UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Exploiting calibration data to understand the energy scale

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on behalf of the Padova group

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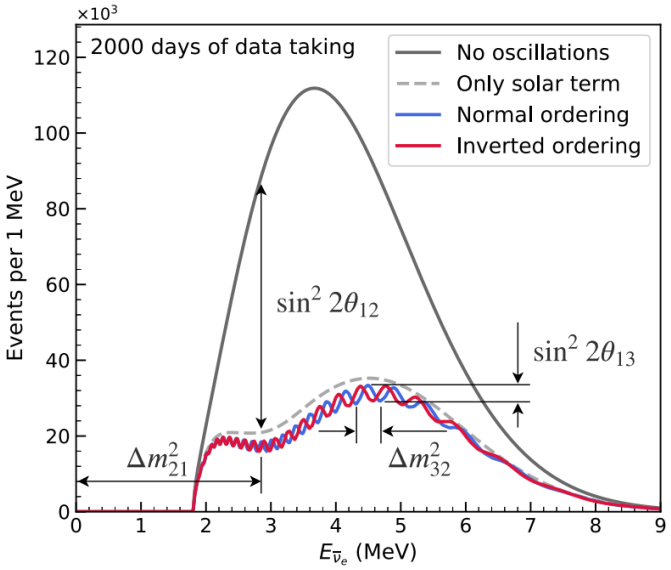
Jiangmen Underground Neutrino Observatory

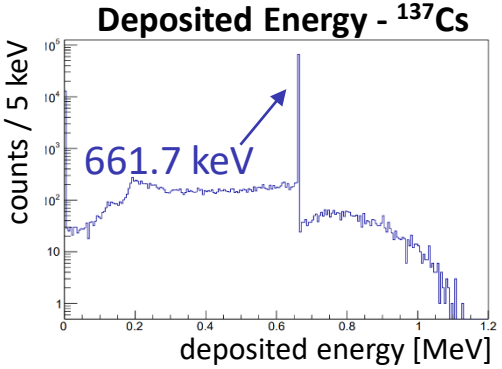
Goal of this work:

- Study of the energy resolution and the non linearity effect through calibration sources for the energy reconstruction.
- Radioactive sources simulated for 100k events inside the assembly
- JUNO Montecarlo framework: detector simulation only, no eletronics

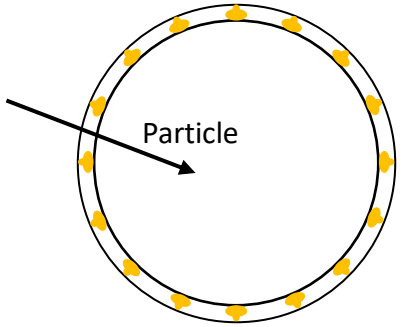


Sources and Porcesses	Emitted Particle	Revelated Energy
^{137}Cs	**γ**	**0.662 MeV**
^{54}Mn	γ	0.835 MeV
^{60}Co	γ	1.173 MeV + 1.333 MeV
^{40}K	γ	1.461 MeV
^{68}Ge	e^+	0.511 MeV + 0.511 MeV
(n,γ)p	γ	2.2 MeV
(n,γ)^{12}C	γ	4.94 MeV o 3.68 MeV + 1.26 MeV

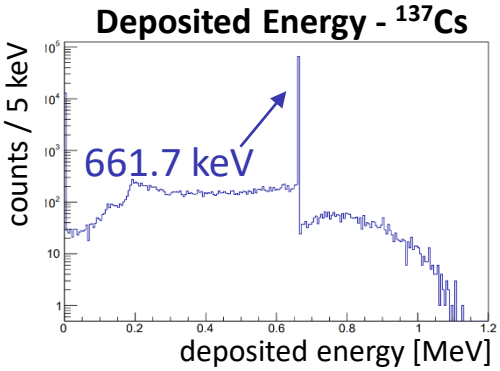
Detector simulations - Recap



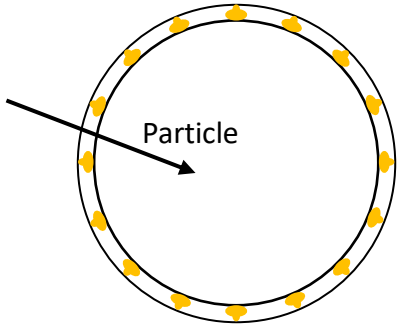
Deposited energy by particles into the LS

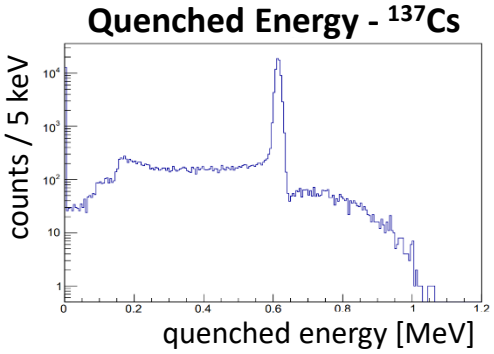


Detector simulations - Recap

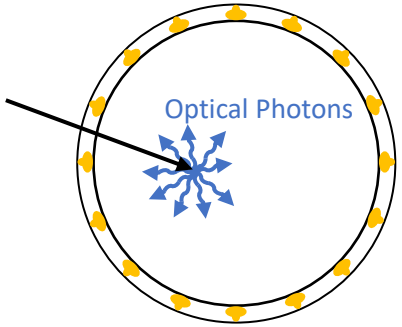


Deposited energy by particles into the LS

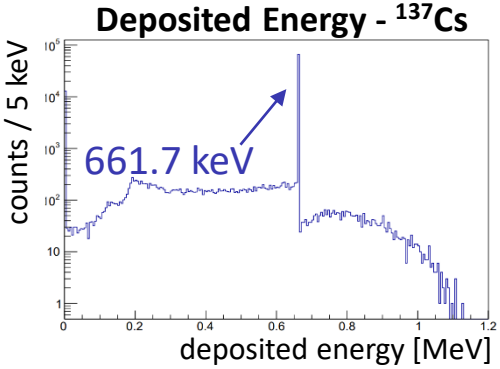




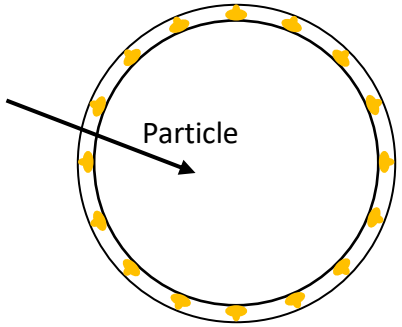
Resulting energy from the production of optical photons. Follows Birks law.

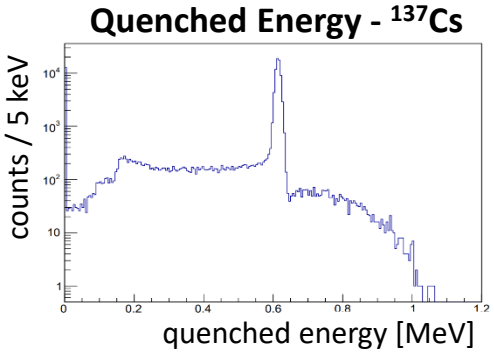


Detector simulations - Recap

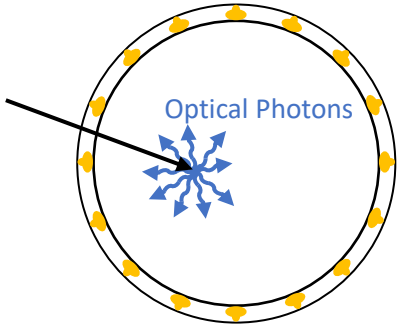


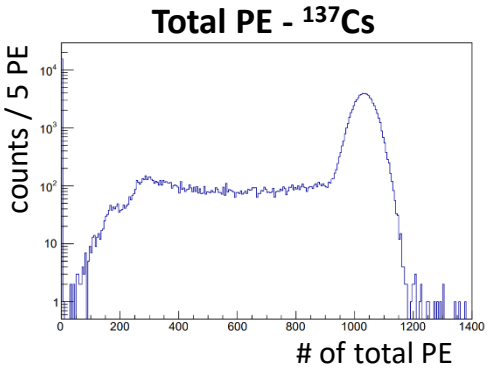
Deposited energy by particles into the LS



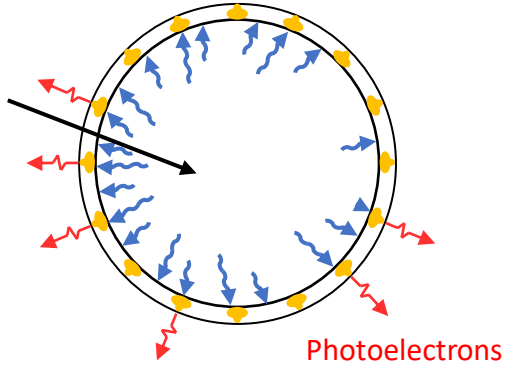


Resulting energy from the production of optical photons. Follows Birks law.

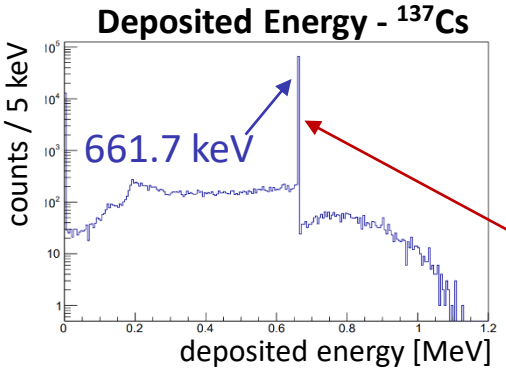


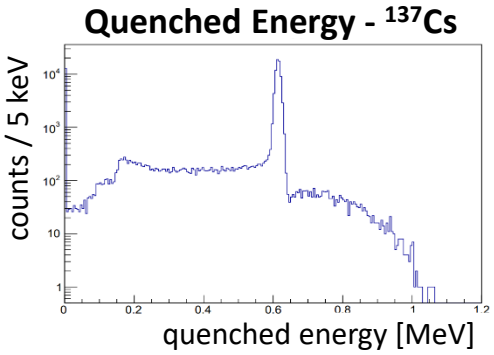


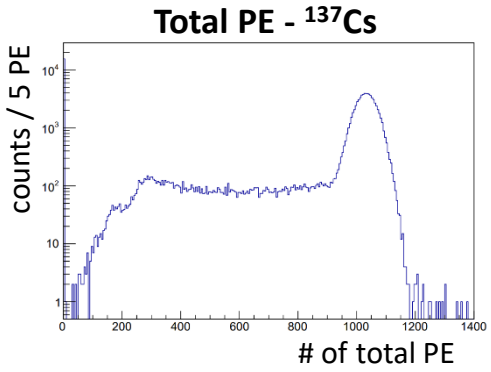
Photoelectrons produced by PMT through photoelectric effect from the optical photons. The most relevant parameter.

