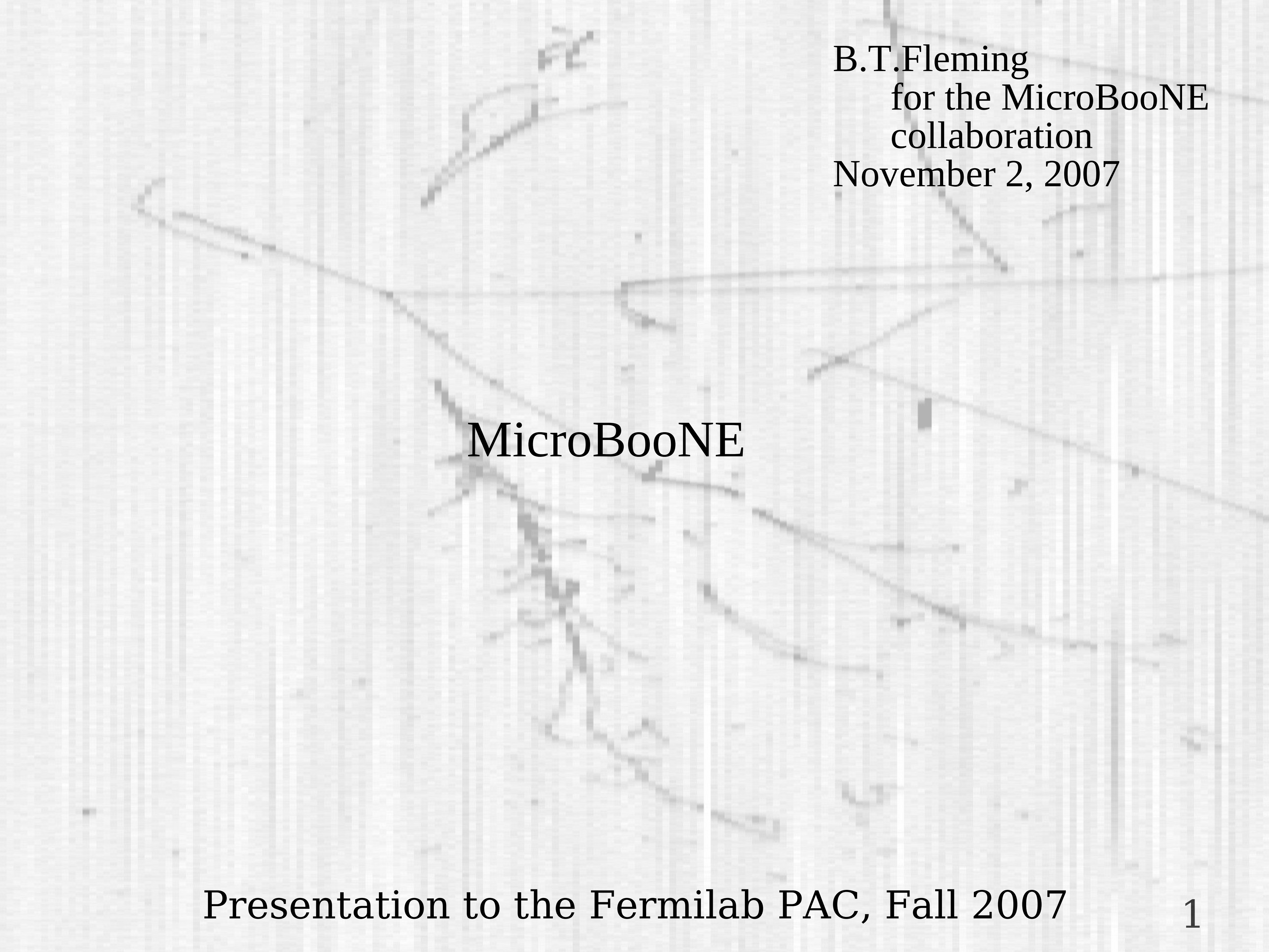


B.T.Fleming
for the MicroBooNE
collaboration

November 2, 2007

MicroBooNE

What are the open questions in Neutrino Physics today?

(from the APS Neutrino Study)

- Neutrinos and the New Paradigm
- Neutrinos and the Unexpected
- Neutrinos and the Cosmos

"Determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino oscillation physics."

MicroBooNE touches on all of these themes

- Neutrinos and the New Paradigm

MicroBooNE is the next necessary step in Liquid Argon TPC technology towards massive detectors for CP Violation physics

- Neutrinos and the Unexpected

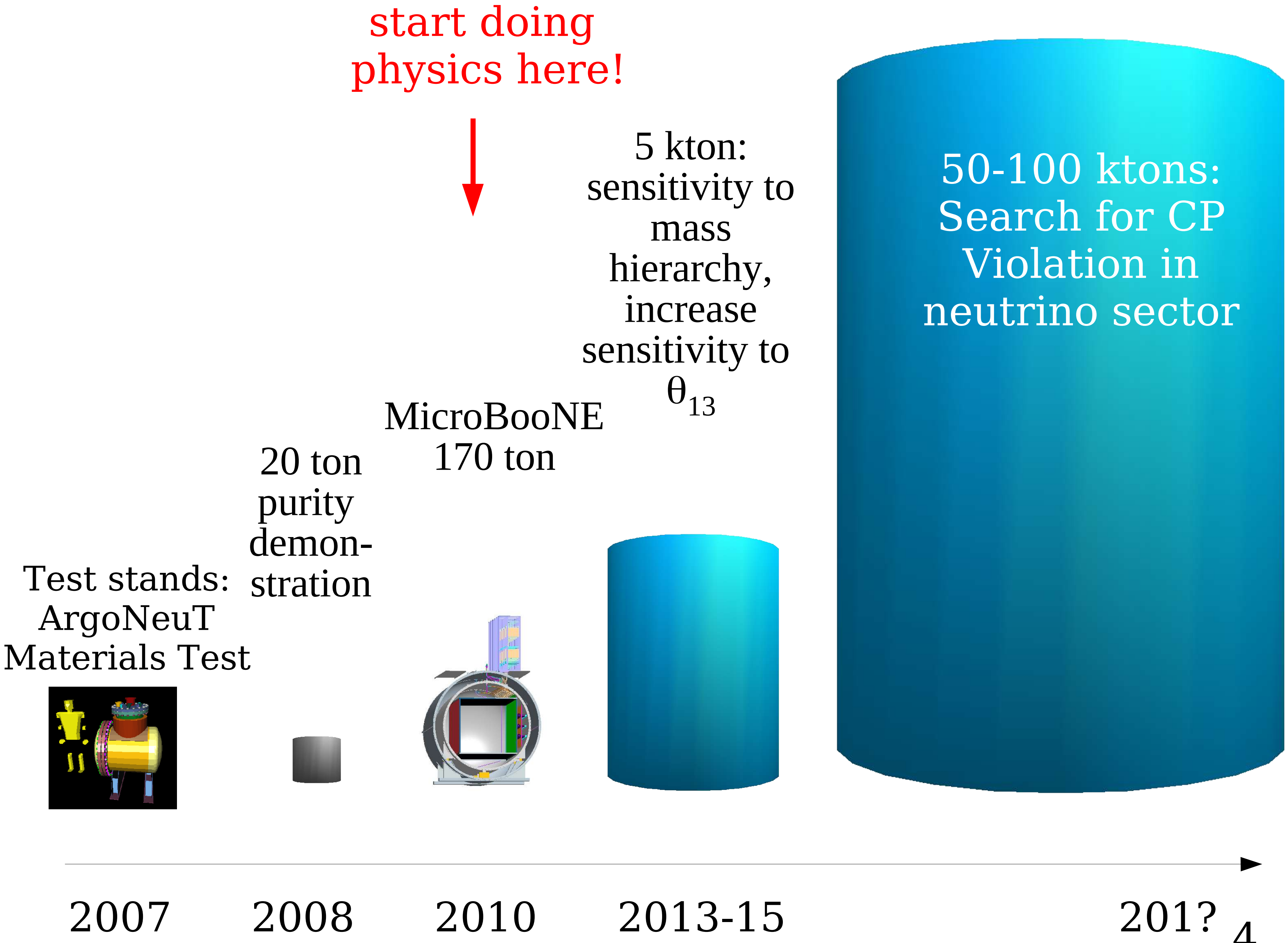
MicroBooNE will address the low energy excess observed by MiniBooNE

- Neutrinos and the Cosmos

If the sizable MiniBooNE excess is photon like, it will impact neutron star cooling and Supernovae

“Determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino oscillation physics.”

MicroBooNE will perform precision cross section measurements in the region of interest for NOvA and T2K



start doing
physics here!

Test stands:
ArgoNeuT
Materials Test

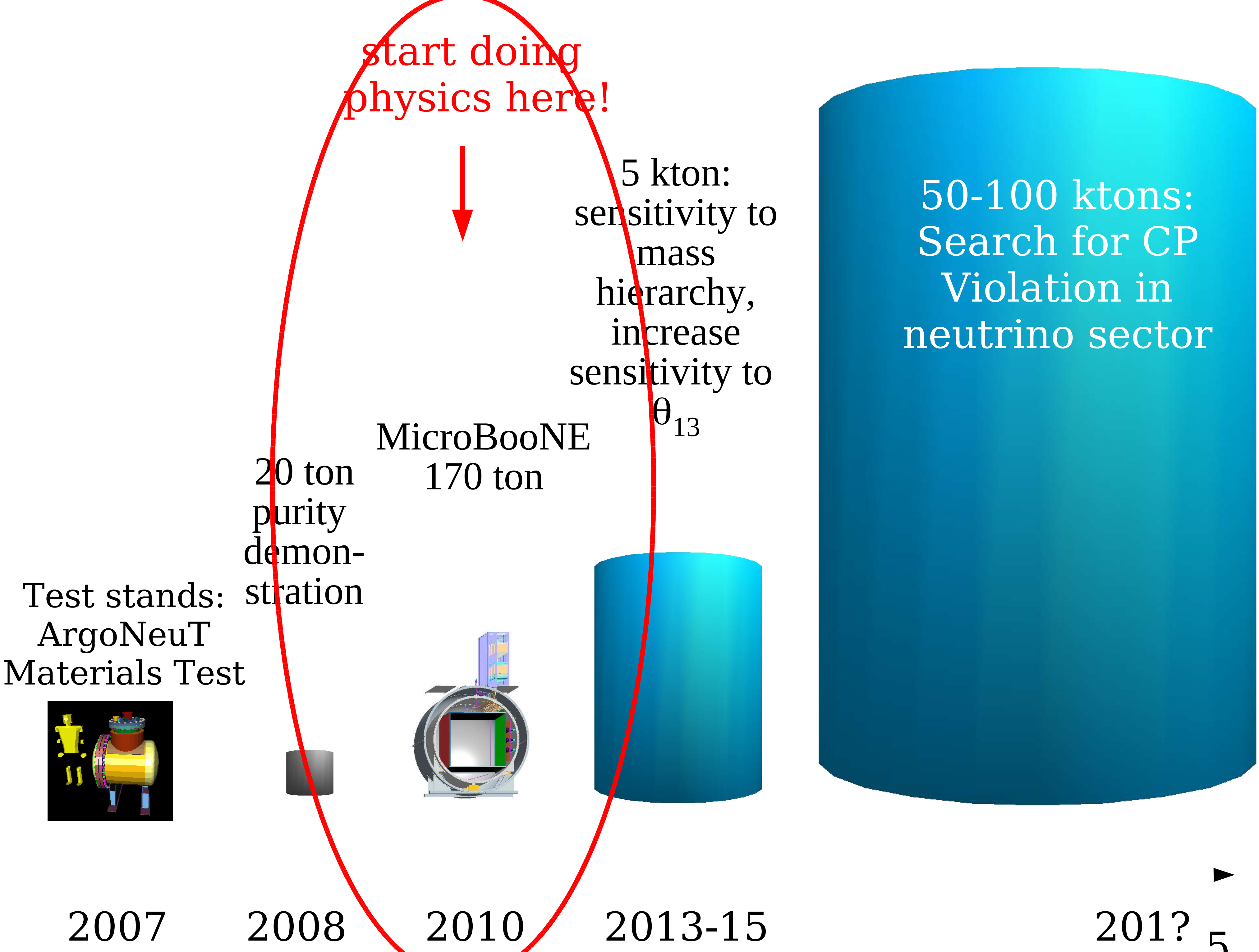
20 ton
purity
demonstration

MicroBooNE
170 ton

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

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

2007 2008 2010 2013-15 201?



start doing physics here!

Test stands:
ArgoNeuT
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20 ton
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sensitivity to
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increase
sensitivity to
θ_{13}

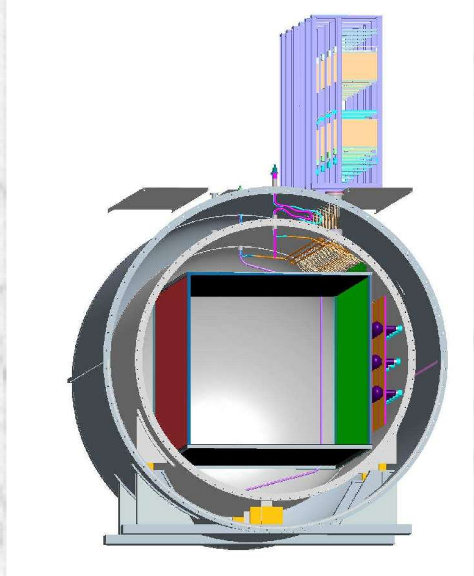
50-100 ktons:
Search for CP
Violation in
neutrino sector

2007 2008 2010 2013-15 201?

MicroBooNE: Liquid Argon Time Projection Chamber

- 70 ton fiducial Liquid Argon TPC detector
- located near the MiniBooNE detector hall
  - collect 6E20 pot from on axis Booster Neutrino Beam
  - collect 8E20 pot from off-axis LE NuMI beam

    (2-3 years of data taking)



MicroBooNE on axis BNB and off-axis NuMI beam

Booster beam

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

H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecki, J. Mead,
V. Radeka, S. Rescia, J. Sondericker, B. Yu
Brookhaven National Lab

L. Bugel, J.M. Conrad, V. Nguyen, M. Shaevitz, W. Willis†
Columbia University

C. James, S. Pordes, G. Rameika
Fermi National Accelerator Lab

C. Bromberg, D. Edmunds
Michigan State University

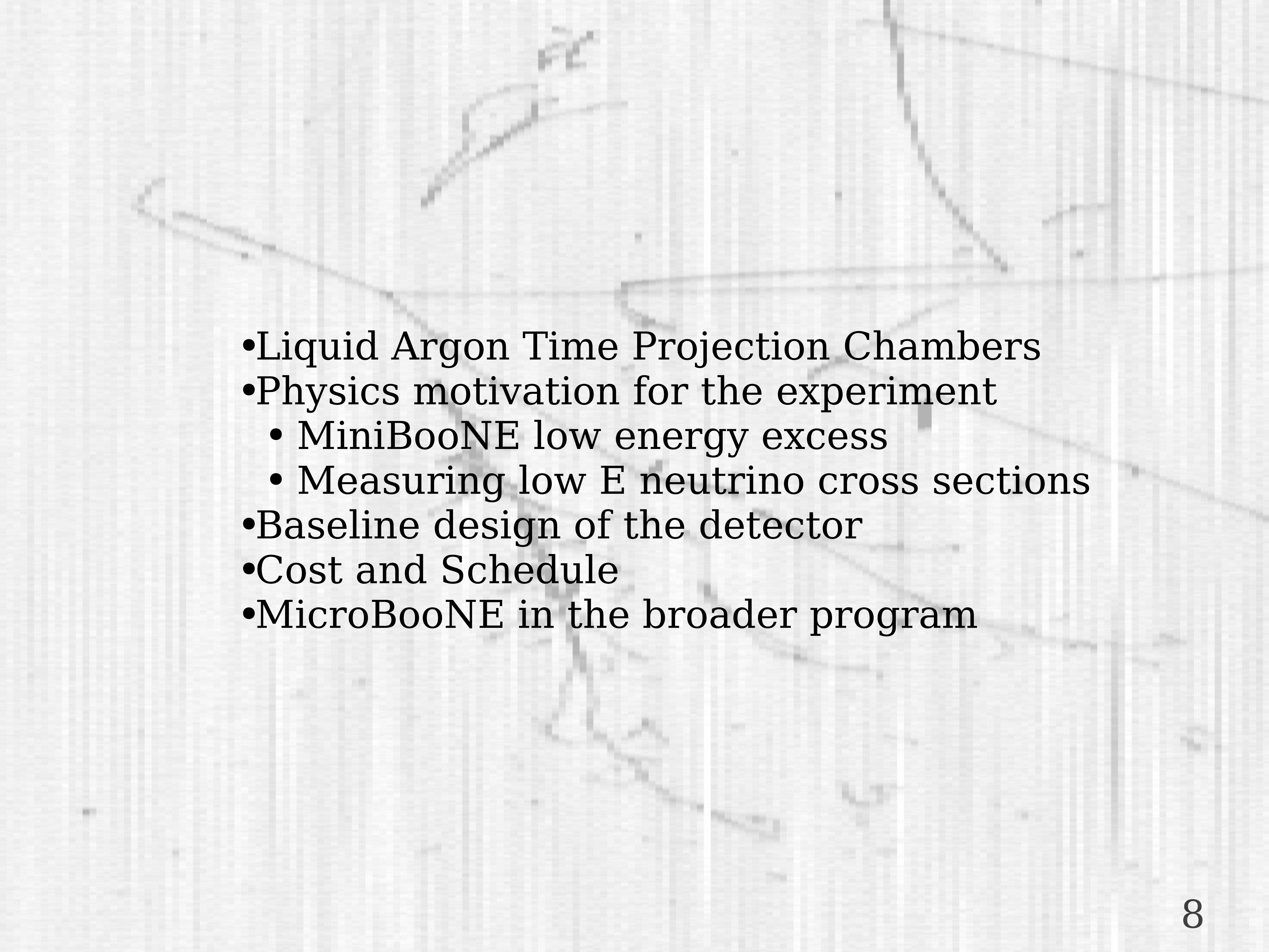
P. Nienaber
St. Mary's University of Minnesota

