# High-Pressure Xenon Gas TPC for Neutrinoless Double Beta Decay

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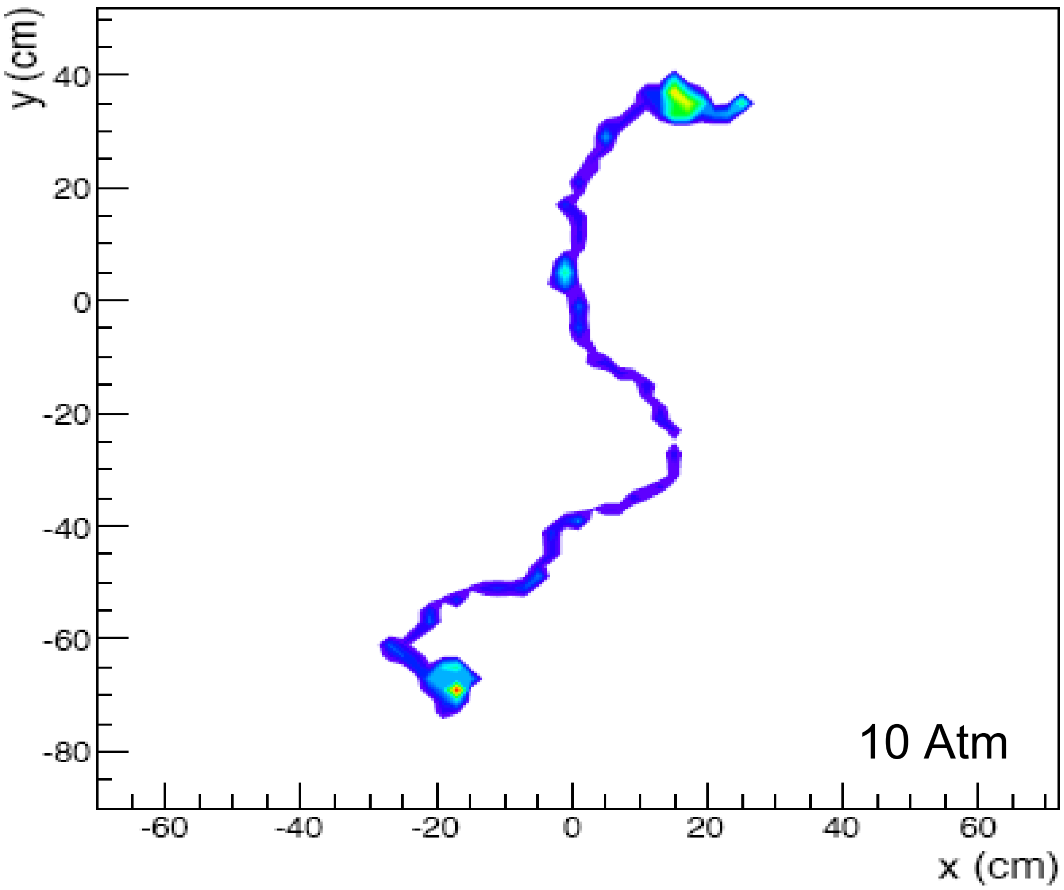
With David Nygren & Helmuth Spieler

LBNL

# HPXe Electro-Luminescent TPC

- Primary Goal #1: Energy resolution
  - $\delta E/E \leq 5 \times 10^{-3}$ FWHM at Q-value (2.46 MeV)
  - Must be demonstrated at MeV energies!
- Primary Goal #2: 3 -D tracking
  - Multiple scattering $\Rightarrow$ complex topologies
  - Verify meatball recognition efficiency!

