Hunting ^{40}K

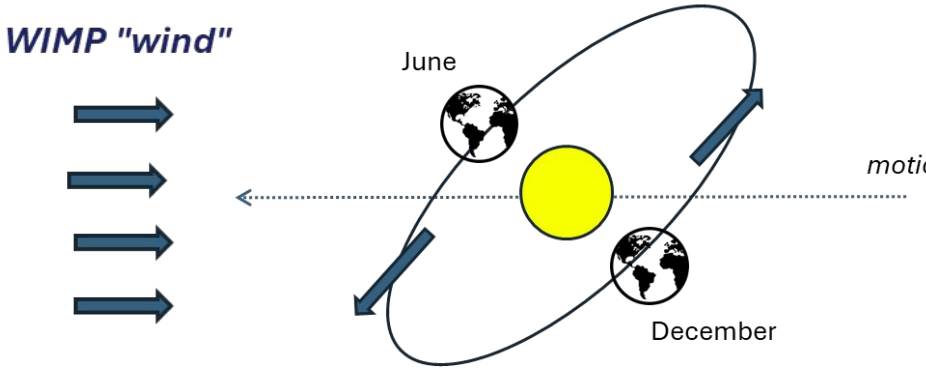
using NaI(Tl) crystals for the SABRE Collaboration

Sanjay Sharma Poudel
Valeria Trabattoni
Sara Tullio

Tutors: *Krzysztof Szczepaniec, Giuseppe Di Carlo*

***Gran Sasso Hands-on 2025**, 18/09/2025*

Dark Matter annual modulation



Period: 1 year
Maximum: 2nd of June

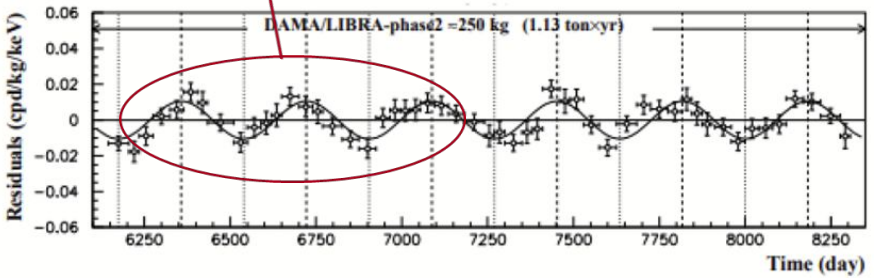
Event rate

$$R(t) = S_0 + S_m \cos \frac{2\pi}{T}(t - t_0)$$

Theoretical considerations:

- Dark Matter halo (isotropic distribution)
- Orbital velocity of the Sun with respect to the galactic center
- Revolution motion of the Earth around the Sun

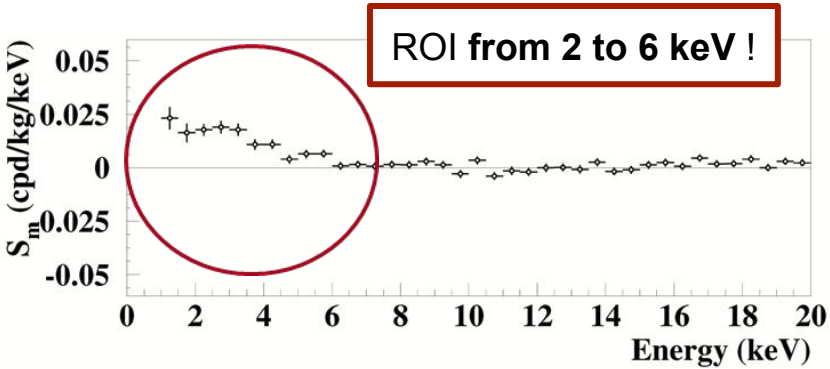
DAMA/LIBRA



R. Bernabei et al. "First Model Independent Results from DAMA/LIBRA–Phase2"

SABRE

Goal: independent replication of the DAMA/LIBRA signal !!



