L'esperimento GERDA

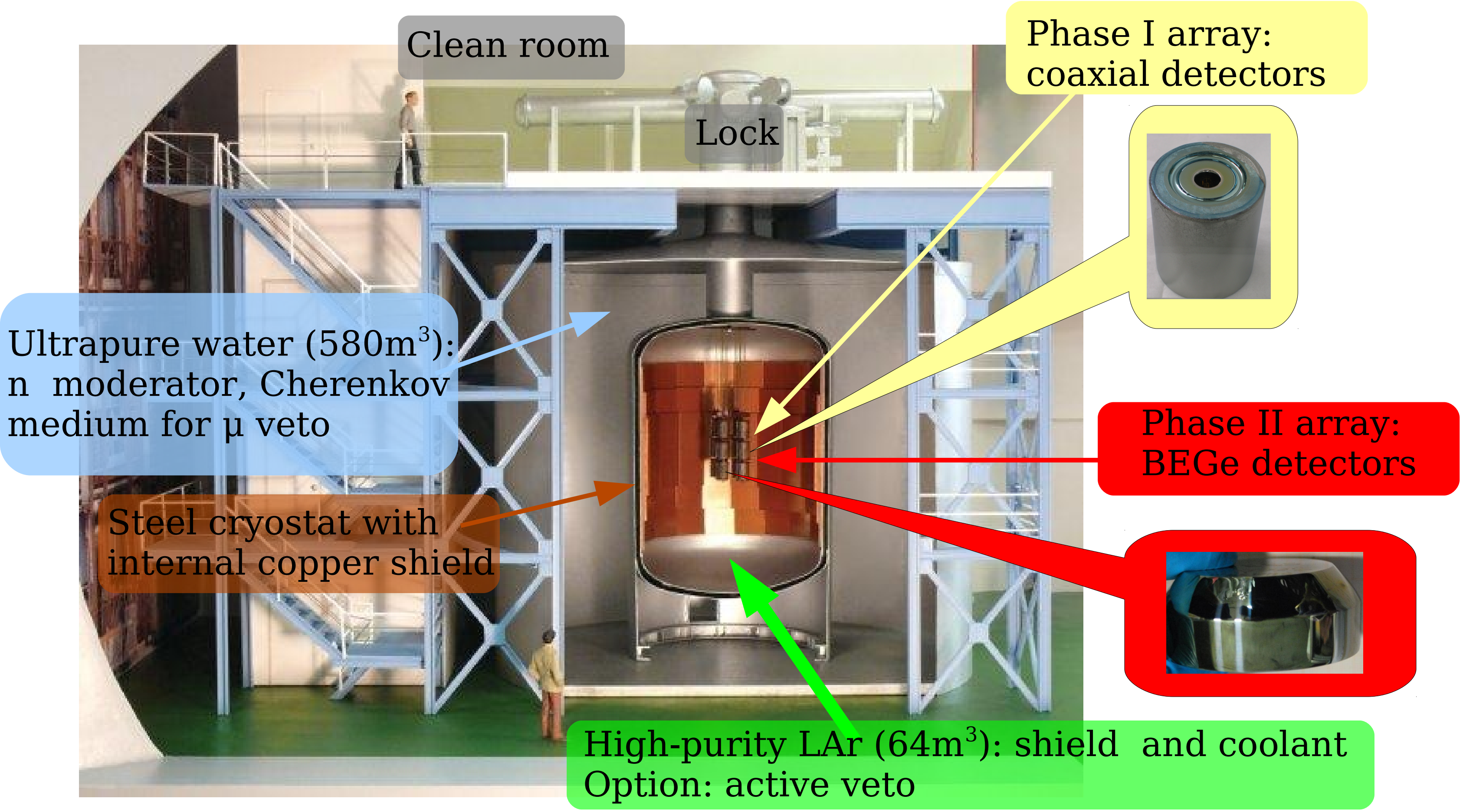
Riccardo Brugnera

Sommario:

- L'apparato in breve
- Fase I
- verso la Fase II
- Anagrafica
- Richieste

Gerda @ LNGS: Background reduction

- Graded shielding against ambient radiation
- Rigorous material selection, avoid exposure above ground for detectors



The Gerda experiment for the search of $0\nu\beta\beta$ decay in ^{76}Ge

Eur. Phys. J. C (2013) 73:2330

Fine della Fase I:

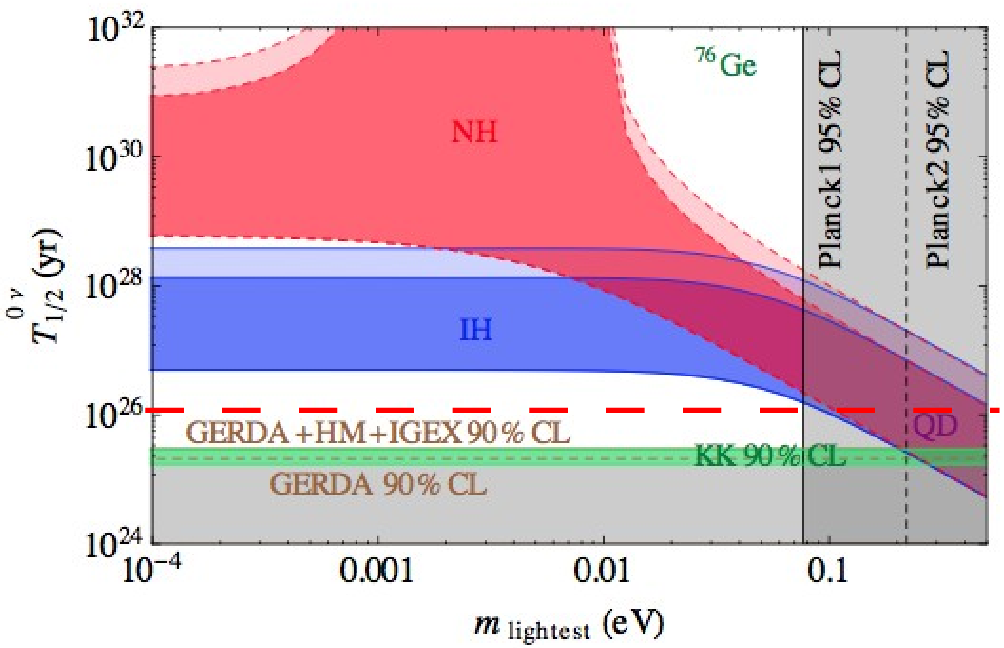
l'articolo è stato pubblicato:
PRL 111 (2013) 122503

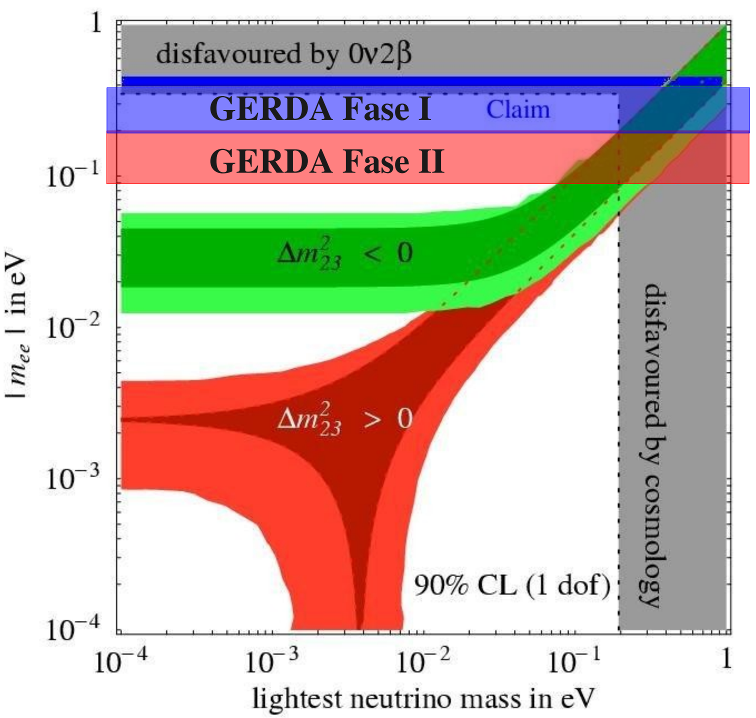
- **Raggiunti gli obbiettivi di GERDA per la Fase I**
  - BI dopo la PSD: 0.01 cts/(keV· kg · yr)
  - Esposizione: 21.6 kg · yr
- **Nessun segnale di $0\nu\beta\beta$ al $Q_{\beta\beta}$= 2039 keV; best fit $N^{0\nu}$ = 0**
  - L'ipotesi H_0 con solo bkg molto favorita
  - Il claim è fortemente sfavorito (indipendentemente da NME e dal processo fisico)
- **Bayes factor / p-value**
  - **GERDA** $\approx 10^{-2}$
  - **GERDA** + IGEX + HdM $\approx 10^{-4}$
- **Limiti su $T^{0\nu}_{1/2}$**
  - **GERDA: $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$ yr (90% C.L.)**
  - **GERDA** + IGEX + HdM: **$T^{0\nu}_{1/2} > 3.0 \cdot 10^{25}$ yr (90% C.L.) ($< m_{ee} > < 0.2 – 0.4$ eV)**
- Risultati raggiunti dopo soli 21.6 kg · yr di esposizione, grazie ad un **fondo molto basso**: conteggi di bkg in una finestra di $\pm 2\,\sigma$ dopo i tagli di analisi:

  0.01 cts/(mol· yr) (cf. EXO: 0.07, KL: 0.67)
- **… ed ora inizia la transizione verso la Fase II**

Fase II: gli obbiettivi

- raggiungere un BI ~ 10^{-3} cts/(keV· kg· yr)
- esposizione ~ 100 kg·yr ⟶ $\mathbf{T^{0\nu}_{1/2} > 1.3 \cdot 10^{26}}$ **yr**
- $<m_{\beta\beta}> \leq$ 0.09-0.15 eV





Alcuni punti chiave della Fase II

- **aumento della massa**: 30 rivelatori BEGe arricchiti (**20.1 kg**)
  - già prodotti dalla Canberra Olen
  - completamente provati ad Hades (Belgio)
  - primo campione di BEGe già impiegati nella Fase I
  - tutti e 30 BEGe ai LNGS
- **riduzione del background di un fattore ~10 rispetto alla Fase I**
  - bonding dei rivelatori e nuovi holders (meno radioattivi)
  - nuovi cavi di segnale e di HV (meno radioattivi)
  - nuovo FE meno radioattivo e con caratteristiche ottimizzate per i nuovi rivelatori
  - PSA discrimination
  - **liquid argon veto instrumentation**
- **nuovo lock**

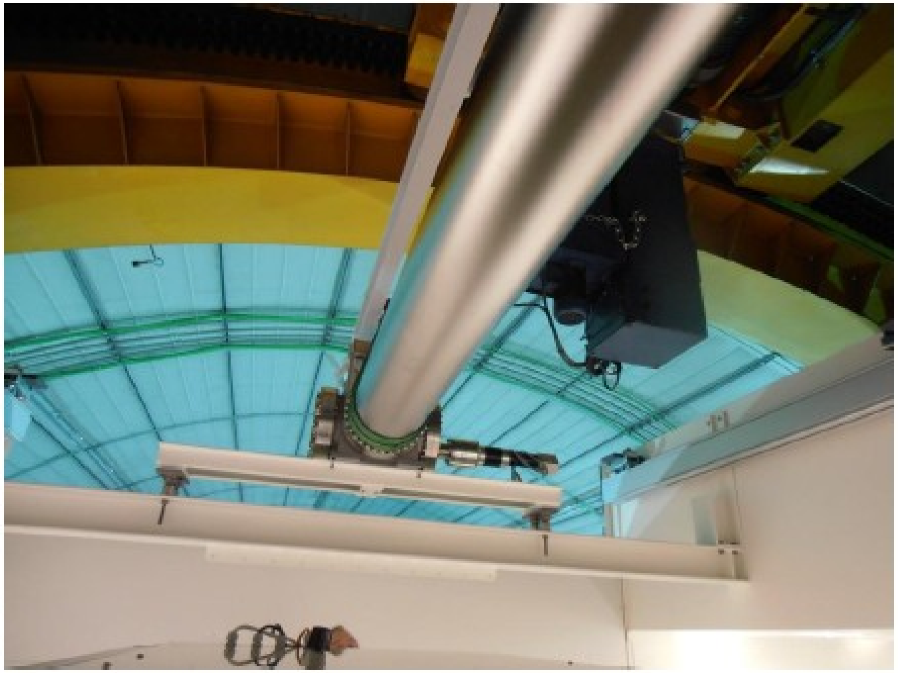
Il Lock di Fase II

- è arrivato ai LNGS ed è stato installato

Il Lock di Fase II

Positioning with vertical tube

Placing motor support

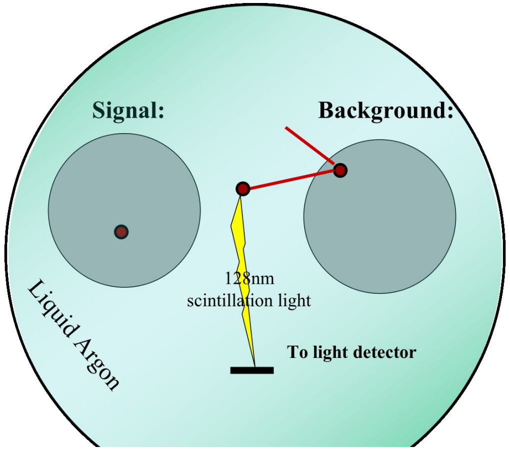


- New shutter support now secured to the floor (HEB700 beam)
  - Bellows can be loosened