# Topology: “spaghetti, with meatballs”




ββ events: **2**

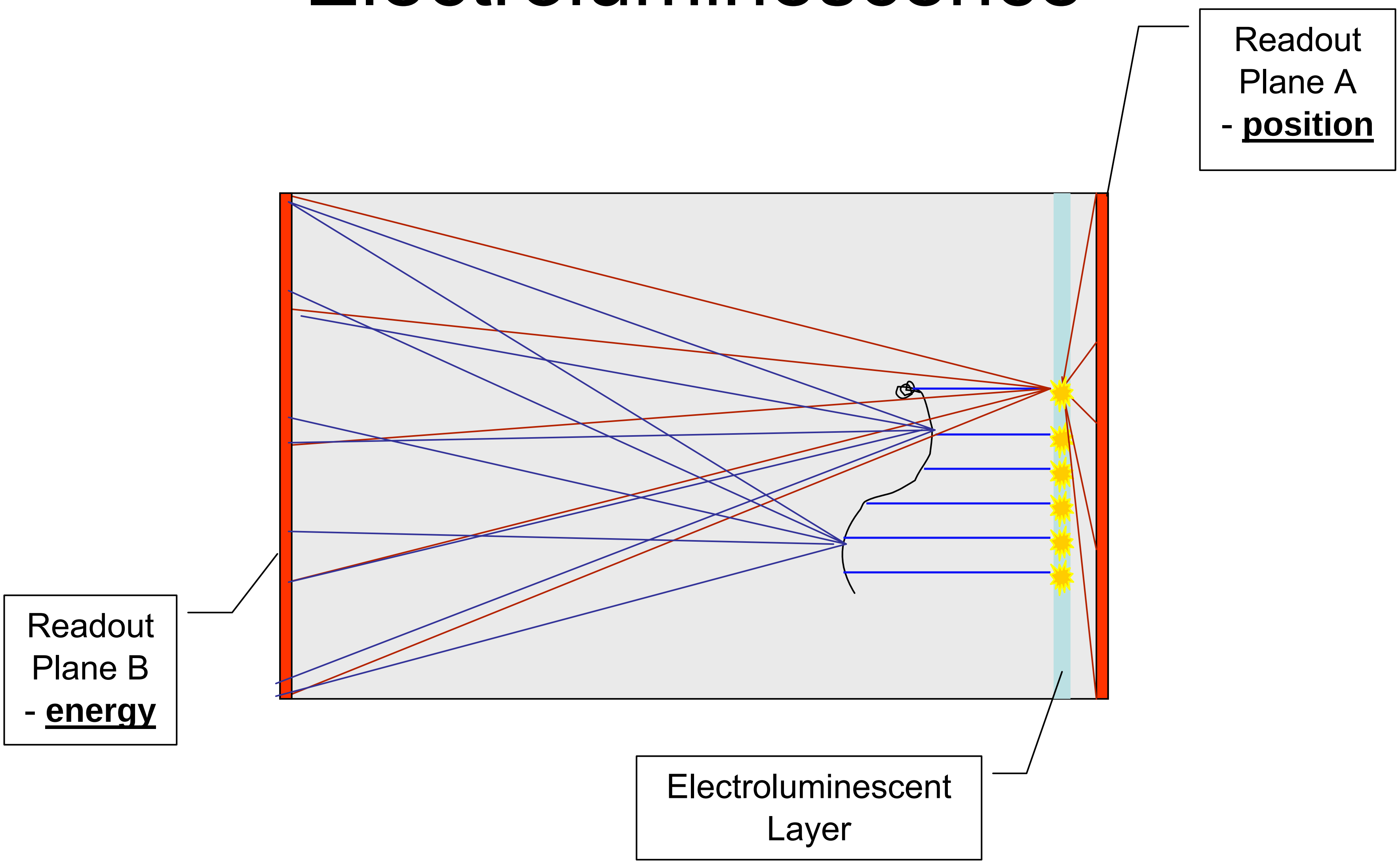
γ events: **1**

Gotthard TPC:

~ x30 rejection

Slide: NEXT collaboration

# Separated Function TPC with Electroluminescence



# Xenon: Strong dependence of energy resolution on density!

*A. Bolotnikov, B. Ramsey / Nucl. Instr. and Meth. in Phys. Res. A 396 (1997) 360–370*

