GERDA: Recent Results and Future Plans

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RICAP 13, Rome
23/05/2013

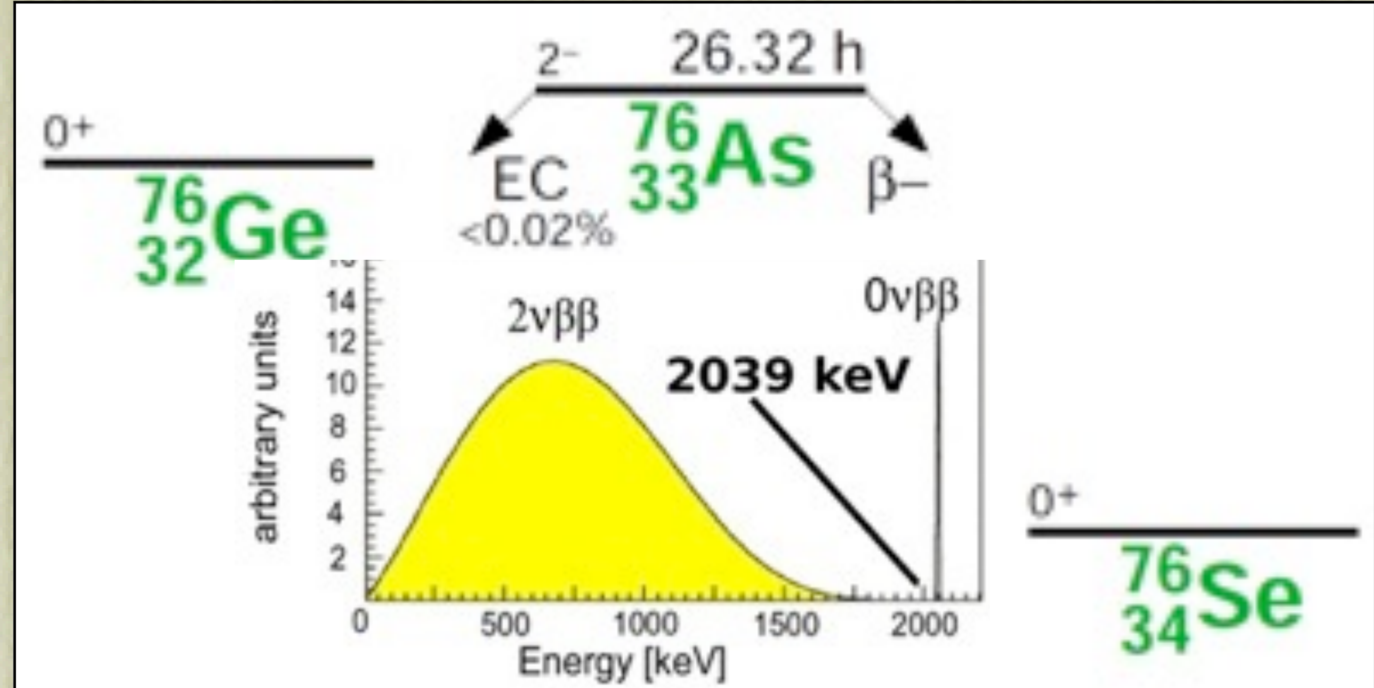
TECHNISCHE UNIVERSITÄT DRESDEN

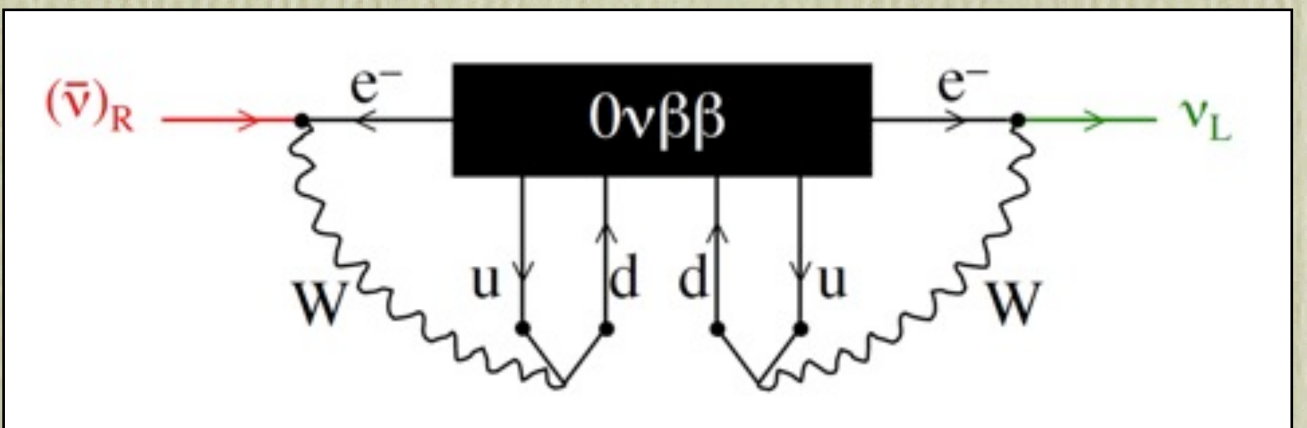
Institut für Kern- und Teilchenphysik

Double Beta Decay

$$2\nu\beta\beta : (Z, A) \rightarrow (Z+2, A) + 2e^- + 2\bar{\nu}_e$$

$$0\nu\beta\beta : (Z, A) \rightarrow (Z+2, A) + 2e^-$$





Schechter-Valle theorem:
If 0νββ exists, it can always be interpreted as a neutrino Majorana mass term

- Lepton number violation

Effective neutrino mass:

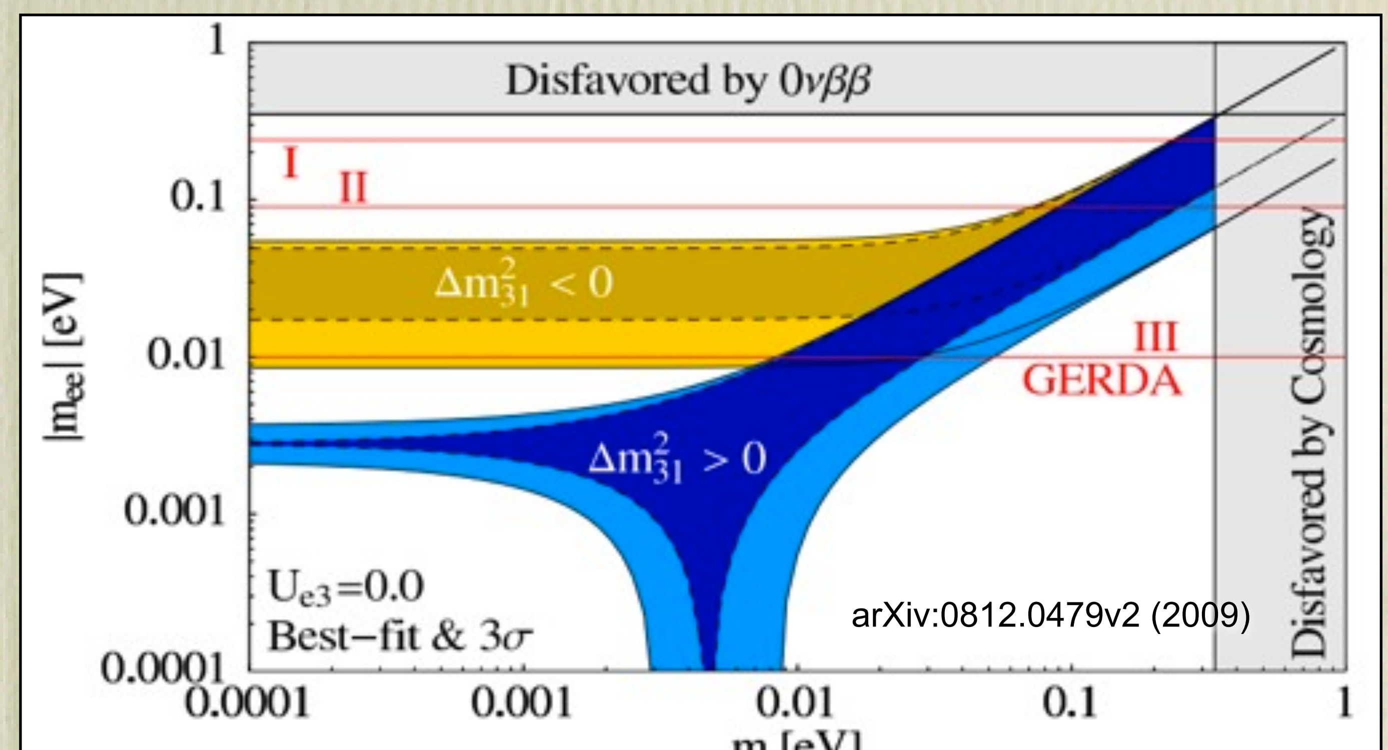
(only for dominant light Majorana neutrino exchange)

$$\left(T_{1/2}^{0\nu}\right)^{-1} = F^{0\nu} \cdot |\mathcal{M}^{0\nu}|^2 \cdot |m_{ee}|^2$$

$F^{0\nu}$: phase space factor

$\mathcal{M}^{0\nu}$: nuclear matrix element

m_{ee} : effective neutrino mass



Double Beta Decay Experiments

Sensitivity: (for gaussian background)

$$T_{1/2}^{\text{limit}} \propto \alpha \cdot \eta \cdot \epsilon \cdot \sqrt{\frac{M \cdot T}{B \cdot \Delta E}}$$

α : isotopic abundance

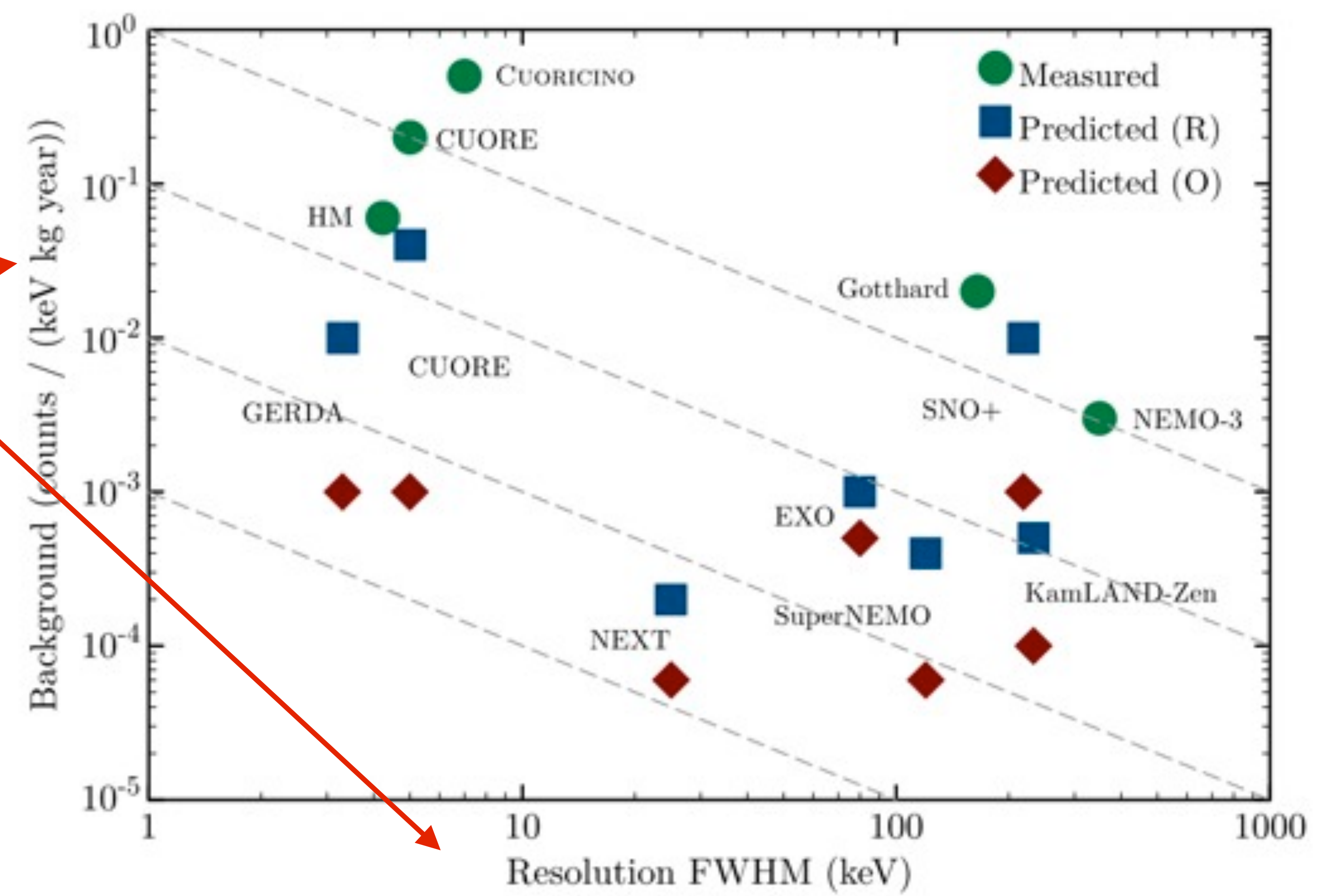
η : active volume fraction

ϵ : detection efficiency

$M \cdot T$: exposure

B : background index

ΔE : energy resolution



Claim of discovery in ^{76}Ge by subset of HdM experiment:

$$T_{1/2}^{0\nu} = 1.19 \cdot 10^{25}\,\text{yr}$$

Physics Letters B 586 (2004) 198–212

Best limits ^{76}Ge:

$$\text{IGEX} : T_{1/2}^{0\nu} \geq 1.6 \cdot 10^{25}\,\text{yr (90\% C.L.)}$$

$$\text{HdM} : T_{1/2}^{0\nu} \geq 1.9 \cdot 10^{25}\,\text{yr (90\% C.L.)}$$

New limits also for ^{136}Xe from EXO and Kamland-ZEN

The GERDA Collaboration

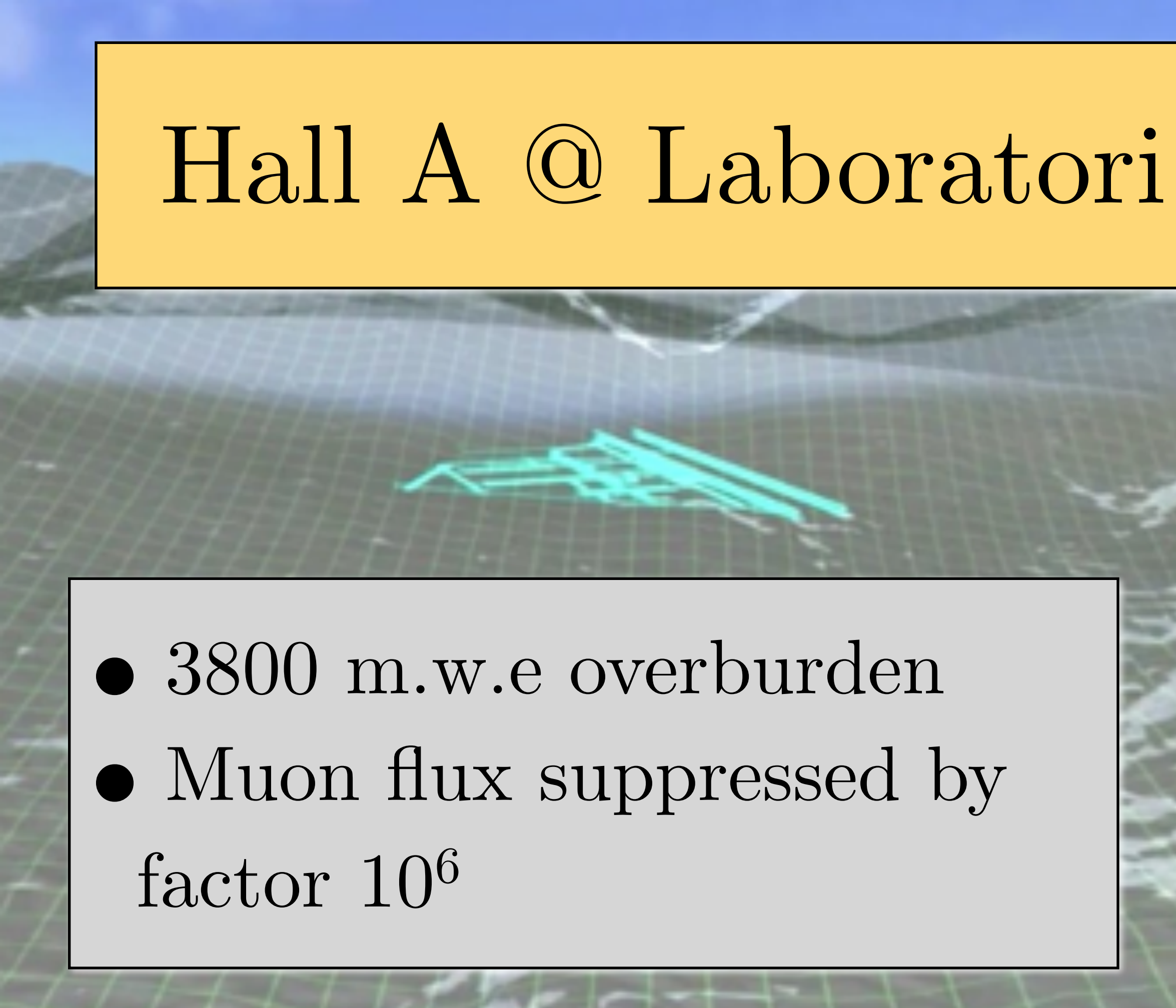
K.-H. Ackermann[13], M. Agostini[14], M. Allardt[3], M. Altmann[13,b], E. Andreotti[5,18], A.M. Bakalyarov[12], M. Balata[1], I. Barabanov[10], M. Barnabé Heider[6,14,20], N. Barros[3], L. Baudis[19], C. Bauer[6], N. Becerici-Schmidt[13], E. Bellotti[7,8], S. Belogurov[11,10], S.T. Belyaev[12], G. Benato[19], A. Bettini[15,16], L. Bezrukov[10], T. Bode[14], V. Brudanin[4], R. Brugnera[15,16], D. Budjáš[14], A. Caldwell[13], C. Cattadori[8], A. Chernogorov[11], O. Chkvorets[6,21], F. Cossavella[13], A. D‘Andragora[1,22], E.V. Demidova[11], A. Denisov[10], A. di Vacri[1,23], A. Domula[3], V. Egorov[4], R. Falkenstein[18], A. Ferella[19], K. Freund[18], F. Froborg[19], N. Frodyma[2], A. Gangapshev[10,6], A. Garfagnini[15,16], J. Gasparro[5,24], S. Gazzana[6,1], R. Gonzalez de Orduna[5,c], P. Grabmayr[18,a], V. Gurentsov[10], K. Gusev[12,4,14], K.K. Guthikonda[19], W. Hampel[6], A. Hegai[18], M. Heisel[6], S. Hemmer[15,16], G. Heusser[6], W. Hofmann[6], M. Hult[5], L.V. Inzhechik[10,25], L. Ioannucci[1], J. Janicskó Csáthy[14], J. Jochum[18], M. Junker[1], R. Kankanyan[6], S. Kianovsky[10], T. Kihm[6], J. Kiko[6], I.V. Kirpichnikov[11], A. Kirsch[6], A. Klimenko[4,10,6], M. Knapp[18,c], K.T. Knöpfle[6], O. Kochetov[4], V.N. Kornoukhov[11,10], K. Kröninger[13,26,27], V. Kusminov[10], M. Laubenstein[1], A. Lazzaro[14], V.I. Lebedev[12], B. Lehnert[3], D. Lenz[13,c], H. Liao[13], M. Lindner[6], I. Lippi[16], J. Liu[13,28], X. Liu[17], A. Lubashevskiy[6], B. Lubsandorzhiev[10], A.A. Machado[6], B. Majorovits[13], W. Maneschg[6], G. Marissens[5], S. Mayer[13], G. Meierhofer[18,29], I. Nemchenok[4], L. Niedermeier[18,c], S. Nisi[1], J. Oehm[6], C. O’Shaughnessy[13], L. Pandola[1], P. Peiffer[6,30], K. Pelczar[2], A. Pullia[9], S. Riboldi[9], F. Ritter[18,31], C. Rossi Alvarez[16], C. Sada[15,16], M. Salathe[6], C. Schmitt[18], S. Schönert[14], J. Schreiner[6], J. Schubert[13,c], O. Schulz[13], U. Schwan[6], B. Schwingenheuer[6], H. Seitz[13], E. Shevchik[4], M. Shirchenko[12,4], H. Simgen[6], A. Smolnikov[6], L. Stanco[16], F. Stelzer[13], H. Strecker[6], M. Tarka[19], U. Trunk[6,32], C.A. Ur[16], A.A. Vasenko[11], S. Vogt[13], O. Volynets[13], K. von Sturm[18], V. Wagner[6], M. Walter[19], A. Wegmann[6], M. Wojcik[2], E. Yanovich[10], P. Zavarise[1,33], I. Zhitnikov[4], S.V. Zhukov[12], D. Zinatulina[4], K. Zuber[3],

