Two-neutrino double beta decay in CUORICINO

Laura Kogler for the CUORICINO collaboration
UC Berkeley/LBNL

Japan-US seminar on "Double Beta Decay and Neutrinos"

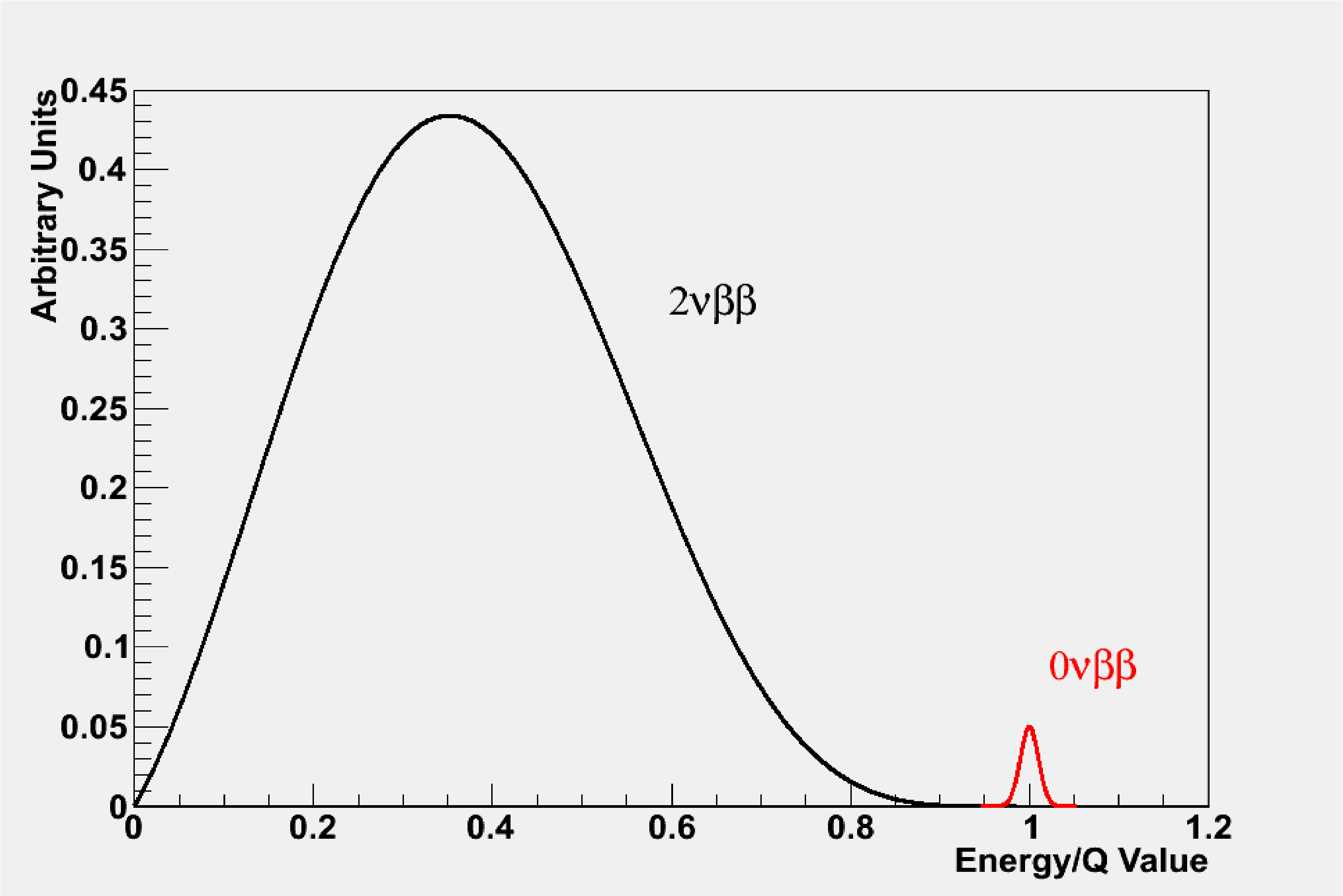
12. October 2009

Outline

- Overview of $2\nu\beta\beta$ measurements
- Prior measurements in ^{130}Te
- CUORICINO experimental setup
- Expected sensitivity and results
- Conclusion