Il Lock di Fase II

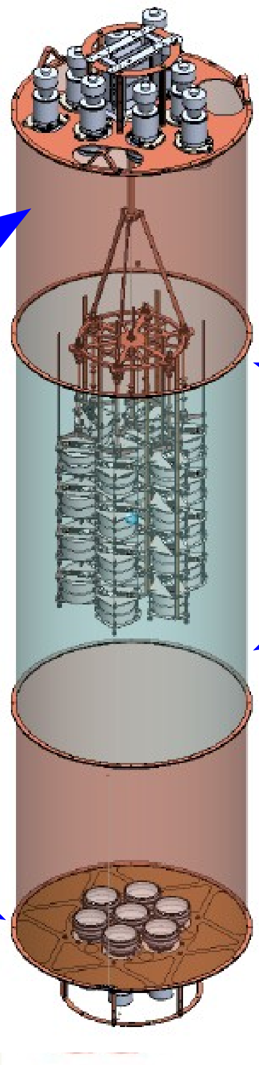
- tubo verticale dentro la glove box

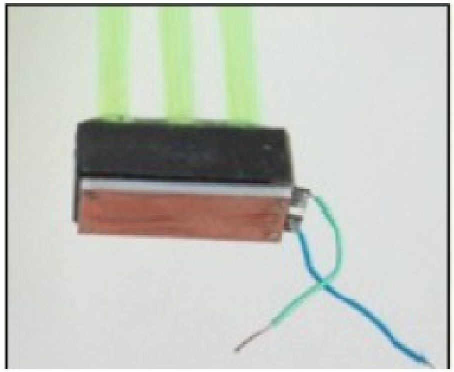
LAr instrumentation



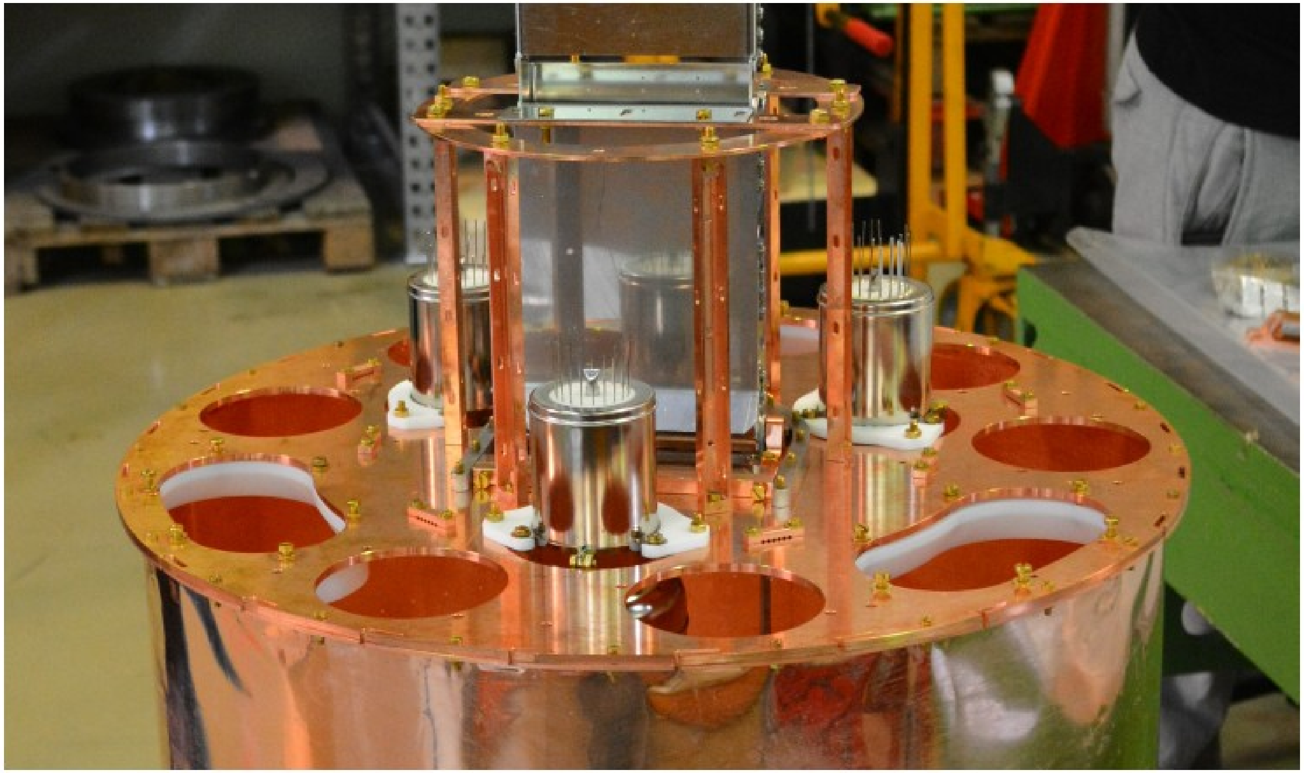
Cilindro centrale:
SiPMs + WLS Fibers

Top/Bottom: PMTs





LAr instrumentation



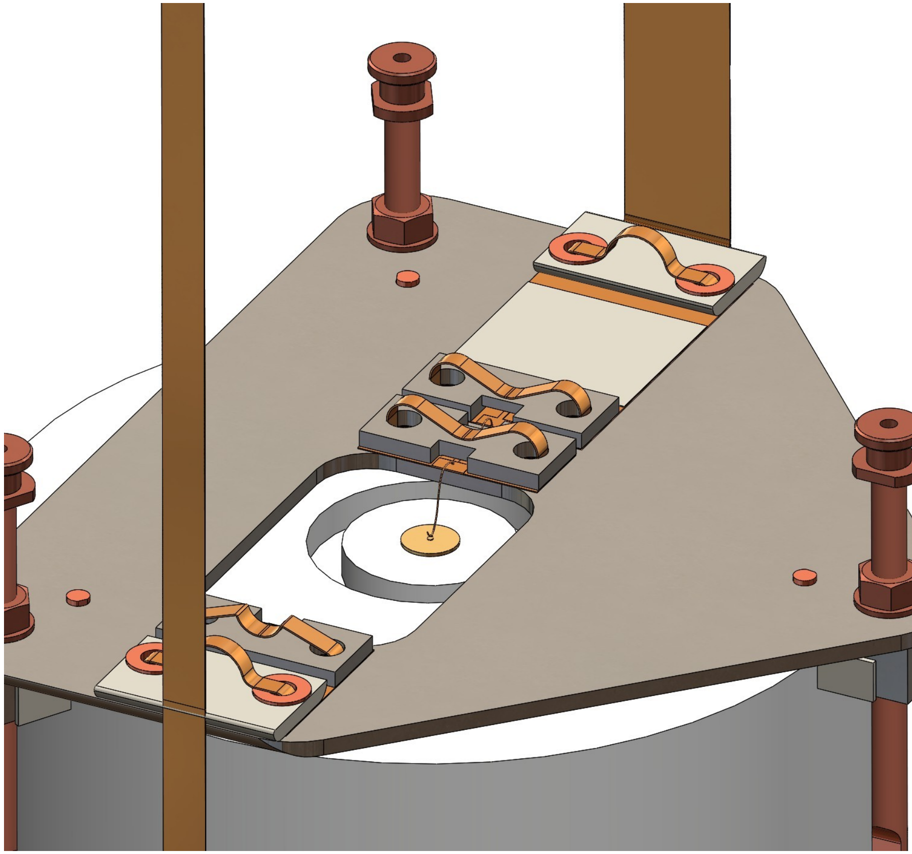
top plate

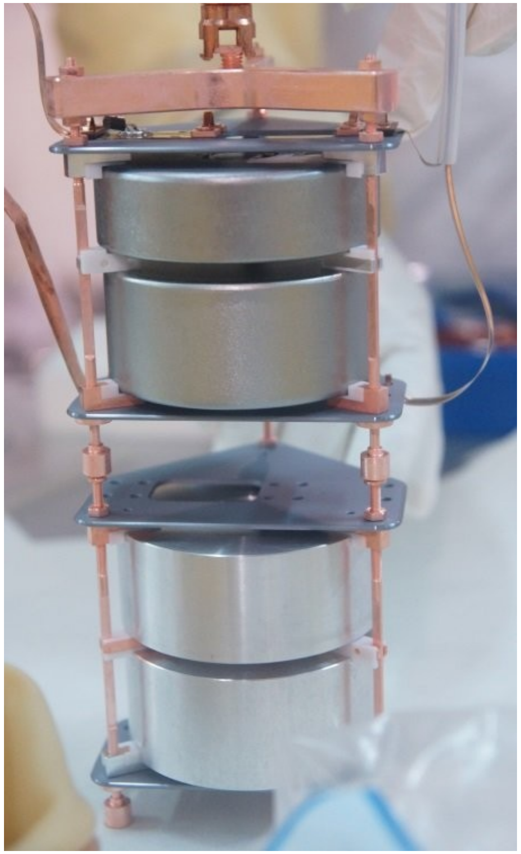
R11065-20 MOD

La parte dei PMTs è pronta.

… invece le fibre sono in ritardo

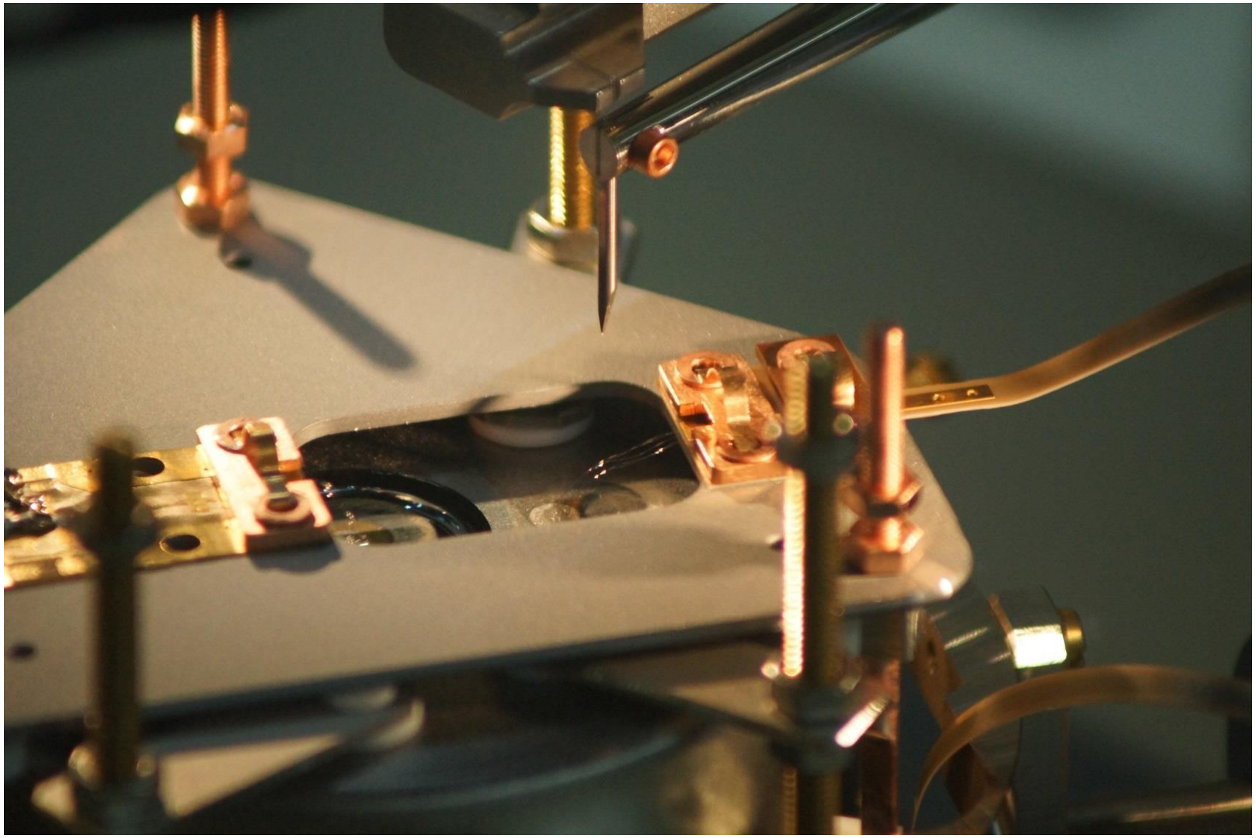
Nuovi holders per i rivelatori





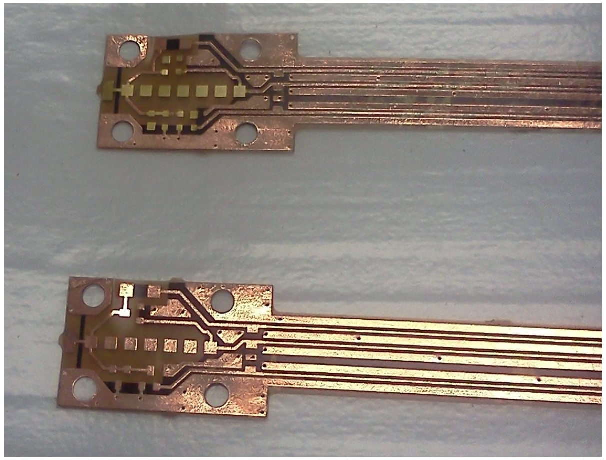
- Materiali: silicio "semiconductor-grade" + rame
- Un rivelatore semi-coax oppure due BEGe per unità

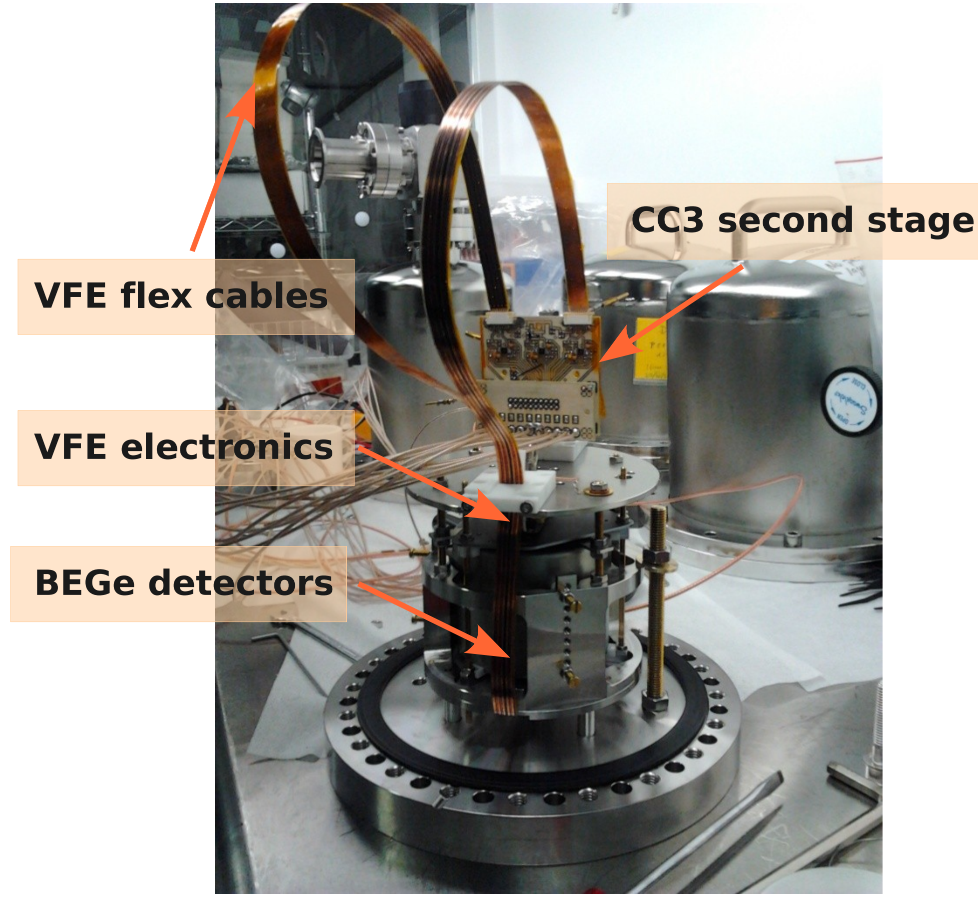
Bonding dei rivelatori



- Pads in Al sui rivelatori permettono contatti wire-bonding

Cavi Very-Front-End + FE

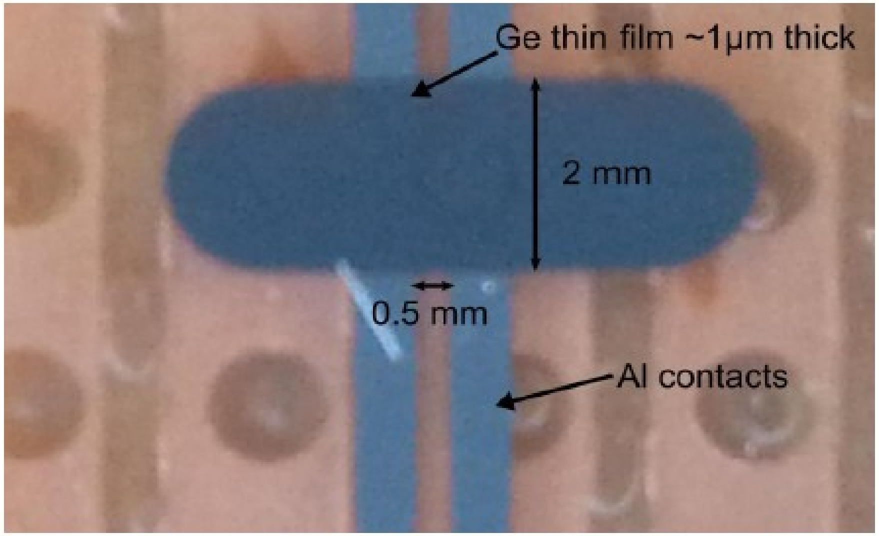




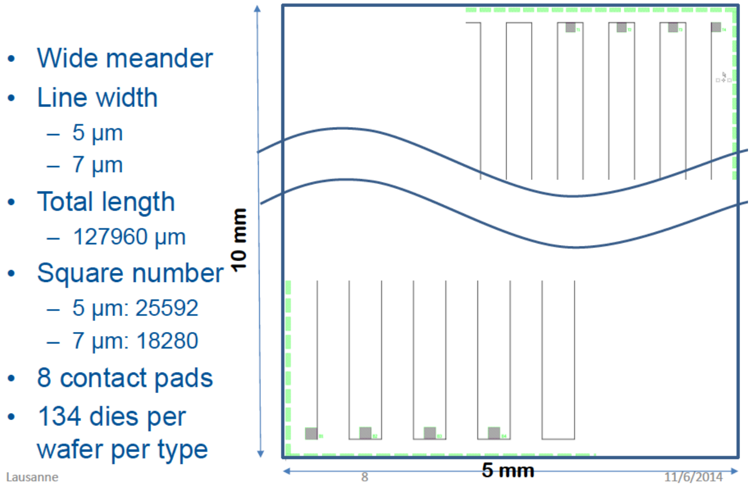
- Cavi flessibili in cuflon vicino ai rivelatori
- FET e feedback network “bondati” direttamente sul cavo
- Vari tests di integrazione in progress
- Problemi con le resistenze di feedback (capacità parassite!), R&D su nuove resistenze
- Ritardi nella produzione finale !

