Impact of flux uncertainties for SBND

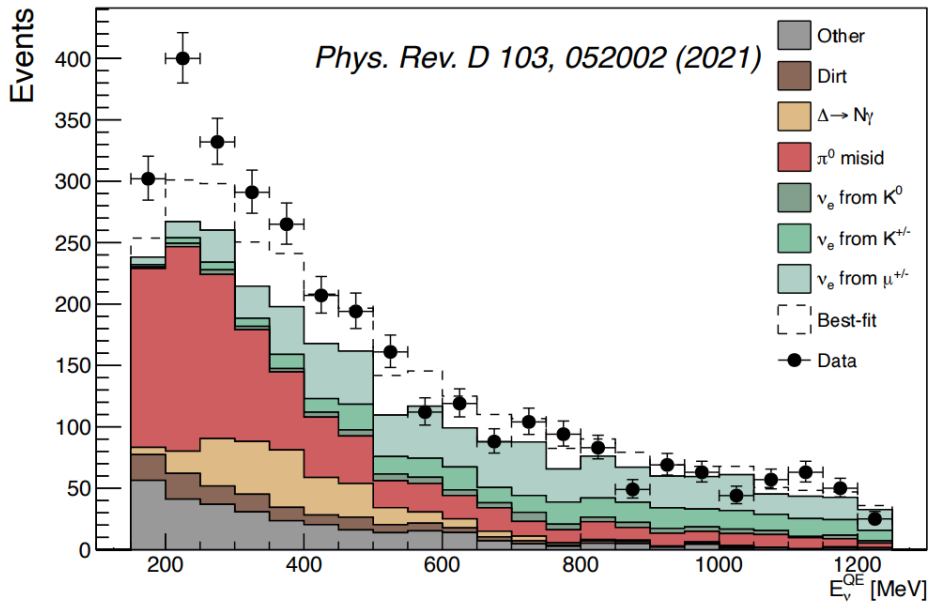
Andrew Furmanski

NA61/SHINE workshop

16th December 2022

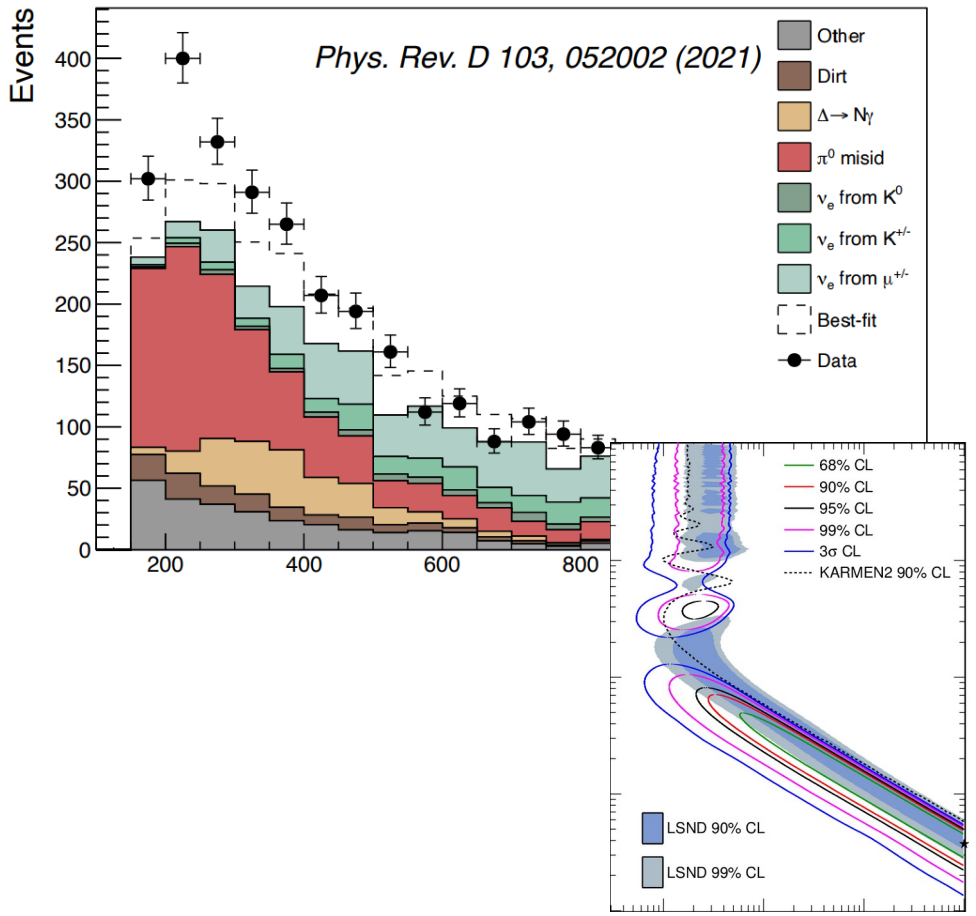
Short Baseline Oscillations

- Excess electron-like events at MiniBooNE



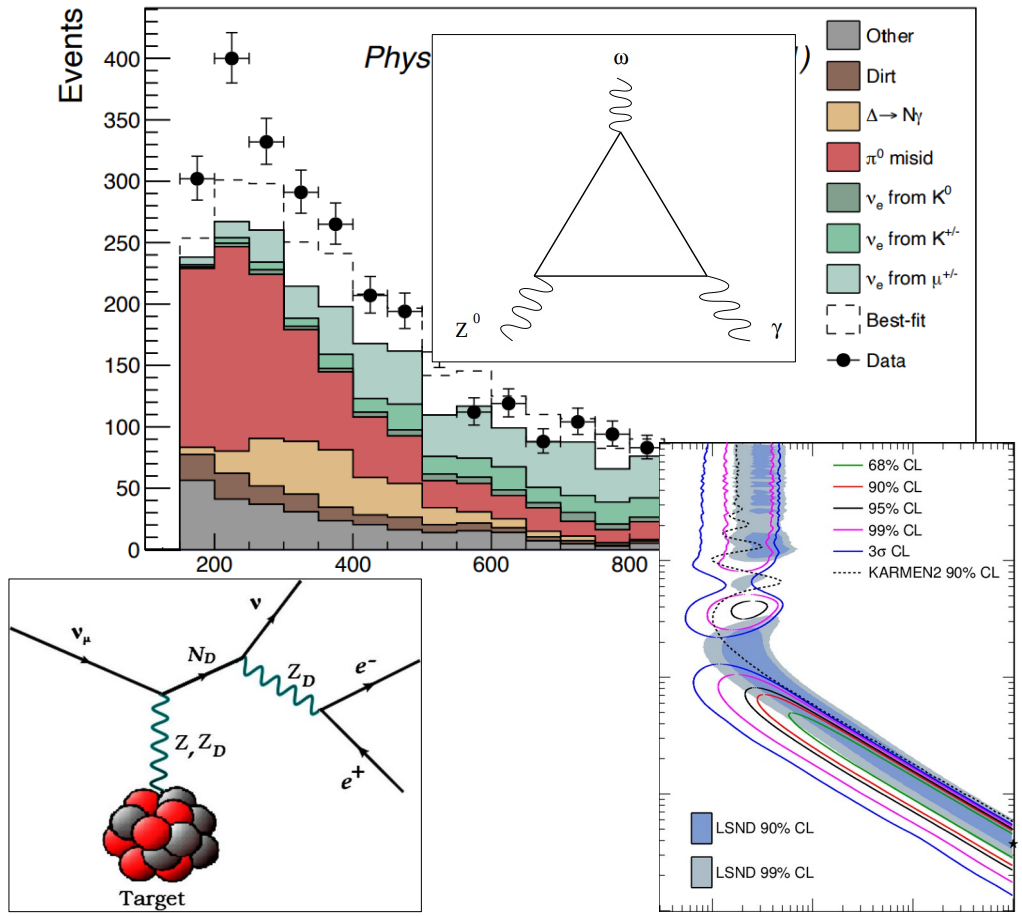
Short Baseline Oscillations

- Excess electron-like events at MiniBooNE
