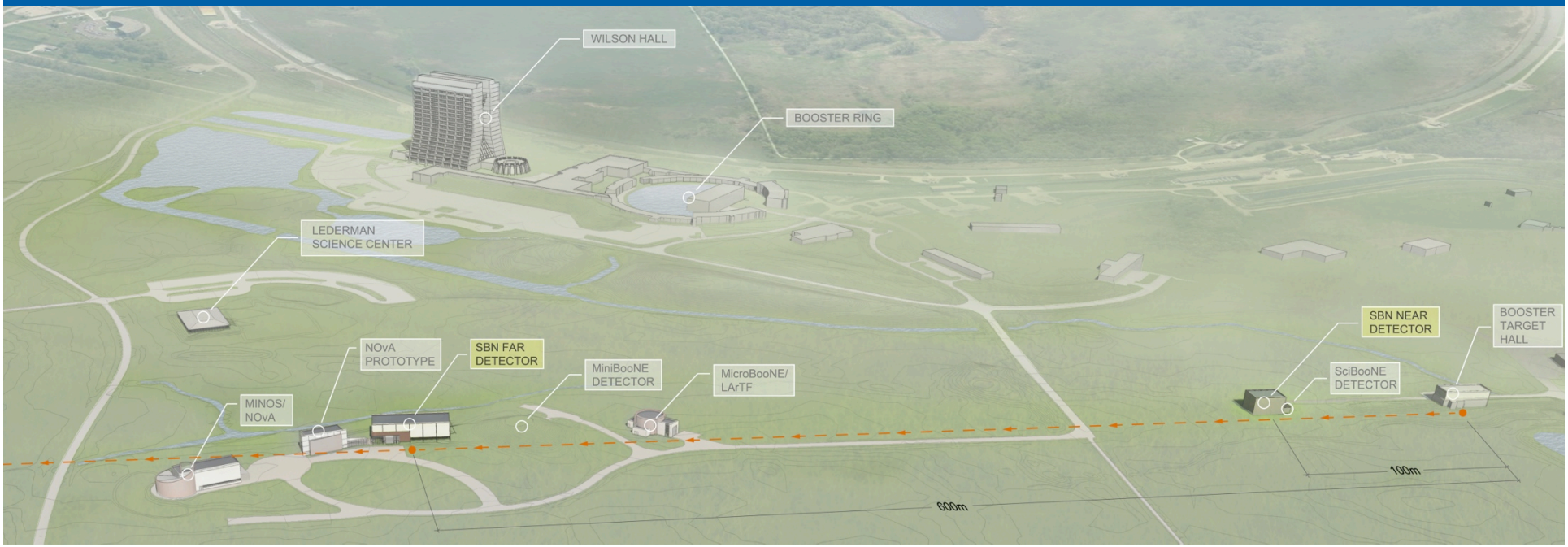


SBN Program Overview

Peter Wilson – SBN Program Coordinator

Director's Progress Review of the SBN Program

15 December 2015

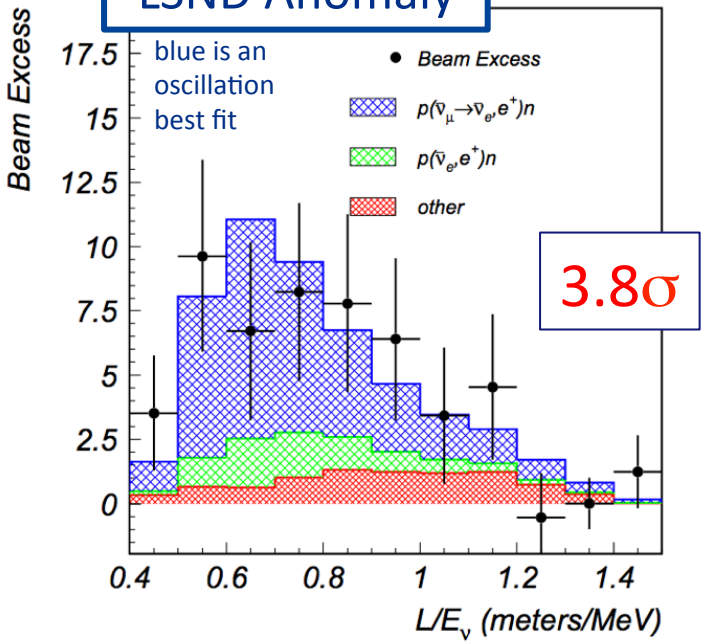
Outline

- Program physics motivation and program requirements
- Scope of the SBN program
- Resources: funding sources and agreements
- DOE cost summary
- Program schedule
- Summary

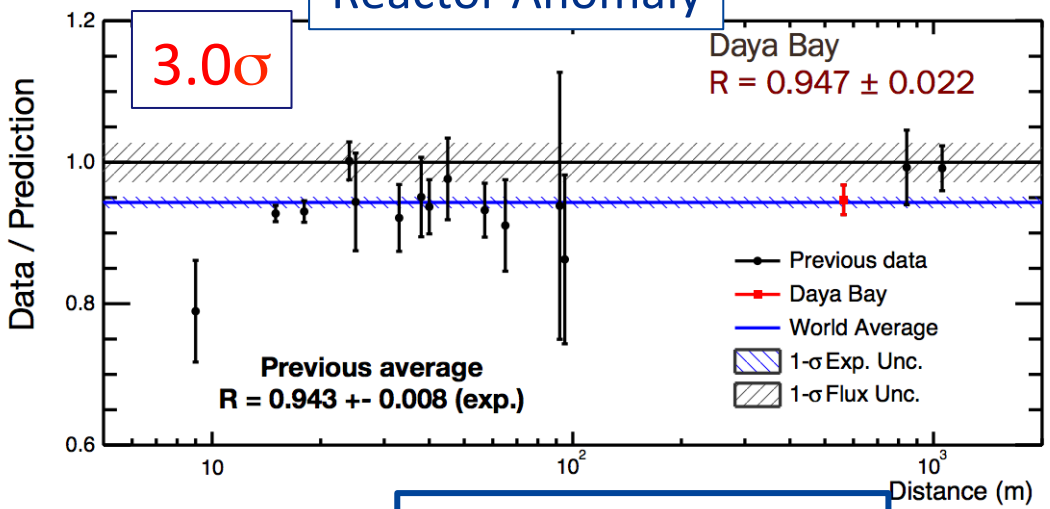
SBN Physics Program and Requirements

Existing SBL (high Δm^2) Anomalies

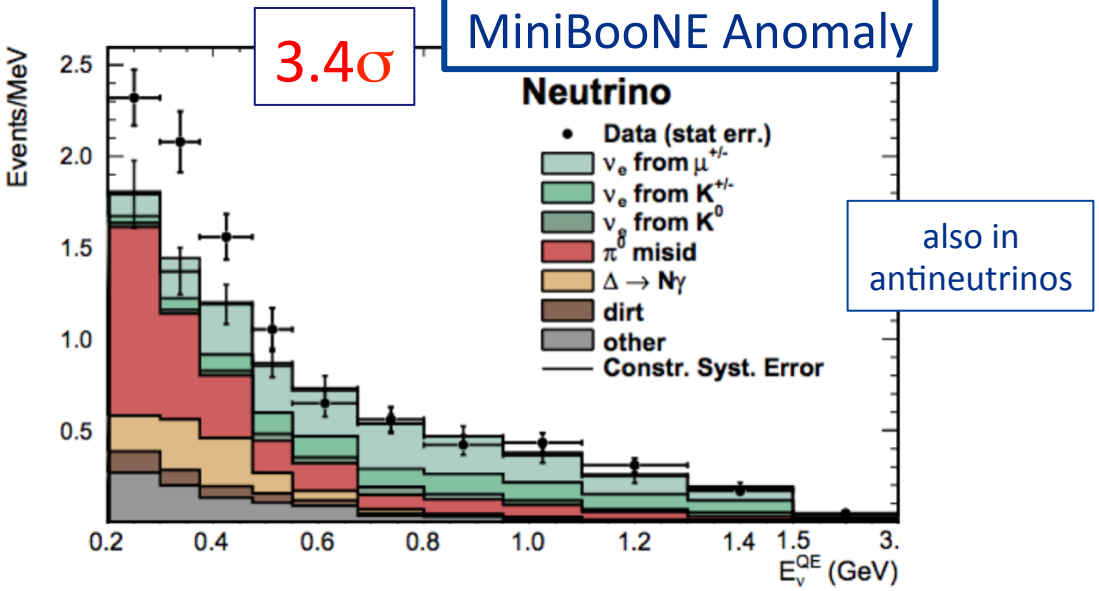
LSND Anomaly



Reactor Anomaly



MiniBooNE Anomaly

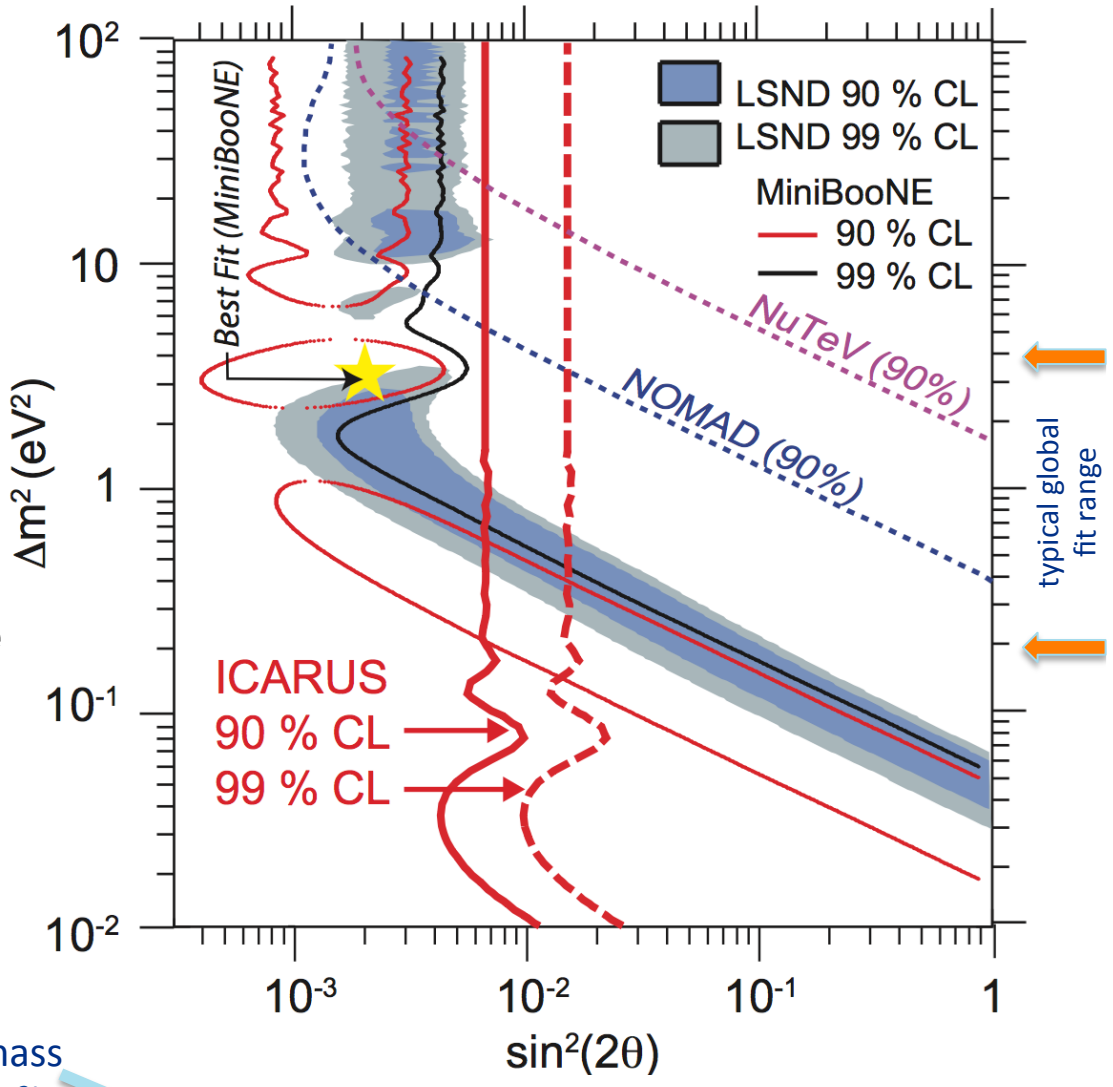


also in antineutrinos

Are these results evidence of new physics or caused by challenging SM backgrounds?

Where to look: Possible Sterile Neutrino Parameters

- Many global analyses that incorporate the positive and null results available
  - Kopp et al.
  - Conrad et al.
  - Giunti et al. ....
- Positive signals in $\nu_\mu \rightarrow \nu_e$ (and $\overline{\nu}$) and ν_e disappearance (and $\overline{\nu}$)
- But, no ν_μ disappearance



Recall the standard active neutrino mass splittings are down here (10^{-3} - 10^{-5} eV^2)

Brief History of SBN at Fermilab

2003-13 MiniBooNE and SciBooNE: 1st Gen on Booster Neutrino Beam

2009-15 Construct and install MicroBooNE (address MiniBooNE anomaly)

2009-13 Proposals for ν_s search using multiple LArTPC detectors:

- X ICARUS@CERN: no ν beam at CERN
- X LAr1@FNAL: too expensive

Jan 2014 Two proposals to Fermilab for next phase at BNB:

- P-1052: Updated ICARUS-T600 + new T150 (near detector) ν_s search
- P-1053: LAr1-ND* + MicroBooNE (goal kton scale far detector)

2014 Proponents of ICARUS, LAr1-ND, and MicroBooNE (+CERN, +FNAL) together develop a coherent SBN physics program

Jan 2015 SBN Proposal presented to PAC

Oct 2015 MicroBooNE starts data-taking with beam: 2nd Gen on BNB starts

* Name change : LAr1-ND ➔ Short-Baseline Near Detector (SBND)

P5 Recommendations

Building for Discovery

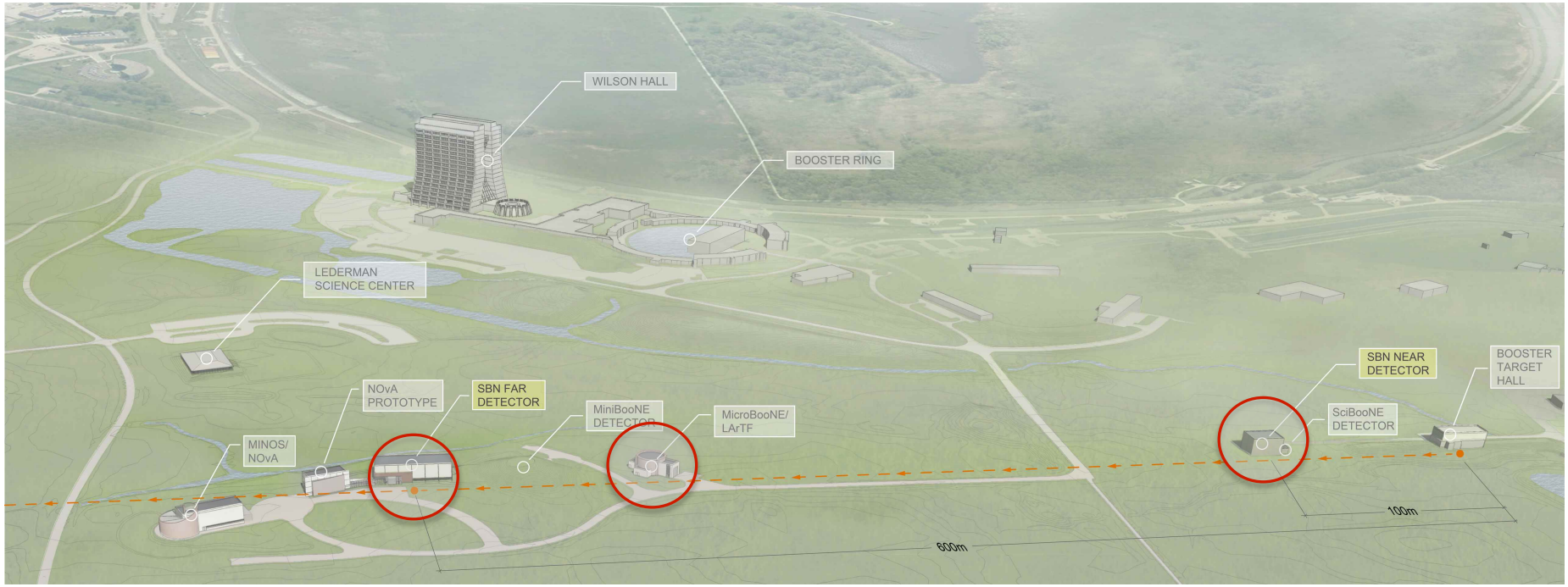
Strategic Plan for U.S. Particle Physics in the Global Context

