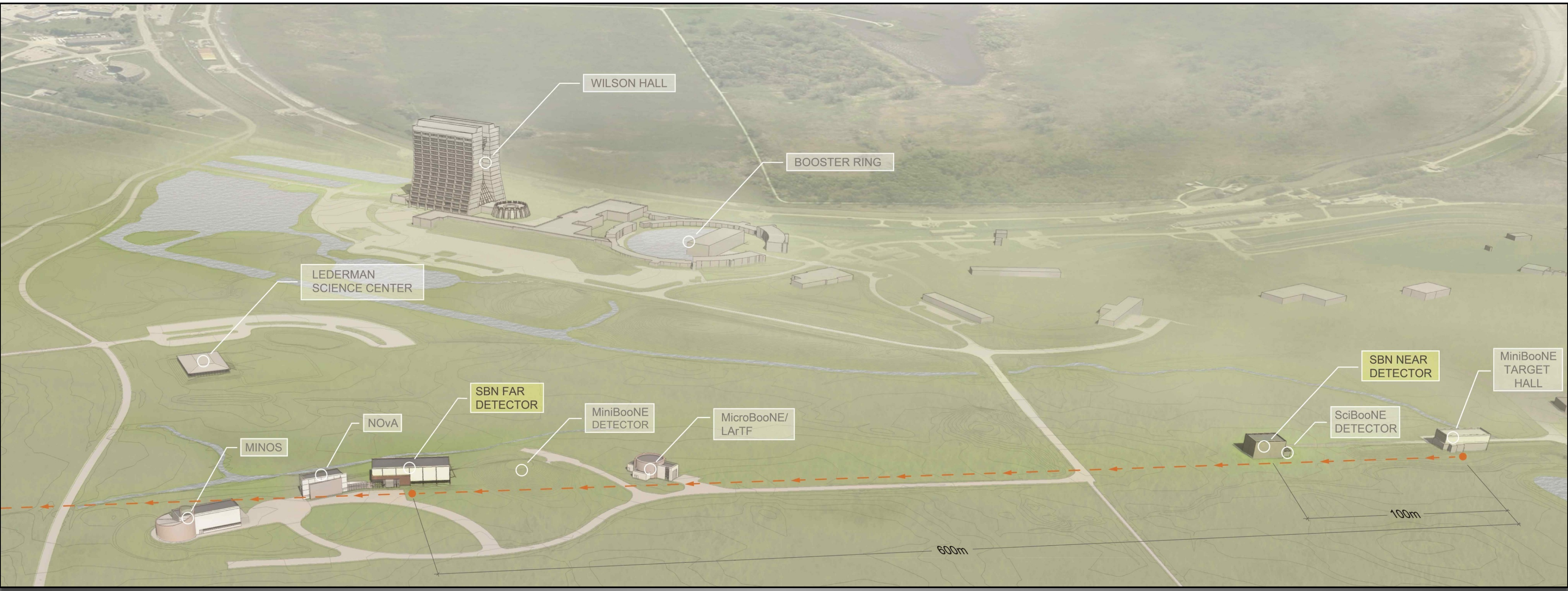
The SBN (Short-Baseline Neutrino) Physics Program at Fermilab



ELBNF Proto-Collaboration Meeting

January 22-23, 2015

David Schmitz

THE UNIVERSITY OF CHICAGO

FNAL Neutrino Platform

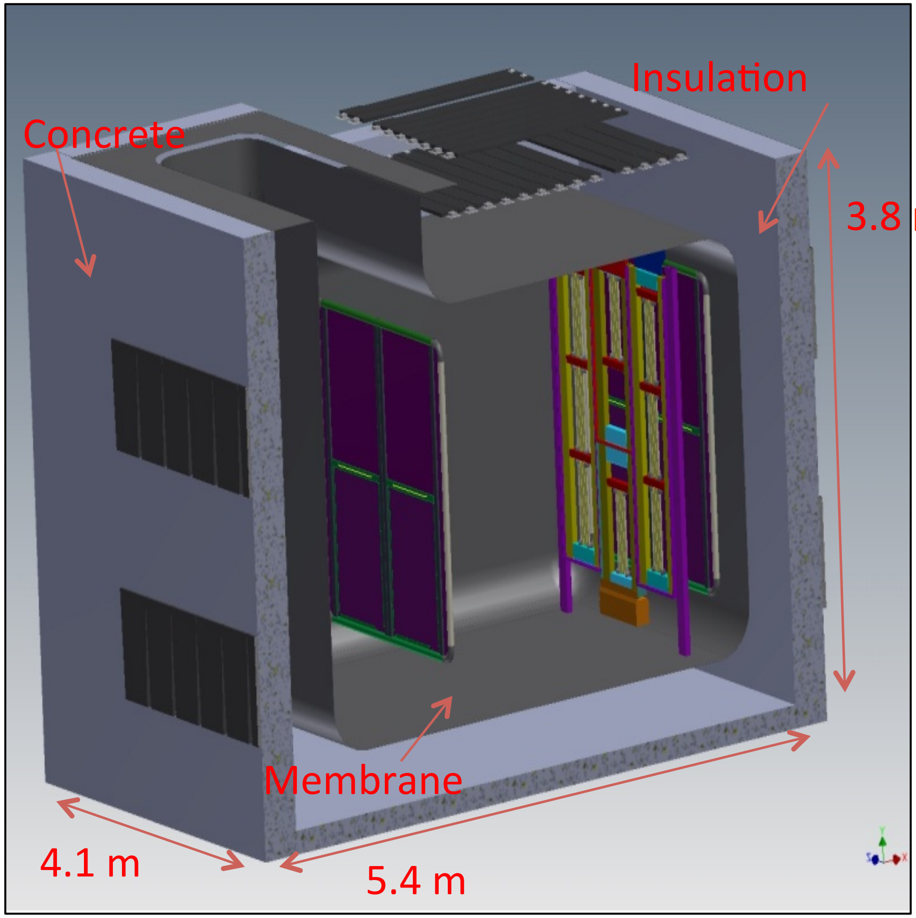
- Marzio told us about the ambitious 'CERN Neutrino Platform' and the many efforts being pursued to help move us toward LBNF

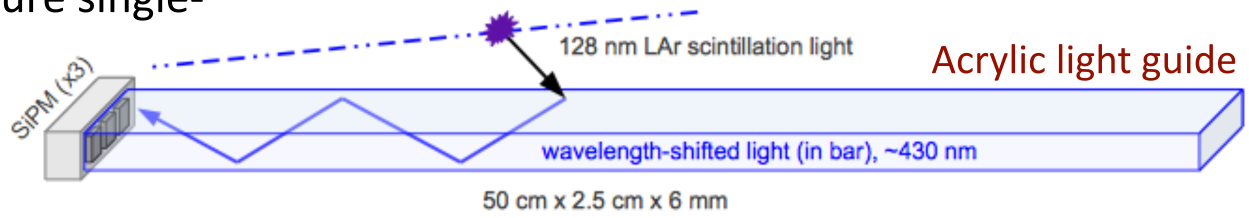
- The 'Fermilab Neutrino Platform', if you will, similarly describes a set of R&D efforts, particle test beam experiments, software development, and technical support of the experimental neutrino program

- Fermilab is also home to two of the world's best neutrino beams, enabling an on-going program of neutrino experiments that will help us to a better LBNF experiment in the future
  - I will spend most of my time this morning telling you about the developing short-baseline neutrino program on the Booster Neutrino Beam

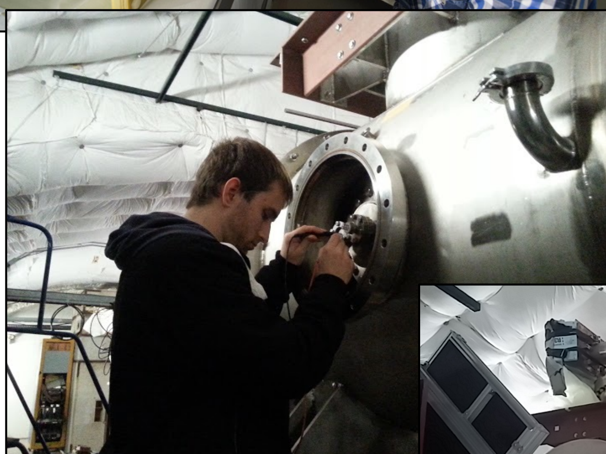
35-ton Membrane Cryostat with TPC

- LBNE-supported LAr-TPC development
- Test design features useful for scale-up
  - Membrane cryostat
  - Modular anode assembly - allows study of inter-modular gap reconstruction impact
  - Cold digital electronics
  - Triggerless DAQ
  - PMT-less photon detection
- Phase I
  - Cryostat only
  - Ran winter 2014
  - Demonstrated purity in membrane cryostat
- Phase II
  - Fully instrumented TPC
  - Currently being assembled at FNAL PC4
  - Will take cosmic data in Spring 2015
  - Run Plan/Data analysis being prepared – opportunities to participate!
- Results will inform any future single-phase LArTPC



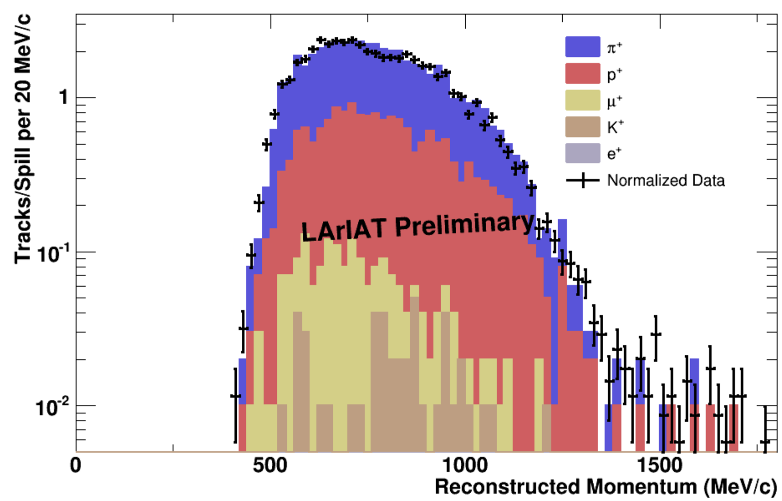


LArIAT Experiment at MCenter Test Beam



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

32 GeV π^+ on Target, +100 A Magnet Current



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

SBN Program, A Little History

- Ideas to use multiple LAr detectors to address the short-baseline anomalies have been under consideration since mid 2000s (ICARUS, LAr1 proposals)
- At the January 2014 meeting of the Fermilab Physics Advisory Committee (PAC) two new proposals were put forward:
  - P-1052: ICARUS@FNAL
    - Proposal to relocate an updated ICARUS-T600 detector to the BNB and to construct a new one-fourth scale detector based on the same design to serve as a near detector for oscillation searches.
  - P-1053: LAr1-ND
    - Realizing the physics program enabled in a first phase with a ND + MicroBooNE, LAr1-ND was proposed as the next phase in the BNB program (to possibly be followed by 1kton scale far detector).
- Soon after, proponents of the LAr1-ND and ICARUS proposals, members of the MicroBooNE collaboration, as well as representatives from Fermilab, INFN and CERN, started working together to develop a plan for a coherent SBN physics program.

