$\beta\beta0\nu$ Experiments

CHIPP plenary meeting
Appenberg, August 24-25, 2009

Razvan Gornea

Double Beta Decay

- Rare nuclear transition between same mass nuclei
  - Energetically allowed for even-even nuclei

$\beta\beta 2\nu:$ $$(Z,A) \rightarrow (Z+2,A) + e_1^- + \bar{\nu}_1 + e_2^- + \bar{\nu}_2$$

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

Allowed in SM and already observed!

$\beta\beta 0\nu:$ $$(Z,A) \rightarrow (Z+2,A) + e_1^- + e_2^-$$

Neutrinos are Majorana particles!

$\Delta L = 2$ $$(Z,A) \rightarrow (Z+2,A) + e_1^- + e_2^- + \chi$$

$$\nu \equiv \bar{\nu} \quad m_\nu \neq 0$$

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

$$\langle m_{\beta\beta} \rangle^2 = \left|\sum_k m_k U_{ek}^2\right|$$

The GERDA Experiment

CHIPP plenary meeting
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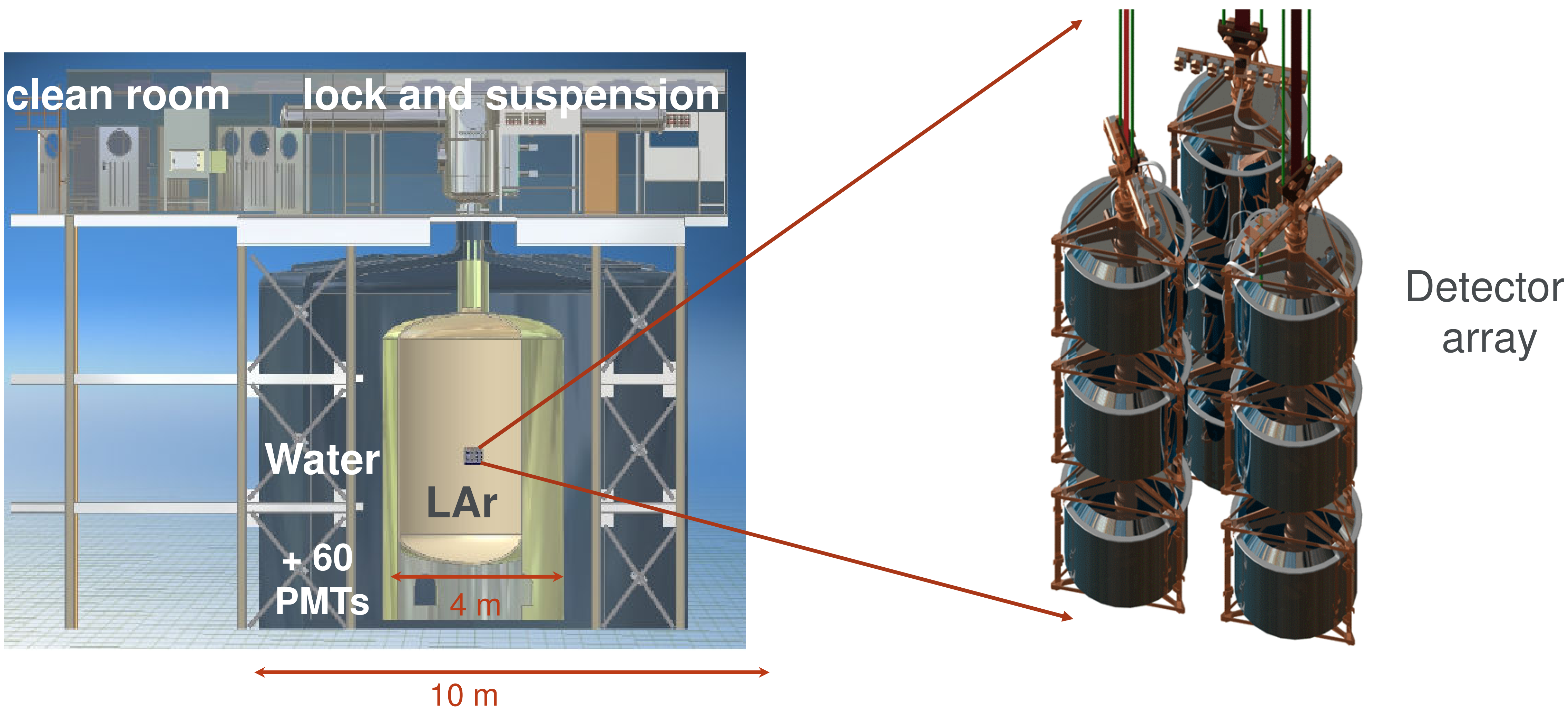
Laura Baudis
University of Zurich

The GERDA concept

- 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



GERDA Goals

- Phase I: 18 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

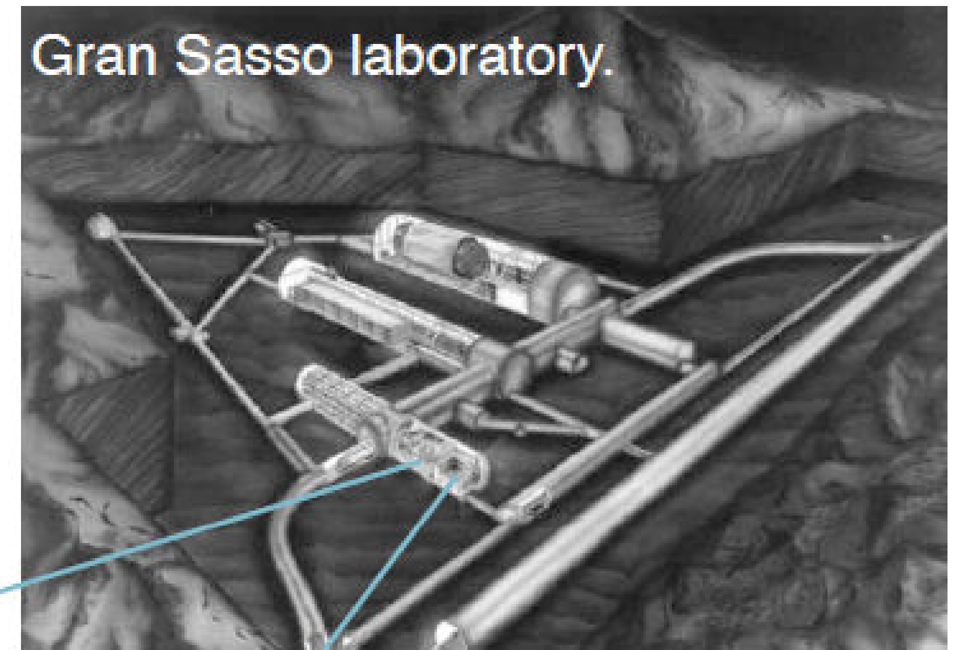
If claim true, phase I will see:
signal: 13 events
BG: 3 events
(in 20 keV window at 2 MeV)

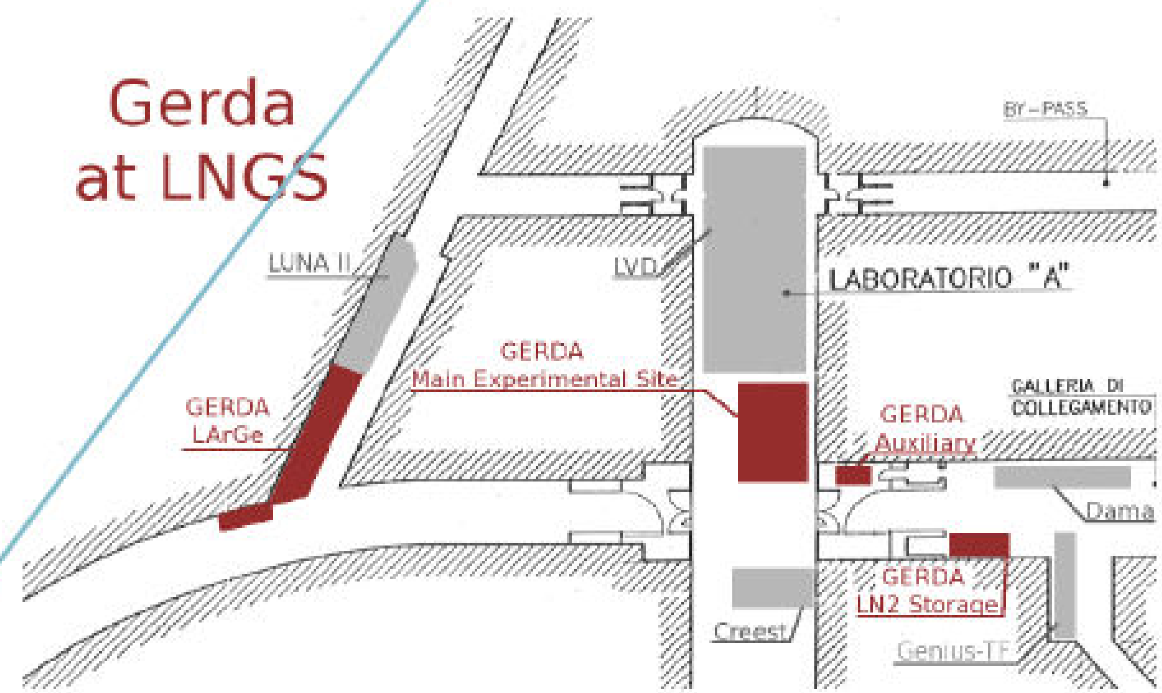
- Phase II: 40 kg enriched ^{76}Ge detectors, background: 10^{-3} counts/(kg keV yr)
- Sensitivity reach after an exposure of 150 kg years:

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

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

The GERDA Experiment at LNGS





Status of GERDA (August 2009)

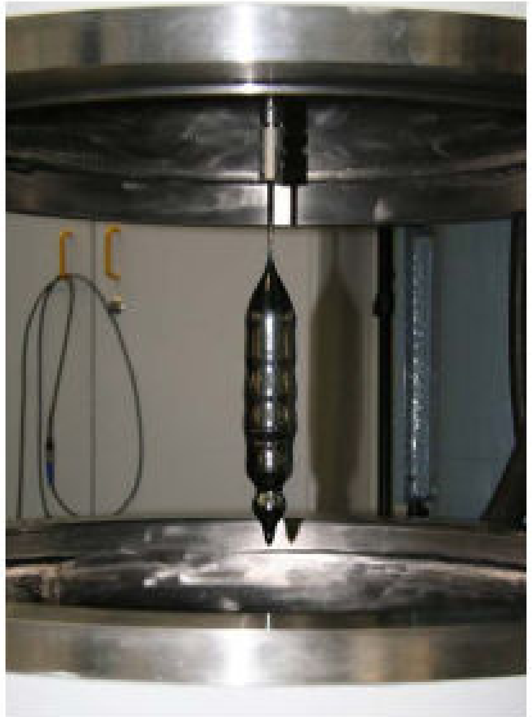
- Double walled, stainless steel LAr cryostat,
- water tank, superstructure, electrical
- system and clean room installed at LNGS

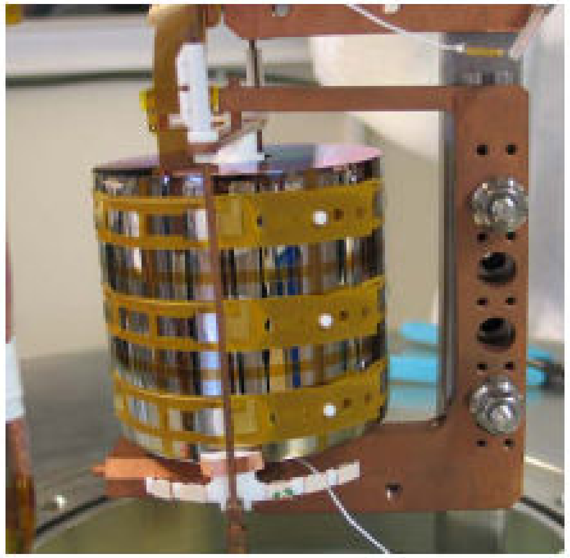
- Phase-I detectors have been tested in LAr
- in the GERDA Detector Lab at LNGS
- (FWHM ~ 2.5 keV at 1332 keV, leakage current stable)

- Lock and gas handling system, as well as
- muon veto under installation

- **Detector commissioning planned for fall 2009**

- Concomitantly: R&D effort for phase II detectors
- (18-fold segmented, n-type and/or BEGe p-type)





Phase-II prototype

Status of GERDA (August 2009)

LAr cryostat
(March 2008)

Water tank
(July 2008)

Cleanroom
(May 2009)

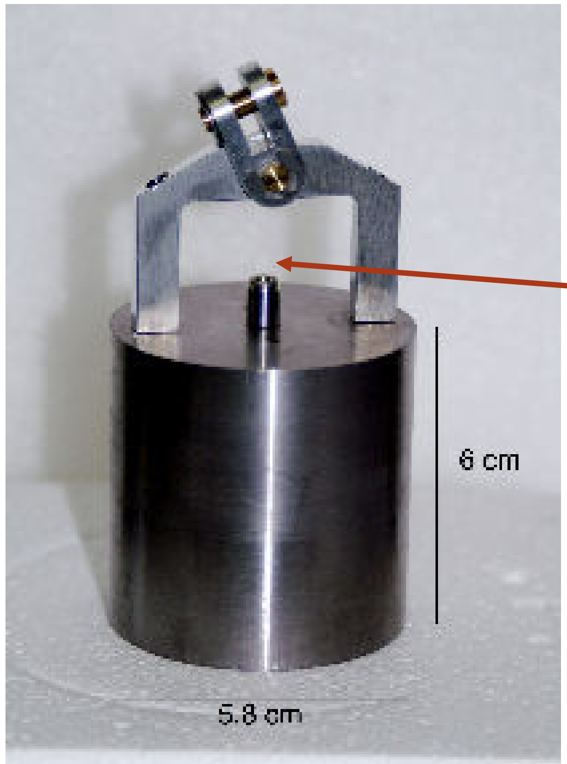
PMT mounting
(May 2009)

August 2009: lock-system under installation at LNGS

Detector commissioning: planned for fall 2009

Contributions of UZH group

- **Phase I: calibration system (leading Calibration Task Group)**
  - ➡type and source/absorber configuration
  - ➡screening of absorber materials (W, Densimet, Ta) with HPGe detector (Gator) at LNGS
  - ➡simulation of gamma and neutron backgrounds in source parking position
  - ➡source strength for pulse shape discrimination of single versus multiple-site events
  - ➡dynamic database with calibration parameters
  - ➡long-term maintenance of calibration system



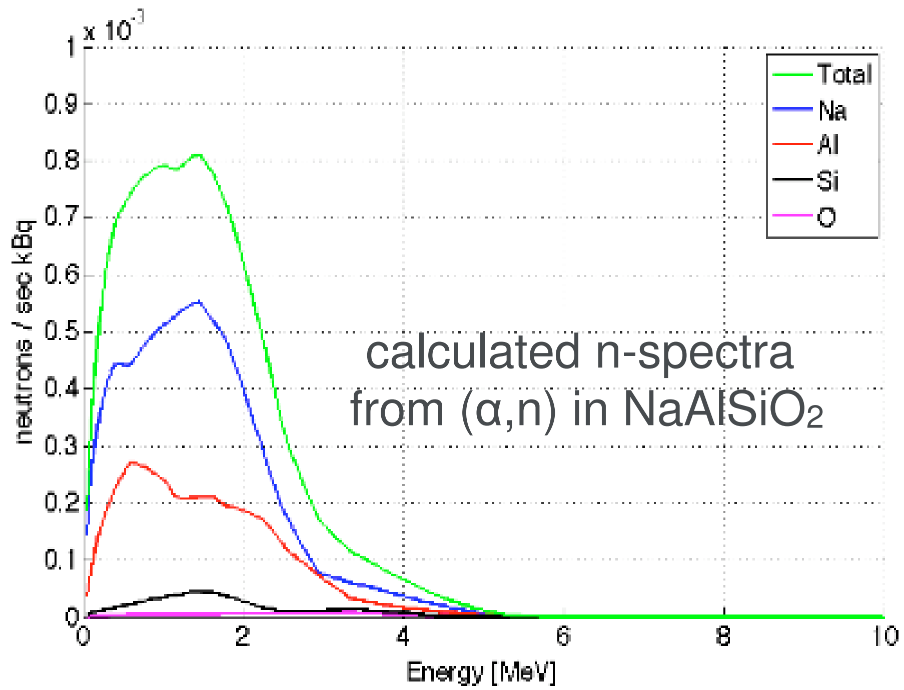
Ta absorber with r = 29 mm, h = 60 mm

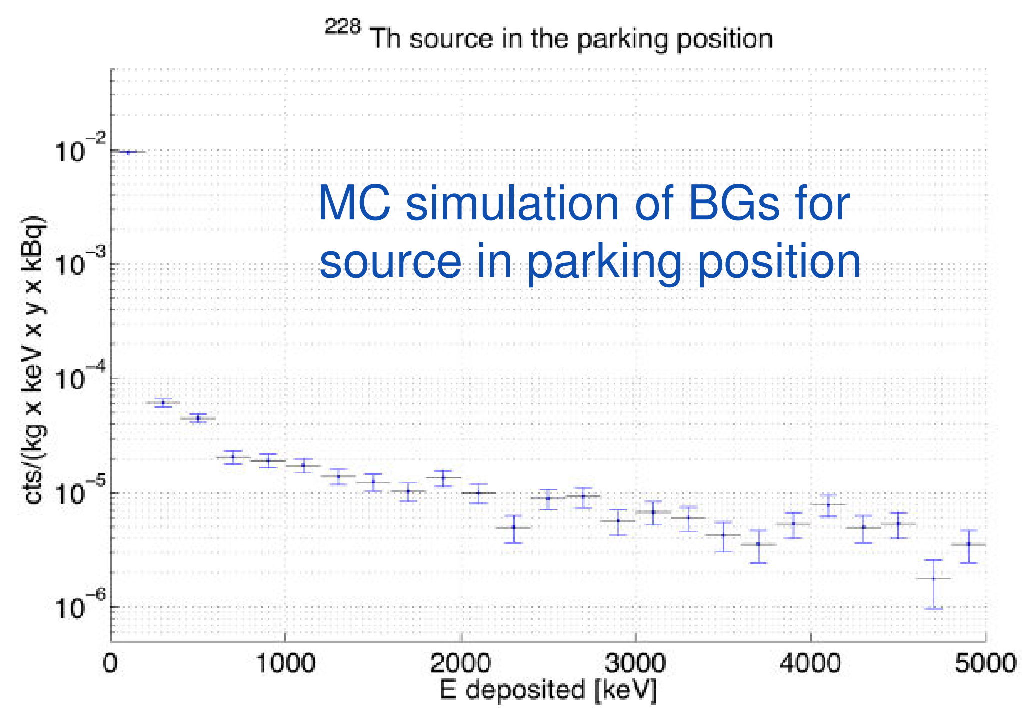
Custom made ^{228}Th source in stainless steel capsule

