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Temperature Dependence of $CdMoO_4$ Scintillation Properties

--- a new material for Neutrinoless Double Beta Decay

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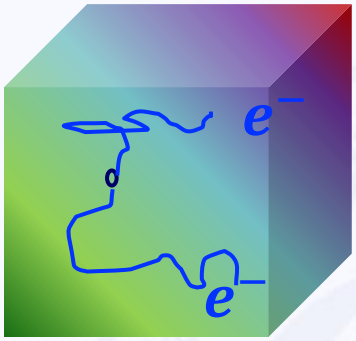
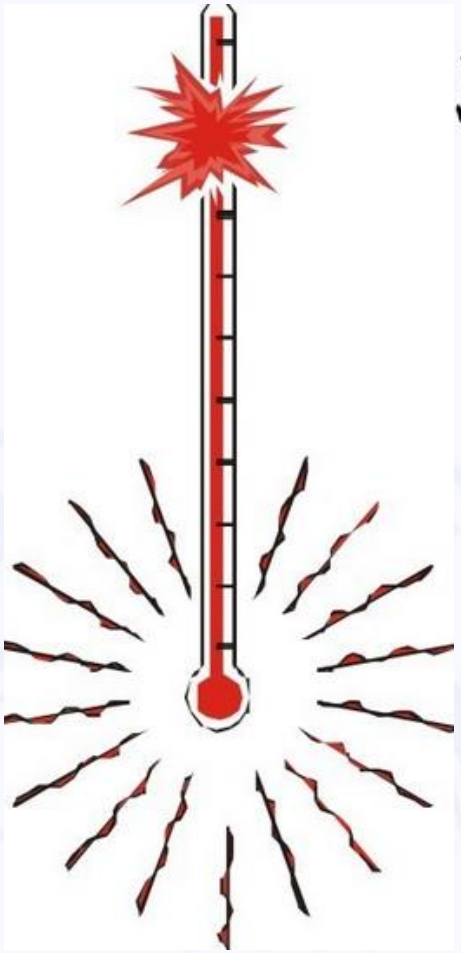
August, 2016

Outline

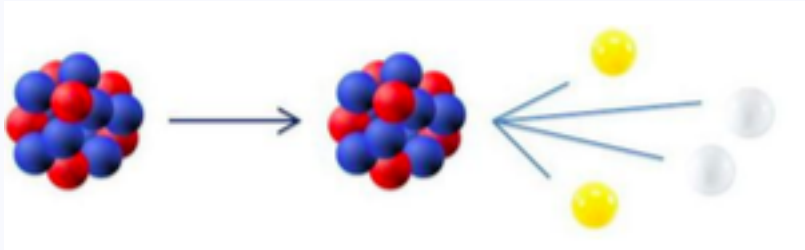
- Motivation
- Research Method
- Present Work
- Conclusion
- Next to do

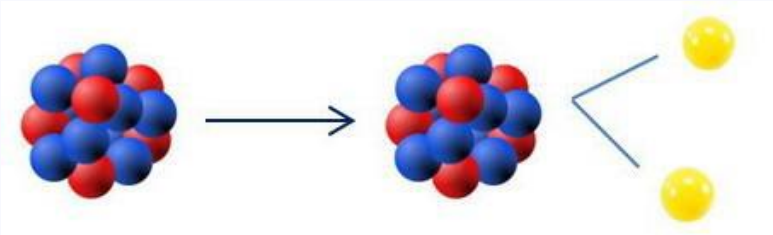


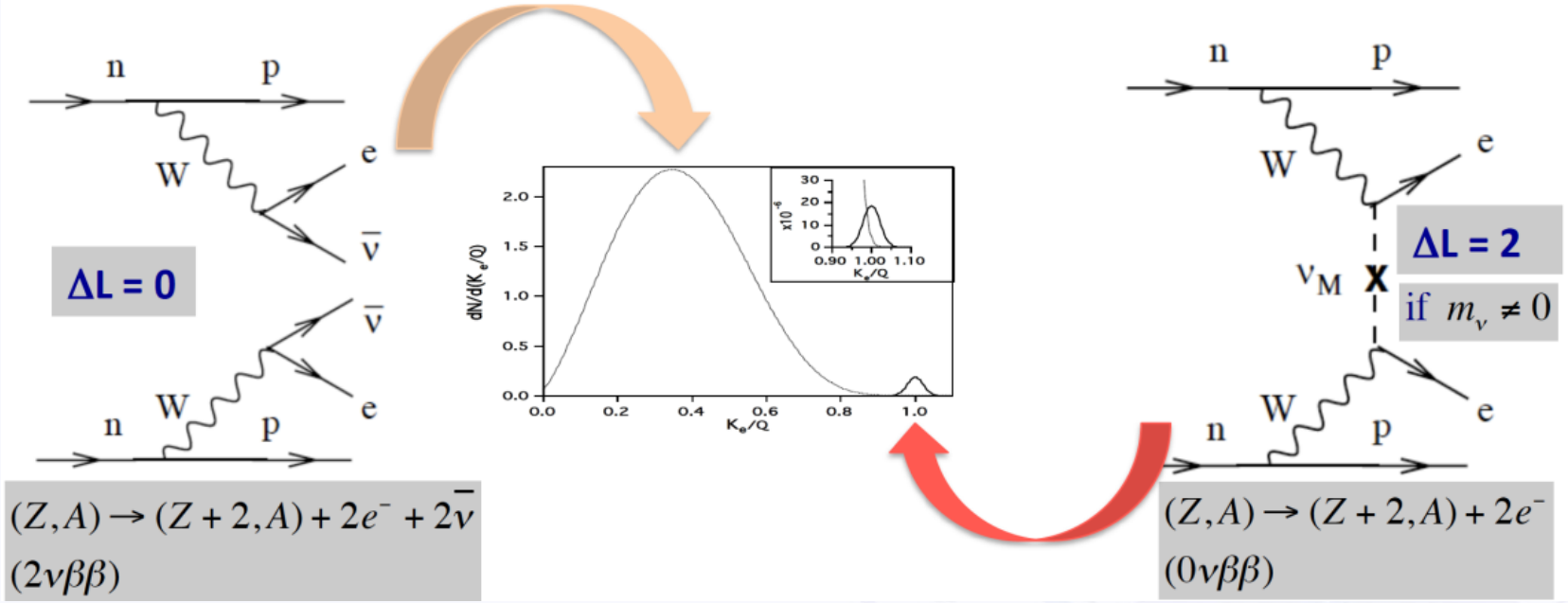


Motivation

Neutrinoless double beta decay (0vDBD)







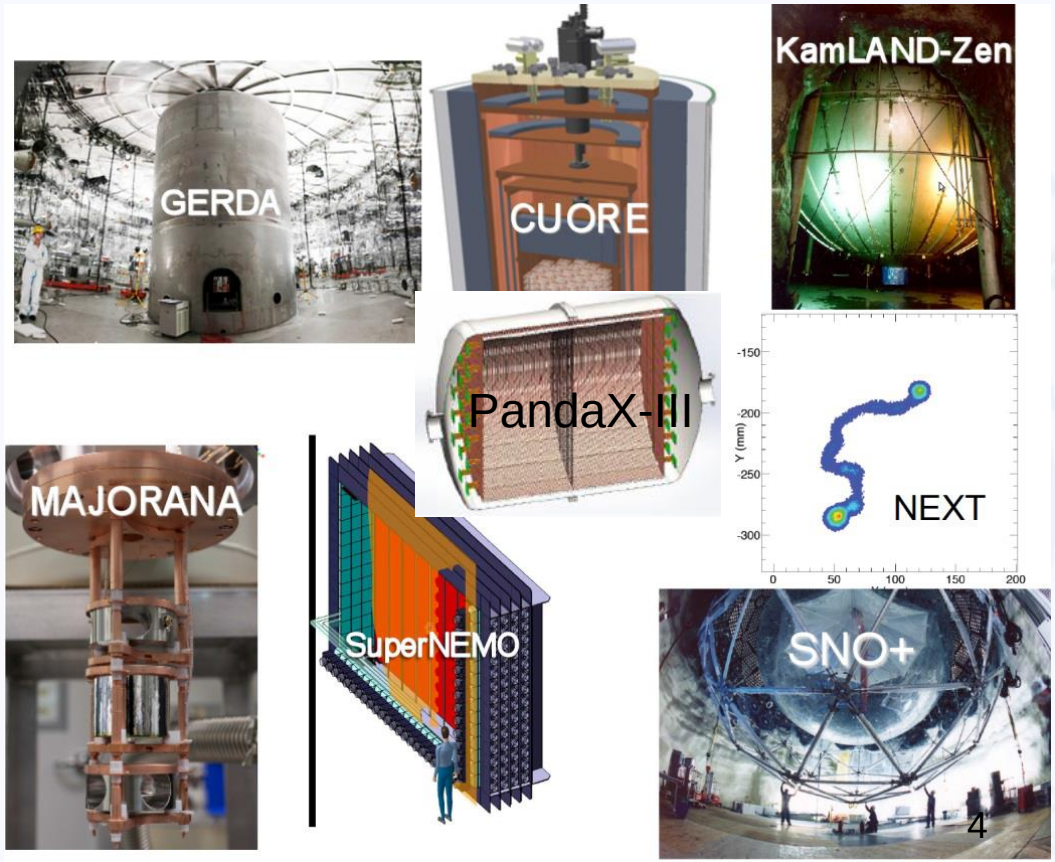
$\nu_e \neq \bar{\nu}_e \quad m_{\nu_e} = 0$ Dirac

$\nu_e = \bar{\nu}_e \quad m_{\nu_e} \neq 0$ Majorana

Why 0vDBD is important

- $\Delta L = 2$ new physics beyond SM
- Absolute neutrino mass scale (ν oscillations give only $m^2(\nu_i) - m^2(\nu_j)$)
- ν is Majorana or Dirac particle (Majorana gives see-saw mechanism to explain smallness of ν masses)……

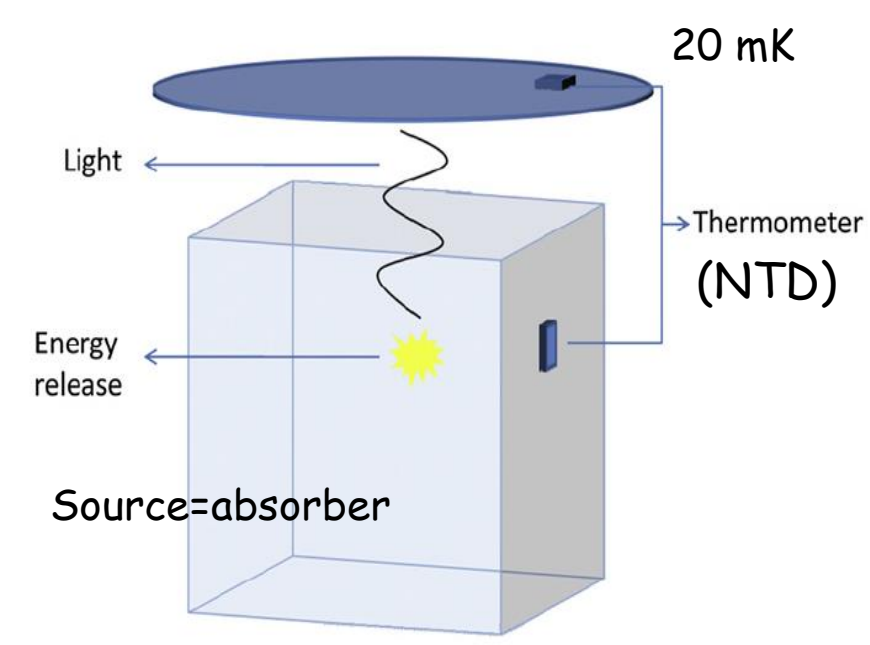
Next generation of 0vDBD experiments will use different technologies and approaches:



Research Method

Detector choice

bolometers = low temperature calorimeters



Scintillating bolometers

Properties of bolometers

- Wide choice of different absorber material
- High energy resolution FWHM
- Low energy threshold for particle detection
- Particle identification capability in hybrid measurements of heat-light or hear-ionization energies.

