EXO-200

Nicole Ackerman

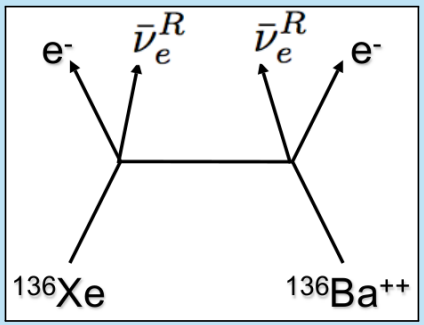
SLAC National Accelerator Laboratory
Stanford Department of Physics

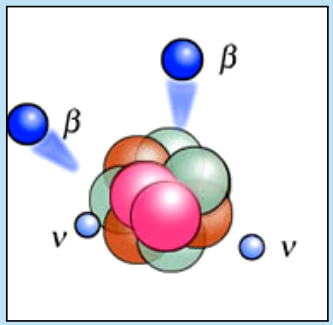
July 31st, 2009
APS DPF Meeting

DOUBLE BETA DECAY

STANDARD MODEL 2-ν

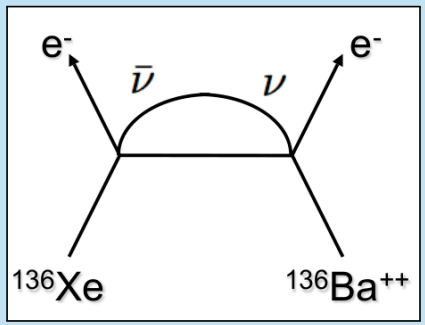
$$[T^{2\nu\beta\beta}_{1/2}]^{-1} = G^{2\nu\beta\beta}|M^{2\nu\beta\beta}|^2$$

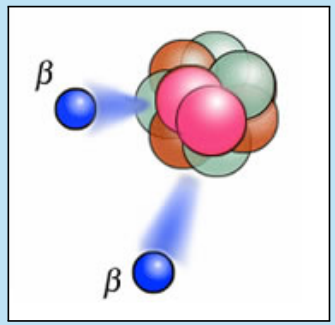




NEUTRINOLESS

$$[T^{0\nu\beta\beta}_{1/2}]^{-1} = G^{0\nu\beta\beta}|M^{0\nu\beta\beta}|^2|\langle m\rangle|^2$$



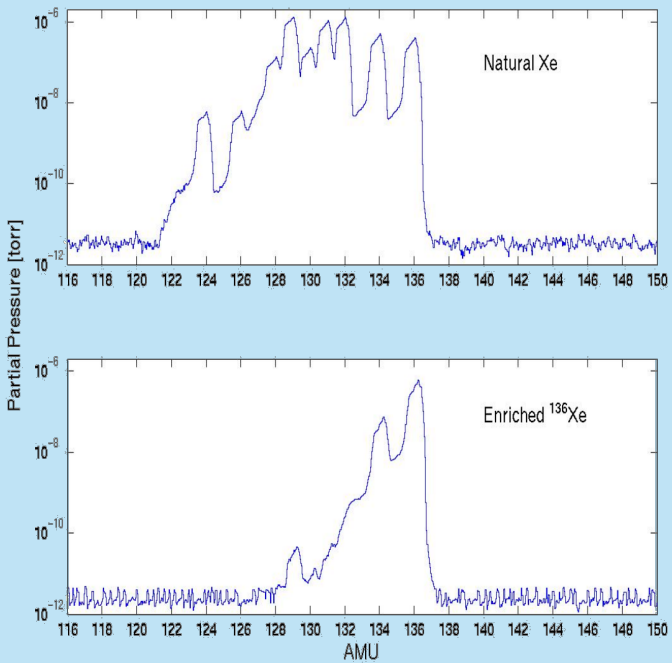


MASS MEASUREMENT

$$\langle m_{\beta\beta}\rangle = |\sum_{i=1}^{3} U_{ei}^2 m_i e^{i\alpha_i}| \propto [T^{0\nu\beta\beta}_{1/2}]^{-1/2}$$

^{136}Xe

Xe Isotopes



Mass spectra from RGA – 2001 test sample enriched to 89.5% in Xe^{136}.

Current Limits

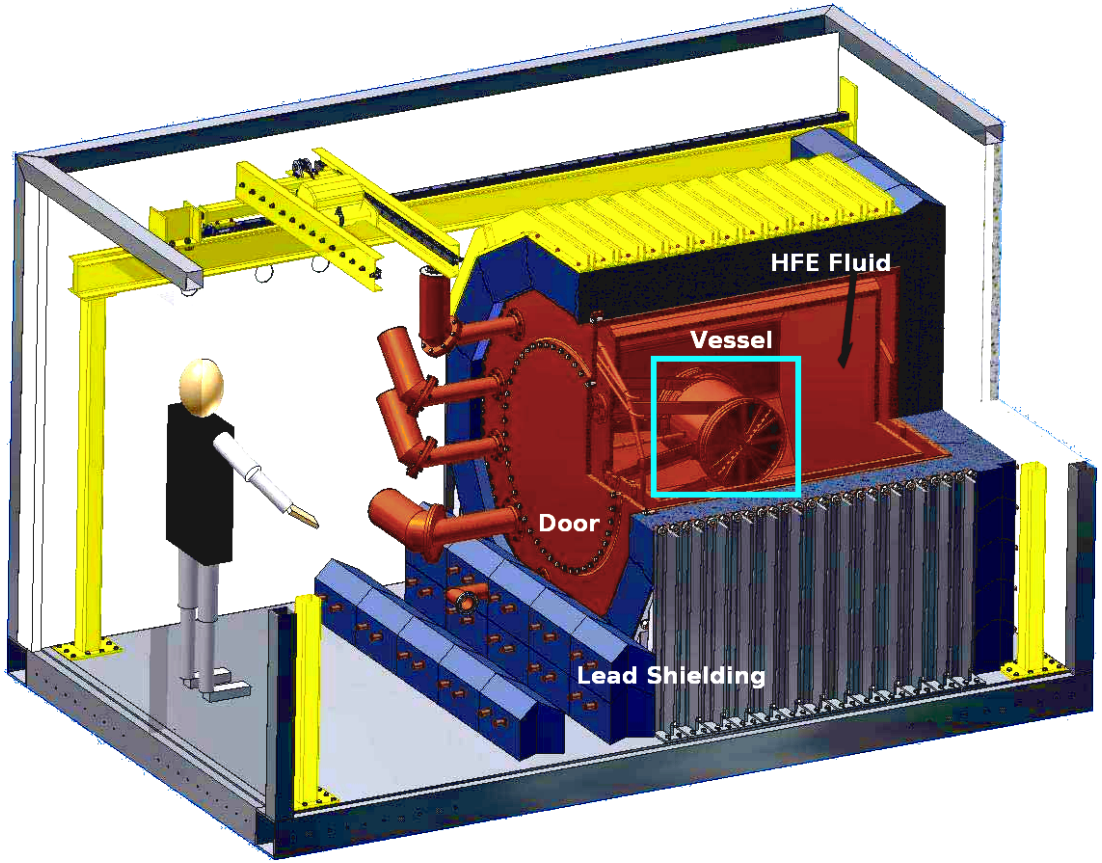
$$T_{1/2}^{0\nu\beta\beta} > 1.2 \times 10^{24} \text{ year}$$

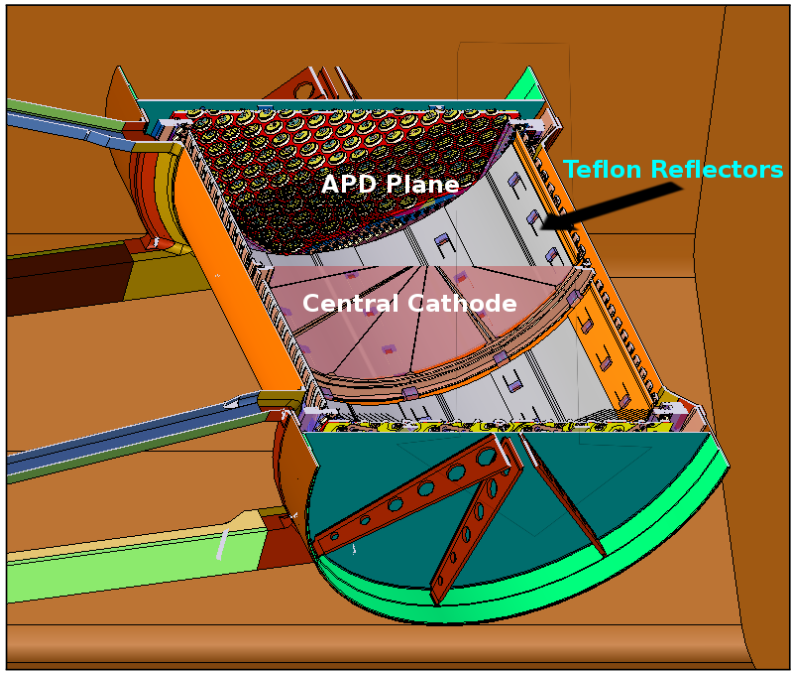
$$T_{1/2}^{2\nu\beta\beta} > 1 \times 10^{22} \text{ year}$$

Xe Advantages

- High Q: 2.48 MeV
- Scintillation and Ionization
- Purification, reusability
- Easy to enrich
- Background rejection with Ba^{++} identification

CRYOSTAT DESIGN





Massive Effort on Materials Qualification - Database of ∼330 Entries

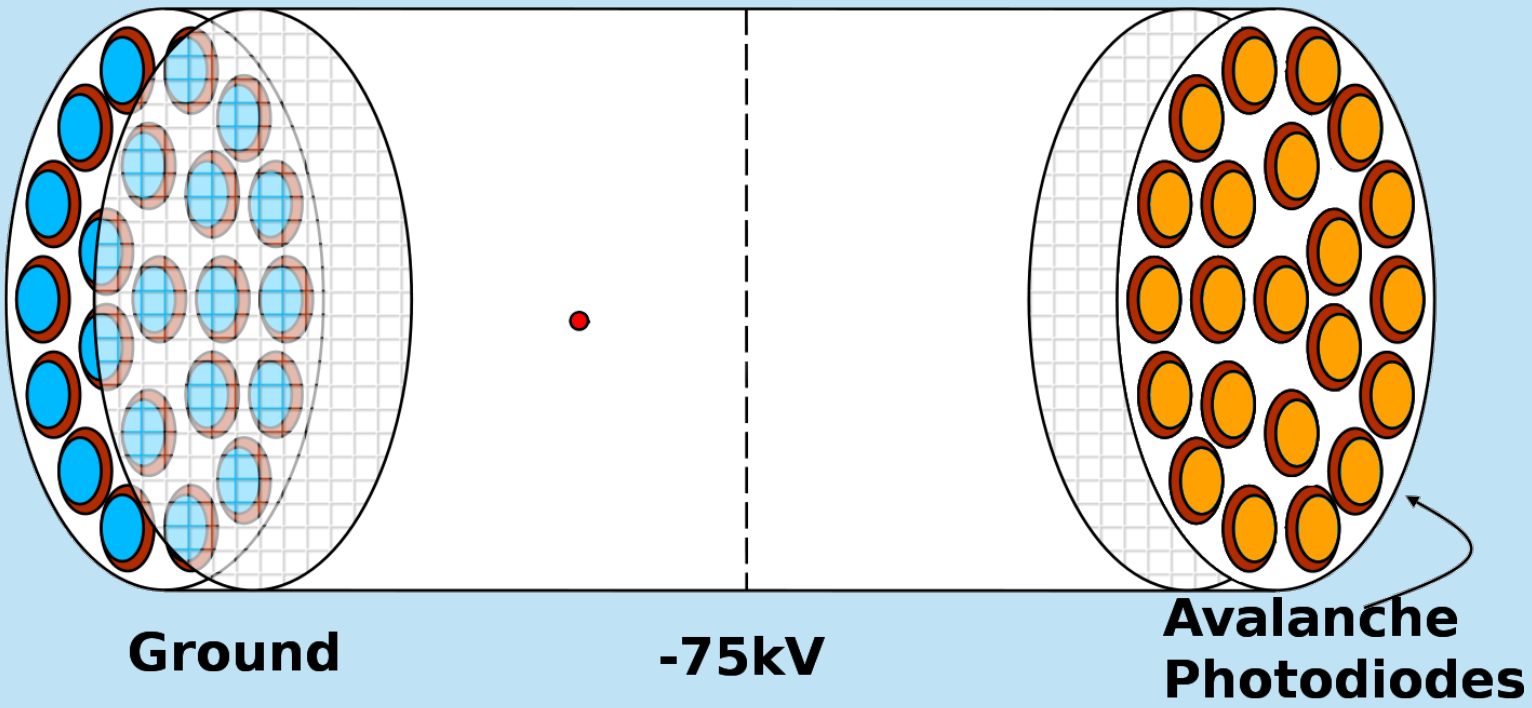
D. S. Leonard *et al.*, NIM A Volume 591, Issue 3, July 2008, Pages 490-509

