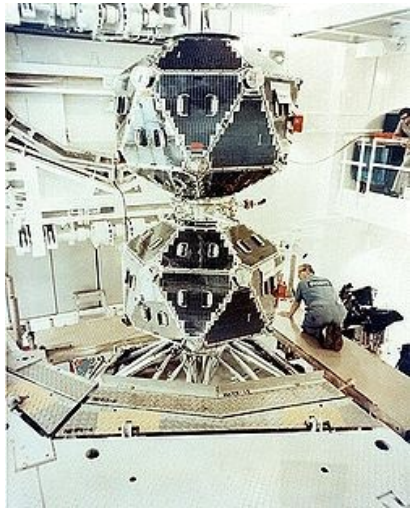


POLAR-2: Towards Large Scale Gamma-ray Polarimetry

Johannes Hulsman on behalf of the POLAR-2 Collaboration

POLAR-2 Collaboration: www.astro.unige.ch/polar-2/

Gamma Ray Bursts

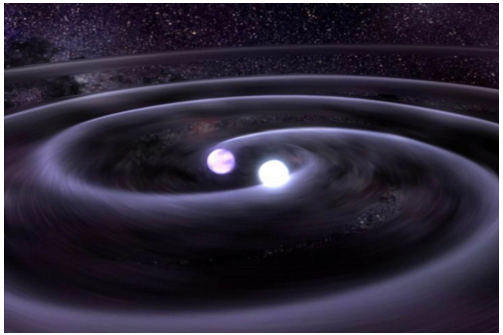


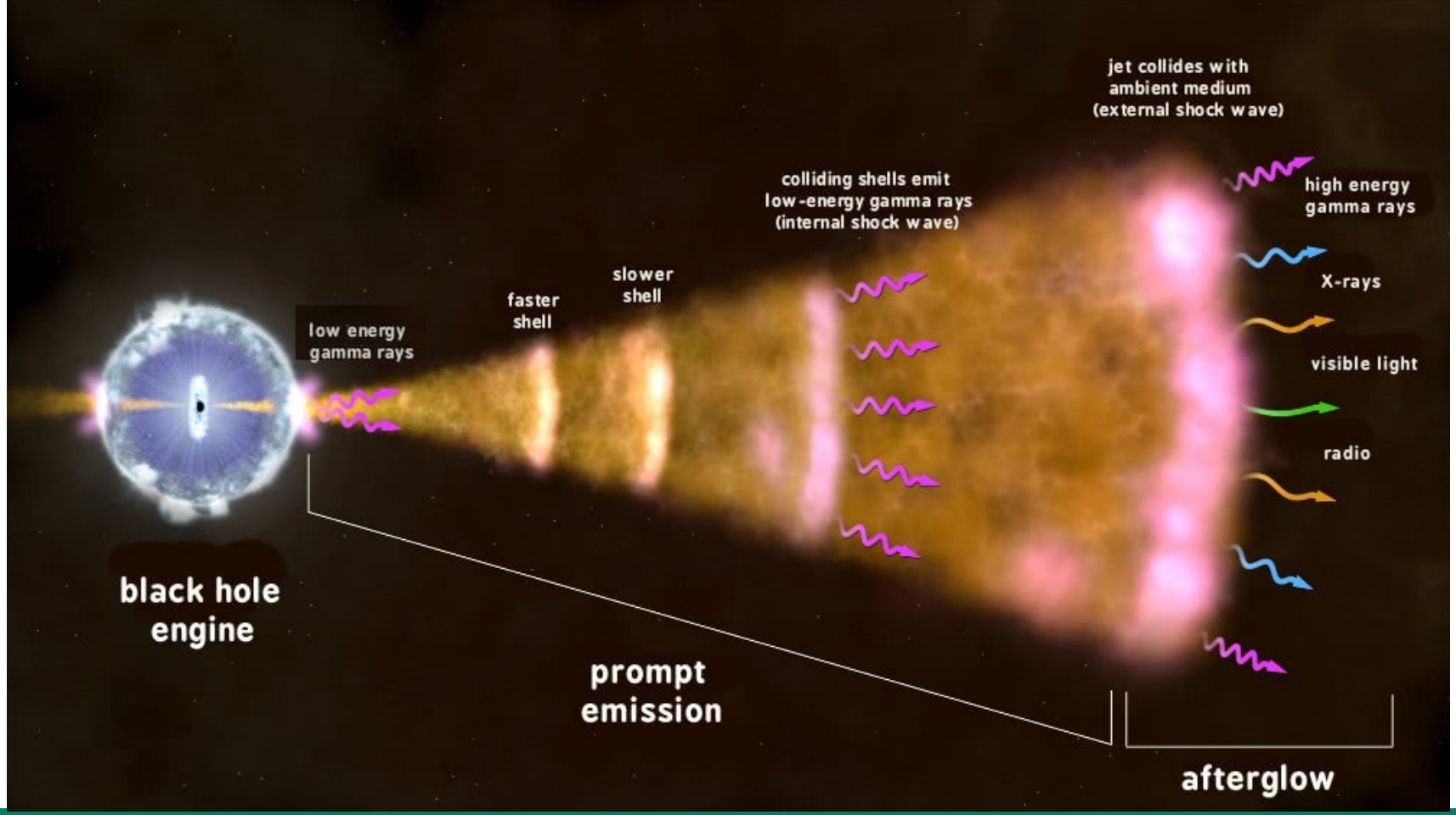
GRB:
- first discovered in 1960s by Vela satellites
- brightest and most energetic astrophysical processes ($E>10^{53}$ erg)
- prompt emission followed by afterglow
- BATSE: *can be divided into 2 subclasses*

long prompt emission (t > 2s)

short prompt emission (t < 2s)

GRB170817A: "from binary neutron star mergers" (Fermi-GBM, INTEGRAL, LIGO and VIRGO)




jet collides with
ambient medium
(external shock wave)
colliding shells emit
low-energy gamma rays
(internal shock wave)
high energy
gamma rays
X-rays
visible light
radio
slower
shell
faster
shell
low energy
gamma rays
black hole
engine
prompt
emission
afterglow