R. Bernabei et al. "First Model Independent Results from DAMA/LIBRA–Phase2"

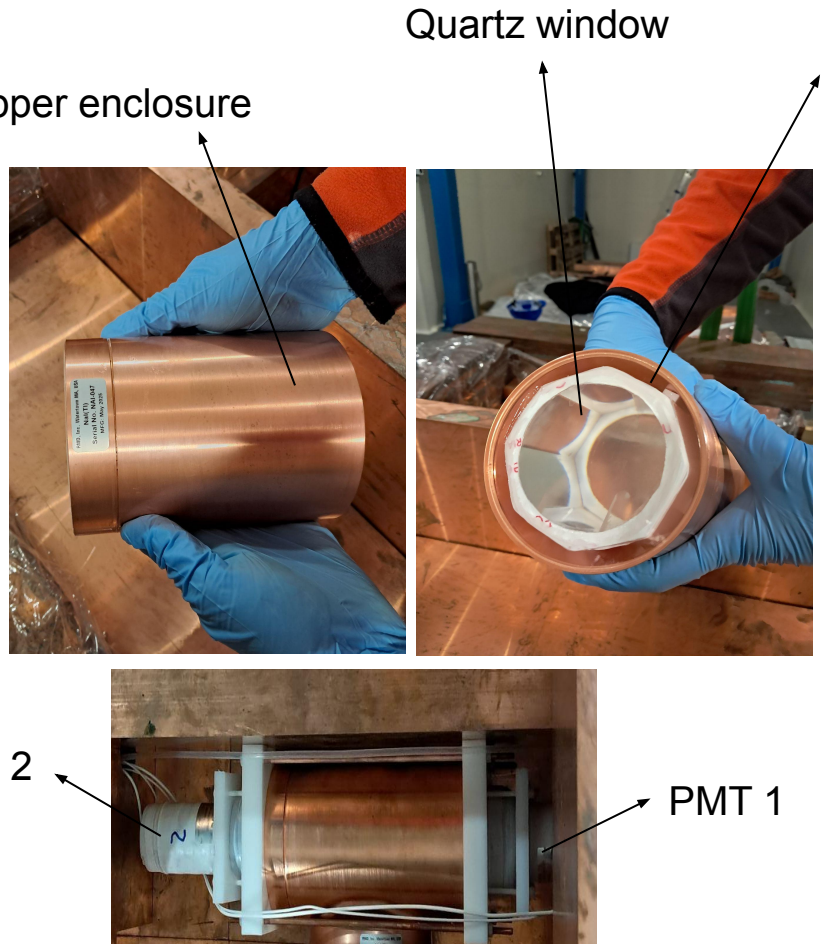
Need for **new experiments:**

- Higher sensitivity
- Low energy threshold (1 keV limit)
- Reduction of background events

The **SABRE** experiment:

- **NaI(Tl) crystals:** same target material
  - Difficulties in producing ultra-pure crystals: 10 years of SABRE crystals research
- **Photomultiplier Tubes** (PMTs) for scintillation light readout
  - Low-background PMTs coupled with NaI(Tl) crystals

