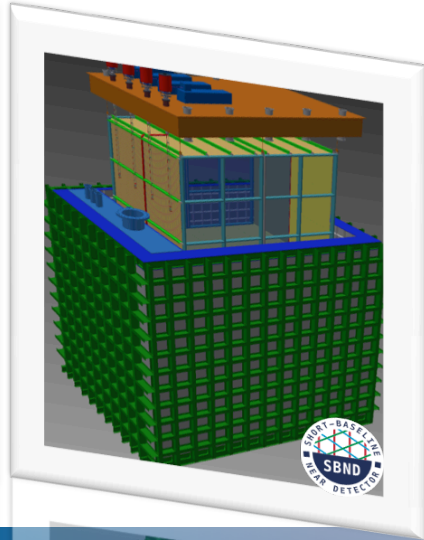
SBN: The Analysis and Software Infrastructure Status/Plans



PAC Meeting, Fermilab

January 19, 2016

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for the SBN Collaborations

*on leave of absence from INFN, Laboratori Nazionali del Gran Sasso, Italy

Outline: SBN Efforts toward Coordinating Plans

- In this presentation we address one of the PAC charge questions about the SBN program

  iii) Is adequate progress being made towards coordinating plans for analysis across all three SBN experiments*?*

- Ongoing Analysis Efforts and SBN Coordination across the three experiments – Current Status and Plans
  - *Analysis/Software Development:*
    - Common LAr software environment
  - *Joint analysis Efforts:*
    - Surface operation and cosmic background mitigation
    - Physics of the BNB upgrade
  - *Technical Coordination:*
    - DAQ and online systems
    - Cosmic ray taggers
    - Photon detectors

Science Goals of the SBN Program

- 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 (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**, 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 applying it at very large scales for long-baseline physics in DUNE

The SBN Proposal

Scientific proposal and conceptual design report for the SBN program (Jan 2015)

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://arxiv.org/abs/1503.01520

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

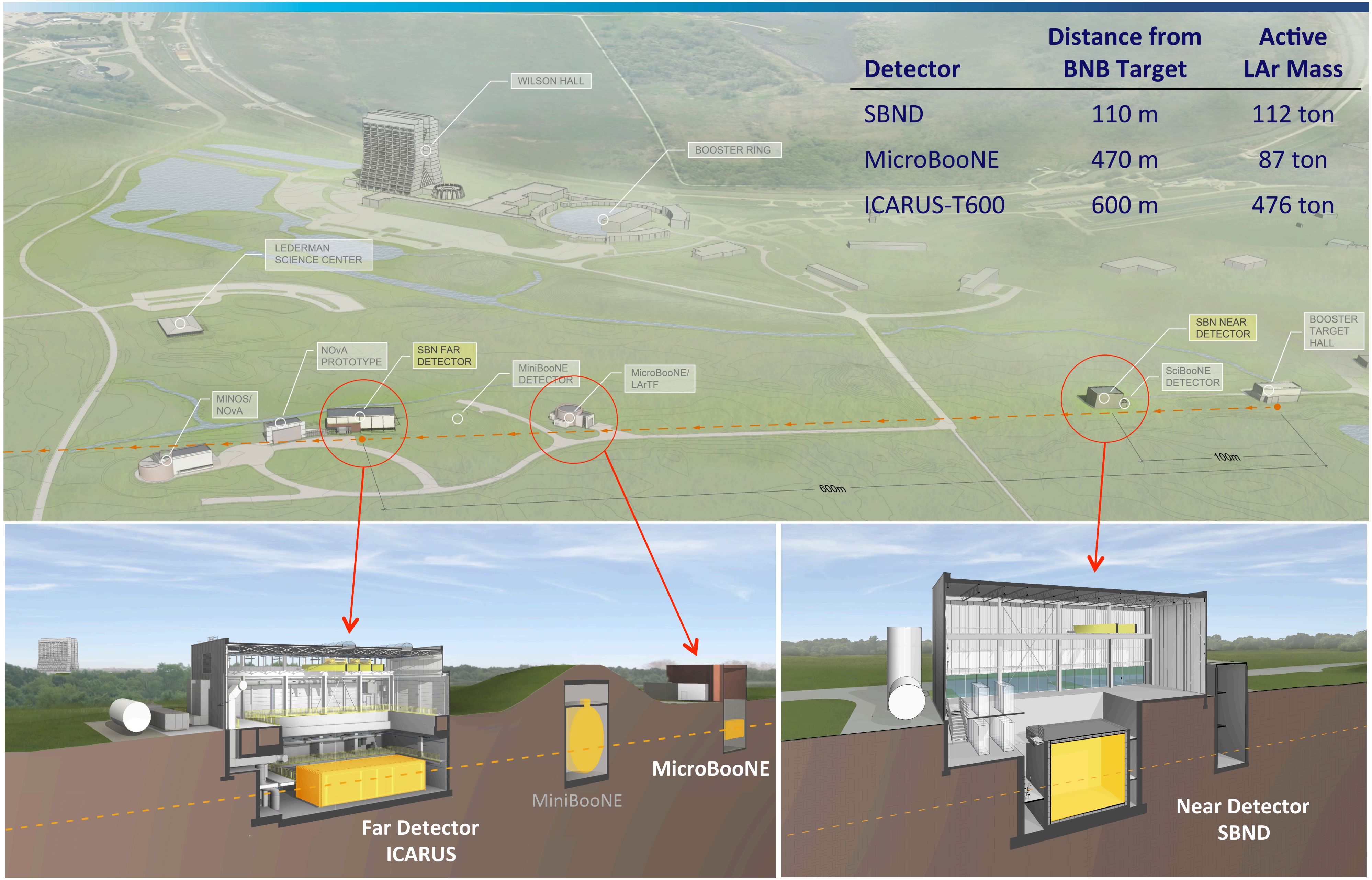
Part VI: Coordination and Schedule

218 authors from 22 US and 23 non-US institutions

Collaborations have all continued to grow through 2015

The Three-Detector SBN Program

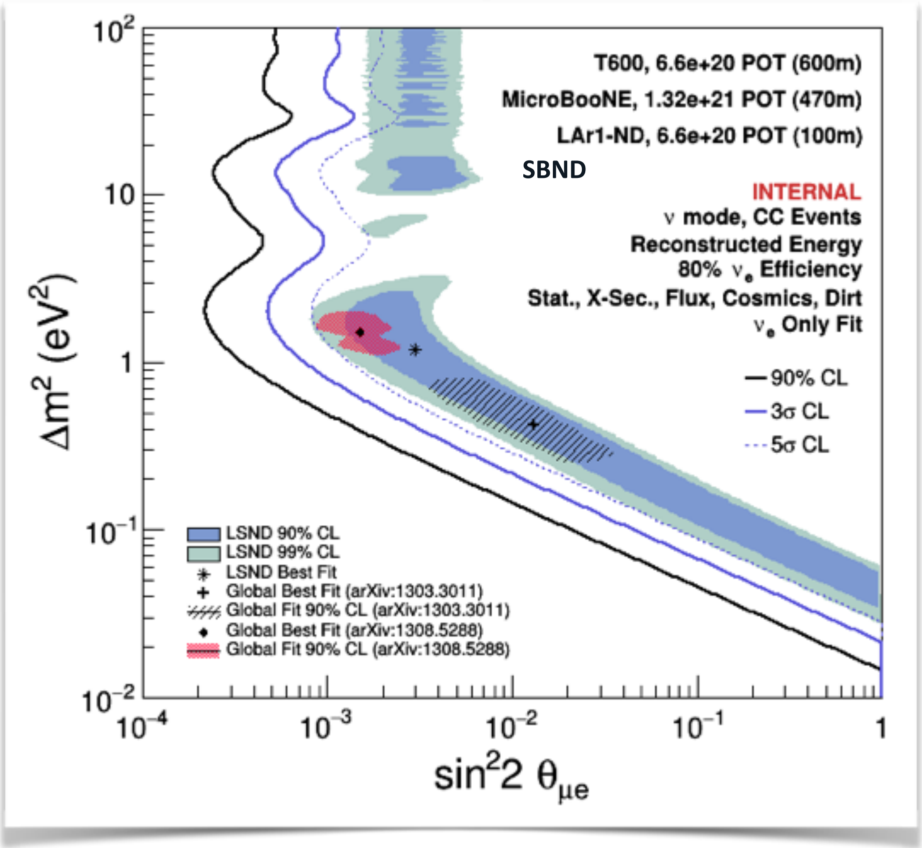
Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS-T600	600 m	476 ton



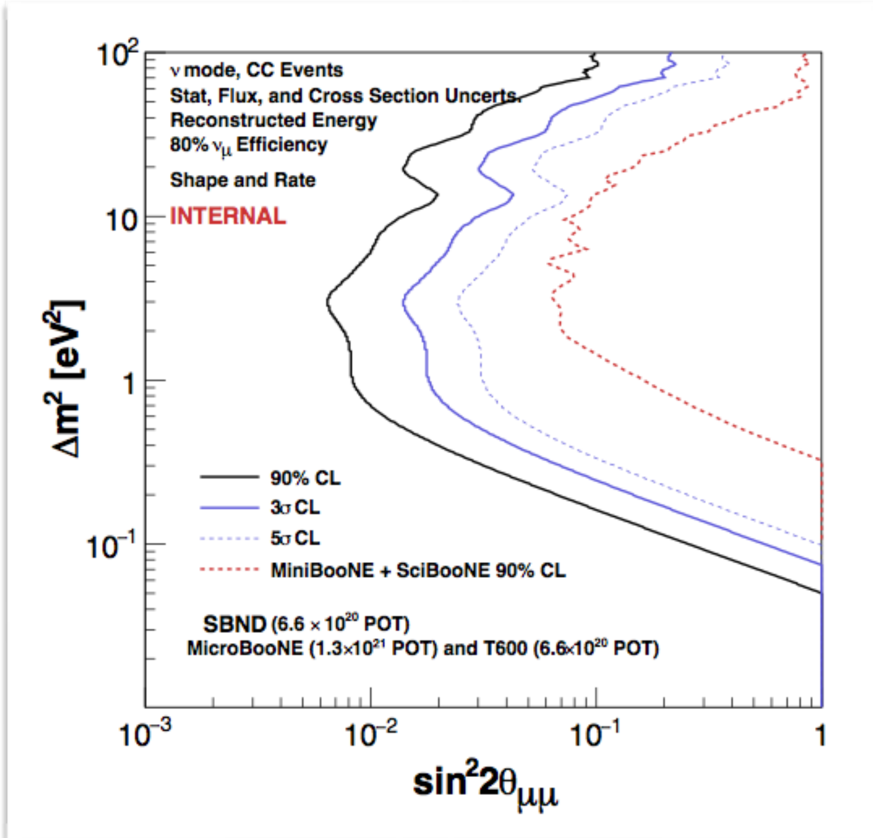
Physics Reach of the SBN Program

- Oscillation sensitivity of the SBN program has been evaluated <u>in a joint effort by three collaborations</u>
  - *Based on full simulations of all known backgrounds and systematic uncertainties* <u>for all three detectors using common BNB flux generators</u>