- Interpret as oscillations
  - Leads to ~eV scale neutrino hypothesis



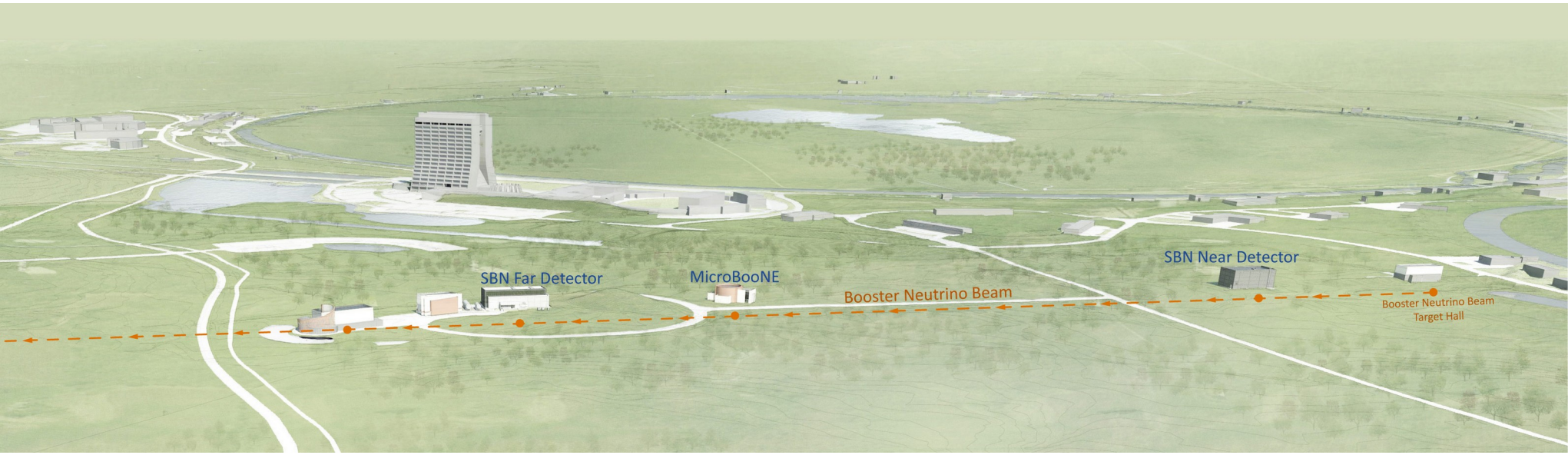
Short Baseline Oscillations

- Excess electron-like events at MiniBooNE
- Interpret as oscillations
  - Leads to ~eV scale neutrino hypothesis
- Interpret as photons, e^+e^- pairs
  - Huge landscape of options!