S. Kopp, K. Lang
University of Texas at Austin

C. Anderson, B.T.Fleming*, S. Linden, M. Soderberg, J. Spitz
Yale University

28 scientists
from
2 national labs
5 universities

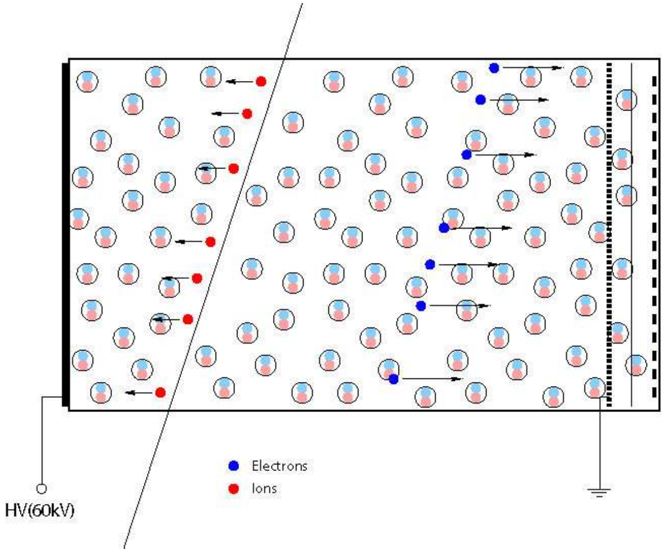
* Spokesperson
† Deputy Spokesperson



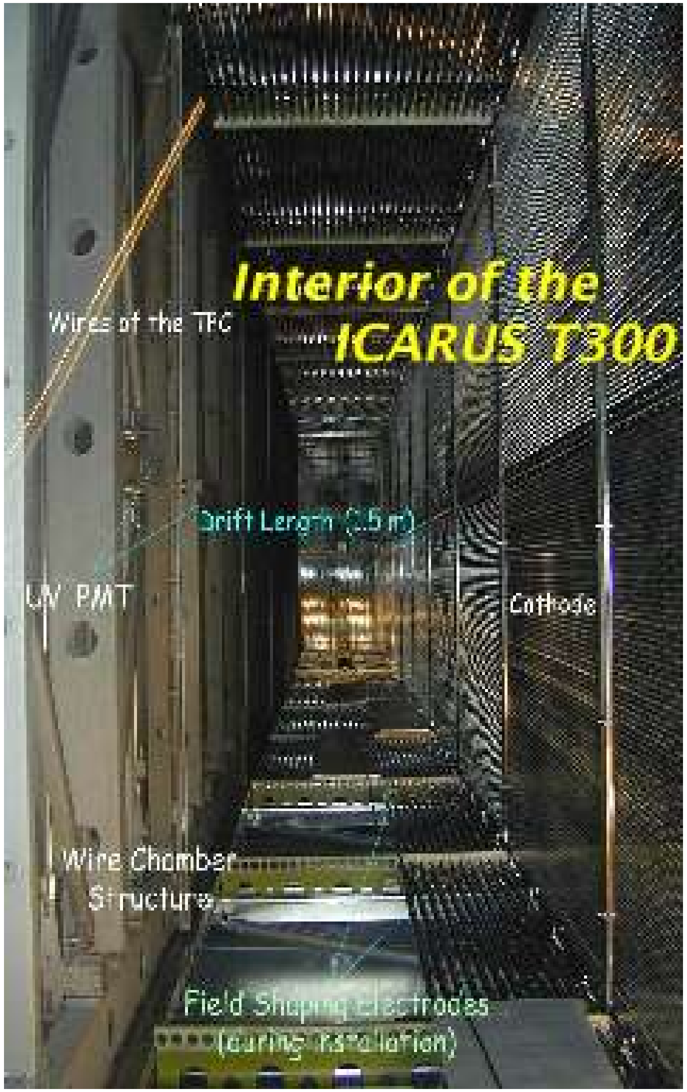
- •Liquid Argon Time Projection Chambers
- •Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- •Baseline design of the detector
- •Cost and Schedule
- •MicroBooNE in the broader program

Liquid Argon TPCs:

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

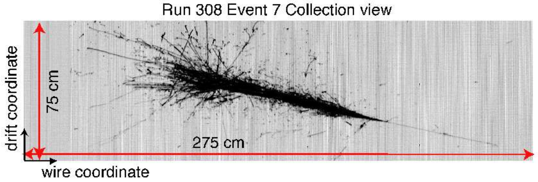


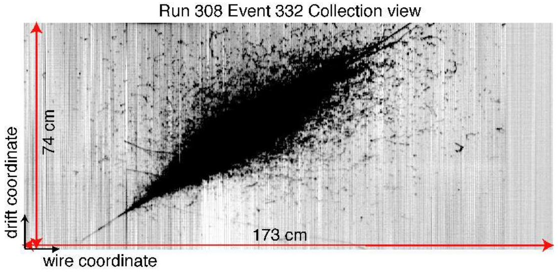
Drift ionization electrons
over meters of pure
liquid argon to collection
planes to image track

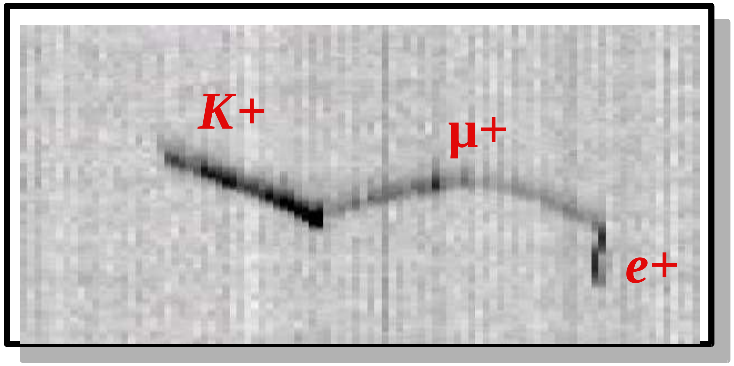


extensive experience from ICARUS
effort

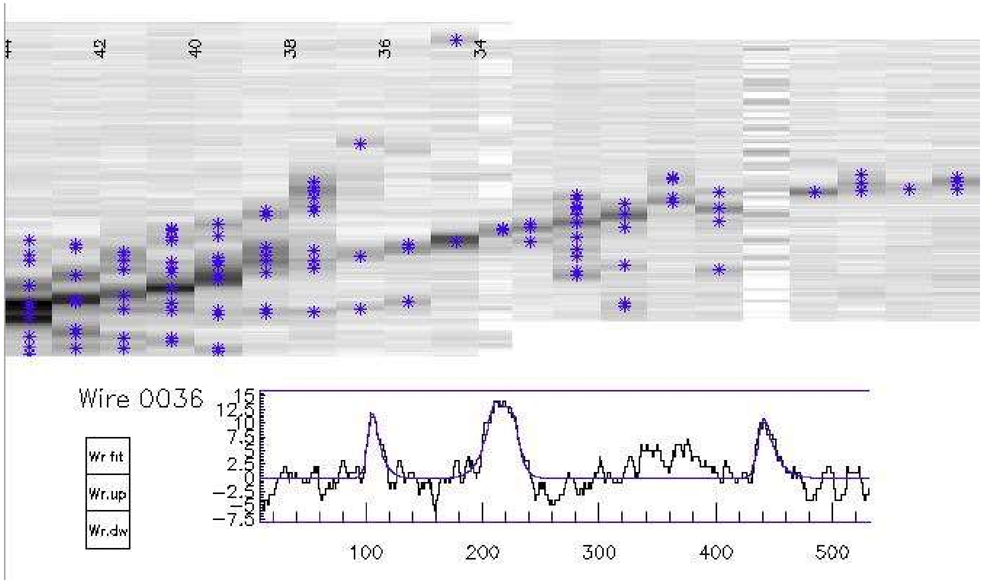
Particles in LArTPCs







T300 data from Pavia test run 2001



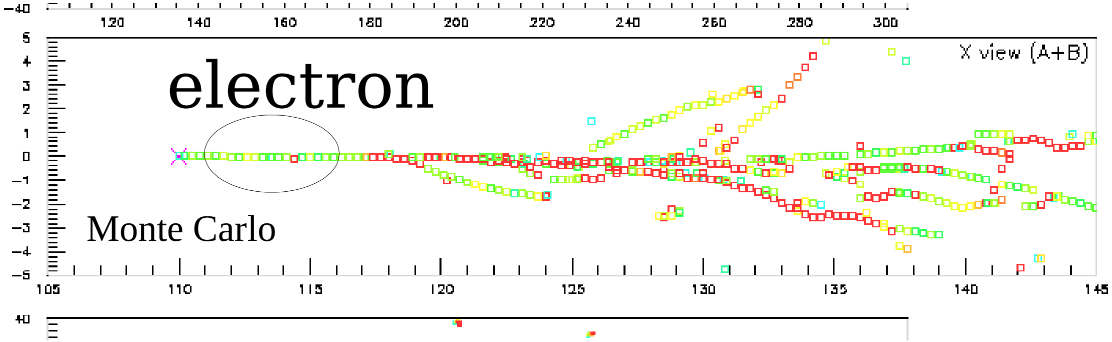
Hadronic shower from Yale TPC run, April 2007

Achieve 80-90% efficiency for electron neutrino interactions

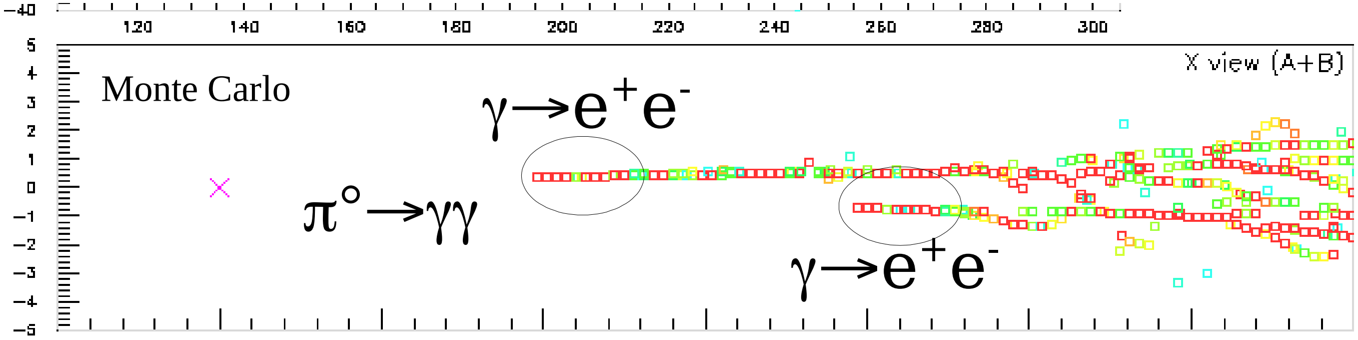
→ *Use topology to differentiate event classes*

LArTPCs image events *and collect charge*

do e/γ separation via dE/dx



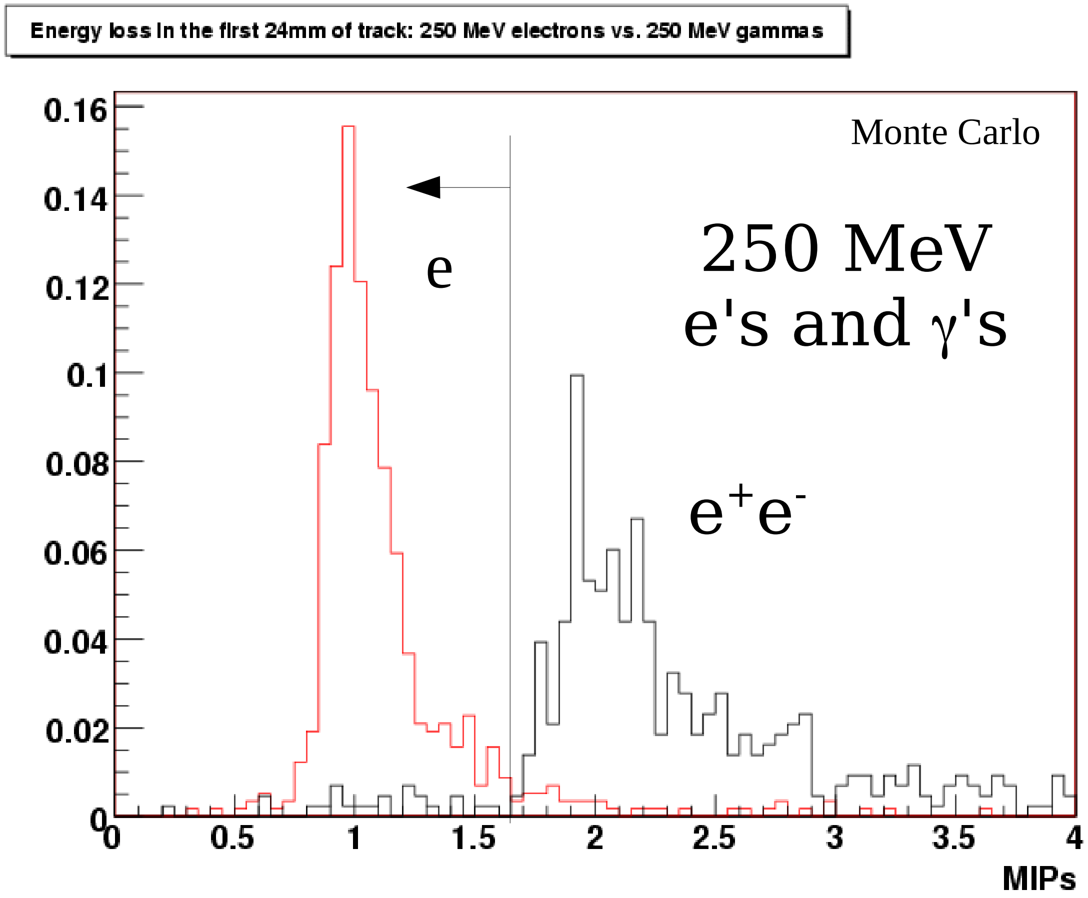
look in first couple cm of track before shower begins



