The Short-Baseline Neutrino Program

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On behalf of the MicroBooNE, ICARUS, and SBND Collaborations

48th Annual Fermilab Users Meeting
June 10th, 2015

THE UNIVERSITY OF CHICAGO

Sterile Neutrinos

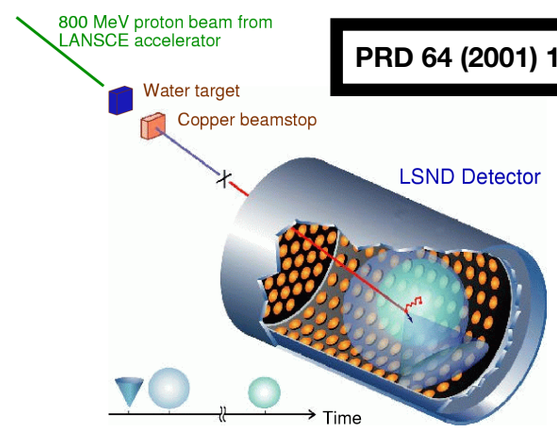
- Anomalies in a variety of experiments provide hints to the possible existence of sterile neutrinos

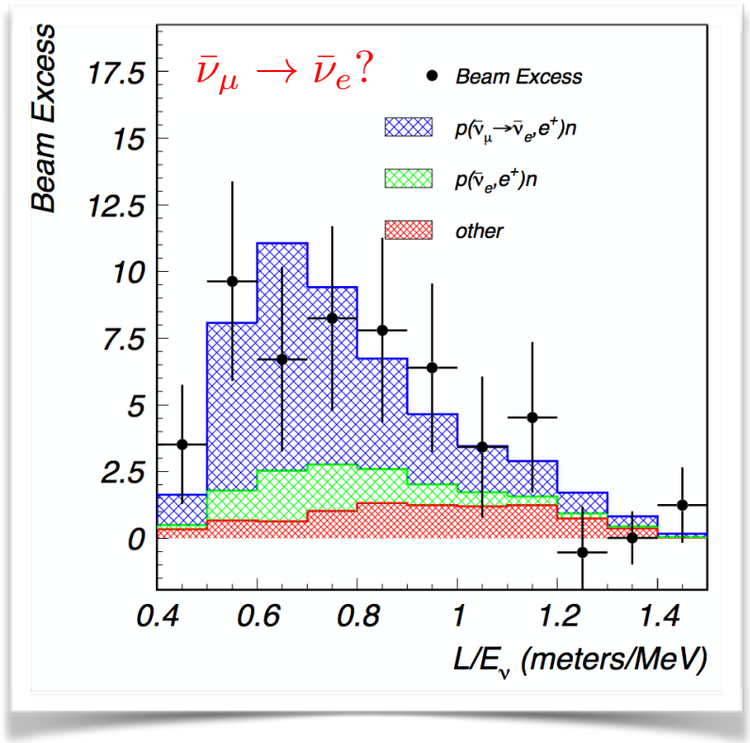
- The most significant of these come from LSND

- MiniBooNE followed up and also found anomalies

LSND

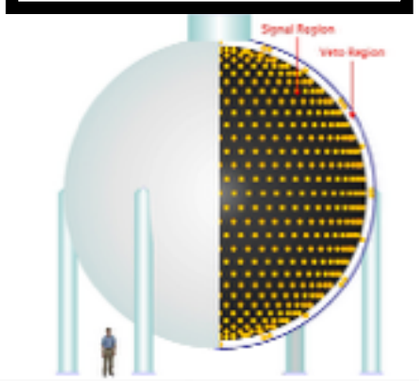
PRD 64 (2001) 112007

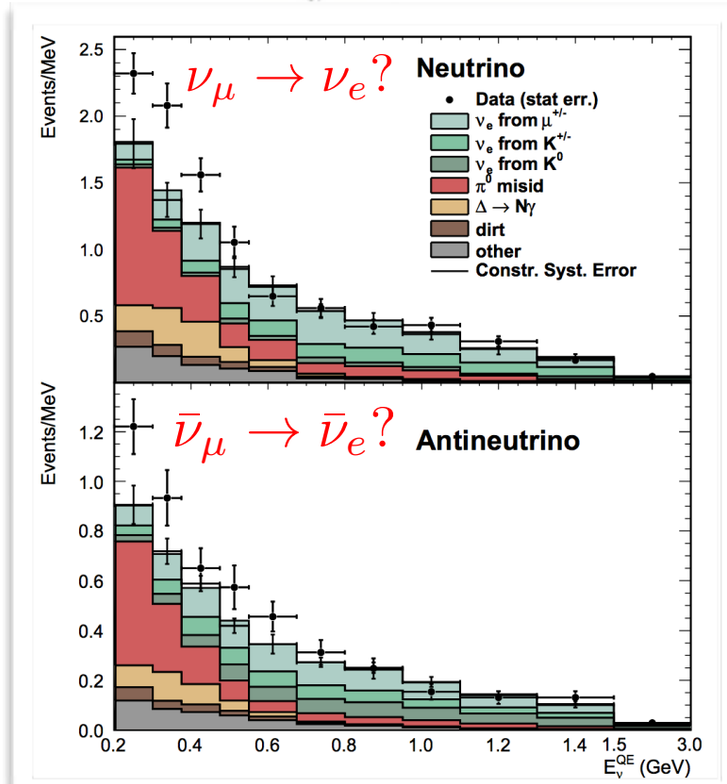




MiniBooNE

PRL 110 (2013) 161801



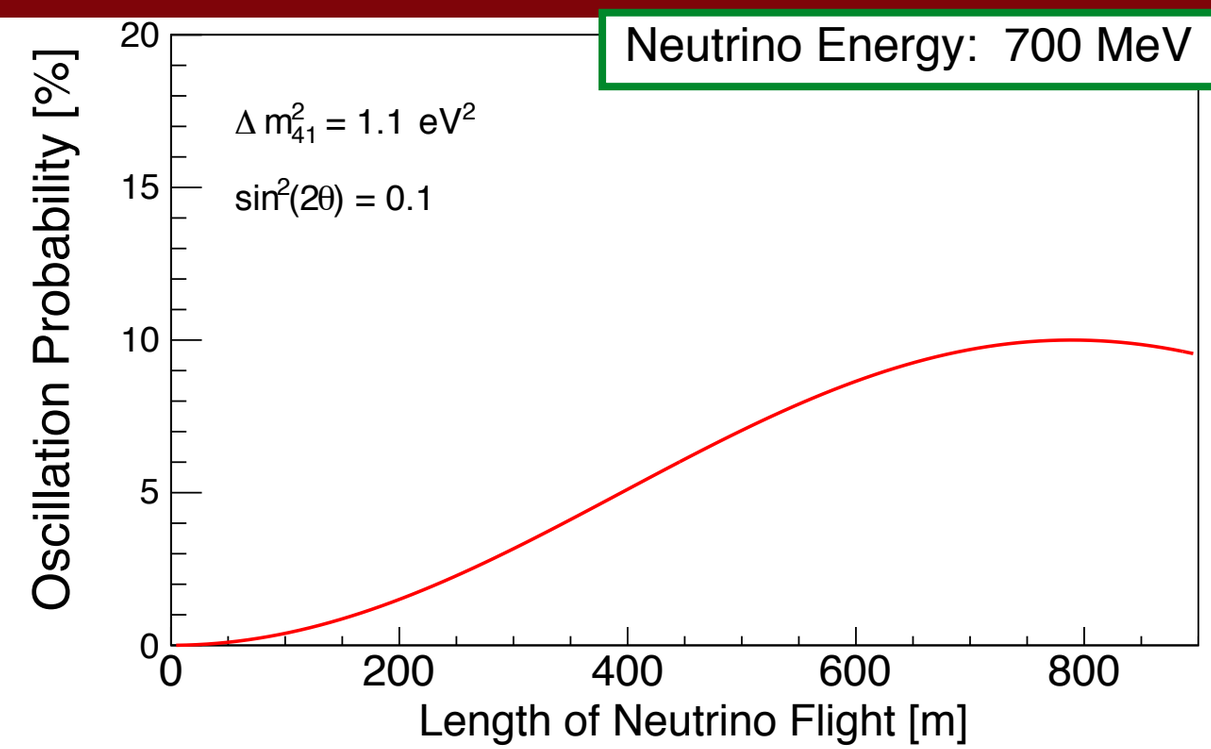


These results can be interpreted as oscillations involving sterile neutrinos with $\Delta m^2 \sim 1 eV^2$ and an $L/E \approx 1$ km/GeV

Sterile Neutrino Oscillations

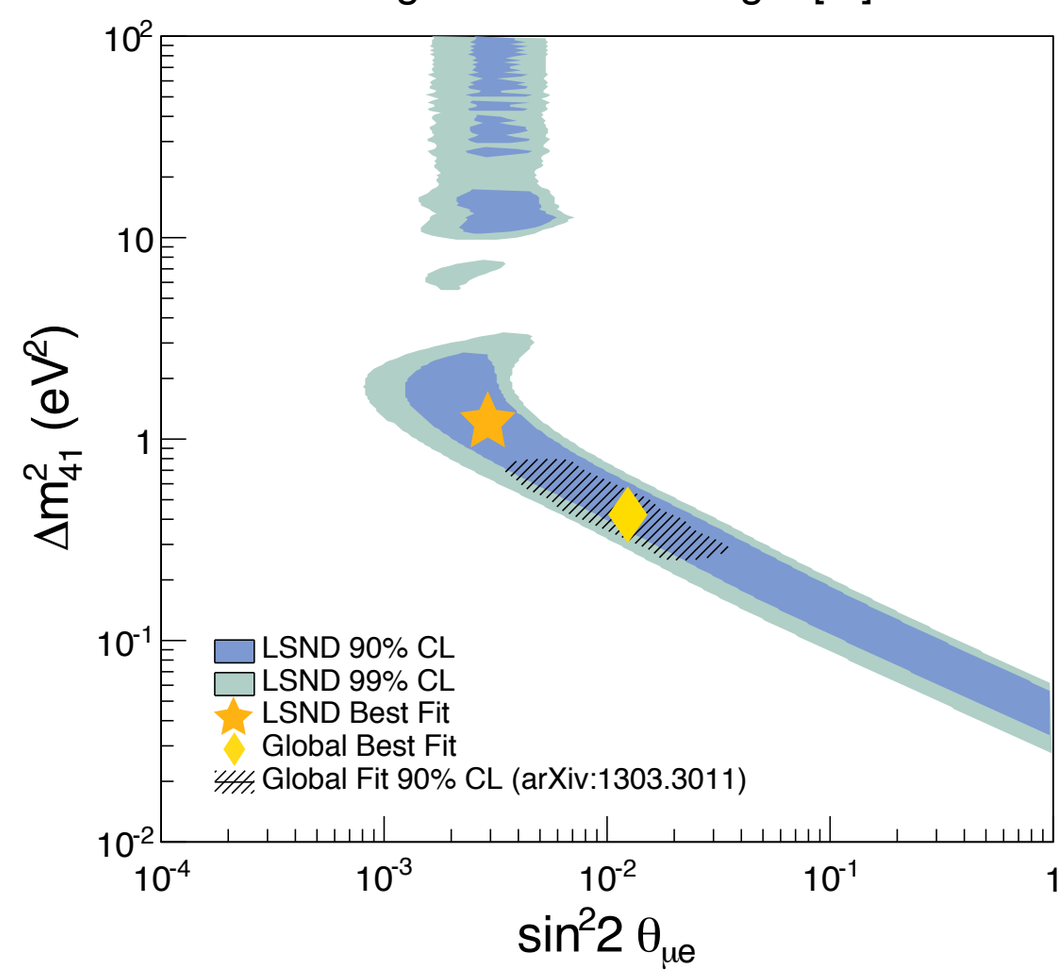
- The large mass splitting means at short-baselines we are effectively decoupled from standard neutrino oscillations

$$P^{3+1}_{\nu_\alpha \to \nu_\beta} = \sin^2 2\theta \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

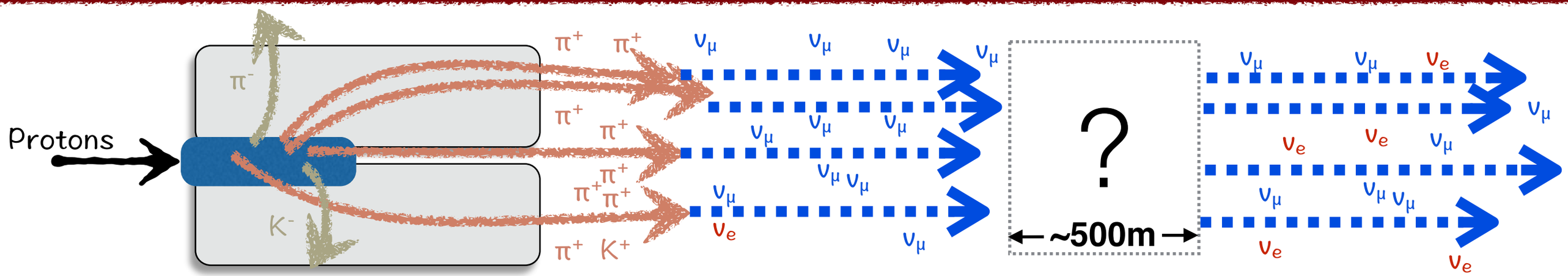


- We search for these oscillations by looking for the transformation of one active neutrino flavor into another

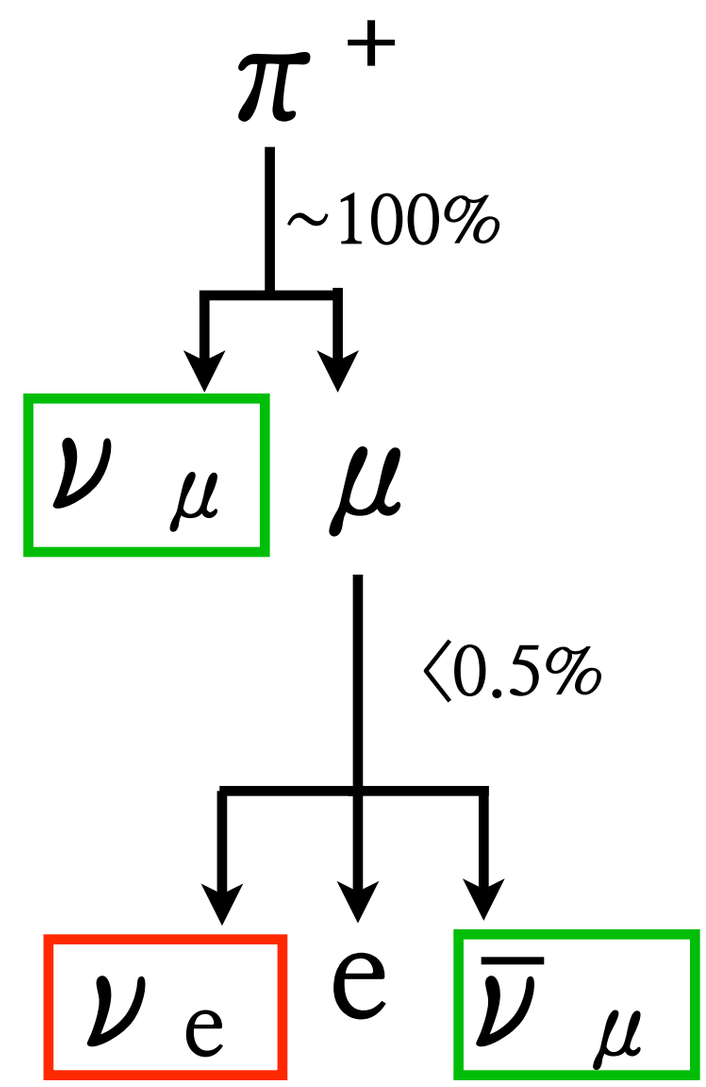
- Resolving these small effects require control of systematic uncertainties



