EXO experiment

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CHIPP, Lausanne, September 2008

Double beta decay

EXO collaboration searches for neutrino-less double beta decay using enriched ^{136}Xe

- **Rare nuclear transition between same mass nuclei**
  - **Energetically allowed for even-even nuclei**
  - **Usually from ground state to ground state**

- $(Z,A) \rightarrow (Z+2,A) + e^-_1 + \underline{\nu}_1 + e^-_2 + \underline{\nu}_2$
- $(Z,A) \rightarrow (Z+2,A) + e^-_1 + e^-_2$
- $(Z,A) \rightarrow (Z+2,A) + e^-_1 + e^-_2 + \chi$

$$[T^{0\nu}_{1/2}(0^+ \rightarrow 0^+)]^{-1} = G^{0\nu}(E_0, Z) \left| M^{0\nu}_{\rm GT} - \frac{g_V^2}{g_A^2} M^{0\nu}_{\rm F} \right|^2 \langle m_\nu \rangle^2$$

Phase space factor

Nuclear matrix elements

$$\langle m_\nu \rangle^2 = \left| \sum_i^N U_{ei}^2 m_i \right|^2 = \left| \sum_i^N |U_{ei}|^2 e^{\alpha_i} m_i \right|^2$$

S.R. Elliott & P. Vogel, Ann. Rev. Nucl. Part. Sci. 52 (2002) 115

- **Observation of neutrino-less double beta decay would provide information about the nature of the neutrino and help to determine the mass pattern**
  - **$m_\nu \neq 0$ (required)**
  - **$\nu = \underline{\nu}$ (required)**
  - **$\Delta L = 2$ (conserved in S.M.)**
  - **$\langle m_\nu \rangle$, "effective mass" is the average over neutrino masses**
- **Combined with data from neutrino oscillation experiments**
  - **$m_\nu \neq 0$ (already determined)**
  - **Δm^2_{ij} only defines a lower limit on neutrino mass scale**
  - **$\Delta m^2_{atm} \approx 3 \times 10^{-3}$ eV^2**
  - **$\sin^2 2\theta_{atm} \approx 1.0$**
  - **$\Delta m^2_{sol} \approx 5 \times 10^{-5}$ eV^2**
  - **$\sin^2 2\theta_{sol} \approx 0.8$**

Computations for ^{136}Xe

$T_{1/2}$: 48.4, 13.2, 8.8, 21.2, 7.2 X 10^{26} years for $\langle m_\nu \rangle$ = 50 meV

Q = 2479 keV

8.9 % natural abundance

EXO collaboration

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- P.Vogel from **Physics Dept Caltech, Pasadena CA, USA**
- A.Bellerive, M.Bowcock, M.Dixit, C.Hargrove, E.Rollin, D.Sinclair, V.Strickland from **Carleton University, Ottawa, Canada**
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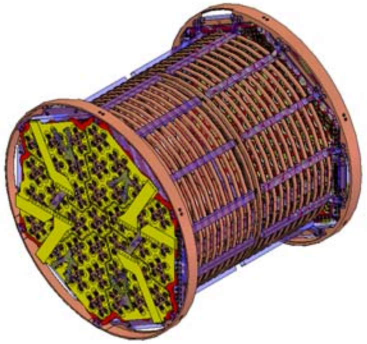
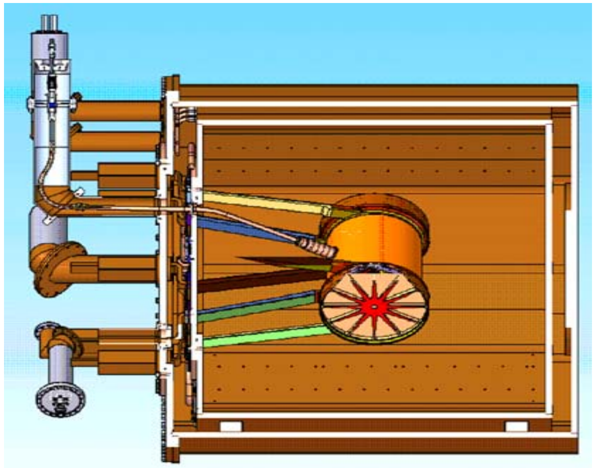
- J.Farine, D.Hallman, C.Virtue, U.Wichoski from **Laurentian University, Canada**
- H.Breuer, C.Hall, L.Kaufman, S. Slutsky, Y-R. Yen from **University of Maryland, College Park MD, USA**
- K.Kumar from **University of Massachusetts, Amherst, USA**
- ***M.Auger, R.Gornea, F. Juget, J-L.Vuilleumier, J-M.Vuilleumier*** **from LHEP, Bern University, Switzerland**
  N.Ackerman, M.Breidenbach, R.Conley, W.Craddock, J.Hodgson, D.McKay, A.Odian, C.Prescott, P.Rowson, K.Skarpaas, J.Wodin, L.Yang, S.Zalog from **SLAC, Menlo Park CA, USA**
- J.Anthony, L.Bartoszek, R.DeVoe, P.Fierlinger, B.Flatt, G.Gratta, M.Green, S.Kolkowitz, F.LePort, M.Montero-Diez, R.Neilson, M. Noske, K.O'Sullivan, A.Pocar, K.Twilker from **Physics Dept, Stanford University, Stanford CA, USA**