Gamma Ray Bursts

GRB:
- extensive analysis on **spectral** and **temporal profile** of γ-ray emissions
- relatively few instruments for **polarization measurements**
  -> polarization degree (PD) and angle (PA) very helpful

- Some Theoretical models:

Model A:
- synchrotron radiation from large-scale dynamic magnetic fields since beginning of jet
- linear PD up to 56%

arxiv.org/abs/astro-ph/0305410

Model B:
- synchrotron radiation from highly ordered magnetic fields
- linear PD can be 40% for some GRBs

arxiv.org/abs/astro-ph/1308.5733

Model C:
- photospheric emissions model
- PD about few percent above 100keV
- PD abut 50% below 1keV

arxiv.org/abs/astro-ph/1611.01451

Gamma Ray Bursts

GRB:
- extensive analysis on **spectral** and **temporal profile** of γ-ray emissions
- relatively few instruments for **polarization measurements**
  -> polarization degree (PD) and angle (PA) very helpful

We need a dedicated polarimeter instrument!

- Some Theoretical models:

Model A:
- synchrotron radiation from large-scale dynamic magnetic fields since beginning of jet
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Model C:
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- PD about few percent above 100keV
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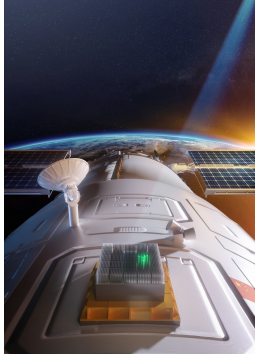
GRB Polarimetery Measurements



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

Past Instruments:

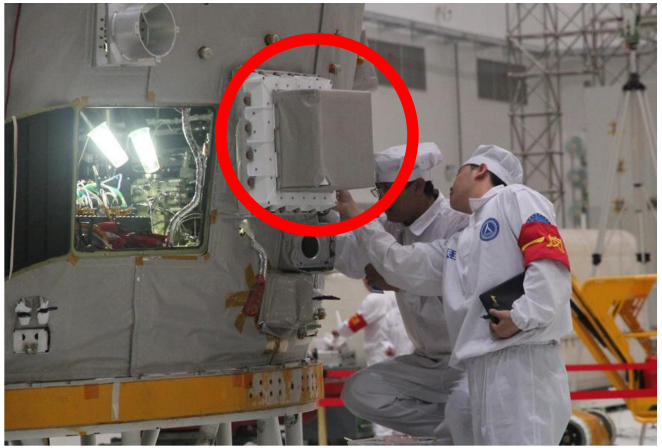
- GAP (50keV – 300keV)
- COSI (200keV – 5MeV)
- **POLAR (50keV - 500keV)**

Future Instruments:

- PRAXyS (2keV – 10keV)
- XL-Calibur (15keV – 80keV)
- LEAP (30keV – 500keV)
- eXTP (0.5keV – 30keV)
- IXPE (2keV – 8keV)
- **POLAR-2 (20keV – 800keV)**

GRB Polarimetery Measurements (POLAR)

- most extensive and detailed analysis on GRB polarization from POLAR
- launched in Sep. 2016 on Chinese Space Laboratory Tiangong-2 (TG-2)
- operational for 6 months
- 55 GRBs analysed and cataloged in https://arxiv.org/abs/2009.04871

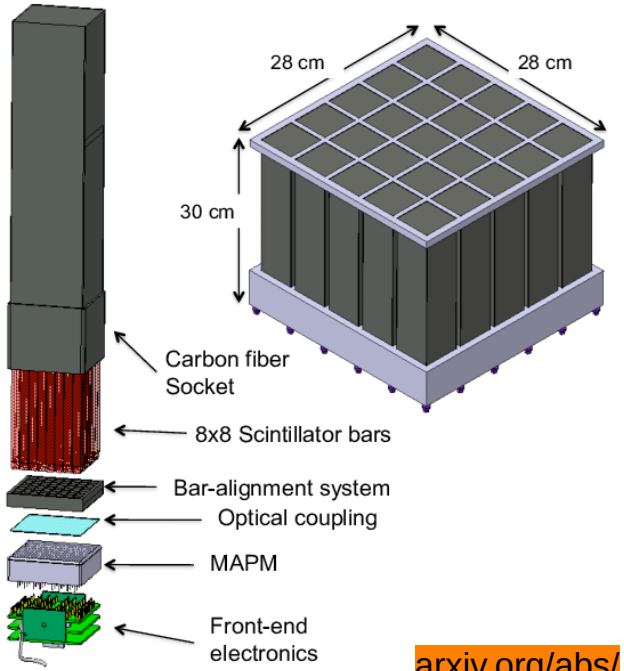


GRB Polarimetery Measurements (POLAR)

- 25 modules in a 5x5 layout

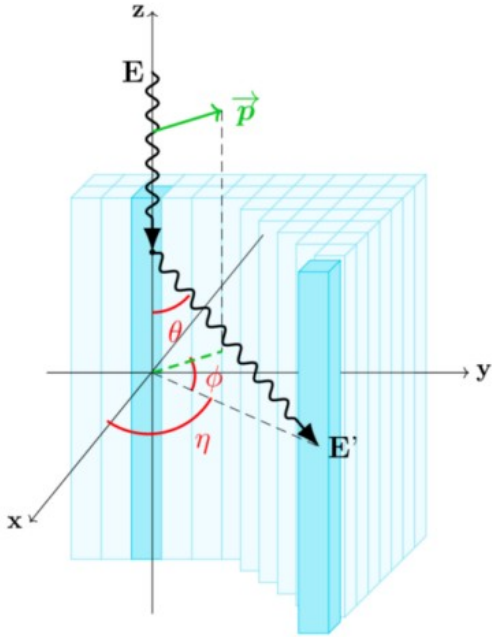
- each module:
  - 64 scintillators in a 8x8 layout
  - read out by a MAPMT
  - each scintillator: 5.8x5.8x200mm