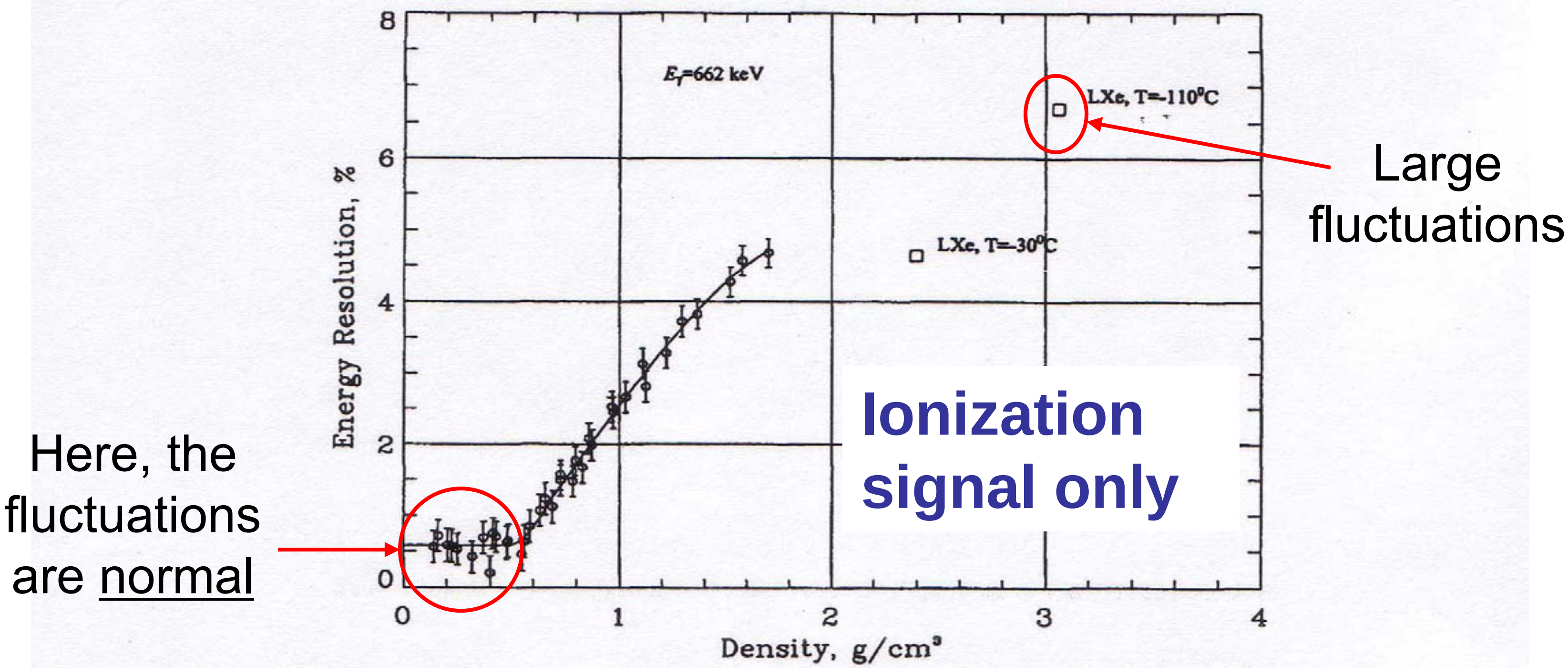



Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

For $\rho$ <0.55 g/cm$^3$, ionization energy resolution is “intrinsic”

# LXe or HPXe?

With high-pressure xenon (HPXe)

measurement of ionization **alone**

is sufficient to obtain **near-intrinsic energy** resolution…

What is the “intrinsic” energy resolution?

# Intrinsic energy resolution

$$\delta E/E = 2.35 \cdot (F \cdot W/Q)^{1/2}$$

- $F \equiv$ Fano factor: $F = 0.15$ (HPXe) (LXe: F ~20)
- $W \equiv$ Average energy per ion pair: W ~ 25 eV
- $Q \equiv$ Energy release in decay of $^{136}Xe$: ~2500 keV

$$\delta E/E = \underline{2.8 \times 10^{-3}} \text{ FWHM (HPXe)}$$

N = Q/W ~100,000 primary electrons

$\sigma_N = (F \cdot N)^{1/2}$ ~120 electrons rms!

# Gain and noise

Impose a requirement:

(noise + fluctuations) $<$ 120 $e^{-}$

Need gain G with **very** low noise/fluctuations!

**Uncorrelated fluctuations, add in quadrature:**

$$\sigma = ((F + G) \cdot N)^{1/2}$$

**F $\equiv$ constraint due to fixed energy deposit**

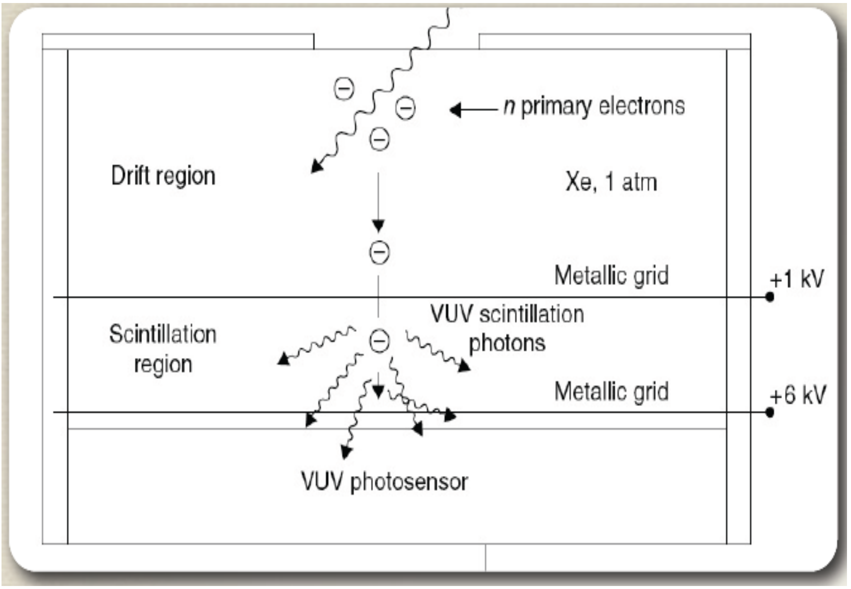
**G $\equiv$ noise/fluctuations of detection process**