Where electrons deposit
1 MIP = green

γ→e+e- deposit
2 MIPs = red

GEANT4 Monte Carlo
Simulation



MIP deposition in first 2.4 cm of track

For electron efficiency of 80%

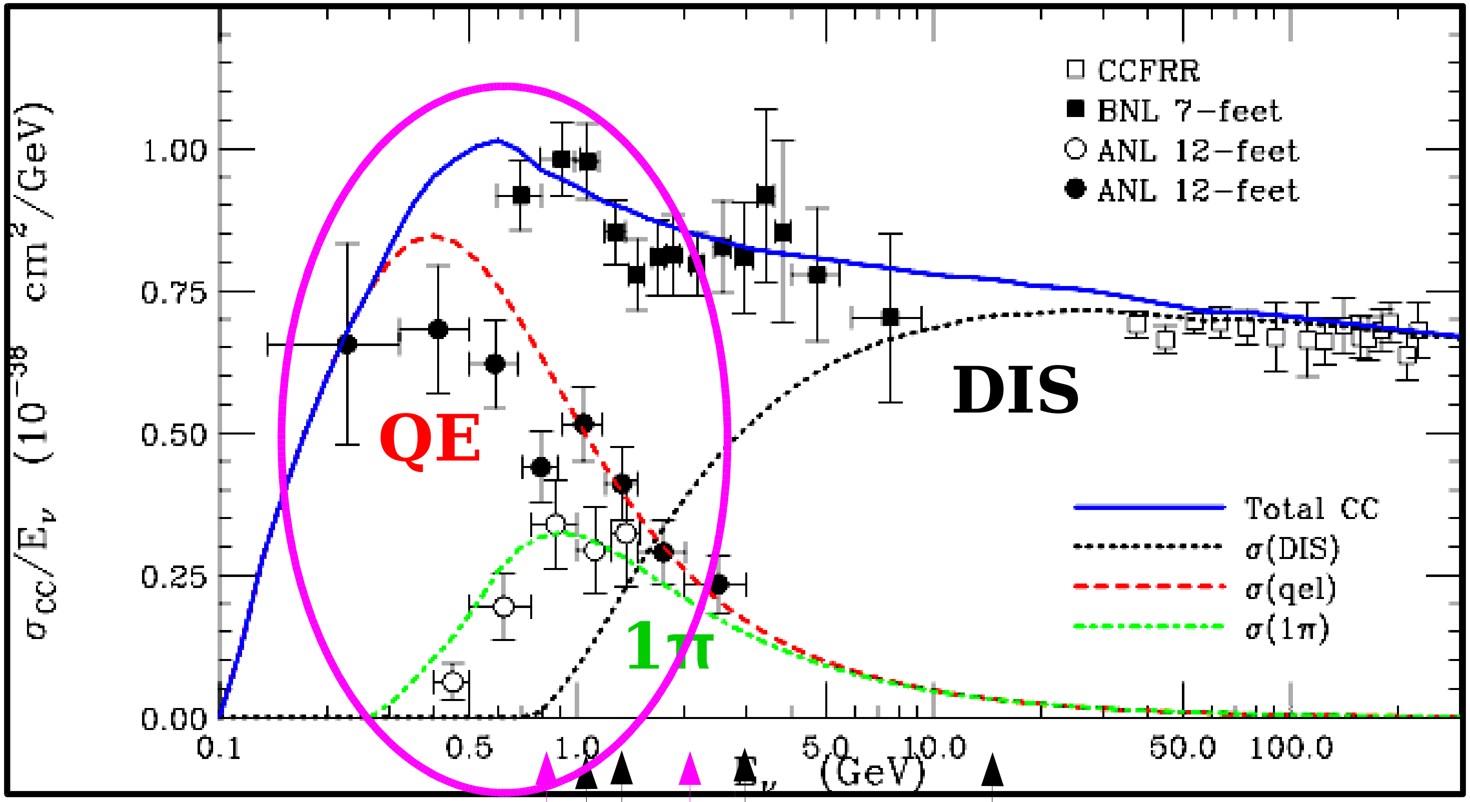
γ contamination is <5%

Similar studies report 90% electron efficiency for 6.5% γ contamination

Sensitivity calculations for MicroBooNE assume 6 ± 10% contamination

No other low energy accelerator neutrino experiment has been able to differentiate electrons from photons....

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



MiniBooNE
SciBooNE
BNB

T2K

K2K

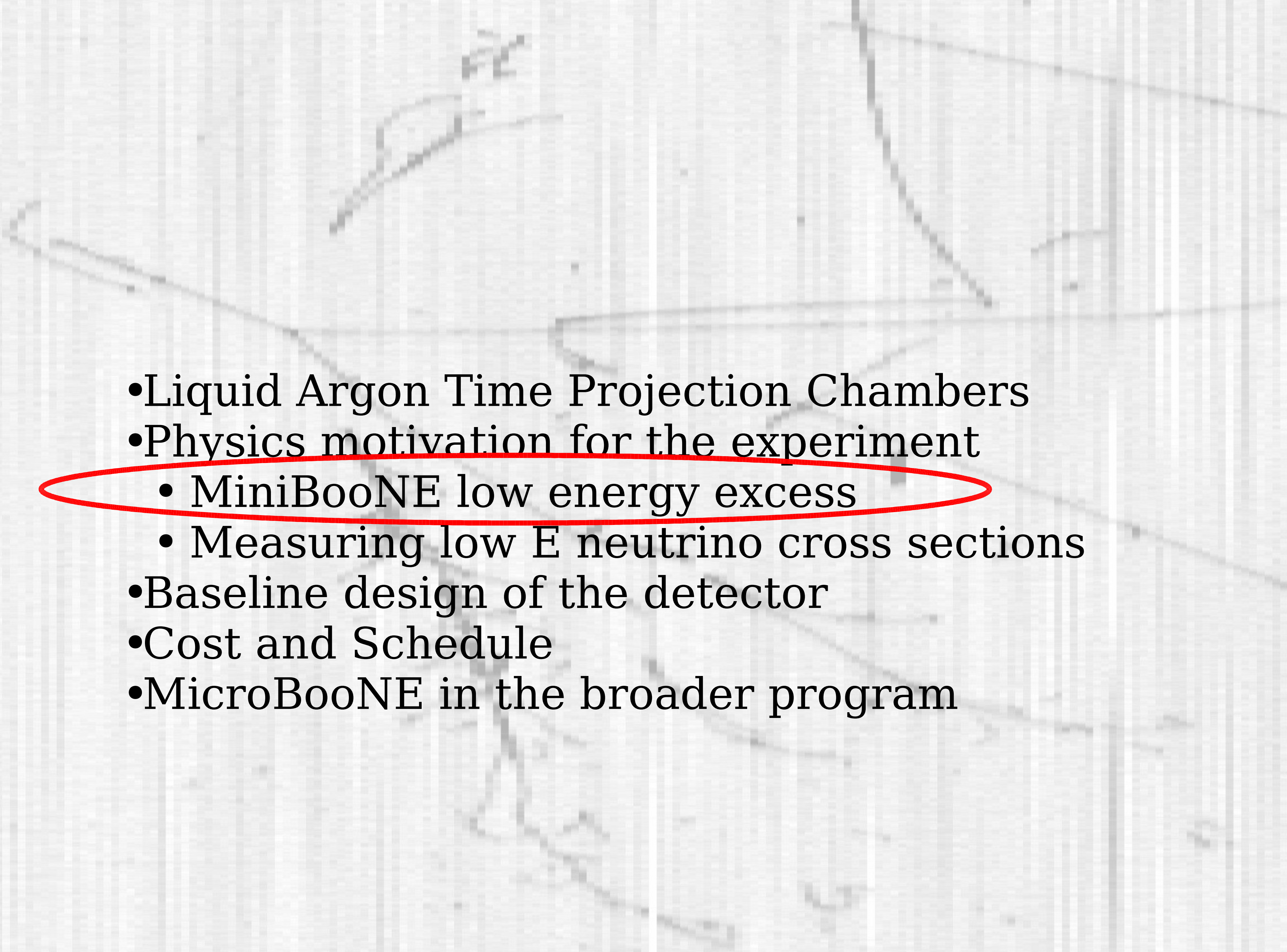
NOvA:
NuMI
off-axis

MINOS
MINERvA
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
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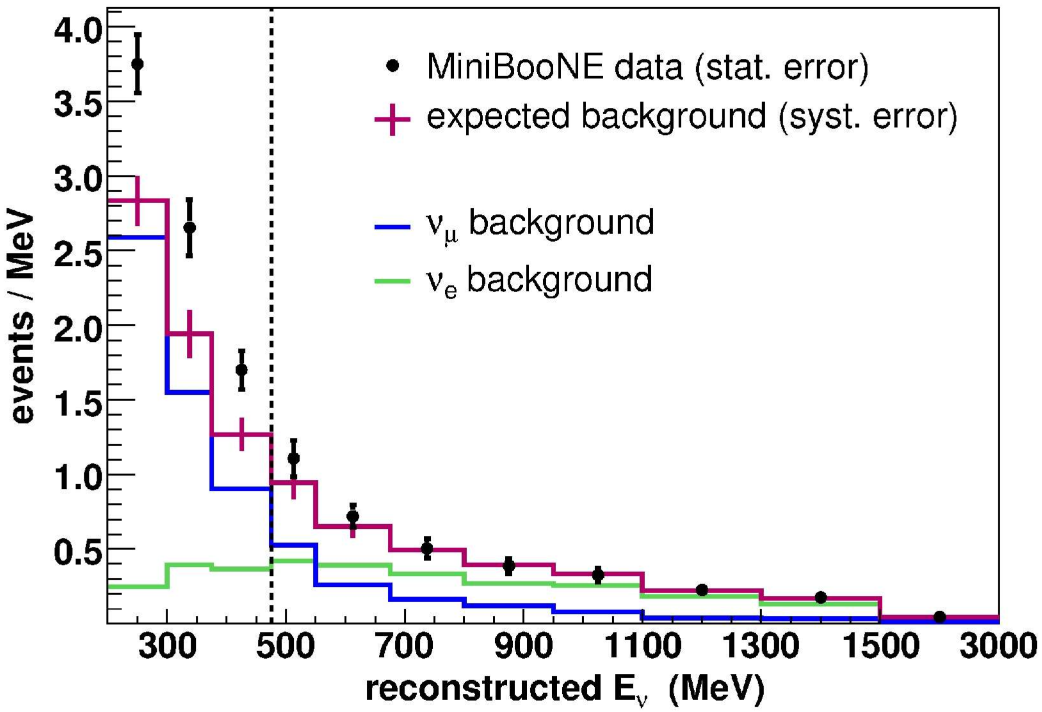
MiniBooNE Low Energy Excess



	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*

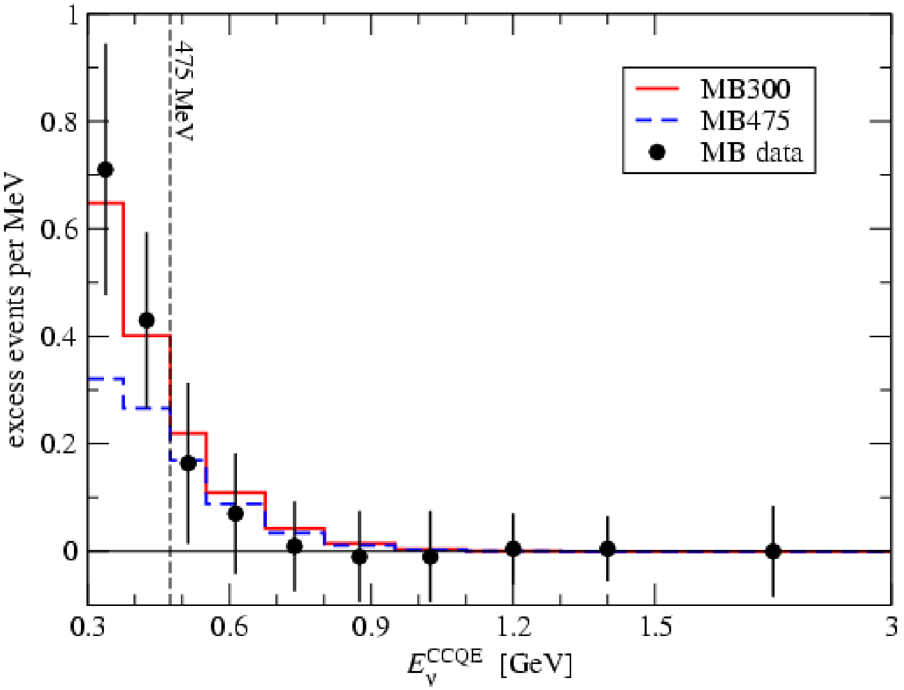
What do they suggest?

Interpretation as electron neutrinos

Oscillations to Sterile νs

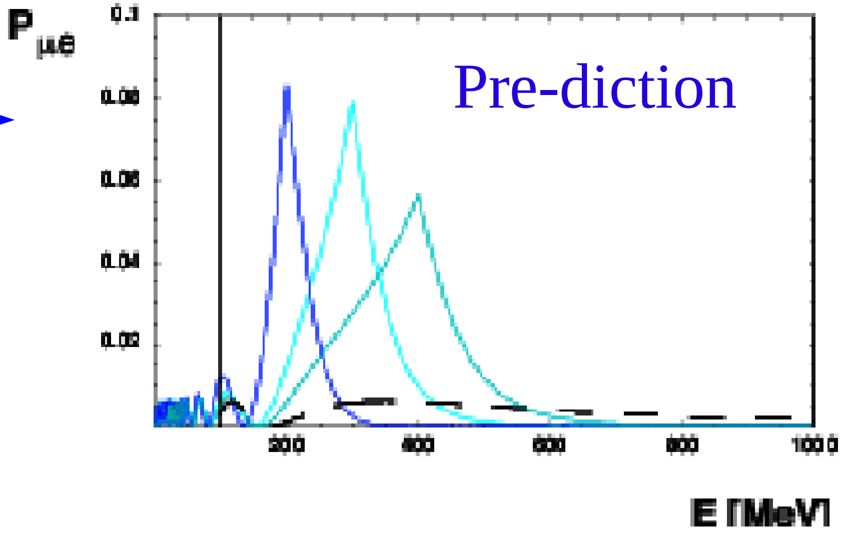
- hep-ph/0705.0107v1

Maltoni and Schwetz 3+2 CPV model fits MiniBooNE and LSND excesses. Tension with NSBL.



- hep-ph/0706.1462
- hep-ph/0710.28985
- hep-ph/0702049
- hep-ph/0504096

Pakvasa, Pas, Weiler: Sterile neutrinos that can travel in extra dimensions oscillate with SM neutrinos



Pre-diction

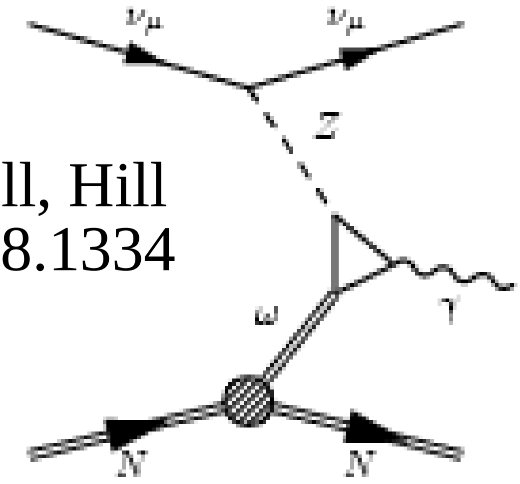
Neutrino decay, Lorentz Violation, ...

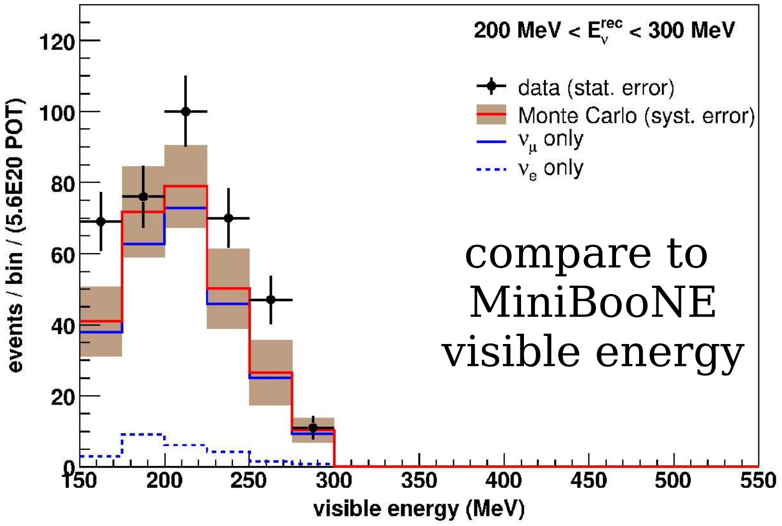
- hep-ph/0707.4953
- hep-ph/0606154
- hep-ph/0602237
- hep-ph/0707.2285

Intepretation as photons

Standard Model process with potentially big implications....
- low energy neutrino physics (relevant for T2K)
- Neutron star cooling
- Understanding why Supernovae explode
  (“crucial to astrophysics” DUSEL S1 WG)

Harvey, Hill, Hill
hep-ph/0708.1334





compare to
MiniBooNE
visible energy

No matter what, this excess must be understood.