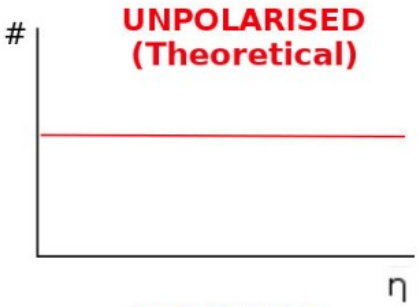
- effective area of 400cm^2 at 300keV

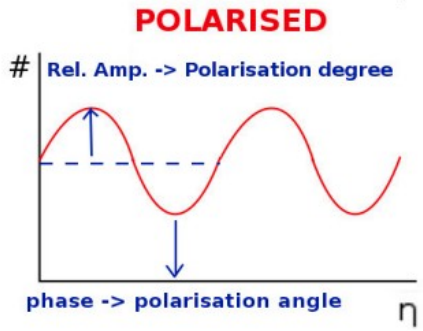


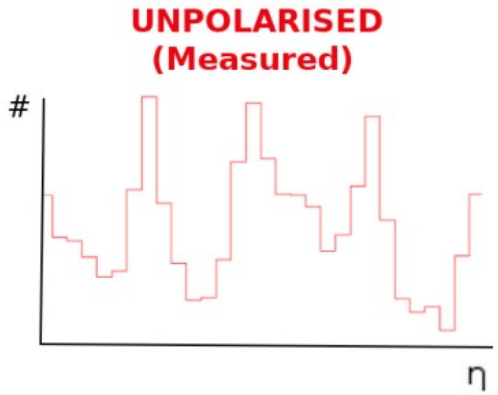
arxiv.org/abs/1612.04098

GRB Polarimetery Measurements (POLAR)









Scattering angle depends polarization of incoming photon

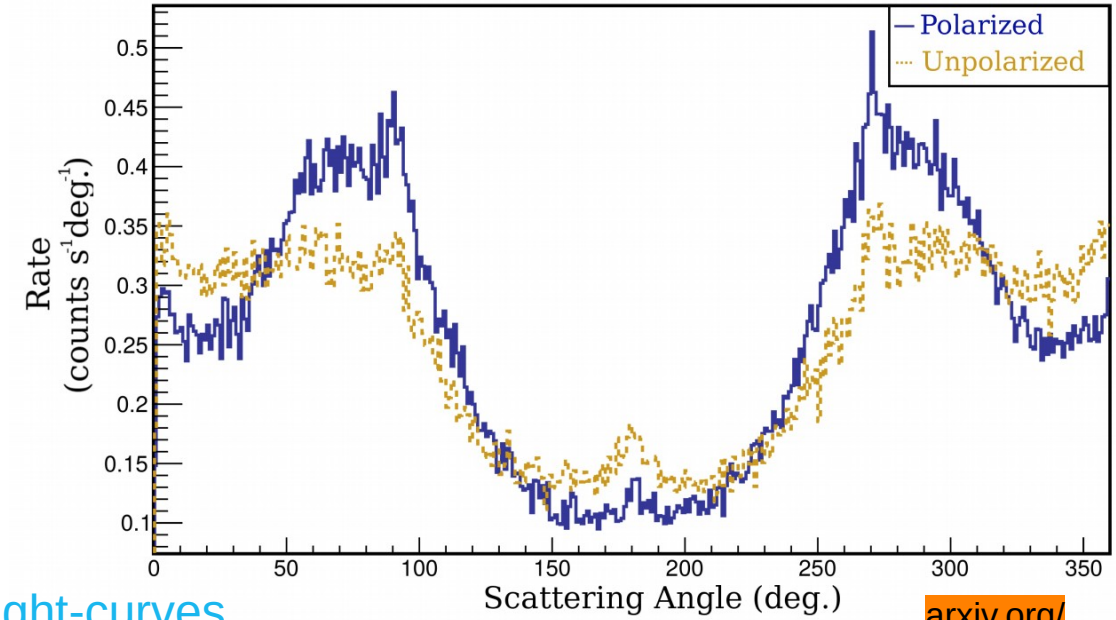
https://doi.org/10.1007/BF01366453

GRB Polarimetery Measurements (POLAR)

- polarization angle from scattering angle of photons between two scintillators within 100ns

- azimuthal scattering angle commonly referred to as the *modulation curve*

- some POLAR data in www.astro.unige.ch/polar/grb-light-curves



arxiv.org/abs/2009.04871

GRB Polarimetery Measurements (POLAR)

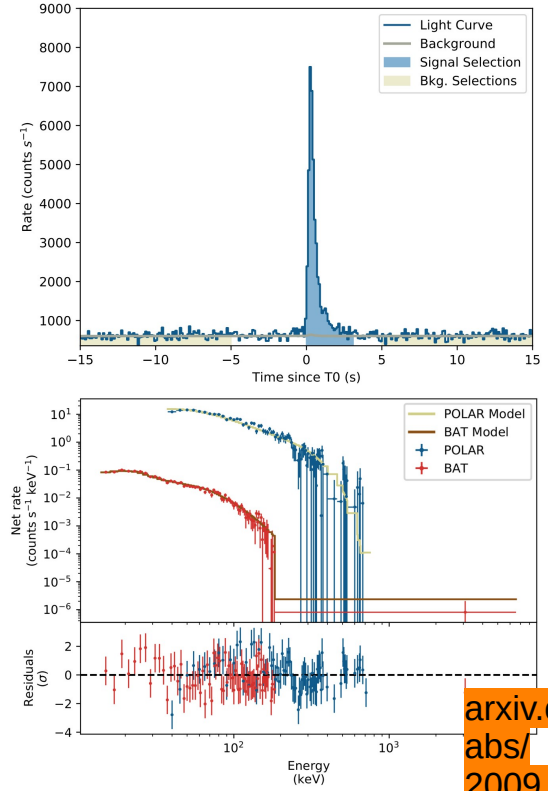
I) time integrated results: no polarization for prompt emissions between 30keV and 750keV
-> disagreement with “Model B”

II) temporal evolution of PD and PA are in agreement with most theoretical models

