SEARCH FOR DOBLE BETA DECAY OF ^{106}Cd IN THE TGV-2 EXPERIMENT

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on behalf of TGV collaboration

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Experiment TGV-2

Telescope Germanium Vertical

Laboratoire Souterrain de Modane, France

Phase I ~ 10g (12 samples) of ^{106}Cd (75%), ~ 3.2 g (4 samples) of Cd-nat. (~ 4.25 x 10^{22} atoms of ^{106}Cd) T= 8687h
(Feb.2005 – Feb.2006)

Phase II ~ 13.6 g (16 samples) of ^{106}Cd (75%)
(~ 5.8 x 10^{22} atoms of ^{106}Cd) T = 12900h
(Dec.2007 – July 2009)

Background I no samples (Aug.2009 – Mar.2010)

Background II 16 samples of Cd.-nat (April 2010 -Nov.2013)

Phase III ~ 23.2 g (16 samples) of ^{106}Cd (99.57%)
(~ 1.3 x 10^{23} atoms of ^{106}Cd) T = 8198h +…
(Feb.2014 – …..) in progress

SEARCH FOR DOUBLE BETA DECAY

- At present **$2\nu2\beta^-$** decay was detected in **11** nuclei:

^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd, ^{238}U

"Positive" results in search for 2νEC/EC decay

- **2νEC/EC** in **^{130}Ba** was detected in geochemical experiment (A.P.Meshik et al.. Phys. Rev. C **64**, 2001, 035205).
- **2νEC/EC** in **^{78}Kr** (indication) (Yu.M.Gavrilyuk et al., Phys. Rev. C **87**, 2013, 035501).

DOUBLE BETA DECAY OF ^{106}Cd

EC/EC $2e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + (2\nu_e) + (\gamma)$

Experimental signature : 2KXPd (+ γ for e.s.)

β+/EC $e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + e^+ + (2\nu_e) + (\gamma)$

Experimental signature : KXPd + 2γ 511 (+ γ for e.s.)

β+β+ $^{106}Cd \rightarrow {}^{106}Pd + e^+ + e^+ + (2\nu_e) + (\gamma)$

Experimental signature : 4γ 511 (+ γ for e.s.)

0νEC/EC DECAY to the ground state

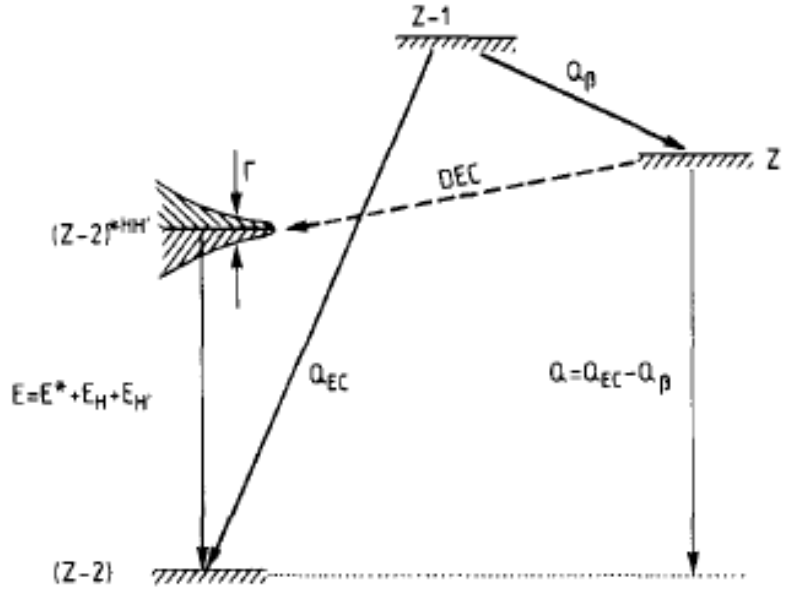
$2e_b^- + (A,Z) \rightarrow (A,Z-2) + 2X + (\gamma_{brem}, 2\gamma, e^+e^-, e^-_{int})$

$E\gamma,.. = \Delta M - \varepsilon_{e1} - \varepsilon_{e2}$

Suppression factor is ~ 10^4 (in comparison with ECβ+(0ν)) –

M. Doi and T. Kotani, Prog. Theor. Phys. 89 (1993)139.

0νEC/EC Resonance Transitions (A,Z)→(A,Z-2)$^{*HH'}$



Atom mixing amplitude

ΔM

$$E \simeq E^* + E_H + E_{H'},$$

$$\Gamma \simeq \Gamma^* + \Gamma_H + \Gamma_{H'}.$$

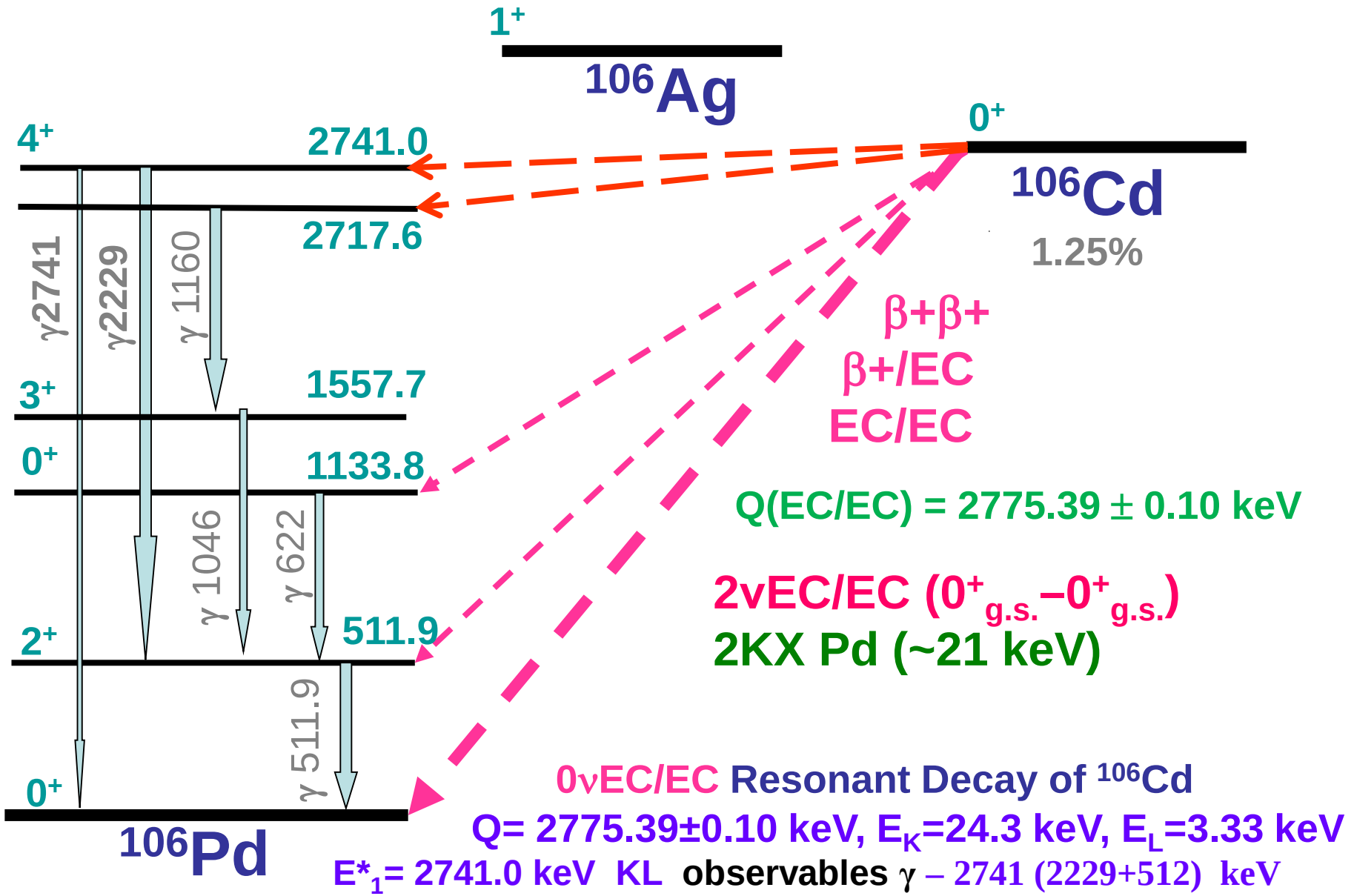
Decay rate

$$\frac{1}{\tau} \simeq \frac{(\Delta M)^2}{(Q-E)^2 + \frac{1}{4}\Gamma^2}\Gamma,$$

J. Bernabeu, A. DeRujula, C. Jarlskog, Nucl. Phys. B 223, 15 (1983)

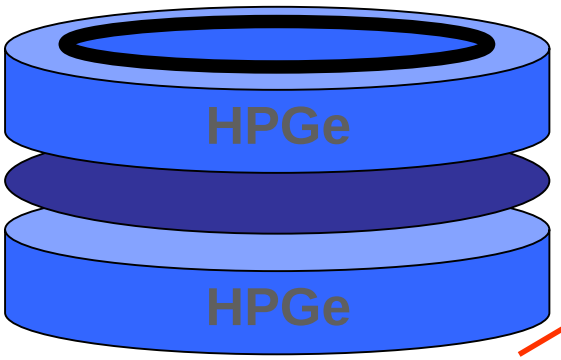
Enhancement factor on the level of 10^4-10^6 may be obtained for $|Q-Q'_{res}| < 1$ keV

