Final results of the CUPID-0 Phase I experiment

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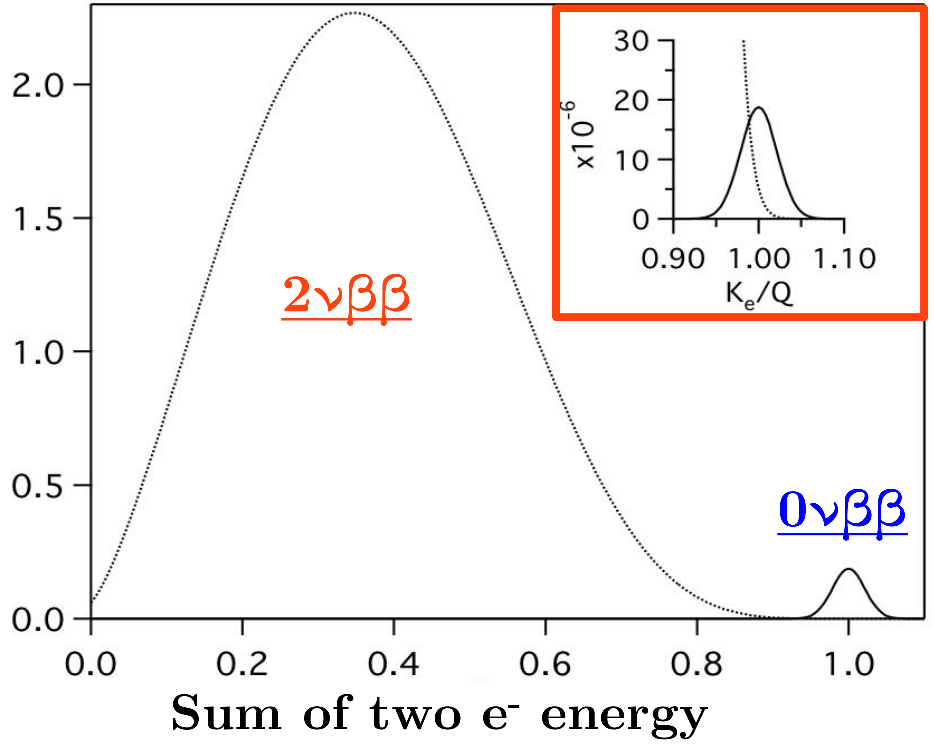
On behalf of the CUPID-0 collaboration

CUPID-0

The first enriched scintillating bolometer ββ experiment



2νββ

$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}$

0νββ:

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

^{82}Se

$Q_{\beta\beta} = (2997 \pm 0.3)$ keV

Performing resolution

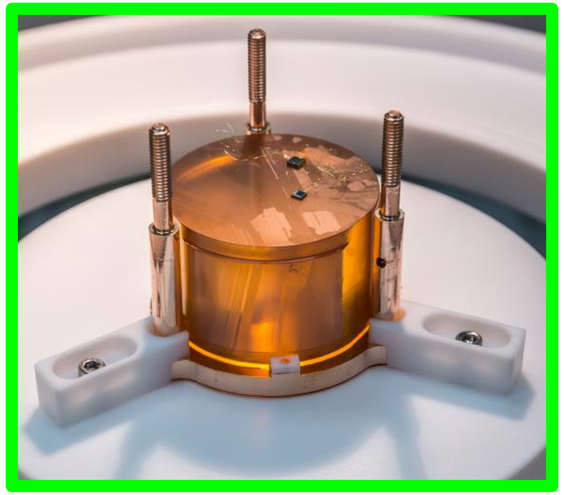
At the Q value

Low Background

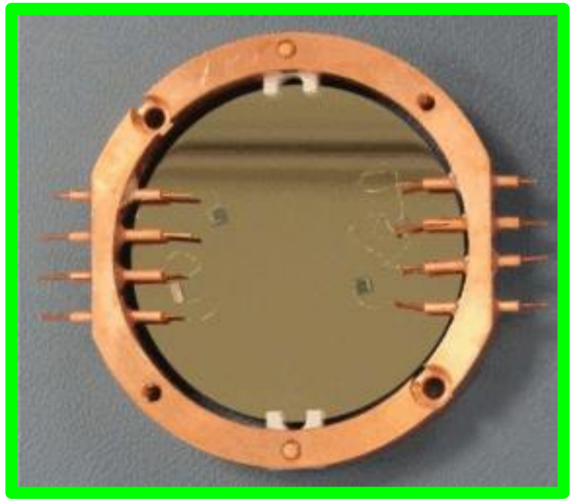
Few counts expected

CUPID-0 Detector

Scintillating
$Zn^{82}Se$ crystals.



Bolometric **Ge**
Light detectors



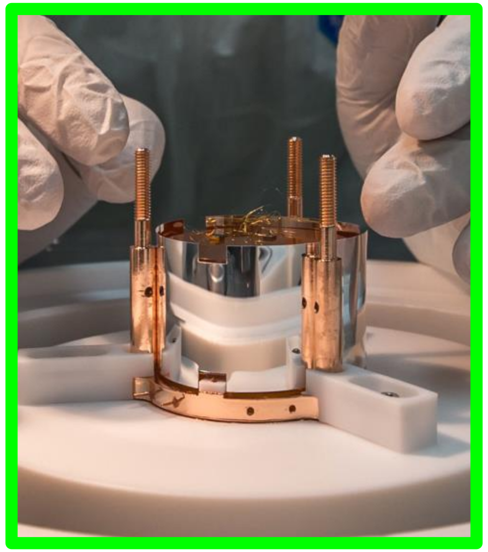
Heat signal:

bolometric high resolved output

Light signal:

particle identification

- **26 ZnSe crystals**
  - 24 enriched in ^{82}Se (95%) + 2 naturals
- **Total mass= 10.5 kg**
  - ^{82}Se mass =5.17 kg ($3.8 \cdot 10^{25}$ ββ emitters)



Vikuiti Reflector
More collected light

NOSV Copper
Surface cleaned

O. Azzolini et al. (CUPID), Eur. Phys. J. C 78, 428 (2018), arXiv:1802.06562

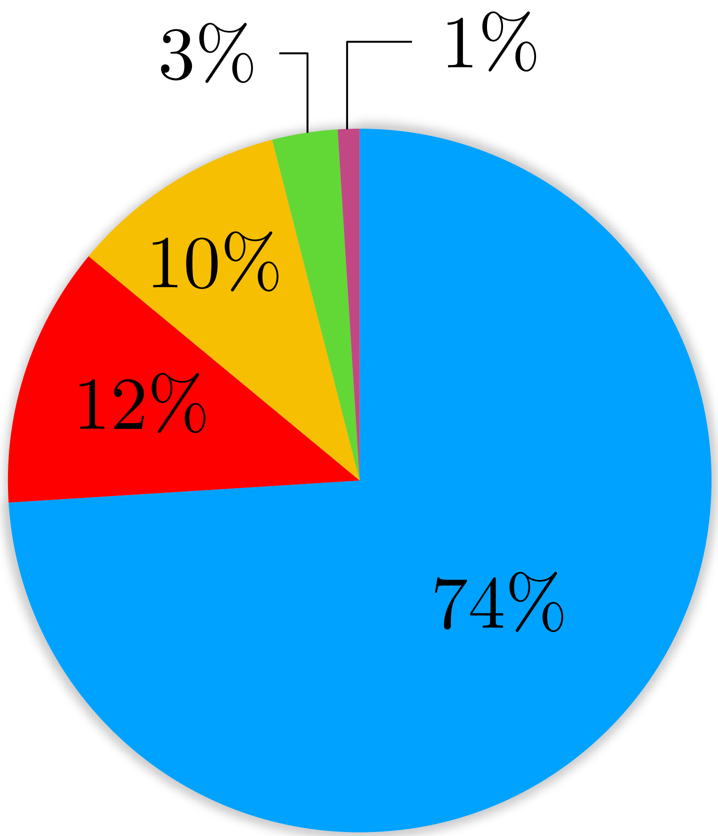
CUPID-0 Time-line

2017 — **Commissioning**

June 2017 – December 2018 — **Phase I**

560 d with 74% of livetime

2019 — **Preparation of Phase II**



^{56}Co Energy Calibration

^{232}Th Energy Calibration

System manteinance

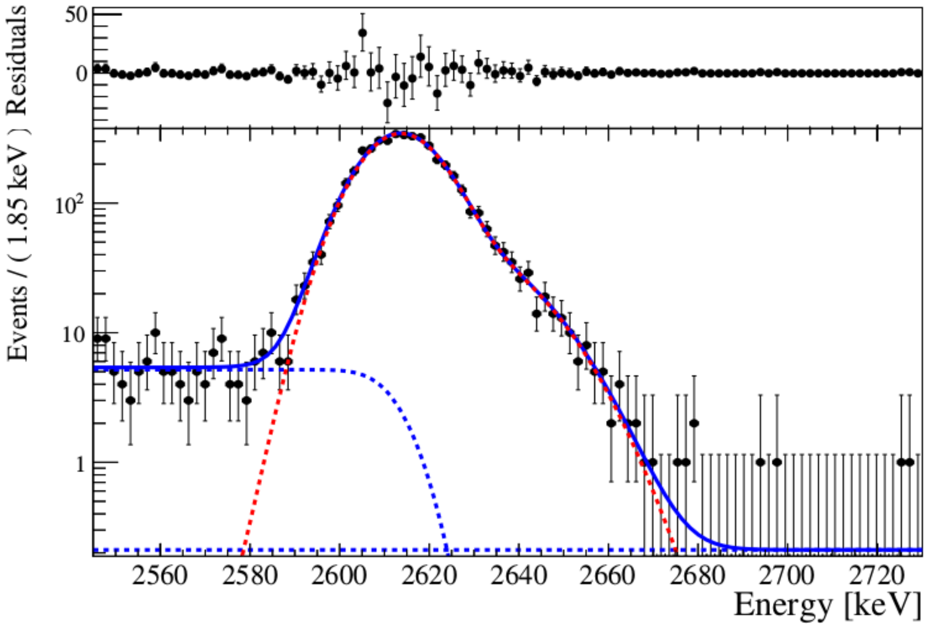
AmBe source
βγ Shape Characterization in the ROI