III) trace hints that PA within single peak GRBs

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

POLAR-2 mission



GRB170101A

arxiv.org/abs/2009.04871

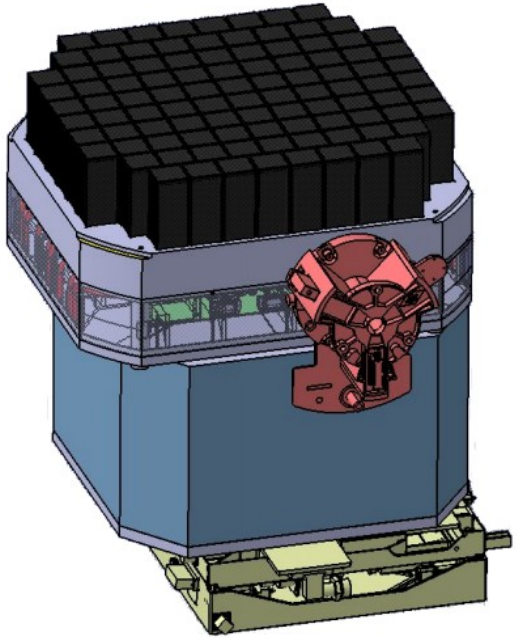
POLAR-2

- successor to POLAR
- manifested for launch in 2024 on the China Space Station (CSS)
- 2 year mission

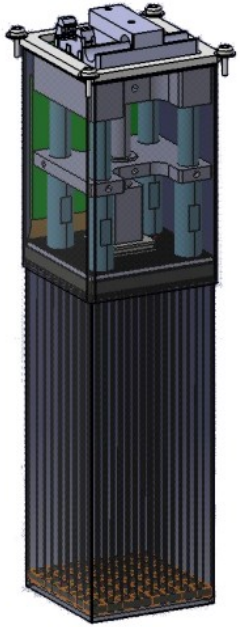
Major Upgrades:

- MAPMTs -> SiPM
- scintillator length reduced from 200mm to 125mm
- replace Vikuiti reflective foils with Claryl (increase scintillator surface area by 3.5%)
- scintillators not truncated (bigger surface area & reduce photon loss – Liouville's Theorem)
- change scintillator material from EJ-248M to EJ-200 (52% longer light attenuation and 9% better scintillation efficiency)

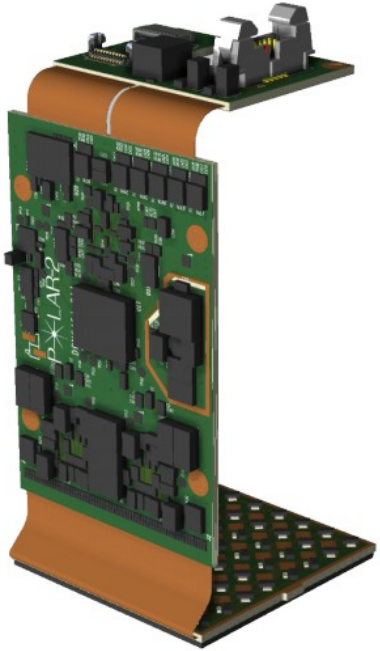
POLAR-2



Full Instrument



Single Module



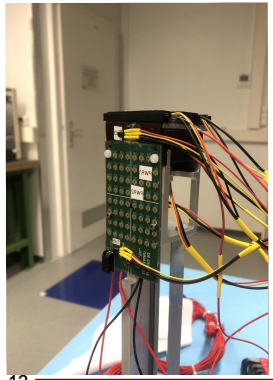
Module FEE

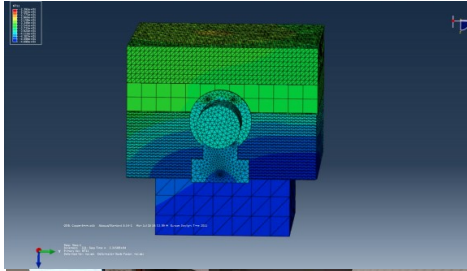
Development on Polarimeter

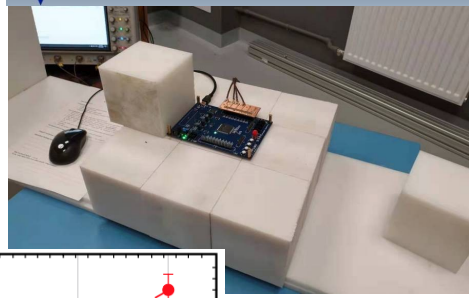
- radiation tests for critical components
  - protons, neutrons, gammas, betas

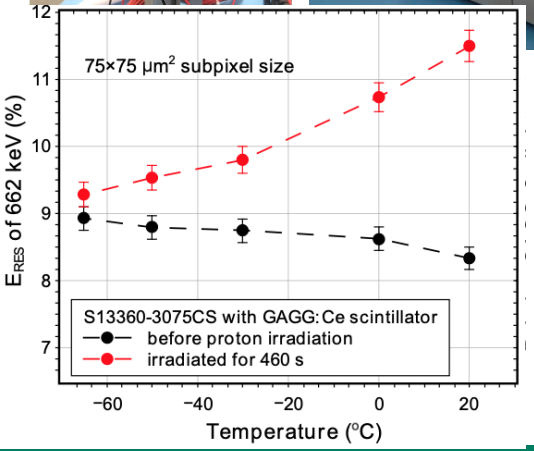
- thermal tests for most efficient cooling

- SiPM radiation damage
  - S13361-6075NE-04 of interest to us
  - dark current decreases with lower temperatures
  - energy resolution increases from 8.7% to 10.2% (662KeV line)
  - proton (and neutron) radiation campaigns ongoing
  - organizing dedicated “SiPM radiation damage” workshop









