Fermilab

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Coherence of Current Neutrino Research and Operations

Sam Zeller

Institutional Review

11 February 2015

Neutrino Sessions

- **Sam Zeller**: Coherence of the current experimental program
  (MINOS+, MINERvA, NOvA, MiniBooNE, MicroBooNE)
- **Peter Wilson**: Coherence of the future SBN and LBNF programs
  Wed 3:45, One East
- **Steve Brice**: Platform that is supporting our neutrino activities
  Thurs 9:15, One West

- Technical & Computing Resource Allocation
  Wed 11:00, Comitium
- Discussion with Neutrino Users
  Wed 1:00, Black Hole
- Proton Economics
  Wed 14:15, Black Hole
- Neutrino Theory
  Thurs 11:00, Black Hole
- Neutrino & Muon Recap
  Thurs 1:30, Black Hole

Stats on Current Neutrino Experiments

Experiment	# authors	# institutions	Headline measurement(s)	# analysis topics	# physics publications to date	total # citations to date	current h Index	# PhD theses to date
MiniBooNE	84	18	Test oscillation interpretation of LSND anomaly	29	23	2,885	23	18
MINOS(+)	116	32	Measure θ_{23} and Δm^2_{32}	22	32	3,323	25	70
MINERvA	65-80	20	Neutrino Cross-sections	44	7	115	4	10
NOvA	208	38	Neutrino mass hierarchy	27				1
MicroBooNE	137	24	Probe MiniBooNE low E excess, nu xsecs	33				

source: http://neutrino.fnal.gov/breadth/index.html

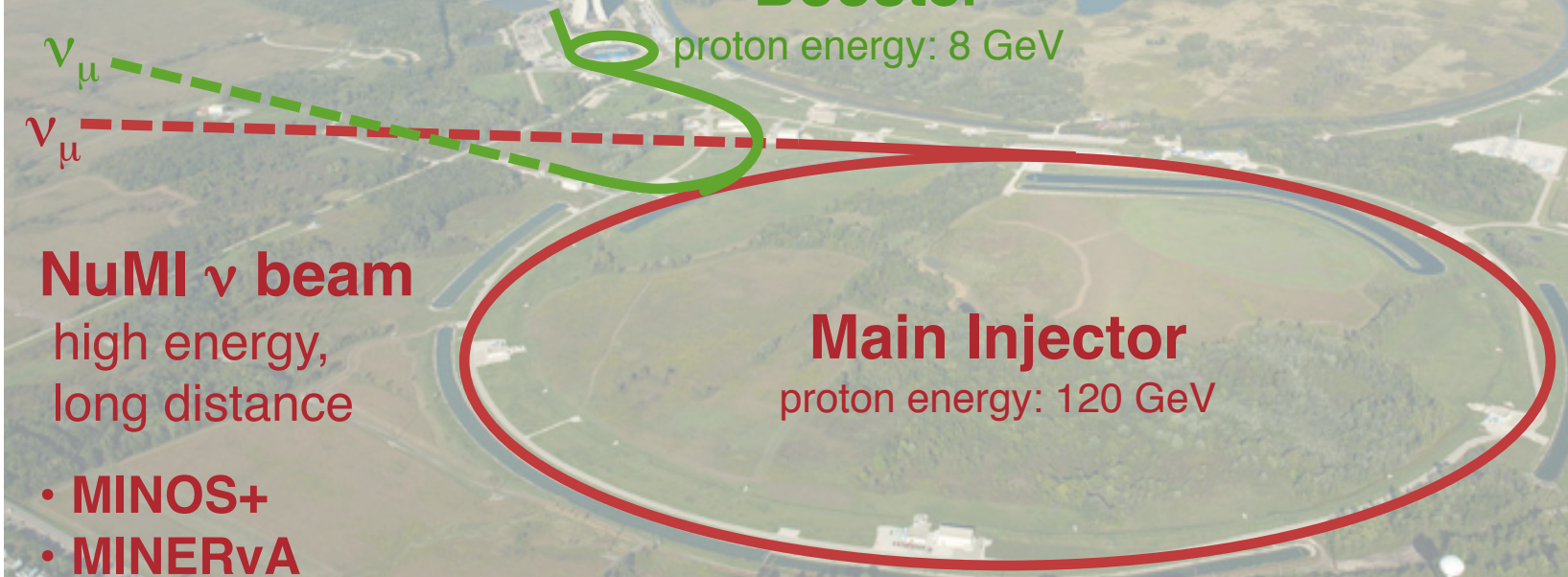
- there is a vibrant ν community that is active at Fermilab
- at present, there are **405** unique users from Univs/other labs from **79** unique institutions who participate in these 5 exps *(MiniBooNE, MINOS+, MINERvA, NOvA, MicroBooNE)*
- **99** students have graduated so far on this experimental program

Current Fermilab Neutrino Experiments

Booster ν beam
low energy, short distance

- **MiniBooNE**
- **MicroBooNE**

- Fermilab is host to a vital ν program that makes use of two ν beams



NuMI ν beam
high energy,
long distance

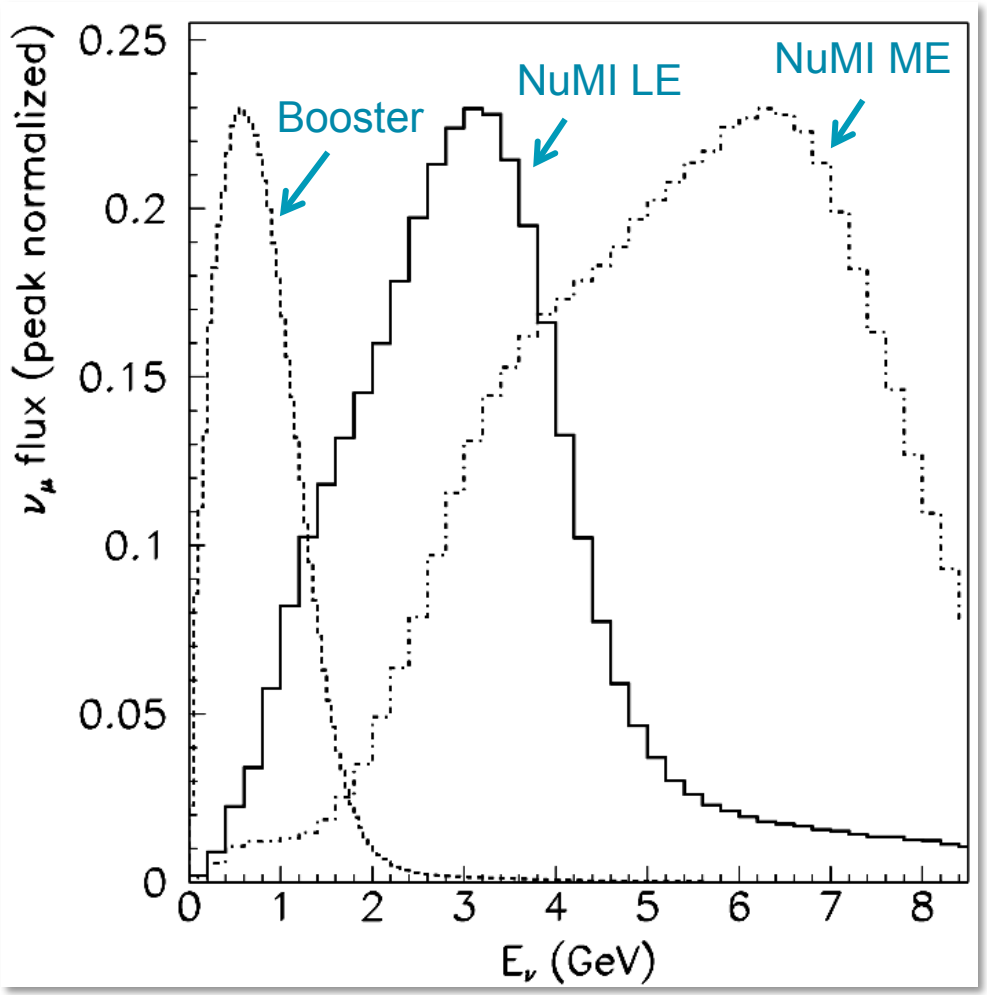
- **MINOS+**
- **MINERvA**
- **NOvA**

- these experiments are at a variety of stages; will discuss the evolution of this program …

4

Neutrino Spectra

- in the last 15 years, this facility has delivered > 3x more POT to ν experiments than Asia/Europe combined
- these beams span a very wide range of ν energies that enables a tremendous amount of physics
- physics focus:
  - neutrino mixing matrix
  - sterile neutrinos
  - neutrino interactions



(on-axis beam spectra)

Revealing the Pattern of Neutrino Mixing

MINOS/MINOS+

precision $\Delta m^2_{\mu\mu}$ → new physics

735 km

long-baseline
neutrino experiments

NOvA

mass hierarchy
810 km

LBNF

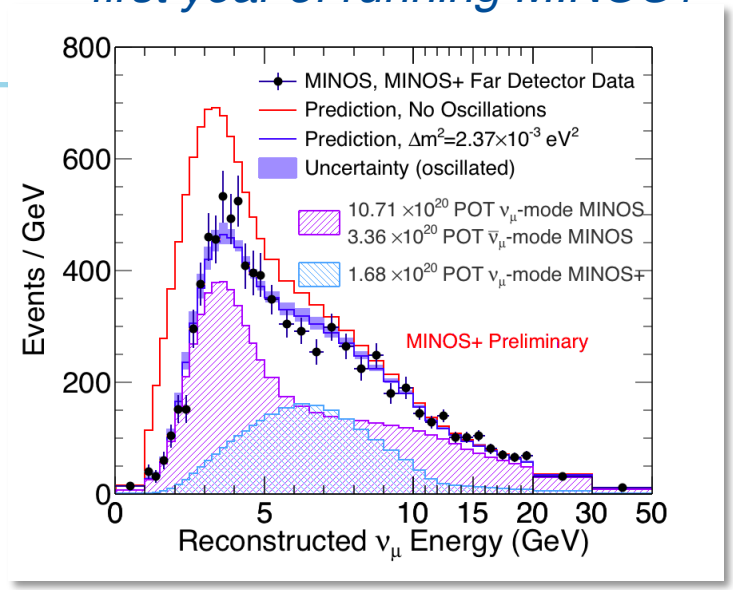
CP violation
underground physics
1300 km

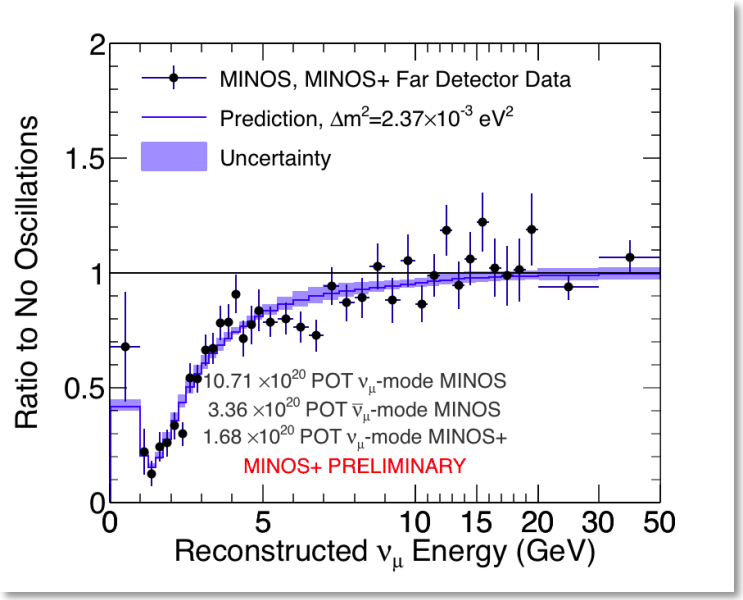
(Peter Wilson's talk)

MINOS+

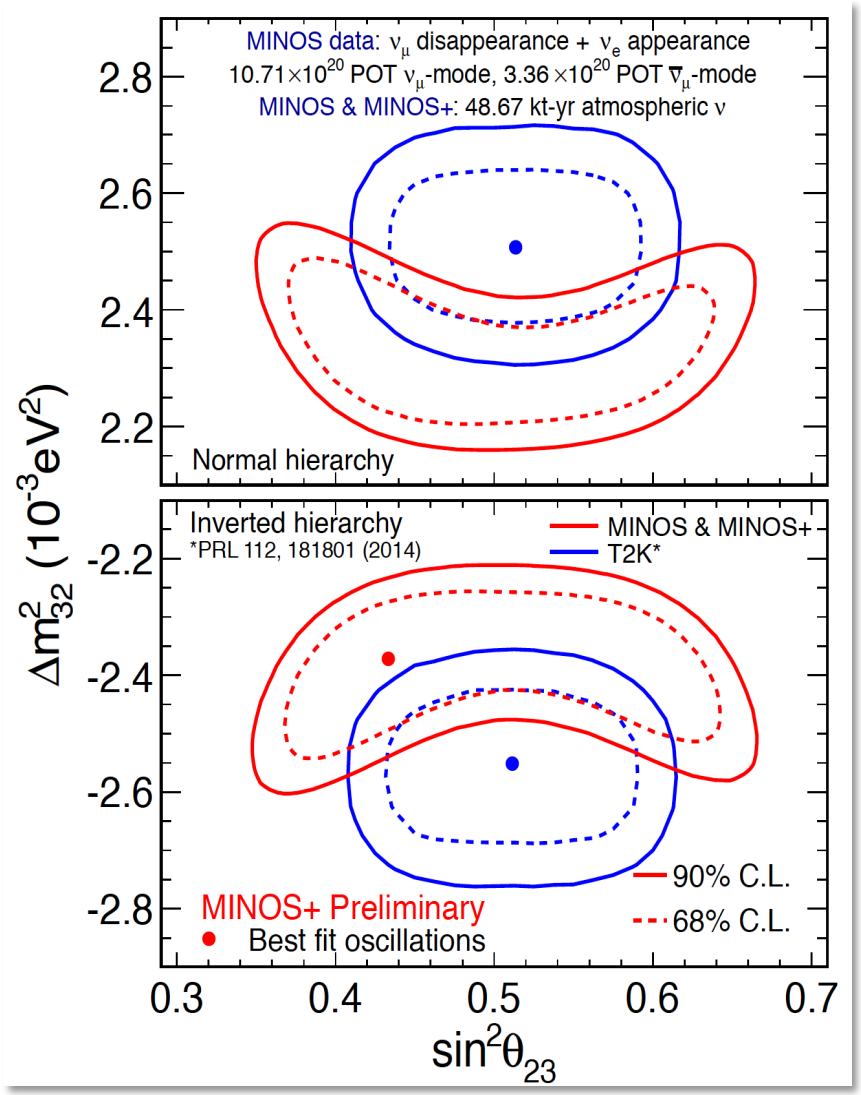
- MINOS+ is a continuation of the highly successful MINOS program now in the NOvA ME beam
- test for non-standard oscillations in this higher energy ME beam
  - *search for sterile ν's, NSI, and other new phenomena*
  - *detailed map of the oscillation spectrum*
  - *improved measurement of "standard" neutrino oscillation parameters*
- robust, well understood detectors >95% uptime *(MINOS ND critical part of MINERvA)*
- NuMI collected 3.1x10^{20} POT (ME) last year, 2nd best year in lab's history

first year of running MINOS+





Progress on Standard Paradigm Tests



- current experimental situation
- appearance & disappearance beam & atmospheric

Inverted Hierarchy

$$|\Delta m^2_{32}| = 2.37^{+0.11}_{-0.07} \times 10^{-3}\text{eV}^2$$
$$\sin^2\theta_{23} = 0.43^{+0.19}_{-0.05}$$
$$0.36 < \sin^2\theta_{23} < 0.65 \text{ (90\% C.L.)}$$

Normal Hierarchy

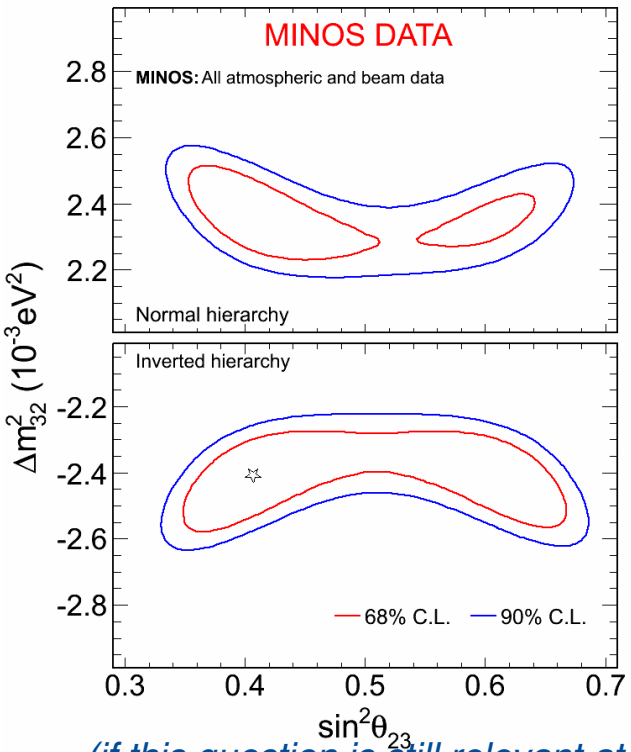
$$|\Delta m^2_{32}| = 2.34^{+0.09}_{-0.09} \times 10^{-3}\text{eV}^2$$
$$\sin^2\theta_{23} = 0.43^{+0.16}_{-0.04}$$
$$0.37 < \sin^2\theta_{23} < 0.64 \text{ (90\% C.L.)}$$

- shows allowed regions with ~11 kt-yrs of additional atmospheric data from MINOS+

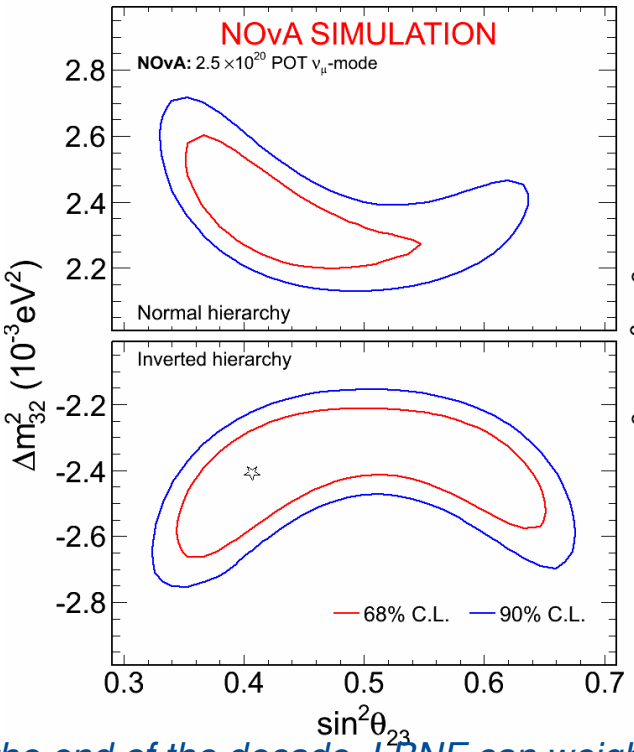
Projections for Combining Results

- we are making the transition to precision neutrino studies
- probing different parts of the oscillation curve; any observed difference from maximal mixing will be of great interest

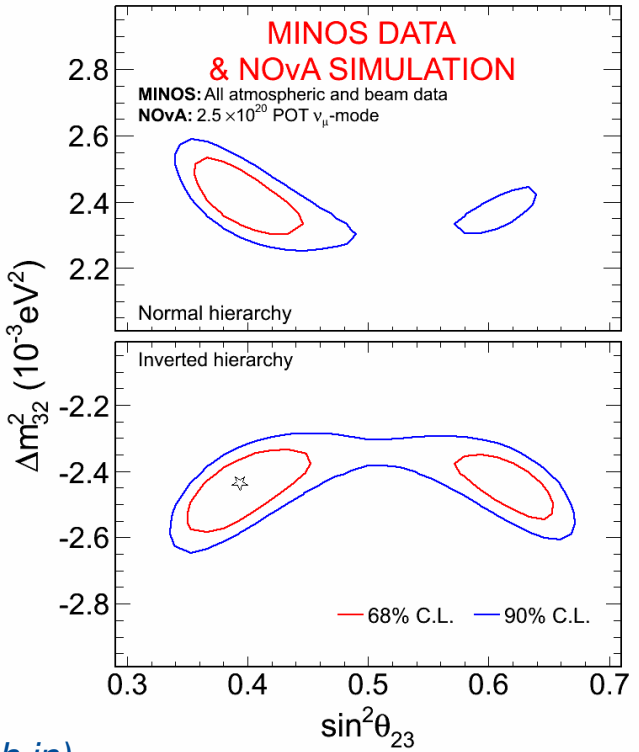
published MINOS



NOvA 2.5x10^{20} POT



MINOS + NOvA



(if this question is still relevant at the end of the decade, LBNF can weigh in)

