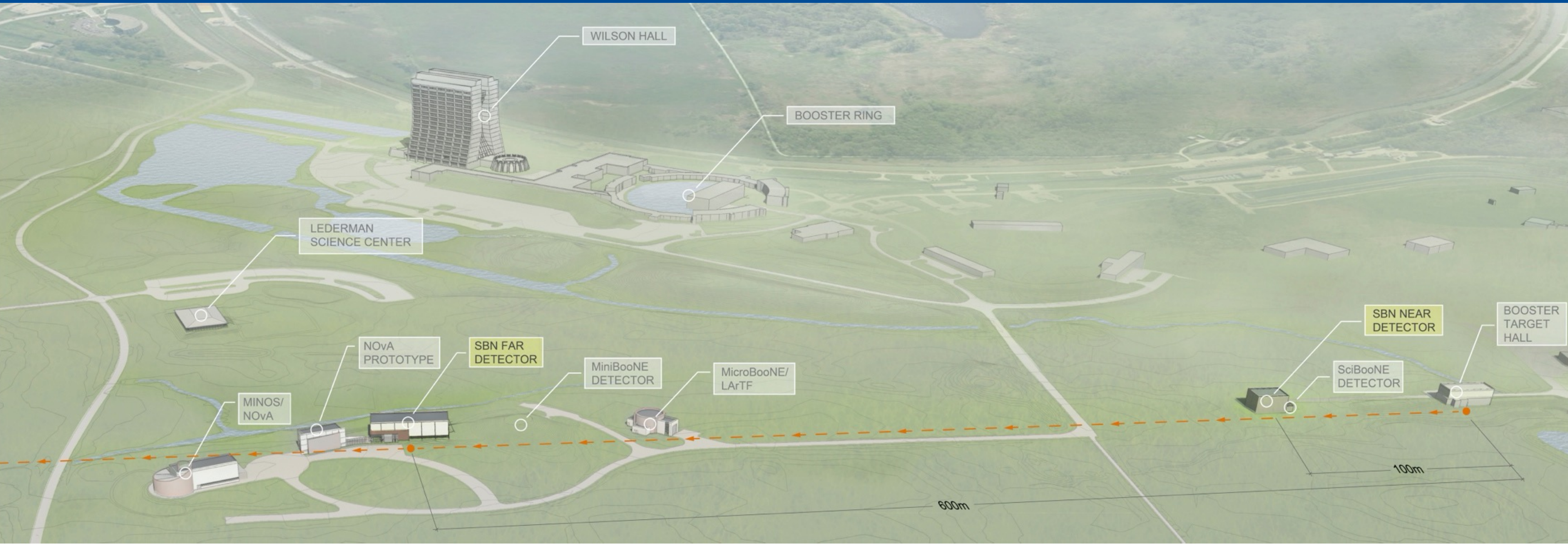


SBN Working Groups Update

SBN Oversight Board Meeting

June 11th, 2021

Ornella Palamara

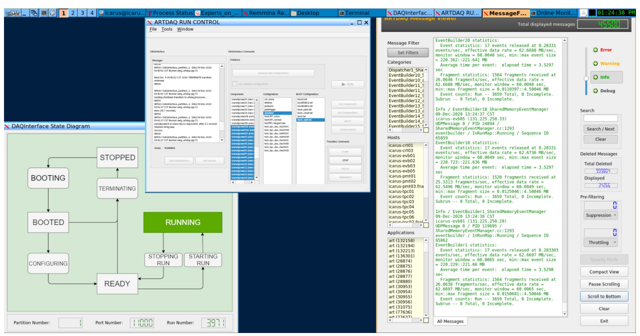
SBN Working Groups

- SBN DAQ and Data Pre-Processing *[conveners: Bill Badgett, Angela Fava, Wes Ketchum, Yun-Tse Tsai]*
  - *Goal*: Develop common tools for **trigger, data acquisition and data pre-processing**, and coordinate activities in those areas.
- SBN Slow Controls *[convener: Geoff Savage]*
  - *Goal*: Develop **control systems** based on **hardware and software interfaces** as much as possible identical for the two detectors.
- SBN Cosmic Ray Tagger *[conveners: Umut Kose, Igor Kreslo, Minerba Betacourt]*
  - *Goal*: Review the **CRT production status and the installation plans** for the two detectors, develop common CRT **DAQ and monitoring.**
- SBN Analysis Infrastructure *[conveners: Wes Ketchum, Joseph Zennamo]*
  - *Goal:* Coordinate and address **data and software infrastructure** and **computing resource needs** across the SBN
- SBN Analysis *[conveners: Daniele Gibin, Ornella Palamara]*
  - *Goal:* Take care of all the aspects of the multi-detector physics analysis for **SBN sterile neutrino oscillation searches**

SBN DAQ and Data Pre-processing WG