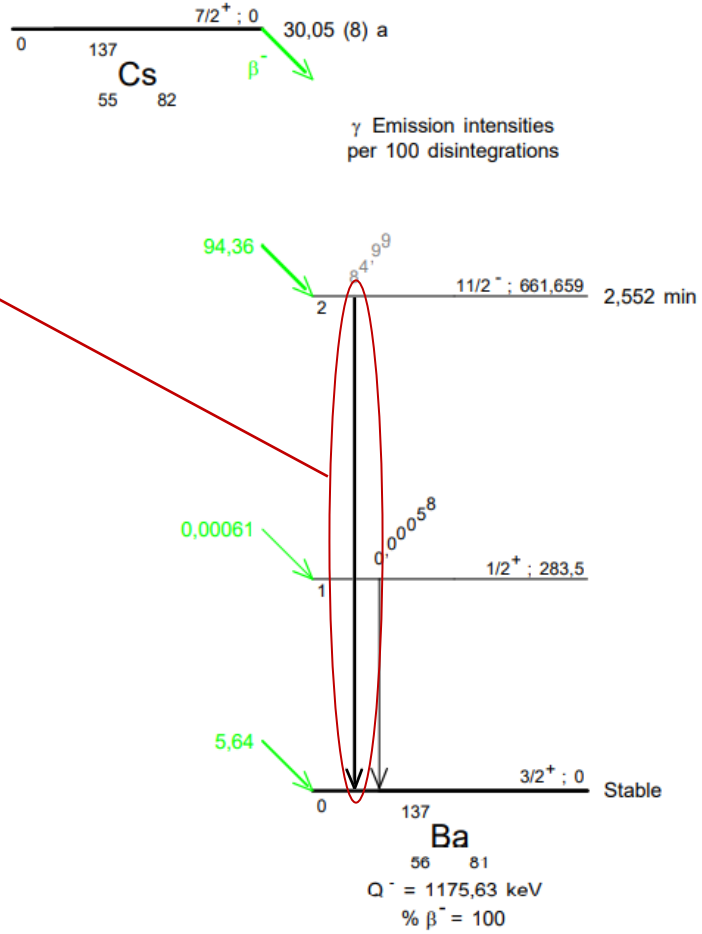


Detector simulations – ^{137}Cs



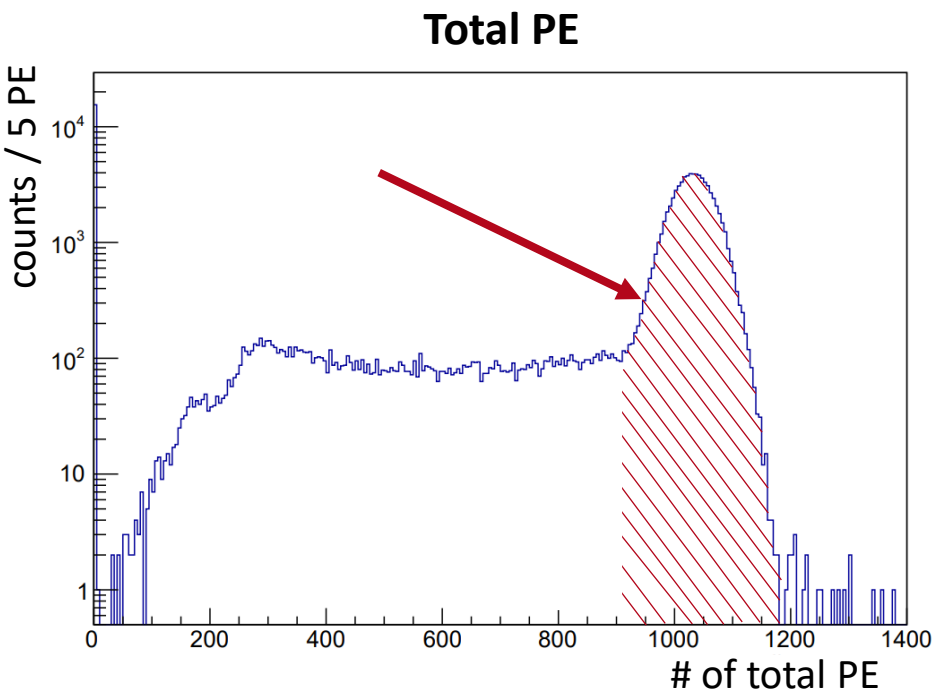






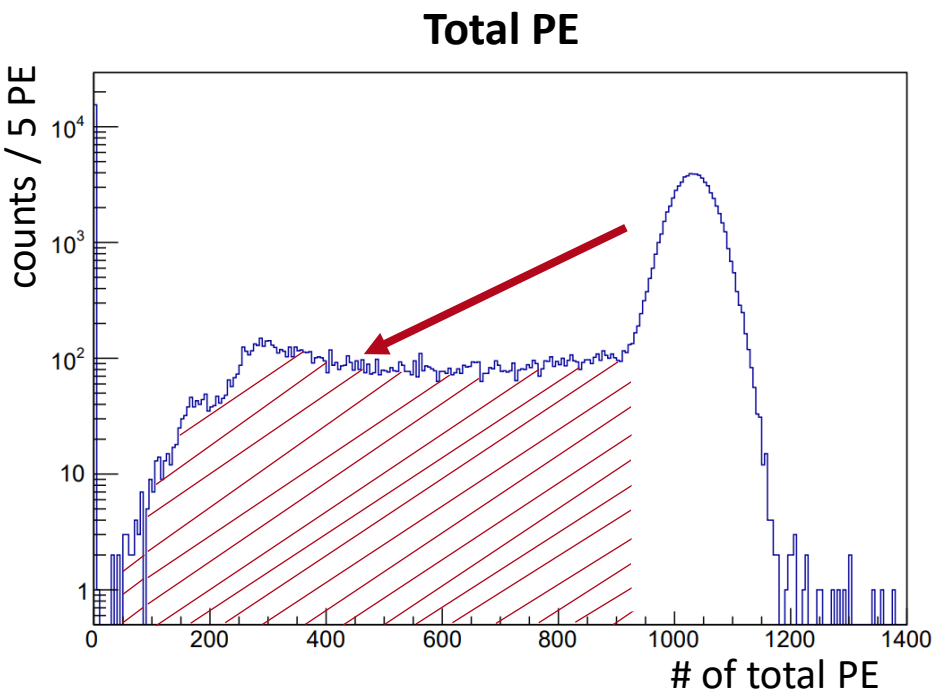
Total PE – ^{137}Cs

- Photopeak: gammas that deposit all their energy in the LS



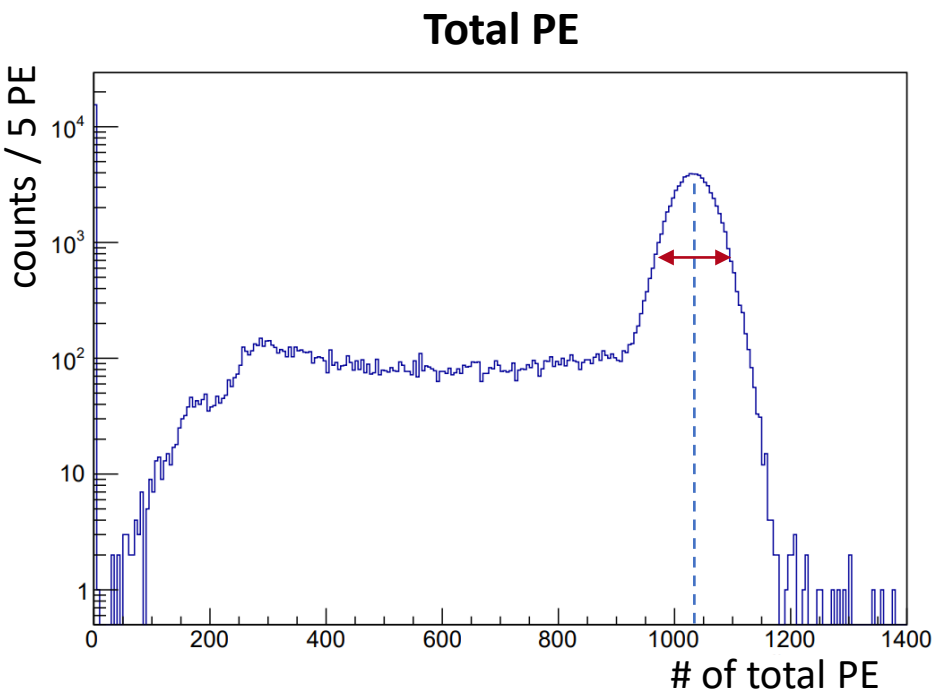
Total PE – ^{137}Cs

- Photopeak: gammas that deposit all their energy in the LS
- Tail at low energies: gammas that lost some energy in the assembly



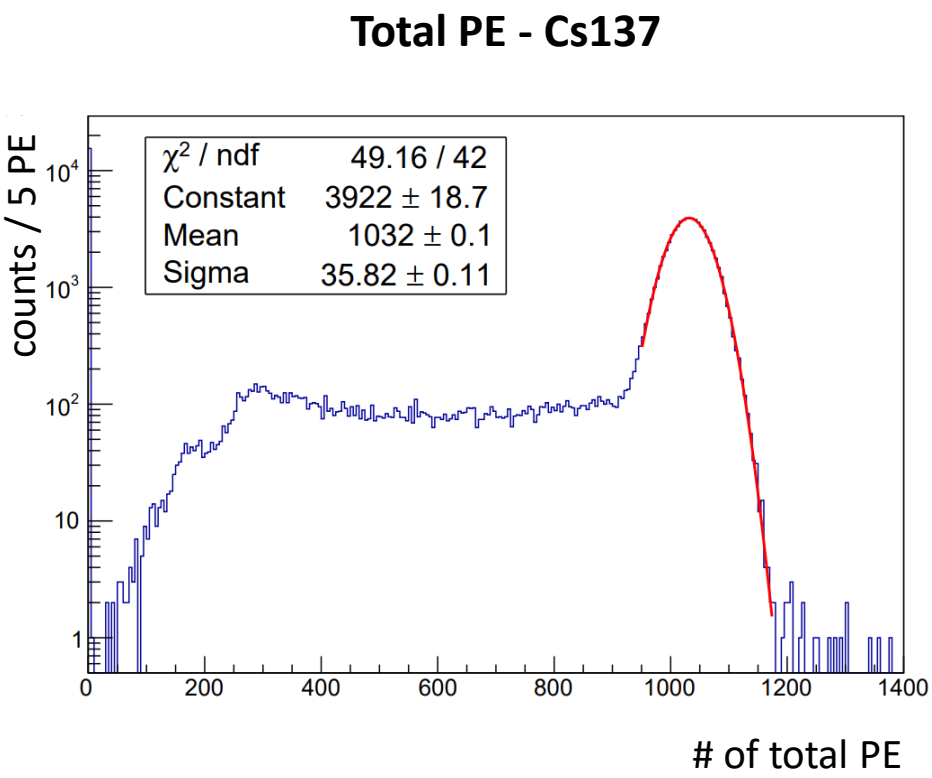
Total PE – ^{137}Cs

- Photopeak: gammas that deposit all their energy in the LS
- Tail at low energies: gammas that lost some energy in the assembly
- For non linearity and resolution, we need the centroid and the width of the photopeak
- Now are shown some methods we used



1. Gaussian fit of the photopeak

- Gaussian fit
- Neglected tail at low energies



2.Functions that include the tail

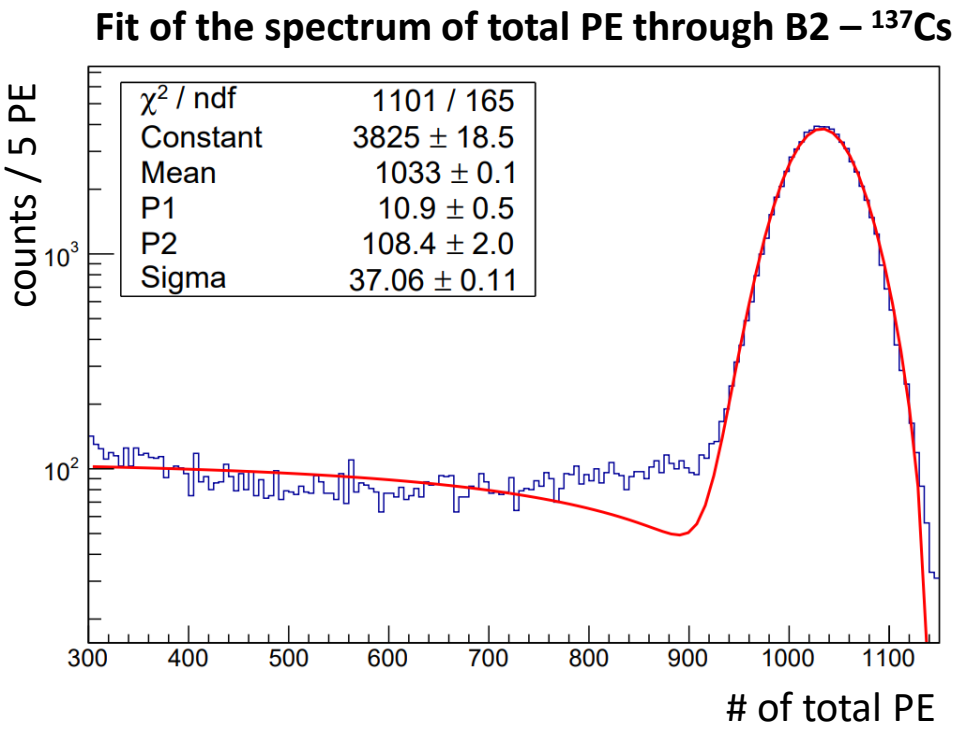
B2	$Gauss(x;M,\sigma,C)+P_2\left(1-e^{P_1\frac{x-M}{2\sigma}}\right)$
B3	$Gauss(x;M,\sigma,C)+P_3\left(\frac{1}{2}-\frac{1}{\pi}\arctan\left(\frac{M-P_2\sigma-x}{P_1\sigma}\right)\right)$
B4	$Gauss(x;M,\sigma,C)+P_1\left(1-(1+\frac{(x-M)^2}{\sigma^2})^{-1}\right)$
B5	$Gauss(x;M,\sigma,C)+\ P_1\left(1+e^{\frac{x-M}{(0.75FWHM)}}\right)^{-1}$
B6	$Gauss(x;M,\sigma,C)+P_1\cdot\frac{1}{2}\mathrm{erfc}\left(\frac{x-M}{\sqrt{2}\sigma}\right)$
B7	$\begin{cases} Gauss(x;M,\sigma,C)+P_1\cdot\frac{1}{2}\left(2-e^{2\frac{x-M}{\sigma}}\right) per\ x<M \\ Gauss(x;M,\sigma,C)+P_1\cdot\frac{1}{2}\,e^{2\frac{x-M}{\sigma}} per\ x>M \end{cases}$

M=Mean, C=Const

Debertin, K., & Helmer, R.G. (1988). Gamma- and X-ray spectrometry with semiconductor detectors. Netherlands: North-Holland.

