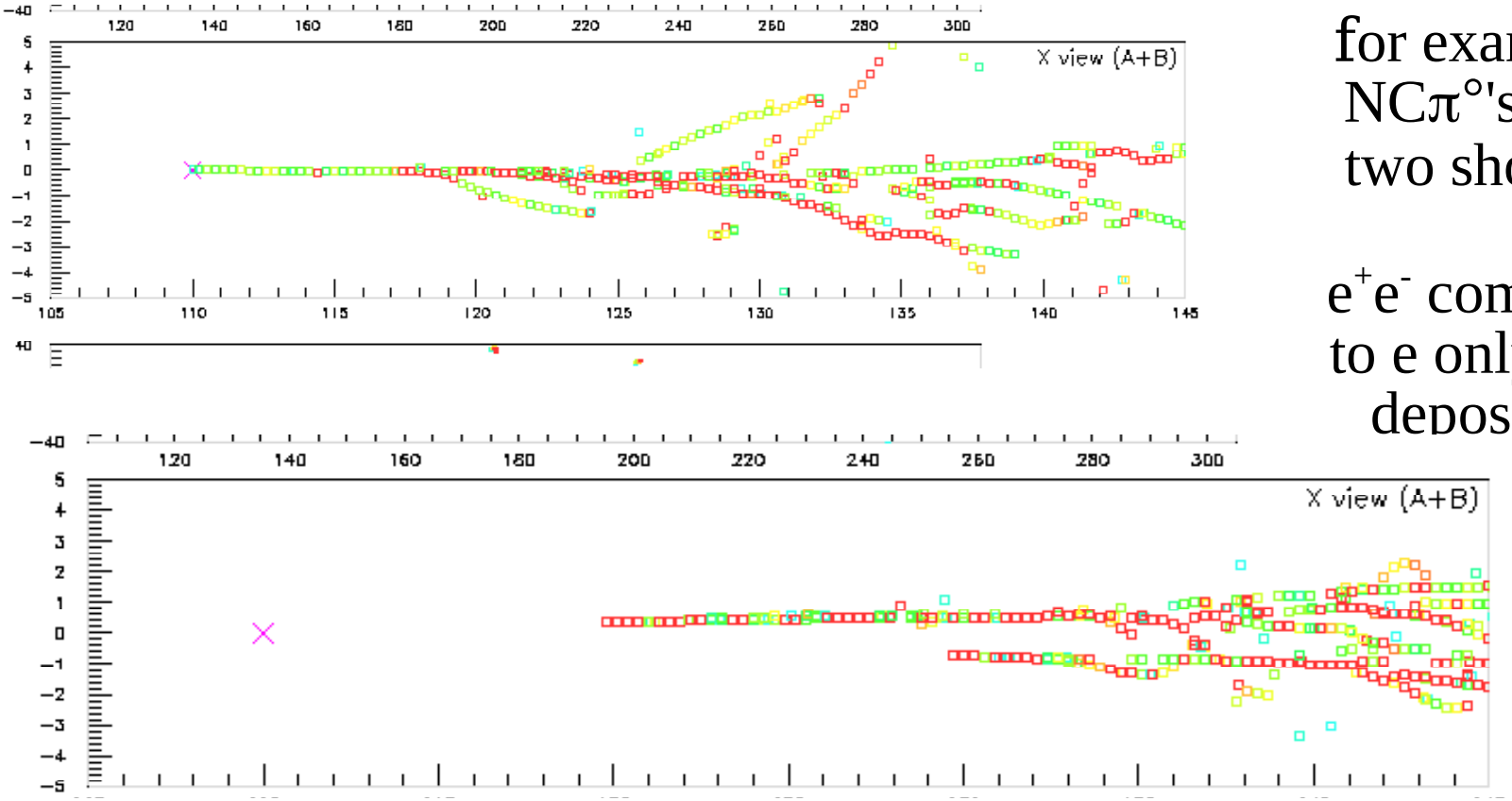
B.T.Fleming
Yale U.
May 31, 2006

Ideas on LArTPC detectors
Presentation to FNAL Steering Committee

- Motivation for using LArTPCs for neutrino physics
- Existing and future R&D in the US
- Discovery potential for
  - “small” on-site LArTPC experiments
  - LArTPCs for long baseline in the mid-term

LArTPCs image events and collect charge
ID events via topology and dE/dx



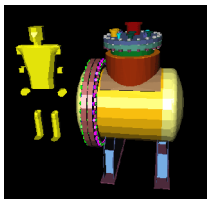
for example:
NCπ°'s have two showers

$e^{+}e^{-}$ compared to e only MIP deposition

Excellent for 0.1 - 10 GeV neutrino physics!
(both cross section and oscillation physics)

start doing physics here!

test stands



150 ton purity demonstration

Possible FNAL sited experiments (50-1000 tons)

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

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

2007

2008-9

2013-15

201?

start doing physics here!

5 kton: sensitivity to mass

50-100 ktons: Search for CP in ctor

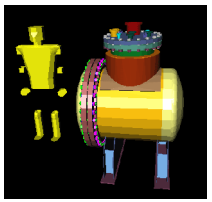
People actively involved in R&D in the US:
Fermilab: Bruce Baller, Dave Finley, Cat James, Doug Jensen, Hans Jostlein, Stephen Pordes, Gina Rameika, Niki Saoulidou

Michigan State: Carl Bromberg, Dan Edmunds

Yale: Colin Anderson, Alessandro Curioni, Bonnie Fleming, Steven Linden, Mitch Soderberg, Josh Spitz

dem

test stands



2007 2008-9 2013 -15 201?

start doing
physics here!

5 kton:
sensitivity to
mass

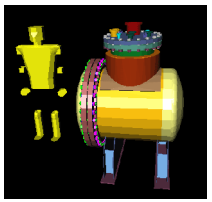
50-100 ktons:
Search for CP
in
ctor

Interested groups for future actitivies:

Columbia: **Bill Willis**, Janet Conrad, Mike Shaevitz
Texas A&M: James White
Tufts: Hugh Gallagher, Tony Mann, Jack Schnepps
UT Austin: Karol Lang
UCLA: David Cline, Hanguo Wang

dem

test stands



2007 2008-9 2013-15 201?

start doing physics here!

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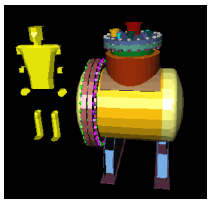
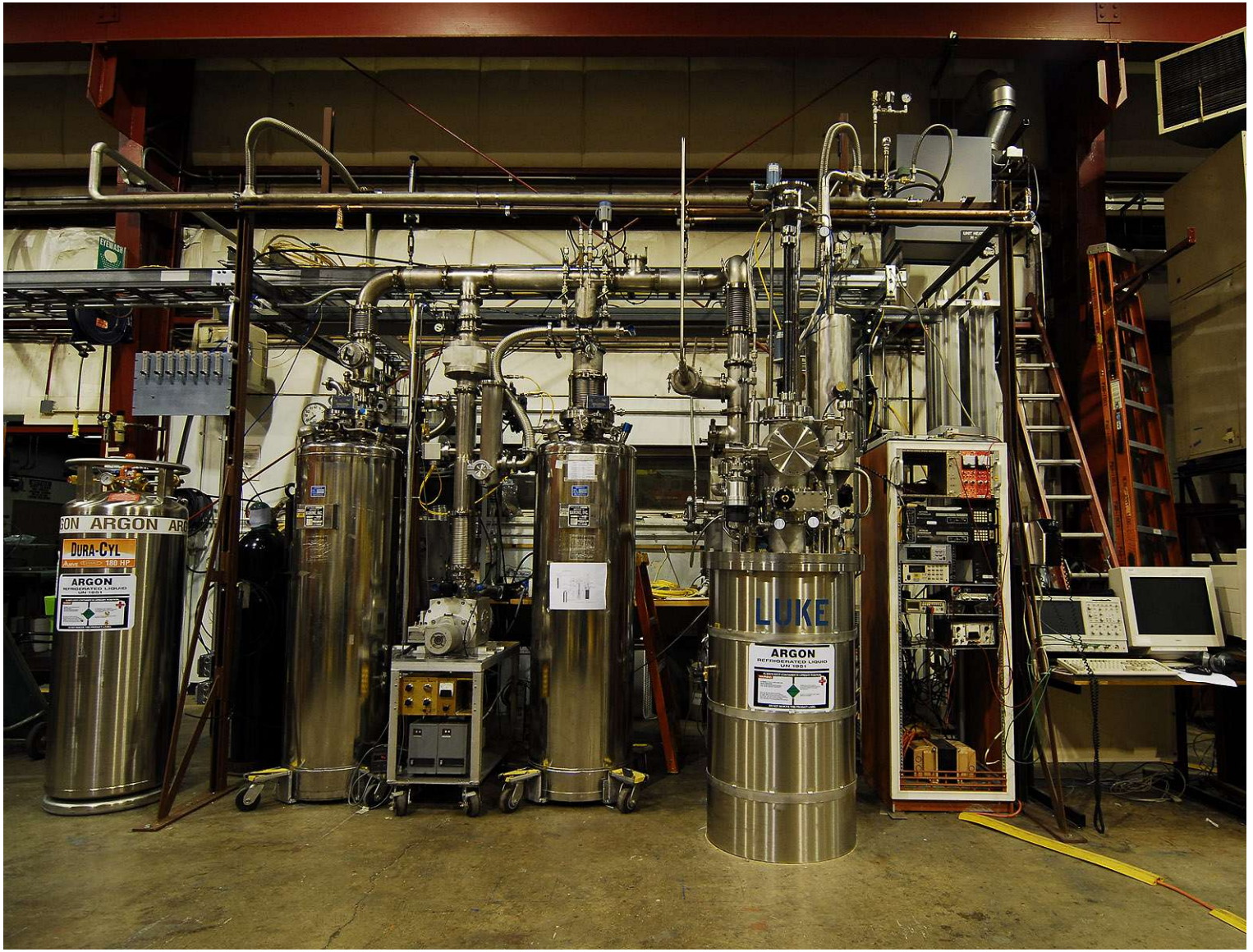
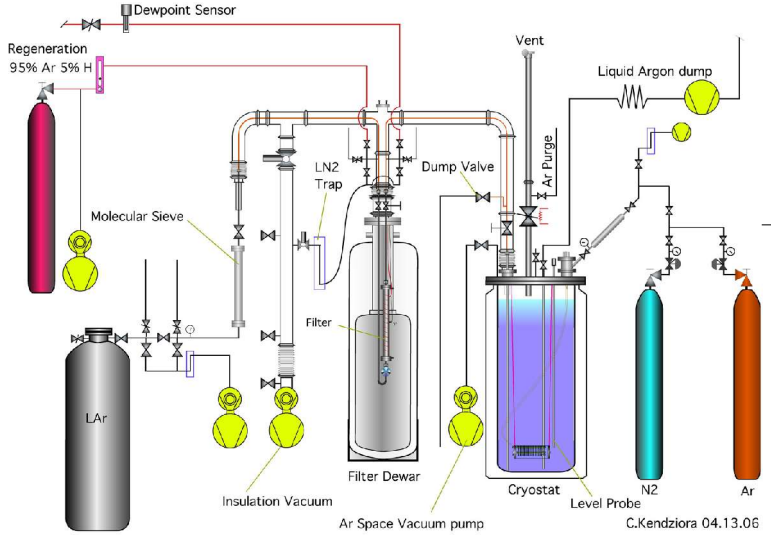
test stands

