SBN Program Status

Peter Wilson

Fermilab PAC – July 2017

6 July 2017

Outline

- Scope and organization of the SBN program
- Infrastructure Progress
- ICARUS Progress
- SBND Progress
- Program cost and budget
- Summary

SBN Program Scope and Organization

SBN Program Scope

Construction and installation (aka Phase 1):

✓ Design and construct two buildings: GPPs
- Design, construct, and install the SBND detector
- Refurbish and install ICARUS T600 detector
- Design, construct, and install infrastructure (eg cryogenics)

Primary DOE contributions: infrastructure, assembly and installation

Operations (aka Phase 2):

- Operate MicroBooNE detector – FY15 on
- Cold commission and operate ICARUS detector - start FY18
- Cold commission and operate SBND detector – start FY19

SBN Work Breakdown for Construction

- WBS 1 Program Management
- WBS 2 SBND
  - Management
  - Prelim Design
  - TPC
  - PMT System
  - Calib. Laser
    - Cosmic Tagger
  - TPC Electronics
  - Local DAQ
  - Installation
  - ND Cryostat
- WBS 3 ICARUS T600
  - Management
  - TPC Refurbish
  - PMT System
  - Cosmic Tagger
  - TPC Electronics
  - Local DAQ
  - FD Cryostat
- WBS 4 Infrastructure and Installation
  - Management
  - Conventional Facilities
  - Cryogenics
  - Installation
  - Online Systems
  - ICASUS Cosmic Tagger
  - Overburden

SBN Work Breakdown for Construction

WBS 1

WBS 1 Program Management

Program Coordinator: Peter Wilson
Deputy: Cat James

WBS 2

WBS 2 SBND

Technical Coordinator: Brian Rebel

- TPC
- PMT System
- Calib. Laser
- Cosmic Tagger
- TPC Electronics
- Local DAQ
- Installation
- ND Cryostat

WBS 3

WBS 3 ICARUS T600

Technical Coordinator: Claudio Montanari (CERN-INFN)
Deputy: Andrea Zani (CERN)

- TPC Electronics
- Local DAQ
- FD Cryostat

WBS 4

WBS 4 Infrastructure and Installation

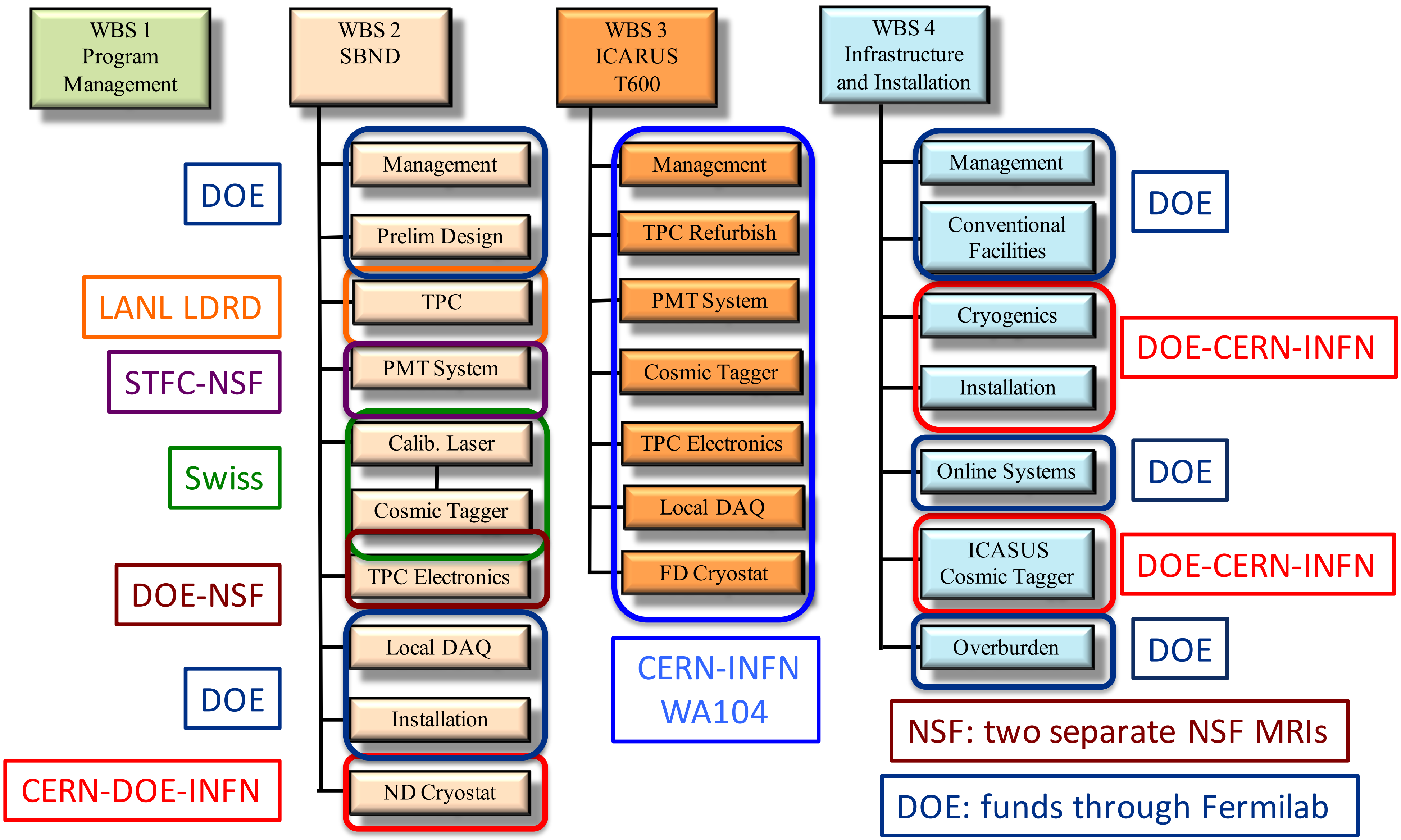
Technical Coordinator: Cat James

- Facilities
- Cryogenics
- Installation
- Online Systems
- ICASUS Cosmic Tagger
- Overburden

Definitions:
L1 Manager = TC
L2 Manager is next level below

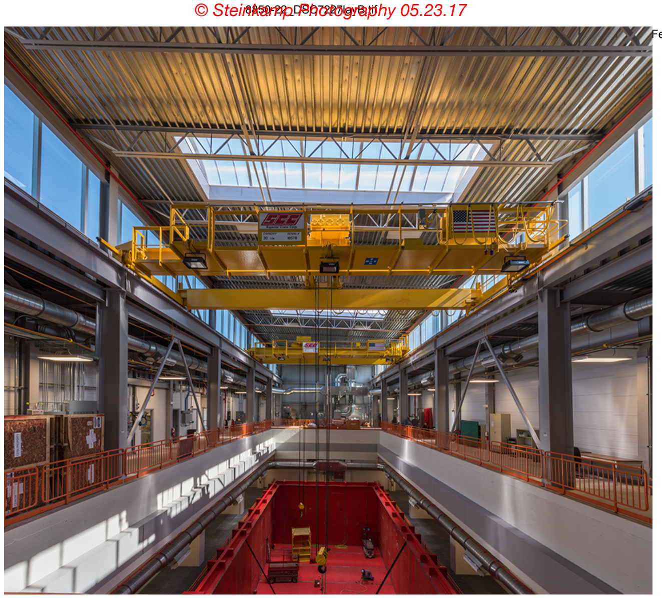
MS Project File covers WBS 1-4

SBN Work Breakdown – Funding Sources



Infrastructure Progress

SBN FD Building - Done



Completed on schedule and budget – working on post construction outfitting

Short Baseline Neutrino

SBN ND Building - Done

 76

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Holabird Root Fermilab 1st Edit

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Holabird Root Fermilab 1st Edit

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Holabird Root Fermilab 1st Edit

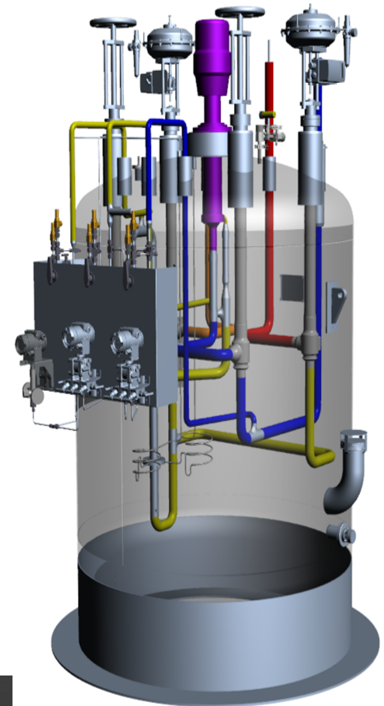
Completed on schedule and budget – working on post construction outfitting

Cryogenics – WBS 4.3

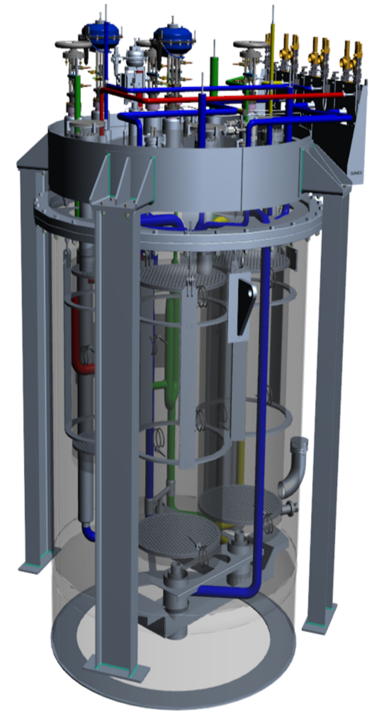
- Overview and Scope - four parts, divided between institutions
  - Internal – CERN/INFN for ICARUS, FNAL for SBND
    - Portions of the cryogenics which are inside the cryostats
  - Proximity – CERN for both detectors
    - Bulk of the Ar system: circulation, re-condensing, filtration
    - CERN contract with DEMACO for SBN and ProtoDUNEs
  - External - FNAL for both detector
    - LN2 circulation to condensers and heat exchangers
    - Filling and storage for all cryogens
  - Controls – FNAL for both detectors
    - Readback of all devices; programming of feedback loops; monitoring and logging
- All systems go through Fermilab Operational Readiness Clearance (ORC) review process. This starts during the design process.

Far Detector Cryogenics

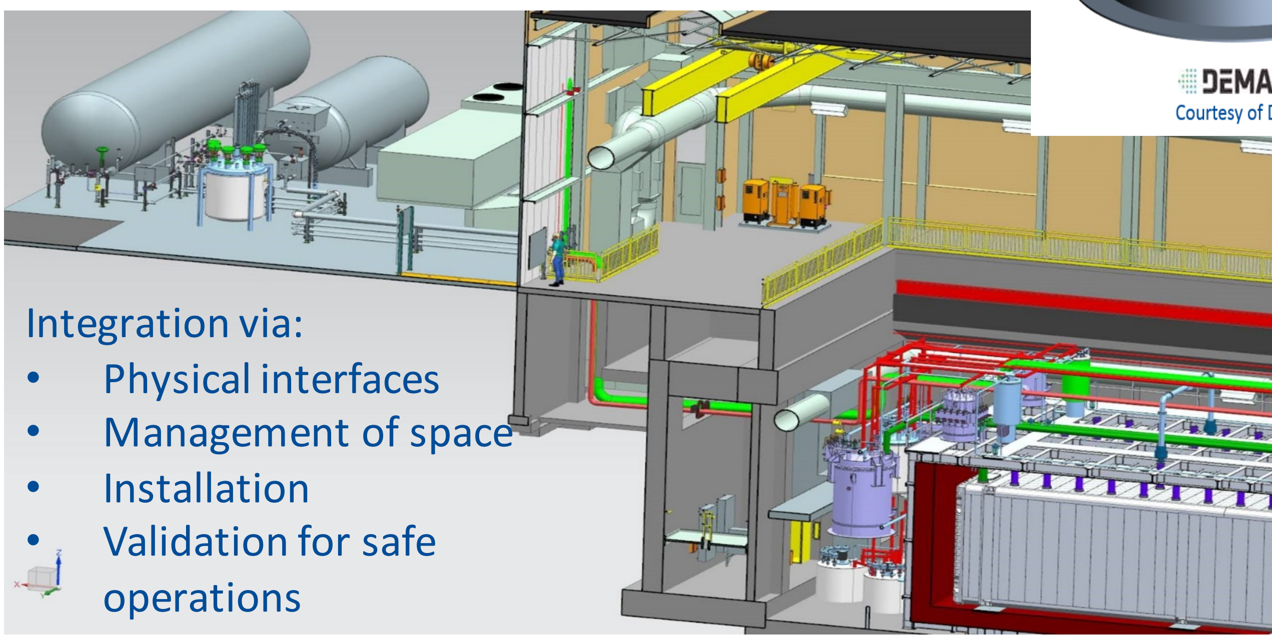
- Current Status
  - All proximity valve boxes are designed and fabrication has started at DEMACO
  - Procurement of parts for External and Controls portions is nearly complete
  - Pre-assembly of the FD External piping has begun