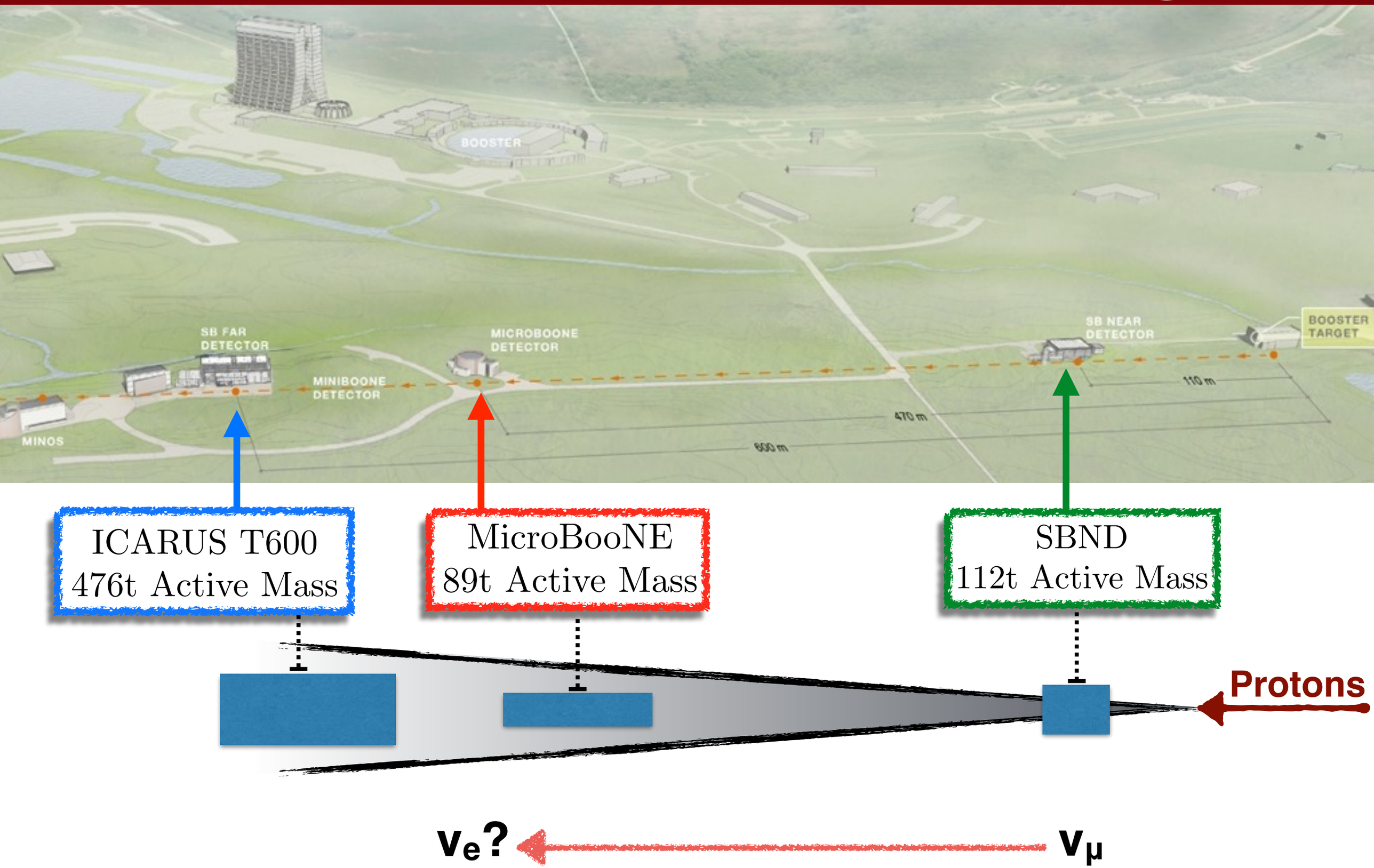
Booster Neutrino Beam



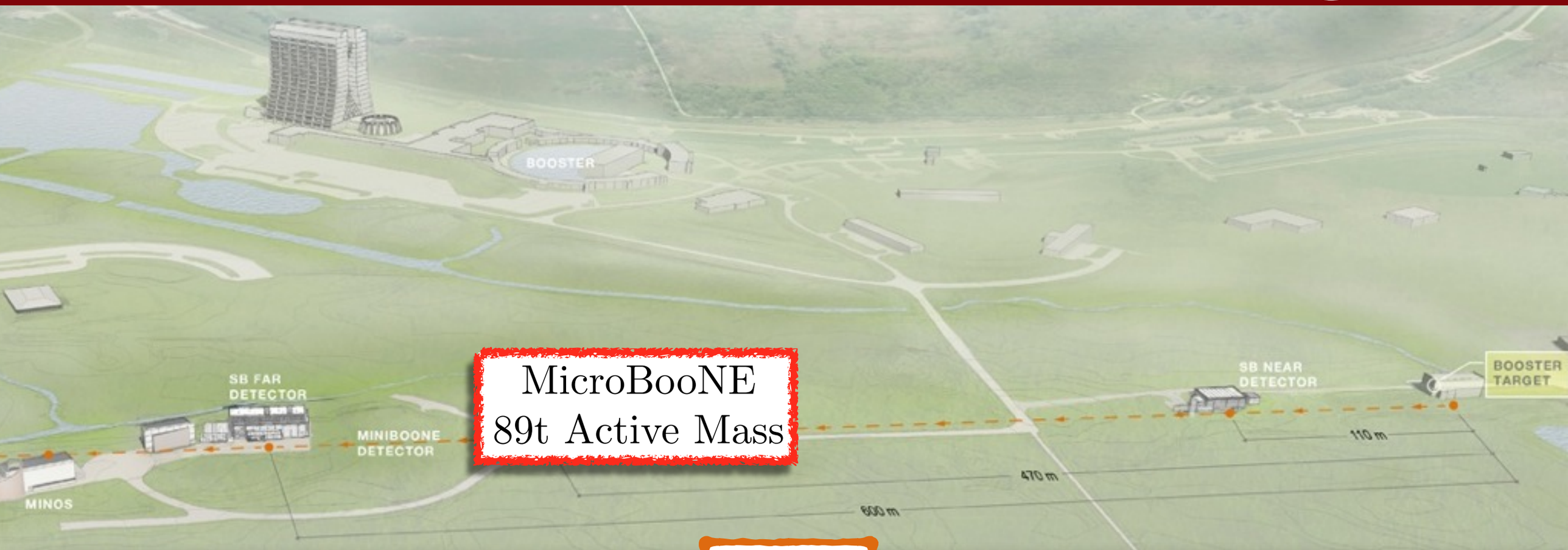
- Booster Neutrino Beam has been stably run for a decade and is well characterized
- Mesons from 8 GeV proton-beryllium collisions are focused forward by a magnetic horn
- This results is a beam of mostly muon neutrinos, where we can search for flavor disappearance and appearance



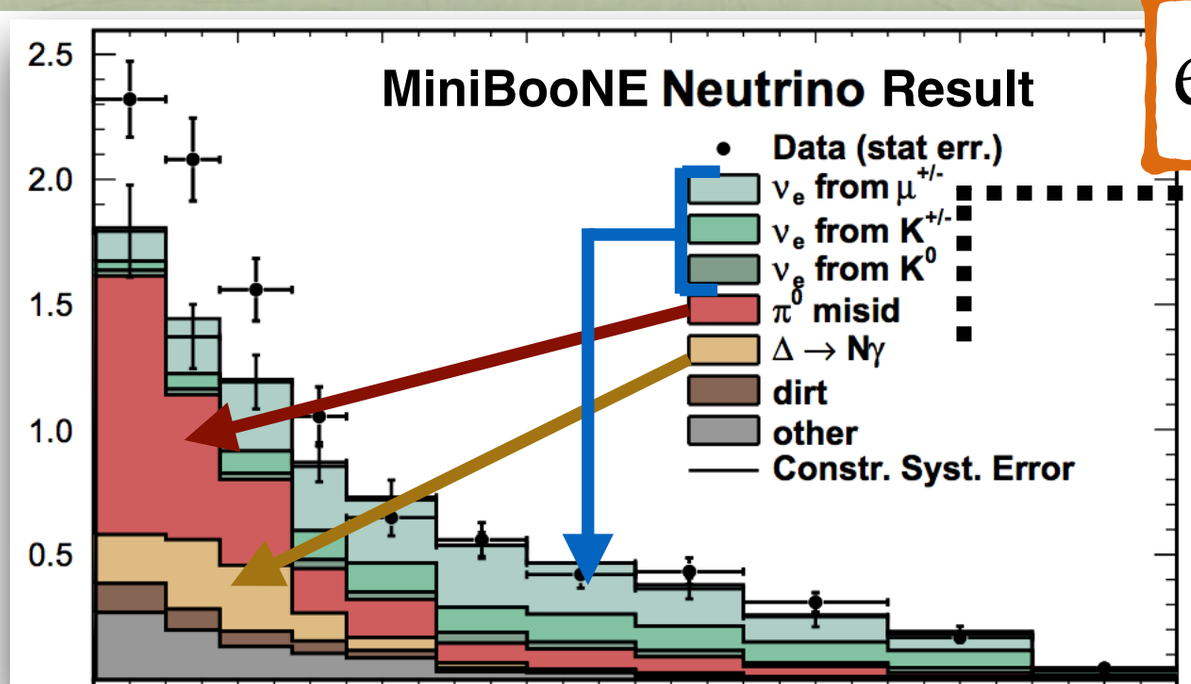
Short-Baseline Neutrino Program



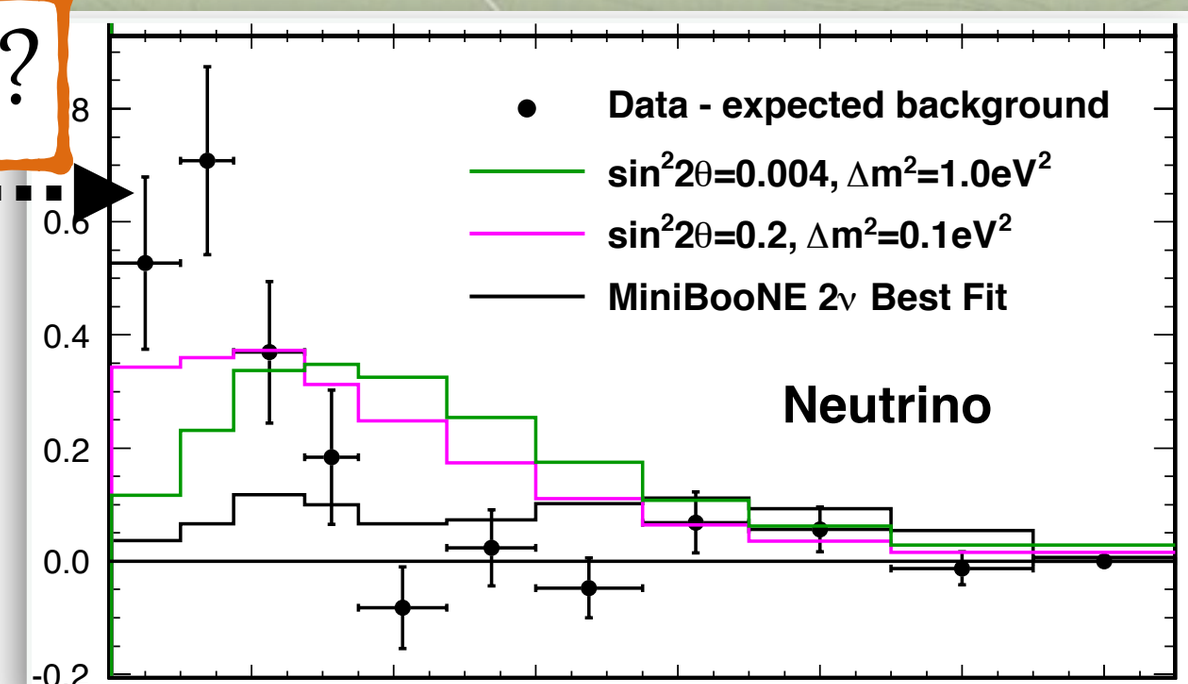
Short-Baseline Neutrino Program



MicroBooNE
89t Active Mass

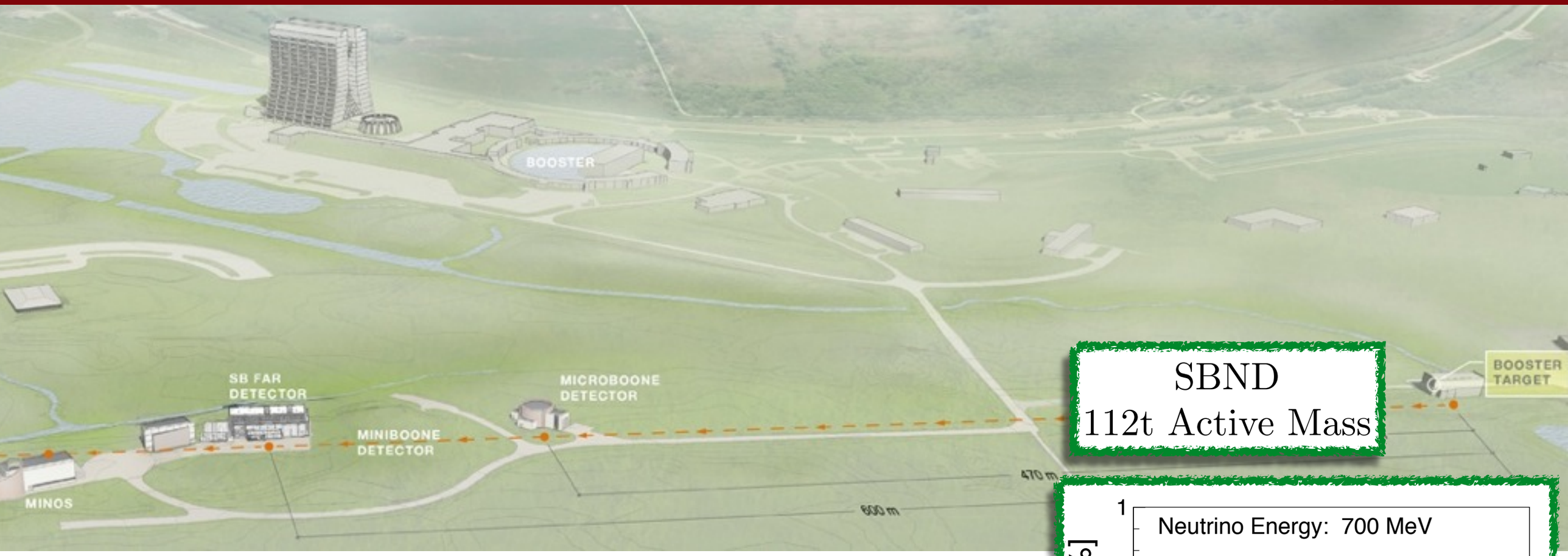


e or γ?

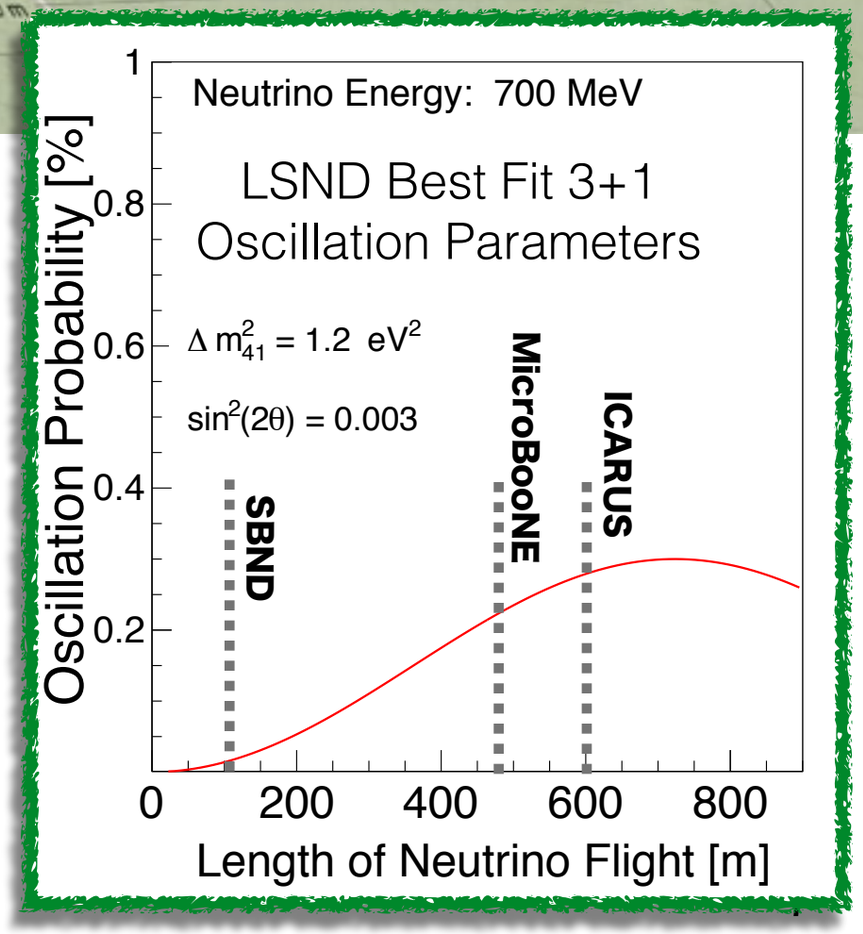


PRL 110 (2013) 161801

Short-Baseline Neutrino Program

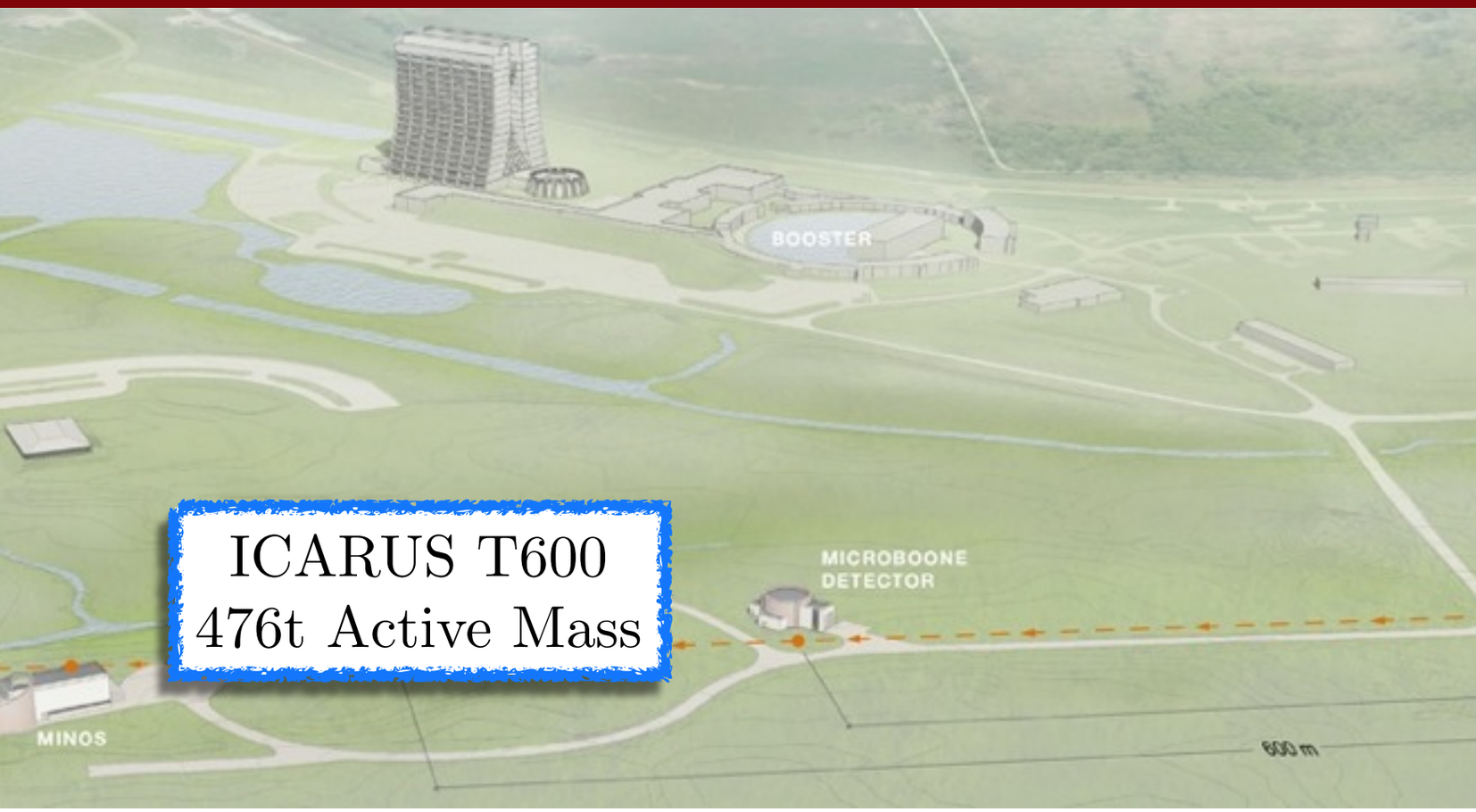


SBND
112t Active Mass



- SBND will provide a detailed characterization of the beam before oscillations can occur
- This allows for the cancelation of many of the dominant systematics

Short-Baseline Neutrino Program



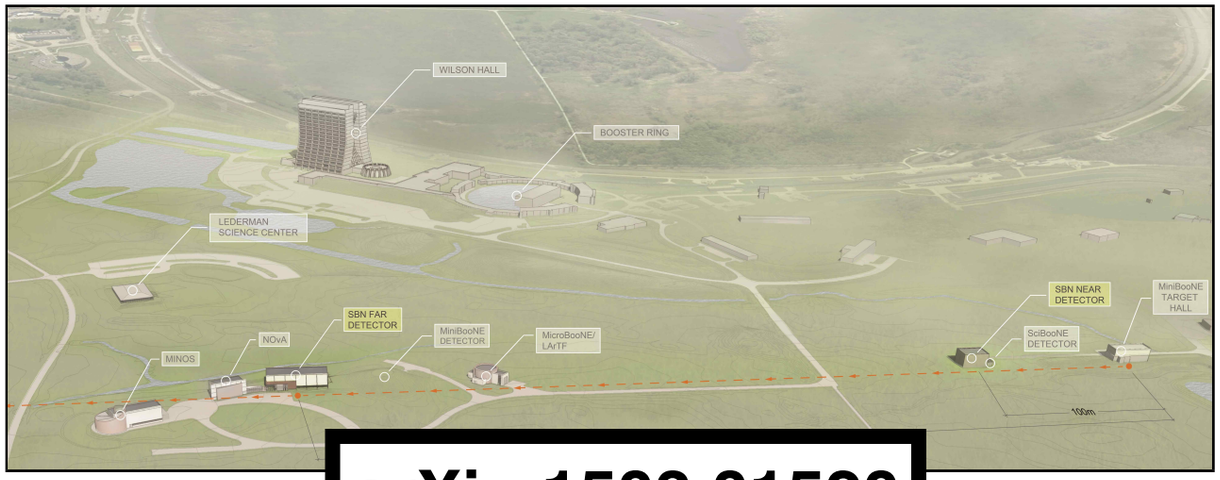
ICARUS T600
476t Active Mass

- The ICARUS T600 is the largest LAr TPC ever built, 7 times larger than MicroBooNE
- This mass provides us with high sensitivity to oscillated neutrinos allowing for a precision search

