24th International School of Cosmic Ray Astrophysics

Characterization and expected performance of the LISA particle detector (and beyond…)

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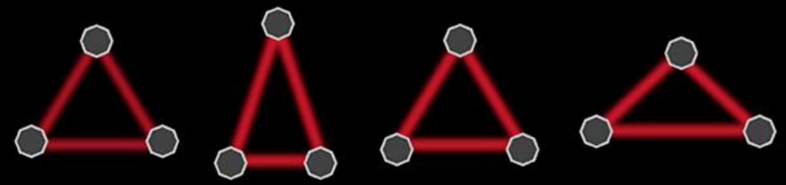
IEEC Institut d'Estudis Espacials de Catalunya

LISA - LASER INTERFEROMETER SPACE ANTENNA

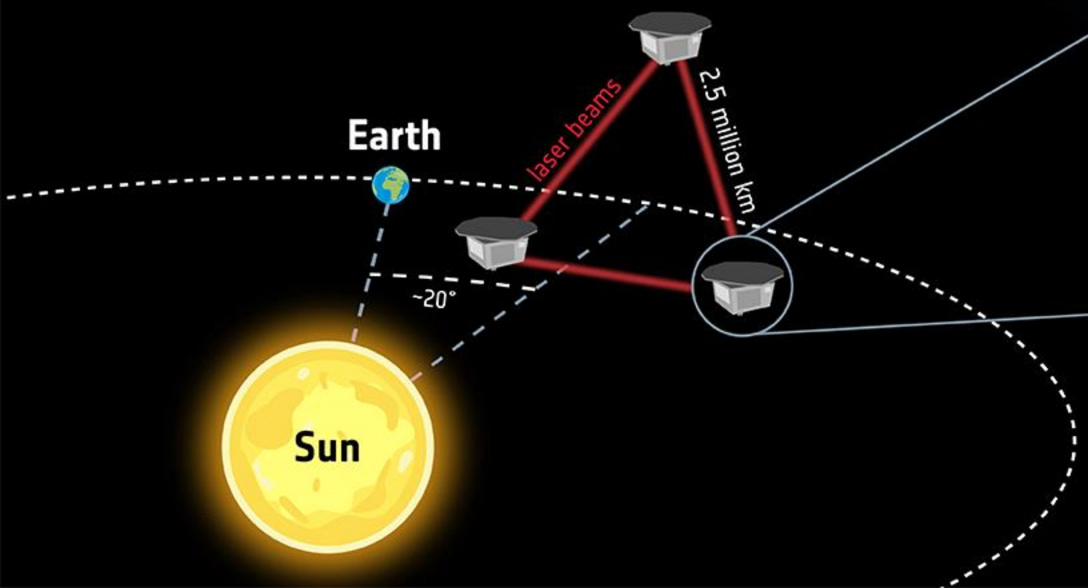
Gravitational waves are ripples in spacetime that alter the distances between objects. LISA will detect them by measuring subtle changes in the distances between **free-floating cubes** nestled within its three spacecraft.

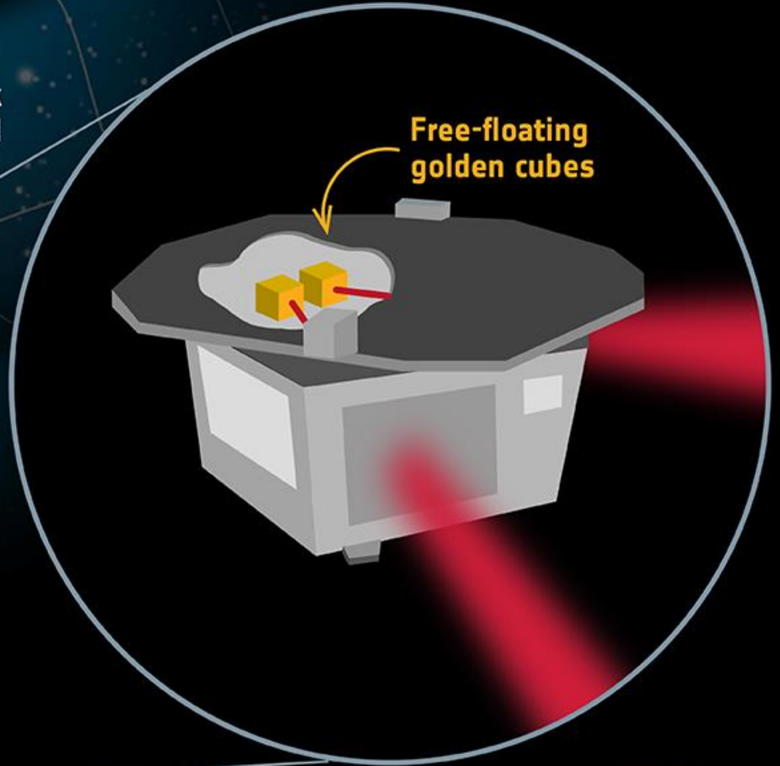
3 **identical spacecraft** exchange **laser beams**. Gravitational waves change the distance between the **free-floating cubes** in the different spacecraft. This tiny change will be measured by the laser beams.



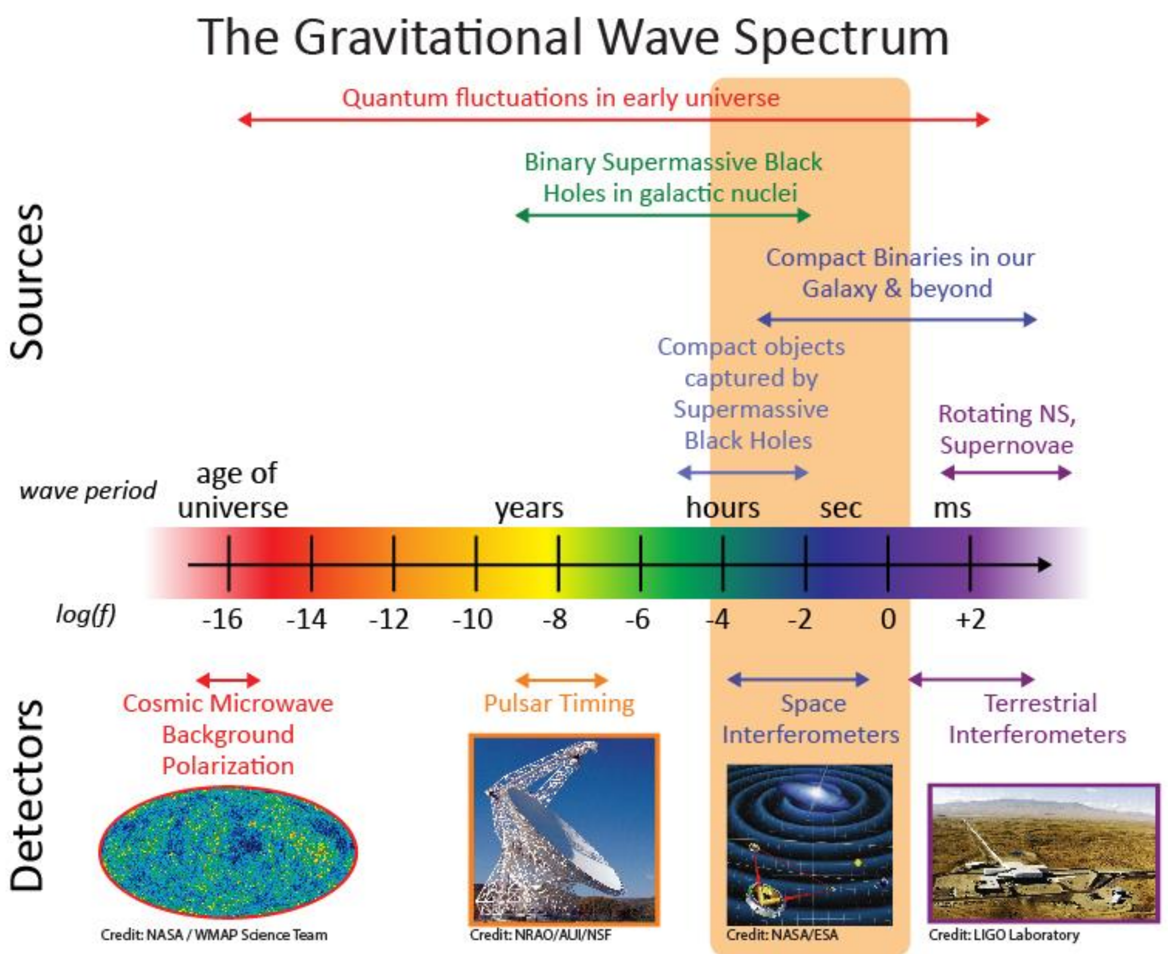
* *Changes in distances travelled by the laser beams are not to scale and extremely exaggerated*

Powerful events such as **colliding black holes** shake the fabric of spacetime and cause gravitational waves



