RESULTS WITH A $LI_6EU(BO_3)_3$ BOLOMETER AT LNGS

F.ORIO - INFN ROMA

ON BEHALF OF

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REASONS FOR INTEREST

- Eu α decay
- neutron detection
- solar axions
  searches

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Natural Europium

^{151}Eu (47.81%) — *^{153}Eu (52.19%)*

Both are potentially α active

Q_α=1965.0±1.1 keV
$T_{1/2}$ ~ 10^{17}-10^{19} y

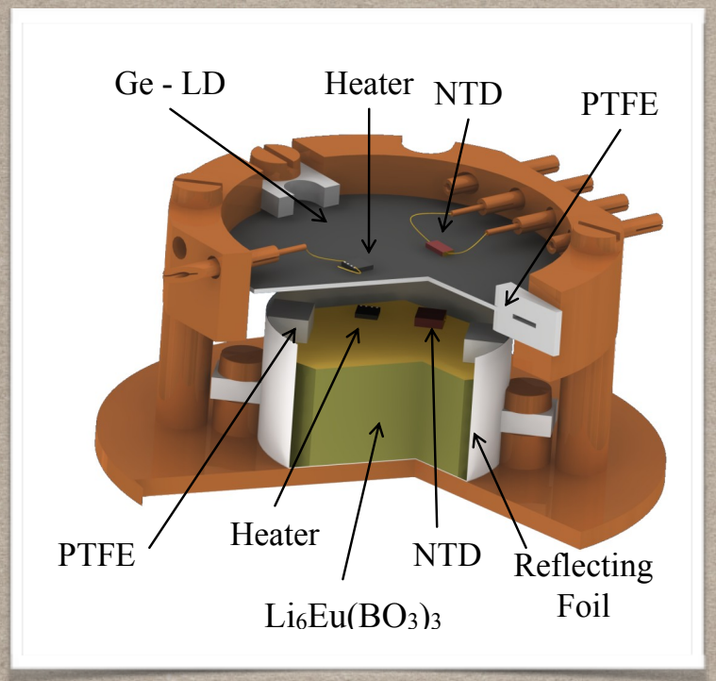
Q_α=272.4±2.0 keV
$T_{1/2}$ ~ 10^{140} y

Not observable

Only results obtained from a CaF_2:Eu

first indication: $T_{1/2} = 5^{+11}_{-3} \times 10^{18}$ y
limit: $T_{1/2} > 1.7 \times 10^{18}$ y
Belli et al., Nucl. Phys. A 789, 15 (2007)