Short-Baseline Neutrino Program

- The goal of SBN is to perform a definitive search for sterile neutrino oscillations
  - The three collaborations worked together to design such a program
- The resulting proposal contained a careful examination of all known backgrounds and systematic uncertainties

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



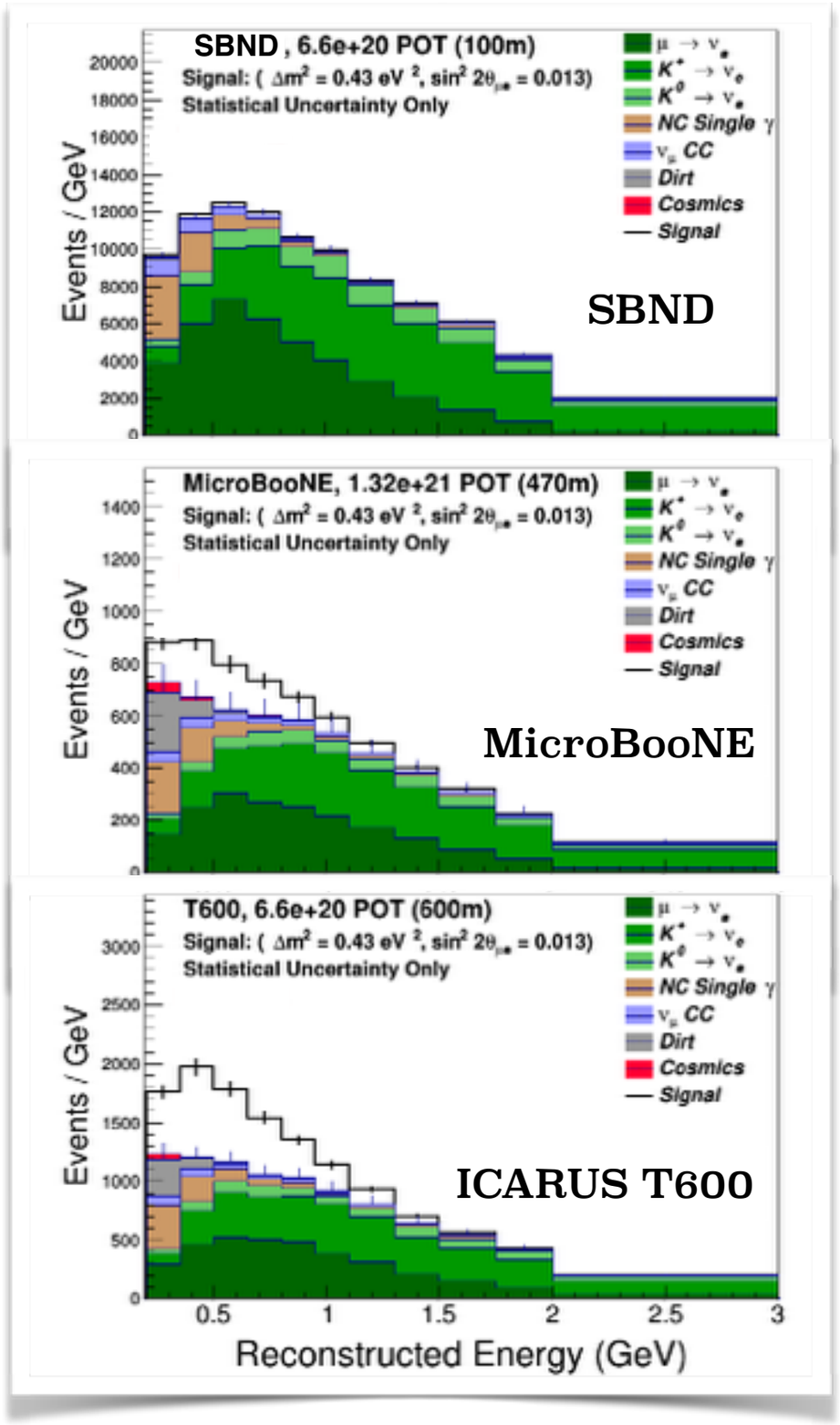
arXiv:1503.01520

"The Committee recommends Stage 1 approval for the SBN program…"

~Fermilab Physics Advisory Committee, January 2015

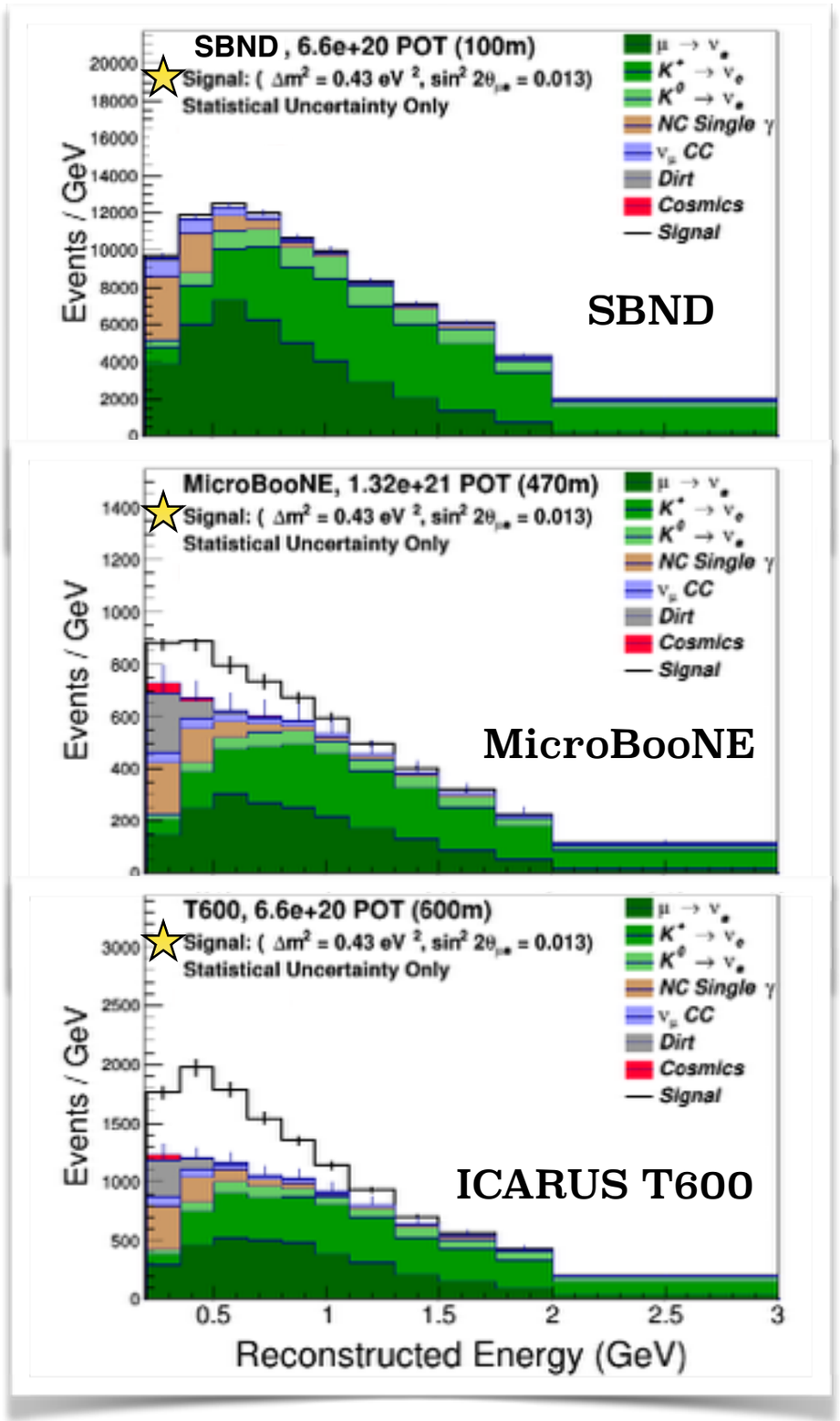
The laboratory has since approved the program!

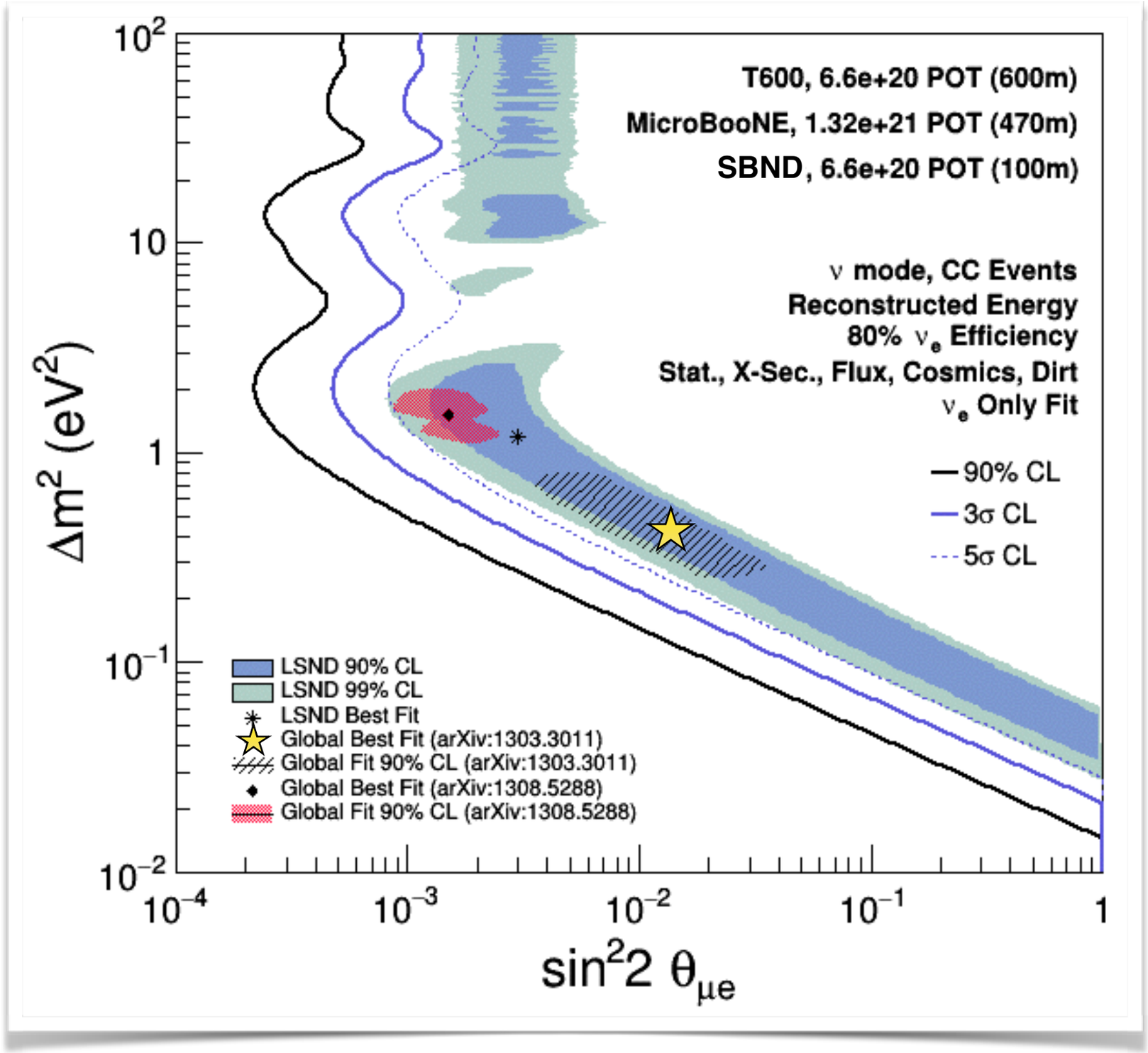
Electron Neutrino Appearance



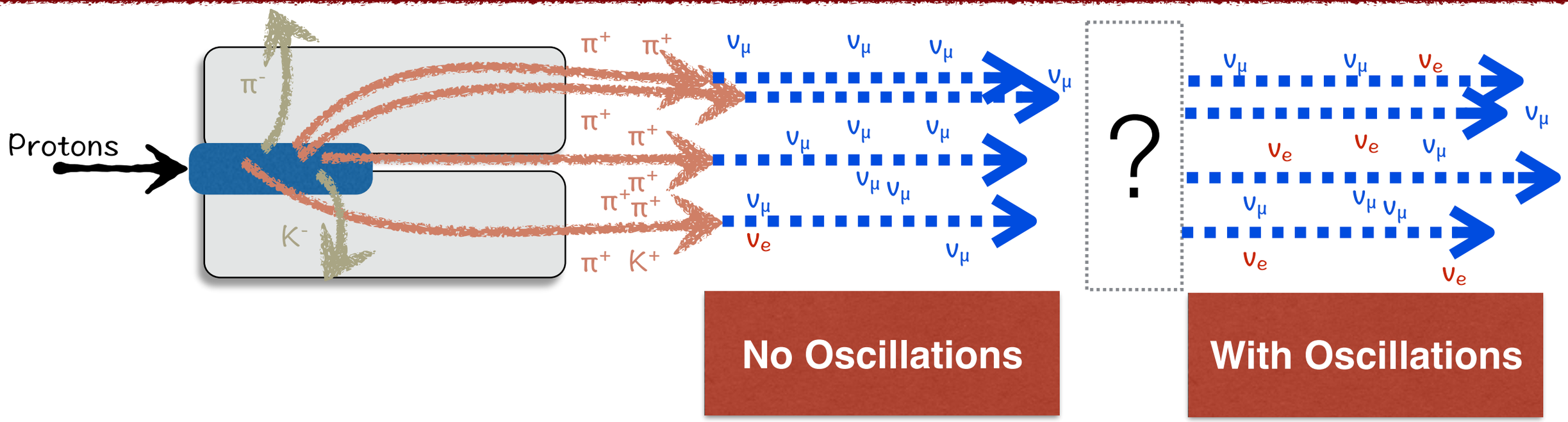
- The proposal leveraged the expertise gained by MiniBooNE both for the neutrino flux and the uncertainties on that flux
- By using a series of three LAr TPCs we are able to greatly reduce the photon-like backgrounds compared to MiniBooNE
- Given its large mass and far location ICARUS provides exquisite sensitivity to the oscillated signal

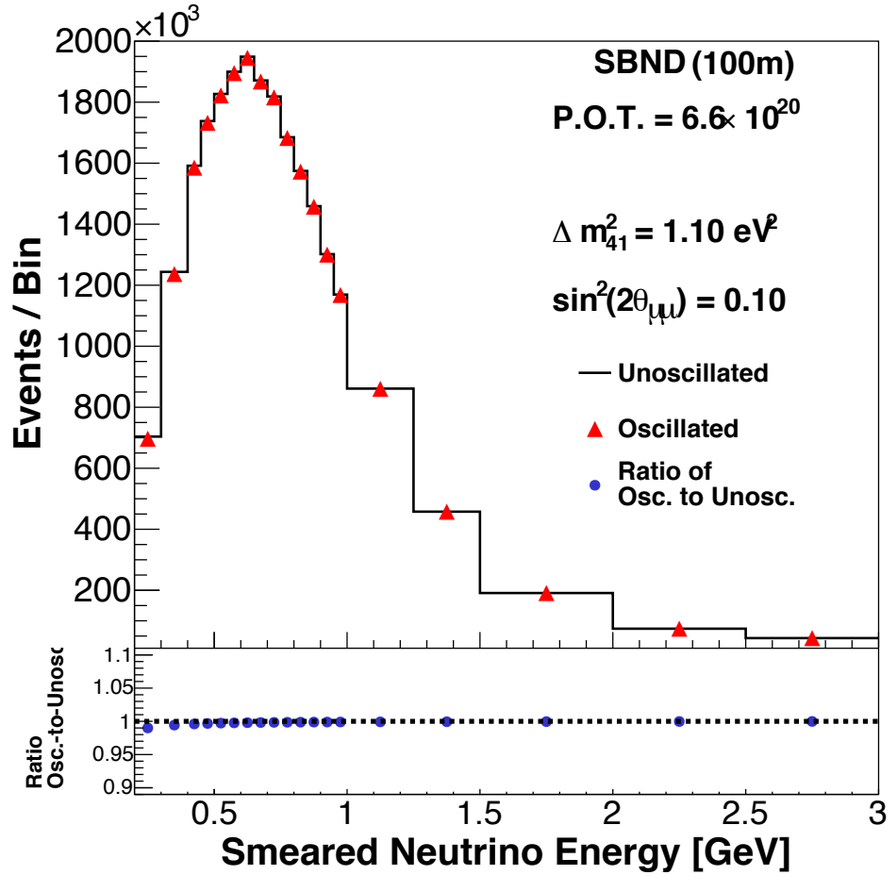
Sensitivity: Electron Neutrino Appearance