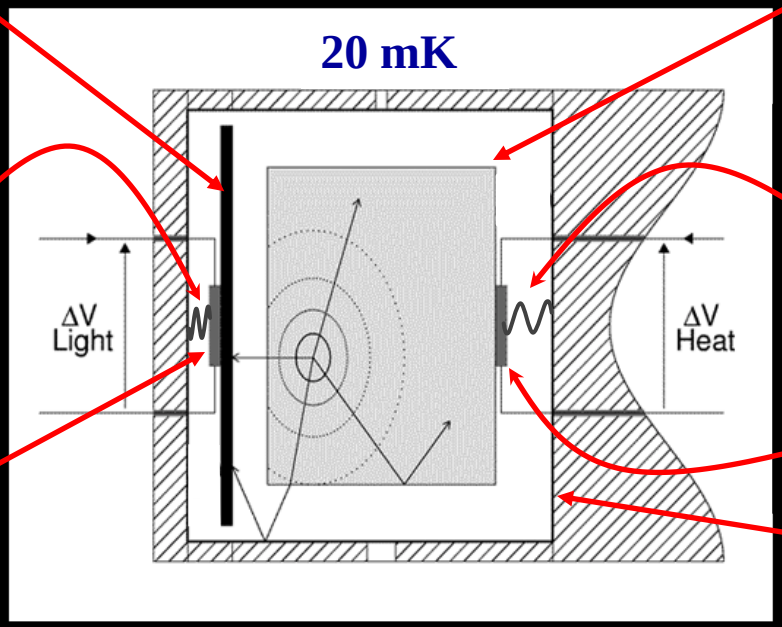
- tech. suggested in 1985 by E. Fiorini and T.O. Niinikoski
- the first Te detector worked in 1989
- first bolometric DBD experiment in 1997
- predecessor of CUORICINO : 20 crystal array (MiDBD)
- other applications: Dark Matter detection (CDMS, Edelweiss, CRESST)

The Scintillating Bolometer

Optical bolometer (Ge disk)

Cu frame

Scintillating crystal (absorber)



Thermal link

Thermal link

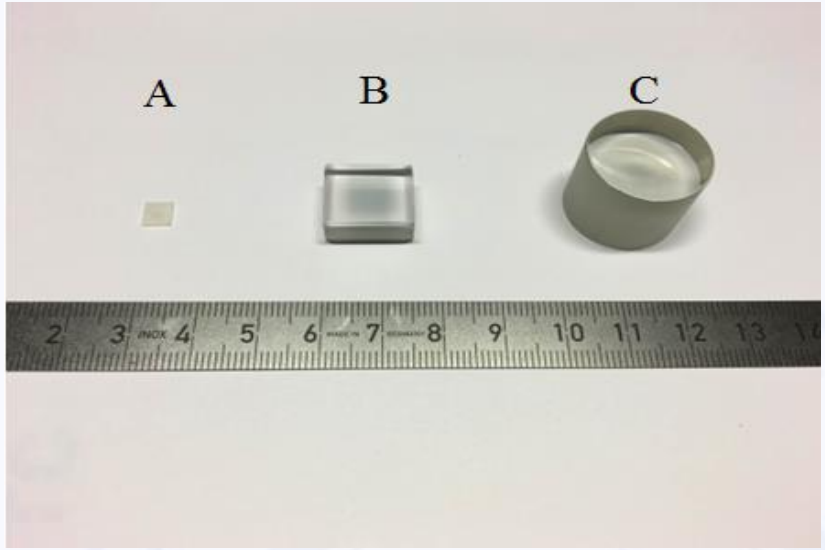
Ge-NTD thermistor

Ge-NTD thermistor

Internal reflecting cavity (Cu coated with Ag)

Properties of $^{100}_{42}Mo$ and $^{116}_{48}Cd$

Isotope	Qββ (MeV)	Isotopic abundance (%)	
48Ca	4.27	0	
76Ge	2.04	7.8	
82Se	3	9.2	
96Zr	3.35	2.8	
100Mo	3.03	9.6	✓
116Cd	2.8	7.5	✓
128Te	0.87	31.7	
130Te	2.53	34.5	
136Xe	2.48	8.9	
150Nd	3.37	5.6	



$CdMoO_4$ crystal from NingBo University

Present Work

Simulation

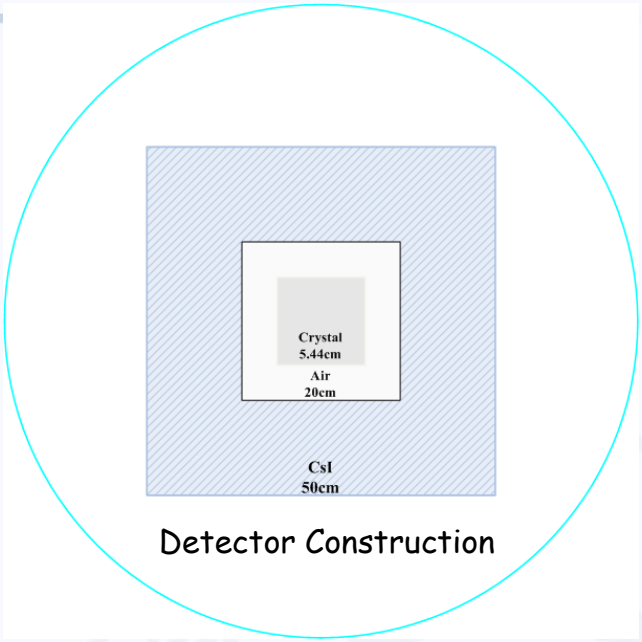
Crystal: $CdMoO_4$

NingBo University:

$\phi 20.8 \times 16.5mm$

$M = 34.8g$

Density: $6.207 g/cm^3$



Detector Construction

1kg 100% enriched $^{116}Cd^{100}MoO_4$

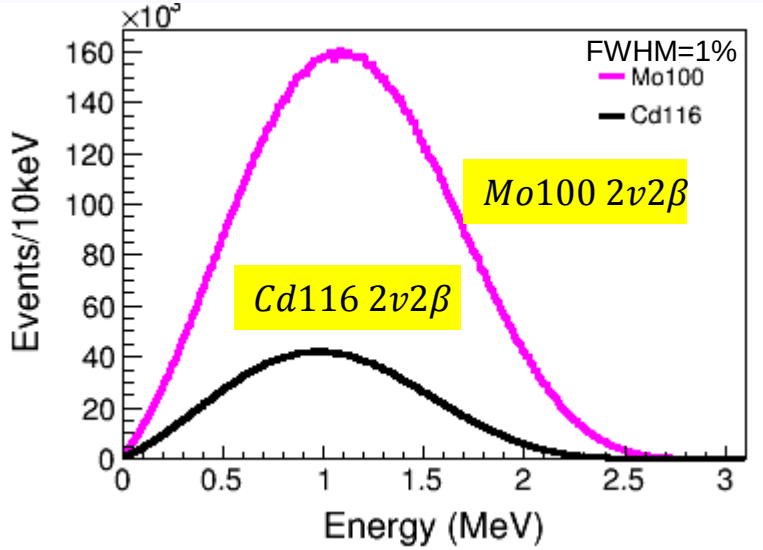
Parent Isotope	$T_{1/2}$ (years)	t = 100(years)
^{100}Mo	2νββ $(7.1 \pm 0.4) \times 10^{18}$	2.0996641×10^7
	0νββ 1.1×10^{24}	136
^{116}Cd	2νββ $(2.9 \pm 0.2) \times 10^{19}$	5.140557×10^6
	0νββ $> 1.7 \times 10^{23}$	878

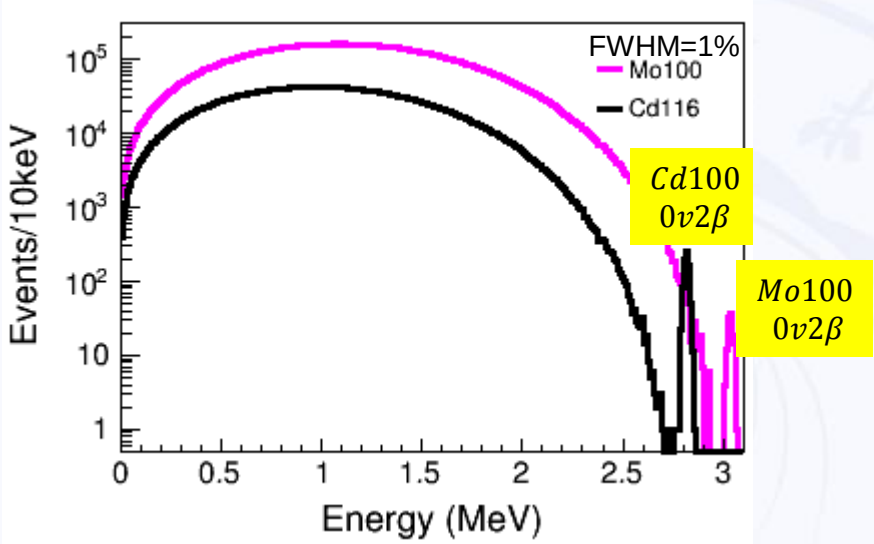
V. Tretyak - DECAY0 event generator for initial kinematics of particles in alpha, beta and double beta decays

Date/Time: Tuesday, 17 March 2015 - 14:30 (Europe/Rome)
Location: LNGS (Pontecorvo room)
Chairperson: Vladimir I. Tretyak (Institute for Nuclear Research Kyiv)
Info: massimo.mannarelli@lngs.infn.it

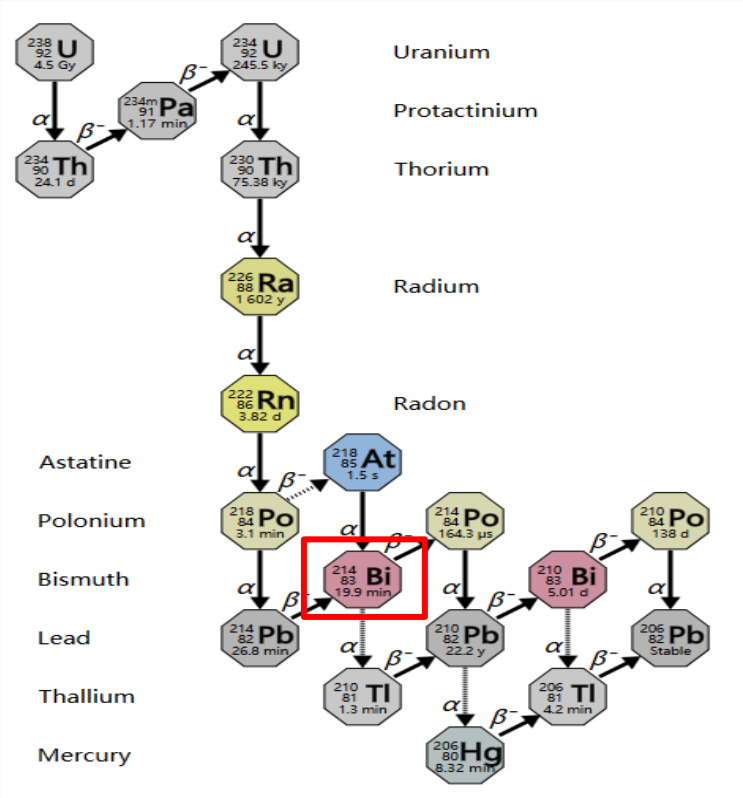
Національна Академія Наук України
Інститут ядерних досліджень
Відділ фізики лептонів
Lepton Physics Department
Institute for Nuclear Research
National Academy of Sciences, Ukraine

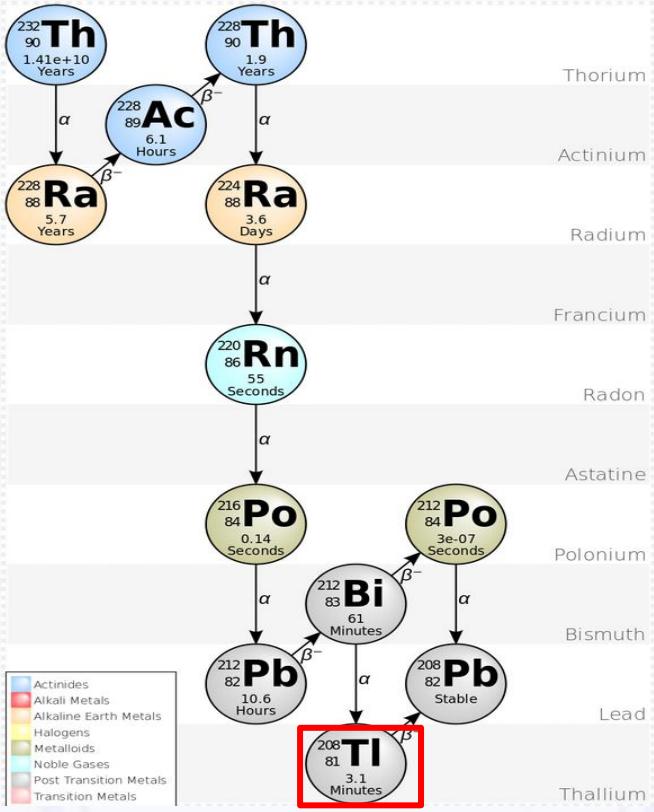
- For the decay process of $^{100}_{42}Mo$ and $^{116}_{48}Cd$, the initial kinematics of the two emitted electrons are given by DECAY0 event generator.