2.Fit through funcitons that include the tail – ^{137}Cs

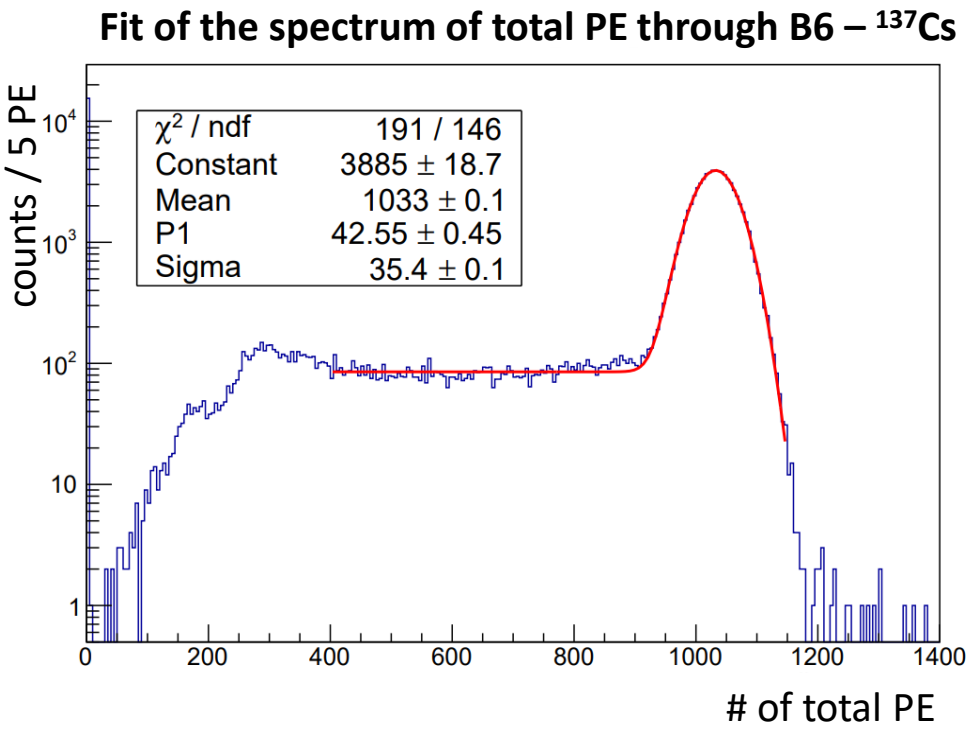
- B2 : wrong concavity at low energies



2.Fit through funcitons that include the tail – ^{137}Cs

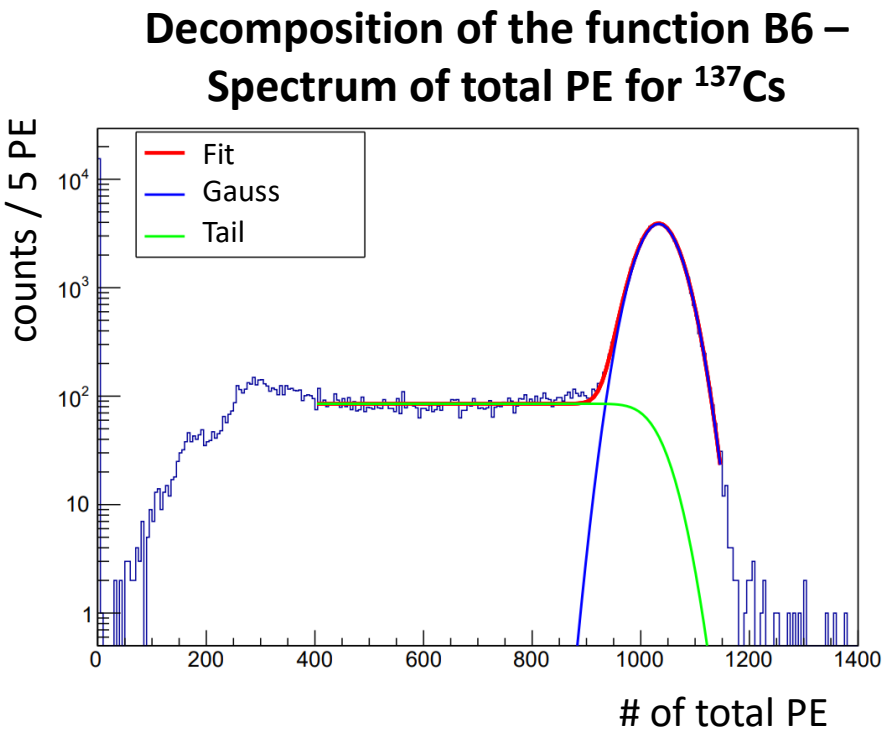
- B2 : wrong concavity at low energies
- B6 has the best χ^2 and is the most meaningful physically
- $B6 = Gauss(x; M, \sigma, C) +$

  $+ P_1 \cdot \frac{1}{2} \mathrm{erfc}\left(\frac{x-M}{\sqrt{2}\sigma}\right)$
- B6 for the fit of the spectra for alll the other sources



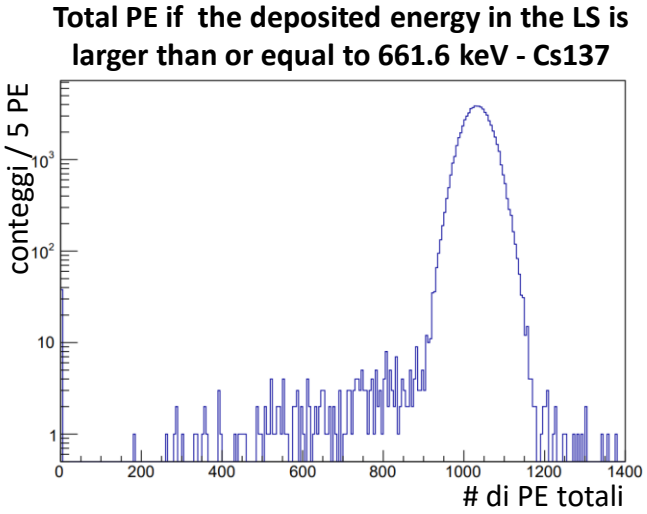
2.Fit through the function B6

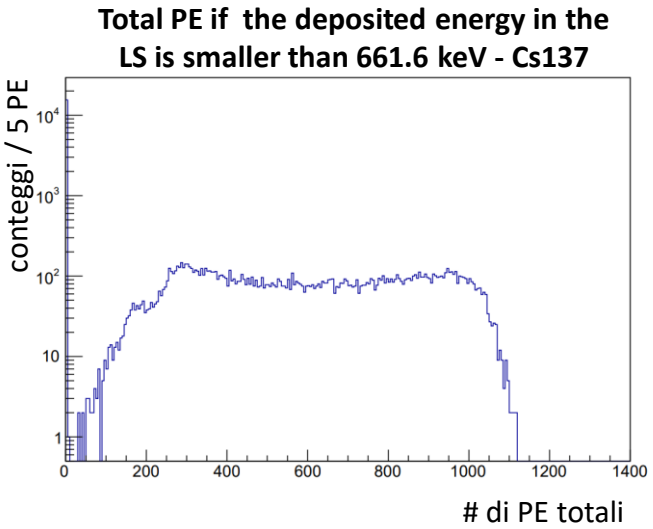
- The concavity in the tail is not well described
- For a good parametrization we may need a lot of parameters
- We need another way to describe the tail



3.PDF of the tail through Montecarlo

- We want the PDF of the tail using the results of the Montecarlo.
- We need to separate the photopeak from the tail
- Cut the values of deposited energy under a threshold
- The threshold does not gives us a clean cut, we are investigating





3.PDF of the tail through Montecarlo

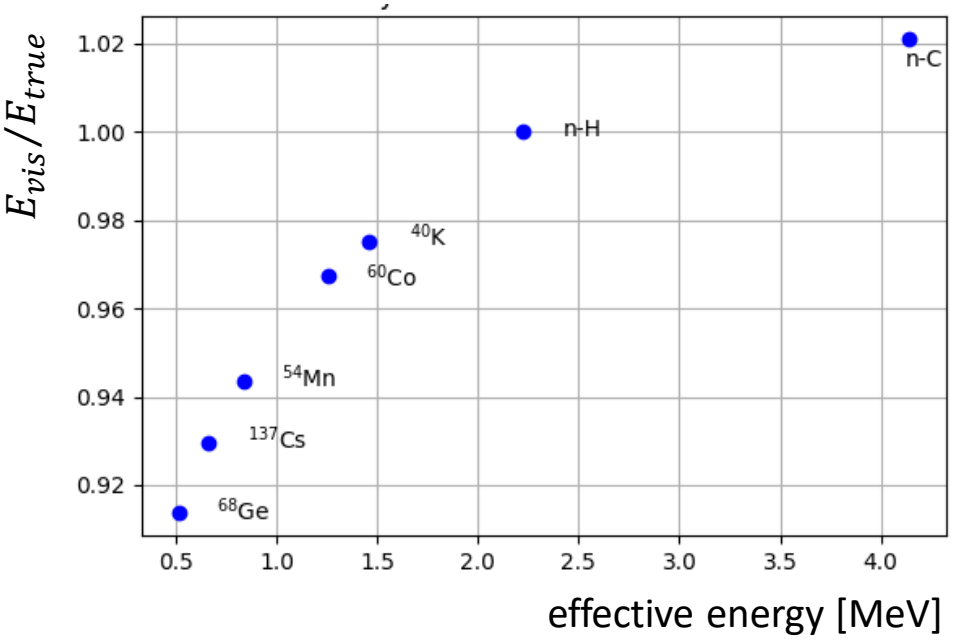
- We want the PDF of the tail using the results of the Montecarlo
- We need to separate the photopeak from the tail
- Cut the values of deposited energy under a threshold
- The threshold does not gives us a clean cut, we are investigating
- We need to have a variable that distinguishes the energy deposited by all the different particles – we are working on this
- Edep-prmtrkdep should be the deposited energy for each particle and its secondaries

```
root [4] prmtrkdep->Show(0)
======> EVENT:0
 evtID            = 0
 nInitParticles   = 1
 PDGID            = 1000551370
 TrackID          = 1
 edep             = 0.618465
 edepX            = 55.2781
 edepY            = -236.242
 edepZ            = -80.0194
 Qedep            = 0.566387
 QedepX           = -98.7826
 QedepY           = -238.299
 QedepZ           = -76.4347
 edepNotInLS      = 0.328971
```

Non Linearity

- Non linearity depending on effective energy
- For some decays are emitted multiple paricles
- Quenching and PE production aren't linearly dependent on particle energy

Non linearity curve – Normalization at 2.22 MeV

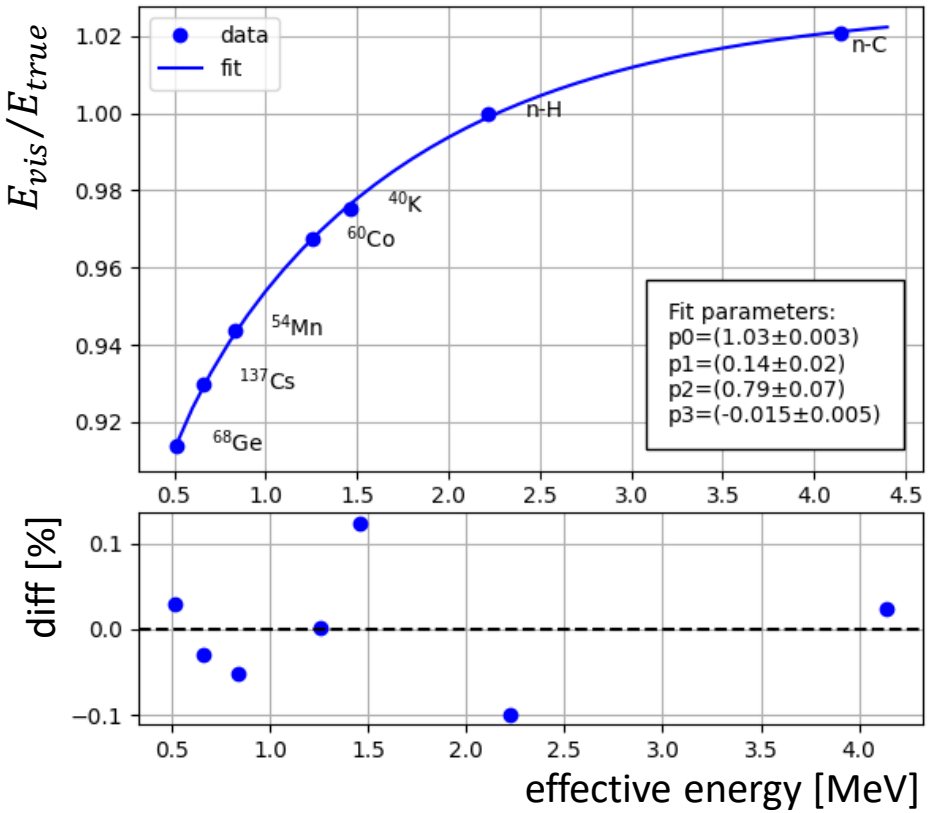


Non Linearity

- Non linearity depending on effective energy
- For some decays are emitted multiple paricles
- Quenching and PE production aren't linearly dependent on particle energy
- Fit through the function*:

$$\frac{E_{vis}}{E_{true}} = \frac{p_0 + \frac{p_3}{E_{eff}}}{1 + p_1 e^{-p_2 E_{eff}}}$$

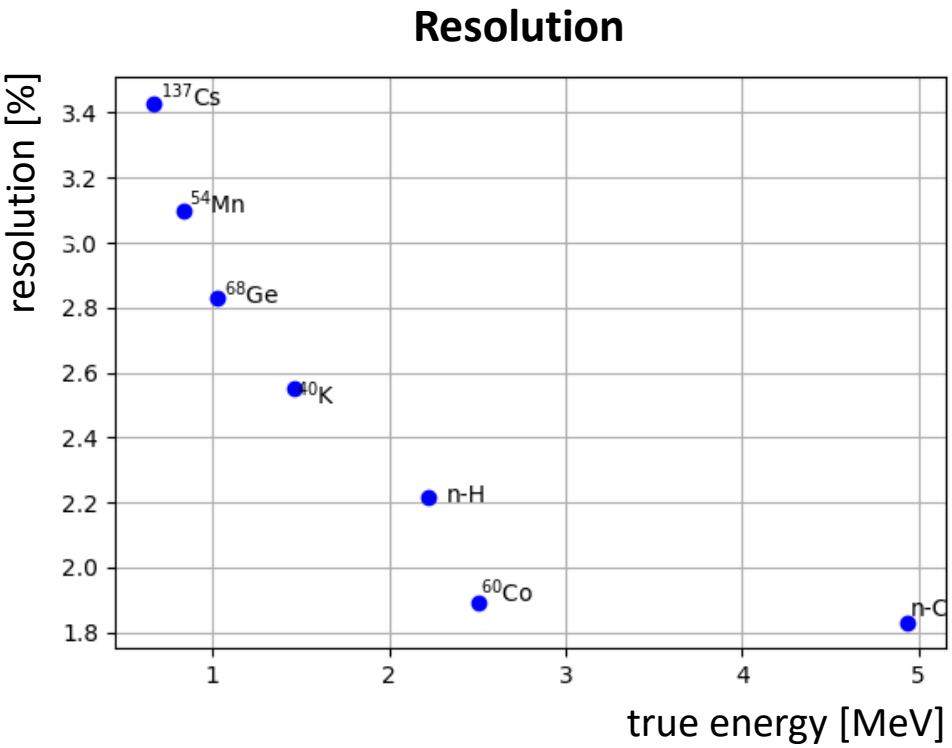
Non linearity curve – Normalization at 2.22 MeV



*A. Abusleme et al., "Calibration strategy of the JUNO experiment", JHEP 03 (2021) 004, arXiv: 2011.06405