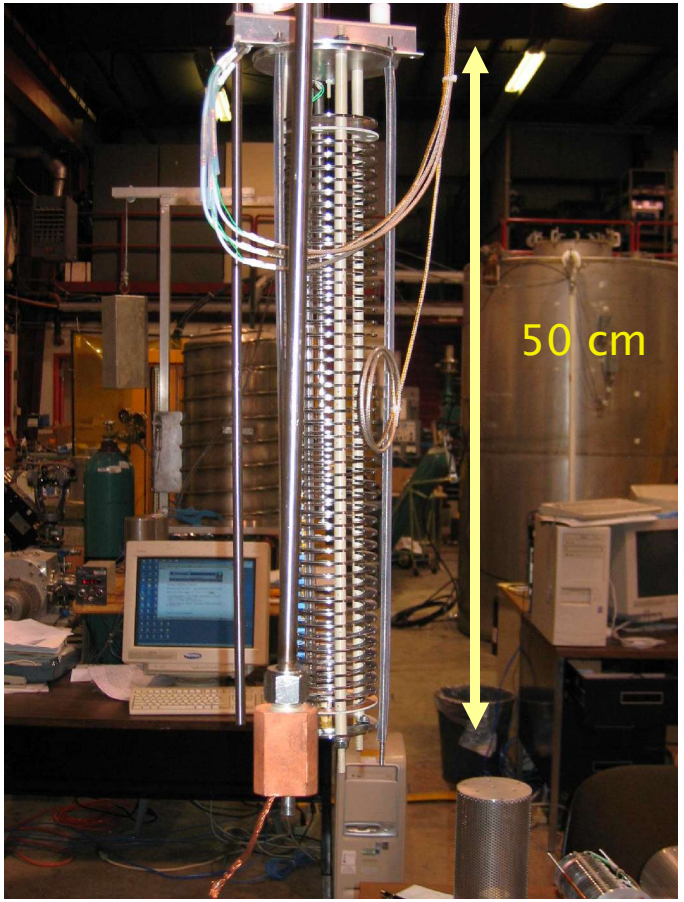


2007 2008-9 2013-15 201?

LAr purity, TPC and Cryogenics: Extensive work at PAB



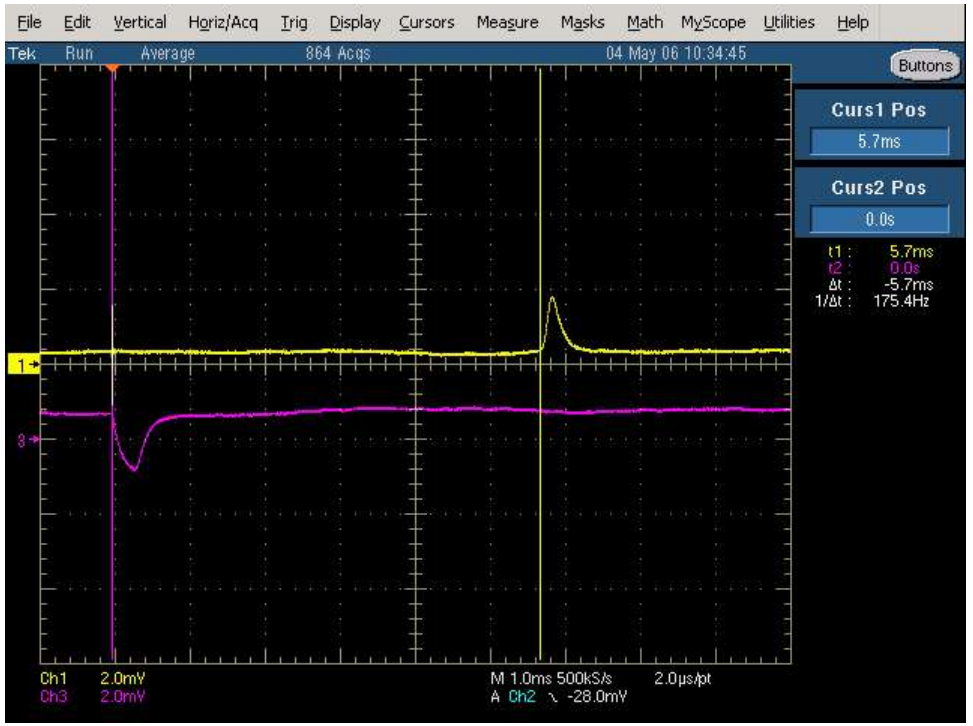




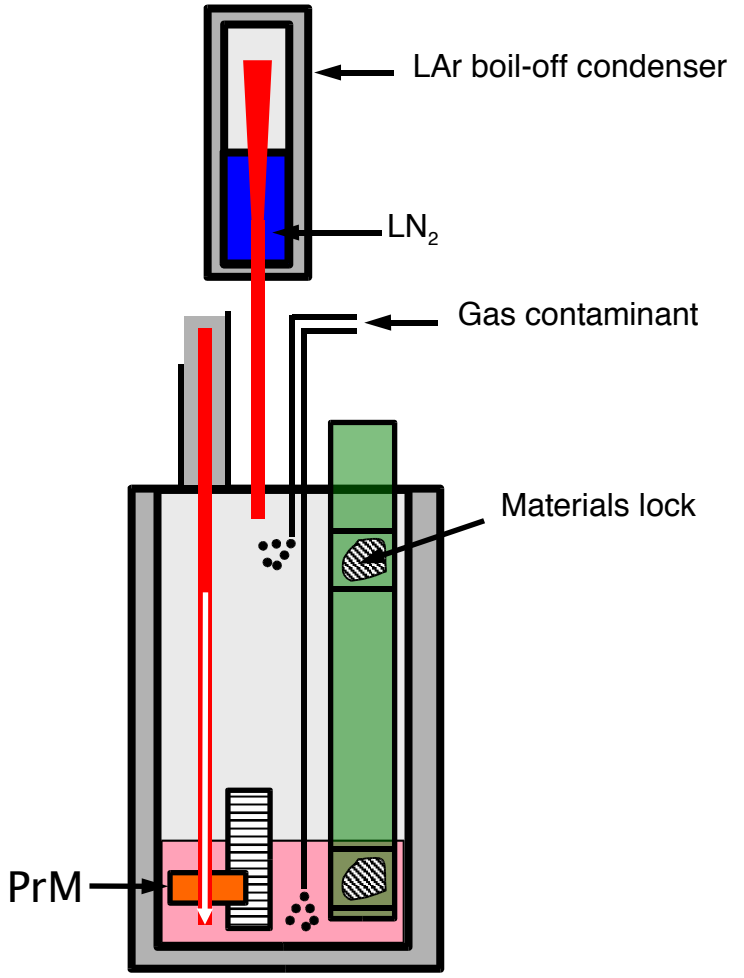
Long drift test studies using Materials Test Stand at FNAL:
-Trigon filter, developed at FNAL
→ regenerated in line
-measure purity via ICARUS style purity monitor
50 cm long drift

