Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

Neutrinos

Regina Rameika

Fermilab Institutional Review

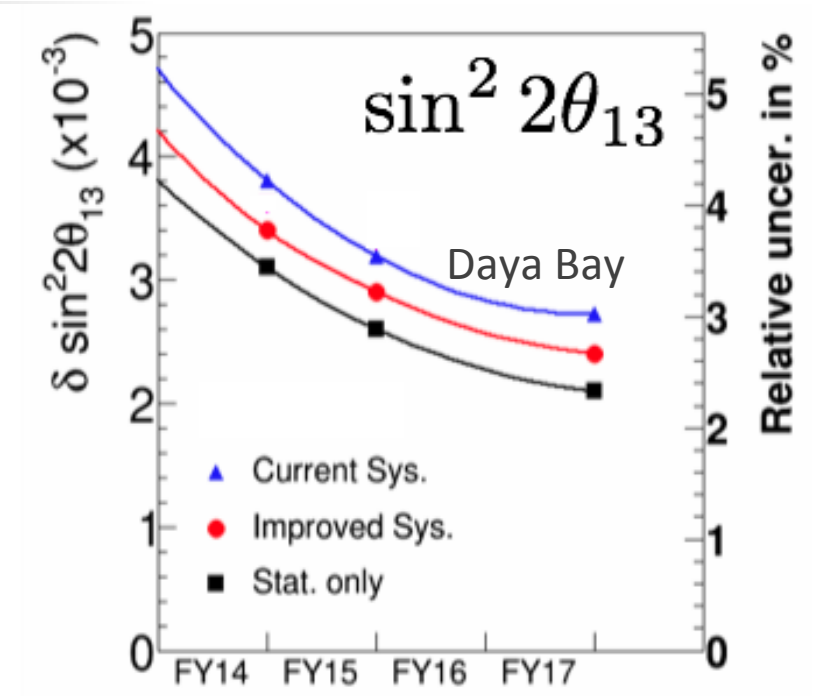
10 February 2015

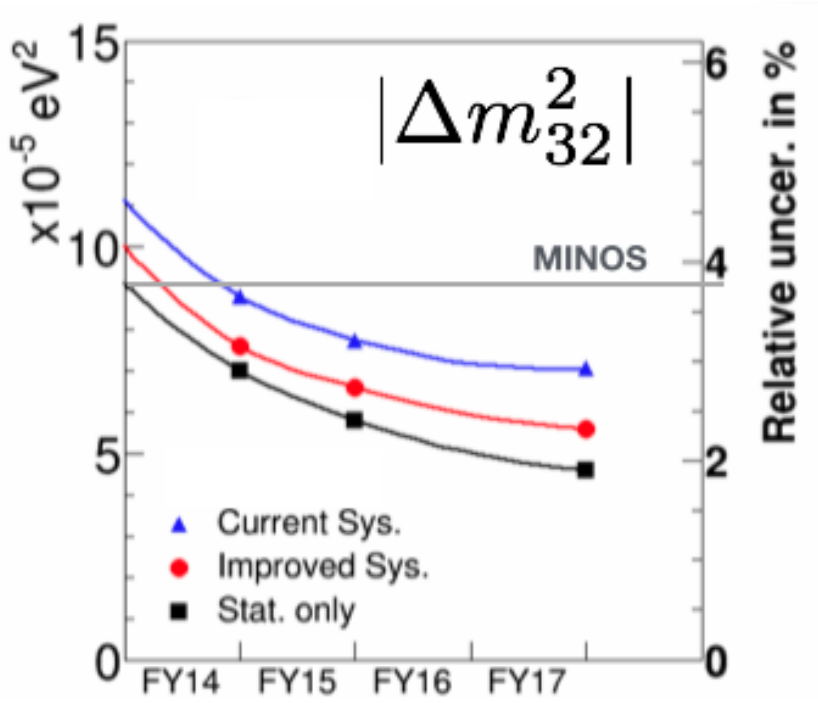
Topics

- The Neutrino Landscape, P5 and Fermilab's strategy for neutrinos
  - On-going
  - Near-term
  - End-state
- Tactics for executing the strategy
  - Concept of a "Neutrino Platform"
  - Building *coherence* and *synergy*

The Neutrino Landscape

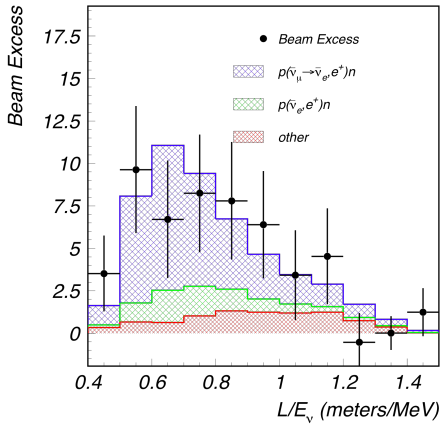
- We have learned a lot in the past two decades
- Instead of asking whether neutrinos have mass, or how big (or small) is theta13 :

