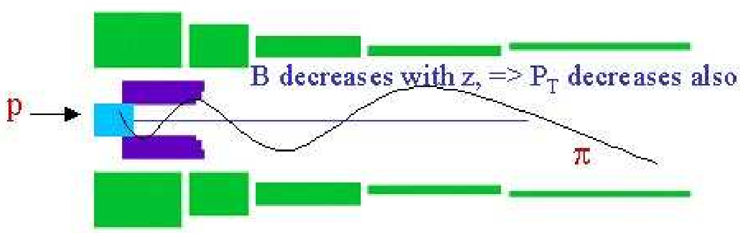
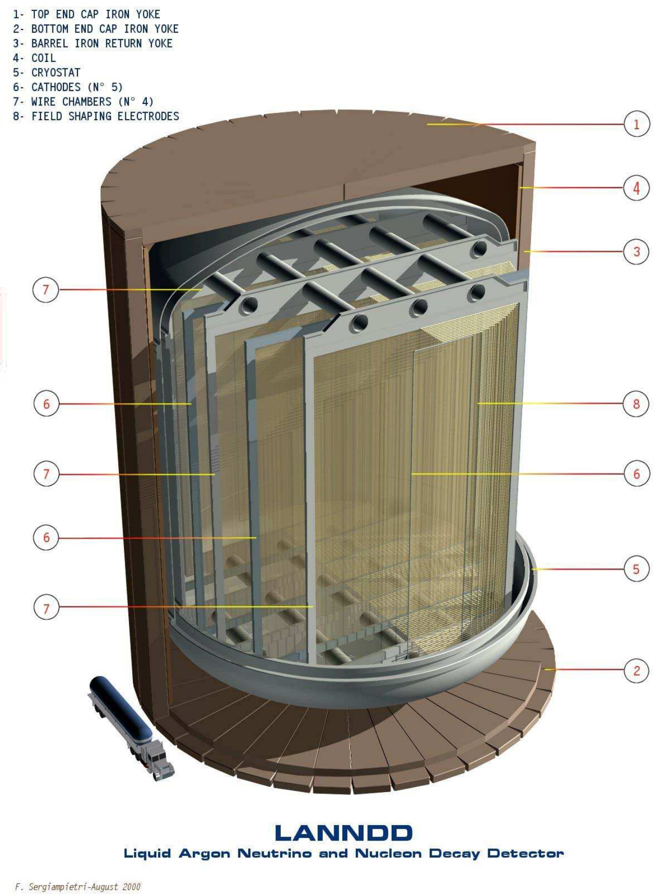
Large and Small (Far and Near) Liquid Argon Detectors for Accelerator Neutrino Beams





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NuINT'02

UC Irvine, December 15, 2002

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Post-Nobel Opportunities

Data from atmospheric and solar neutrino experiments

$\Rightarrow$ Rich follow-up physics at accelerators and reactors.

Parameter	Atmos.	Solar	Accel.	Reactor	β Decay
$\lvert\Delta M^2_{23}\rvert$	ID		*PM*		
θ_{23}	ID		*PM*		
$\lvert\Delta M^2_{12}\rvert$		ID	*PM*	*PM*	
Sign(ΔM^2_{12})		ID = PM			
θ_{12}		ID	*PM*	*PM*	
ν_{sterile}			*ID, PM*		
Sign(ΔM^2_{23})			*ID = PM*	*ID = PM*	
θ_{13}			*ID, PM*	*ID*	
Δ_{CP}			*ID, PM*		
M_ν					*ID*

(ID = Initial Discovery, PM = Precision Measurement)

No evidence for proton decay, "theories" apparently not falsifiable,

$\Rightarrow$ Linkage with neutrino expts. should be driven by the latter.

Visions of Grandeur

If CP violation is measurable in the neutrino sector, it will require a very substantial effort.

Three grand visions (each on 3 continents $\Rightarrow$ 9 giant expts.?):

1. 1-4 MW Superbeams (ν_μ from π decay) + 0.1-1 Mton detectors [limited to $\sin^2 2\theta_{23} \gtrsim 0.005$ by ν_e in beam] (\$0.5-1.5B).
2. β beams ($\bar{\nu}_e$ from ^{6}He, ν_e from ^{19}Ne) + 1-Mton detectors (\$1.5B).
3. Neutrino factory ($\mu \to \nu_\mu \bar{\nu}_e e$) + 0.1-1 Mton detectors (\$2-3B).

Physics case: Must first determine if $\sin^2 2\theta_{13}$ is large enough to justify expense of a grand effort to measure δ_C.

Budget reality: Implementation of these grand visions will require sacrifice of smaller efforts.

$\Rightarrow$ Need success of near-term, mid-sized efforts before launch a big experiment.

Corollary: A megaton proton-decay expt. should be deferred until the linked path to a large accelerator-based neutrino expt. is clear.

Multimegawatt Sources

Rate $\propto$ (neutrino flux) (detector mass).

Cost optimization $\Rightarrow$ Source cost $\approx$ Detector cost.

