The EXO experiment

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3-rd CHIPP Swiss neutrino workshop

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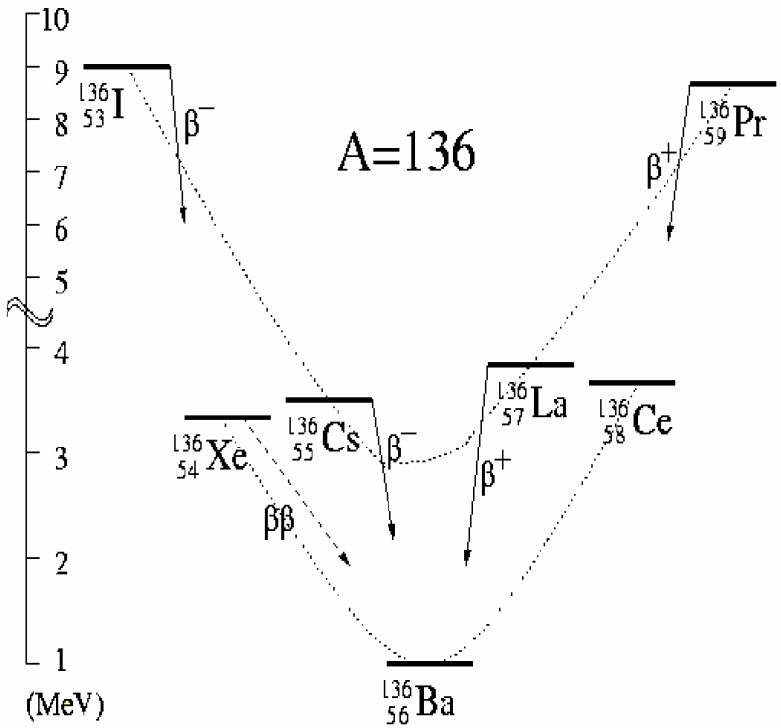
Double beta decay

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

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



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

New physics potential

- **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
  - $\sin^2 2\theta_{sol} \approx 0.8$

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

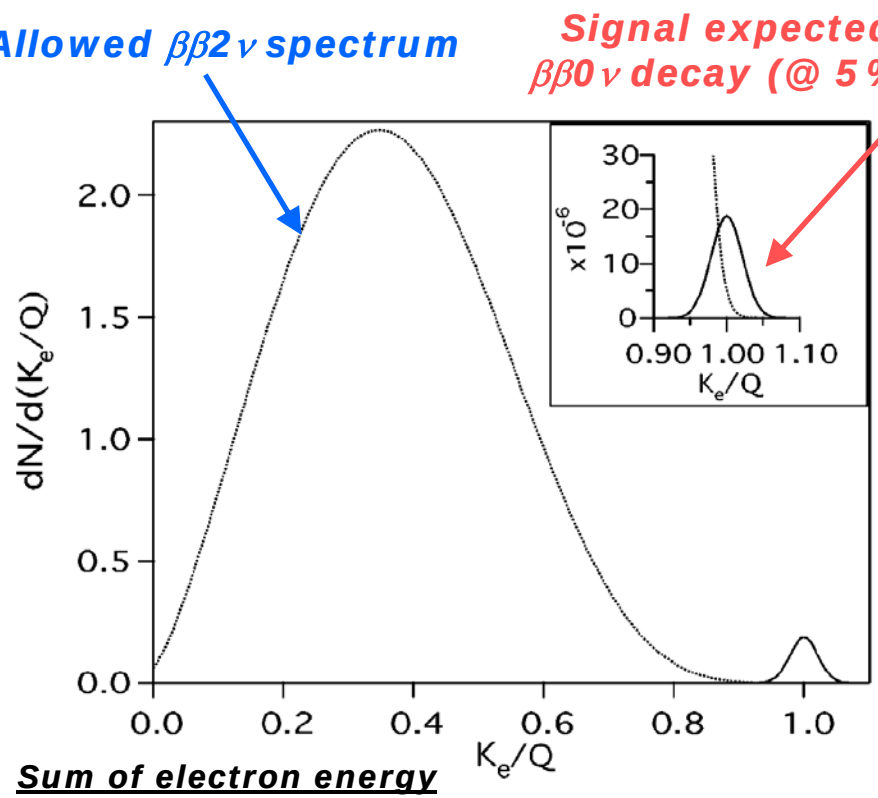
$$\left[T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) \right]^{-1} = G^{0\nu}(E_0, Z) \left| M^{0\nu}_{\mathrm{GT}} - \frac{g_V^2}{g_A^2} M^{0\nu}_{\mathrm{F}} \right|^2 \langle m_\nu \rangle^2$$

Phase space factor

Nuclear matrix elements

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

Double beta signal



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

Allowed ββ2ν has not yet been observed for ^{136}Xe!

