B.T.Fleming
for the MicroBooNE
collaboration
November 2, 2007

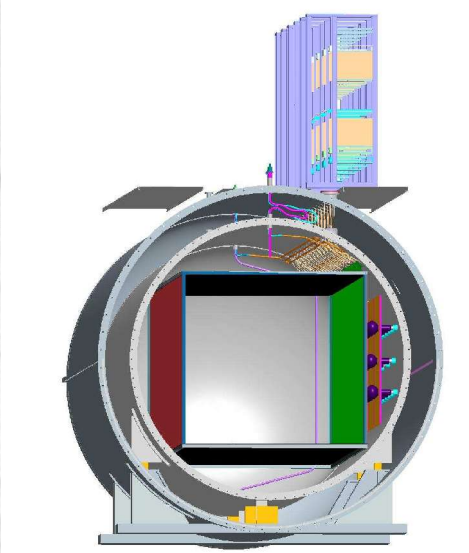
MicroBooNE

Presentation to the Fermilab PAC, Fall 2007

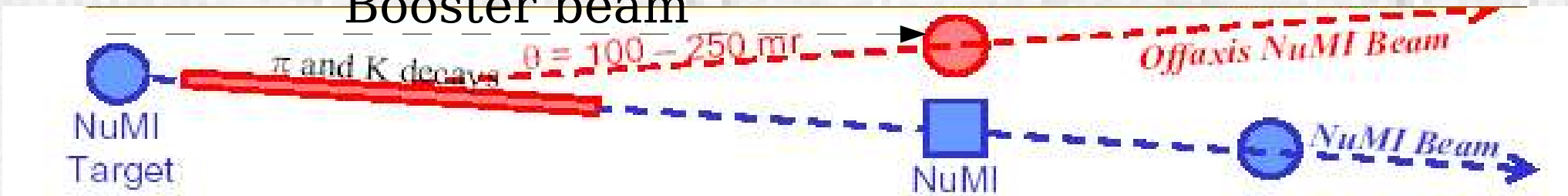
MicroBooNE: Liquid Argon Time Projection Chamber

- Address the MiniBooNE low energy excess
- Perform precision neutrino cross section measurements
- Take the next necessary step in LArTPC R&D towards long baseline CP violation physics

Exposed to on axis BNB and off-axis NuMI beam



70 ton fiducial volume LArTPC



Strong Collaboration brings together people with expertise in LAr, LArTPCs, and neutrino physics

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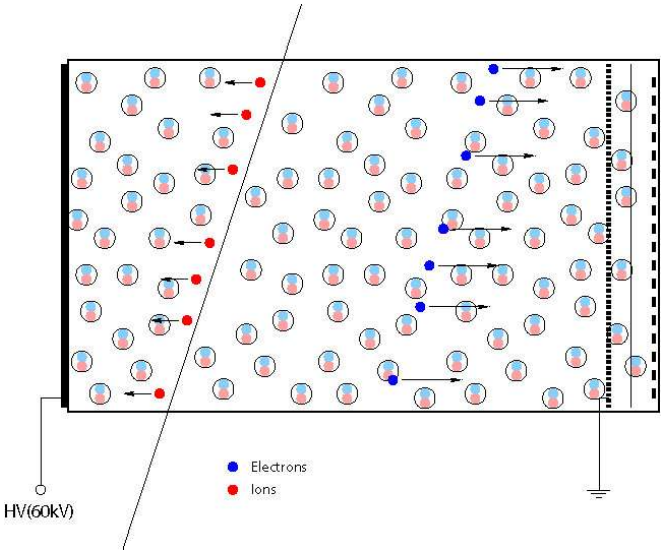
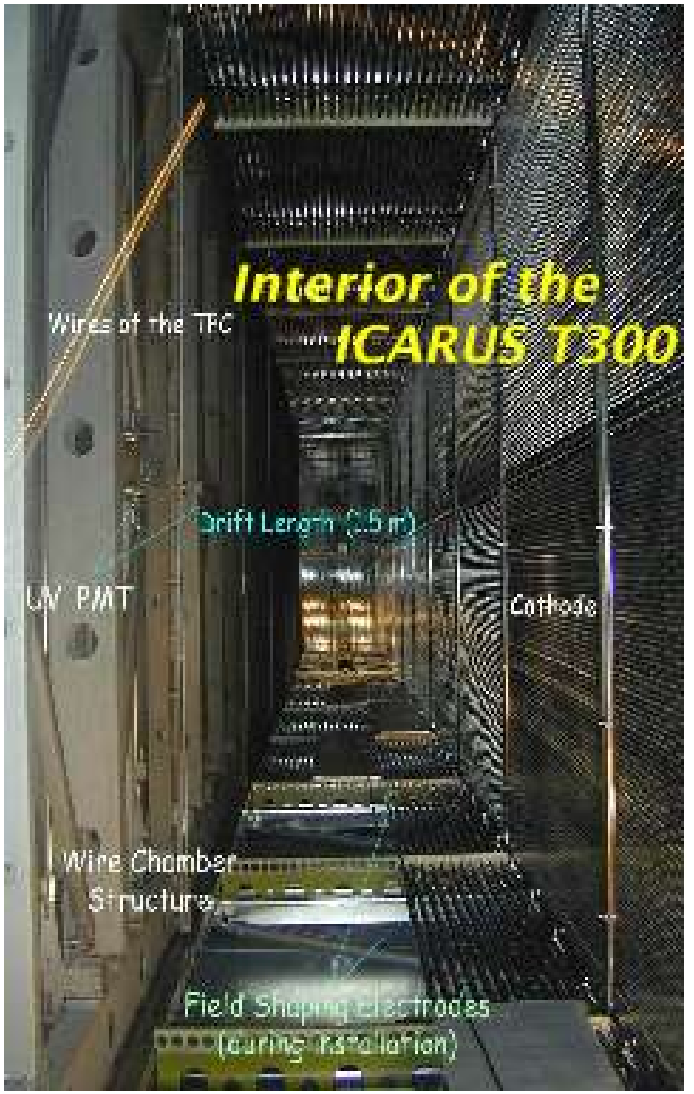
- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

Liquid Argon TPCs:

passing charged particles
ionize Argon:
55,000 electrons/cm

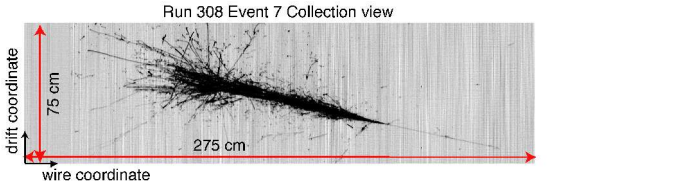


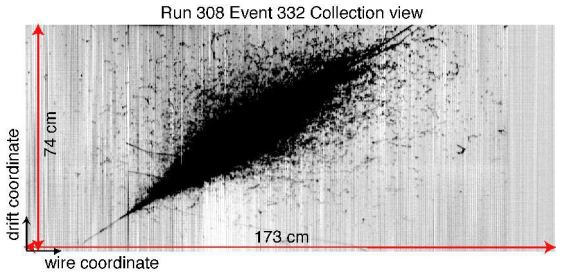


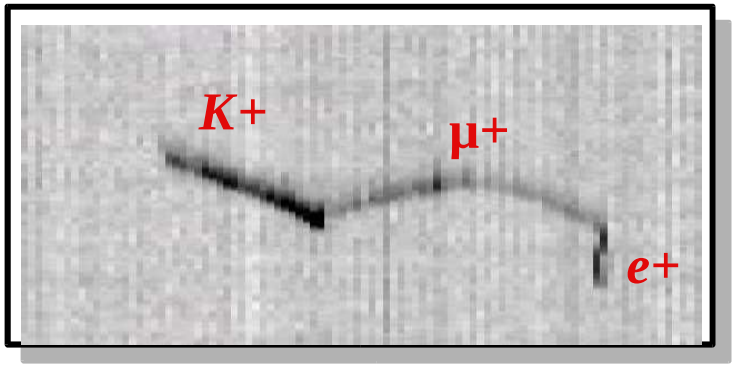
Drift ionization electrons over meters of pure liquid argon to collection planes to image track

extensive experience from ICARUS effort

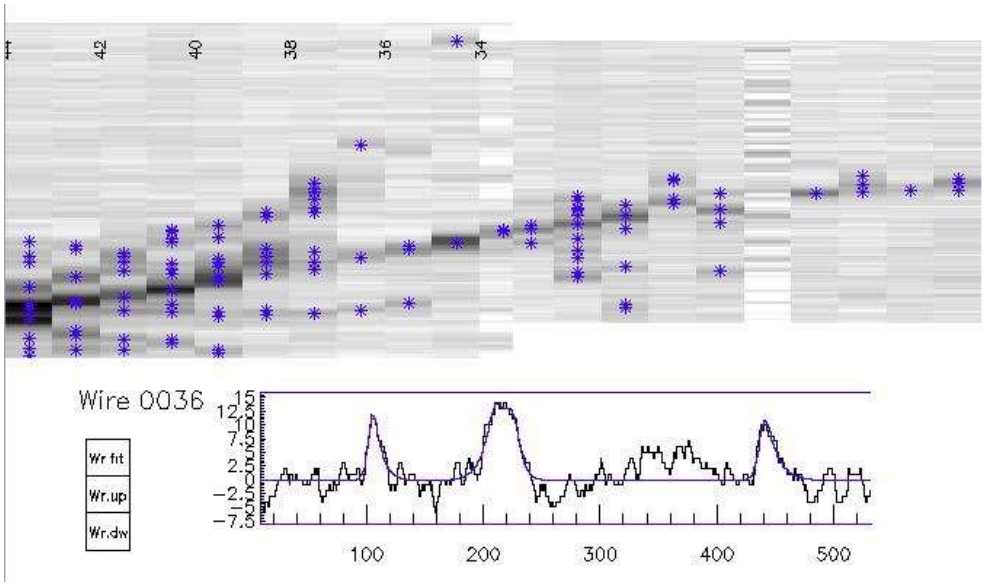
Particles in LArTPCs







T300 data from Pavia test run 2001

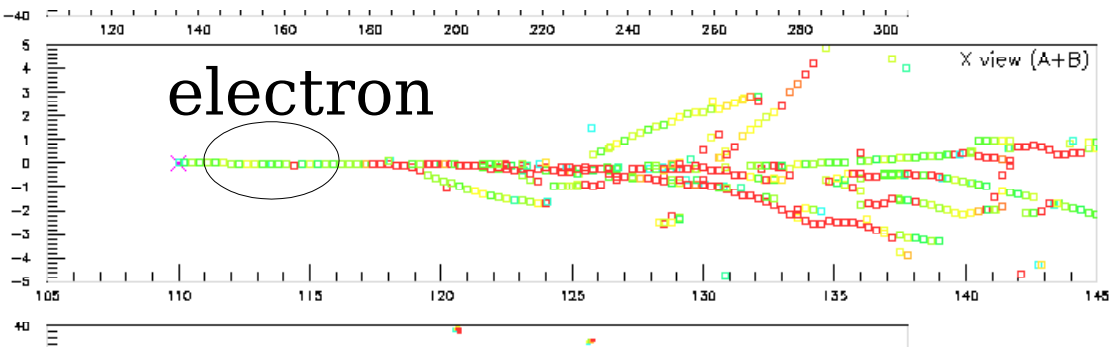


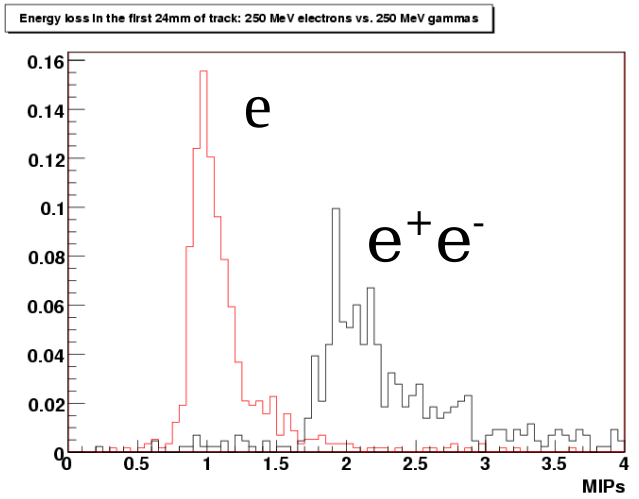
Hadronic shower from Yale TPC run, April 2007

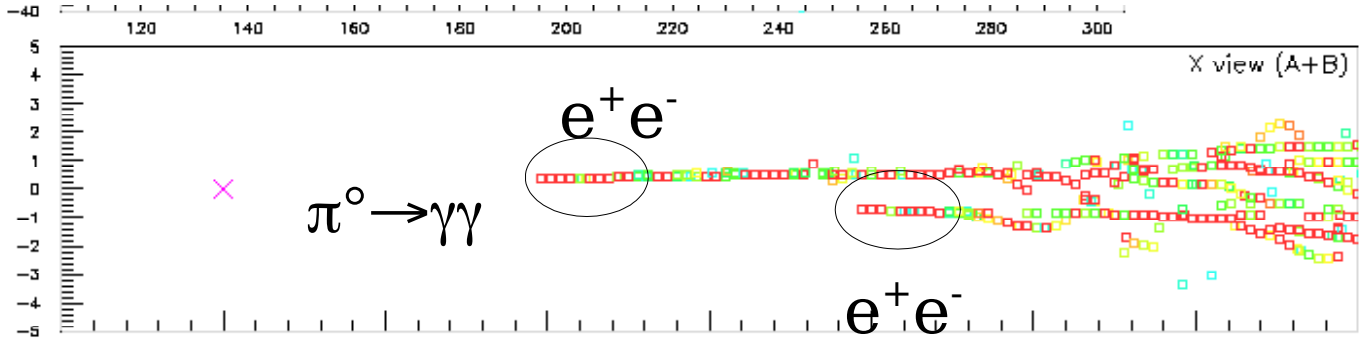
→ *Use topology to differentiate event classes*