Tested in 20 thermal cycles in LN

A low-neutron emission calibration source

- ^{228}Th source, $T_{1/2}$ = 1.9 years; main lines of interest for GERDA:
- ^{208}Tl peak at 2615 keV, SEP (close to Q-value) at 2103 keV, DEP (single-site events) at 1592 keV
  ➡Problem: α-emission (E_{α}=5.2 - 8.8 MeV)
  ➡ (α,n)-reactions with $NaAlSiO_2$ ceramic into which ^{228}Th is embedded

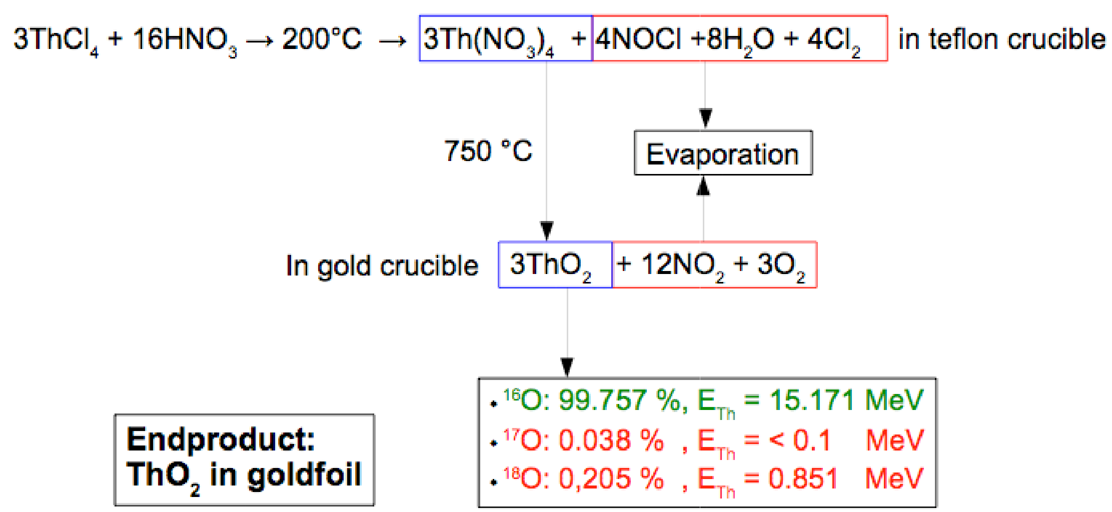




- n-flux calculated with SOURCES4mv, and measured with 3-He detector at LNGS:
  ➡**~ 4 x 10^{-2} n/(s kBq)**
- MC simulations of induced backgrounds (source 350 cm above Ge-array, in parking position)
  ➡**B ≈ 10^{-3} counts/(kg keV yr) for a 100 kBq source** (background goal of phase-II!)

A low-neutron emission calibration source

- **Solution:** ^{228}Th embedded in Au; E_{th} for (α,n)-reactions is 9.94 MeV > 8.8 MeV
- Built in collaboration with PSI (R. Dressler, R. Eichler, D. Schumann)
- 20 kBq $^{228}ThCl_4$ solution from E&Z; processing at PSI; encapsulation/certification at E&Z



Preparing the gold crucible

Adding nitric acid to the $^{228}ThCl_4$ solution

200 °C

Refilling $^{228}Th(NO_3)_4$ into the goldcrucible

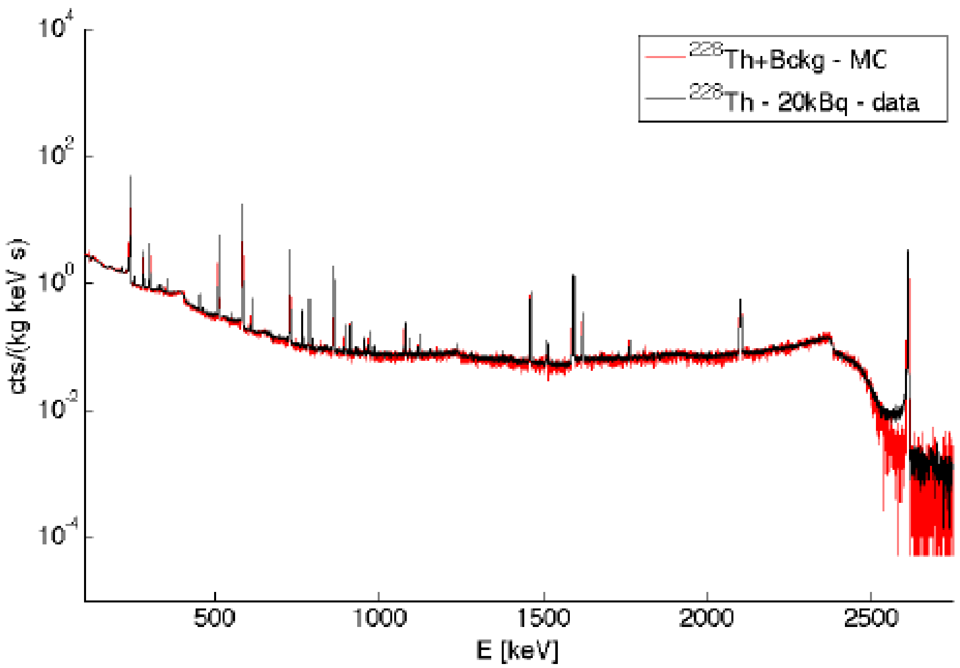
200 °C

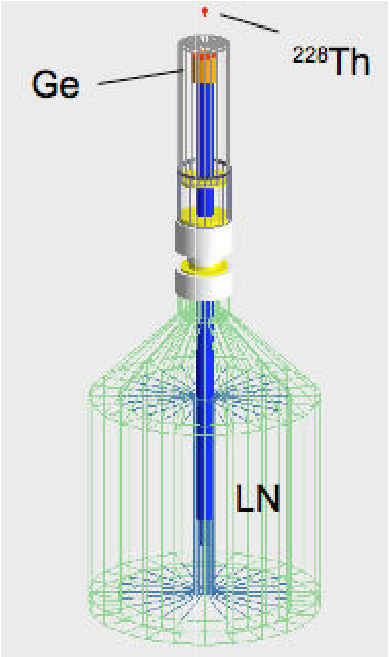
Burning out remanents

750 °C

Characterization of the low-neutron source

- **Gammas: HPGe detectors in UZH lab and Gator-detector at LNGS**
  ➡best-fit (data/MC) activity: ~ (20.2 ± 0.4) kBq





HPGe detector in UZH lab (here operated in vacuum)

- **Neutrons: estimated with SOURCES4mv; source measured with 3-He detector at LNGS**
- (D = 5 cm, L = 30 cm, gas mix: CO_2:Ar:^{3}He = 91:1520:2950; PE n-moderator)

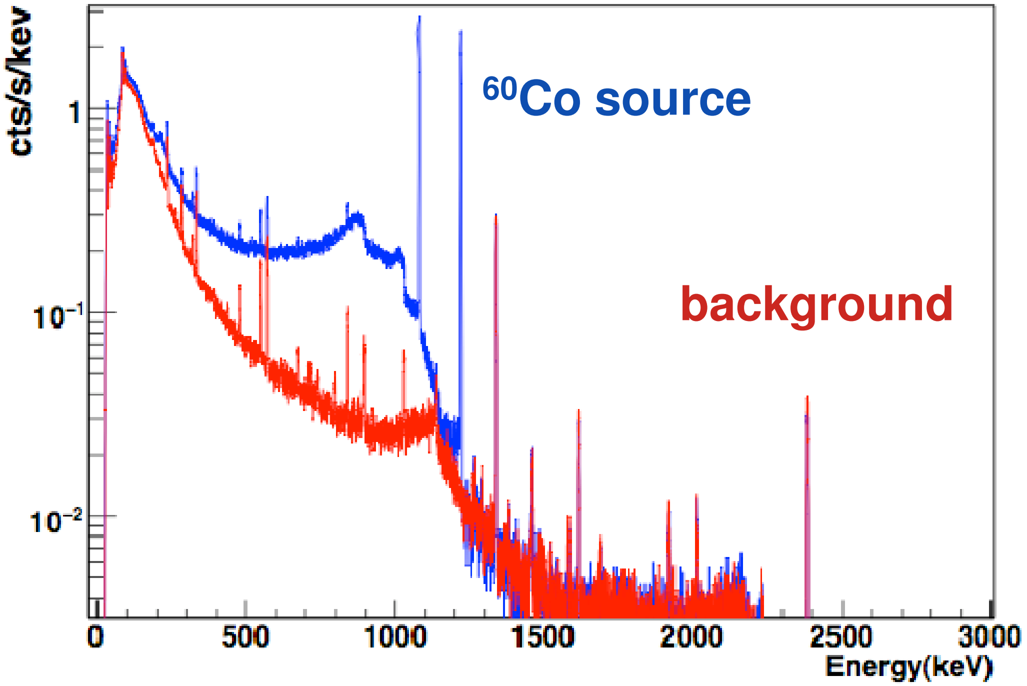
➡n-rate from ThO_2: 5 x 10^{-4} n/(s kBq)
➡factor of ~ 116 reduction in backgrounds

3-He detector at LNGS

Contributions of UZH group

- R&D and test facility for GERDA Phase-II detectors
  - ➡R&D (with Canberra and a few collaborating institutions) on broad-energy, point contact Ge (BEGe) detectors from enriched ^{76}Ge materials
  - ➡crystal pulling (from depleted material) now at Canberra, Oakridge; detectors in fall 2009
  - ➡liquid argon test facility at UZH: built and tested with 300 g n-type HPGe crystal
  - ➡test of one highly-segmented Ge detector and performance comparison with BeGE detector to aid in decision on which design to adopt for phase II

n-type, natural HPGe detector before LAr immersion tests



^{60}Co calibration and background spectrum in UZH test facility

The EXO Experiment

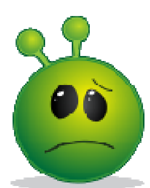
CHIPP plenary meeting
Appenberg, August 24-25, 2009

