

Neutrinos in Venice
Venice, December 3-5,

2003

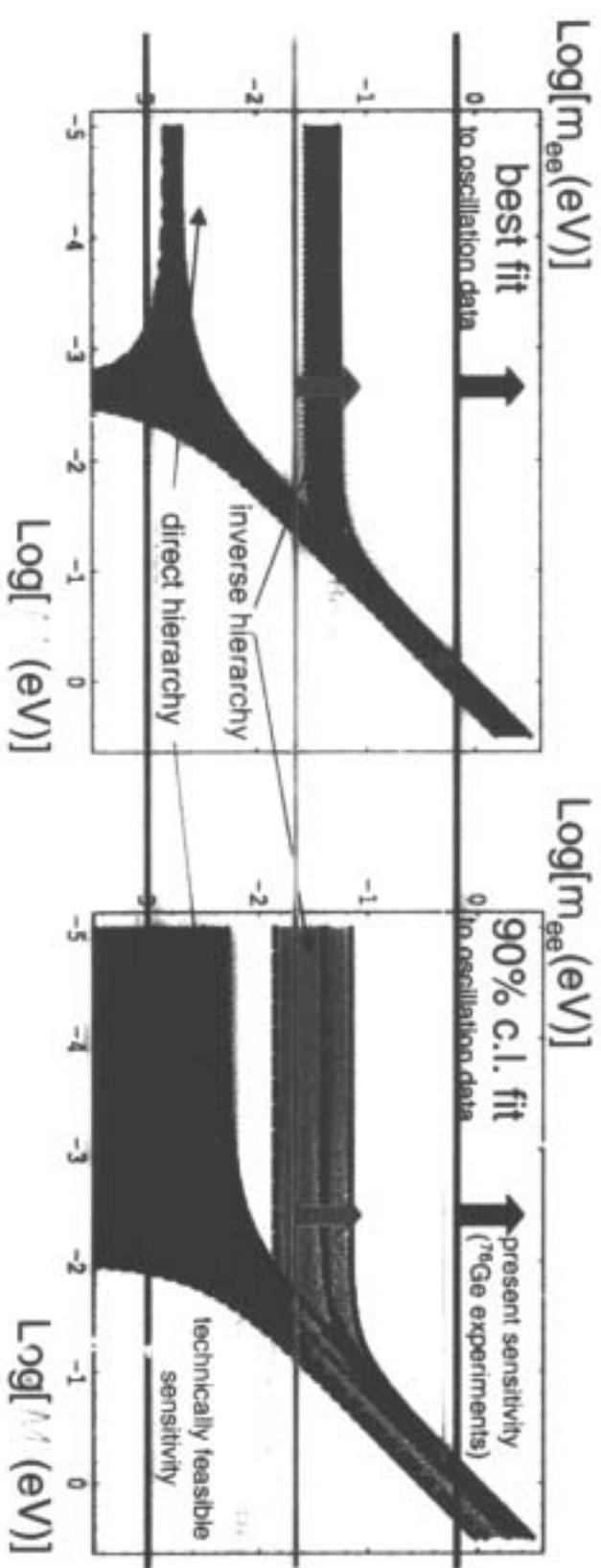
Frank Avignone
Selected Double-Beta
Decay Experiments

0ν-DBD and neutrino flavor oscillations (2)

0ν-DBD can complete the information coming from oscillations

- fix the absolute mass scale even for vanishing M_3 , m_{ee} is within the reach of next experiments in case of
- determine DIRAC or MAJORANA nature inverse hierarchy or degeneracy
- give information on CP-phases

$$m_{ee} \sim U_{e1}^2 M_1 + U_{e2}^2 M_2 + U_{e3}^2 M_3$$



COBRA	Te-130	10 kg CdTe semiconductors
DCBA	Nd-150	20 kg Nd layers between tracking chambers
NEMO	Mo-100, Various	10 kg of $\beta\beta$ isotopes (7 kg of Mo)
CAMEO	Cd-116	1 t CdWO ₄ crystals
CANDLES	Ca-48	Several tons CaF ₂ crystals in liquid scint.
CUORE	Te-130	750 kg TeO ₂ bolometers
EXO	Xe-136	1 ton Xe TPC (gas or liquid)
GEM	Ge-76	1 ton Ge diodes in liquid nitrogen
GENIUS	Ge-76*	1 ton Ge diodes in liquid nitrogen
GSO	Gd-160	2 t Gd ₂ SiO ₅ :Ce crystal scint. in liquid scint.
Majorana	Ge-76	500 kg Ge diodes
MOON	Mo-100	Mo sheets between plastic scint., or liq. scint.
Xe	Xe-136	1.56 t of Xe in liq. Scint.
XMASS	Xe-136	10 t of liquid Xe
		Elliott, TAUP 2003, Seattle, WA
		Sept. 2003

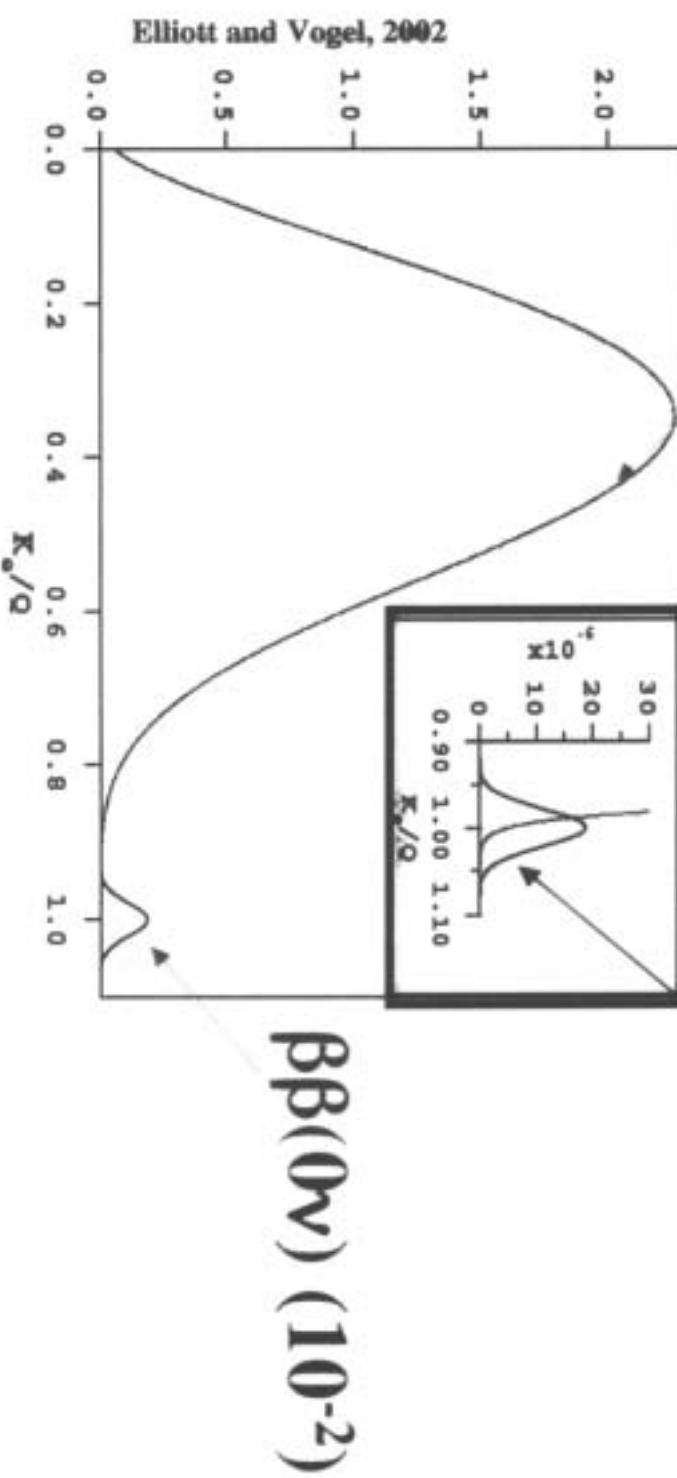


$\beta\beta(2\nu)$ "Background"

Assuming 5% energy resolution

$$\beta\beta(2\nu) \text{ (1)} \\ \beta\beta(0\nu) \text{ (10}^{-6})$$

$$\beta\beta(0\nu) \text{ (10}^{-2})$$



NEMO Experiment

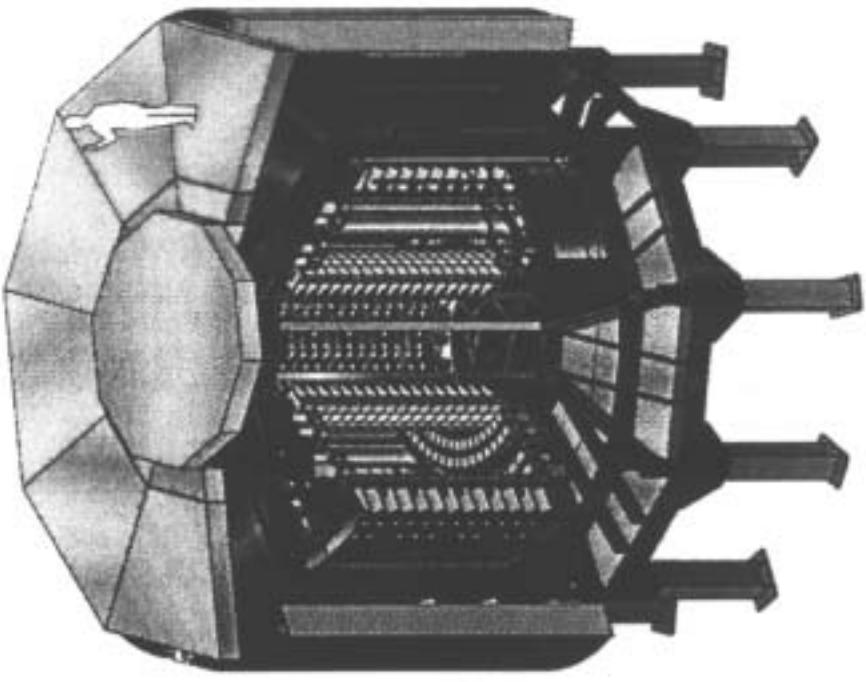
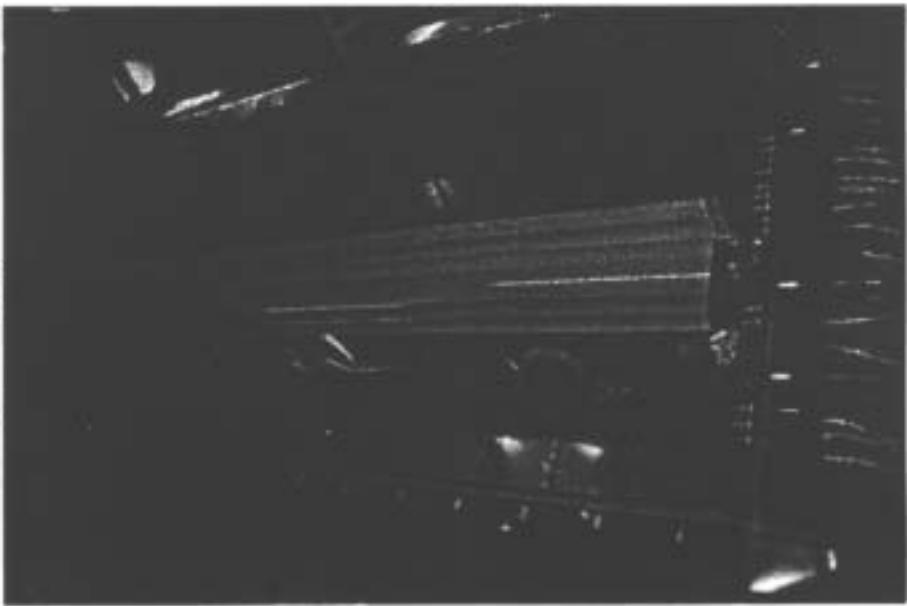
Neutrino Ettore Majorana Observatory

