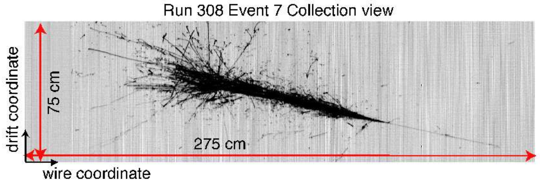
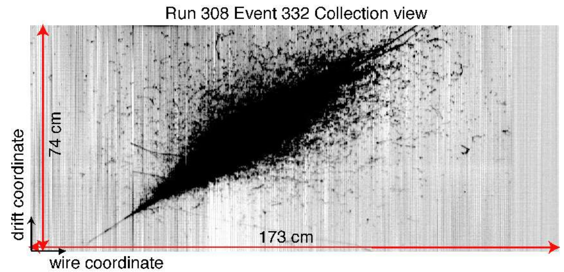
B. T. Fleming
May 20th, 2006
NuSAG

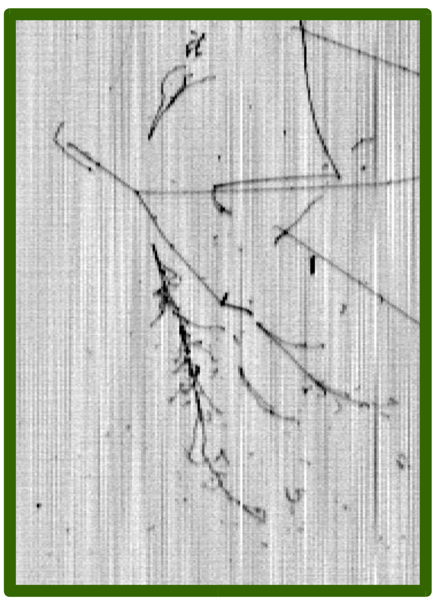
Long Baseline Study
Liquid Argon

- Study LAr worklist
- Simulation Studies
- Technical Issues
- *Plans from here*

Why consider LAr?







Combine fine-grained tracking with total absorption calorimetry

oscillation phyiscs:

high ν_e *efficiency*
good background rejection

Technically feasible on "small" scales (success of the T600)

Realizable R&D path towards massive detectors

growing international effort towards using these detectors for low energy ν physics

How much better? How feasible?

Long Baseline Study: LAr

Simulation Studies:

- Scenarios
    - Off axis NuMI beam at 14 mrad, 810 km
    - at 40 mrad, 810km, and 200km
    - Wide-band beam

efficiencies and resolutions for signal and background

↓

sensitivity studies

Technical Issues:

- Depth vs background
- energy threshold for different channels

  physics beyond accelerator neutrino oscillations
- Technical feasibilty vs detector size
- R&D towards massive detectors

Schedule:

Use existing work and existing tools

→ first pass of what we know now for July report

- pull together efficiencies and resolutions

sensitivity studies

- technical studies

Develop tools to

- advance on efficiencies, purities and resolutions
- understanding backgrounds

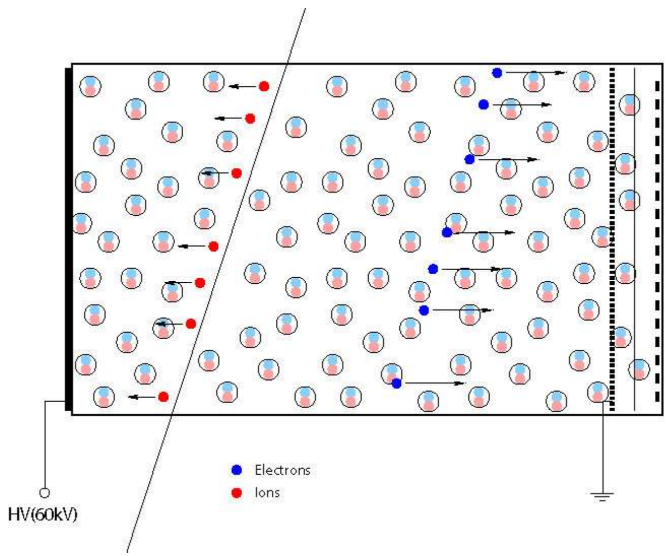
refined sensitivity calculations

- refine technical issues and related open questions
- justifiable 1st pass cost estimates

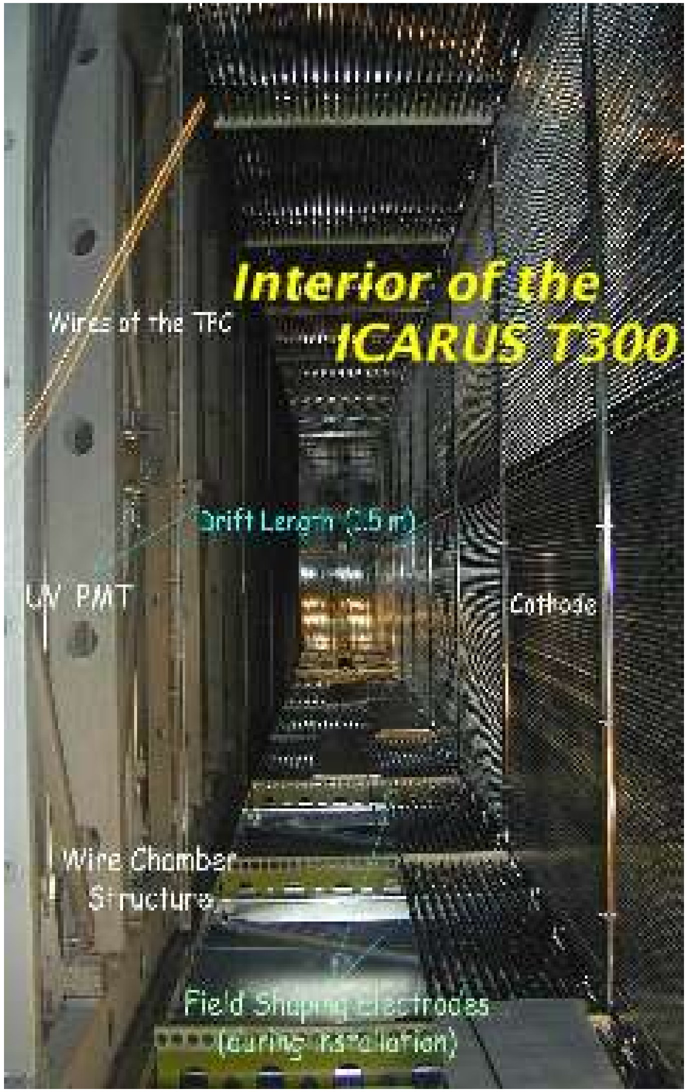
→ October report

Liquid Argon TPCs:

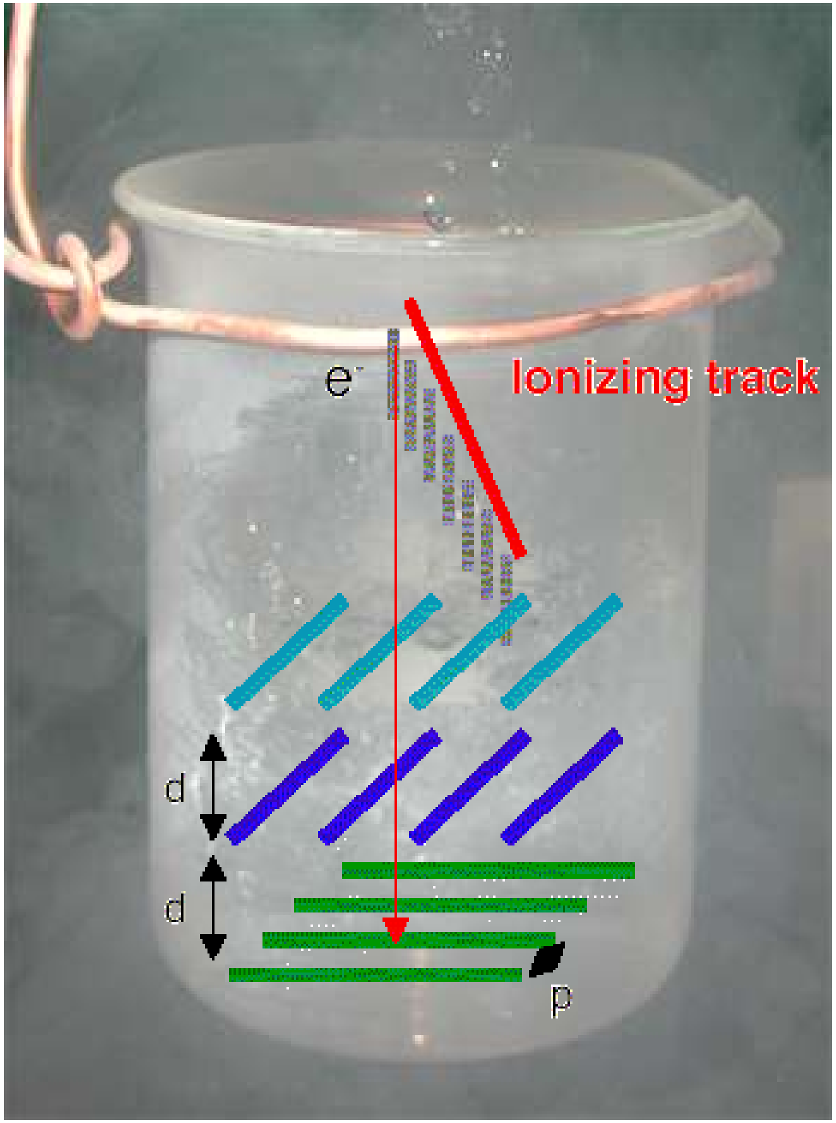
passing charged particles produce 55,000 electrons/cm

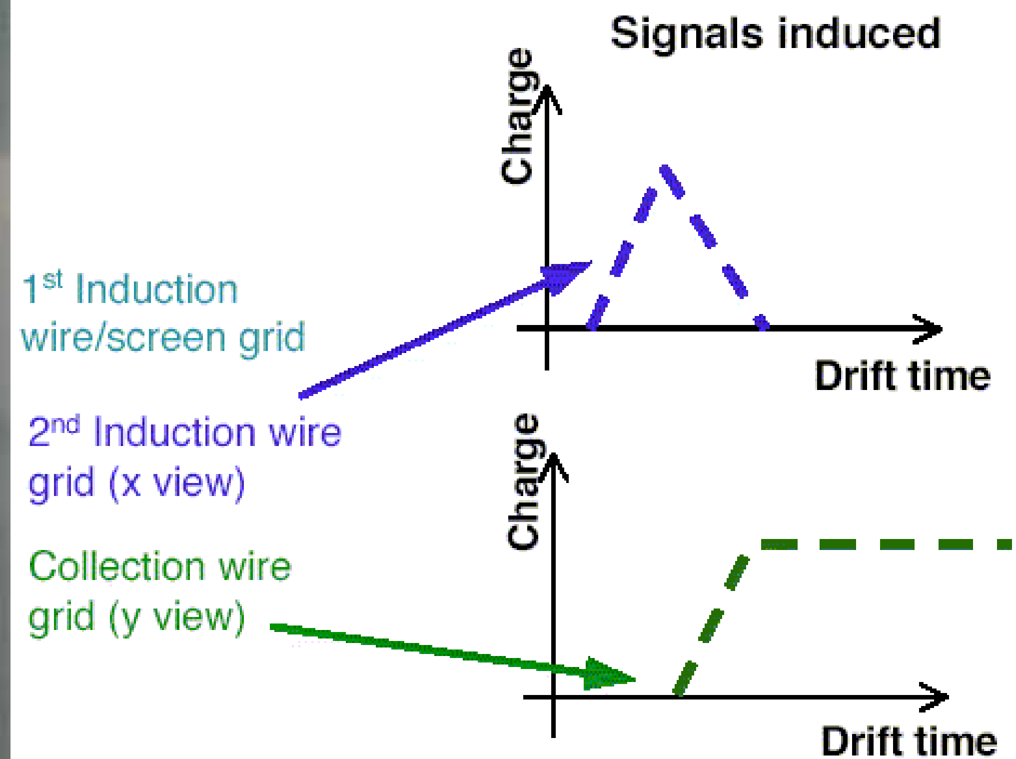


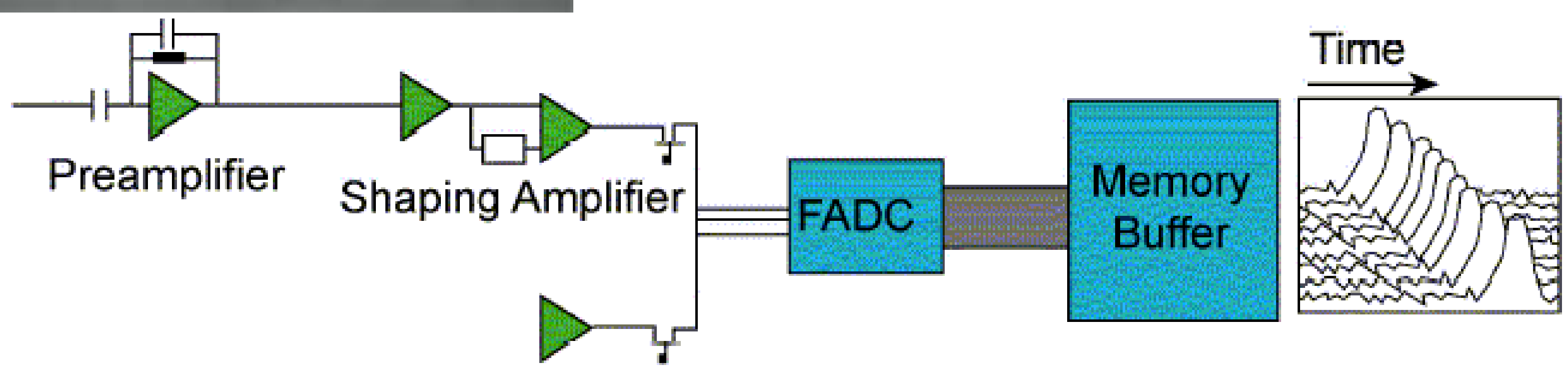
Drift ionization electrons over meters of pure liquid argon to collection planes to image track



Liquid Argon TPC







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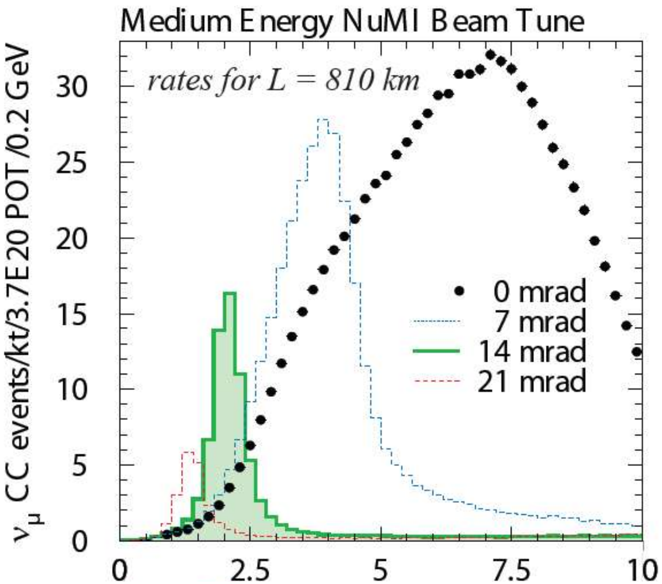
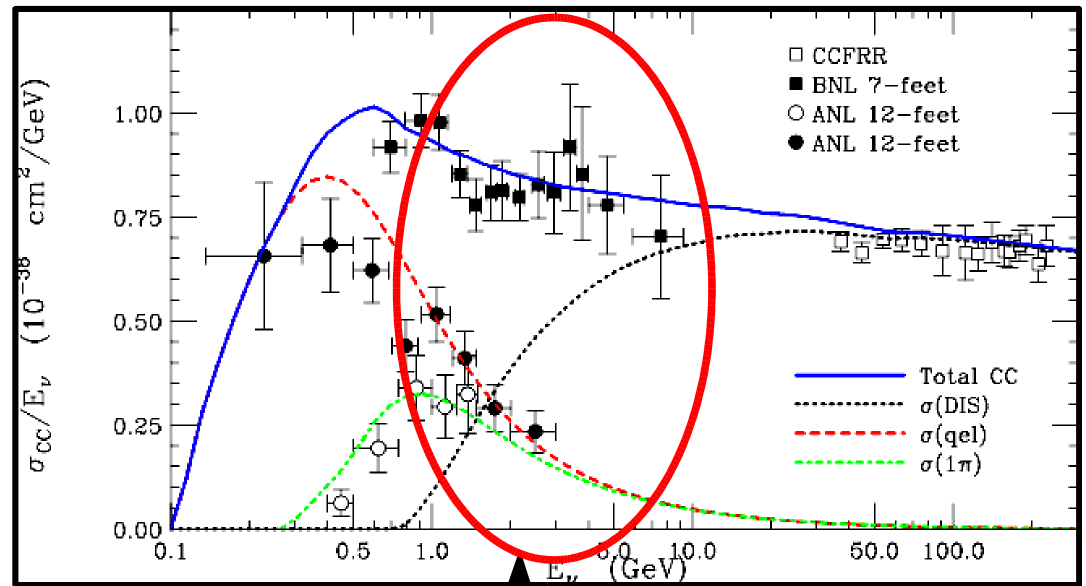
- R&D to get to necessary sizes (brief)

