Strategies for Liquid Argon Detectors at DUSEL

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Physics Program or R&D?

Accelerator neutrino beam at DUSEL is ~ 12 years away.

Our present proposal is to build a 5 kton liquid argon detector for use at that time.

However, that size is too small to have significant physics impact in 2020-2030.

⇒ We are proposing an R&D program rather than a physics program.

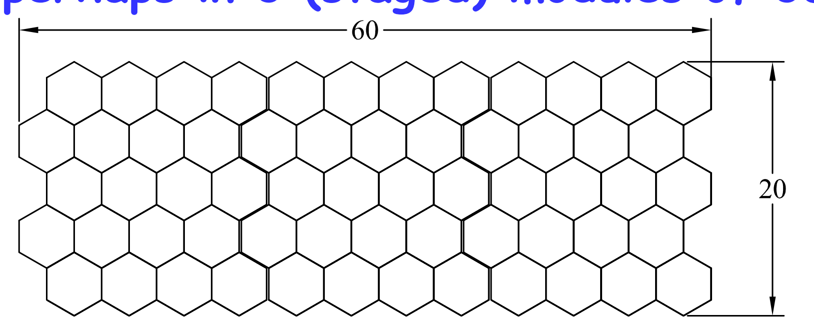
DUSEL needs a major accelerator neutrino physics program to justify its existence.

A water Čerenkov detector may well be too expensive at DUSEL, or deemed redundant with HyperK.

⇒ DUSEL may well desire a giant liquid argon detector in its first round of accelerator neutrino physics.

⇒ We should rise to the challenge of proposing and building such a detector!

Scale: 100 kton total, perhaps in 3 (staged) modules of 35 kton each, which fit in "standard halls".



Example: 35 kton module built from 400 submodules in array 5 x 4 x 20

What Do We Need for a Convincing Proposal for 35 kton Modules?

1. A design (this and following workshops).
2. Hardware demonstration of key features (that have not already been demonstrated).

Key features:

1. Giant cryostat, buildable underground.
2. Detector built from submodules of ~ 100 ton LAr mass, such that the readout planes can be assembled on the surface and lowered in the DUSEL elevator.
3. Cryogenic system to permit operation of the LAr detector deep underground.

Appropriate hardware demonstrations of these features could be made at FNAL, in the NuMI Near Hall.

Option: Magnetized Liquid Argon Detector

If the detector could tell neutrino from antineutrino events, then could use a novel "solenoid horn" neutrino beam to speed up data rate. [Next 2 slides]

An unmagnetized liquid argon TPC may be able to neutrino from antineutrino via a tag on slow protons (μBooNE should be able to confirm this):

$$\nu n \to p e^- X \quad vs. \quad \bar{\nu} p \to n e^+ X \qquad \text{where } X \text{ contains an even number of charged mesons,}$$

$$\nu n \to n e^- X \quad vs. \quad \bar{\nu} p \to n e^+ X \qquad \text{where } X \text{ contains an odd number of charged mesons,}$$

[Final-state interactions of pions in nuclei may invalidate this technique.]

However, it would be prudent to design a detector that could be augmented with a magnetic field – by winding a superconducting transmission line around the cryostat. [See slide 7]

Physics Issue:

If $\sin^2\theta_{13}$ is less than 0.01, doesn't make sense to build a neutrino superbeam for DUSEL; rather, one should build a Neutrino Factory based on neutrinos (and antinuetrinos) from decays of muons, i.e., $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$.

Then can detect $\nu_e \to \nu_\mu$ oscillations via a final-state muon, but must identify sign of the muon to suppress interactions of the $\bar{\nu}_\mu$.

A liquid argon TPC is an excellent detector both of neutrino superbeams and a Neutrino Factory!

Solenoid Capture System for a Superbeam

- Pions produced on axis inside the (uniform) solenoid have zero canonical angular momentum, $L_z = r(P_\varphi + eA_\varphi / c) = 0, \;\Rightarrow\; P_\varphi = 0$ on exiting the solenoid.
- If the pion has made exactly 1/2 turn on its helix when it reaches the end of the solenoid, then its initial P_r has been rotated into a pure P_φ, $\Rightarrow$ $P_r = 0$ on exiting the solenoid.