S. Pordes, FNAL

a 5.7 millisecond drift with the long PrM



Lifetime Measurements:
> 8ms lifetimes achieved.
Example here: 5.7ms drift



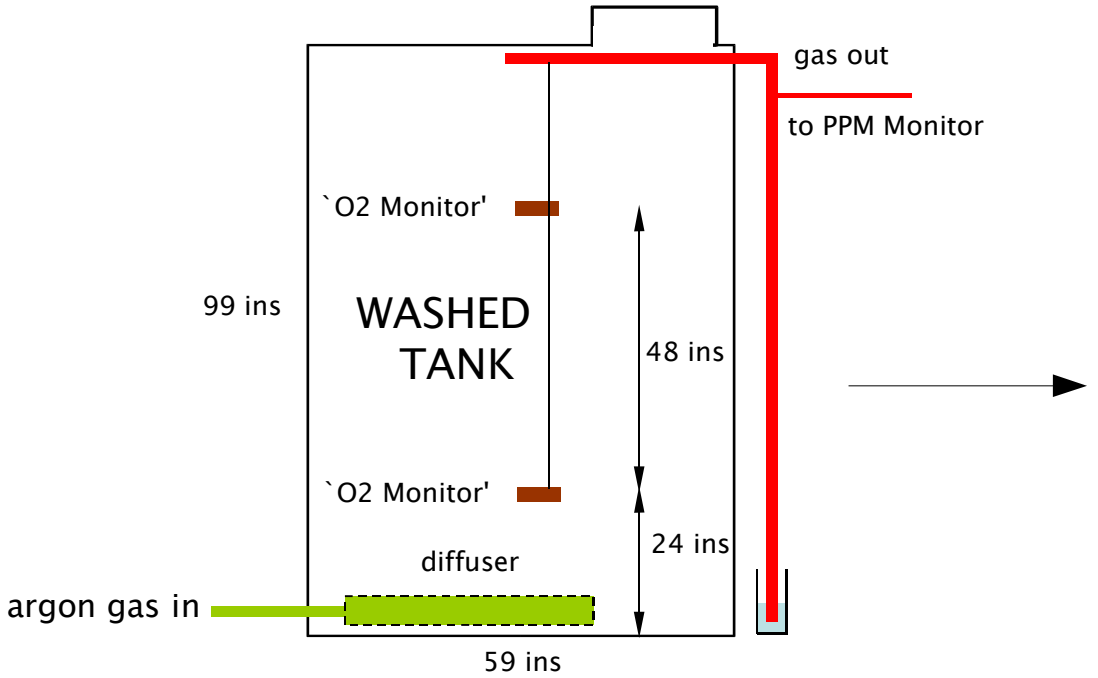
Materials test station..
(new closed system cryostat)
Developing in-cryostat thermal pump

T. Tope

S. Pordes, FNAL

Purity in “industrial” vessel

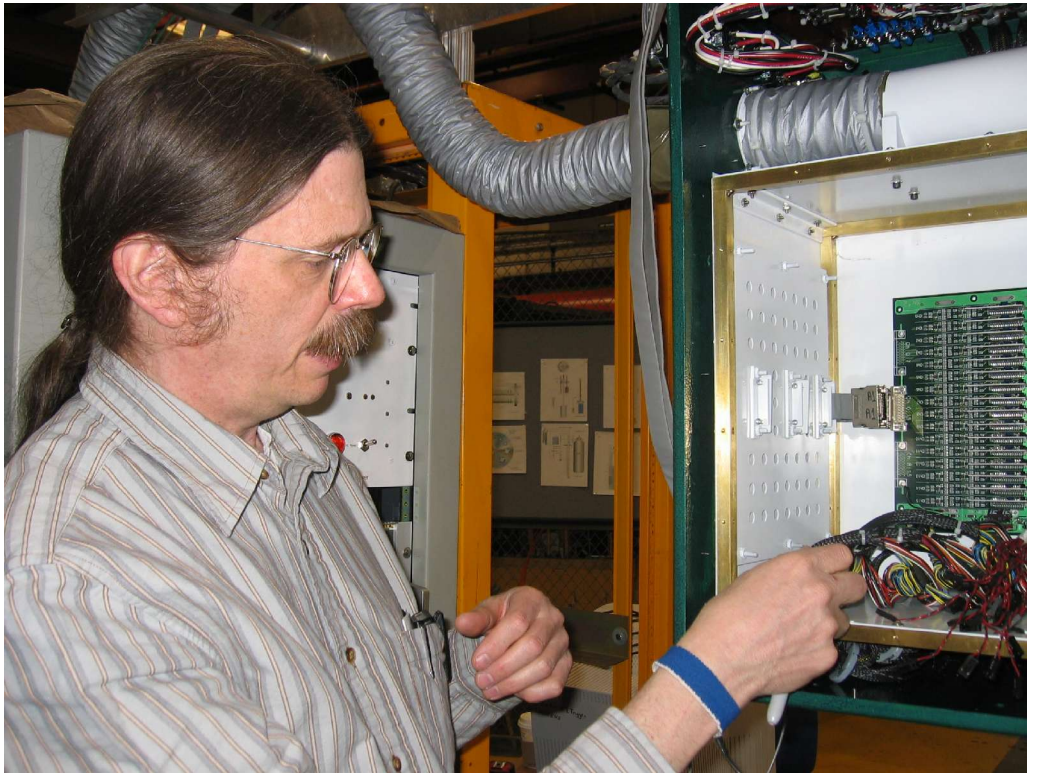
Large vessels will not be taken down to vacuum
Clean via purge with clean Argon gas



tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h (reading for air was 86 scfh)
climb rate ~ 3.8 f/h

Next step here: 150 ton tank purity demonstration

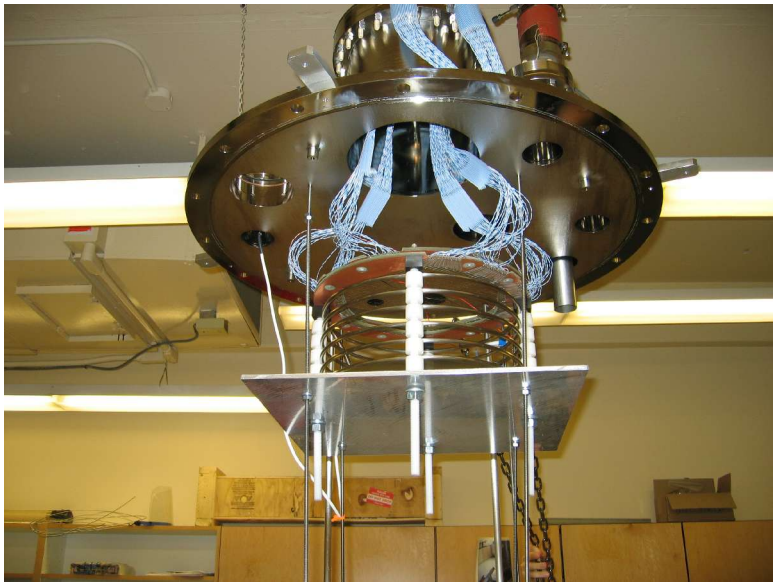
Electronics development MSU



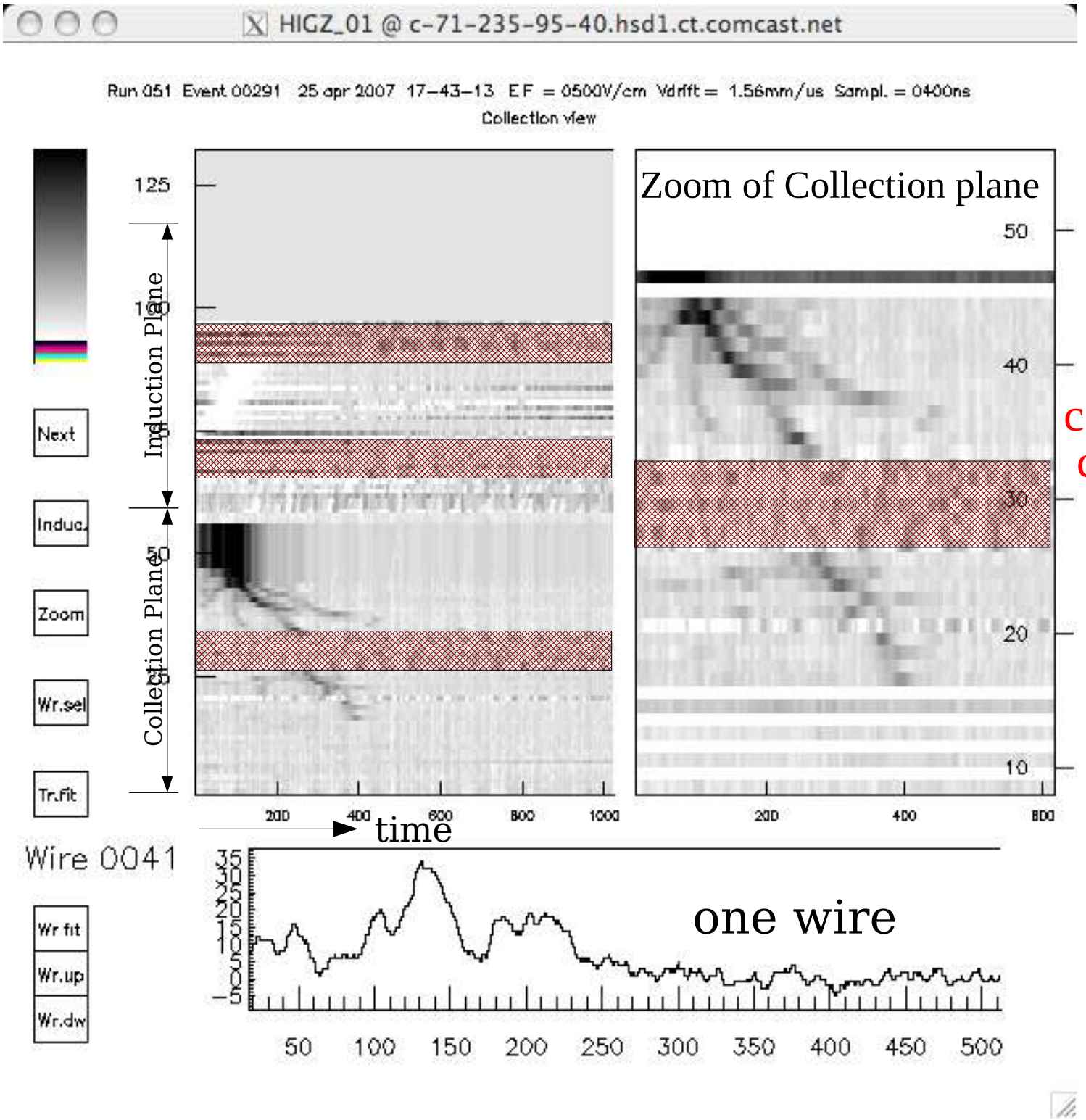
development of electronics, under test in PAB
working to see tracks in small TPC