EXO collaboration

- K.Barry, D.Leonard, E.Niner, A.Piepke from **Physics Dept, University of Alabama, Tuscaloosa AL, USA**
- 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**
- C. Benitez-Medina, S.Cook, W.Fairbank Jr., K.Hall, B.Mong from **Colorado State University, Fort Collins CO, USA**
- M.Moe from **Physics Dept, UC Irvine, Irvine CA, USA**
- D.Akimov, I.Alexandrov, A.Burenkov, M.Danilov, A.Dolgolenko, A.Kovalenko, V.Stekhanov from **ITEP Moscow, Russia**
- 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**

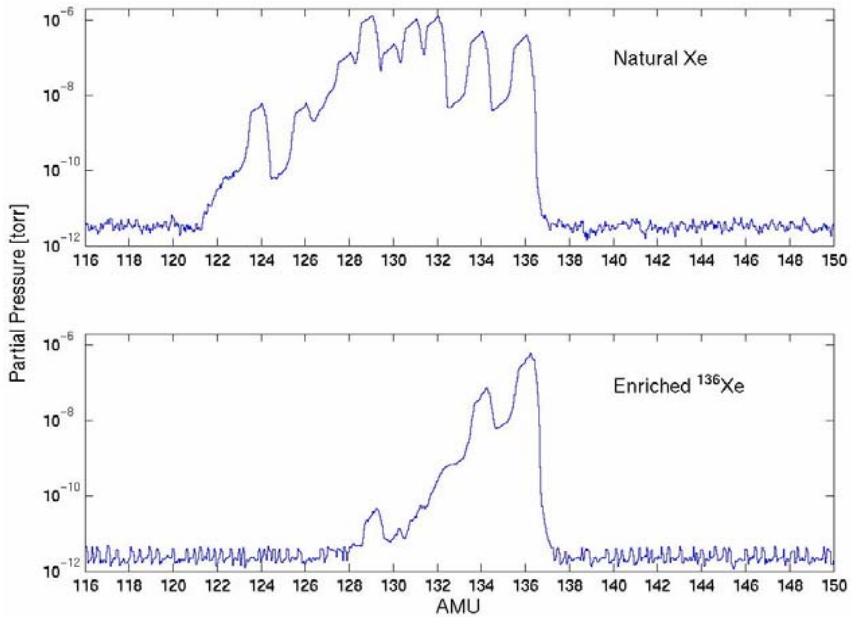
- ***M.Auger, R.Gornea, F. Juget, G. Giroux, G. Lutter, J-L.Vuilleumier, J-M.Vuilleumier*** **from LHEP, Bern University**

- 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**

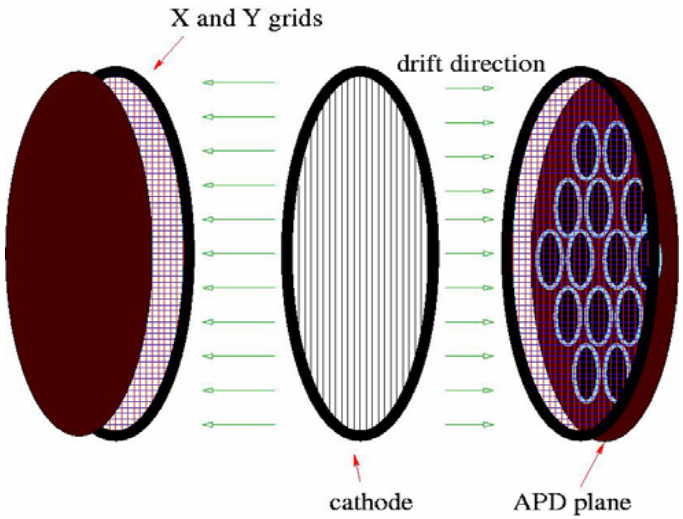
^{136}Xe enrichment

Enrichment facility in Russia

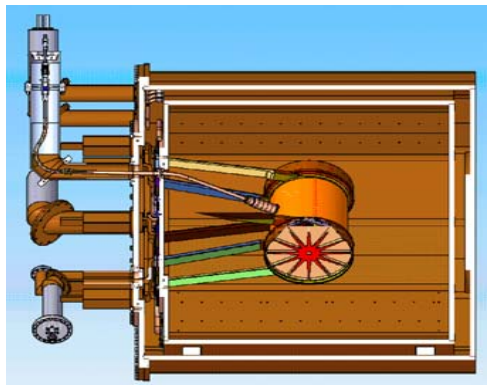
200 kg 80% enriched Xe available!