ν_e Appearance



ν_μ Disappearance



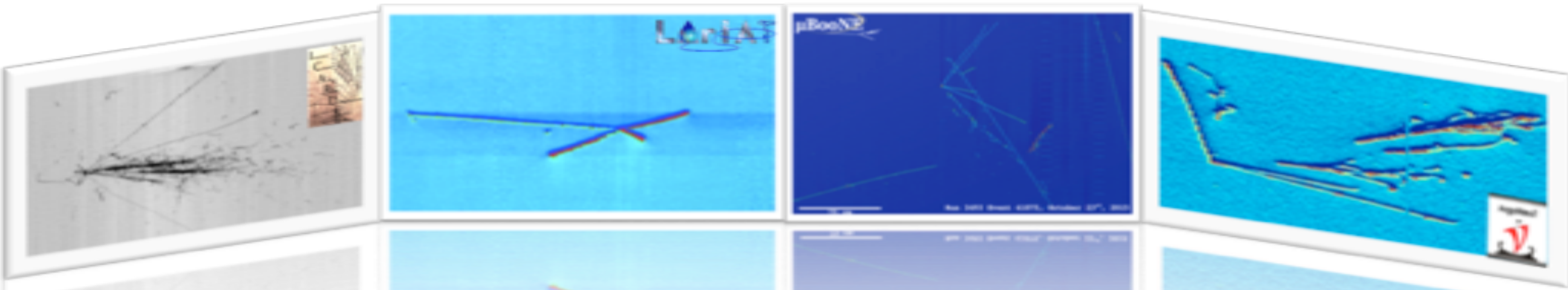
Since January 2015

- Development of the SBN physics proposal
  - *Spearheaded by a five member Task Force representing FNAL, CERN, and the three collaborations as well as a set of Working Groups with co-conveners and members from each of the collaborations*
  - *4 WGs: flux and systematics, cosmics, cryogenic infrastructure, civil construction*

- Following the proposal
  - *SBN Executive Board consisting of collaboration spokespersons and SBN Program Coordinator formed to facilitate continued communication*

- With Stage 1 approval granted after the January 2015 PAC, *focus of collaborations* has been on *detector design, construction, and operation* - Excellent technical progress in 2015!

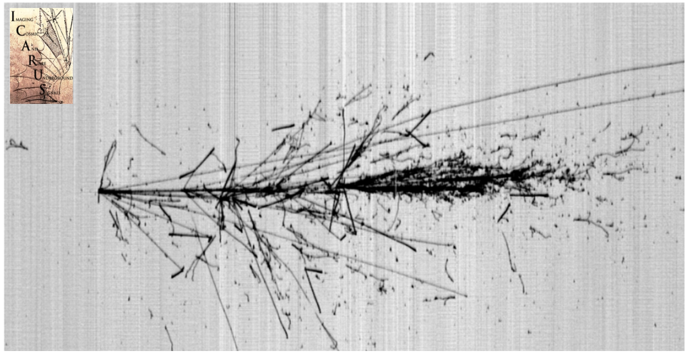
- Analysis and software development has continued in parallel with both short- and long-term aims
  - *Emphasis tends to be where input is needed for detector or program design →*



Joint Analysis/Software development

Reconstruction/Analysis Software Coordination

- Software development effort - Continued Analysis Tool development
  - *LArSoft provides a common software infrastructure for the sharing of reconstruction and simulation codes used by different liquid argon TPC experiments*
    - ArgoNeuT, MicroBooNE, LArIAT, SBND, DUNE, etc. use the LArSoft framework
  - *ICARUS developed their own analysis software for the Gran Sasso physics run before the start of the LArSoft project*



    - LArSoft experts from MicroBooNE have joined ICARUS over the past year
    - ICARUS reconstruction workshop (July 2015, CERN) included LArSoft experts from Fermilab and reconstruction developers from MicroBooNE to discuss the situation of reconstruction and analysis infrastructures of the experiments and start planning future common steps
    - Representatives of ICARUS attended the art-LArsoft school (August 2015, Fermilab), to improve technical knowledge of the LArsoft framework and inform taking a decision on a common reconstruction/analysis framework

Reconstruction/Analysis Software Coordination

- LArTPC Reconstruction workshop (Fermilab October 2015) with all stakeholders
  - *Organized and attended by Fermilab and CERN computing experts together with representatives from all of SBN (MicroBooNE, ICARUS, and SBND), DUNE, and LArIAT experiments*
  - ***Assessment workshop:*** *to review the current status of LArTPC event reconstruction and analysis - challenges and lessons learned*
  - ***Requirements workshop****: to define requirements for a LArTPC software platform that will support the analysis needs of LArTPC experiments over the next ~decade*
  - *Requirements document now in draft, authored by workshop participants*
    - https://cdcvs.fnal.gov/redmine/projects/lartpc-requirements/repository/revisions/master/entry/new-document/requirements.pdf
  - *Some examples:* ***i)*** *physics algorithm performance,* ***ii)*** *ability to use multiple physics algorithms in end-to-end analysis of data,* ***iii)*** *increased functionality of event visualizations,* ***iv)*** *enable effective use of multi-core and new computer hardware technologies,* ***v)*** *ease of use and distribution for international collaborations,* ***vi)*** *inclusion of new external software components such as event generators and hadronic simulation codes*
- Next step is to plan future work based on published requirements – again involving all participants

Reconstruction/Analysis Software Coordination

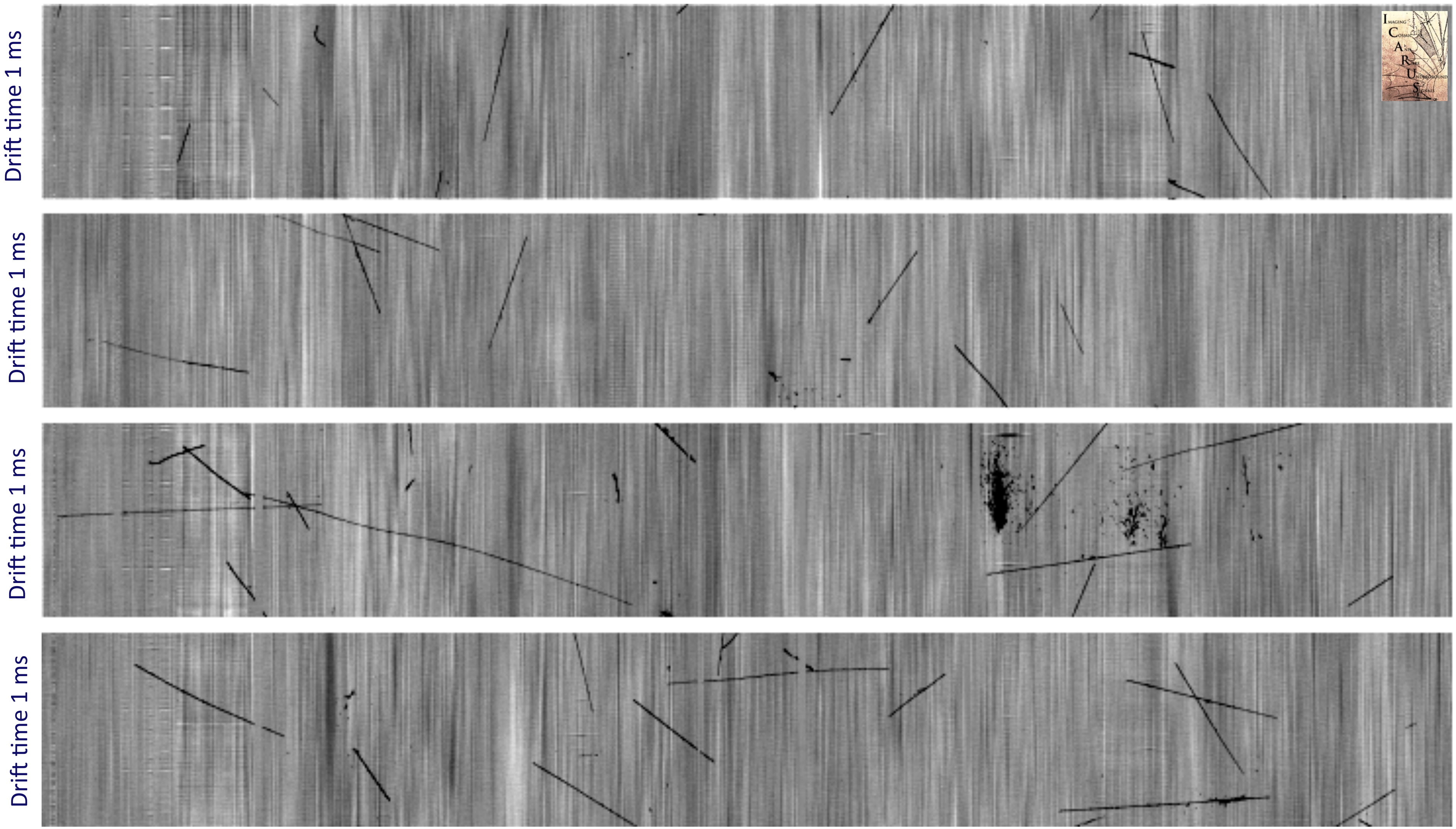
- *Steering Group* composed by LArSoft team, LArTPC experiment spokespeople and software experts
  - *Meets monthly to drive developments on LArTPC event reconstruction, prioritize work, and plan for the future*
- LBNC also working with the LArTPC groups – to receive reports on assessment, planning and future work for software and analysis