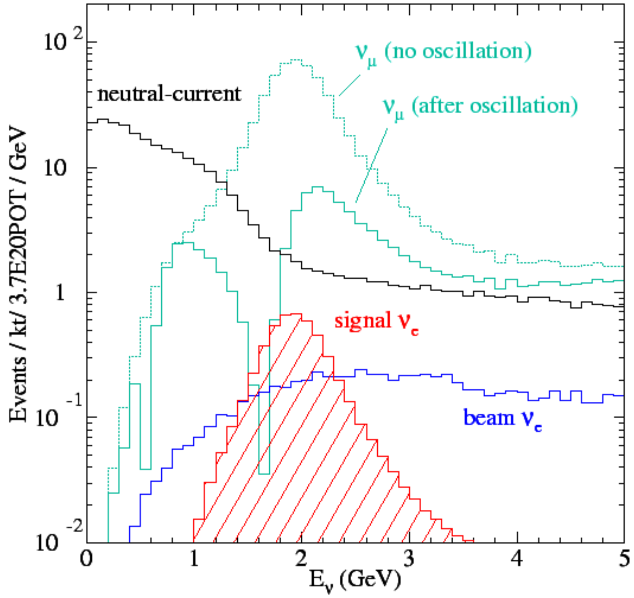
- Off axis NuMI beam at 14 mrad, 810 km



NOvA location

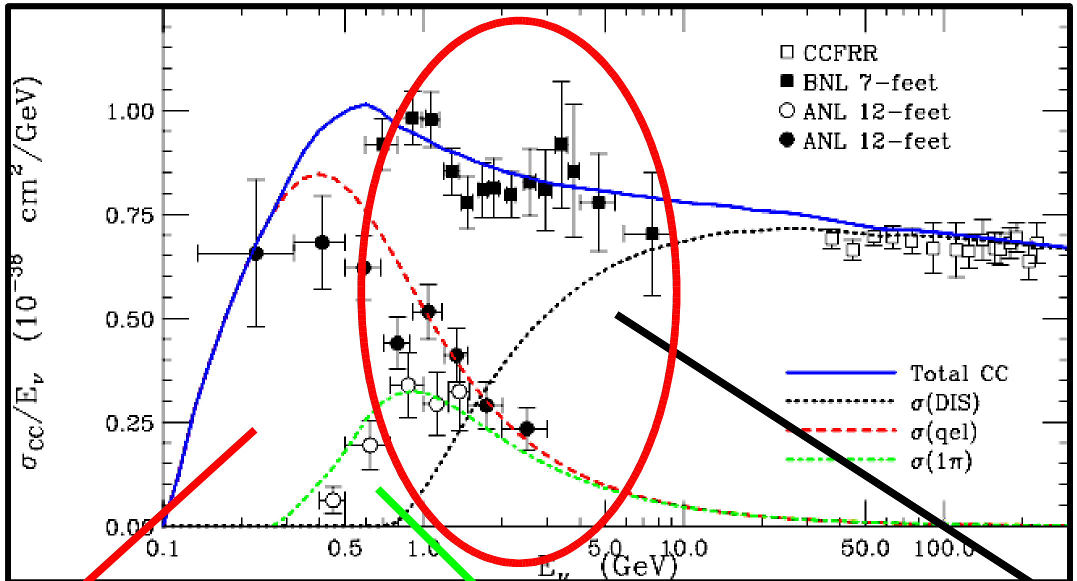


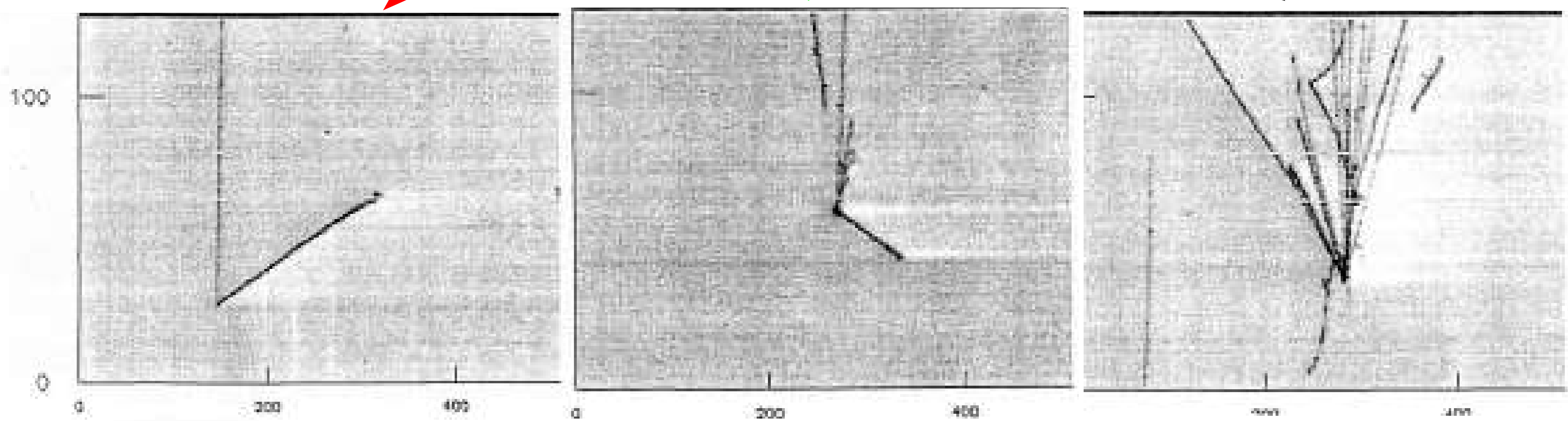
NuMI off-axis at 14 mrad



NOvA expected event spectra:

biggest backgrounds are neutral current events and beam ν_es





•Existing reconstruction....
- hand scan study (Tufts U. group)
- automated reconstruction (ETHZ group)

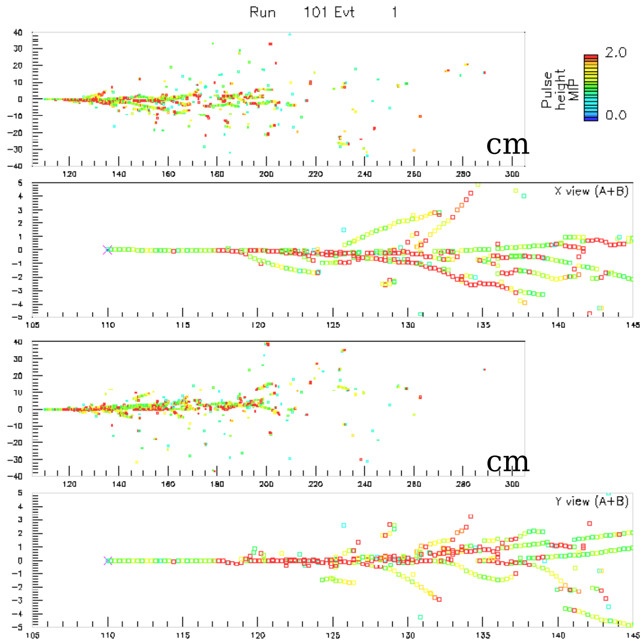
reconstruction work for study in progress

Differentiating electrons from π^0's at 1.5 GeV

Dot indicates hit
color indicates collected charge
green=1 mip, red=2 mips

X plane → zoom in

Y plane → zoom in

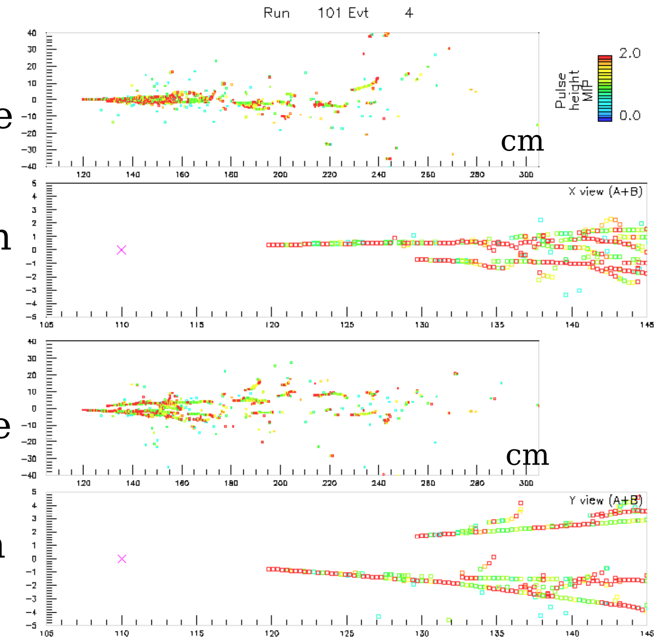


Electrons

Single track (mip scale) starting from a single vertex

X plane → zoom in

Y plane → zoom in



π^0

Multiple secondary tracks can be traced back to the same primary vertex

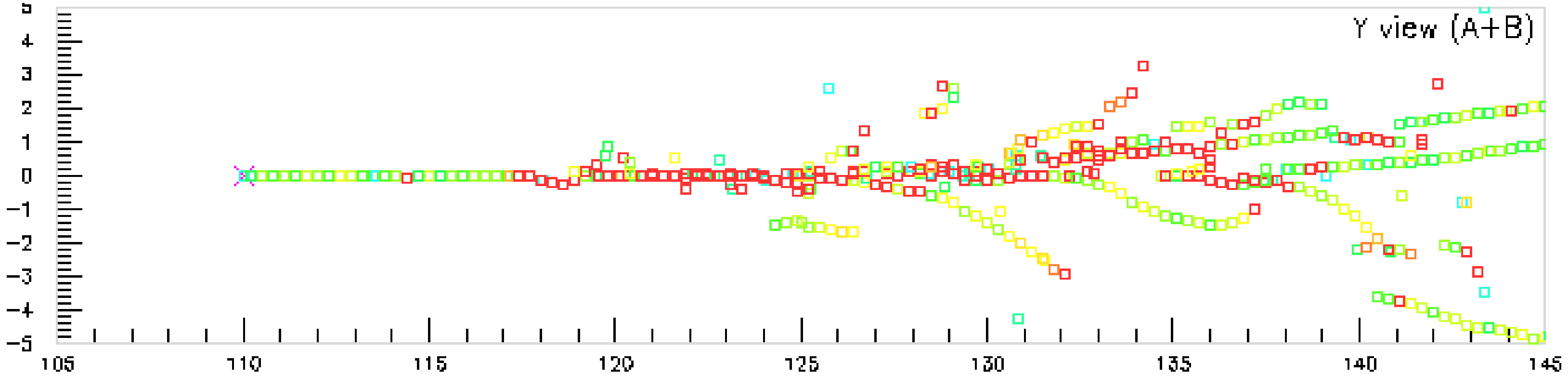
Each track is two electrons – 2 mip scale per hit

Use both topology and dE/dx to identify interactions

Efficiency and Rejection study

Analysis: blind scan of 450 events, carried out by 4 undergraduates with additional scanning of “signal” events by experts.

- NOvA 14mrad flux
- Neutrino event generator: NEUGEN3. Used by MINOS/NOvA collaboration. Hugh Gallagher (Tufts) is the principal author.
- GEANT 3 detector simulation: trace resulting particles through a homogeneous volume of liquid argon. Store energy deposits in thin slices.



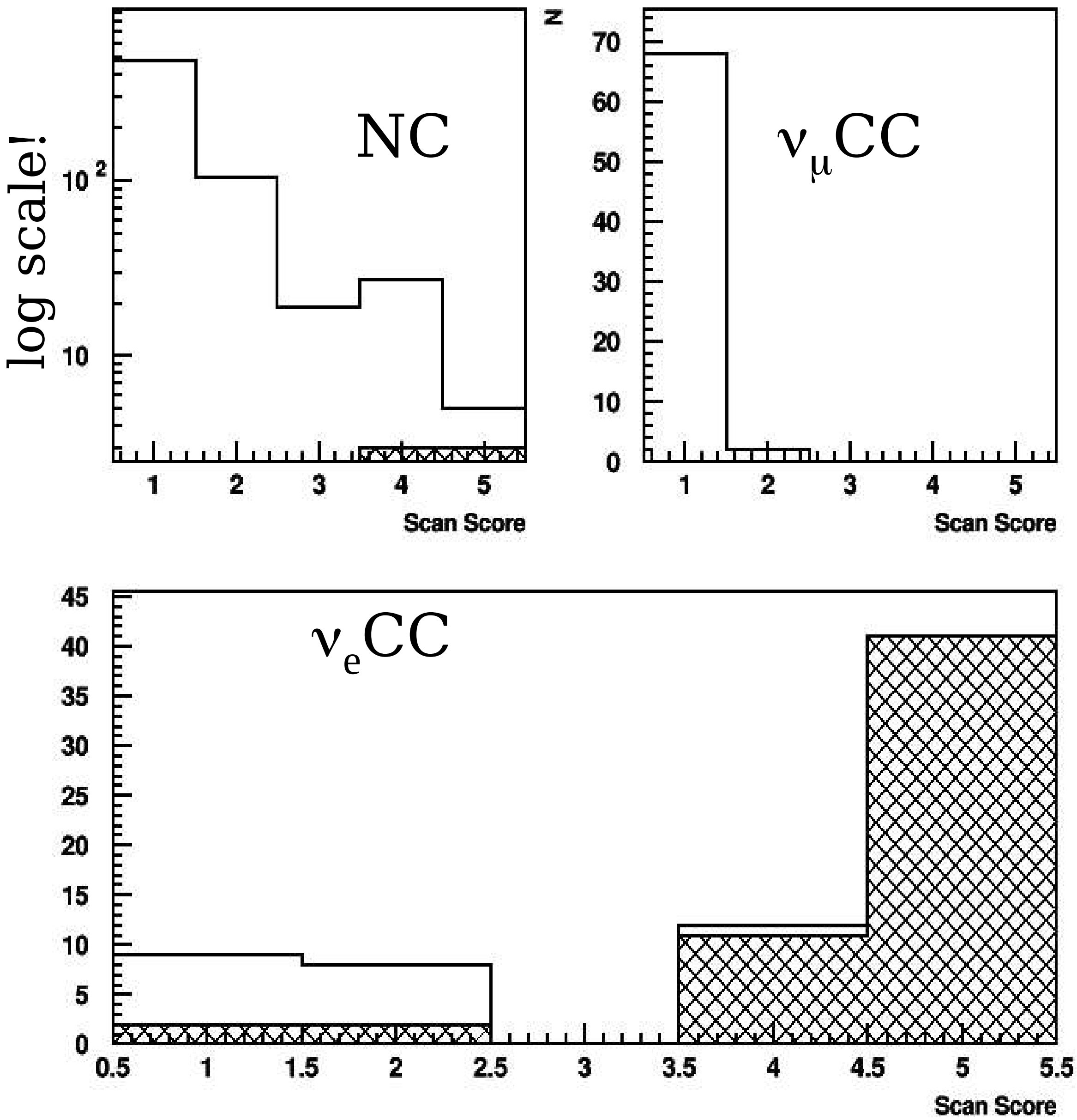
Tufts University Group

Training samples:
50 events each of ν_eCC, ν_μCC and NC

-individual samples to train
-mixed samples to test training

Blind scan of 450 events scored from 1-5 with

- signal=5
- background=1



plain region: students
Hatched region: experts

Tufts University Group

Overall efficiencies, rejection factors

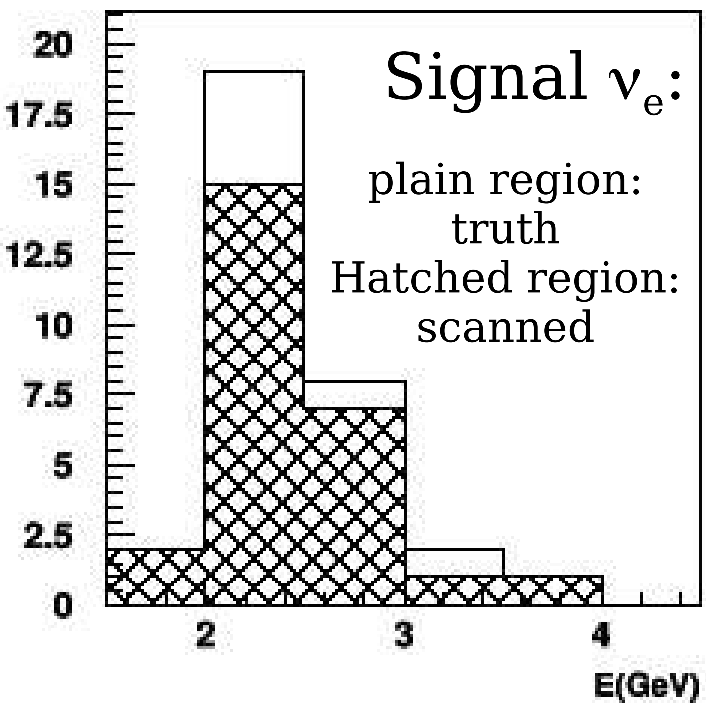
	N	pass	ε	η
NC	290	4	-	72.5
signal ν_e	32	26	0.81	-
Beam ν_e: CC	24	14	0.58	-
NC	8	0	-	