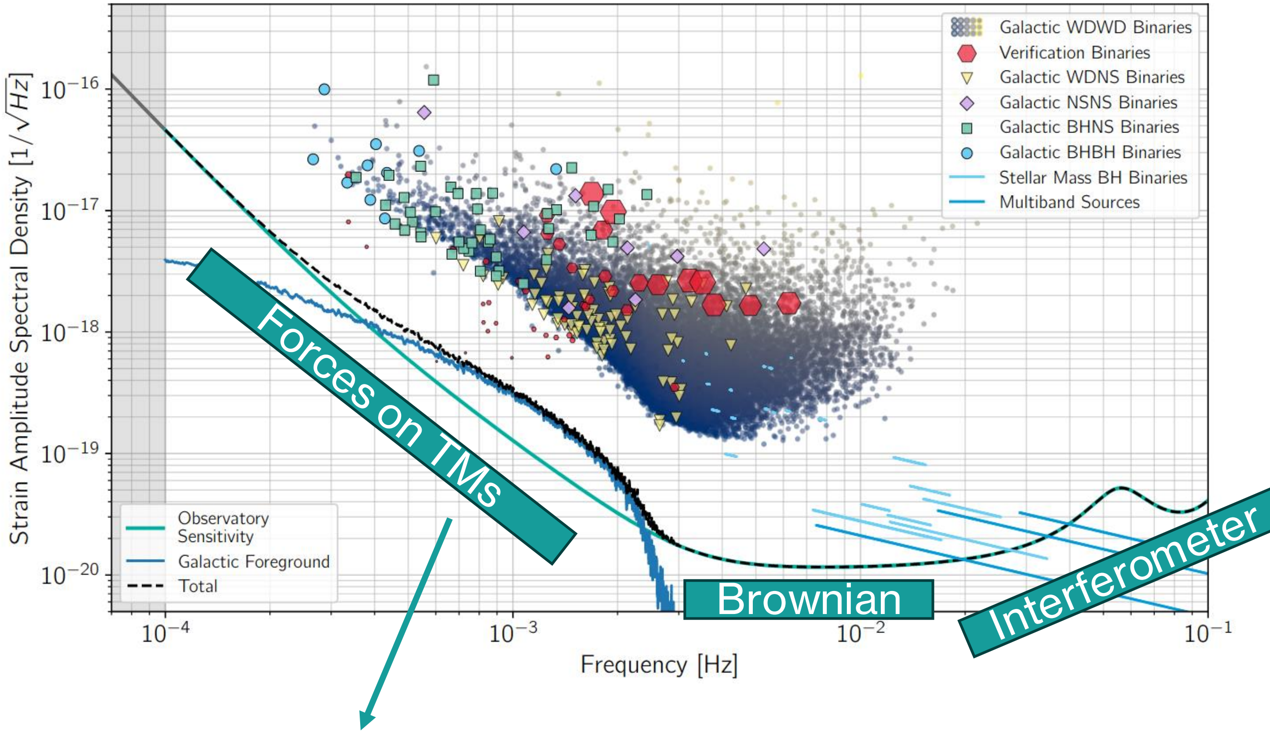


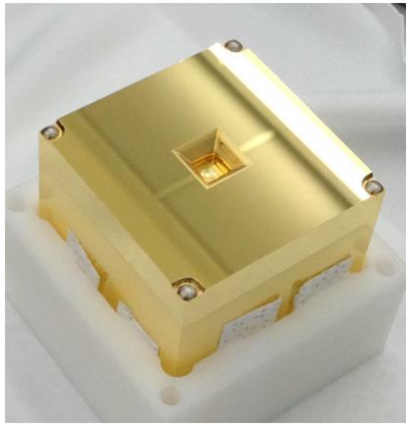
LISA sensitivity



lisa.nasa.gov

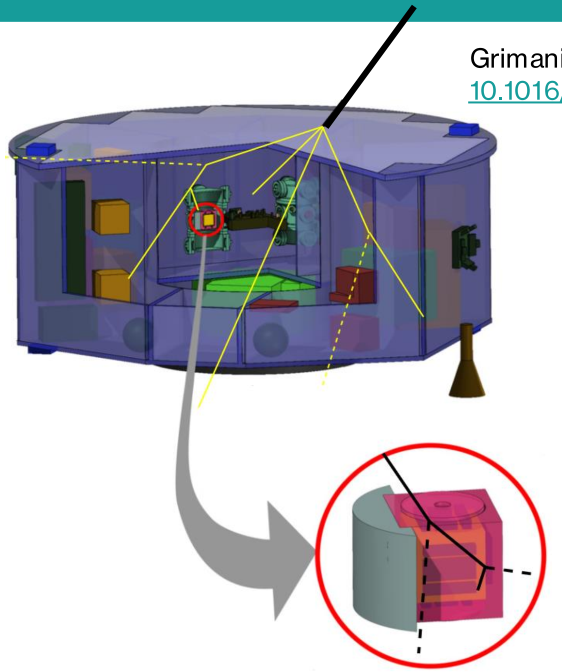
LISA Redbook





LISA Pathfinder Test Mass
sci.esa.int

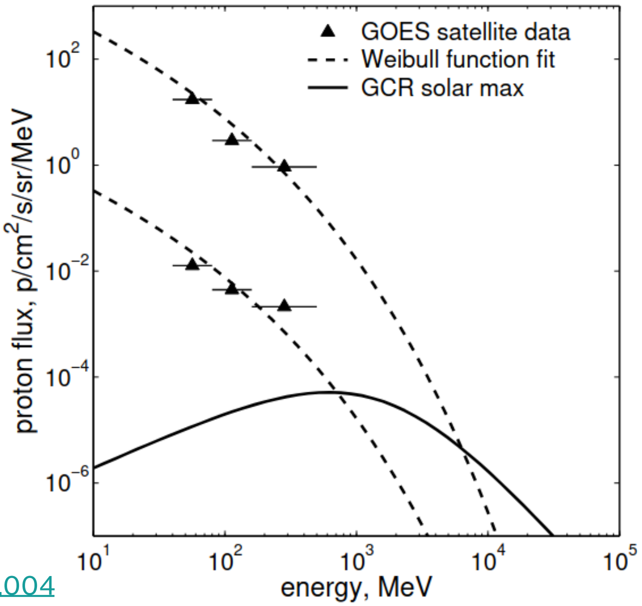
Motivation: test mass charging



Grimani et al., 2024
10.1016/j.jheap.2024.03.004

- Background radiation may create secondary particles within the spacecraft
- Test mass gets charged producing acceleration noise

- Expected backgrounds:
  - **Cosmic Rays** (CR): isotropic, slow changing
  - **Solar Energetic Particles** (SEPs): spurious, directional, fast changing, orders of magnitude more intense than CR
- Mainly concerned about **p > 100 MeV**

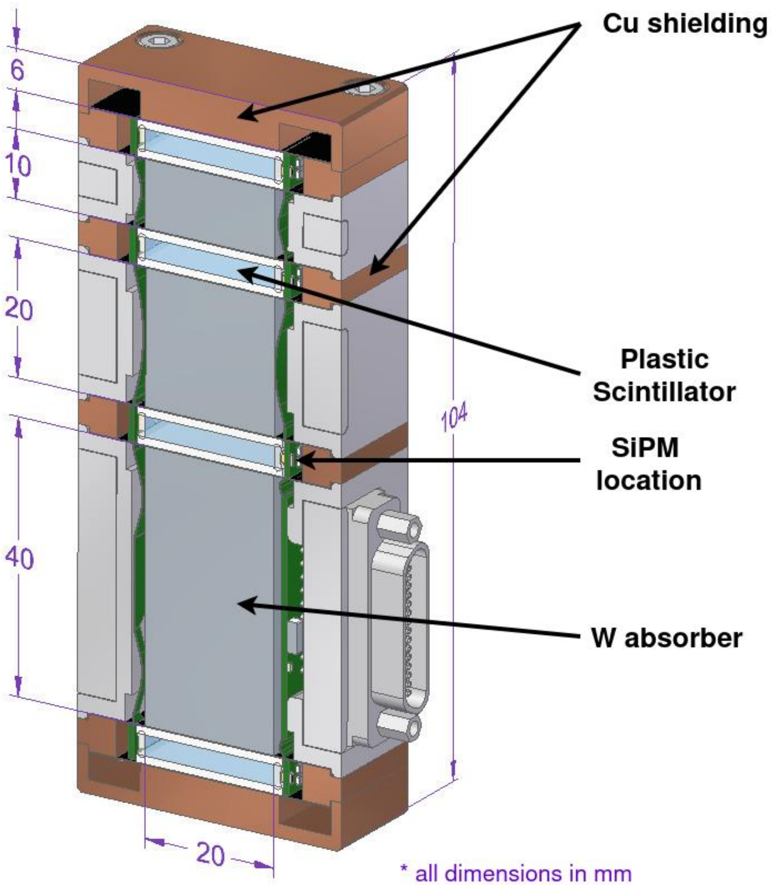


Araujo et al, 2005
10.1016/j.astropartphys.2004.09.004

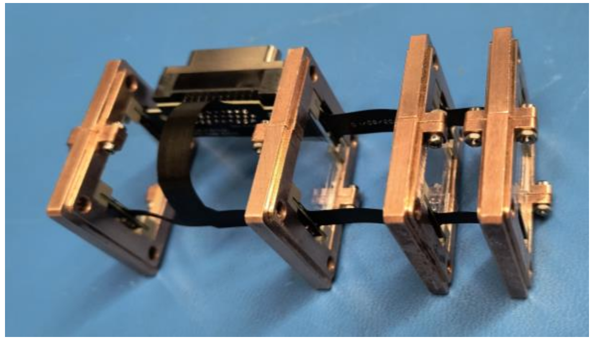
The Radiation Monitor

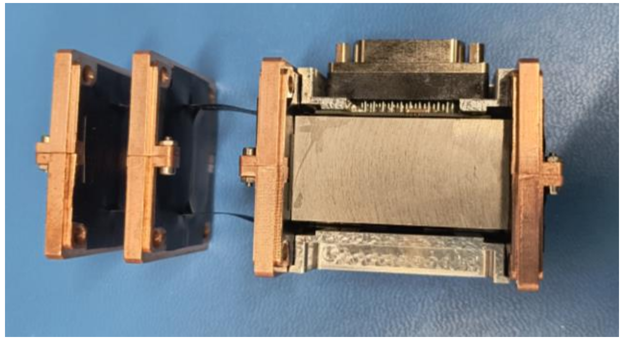
- Consists of:
  - Telescopic stack of area 20x20 mm²
  - Plastic scintillators + SiPM for sensing
  - W absorbers to "slowdown" the incoming protons
  - Shielded with Cu

