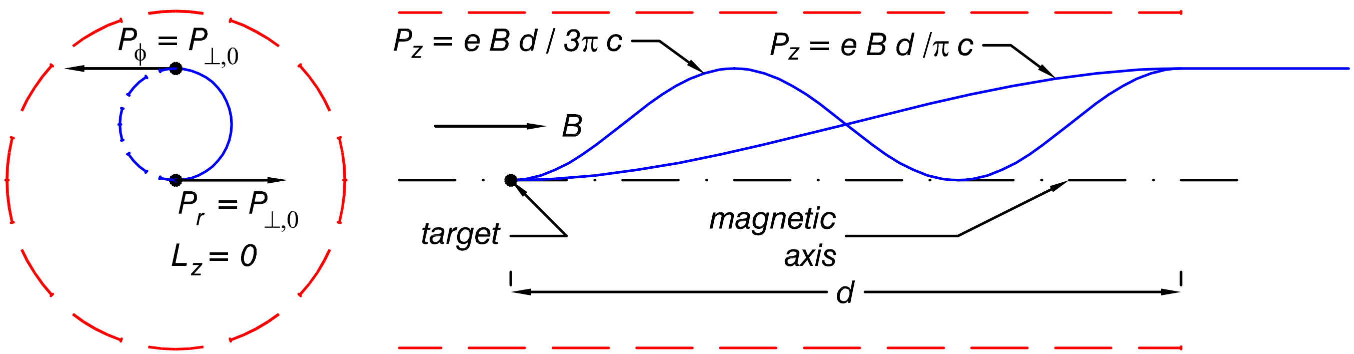
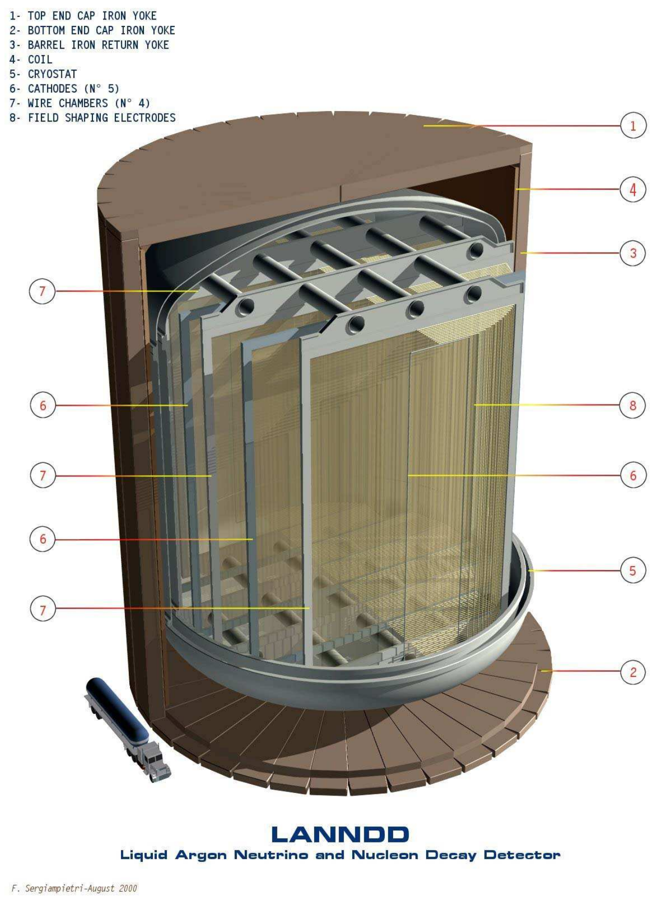
Solenoid Horn to Produce a Multiband Beam for Neutrino Oscillation Studies





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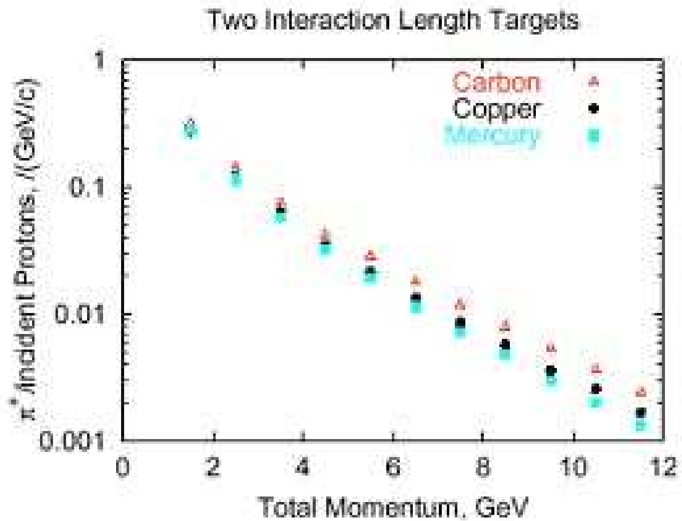
UCLA, December 5, 2003