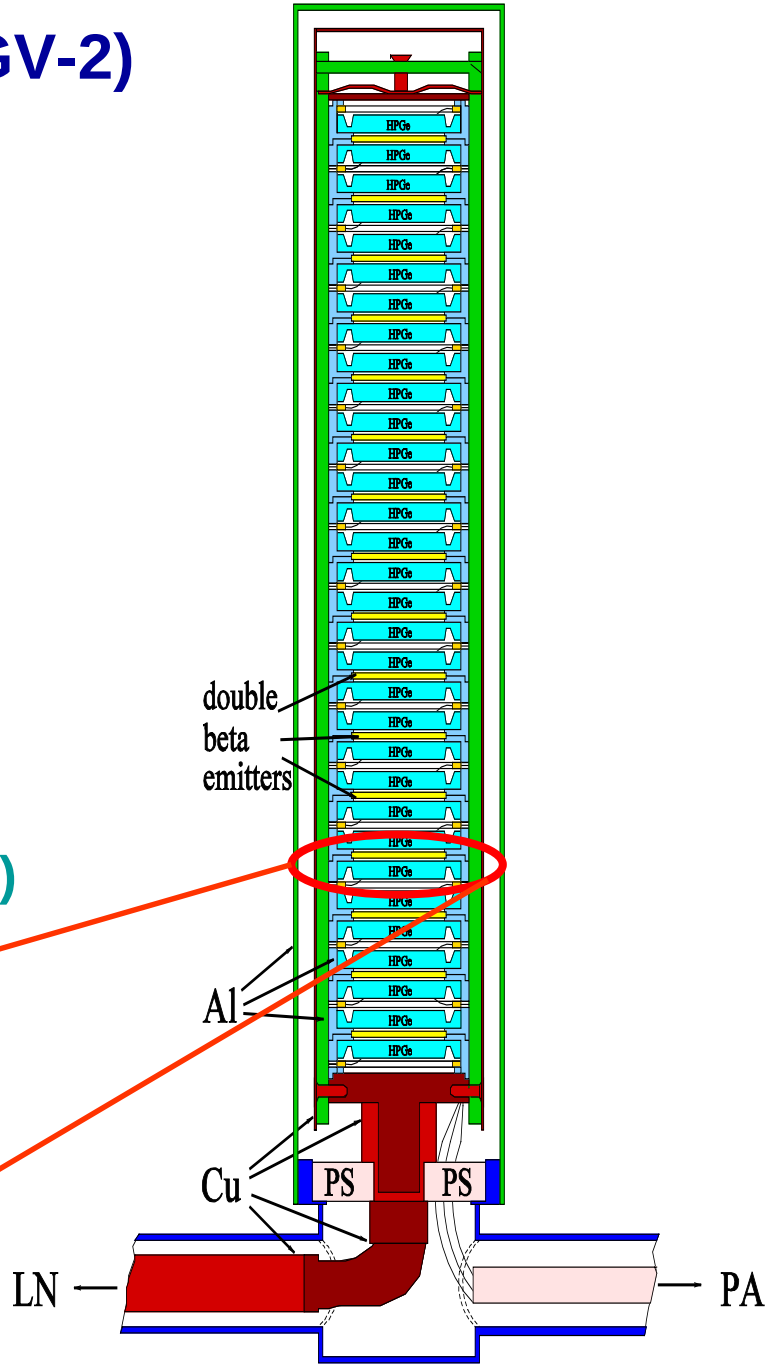
Z. Sujkowski, S. Wycech,Phys. Rev. C 70 (2004) 052501.


1+
106Ag
0+
106Cd
1.25%
4+
2741.0
2717.6
γ2741
γ2229
γ 1160
3+
1557.7
0+
1133.8
γ 1046
γ 622
2+
511.9
γ 511.9
0+
106Pd
β+β+
β+/EC
EC/EC
Q(EC/EC) = 2775.39 ± 0.10 keV
2νEC/EC (0+g.s.–0+g.s.)
2KX Pd (~21 keV)
0νEC/EC Resonant Decay of 106Cd
Q= 2775.39±0.10 keV, EK=24.3 keV, EL=3.33 keV
E*1= 2741.0 keV KL observables γ – 2741 (2229+512) keV
E*2= 2717.6 keV KK observables γ – (1160 + 1046 + 512) keV
E*3= 2737 keV (?) KL observables γ – ?
Phase III - Search for 0νEC/EC decay of 106Cd → Obelix det.

Telescope Germanium Vertical (TGV-2)

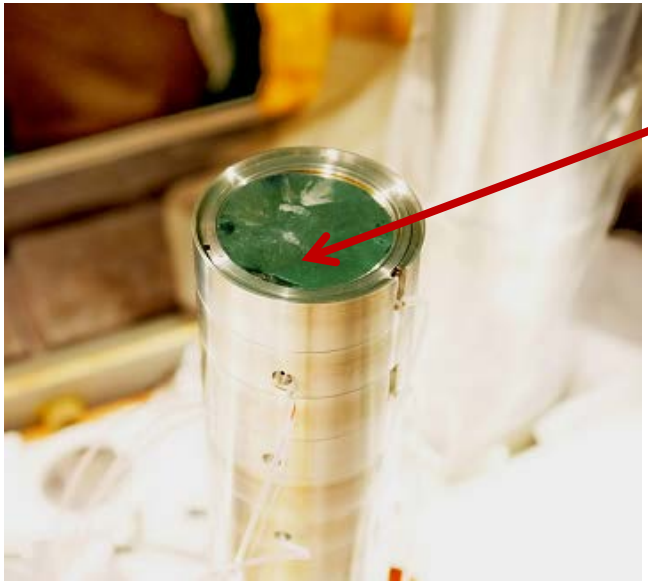
32 HPGe planar detectors ∅60 mm x 6 mm
with sensitive volume: 20.4 cm^2 x 6 mm
Total sensitive volume: ~400 cm^3
Total mass of detectors: ~3 kg
Total area of samples : 330 cm^2
Total mass of sample(s) : 10 ÷ 25 g
Total efficiency : 50 ÷ 70 %
E-resolution : 3 ÷ 4 keV @ ^{60}Co
LE-threshold : 5 ÷ 6 keV
Double beta emitters:
16 samples (~70μm) of ^{106}Cd (enrich.99.57%)
~23.2 g (~ 1.3 x 10^{23} atoms) of ^{106}Cd

