# Status and Perspectives of the COBRA-Experiment

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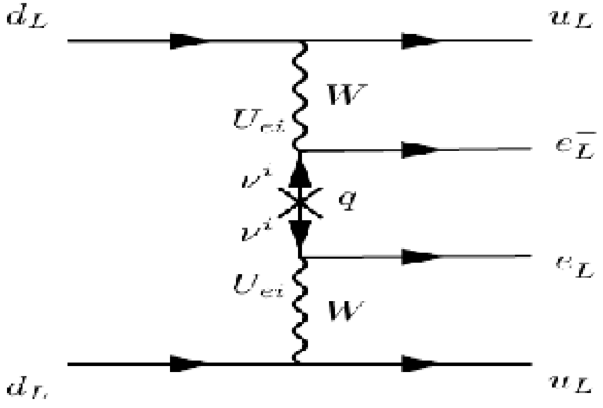
for the COBRA Collaboration



technische universität
dortmund

Deutsche
Forschungsgemeinschaft
DFG

January 2015 Hirschegg

# Status and Perspectives of the COBRA-Experiment

double beta decays

CdZnTe (CZT) detectors

COBRA demonstrator

perspectives

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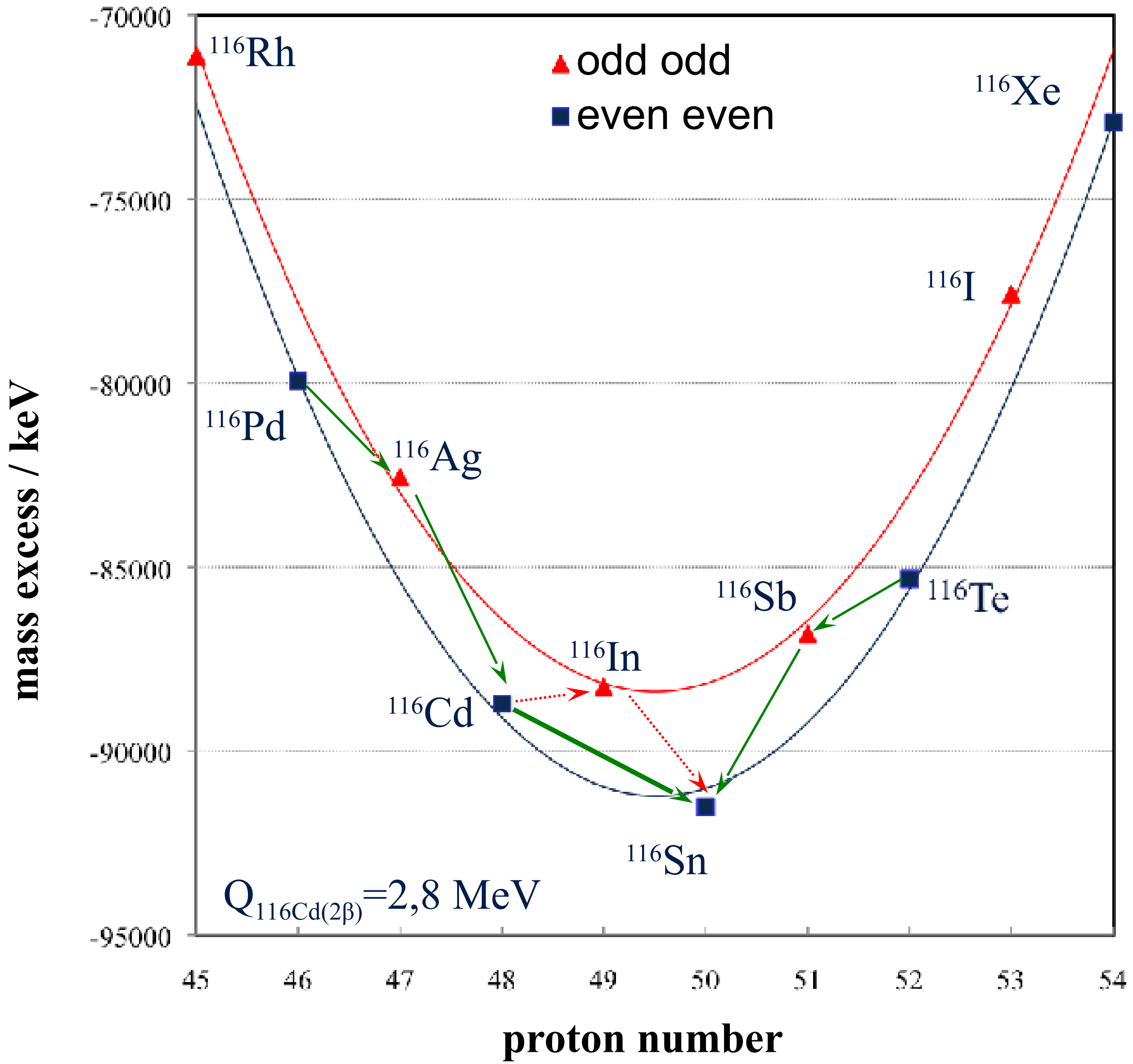
# COBRA -
# **C**dZnTe-**0**-neutrino double-**B**eta decay **R**esearch **A**pparatus



ββ-decay:

- only even-even nuclei
- if no normal beta decay

0νββ-decay answers:

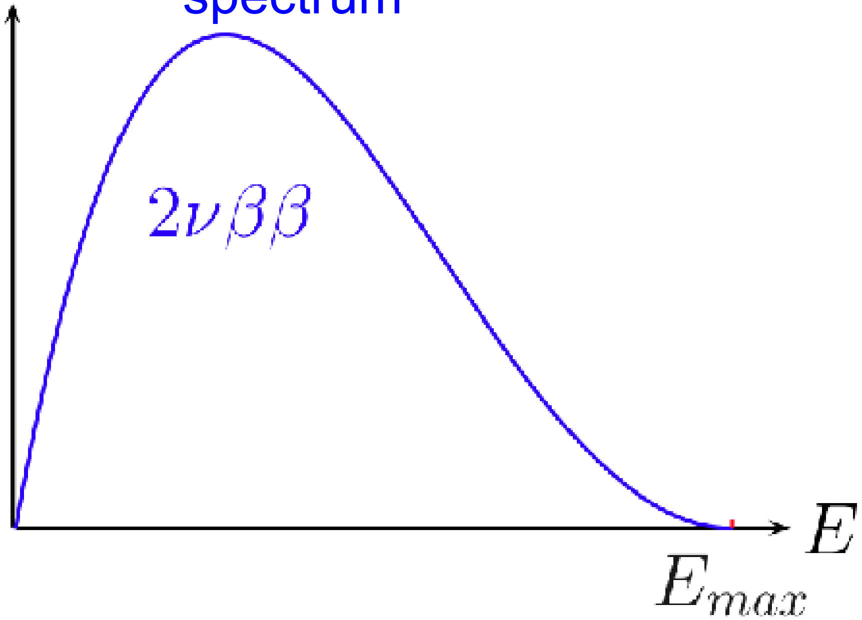
- neutrino = antineutrino = Majorana neutrino?
- neutrino rest mass

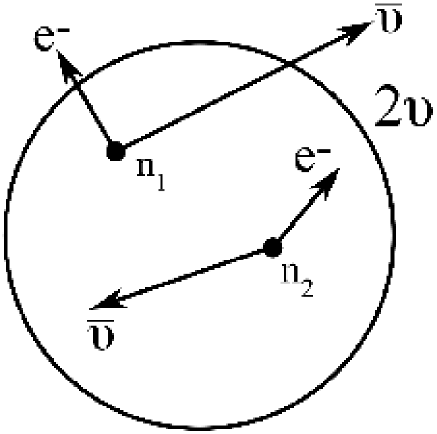
# double beta decays

2 possible double beta decays:

- neutrino accompanied: (A, Z) ⟶ (A, Z+2) + $2e^-$ + $2\bar{\nu}_e$

continuously distributed electron spectrum





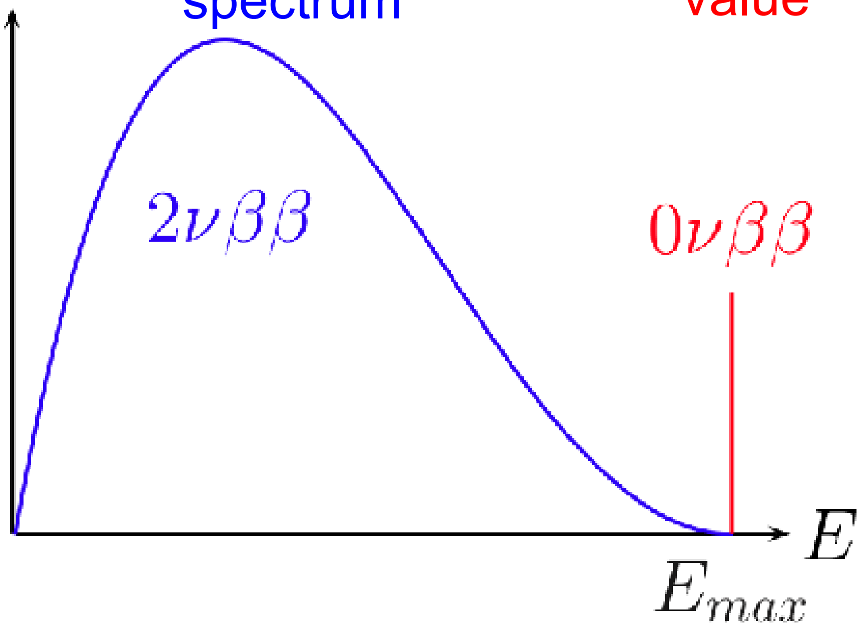
# double beta decays

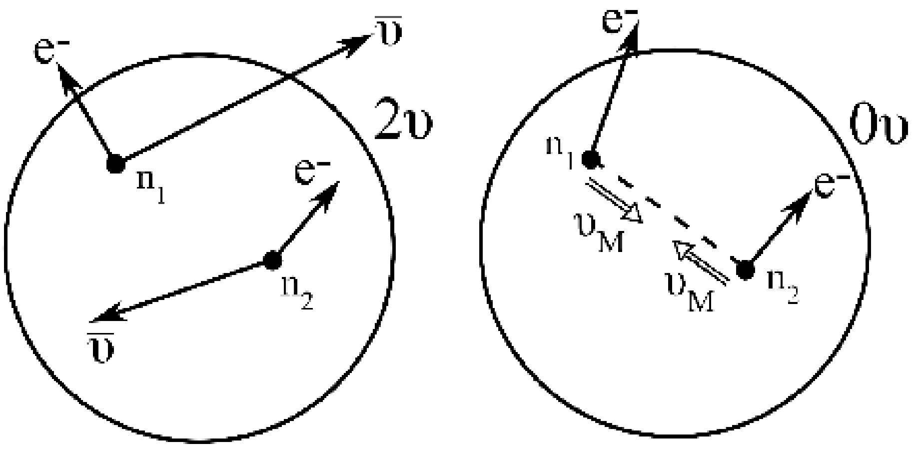
## 2 possible double beta decays:

- neutrino accompanied: $(A, Z) \longrightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$
- neutrinoless: $(A, Z) \longrightarrow (A, Z+2) + 2e^-$

continuously distributed electron spectrum

line at Q-value





physics beyond SM:
violation of Lepton number conservation

# double beta decays

phase space integral matrix elements effective Majorana mass

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}(Q,Z)\,\left|M_{GT}^{0\nu} - M_{F}^{0\nu}\right|^{2}\left(\frac{\langle m_{\nu_e}\rangle}{m_e}\right)^{2}$$

$$T_{1/2}\Big|_{\det} \propto \alpha\,\varepsilon_{tot}\sqrt{\frac{M\cdot t}{\Delta E\cdot B}}$$

| | |
|---|---|
| $\alpha$ | isotopic abundance |
| $\varepsilon_{tot}$ | total detection efficiency |
| $M$ | detector mass |
| $t$ | livetime of experiment |
| $\Delta E$ | energy resolution |
| $B$ | background level |

2νββ-decay: measured half life ~ $10^{20}$ y

0νββ-decay: limits: half life > $10^{26}$ y

# CdZnTe detectors

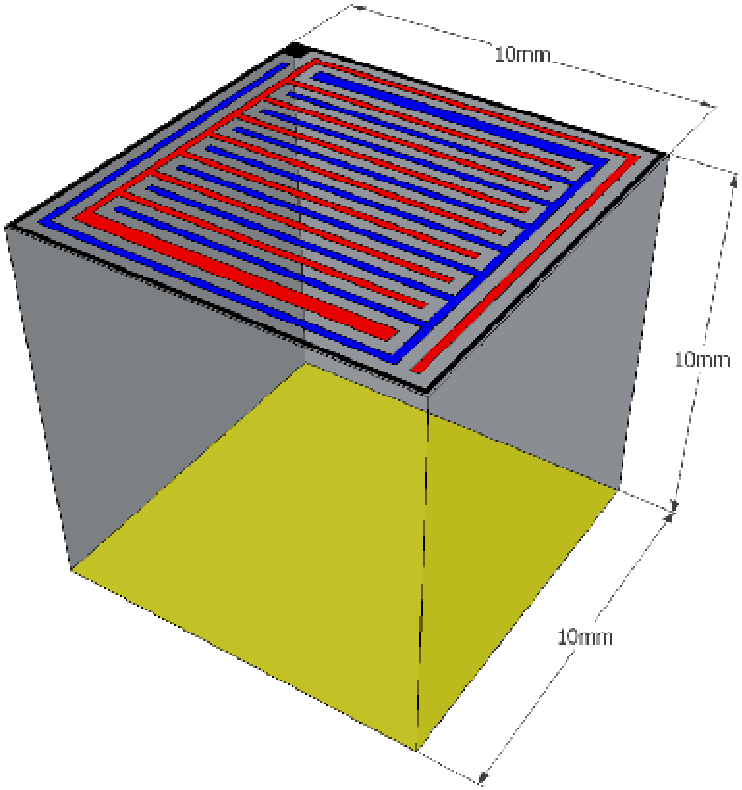
- CdZnTe (CZT) semiconductor detector
  → intrinsically pure, good energy resolution
- detector = source → high detection efficiency
- 9 ββ decay isotopes
  - $^{116}$Cd: Q-value (2813keV), high phase space
  - $^{130}$Te: Q-value (2527keV), high natural abundance (34%)
  - $^{106}$Cd: Q-value (2770keV), all $\beta^+\beta^+$-decay modes
- room temperature
- low mobility-lifetime product (holes):
  → single polarity detector
  → Co-planar Grid technology (CPG)

# CZT detectors: Co-planar Grid

- Luke(1994): similar to Frisch-Grid in gas detectors

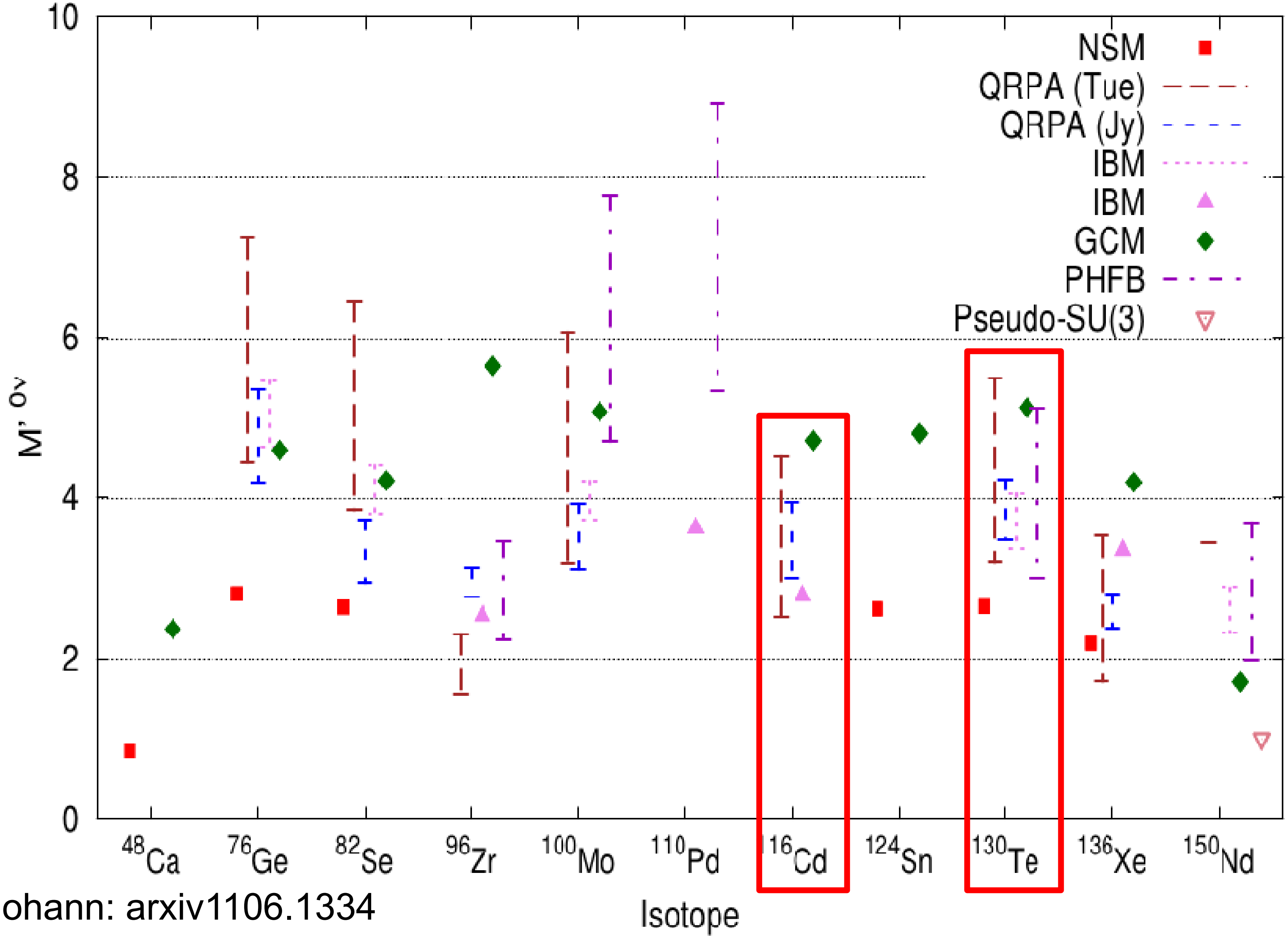
Appl. Phys. Lett. 65: 2884-2886, 1994

- 2 comb-shaped anodes
- planar cathode
- read out of both anode signals
  → simple electronics
- energy ∝ difference of anodes
- interaction depth ∝ ratio of anodes