Motivation for 2νββ Measurement

- 2νββ is an unavoidable background to 0νββ



Motivation for $2\nu\beta\beta$ Measurement

- $2\nu\beta\beta$ is an unaviodable background to $0\nu\beta\beta$
- $2\nu\beta\beta$ measurements can be used to check or improve matrix element calculations for $0\nu\beta\beta$
  - Matrix elements are one of the major uncertainties associated with $0\nu\beta\beta$
  - $2\nu\beta\beta$ is one of the few experimentally observable processes that provides input/verification to models
  - $2\nu\beta\beta$ is commonly used to set the particle-particle interaction strength in QRPA models
  - However, $2\nu\beta\beta$ and $0\nu\beta\beta$ matrix elements are NOT identical

$2\nu\beta\beta$ Decay Rate and Spectrum

- The decay rate for $2\nu\beta\beta$ is given by:

$$\frac{1}{T_{1/2}^{2\nu}} = G^{2\nu}(E_0, Z)\left| M_{GT}^{2\nu} - \frac{g_V^2}{g_A^2} M_F^{2\nu} \right|^2$$

where $G^{2\nu}$ is the phase space factor, M_{GT} and M_F are the Gamow-Teller and Fermi matrix elements, and g_V and g_A are the vector and axial-vector coupling constants.

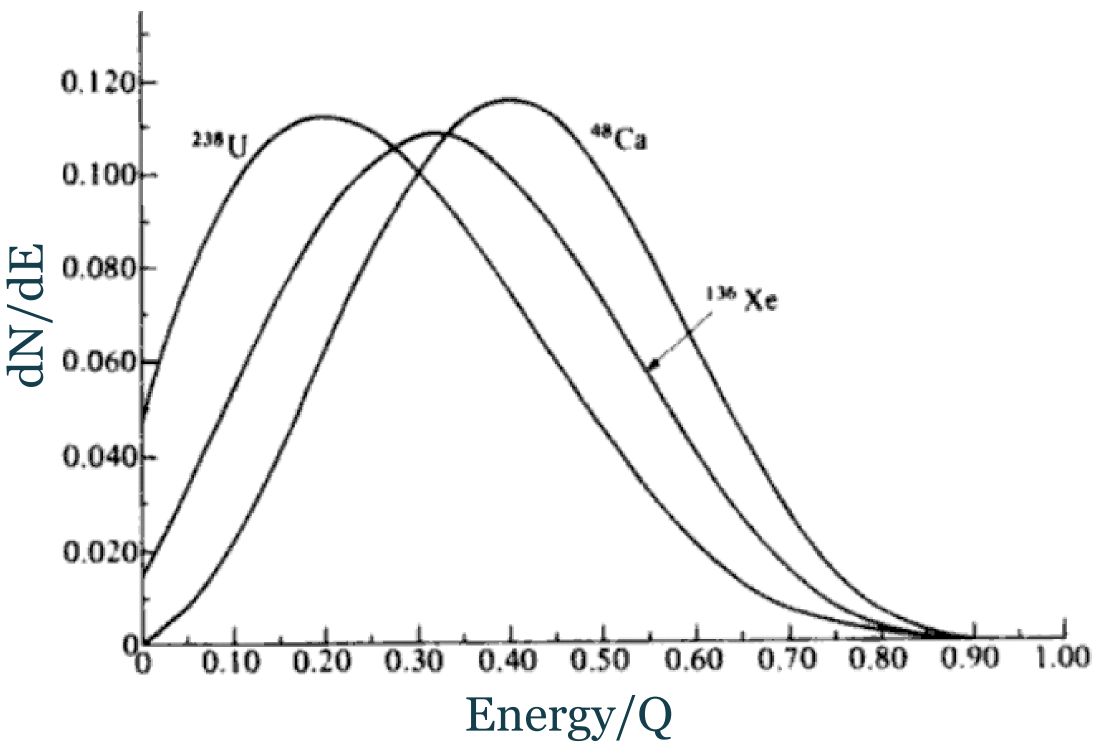
- The form of the decay rate is similar to the neutrinoless expression, but is independent of $<m_{\beta\beta}>$, and with different M_{GT} , M_F and $G^{2\nu}$
- Using an approximation for the Fermi factor (Primakoff & Rosen 1959), the energy spectrum is given by:

$$\frac{dN}{dE} \sim E(Q-E)^5 \left(1 + 2E + \frac{4E^2}{3} + \frac{E^3}{3} + \frac{E^4}{30}\right)$$

