



Hunting ^{40}K using NaI(Tl) crystals for the SABRE Collaboration

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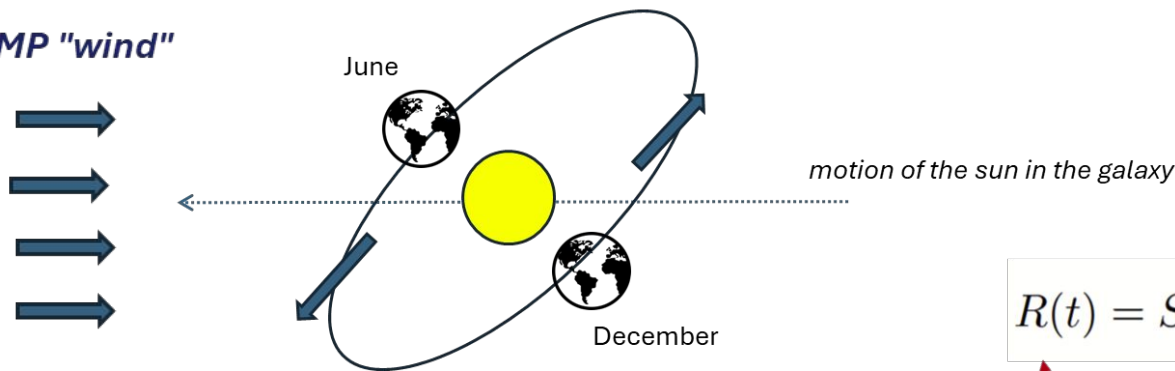
Tutors: Krzysztof Szczepaniec, Giuseppe Di Carlo

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



Dark Matter annual modulation

WIMP "wind"



Period: 1 year
Maximum: 2nd of June

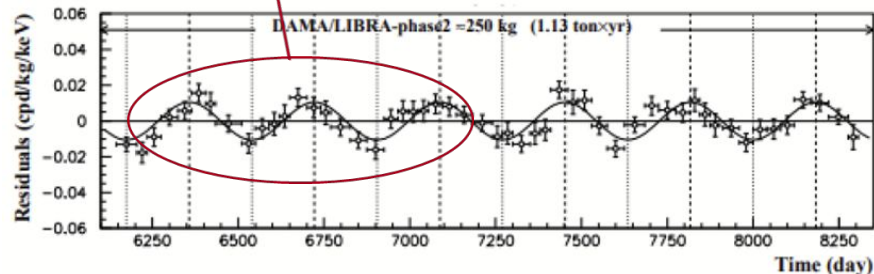
Theoretical considerations:

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

Event rate

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

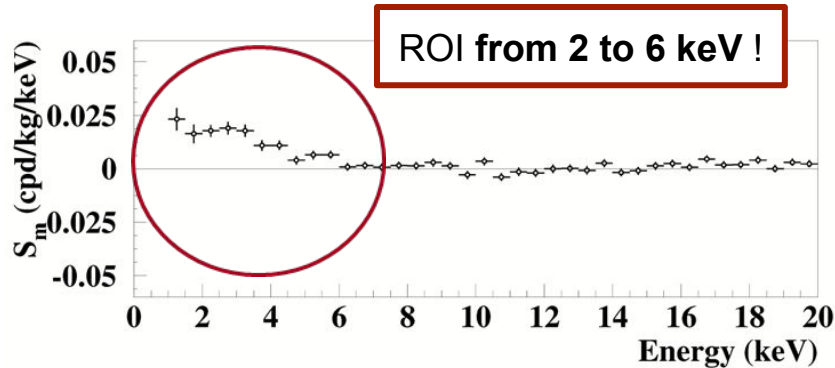
DAMA/LIBRA



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



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:

- **Nal(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 Nal(Tl) crystals

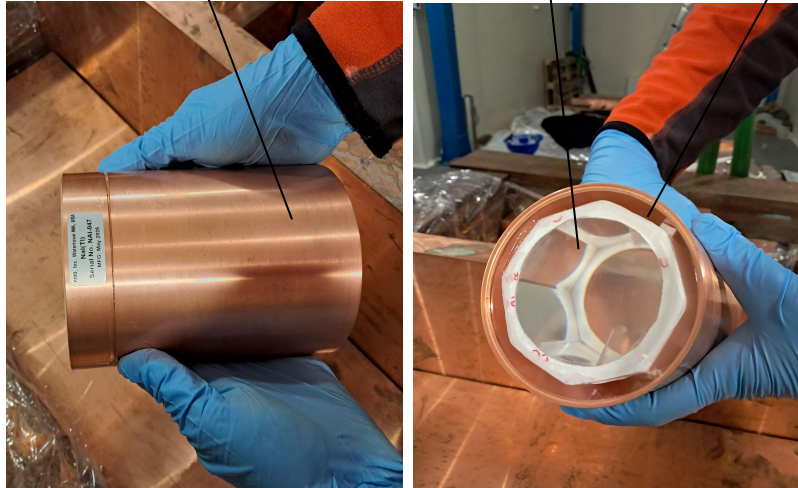
SABRE



Copper enclosure

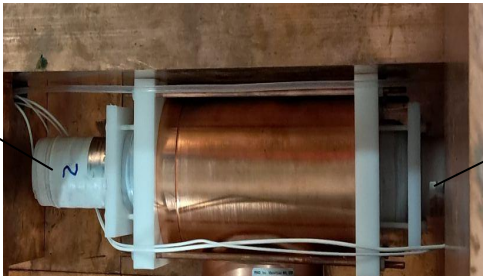
Quartz window

Teflon reflector



PMT 2

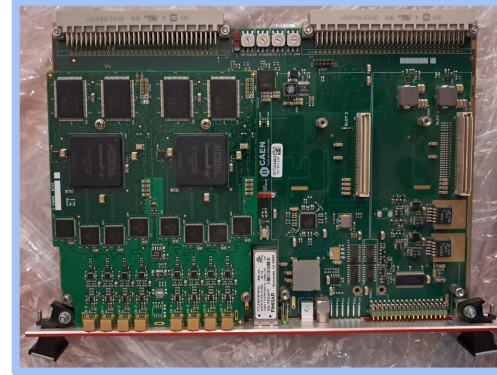
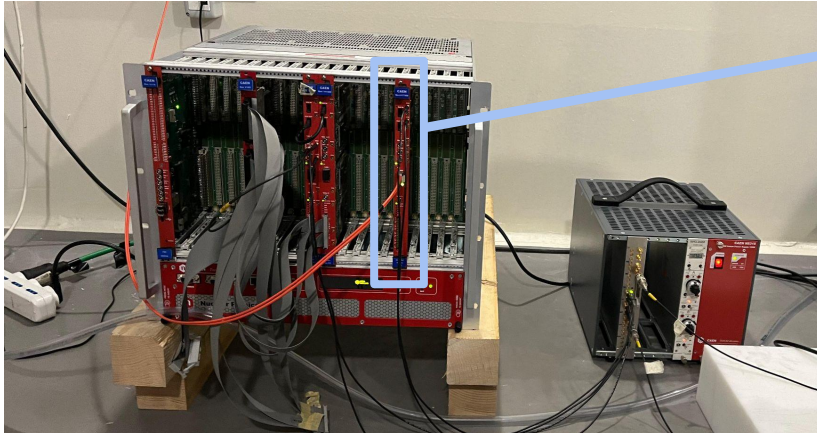
PMT 1