NIMA 708: 1-6, 2013

# nuclear matrix elements

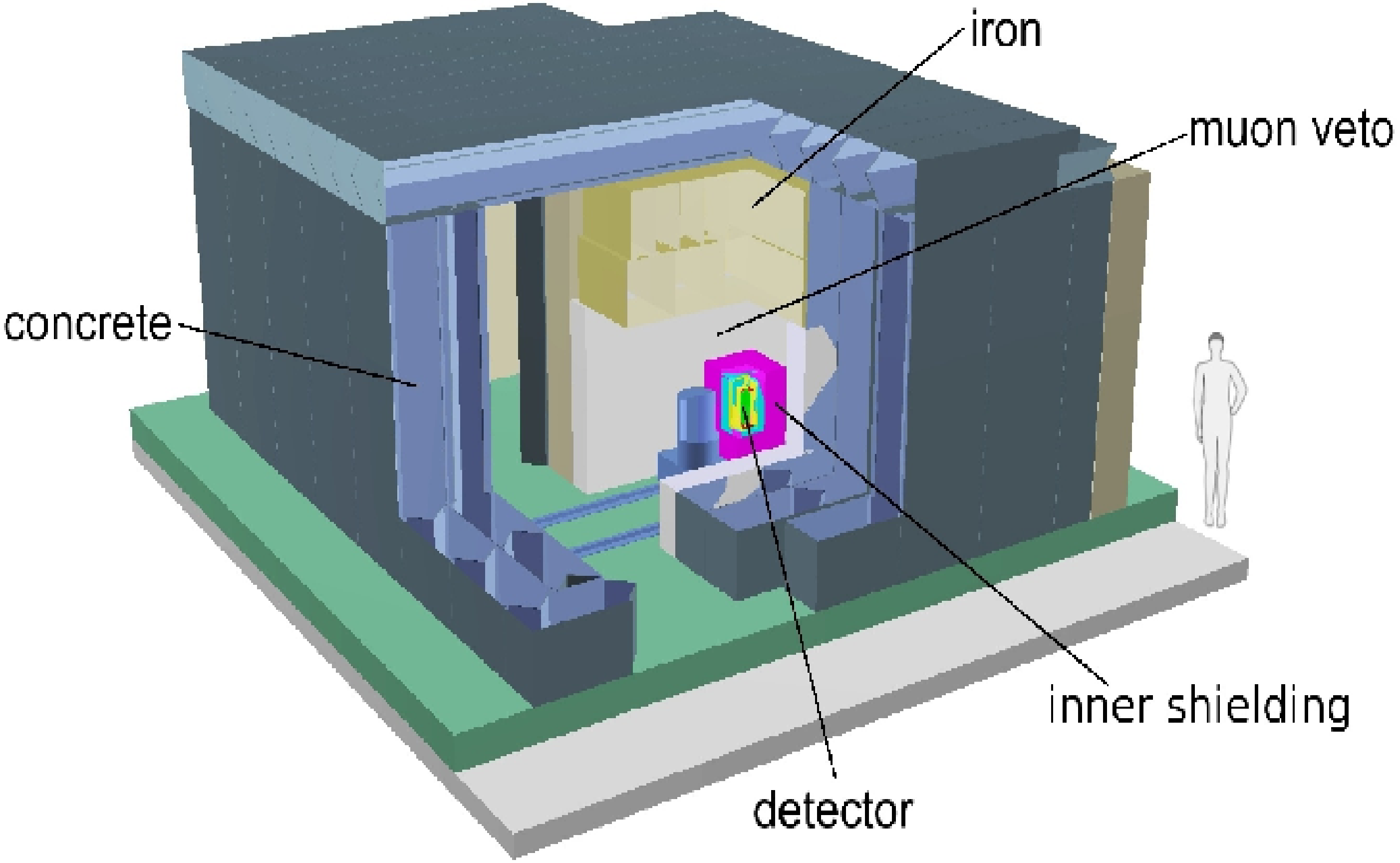


Rodejohann: arxiv1106.1334

# material selection: Dortmund Low Background Facility (DLB)

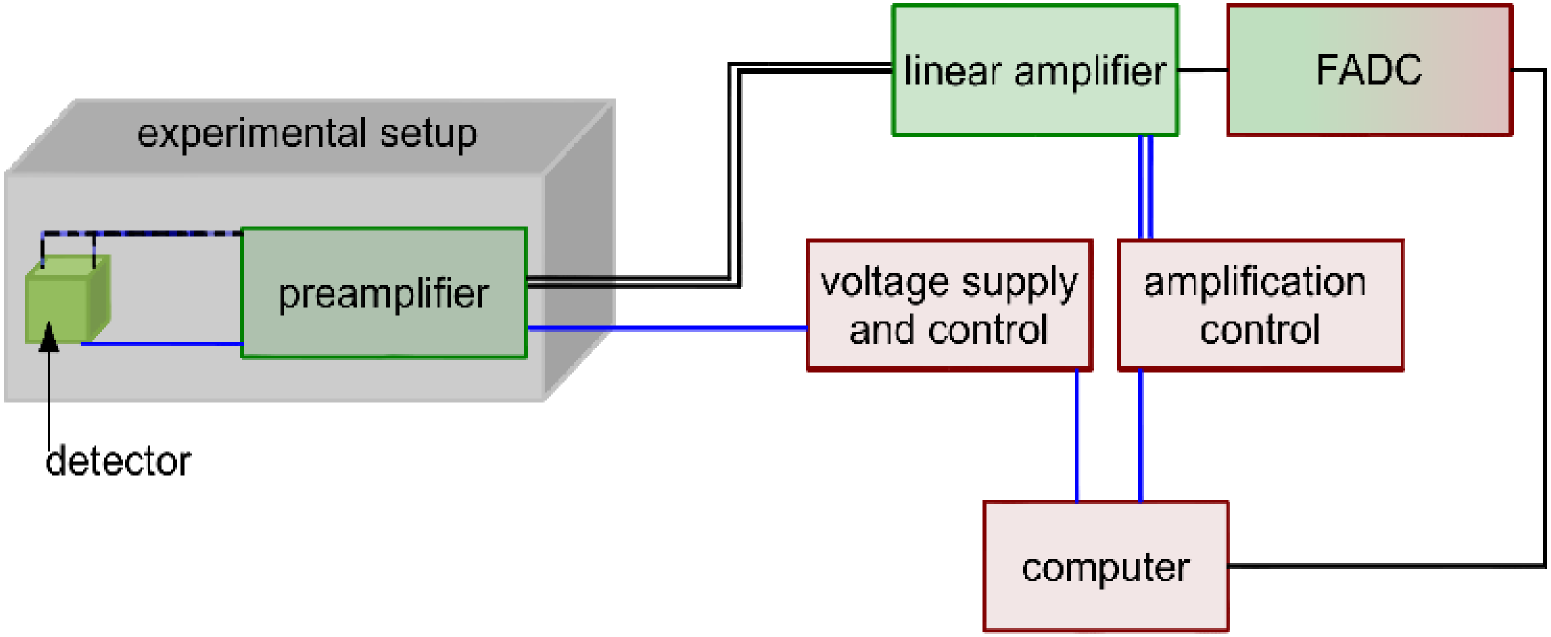
low count rate Germanium detector at earth surface

- ~330t concrete + iron
  → 10mwe
- 2.5 cts / kg / min
  40 … 2700keV
- sensitivity:
  < 100mBq/kg



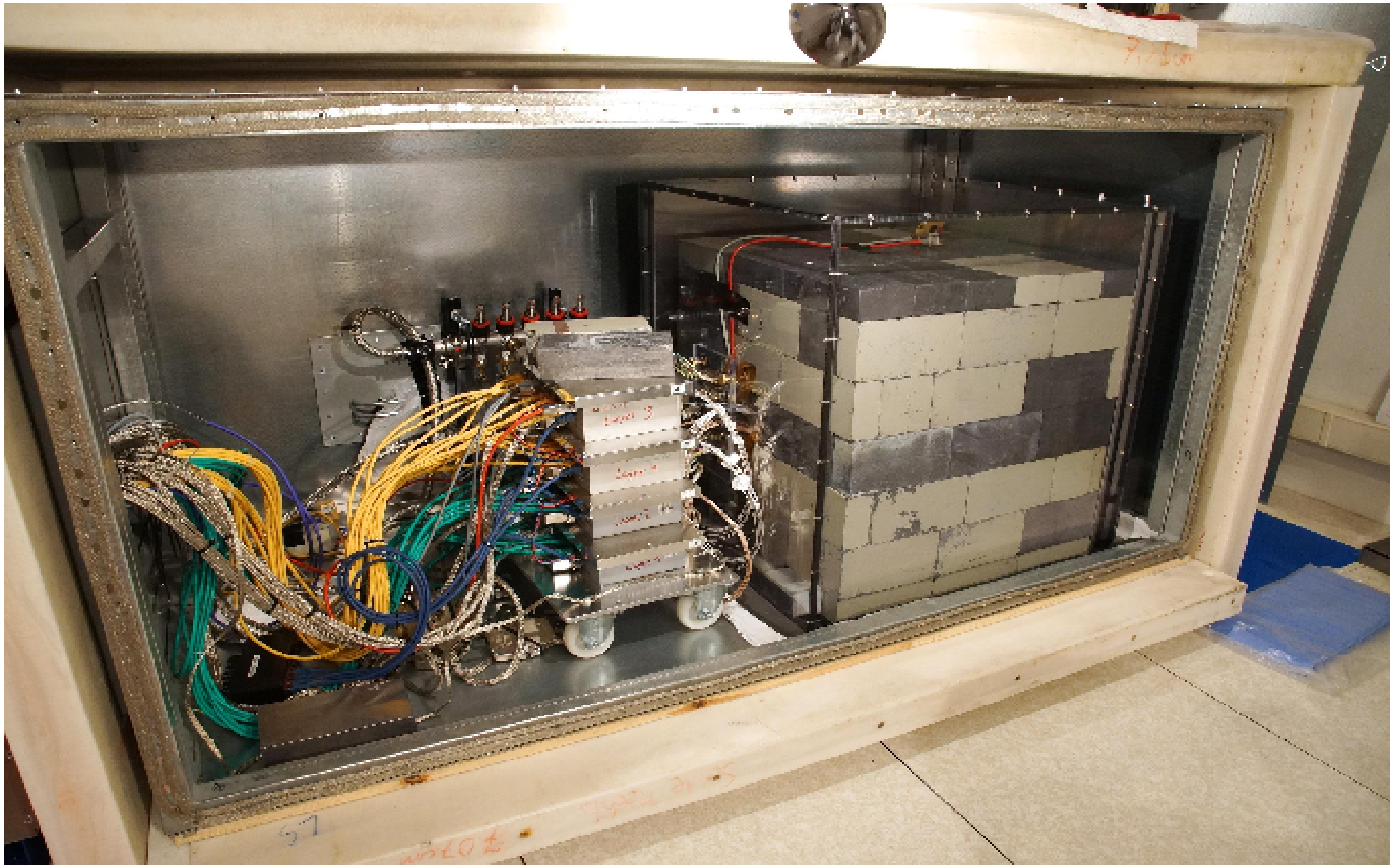
# demonstrator setup @ Gran Sasso Lab (LNGS)

- custom designed read-out electronics
  - robust and stable: differential signal transmission
  - remote control
- FADCs record complete pulse shapes → pulse shape analysis