Key improvements in MicroBooNE are:

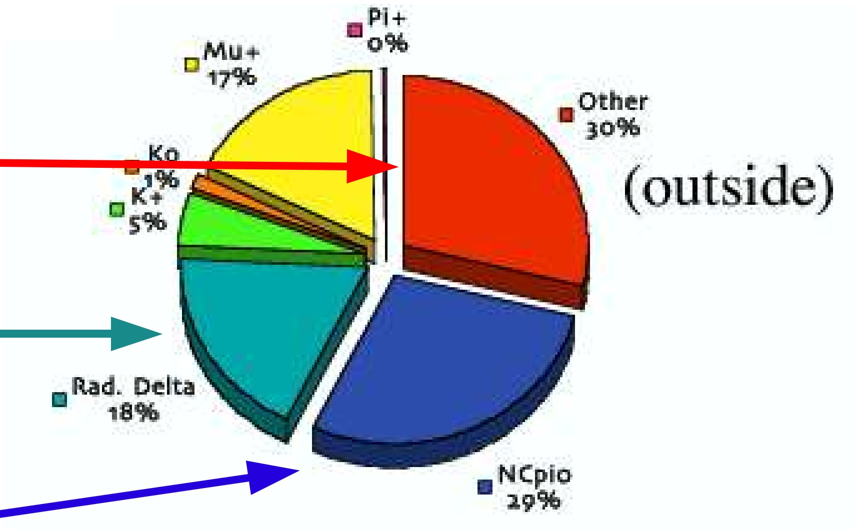
- e/γ separation capability removes ν_μ induced single γ backgrounds

Dirt: Primarily NCpi0 interactions where only one γ enters detector

Radiative Delta: $\Delta \rightarrow N\gamma$

NCpi0: Asymmetric decays where only one γ is visible

$$\nu + N \rightarrow \nu + N + \gamma + \cancel{\gamma}$$



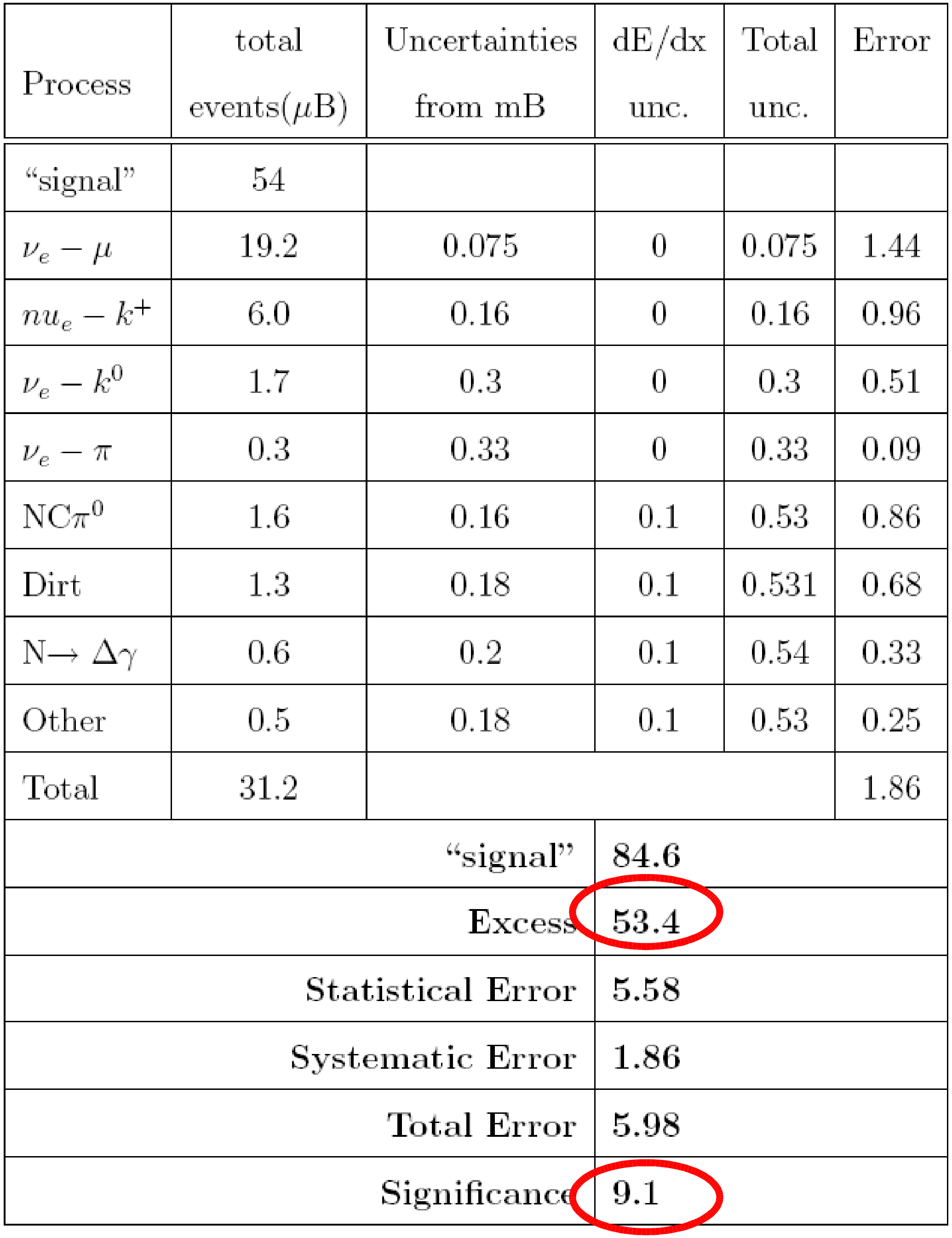
background fractions below 475 MeV

- electron neutrino efficiency: ~x2 better than MiniBooNE
- sensitivity at low energies (down to tens of MeV compared to 200 MeV on MiniBooNE

To determine MicroBooNE sensitivity:

- Apply dE/dx tag to single γ backgrounds
- Apply x2 efficiency to "signal" and intrinsic ν_es
- Scale MiniBooNE event rates to MicroBooNE's ~70 ton fiducial volume
- Beam request: 6E20 pot total

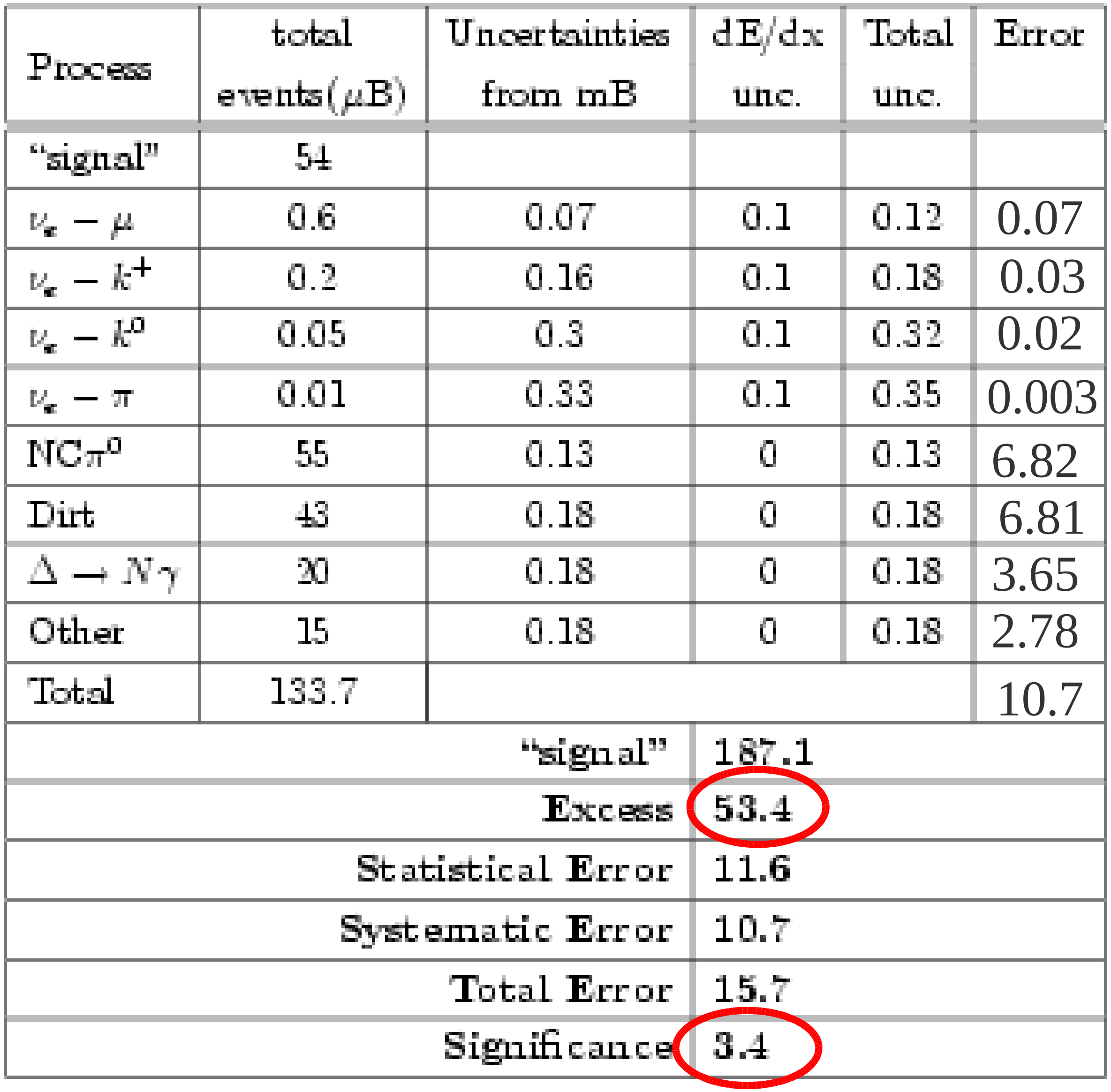
Conservative Estimate:
Does not include improved background rejection due to topology or understanding of the beam



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
N$\rightarrow \Delta\gamma$	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		

If the excess is photons:

- efficiency ~x2 better than MiniBooNE for γs
- 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	0.07
$\nu_e - k^+$	0.2	0.16	0.1	0.18	0.03
$\nu_e - k^o$	0.05	0.3	0.1	0.32	0.02
$\nu_e - \pi$	0.01	0.33	0.1	0.35	0.003
NCπ^o	55	0.13	0	0.13	6.82
Dirt	43	0.18	0	0.18	6.81
$\Delta \rightarrow N\gamma$	20	0.18	0	0.18	3.65
Other	15	0.18	0	0.18	2.78
Total	133.7				10.7
“signal”			187.1		
Excess			53.4		
Statistical Error			11.6		
Systematic Error			10.7		
Total Error			15.7		
Significance			3.4		

- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
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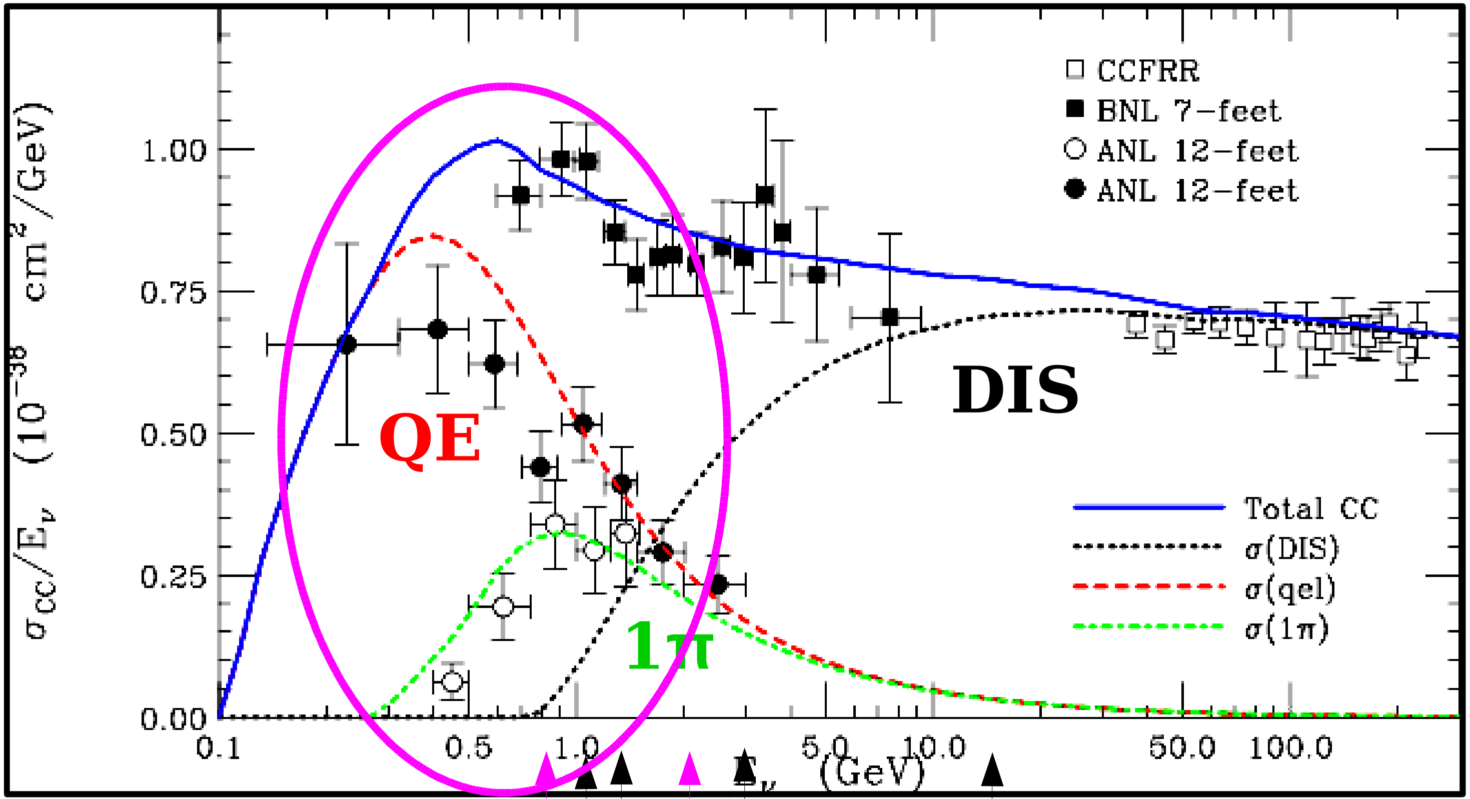
- Important for next generation neutrino
- oscillation experiments
- Interesting in their own right

BNB and NuMI beams span this rich energy region well.