19 institutions

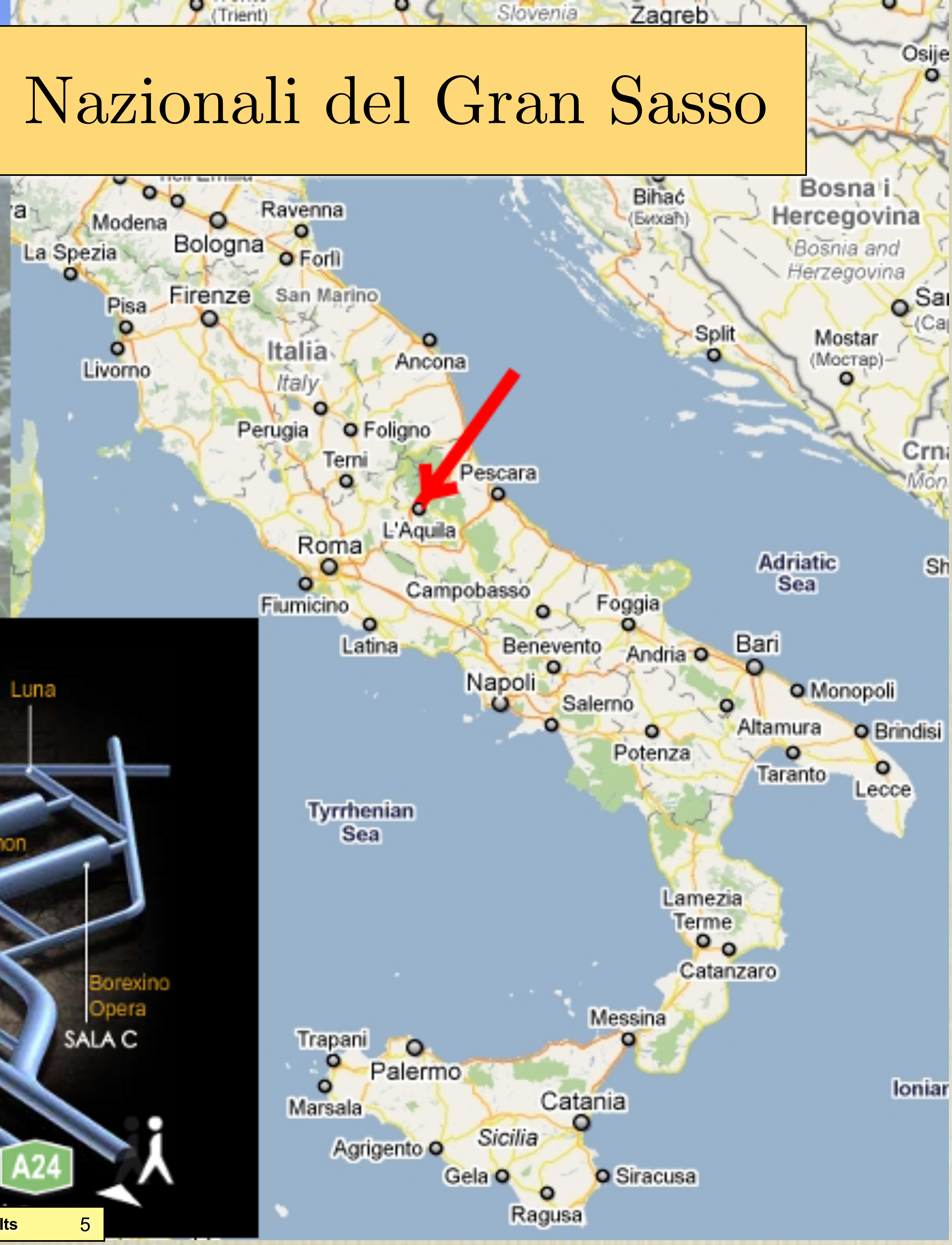
6 countries

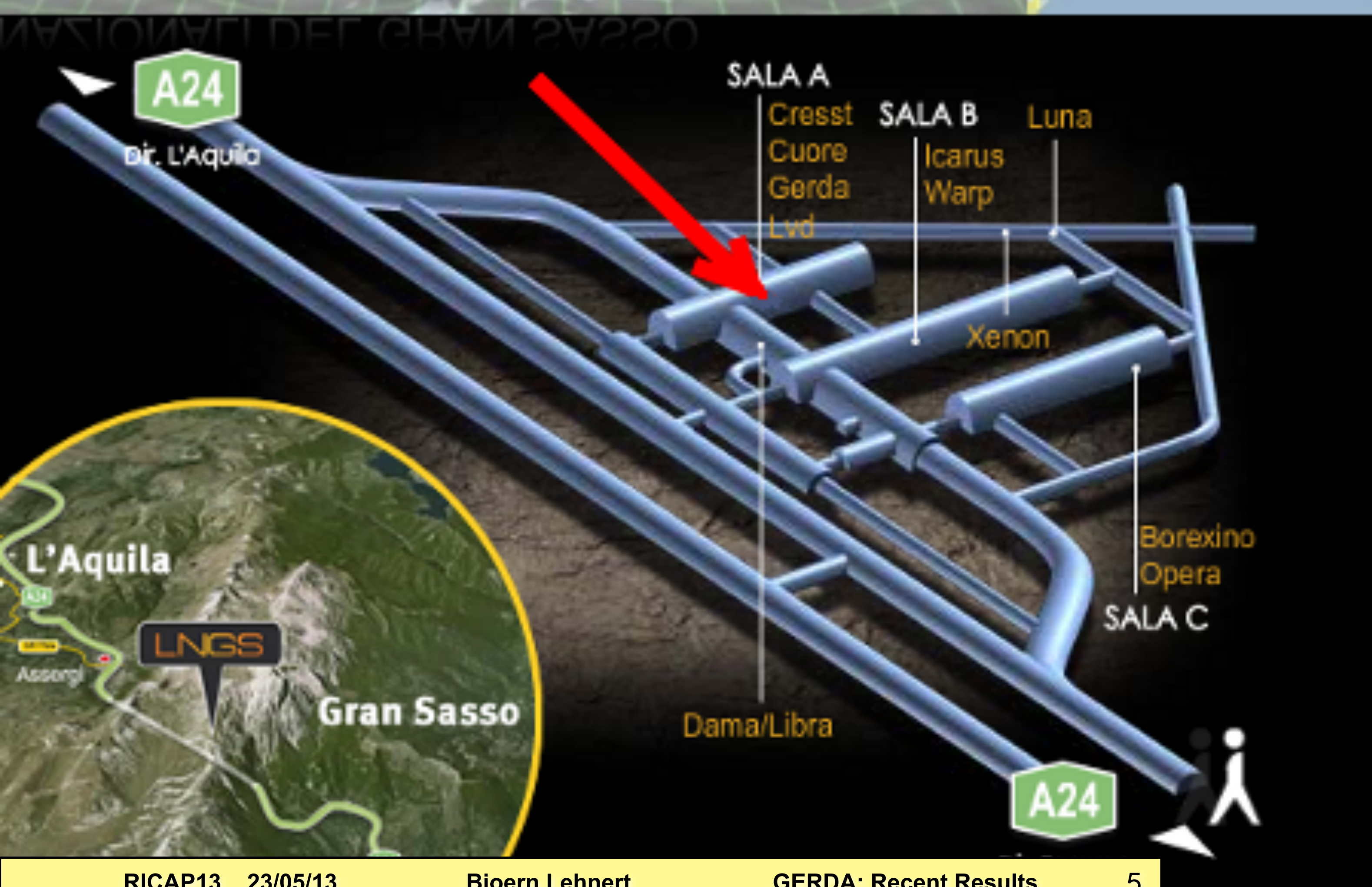
~110 members

Hall A @ Laboratori Nazionali del Gran Sasso



- 3800 m.w.e overburden
- Muon flux suppressed by factor 10^6

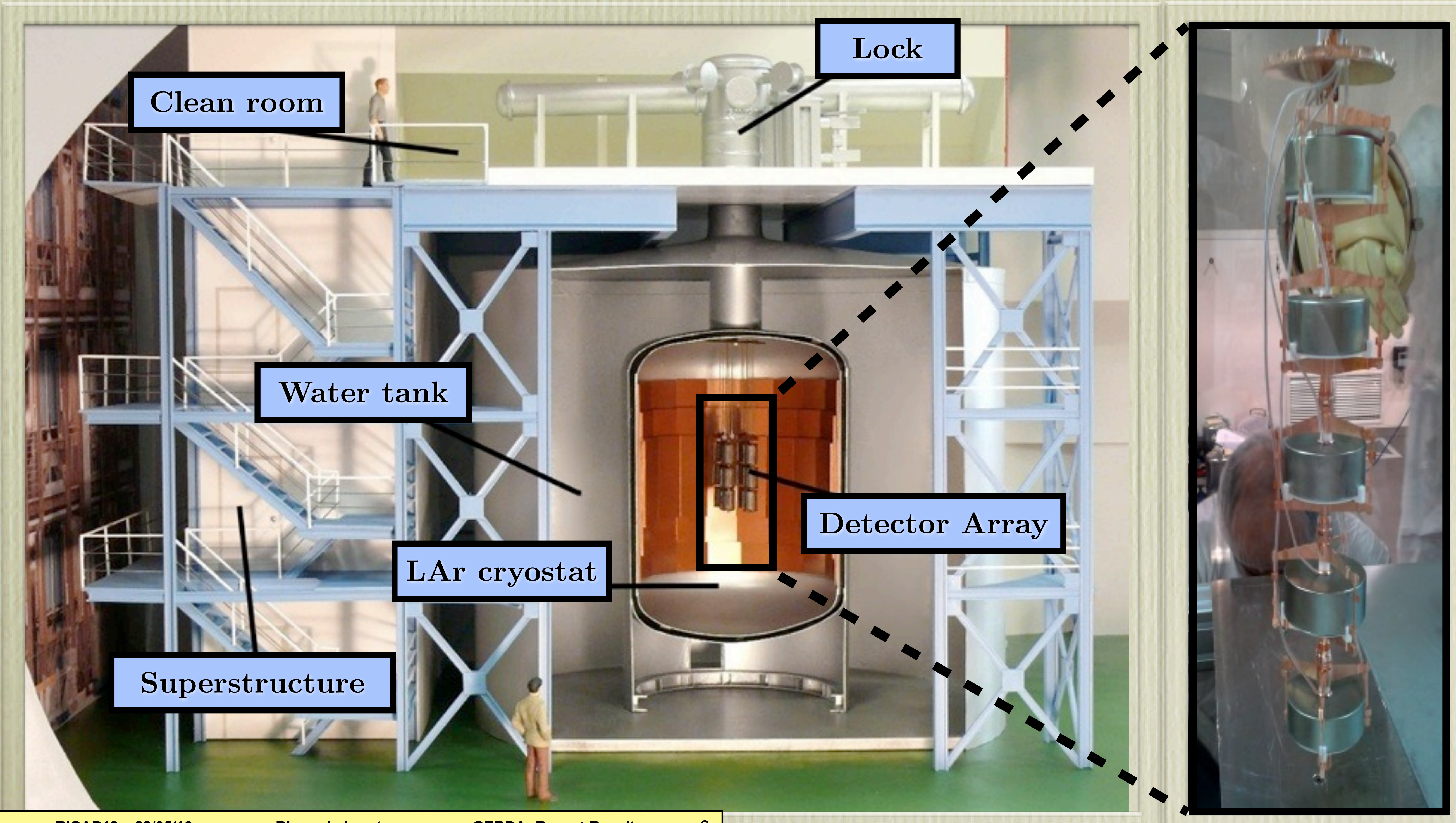




GERDA: GERmanium Detector Array

Novel idea: Operate HPGe detectors naked in liquid argon (LAr)

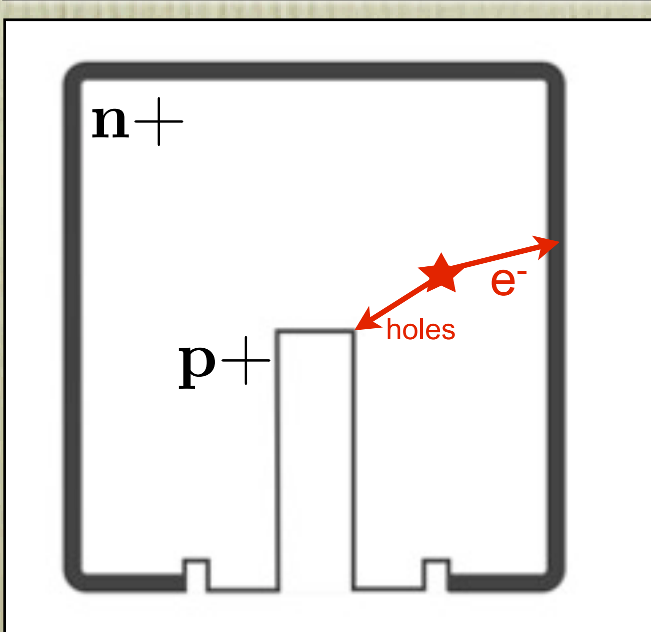
- Liquid argon serves as cooling, shielding and active veto



GERDA Physics Phases

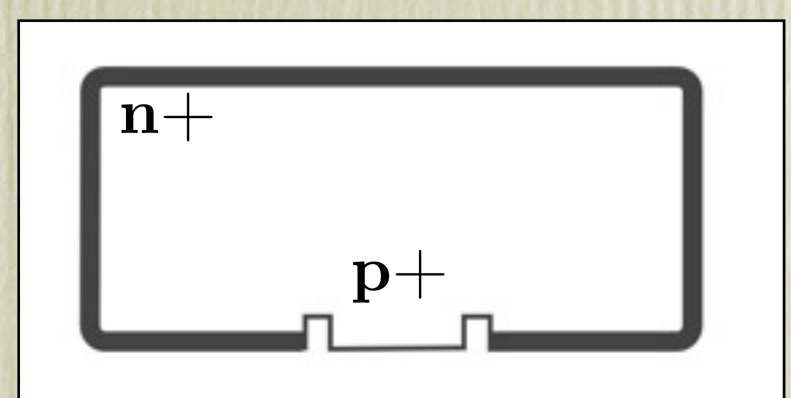
Phase I: Nov 12 - May 13

- 6 to 8 coaxial detectors from Heidelberg Moscow and IGEX
- ~18 kg enriched germanium
- ΔE ~4.5 keV @2.6 MeV
- 4 to 5 BEGe's deployed in Phase I since June 2012
- Exposure aim 20 kg yr (good chance to scrutinize claim)
- Blinded analysis