LArTPCs image events *and collect charge*

→ do e/γ separation via dE/dx





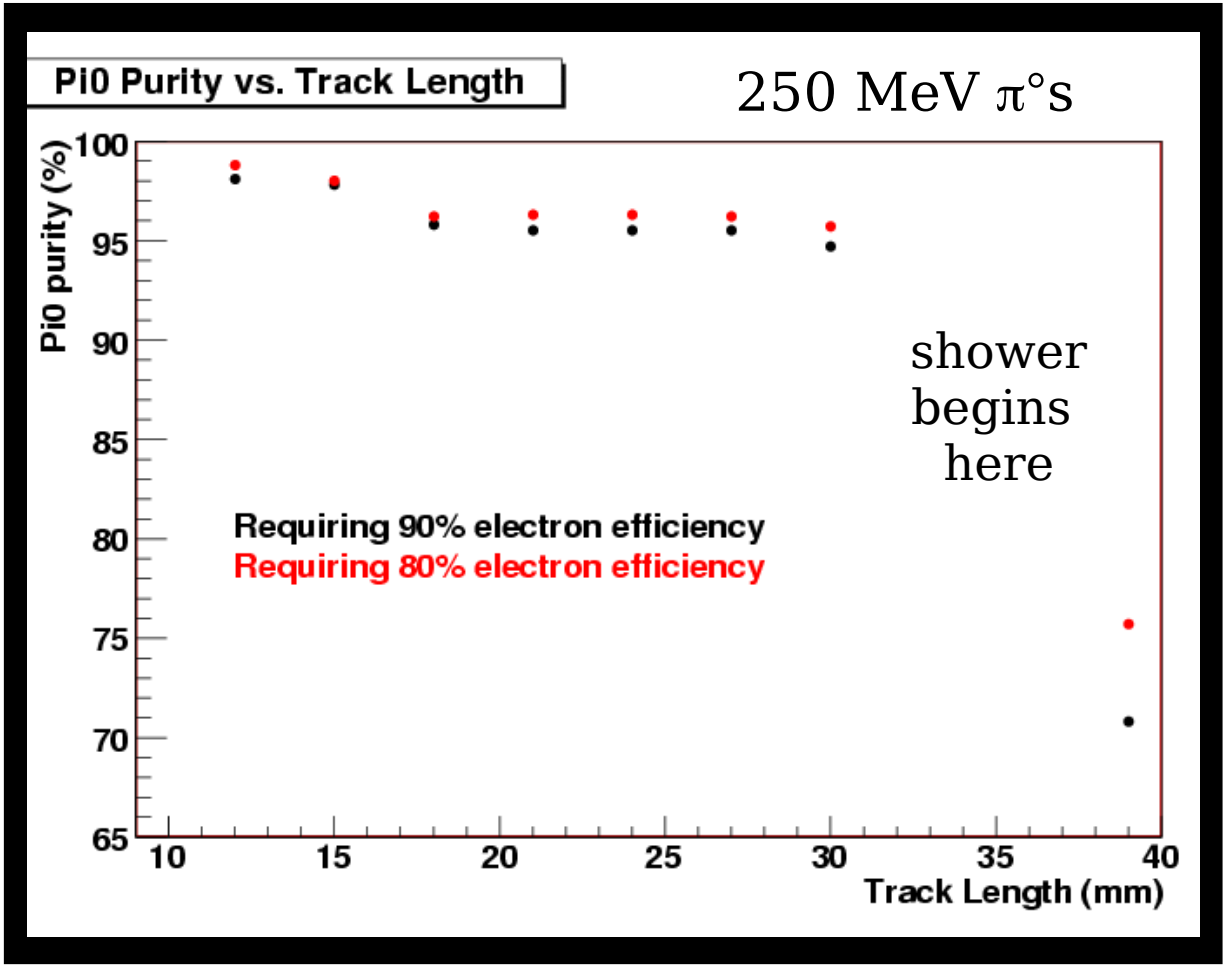


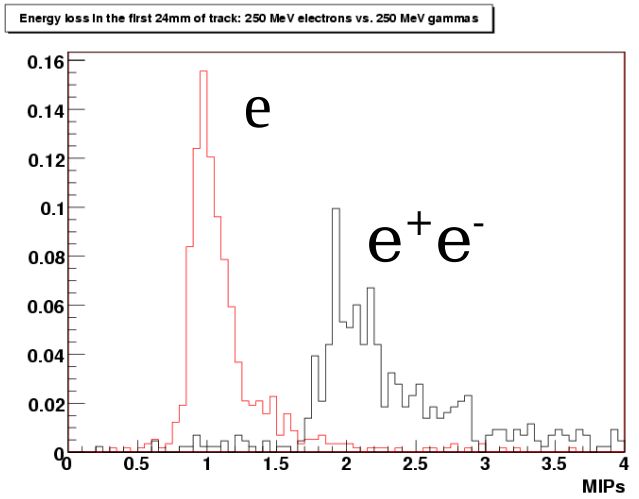
Within first 24mm MIP deposition separates electrons from photons

No other low energy neutrino experiment has been able to diffentiate electrons from photons!

LArTPCs image events *and collect charge*

→ do e/γ separation via dE/dx





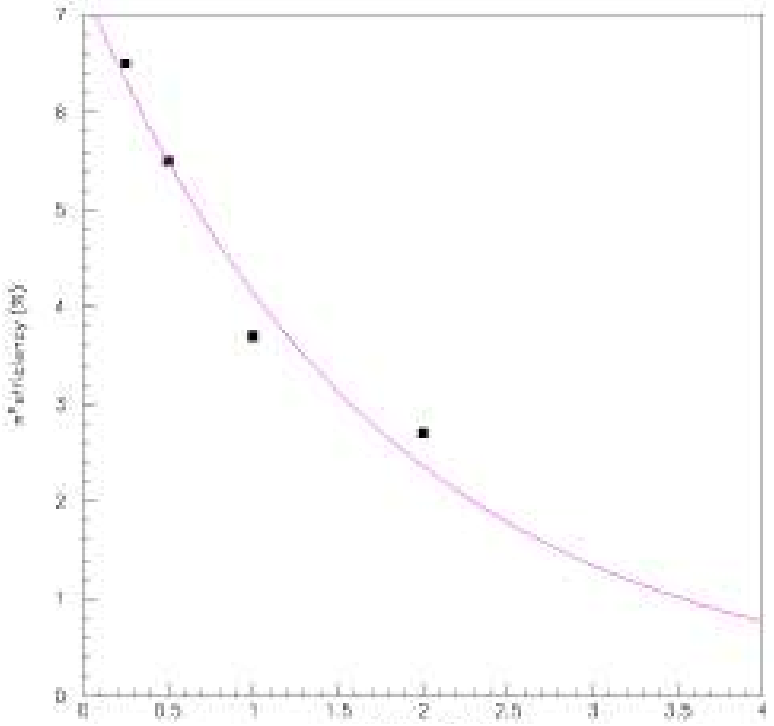
MicroBooNE Monte Carlo simulation: GEANT4

For 80% electron efficiency neutral pion inefficiency is <5%

LArTPCs image events *and collect charge*

→ do e/γ separation via dE/dx

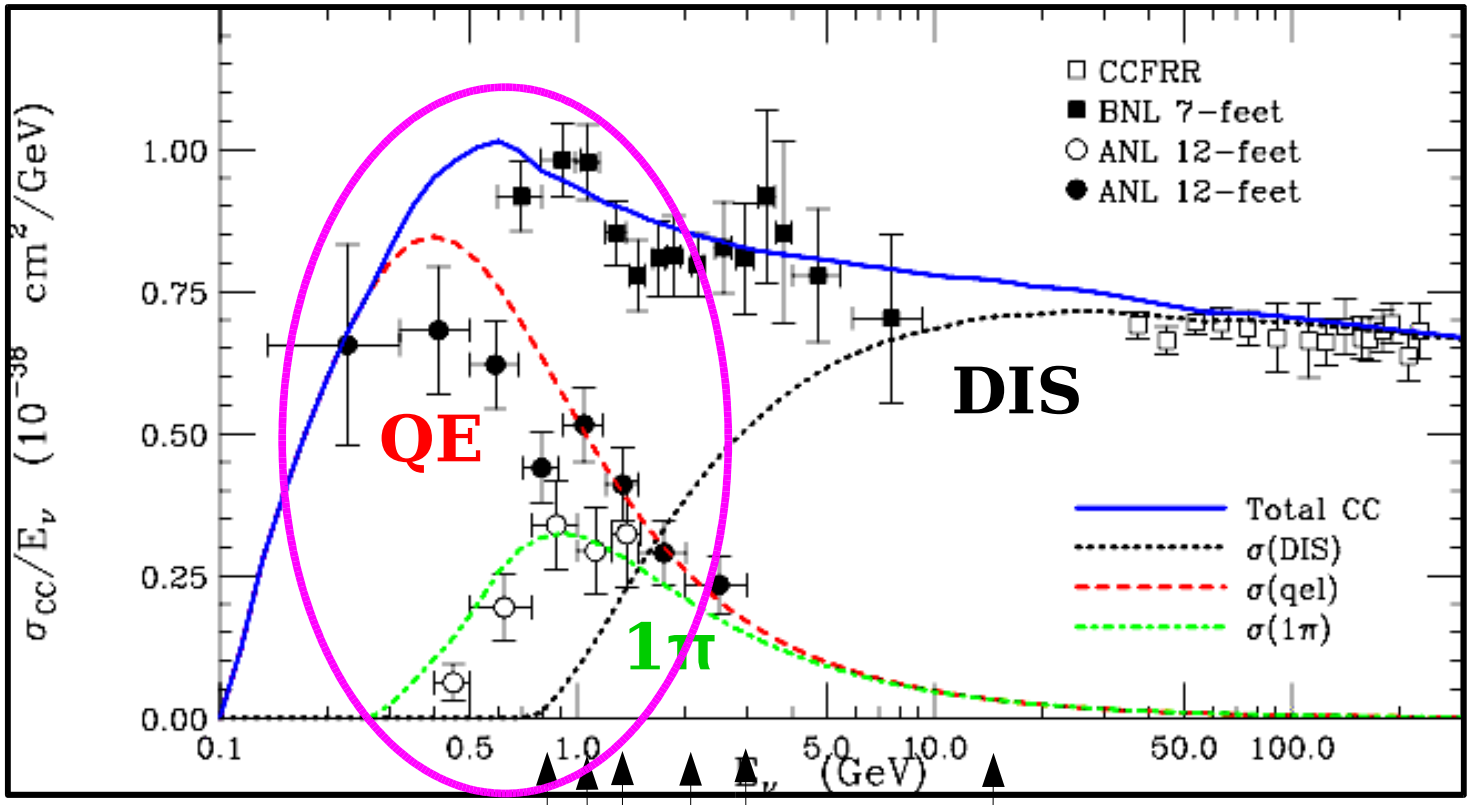
Other studies are consistent with these results...



π° inefficiency vs energy:
at 250 MeV, inefficiency is ~6%

Conservatively assume 6% ± 10%

Need fine-grained detectors and
e/γ separation to understand this rich energy regime!



MiniBooNE

T2K

K2K

NOvA:
NuMI
off-axis

NuMI
on-axis

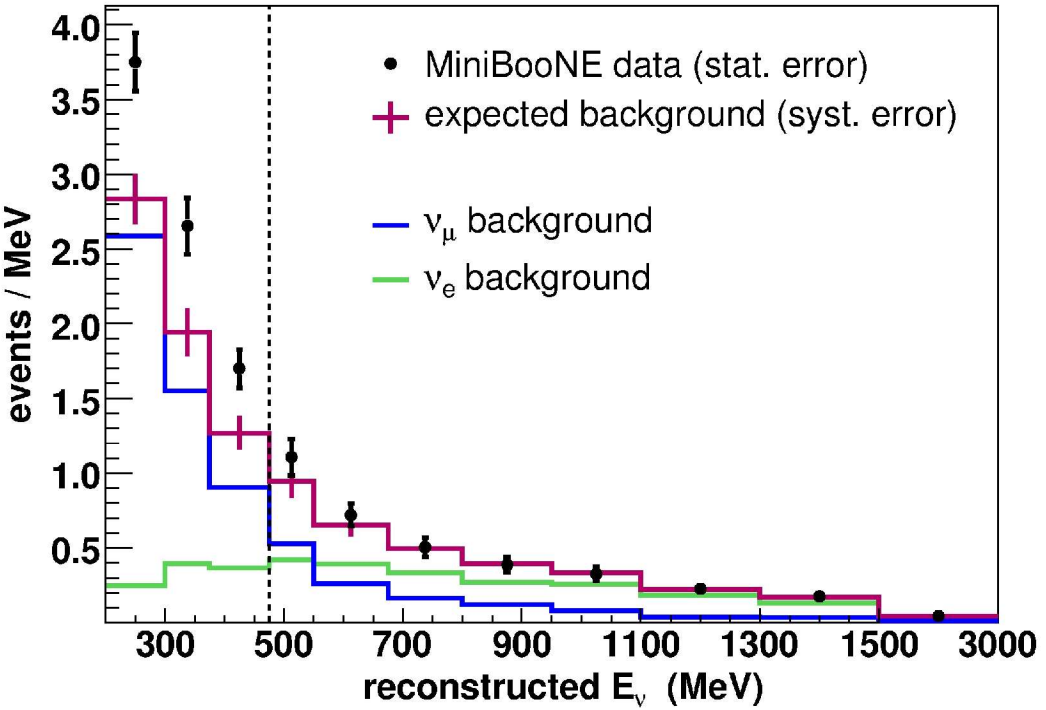
CNGS
T600

Running and
future beams

Key for
future ν
experiments!

- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

MiniBooNE Low Energy Excess



reconstructed neutrino energy bin (MeV)	200-300	300-475
total bkgnd	284±25	274±21
ν_e intrinsic	26	67
ν_μ induced	258	207
NC π^0	115	76
NC $\Delta\rightarrow N\gamma$	20	51
Dirt	99	50
other	24	30
data	375±19	369±19

What are these events?

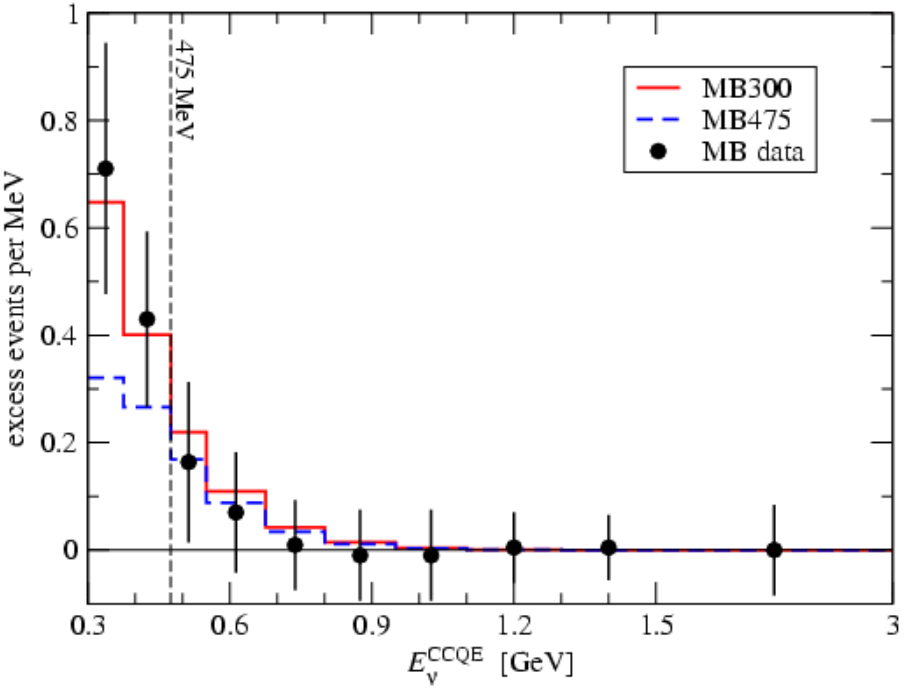
- *Basic checks show no unusual features (ring-like, distributed evenly in space/time)*
- *In a region of high, but well-constrained backgrounds*
- *Persist at lower energies*
- *xxxxx in off-axis NuMI beam*

What do they suggest?