The 2014 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.

The SBN Proposal

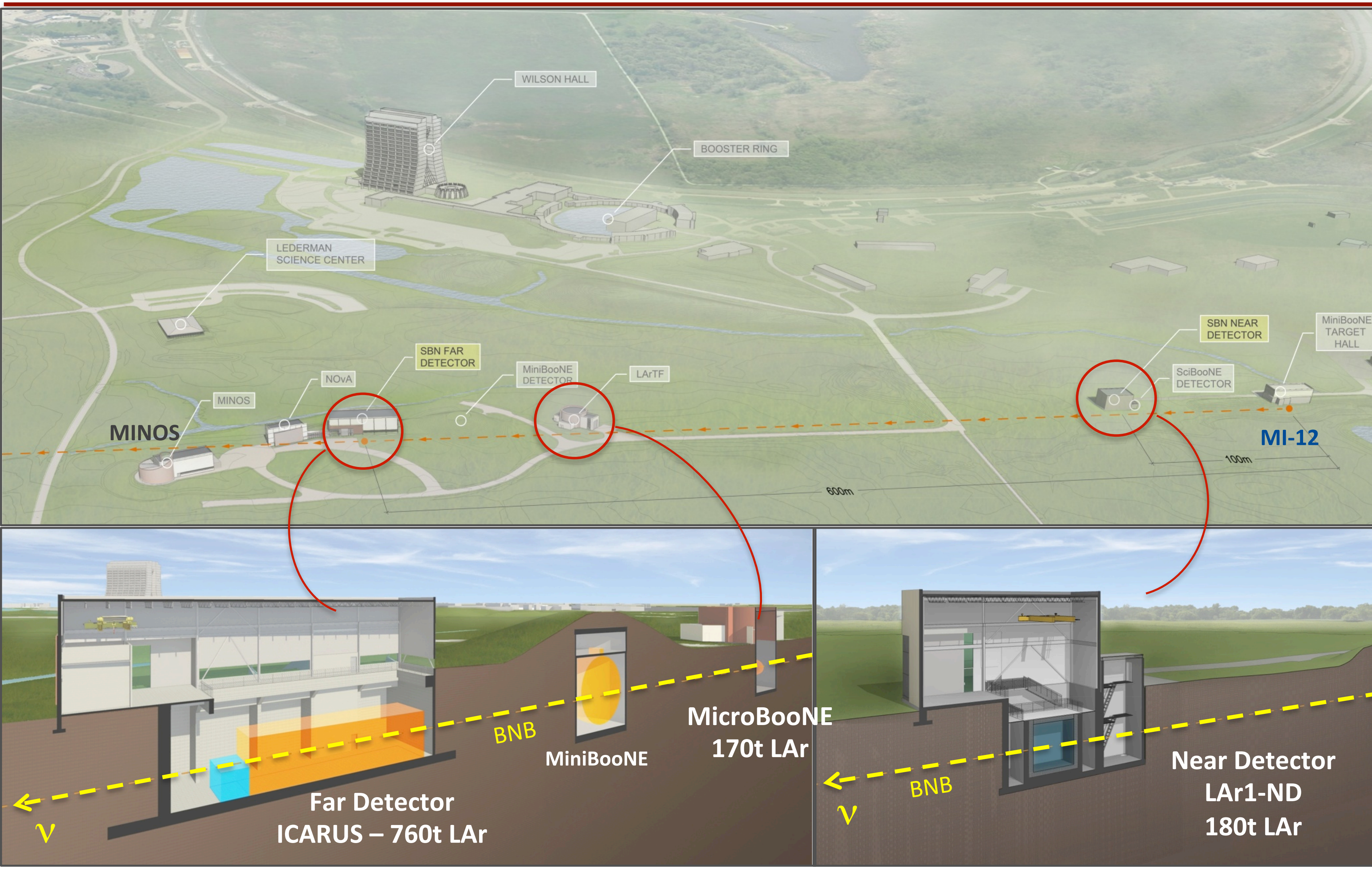
- Returned to the January 2015 PAC meeting (last week) with an updated proposal:

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

- The SBN program will consist of three LAr-TPC detectors:
  - **ICARUS-T600:** the only large-scale LAr-TPC in the world exposed to a neutrino beam
  - **MicroBooNE:** the largest LAr-TPC built in the US, starting operations in 2015
  - **LAr1-ND:** providing a new opportunity for development on the path to LBNF

- These three detectors and the international teams of physicists and engineers realizing them represent a significant scientific as well as R&D opportunity toward the future LBN program.

The LAr-Based SBN Program at FNAL



MicroBooNE

❖ The first phase of the next generation SBN Program begins this year with MicroBooNE coming online soon!

- **Physics**:
  - *address MiniBooNE low energy excess*
  - *measure ν cross sections on argon*
- **R&D**:
  - *argon fill without evacuation*
  - *cold front-end electronics*
  - *long drift (2.5m)*
  - *near surface operation*
  - *automated event reconstruction*

ICARUS-T600, WA104

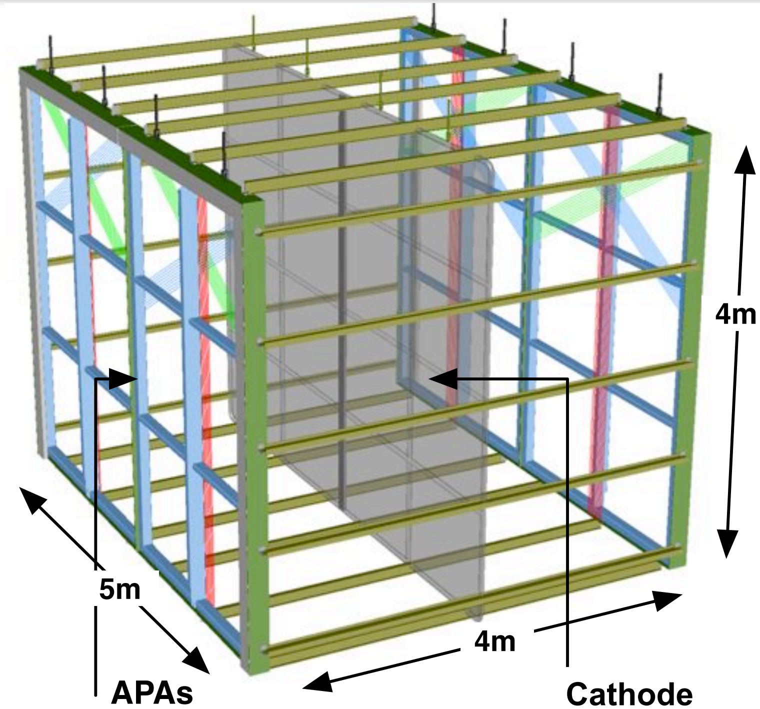
- ❖ Successfully operated at Gran Sasso in CNGS beam
  - Achieved electron lifetimes > 15 ms
  - Physics program including limits on sterile neutrinos
- ❖ ICARUS-WA104 project at CERN
  - Refurbish ICARUS-T600 w/ new cryostats, electronics, upgraded light collection
  - Move from Gran Sasso to CERN,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

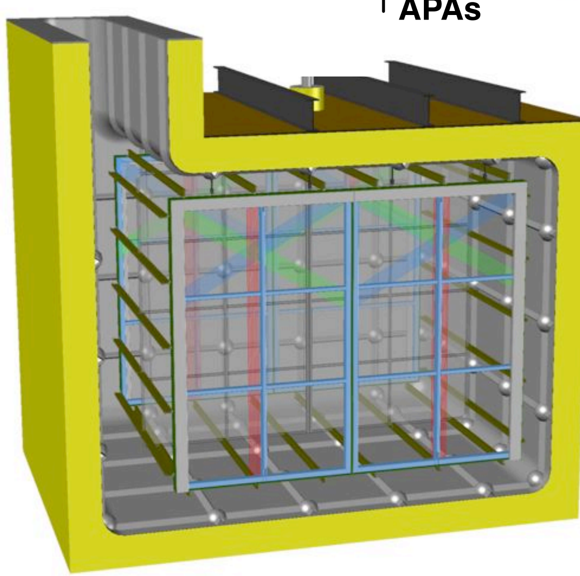
Ready to leave LNGS

First T300 in Cleanroom at CERN

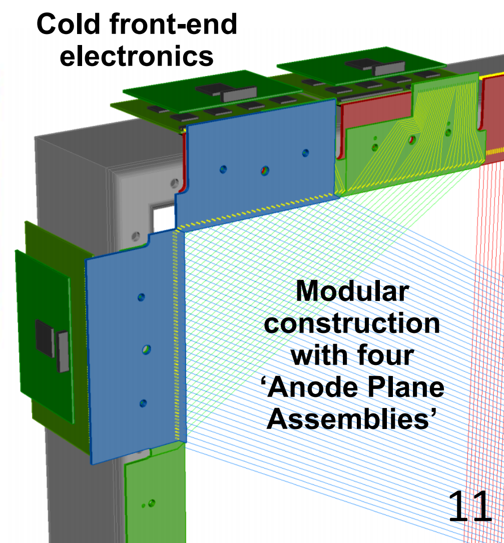
LAr1-ND, T-1053

- A new detector, building on experience from ICARUS, MicroBooNE, 35ton, and based on current LBNE designs
- Provides an opportunity for prototyping baseline designs or developing alternative system designs
  - For example, LAr1-ND is an excellent test-bed for light collection concepts being developed for LBNF physics
- LAr1-ND approved at FNAL as T-1053 in summer 2014, now developing design, pursuing needed R&D