ββ physics
Exposure: 9.95 kg·y

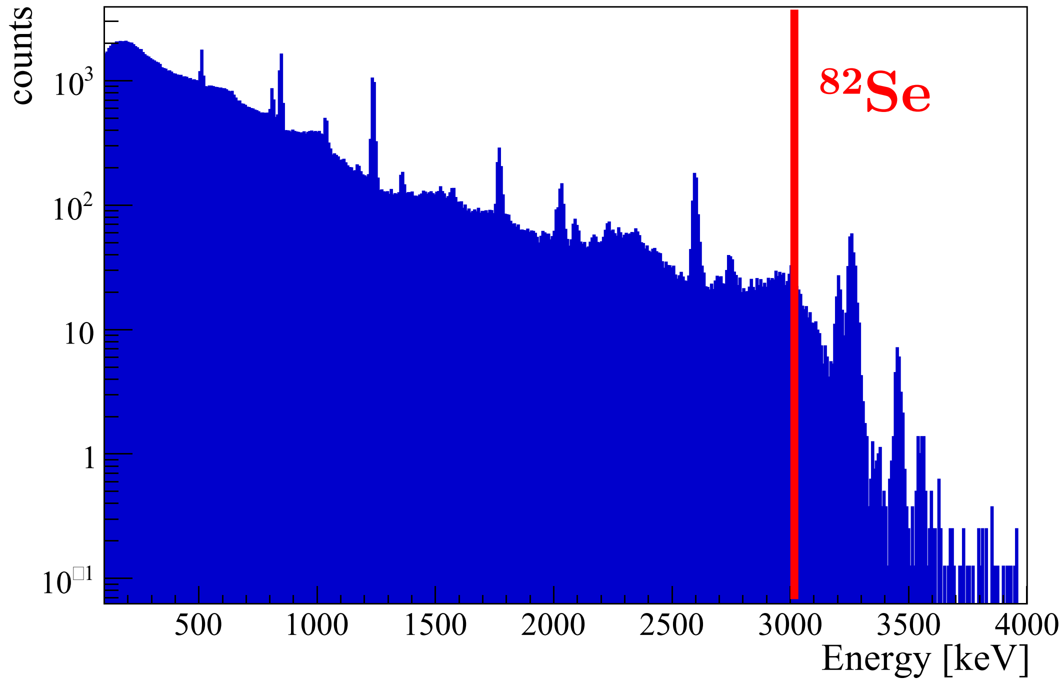
Calibrations

^{232}Th Energy Calibration

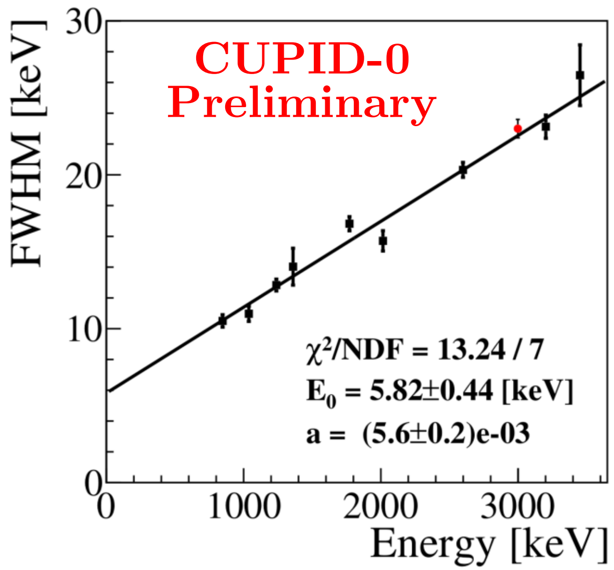
- Periodic Bolometer calibration and light detector intercalibration
- Response function: Double Gaussian
  - Also observed in other bolometers



^{56}Co Energy Calibration



- Check of the energy reconstruction
- Evaluation of FWHM energy resolution @ ^{82}Se Q