Projections for Combining Results

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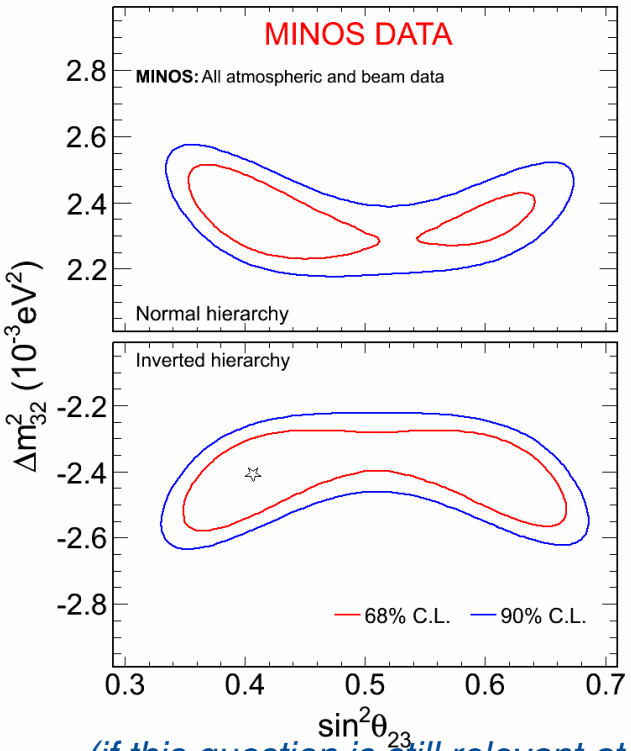
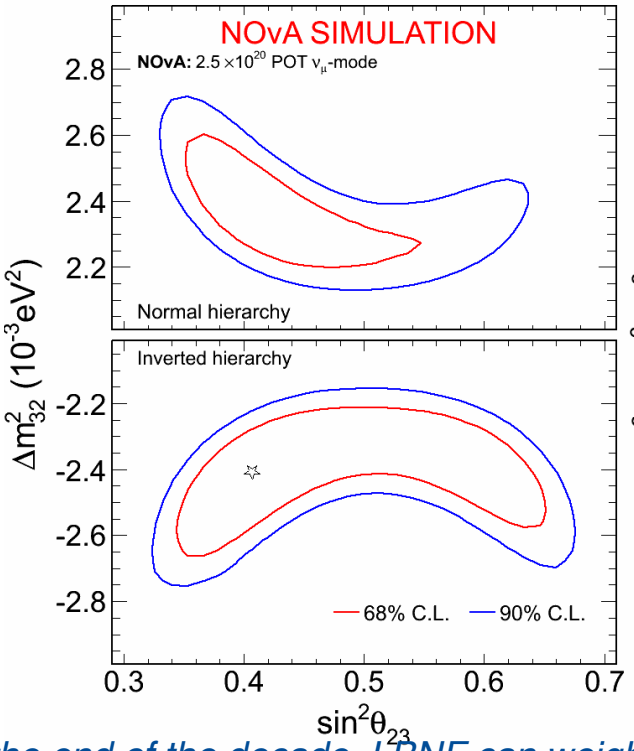
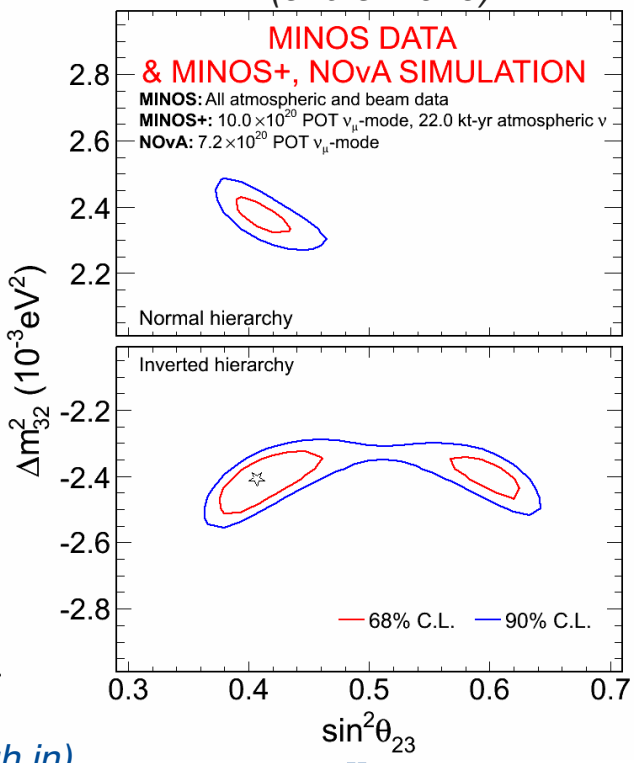
published MINOS



NOvA 2.5x10^{20} POT



MINOS, NOvA, MINOS+
(end of 2016)



(if this question is still relevant at the end of the decade, LBNF can weigh in)

NOvA

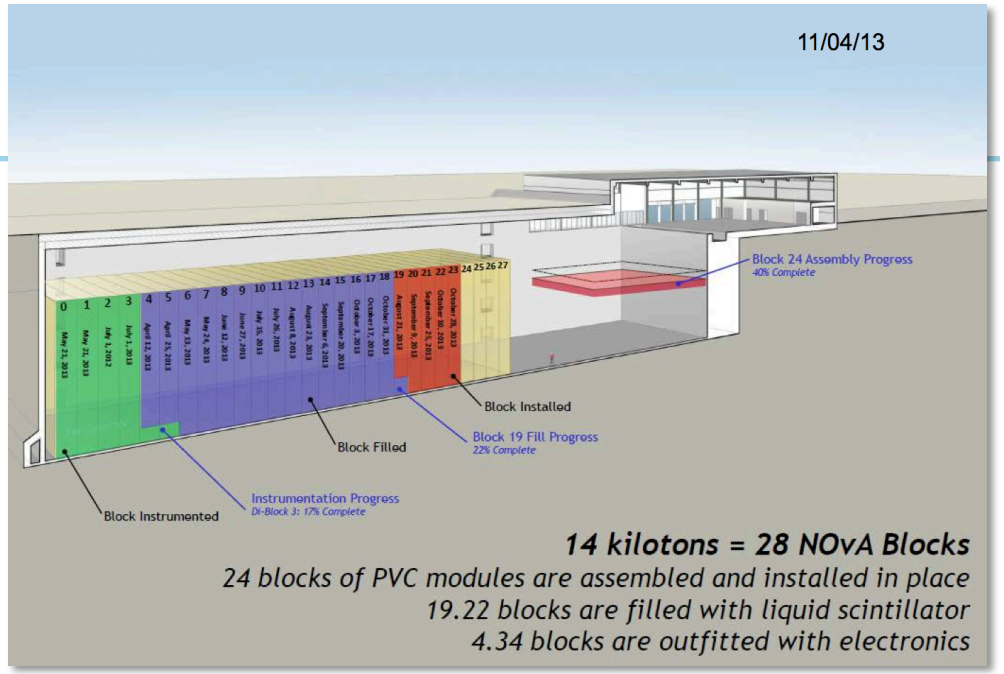
- this is the largest distance an accelerator source of ν's has ever been sent …
- will study $\overset{(-)}{\nu}_{\mu} \longrightarrow \overset{(-)}{\nu}_{e}$ oscillations over a distance of 810 km
- the world's most intense ν beam and an off-axis detector

  - *high precision ν oscillation measurements (test our picture)*
  - *mass hierarchy*
  - *glimpse at CP violation*

NOvA Far Detector

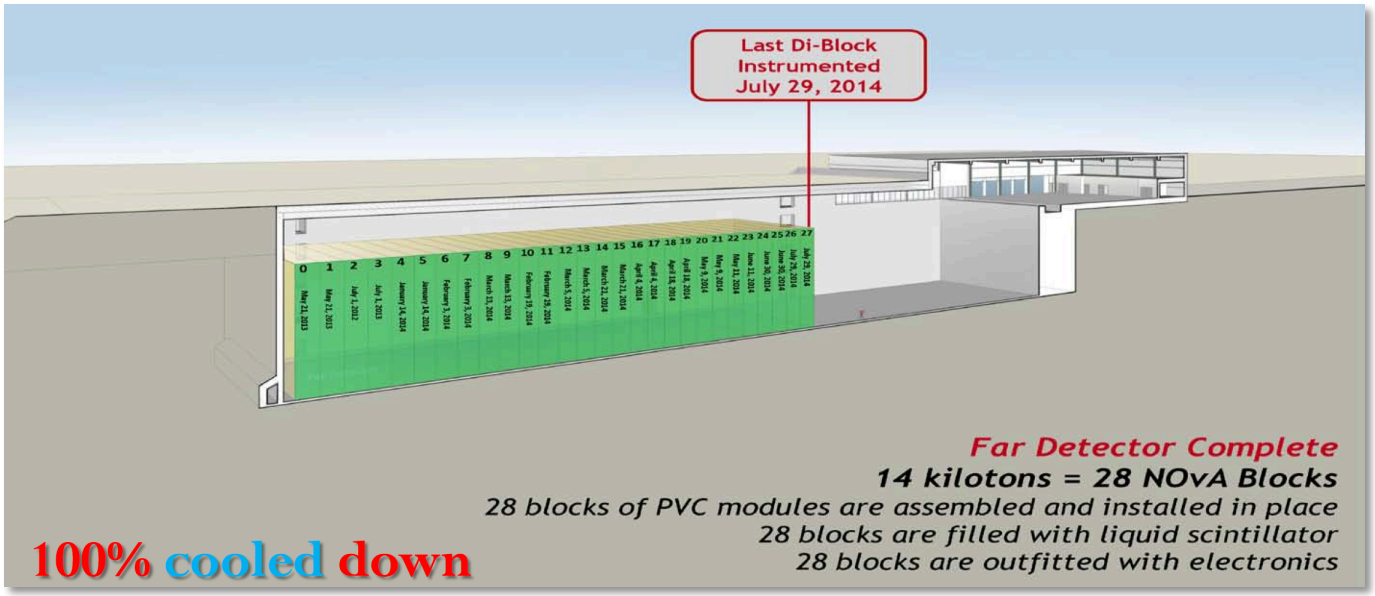
last review
(S&T review Nov 2013)

- 86% of modules installed
- 69% filled with scintillator
- 15% outfitted with electronics



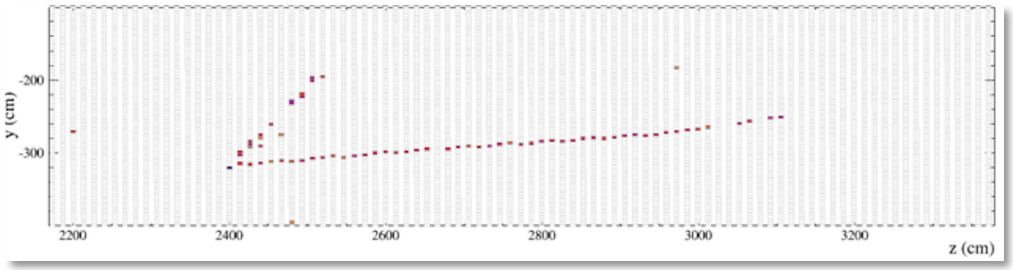
August 2014

- far detector complete!



NOvA

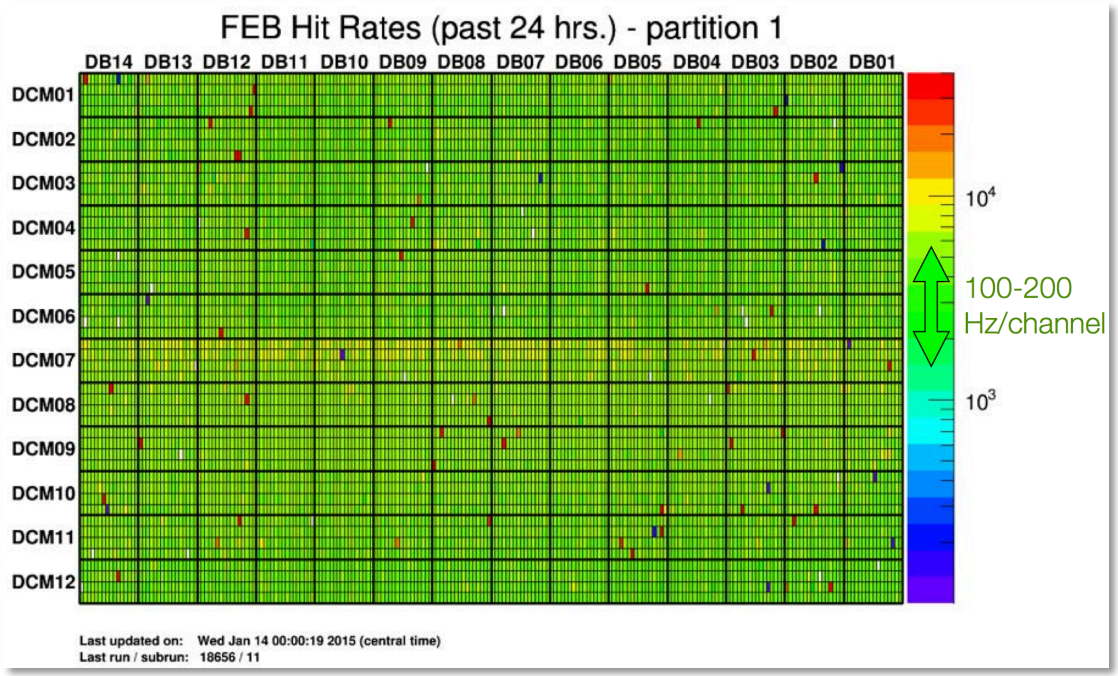
- project CD4 signed in Sept 2014
- Operational Readiness Review on Oct 28, 2014
- operations now managed by the NOvA collaboration in close consultation with Fermilab's ND



one of the first ν_μ CC events
(muon crosses 800 planes ~ 5.3m)

NOvA Far Detector

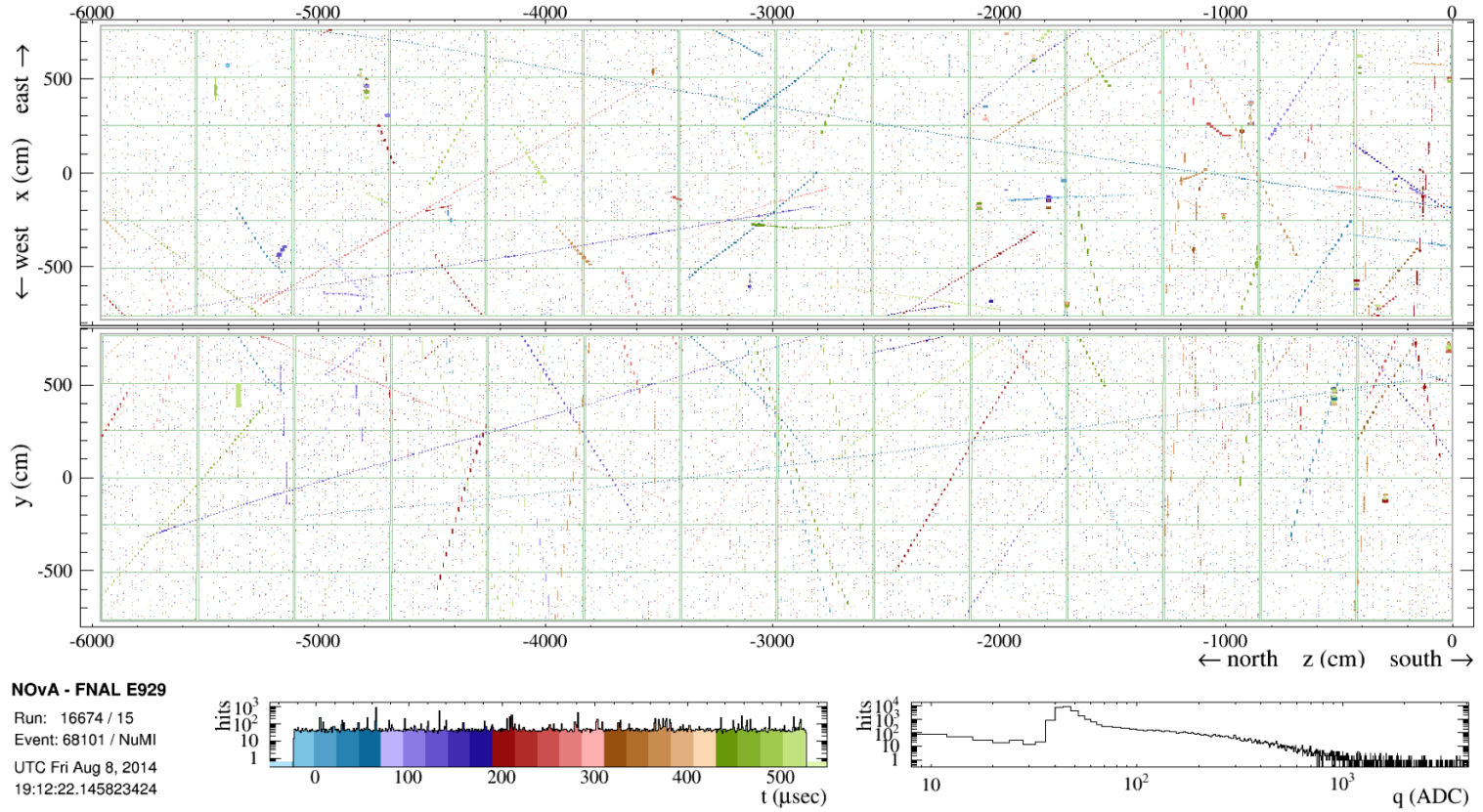
- retrofit work performed during 2014 shutdown to replace APDs with marginal performance (23%) and some faulty hose fittings
- 10,752 front end boards shown by hardware address
- >99% of channels are active
- have been in routine operation with the complete 14 kton FD since Nov 2014
- >95% uptime



(hit map shows channel occupancy)

NOvA Far Detector

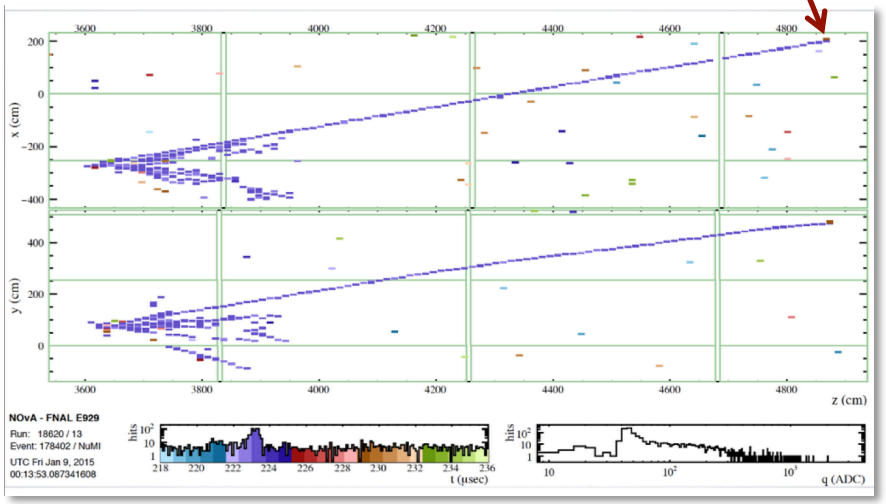
- raw data from 500 μs of far detector activity