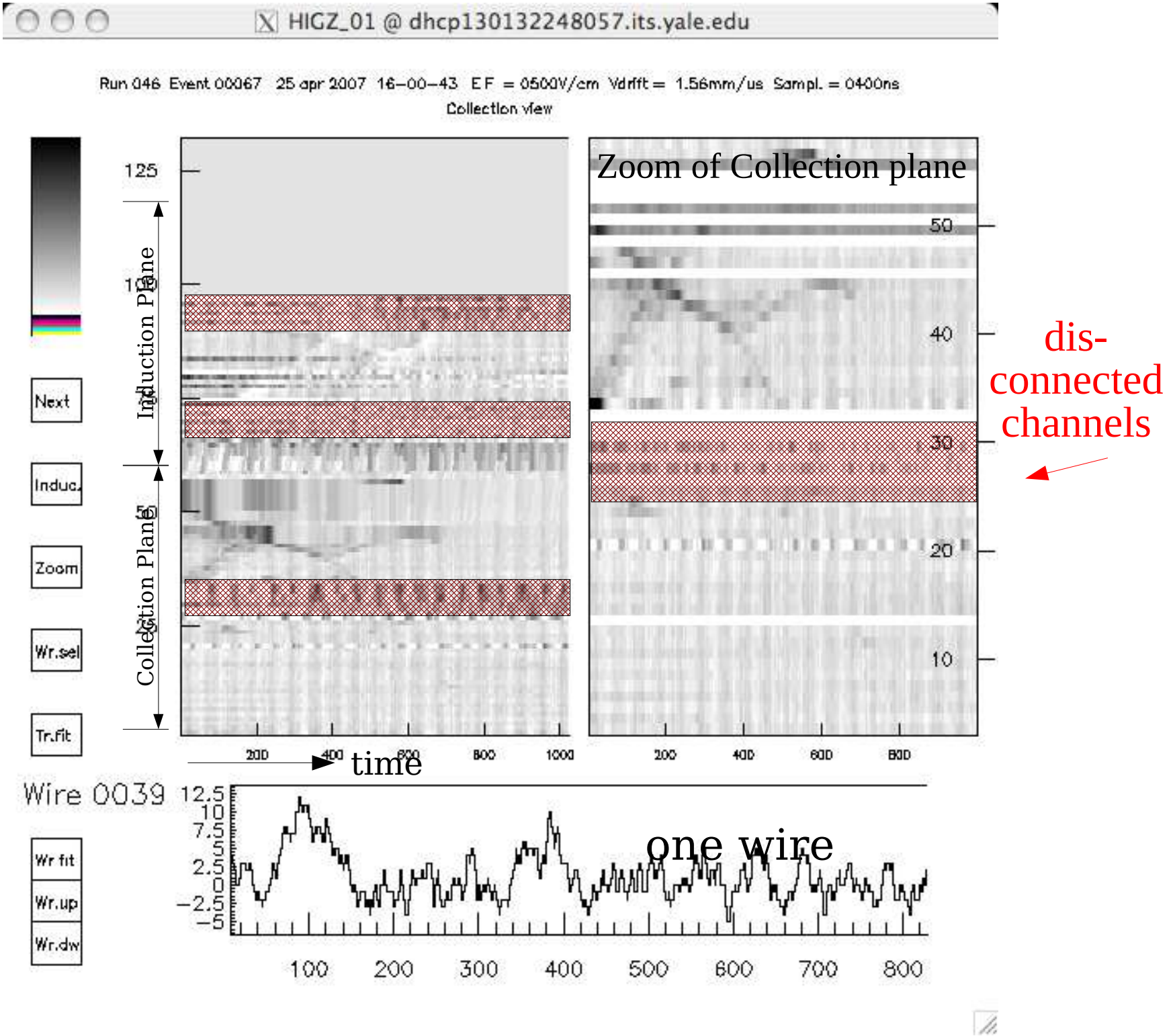
Seeing first tracks at Yale (first ever in the US)

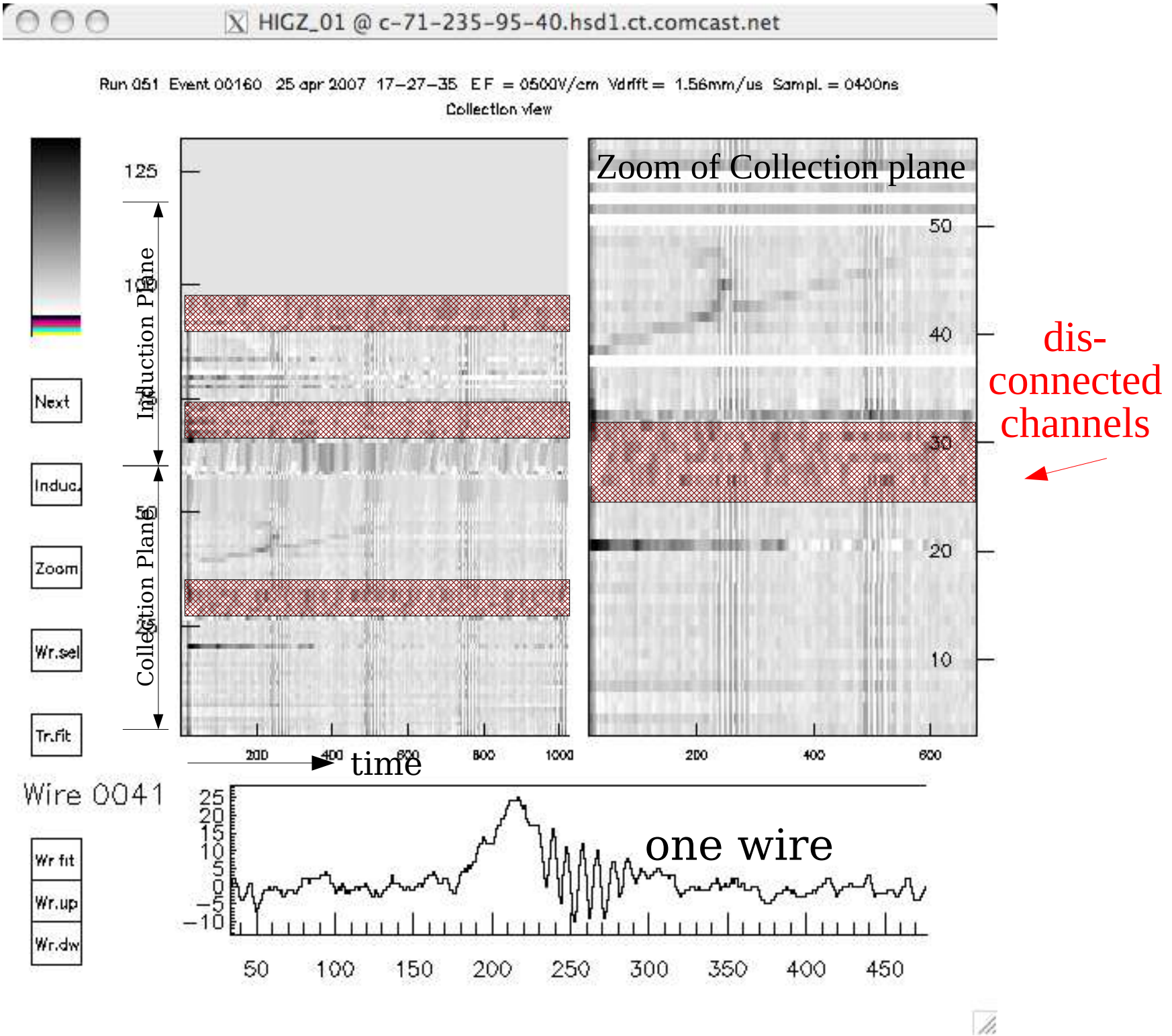
LAr: Small lab testing purity and TPCs
First tracks seen last month!



Funded through a DOE
Advanced Detector Research Grant


HIGZ_01 @ c-71-235-95-40.hsd1.ct.comcast.net
Run 051 Event 00291 25 apr 2007 17-43-13 EF = 0500V/cm Vdrift = 1.56mm/us Sampl. = 0400ns
Collection view
Zoom of Collection plane
Induction Plane
Collection Plane
Next
Induc.
Zoom
Wr.sel
Tr.fit
time
Wire 0041
Wr fit
Wr.up
Wr.dw
one wire
dis-
connected
channels


HIGZ_01 @ dhcp130132248057.its.yale.edu
Run 046 Event 00067 25 apr 2007 16-00-43 EF = 0500V/cm Vdrift = 1.56mm/us Sampl. = 0400ns
Collection view
Zoom of Collection plane
Induction Plane
Collection Plane
Next
Induc.
Zoom
Wr.sel
Tr.fit
time
dis-
connected
channels
Wire 0039
Wr fit
Wr.up
Wr.dw
one wire


HIGZ_01 @ c-71-235-95-40.hsd1.ct.comcast.net
Run 051 Event 00160 25 apr 2007 17-27-35 EF = 0500V/cm Vdrift = 1.56mm/us Sampl. = 0400ns
Collection view
Zoom of Collection plane
Induction Plane
Collection Plane
Next
Induc.
Zoom
Wr.sel
Tr.fit
time
dis-
connected
channels
Wire 0041
Wr fit
Wr.up
Wr.dw
one wire

Now -- See neutrino interactions!