SBN

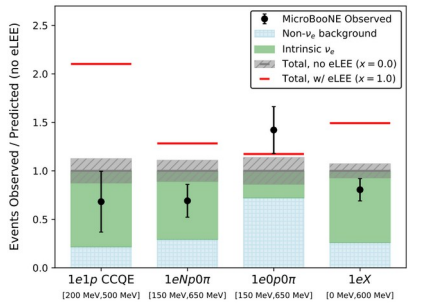
- Three liquid argon TPC neutrino detectors
  - Approx. 1kton total active mass
  - Baselines from 110m to 600m
- World-leading eV-scale oscillation sensitivity



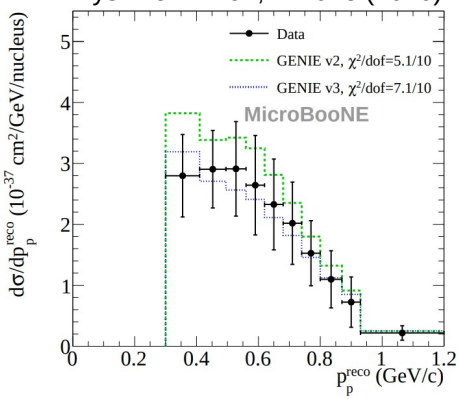
MicroBooNE

- Data run ended last year
- First results limit sterile neutrino parameter space
- Also used for BSM searches
- And a wealth of neutrino-argon interaction measurements

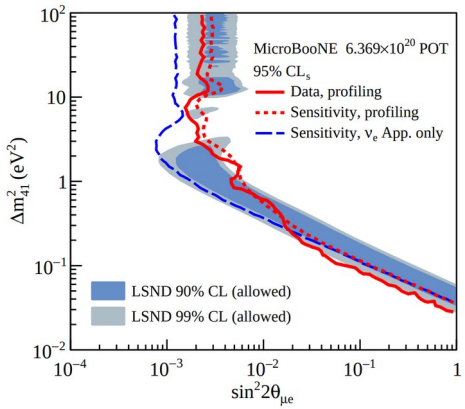
Phys. Rev. Lett. 128, 241801 (2022)

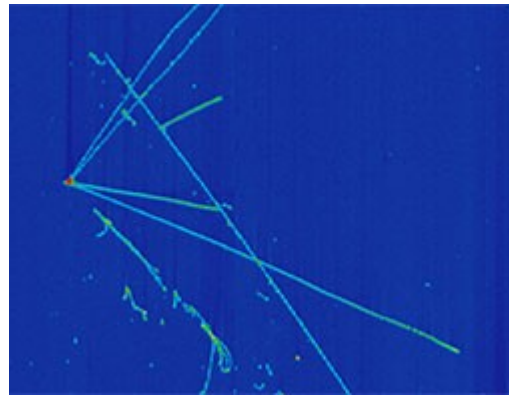


Phys. Rev. D102, 112013 (2020)

