# Noble Liquid Tracking Detectors

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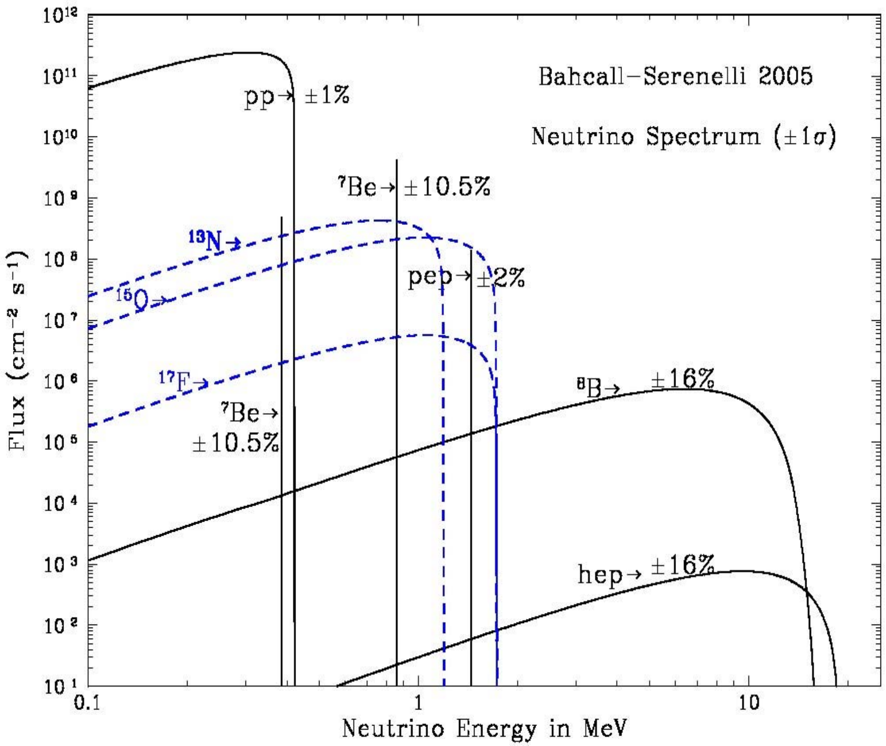
# Solar Neutrinos over the full spectrum

- Most neutrinos come from the pp fusion reaction, with an average energy about ten times lower than the threshold of the current real-time experiments in the MeV range; we aim to reach the KeV range
- The Solar Constant gives an accurate estimate of the number of these neutrinos at the source, allowing precision measurements of neutrino disappearance and matter effects from the spectrum of neutrinos observed through the scattering on target electrons
- The comparison of neutrinos from different reactions provides unique information on the physics of the Sun



# Tracking in the Cryogenic Liquids: LHelium and LNeon

- Requirements for LHe/LNe detector
  - A target mass of more than 5 tons -> long drift ~5m (in LHe)
    - At least 5T, 35 $m^3$ LHe fiducial volume or 5T, 4 $m^3$ LNe fiducial volume for ~1000 solar neutrino events per year.
  - Good (<mm) spatial resolution to allow range determination, track direction and Compton clusters
    - Lowest radiation loss to minimize multiple scattering for 100-300KeV electrons, visible range down to ~100KeV
  - Great purity, to allow long drift path and low embedded background in the liquid (LHe shows *no* solutes)
    - Slow drift, to allow a huge number bits to be read out
  - Good total charge measurement for energy
    - For even lower energies, for neutrino magnetic moment for example, energy resolution is key
  - Low background

# The Voxel Challenge

(pixel = 2-D detection element, voxel = 3-D element)

- We are looking for sub-mm resolution, say O(100) microns, so a cubic meter has $10^{12}$ voxels.
- The challenge is to obtain the fundamental resolution, to supply a thinkable detector structure and to read it out.
- For a homogeneous medium, one dimension must use a drift, so the resolution is limited by diffusion. The Einstein-Nernst law for thermal diffusion

$$\sigma = \sqrt{\frac{2kTd}{eE}}$$

gives us few handles to get the desired resolution once we have fixed, d, the dimension of the detector: seemingly T and E.

