EXO & GERDA

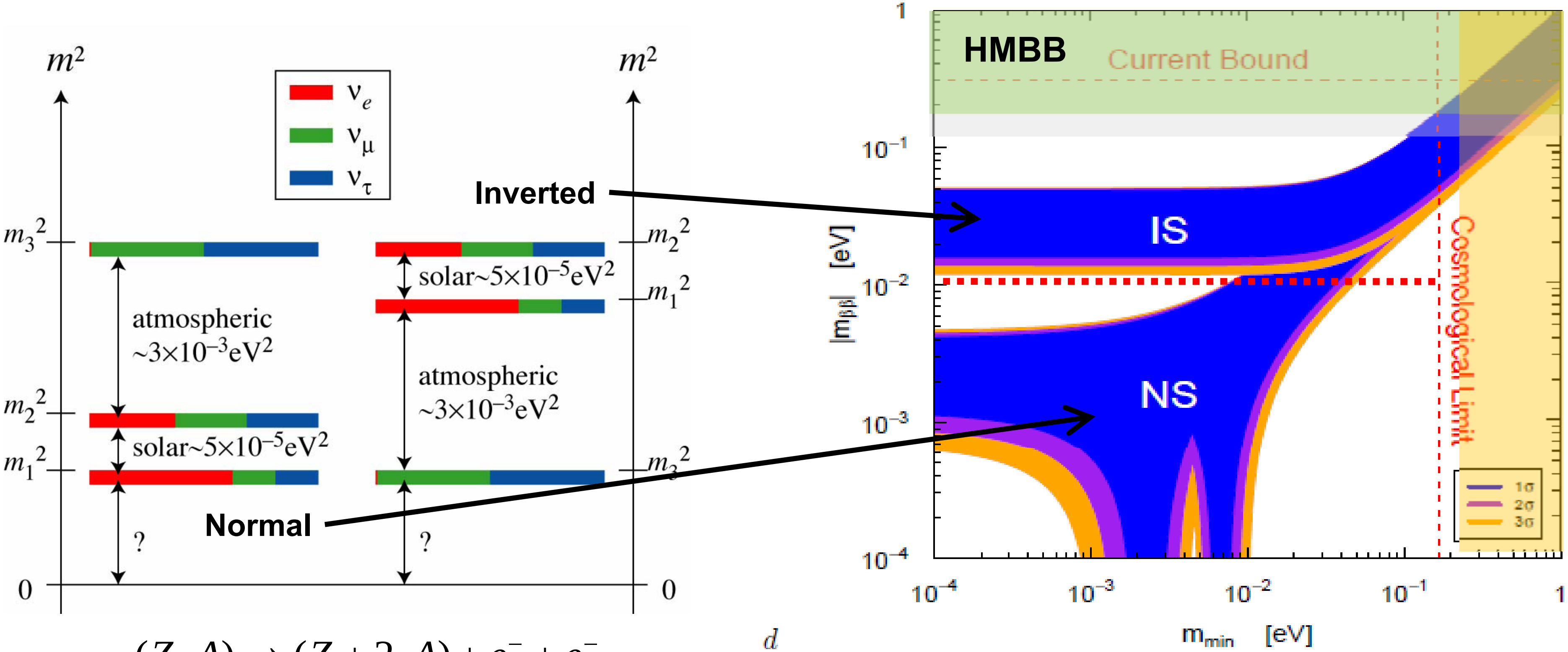
Swiss contributions to $0\nu bb$ searches

CHIPP Annual Plenary Meeting
Kartause Ittingen, September 13-14, 2012

Razvan Gornea

Albert Einstein Center for Fundamental Physics
LHEP, Bern University

Neutrino-less Double Beta Decay

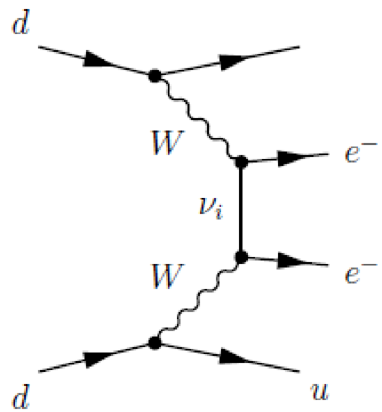


$$(Z, A) \rightarrow (Z+2, A) + e_1^- + e_2^-$$

$$\left[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)\right]^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\left|M^{0\nu}\right|^2 \left\langle m_{\beta\beta}\right\rangle^2$$

$$\left\langle m_{\beta\beta}\right\rangle = \left|\sum_{k=1}^{3} m_k \left|U_{ek}\right|^2 e^{i\alpha_k}\right| \quad \text{Majorana}$$

$$\left\langle m_{\beta\beta}\right\rangle = 0 \quad \text{Dirac}$$



Lepton number violating process

Majorana or Dirac neutrino

Mass hierarchy

Absolute neutrino mass

Enriched Xenon Observatory

EXO-200

EXO Project & EXO-200 Phase

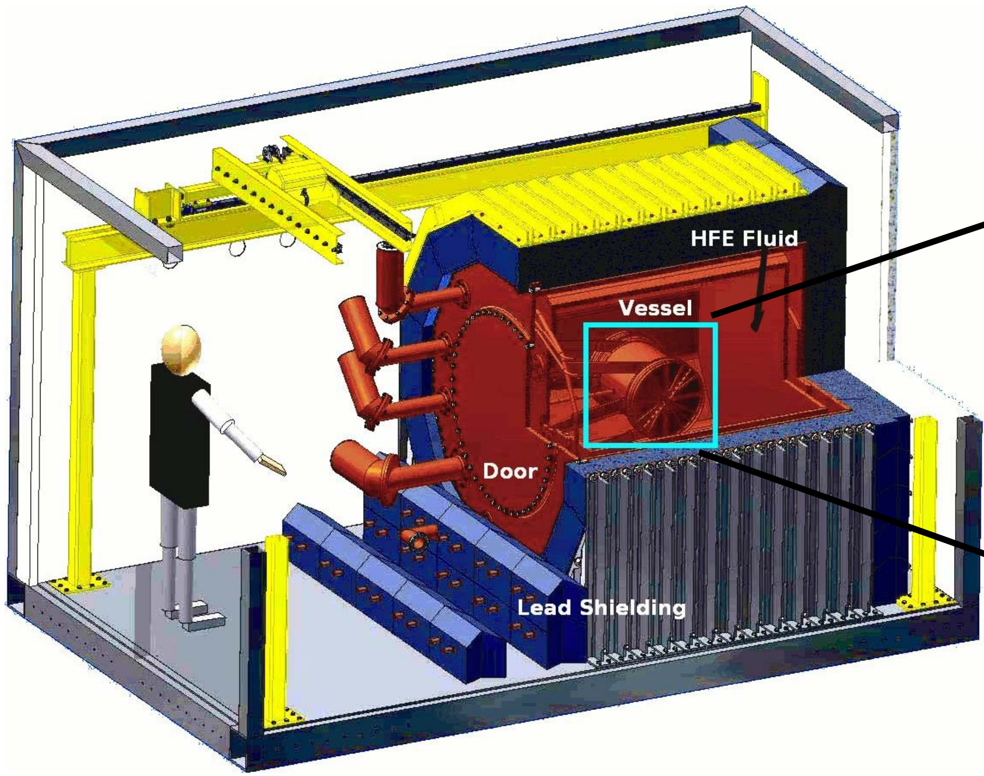
- EXO searches for neutrino-less double beta decay using ^{136}Xe
  - ➡Ton scale implementation either as liquid or gas phase TPC
  - ➡Relatively large Q value (2457.8 keV) and straight forward enrichment technique
  - ➡^{136}Ba daughter tagging either in-situ or in external RF cage

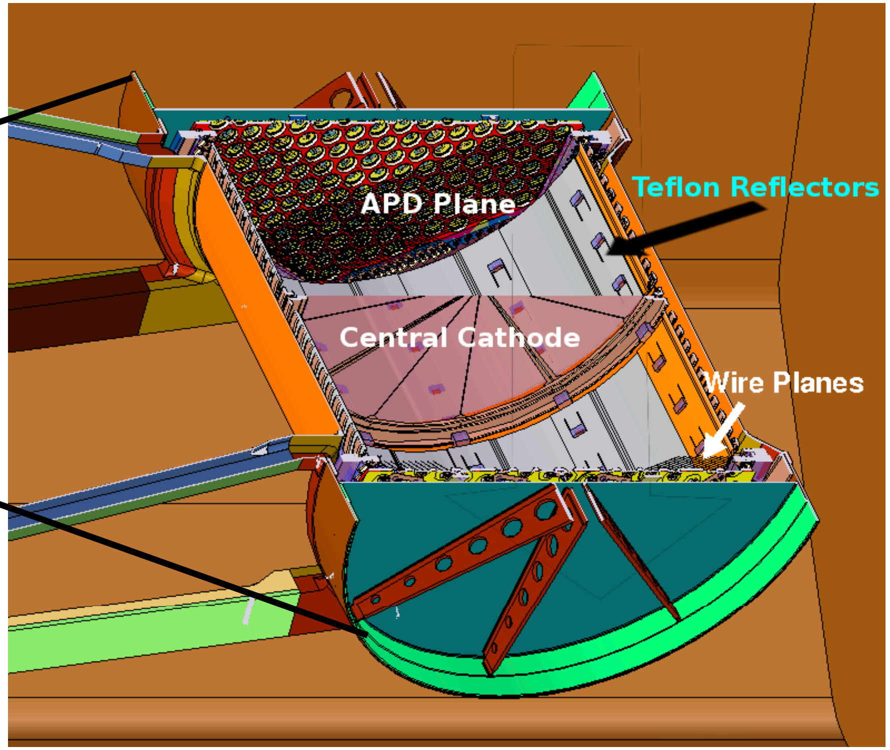
- EXO-200 is the first phase using 200 kg of 80% enriched Xe
  - ➡Major R&D effort precursory to the ton-scale experiment
  - ➡Exploration of the quasi-degenerate region with ^{136}Xe
  - ➡Measurement of the allowed double beta decay in xenon $T_{1/2} = 2.1 \times 10^{21}$ years
  - ➡No Ba ion tagging but massive progress for radioactive background reduction and energy resolution improvement (scalable to future detectors)