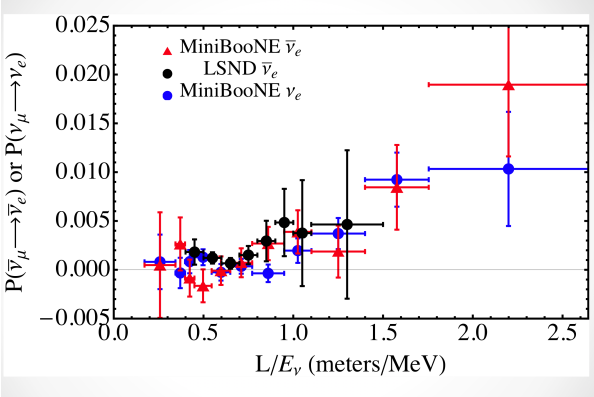




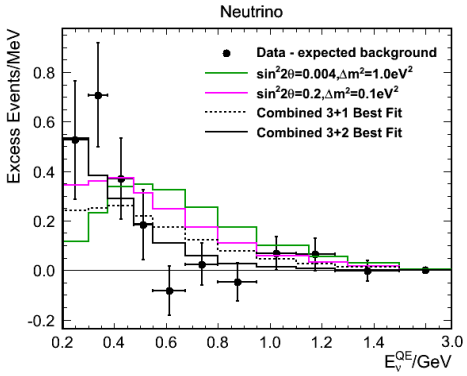
From L. Whitehead, WINP

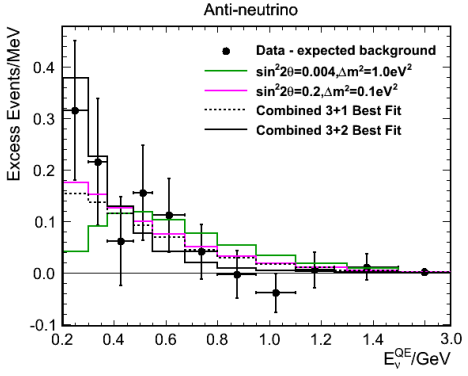
Neutrino Anomalies ⟹ 3 + N(?) neutrinos

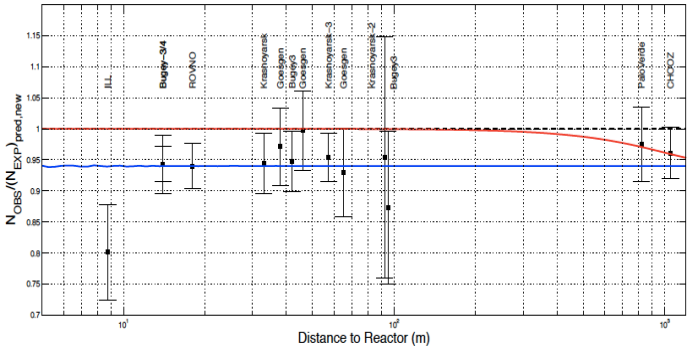




LSND, MiniBooNE, Reactors, sources,…







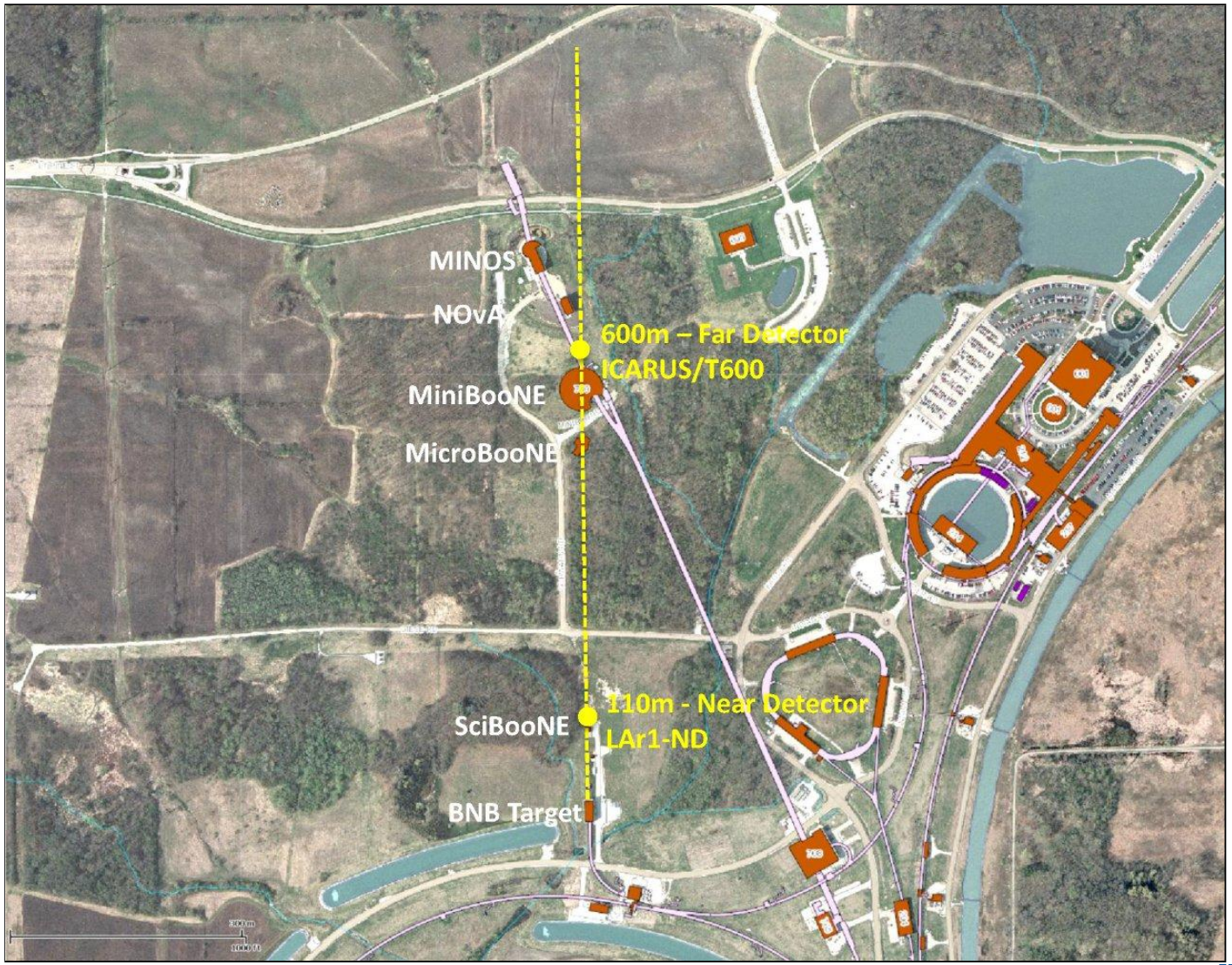
From B. Louis, WINP

Fermilab

Neutrinos and P5

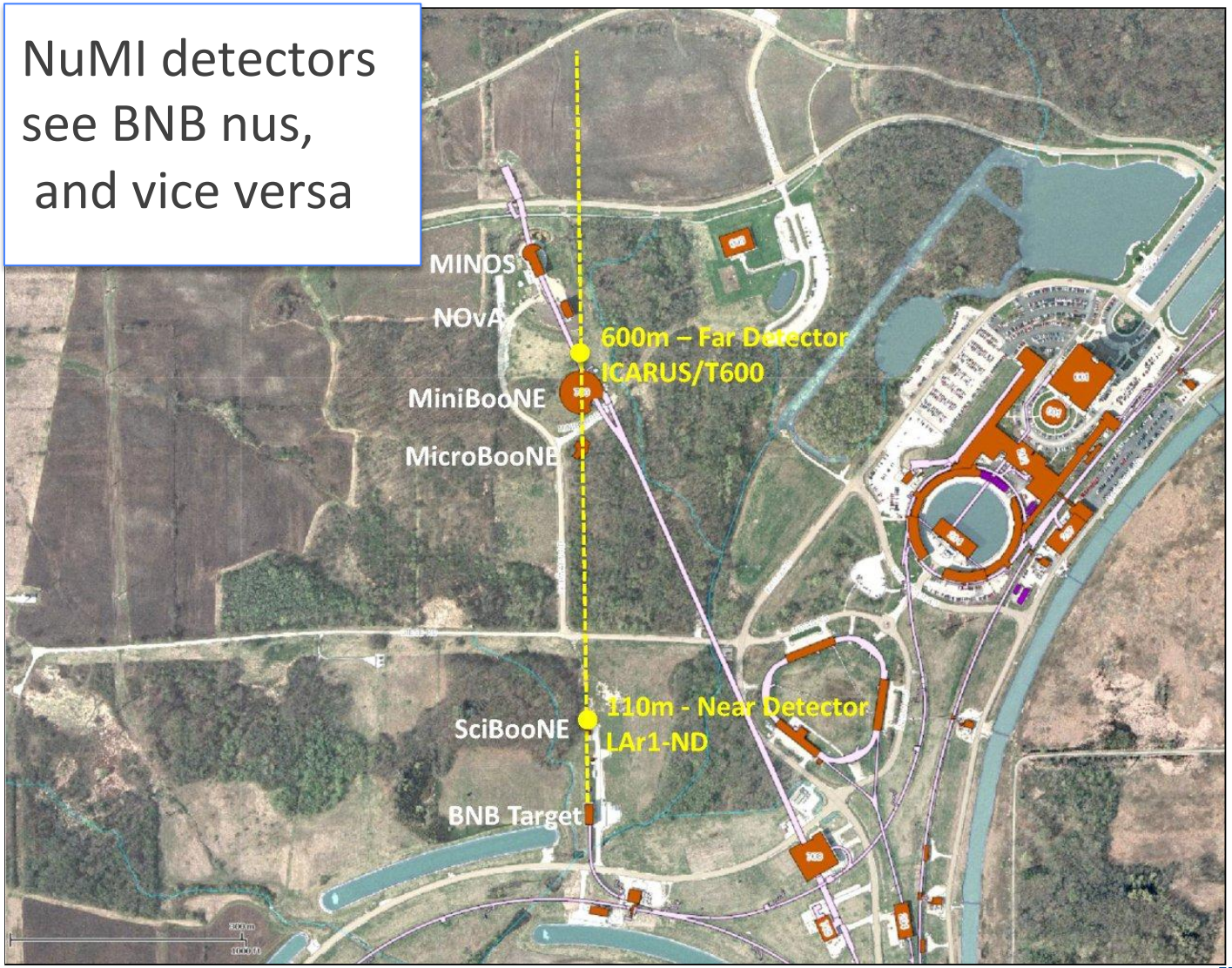
- The U.S., in collaboration with international partners, develop a coherent short- and long-baseline program hosted at Fermilab
- Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S.
- Upgrade the Fermilab proton accelerator complex to provide more than 1MW by the time of first operation of the new long-baseline neutrino facility
- Select and perform a set of short term, small scale short-baseline experiments to conclusively address experimental hints of physics beyond the three-neutrino paradigm
  - Some of the small-scale experiments should “use liquid argon to advance the technology and build the international community for LBNF at Fermilab