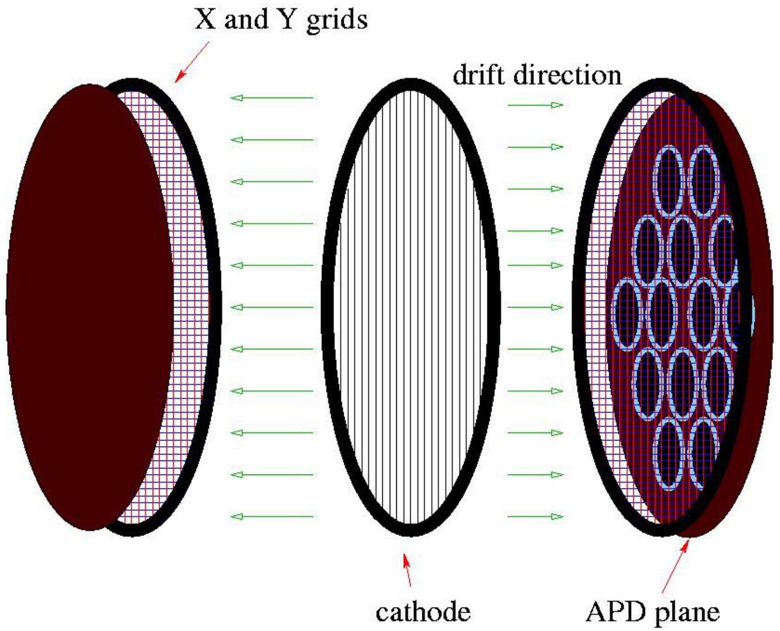
EXO-200 project

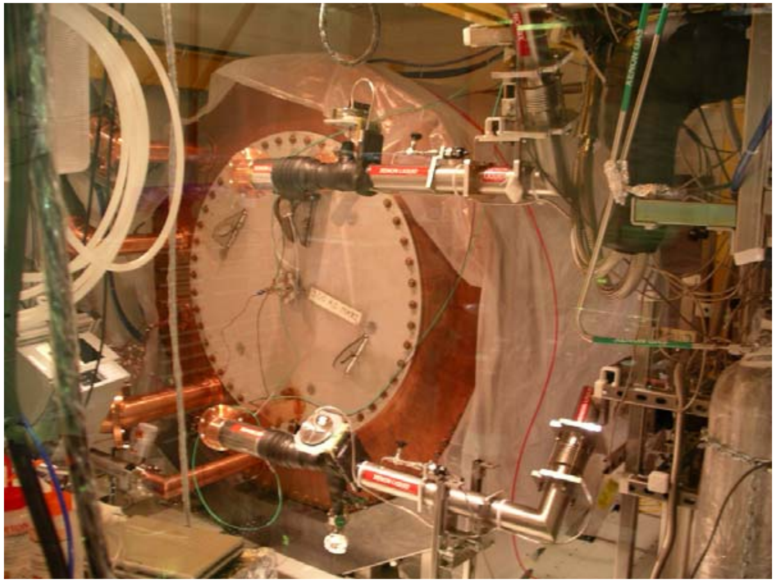
200 kg of 80% enriched Xe available (A = 136)

Light & charge readout!