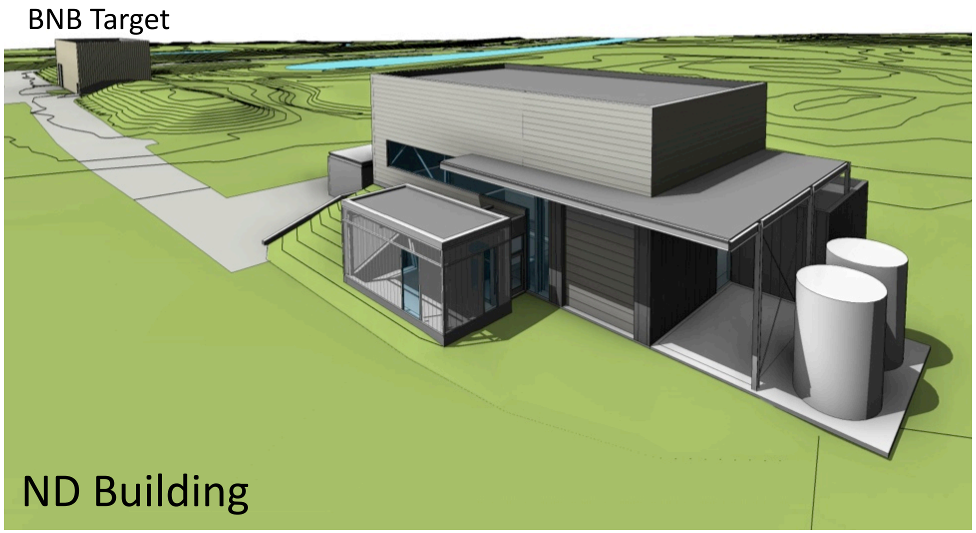


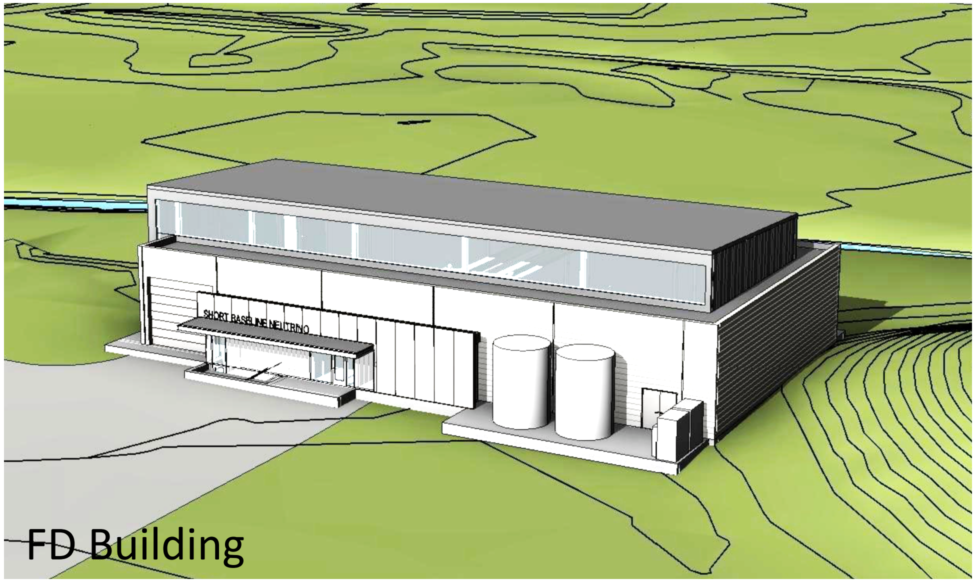
Membrane cryostat



SBN Infrastructure

- Advanced designs on experimental halls, construction to begin in 2015
- A joint CERN-Fermilab engineering team has been formed to develop cryostats and cryo systems
- Cryo plant designs for near and far detectors being developed together to take advantage of common solutions





SBN ⇔ LBN Physics Goals

❖ The physics goals of SBN are complementary to the goals of LBNF and extend the overall reach of the global neutrino physics program:

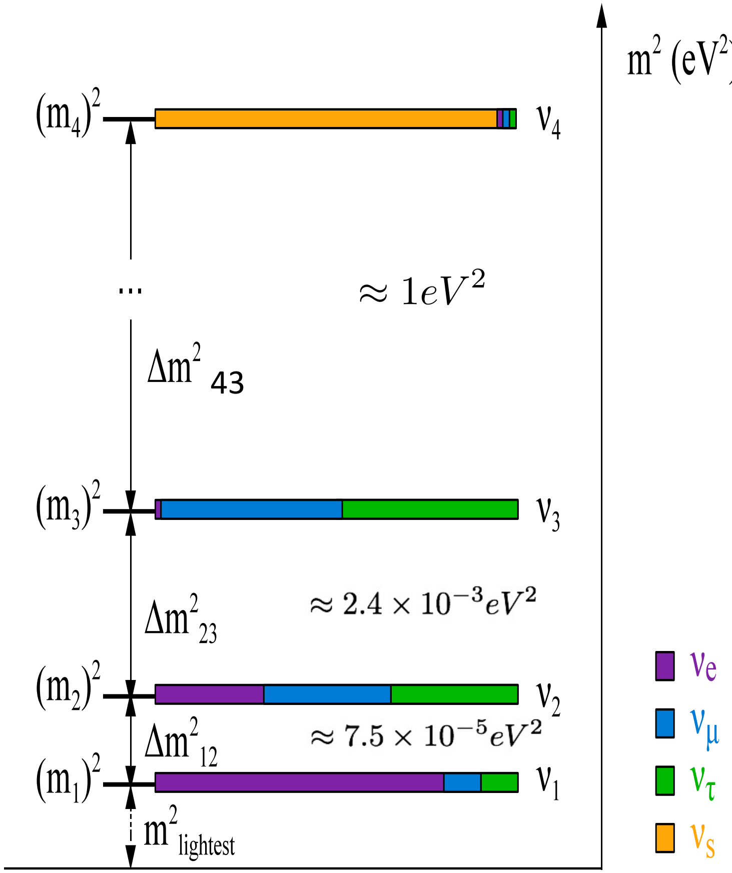
- A major physics goal of LBNF is to "test the 3-ν paradigm"
- SBN will contribute directly to this question through either a **major discovery** or by ruling out additional light neutrinos in a range hinted at by previous anomalies
- LBNF measurements will depend upon good knowledge of ν-Ar interactions
- SBN will study these interactions in detail with **millions of events** in the few hundred MeV to few GeV energy range

Three Neutrino Paradigm, Sterile Neutrinos

- Results from multiple experiments have hinted at a possible additional oscillation
- While each of the measurements alone lack the significance to claim a discovery, together they could be hinting at important new physics

Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

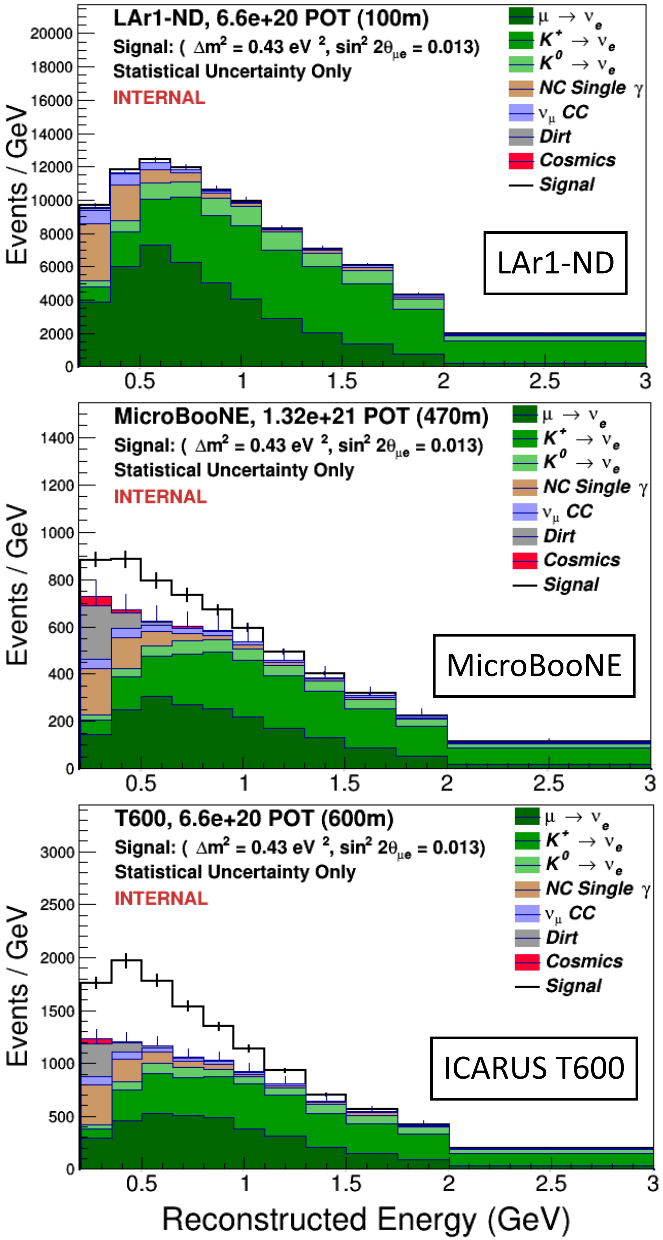
K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