$\Rightarrow$ Point-to-parallel focusing for

$$P_\pi = eBd / (2n + 1)\,\pi c.$$

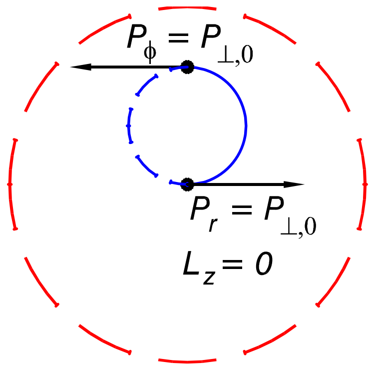
$\Rightarrow$ Narrowband (less background) neutrino beams of energies

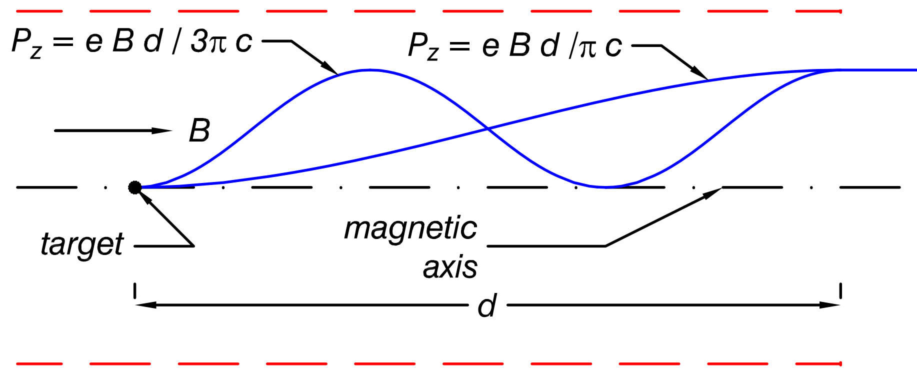
$$E_\nu \approx \frac{P_\pi}{2} = \frac{eBd}{(2n+1)2\pi c}.$$

$\Rightarrow$ Can study several neutrino oscillation peaks at once,

$$\frac{1.27 M_{23}^2[\mathrm{eV}^2]\; L[\mathrm{km}]}{E_\nu[\mathrm{GeV}]} = \frac{(2n+1)\pi}{2}.$$

(Marciano, hep-ph/0108181)





(KTM, physics/0312022)

Study both ν and $\bar{\nu}$ at the same time.

$\Rightarrow$ Detector must tell ν from $\bar{\nu}$.

$\Rightarrow$ MIND, TASD magnetized iron detectors.

$\Rightarrow$ Liquid argon TPC that can identify slow protons:

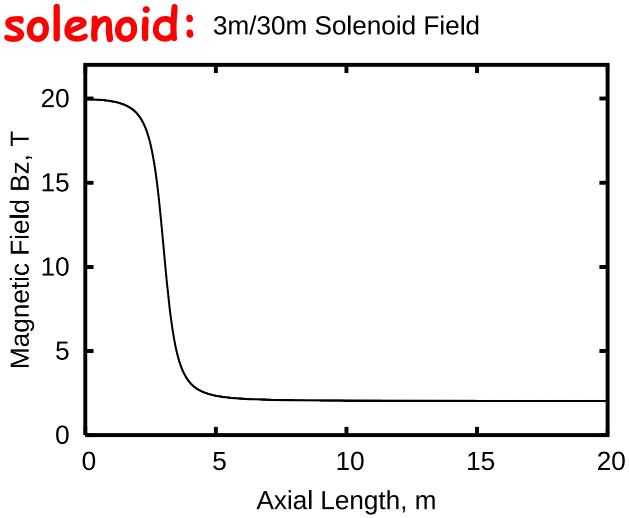
$\nu\, n \to p\, e^- X$ vs. $\bar{\nu}\, p \to n\, e^+ X$ etc.

(or magnetized liquid argon TPC).

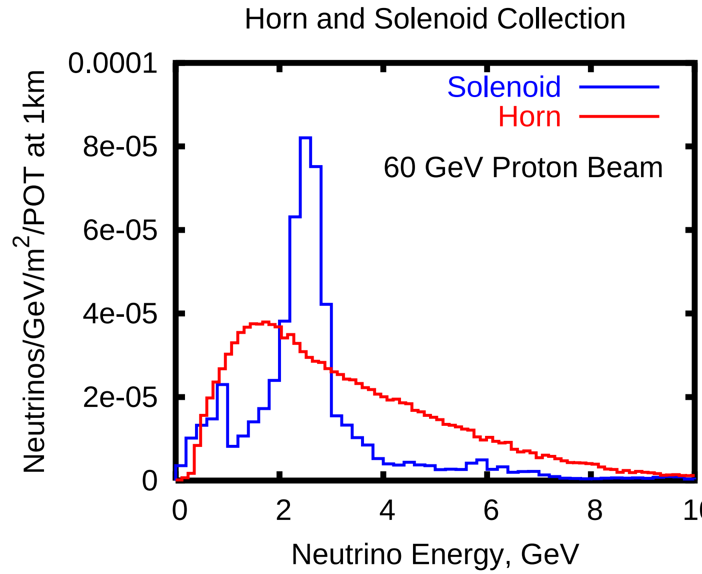
Simulation of Solenoid Horn

(H. Kirk and R. Palmer, *BNL*, NuFACT06)