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

May, 2014

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

SBN Program – Three detectors



ICARUS	MicroBooNE	SBND	Produce
Fewer ν_μ ?	Fewer ν_μ ?	ν_μ	ν_μ
More ν_e?	More ν_e?	~1% ν_e	~1% ν_e

110m

470m

600m

The SBN Proposal

- Returned to the January 2015 PAC meeting with an updated proposal:

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

Submitted jointly by ICARUS, MicroBooNE and SBND (LAr1-ND)
http://sbn-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=269

Part I: SBN Physics Program

Part II: Near Detector Conceptual Design

Part III: T600 Design and Refurbishing

Part IV: Infrastructure and Civil Construction

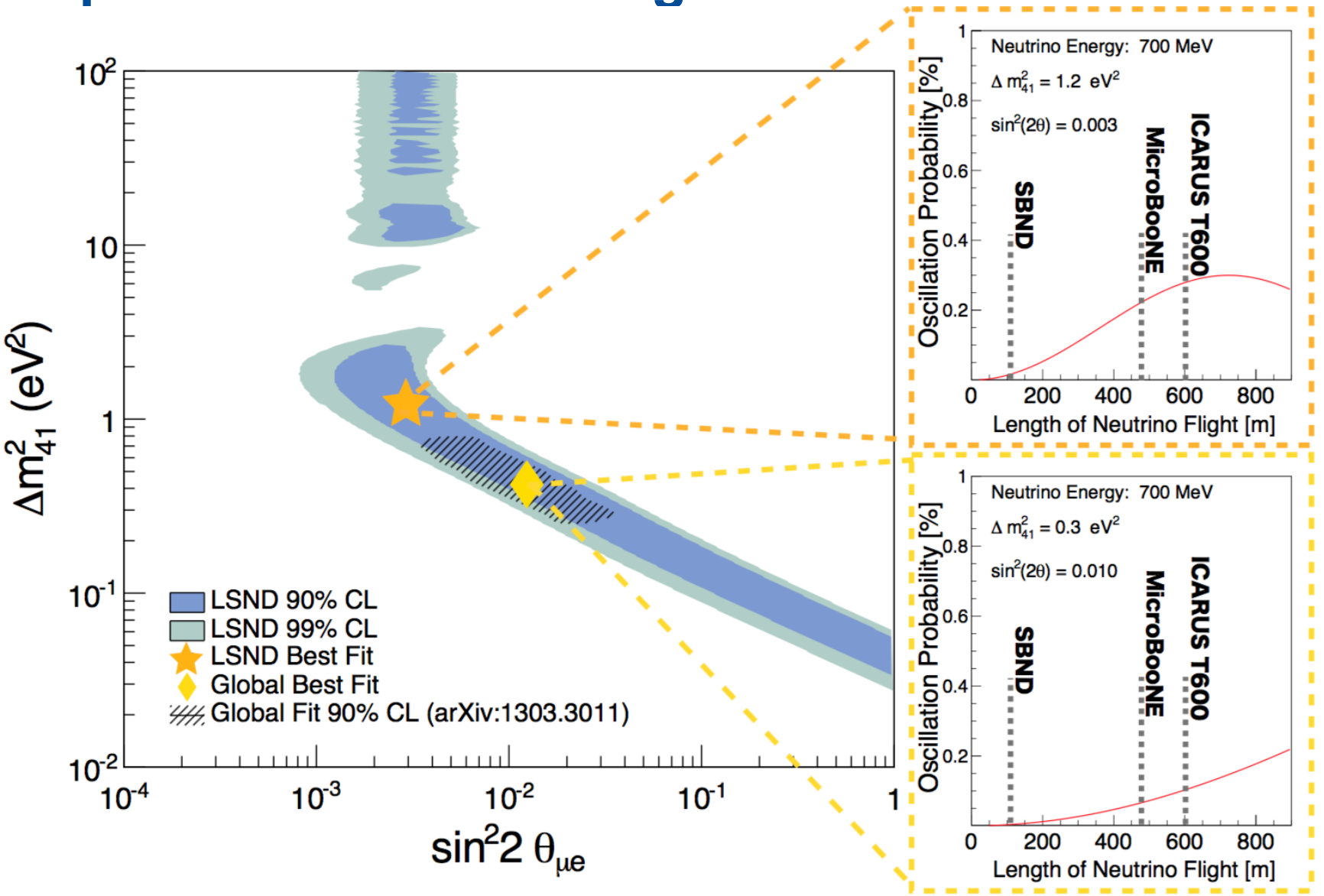
Part V: Booster Neutrino Beam

Part VI: Coordination and Schedule

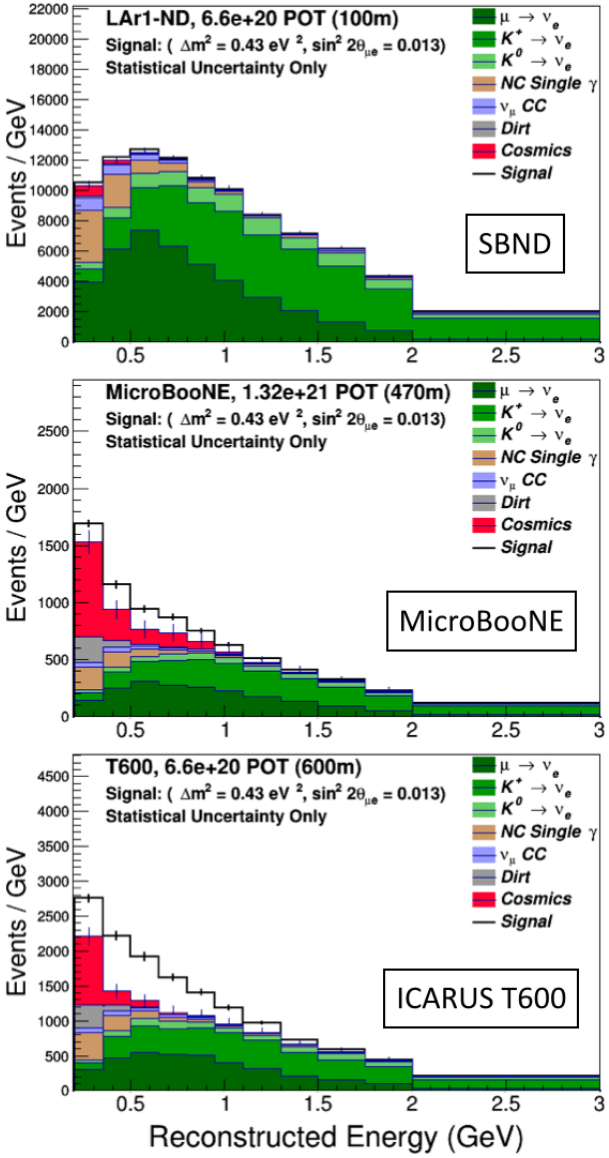
Program Conceptual Design Report

Stage 1 Approval in February 2015
Goal: Operations with beam by 2018

Sample 3+1 Oscillation Signals in SBN

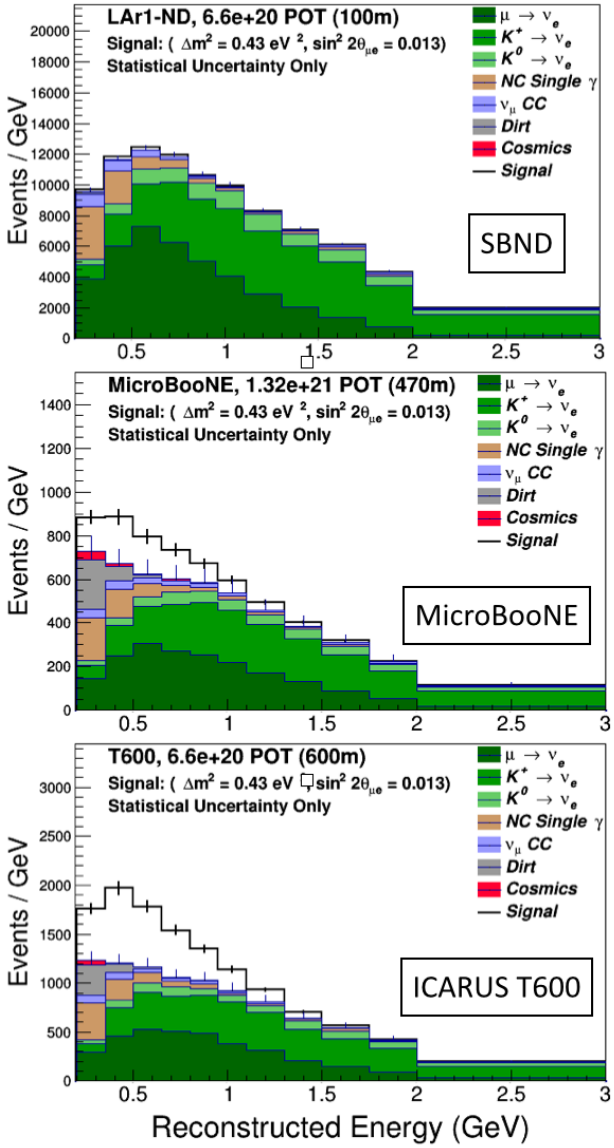


Cosmogenic Backgrounds

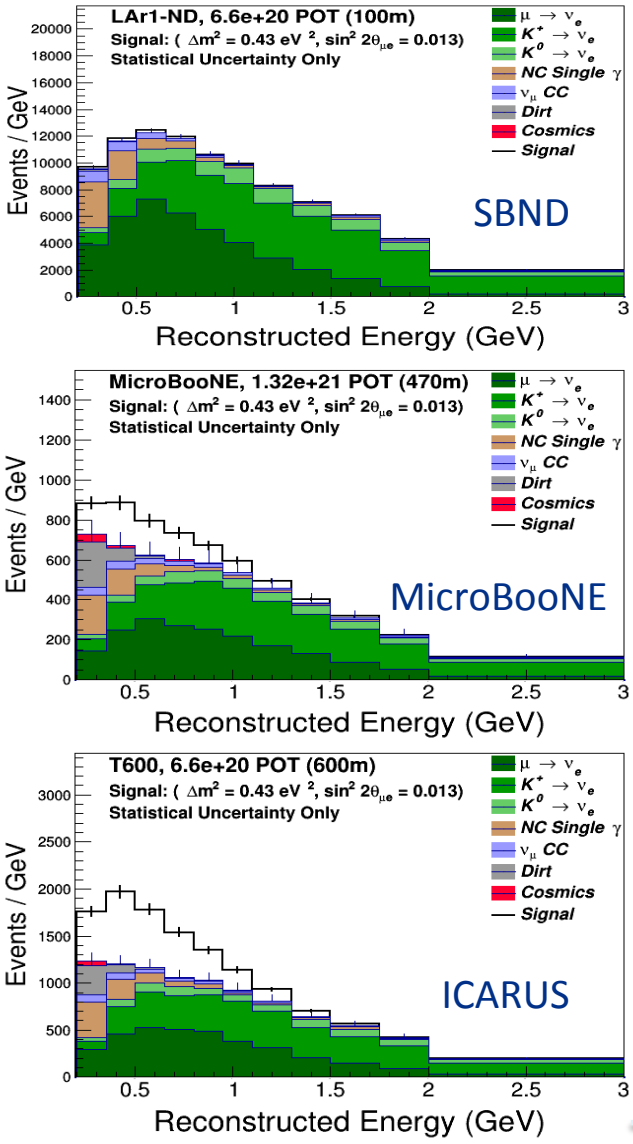


External cosmic ray tracker (CRT) systems can be employed to identify contaminated beam spills

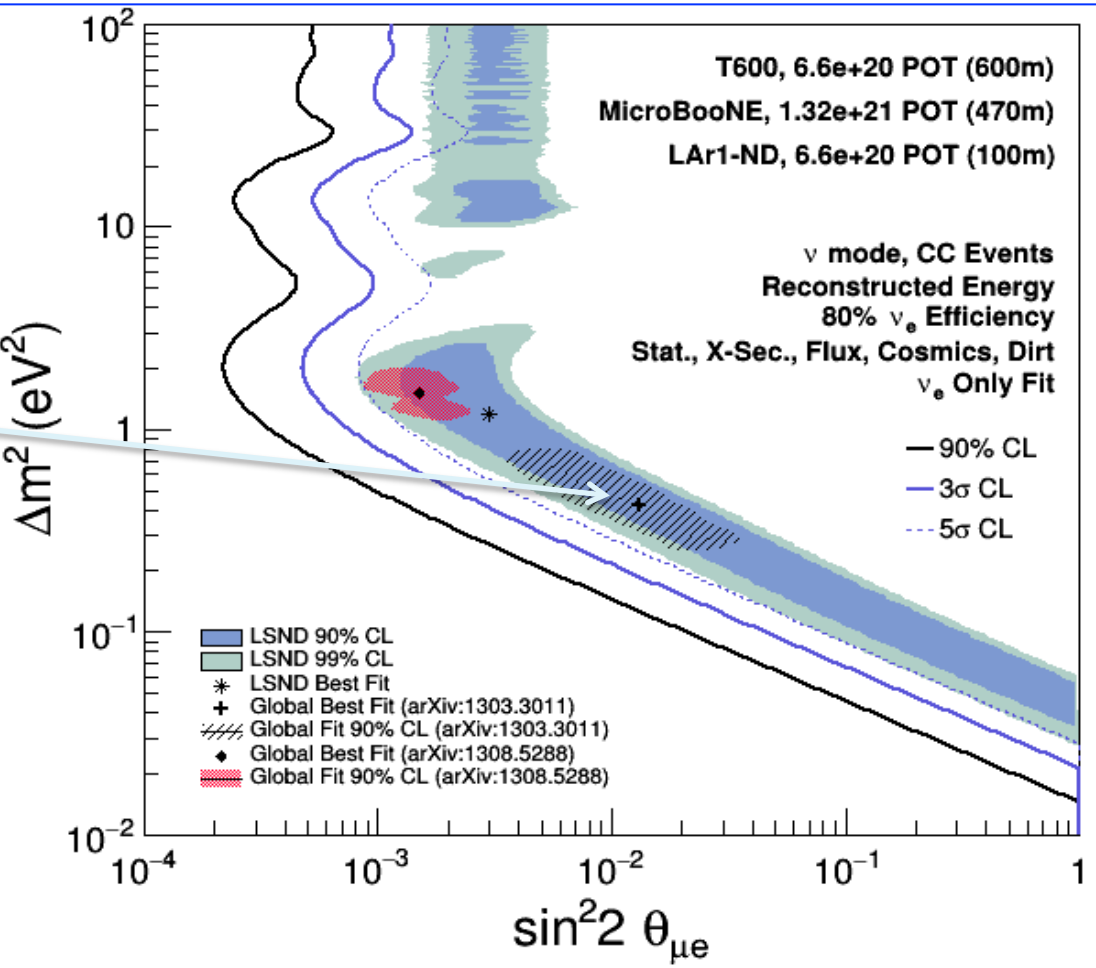
Off-beam triggers can be used to measure cosmic backgrounds to high precision – so negligible systematic uncertainties