# Gain mechanisms

- Amplification by electronics alone:
  - FE noise ~ several hundred electrons rms
- Avalanche gain in gas around wires:
  - **G** ~ 0.8 - early fluctuations are amplified
- Microstructures: GEM, Micromegas,...
  - **G?** G? stability? ageing? quenching? scale?

# Electro-Luminescence (EL) is the key
## (Gas Proportional Scintillation)

- Physics process generates ionization signal
- Electrons drift in low electric field region
- Electrons enter a high electric field region
- Electrons gain energy, excite xenon: 8.32 eV
- Xenon radiates VUV (≈175 nm, 7.5 eV)
- Electron starts over, gaining energy again
- <u>Linear</u> growth of signal with voltage
- Photon generation up to ~1000/e, but <u>no</u> ionization
- No exponential growth ⇒ **<u>fluctuations are very small (< 1 $e^-$ RMS)</u>**



# Virtues of Electro-Luminescence in HPXe

- Linearity of gain versus pressure, HV
- Immune to microphonics
- Absence of positive ion space charge
- Absence of ageing, quenching of signal
- Isotropic signal dispersion in space
- Trigger, energy, and tracking functions accomplished with optical detectors

# Fluctuations & Total signal at Q-value

$Q/W = N = 1 \times 10^5$

**Uncorrelated fluctuations:** $\sigma = ((F + G) \cdot N)^{1/2}$

For **G** $\leq F = 0.15 \Rightarrow n_{pe} \geq 10$ (per primary electron)

$\Rightarrow$

$N_{pe} \geq 1 \times 10^6$

One million photoelectrons!

However:

$N_{pe}$ is spread out over >100 PMTs and 10 - 100 μs

No dynamic range problem

# EL in 4.5 bar of Xenon (Russia - 1997)

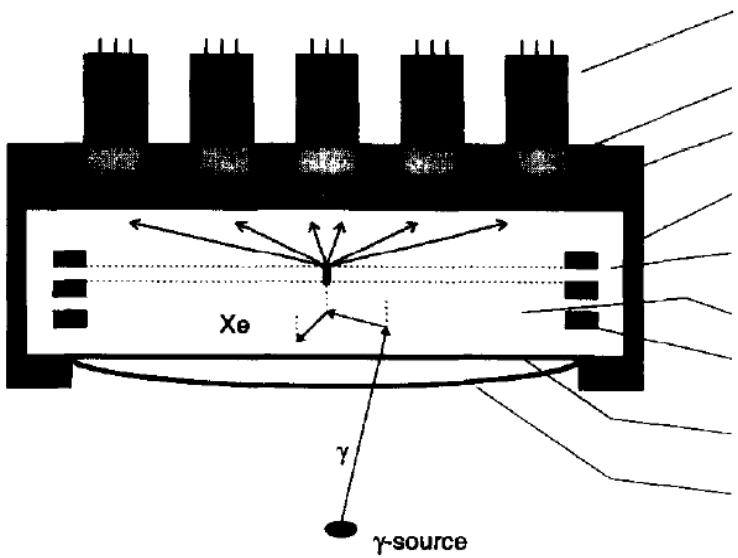
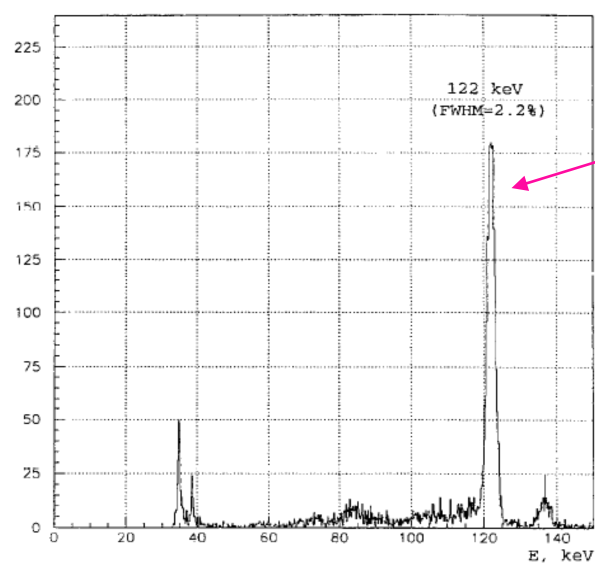



Fig. 1. Schematic diagram of the gas scintillation drift chamber with 19 PMT matrix readout.