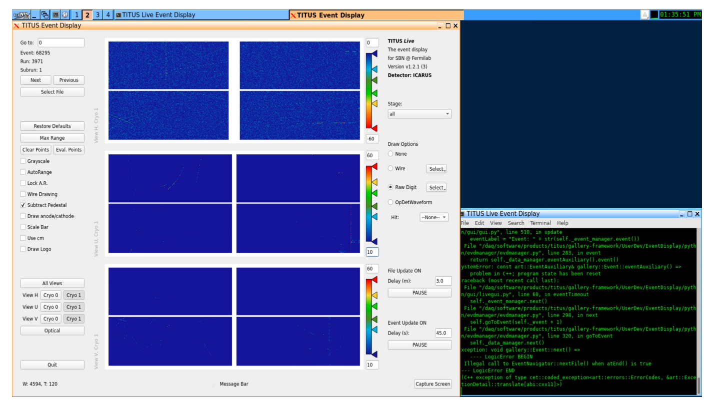
❑ SBN common efforts

- ❑ Run Control, online monitoring
- ❑ Improvements in event synchronization for PMT DAQ, allowing ‘multi-window’ readout to collect flashes from both the neutrino beam and cosmic rays occurring during the TPC drift period
- ❑ Full incorporation of trigger information into data stream and event timing
- ❑ Interfaces/additional information in data stream for offline for Proton on Target (POT) accounting



Run Control

Live Event Display

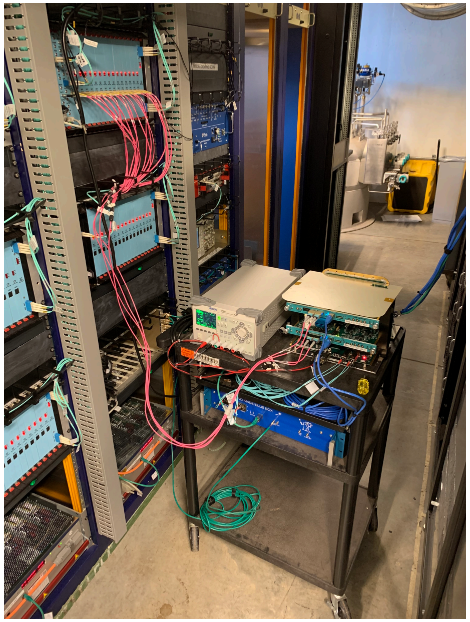


❑ ICARUS

- ❑ **See ICARUS status update by Angela Fava**
- ❑ Online event filtering / streaming BNB and NuMI events to different files (improving offline data handling)

SBN DAQ and Data Pre-processing WG

- SBND
  - Continue TPC readout stress tests and continue trigger integration
  - Began installation of TPC Cold Electronics Power rack
  - Installed production Timing interface server
  - Set up DAQ production network, begin testing TPC readout
  - Planning Photon Detector System readout and power racks installation
  - Receive part of the X-Arapuca light detection system readout electronics, planning for testing
  - Set up a test stand for X-Arapuca readout, the last system to be integrated