EXO-200 project

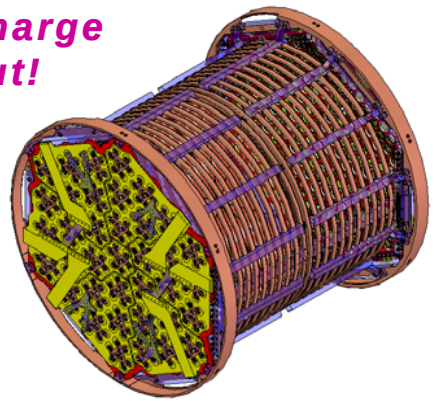


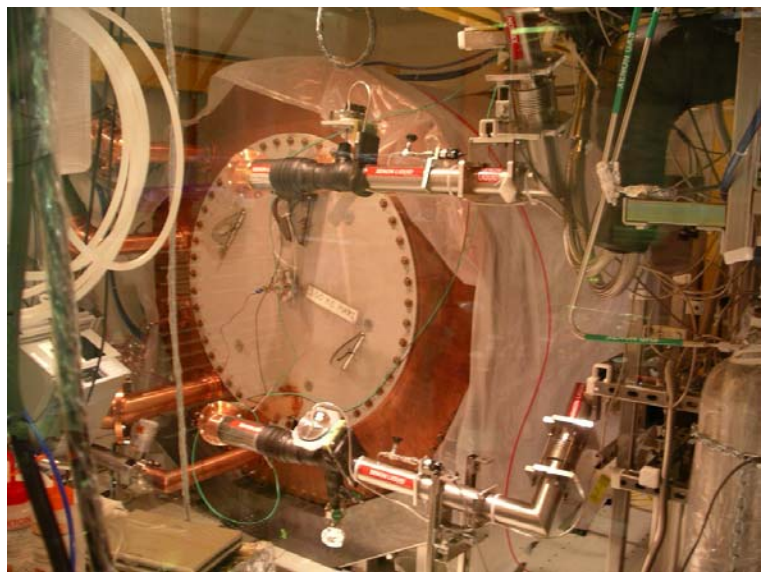
Liquid phase Xe TPC with very low radioactive background



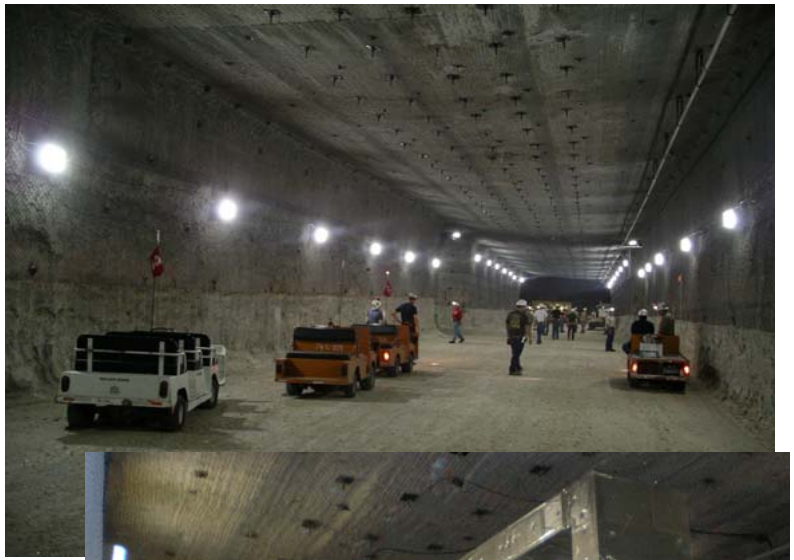
200 kg of 80% enriched Xe

Light & charge readout!





Installation at WIPP



Waste Isolation Pilot Plant
Carlsbad, New Mexico
300 m deep salt mine dedicated to nuclear waste 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**

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

The ultimate background is the $\beta\beta 2\nu$

Good energy resolution is essential!

Physics runs starting in April 2009. Projected run time: ~ 2 years

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

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

1) Rodin, et. al., Nucl. Phys. A 793 (2007) 213-215
2) Caurier, et. al., arXiv:0709.2137v1

Ba^+ tagging R&D

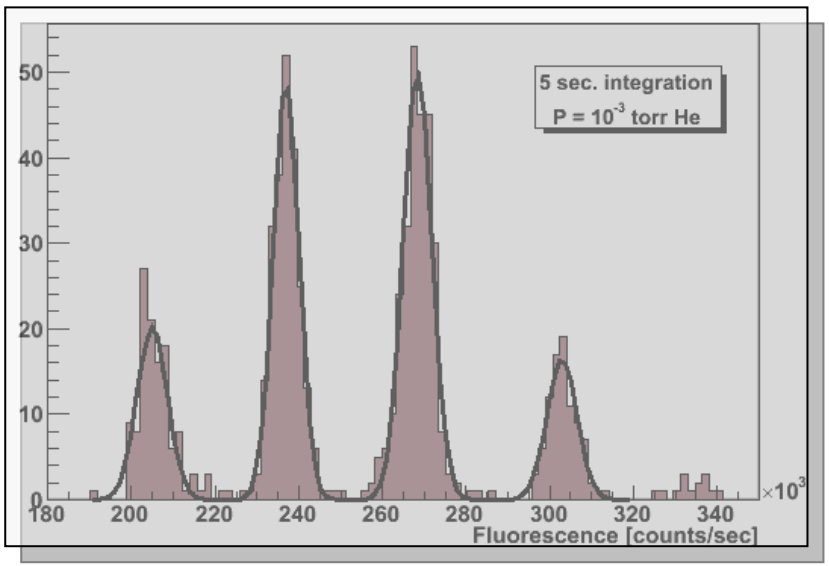
Easy $Ba^{++} \rightarrow Ba^+$ conversion expected