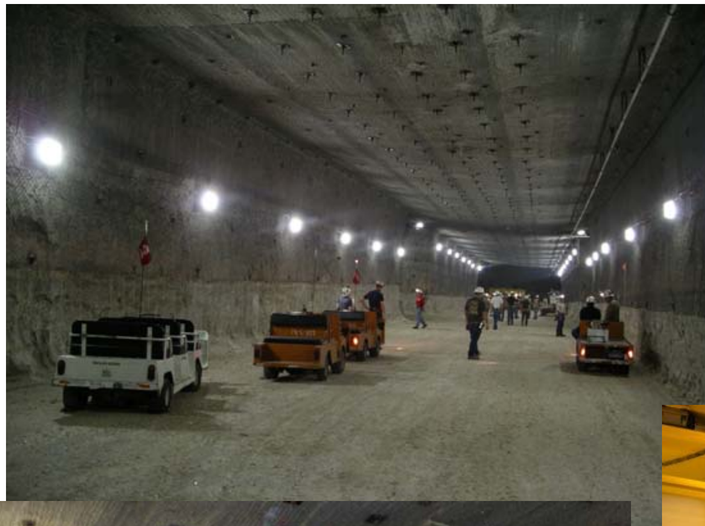








Installation at WIPP



Waste Isolation Pilot Plant
Carlsbad, New Mexico
300 m deep salt mine dedicated to nuclear wasted disposal
remote experimental area available!

Expected performance

- Very low radioactive background expected
  - *Careful selection of materials*
  - *Optimized custom design*
  - *Manufacturing, handling and installation in clean rooms*
- Very good energy resolution

$$\frac{S}{B} = \frac{m_e}{7Q\delta^6}\frac{\Gamma_{0\nu}}{\Gamma_{2\nu}} = \frac{m_e}{7Q\delta^6}\frac{T_{1/2}^{2\nu}}{T_{1/2}^{0\nu}}$$

Good energy resolution is essential!

The ultimate background is the $\beta\beta2\nu$

Physics runs starting in April 2009
Targeted run time: about two years

Note: $\beta\beta2\nu$ not yet observed for ^{136}Xe, limit at $T_{1/2} > 1.2*10^{24}$ years (90% CL)

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) 213-215
2) Caurier, et. al., arXiv:0709.2137v1

Ba^+ tagging R&D

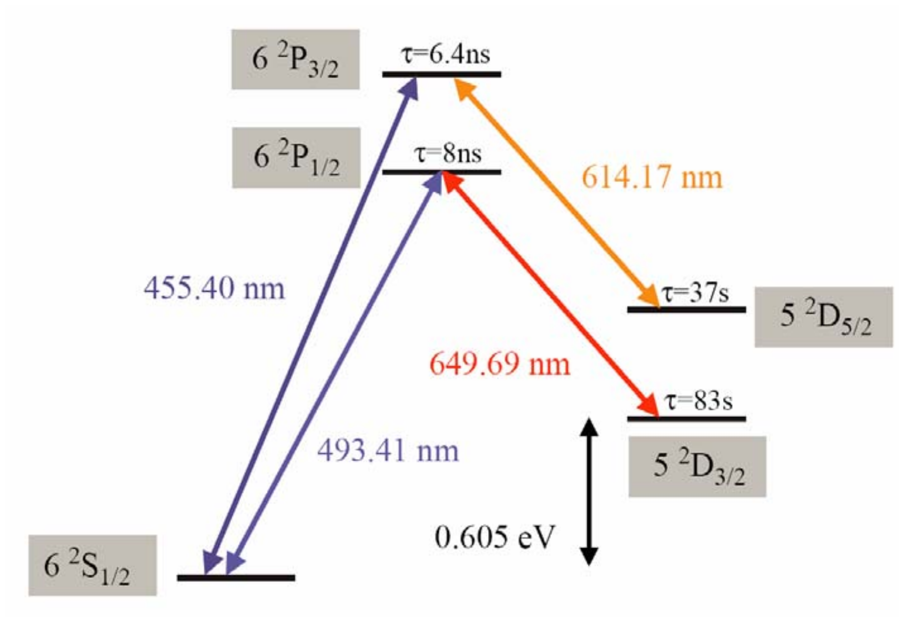
Easy $Ba^{++} \rightarrow Ba^+$ conversion expected