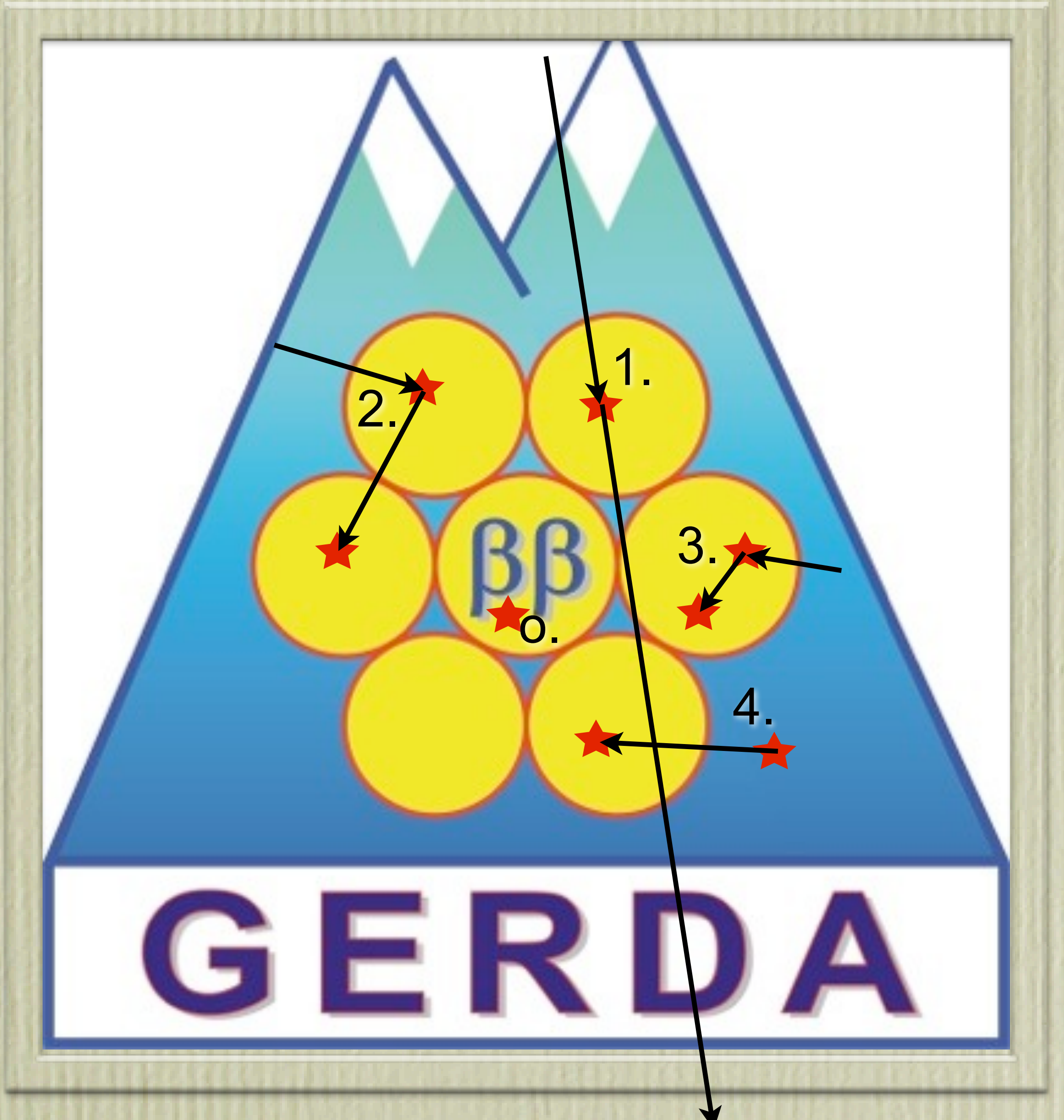


Phase II: Start 2013

- 30 additional enriched BEGe Detectors
- Additional ~20 kg enriched germanium
- Enhanced pulse-shape properties and ΔE (FWHM ~3 keV @2.6 MeV)
- Background aim: 10^{-3} cts/(keV kg yr)
- Exposure aim >100 kg yr to explore 10^{26} yr range



Background Mitigation



Event types and rejections:

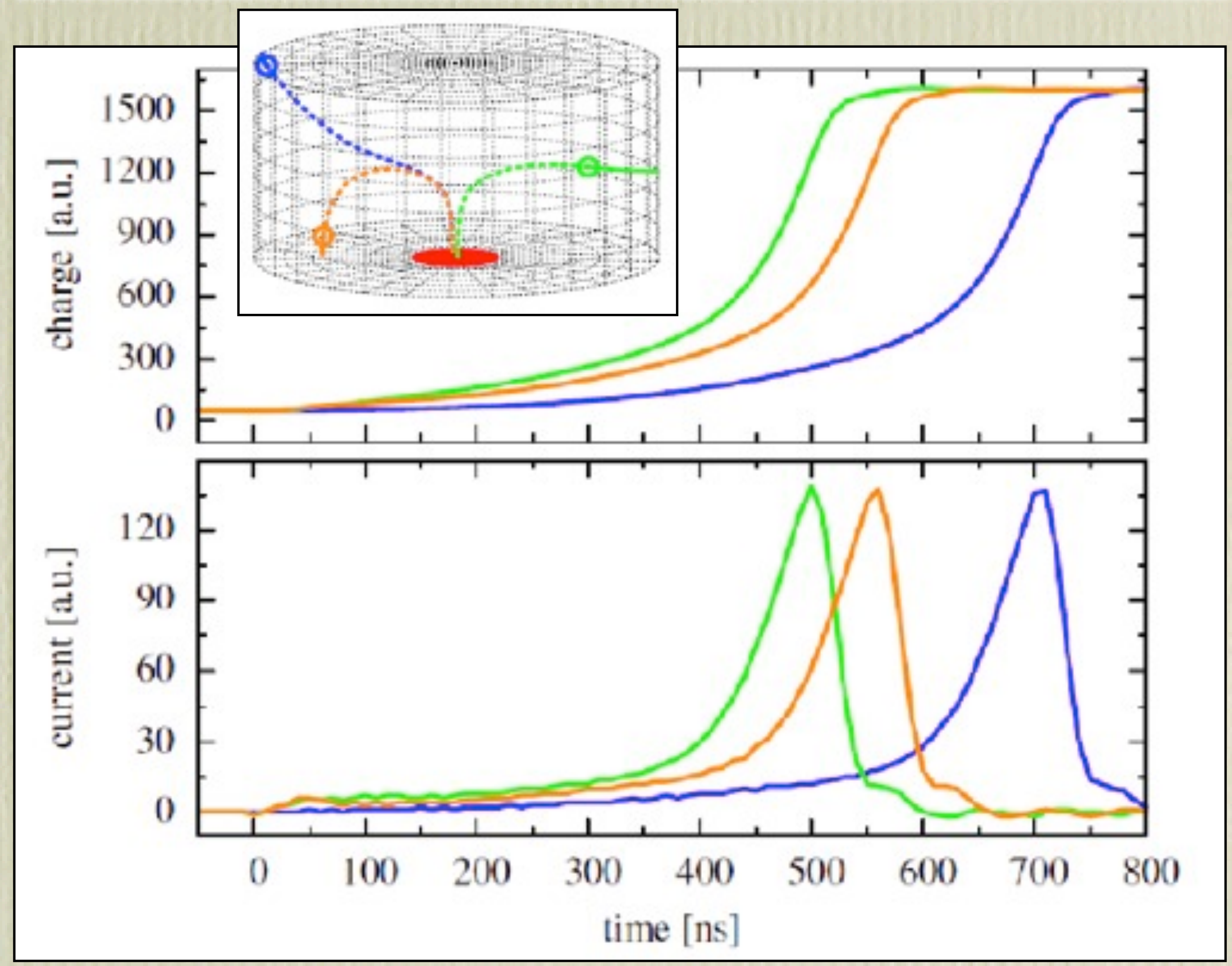
0. 0νββ signal (single site)

1. Muon Cherenkov veto

2. Detector anti coincidence veto

3. Pulse shape discrimination (multi site)

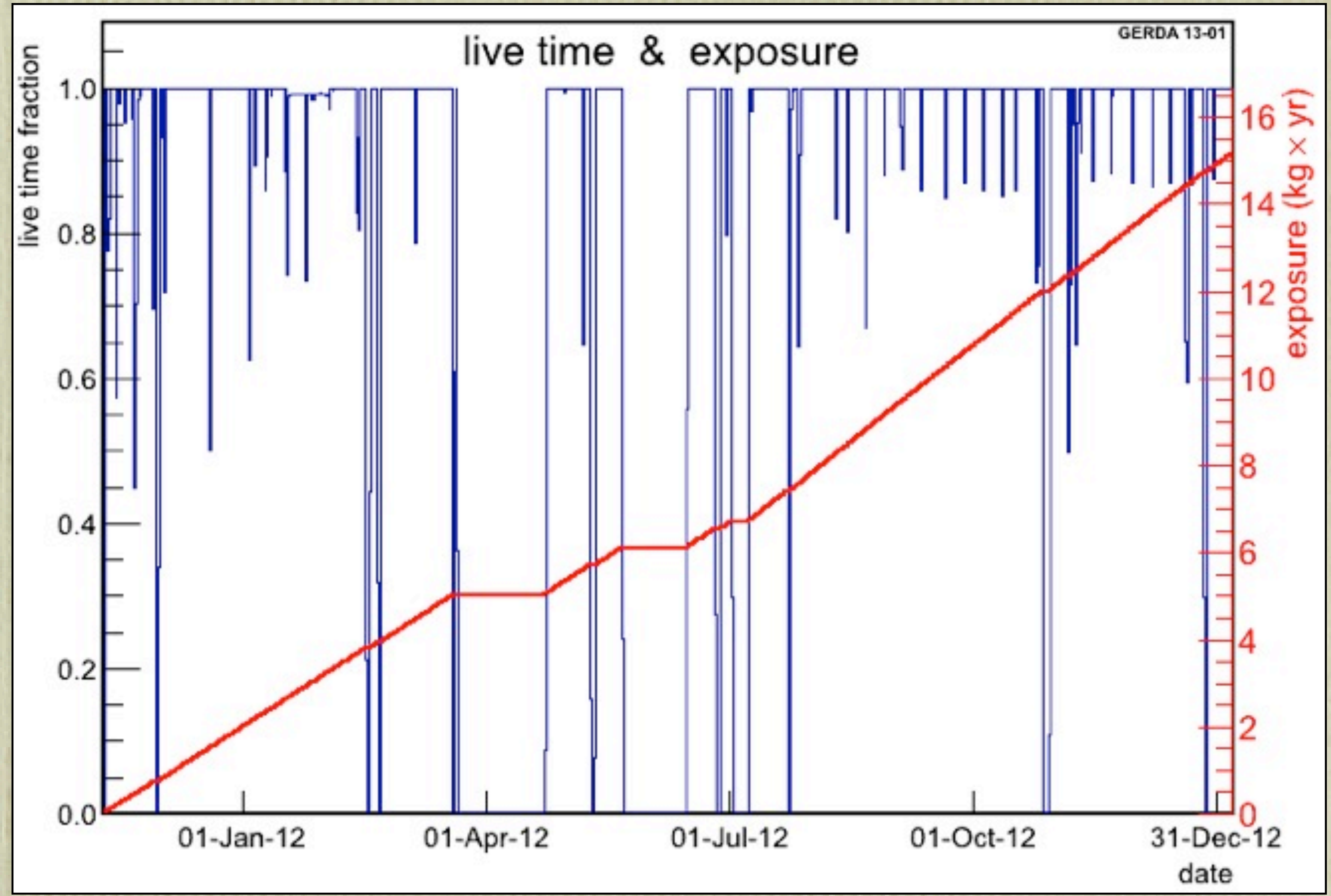
4. LAr scintillation veto



Phase II improvements:

- Pulse shape discrimination improved with BEGe detectors
- LAr scintillation veto

Exposure and Duty Cycle



Preliminary exposure for Phase I [kg yr]

Total ^{enr}Ge: 21.6

Total ^{nat}Ge: 6.2

Fixed Phase I data set:

556 calendar days

First event: 2011, Nov 9, 17:50:20

Last event: 2013, May 21, 10:32:34

Duty cycle: 88%

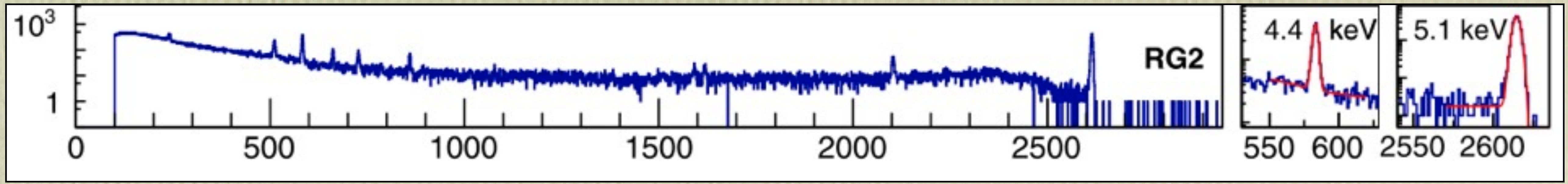
Splitting data

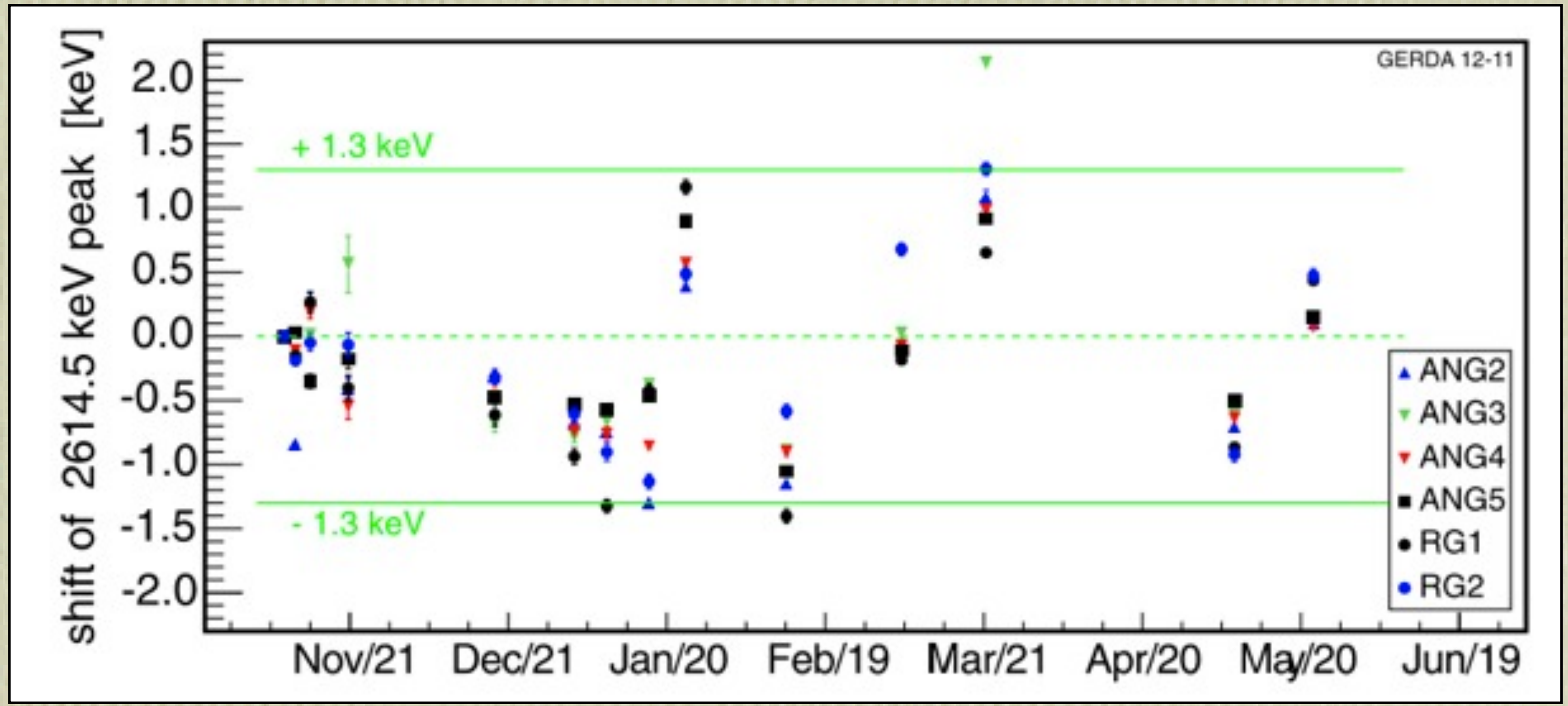
into sets according to detectors class and run performance (e.g. background index, noise)

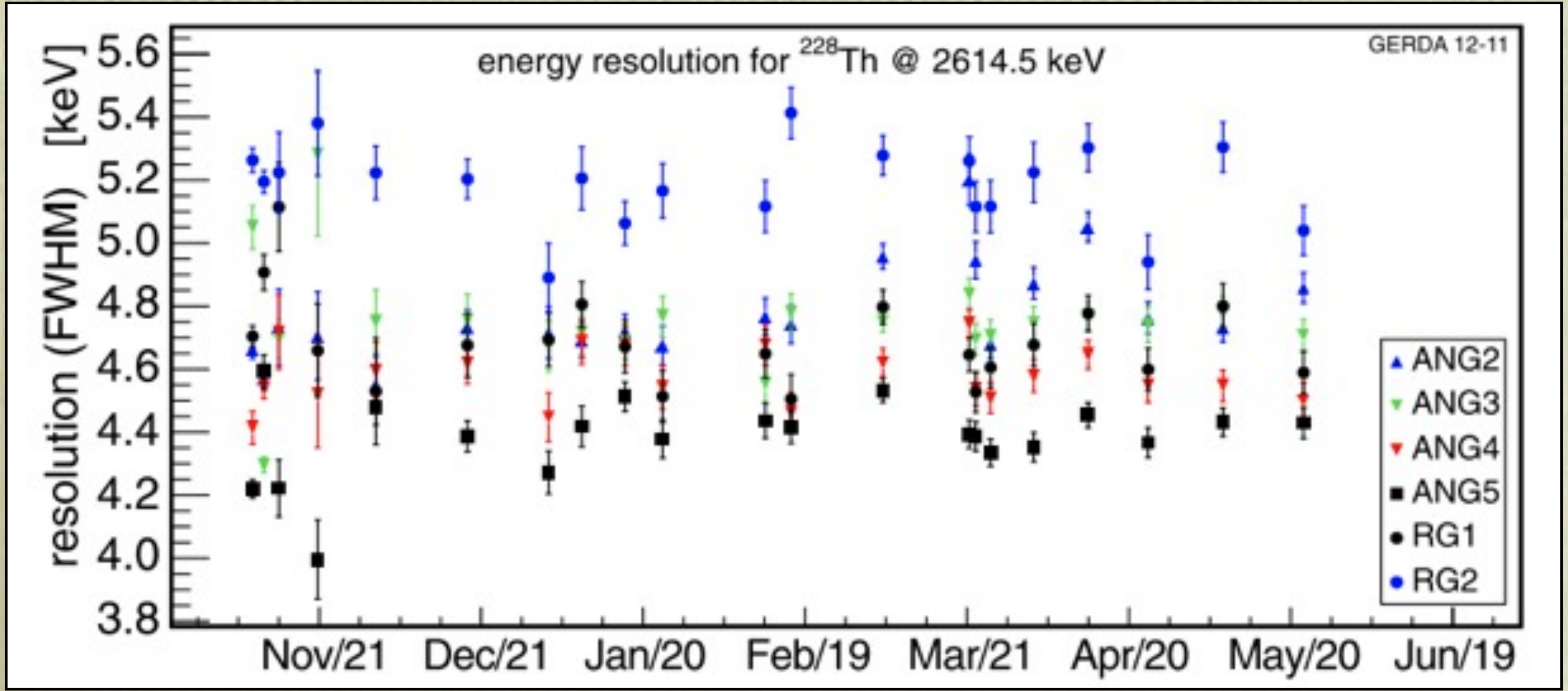
Exposure [kg yr]

- Golden set: 17.9
- Silver set: 1.3
- BEGe set: 2.4

Run Calibration and Stability







Detector calibration with 3 Th228 sources 1h per week

- Energy shift usually <1 keV between calibrations
- Energy resolution stable

FWHM @ 2.6MeV:
(mass weighted average)
Coaxial: 4.5 keV
BEGe: 3.0 keV

Background Spectrum

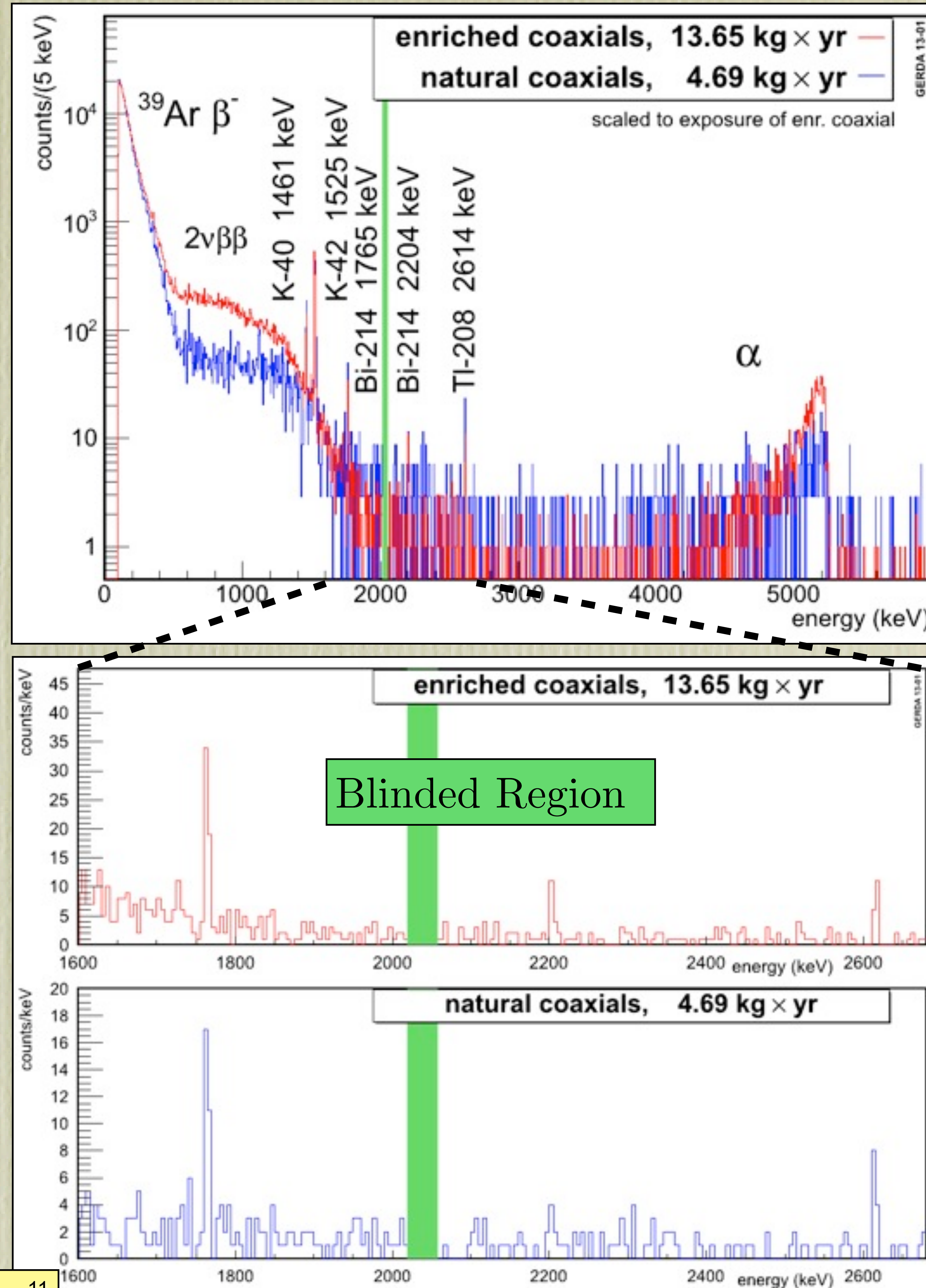
Main features:

- ^{39}Ar (565 keV β, 1 Bq/l LAr)
- 2νββ (GERDA measurement)
- ^{42}K from inside LAr
- Alphas on the surface
- Decay chain gamma lines