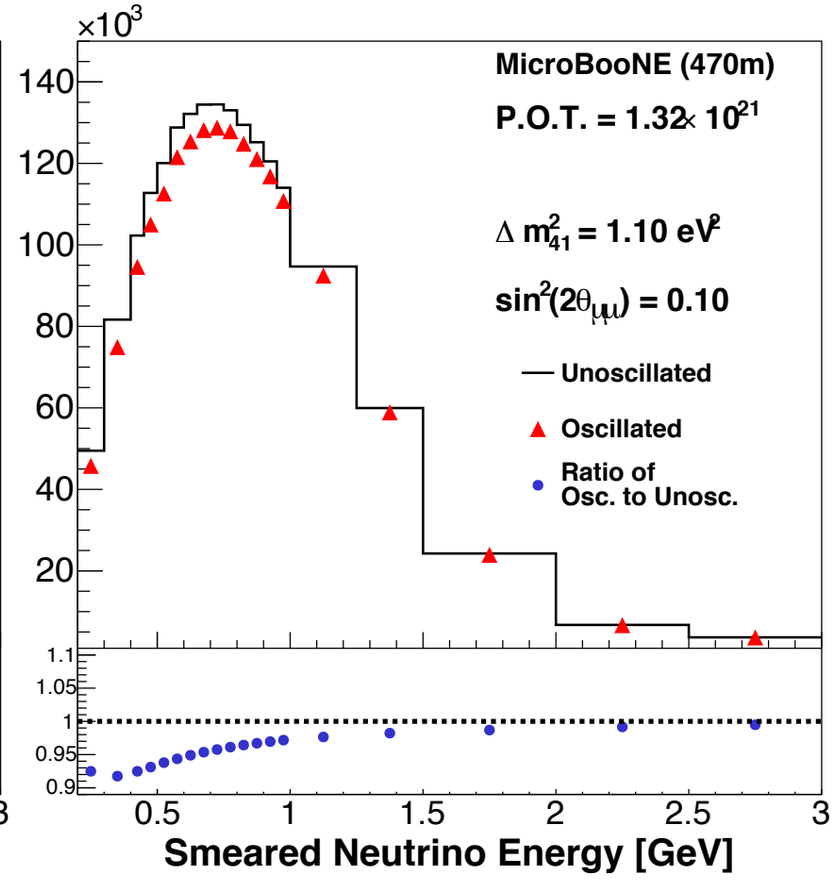


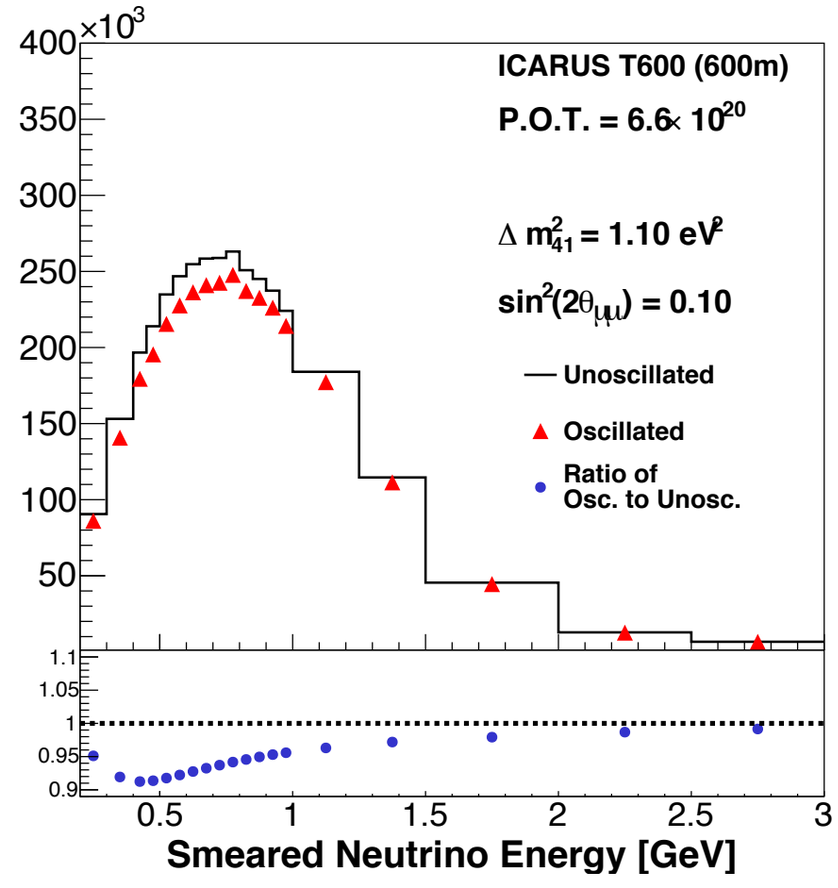


Disappearance Signature

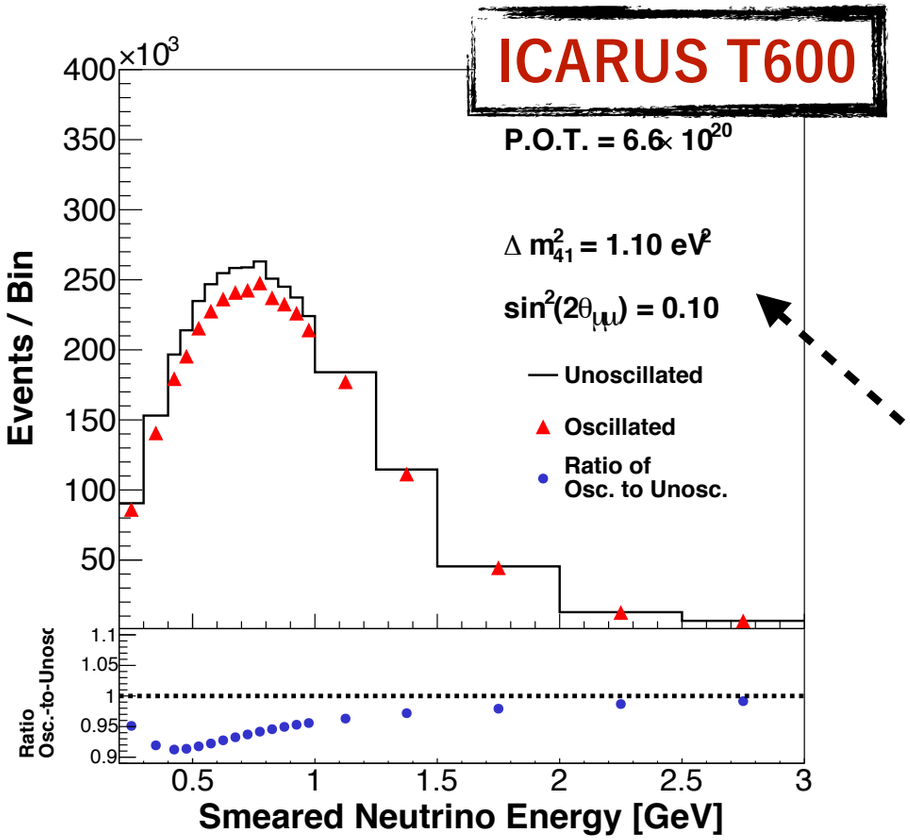


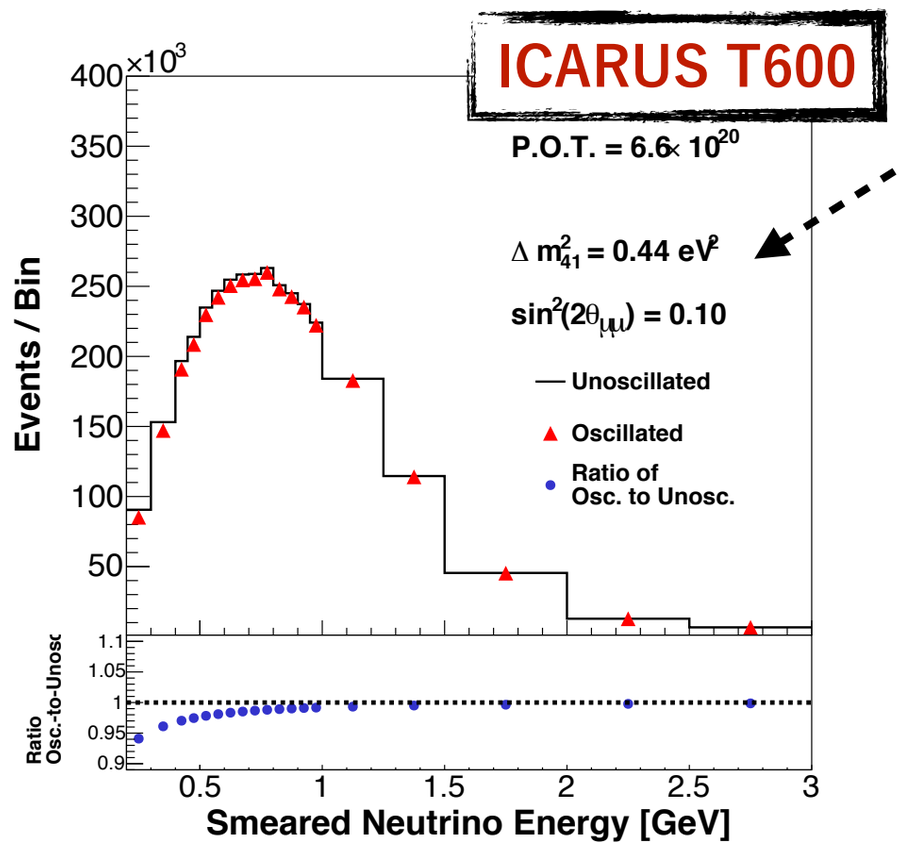


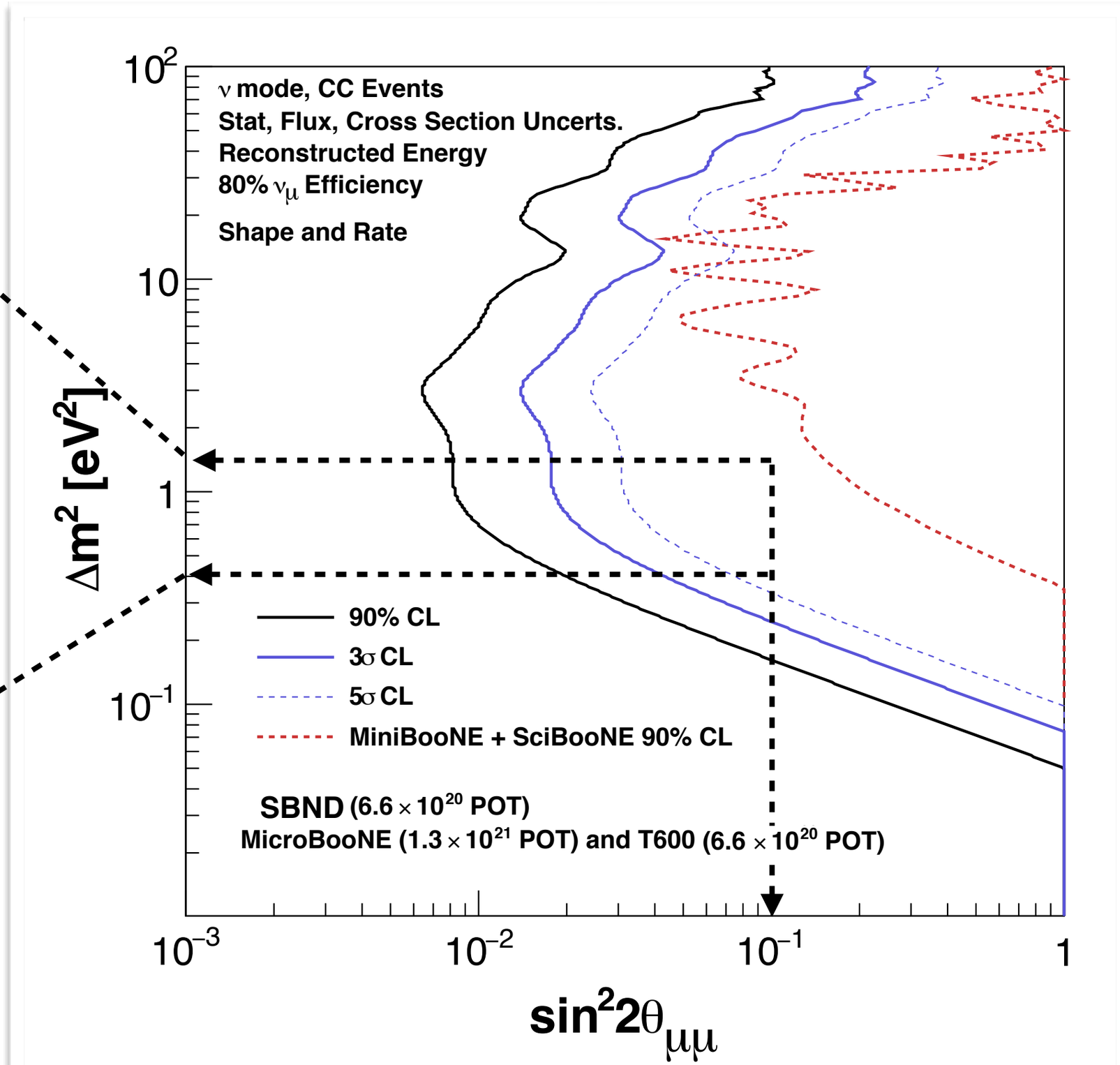




Sensitivity: Muon Neutrino Disappearance

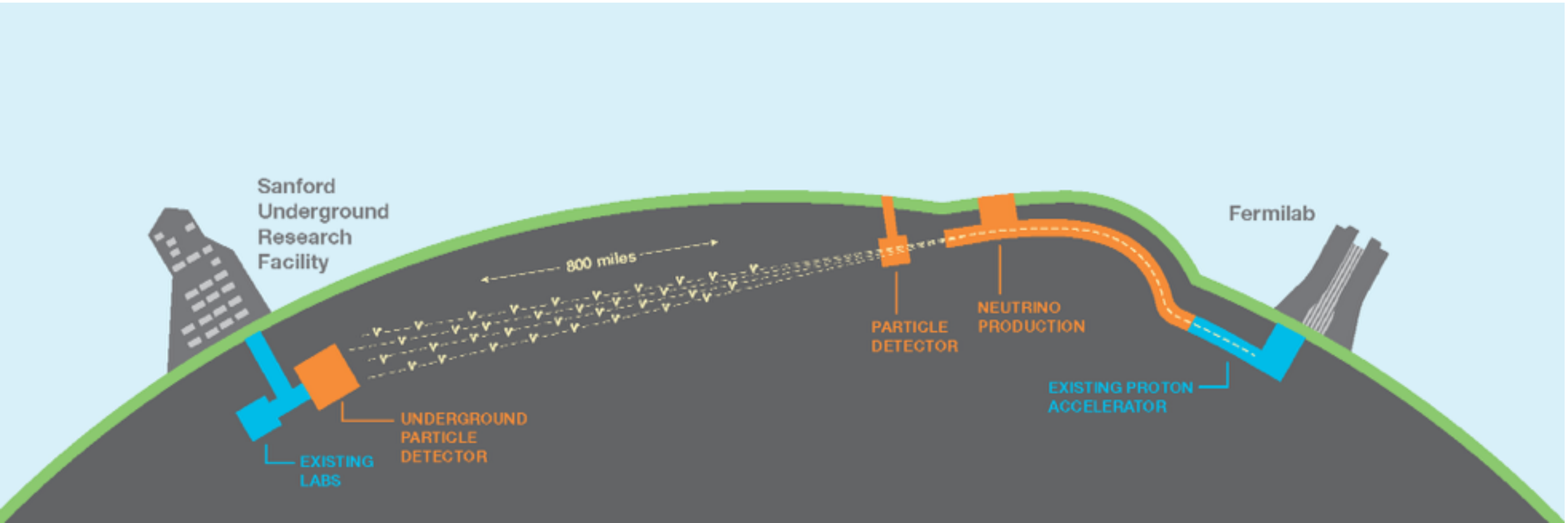






Ties to Long-Baseline Program

- This program is a platform to develop the technical and analysis techniques necessary for the long-baseline program
  - Bringing together the LAr TPC expertise from all over the world to collaborate on mid-scale detector development
  - Designing and validating event reconstruction on a large number of neutrino events
  - Detailed studies of GeV-scale ν-Ar cross sections

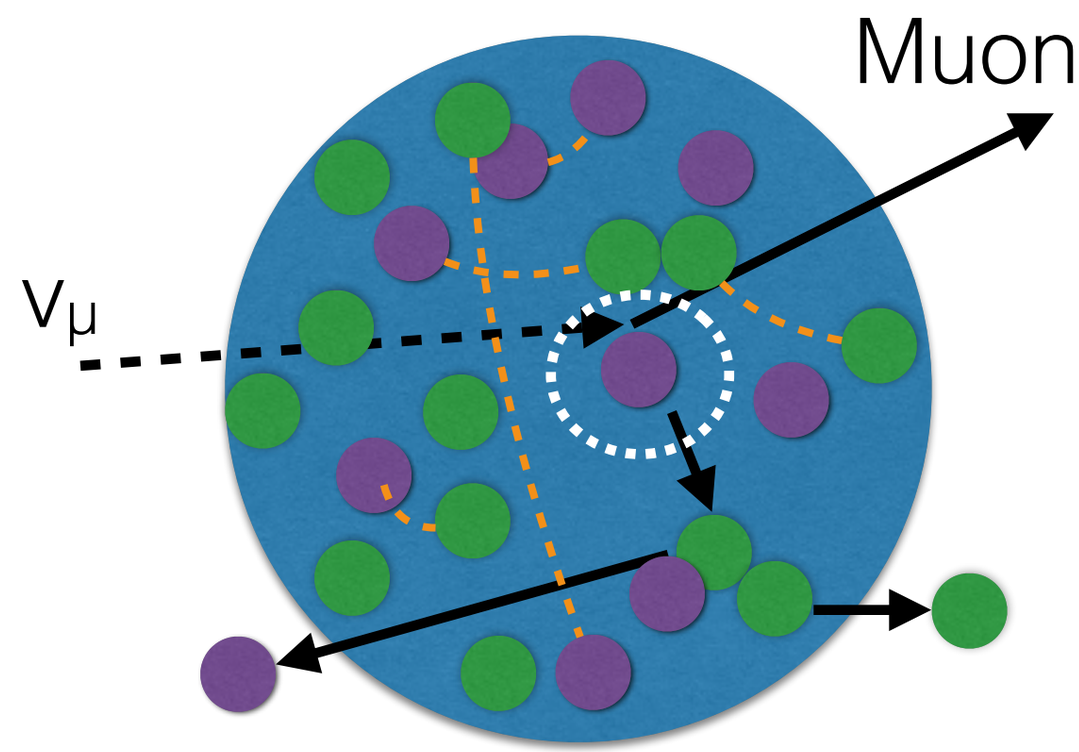


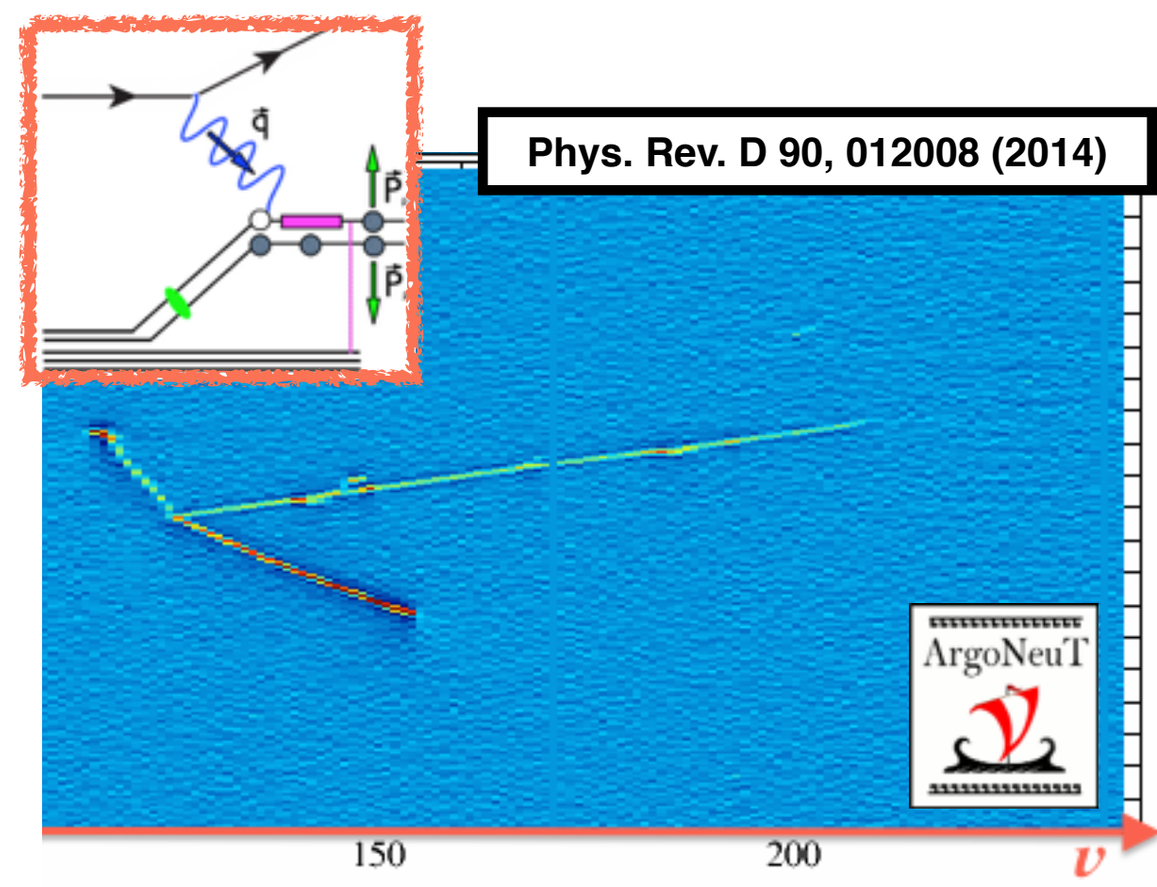
Cross Sections At the SBN

- MicroBooNE will lay the ground work for an intense cross section program to characterize ν-Ar interactions