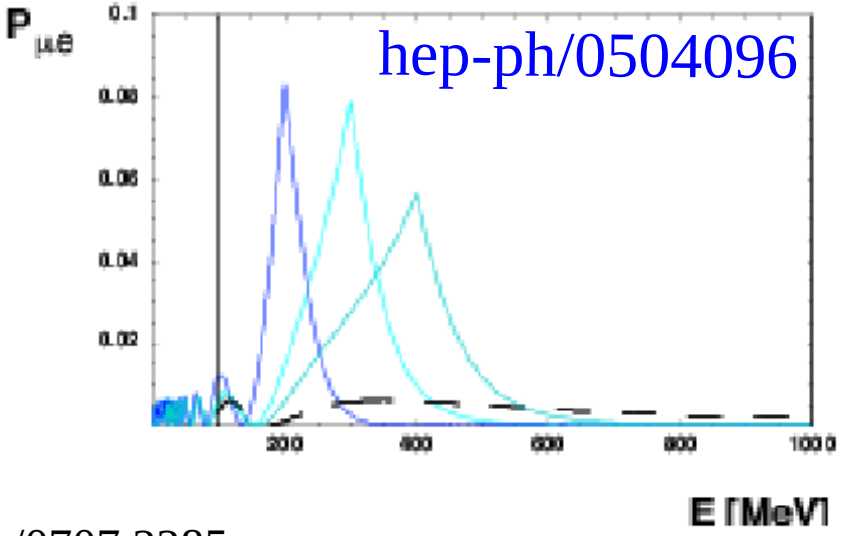
Interpretations as electron neutrinos

3+2 models include CP
fits MiniBooNE and LSND
very well

tension when
disappearance
expts are included



hep-ph/0705.0107v1



← Sterile neutrinos that
can travel in Extra Dimesions
responsible for anomaly:

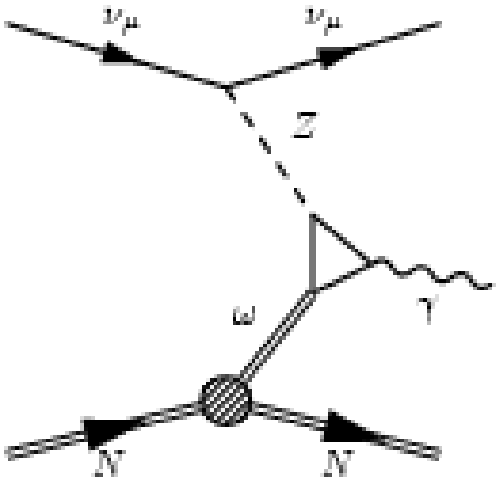
Pre-diction that we would
see a low energy excess!

hep-ph/0707.2285
hep-ph/0606154 and others.....
hep-ph/0705.0107

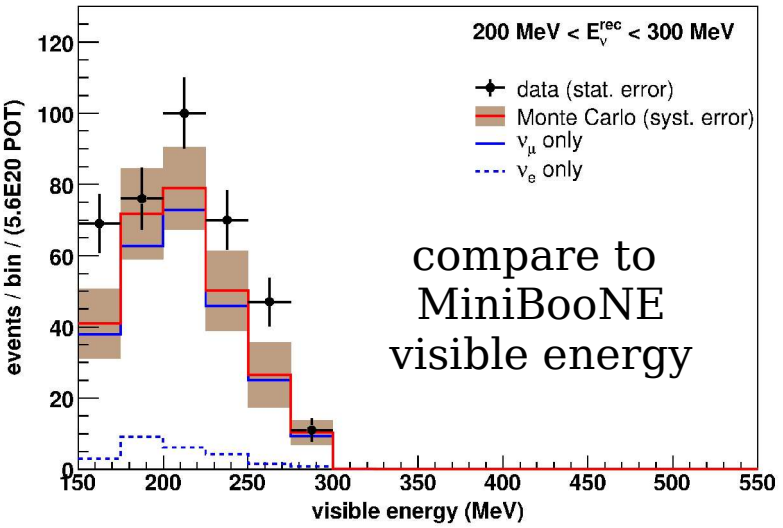
Intepretation as photons

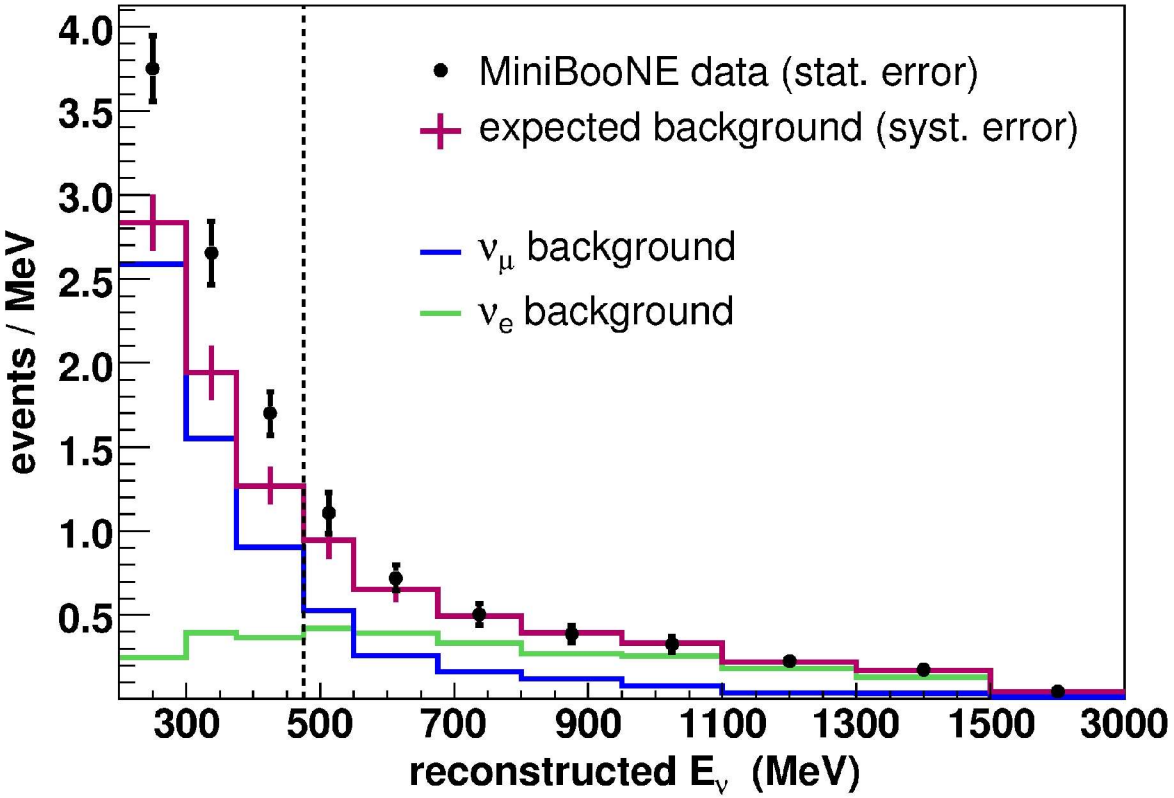
Standard Model process not yet calculated?

hep-ph/0708.1334



will affect neutron-star cooling.....





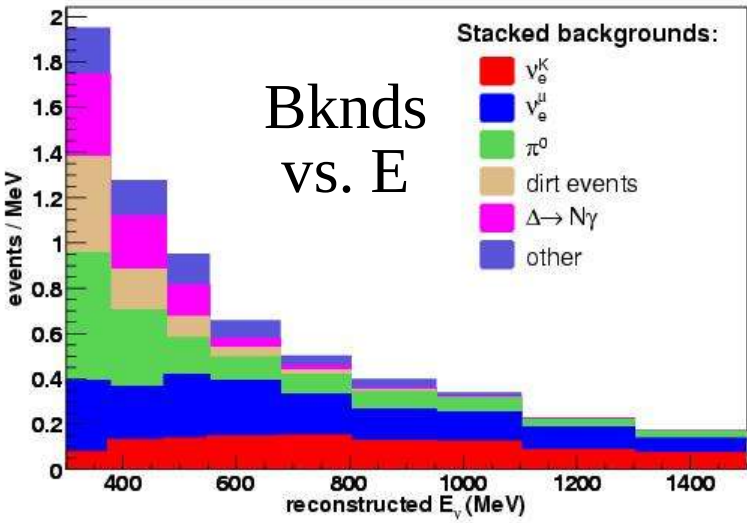
Problem with MiniBooNE detector:
cannot differentiate electrons from photons

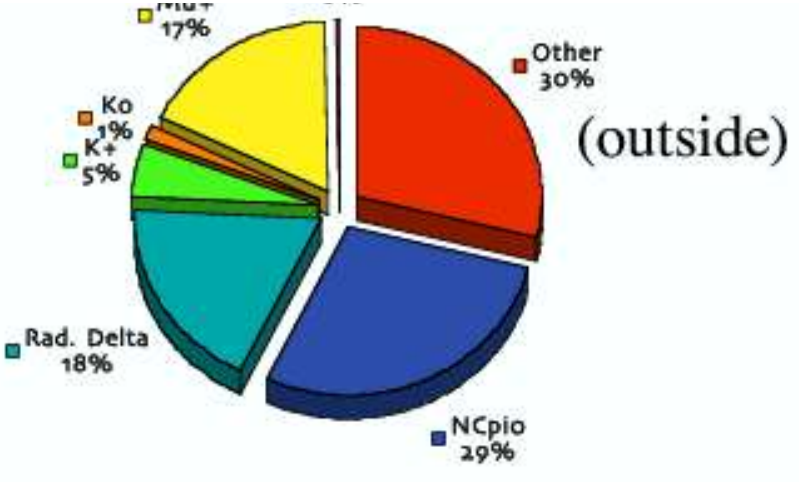
- cannot reduce photon background at low E_ν
- cannot interpret the excess as electron neutrino like or photon like

Need LArTPC technology to address this!

Key improvements in MicroBooNE are:

- e/γ separation capability which removes ν_μ misID
- electron neutrino efficiency (~x2 better than MiniBooNE)
- sensitivity at low energies (down to tens of MeV compared to 200 MeV on MiniBooNE





background fractions at lowest energies

Fold dE/dx tag into predictions from MiniBooNE to determine MicroBooNE sensitivity

Process	200-300 MeV (mB)	300-475 MeV (mB)	total events (mB)	Scaling factor	total events (μB)
"signal"	91	96	187	0.29	54
Backgrounds from Intrinsic ν_es					
$\nu_e - \mu$	19.2	48	67.2	0.29	19.2
$\nu_e - k^+$	7	14	21	0.29	6.0
$\nu_e - k^0$	2	4	6	0.29	1.7
$\nu_e - \pi$	0	1	1	0.29	0.3
Backgrounds from ν_μ misIDs					
NCπ^0	115	76	191	0.0084	1.6
Dirt	99	50	149	0.0084	1.3
$\Delta \rightarrow N\gamma$	20	51	71	0.0084	0.6
Other	24	30	54	0.0084	0.5
Total	286	274	560		31.2

Detector size based on sensitivity, and beam request

Process	total events(μB)	Uncertainties from mB	dE/dx unc.	Total unc.	Error
"signal"	54				
$\nu_e - \mu$	19.2	0.075	0	0.075	1.44
$\nu_e - k^+$	6.0	0.16	0	0.16	0.96
$\nu_e - k^0$	1.7	0.3	0	0.3	0.51
$\nu_e - \pi$	0.3	0.33	0	0.33	0.09
NCπ^0	1.6	0.16	0.1	0.53	0.86
Dirt	1.3	0.18	0.1	0.531	0.68
$\Delta \rightarrow N\gamma$	0.6	0.2	0.1	0.54	0.33
Other	0.5	0.18	0.1	0.53	0.25
Total	31.2				1.86
			"signal"	**84.6**	
			Excess	**53.4**	
			Statistical Error	**5.58**	
			Systematic Error	**1.86**	
			Total Error	**5.98**	
			Significance	**9.1**	

This does not include improved background rejection due to topology or understanding of the beam

If the excess is photons:

- efficiency ~x2 better than MiniBooNE for gammas
- dE/dx tag reduces ν_e intrinsic backgrounds

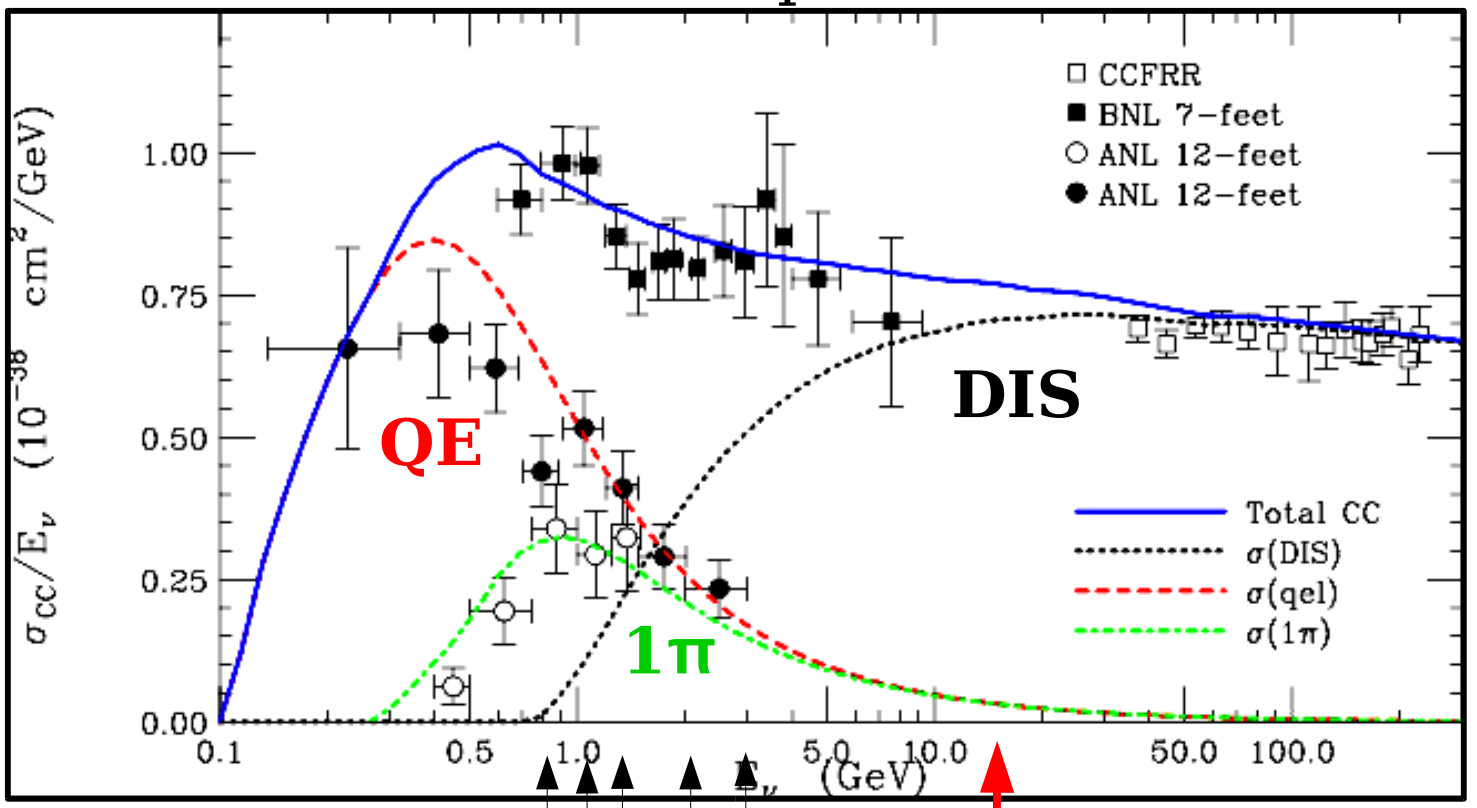
Process	total events(μB)	Uncertainties from mB	dE/dx unc.	Total unc.	Error
"signal"	54				
$\nu_e - \mu$	0.6	0.07	0.1	0.12	
$\nu_e - k^+$	0.2	0.16	0.1	0.18	
$\nu_e - k^0$	0.05	0.3	0.1	0.32	
$\nu_e - \pi$	0.01	0.33	0.1	0.35	
NCπ^0	55	0.13	0	0.13	
Dirt	43	0.18	0	0.18	
$\Delta \rightarrow N\gamma$	20	0.18	0	0.18	
Other	15	0.18	0	0.18	
Total	133.7				
			"signal"	187.1	
			Excess	**53.4**	
			Statistical Error	**11.6**	
			Systematic Error	**10.7**	
			Total Error	**15.7**	
			Significance	**3.4**	

Results from NuMI on low energy excess embargoed for now

- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

- Important for next generation neutrino
- oscillation experiments
- Interesting in their own right