T962 project

Expose a small (~250 liter active volume) LArTPC to the NuMI neutrino beam

- See low energy (1-3 GeV) neutrino interactions in a LArTPC
  - specifically NCπ°s and ν_e
- gain experience operating stably over months

These are firsts:

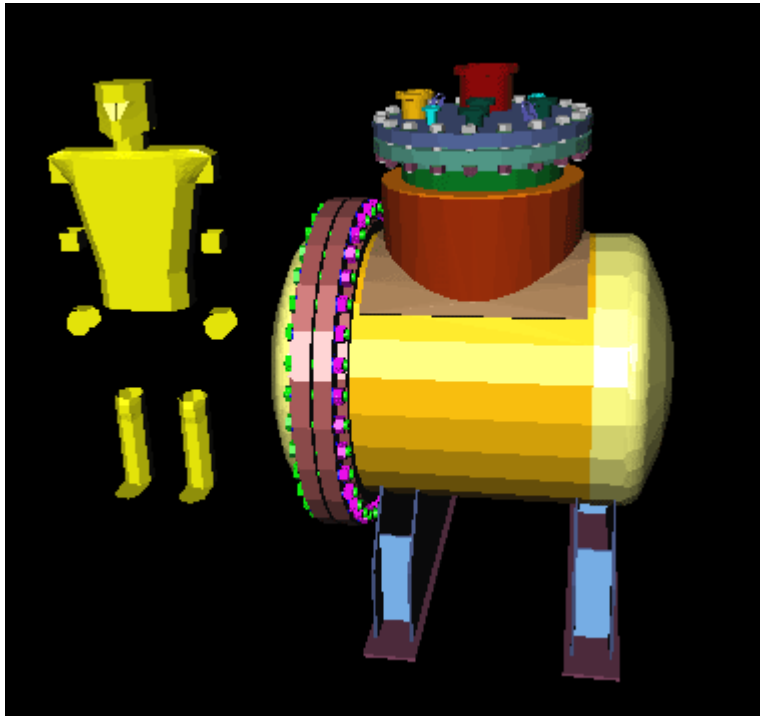
- only other TPC to see neutrinos was ICARUS 50l
  - 50 liter volume
  - 24 GeV beam
  - published ~100 ν_μ CCQE events

Neither the 50 liter nor other TPCs (including T600) has operated continuously, for months, underground.

funded via NSF CAREER grant

Cryostat:

- ~500 liters total volume
- ~250 liters active volume
- .5 x .5 x 1m TPC



sit just upstream of the MINOS near detector (as PEANUT has done)

use MINOS as muon catcher

~300 ν_μ CC events/day → Scheduled run: Dec '07 to May '08

start doing physics here!

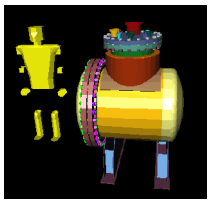
5 kton: sensitivity to mass hierarchy, increase sensitivity to θ_{13}

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

Possible FNAL sited experiments (50-1000 tons)

150 ton purity demonstration

test stands



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Ideas from various people for FNAL sited LArTPC neutrino experiments:

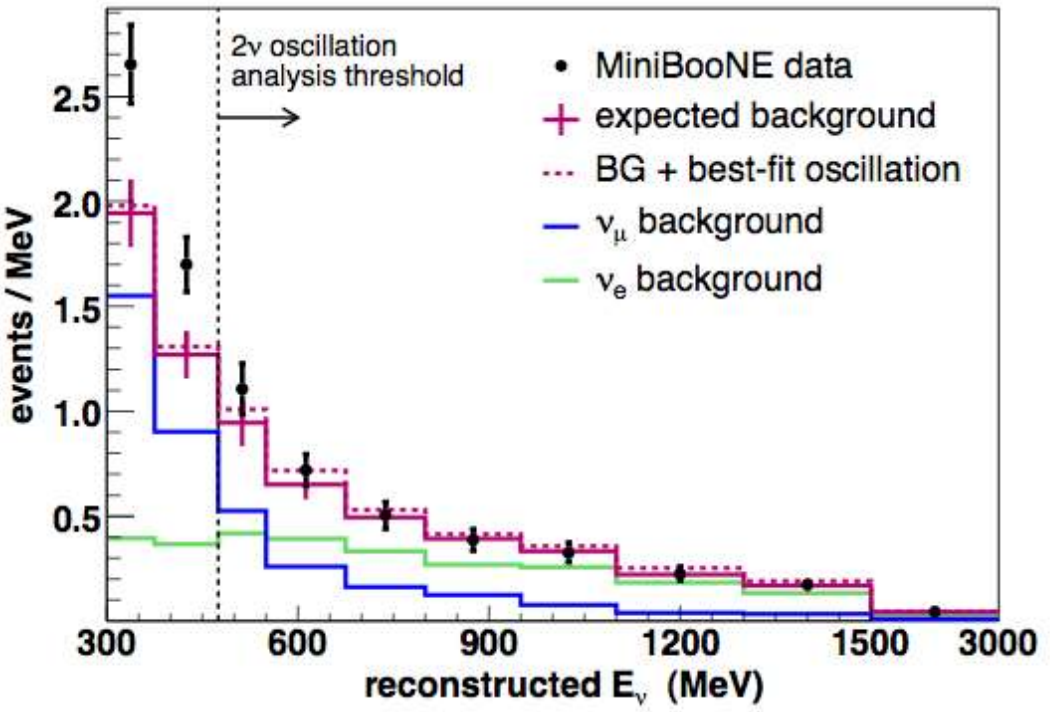
- MiniBooNE follow-on to understand low energy discrepancy, using BNB and/or NuMI beam
- Cross section measurements
  - Using BNB, cited in SciBooNE hall post SciBooNE
  - Using NuMI beam (ν-e elastic stattering)
  - Using TeVatron beam (ν-e elastic scattering, ν-tau production?)
- Fine-grained near detector for NOvA

MiniBooNE follow-on:

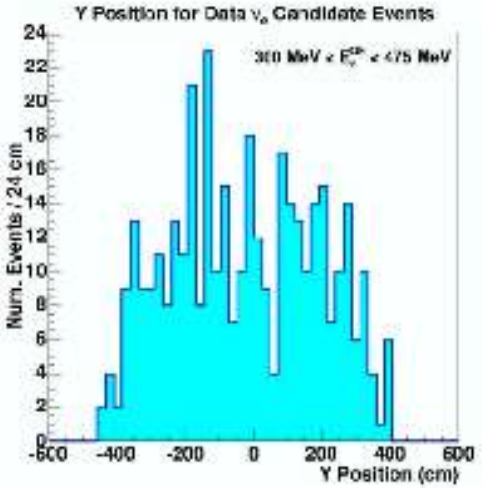
If low energy events are not “SM” (miniBooNE should know this < 6 months)

need to investigate no matter what

- new physics
- something we need to understand for next set of experiments in this energy range (NOvA and beyond)



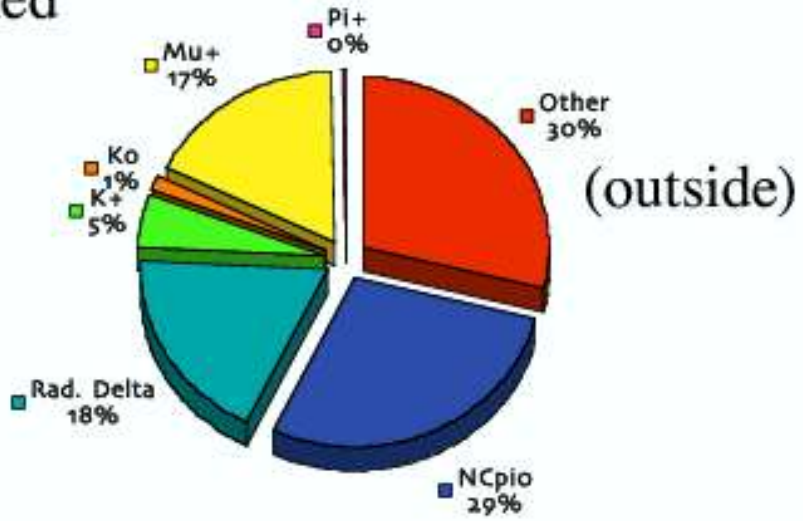
What we already know about these events.....



- They are spread throughout the run,
- They show no bias in event timing
- They show no bias in spatial distribution (they are not from outside)
- The backgrounds in this region are large, but they are well constrained

intrinsic ν_e

ν_μ mis-id



(outside)

Likelihood Analysis

300 MeV to 475 MeV

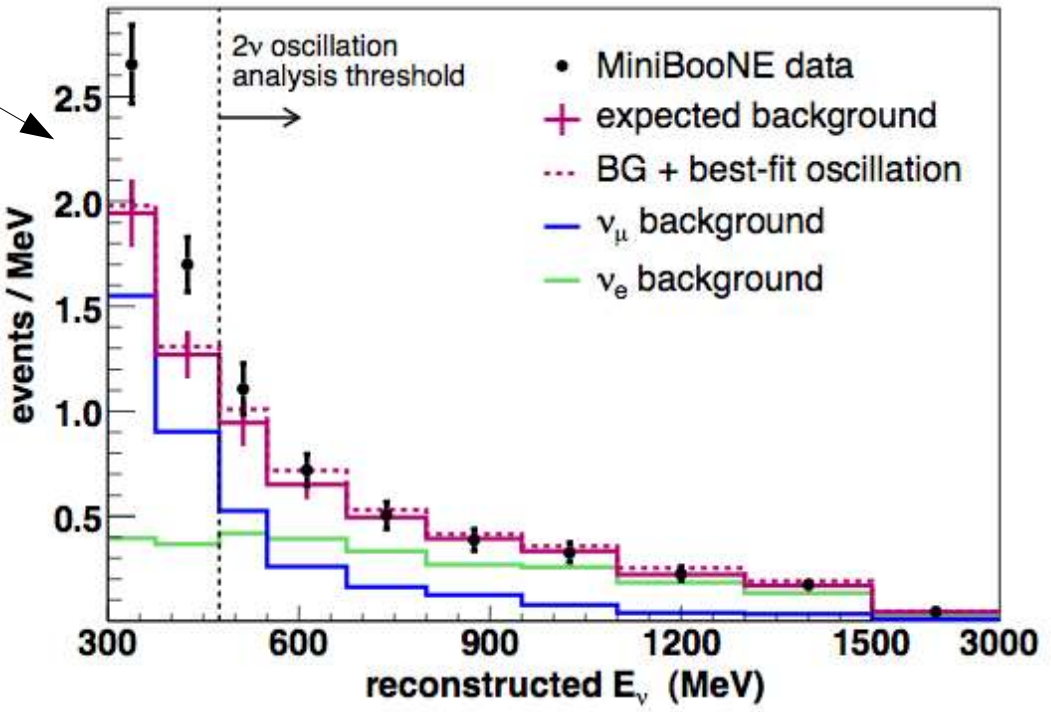
MiniBooNE follow-on:

Like a detector that is
- sensitive at low energies
- low background

If nearly background free, need an order of magnitude less detector

- small to reduce cost

does the excess keep rising?
turn over?