- Building off this the SBND will record **1.5 million** neutrino interactions **per year** allowing for detailed studies of exclusive final states

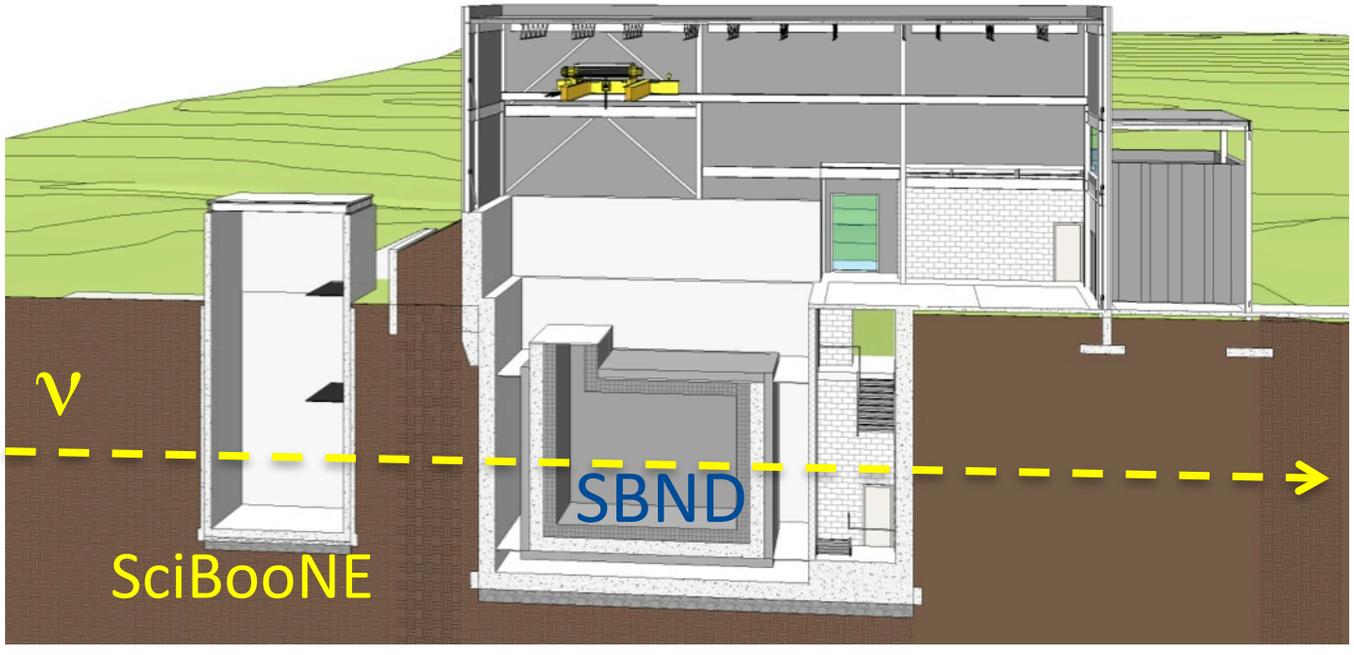
- The T600 sits in the NuMI beam far off-axis, allowing it to record a large statistics sample of higher energy neutrino interactions



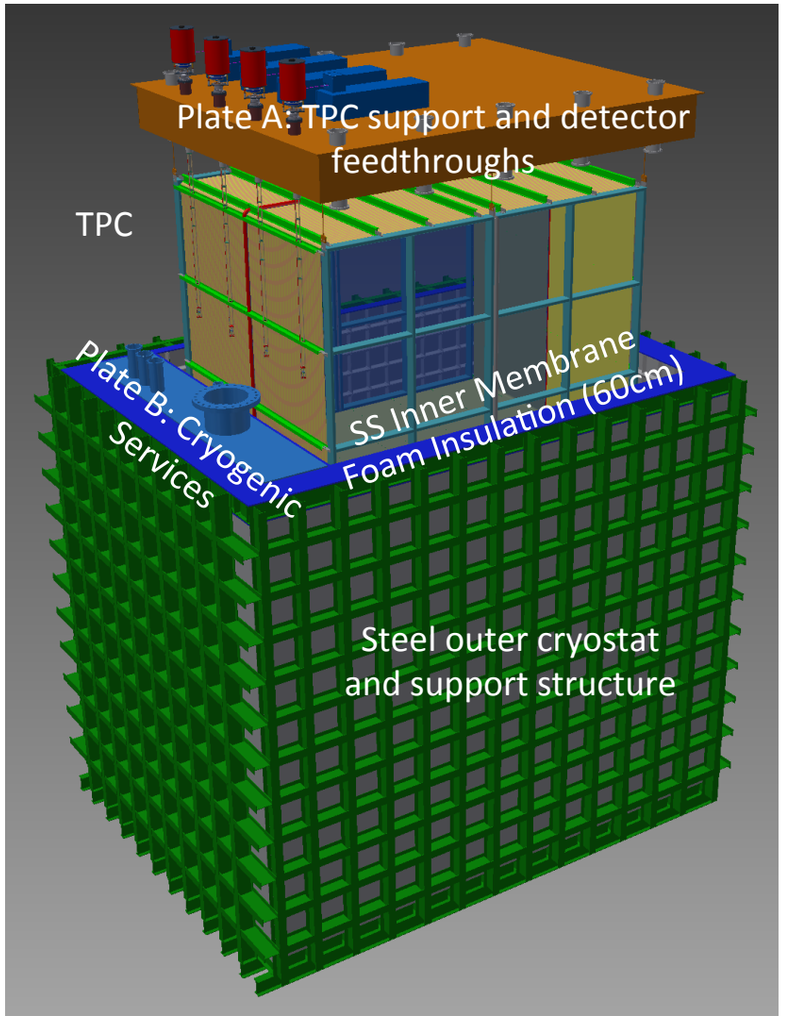


Building the Program: SBND

- The near detector building is finalizing its design with construction scheduled to begin August 2015

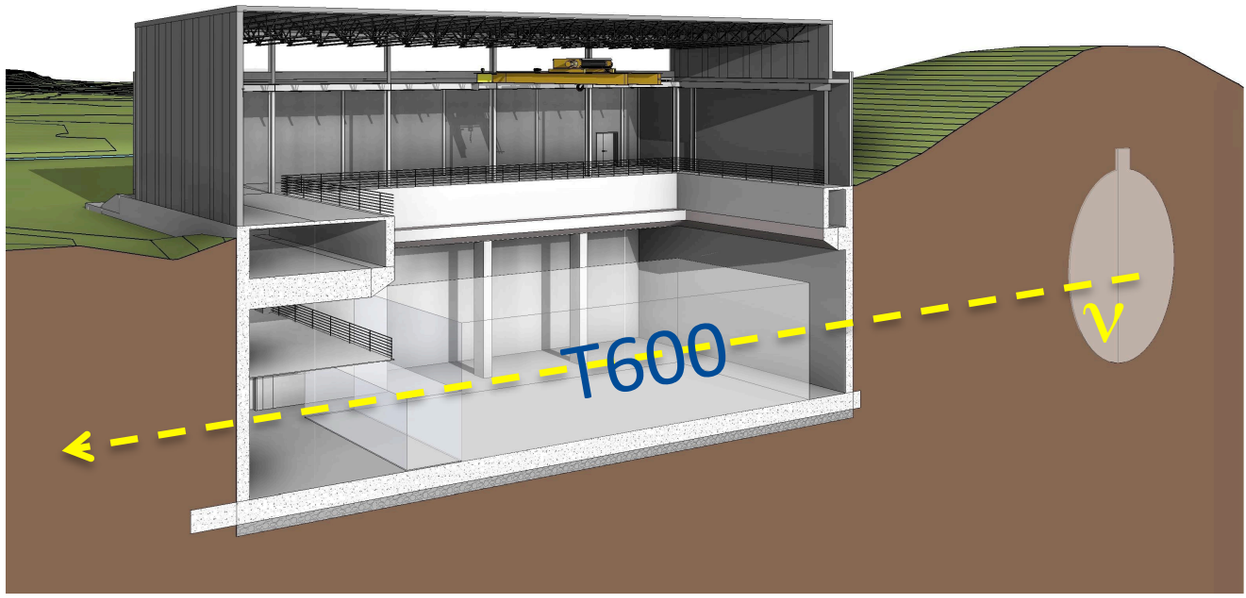


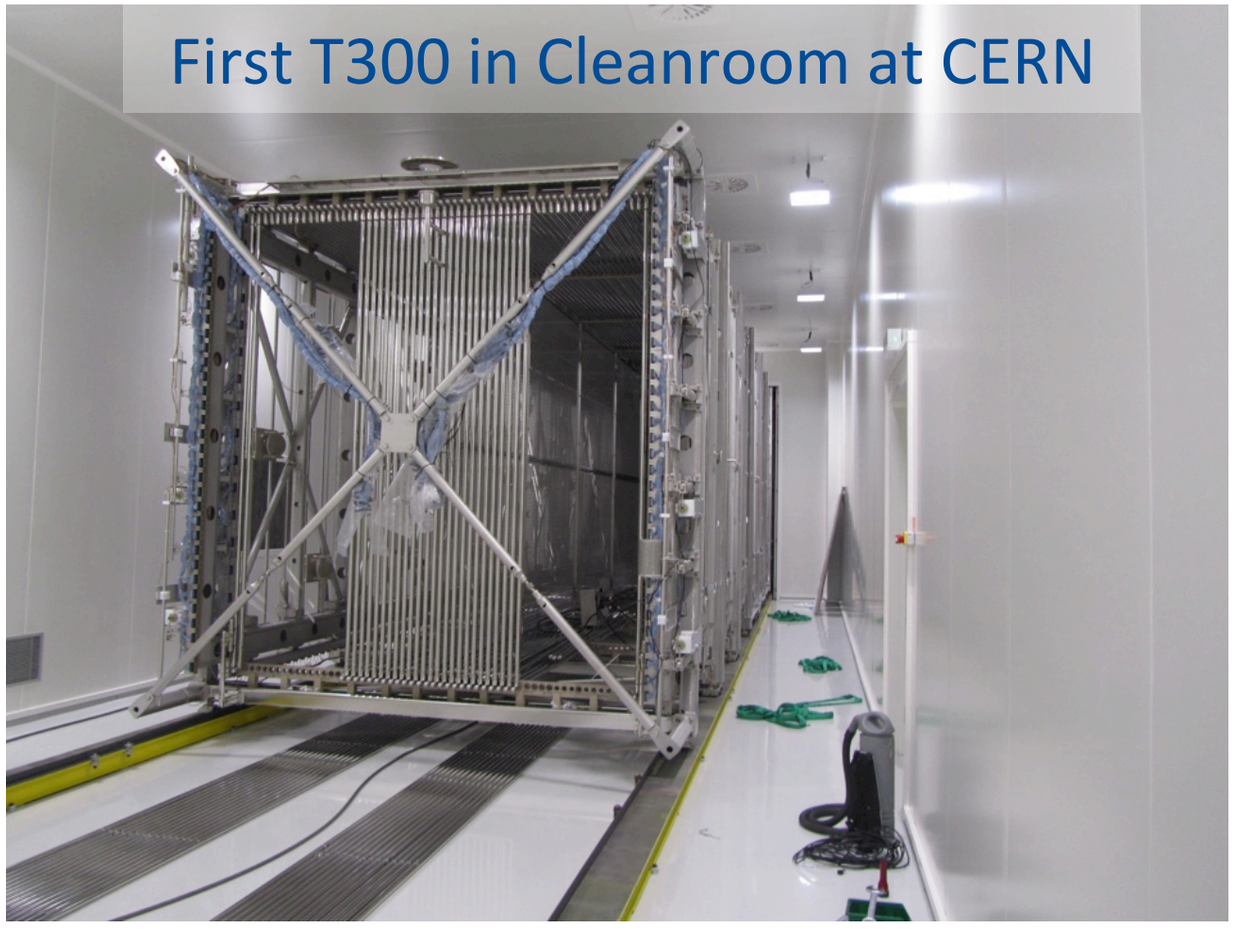
- The designs for the cryostat and TPC are maturing quickly with close collaboration between Fermilab, CERN, and many institutions!



Building the Program: ICARUS T600

- The building which will house the far detector has been finalized!
- The refurbishment of the T600 has already begun at CERN
- The first of the two T300 modules will be finished by the end of 2015 and the second module by the end of 2016





Moving Forward

- The groundbreaking for the SBN detector buildings will take place this June
- This starts an exciting period for all three collaborations, where activities range from design, to construction, to commissioning
- MicroBooNE will provide us the first look at what we might be seeing at short-baselines

Finding Sterile Neutrinos Would be Revolutionary!

Thank You From

The ICARUS-WA104 Collaboration

M. Antonello[16], B. Baibussinov[31], V. Bellini[5], P. Benetti[32], S. Bertolucci[6], H. Bilokon[15], F. Boffelli[32], M. Bonesini[17], J. Bremer[6], E. Calligarich[32], S. Centro[31], A.G. Cocco[19], A. Dermenev[20], A. Falcone[32], C. Farnese[31], A. Fava[31], A. Ferrari[6], D. Gibin[31], S. Gninenko[20], N. Golubev[20], A. Guglielmi[31], A. Ivashkin[20], M. Kirsanov[20], J. Kisiel[38], U. Kose[6], F. Mammoliti[5], G. Mannocchi[15], A. Menegolli[32], G. Meng[31], D. Mladenov[6], C. Montanari[32], M. Nessi[6], M. Nicoletto[31], F. Noto[6], P. Picchi[15], F. Pietropaolo[31], P.Płoński[42], R. Potenza[5], A. Rappoldi[32], G. L. Raselli[32], M. Rossella[32], C. Rubbia[*,6,11,16], P. Sala[18], A. Scaramelli[18], J. Sobczyk[44], M. Spanu[32], D. Stefan[18], R. Sulej[43], C.M. Sutera[5], M. Torti[32], F. Tortorici[5], F. Varanini[31], S. Ventura[31], C. Vignoli[16], T. Wachala[12], and A. Zani[32]

The LAr1-ND Collaboration

C. Adams[45], C. Andreopoulos[23], A. Ankowski[41], J. Asaadi[40], L. Bagby[10], B. Baller[10], N. Barros[33], M. Bass[30], S. Bertolucci[6], M. Bishai[3], A. Bitadze[25], J. Bremer[6], L. Bugel[26], L. Camilleri[9], F. Cavanna[a,10], H. Chen[3], C. Chi[9], E. Church[10], D. Cianci[7], G. Collin[26], J.M. Conrad[26], G. De Geronimo[3], R. Dharmapalan[1], Z. Djurcic[1], A. Ereditato[2], J. Esquivel[40], J. Evans[25], B.T. Fleming[45], W.M. Foreman[7], J. Freestone[25], T. Gamble[37], G. Garvey[24], V. Genty[9], D. Göldi[2], H. Greenlee[10], R. Guenette[30], A. Hackenburg[45], R. Hänni[2], J. Ho[7], J. Howell[10], C. James[10], C.M. Jen[41], B.J.P. Jones[26], L.M. Kalousis[41], G. Karagiorgi[25], W. Ketchum[24], J. Klein[33], J. Klinger[37], U. Kose[6], I. Kreslo[2], V.A. Kudryavtsev[37], D. Lissauer[3], P. Livesly[22], W.C. Louis[24], M. Lu□thi[2], C. Mariani[41], K. Mavrokoridis[23], N. McCauley[23], N. McConkey[37], I. Mercer[22], T. Miao[10], G.B. Mills[24], D. Mladenov[6], D. Montanari[10], J. Moon[26], Z. Moss[26], S. Mufson[14], M. Nessi[6], B. Norris[10], F. Noto[6], J. Nowak[22], S. Pal[37], O. Palamara[*,b,10], J. Pater[25], Z. Pavlovic[10], J. Perkin[37], G. Pulliam[40], X. Qian[3], L. Qiuguang[24], V. Radeka[3], R. Rameika[10], P.N. Ratoff[22], M. Richardson[37], C. Rudolf von Rohr[2], D.W. Schmitz[*,7], M.H. Shaevitz[9], B. Sippach[9], M. Soderberg[40], S. Söldner-Rembold[25], J. Spitz[26], N. Spooner[37], T. Strauss[2], A.M. Szelc[25,45], C.E. Taylor[24], K. Terao[9], M. Thiesse[37], L. Thompson[37], M. Thomson[4], C. Thorn[3], M. Toups[26], C. Touramanis[23], R.G. Van De Water[24], M. Weber[2], D. Whittington[14], T. Wongjirad[26], B. Yu[3], G.P. Zeller[10], and J. Zennamo[7]

The MicroBooNE Collaboration

R. Acciarri[10], C. Adams[45], R. An[13], A. Ankowski[41], J. Asaadi[40], L. Bagby[10], B. Baller[10], G. Barr[30], M. Bass[30], M. Bishai[3], A. Blake[4], T. Bolton[21], C. Bromberg[27], L. Bugel[26], L. Camilleri[9], D. Caratelli[9], B. Carls[10], F. Cavanna[a,10], H. Chen[3], E. Church[10], G.H. Collin[26], J.M. Conrad[26], M. Convery[39], S. Dytmam[34], B. Eberly[39], A. Ereditato[2], J. Esquivel[40], B.T. Fleming*[45], W.M. Foreman[7], V. Genty[9], D. Göldi[2], S. Gollapinni[21], M. Graham[39], E. Gramellini[45], H. Greenlee[10], R. Grosso[8], R. Guenette[30], A. Hackenburg[45], O. Hen[26], J. Hewes[25], J. Ho[7], G. Horton-Smith[21], C. James[10], C.M. Jen[41], R.A. Johnson[8], B.J.P. Jones[26], J. Joshi[3], H. Jostlein[10], D. Kaleko[9], L. Kalousis[41], G. Karagiorgi[25], W. Ketchum[24], B. Kirby[3], M. Kirby[10], T. Kobilarcik[10], I. Kreslo[2], Y. Li[3], B. Littlejohn[13], D. Lissauer[3], S. Lockwitz[10], W.C. Louis[24], M. Lu□thi[2], B. Lundberg[10], A. Marchionni[10], C. Mariani[41], J. Marshall[4], K. McDonald[35], V. Meddage[21], T. Miceli[28], G.B. Mills[24], J. Moon[26], M. Mooney[3], M.H. Moulai[26], R. Murrells[25], D. Naples[34], P. Nienaber[36], O. Palamara[b,10], V. Paolone[34], V. Papavassiliou[28], S. Pate[28], Z. Pavlovic[10], S. Pordes[10], G. Pulliam[40], X. Qian[3], J.L. Raaf[10], V. Radeka[3], R. Rameika[10], B. Rebel[10], L. Rochester[39], C. Rudolf von Rohr[2], B. Russell[45], D.W. Schmitz[7], A. Schukraft[10], W. Seligman[9], M. Shaevitz[9], M. Soderberg[40], J. Spitz[26], J. St. John[8], T. Strauss[2], A.M. Szelc[25,45], N. Tagg[29], K. Terao[9], M. Thomson[4], C. Thorn[3], M. Toups[26], Y. Tsai[39], T. Usher[39], R. Van de Water[24], M. Weber[2], S. Wolbers[10], T. Wongjirad[26], K. Woodruff[28], M. Xu[13], T. Yang[10], B. Yu[3], G.P. Zeller*[10], J. Zennamo[7], and C. Zhang[3]