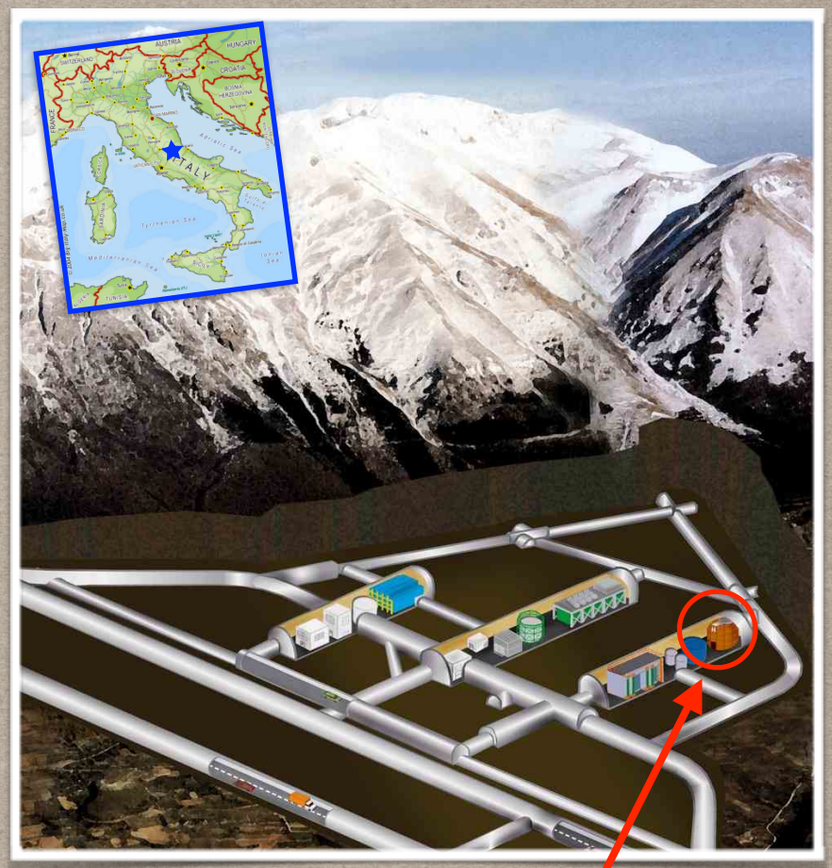
THE DETECTOR



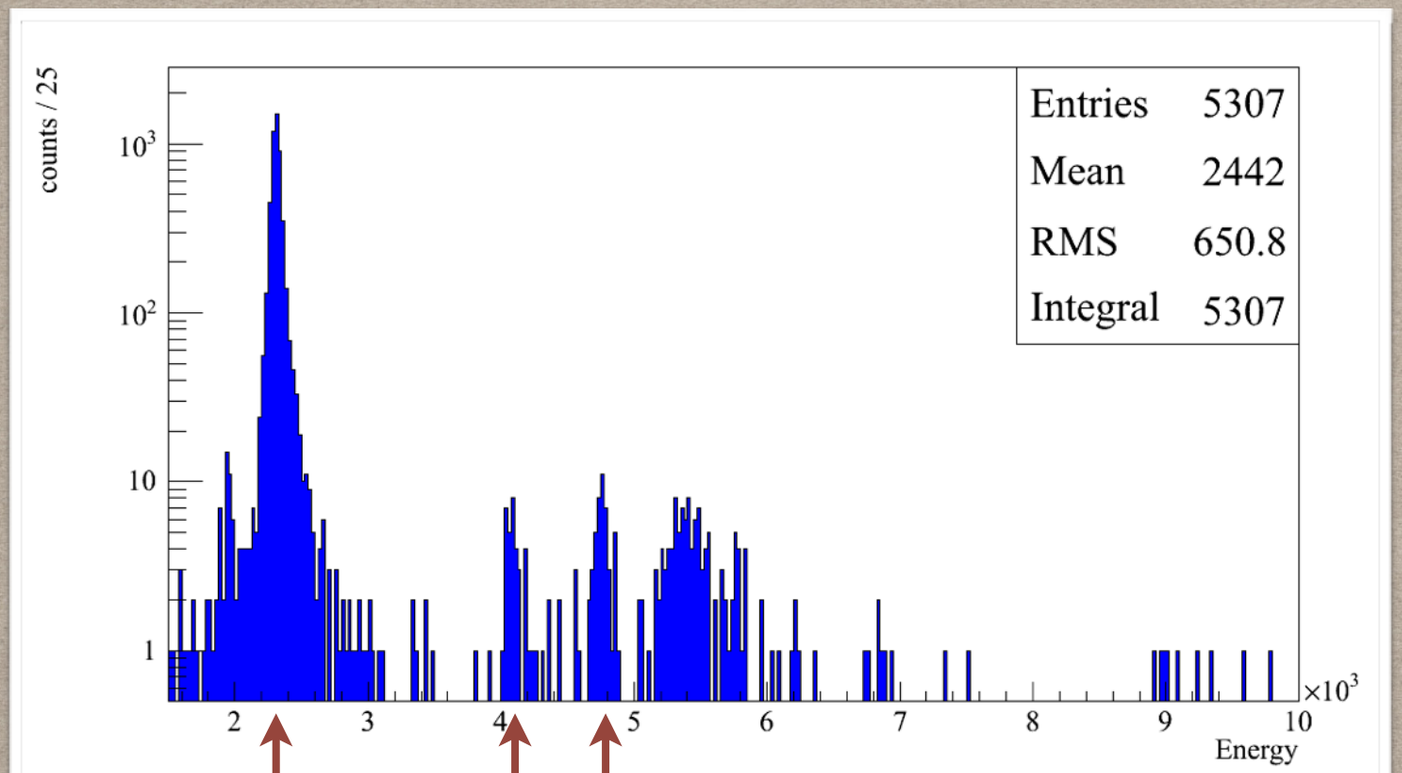
- 6.15 g $Li_6Eu(BO_3)_3$ crystal
  - Growth: Czochralski method in air atmosphere
  - Materials: high purity (99.99%) Li_2CO_3 ,Eu_2O_3 and B_2O_3
  - Shape: irregular
- The crystal was surrounded by a reflecting foil (3M VM2002)
- The crystal was faced to a Ge disk (⌀50 mm×300 μm) used as light detector
- Both were equipped with NTD thermistors, glued via resin epoxy glue