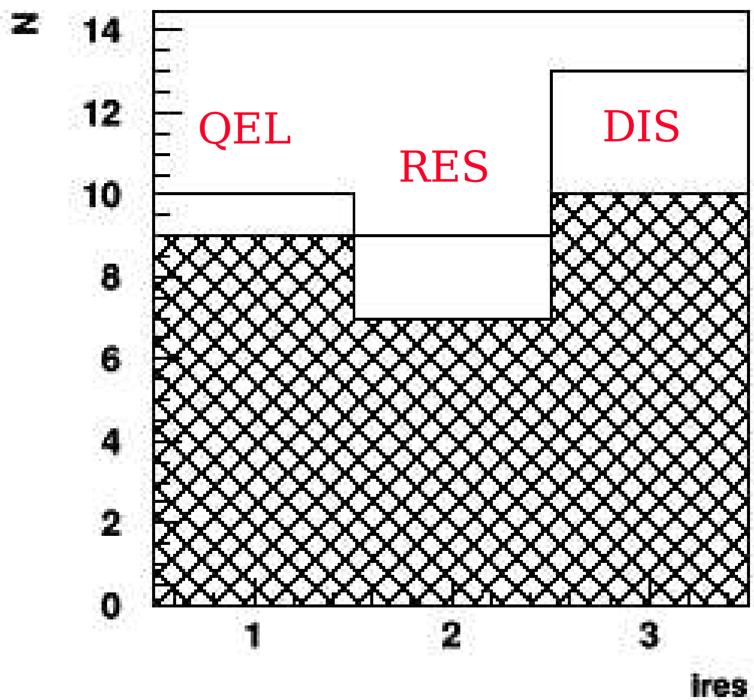
81 ± 7% ν_e efficiency

~58% beam ν_es

Efficiencies

90% 77% 70%





Tufts University Group

LArTPCs

- Total absorption calorimeter
- 5mm sampling
  -> 28 samples/rad length
- energy resolution

→ ν_e efficiency
NC rejection

First pass studies using hit level MC show
~80 ± 7 % ν_e efficiency and
NC rejection factor ~70 (99 ± 1% eff.)

Studies from groups
working on T2K LAr indicate 85-95% ν_e efficiency

move towards automated reconstruction
→ *progress expected by final report for this study*

Assuming 90% ν_e efficiency and NC background rejection well below ½ of the intrinsic ν_e beam backgrounds, how sensitive are these detectors?

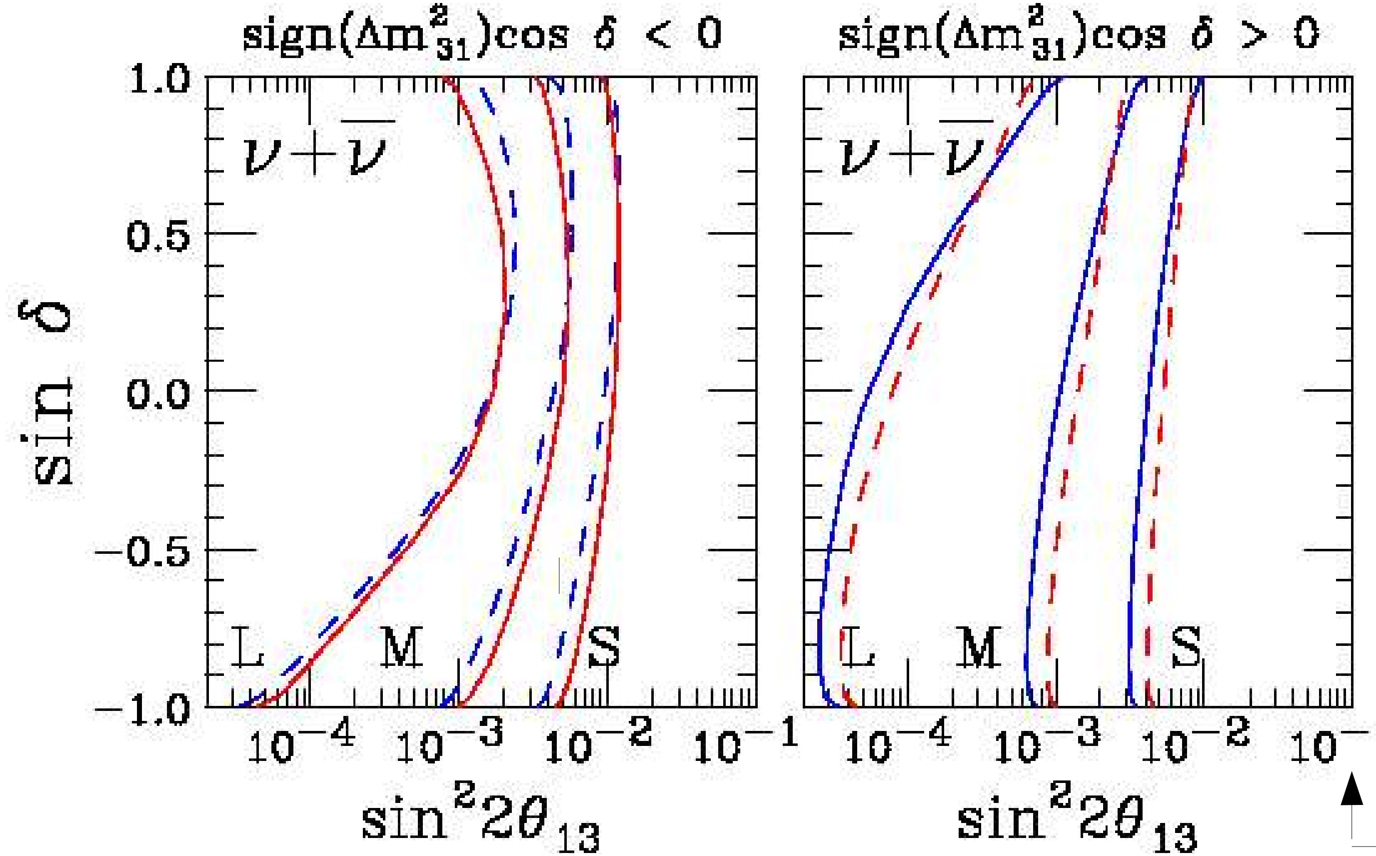
Sensitivity = detector mass x detector efficiency x protons on target/yr x # of years

"Equivalent" detectors

	Small	Medium	Large
NOvA	30kTon	30kton + PD or x5 mass or exposure	30kton + PD + x5 mass or exp.
LArTPC (90% ν_e eff.)	8kton	40kton	40kton + PD or exposure

hep-ph/0505202

Sensitivity to CP phase(sin δ) vs $\sin^2 2\theta_{13}$ for



Sensitivities assume 3 years running each in ν and ν̄ mode

CHOOZ limit

most restrictive:

cos δ <0, normal hierarchy

cos δ >0, inverted hierarchy

least restrictive:

cos δ >0, normal hierarchy

cos δ <0, inverted hierarchy

Long Baseline Study: LAr

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efficiencies and resolutions for signal and background

↓

sensitivity studies

Technical Issues:

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- R&D to get to necessary sizes (brief)

NOvA has considered sensitivity at a variety of different off-axis locations to access the 2nd max

2nd Maximum experiment

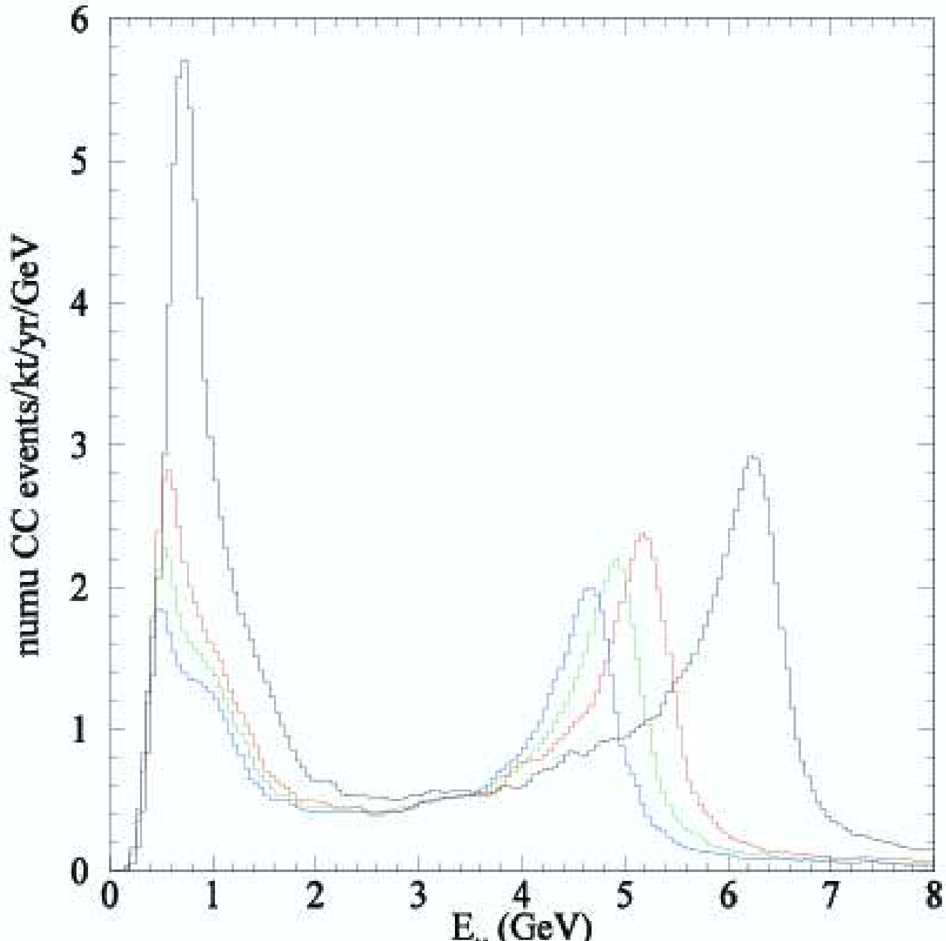
Mark has produced beam spectra that peak near the second maximum (525 MeV at 810 km)

30 km off-axis

36 km off-axis

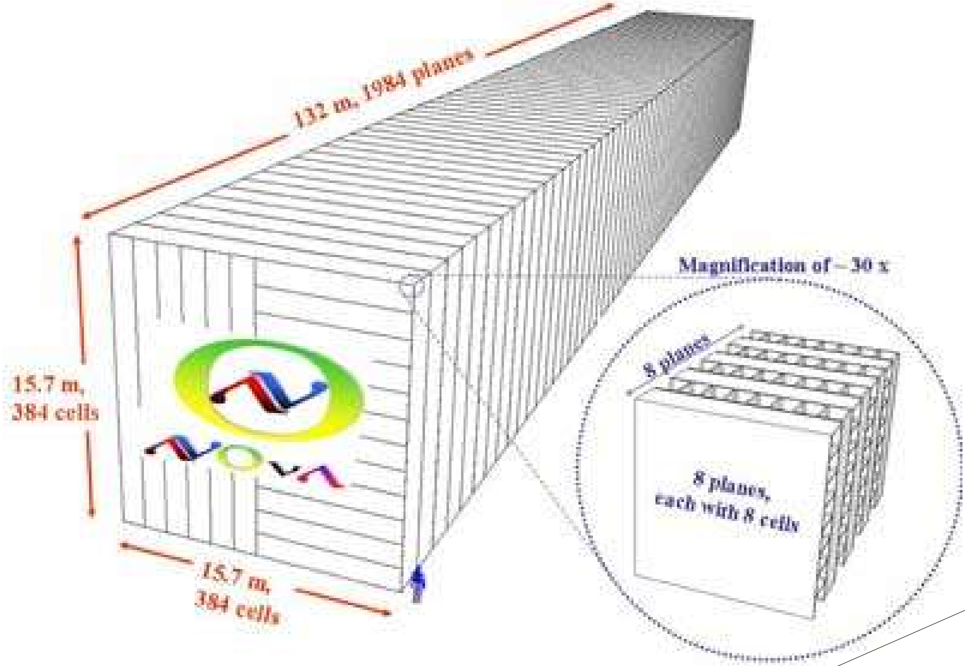
38 km off-axis

40 km off-axis



slide from Peter Litchfield

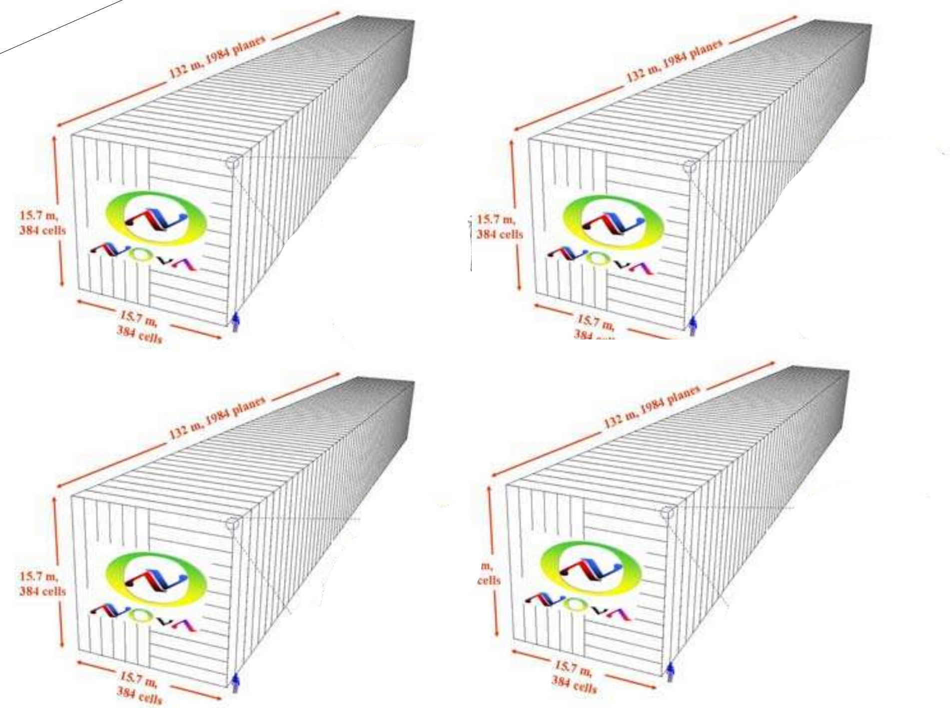
NOvA at the 2nd maxima:



- alternating xy cells of liquid scintillator
- cells: 15.7m x 3.87cm x 6.0 cm
- 0.8mm looped WLS fiber in each cell for light collection
- WLS fibers read-out by APDs
- 80% active material

for 2nd detector location:

- scale to 100kton
- detector at 735km
- 5 year neutrino run



2^{nd} maximum experiment

I ran my selection program with the variables and cuts I used to examine the Booster 8 GeV beam in Nova and a very minimum of tuning (~2 hours)

Parameters: 100kton detector, 5 years run, 3.7 10^{20} pot at 735km
m^2=0.0025 eV^2, $\sin^2 2\ _{23}$=1, $\sin^2 2\ _{13}$=0.1

km	Sig ν_es	Selected e_{osc}		misID NC	e_{beam}	FOM
30	292	55		69	15	5.9
36	223	51		49	11	6.4
38	188	43		43	10	5.8
40	156	36		39	10	5.1

compare to FOM of ~25 for NOvA on axis

slide from Peter Litchfield

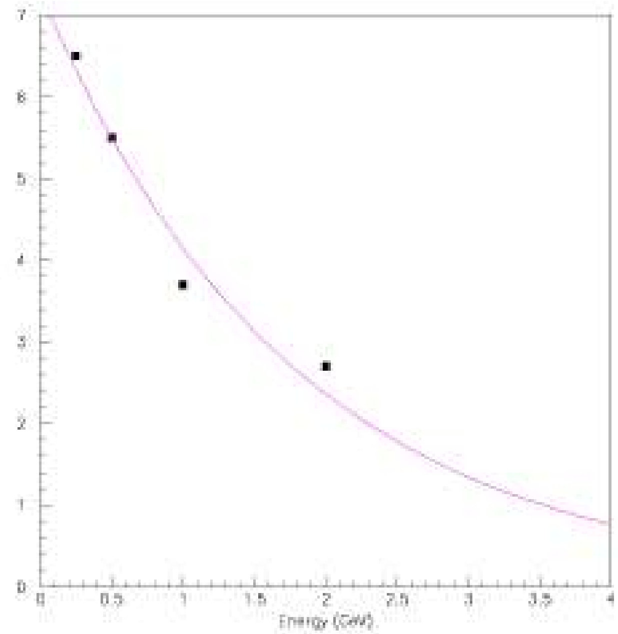
Are misID NCs a problem at low energies in LAr?