Razvan Gornea
Albert Einstein Center for Fundamental Physics
Laboratory for High Energy Physics
University of Bern

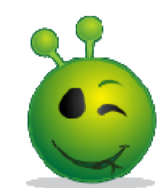
EXO Project & EXO-200 Phase

- EXO project searches for double beta decay using ^{136}Xe
  - ➡Ton scale implementation either as liquid or gas phase TPC
  - ➡Relatively large Q value (2479 keV) and straight forward enrichment technique
  - ➡^{136}Ba daughter tagging either in-situ or in external RF cage

$$\langle m_{\beta\beta} \rangle \propto \left(\frac{1}{Nt} \right)^{1/4}$$



No Background! $$\langle m_{\beta\beta} \rangle \propto \sqrt{\frac{1}{Nt}}$$

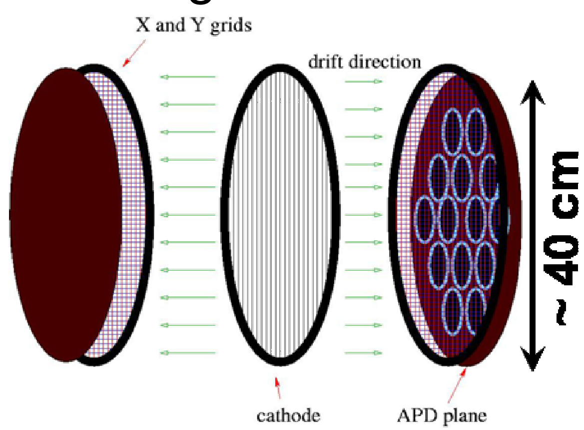


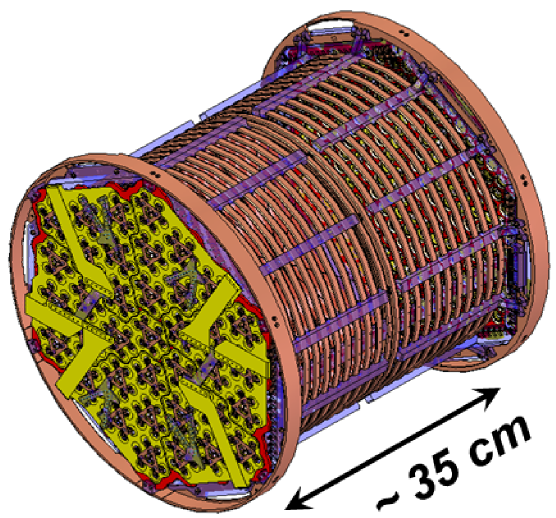
- EXO-200 is the first phase using 200 kg of 80% enriched Xe
  - ➡Major R&D effort precursory to the ton-scale experiment
  - ➡Exploration of the quasi-degenerate region with ^{136}Xe
  - ➡Allowed double beta decay never observed in xenon!
  - ➡No tagging but massive progress for radioactive background reduction and energy resolution improvement (easily scalable to future detectors)

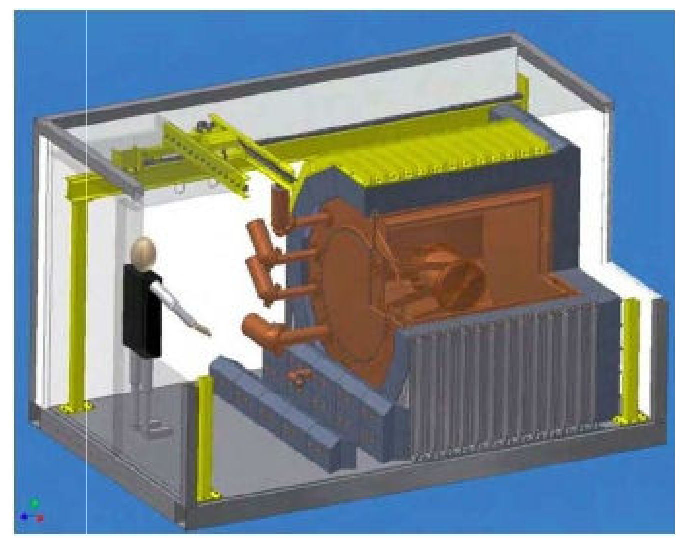
EXO-200 Detector

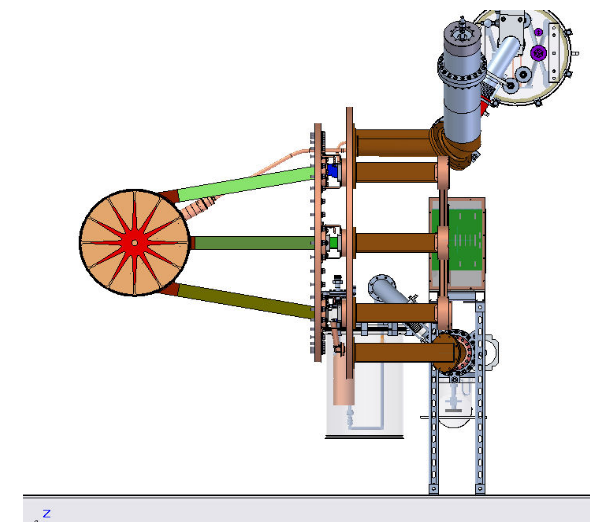
- **Liquid xenon TPC with two cylindrical drift volumes**
  - ➡ Charge collection using 114 by 114 wire planes (at 60º pitch)
  - ➡ Scintillation light readout using 37 groups of 7 bare LAAPD (Large Area Avalanche Photodiodes) at both end caps
- **High purity copper cryostat with external refrigeration-based cooling**

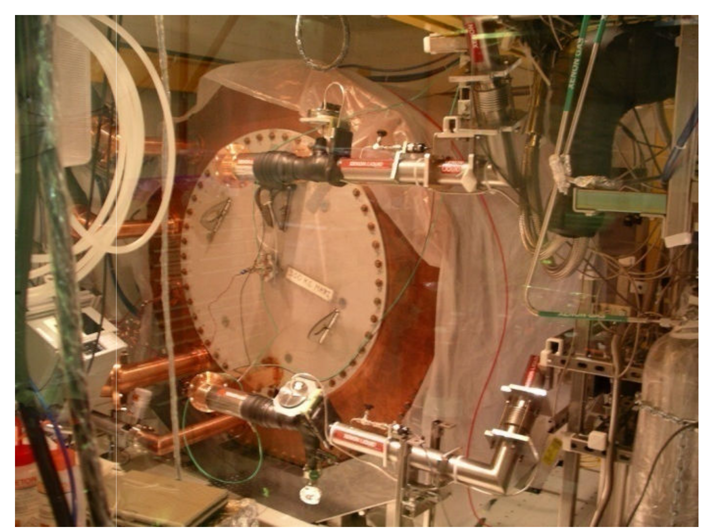
~ 115 kg fiducial mass

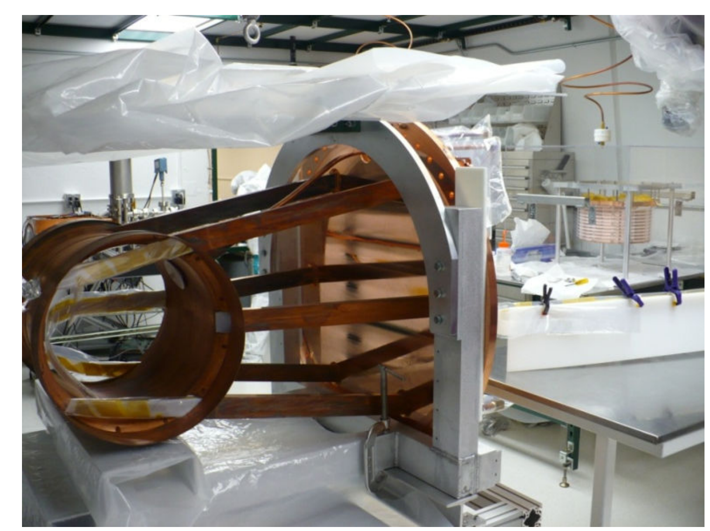






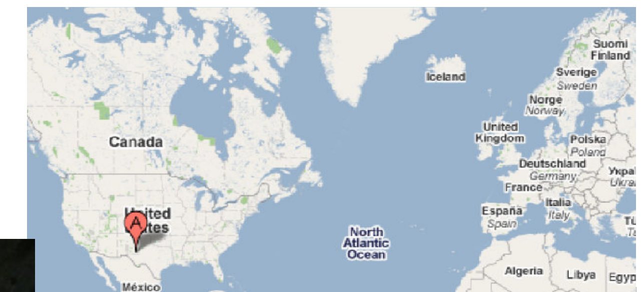






Experiment Installation

- **Waste Isolation Pilot Plant** (WIPP), Carlsbad, New Mexico
  - ➡about 1600 m.w.e. (muon flux reduction by ~ 10×)
- **Large experimental area available!**



Expected Performance

- Very low radioactive background
  - ➡Careful selection of materials, optimized custom design
  - ➡Manufacturing, handling and installation in cleanroom
- Very good energy resolution
- Chamber underground installation this fall
- **Physics runs starting in 2010, 2 years run time!**