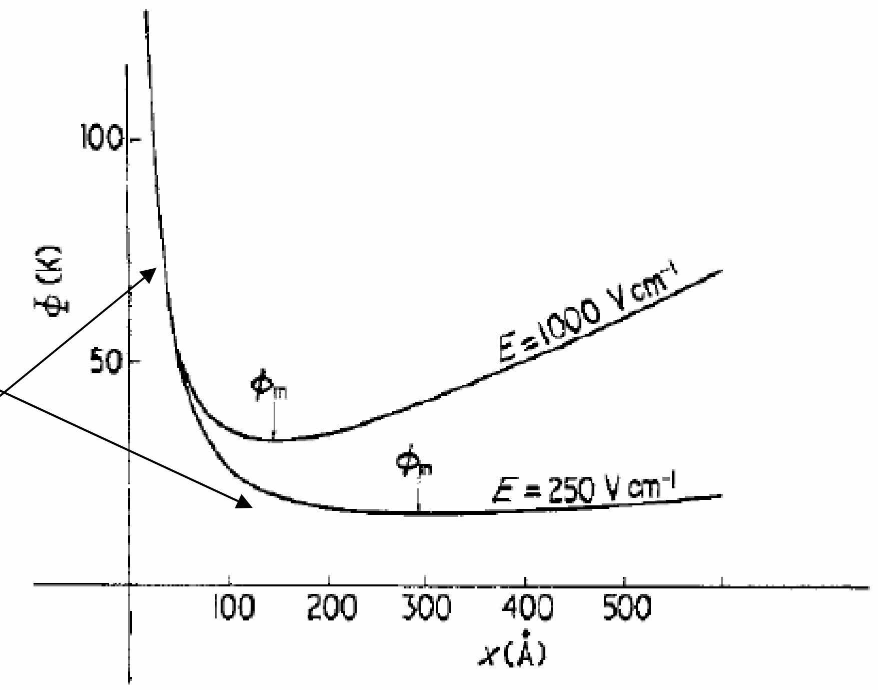
- For pure heavy noble liquids, the electrons heat up in even modest electric fields, T reaches hundreds or thousands of degrees.
- A massive charge carrier, like an ion, remains thermal for much higher E.
- Diffusion is thermally driven; lowering the temperature T cuts diffusion.
- The equilibrium negative charge carrier in liquid neon (also hydrogen and helium) is not a free electron, but a 1-2nm bubble containing the electron (or electrons). The positive carrier is a "snowball" with ion$^+$ inside, with comparable mobility.
- The origin of the bubble is a strong (Pauli) repulsion between the electron and the neon/helium atoms. For heavy atoms like Argon, this is compensated by the polarization of the atom.

# Characteristic of eBubbles in LNe

- Diameter 2nm, i.e. cavity lacking a ~80 Ne.
- For E=1KV/cm and T=27K, v=16mm/s, $\sigma$ = 220$\mu$m averaged over 1m drift.
- eBubble remains thermal up to 40KV/cm, field-ionizes around 400KV/cm.
- Liquid-gas interface (with repulsive image force) holds the electron for a time dependant on T and E, adjustable from seconds to microseconds.

# Trapping e-Bubbles at the Liquid-Vapor Interface

- Dielectric discontinuity at the interface ($\varepsilon_l > \varepsilon_v$)
- Potential well just beneath surface
- e-Bubble has some probability of tunneling through potential barrier in time




Schoepe, W. and G.W. Rayfield, Phys. Rev. A, 7, 6, 1973.

# e-Bubble

## The Detector Medium

### LHe

- $\rho$ = 0.125 g/cm$^3$
- Long tracks (1-7 mm, 100-300 keV)
- Good pointing capability

### LNe

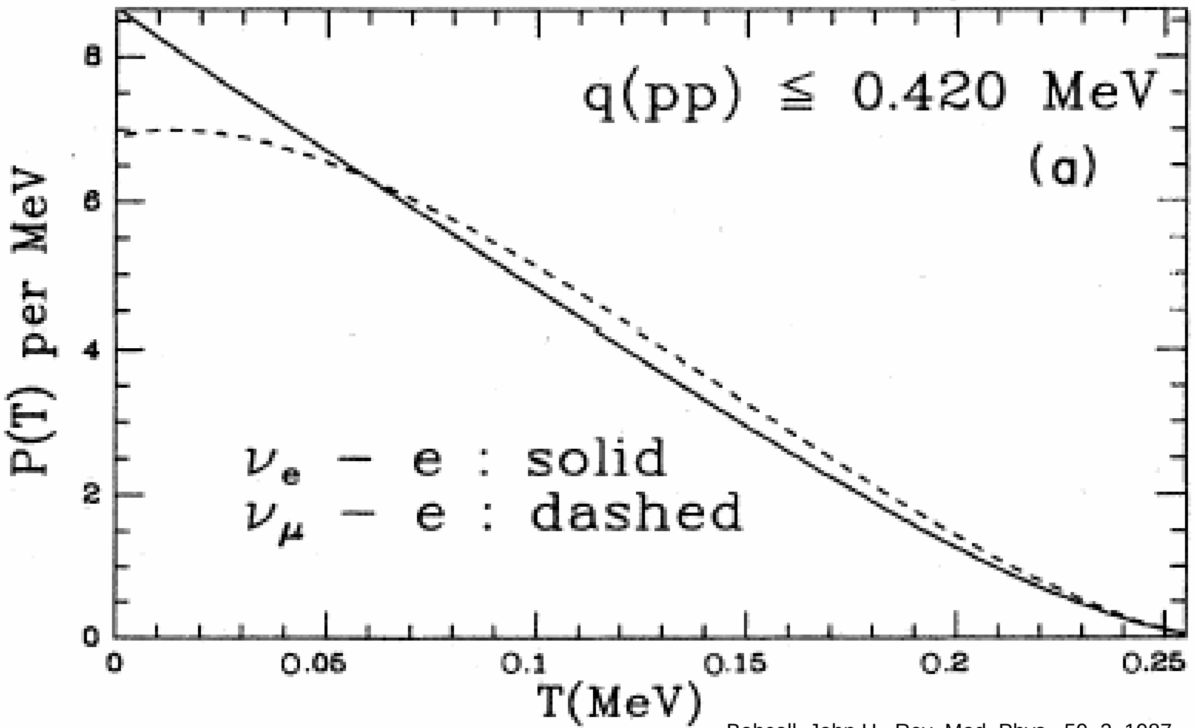
- $\rho$ = 1.24 g/cm$^3$
- Short tracks (700 $\mu$m, 300 keV)
- Pointing only for highest energy E$\nu$>1MeV
- Self-shielding

