HPGe detector(s) for the measurements of X-rays from kaonic transitions in solid targets at DAPHNEat DAPHNE

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and SIDDHARTA-2 collaboration

- Preparation of the measurement of the charged kaon mass with HPGe detector at DAPHNE
- Properties of the existing HPGe detectors

Croatian Science
Foundation Project 8570

Nuclear E2 resonance effects in kaonic molybdenum isotopes, online 08.04.2022.

Motivation

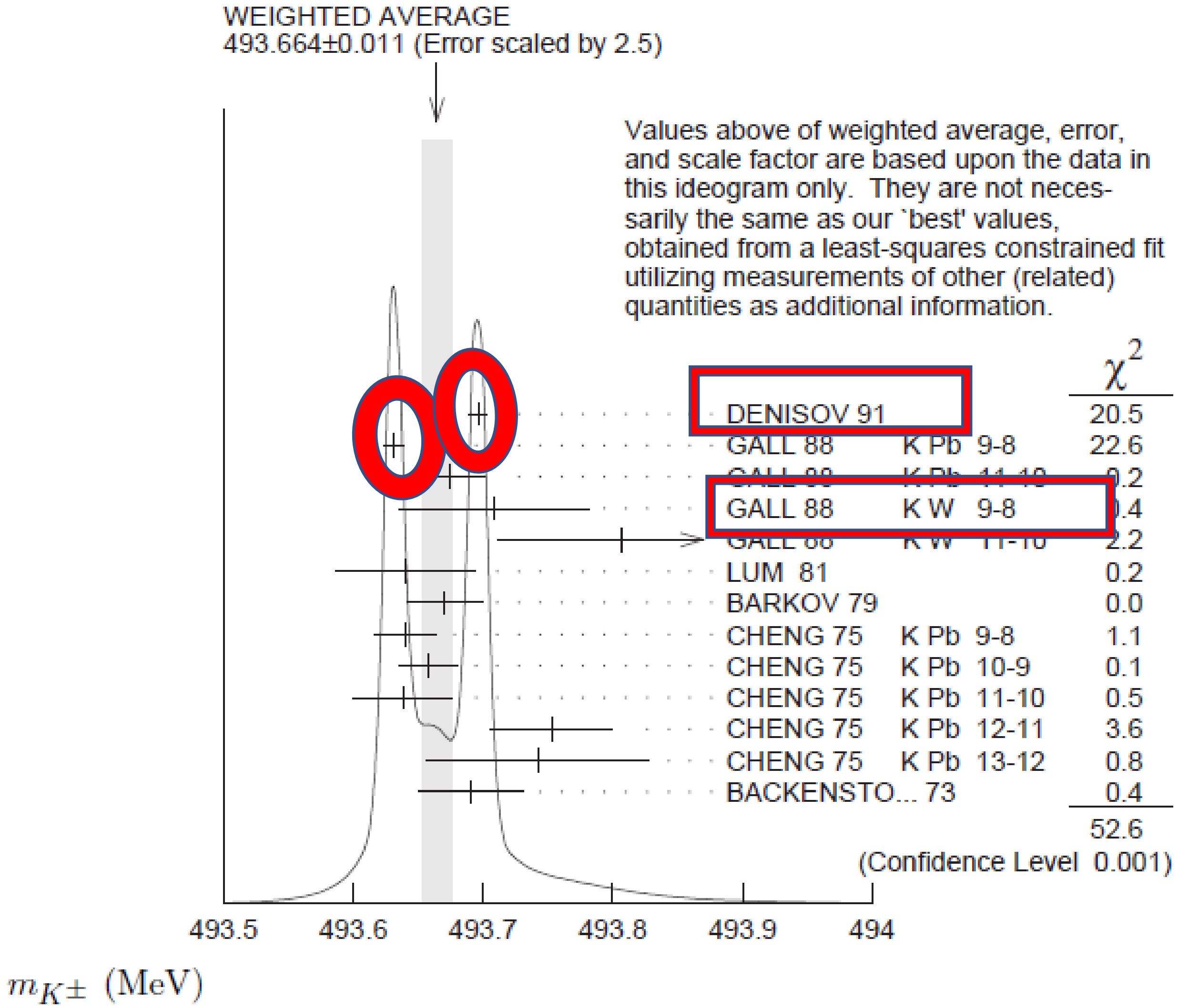
- The accuracy of the determination of the charged kaon mass *(m_K=493.677±0.013 MeV, 26 p.p.m.)* is much less than the accuracy of the charged pion mass *(m_π=139. 57061±0.00023 MeV, 1.6 p.p.m.)*, PDG2020.
- Serious disagreement between the two precise measurements

->Large scaling factor: S=2.4 *(m_K=493.677±0.005 MeV)*

- Kaon mass has large influence on the K^-N scattering lengths and through them on the kaon-nucleon sigma terms and eventually degree of chiral symmetry breaking.
- Kaonic atoms, charmed mesons, searches beyond standard model

Previous measurements, motivation

PDG 2020:



PDG2020

m_K=493.679 ± 0.013 MeV

The main disagreement is between the two most recent and precise measurements (x-ray energies from kaonic atoms):

m_K=493.696±0.007 MeV

A.S. Denisov et al. JEPT Lett. 54 (1991)558

K^- ^{12}C, crystal diffraction spectrometer

(6.3 eV at 22.1 keV), 4f-3d

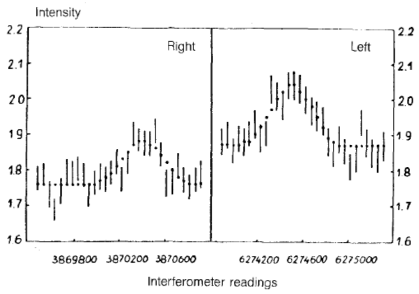


FIG. 1. Right and left reflections of the $4f$-$3d$ transition of the K^-–^{12}C atom. The interferometer readings are plotted along the abscissa; the detector count rate per 10^{12} protons is plotted along the ordinate. The vertical lines are the experimental values with the corresponding error; the heavy points are the results of a fit.

m_K=493.636±0.011 MeV

K.P. Gall et al. Phys. Rev. Lett. 60 (1988)186

K^- Pb, K^- W; HPGe detector (1 keV), **K^-Pb (9 -> 8),**

K^-Pb (11 -> 10), K^-W (9 -> 8), K^-W (11 -> 10),

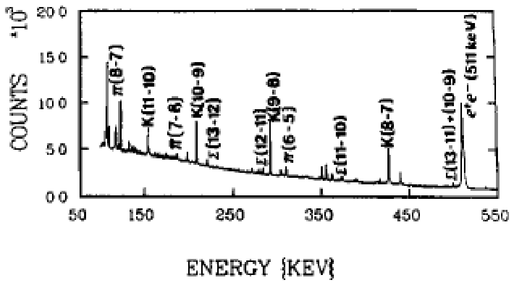


FIG. 1. Untagged Pb x-ray spectrum showing intense kaonic x-ray transitions.

Average m_K=493.679 ± 0.006 MeV S=2.4

Principles of measurements of kaon mass in kaonic atoms

- Measure X-ray energies in kaonic atoms for transitions not influenced by strong interactions.

- In order to determine the kaon mass, the experimental energies have to be compared with the calculated energies obtained with a certain K-mass value (corrections: vacuum polarization, electron screening, non-circular trasitions)

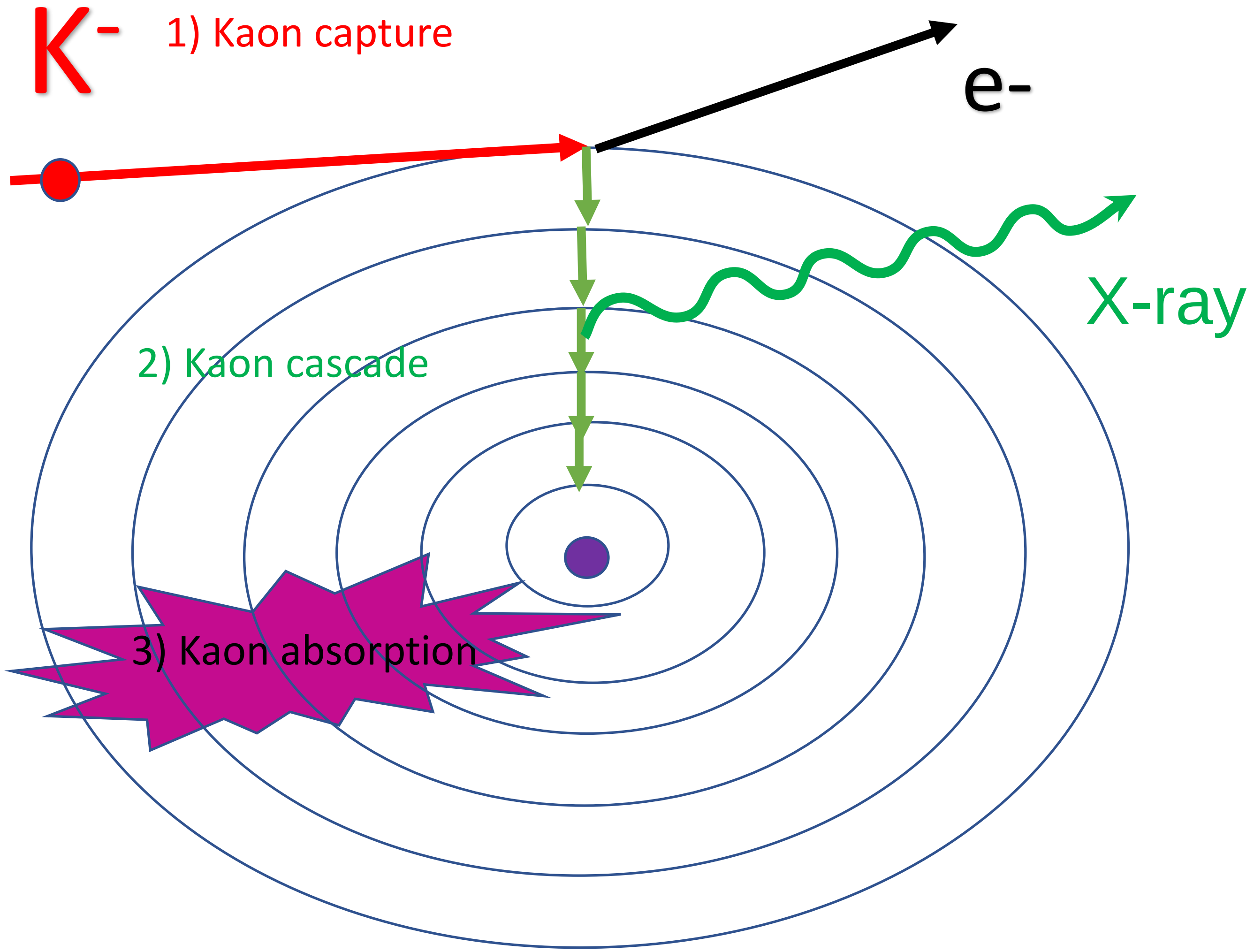
- Measurements with HPGe detectors and with crystal diffraction spectrometer, TES, …