DEMACO
Courtesy of Demaco



DEMACO
Courtesy of Demaco

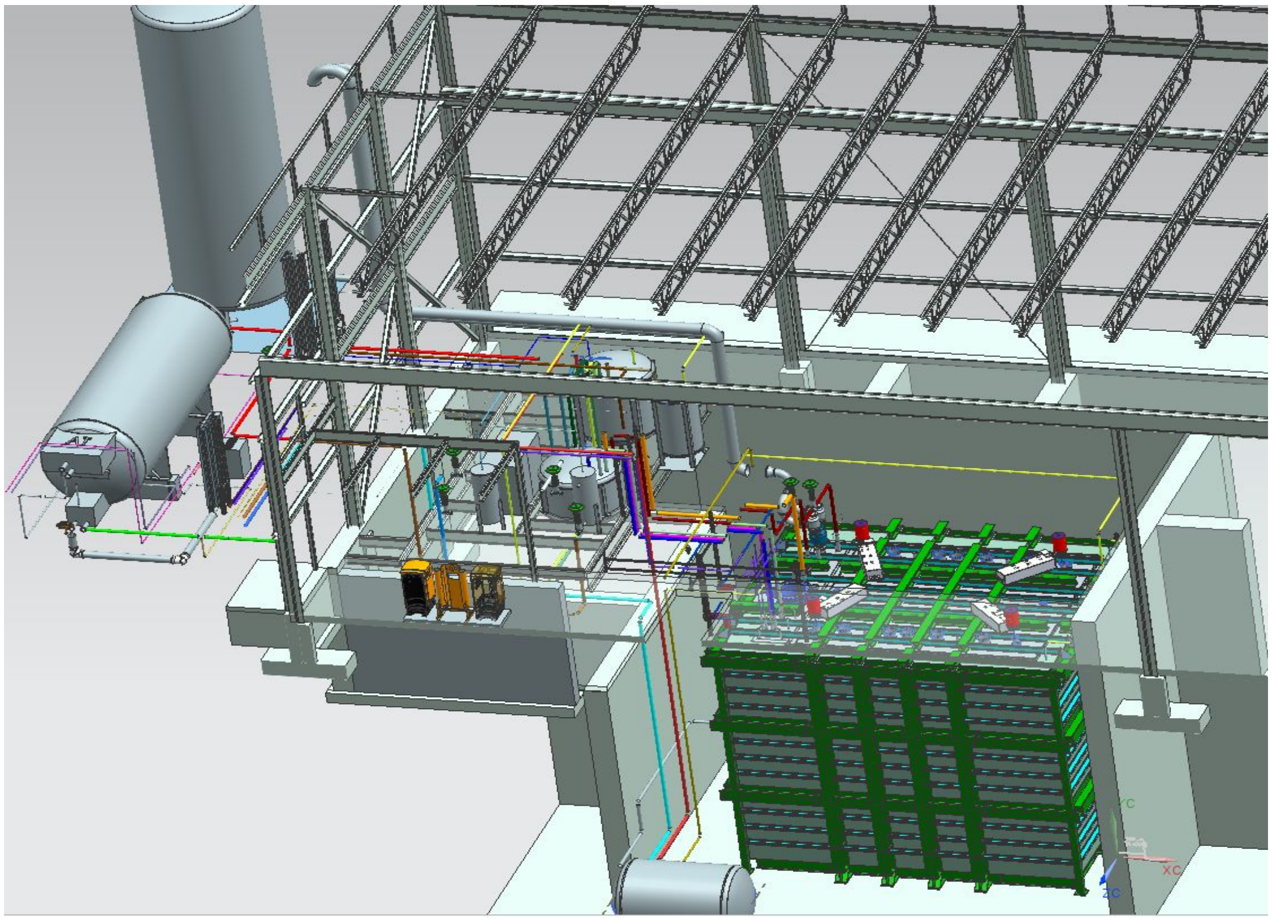


Integration via:

- Physical interfaces
- Management of space
- Installation
- Validation for safe operations

Near Detector Cryogenics

- Current Status
  - Final design for Near Detector is expected to begin in early 2018



Overburden - WBS 4.7

- Design, procure and install 3m of reinforced concrete shielding over both detectors
  - Detectors both sit just below grade - building designs provide concrete/dirt around the sides and the ability to support blocks above the detector pits
  - 1st layer are engineered “bridge” blocks, made to span the open space over the detectors and support the total overburden weight
    - These must be purchased; design is complete – part of GPP
  - 2nd and 3rd layers are shield blocks of various sizes obtained from around the Fermilab site
    - All are identified but remain in their current location; retrieval when needed
- Installation occurs after a detector is filled with liquid argon, and its systems are commissioned and verified as operational

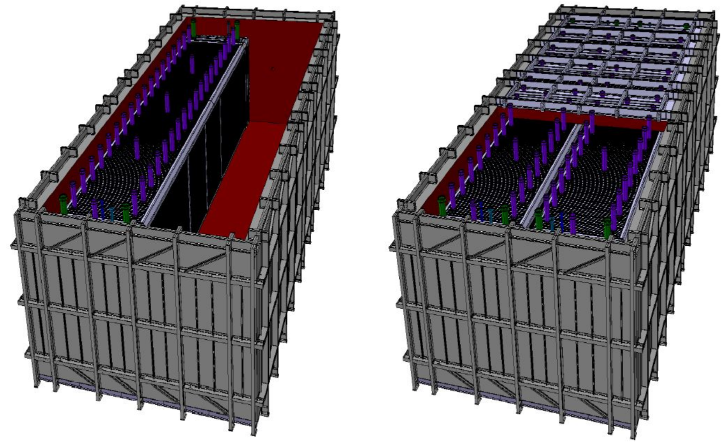
Don’t bury a detector until we know it is working

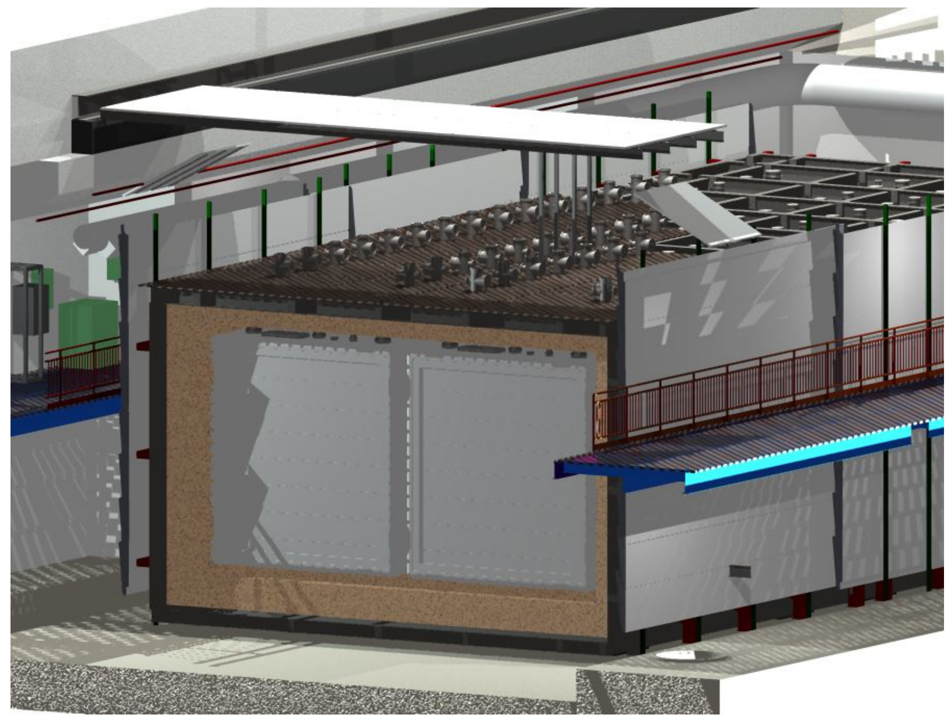
Anticipate that the Far Detector overburden will be in place 1-2 years before Near

ICARUS Progress

ICARUS Overview : Parts

- ICARUS cryostat design
  - Updated design from Gran Sasso operation
  - Each T300 TPC (two T300s = one T600) sits inside a Cold Vessel which is the cryostat to contain the LAr
  - The two cold vessels are placed inside a steel box, Warm Vessel, which is lined with foam insulation





ICARUS TPCs – WA104

- Refurbishment of the TPC and fabrication of the cryostat cold vessels completed w/2nd TPC pulled into the cryostat March 29
- Remaining milestones:
  - Arrival of T600 at Fermilab (July 2017)
  - Delivery of warm vessel insulated roof (August 2017)
  - Delivery of internal cryogenics, including cold shields (September 2017)
  - Delivery of chimneys, feed-throughs, and detector readout systems (Late 2017 – early 2018)
  - Top CRT modules (2018)
- Focus is moving to installation activities at Fermilab with the TPC/vessels in transit

Pulling the 2nd T300 into its cryostat – March 29

ICARUS Transport

- Cold vessels w/TPCs departed CERN June 12 - arrival at Fermilab in late July.
- Follow at:

  #ICARUSTrip

  http://icarustrip.fnal.gov

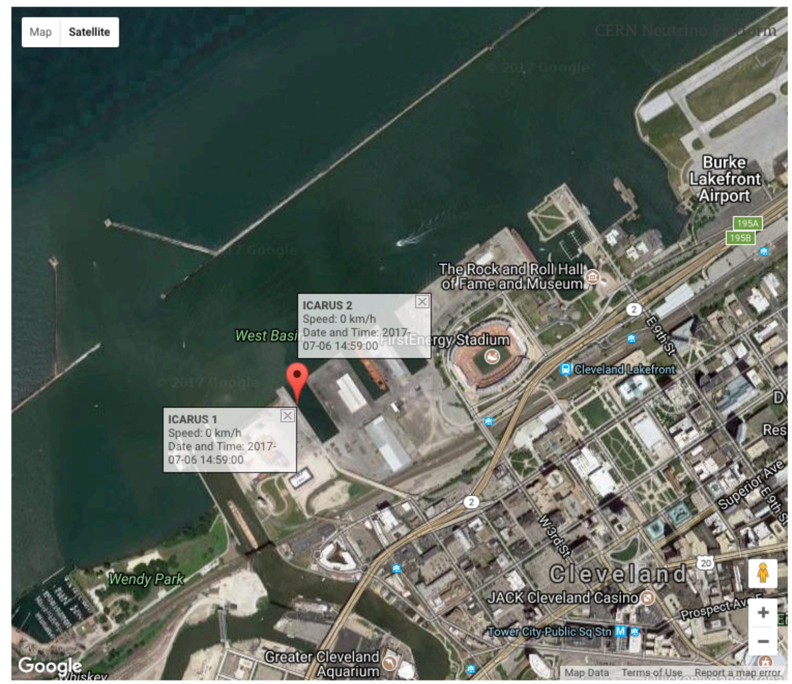
  http://cenf-wa104.web.cern.ch/wa104org/icarus-transportation-cern-fnal

Ready to leave CERN on June 12

Loading at Antwerp on June 23

Route Planning	Route Schedule
Dep. CERN	12 June 2017
↓ truck	
Arr. Basel (CH)	16 June 2017
Dep. Basel (CH)	16 June 2017
↓ barge	
Arr. Antwerp (BE)	20 June 2017
Dep. Antwerp (BE)	23 June 2017
↓ ship	
Arr. Burns Harbor (USA, IN)	appr. 23-24 days after departure from Antwerp
↓ truck	
FERMILAB	appr. 2 days after dep. from Burns Harbor

Photos from the transportation



Stop at Port of Cleveland on July 6

ICARUS Installation – WBS 4.4

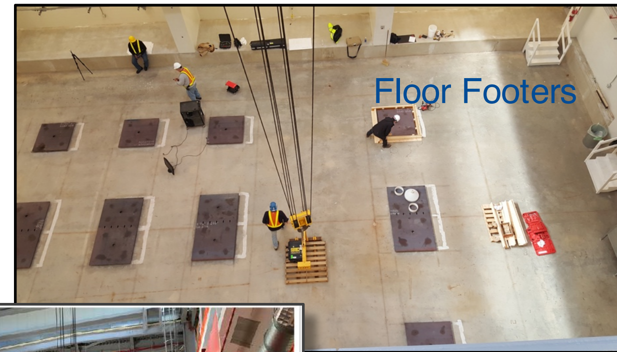
- Joint effort of Fermilab, INFN, CERN and collaboration
  - CERN : insulated warm vessel and cold vessels (w/eng. documents). Transport of detectors to Fermilab. Technical labor for specific installations.
  - INFN & ICARUS collaboration : detector readout systems, internal cryogenics piping and instrumentation etc. Technical labor for installation and collaborators with historical knowledge.
  - Fermilab : personnel in support of installation, including engineering; specific support hardware; provides guidance through ORC and personnel to develop review material.