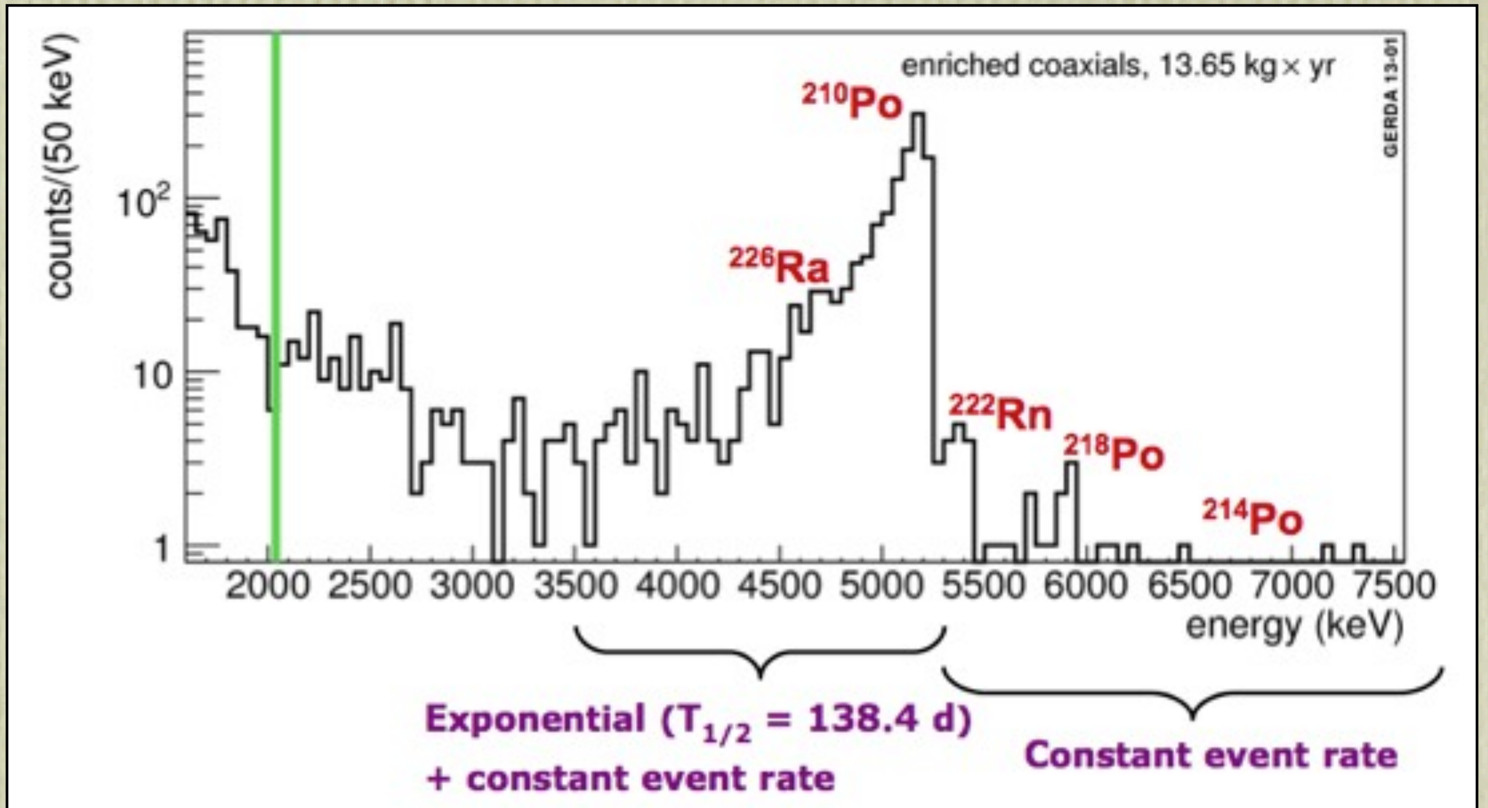
Preliminary Background Index

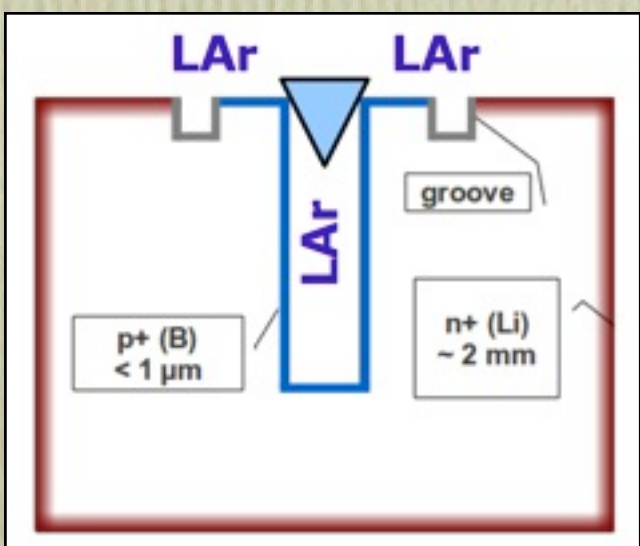
in counts/(kg yr keV) in $Q_{\beta\beta}$ ±100 keV

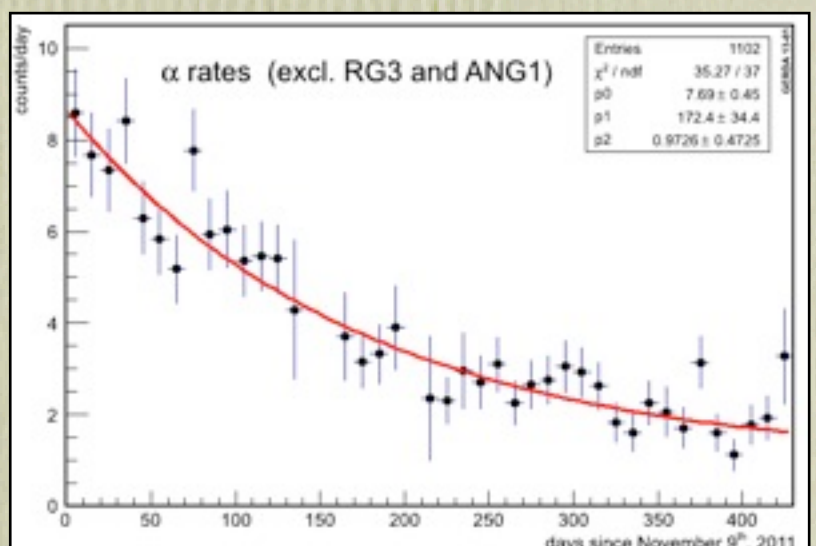
Golden set	0.019
Silver set	0.063
BEGe set	0.041
Phase I aim	0.01
Phase II aim	0.001
(HDM)	0.17



Alpha Background

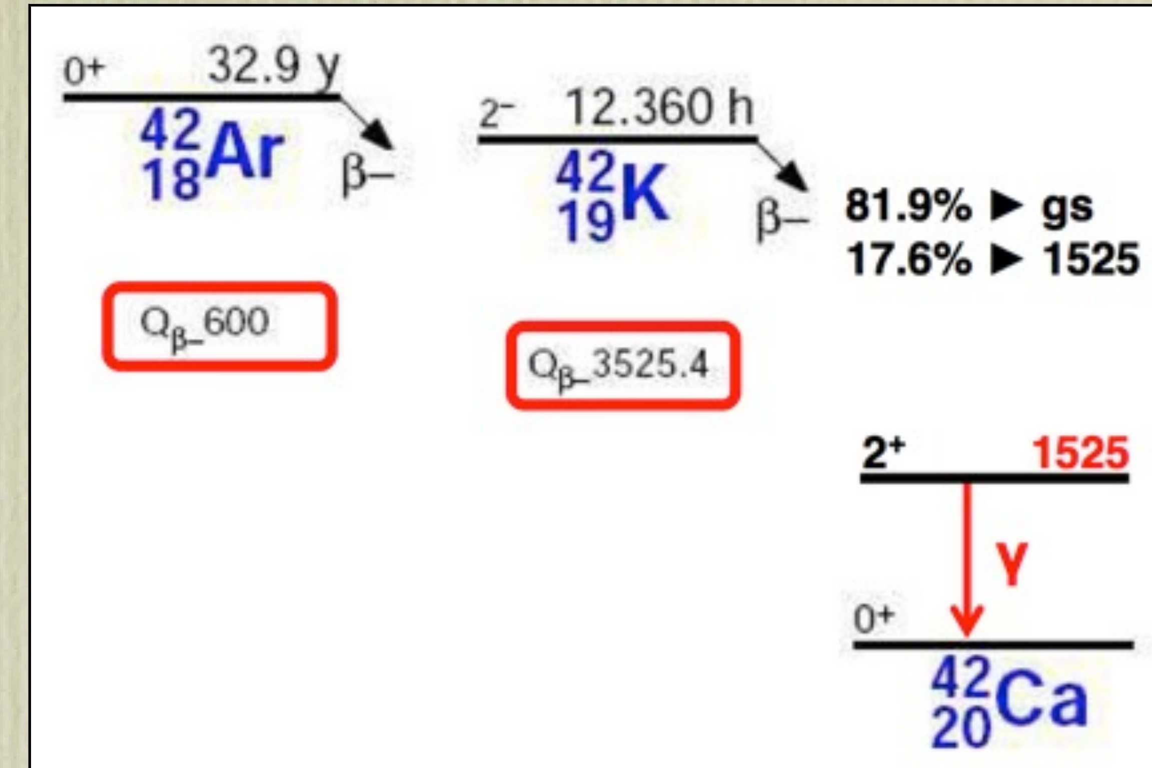




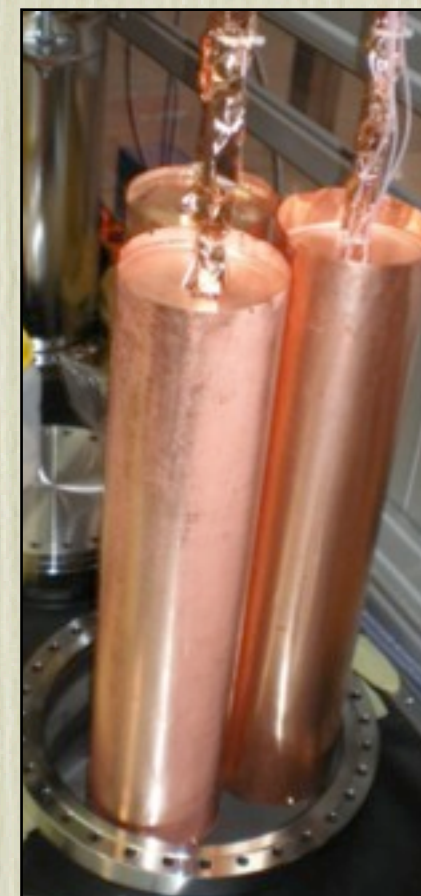


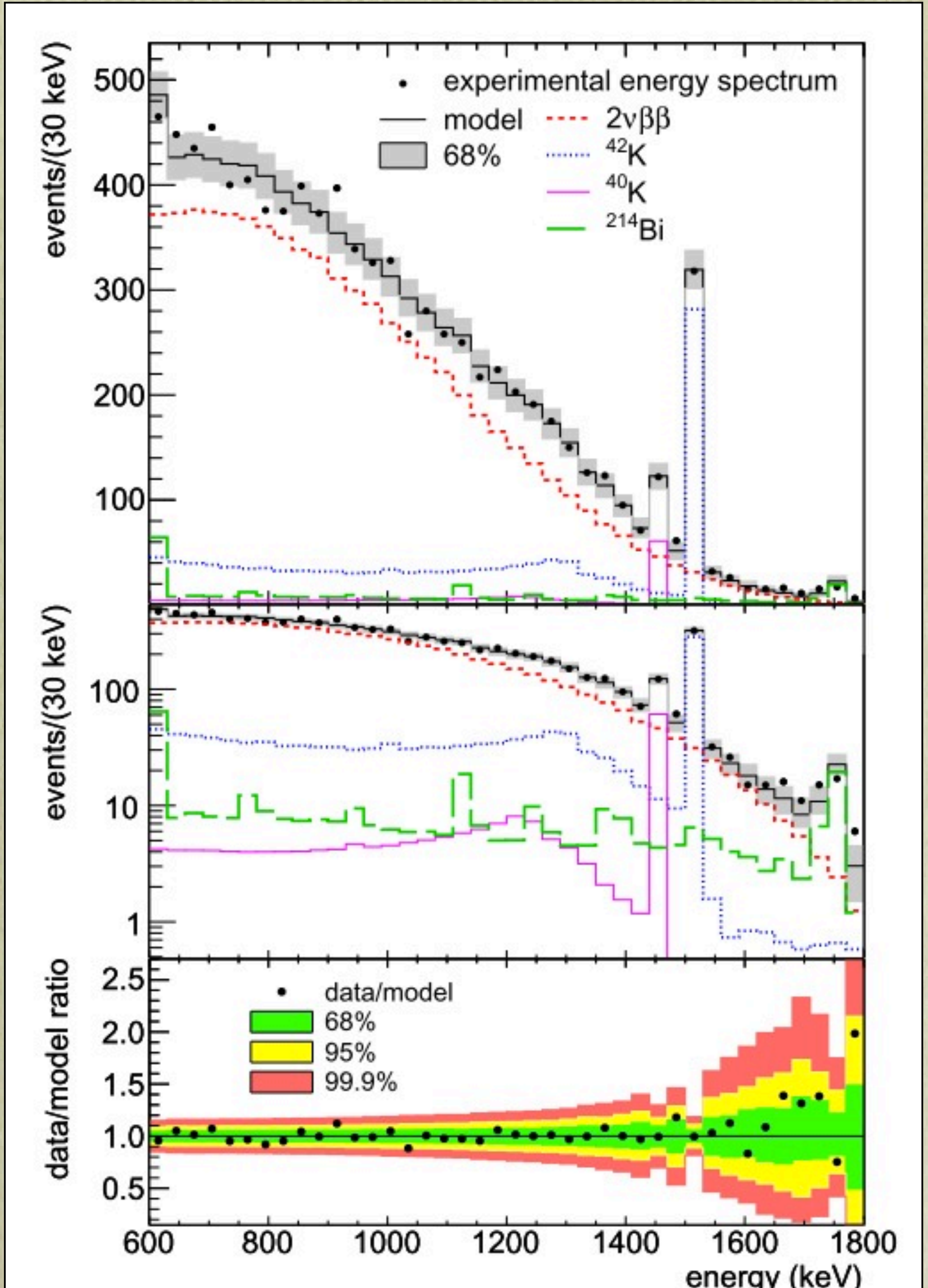
- Alpha decays close to thin p+ dead layer
- Rate decays in agreement with ^{210}Po $T_{1/2}$

K42 Background



- Largest expected bg for Phase II
- ^{42}K bg mitigation
  - Mini shroud
  - Electric fields
  - LAr veto
  - Pulse shape discrimination