EXO-200 Detector

- **High purity copper cryostat with external cooling**
- **Liquid xenon TPC with two cylindrical drift volumes**
  - ➡**Charge collection using 114 by 114 wire planes (at 120º pitch)**
  - ➡**Scintillation light readout using 37 groups of 7 bare LAAPD (Large Area Avalanche Photodiodes) at both end caps**

Ultra-low radioactivity materials
Mass minimized around the TPC
Fiducial volume closely enveloped





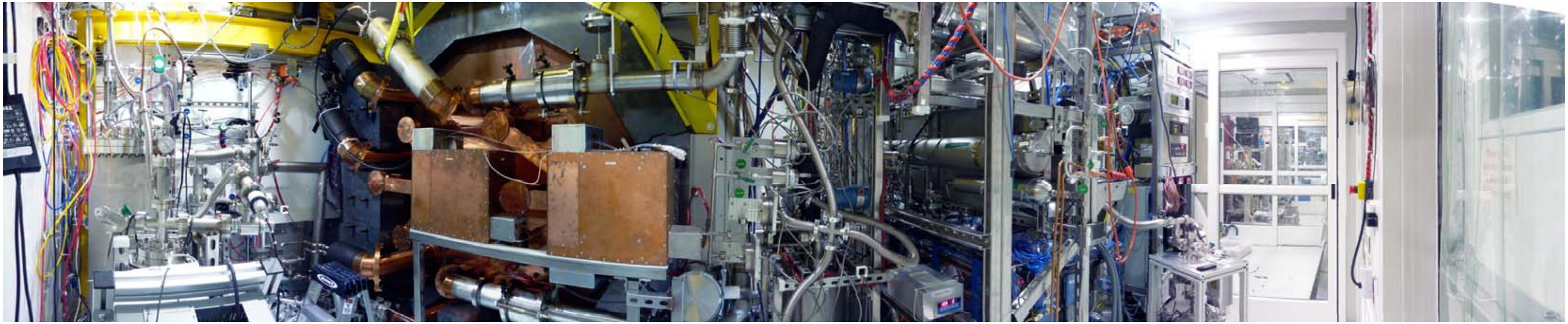
EXO-200 Location

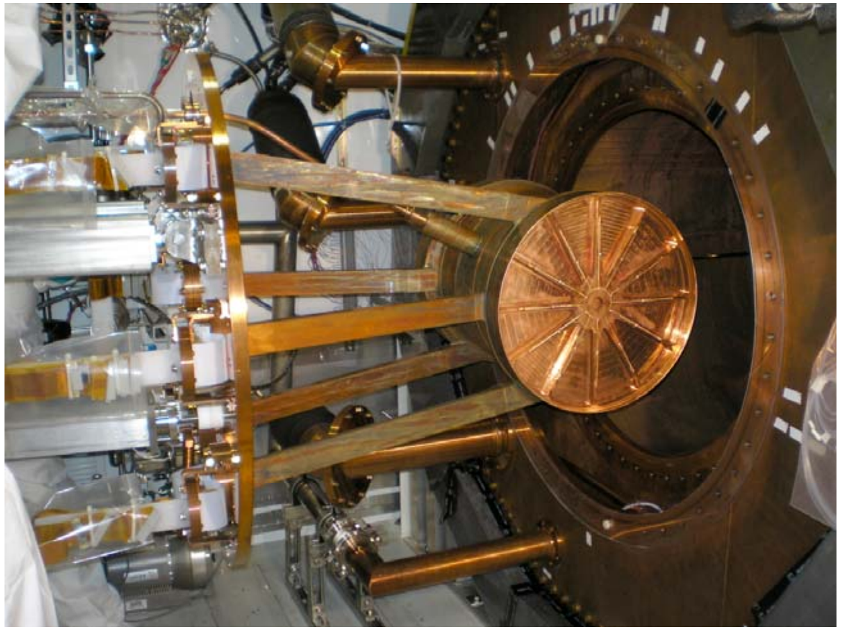
- Waste Isolation Pilot Plant (WIPP), Carlsbad (53 km), New Mexico, USA
  - ➡650 m flat overburden (salt bed, 20 Bq/m^3)
  - ➡~ 1600 m.w.e. (muon flux reduction by ~ 1000X)
- Large experimental area available!