A. Bolozdynya et al. / Nucl. Instr. and Meth. in Phys. Res. A 385 (1997) 225–238

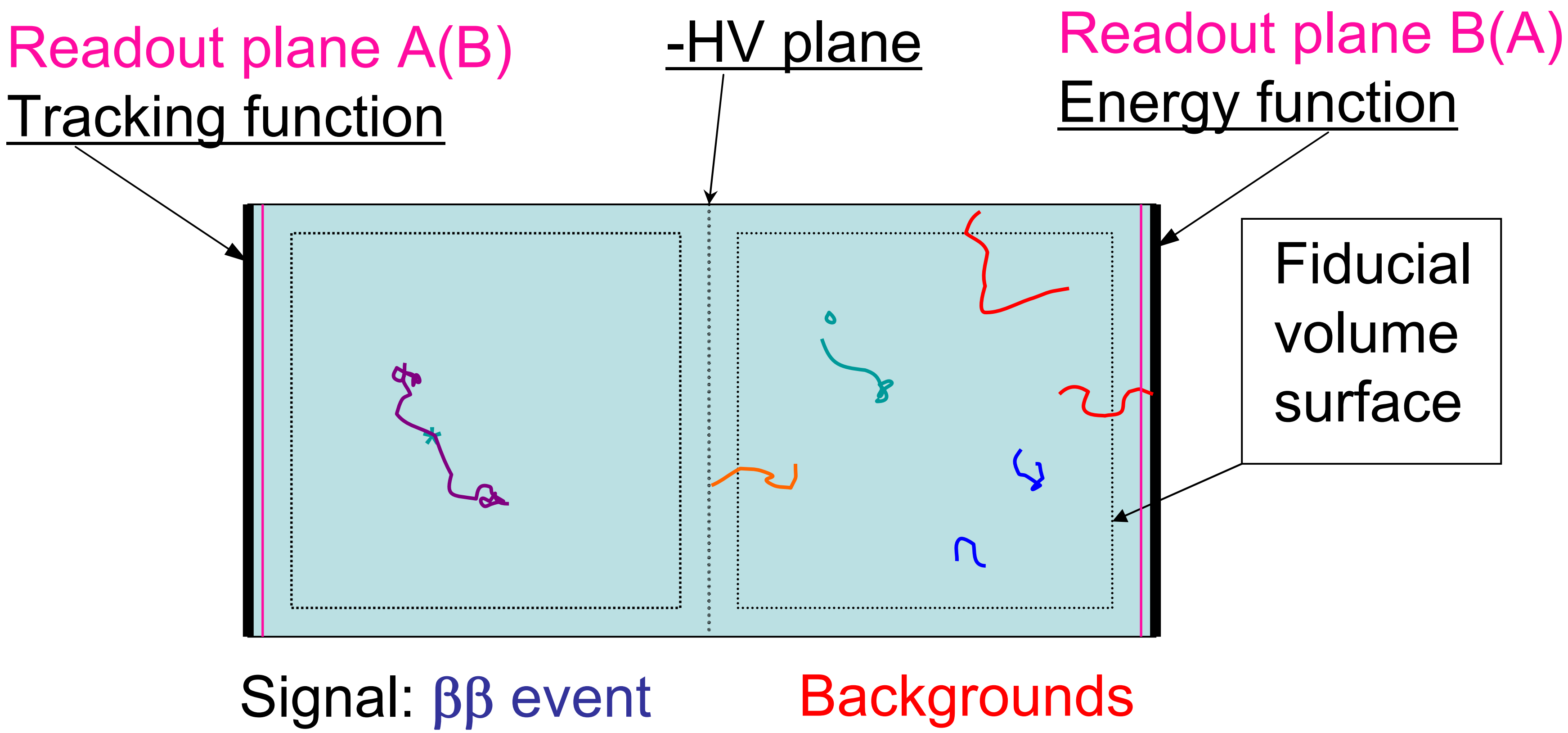



This resolution corresponds to

$\delta E/E = 5 \times 10^{-3}$ FWHM

-- if extrapolated ($E^{-1/2}$) to $Q_{\beta\beta}$ of 2.5 MeV

# Separated-function symmetric TPC:



# High-pressure xenon EL TPC

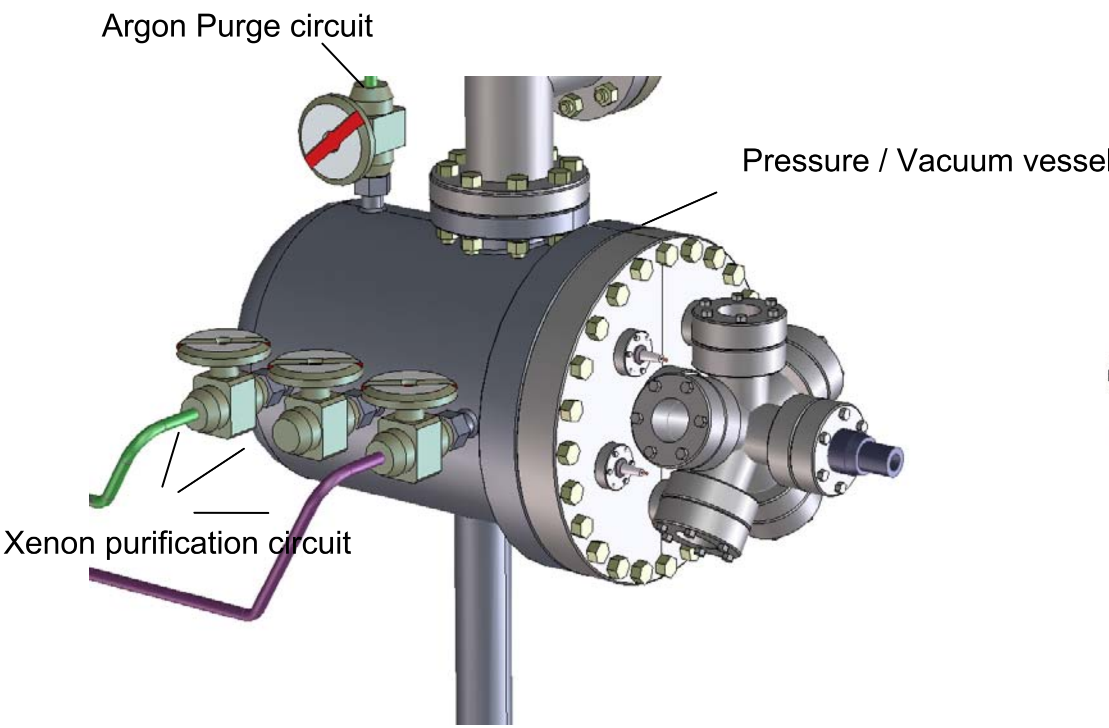
- Ideal fiducial volume
  - Closed, seamless, fully active, variable,...
    - No dead or partially active surfaces