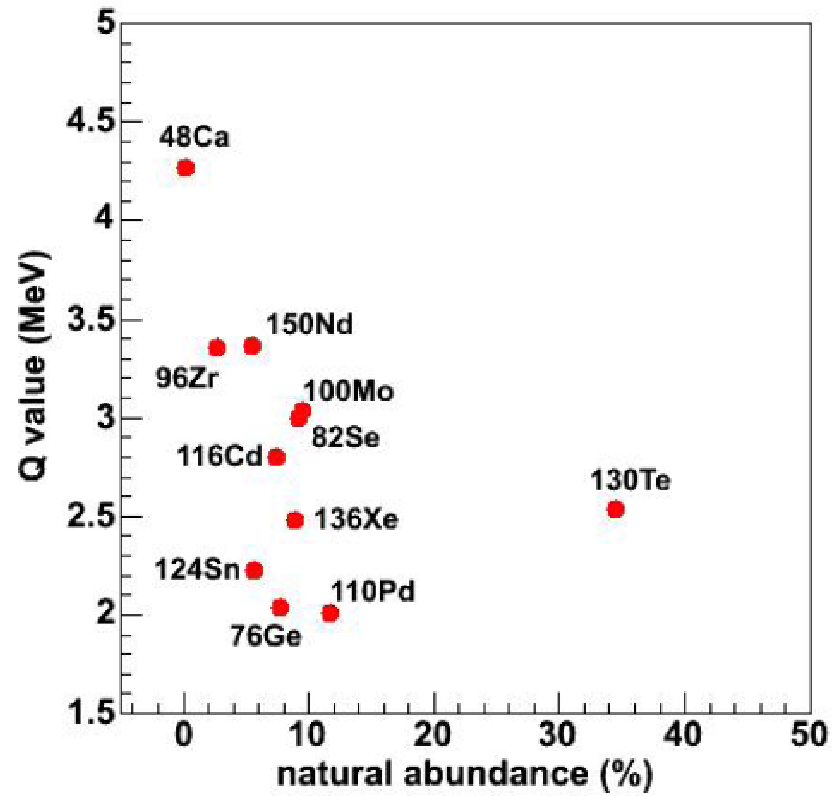
Challenges of 2νββ Measurement

- Broad spectrum overlaps natural γ and β radiation

Summed electron energy spectrum [1]



Double Beta Decay Q-Values



[1] Boehm & Vogel, *Physics of Massive Neutrinos*, 1992

Challenges of 2νββ Measurement

- Broad spectrum overlaps natural γ and β radiation
- Background reduction strategy is necessary
  - Full Monte Carlo simulation of backgrounds
  - Other background subtraction method…

Challenges of 2νββ Measurement

- Broad spectrum overlaps natural γ and β radiation
- Background reduction strategy is necessary
  - Full Monte Carlo simulation of backgrounds
  - Other background subtraction method…
- CUORICINO strategy:
  - Use crystals with different enrichment as “blanks” for background subtraction

Prior 2νββ Measurements in ^{130}Te

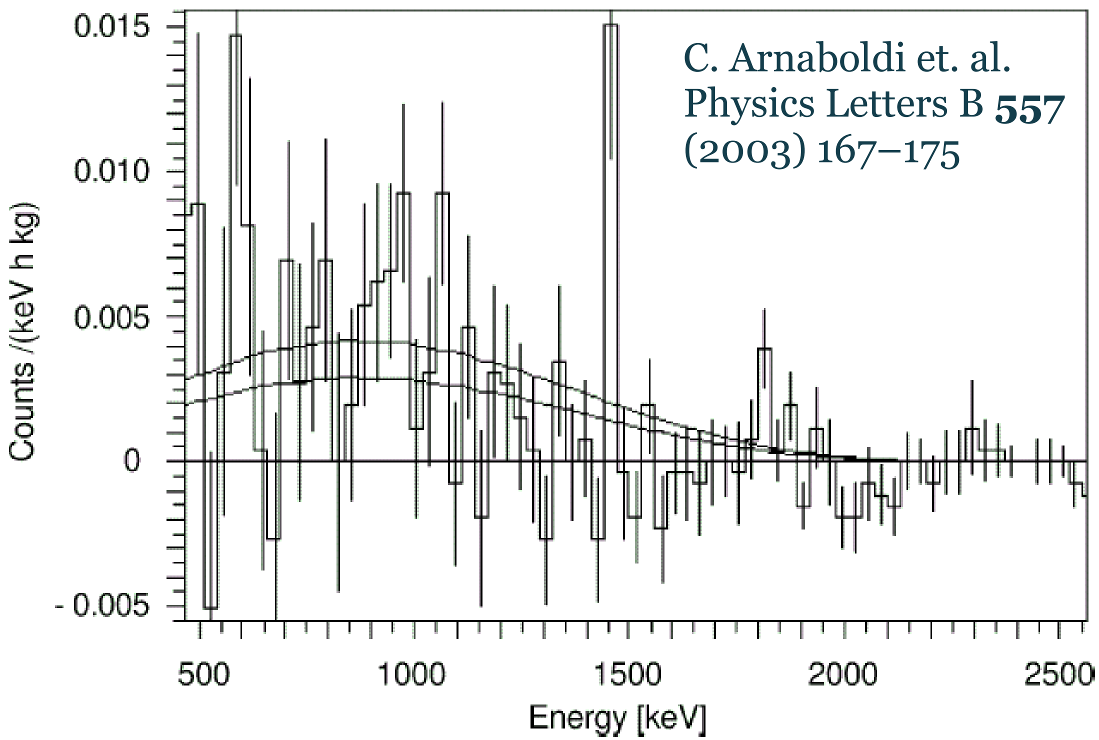
- Geochemical experiments
- MiBeta
- NEMO3