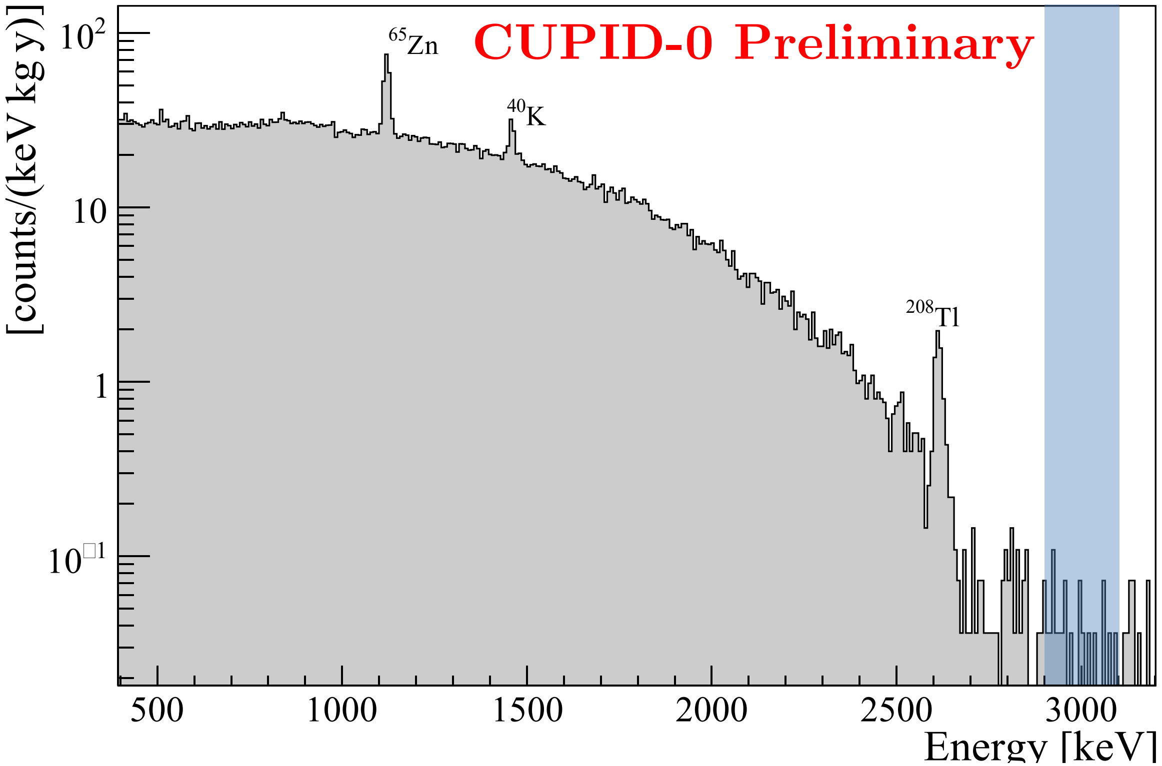


FWHM @ $Q_{\beta\beta}$

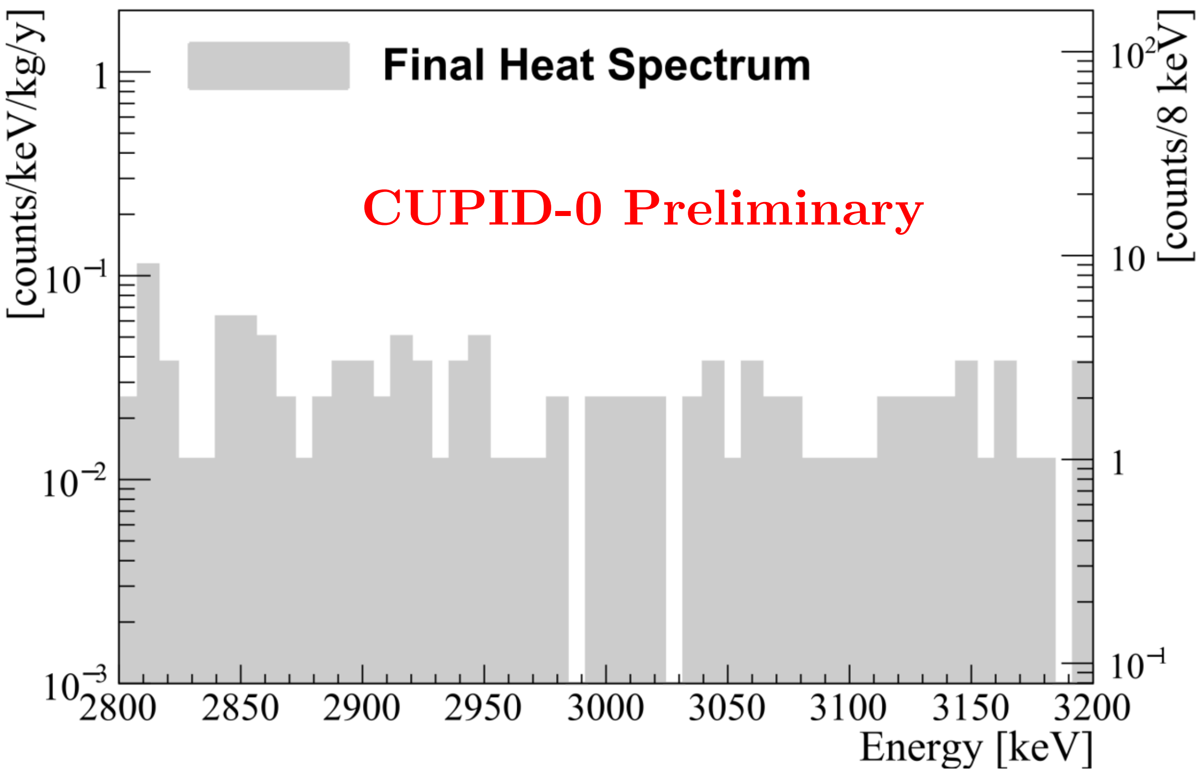
(20.0 ± 0.6) keV

$0\nu\beta\beta$ search

Total Background spectrum



$0\nu\beta\beta$ ROI



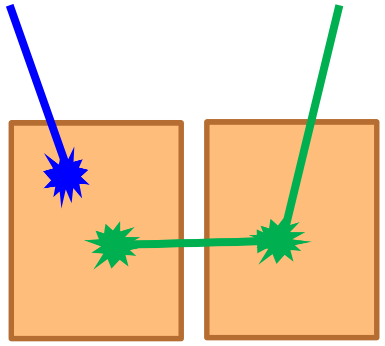
$$\mathrm{BKG} = (3.2 \pm 0.4) \cdot 10^{-2}\ \mathrm{cnts}/(\mathrm{keV} \cdot \mathrm{kg} \cdot \mathrm{y})$$

Basic Selections

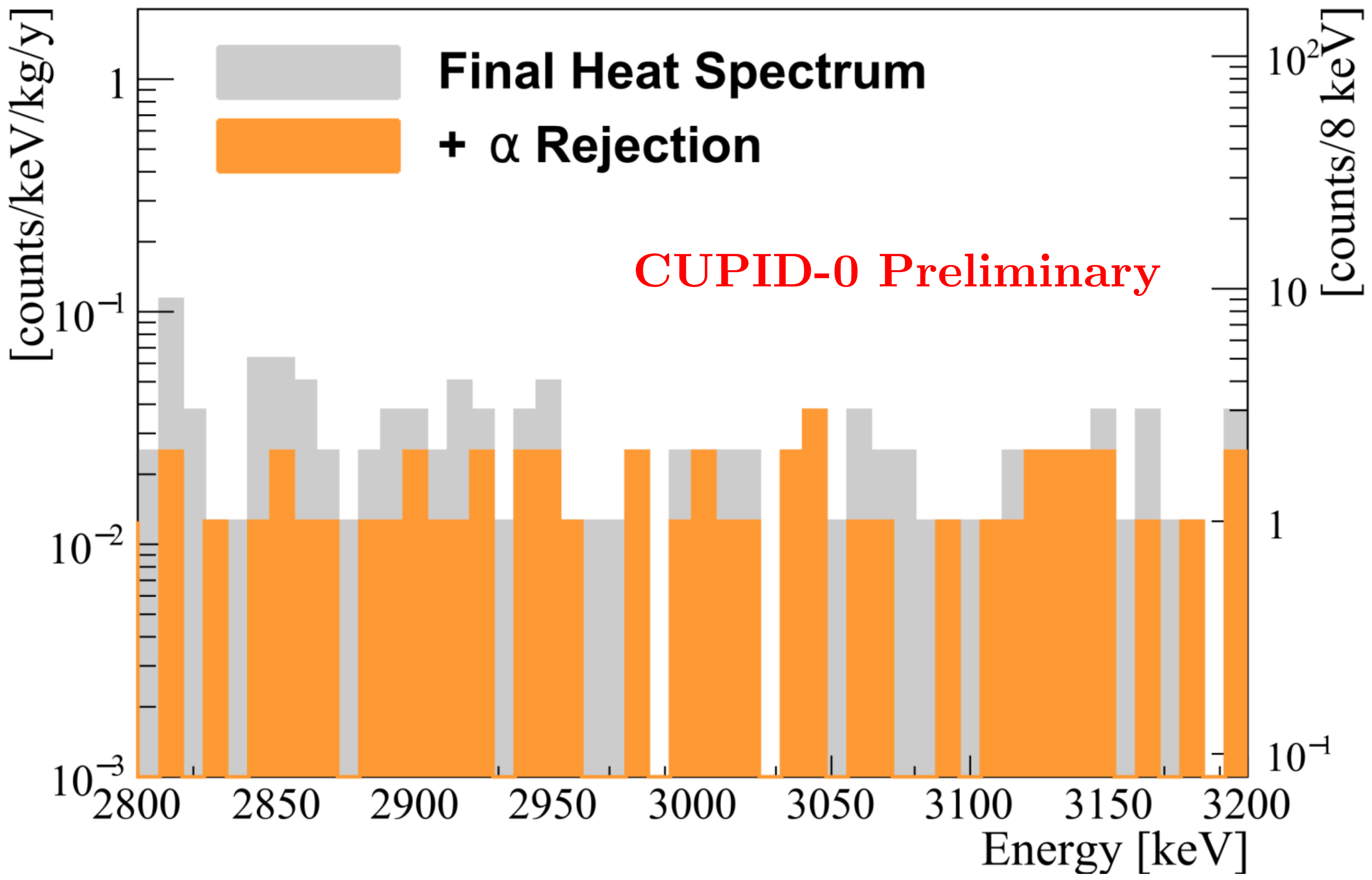
Rejection of "non-particle-like" events through pulse shape on thermal pulses

Multiplicity (M)

Anti-coincidence between crystals (ΔT=20ms)