  - 100.000% charged particle sensitivity
    - Reject all backgrounds from surfaces (not shown yet!)
  - Use $t_0$ (primary scintillation) to place event in z
    - Ample signal over most of 2ν spectrum
  - Topological rejection of single-electron events
    - Factor of at least 30 expected (Gotthard TPC)

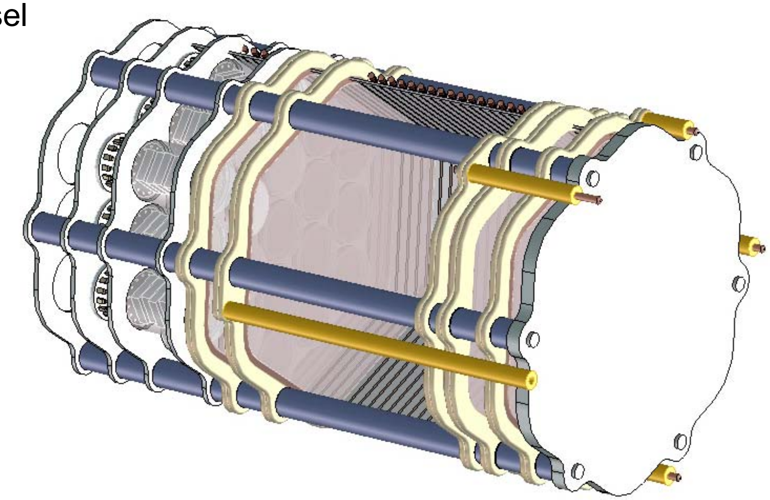
# Goals in US

- Near-term:
  - Construct 10 - 20 bar HPXe 19 PMT TPC, demonstrate energy resolution goal at 662 keV, together with NEXT collaboration.