- Technique is based on measuring isotopic abundances of daughter element in a sample of parent ore
- Parent ore is dated based on geologic environment or by other radiochemical dating methods (K-Ar, U-He, etc.)
- Measurements done on various samples since 1949 have yielded half-lives spanning almost 1 order of magnitude for ββ decay of ^{130}Te

$$T_{1/2} = 3 \cdot 10^{20} - 2.6 \cdot 10^{21}\ y$$

Prior 2νββ Measurements in ^{130}Te

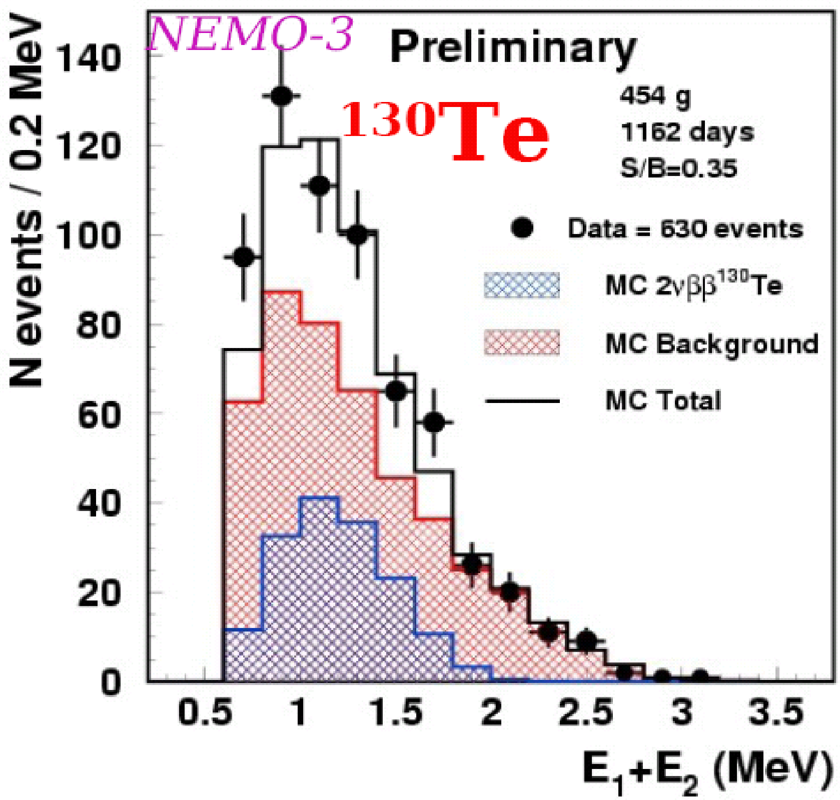
- Geochemical experiments
- MiBeta
  - Used same enriched crystals as Cuoricino
  - Large systematic error due to non-uniform background in crystals (external source)
- NEMO3



$$T_{1/2} = [6.1 \pm 1.4(\text{stat}) +2.9, -3.5\ (\text{syst})] \cdot 10^{20}\ \text{y}$$

Prior 2νββ Measurements in ^{130}Te

- Geochemical experiments
- MiBeta
- NEMO3
  - Source inserted as thin foil.
  - Detector has both tracking and calorimeter components.
  - Results from June 2009