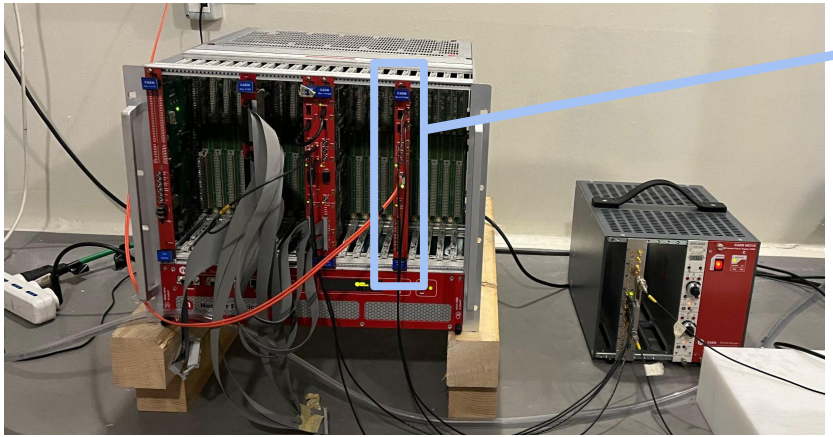
SABRE

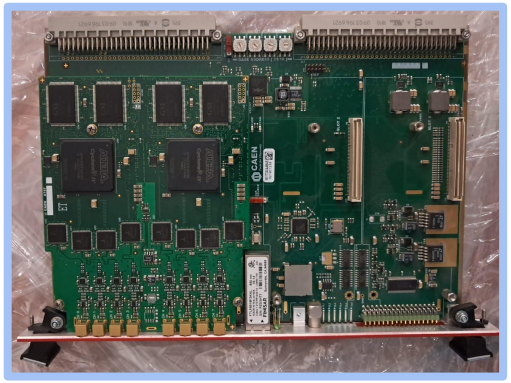


The **SABRE** experiment

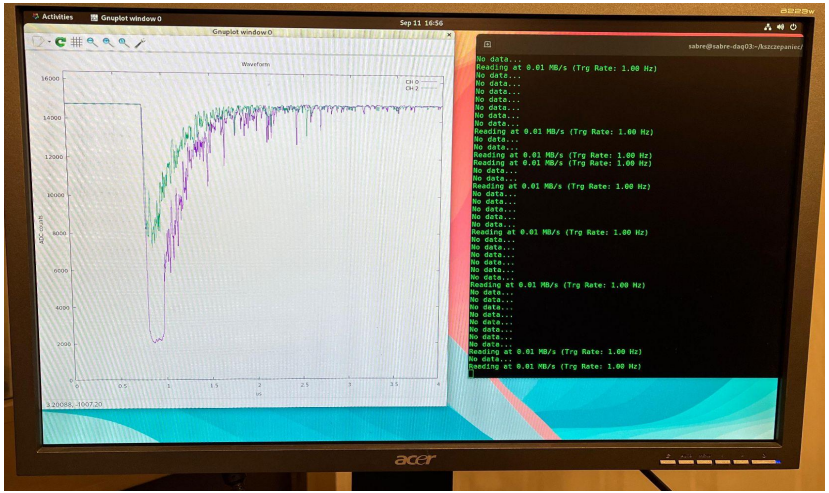
- **NaI(Tl) crystals:** same target material
  - Difficulties in producing ultra-pure crystals: 10 years of SABRE crystals research
- **Photomultiplier Tubes** (PMTs) for scintillation light readout
  - Low-background PMTs coupled with NaI(Tl) crystals

DAQ setup





CAEN 16 channel 14 bit 500 MS/s digitizer.



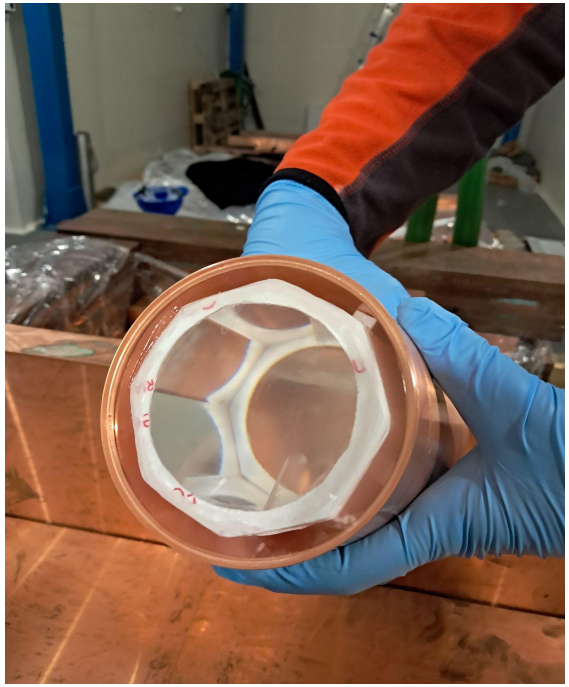
- PMTs are powered through the HV power supply
- When triggered i.e., **coincidence method**, signals from the PMTs are amplified, digitized, and finally acquired, stored and ready to be analyzed

WaveDump software provided by CAEN to input the acquisition parameters.

Hands-On Activity: our motivation

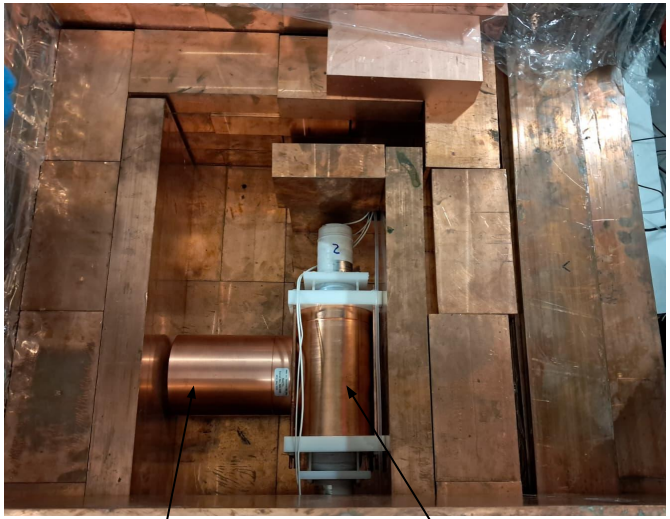
- The Collaboration noticed **^{40}K peaks** when measuring the radiopurity of an enclosed crystal with a Germanium detector
- The powder used to grow the NaI(Tl) crystal was characterized and **no ^{40}K contamination** was found
- The only other material that could have been contaminated was **one/both of the windows ….**

but which one?