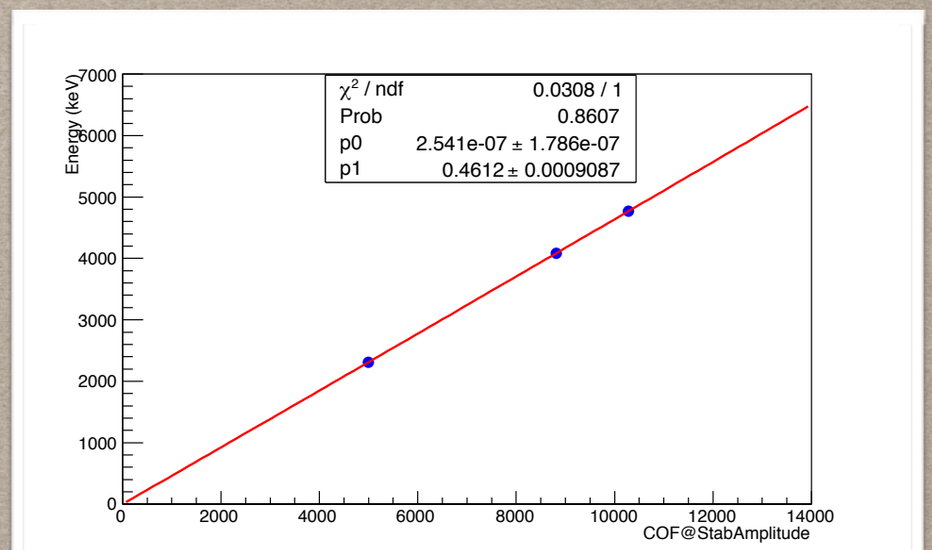
THE DATA TAKING @LNGS

- Operated in Oxford 200 $^{3}He/^{4}He$ dilution refrigerator
- Data collected for a total live time of 462.2 h
- Detector calibrated using internal α lines (crystal contaminations)
- Light detector was calibrated using ^{55}Fe source