TIME PROJECTION CHAMBER

DESIGN CONSIDERATIONS

- Low Background
- Large Mass
- Resolution

WHAT WE SEE



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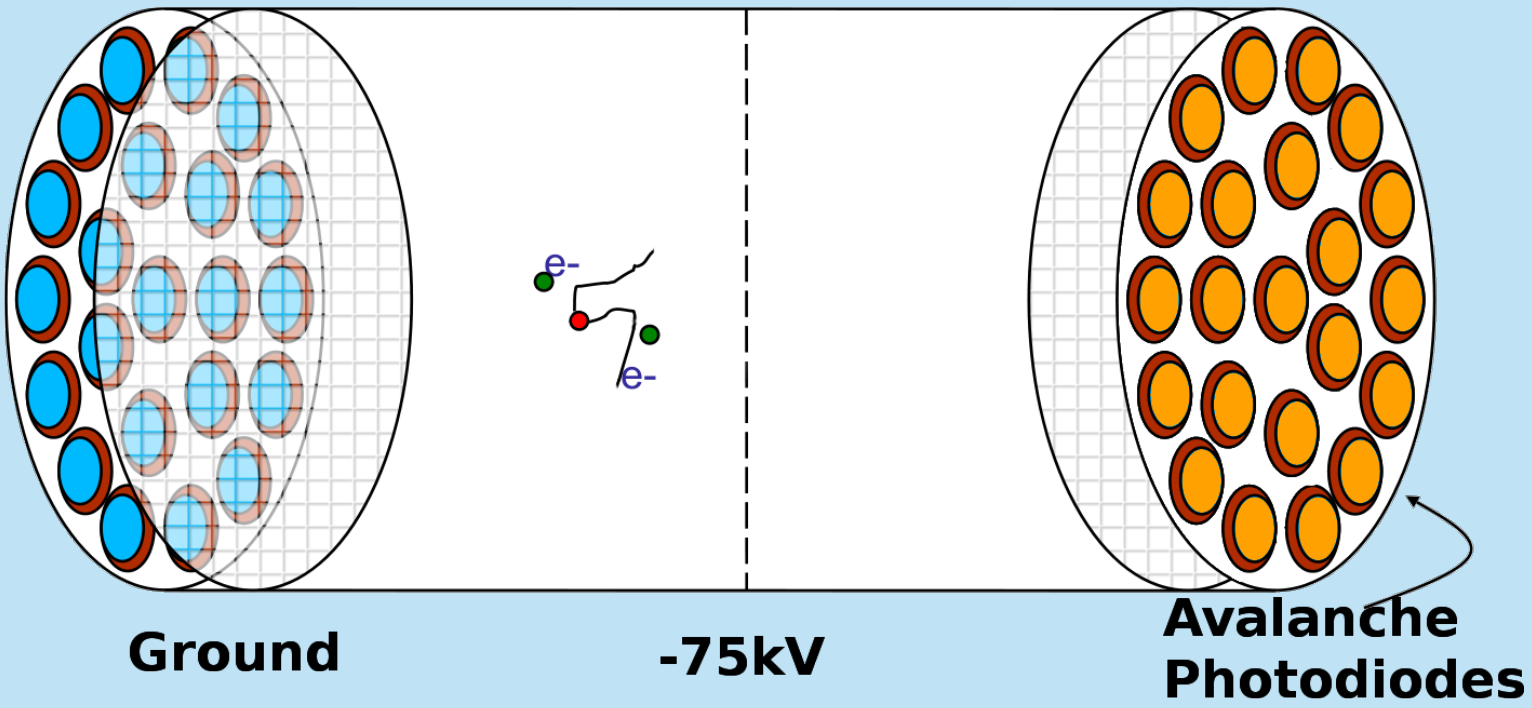

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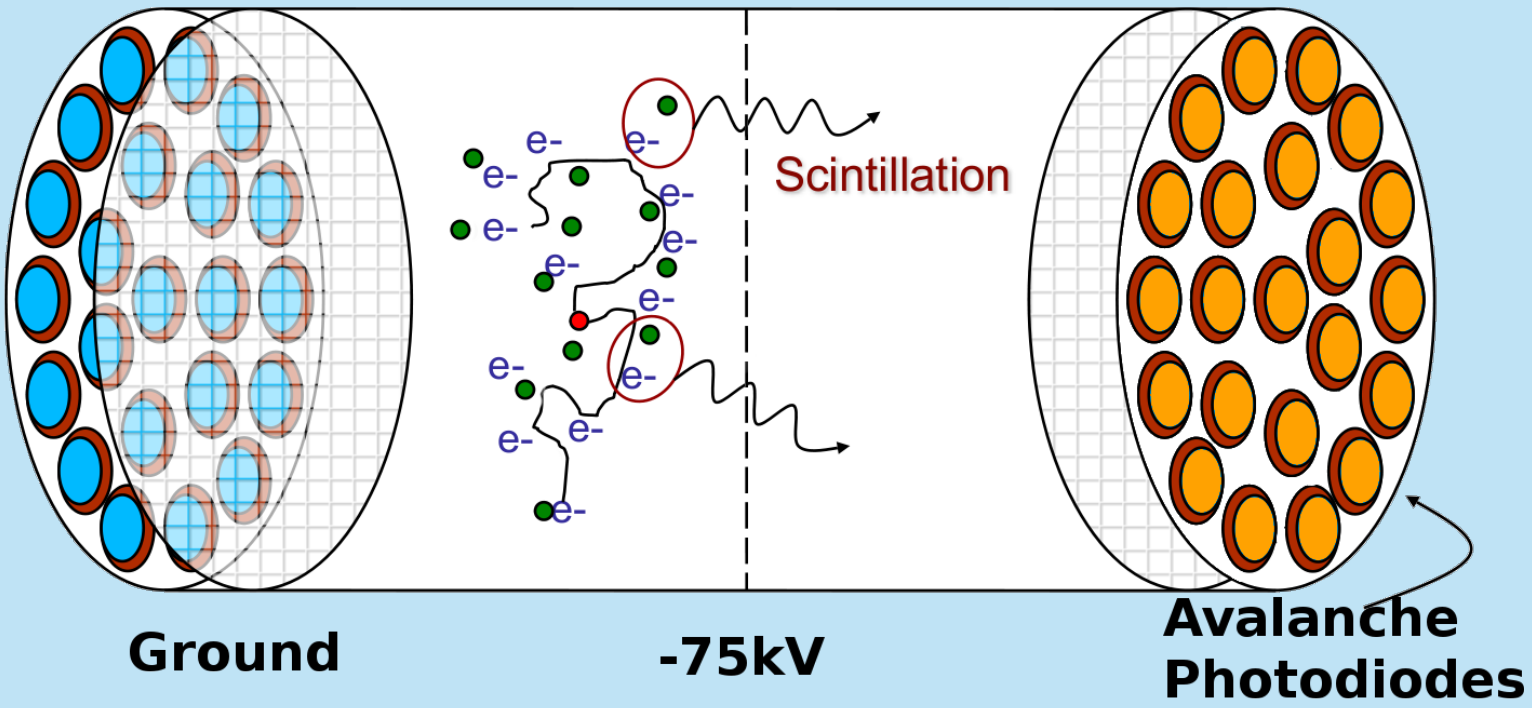

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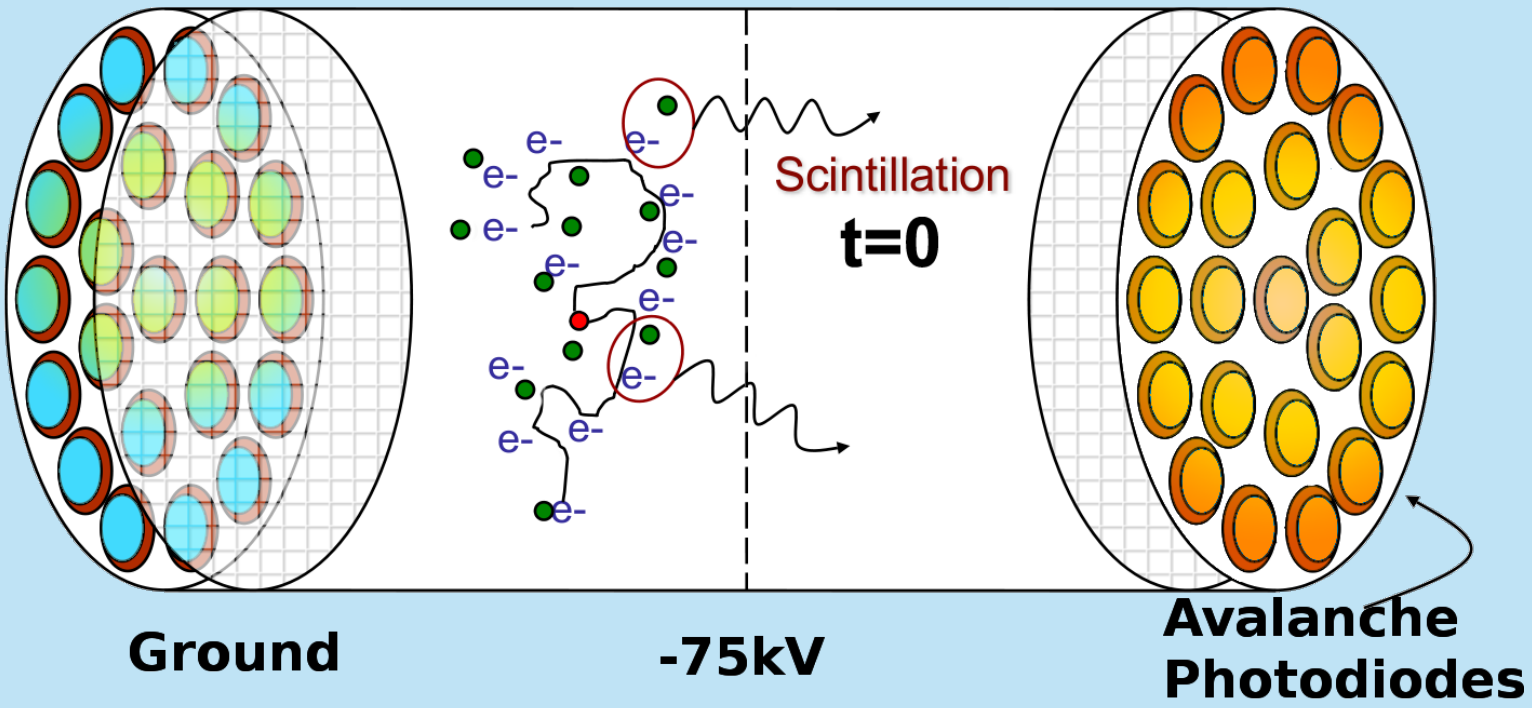