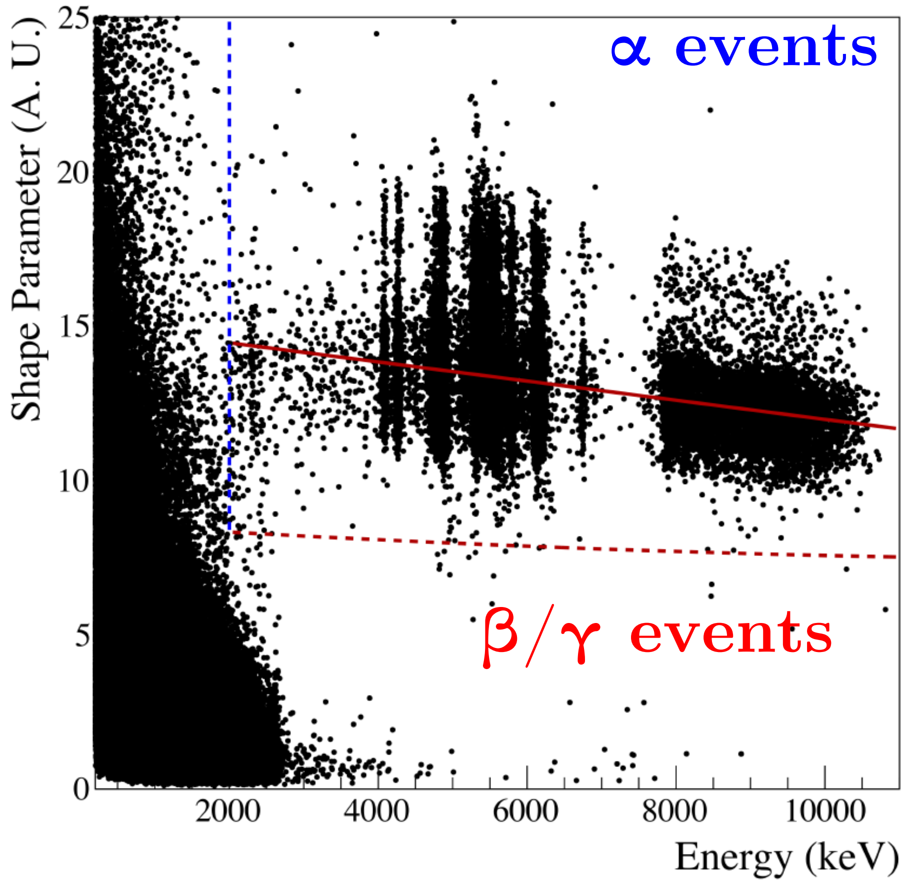


Background – Alpha Rejection



Light Signal depends on particle type

Selection based on light shape parameter

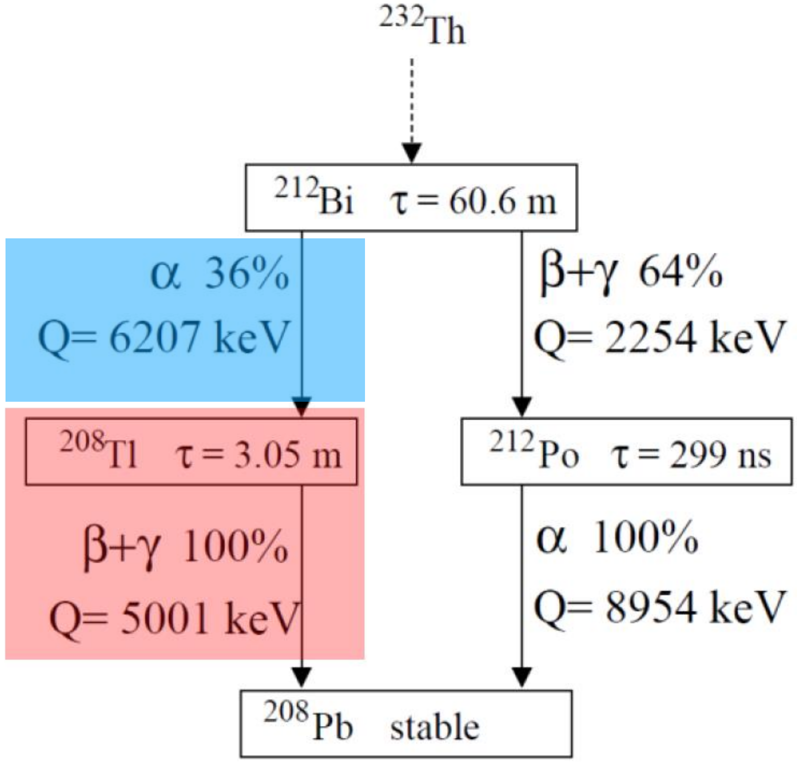


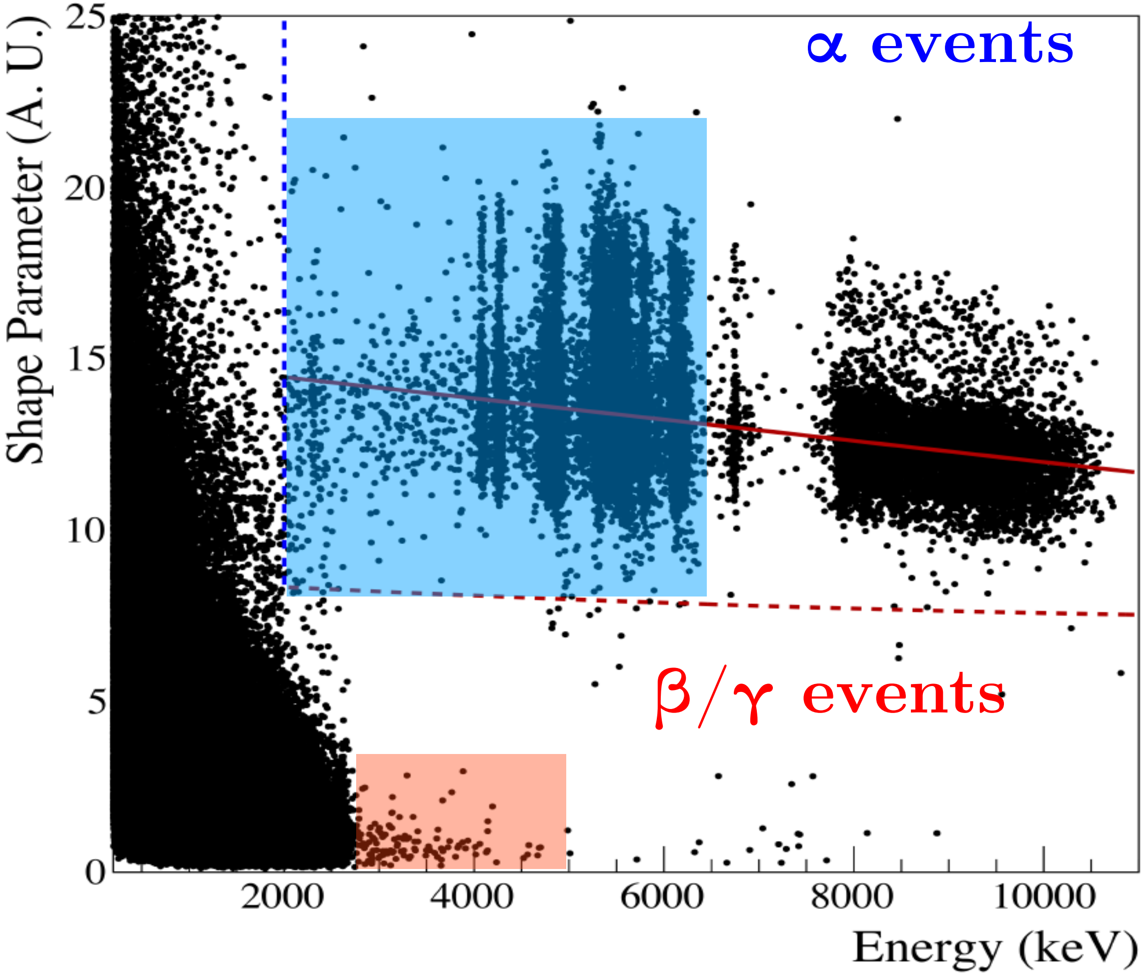
$$\mathrm{BKG} = (3.2 \pm 0.4) \cdot 10^{-2}\ \mathrm{cnts/(keV \cdot kg \cdot y)}$$

$$\mathrm{BKG} = (1.3 \pm 0.2) \cdot 10^{-2}\ \mathrm{cnts/(keV \cdot kg \cdot y)}$$

Background – Delayed coincidences rejection

Delayed ^{212}Bi-^{208}Tl (α/β) coincidences



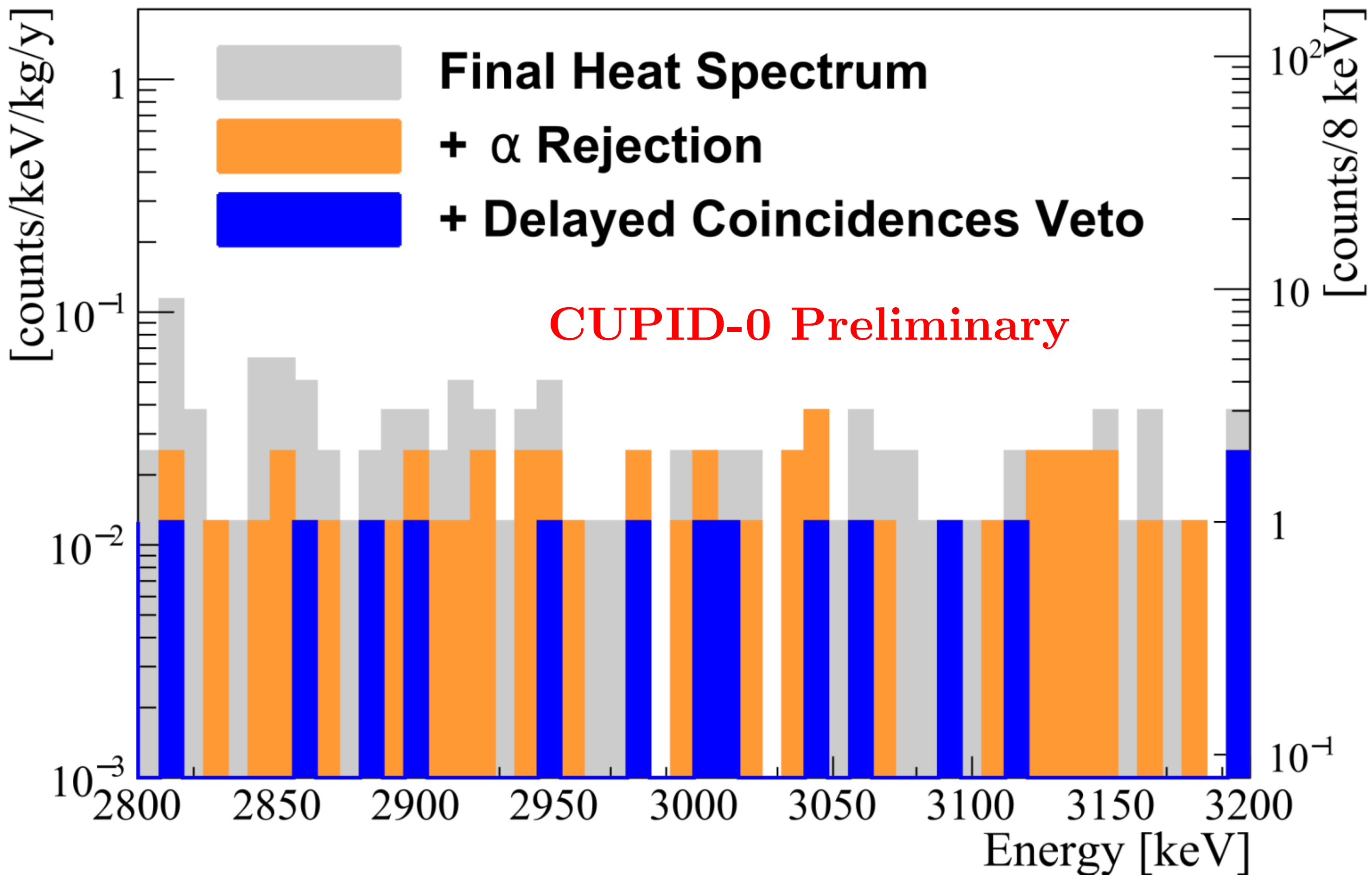


Selection of ^{212}Bi α events

- α pulse shape
- 2.0 MeV<Energy<6.5MeV
  - Degraded tag

⟶ **Veto** for 7 half-life

Background – Delayed coincidences rejection



$(3.5^{+1}_{-0.9}) \cdot 10^{-3}$ cnts/(keV · kg · y)