Best limit on ββ2ν in ^{136}Xe

$$T_{1/2}^{2\nu} > 1.2\times10^{24}\, y\ @\ 90\% C.L.$$

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5 MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu}$ (yr, 90%CL)	Majorana mass (meV)	
							QRPA[1]	NSM[2]
EXO-200	**0.2**	**70**	**2**	**1.6**	**40**	**$6.4*10^{25}$**	**133**	**186**

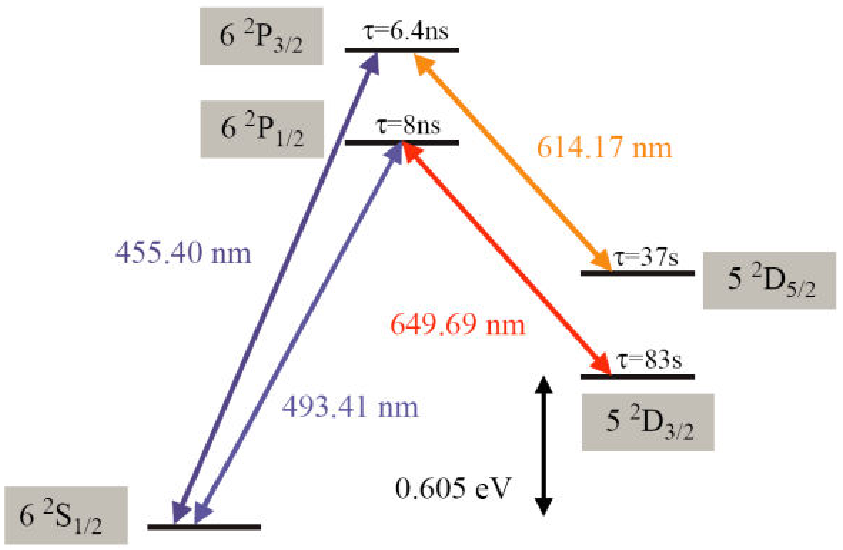
1) *Rodin et. al., Nucl. Phys. A 793 (2007) 213*
2) *Caurier et. al., arXiv:0709.2137v1*

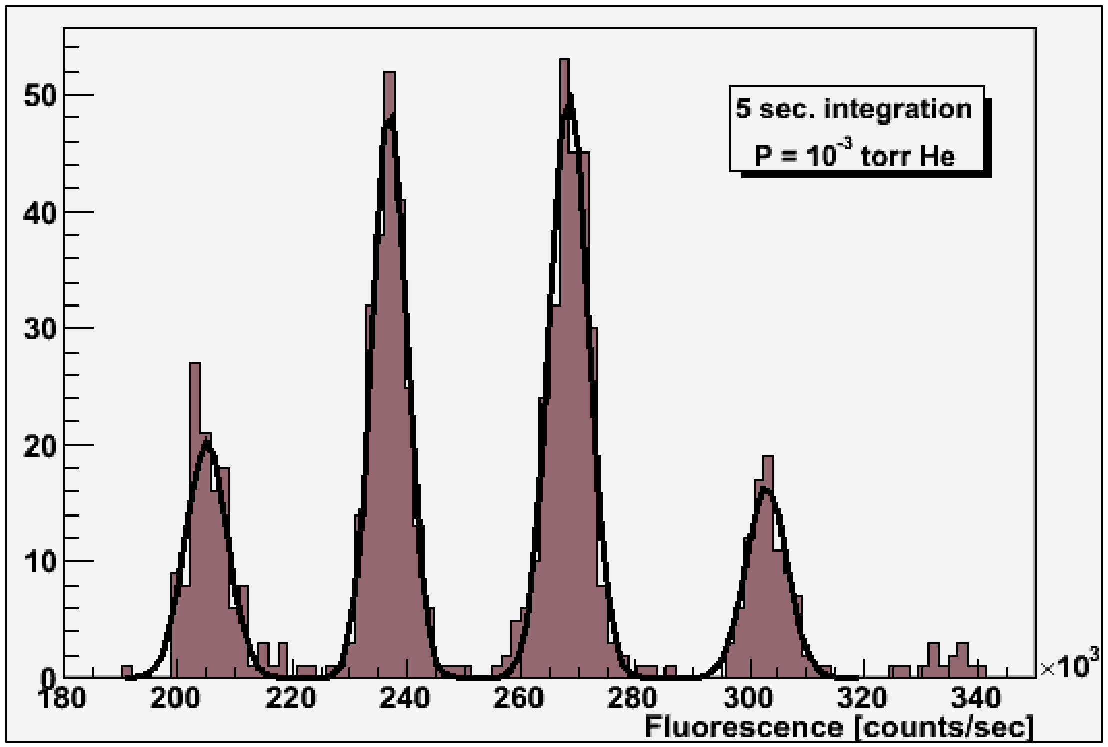
Expected signal for ^{76}Ge ββ0ν claim …

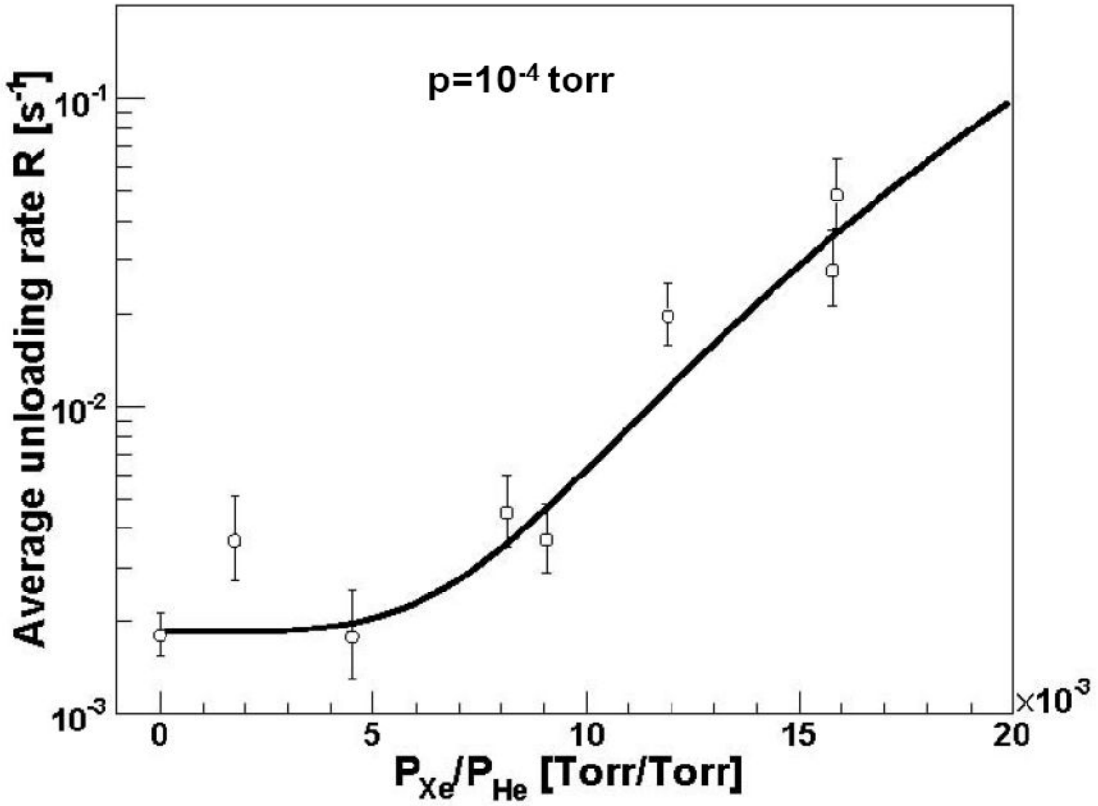
QRPA: 46 events (5.0 σ)
NSM: 170 events (11.7 σ)

Ba^+ Tagging

- $Ba^{++} \rightarrow Ba^+$ conversion expected
  - ➡Ionization potentials:
    - Xe^+ = 12.13 eV vs. Ba^+ = 5.21 eV
    - Xe^{++} = 21.21 eV vs. Ba^{++} = 10.00 eV
  - ➡Solid Xe band gap ***(Phys. Rev. B10 4464 1974)***
    - E_G = 9.22 +/- 0.01 eV
  - ➡"Liquid Xe ionization potential" close to E_G ***(J. Phys. C: Solid State Phys. Vol. 7 1974)***
    - 9.28 to 9.49 eV range
  - ➡Use of additives for gas based detectors