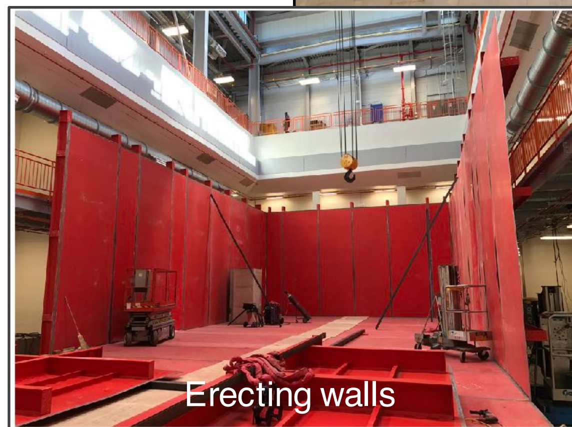
- New ground for Fermilab : vendors performing work on-site who are not hired by us – they work for CERN

  *first instance in progress now : insulation contra*ctor

ICARUS Installation Progress

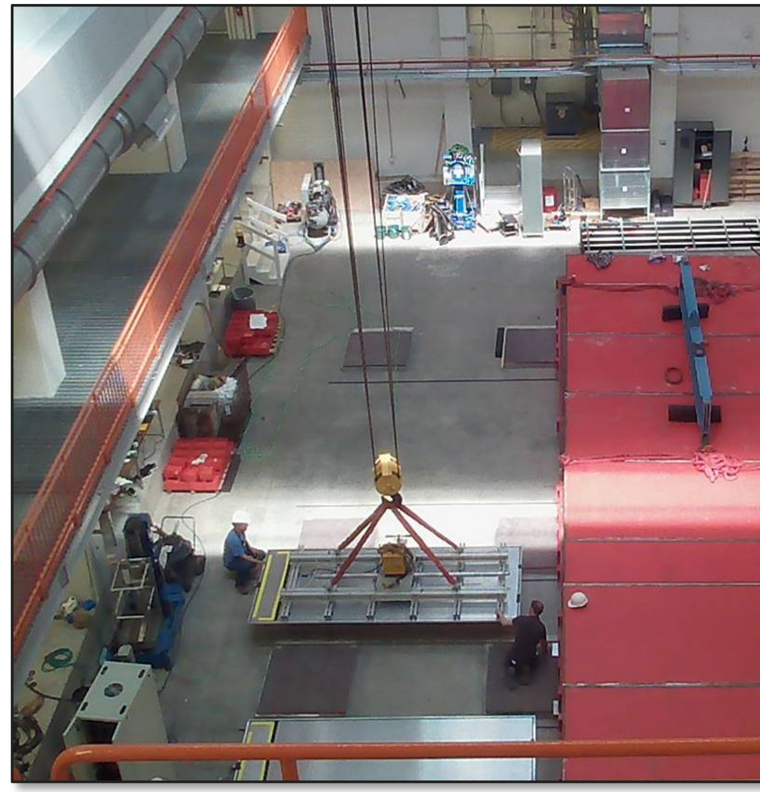
- Installation began in February
  - Load-bearing pads on the building floor
    - Provided by Fermilab, following guidelines from CERN engineers who designed the warm vessel
  - Received the warm vessel parts provided by CERN
- May
  - Assembly of warm vessel steel box
    - CERN and INFN technical crew with CERN supervision
    - Fermilab provided logistics, crane ops, welding
- June/July
  - Insulate the warm vessel : CERN contractor
- Planning
  - Installation rigging contract
  - Cryogenics and readout installation





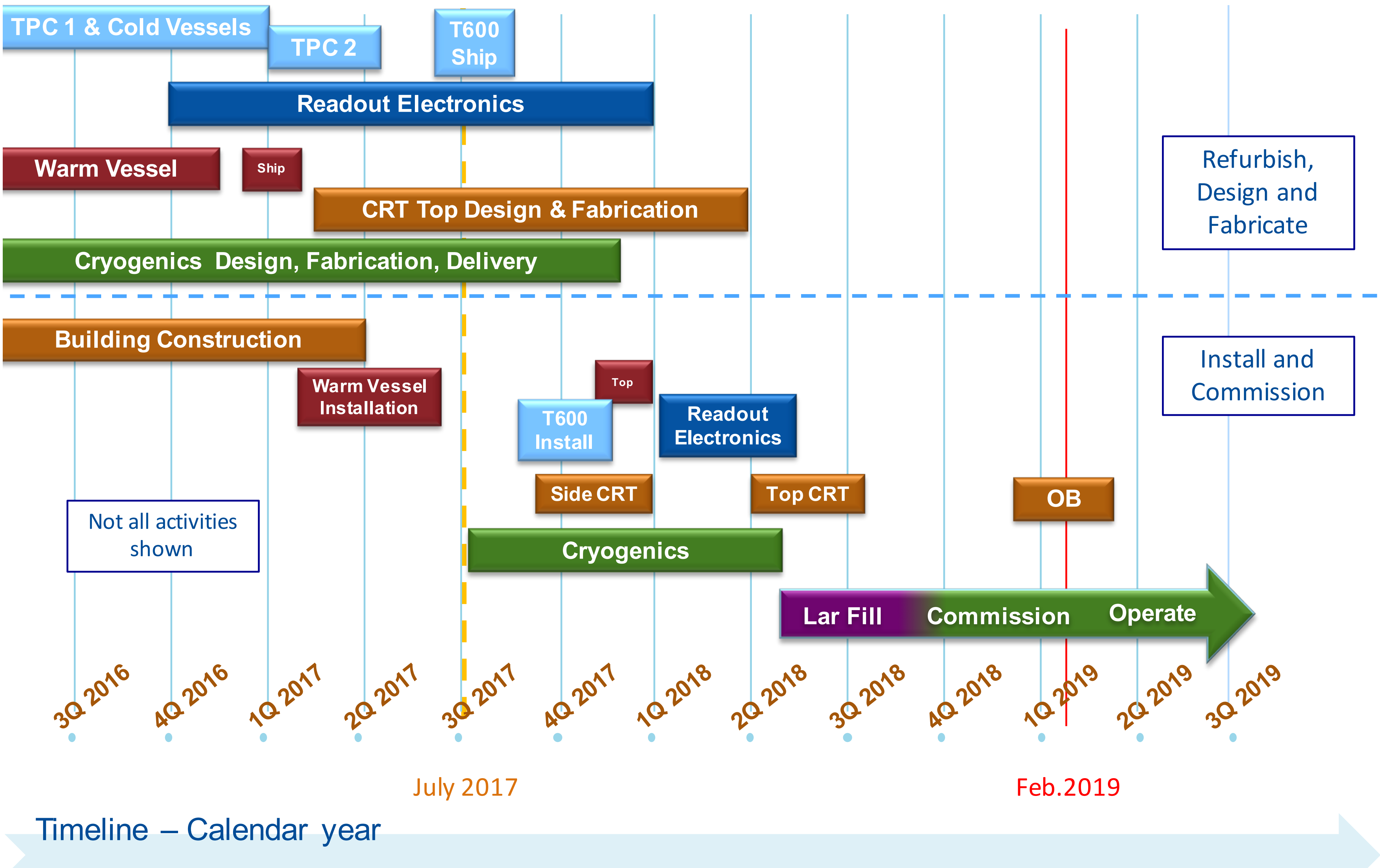
ICARUS CRT – WBS 4.6

- CERN / INFN
  - Top CRT : New scintillator panels, SiPM output, CAEN readout (same as MicroBooNE and SBND)
    - Components being procured, final designs and prototypes
- FNAL: Sides, Bottom, mechanical support
  - Side scintillator : MINOS w/new SiPM output, CAEN readout.
    - Checkout of modules this summer
    - Testing prototype readout
  - Bottom Scintillator : Double-Chooz scintillator from UChicago/VATech.
    - 4 of 14 install, remainder ready to install
  - All mechanical support, design and fabrication : Top, Sides, Bottom
    - Design in progress



Installing Bottom CRT Panels

Far Detector Timeline (Technically Driven)

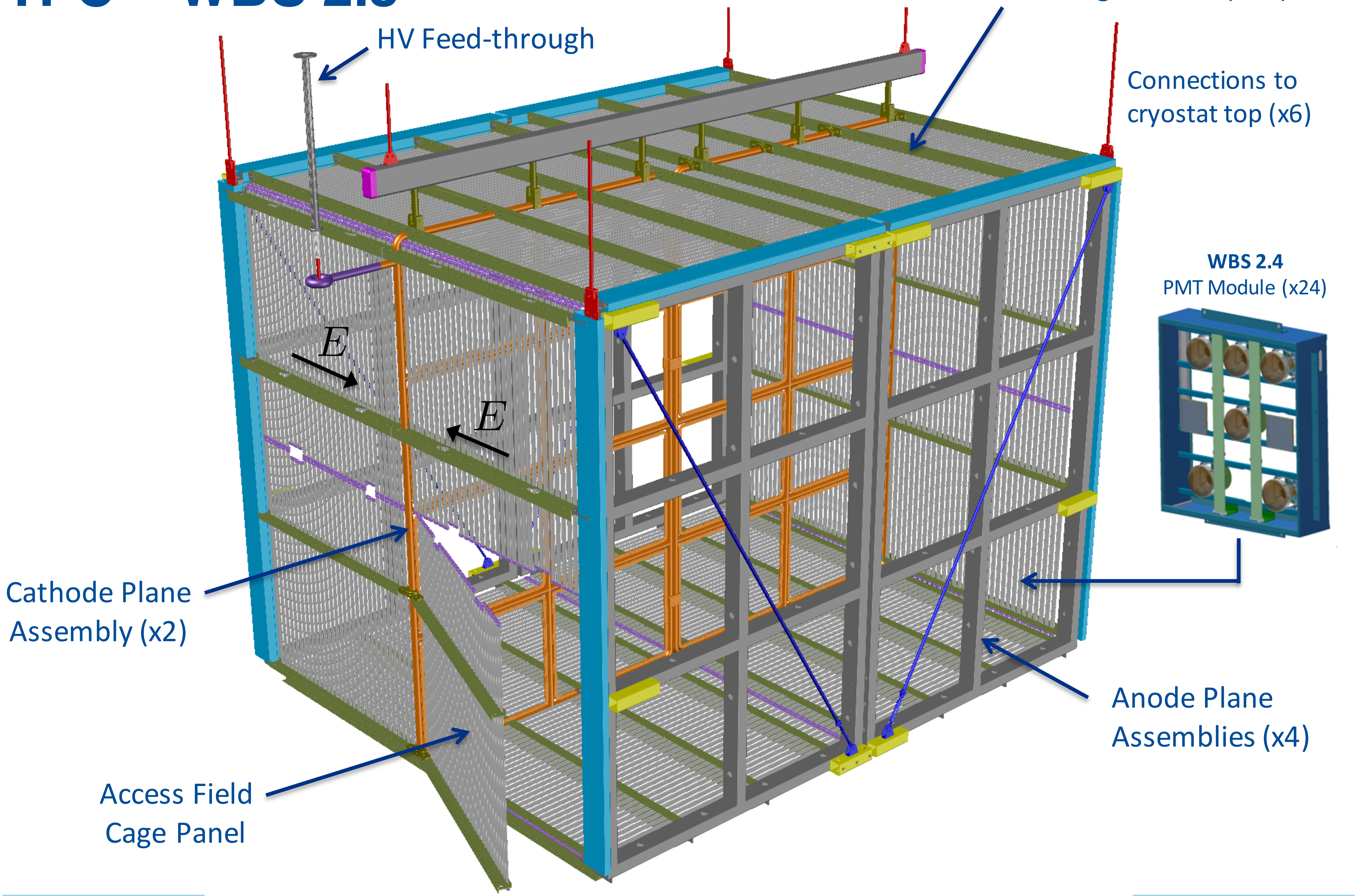


Short Baseline Neutrino

SBND Progress

TPC – WBS 2.3

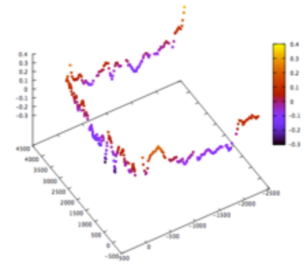
Fermilab

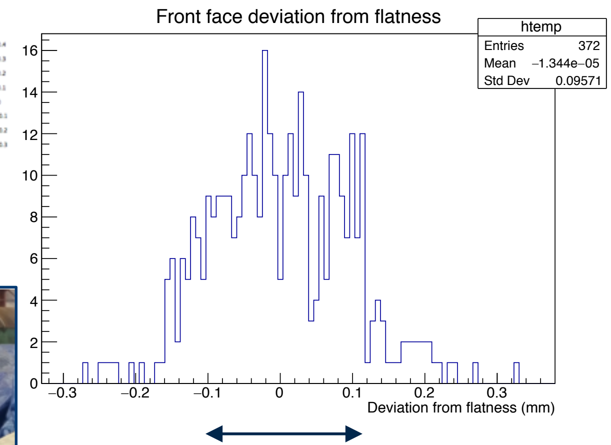


Short Baseline Neutrino

TPC Construction Progress

First 3 of 4 APA frames complete and ready to ship





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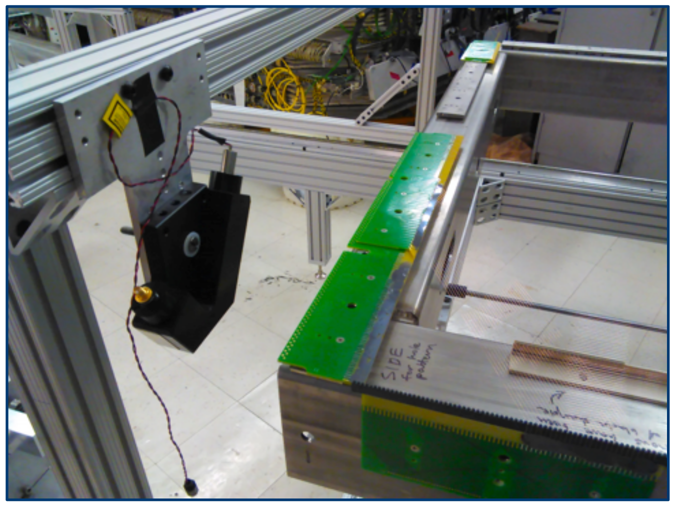


Prototype wiring activities in the UK and US.
Production Readiness Reviews scheduled for July (UK) and September (US).
Wired and tested APAs to be delivered to Fermilab in Spring 2018.