SBN ν_e Appearance Sensitivity



~5σ coverage of LSND 99% CL Region for 6.6×10^{20} P.O.T. ~ 3 years (13.2×10^{20} for MicroBooNE)



SBN Science Goals

- Directly follow up on the **MiniBooNE neutrino anomaly** by utilizing the LArTPC technology to determine the composition of the observed excess as electrons or photons (MicroBooNE during Phase I)

- Apply the advantages of the LArTPC technology and *multiple detectors at different baselines* to the question of high-Δm^2 **sterile neutrino oscillations** for the *first time*, testing current allowed oscillation parameters at $\geq 5\sigma$ (Phase II)

- Study ν-Argon interaction physics using **millions of events** from both the Booster and Main Injector neutrino beams at Fermilab

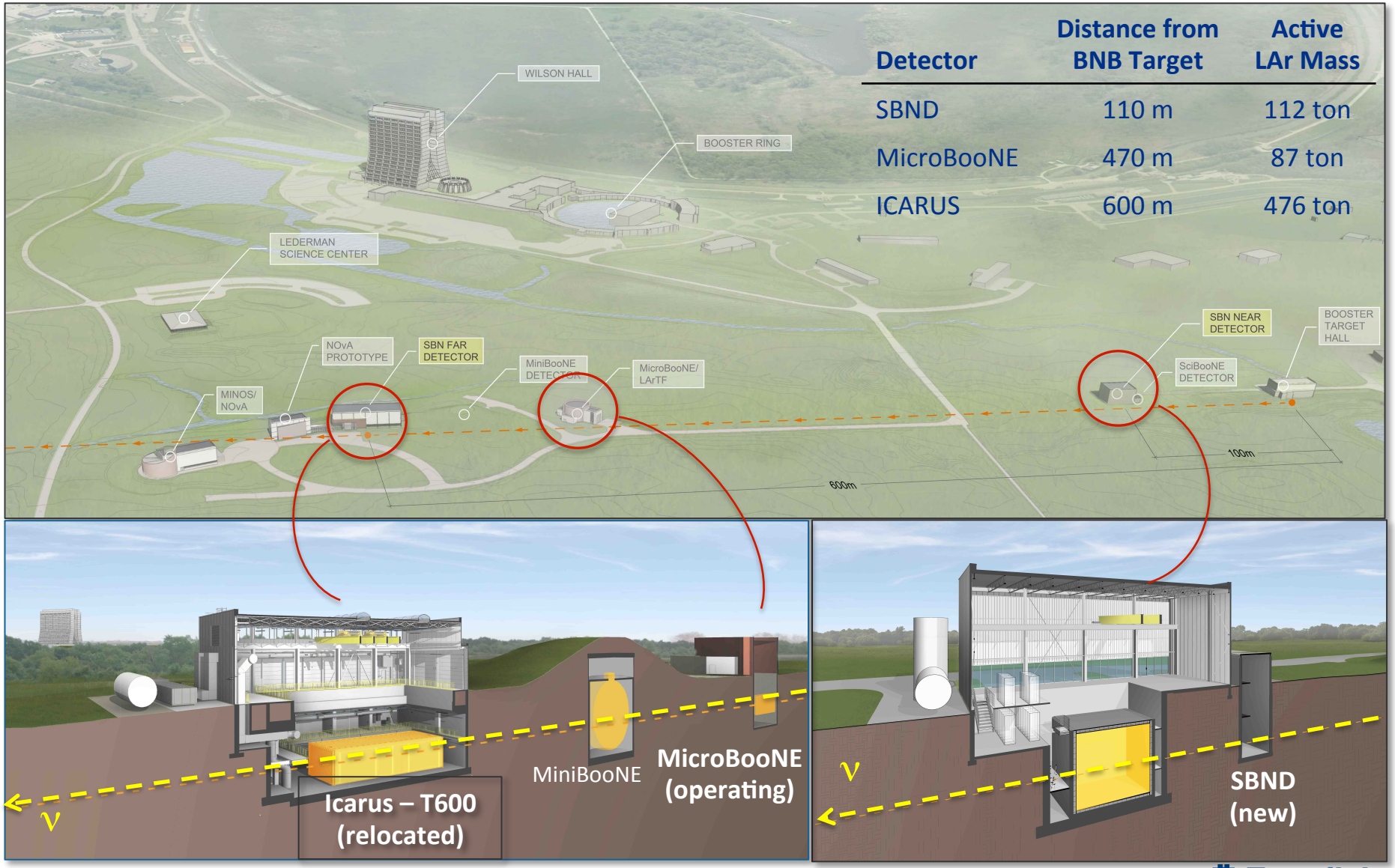
- Further **develop the LArTPC technology** toward the aim of applying it at very large scales for long-baseline physics in DUNE

Program Requirements and Assumptions

- Multiple LAr TPCs at different baselines
  - Flux systematics
  - Detector systematics
- Large far detector (~ 500t fiducial mass)
  - Statistics limited by far detector mass x neutrino flux x time
  - Program priority: earliest possible far detector operations
- Large integrated neutrino flux (> 6.6×10^{20} P.O.T. equivalent)
  - Statistics limited by far detector mass x neutrino flux x time
  - Implies 3+ years of beam
- Detector overburden and cosmics identification
  - Reject large cosmic background in TPC drift time

SBN Program Scope

SBN Program – Three detectors



Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton

SBN Program

Phase 1 (covered by this review):

- Design and construct two buildings
- Refurbish and install ICARUS T600 detector
- Design, construct, and install new ICARUS components
- Design, construct, and install the SBND detector
- Design, construct, and install infrastructure (eg cryogenics)

Phase 2 (not covered):

- Cold commissioning of ICARUS T600 and SBND detectors
- Physics operations and physics analysis of ICARUS, MicroBooNE and SBND detectors

SBN Program

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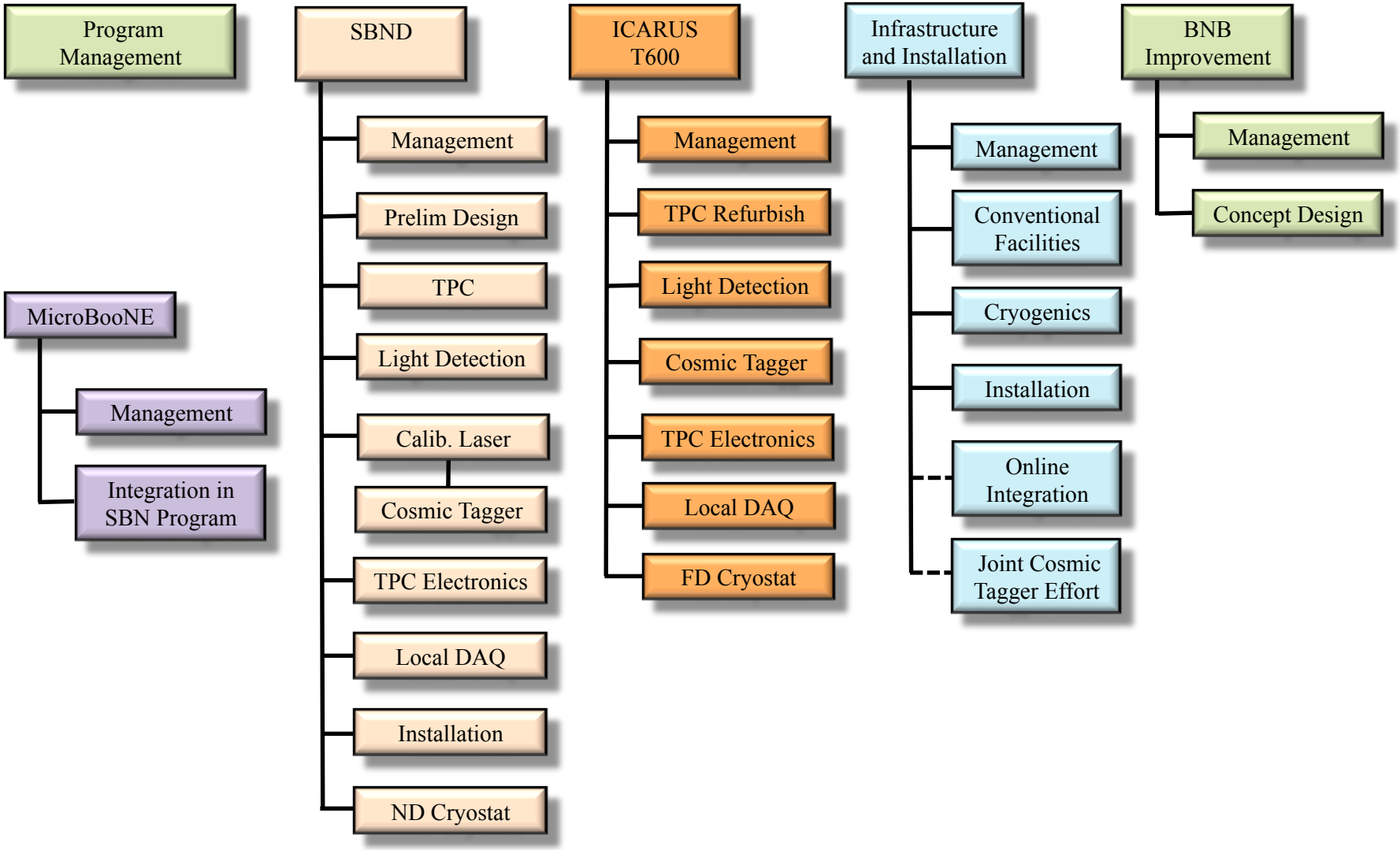
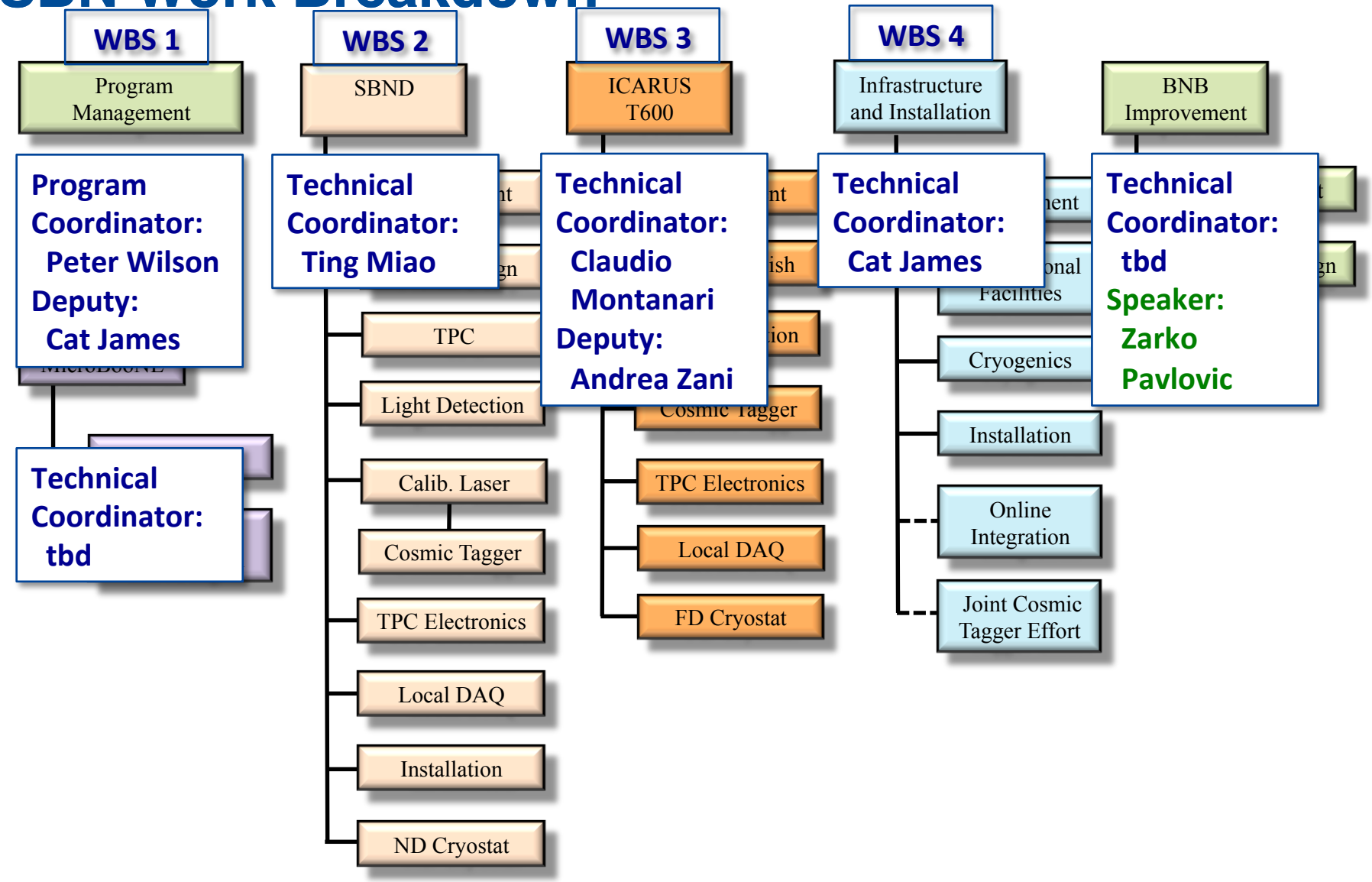
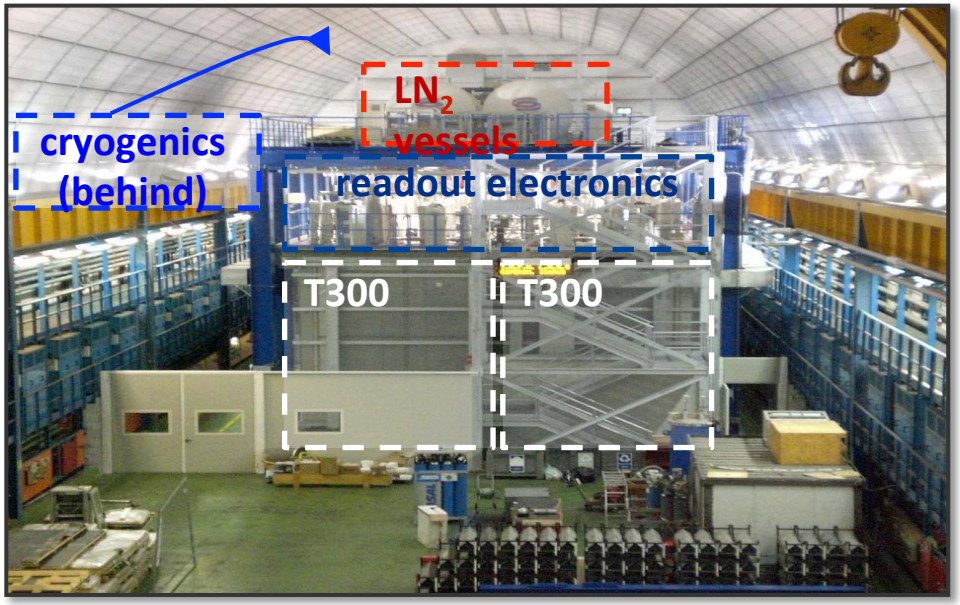
SBN Work Breakdown