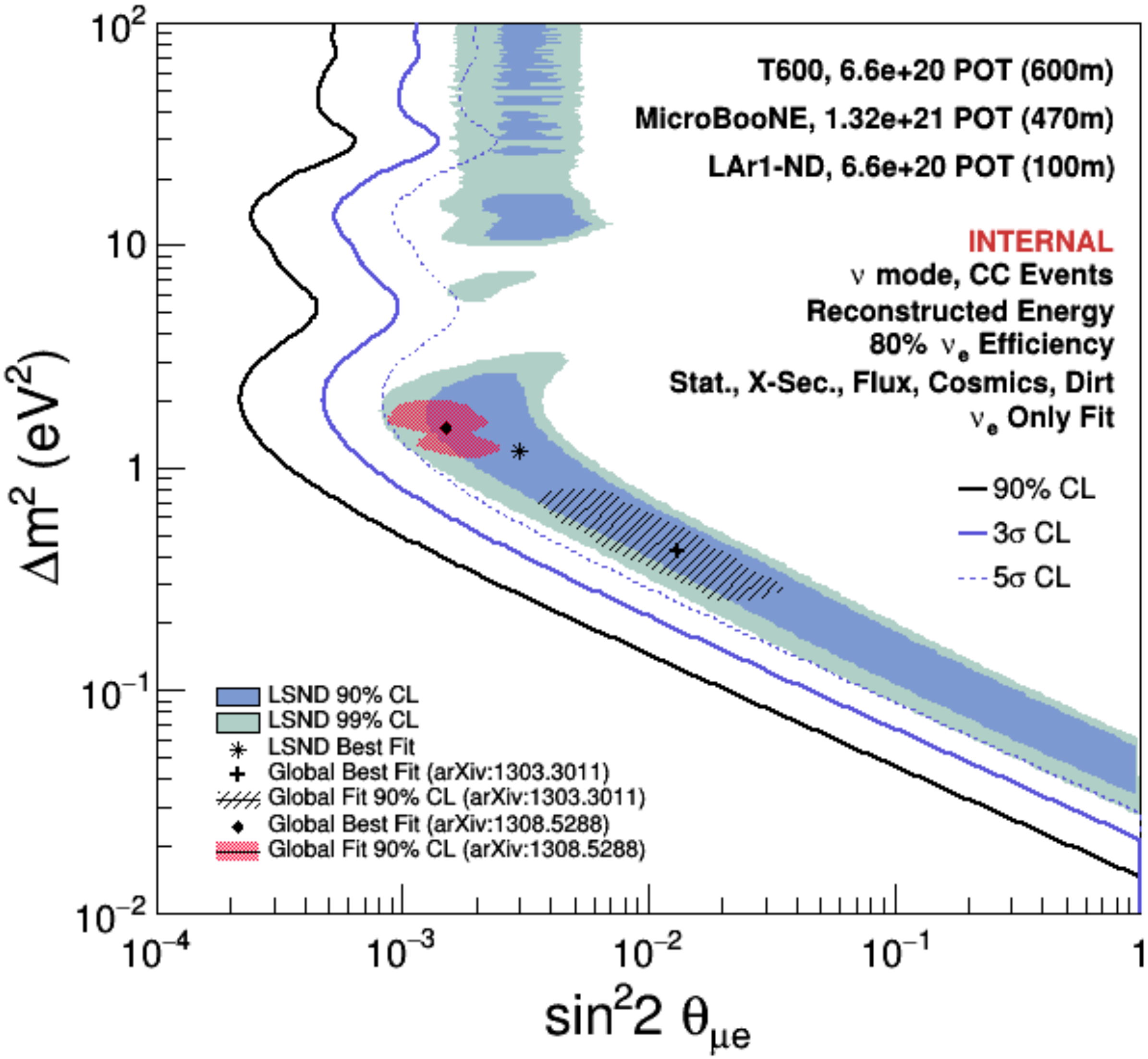


One thing is certain…

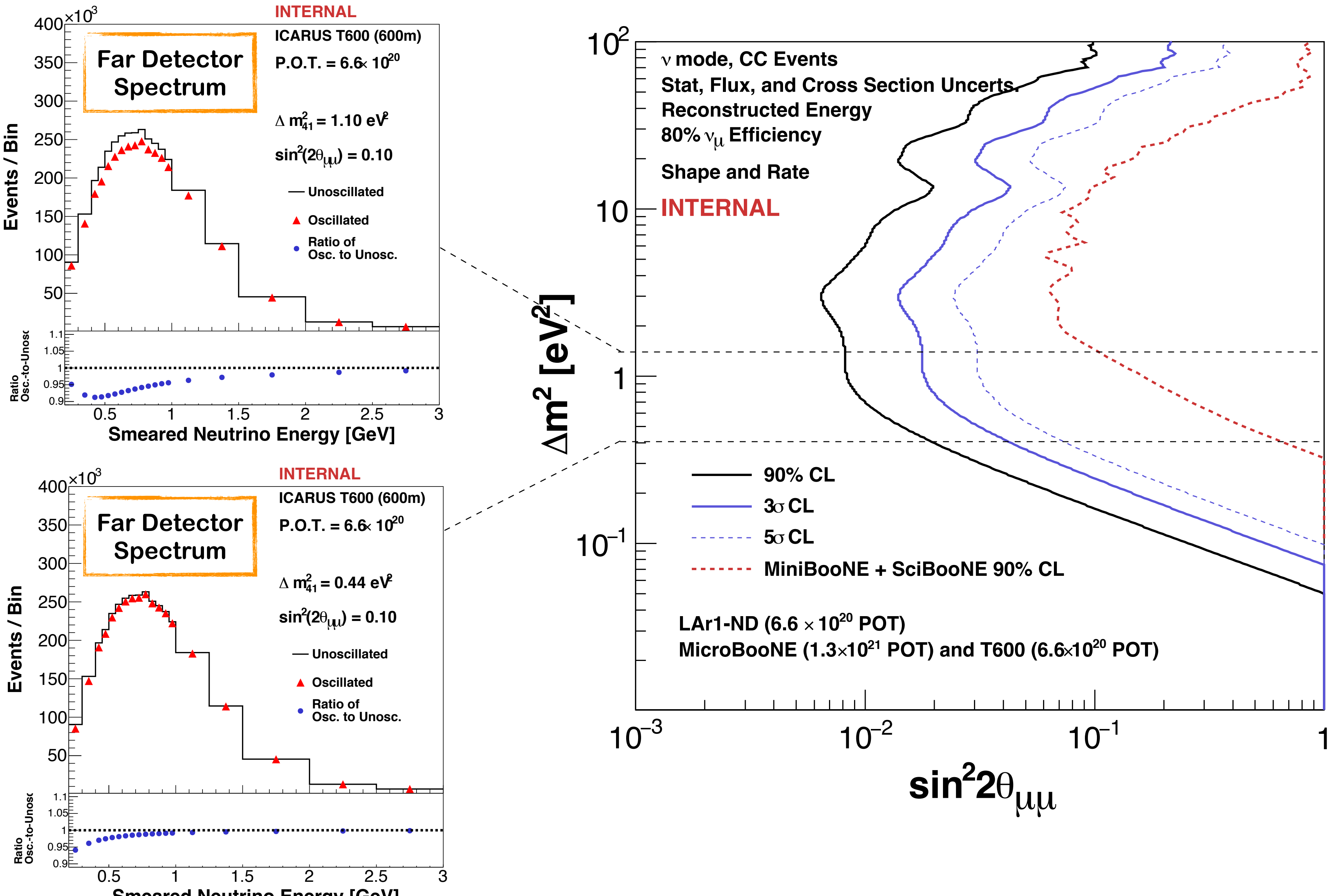
The discovery of a light sterile neutrino would be monumental for particle physics and cosmology

SBN ν_e Appearance Sensitivity



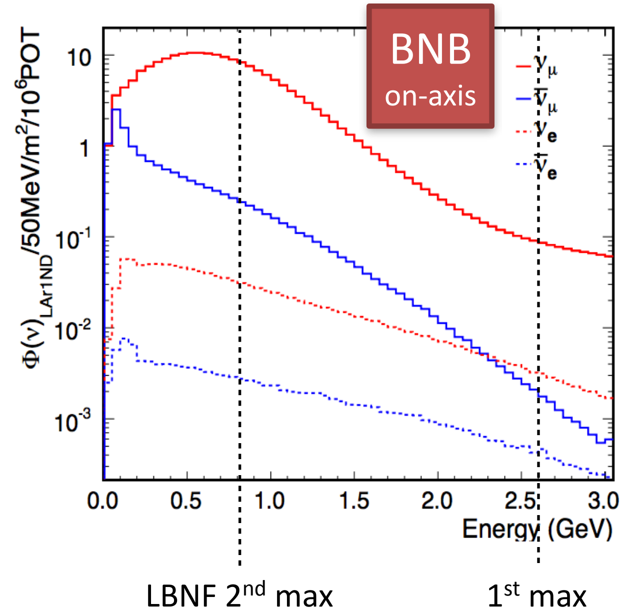


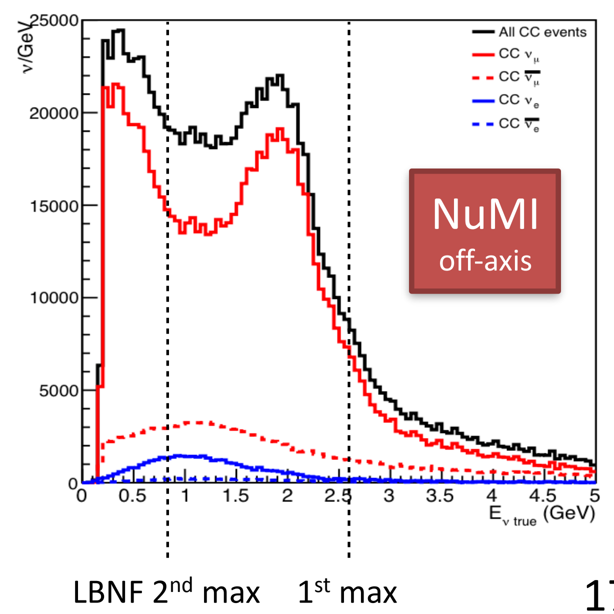
SBN ν_μ Disappearance Sensitivity



Neutrino Interaction Physics and Event Reconstruction

- SBN detectors will provide huge data sets from the BNB on-axis and the NuMI off-axis fluxes
  - ND will record ~1.2M CC interactions in the fiducial volume per 2.2e20 pot, ~year of running (~7,000 ν_e)
  - Large complementary samples in MicroBooNE and T600
  - Order 100k NuMI off-axis events in T600 per year
- High statistics, precision measurements of neutrino+Ar cross sections in the relevant energy range are an important component in reaching systematics at level of 1% in LBNF
- Large data sets will require that event reconstruction and analyis become fully automated
  - Precision testing of event reconstruction and identification techniques possible with large SBN data sets
  - This development for SBN physics will have direct impact for LBN in the future
- The LHC experiments produced physics extremely quickly, benefiting from enormous expertise developed at the Tevatron and LEP before it. LBNF can get to physics faster with the detailed studies of neutrino interactions in argon possible at the SBN