Neutrinos at Fermilab : NuMI and BNB



Neutrinos at Fermilab : NuMI and BNB

NuMI detectors see BNB nus, and vice versa



Neutrinos at FNAL : current program

- NOvA (long-baseline, NuMI)
  - Operating with full detectors, near and far
  - Typical beam power 300 – 400 kW
- MINERvA (short-baseline, NuMI)
  - Neutrino data in medium energy beam
- MINOS+ (long-baseline, NuMI)
  - Will collect data through FY16
- MicroBooNE (short-baseline, BNB)
  - Commissioning and getting ready to fill
  - Hoping to get BNB neutrinos before summer shutdown

See breakout talk by Sam Zeller for details

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).

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).

These accomplishments come from the leadership of the collaborations and the many collaborators from universities, other laboratories and Fermilab

Fermilab

New proposals for near-term execution

- ANNIE (Stage 1 approval for Phase 1)
  - measure neutron production in ν interactions on water, address background in proton decay searches and supernova events
  - creates an opportunity to demonstrate the LAPPD light collection
- Captain Minerva (and Captain BNB) (full proposals need to be developed)
  - off-axis BNB running: low energy neutrino cross sections (10's of MeV, in SNν range)
  - NuMI running (CAPTAIN MINERvA): medium energy neutrino cross sections and nuclear effects (few GeV, accelerator and atmospheric ranges)

To provide adequate support for modest initiatives such as these we need to be nimble and flexible ; we need to be able to adjust the timeline of activities for the longer term projects

Laboratory Objectives for Neutrinos

- Deliver world's highest power accelerator beams for neutrinos
  - NuMI and BNB : 400kW, 700kW, 15Hz
  - PIP–II (>1 MW beam) and PIP-III (multi-megawatt beam)
  - Fully exploit science of NOvA
- Establish the Short Baseline Program
  - MicroBooNE taking data beginning in 2015
  - LAR1-ND built and taking data by 2018
  - Get ICARUS to FERMILAB and taking data by 2018
- Establish LBNF and ELBNF
  - Cavern construction begins in 2017 at SURF
  - 10 kt of LAr installed in 2021
  - Additional 30kT space excavated by 2021
  - Neutrino beamline complete in 2023
  - Full detector complete in a timely manner
- Enhance the Fermilab neutrino platform in support of detector R&D and new initiatives
  - Exploit existing facilities
  - Develop existing facilities to add capability
  - Consider flexibility in design of new facilities

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"End-state" : where we want to be in 2025

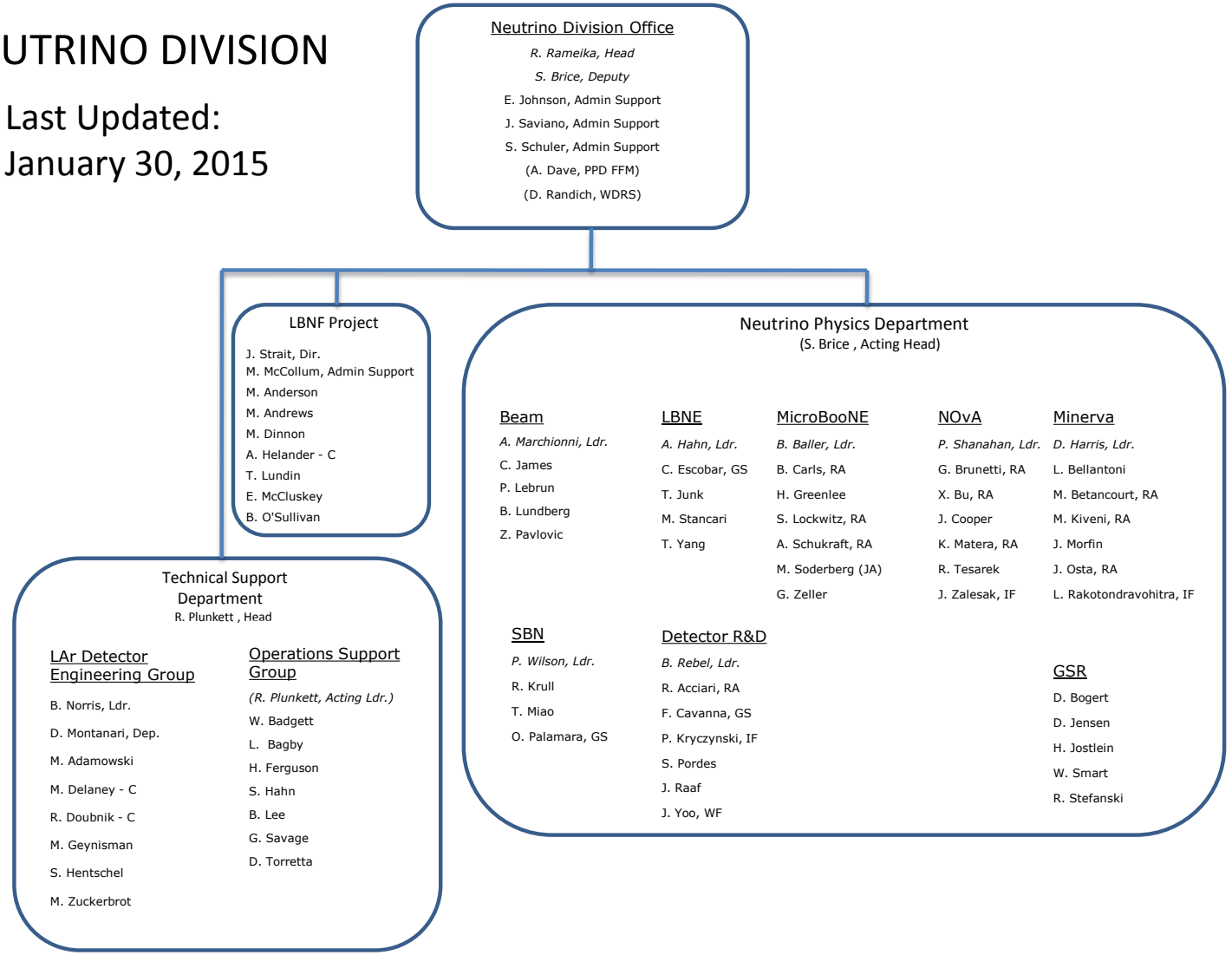
- Enhance the Fermilab neutrino platform in support of detector R&D and new initiatives
  - Exploit existing facilities
  - Develop existing facilities to add capability
  - Consider flexibility in design of new facilities