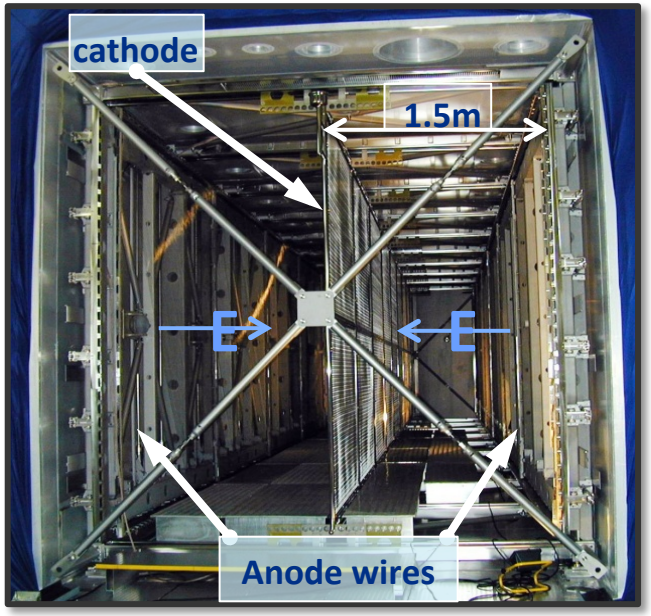


SBN Work Breakdown



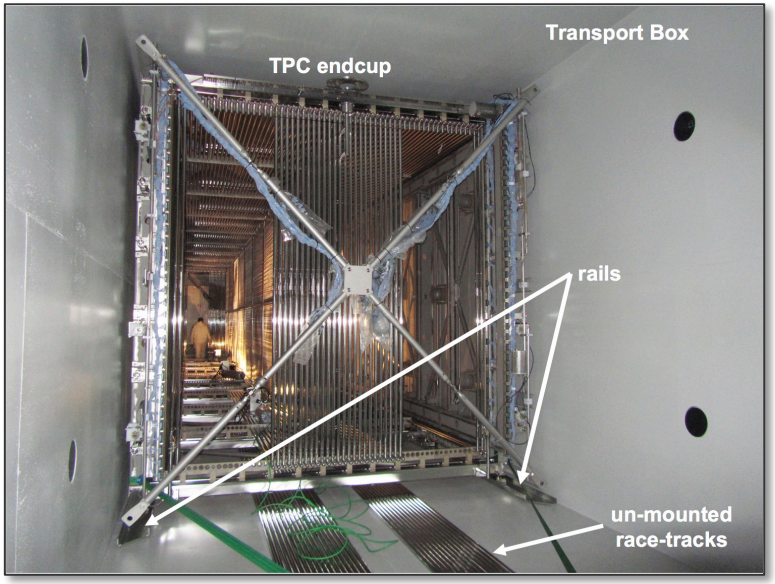
ICARUS-T600 at Gran Sasso





- Two identical modules (T300):
  - 3.6x3.9x19.6m^3 each
  - LAr active mass: ~476 t
  - Drift length = 1.5 m (1 ms)
  - Very high LAr purity achieved (τ_{ele} ~ 15ms)
- Two TPCs per module
  - 3 readout wire planes at 0, ±60°
  - ~ 54000 wires, 3 mm pitch and plane spacing
  - Charge measurement on collection plane
- PMTs for scint. light detection
  - 8” tubes (20 in one module, 54 on other)
  - VUV sensitive (128nm) with TPB wavelength shifter coating

ICARUS T600 Transport to CERN



Move to CERN completed
December 2014

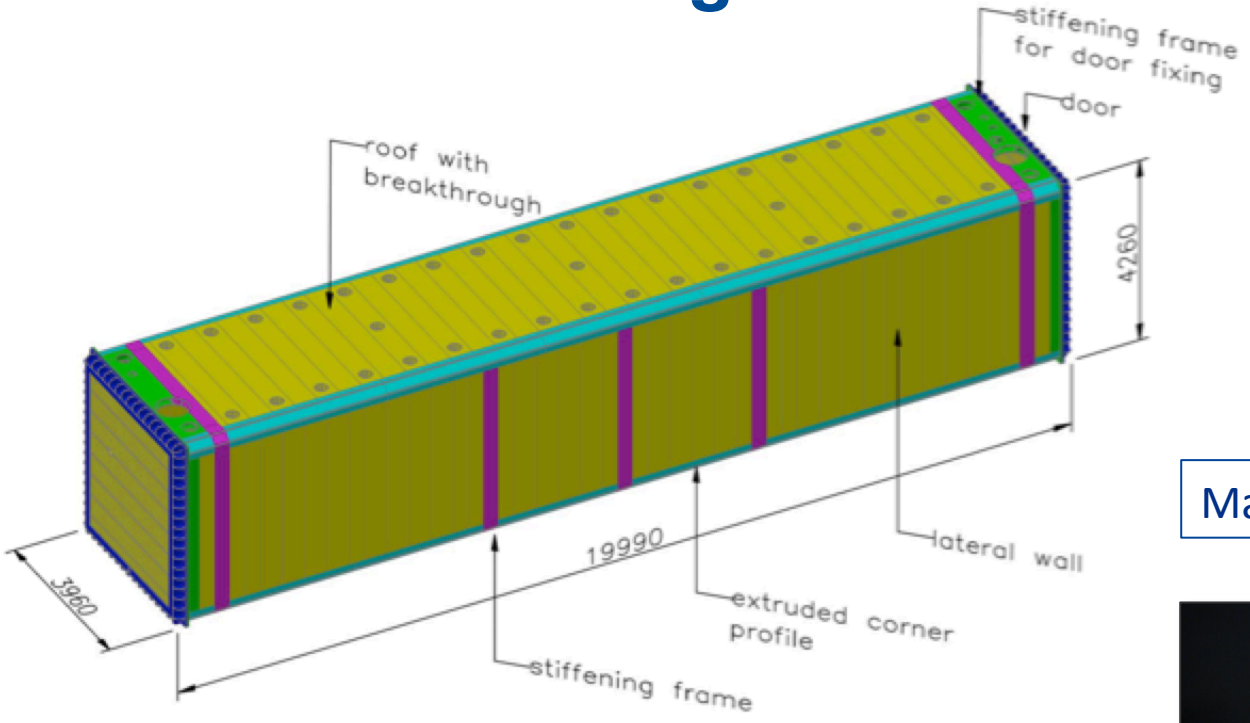
Scope of ICARUS Work at CERN (WA104)

- TPC refurbishing in progress:
  - New cryostats
  - Flatten cathodes
  - Replace internal TPC cabling
  - New HV decoupling boards
  - New 8” PMTs (90 per wire plane)
  - Upgrade TPC readout electronics
- Rebuild cryogenic system
- In planning stage (some may be DOE scope):
  - Cosmic Ray Tagger system
  - DAQ System

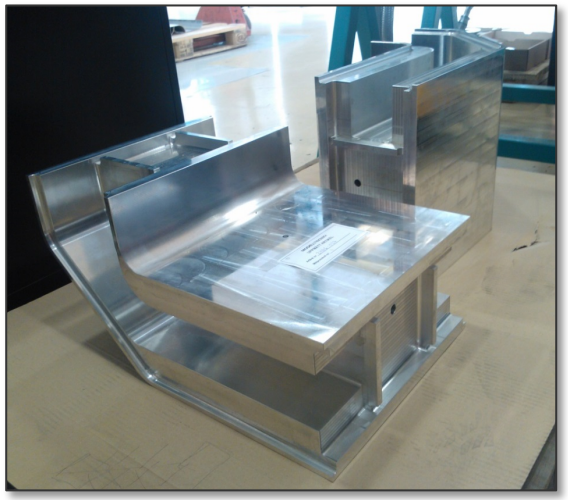
Details in talk by Claudio Montanari and Detector Breakout Session

First TPC Module in CERN Cleanroom

New Cold Vessel Design



Machined U-frame Corner



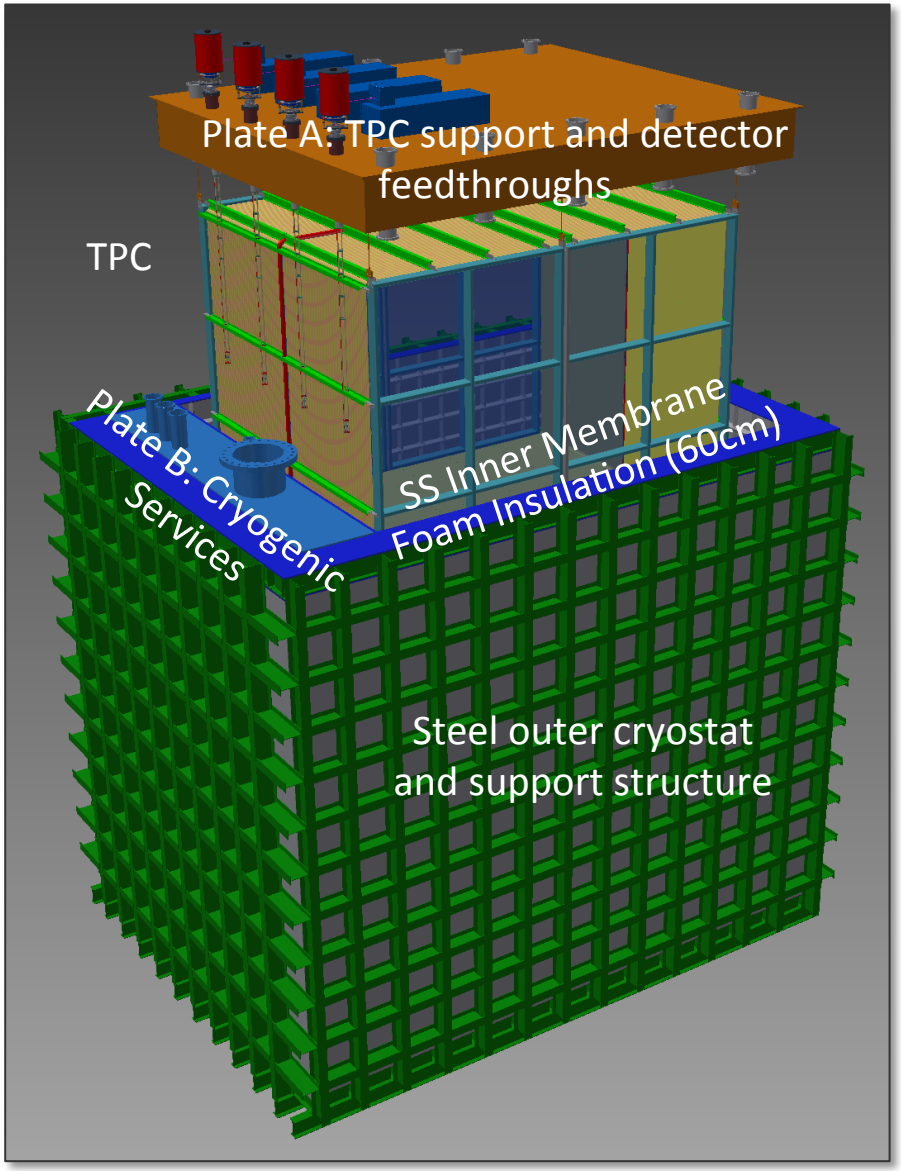
- Custom Al extrusions welded into panels at vendor
- U-frames assembled at CERN
- Final assembly at CERN

Details in talk by Claudio Montanari and Infrastructure Breakout Session

SBND Detector

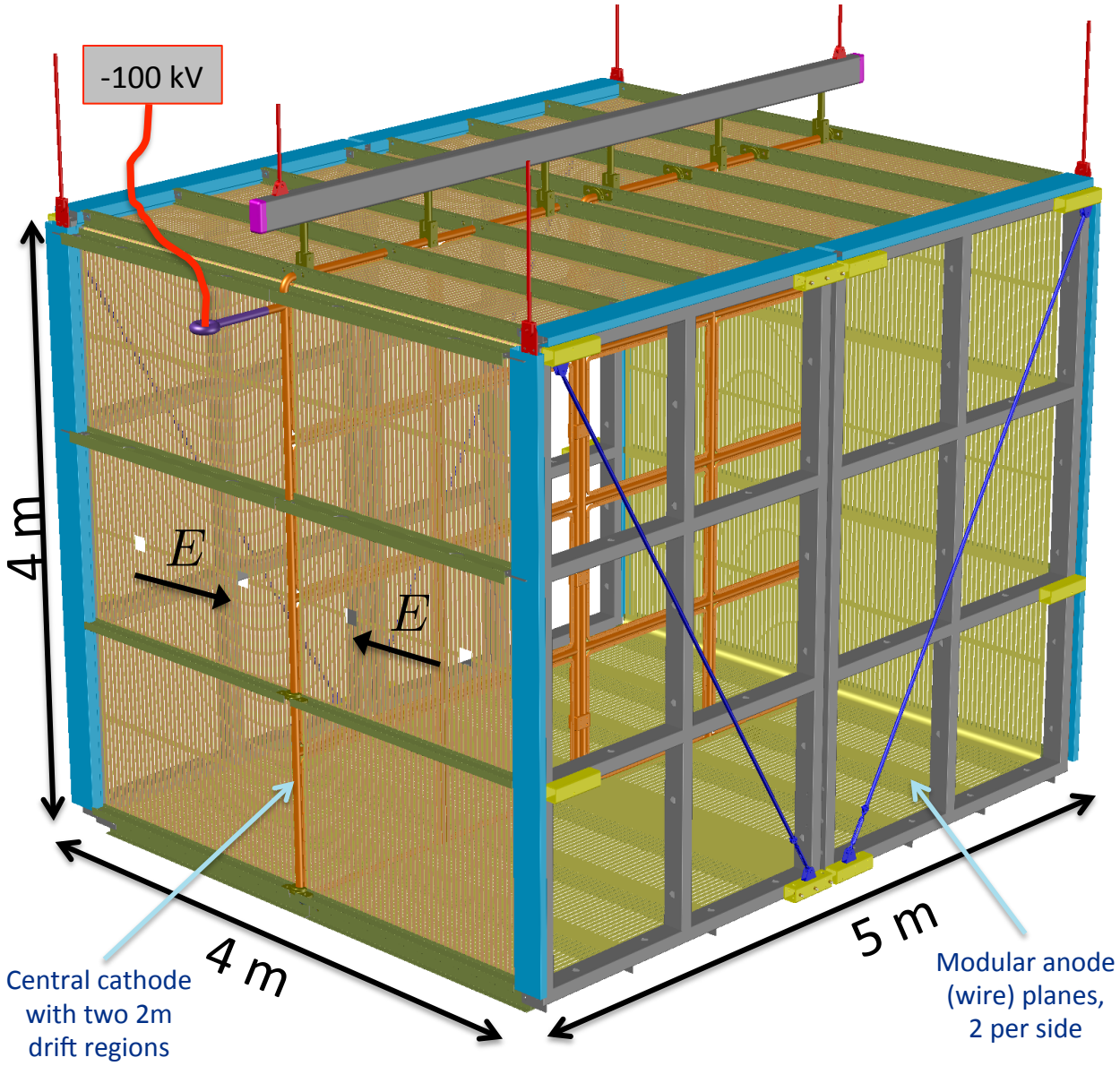
- Completely new detector incorporating experience from ICARUS, MicroBooNE, LBNE 35 ton
- Coordinate with DUNE on designs
- Scope of work:
  - TPC design and construction
  - PMT (8”) system
  - Laser Calibration system
  - Cosmic Ray Tagger
  - Cold TPC readout electronics
  - DAQ (and electronics infra)
  - Membrane cryostat
  - Integration and Installation