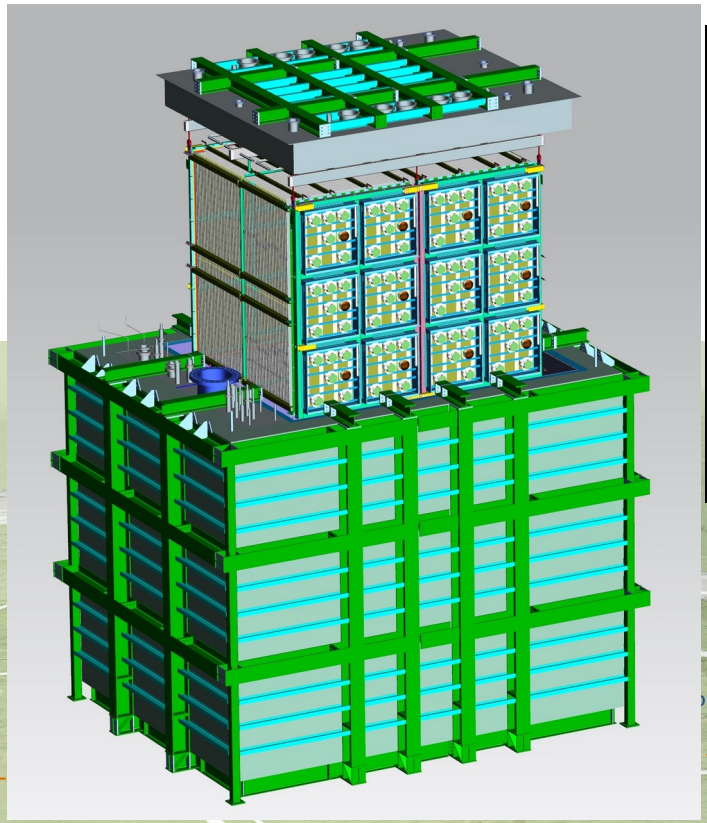


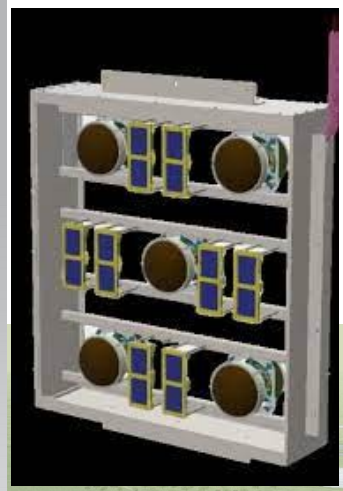
arXiv:2210.10216





SBND

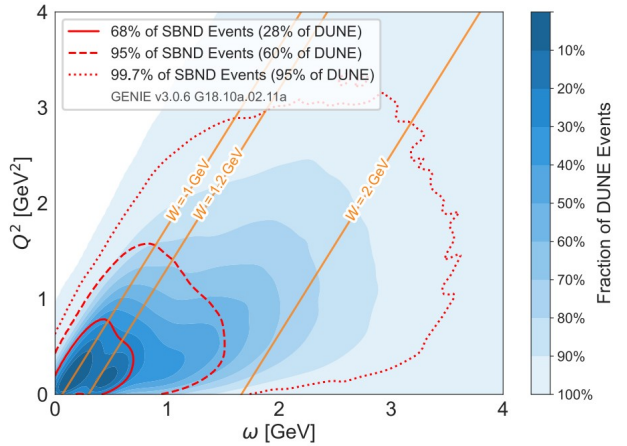




- ~100 ton LAr TPC
- 110m from beam target
- Serves as “near detector” for SBN
- Also a large single-detector physics program
- Significant improvements over MicroBooNE

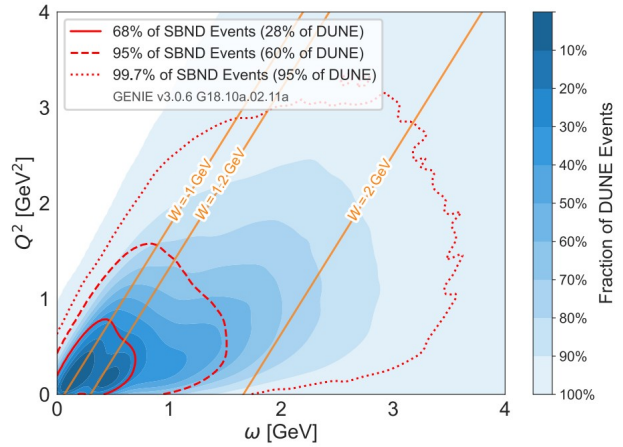
SBND physics program

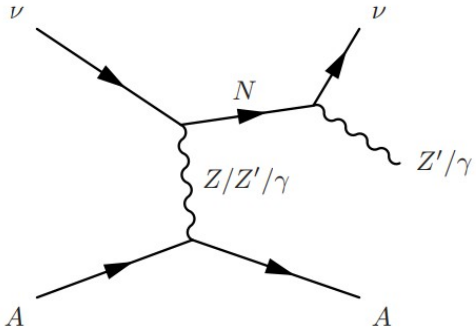
- Neutrino-nucleus interaction measurements