Study on e/π° separation
down to low energies

A. Rubbia

•dE/dx in first 2.4 cm studied for 1000 e and π° events (simulation with noise): 0.25, 0.5, and 2 GeV

surviving pion fraction



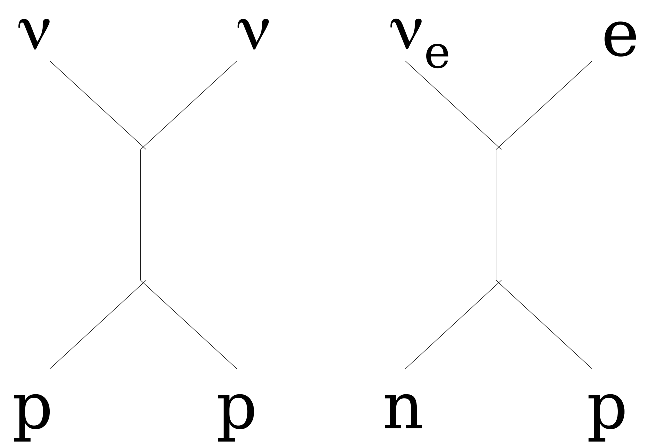
efficiency decreases as E increases (as Compton Scattering process decreases)

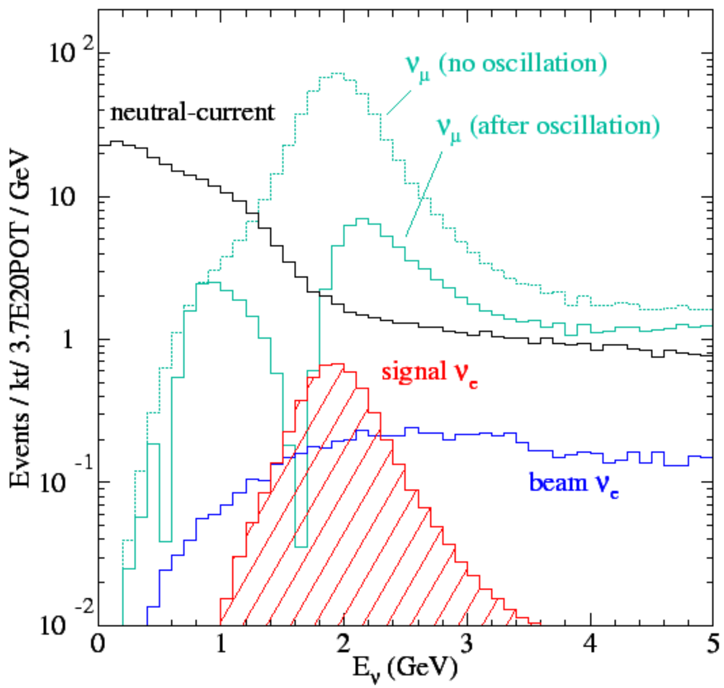
Figure 33: Survival π^0 efficiencies as a function of the incoming energy. The points are simulations and the cu
is the result of an exponential fit.

•fold in vertex separation from hand scan: overall 0.2% inefficiency
•fold in beam flux (pion production dropping rapidly at low energies)

What about NC elastic misID at low energies?

At low energies neutral current elastics are misIDed as ν_eCC





MisID low energy protons as electrons

Should not be a problem as electrons can be IDed down to at least 10 MeV in LAr.....

Assuming efficiencies from Tufts study.......

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36	223	51		49	11	6.4
38	188	43		43	10	5.8
40	156	36		39	10	5.1
LAr at 36	223	178		5	38	27

compare to FOM of ~25 for NOvA on axis

slide from Peter Litchfield

Goals for July report:

Combine

- generated fluxes
- existing efficiencies, resolutions, and backgrounds

→ sensitivity calculations

Goals for October

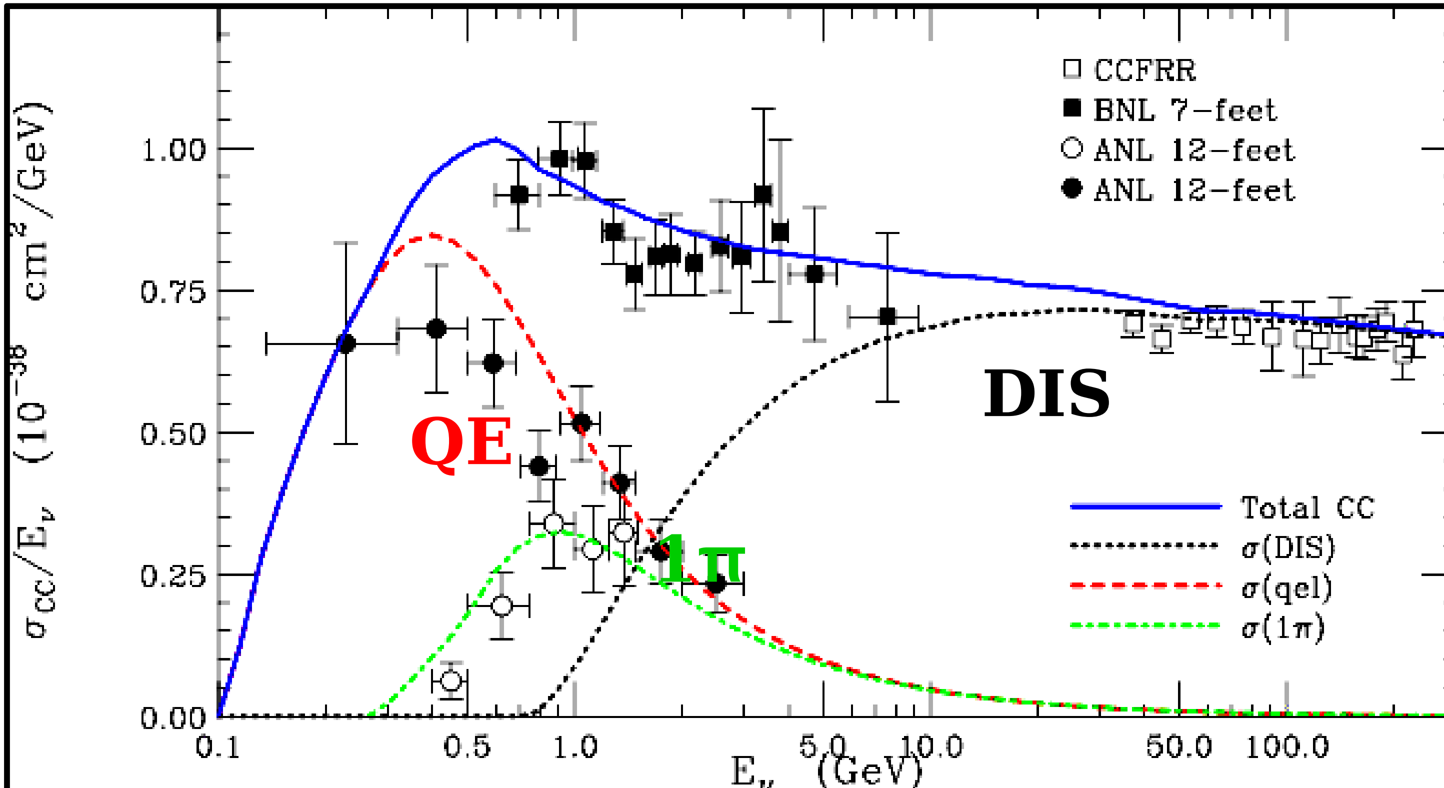
- study efficiencies using hit level MC (have several options)
- work on first pass of automated reconstruction

→ refined sensitivity calculations

How good is NCπ° production at 0.5 GeV and below?

How well can low energy protons be separated from low energy electrons?

How good is the energy resolution at very low energies?



0.5-10 GeV

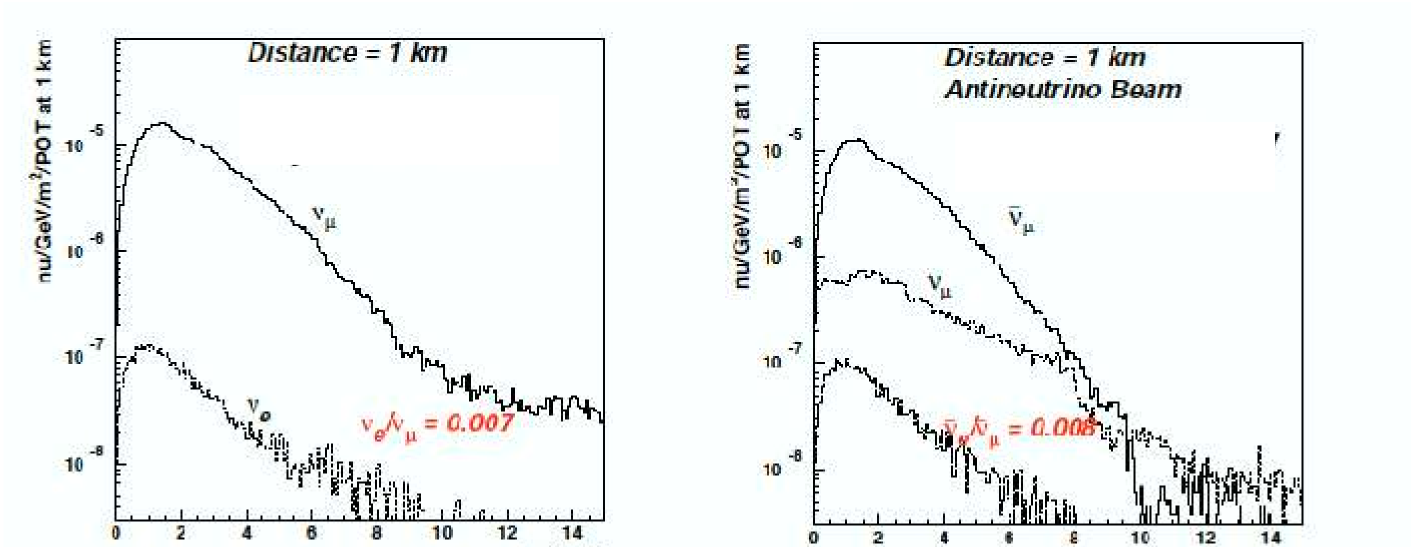
Wide-band beam
to DUSEL

- Significant contribution from DIS
- higher energy NC pi0
  - more forward
    - harder to reconstruct

50 lt
in NOMAD
beam

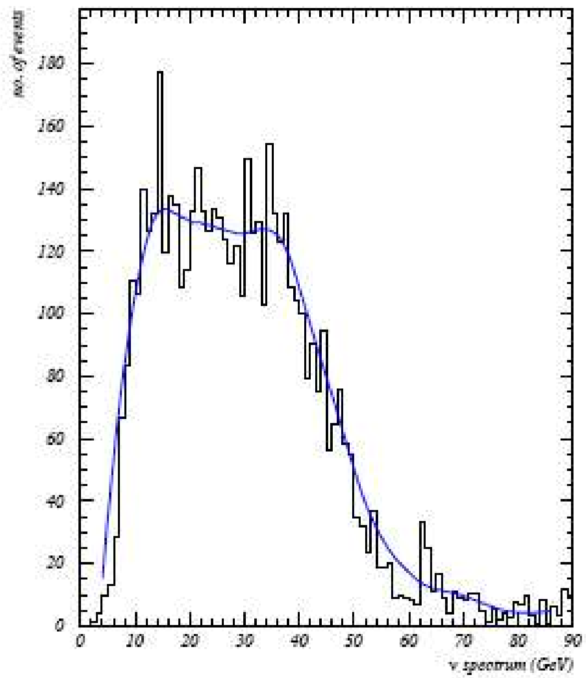
LAr neutrino
data

Wideband Flux



Fluxes do not overlap: however, relevant overlap is in Q^2.

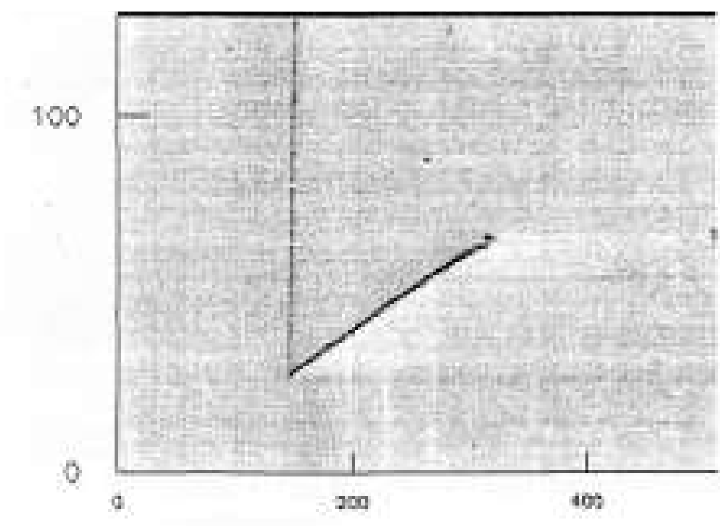
With fine-grained capabilites of LAr -> can tease out low Q^2 events from large DIS sample

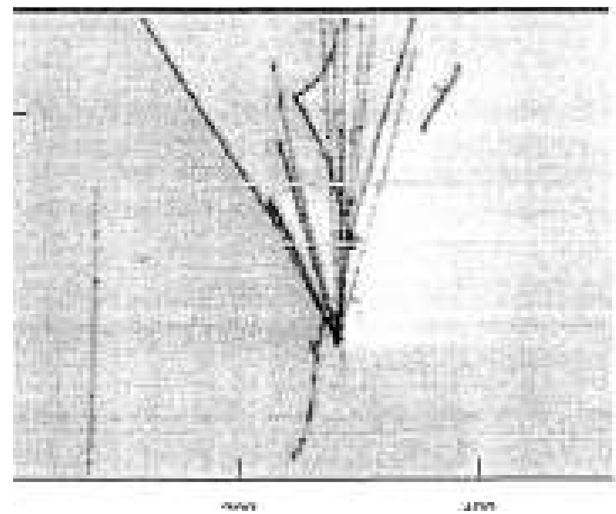


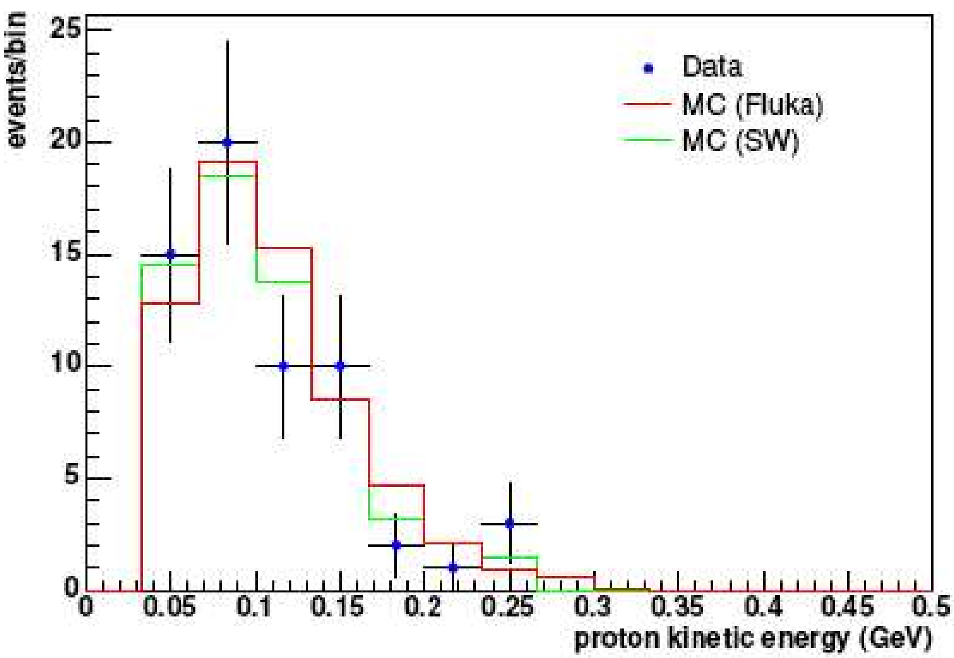
NOMAD Flux

- good for relevance of data
- good indication for success of reconstrucing at higher energies