SBN Proposal Author List

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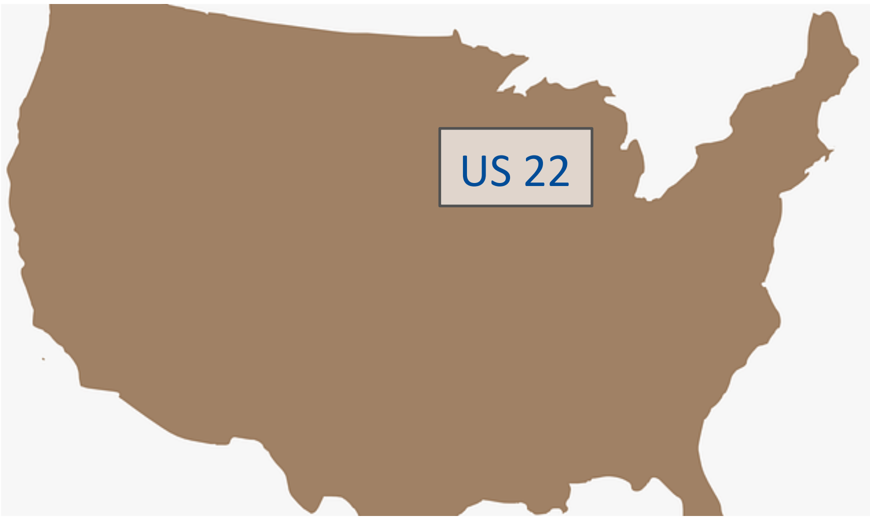
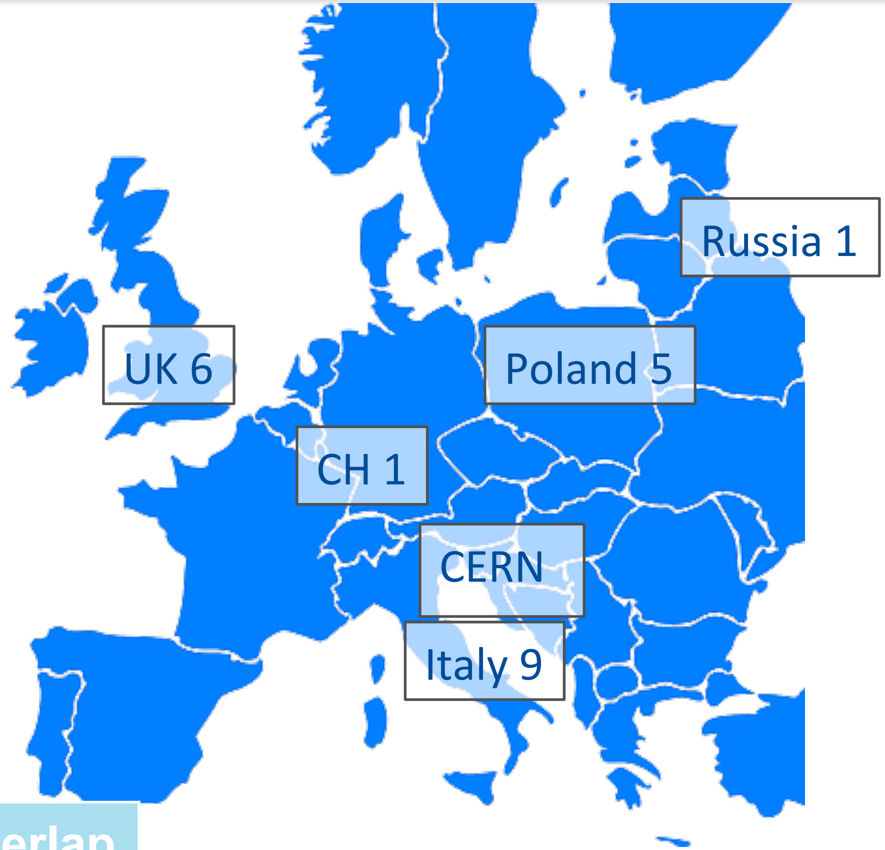
Collaboration spokespeople
Fermilab SBN Program Coordinator

Current SBN Institutions





Collaboration	Authors	Overlap
ICARUS-WA104	57	
LAr1-ND	108	6
MicroBooNE	118	59
All SBN (excl overlaps)	**218**	

	SBN	SBN-ELBNF Overlap
US	22	20
non-US	23	19

Synergies with Long-Baseline Program, Summary

- Development and testing of detector systems toward long-baseline detectors… examples:
  - Maintain purity in fully instrumented vessels
  - Prototyping of baseline or alternative detector system designs (wire attachement & winding, light collection, laser system, DAQ/Readout, etc.)
  - Development, evaluation, and validation of cold electronics
  - Lessons learned in design, fabrication, installation, long-term operation, etc.

- Physics inputs SBN ➔ LBN
  - High statistics, precision measurements of neutrino+Ar cross sections

- Transferable analysis development
  - Precision testing of LAr calibration, reconstruction, and event identification techniques with large neutrino data sets
  - Detailed systematics evaluation for sensitive oscillation measurements in the relevant channels including $\nu_\mu \rightarrow \nu_x$ and $\nu_\mu \rightarrow \nu_e$

Synergies with Long-Baseline Program, Summary

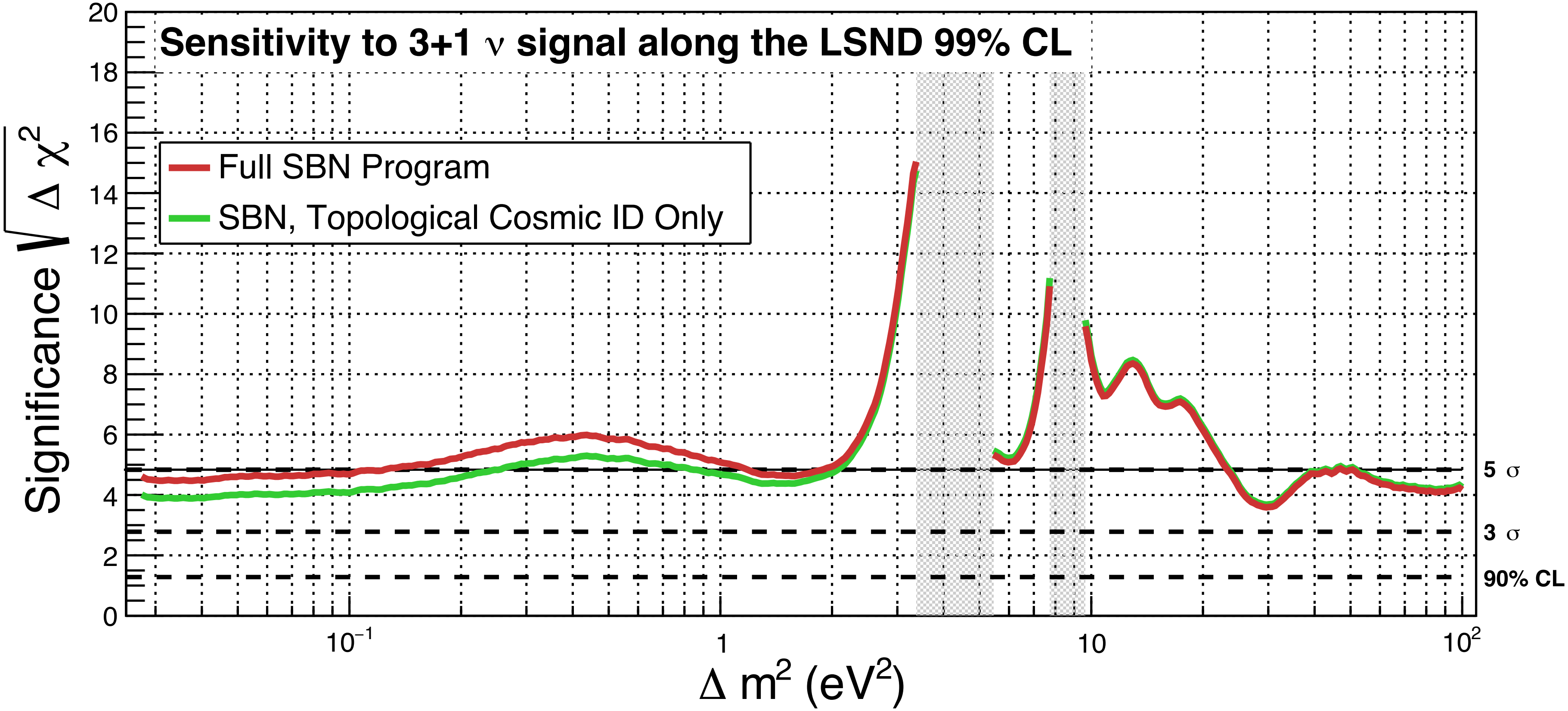
- Optimization of LBNF connection
  - We have spent the past year confirming that we can pursue this physics with the SBN detectors. Now is the time to optimize technical designs for the SBN physics program and for optimal connection to LBNF goals

- Collaboration and community
  - The SBN Proposal is the result of active international participation in a program hosted at FNAL. SBN will be an excellent place to further develop effective international collaboration at a smaller scale than LBNF
  - International coordination in realization of SBN detectors
    - Major contributions from both domestic and international groups
    - CERN/INFN T600 refurbishing, CERN/FNAL development of cryogenics and other critical infrastructure
    - US/UK/CH university groups (so far) with big contributions to LAr1-ND detector construction

- Building a knowledge base with the technology and data analysis, doing physics
  - Students and postdocs (and faculty) working on SBN gain valuable experience applicable to the challenges we will face on LBN
  - People want to confront data, do physics! SBN is an ideal opportunity.