### e-Bubbles

- Minimum ionizing (low dE/dx)
- Pure (long drifts, low internal background)

# The Physics of solar (pp) neutrinos lies in the lowest energy $E_e$

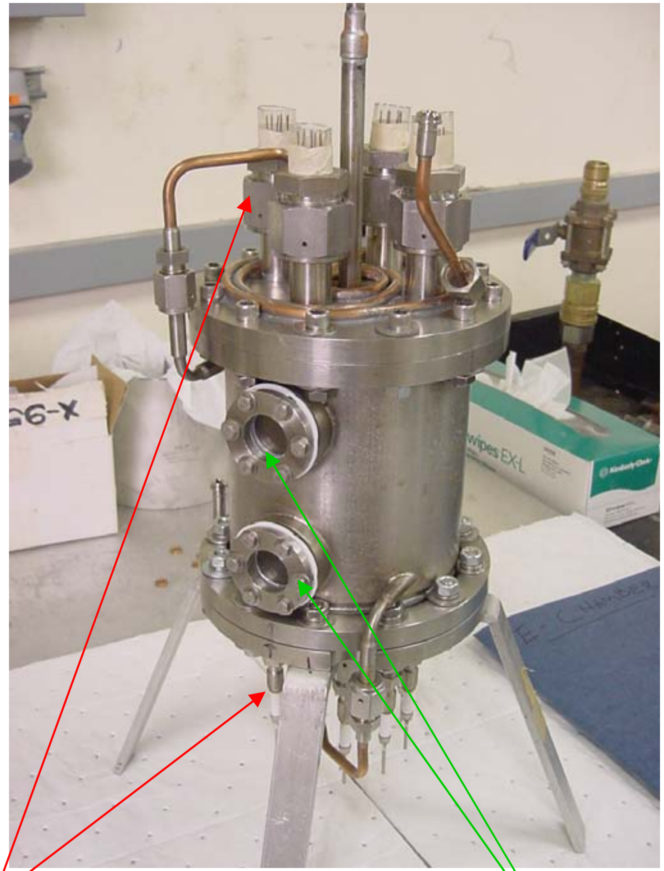
- A precise measurement of the low energy neutrino spectrum would test our understanding of solar ν‘s & the process by which the sun shines.
- No other experiment/detector proposes to access the KeV range of scattered $e^-$




Bahcall, John H., Rev. Mod. Phys., 59, 2, 1987.

- Focus on the lower scattered electron energy as the Signal increases at lower energies and the Background decreases

10 cm test cell & cryostat




HV & LV feedthrus

5 Windows

It is possible to operate at temperatures and pressure over a wide range, ~1K-300K and up to ten atmospheres.

Used to investigate the properties of ebubbles which will give us access to the aforementioned low-energy solar neutrinos.

# So what do we need?

1. Gain

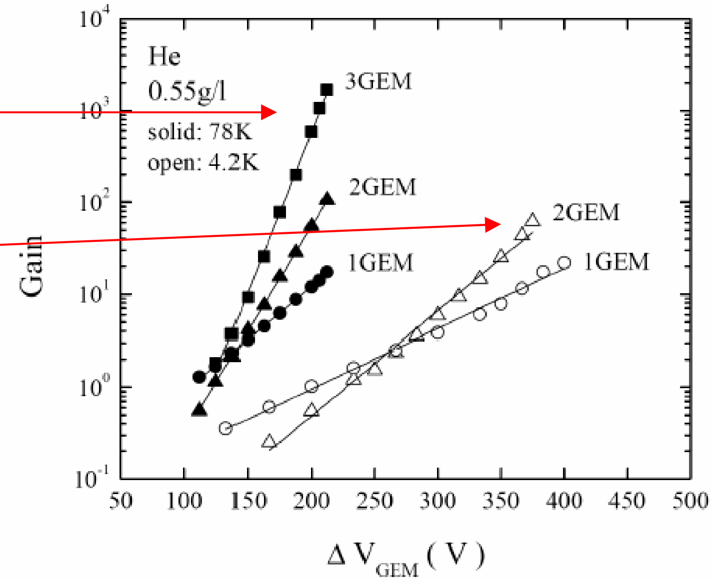
# We need GAIN to see O(KeV) electrons

- We need avalanche gain to reach the few KeV threshold required by the physics
- We do not expect to achieve avalanche gain in the liquid.
- We achieved gain in vapor above the liquid, through collaboration with Alexei Buzulutskov at Novosibirsk. Gain in Helium/Neon & Penning mixtures in GEM detectors was achieved.
- We also note that the avalanche is known to produce light, offering another read-out mode.
- This also motivates us to look at the behavior of the electrons at the liquid-vapor interface.