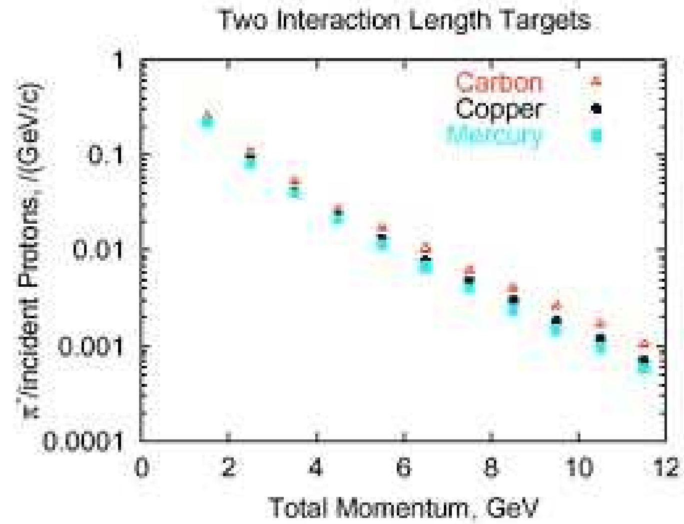
http://puhep1.princeton.edu/nufact/

physics/0312022

A "Conventional" Neutrino Horn

If desire secondary pions with $E_\pi \lesssim 0.5$ GeV (neutrino factories), a high-Z target is favored, but for $E_\pi \gtrsim 1$ Gev ("conventional" neutrino beams), low Z is preferred.

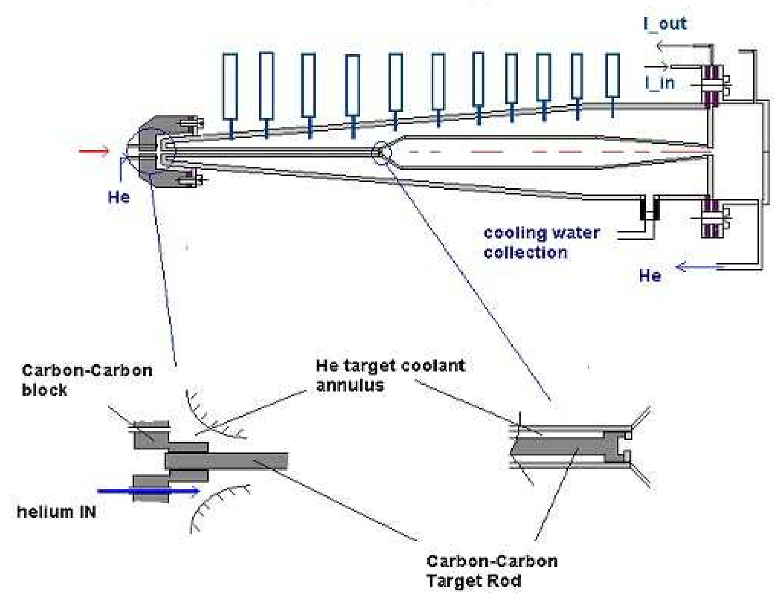




A conventional neutrino horn works better with a point target (high-Z).

Small horn ID is desirable ⇒ challenge to provide target cooling for high beam intensity.