Test setup

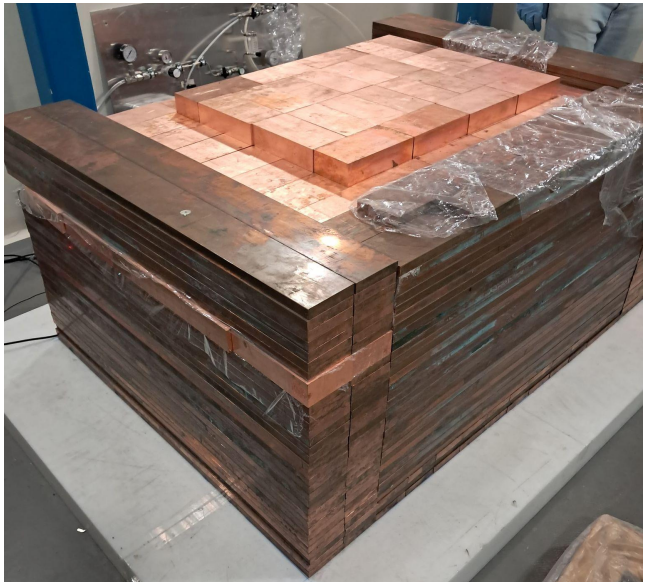
We used a different NaI(Tl) crystal as a **spectrometer** to detect the potential ^{40}K contamination in the windows



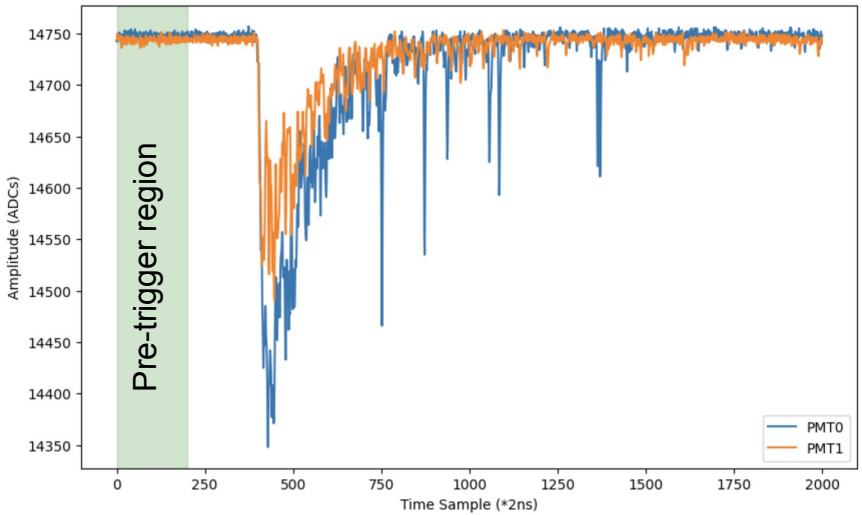
Spectrometer

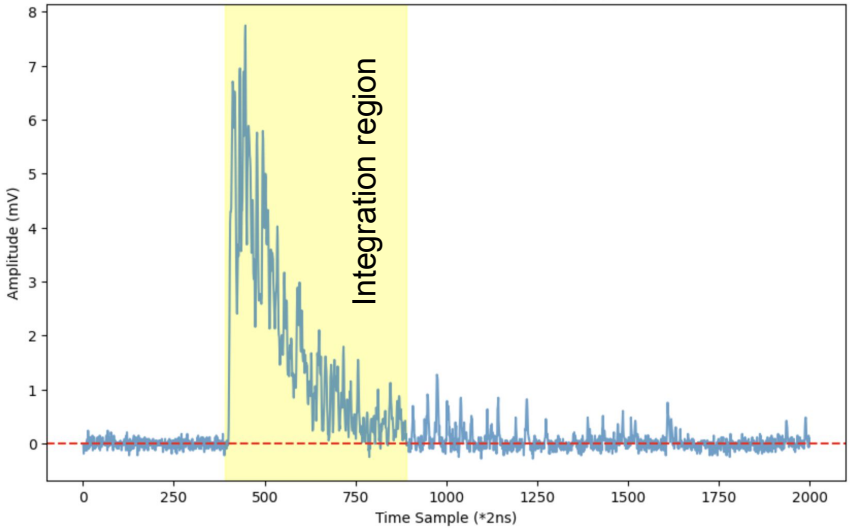
Crystal under test: **two runs** (one for each window)