New Organization to aid in meeting these objectives : The Neutrino Division

- Vision
  - Guide Fermilab to be the world-leading accelerator neutrino laboratory
- Mission
  - Provide a visible organizational home for the Fermilab neutrino community
  - Provide operations support for running experiments
  - Support foundational activities for the program of experiments
- Organization
  - Modest in size and resources as we start out
  - Plan to grow to meet demands of the expanding program
  - Developing strong connections to other Laboratory organizations

NEUTRINO DIVISION

Last Updated:
January 30, 2015



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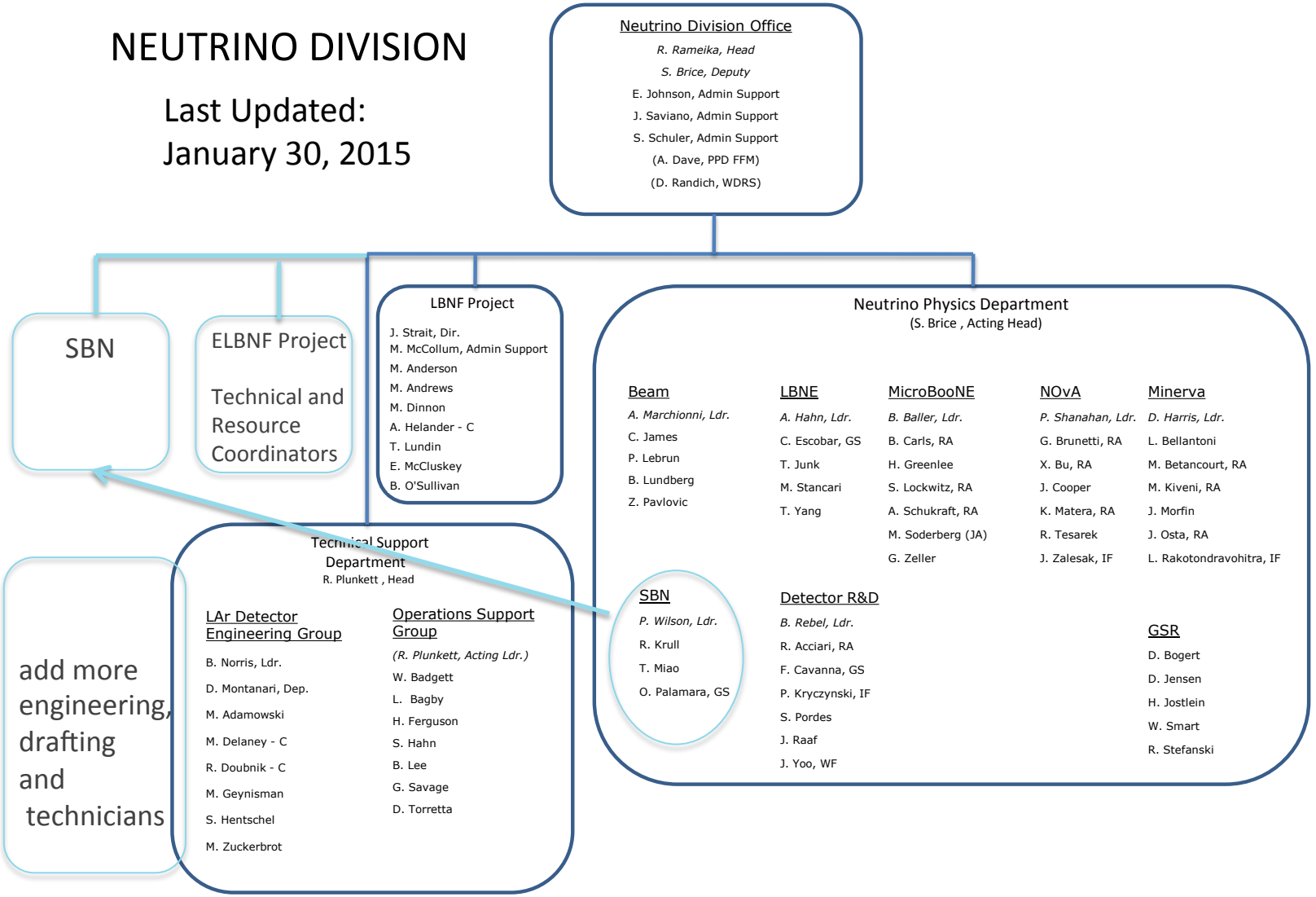


2103 S&T Review recommendation and response

1. The review panel recommended that the lab formulate a coherent plan for its small and mid-scale neutrino experiments, which should include a timeline for physics and technical milestones. The reviewers did not find the suite of neutrino experiments to be adequately coordinated into a program that had decisive physics goals that lend support to the lab's flagship experiment, the Long Baseline Neutrino Experiment (LBNE).

Significant progress has been made since the S&T review. Two proposals were obtained for the near term program and they have been reviewed by the Fermilab PAC.

A roadmap for an integrated and globally neutrino program hosted at Fermilab that includes the small, mid-scale, and flagship program is emerging.

The goals of the small and mid-term experiments are:

- Address anomalies in the neutrino sector
- R&D on LAr detector technology that mitigates risk to LBNE
- Development of analysis techniques and the needed physic engineering measurements with a large (1E6) sample of neutrino-Argon interactions
- Community development: assembling the teams and training the generation of scientists needed to execute the flagship program

A broad consensus is emerging among the U. S. and European partners on the need for an integrated global partnership, not only for the flagship program, but for the nearer term program as well—an 'umbrella-like' approach for assuring an optimal coordinated program is a key piece of the roadmap.

Discussions among CERN, Fermilab, Europe and America are ongoing.