<u>Cleanroom modules</u>
Detector, cryostat, gas handling

<u>Utility modules</u>
UPS, shop, gas containers

EXO-200 Installation

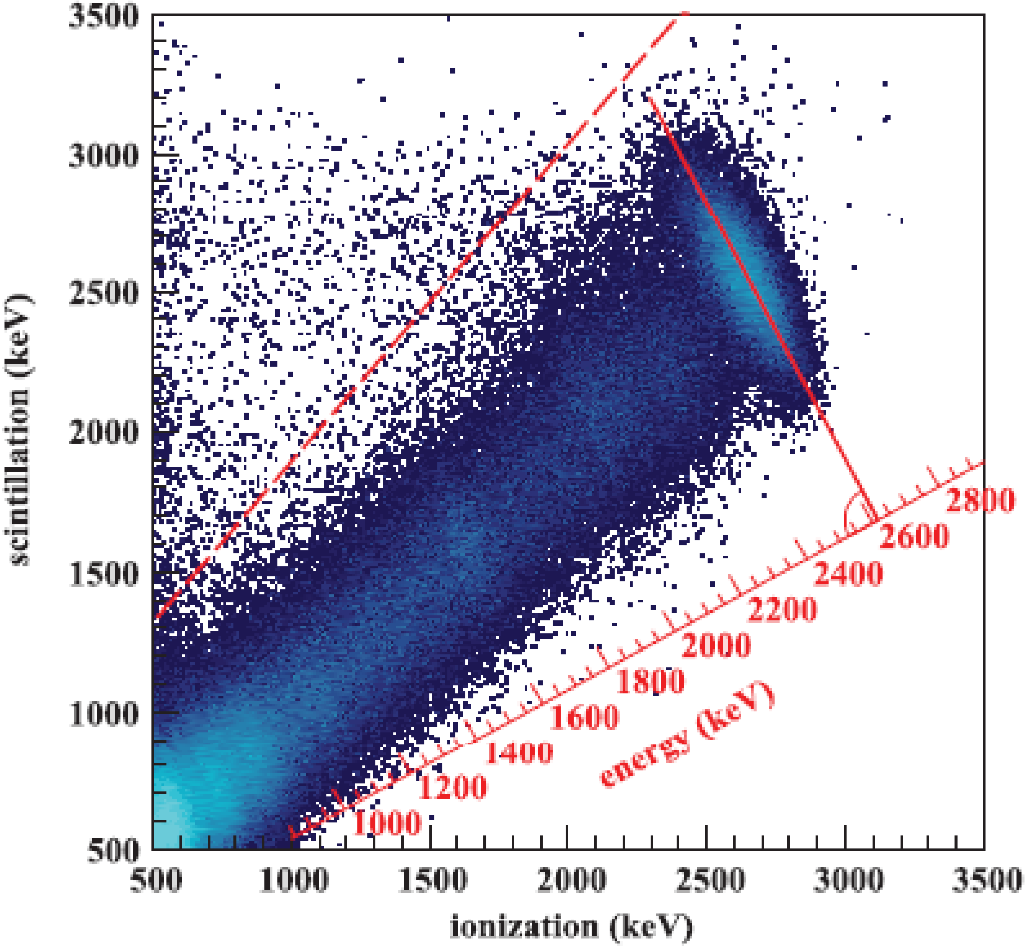


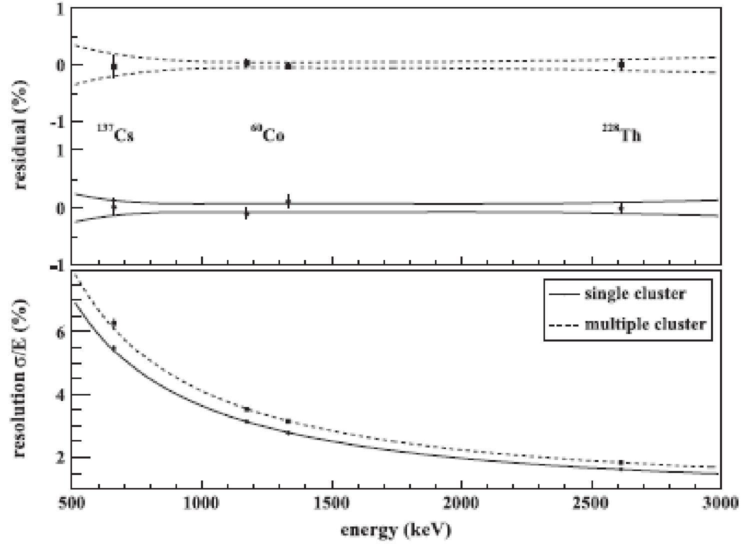


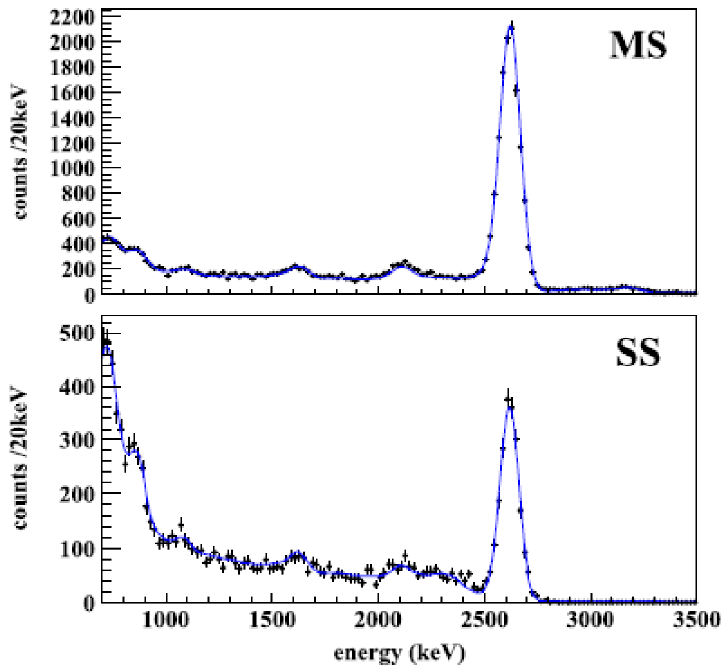
TPC installation

EXO-200 calibration

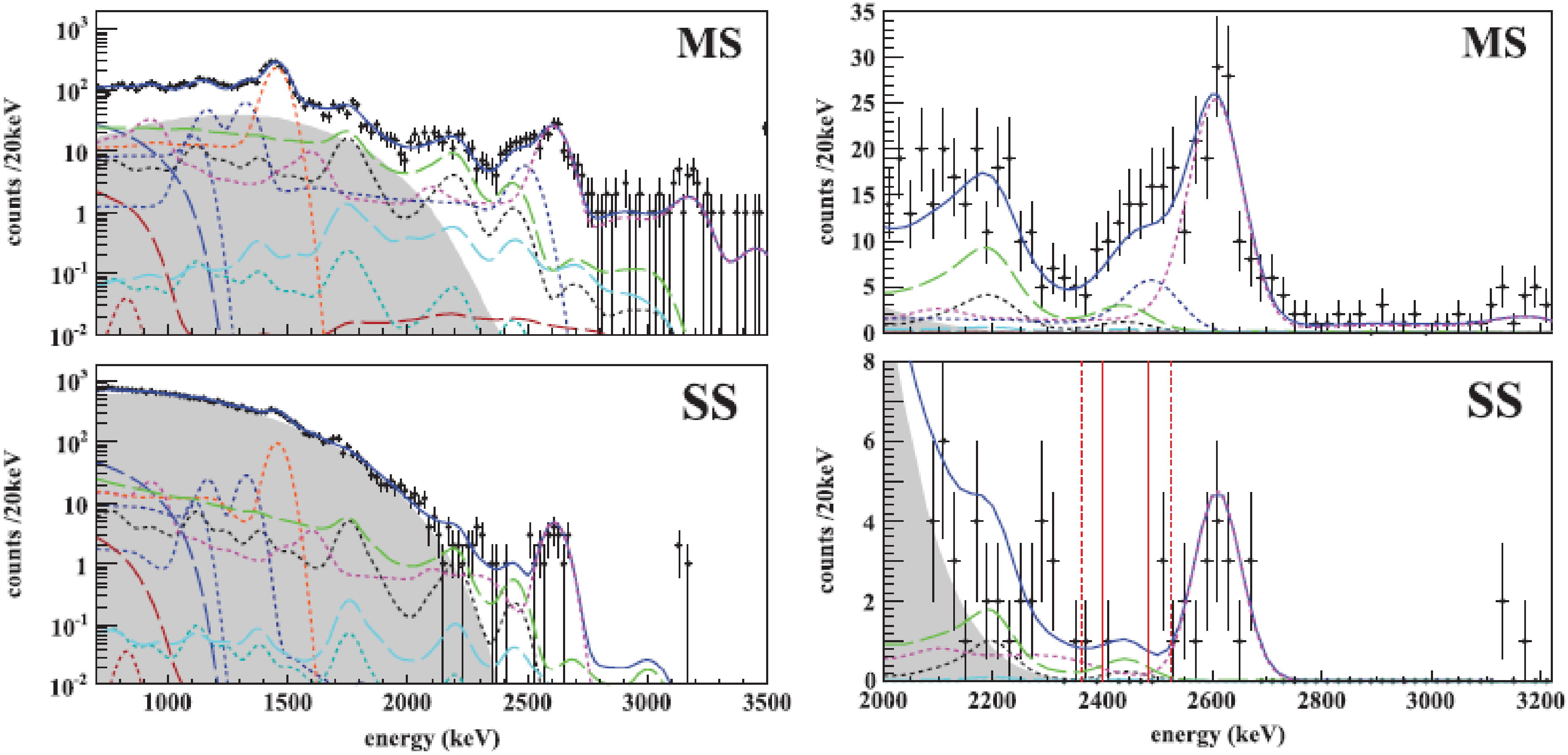
Th-228 calibration





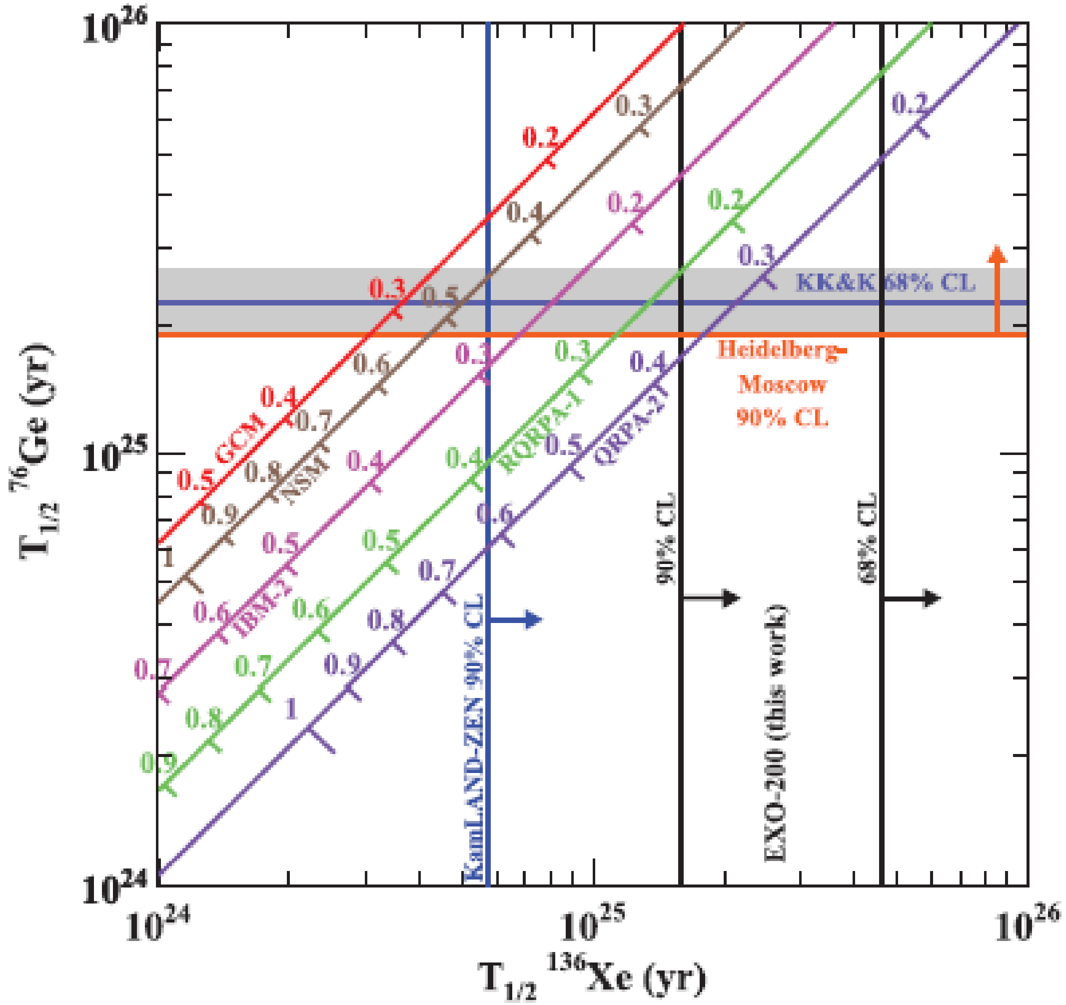


EXO-200 residual background



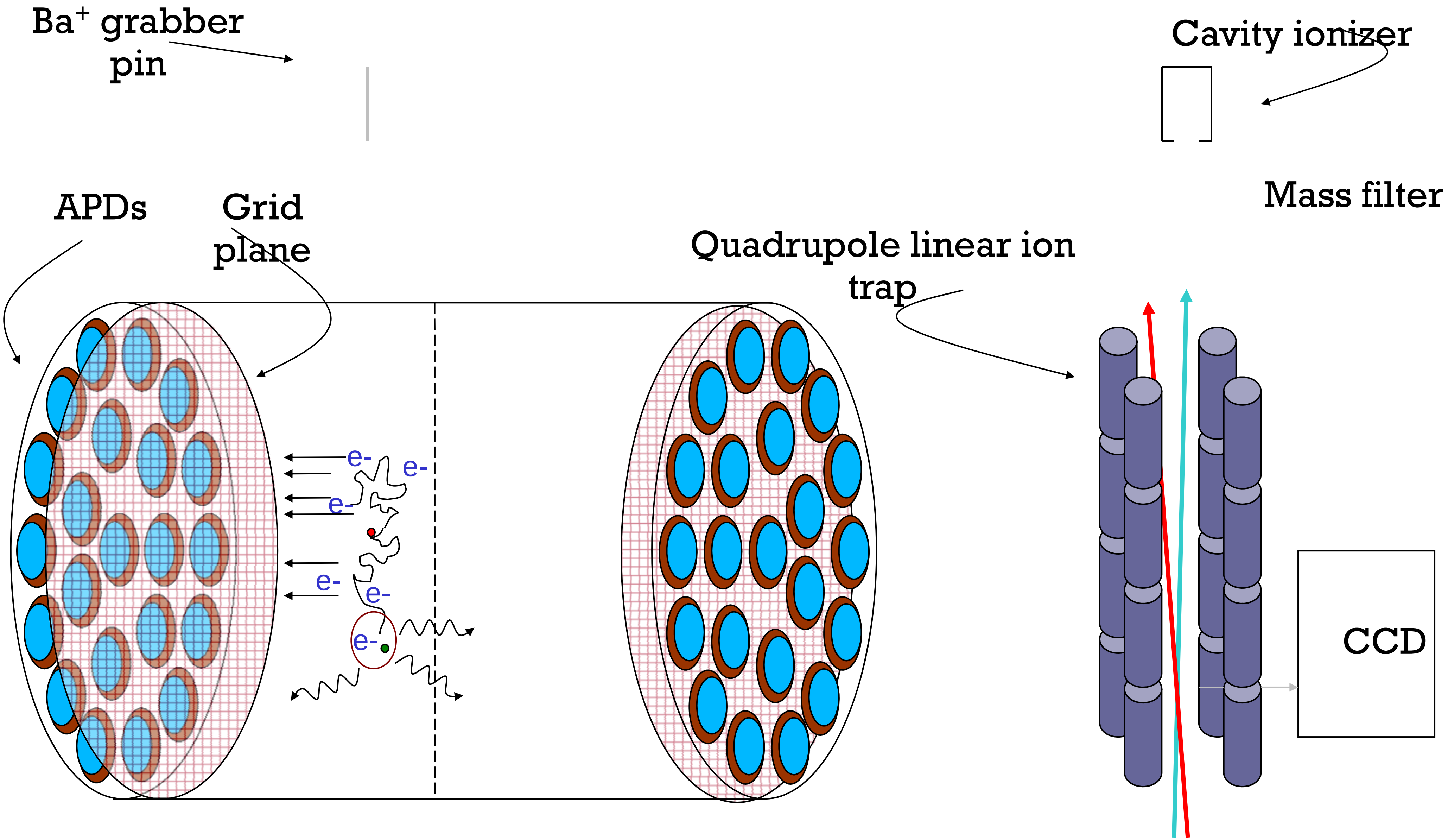