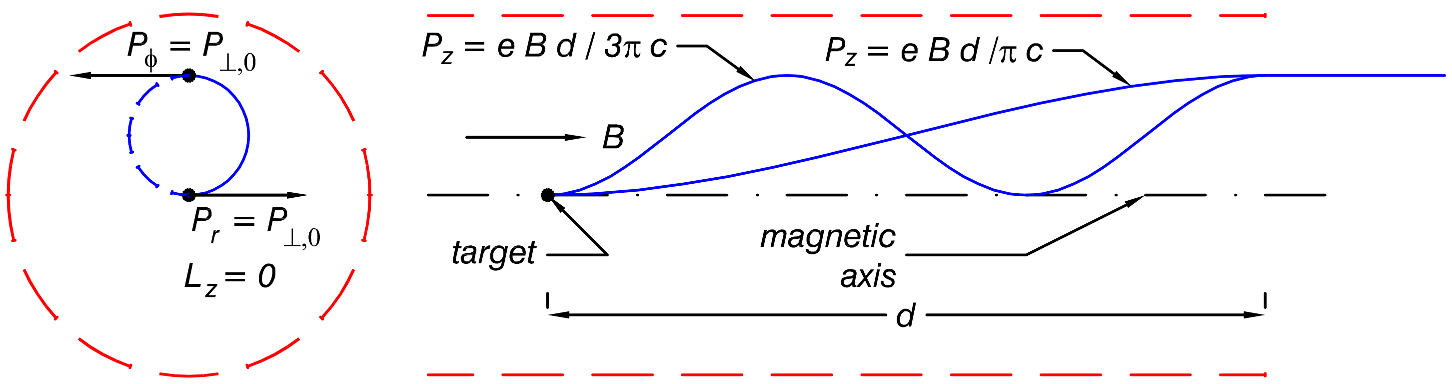
Aggressive design: carbon-carbon target with He gas cooling may be viable at 2 MW:



A Solenoidal Targetry System for a Superbeam

- A precursor to a Neutrino Factory is a Neutrino Superbeam based on decay of pions from a multimegawatt proton target station.
- 4 MW proton beams are achieved in both the BNL and FNAL (and CERN) scenarios via high rep rates: $\approx 10^6$/day.
- Classic neutrino horns based on high currents in conductors that intercept much of the secondary pions may have lifetimes of only a few days in this environment.
- Consider instead a solenoid "horn" with conductors at larger radii than the pions of interest – similar to the Neutrino Factory capture solenoid.
- Pions produced on axis inside the solenoid have zero (canonical) angular mometum, $L_z = r(P_\phi + eA_\phi/c) = 0$,
  $\Rightarrow P_\phi = 0$ on exiting the solenoid.
- If the pion has made exactly 1/2 turn (or an odd number of half turns) on its helix when it reaches the end of the solenoid, then its initial P_r has been rotated into a pure P_ϕ, $\Rightarrow P_\perp = 0$ on exiting the solenoid,
  $\Rightarrow$ Point-to-parallel focusing.

Narrowband Beam via Solenoid Focusing



- The point-to-parallel focusing occurs for $P_\pi = eBd/(2n+1)\pi c$.
- $\Rightarrow$ Narrowbeam neutrino beam with peaks at

$$E_\nu \approx \frac{4}{9}\frac{eBd}{(2n+1)2\pi c}.$$

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

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

- Get both ν and $\bar{\nu}$ at the same time (while ν_e and $\bar{\nu}_e$ suppressed),

  $\Rightarrow$ Must use detector that can identify sign of μ and e,

  $\Rightarrow$ Magnetized liquid argon TPC.

Can Study CP Violation at $L/E = (2n + 1)500$ km/GeV

[Marciano, hep-ph/0108181, Diwan *et al.*, hep-ph/0303081]

The nth maximum of ν_2-ν_3 oscillations occurs at $L/E \approx (2n + 1)400$ km/GeV.

The CP asymmetry grows with distance:

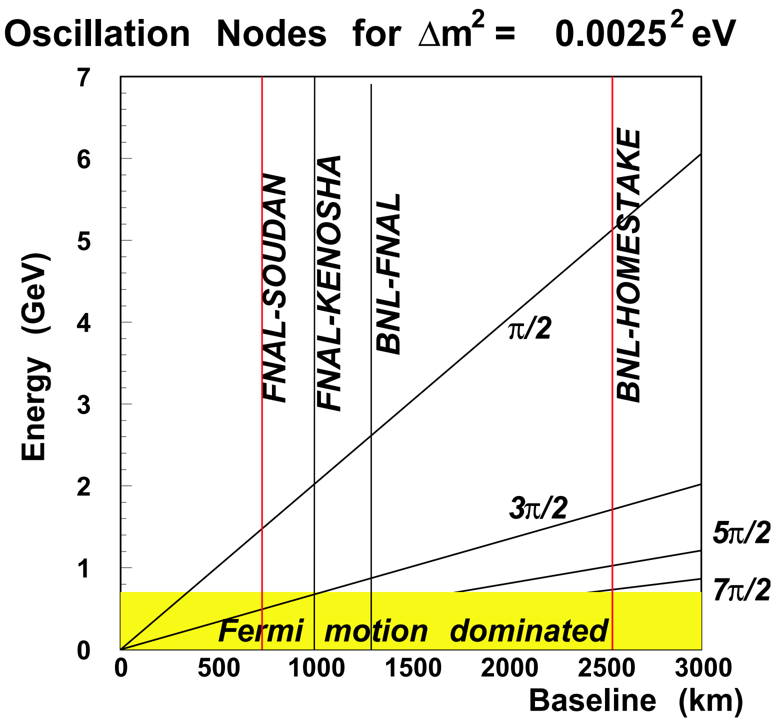
$$A = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{2 s_{12} c_{12} c_{23} \sin\delta}{s_{23} s_{13}} \left(\frac{\Delta m^2_{12}}{\Delta m^2_{23}}\right) \frac{\Delta m^2_{23} L}{4 E_\nu}$$