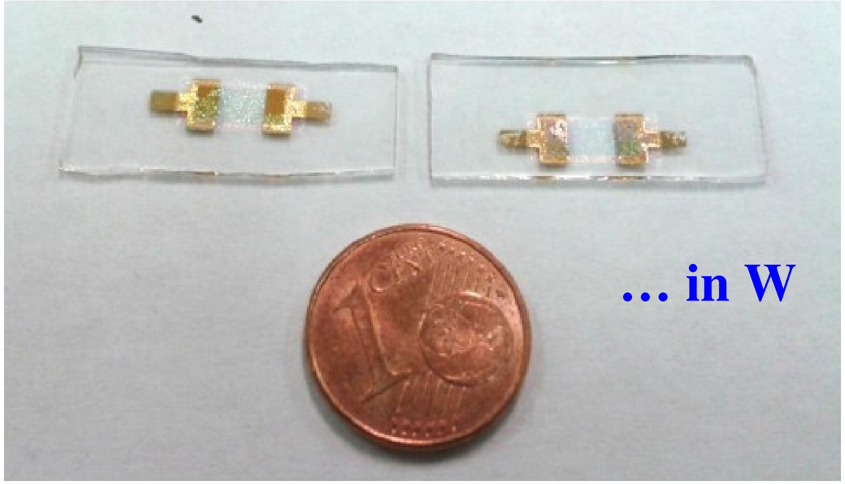
R&D sulle resistenze per il FE

… in Ge amorfo



… in TiN





… in W

- ◆ risultati ancora insufficienti
- ◆ il lavoro continua

Possibile cronogramma

- **Agosto/Settembre 2014**: Inserzione del sistema di Veto con PMTs
- **Settembre/Ottobre 2014**: Inserzione del sistema di Veto con PMTs + una stringa di rivelatori al Ge.
- **Fine 2014**: Inserzione sistema completo (PMTs +Fibre+Tutti i rivelatori a Ge).

Attività di Padova nel 2015

- Ulteriori analisi dati di Fase I (^{42}Ar, ...)
- Analisi dati di HADES (responsabile A. Garfagnini)
- Test a Legnaro sul Tavolo Compton
- Manutenzione e sviluppo Slow Control + sistema di rete di GERDA in Sala A
- Partecipazione al commissioning della Fase II (Run Team)
- Vari duties all'interno della Collaborazione
- ...

Richieste finanziarie

Missioni	25.0 keuro
Consumo	7.0 keuro
Inventario	7.0 keuro
Apparati	16.0 keuro

Richieste ai Servizi della Sezione

Officina Meccanica	2 m.u.
Progettazione Mecc.	2 m.u.
Officina elettronica	2 m.u.
Calcolo e reti	2 m.u.

Anagrafica

Bettini A.	PO	0%
Brugnera R.	PA	70%
Garfagnini A.	RU	20%
Hemmer S.	PostDoc	100%
Lippi I.	Ric. INFN	60%
Medinaceli E.	PostDoc	70%
Sada C.	RU	100%
C. Sirignano	RU	10%
Stanco L.	Dir. di Ric.	20%
Von Sturm K.	dott.	100%

10 persone **5.5 FTE**

backup slides

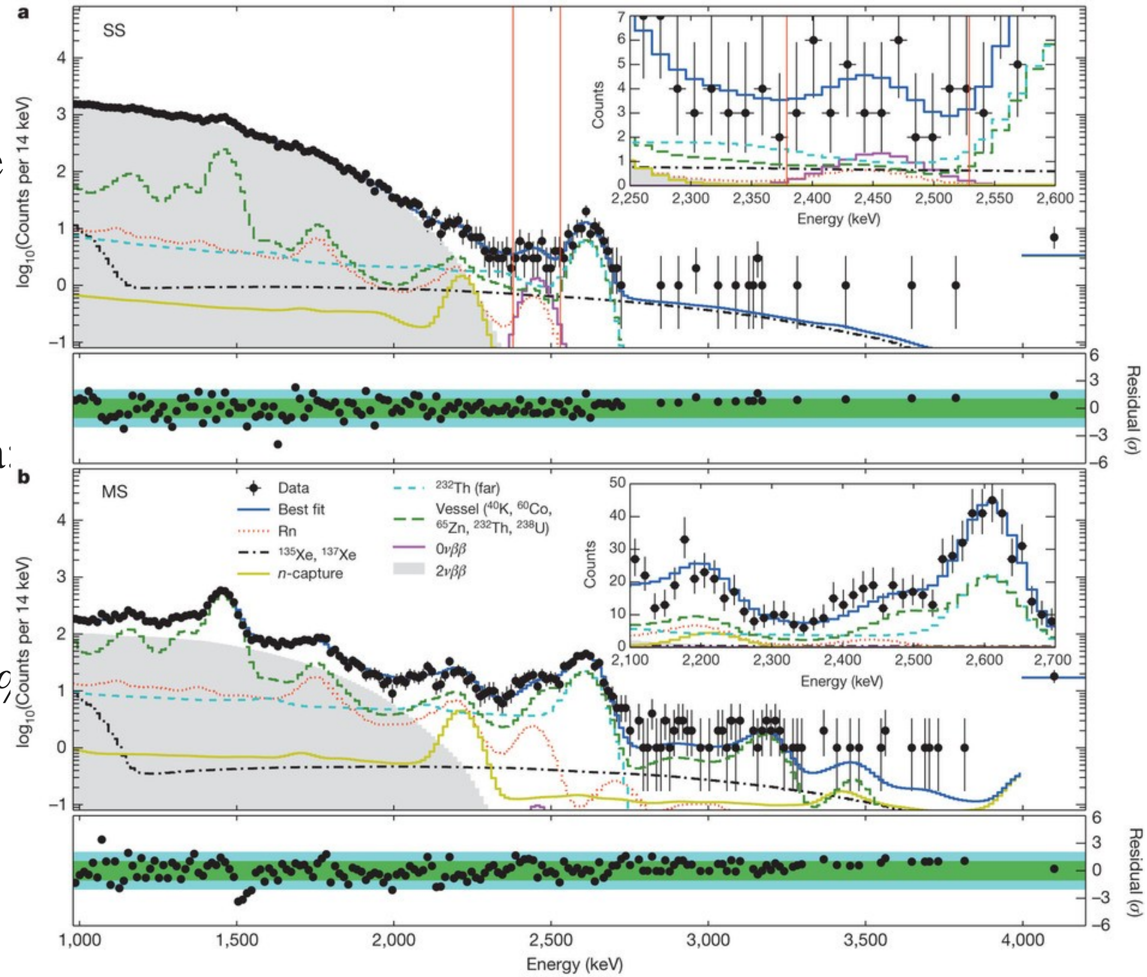
EXO-200

- Statistica riguardante 2 anni di presa dati: ~130 kg·yr 4 volte la precedente pubblicazione

- Miglioramenti nell'analisi e risoluzione del rivelatore

- Sensibilità sulla half-life migliorata: $1.9 \cdot 10^{25}$yr

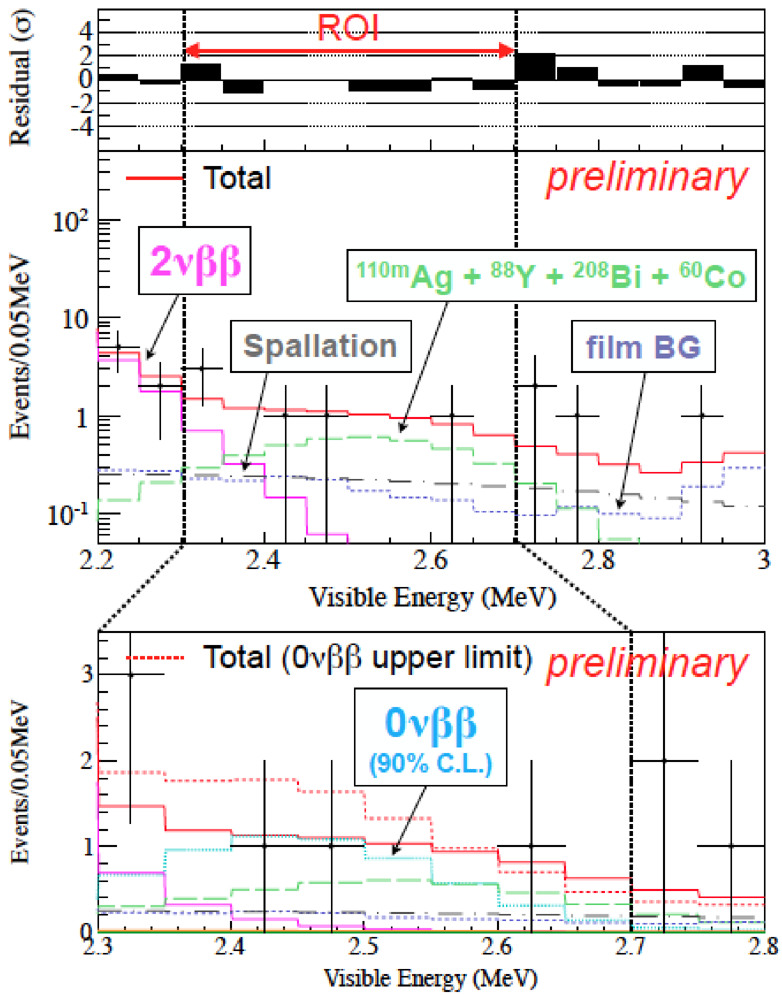
- Nessun segnale di doppio beta: limite sull'half-life **$1.1 \cdot 10^{25}$yr** al 90% C.L. ($1.6 \cdot 10^{25}$yr al 90% C.L.)



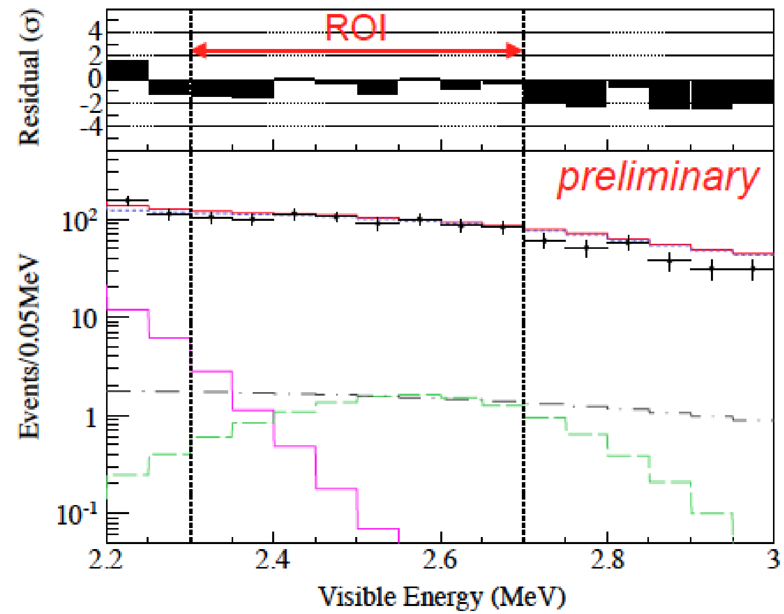
KamLAND-Zen

Fit to Energy Spectra for $0\nu\beta\beta$

Internal (R < 1.0 m)



External (1.0 < R < 2.0 m)



Fit to Energy-Volume 2D spectra

Limits on $0\nu\beta\beta$ at 90% C.L.

< 17.0 events/day/kton-LS

↓

$T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr

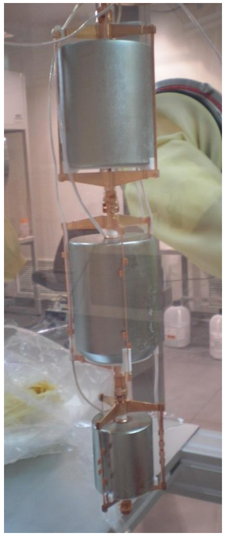
KamLAND-Zen

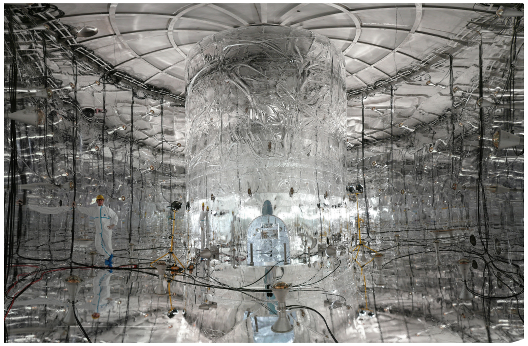
- The overall reduction factor for the ^{110m}Ag background including the decay is more than 10.
- New results from KamLAND-Zen are presented.

KamLAND-Zen limits on $0\nu\beta\beta$ at 90% C.L.