# Helium

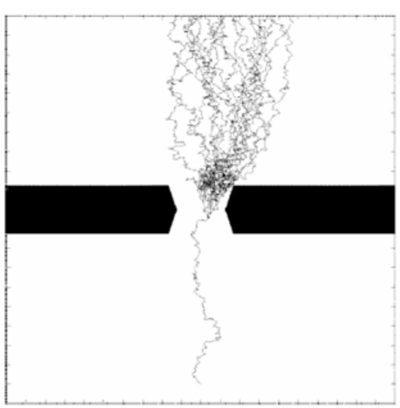
(accepted NIM A: physics/0504184)

- Tested 1,2,3 foil GEM structures (CERN) in He, Ne, Ne+$H_2$
- Gain in He at higher temperatures most likely due to Penning effect of impurities which freeze out at LHe temperature
- Gains of 40x in 2GEM were attained

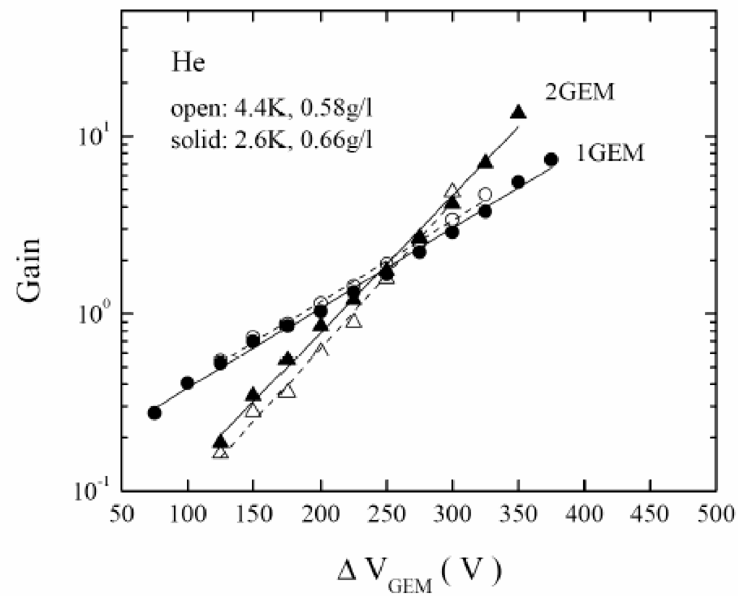



- No additional temperature affect observed in going from 4.4-2.6K

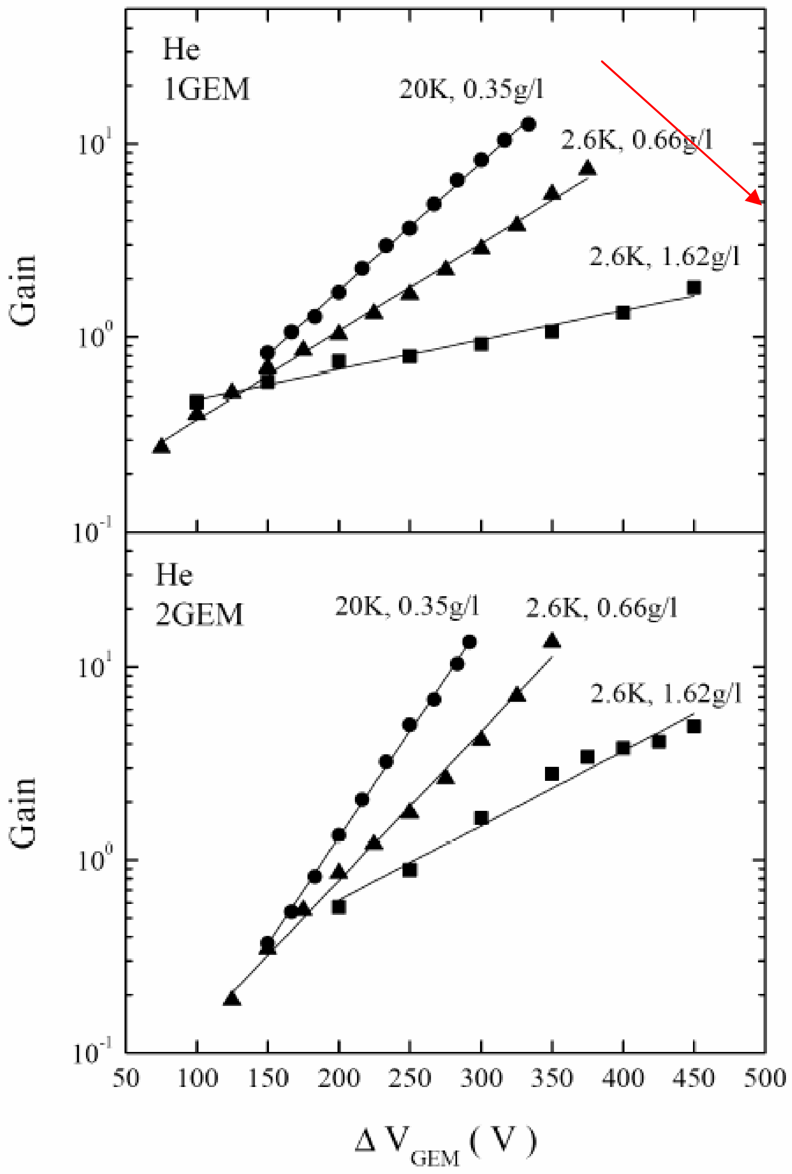