Existing data from 50 liter ICARUS run

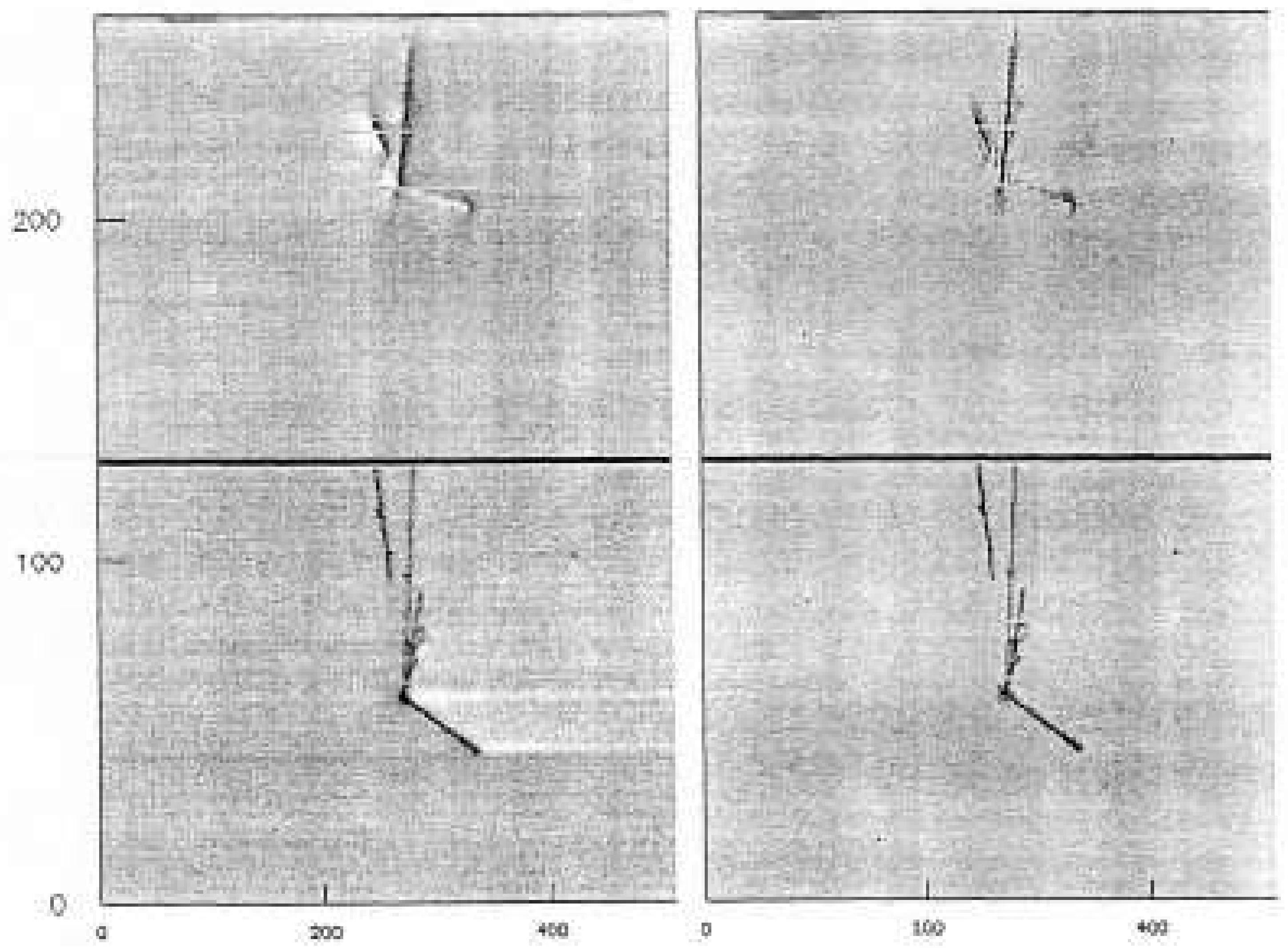






Clean sample (~100 evts) of reconstructed CCQE events teased out of DIS events (sample used was ½ of 1.5% CCQE)

Charged Current
π^0 interactions



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How well can we reconstruct DIS events?
How well can we reconstruct high momentum NCpi0 events?
How good is the energy resolution over this broad range?

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- R&D to get to necessary sizes (brief)

How much depth is needed?

Cosmic backgrounds primarily from

- crossing muons and decay products
- neutrons
- photons

Effect on

- beam physics
- nucleon decay searches
- Atmospheric neutrinos
- Solar neutrinos
- Supernovae searches

Beam physics:
Cosmic Muon estimates for the surface
for a 15kton detector

live time: 2.5ms for 3m drift
at 100 kHz, 250 total coincident passing cosmics…

these should not be a background (reconstructable)
but can cause “dead space”

Assume one cosmic “blurs” 2cm x 1.5 cm
= 4 wires x 10 μs
in the drift direction, by the vertex (crucial place)

folding in total plane area: inefficiency is 1.5×10^{-4}
(small)

cosmics greatly reduced with even minimal overburden

Beam physics cont:
photons
for a 15kton detector on the surface

worrisome, as long live time greatly increases
coincident background

gain (compared to a conventional detector)
in surface to volume (x2)
efficiency (x3)

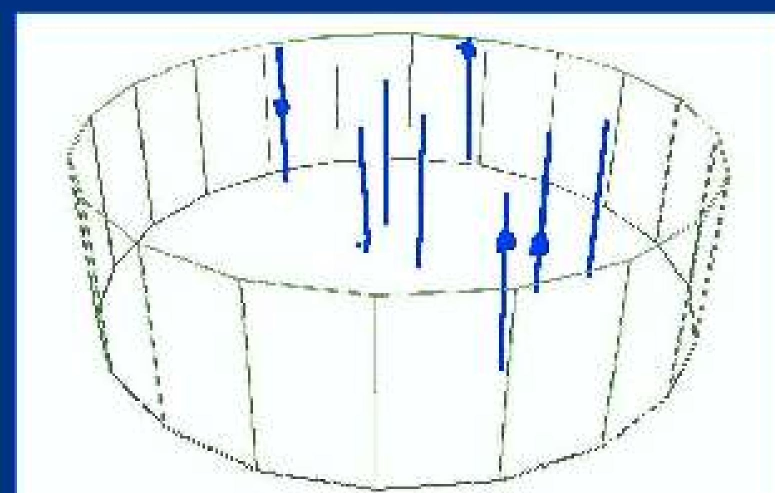
but lose x250 in live time

- *need better estimates*
- *sacrifice outer 1.5 m of detector?*
- *some minimal overburden....*

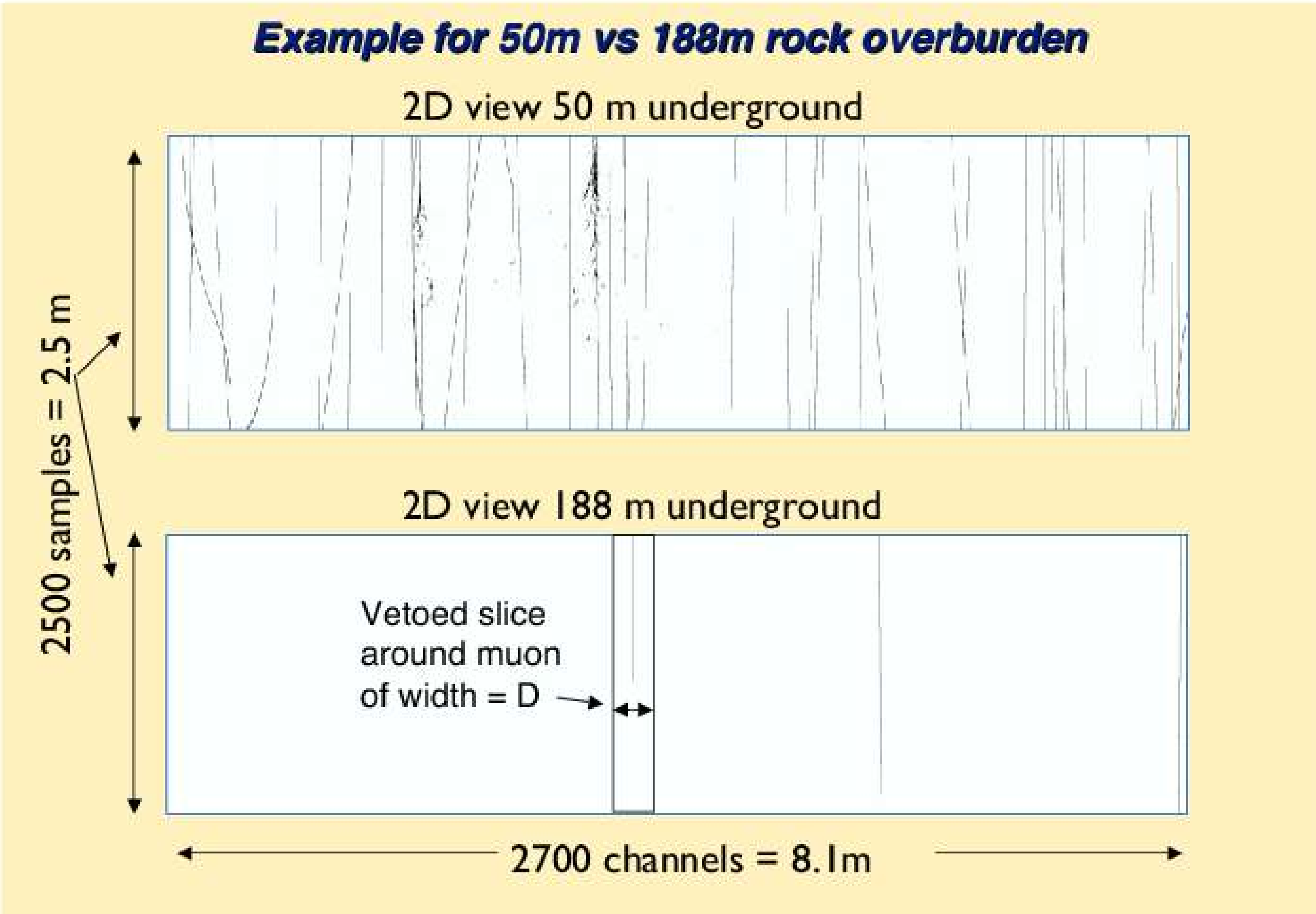
Preliminary assessments on detector depth

- It is generally assumed that the detector will be located deep underground in order to shield it from cosmic rays.
  - ➥ **Is a shallow depth operation possible?**
- This is not a trivial question. We have started to perform detailed simulations to understand operation at a shallow depth (At a minimum of 50 meter underground and below)
- Preliminary results on (a) crossing muons rates which are important to design detector readout system and fiducial volume definition (b) background to proton decay searches associated to cosmogenic backgrounds

Underground muons are essentially vertical and in our drift configuration point along the drift direction to minimize impact on number of touched channels.
When a muon cross the detector, we "veto" a slice around it of width = D



from A. Rubbia, NUFACT 05



from A. Rubbia, NUFACT 05

Crossing muon rates at different detector depths

Muon flux on surface = 70 m^{-2} s^{-1} sr^{-1} with E_μ > 1GeV

Depth rock	Total crossing muons (E> 1GeV) per 10ms	Fiducial mass after slice of size D around each muon is vetoed		
		D=10 cm	D=20 cm	D=30 cm
Surface	**13000**	...	...	...
50 m	**100**	50 kton	25 kton	10 kton
188 m	**3.2**	98 kton	96 kton	94 kton
377 m (1 km w.e)	**0.65**	100 kton	100 kton	100 kton
755 m (2 km w.e)	**0.062**	100 kton	100 kton	100 kton
1.13 km (3 km w.e)	**0.010**	100 kton	100 kton	100 kton

from A. Rubbia, NUFACT 05

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physics beyond accelerator neutrino oscillations

- Technical feasibilty vs detector size
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continue studies of depth vs cosmic backgrounds
and impacts on other phyiscs