Additional Fermilab Contributors

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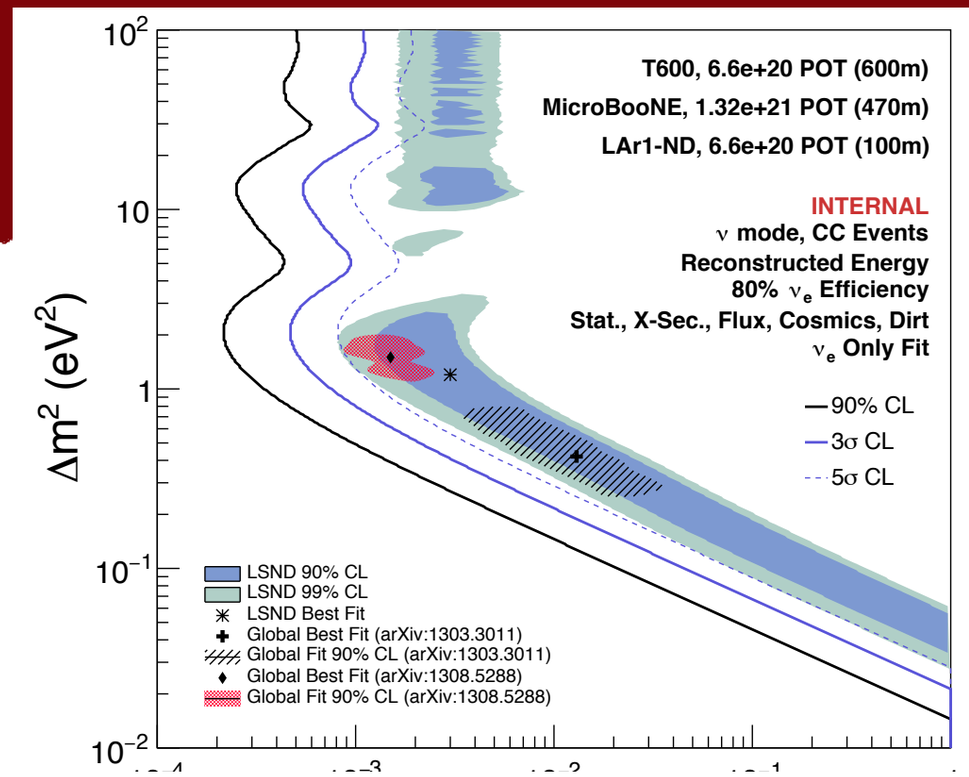
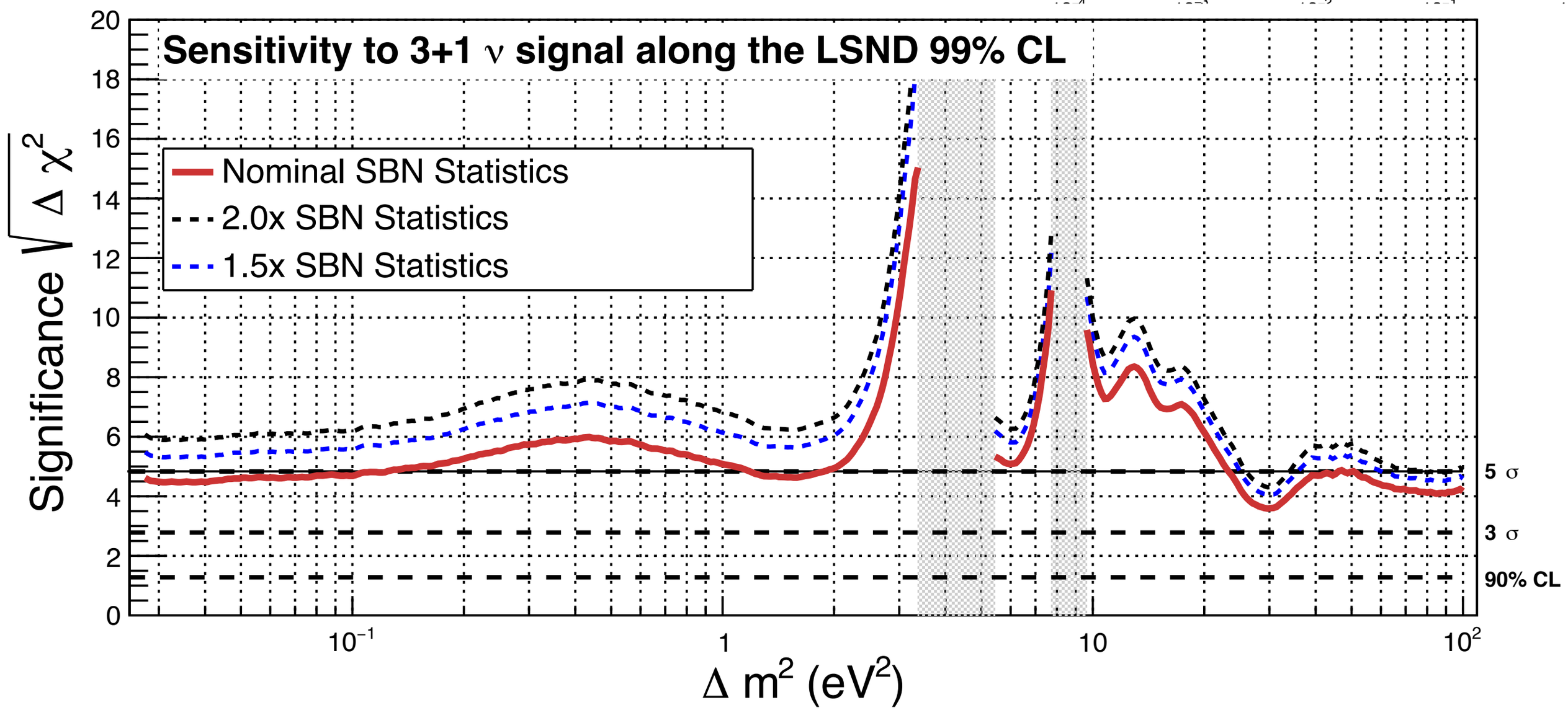
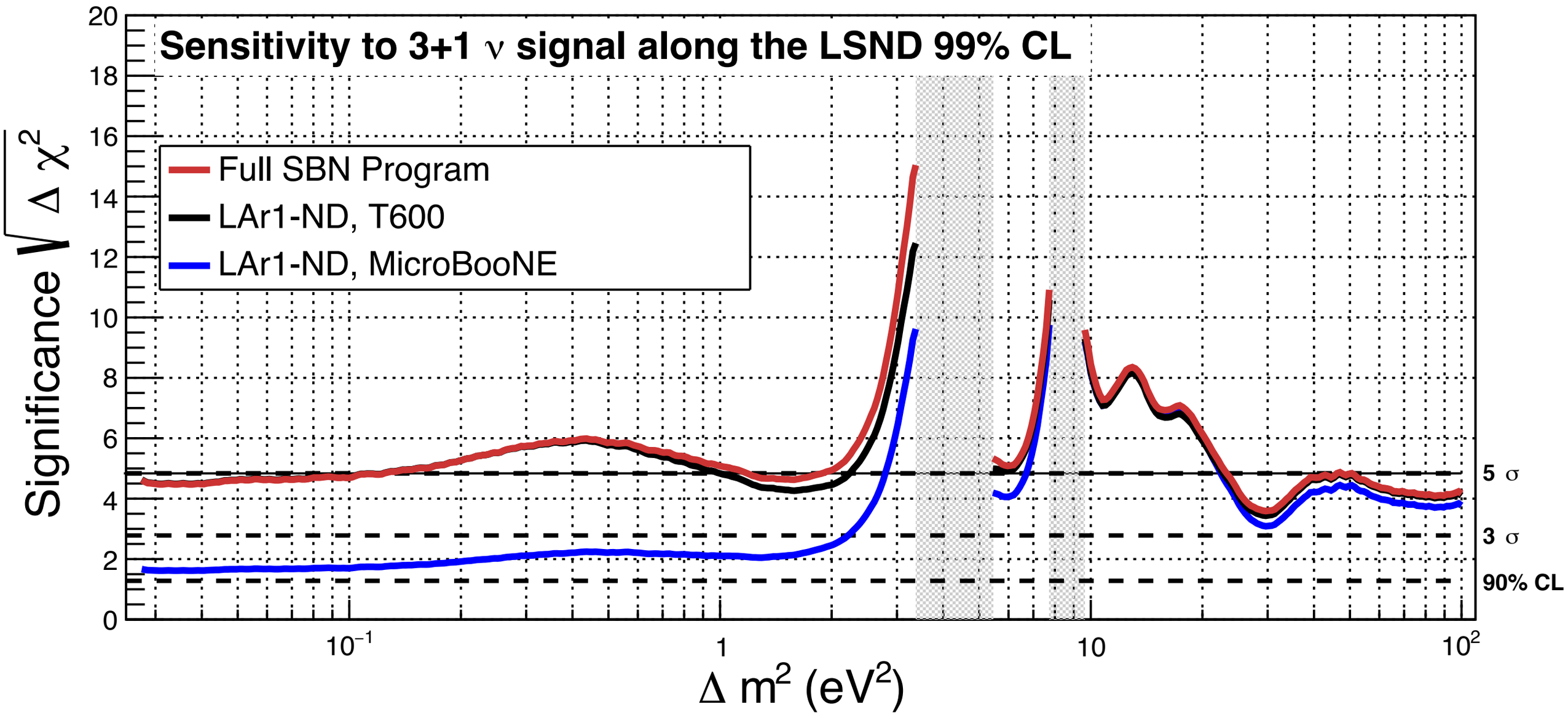
Backups

Effect of More Statistics





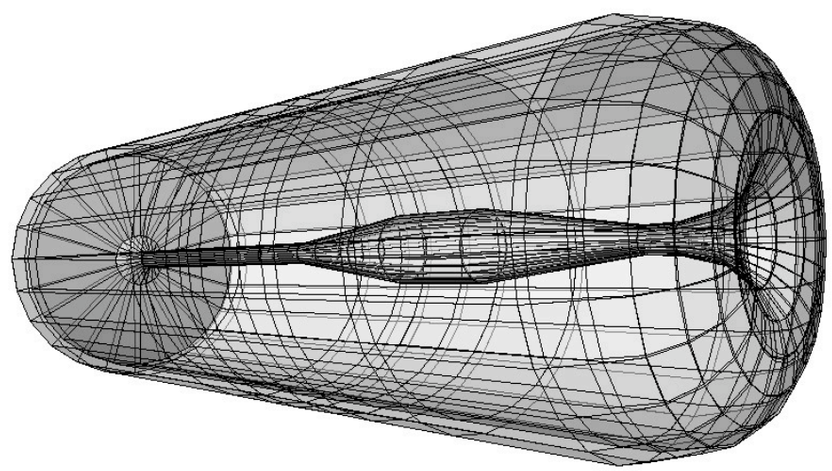
SBN Detectors

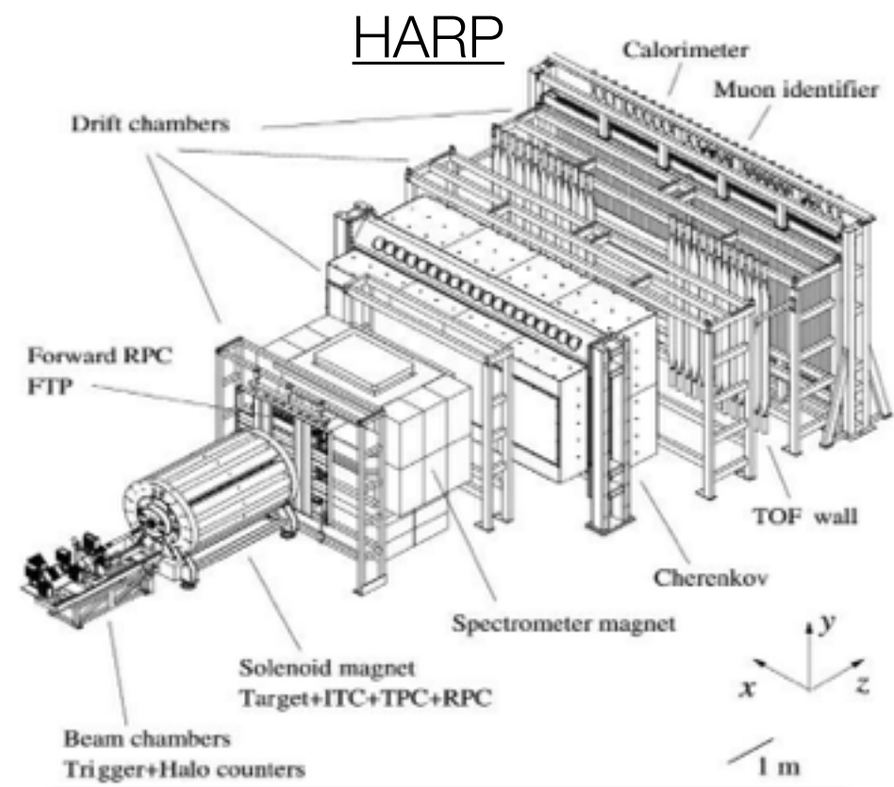


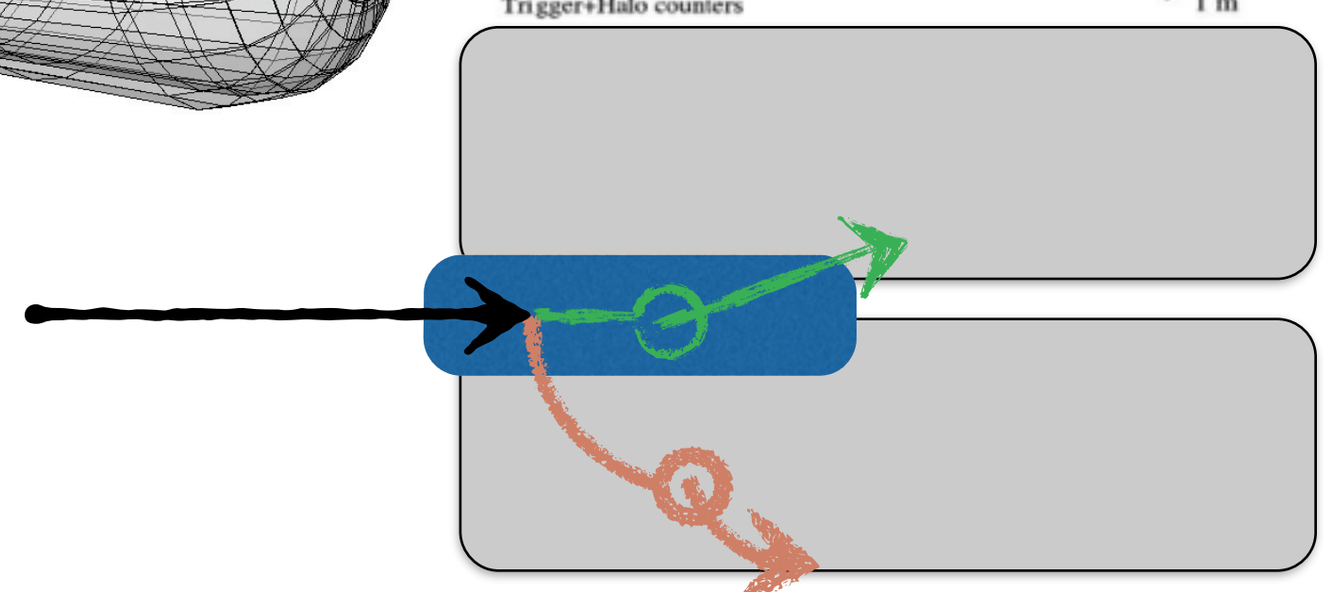
Systematics

Systematic Uncertainties: Neutrino Flux

- Hadron Production
  - Charged Pions
  - Kaons
- Beam Focusing
  - Current
  - Skin Effects
- Secondary Interactions
  - Within the target and horn