Details in talks by Ting Miao and Detector breakout sessions



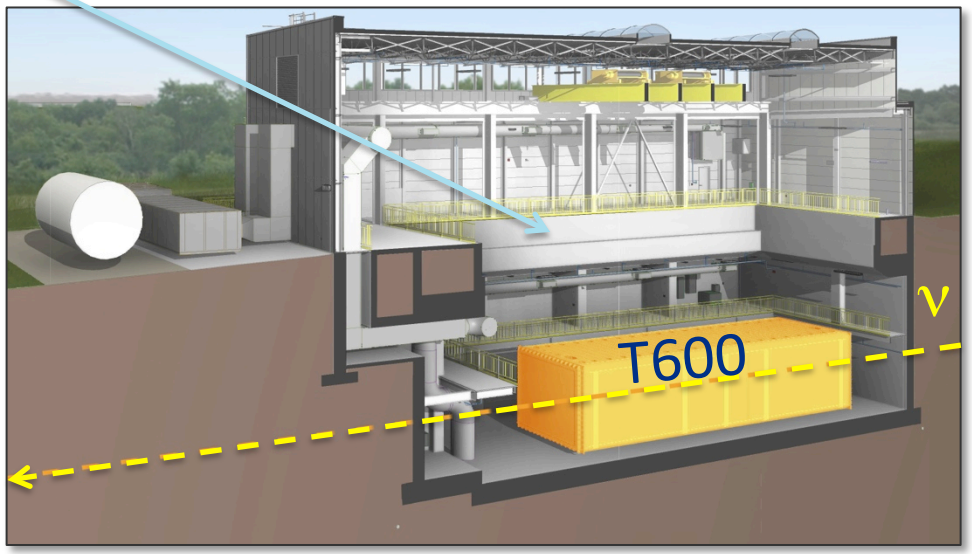
SBND TPC

- Joint design and construction project of UK-US Univs
- Fabricate components in 2017
- Assemble and install at FNAL in 2017



Far Detector Building

- Close cooperation between ICARUS, CERN and Fermilab on design requirements and review.
- Designed for 3m concrete overburden over detector to mitigate cosmogenic backgrounds for near surface operation
- Milestones:
  - ✓ Aug 2014 Start preliminary design
  - ✓ Mar 2015 Design complete
  - ✓ April 2015 Construction contract bidding
  - ✓ July 2015 Construction Start
  - ✓ Sept 2015 Excavation complete
  - ❑ Jan 2016 Concrete complete
  - ❑ June 2016 Building envelope complete
  - ❑ Oct 2016 Beneficial Occupancy

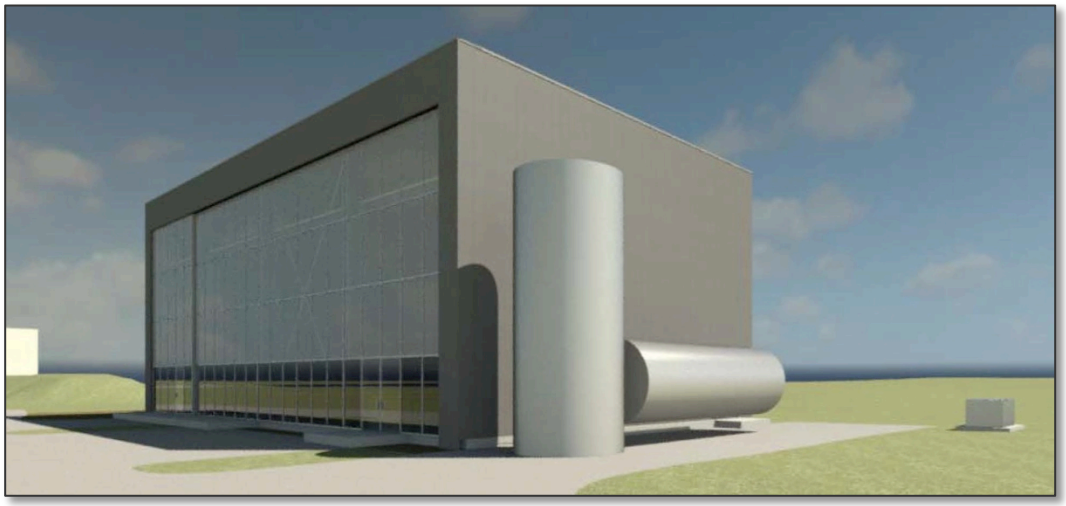


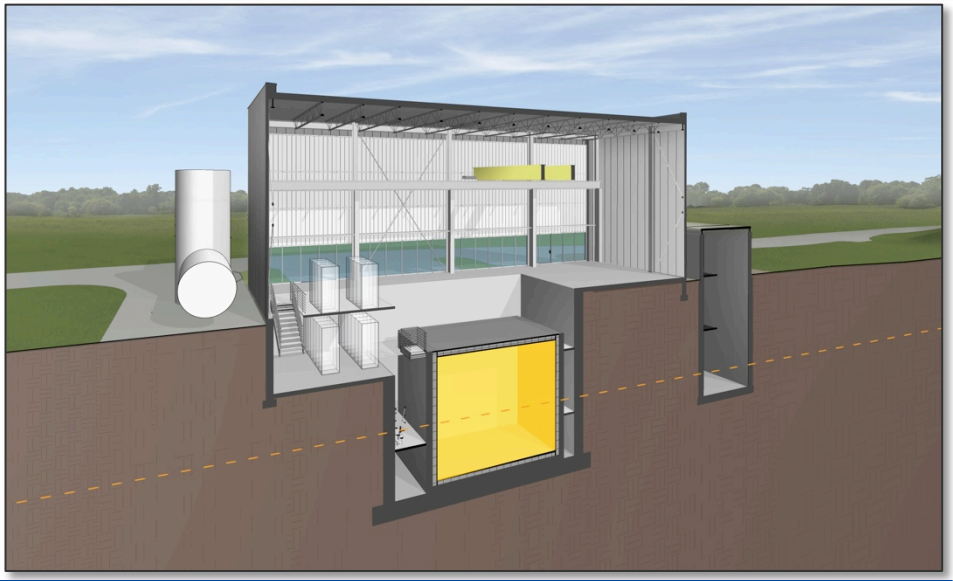
Details in talks by Cat James and Steve Dixon

Far Detector Building Progress

Near Detector Building

- Designed for 3m concrete overburden inside building to mitigate cosmogenic backgrounds for near surface operation
- Milestones:
  - ✓ Jan 2015 Design start
  - ✓ May 2015 60% Design complete
  - ✓ July 2015 Final design review
  - ✓ Aug 2015 Design complete
  - ✓ Oct 2015 Bidding complete
  - ❑ Dec 2015 Notice to proceed
  - ❑ Mar 2016 Construction start
  - ❑ Nov 2016 Beneficial Occupancy





Details in talks by Cat James and Steve Dixon

Detector Overburden

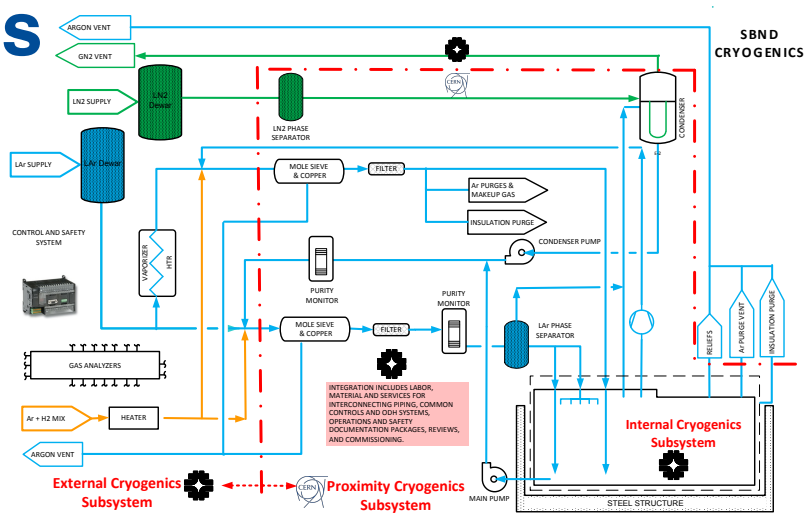
- Cosmic backgrounds in proposal assumed 3m of concrete overburden over both near and far detectors
  - Buildings designed to accommodate but not included in GPPs
- Scope for both detectors:
  - 40” thick (1.01m) of new bridging concrete blocks
  - 72” (1.78m) thick of recovered concrete shield blocks
  - Includes installation of blocks
  - Included in plan for DOE deliverables in FY18

Details in talks by Cat James and Infrastructure Breakout

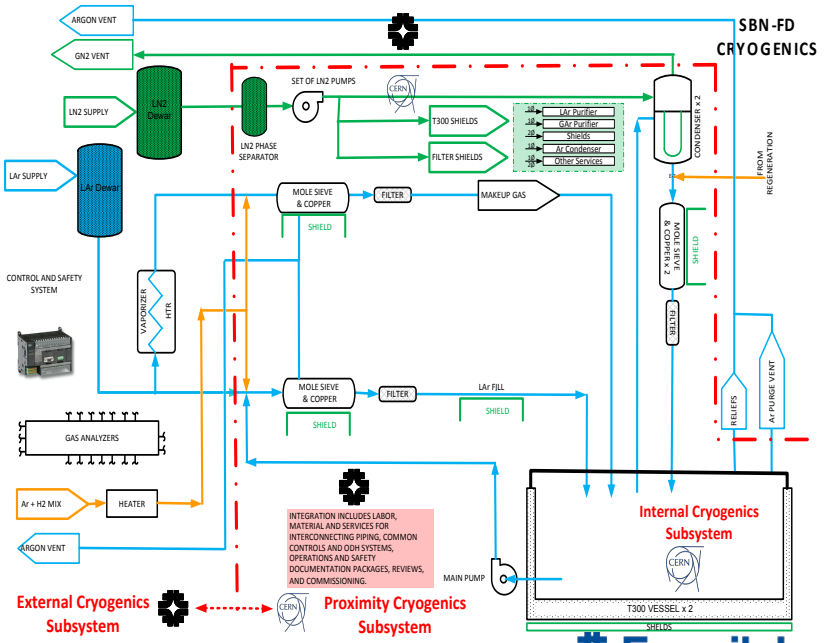
Scope of Cryogenics Systems

- Rebuild ICARUS cryogenic system
- New SBND cryogenic system
- Joint CERN-Fermilab responsibility
- Worked partitioning:
  - Internal : inside the cryostat
    - ICARUS – CERN scope
    - SBND – Fermilab scope
  - Proximity : Argon circulation & filtering
    - SBND & ICARUS - CERN scope
  - External : Nitrogen & Argon delivery
    - SBND & ICARUS - Fermilab scope
  - Controls – Femilab scope

Details in talk by Cat James and Infrastructure Breakout

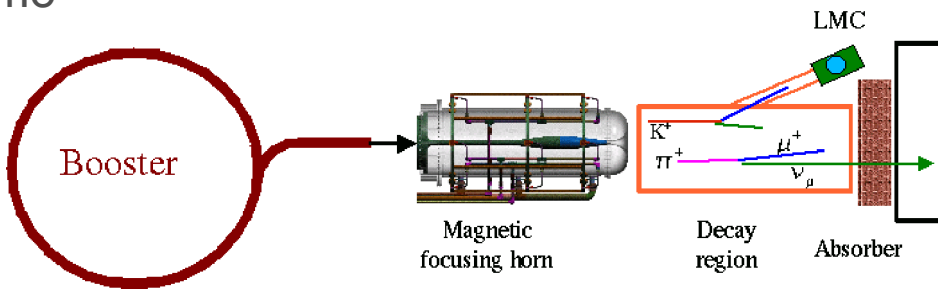


Process Flow Diagrams



Booster Neutrino Beamline Improvements

- The sterile ν search is limited by far detector statistics
  - Detector mass x Neutrino flux x Time
- Increased ν flux would further secure the program sensitivity
  - Higher ν production efficiency
  - More protons on target (P.O.T.)

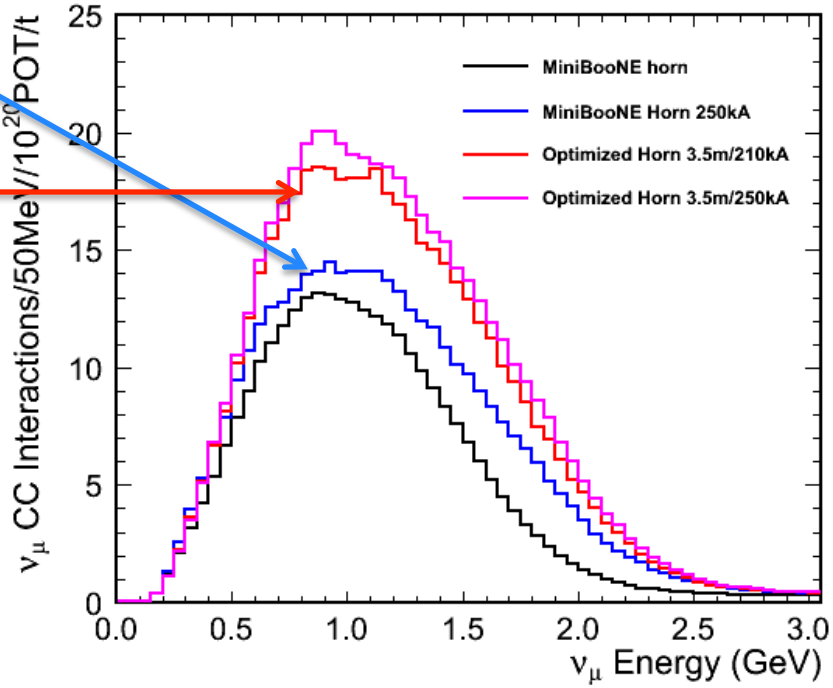


- Current BNB ν energy distribution optimized for MiniBooNE
  - LAr-TPCs more tolerant of high energy tail (distinguish NC π^0 background)
  - Allows for reconsideration of target and horn design
- BNB P.O.T. rate was limited to 5 Hz average matching Booster capability
  - After PIP, Booster could deliver up to 15 Hz when NUMI beam and Muon program is off
  - Upgraded power supply would permit more opportunistic use of beam pulses

Booster Neutrino Beamline Improvements

PreConceptual design work considered three horn options:

- × Two horn system plus new PS: does not fit in existing target pile
- × MiniBooNE-style horn + PS mods
- ✓ New 3.5m horn design + PS mods:
  - Add 60-70% more neutrinos
  - Less expensive that increasing detector mass
- Conceptual design in early 2016
- Preliminary cost estimate: $6.5M