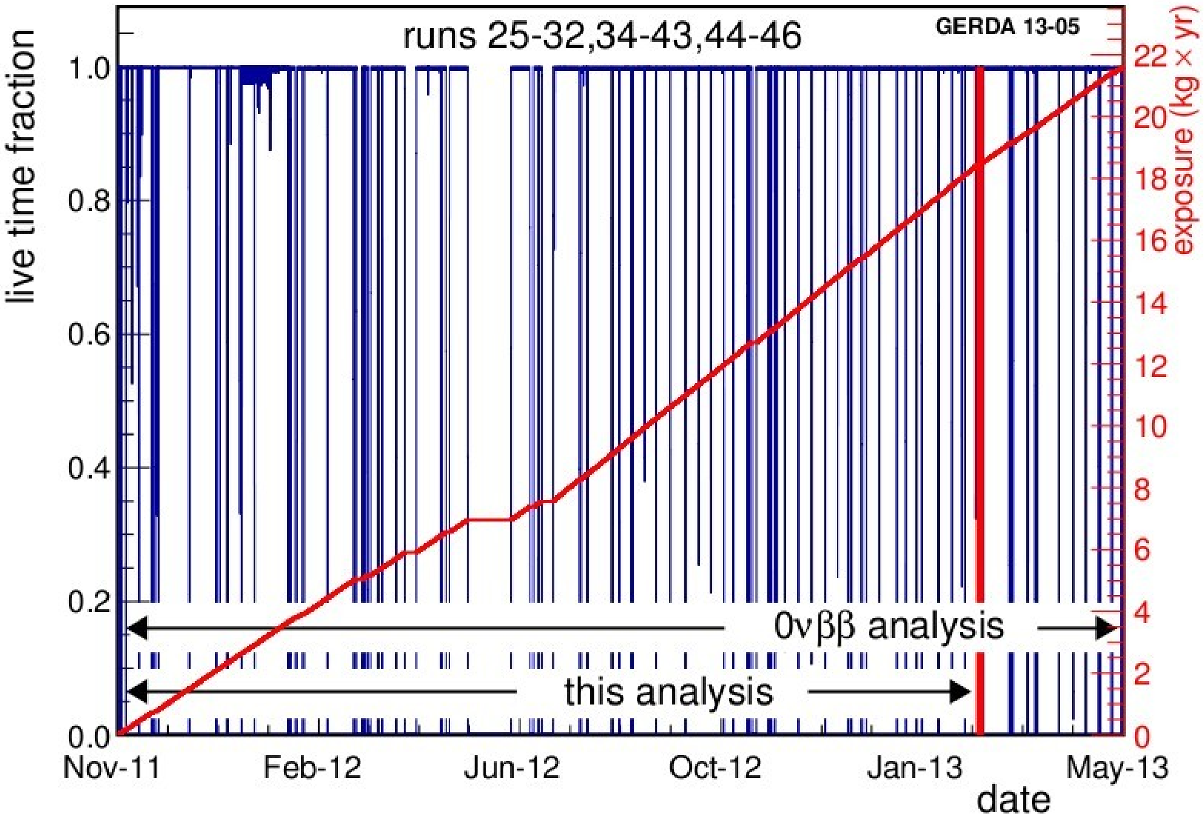
Phase 1 (213 days)	$T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr	*preliminary*
Phase 2 (115 days)	$T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr	
Combined	**$T^{0\nu}_{1/2} > 2.6 \times 10^{25}$ yr**	

The GERDA experiment





Dati raccolti durante la Fase I



Fase I:

9/11/2011

21/05/2013

Exposure:

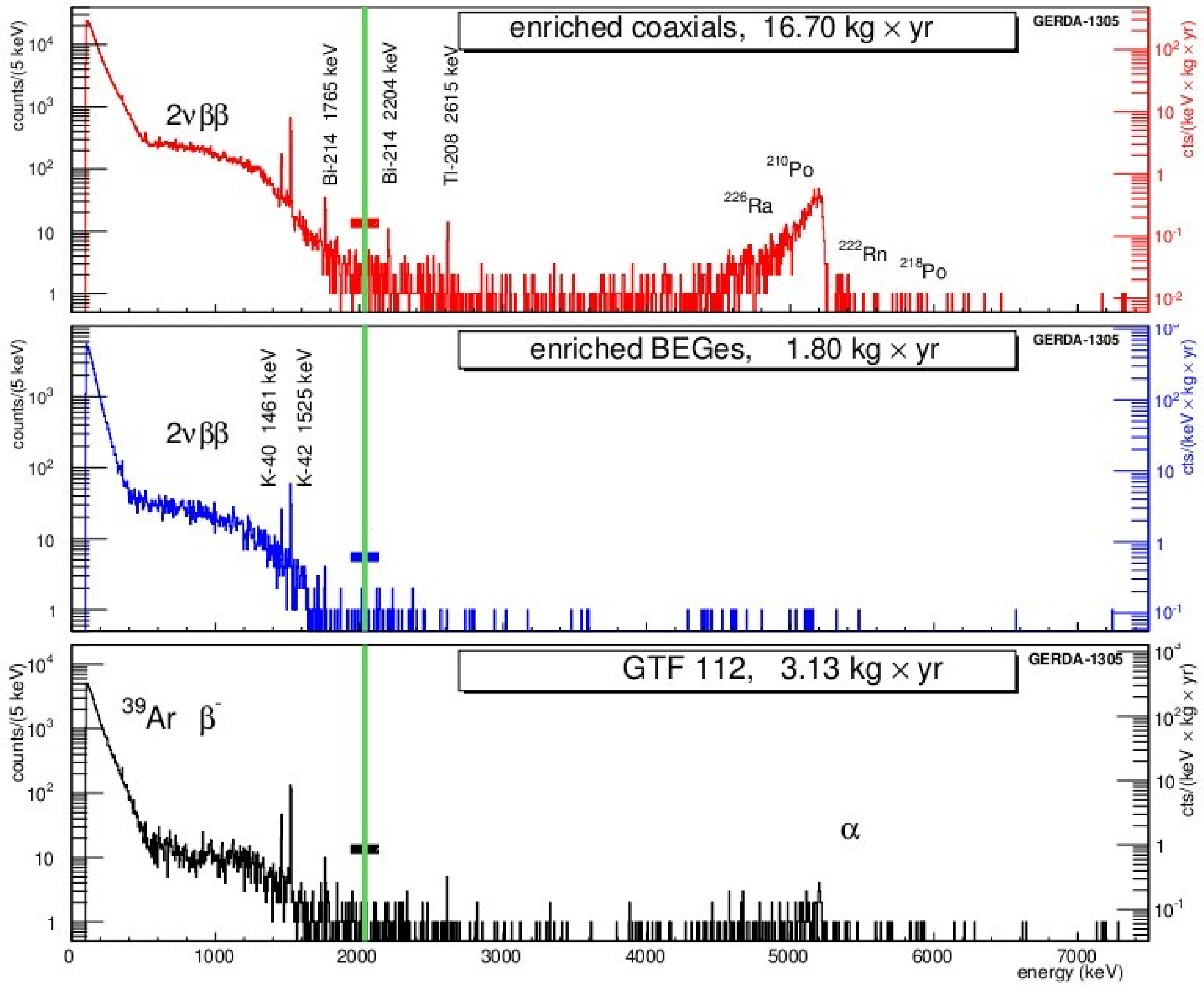
21.6 kg·yr

19.2 kg·yr (coax)

2.4 kg·yr (BEGe)

\+

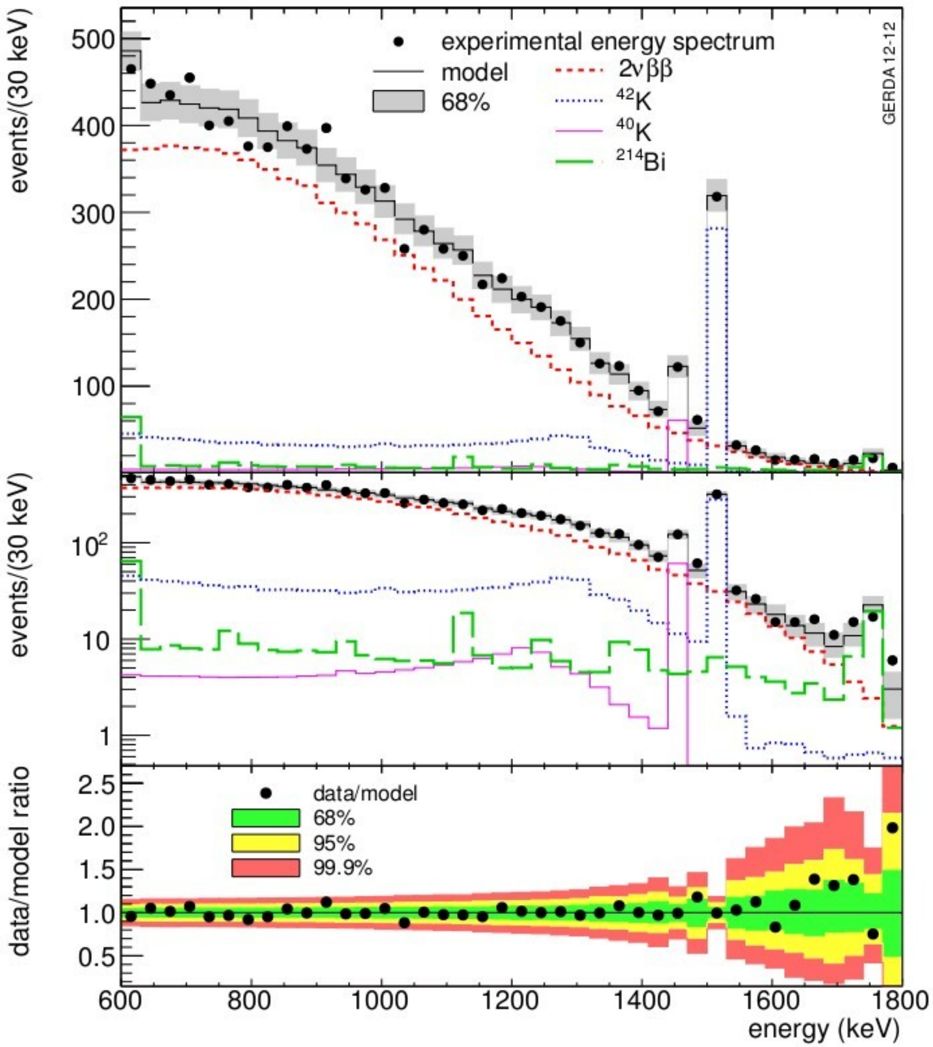
4.0 kg·yr (Ge naturale)

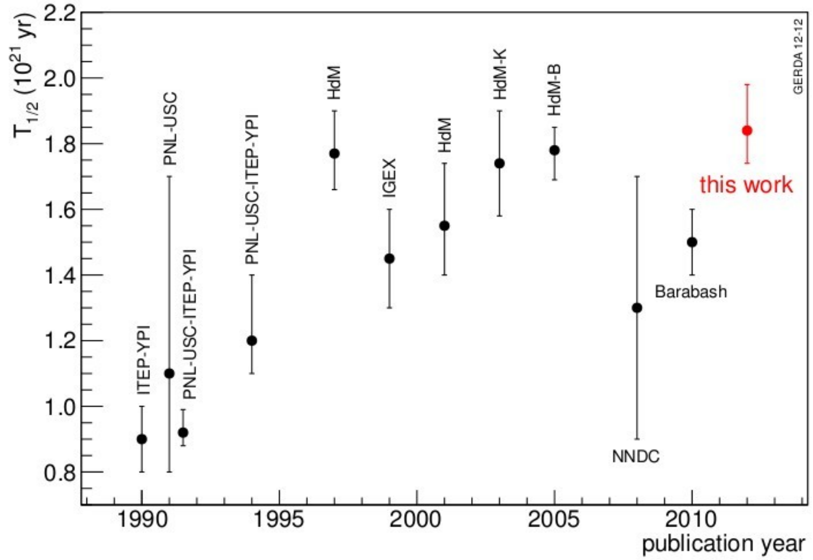


blinding fino al 1/05/2013: 40 keV attorno al $Q_{\beta\beta}$ = 2039 keV

blinding dal 1/05/2013 al 21/05/2013: 10 keV per i coax + 8 keV per i BEGe

unblinding finale: 13/06/2013



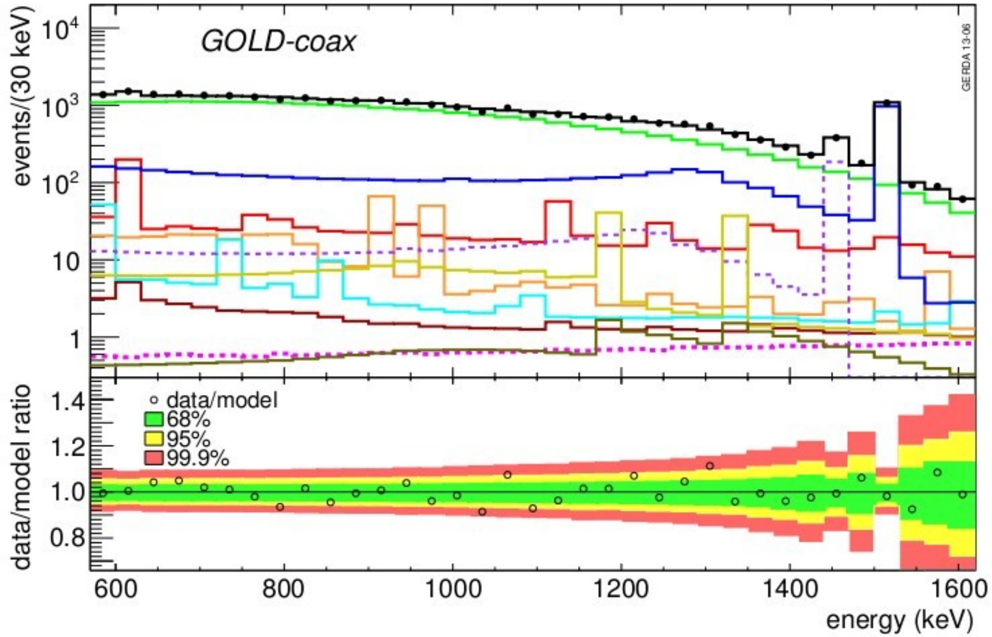


Con i primi 5.04 kg·yr:

$$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08\ fit}\ {}^{+0.11}_{-0.06\ syst}) \cdot 10^{21}\ yr$$

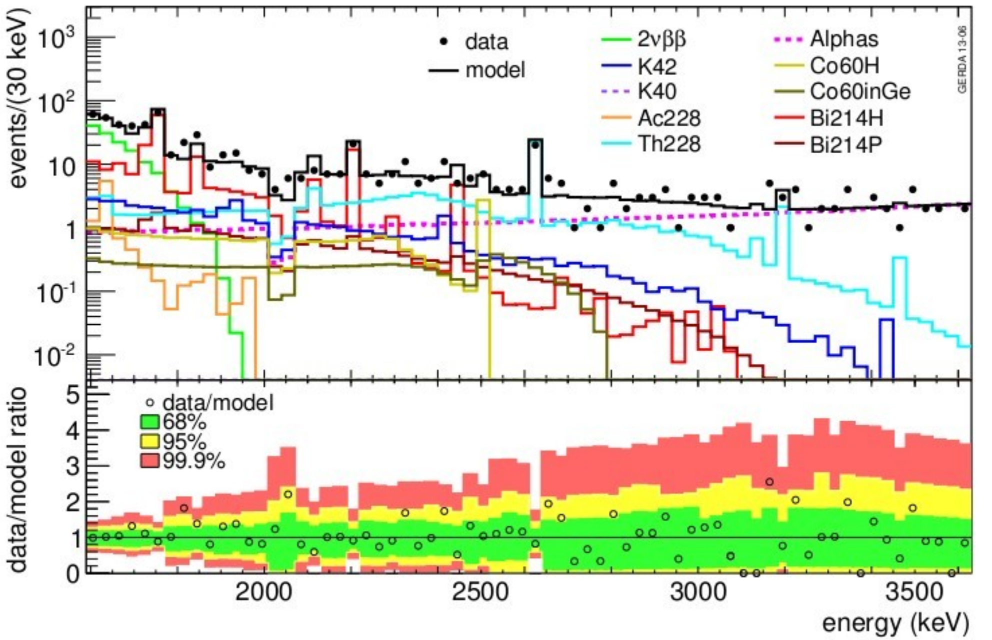
Signal to background: 4:1

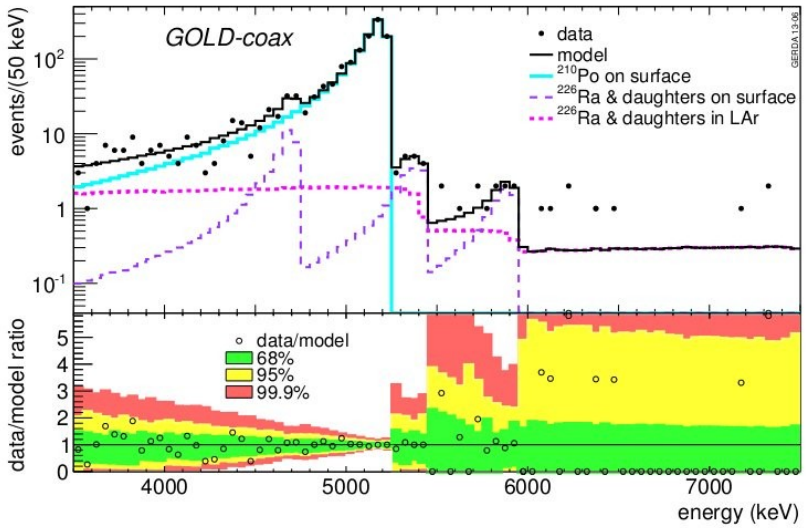
The GERDA collaboration
J. Phys. G 40 (2013) 035110