Copper shielding all around the crystals

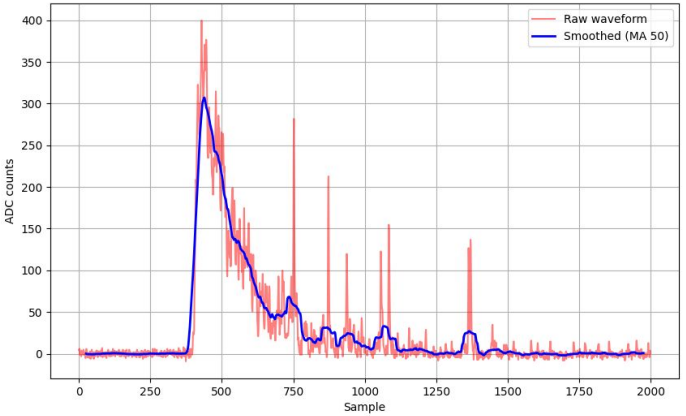


First analysis from raw data



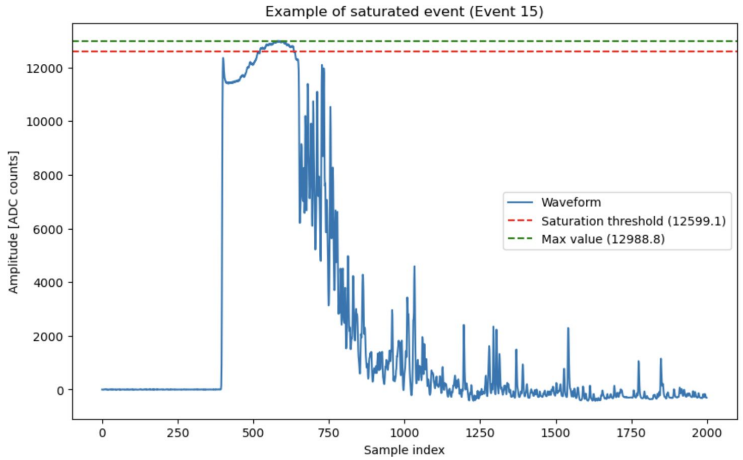


- Baseline calculation and subtraction
- Signal inversion
- ADCs to mV conversion
- Attempt to de-noise waveforms
- Charge integration → **Energy spectrum**

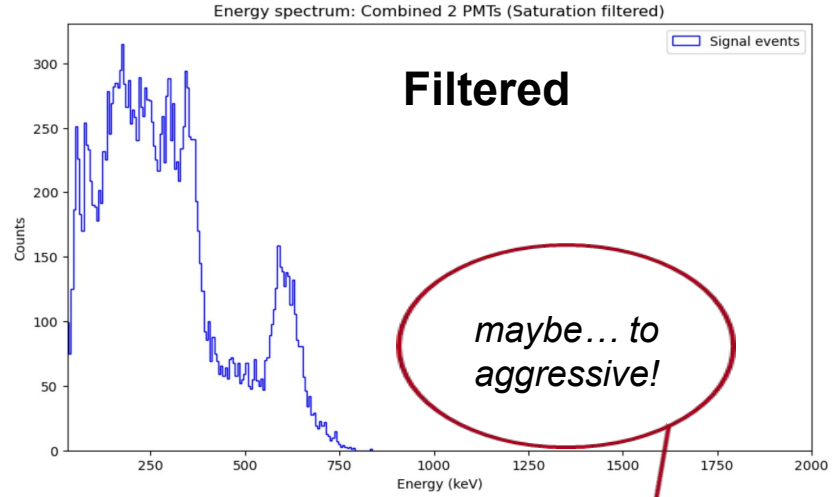


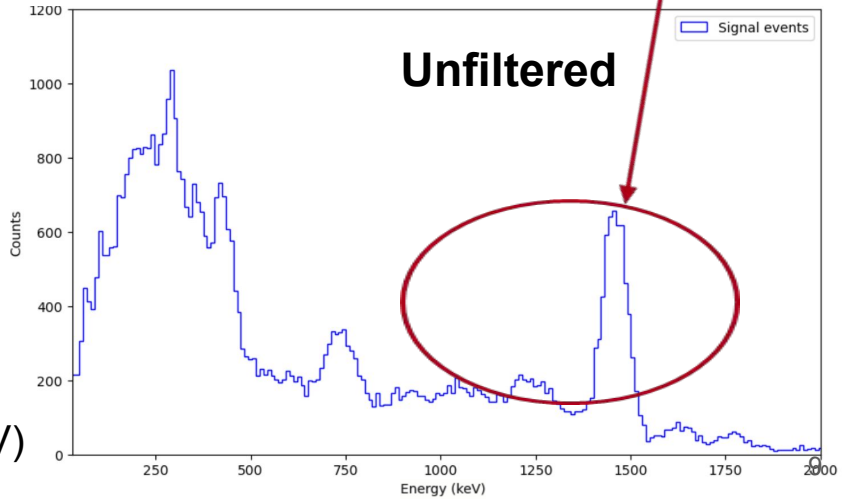
Saturated waveforms

- Amplified signals **saturate**



- Firstly we attempt to **filter** this kind of events





"Quick calibration" of the energy scale from ADCs to keV has been done looking at the ^{214}Bi peak (609 keV)