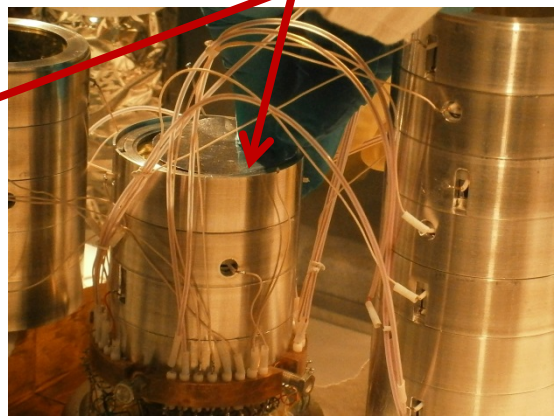


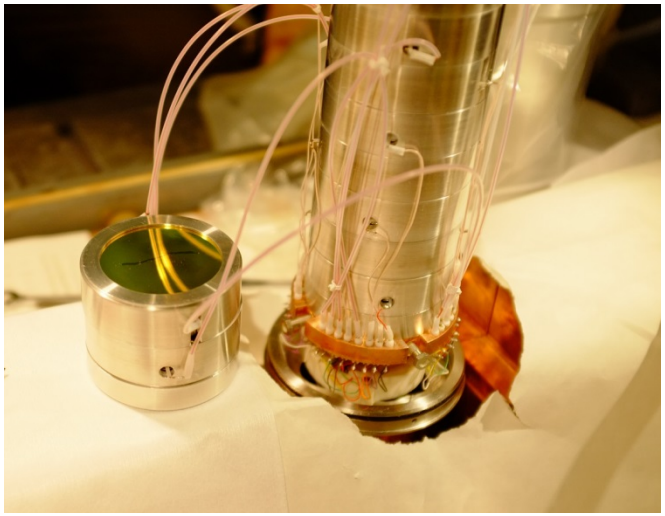


Detectors and foils of TGV-2

^{106}Cd

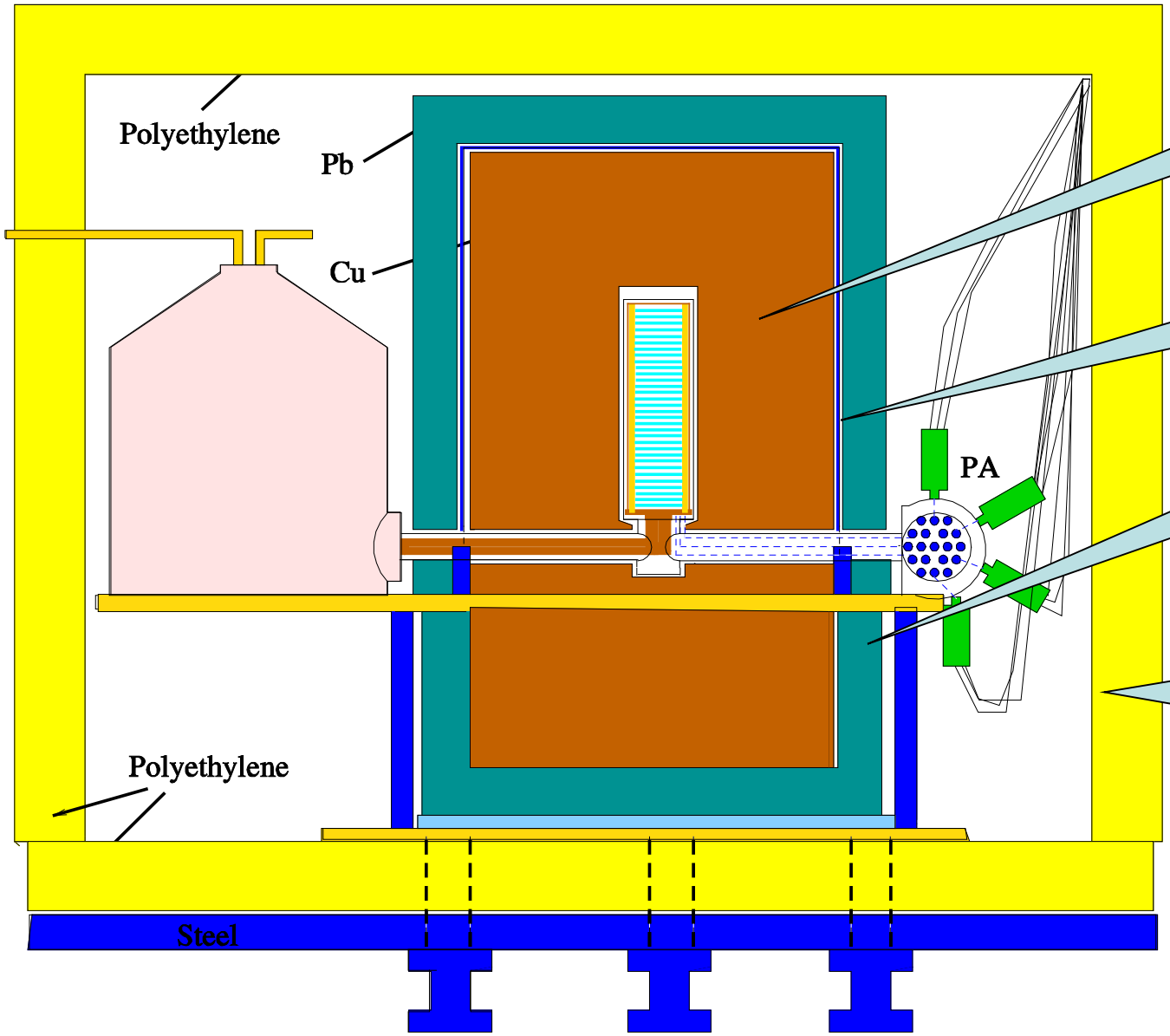






16 circle foils:
thickness = 70±10 mg/cm^2
diameter = 52 mm
mass = 23.166 g
enrichment= 99.57%.

PASSIVE SHIELDING



Copper
> 20 cm

Airtight box

Lead
> 10 cm

Polyethylene filled with boron 16 cm

Modane Underground Laboratory, France
(4800 m w.e.)
4 muons /day / m^2

Copper shielding

Airtight box

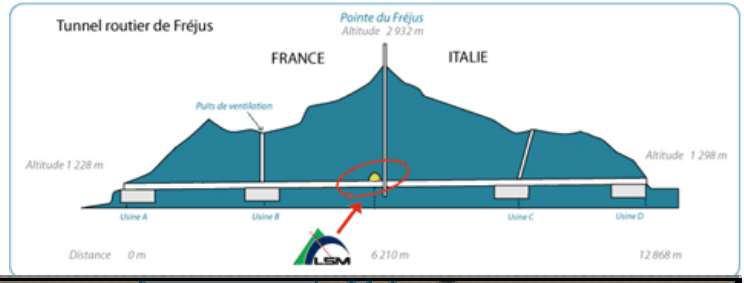
Lead shielding

Tube for calibration source

Lead shielding

Neutron shielding

Laboratoire Souterrain de Modane



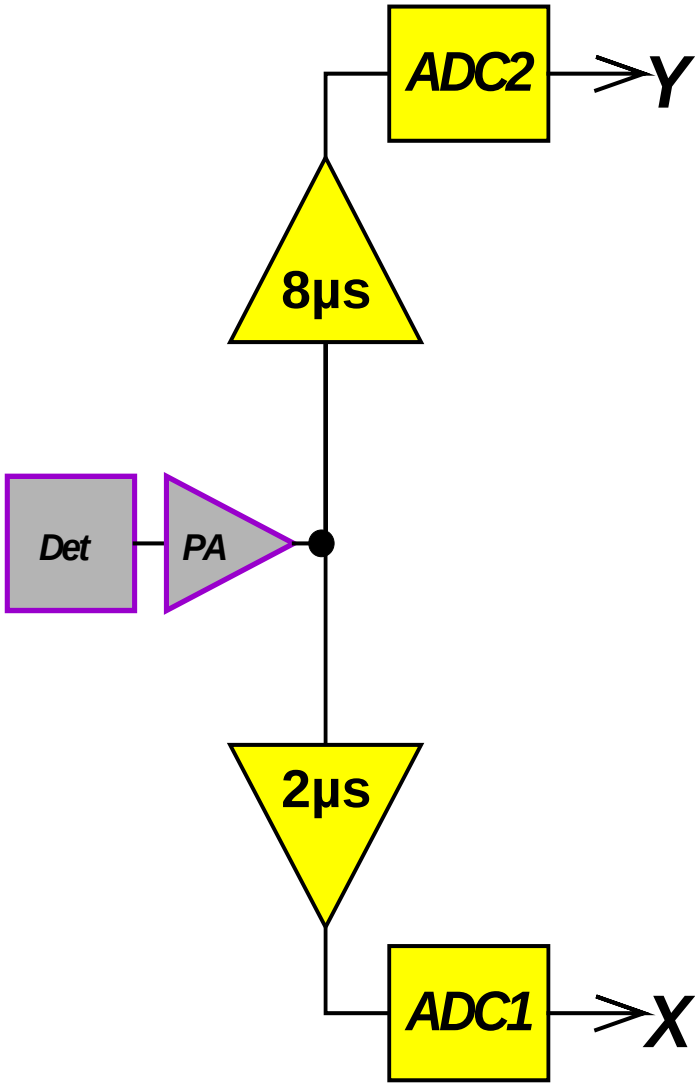
Fréjus Tunnel at the French-Italian border

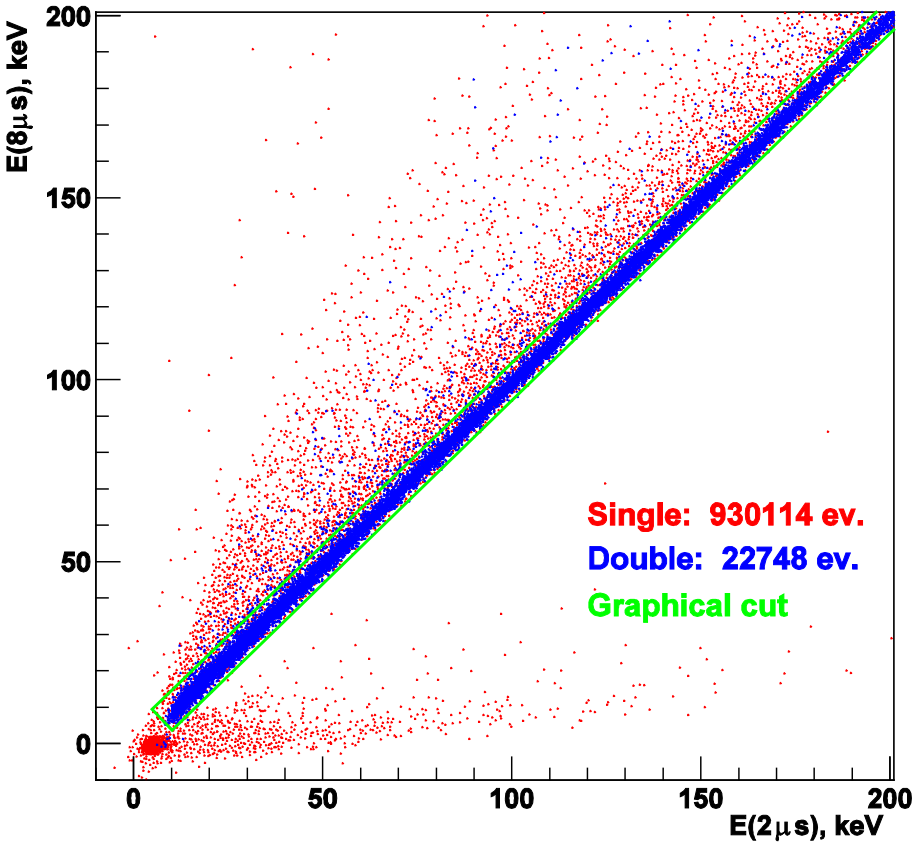
Depth - 1800 m of rock (4800 mwe)