Concept of a *Neutrino Platform*

- Introduced by Marzio Nessi (CERN) approximately 1 year ago

A few major statements/events in Europe

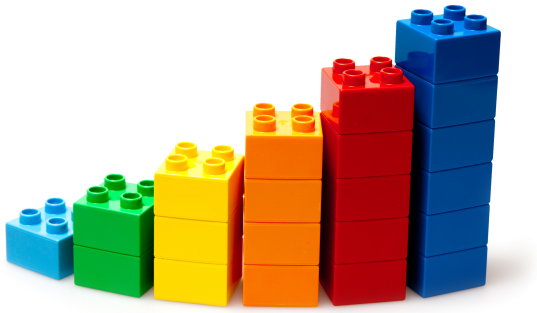
- European Strategy : *"CERN should develop a neutrino program to pave the way for a substantial European role in future long-baseline experiments"*
- *APPEC Paris meeting dedicated to Large Neutrino Infrastructures, where most FAs and leaders in the field where present and have started drafting a possible future strategy*
  - *CERN broke symmetry and announced that it will freeze for the moment all types of Neutrino beams at CERN (Short and Long Baseline) in favor of common activities in the US and Japan → **CERN Neutrino Platform***
- *During the June 2014 Council meeting, CERN has released an important amount of resources for a CERN Neutrino Platform, as part of its medium term plan (next 5 years)*

From presentation at Jan. 22 ELBNF meeting

ν Platform Initial Mandate

- Assist the various groups in their R&D phase (detectors and components) in the medium term and give coherence to a fragmented European Neutrino Community
- Provide to the ν community a test beam infrastructure (charged particles)
- Bring R&D to the level of technology demonstrators in view of major technical decisions
- Continue R&D on ν beam, as a possible base for further collaborations
- Support the short baseline activities
- Support the long baseline activities

The "Fermilab Platform" is composed of the building blocks upon which we build an experimental program



Small Tests

Small Experiments

i.e. ArgoNeuT

Medium Experiments

i.e. MINERvA MicroBooNE

Large Experiments

i.e. NOvA, MINOS

Very Large Experiments

i.e. ELBNF

Fermilab Neutrino Platform

Fermilab Neutrino Platform

Accelerator Division

Neutrino Beams : NuMI, BNB

Charged Particle Test beams

High Power Targets and Horns

Facility Engineering Support Services

Neutrino Division

Detector R&D test stands

Detector Halls : NuMI, SciBooNE, LArTF

Neutrino Beam Group

Collaboration with theorists

ND Operations Support

Neutrino Physics Center

ROC West

Particle Physics Division

Scientific Computing Division

GENIE

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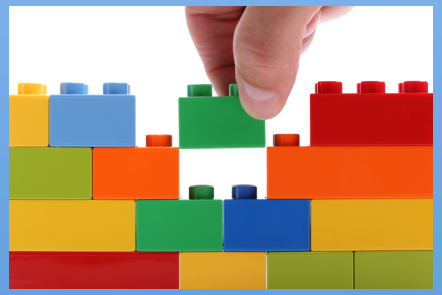
ART

ARTDAQ

LArSOFT

NuTools



Core Computing Division

Technical Division

Fermilab Neutrino Platform

See talk by S. Brice in breakout session

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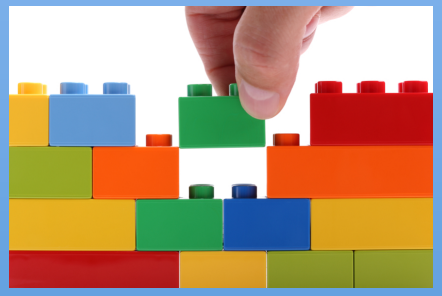

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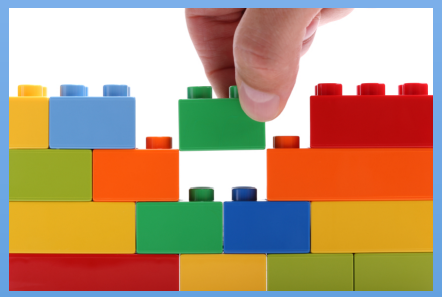


Facility Engineering Support Services

Particle Physics Division

Core Computing Division

Technical Division

Establishing a *Neutrino Physics Center*

- Take some inspiration from the LHC Physics Center (LPC)
- Make Fermilab a hub for the Neutrino User Community to get support for on-going, near term and long term projects
- Support Guests & Visitors, Intensity Frontier fellows, collaboration spokesperson “buy-outs”, international students, etc.
  - Provide office space and administrative support for meetings, travel, etc.
- Support series of lectures, seminars, workshops
- Support the infrastructure needed for new ideas in detector development.
- Collaborate with theory colleagues to bring the theory and experimental teams together to work on timely issues : i.e. model of neutrino-nucleon interactions, models for NSI, etc.
- Some of these ideas are already in development; want to formalize more in upcoming year(s)

Large Neutrino Detectors → Large Projects

- Since 1998, beginning with NuMI/MINOS, the large detectors have required major project initiatives to execute the construction : i.e NOvA, and even MicroBooNE
- LBNF and ELBNF will be the same…

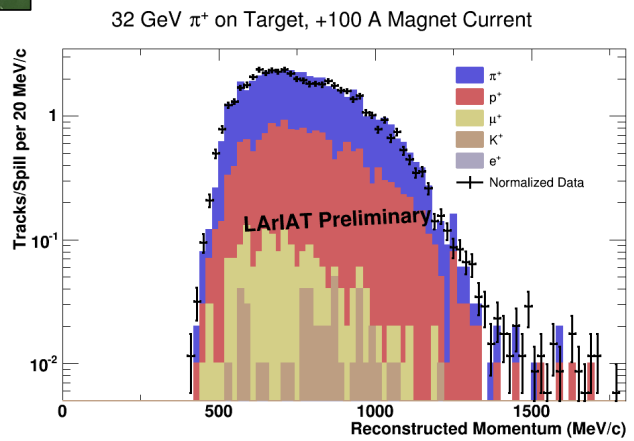
- Care must be taken to incorporate “small scale” components to these projects that will support and nurture the experimental collaboration that will eventually be responsible for the scientific output of the program.