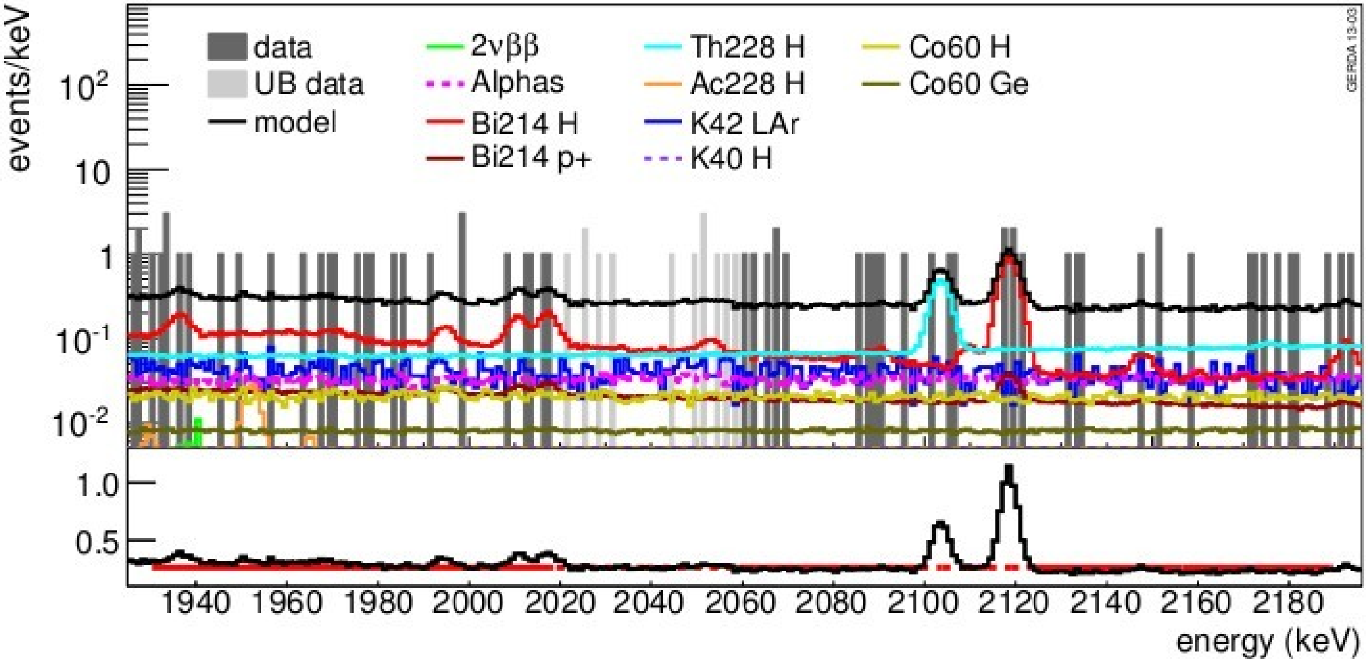


The background in the neutrinoless double beta decay experiment GERDA, arXiv: 1306.5084v1

Esposizione impiegata: **15.4** kg·yr







Background index al $Q_{\beta\beta}$ dal modello: $\mathbf{1.85^{+0.08}_{-0.09}}$ **10^{-2} cts/(keV·kg·yr) GOLD-coax**

$\mathbf{3.81^{+0.06}_{-0.06}}$ **10^{-2} cts/(keV·kg·yr) BEGe**

Per i coassiali i fondi principali al $Q_{\beta\beta}$ sono:

^{214}Bi (holders), ^{228}Th (holders), ^{42}K (LAr), α (superficie p+)

Per i BEGe i fondi principali al $Q_{\beta\beta}$ sono:

^{42}K (superficie n+), ^{214}Bi (holders), ^{228}Th(holders), ^{42}K (Lar), α (superficie p+)

Background index al $Q_{\beta\beta}$ dal modello: **$1.85^{+0.08}_{-0.09}$ 10^{-2} cts/(keV·kg·yr) GOLD-coax**

$3.81^{+0.06}_{-0.06}$ 10^{-2} cts/(keV·kg·yr) BEGe

Background index al $Q_{\beta\beta}$ dai dati: **$1.75^{+0.26}_{-0.24}$ 10^{-2} cts/(keV·kg·yr) GOLD-coax**

$3.61^{+1.32}_{-0.97}$ 10^{-2} cts/(keV·kg·yr) BEGe

Usando l'exposure dei GOLD-coax (17.90 kg·yr) e il loro BI la sensibilità vale:

$T^{0\nu}_{1/2} > 1.9 \cdot 10^{25}$ yr (90% C.L.) analisi frequentista

(mediana del 90% percentile della profile likelihood)

$T^{0\nu}_{1/2} > 1.7 \cdot 10^{25}$ yr (90% C.I.) analisi bayesiana

(mediana del 90% percentile della probabilità a posteriori marginalizzata $p(T^{0\nu}_{1/2}|\text{spectrum},H)$

La sensibilità di GERDA è circa 10% migliore perchè c'è più esposizione (SILVER-coax + BEGe). Ulteriore miglioramento con la pulse shape discrimination.

Passi ulteriori verso la pubblicazione ...

Pubblicazione dell'articolo sulla Pulse Shape Discrimination (entro la settimana)

… **seminario** di S. Schonert al GS a **metà luglio**
… e contemporanea pubblicazione dell'**articolo sullo $0\nu\beta\beta$** prima di EPS2013.

Fase II: gli obbiettivi

- raggiungere un BI ~ 10^{-3} cts/(keV· kg· yr)
- esposizione ~ 100 kg·yr ⟶ $\mathbf{T^{0\nu}_{1/2} > 1.3 \cdot 10^{26}}$ **yr**
- $\langle m_{\beta\beta} \rangle \leq$ 0.09-0.15 eV

Stato della Fase II

- **aumento della massa**: 30 rivelatori BEGe arricchiti (**~ 20 kg**)
  - già prodotti dalla Canberra Olen
  - completamente analizzati ad Hades (Belgio)
  - i primi 5 BEGe di fase II già impiegati nella Fase I per quasi 1 anno

- **riduzione del background di un fattore 10 rispetto alla Fase I**
  - nuovi cavi di segnale e HV con più basso budget radioattivo
  - nuovo FE cards meno radioattivo e con caratteristiche ottimizzate per i nuovi rivelatori
  - Pulse Shape Discrimination
  - **liquid argon veto instrumentation**

- **nuovo lock system** per l'inserimento dei rivelatori nel criostato

The HEROICA project

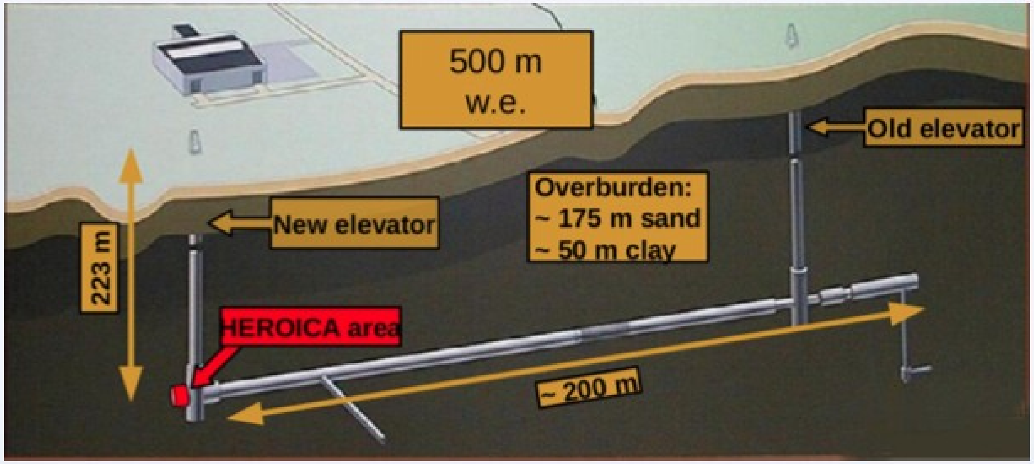
Resp. A. Garfagnini

Production of 30 new ^{enr}Ge BEGe detectors (~20 kg)

- **Do all detectors meet quality requirements?**
- **Determine all diode parameters (resolution, active volume, depletion voltage,...) before deployment in GERDA**

HEROICA (Hades Experimental Research Of Intrinsic Crystal Appliances):
A facility for fast and precise characterization of Ge detectors

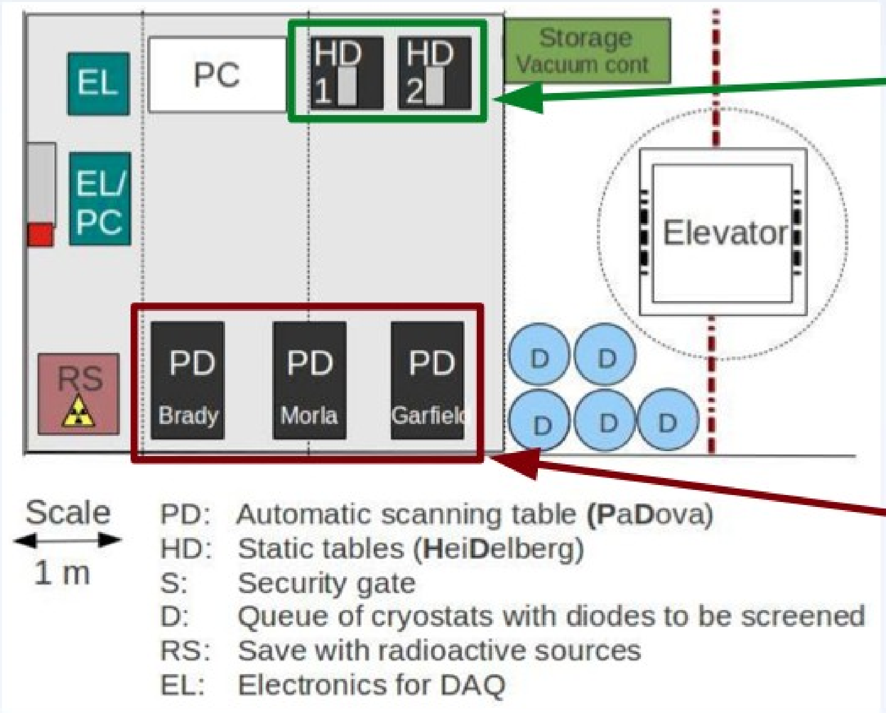
Located at HADES (High Activity Disposal Experimental Site) at Belgian Nuclear Research Center SCK·CEN, Mol, Belgium:



- 223 m clay and sand overburden (500 m w.e.) minimize cosmic radiation
- Vicinity to diode manufacturer (~20 km)
- Also used for diode storage

The HEROICA setups

Resp. A. Garfagnini



2 fixed-source measurement setups

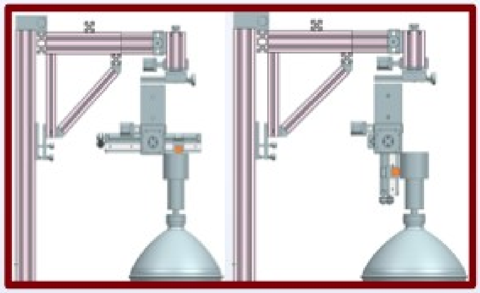
- Lead castle with copper lining for screening
- Available sources: ^{60}Co, ^{228}Th, ^{241}Am, ^{133}Ba

3 scanning setups

- Top and lateral surface scans (1mm / 1° step precision)
- Available sources: 5MBq ^{241}Am

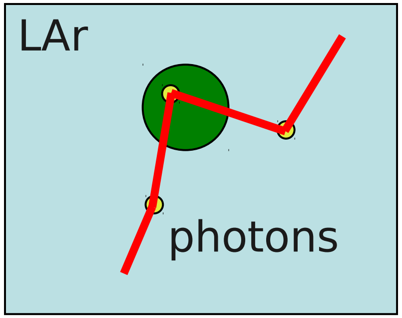
Fully equipped with DAQ systems (FADC, MCA), HV supplies and network for data transfer

Complete characterization of 2 detectors/week

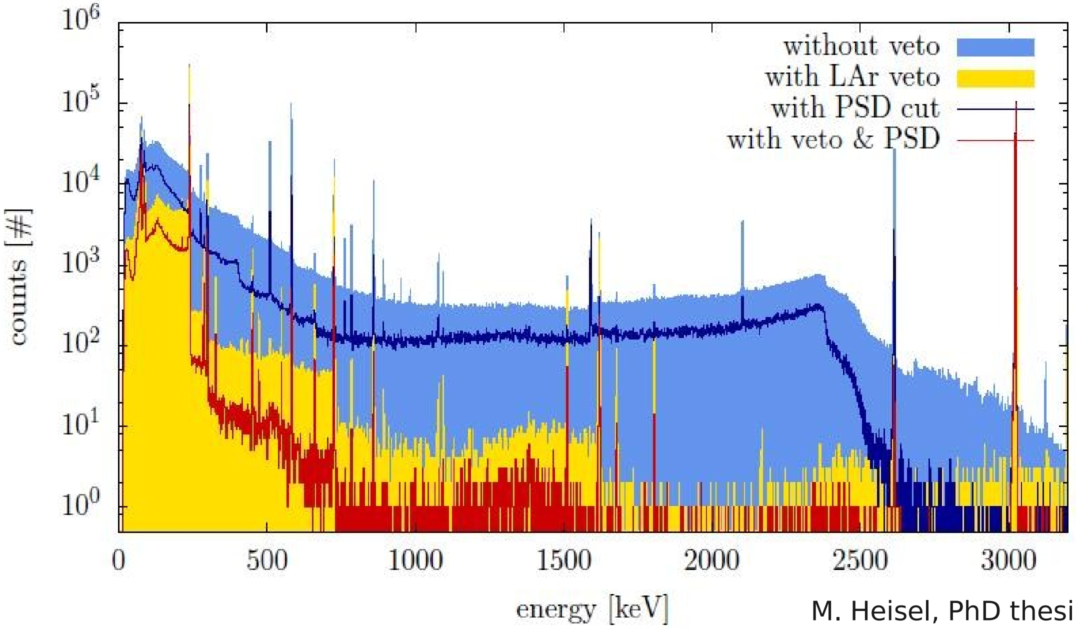


Status of the Phase II: LAr veto instrumentation

Detection of coincident LAr scintillation light to discriminate background



data from LARGE: a test facility at LNGS



M. Heisel, PhD thesis
M. Agostini et al., J. Phys.: Conf. Ser. 375 (2012) 042009

Combining PSD of BEGe detector and LAr veto:
measured suppression factor at $Q_{\beta\beta}$, e.g. $\approx 10^3$ for a ^{228}Th calibration source inside cryostat.

Stato della Fase II

Tempistica:

- In luglio svuotamento della Water Tank: ispezione generale del criostato + riparazione di alcuni PMT

- In settembre tutti i rivelatori al GS

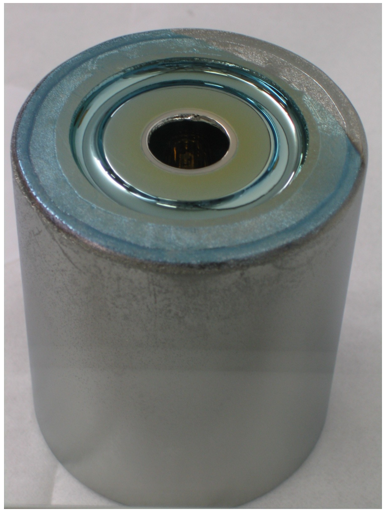
- In ottobre/novembre inizio delle operazioni di installazione del lock

Attività di Padova nel 2014

- Ulteriori analisi dati di Fase I (limiti sui Majoroni, ^{42}Ar)
- Analisi dati di HADES (responsabile A. Garfagnini)
- Ulteriori tests di caratterizzazione ad HADES
- Test a Legnaro sul Tavolo Compton
- Manutenzione e sviluppo Slow Control + sistema di rete di GERDA in Sala A
- Partecipazione al commissioning della Fase II (Run Team)
- Vari duties all'interno della Collaborazione
- ...