- Xe and Ba ionization potentials
- **Xe^+ = 12.13 eV / Ba^+ = 5.21 eV**
- **Xe^{++} = 21.21 eV / 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**

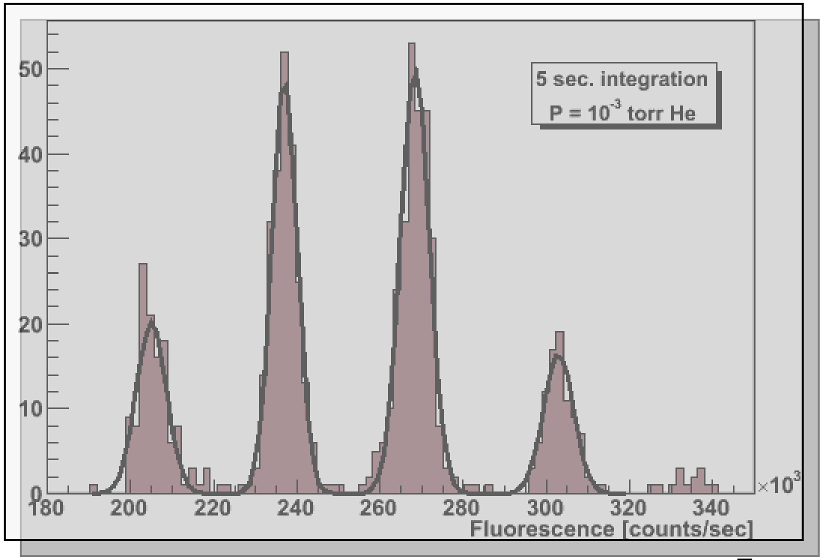
$$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/(Nt)^{1/4}$$