~ 1.5 #/ton/yr/keV for ±1σ @ Q = 2458 keV

EXO-200 Performance



Limit from the Gotthard Experiment $T_{1/2}^{0\nu} > 4.4 \times 10^{23}\, y @ 90\% C.L.$

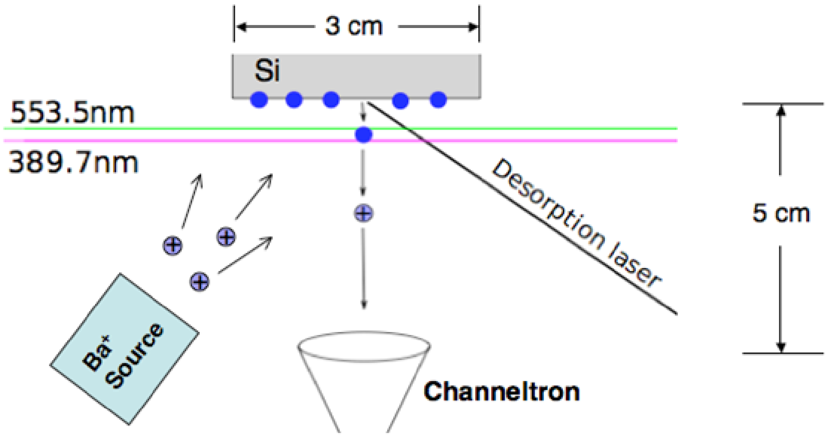
Ion Tagging Cartoon

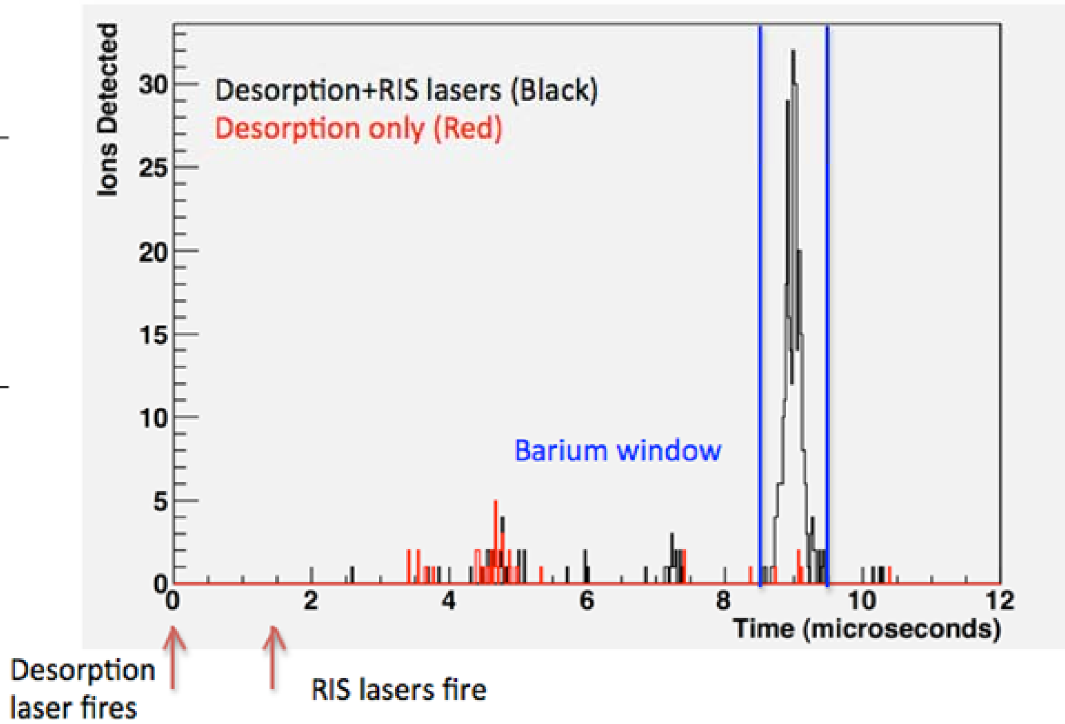


Resonant Ionization Spectroscopy

Use of atomic resonances to selectively obtain a high yield for Ba ionization

Lasers tuned to specific Ba atomic transitions push the atom to a highly excited state from which it decays to a lower energy ionized state