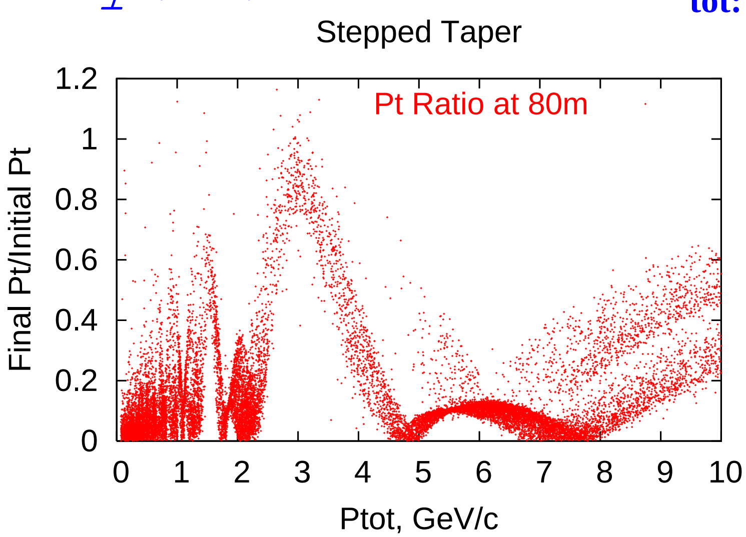
***B* vs. *z* for 3 + 30 m solenoid:**



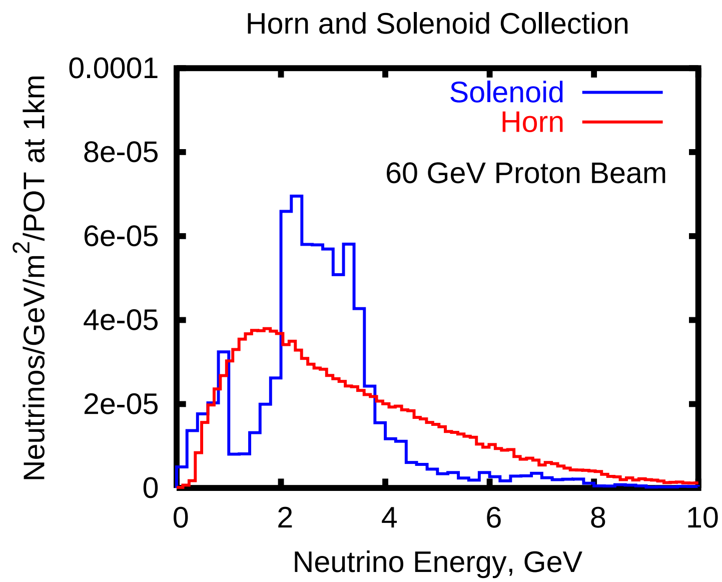
3-m solenoid gives 2 narrow peaks in ν spectrum:



⇒ $P_\perp$ minimized at selected P_{tot}:

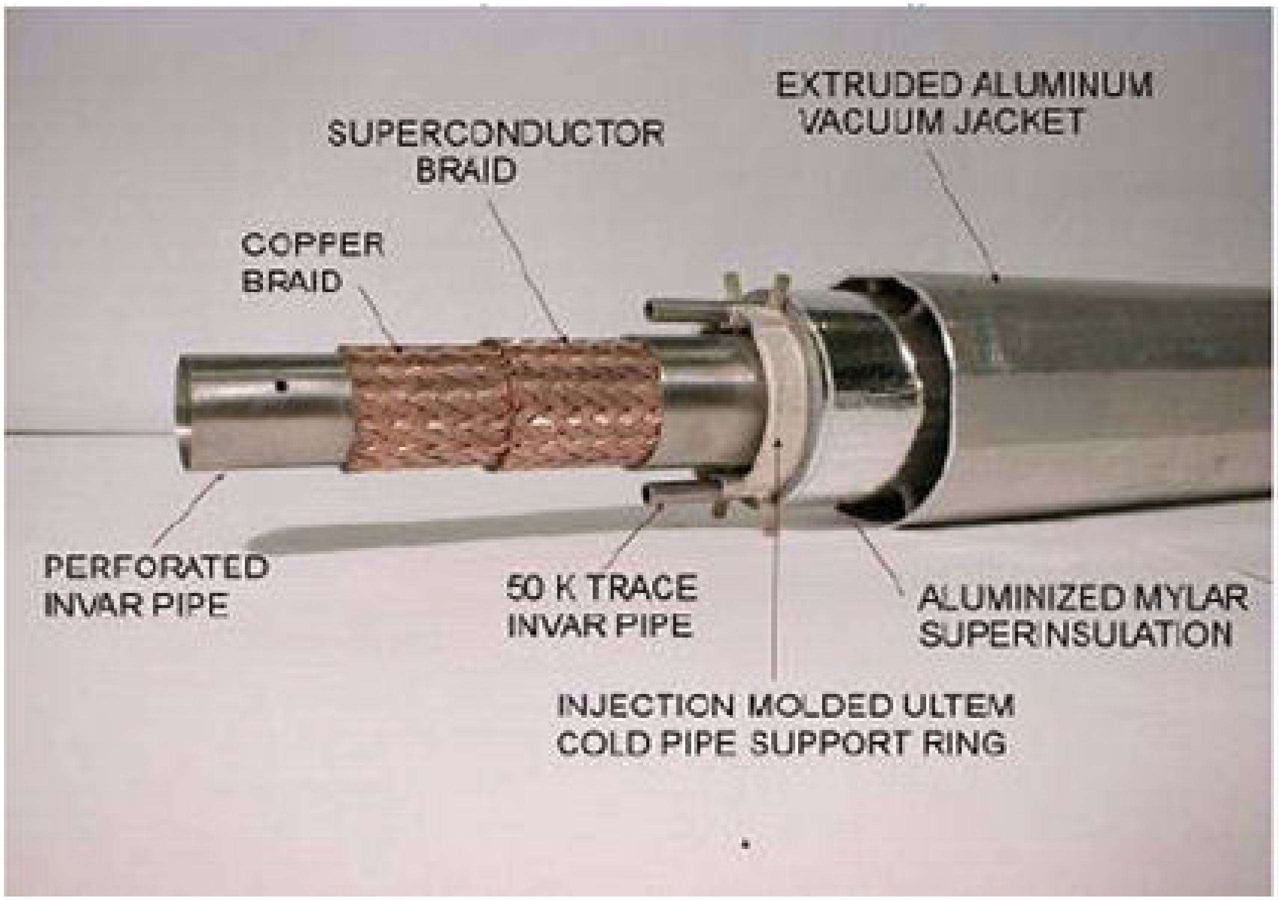


3+30-m solenoid broadens the higher energy peak:



Results very encouraging, but comparison with toroid horn needs confirmation.

Superconducting Transmission Line Can Be Wrapped Around a Large Detector



SCTL not just a "concept" – prototyped, tested and costed for the VLHC Project at Fermilab, ≈ $1k/m.

I = 7.5 MA. ⇒ B = 0.5 T for coil of ~ 50 turns.

For a 35 kton module, one turn ~ 200 m, ⇒ only ~ $10M for the coil.

Field likely to be vertical, ⇒ horizontal drift favored.

Comments about the Focusing Solenoid

Solenoid cast $\propto$ stored energy $\propto$ $(B\ r)^2 d$

Length d $\propto$ p/B, where p = momentum of focus.

Maximum captured $p_T \propto B\ r$.

$\Rightarrow$ Cost $\propto$ 1/B

$\Rightarrow$ Favors shorter solenoid, with higher field.

Field should be uniform within solenoid for ideal focusing.

No flux return.

Better to increase current density at solenoid ends to flatten the field profile.

B. Lundberg suggests that a solenoid followed by a horn pair could provide sign selection. This would be better with a short solenoid.

Comments about the Target

Optimal target radius quite small for carbon target in toroidal horn (Lundberg).

⇒ Must mitigate severe radiation damage by FREQUENT target changes.

Solenoid focusing scheme does not constrain the target diameter.

⇒ Should do study to assess viability of a larger diameter carbon target.

Can also consider "waterfall" targets of mercury, or liquid lithium.

Could also consider flowing tungsten powder (Densham, RAL).