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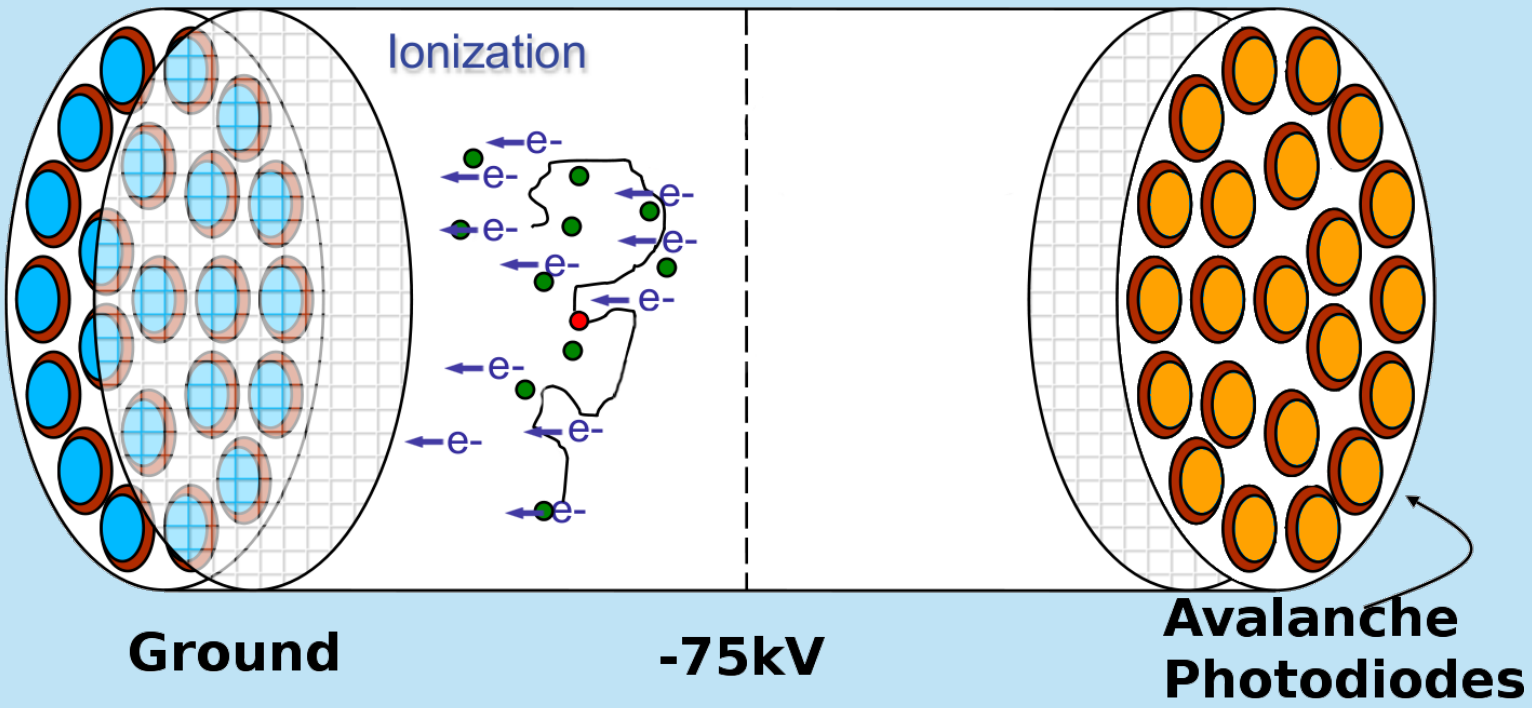

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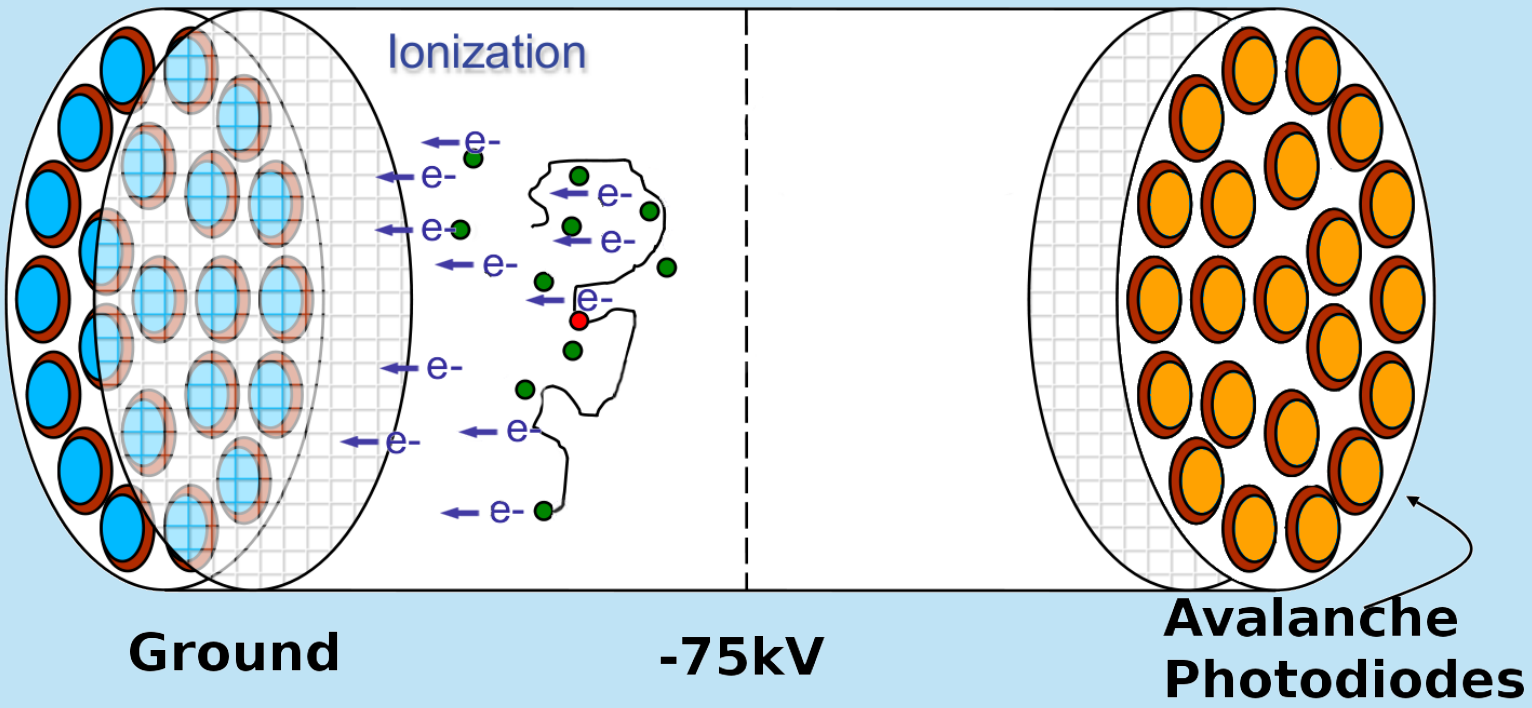

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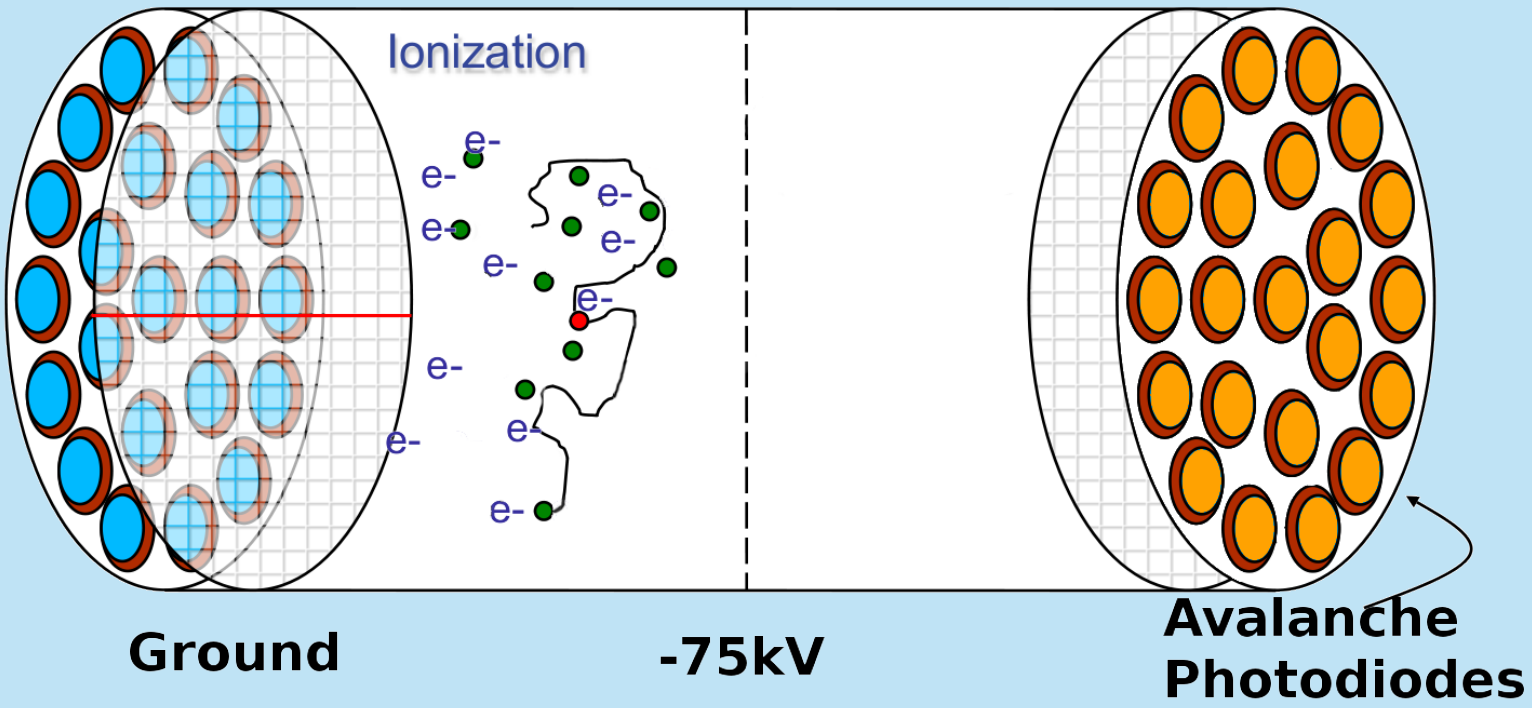