Internal backgrounds (U/Th chains)





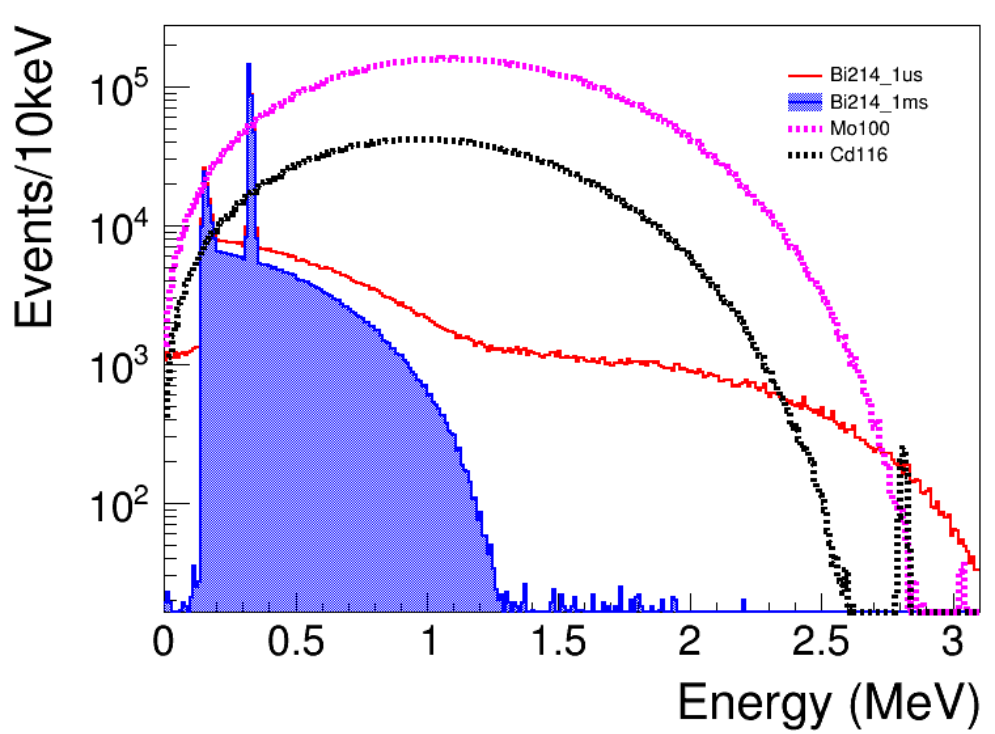
Backgrounds ^{214}Bi (U-238 chain) and ^{208}Tl (Th-232 chain) 0.1mBq/kg:

$$N = 0.1 \times 10^{-3} \times 1 \times 365 \times 24 \times 3600 \times 100 = 3.1536 \times 10^{5}$$

Elsevier B. V, et al., "Development of $CaMoO_4$ crystal scintillators for a double beta decay experiment with ^{100}Mo," Nuclear Instruments and Methods in Physics Research A 584 (2008) 334-345

- Bi214 with 0.1mBq/kg

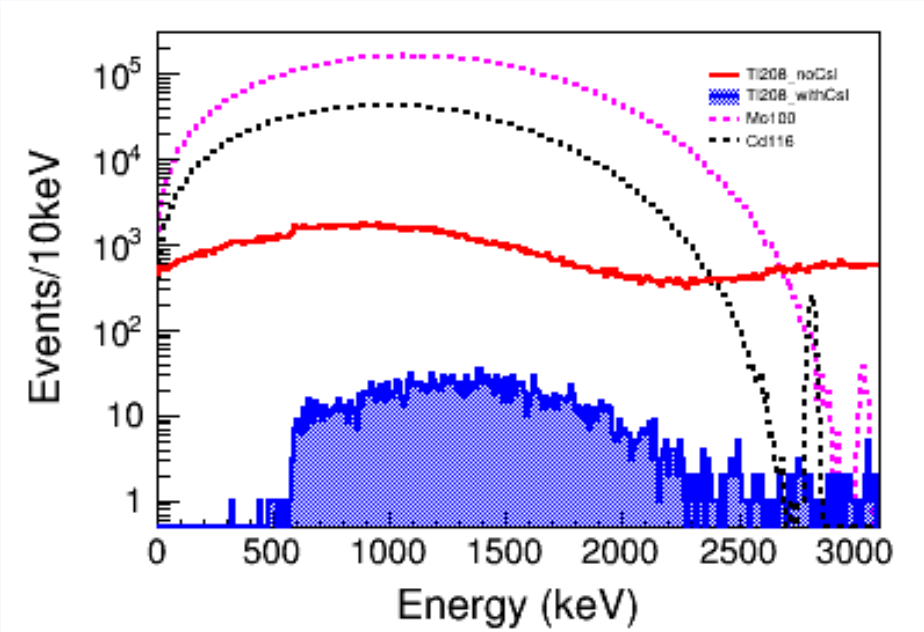
$$^{214}Bi\ (Q_\beta = 3.27MeV,\ T_{1/2} = 20min) \rightarrow\ ^{214}Po(Q_\alpha = 7.83MeV,\ T_{1/2} = 169\mu s)$$



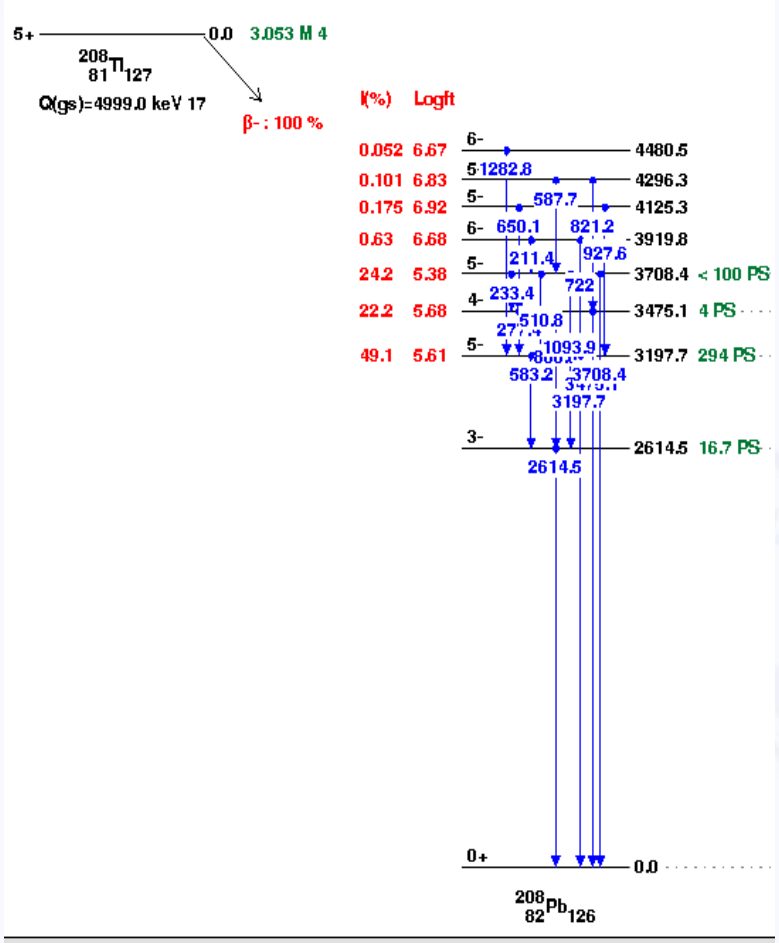
Use a 1ms time window to suppress the background from ^{214}Bi, the red line is not use the coincidence method.

Peaks: $^{210}Pb\ (147keV) \xrightarrow{\beta\ decay(Q=63.5keV)} {}^{210}Bi\left(147keV, T_{1/2} = 5.012D\right)$

- Tl208 with 0.1mBq/kg



Use the 4π gamma veto system to decrease external background from ^{208}Tl, the red line is not use the veto method.



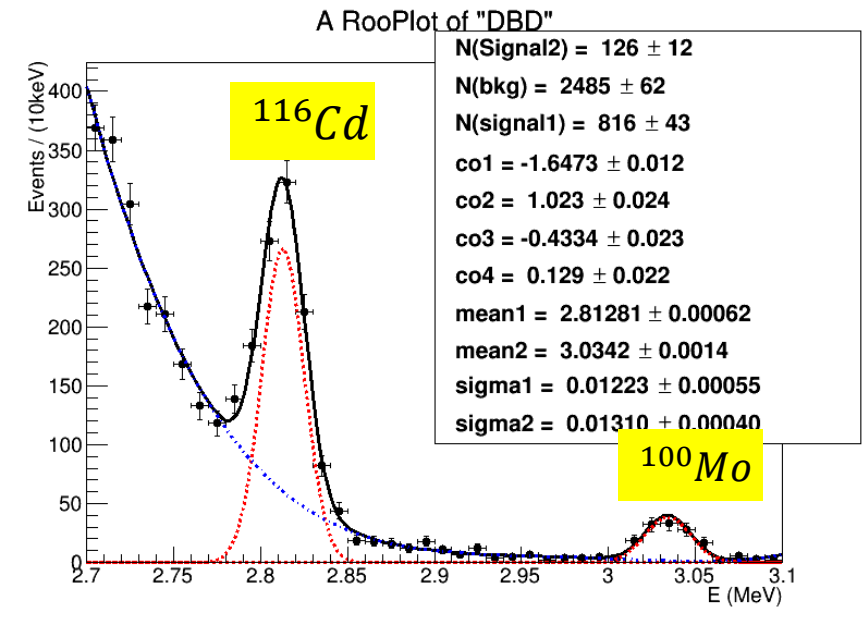
$^{208}Tl\ (Q_\beta = 5MeV) \rightarrow\ ^{208}Pb$

- MC-study results

- assuming
  the energy resolution is FWHM = 1%.

  the realistic backgrounds from the 2v2β decay of ^{100}Mo and ^{116}Cd.

  internal pollutions by ^{208}Tl and ^{214}Bi (both with 0.1mBq/kg).



- The estimated sensitivity for 0vDBD experiment with 100 kg · year's running is on the level of $\lim T_{1/2}^{0\nu\beta\beta} > 0.91 \times 10^{25}$ yr (^{100}Mo) and $\lim T_{1/2}^{0\nu\beta\beta} > 0.93 \times 10^{24}$ yr (^{116}Cd) at 90% C.L.

  $\lim T_{1/2}^{0\nu\beta\beta} > 1.1 \times 10^{24}$ yr (^{100}Mo) and $\lim T_{1/2}^{0\nu\beta\beta} > 1.7 \times 10^{23}$ yr (^{116}Cd)

- It indicates that $CdMoO_4$ scintillator with $^{100}_{42}Mo$, $^{116}_{48}Cd$ of double target nuclides is a very attractive one in this field.

Low temperature test platform (Laser)