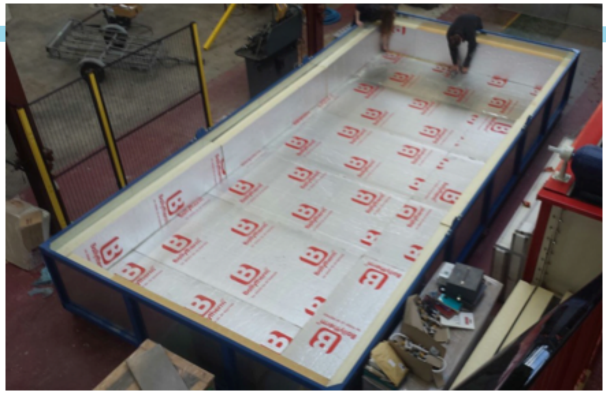
CPA production

APA QC: Cold Test

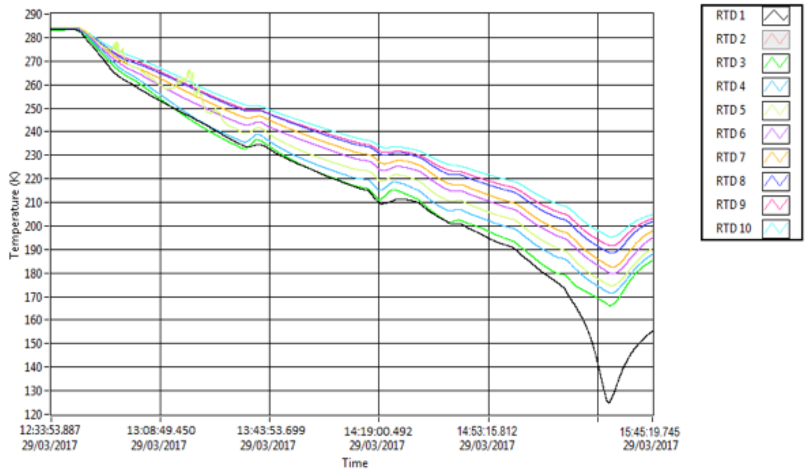
- Insulated, actively cooled and monitored boxes for APA Quality Control at wiring sites
  - Large enough for both SBND and ProtoDUNE APAs

- Initial cool down tests with UK system successful

- US system under development between SBND groups and PSL Wisconsin (ProtoDUNE)



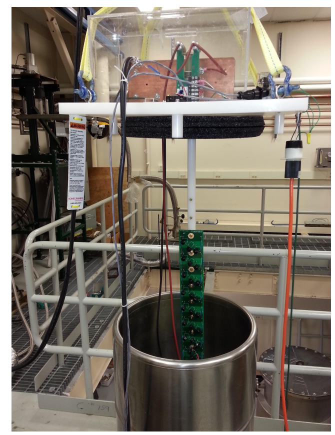
Full scale APA cold testing setup at Daresbury

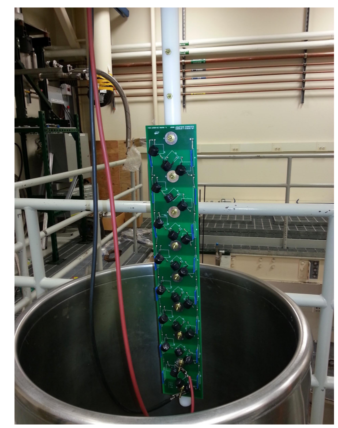


HV System – Feed-through and Field Cage

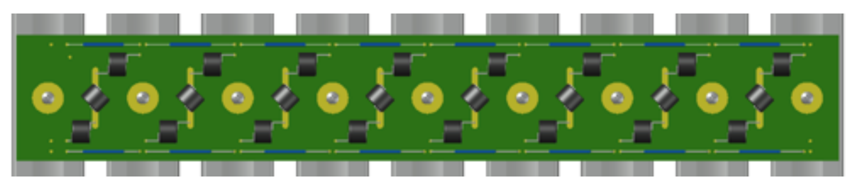
- FT: contract sent out by Yale in March to produce two SBND feed-through assemblies.
  - Expecting to receive prototype FT in July
  - Getting ready for cold test at Yale campus

- Field Cage: SBND uses very similar design to ProtoDUNE-SP.
  - Order for extruded aluminum profiles for both ProtoDUNE and SBND placed last month through CERN

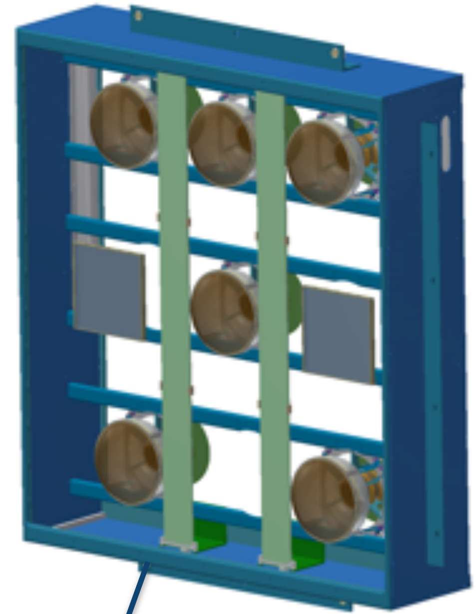




  - High Voltage Divider Board cold tests are on-going at Yale.

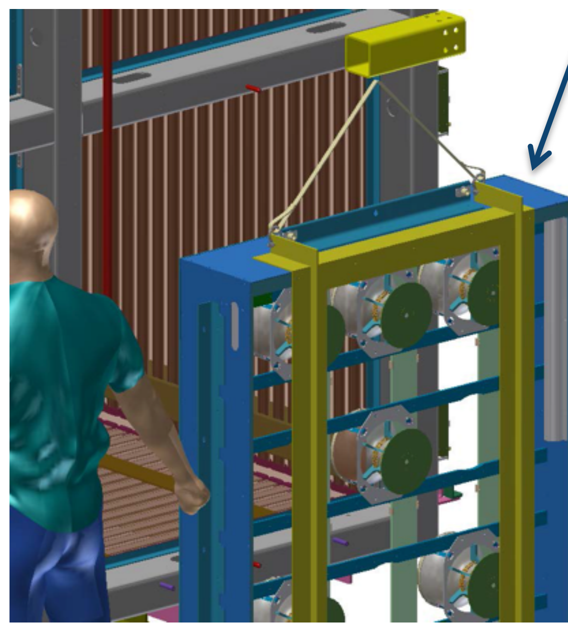


PMT Photon Detection - WBS 2.4

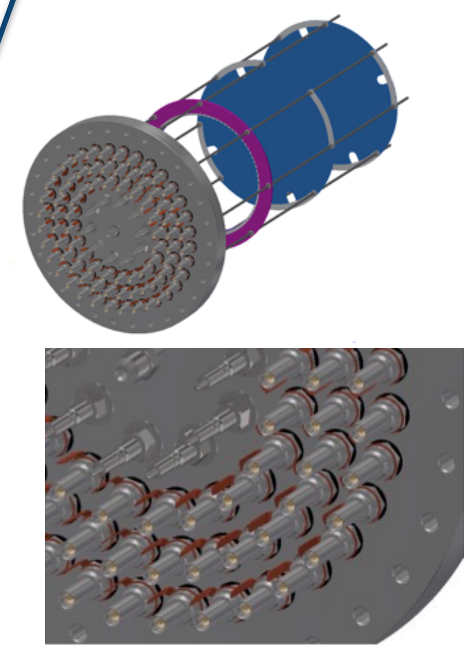


- High performance system with 144 8” PMTs and CAEN fast digitizing readout electronics
  - Hardware purchased and in hand
  - System fully funded through LANL LDRD Award