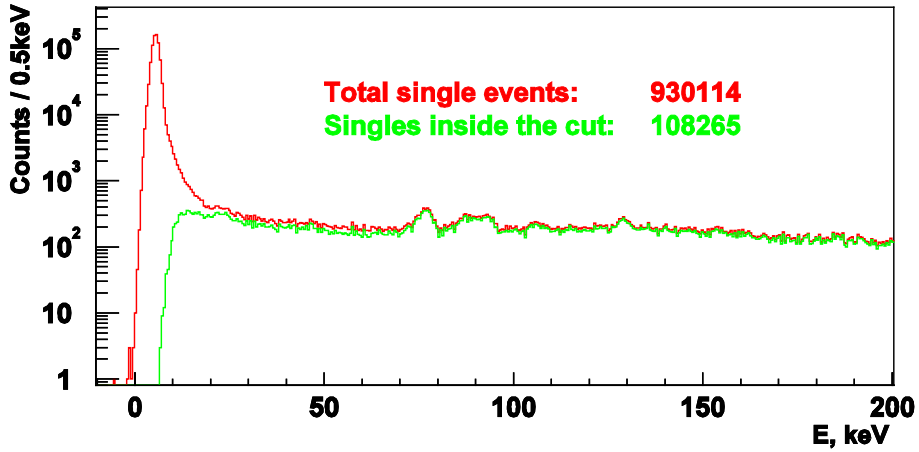
Muons flux - 4 muons / m^2 x day^{-1} ($2x10^6$ reduction factor)

Neutrons flux - 3000 fast neutrons (>1MeV) per m^2 and per day (1000 reduction factor)

Suppression of microphonic noise

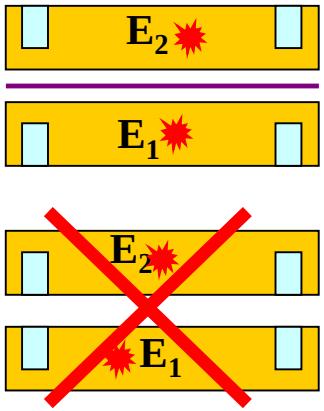






KK TGV signal patterns $\beta^+\beta^+$

KK-pair

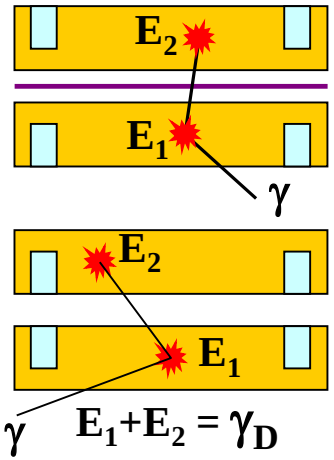


$E_1=E_2=K_{Pd}$

γ_D-single

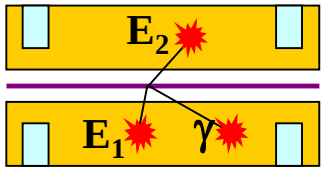
$E_1=\gamma_D$

γ_D-paired



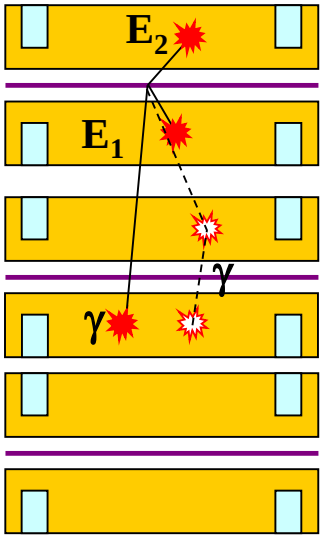
$E_1+E_2=\gamma_D$

1.



(KK+γ_D)-pair

2.



(KK)-pair +

γ_D-satellite (single or paired)