Lowest background ever measured with a calorimeter

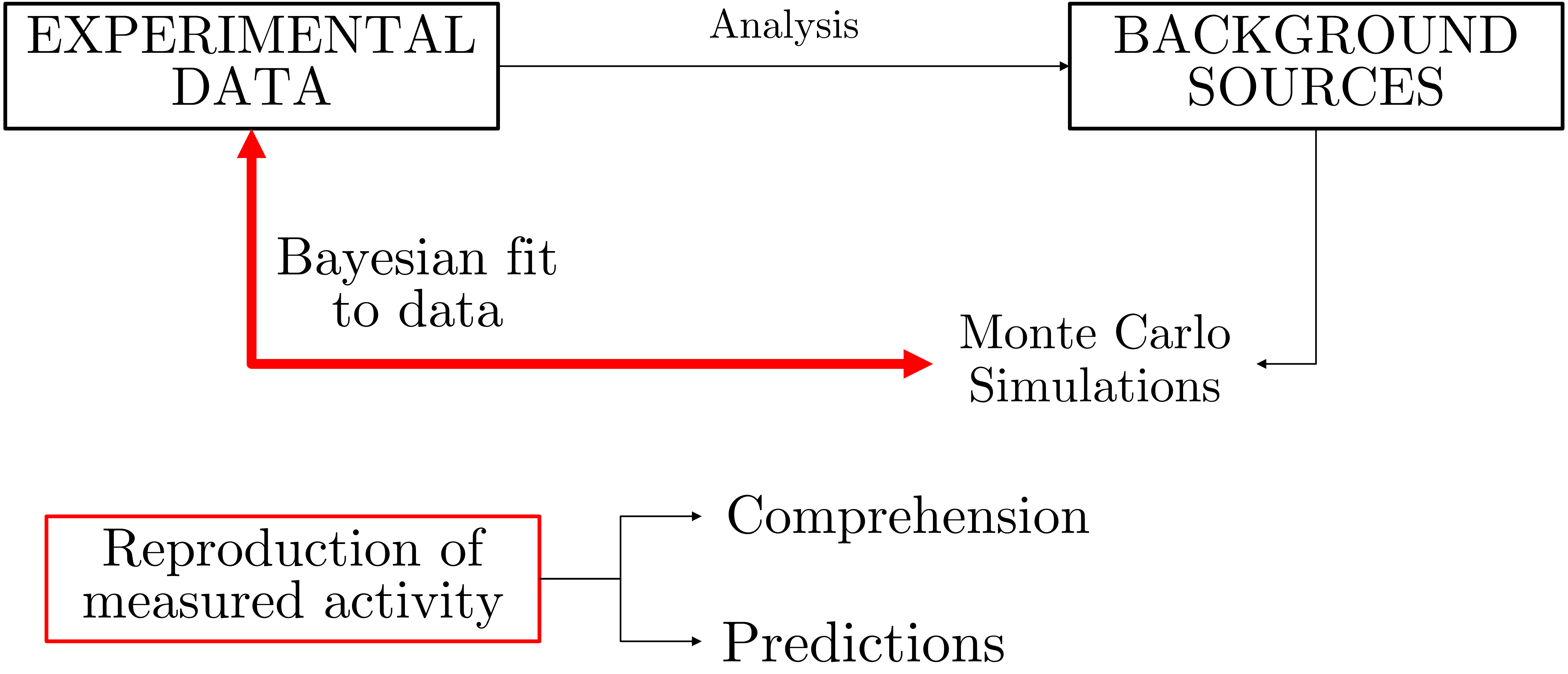
Total cut efficiency:
(86±1)%

No evidence of 0νββ signal

$T^{0\nu}_{1/2} > 3.5 \cdot 10^{24}$ yr @90% C.I.

Background Model

A complete model of the background sources



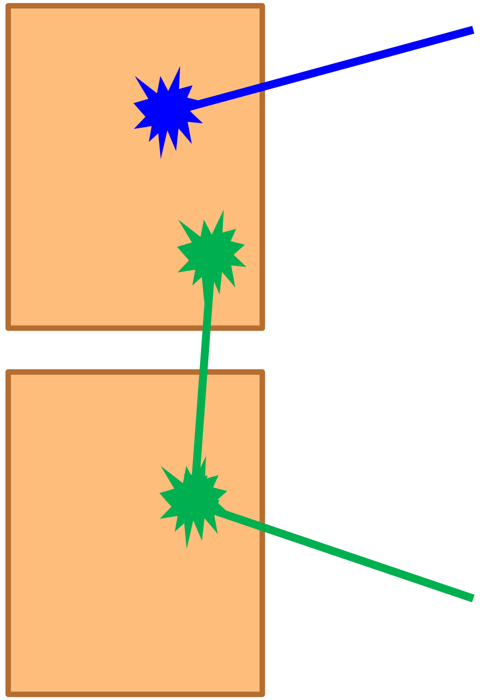
O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

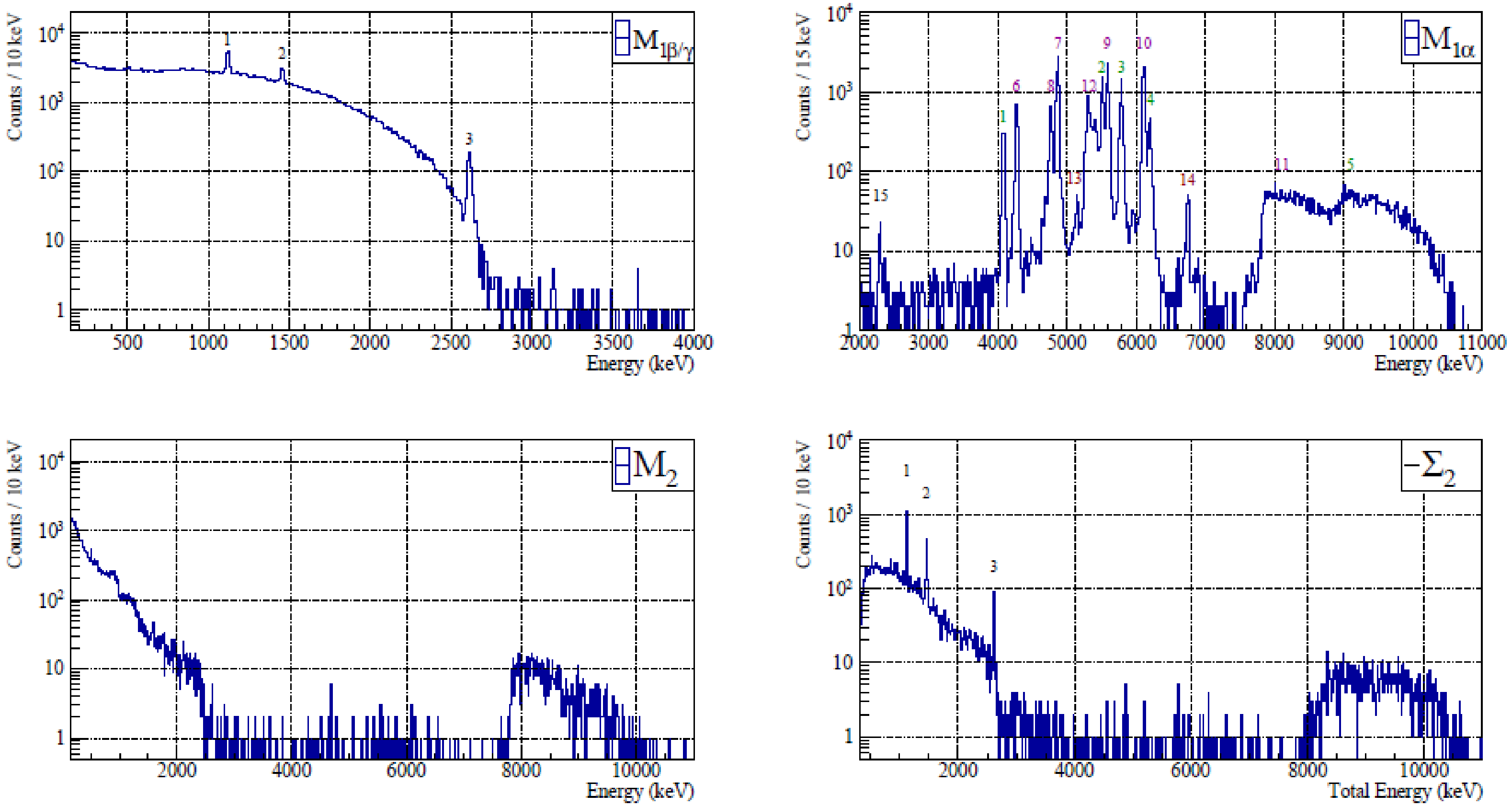
Experimental data for the model

Divided according to multiplicity and particle type →

- M1 α – β/γ
- M2 / M2 sum (Σ2)
- M>3 (to constraint Muons)

