Società Italiana di Fisica

GRAN SASSO SCIENCE INSTITUTE

Search for neutrinoless double beta decay with CUPID-0

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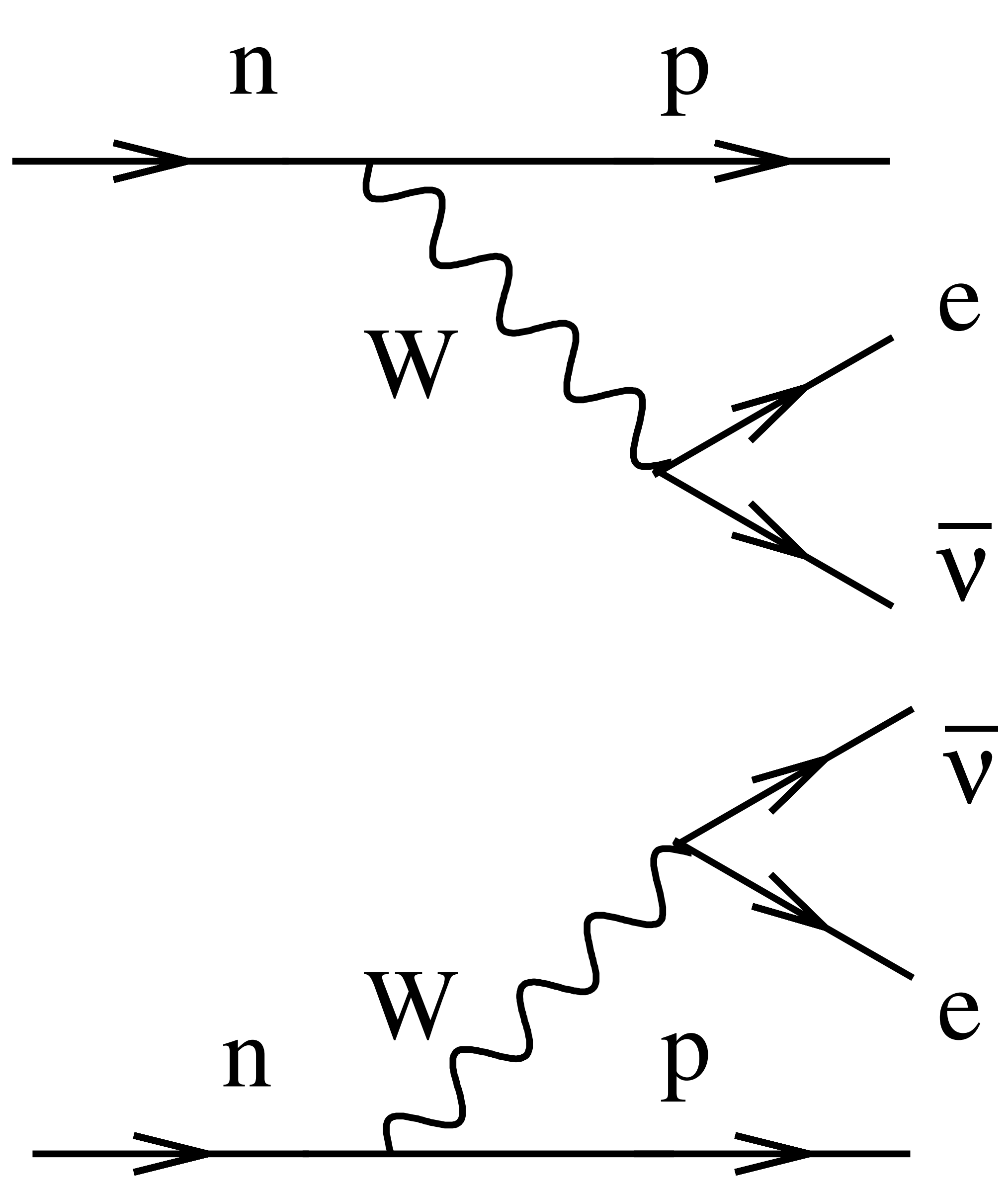
106° congresso SIF

Neutrinoless double beta decay

Why to search for 0νββ?

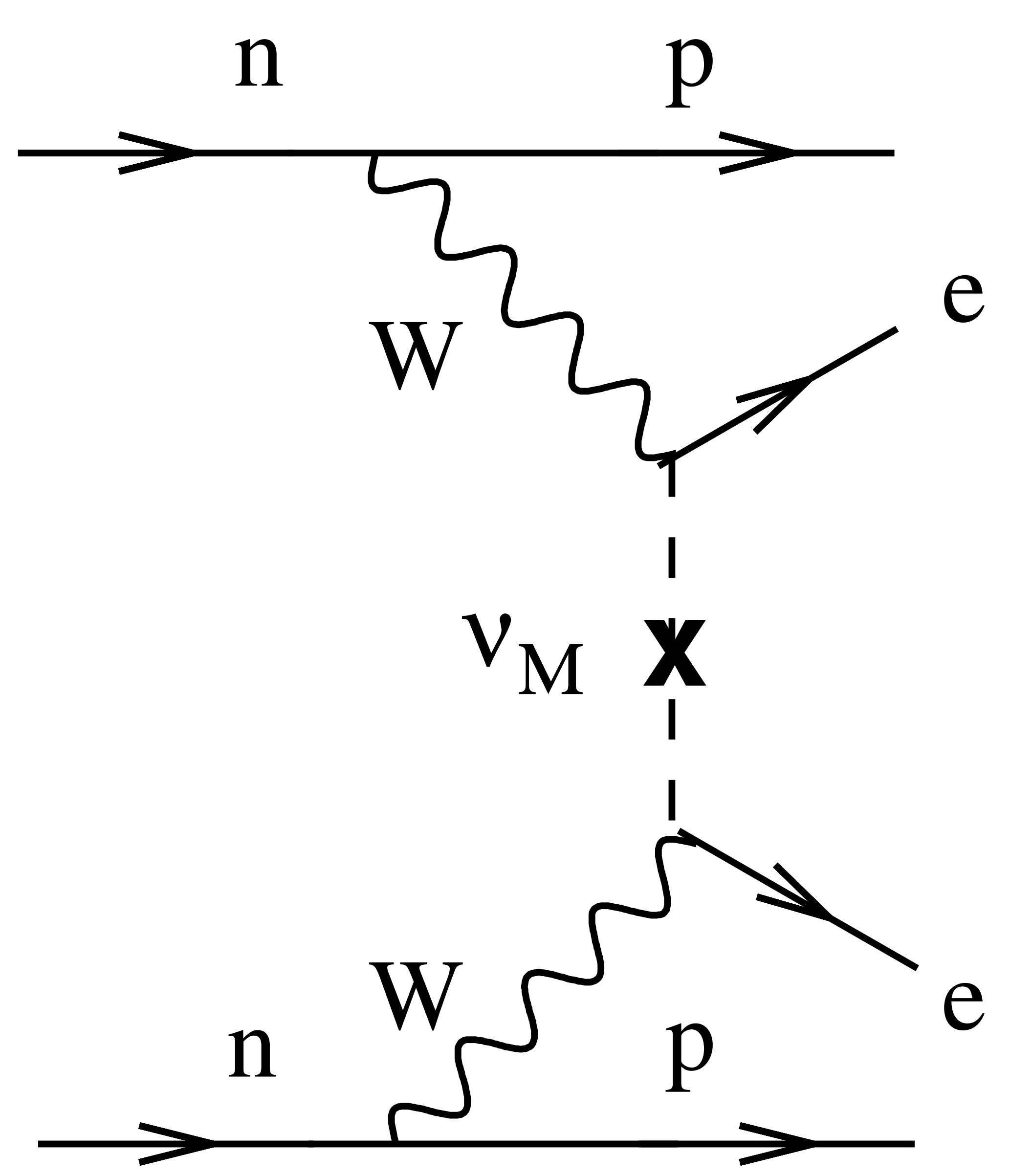
- Lepton Number Violation process (**$\Delta L = 2$**), not conserving the B-L symmetry of the SM;
- Validation of the **see-saw mechanism**;
- Neutrinos coincide with their antiparticles (**Majorana particles**);
- Limits on **neutrinos absolute mass scale**:

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\left|M^{0\nu}\right|^2\left(\frac{m_{\beta\beta}}{m_e}\right)^2$$



2ν mode:

- Allowed in SM;
- Already observed for several nuclei;
- Half-lives of the order ~ 10^{18} - 10^{21} y;



0ν mode:

- Not allowed in SM;
- Never observed;
- Limits on the Half-life: $T_{1/2} > 10^{25}$ - 10^{26} y;

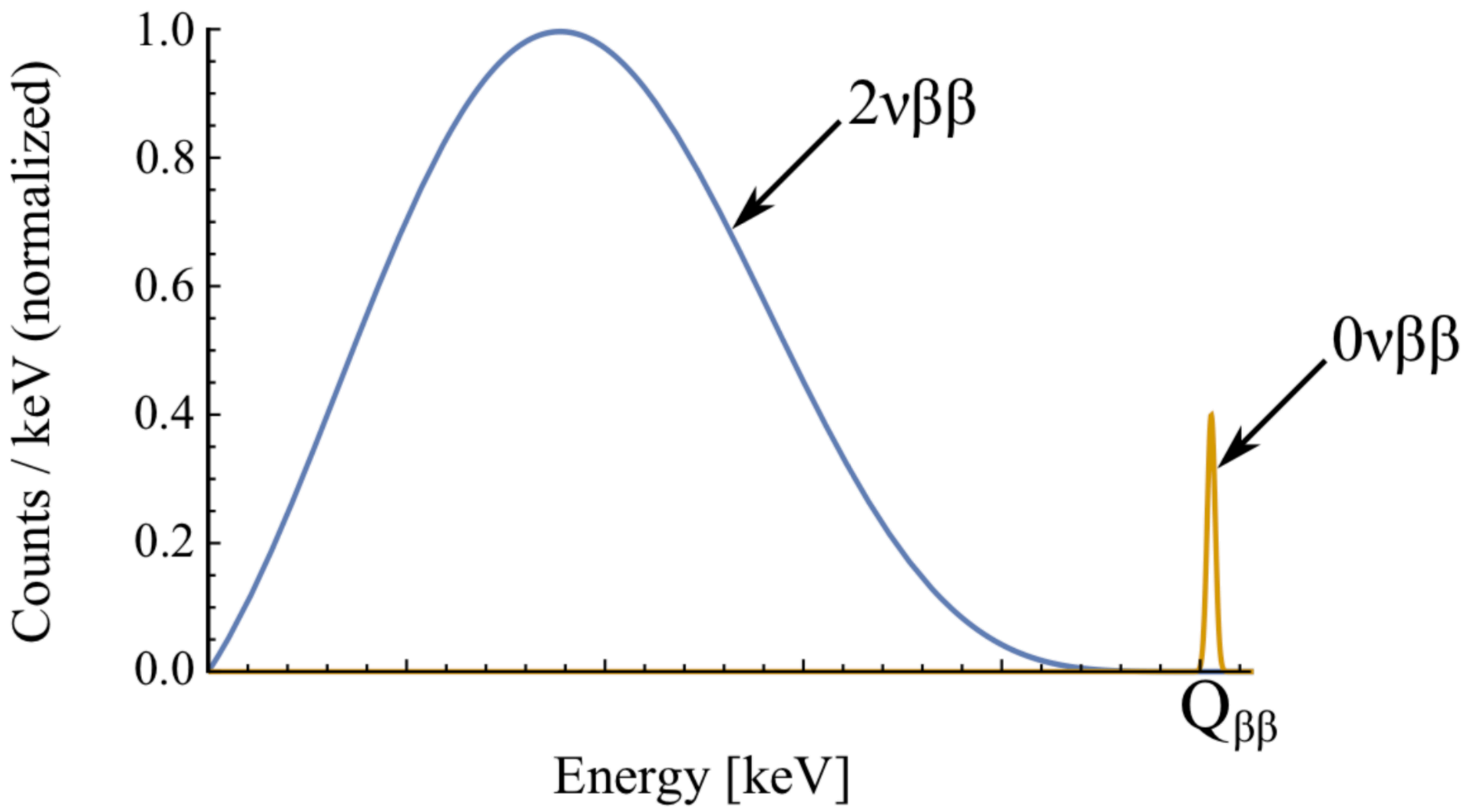
Experimental search

Main experimental signature:

Monochromatic peak centered at $Q_{\beta\beta}$ over the $2\nu\beta\beta$ tail;

Two body decay:

$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$



Experimental sensitivity:

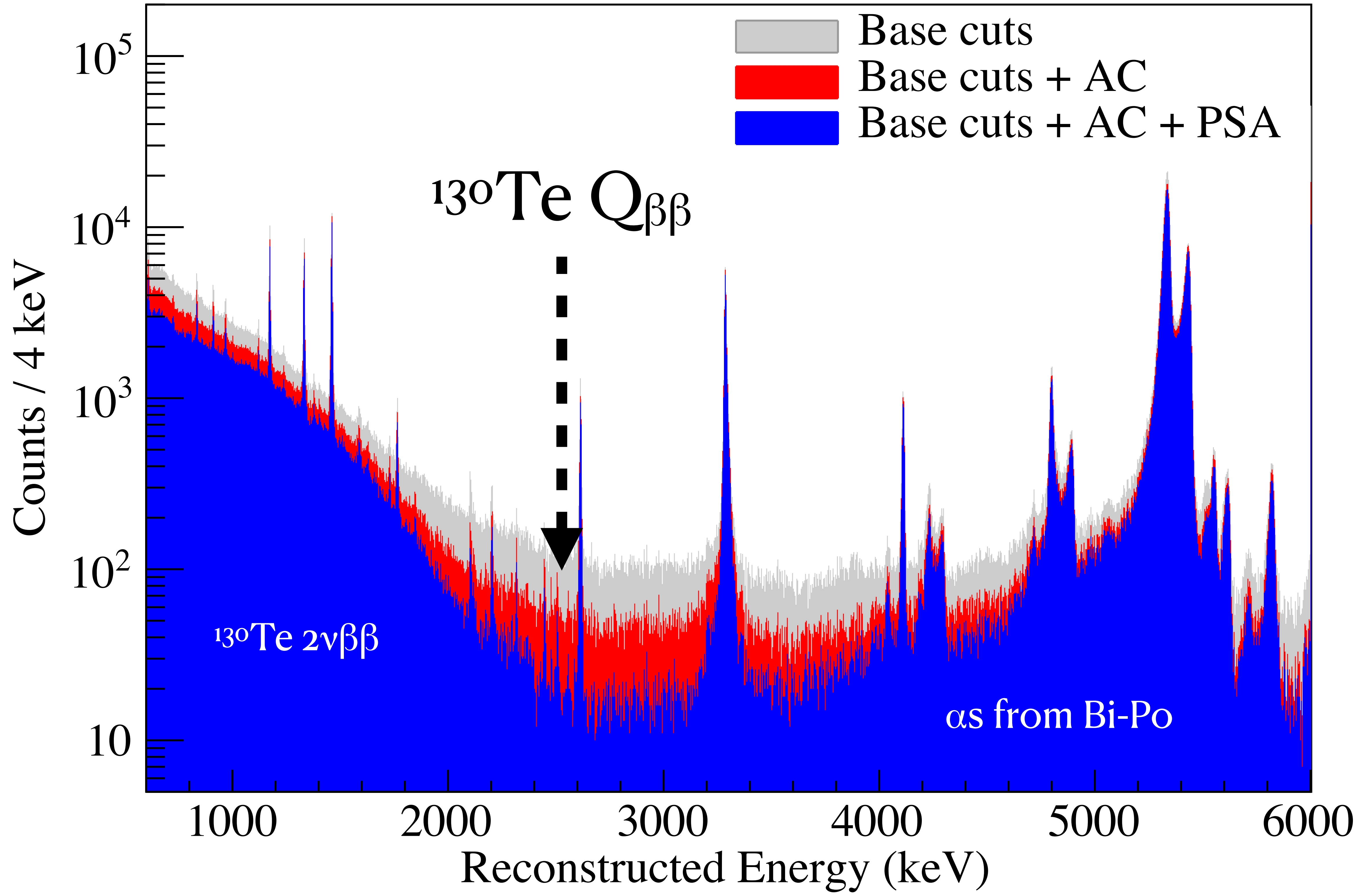
$$S_{0\nu} \propto \epsilon \sqrt{\frac{M \cdot T}{b \cdot \Delta}}$$