- Allows to:
  - Measure fast changes in flux
  - Have an estimation of the spectra
  - Veto fake GW triggers



First built prototype





The Radi

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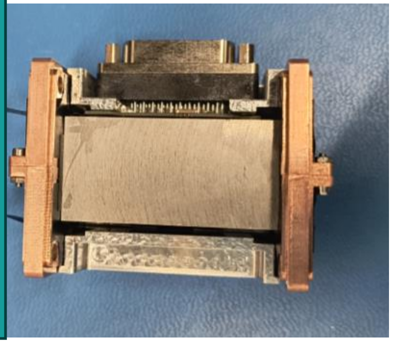
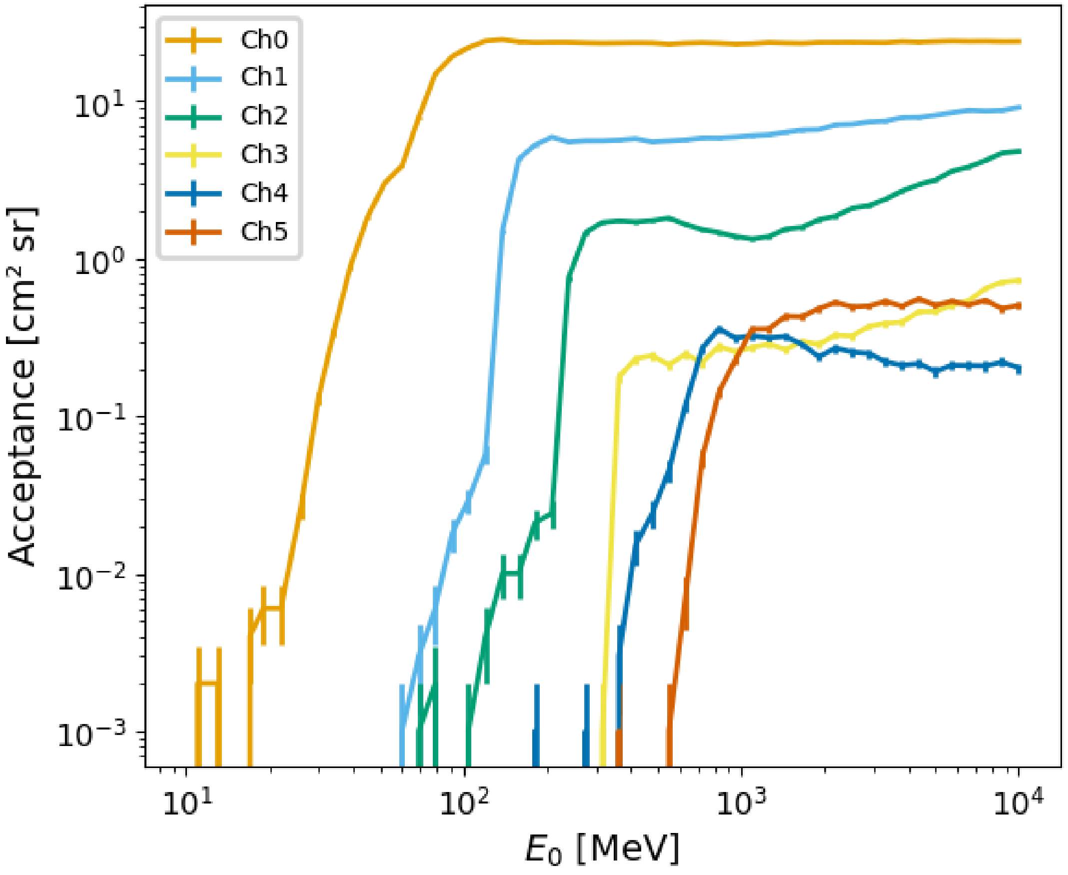


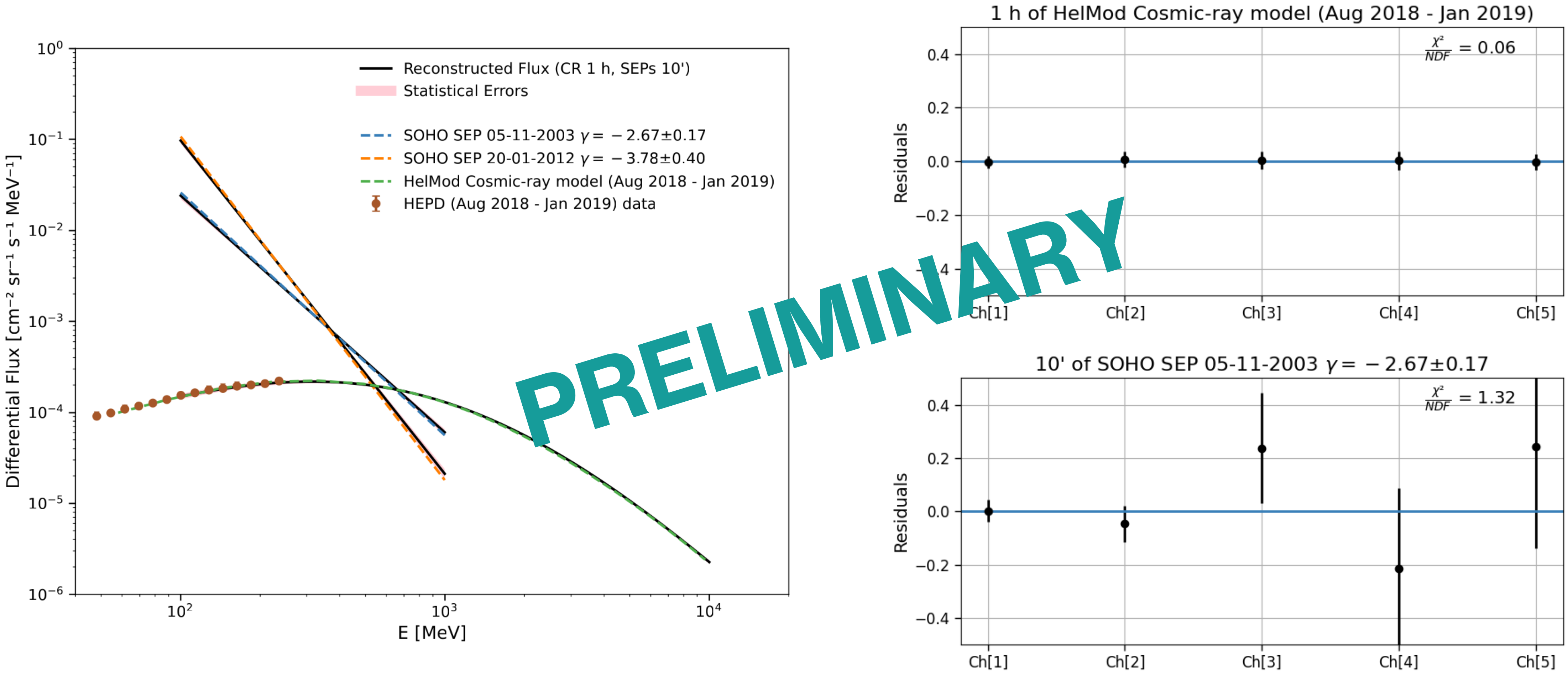
Acceptance and data output

- Monte Carlo simulations with Geant 4
- RM response under isotropic proton flux at different energies
- **5 energy channels** (defined by the signal created in each scintillator)