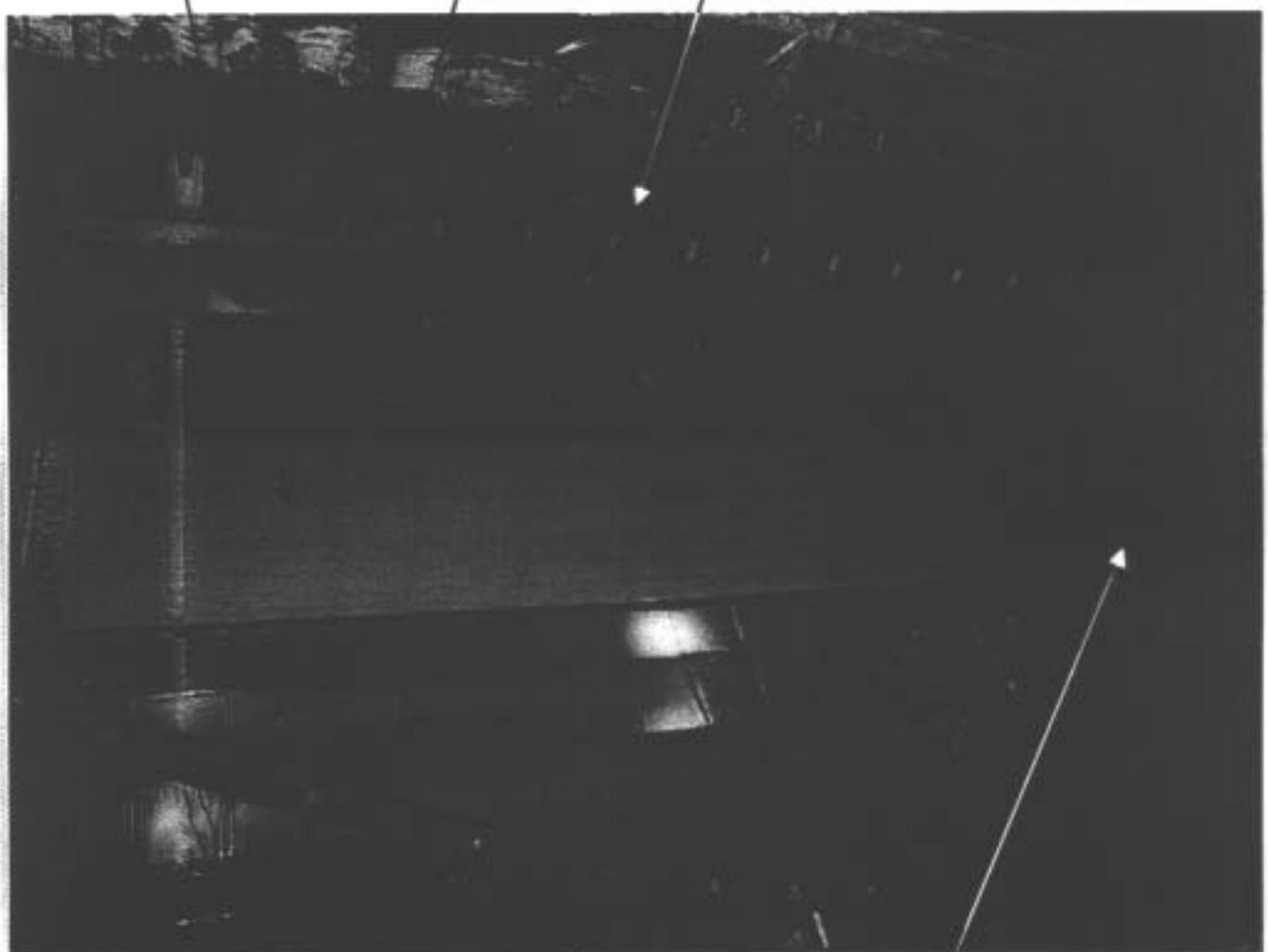
- Search for neutrinoless double beta decay
- Study several isotopes
 Mo^{100} , Sc^{82} , Te^{130} , Cd^{110} , Fr^{220} , Cn^{113} , Nd^{150}
- Tag and measure all the components of background
 e^- , e^+ , γ , α , neutrons
- “zero background” experiment

NEMO-3 Detector

Located in Modane Underground Laboratory

- sources: 20 m^2 , total mass ~ 10 kg, thickness ~ 60 mm
- Tracking detector (6180 Geiger cells in He+alcohol): Vertex $\sigma_t = 5 \text{ mm}$, $\sigma_r = 1 \text{ cm}$
- Calorimeter: (1940 plastic scintillators + PMTs low radioactivity) $\sigma_t/E = 3\%$ at 3 MeV
- γ and neutron shield: Iron shield (18 cm) + water shield + wood shield + parafin
- magnetic field $B=25 \text{ G}$
- all materials low radioactivity (total activity in ^{208}Tl and $^{214}\text{Bi} \approx 300 \text{ Bq}$)