Goals: measure emission spectra and decay time

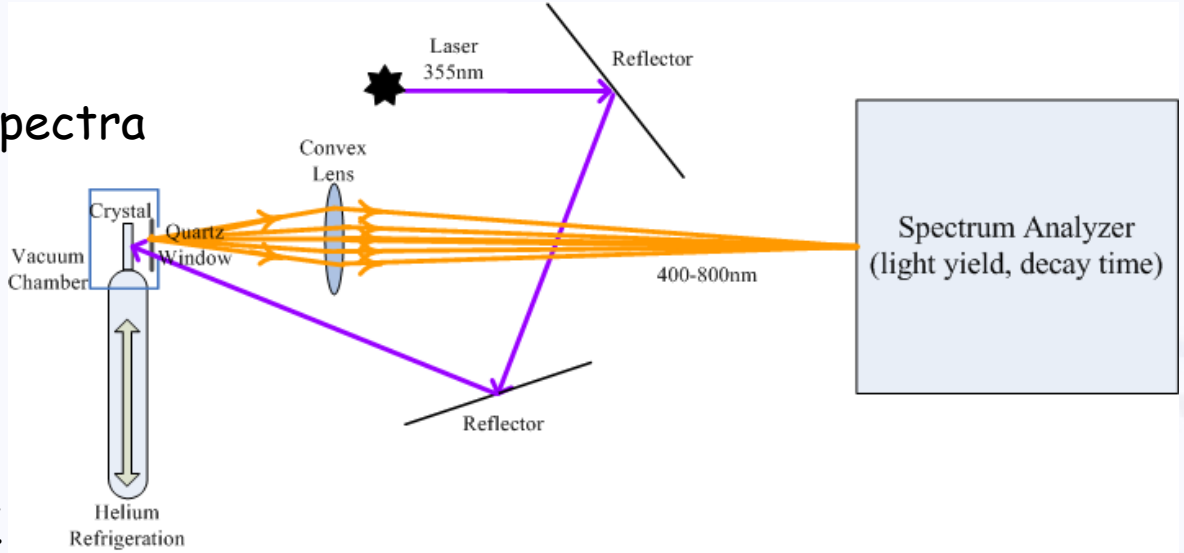
Sample: $CdMoO_4$

Size: $5 \times 5 \times 1mm^3$

Temperature: 22K – 300K

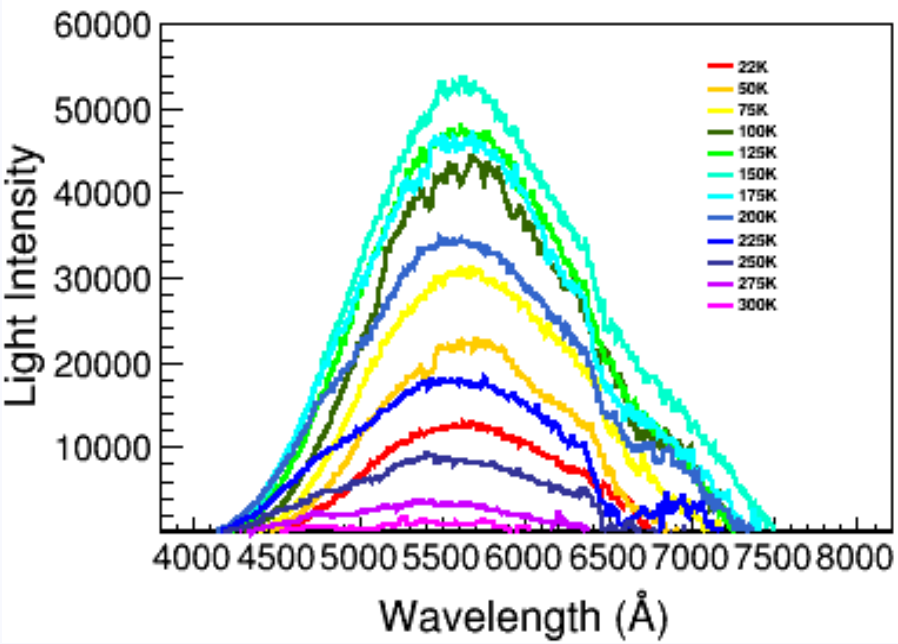
Laser: 355 nm

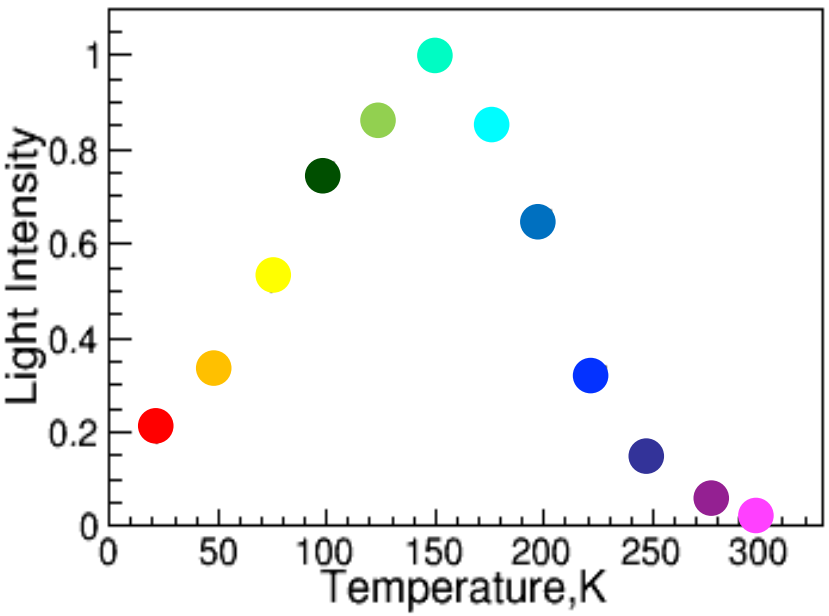
PMT: Hamamatsu R928



Temperature dependence of light yield

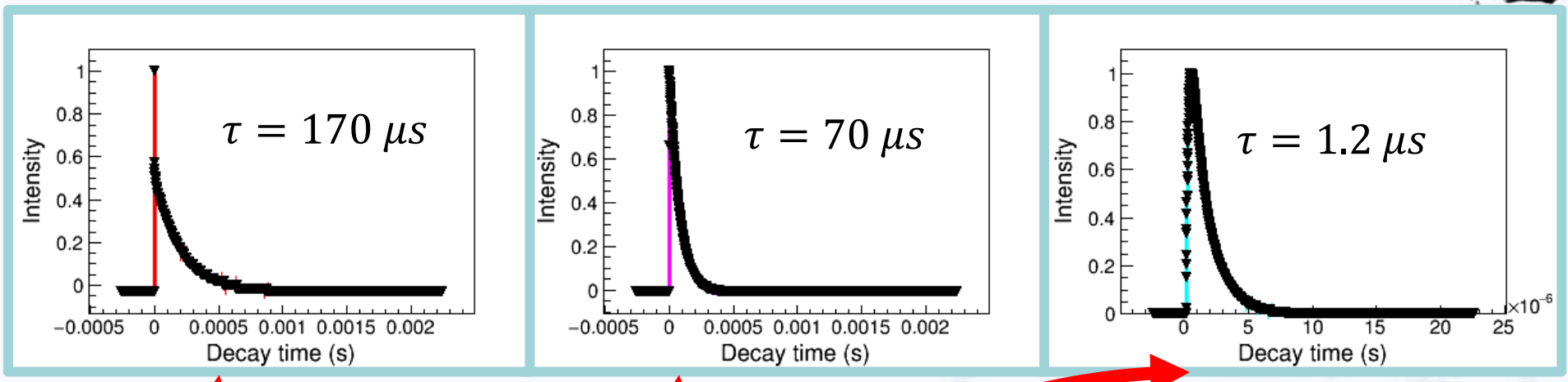
The $CdMoO_4$ crystal excited with laser of 355nm exhibits a broad emission bands peaked at 551nm.



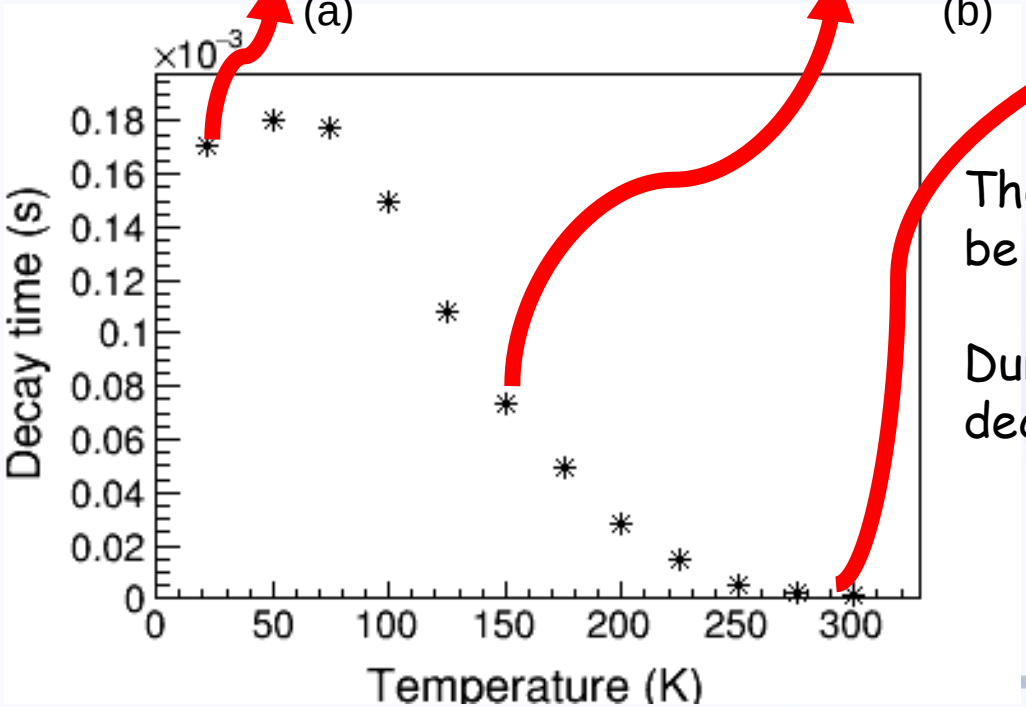


At room temperature, $CdMoO_4$ emits very faint light. With decreasing temperature, the light yield reaches a maximum at ~150 K. Further temperature decrease causes a reduction of the emission intensity.

Temperature dependence of decay time



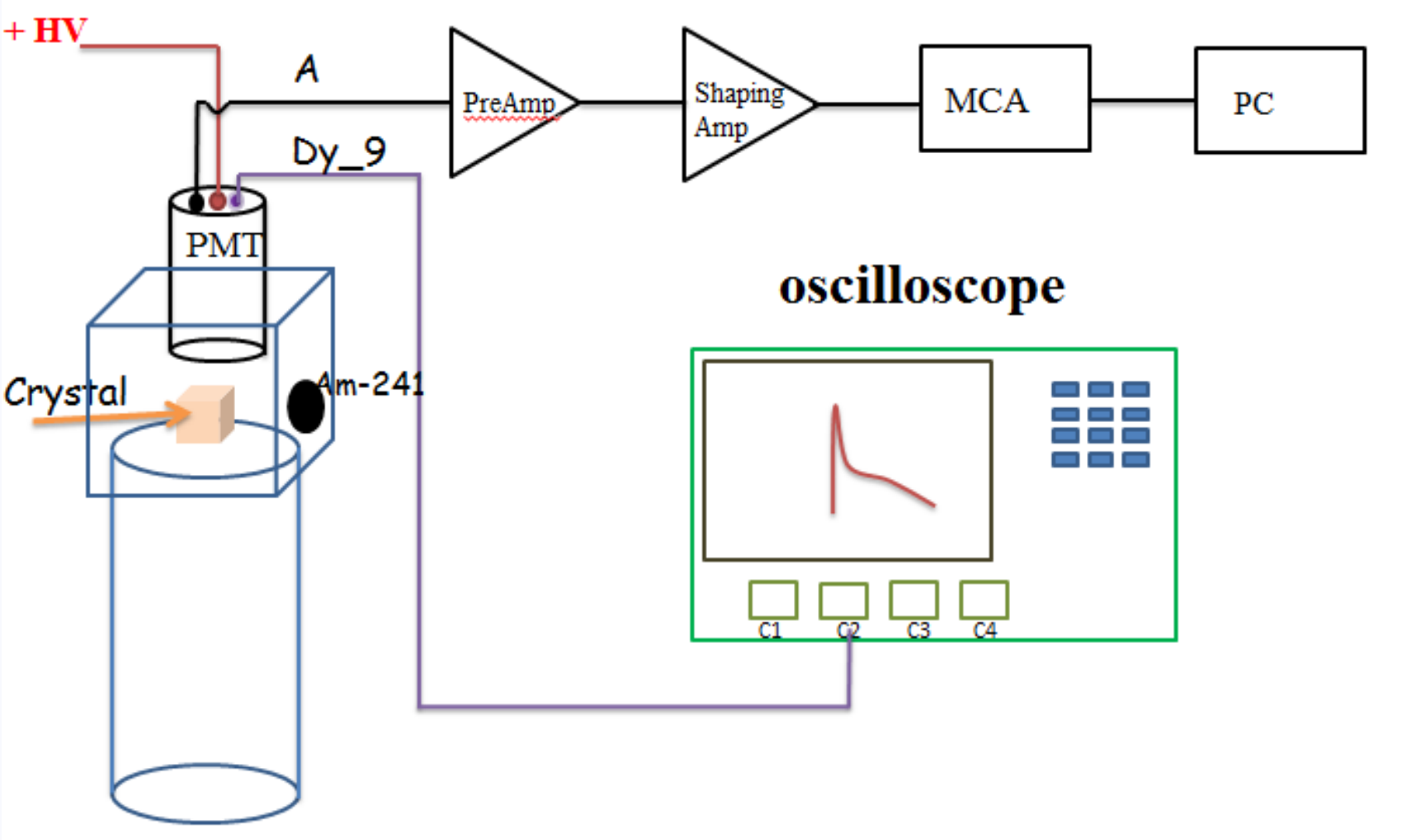
(a) (b) (c)



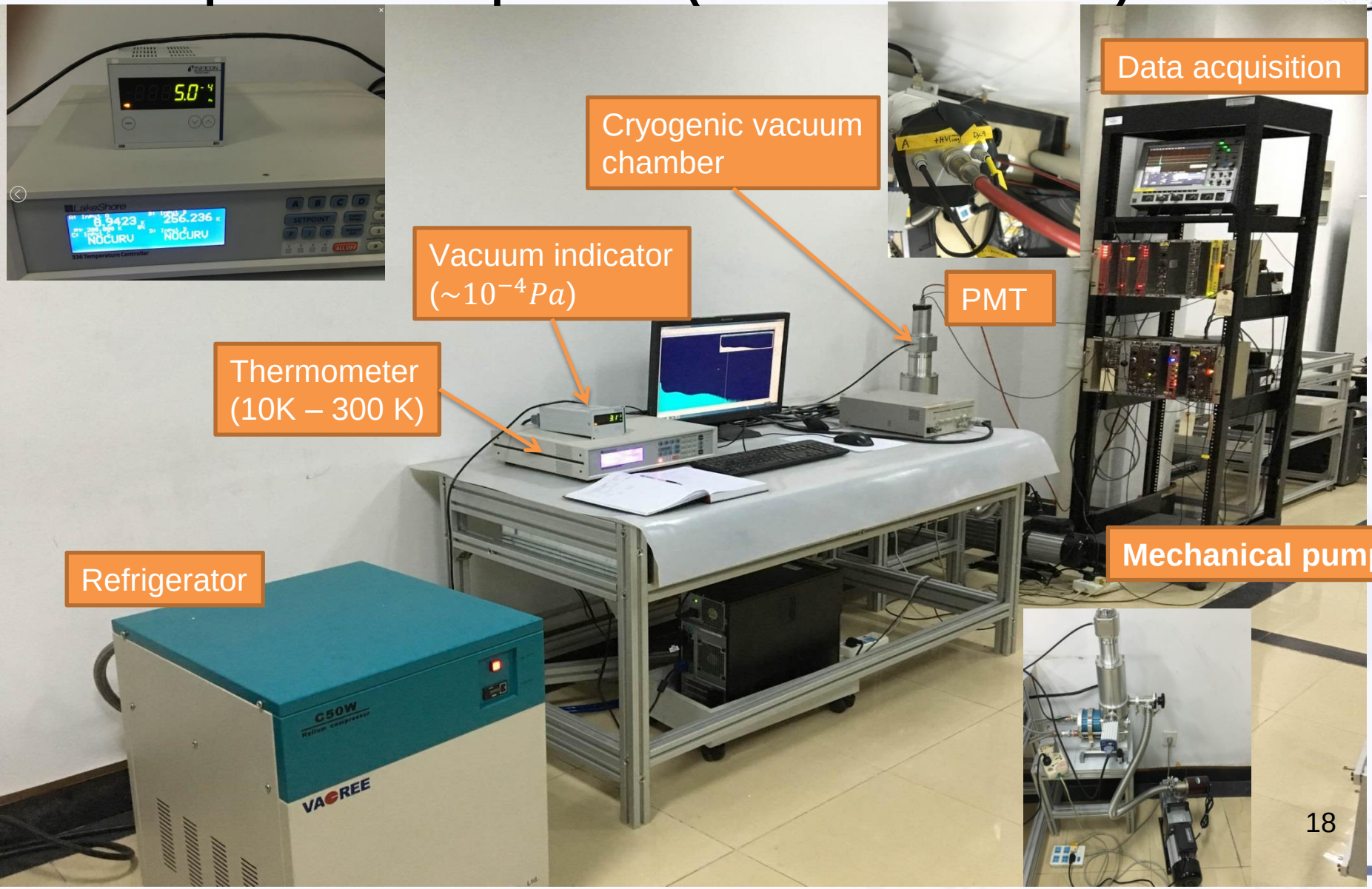
The main decay time constant is found to be 1.2 μs at room temperature (T = 300 K).