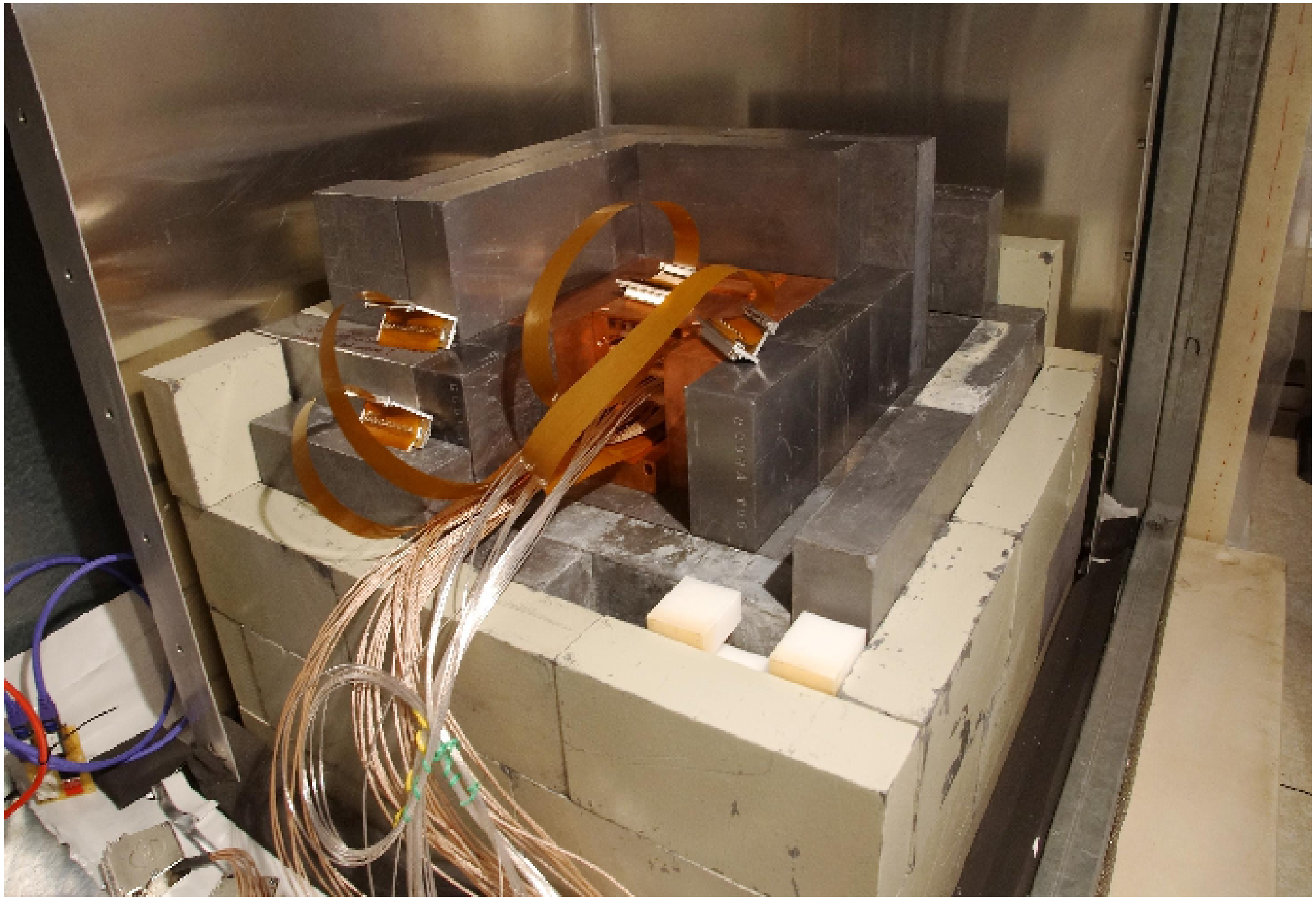
# demonstrator setup @ Gran Sasso Lab

- 1400m rock (ca. 3700mwe) + additional shielding layers

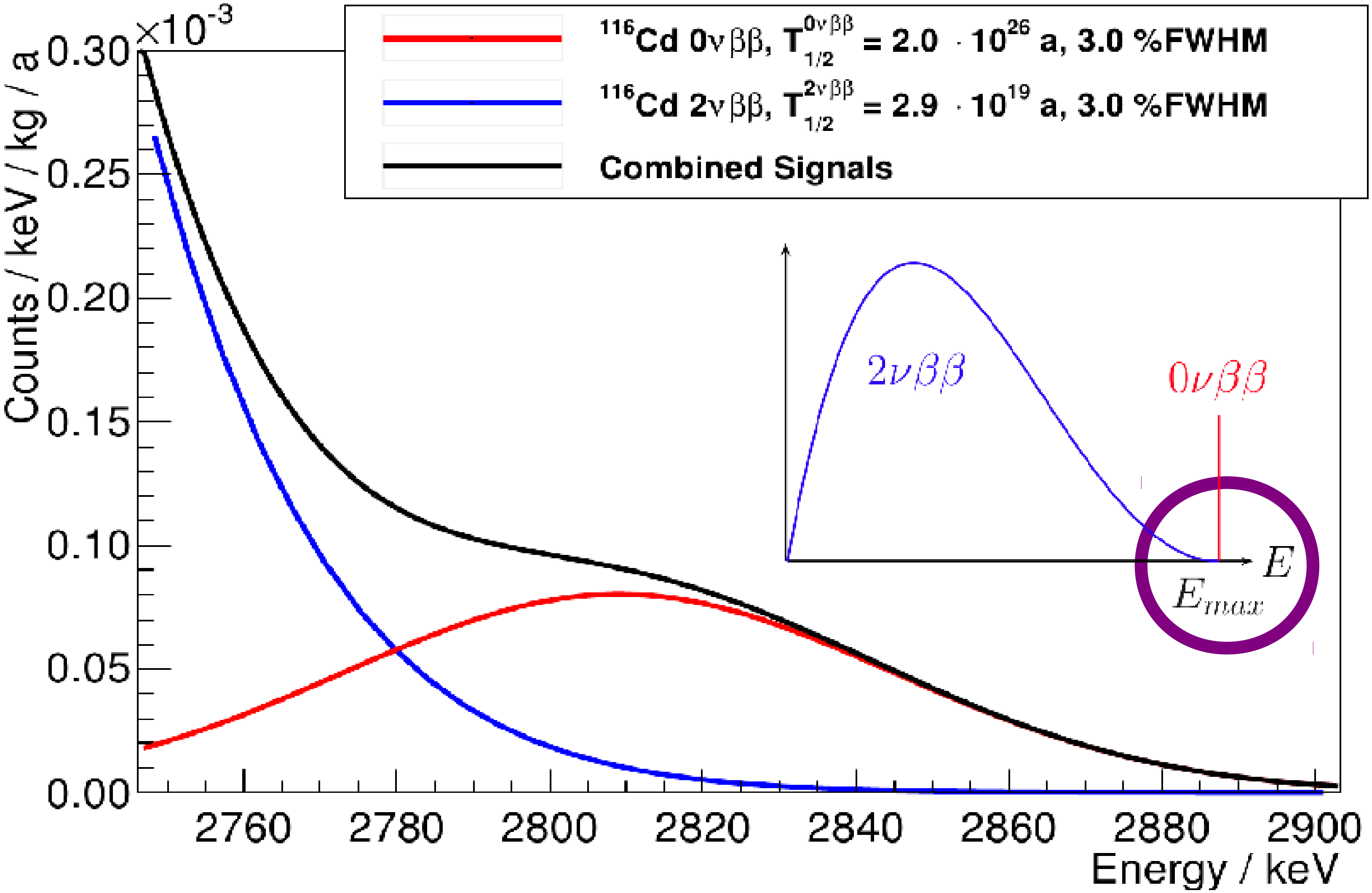


# demonstrator setup @ Gran Sasso Lab

- 1400m rock (ca. 3700mwe) + additional shielding layers
- 64 detectors: 4 layers à 4x4 detectors → 400g

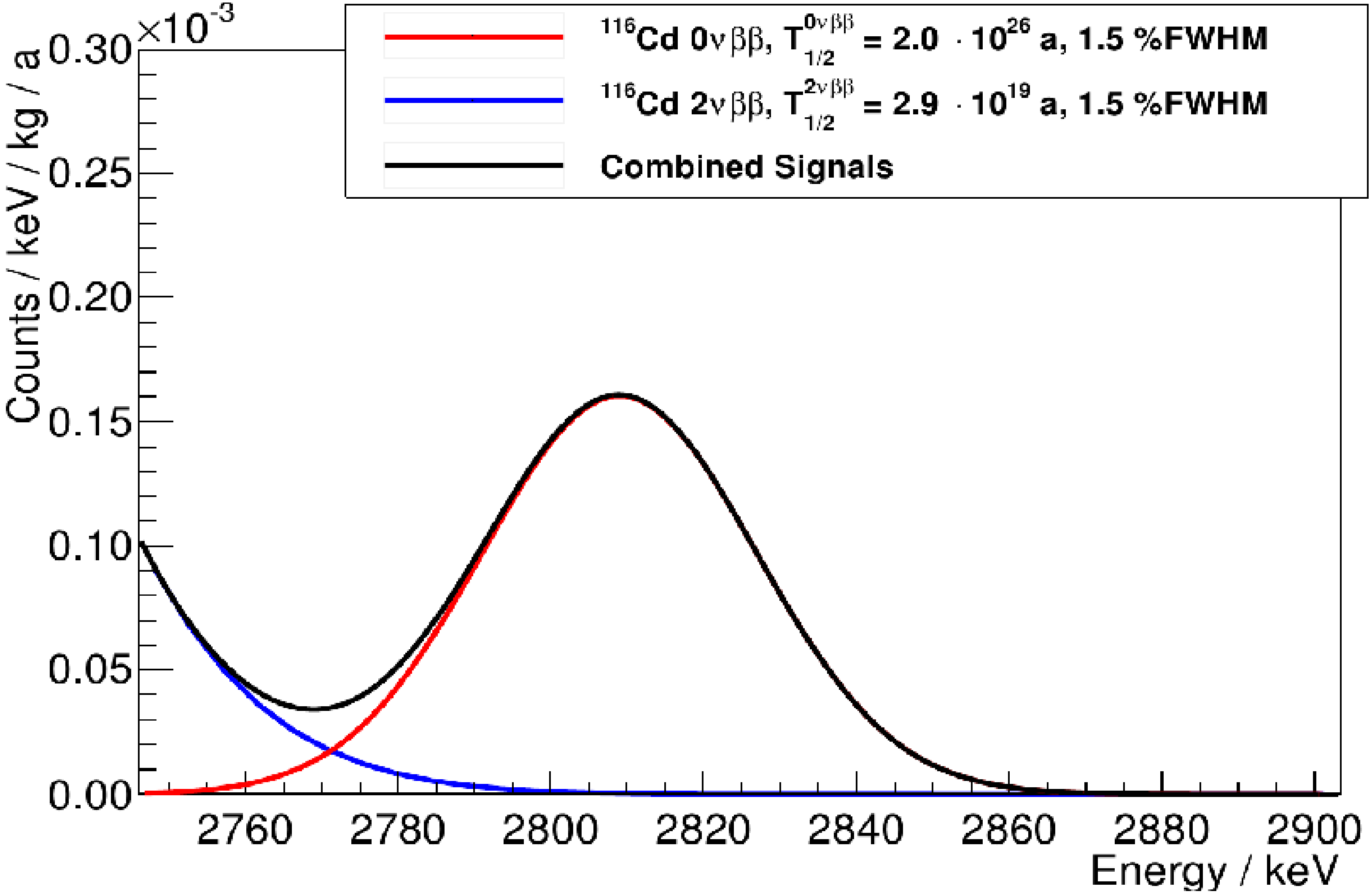


# energy resolution



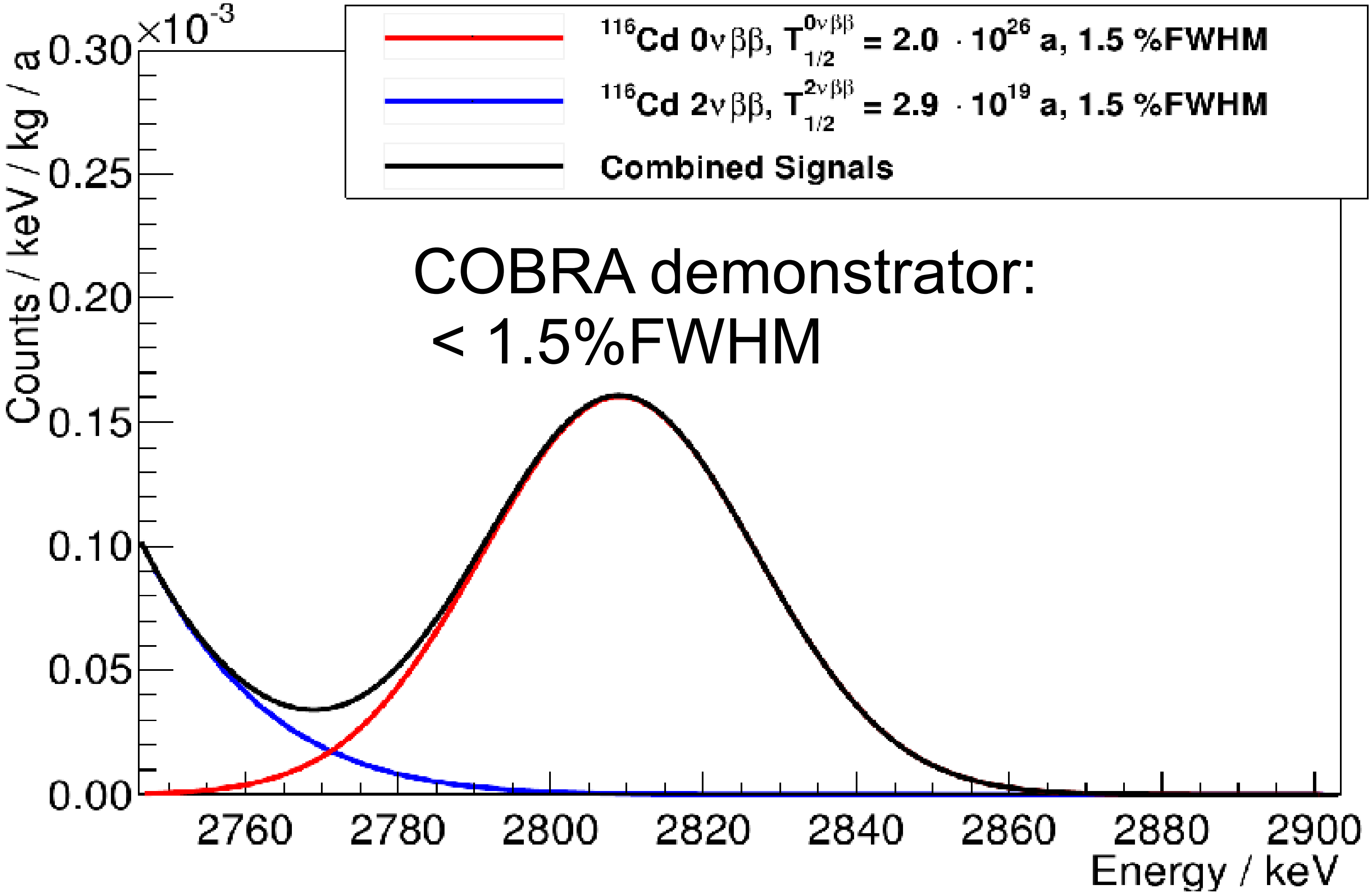
3% energy resolution: 0νββ-line hard to distinguish

# energy resolution



1.5% energy resolution: 0νββ-line clearly seen

# energy resolution



COBRA demonstrator:
< 1.5%FWHM

1.5% energy resolution: 0νββ-line clearly seen

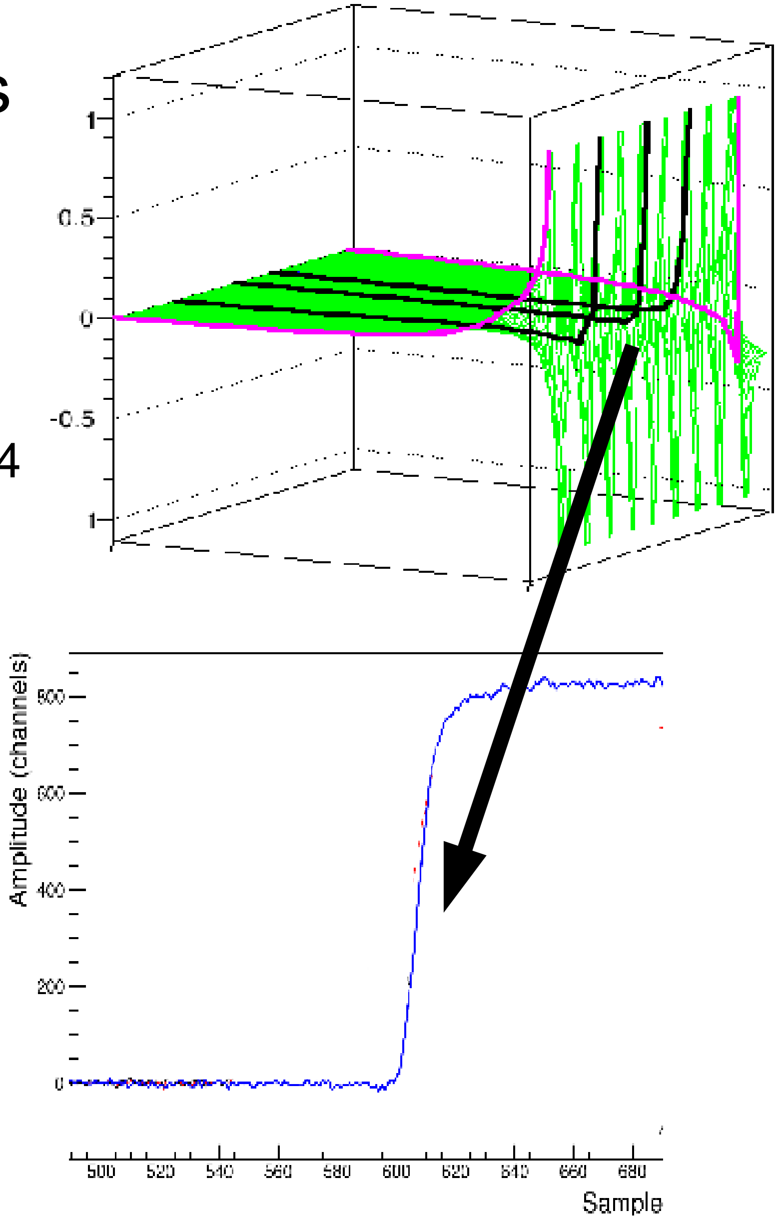
# pulse shape analysis

lateral surface events (LSE):