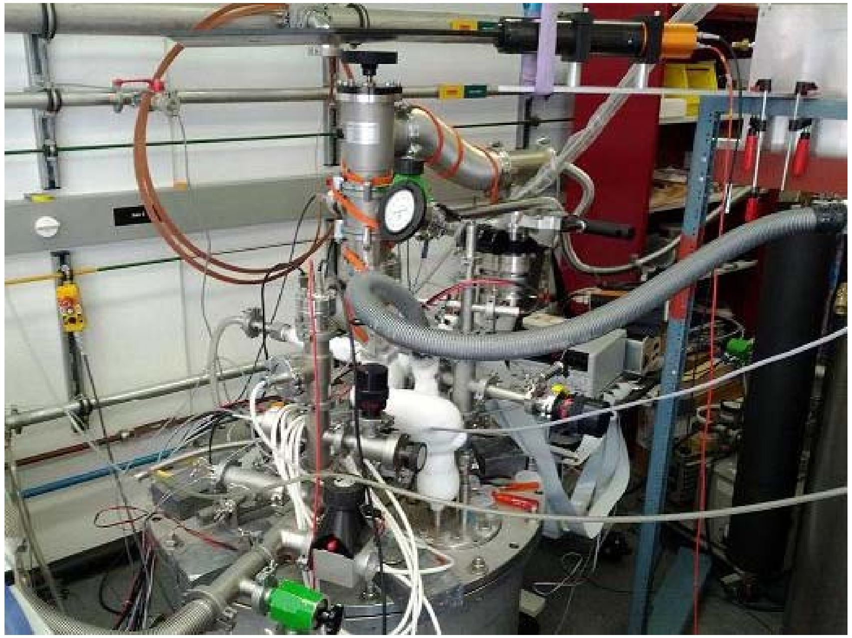


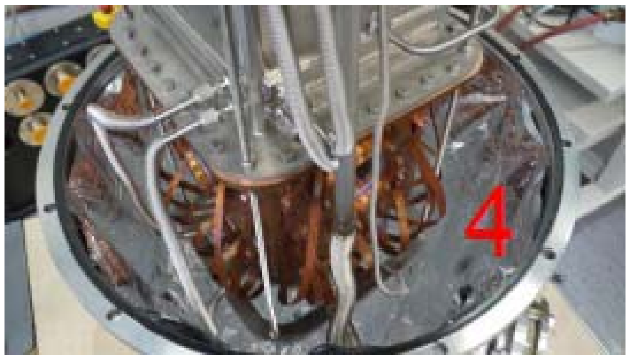
Reached efficiency ~ 10^{-2}

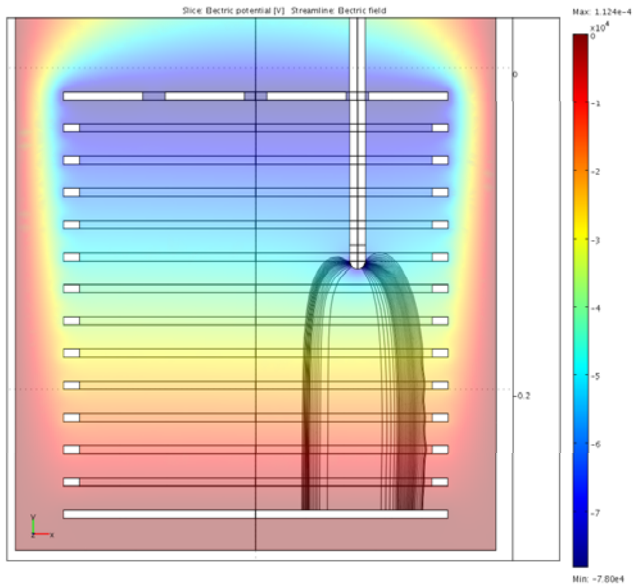
New setup targeting "single ion detection" in preparation

Probe Insertion R&D in Bern

Test cryostat for probe insertion in liquid Xe TPC
COMSOL based simulations of the electric field configuration







Bern Ba tagging R&D Roadmap

- Cryostat commissioning for liquid CF4 *and xenon* safe operation
- *Electrostatic simulations to determine the best geometry for a liquid TPC adapted to the insertion of an ion collection probe (good energy resolution is a priority)*
- TPC instrumentation with charge and scintillation light readout followed by commissioning using muons and gamma sources

- *Engineering of the mechanical displacement device along with fluid dynamics simulations to define the operational parameters for the probe*
- Device construction and integration with the cryogenic setup followed by operational tests using Rn-222 → Po-218 → Pb-214 chain
- *Study of the barium ion properties and behavior in a large size realistic test environment*

Conclusion

EXO-200 installed and commissioned
Took & continuing data taking with enriched xenon
Published new limit for the neutrino-less double beta decay!

Measured $T_{1/2}$ for the allowed double beta decay in Xe-136!

Various techniques are explored for barium tagging in
preparation for next ton-scale detector

The EXO Collaboration

University of Alabama, Tuscaloosa AL, USA - D. Auty, M. Hughes, A. Piepke, K. Pushkin, M. Volk

University of Bern, Switzerland - M. Auger, S. Delaquis, D. Franco, G. Giroux, R. Gornea, T. Tolba, J-L. Vuilleumier, M. Weber

California Institute of Technology, Pasadena CA, USA - P. Vogel

Carleton University, Ottawa ON, Canada - A. Coppens, M. Dunford, K. Graham, C. Hägemann, C. Hargrove, F. Leonard, C. Oullet, E. Rollin, D. Sinclair, V. Strickland

Colorado State University, Fort Collins CO, USA - S. Alton, C. Benitez-Medina, C. Chambers, Adam Craycraft, S. Cook, W. Fairbank, Jr., K. Hall, N. Kaufold, T. Walton

Drexel University, Philadelphia PA, USA - M.J. Dolinski

University of Illinois, Urbana-Champaign IL, USA - D. Beck, J. Walton, M. Tarka, L. Yang

IHEP Beijing, People's Republic of China - G. Cao, X. Jiang, L. Wen, Y. Zhao

Indiana University, Bloomington IN, USA - J. Albert, T. Johnson, L.J. Kaufman

University of California, Irvine, Irvine CA, USA - M. Moe

ITEP Moscow, Russia - D. Akimov, I. Alexandrov, V. Belov, A. Burenkov, M. Danilov, A. Dolgolenko, A. Karelin, A. Kovalenko, A. Kuchenkov, V. Stekhanov, O. Zeldovich

Laurentian University, Sudbury ON, Canada - E. Beauchamp, D. Chauhan, B. Cleveland, J. Farine, B. Mong, U. Wichoski

University of Maryland, College Park MD, USA - C. Davis, A. Dobi, C. Hall, S. Slutsky, Y-R. Yen

University of Massachusetts, Amherst MA, USA - T. Daniels, S. Johnston, K. Kumar, A. Pocar, J.D. Wright

University of Seoul, South Korea - D. Leonard

SLAC National Accelerator Laboratory, Menlo Park CA, USA - M. Breidenbach, R. Conley, K. Fouts, R. Herbst, S. Herrin, J. Hodgson, A. Johnson, R. MacLellan, A. Odian, C.Y. Prescott, P.C. Rowson, J.J. Russell, K. Skarpaas, M. Swift, A. Waite, M. Wittgen, J. Wodin

Stanford University, Stanford CA, USA - P.S. Barbeau, J. Bonatt, T. Brunner, J. Chaves, J. Davis, R. DeVoe, D. Fudenberg, **G. Gratta**, S.Kravitz, M. Montero-Díez, D. Moore, I. Ostrovskiy, K. O'Sullivan, A. Rivas, A. Sabourov, D. Tosi, K. Twelker

Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino

Status of the GERDA Experiment

GERDA

University of Zurich[UZH]

GERDA physics goals

- Detect the neutrinoless double beta decay in ^{76}Ge
- Obtain information on the nature of neutrinos and on the effective Majorana neutrino mass