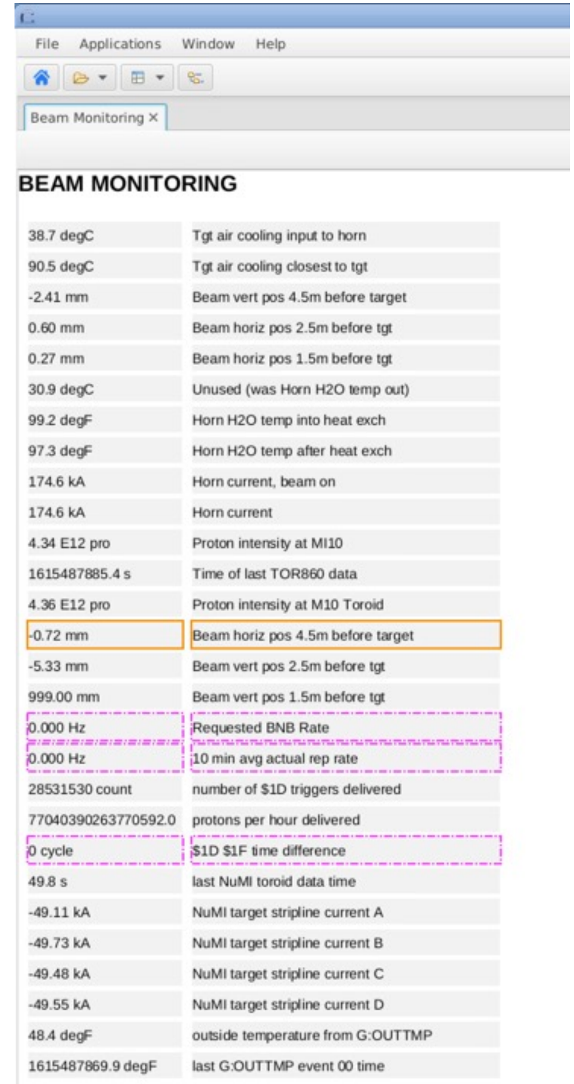


Test Stand (ND building)

Power supply

SBN Slow Controls WG

- SBN common efforts
  - Addition of CRT data monitoring into online monitoring interface
  - Beam Monitoring



- ICARUS
  - See ICARUS status update by Angela Fava

- SBND
  - Set up and configure Detector Slow Control (DCS) production network
  - Installed production DSC server and moved DCS processes to their final location