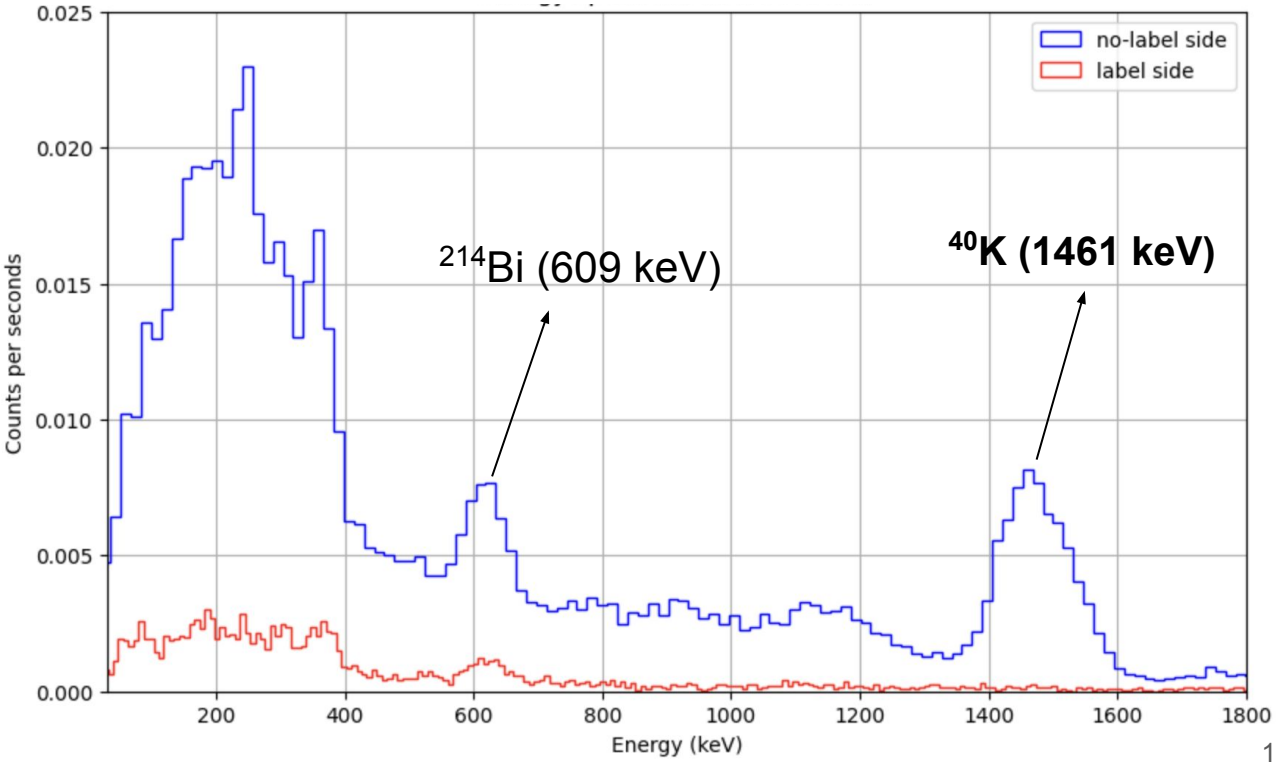
Energy spectrum (from PMT1 + PMT2)

For **high energies**, we can use directly **unamplified signals** from PMTs

Advantage:
no saturated waveforms

It is clear now which window is contaminated by ^{40}K!