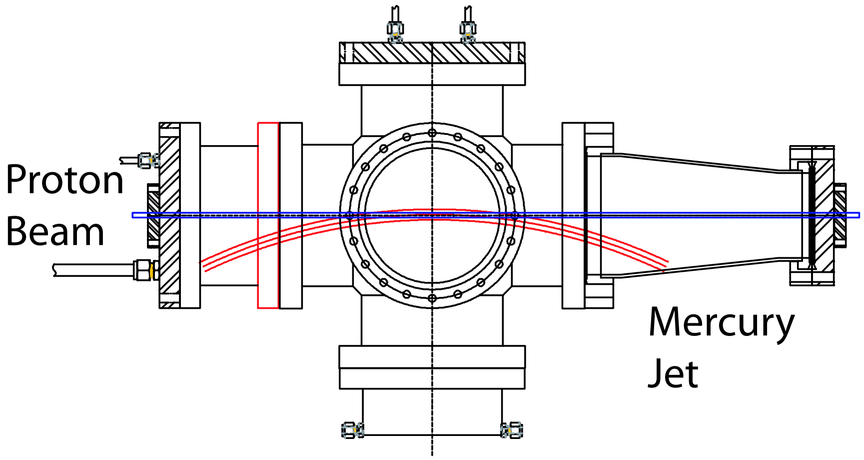
Cost of 4 MW proton source for neutrino beams is less than cost of a 1 Mton neutrino detector.

$\Rightarrow$ Strong interest in developing 4-MW proton sources for neutrino beams (+ neutron spallation, accelerator production of tritium, accelerator transmutation of radioactive waste, ...)

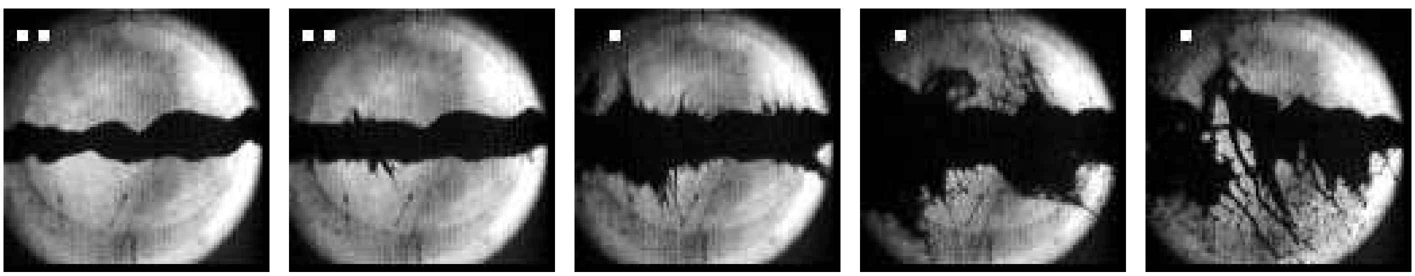
But, solid targets not viable at 4-MW due to beam heating, thermal shock and radiation damage,
$\Rightarrow$ Free liquid jet target may be the most appropriate.

BNL E-951 is presently exploring feasibility of mercury jet targets (+ other backup options).

Studies of Proton Beam + Mercury Jet



1-cm-diameter Hg jet in 2e12 protons at $t = 0, 0.75, 2, 7, 18$ ms.



$$\text{Model:} \qquad v_{\text{dispersal}} = \frac{\Delta r}{\Delta t} = \frac{r\alpha\Delta T}{r/v_{\text{sound}}} = \frac{\alpha U}{C} v_{\text{sound}} \approx 50 \text{ m/s}$$

for $U \approx 100$ J/g.

Data: $v_{\text{dispersal}} \approx 10$ m/s for $U \approx 25$ J/g.

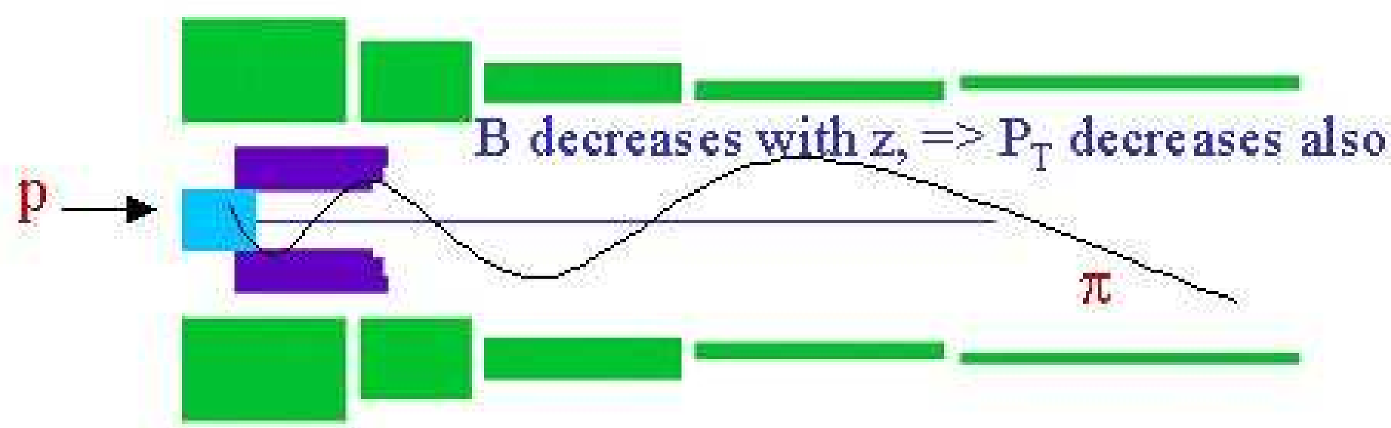
$v_{\text{dispersal}}$ appears to scale with proton intensity.

The dispersal is not destructive.

Next step: Mercury jet in beam inside 15-T magnetic field.

The Neutrino Horn Issue

- 4 MW proton beams are achieved in BNL, CERN and FNAL 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 will 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 (*c.f.*, Neutrino Factory Design).
- Adiabatic reduction of the solenoid field along the axis,
  $\Rightarrow$ Adiabatic reduction of pion transverse momentum,
  $\Rightarrow$ Focusing.