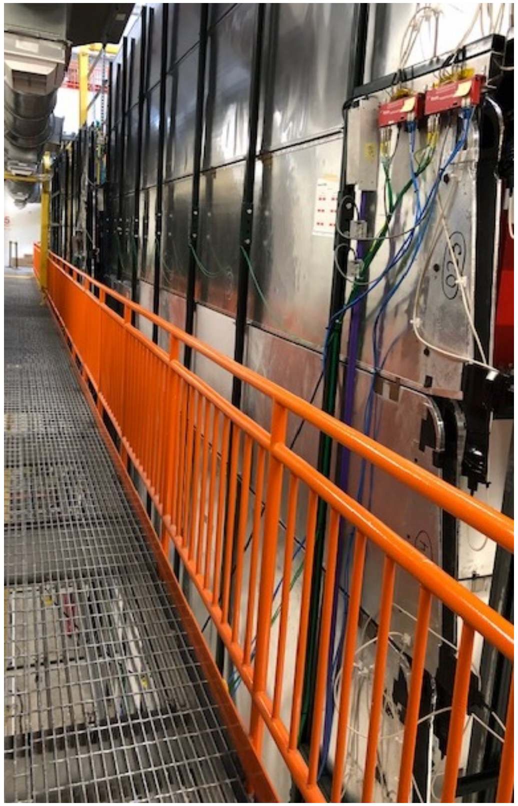
SBN Cosmic Ray tagger WG

ICARUS

- Four sides of the ICARUS detector have been covered with the CRT modules

East Side

West Side



South Side

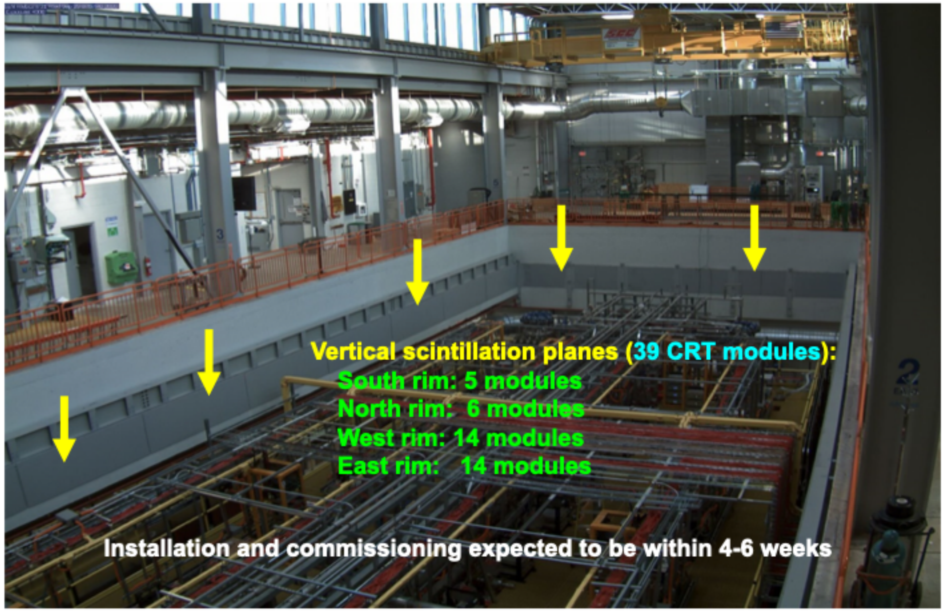
- Installation has been performed by collaborators from different institutions (Fermilab, Colorado State Un., Un. of Pittsburgh and Southern Methodist Un.)
- Commissioning is in progress

SBN Cosmic Ray tagger WG

- Top ICARUS CRT:
  - All modules, electronics and cables of the top CRT are at Fermilab
  - Vertical support structures scheduled to be installed after June 28
  - The work for the horizontal plane installation will begin once the supports are in place, scheduled for Summer 2021.