E_1+E_2 != 511 keV

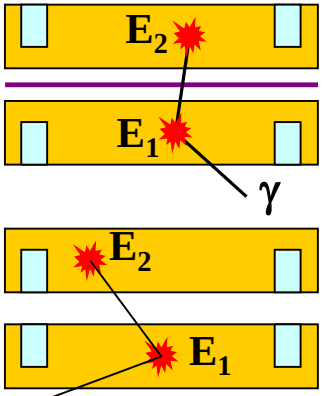
E_1<511 keV

γ_{511}-fired

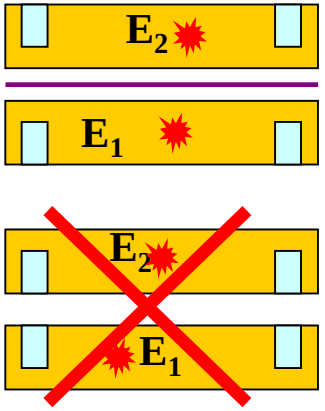
E_1=511 keV

γ_{511}-single

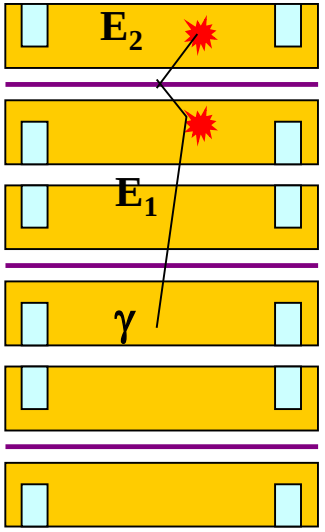
E_1+E_2=511 keV



γ_{511}-paired

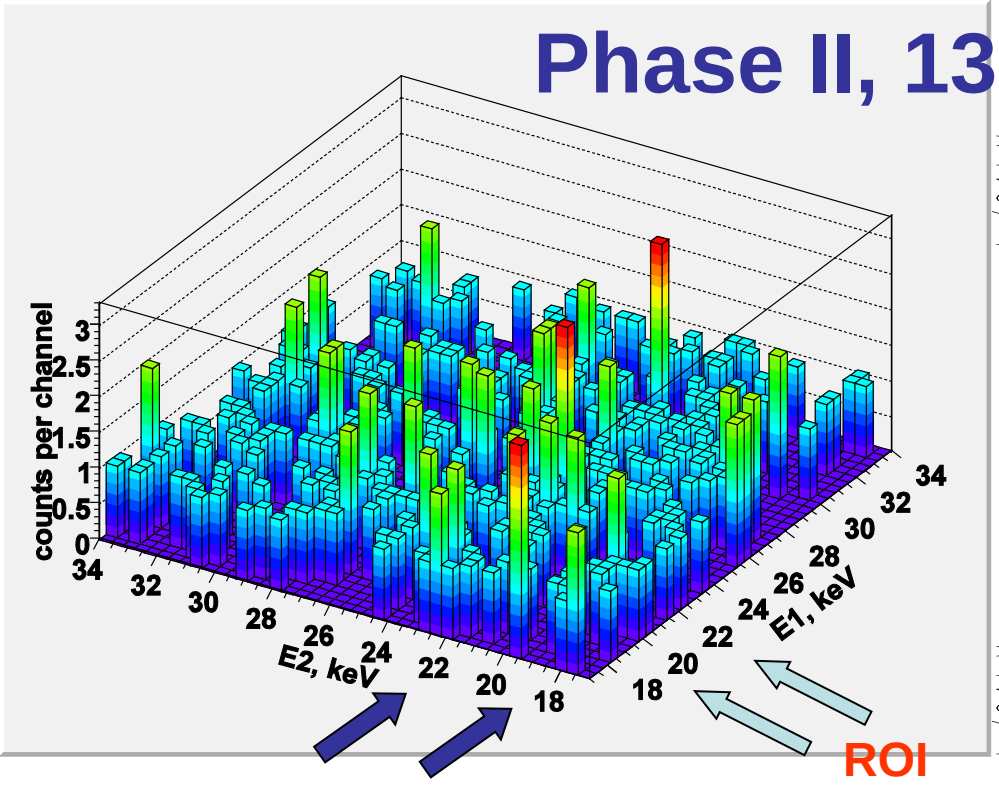


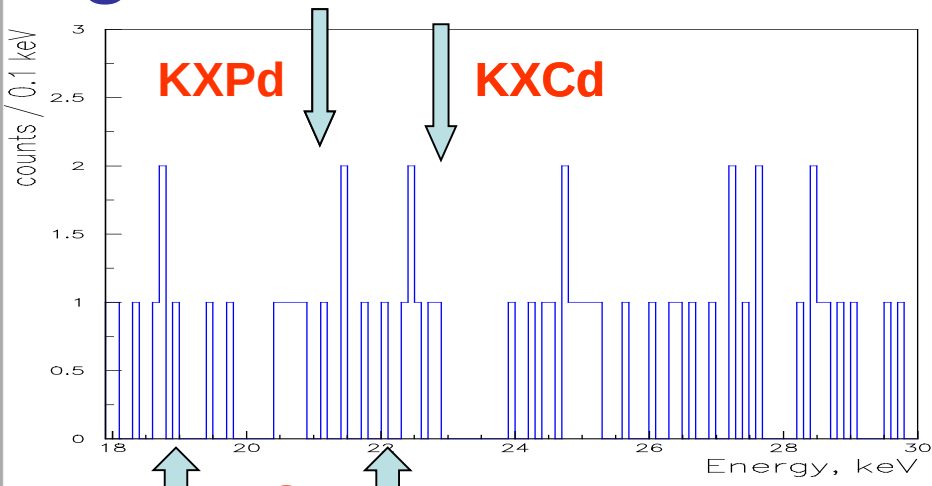
ββ-pair candidate

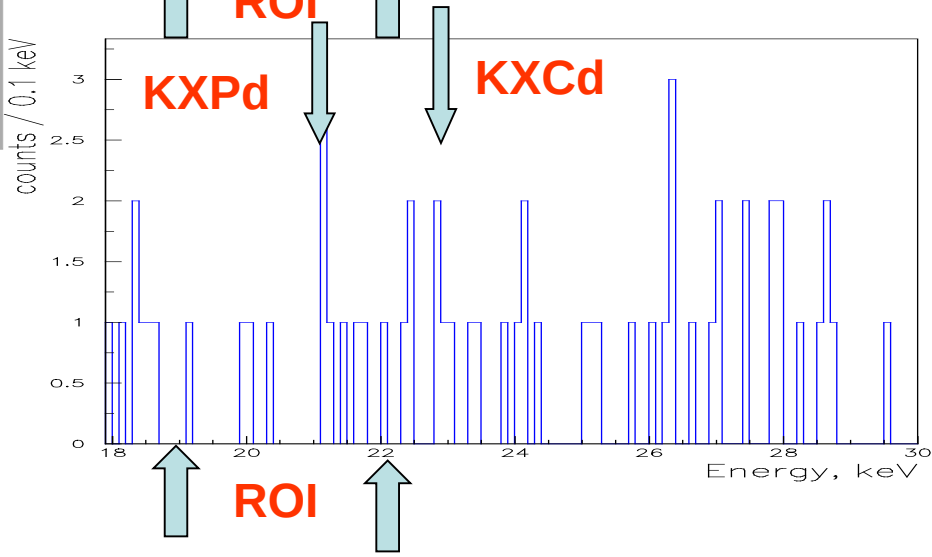


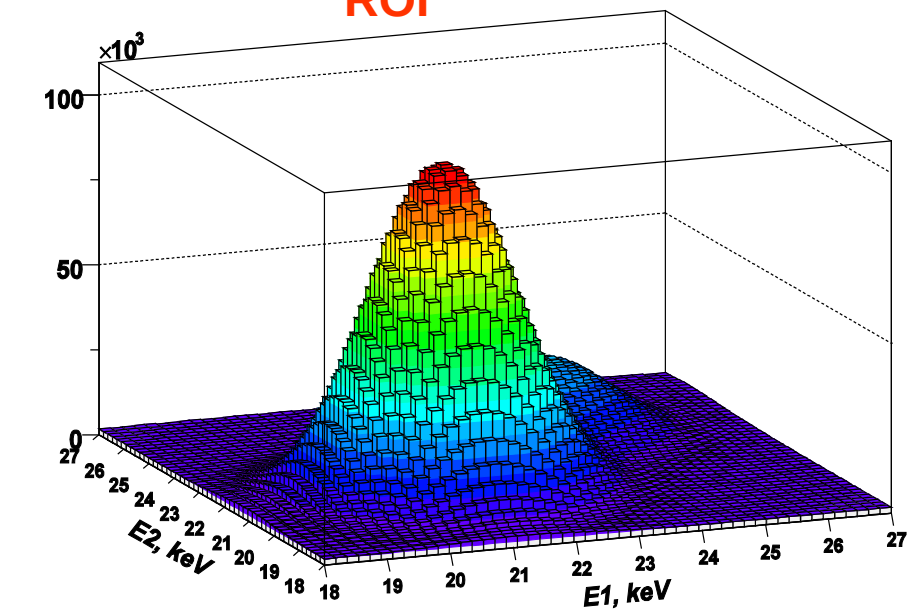
ββ-pair + γ-satellite (single, paired, or fired)

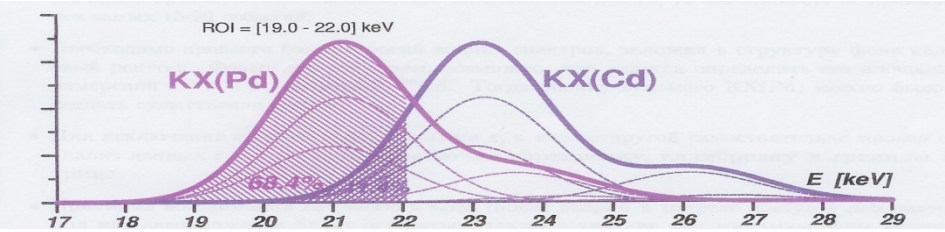
Phase II, 13.6g of ^{106}Cd, T=12900h











TGV-2 limits on double beta decay of ^{106}Cd

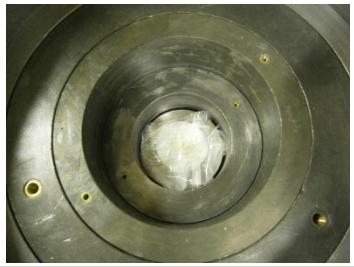
Decay mode	Final level of ^{106}Pd	$T_{1/2}$, yr (90%CL) Phase I	$T_{1/2}$, yr (90%CL) Phase II
$2\nu EC/EC$	0^+g.s.	3.0×10^{20}	4.2×10^{20}
	2^+, 511.9 keV	4.2×10^{19}	1.2×10^{20}
	0^+_1, 1134 keV	3.1×10^{19}	1.0×10^{20}
$0\nu EC/EC$	2717.6 keV	–	1.6×10^{20}
$0\nu EC/EC$	4^+, 2741 keV	–	1.8×10^{20}
$2\nu\beta^+/EC$	0^+g.s.	5.9×10^{19}	1.1×10^{20}
	2^+, 511.9 keV	5.9×10^{19}	1.1×10^{20}
	0^+_1, 1134 keV	1.1×10^{20}	1.6×10^{20}
$0\nu\beta^+/EC$	0^+g.s.	–	1.1×10^{20}
	2^+, 511.9 keV	–	1.1×10^{20}
	0^+_1, 1334 keV	–	1.6×10^{20}
$2\nu\beta^+\beta^+$	0^+g.s.	6.0×10^{19}	1.4×10^{20}
	2^+, 511.9 keV	5.7×10^{19}	1.7×10^{20}
$0\nu\beta^+\beta^+$	0^+g.s.	–	1.4×10^{20}
	2^+, 511.9 keV	–	1.7×10^{20}
$2\nu\beta^+\beta^+\chi^\circ$	0^+g.s.	–	1.3×10^{20}

$T_{1/2}$th.~10^{20}–10^{22}y

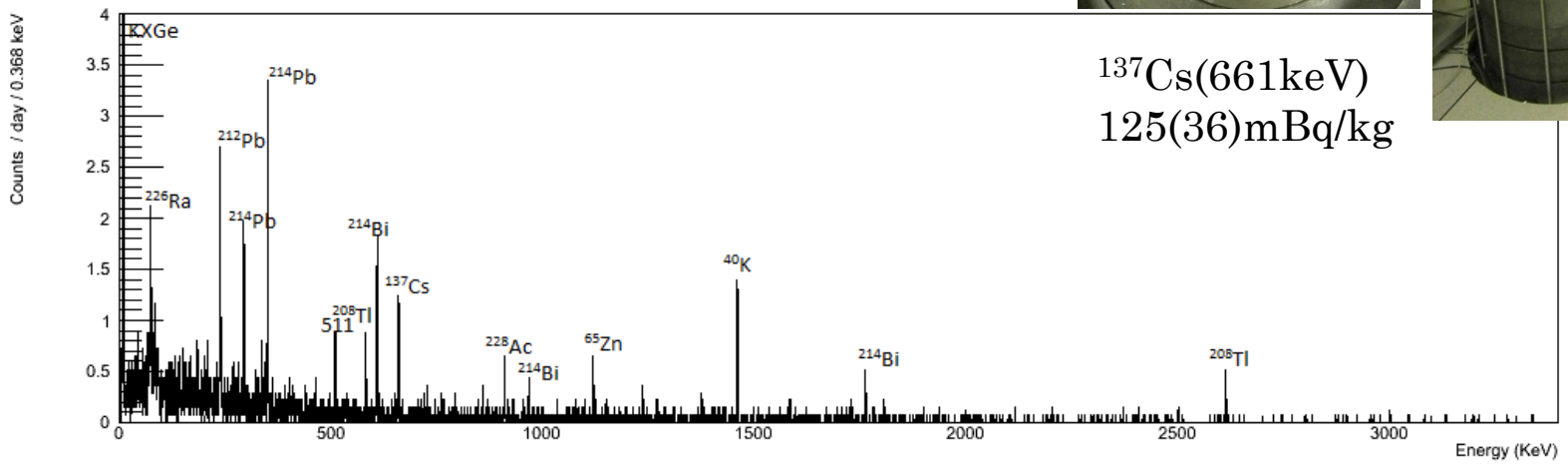
N.I.Rukhadze et al., Journal of Physics: Conference Series 375 (2012) 042020.