TPB coating (wavelength shifter) of PMTs at INTLVAC in Canada



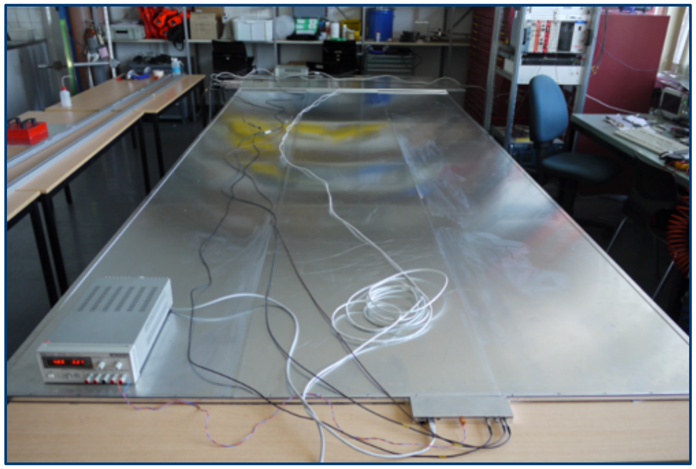
Mounting box and integration design

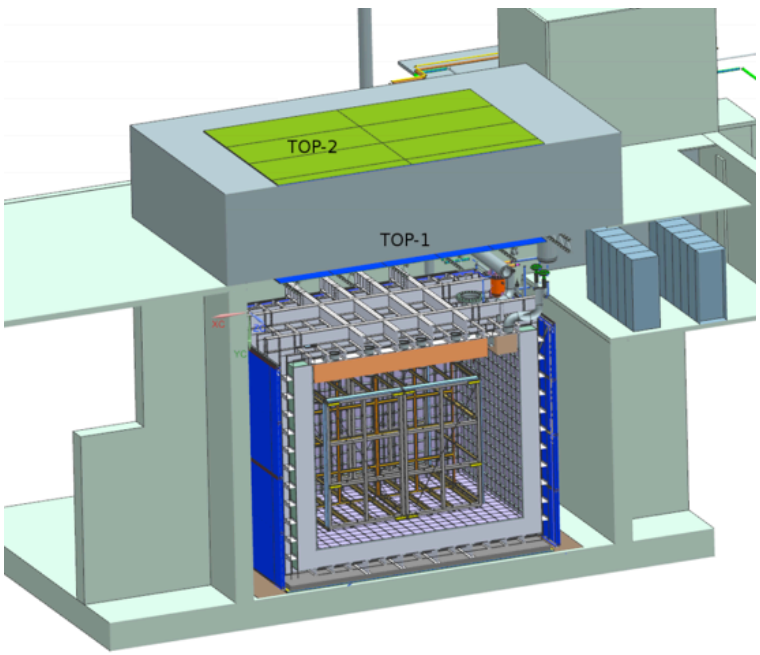


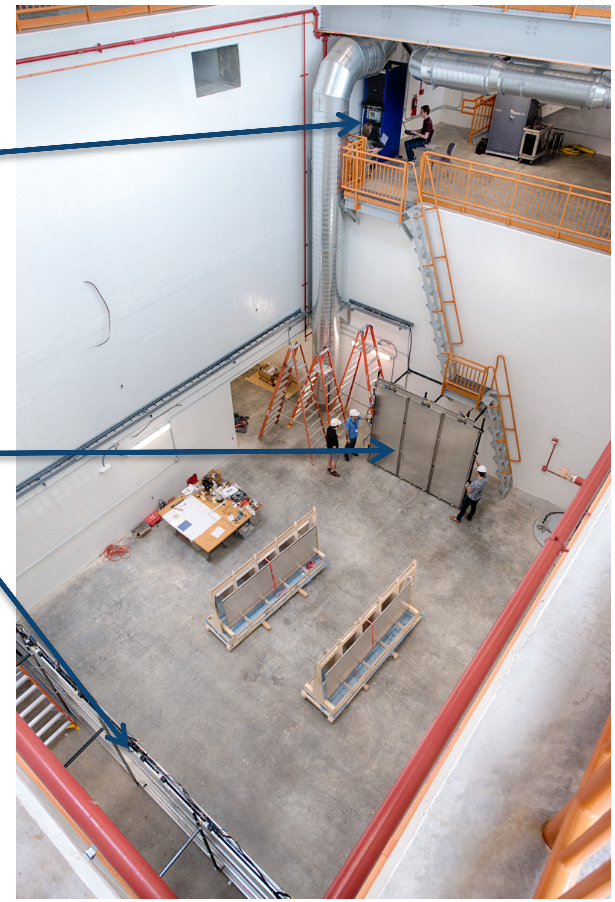
Feed-through design

Cosmic Ray Tagger and Laser Calibration

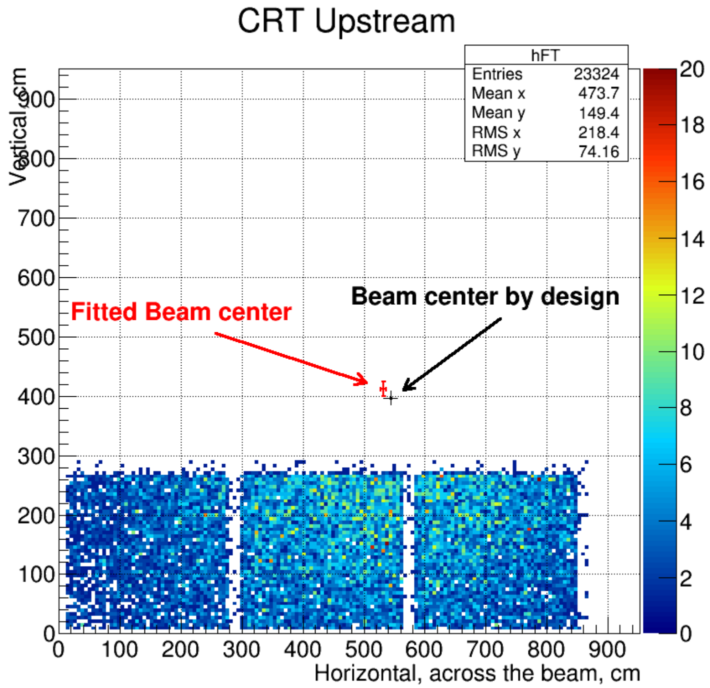
- CRT & Laser systems provided by University of Bern (Swiss NSF funded)
- CRT in production at Bern, bottom panels all at Fermilab and test underway in the SBND pit

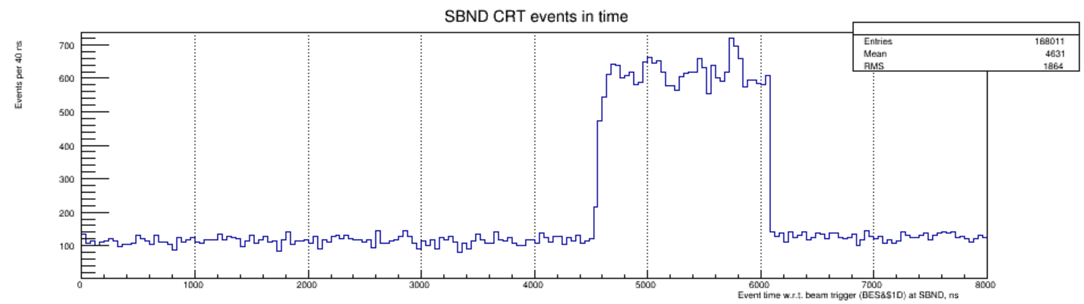


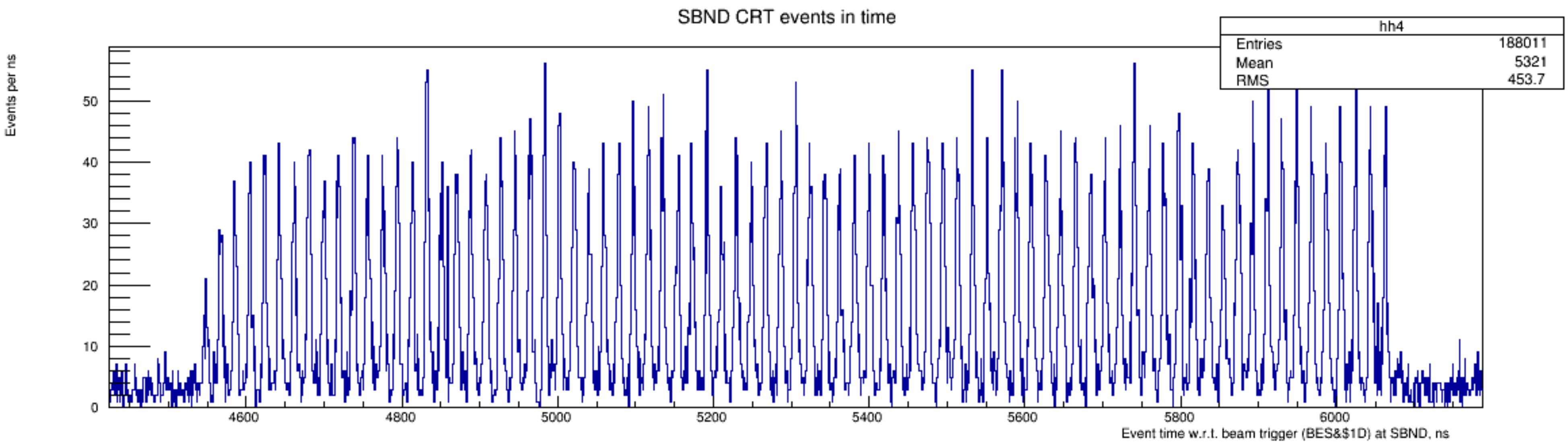




SBND CRT sees BNB!





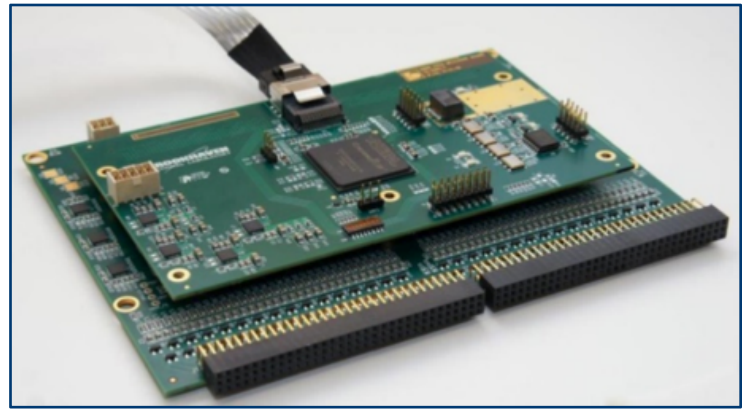


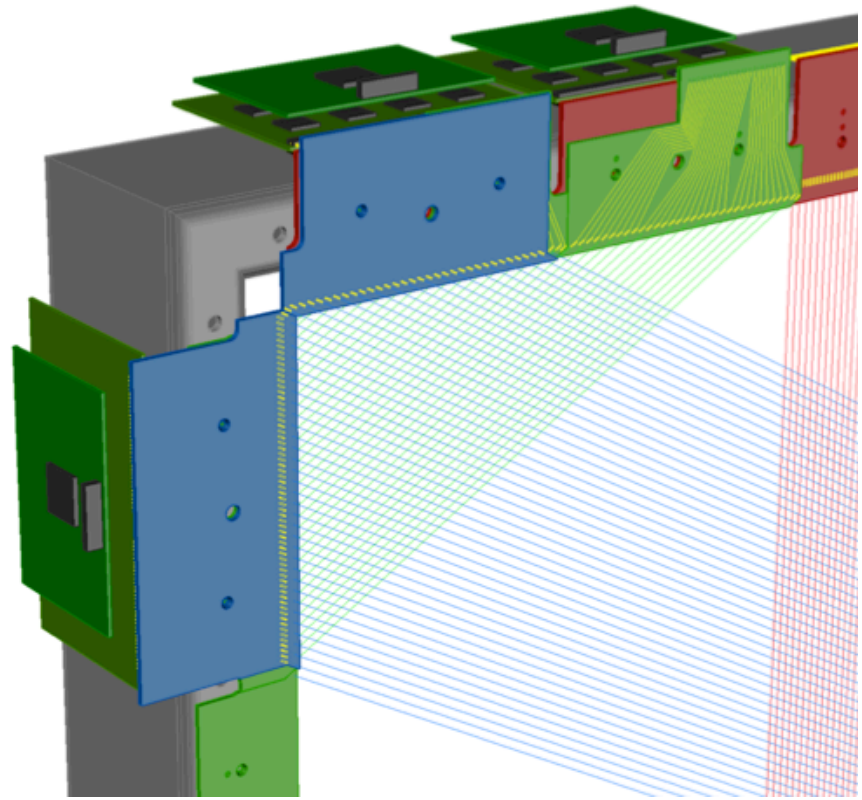
Short Baseline Neutrino

TPC Electronics

- SBND and ProtoDUNE-SP began strongly aligned in plans for front-end TPC electronics with only minor differences for APA layouts.
  - FEMB (front-end mother board) and WIB (warm interface board) developed for SBND and later modified for ProtoDUNE implementation.
- An Independent Technical Review of the electronics system in October 2016 revealed performance issues with the ADC ASIC (version P1) and was deemed not suitable for SBND
  - **SBND now carefully considering ADC options to satisfy technical requirements for the SBND physics program while keeping cost impacts minimized**

128-channel FEMB with 8 Amplifier and 8 ADC ASICs
FPGA mezzanine for multiplexing and data readout.





TPC Electronics ADC Options

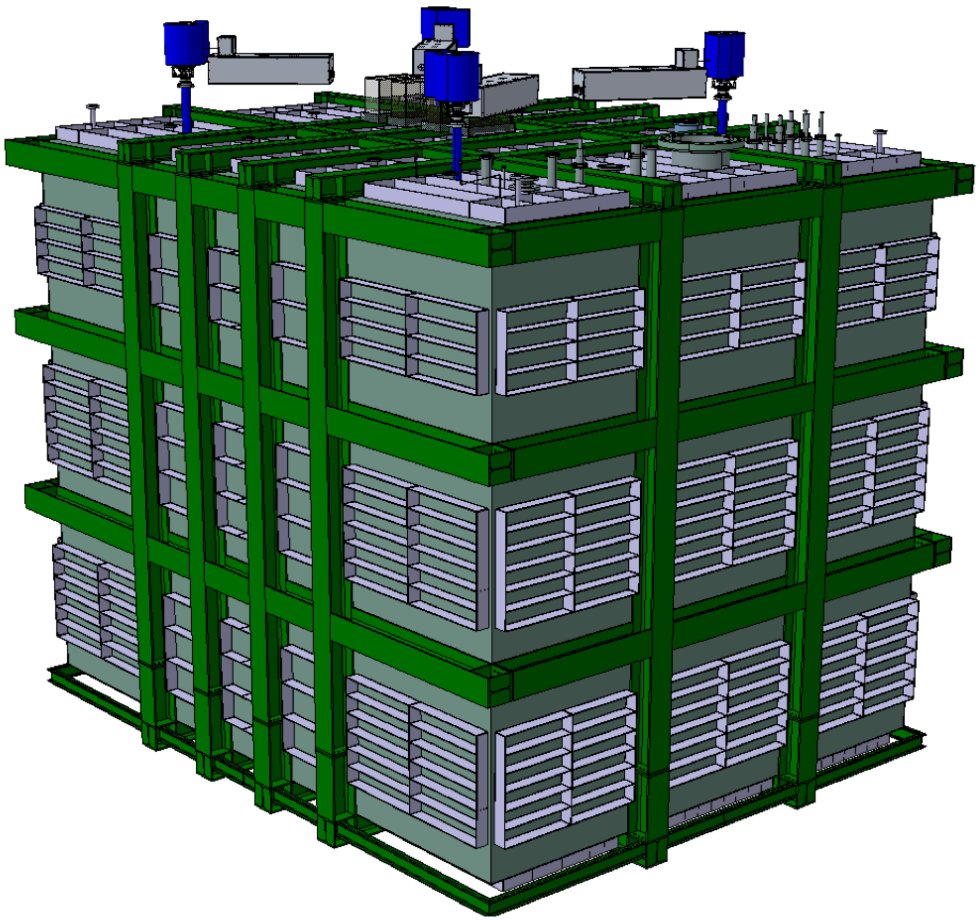
1. Commercial off the shelf (COTS) ADC operated in LAr temp
   - Requires qualification for cold operation; promising tests of three models at LN2 temps demonstrate excellent yield (all) and linearity (2 of 3)
   - Next step: stress tests of 1 or 2 models at BNL/FNAL to qualify for long term operation
2. Warm ADC system
   - Several examples of working systems in MicroBooNE, ICARUS, LArIAT
   - Has significant integration implications due to larger cable count
3. Multiple P1 ADC ASICs per channel
   - Dual-gain: a high gain path to provide improved resolution on signals up to mip-scale
   - Requires qualification of a commercial op-amp for cold operation
   - Detailed simulation studies to understand realistic performance of such a system are required