Rich energy regime in region of many existing and future neutrino experiments



MiniBooNE

T2K

K2K

NuMI off-axis

NuMI on-axis

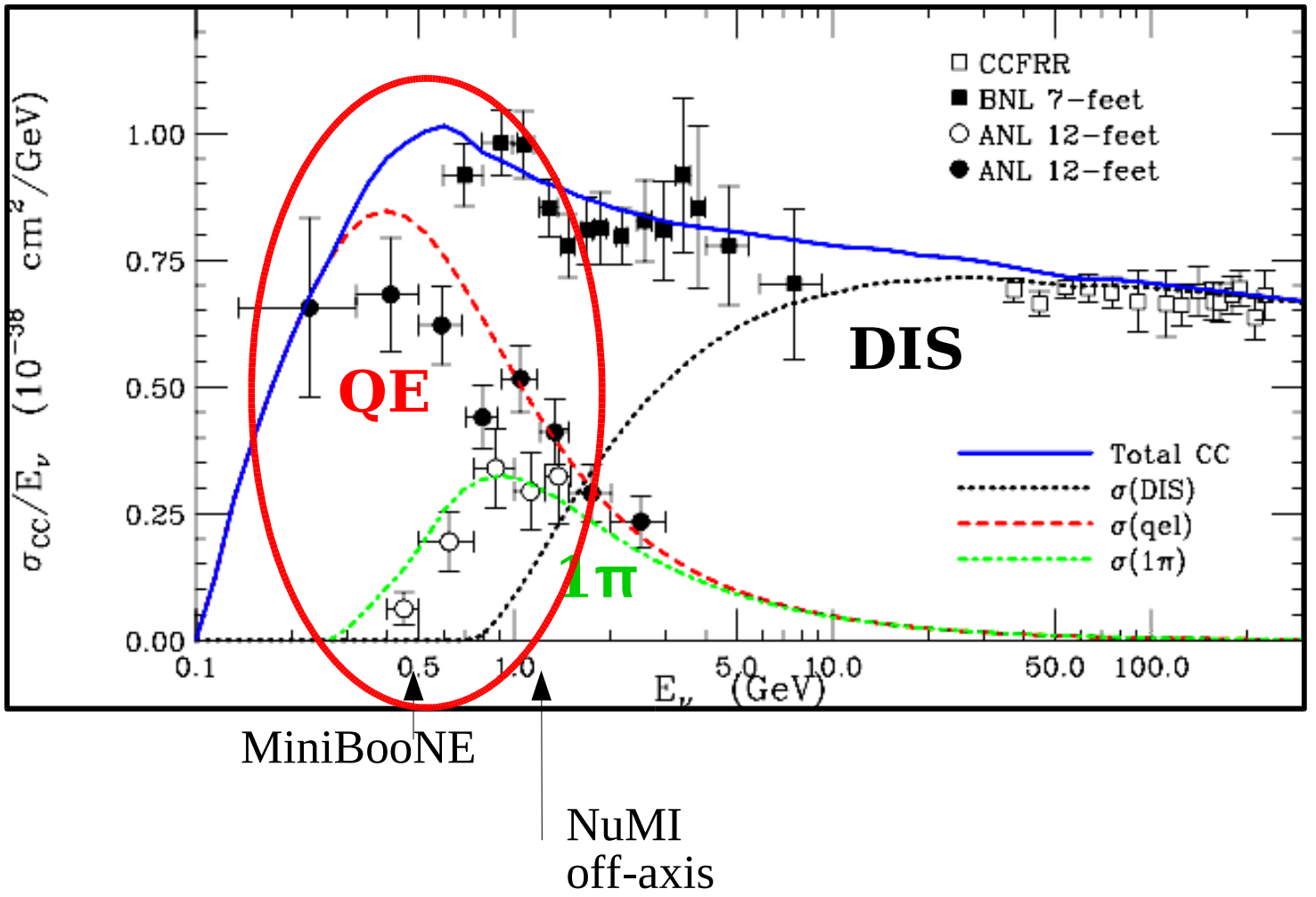
CNGS T600

higher energy low statistics

Running and future beams

LAr neutrino experiment

BNB and NuMI beams span this region well.



Unlike most neutrino experiments in this region, MicroBooNE can perform precision cross section measurements with fine-grained detector and dE/dx ⇒ e/γ separation

Basis of Existing QE σ Knowledge

$< E_\nu >$	Exp	Mode	Target	Year	# QE events
0.7 GeV	ANL	ν	D_2	1973	166
0.5 GeV	ANL	ν	D_2	1977	600
2 GeV	CERN	ν	C_3H_8	1979	26
2 GeV	GGM	ν	C_3H_8	1979	622
0.5 GeV	ANL	ν	D_2	1981	1737
1.6 GeV	BNL	ν	D_2	1981	1138
5-200 GeV	FNAL	ν	D_2	1983	362
6 7 GeV	SKAT	ν	CF_3Br	1988	464
9 GeV	SKAT	ν	CF_3Br	1990	540
54 GeV	BEBC	ν	D_2	1990	552
1.6 GeV	FNAL	ν	D_2	1990	2538
5-7 GeV	SKAT	ν	CF_3Br	1992	1465
2 GeV	GGM	$\overline{\nu}$	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	$\overline{\nu}$	H_2	1980	13
16 GeV	FNAL	$\overline{\nu}$	NeH_2	1984	405
6-7 GeV	SKAT	$\overline{\nu}$	CF_3Br	1988	52
9 GeV	SKAT	$\overline{\nu}$	CF_3Br	1990	159
5-7 GeV	SKAT	$\overline{\nu}$	CF_3Br	1992	256

Existing data on fine-grained detectors is minimal!

Interesting channel: Recent measurements of M_A

K2K 1.20 ± 0.12 GeV

MiniBooNE 1.25 ± 0.12 GeV

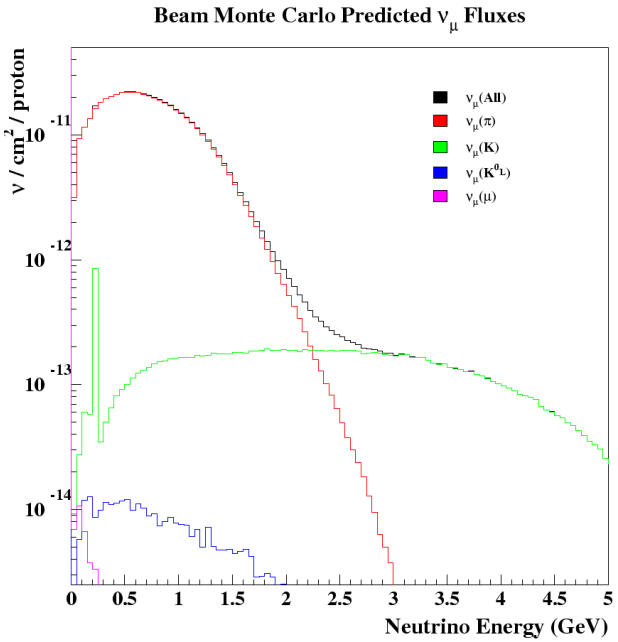
inconsistent with

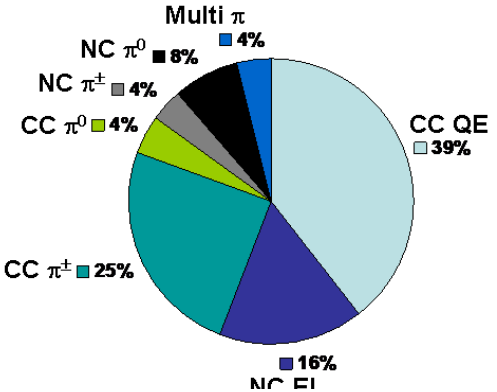
world average 1.03 ± 0.02 GeV

MINERvA will measure M_A above 1-2 GeV

MicroBooNE at 1 GeV and below.....

BNB

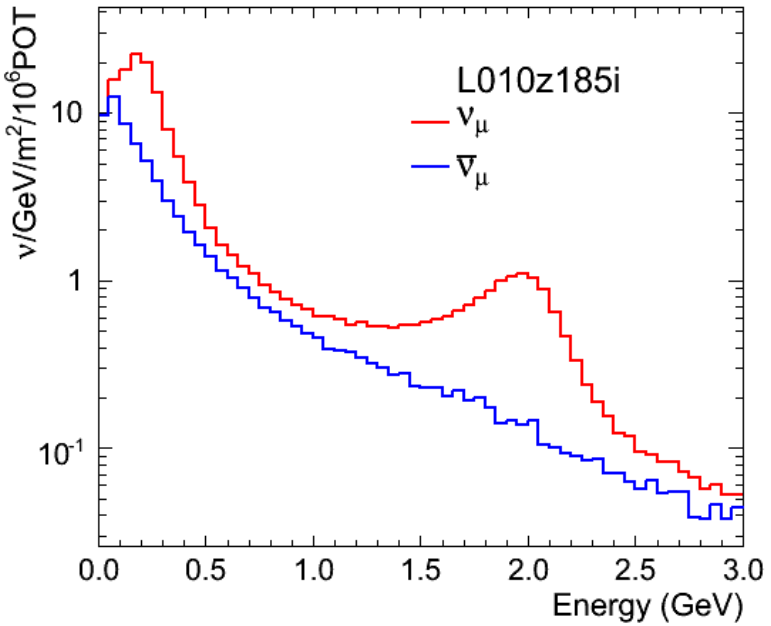


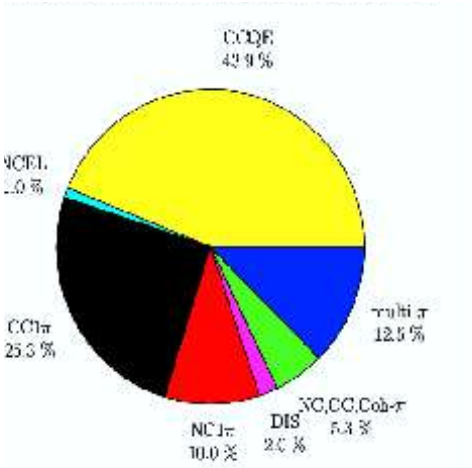


Sizable event rates!

For 6E20 pot
~100k total
~40,000 ν_μ CCQE
~8000 NCπ°

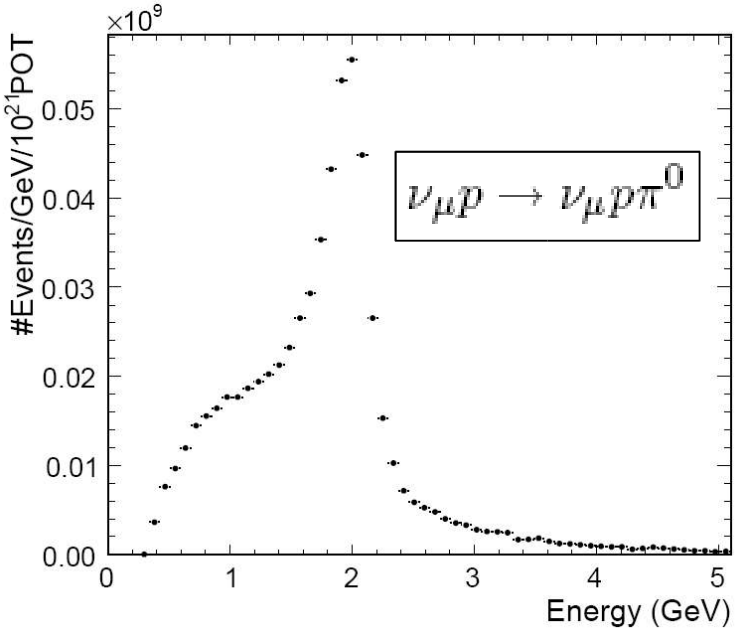
NuMI

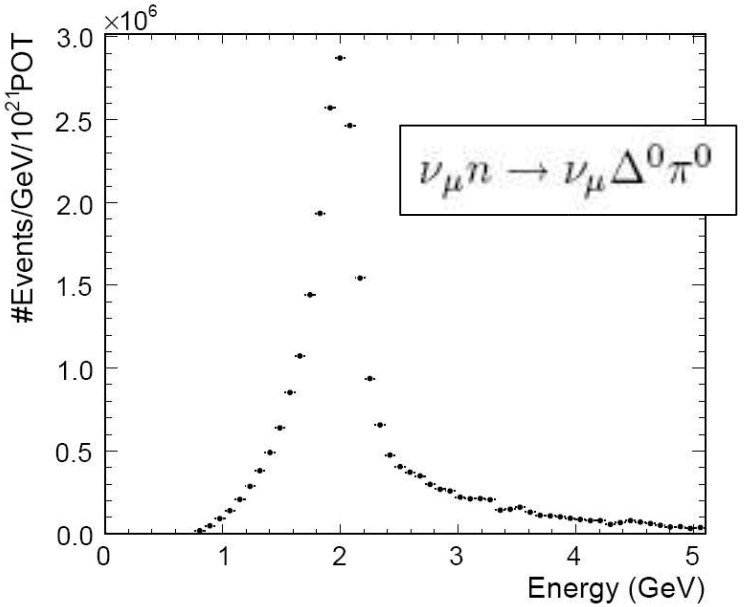


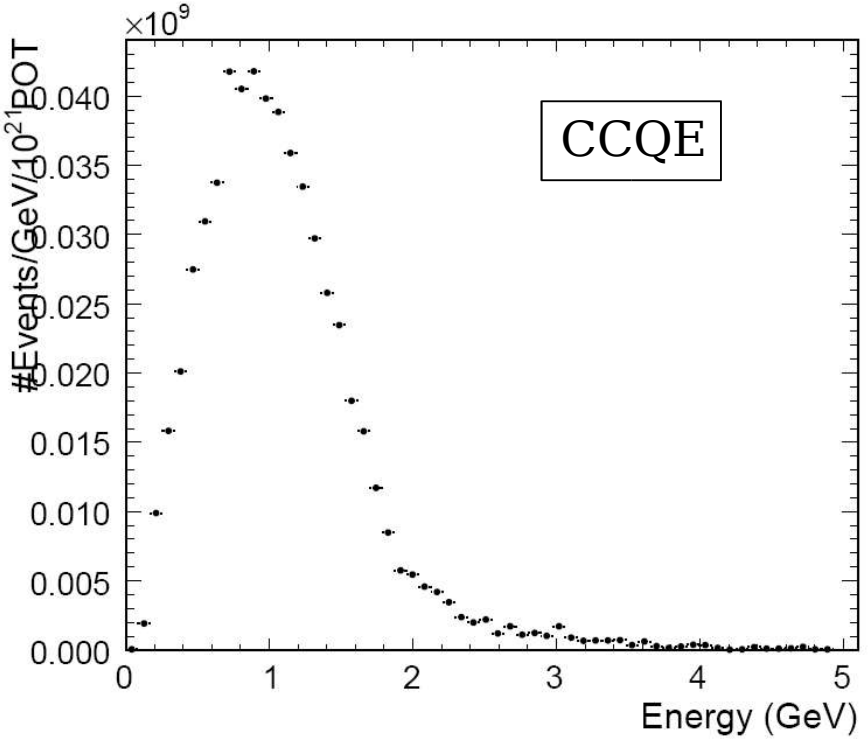


For 8E20 pot
~60k total
~20,000 ν_μ CCQE
~xxxx NCπ°

Collect samples of signal ν_es and background NCπ^0s in energy region of interest for NOvA