- *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**

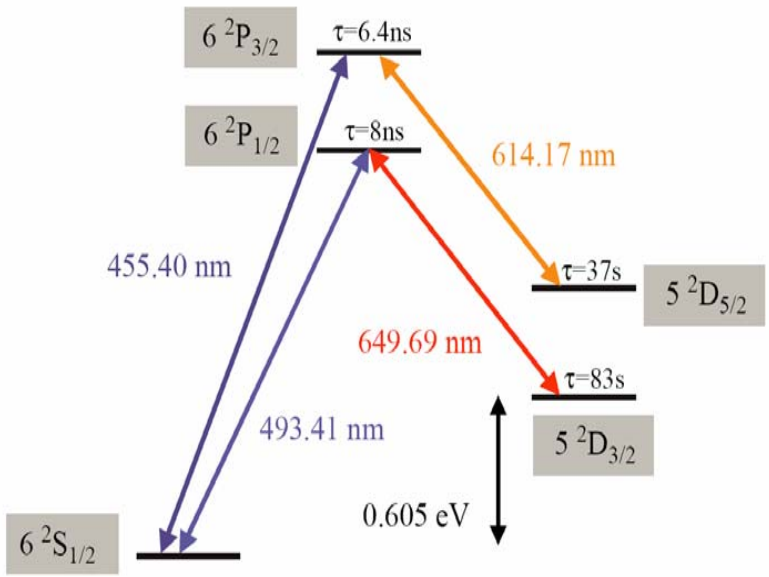
$$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/(Nt)^{1/4}$$

Measurement without background

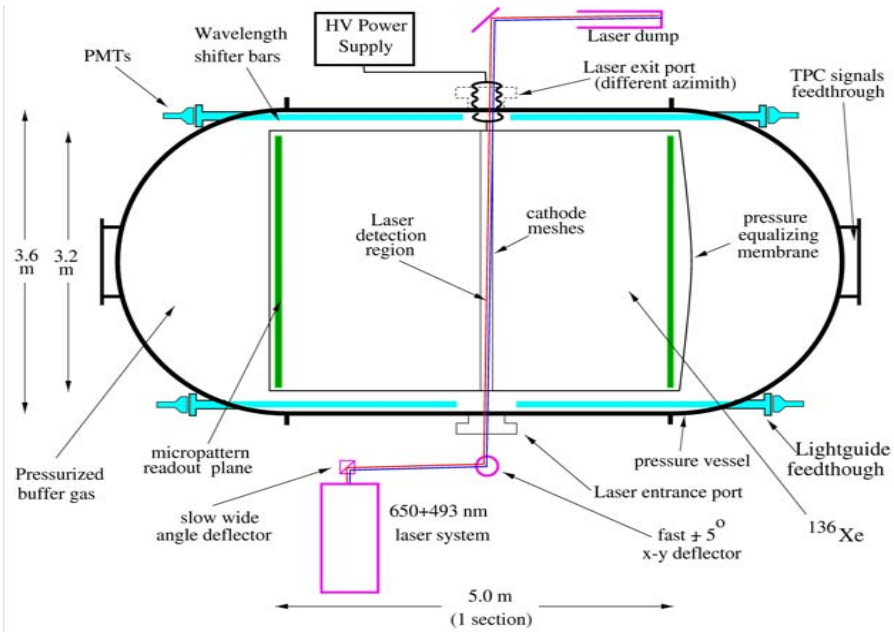
$$\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/\sqrt{Nt}$$