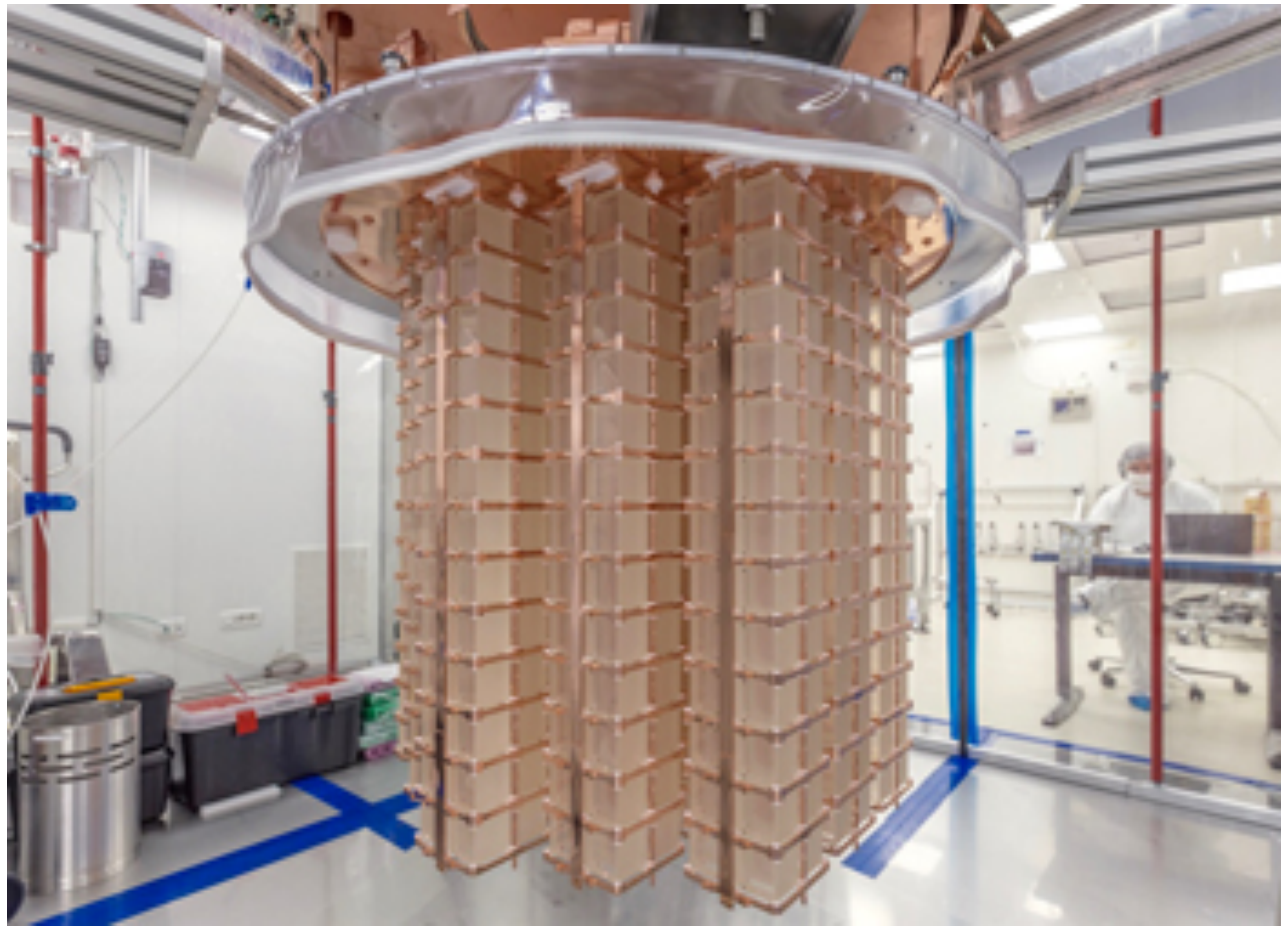
- ϵ: detection **efficiency**;
- M: source **mass** [kg];
- T: measure **time** [y];
- b: **background rate** [counts/keV/kg/y];
- Δ: experimental **resolution** [keV];

At **zero background limit**: $S_{0\nu} \propto \epsilon \cdot M \cdot T$

The CUORE experiment

- Ton-scale: 998 TeO_2 crystals;
- Total ^{130}Te mass: 206 kg;
- $Q_{\beta\beta}(^{130}Te)$ = 2530 keV;





- Main background: **degraded α particles**;
- B.I.: **$(1.4 \pm 0.2)\times10^{-2}$ counts/keV/kg/y**;

For the bolometric technique and the thermal model see S. Quitadamo's talk (link).

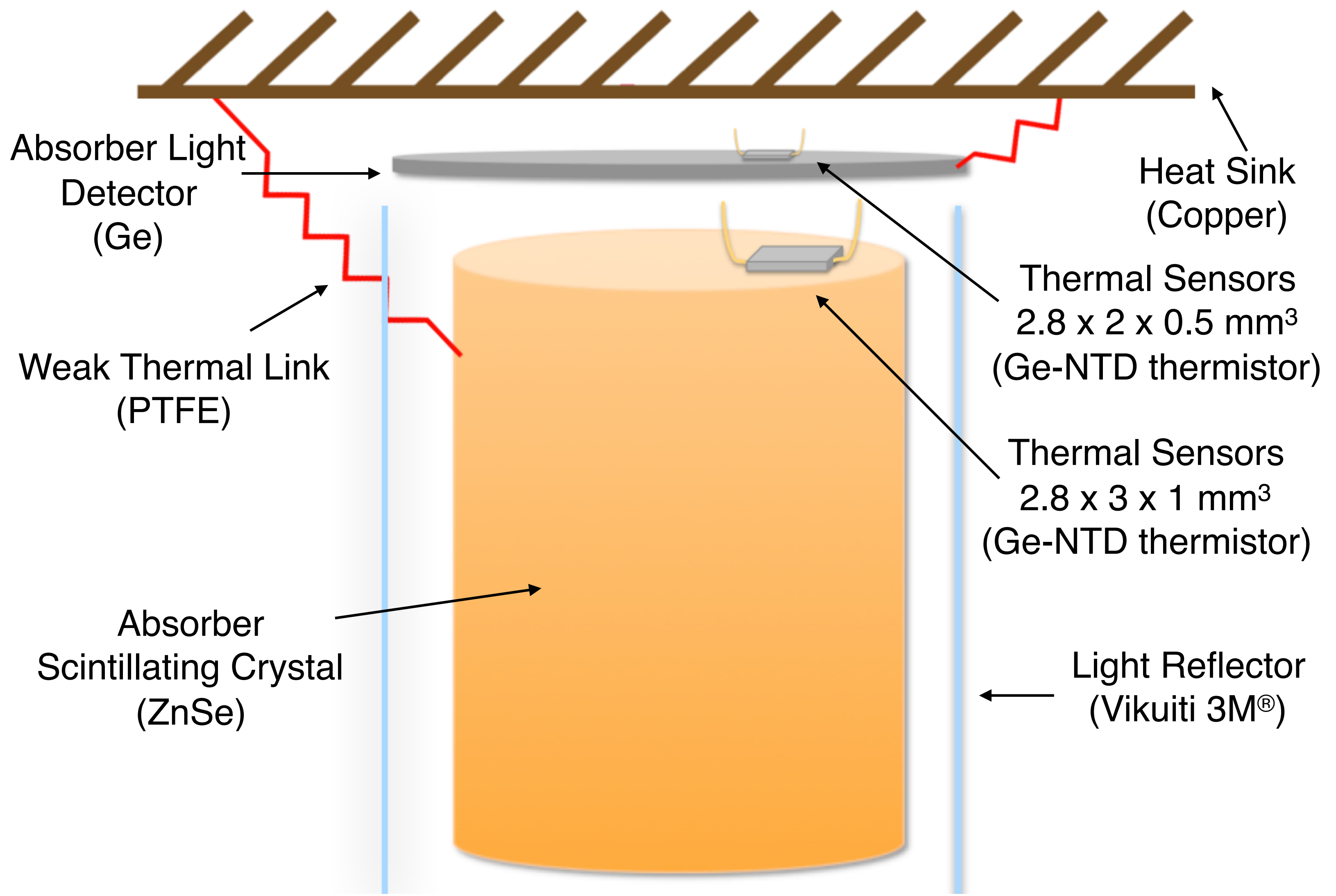
Needs for particle ID with cryogenic calorimeters…