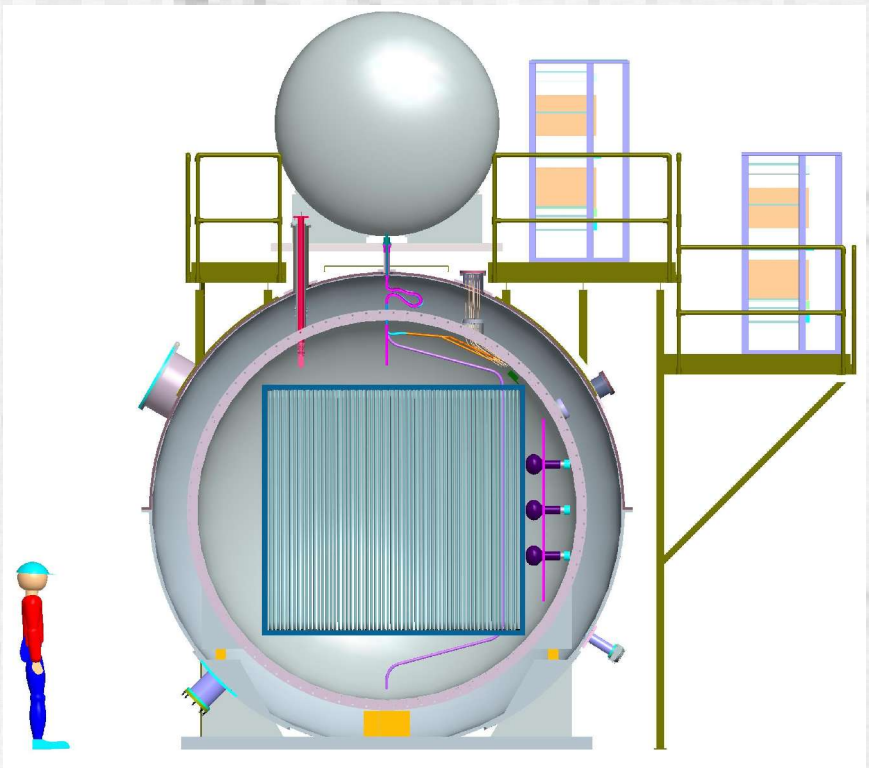




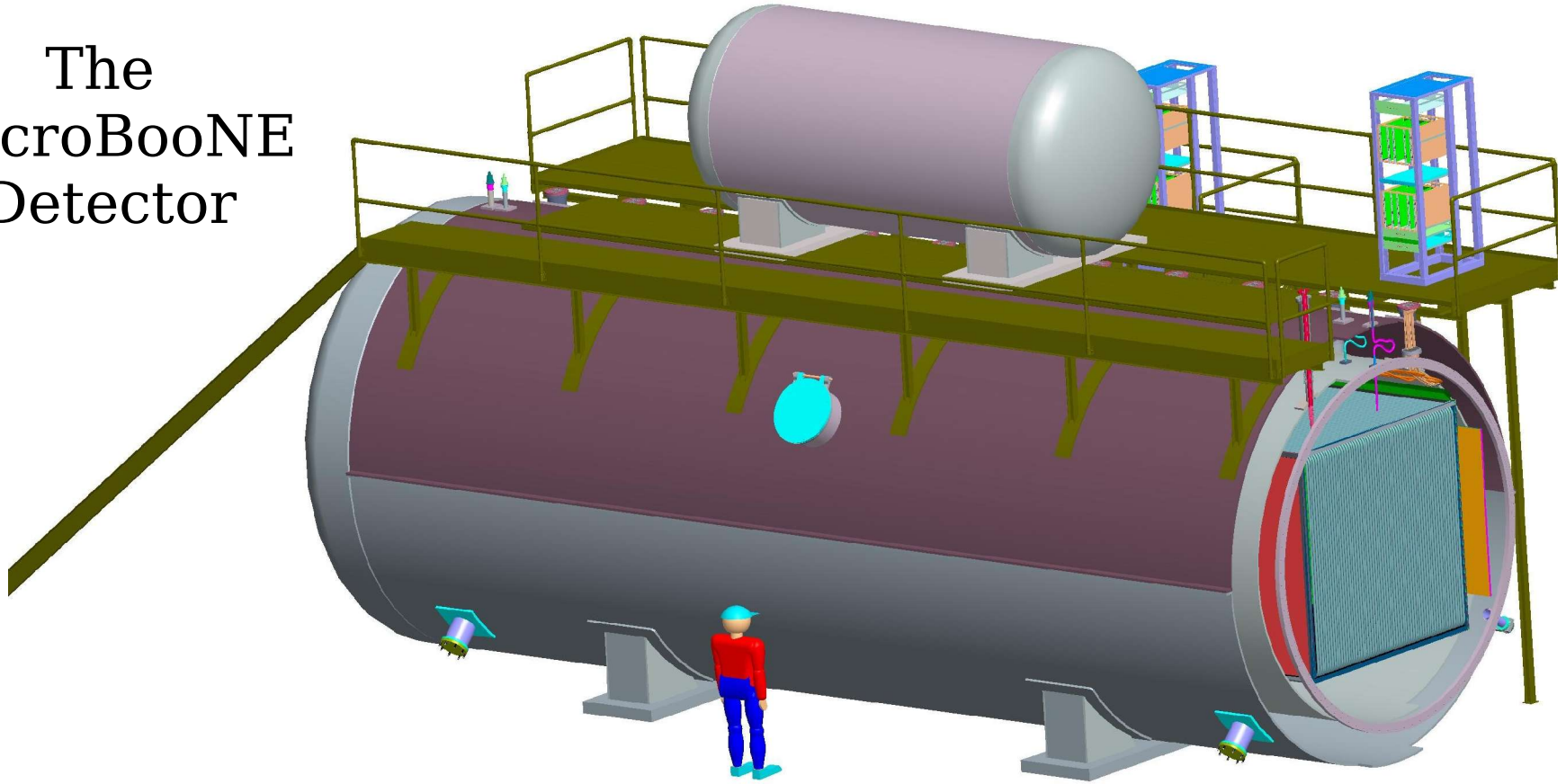
Note: For running in LE mode. In ME mode, rate and shape worsen considerably.

Window in which to collect data beforethe NOvA ME beam run!

- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

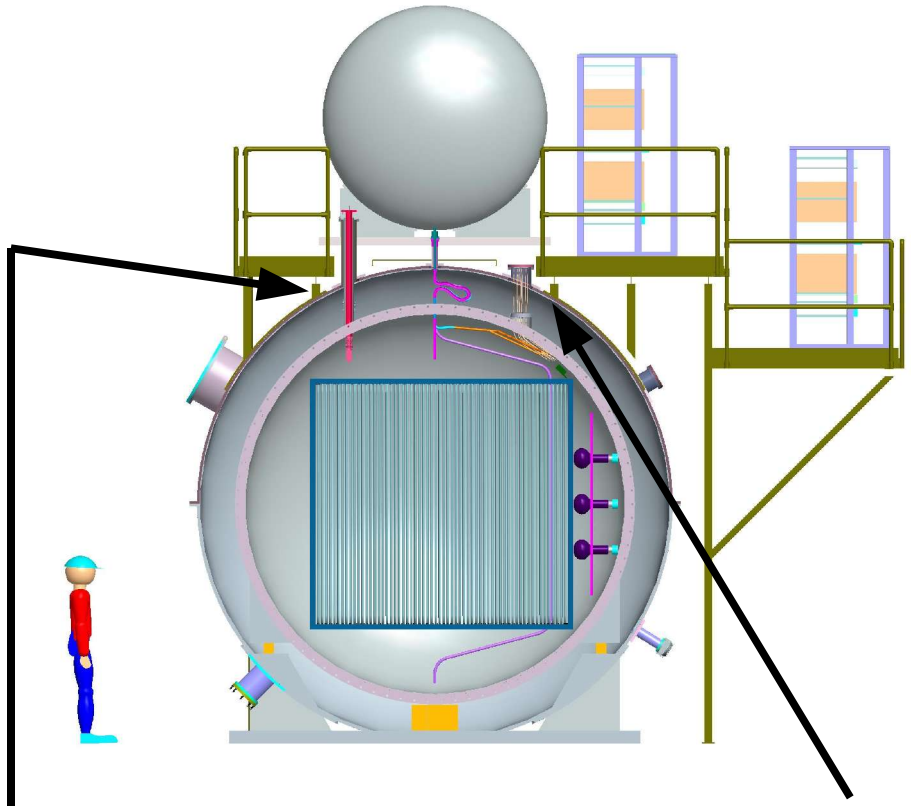


The MicroBooNE Detector



- Outer vessel: 4.7 m in diameter, 13.5 m long
- Contains 170 tons liquid Argon
  - 100 tons Active Volume (2.5m x 2.5 m x 12 m TPC)
  - 73 tons Fiducial volume (25cm buffer on all sides)
- Catwalk supports Cryogenic and Electronic system componenets

Cryogenics:



Inner cold vessel:
3.8m OD, 13.2m long
Outer warm vessel:
4.7m OD, 13.5m long

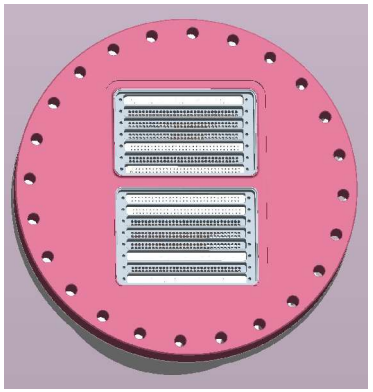
Temperature controlled via LN_2 cooling loops to within 1K

- boil off argon
- control operating temperature and pressure

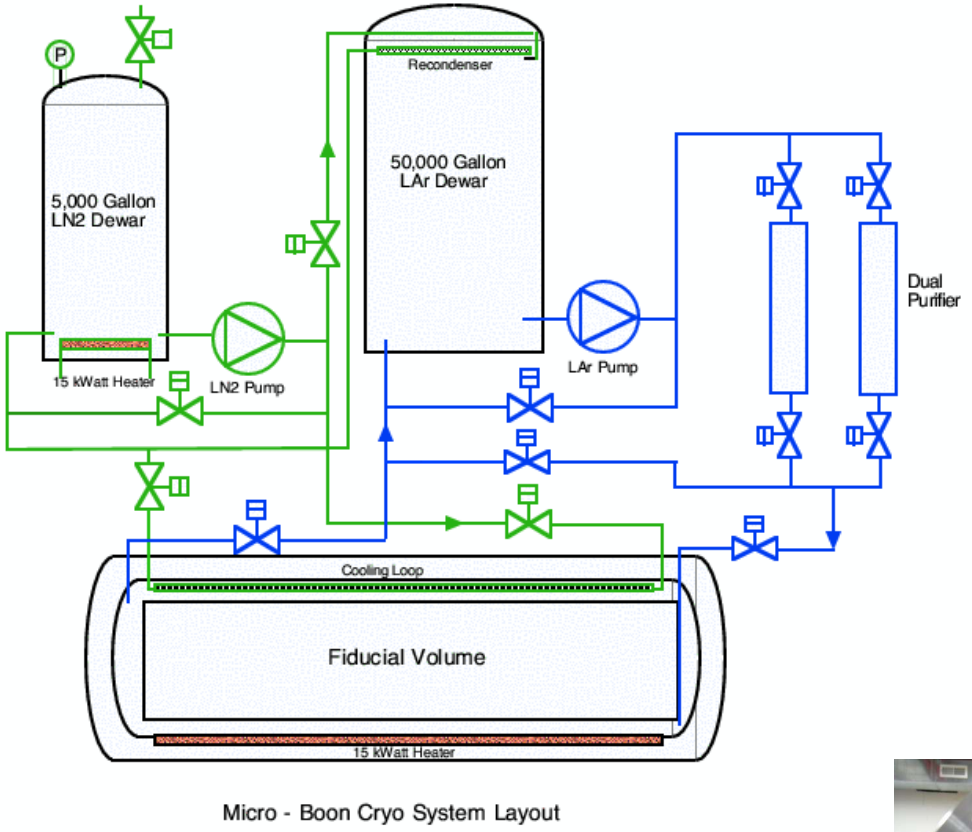
Vacuum feedthroughs penetrate warm and cold vessels and carry signal/calibration/monitoring channels

Based on ATLAS experience with 180k channels installed and operated for >1 year

HV feedthrough (200 kV) -- ICARUS solution (warm feedthrough) still under study



Purification



Micro - Boon Cryo System Layout

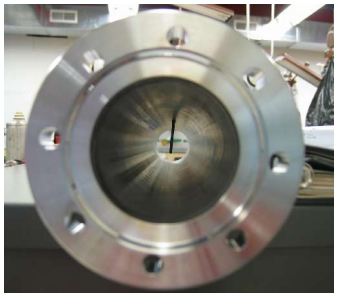
Liquid Argon is continuously purified to 0.1 ppb O2 impurities

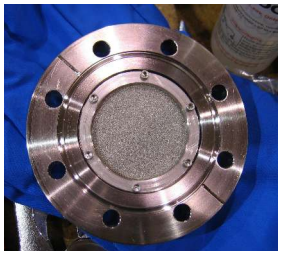
Flow rate: 10 gallons/minute
-> 2 days for complete volume exchange

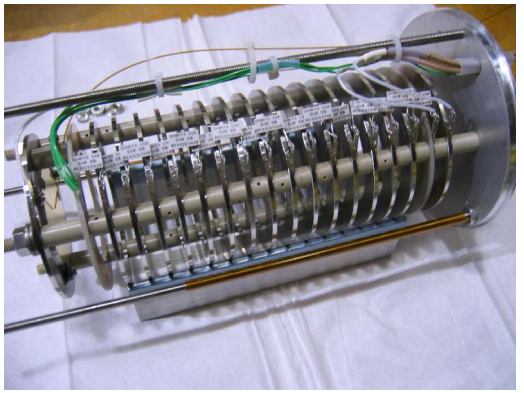
50,000 gallon storage dewar:
- Filtration prior to main vessel fill
- LAr storage in case of access

Filter system: based on ICARUS design but....
- non proprietary
- filters can be regenerated in situ

System designed at FNAL
Demonstrated at FNAL and Yale

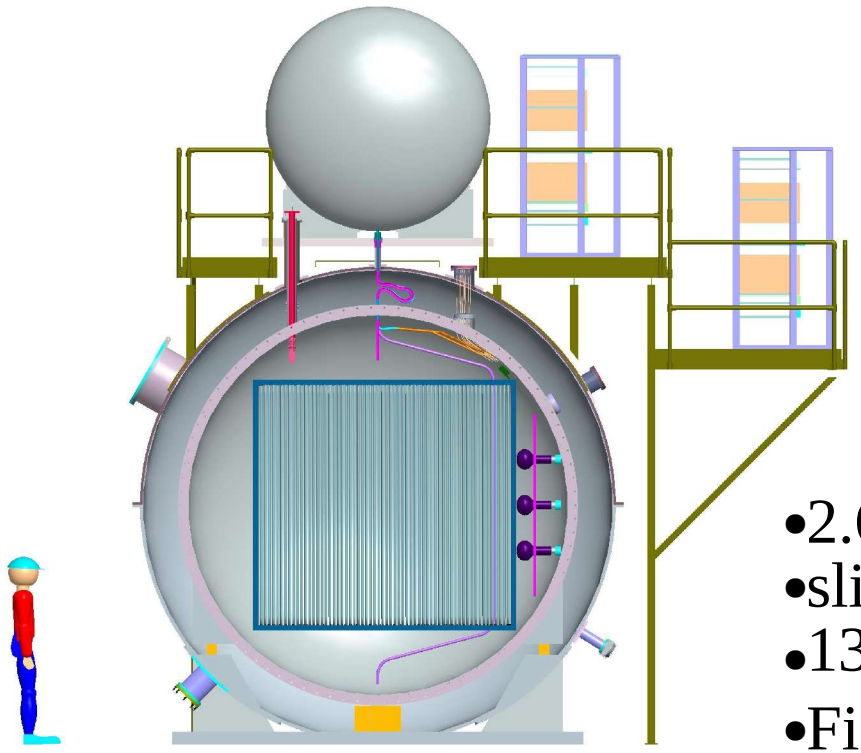






ICARUS style purity monitors will measure purity in situ

Inner Detector: Field Cage

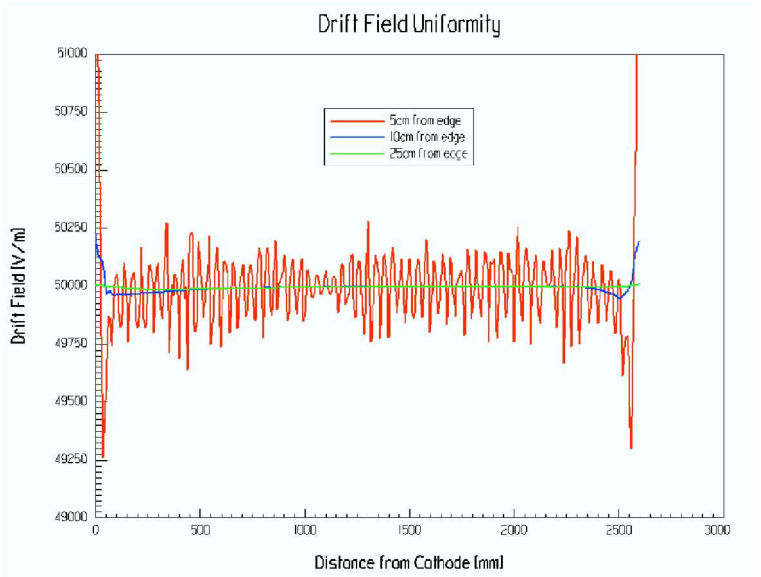


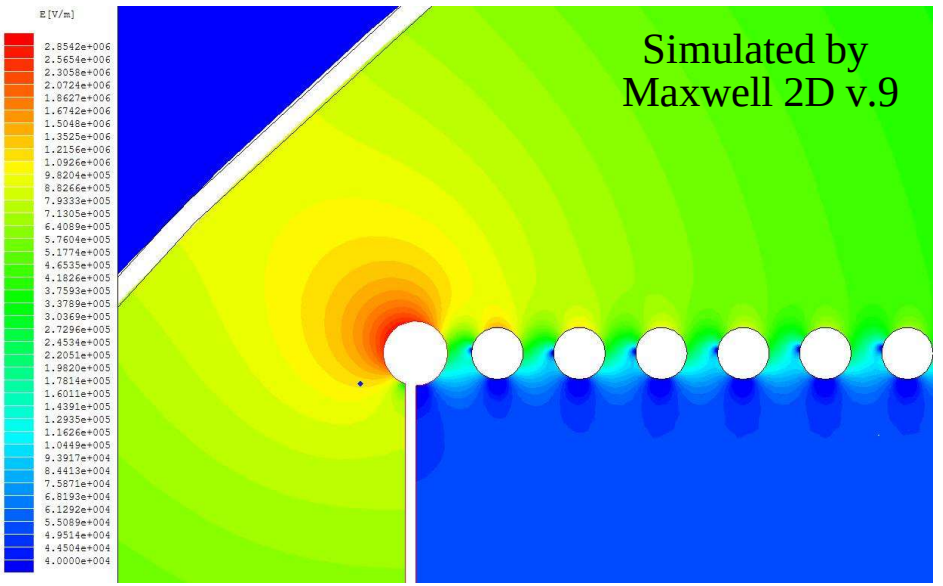
Design considerations:

- electron mobility
- temperature gradients
- Diffusion and recombination
- electron lifetime
- electronics Signal/Noise

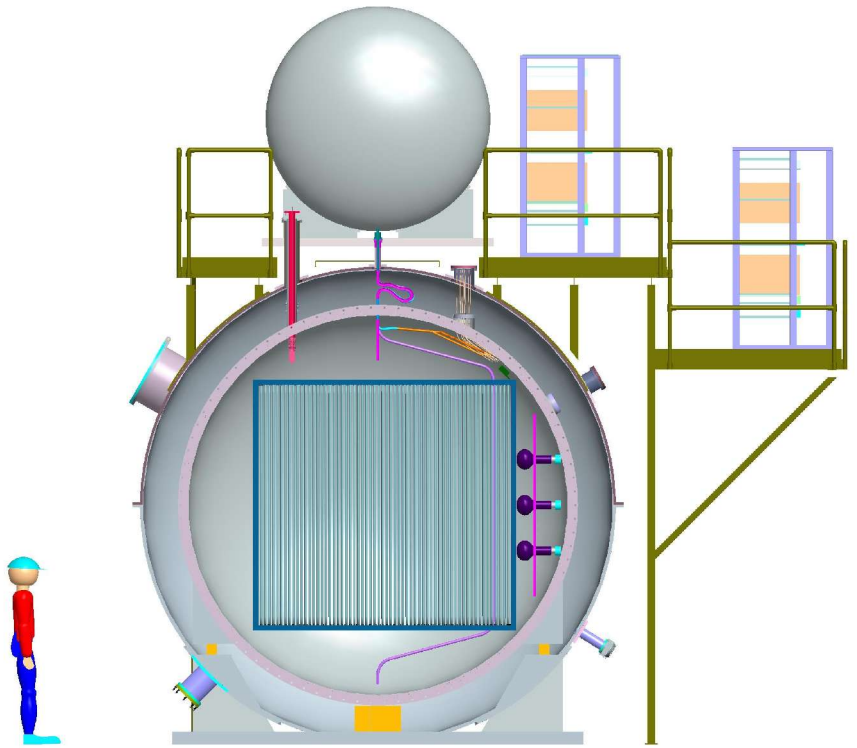
↓

- 2.6 m drift (2.6m x 2.6m x 12m)
- slightly offset for HV clearance
- 130kV HV for v_{drift}=1.6mm/μs
- Field cage: SS tubes step voltage in 2kV



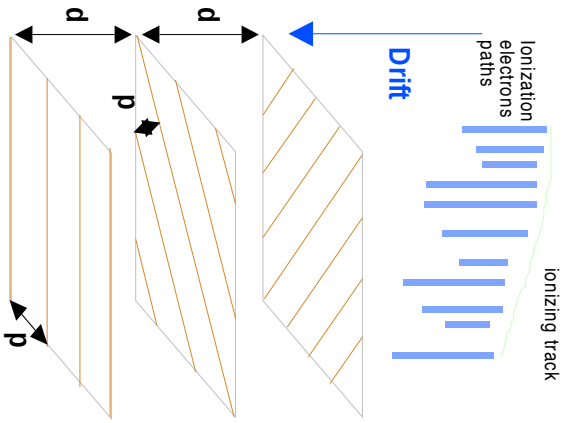


Inner Detector: Wire Planes



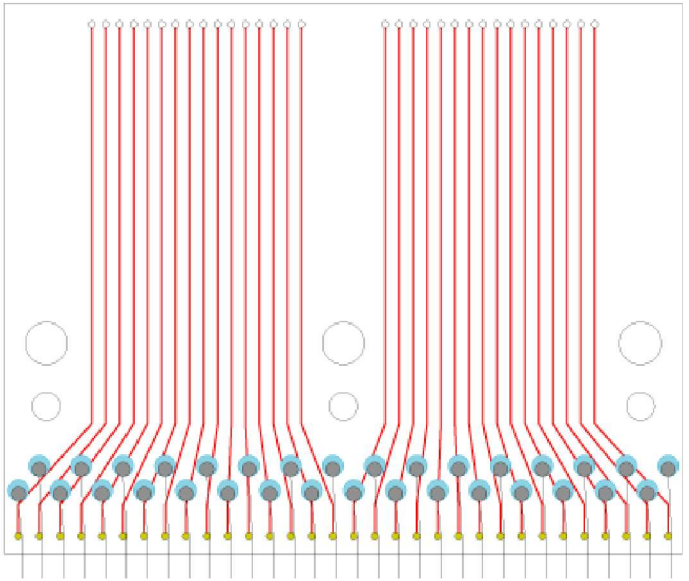
Signal electrodes

- 2 induction planes at ± 60°
- 1 vertical collection plane
- electrodes: 150 mm gold plated SS



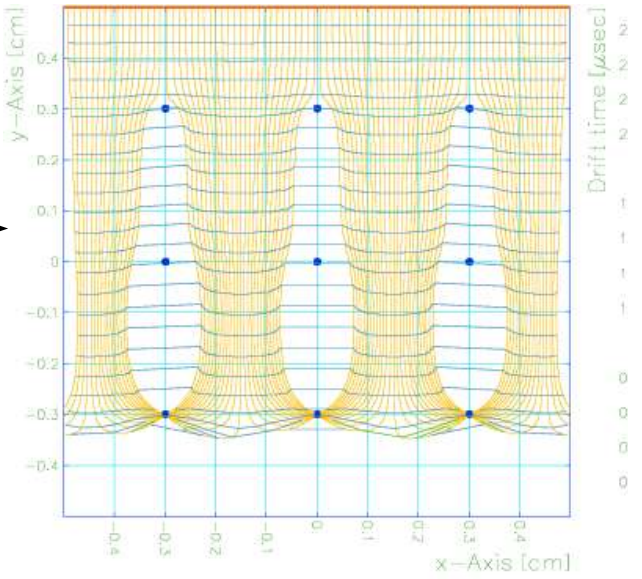
3mm wire pitch
Planes biased at : -204V,0V,400V

Total of ~12k channels

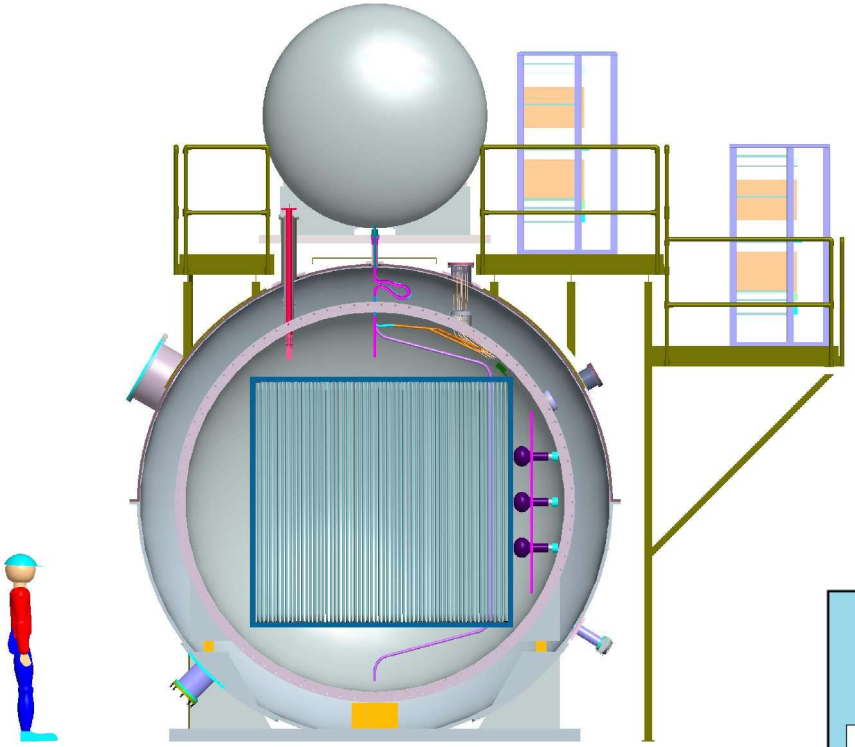


Ionization electron drift lines for a uniform track (Garfield-9) →

Wire holder guides wires to pre-amp and crimps in place ←



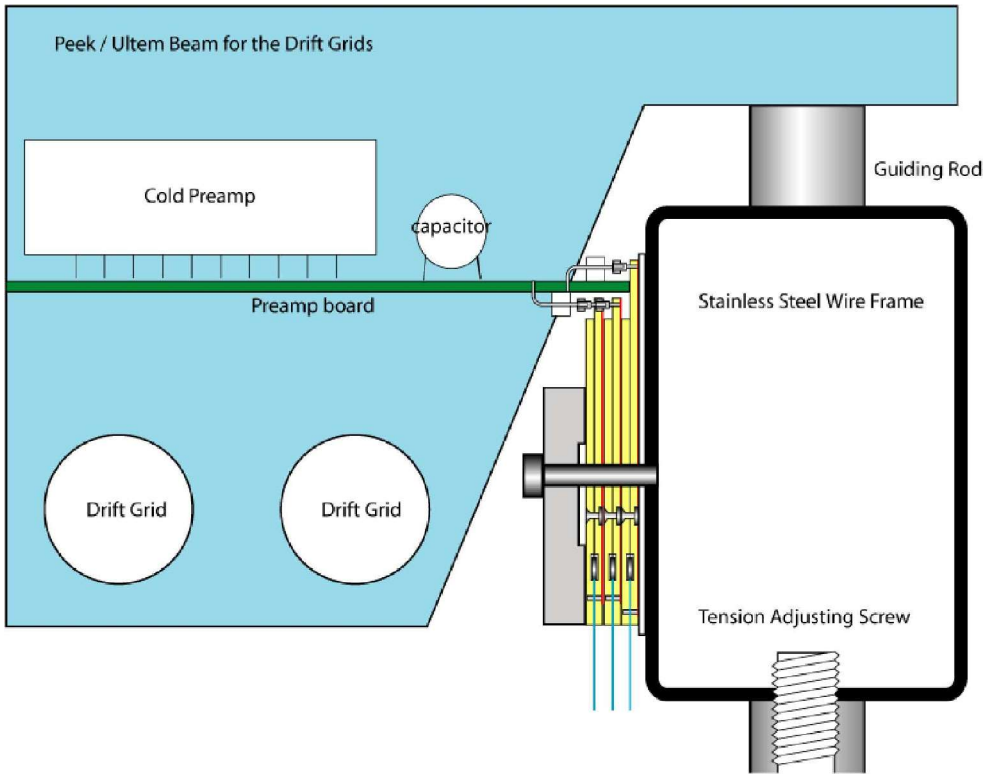
Inner Detector: Mechanical Support



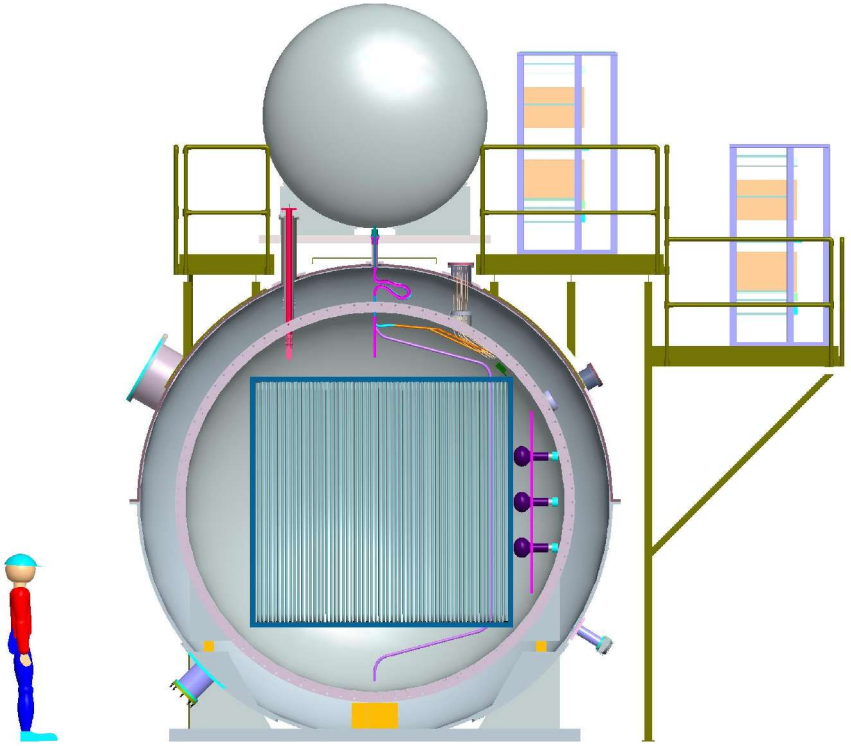
Mechanical support
of wires and wire frames

figs 4.23 and 4.27

could include this....