Multiplicity (M)
Crystals triggered in 20ms



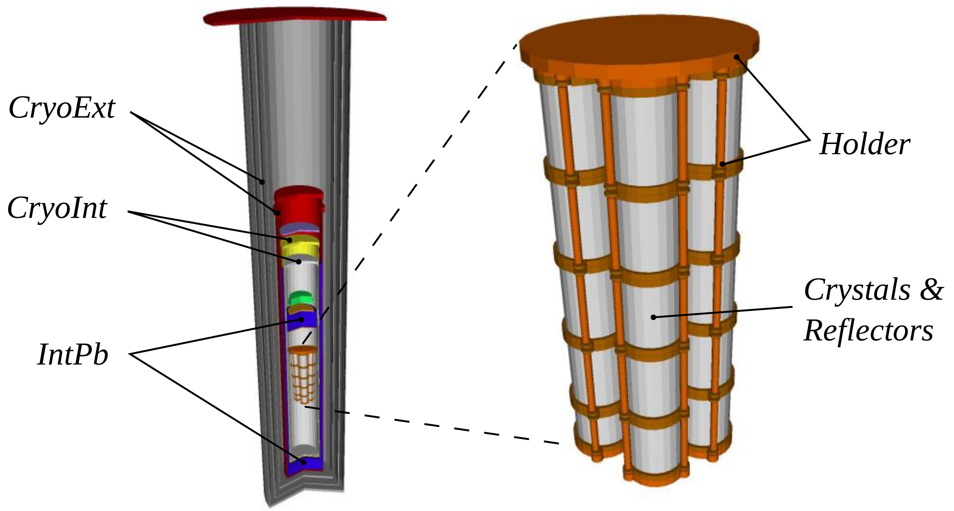


Background source identification

O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

Background sources

- Localization in the detector



- Radiation type

Natural Chains

- Fathers + saecular equilibrium breaking points

Single isotopes

- 40K, 54Mn, 65Zn, 60Co, ...

Muons

- Depth of contamination

Surface

Exponential profile

Monte Carlo simulations

Generation

Detection

O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

Additional informations

O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

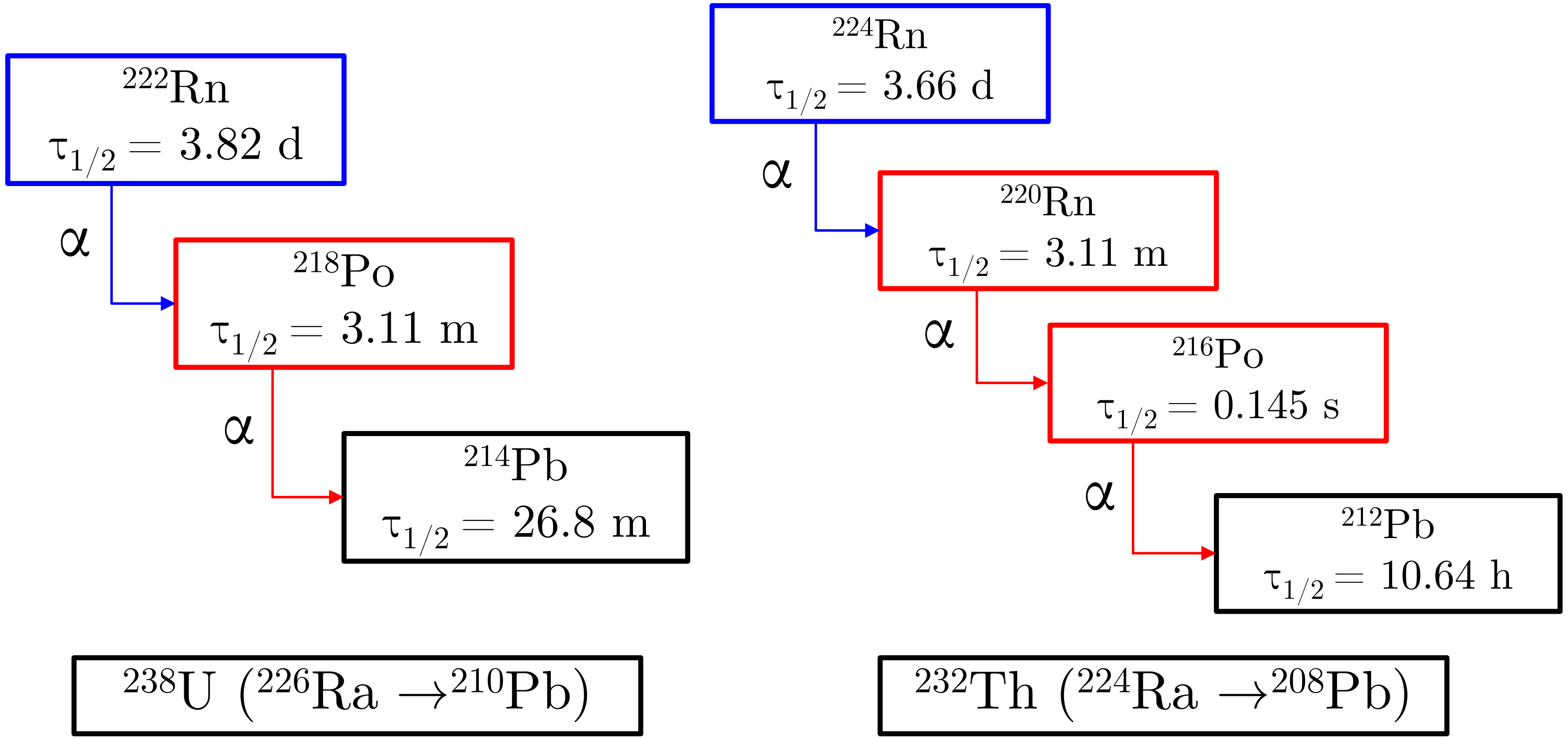
MODEL

- 33 background sources → Linear combination

Coefficients = Activities

PRIORS

- Experimental signatures
  - α/α coincidences
- Previous contamination measurements
  - Reflective foil