Ricercando con il ^{76}Ge

$$T^{0\nu}_{1/2} \sim \epsilon \cdot f \cdot \sqrt{\frac{M \cdot t_{run}}{BI \cdot \Delta E}}$$



Rivelatore a Ge closed-ended

$T^{0\nu}_{1/2}$: sensitivity to ...
ε: efficiency
f: abundance of 0νββ isotope
M: detector mass

t_{run}: measurement time
BI: background index
ΔE: energy resolution at $Q_{\beta\beta}$

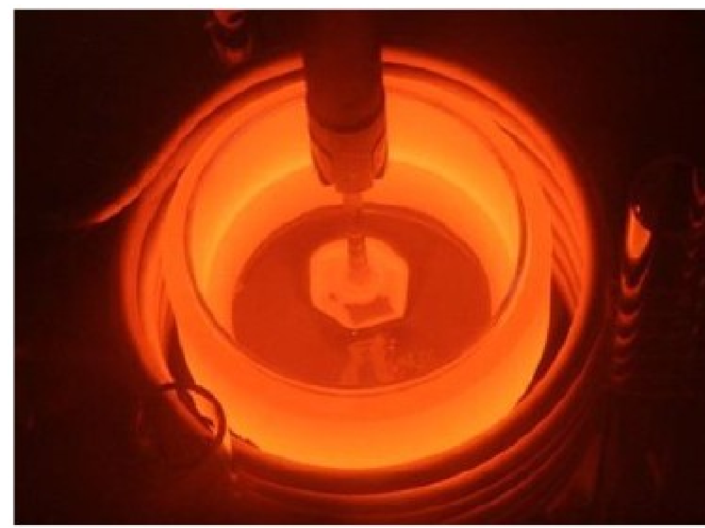
Advantages of Germanium:

- **High ε**: Source = Detector
- **Small instrinsic BI**: High purity Ge
- **Excellent ΔE**: FWHM ~ (0.1-0.2)%
- Well-established technology

Disadvantages of Germanium:

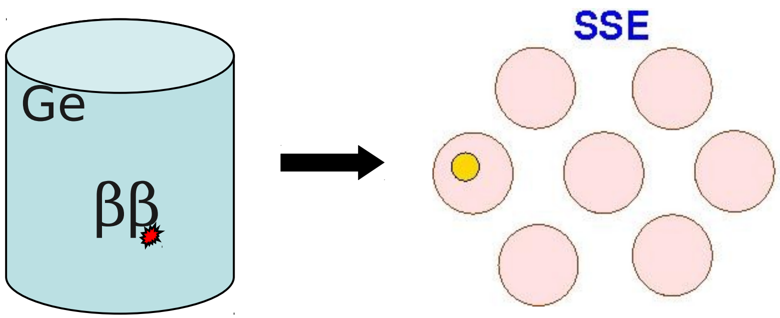
- at $Q_{\beta\beta}$= 2039keV more challenging to reach **low enough background**
- **Small f of ^{76}Ge:** 7.8% → Enrichment needed!
- Limited sources of crystal & detector manufacturers
- Small $G^{0\nu}(Q_{\beta\beta},Z)$

Arricchimento in ^{76}Ge



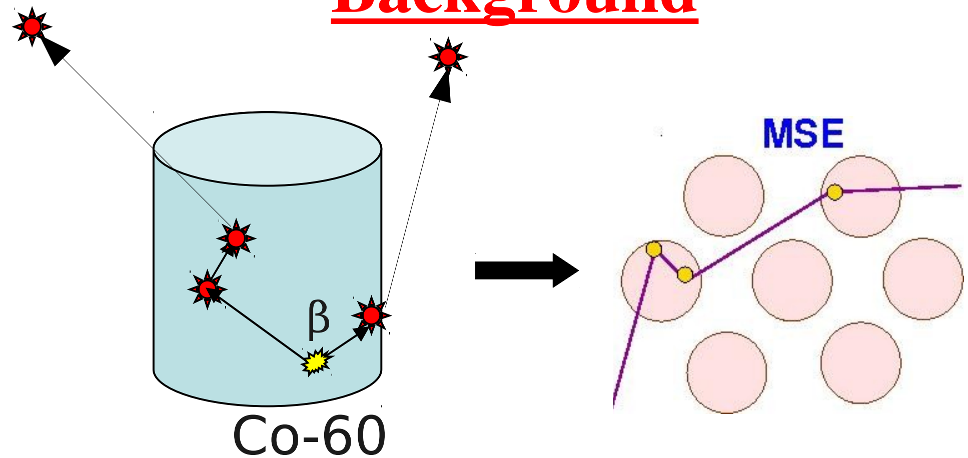
Background reduction

Signal



Point-like (single-site) energy deposition inside one HP-Ge diode (Range: ~ 1 mm)

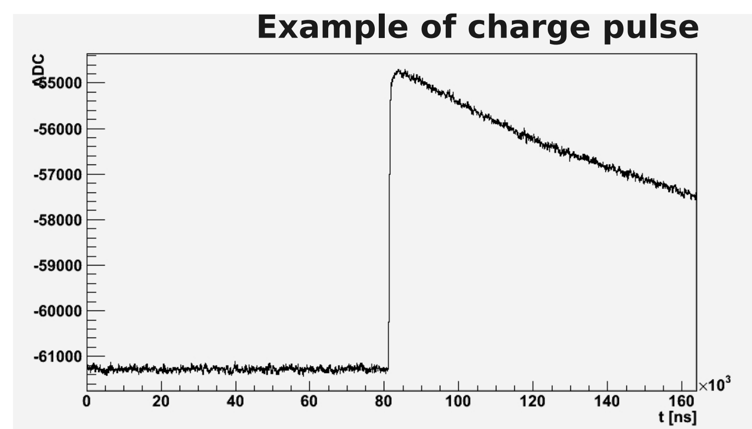
Background



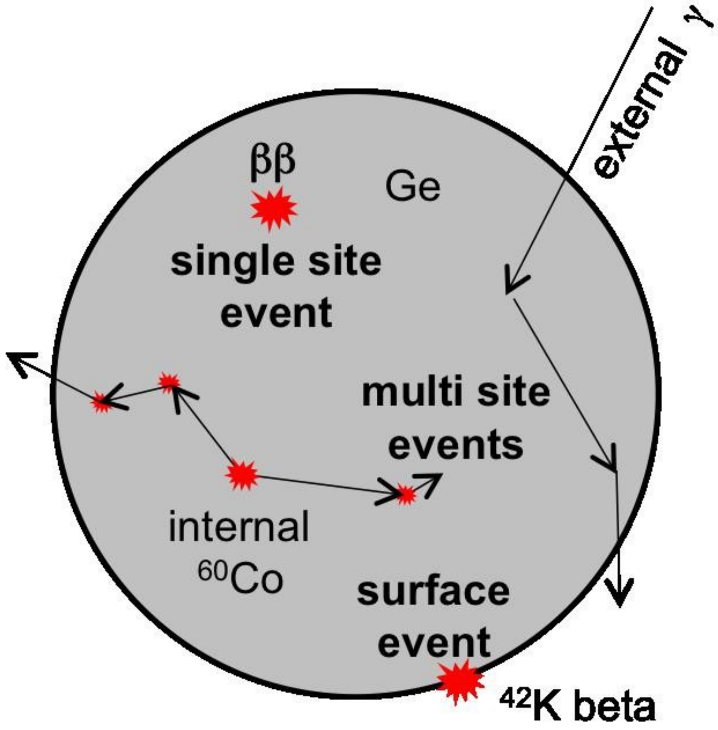
Multi-site energy deposition inside HP-Ge diode (Compton scattering)

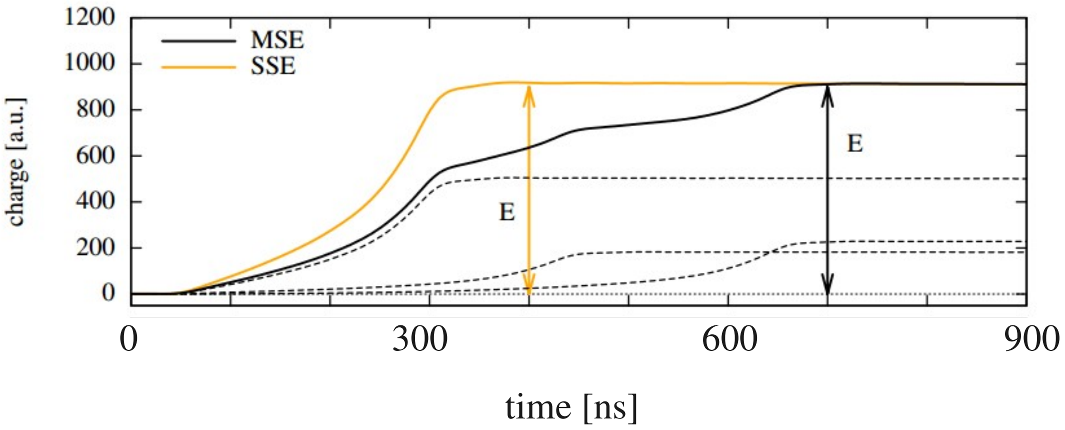
Signal analysis:

- anti-coincidence between detectors
- pulse shape analysis (PSA) with Phase II BEGe detectors



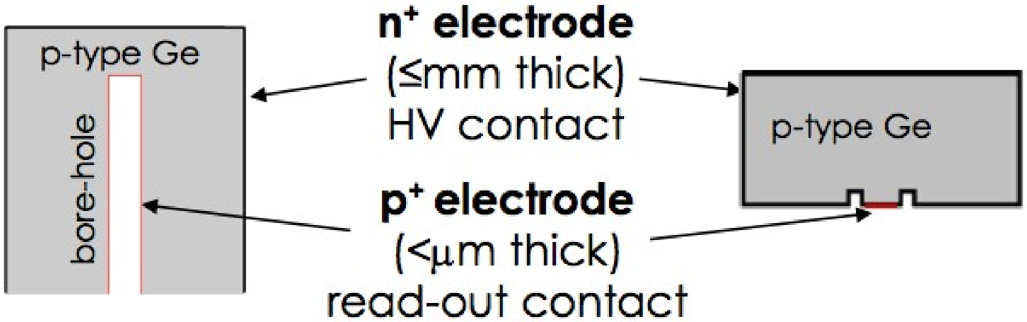
Background reduction





Modified Broad-Energy Ge detectors

GERDA Phase I: semi-coaxial Ge detector



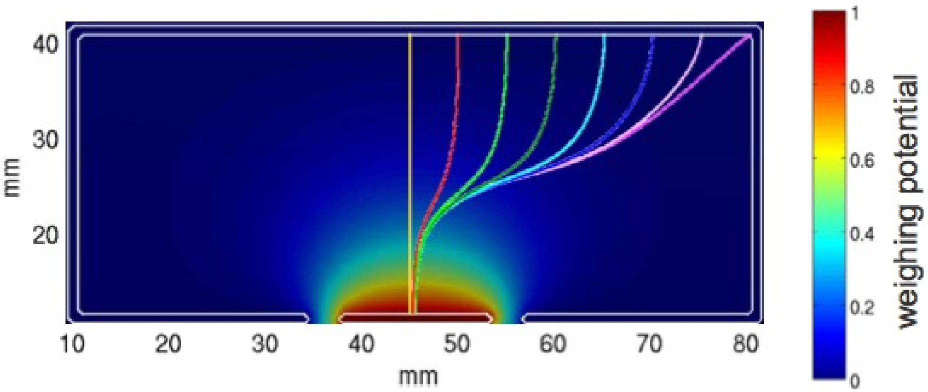
GERDA Phase 2: **modified BEGe detector**

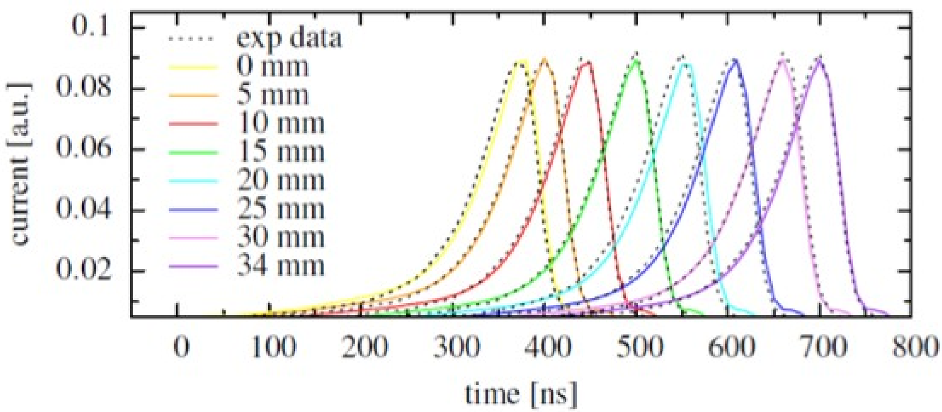
BEGe advantages:

1) smaller p+ electrode ⇒ less capacitance ⇒ **less noise** ⇒ **better energy resolution**

⇘

2) favourable internal electric field distribution ⇒ **powerful PSD capability**





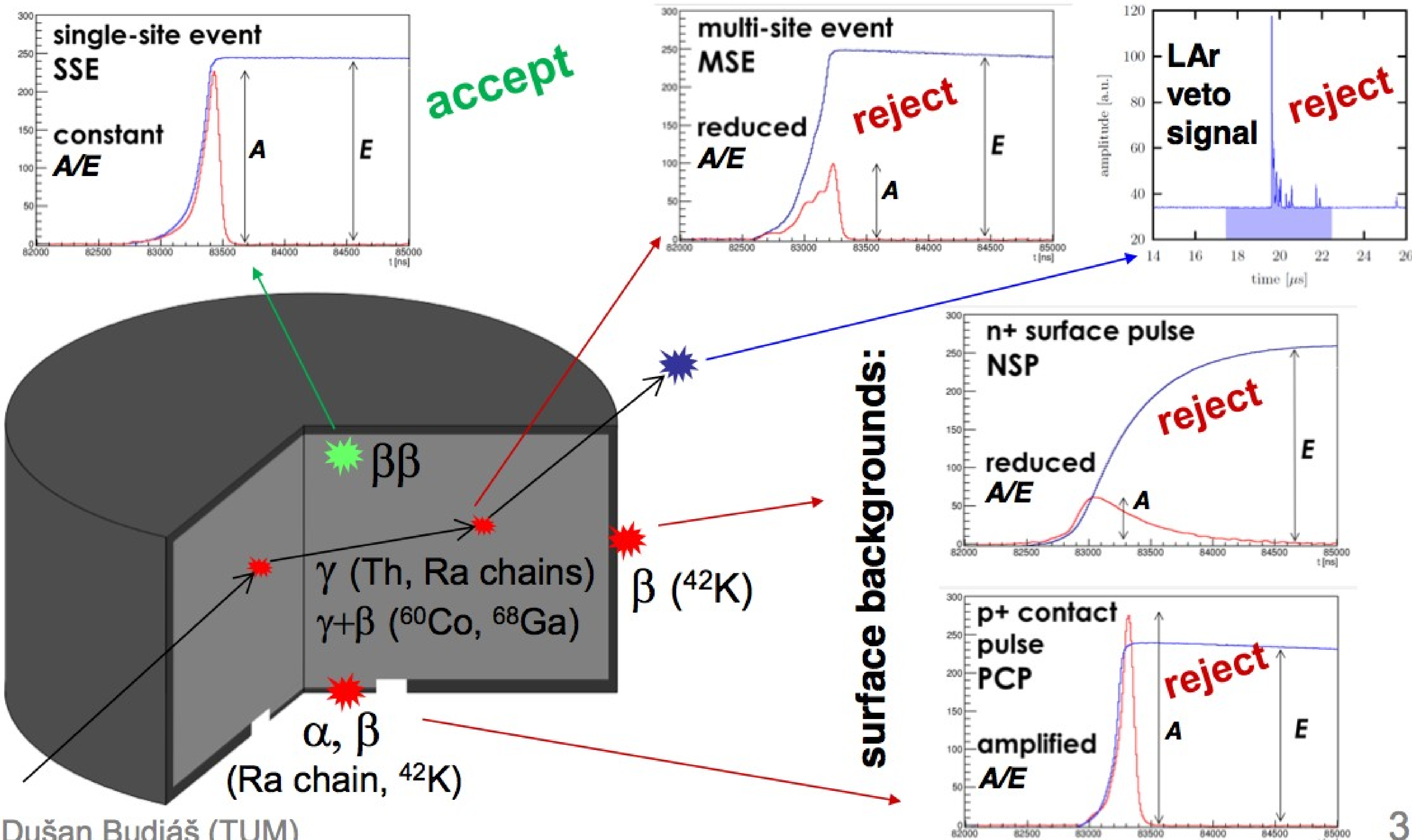
- ➢ narrow peak in current signal
- ➢ signal shape independent of interaction position (same final trajectory)
- ➢ current amplitude depends only on energy of interaction (~95% of volume)