recognize and veto by pulse shape characteristics

NIMA 749: 27-34, 2014

Shockley-Ramo: weighting potential



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NIMA 749: 27-34, 2014

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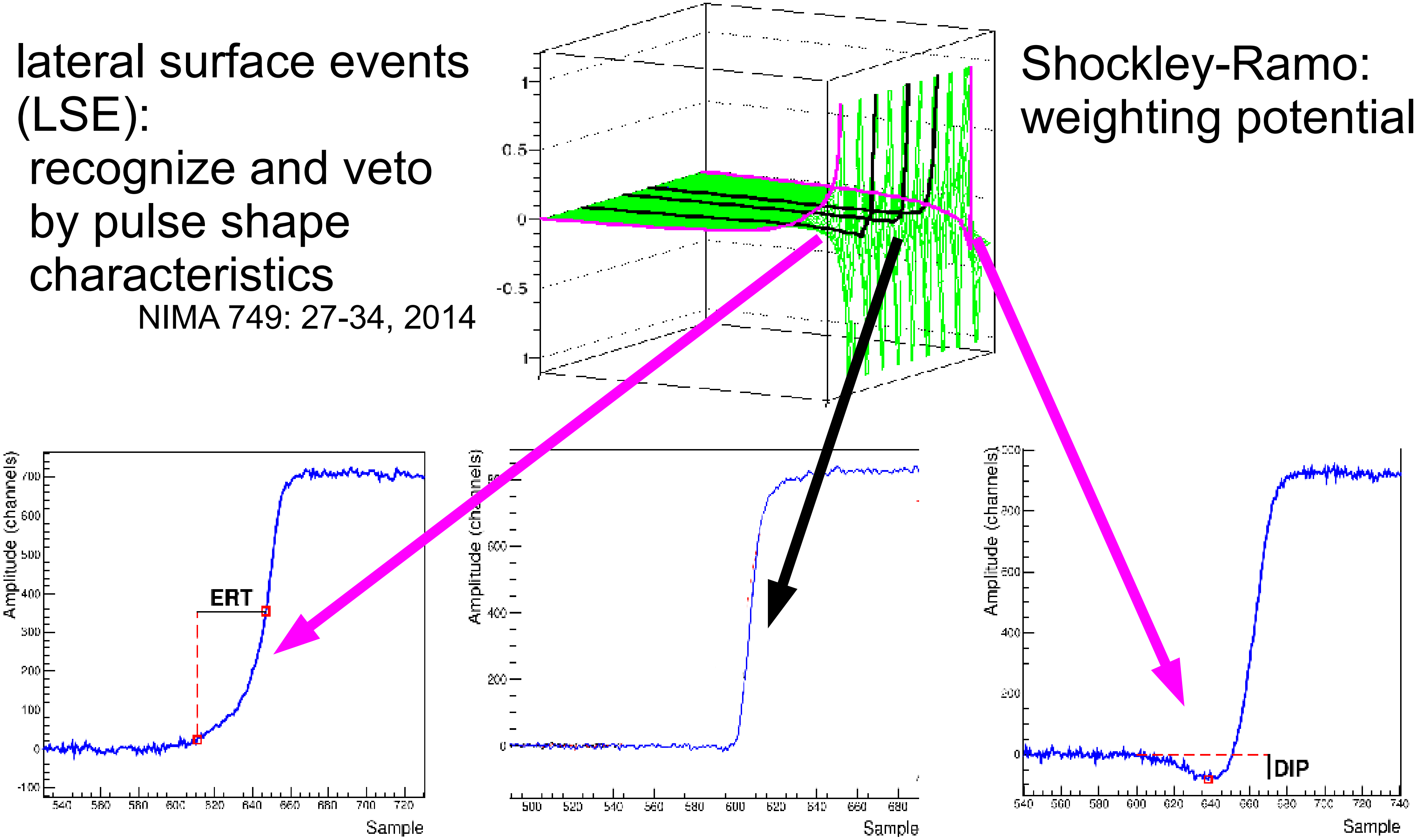
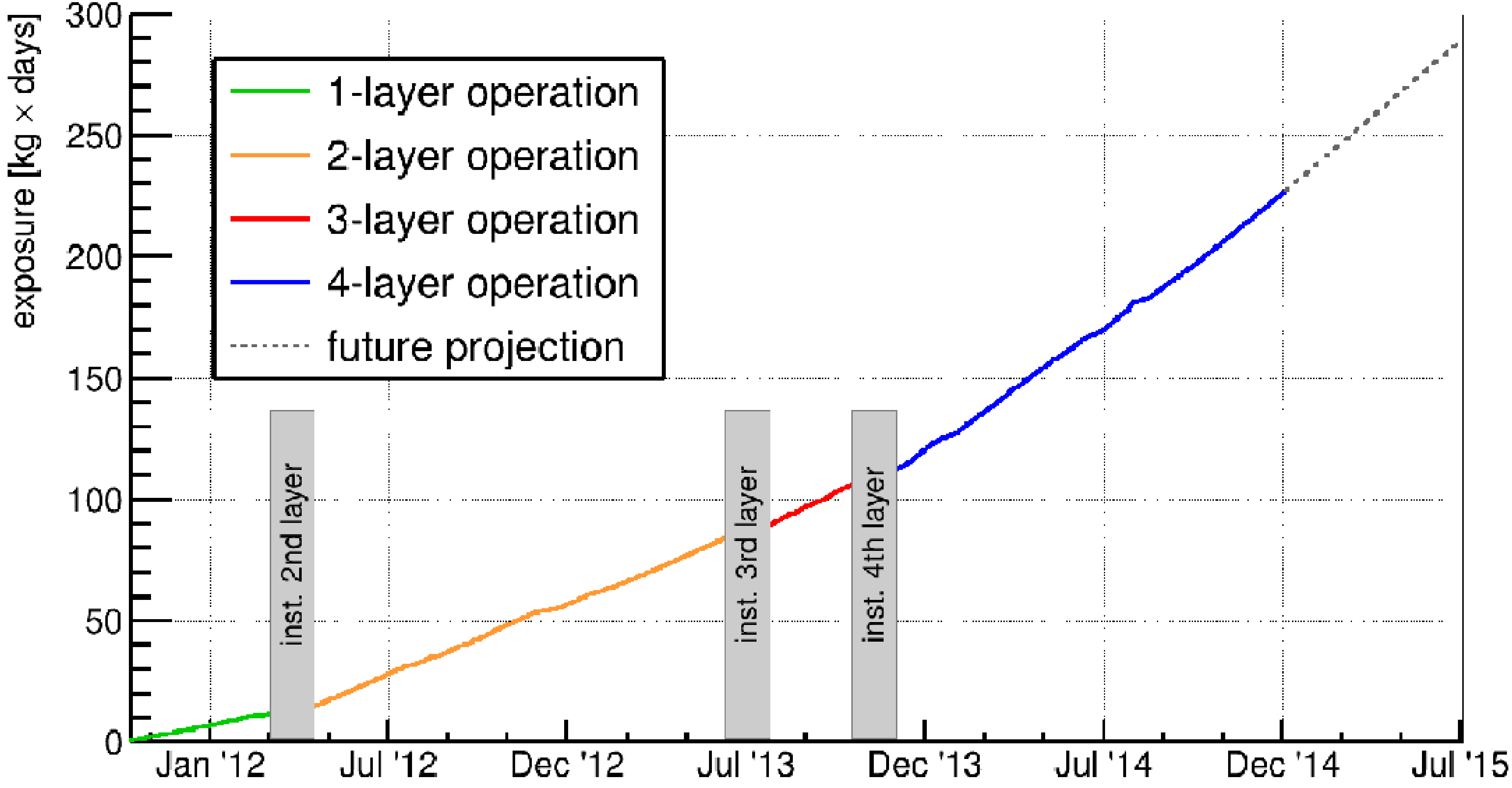
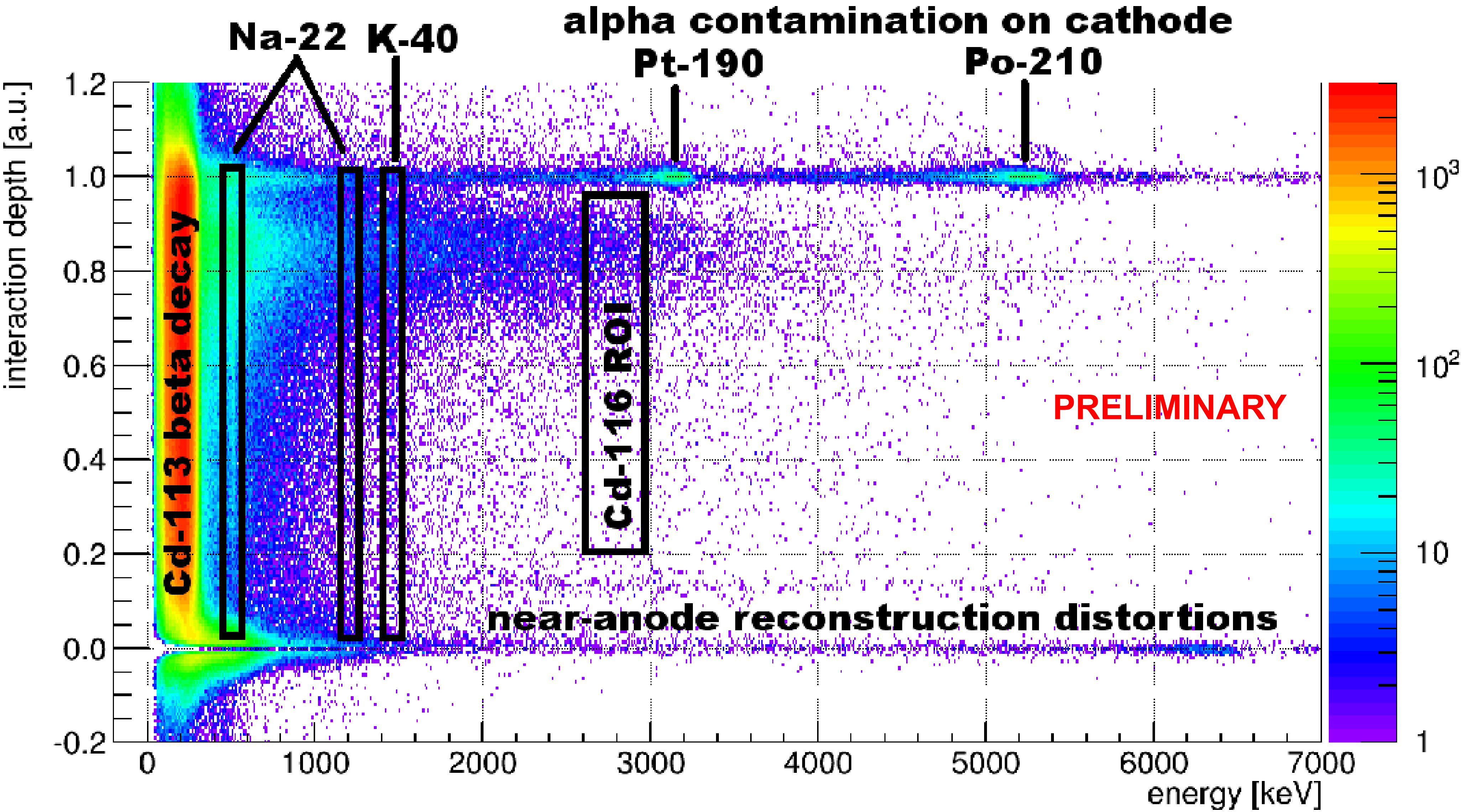