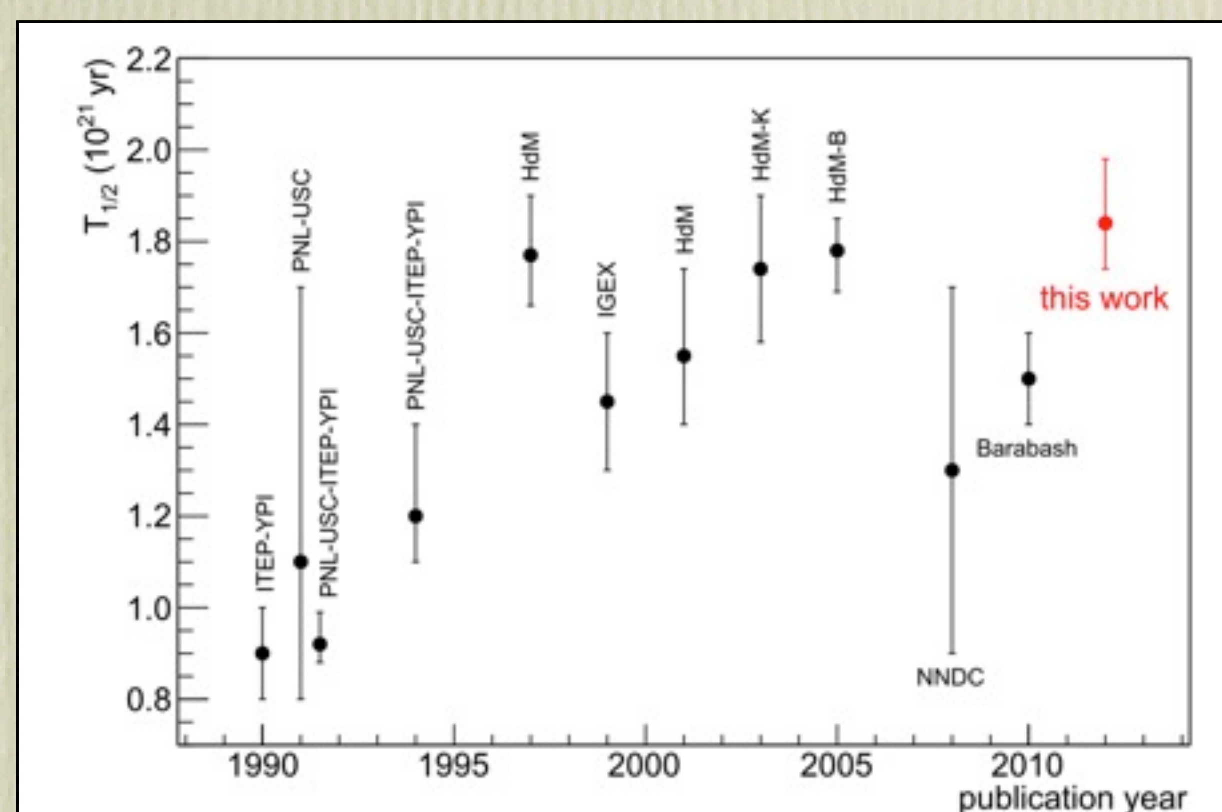
2νββ Measurement

(J.Phys.G 40 (2013) 035110)

- Binned ML fit with 32 parameters (Bayesian analysis)
- 5.04 kg yr exposure: 7030 2νββ events
- Larger than previous S/B ratio: 4:1

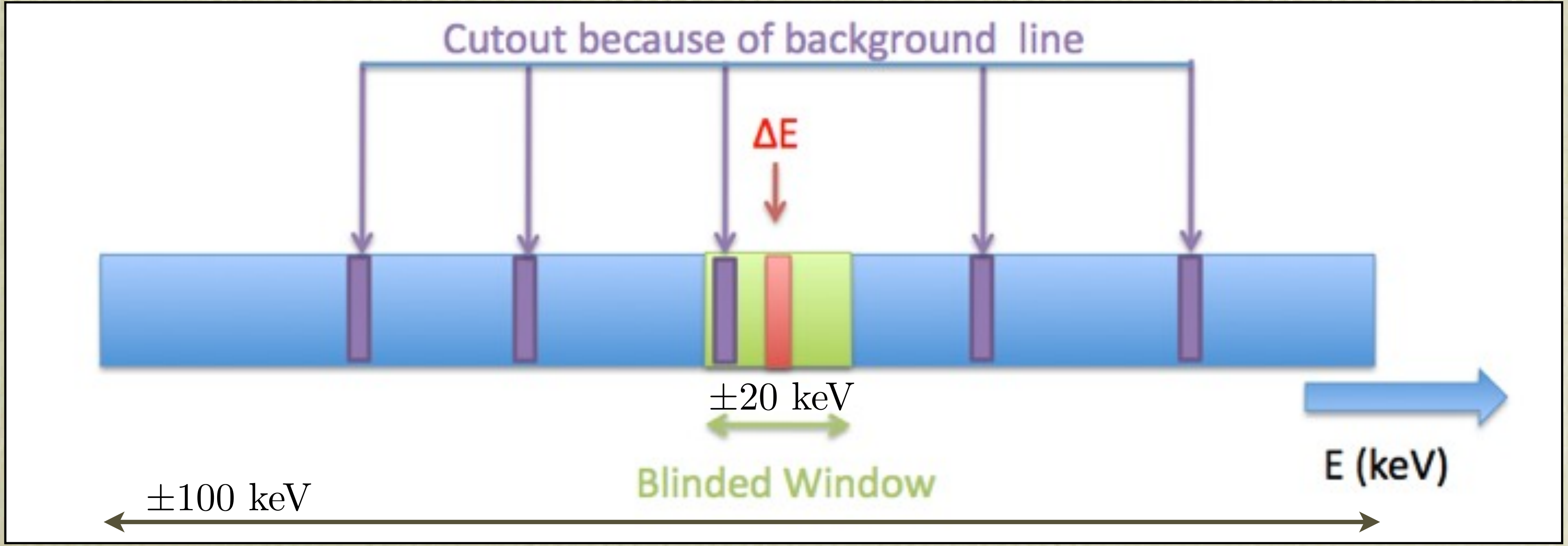
GERDA Result

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

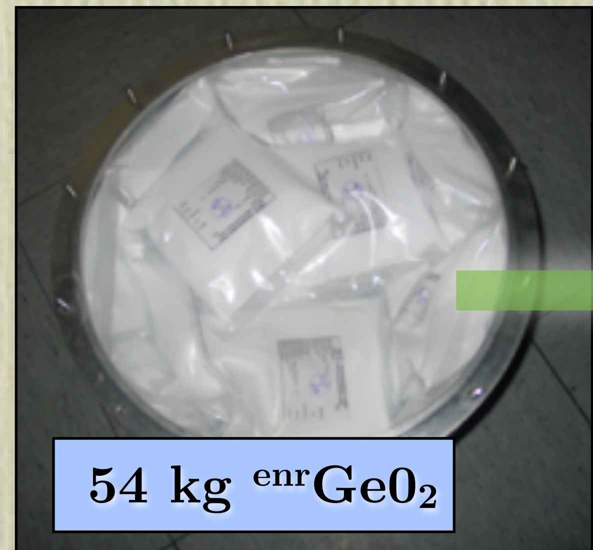


Phase I: $0\nu\beta\beta$ Blinded Analysis

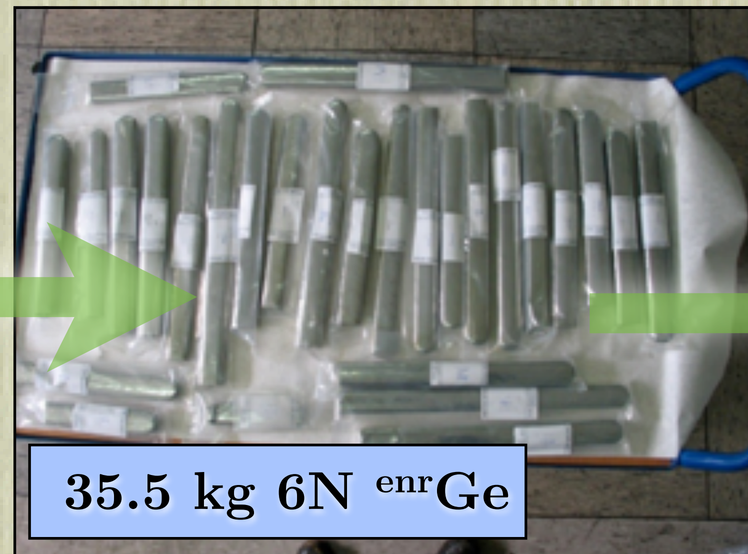
1. Data after Jan 2012 is blinded in ±20 keV around $Q_{\beta\beta}$
   - Avoid tuning the analysis towards signal or no-signal outcome
2. All data processing, quality cuts and statistical analysis methods are being fixed
   - Paper with background model and analysis parameters published on arXiv prior to final unblinding
3. Final unblinding foreseen at GERDA Collaboration meeting June 2013
4. Presentation of result at seminar at LNGS along with publication



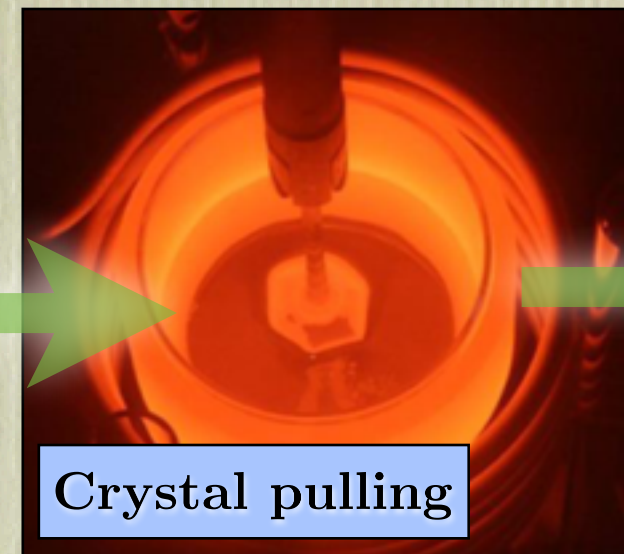
Phase II: BEGe Detectors



54 kg $^{enr}GeO_2$



35.5 kg 6N ^{enr}Ge

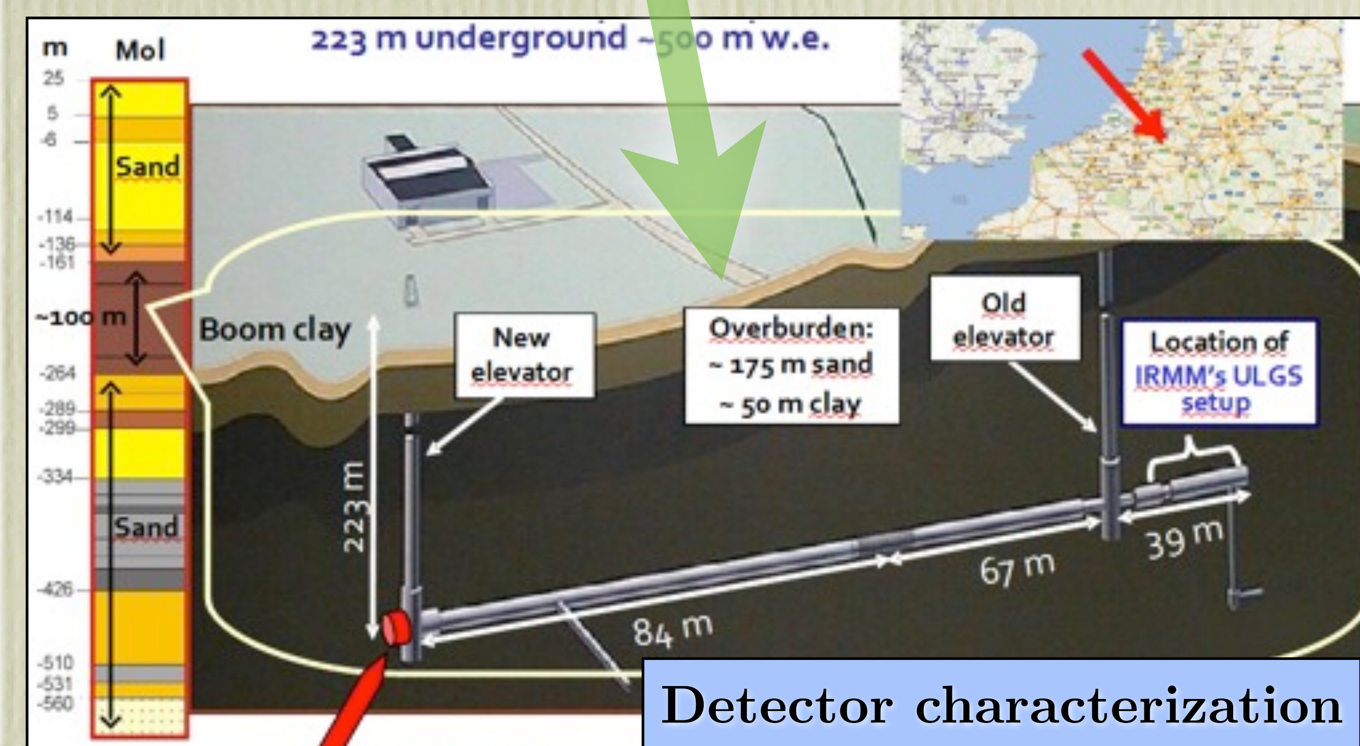


Crystal pulling

7 crystals

30 BEGe detectors

- Whole production chain from $^{enr}GeO_2$ to BEGe diode organized by GERDA and tested with ^{dep}Ge (JINST 8 P04018 2013)
- Total gain 30 BEGes with 20.5 kg (58 % yield)
- Detector characterization in HADES underground facility, Belgium
- Exposure to cosmic rays reduced as much as possible:
  - Transport in shielded container
  - Storage and testing underground