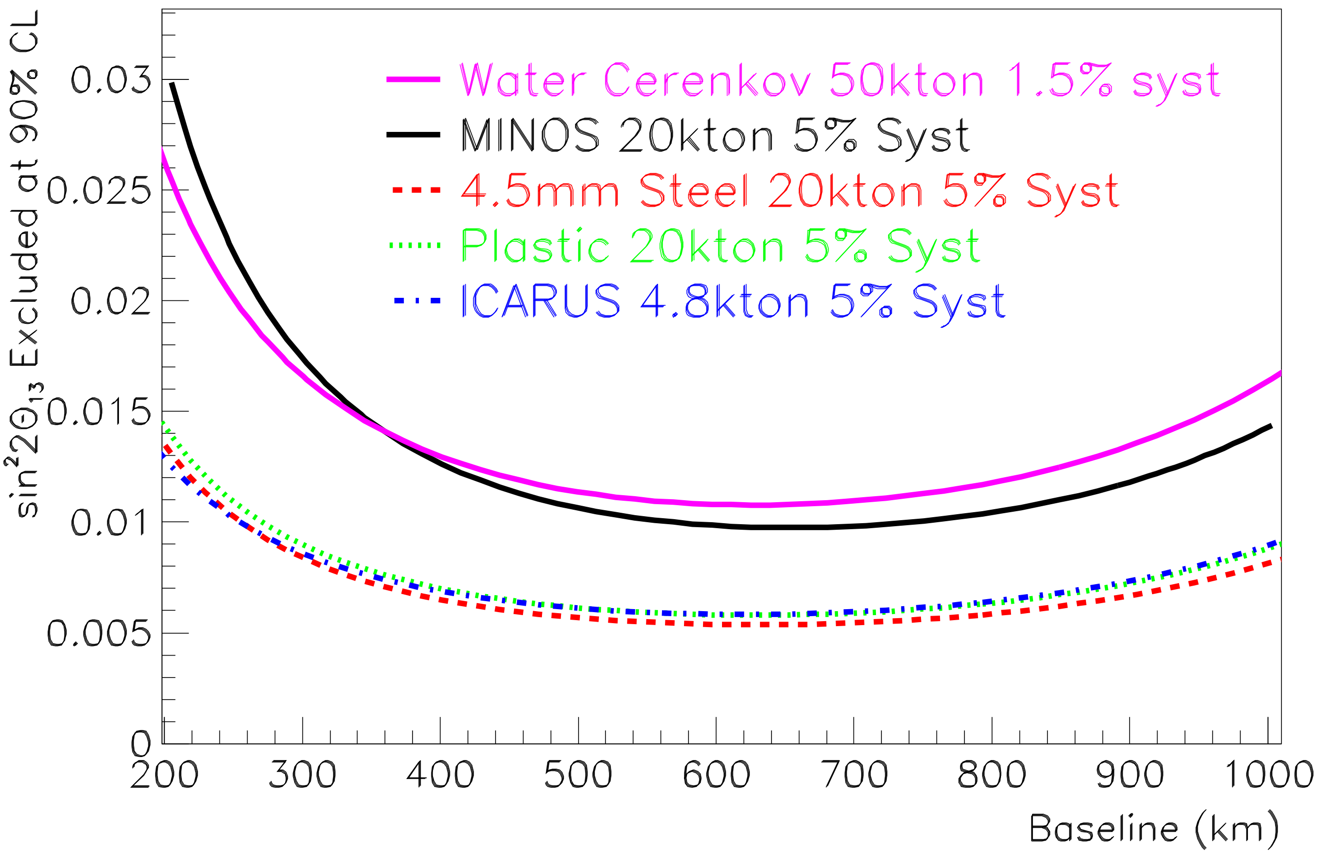


- No sign selection in horn, $\Rightarrow$ Both ν_u and $\bar{\nu}_m u$, $\Rightarrow$ Detector must measure sign of final-state μ or e.

See, http://pubweb.bnl.gov/users/kahn/www/talks/Homestake.pdf

Liquid Argon the Best Detector to Study $\sin^2 2\theta_{13}$ in the NUMI Beamline