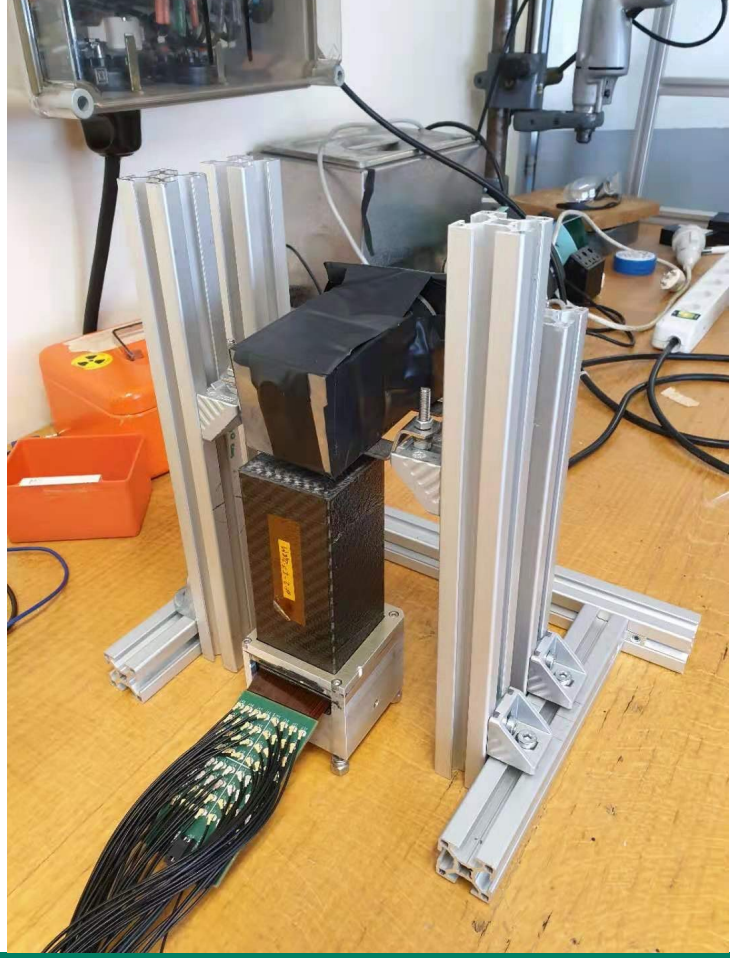
arxiv.org/abs/2003.09731

Development on Polarimeter

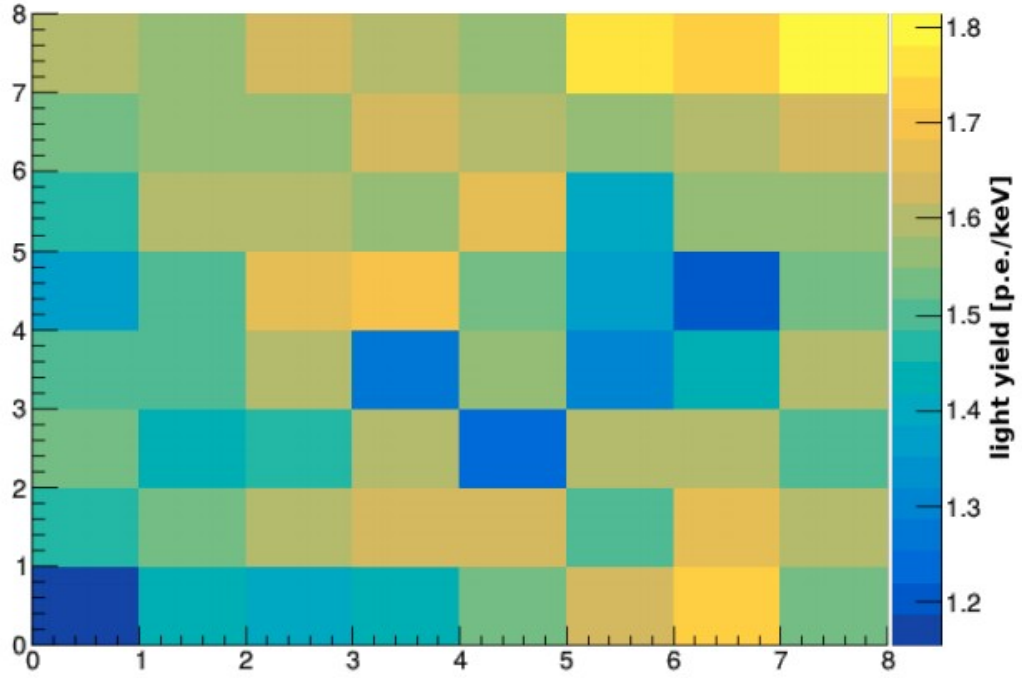
Prototype Module Test:

- scintillators made of EJ-248M
- not truncated
- Hamamatsu S13361-6075NE-04 SiPM
- read out by 2x 32-channel CITIROC 1A front-end ASICs
- 12um Claryl foils used
- room temperature