Garfield Simulation of GEM avalanche



$\Delta V_{GEM}$

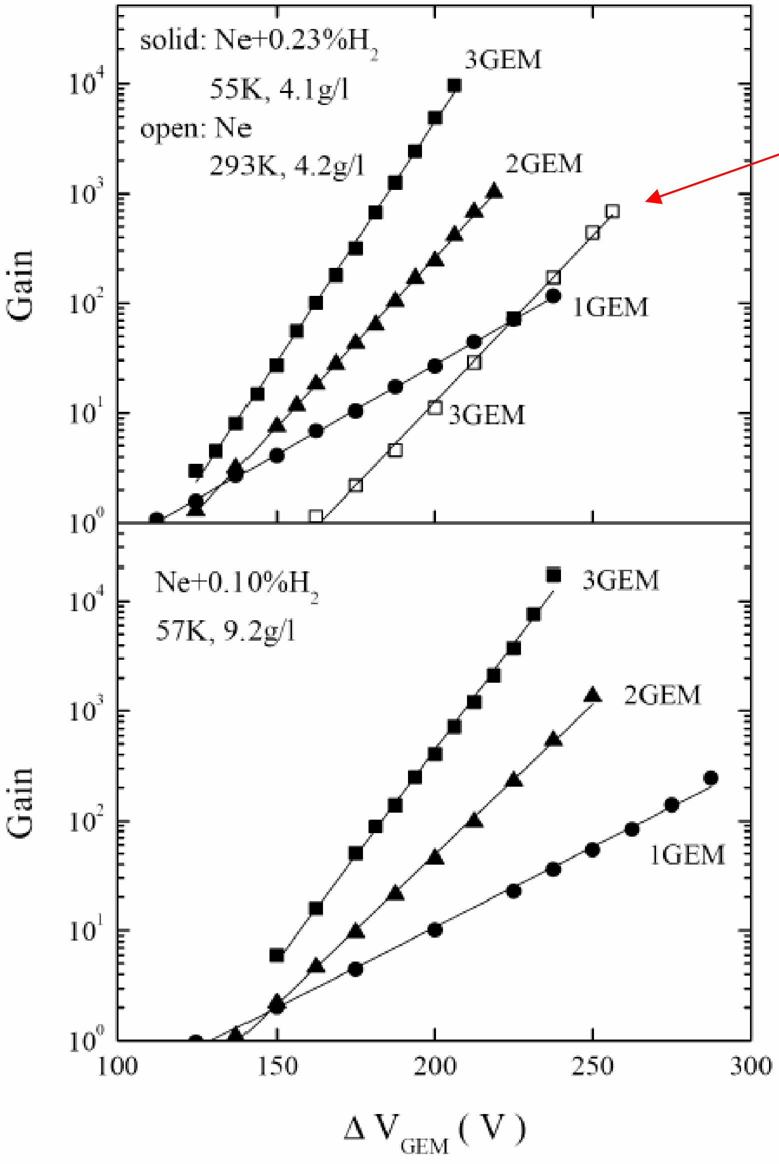


# Helium

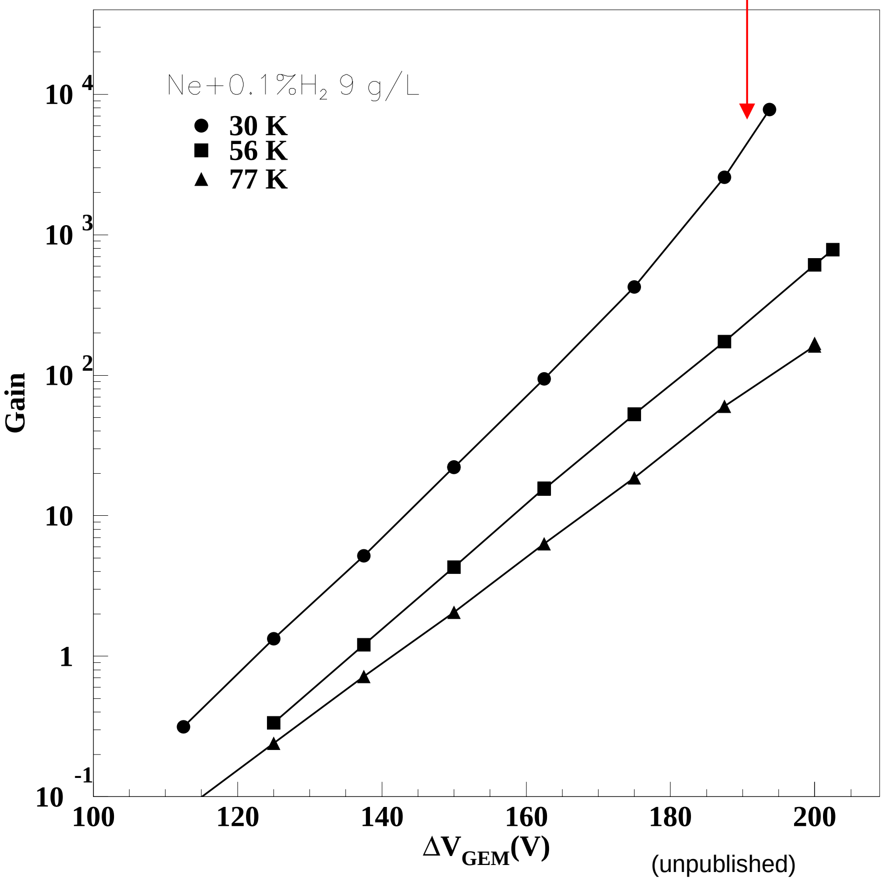



Any gain which we did achieve at low temperature decreased with increasing density.

# Neon




- Neon at densities within a factor 2-5 of saturated vapour density showed gain, further enhanced by addition of $H_2$.
- Gain of $10^4$ at 30K achieved with small addition of $H_2$.




(unpublished)

# So what do we need?

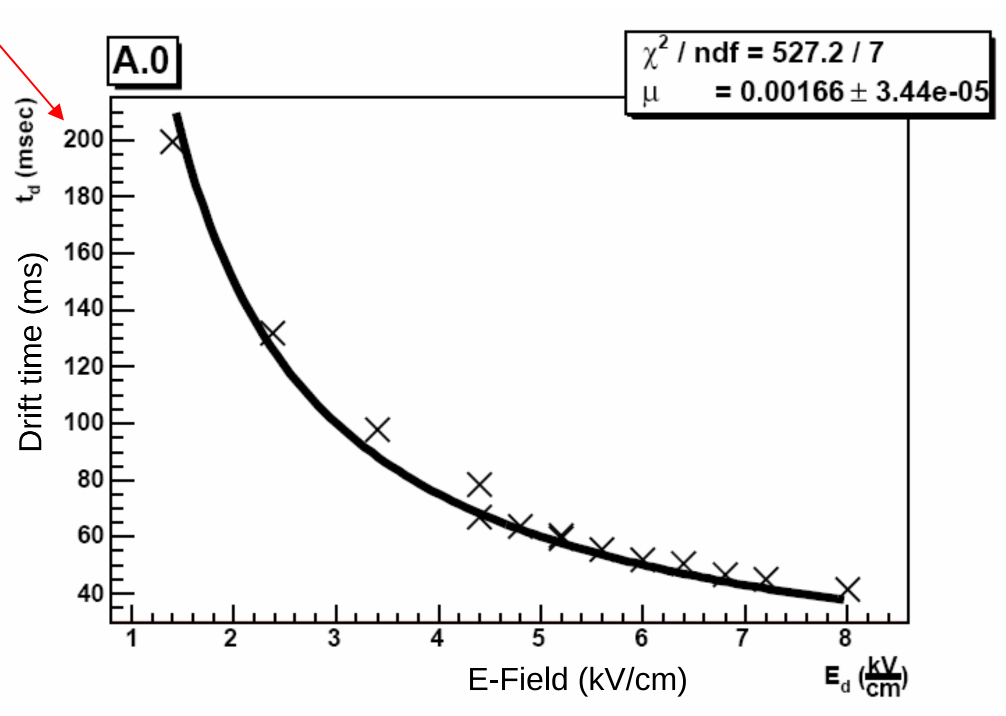
1. Gain ✓
   - $10^4$ in Ne+0.1%$H_2$ at 30K
2. Attain long drift in liquid

Experimental Run: Observation of ebubbles in LNe

# Mobility

- Attained lifetimes of 200ms without ensuring absolute purity of Ne.
- $1.66 \times 10^{-3} < \mu < 1.9 \times 10^{-3}$ ($cm^2/Vs$)
- The measured mobility was consistent with previously determined ebubble mobility in LNe

(Storchak et. al., Phys.ReV.A76,1996 & Bruschi et. al., Phys. Rev. Lett. 28, 1972).