SBN Joint Analysis Efforts

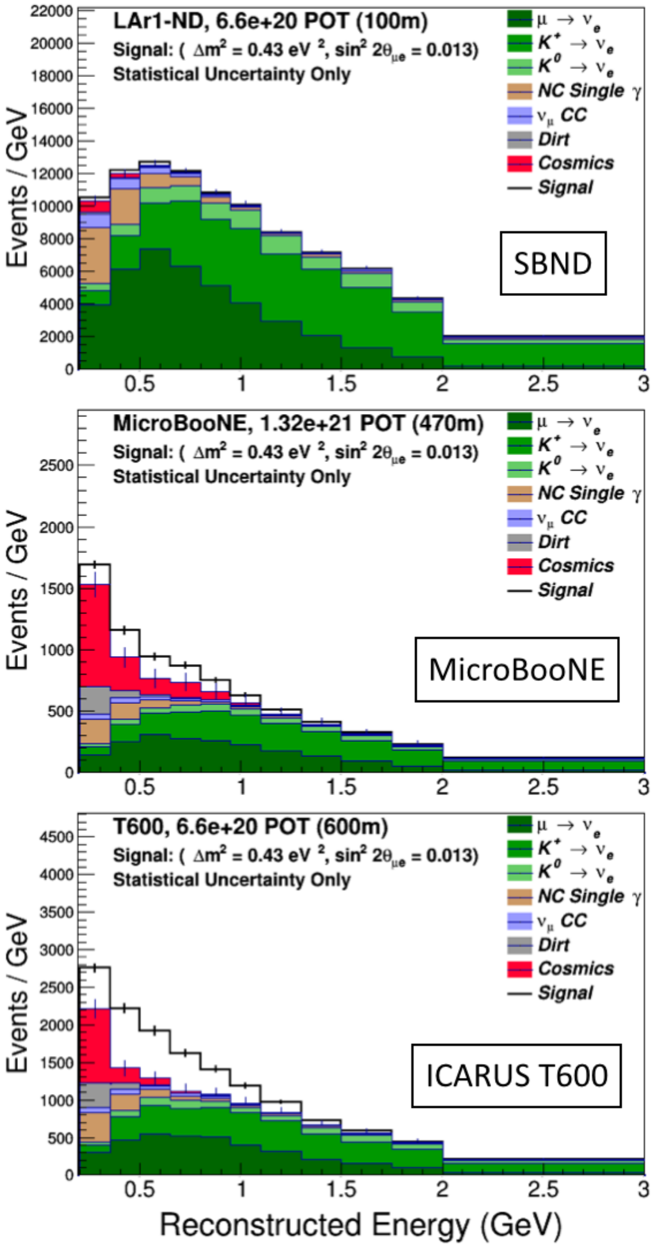
- *Mitigation of cosmogenic backgrounds & validation of cosmic ray simulations with data*
- *Physics of the BNB upgrade*

Cosmogenic Backgrounds

ICARUS T300 - Pavia run - Cosmic ray events

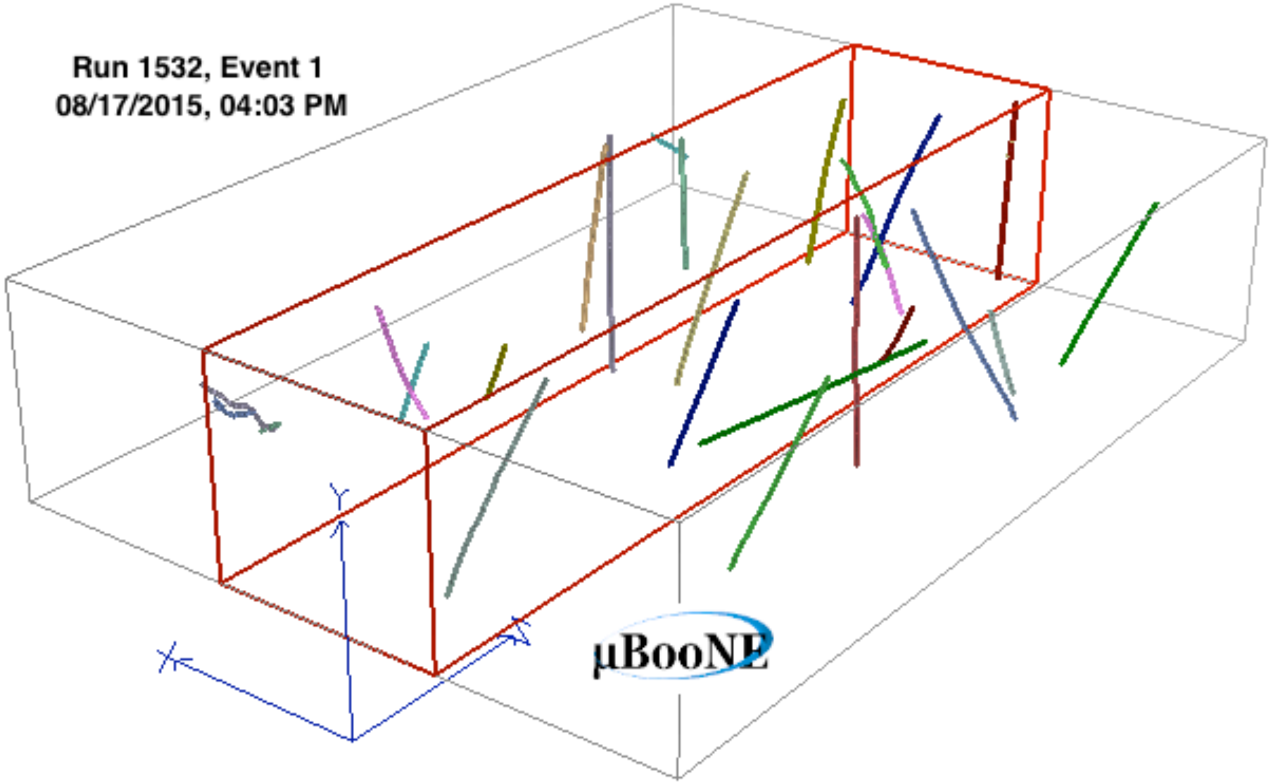


Cosmogenic Backgrounds



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

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



MicroBooNE cosmic data with 3D reconstruction!

Mitigation of Cosmogenic Backgrounds

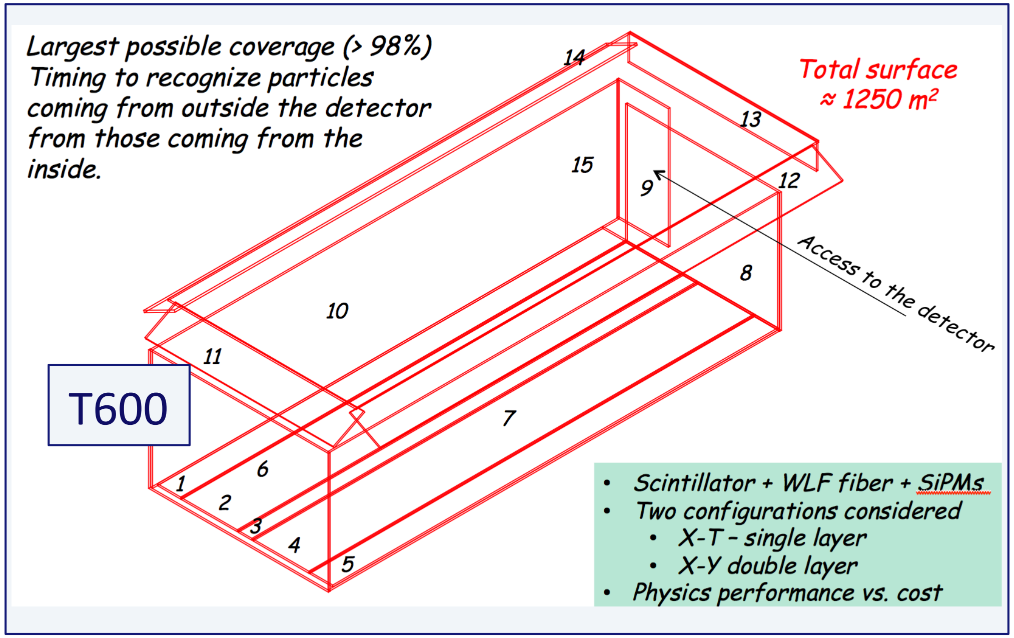
- Both the near and far detector buildings have been designed to accommodate up to 3m of concrete shielding directly above the detectors and MicroBooNE has proposed adding overburden