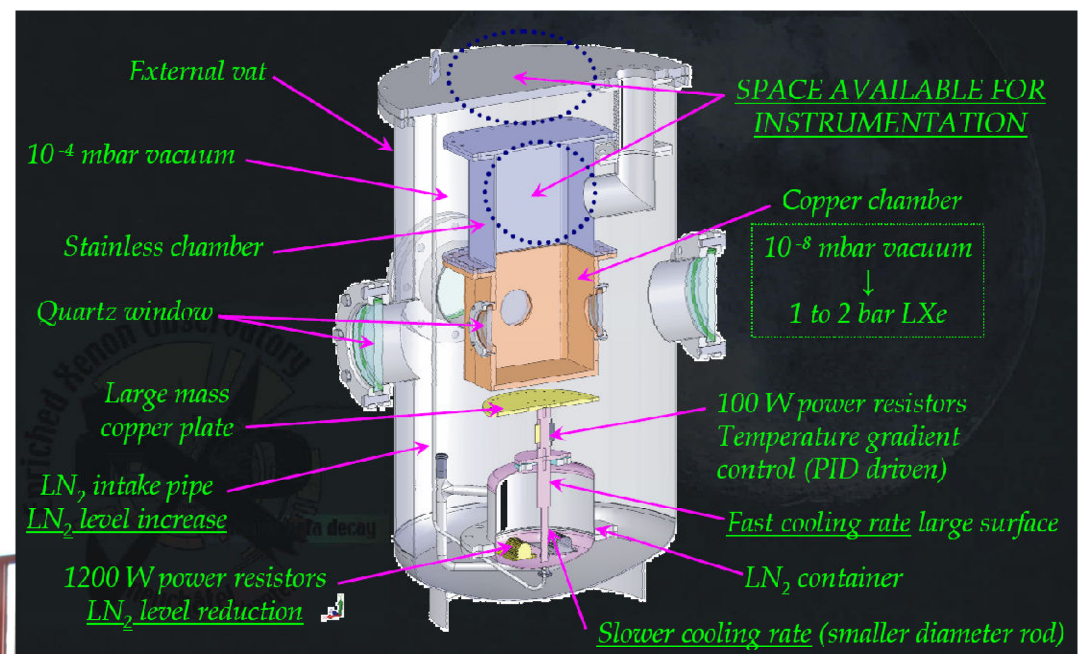


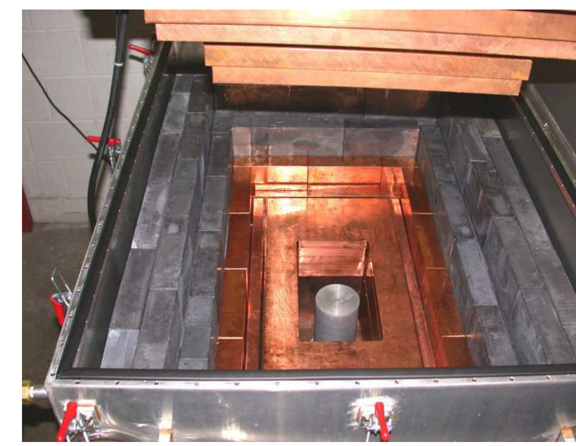


Main activities at Bern

- EXO-200 materials and components radiopurity qualification using a Ge detector
- R&D on the liquid and gas phase options for the future ton-scale detector
  - ➡Development of a liquid Xe cryostat for Ba^+ extraction tests
  - ➡Operation of a Micromegas based TPC using high pressure $Xe(CF_4)$ mixtures
  - ➡Primary scintillation light readout using various techniques

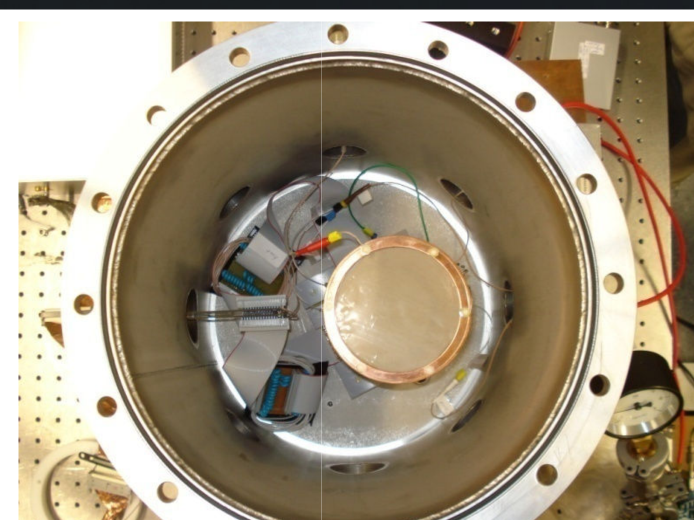
LN_2 cooling and electrical heating
100 kg of LXe maximum capacity
Operation at high pressure possible
Quartz windows for optical access





400 cc low background Ge detector
High purity copper and lead shield
Radon tight container and N_2 purging

Sensitivity:
100 pg/g for ^{232}Th and ^{238}U chains
1 μg/g for K concentration

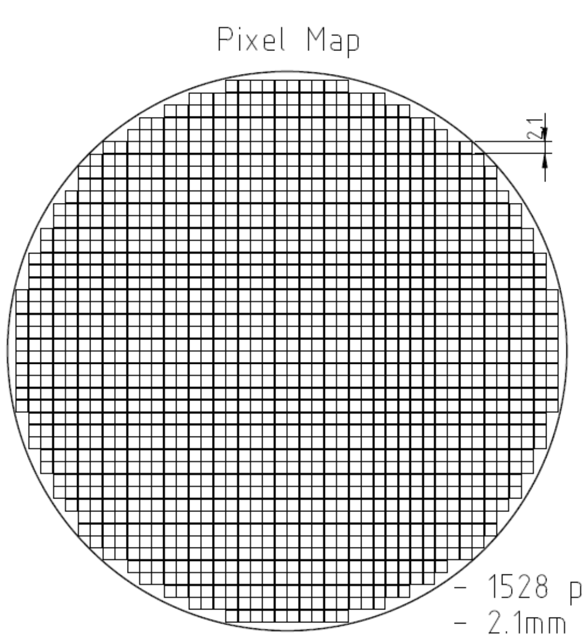


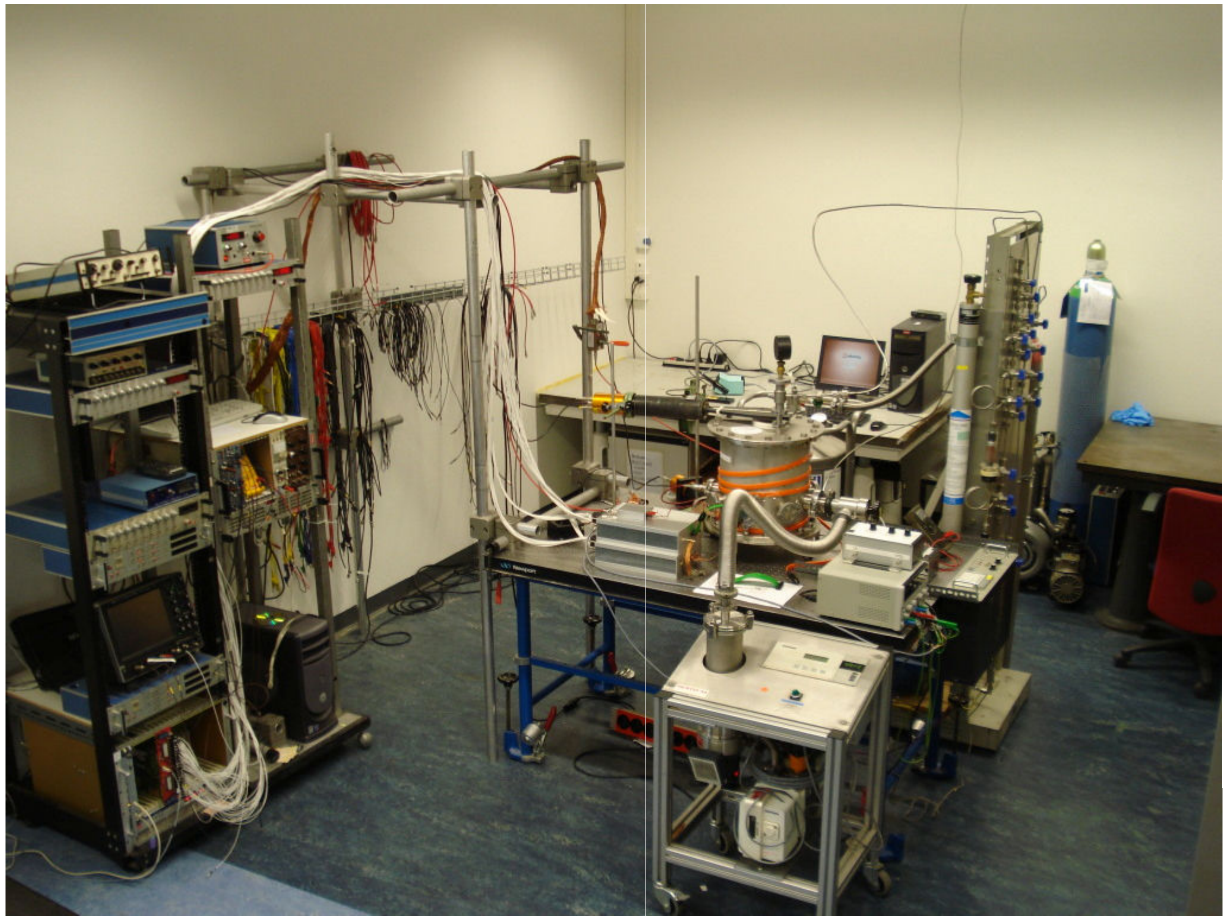
mini-TPC setup for 10 cm diameter Micromegas detectors

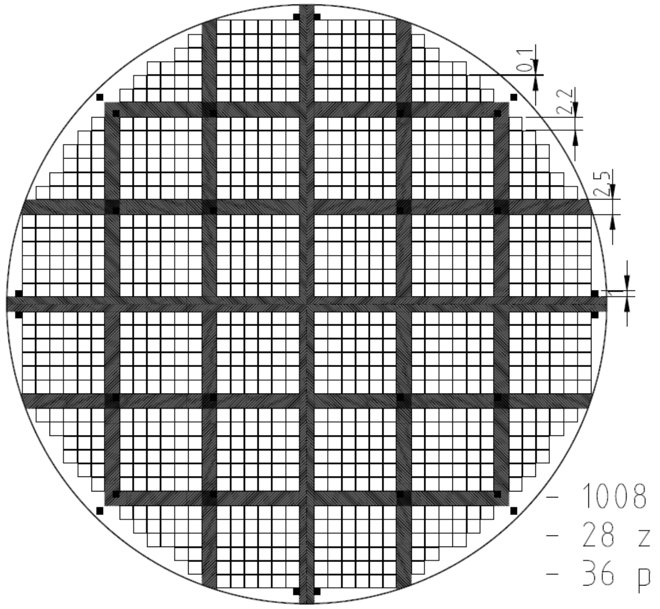
Tracking in high pressure gas (up to 10 bars)
Energy resolution optimization