Measurement without background

$$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/\sqrt{Nt}$$



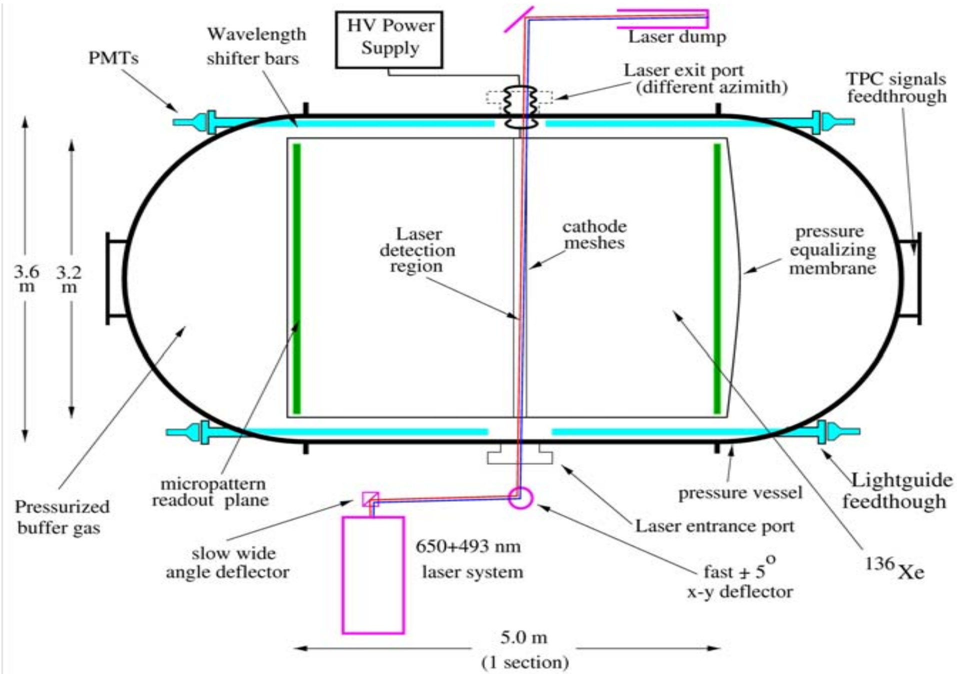
Observed in a RF cage

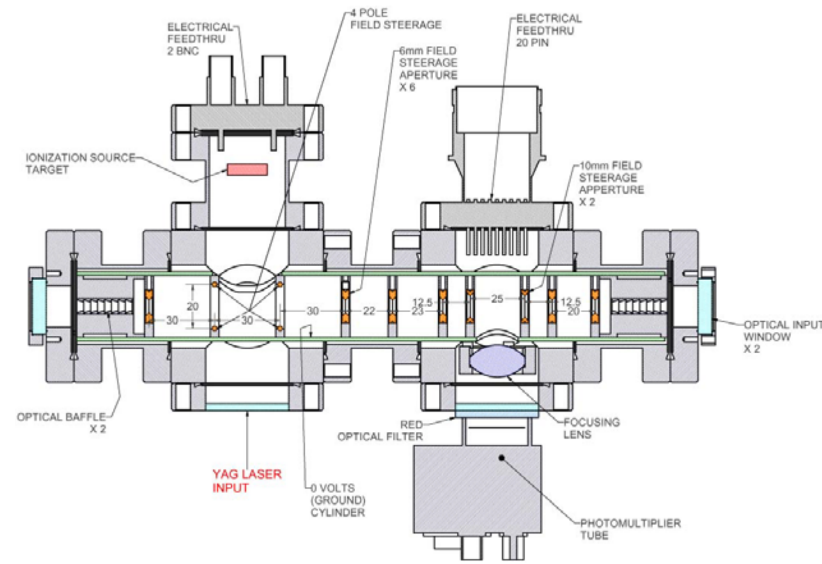


Future plans …

Gas TPC with in-situ Ba^+ tagging

Targeted performance:
$T_{1/2}$ better than 10^{27} years



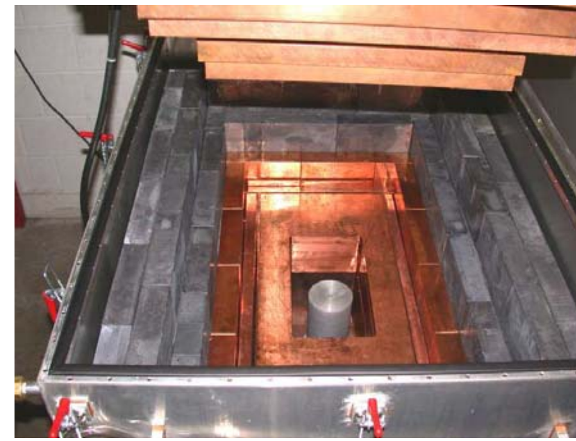


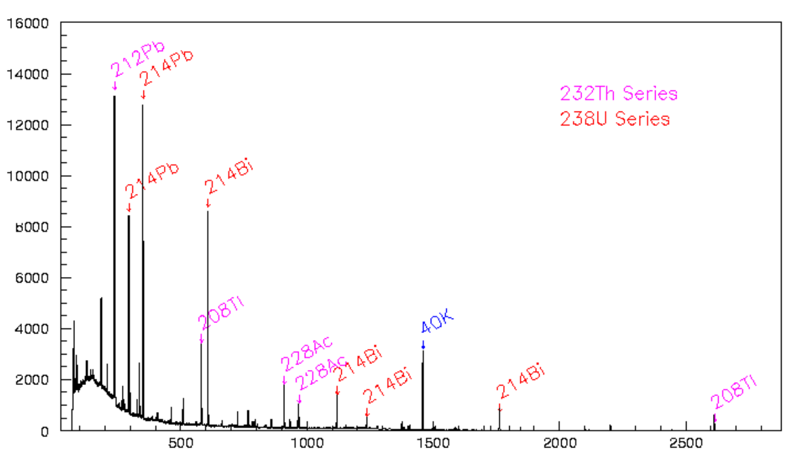
- *Large active mass*
- *Operation at high pressure*
- *No ion fishing and transport*
- *Deeper location*
- *Very high energy resolution*
- *Tracking and background ID*