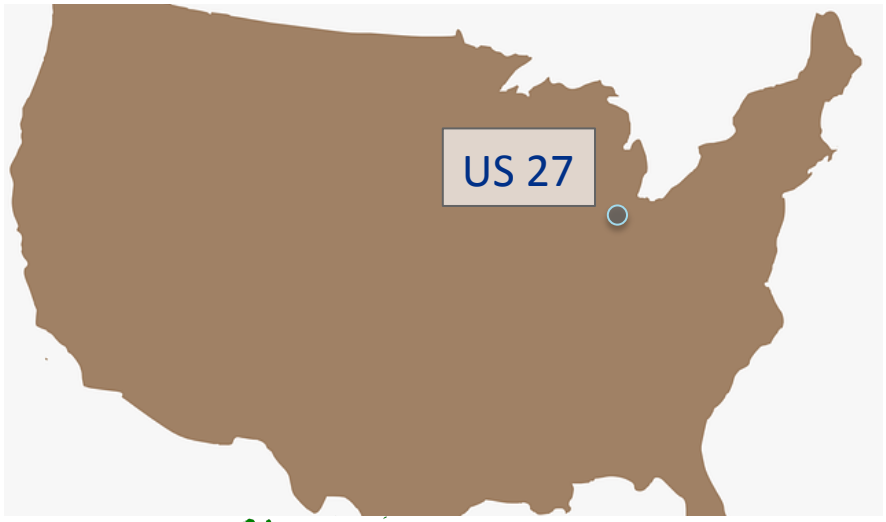
- Ready to use Accelerator Improvement Project (AIP) funds starting in FY17 (F17-19)

Details in talk by Zarko Pavlovic

Resources and Agreements

SBN Institutions

Over 225 Authors Total



Institutions	SBN	SBN-DUNE Overlap
US	27	25
Non-US	28	24

Primary SBN Funding Sources

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

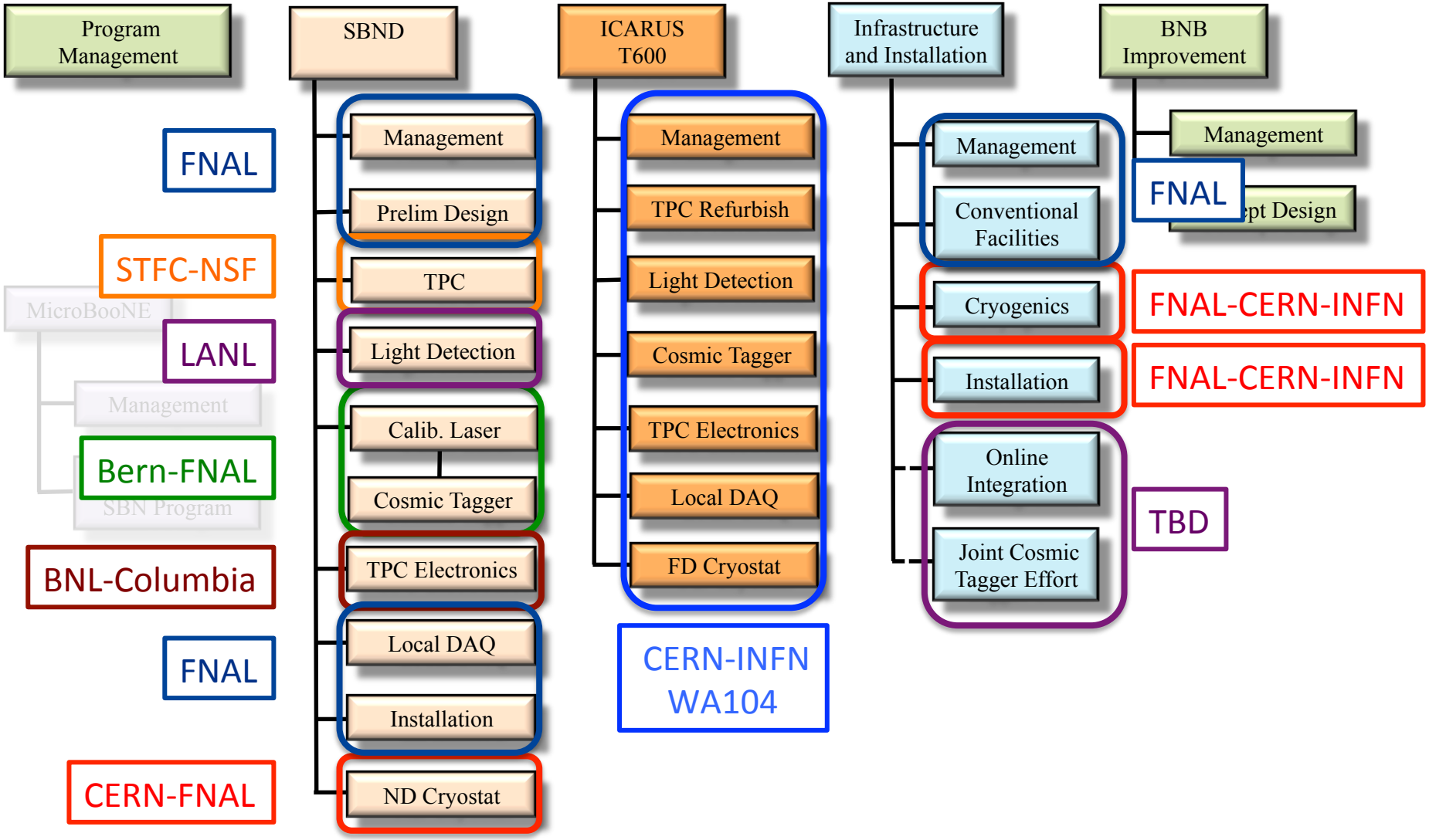
INFN

CERN

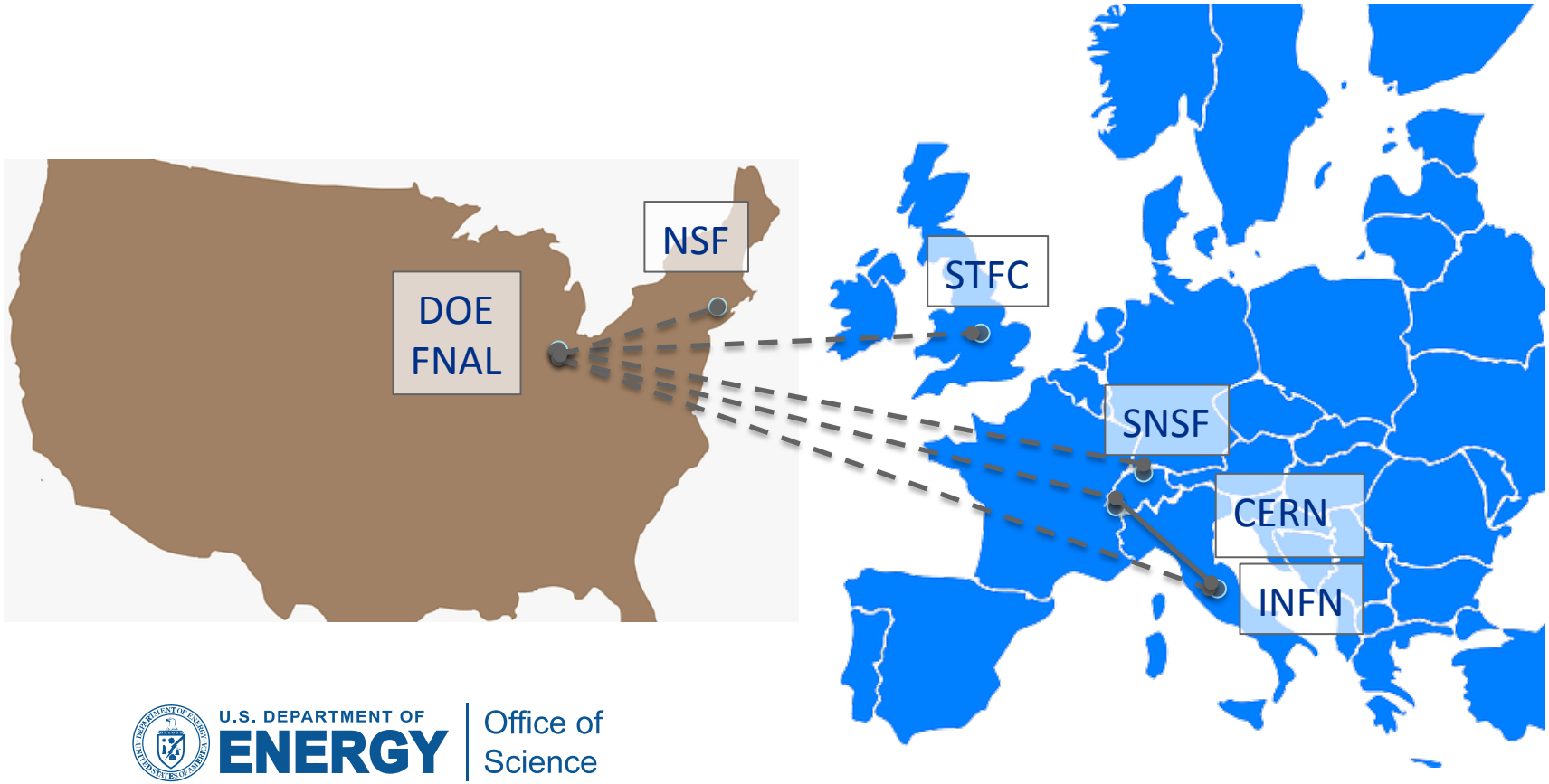
Science & Technology Facilities Council

FNSNF
Swiss National Science Foundation

SBN Work Breakdown - Funding Source



Main International Agreements



U.S. DEPARTMENT OF ENERGY | Office of Science

Agreement Status
— Signed
- - In development

NSF

INFN

CERN

Science & Technology Facilities Council

FNSNF
Swiss National Science Foundation

ICARUS refurbishment at CERN (WA-104)

Addendum No. 02

to the
Memorandum of Understanding
for Collaboration in the Neutrino Program

WA104

Improving the ICARUS T600 Liquid Argon Time Projection Chamber (LAr TPC) in order to prepare for its operation at shallow neutrino depths.

Version_22-11-2014

The European Organization for Nuclear Research (CERN)

and

The INFN, on behalf of the WA104 Collaboration

endorse the Present Addendum to the Memorandum of Understanding with the indicated improvements of ICARUS T600 and with the related R&D on Liquid Argon Time Projection Chamber (LAr TPC).

for CERN 25/11/2014

The Director of Reasearch and Computing

Sergio Bertolucci

For INFN, on behalf of INFN participating Institutes

The President

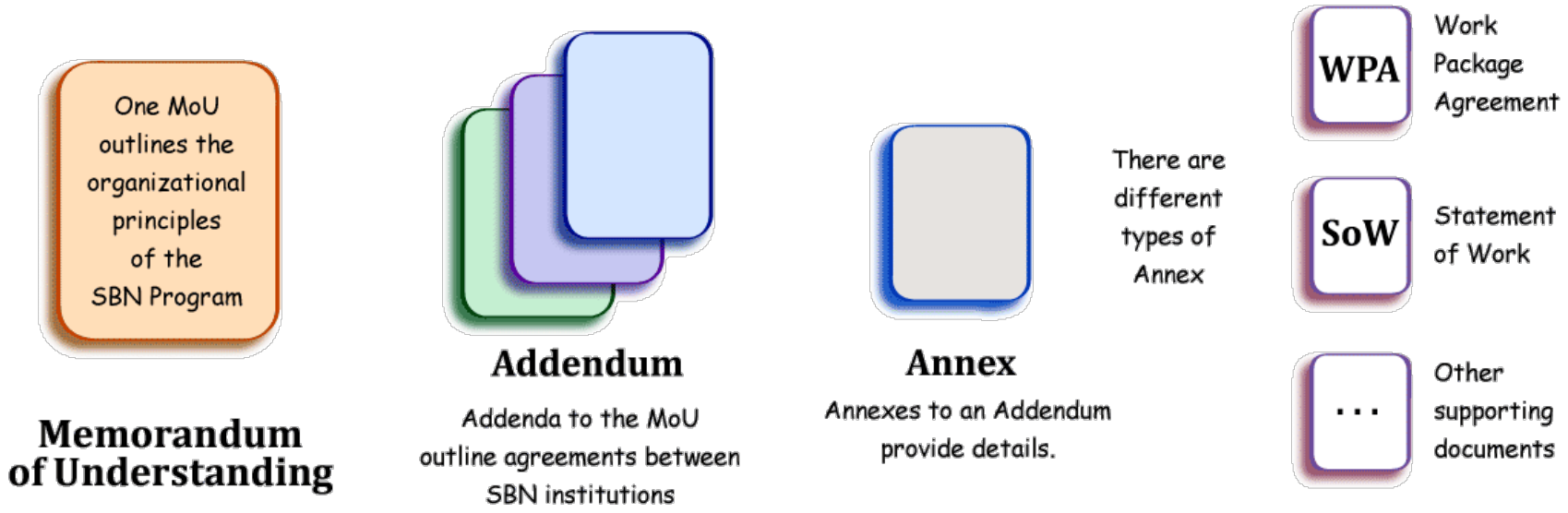
ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE
Prof. Fernando Ferroni

Signature

Place and Date

ROMA, 28 NOV. 2014

Proposed SBN Program Agreement Structure



- Draft MOU ready for review
- Drafts of first Addenda and Annexes ready for review
  - Bi-lateral covering design, construction and installation
  - Later: multilateral for operations and multilateral for physics
- Work Package Agreements drafted for cryogenics activities, SBND cryostat, several components of SBND
- Fermilab Sharepoint page for SBN agreements:

https://web.fnal.gov/collaboration/sbn/_layouts/15/start.aspx#/SitePages/SBN_Agreements.aspx

ICARUS Contributions and Agreements

	DOE	NSF	CERN	INFN	WPA/SOW Status
T600 Refurbishing including new PMTs, Cryostats			50%	50%	WA104 Signed
TPC Electronics				100%	Add to WA104?
T600 Transport to FNAL			tbd	tbd	Add to WA104?
Cosmic Ray Tagger	tbd	?	25%*	25%*	WA104 Signed + ?
Civil Construction	100%				N/A
Overburden	100%				N/A
Cryogenics	~45%		~45%	~10%	Ready to sign
DAQ	tbd		tbd	>50%	Not started
Integration and Installation	>50%		tbd	tbd	Not started

* $1.2M CHF in WA104 agreement, estimate need at least 2 times this (core cost)
tbd – expect contribution but fraction not determined
? – possible future proposal
tbd – expect contribution but fraction not yet determined

SBND Contributions and Agreements

	DOE	NSF	CERN	UK STFC	SNSF	LANL LDRD	WPA/SOW Status
TPC Design and Fabrication		~50%		~50%			Prelim Draft
TPC Electronics	85%	15%					Signed
PMT System						100%	Prelim Draft
Calibration Laser					100%		Final Draft
Cosmic Ray Tagger					100%		Final Draft
Cryogenics	~50%		~50%				Final Draft
Cryostat	~10%		~90%				Prelim Draft
DAQ	100%						N/A
Integration and Installation	100%						N/A
Civil Construction	100%						N/A
Overburden	100%						N/A

tbd – expect contribution but fraction not yet determined

DOE Cost Estimate

Program Schedule Development

- Integrated program schedule created using Microsoft Project
  - Maintained by SBN Program Office at Fermilab
- ICARUS-WA104 activities at milestone level (no resources)
- SBND activities detailed with resources – relatively mature
  - Bottoms up from L2 managers
  - Includes in-kind contributions
- Infrastructure
  - Civil construction activities at milestone level
  - Cryogenics includes sharing of responsibilities with CERN – New (Nov 2015)
  - Far detector integration as a Planning Package – New (Nov 2015)
- Not yet included (plan still in development):
  - Cosmic Ray Tagger for ICARUS
  - Common Online Integration
- Keep separate schedule:
  - BNB improvements – will make a separate schedule for AIPs

DOE Funding

- Building construction: General Plant Project (GPP) funds
- SBND design, construction and installation (incl cryogenics):
  - Detector R&D funds in a dedicated Budget & Reporting category
  - Managed by Neutrino Division
  - Budget FY15-18 ($3.0M, $3.0M, $3.0M, $1.5M)
  - Labeled: “R&D”
- ICARUS infrastructure design and installation support:
  (Also common activities such as management)
  - Detector operations funds fenced within Neutrino Division budget
  - Budget FY15-18 ($0.3M, $2.9M, $2.9M, $2.9M)
  - Labeled “OPS”
- BNB Improvements requested:
  - Accelerator Improvement Project (AIP) Funds FY17-19 $6.5M total