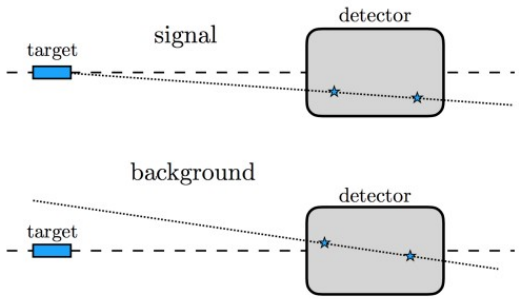


SBND physics program

- Neutrino-nucleus interaction measurements
- BSM physics searches

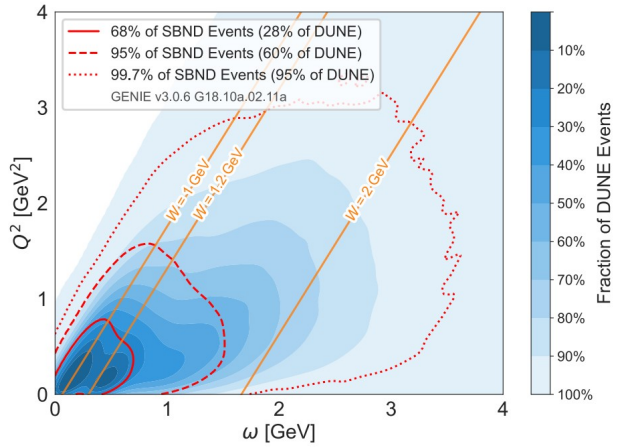


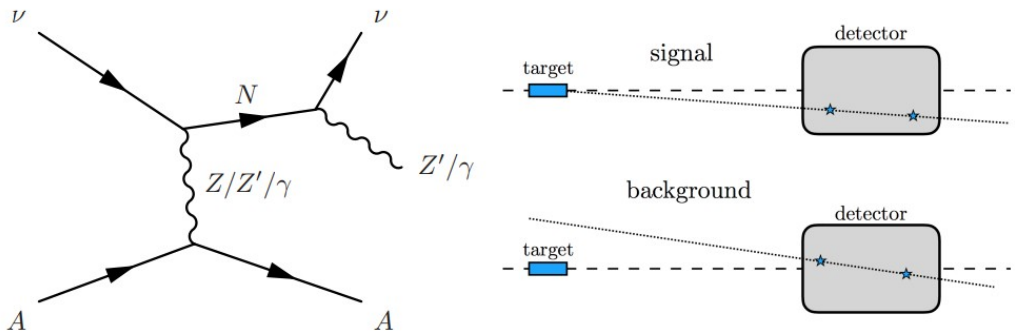


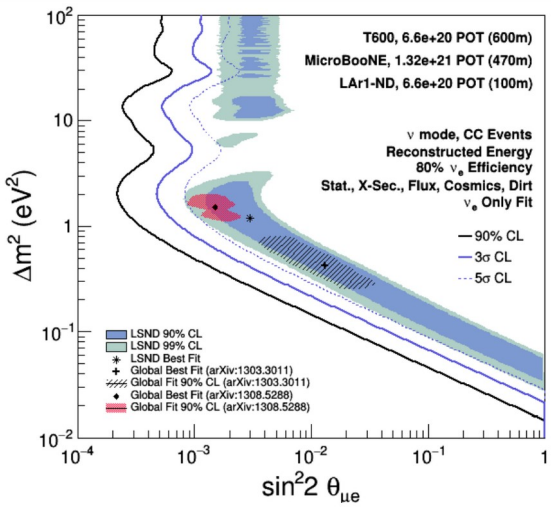


SBND physics program

- Neutrino-nucleus interaction measurements
- BSM physics searches
- Near Detector for SBN oscillation measurements
- And standalone osc searches