During cooling to 22 K the scintillation decay time increases up to 170 μs.

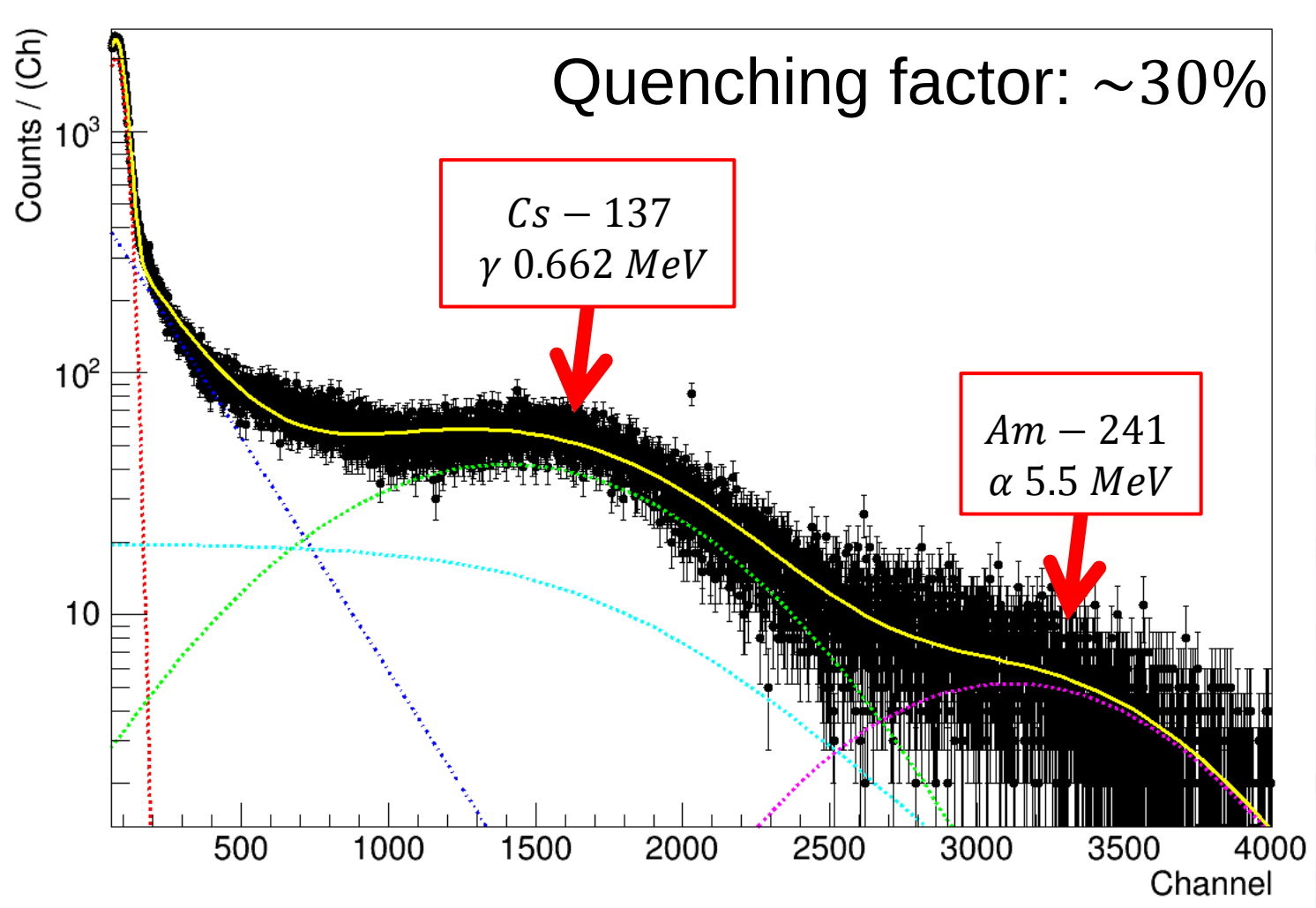
Low temperature test platform (Radioactive source) Schematic



Low temperature test platform (Radioactive source)



BGO crystal at 150 K



Summary

- MC-study shows that $CdMoO_4$ crystal is able to offer the interesting information of 0vDBD both of $^{100}_{42}Mo$, $^{116}_{48}Cd$ nuclides.
  $\lim T_{1/2}^{0\nu\beta\beta} > 0.91 \times 10^{25}$ yr (^{100}Mo) and $\lim T_{1/2}^{0\nu\beta\beta} > 0.93 \times 10^{24}$ yr (^{116}Cd)

- Experimental testing data demonstrates the scintillating properties of $CdMoO_4$ crystal relying on different temperature.

- Characteristics of BGO crystal responding to α-source ($^{241}_{95}Am$, 5.5 MeV) and γ-source ($^{137}_{55}Cs$, 0.662MeV) is given.

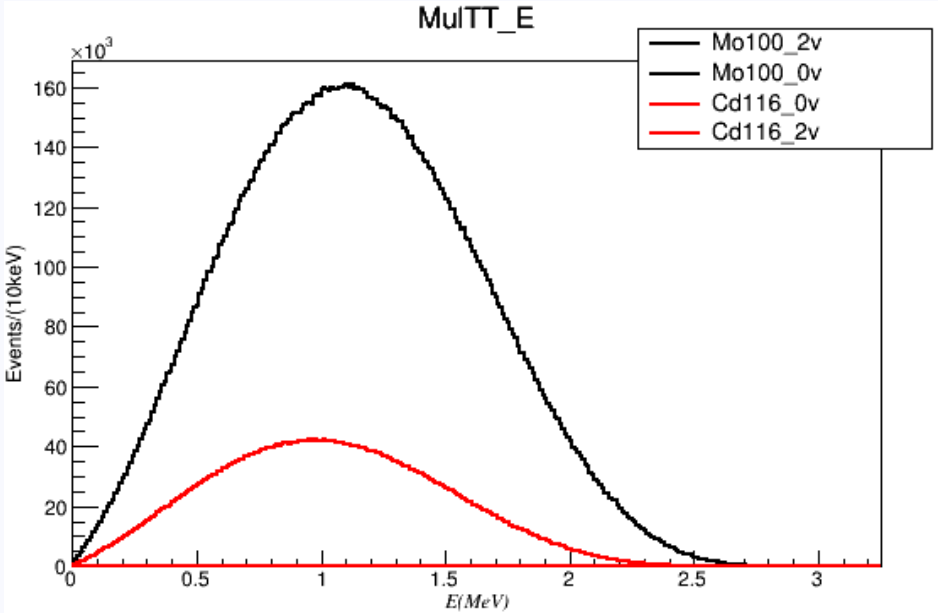
Next to do

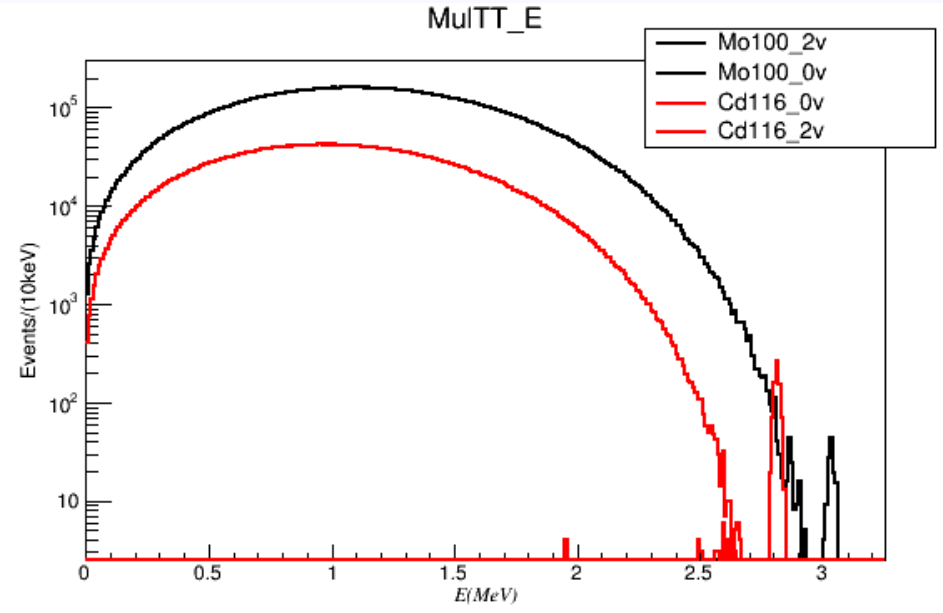
Measure the $CdMoO_4$ scintillation properties using α-source ($^{241}_{95}Am$, 5.5 MeV) and γ-source ($^{137}_{55}Cs$, 0.662MeV) based on the low temperature test system.