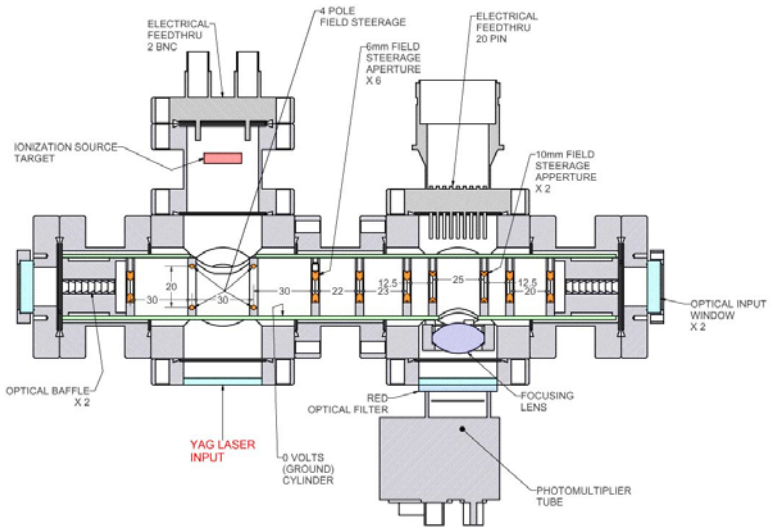
Observed in a RF cage



Future plans …



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



Gas TPC with in-situ Ba^+ tagging

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

Swiss group activities

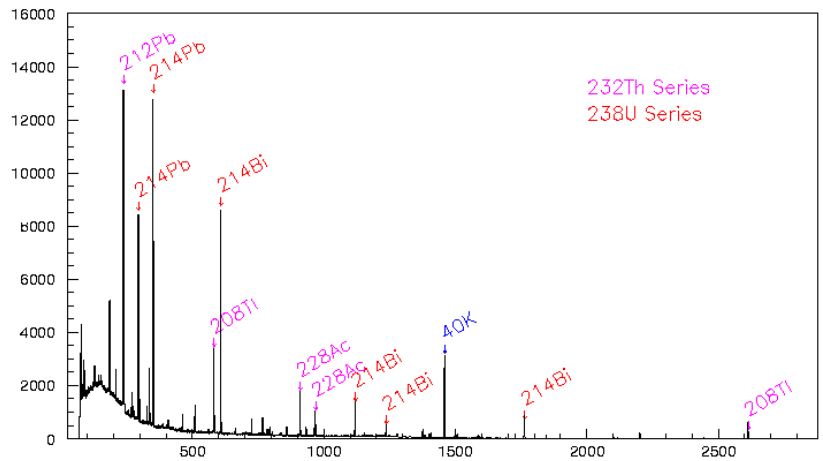
- **Material qualification using the Ge detector installed in the “Vue des Alpes” tunnel**
- **R&D for the liquid and gas phase detectors**
  - ***Cryostat development***
  - ***Micromegas TPC operation at high pressure***
  - ***Light readout using fibers***
- **Design and manufacturing of EXO-200 cryostat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

“Vue des Alpes” setup

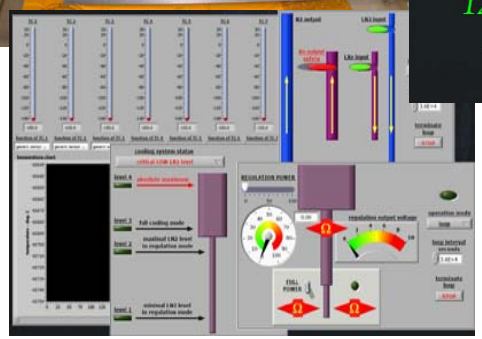
400 cc low background Ge detector
High purity copper and lead shield
Radon tight container + N_2 purging

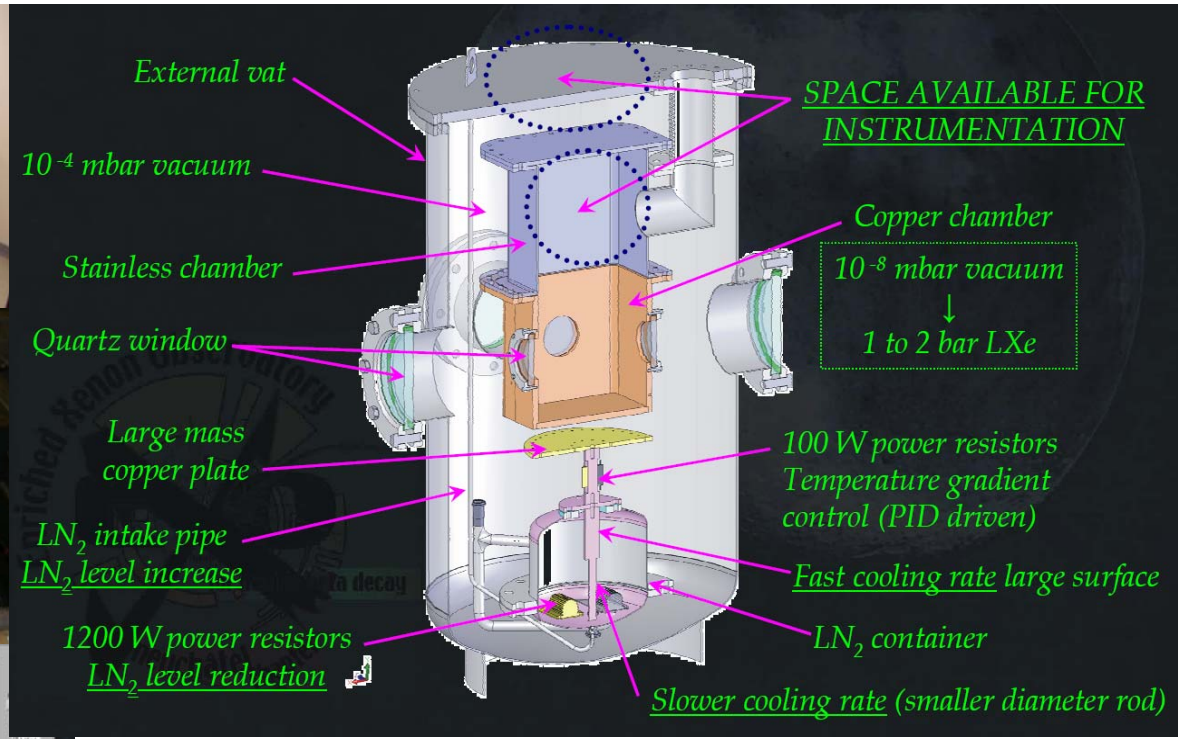
100 pg/g sensitivity for ^{232}Th and ^{238}U chains