# So what do we need?

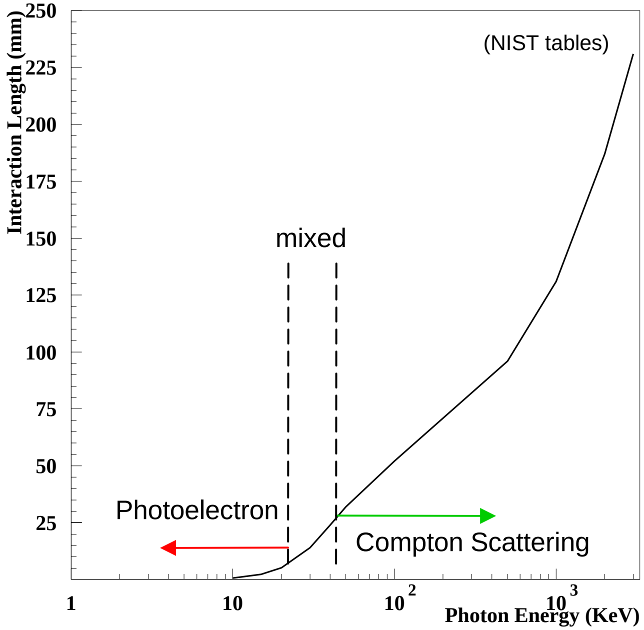
1. Gain
   - $10^4$ times in Ne+0.1%$H_2$
2. Attain long drift in liquid
   - Observed 200ms lifetimes in LNe
3. Study Liquid-vapour interface
   - Underway at the moment
   - Have observed charges moving through the surface

# LNe is self shielding

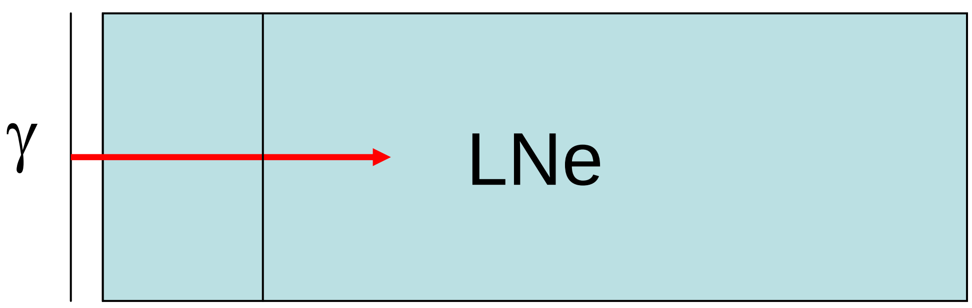
- Backgrounds from Low energy $\gamma$'s are not a problem
- Backgrounds from MeV $\gamma$'s with improbable KeV electron scatters

1. LNe allows for self shielding in the active tracker volume.
2. Spatial resolution allows a Compton cluster of several electrons to be identified.

Below 50KeV in the Compton chain all the energy goes into the next interaction as a photoelectron and the chain stops. Hence the last gap is O(1cm).



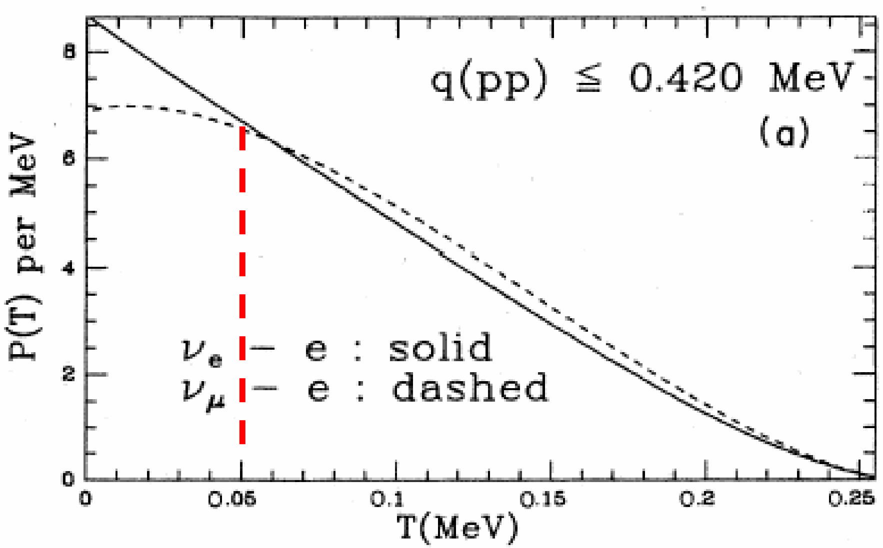
# Look at Background from $\gamma$'s




U-238 Series – Bi214: 0.609MeV (14.5%)
Th-232 Series – Tl208: 2.614MeV (10.8%)

Simple Geant 4.7.1 simulation

- 1 compton or p.e. in Fiducial volume
- Secondary 0.01MeV<E<0.250MeV (0.001MeV<E<0.050MeV)
- 100,000 events/$\gamma$ energy