 [D. Budjáš et al., JINST 4:P10007,2009] [M. Agostini et al., JINST 6:P03005, 2011]

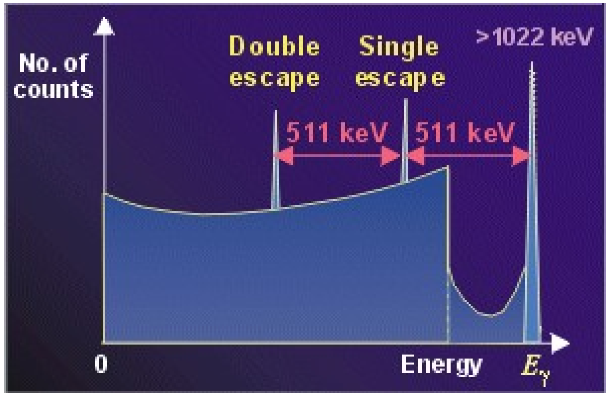
GERDA Phase II background identification tools

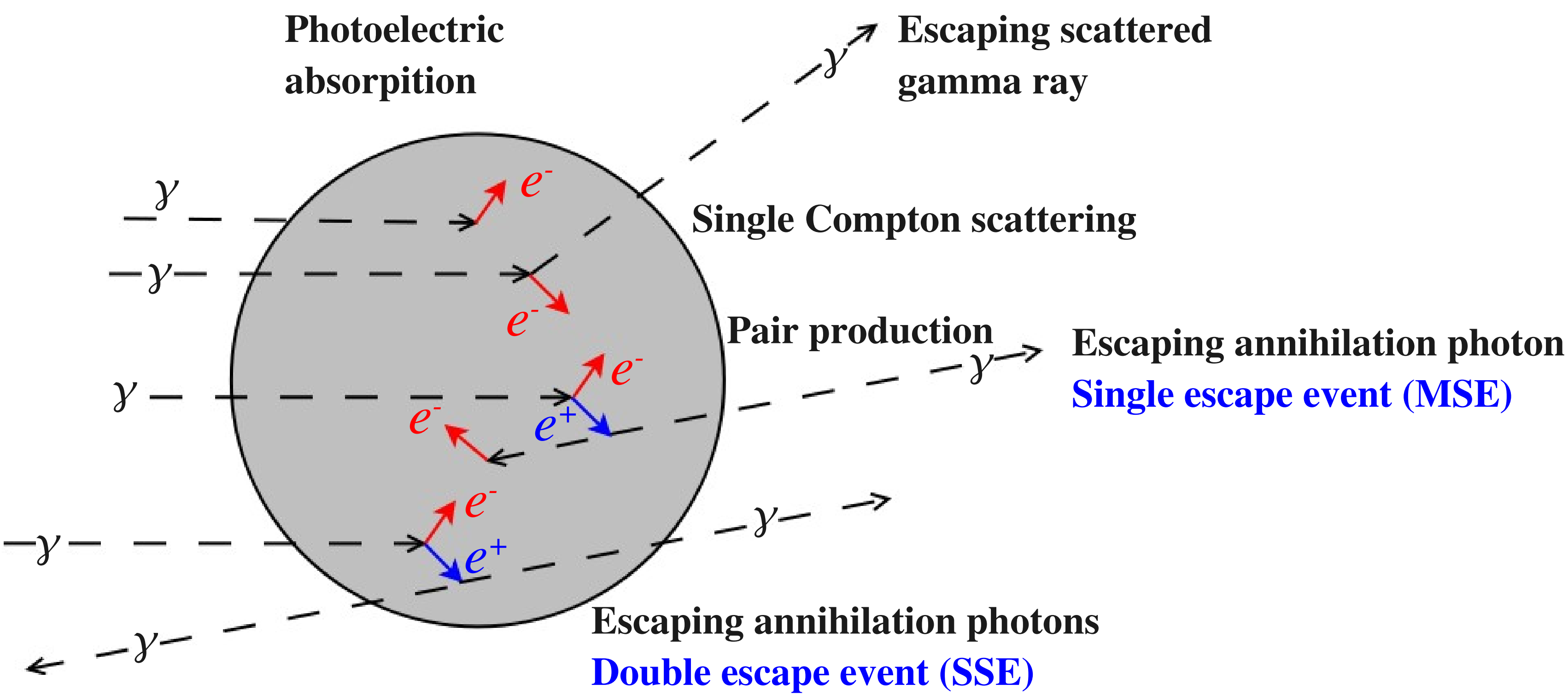
- identification and discrimination of events by **PSD** and **LAr veto**:

ββ-decay: β range in Ge ~mm **γ-ray backgrounds:** range in Ge ~cm

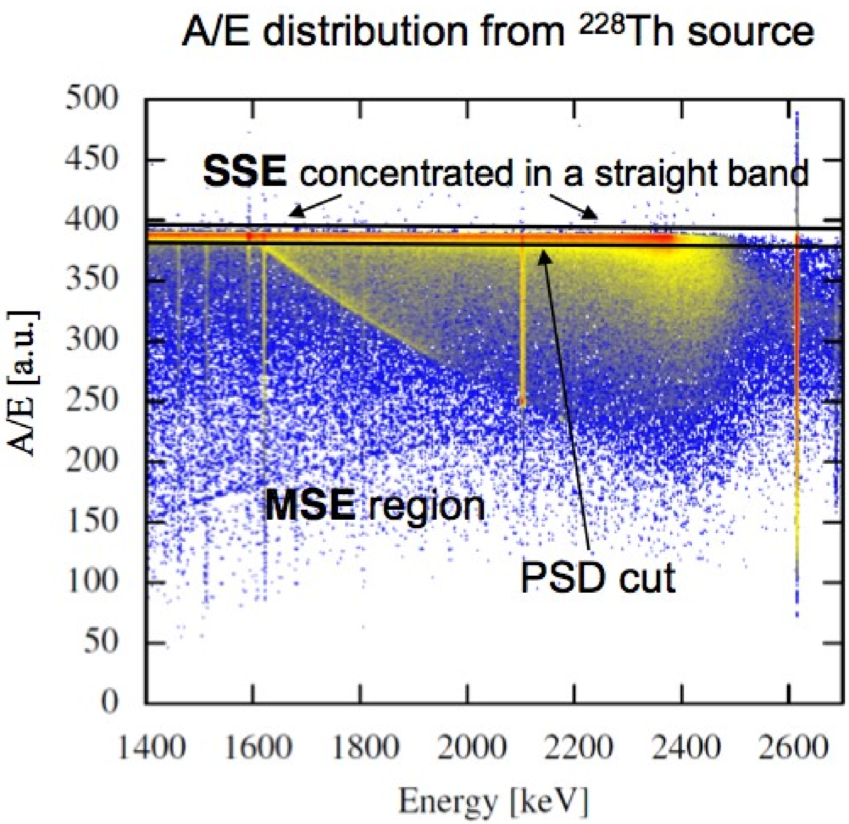


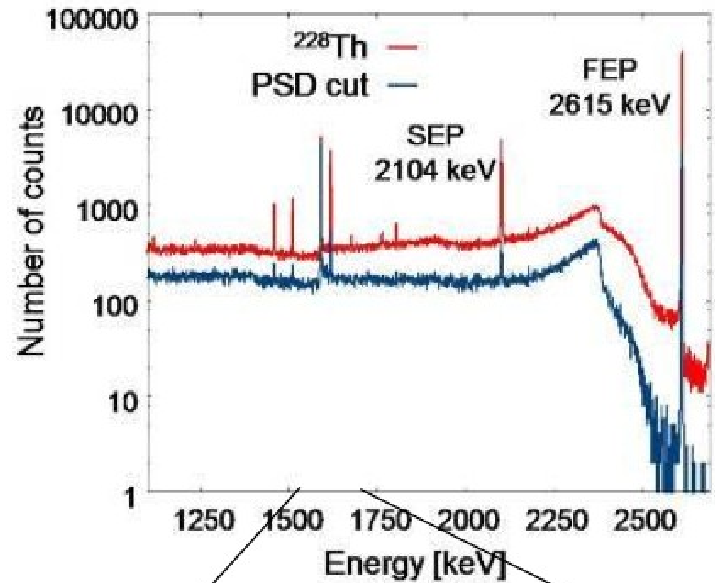
Proxy per SSE e MSE

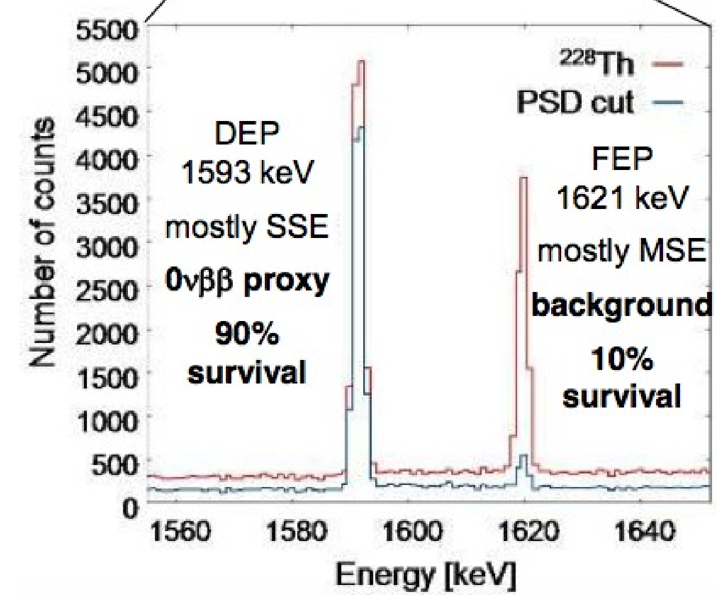




Background rejection using A/E cut with BEGes







[D. Budjáš et al., JINST 4:P10007,2009]
[M. Agostini et al., JINST 6:P03005, 2011]

Scintillazione nell'Ar (liquido)

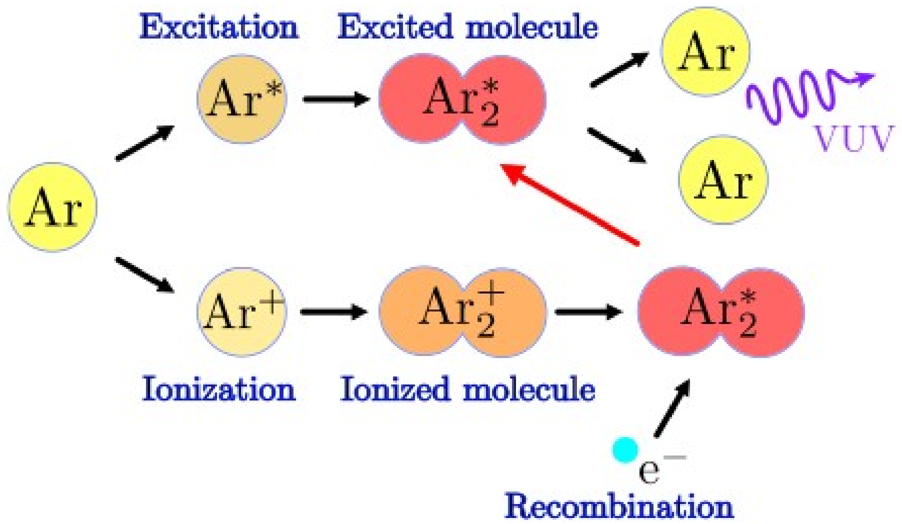
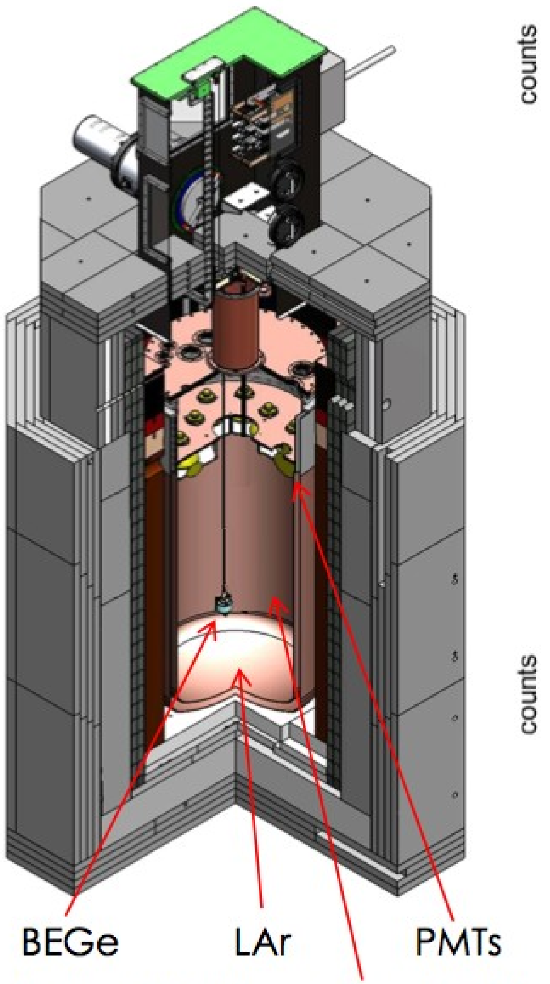