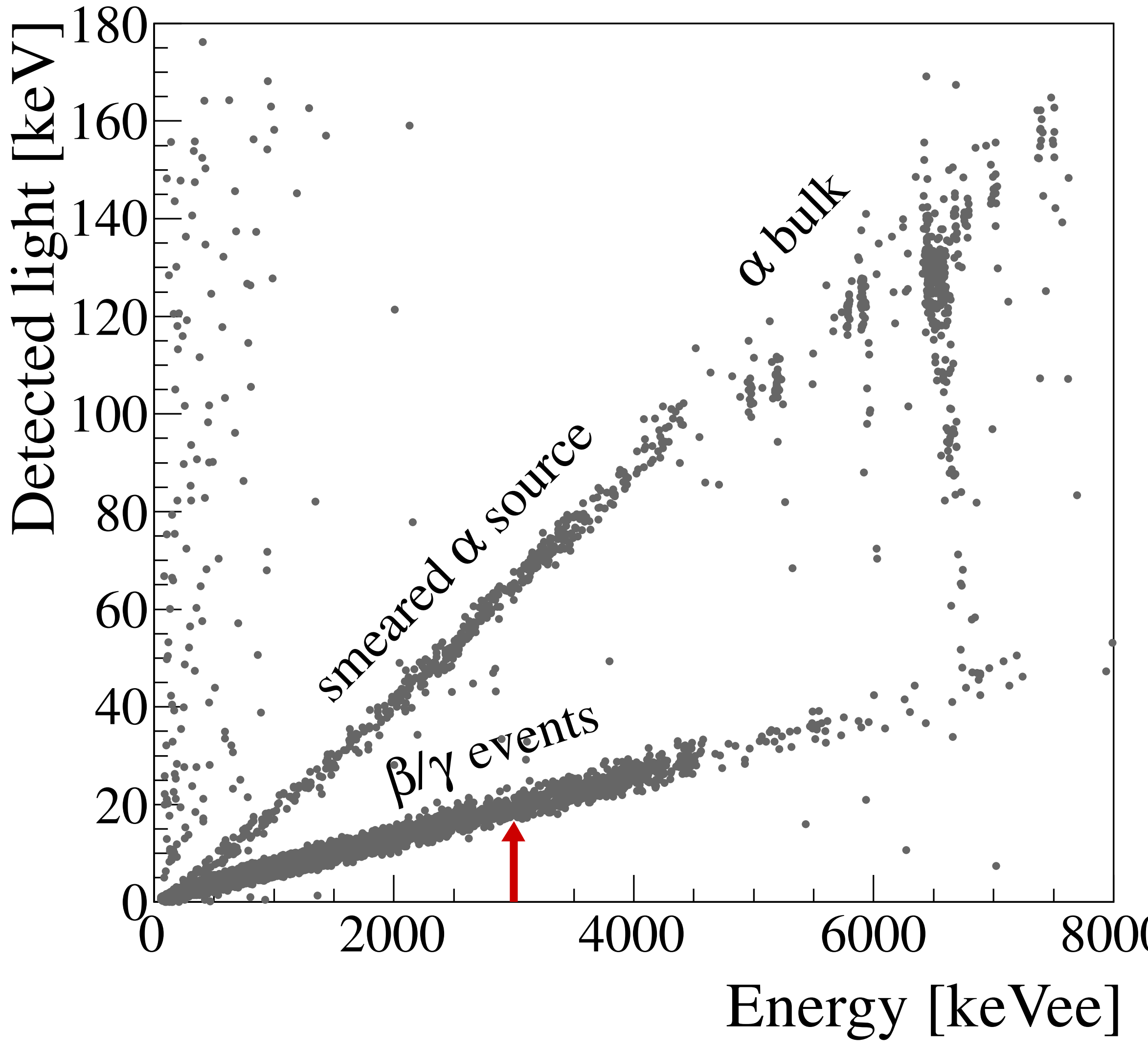
Scintillating cryogenic calorimeters

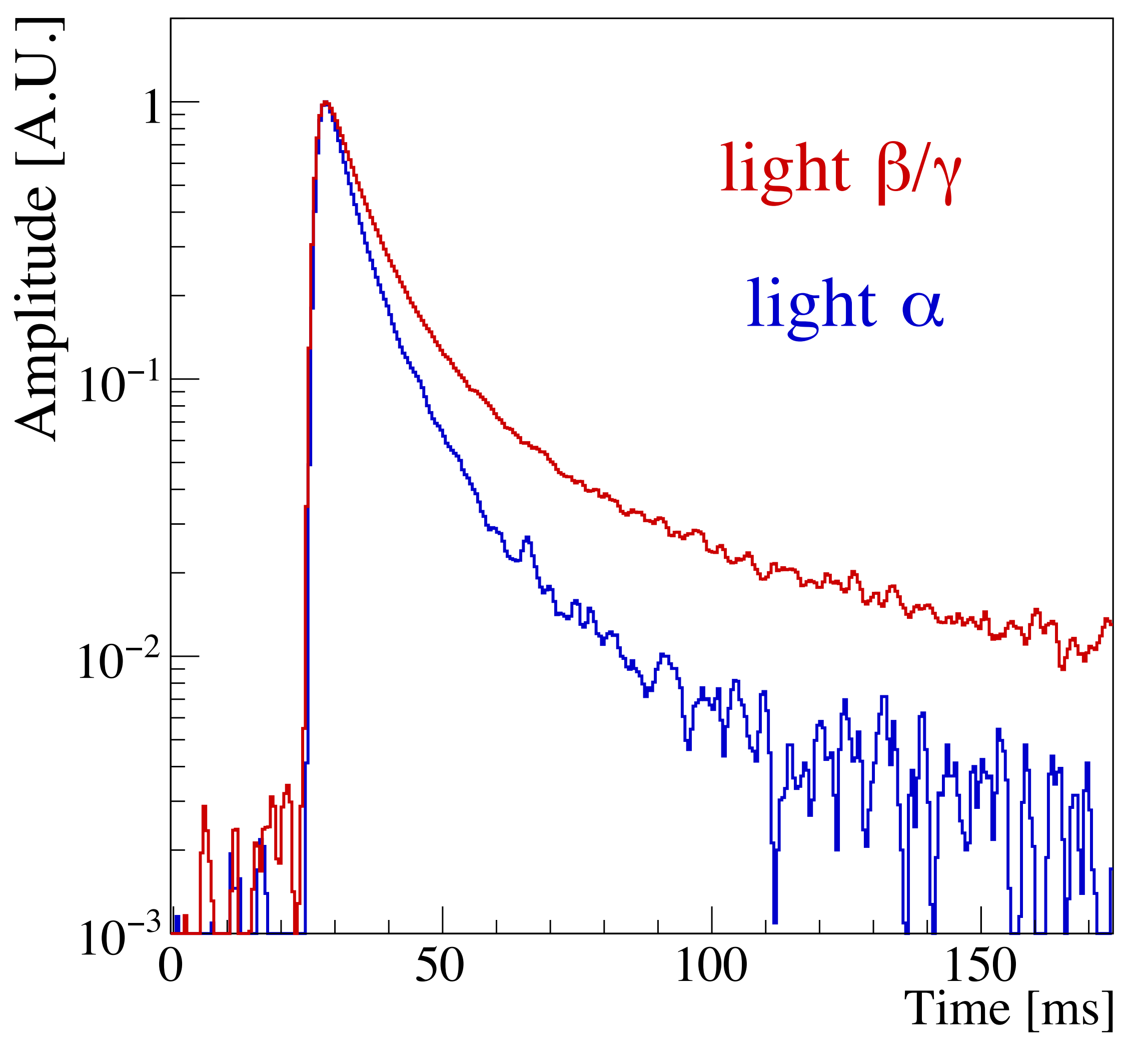
Scintillating calorimeters operating at cryogenic temperature ~10 mK → double read-out via heat & light.