Kaonic atom formation

Kaon cascade -> X-rays

Kaon absorption

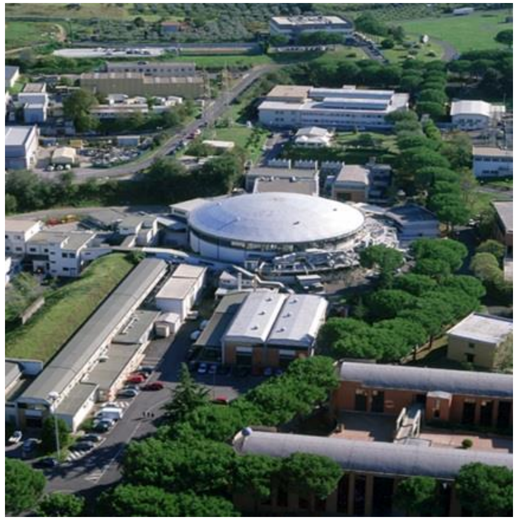
X-ray energies in kaonic atoms



Interesting X-rays from the the transitions in the middle of spectrum:

- No influence from strong interaction
- avoid electron screening of nuclei

$e^+e^- \rightarrow \phi \rightarrow K^+K^-$, $E_K \approx 16$ MeV

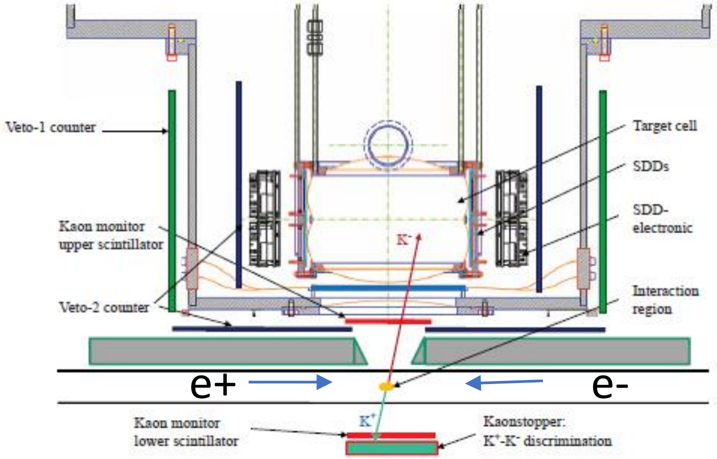


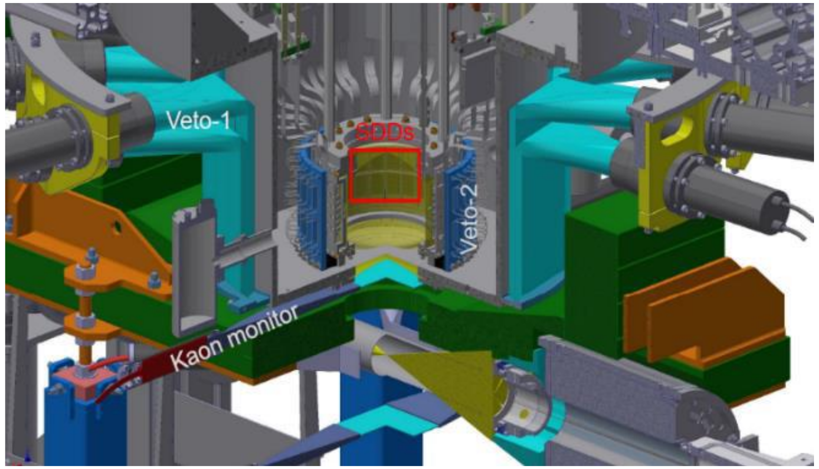
-> Our aim is to do measurements with HPGe detector(s) during SIDDHARTA-2 run at DAϕNE - using the available space at the SIDDHARTA-2 interaction region and with different solid targets.

SIDDHARTA-2 at DAϕNE

Silicon Drift Detector for Hadronic Atom Research by Timing Application

2021/2022 SIDDHARTA-2 run: X-ray transitions in gaseous targets: deuterium, helium, …





Advantage: DAϕNE is producing low momenta kaon pairs – no need for degrader. No secondary particles in the beam.

Disadvantage: High electromagnetic background from the beam close to the interaction point (unknown!).

Background originating from the kaons absorbed in nuclei.

Measurement at DAϕNE with HPGe during SIDDHARTA-2 run

Interaction point

Positions of the target and the HPGe detector is restricted by SIDDHARTA-2 setup

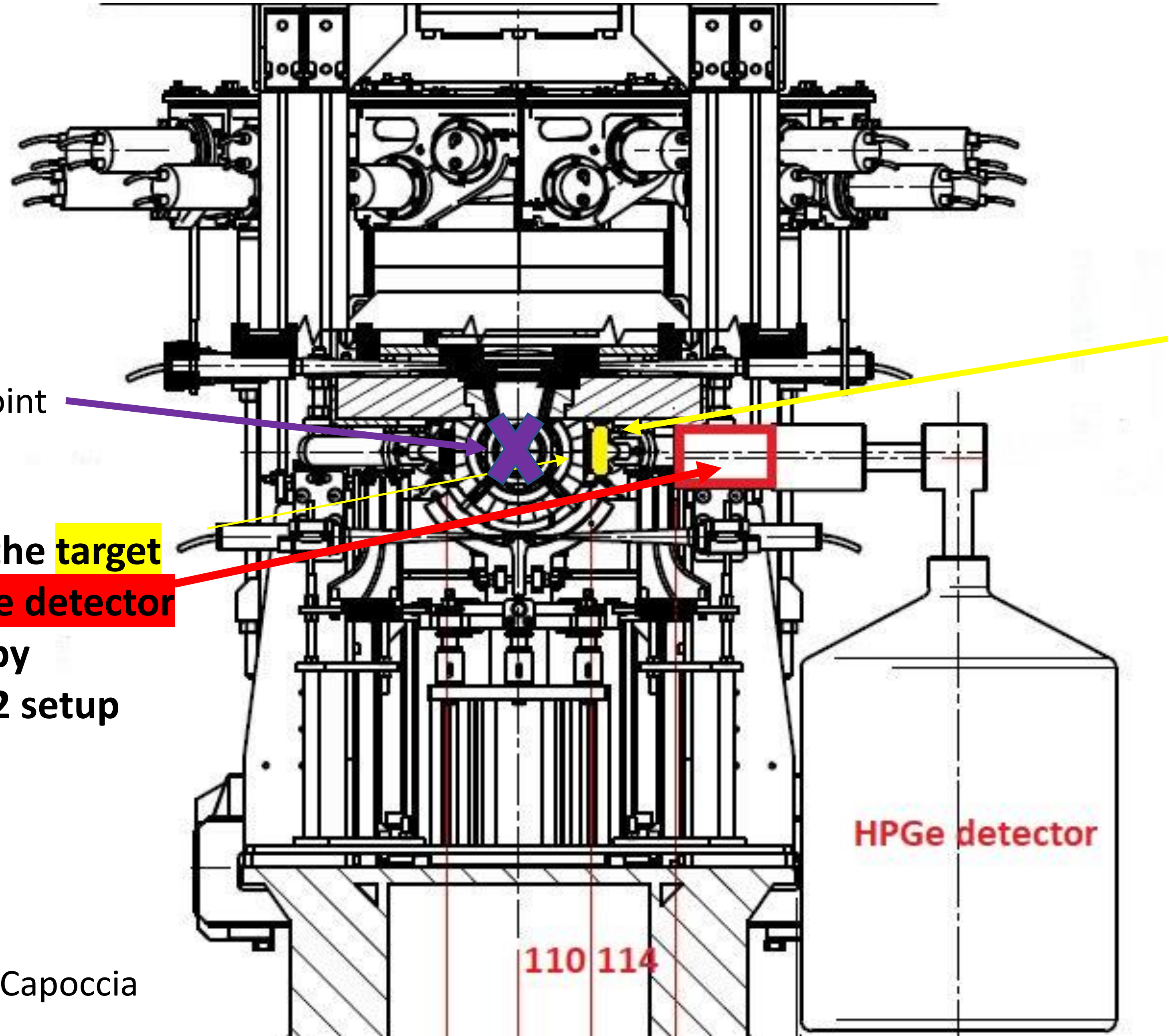


Figure: Cesidio Capoccia

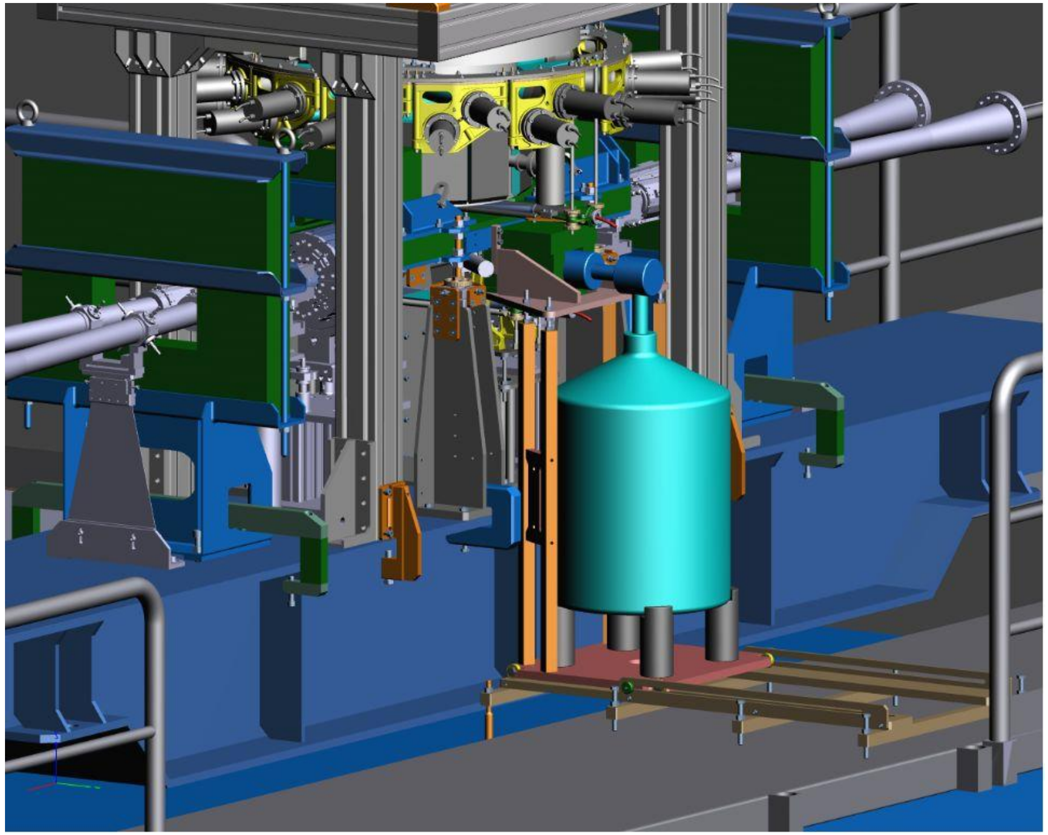
HPGe detector system is independent of SIDDHARTA-2

Signal from the luminometer ($80x40x2\ mm^3$) as a trigger for HPGe detector.