$\beta\beta$ isotope foils

scintillators

Calibration tube

PMTs

Cathodic rings
Wire chamber

AUGUST 2001

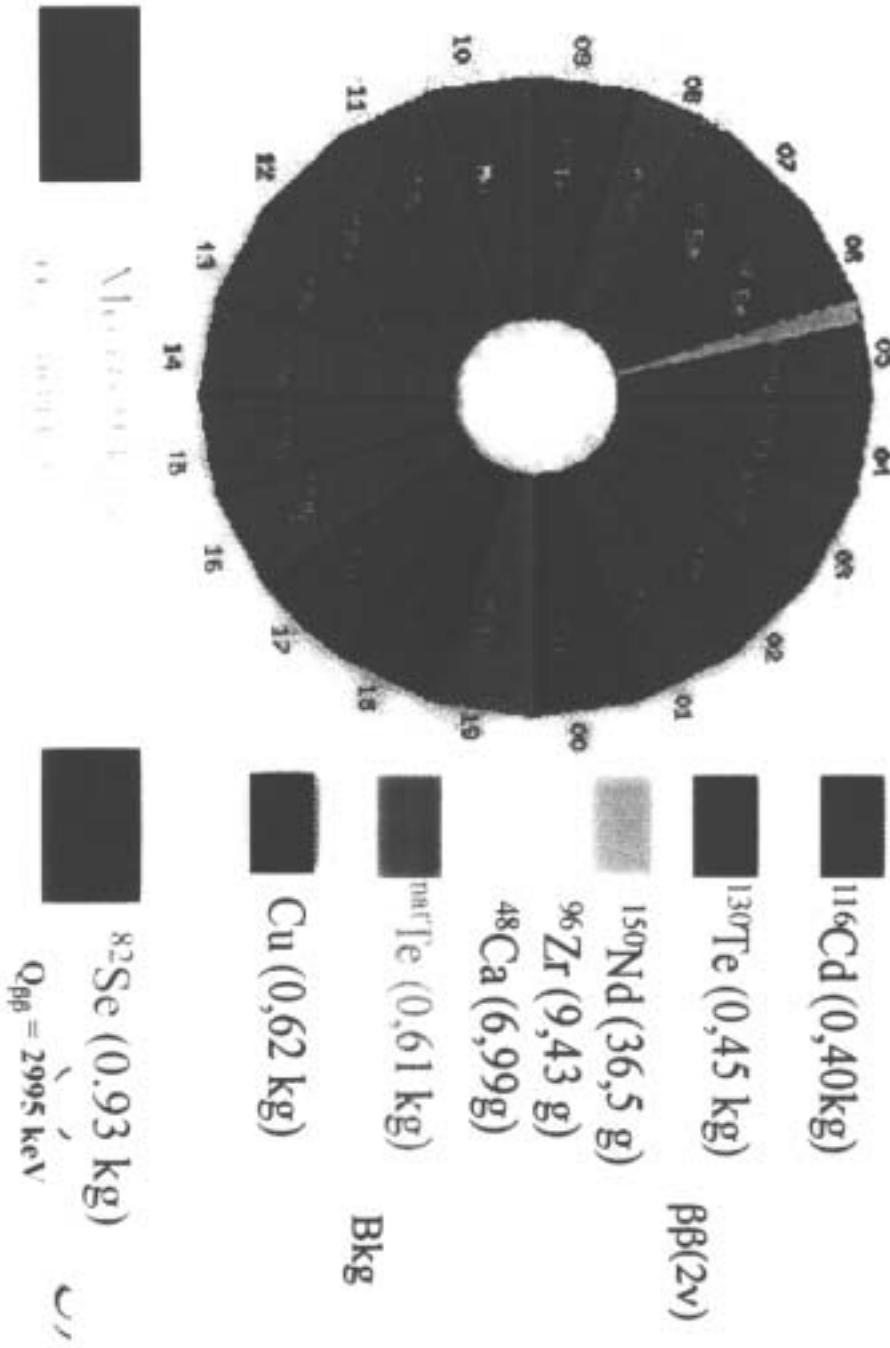


June 2002 : tests runs

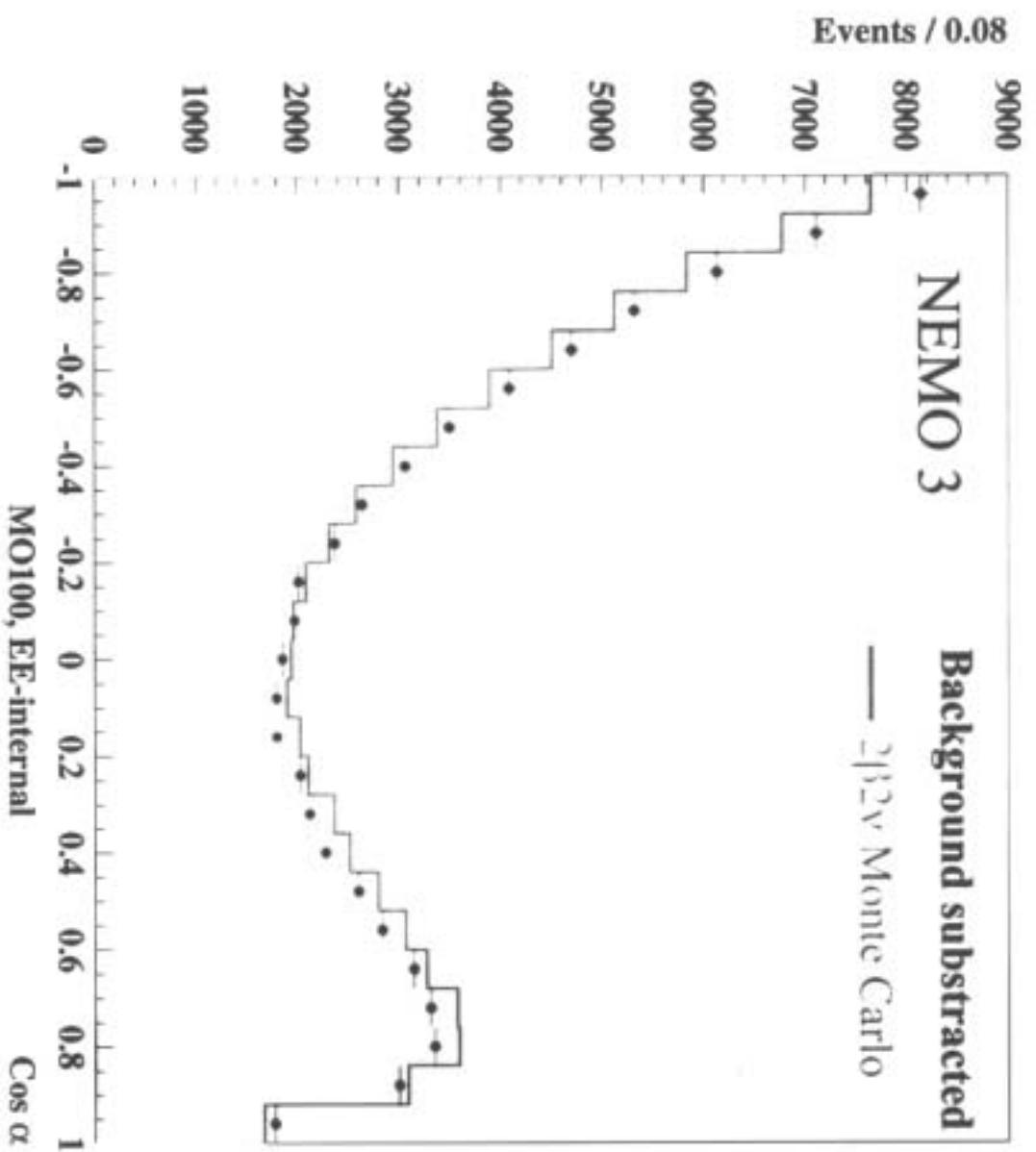
February 2003 : beginning of data taking

Sources in NEMICO-3 detector

Sources $\beta\beta$ (thickness $\sim 60 \text{ mg/cm}^2$)

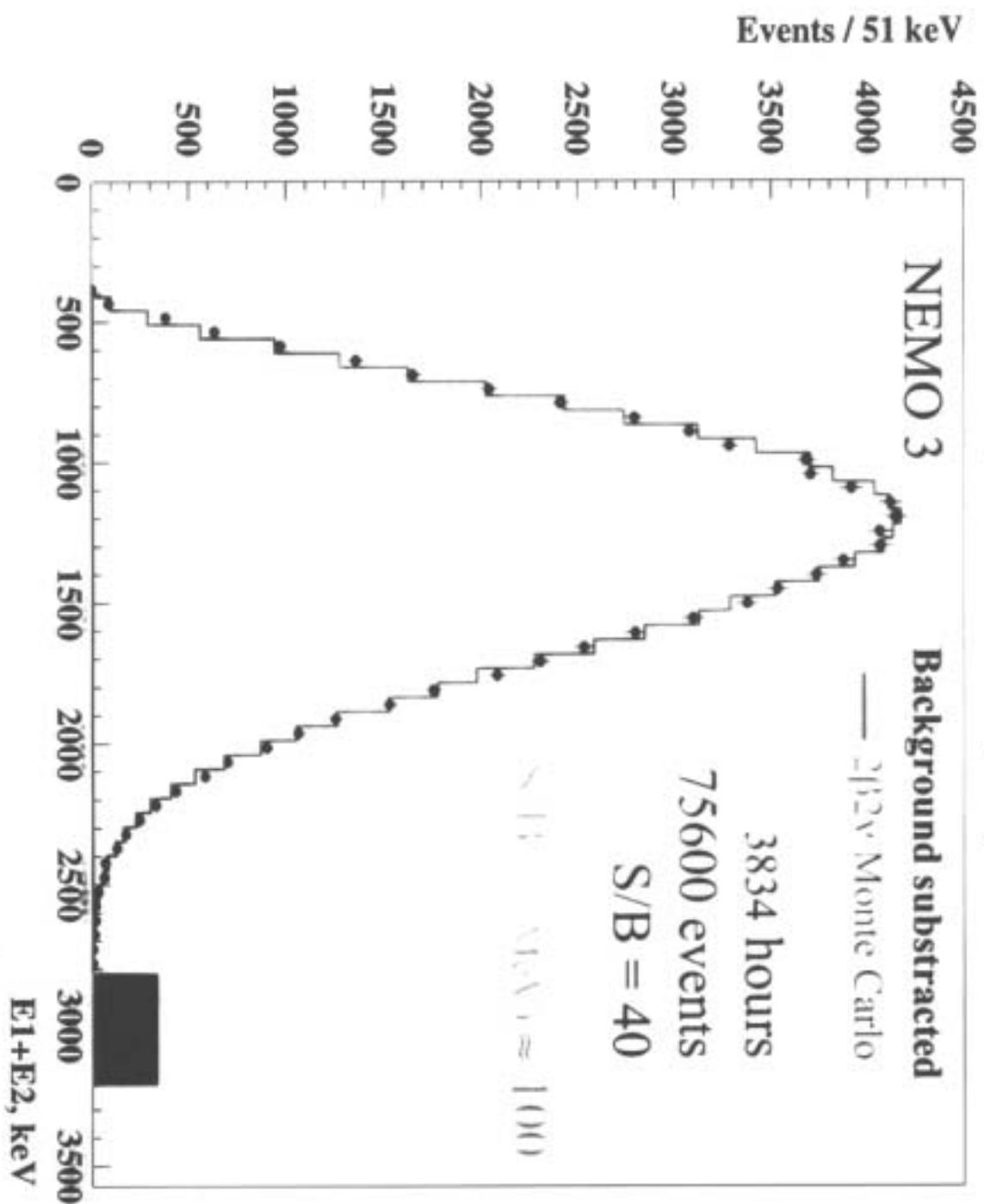


^{100}Mo $2\beta^2\nu$ angular distribution



^{100}Mo $2\beta^2\nu$ preliminary results

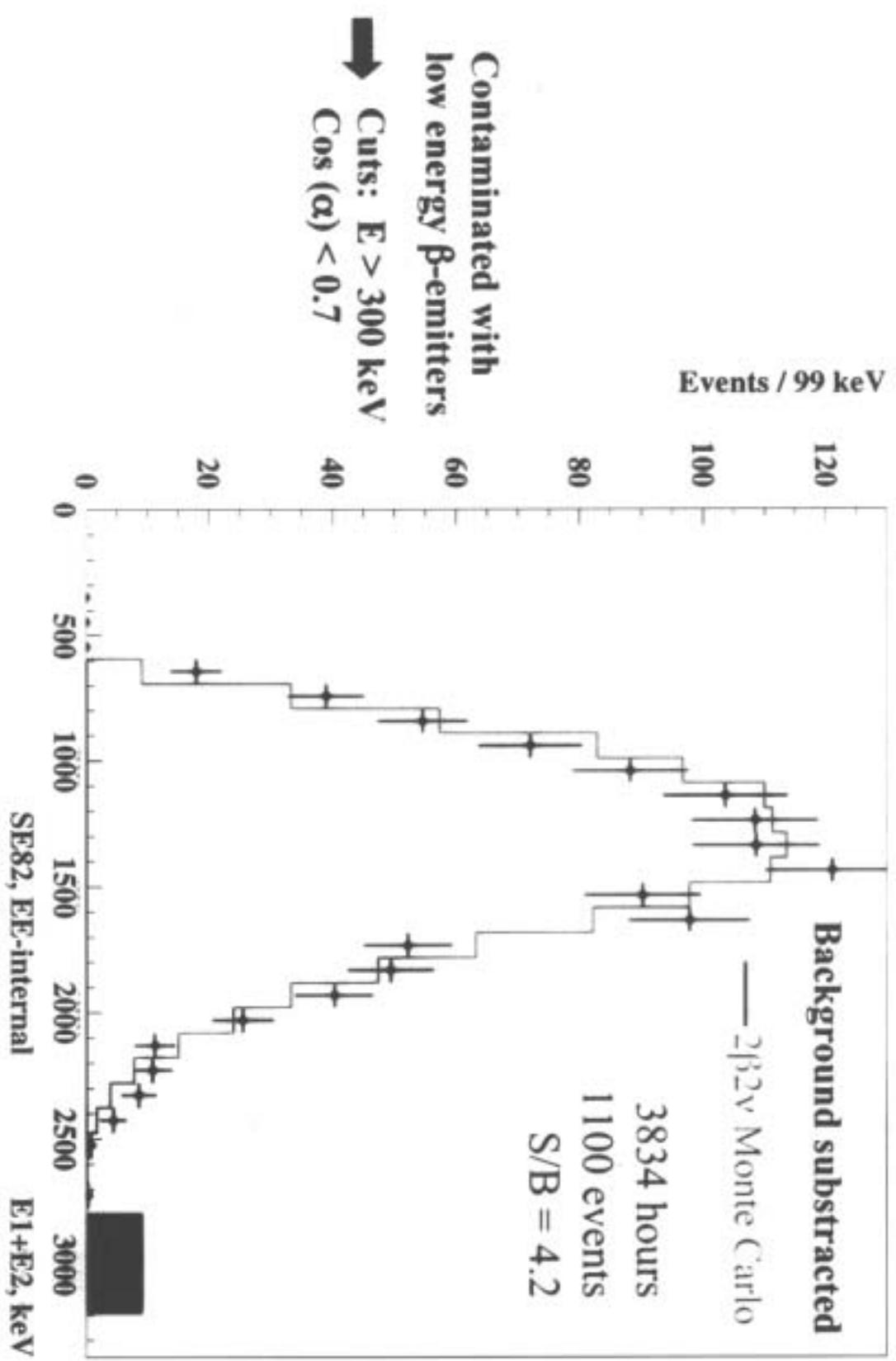
(14 Feb. 2003 – 30 Sep. 2003)



$$I_{\nu\nu} = N \pm 0.010 \quad (\sqrt{N}) \pm 0.010 \quad (\sqrt{\sqrt{N}}) \times 10^{-10}$$