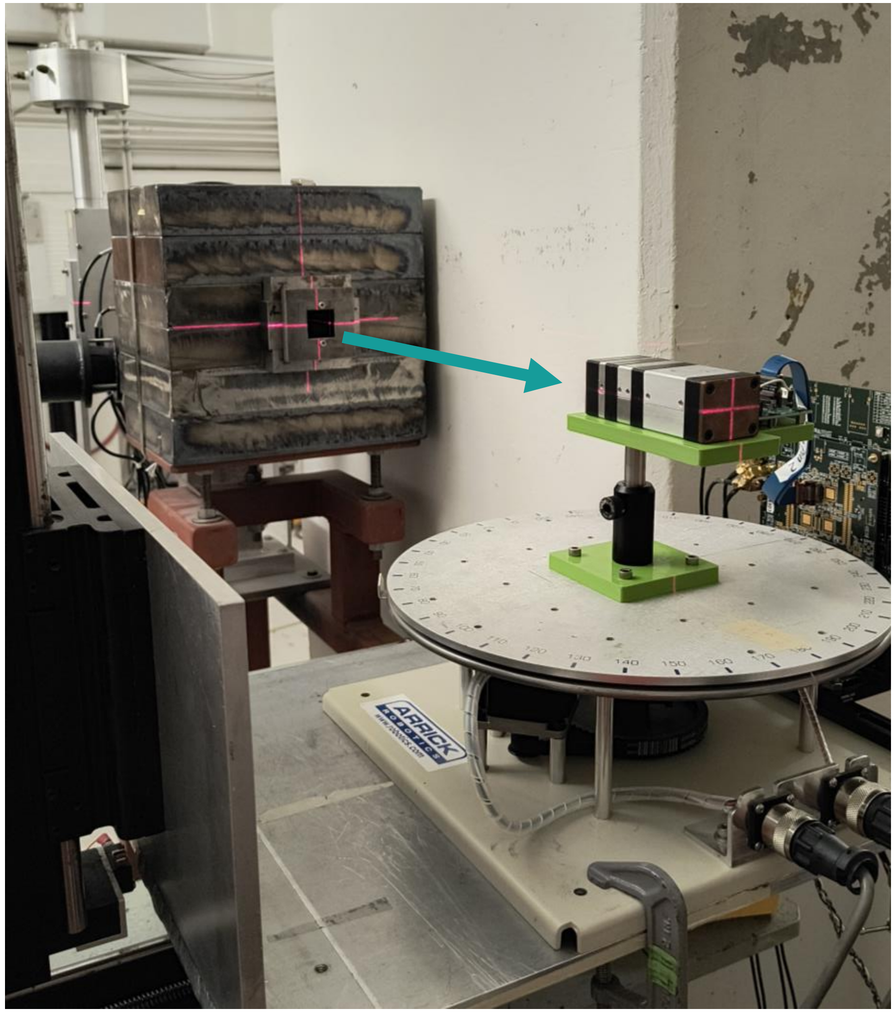
- Every detection recorded is classified into one channel
- The RM will record **count rates** on each of this channels



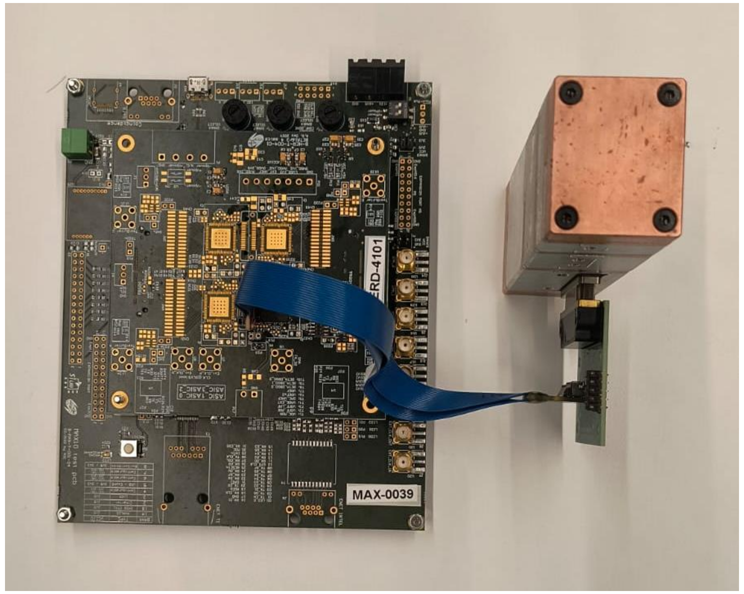
Flux reconstruction capabilities



Characterization in a test beam campaign

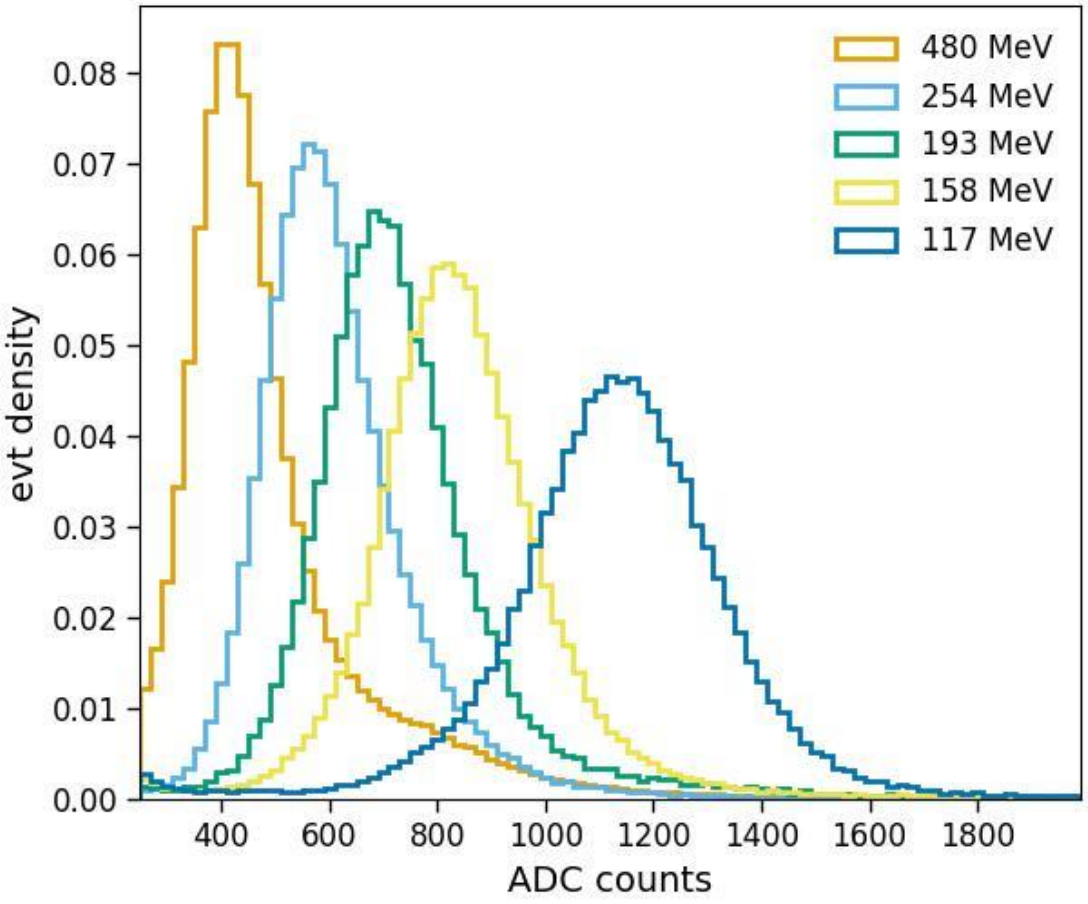


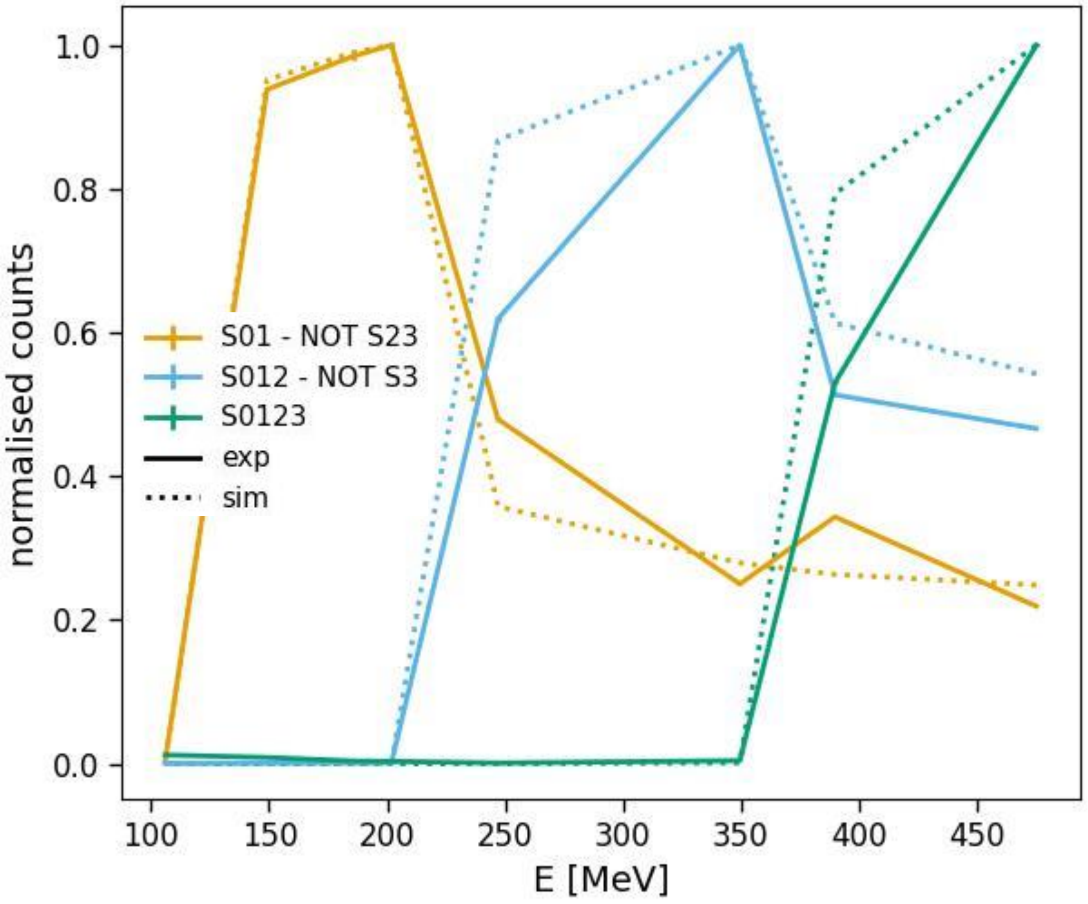
- TRUMF facilities in Vancouver, Canada
- Protons from 117 to 480 MeV
- Validate simulations and acquisition trigger