$$P(N|N)_{Q_{value}}$$

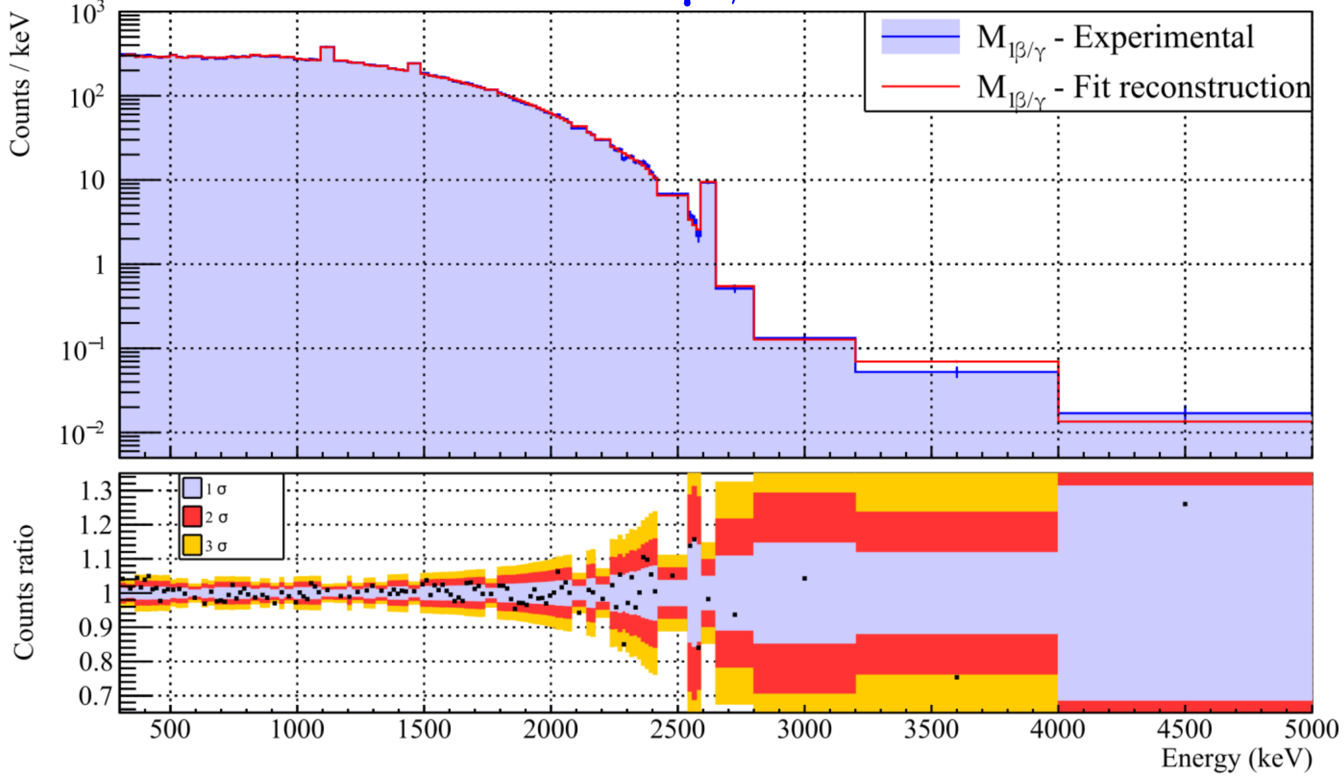
Depends on source localization

Daughter/parent gives a prior on surface vs bulk contaminations

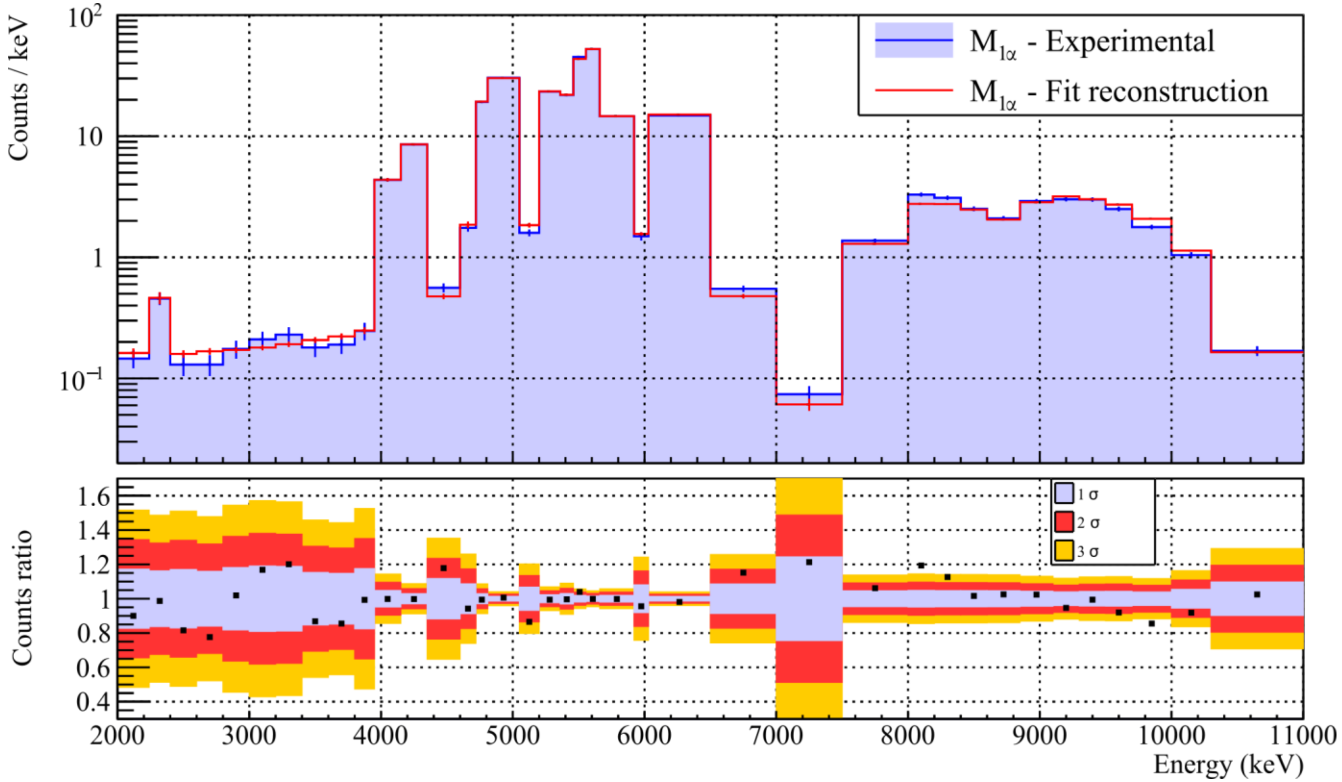
Reconstruction results: M1 Spectra

- Full spectrum reconstruction
- Peaks and continuum are well modelled

M1 β/γ



M1 α



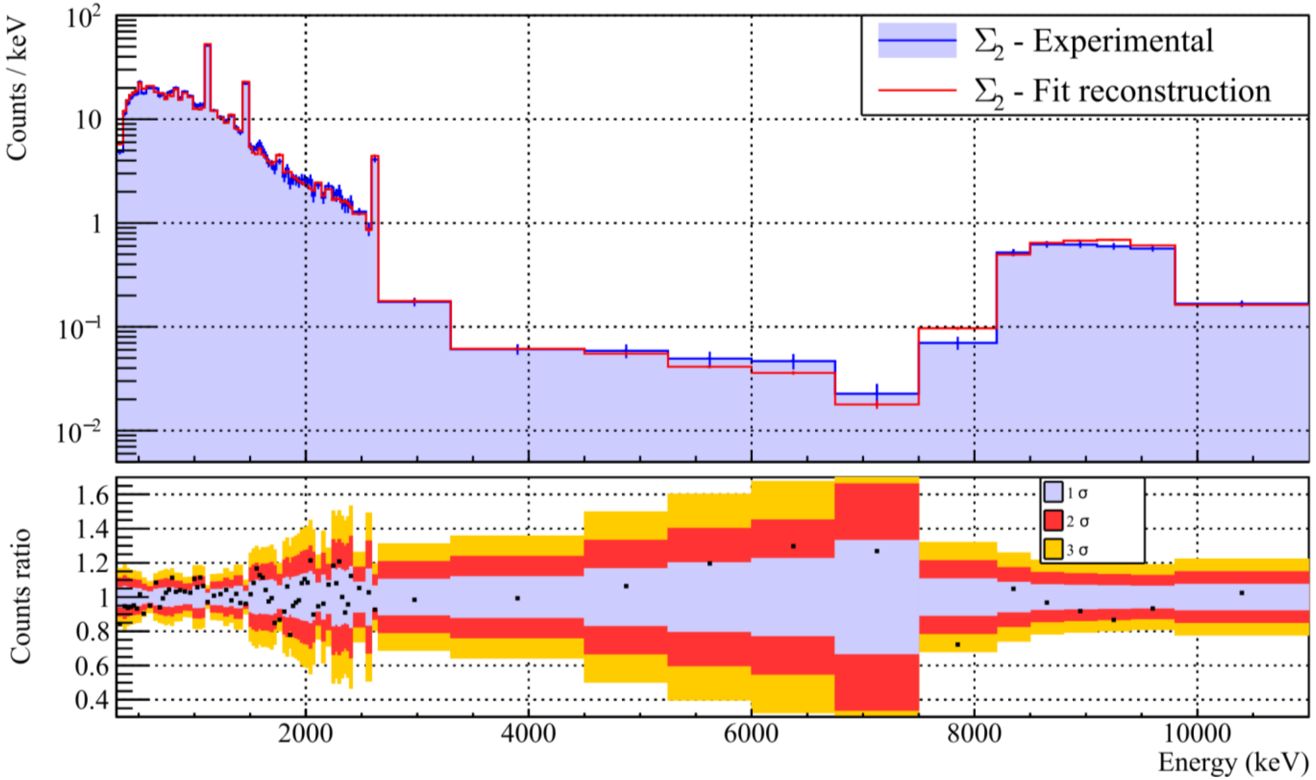
The α – β/γ separation allows to disentangle the different contributions