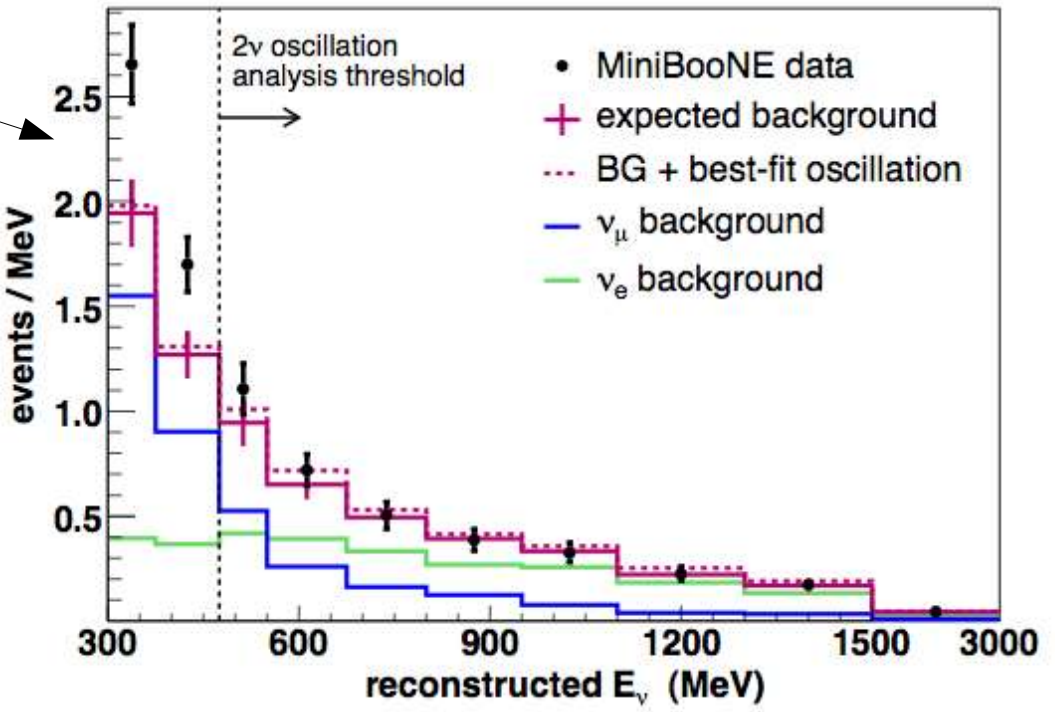
MiniBooNE follow-on:

Like a detector that is
- sensitive at low energies
- low background

If nearly background free, need an order of magnitude less detector

- small to reduce cost

LArTPCs can ID all ν_μ backgrounds that are rising
ν_e intrinsics turning off...



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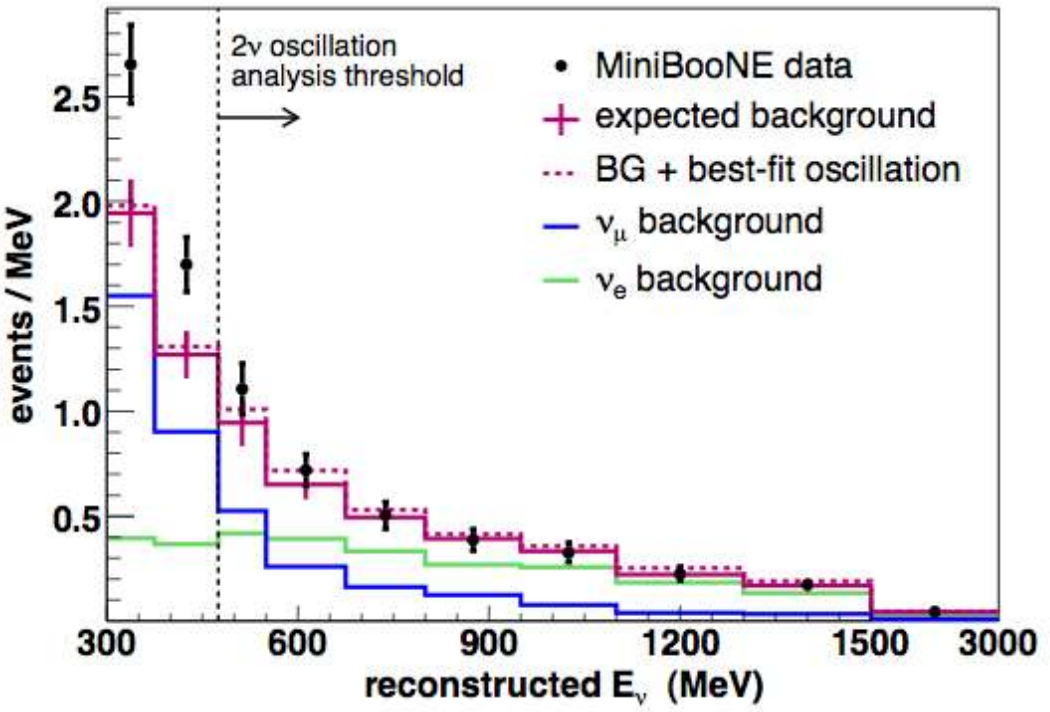


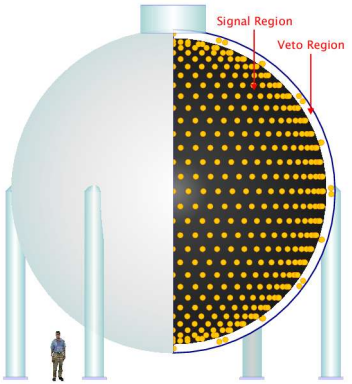
MiniBooNE follow-on:

~~Boone~~

microBooNE

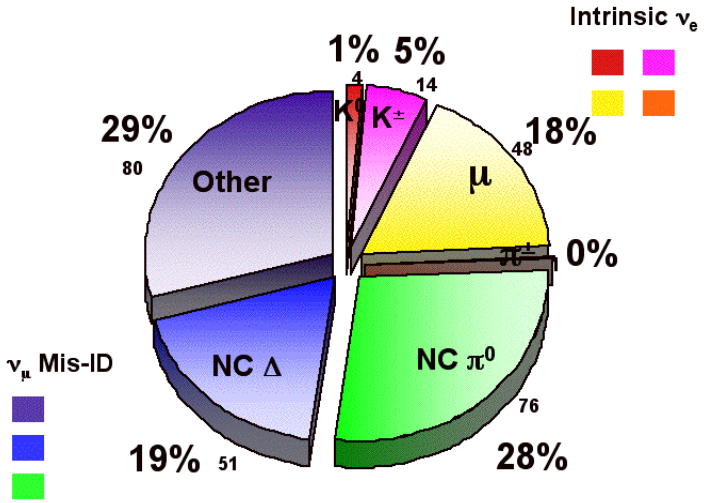
Contacts: B. Fleming, B. Willis

- 50 ton fiducial volume LArTPC (10 times smaller than mBooNE)
- located on or nearly on axis on BNB and off-axis for NuMI beam to use BNB and/or NuMI beam
  - In the MiniBooNE hall if modularized
  - in the NuMI surface building

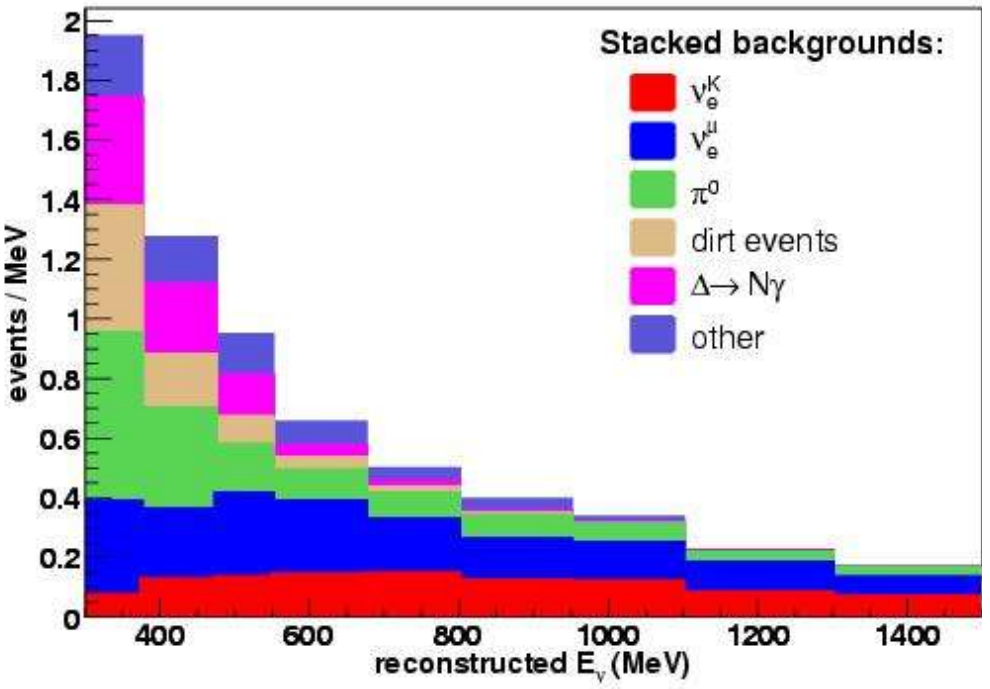


one pager will be submitted

Backgrounds from ν_μ misID are peaking at low energies



event composition
in 300-475 MeV bin



LArTPCs can resolve these backgrounds
(ie: ID NCπ°s, νmisID, dirt events (π°), etc.)