$^{82}\text{Se} - 2\beta^2\nu$ preliminary results

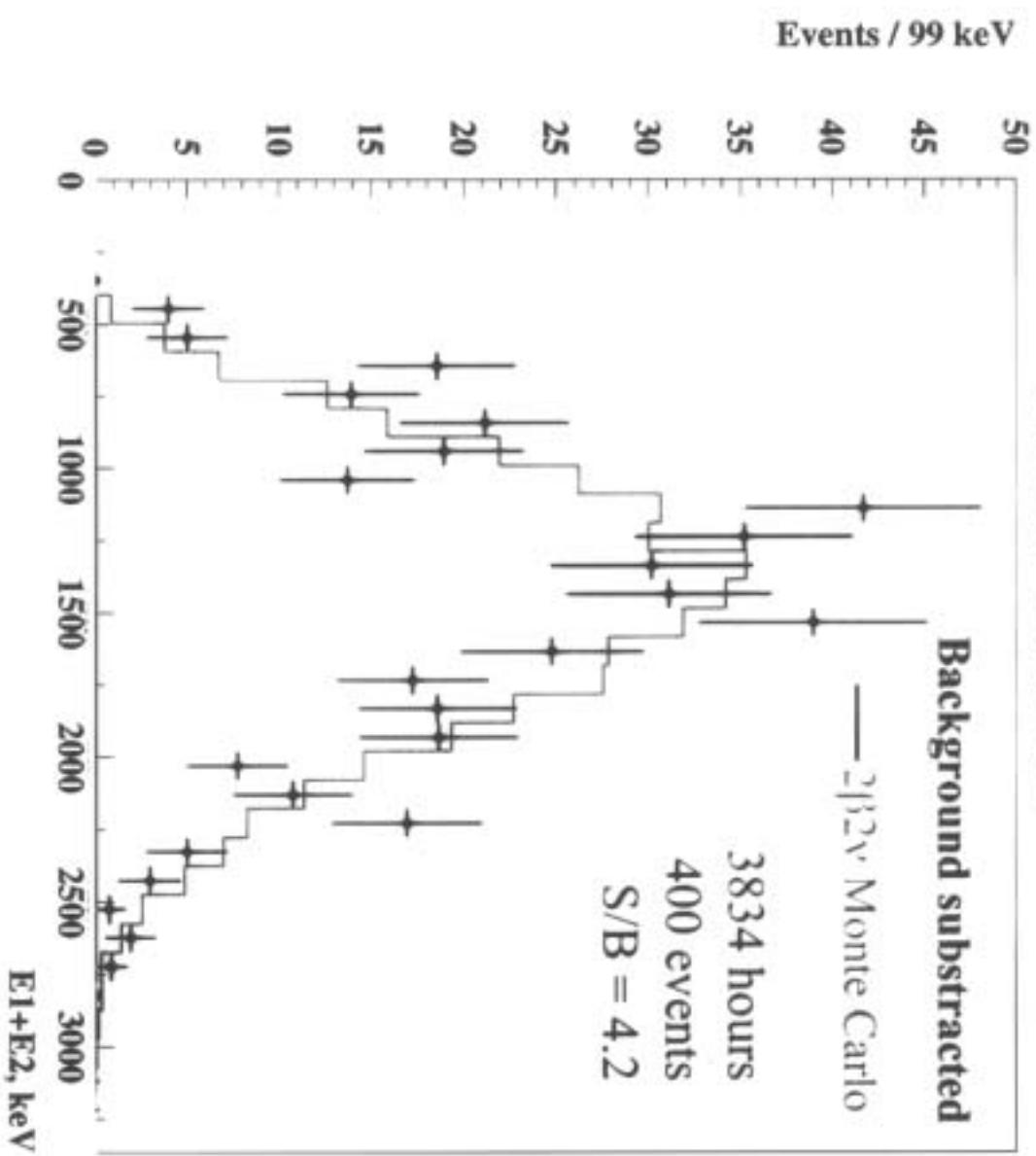
(14 Feb. 2003 – 30 Sep. 2003)



$$I_{\gamma\gamma} = (0.52 \pm 0.25) (\sin(0) + 0.9 (\sin(0) \times 10^{-1})$$

$\text{Li}^{+}\text{N}_2(2\beta^2\nu)$ preliminary results

(June 2002 – 30 Sep. 2003)



750 kg T_e0²

RARE EVENTS

FOR

Cryogenic Underground Observatory

COURSE

The Future



The CUORE project

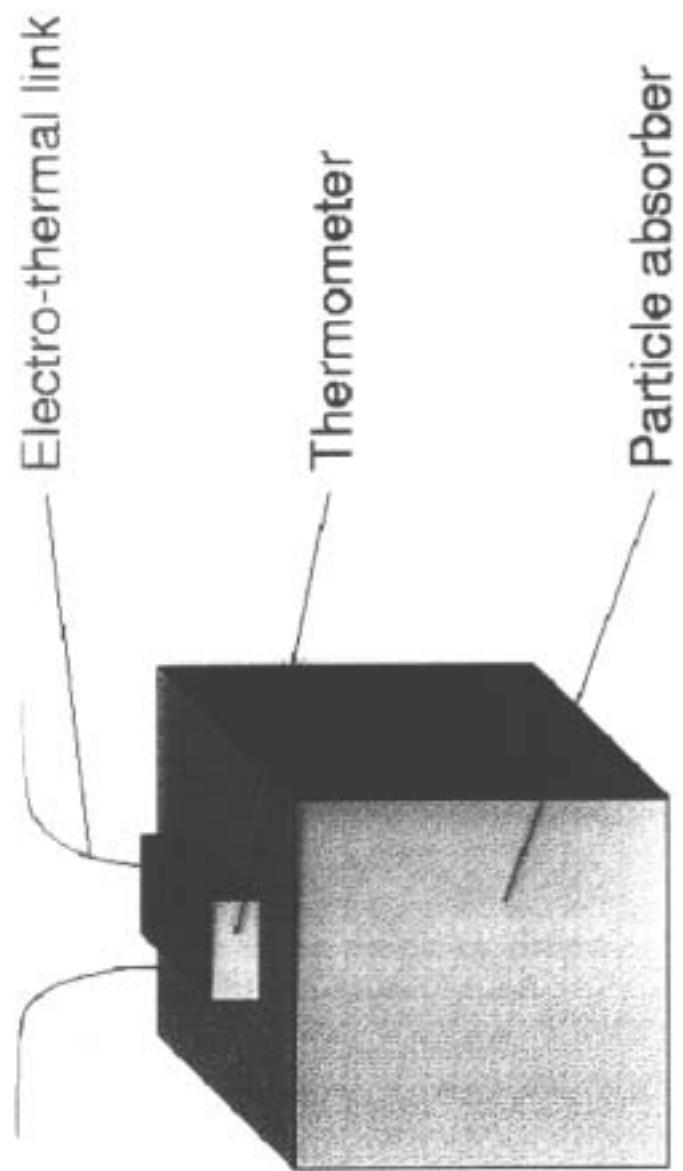
Cryogenic Underground Observatory for Rare Events

THE CUORE COLLABORATION:

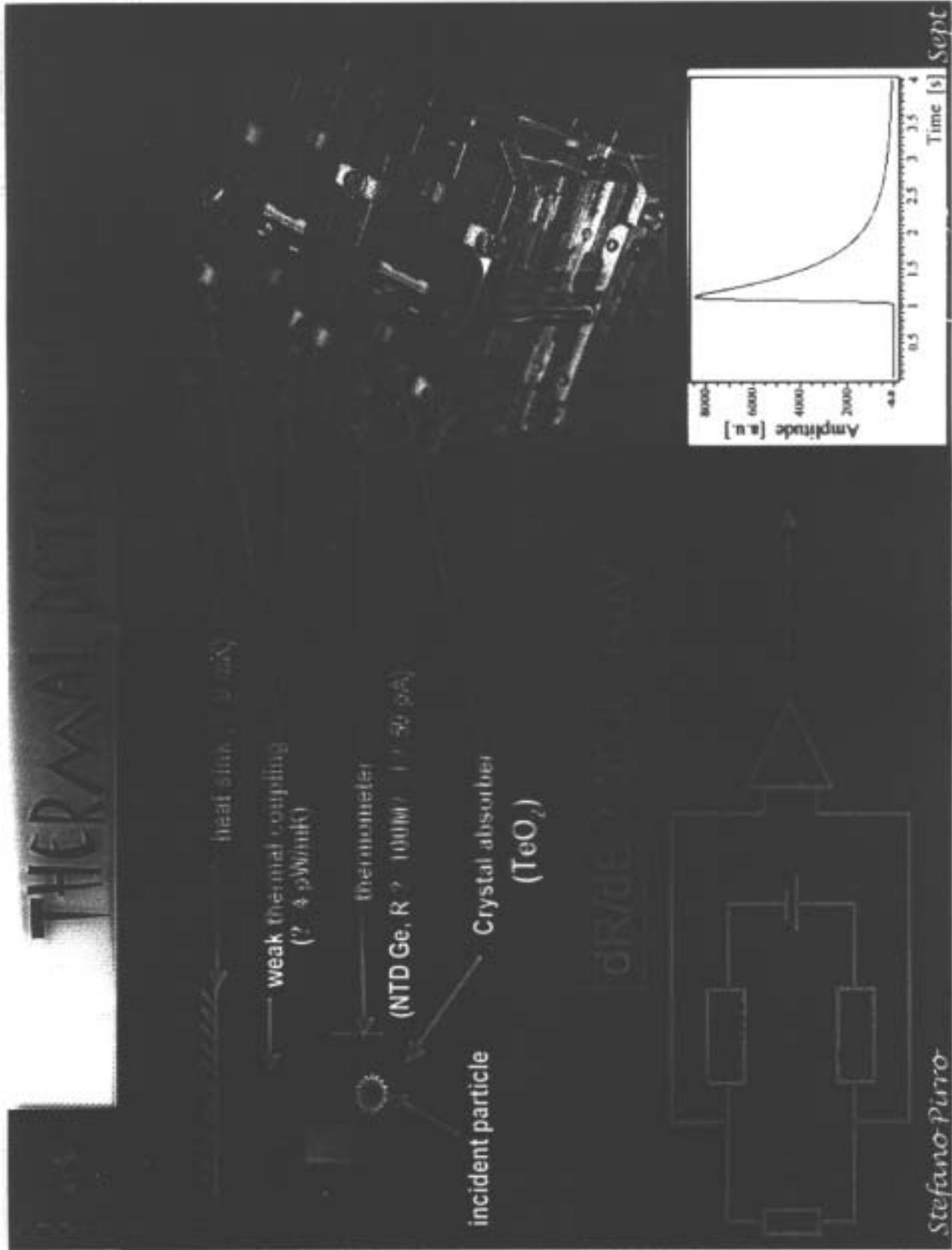
- ♥ Dipartimento di Fisica dell'Università and Sez. INFN di Milano- Milano - Italy
- ♥ Lawrence Berkeley Laboratory, Berkeley - California- USA
- ♥ Dipartimento di Fisica dell'Università and Sez. INFN di Firenze- Firenze- Italy
- ♥ Kamerling Onnes Laboratory, Leiden University- Leiden -The Netherlands
- ♥ Laboratori Nazionali del Gran Sasso, INFN - L'Aquila - Italy
- ♥ Department of Physics and Astronomy, University South Carolina
- Columbia S. C. - USA
- ♥ Laboratori Nazionali di Legnaro, INFN - Padova - Italy
- ♥ Lab. of Nucl. and High En. Physics, University of Zaragoza - Zaragoza - Spain

spokesman: prof. E. Fiorini
Università di Milano

RIVELATORI TERMICI
E.F. and T.Niinikosky (1984)