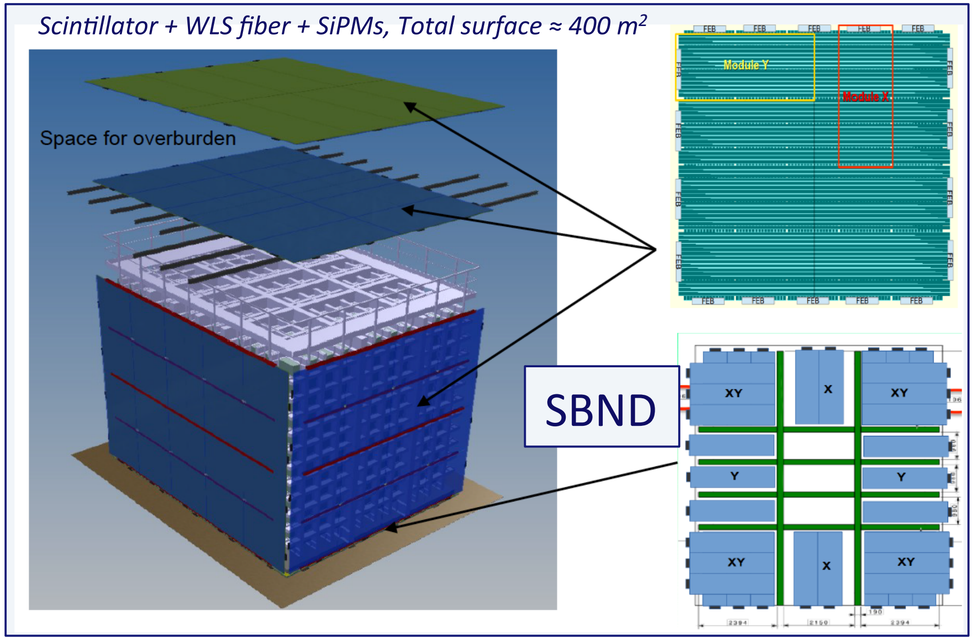
- Overburden provides significant rejection power for many ν_e-like backgrounds induced by cosmic rays other than muons
  - *Near 100% reduction of **primary** protons, neutrons, pions, and gammas that enter the TPCs without OB*
  - *Modest increase in **secondaries** generated in OB (e.g. 1% increase in secondary protons and 7% increase in secondary neutrons with 3m concrete OB according to a recent SBND simulation study)*

- This leaves photons generated by cosmic muons near or inside the detector as the primary source of cosmogenic backgrounds in the ν_e analysis

Cosmic Ray Taggers Design

- The SBN proposal (Jan. 2015) assumed a 3m concrete overburden and a Cosmic Ray Tagger (CRT) for both the near and far detectors and MicroBooNE has recently proposed installing a CRT
- SBND and MicroBooNE CRT are being designed and constructed
- ICARUS CRT is being designed





SBN Task Force on Cosmic ray Mitigation

- For the SBN proposal (Jan 2015), the three collaborations performed independent simulations to study the impact of cosmic rays, the need of cosmic-ray tagger systems and overburden

- These simulations have been refined by all three collaborations over the past year to compare/validate those results and push on new studies
  - *MicroBooNE cosmic ray task force, now started analyzing data*
  - *SBND complete detector geometry in place*
  - *Expanded ICARUS group initiated studies to refine the understanding of the cosmic ray backgrounds for the SBN measurement*

- Joint *Cosmic Ray Mitigation Task Force for SBN Detectors* formed in Nov. 2015 to define the requirements and implementation of the overburden and cosmic ray tagger systems for the SBN detectors
  - *Conveners: one representative for each experiment*
  - *Preliminary report next month*

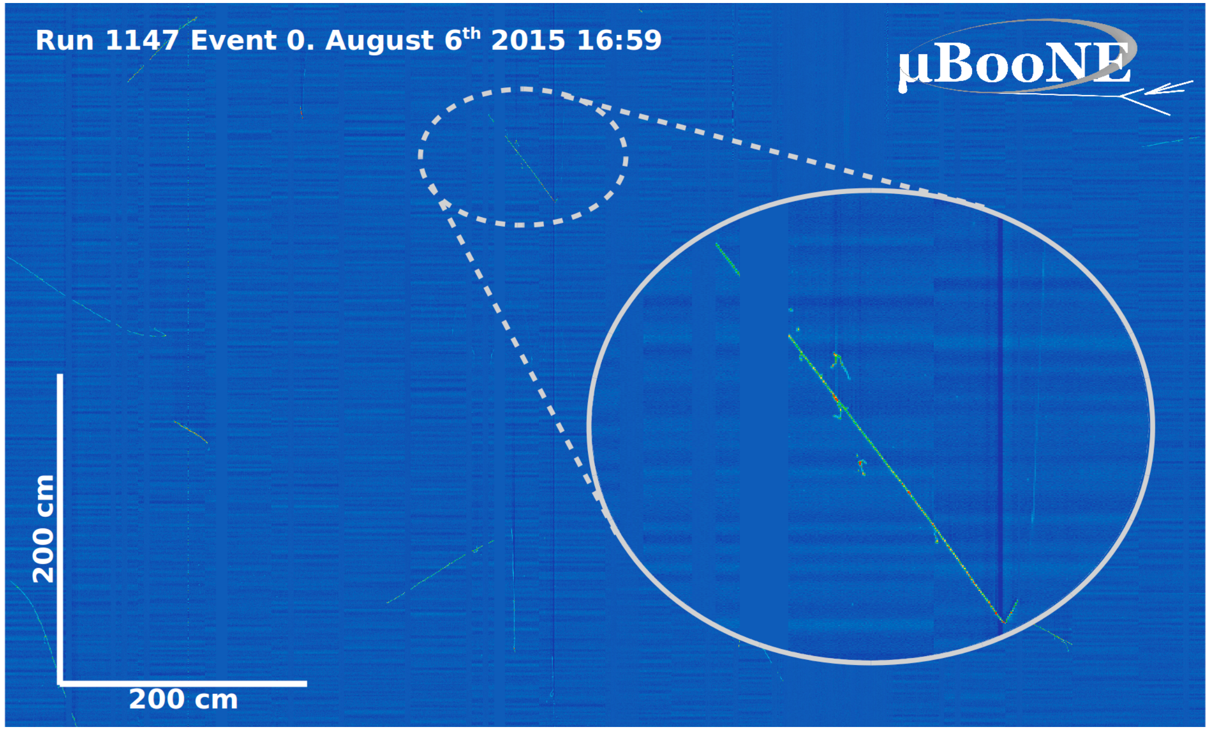
Joint Task Force *charged with assimilating available information and performing any new analysis needed to address specific questions related to overburden and CRT systems*

Cosmics Task Force Charge

- Main questions that are now being addressed jointly by all the three experiments for each of the detectors
  - *Accurate description of building/detector geometry in the simulations*
  - *Impact and required thickness (1m, 2m, 3m) of the overburden*
  - *Cosmic tagger system (CRT) configuration and performance requirements (spatial granularity, time resolution, number of layers)*
  - *Additional rejection from the cosmic tagger systems relative to internal light collection system*
  - *Impact of activity from secondary particles (from cosmic rays and beam interactions) on cosmic taggers*
  - *Identify areas <u>where common technical solutions</u> for the CRTs could be used for SBND, MicroBooNE and ICARUS-T600, ex.*
    - already designed SBND readout electronics to be used for all detectors
    - common scintillator strip size/configuration be used for at least part of the systems
- Working on protocol for internal-documents sharing

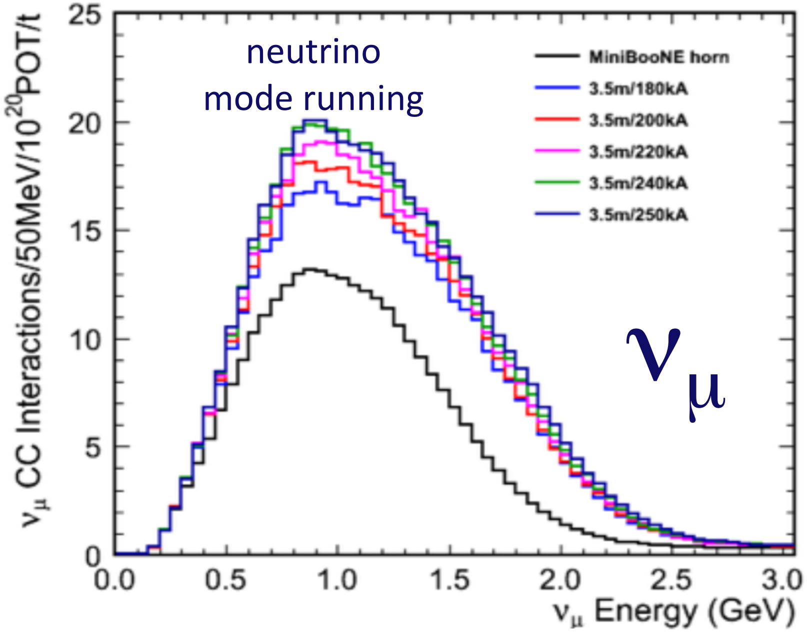
Validation of cosmic ray simulations

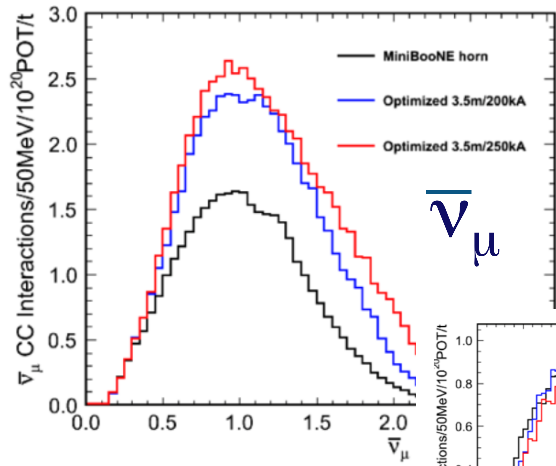
- Cosmic ray simulations have to be validated with real data
  - *ICARUS is considering the feasibility of setting up a test facility to verify the simulations and expectations for cosmic rays*
  - *MicroBooNE now has cosmic ray data that can be valuable for all three detectors and will make that available for the whole SBN program.*



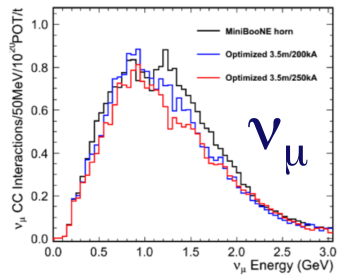
Booster Neutrino Beam Improvements

- Far detector statistics are key to ν_e appearance sensitivity
  - *(Detector mass) x (Neutrino flux) x (Time)*
- Possible BNB upgrade paths:
  1. *Increase focusing efficiency of target/horn system*
     – Optimize horn length, inner conductor, and current
  2. *Increase rate at which horn system is capable of running*
     – Booster can operate at 15 Hz, existing horn at 5 Hz (limited by mechanical integrity and power supply)
- Detailed study carried out by a team at FNAL: gains up to ~**1.8× in event rate** possible with longer horn design and upgraded power supply





antineutrino
mode running



Upgrades of the BNB beamline

- Following one the recommendations at the December 2015 SBN Program Director's Progress Review:

  "Perform simulations to clarify the additional sensitivity reach from the new flux spectrum, quantify at what POT systematics start to dominate, and the dependence on assumptions about NC pi0 rejection and cancellation of errors in the near/far ratio."