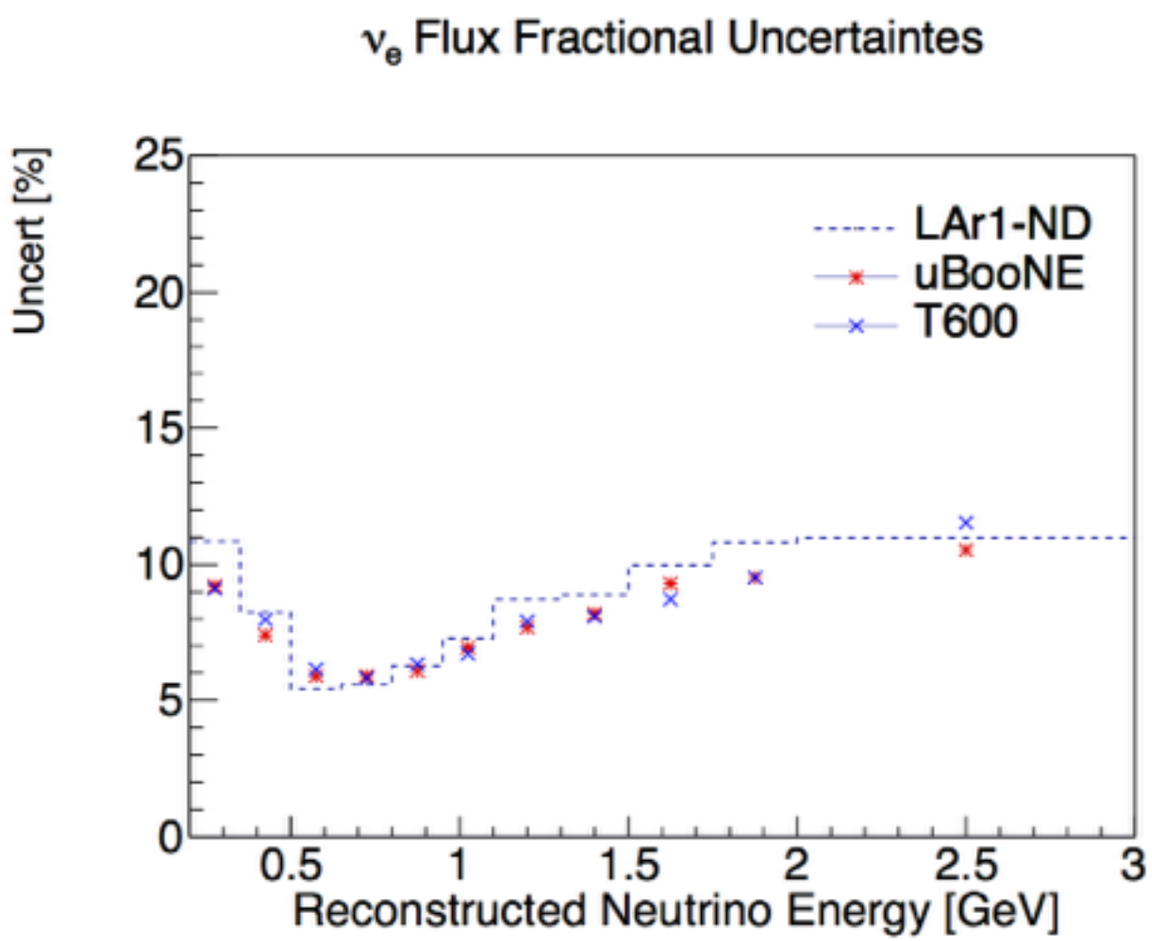


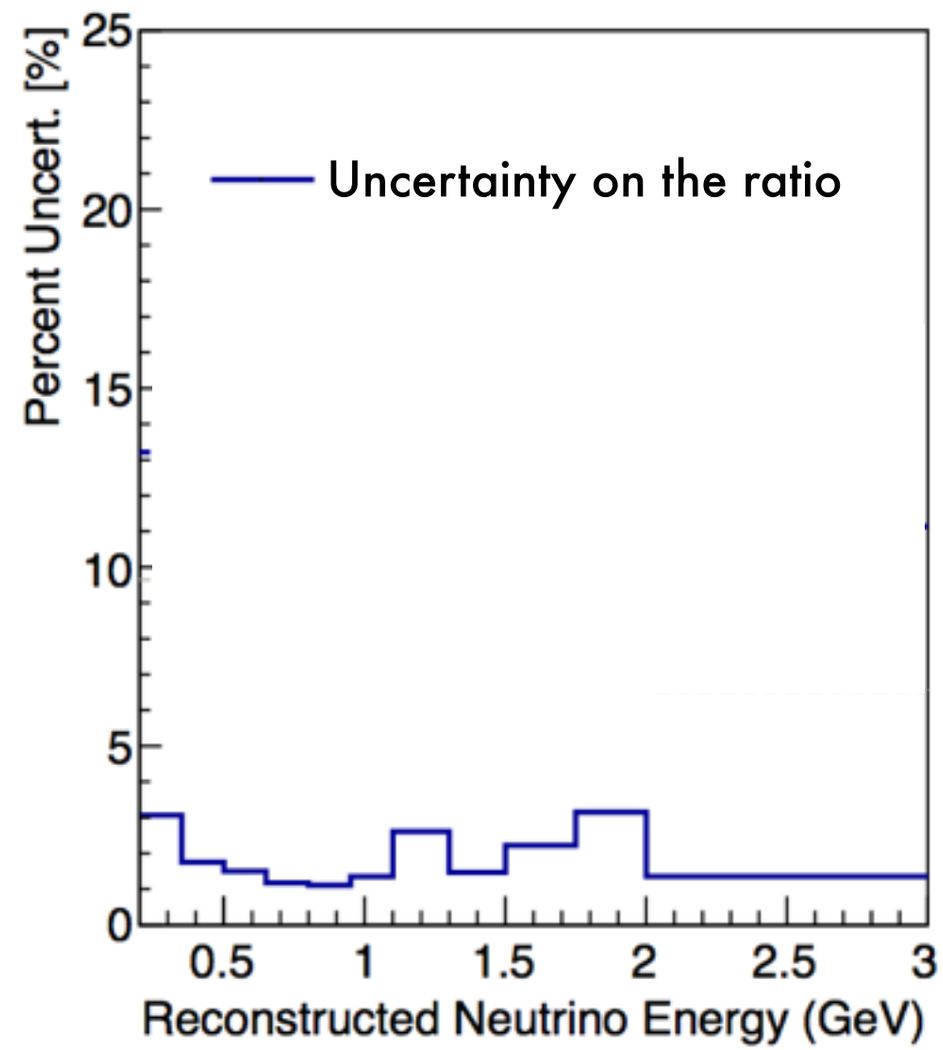




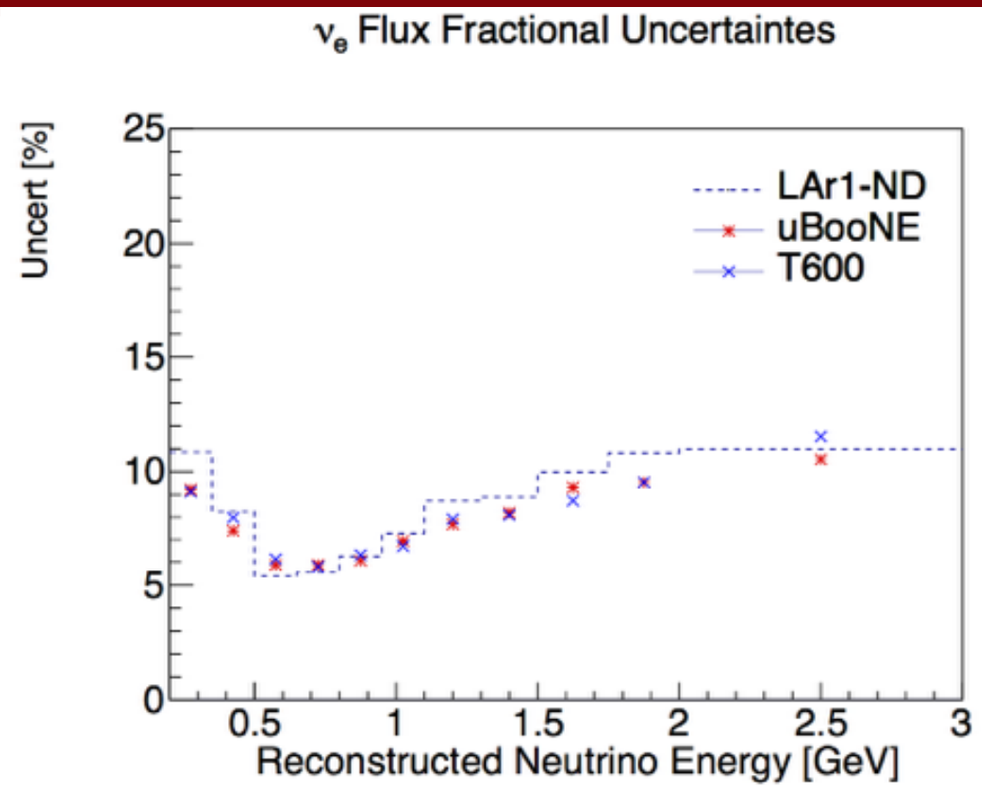
Systematics

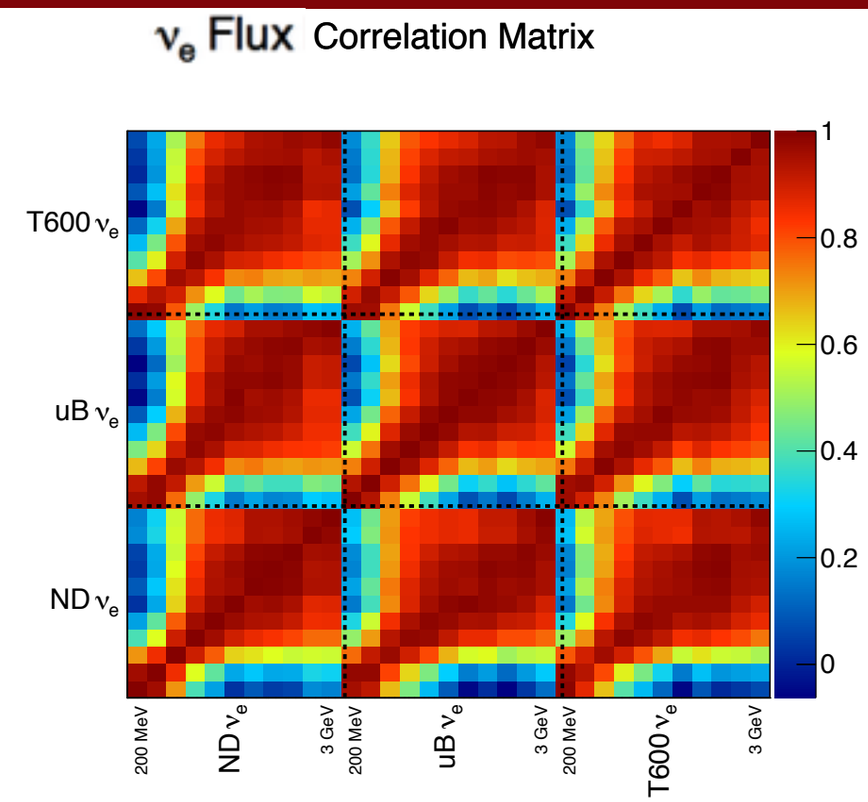
Systematic Uncertainties: Neutrino Flux

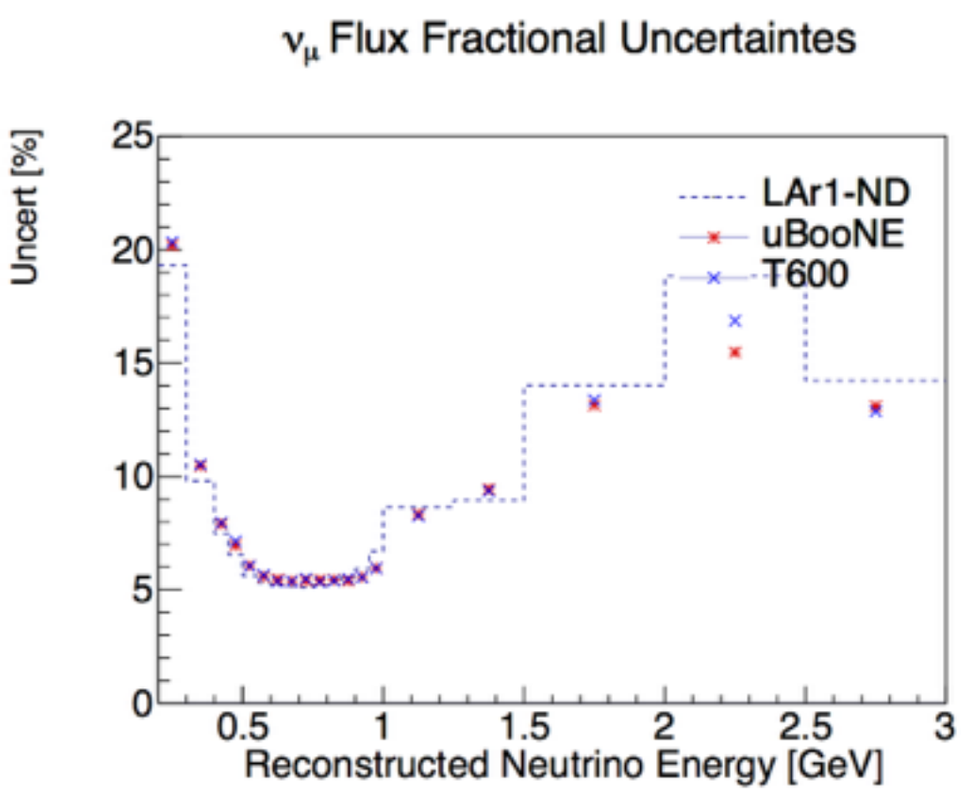


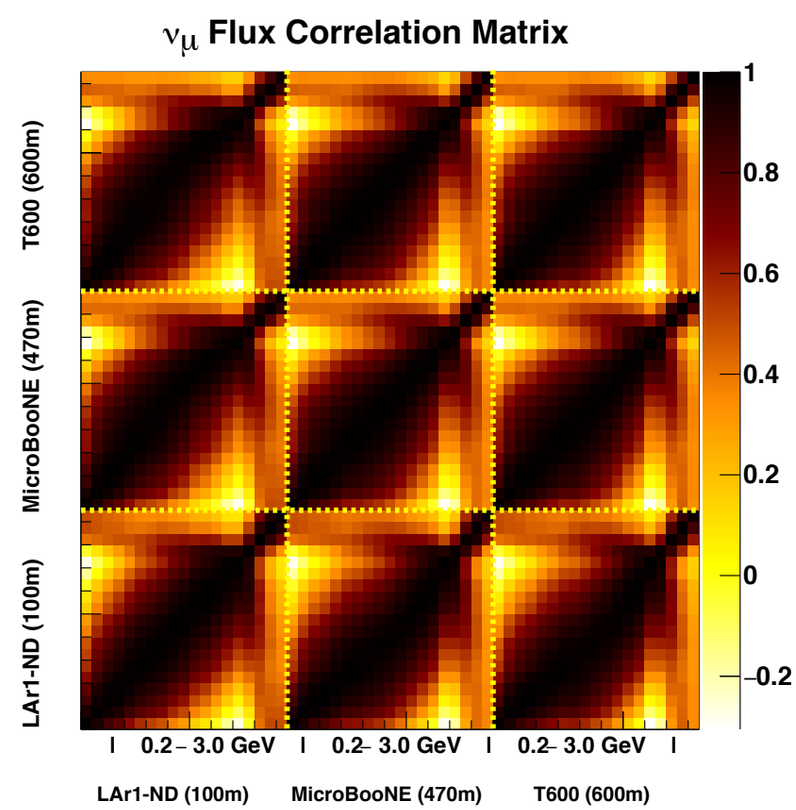


Systematics





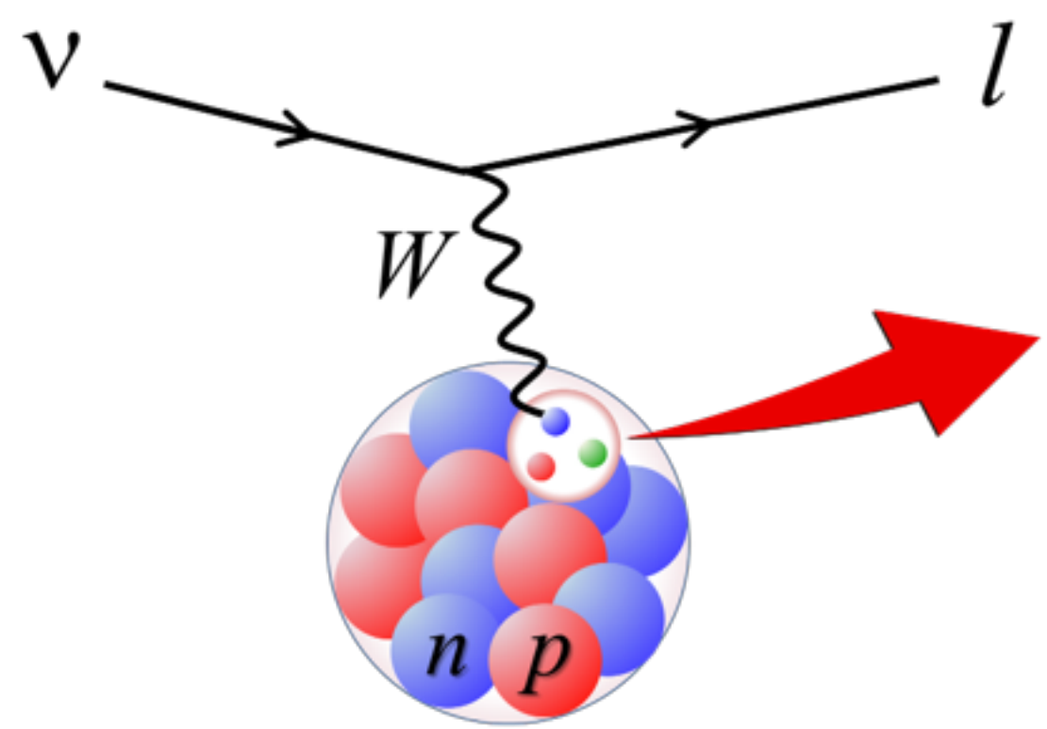




Systematics

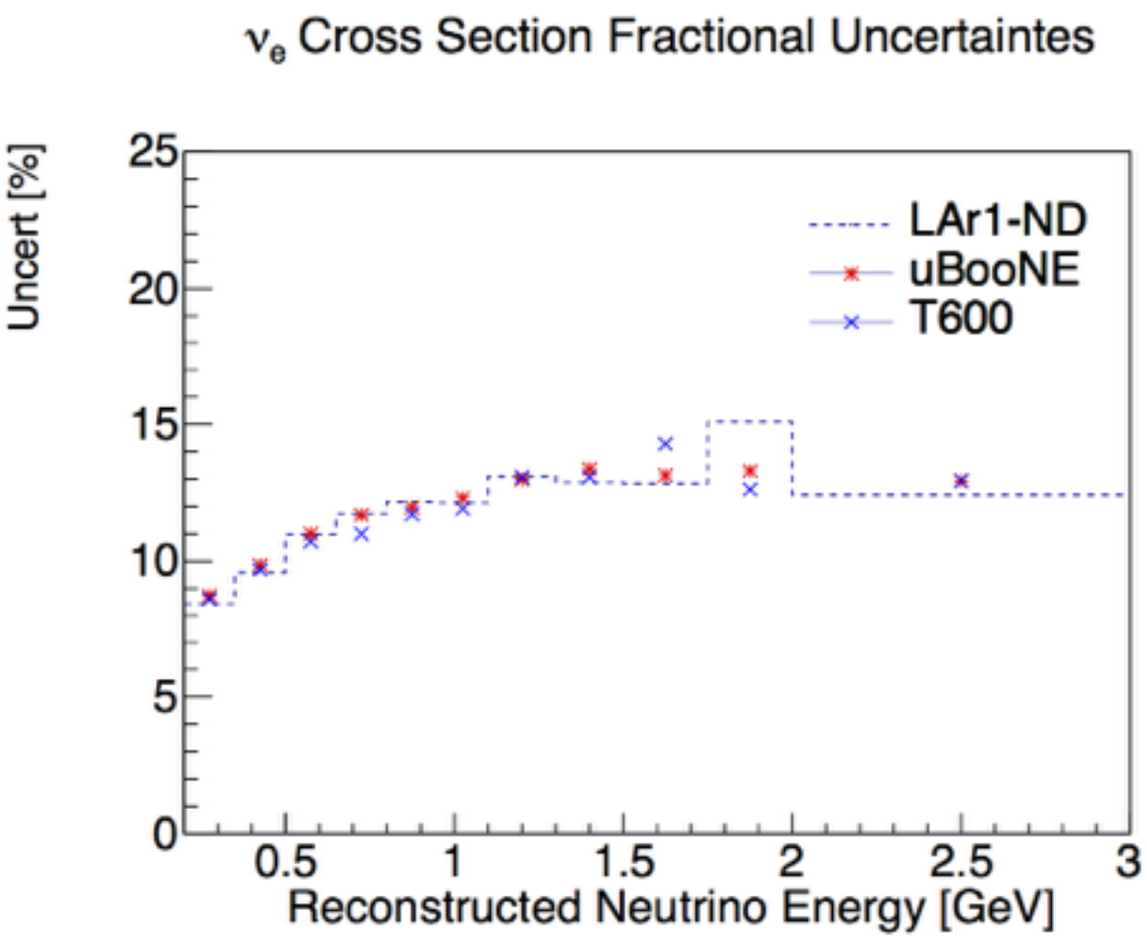
Systematic Uncertainties: ν -Argon Cross Sections