Intrinsics are dropping at low energies

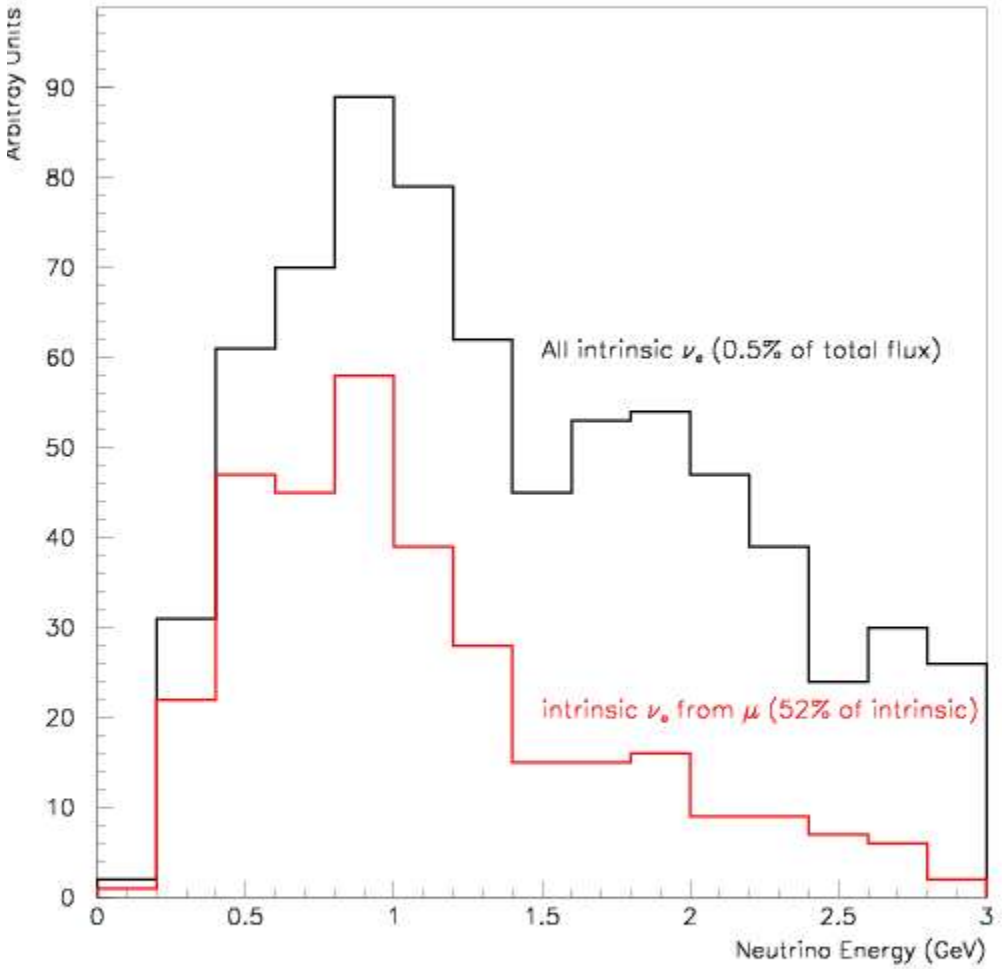
small in the 250-500 MeV bin

minimal below this (dropping xsecs)

dominated by ν_es from muon decay

constrain using ν_μ events ala MiniBooNE

Backgrounds from Intrinsics....



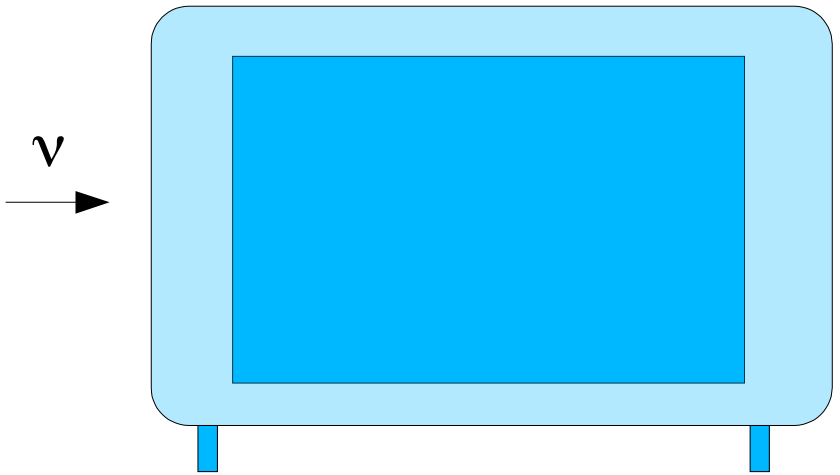
MiniBooNE sees:
~100 signal events plus
20 events from
intrinsic ν_e (+ **misIDs**)

microBoonE sees:
~20 signal events (x2 eff)
+ 4 intrinsic (know to 20%)
20 ±5 ±1

Fine-grained near detector for NOvA:

- precise measurement of ν_e intrinsics
- precise cross section measurements in general

For example: If you want ~10k ν_e interactions

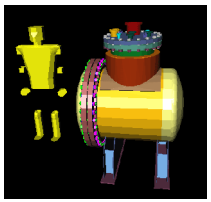


3x3x5m LArTPC active volume (63 tons)
translates to 2x2x3.5m fiducial volume (20 tons)
(π° showers are, at largest, 1x1x1.5m)

for 100 ν_es per ton per year run for 5 years as per NOvA and collect ~10k events

R&D from microBooNE and test stands prepare you for 5kton

test stands



150 ton purity demonstration

Possible FNAL sited experiments (50-1000 tons)

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

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

2007 2008-9 2013-15 201?

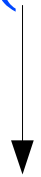
LArTPCs for long baseline program in the *mid*-term

Significantly improve the long baseline program with a 5kton LArTPC sited at Ash River

- factor of 2 improvement in θ_{13}

sensitivity to mass hierarchy : US long baseline only....

- advance LArTPC technology towards longer term long baseline program (where you MUST use LAr)