Thank you

Back up

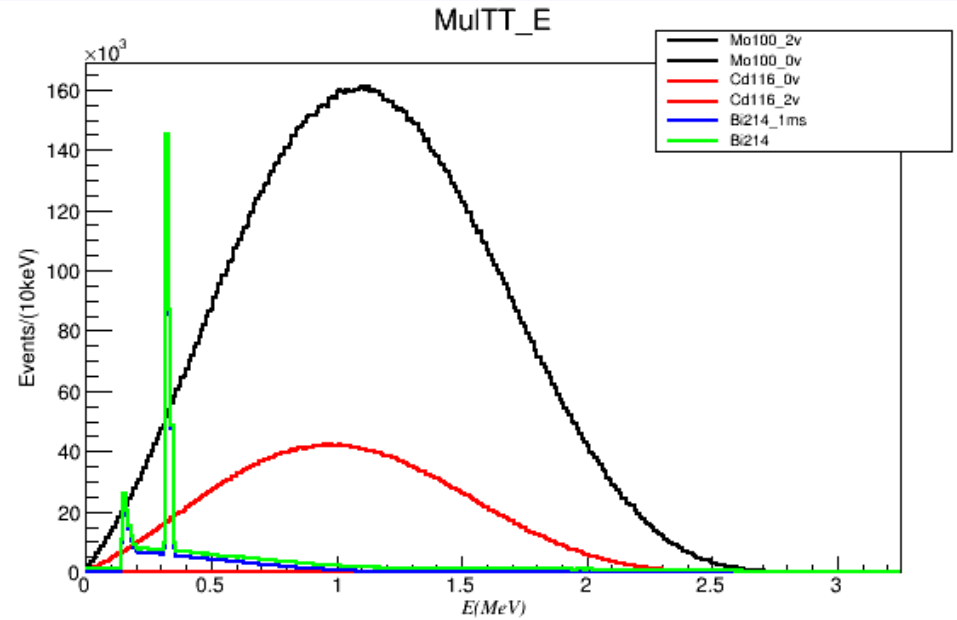
^{100}Mo ^{116}Cd

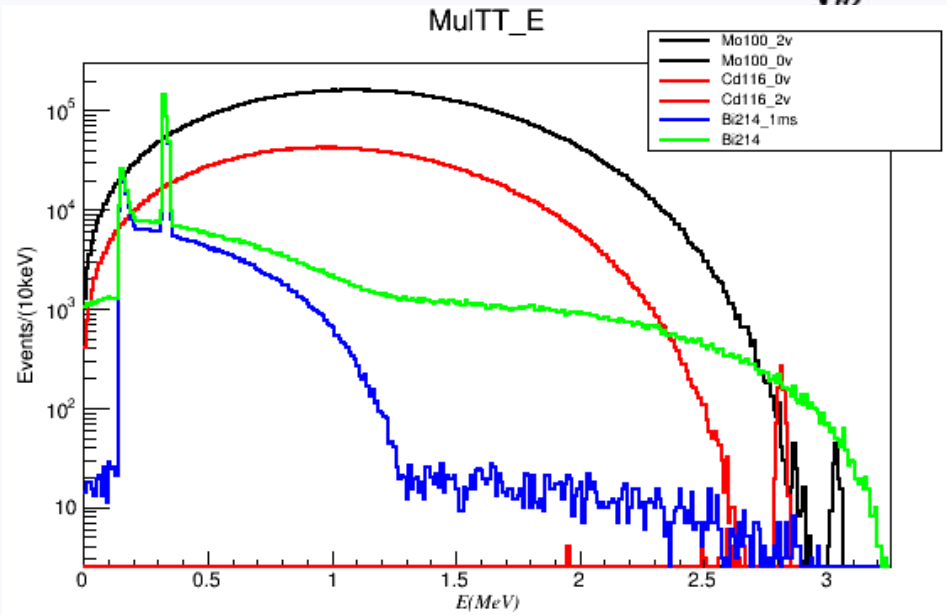




FWHM=1%

^{214}Bi





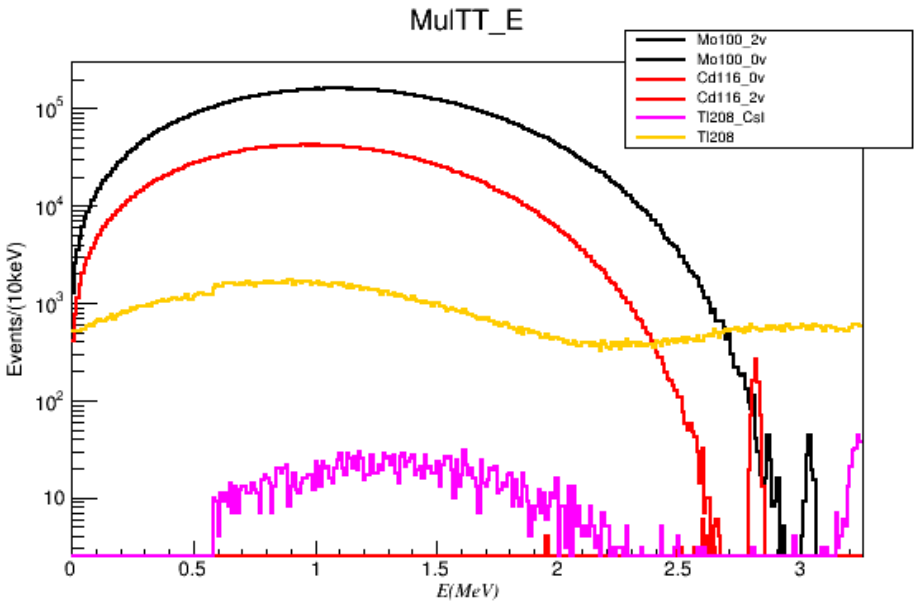
$^{214}Bi\ (Q_\beta = 3.27MeV, T_{1/2} = 20min) \rightarrow {}^{214}Po(Q_\alpha = 7.83MeV, T_{1/2} = 169\mu s)$

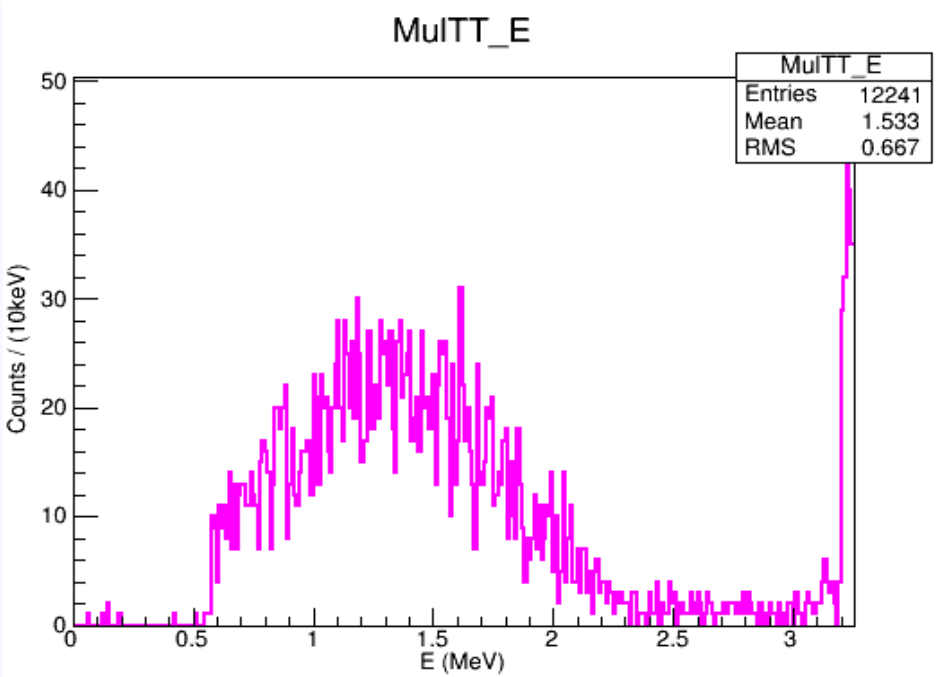
Peaks: $^{210}Pb\ (147keV) \xrightarrow{\beta\ decay(Q=63.5keV)} {}^{210}Bi\left(147keV, T_{1/2} = 5.012D\right)$

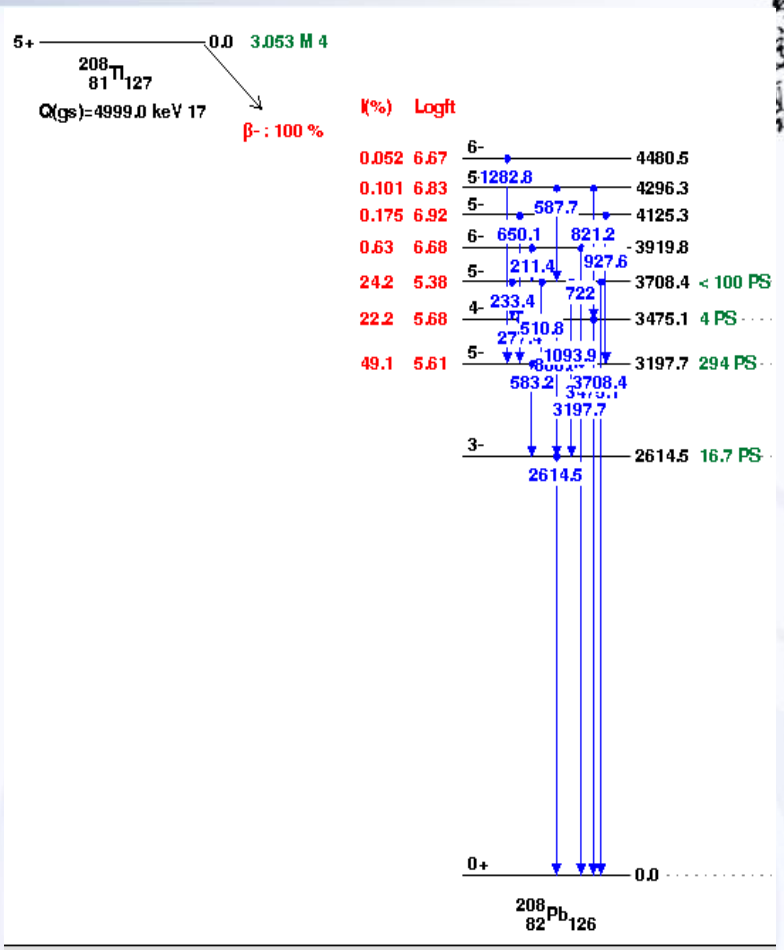
$^{214}_{83}Bi \rightarrow {}^{214}_{84}Po(1729.6) \rightarrow {}^{214}_{84}Po(609.3) \rightarrow {}^{214}_{84}Po(0) \rightarrow {}^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi(46.5) \rightarrow {}^{210}_{83}Bi(0) \rightarrow {}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb$