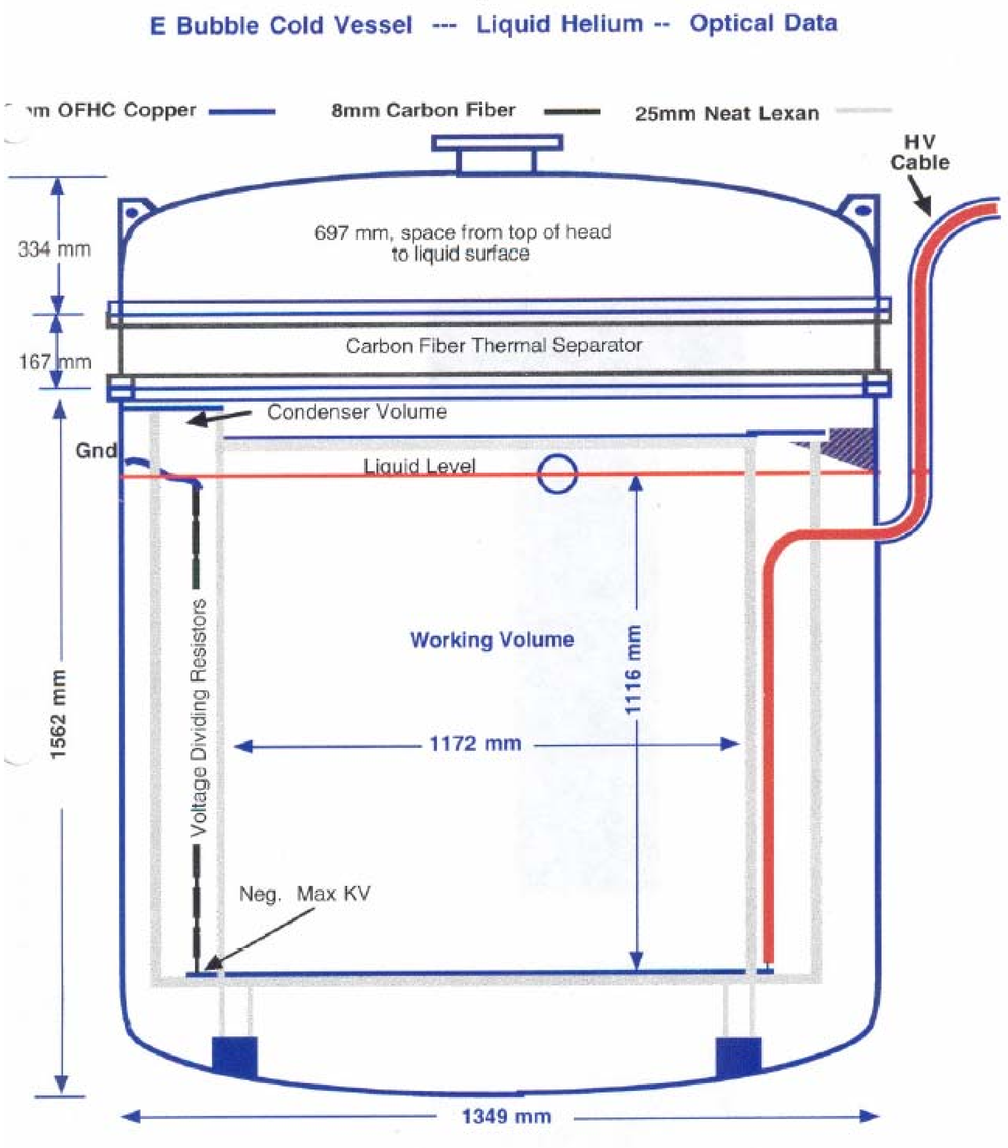



| Fiducial Cut (cm) | 0.609 MeV | 2.614MeV |
|---|---|---|
| 10 | 4065 (1059) | 2028 (521) |
| 15 | 2711 (801) | 1423 (387) |
| 25 | 1338 (480) | 937 (290) |
| 30 | 968 (360) | 793 (251) |
| 50 | 253 (93) | 407 (130) |

Per 100,000 events

# 1 $m^3$ Prototype ebubble LNe Detector:

- Continue to design 1$m^3$
- Currently making measurements on the trapping times of ebubbles at LNe surface in existing 10cm test cell
    - Study photo ejection of $e^-$ from liquid/vapour interface
    - Measure light from GEM




* Including space for optical readout – P. Takacs

J. Sondericker V3.0 , July 2005

# Summary

- Pursuing development of a 1 $m^3$ LNe ebubble chamber
    1. High Gain in $Ne+H_2$
    2. Long drift times
    3. Trapping at the vapour/liquid interface
- Continue to evaluate bubble characteristics and evaluate several options for a solution to the tracking read-out.
- A range of interesting neutrino physics problems would benefit from these tracking detectors, at high energies as well as low
- We are concentrating on definite ideas for a SNOLAB experiment on solar neutrinos down to KeV energies