ALPHA CALIBRATION





^{230}Th @ 4770 keV

^{232}Th @ 4083 keV

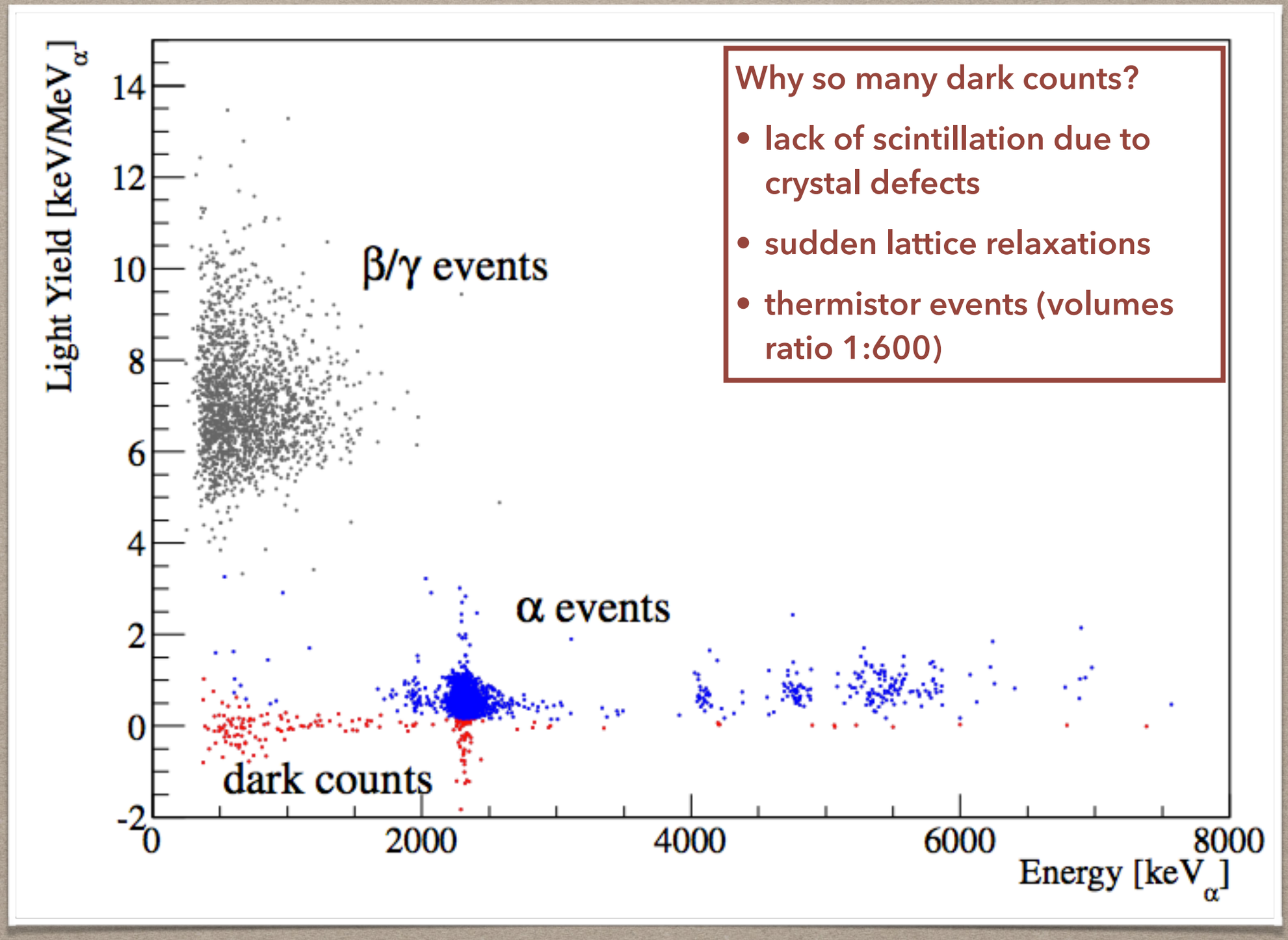
^{147}Sm @ 2310 keV

$E = ax^2 + bx$