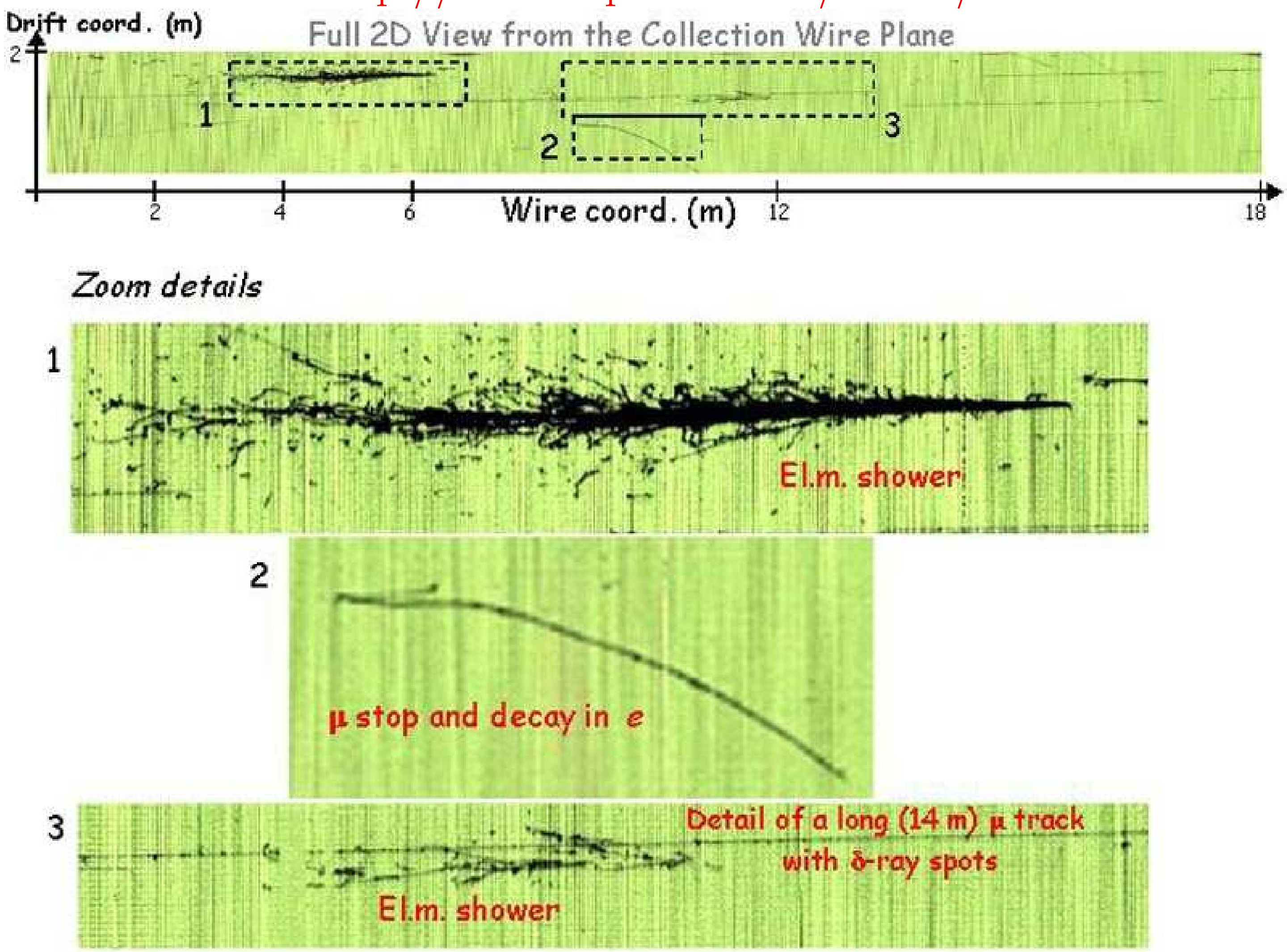
- $\approx$ 10 times better per kton than water Čerenkov for $\nu_\mu \to \nu_e$ appearance at 1-2 GeV (Harris).

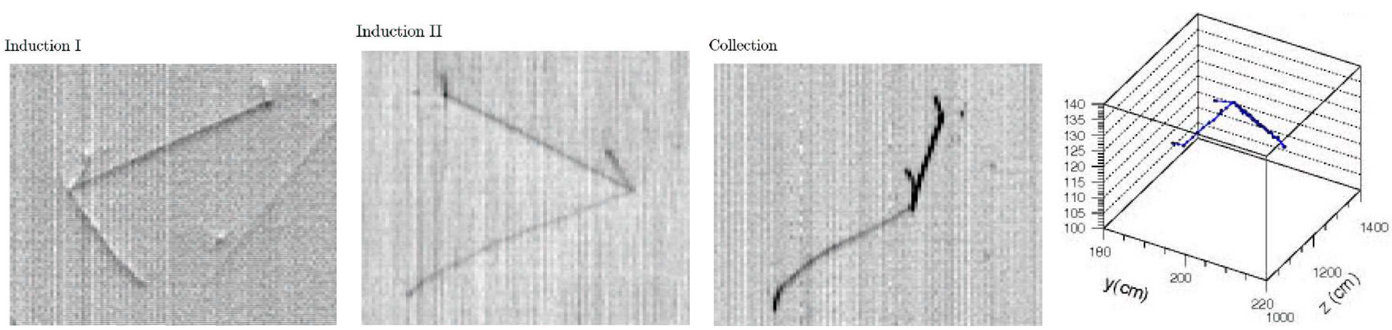


- Density = 1.4; X_0 = 14 cm; can drift electrons 2-4 m.
- 100% sampling tracking and calorimetry.
- Construction is simplest of large neutrino detector options.
- Best rejection of neutral current backgrounds, including soft π^0's.