# low background physics data

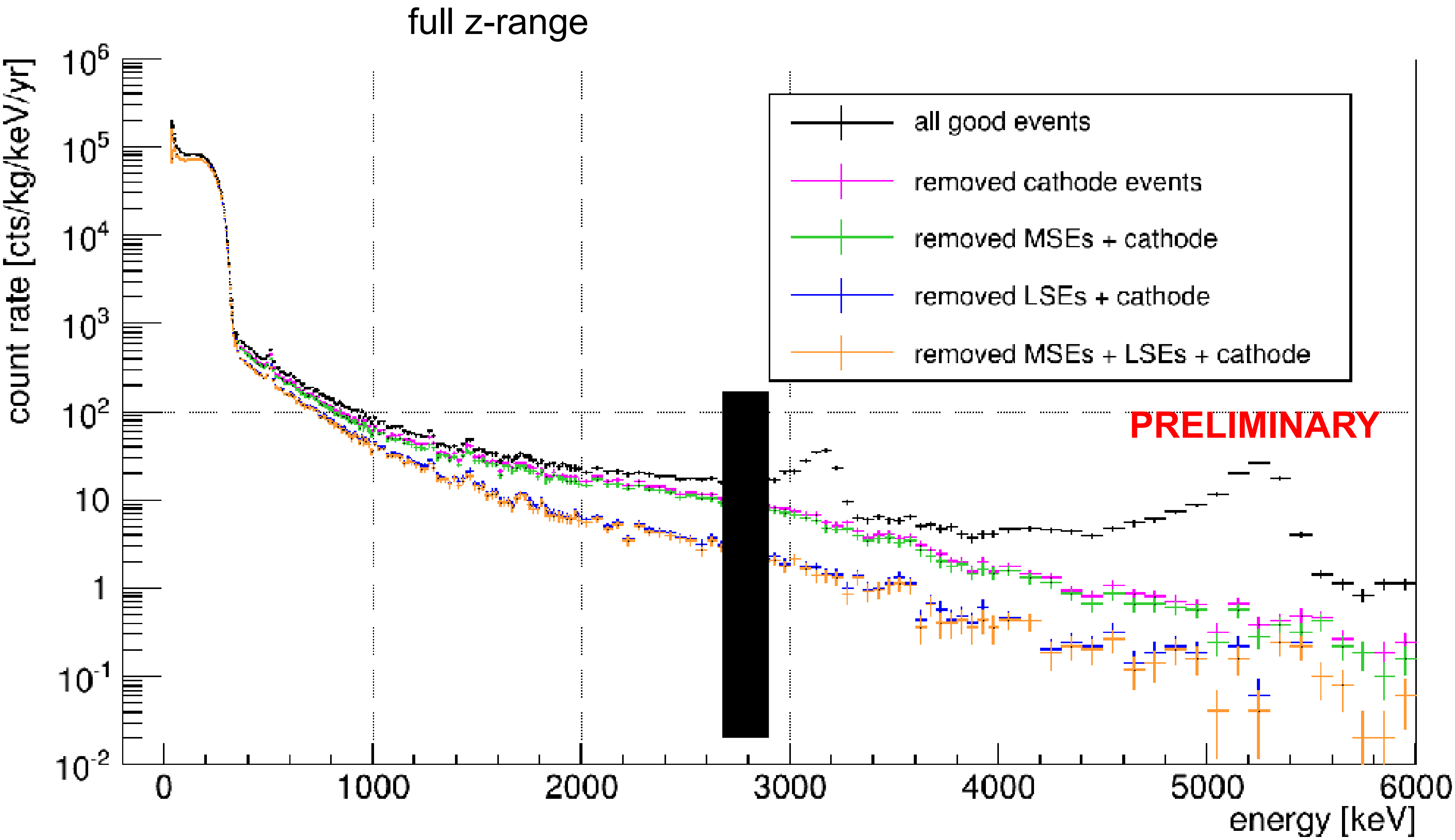
2.6 kg days / months / detector layer



# low background physics data

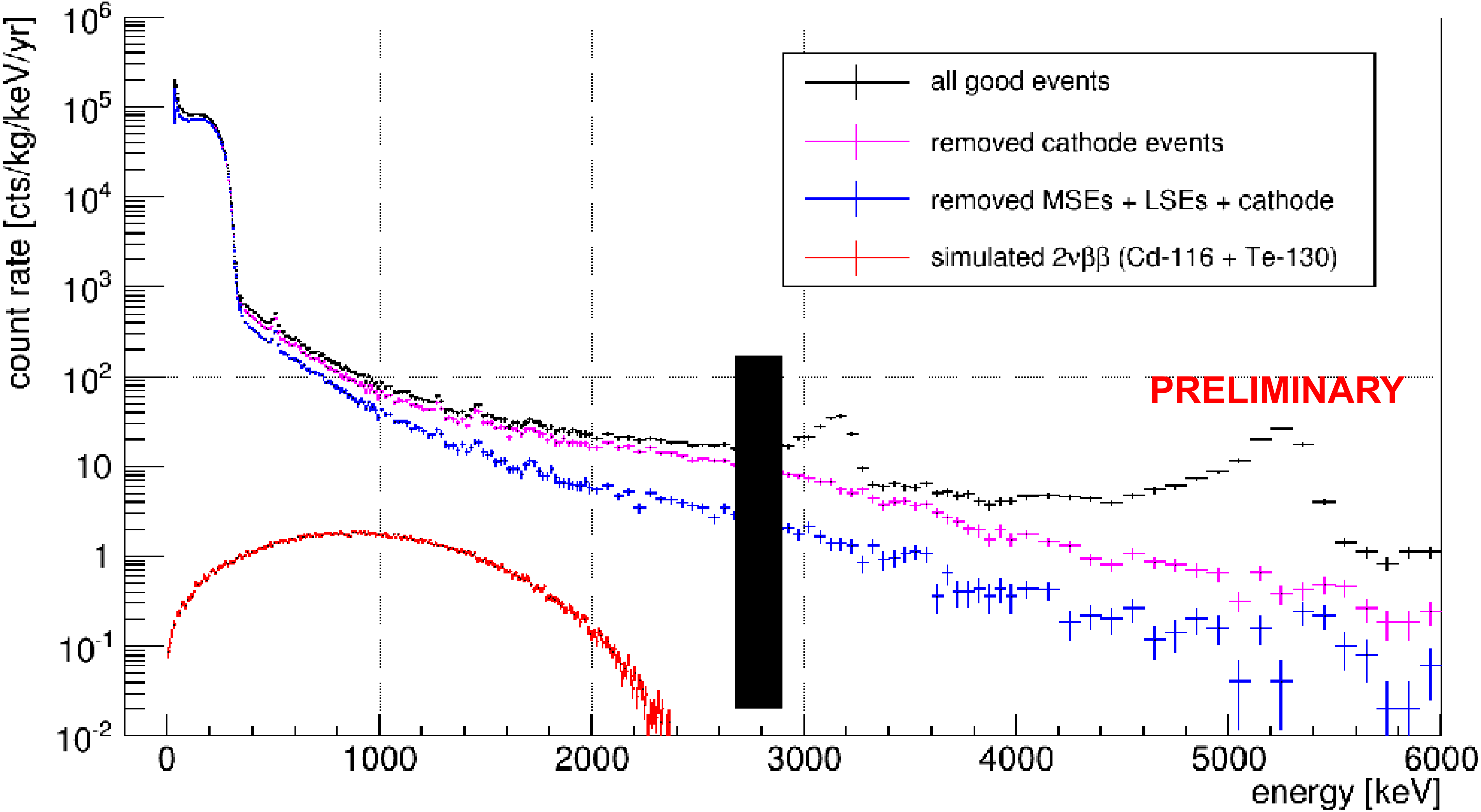


# low background physics data



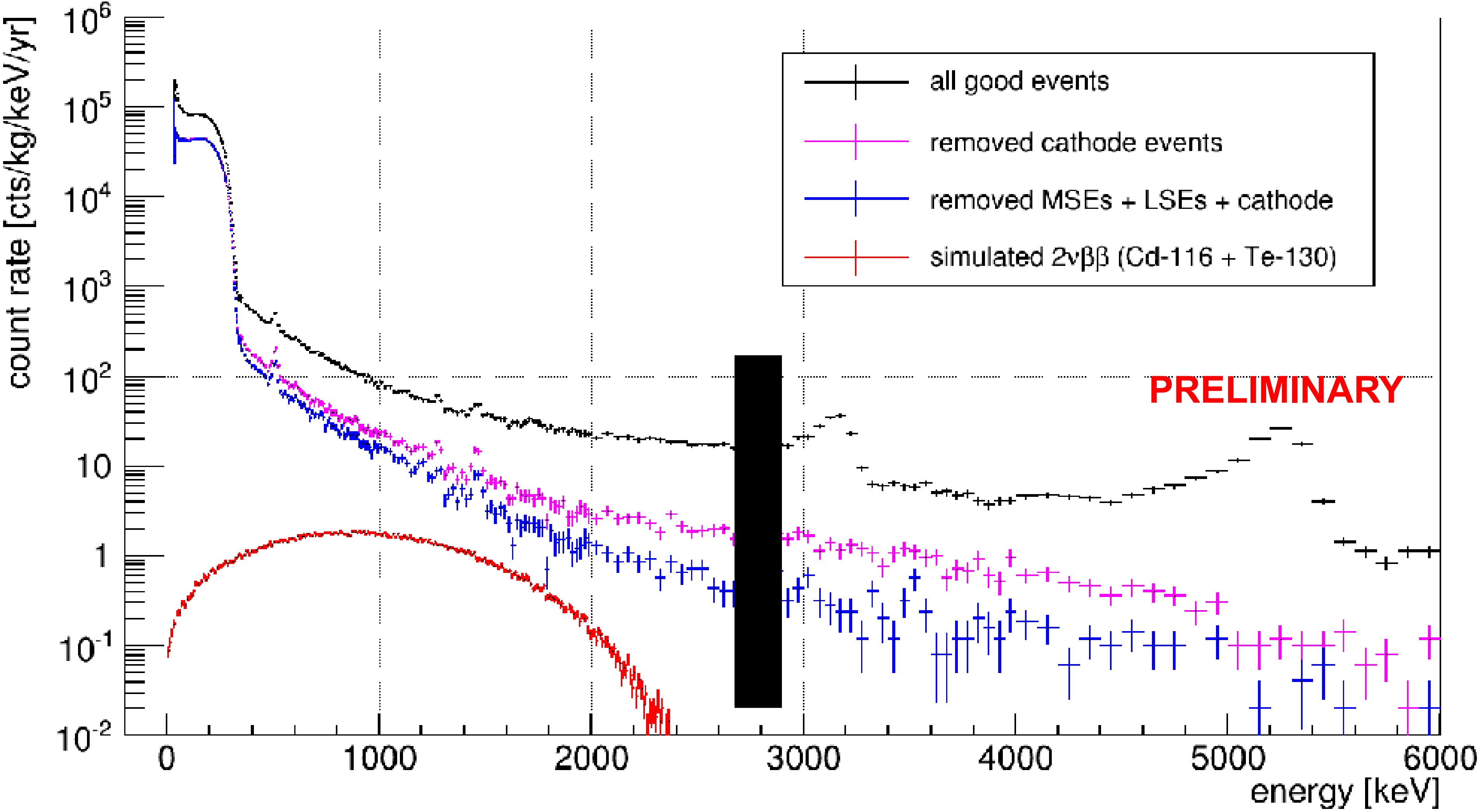
# low background physics data

full z-range



# low background physics data

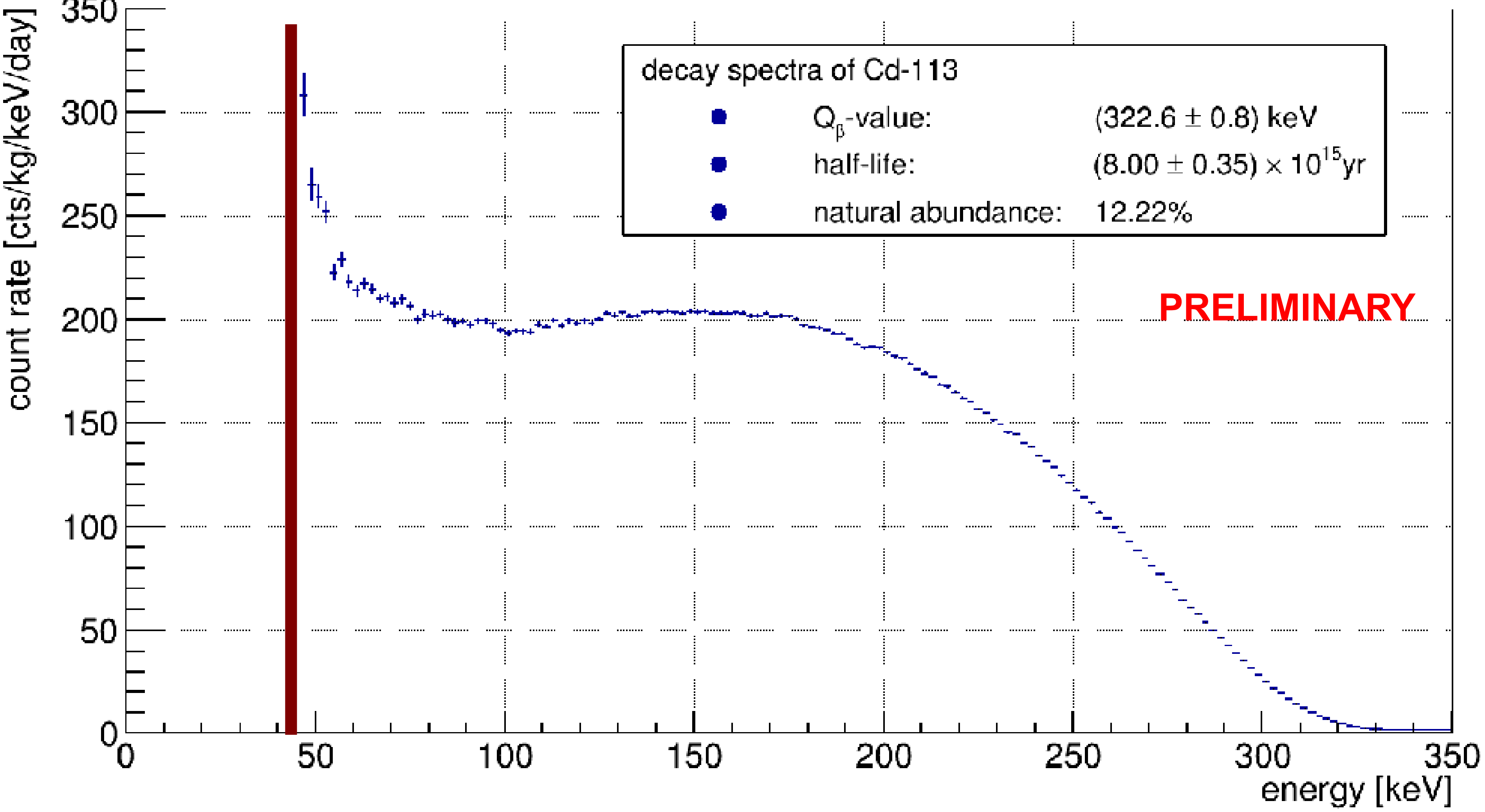
low z-range



# Cd-113 fourfold forbidden beta decay

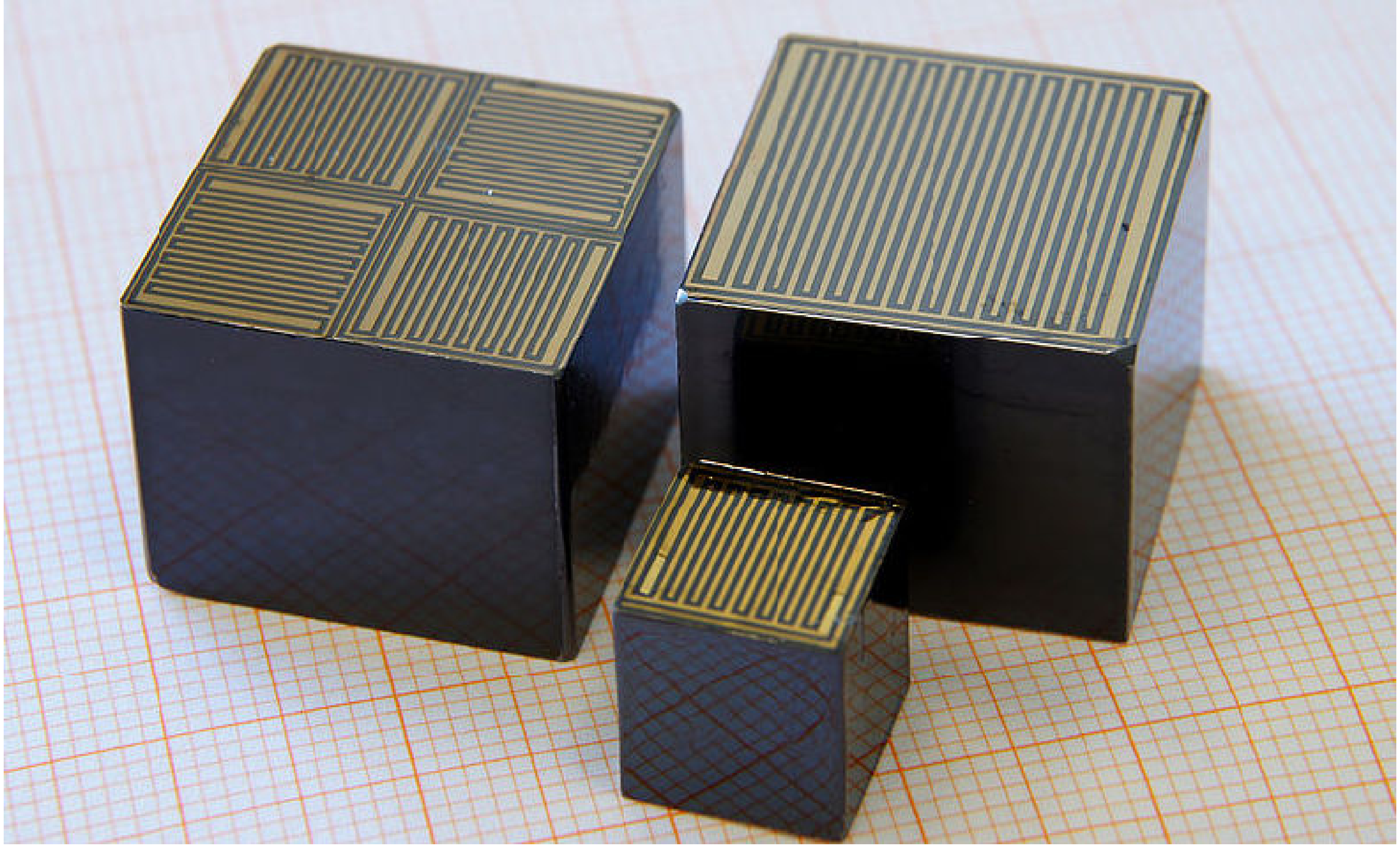
$$^{113}_{48}\mathrm{Cd} \rightarrow {}^{113}_{49}\mathrm{In} + e^- + \bar{\nu}_e$$

$$J^P_{^{113}\mathrm{Cd}} = \frac{1}{2}^+ \rightarrow J^P_{^{113}\mathrm{In}} = \frac{9}{2}^+ \Rightarrow \Delta J = 4, \quad \Delta P = 0$$



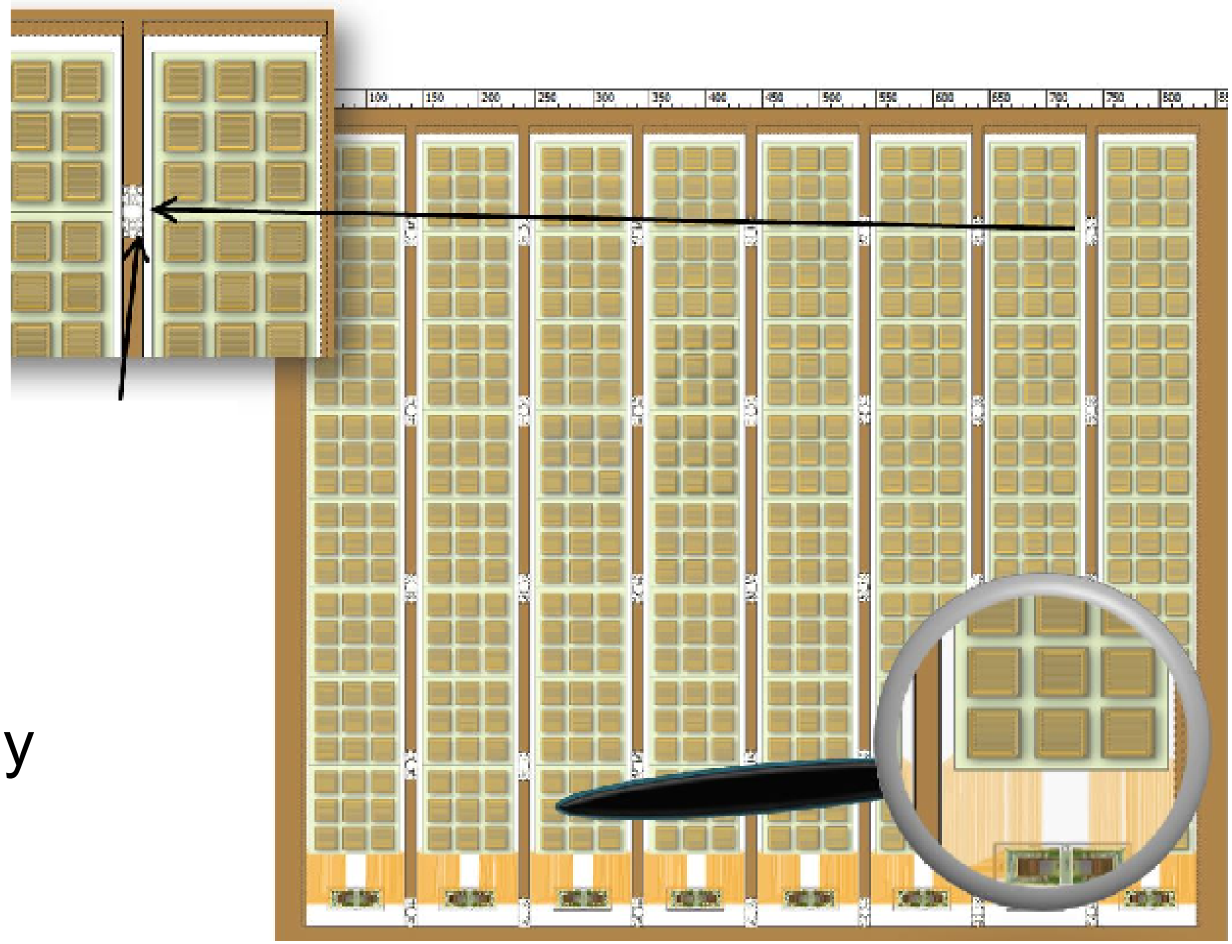
# perspectives for COBRA

larger detectors → detection efficiency, surface to volume ratio



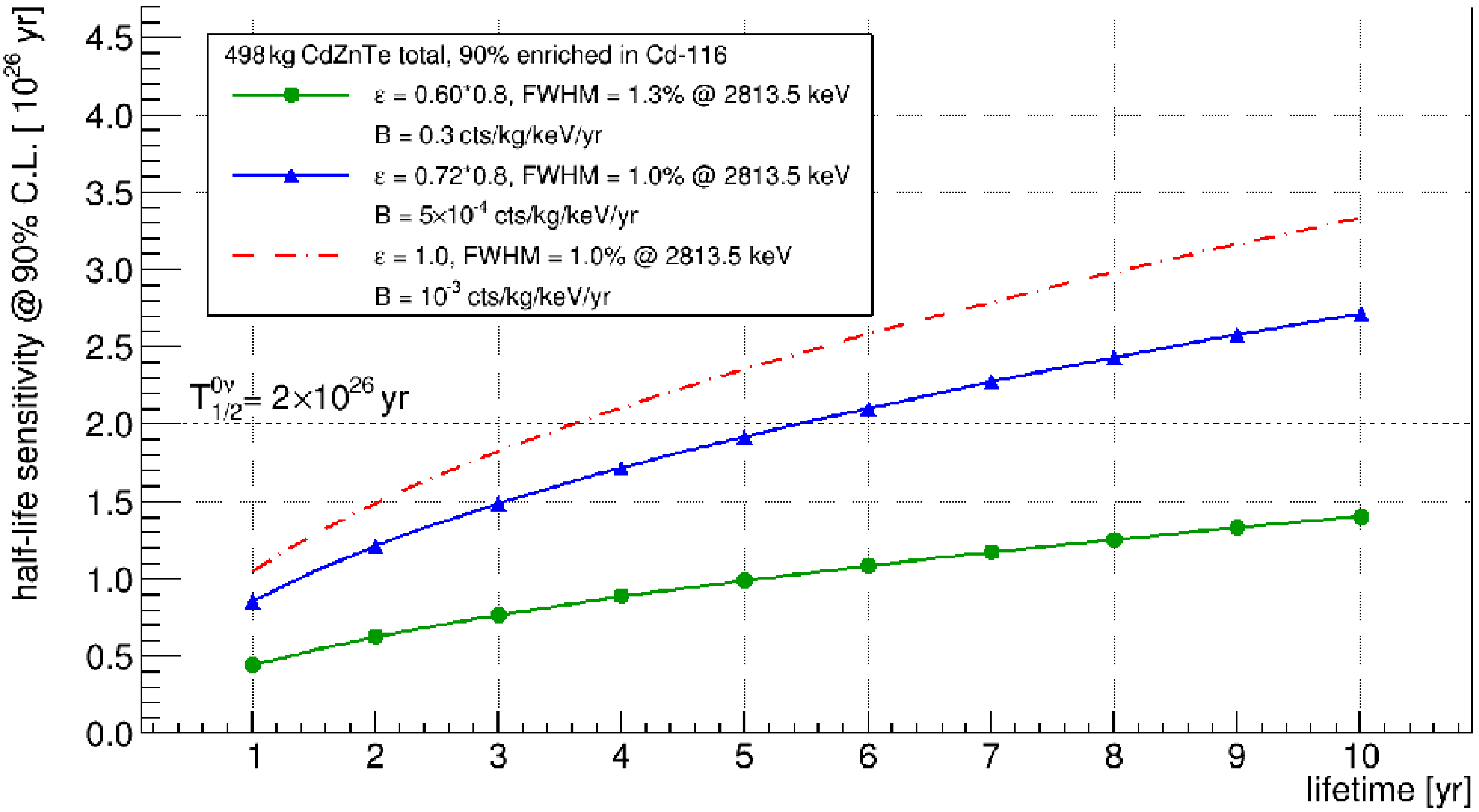
# perspectives for COBRA

- array of ~10k detectors
- ASIC readout
- fits into present lab
- simulations of background components
- cleanroom handling
- coincidence analysis



- overall aim: $T_{1/2} > 2 \times 10^{26}$ y
  inverted neutrino mass hierarchy!