The **SABRE** experiment

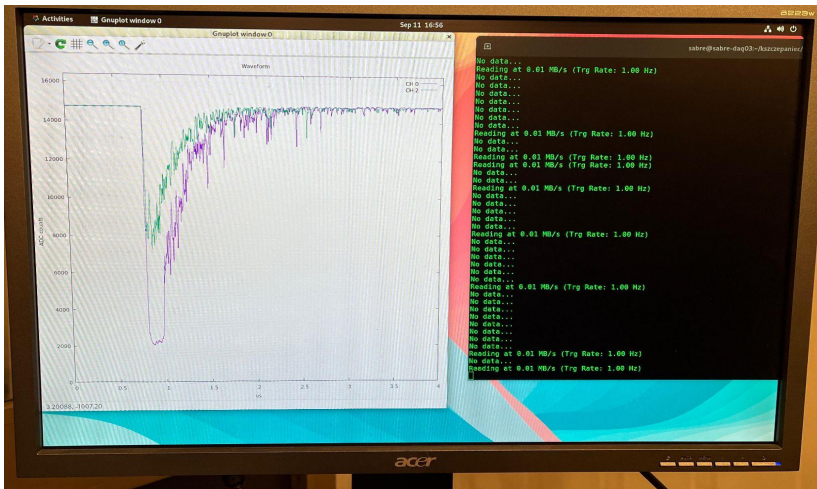
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DAQ setup



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



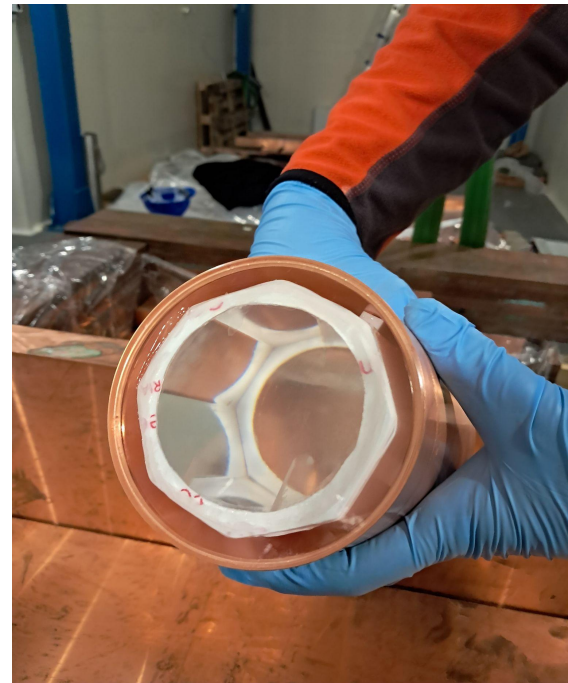
WaveDump software provided by CAEN to input the acquisition parameters.

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 $\text{NaI}(\text{TI})$ 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**

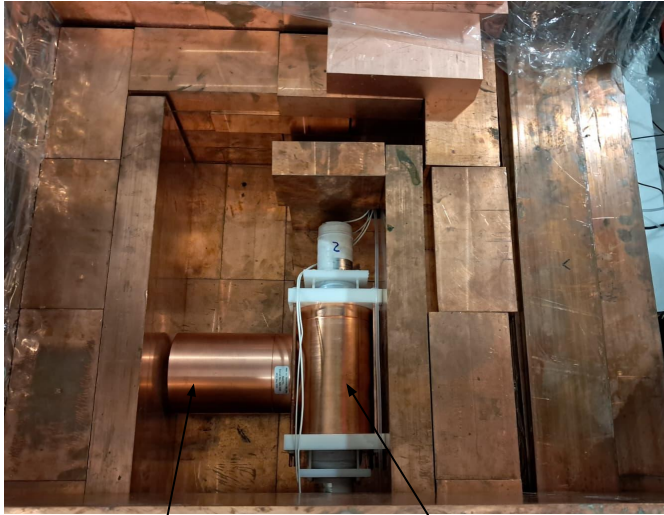


but which one?