$$\Rightarrow \frac{\delta A}{A} \approx \frac{1}{A\sqrt{N}} \propto \frac{E_\nu}{L\sqrt{N}} \approx \text{ independent of } L \text{ at fixed } E_\nu.$$

$N_{\rm events} \propto 1/L^2$,
$\Rightarrow$ Hard to make other measurements at large L.

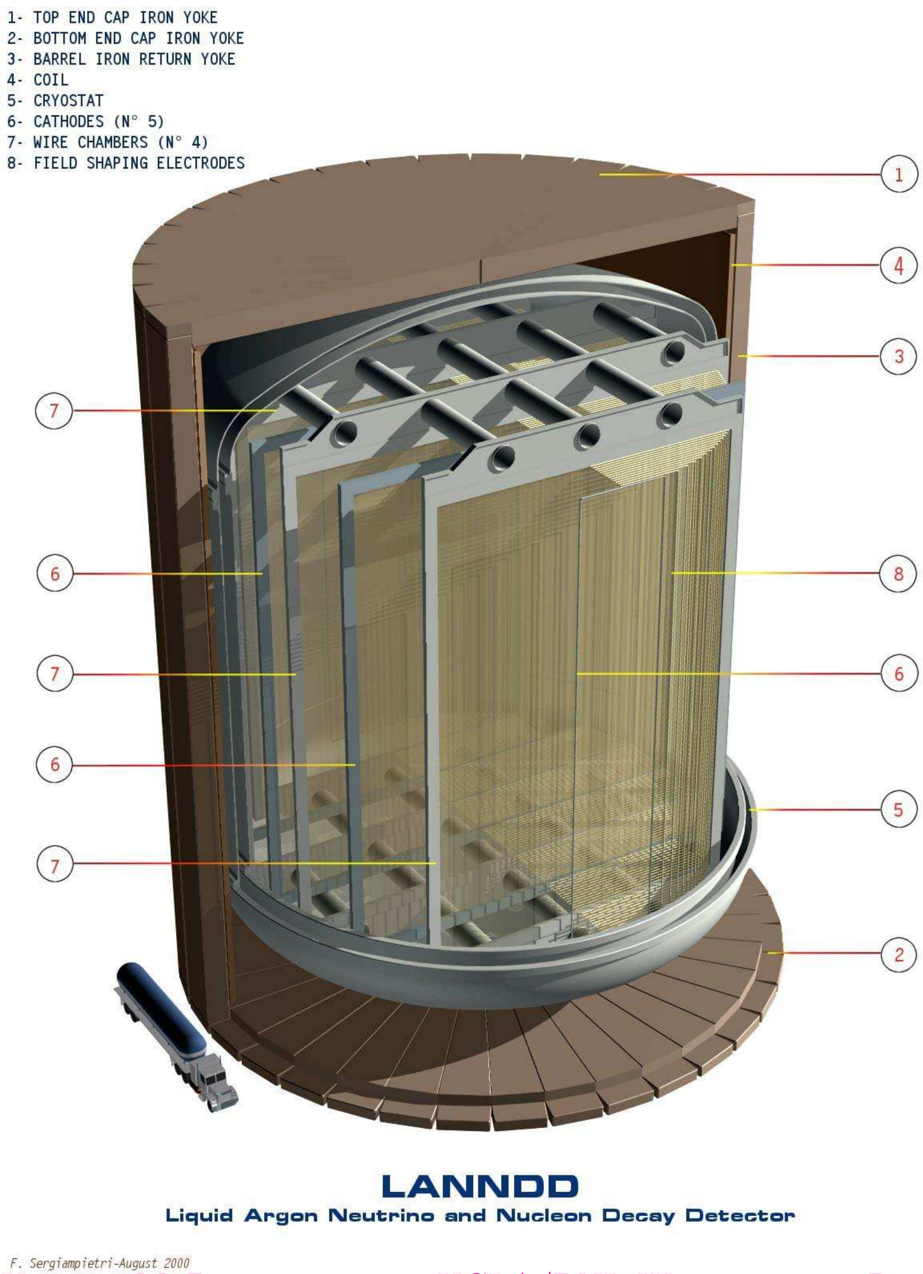
Low E_ν favorable for CP violation measurements.