1 μg/g sensitivity for K concentration



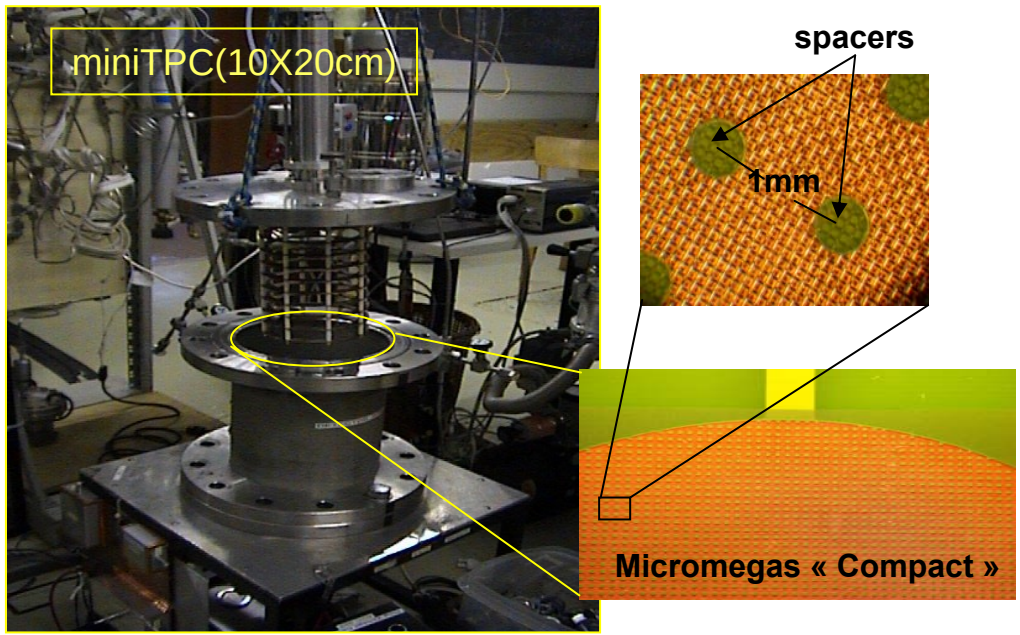
Cryostat development





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 tested:
- ***70, 100 and 250 μm***