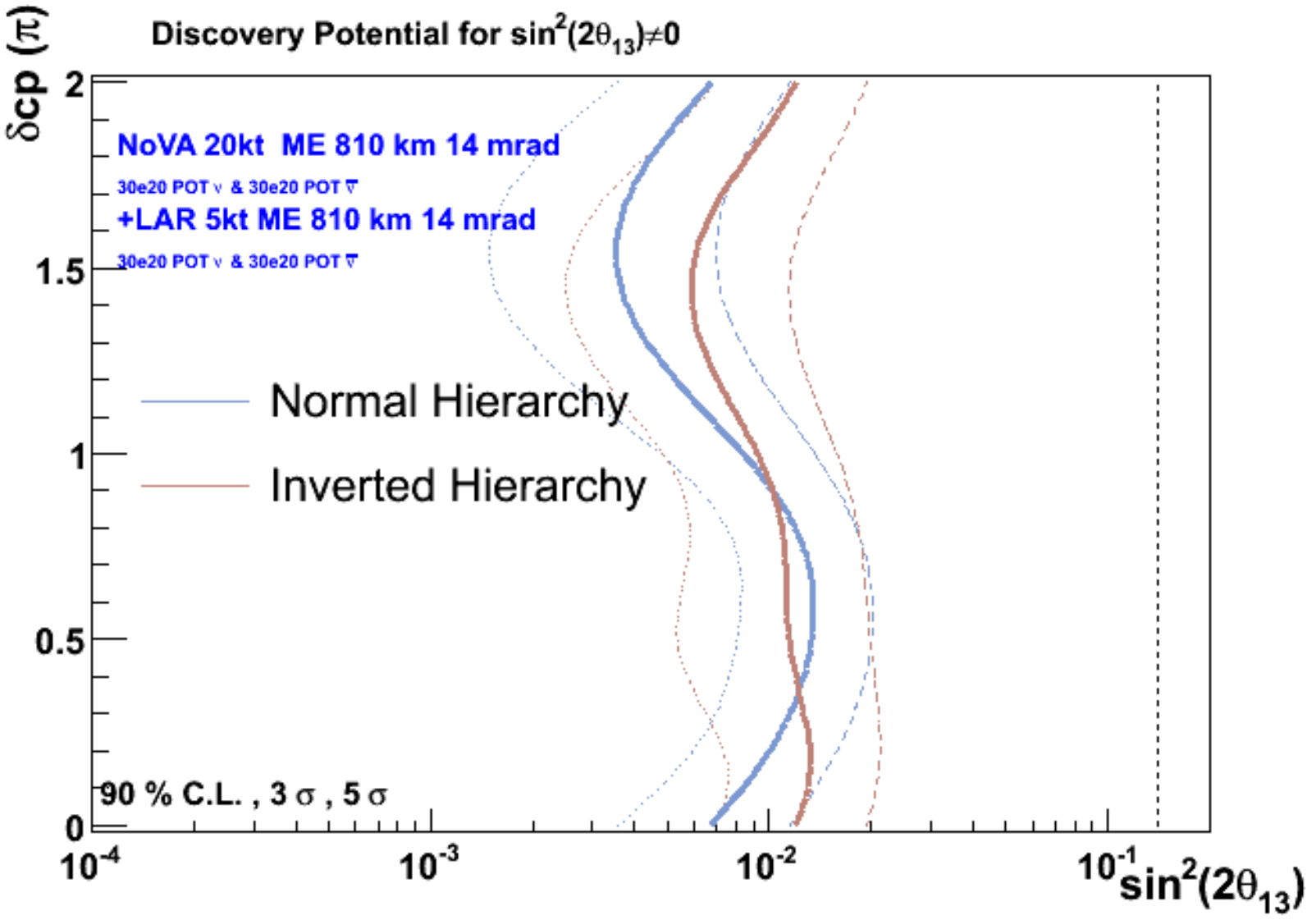


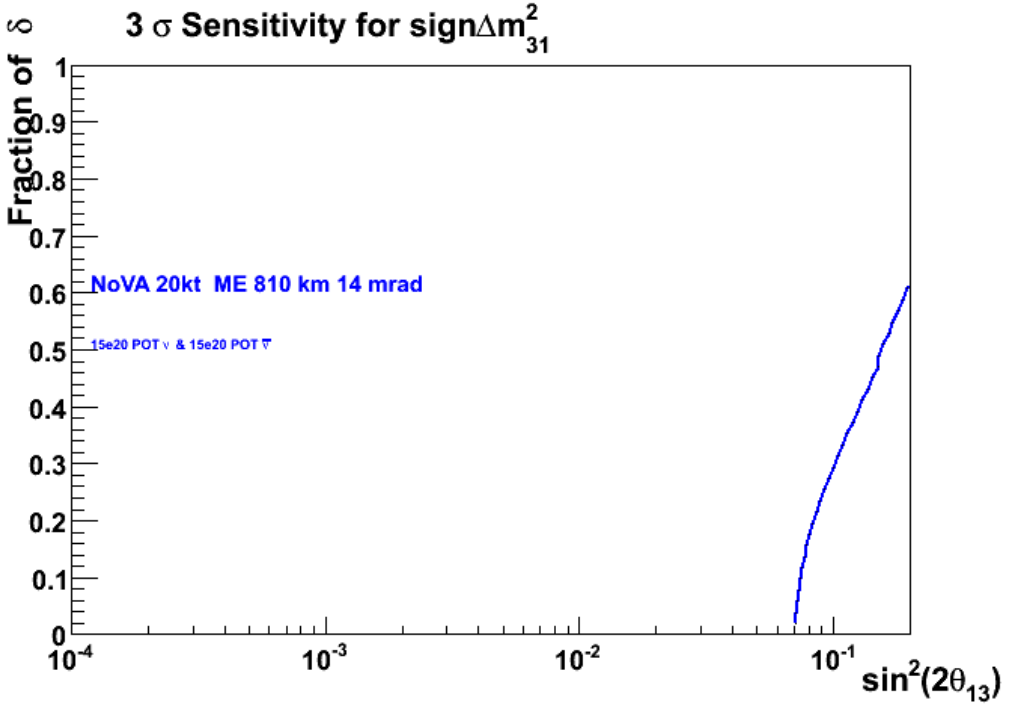
Perfect program for mid-term

→ after microBooNE and test stands

→ before ILC decision point:

- maintain US lead in long baseline physics
- run parasitically to NOvA (no proton problem)
- costs ramp up as NOvA costs ramp down

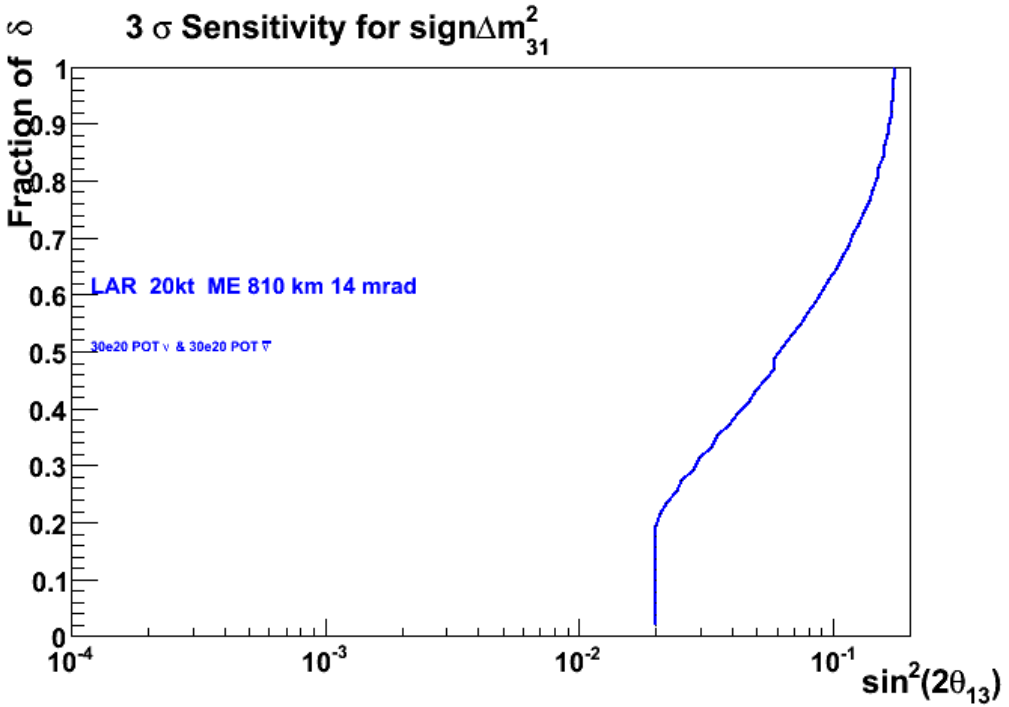

Discovery Potential for sin²(2θ13)≠0
δcp (π)
NoVA 20kt ME 810 km 14 mrad
30e20 POT ν & 30e20 POT ν̄
+LAR 5kt ME 810 km 14 mrad
30e20 POT ν & 30e20 POT ν̄
Normal Hierarchy
Inverted Hierarchy
90 % C.L. , 3 σ , 5 σ
2
1.5
1
0.5
0
10⁻⁴
10⁻³
10⁻²
10⁻¹
sin²(2θ13)



Sensitivity to mass hierarchy for NOvA

Sensitivity using 20kton LArTPC

(or the 5kton with an intense neutrino source)



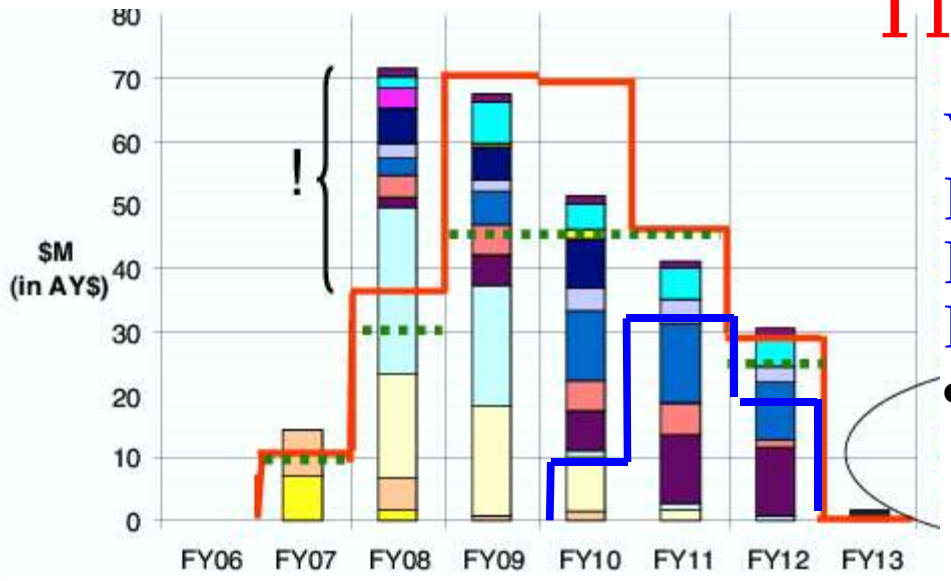
Fermilab Program

Energy Frontier

Neutrino Physics

FY	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Tevatron	Operation															
LHC	Construction					Operation										
LHC Upgrade		R&D				Construction						Operation				
ILC		R&D					Decision					Construction				
MINOS																
NOvA							To be approved									
MINERvA																
MiniBooNE																
SciBooNE																
Long baseline ν		R&D					Decision					Construction				

Very rough



Timing is perfect....

Very rough funding profile:
FY10: 10M
FY11: 30-40M
FY12:10-20M

- Design and construction underway by "Decision point": Know if technology is viable for long baseline program

Technologically driven schedule --> extremely aggressive funding profile

Summary

Active R&D program in the US that is growing

Discovery potential in the near term using LArTPCs! (microBooNE)

5kton at Ash River for long baseline physics in the mid-term

Massive LArTPCs for CP Violation in the longer term

Capability depends on δ and θ_{13}

The CP Violation Parameter

Three Neutrino Mixing Matrix:

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

From Atmospheric and Long Baseline Disappearance Measurements

From Reactor Disappearance Measurements

From Long Baseline Appearance Measurements

From Solar Neutrino Measurements

Chooz limit is $\sin^2 2\theta_{13} \sim 0.1$

A number of ideas out there on what new physics they could suggest....

“Shortcuts in Extra Dimensions and neutrino physics” hep-ph/0611263 (prediction of a low energy signal)

“Explaining LSND with a Decaying Sterile Neutrino” hep-ph/0505216

“A Three-flavor, Lorentz-violating Solution to the LSND Anomoly”
hep-ph/0602237

“Sterile Neutrino Oscillatyions after the First MiniBooNE Result” hep-ph/0705.0107 (3+2 model)