$\beta\ decay\ Q = 1162keV$ $\alpha\ decay, Q = 5407keV, T_{1/2} = 138D$

^{208}Tl

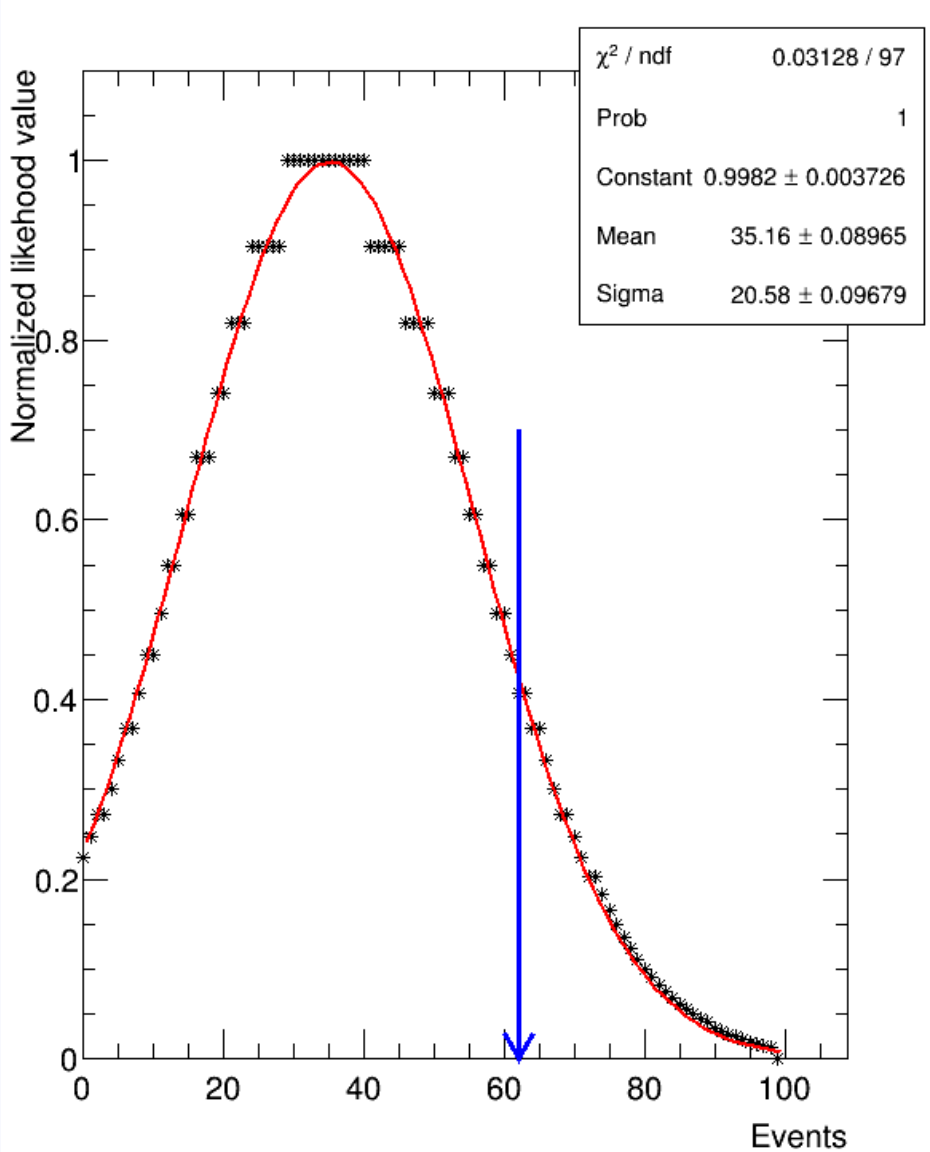






$^{208}Tl\ (Q_\beta = 5MeV) \rightarrow\ ^{208}Pb$

^{116}Cd Half-life Limit




```
prob>=0.9, N=62.057
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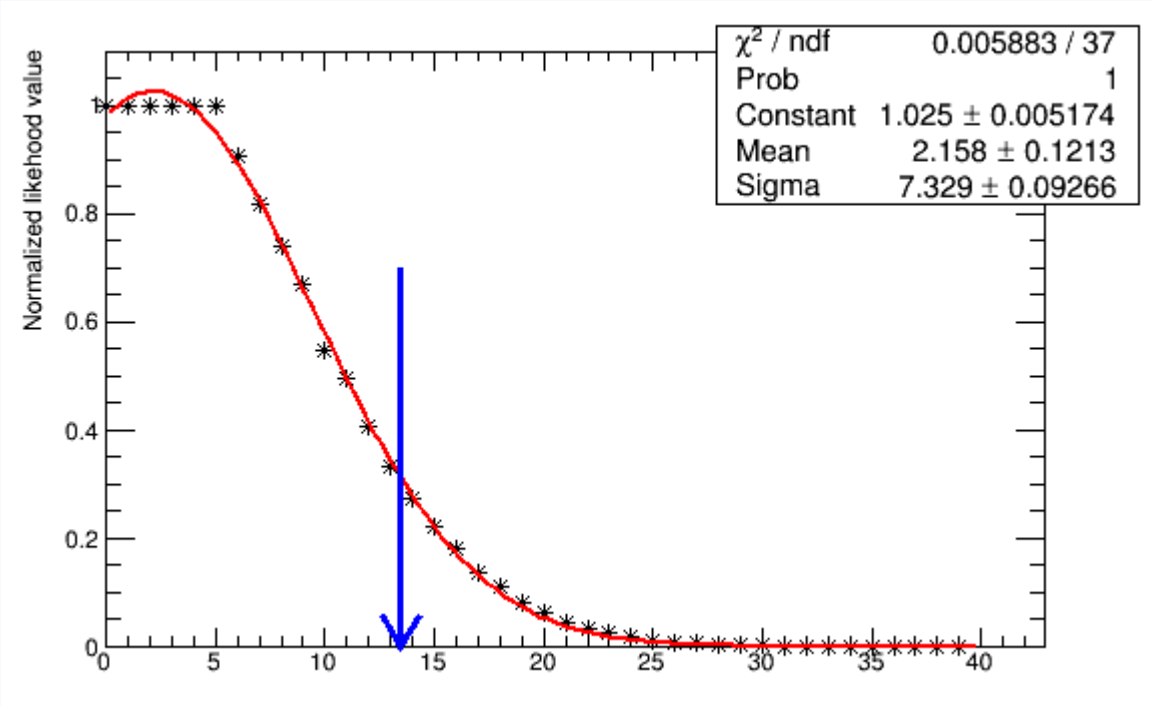
$$T_{1/2} = 0.93 \times 10^{24} yrs$$

$$T_{1/2} = 1.7 \times 10^{23} yrs$$

^{100}Mo Half-life Limit

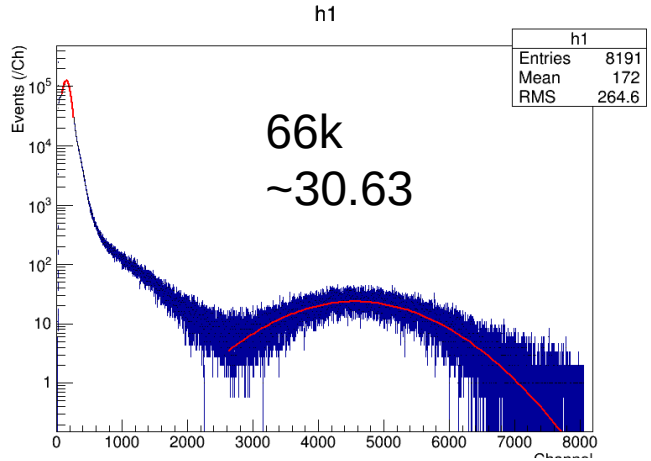


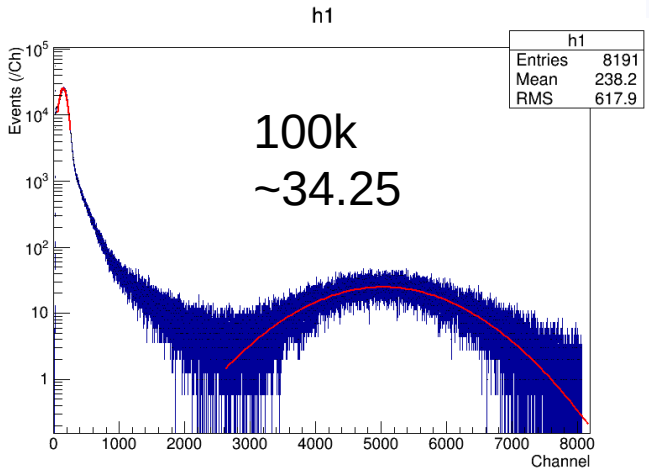