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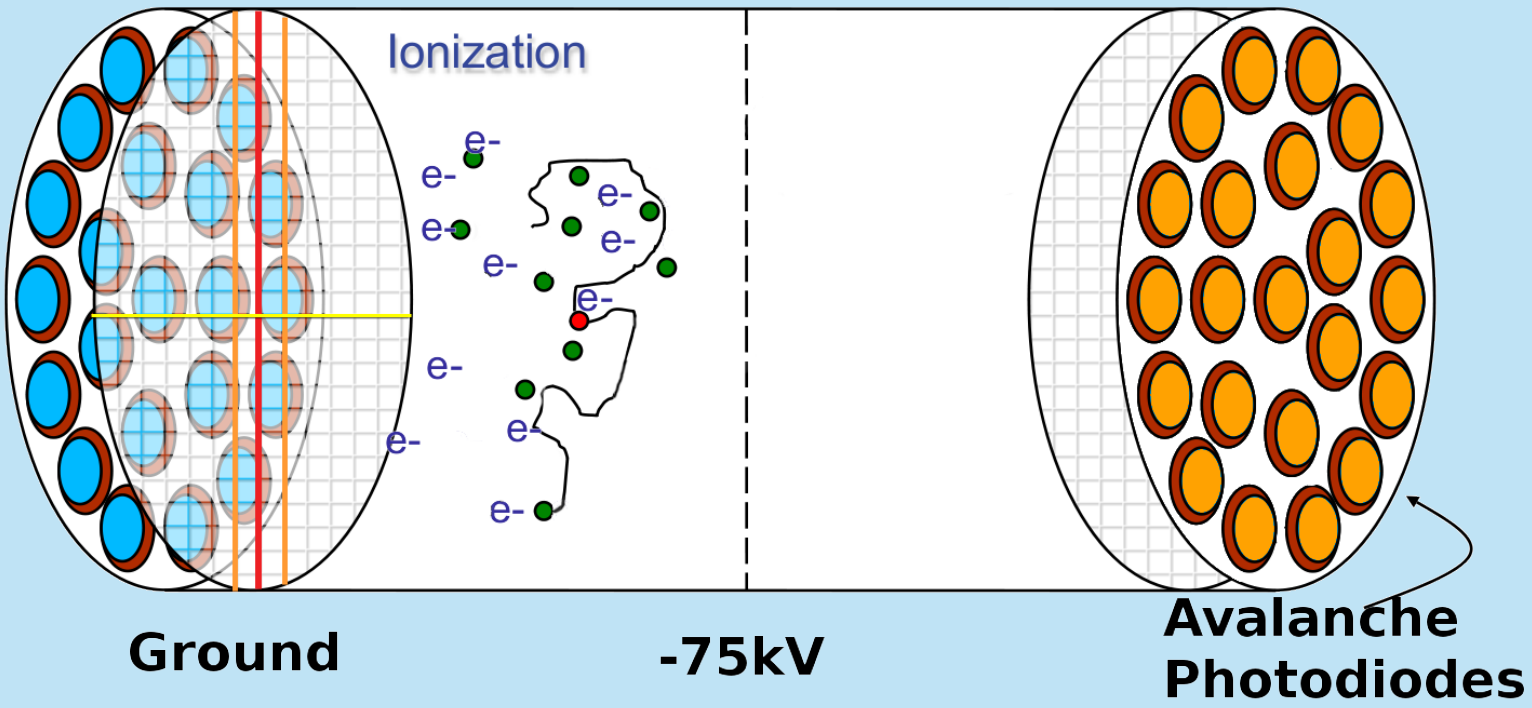
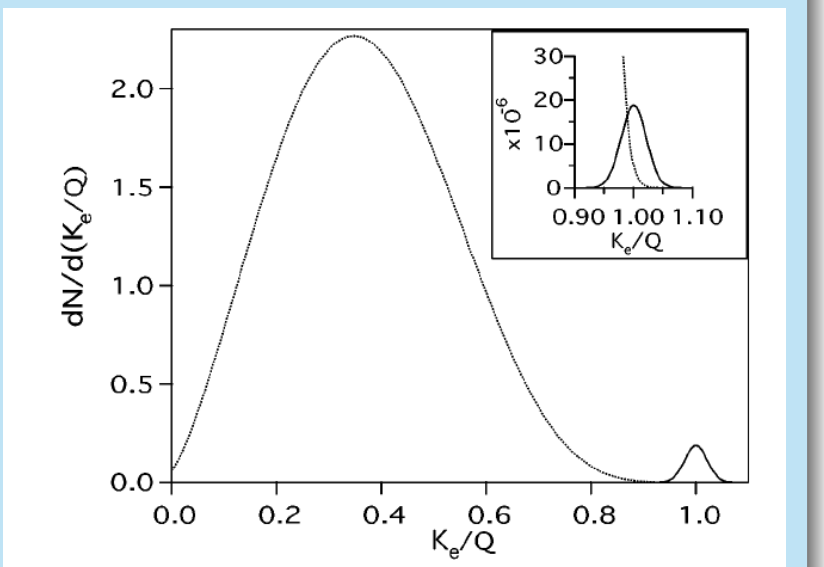
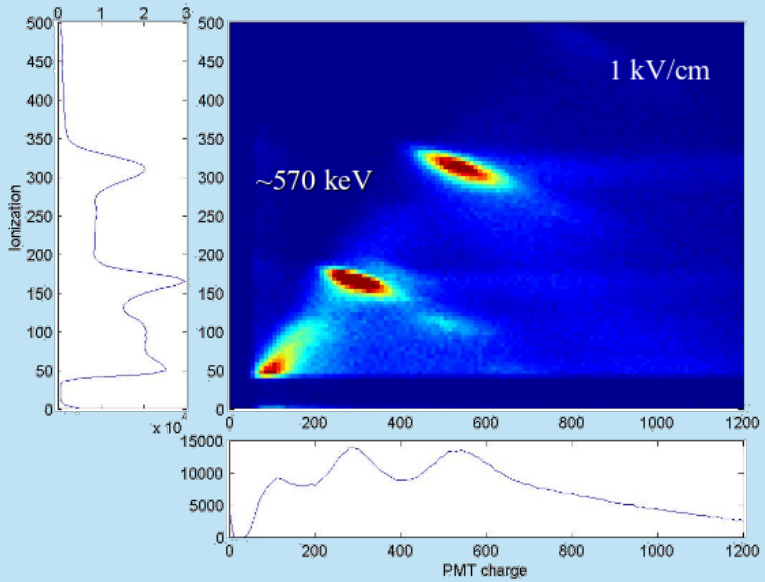


MEASUREMENT STRATEGY

$\sum E(e^-)$ MEASUREMENT



ANTICORRELATION



Shown in 2003 (Phys. Rev. B 68)

Spatial information identifies:

- Multi-site events (background)
- Surface contamination (if needed)

EXO-200 MEASUREMENT POSSIBILITIES

EXO-200 SENSITIVITIES

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @2.5 MeV (%)	Radioactive BG (events)	$T^{0\nu}_{1/2}$ (yr) 90%CL	Majorana Mass (meV) QRPA[1]	NSM[2]
EXO200	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

TESTING KLAPDOR-KLEINGROTHAUS'S OBSERVATION

$$T_{1/2}(Ge) = 2.23^{+0.44}_{-0.31} \times 10^{25} \text{ years } (\pm 3\sigma)$$

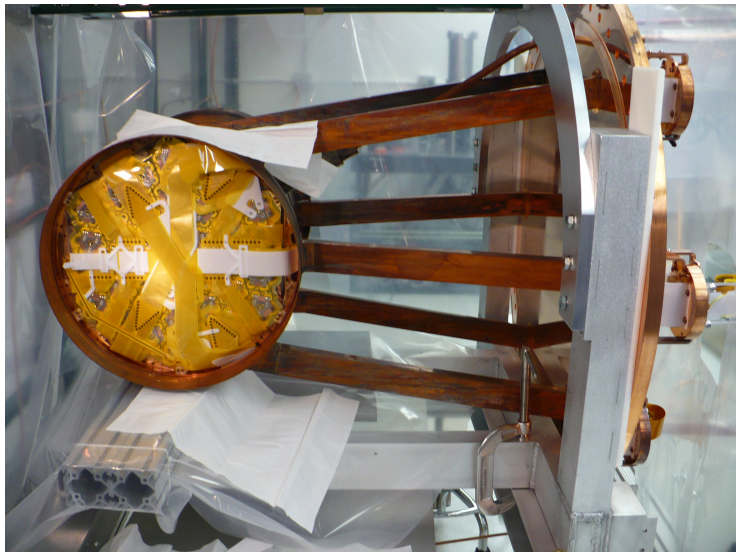
Mod.Phys.Lett.A21 2006

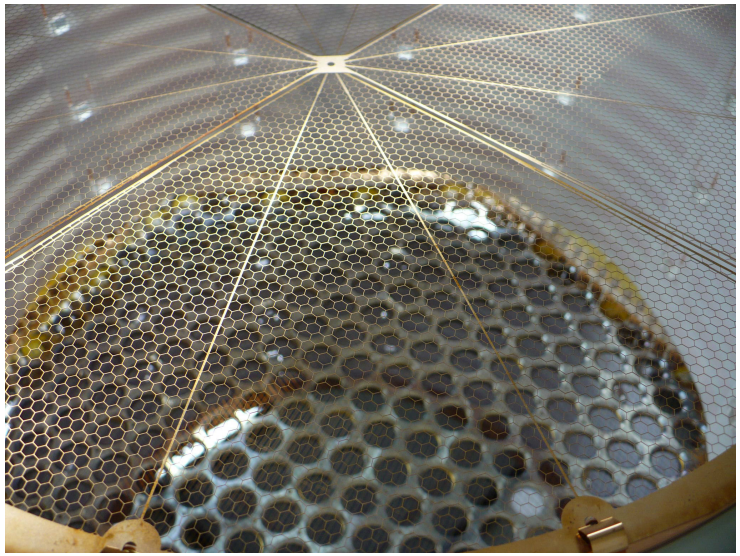
2 years of EXO-200:

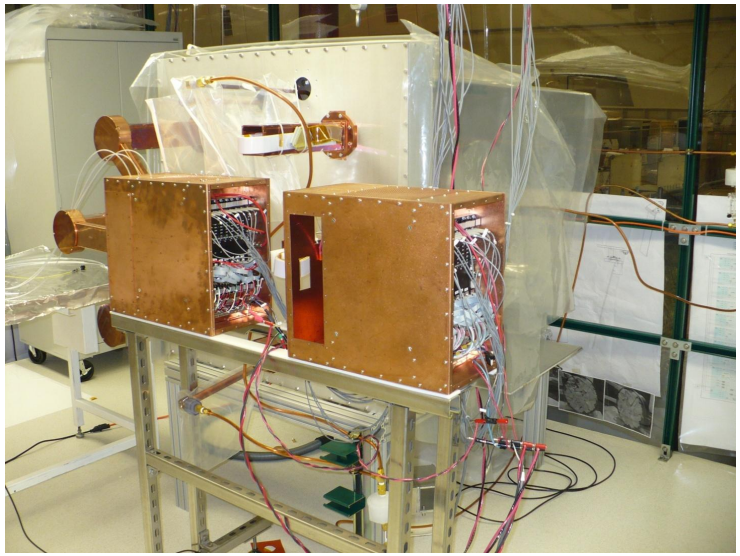
Worst case (QRPA, upper limit): 46 events, 40 background$\rightarrow$ 5.0σ