MiniBooNE
SciBooNE
BNB

T2K

K2K

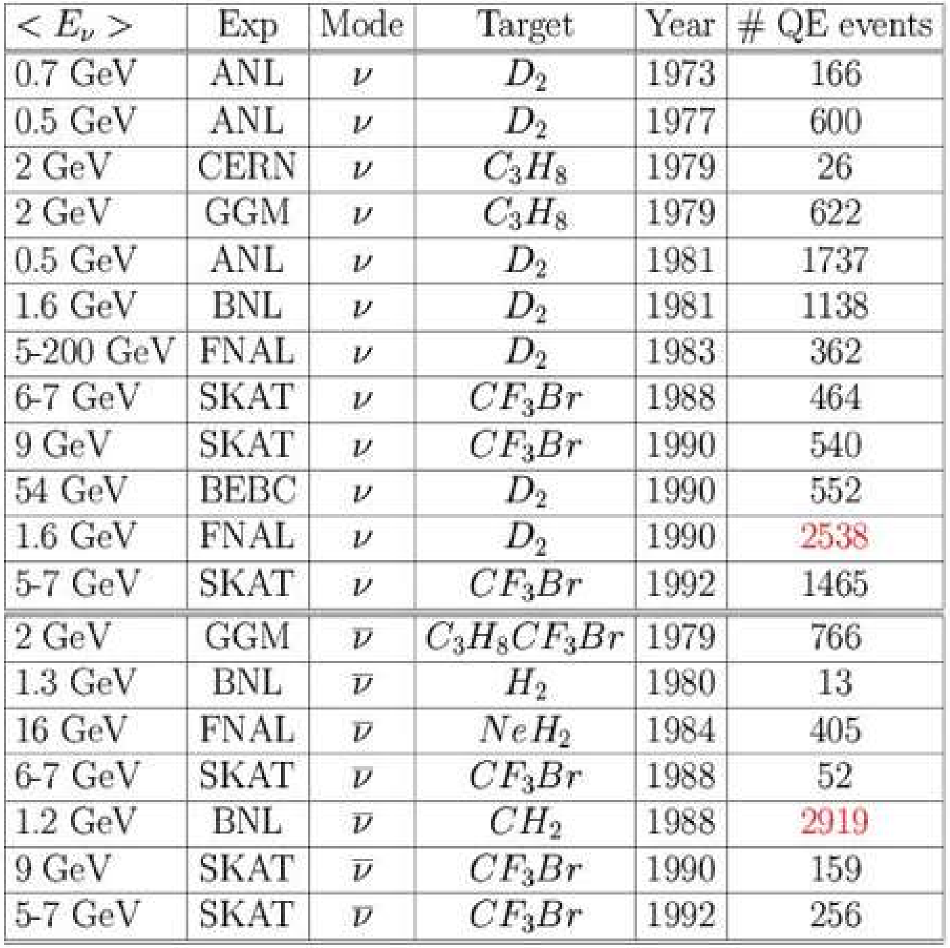
NOvA:
NuMI
off-axis

MINOS
MINERvA
NuMI
on-axis

CNGS
T600

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

Basis of existing QE σ data



$< E_\nu >$	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	$\bar{\nu}$	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	$\bar{\nu}$	H_2	1980	13
16 GeV	FNAL	$\bar{\nu}$	NeH_2	1984	405
6-7 GeV	SKAT	$\bar{\nu}$	CF_3Br	1988	52
1.2 GeV	BNL	$\bar{\nu}$	CH_2	1988	2919
9 GeV	SKAT	$\bar{\nu}$	CF_3Br	1990	159
5-7 GeV	SKAT	$\bar{\nu}$	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

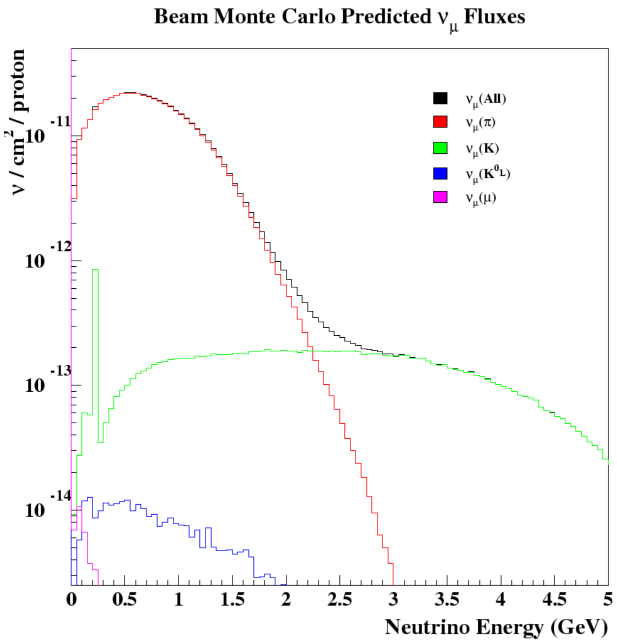
world average 1.03 ± 0.02 GeV

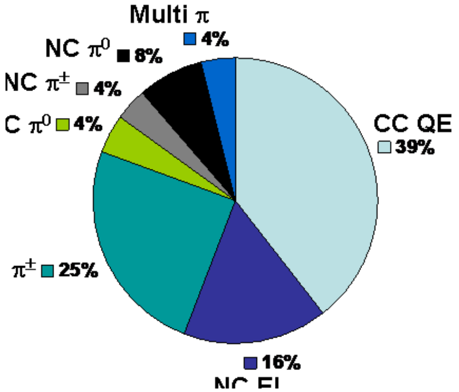
MINERvA will measure M_A above 1-2 GeV

MicroBooNE at 1 GeV and below…..

Sizable event rates

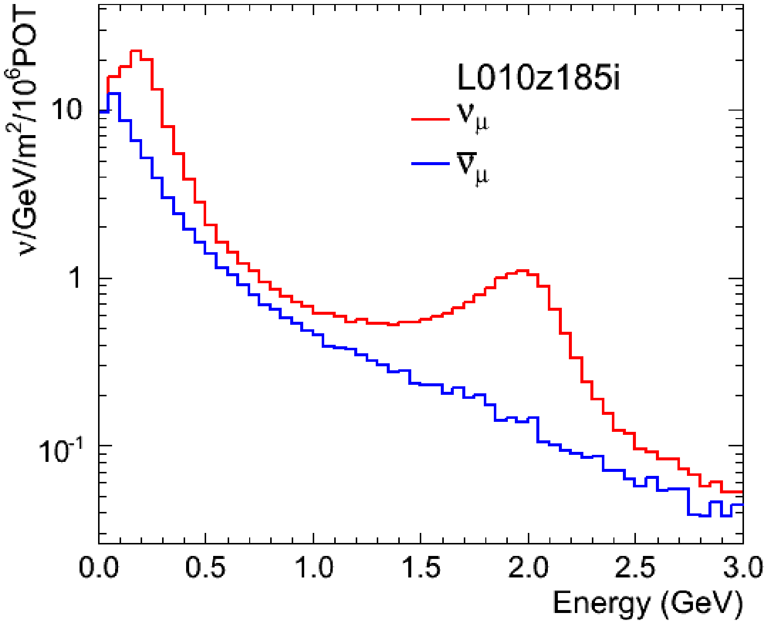
BNB

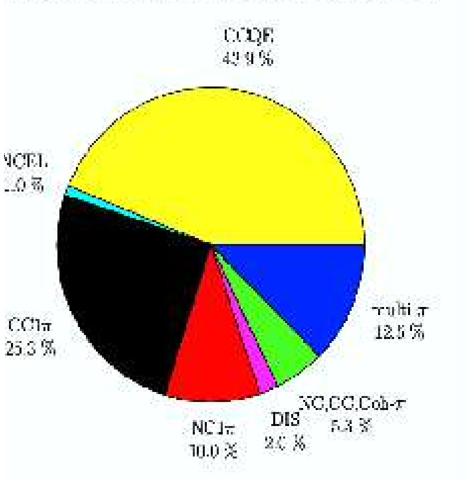




For 6E20 pot
~100k total
~40,000 ν_μ CCQE
~8000 NCπ°

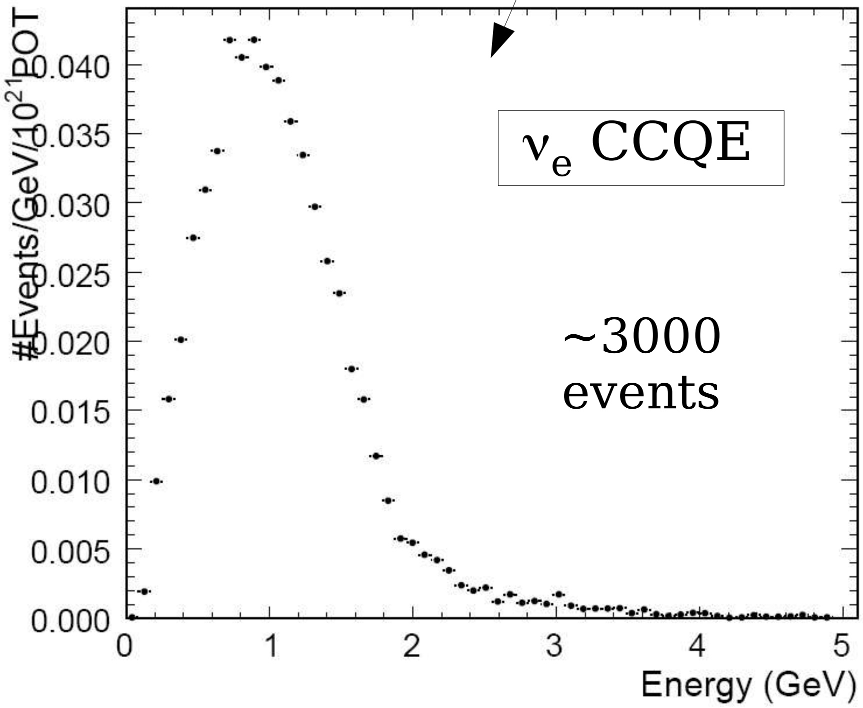
NuMI off-axis

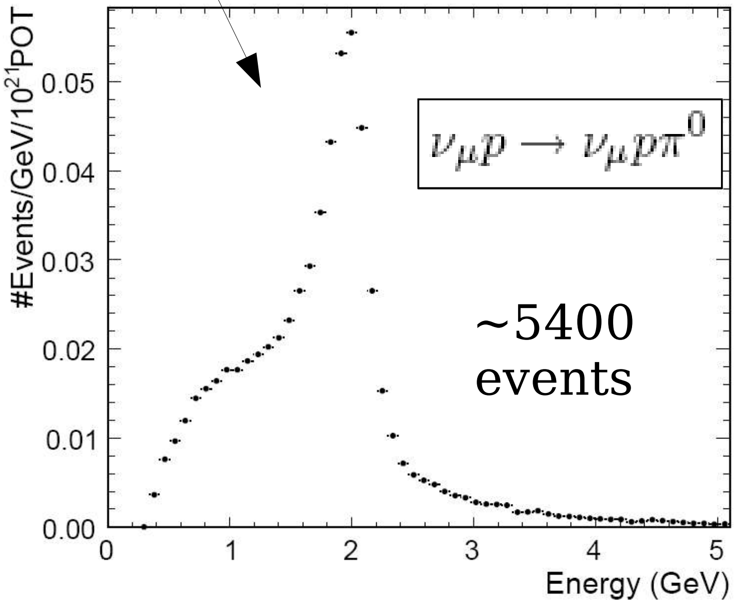




For 8E20 pot
~60k total
~30,000 ν_μ CCQE
~5400 NCπ°

LE NuMI off-axis beam in MicroBooNE: Will collect events of interest to NOvA signal ν_es and background NCπ°s





clean samples with e/γ separation

Time window in which to collect data in LE mode before the NOvA ME beam run.
In ME mode, rate and shape worsen considerably.

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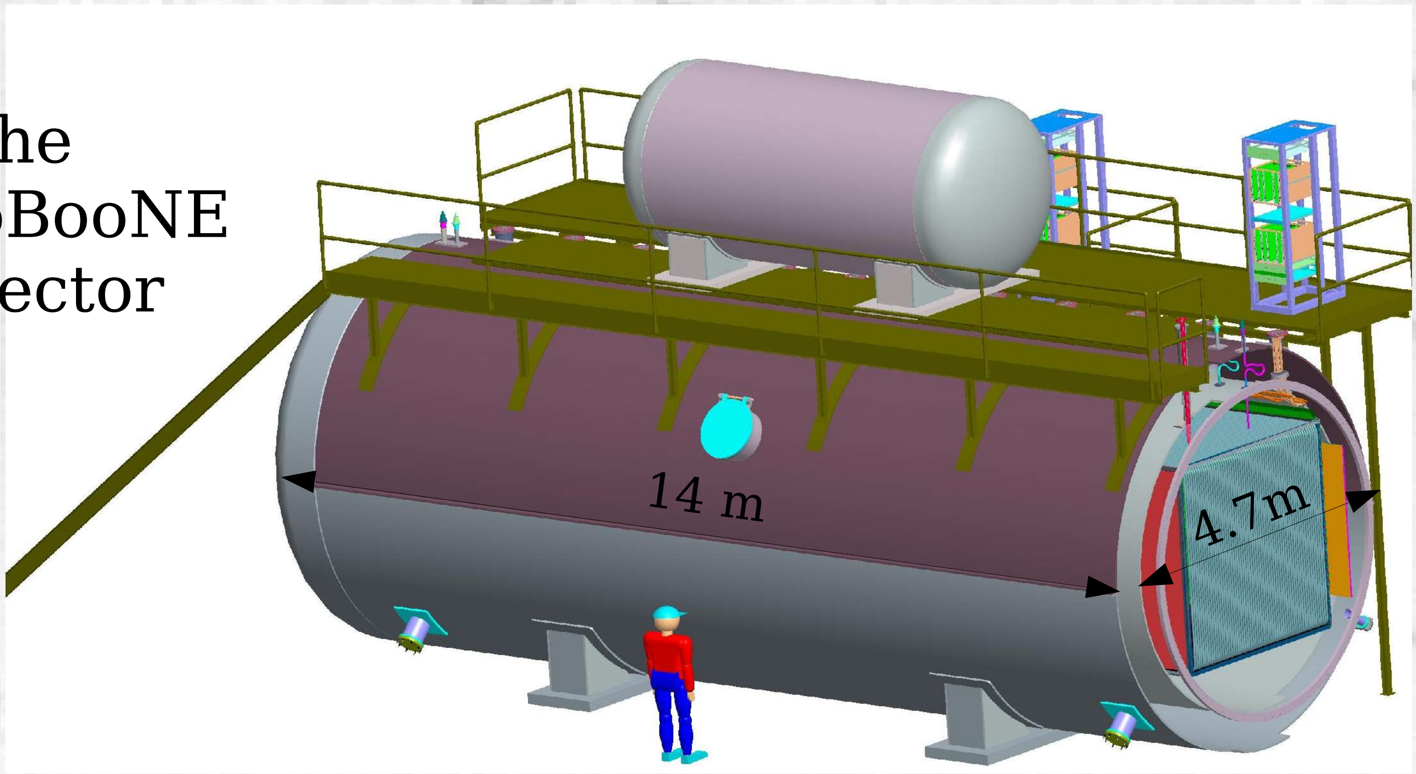
The MicroBooNE Detector



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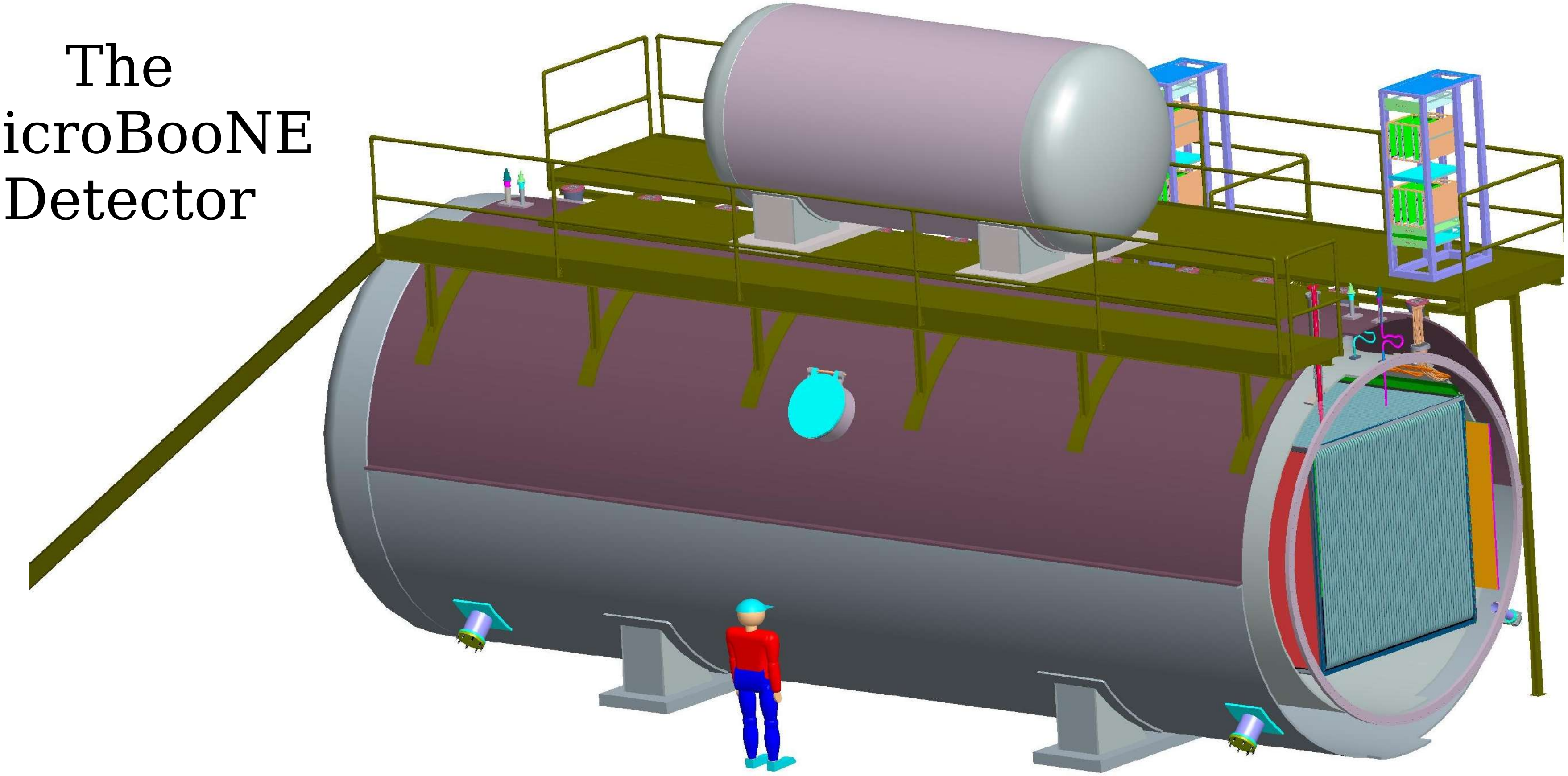