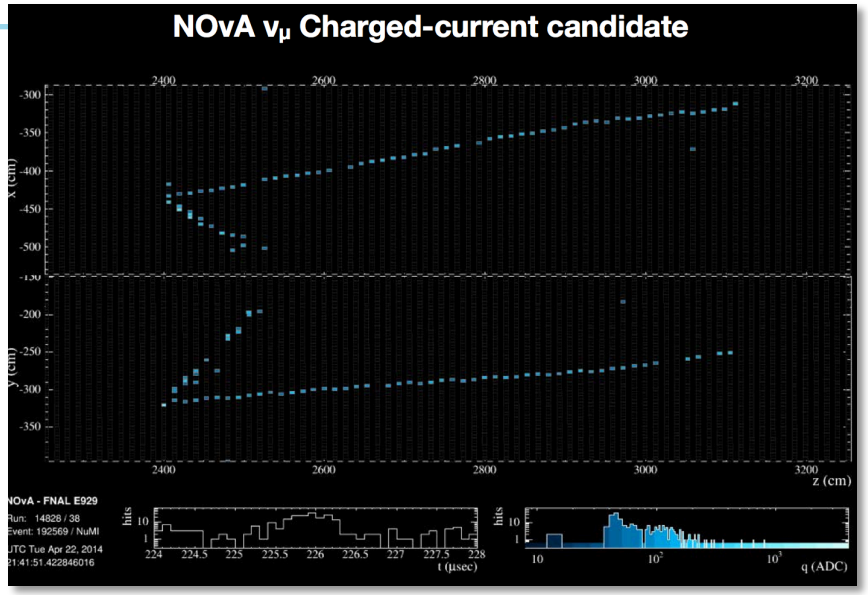


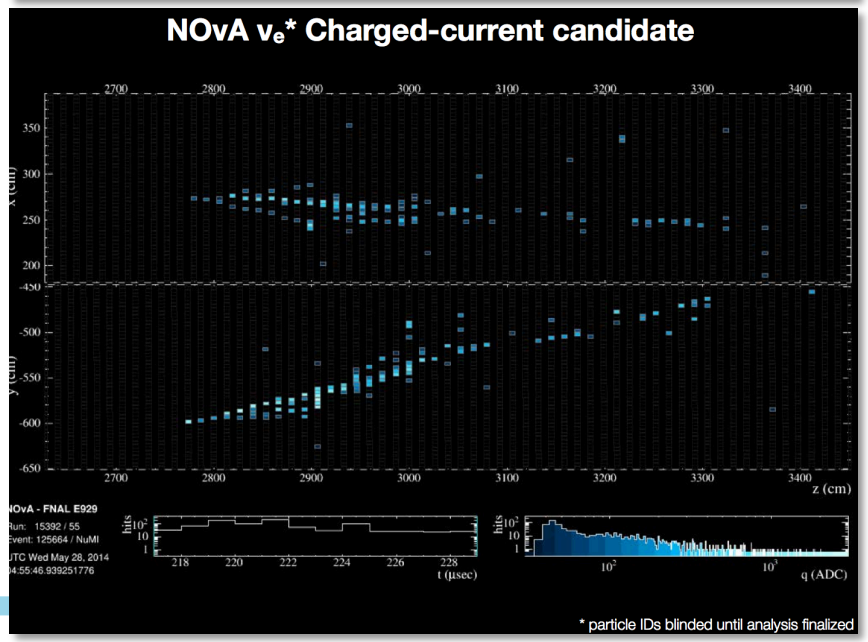
NOvA Far Detector

(isolating ν interactions in the FD)

- cosmic ray rejection bench-marked to better than 20M:1 for ν_e appearance
- FD analyses in progress; will also give us very valuable experience doing analyses will be doing in LBNF





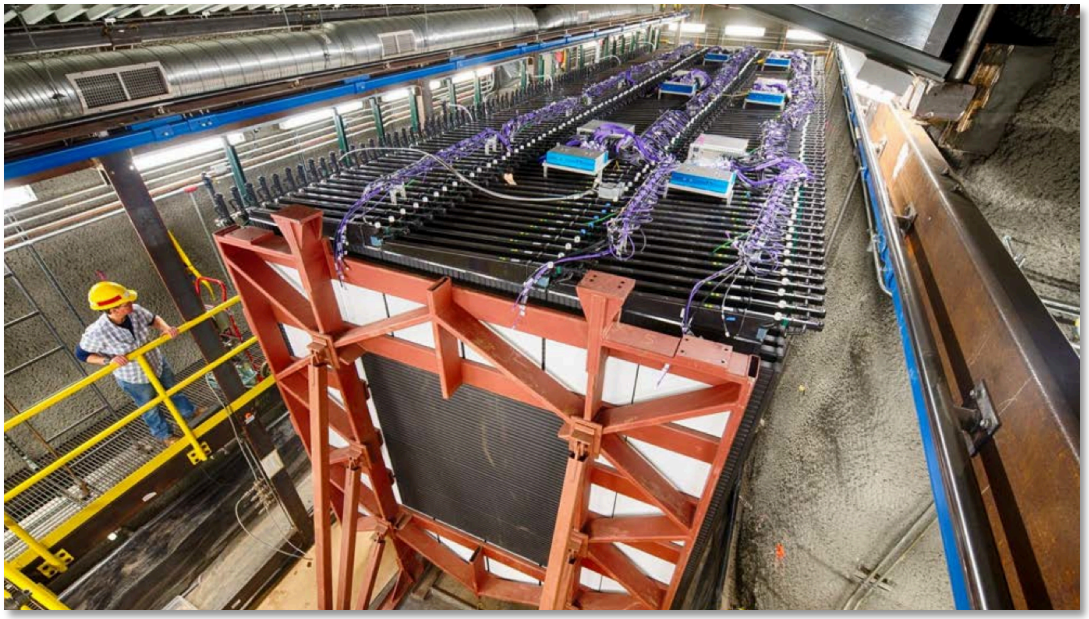


NOvA Near Detector

last review:
(S&T review Nov 2013)

- cavern complete
- ½ of PVC blocks in place
- not yet filled
- not instrumented

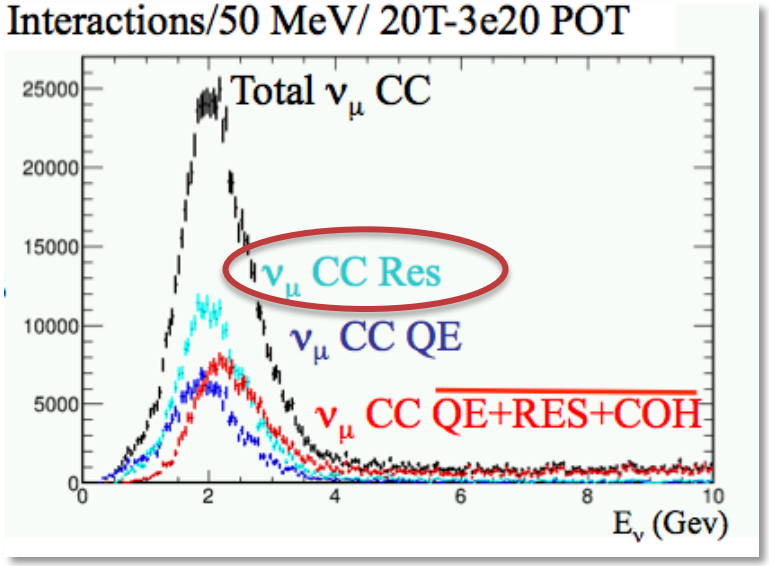
today:



- ND completed in Aug 2014
- running with >95% uptime
- 2M+ events collected already!
  (largest data set ever collected in this energy range)

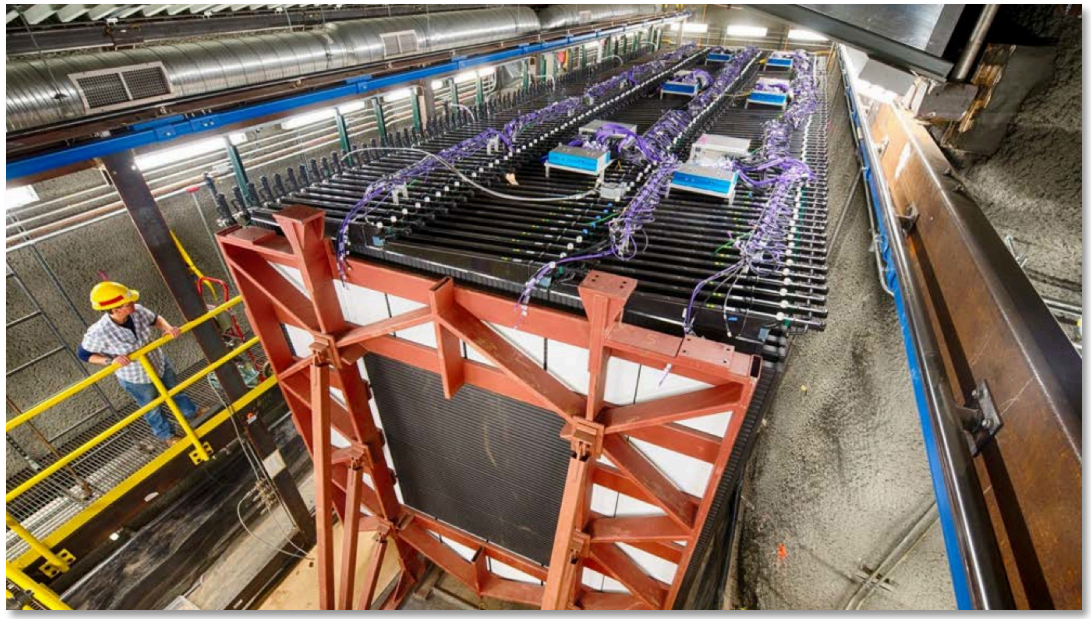
NOvA Near Detector

- this data will probe an important region in between MiniBooNE and MINERvA



(NOvA simulation)

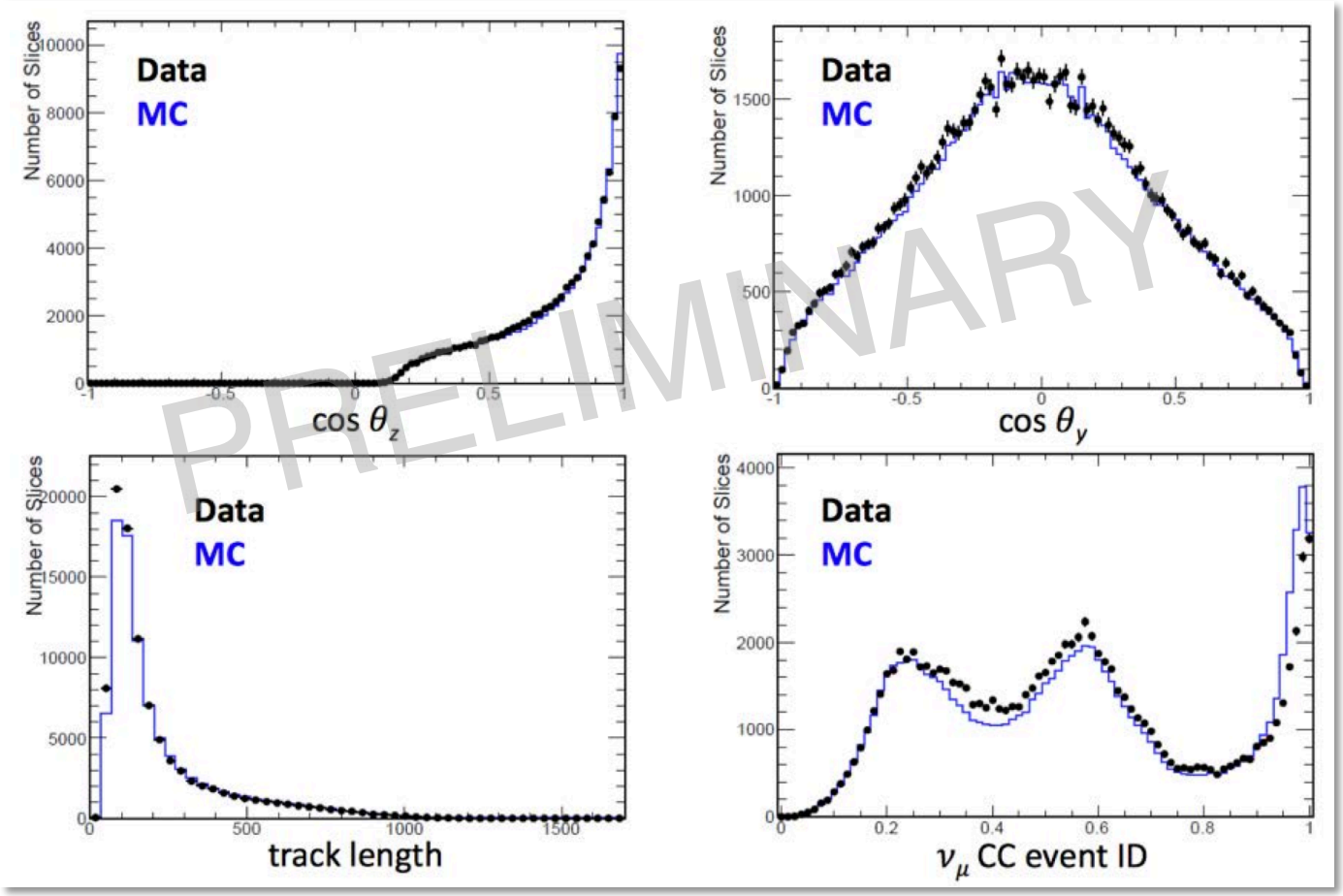
today:



- ND completed in Aug 2014
- running with >95% uptime
- 2M+ events collected already!

NOvA Near Detector

- intensive studies going on with near detector data



- reconstructing kinematics in these large ND data sets
- used for data quality and detector performance

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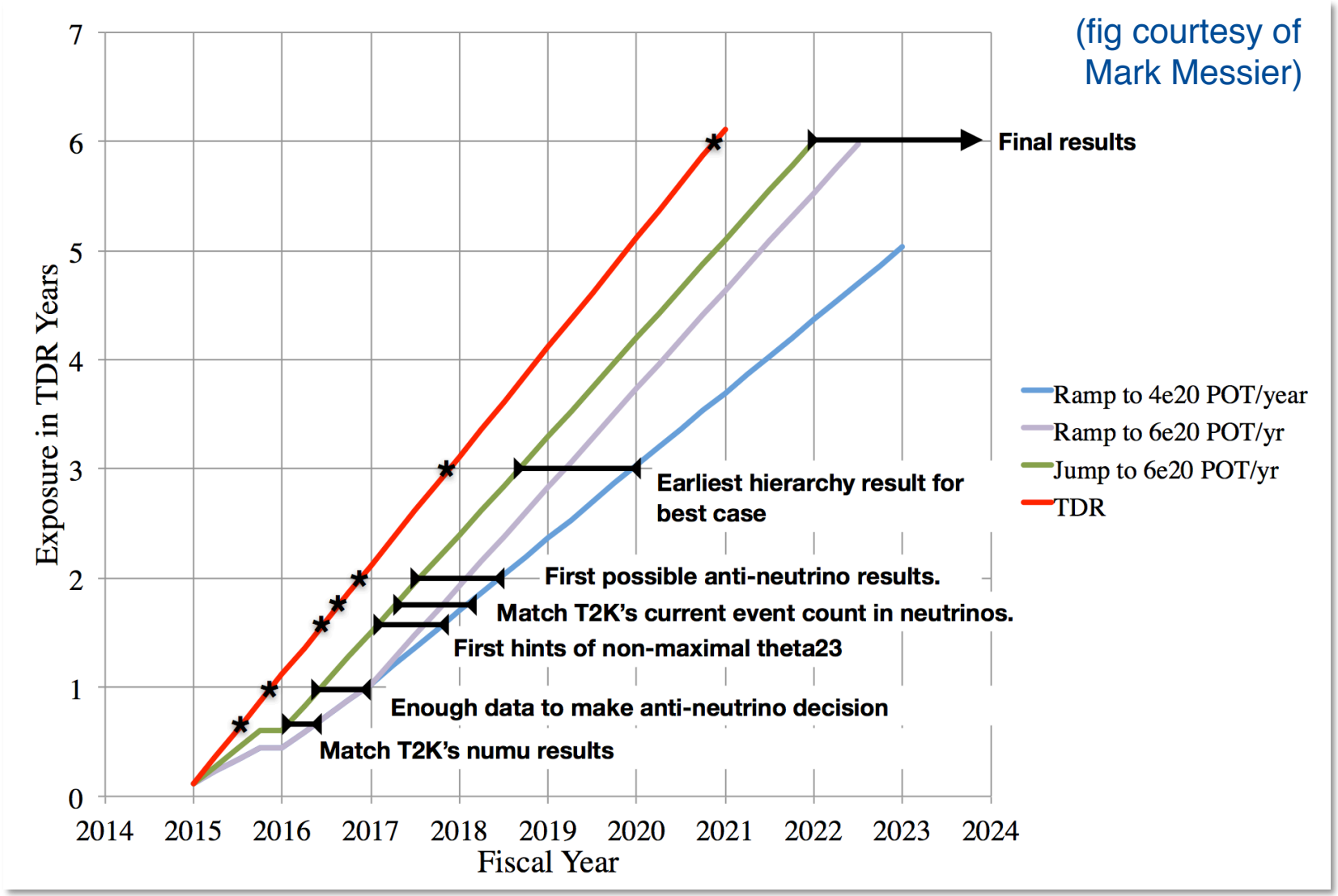
NOvA Plans

- 1/3 of a TDR year worth of POT collected *(TDR year = 6E20 POT, 14 kton)*
- plan is to release first ν_μ and ν_e results by summer
  - *$\nu_\mu \rightarrow \nu_e$: 5.6 events on a background of 2.8 events in neutrino mode*
- goal is to hit peak operations of 400 kW this year; reaching 700 kW operations in the Main Injector in 2016
  (session on proton economics, Wed 2:15, Black Hole)
- NOvA should > double its current data set by mid-2016
  - *$\nu_\mu \rightarrow \nu_e$: 16.6 events on a background of 7.6 events in neutrino mode*
- will likely stay in neutrino mode until 2016; should have enough statistics at that time to make a decision about whether or not to switch to antineutrino running
  - *depends on comparison to T2K and beam power*