- Ge detectors directly submersed in LAr

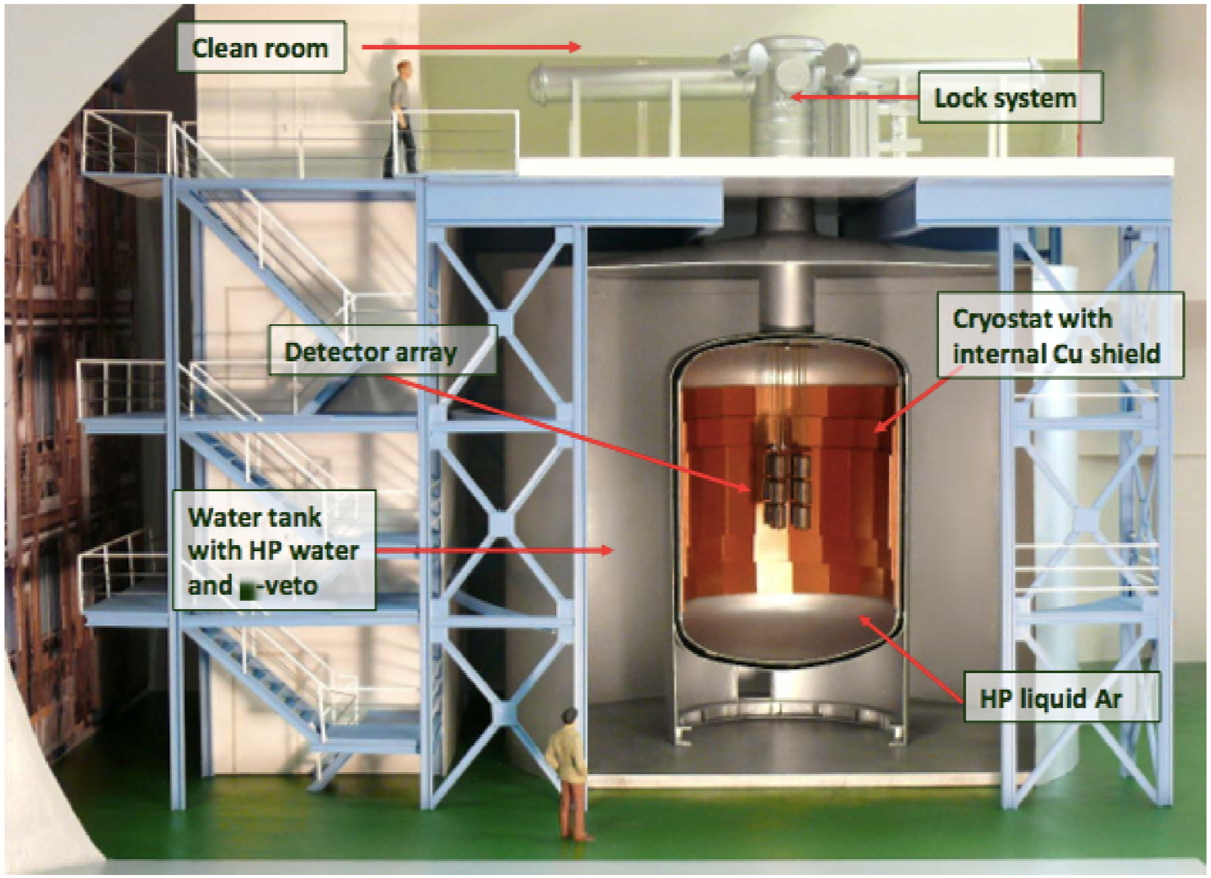
➡ LAr as cooling medium and shielding (U/Th in LAr < 7×10^{-4} µBq/kg)

➡ a minimal amount of surrounding materials

- Phased approach with existing and new enriched detectors

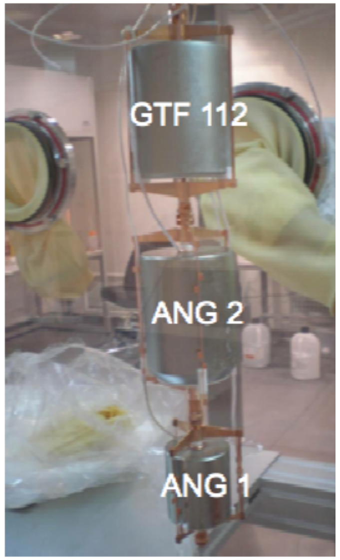
➡ increase target mass

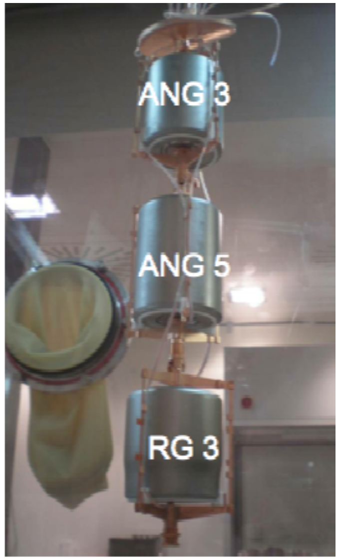
➡ further reduction of backgrounds by LAr instrumentation and improved single- versus multiple-site interactions



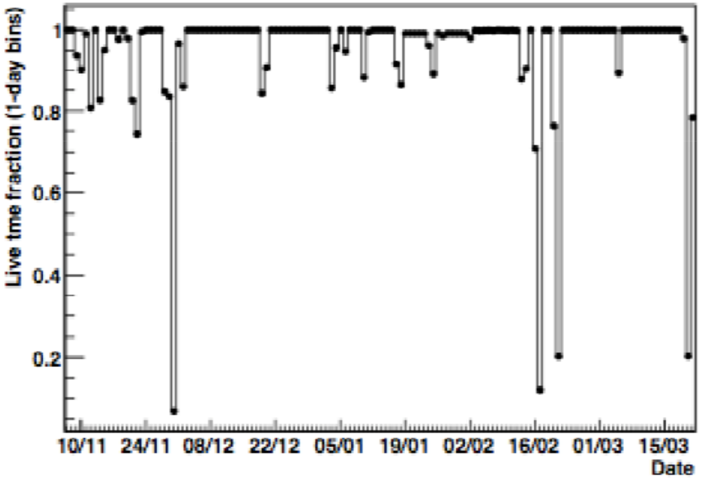
The GERDA Experiment

- HPGe detectors in liquid argon ($^{238}U/^{232}Th$ in LAr < 7×10^{-4} µBq/kg)





- Physics run started on November 9, 2011



GERDA physics goals

- Phase I: ~15 kg ^{76}Ge detectors; background: 10^{-2} counts/(kg keV yr)
- Sensitivity reach after an exposure of 30 kg years:

$$T_{1/2}^{0\nu} > 3.0 \times 10^{25}\, yr$$

$$\langle m_{\nu e} \rangle < 0.27 eV$$

Claim of evidence for 0vbb-decay:
signal: 28.8 ± 6.9 events
BG level: 0.11 counts/(kg keV yr)
HVKK et al., PLB 586 (2004) 198-212

If claim true, phase I will see:
signal: 13 events
BG: 3 events
(in 20 keV window around Q-value, 2039 keV)

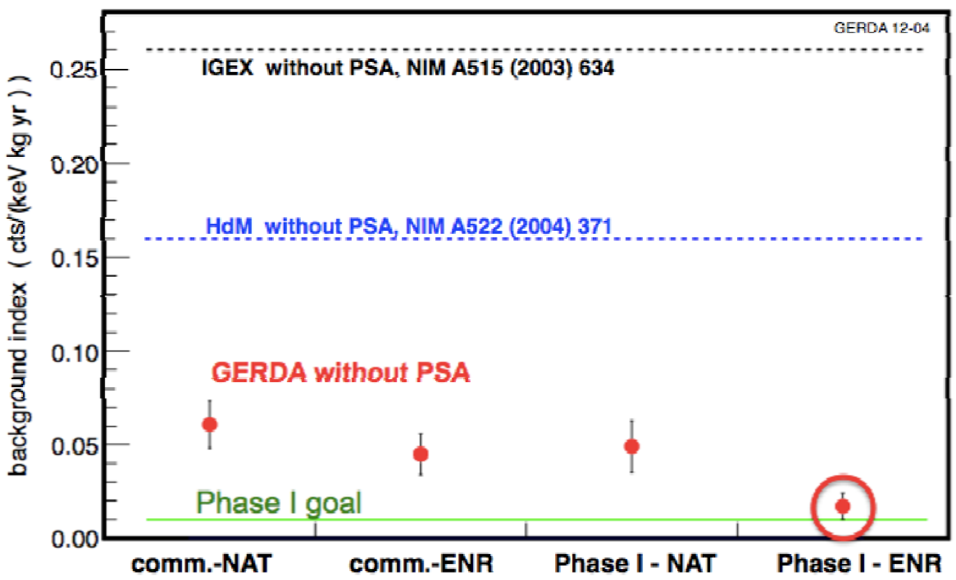
- Phase II: ~ 40 kg enriched ^{76}Ge detectors, background: 10^{-3} counts/(kg keV yr)
- Sensitivity reach after an exposure of 150 kg years:

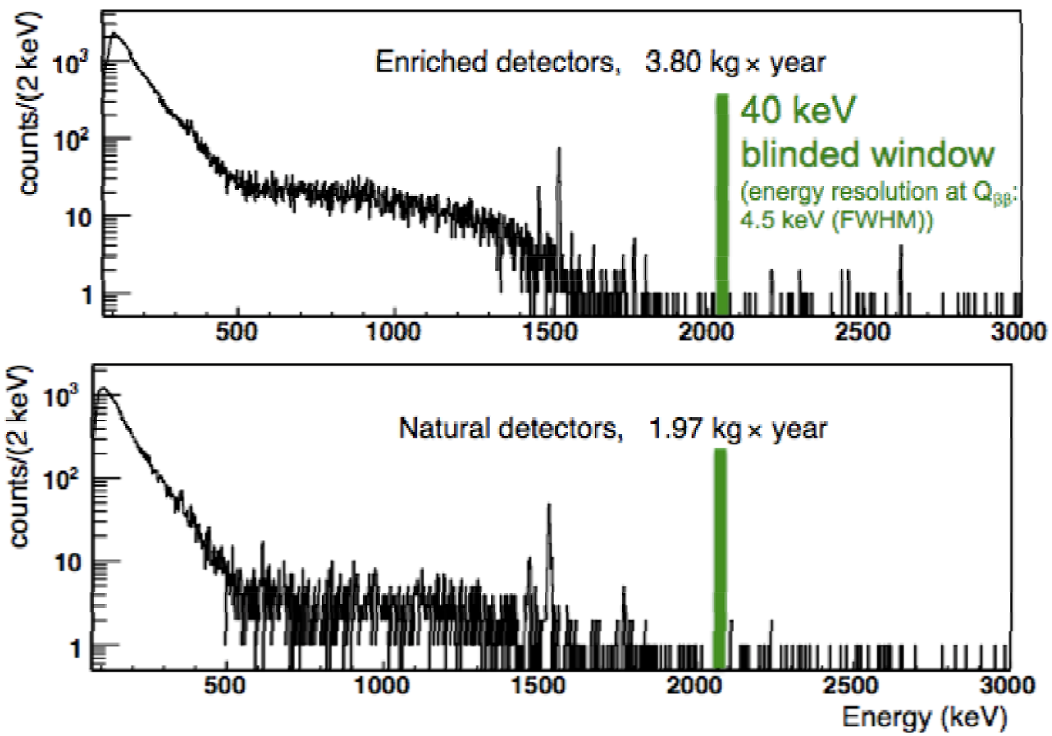
$$T_{1/2}^{0\nu} > 15 \times 10^{25}\, yr$$

$$\langle m_{\nu e} \rangle < 0.11 eV$$

GERDA low-background spectrum

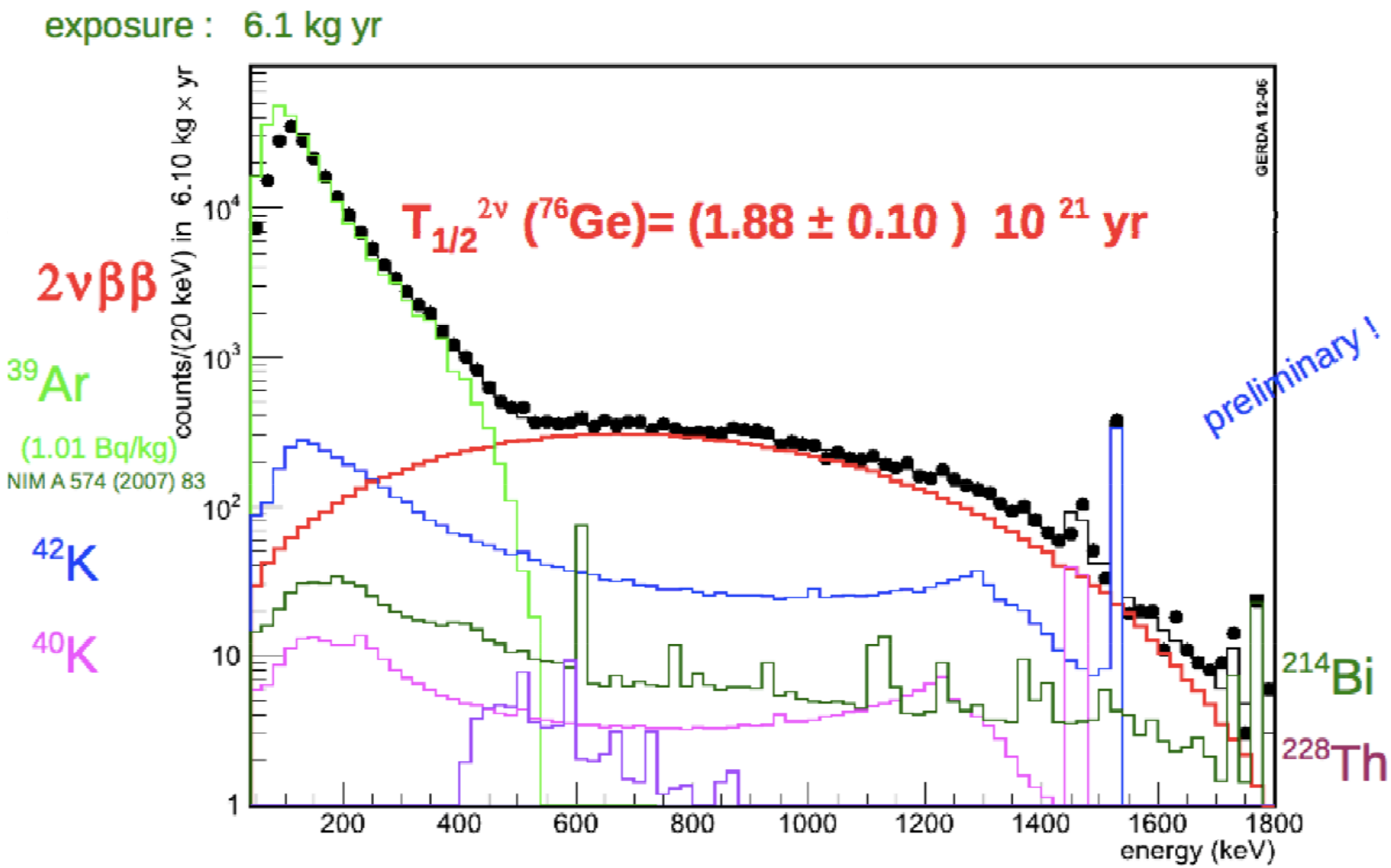
- Background goal of ~ 10^{-2} events/(kg yr keV) was reached
- Phase II (BEGe) detectors in production and testing
- LAr instrumentation (PMTs or SiPM & scintillating fibers) in development
- End of phase I and start of phase II: spring 2013