-> Hardware preparations

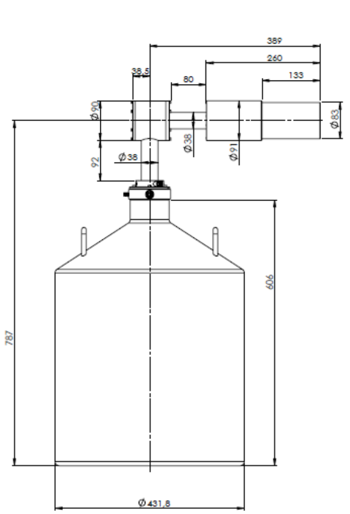
-> Simulations (GEANT4)

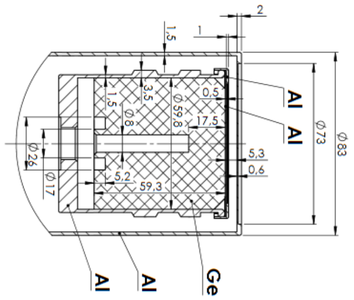
HPGe in DAPHNE – drawing, reality



Measurement at DAϕNE with HPGe during SIDDHARTA-2

BSI HPGe detector with
transistor reset preamplifier (TRP).





HPGe active detector diameter ~60 mm, height ~60 mm.

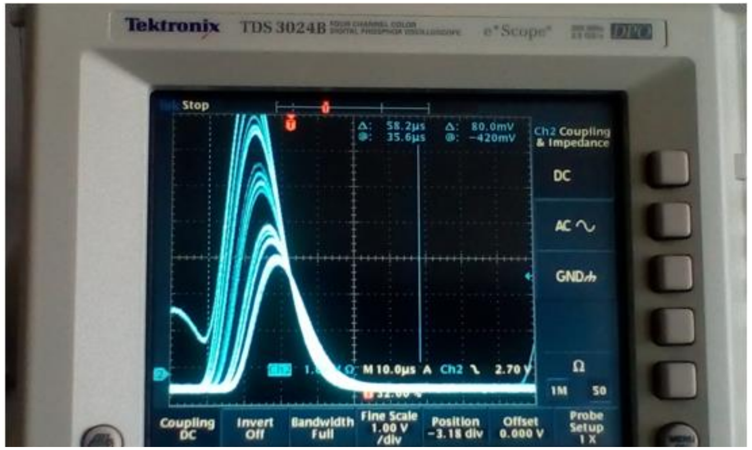
Data acquisition:
- analog electronics
- **fast pulse digitizer**

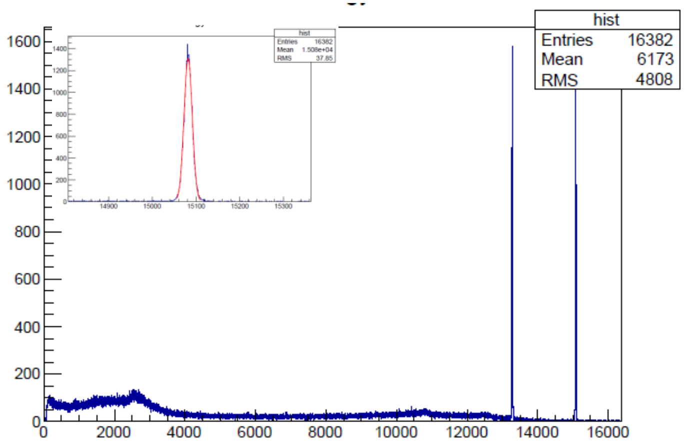
3.1. Detection unit GCD-30185 characteristics

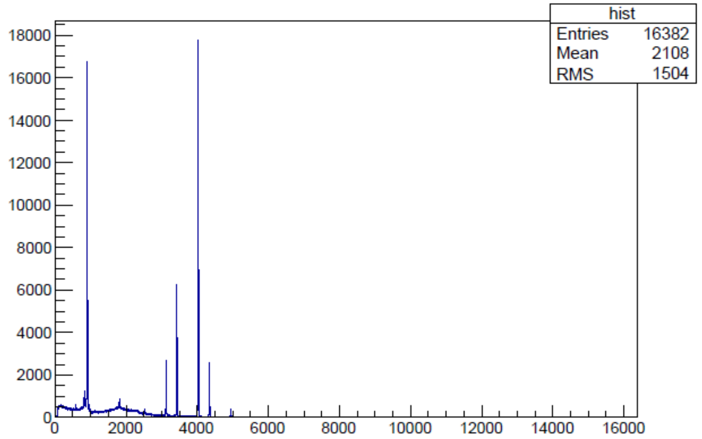
#	Parameter	Value
1.	Relative efficiency (with respect to 3'' x 3'' NaI detector and Co-60 source mounted 25 cm above the detector) at 1.33 MeV γ-photon	> 30 %
2.	Energy resolution* at • 122 keV • 477.6 keV • 1.33 MeV **Measured with spectrometric device MS Hybrid at input count rate 1000 pulses/sec, shaping time constant = 6 μsec*	875 eV 1400 eV 1850 ± 30 eV
3.	Peak shape: • FWTM/FWHM • FW.02M/FWHM	< 1.9 < 2.65
4.	Spectral Broadening of FWHM up to 100,000 counts/sec for 1.33 Mev	< 8 %
5.	Peak position shift	< +/- 0.018 %
6.	Peak to Compton ratio, not worse	58 : 1
7.	Energy range of detector operation	40 keV – 3 MeV
8.	Material of input window	Al
9.	Cooling time	< 8 hours
10.	Liquid nitrogen holding time in Dewar vessel	> 15 days
11.	Dewar volume	30 l
12.	Preamplifier (built – in detector capsule) with cooled FET and transistor reset preamplifier (TRP) • Preamplifier power supply is ±12 V with 9 pin connector compatible with NIM standards • TTL signal to shut down the HV: - detector warm -0V; - detector cold: +5V • HV INHIBIT – BNC	

Laboratory tests of HPGe (BSI - TRP preamp) & *analog electronics*

Signal from spectroscopy amplifier







Signal from preamp of HPGe with TRP

Pb lines

Stability tests

^{60}Co, ^{133}Ba spectra,

resolutions: 0.870 keV at 81 keV

→ 1.06 keV at 302.9 keV

1.11 keV at 356 keV

1.67 keV at 1330 keV

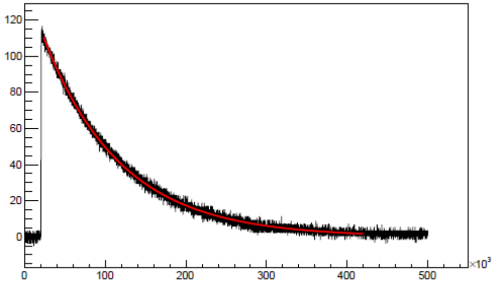
CAEN spectroscopy amplifier N968, Canberra Multiport II, Canberra Genius DAQ + analysis

Laboratory tests of HPGe (BSI - TRP preamp) & fast pulse digitizer, CAEN DT5781 4 ch, 14 bit,

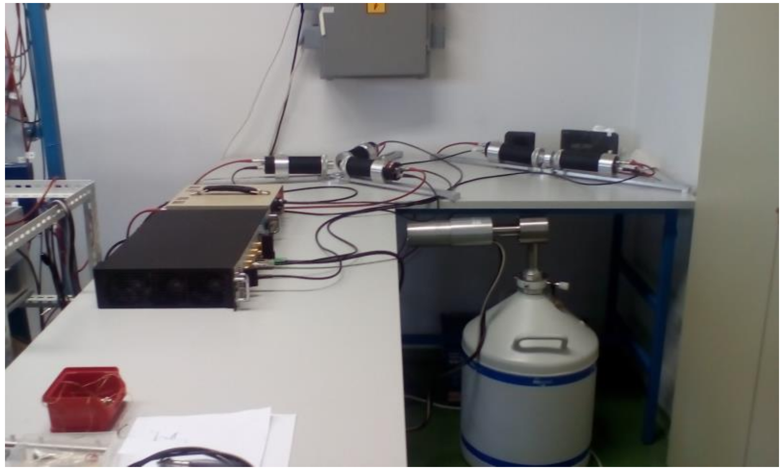
CAEN DT5781 4 ch, 14 bit, 10ns sampling time

Signal from spectroscopy amplifier ~20 μs (shaping time 6 μs), restriction on the rate.

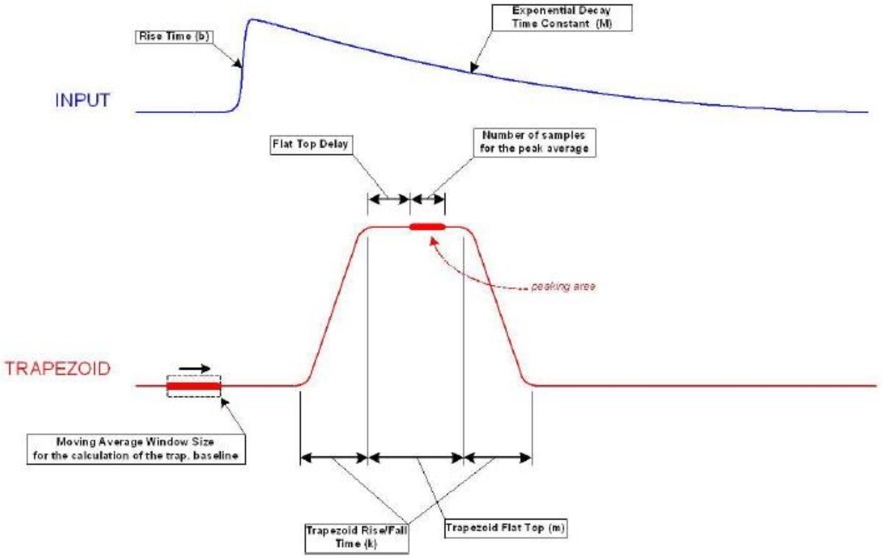
Signal from HPGe with RC preamp



Signal from preamp of HPGe with TRP



- **Digital Pulse Processing** for Pulse Height Analysis firmware , based on V.T. Jordanov et al. Nucl. Instr. Meth. A 353 (1994) 337