ICARUS – a Working Liquid Argon Detector

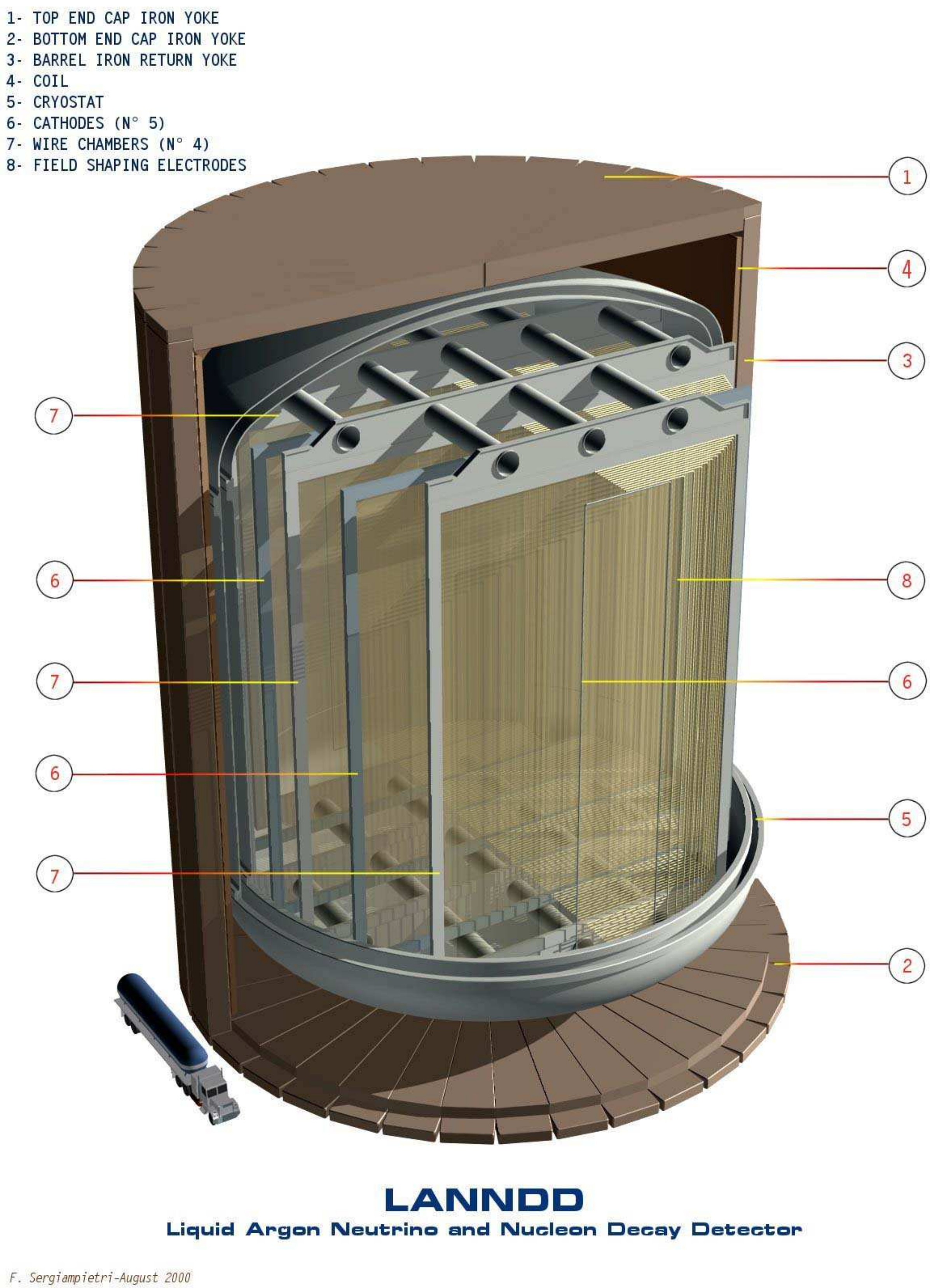
http://www.aquila.infn.it/icarus/





- Operates at the Earth's surface with near zero overlap of cosmic ray events.
- Operates with deadtimeless, selftriggering electronics.

LANNDD – 100 kton Liquid Argon Neutrino and Nucleon Decay Detector



Is a 100-kton Liquid Argon Detector Feasible?

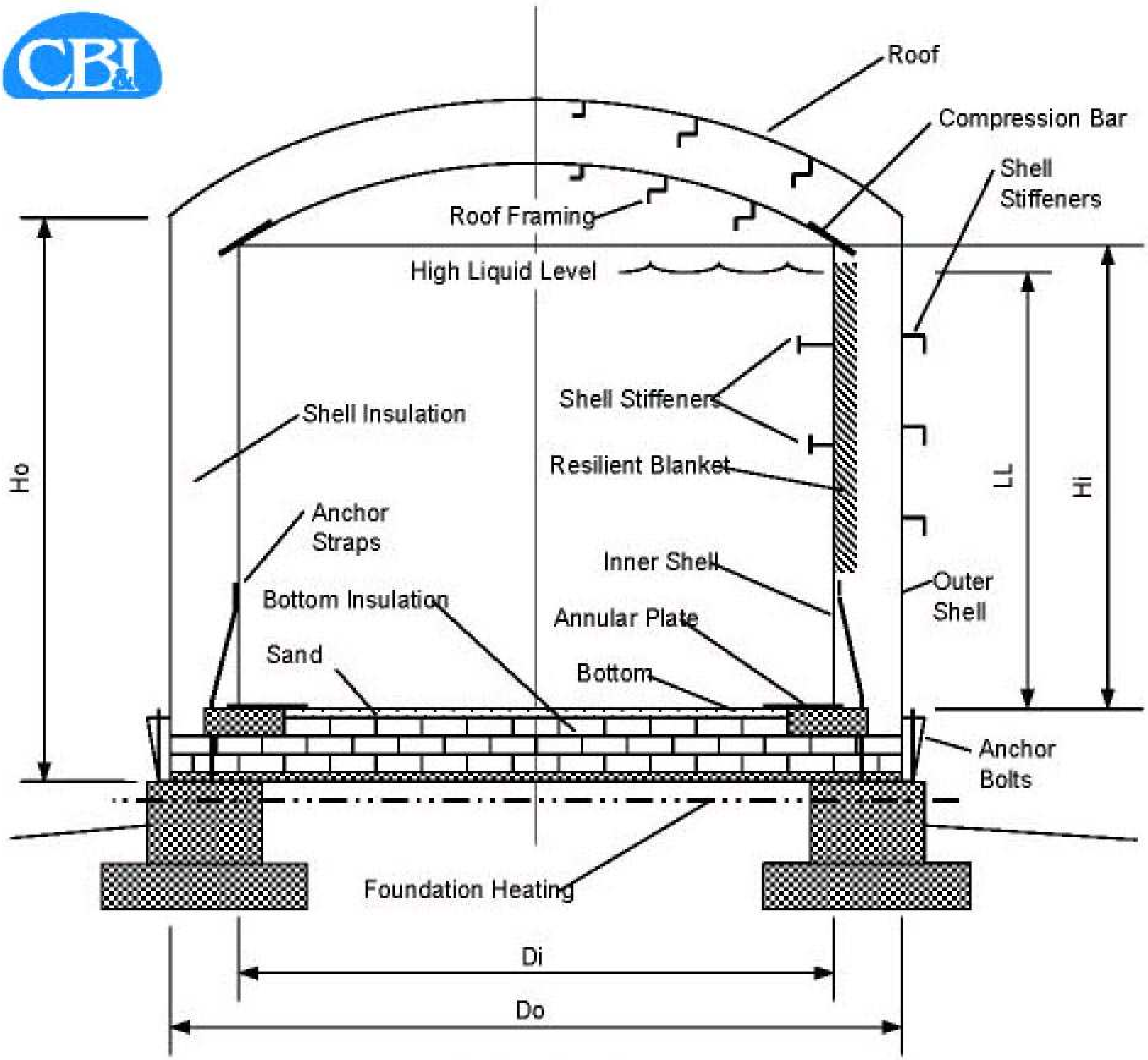
- Use mature, low-cost technology of liquid methane storage tanks (up to 300 kton based on existing structures).
  Preliminary budget estimate from industry of < \$20M for a 100-kton tank, IF built on the SURFACE.