If (still) need to disentangle matter effects from CP asymmetries, use the $n = 0$ and 1 oscillation maxima with E_1 as low as possible,
Ex: FNAL-Kenosha (986 km),
BNL-FNAL (1286 km).

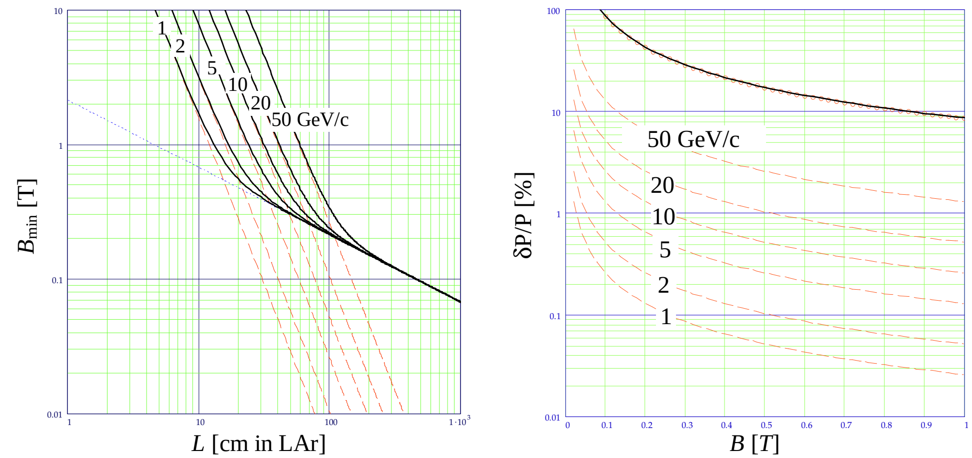


LANNDD = A Magnetized Liquid Argon Detector Concept

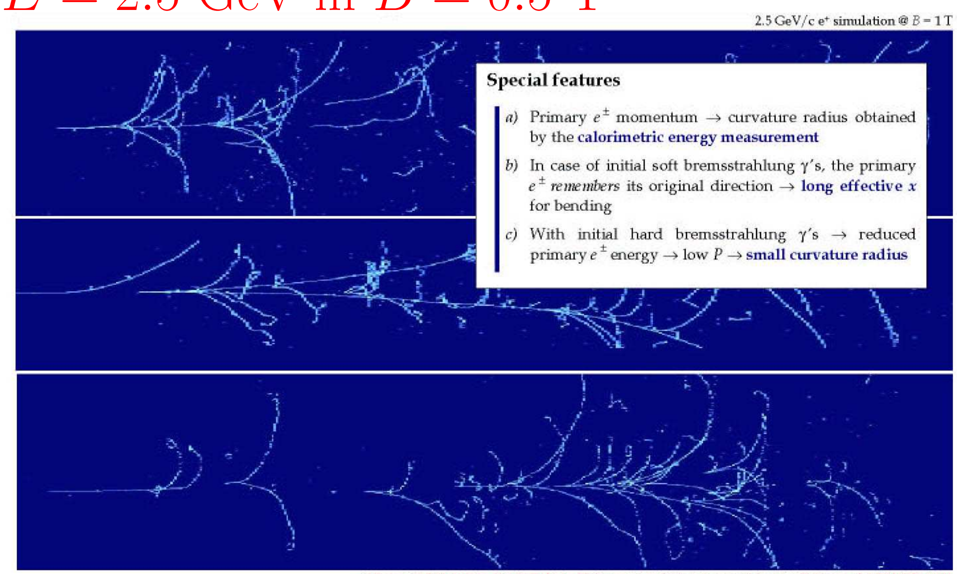
Still a Good Idea!



Muons: Easy to tell sign even if $B = 0.1$ T



Electrons: Can tell sign to 4 σ for $E = 2.5$ GeV in $B = 0.5$ T



A. Bueno, M. Campanelli, A. Rubbia, *IX International Workshop on "Neutrino Telescopes"*, VENICE, 2001