ΔE @ 5 keV ~100 mK ~1 mg <1 eV ~5 eV @ 2 MeV ~10 mK ~1 kg <10 eV ~keV

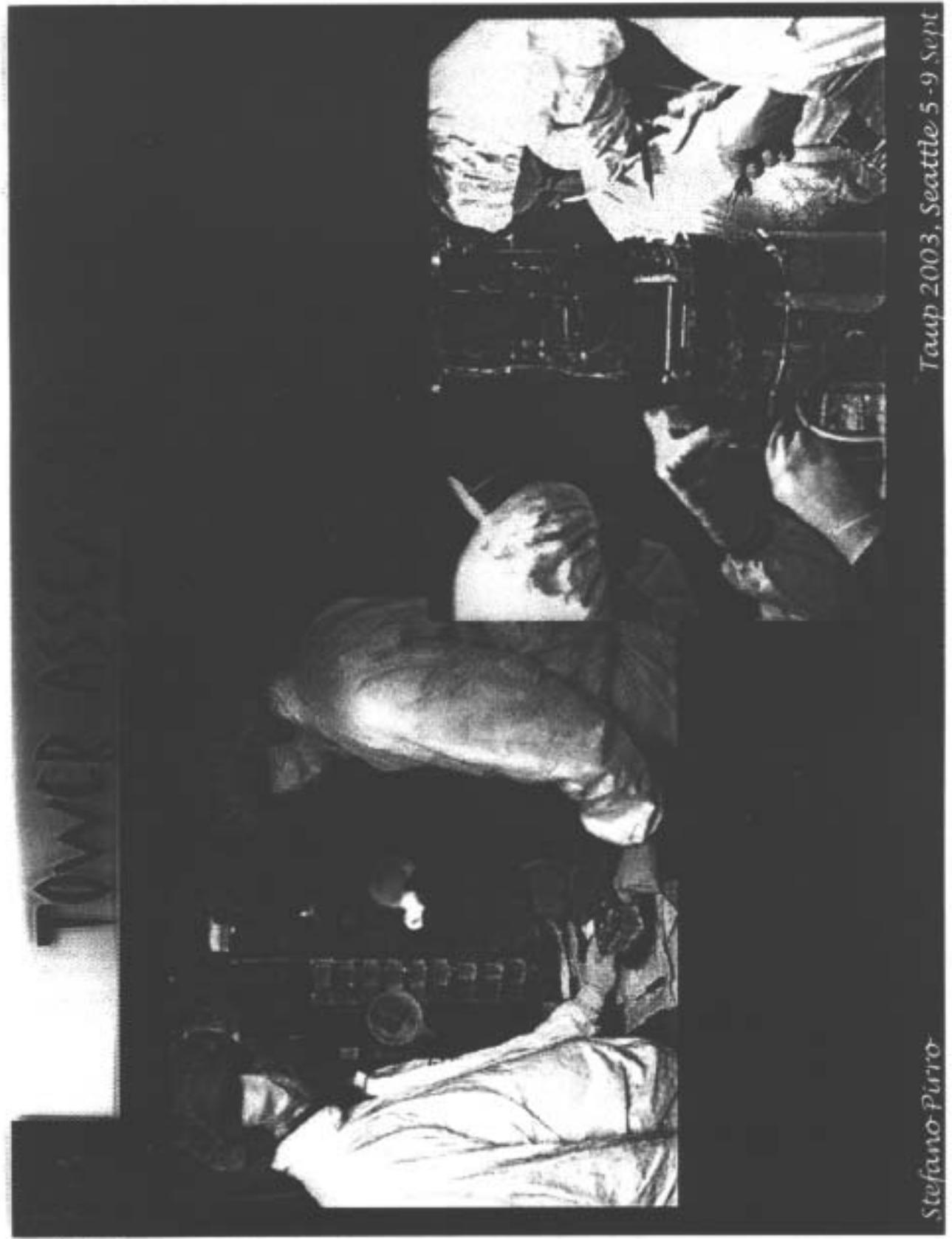






Stefano Puro

Tauup 2003, Seattle 5-9 Sept

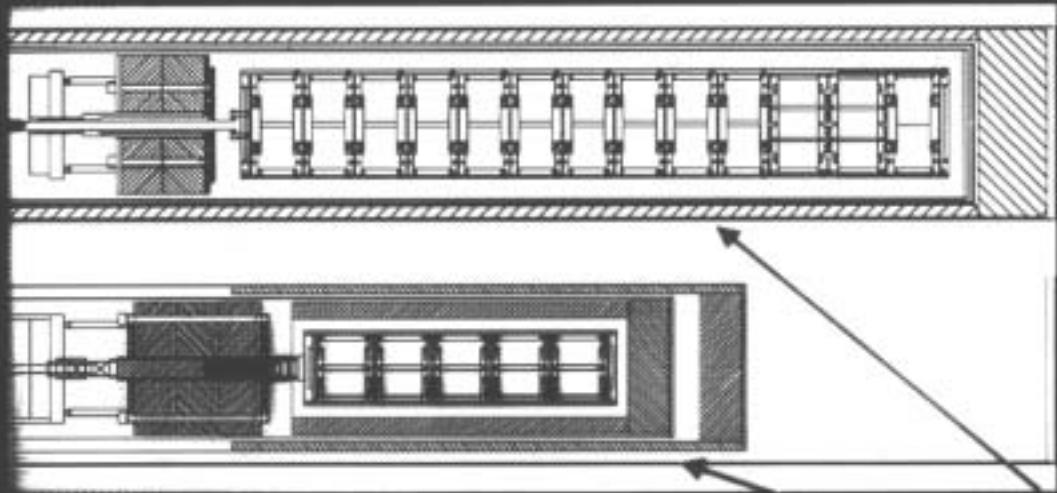


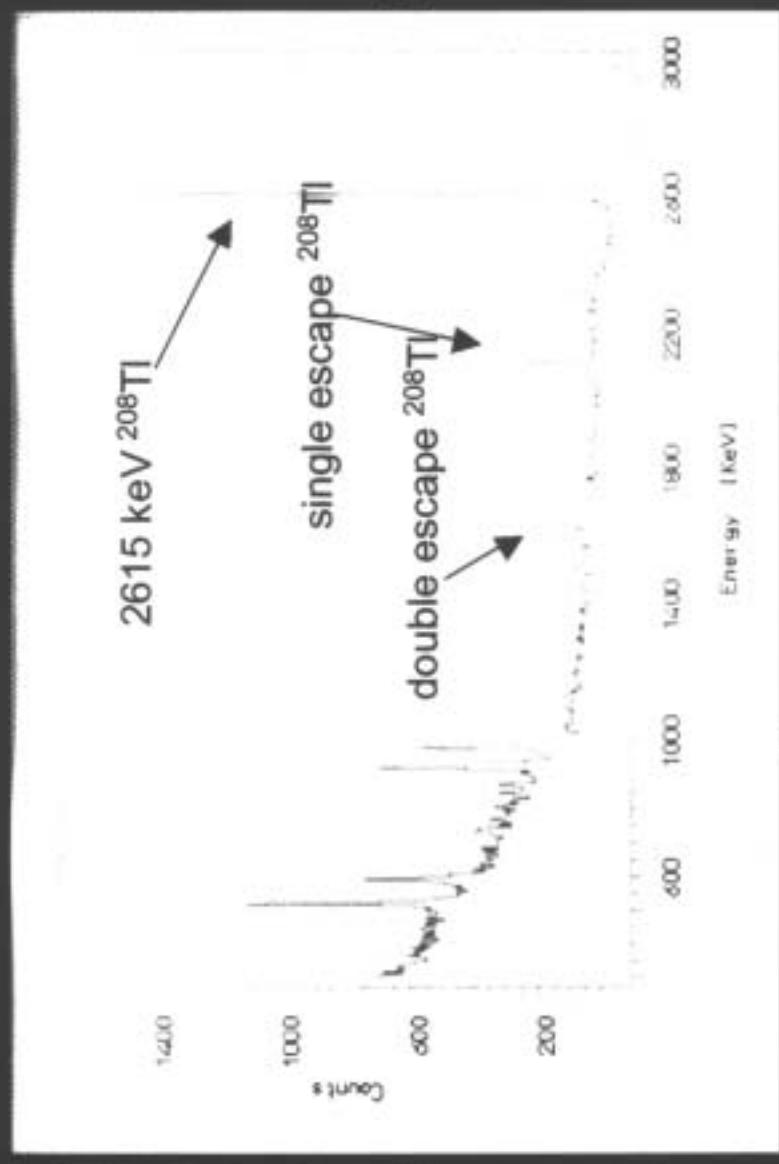
Stefano Purio

Traup 2003, Seattle 5-9 Sept

Taup 2003, Seattle 5-9 Sept

Stefano Pirro





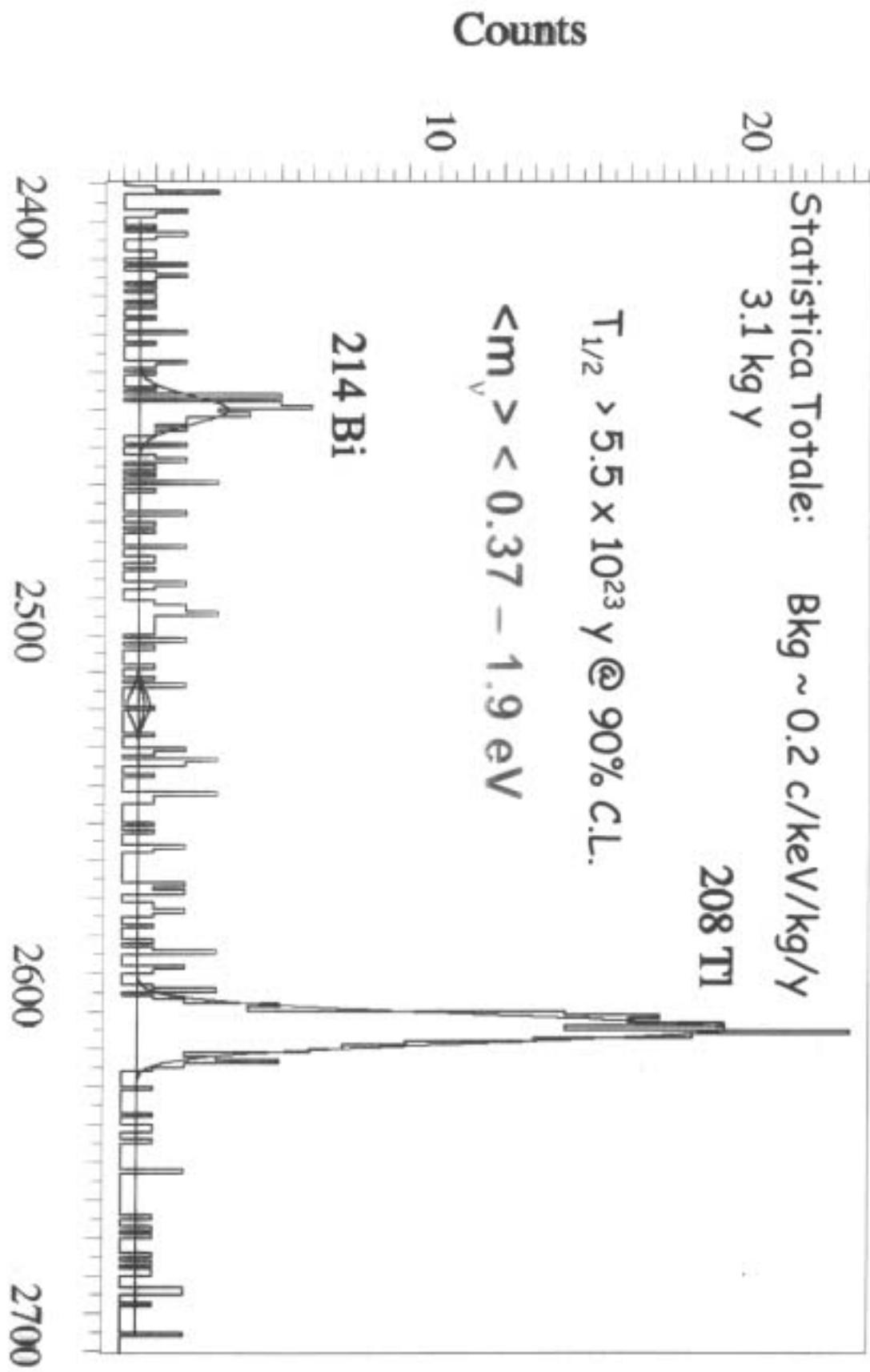
$E_{\text{FWHM}} = ? \text{ keV} @ 2615 \text{ keV}$