Thank you!

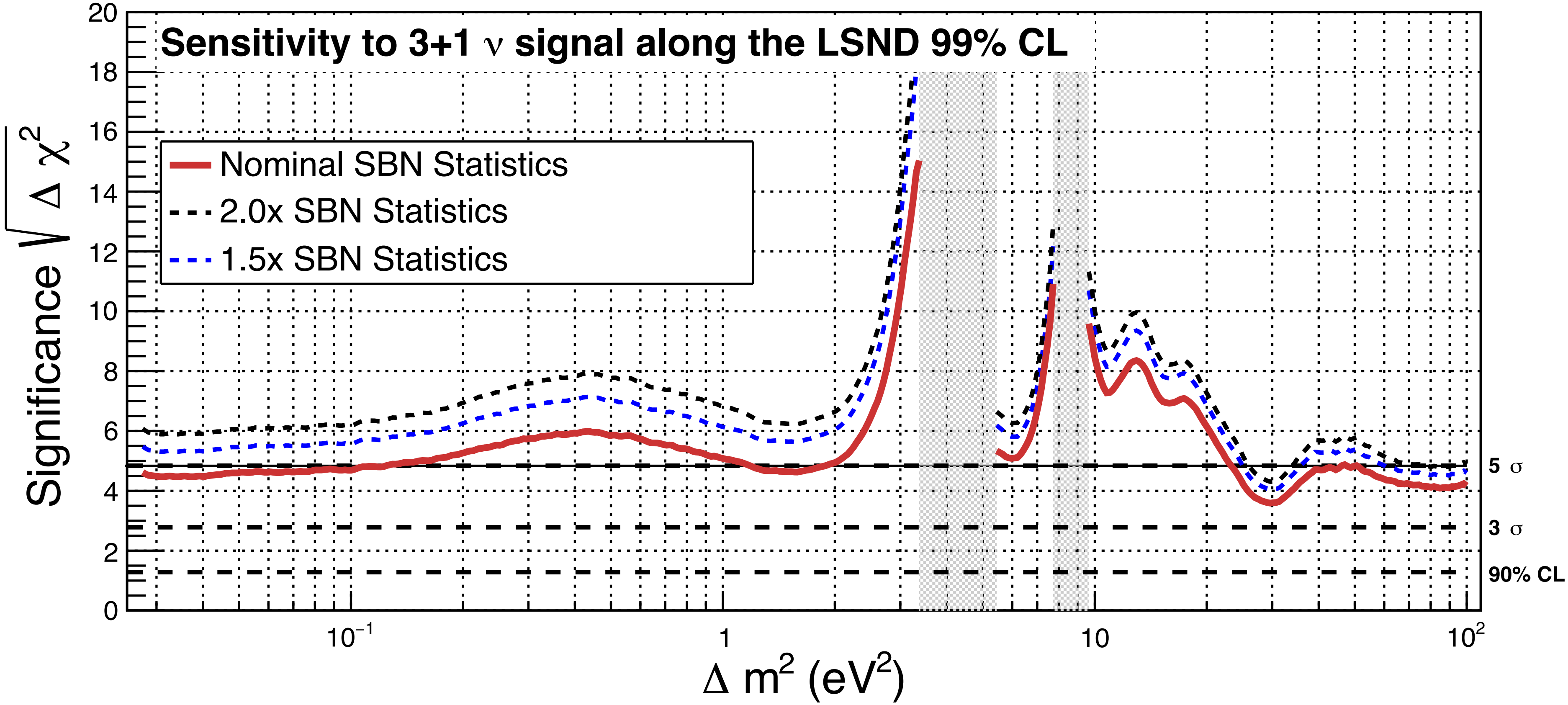
Impact of Cosmic Backgrounds



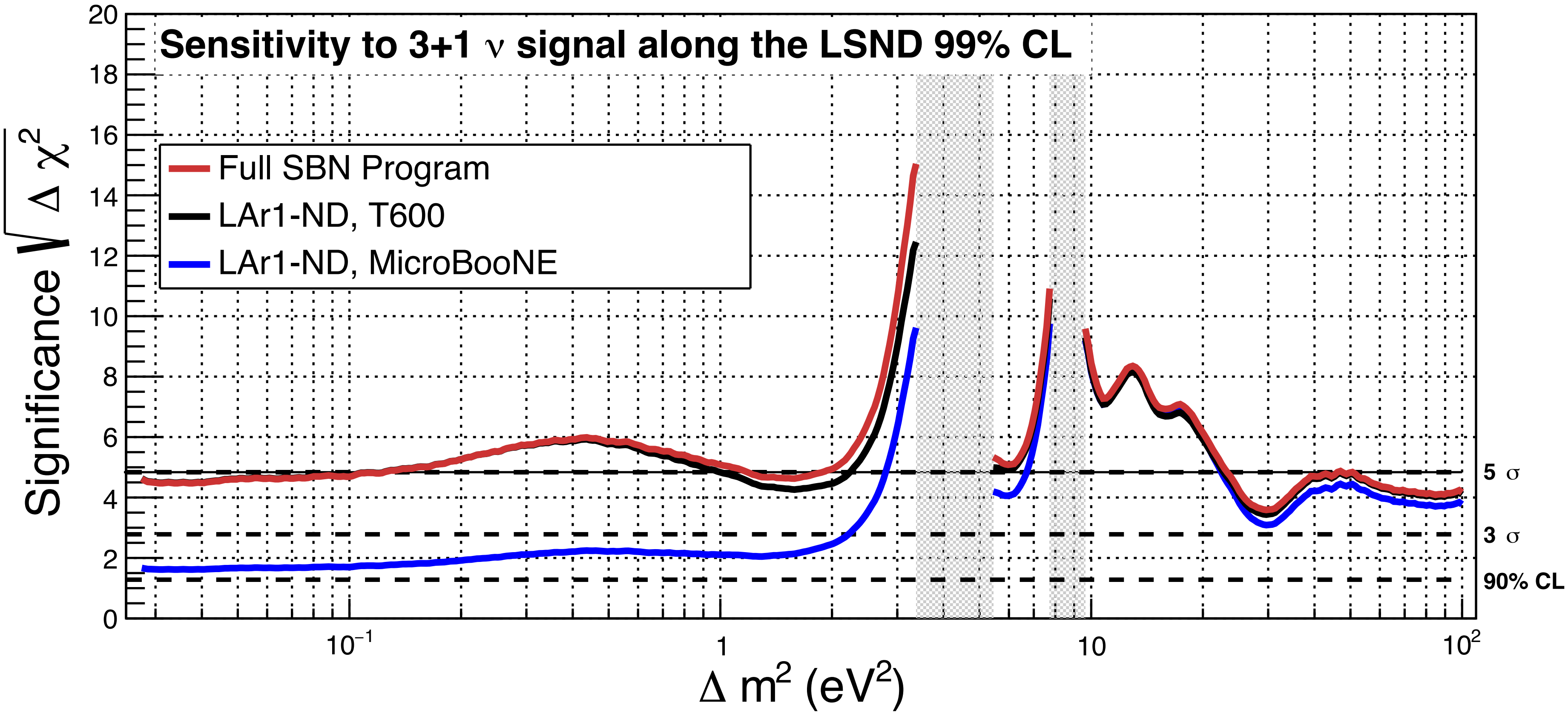
- ❖ Stronger rejection of cosmic backgrounds through cosmic tagging and timing improves the sensitivity ~0.75σ at low Δm^2

Impact of Increased ν_e Statistics

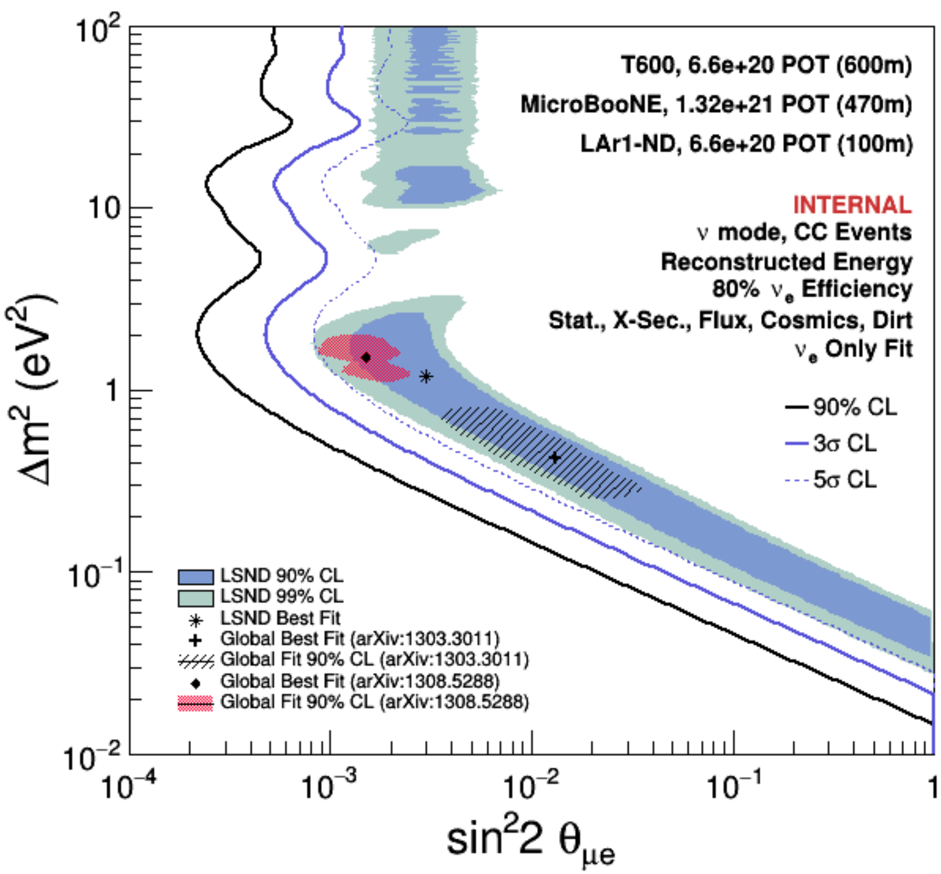
- Increased exposure through, for example, improved BNB performance has a major impact