Resolution

- Resolution as $\frac{\sigma}{Mean} \cdot 100$, depending on true energy

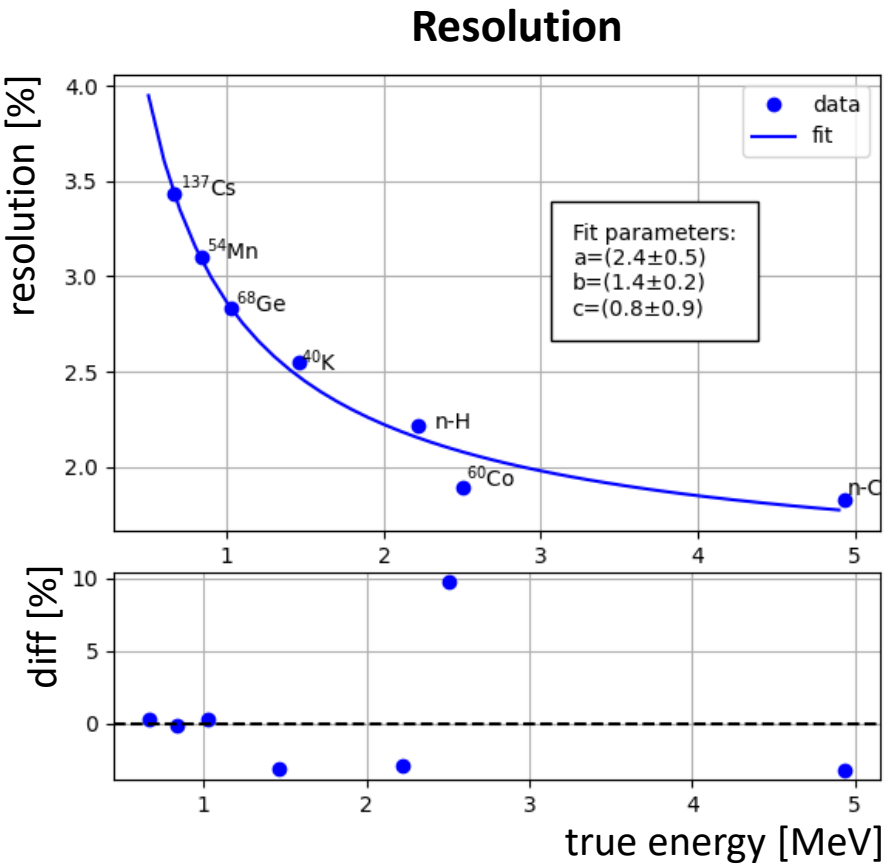


Resolution

- Resolution as $\frac{\sigma}{Mean} \cdot 100$, depending on true energy
- Fit through the function*:

$$\frac{\sigma_{E_{vis}}}{E_{vis}} = \sqrt{\left(\frac{a}{\sqrt{E_{vis}}}\right)^2 + b^2 + \left(\frac{c}{E_{vis}}\right)^2}$$

- Resolution near 3% at 1 MeV



*A. Abusleme et al., "Calibration strategy of the JUNO experiment", JHEP 03 (2021) 004, arXiv: 2011.06405

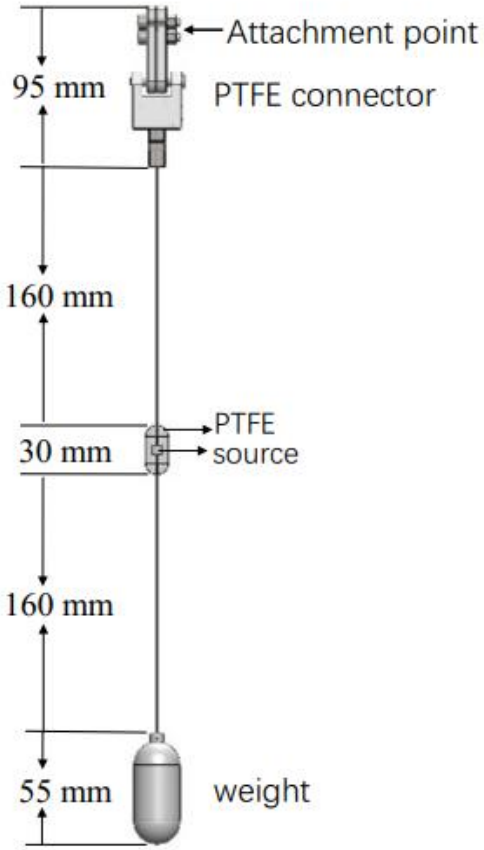
Conclusions

- Analisis of the response of the detector to calibration sources
- Estimation of the centroid and width of the photopeak through a fit
- For now we used the B6 function to include the tail in the fit
- Study of non linearity (at most at 7%) and resolution (around 3% at 1 MeV)
- Our next goal is to fit the spectrum including the PDF of the tail from the Montecarlo

Thank you for the attention!

Backup

Assembly

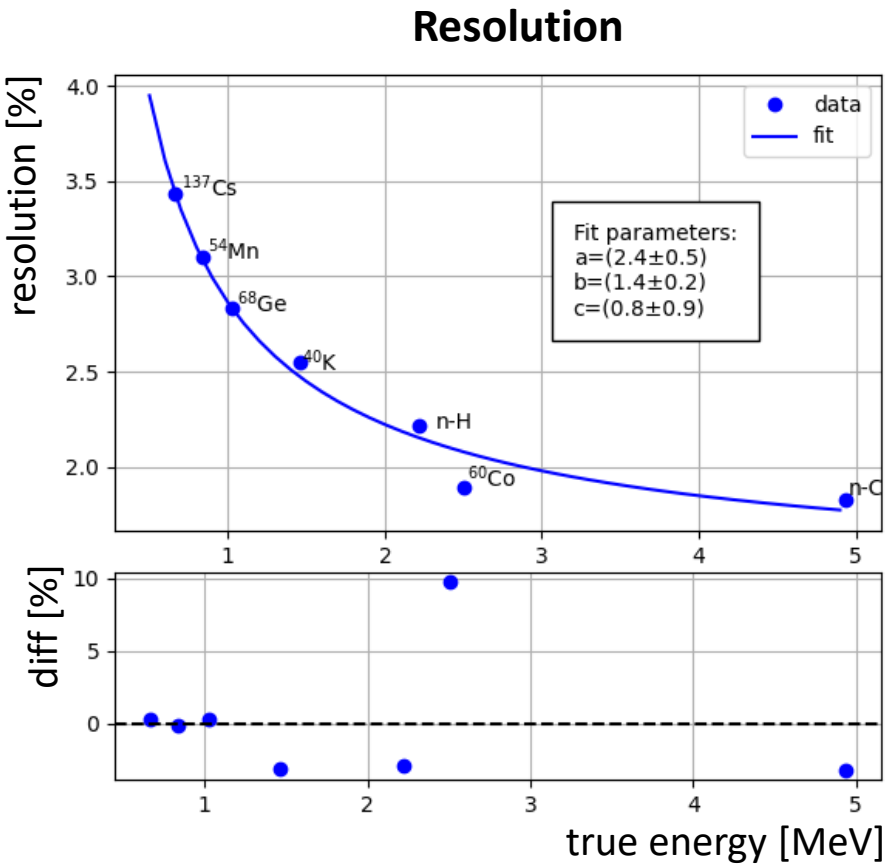

Attachment point
95 mm
PTFE connector
160 mm
PTFE
30 mm
source
160 mm
55 mm
weight

Resolution

- Fit through the function*:

$$\frac{\sigma_{E_{vis}}}{E_{vis}} = \sqrt{\left(\frac{a}{\sqrt{E_{vis}}}\right)^2 + b^2 + \left(\frac{c}{E_{vis}}\right)^2}$$

- a = statistical term, related to the Poissont statistic of number of PE
- b = constant not dependent on energy, dominated by position non-uniformity
- c = contribution of back ground noise i.e. the dark nois from the PMTs



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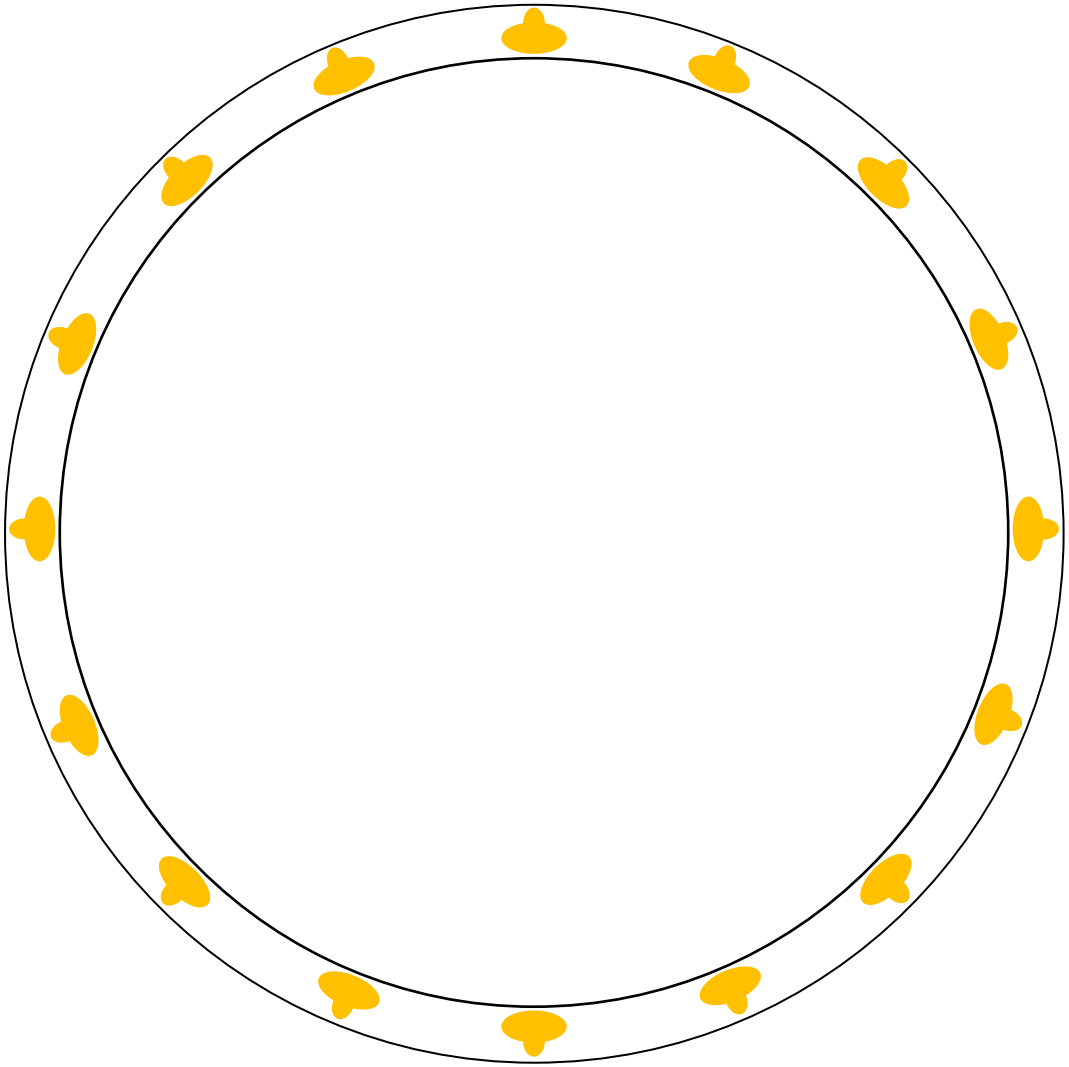
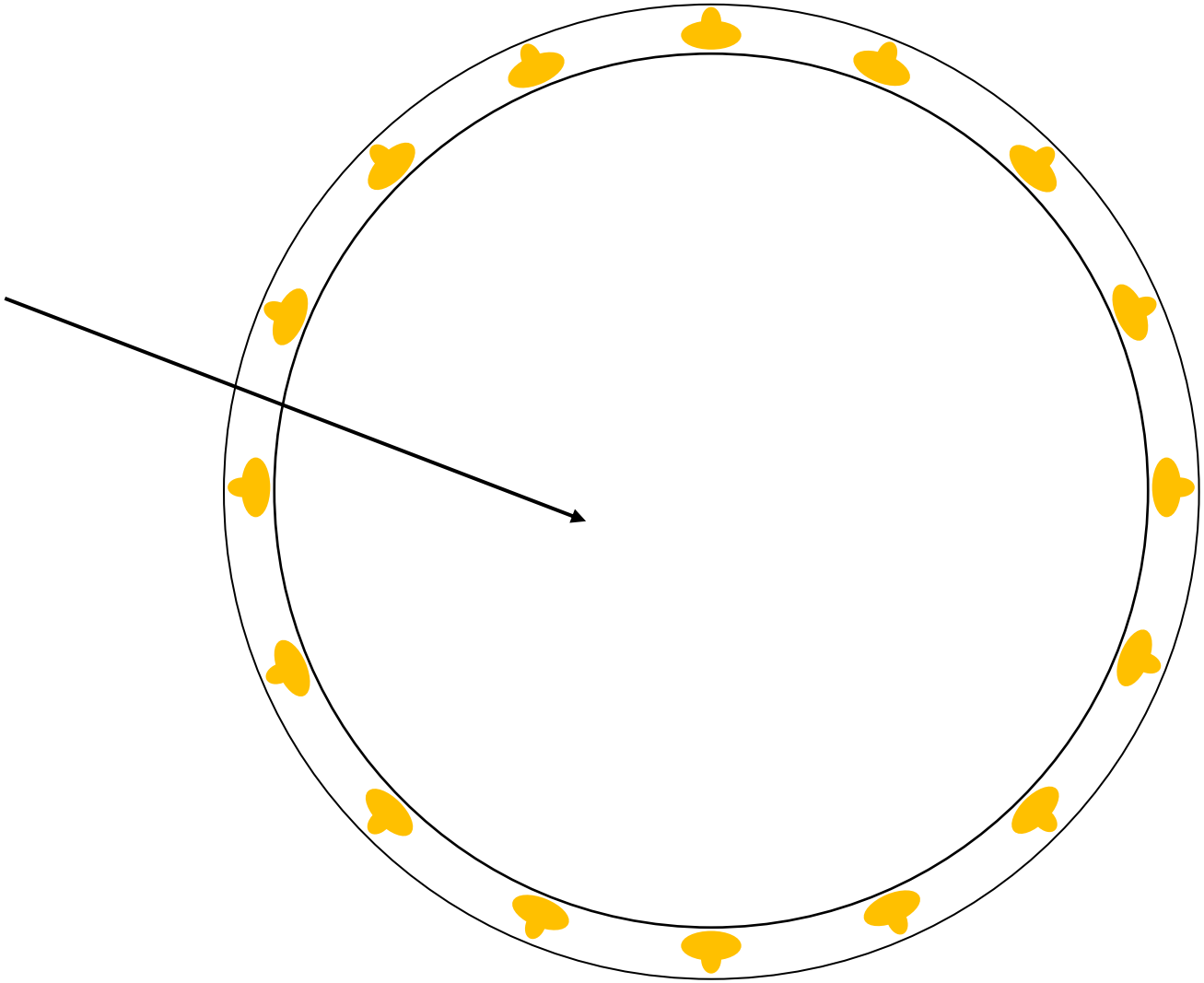
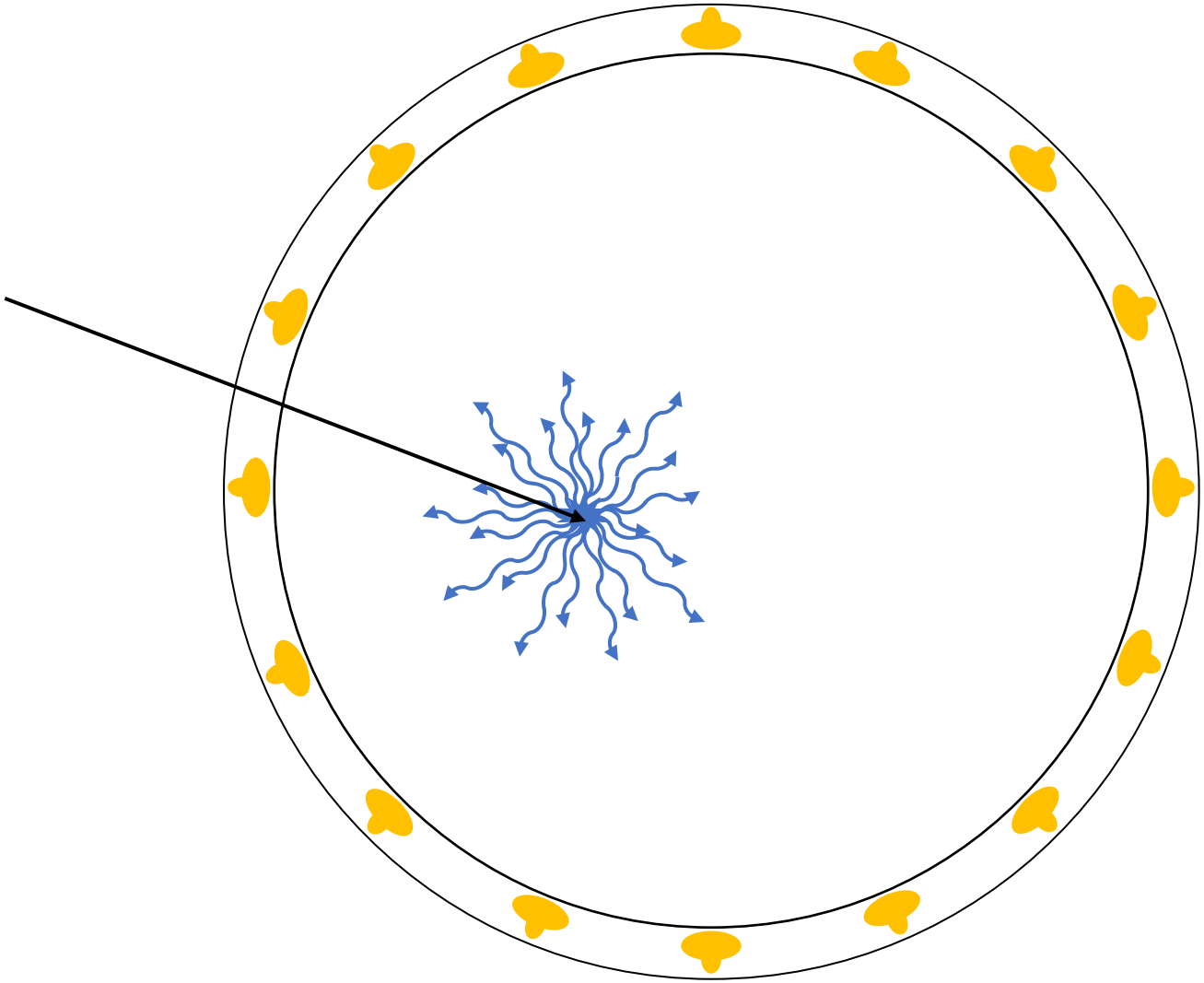