# perspectives for COBRA



# conclusion

- search for 0νββ-decay using CdZnTe 3D-detector array
- promising: good material and detector properties
- demonstrator setup @ LNGS: 64 Co-planar Grid detectors
  - Jan 2015: 220kg days high quality low background data → continuing
  - background level: 2.4 $keV^{-1}\ kg^{-1}\ y^{-1}$ / 0.5 $keV^{-1}\ kg^{-1}\ y^{-1}$
- perspectives: large scale setup
  - larger detectors
  - ASIC read-out

→ sensitivity: $T_{1/2} > 2 \times 10^{26}$ y

# backup slides

# Dortmund Low Background Facility

- Detection Limits:

| Isotope | Energy /keV | DLB/mBq/kg |
|---|---|---|
| 208Tl | 583.19 | 20 |
| 214Bi | 609.31 | 39 |
| 137Cs | 661.6 | 18 |
| 228Ac | 911.20 | 81 |
| 40K | 1460.83 | 346 |
| 214Bi | 1764.49 | 168 |

- 7 days measurement lifetime
- cylindrical sample: 40mm x 70mm
- DIN 25482-5 95% c.l.

# possible underlying ΔL = 2 processes of 0νββ

- right-handed weak currents (V+A interactions) ← might be testable
- R-parity violating SUSY (λ'111 )
- double charged Higgs-bosons
- Kaluza-Klein excitations ← might be testable

Schechter-Valle theorem:

- neutrinos are Majorana particles independent of the dominant mechanism driving the decay
  - always possible to draw Feynman diagram for Majorana mass, but contribution to 0νββ-decay unknown

- nuclear matrix elements sensitive to KK-excitations → comparing different measured isotopes might yield information on that.
- big effect might be caused by V+A interactions. single electron energy spectrum and the opening angle between the two emitted electrons is completely different compared to the neutrino mass mechanism; alternative process like β + /EC has an enhanced sensitivity to V+A interactions and also 0+ → 2+ should dominated by this process

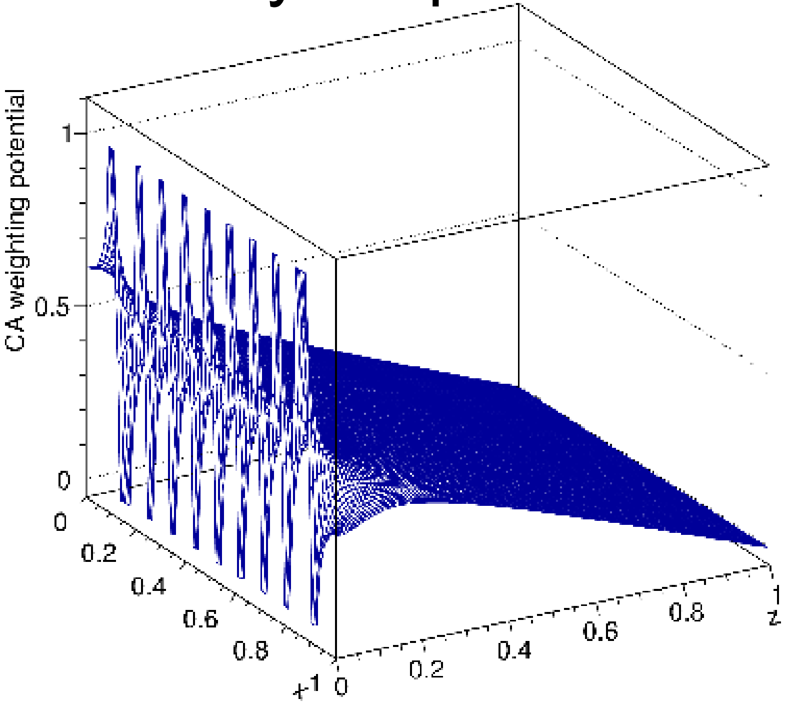
Zuber: arXiv:1002.4313

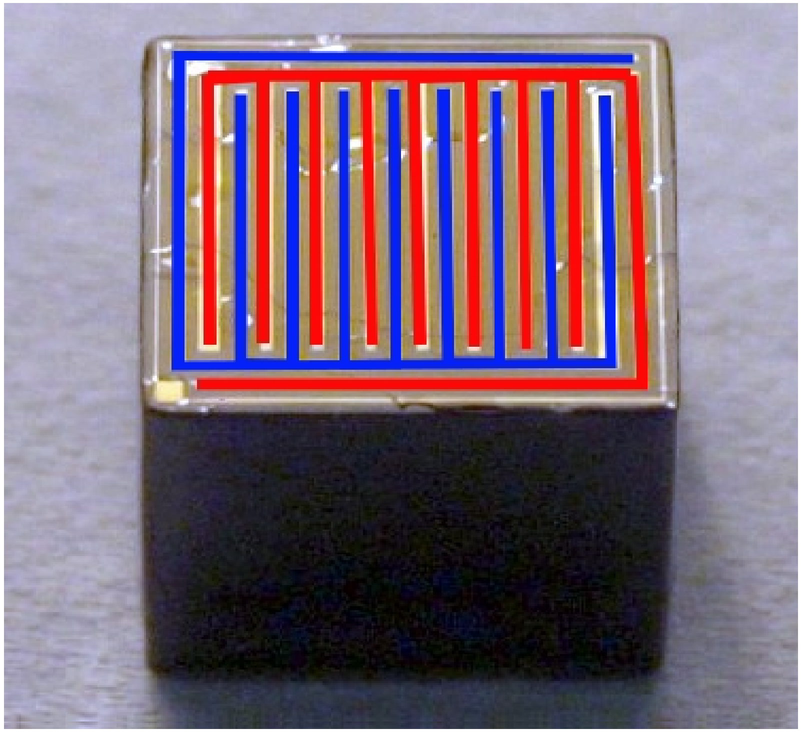
# CZT detectors: Co-planar Grid

- Luke(1994): analog Frisch-Grid in gas detectors

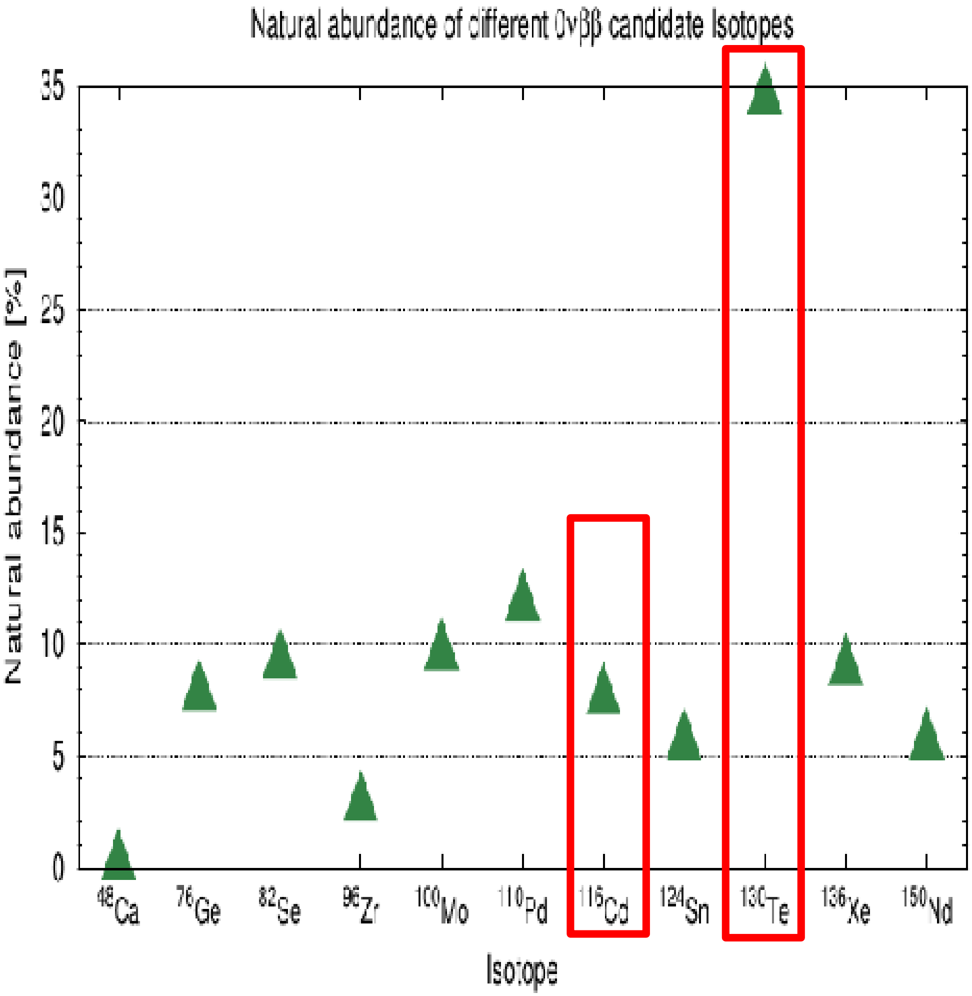
Appl. Phys. Lett. 65:2884

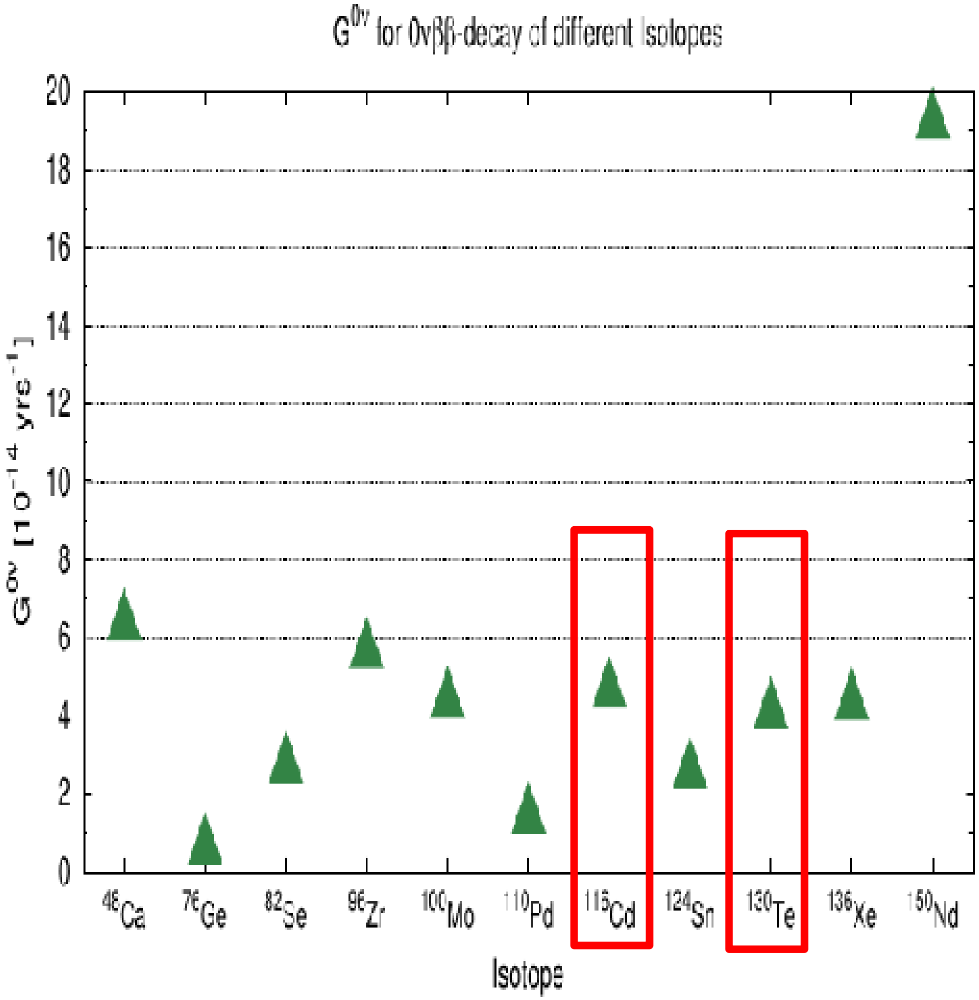
- 2 comb-shaped anodes, planar cathode
- weighting potential splits up at anodes
- read out both anode signals
  → relatively simple electronics