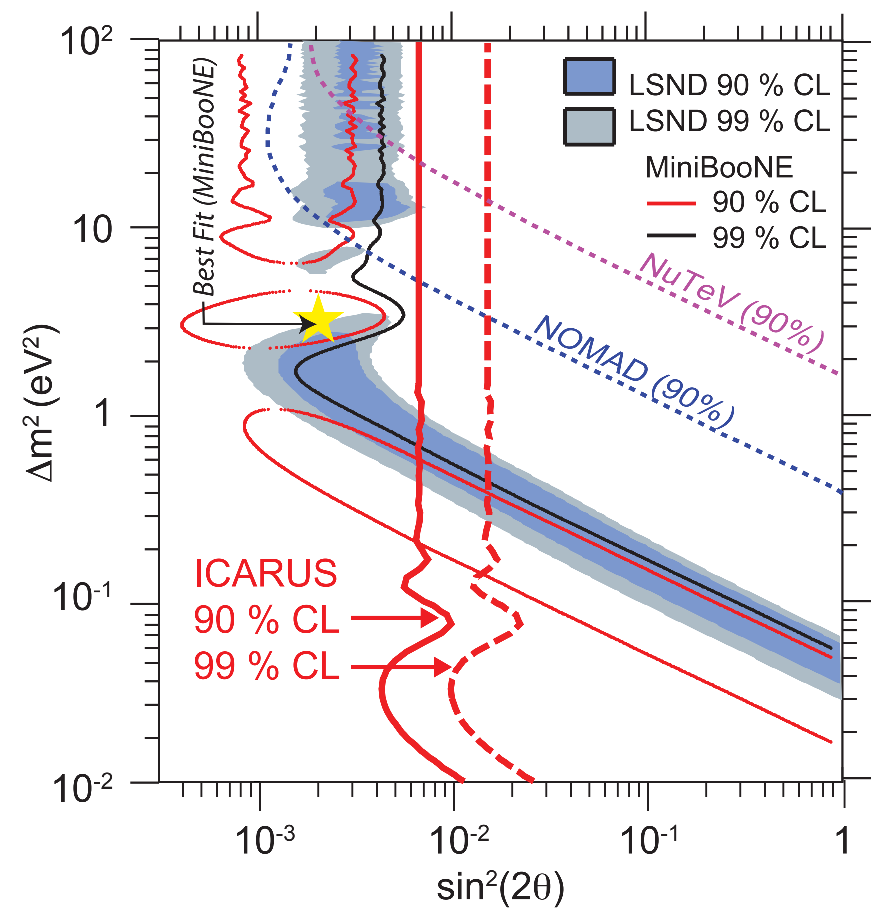


SBN Detectors



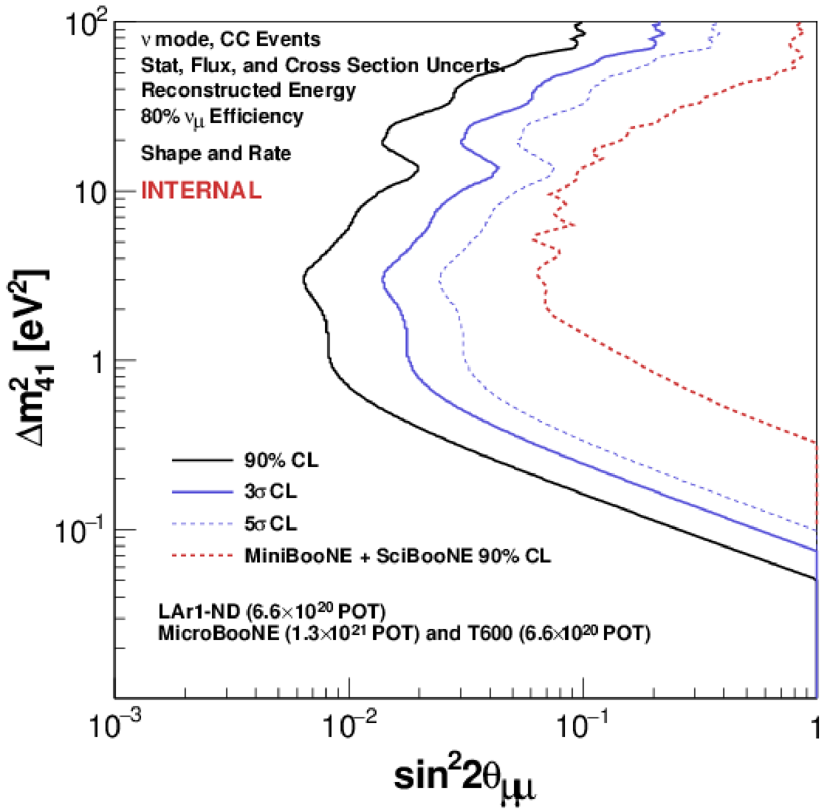
Compare to MiniBooNE Neutrino Mode

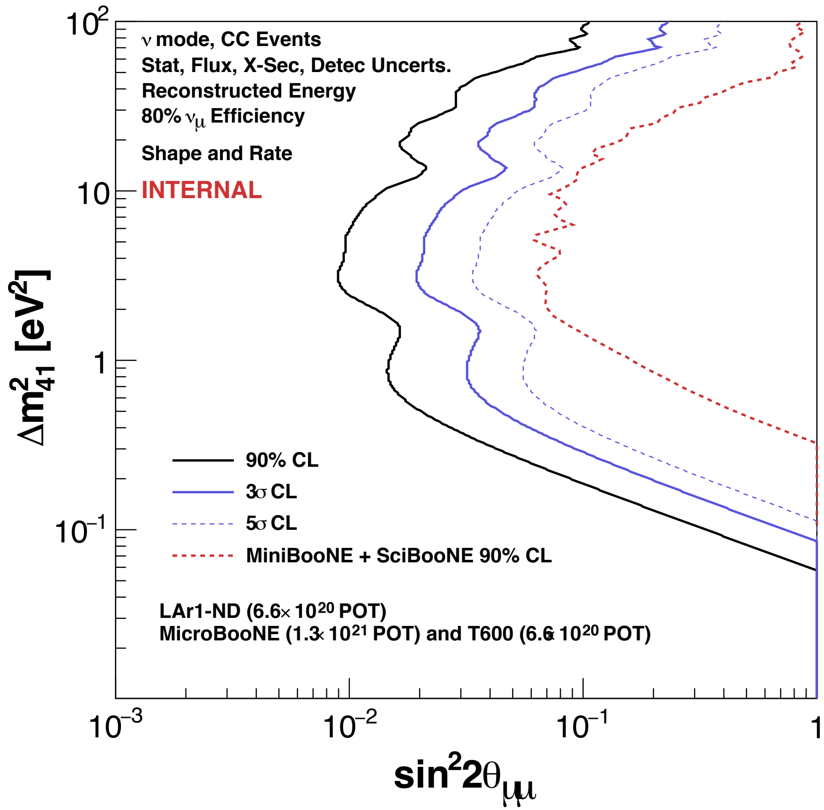




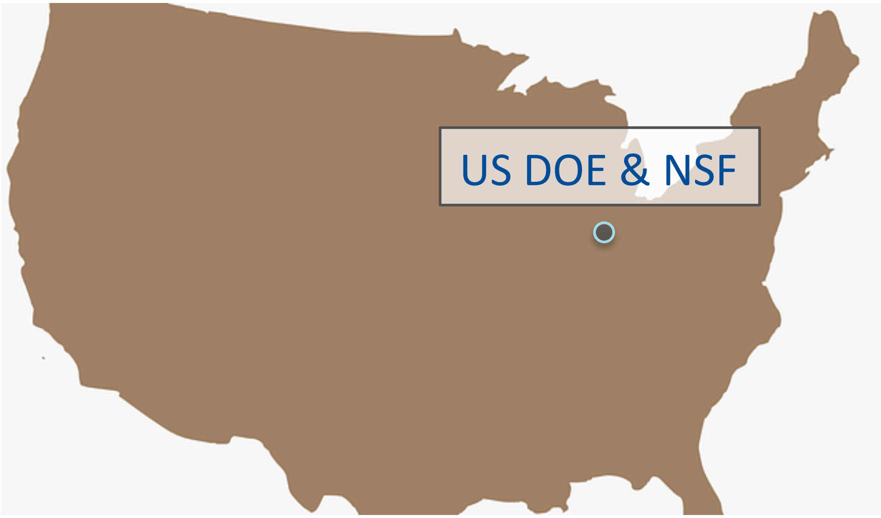
ν_μ Sensitivity with Detector Systematics