-nucleon decay details

-SN detection details

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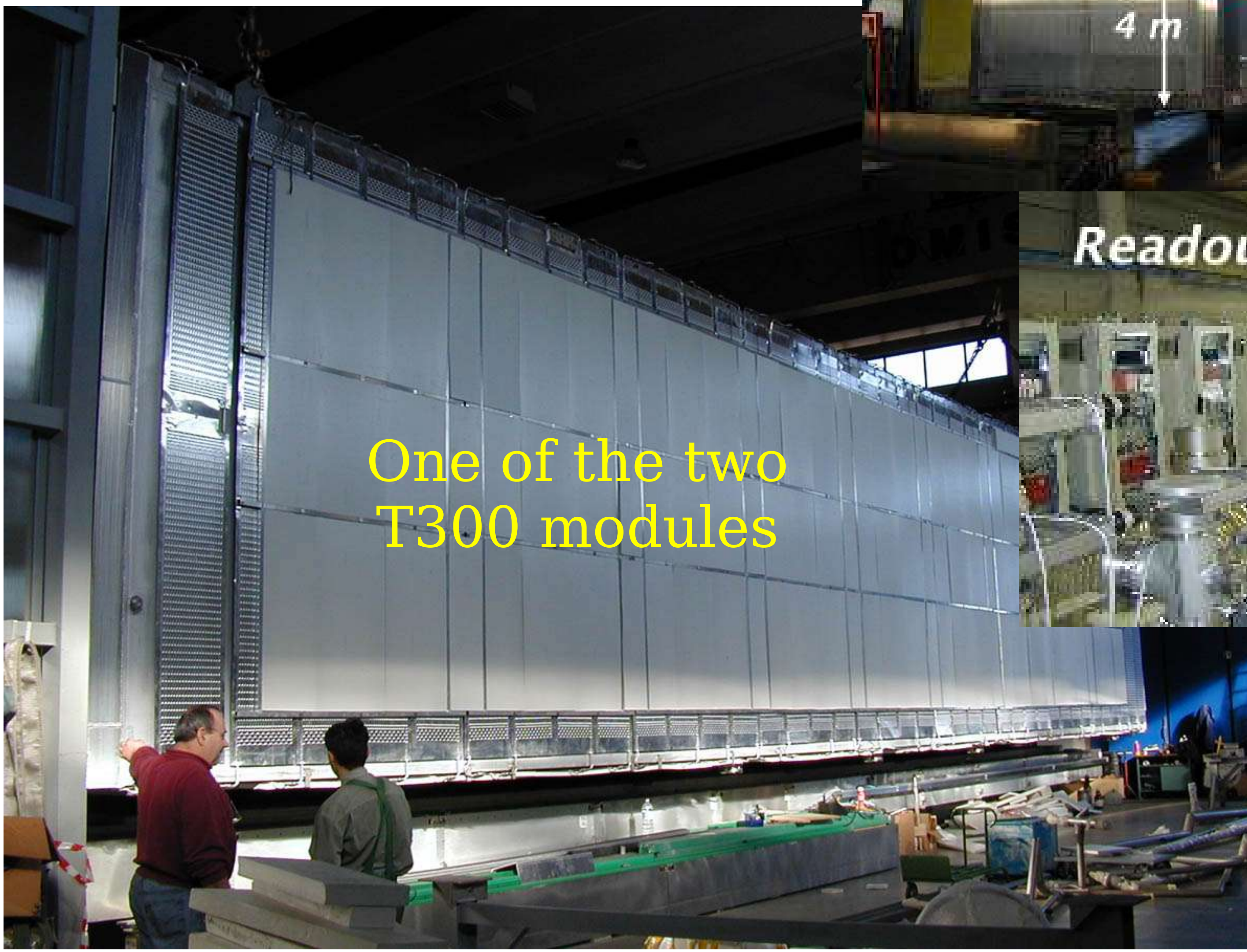
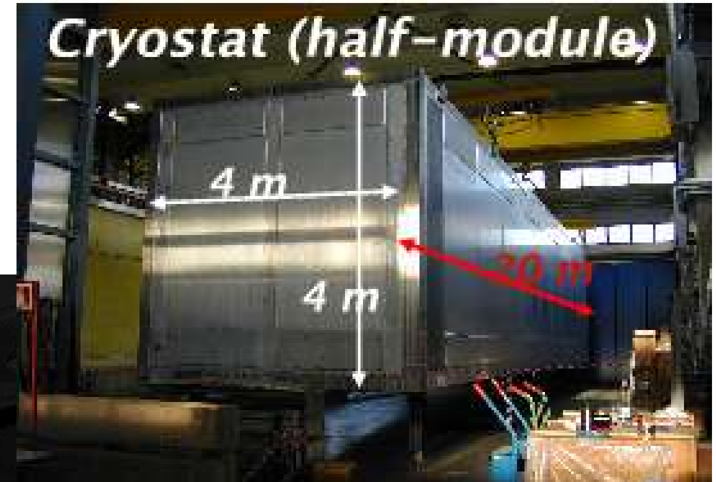
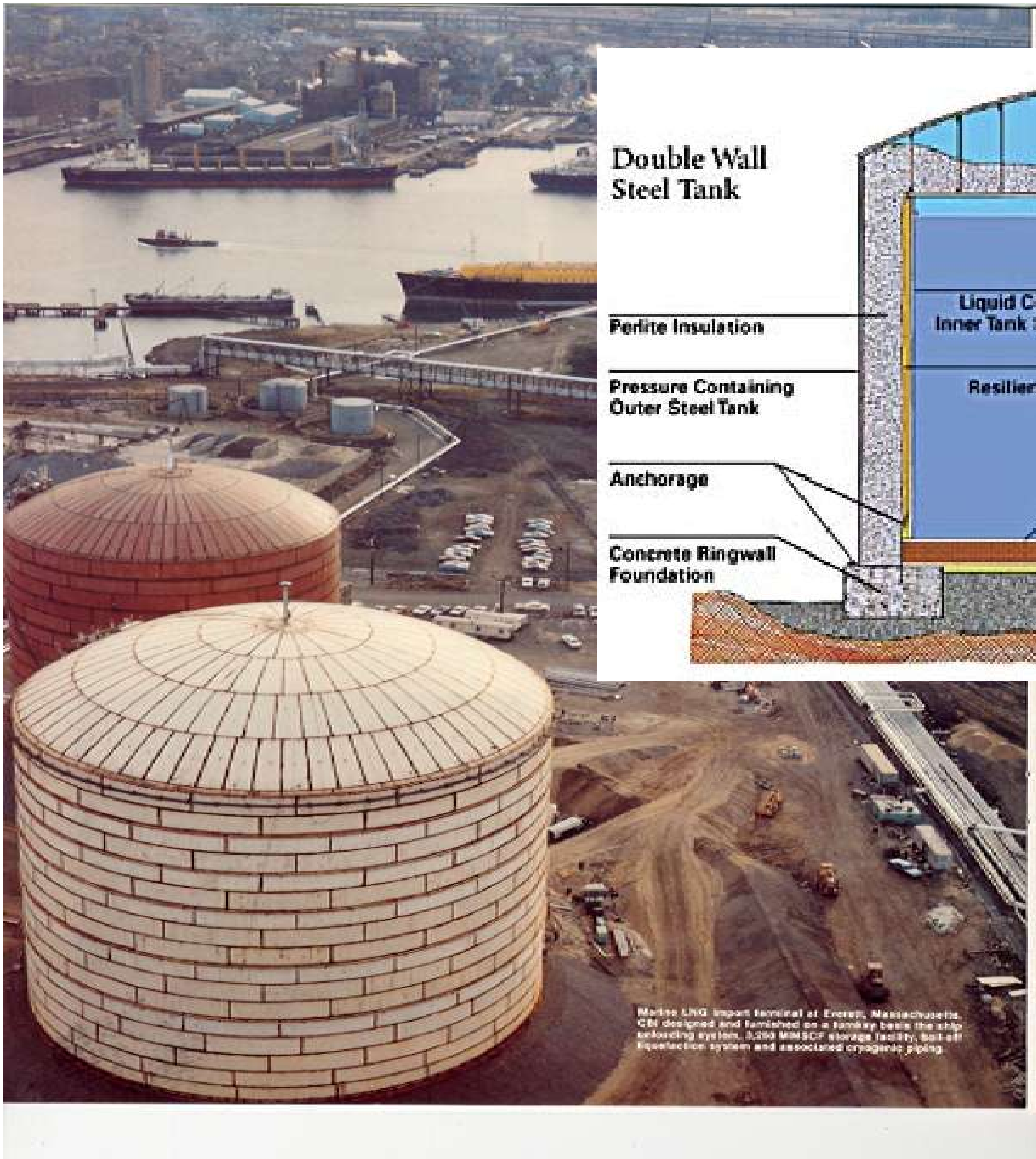
ICARUS: prototype work
late 80's -> 2000
24cm drift -> $10m^3$

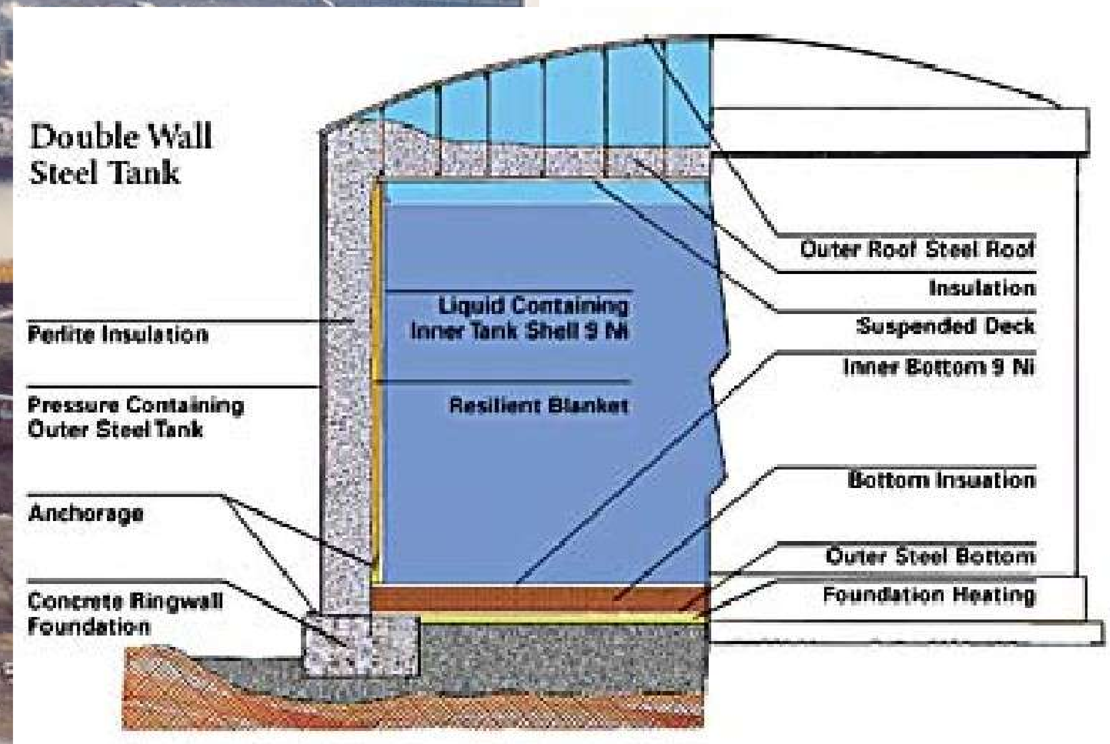




tested above
ground in Pavia
in 2001
now below
ground in
Gran Sasso

technical feasiblity demonstrated for "small" scales

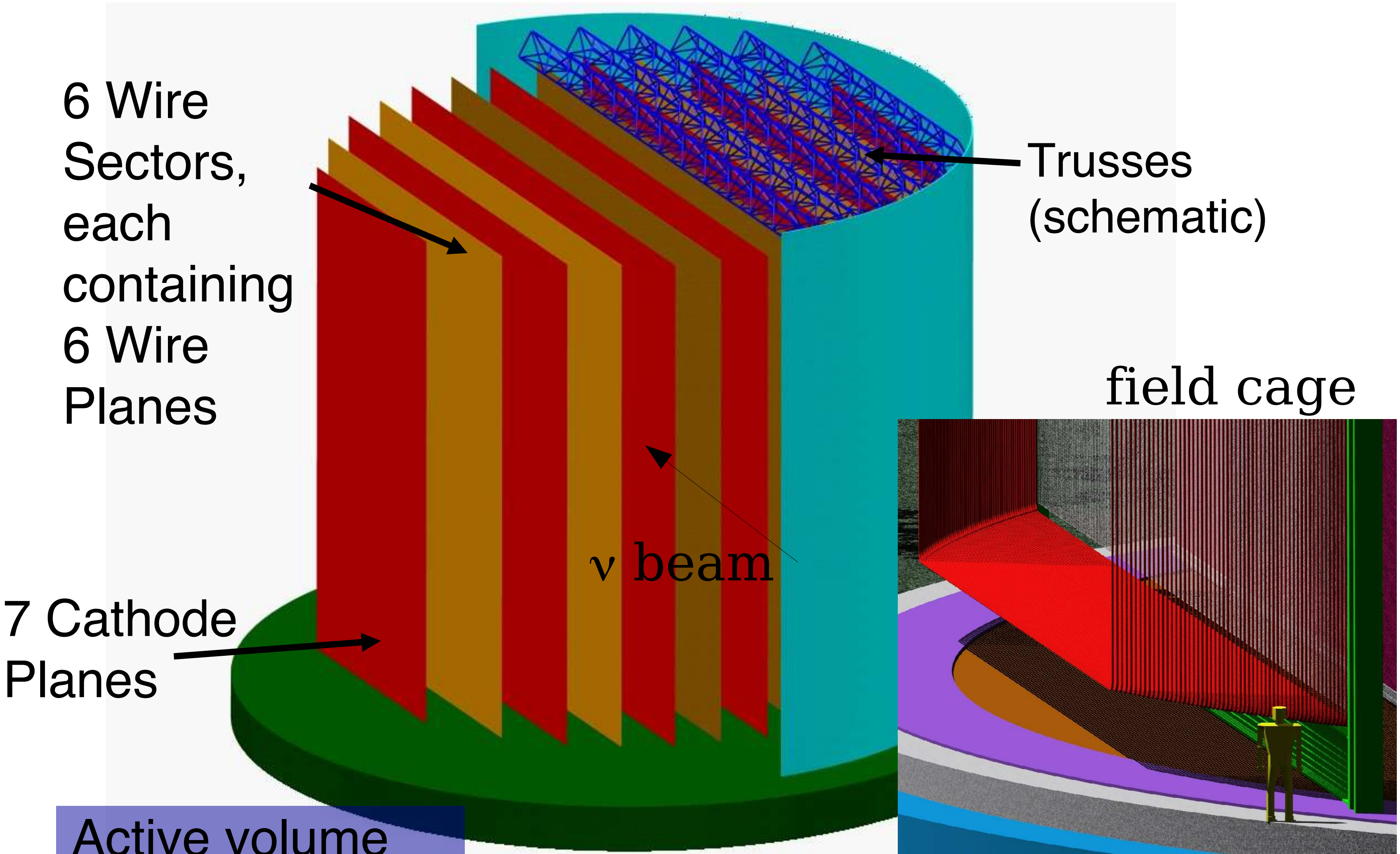




Many large LNG tanks in service

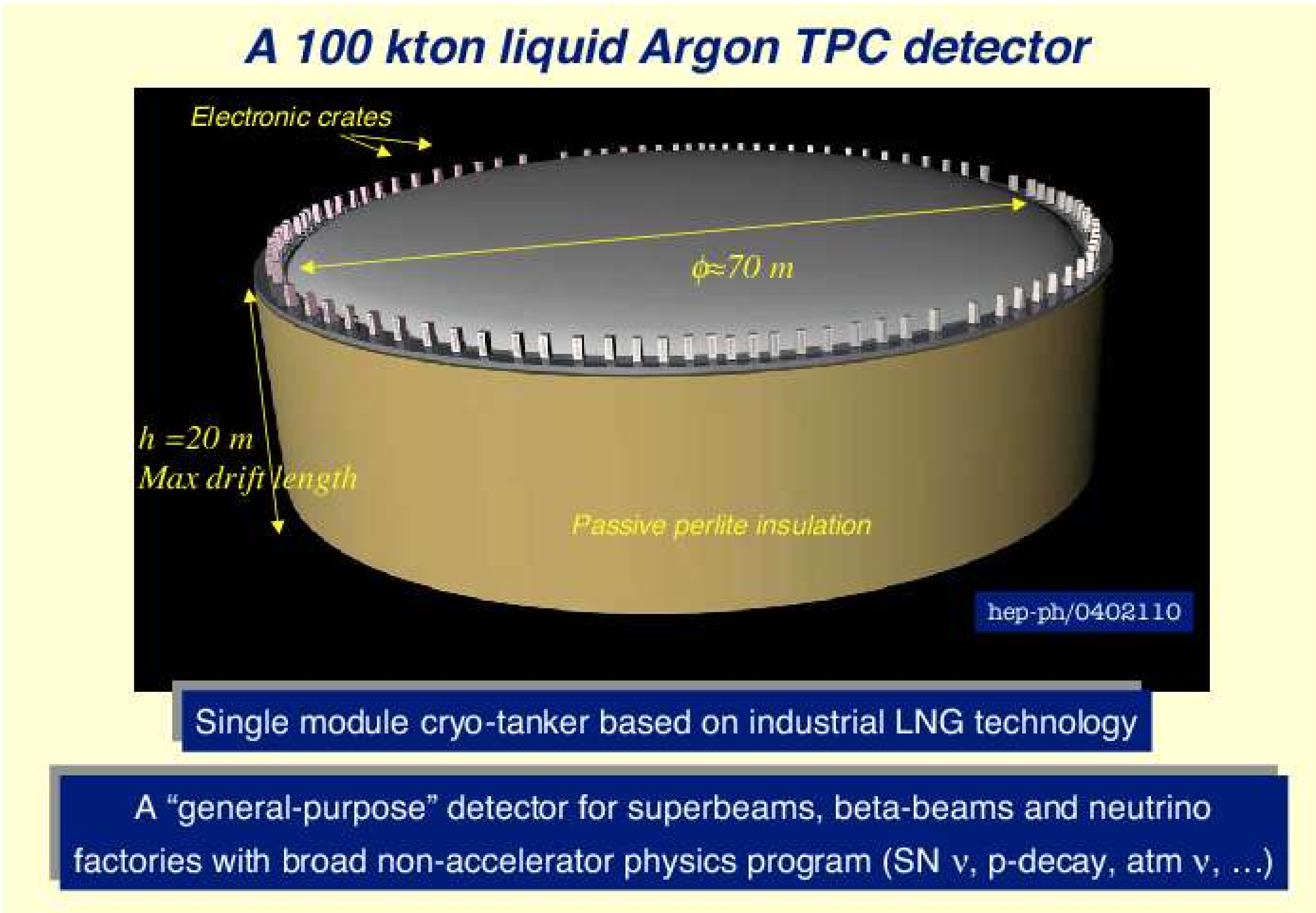
Excellent safety record
Last failure in 1940 understood

Modularized drift regions inside tank



Active volume
Diameter: 40m
Height: 30m

Scalable → 15-50 kTons
4 - 6 wire planes



from A. Rubbia's talk at NuFACT05

Challenges for massive “multi-drift region” detector

Purity:

3 m drift in LAr

purification - starting from atmosphere (cannot evacuate detector tank)

- effect of tank walls & non-clean-room assembly process

Wire-planes:

***long wires** - mechanical robustness, tensioning, assembly, breakage/failure*

Signal processing:

***electronics** - noise due to long wire and connection cables (large capacitance)*

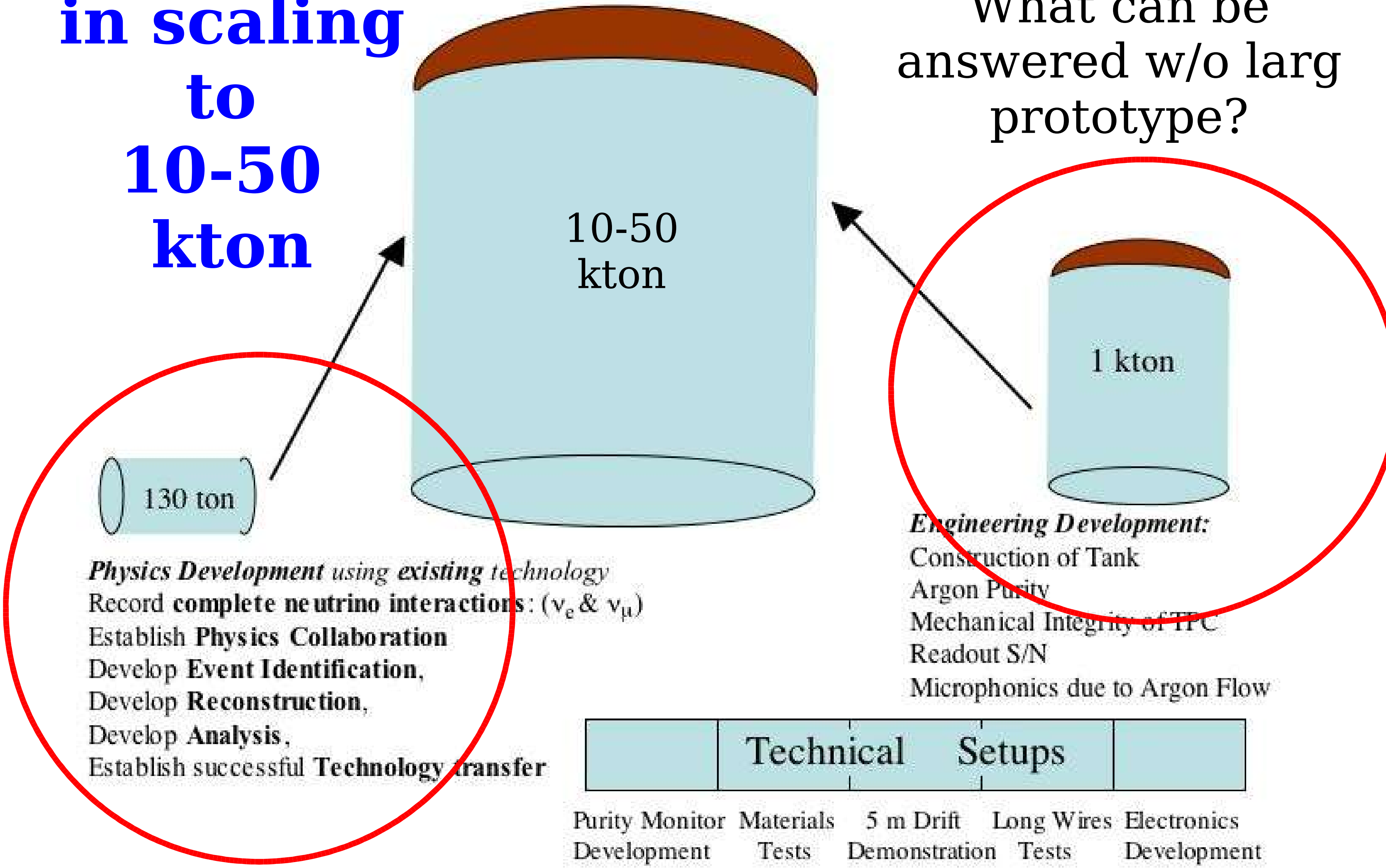
surface detector - data-rates,

- automated cosmic ray rejection

- automated event recognition and reconstruction

Engineering questions in scaling to 10-50 kton

from where can you scale?
What can be answered w/o larg prototype?



What are the added challenges of going underground?

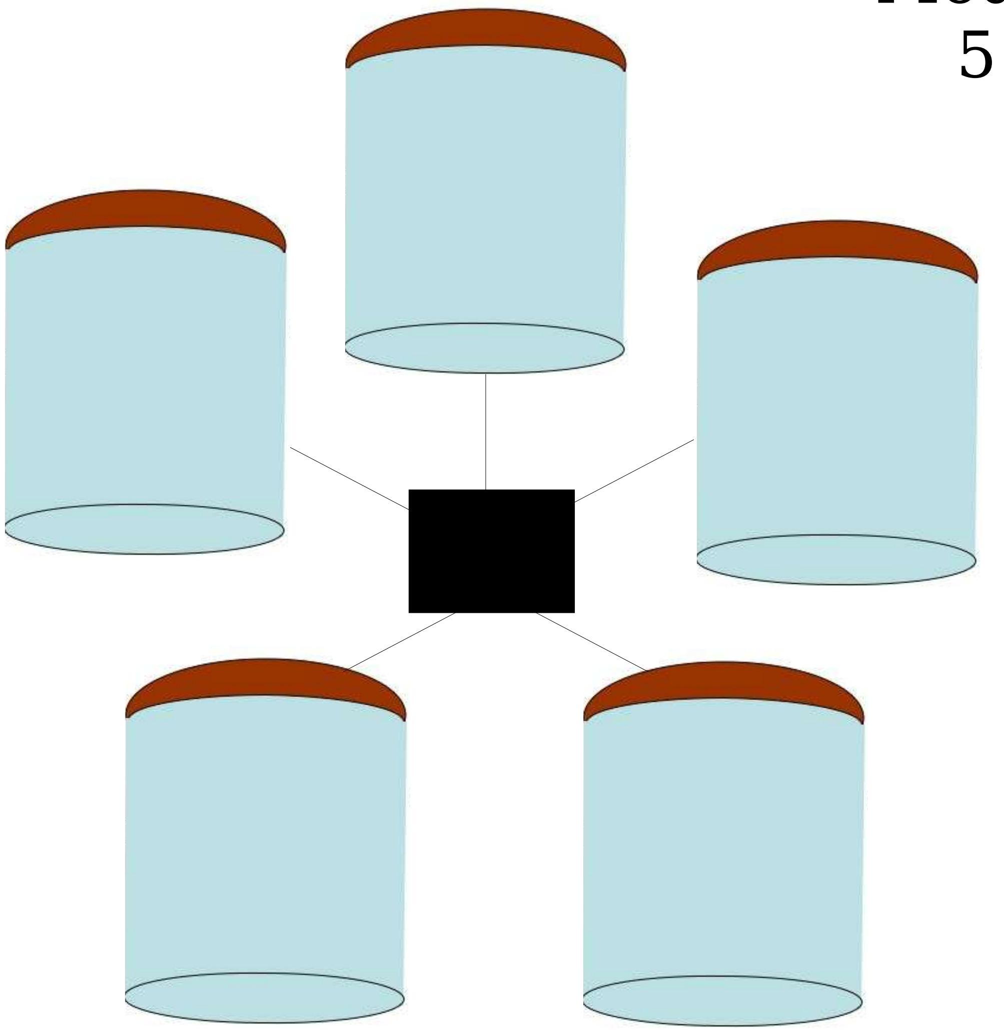
-underground construction
- *-how deep underground is deep?*
- *-how large a cavern is needed?*

-safety considerations
- *-how deep is deep?*
- *-LAr spill containment*

-cost……

Is 50-100 ktons the right size?

Modularize: build 5 10-20 kton detectors



what do you gain?
-phased construction
-reduction of systematics
-ease of engineering?

what do you lose?
-cost (pedestal cost)
-fiducial volume

LArTPCs: technology with a lot of promise: How much better is it for options beyond NOvA for beam physics and beyond?

Existing work to understand efficiencies and resolutions in the 0.5-10 GeV enegy range for sensitivity calculations

- Estimates for sensitivites for phyiscs beyond oscillations
- Study of technical issues for massive LArTPCs and considerstions for underground work

July report

Develop tools to

- advance on efficiencies, purities and resolutions and backgrounds

refined sensitivity calculations

- refine technical issues and related open questions
- jusfiable 1st pass cost estimates

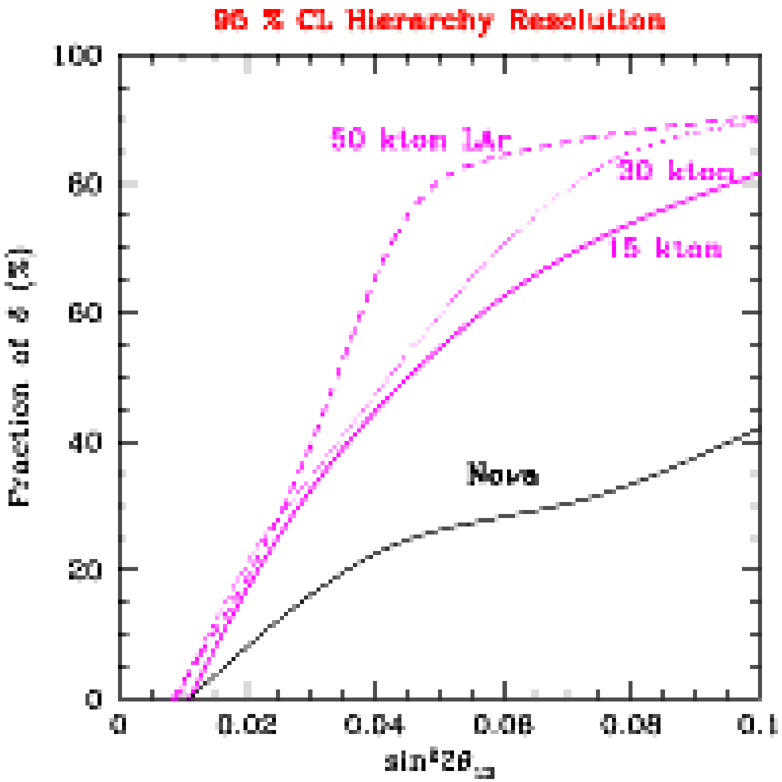
October report

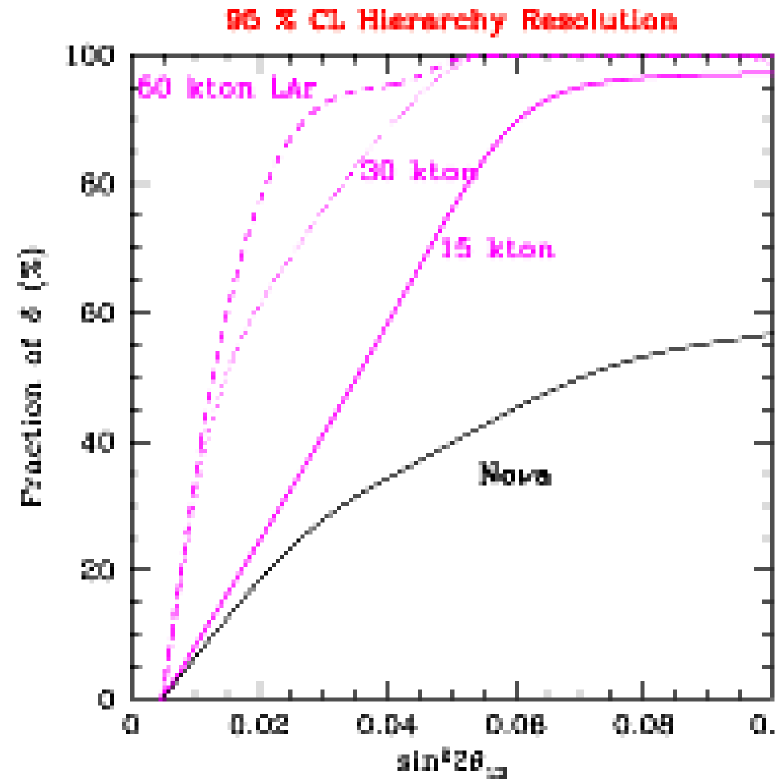
Backup Slides

SuperNOvA sensitivities with LAr.....

"Determining the Neutrino Mass Hierarchy and CP-Violation in NOvA with a Second Off-axis Detector"

O. Mena, S. Palomares-Ruiz, S. Pascoli. hep-ph/0510182





6.5 e20 pot/yr

Exposure (yrs):

Far: 3 nu + 3 nubar

Near + Far: 6 nu + 2 nubar

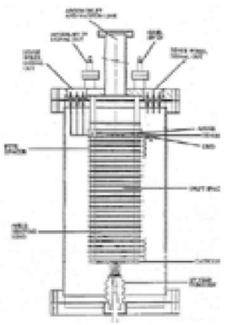
Proton Driver: 25e20 pot/yr

Exposure (yrs):

Far: 3 nu + 3 nubar

Near + Far: 3 nu + 1 nubar

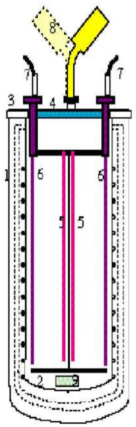
Technical Feasibility:
History of prototype work on ICARUS



24 cm drift wires chamber

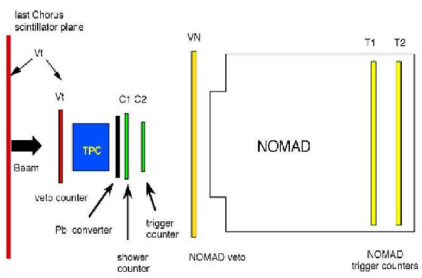
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

50 litres prototype
1.4 m drift chamber



1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

Neutral current event with 1 GeV π^0

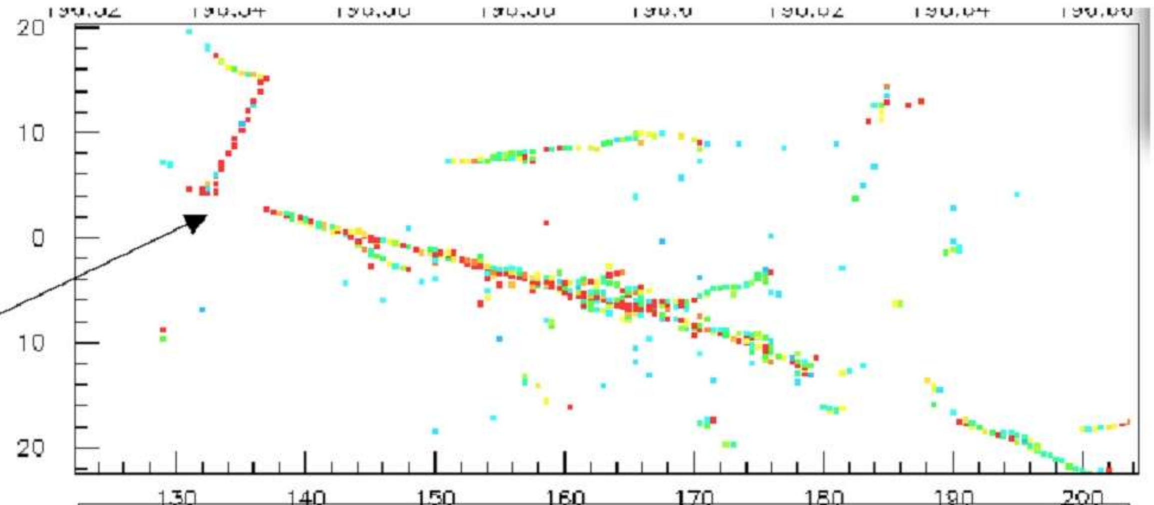
$$\nu_\mu + \mathrm{n} \rightarrow \nu_\mu + \pi^+ + \pi^- + \pi^0 + \mathrm{n}$$