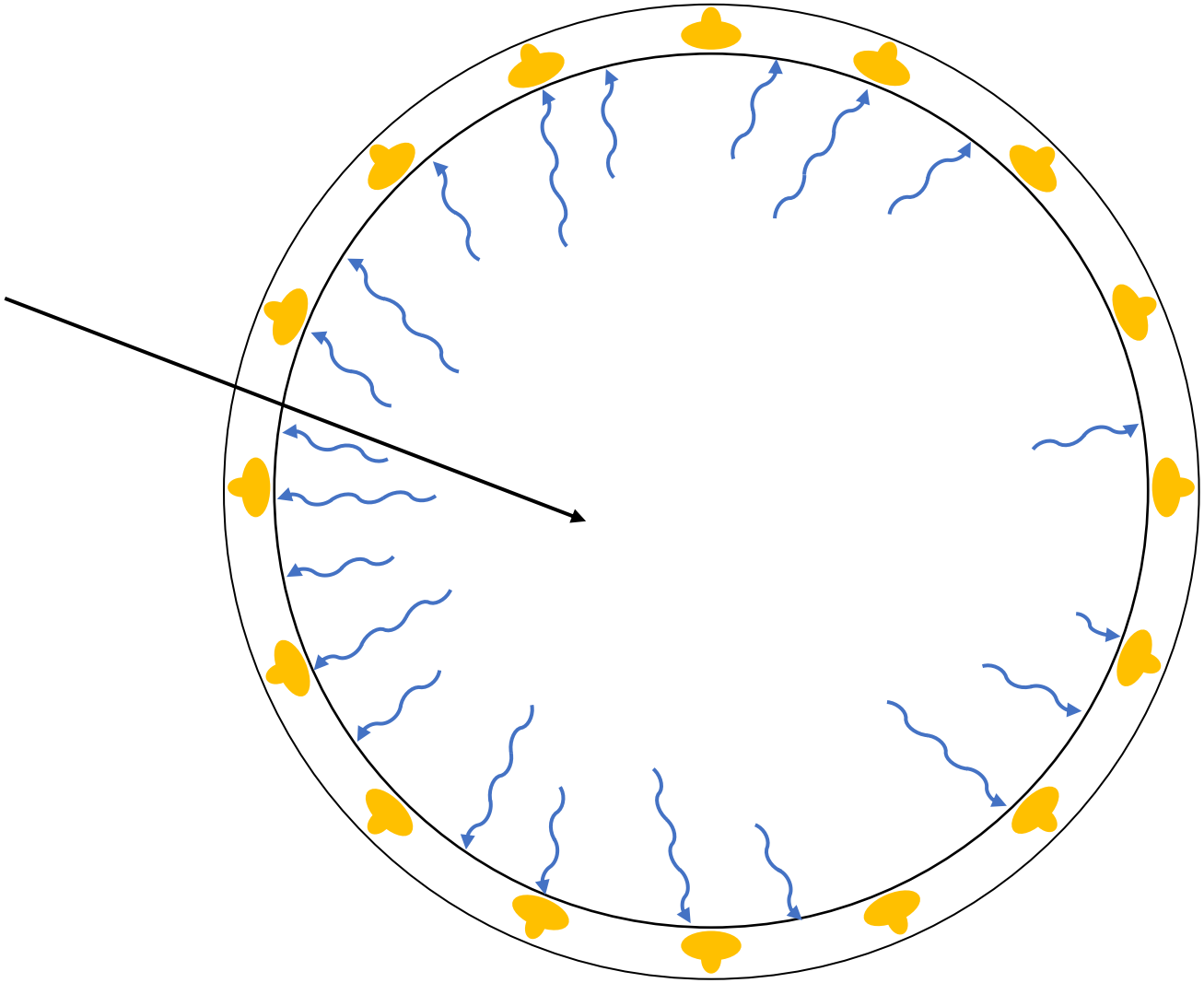
Jiangmen Underground Neutrino Observatory



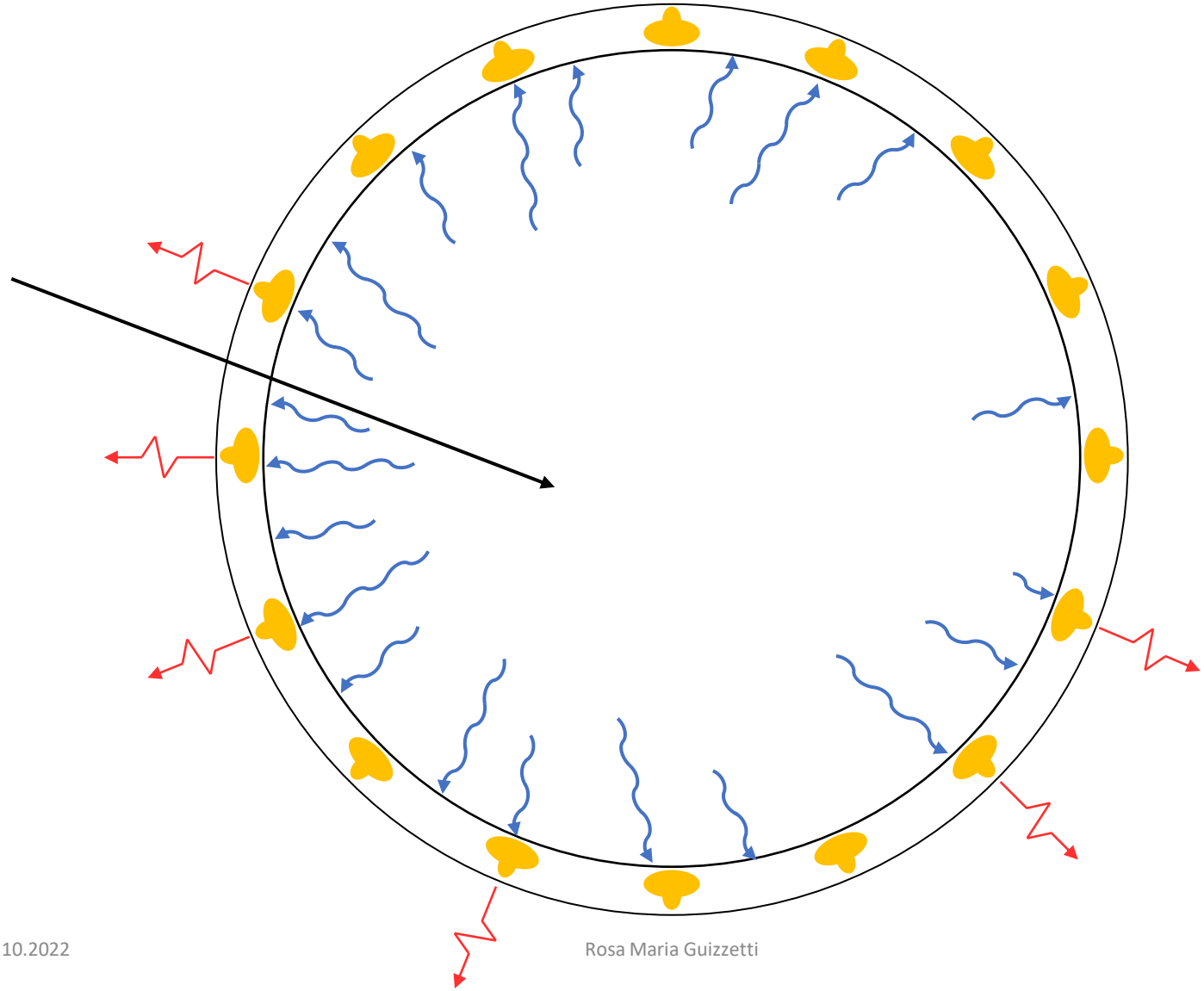
Jiangmen Underground Neutrino Observatory



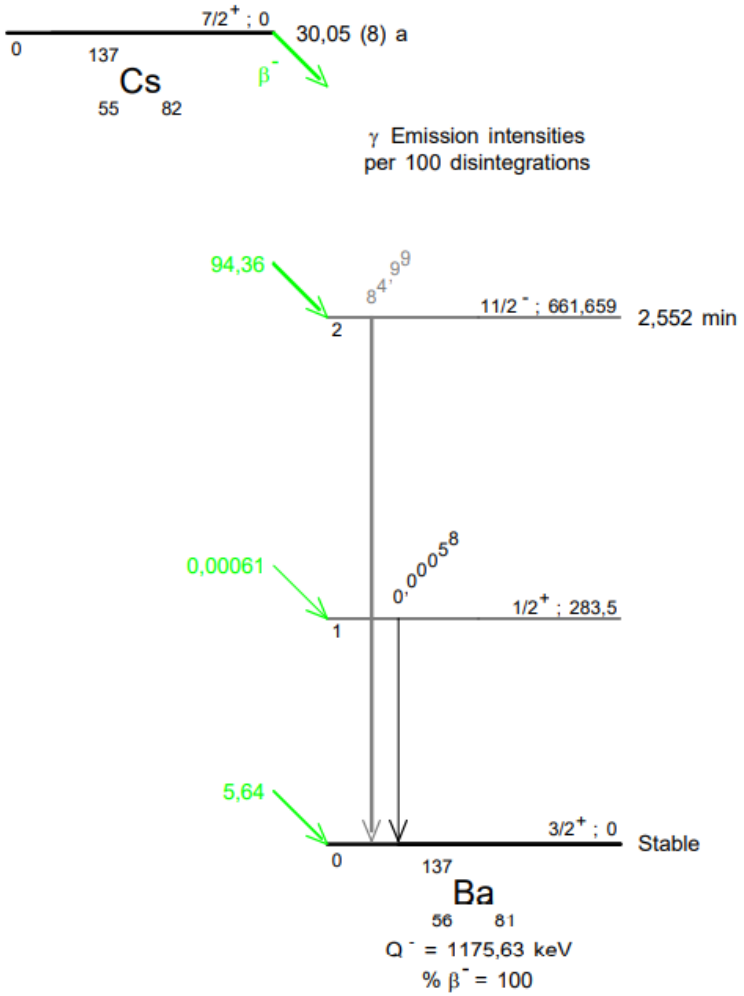
Jiangmen Underground Neutrino Observatory