- 100 kton of liquid argon = 10% of USA annual production.
  $\Rightarrow$ Deliver one trailer-load every 2 hours from Chicago,....
  Only 5 ppm O_2 grade available in large quantities,
  $\Rightarrow$ On-site liquid-phase purification via Oxisorb (MG).
  Raw material, delivery + purification $\Rightarrow$ \$0.8M/kton.

- ICARUS electronics from CAEN @ \$100/channel.
  3 mm wire spacing $\Rightarrow$ 300k ch $\Rightarrow$ \$30M.
  9 mm wire spacing $\Rightarrow$ 100k ch $\Rightarrow$ \$10M.
  High capacity of long wires $\Rightarrow$ signal may be too weak to use 3 mm spacing.

- With neutrino beam, record every pulse (10^{-3} duty factor).
  Cosmic rays occupy $\approx 10^{-3}$ of active volume,
  $\Rightarrow \quad \approx 10$ MB data per trigger.
  $\Rightarrow$ Modest (< \$10M) DAQ/computer system.

200-kton Cryogenic Tanks Used for LNG Storage

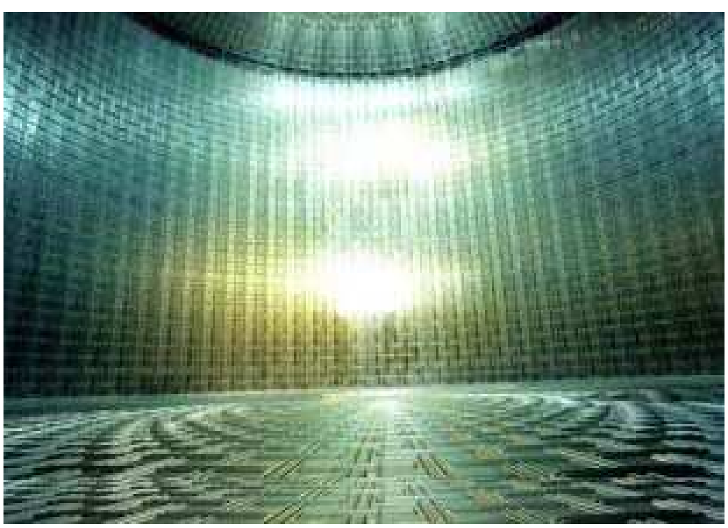


Double Wall & Double Roof Tank

	Feet
Di =	165
Hi =	117.9803
LL =	117.7303
Do =	173
Ho =	118.0443

Chicago Bridge & Iron: can build 100-kton LAr tank for < $20M.