Inner Detector:Readout electronics

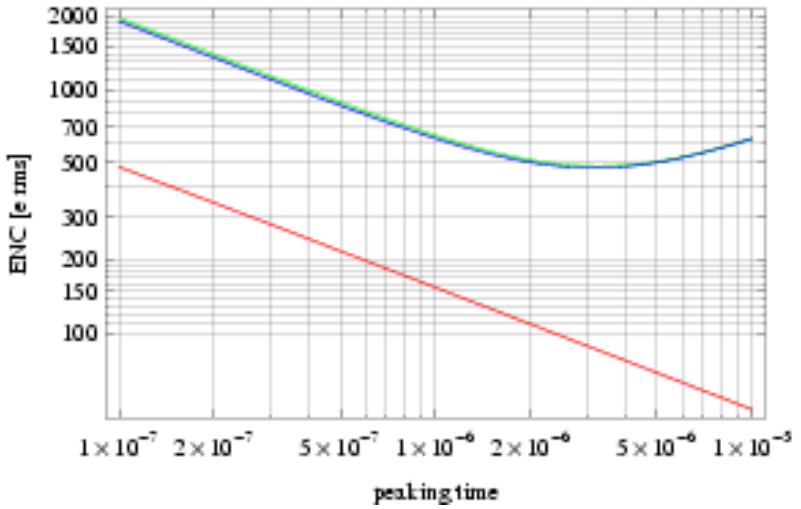


Design Considerations

- dynamic range:
  - MIP readout (2.1 MeV/cm) for e/γ
  - ionization from recoil protons and EM showers up to 3 GeV
- Wire proximity: minimize coherent noise
- Sampling Rate for shaper: 2 MHz
- Data taking modes: beam, calib, nhit,...
- minimize power consumption

Overall: Maximize Signal/Noise
minimize inteconnection lengths

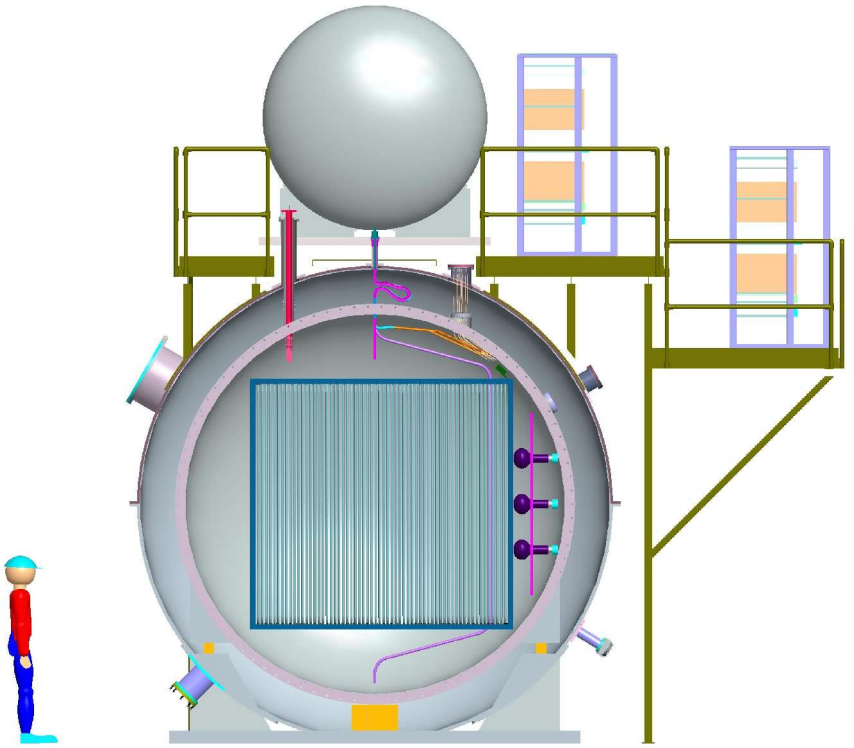
Cryogenic pre-amplifiers



Need to achieve 1 MIP resolution
1 MIP = 2.1 MeV/cm
or 0.6 MeV/3mm = 15k electrons

attenuated to ~3k es over 2.6m drift
Noise of ~1700es on warm pre-amps
is too much!

Inner Detector:Readout electronics



Cold electronics:
S/N ~20-30

primarily from reduced capacitance

warm	cold
400 pF	150pF

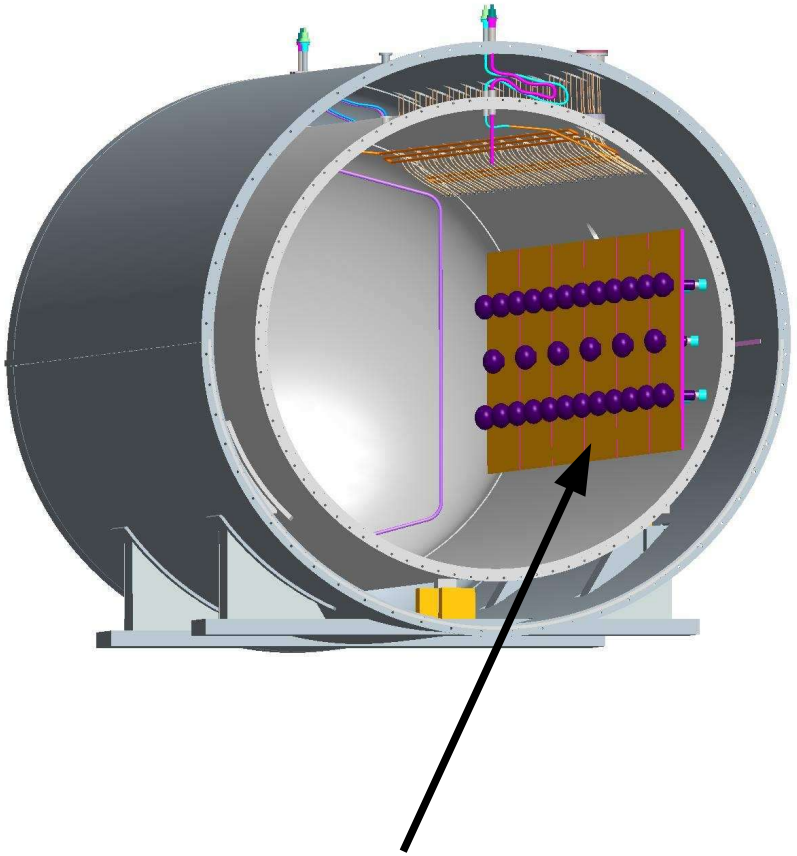
- length of electrodes
- readout connections
- cable lengths from WC to feedthrough

Pros:
- Avoids transmission of low level signals
- May allow for fewer signal feedthroughs
- Reliability

Cons
- Bubbling
- Cryogenic load
- Argon purity

Many years experience designing and operating cold electronics in HEP experiments!

Inner Detector :PhotoMultiplier Tubes



60 PMTs are located in “lune” behind the TPC WC planes

Neutrino interaction rate:
⇒1spill in 200

Cosmic interaction rate:
⇒ 6 per ~3ms drift readout

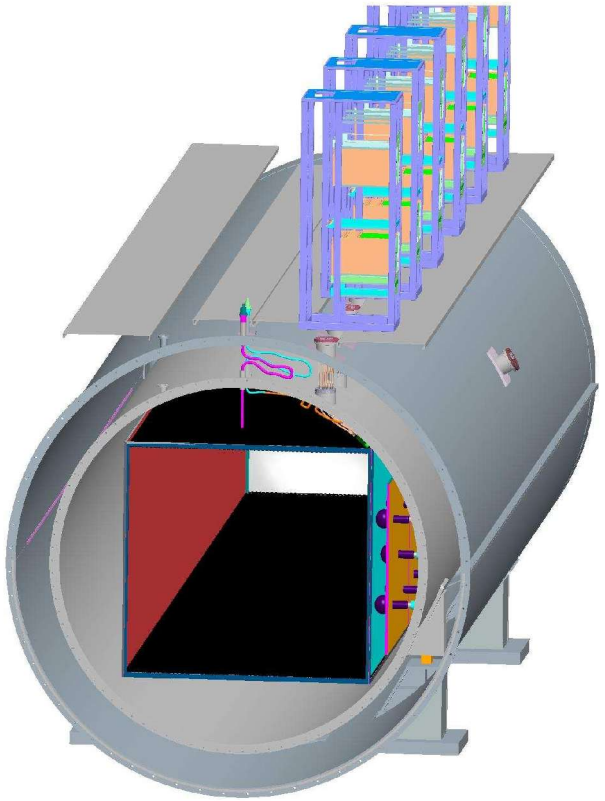
PMTs tag spills with neutrino interactions by looking for prompt light signal in coincidence with 1.6 ms spill from the BNB

Prompt light: 128 nm scintillation light (10^4 photons/MeV)

PMTs used in ICARUS T600 operable at cryogenic temps.

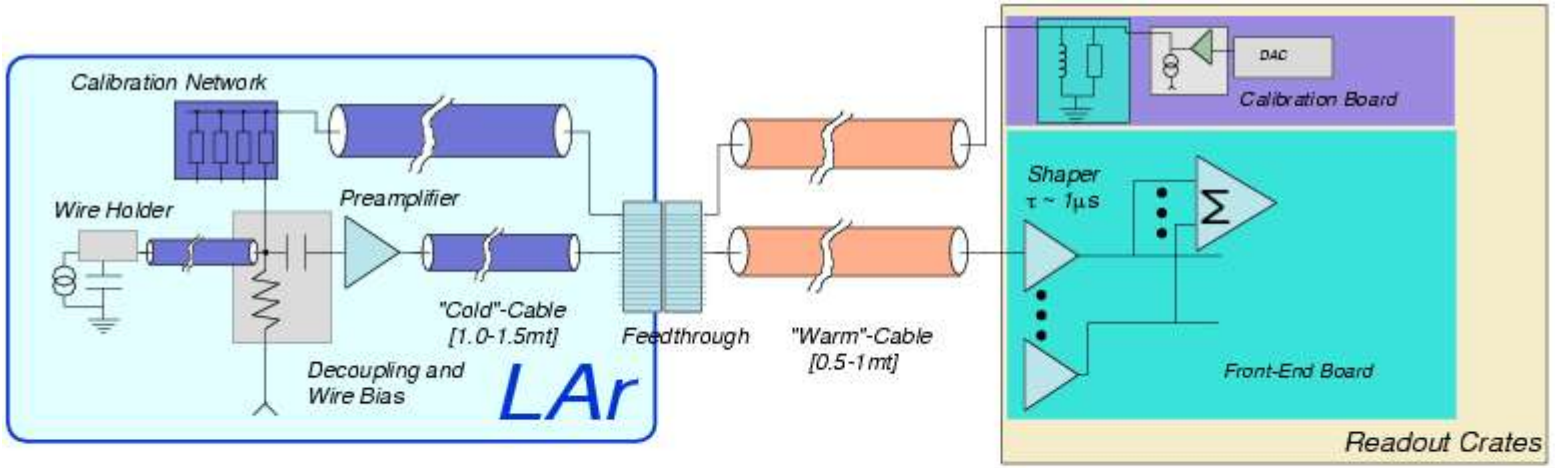
128nm light shifted to the visible via WLS painted on PMT face

Readout Architecture

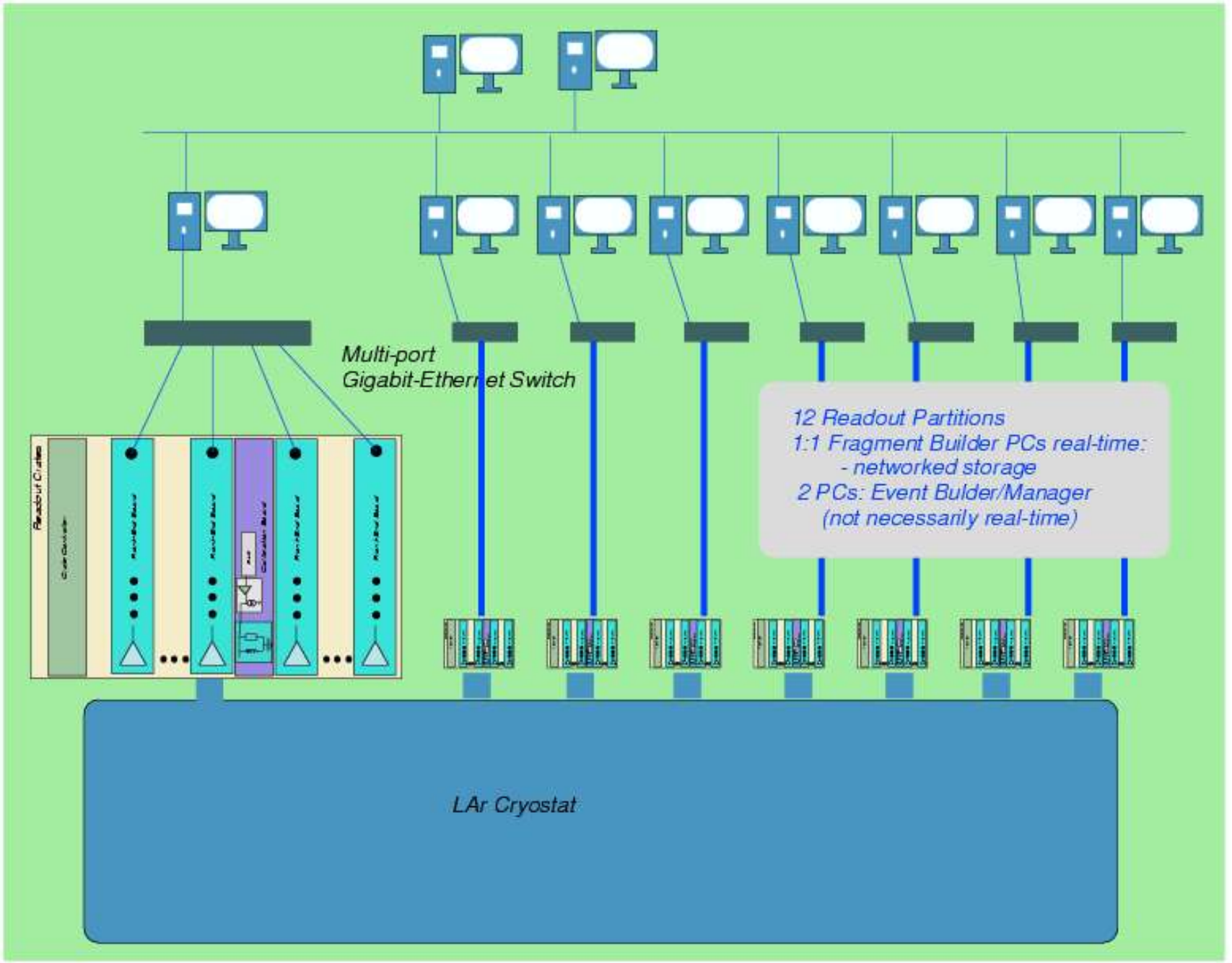


Processing and temporary storage of readout from 12,000 channels

12 readout crates for 12 feedthroughs
- signals are shaped
- continuously sampled at 20msps
- digitized in ADCs
- FPGA for data processing and signal reduction