Swiss group activities

- Material qualification using the Ge detector installed in the “Vue des Alpes” tunnel
- R&D for the liquid and gas phase detectors
  - Cryostat development
  - Micromegas TPC operation at high pressure
  - Light readout using fibers
- Design and manufacturing of EXO-200 cryostat (completed)
- Installation and operation underground shifts

"Vue des Alpes" setup

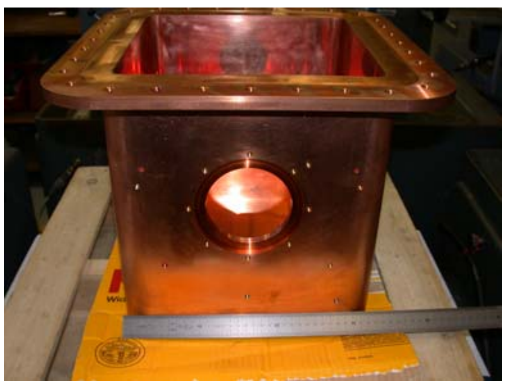


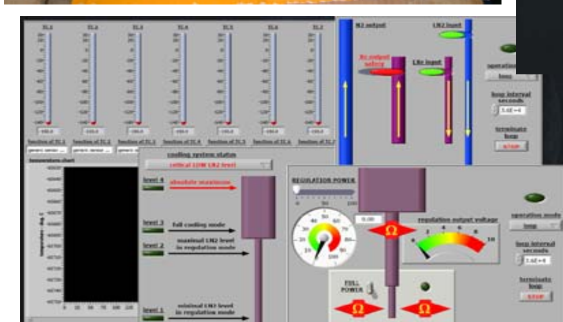


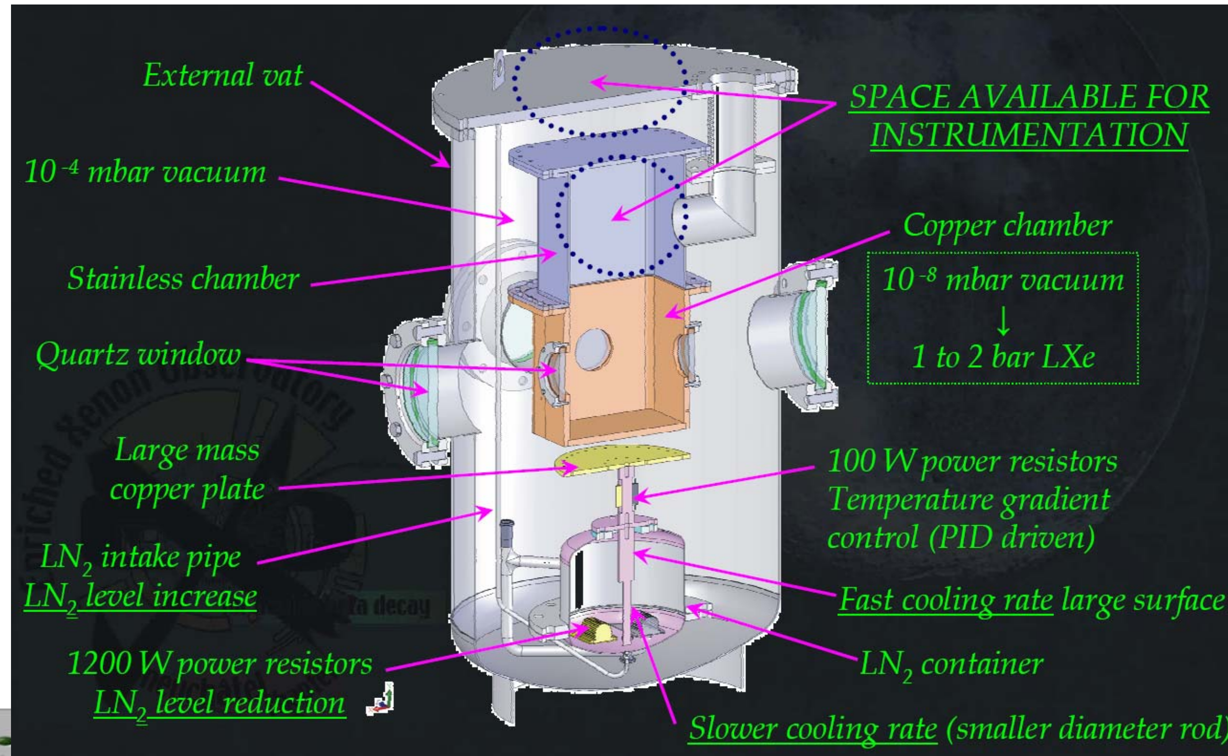
400 cc low background Ge detector
High purity copper and lead shield
Radon tight container and nitrogen purging