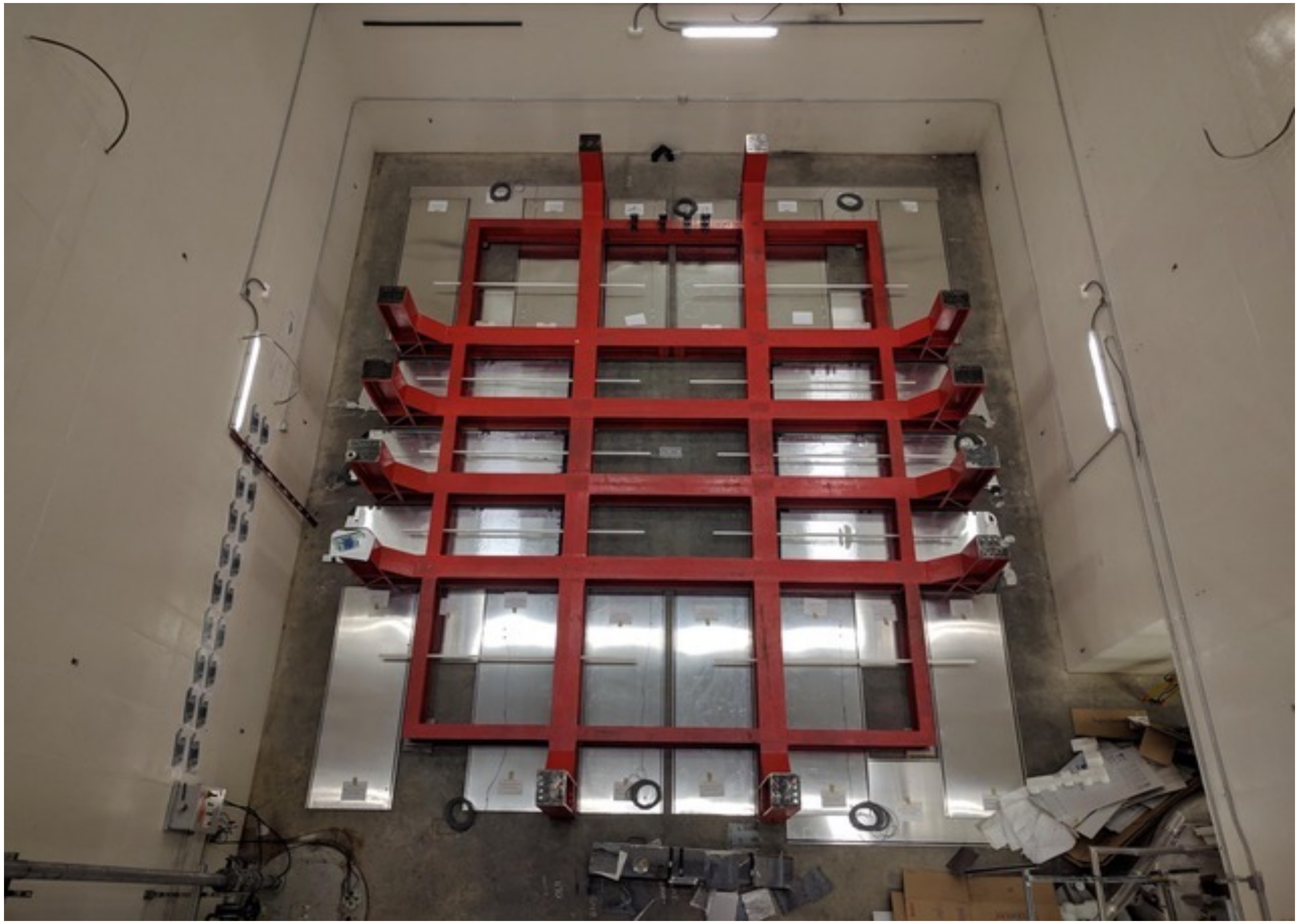
Modules at Fermilab

Location for the modules



SBN Cosmic Ray Tagger WG

SBND: **CRT Bottom layer installed** (Sept. 2019)

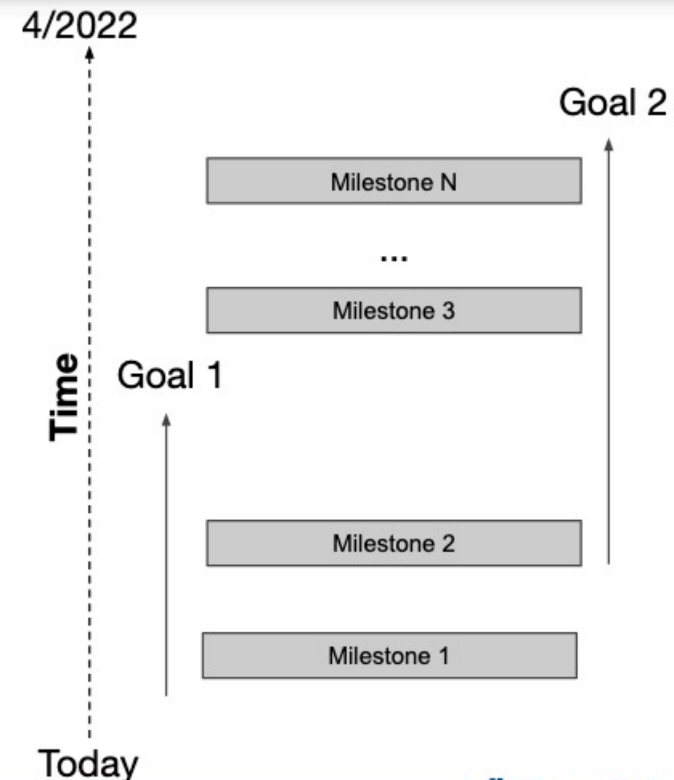


SBN AI Conveners Planning Retreat

The goal of the retreat was to create a road map of our path for the next year

To do this we established a set of "Goals" that we hope to have achieved in one-year

These will be reinforced by milestones that enable us to plan effort and gauge progress toward achieving our goals