Evaluation board + RM

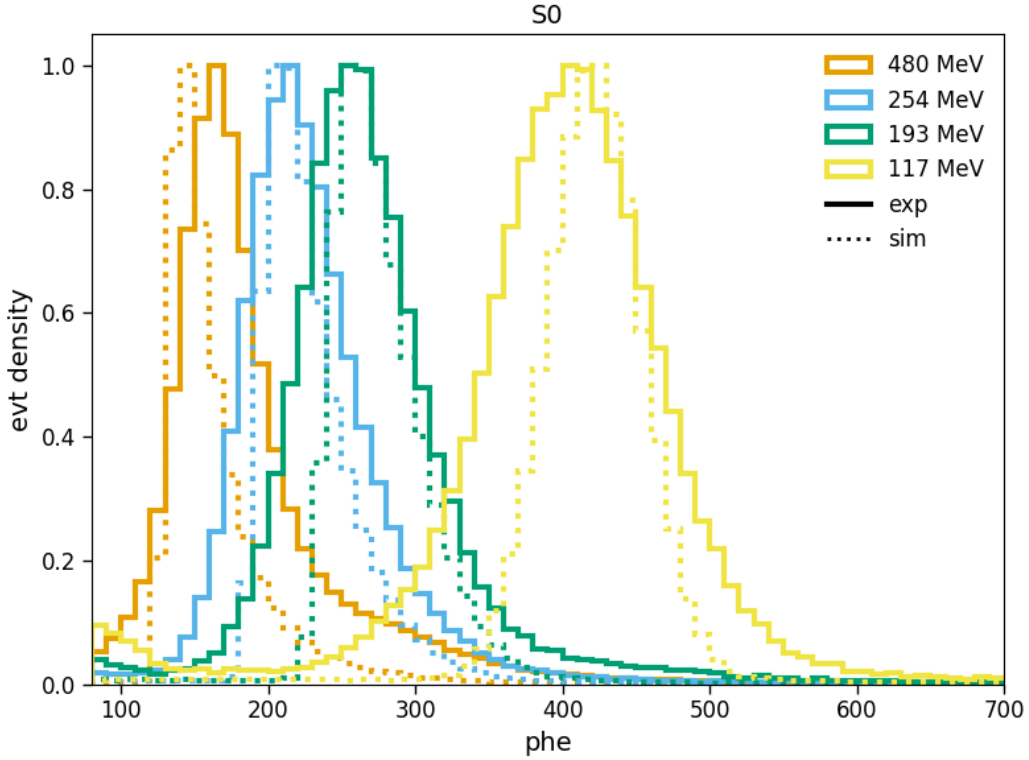
Characterization in a test beam campaign

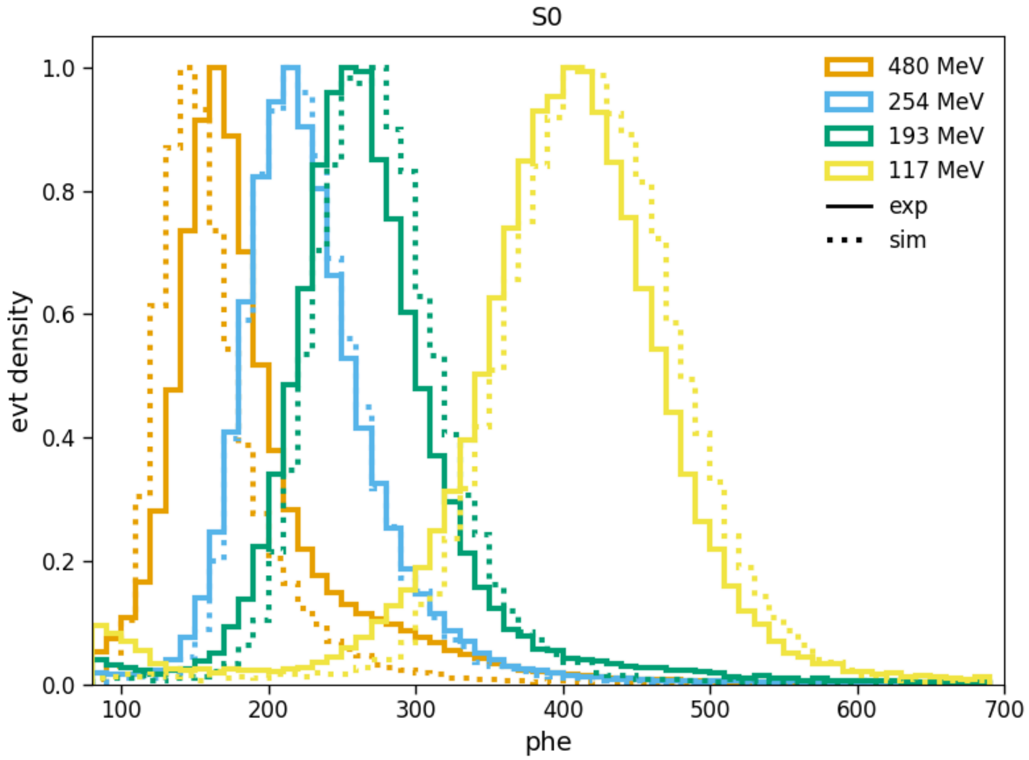




Feedback to simulations

- Fine-tune simulations with experimental results
- Addition of artificial noise: 11% resolution
  - Contribution from: scintillator, SiPM and electronics

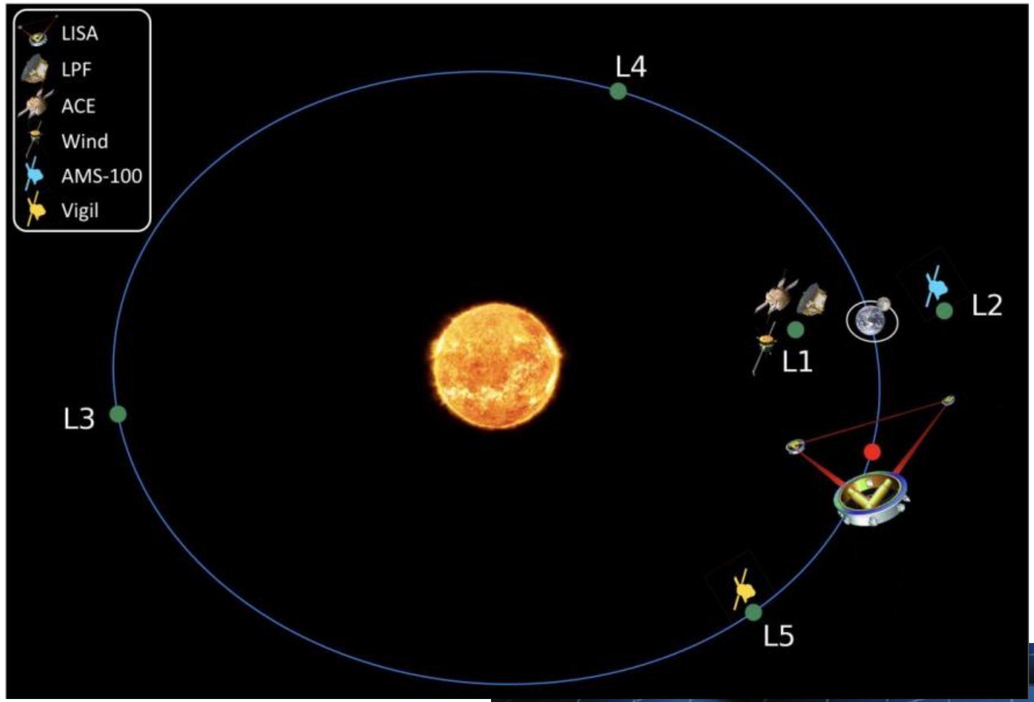


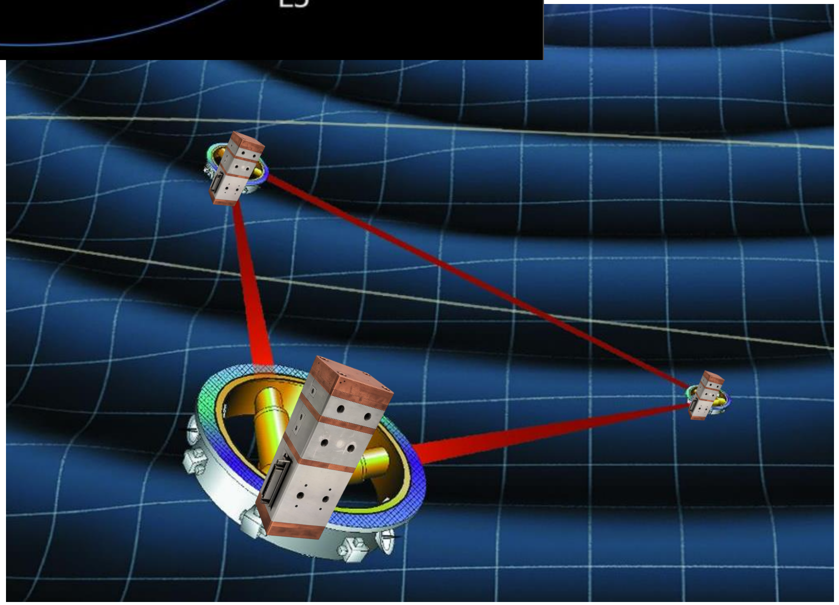


Beyond LISA…

- Proton flux measurements:
  - In an unstudied region
  - Uncommon energy range (for SEPs)