Best case (NSM, lower limit) :170 events, 40 background$\rightarrow$$11.7\sigma$

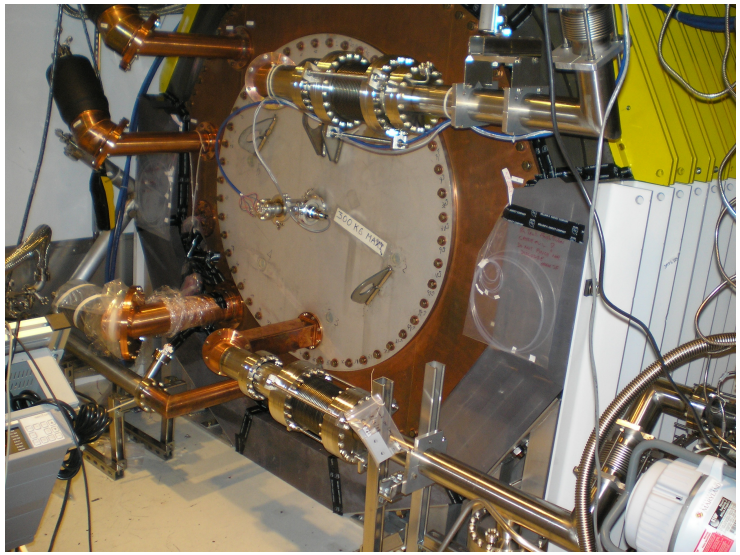
TPC CONSTRUCTION

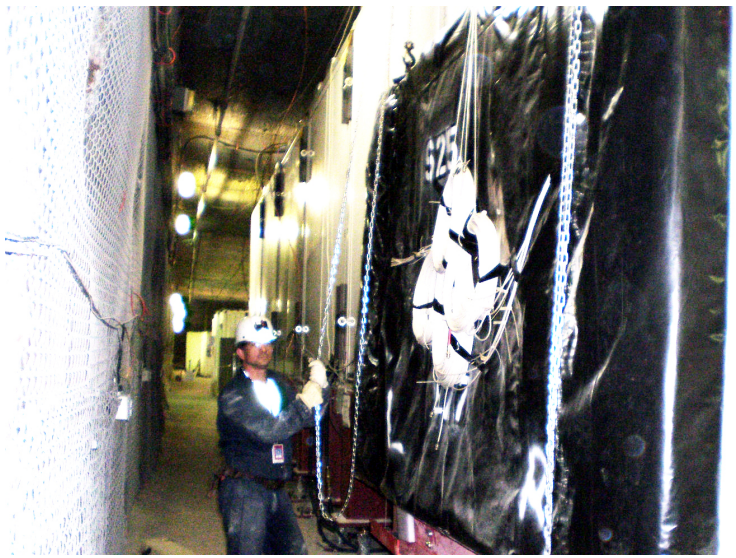


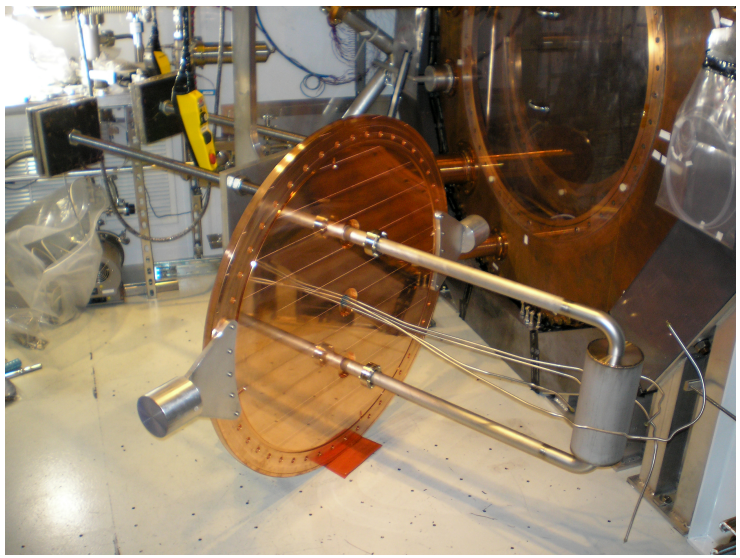




INSTALLATION AT WIPP







EXO SENSITIVITIES

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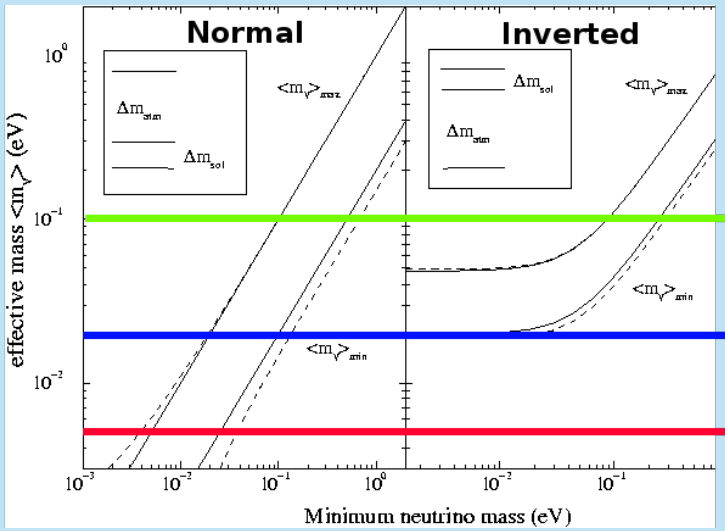
Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @2.5MeV (%)	$2\nu\beta\beta$ BG (events)	$T^{0\nu}_{1/2}$ (yr) 90%CL	Majorana Mass (meV) QRPA[1]	NSM[2]
Conservative	1	70	5	1.6	0.5 (use 1)	2×10^{27}	24	33
Aggressive	10	70	10	1	0.7 (use 1)	4.1×10^{28}	5.3	7.3

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

CONSTRAINING MIXING HIERARCHY

$\langle m_{\beta\beta} \rangle$



EXO DEVELOPMENT POSSIBILITIES

ALREADY ACHIEVED

- 200 kg LXe Experiment with 80
- Single Ba Ion Trap and Identification

LXE R&D

- In Situ Ba tagging in liquid
- Ba grabbing probe

GXE R&D

- High pressure vessel
- Test Chamber
- Ba Tagging in gas

SUMMARY

Many avenues available for achieving a background-free ton-scale xenon detector to probe the Majorana nature of the neutrino!

EXO COLLABORATION

K.Barry, E.Niner, A.Piepke
Physics Dept, University of Alabama, Tuscaloosa AL

P.Vogel
Physics Dept Caltech, Pasadena CA

M.Dixit, K.Graham, C.Green, C.Hagemann, C.Hargrove, E.Rollin, D.Sinclair, V.Strickland
Carleton University, Ottawa, Canada

C.Benitez-Medina, S.Cook, W.Fairbank Jr., K.Hall, B.Mong
Colorado State University, Fort Collins CO

M.Moe
Physics Dept UC Irvine, Irvine CA

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

B.Aharmim, K.Donato, J.Farine, D.Hallman, U.Wichoski
Laurentian University, Canada

H.Breuer, C.Hall, L.Kaufman, S.Slutsky, Y-R.Yen
University of Maryland, College Park MD

K.Kumar, A. Pocar
U. of Massachusetts, Amherst MA

M.Auger, G.Giroux, R.Gornea, F.Juget, G.Lutter, J-L.Vuilleumier, J-M.Vuilleumier
Laboratory for High Energy Physics, Bern, Switzerland

N.Ackerman, M.Breidenbach, R.Conley, W.Craddock, S. Herrin, J.Hodgson, D.Mackay, A.Odian, C.Prescott, P.Rowson, K.Skarpaas, K.Wamba, J.Wodin, L.Yang, S.Zalog
SLAC, Menlo Park CA

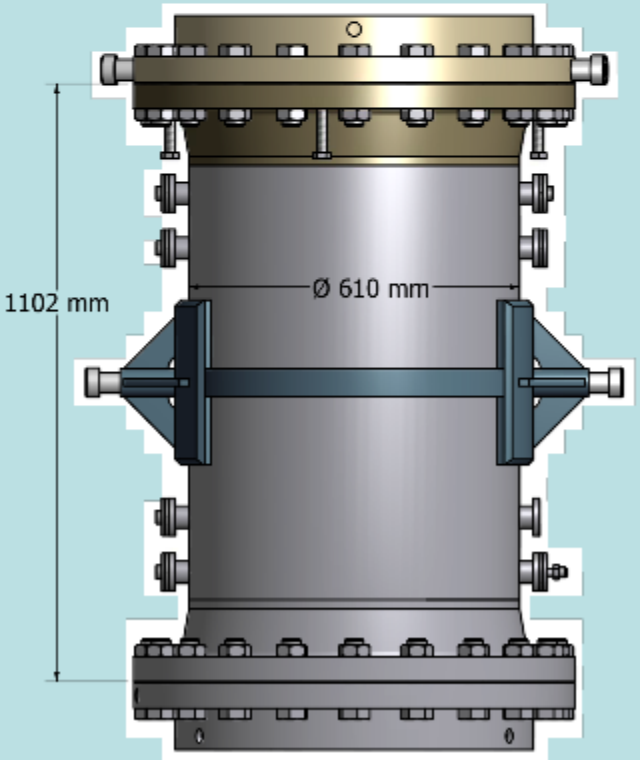
L.Bartoszek, R.Cooper, R.DeVoe, M.Dolinksi, P.Fierlinger, B.Flatt, G.Gratta, M.Green, F.LePort, M.Montero Díez, R.Neilson, A.Reimer-Müller, A.Rivas, K.O'Sullivan, K.Twelker
Physics Dept Stanford University, Stanford CA

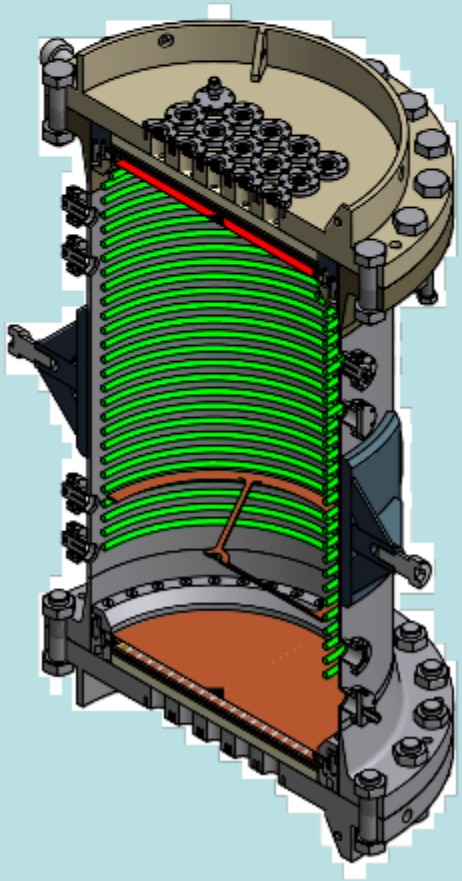
Gas Phase R&D

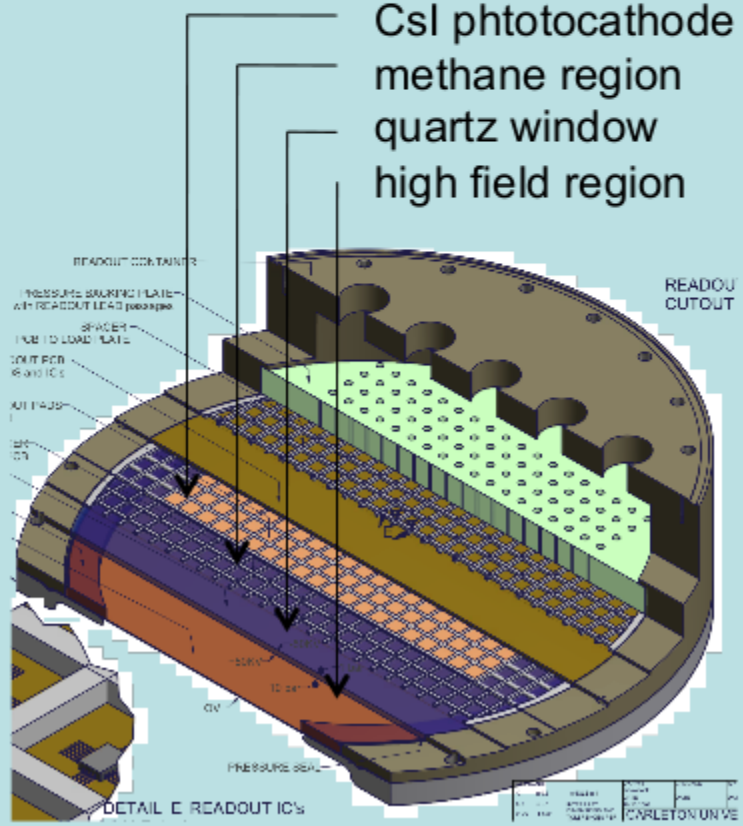
- 10 Bar Pressure Vessel
- contain 1 MeV electrons
- segmented readout (tracking)