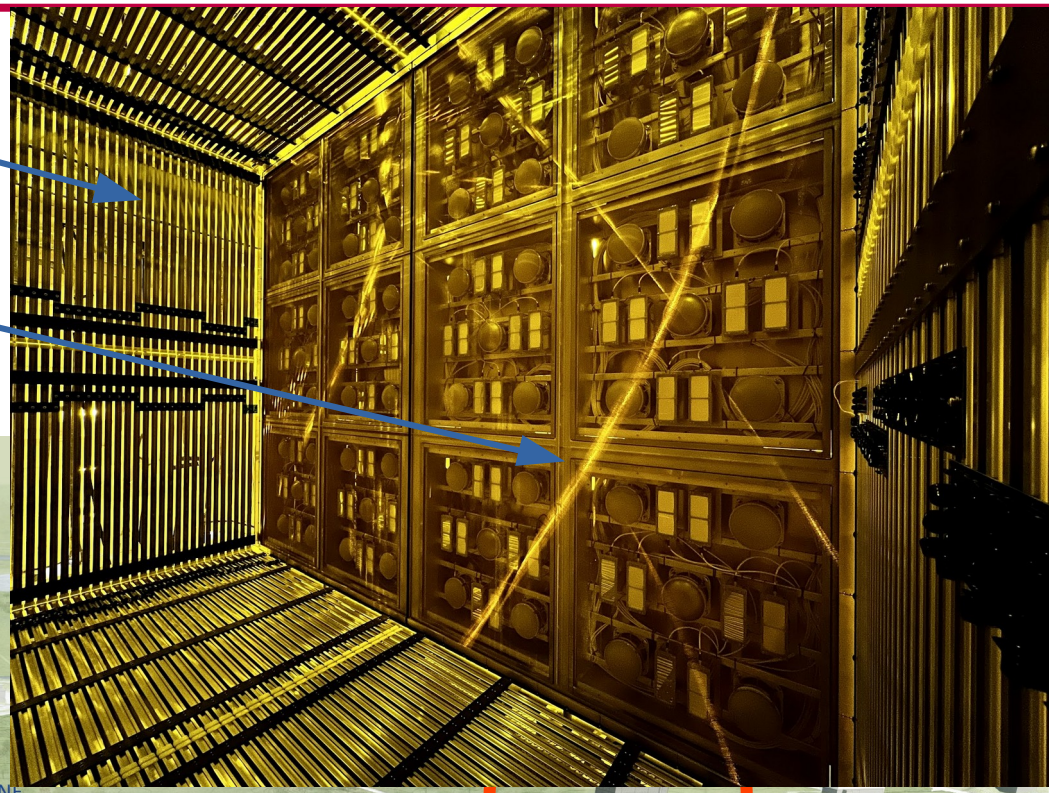


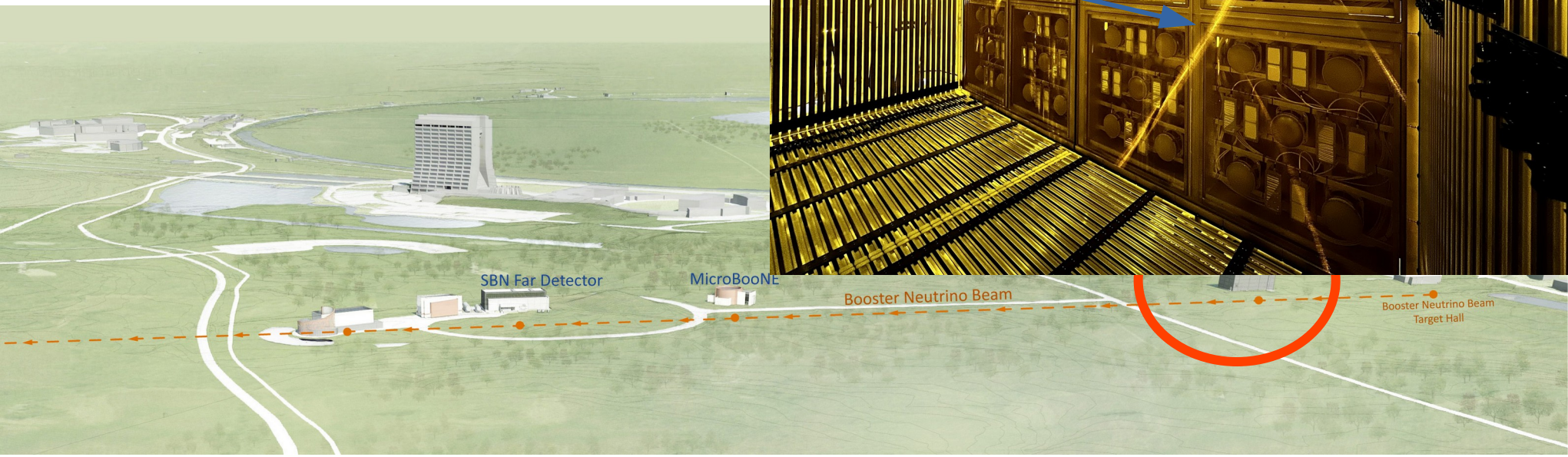


SBND

Two TPCs (one shown)

~10,000 readout wires (few-mm resolution)