3% uncorrelated detector systematic

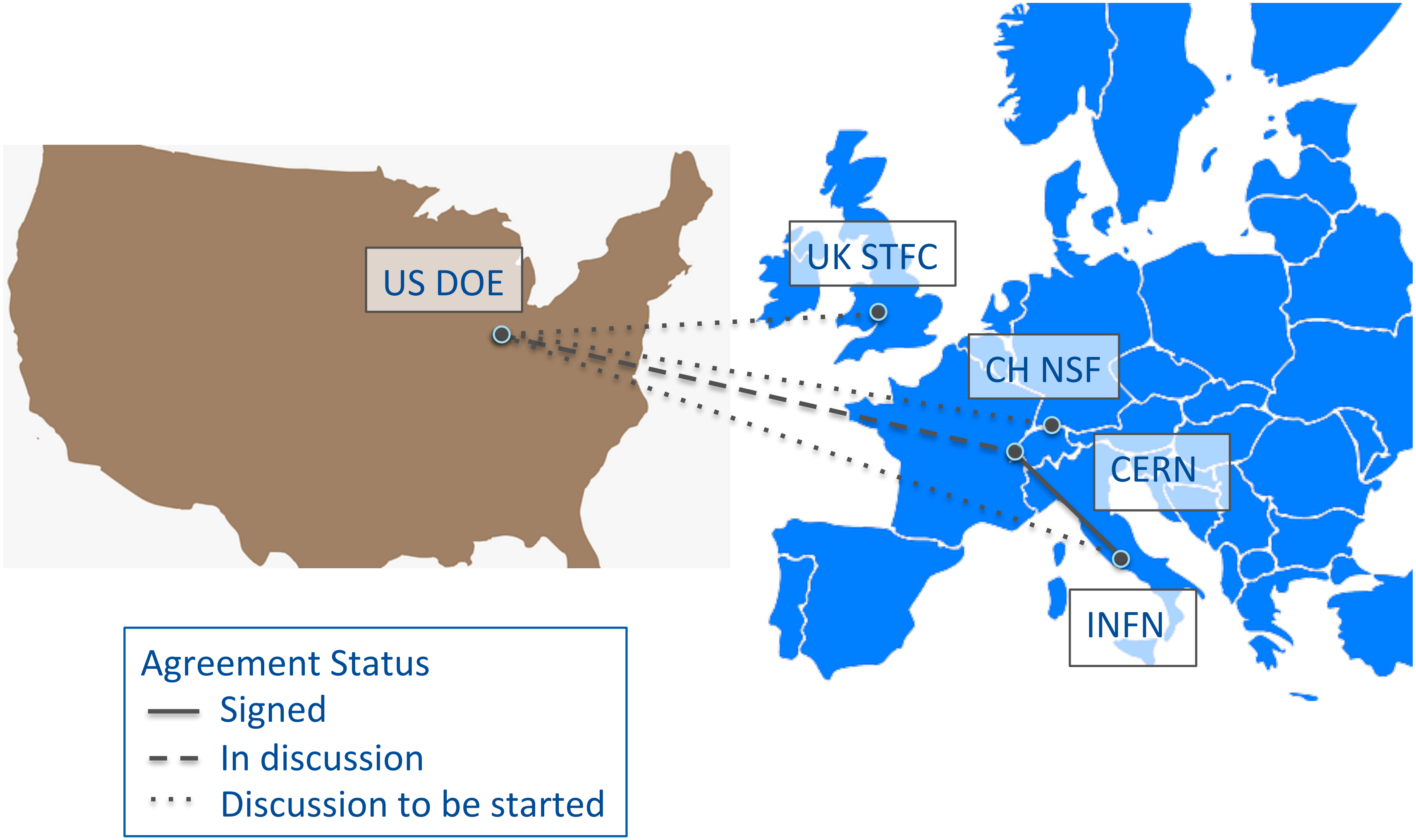




Main Funding Sources



Main International Agreements

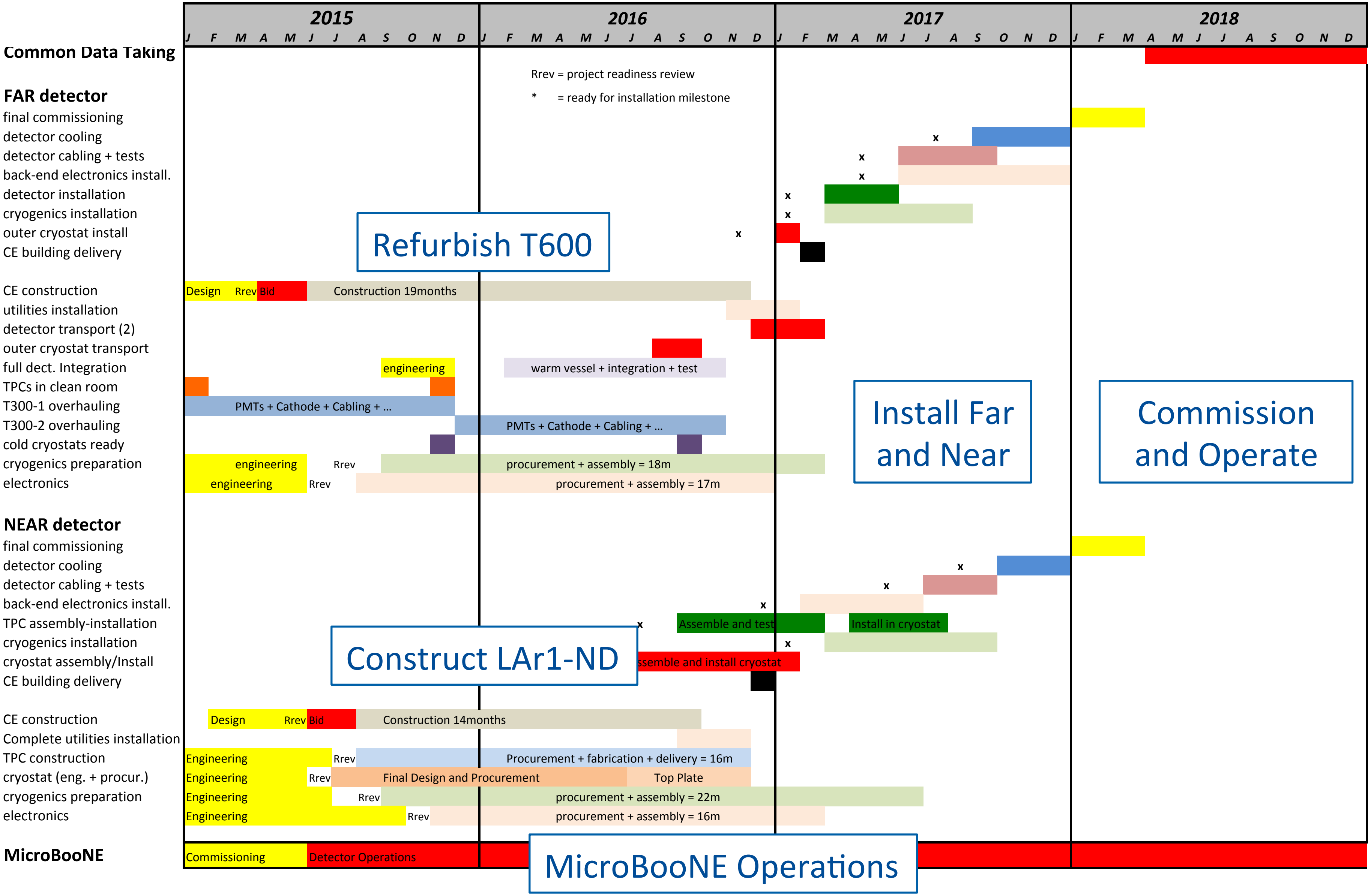


SBN Detectors, Timeline

- SBN is an opportunity to further develop the LAr-TPC technology and to **demonstrate its use in making precision measurements in neutrino physics**
- Detector assembly on an aggressive schedule, with first data in 2018

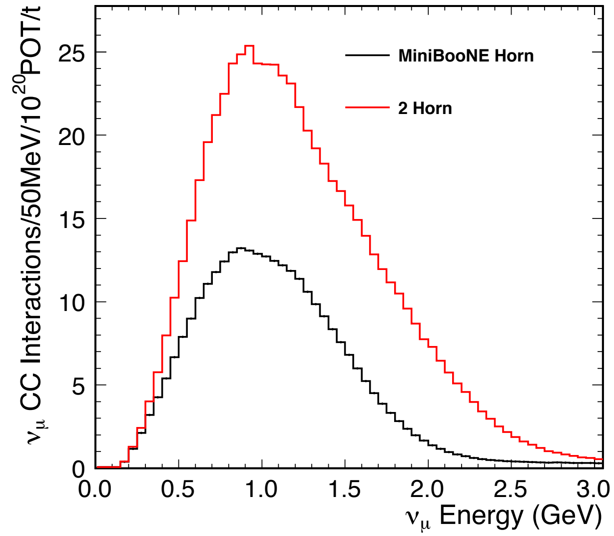
2015	2016	2017	2018
MicroBooNE running ***WA104 ICARUS-T600 refurbishment at CERN has begun*** ***Develop ND technical designs & project schedules*** ***Ground breaking on FD and ND buildings***	***ND and FD building construction completed*** ***Complete T600 refurbishing*** ***ND cryostat construction*** ***ND TPC system construction*** ***Cryogenics system fabrication***	***T600 arrives at Fermilab*** ***T600 installation*** ***ND active detector assembly and installation*** ***Cryogenic system construction for ND and FD***	***Liquid Ar fill and commissioning*** ***Neutrino Data!***

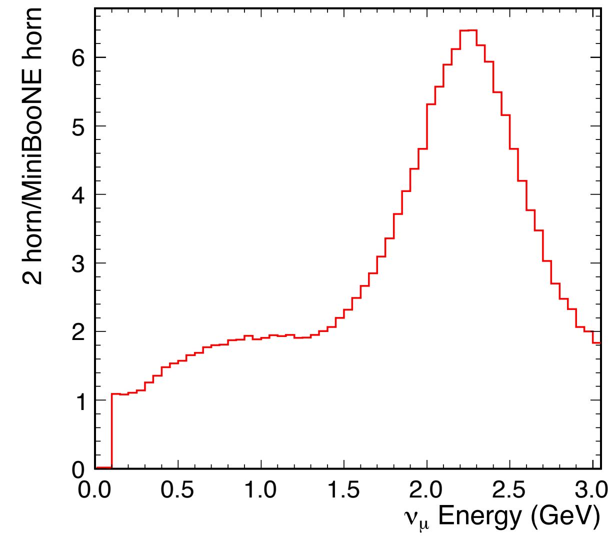
Program Schedule



BNB Improvements

- Increased ν statistics would further secure the program sensitivity
  - More protons on target
  - Higher ν production efficiency
- BNB ν energy distribution optimized of MiniBooNE Cherenkov detector
  - LAr-TPCs can tolerate high energy tail
- Reconfiguration to a two horn system could provide factor of two more ν/p.o.t.
- Modest reconfiguration of proton beamline provides space for 2nd horn
- Cost will be in new horn(s), power supply(ies) and collimator
- Detailed cost and schedule estimate needed





Institution List

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[2]Universität Bern, Laboratory for High Energy Physics, Bern, Switzerland
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[4]University of Cambridge, Cambridge, UK
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[43]National Centre for Nuclear Research, Warsaw, Poland
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