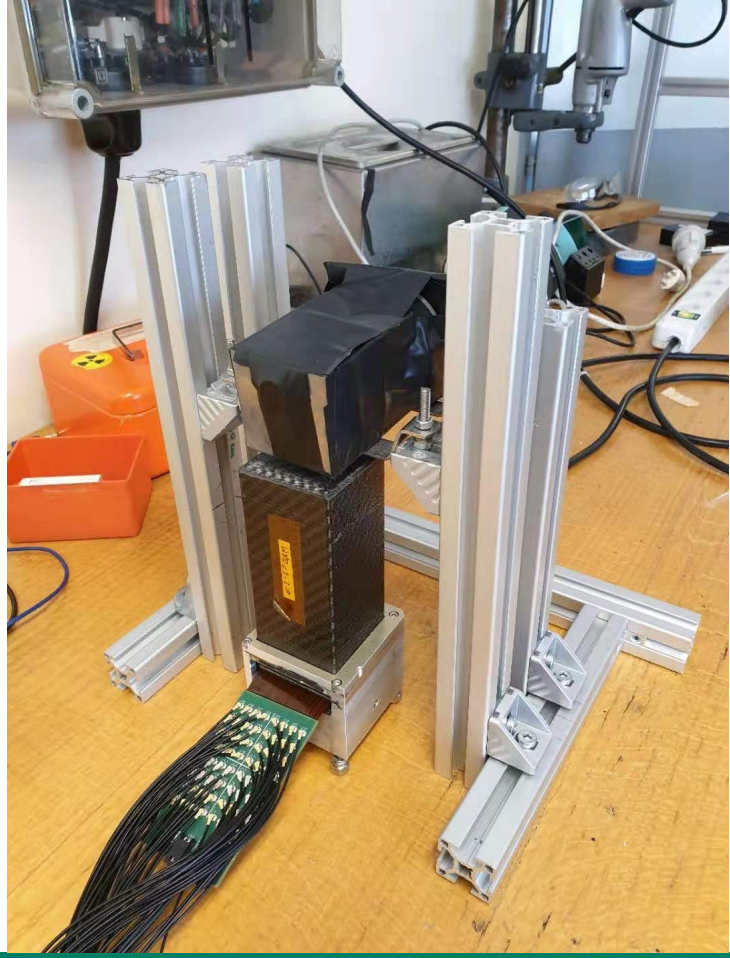
- irradiated at CERN with Am-241 source



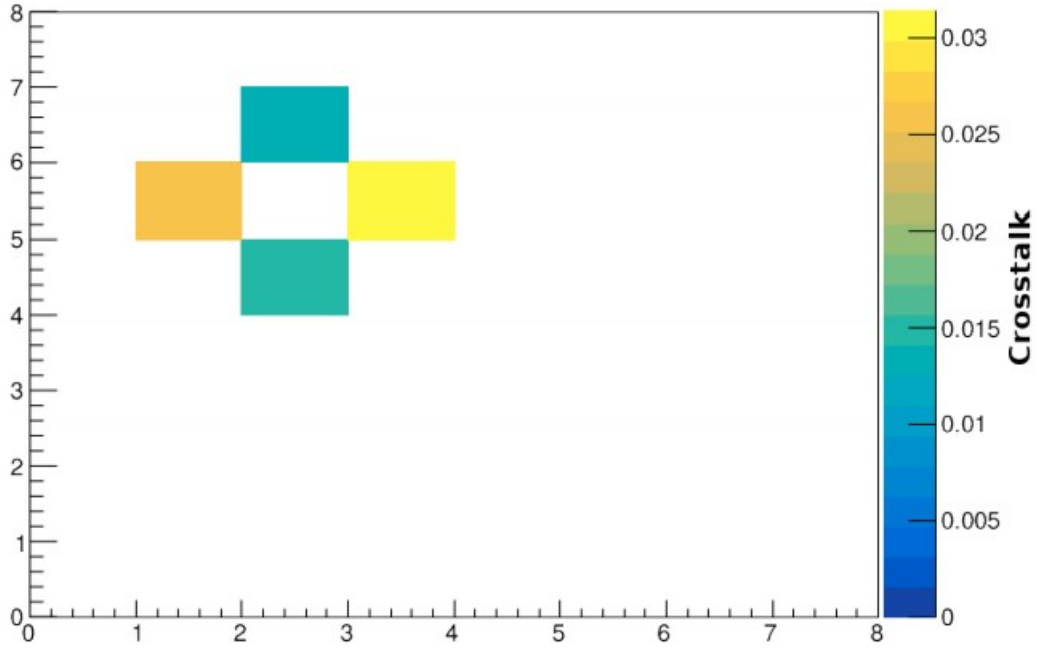
Development on Polarimeter



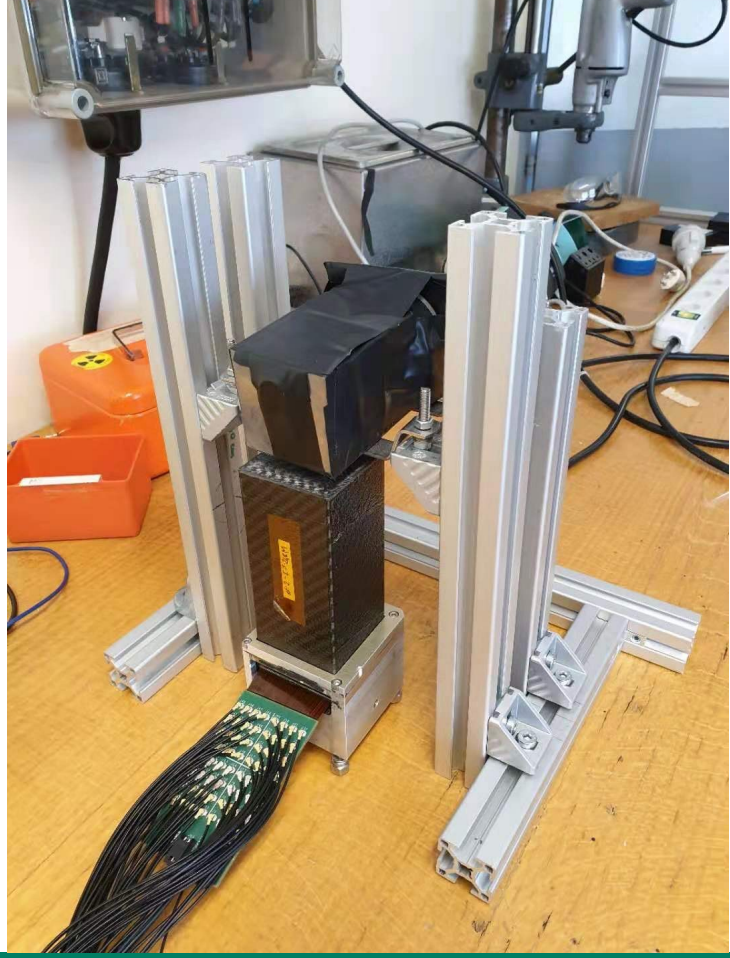
1.6 p.e./keV (0.3p.e./keV for POLAR)



Development on Polarimeter



cross talk 1-2.5% (~15% for POLAR)