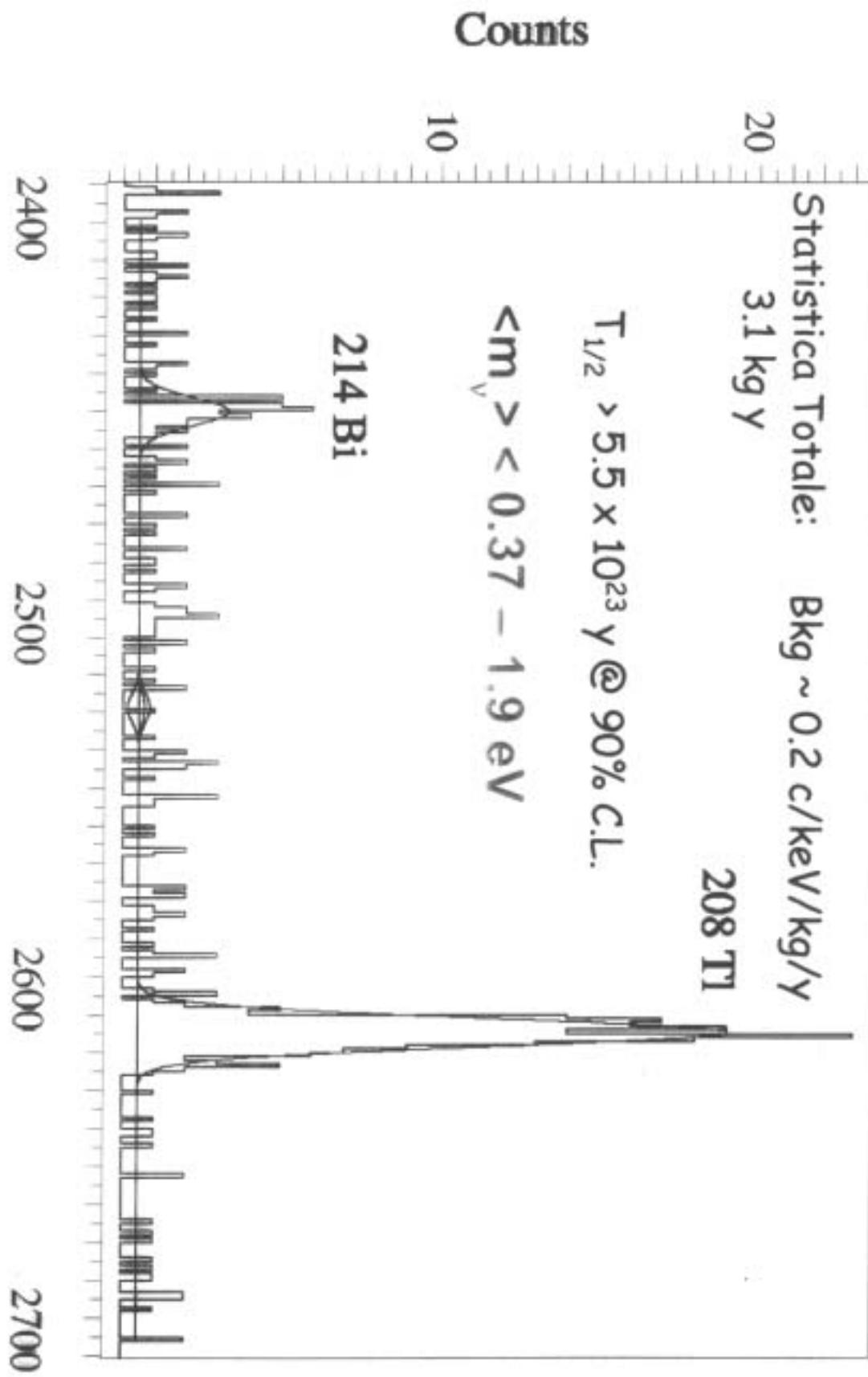
Stefano Piro

TauD 2003, Seattle 5-9 Sept

I limiti sui DDB-O_V

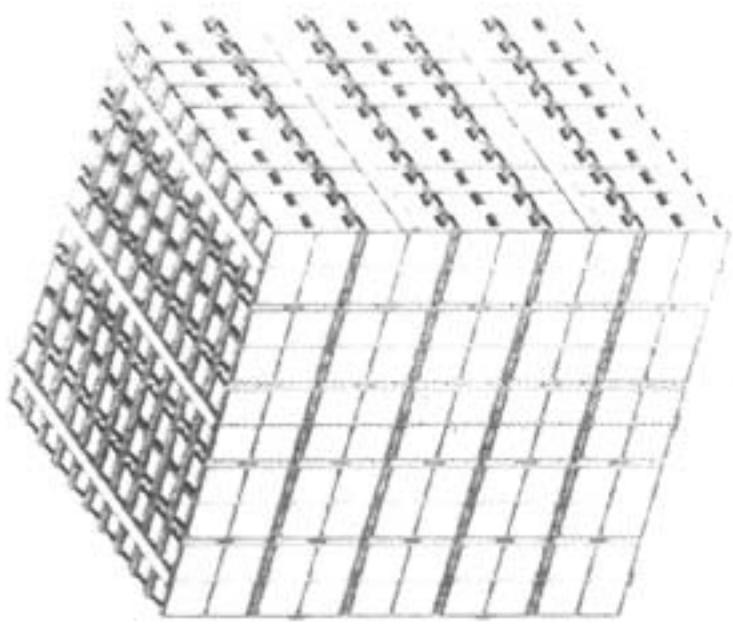


I limiti sui DDB-O_V

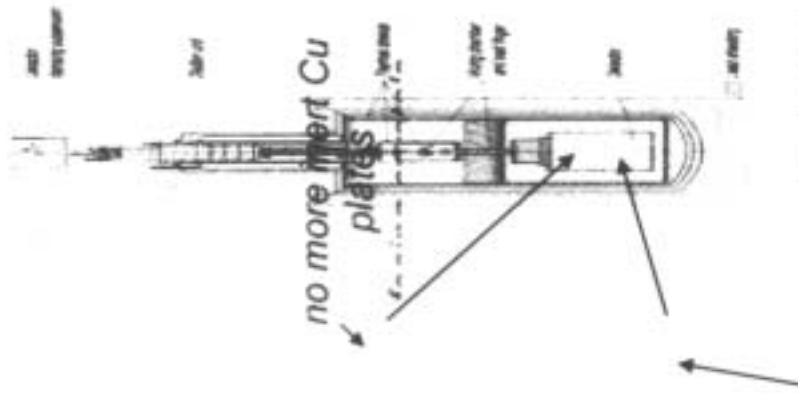


C1 (one)
double concentric
doubling

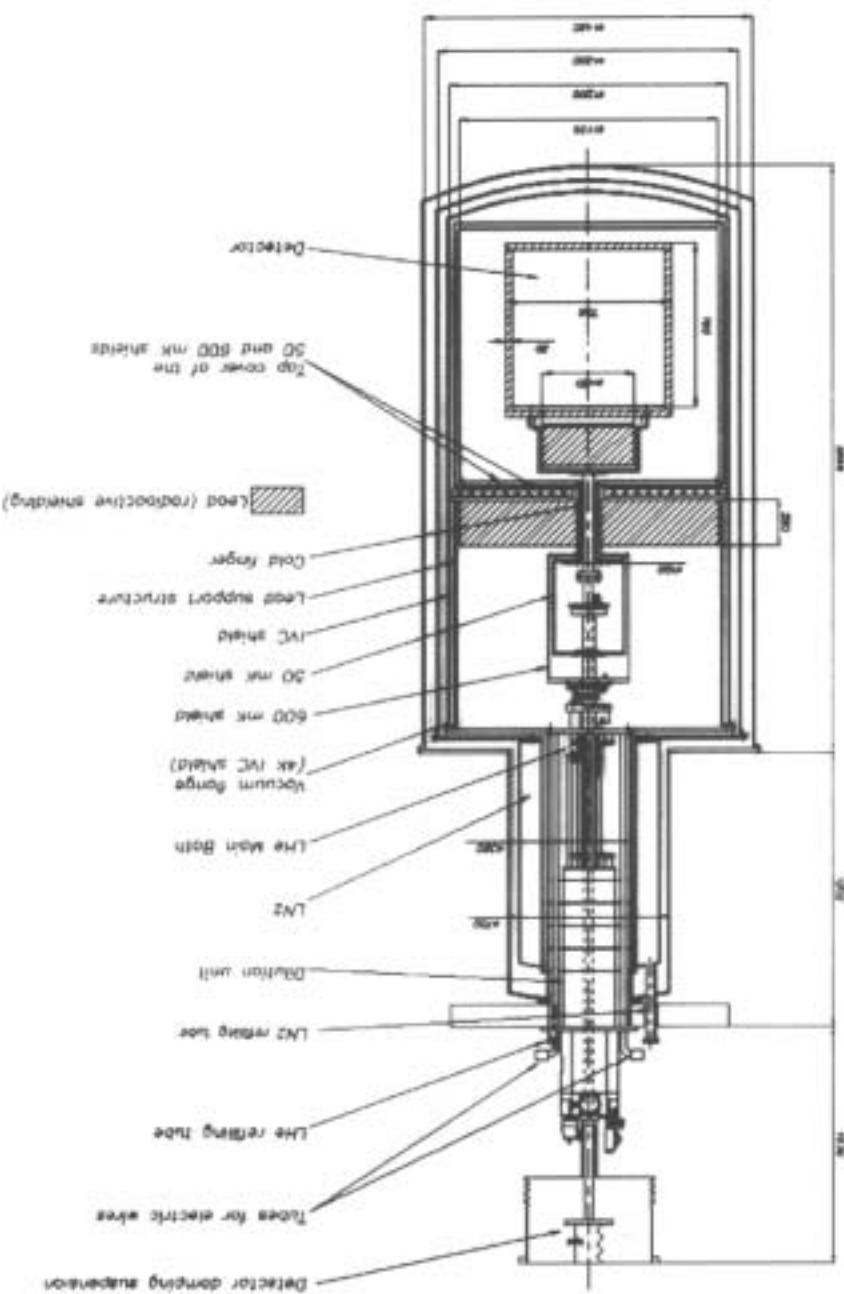
. They have been already tested $\Delta E = 46 \text{ keV}$ @ 46 keV
and 3.2 keV @ 5.4 keV



100 kg/cm²
 ΔE
1000 keV



Special dilution
refrinator



Cryogenic Underground Observatory for Rare Events

The CUORE project





Next Generation Ge-Detection Experiment

“Ideal Experiment”

- Large Mass
- Good source radiopurity
- Demonstrated technology
- Natural isotope

- Small volume, source = det.
- Good energy resolution
- Ease of operation
- Large Q-value, fast $\beta\beta(0\nu)$
- Slow $\beta\beta(2\nu)$ rate

- Identify daughter
- Event reconstruction
- Nuclear theory

Majorana

- ~500 kg of 86% ^{76}Ge
- Intrinsic Ge
- “Ready to Go”

- Fiorini “internal source” method
- 3-4 keV at 2039 keV, 0.2%
- Ge detectors are relatively simple
- 2039 keV, > most backgrounds
- 10^{21} yrs

- segmentation, modularity, PSD
- Low A - Shell Model and QRPA



Duke U.
North Carolina State U.
TUNL
Argonne Nat. Lab.
JINR, Dubna
ITEP, Moscow
LLNL
New Mexico State U.
Pacific Northwest Nat. Lab.

U. of Washington
LANL
U. of South Carolina
Brown
Univ. of Chicago
RCNP, Osaka Univ.
Univ. of Tenn.
Oak Ridge Nat. Lab.
LBNL





Majorana Reference Plan

- A review of germanium basics
- The Majorana reference plan
 1. 500 kg enriched 86% ^{76}Ge
 2. Many crystals, each segmented
 3. Advanced signal processing
 4. Special low background materials