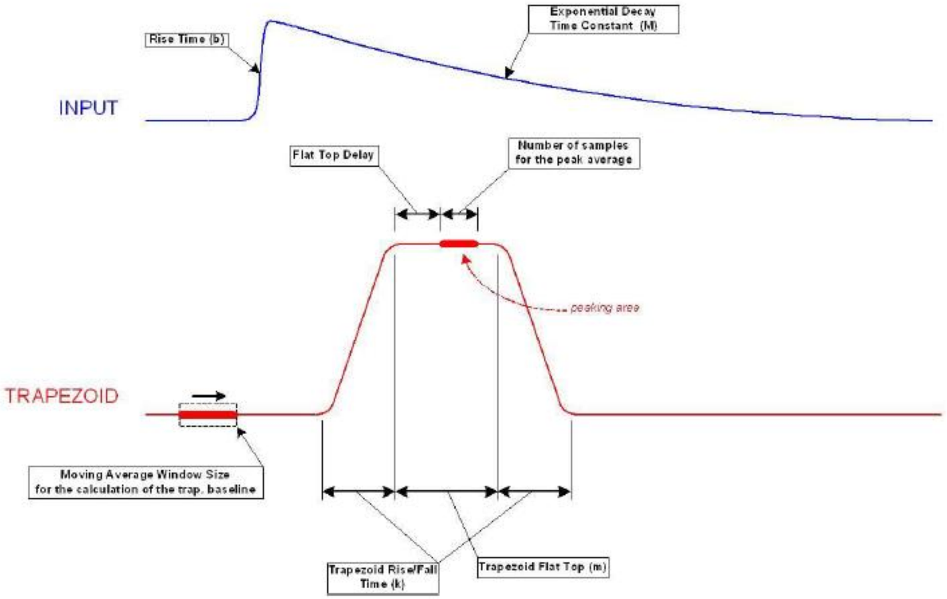


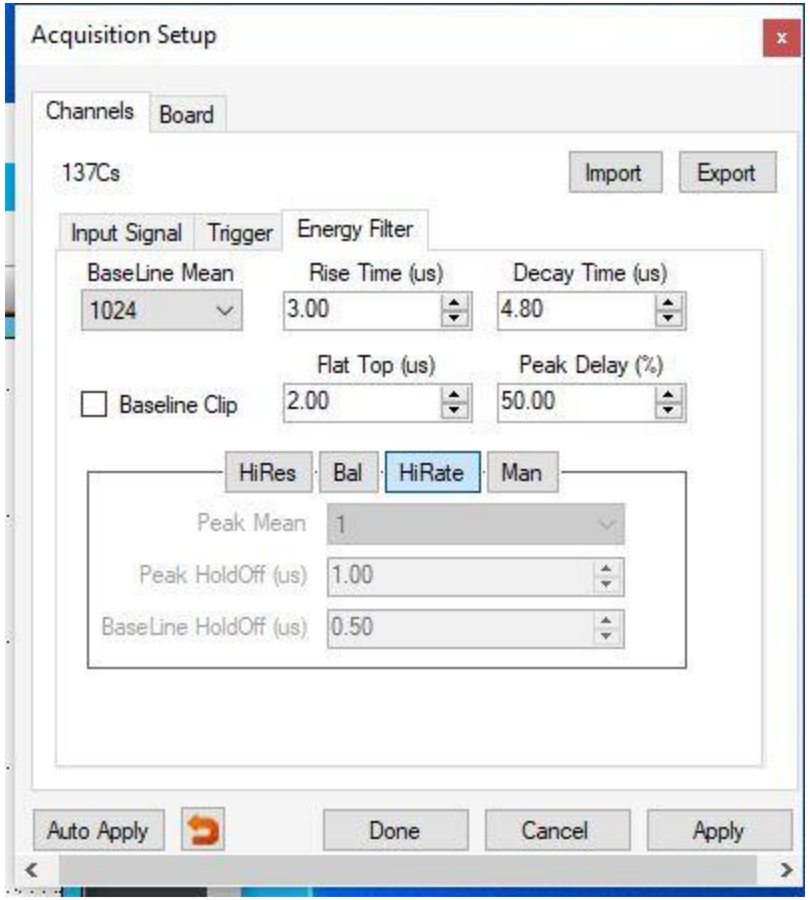
Possible rates up to 150 kHz, something worse resolution

- **Coincidences** – HPGe + luminometer

Adjustment of the parameters for energy reconstruction

V.T. Jordanov et al. Nucl. Instr. Meth. A 353 (1994) 337

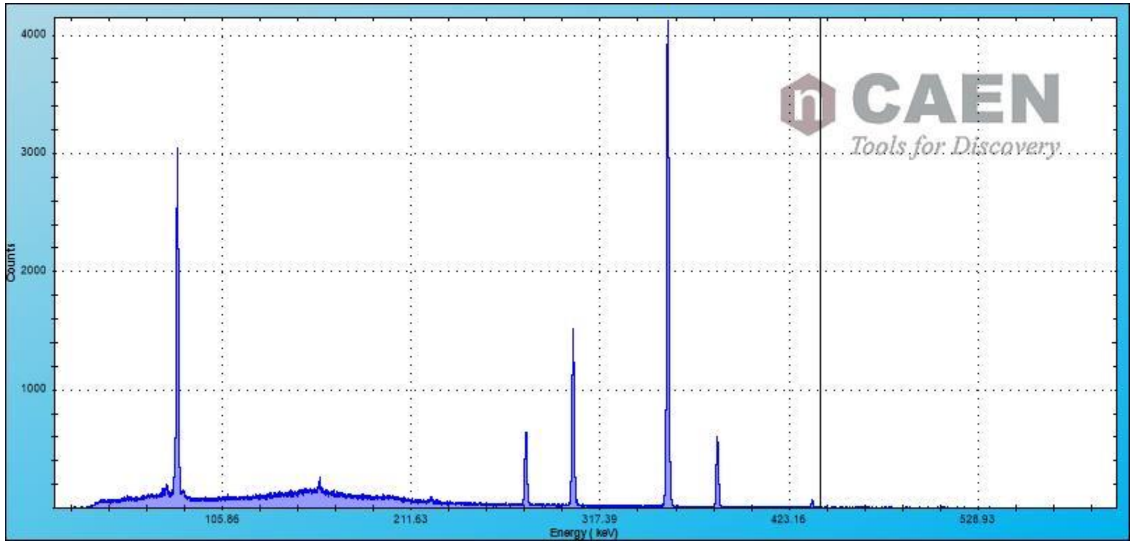




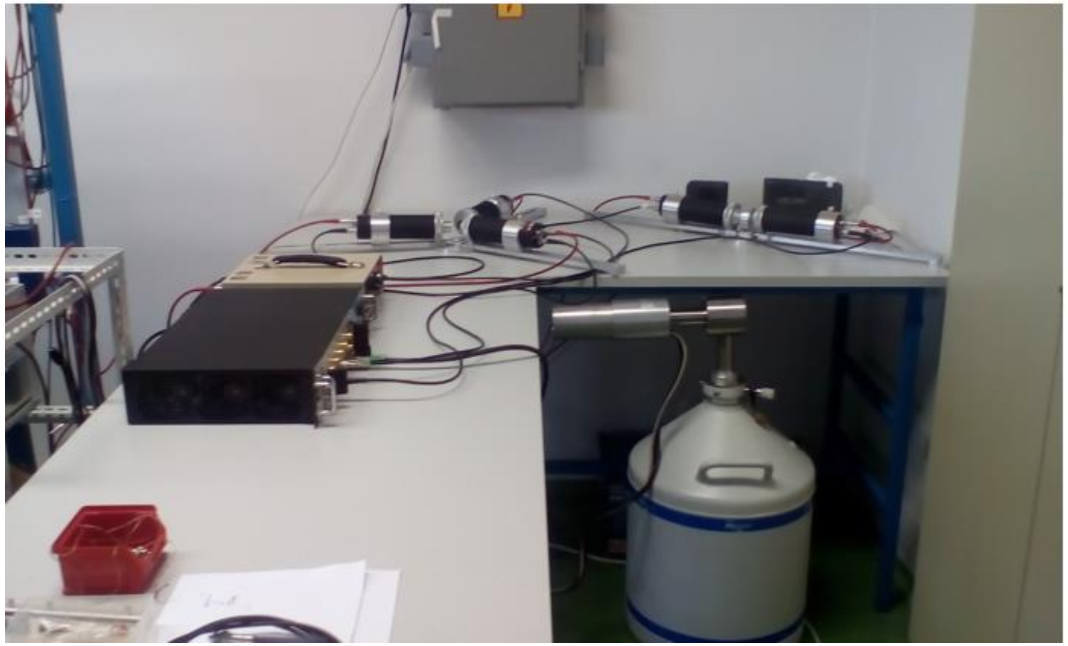
Laboratory tests (Zagreb) of HPGe (BSI - TRP preamp) & fast pulse digitizer, CAEN DT5781 4 ch, 14 bit,

CAEN DT5781 4 ch, 14 bit, 10ns sampling time

Tests: ^{133}Ba



- **Digital Pulse Processing** for Pulse Height Analysis firmware , based on V.T. Jordanov et al. Nucl. Instr. Meth. A 353 (1994) 337



Low rates – same resolution as with conventional electronics
High rates – 10-20% worse resolution

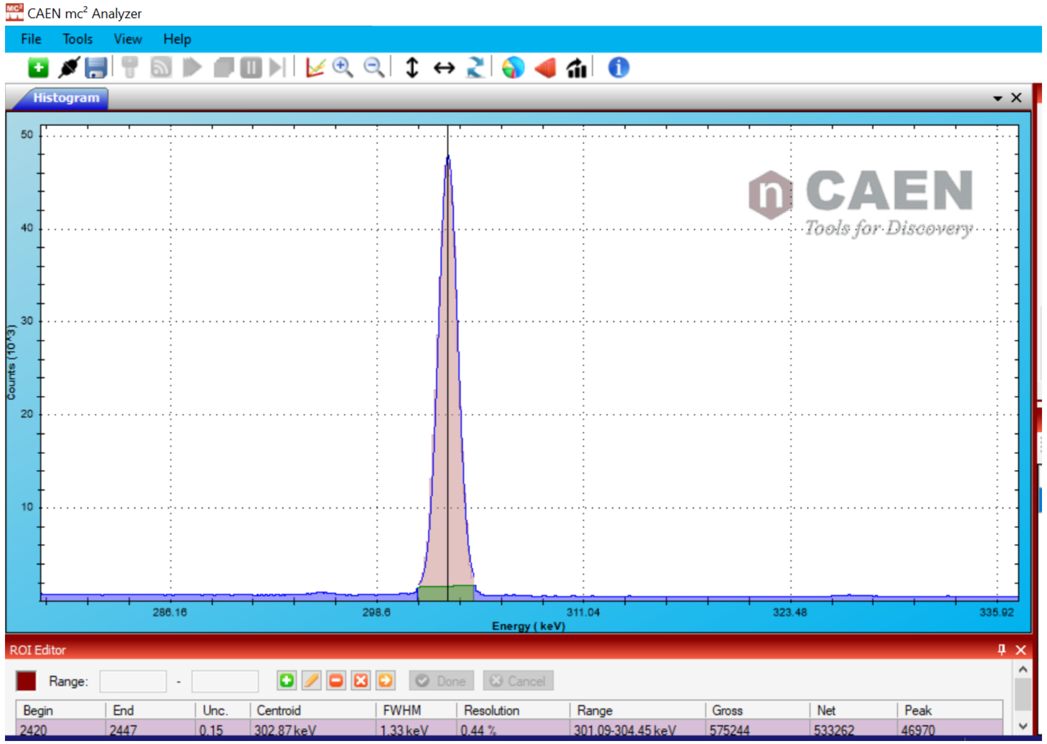
HPGe at the LNF, July 2021,
holder + shielding, tests Oct., Nov. 2021