Test setup

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



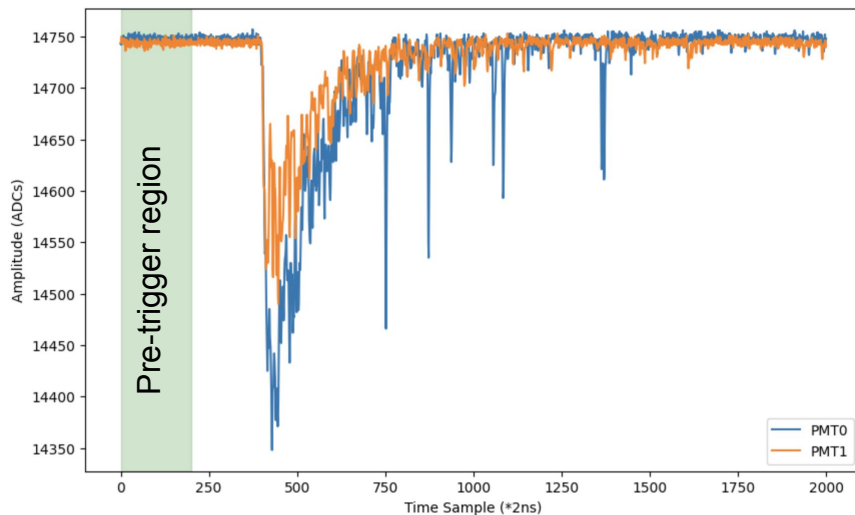
Spectrometer

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

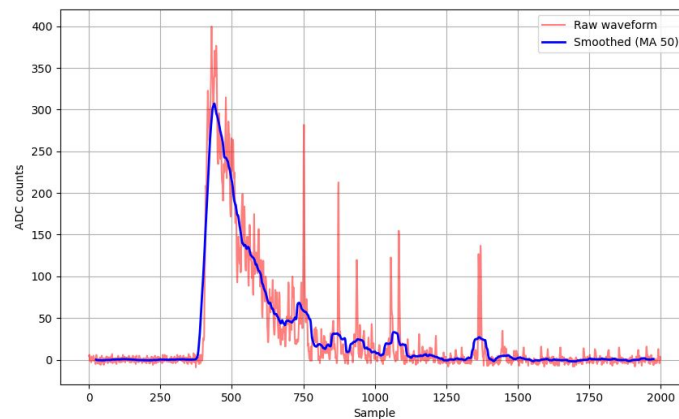
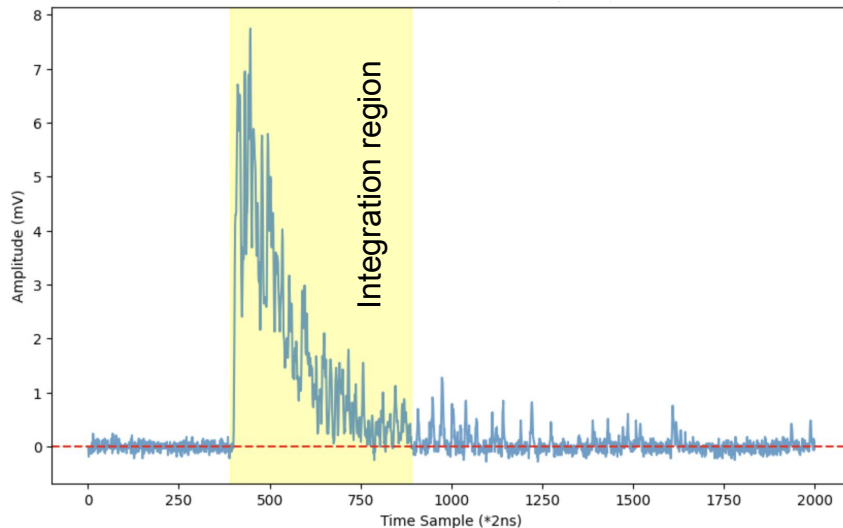
Copper shielding all around the crystals