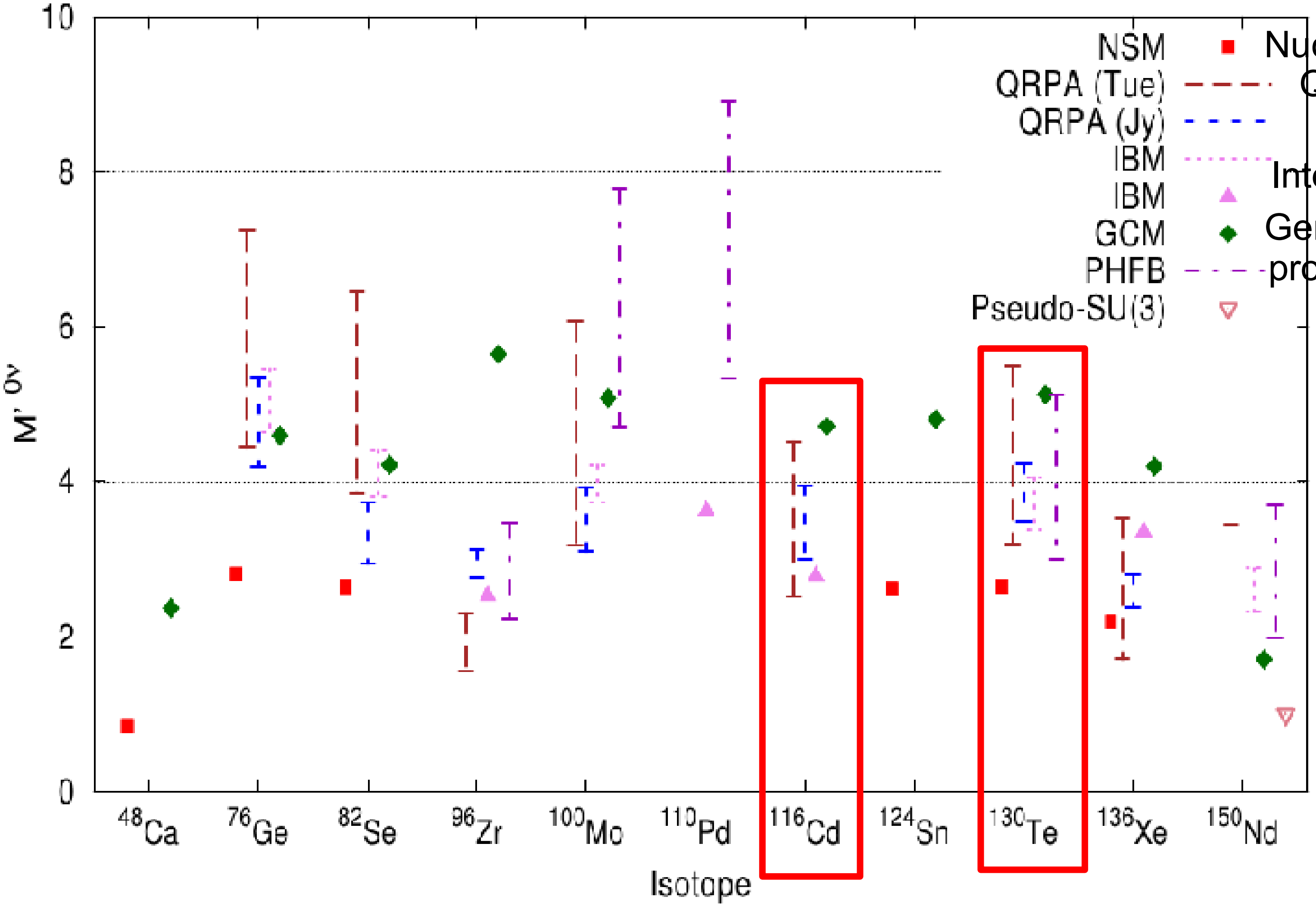
# natural abundance and phase space





Rodejohann: arxiv1106.1334

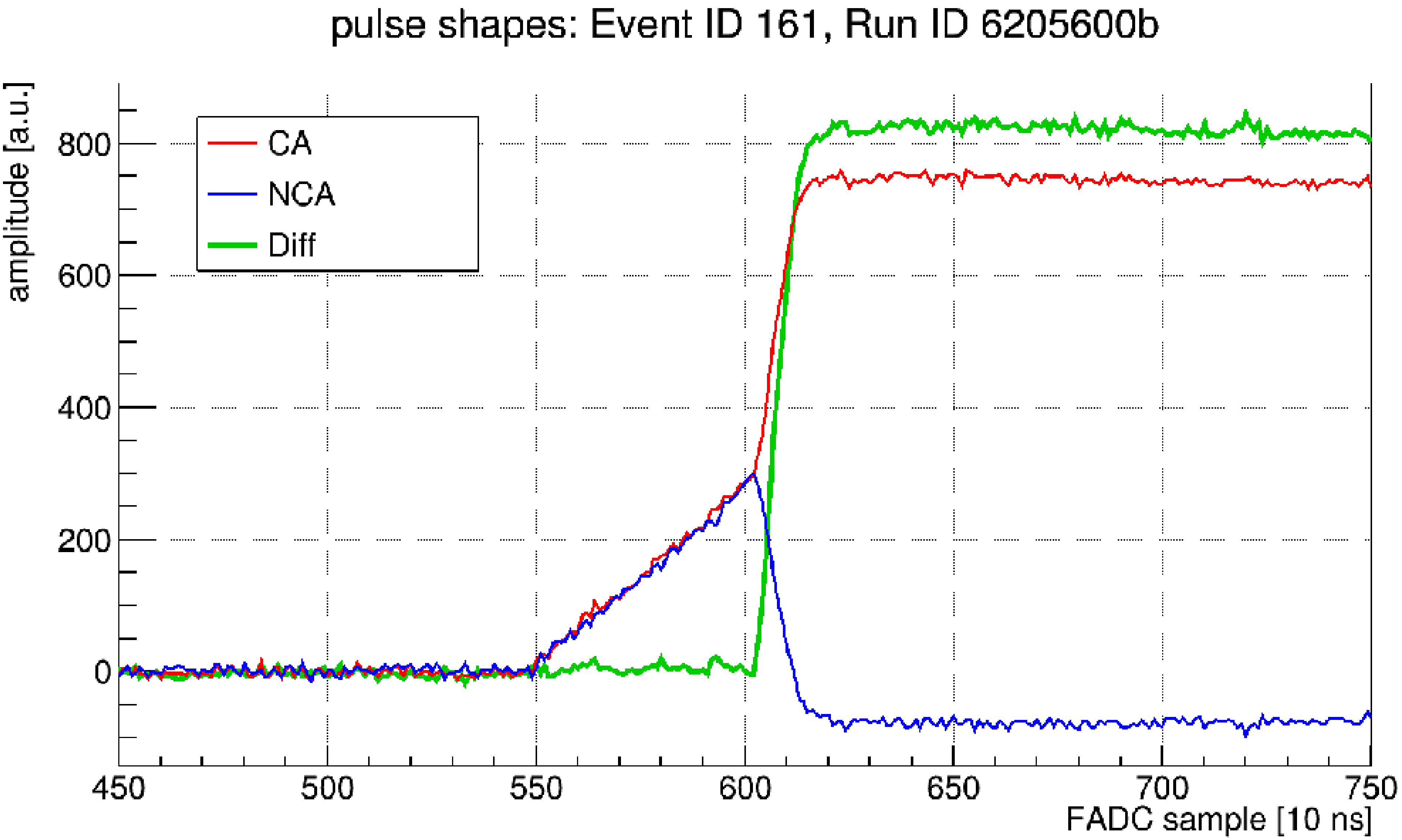
# nuclear matrix elements



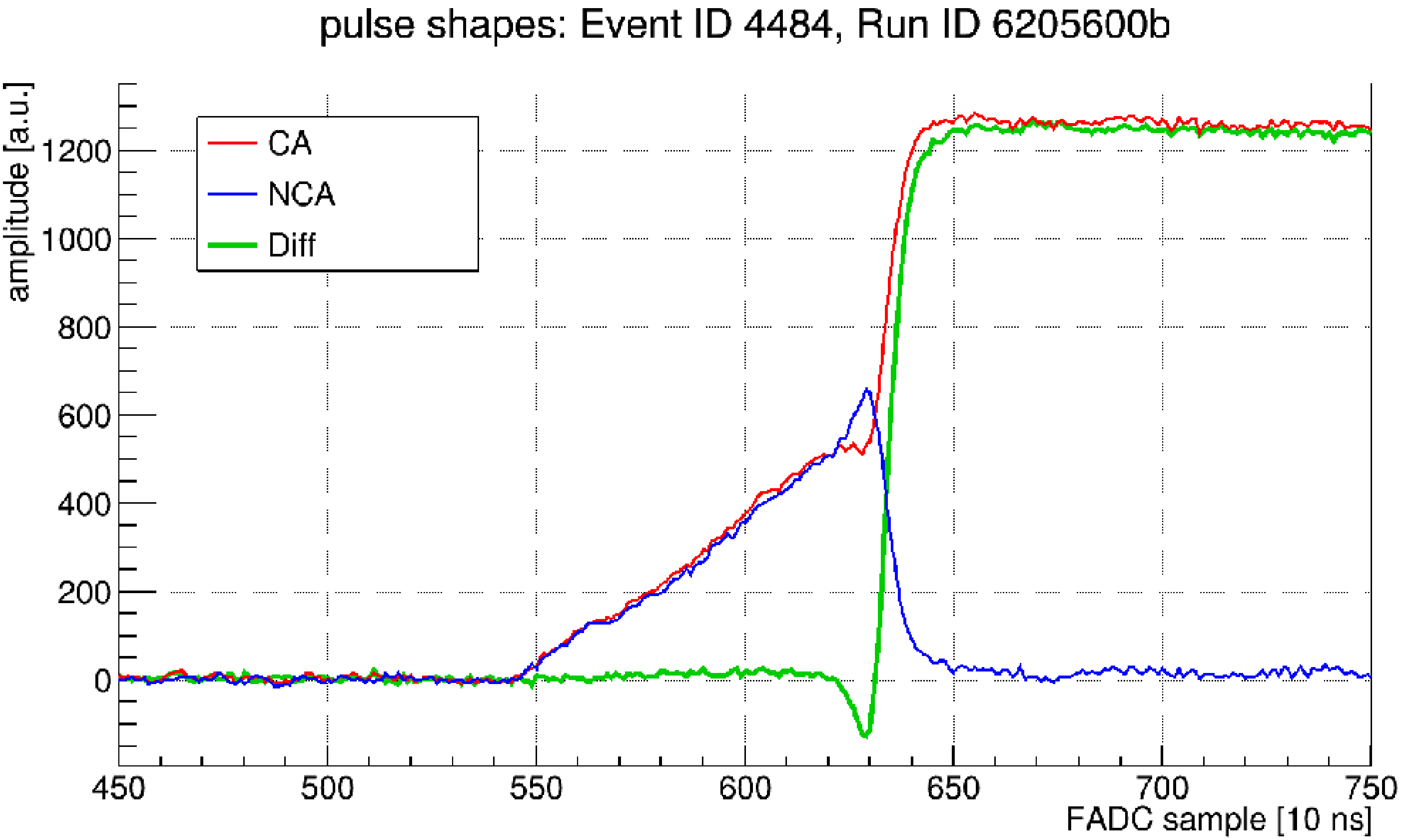
Nuclear Shell Model
Quasi-particle Random Phase Approximation
Interacting Boson Model
Generating Coordinate Method
projected Hartree-Fock-Bogoliubov model