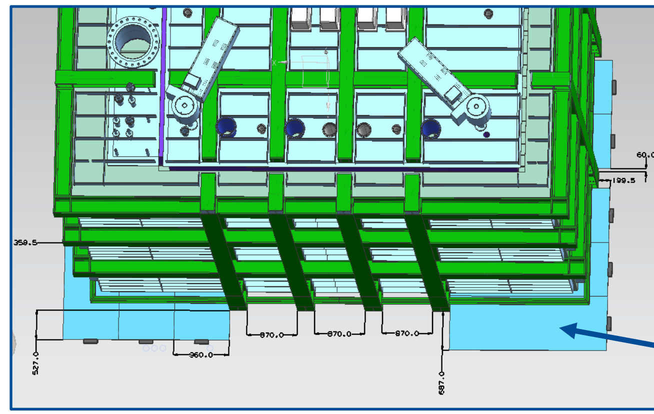
- Cold ADC Steering Committee (Chair: Mike Shaevitz) has been working since February to evaluate cold ADC options and steer the work needed to inform a decision.

- Just launched: Warm ADC Working Group (Chair: Georgia Karagiorgi) to provide detailed schedule and cost estimates for this option.

Cryostat

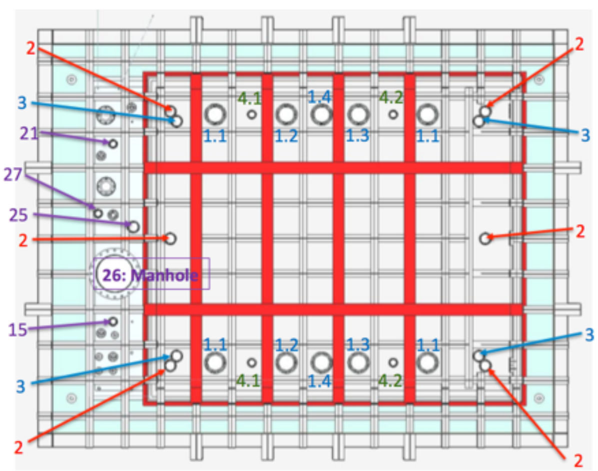
- Design from CERN: SBND a 3rd generation prototype for DUNE
  - Based on lessons being learned now from 1x1x3 m^3 and ProtoDUNEs





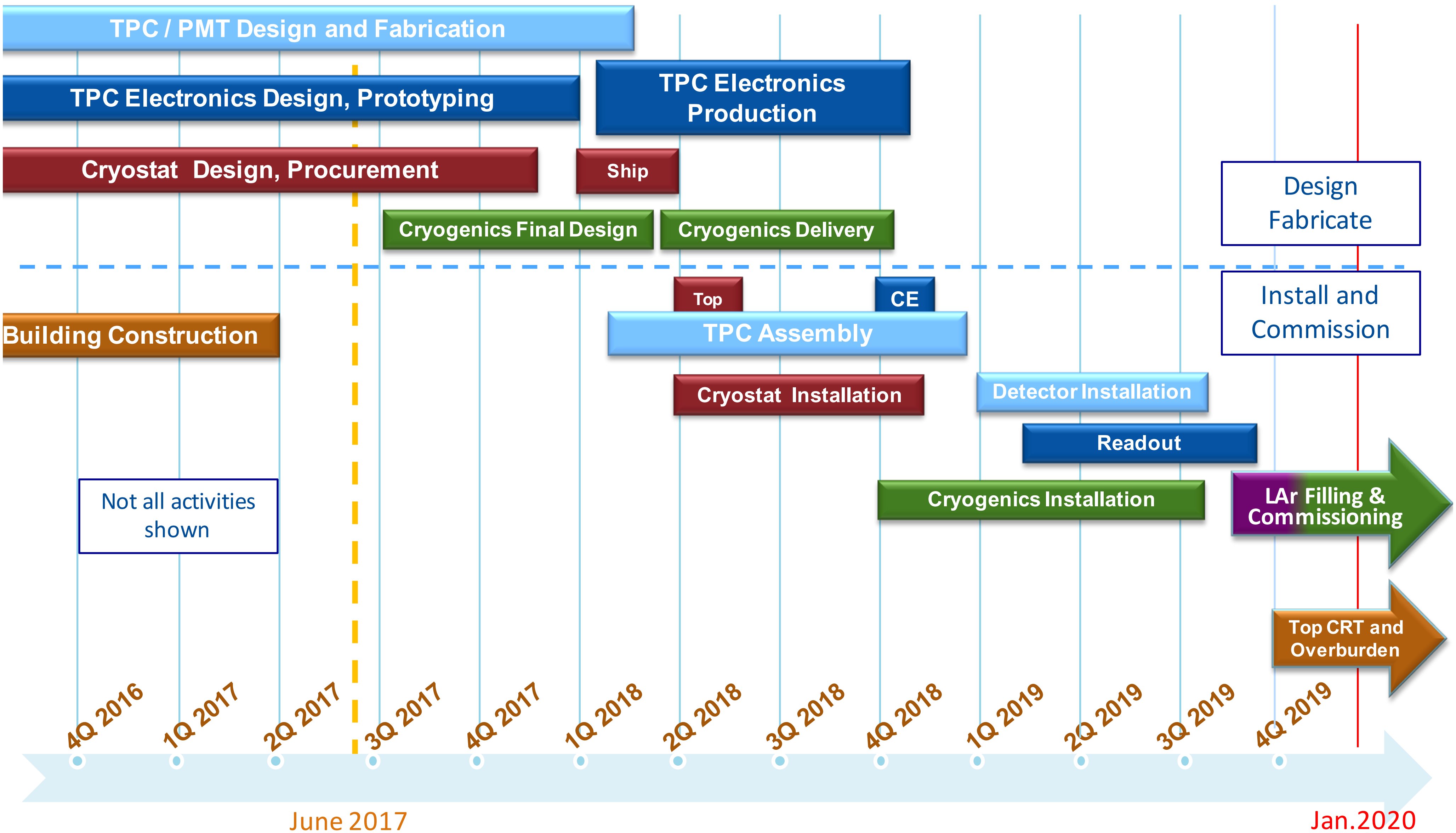
Cryostat interfaces with CRT panels

bottom CRT panels



Cryostat lid a key integration element for TPC

Near Detector Timeline (Technically Driven)



Timeline – Calendar year

Management, Budget and Costs

The following is a condensed version of slides shown at DOE-OHEP briefing on SBN on June 21

Program Management

- SBN program conceived during the P5 process as a campaign not a 413b project
- Manage the construction and installation tasks using standard project management tools
  - Resource Loaded Schedule (RLS)
  - Design, construction and installation readiness reviews
  - PMGs including lab and agency representatives (Mar ’16 on)
  - Report at Fermilab Project Oversight Group (POG)
  - Fermilab Director’s reviews of SBN Program: Dec 2015, Dec 2016 and planned Sept 2017
- Differences from a 413b project:
  - No CD process setting a TPC, KPPs, and completion date
  - Funding as available – contingency through scope or timeline

DOE Funding

- SBN program is funded from two sources within the Fermilab budget:
  - Dedicated ”R&D” funds at level of $10.5M over FY15-FY18
  - Detector and Computing Operations funds (Detector OPS) within the Neutrino Division
- The SBN buildings were constructed as General Plant Projects and are not included in the following discussion

- Funding and obligation (cost) summaries to follow show whole program starting in FY15 including construction and operations phases of each detector
  - Include MicroBooNE operations funding and obligations
  - This is a change from previous presentations (e.g. Director’s Reviews)
  - Allows more complete analysis of the effect of delays and tradeoff’s of options

Current Funding Assumptions (pre-PBR)

- Flat-flat budget for all FNAL Neutrino Division operations funds in FY18 and beyond
- So called “R&D” funds capped at $10.5M over FY15-18
- Impact of other scenarios will be analyzed later this summer

Program obligations

- Construction and installation
  - From resource loaded schedule for WBS 1-4
  - Schedule is technically driven and aspirational
  - Not resource leveled or matched to a funding profile
- Commissioning and operation assumptions
  - Steady state MicroBooNE operations
  - For ICARUS and SBND, use MicroBooNE experience as model for commissioning year and steady state
  - Includes LAr fill (first year), LN2 (every year), misc M&S and technical labor

SBN Budget and Obligations – Technically Driven

Funding Summary	Actual		Budget	Proposed				
	FY15	FY16	FY17	FY18	FY19	FY20	FY21	Total
KA22 02 022 Funding	$ 2,517	$ 3,643	$ 5,002	$ 5,552	$ 5,802	$ 5,802	$ 5,802	$ 34,120
KA22 03 03 Funding	$ 3,000	$ 3,000	$ 3,000	$ 1,500				$ 10,500
Total Funding	$ 5,517	$ 6,643	$ 8,002	$ 7,052	$ 5,802	$ 5,802	$ 5,802	$ 44,620

Obligation Plan	Actual		Budget	Proposed				
	FY15	FY16	FY17	FY18	FY19	FY20	FY21	Total
Program Management - Scientists	$ -	$ 938	$ 966	$ 995	$ 512	$ 264	$ 136	$ 3,811
Construct and Install (Phase 1)	$ 1,709	$ 3,915	$ 8,678	$ 7,900	$ 3,433	$ 336	$ -	$ 25,972
ICARUS Construct and Install	$ -	$ 592	$ 2,381	$ 1,717	$ 72	$ -	$ -	$ 4,763
SBND Construct and Install	$ 1,145	$ 1,532	$ 3,761	$ 3,310	$ 736	$ -	$ -	$ 10,485
Common Construct and Install	$ 564	$ 1,791	$ 2,536	$ 2,873	$ 2,625	$ 336	$ -	$ 10,724
Operations (Phase 2)	$ 2,008	$ 1,614	$ 1,347	$ 3,324	$ 2,626	$ 4,372	$ 4,117	$ 19,407
MicroBooNE Operations	$ 2,008	$ 1,614	$ 1,347	$ 1,265	$ 1,299	$ 1,336	$ 1,374	$ 10,243
ICARUS Operations	$ -	$ -	$ -	$ 2,059	$ 1,327	$ 1,365	$ 1,403	$ 6,154
SBND Operations	$ -	$ -	$ -	$ -	$ -	$ 1,671	$ 1,340	$ 3,011
Total Obligations	$ 3,717	$ 6,467	$ 10,991	$ 12,218	$ 6,572	$ 4,971	$ 4,253	$ 49,189
Total Funding	$ 5,517	$ 6,643	$ 8,002	$ 7,052	$ 5,802	$ 5,802	$ 5,802	
Carryover	$ 1,800	$ 1,976	$ (1,013)	$ (6,180)	$ (6,949)	$ (6,119)	$ (4,570)	

Construction from current technically driven RLS file

Operations turn-on assumes technically driven construction

Carryover (FY X) = Funding (FY X) + Carryover (FY X-1) – Obligations (FY X)

SBN Budget and Obligations – Resource Limited

Funding Summary	Actual		Budget	Proposed				
	FY15	FY16	FY17	FY18	FY19	FY20	FY21	Total
KA22 02 022 Funding	$ 2,517	$ 3,643	$ 5,002	$ 5,552	$ 5,802	$ 5,802	$ 5,802	$ 34,120
KA22 03 03 Funding	$ 3,000	$ 3,000	$ 3,000	$ 1,500				$ 10,500
Total Funding	$ 5,517	$ 6,643	$ 8,002	$ 7,052	$ 5,802	$ 5,802	$ 5,802	$ 44,620