First analysis from raw data

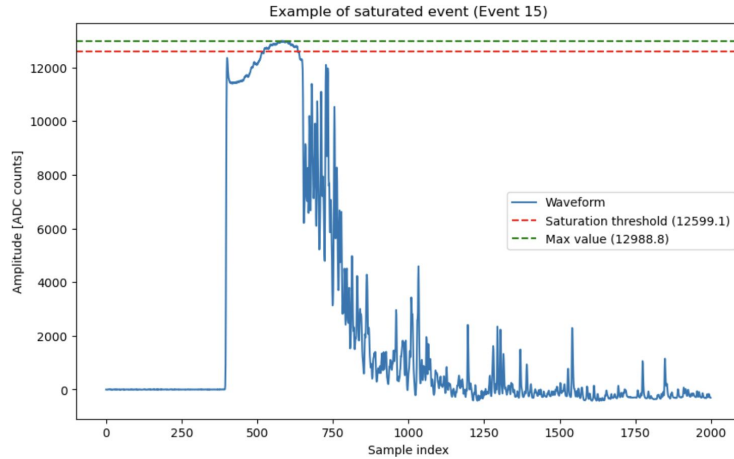


- Baseline calculation and subtraction
- Signal inversion
- ADCs to mV conversion
- Attempt to de-noise waveforms
- Charge integration → **Energy spectrum**



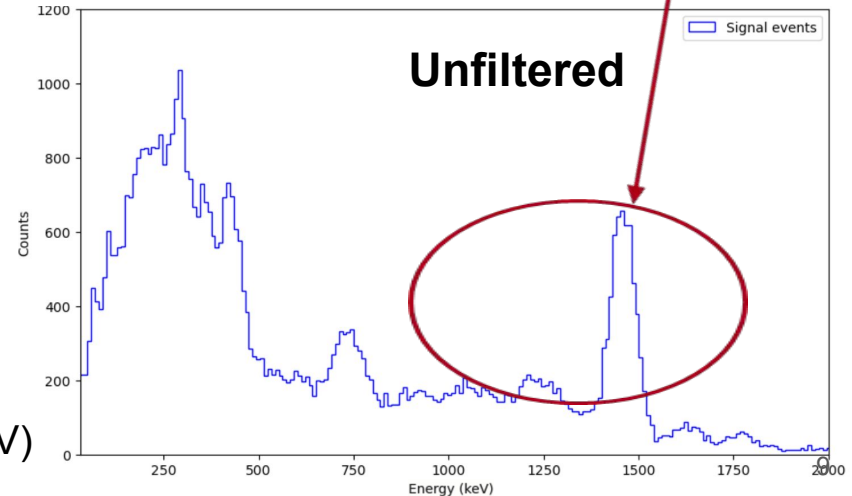
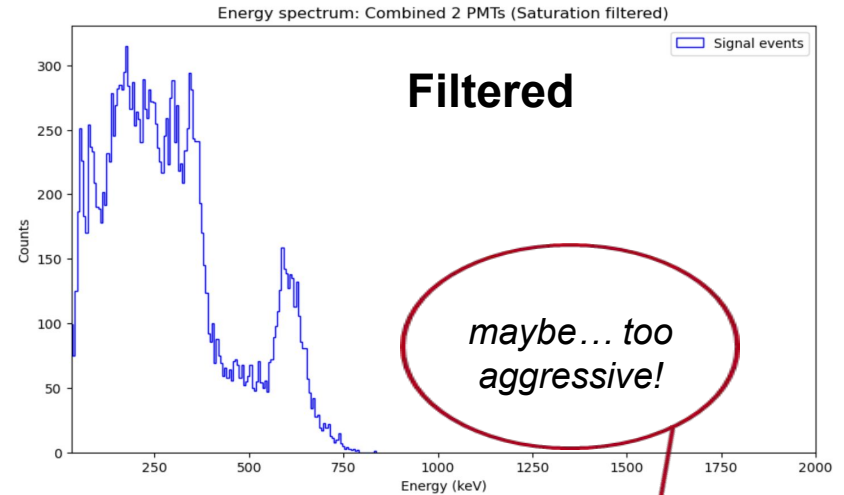
Saturated waveforms

- 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)