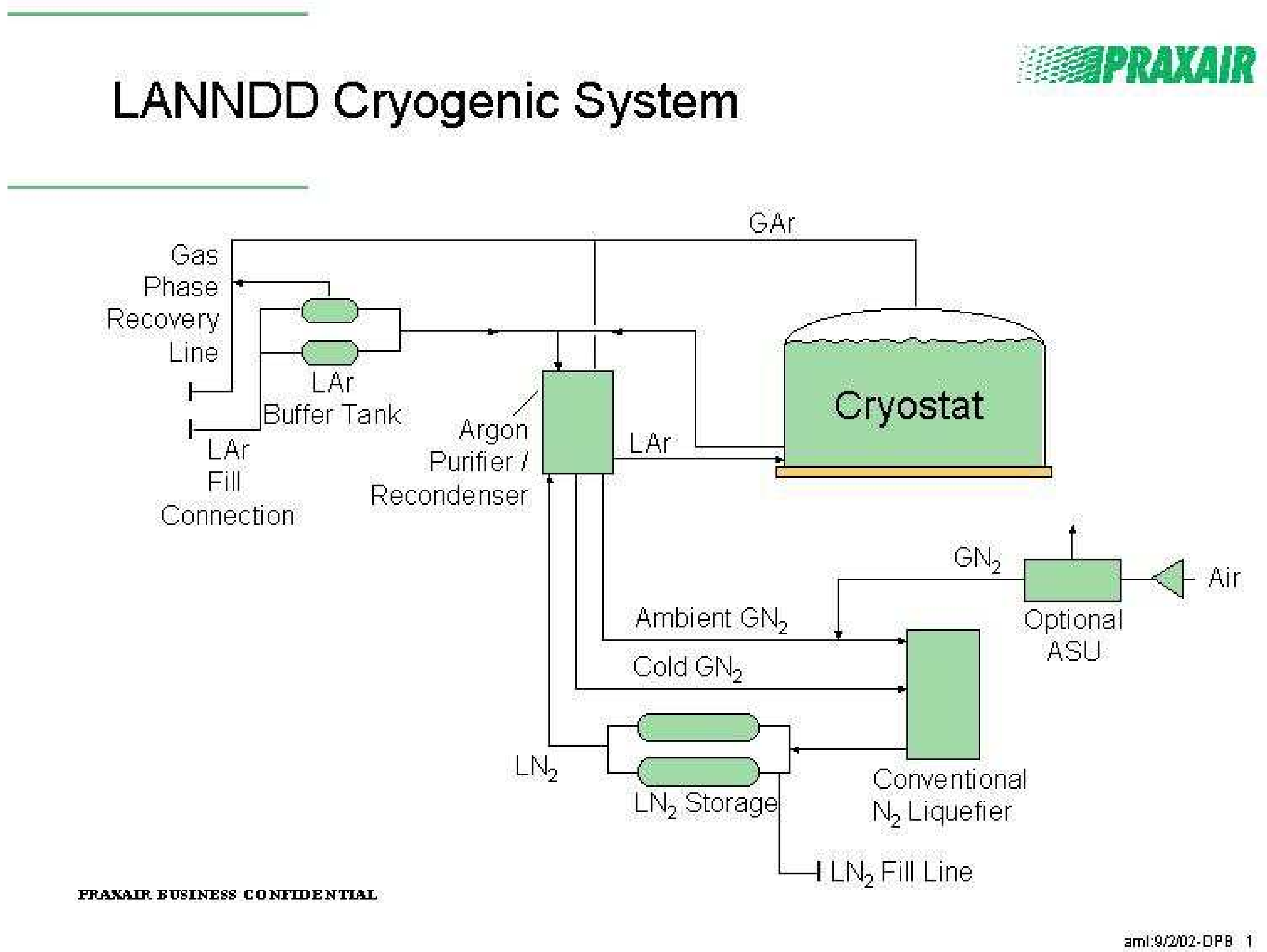
Cryogenic LNG Storage Tanks



Strong Interest by Praxair

Praxair is the leading USA vendor of liquid argon.

The Praxair R&D Lab in Tonawanda, NY is same Union Carbide lab that provided the expertise to build the Oak Ridge gaseous diffusion plant in the 1940's.



100 kton of Liquid Argon as a Detector for $p \to K^+\bar{\nu}$

Efficiency for this mode is $\approx$ 10 times that of water Čerenkov.

This mode favored in many SUSY models.

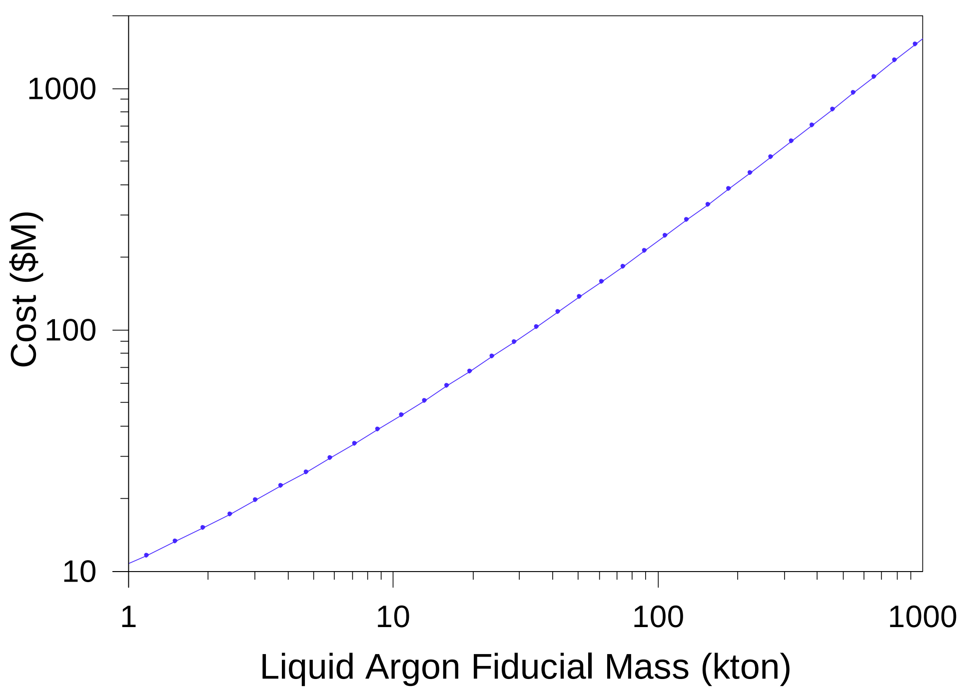
Can a Proton Decay Search Be Done at the Surface?

- The signature of the decay $p \to K^+\overline{\nu}$ is particularly clean: $K^+ \to \pi^+ \to \mu^+ \to e^+$.
  $\Rightarrow$ Maybe "no background" to 10^{35} year even at surface.
  Worry: $\approx 10^5$ n+$p \to K^+\Lambda(\Sigma)$ per Mton-year (astro-ph/0208381).
- Need 100% duty factor for proton decay search.
  $\Rightarrow\approx$ 10 GB/sec data rate at surface.
- May need to go underground (100 m?) to suppress the data rate.
  $\Rightarrow$ Additional $100M to site detector underground.
- Cheaper to buy a big DAQ system and operate at the surface – if backgrounds are OK there.