a: $(2.5 \pm 1.8) \times 10^{-7}$

b: 0.4612 ± 0.0009

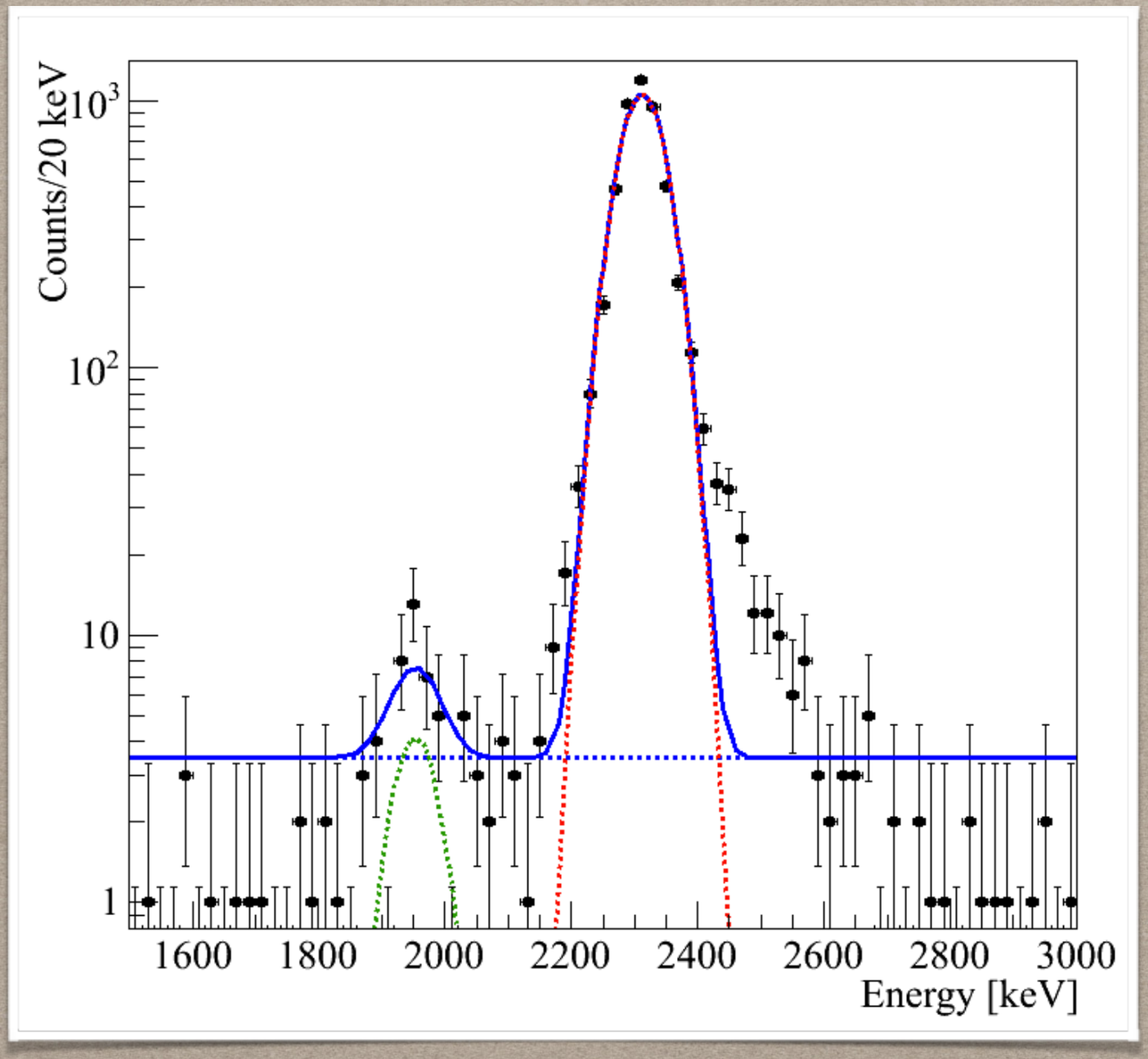
LIGHT YIELD VS HEAT



Why so many dark counts?