 5. Deep underground location
- Background reduction
- Sensitivity vs. time



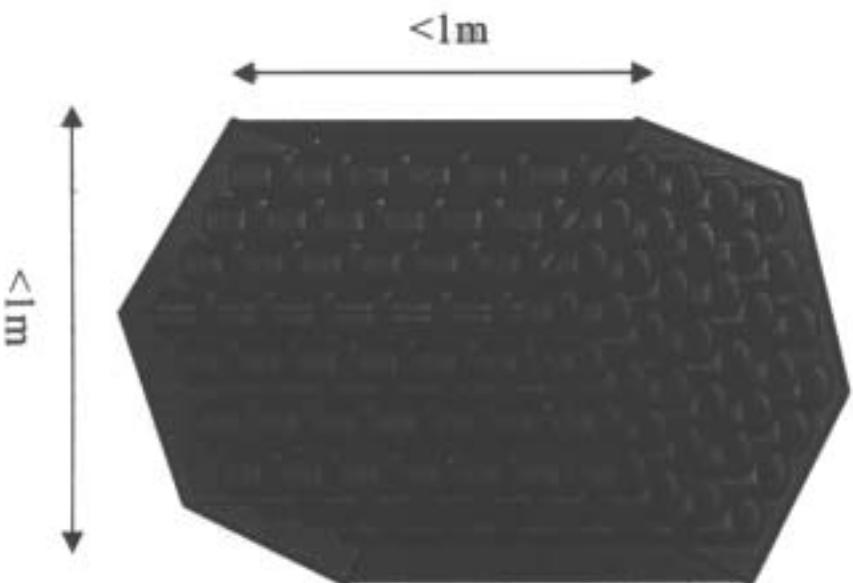
Majorana ν Overview

- $0\nu\beta\beta$ decay of ^{76}Ge potentially measured at 2039 keV
- Sensitive to effective Majorana ν mass below 45 meV
- Based on well known ^{76}Ge detector technology plus:
 - Pulse-shape analysis
 - Detector segmentation
 - *Ready to begin now*
- Requirements:
 1. 500 kg enriched 86% ^{76}Ge
 2. Many crystals, each segmented
 3. Advanced signal processing
 - Pulse-shape discrimination
 4. Special low-background materials
 5. Deep underground location



► Reference Configuration

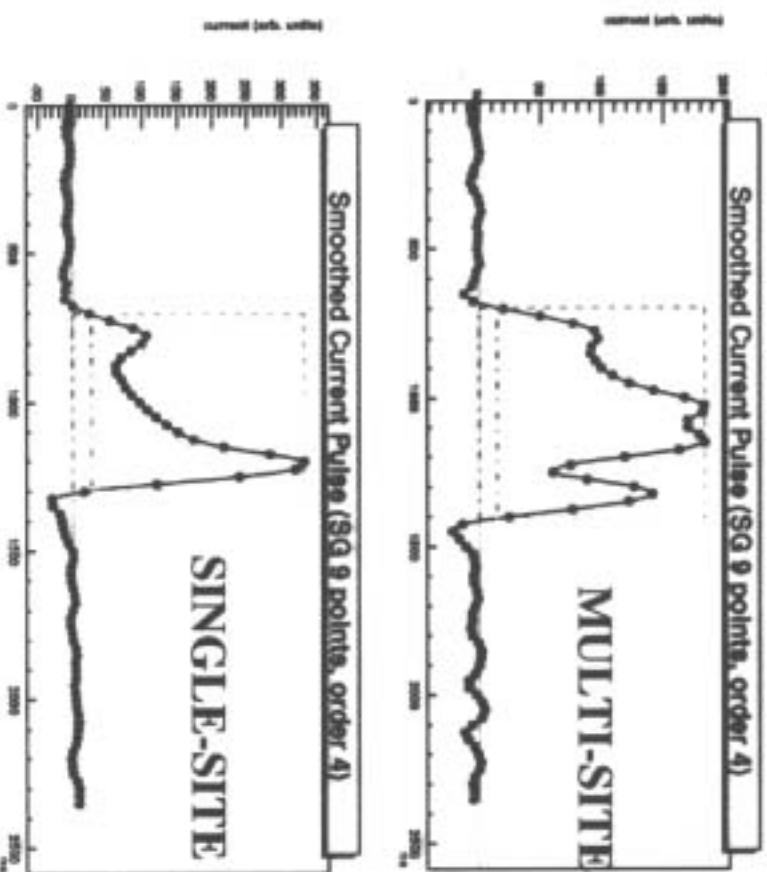
Alternative Packaging



- Would boost crystal to crystal background suppression
- Could take advantage of new shielding opportunities
- Might use alternative cooling methods
- Would require methods for progressive commissioning and periodic maintenance



Requirement 3: Pulse Shape Analysis



- Pulse shape analysis uses digital waveform to identify MULTI-SITE events
- Pulse shape analysis is sensitive to the “radial” separation of MULTI-SITE events
 - Rejects 74% of MULTI-SITE
 - Keeps 80% of desired signal
- This capability has been demonstrated on commercially available, digital spectroscopy hardware

Full-energy 1621-keV γ (top) and 1592-keV DEP (bottom) waveforms from a 120% P-type Ortec HPGe detector (experimental data)



Requirement 2: Detection Segmentation

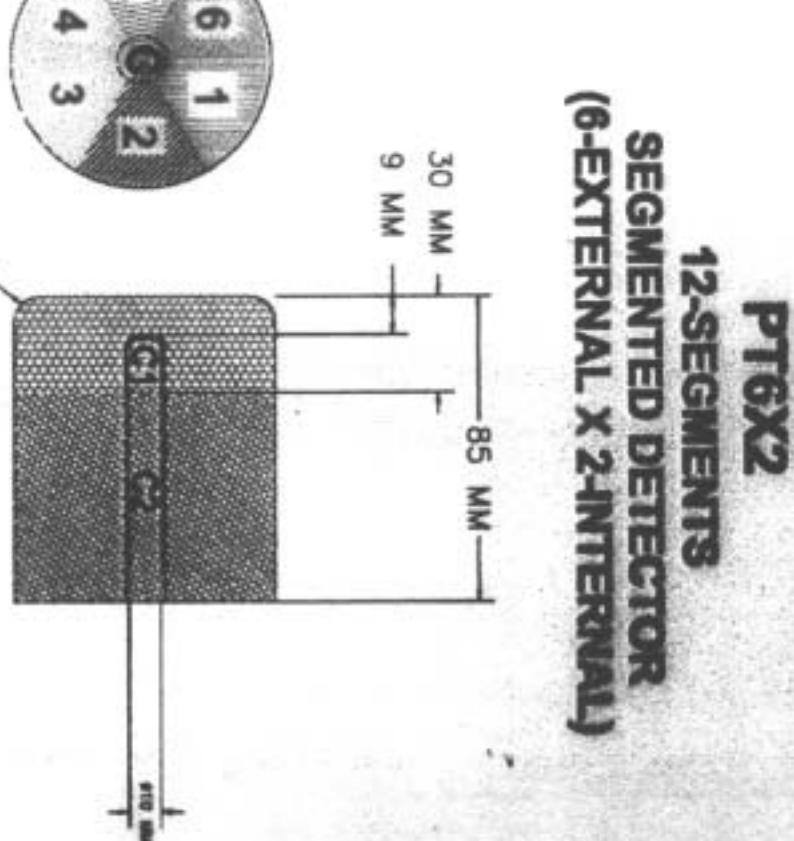
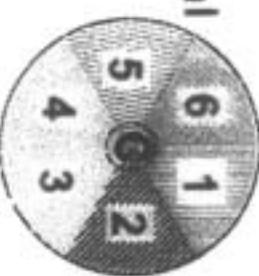
- Double-beta decay is a **SINGLE SITE** phenomenon
- Most backgrounds are **MULTI-SITE** phenomena