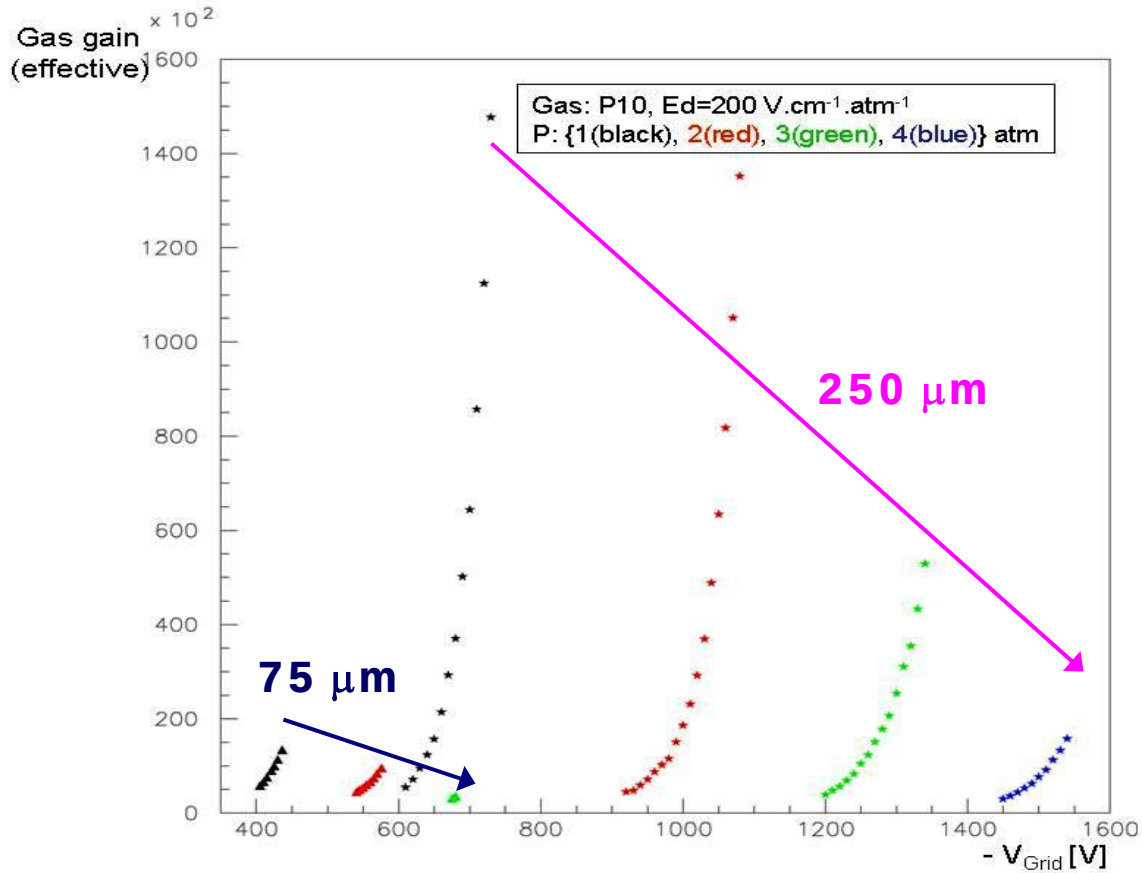
Range of drift voltages:
- ***200 to 300 V/cm/bar***

Xe + CF_4, Xe + isobutene

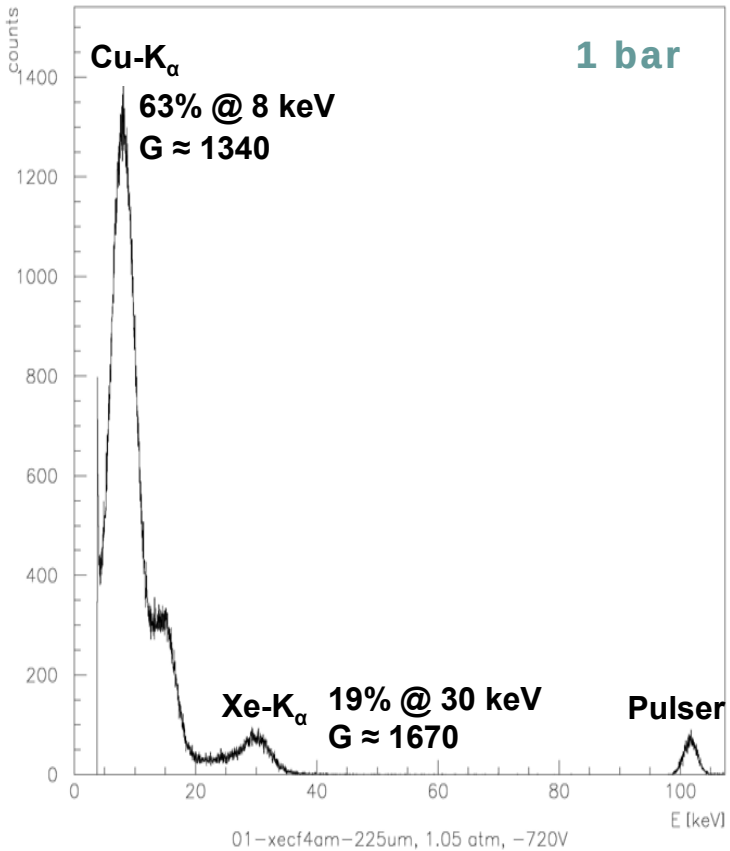
CF_4 advantageous:
- ***increased drift velocity***
- ***reduced diffusion***
- ***does not absorb light (required for t_0)***