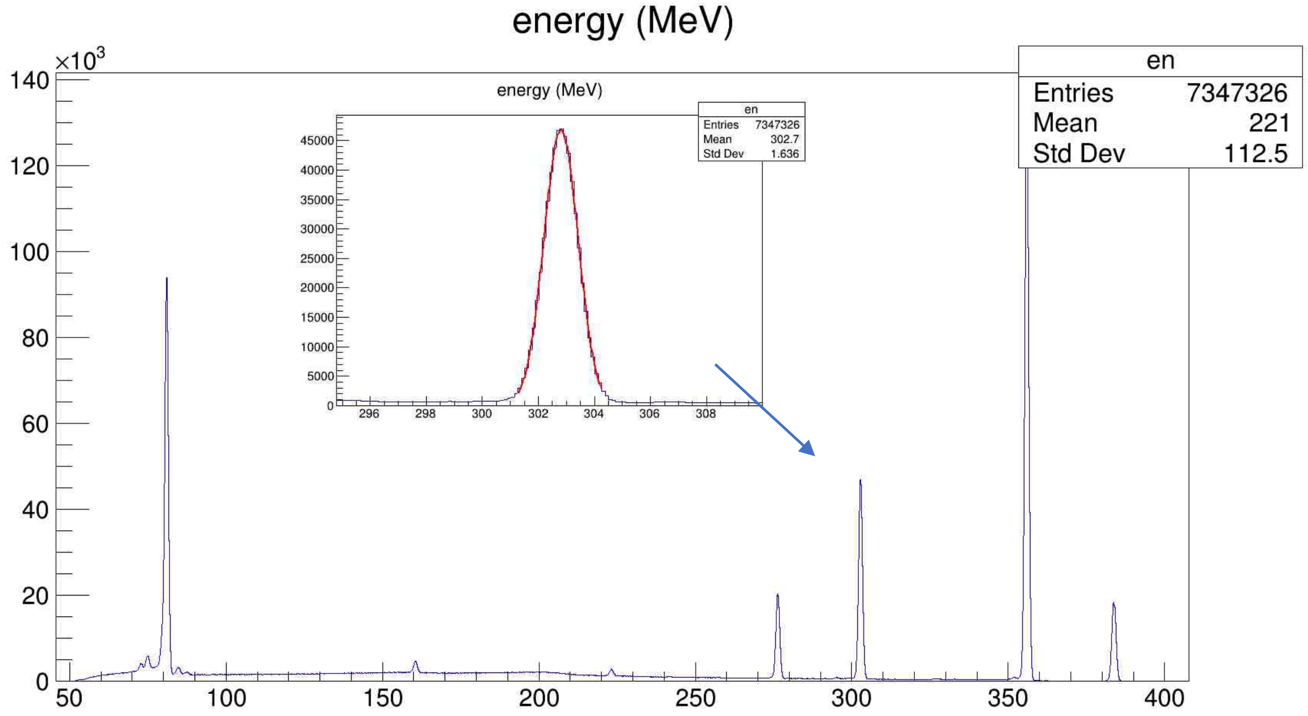
Tests in the lab at LNF, ^{133}Ba

Resolution, at 302.9 keV:

FWHM ~ 1.33 keV (1.4 keV?)

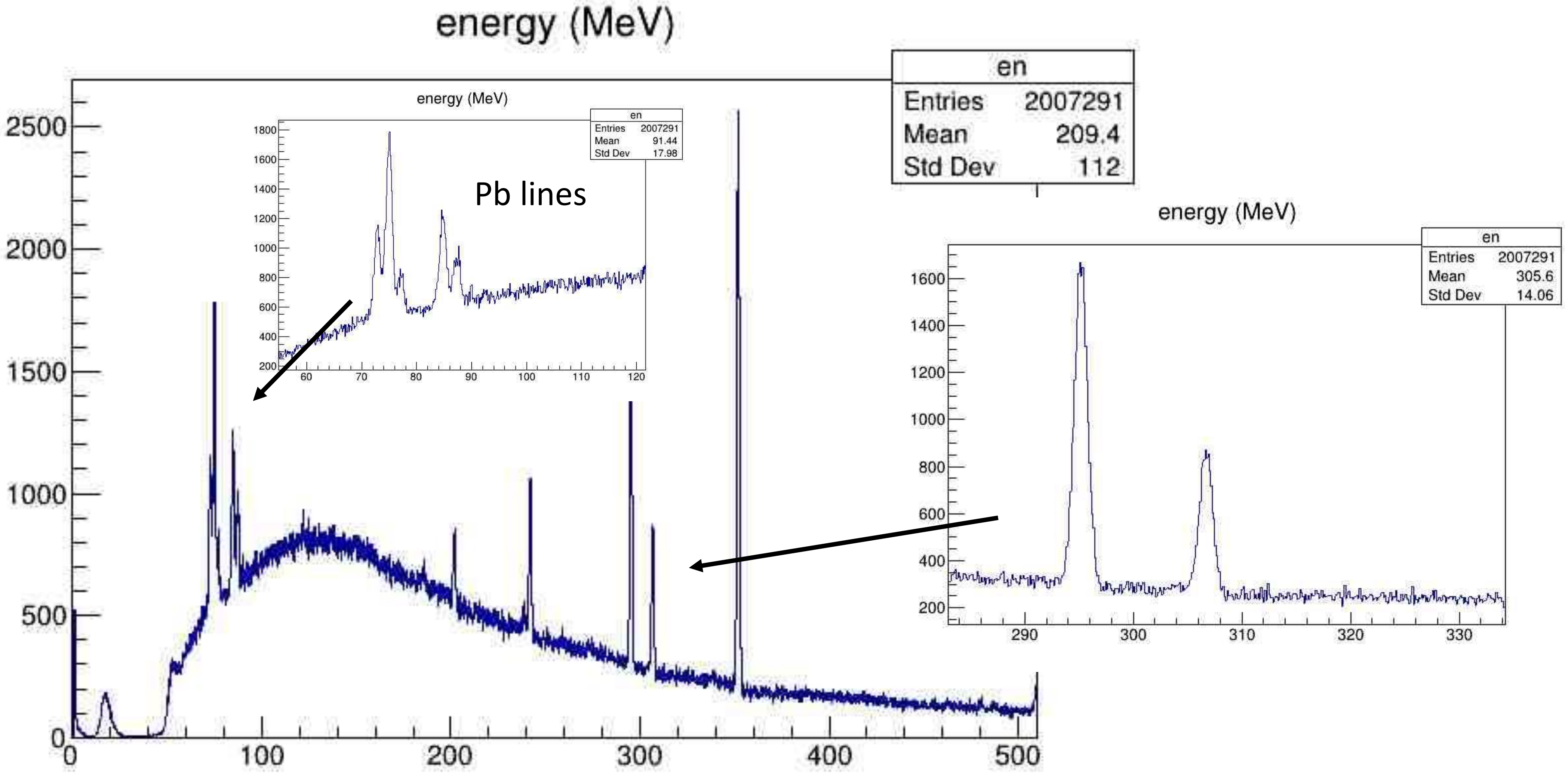
(analysis of the data from binary file, event on event basis)





(Resolution with analog electronics: 1.06 keV):

Measurements of the background in DAPHNE, without beam, 1 day of measurement



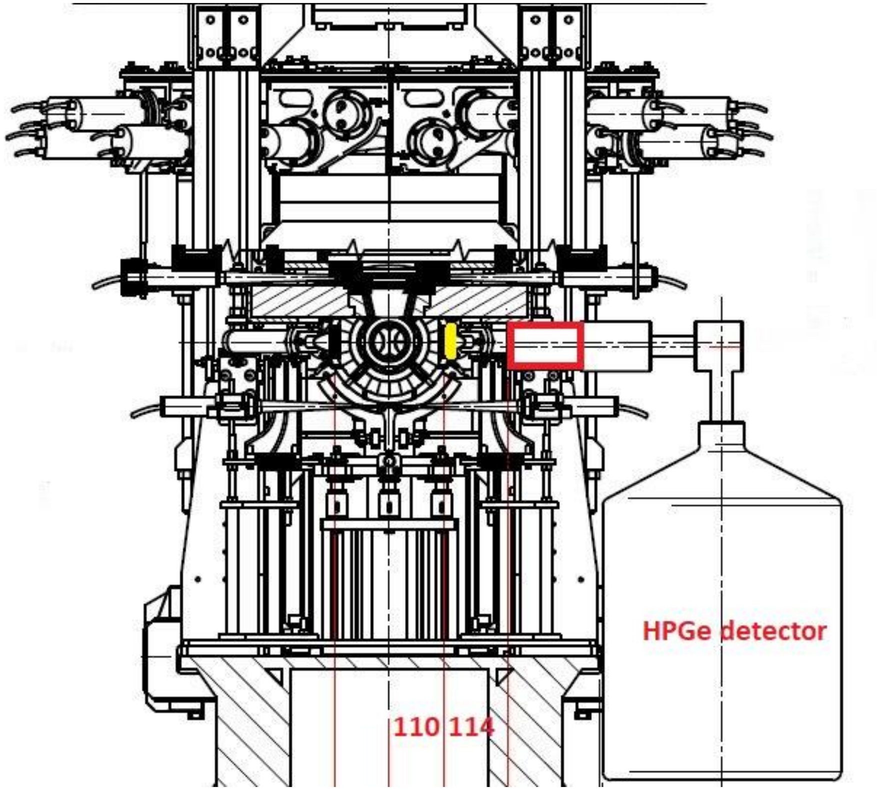
Waiting for the tests and measurements with the beam…

Simulations – GEANT4

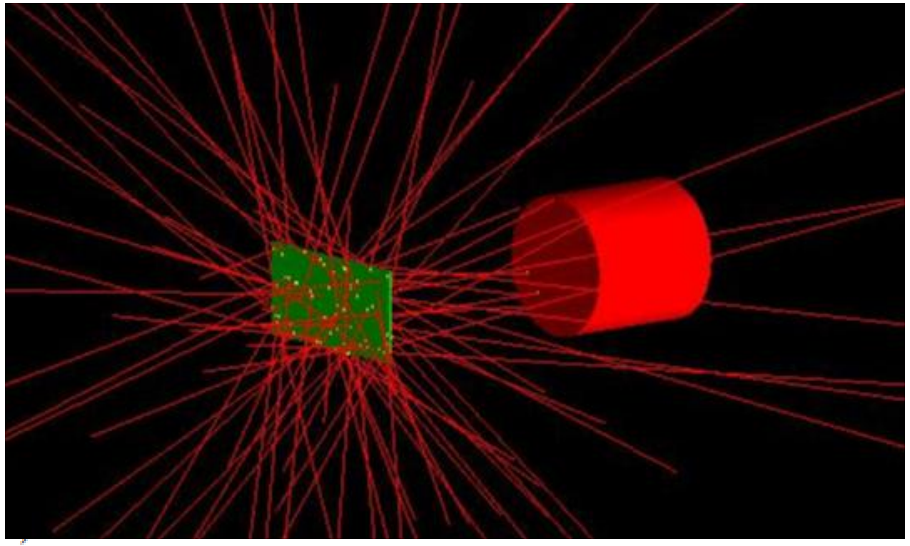
- To estimate the thickness and size of the target, setup configuration and HPGe efficiency
- To estimate background – from the beam (?) and from the kaon absorption and to determine optimal position of the detector and target (+ target size) and shielding .
- To estimate required time for the measurements.