- **Source = detector** → High efficiency;
- Excellent **energy resolution** (<1%);
- Modular design → **large scalability**;
- Possibility to study **different isotopes**;
- $LY_\alpha \neq LY_\beta$ and shape parameters allow **Particle identification**;

More on I.Nutini's invited talk (link);



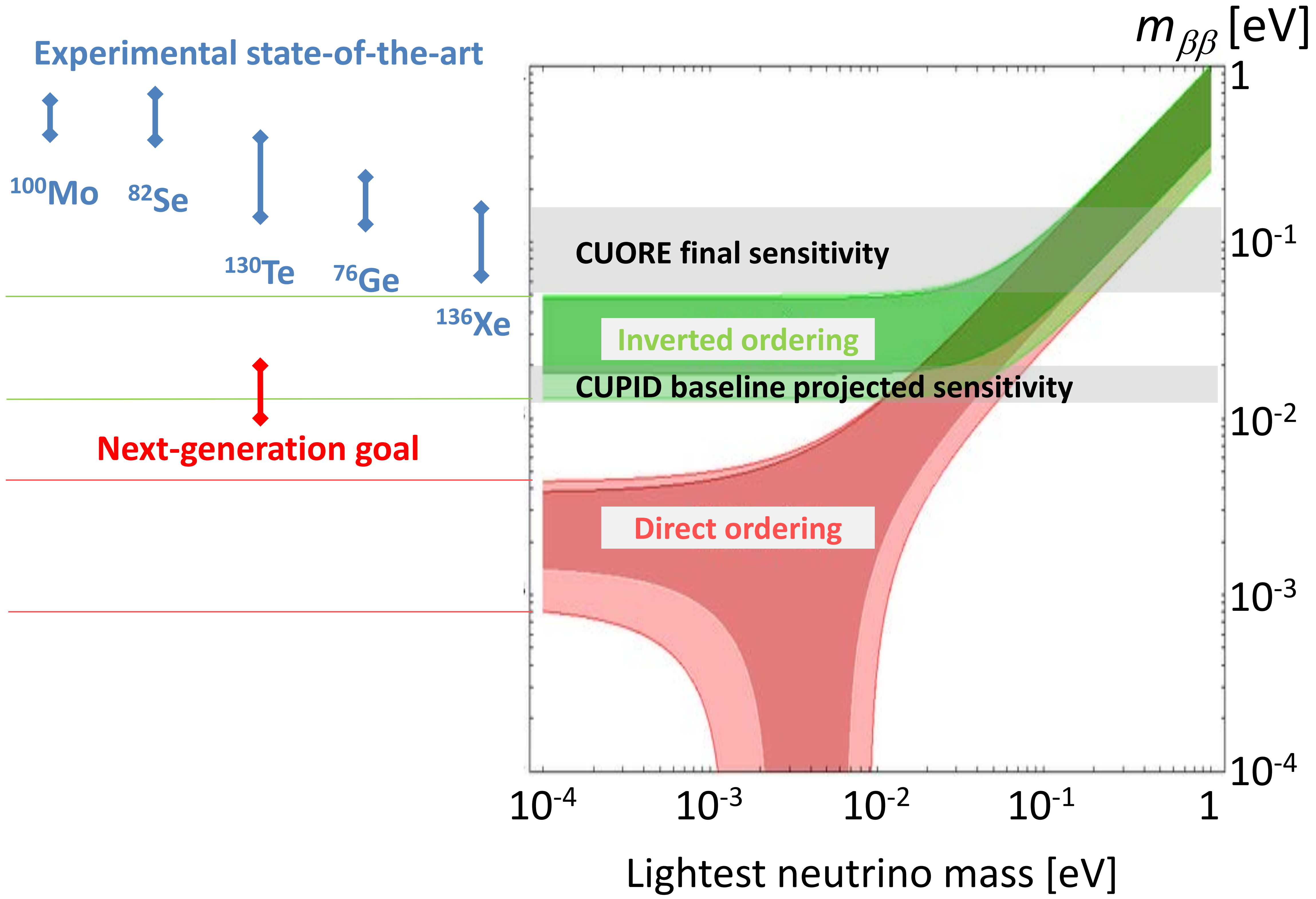




The CUPID project

- Next generation ton-scale experiment based on enriched $Li_2{}^{100}MoO_4$ scintillating crystals (arXiv:1907.09376);
- **$Q_{\beta\beta}(^{100}Mo) = 3035$ keV**;
- Target BI **~ 10^{-4} counts/keV/kg/y**;
- Expected to cover the entire inverted mass hierarchy of neutrino mass;
- Pilot experiments:
  - **CUPID-0** → enriched $Zn^{82}Se$ crystals;
  - **CUPID-Mo** → enriched $Li_2{}^{100}MoO_4$ crystals;

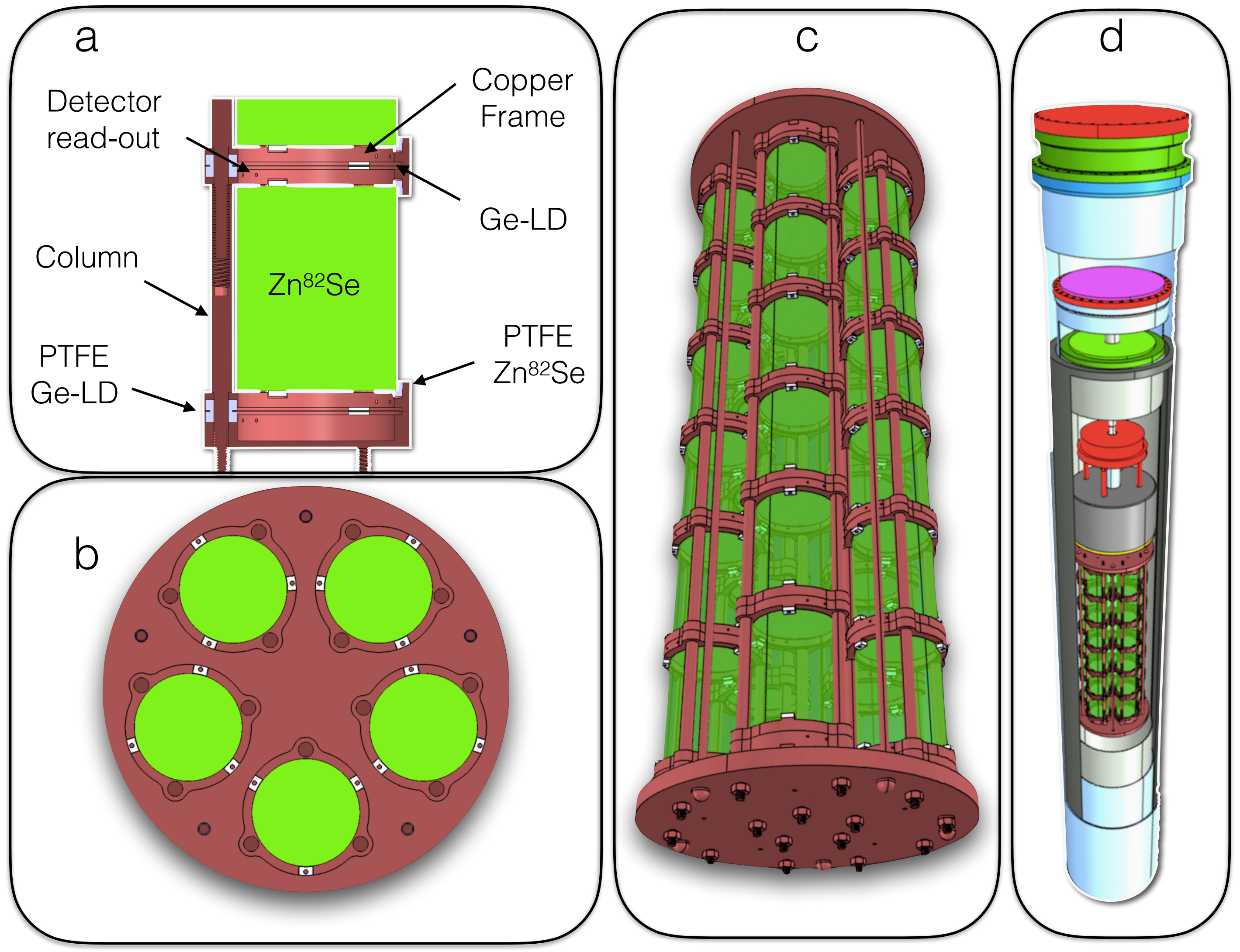
Cuore Upgrade with Particle IDentification