- Three spacecrafts:
  - Different arrival times
  - Slightly different orientations
  - Together with magnetometers





Highlights

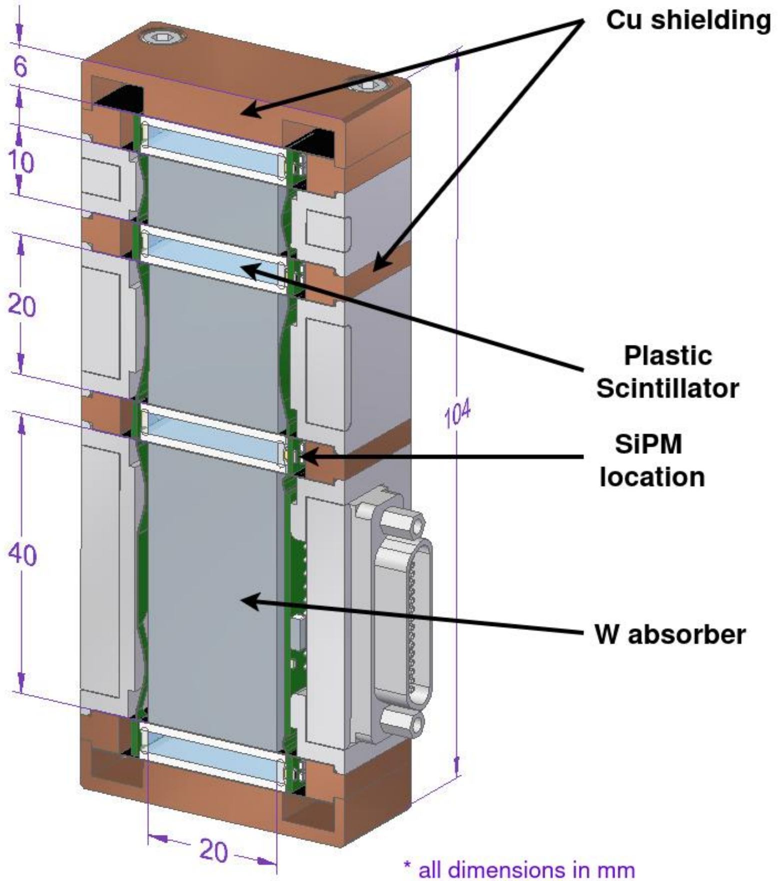
- Performance of the RM was evaluated with simulations and experiments (with a proton beam)
- Simulations validated with experimental data
- The RM data can be used to reconstruct the spectrum of CRs and SEP events
- Direction reconstruction capabilities under study

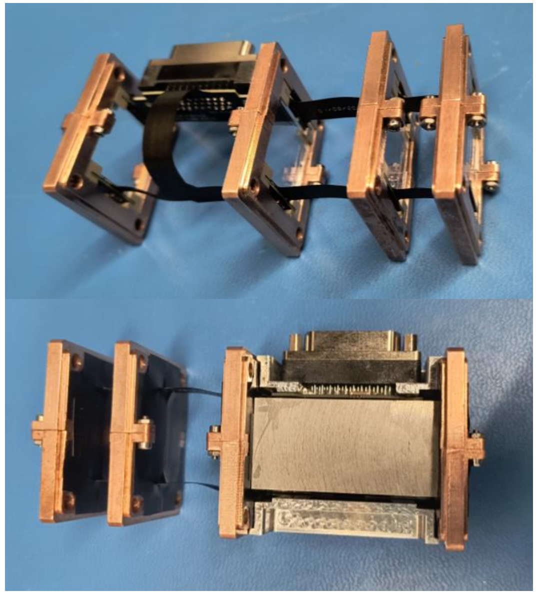
- HECTOR, a CubeSat-sized demonstrator, will be flying by the end of the year along other LISA Science Diagnostics Subsystem instrumentation

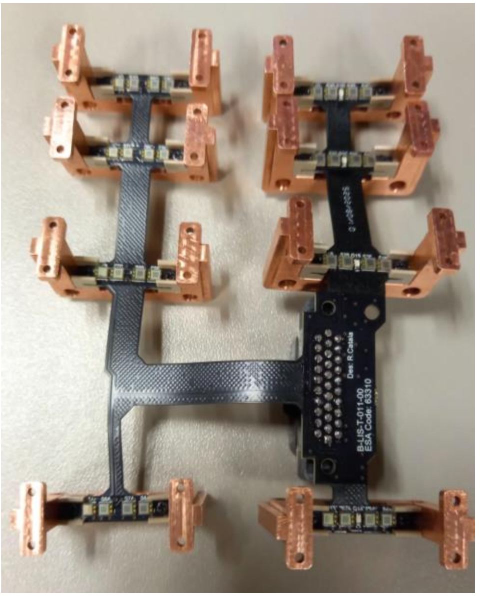
BACKUP

Details on the Radiation Monitor

- Plastic scintillators: BC-404
- Reflector: Berghof Optical PTFE (teflon)
- SiPM: Hamamatsu 14160-1315PS
- Absorbers: W alloy; density = 17.3 g/cm³
- Shielding Cu; thickness = 6 mm | p > 70 MeV
- BETA ASIC for processing and digitization of the SiPM signals
- FPGA for trigger and data preprocessing:
  - Register the count rates of the detector channels
  - Generate histograms with calibration data

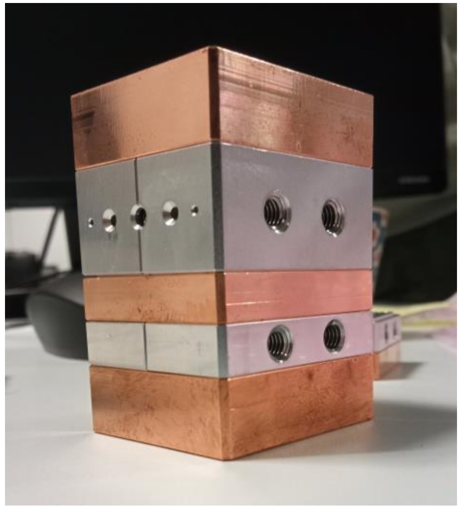


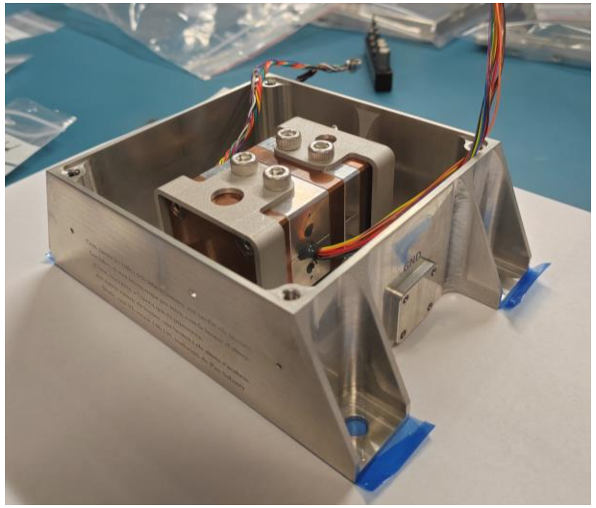


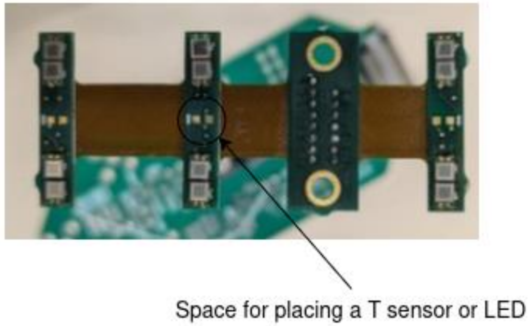


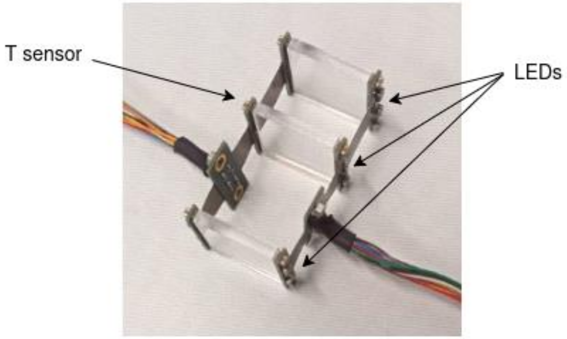
HECTOR

- Demonstrator within ILIADA
  - Fits 1U
  - Temperature sensor for SiPM gain correction
  - Calibration LEDs
- LEO orbit
  - Heliosynchronous at 540 km
- Scheduled launch at the end of this year
- Expected duration: 3 years