Obligation Plan	Actual		Budget	Proposed				
	FY15	FY16	FY17	FY18	FY19	FY20	FY21	Total
Program Management - Scientists	$ -	$ 938	$ 966	$ 995	$ 512	$ 264	$ 136	$ 3,811
Construct and Install (Phase 1)	$ 1,709	$ 3,915	$ 8,678	$ 7,900	$ 3,433	$ 336	$ -	$ 25,972
ICARUS Construct and Install	$ -	$ 592	$ 2,381	$ 1,717	$ 72	$ -	$ -	$ 4,763
SBND Construct and Install	$ 1,145	$ 1,532	$ 3,761	$ 3,310	$ 736	$ -	$ -	$ 10,485
Common Construct and Install	$ 564	$ 1,791	$ 2,536	$ 2,873	$ 2,625	$ 336	$ -	$ 10,724
Operations (Phase 2)	$ 2,008	$ 1,614	$ 1,347	$ 1,265	$ 3,358	$ 2,701	$ 4,480	$ 16,772
MicroBooNE Operations	$ 2,008	$ 1,614	$ 1,347	$ 1,265	$ 1,299	$ 1,336	$ 1,374	$ 10,243
ICARUS Operations	$ -	$ -	$ -	$ -	$ 2,059	$ 1,365	$ 1,403	$ 4,827
SBND Operations	$ -	$ -	$ -	$ -	$ -	$	$ 1,702	$ 1,702
Total Obligations	$ 3,717	$ 6,467	$ 10,991	$ 10,160	$ 7,304	$ 3,300	$ 4,616	$ 46,554
Total Funding	$ 5,517	$ 6,643	$ 8,002	$ 7,052	$ 5,802	$ 5,802	$ 5,802	$ 44,620
Carryover	$ 1,800	$ 1,976	$ (1,013)	$ (4,121)	$ (5,622)	$ (3,121)	$ (1,935)	

Operations turn-on likely to occur later as construction schedules shift

Next steps for planning SBN program

- In process of adapting the plan to address changing technical schedules and funding limited effort
  - Move from technically driven to funding limited schedule (e.g. FY18)
  - Examine staging and possible de-scoping options
  - Reminder: detectors are primarily in-kind contributions: CERN, INFN, NSF, Swiss, UK-STFC
- Tools now in place to model scenarios for funding, construction scope and schedule, and operations timelines
- The Technical Coordinators and L2s already charged with examining alternate plans to reduce DOE costs.
  - Use of more student and postdoc labor
  - Value engineering: reuse of equipment and alternate technical solutions
  - Seek additional support from collaborating institutions.
- Engaging with collaborations:
  - SBND Institutional Board and Collaboration meetings
  - ICARUS PIs meeting

Staging – de-scoping challenge

- Most simple changes have significant impact:
  - Concrete overburden for ICARUS and SBND are already planned for purchase and installation after the LAr fill of each detector
  - Readout electronics for ICARUS side CRT modules could be purchased/installed later but would not want to delay much past LAr fill
  - SBND TPC size and channel count already set by completed APA frames
- Examples:
  - FNAL Cryogenics team looking at M&S reductions through reuse of equipment such as controls hardware. Working with CERN and DEMACO for past year on value engineering of systems including optimizations with ProtoDUNEs
  - Look hard at costs of the SBND TPC electronics options

Priorities for FY18

- ICARUS
  - Support installation activities for vessels, cryogenics and electronics with CERN, INFN and collaboration
  - Complete installation of cryogenics in collaboration with CERN
  - Cool down and fill detector (if ready)
- SBND
  - Support the decision on TPC electronics by early FY18
  - Support assembly of the TPC at FNAL (engineering, fixtures and technicians)
  - Support installation of cryostat (if ready)
  - Support completion of cryogenics design in collaboration with CERN
  - If funds available start preproduction of TPC electronics

Selected Upcoming Milestones

- July:
  - Create schedule baseline, start change control and status tracking
  - ICARUS T600 arrives at Fermilab
  - SBND APA wire winding review (UK)
- August:
  - Re-planning of FY18-on to match funding profile(s)
  - ICARUS T600 vessels inspection, sealing and vacuum test
- September:
  - Director's Review (Sept 26-27)
  - ICARUS cold shields delivered; rigging contract placed
  - SBND APA wire winding review (US); warm electronics report
- October
  - Adjust plan based on Director's review input
  - ICARUS T600 cold vessels installed
- November
  - ICARUS install readout chimneys and warm vessel top
  - SBND Cold ADC committee report
- December
  - ICARUS begin cryogenics installation
  - SBND decision on TPC electronics

Summary

- The **International participation** in the SBN program helps to build/maintain the neutrino physics community at Fermilab.
- The **construction**, **operation**, and **analysis of data** from SBN will undoubtedly provide significant new knowledge and important lessons to the LAr community working toward DUNE.
- The SBN program is piloting many areas interaction with CERN and other international collaborators for DUNE/LBNF (e.g.):
  - Equivalency of European and American engineering codes and standards
  - Duty free import of scientific equipment
- Tremendous **progress** in the development of the program
  - The ICARUS detector is on its way to Fermilab and will arrive soon.
  - Installation for ICARUS is already underway
  - SBND is making excellent technical progress toward construction of the detector.
- Re-planning is in progress to match more realistic technical and funding scenarios.

Backup Slides

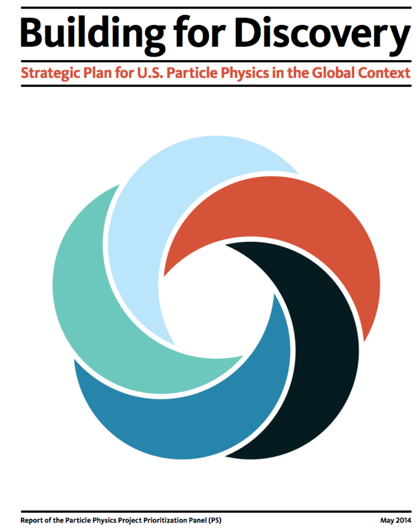
SBN Scientific Goals

Fermilab

US Particle Physics Prioritization Report

P5 Report, May 2014

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


Building for Discovery

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

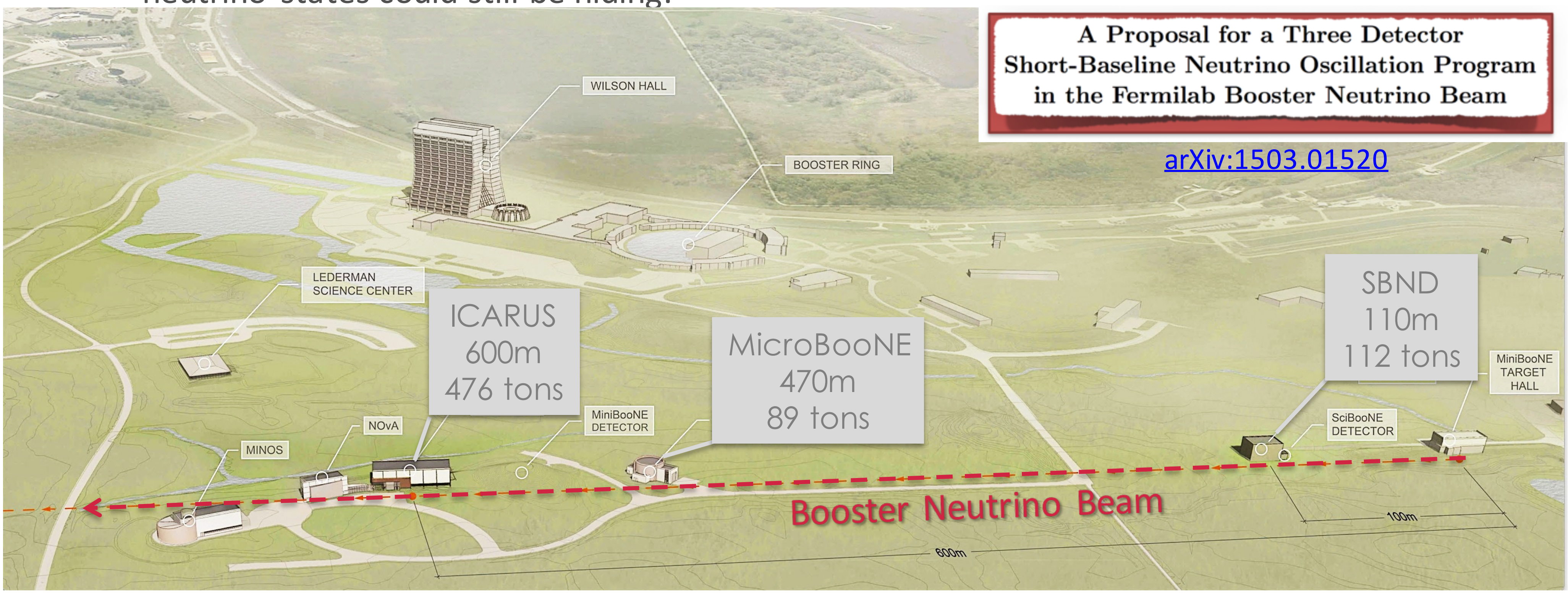
Report of the Particle Physics Project Prioritization Panel (P5)

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.

The Three Detector SBN Program

- **Three LAr TPC detectors located along the Booster Neutrino Beam (BNB)**
  - Same beam, same neutrino target, same detector technology → **minimize systematics**
- **MicroBooNE has been operational with beam since 2015**
  - MicroBooNE designed very specifically to be sensitive to the MiniBooNE observed anomaly
- **Full SBN Program approved in Feb 2015**
  - Addition of ICARUS and SBND extends science reach from a specific anomaly to the **world-leading neutrino oscillation search experiment** at $\Delta m^2 \sim 1$ eV^2
  - Up-to-date global analysis of experimental data indicate this as the region where light sterile neutrino states could still be hiding!