Fermilab

SBN Analysis Infrastructure WG

Goals For Next Year

1. **Enable the reconstruction, simulation, and analysis in support of first ICARUS neutrino data, SBN simulation, and SBND commissioning (Jan ‘22)**
   - Generally target summer conferences
2. **Enable a complete 2.2e20 POT production for ICARUS and SBND sim. and ICARUS data (June ‘22)**
   - Supporting enable “at scale” SBN Productions
3. **Enable the timely end-to-end analysis of this production with full systematic uncertainties (July ‘22)**
   - Enabling full SBN Oscillations analysis

Fermilab

SBN Analysis WG

"Status of the SBN Analysis Working Group" presented by Daniele Gibin at the Physics Advisory Committee (PAC) meeting on June 8th, 2020

Status of the SBN Analysis Working Group

Fermilab PAC Meeting
June 8th, 2021

D. Gibin, O. Palamara

SBN Analysis I PAC Meeting - June 8 2021

Outline

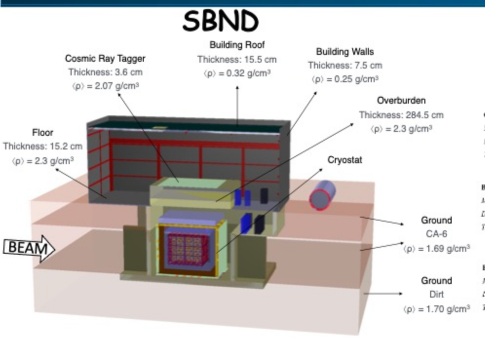
1. Introductory remarks
2. Overburden studies
3. Update on SBN Analysis WG activities
4. Software infrastructures and computing resources

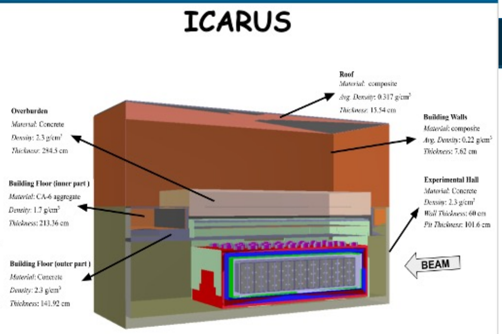
SBN Analysis I PAC Meeting - June 8 2021 Slide: 2

SBN Analysis WG

Overburden Studies

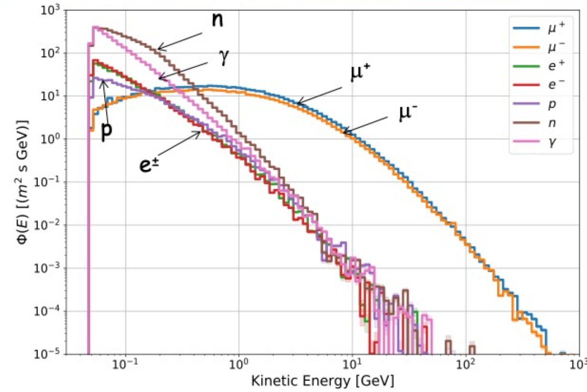
Description of the experimental setups





- Accurate description of geometry and composition of the two experimental setups used for MC simulations and data reconstruction (recently revised in detail).

MC simulation of cosmic rays



Cosmic particle fluxes at 226 m above sea level (smaller contributions from K/π are not shown)

Cosmic rays simulation in SBND and ICARUS setups

- The common cosmic ray SBND/ICARUS simulations through the detectors have been performed in different geometrical configurations, introducing step by step various part of the experimental setups to understand their role in the reduction of the cosmic rays reaching the active detectors. In particular:
  1) "LAr only", i.e. including only the liquid argon volume and without anything else (i.e. without building, pit, the cryostat, etc);
  2) "no overburden", adding to 1) the detector infrastructures, the pit, the surrounding dirt and the materials of the experimental hall;
  3) "overburden" i.e. 2) plus the 285 cm thick overburden.
- For each configuration an event statistics corresponding to the total 211 s expected BNB exposure (6.6×10^{20} pot delivered statistics) of in-spill cosmic rays has been simulated, recording the particles reaching the active liquid argon. Out of spill cosmics are not included.
- The study is focusing on backgrounds to νeCC appearance signal.
- E.m. showers with E>200 MeV are considered, using MC "true" variables without a complete event reconstruction; e-γ separation is not applied; simple π^0 rejection based on the presence of a second γ with E>100 MeV (as in the Proposal).