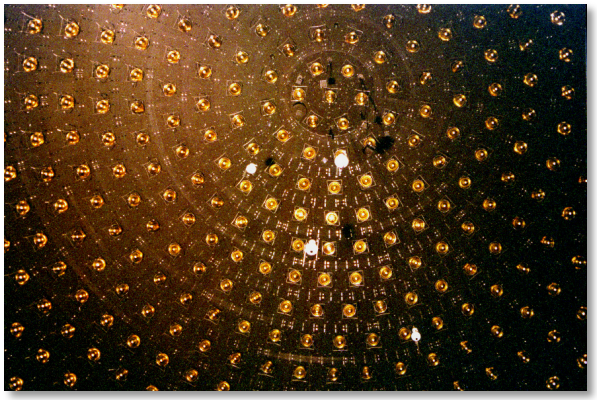
Projected Physics Milestones for NOvA



Searching for Sterile Neutrinos

MiniBooNE

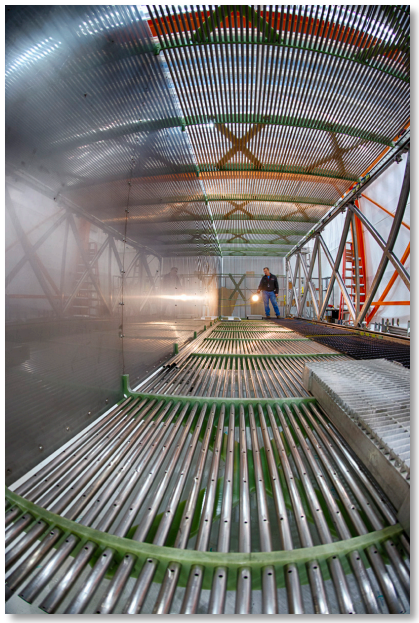
first accelerator-based DIF scrutiny of LSND



short-baseline neutrino experiments

MicroBooNE

examination of MiniBooNE low energy excess

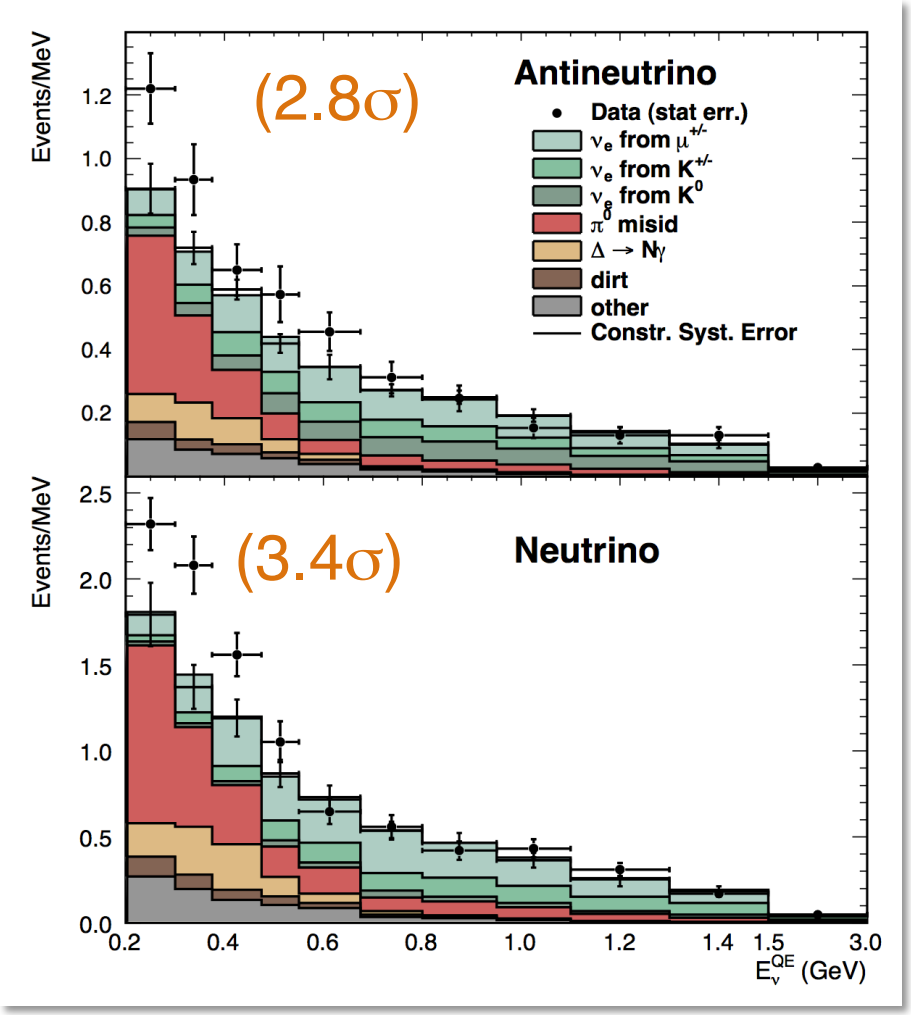


SBN

significantly expanded sterile ν reach with multiple LAr TPCs

(Peter Wilson's talk)

MiniBooNE



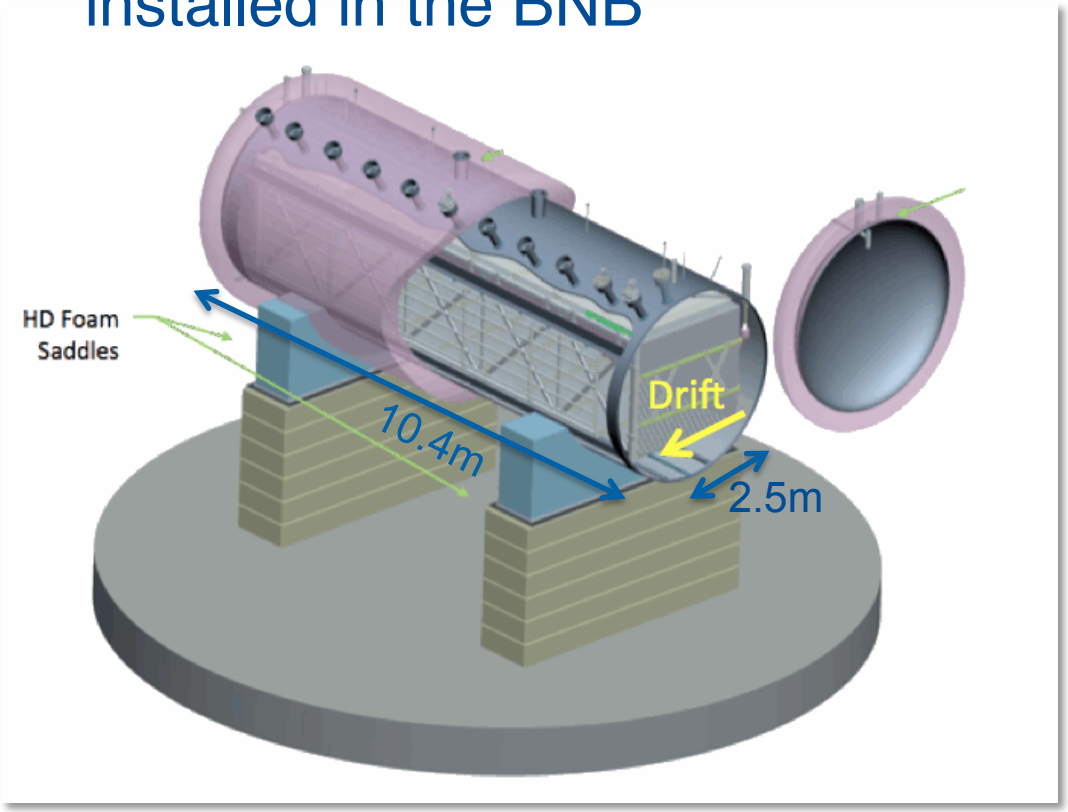
Aguilar-Arevalo, PRL 110, 161801 (2013)

- published its final $\nu_\mu \rightarrow \nu_e$ oscillation results
  - *6.46E20 POT in ν mode*
  - *11.3E20 POT in anti-ν mode*
- observe an excess of low energy events in both modes
- source of excess is still unknown
  - e^-
  - γ

→ MicroBooNE!

MicroBooNE

- 170 ton LAr TPC that is now installed in the BNB



- MicroBooNE will also play an important role in the SBN program

- physics goals:
  - *address MiniBooNE low energy excess*
  - *make 1st low energy neutrino cross section measurements on Ar*
- technical advancements:
  - *argon fill without evacuation (1st demonstrated in LAPD)*
  - *cold front-end electronics*
  - *long drift (2.5m)*
  - *near surface operation*
  - *automated reconstruction*

MicroBooNE

- a lot has happened since the last review …
  - *spring 2014: 1st phase of cryo system exercised*
  - *June 2014: detector moved to LArTF*
  - *Dec 2014: CD-4 granted*
- we are now commissioning
- platform and pit level of LArTF were classified as ODH1 status last week
- filling with argon this spring

(working with ND on a detailed cryo commissioning schedule)

MicroBooNE

- extremely fortunate to have a lot of students & postdocs who are fully participating in (and leading) detector commissioning activities and preparing for 1st data with this new device

S. Gollapinni (KSU), D. Caratelli (Columbia), D. Kaleko (Columbia)

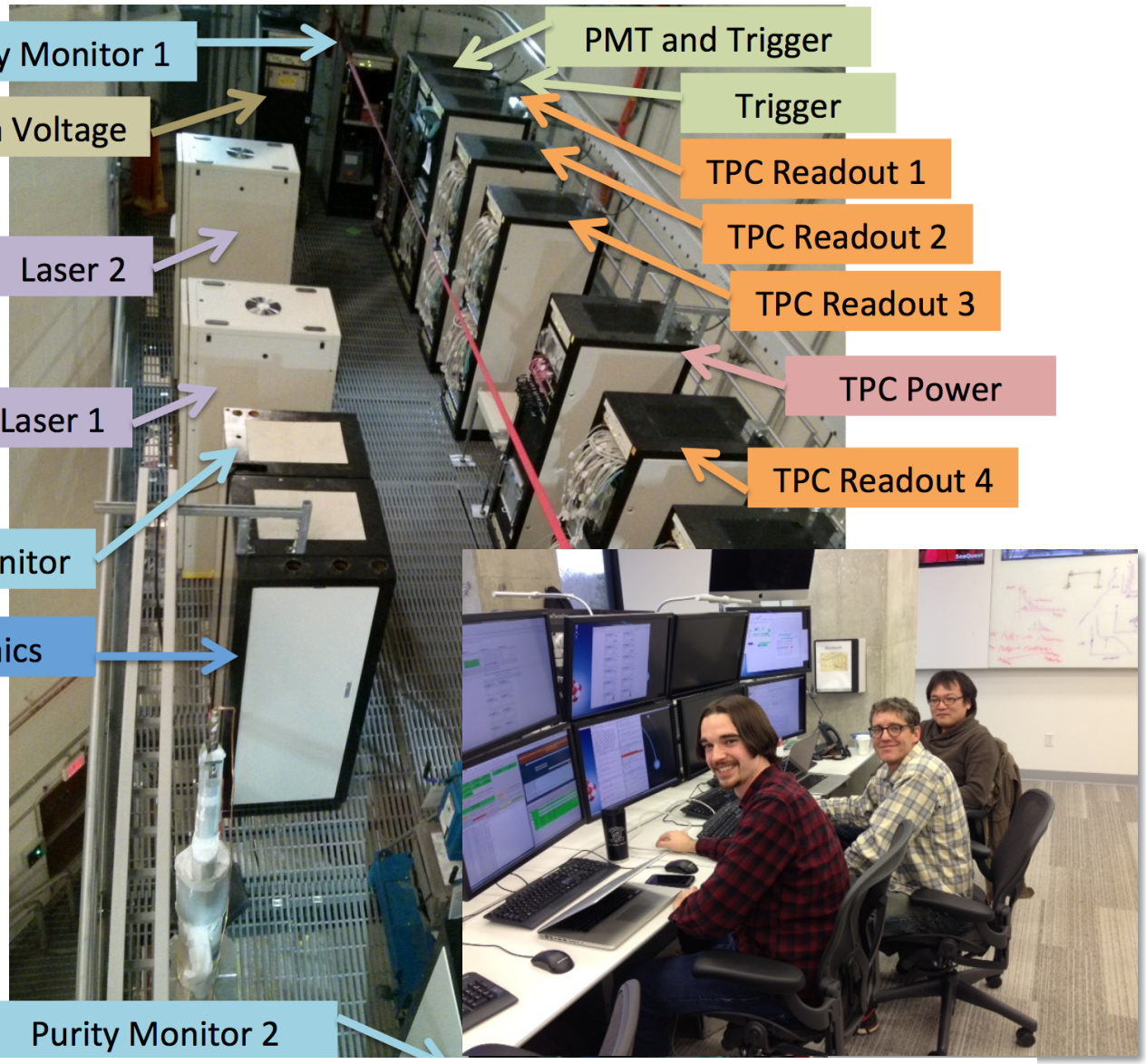
A. Schukraft (FNAL)

M. Mooney (BNL), J. Joshi (BNL), Y. Li (BNL)

- MicroBooNE commissioners: Bruce Baller (FNAL), Matt Toups (MIT)

MicroBooNE

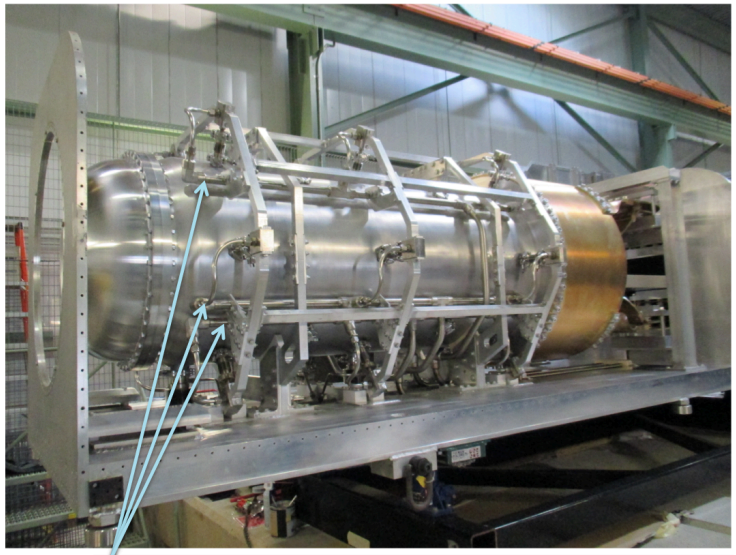
- we are reading out the detector!
- have readout all 9 TPC crates + PMT crate in ROC-W
- are exercising the DAQ & slow controls
- offline review Feb 23-24, 2015

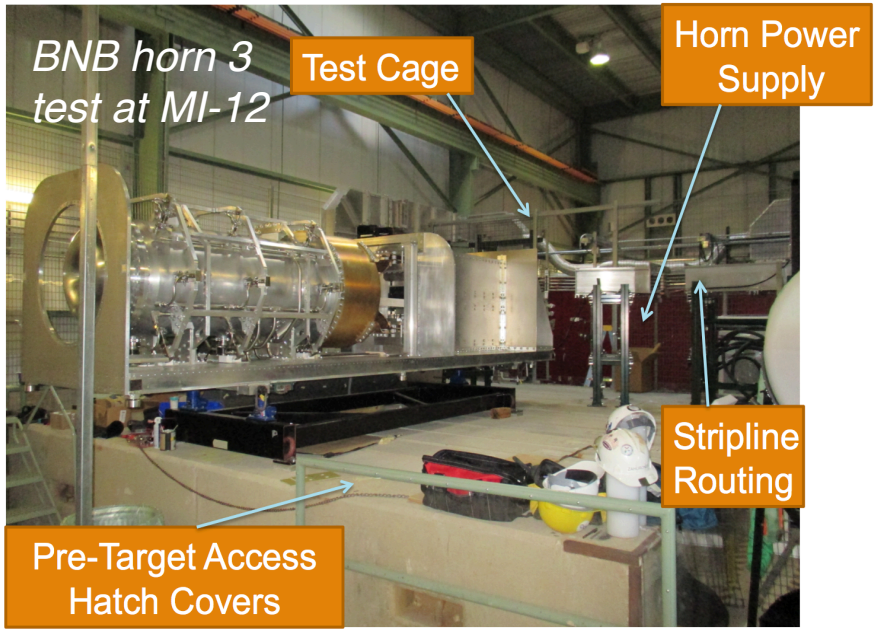


Wes Ketchum (LANL), Eric Church (FNAL), Kazu Terao (Columbia) in ROC-W

Replacing the BNB Horn

- horn 2 + target had been in service since Oct 2004, pulsed >400M times
  - *in Nov, 2 of the 4 operational water headers became clogged & efforts to unclog them were unsuccessful*
    → work is underway to replace horn
- getting excellent support from AD
- BNB beam should be ready the week of April 7th
  (+2-4 weeks if support adjusters also need to be replaced)
- μB is approved to run MiniBooNE to provide a ν rate verification



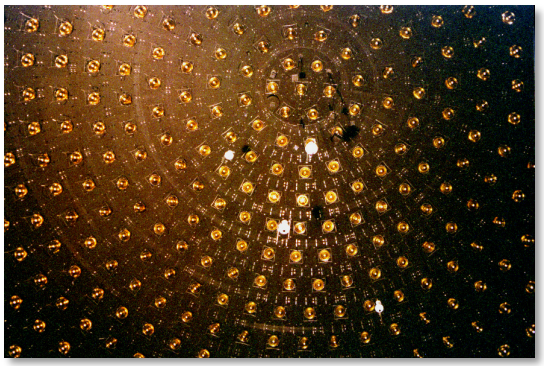


Understanding How Neutrinos Interact with Nuclei

short-baseline
neutrino experiments

MiniBooNE

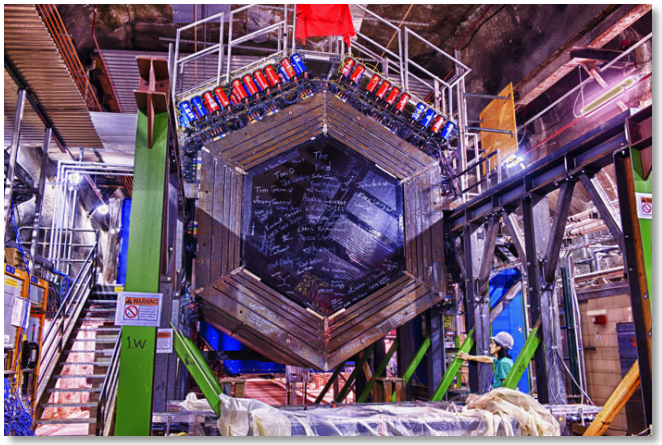
ground-breaking ν cross sections



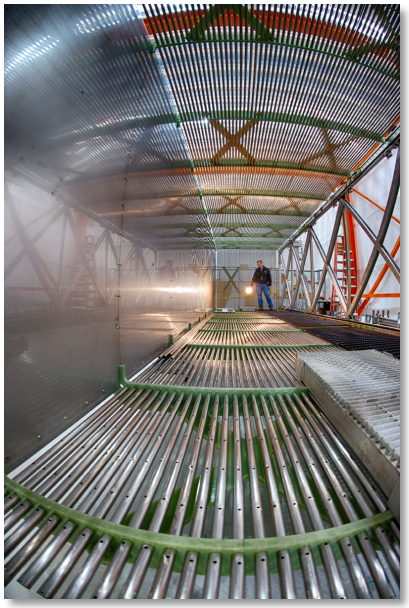
(BNB)

MINERvA

multiple nuclear targets,
extended energy reach



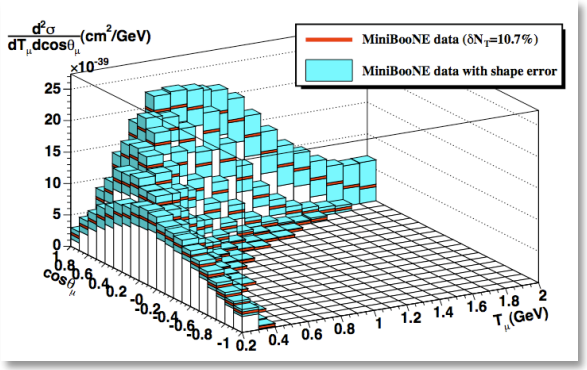
(NuMI)



MicroBooNE

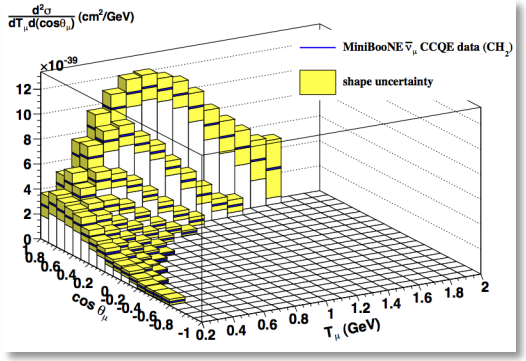
cross sections
on argon

MiniBooNE Cross Section Program



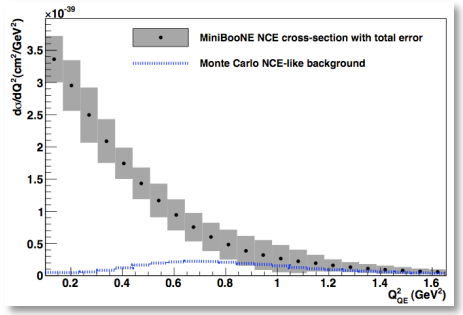
ν quasi-elastic scattering

- Phys. Rev. Lett. 100, 032301 (2008)
- Phys. Rev. D81, 092005 (2010)



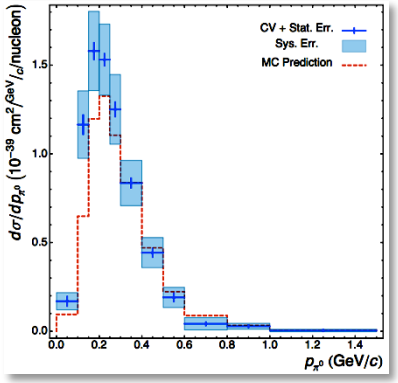
$\bar{\nu}$ quasi-elastic scattering

- Phys. Rev. D84, 072005 (2011)
- Phys. Rev. D88, 032001 (2013)