```
prob>=0.9, N=13.457
```

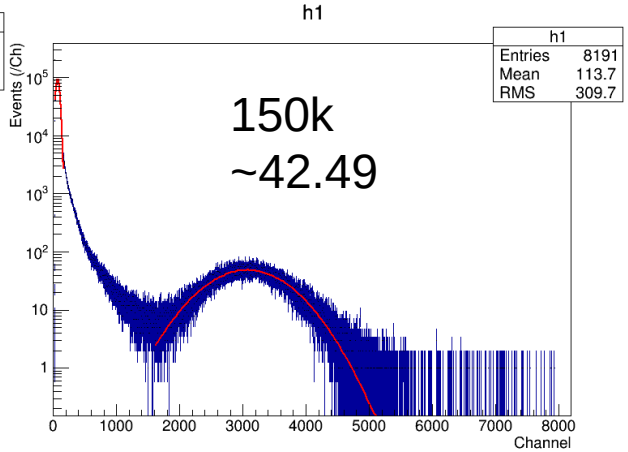
$$T_{1/2} = 9.1 \times 10^{24} yrs$$

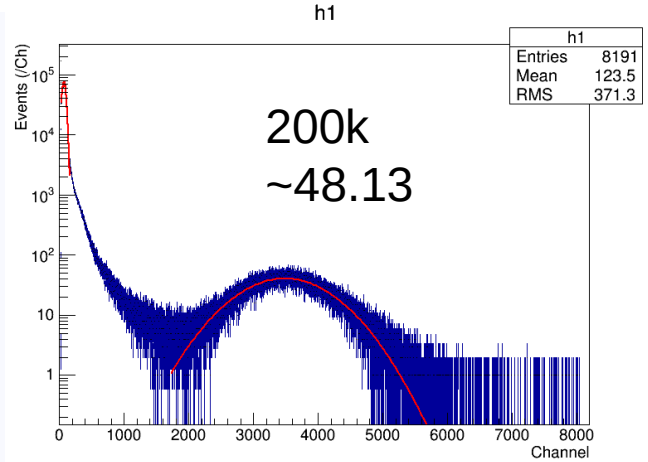
$$T_{1/2} = 1.1 \times 10^{24} yrs$$

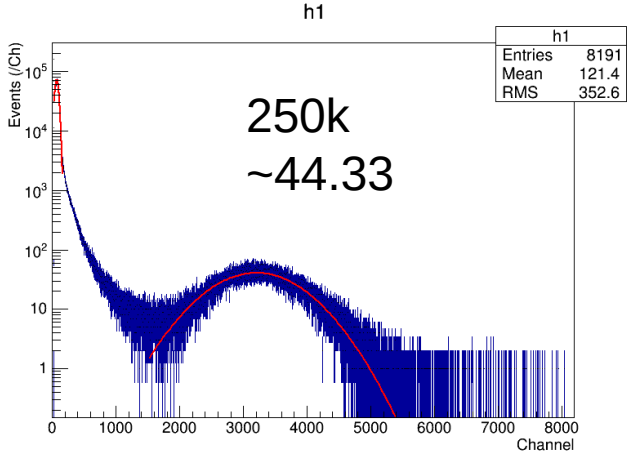
Am-241

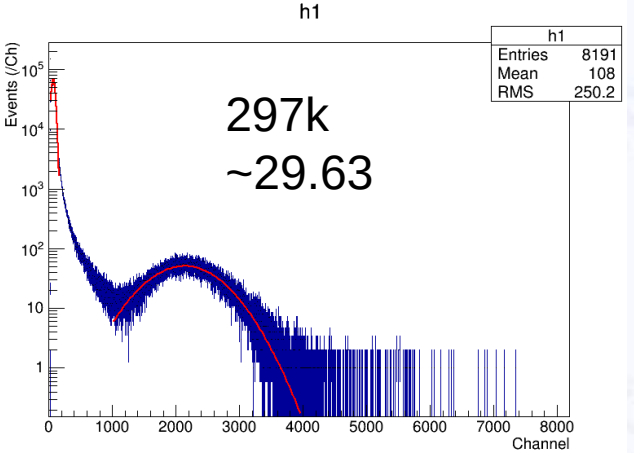

h1
h1
Entries 8191
Mean 172
RMS 264.6
66k
~30.63
Events (/Ch)


h1
h1
Entries 8191
Mean 238.2
RMS 617.9
100k
~34.25
Events (/Ch)
Channel

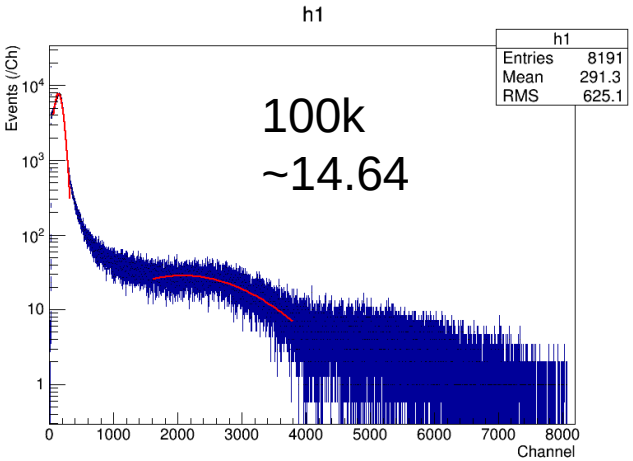

h1
h1
Entries 8191
Mean 113.7
RMS 309.7
150k
~42.49
Events (/Ch)
Channel

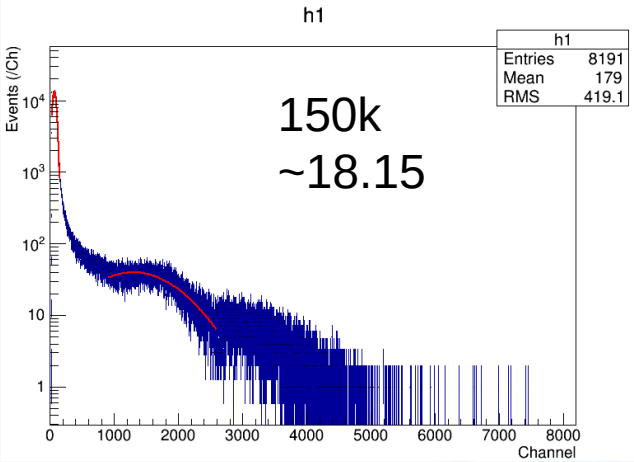

h1
h1
Entries 8191
Mean 123.5
RMS 371.3
200k
~48.13
Events (/Ch)
Channel

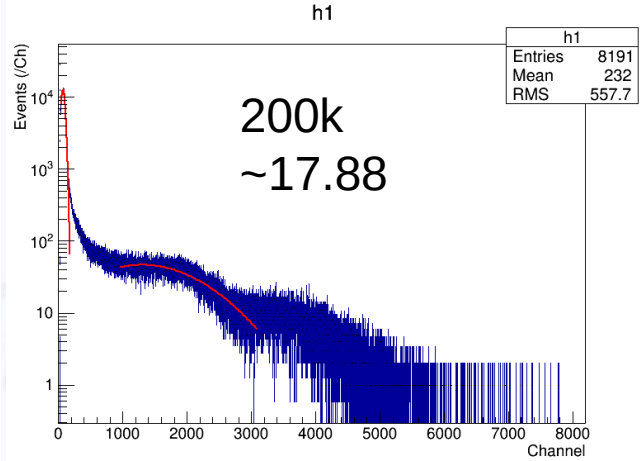

h1
h1
Entries 8191
Mean 121.4
RMS 352.6
250k
~44.33
Events (/Ch)
Channel

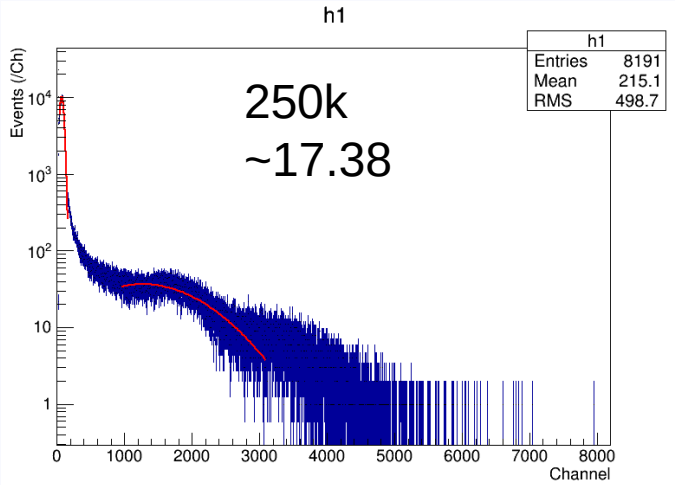

h1
h1
Entries 8191
Mean 108
RMS 250.2
297k
~29.63
Events (/Ch)
Channel

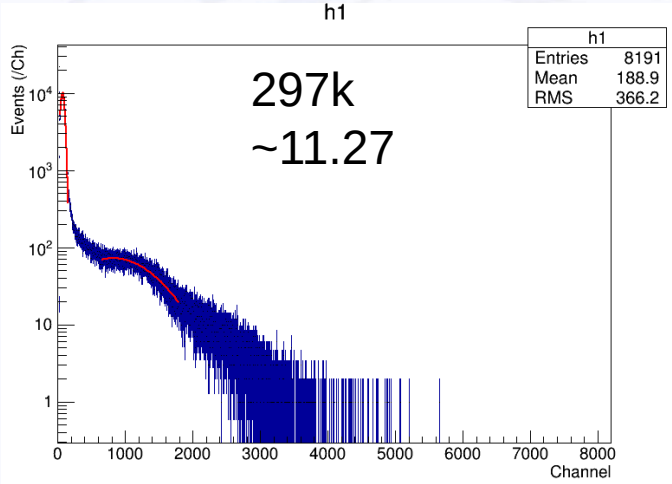
Cs-137


h1
h1
Entries 8191
Mean 291.3
RMS 625.1
100k
~14.64
Events (/Ch)
Channel


h1
h1
Entries 8191
Mean 179
RMS 419.1
150k
~18.15
Events (/Ch)
Channel

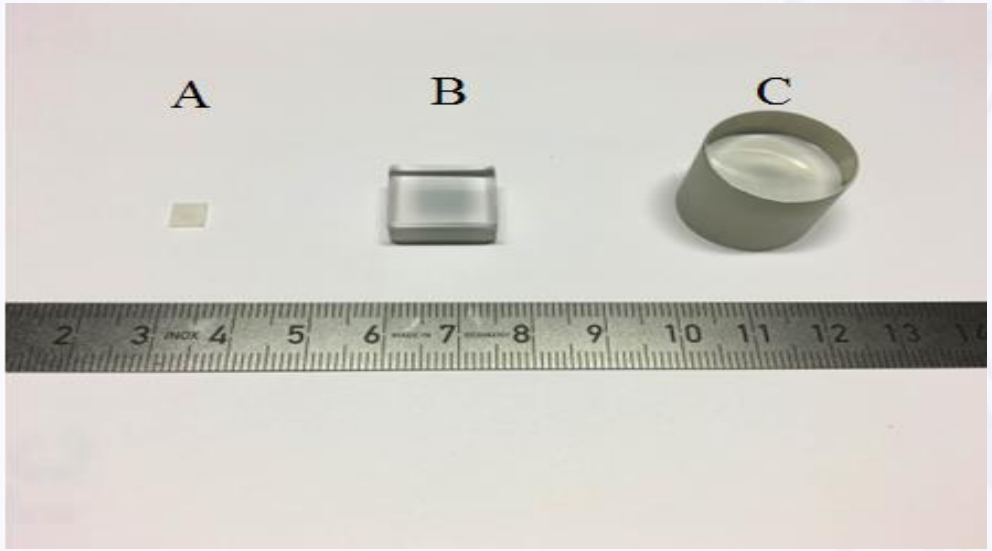

h1
h1
Entries 8191
Mean 232
RMS 557.7
200k
~17.88
Events (/Ch)
Channel


h1
h1
Entries 8191
Mean 215.1
RMS 498.7
250k
~17.38
Events (/Ch)
Channel


h1
h1
Entries 8191
Mean 188.9
RMS 366.2
297k
~11.27
Events (/Ch)
Channel

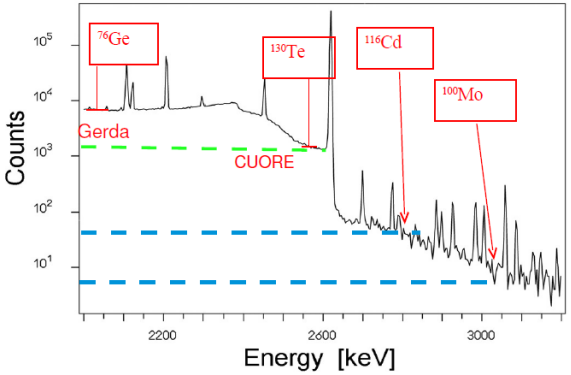
Properties of $^{100}_{42}Mo$ and $^{116}_{48}Cd$

Parent Isotope	Isotopic Abundance (%)	Q value (keV)	$T_{1/2}^{2\nu\beta\beta}$ (years)	$T_{1/2}^{0\nu\beta\beta}$ (years)
$^{100}_{42}Mo$	9.82	3034	$(7.1 \pm 0.4) \times 10^{18}$	$> 1.1 \times 10^{24}$
$^{116}_{48}Cd$	7.49	2813	$(2.9 \pm 0.2) \times 10^{19}$	$> 1.7 \times 10^{23}$



BOLUX: The (far) Future

A STRAIGHTFORWARD GAIN IN BACKGROUND:
ISOTOPES WITH HIGHER Q-value



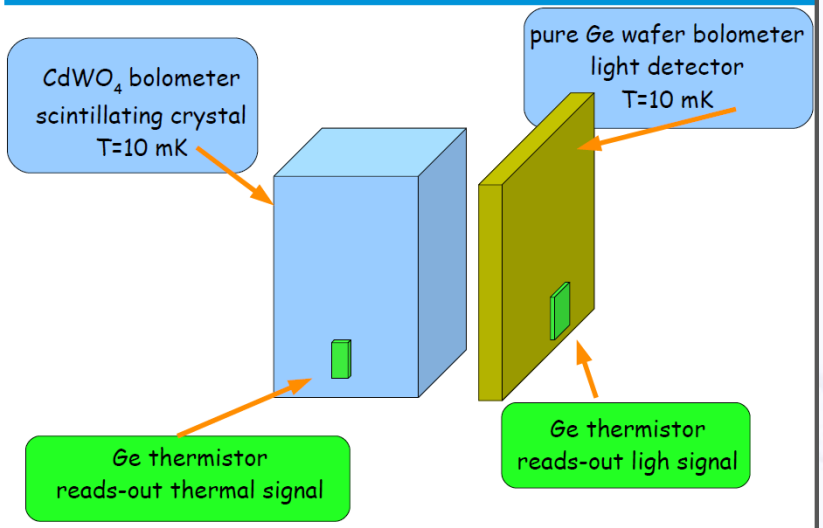
above 2.6 MeV the γ rate is 1-2 order of magnitude lower

BUT

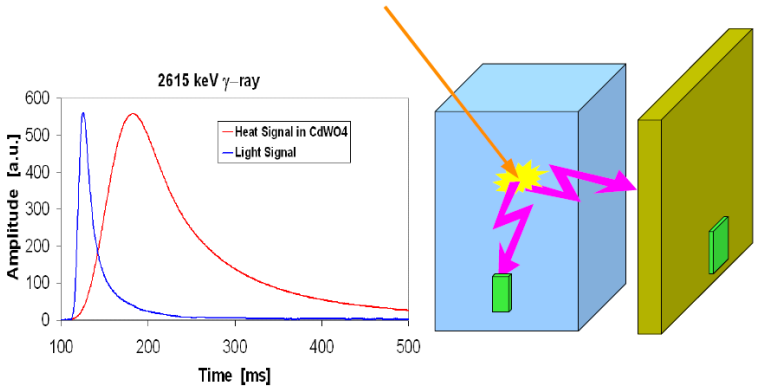
there is α background potentially dangerous

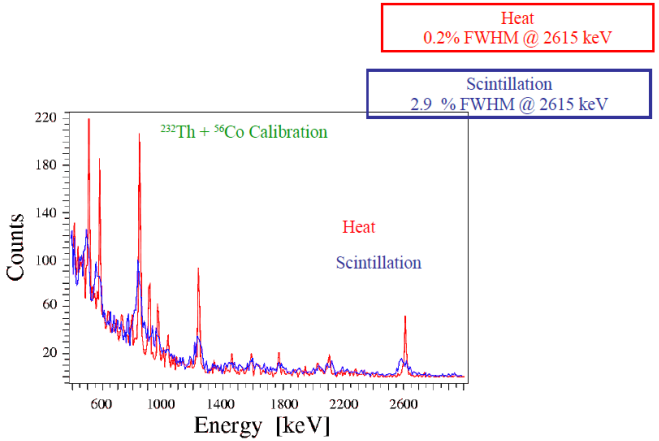
Environmental *underground* background:
^{238}U and ^{232}Th trace contaminations

BOLUX: The (far) Future



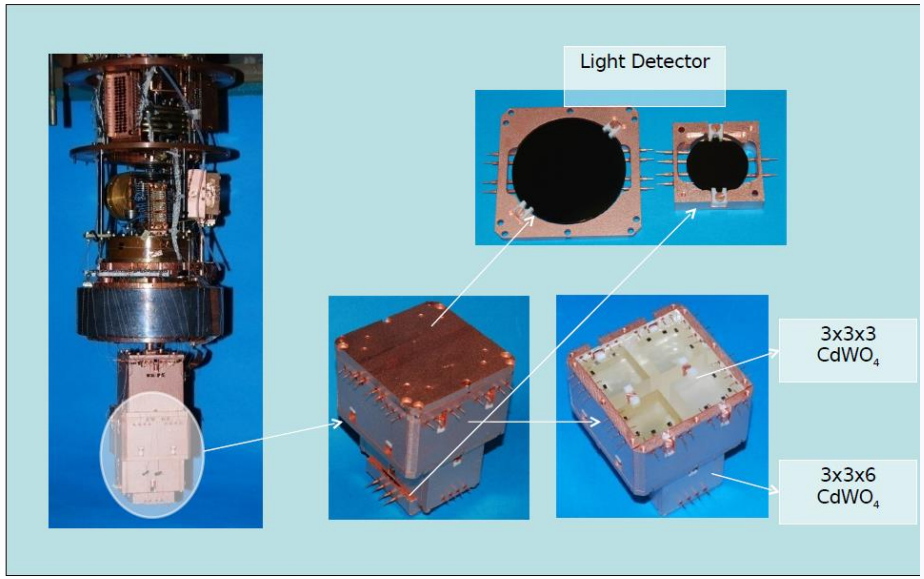
BOLUX: The (far) Future



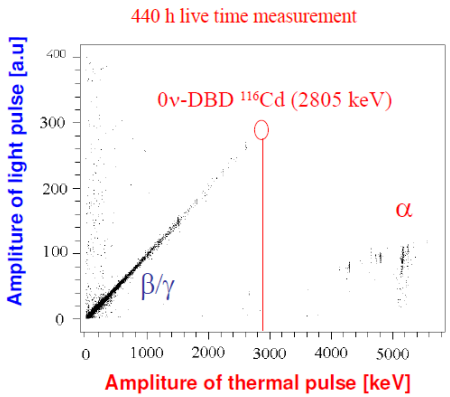


2.9% FWHM is the best result ever achieved with $CdWO_4$ as scintillator

BOLUX: The (far) Future

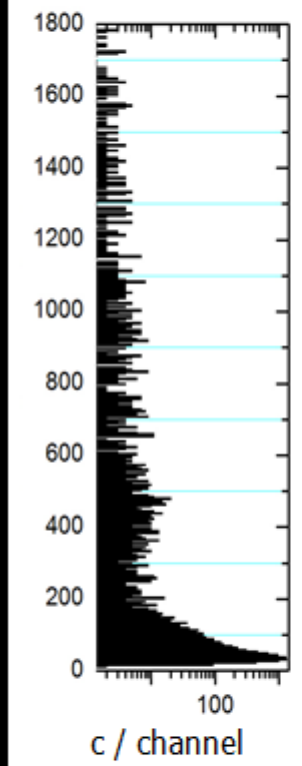


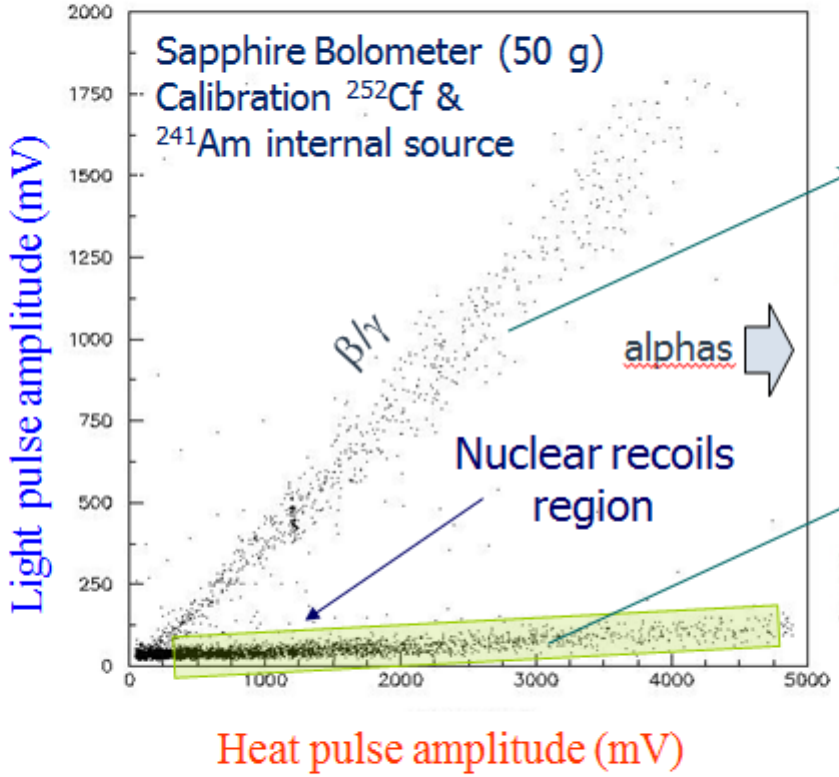
BOLUX: The (far) Future



β/γ and α are clearly separated
α background can be rejected with high efficiency

Particle Discrimination Capability





Detector response