Jiangmen Underground Neutrino Observatory

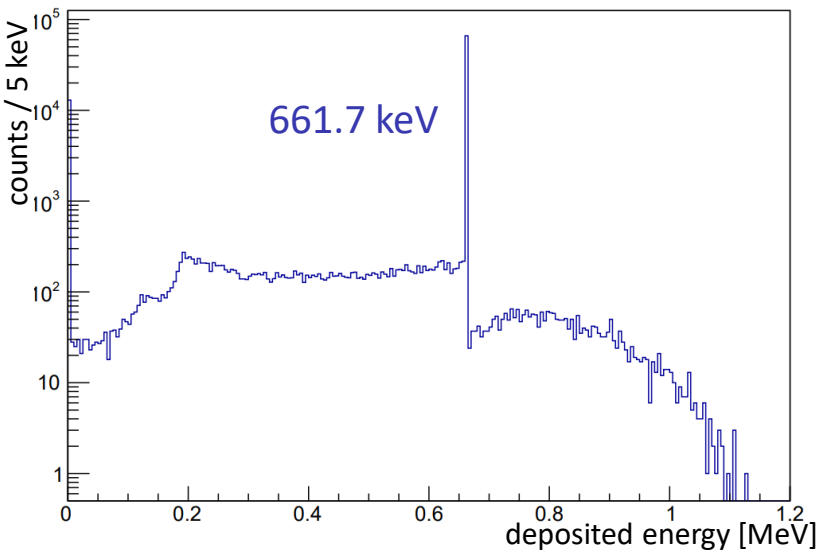


^{137}Cs Decay

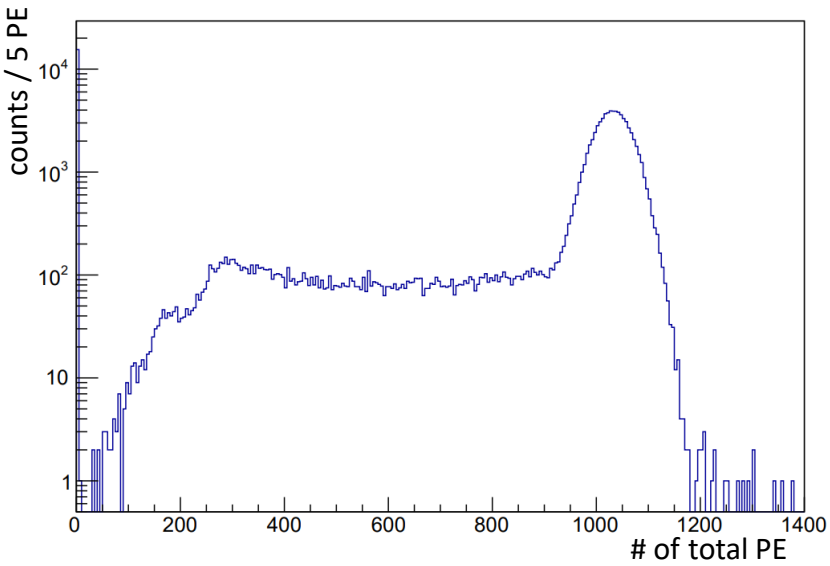

7/2+ ; 0
30,05 (8) a
0
137
Cs
55
82
β-
γ Emission intensities
per 100 disintegrations
94,36
8 4 . 9 9
11/2- ; 661,659
2,552 min
2
0,00061
0 , 0 0 0 5 8
1/2+ ; 283,5
1
5,64
3/2+ ; 0
Stable
0
137
Ba
56
81
Q- = 1175,63 keV
% β- = 100

^{137}Cs Simulation

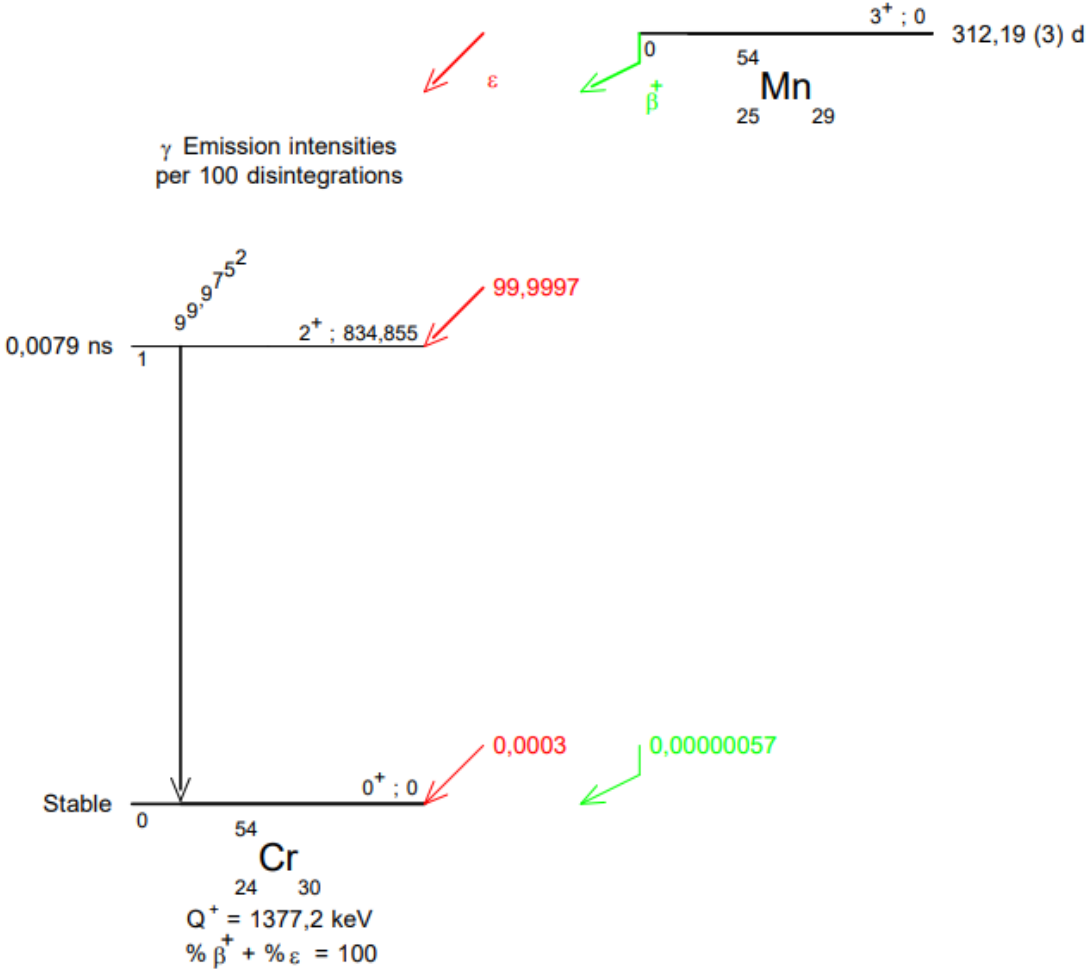
Deposited Energy



Total PE

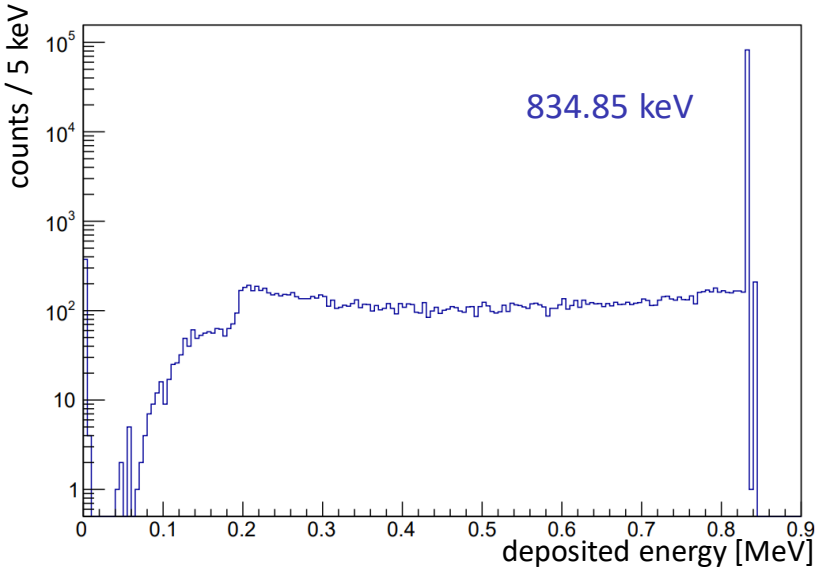


^{54}Mn Decay

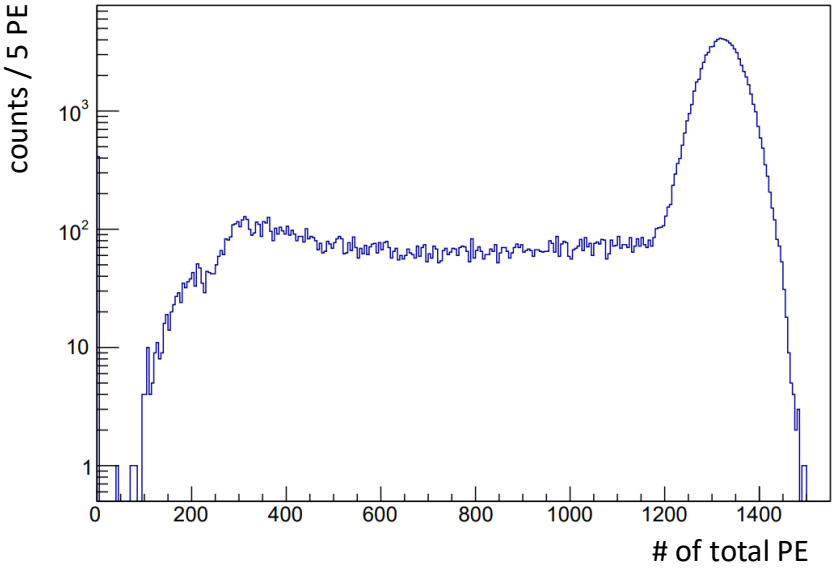

3+ ; 0
312,19 (3) d
0
54
Mn
25
29
ε
β+
γ Emission intensities
per 100 disintegrations
99,9997
0,0079 ns
2+ ; 834,855
1
0,0003
0,00000057
Stable
0+ ; 0
0
54
Cr
24
30
Q+ = 1377,2 keV
%β+ + %ε = 100