- Charge SBND, MicroBooNE, ICARUS and BNB experts with addressing the physics reach for different beams configurations (by May 2016)

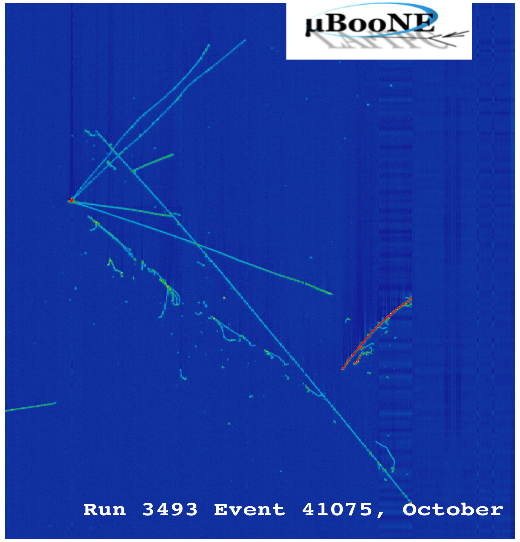
Technical coordination

Technical Coordination

- Cosmic Ray Tagger Systems
  - *Common solutions in scintillator tracker design and readout electronics*
- DAQ
  - *Lots of activity involving SBND, MicroBooNE, and ICARUS DAQ experts to consider common DAQ software solutions, data formats, etc.*
  - *One-day SBN-DUNE workshop held in November 2015 to explore possible synergies within DAQ and readout electronics*
  - *SBN program initiating a joint online systems working group with participation from all three collaborations*
- Photon Detection
  - *SBND working with ICARUS on PMT-based photon detection system.*
    - SBND to use same PMTs, 8” Hamamatsu R5912
    - Plan to send SBND PMTs to CERN for wavelength shifter coating and performance testing/characterization in same facility used for ICARUS
    - SBND and ICARUS working together on electronics and DAQ system

Summary: SBN Analysis/Software coordination

- SBN detectors have made enormous technical progress in 2015
  - *MicroBooNE is taking data! SBN phase-I now operational! MicroBooNE data analysis in progress.*
  - *ICARUS T600 refurbishment is progressing well at CERN*
  - *SBND TPC is in final design phase, construction to begin in early 2016*
  - *Civil construction on-going*
  - *Improved beam designs being explored*



- PAC comments on SBN analysis from June 2015 Report:

"…There appears, however, to have been very little progress on coordinating the plans for analysis across all three of the experiments. While this process is understandably sociologically complex, it is nevertheless critical to the success of the SBN program. Questions that range from data formats to common flux generators to blind analysis schemes will need to be answered, and quickly."

Summary: SBN Analysis/Software coordination

- Progress toward unified analysis across the collaborations
  - *Continued collaboration on important aspects of SBN physics through joint Task Forces - e.g. cosmic backgrounds; impact of BNB upgrades*
  - *Close communication on hardware also a valuable ingredient in preparing for common data analysis in the future - e.g. joint efforts on DAQ and online systems to define data formats; use of same photon detection system; common hardware for cosmic ray tagger systems*
  - *Adoption of common reconstruction/analysis framework is the first step for interconnections/synergies and effective use of resources between different LArTPC projects and is crucial for the joint analysis of the three SBN experiments*
  - *Development of longer-term strategies (in progress)*
    - Too soon to define details like blind analysis schemes. Experience with BNB neutrino analysis and cosmic ray mitigation from MicroBooNE data valuable input
    - Sharing results of development progress on a continuous basis – e.g.: future extensive workshops devoted to LArTPC reconstruction
    - Joint Steering Committee for software, Task Forces, and Working Groups

With major progress on detectors and continued analysis efforts on multiple fronts, we are well on our way to an exciting SBN physics program!

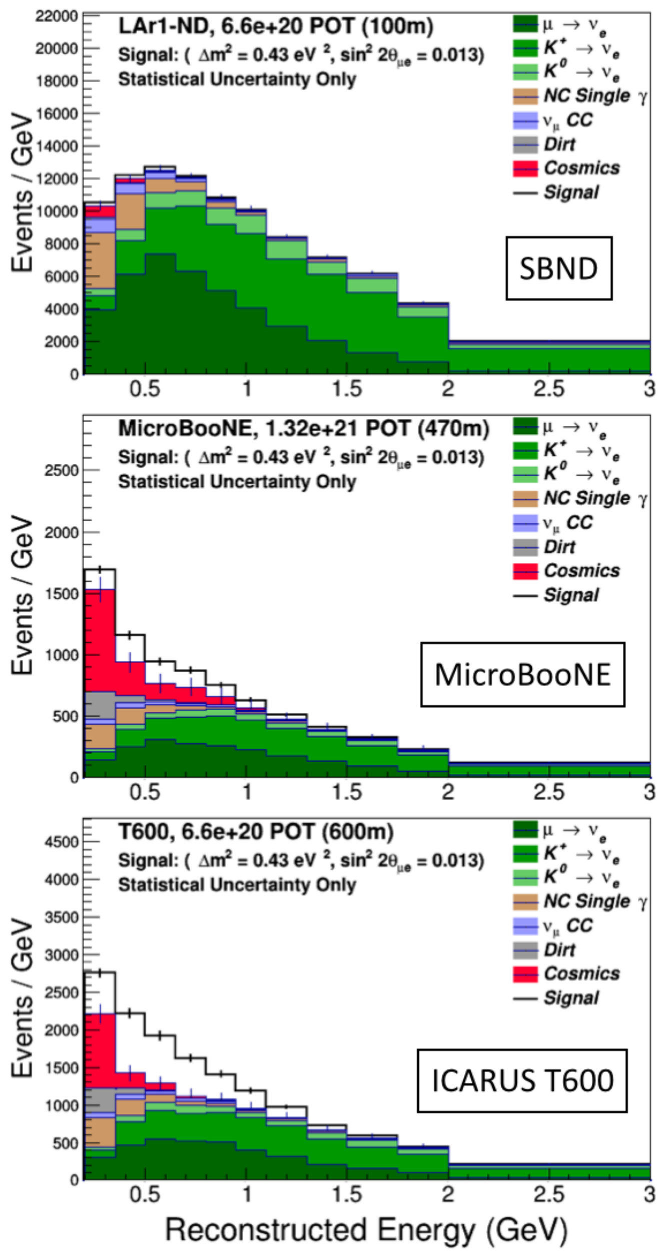
Extras

Physics Reach of the SBN Program

- Oscillation sensitivity of the SBN program has been evaluated in a joint effort by three collaborations
  - *Based on full simulations of all known backgrounds and systematic uncertainties*

    - **intrinsic** ν_e content of the beam
    - **photons** induced by **neutral current** interactions
    - **neutrino interactions** in the **material surrounding the detectors**
    - **cosmogenic photons**
    - **neutrino flux** and **neutrino-argon cross section systematics** and **detector-to-detector systematics** included in the sensitivity analysis

Backgrounds & Oscillation Signals in SBN

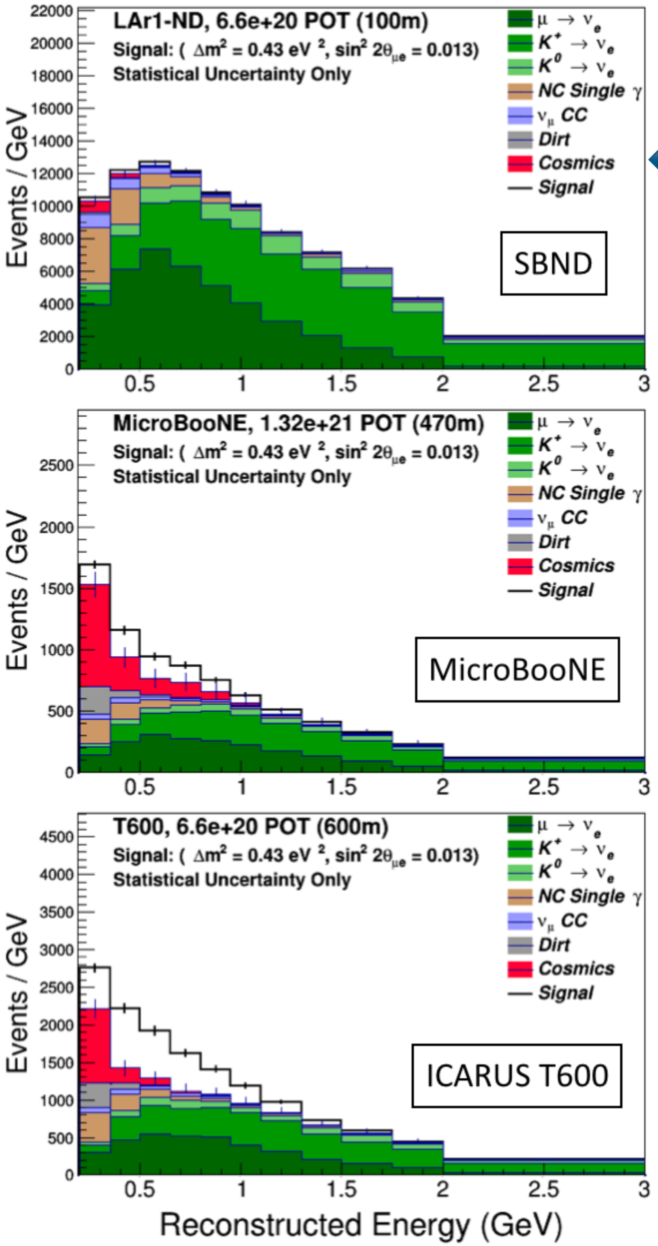


- **Electron neutrino CC interactions**
  - $\pi \rightarrow \mu \rightarrow \nu_e$
  - $K^+ \rightarrow \nu_e$
  - $K^0 \rightarrow \nu_e$
  - Sample appearance signal