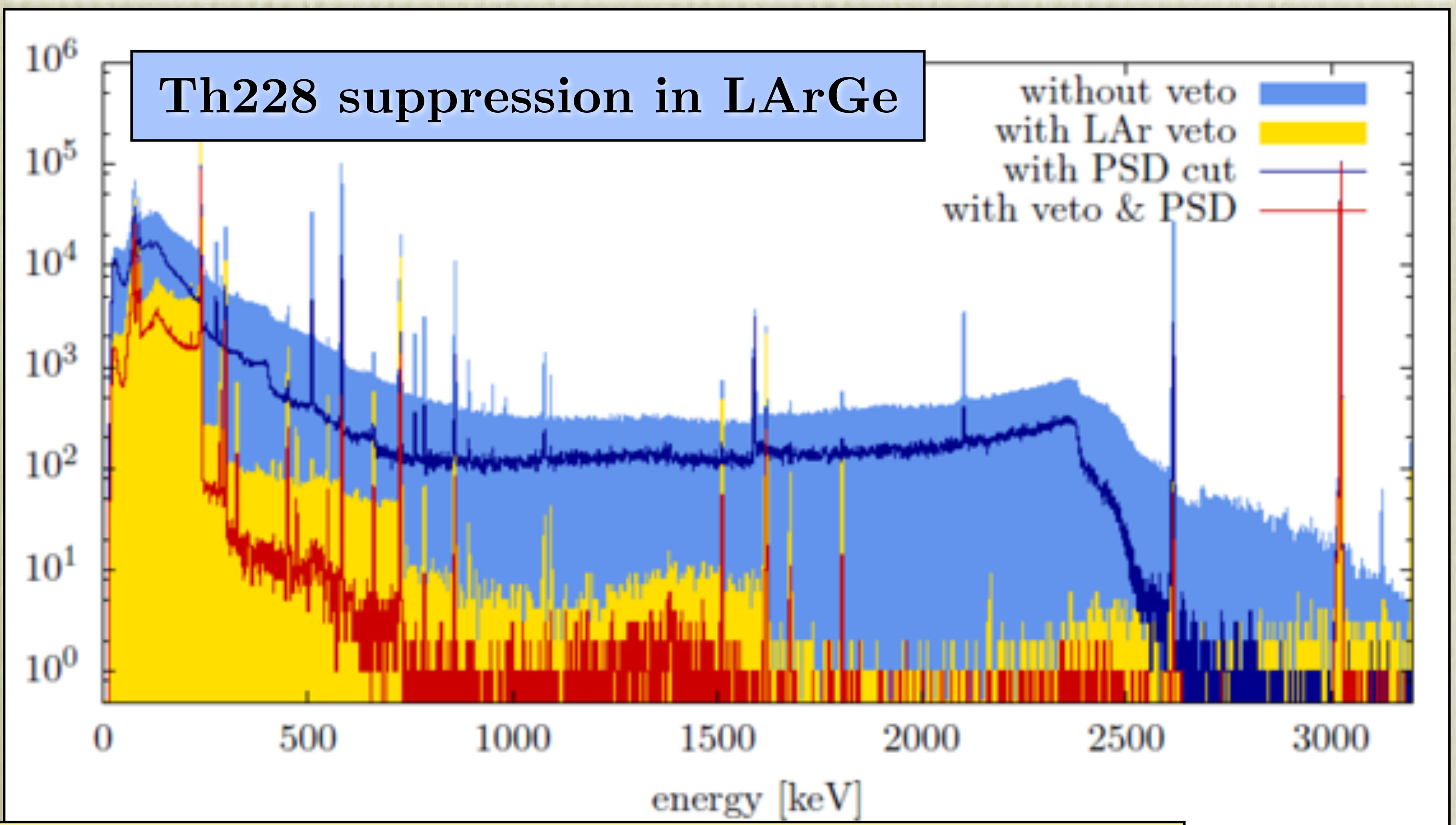


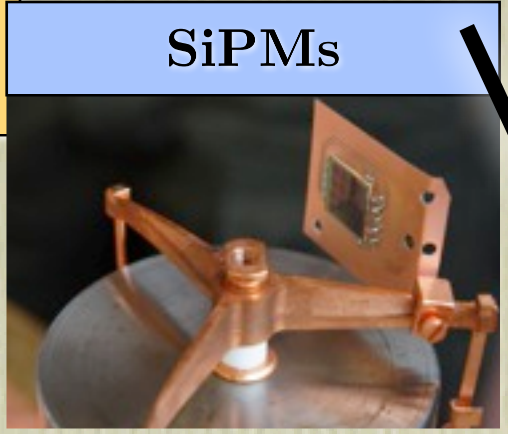
Detector characterization

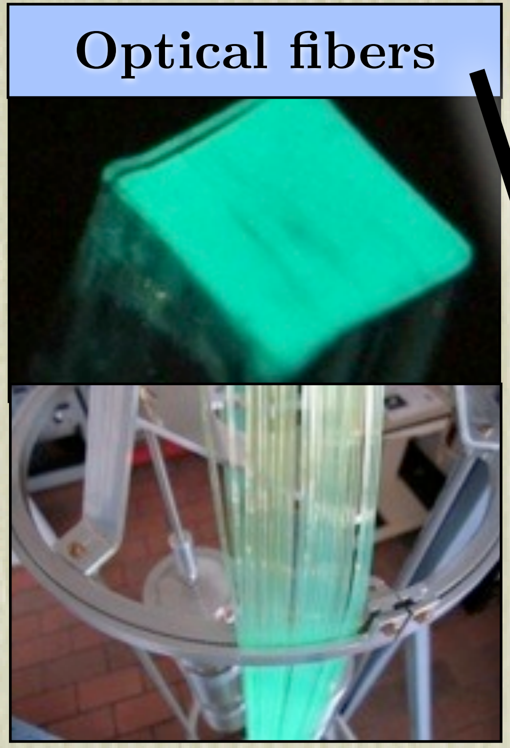
Selected area for BEGE acceptance tests

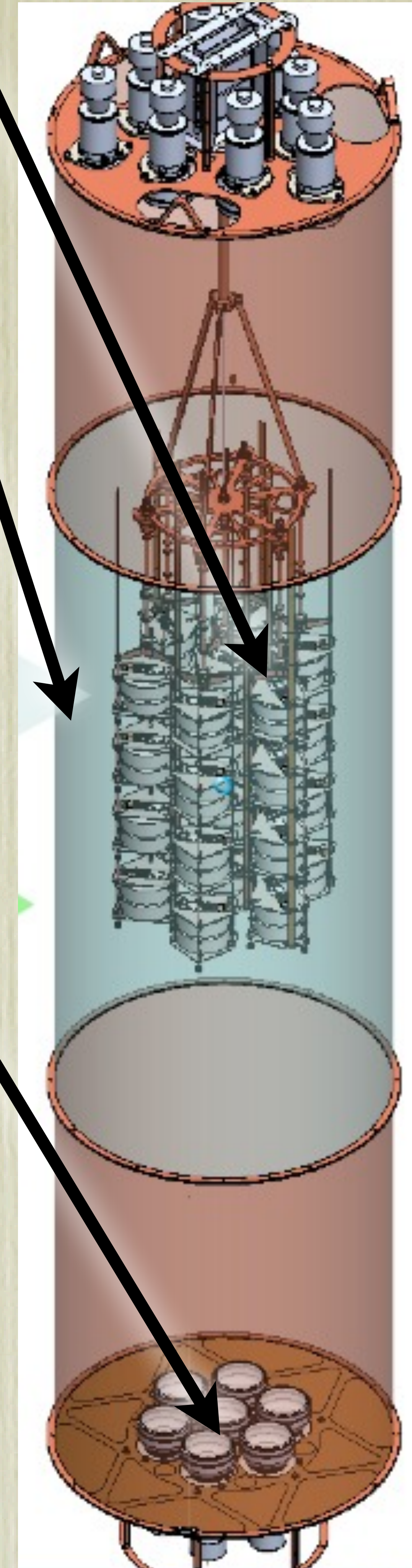
Phase II: LAr Scintillation Veto

- Experimental prove of principle in R&D facility LArGe (LNGS)
- Investigation of different design principles for GERDA with tuned MC simulations:
  - **PMT arrays** on top and bottom
  - **Fiber shroud** with SiPM readout
  - **SiPMs** inside mini shroud (if deployed)
- Combination of designs is favored









Conclusions & Outlook

- GERDA finished Phase I of data taking on May 21st 2013
- Unblinding planned for June 2013 and result will be presented in seminar at LNGS
- Phase II preparation ongoing and hardware integration this summer
- Main Phase II improvements:
  - BEGe detectors
  - LAr scintillation veto

Thank you for the attention!

Lets see what comes out of the box next month...

History

LOW-RADIOACTIVITY
BACKGROUND TECHNIQUES

G. Heusser

Max-Planck-Institut für Kernphysik, P.O. Box 103 980, D-69029 Heidelberg, Germany

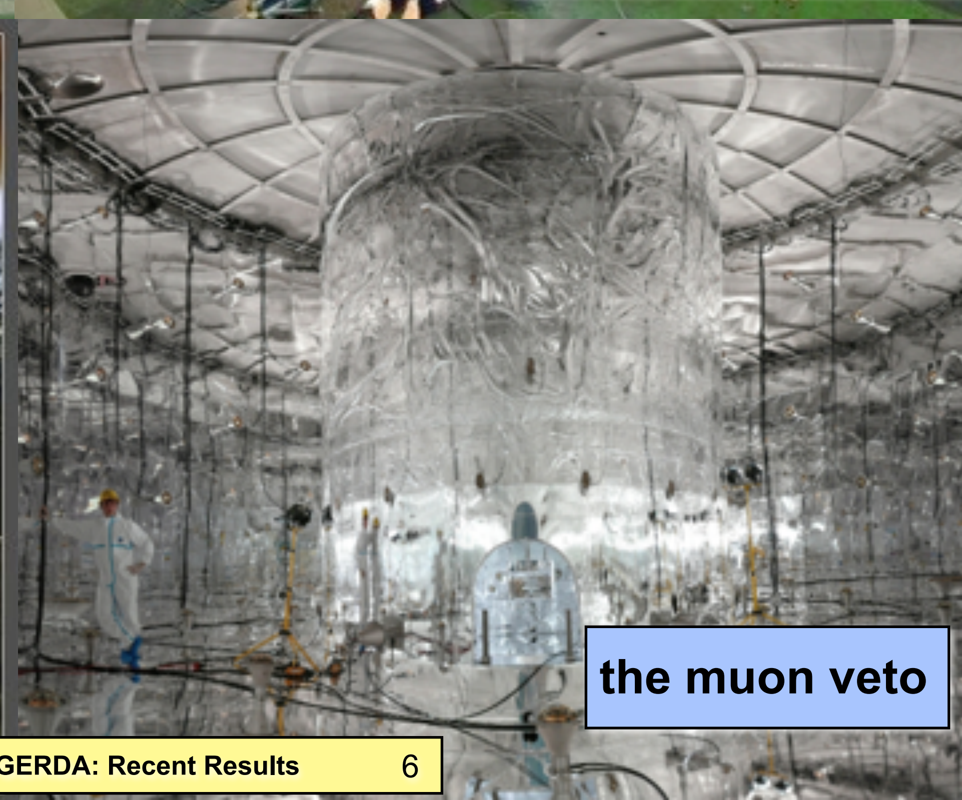
the idea '95

Hall A before construction

water tank construction

Hall A today

the cryostat



the muon veto

official inauguration

Gamma Lines Compare with Heidelberg Moscow