$$(1\ \mathrm{GeV})\ \pi^0 \rightarrow \gamma + \gamma$$

3.5% X_0 samples

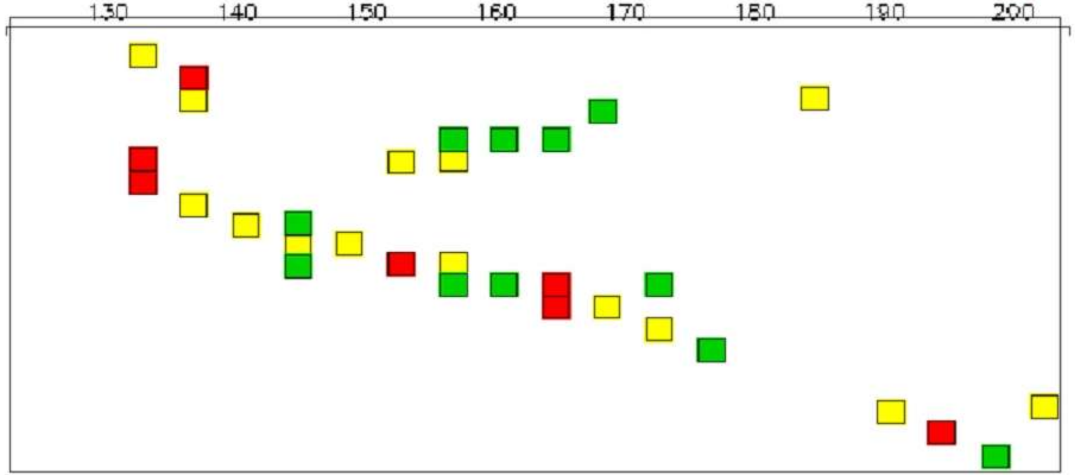
in all 3 views

4 cm gap



12% X_0 samples

alternating x-y

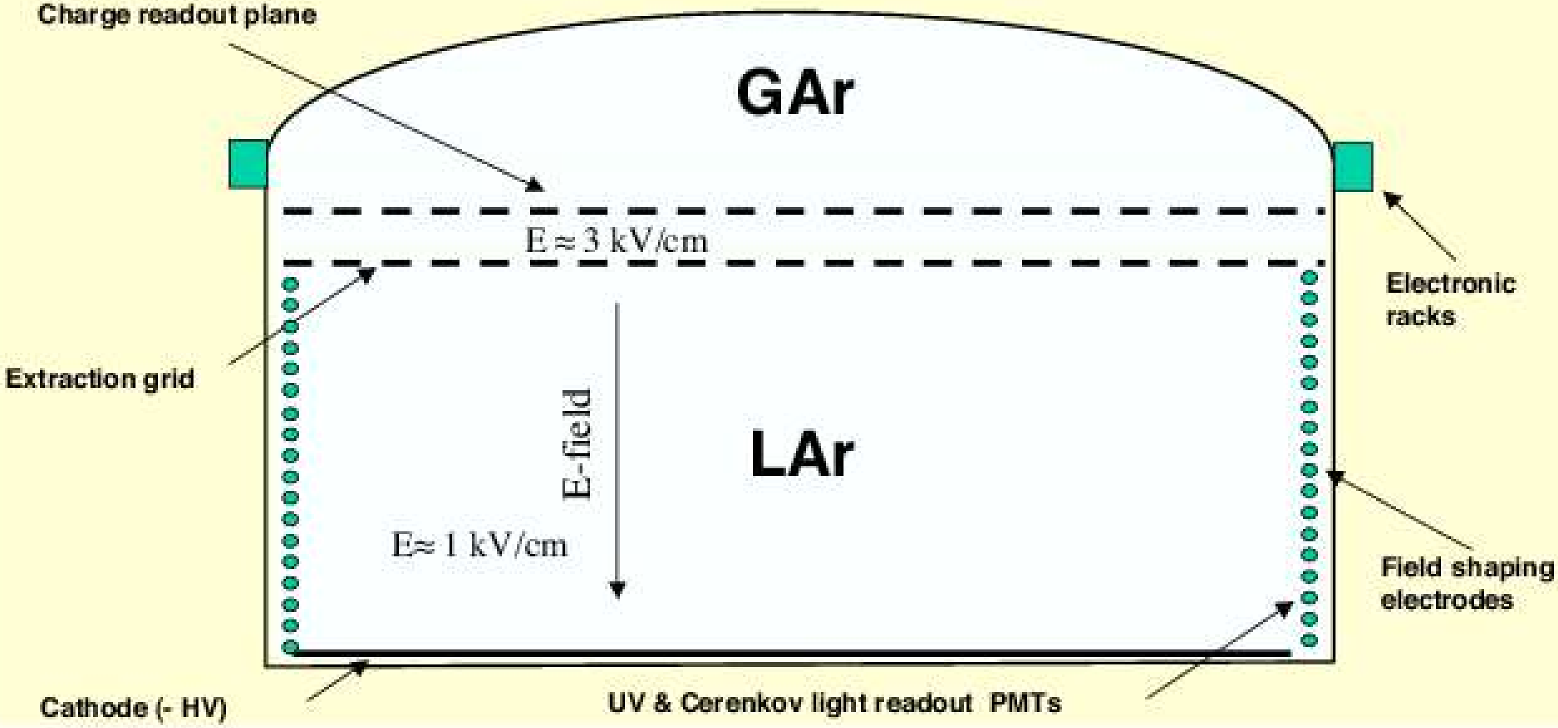


What are the advantages/disadvantages of this design?

A tentative detector layout

Single detector: charge imaging, scintillation, Cerenkov light

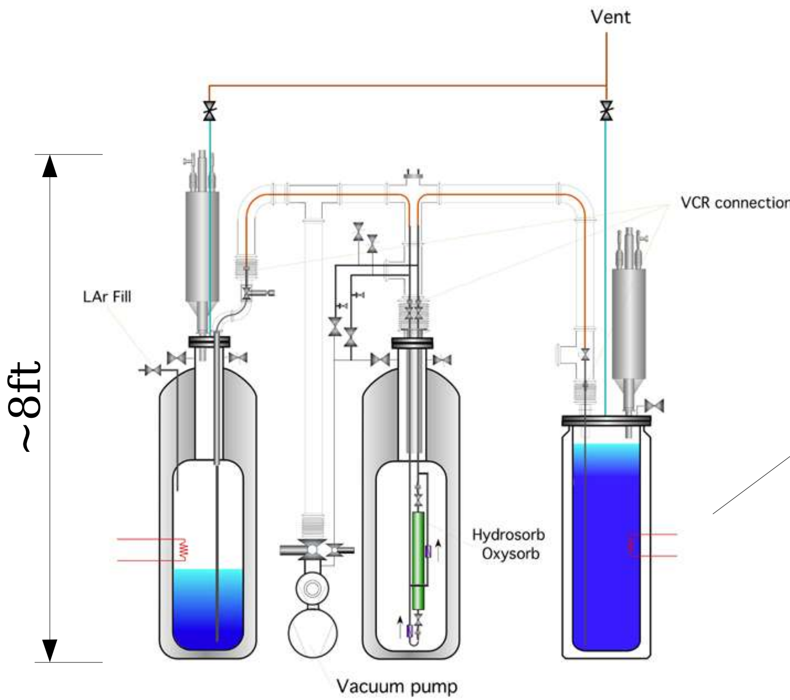
Dewar	$\phi \approx 70$ m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability



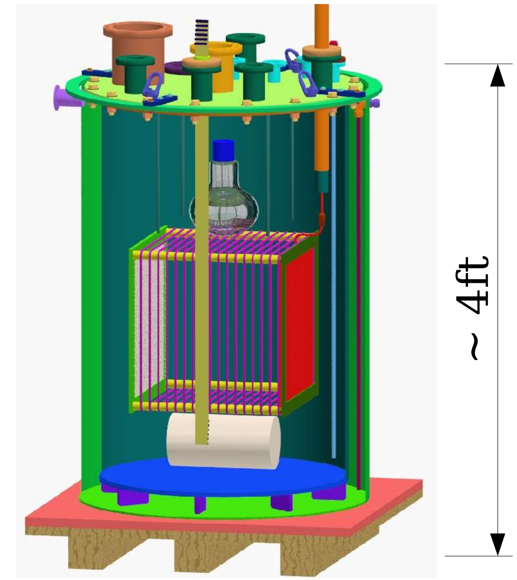
magnetized LAr?

from A. Rubbia's talk at NuFACT05

R&D efforts underway



at FNAL

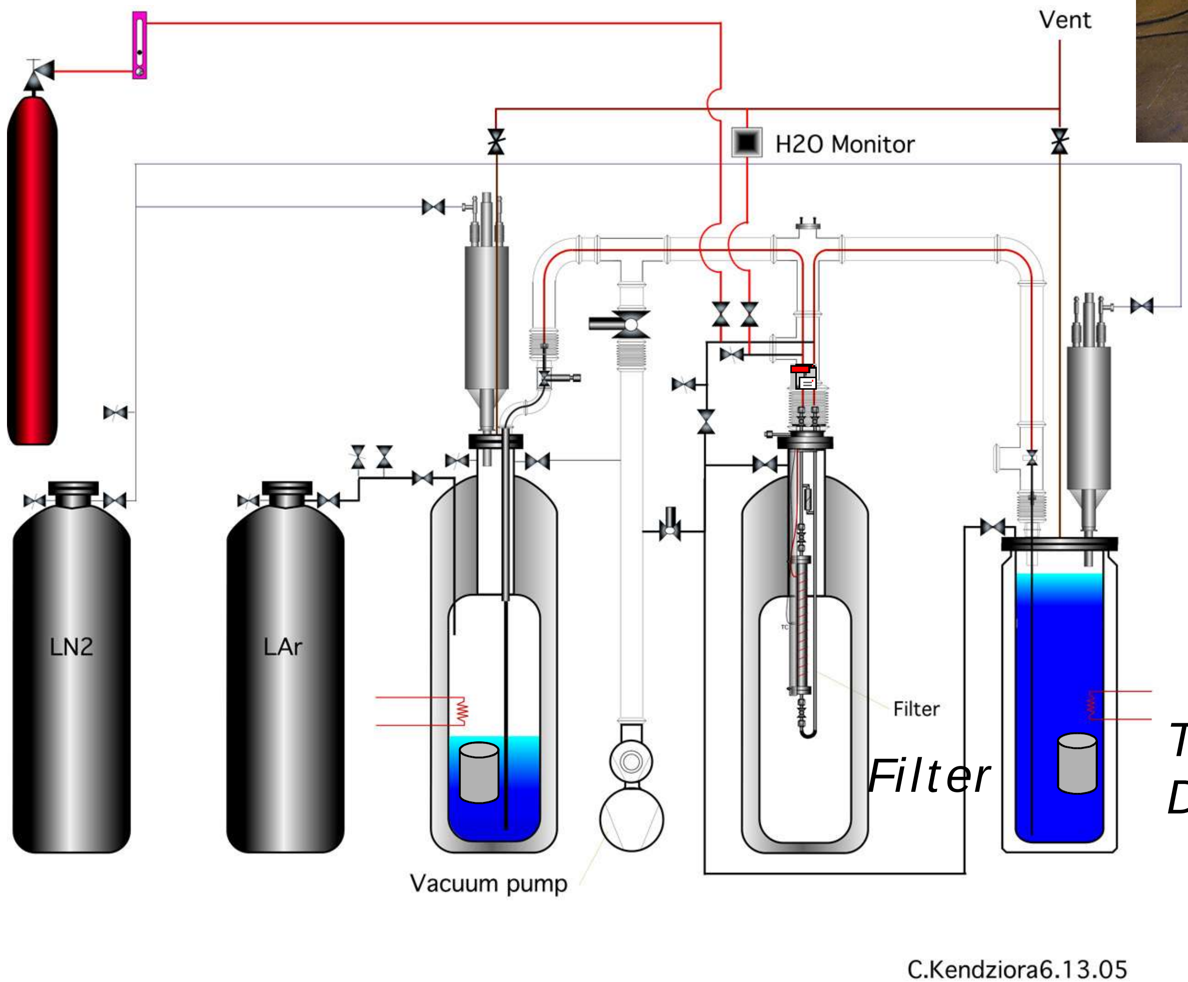


at Yale

at UCLA/
CERN

Material tests

System at Fermilab for testing filter materials and the contaminating effects of detector materials (e.g. tank-walls, cables)



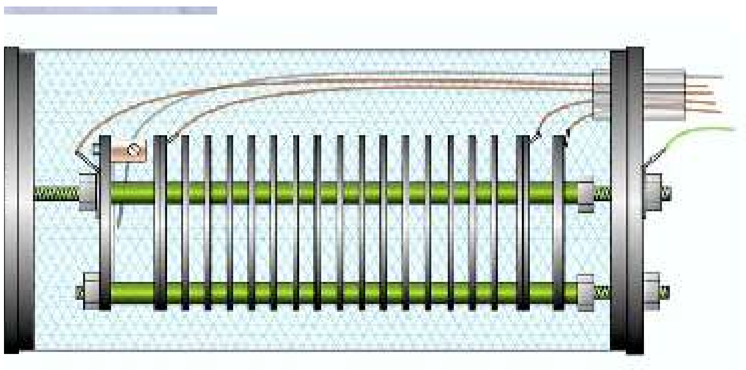
Filter

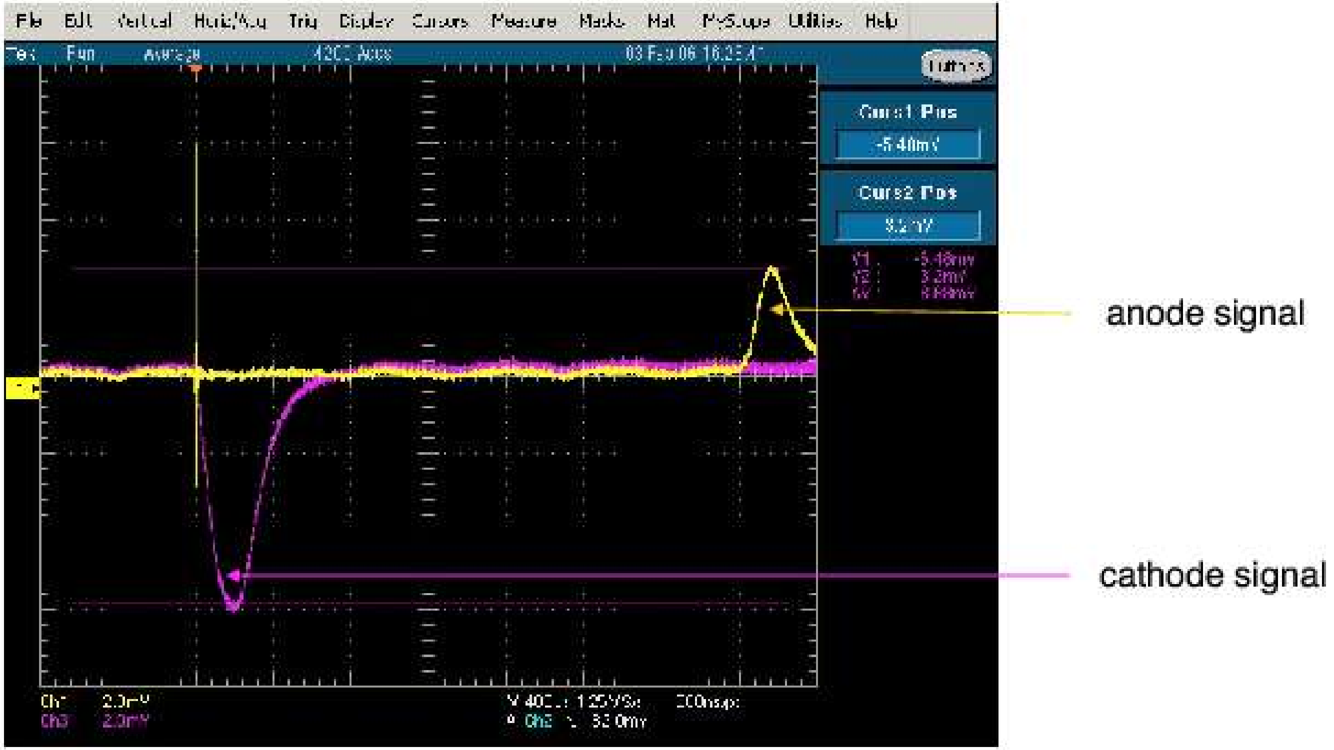
ICARUS purity monitor

G. Carugno et al., NIM. A292 (1990

Test Samples Dewar

purity monitor measures transmission of electrons from cathode to anode





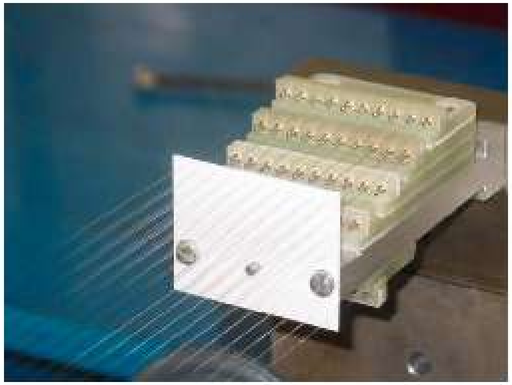
a 2.8 millisecond drift, $Q_{anode}/Q_{cathode} \sim 0.4^{(*)}$

(*) peaks need some correction for cathode signal rise-time

Long wires tests

Long wire tests (ultimately in a LN_2 vessel)

A first setup in air of 20 meter long wires to study noise (microphonics) and have a first stab at electronics.



- ***measurements of the mechanical properties of the wires both at room temperature and in LAr***
  - *100 μ and 150 μ Stainless Steel 304V*
- ***develop wire holders that work at cryogenic temperature and do not pollute LAr***
- ***determination of wire tension***
  - *electrostatic stability*
  - *wire supports*
- ***study of noise on long wires***
  - *mechanical vibrations (i.e. induced by LAr flow)*
  - *measure damping effect of LAr on wire oscillations*
  - *study of electronics coupled to long wires (large input capacitance !)*