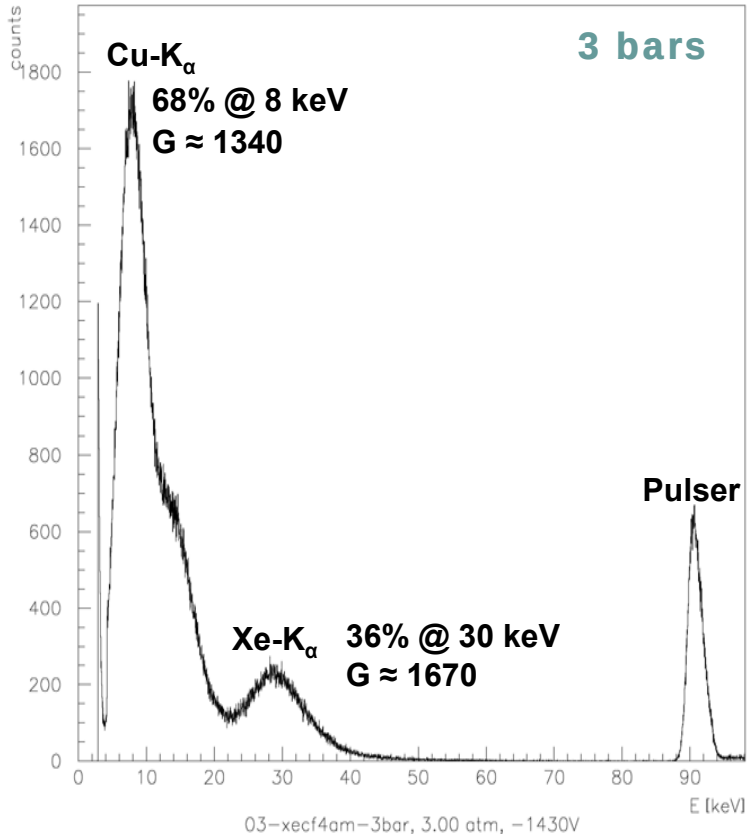
Studies done by Leila Ounalli

Operation at high pressure



Energy resolution





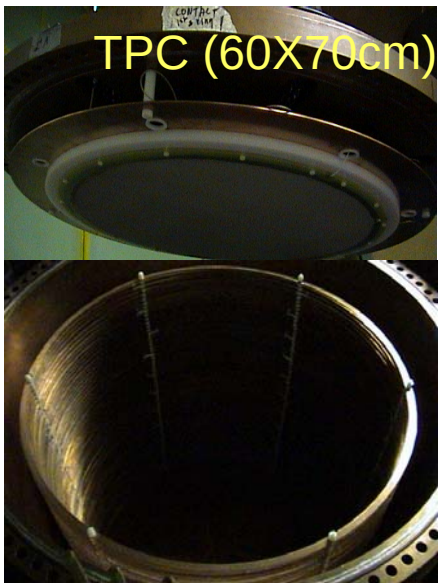
98% Xe + 2% CF_4

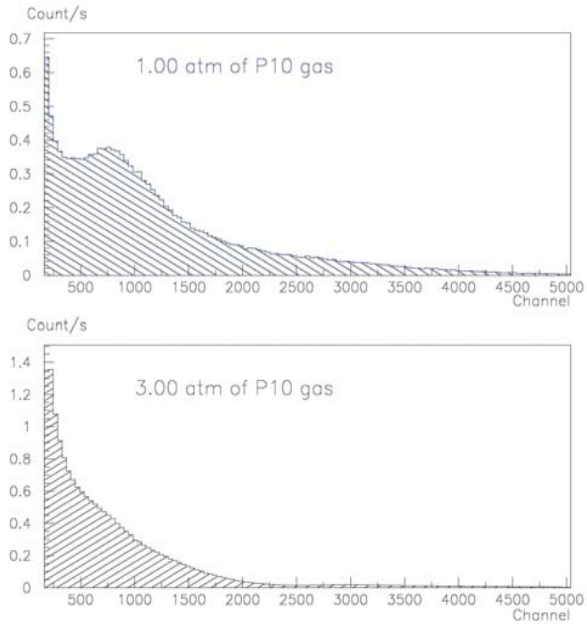
Future Micromegas TPC R&D

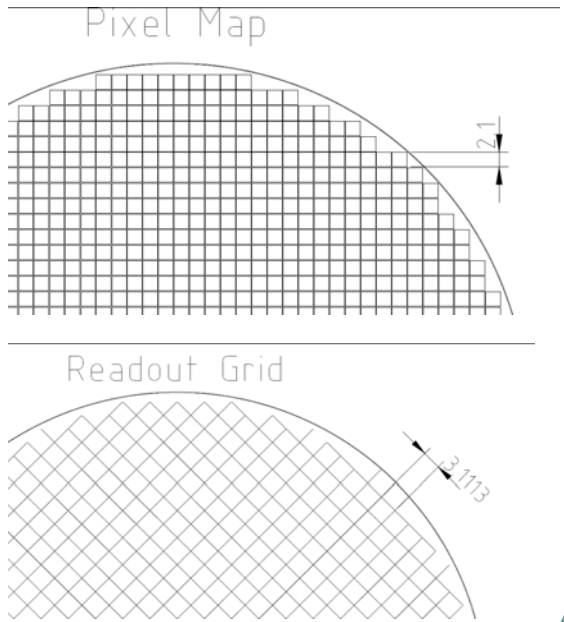
Reuse the available infrastructure, mini-TPC (10 cm) and Gothar TPC (50 cm), with improved Micromegas detectors!

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**