O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

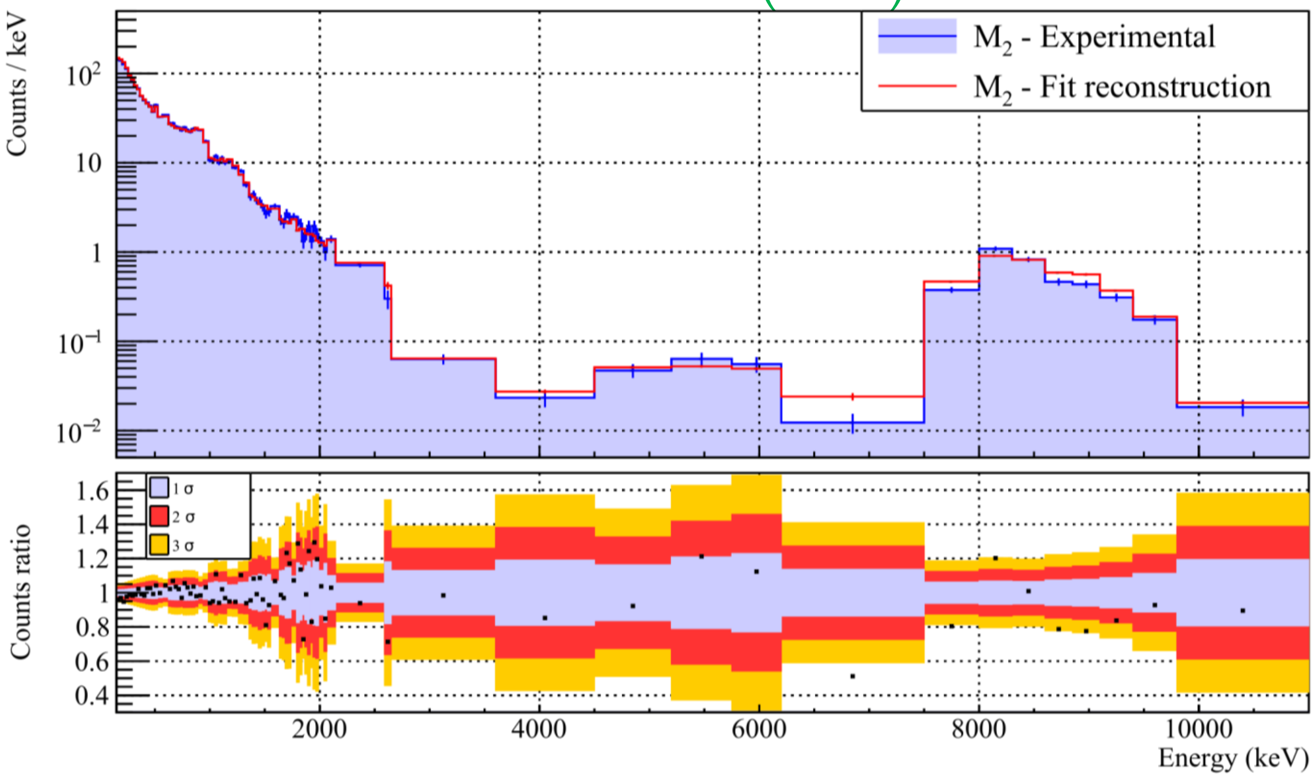
Reconstruction results: M2 spectra

- Both α and β/γ regions are well modelled in peaks and continuum
  - The surface/bulk prior is a key ingredient

M2



M2 sum (Σ2)



Some differences on the Bi-Po pileup

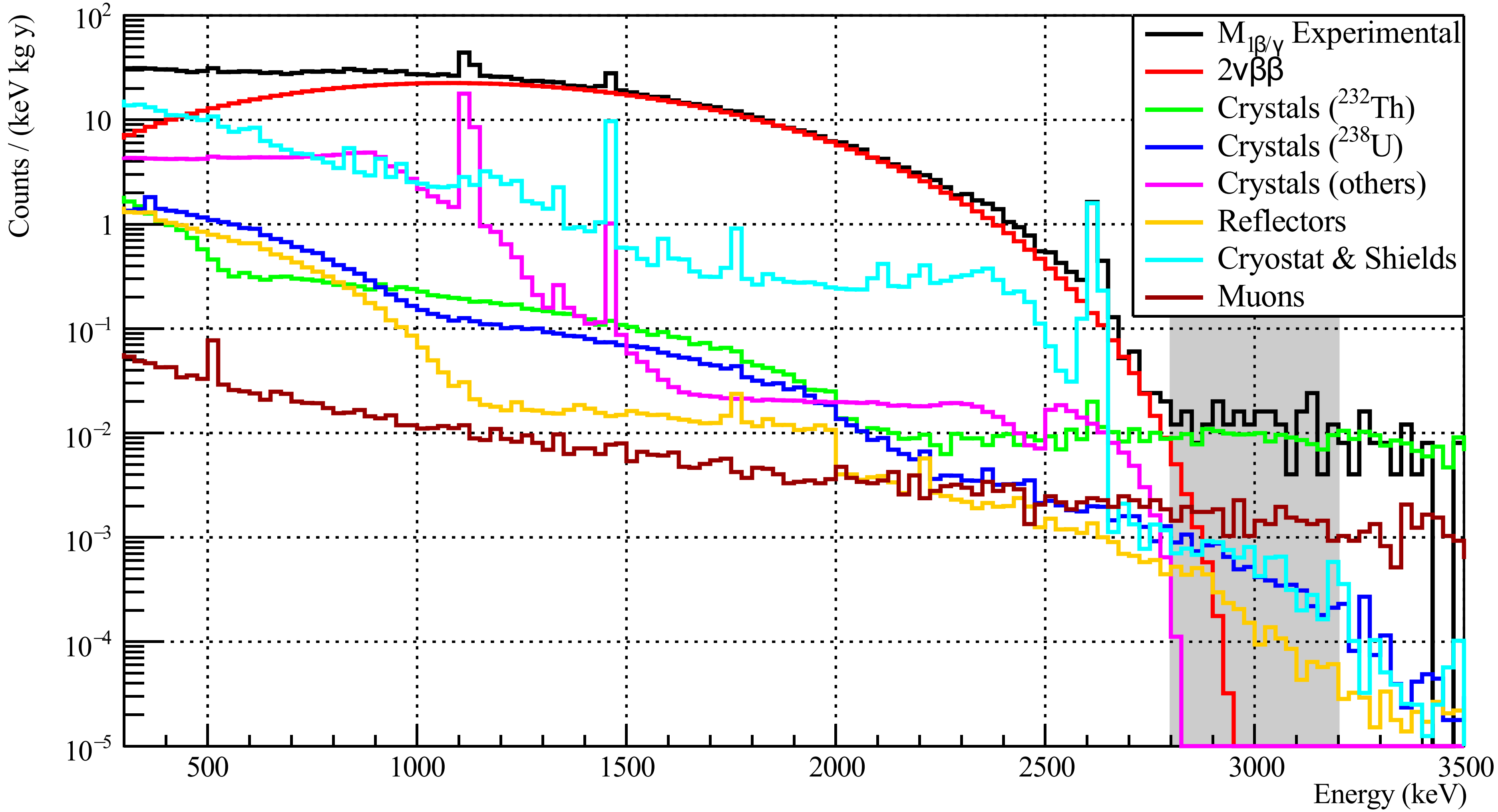
- Imperfect reconstruction of the deposited energy

$^{214}Bi \rightarrow ^{218}Po$

$^{212}Bi \rightarrow ^{212}Po$

O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

Result: Beta/Gamma spectrum



In the ROI

^{232}Th is dominant, because no delayed cut is applied

Delayed coincidences

Muons give 44% of residual background

$2\nu\beta\beta$ is a dominant contribution

Possibility to perform detailed study on this decay

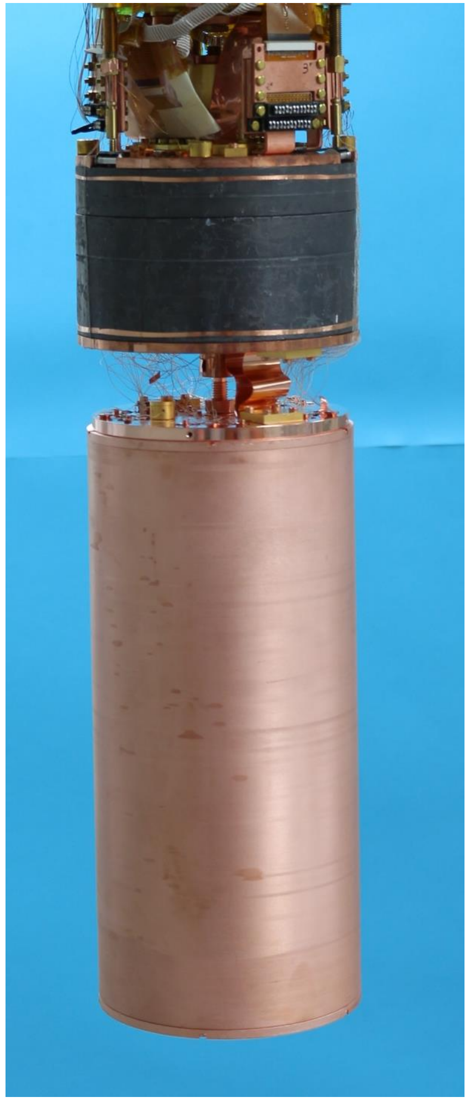
O. Azzolini et al. (CUPID), (2019), arXiv:1904.10397 [nucl-ex].

Phase II upgrade

- μ are the main residual background
  - Installation of μ-veto

No reflective foil
- Sensitivity to M2 α events

New clear Cu Shield
- Thermalization
- Additional shielding



NOW COOLING

CUPID 0: current results and future perspectives

- CUPID-0 is the first large array of enriched scintillating bolometers

- We reached the lowest background level achieved with bolometric experiments:

$$(3.5^{+1}_{-0.9}) \cdot 10^{-3}\ \text{cnts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$$

- A complete background model has been developed
  - Major ROI background (^{208}Tl β events) is reduced with delayed cut
  - Muons give 44% of residual counts

- Phase II upgrade focused on background improvement
  - Muon veto installed
  - No Reflective foil: M2 alpha events direct tagging
  - Additional shielding