For CUPID R&D See A. Ressa's talk (link)

The CUPID-0 experiment

- Located at LNGS;
- 24 ZnSe crystals enriched at >95% of ^{82}Se + two natural ones;
- **$Q_{\beta\beta}(^{82}Se) = (2997.9 \pm 0.3)$ keV** → low background region;
- 31 Ge Light detectors;
- GeNTD thermistors as temperature sensors;
- Reflective foils to increase light collection;
- Total mass: **10.5 kg ZnSe**;



CUPID-0: search for ^{82}Se $0\nu\beta\beta$

- Final exposure: **9.95 kg × y;**
- Resolution at $Q_{\beta\beta}$: **(20.05 ± 0.34) keV;**
- $T_{1/2}$ ($0\nu\beta\beta$ ^{82}Se) > **3.5 × 10^{24} y (90% C.I. limit);**

  5.0 × 10^{24} y (Median Sensitivity);

Selecting only particle signals:

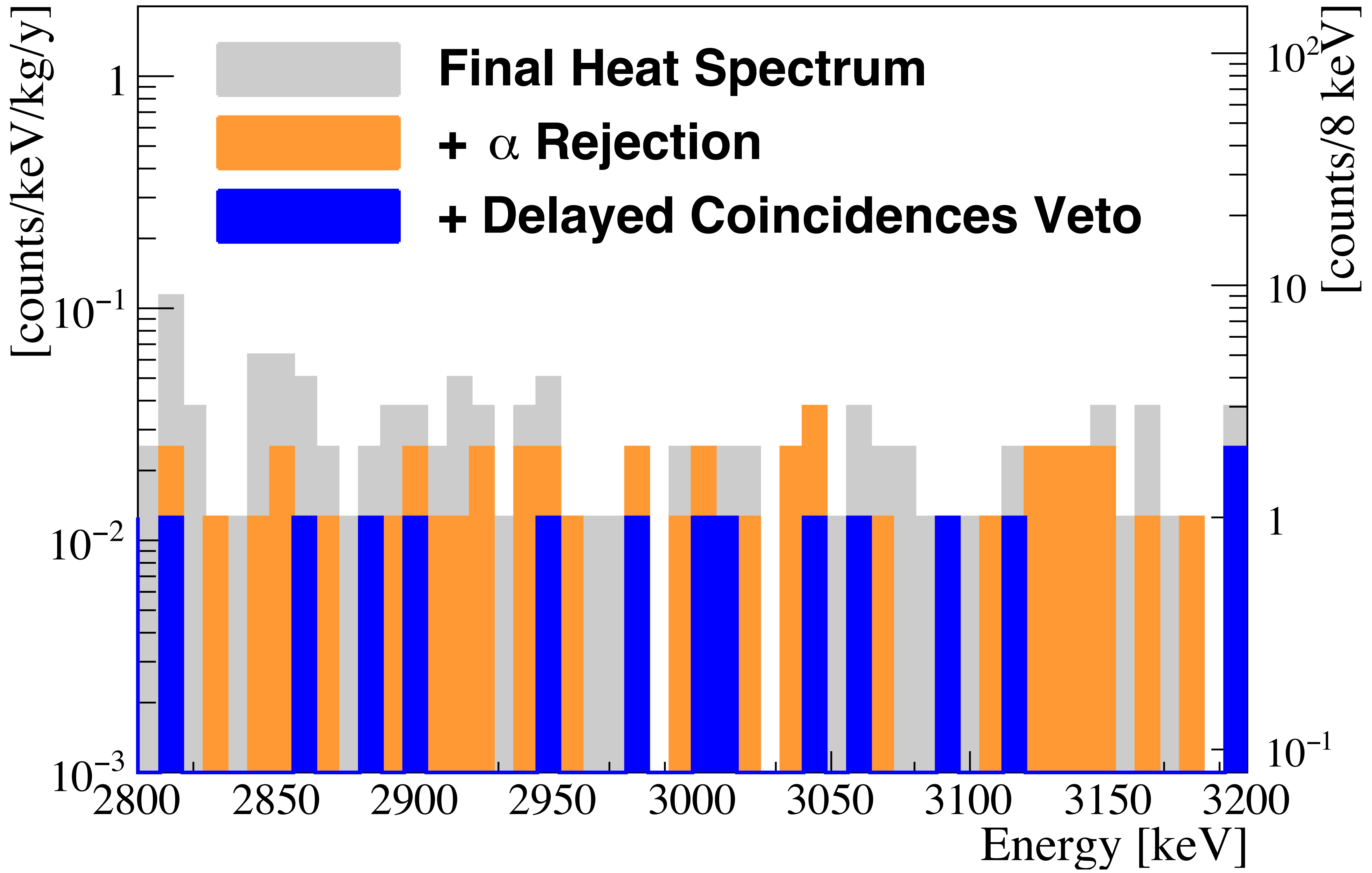
⇒ 3.2 × 10^{-2} counts/(keV kg y)

Selecting only β/γ:

⇒ 1.3 × 10^{-2} counts/(keV kg y)

Removing ^{208}Tl events:

⇒ 3.5 × 10^{-3} counts/(keV kg y)



Phys. Rev. Lett. 123, 032501 (2019)