Measurement of ^{106}Cd with 600 cm^3 HPGe detector Obelix, November 2013, T=395 h

16 circle foils of ^{106}Cd
with enrich. 99.57%
Ø = 52 mm
thick. 70(10) mg/cm^2
mass = 23.166 g

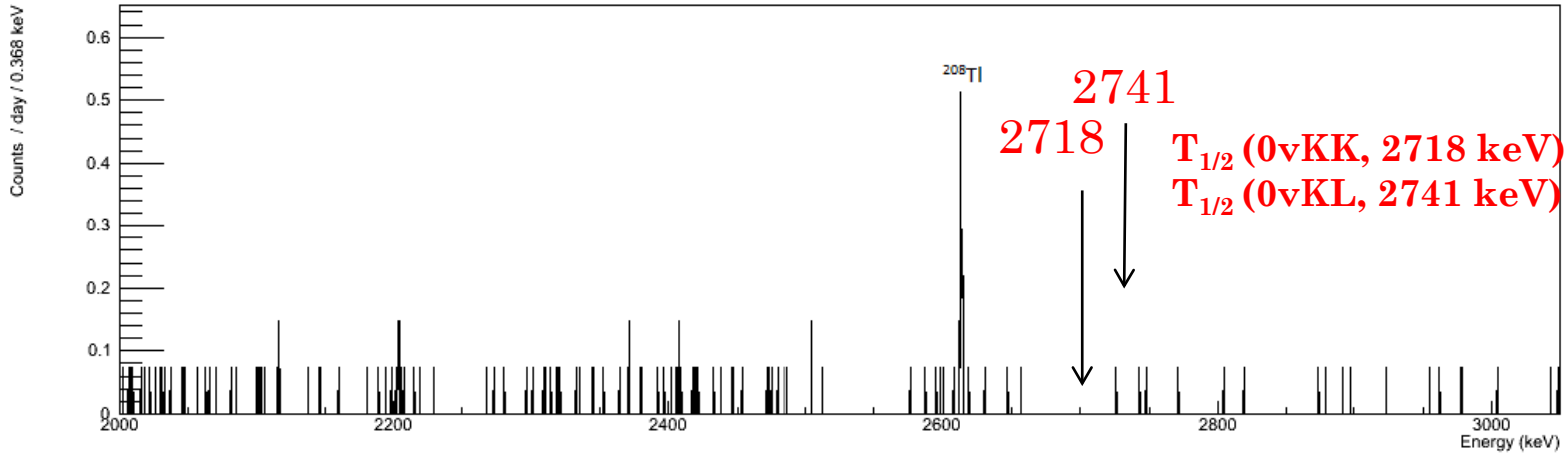


Measurement 106Cd 2013



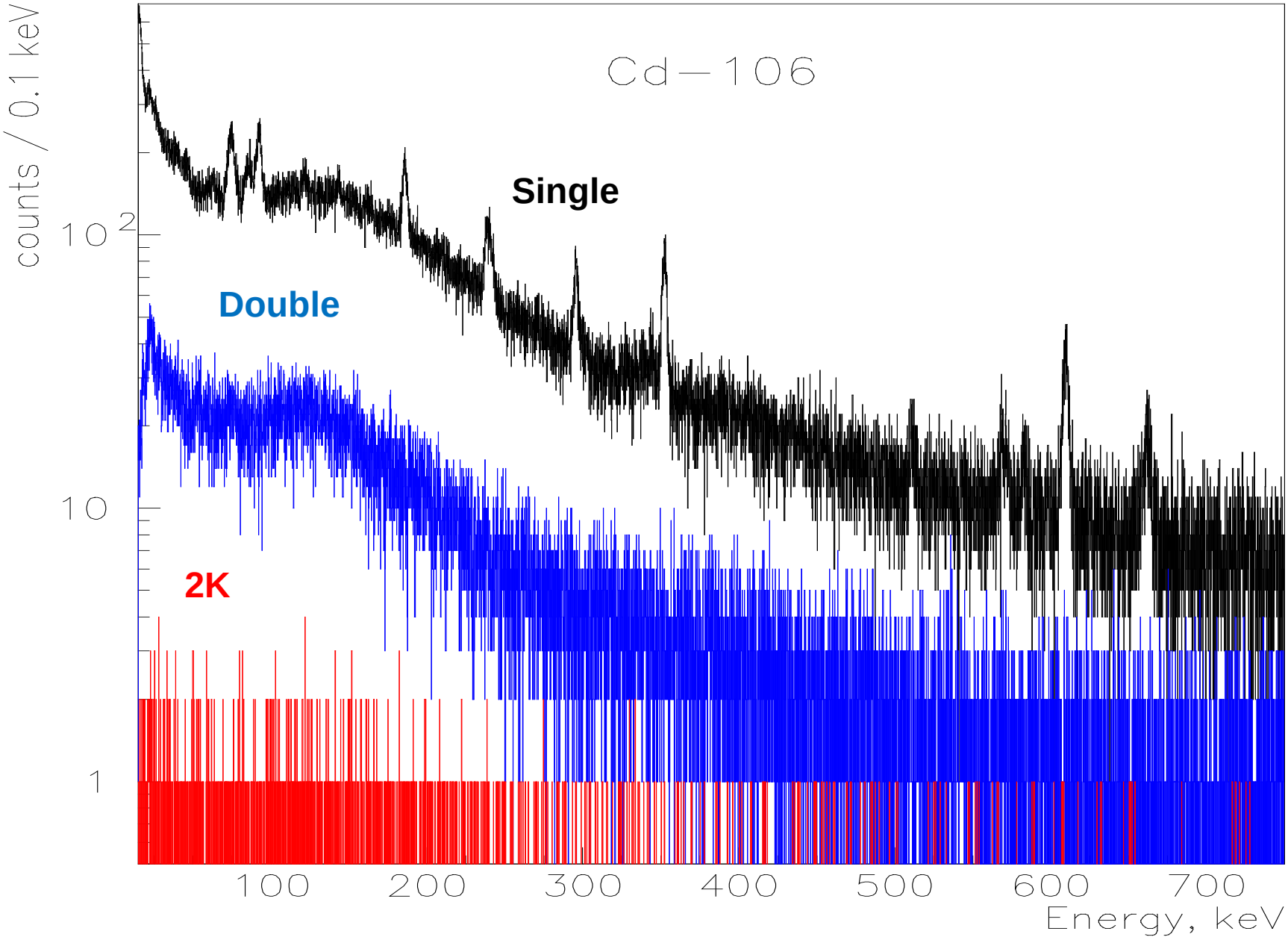
^{137}Cs(661keV)
125(36)mBq/kg

Region of interest 106Cd

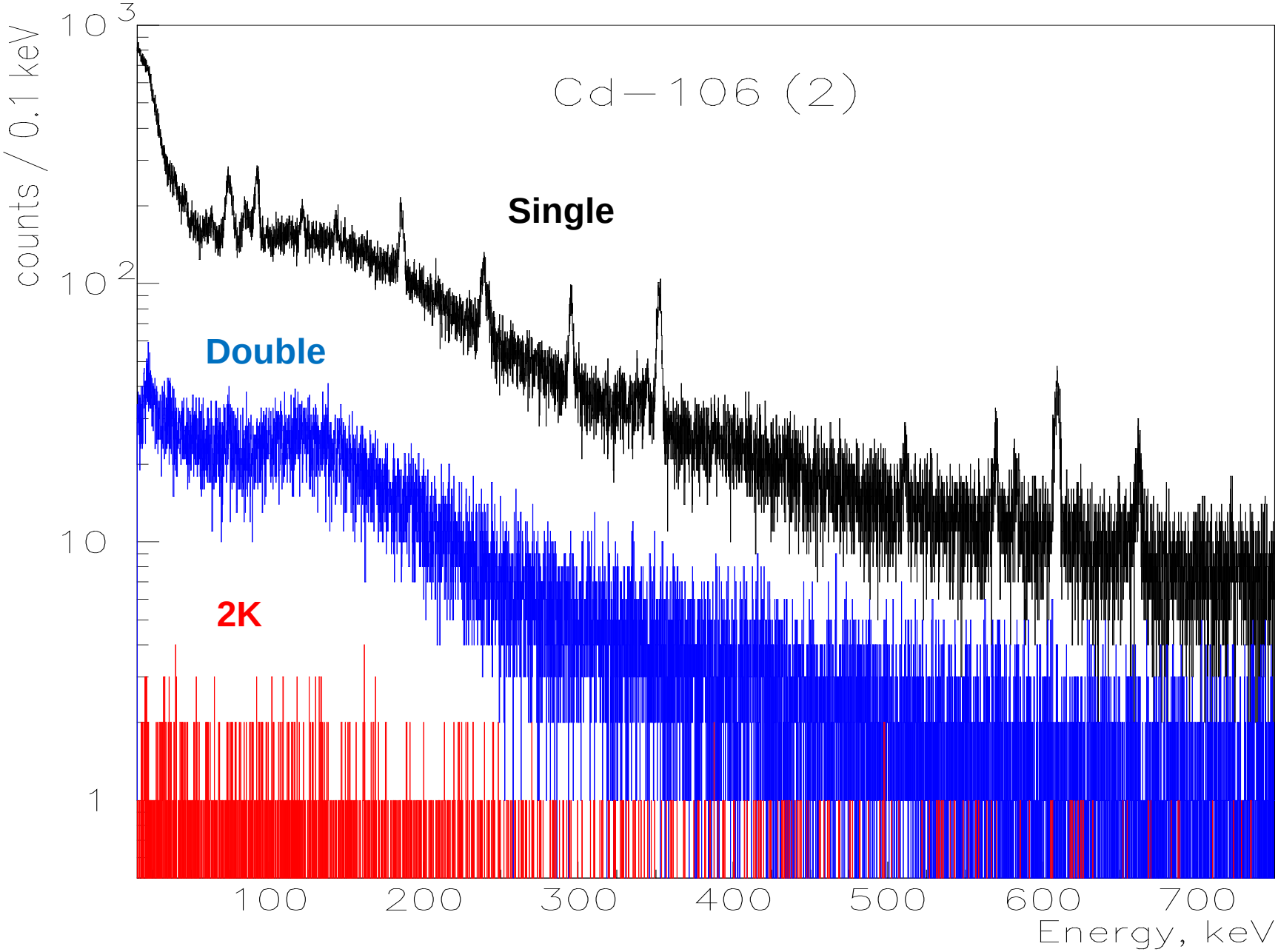