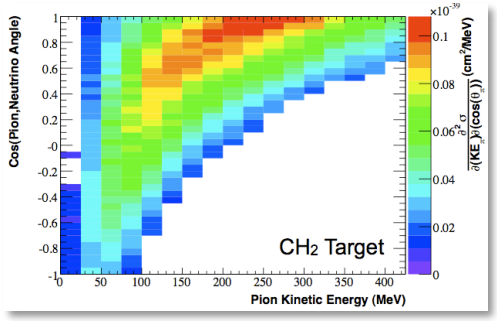
ν and $\bar{\nu}$ NC elastic scattering

-Phys. Rev. D82, 902005 (2010)
- Phys. Rev. D91, 012004 (2015)



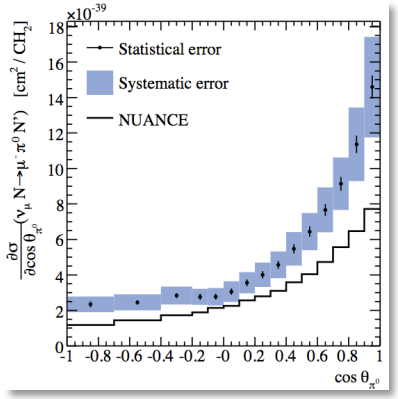
NC π^0 production

- Phys. Lett. B664, 41 (2008)
- Phys. Rev. D81, 013005 (2010)



CC π^+ production

- Phys. Rev. Lett. 103, 081801 (2009)
- Phys. Rev. D83, 052007 (2011)

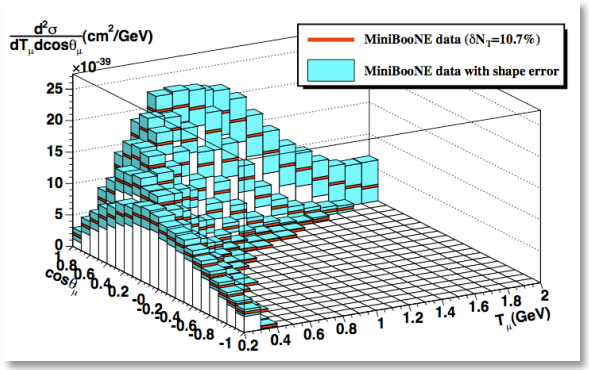


CC π^0 production

- Phys. Rev. D83, 052009 (2011)

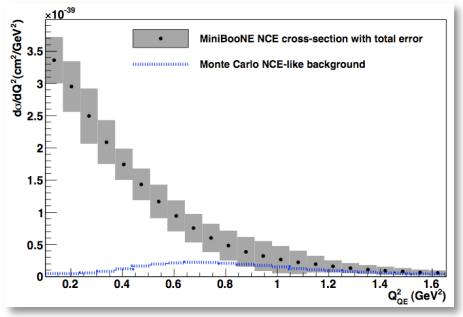
- 11 σ_ν papers, have >850 citations (2008-2014)

MiniBooNE Cross Section Program



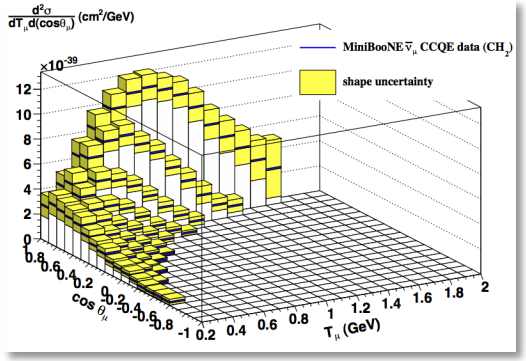
ν quasi-elastic scattering

- Phys. Rev. Lett. 100, 032301 (2008)
- Phys. Rev. D81, 092005 (2010)



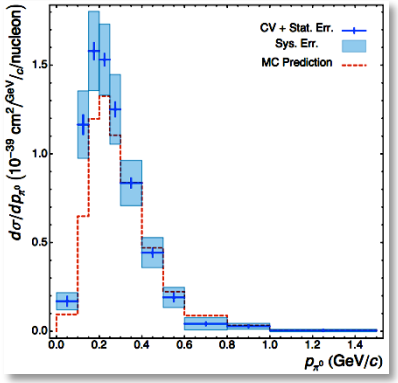
ν and $\bar{\nu}$ NC elastic scatter

-Phys. Rev. D82, 902005 (2010)
- Phys. Rev. D91, 012004 (2015)



$\bar{\nu}$ quasi-elastic scattering

- Phys. Rev. D84, 072005 (2011)
- Phys. Rev. D88, 032001 (2013)



NC π^0 production

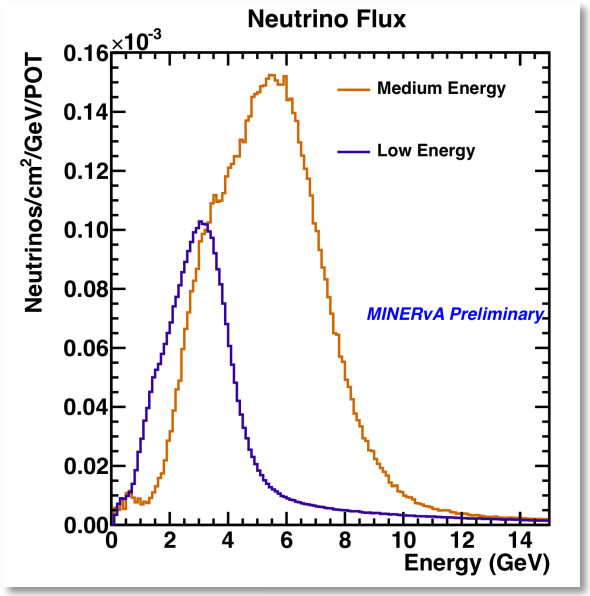
- Phys. Lett. B664, 41 (2008)
- Phys. Rev. D81, 013005 (2010)

- this has a direct effect on oscillation experiments; this physics impacts:
  - # signal, background processes you collect
  - final state particles you observe
  - what you infer for Eν
- e.g., QE scattering σ_ν underpredicted by ~40% at 1 GeV
- this is a big deal

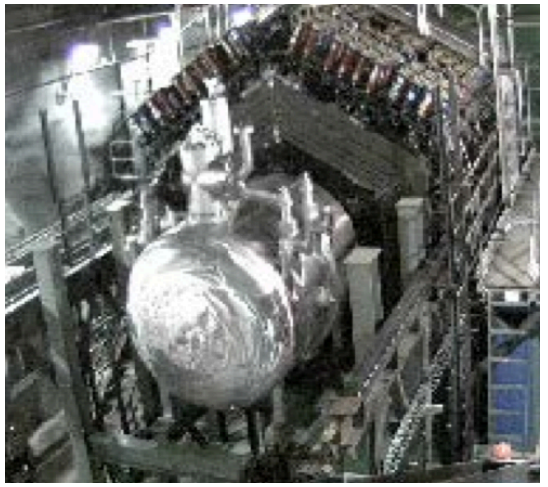
we really don't understand the nuclear effects involved!

MINERvA

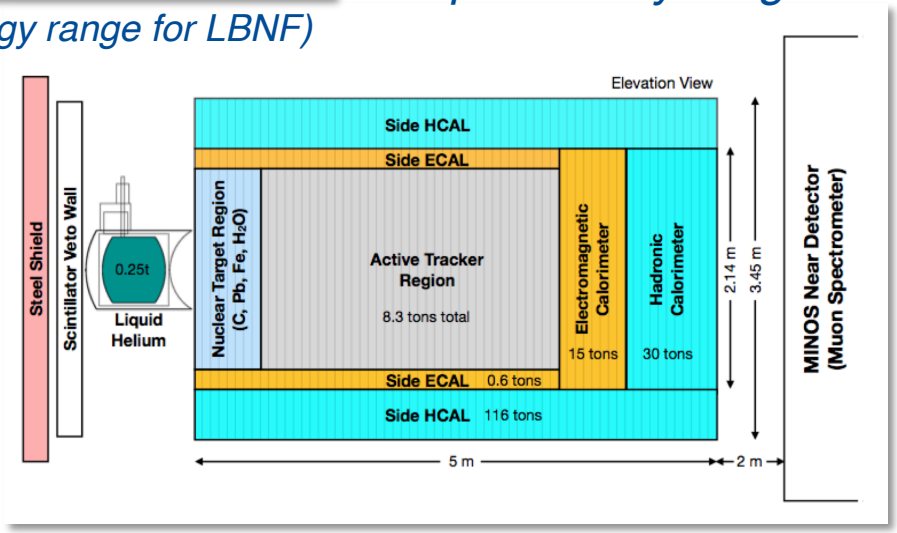
- dedicated ν interaction exp that has been operating since 2010
- producing precision σ_ν measurements on a variety of nuclear targets (He, C, H_2O, Fe, Pb) over a wide range of ν energies (LE, ME)
- upstream nuclear target region + fully active solid scintillator tracking region + MINOS ND as μ spectrometer; >97% uptime



(critical energy range for LBNF)



liquid He cryotarget

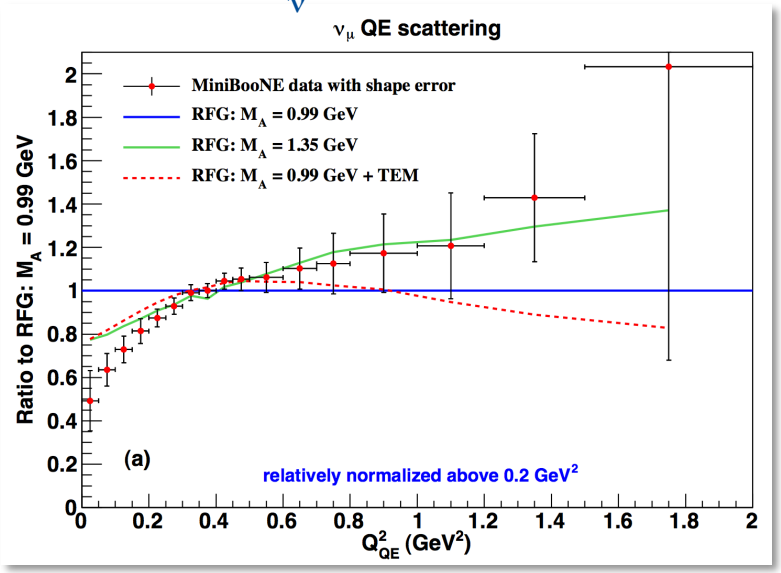


Fermilab

(shows the power of this combined data)

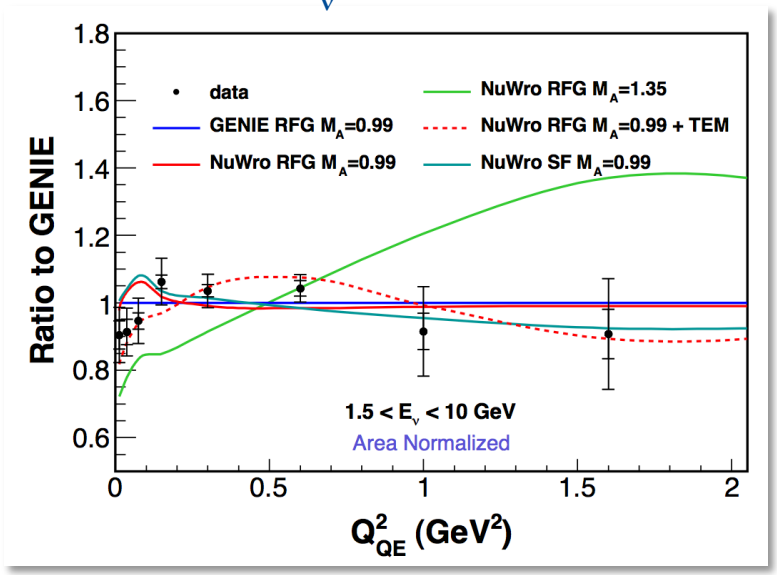
A Nice Example

MiniBooNE ν_μ QE (BNB)
$\langle E_\nu \rangle$= 0.8 GeV



J. Grange, C. Juszczak, J. Sobczyk, GPZ, PRD 89, 073018 (2014)

MINERvA ν_μ QE (NuMI)
$\langle E_\nu \rangle$= 3 GeV



G. Fiorentini et al., PRL 111, 022502 (2013)

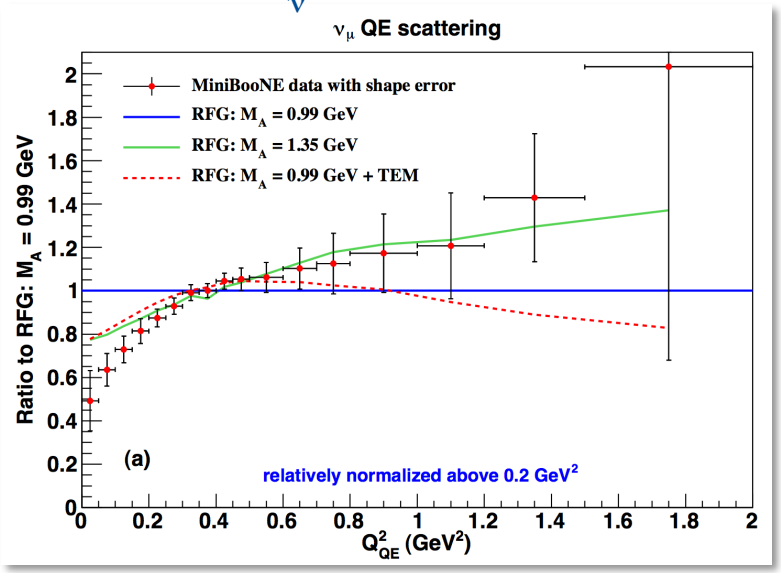
- are we mismodeling the axial form factor or nuclear effects? (or both)
  - *MiniBooNE: both increasing the axial mass and adding nucleon correlations can describe the data*
  - *MINERvA: at higher ν energies, these effects pull apart!*

getting this right is important!

(shows the power of this combined data)

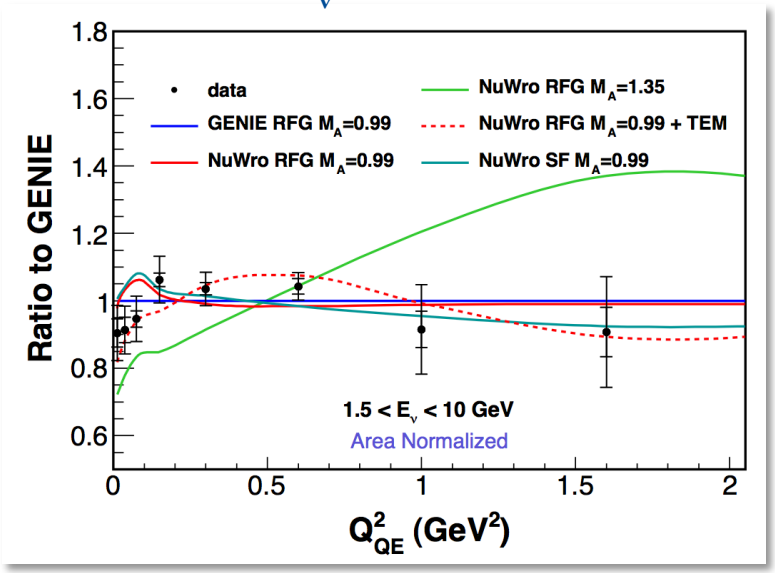
A Nice Example

MiniBooNE ν_μ QE (BNB)
$\langle E_\nu \rangle$= 0.8 GeV



J. Grange, C. Juszczak, J. Sobczyk, GPZ, PRD 89, 073018 (2014)

MINERvA ν_μ QE (NuMI)
$\langle E_\nu \rangle$= 3 GeV



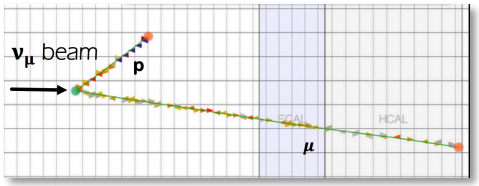
G. Fiorentini et al., PRL 111, 022502 (2013)

- are we mismodeling the axial form factor or nuclear effects? (or both)

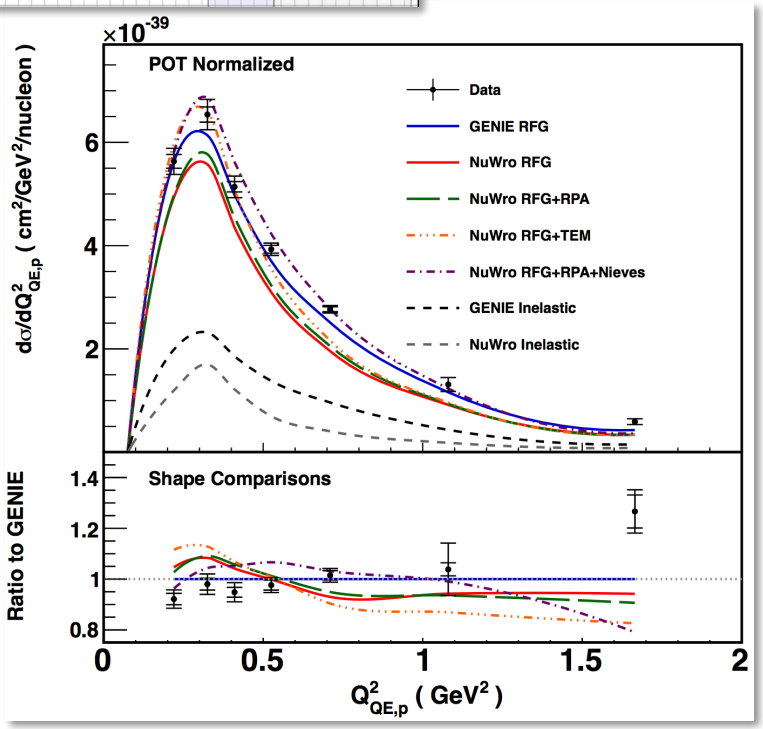
  - Hill (Chicago), Kronfeld (FNAL), Meyer (Chicago) working with MINERvA & MiniBooNE to test a 1st principles calc of the axial form factor using lattice QCD

getting this right is important!

Examining the Hadronic Side



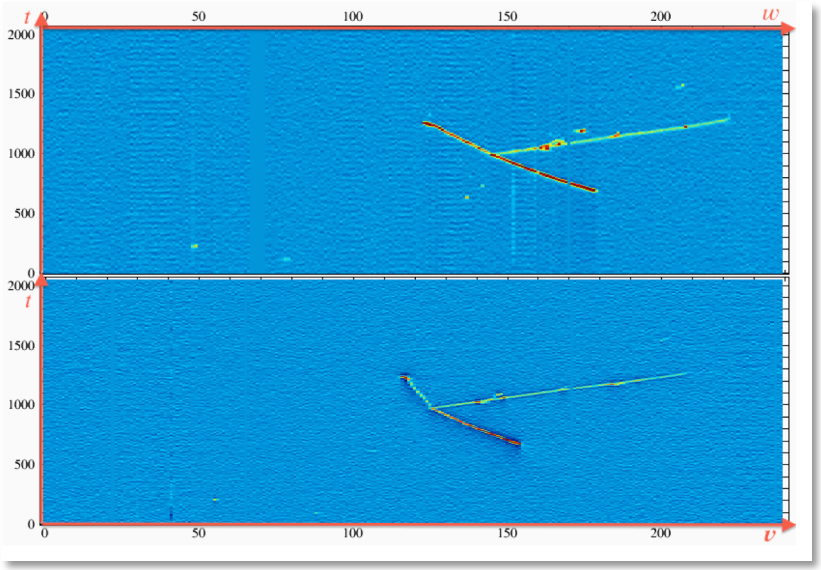
MINERvA:



T. Walton et al., arXiv:1409.4497

- new QE analysis with an identified proton in final state

ArgoNeuT:



R. Acciarri et al., PRD 90, 012008 (2014)

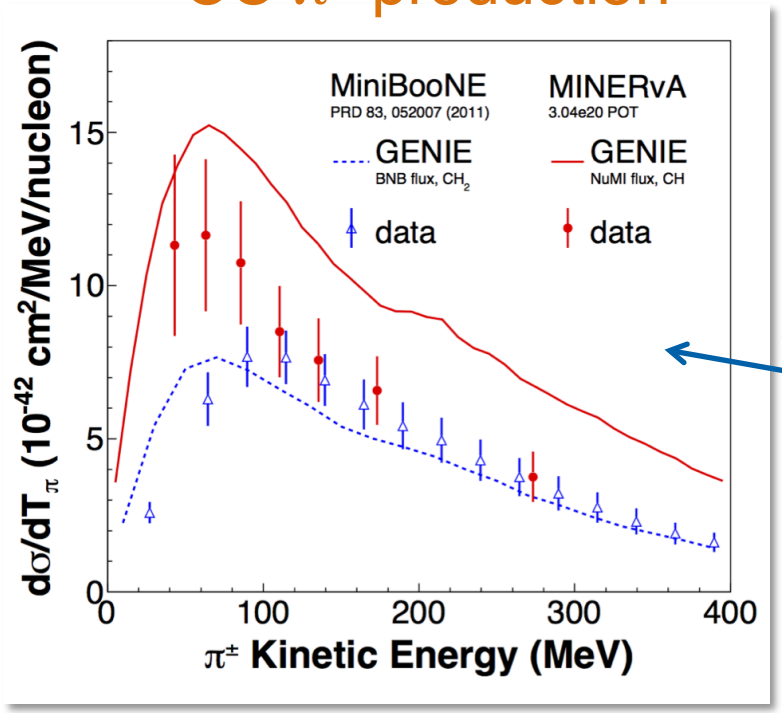
- observation of energetic back-to-back protons a sign of short range correlations

Fermilab

MINERvA

- there are a lot of new results coming out of MINERvA's LE run (5 publications last year!)