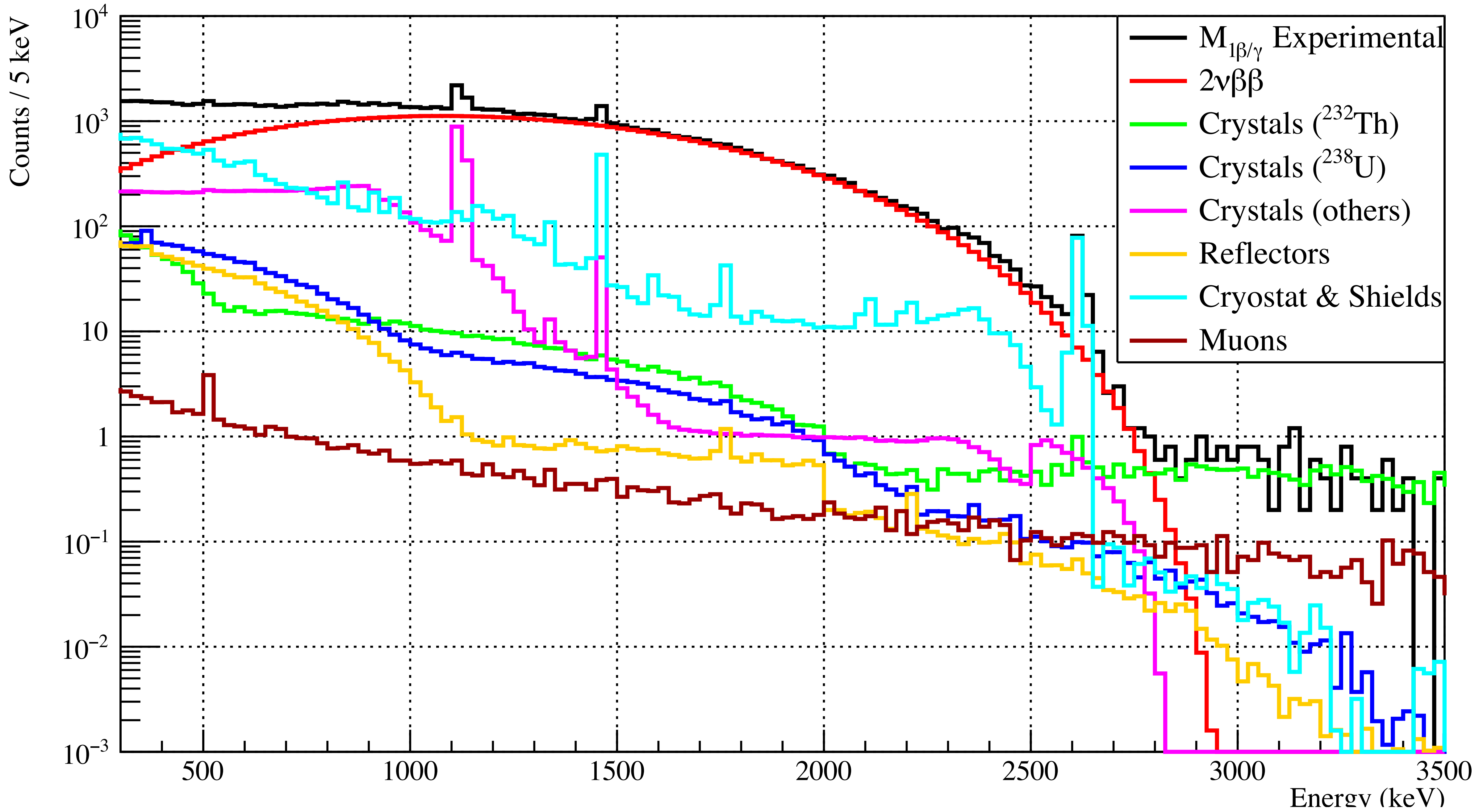
CUPID-0: background model

Crucial step towards the comprehension of the background in experiments based on scintillating calorimeters.

ROI (2.8 - 3.2 MeV)

Component	ROI_{bkg} rate (10^{-4}counts/(keV kg yr))	Source	ROI_{bkg} rate (10^{-4}counts/(keV kg yr))
Crystals	$11.7 \pm 0.6\ ^{+1.6}_{-0.8}$	^{232}Th– bulk	$3.4 \pm 0.6 \pm 0.1$
		^{232}Th–surf	$3.4 \pm 0.5\ ^{+1.0}_{-0.7}$
		^{238}U–surf	$4.9 \pm 0.3\ ^{+1.3}_{-0.3}$
Reflectors & Holder	$2.1 \pm 0.3\ ^{+2.2}_{-1.0}$	^{232}Th	< 3.3
		^{238}U	$1.8 \pm 0.3\ ^{+1.4}_{-0.9}$
Cryostat & Shields	$5.9 \pm 1.3\ ^{+7.2}_{-2.9}$	^{232}Th	$3.5 \pm 1.3\ ^{+7.4}_{-3.3}$
		^{238}U	$2.4 \pm 0.4\ ^{+4.1}_{-0.7}$
Subtotal	$19.8 \pm 1.4\ ^{+6.6}_{-2.7}$		
Muons	$15.3 \pm 1.3 \pm 2.5$		
$2\nu\beta\beta$	6.0 ± 0.3 ($< 3 \times 10^{-6}$ counts/(keV kg yr) in [2.95–3.05] MeV range)		
Total	$41 \pm 2\ ^{+9}_{-4}$		
Experimental	$35\ ^{+10}_{-9}$		

Eur. Phys. J. C 79, 583 (2019)



- ~44% muons;
- ~33% contaminations ZnSe crystals;
- ~17% cryostat;
- ~6% reflecting foil and holders;

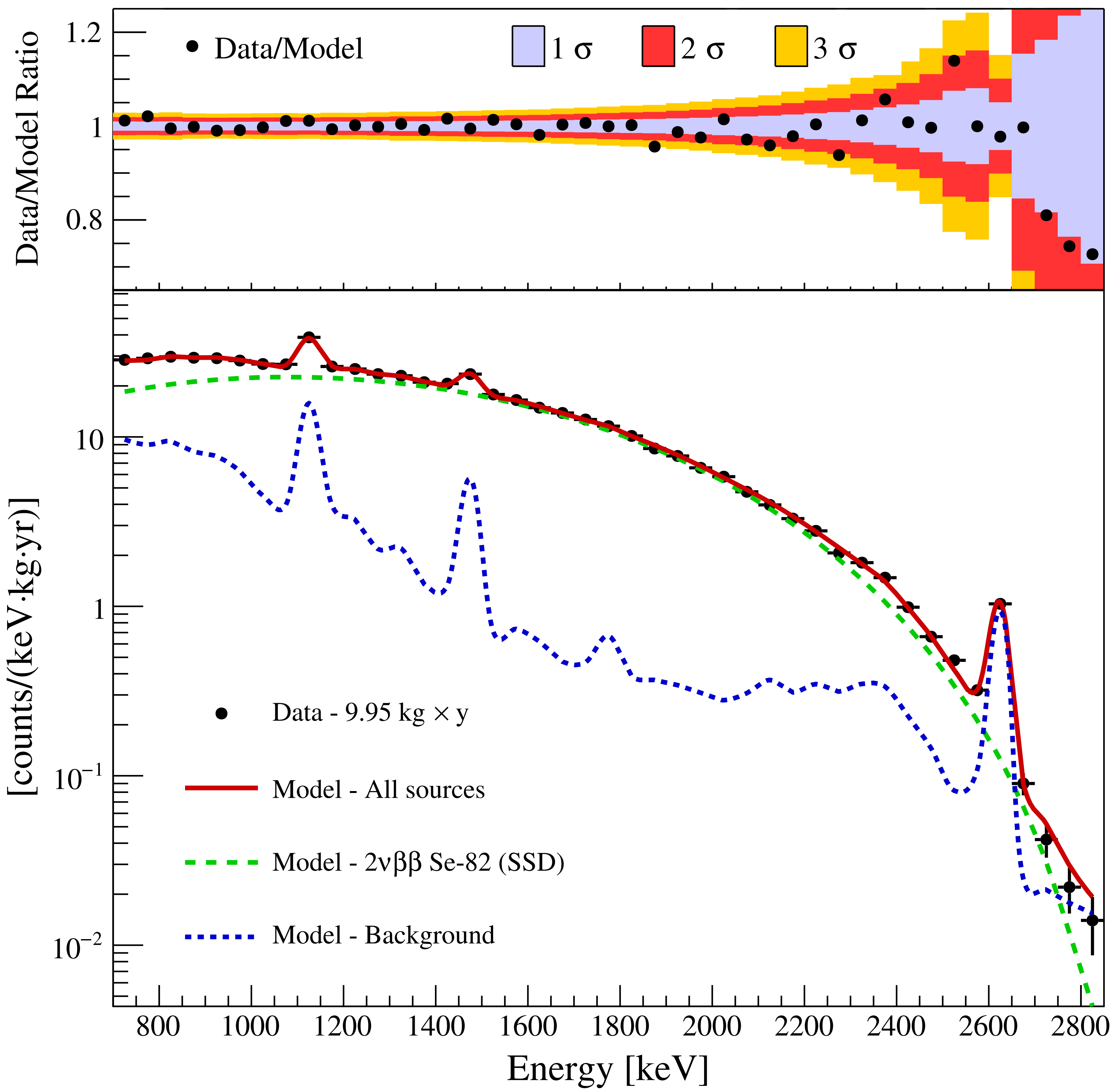
CUPID-0: Measurement of ^{82}Se 2νββ half-life