Small scale/fast-track projects = additional training ground

LArIAT Experiment at MCenter Test Beam

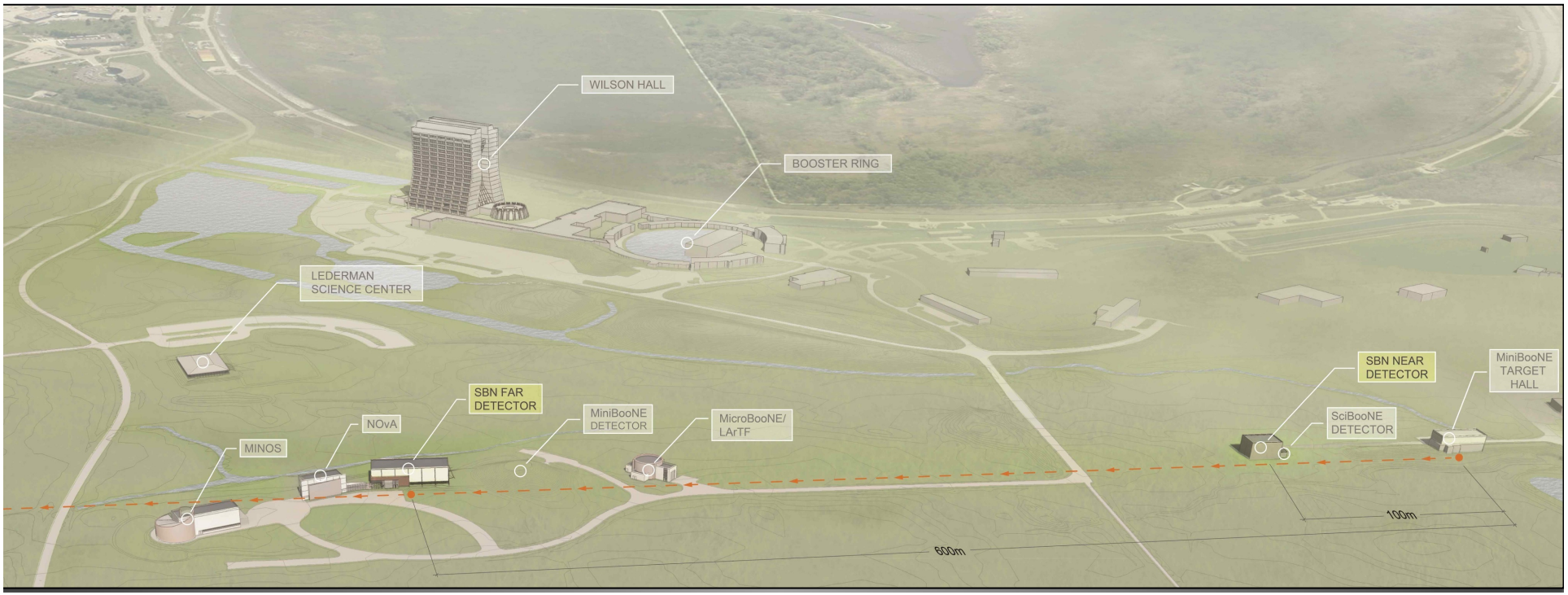
LArIAT Collaboration:
~70 people, 20 institutions
(US, UK, Italy, Japan)

- Beamline, DAQ, and trigger commissioned, Fall 2014
- LArTPC completed and installed in cryostat, cryostat moved to MCenter, Winter 2014/15
- Cryogenic infrastructure installation ongoing
- Planned Run 1, Winter/Spring 2015



SBN Program

- 3 LAr-TPC detectors in BNB : MicroBooNE + LAr1-ND +ICARUS T-600
- Stage 1 approval from PAC
- Conventional Facility project on GPP funding ready to launch

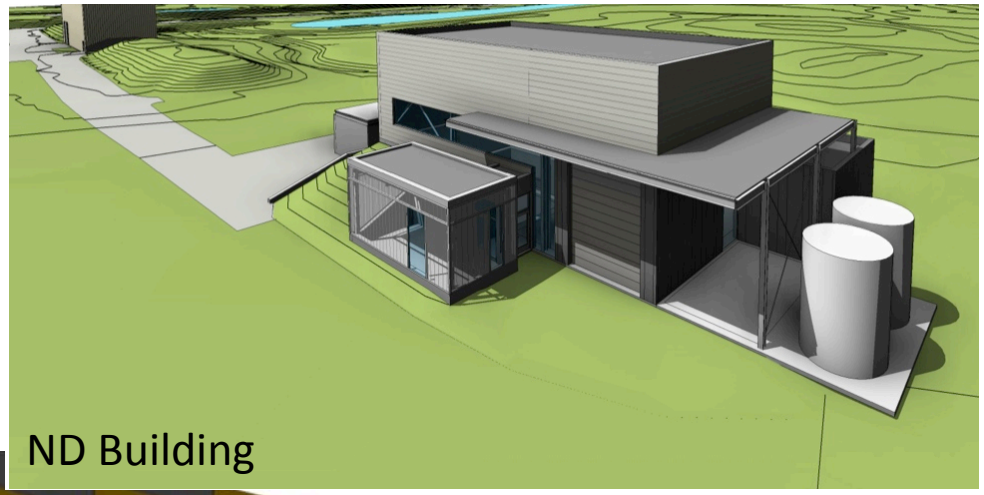


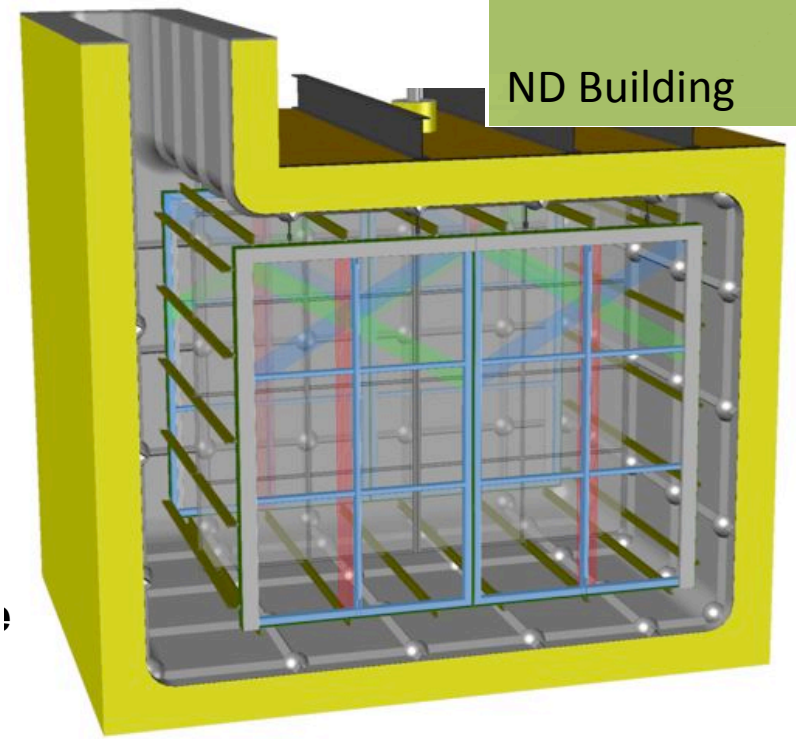
MicroBooNE

June 26, 2014

October 2014

LAr1-ND





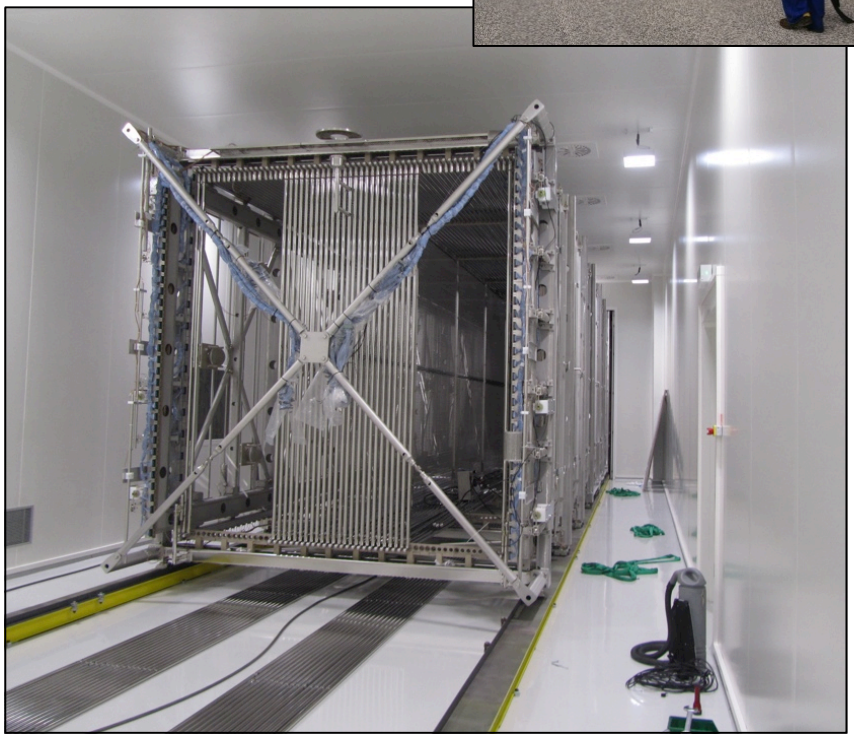
Design builds on
MicroBooNE,
LBNE 35 ton prototype