Intrinsic beam ν_e

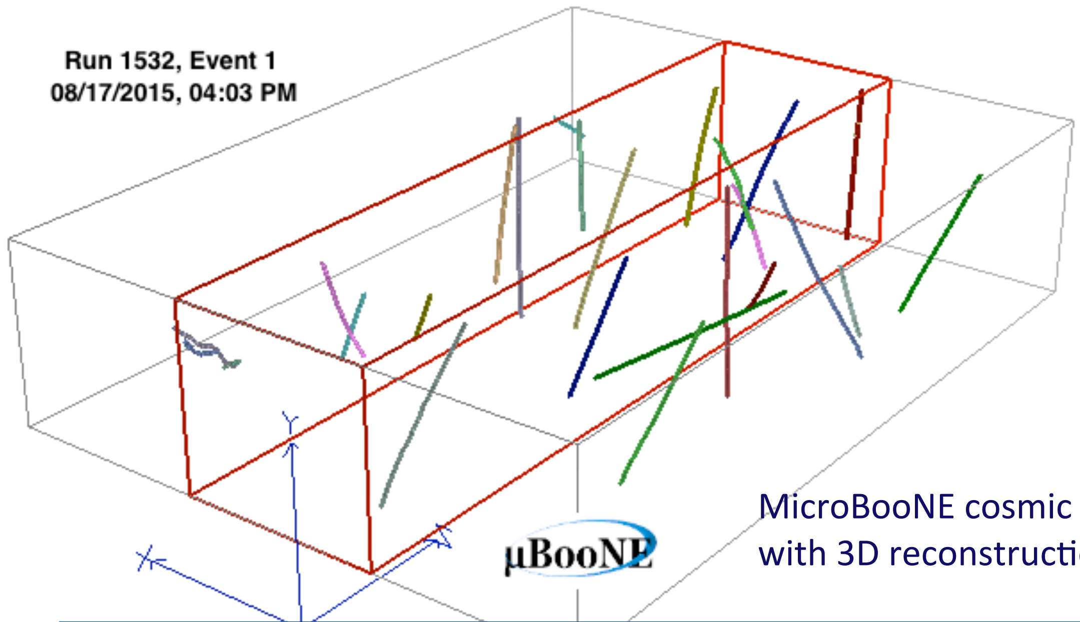
- **Photon-induced e.m. shower backgrounds**
  - NC misIDs
  - ν_μ CC misIDs
  - "Dirt" Backgrounds: beam-related but out-of-detector interactions
  - Cosmogenic photon sources

Mitigation of 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



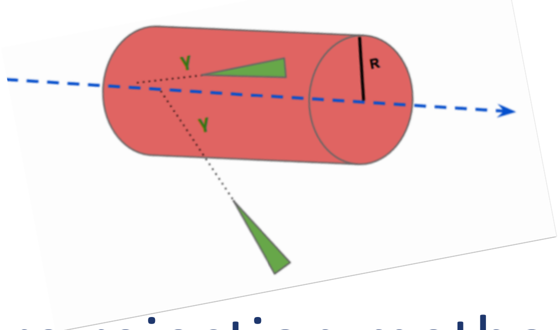
MicroBooNE cosmic data with 3D reconstruction!

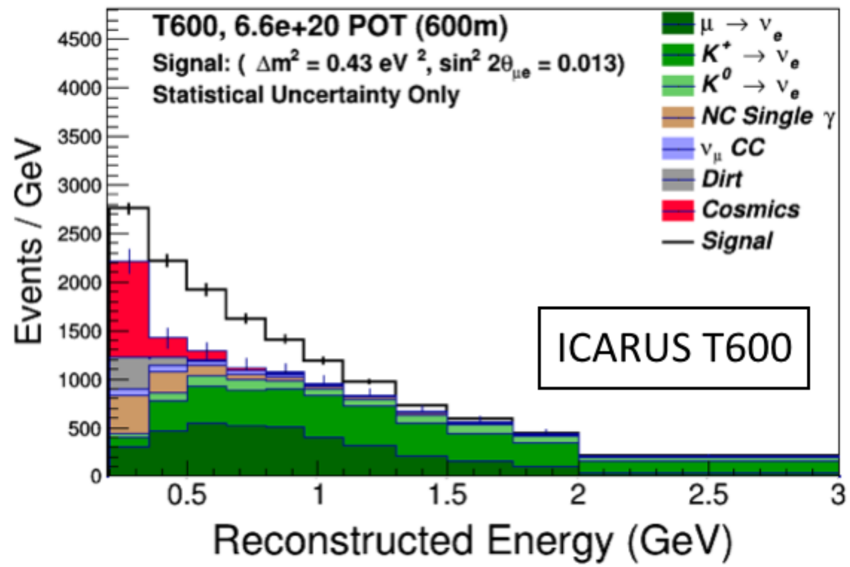
Detector	Neutrino interaction every N spills	Cosmic muon in beam spill time every N spills
SBND	20	250
MicroBooNE	600	200
ICARUS-T300	350	100

Mitigation of Cosmogenic Backgrounds

❑ Software rejection methods:

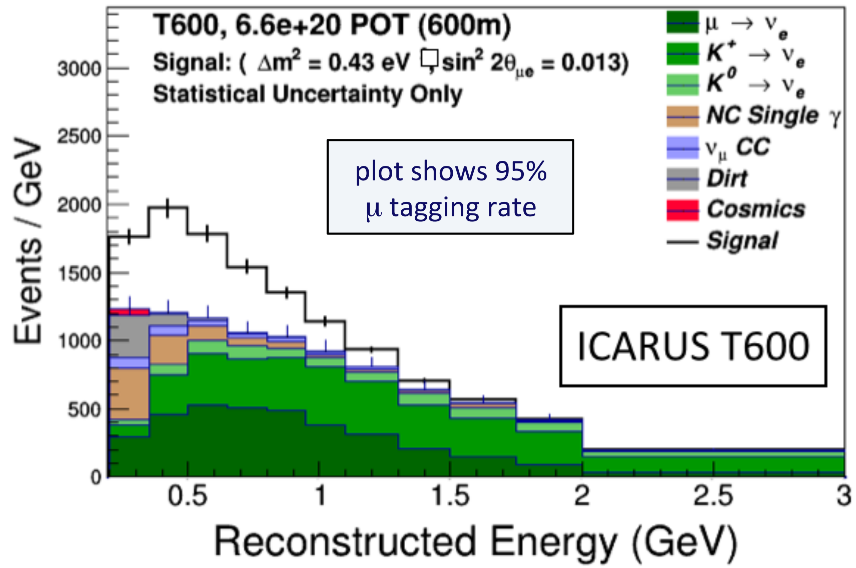
- *dE/dx at initial part of showers → factor ≈10*
- *Fiducial volume for photons produced outside*
- *Shower distance from parent muon track → 15 cm radius rejects >99% of γ > 200 MeV*



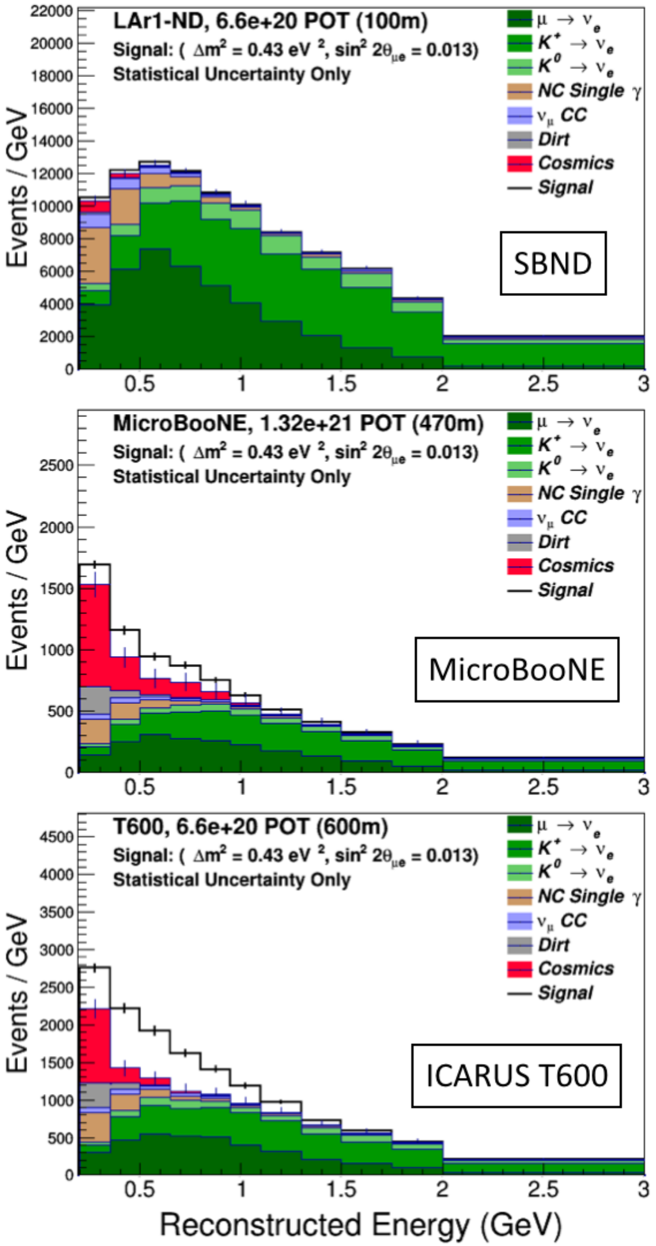


❑ Hardware rejection methods:

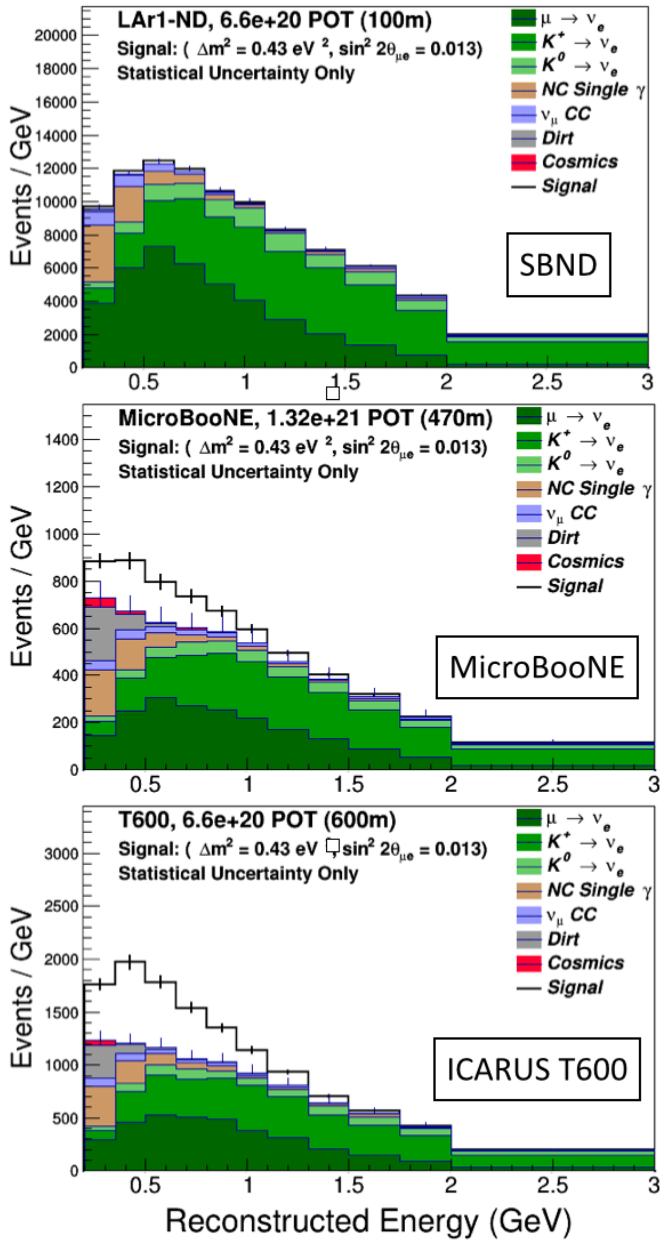
- *Internal photon detectors*
  - Performance depends on position-time matching resolution of system
- *External cosmic ray tagging system*
  - Reject beam triggers with in-time signals in the CRT, suppressing cosmogenic backgrounds with a small and measurable efficiency loss on ν events (3%)



Cosmogenic Backgrounds



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



Off-beam triggers can be used to measure cosmic backgrounds to high precision *so small systematic uncertainties - all about statistics*

SBND CRT

CRT Module structure

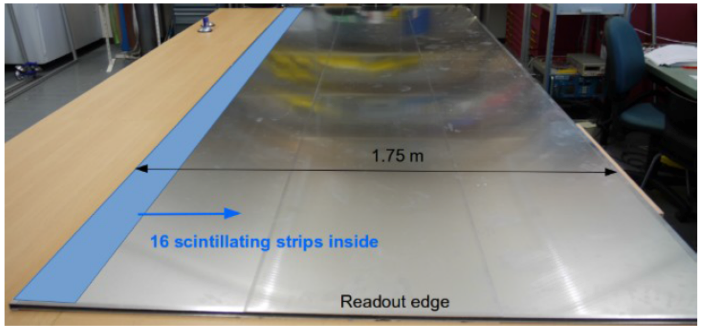
16 strips per module

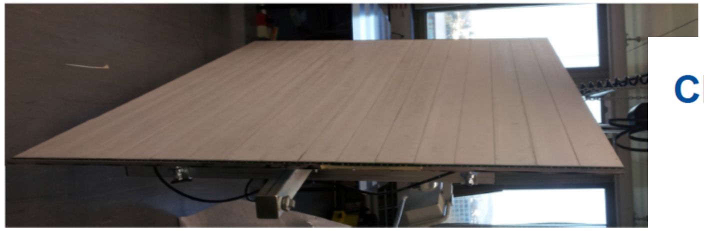
Module length:
3.6m & 4.5m

Module width: ~1.8m

Aluminum case
(2-4 mm thick)

Robust, self-supporting

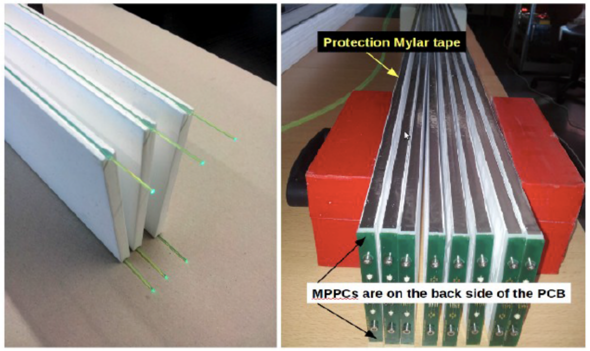




CRT Strip structure

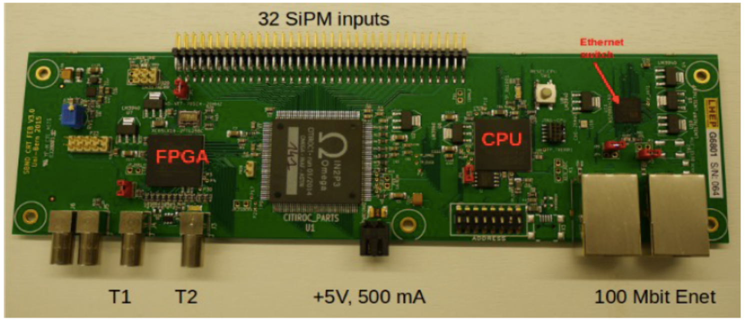
Scintillator: USMS-03 (PS+PTP+POPOP)
Reflective surface (UNIPLAST technology)
WLS fibers: Kuraray Y11(200)MS, 1mm diameter
Optical glue: ESA 7250 polysiloxane compound
SiPM: Hamamatsu S12825-050P

2 SiPMs per strip



SBND CRT

CRT Front-End electronic Board (FEB)



SBN ⚙Fermilab
7 12/6/15 I. Kreslo | SBND Cosmic Ray Tagger, presentation at SBN Directors Progress Review

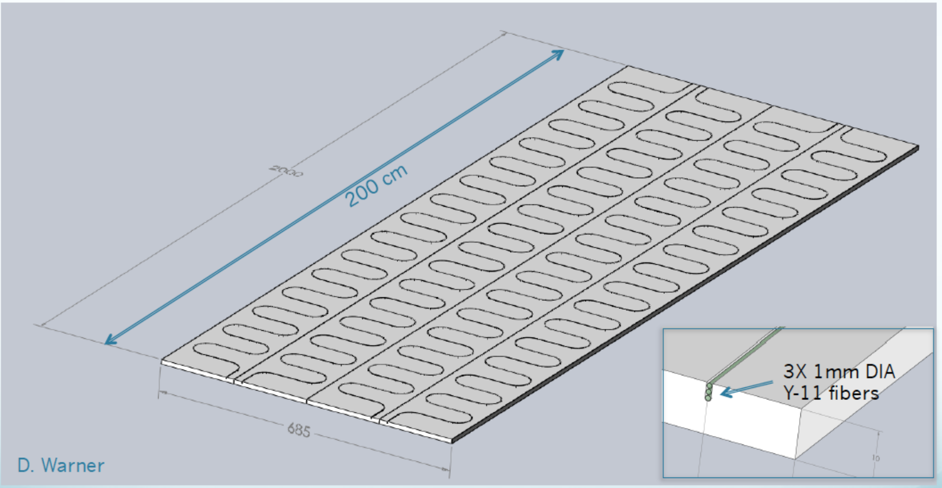
CRT Performance Summary

Muon flux coverage	~ 94%
Muon detection efficiency	95% to 99%
Coordinate resolution	< 2 cm (2D)
Time tag accuracy w.r.t 1 PPS	2-6 ns RMS (electronics: 1.3 ns)
Amplitude dynamic range	100 p.e. => 3 x MIP Optional: 500 p.e. => 15 x MIP
S/N ratio for MIP	120
Detection threshold at S/N=4	70 keV

ICARUS CRT

- Two scintillator configurations considered:
  - X-Y double lays (same as SBND/MicroBooNE)
  - X-T single layer

X-T Module Concept



Use time/amplitude from each end to get longitudinal hit position
Based on T2K ND280 & WAGASCI counters
2 m counters w/ single fiber yield ~20 pe near end / 4 pe far end

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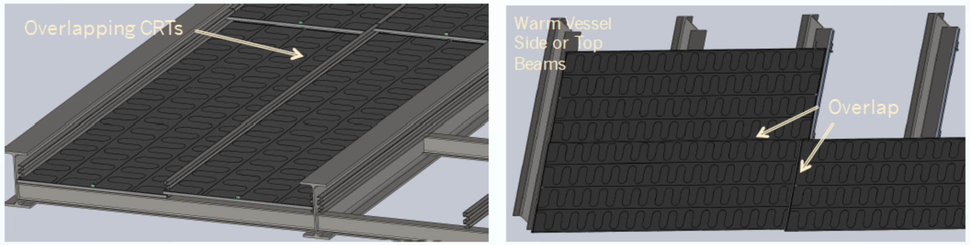
Module Mounting Concepts



- Side and top CRT panels mount to outside of warm vessel structure
  - Panels overlap in both directions -> ~1% dead area
- CRT panels under the warm vessel supported by rails mounted to support beam
  - Panels overlap in both directions
  - ~3% dead area due to support beams and structure
- All panels may be installed after warm vessel installation
- ~900 panels for full coverage 2m X 685mm X-T design