Proposal describes details of detector design:

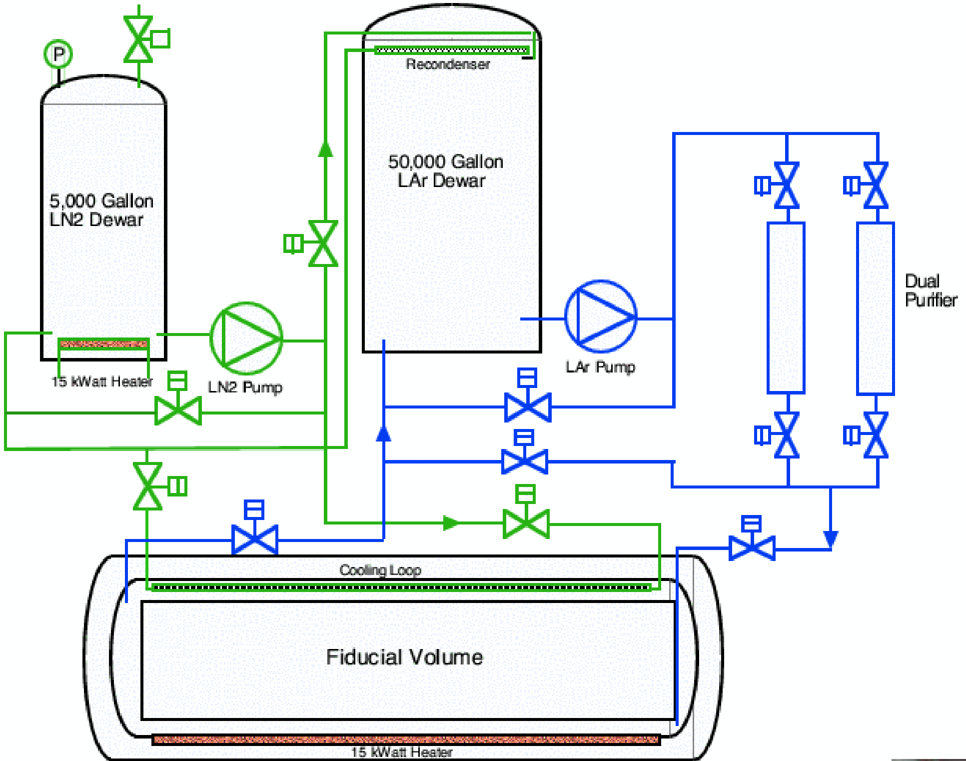
- Cryogenics and Purification
- Field Cage and TPC
- Cold electronics, Readout, and DAQ
- Photo-Multiplier Tubes

Purification

Liquid Argon is continuously purified to 0.1 ppb O_2 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

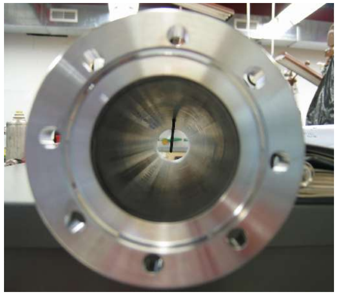


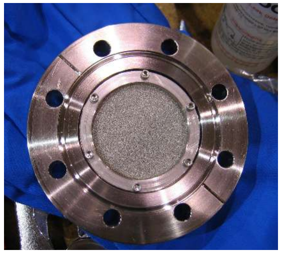
Micro - Boon Cryo System Layout

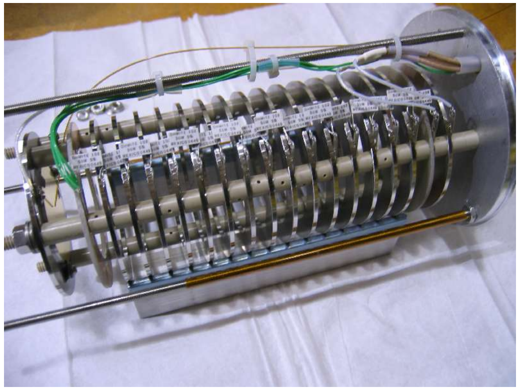
Filter system: based on ICARUS design but....
- non proprietary
- filters can be regenerated in situ

System designed at FNAL
Demonstrated at FNAL and Yale

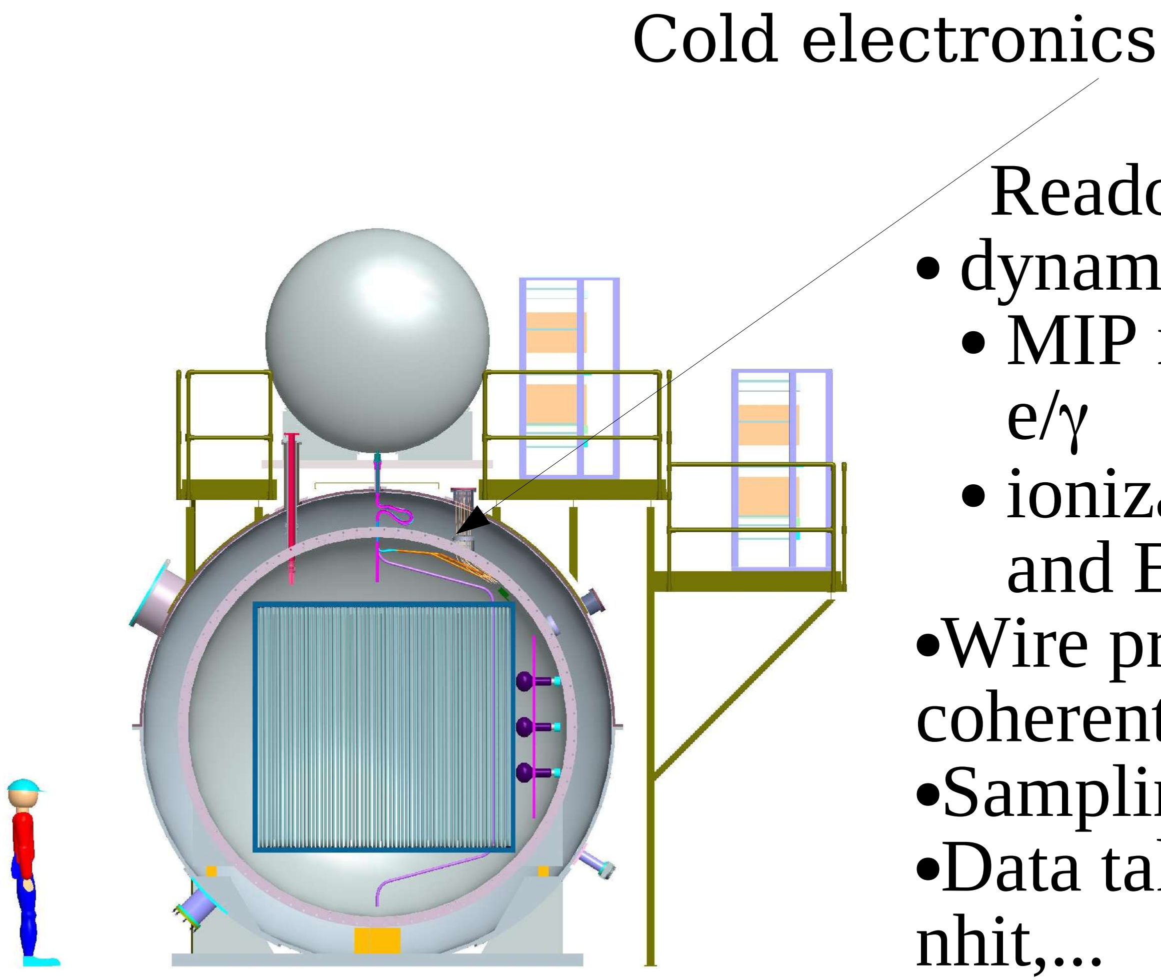
MicroBooNE: Use these in a running physics experiment







ICARUS style purity monitors will measure purity in situ



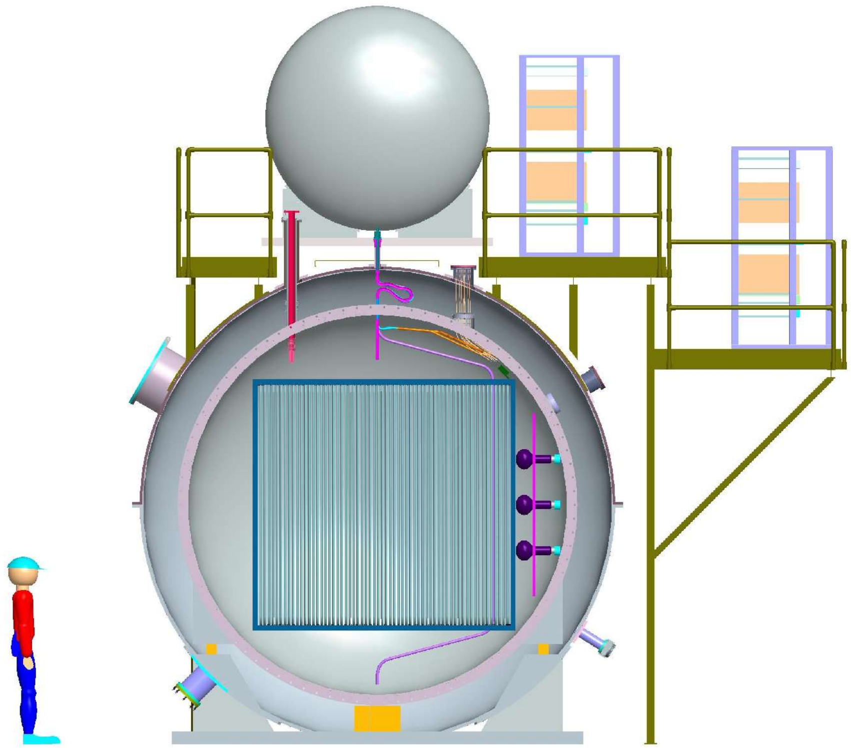
Readout design considerations

- 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 and random noise
- Sampling Rate for shaper: 2 MHz
- Data taking modes: beam, calib, nhit,...
- minimize power consumption

Overall: Maximize Signal/Noise minimize signal connection lengths

Cryogenic pre-amplifiers
S/N ~20--30
x4 noise reduction compared to warm electronics

Cold Electronics cont.



Pros:

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

Cons

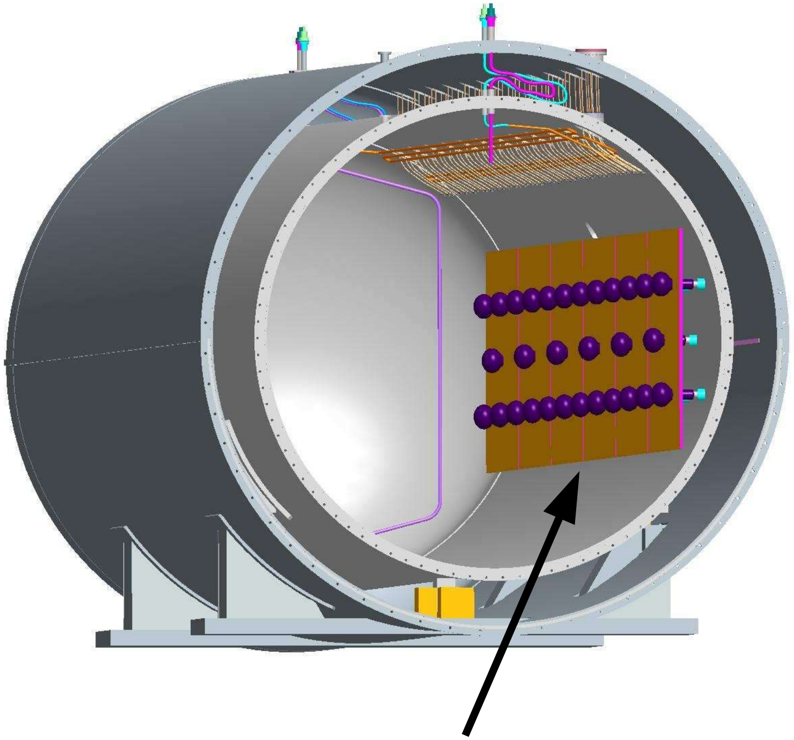
- Bubbling
- Cryogenic load
- Argon purity

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.

Beyond MicroBooNE: Cold electronics will be a must for massive detectors

Photo-Multiplier Tubes



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

Reduce backgrounds:

Neutrino interaction rate:
⇒1spill in 200

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

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

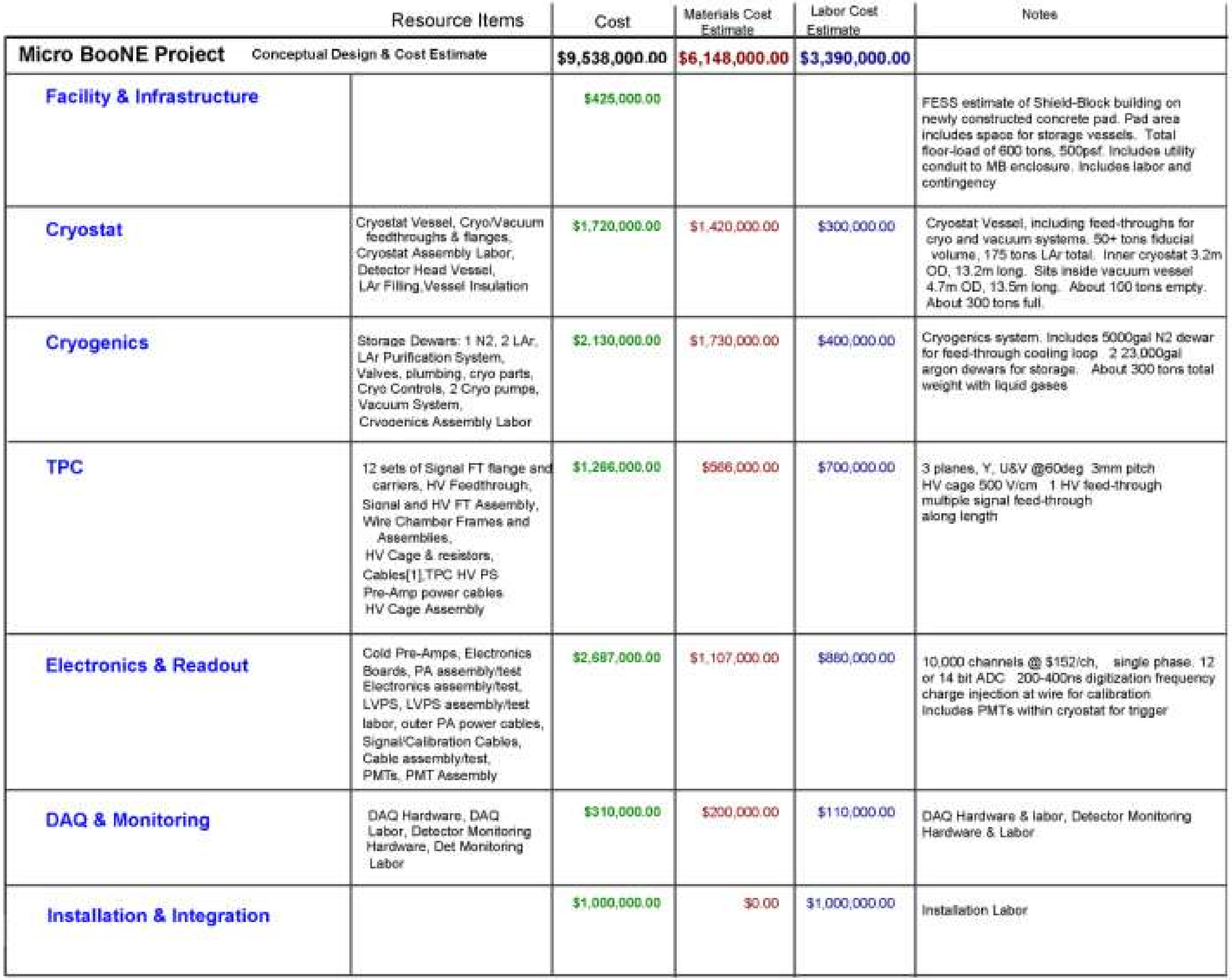
Prompt light: 128 nm scintillation light (40k photons/MeV) shifted to visible with WLS coating