- Longer-term:
  - Construct 10 - 20 bar HPXe 122 PMT TPC, demonstrate energy resolution and tracking goals at ~2500 keV, together with NEXT collaboration.

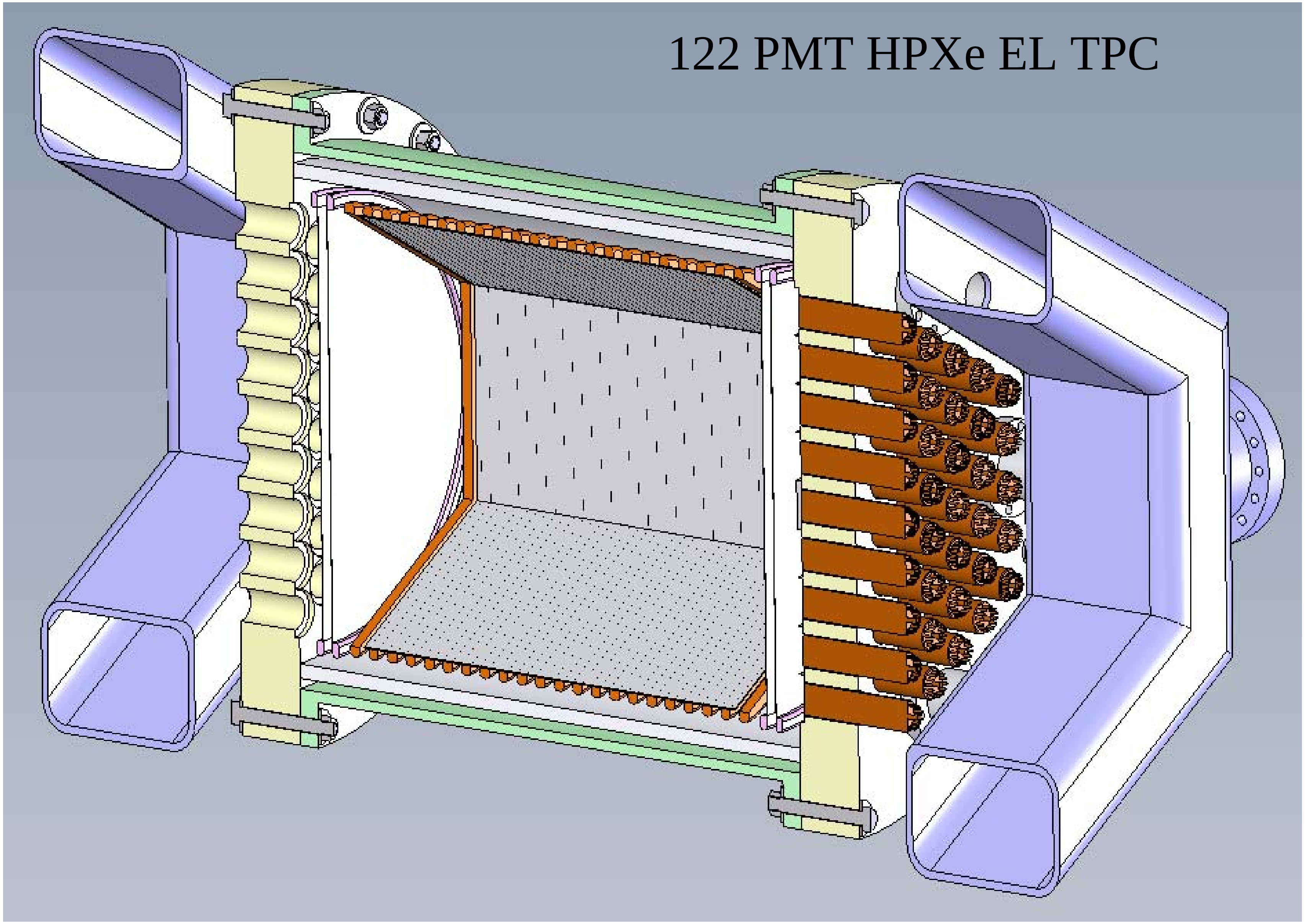
# 19 PMT HPXe TPC: 10 liter @ 20 Atm



Goal: $\delta E/E$ resolution (662 keV), and to explore sensitivity of energy resolution to drift E-field