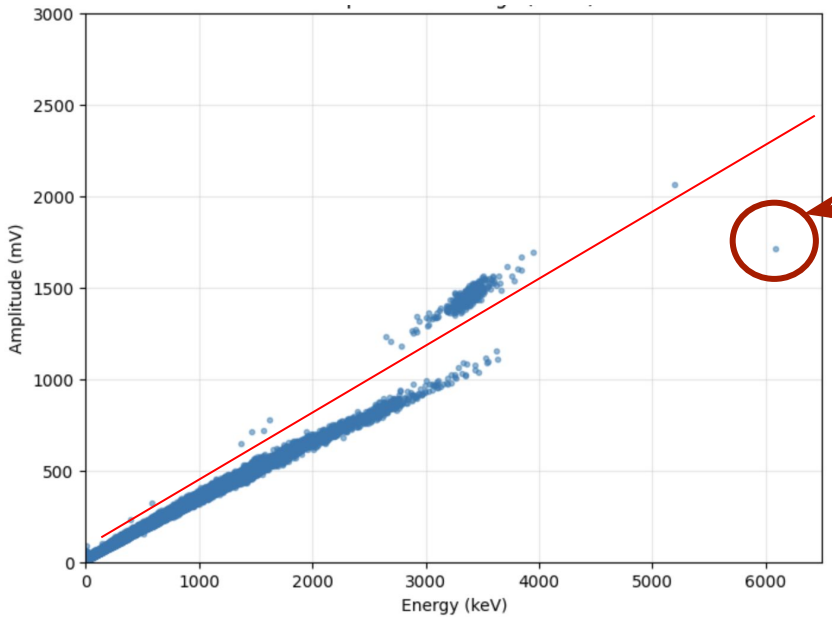
Comparison between the two runs

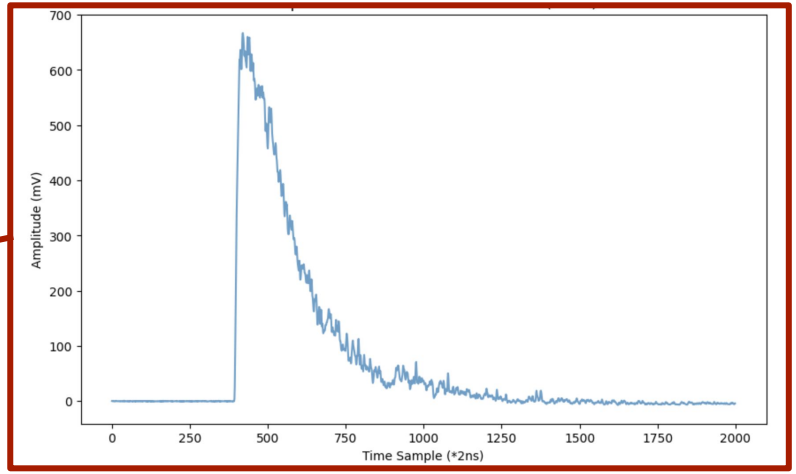


Particle identification

Two distinct bands:

- The lower slope corresponds to gamma/beta, calibrated on the gamma energy scale
- The higher slope band corresponds to alpha particle (quenching and different light yield in NaI(Tl))





- **Circled event** is likely a muon (no saturation or pile-up)

Conclusions from data

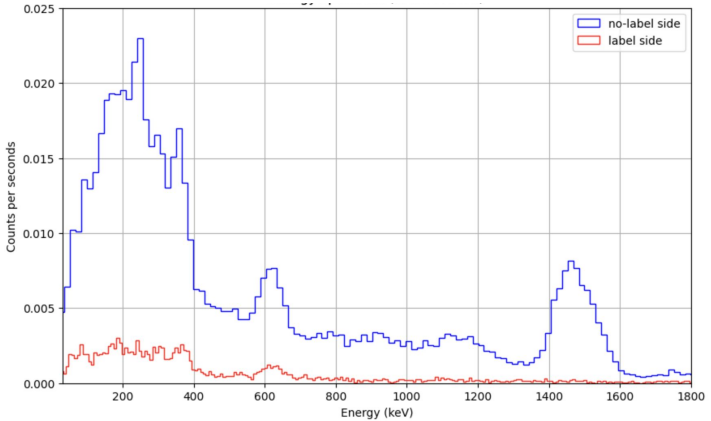
- The window in the **no-label side** was the one **contaminated** with ^{40}K

- Activity estimation:
  - Activity obtained from the 1461 keV peak which has a branching ratio of about 10%: 56.3 mBq
  - Considering the branching ratio
  - Also, taking into account the geometrical efficiency correction
  - Finally, with the detector efficiency inclusion,

Total activity: 12 Bq with some uncertainty (rough estimate)

Factors of **uncertainty**:

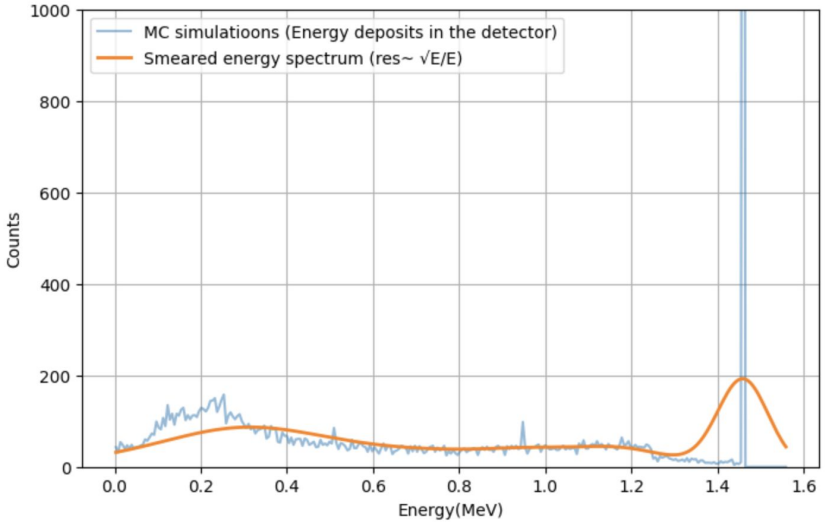
- Detector geometry consideration
- Energy resolution of the measurement
- Energy threshold of detection