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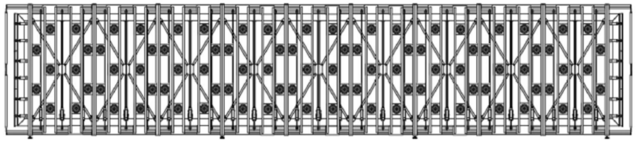
ICARUS PMT Light Detection system

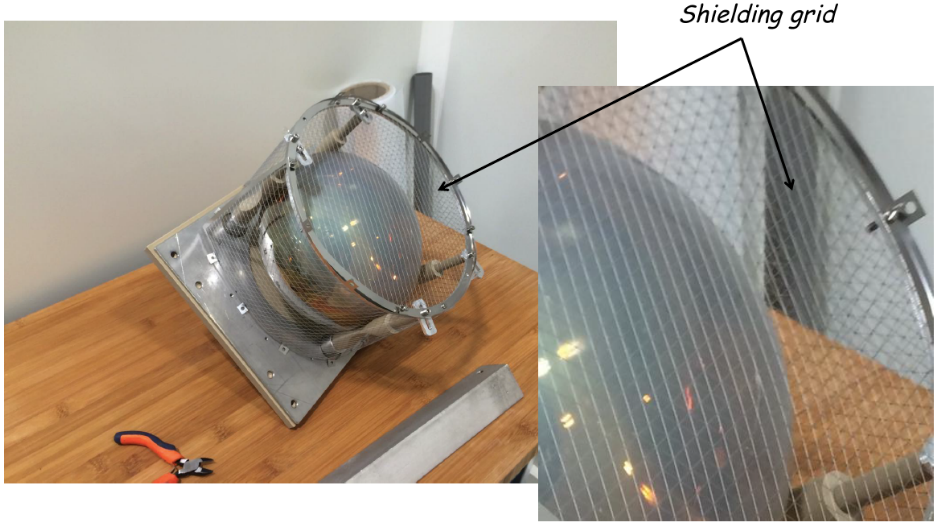
- The refurbished light collection system consists of 90 PMTs 8" HAMAMATSU R5912-MOD for TPC, installed behind each wire planes (360 PMTs in the whole T600). About 200 $\mu g/cm^2$ of TPB wavelength shifter is deposited on each PMT window. The photo-cathode coverage corresponds to 5% of the wire plane area.
- The number of photoelectrons collected per MeV of deposited energy in a single TPC is ~ 15 phe/MeV, allowing the possibility to trigger low energy events with fairly high threshold and multiplicity.



Z axis (beam direction)

- An event localization better than 0.5 m and an initial classification of different topologies (cosmic μs, e.m. showers, ν_μ CC) can be obtained exploiting the arrival time of prompt photons and the collected light signal intensity.
- Fast laser pulses will be provided to each PMT by a system of optical fibers for timing calibration.

ICARUS PMT System Slide: 5



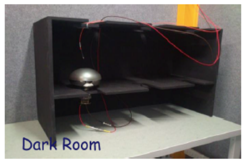
ICARUS PMT System Slide: 7

PMT tests at CERN

- Test and characterization of all PMTs at warm temperature;
- 10% of PMT is also tested at cryogenic temperature (all PMTs are mechanically tested in LN2 by Hamamatsu);
- Deposition by evaporation of TPB on all PMTs' window.

Activity on the PMTs are organized at CERN in three different areas:

Warm tests
IdeaSquare building (B3179)



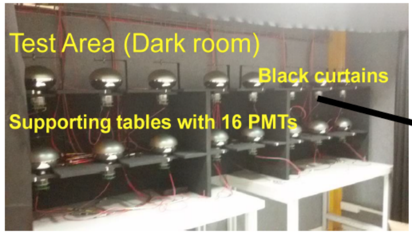
Cold tests
building 182

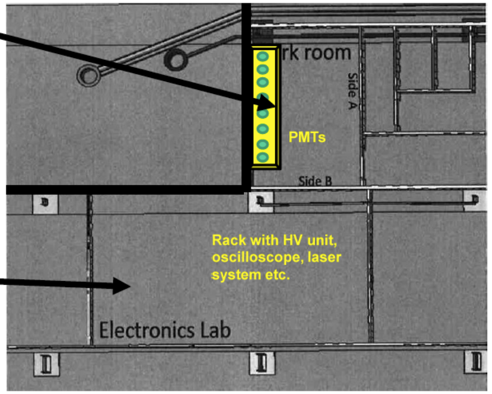
TPB deposition
TE-Laboratory hall (B169)

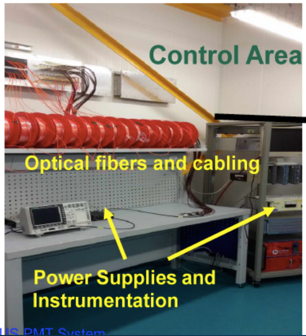
ICARUS PMT System Slide: 9

ICARUS PMT Light Detection system

The PMT warm-test area



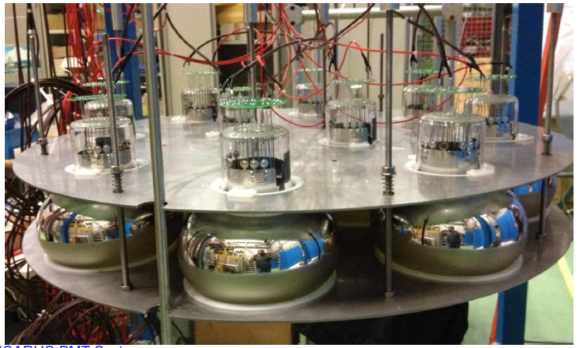




Ideasquare Lab

The PMT cold-test area (B182)

This area is equipped with electronics and cryogenic facilities which allows the characterization of the PMTs directly immersed in liquid Argon.

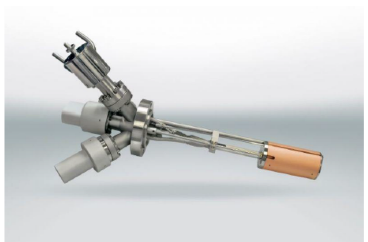


ICARUS PMT System Slide: 12

The evaporation process

The TPB coating is carried out by means of a thermal evaporation system installed in building B169. The evaporator is made up of a Knudsen cell inside a vacuum chamber (10^{-5}mbar).

At 210°C, TPB starts to evaporate and produces a coating on the surface of the PMT.



ICARUS PMT System Slide: 14

The activities of the upgrading of the T600 light detection system are proceeding according to programmed schedule:

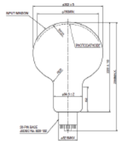
- All the 20 PMTs of the pre-series have been tested at room and at cryogenic (87 K) temperature; the measures are consistent with the nominal values given by the manufacturer and are compliant with the requirements for installation in the T600.
- First PMT batch of series production (80 units) was delivered at CERN and a third batch (100 samples) is expected by December 2015.
- Evaporation area and instrumentation are ready for series production.
- All necessary material and instrumentation for final PMT installation in T600 have been ordered and are being delivered.

ICARUS PMT System Slide: 20

SBND PMT Light Detection system

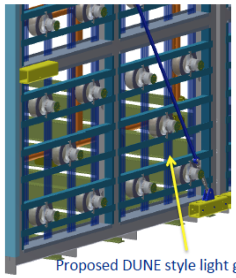
PDS Technical Status

- **PMTs**
  - Decided on the Hamamatsu R5912 Cryogenic PMT.
  - Robust and proven cryogenic PMT
    - Same choice as ICARUS uB, miniCLEAN.
    - 10 stage 10^7 gain.
    - 1.5 nsec Gaussian timing resolution for single photo-electron.
    - PMT base will be mini-CLEAN design (Photo-cathode at ground).
    - Tetraphenyl butadiene TPB wavelength shifting (128 nm -> 425 nm peak) film coated directly on PMT glass.
  - Total of 120 8” R5912 PMTs will achieve up to ~15 photo-electrons/MeV at 2m from PMT plane.
  - Negotiating with Hamamatsu with order to be placed in the new year.
  - Discussions with ICARUS to perform TPB evaporative coating and testing of PMTs at CERN.

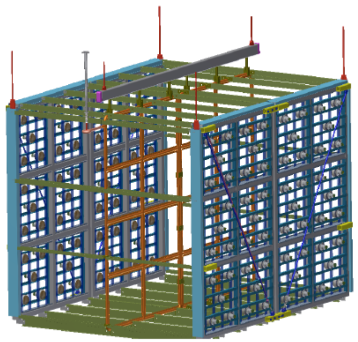


PDS Technical Status

- **Support structure and PMT mounting**
  - Jan Boissevain (LANL engineer) has started work on support structure design, fully integrated with FNAL CAD/setp file models.
  - PMT support structure will bolt onto TPC frame. Integration into TPC needs to take account of TPB light sensitivity.
    - Dry weight per APA 124 kg; Buoyancy weight 50 kg.
  - Cable plant and cold feed thru needs to be designed.
  - PMT support structure will be designed to accept DUNE style light guide bars.



Proposed DUNE style light guide bars fill in space between PMTs.



Adding center PMT increases total to 120 PMT’s

Technical Status

- **Electronics**
  - Options: CAEN, ANL, Nevis, others…
  - Desirable to use common system between SBND and ICARUS.
  - Fast digitization allows complete characterization of PMT pulse shape (~10-20 nsec width).
  - CAEN has two models available with large memory option (~5 Ms/channel => 0.01 sec):
    - 1725: 250 MHz and 14 bits, 16 channel/board, ~$700/channel
    - 1730: 500 MHz and 14 bits, 16 channel/board, ~$1000/channel
    - 14 bit ADC would provide 2^5 charge bits for single PE and a dynamic range of around 512 PE.
    - Fiber optic readout (80 Mbit/s per link), 64 MHz external clock input/sync, onboard triggering/filtering options, FPGA programming support.
  - ANL design has similar features, but requires some up front engineering development (different ADC than current SiPM design).
  - Begun work with DAQ group on interface/sync issues.