SBN Analysis WG

Overburden Studies

Effect of overburden on primary fluxes

- Shielding effect of the materials of cryostats, buildings and detector location in a pit and overburden (OB) on the rate of primary cosmics reaching the Active Volume (AV):

Particle	Detector	without OB (Hz)	with OB (Hz)	without OB/ with OB
μ	SBND	3928	3144	1.25
	ICARUS	17117	12761	1.34
n	SBND	256	11.2	23
	ICARUS	1426	6.8	210
γ	SBND	16	0.19	83
	ICARUS	116	0.03	3542
p	SBND	9	0.18	48
	ICARUS	54	0.10	533

Rate (Hz) of primary cosmics E_k>50 MeV entering AV *without and with overburden.*

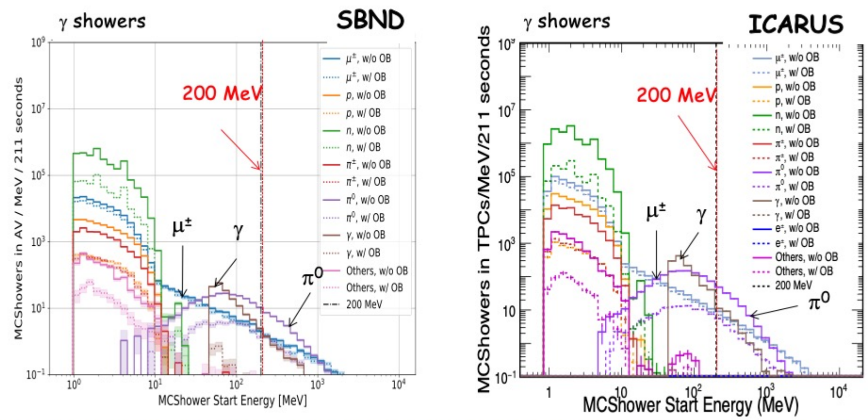
Surrounding materials produce similar effects for SBND and ICARUS.

- *Fundamental role of overburden in suppressing the most challenging neutral particles "invisible" to CRT. Beside the general reduction of cosmic flux, neutrons and photons can be strongly suppressed only by the overburden:*
  - Primary neutrons are suppressed by a factor ~20 in SBND and ~200 in ICARUS where the overburden completely closes the pit aperture.
  - Primary γ are suppressed by a factor ~80 in SBND while almost fully removed in ICARUS

SBN Analysis I PAC Meeting - June 8 2021 Slide: 10

e.m. showers from cosmic rays

- e± initiated showers clearly branch off their parent μ and do not represent a background.
- Overburden reduces the most serious background due to γ initiated showers >200 MeV.



γ initiated showers in active volume (211 s): without (solid lines) and with OB (dashed lines) classified based on shower mother particle

SBN Analysis I PAC Meeting - June 8 2021 Slide: 12

Overburden Studies

Comparing γ initiated showers from different sources

- Cosmogenic γ showers from present study (after rejecting π^0 with γ_1>200 MeV γ_2>100 Mev):

e.m. E>200 MeV in FV	SBND		ICARUS	
	without OB	with OB	Without OB	With OB
events with π^0	297	44	2059	174
Primary γ	45	0	501	0

- As a comparison, e.m. showers by BNB ν NC interactions in LAr producing a single π^0 and by BNB ν interacting outside the active volume result (after π^0 rejection):

e.m. E>200 MeV in FV	SBND	ICARUS
ν NC interactions in LAr with 1 π^0	45932	6585
Events with 1 π^0 from ν in "Dirt"	2791	630

- Note that the contribution from ν interactions in the overburden are negligible.
- These tables include all γ initiated showers in the fiducial volume (FV) generated by different sources and corresponding to events with different topologies.
- The studies focus on counting of γ-showers with simple π^0 identification criteria. In the actual data analysis each background source has to be addressed separately by exploiting all the event features like vertex reconstruction when present, e-γ identification by dE/dx, conversion distance from vertex and proper π^0 identification.