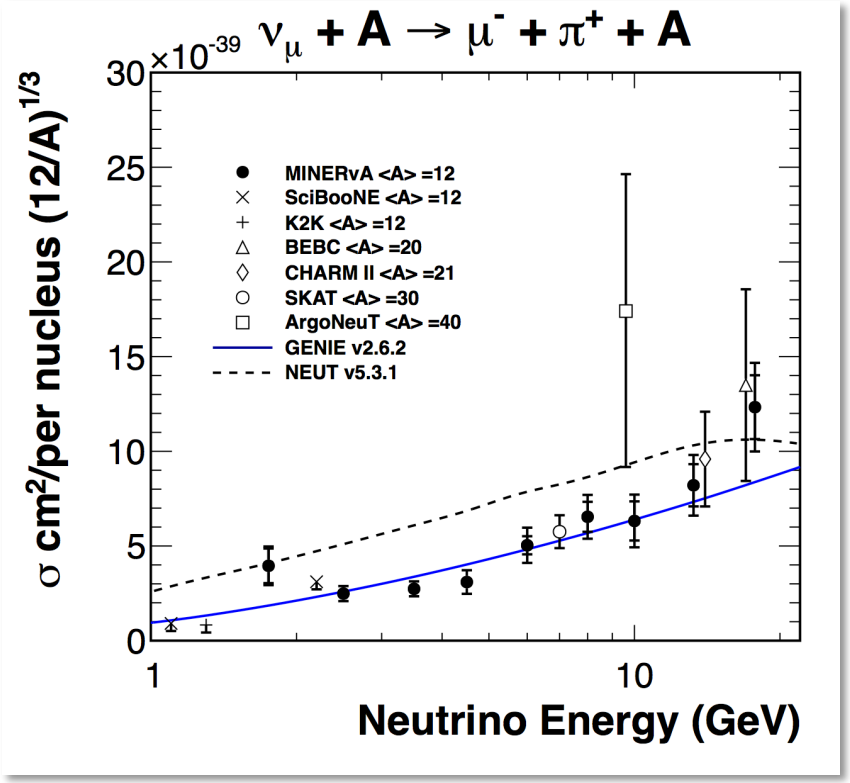
CC π^+ production



(dominant interaction channel in NOvA)

MINERvA: B. Eberly et al., arXiv:1406.6415
MB: A.A. Aguilar-Arevalo, PRD 83, 052007 (2011)

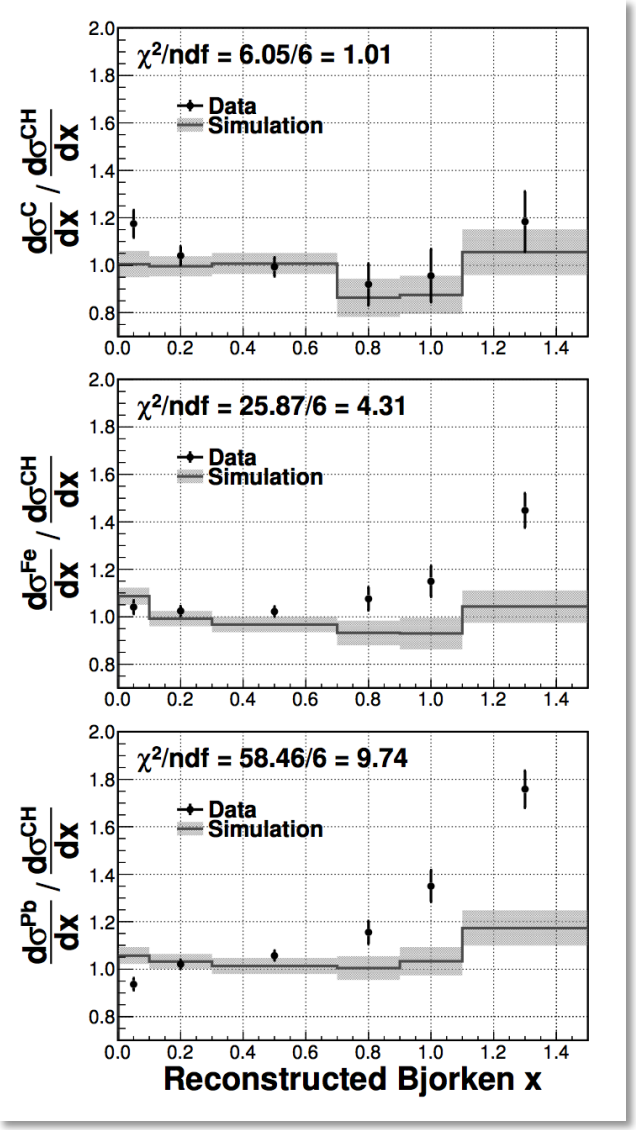
CC coherent π^+ production



MINERvA: A. Higuera, PRL 113, 261802 (2014)
ArgoNeuT: R. Acciarri et al., PRL 113, 261801 (2014)

(this is a capability that MINERvA uniquely has)

MINERvA Nuclear Target Data



C/CH

Fe/CH

Pb/CH

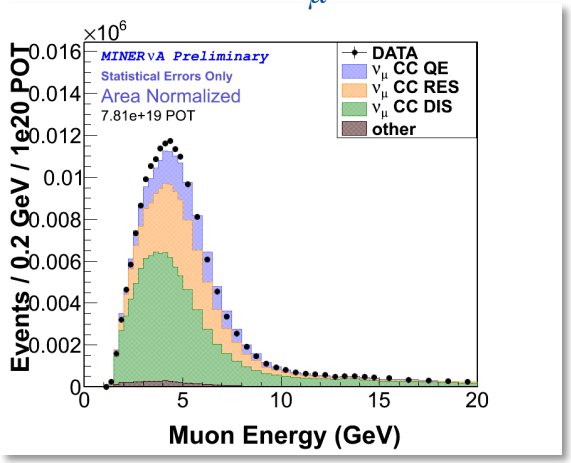
- how are CC interactions modified by the nucleus?
- excess at high x increases with size of the nucleus
- these effects are not reproduced by current neutrino event generators
- MINERvA will also examine this in the ME data with increased statistics

B. Tice et al., PRL 112, 231801 (2014)

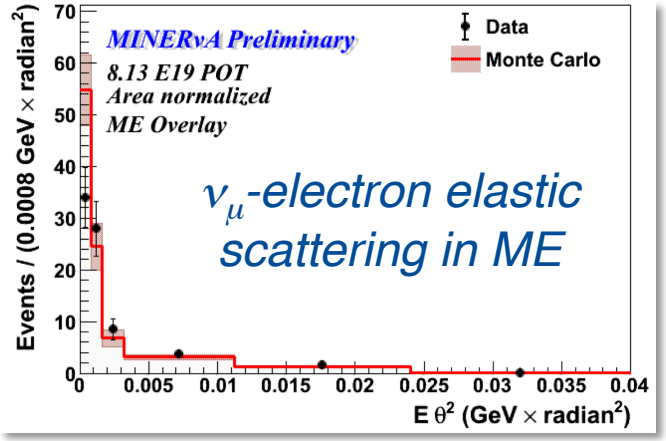
MINERvA in the Medium Energy Beam

- ME running started in Sept 2013
  >1M events written to tape already
- largest physics impact from this data will come from nuclear target ratio measurements (need full statistics)
- in the meantime, MINERvA is measuring exclusive channels;
  this is possible even in high rate/multiplicity environment

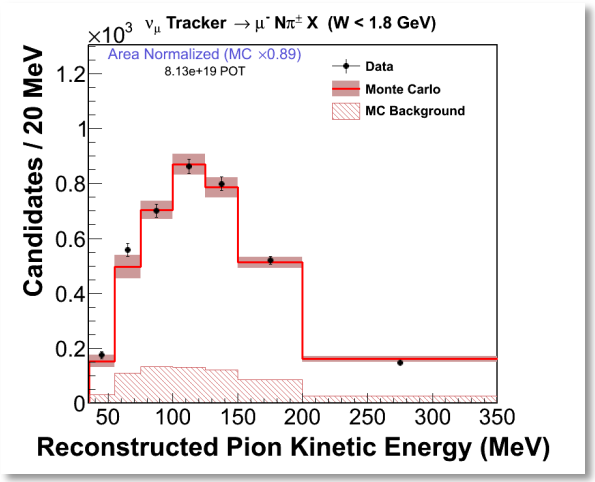
inclusive ν_μ CC in ME



ν_μ-electron elastic scattering in ME



ν_μ CC $\pi^\pm$ production in ME

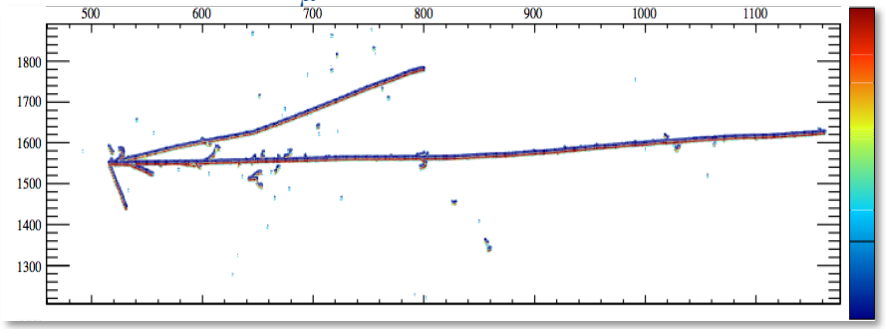


What's Next? ν Interactions in Argon

- neutrino interaction measurements in argon are a direct input to the future long-baseline neutrino program (LBNF)

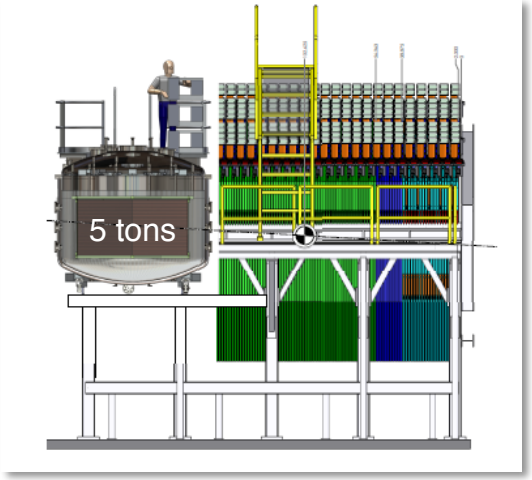
- BNB: 2nd oscillation maximum
  MicroBooNE → LAr1-ND

(simulated ν_μ CC event in MicroBooNE)



- MicroBooNE: ~100k ν_μ CC events
- LAr1-ND: ~3M ν_μ CC events
  (6.6E20 POT)

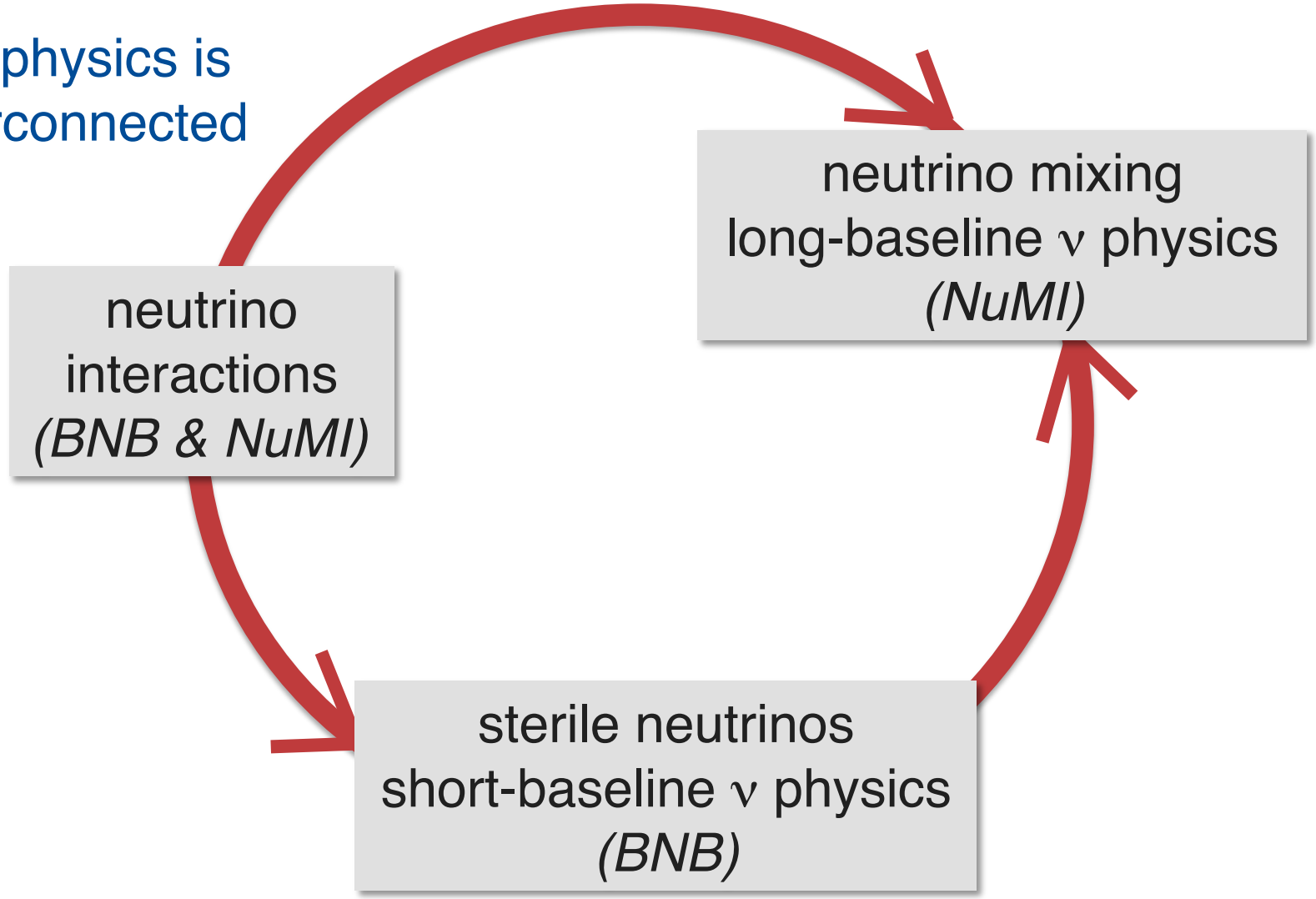
- NuMI: 1st oscillation maximum
  ArgoNeuT → CAPTAIN/NuMI



- ArgoNeuT: ~2k ν_μ CC events
- CAPTAIN: >500k ν_μ CC events
  (6E20 POT)

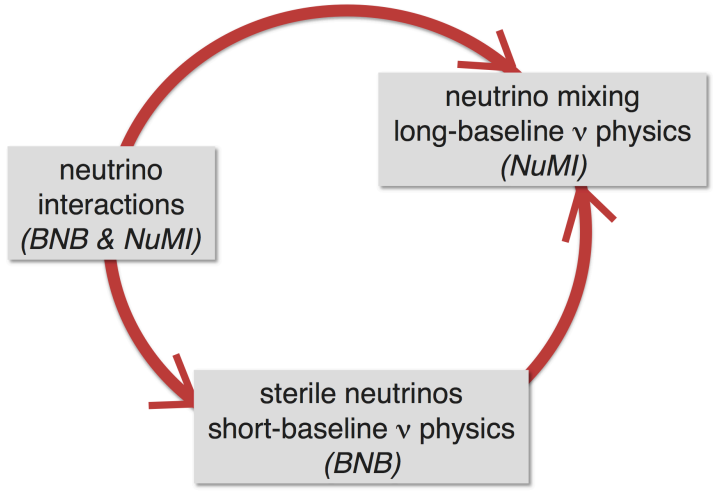
How This All Comes Together

- this physics is interconnected



Summary

- Fermilab hosts a diverse, world leading program in accelerator based ν physics using two intense ν beams:
  - 3 experiments operating in NuMI beam now **(MINOS+, MINERvA, NOvA)**
    → NOvA has been taking data with full 14 kton FD at Ash River!
  - 1 experiment to start operations in the BNB very soon **(MicroBooNE)**
- in particular, this family of experiments is a primary contributor to our understanding of …
  - long baseline ν oscillations
  - short baseline ν oscillations
  - ν-nucleus interactions



- the ν community is doing excellent world class physics here at Fermilab!

Scientific and Technical Publications (2013-2015)

ArgoNeuT

R. Acciarri *et al.*, "First Measurement of Neutrino and Antineutrino Coherent Charged Pion Production on Argon", Phys. Rev. Lett. 113, 261801 (2014).

R. Acciarri *et al.*, "The Detection of Back-to-Back Proton Pairs in Charged Current Neutrino Interactions with the ArgoNeuT Detector in the NuMI Low Energy Beam Line", Phys. Rev. D90, 012008 (2014).

R. Acciarri *et al.*, "Measurements of Inclusive Muon Neutrino and Antineutrino Charged Current Differential Cross Sections on Argon in the NuMI Antineutrino Beam", Phys. Rev. D89, 112003 (2014).

R. Acciarri *et al.*, "A Study of Electron Recombination Using Highly Ionizing Particles in the ArgoNeuT Liquid Argon TPC", JINST 8, P08005 (2013).

MicroBooNE (by MicroBooNE Collaborators)

L.F. Bagby *et al.*, "Breakdown Voltage of Metal Oxide Resistors in Liquid Argon", JINST 9, T11004 (2014).

R. Acciarri *et al.*, "Liquid Argon Dielectric Breakdown Studies with the MicroBooNE Purification System", JINST 9, P11001 (2014).

J. Asaadi et *al.*, "Testing of High Voltage Surge Protection Devices for Use in Liquid Argon PC Detectors", JINST 9, P09002 (2014).

T. Briese *et al.*, "Testing of Cryogenic Photomultiplier Tubes for the MicroBooNE Experiment", JINST 8, T07005 (2013).

B.J.P. Jones *et al.*, "Photodegradation Mechanisms of Tetraphenyl Butadiene Coatings for Liquid Argon Detectors", JINST 8, P01013 (2013).

B.J.P. Jones *et al.*, "A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level", JINST 8, P07011 (2013).

MiniBooNE

A.A. Aguilar-Arevalo *et al.*, "Meaurement of the Antineutrino Neutral Current Elastic Differential Cross Section", Phys. Rev. D91, 012004 (2015).

A.A. Aguilar-Arevalo *et al.* "First Measurement of the Muon Antineutrino Double Differential Charged Current Quasi Elastic Cross Section", Phys. Rev. D88, 032001 (2013).

A.A. Aguilar-Arevalo *et al.*, "Improved Search for $\nu_\mu \rightarrow \nu_e$ Oscillations in the MiniBooNE Experiment", Phys. Rev. Lett. 110, 161801 (2013).