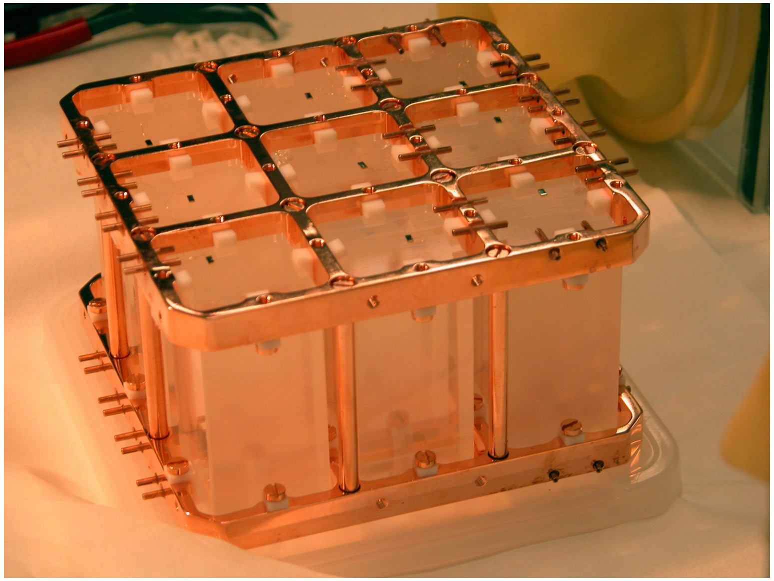


V. Tretyak, MEDEX conference, June 2009

$$T_{1/2} = [6.9 \pm 0.9(\text{stat}) \pm 1.0(\text{syst})] \cdot 10^{20}\ \text{y}$$

Enriched Crystals in Cuoricino

- 2 crystals enriched to 75.0% ^{130}Te
- 2 crystals enriched to 82.3% ^{128}Te
- Enriched crystals are 3×3×6 cm^3 and 330 g.
- Total mass of ^{130}Te ~350 g

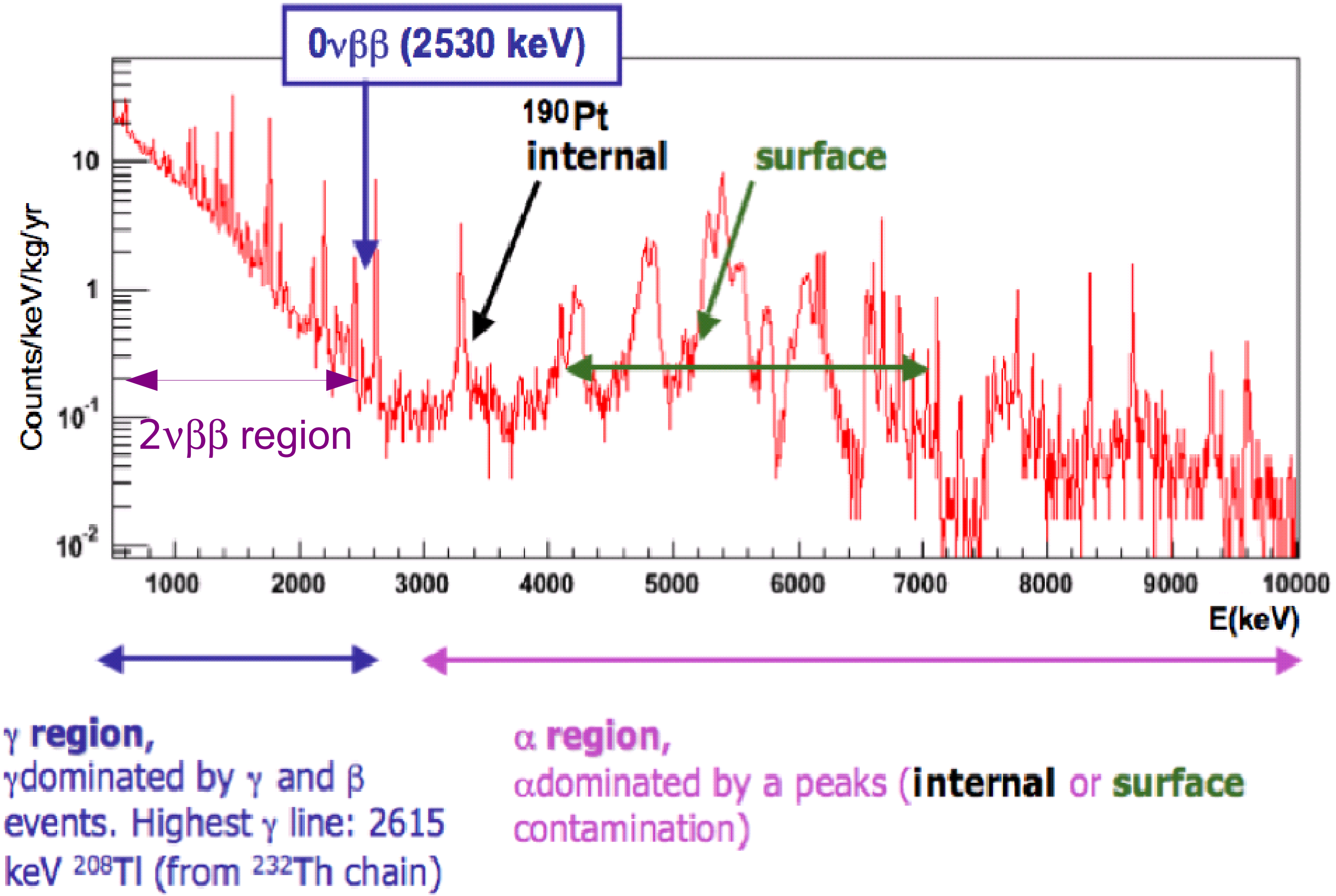


Nat.	128-A	Nat.
130-A	Nat.	130-B
Nat.	128-B	Nat.