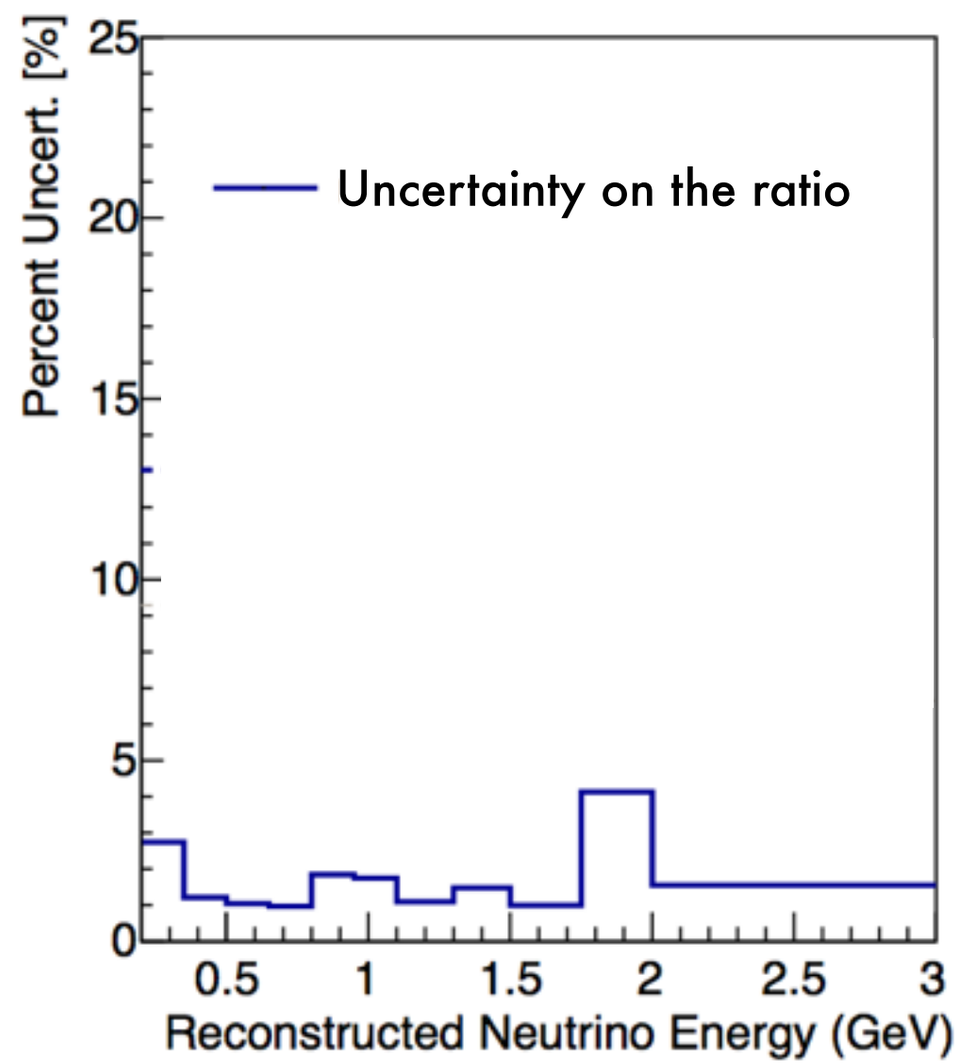
The three detectors use the same target nucleus but differences in the flux, detector acceptances, and other effects can lead to a different composition of event types which can lead to systematic differences between the detectors



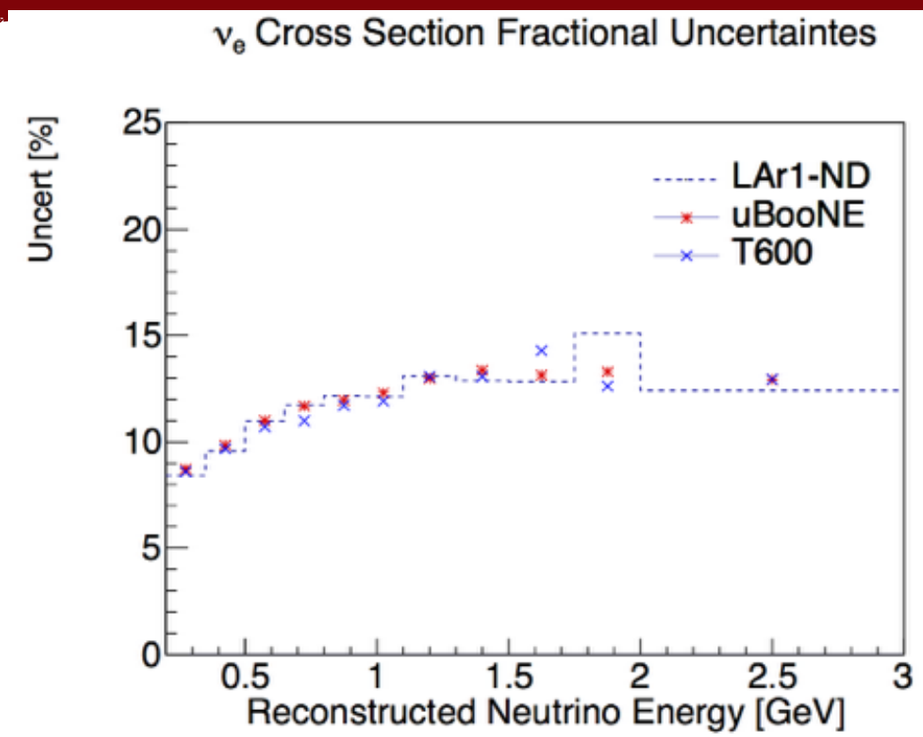
Systematics

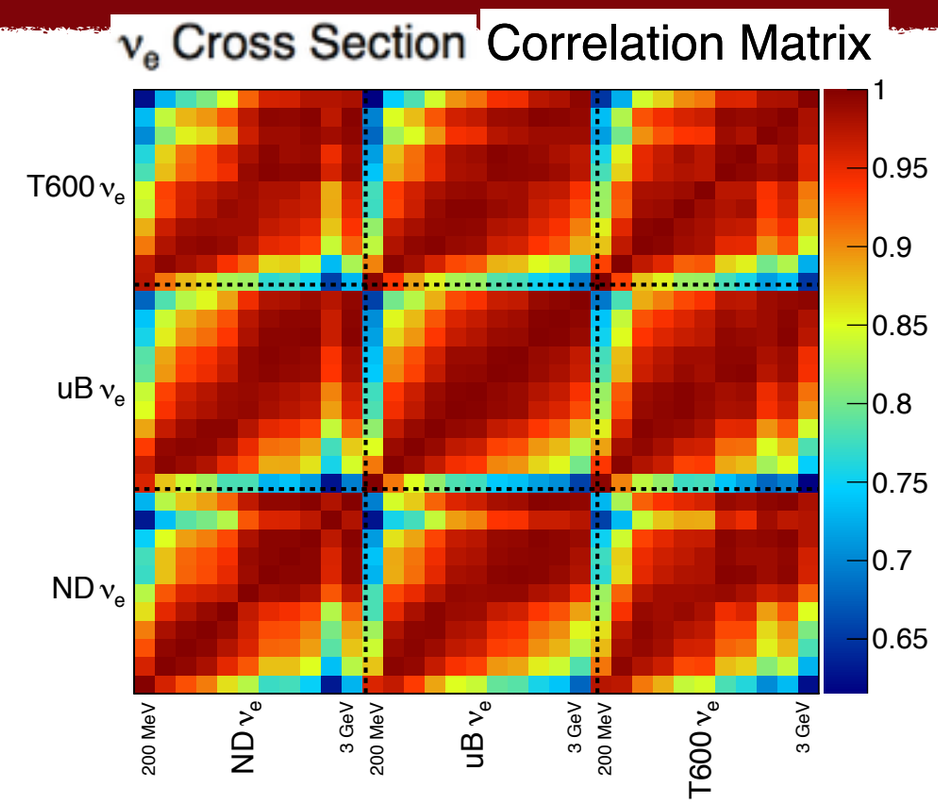
Systematic Uncertainties: ν -Argon Cross Sections

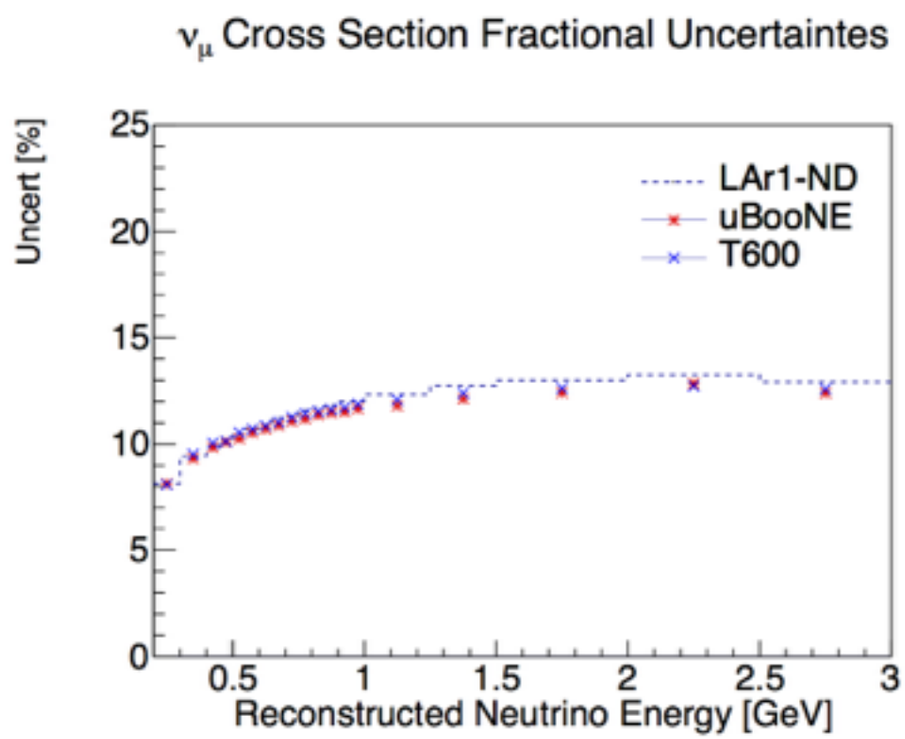


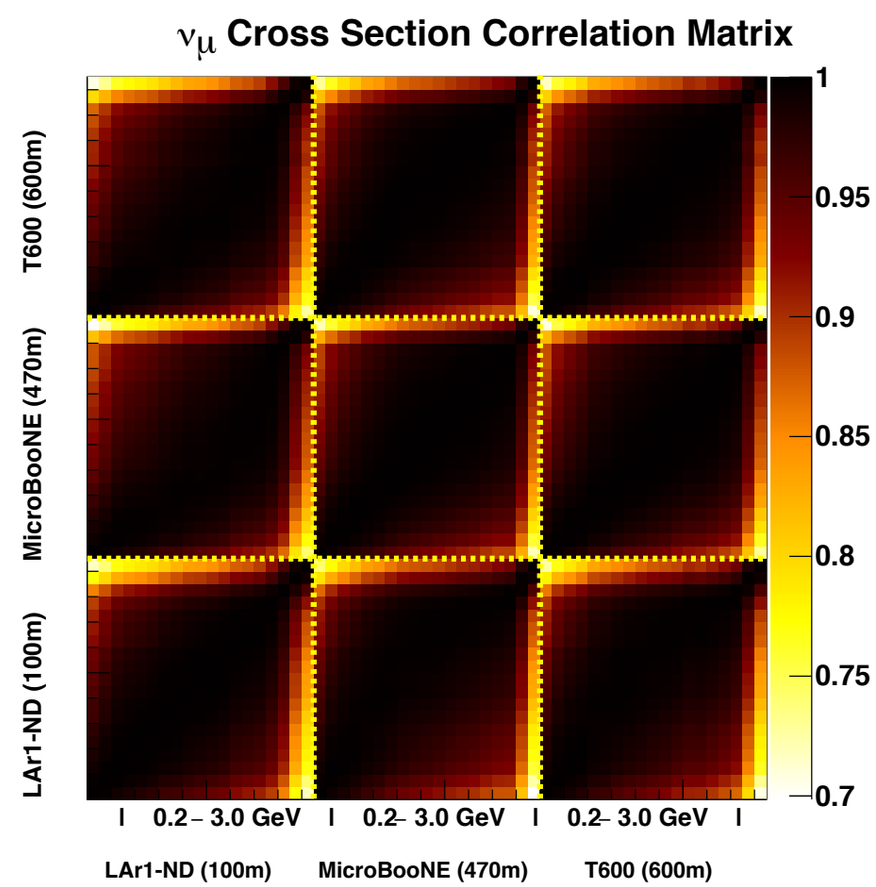


Systematics



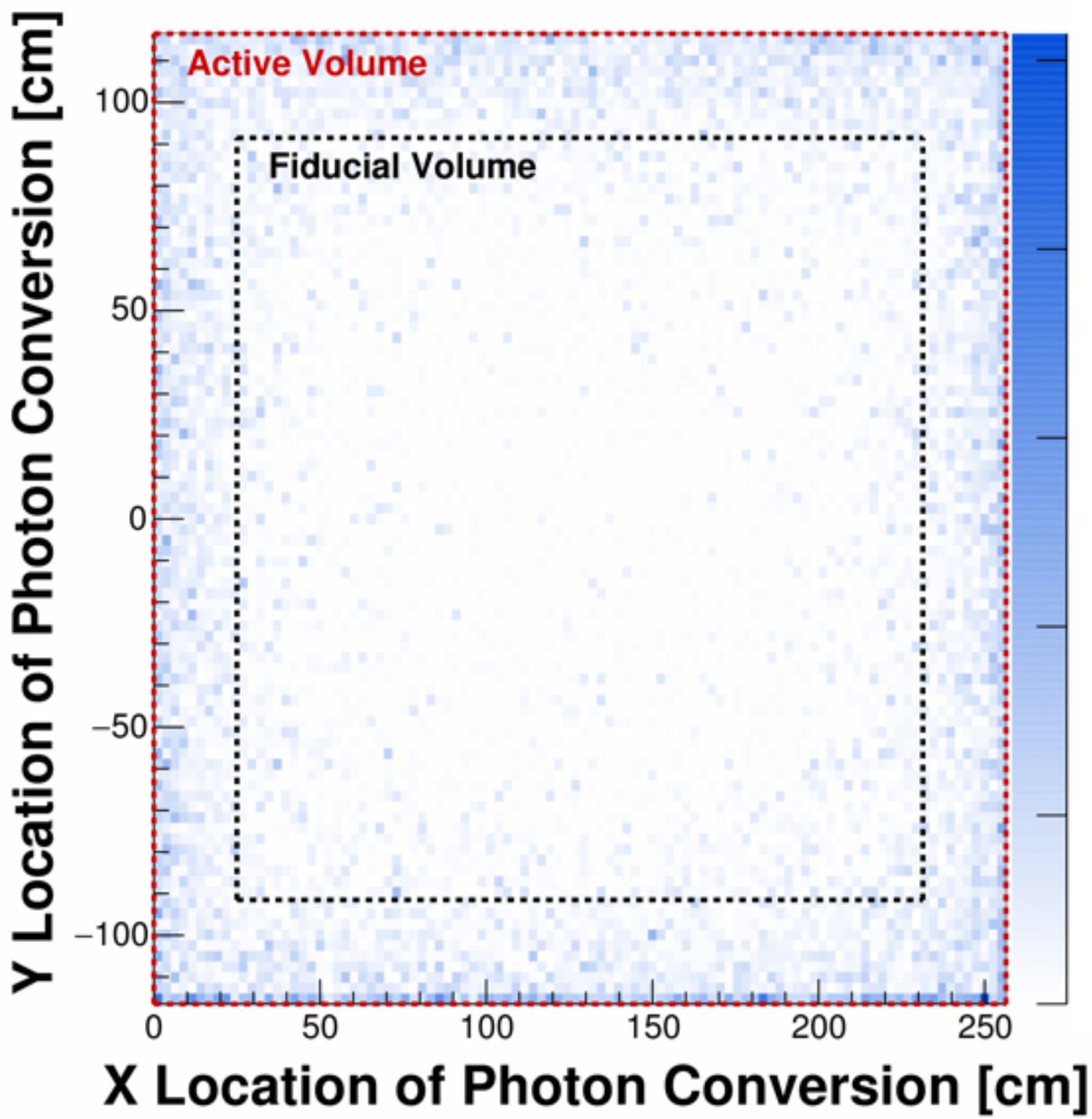






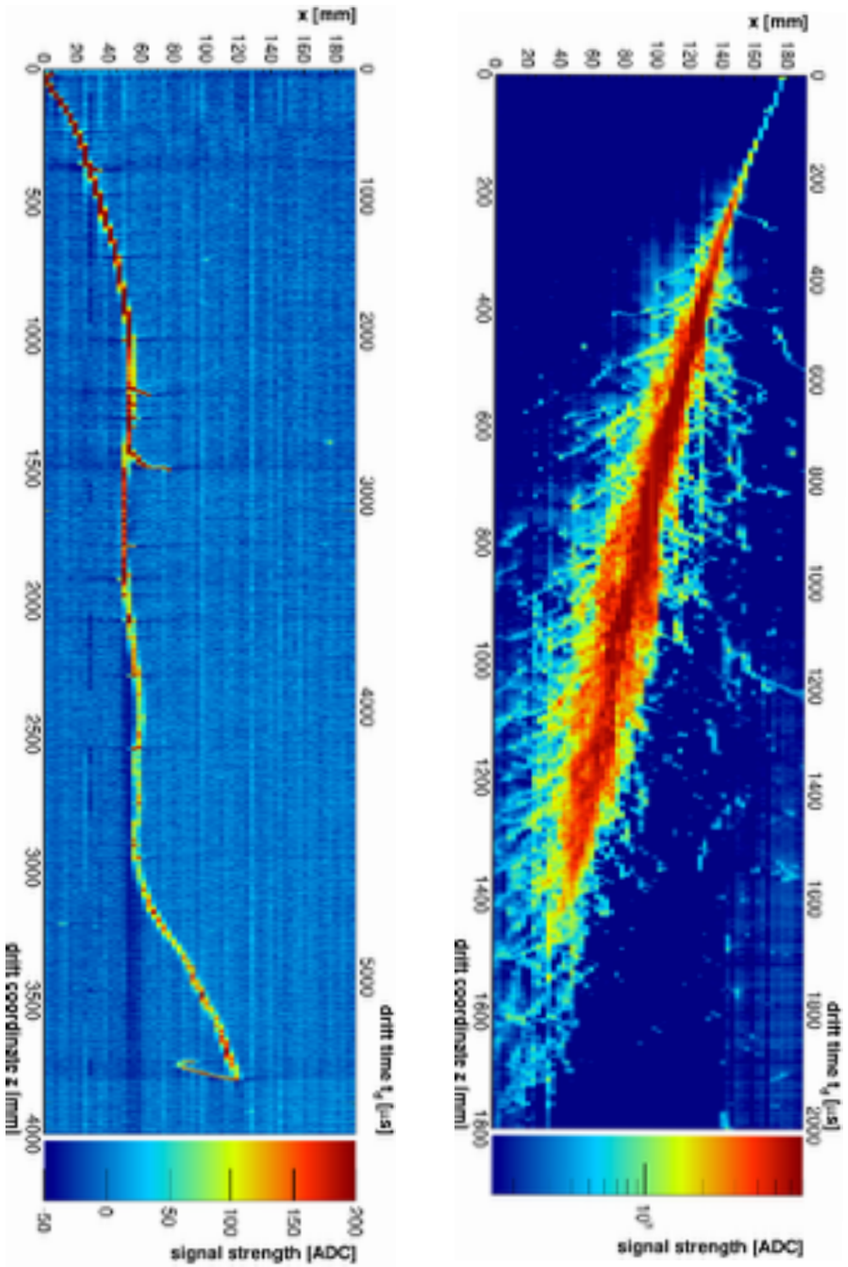
Systematics

Systematic Uncertainties: "Dirt" Background



Systematics

Systematic Uncertainties: Cosmic Ray Background

- One positive aspect of cosmic induced background is that we can measure it directly with arbitrarily high precision
- Using off beam random triggers we will be able to build a large sample of cosmic events
    - The systematic uncertainty on this background becomes the statistical uncertainty of those measurements

ArgonTube Cosmic Ray Events