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

Cryostat development



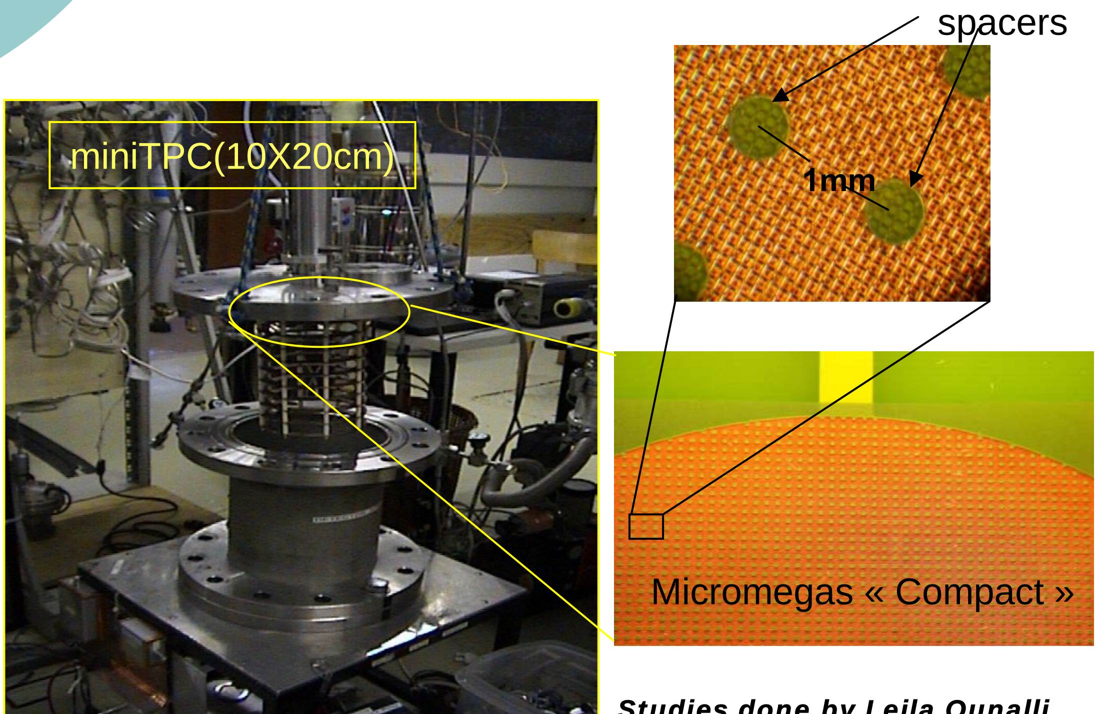


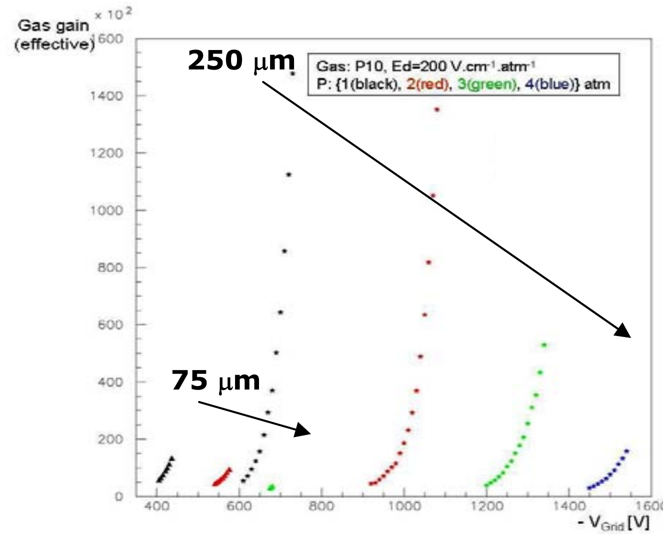


LN_2 cooling and electrical heating
100 kg of LXe maximum capacity
Operation at high pressure possible
Quartz windows for optical access

Micromegas TPC

Objectives:
- *operation at high pressure*
- *energy resolution optimization*
- *additives selection*





Multiple amplification gaps tried:
- *70, 100 and 250 μm*

Drift voltages:
- *200 to 300 V/cm/bar range*

Xe + CF_4, Xe + isobutene

CF_4 advantageous:
- *increased drift velocity, reduced diffusion, does not absorb light (required for t_0)*

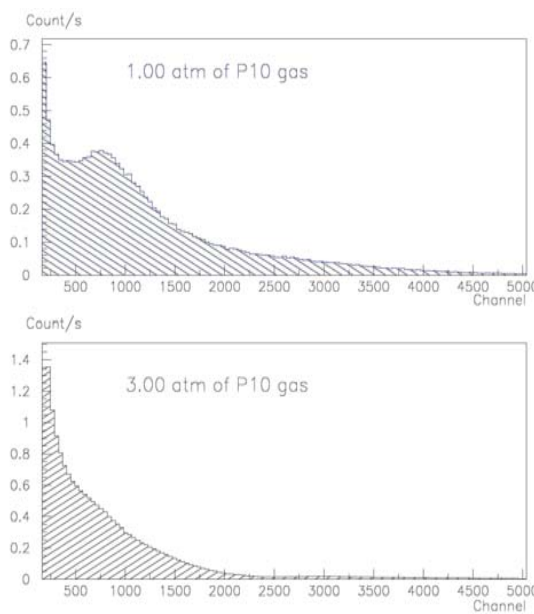