Note: All budgets and costs shown are fully burdened

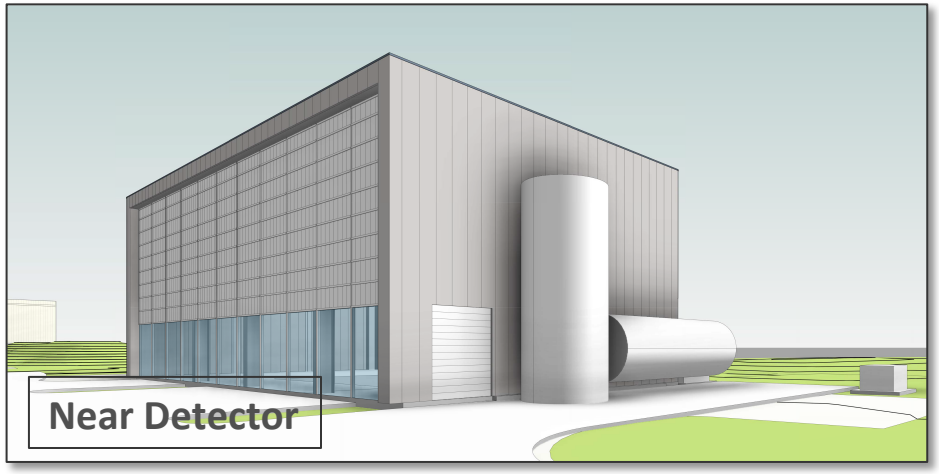
Conventional Facilities – GPP Funds

Budget in K$	FY14	FY15	FY16	Total
Site Development		1,500	700	2,200
Near Detector		2,050	3,300	5,350
Far Detector	1,000	5,298	3,502	9,800
Total	1,000	8,848	7,502	17,350

Budget covers :

- Engineering Design (EDIA)
- Construction Contract
- Management reserve

Managed by Fermilab Facilities Engineering Services Section (FESS)

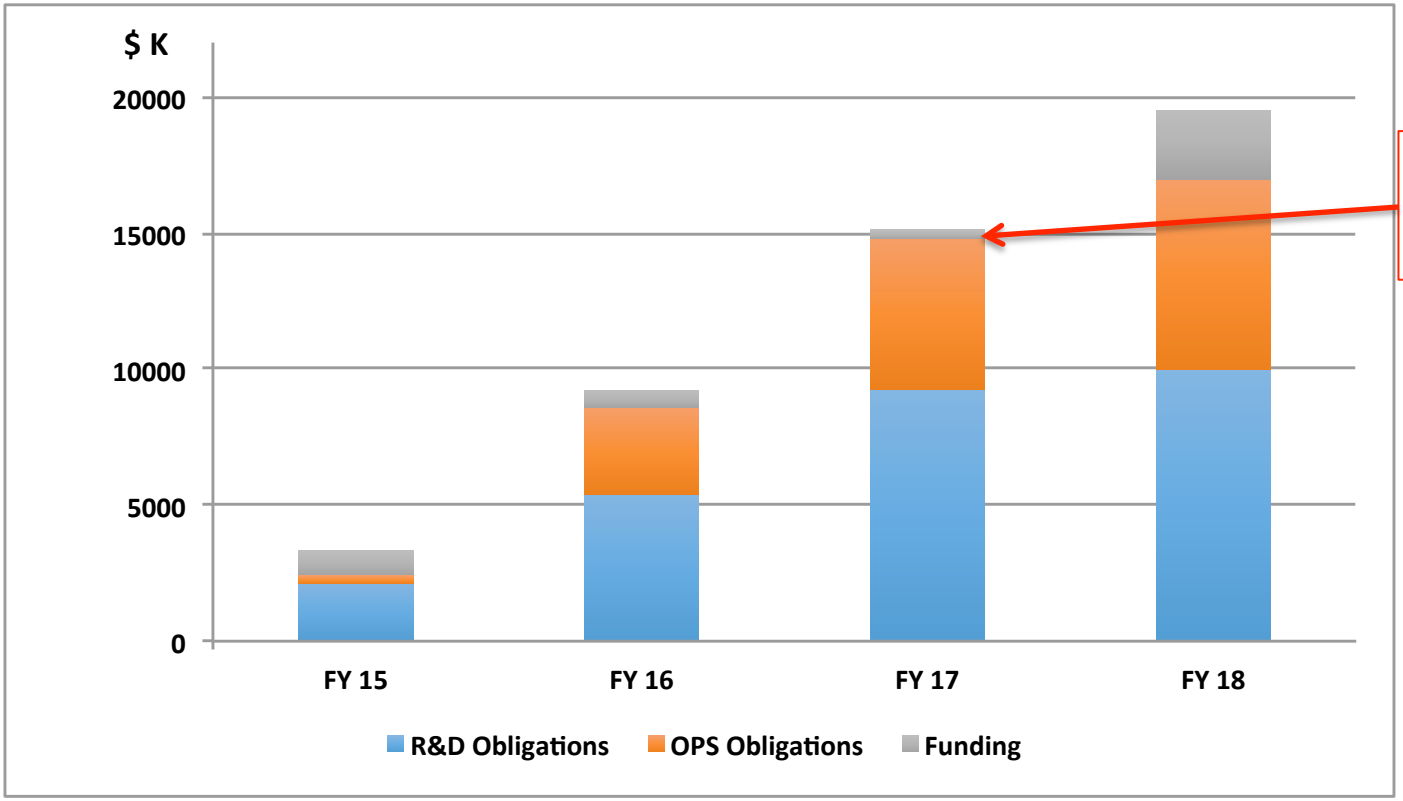


DOE Base Cost Estimate

	Each FY $K	FY 15	FY 16	FY 17	FY 18
SBND	R&D Funding	3,000	3,000	3,000	1,500
	R&D Cost	592	4777	3899	715
	R&D Obligations	2,119	3,286	3,862	715
ICARUS and Common	OPS Funding	315	2,900	2,900	2,900
	OPS Cost	315	2863	2355	1468
	Ops Obligations	315	2863	2355	1468

- Cost rollup just completed (Dec 1)
  - No resource leveling
- Cumulative: R&D costs exceed budget in FY17
- Very little Management Reserve

DOE Cumulative Obligations



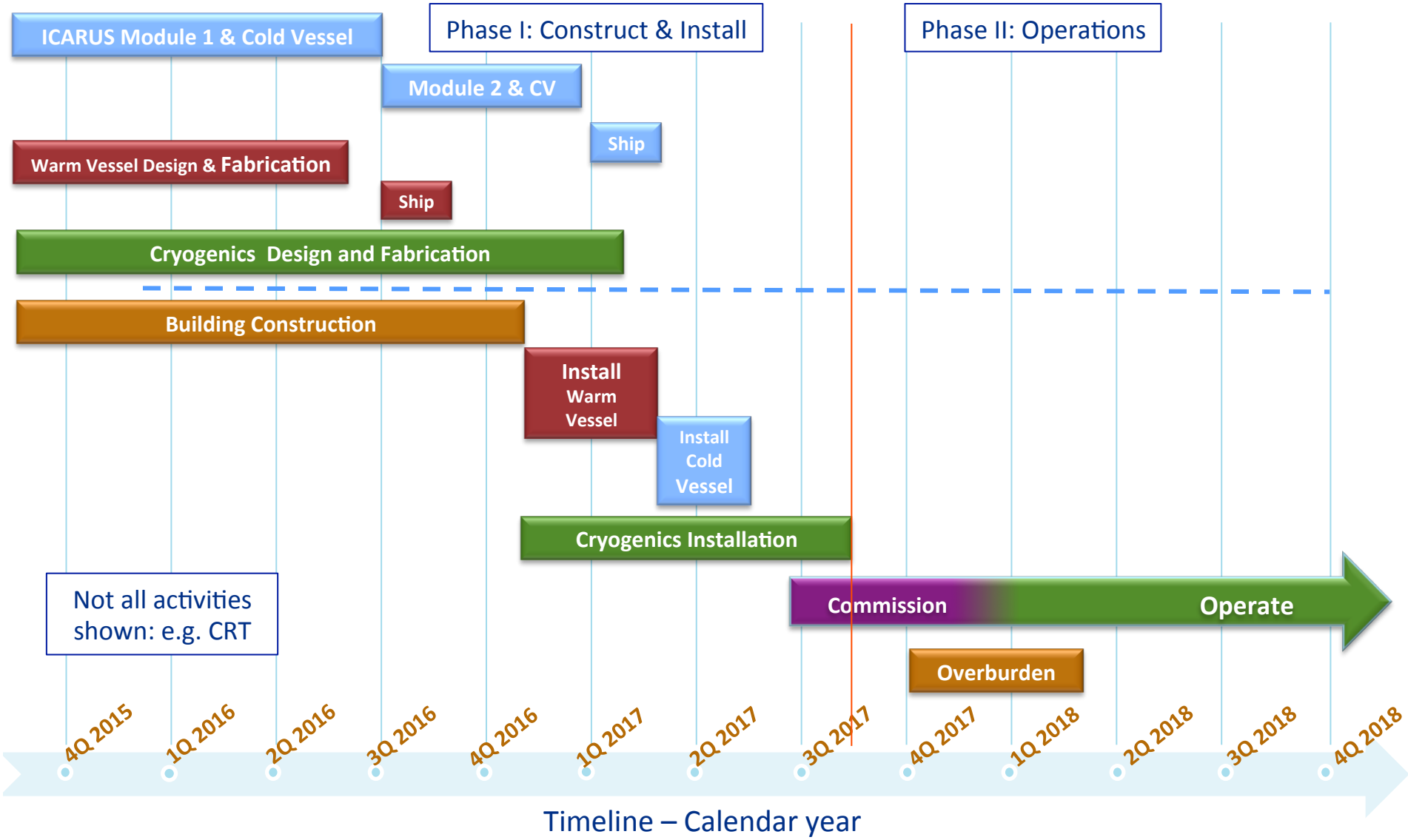
No Management Reserve in FY17

Each FY $K	FY 15	FY 16	FY 17	FY 18
R&D Funding	3,000	3,000	3,000	1,500
R&D Cost	592	4777	3899	715
R&D Obligations	2,119	3,286	3,862	715
OPS Funding	315	2,900	2,900	2,900
OPS Cost	315	2863	2355	1468
Ops Obligations	315	2863	2355	1468

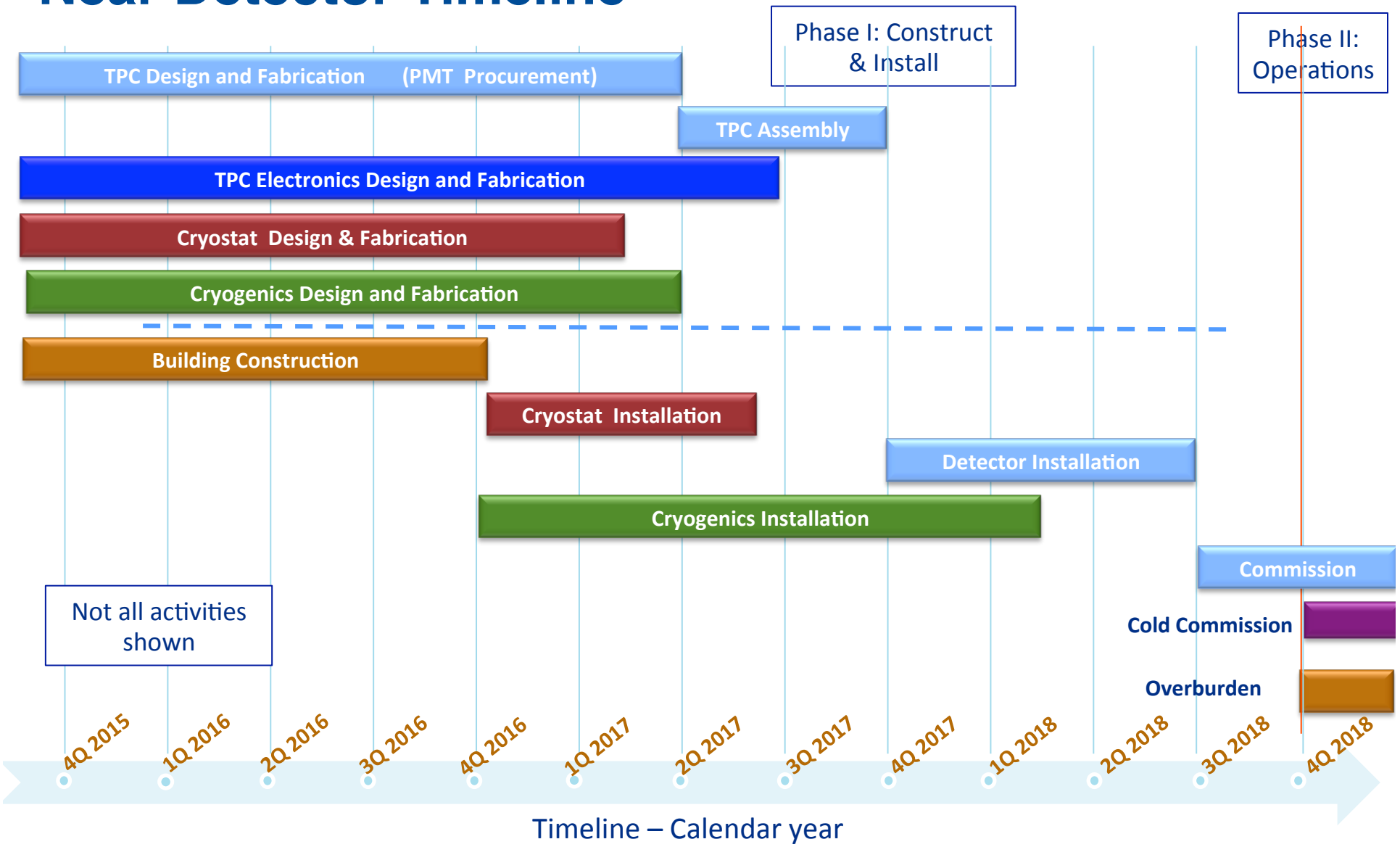
Discuss in Management Breakout

Schedule

Far Detector Timeline



Near Detector Timeline



Program Coordination

SBN Program Office

- Support realization of the SBN detectors and infrastructure at Fermilab
  - Work with program Technical Coordinators
- Ensure that detectors and infrastructure are compliant with Fermilab/DOE ES&H standards
- Assist in quality assurance planning
- Plan and oversee DOE funded components of the program
- Consists primarily of members of the Fermilab Neutrino Division

Program Coordinator – *Peter Wilson*

Deputy Coordinator – *Catherine James*

Program Mechanical Engineers

SBND integration – *Joseph Howell (PPD)*

ICARUS integration – *Andy Stefanik*

Program Electrical Coordinator – *Linda Bagby*

Logistics Coordinator – *Michael Dinnon*

ES&H Coordinator – *Angela Aparicio*

CERN-INFN-Fermilab Safety Coordination:

Fermilab POC – *Min Jeong Kim*

CERN POC – *Olga Beltramello (CERN-PH)*

Project Controls – *Richard Krull*

Financial Officer – *Molly Anderson*

Administrative Support – *Etta Johnson*

SBND TC – *Ting Miao*

ICARUS TC – *Claudio Montanari*

Infrastructure TC – *Catherine James*

Environment Safety Health and Quality Assurance

- SBN program work is distributed across many institutions in US and Europe. Work will be done following ES&H rules and oversight of the local institution.
- All equipment to be installed and operated at Fermilab must satisfy Fermilab ES&H Manual (FESHM) and pass the Operational Readiness Clearance Process
- Early evaluation during the design and fabrication process will streamline the process. Examples:
  - Process being put in place for evaluation of electronics designs prior to fabrication. Based lessons from MicroBooNE
  - Preliminary ODH analysis part of building design process (SBN docDB 377)
  - Planning for membrane cryostat qualification: agreement on process between CERN Neutrino Platform, SBN and LBNF (SBN docDB 651)
- Integrated Safety Management Plan is in draft form (SBN docDB 781)

Coordination of Common Solutions

- SBN cryogenics will share designs where applicable
- SBND working with ICARUS on PMT-based photon detection system
  - Take advantage of experience and facilities set up at CERN
- Cosmic Ray Task force being started to address common needs
- SBN – DUNE coordination:
  - SBND and DUNE actively planning common Cold Electronics design and testing plan
  - SBND pursuing light guide photon detection system as R&D toward DUNE
  - Started common DAQ planning with DUNE (November workshop)

Summary

Status Summary

- Buildings progressing well: construction completion fall 2016
- ICARUS progressing well:
  - First T300 refurbishing will complete early 2016, second in mid-2016
  - Delivery of new PMTs started
  - Cryostat fabrication underway
  - New TPC electronics to fabrication contract early in 2016
- SBND designs nearing final stages
  - TPC in final design and preparing for fabrication
  - Redesigned cold ASICs nearing prototype fabrication submission
  - Cryostat nearly ready for contracts
  - Preliminary integration and installation plan nearly complete

Status Summary (cont)

- Plan to address cosmic backgrounds still developing
  - Plan for overburden developed – New in Nov 2015
  - SBND Cosmic Ray Tagger (CRT) design ready for final design review
  - Design for ICARUS CRT in development
    - Need additional funding (e.g. not in DOE budget)
  - Initiating Joint SBN Cosmics Task Force (ICARUS, MicroBooNE and SBND) to finalize requirements and designs

Talk by Bob Wilson

- Plan for Online systems still developing
  - Capturing requirements for backend hardware and software
    - SNB-DUNE DAQ Workshop in November

Talk by Wes Ketchum

  - Build on existing ICARUS and MicroBooNE capabilities
  - Examining choices for hardware and software platforms
- ICARUS Integration and Installation Plan

Talk by Andy Stefanik

  - New Fermilab Team: Scientist, Engineer, Designer – Started Nov 2015

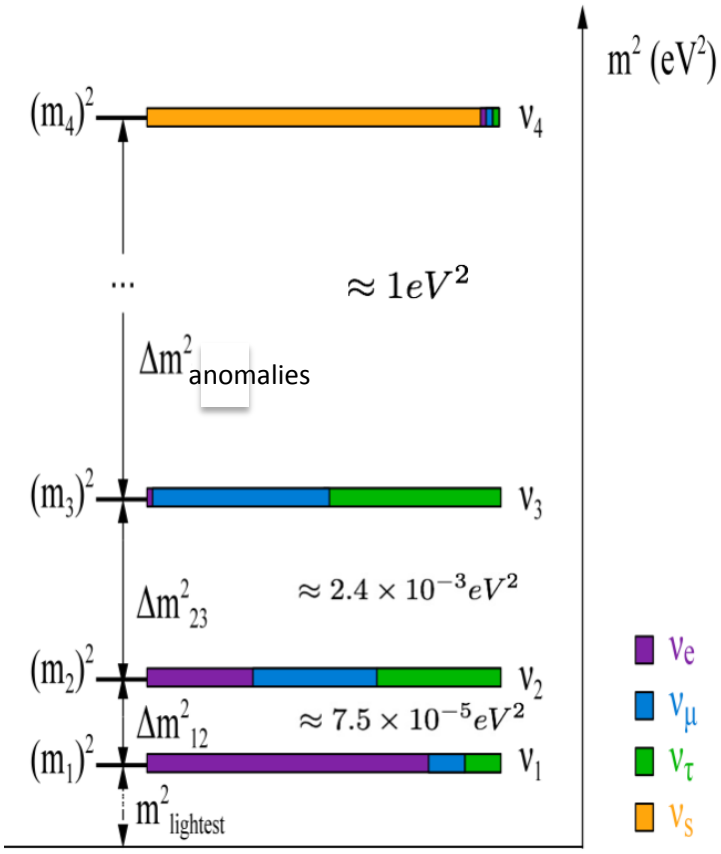
Conclusions – Charge Questions

- Scope of SBN Program defined:
  - Deliverables identified for partnering organizations covering almost all of the program scope
  - MOU and agreements in draft form
  - Primary uncovered deliverable is ICARUS Cosmic Ray Tagger (CRT)
- Designs documented in CDR have progressed to Preliminary or Final stage
  - Subsystem design reviews in progress
  - Process to complete reviews of all systems
- Base cost estimate developed for defined DOE deliverables
  - Little management reserve within current budget guidance to cover contingency or additional scope (e.g. CRT)
- ES&H plans in place taking advantage of experience from MicroBooNE and DUNE 35 ton Prototype

Backup Slides

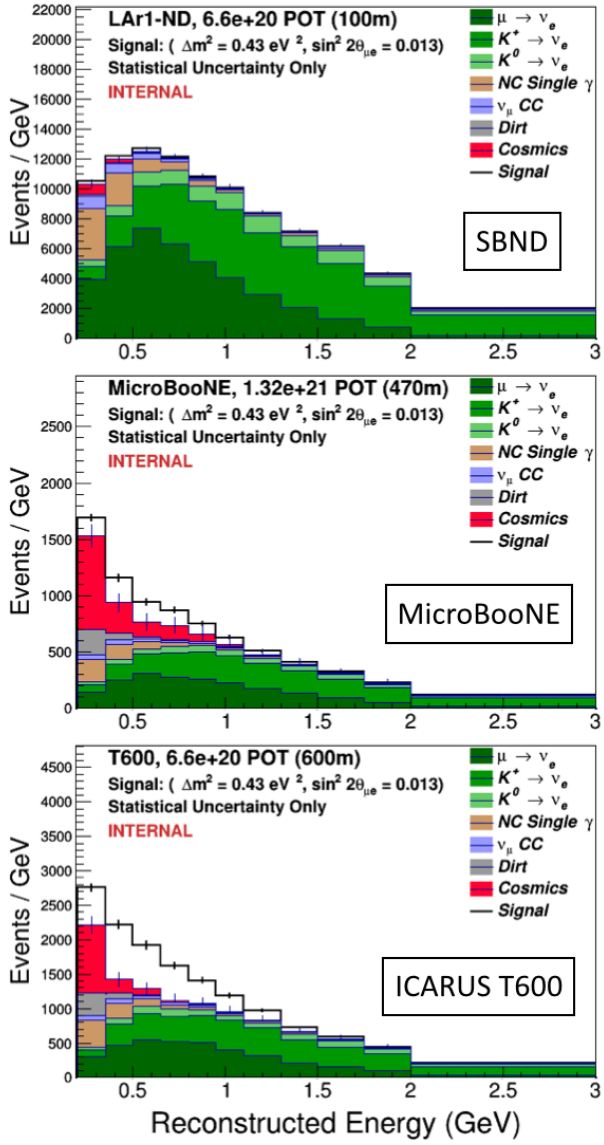
Physics Beyond the 3-ν SM?

- In principle, oscillations can provide a window onto particle sectors not accessible through SM interactions
  - i.e. no strong, EM, or weak interactions
  - e.g. 'sterile' neutrinos
- Turns out anomalies are present in some existing data
  - While each of the measurements alone lack the significance to claim a discovery, together they could be hinting at important new physics
- The SBN program will contribute directly to this question either by making a significant discovery or by ruling out oscillations in a range hinted at by previous results



Very sensitive experiments are needed. Factor 10 smaller $\nu_\mu \rightarrow \nu_e$ oscillation probabilities than for θ_{13}!

Backgrounds & Oscillation Signals in SBN

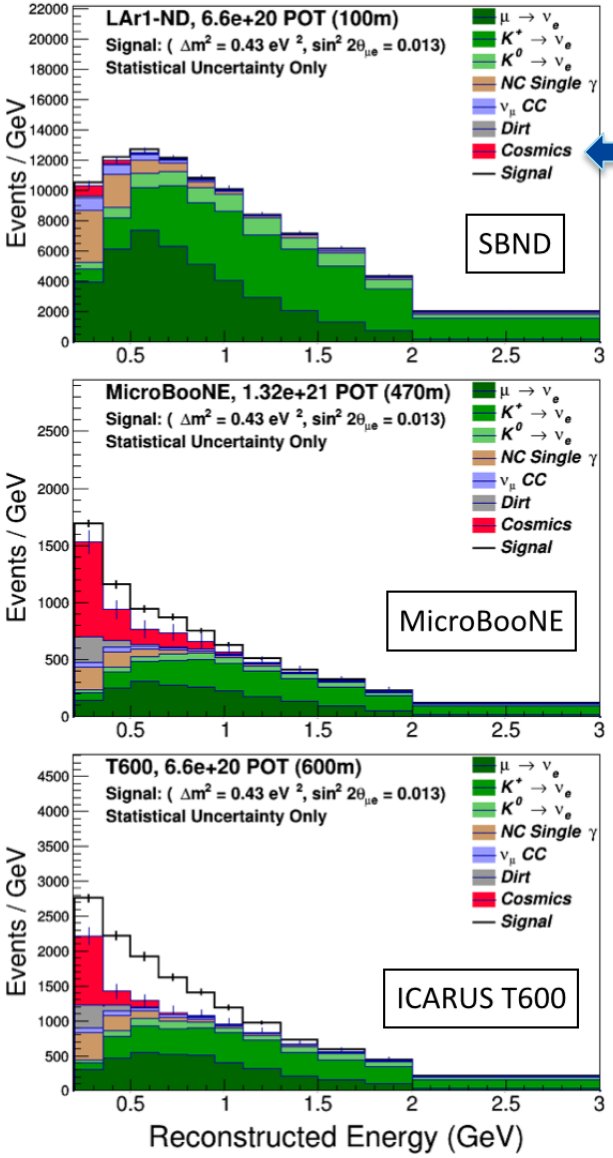


- Electron neutrino CC interactions
  - $\pi \rightarrow \mu \rightarrow \nu_e$
  - $K^+ \rightarrow \nu_e$
  - $K^0 \rightarrow \nu_e$

  → Intrinsic beam ν_e
  - Sample appearance signal

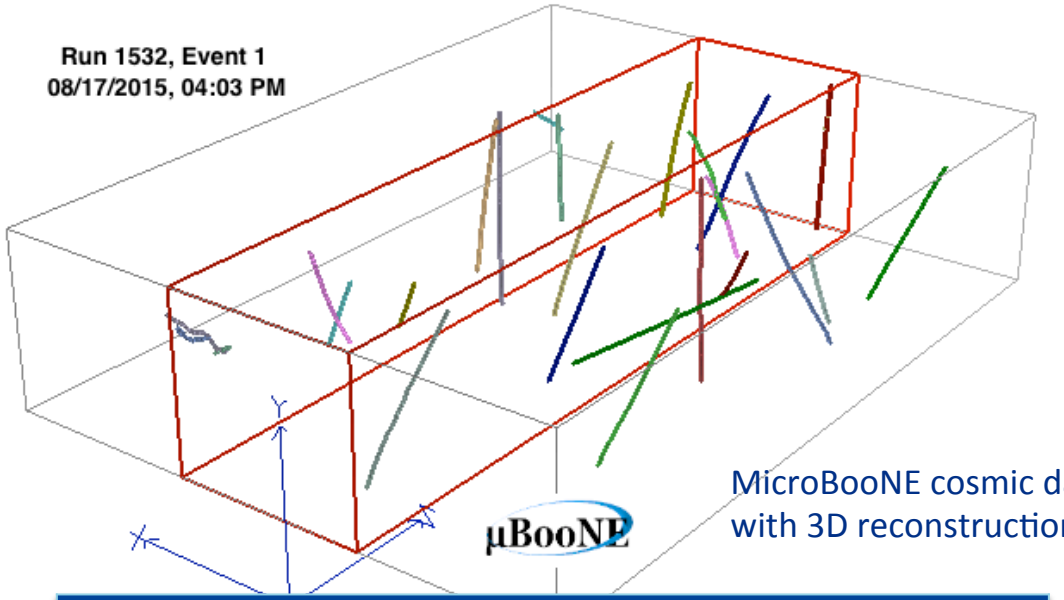
- Photon-induced e.m. shower backgrounds
  - NC misIDs
  - ν_μ CC misIDs
  - "Dirt" Backgrounds: beam-related but out-of-detector interactions
  - Cosmogenic photon sources

Cosmogenic Backgrounds



- The problem: 1000x longer charge drift time than the beam spill time!

1.6 μs beam spill vs. 1-2 ms TPC drift time



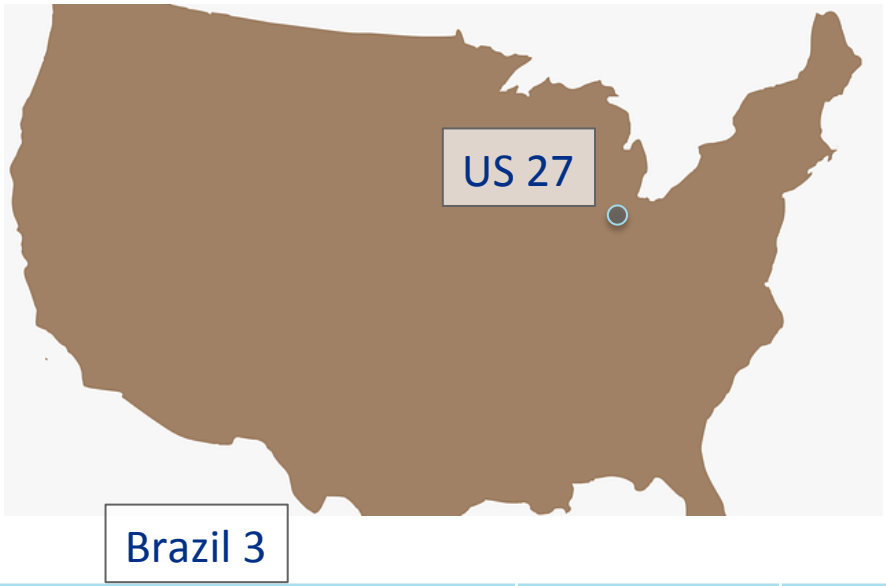
MicroBooNE cosmic data with 3D reconstruction!

Detector	Neutrino interaction every N spills	Cosmic muon in beam spill time every N spills
SBND	20	250
MicroBooNE	600	200
ICARUS-T300	350	100

Scope of SBN Program Phases

Phase 1 (2015-18)	Included in this Review
Run 1 operations and physics of MicroBooNE	No
Design, construct, and install buildings and infrastructure	Yes
Refurbish, transport, and install ICARUS-T600	Yes
Design, construct, and install new ICARUS components	Yes
Design, construct, and install SBND	Yes
Upgrade Booster Neutrino Beam	*Yes*
Develop software and analysis tools	No
Phase 2 (2017-on)	
Fill and cold commission ICARUS	No
Fill and cold commission SBND	No
Operate three detectors	No
Physics analysis with three detectors	No

SBN Institutions and Authors



Collaboration	Authors	Overlap
ICARUS	~70	~6+8
SBND	112	~59
MicroBooNE	140	
All SBN (excl overlaps)	**~225**	

Institutions	SBN	SBN-DUNE Overlap
US	27	25
Non-US	28	24