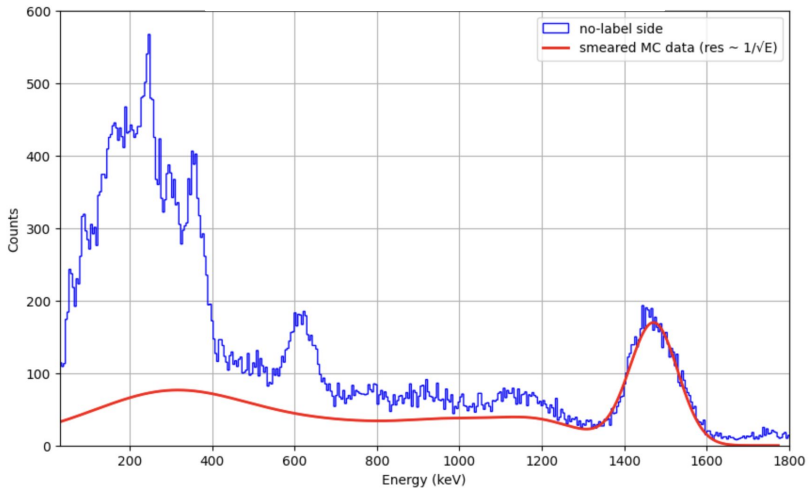
Comparison between MC simulations and our data

- **MC simulations** of our setup were provided by the SABRE team

Gaussian **smear** of the spectrum



Scaling and **comparison** with data

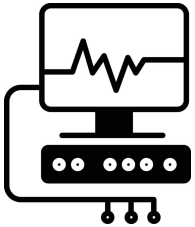


- The comparison allows a **more accurate estimation** of the ^{40}K activity (geometrical efficiency, detection efficiency …)

Finally… What did we learn?

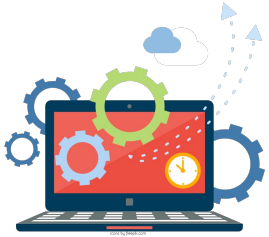
Hardware

- Managed cables and connectors (HV signals, clocks, digitizers, …)
- Understood the role of **each hardware component**



DAQ (Data Acquisition)

- Configured DAQ systems with *WaveDump* (widely used in the field)
- Learned to access and control CAEN registers and modules
- Understood the full **DAQ workflow** step by step

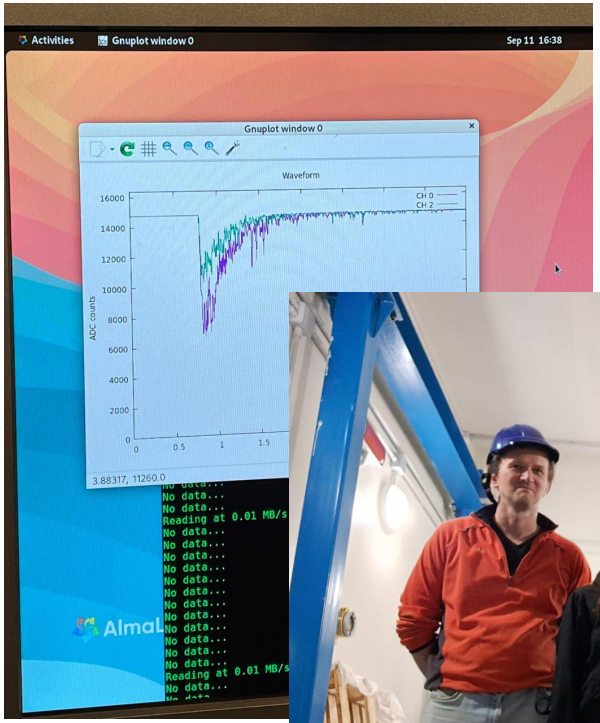


Analysis

- Processed waveforms into **spectra**
- Applied **analysis cuts**, denoising, and filtering
- Performed activity extrapolation and interpretation of **results**
- Smearing of theoretical spectra to match the measurements

GRAN SASSO hands-on 2025
PhD school on experimental astroparticle physics
September 8th - 18th, 2025

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso



Thank you for the attention!

Special thanks to our tutors – for surviving our endless questions