- lack of scintillation due to crystal defects
- sudden lattice relaxations
- thermistor events (volumes ratio 1:600)

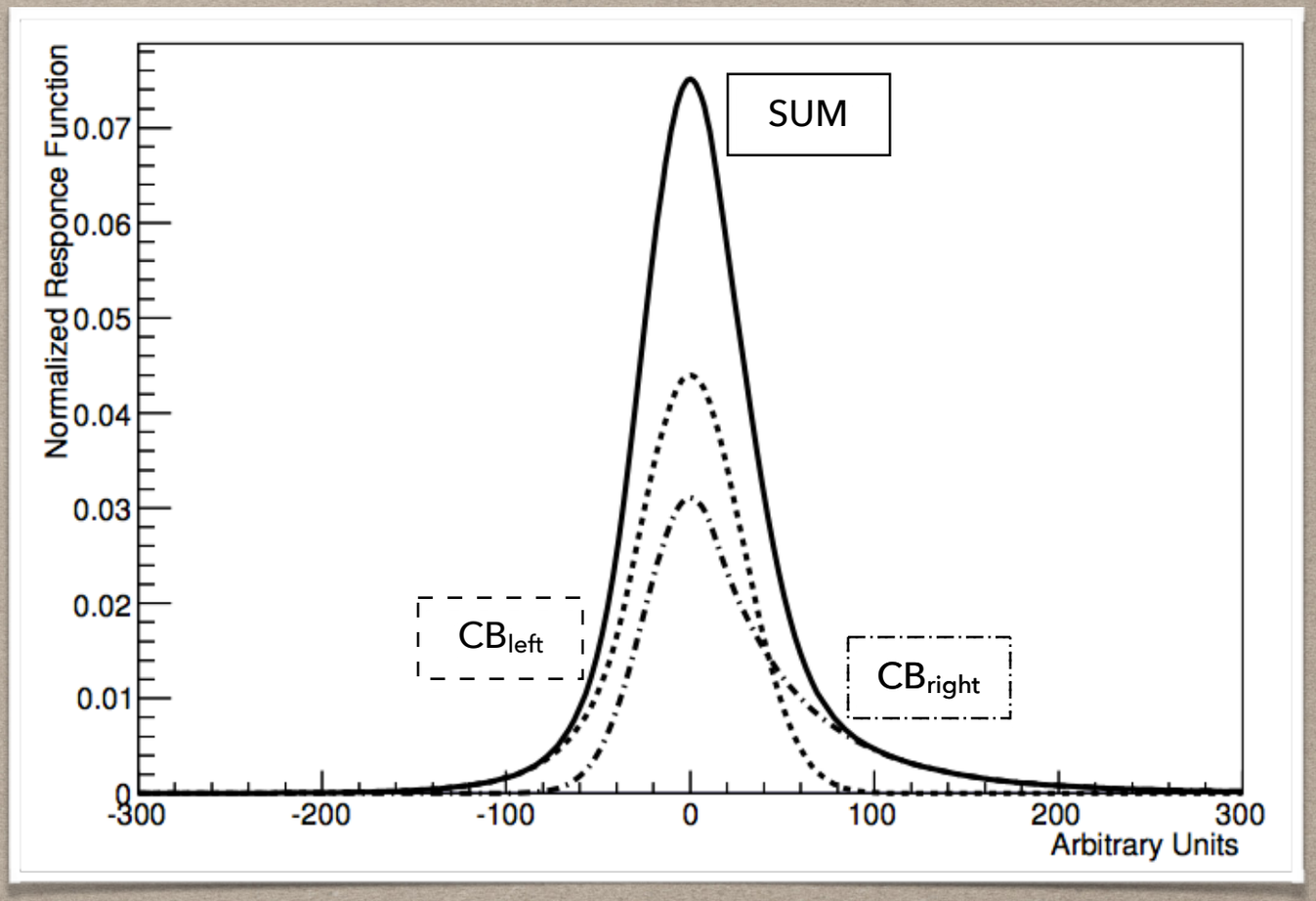
A CLOSER LOOK TO ^{147}SM PEAK



- There is a clear peak in proximity of the ^{151}Eu Q-value
- Gaussian shape does not fit the spectrum

NON-GAUSSIANITY

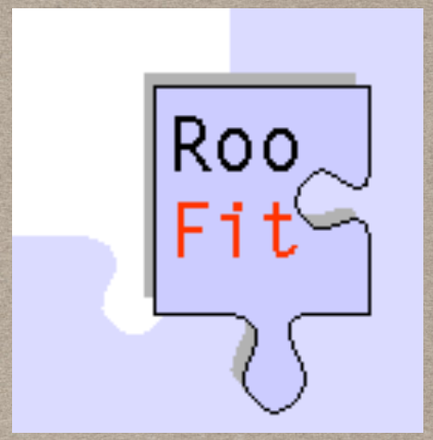
- There is no clear physics motivation but the detector response function is not a gaussian.
  - Possible explanations? Position effects, crystal inhomogeneity, surface events...????