Beyond MicroBooNE: PMT implementation in massive detectors

- background rejection
- T_0 for non beam events

- 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

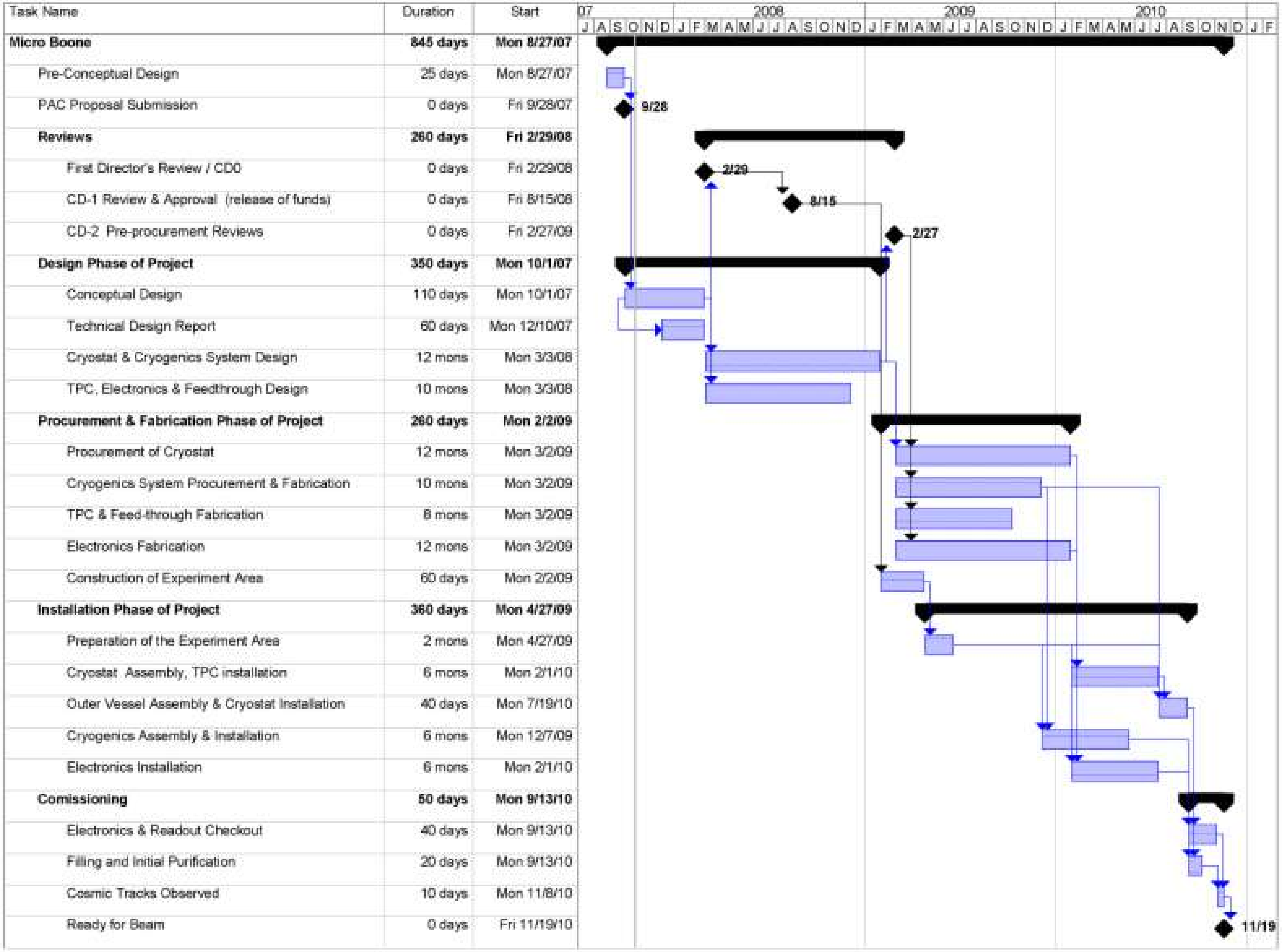
Cost: Total Materials = $ 6.1M



	Resource Items	Cost	Materials Cost Estimate	Labor Cost Estimate	Notes
Micro BooNE Project Conceptual Design & Cost Estimate		**$9,538,000.00**	**$6,148,000.00**	**$3,390,000.00**	
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, PMTs, PMT Assembly	$2,687,000.00	$1,107,000.00	$880,000.00	10,000 channels @ $152/ch, single phase. 12 or 14 bit ADC 200-400ns digitization frequency charge injection at wire for calibration Includes PMTs within cryostat for trigger
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

pursuing funding through DOE, NSF, University sources

Schedule determined by design, construction, and commissioning



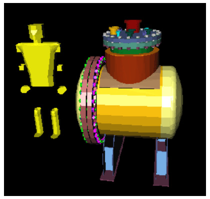
Task Name	Duration	Start
Micro Boone	**845 days**	**Mon 8/27/07**
Pre-Conceptual Design	25 days	Mon 8/27/07
PAC Proposal Submission	0 days	Fri 9/28/07
Reviews	**260 days**	**Fri 2/29/08**
First Director's Review / CD0	0 days	Fri 2/29/08
CD-1 Review & Approval (release of funds)	0 days	Fri 8/15/08
CD-2 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	60 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	8 mons	Mon 3/2/09
Electronics Fabrication	12 mons	Mon 3/2/09
Construction of Experiment Area	60 days	Mon 2/2/09
Installation Phase of Project	**360 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 11/19/10

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

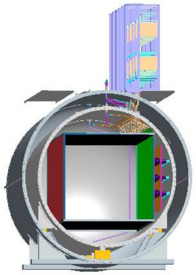
start doing physics here!

Test stands:
ArgoNeuT
Materials Test

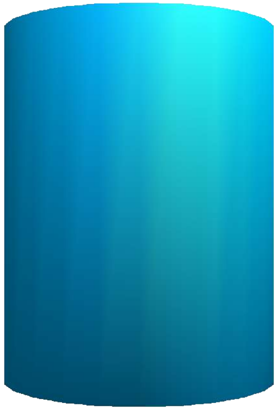


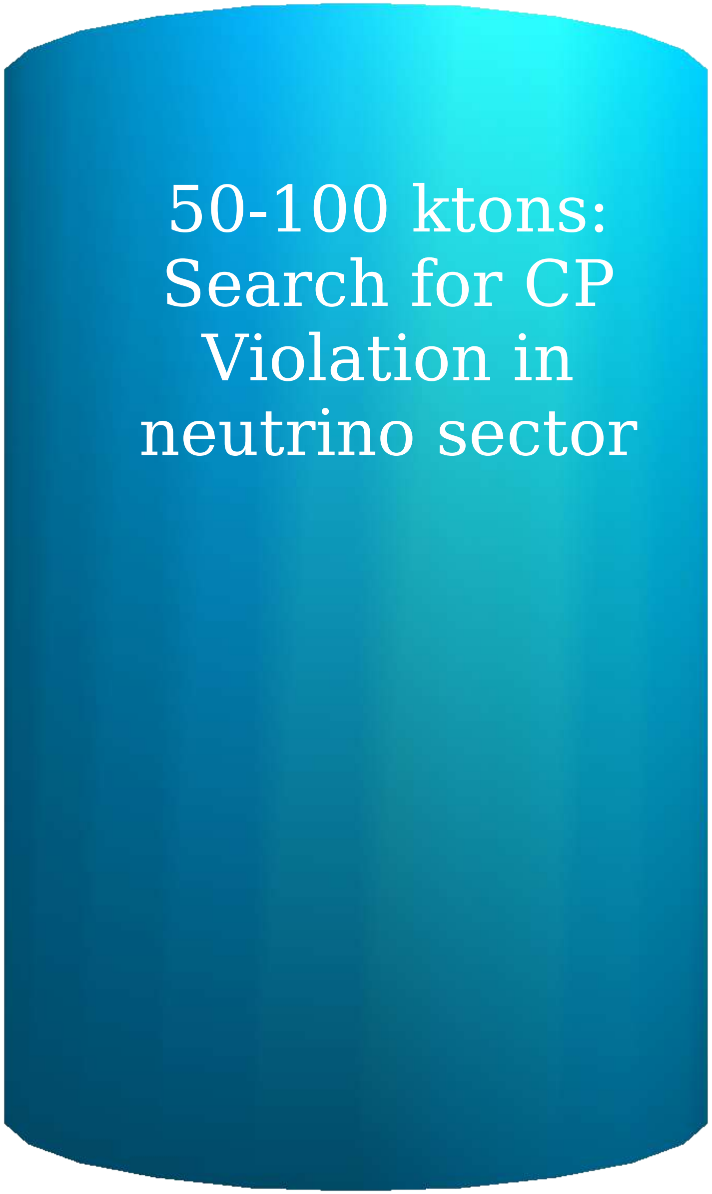
20 ton
purity
demonstration

MicroBooNE
170 ton



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





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

2007 2008 2010 2013-15 201?

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"

Fermilab Steering Group, 2007

The ability of the MicroBooNE experiment to provide useful information for the long baseline program was seen by the Fermilab Steering Group as a central motivation for the LArTPC R&D program

MicroBooNE is a perfect fit in this phased program.
A physics experiment that drives R&D
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

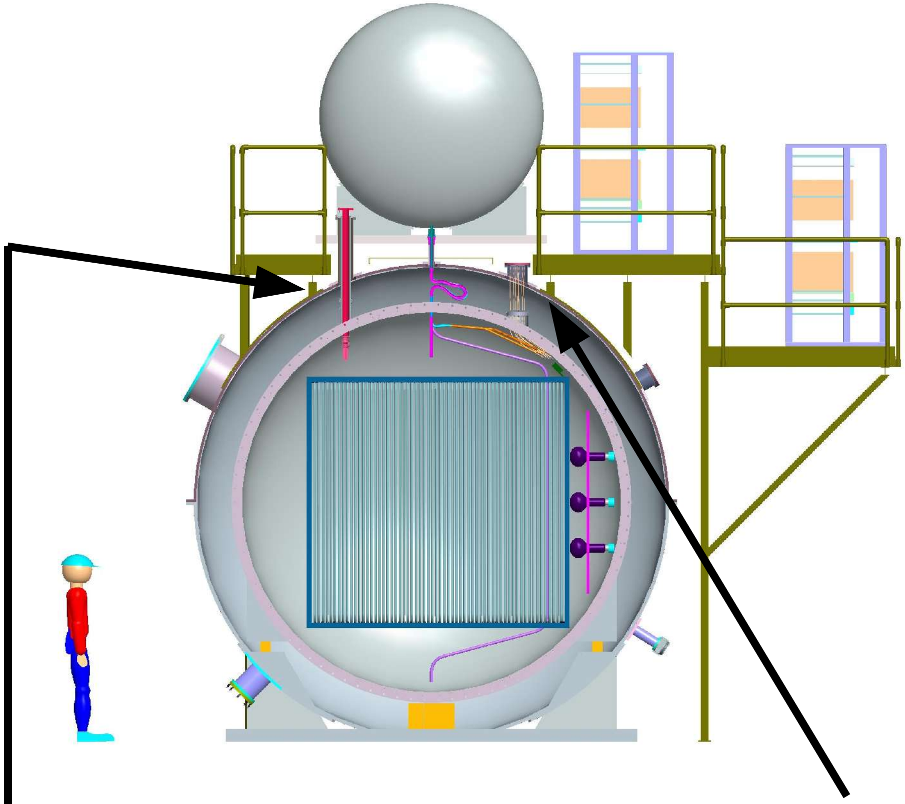
MicroBooNE

- 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 case and the technicalogical program for MicroBooNE by recommending Stage 1 approval.

Backup Slides

Cryogenics:



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

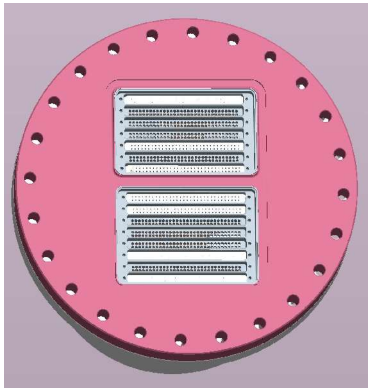
Temperature controlled via LN_2 cooling loops to within 1K

- boil off argon
- control operating temperature and pressure

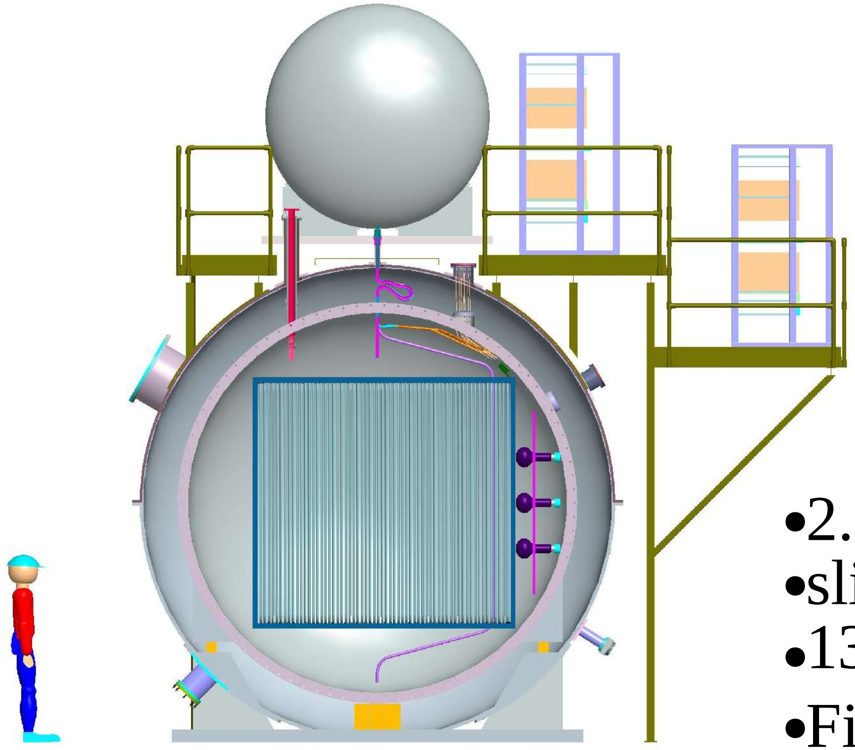
Vacuum feedthroughs penetrate warm and cold vessels and carry signal/calibration/monitoring channels