- electroluminescence: $N_\gamma = 70(E/p - 1)pdx$
  ionization electrons in high electric field
  stimulate emission of photons (175 nm)

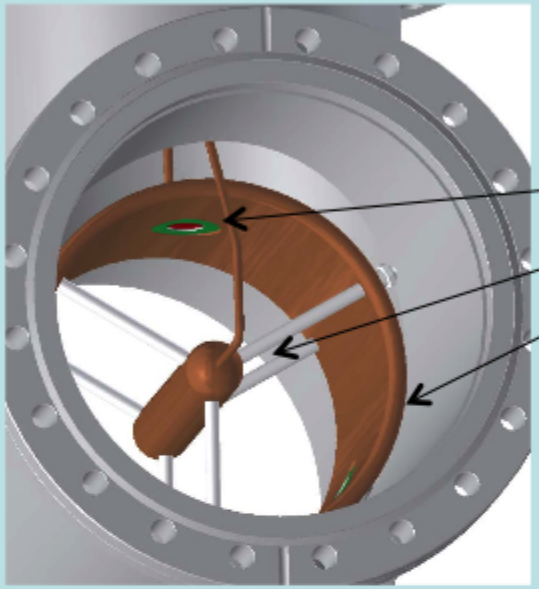
- measure photons with CsI photocathode



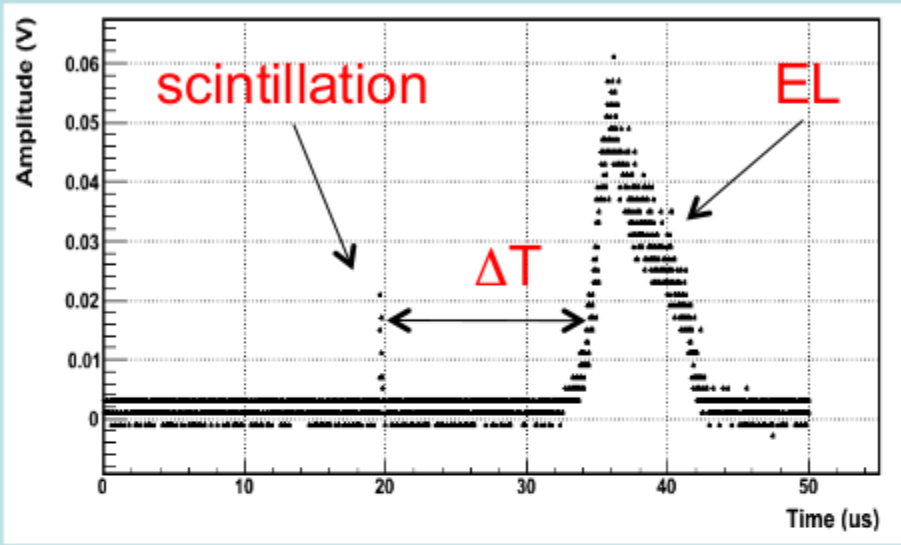


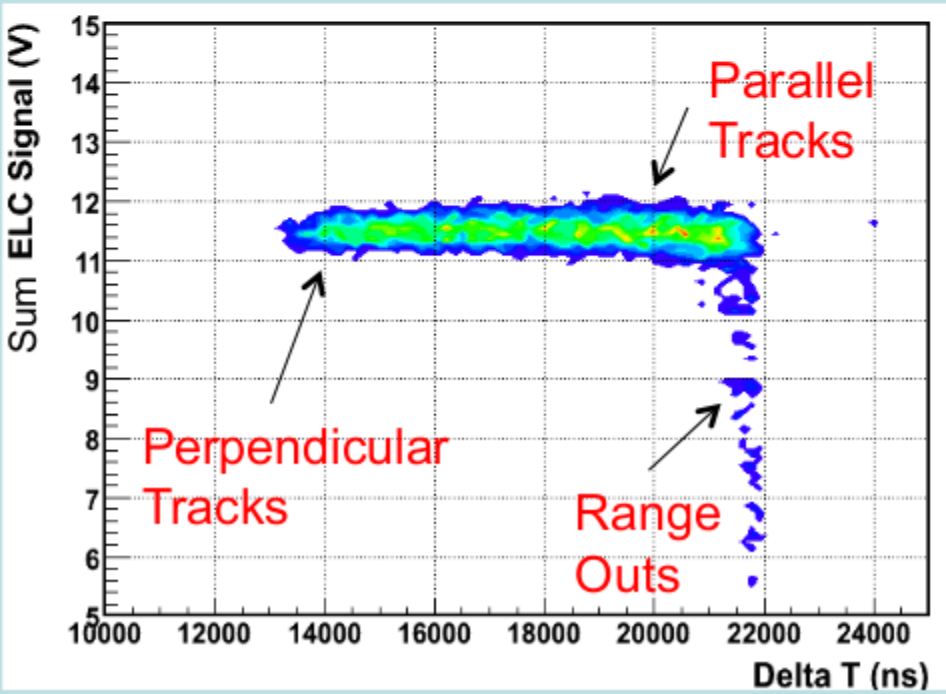


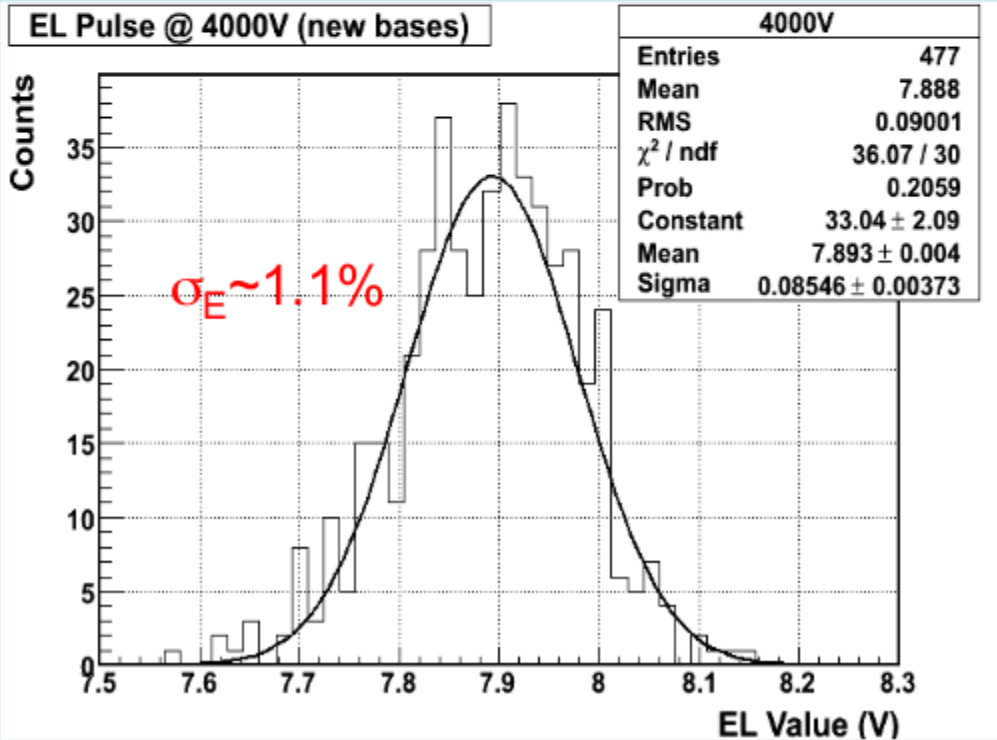
Electroluminescence (EL)