^{54}Mn Simulation

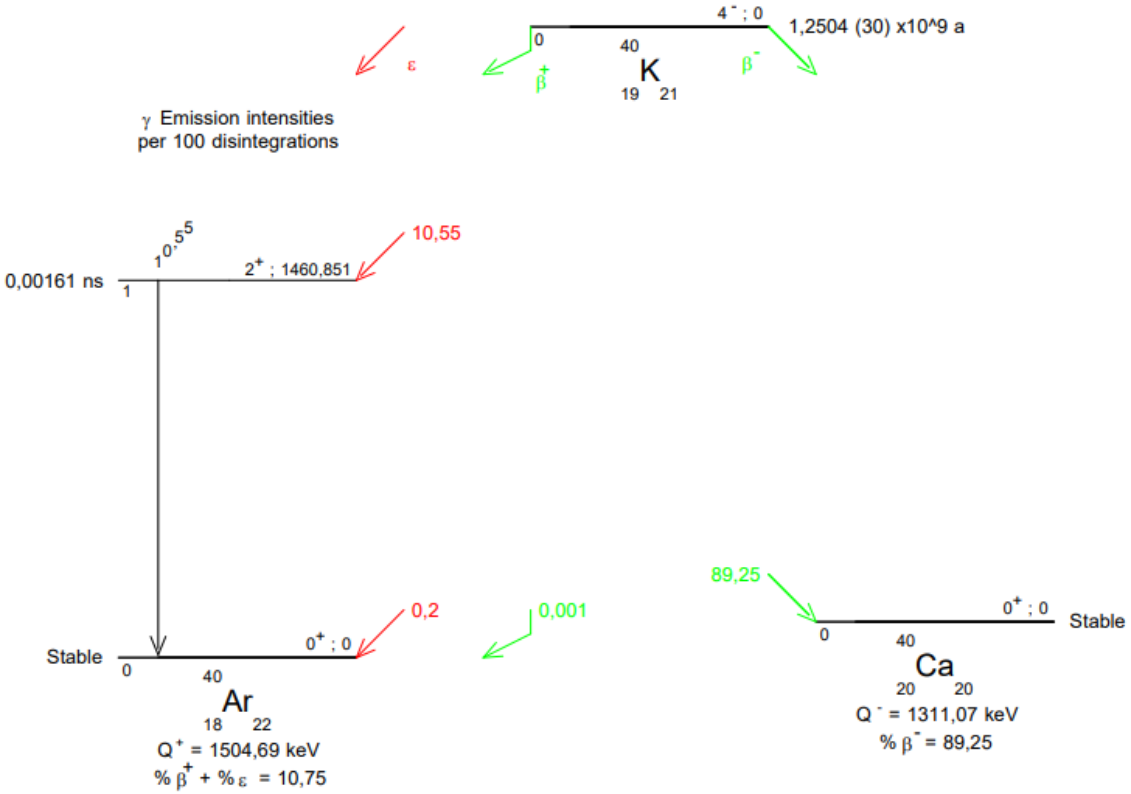
Deposited Energy



Total PE

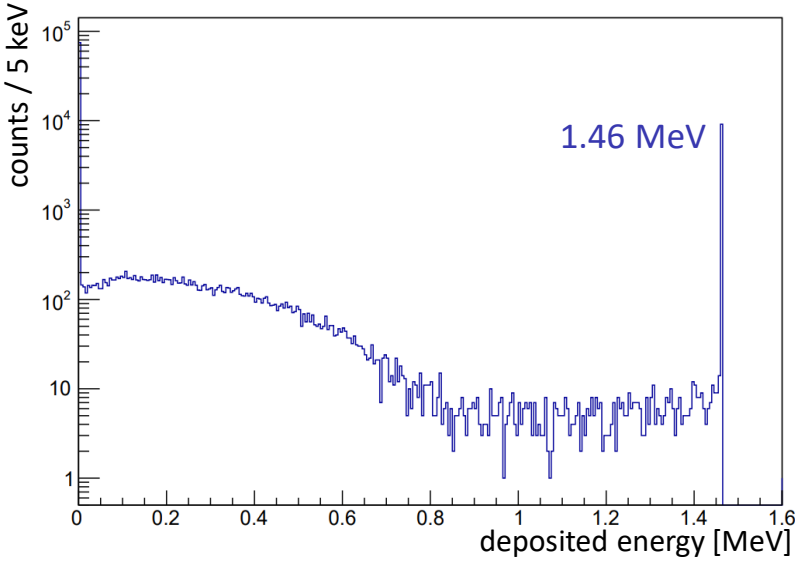


^{40}K Decay

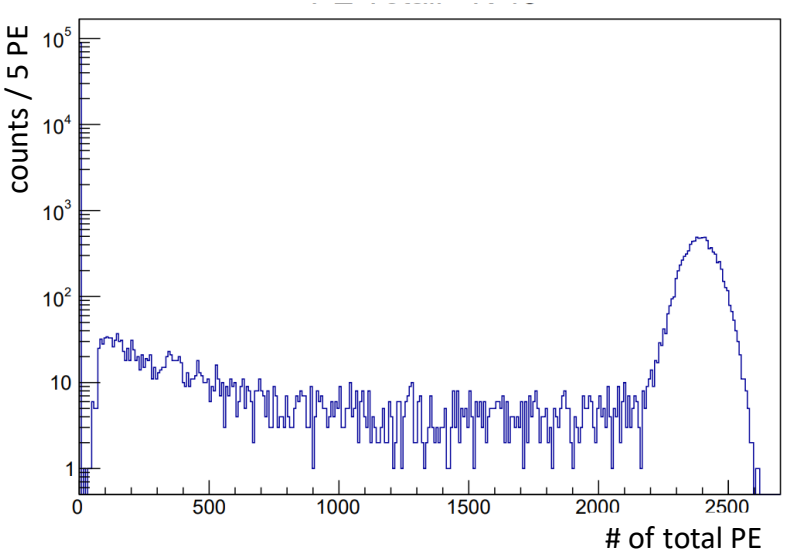

4⁻ ; 0
1,2504 (30) x10^9 a
0
40
K
19
21
ε
β+
β-
γ Emission intensities
per 100 disintegrations
10,55
1,0
5,5
2+ ; 1460,851
0,00161 ns
1
0,2
0,001
89,25
0+ ; 0
Stable
0
40
Ar
18
22
Q+ = 1504,69 keV
% β+ + % ε = 10,75
0+ ; 0
Stable
0
40
Ca
20
20
Q- = 1311,07 keV
% β- = 89,25

^{40}K Simulation

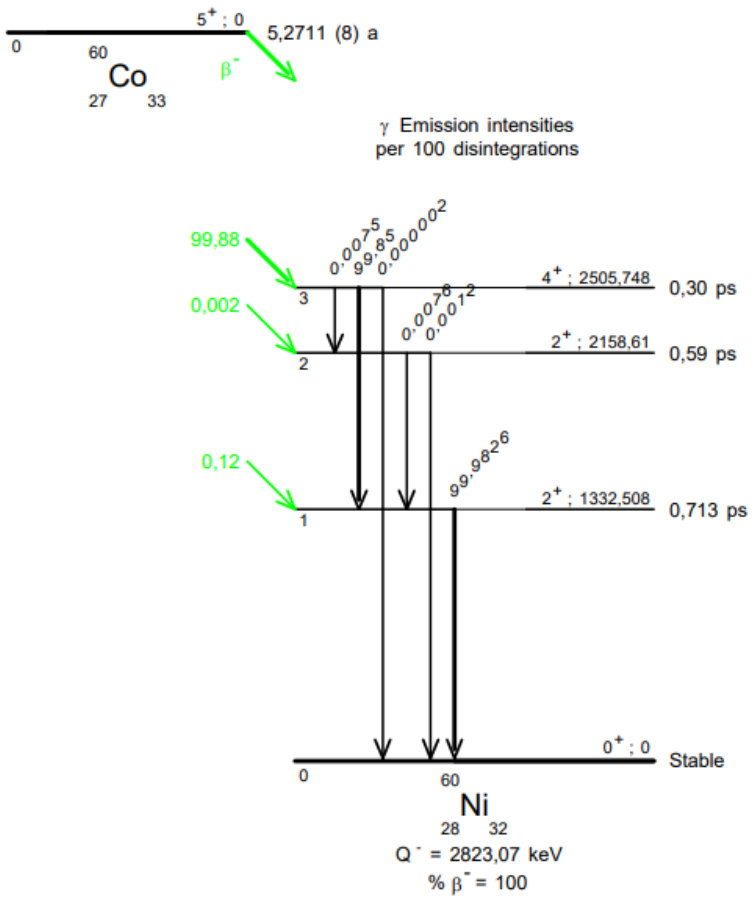
Deposited Energy



Total PE

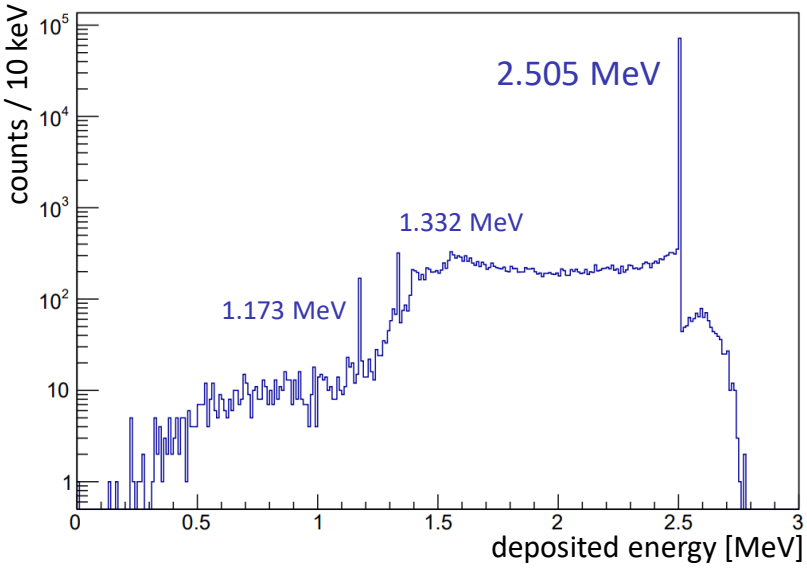


^{60}Co Decay

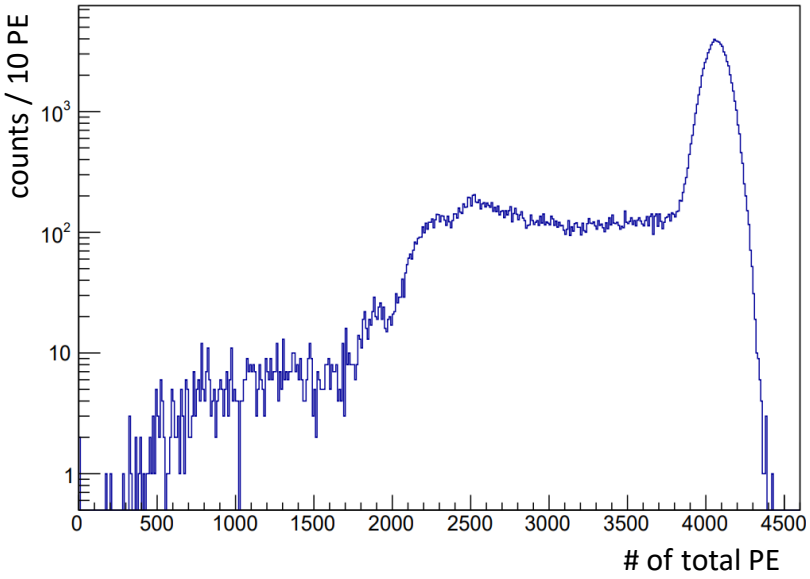

5+ ; 0
5,2711 (8) a
0
60
Co
27
33
β-
γ Emission intensities
per 100 disintegrations
99,88
0,002
0,12
0,0075
99,85
0,00000002
0,0076
0,0012
99,9826
4+ ; 2505,748
0,30 ps
2+ ; 2158,61
0,59 ps
2+ ; 1332,508
0,713 ps
0+ ; 0
Stable
0
60
Ni
28
32
Q - = 2823,07 keV
% β- = 100

^{60}Co Simulation

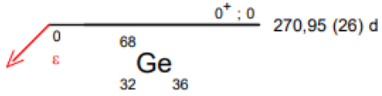
Deposited Energy

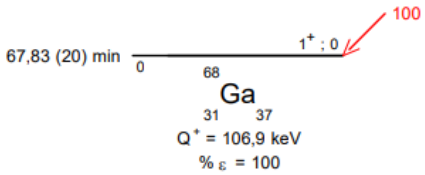


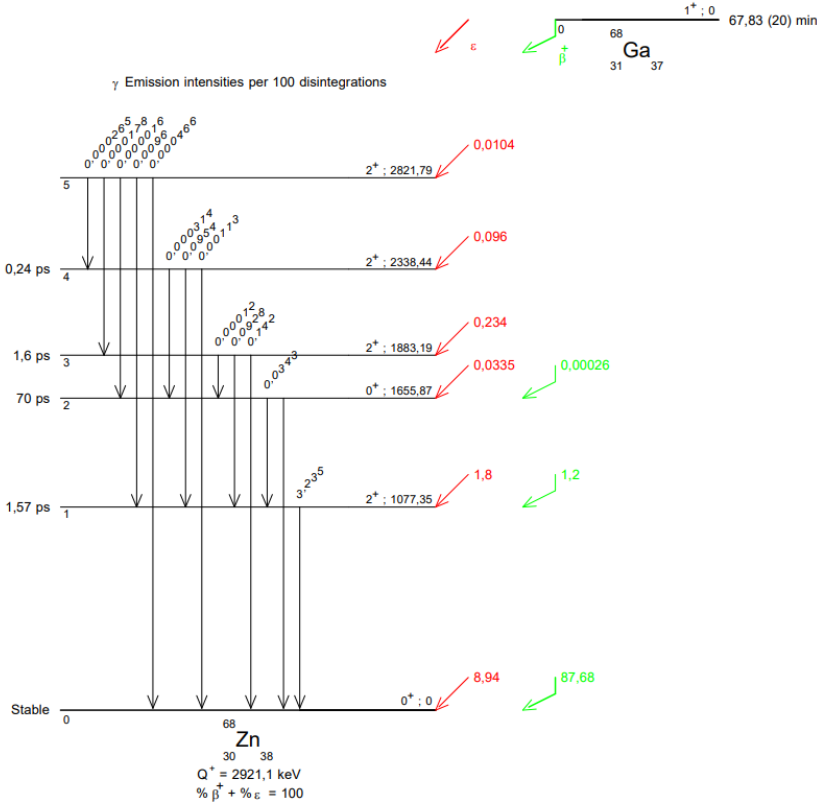
Total PE



^{68}Ge Decay

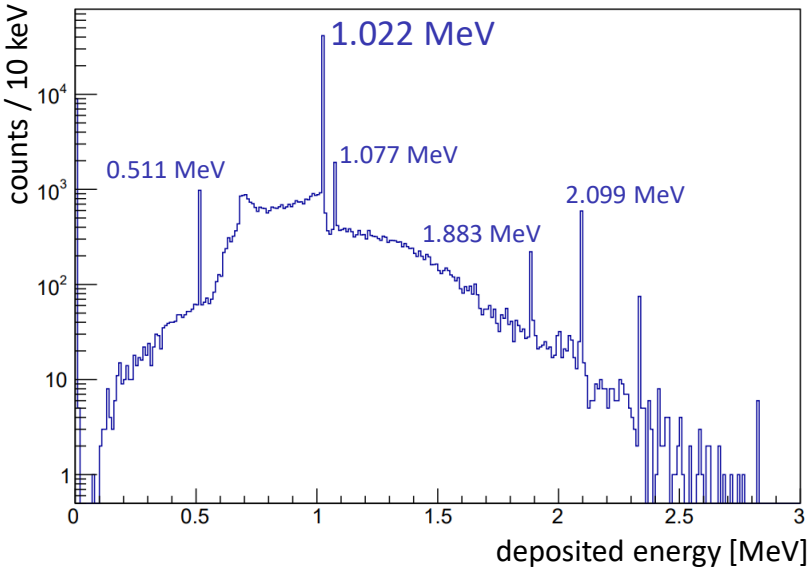

0+ ; 0
270,95 (26) d
0
68
Ge
32
36
ε


67,83 (20) min
1+ ; 0
100
0
68
Ga
31
37
Q+ = 106,9 keV
% ε = 100

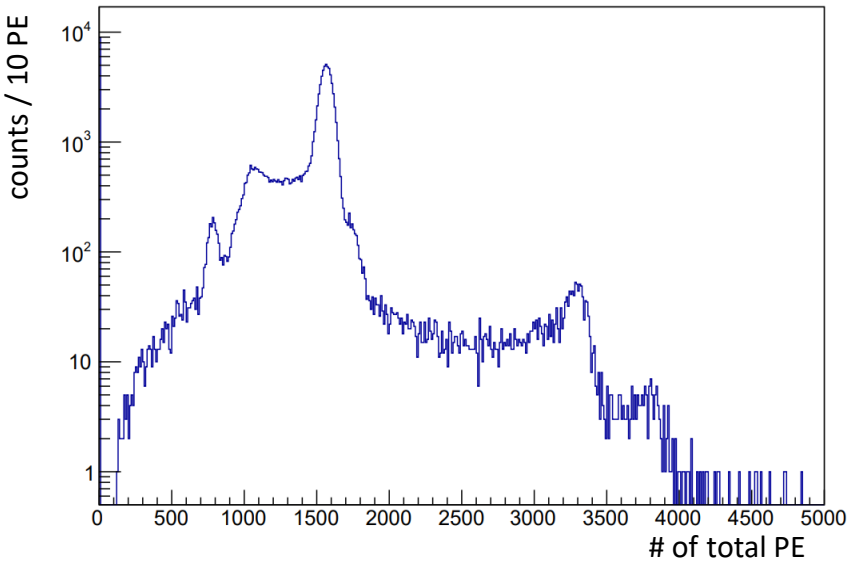

1+ ; 0
67,83 (20) min
0
68
Ga
31
37
ε
β+
γ Emission intensities per 100 disintegrations
2+ ; 2821,79
0,0104
2+ ; 2338,44
0,096
0,24 ps
2+ ; 1883,19
0,234
1,6 ps
0+ ; 1655,87
0,0335
0,00026
70 ps
2+ ; 1077,35
1,8
1,2
1,57 ps
0+ ; 0
8,94
87,68
Stable
68
Zn
30
38
Q+ = 2921,1 keV
% β+ + % ε = 100