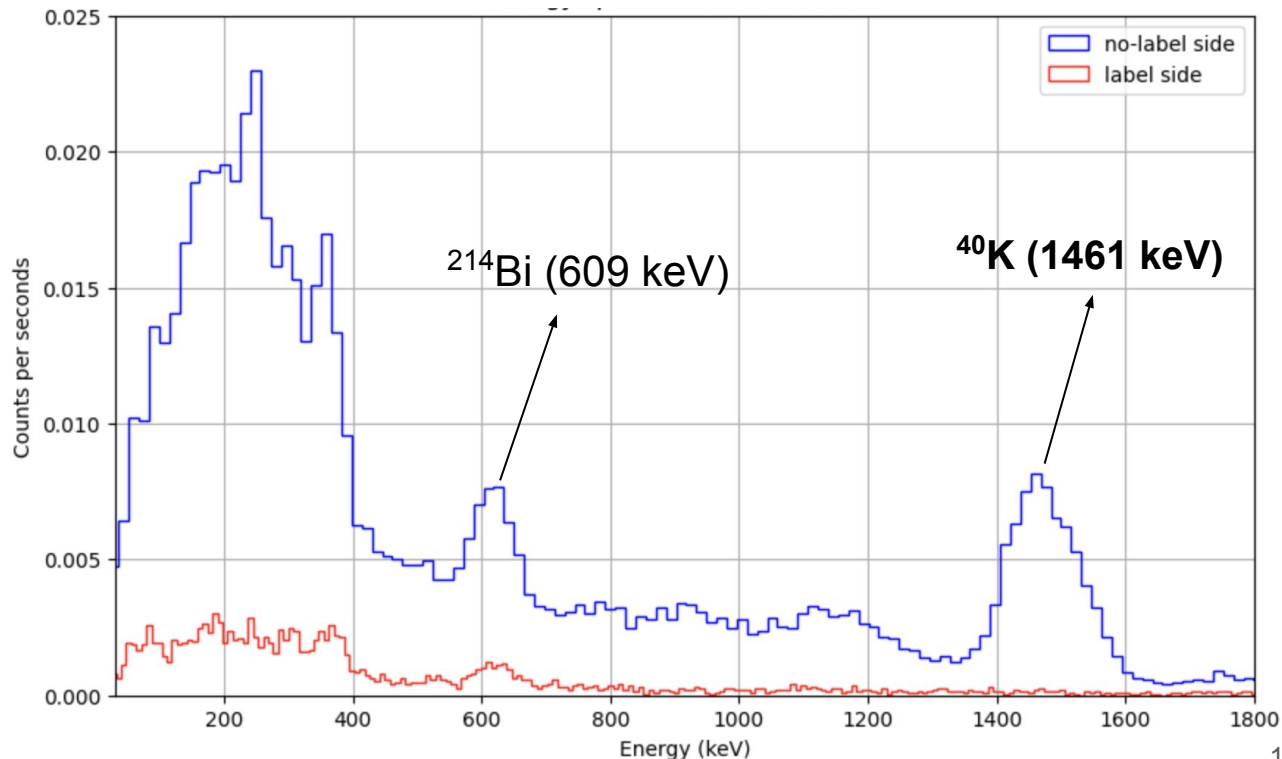
Energy spectrum (from PMT1 + PMT2)

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 !