MINERvA

T. Walton *et al.*, "Measurement of Muon Plus Proton Final States in ν_μ Interactions on Hydrocarbon at $\langle E_\nu \rangle$ = 4.2 GeV", arXiv:1409.4497 [hep-ex].

A. Higuera *et al.*, "Measurement of Coherent $\pi^{+/-}$ Production in Neutrino and Antineutrino Beams on Carbon from E_ν=1.5-20 GeV", Phys. Rev. Lett. 113, 261802 (2014).

B. Eberly *et al.*, "Charged Pion Production in Muon Neutrino Interactios on Hydrocarbon at $\langle E_\nu \rangle$=4.0 GeV", arXiv:1406.6415 [hep-ex].

B.G. Tice *et al.*, "Measurement of Ratios of ν_μ Charged Current Cross Sections on C, Fe, and Pb to CH at Neutrino Energies 2 – 20 GeV", Phys. Rev. Lett. 112, 231801 (2014).

L. Aliaga *et al.*, "Design, Calibration, and Performance of the MINERvA Detector", NIM A743, 130 (2014).

G.A. Fiorentini *et al.*, "Measurement of Muon Neutrino Quasi-Elastic Scattering on Hydrocarbon at $E_\nu \sim 3.5$ GeV", Phys. Rev. Lett. 111, 022502 (2013).

L. Fields *et al.*, "Measurement of Muon Antineutrino Quasi-Elastic Scattering on Hydrocarbon at $E_\nu \sim 3.5$ GeV", Phys. Rev. Lett. 111, 022501 (2013).

MINOS/MINOS+

P. Adamson *et al.*, "Combined Analysis of ν_μ Disappearance and $\nu_\mu \rightarrow \nu_e$ Appearance in MINOS using Accelerator and Atmospheric Neutrinos", Phys. Rev. Lett. 112, 191801 (2014).

P. Adamson *et al.*, "Study of Quasi-elastic Scattering Using Charged Current ν_μ-Iron Interactions in the MINOS Near Detector", Phys. Rev. D91, 012005 (2014).

P. Adamson *et al.*, "Observation of Muon Intensity Variations by Season with the MINOS Near Detector", Phys. Rev. D90, 012010 (2014).

P. Adamson *et al.*, "Search for Flavor Changing Non-Standard Neutrino Interactions by MINOS", Phys. Rev. D88, 072011 (2013).

P. Adamson *et al.*, "Measurement of Neutrino and Antineutrino Oscillations Using Beam and Atmospheric Data in MINOS", Phys. Rev. Lett. 110, 251801 (2013).

P. Adamson *et al.*, "Electron Neutrino and Antineutrino Appearance in the Full MINOS Data Sample", Phys. Rev. Lett. 110, 171801 (2013).

P. Adamson *et al.*, "Comparisons of Annual Modulations in MINOS with the Event Rate Modulation in CoGeNT", Phys. Rev. D87, 032005 (2013).

Backups

Scientific Staff on NOvA

EC = Executive Committee
FCPA = Fermilab Center for Particle Astrophysics
IB = Institutional Board
RA = Research Associate

Phil Adamson
(AD, recycler, slip-stacking)

Sam Childress
(AD, led design of NuMI proton beam, co-coordinator for NuMI/NOvA beam ops)

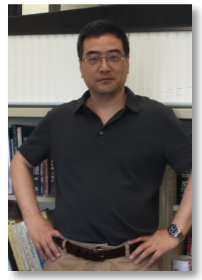
John Cooper
(project manager)

Paul Derwent
(AD, Associate Project Manager, intensity improvements)

Craig Group
(joint appointment, U Virginia, offline computing coordinator)

Ioanis Kourbanis
(AD, Main Injector, beam power improvements)

Pat Lukens
(L2 far detector assembly; now FCPA)



Ting Miao
(L2 near detector assembly; now SBN near detector manager)

Andrew Norman
(SCD, trigger coordinator, DAQ ops, EC, SCD liaison)

Brian Rebel
(calibration co-convener, EC)

Rob Plunkett
(retrofit coordintor, ops manager)

Peter Shanahan
(DAQ ops manager, ν interaction co-convener, EC, IB rep)

Rick Tesarek
(deputy project manager, far detector commissioning coordinator)

Jaroslav Zalesak
(International Fellow, run coordinator)

Bob Zwaska
(AD, beam simulations & data working group)

+ postdocs →

Fermilab

Scientific Staff on NOvA

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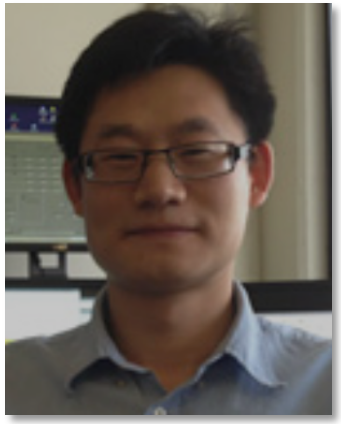
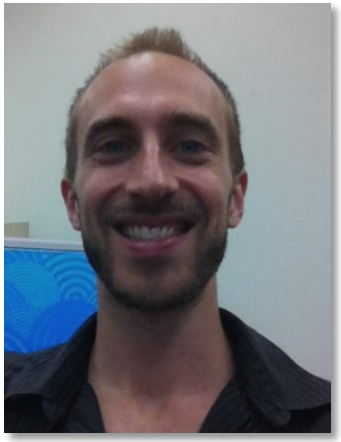
FCPA = Fermilab Center for Particle Astrophysics
IB = Institutional Board
RA = Research Associate

Giulia Brunetti
(RA, beam monitoring and optimization, near detector physics)



Xuebing Bu
(RA, DAQ ops, L3 near detector assembly QA/QC, near detector physics)



Keith Matera
(RA, recent hire, APDs, DAQ ops, near/far ratios)

Pengfei Ding
(SCD, RA, DAQ ops, electron ID)

- two RAs landed new jobs last year: **Denis Perevalov** (data scientist, Allstate), **Mat Muether** (Wichita State University faculty)
- interviewing for 2 new Associate Scientists

Scientific Staff on MicroBooNE

SCD = Scientific Computing Division
AD = Accelerator Division
BNB = Booster Neutrino Beam
ECRA = Early Career Research Award

Bruce Baller
(co-commissioner, LAr reconstruction)

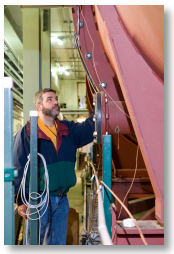
Flavio Cavanna
(guest scientist, σ_v co-convener, LArIAT co-spoke)

Herb Greenlee
(analysis tools co-convener)

Cat James
(deputy project manager)

Hans Jostlein
(emeritus, HV feed-throughs)

Mike Kirby
(SCD, data flow convener)

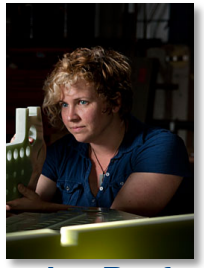


Tom Kobilarcik
(AD, BNB expert)

Byron Lundberg
(beam, HV breakdown)

Alberto Marchionni
(beam)

Brian Rebel
(L2 cryogenics, argon procurement)



Jen Raaf
(L2 TPC assembly, LArIAT co-spoke)

Gina Rameika
(project manager)

Ornella Palamara
(guest scientist, LAr1-ND co-spoke)

Zarko Pavlovic
(beam co-convener)

Stephen Pordes
(material test stand, PAB coordinator)

Mitch Soderberg
(joint appointment Syracuse, σ_v co-convener)

Tingjun Yang
(former reconstruction co-convener, CC inclusive)

Steve Wolbers
(SCD, computing sector liaison)

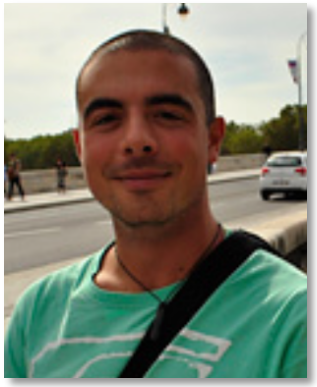
Sam Zeller
(co-spokesperson, DOE ECRA)

+ postdocs ⟶

Fermilab

RA = Research Associate
ND = Neutrino Division

Scientific Staff on MicroBooNE



Roberto Acciarri
(RA thru Zeller's ECRA, argon fill, LArIAT, e^- reconstruction)

Ben Carls
(RA, cryogenics, calibration co-convener, clustering, CC inclusive)

Sarah Lockwitz
(RA, LDRD award, HV feed-throughs, cosmics, CC inclusive)

Anne Schukraft
(RA thru Zeller's ECRA, cable czar, calorimetry, QE, ND seminar co-coordinator)

Scientific Staff on MINERvA

EC = Executive Committee
RA = Research Associate
ND = Neutrino Division

Leo Ballantoni
(MINERvA medium energy testbeam coordinator)

Debbie Harris
(co-spokesperson)

Jorge Morfin
(NuSTEC, international student on-site advisor, EC)

Laza Rakotondravohitra
(student International Fellow, nuclear target ratio analysis)

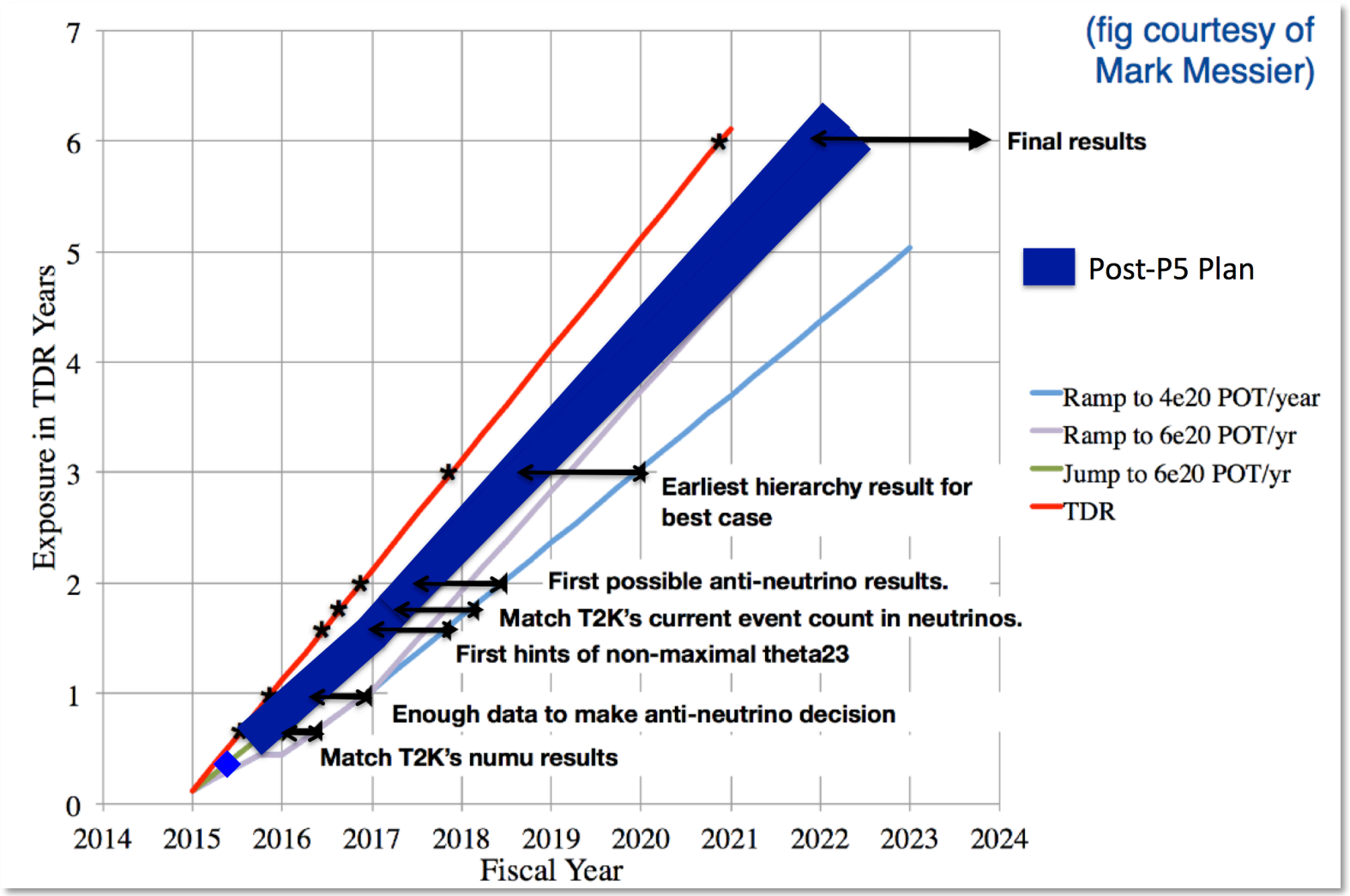
Minerba Betancourt
(RA, analysis subgroup convener, QE, ND seminar co-coordinator)

Joseph Kiveni
(RA, new to MINERvA)

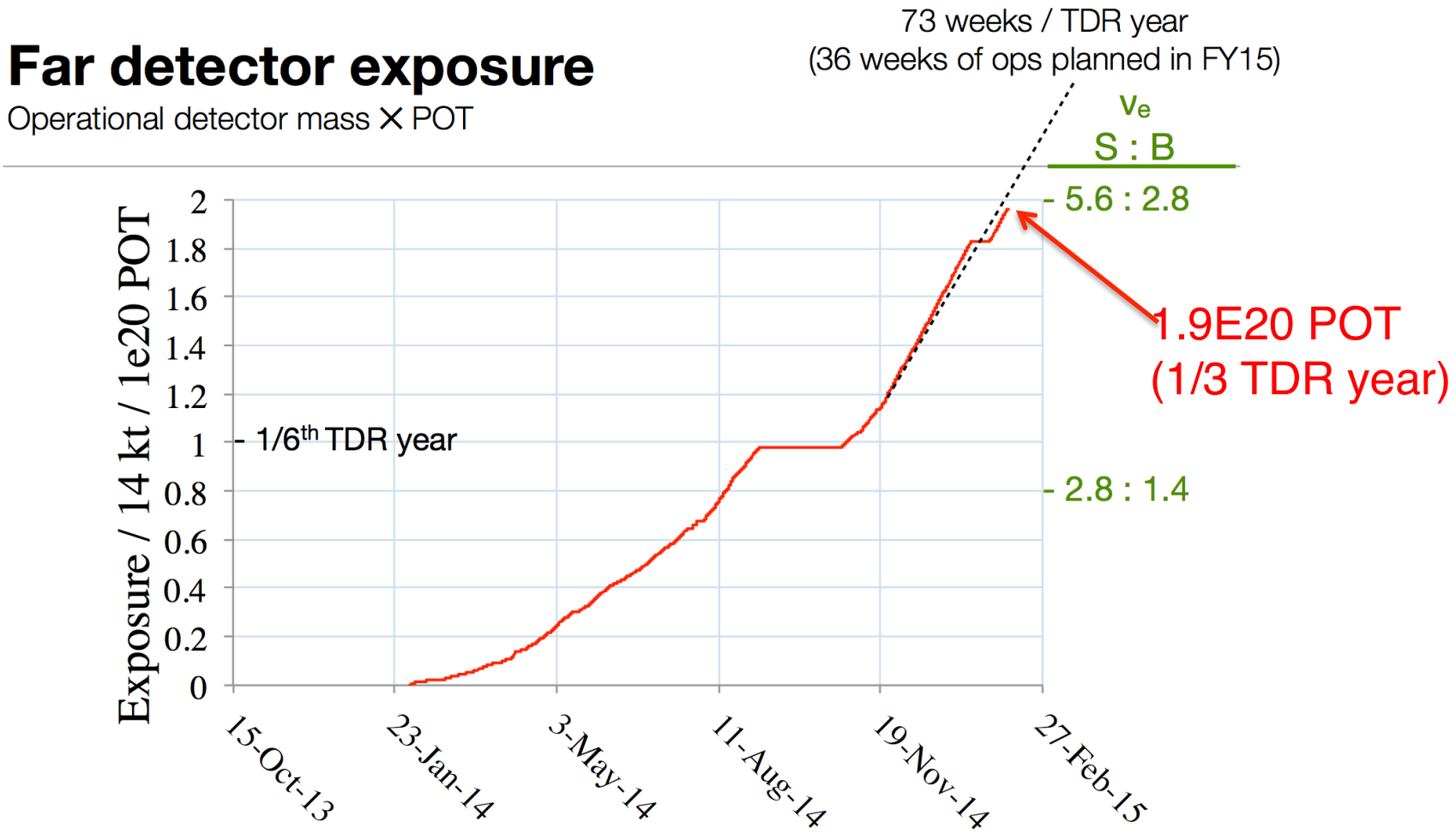
Jyostna Osta
(RA, reconstruction, QE, Saturday AM physics)

(1 TDR year = 6E20 POT, 14 kton)