^{68}Ge Simulation

Deposited Energy

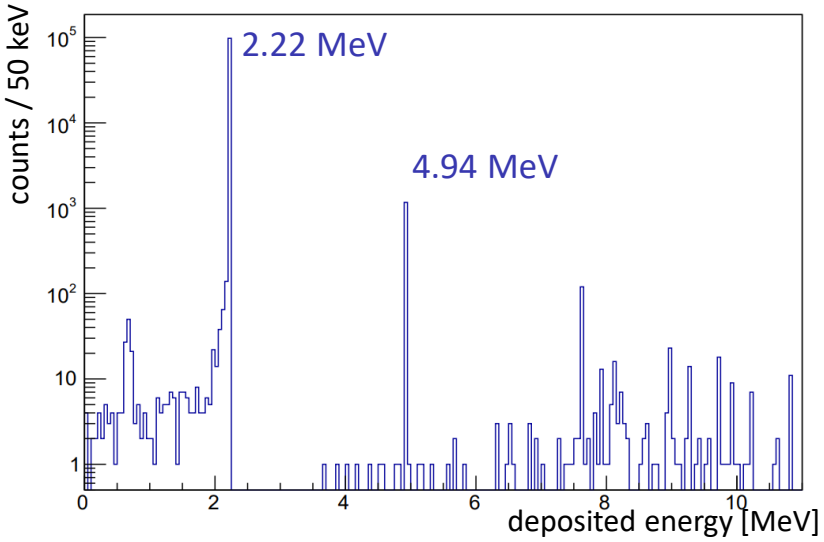


Total PE

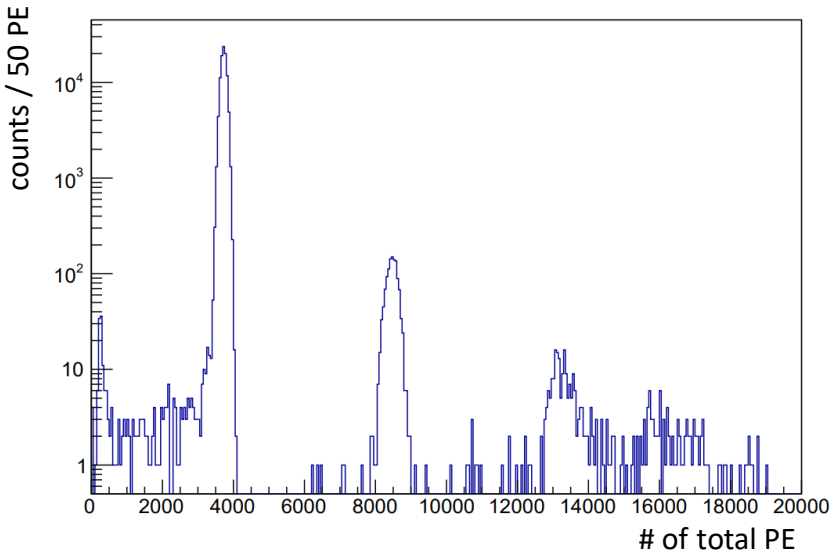


Simulation of neutrons with momentum p = 1 MeV

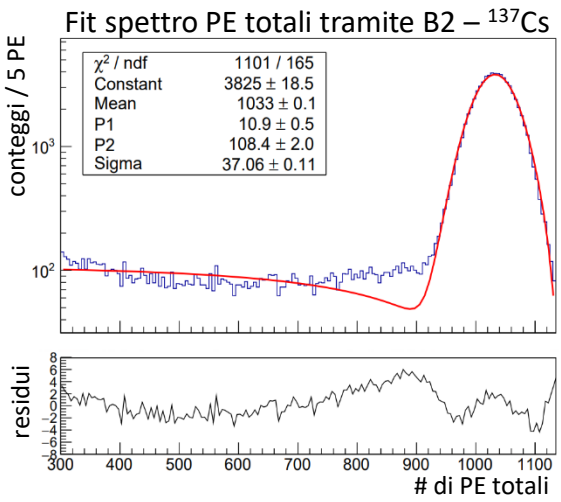
Deposited Energy

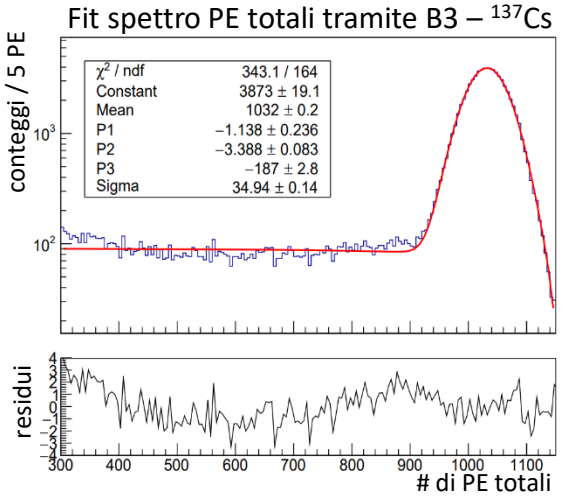


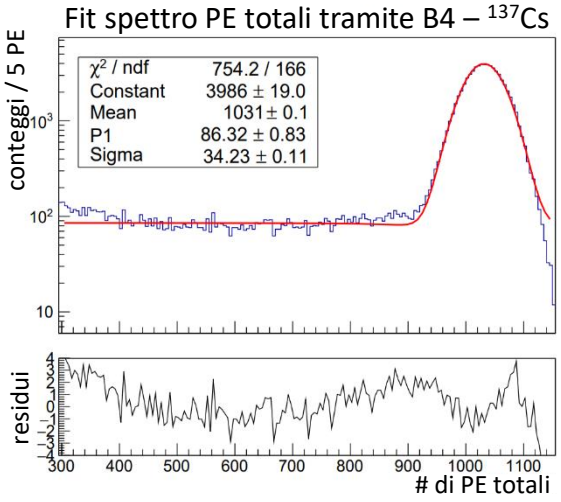
TotalPE

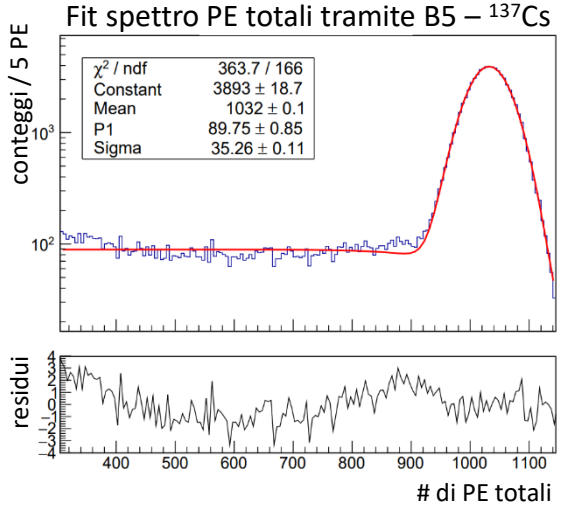


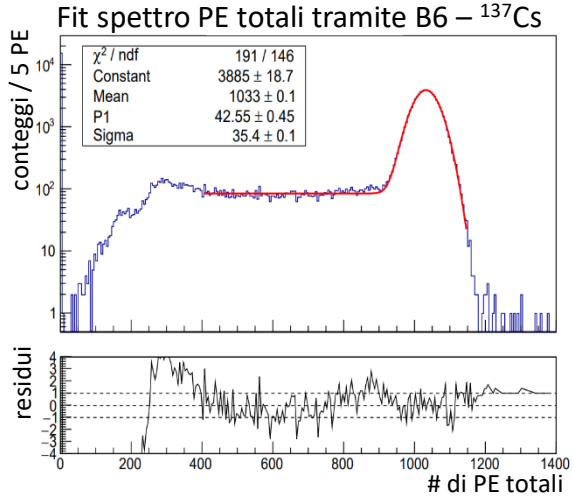
Fit through functions that include the tail - ^{137}Cs

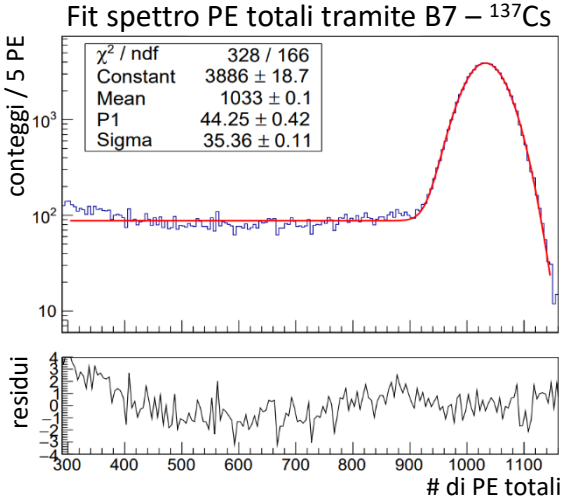






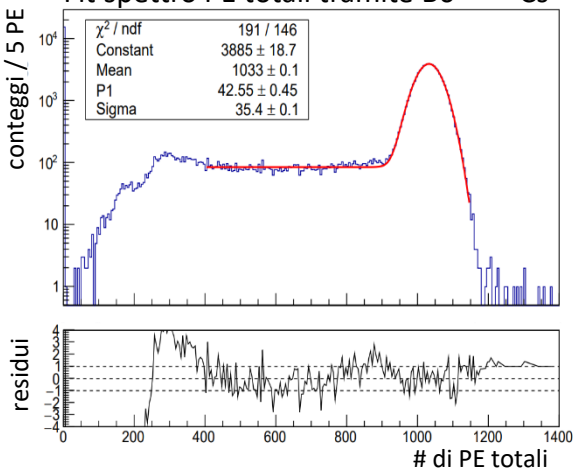




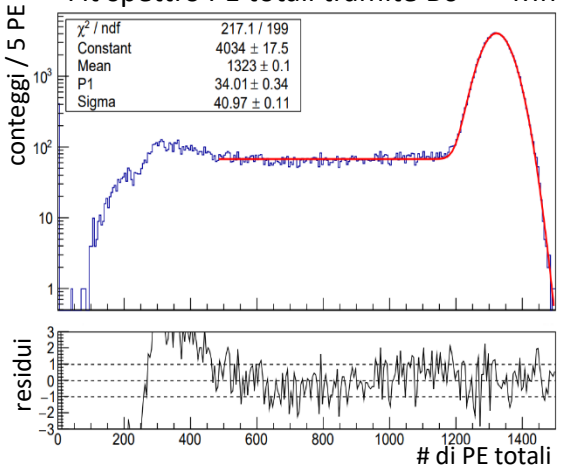


Fit through B6

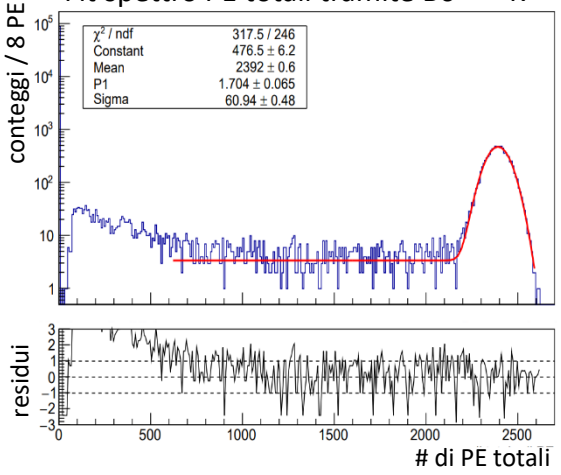
Fit spettro PE totali tramite B6 – ^{137}Cs



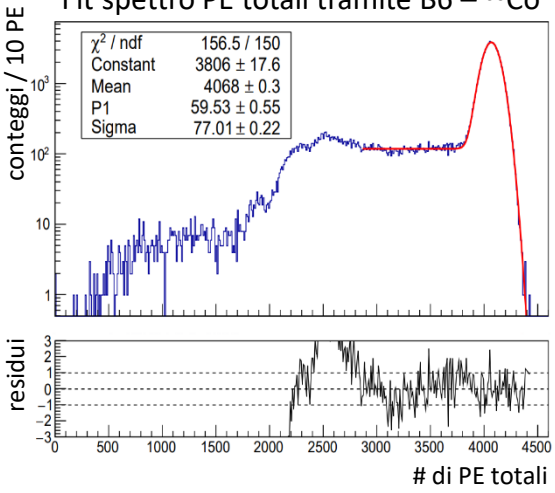
Fit spettro PE totali tramite B6 – ^{54}Mn



Fit spettro PE totali tramite B6 – ^{40}K



Fit spettro PE totali tramite B6 – ^{60}Co



Fit spettro PE totali tramite B6 – ^{68}Ge