- Not all parameters are known: beam background !? – test measurements with the beam are required.

Simple GEANT4 Simulations – HPGe efficiency



X-rays are generated in the lead plate



E(keV) (trans.)	Eff. (%) (0.3 mm)	Eff. (%) (1.1 mm)
90.9 (13 → 12)	0.36	0.11
116.9 (12 → 11)	0.50	0.19
153.9 (11 → 10)	0.64	0.34
208.2 (10 → 9)	0.72	0.51
291.6 (9 → 8)	0.76	0.65
426.2 (8 → 7)	0.76	0.71

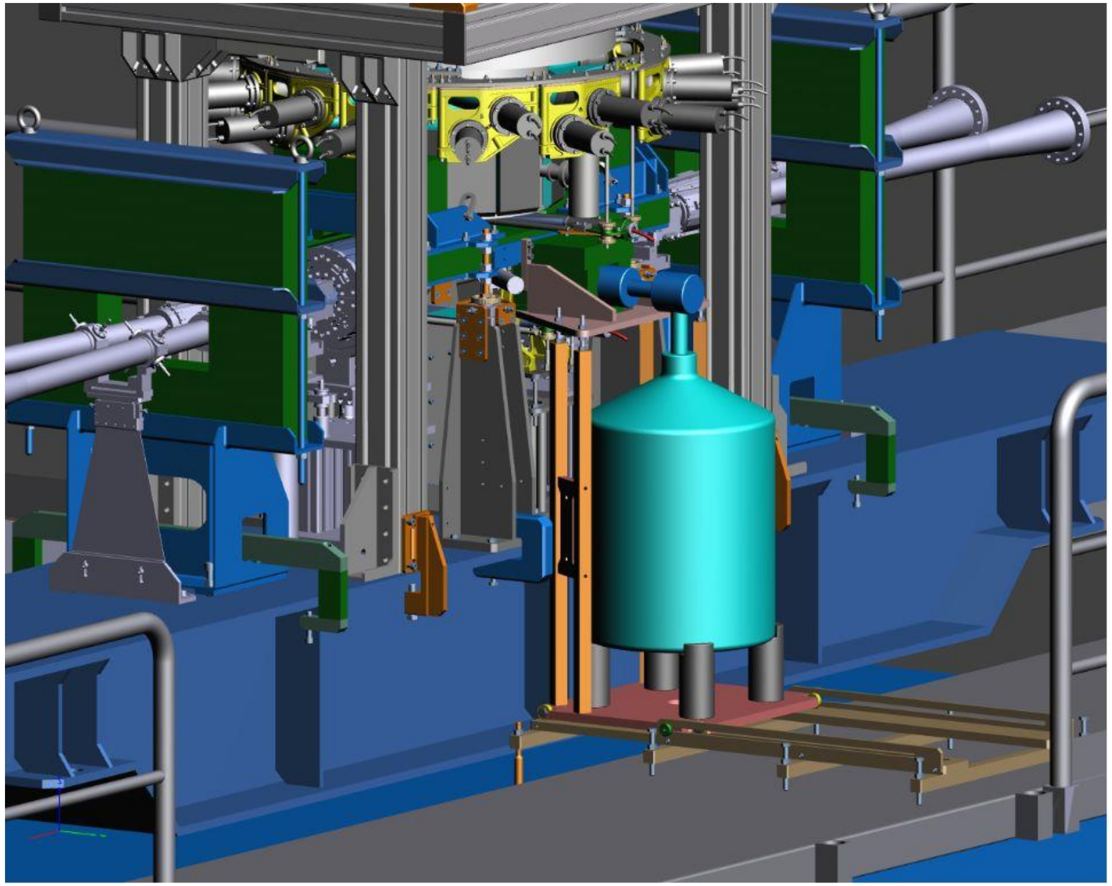
d (mm)	Eff. (%) (0.3 mm)	Eff. (%) (1.1 mm)
110	1.28	1.09
150	0.76	0.65
200	0.45	0.38
300	0.21	0.18
400	0.12	0.11
500	0.07	0.06

Table 1. Efficiencies of the HPGe detector for the X-rays from transitions in kaonic lead for two thicknesses of the target, left. Efficiencies of the HPGe detector for different distances of the HPGe detector from the target, for the X-rays of 291.6 keV and two thicknesses of the target (0.3 mm and 1.1 mm).

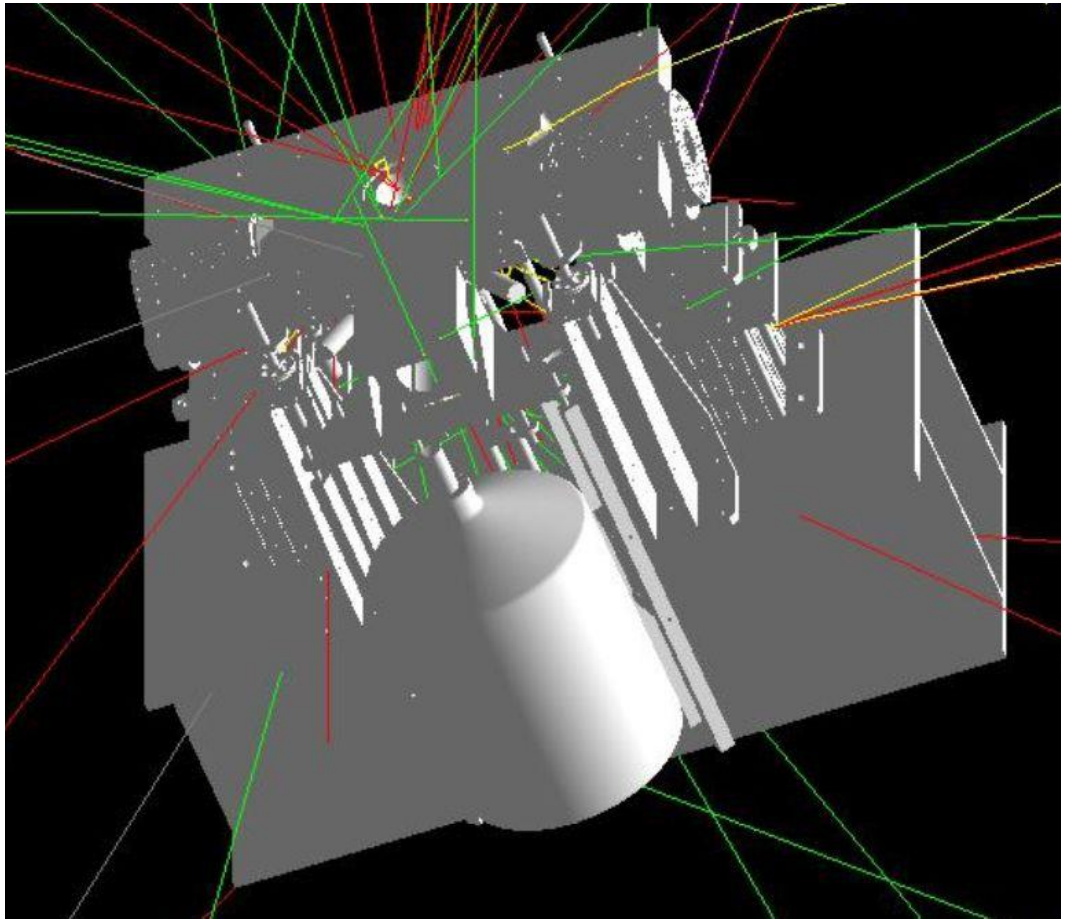
D. Bosnar et al. Acta Phys. Pol.B51 (2020) 115