Data Aquisition

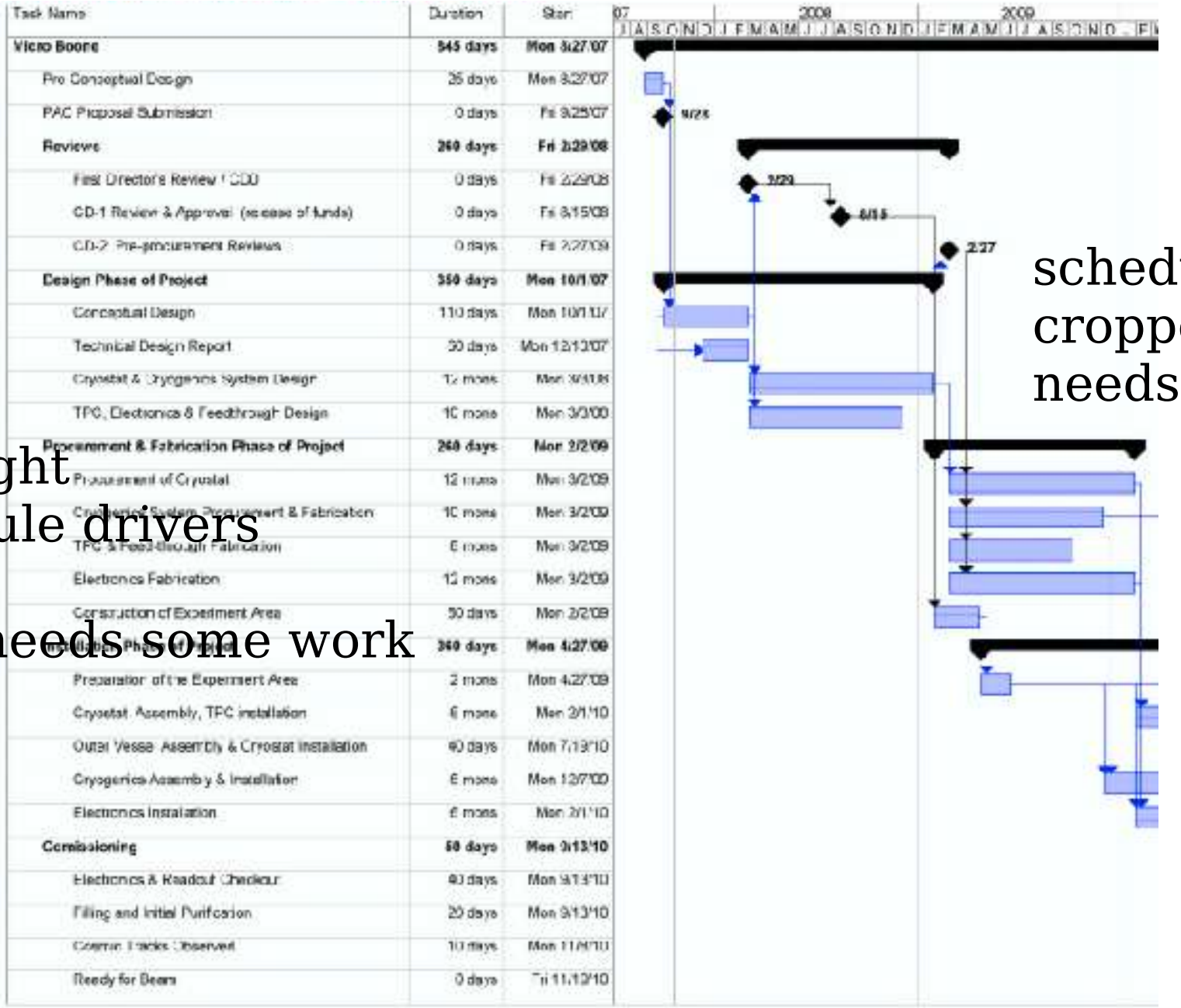


- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

Cost: Total Materials = 6.1M

	Resource Items	Cost	Materials Cost Estimate	Labor Cost Estimate	Notes
Micro BooNE Project **Conceptual Design & Cost Estimate**		**$9,358,000.00**	**$6,048,000.00**	**$3,310,000.00**	
Facility & Infrastructure		$425,000.00			FESS estimate of Shield-Block building on newly constructed concrete pad. Pad area includes space for storage vessels. Total floor-load of 600 tons, 500psf. Includes utility conduit to MB enclosure. Includes labor and contingency
Cryostat	Cryostat Vessel, Cryo/Vacuum feedthroughs & flanges, Cryostat Assembly Labor, Detector Head Vessel, LAr Filling,Vessel Insulation	$1,720,000.00	$1,420,000.00	$300,000.00	Cryostat Vessel, including feed-throughs for cryo and vacuum systems. 50+ tons fiducial volume, 175 tons LAr total. Inner cryostat 3.2m OD, 13.2m long. Sits inside vacuum vessel 4.7m OD, 13.5m long. About 100 tons empty. About 300 tons full.
Cryogenics	Storage Dewars: 1 N2, 2 LAr, LAr Purification System, Valves, plumbing, cryo parts, Cryo Controls, 2 Cryo pumps, Vacuum System, Cryogenics Assembly Labor	$2,130,000.00	$1,730,000.00	$400,000.00	Cryogenics system. Includes 5000gal N2 dewar for feed-through cooling loop 2 23,000gal argon dewars for storage. About 300 tons total weight with liquid gases
TPC	12 sets of Signal FT flange and carriers, HV Feedthrough, Signal and HV FT Assembly, Wire Chamber Frames and Assemblies, HV Cage & resistors, Cables[1],TPC HV PS Pre-Amp power cables HV Cage Assembly	$1,266,000.00	$566,000.00	$700,000.00	3 planes, Y, U&V @60deg 3mm pitch HV cage 500 V/cm 1 HV feed-through multiple signal feed-through along length
Electronics & Readout	Cold Pre-Amps, Electronics Boards, PA assembly/test Electronics assembly/test, LVPS, LVPS assembly/test labor, outer PA power cables, Signal/Calibration Cables, Cable assembly/test,	$2,507,000.00	$1,707,000.00	$800,000.00	10,000 channels @ $152/ch, single phase. 12 or 14 bit ADC 200-400ns digitization frequency charge injection at wire for calibration
DAQ & Monitoring	DAQ Hardware, DAQ Labor, Detector Monitoring Hardware, Det Monitoring Labor	$310,000.00	$200,000.00	$110,000.00	DAQ Hardware & labor, Detector Monitoring Hardware & Labor
Installation & Integration		$1,000,000.00	$0.00	$1,000,000.00	Installation Labor

Technically driven schedule ->



Task Name	Duration	Start
Vicro Boone	**545 days**	**Mon 8/27/07**
Pre Conceptual Design	26 days	Mon 8/27/07
PAC Proposal Submission	0 days	Fri 9/28/07
Reviews	**260 days**	**Fri 2/29/08**
First Director's Review / CDO	0 days	Fri 2/29/08
CD-1 Review & Approval (release of funds)	0 days	Fri 8/15/08
CD-2 Pre-procurement Reviews	0 days	Fri 2/27/09
Design Phase of Project	**350 days**	**Mon 10/1/07**
Conceptual Design	110 days	Mon 10/1/07
Technical Design Report	30 days	Mon 12/10/07
Cryostat & Cryogenics System Design	12 mons	Mon 3/3/08
TPC, Electronics & Feedthrough Design	10 mons	Mon 3/3/08
Procurement & Fabrication Phase of Project	**260 days**	**Mon 2/2/09**
Procurement of Cryostat	12 mons	Mon 3/2/09
Cryogenics System Procurement & Fabrication	10 mons	Mon 3/2/09
TPC & Feed-through Fabrication	6 mons	Mon 3/2/09
Electronics Fabrication	12 mons	Mon 3/2/09
Construction of Experiment Area	30 days	Mon 2/2/09
Installation Phase of Project	**340 days**	**Mon 4/27/09**
Preparation of the Experiment Area	2 mons	Mon 4/27/09
Cryostat Assembly, TPC installation	6 mons	Mon 2/1/10
Outer Vessel Assembly & Cryostat Installation	40 days	Mon 7/19/10
Cryogenics Assembly & Installation	6 mons	Mon 12/7/09
Electronics Installation	6 mons	Mon 2/1/10
Comissioning	**50 days**	**Mon 9/13/10**
Electronics & Readout Checkout	40 days	Mon 9/13/10
Filling and Initial Purification	20 days	Mon 9/13/10
Cosmic Tracks Observed	10 days	Mon 11/8/10
Ready for Beam	0 days	Fri 11/12/10

schedule cropped needs fix

highlight schedule drivers

slide needs some work

Ready for beam in late 2010

- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program

start doing
physics here!

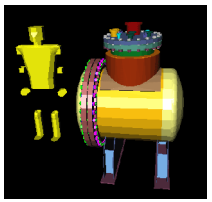
5 kton:
sensitivity to
mass
hierarchy,
increase
sensitivity to
θ_{13}

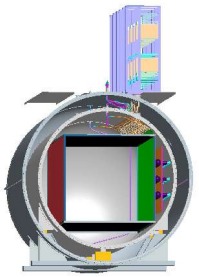
50-100 ktons:
Search for CP
Violation in
neutrino sector

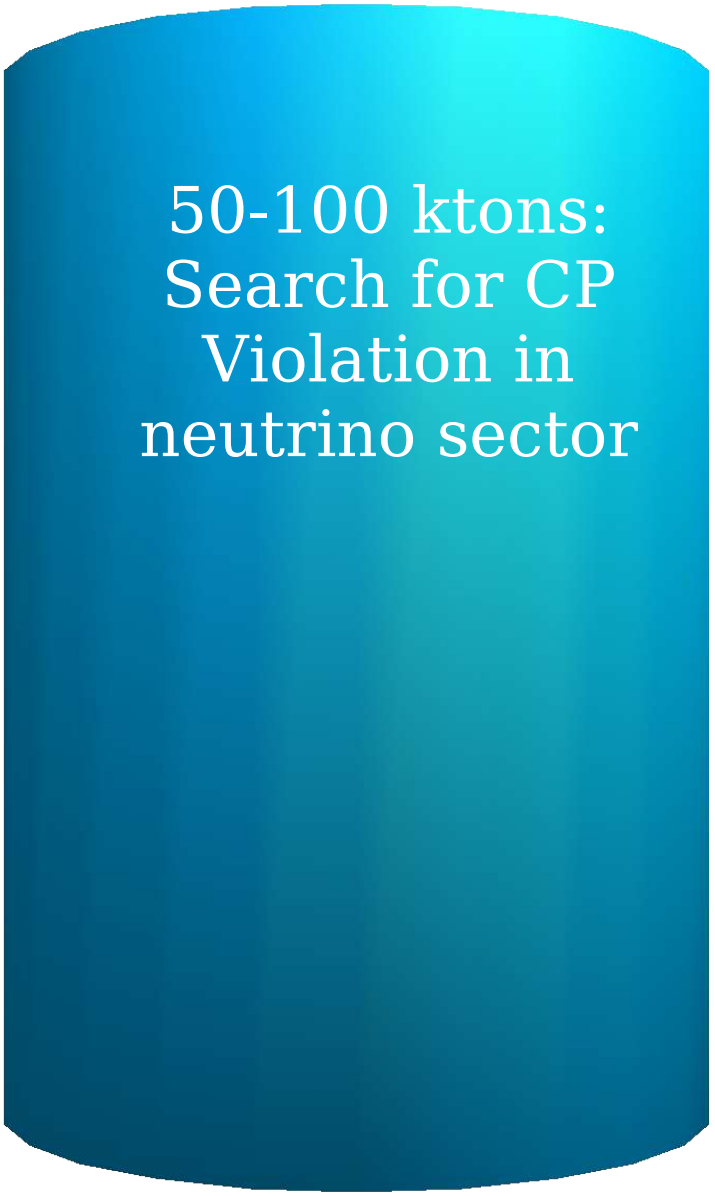
MicroBooNE
170 ton

20 ton
purity
demon-
stration

Test stands:
ArgoNeuT
Materials Test







2007 2008 2010 2013-15 201?

start doing
physics here!

One of the four top level recommendations from the NuSAG report, 2007:

"A phased program with milestones and using technology suitable for a 50-100kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended"

Test stands: demon-

N

Quote from Fermilab Steering Committee on the importance of pursuing LArTPC R&D for the future

2007 2008 2010 2013-15 201?

MicroBooNE is a perfect fit in this phased program.

Gain experience:

- Achieving and maintaining purity (FNAL design)
- Implementing cold, low noise, electronics
- designing, constructing, and installing field cage, wire chambers, PMTs, etc.

Hardware R&D

- Collect large sample of 1 GeV neutrino interactions
  - developing simulation and reconstruction techniques
  - removing cosmic background from surface detector
  - measuring neutrino interactions on Liquid Argon

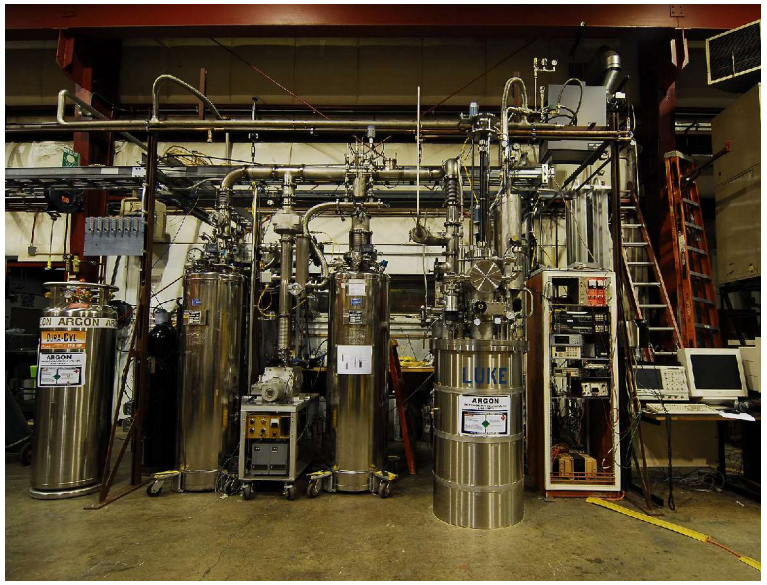
Physics R&D

This R&D program makes the next necessary advances towards massive LArTPC with a design that ensures MicroBooNE will meet its physics goals.

Timeline is important: Must proceed with R&D so as to be ready for technology decision for next step in long baseline program

Achieving and Maintaining purity

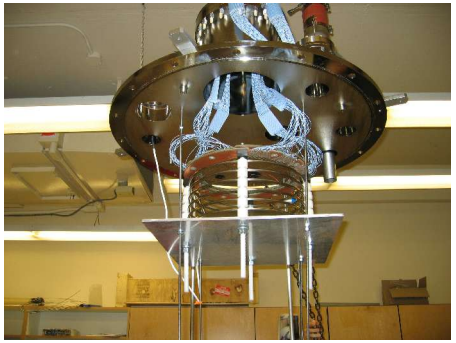
Filter development at FNAL:



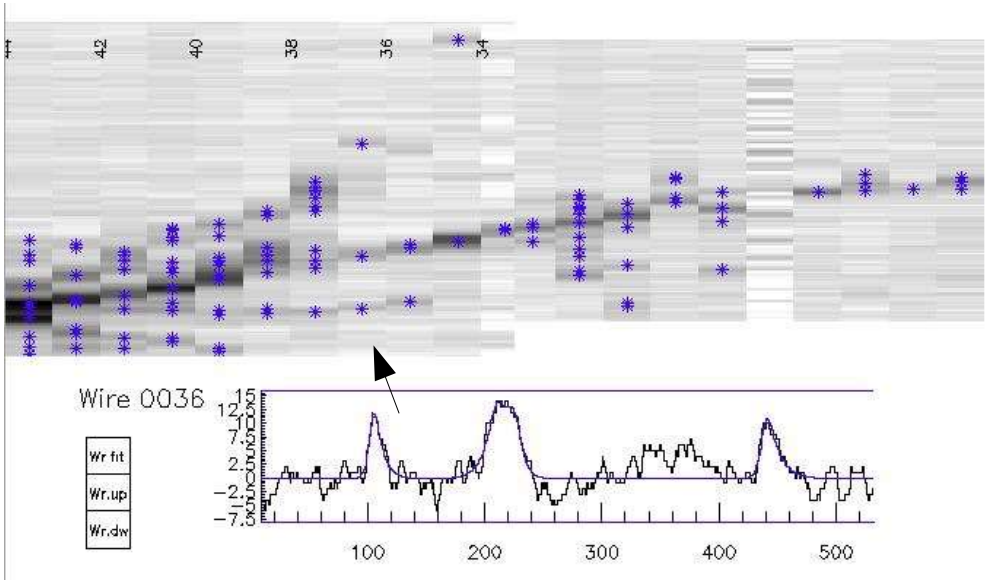
Designed, built, and tested new filters for LAr
- Materials test stand
- ArgoNeuT
- 20 ton purity demonstration

MicroBooNE ⇒ use these in a running physics experiment

Using FNAL filters at Yale
- achieved good purity
- regenerated filters in the lab

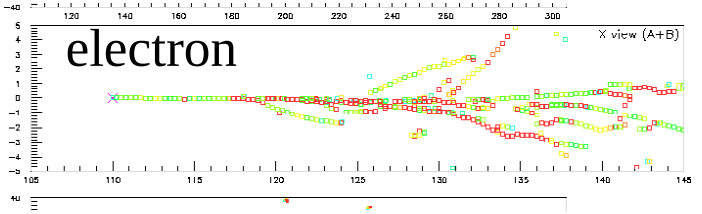


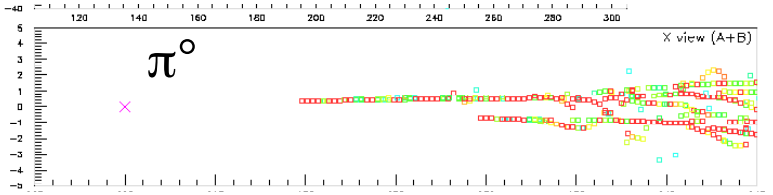
First tracks in US seen April '07!



Cold electronics:

- ~x4 reduction in noise compared to ICARUS
- allows for MIP resolution (2.1 MeV/cm) -> important for e/gamma separation.
- will be crucial for very large detectors with very long wires





Expertise is with BNL team:
Design based on experience with 40,000 channels running for 15 years

- first employed in Helios-NA34 experiment (late 1980s)
- further R&D for the GEM detector and for the ATLAS LAr calorimeter
- Major installation: NA48 experiment and ATLAS.

MicroBooNE

- address the MiniBooNE low energy excess
- precisely measure low energy neutrino cross sections
- make the next necessary step in LArTPC R&D

We ask the PAC to endorse the physics and technological program for MicroBooNE towards Stage 1 approval.

Presentation to the Fermilab PAC, Fall 2007

Backup Slides

todos:
Readout Architecture and
Cold Electronics slide

gamma table

Is Physics R&D and Hardware R&D borne out well enough?