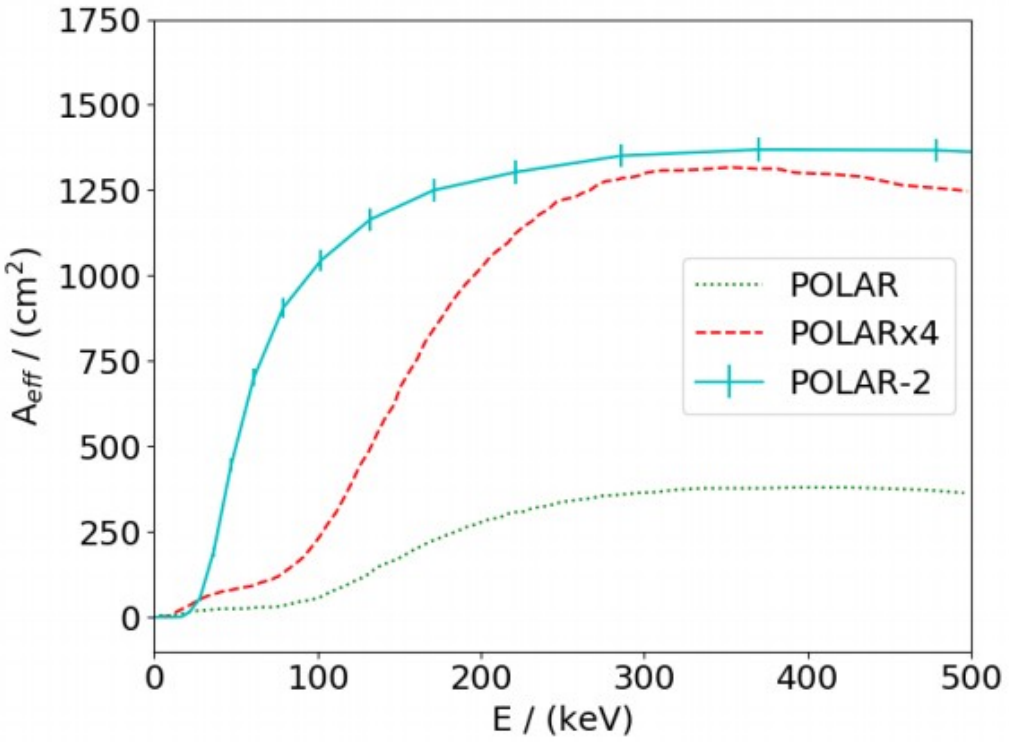
Anticipated Scientific Performance

Gauge scientific performance based on 3 scenarios for a 26.4° off-axis GRB (equal to GRB170114Aseen by POLAR):

POLAR: original POLAR design

POLARx4: scale POLAR by 4 (no technical updates)

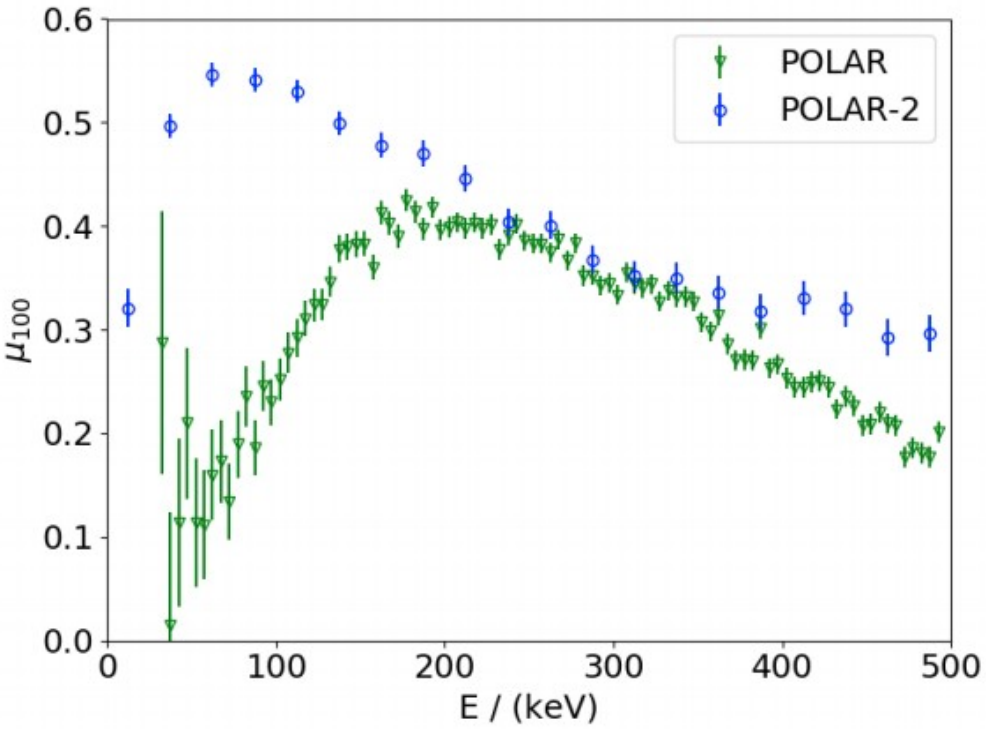
POLAR-2: latest instrument design and detector response



Anticipated Scientific Performance

- modulation factor M_{100} (corresponds to relative amplitude of 100% polarized modulation curve) has improved
  -> almost 0.6 around 100keV

- high quality analyses possible for GRBs with fluence of 2×10^{-6} erg/cm^2
  -> 50 GRBs / year



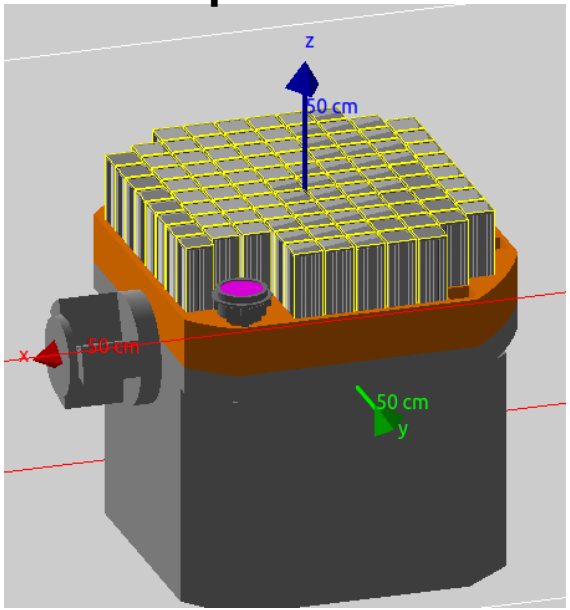
More to come until next meeting ;)

Thank you...