Studies done by Leila Ounalli

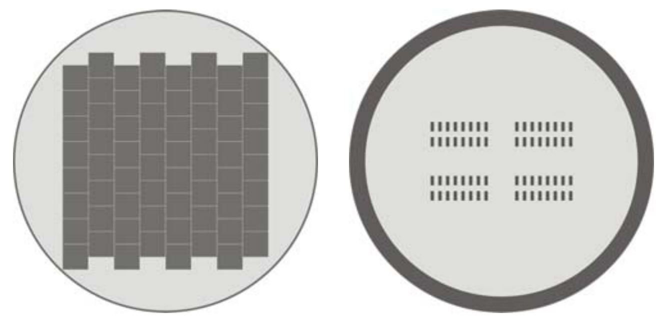
Future Micromegas TPC R&D

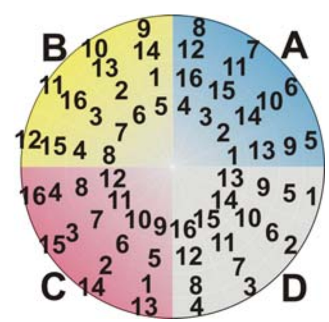
Reuse the available infrastructure, mini-TPC (10 cm) and Gothar TPC (50 cm), with improved Micromegas detectors!

The Gothar TPC available
Already used with a 50 cm
Micromegas detector (P10 gas)

Pressure sealed segmented anodes now available for very large surfaces







Conclusion

- EXO-200 detector soon operational
  - Should allow $\beta\beta 2\nu$ observation with Xe
  - Improved limits on $\beta\beta 0\nu$ expected
- Swiss group R&D work performed on both liquid and gas options
- Continuous operation of a low background Ge detector for material qualification