- Segmentation allows a simple but very effective cut on **MULTI-SITE** events

- For ^{60}Co , rejects 86%

- Keeps 91% of desired signal

- Sensitive to axial and azimuthal (z and ϕ) separation of depositions

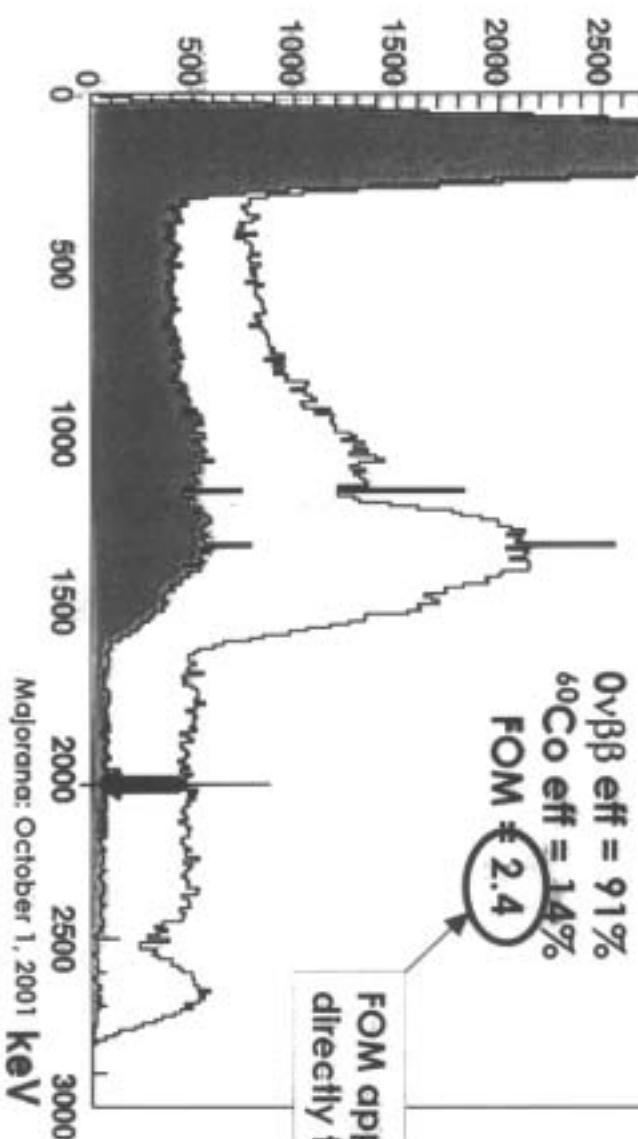
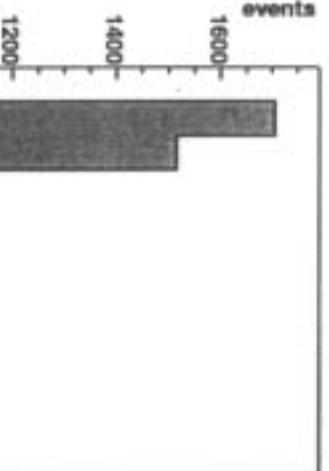
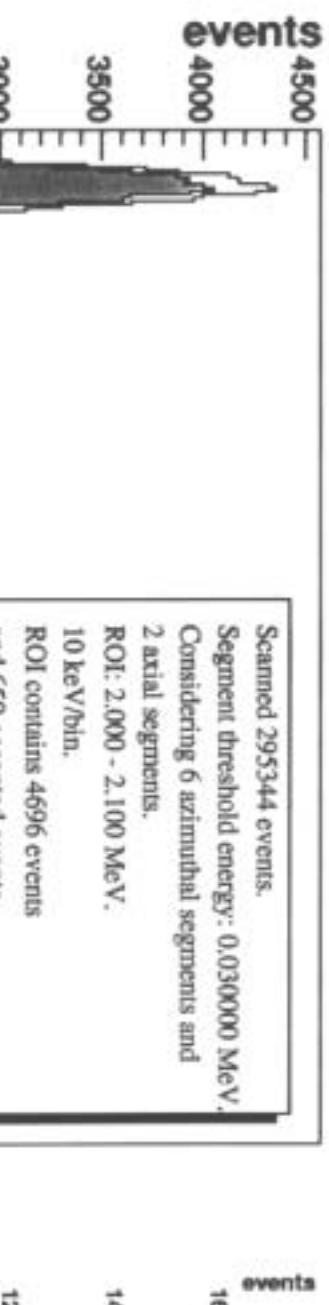


6 SIDE CHANNELS
2 CENTER CHANNELS
TOTAL = 8 PREAMPLIFIERS

A Monte-Carlo Example

Internal ^{60}Co before and after one-segment cut

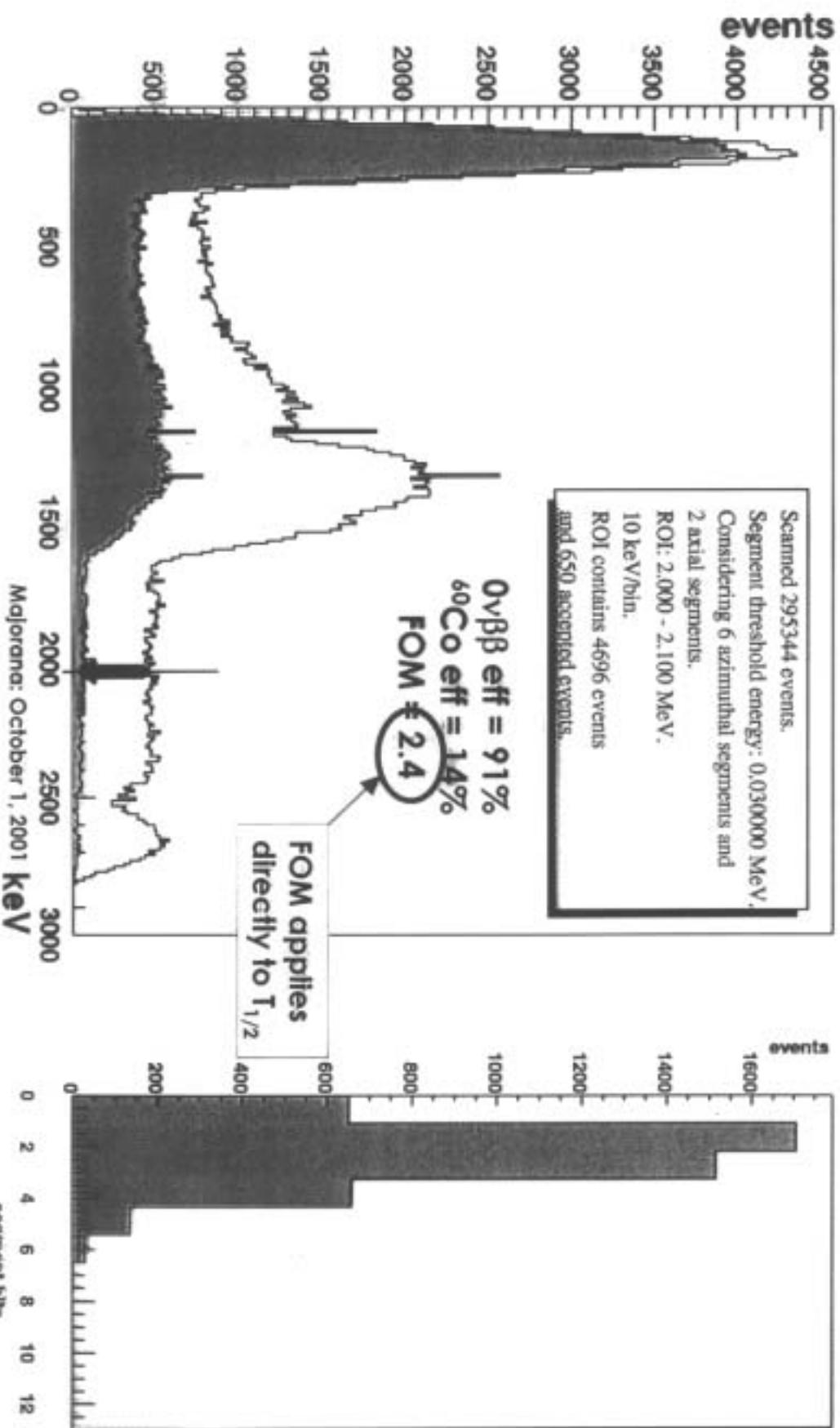
ROI: Segments Hit



A Monte-Carlo Example

Internal ^{60}Co before and after one-segment cut

ROI: Segments Hit





• Los Alamos



- Japan
 - RCNP, Osaka Univ.
 - Univ. of Tokushima
 - Inter. Christian Univ.
 - OULNS, Osaka Univ.
- United States
 - Univ. of Washington
 - LANL
 - Univ. of North Carolina
 - FNAL
- Russia
 - IHEP, Protvino
 - VNIEF, Sarov
 - JINR, Dubna
- Switzerland - CERN
- Czech Republic - Charles Univ.



- 3.3 tons ^{100}Mo , 1-kg prototype approved and started
- Solar neutrino CC sensitivity
- Enrich via centrifuge or laser ionization separation
- Scintillator/source sandwich
 - Or possibly bolometer
 - Metal loaded liquid scintillator
- Position and single E_β data play big role in $\beta\beta(2\nu)$ and U,Th rejection.
- 14% efficiency
- ELEGANTS is precursor.





- Technique looks best for both $\beta\beta$ transitions.

- High resolution.

- For transition to 0^+_1 state, 596-keV 540-keV cascade gives background - free spectrum. For g.s., 3034-keV Q-value helps.
- Comparable sensitivity to ^{76}Ge , but with cascade tag.
- Mo is a superconductor. Equilibration between broken pairs and lattice very slow. Non-metallic compound will be better. (possibly MoSi_2)
- Subdivision at $\sim 10^{-10} \mu$ needed to measure cascade gammas.
- Isotopic enrichment highly desirable.



Super-module of Mo films and fiber/plate scintillators.

1. Position read-out by fibers with 2.2m - 2.2 m - 0.4 mm
2. Energy read-out by plate scintillators with E resolution $\sigma \sim 2\%$ including the Mo film (20 mg / cm²).
3. Mo 1 ton (85 % enriched in ¹⁰⁰Mo by centrifugal separation of MoF₆ gas).
4. Total 4 units, Mo 1 ton (¹⁰⁰Mo 0.85 t).
One unit 2.2m - 2.2m - 2 m, 260 modules.
One module 2.2 m-2.2 m-7.6 mm.