Cuoricino Floor 12

Cuoricino Backgrounds

- Bulk and surface contaminations
- Cosmogenic activation of materials
- Cosmic ray muons
- Environmental and spallation neutrons
- Gamma rays from LNGS environment

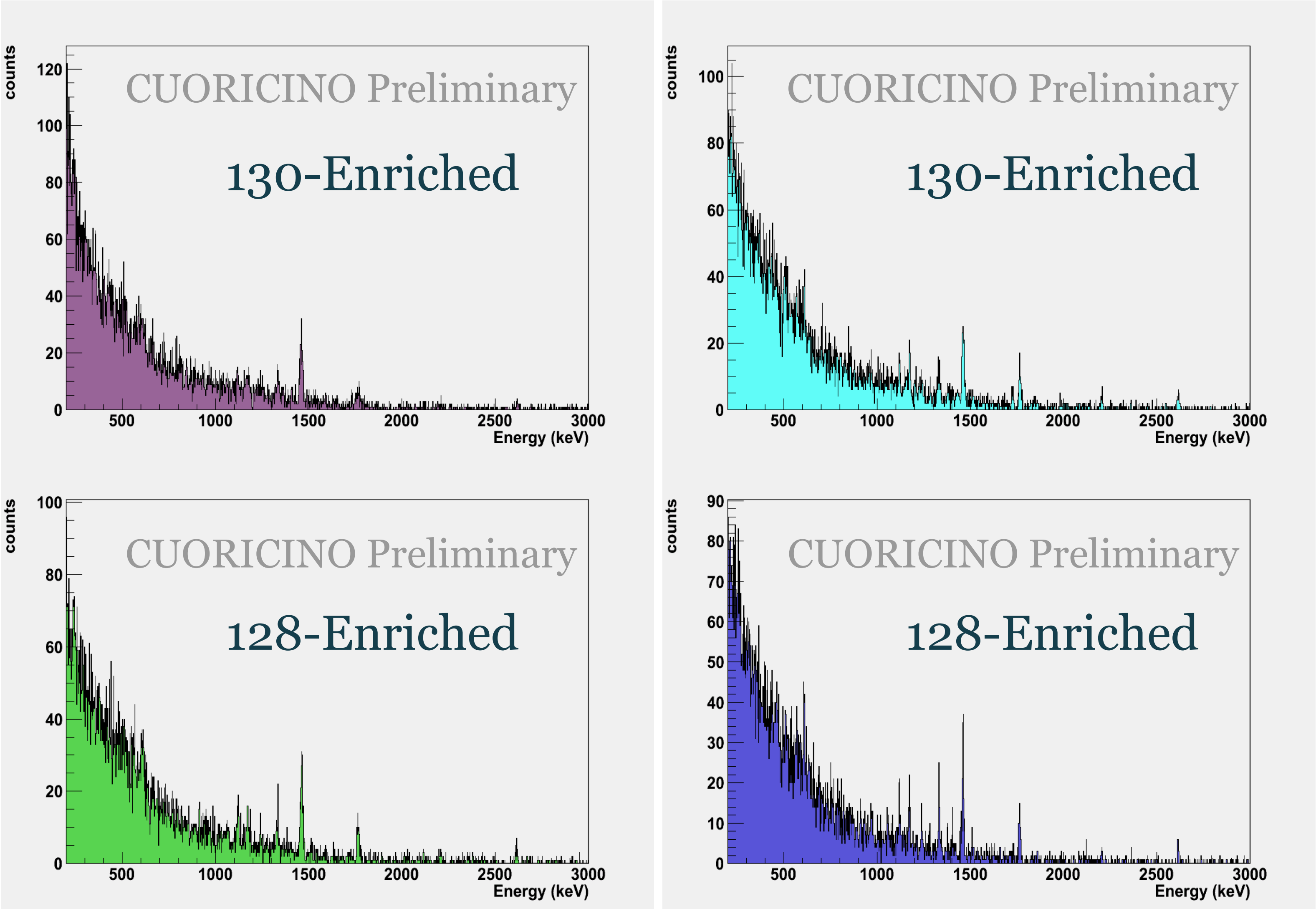


Cuts to reduce backgrounds

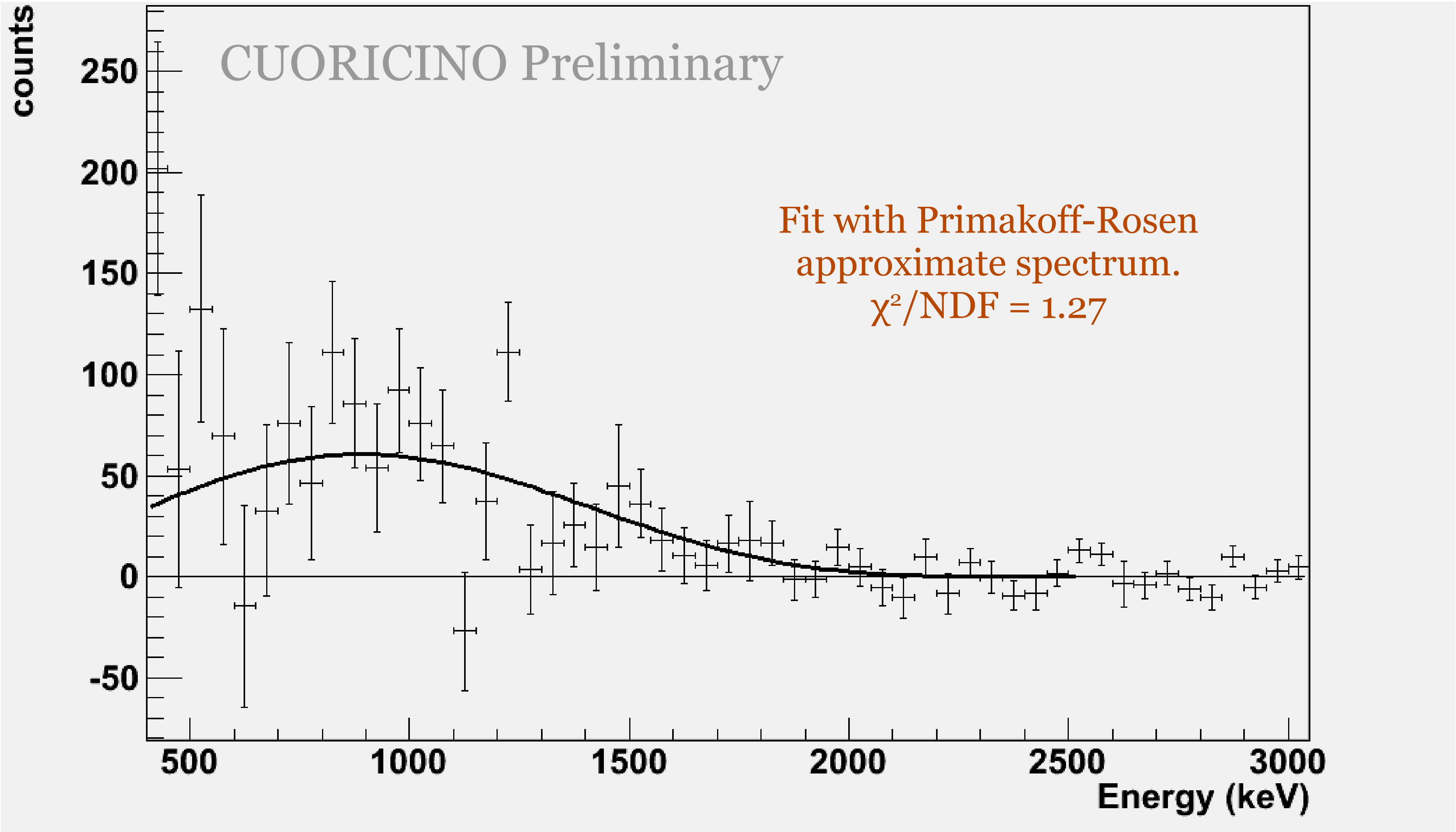
Cut type	Approx. signal loss
• Anti-coincidence	
– Cosmic ray induced showers	2% intrinsic 0.6% accidentals
– Surface contaminations	
• Pulse shape	
– Low energy noise	2%
– Pileup events or deformed pulses	
	~ 95 % overall efficiency

Single Crystal Spectra

Entire Cuoricino dataset, excluding high radon runs



Background Subtracted Spectrum



Expected Sensitivity

- Consider only E > 500 keV
- N_{tot} ~ 27000 events in the enriched crystals
- N_{sig} ~1300 events after background subtraction
- A toy Monte-Carlo has been used to evaluate the statistical uncertainty given N_{tot}. The result is σ_{sig}~167, which corresponds to a fractional error on the decay rate of ~13%, similar to other measurements.
- Preliminary analysis conducted with live time blinded, so exact event rate is unknown.