alpha source
anode
cathode

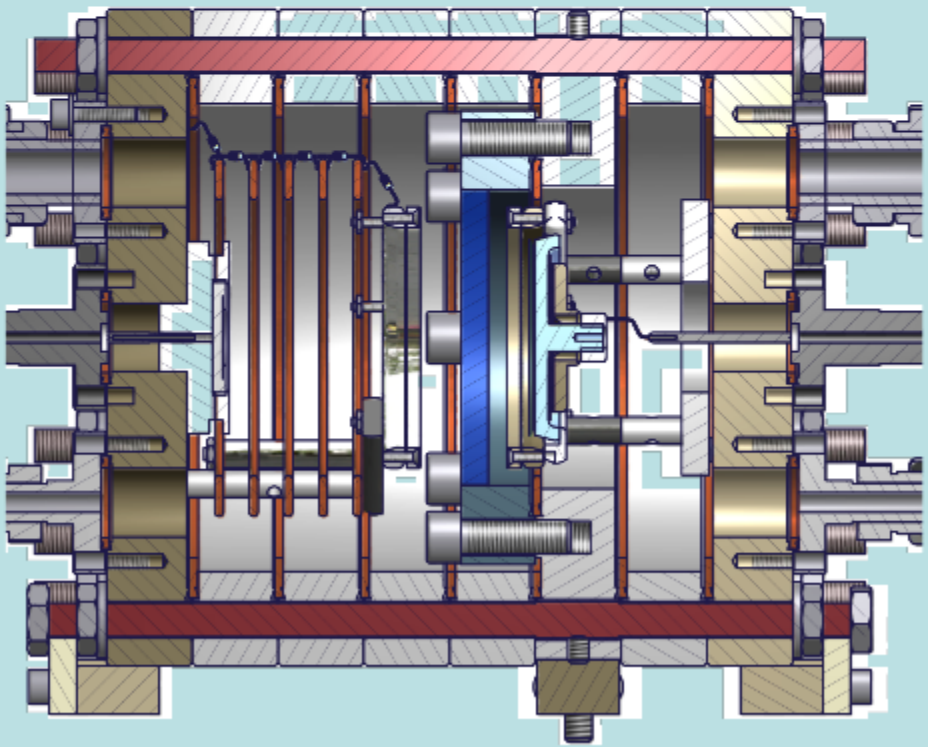


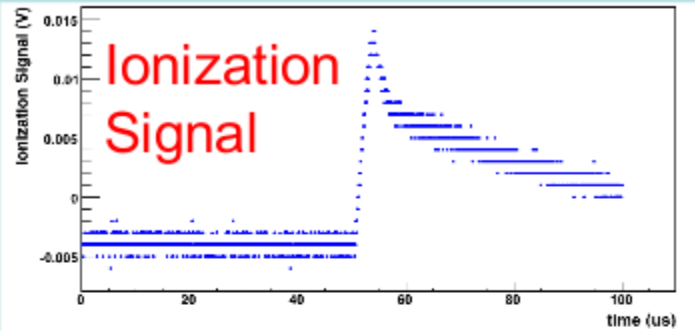


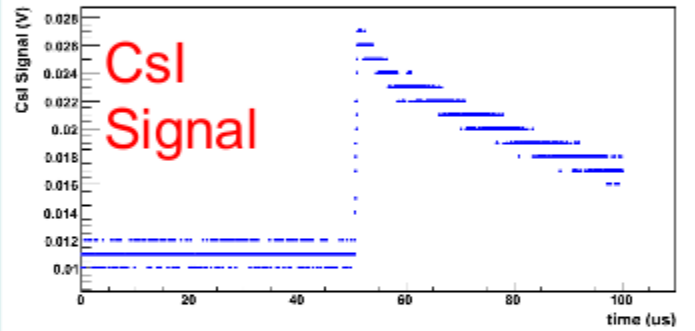


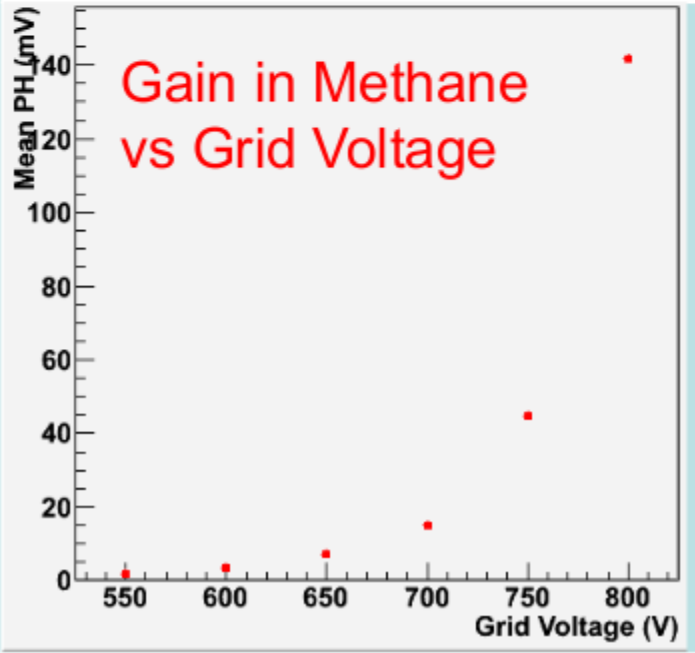
CsI Test Chamber

xenon side	methane side
- alpha source	- quartz window
- drift field	- CsI readout pad
- EL region	- drift field





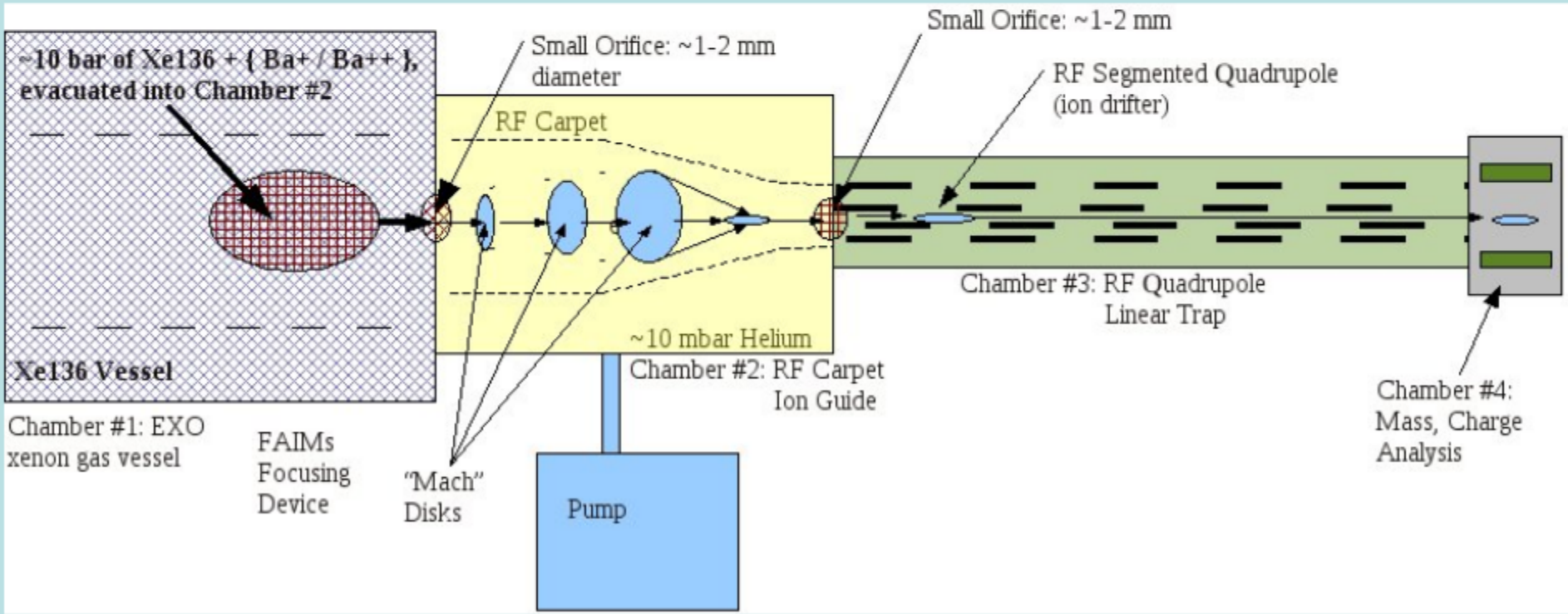




Ba Tag - Ion Transport

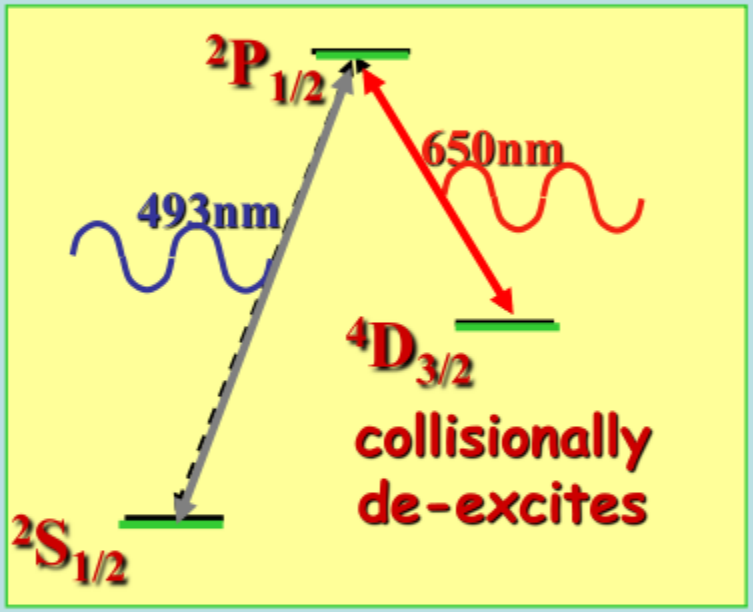
- efficient Ba tag would eliminate all non ββ background
- in-situ tag looks challenging
- instead, transport ion to low-pressure region for ID
- 'commonly' carried out for radioactive ion transport