- We use as detector response function a sum of two crystal balls, evaluating their parameters on the Sm peak

$$\mathrm{RF}(Q,E) = N \cdot [CB_{left}(Q,E) + \delta \cdot CB_{right}(Q,E)]$$

THE FIT PROCEDURE



Using RooFit toolkit we performed a fit:

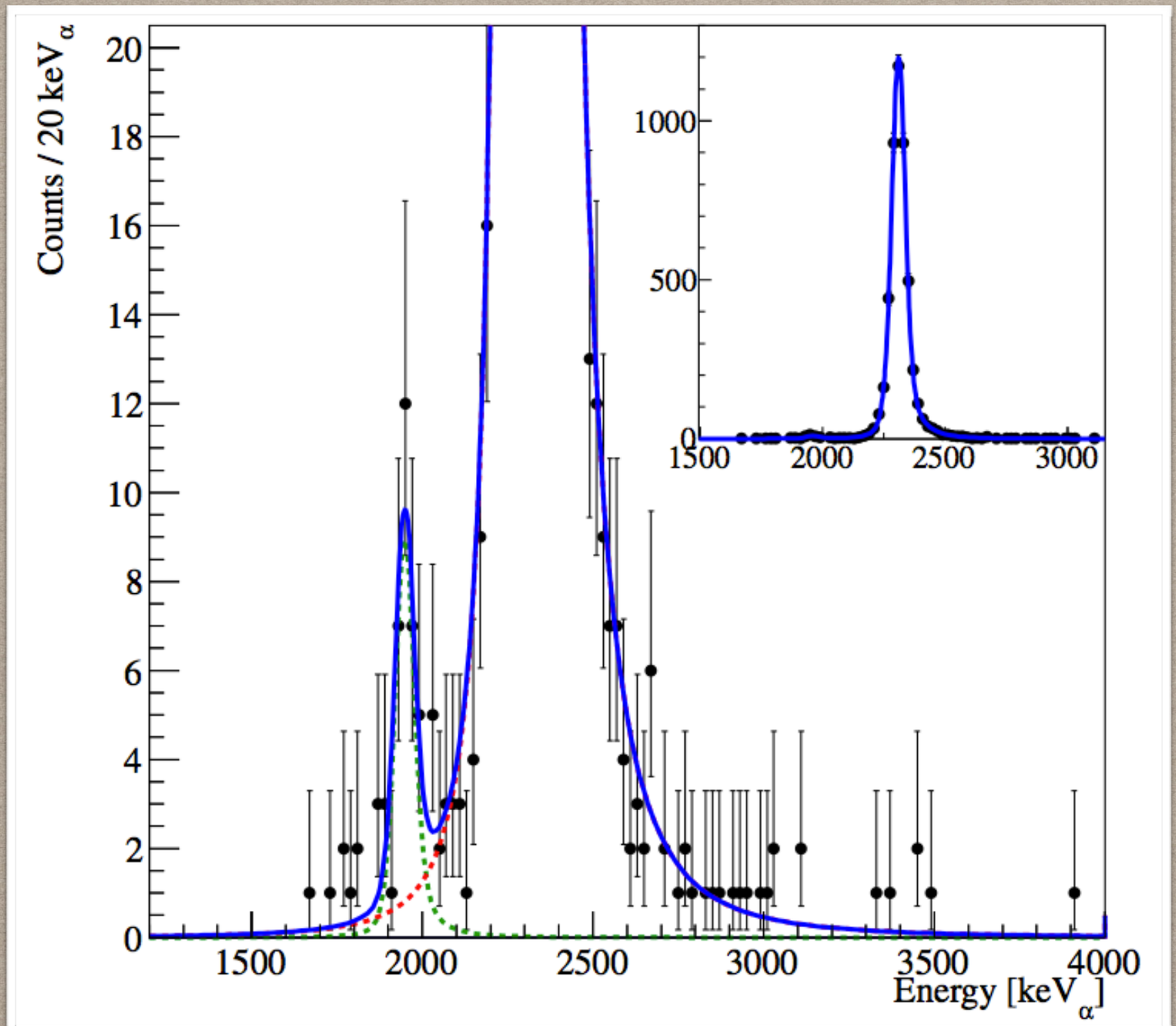
- maximum likelihood
- unbinned
- extended
- simultaneous (cut accepted and cut rejected, to evaluate cut efficiency ε)