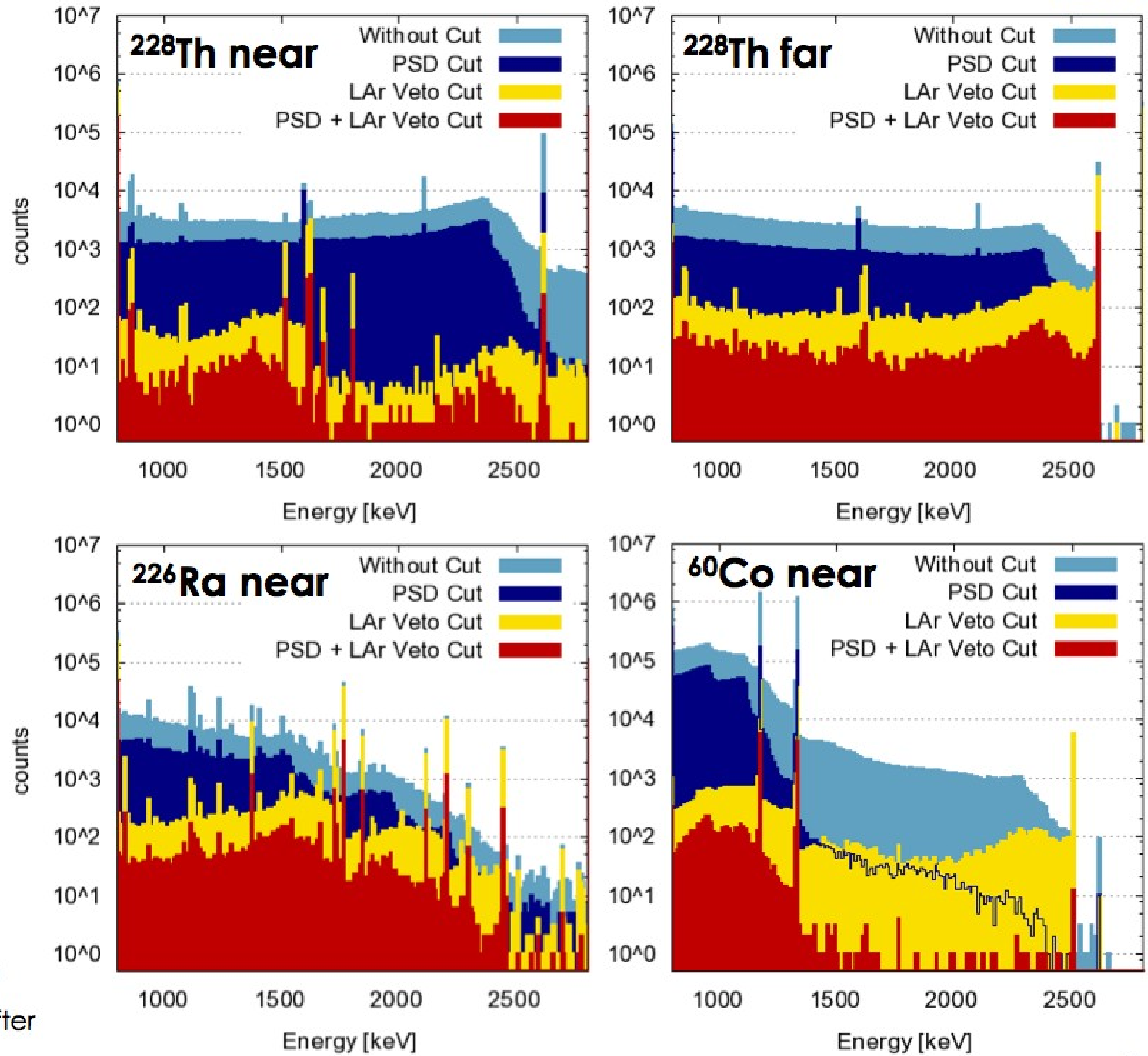
Figure 3.3.1.: Scintillation mechanism of LAr. Ionizing radiation leads to excited or ionized argon atoms. Those atoms form molecules with ground state argon atoms called dimers. Recombining with a free electron an ionized dimer is transformed into an excited dimer (excimer). Those excimers decay under emission of a photon with $\lambda = 126.8\,\text{nm}$. From [A+08].

light yield: $4{\cdot}10^4\ \gamma/\text{MeV}$

PSD and LAr veto studies in LARGE

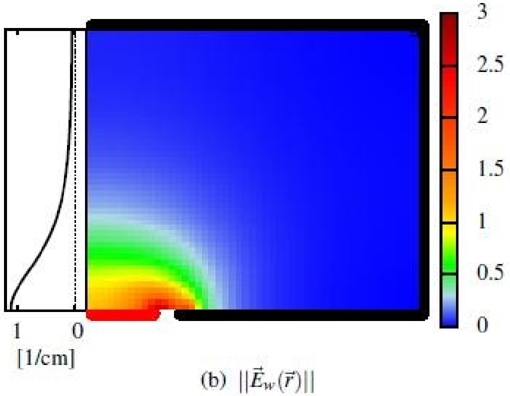
Low background test facility GERDA-LARGE at LNGS:





[M. Heisel, Dissertation, University of Heidelberg (2011)]

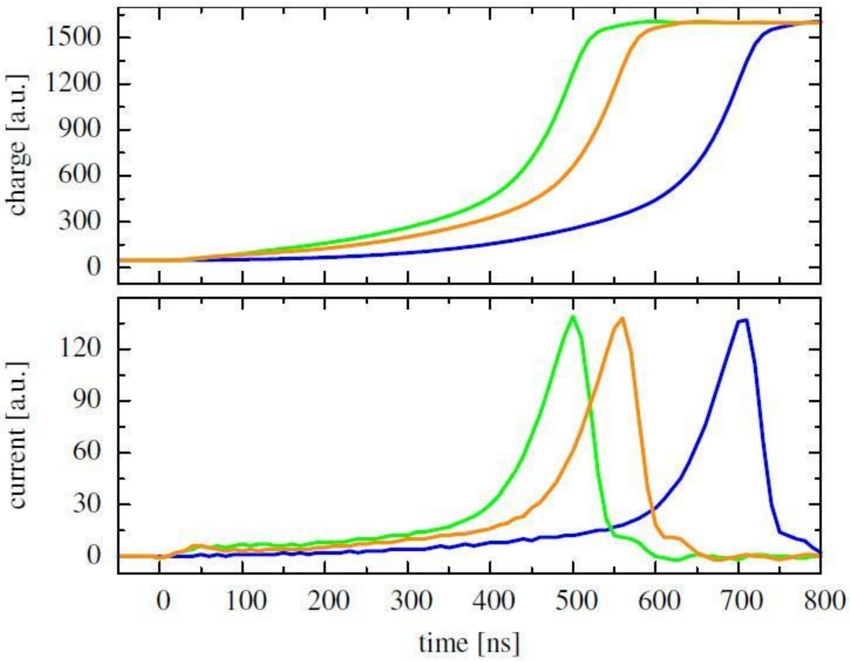
Phase II detectors

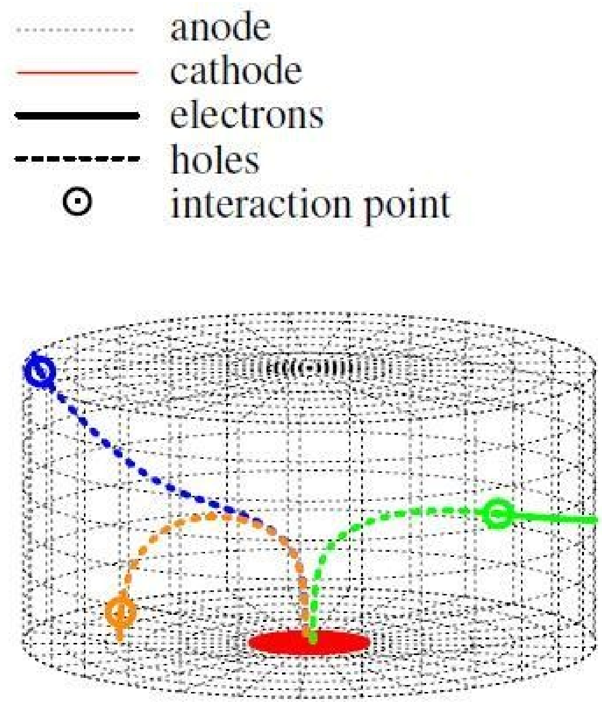


(b) $||\vec{E}_w(\vec{r})||$

Shockley-Ramo Theorem:

$Q(t) = -q \cdot \Phi_w(\mathbf{r}(t))$





GERmanium Detector Array (GERDA)

[a]) INFN Laboratori Nazionali del Gran Sasso, LNGS, Assergi, Italy
[b]) Institute of Physics, Jagiellonian University, Cracow, Poland
[c]) Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[d]) Joint Institute for Nuclear Research, Dubna, Russia
[e]) Institute for Reference Materials and Measurements, Geel, Belgium
[f]) Max Planck Institut für Kernphysik, Heidelberg, Germany
[g]) Dipartimento di Fisica, Università Milano Bicocca, Milano, Italy
[h]) INFN Milano Bicocca, Milano, Italy
[i]) Dipartimento di Fisica, Università degli Studi di Milano e INFN Milano, Milano, Italy
[j]) Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
[k]) Institute for Theoretical and Experimental Physics, Moscow, Russia
[l]) National Research Centre "Kurchatov Institute", Moscow, Russia
[m]) Max-Planck-Institut für Physik, München, Germany
[n]) Physik Department and Excellence Cluster Universe, Technische Universität München, Germany
[o]) Dipartimento di Fisica e Astronomia dell'Università di Padova, Padova, Italy
[p]) INFN Padova, Padova, Italy
[q]) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
[r]) Physik Institut der Universität Zürich, Zürich, Switzerland

The GERDA collaboration

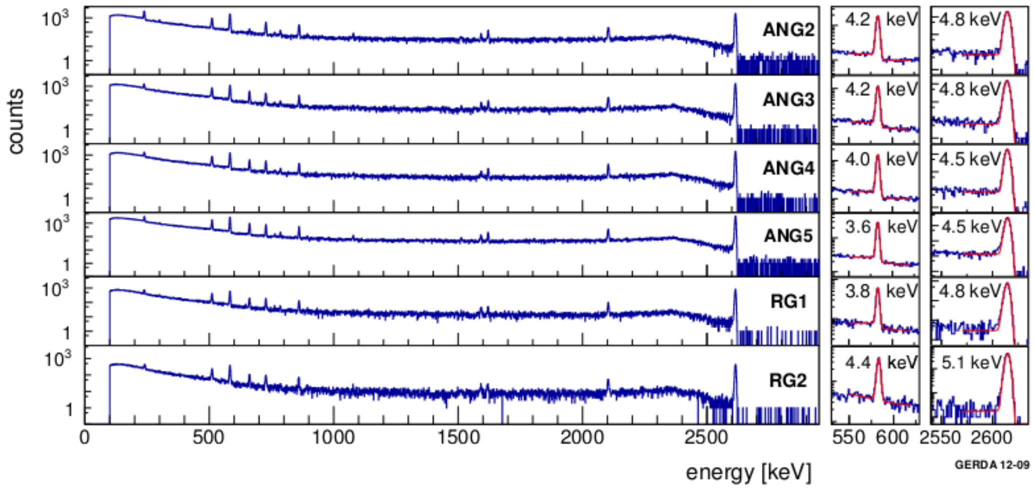
111 members, 18 institutes, 6 countries

- Bare ^{enr}Ge array in liquid Argon
- Shield: high-purity liquid Argon / H_2O
- **Phase I:** 18 kg enriched coaxial detectors (~86%)(HdM/IGEX)
- **Phase II:** add ~20 kg new enriched BEGe detectors
- For future ton scale experiment: Merge with Majorana collaboration (already open exchange of knowledge and technologies)

Energy resolution

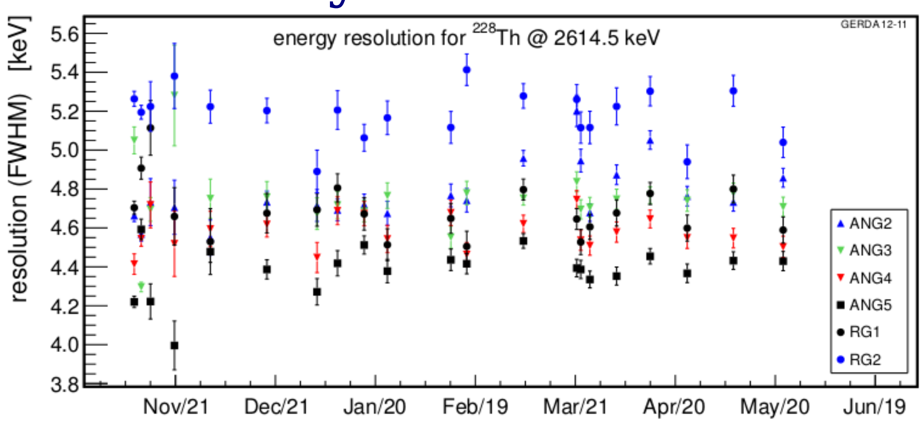
The Gerda experiment for the search of $0\nu\beta\beta$ decay in ^{76}Ge
Eur. Phys. J. C (2013) 73:2330

Calibration spectra for ^{enr}Ge detectors with ^{228}Th source

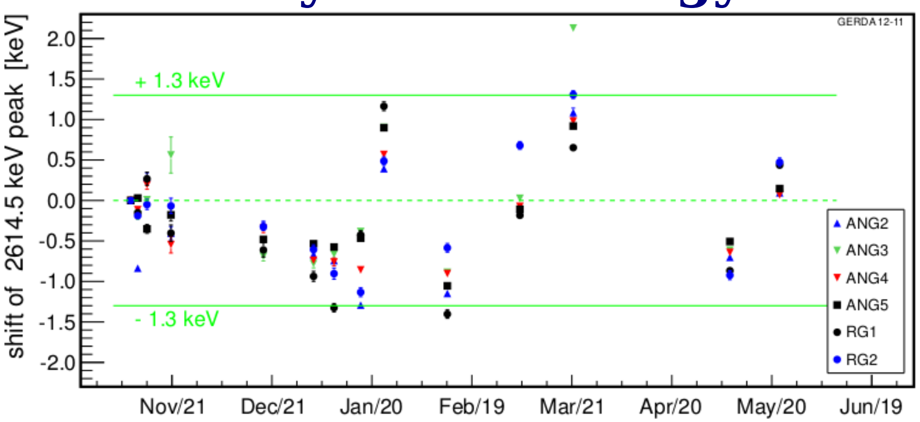


Mass weighted average for **FWHM at $Q_{\beta\beta}$ = 4.5 keV**

Stability of the resolution

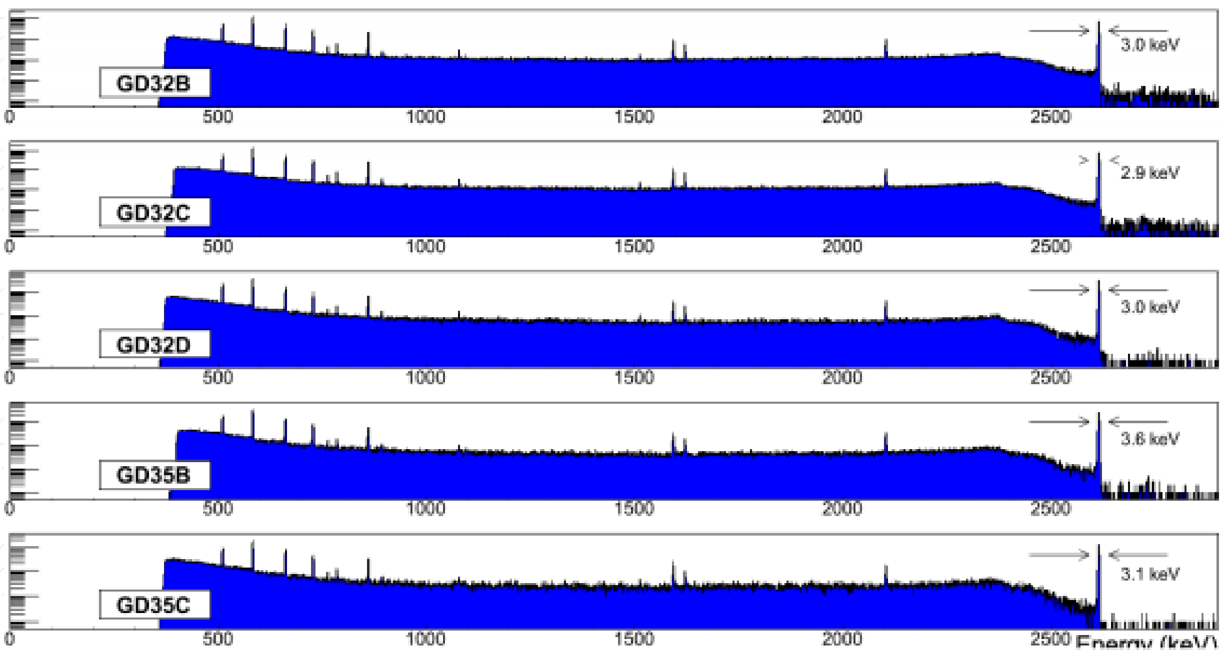


Stability of the energy scale



First BEGe's in GERDA

Calibration spectra



Energy resolution and PSA properties

Detector	E resolution [keV]	A/E res.	A/E res. HADES
Agamennone (GD32B)	*2.88 ± 0.02*	*1.5%*	*0.8%*
Andromeda (GD32C	*2.84 ± 0.02*	*1.7%*	*1.3%*
Anubis (GD32D)	*2.96 ± 0.04*	*1.7%*	*1.6%*
Achilles(GD35B)	*3.61 ± 0.05*	*1.9%*	*0.6%*
Aristoteles(GD35C)	*3.09 ± 0.06*	*1.7%*	*1.7%*