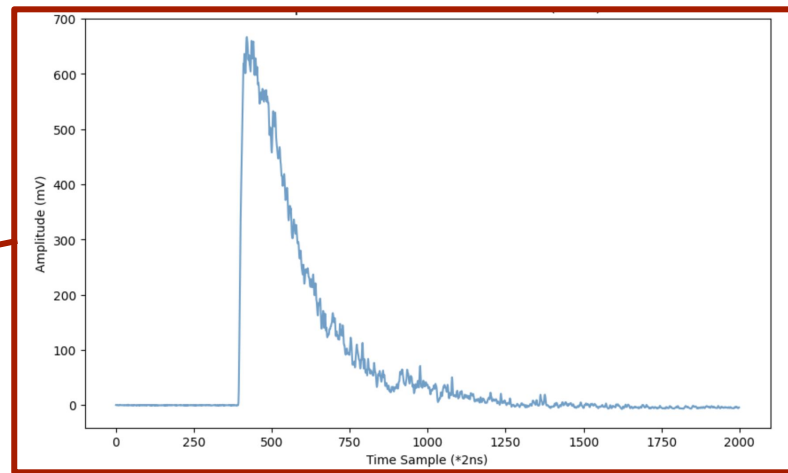
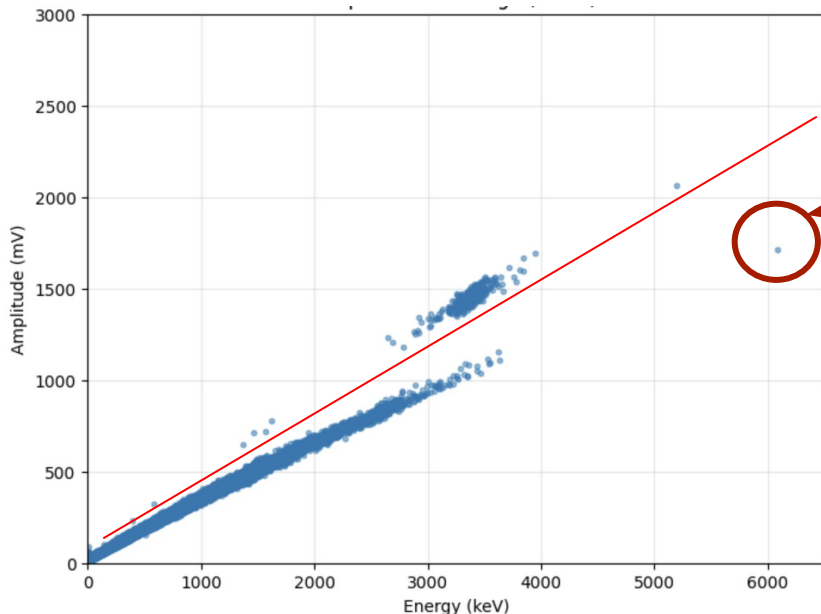
Comparison between the two runs



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)

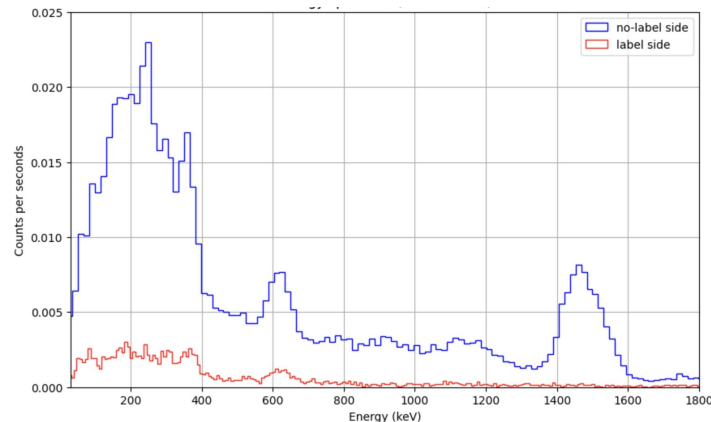
Conclusions from data

- 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**:

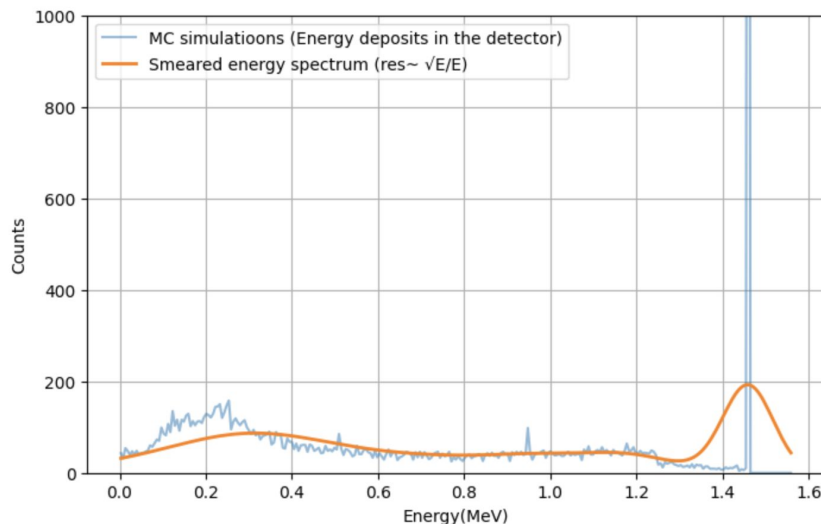
- Detector geometry consideration
- Energy resolution of the measurement
- Energy threshold of detection