$$\mathrm{FF(E)} = \mathrm{N_{Sm}} \cdot \mathrm{RF}(\mathrm{Q_{Sm}}, \mathrm{E}) + \mathrm{N_{Eu}} \cdot \mathrm{RF}(\mathrm{Q_{Eu}}, \mathrm{E})$$

Gaussian constrain with known value

Free parameters

THE RESULTING FIT



N_{Eu}: 37.6 ± 7.5 counts

Q_{Eu}: 1948.9±6.9 keV

FWHM: 65±7 keV

ε_{cuts}: (96.8±0.2)%

N_{Eu} is already corrected for ε_{cuts}

DISCOVERY SIGNIFICANCE

$$q_0 = -2 \cdot \ln \frac{\mathrm{L}(\mathrm{data} \mid \mathrm{bkg}(\hat{\theta}_0))}{\mathrm{L}(\mathrm{data} \mid \hat{\mu} \cdot \mathrm{signal}(\hat{\theta}) + \mathrm{bkg}(\hat{\theta}))}$$

http://arxiv.org/pdf/1202.1488.pdf (Sec. 3.2)

- $\hat{\theta}_0$ and $\hat{\theta}$ are the fit parameter values that maximize the likelihood, in the background-only hypothesis and in the background plus signal hypothesis, respectively.
- The excess of events that we observed gives $q_0 = 54$, corresponding to a 7.4 σ statistical significance.
- The probability that the measured excess of events is produced by a background fluctuation is of the order of 10^{-14}.

^{151}EU HALF-LIFE

Systematics
- Choice of fit interval
- Choice of fit function

- Number of ^{151}Eu atoms: (4.76±0.07)×10^{21} [from HP-ICP-MS measurement]
- ^{151}Eu α decay containment efficiency: 99.98% [from MC simulations]
- Observed number of decays: 37.6±7.5 counts
- Live time of the measurement: 462.2 h

$$T_{1/2} = (4.62 \pm 0.95(stat.) \pm 0.68(syst.)) \times 10^{18}\ y$$

Compatible with theoretical estimations and previous experimental results

CONCLUSIONS

- We operated a 6.15 g $Li_6Eu(BO_3)_3$ crystal as a bolometer, facing it to a bolometric Ge light detector inside a cryogenic facility at LNGS for a total live time of 462.2 hours.

- We report the discovery of ^{151}Eu α decay to ground state of ^{147}Pm with $T_{1/2} = (4.62 \pm 0.95(\text{stat.}) \pm 0.68(\text{syst.})) \times 10^{18}$ y with a 7.4 σ statistical significance.

- We evaluated its Q-value as 1948.9±6.9 keV.

For further details, please see
http://arxiv.org/pdf/1311.2834v2.pdf

BACKUP

CRYSTAL BALL FUNCTION

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

$$B = \frac{n}{|\alpha|} - |\alpha|,$$

$$N = \frac{1}{\sigma(C+D)}$$

$$C = \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right)$$

$$D = \sqrt{\frac{\pi}{2}}\left(1 + \operatorname{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right)$$