NOvA Projections

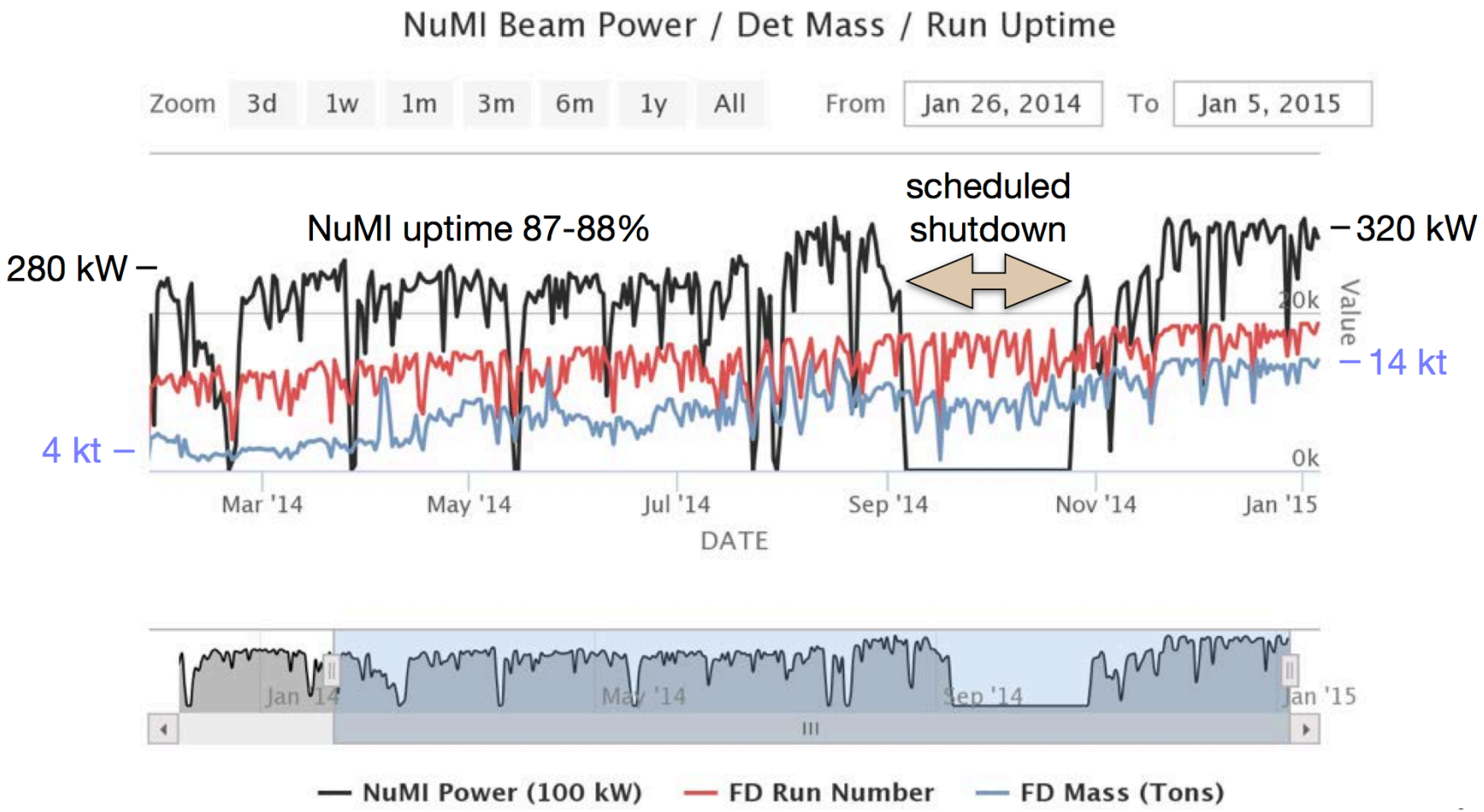


NOvA Far Detector Exposure

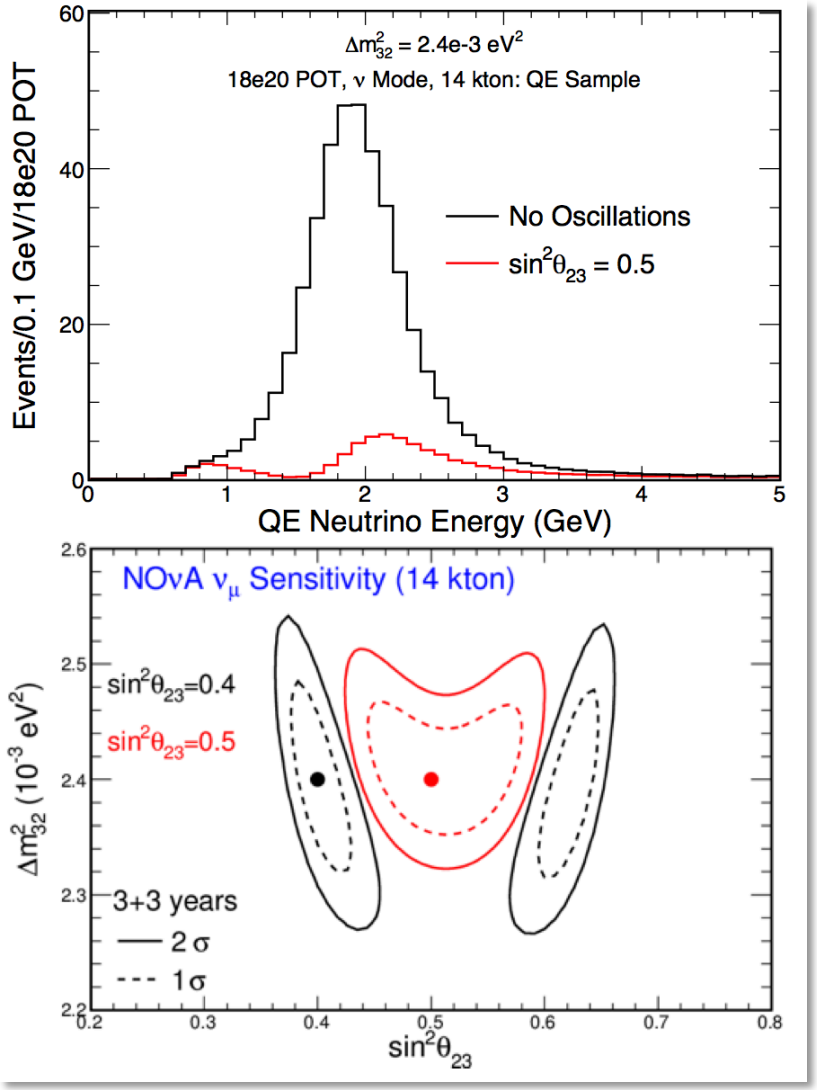


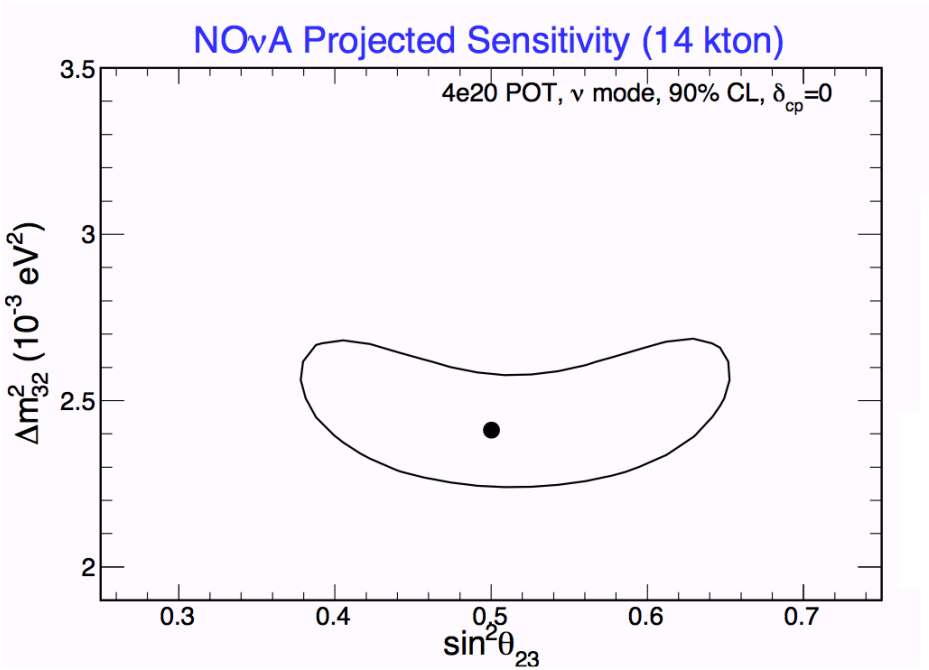
(1 TDR year = 6E20 POT, 14 kton)

2014-2015 NOvA Run Summary



NOvA $\nu_\mu \rightarrow \nu_\mu$





With 4E20 POT (2/3 TDR year) NOvA catches up to current experiments

(NOvA simulation)

Fermilab Neutrino Beam Delivery

Neutrino beam delivery over the last 15 years (POT used for physics):

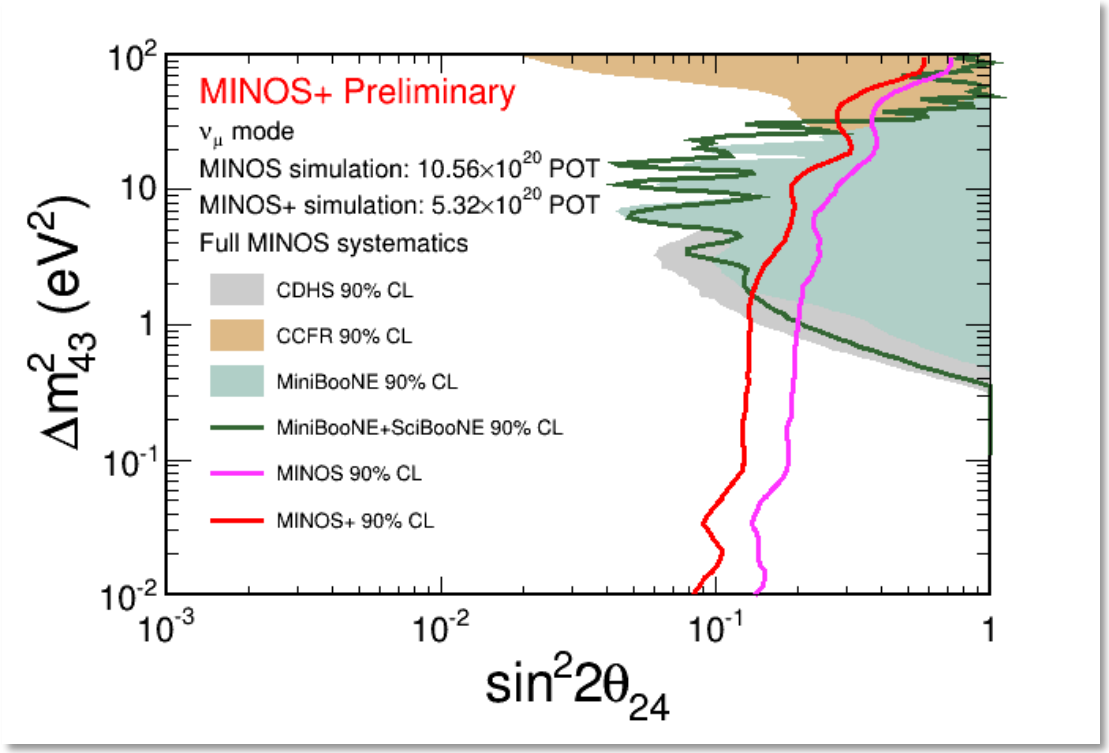
	protons on target ($\times 10^{20}$)	
K2K	0.92	*(hep-ex/0606032)*
T2K	6.57	*(Jan 2010-May 2013, arXiv:1403.1523)*
OPERA/ICARUS	1.80	*(2008-2012 physics run, arXiv:1407.3513)*
	9.29 = total Asia + Europe	
NuMI	14.07	*(10.71 ν, 3.36 anti-ν in LE mode, arXiv:1403.0867)*
BNB	17.73	*(11.27 anti-ν + 6.46 ν, arXiv:1303.2588)*
	31.80 = total Fermilab	

*The U.S. has delivered **3.4 times** the number of protons on target to its neutrino experiments than both Asia and Europe combined.*

(note: does not include T2K antineutrino or NuMI ME running since those results have not been published yet)

Projections for Combining Results

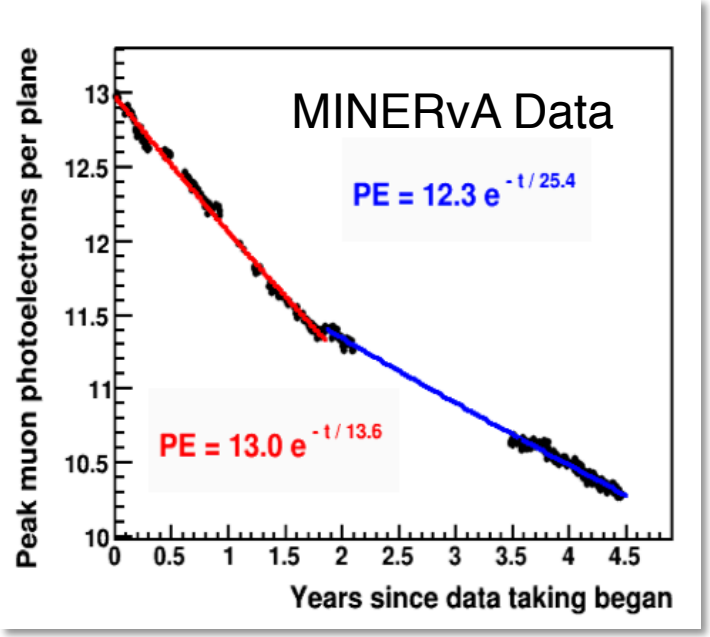
- mixing with sterile neutrinos causes anomalous disappearance of muon neutrinos
- future prospects of a combined sterile neutrino search from disappearance data after 2 years of data-taking in MINOS+

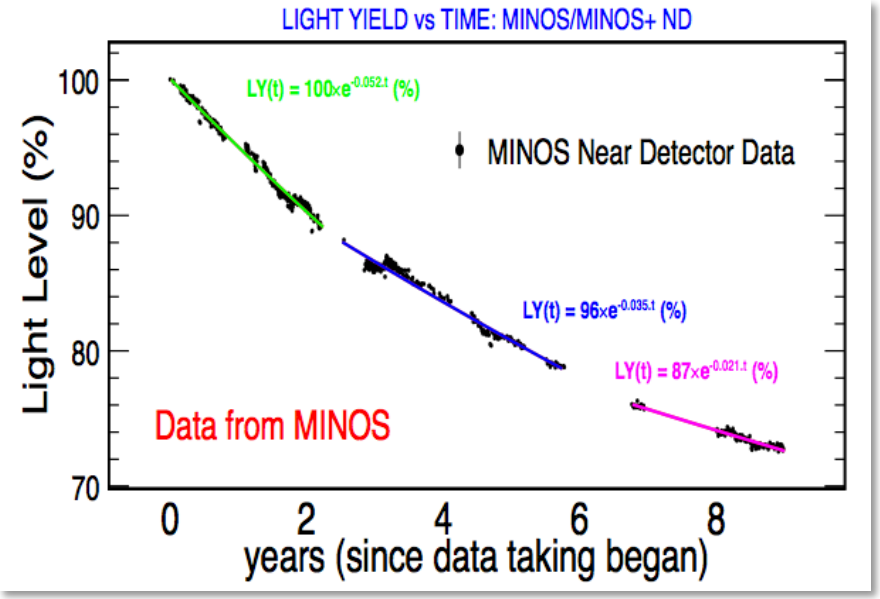


- strongest constraints on $\nu_\mu \rightarrow \nu_s$ disappearance for $\Delta m^2_{43} < 1$ eV^2
- MINOS+ improves sensitivity of the search for sterile ν's by x2

MINERvA and MINOS Over Time

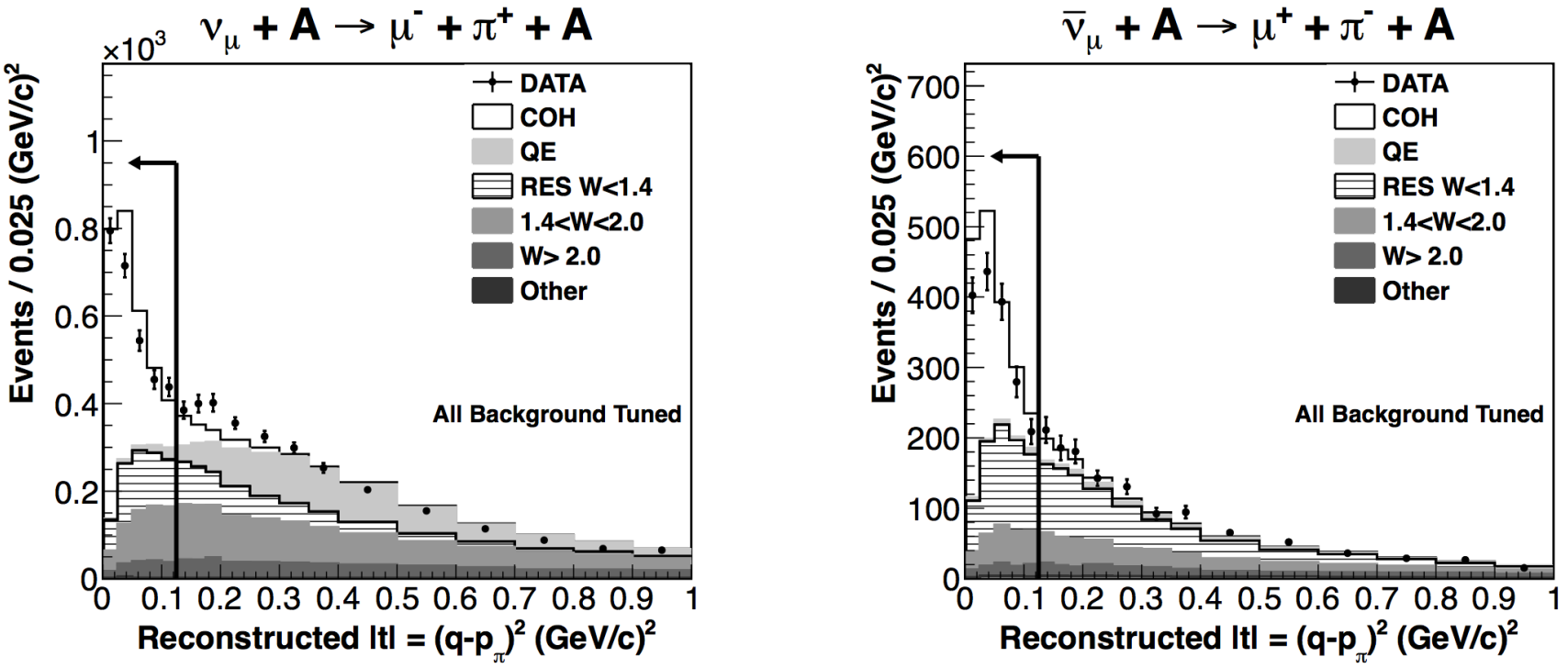
- Light yield of scintillator + fiber decreases over time
- MINERvA and MINOS monitor & simulate this using muons from upstream interactions in the rock
- MINOS: 2% loss/year, MINERvA: 4% loss/year
- Both detectors still have many photoelectrons per MIP going through scintillator, position resolution expected to deteriorate by 30% or less over next 15 years





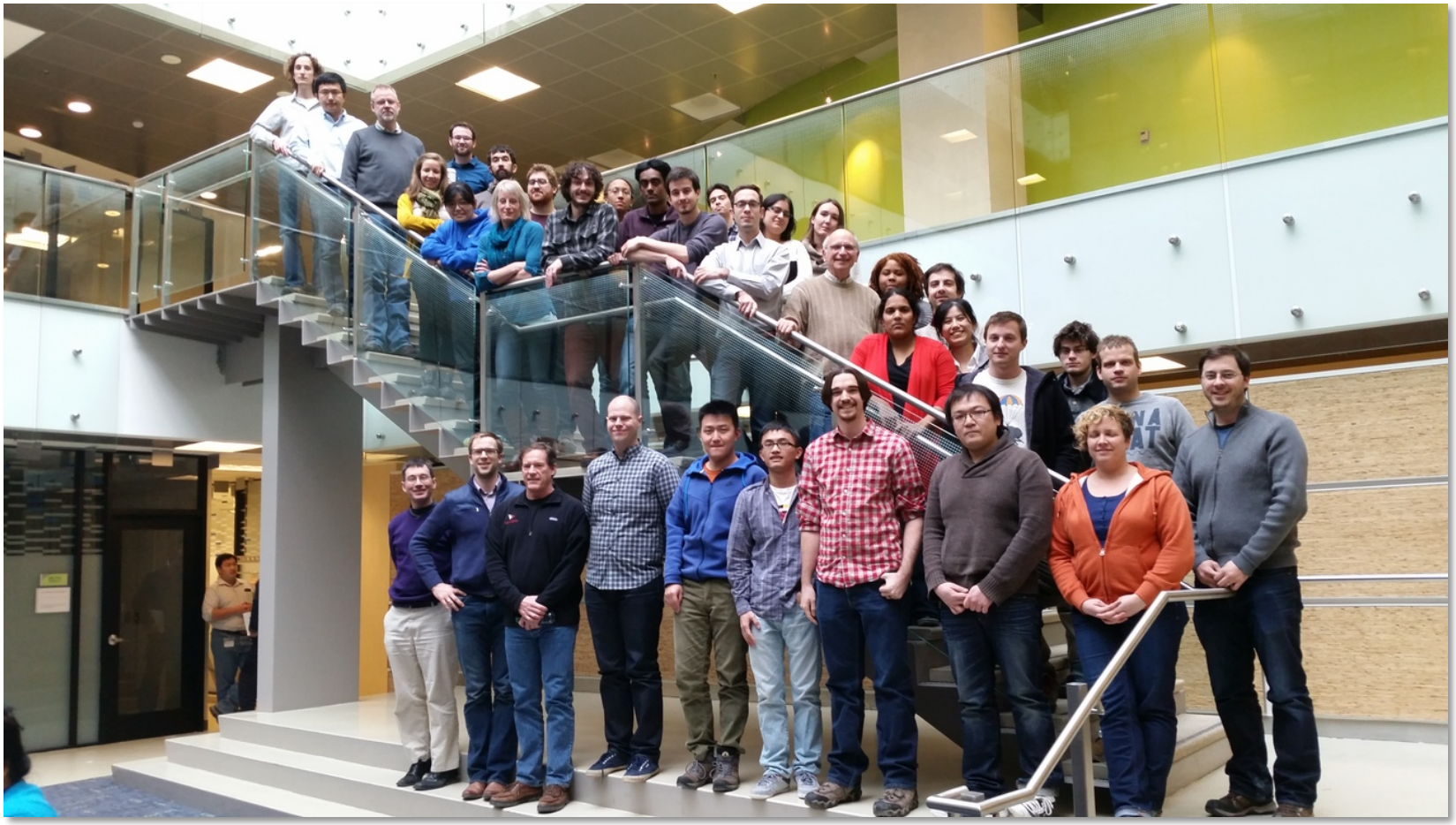
MINERvA Coherent Pion Production

CC coherent π^+ production



MINERvA: A. Higuera, PRL 113, 261802 (2014)

MicroBooNE Reconstruction Workshop (Jan 5-9, 2015)



hosted by Bryce Littlejohn at Illinois Institute of Technology (IIT)