Rodejohann: arxiv1106.1334

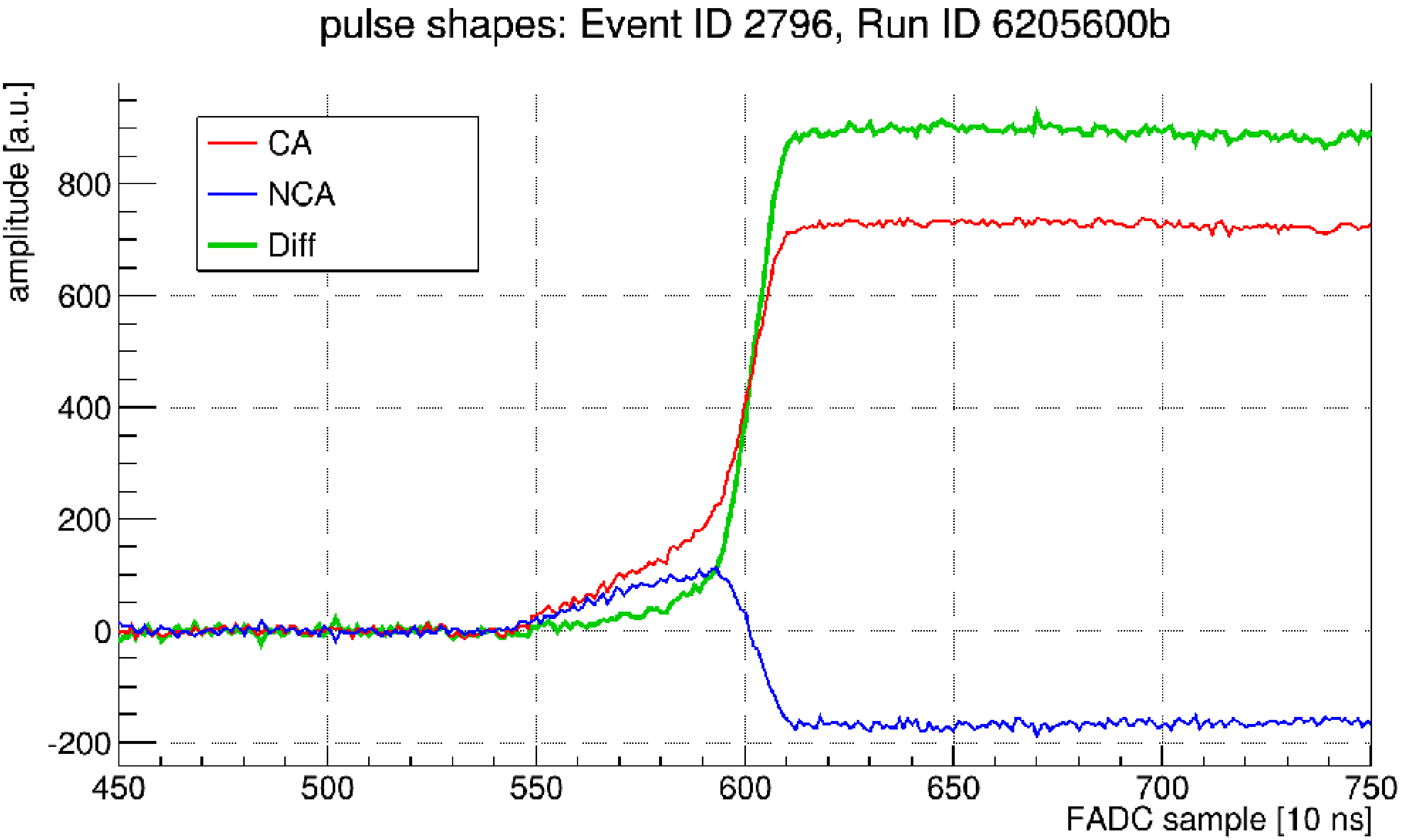
# normal pulse



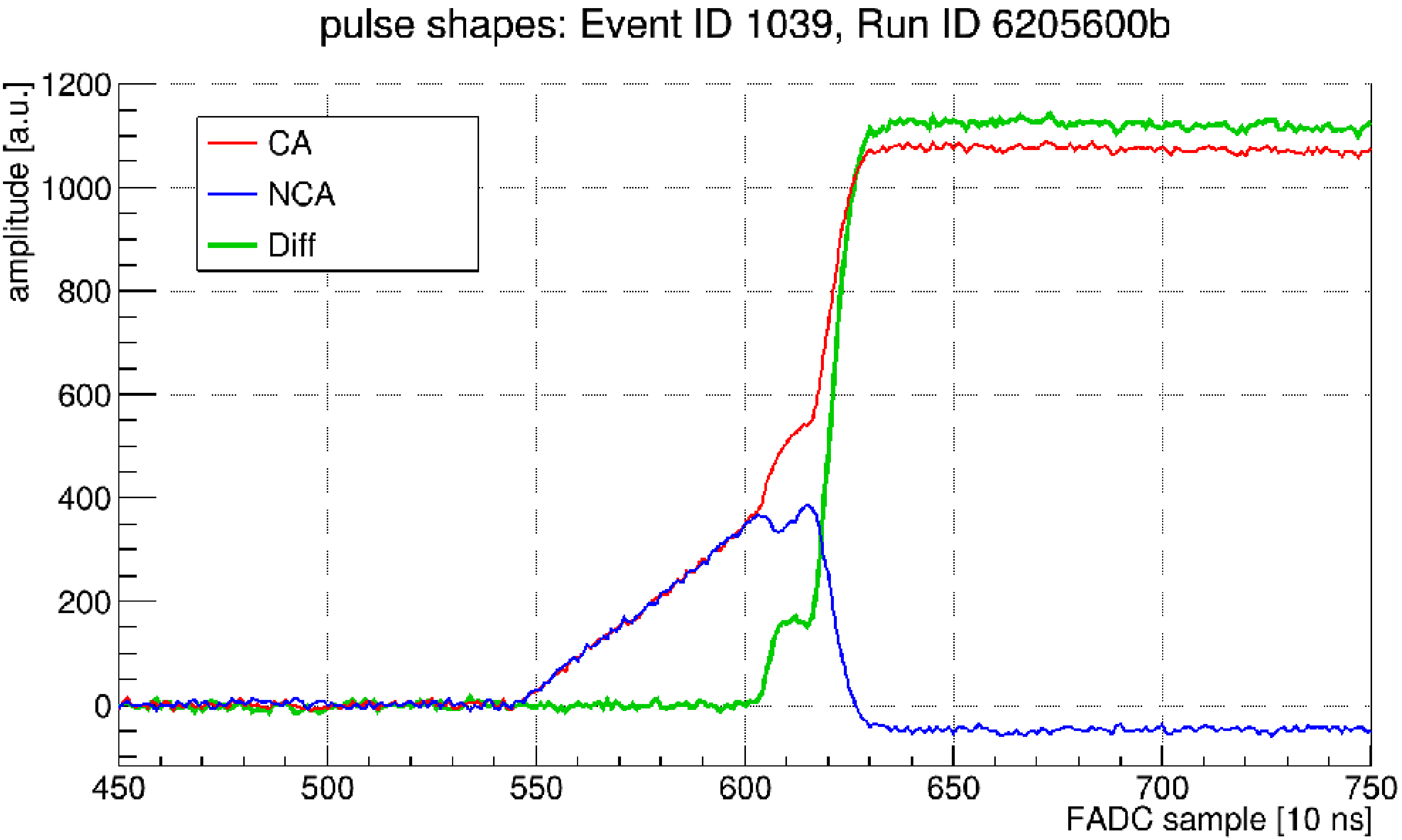
# lateral surface: NCA side



# lateral surface: CA side

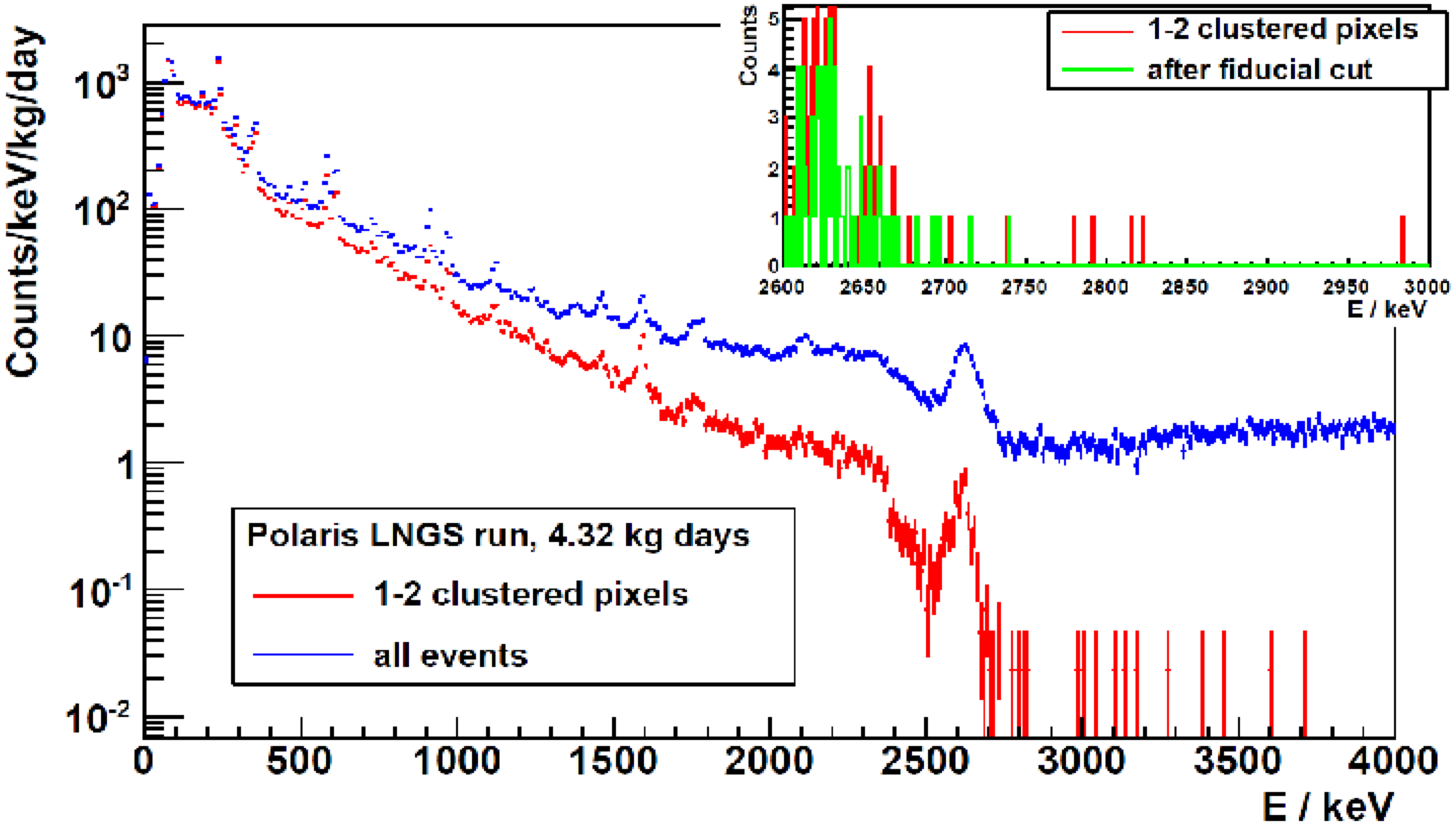


# multi site event



# pixel detectors, thick

- Polaris: Z.He, U. Michigan
- large pixels → no tracking

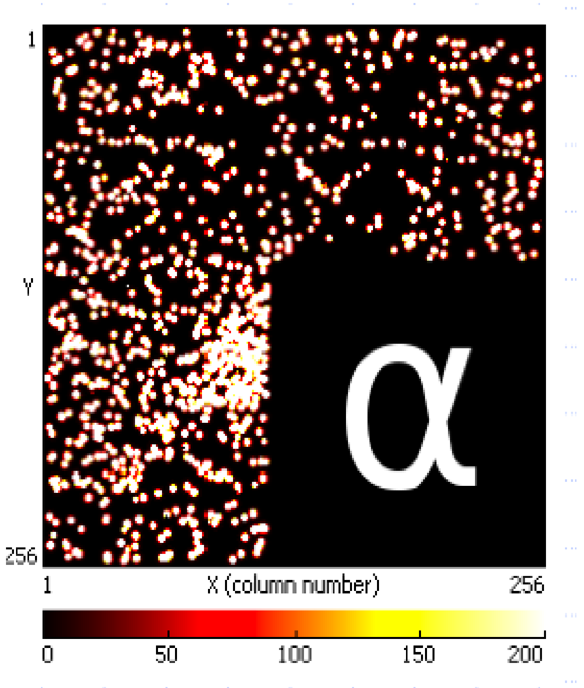


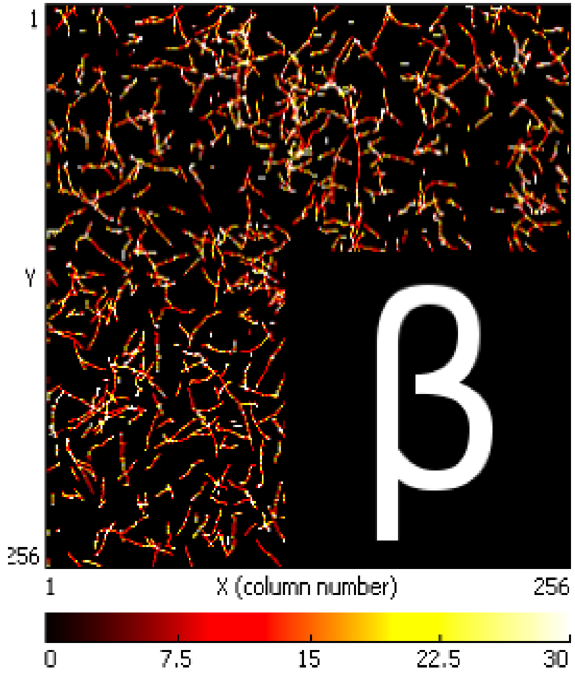
- Cuts on number and position of pixles → 0 cts in ROI in 3 months (~ 4 /keV/kg/y)

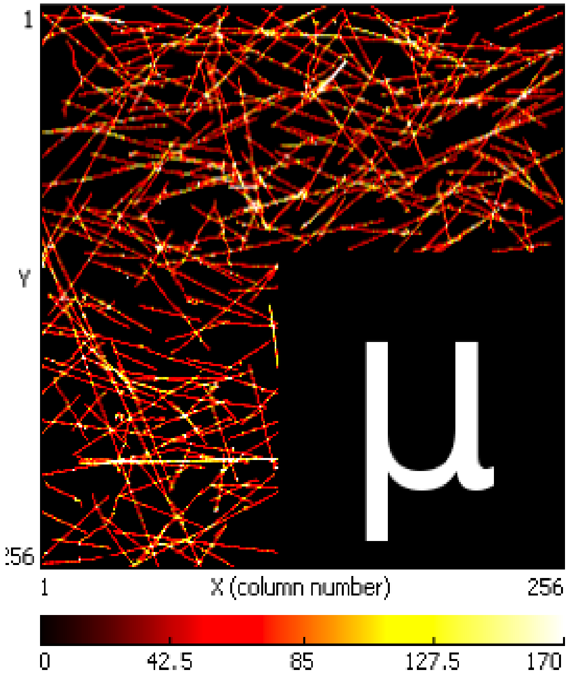
# pixel detectors, thin

- pixel pitch 55μm to 220μm
- small pixels → tracking

→ background reduction ~ 5 orders of magnitude (alphas)



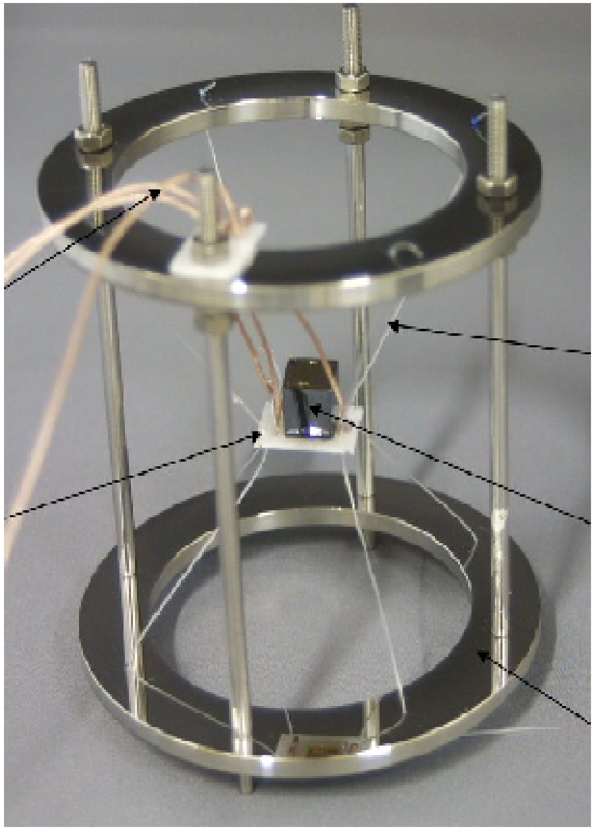


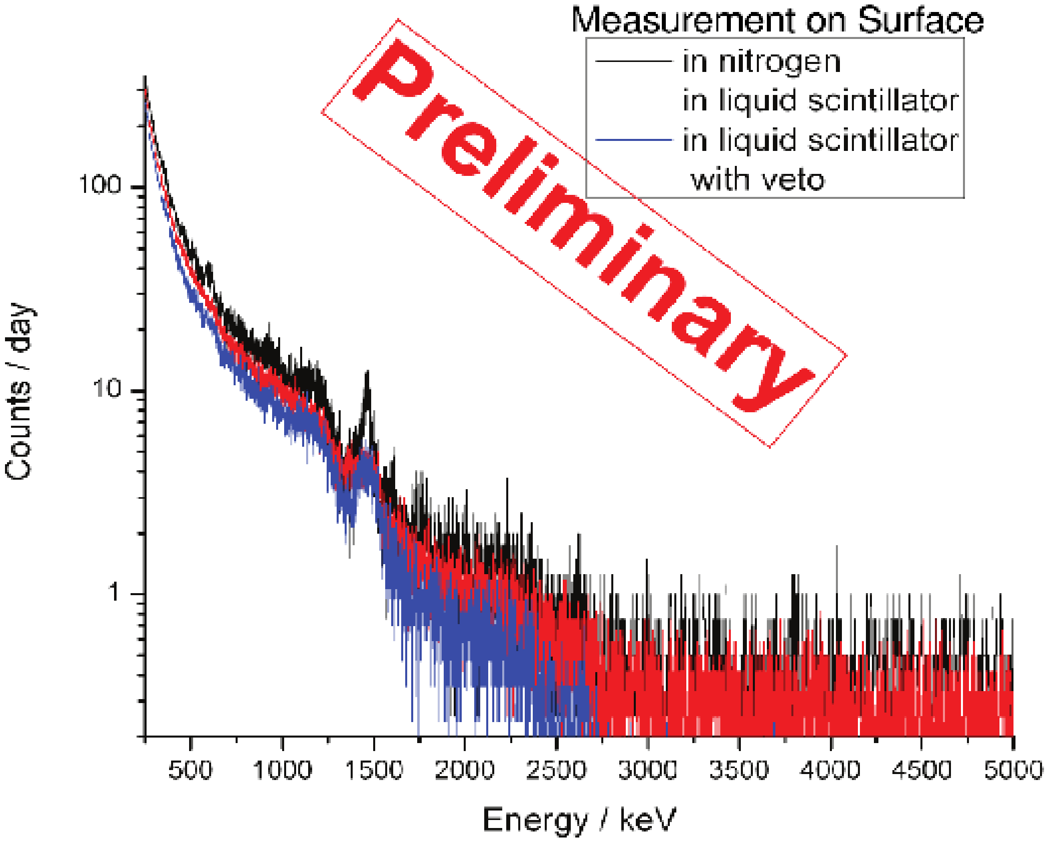


# liquid scintillator

- highly pure liquid scintillator surrounds detectors

  → shielding and veto

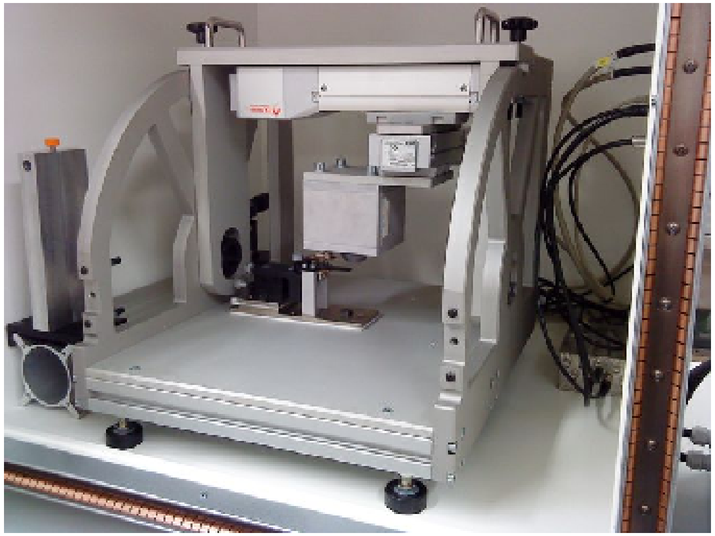


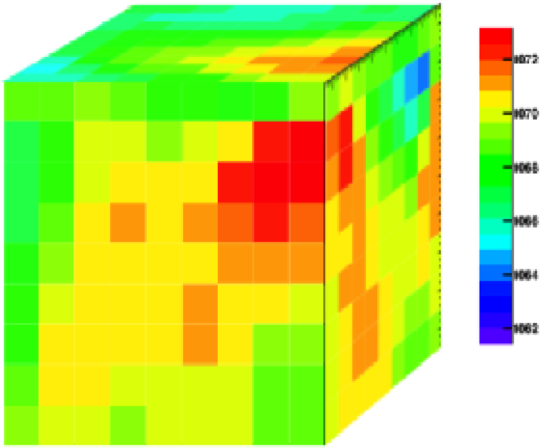


# detector tests

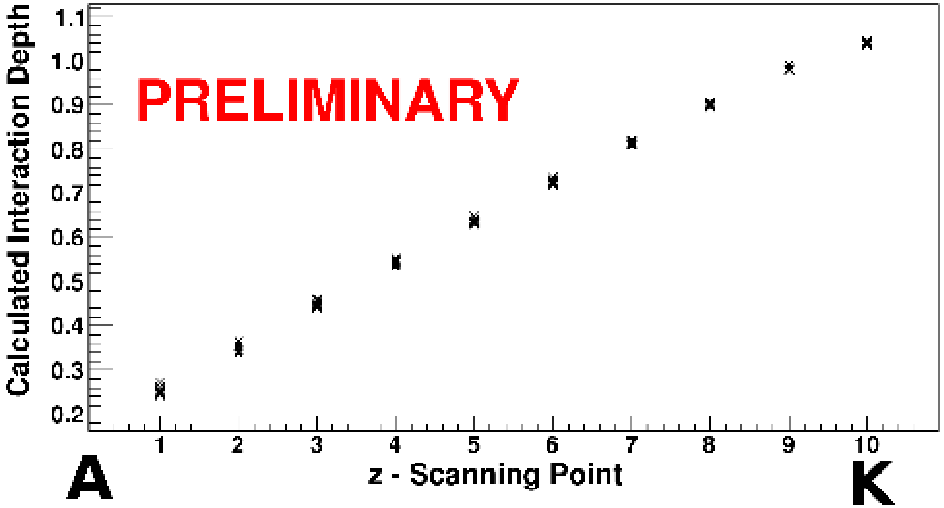
- characterize detectors with collimated γ-radiation

→ full energy- and charge collection efficiency

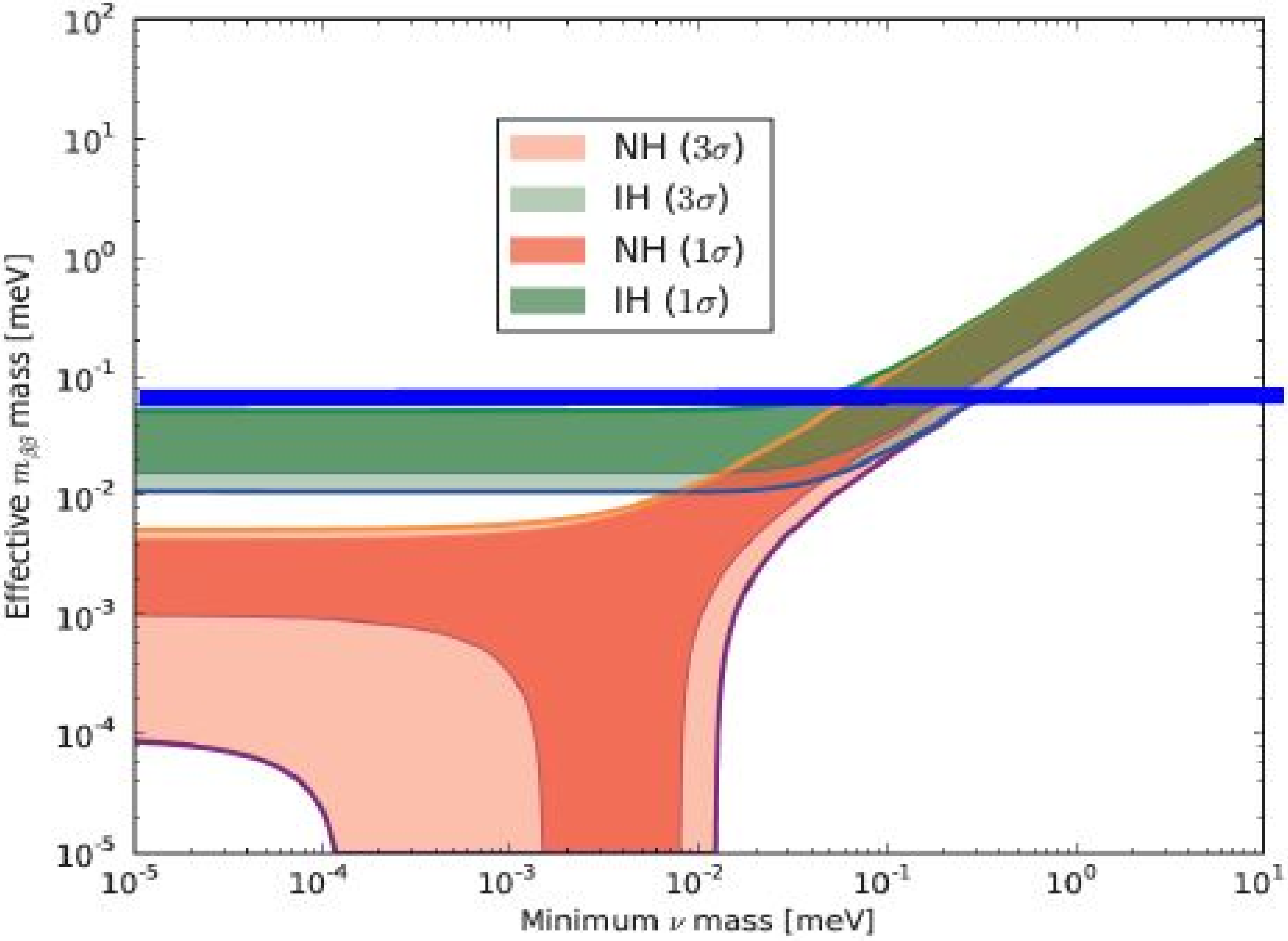




→ verify interaction depth calculation



# neutrino mass hierarchy



# detector production and handling

- growth of CdZnTe ingots
- detector preparation from wafers
- passivate and encapsulate surface:
  - surface protection
  - handling
  - use low background materials