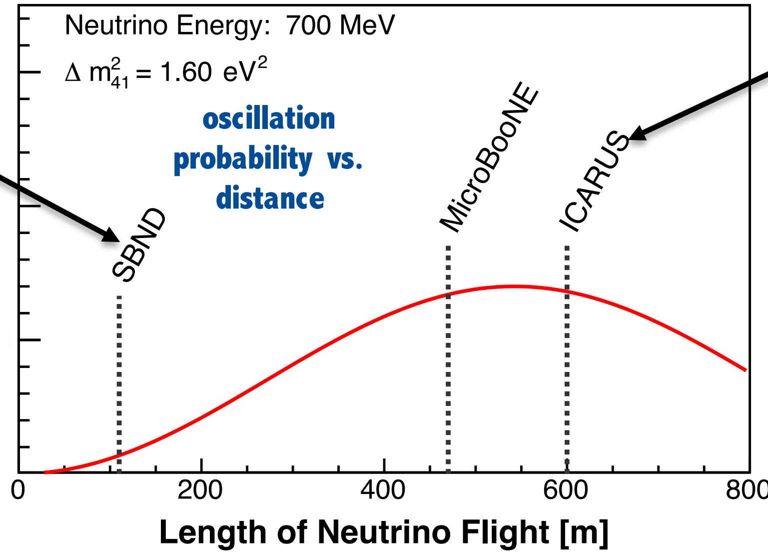


A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

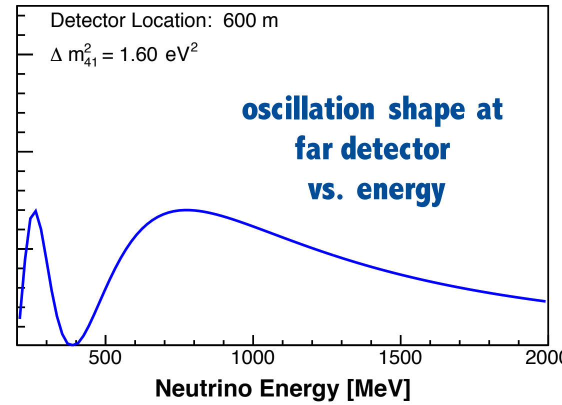
arXiv:1503.01520

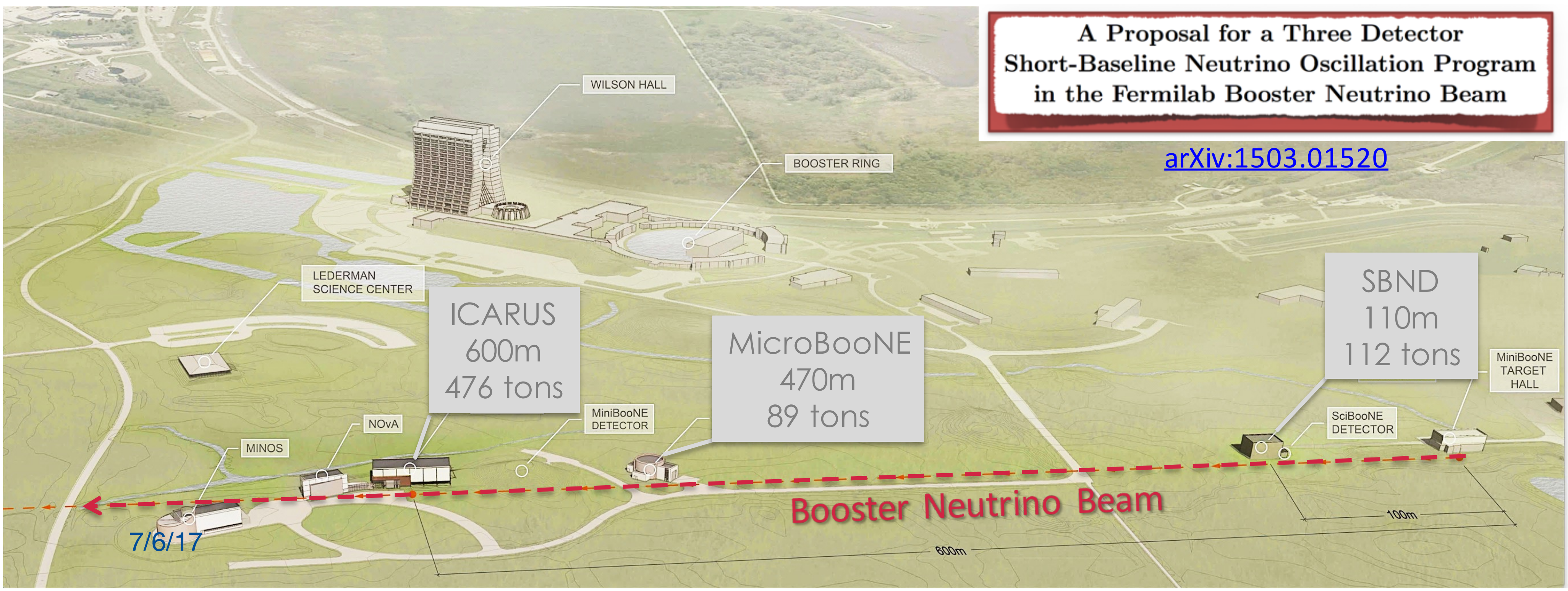
The Three Detector SBN Program

control **systematics** with near detector before oscillations



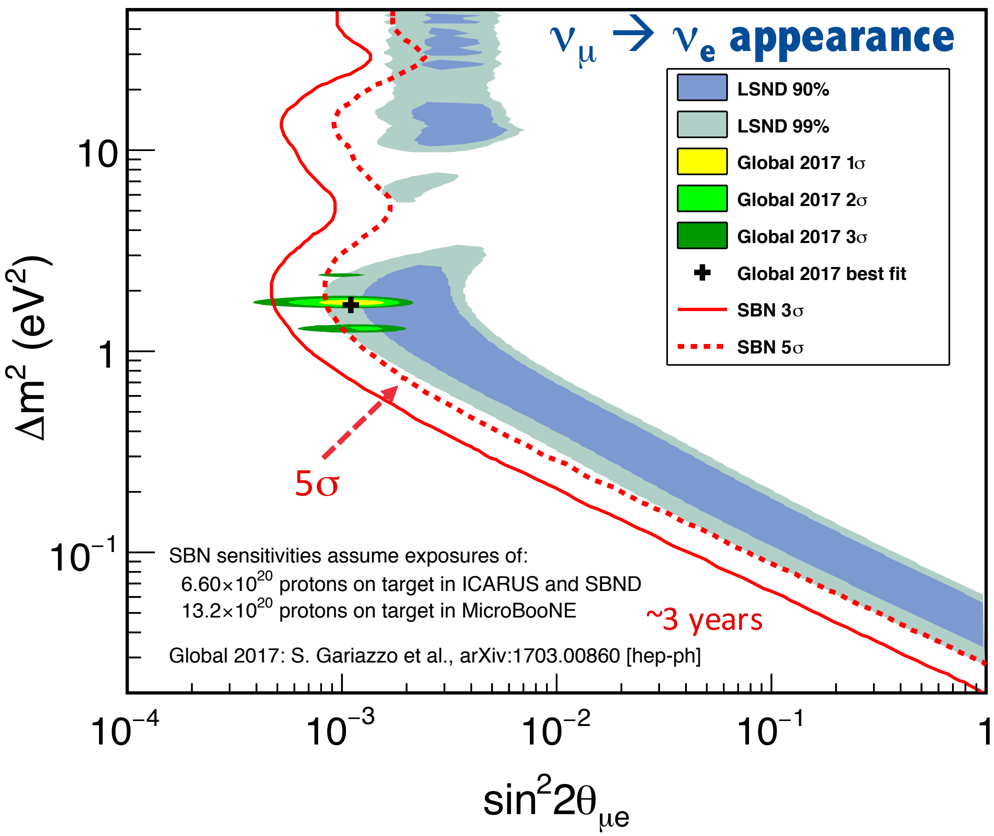
increase **statistics** of oscillation signal by adding far detector mass

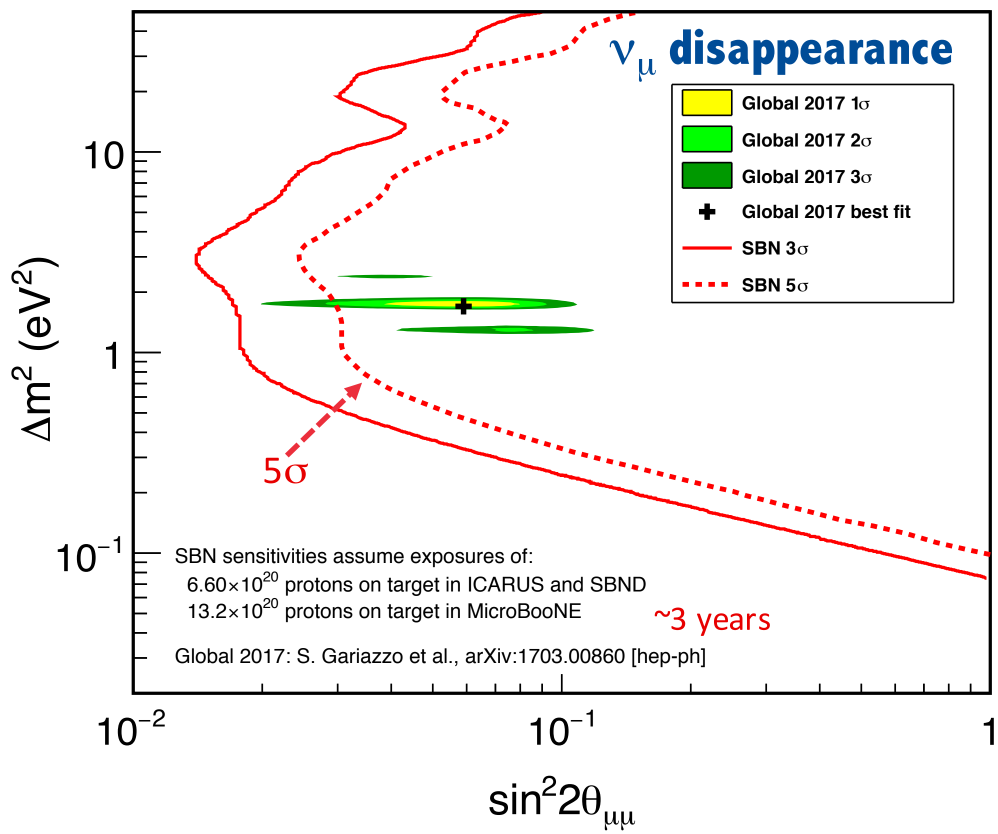




The SBN Oscillation Program

Sensitivities to oscillations ONLY enabled with near and far detectors





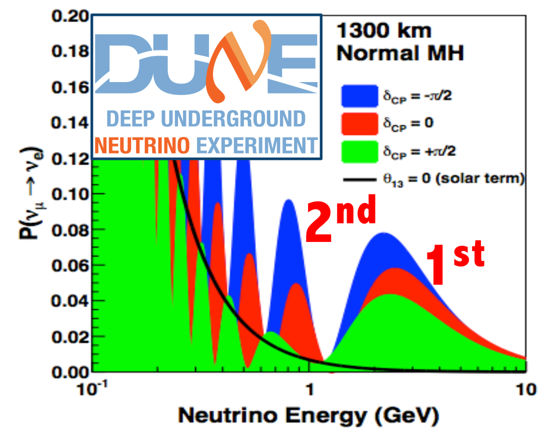
Combination of the SBN detectors enables 5σ coverage of the 99% C.L. allowed region of the original LSND signal and the global best fit values.

ν_e appearance cannot occur without ν_μ disappearance.

This is a critical aspect of verifying an oscillation hypothesis.

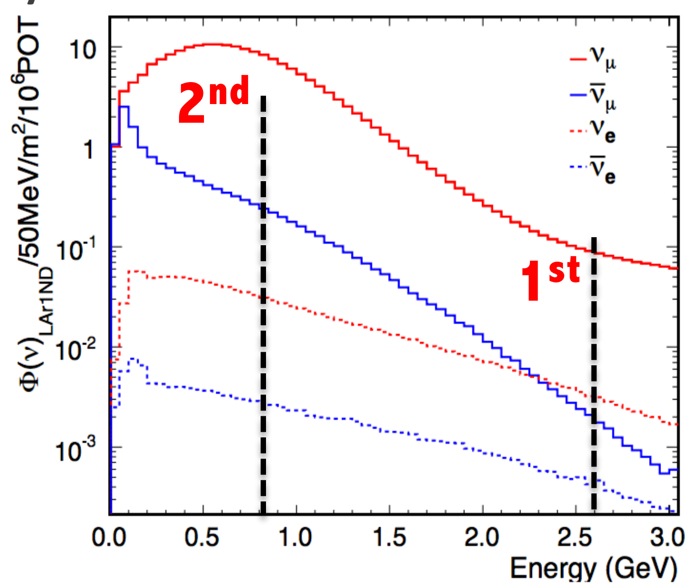
Not only oscillation physics: ν-argon interactions at SBN

SBN will have by far the largest data set of neutrino-argon interactions in the world for the foreseeable future.



- A broad program of ν-argon cross-section measurements at SBN will have direct impact for controlling the largest systematic uncertainties in oscillation measurements at DUNE
  - Large statistics at both the 1st and 2nd DUNE oscillation peaks
  - MicroBooNE is blazing this trail, **but SBND will record the full 3 years of MicroBooNE stats every 2 months of running!**

SBN Fluxes



Some SBND stats (BNB):

1.5M ν_μ CC/year

12k ν_e CC/year

also rare channels, like:

coherent (10^4/yr)

strange prod (10^3/yr)

neutrino-electron (10^2/yr)

+ 100K events per year (**NUMI off-axis**) in **ICARUS,** many at the DUNE 1st osc. max

Dozens of potential scientific results and PhDs!

Short Baseline Neutrino

Other Physics Outputs of the SBN Program

- Transferable analysis development, SBN enables/requires:
  - Development and validation of LAr calibration and reconstruction techniques.
  - Precision testing of event reconstruction and identification with large neutrino data sets.
  - Detailed systematics evaluation for sensitive oscillation measurements in appearance and disappearance channels.

- Collaboration, community, and building a knowledge base in LAr
  - SBN provides direct experimental activity with LAr technology for the global neutrino community working toward DUNE.
  - An active SBN program with **International participation** helps to build/maintain the neutrino physics community at Fermilab that will be centered around DUNE in the future.
  - The students, postdocs, faculty and scientists working on SBN are also working on DUNE, and will go on to lead physics analysis on DUNE in the future.
  - In the mean time, people want to confront data, **do physics!** SBN is an ideal opportunity.

ICARUS Contributions Matrix

WBS	System	DOE	NSF	CERN	INFN	Work Package
3.1, 3.2 & 3.4	T600 Refurbishing including new PMTs, Cryostats			50%	50%	WA104
3.3	TPC Electronics				100%	WA104
3.3, 4.5	DAQ	tbd		tbd	>50%	Not started
3.5	T600 Transport to FNAL			100%		WA104
4.2	Civil Construction	100%				N/A
4.3	Cryogenics	45%		45%	10%	Signed
4.4	Integration and Installation	33%		33%	33%	Draft
4.6, 3	Cosmic Ray Tagger	tbd*		50%	50%	WA101
4.7	Overburden	100%				N/A

All fractions are approximate (5-10% level)
tbd – expect contribution but fraction not determined
CRT: 1.2MCHF in WA104 agreement for top
$400k committed by DOE, overall plan in development

SBND Contributions Matrix

WBS	System	DOE	NSF	CERN	INFN	UK STFC	CH	LANL LDRD	Work package
2.3	TPC Design and Fabrication		50%			50%			Final
2.4	PMT System							100%	Final
2.5	Calibration Laser						100%		Signed
2.5	Cosmic Ray Tagger						100%		Signed
2.6	TPC Electronics	85%	15%						Signed
2.7	DAQ	100%							N/A
2.2 & 2.8	Integration and Installation	100%							N/A
2.9	Cryostat	10%		70%	20%				Draft
4.1	Civil Construction	100%							N/A
4.3	Cryogenics	50%		50%					Signed
4.7	Overburden	100%							N/A

All fractions are approximate (5-10% level)
tbd – expect contribution but fraction not yet determined