SBN Analysis WG

Overburden Studies

Summary on the overburden study

- For the SBN "definitive" sterile neutrino search we must remove as many controllable backgrounds as possible in the experiment setup.
- We have quantified, with accurate description of the geometry and composition of the experimental setups, the different impact of the overburden for SBND and ICARUS, due to their different distance from the neutrino source, LAr mass and geometrical configuration.
- For SBND the improvements that the overburden would bring to the main physics analysis appear to be marginal.
- Even if π^0's from beam neutrino neutral current interactions remain the primary signal background, the important role of the overburden in reducing cosmogenic background in ICARUS and its contribution to reduce the associated systematic uncertainties is confirmed by the new detailed MC calculations.
- The overburden is an essential component for the ICARUS detector due to neutrino over cosmic ratio ~40 times less favorable compared to SBND.
- In addition, in ICARUS, the overburden will significantly reduce the amount of data collected (~25% less cosmic muons in time with the beam) and the subsequent effort and time required for the analysis.

SBN Analysis WG

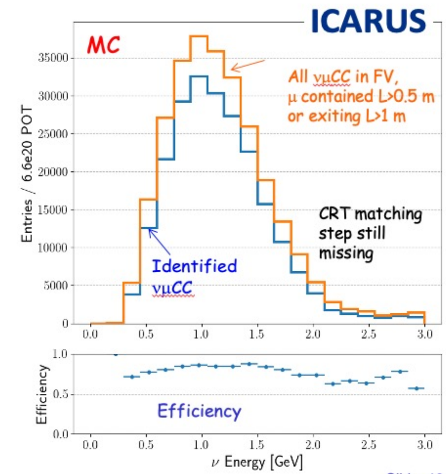
3. Update on SBN Analysis WG activities

- Since our last presentation in December 2020, we have
  - Maintained regular meetings
  - Organized one (online) Workshop - **VI SBN Analysis Workshop** – Tuesday Apr. 6th – Monday April 12th, with contributions from the different SBN Analysis subgroups:
    - Plenary Sessions:
      - Status of reconstruction and event selection;
      - Status of oscillation sensitivities;
      - Status of detector systematics evaluation and impact on oscillation sensitivities;
      - Status of SBN Analysis Infrastructures;
      - Use of Machine Learning tools for SBN;
      - "Looking forward" sessions to discuss improvements and next steps.
    - Parallel working sessions: for different subgroups to meet and discuss results and plan future activities.
  - Organized tutorials on SBN software tools
  - Continued comparisons between ICARUS data and Monte Carlo simulations

Snapshots of some of the current activities in the next slides

Present status of the MC νμCC event selection

- The νμCC event selection is based on:
  - ✓ The μ track exiting the interaction vertex with μ identified by the characteristic dE/dx mip signal and a track length >50 cm if contained or >100 cm if exiting;
  - ✓ TPC-CRT track matching to further reject cosmic backgrounds (this final step is still under development in ICARUS).
- This νμCC event selection procedure was discussed at the last December PAC meeting in particular for SBND, showing a 83.4% efficiency for events inside the fiducial volume (FV).
- The same procedure has been recently applied also to ICARUS showing νμ CC id efficiency > 82% before CRT-TPC matching.
- Strong rejection of cosmics and NC background could be obtained by joint exploitation of TPC, PMT, CRT signals in both detectors.



SBN Analysis Infrastructure WG

4. Software Infrastructures and computing resources

- The SBN requested resources for storage and CPU were prepared by the SBN Analysis Infrastructure WG and presented jointly, along with a breakdown for the individual detectors.
- Awaiting final report but received good responses from Fermilab Computing Resource Scrutiny Group review.
- Actively working with experiment and lab experts to address computing bottlenecks and improve computing efficiency, particularly data I/O.

Detectors		2021	2022	2023
ICARUS	Cumulative Data Storage Needs [PB]	13.7	17.7	24.2
	Grid Computing Needs [CPU MHr]	14.3	20.8	29.1
SBND	Cumulative Data Storage Needs [PB]	1.0	4.6	7.4
	Grid Computing Needs [CPU MHr]	4.0	11.8	19.0