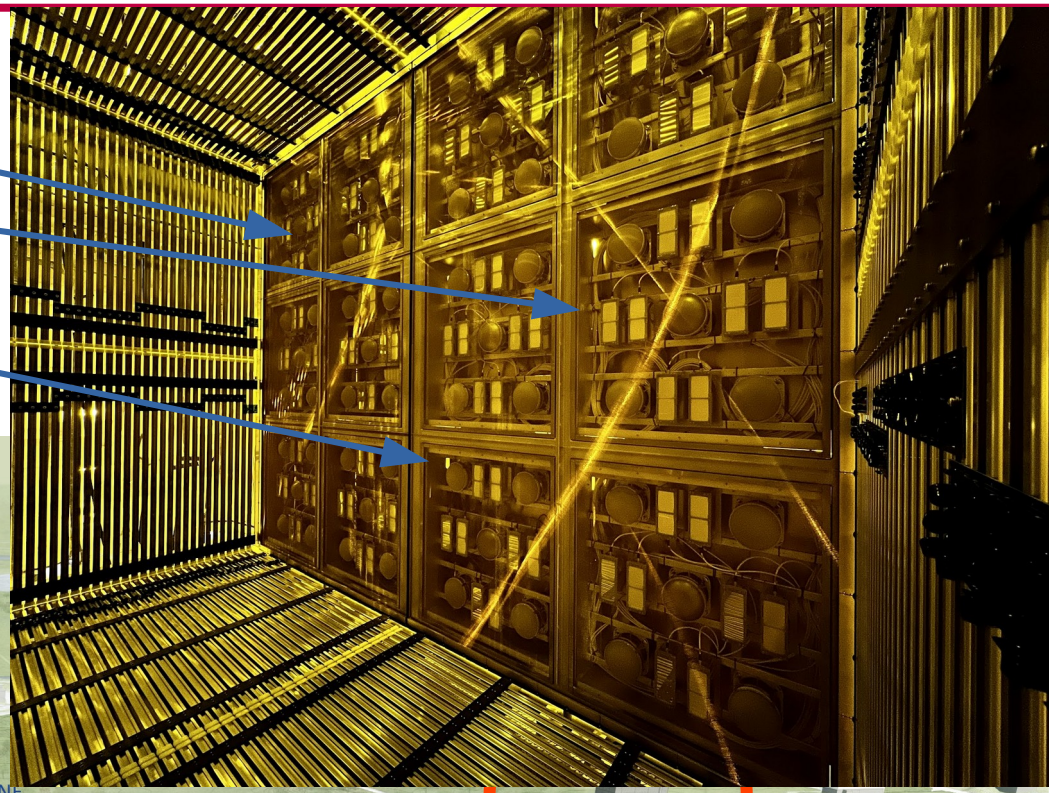


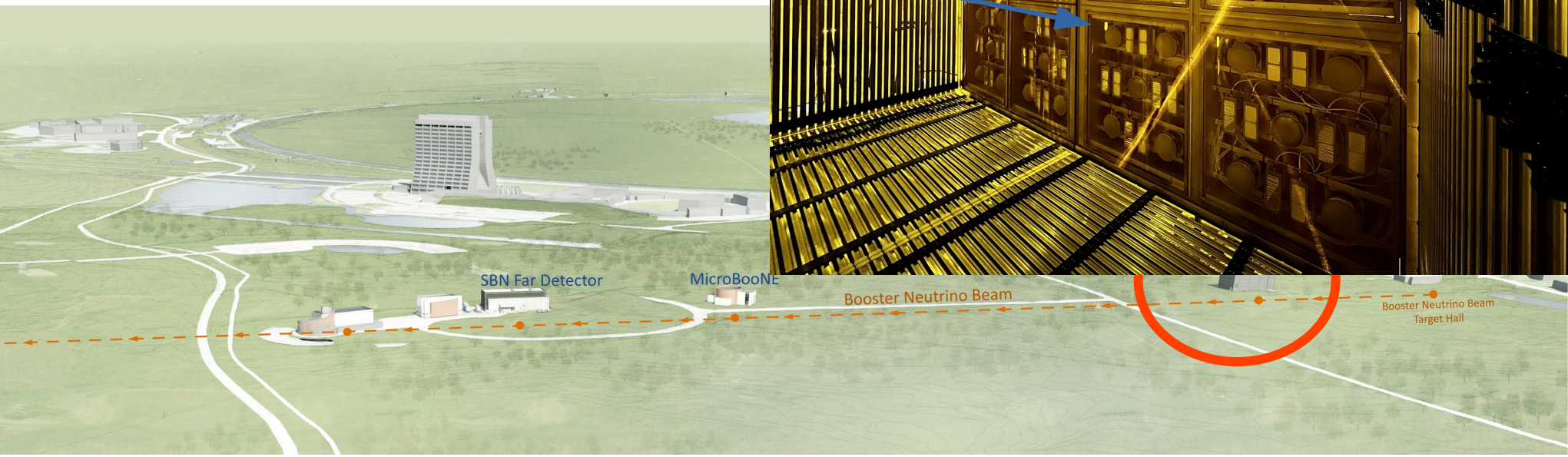


SBND

Large photocoverage

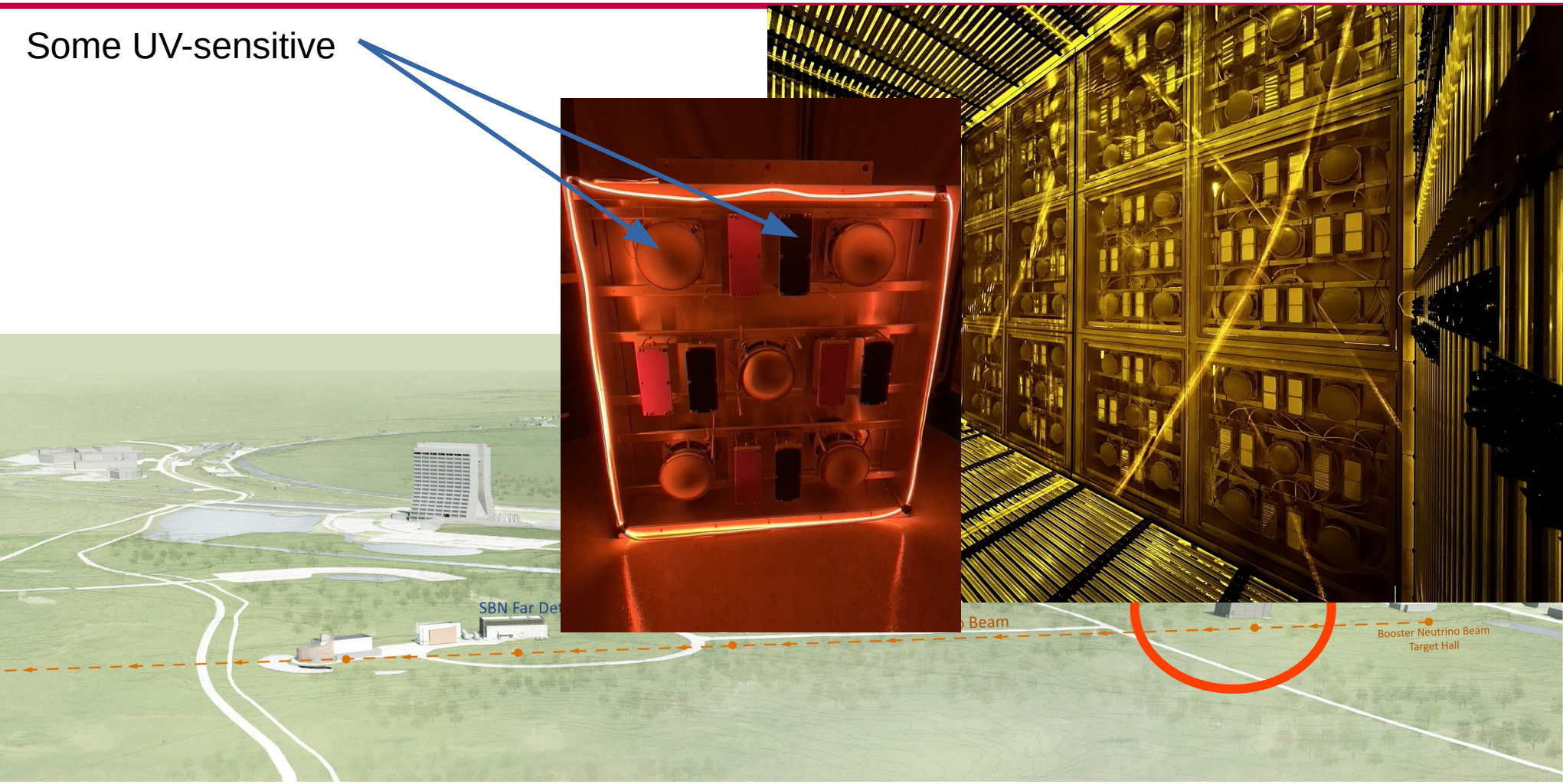