GEANT4 full simulation

CAD drawing

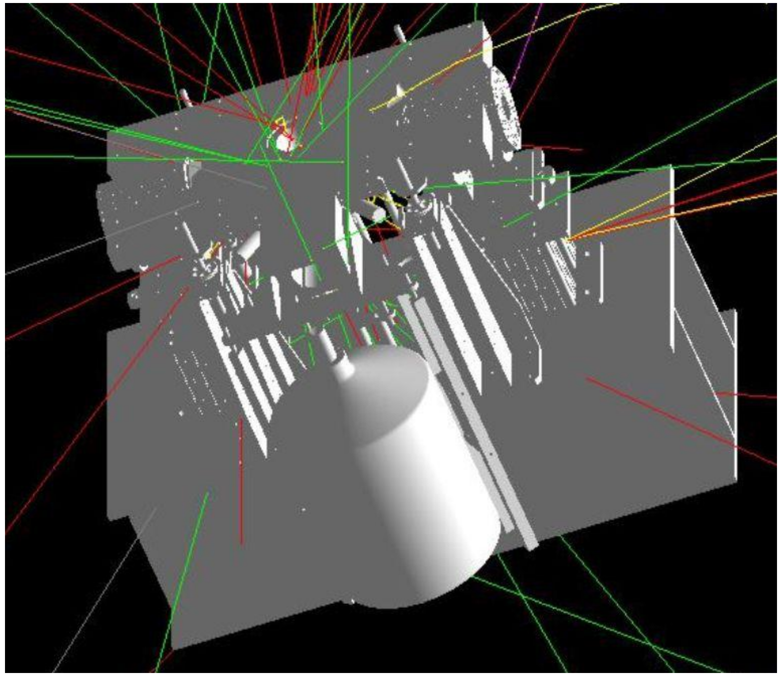


GEANT4 simulation

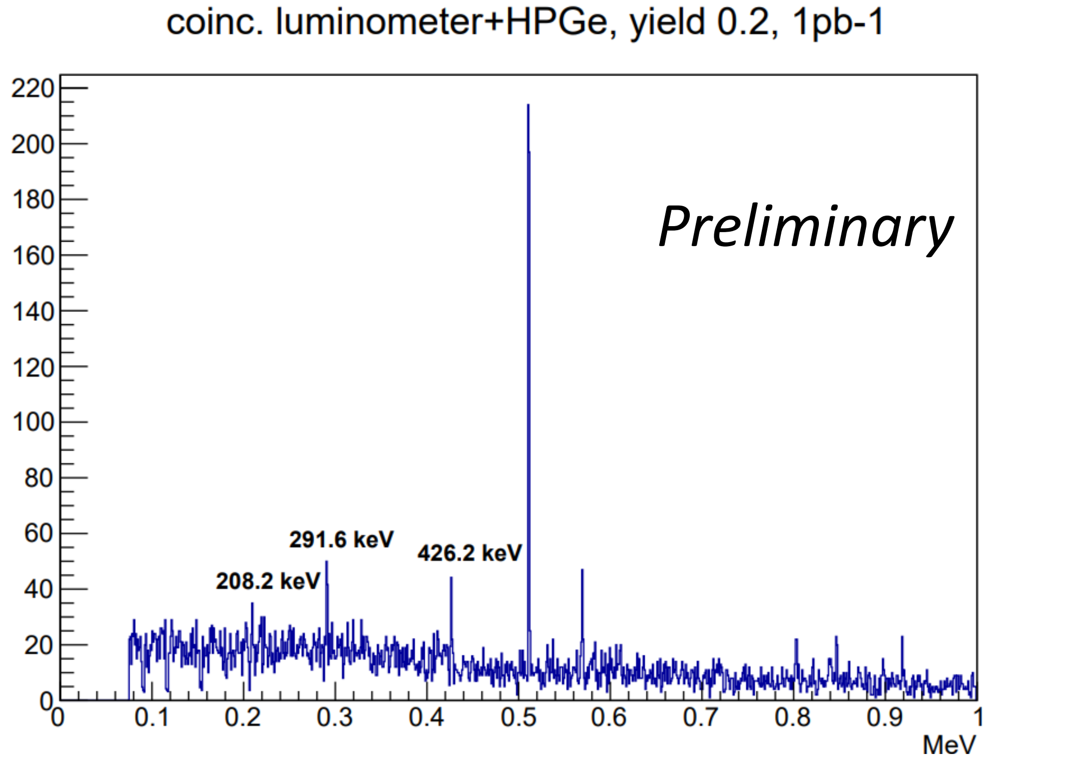


CAD files for selected objects are converted in GEANT4 gdml files for geometry description, different materials are taken into account

GEANT4 full simulation



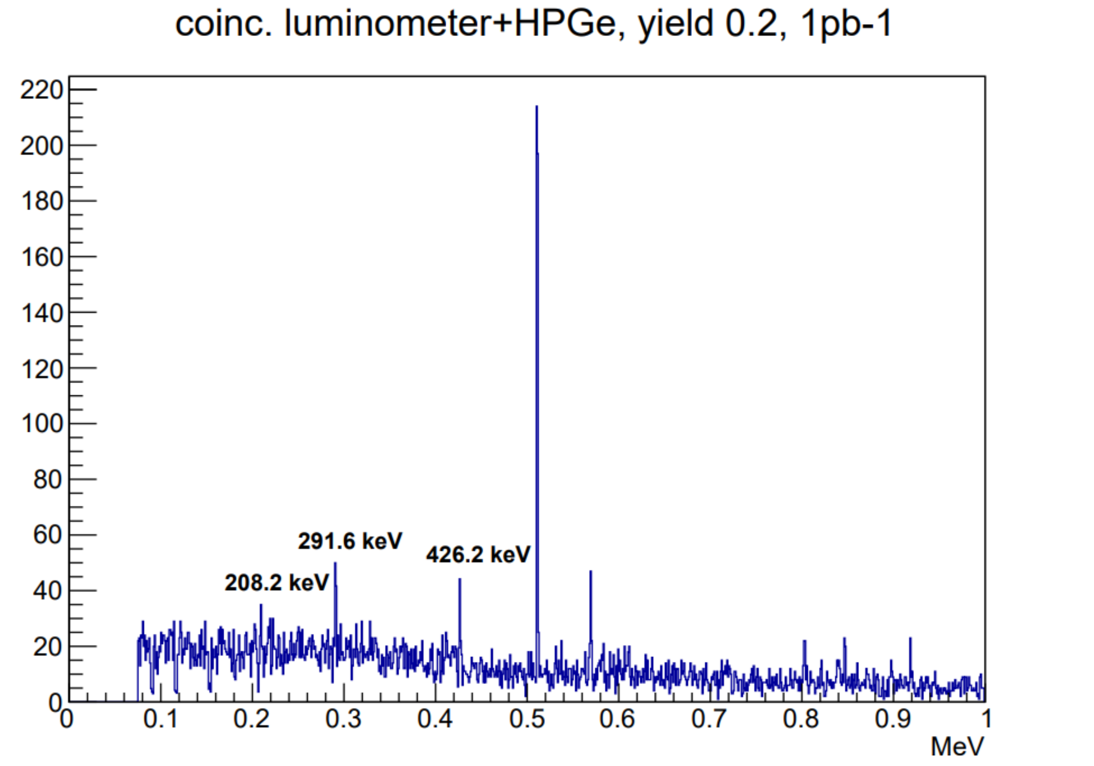
Kaons are generated uniformly in 4π
Only hadronic background., no background from e+e- beams
Front shielding of HPGe detector should be optimized

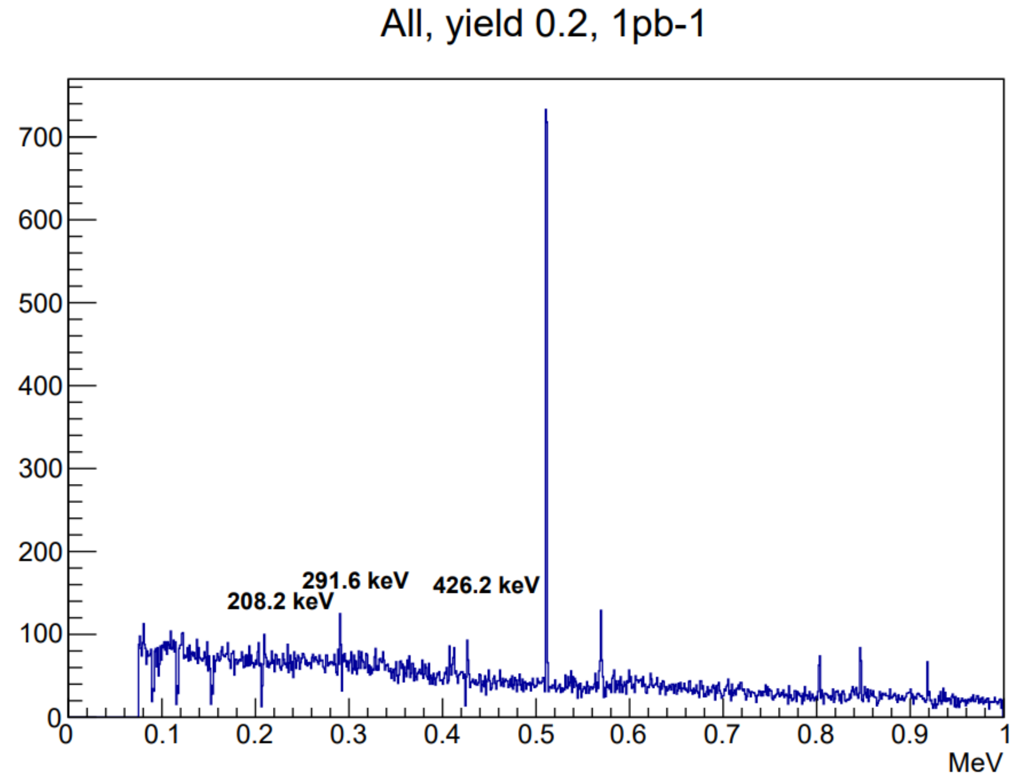


Approx. 50 events (291.6 keV) / pb^{-1},
12 pb^{-1} /day -> approx. 600 events/day.

~9.000 events -> 10 keV precision (15 days)
~25.000 events-> 5 keV precision (40 days)