ICARUS-T600, WA104

- Successfully operated at Gran Sasso in CNGS beam
  - Achieved electron lifetimes > 15 ms
  - Physics program including limits on sterile neutrinos
- ICARUS-WA104 project at CERN
  - Refurbish ICARUS-T600 w/ new cryostats, electronics, upgraded light collection
  - Move from Gran Sasso to CERN, Dec 2014
  - Refurbishing underway!
  - Schedule: TPC delivered to FNAL as soon as building available on-site, currently foreseen as early 2017

Ready to leave LNGS

First T300 in Cleanroom at CERN



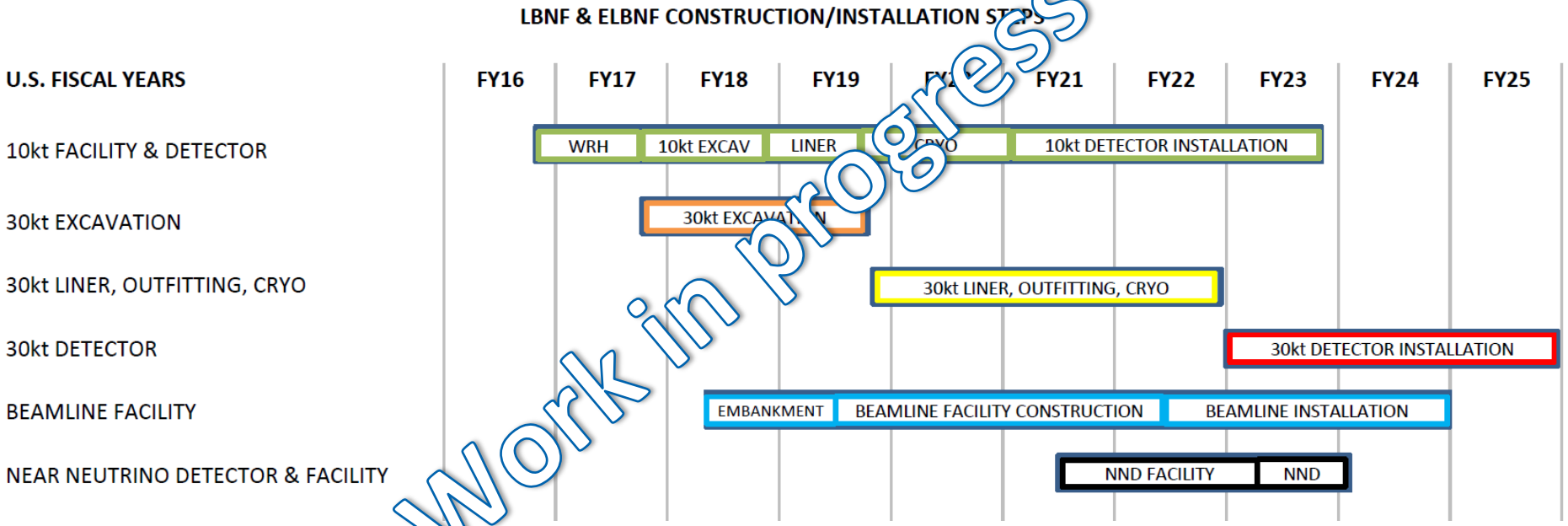
LBNF/ELBNF

- Transition period : LBNE ⟹ LBNF/ELBNF
  - LBNE CD-0 and CD-1 remain in tact
  - A CD-1 “refresh” will define the amended scope for the DOE funded project which now includes :
    - Outfitted cavern, underground for 10kT (fiducial mass) detector
    - Excavated cavern space for additional 30kT (fiducial mass)
    - Cryostat and cryogenics at the far site
      - DOE project coordination
      - In-kind contribution expected
    - Conventional facility at Fermilab for a Near Detector
  - Facility and detector projects are separated
    - Coordinated via an “Experiment-Facility Interface Group” (EFIG)
  - Majority of the detector elements are expected to be contributed by non-DOE partners

LBNF & ELBNF STEPS

Presented by E. McCluskey at ELBNF meeting

- Pieces of the projects can be considered as steps towards the complete experimental goals.
- Implementation will be limited by funding, so choices may need to be made concerning the order and timing of these steps.
- The sequencing of the steps should be aligned with the science strategy set by the collaboration.