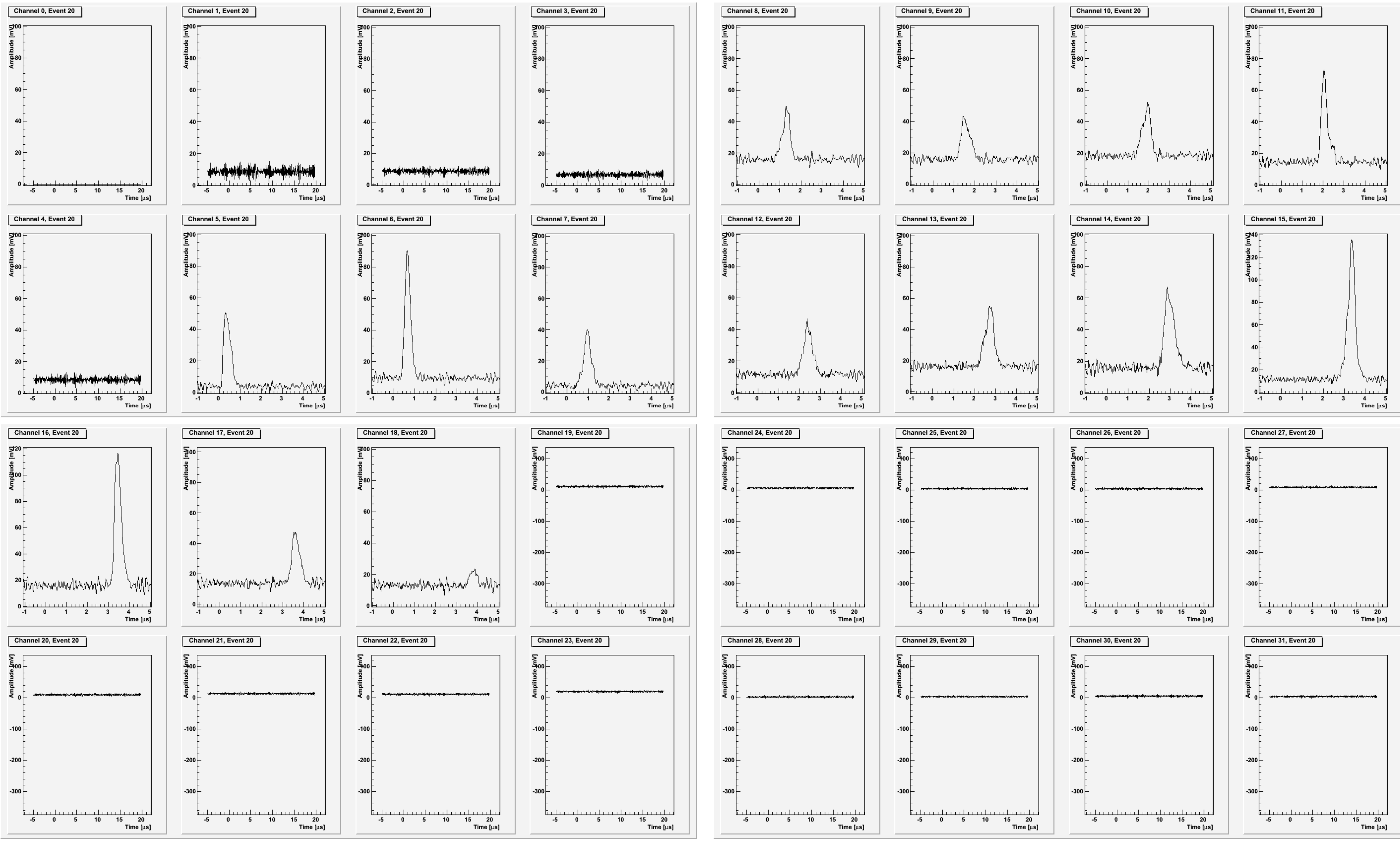
Gas phase R&D in Bern

- New setup dedicated to gas TPC R&D
  - ➡Developed in collaboration with R. De Oliveira (CERN) two designs for Micromegas detectors with a segmented anode (grid) allowing 3-D track reconstruction (manufacturing at TSD, CERN)
  - ➡Vacuum and high pressure gas handling systems
  - ➡Custom low-noise, high-gain and wide bandwidth current preamplifier (64 channels)
  - ➡VME based 62.5 MHz 12-bit FlashADC board (64 channels) and 80 MBy/s computer interface
  - ➡Muon telescope and fast electronics for sophisticated trigger strategies









Channel 0, Event 20
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Channel 28, Event 20
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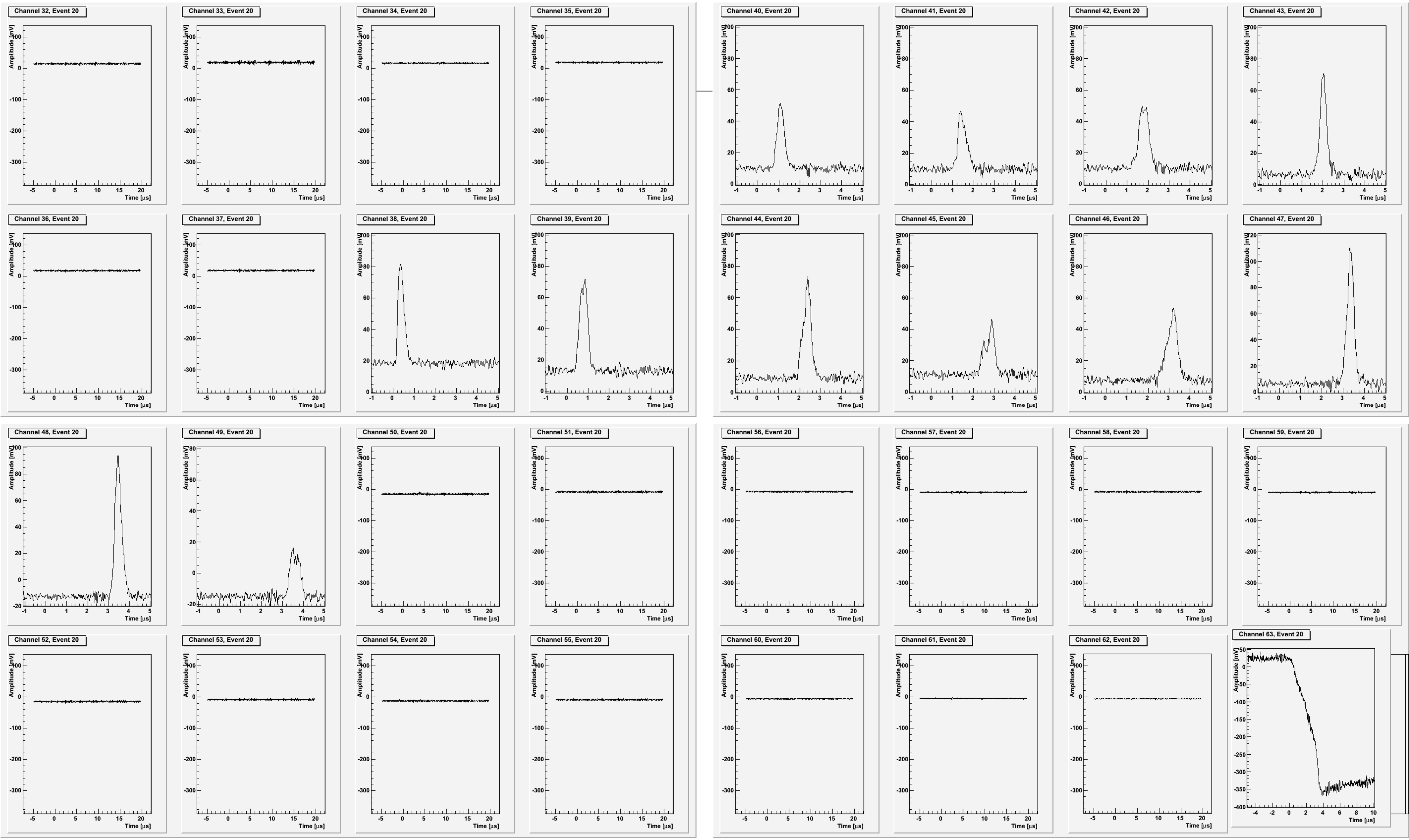
Channel 30, Event 20
Channel 31, Event 20
Amplitude [mV]
Time [µs]