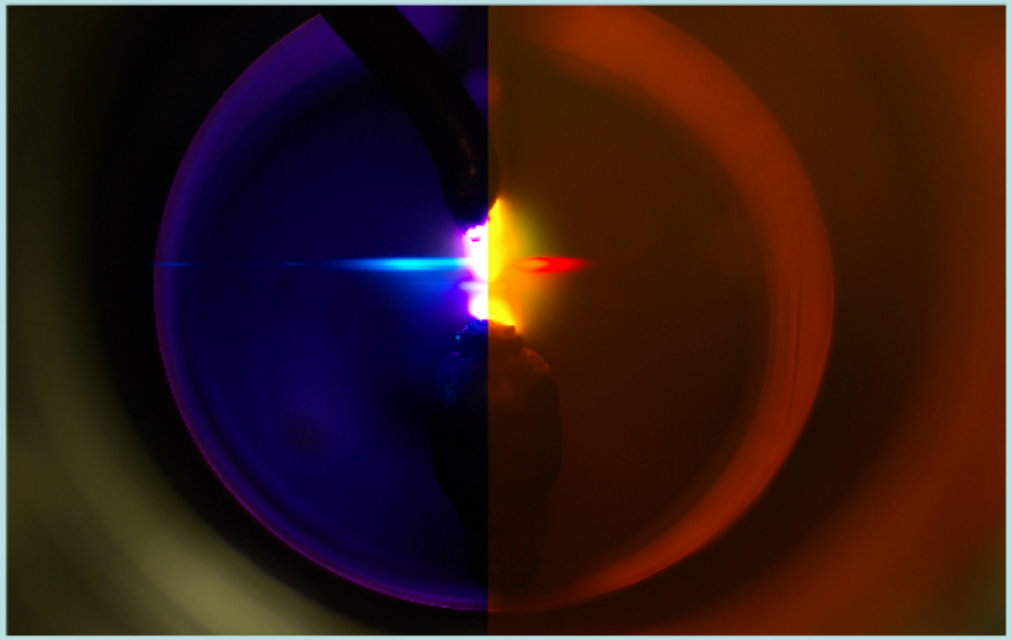
TPC at 10 bar low pressure vacuum Ba ID



Ba ID Techniques

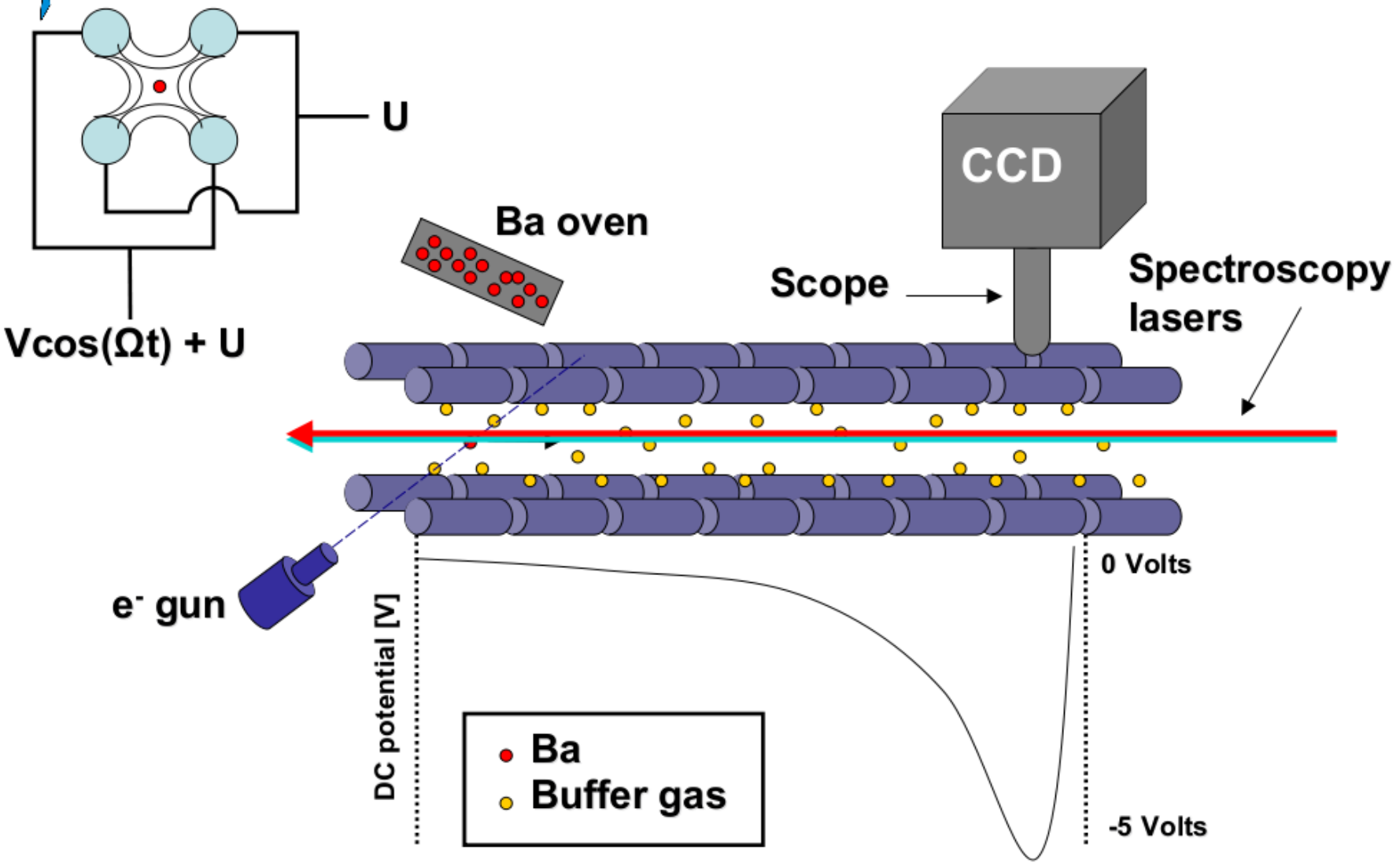
- Ba^+ simple electronic structure
- excite with blue light and look for red



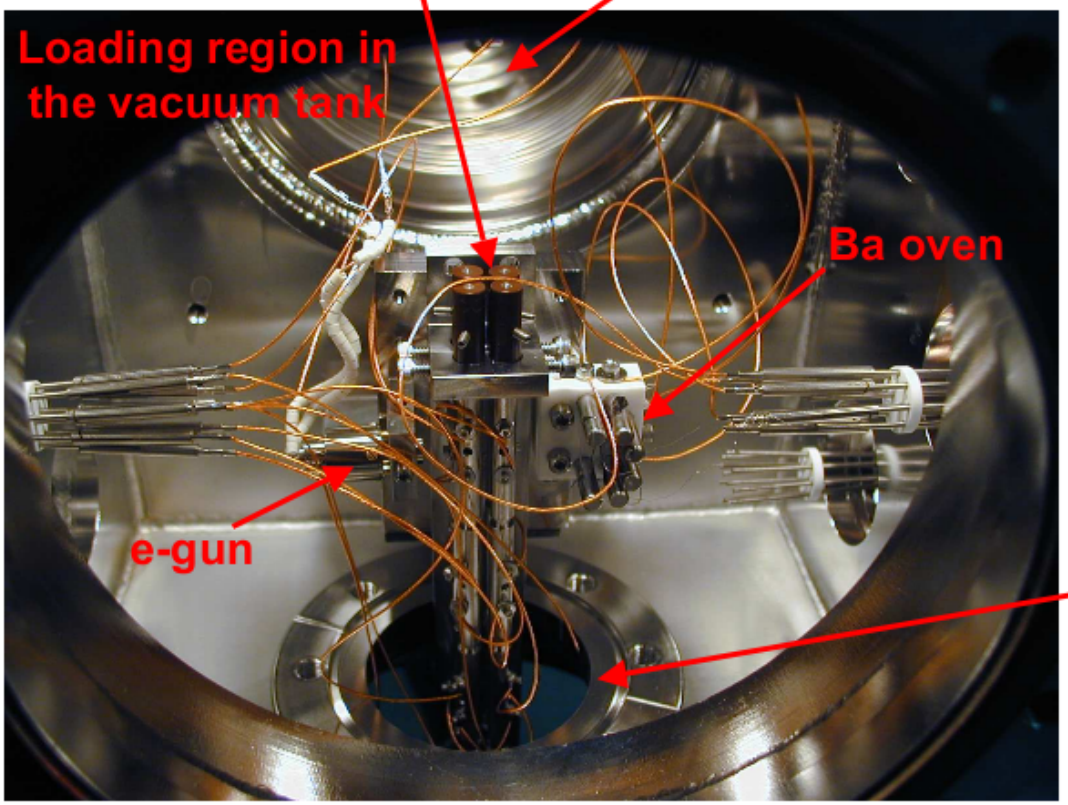


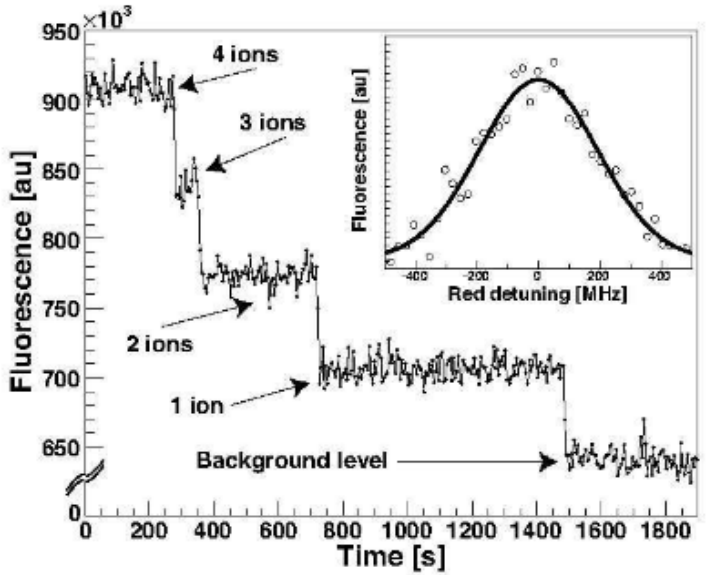
- altervatives: measure mass/charge of ion
  spectroscopy of Ba^{++}

Trapping


U
Vcos(Ωt) + U
Ba oven
CCD
Scope
Spectroscopy lasers
e⁻ gun
DC potential [V]
0 Volts
-5 Volts
Ba
Buffer gas

Trapping



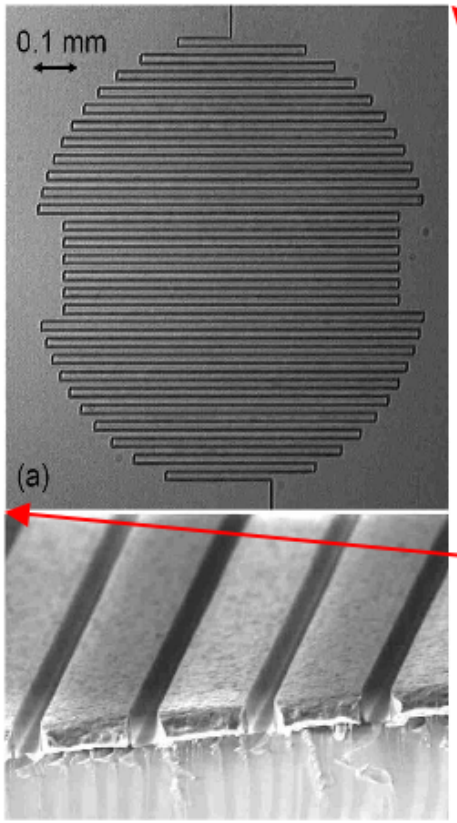


~9σ discrimination in 25s integration

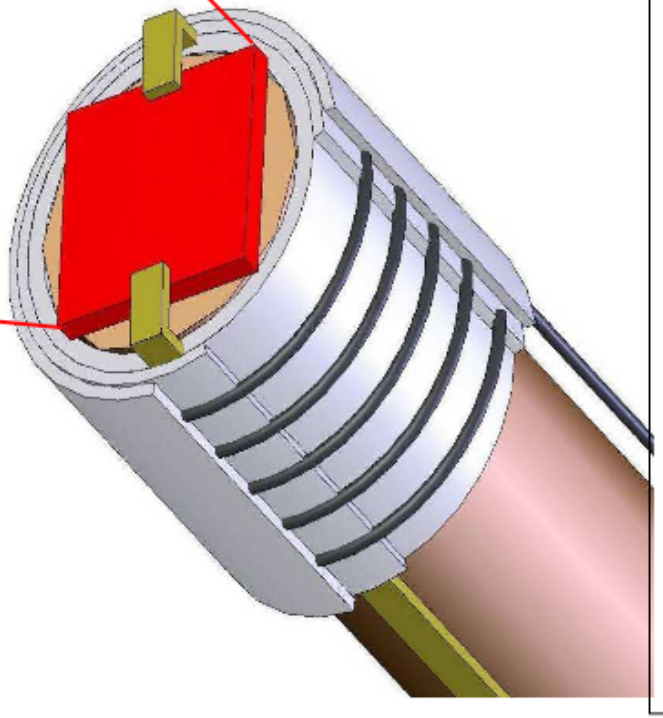
M.Green et al., Phys Rev A 76 (2007) 023404

B.Flatt et al., NIM A 578 (2007) 409

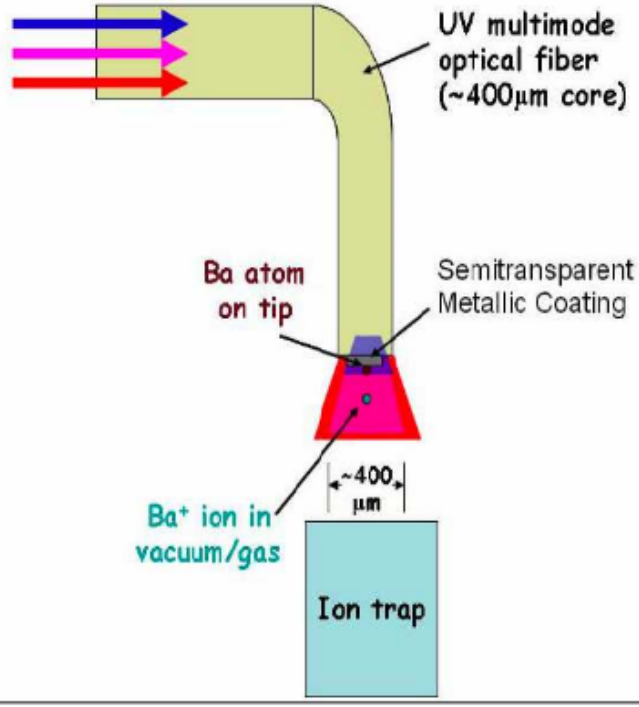
Ba^+ extraction - Liquid phase



Cryogenic probe



Resonance-ionization spectroscopy (RIS)



P.Fierlinger et al, Rev. Sci. Instr. 79, 045101 (2008)