Backup

POLAR-2 (Spectrometer)

Option A

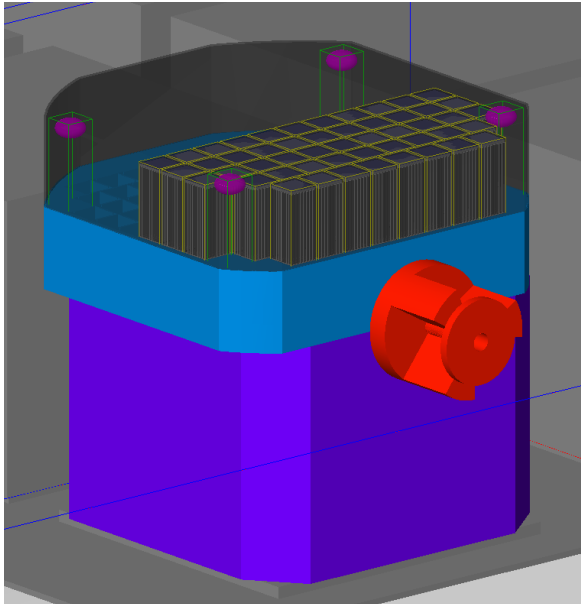


Optimal spectrometer location ongoing

Pro: based on GECAM, good energy resolution (<8%, 6keV to 5MeV) of $LaBr_3$, GECAM readily available

Con: activation $LaBr_3$

Option B



Pro: $CeBr_3$ does not activate in space

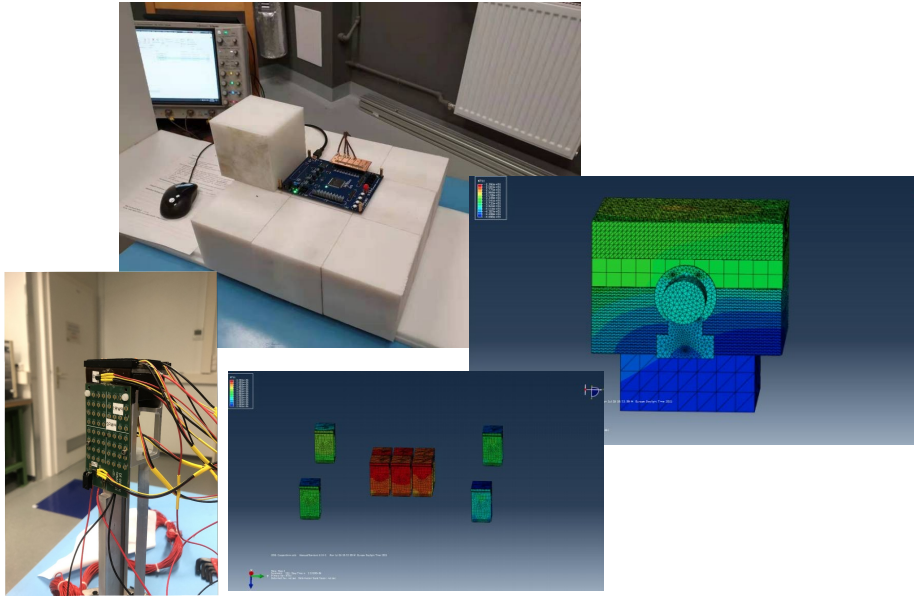
Con: expensive

Development on Polarimeter

- GOWIN FPGA (candidate) irradiated. No errors after an equivalent dose of about 10 years in space.

- Optimized module mechanics for best thermal transport. Current design ensures SiPM to be 10°C lower

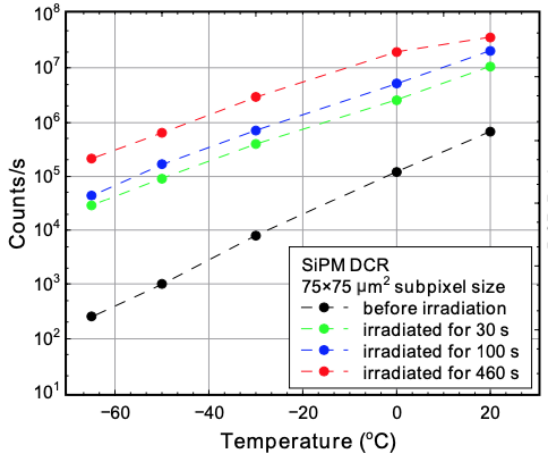
- Optimized instrument design to operate SiPMs at -40°C. Proposed design will be tested in a few months.



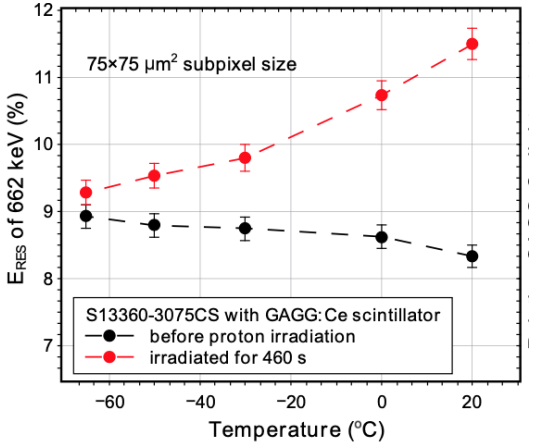
Development on Polarimeter

SiPM Radiation damage:

- S13361-6075NE-04 of interest to us
- dark current decreases with lower temperatures
- energy resolution increases from 8.7% to 10.2% (662KeV line)
- proton (and neutron) radiation campaigns ongoing
- organizing dedicated “SiPM radiation damage” workshop



- 170MeV protons
- 10^7 protons/s/cm²
- ~10^8s in space



arxiv.org/abs/2003.09731