Channel 32, Event 20
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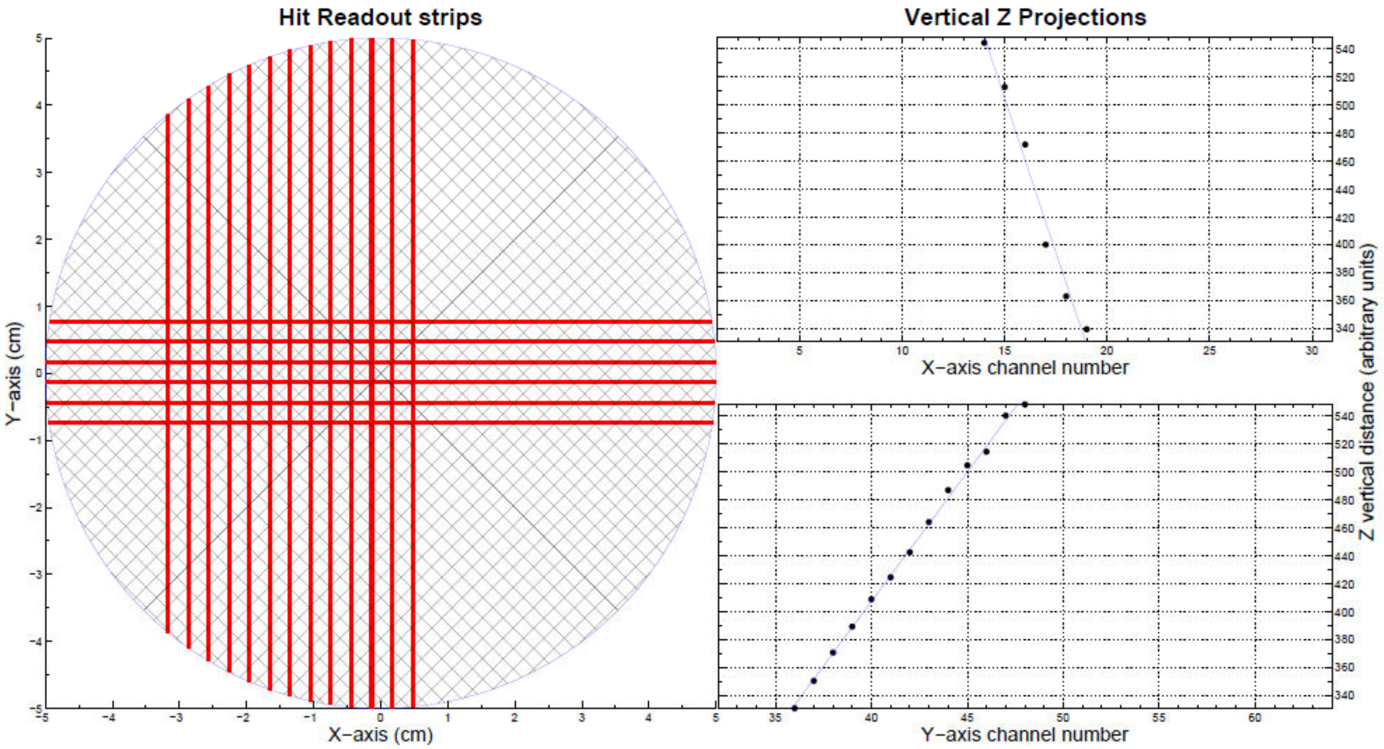
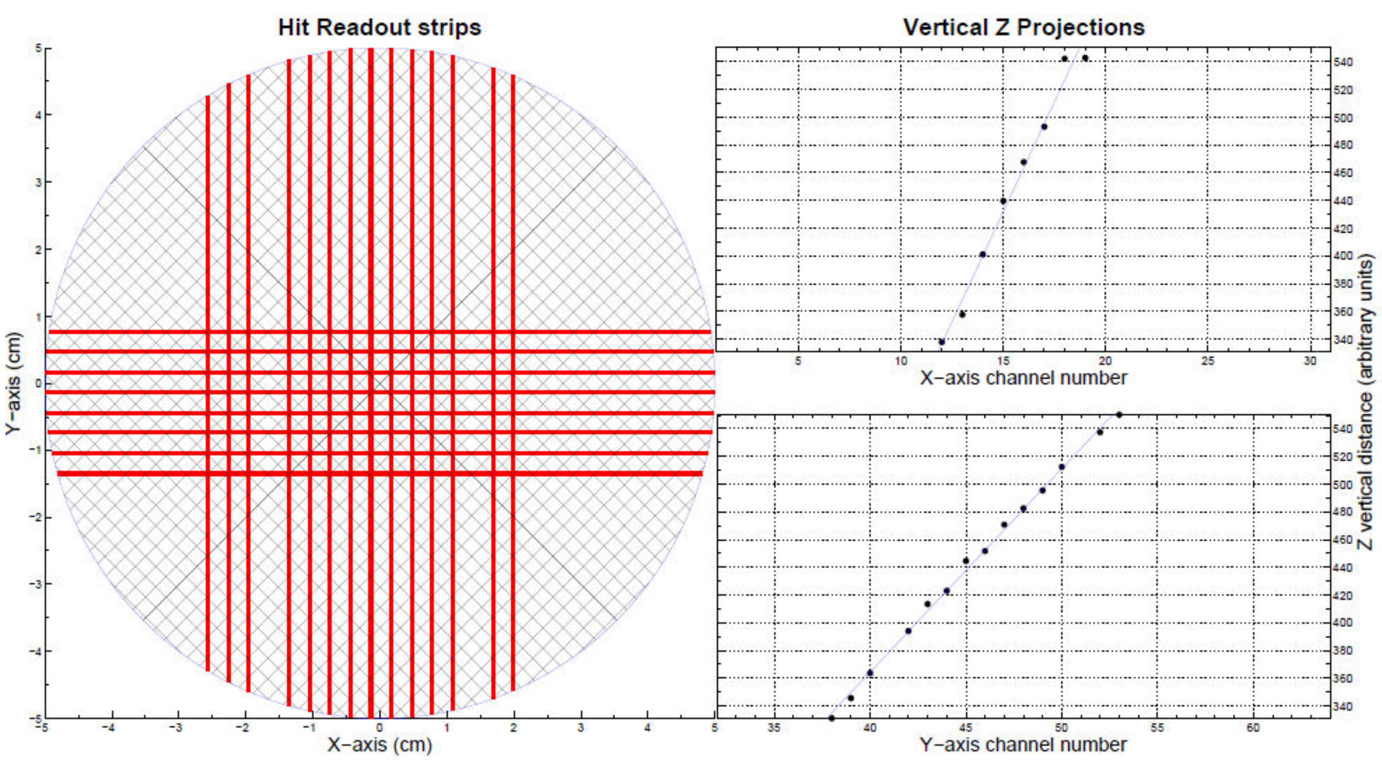
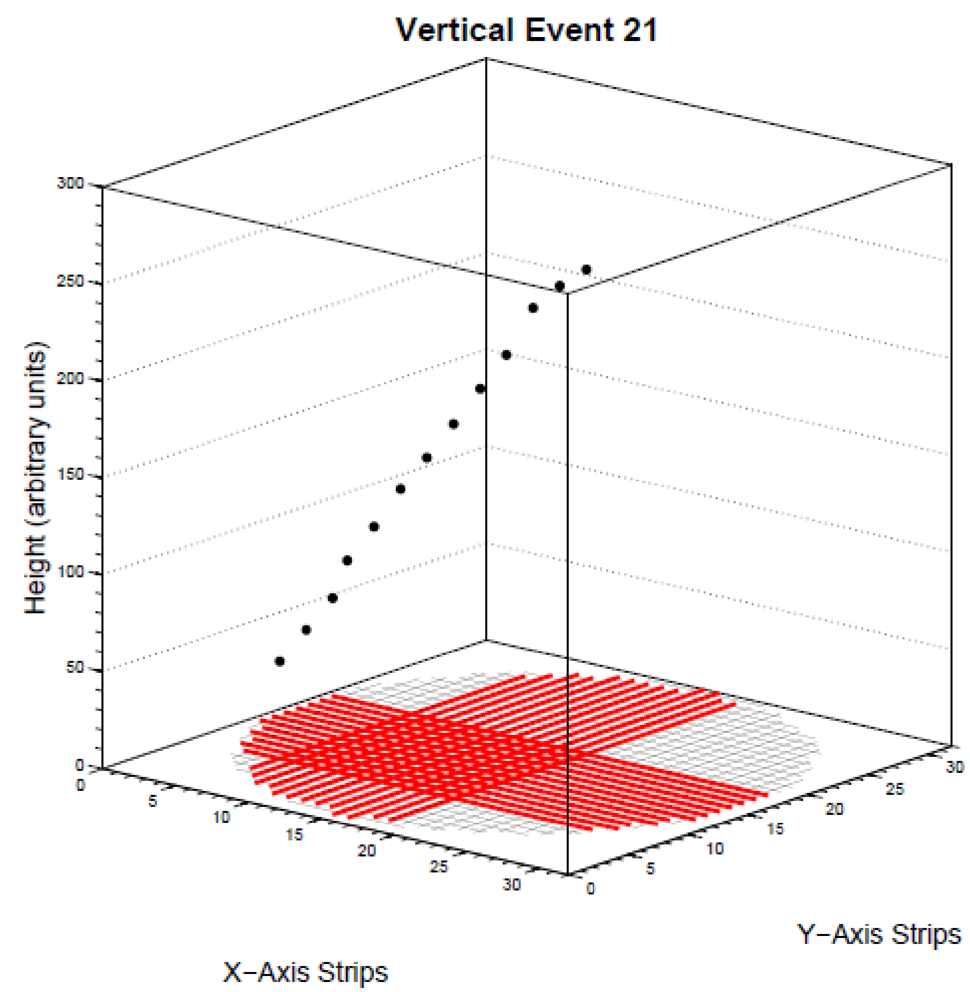
Amplitude [mV]
Time [µs]


Hit Readout strips
Y-axis (cm)
X-axis (cm)
Vertical Z Projections
X-axis channel number
Y-axis channel number
Z vertical distance (arbitrary units)


Hit Readout strips
Y-axis (cm)
X-axis (cm)
Vertical Z Projections
X-axis channel number
Y-axis channel number
Z vertical distance (arbitrary units)


Vertical Event 21
Height (arbitrary units)
X-Axis Strips
Y-Axis Strips

Conclusion

- Swiss groups involved in two dynamic ββ0ν experiments
- For both projects, data taking with the intermediary scale detectors starts soon!
- Larger scale detectors planned for the next years
- R&D work an important Swiss contribution to both experiments