Expected Systematics

- The validity of the background subtraction is expected to be the dominant uncertainty.
- Background sources can be identified from peaks in residual spectrum; their location can be inferred from:
  - Peak shape
  - Coincidence spectrum between neighboring crystals
  - Relative strength of peaks in different crystals
- Backgrounds will be modeled with a detailed Monte Carlo simulation.
- Other systematics (error on efficiencies, energy calibration, etc.) are expected to be small compared to uncertainty in background model.

Conclusion

- A measurement of $2\nu\beta\beta$ of ^{130}Te in CUORICINO appears feasible and would provide a check on recent measurements
- Improvements in measuring this lifetime could inform matrix element calculations which would benefit $0\nu\beta\beta$ searches for neutrino mass.
- This measurement will require careful study of CUORICINO backgrounds.

CUORICINO Collaboration

M. Barucci, L. Risegari and G. Ventura
Dipartimento di Fisica dell' Università di Firenze e Sezione di Firenze dell' INFN, Firenze I-50125, Italy

L. Canonica[1,2], S. Di Domizio[1,2], E. Guardincerri[2,3] and M. Pallavicini[1,2]
1 Dipartimento di Fisica dell'Università di Genova e
2 Sezione di Genova dell'INFN, Genova I-16146, Italy
3 Laboratori Nazionali del Gran Sasso, I-67010, Assergi (L'Aquila), Italy

M. Balata, C. Bucci, P. Gorla, S. Nisi and C. Tomei
Laboratori Nazionali del Gran Sasso, I-67010, Assergi (L'Aquila), Italy

E. Andreotti1,2, L. Foggetta1,2, A. Giuliani1,2, C. Nones1,2, C. Rusconi1,2 and C. Salvioni1,2
1 Dipartimento di Fisica e Matematica dell'Università dell'Insubria , Como I-22100, Italy
2 Sezione di Milano Bicocca dell' INFN, Milano I-20126, Italy

V. Palmieri
Laboratori Nazionali di Legnaro, Via Romea 4, I-35020 Legnaro (Padova)

C.Arnaboldi[1,2], C.Brofferio[1,2], S.Capelli[1,2], L.Carbone[2], M.Carrettoni[1,2], M.Clemenza[1,2], O.Cremonesi[2], E.Ferri[1,2], E.Fiorini[1,2], A. Giachero[2], L.Gironi[1,2], S.Kraft [1,2], C.Maiano[1,2], M. Martinez[2] , A.Nucciotti[1,2], L. Pattavina[1,2], M.Pavan[1,2], G.Pessina[2], S.Pirro[2], E.Previtali[2], D.Schaeffer[2] and M.Sisti[1,2]
1 Dipartimento di Fisica dell'Università di Milano-Bicocca, Milano I-20126, Italy
2 Sezione di Milano Bicocca dell'INFN, Milano I-20126, Italy

F.Bellini, R.Faccini, F.Orio and M.Vignati
Dipartimento di Fisica dell'Università di Roma La Sapienza e Sezione di Roma dell'INFN, Roma I-00185, Italy

J.W.Beeman[1], A.Bryant[2,4], E.E.Haller[1,3], L.Kogler[2,4] and A.R.Smith[2]
1 Materials Science Division, Lawrence Berkeley National Laboratory,Berkeley, CA 94720
2 Nuclear Science Division, Lawrence Berkeley National Laboratory,Berkeley, CA 94720
3 Department of Materials Science and Engineering, University of California at Berkeley, CA 94720, USA
4 Department of Physics, University of California, Berkeley, CA 94720, USA

M.J. Dolinski [1,3], K.Kazkaz[1], E.B. Norman[1,2] M.Pedretti[1] and N.D.Scielzo[1]
1 Lawrence Livermore National Laboratory, Livermore, CA 94550 USA
2 Department of Nuclear Engineering, University of California, Berkeley, CA 94720
3 Department of Physics, University of California, Berkeley, CA 94720, USA

T.D. Gutierrez
California Polytechnic State University, San Luis Obispo, CA 93407 USA

F.T.Avignone III, I.Bandac, R.J.Creswick, H.A.Farach, C.Martinez, L.Mizouni and C.Rosenfeld
Department of Physics and Astronomy, University of South Carolina, Columbia S.C.29208 USA

L.Ejzak, R.H.Maruyama and S.Sangiorgio
University of Wisconsin, Madison, Wisconsin, 53706 USA