GEANT4 full simulation

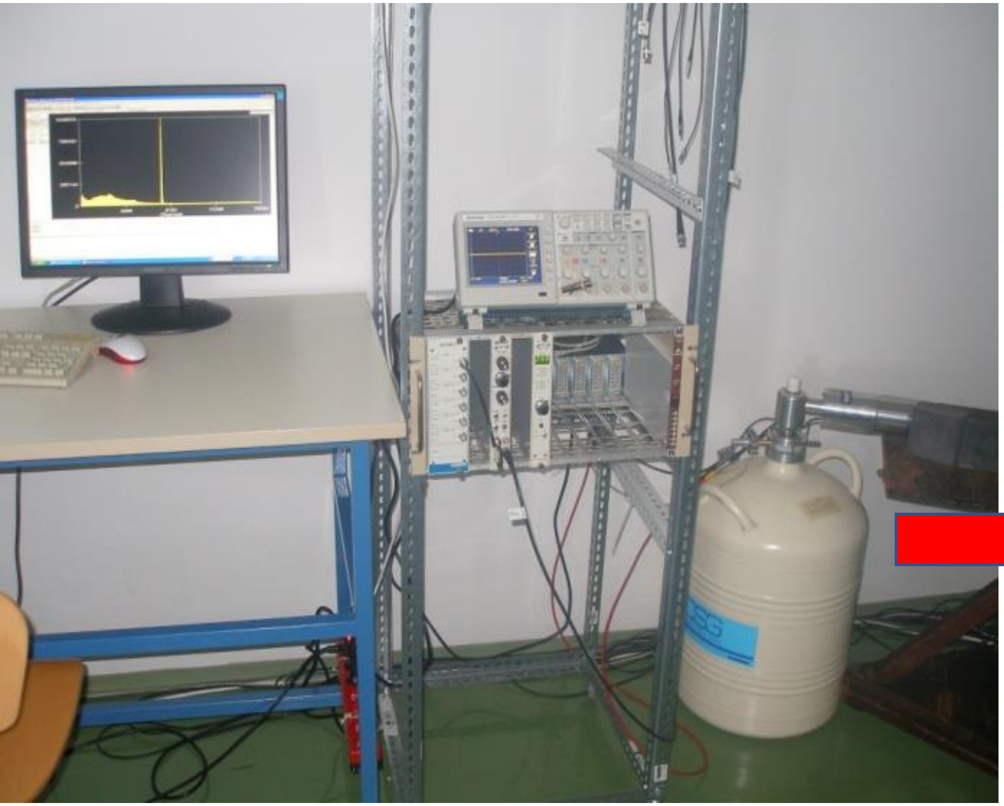




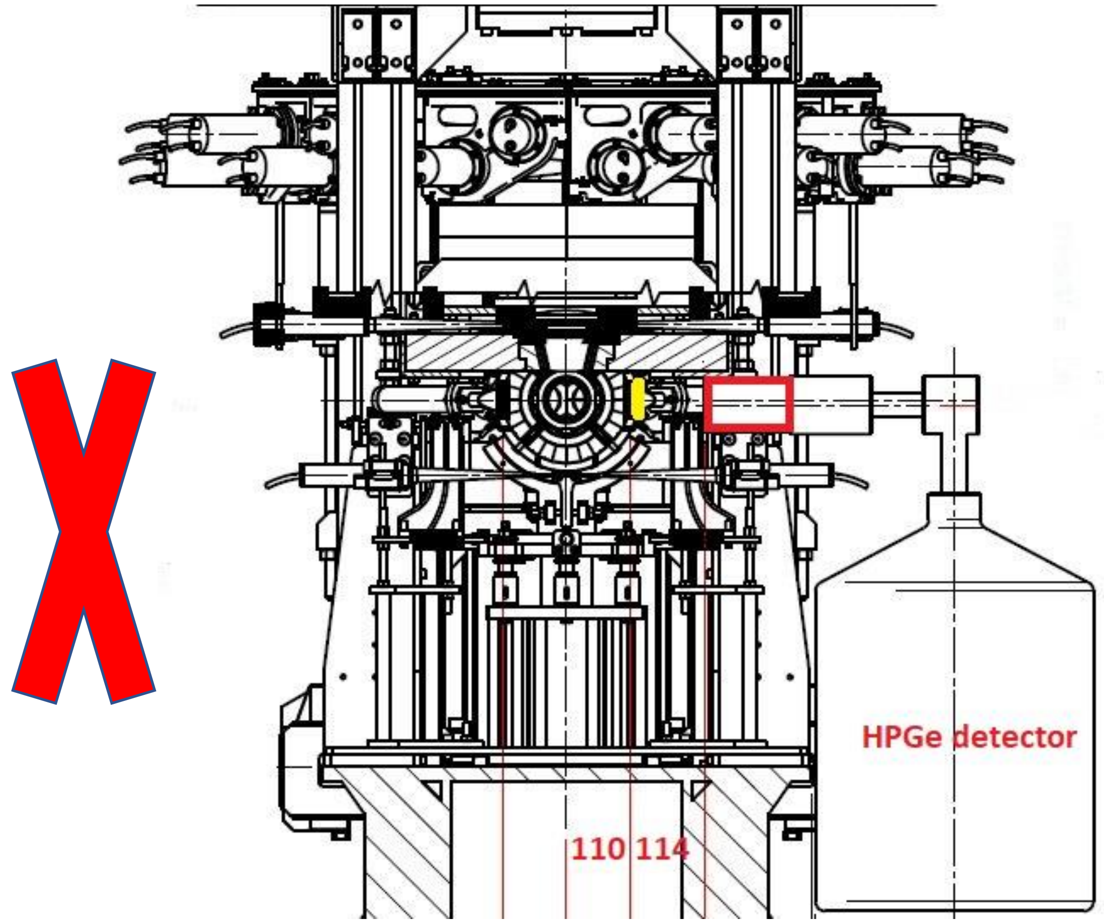
Electromagnetic background ? -> Measurements in the hall

Electromagnetic background will not have influence on this spectra (coincidence luminometer + HPGe), but it can lead to too big pile-ups in the HPGe

Second HPGe detector



Additional HPGe detector
with RC preamplifier (DSG)

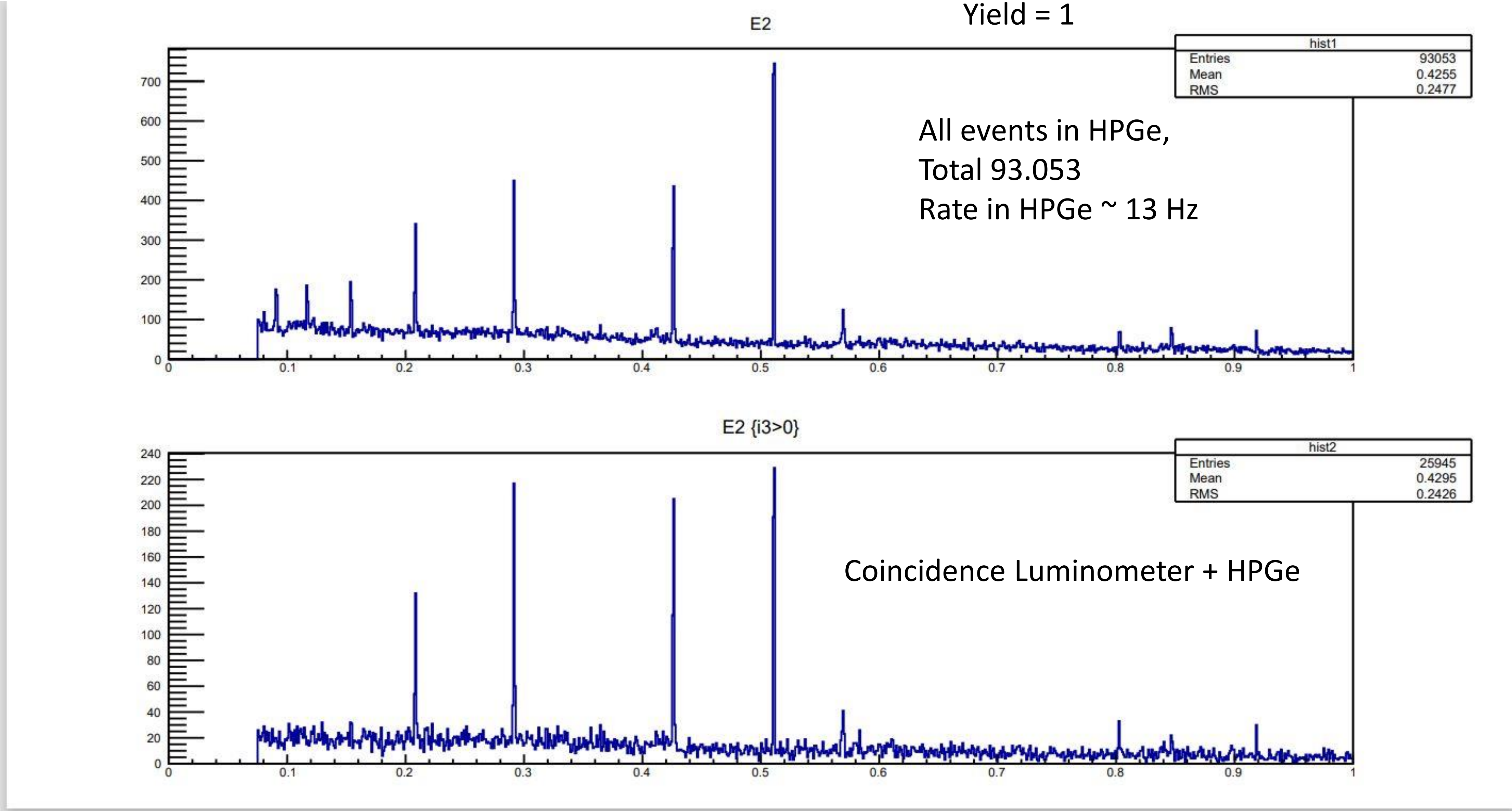


Application for a new HPGe detector and electronics in 2022 ?

Thank you for your attention !

Backup slides

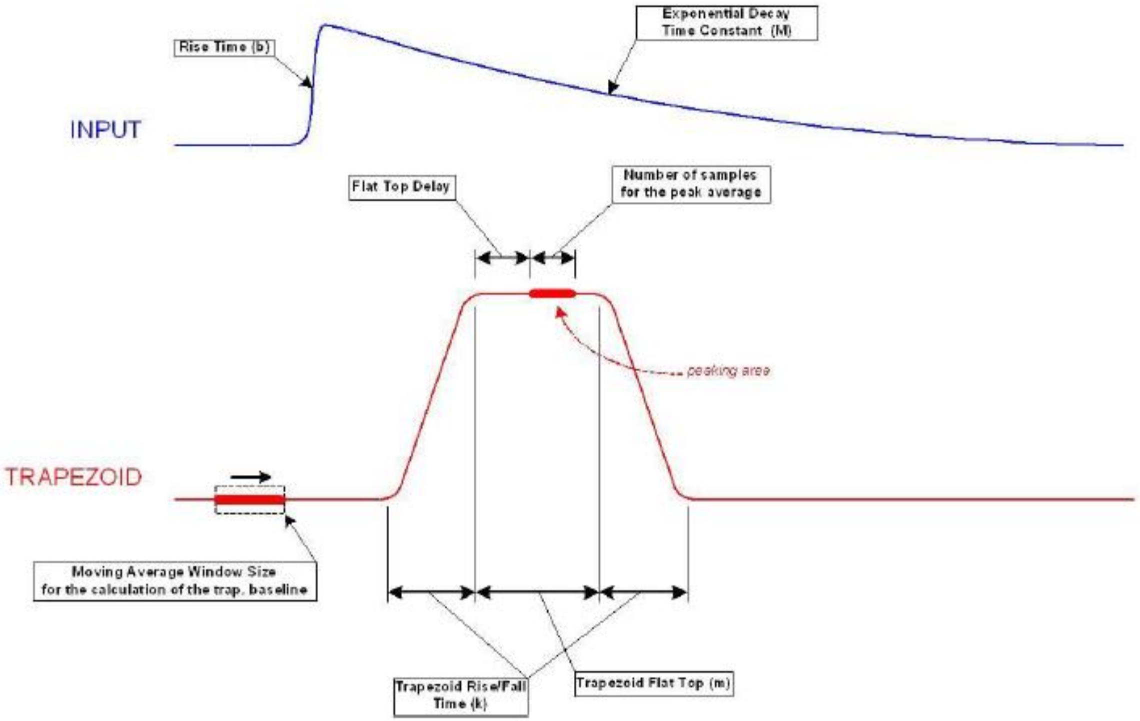
1pb-1 (~2h)



Yield = 1

All events in HPGe,
Total 93.053
Rate in HPGe ~ 13 Hz

Coincidence Luminometer + HPGe


Rise Time (b)
Exponential Decay
Time Constant (M)
INPUT
Flat Top Delay
Number of samples
for the peak average
peaking area
TRAPEZOID
Moving Average Window Size
for the calculation of the trap. baseline
Trapezoid Rise/Fall
Time (k)
Trapezoid Flat Top (m)