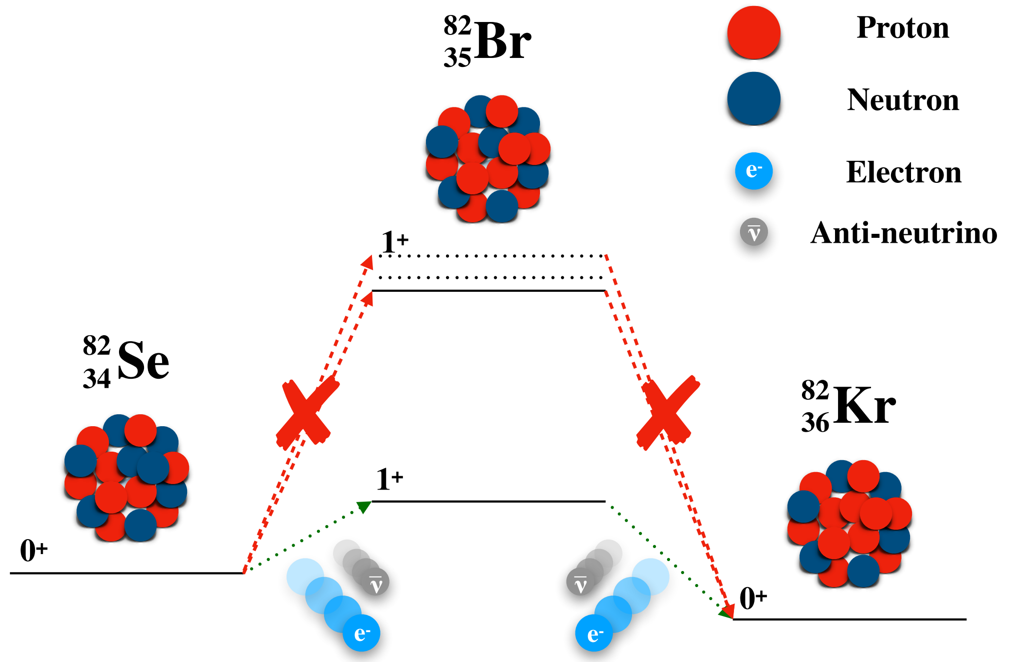
Most precise measurement of 2νββ half-life:

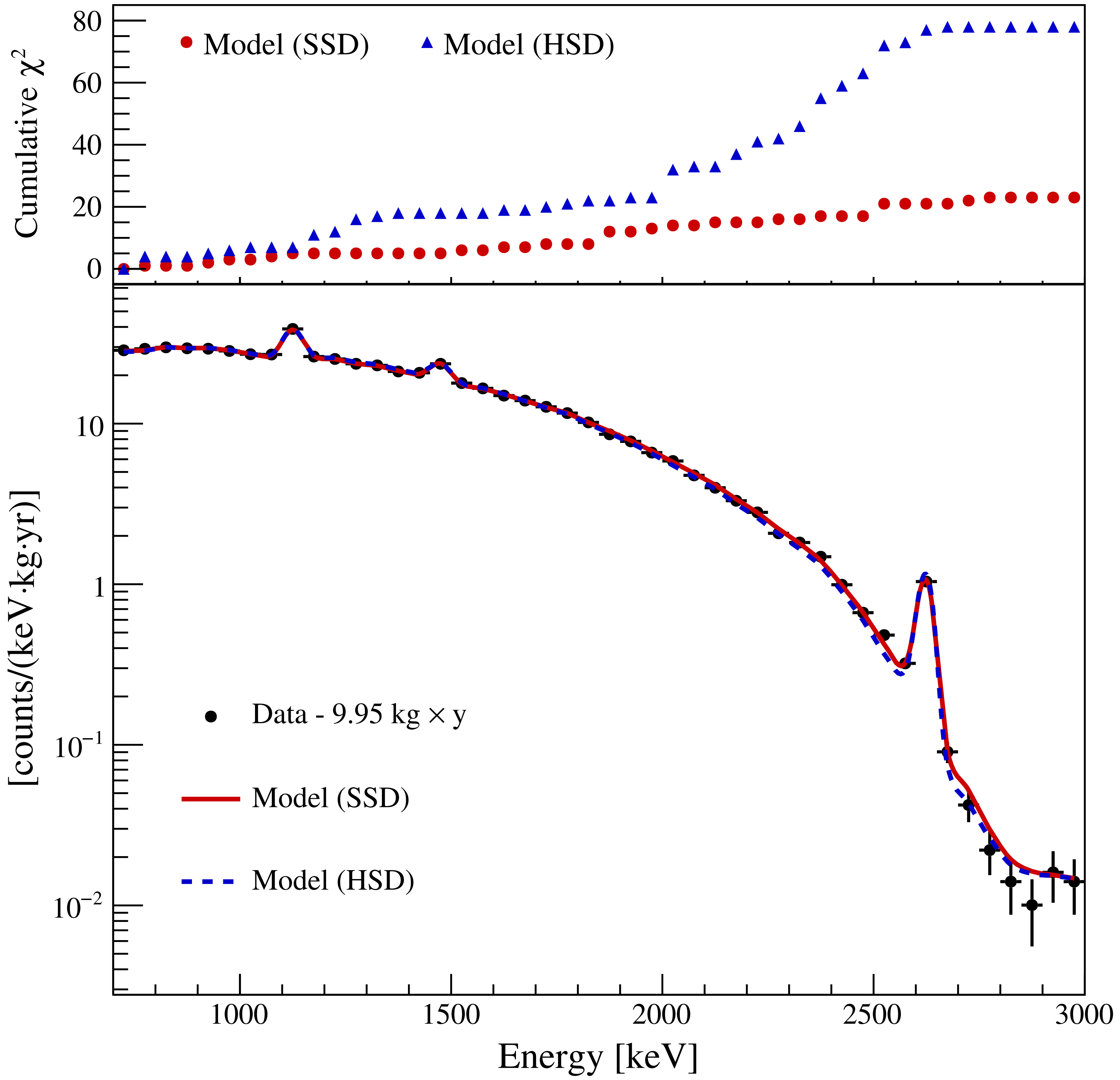
$$T^{2\nu}_{1/2} = [8.60 \pm 0.03(\text{stat})\,^{+0.19}_{-0.13}(\text{syst})] \times 10^{19}\ \text{yr}.$$

result awarded with E. Pancini prize - SIF2020

[Phys. Rev. Lett. 123, 262501 (2019)]







Strong evidence of Single State Dominance on 2νββ of ^{82}Se

SSD: χ^2/ndf = **1.0**

HSD: χ^2/ndf = **1.42**

Conclusion & future perspectives

Other physical results…

- First search for Lorentz violation in double beta decay with scintillating calorimeters

→ Phys. Rev. D 100, 092002 (2019)

- Search of the neutrino-less double beta decay of ^{82}Se into the excited states of ^{82}Kr with CUPID-0

→ Eur. Phys. J. C (2018) 78:888

- Search for neutrinoless double beta decay of ^{64}Zn and ^{70}Zn with CUPID-0

→ Eur. Phys. J. C (2020) 80: 702

Upgrade

- Removal of reflecting foils;
- Muon veto surrounding cryostat;
- Internal copper shield;

Confirmation of the background model

Thanks for the attention!