Budget Estimate (Very Rough)

For a 100-kton detector at the surface:

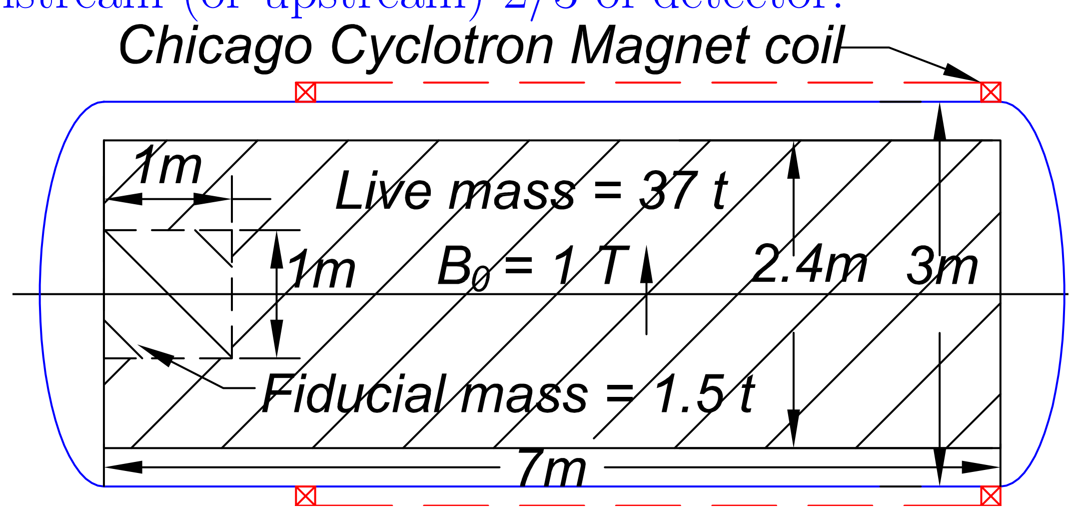
Component	Cost
Liquid argon (industrial grade)	\$70M
Cryo plant, including Oxisorb purifiers	\$10M
Surface site preparation	\$10M
Cryogenic storage tank	\$20M
Electronics (300k channels)	\$30M
Computer systems	\$10M
Subtotal	\$150M
Contingency	\$50M
Total	\$200M



Next Steps

- 40-ton near detector (1.5-ton fid. mass) in off-axis NUMI beam.

- Add Chicago Cyclotron Magnet coils to give $B \approx 1$ T over downstream (or upstream) 2/3 of detector.

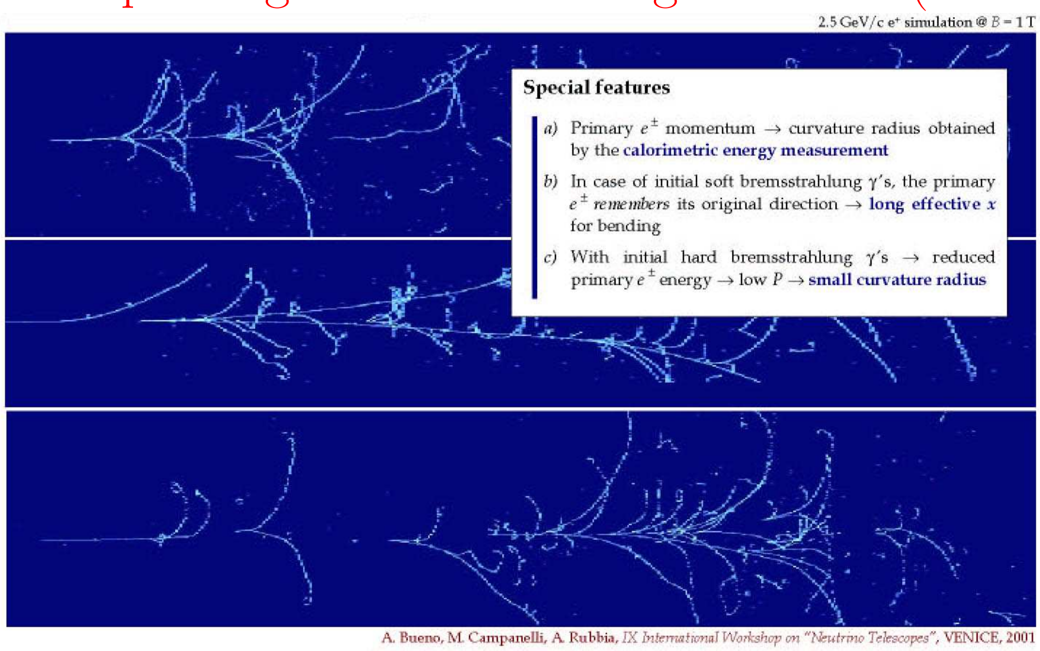


$\Rightarrow 10^5$ CC ν_μ ineractions/year.

LAr Near Detector "premeeting" at SLAC, Jan. 23, 2003.

R&D (see NuMI-PUB-GEN-0880)

- Liquid-phase purification of industrial grade argon via Oxisorb or equivalent (Praxair).
- Mechanics and electronics of wires up to 60-m long.
- Cryogenic feedthroughs, possibly including buffer volume at 150K for low-noise FET's.
- Verification of operation of a liquid argon TPC at 10 atmospheres (as at bottom of a 100-kton tank).
- Study of liquid argon TPC in a magnetic field (BNL P-965).



Should identify sign of $e^{\pm}$ up to ≈ 3 Gev in a 0.5-T field.