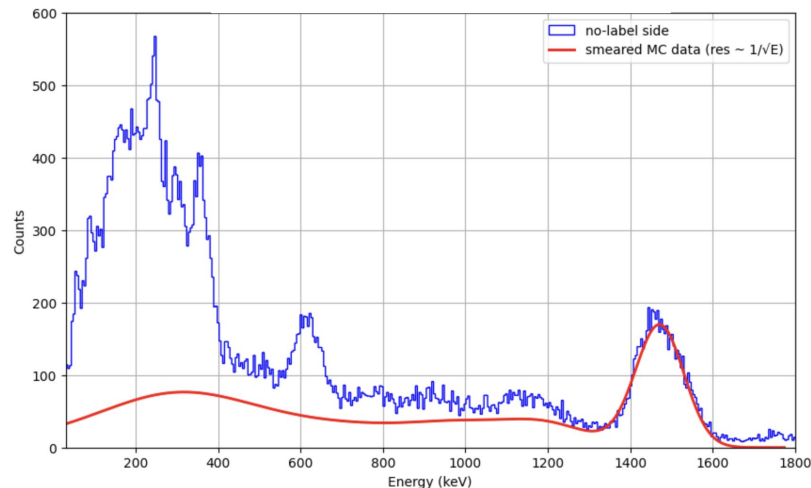
Comparison between MC simulations and our data

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

Gaussian **smear** of the spectrum



Scaling and **comparison** with data



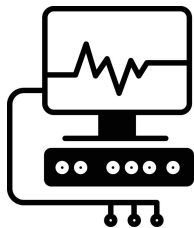
- The comparison allows a **more accurate estimation** of the ^{40}K activity (geometrical efficiency, detection efficiency ...)

Finally... What did we learn?



Hardware

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



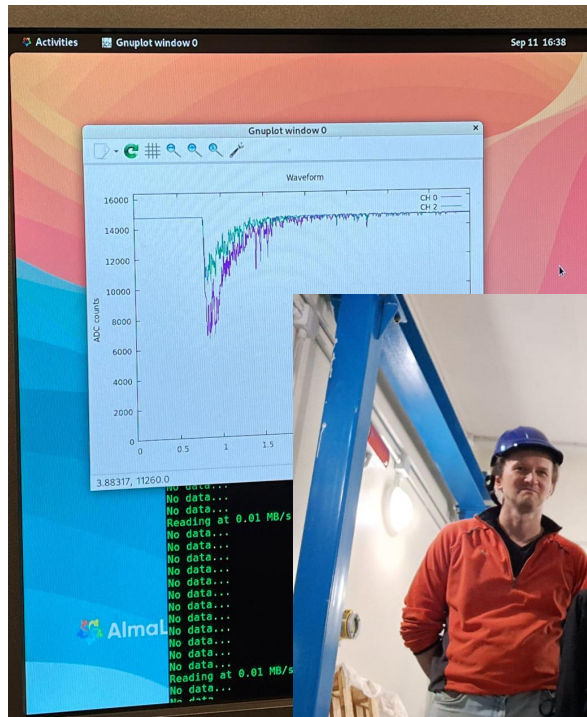
DAQ (Data Acquisition)

- 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



*Thank you for the
attention!*

*Special thanks to our tutors –
for surviving our endless
questions*