Summary and critical path durations only, could be moved in time

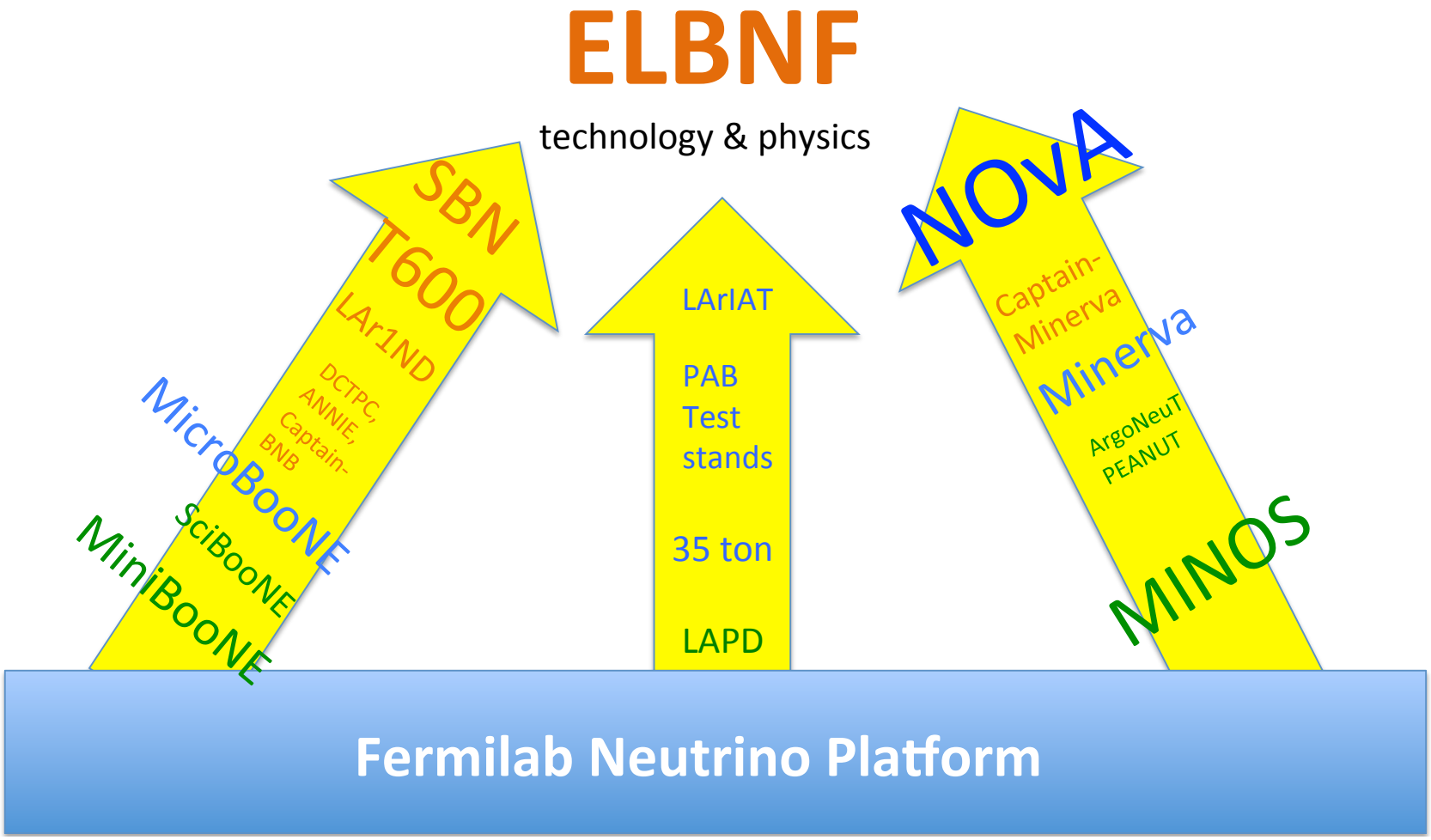
Fermilab

Building coherence between SBN and LBNF/ELBNF

- Four major elements :
  - Physics : understanding neutrino mass and mixing
  - Technology : Liquid Argon TPCs
  - Event generation, reconstruction
  - People, sociology
    - Test beams, prototypes, near-term physics program

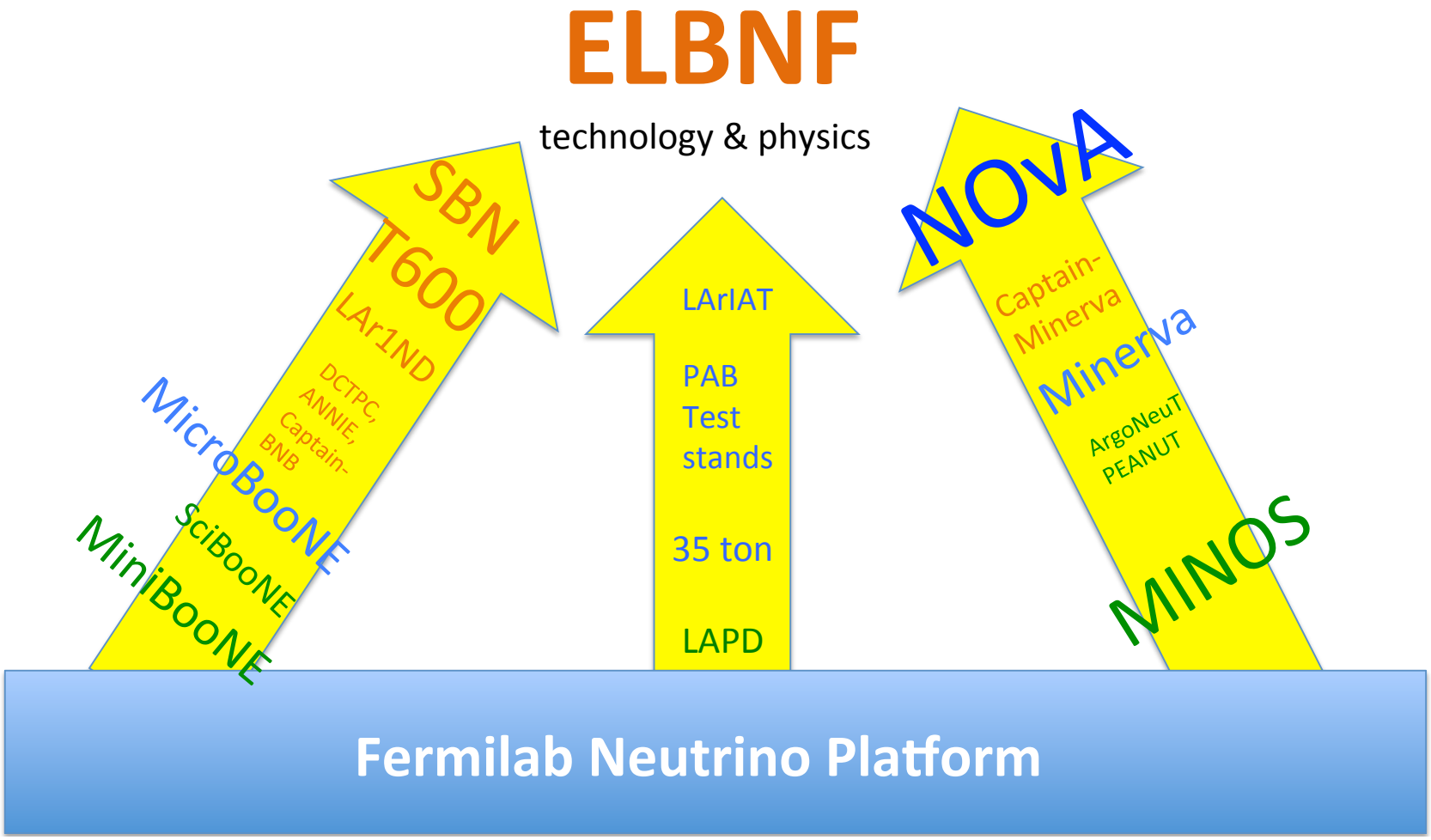
See breakout talk by Peter Wilson

Programs complete
Operations phase
Proposed or planned



More than coherence,
we strive for synergy

Programs complete
Operations phase
Proposed or planned



Fermilab staff working on Neutrino Program

	Neutrino Division	Scientific Computing Division	PPD Theory Group	Accelerator Division	Total
Scientists	24	1	2	5	32
Associate Scientists	1	3			4
Applications Physicists	4	1			5
Engineering Physicicsts and Computing Specialists	4	1			5
Research Associates	10	1	1		12
Guest Scientists/Emeritus	3		1		4
Total	46	7	4	5	62

See summary of individuals on review website

Summary

- Fermilab hosts an active, productive suite of neutrino experiments using the NuMI and BN beams
- The key to the success of our ultimate vision for neutrinos will be to secure the necessary commitments from non-DOE/international partners in a timely manner
- Partnerships on the SBN program are developing rapidly and provide a model for collaboration on the larger scale
- Fermilab is committed to executing this program by supporting the community to participate in all aspects of the existing and emerging program