$T_{1/2}$ (0vKK, 2718 keV) > 1.4×10^{20} y,
$T_{1/2}$ (0vKL, 2741 keV) > 0.9×10^{20} y

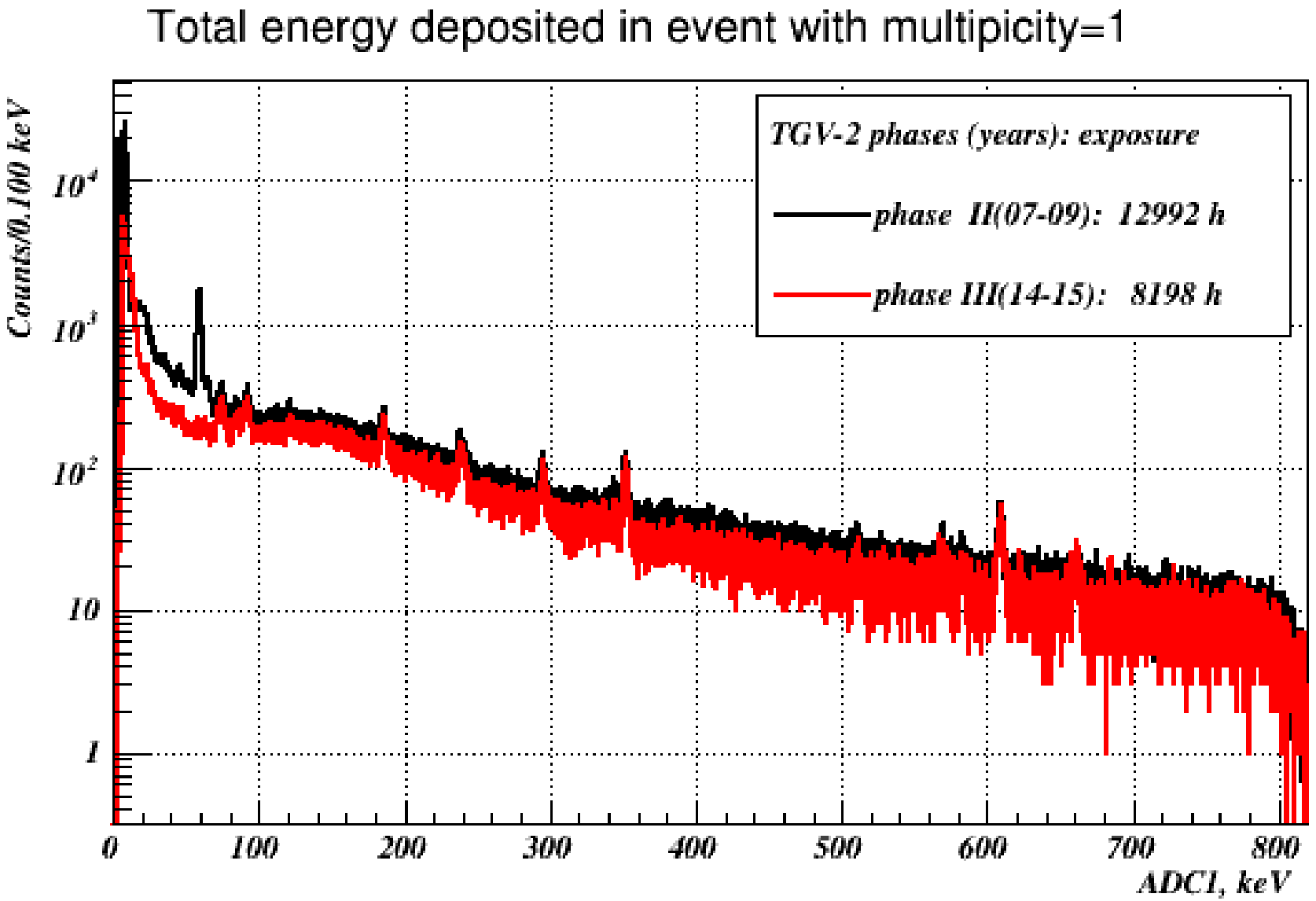
T=8198 h


Cd—106
Single
Double
2K
counts / 0.1 keV
10 2
10
1
100
200
300
400
500
600
700
Energy, keV

T=8198 h

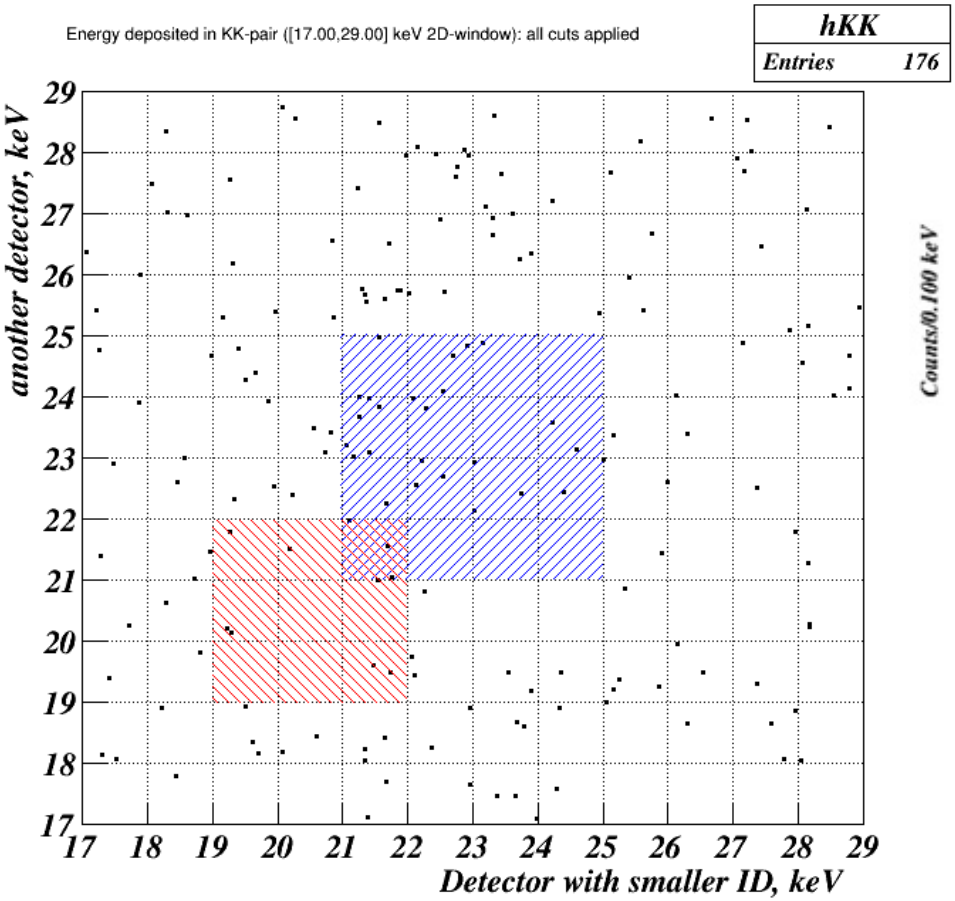

Cd—106 (2)
Single
Double
2K
counts / 0.1 keV
Energy, keV
10 3
10 2
10
1
100
200
300
400
500
600
700