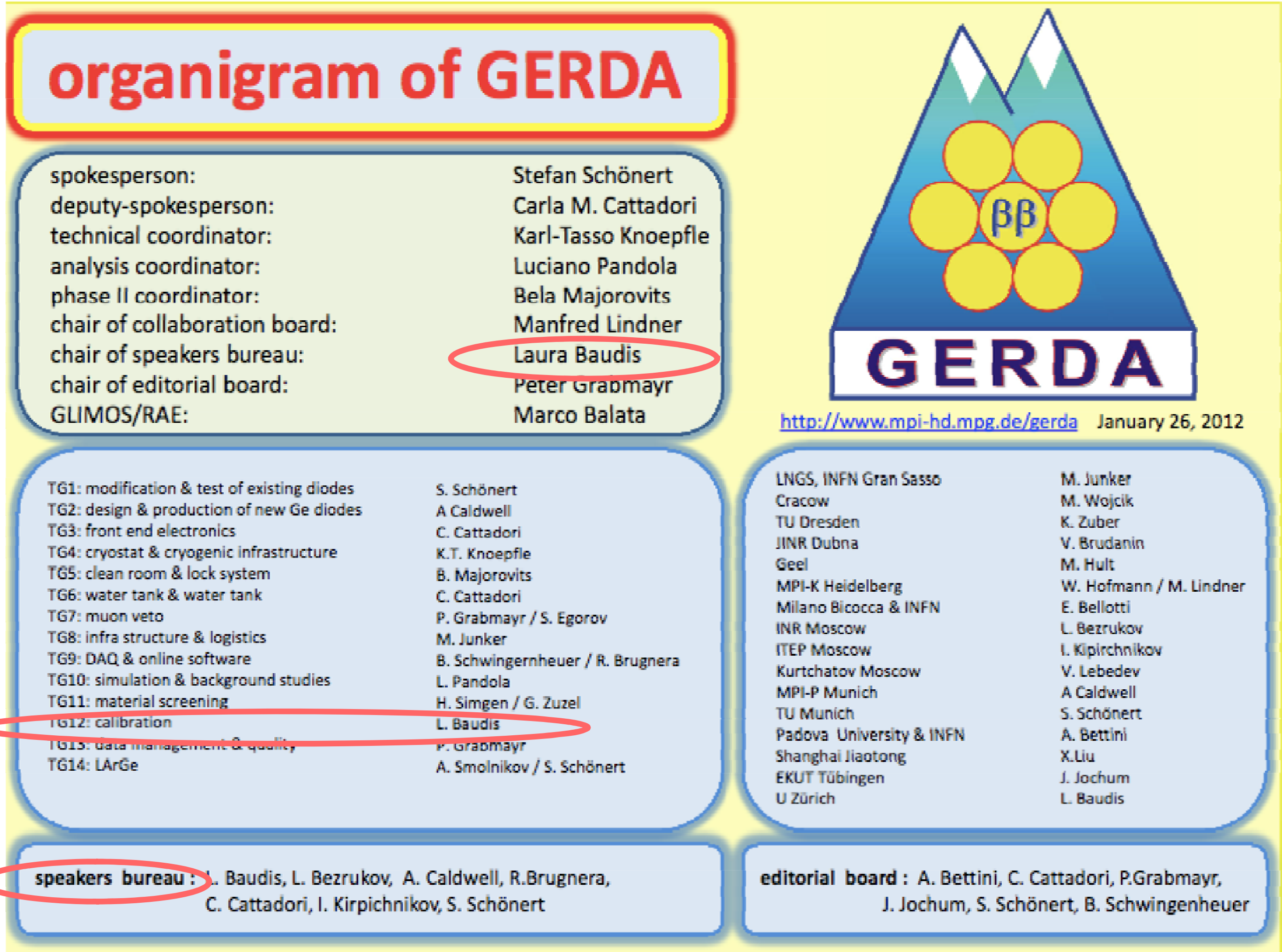
GERDA low-background spectrum

- Analysis of 2-neutrino decay mode - paper to be submitted within this month



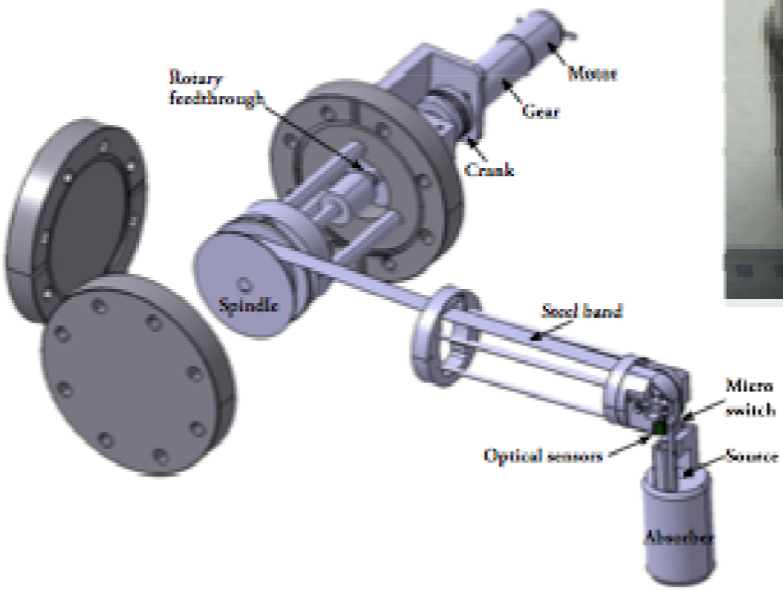
Swiss (and other) involvement

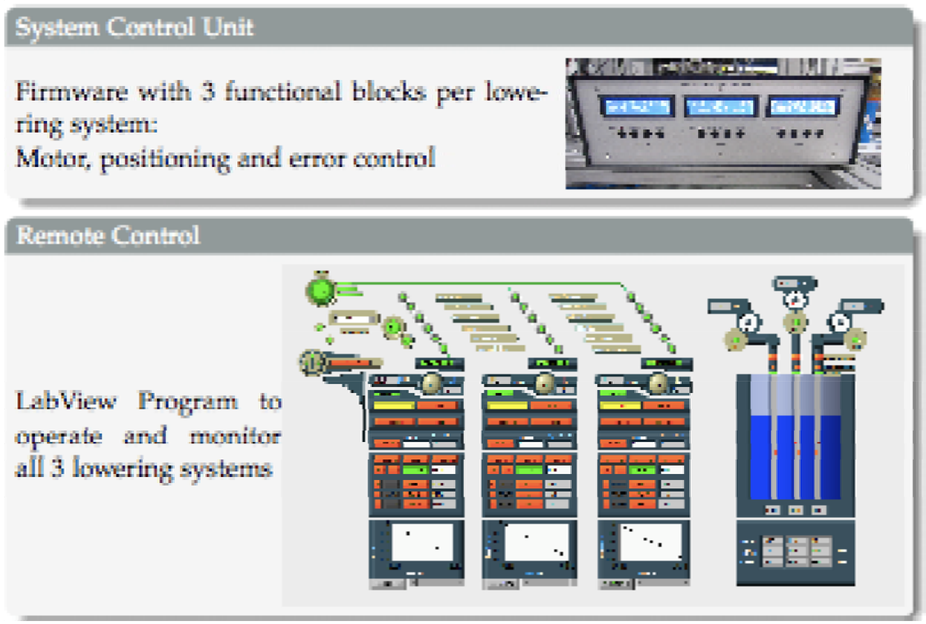
- University of Zurich + 17 institutions from 6 countries (100 members in total)



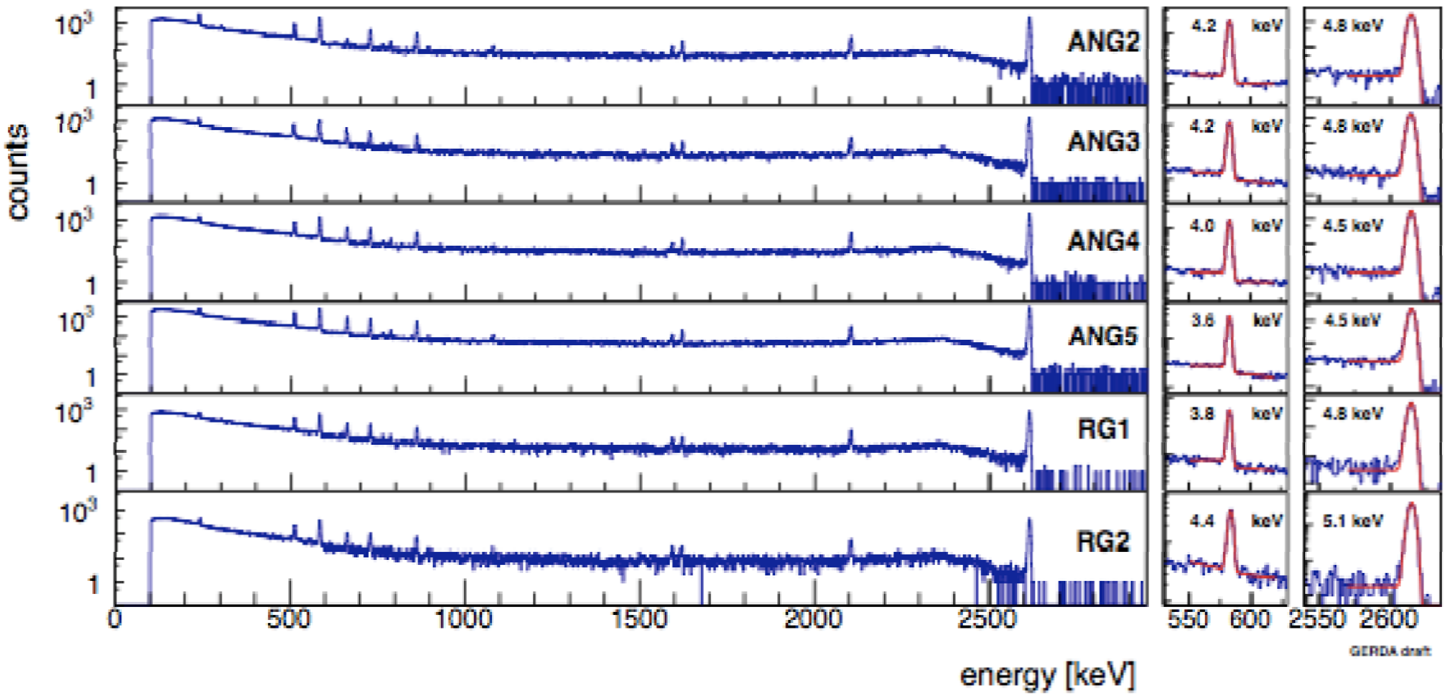
UZH contribution

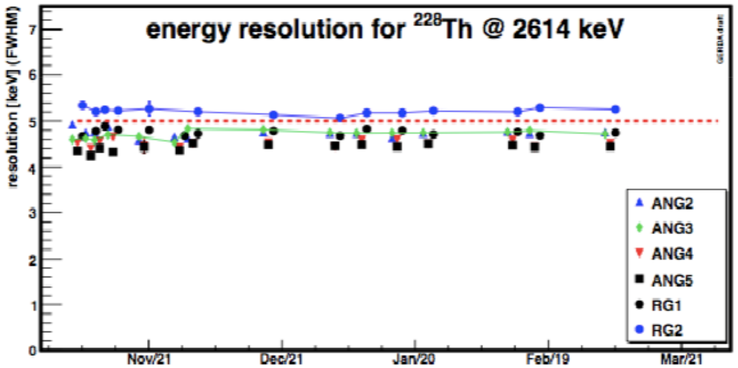
- Calibration system for phase I: hardware, software (positioning and controlling), data analysis, monitoring; low-neutron emission ^{228}Th source built together with PSI
- Three systems built/tested at UZH, installed in GERDA; working reliably since summer 2011 (about 1 calibration run/week)





GERDA calibration





weekly calibrations
UZH maintains database with calibration parameters
checks stability versus time
here: example of energy resolution at 2.6 MeV (FWHM) f

UZH contribution

- R&D on phase II (broad-energy Ge) detectors
- Full production chain successfully tested using ^{dep}Ge material
- Now production and testing of ^{enr}Ge detectors (to be finished by summer 2013)
- Light shifting for LAr instrumentation of phase II (LAr cryostat + PMT +HPGe detector in UZH lab)
- Calibration system for phase II (similar to phase I, additional systems)
- Analysis (PSD, backgrounds) and MC simulations