Azriel Goldschmidt, LBNL @
DBD09 Hawaii Oct 2009

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# Other HPXe efforts

**X-ray spectrometers** - Coimbra

**Gotthard TPC** - pioneering 0-$\nu$ $\beta\beta$ experiment

**Beppo-SAX satellite** 7-PMT 5-bar TPC

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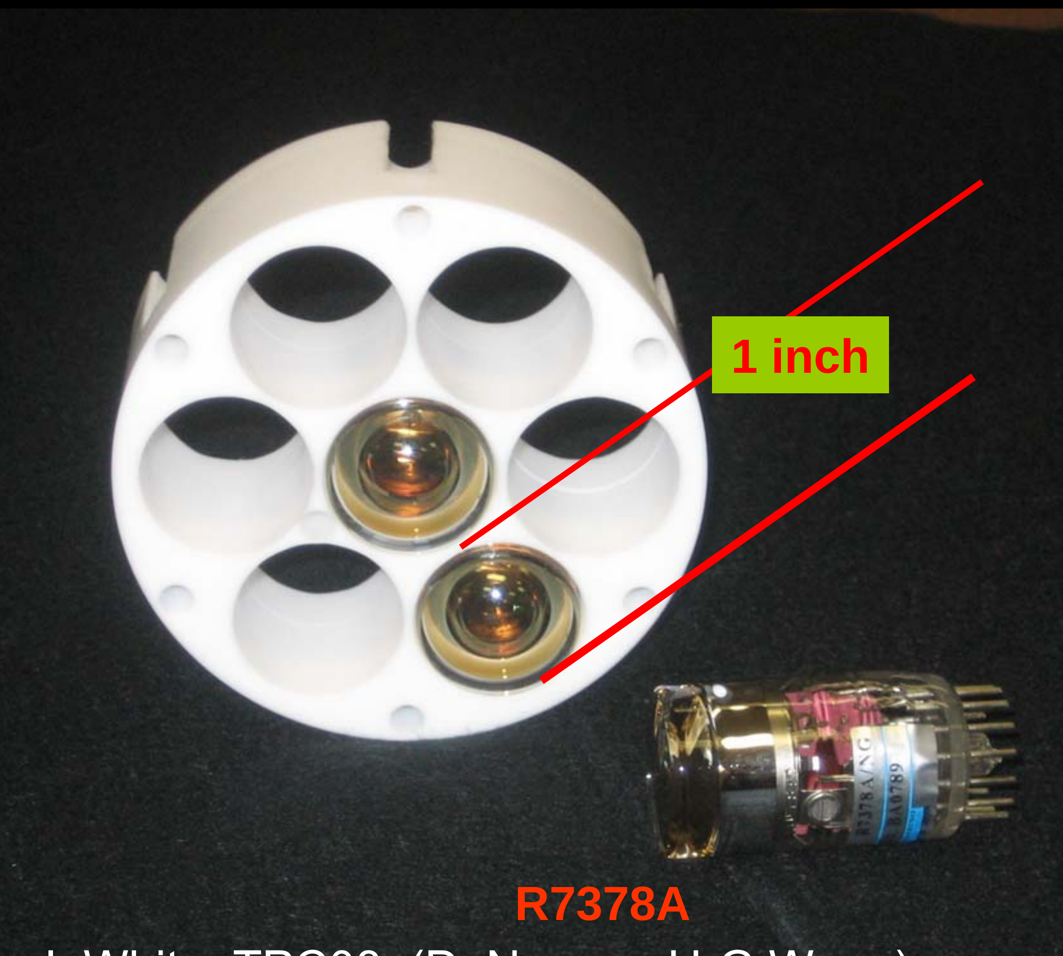
**EXO - gas** $Ba^{++}$ ion tagging, tracking, …

**Texas A&M** 7-PMT 20 bar HPXe TPC

**LBNL-LLNL-TAMU** 19/PMT HPXE TPC

NEXT!

# 7-PMT, 20 bar TAMU HPXe TPC




J. White, TPC08, (D. Nygren, H-G Wang)

Europe:

**NEXT** collaboration

Spain/Portugal/France…

funded: **5M €** !

to develop & construct a 100 kg HPXe TPC for 0-ν ββ decay search at Canfranc Laboratory within five years

## The NEXT Collaboration

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# Perspective

- Why bother with gas? - LXe has momentum

But, with HPXe:

  - Energy resolution: x10 better than LXe
  - Topology: rejection of backgrounds
  - Flexibility: HPXe + neon, Ar + 1% Xe, …
  - Noise: less than one electron rms!
  - HPXe EL TPC may do $\beta\beta$ & WIMP searches
  - New approach may be essential for next scale

# Thanks for your attention!
# The End


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