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

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



Inner Detector: Field Cage

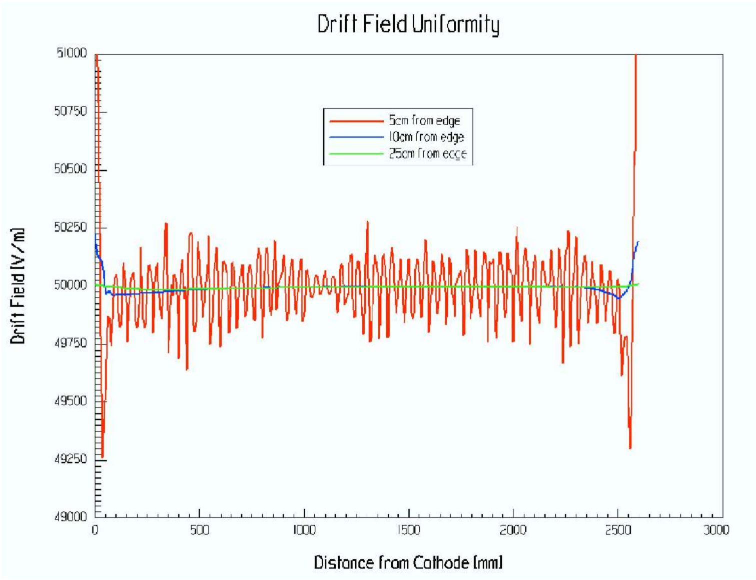


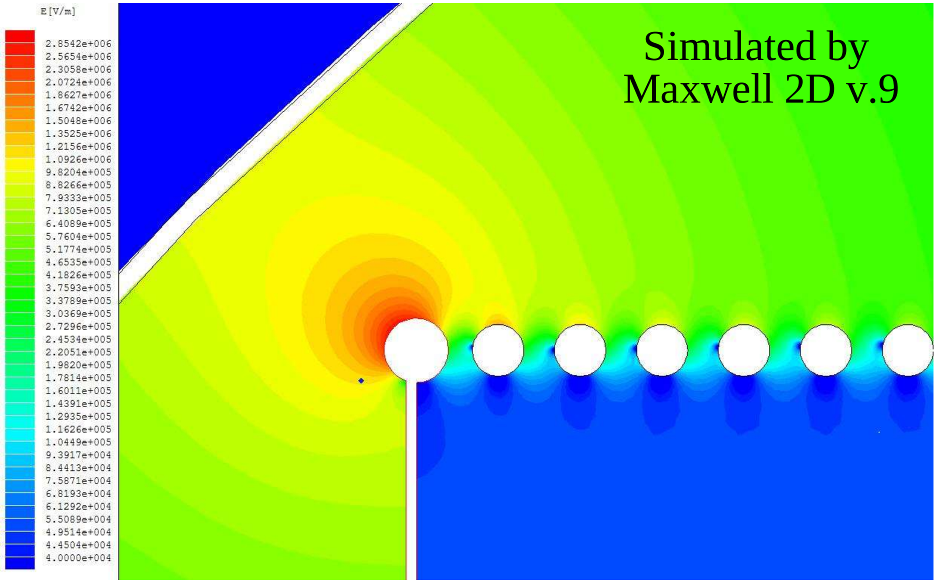
Design considerations:

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

↓

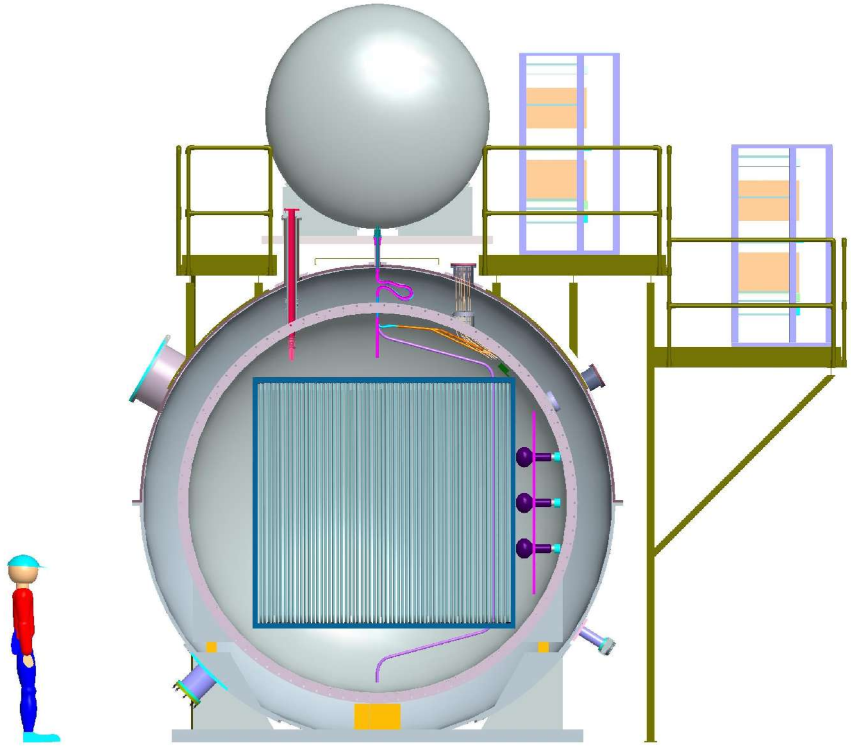
- 2.6 m drift (2.6m x 2.6m x 12m)
- slightly offset for HV clearance
- 130kV HV for v_{drift}=1.6mm/μs
- Field cage: SS tubes step voltage in 2kV





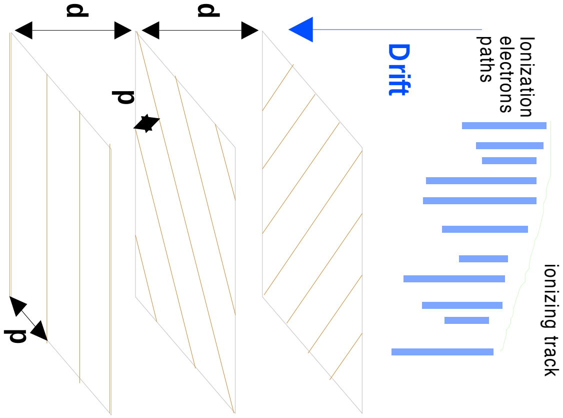
Simulated by Maxwell 2D v.9

Inner Detector: Wire Planes



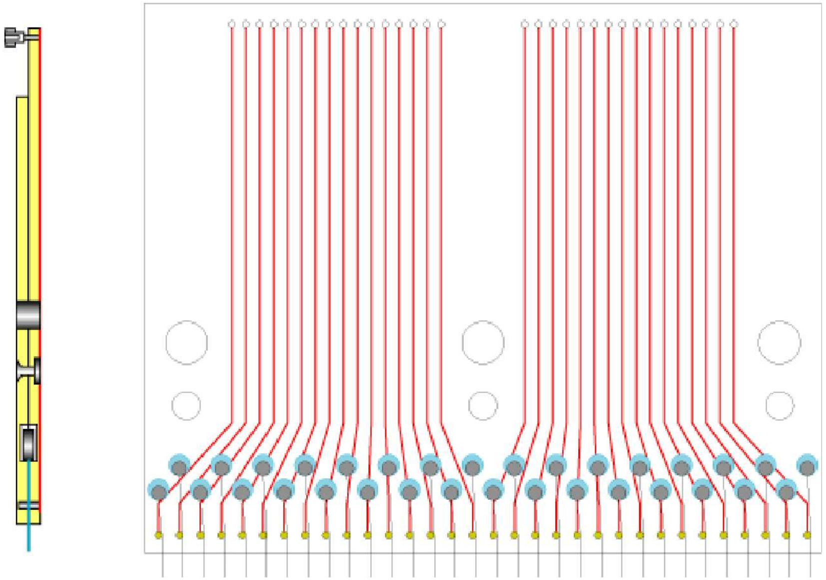
Signal electrodes

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



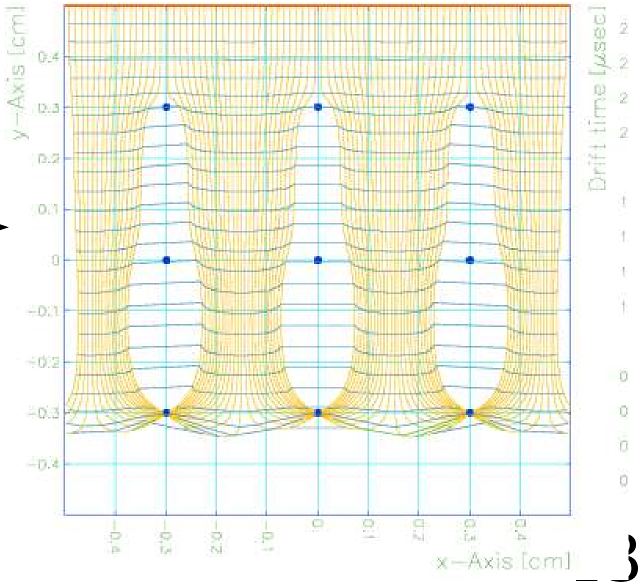
3mm wire pitch
Planes biased at : -204V,0V,400V

Total of ~10k channels

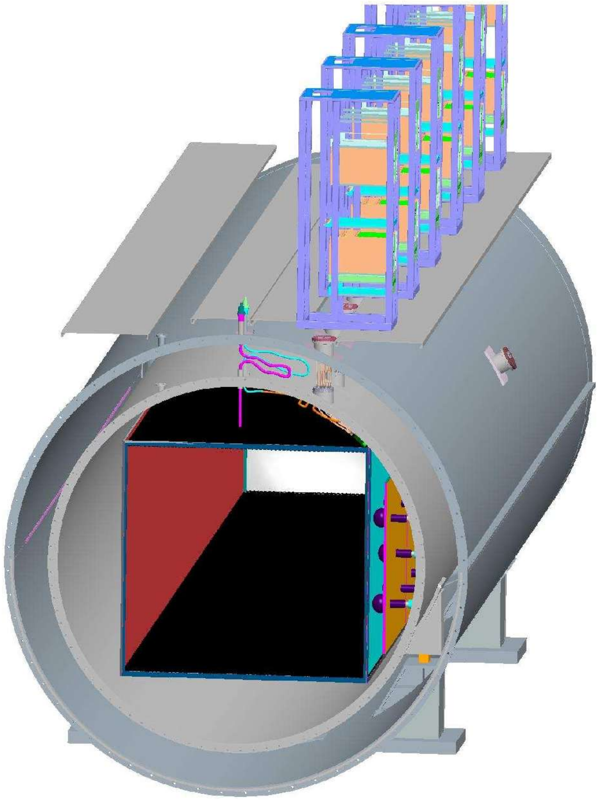


Ionization electron drift lines for a uniform track (Garfield-9)

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

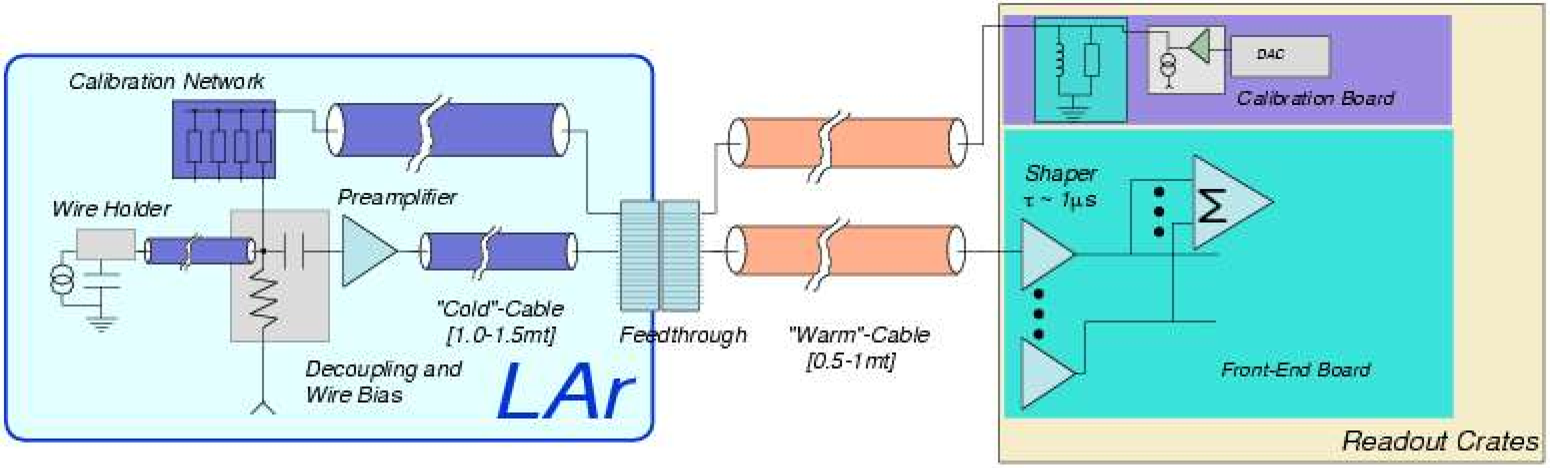


Readout Architecture

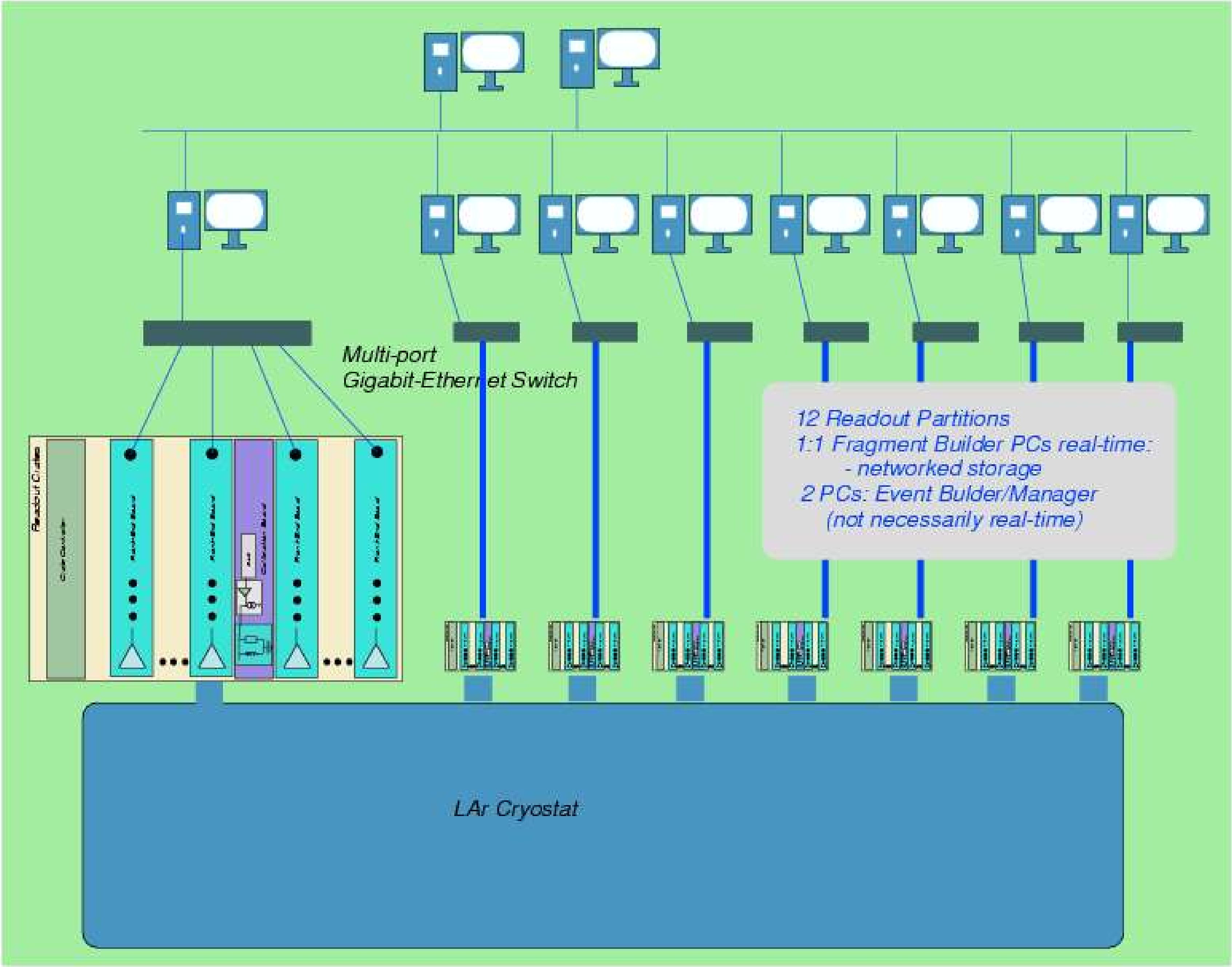


Processing and temporary storage
of readout from 10,000 channels

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



Data Acquisition



12 Readout Partitions
1:1 Fragment Builder PCs real-time:
- networked storage
2 PCs: Event Bulder/Manager
(not necessarily real-time)