Flux reconstruction procedure

- Information: counts recorded by the channels C_i result from the simulated acceptance and the real particle flux ϕ:

$$C_i = \int Aeff_i(E)\phi(E)dE$$

- The goal is to find the best estimation of ϕ, given the counts measured C_i.
- Provided a model for ϕ (e.g., power law, power-law with cut-off, etc.), the negative log-likelihood (NLL) is minimized:

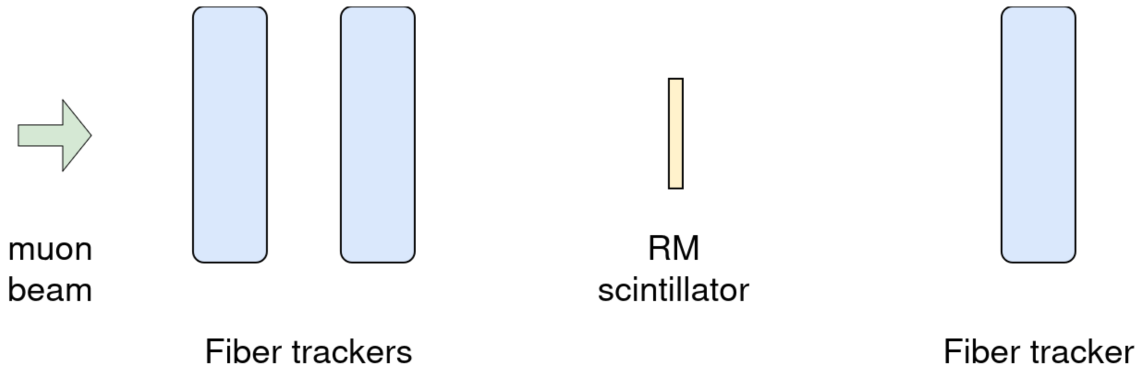
$$NLL = \sum_i (\lambda_i - C_i log \lambda_i)$$

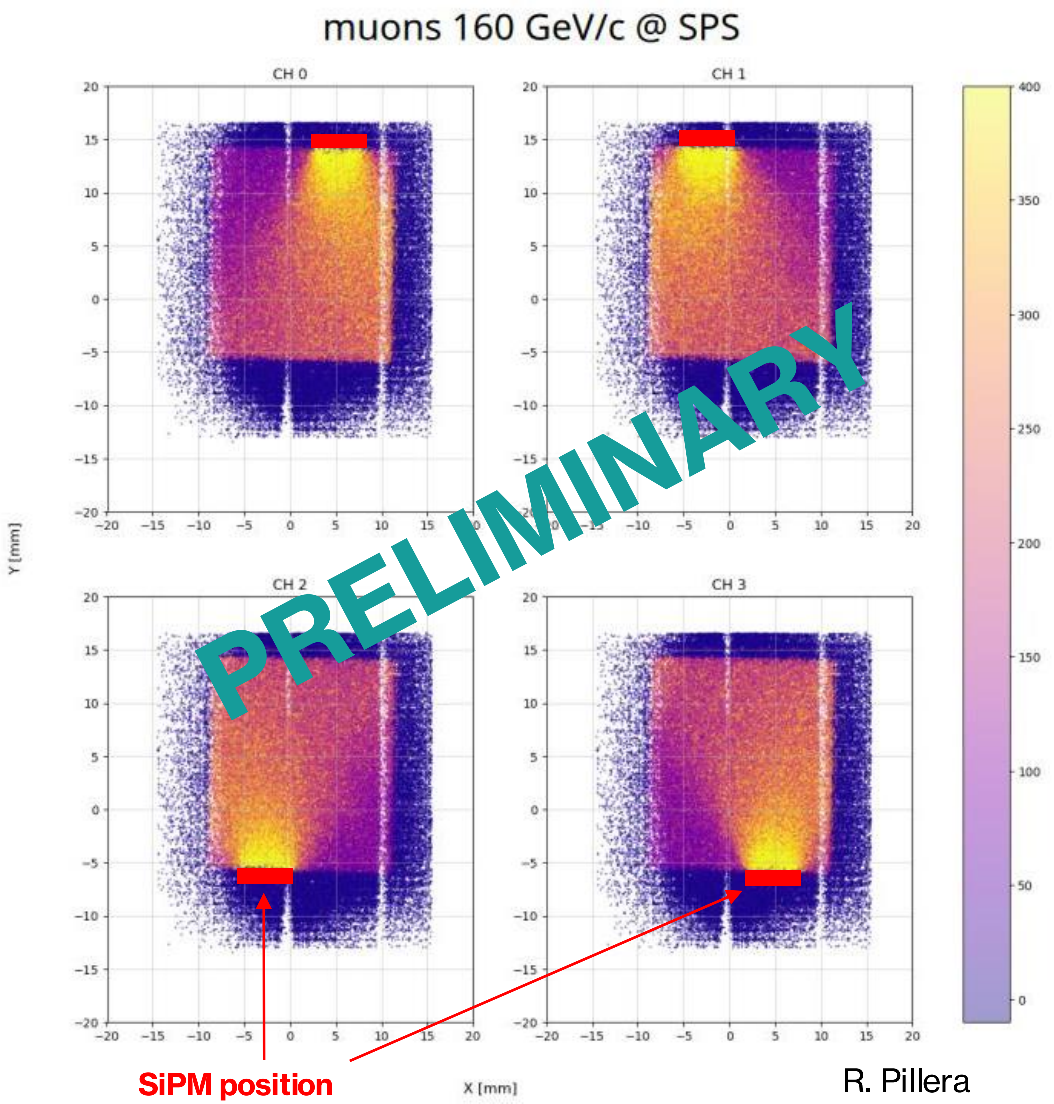
- Where λ_i are the counts predicted by the chosen model ϕ_{model}:

$$\lambda_i = \int Aeff_i(E)\phi_{model}(E)dE$$

Direction reconstruction within the RM

- The response of the SiPM channels within a scintillator is position dependent
  - Test beam at CERN SPS
  - Fiber trackers for position reconstruction
  - Setup:





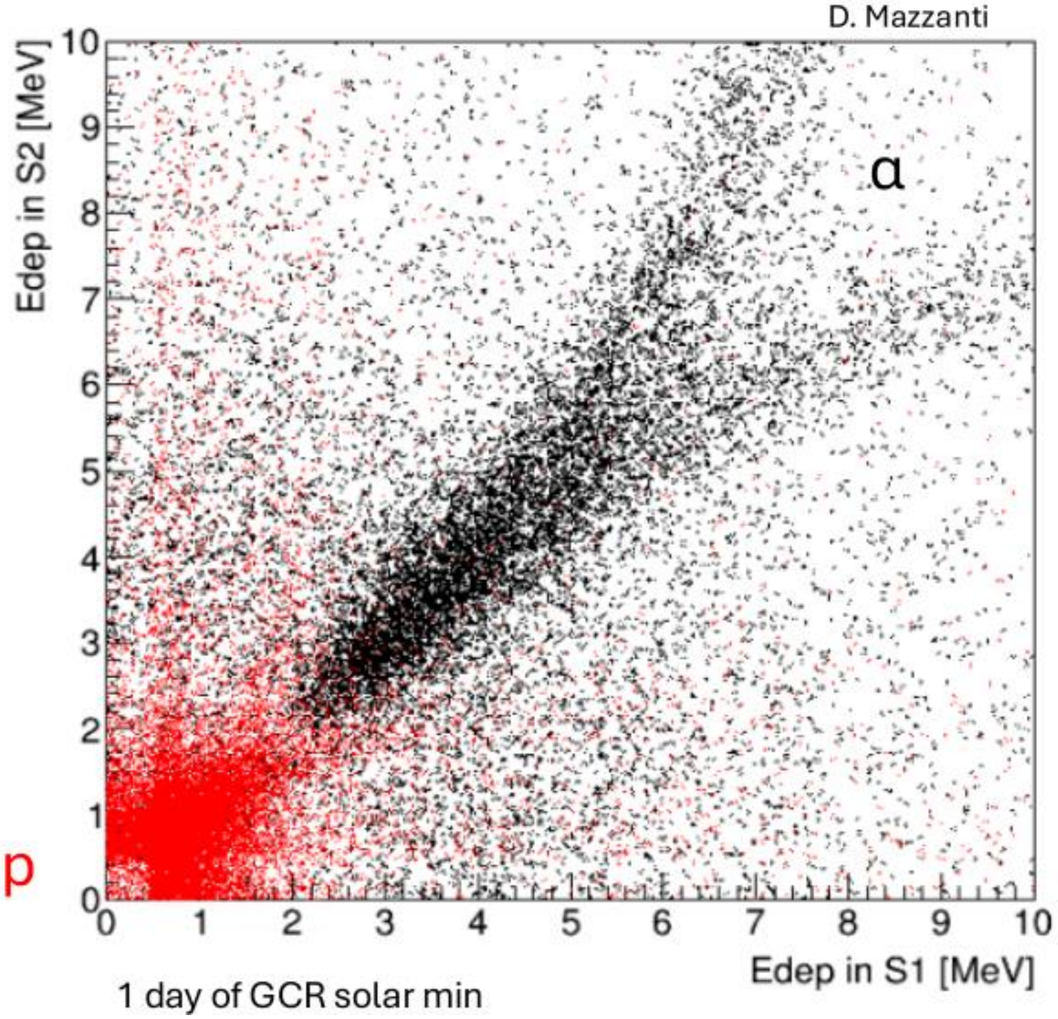
R. Pillera

Charge identification

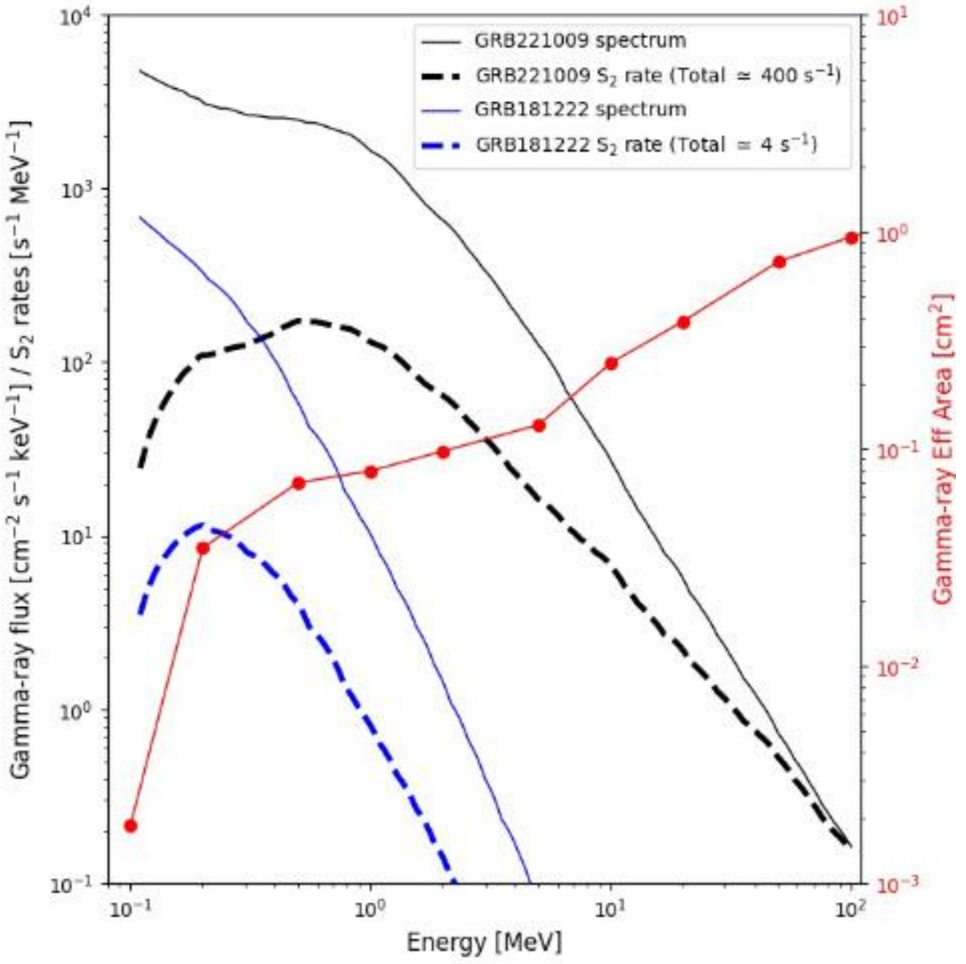
- Energy deposited into the scintillators:

$$E_{dep} \sim Z^2$$

- Dedicated channels for higher Z nuclei can be defined



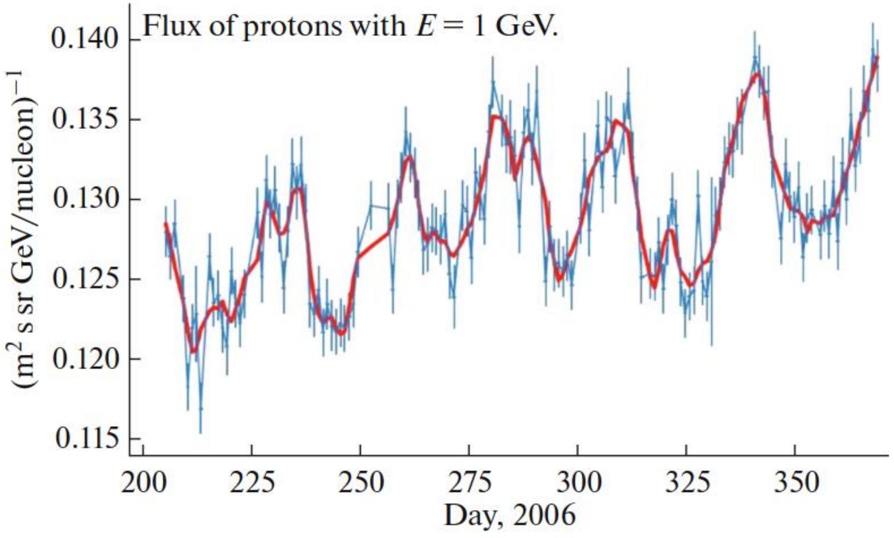
The RM and GRBs



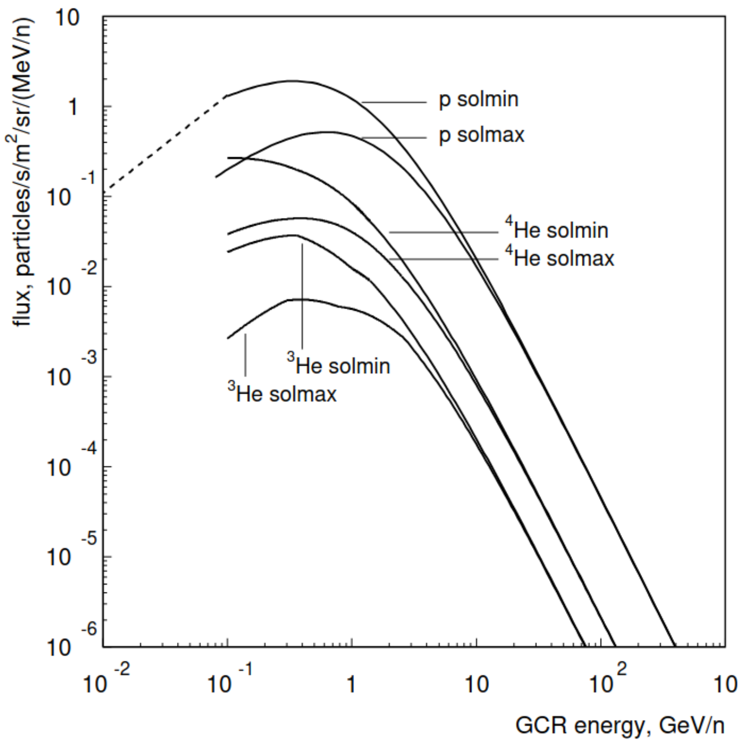
- Simulated the RM response to gamma rays with Geant4
- Total scintillator volume is too small and practically transparent to gamma rays
  - Gamma-ray detection relies on the secondary particles created in the W and Cu parts of the radiation monitor
  - The RM would only detect extreme GRBs like 221009A

(More) Beyond LISA...

GCR: short and long variations



27-day variations in the flux of cosmic protons with the energy of 1 GeV according to the 2007 data from the PAMELA spectrometer.
10.1134/S1063779619060054



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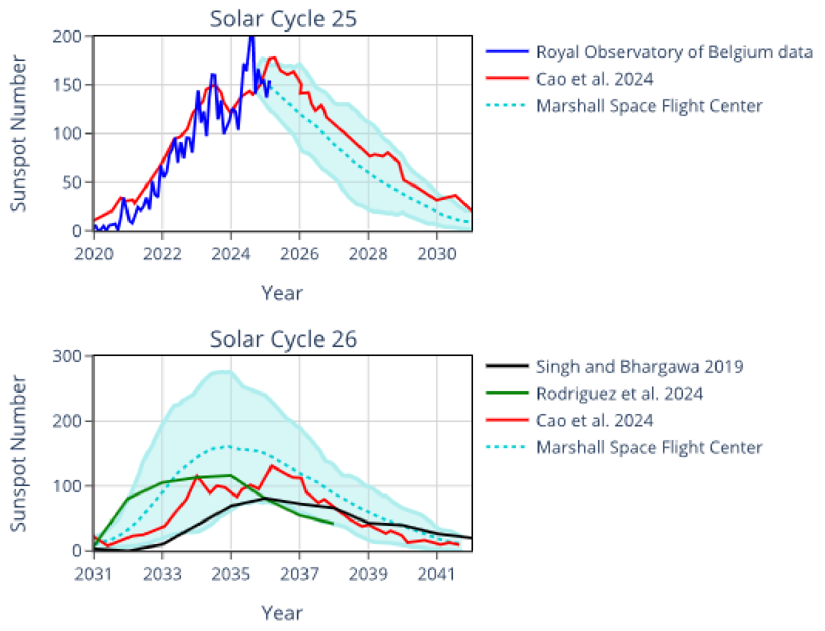

Predictions and observations of sunspot number for the present Solar Cycle 25 and predictions for the Solar Cycle 26
10.1088/1361- 6382/adcb13