Single events

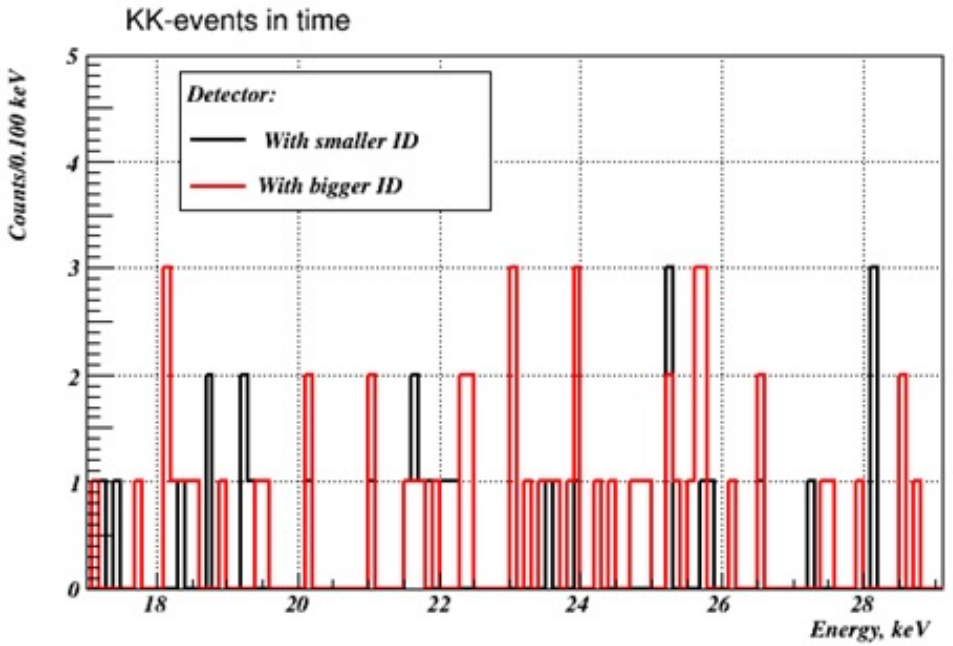


KK-spectra in the ROI (19-22 keV)

2D method

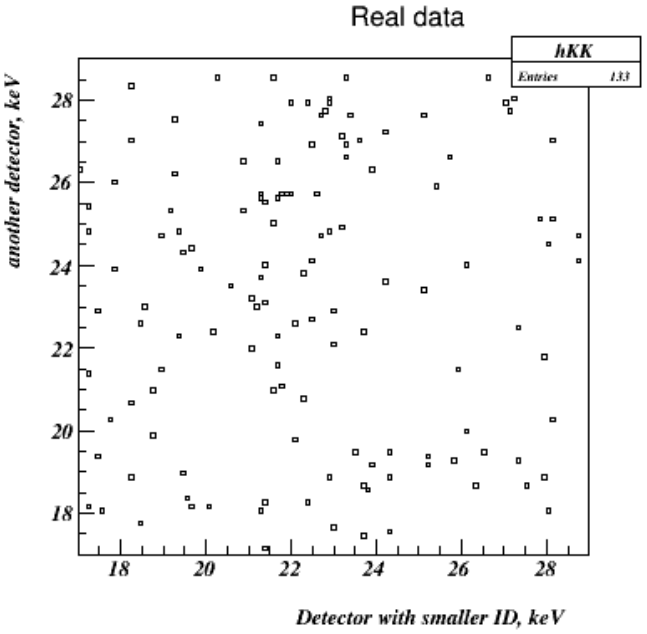


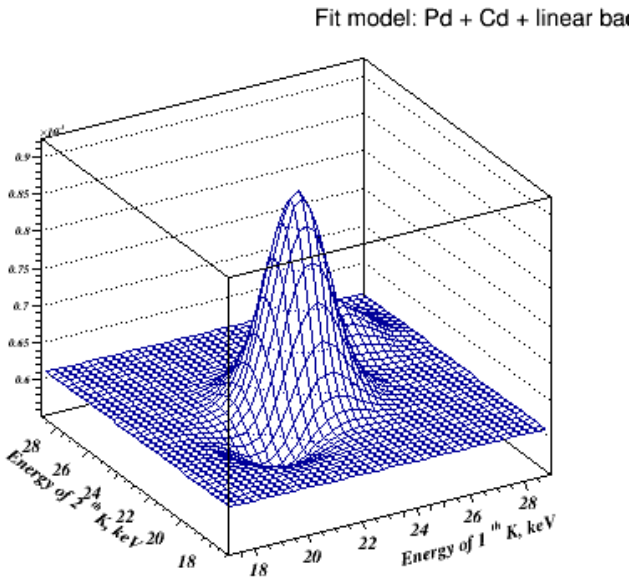
1D method

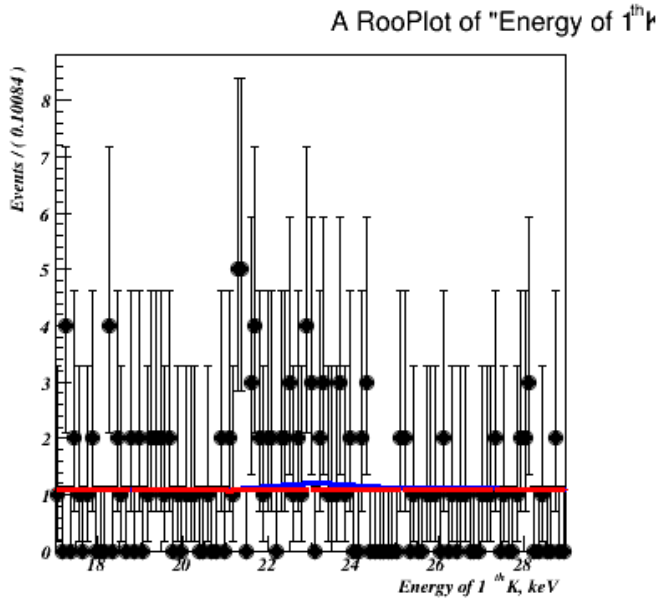


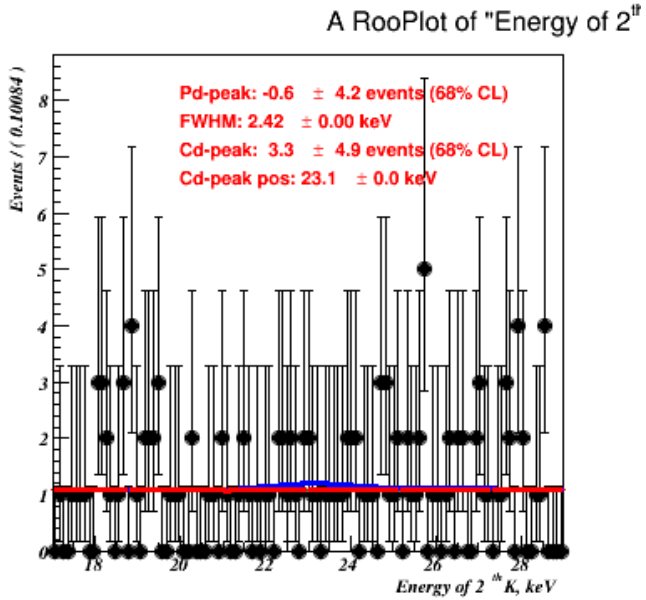
$T_{1/2}(2\nu KK) > 3.1 \times 10^{20}$ y (90%CL)

KK analysis in 2D-method









TGV-2 limits on double beta decay of Cd-106 (at 90% CL)

	Phase II	Phase III
• **0νEC/EC**		
2717.6 keV	$>1.6 \times 10^{20}$	$>1.4 \times 10^{20}$ y (395 h)
2741 keV	$>1.8 \times 10^{20}$	$>0.9 \times 10^{20}$ y (395 h)
• **2νEC/EC**		
(0+→0+,g.s.)	- $T_{1/2} \geq 4.2 \times 10^{20}$ y	3.1×10^{20} y (prelim.)
(0+→2+$_1$,512)	- $T_{1/2} \geq 1.2 \times 10^{20}$ y	8.5×10^{19} y
(0+→0+$_1$,1334)	- $T_{1/2} \geq 1.0 \times 10^{20}$ y	6.0×10^{19} y
• **2νβ$^+$/EC**		
(0+→0+,g.s.)	- $T_{1/2} \geq 1.1 \times 10^{20}$ y	1.7×10^{20} y
(0+→2+$_1$,512)	- $T_{1/2} \geq 1.1 \times 10^{20}$ y	1.3×10^{20} y
(0+→0+$_1$,1334)	- $T_{1/2} \geq 1.6 \times 10^{20}$ y	1.9×10^{20} y
• **2νβ$^+$ β$^+$**		
(0+→0+,g.s.)	- $T_{1/2} \geq 1.4 \times 10^{20}$ y	1.6×10^{20} y
(0+→2+$_1$,512)	- $T_{1/2} \geq 1.7 \times 10^{20}$ y	1.9×10^{20} y

Thank you for attention