PMTs and X-ARAPUCAs





SBND

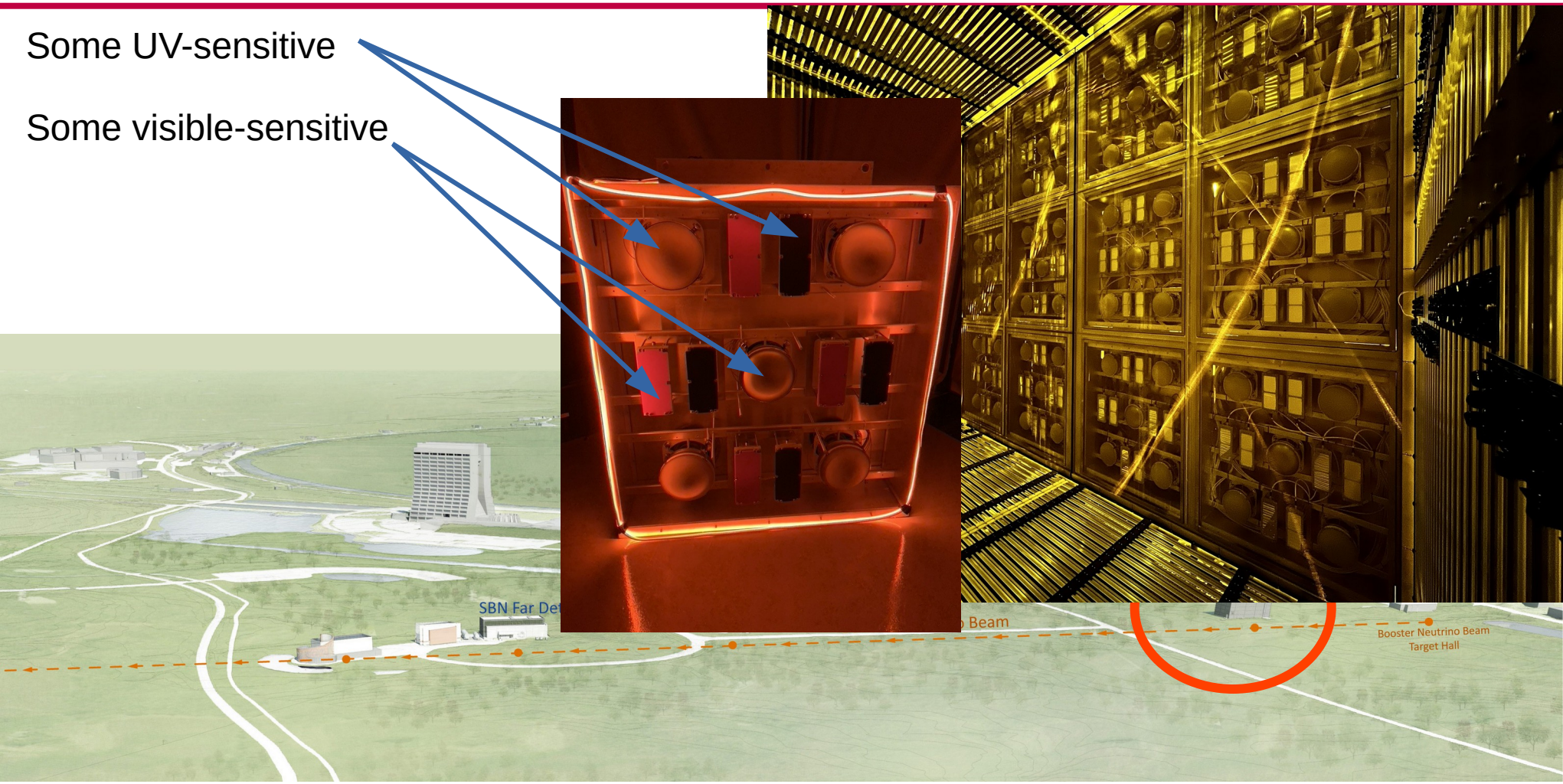
Some UV-sensitive



SBND

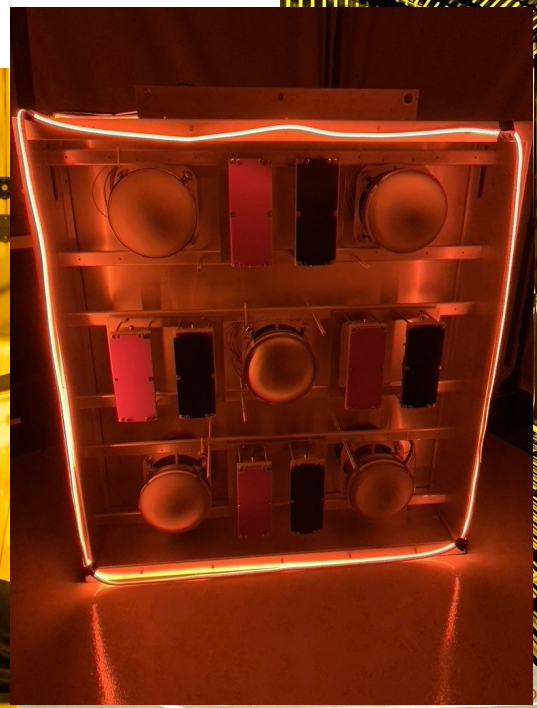
Some UV-sensitive

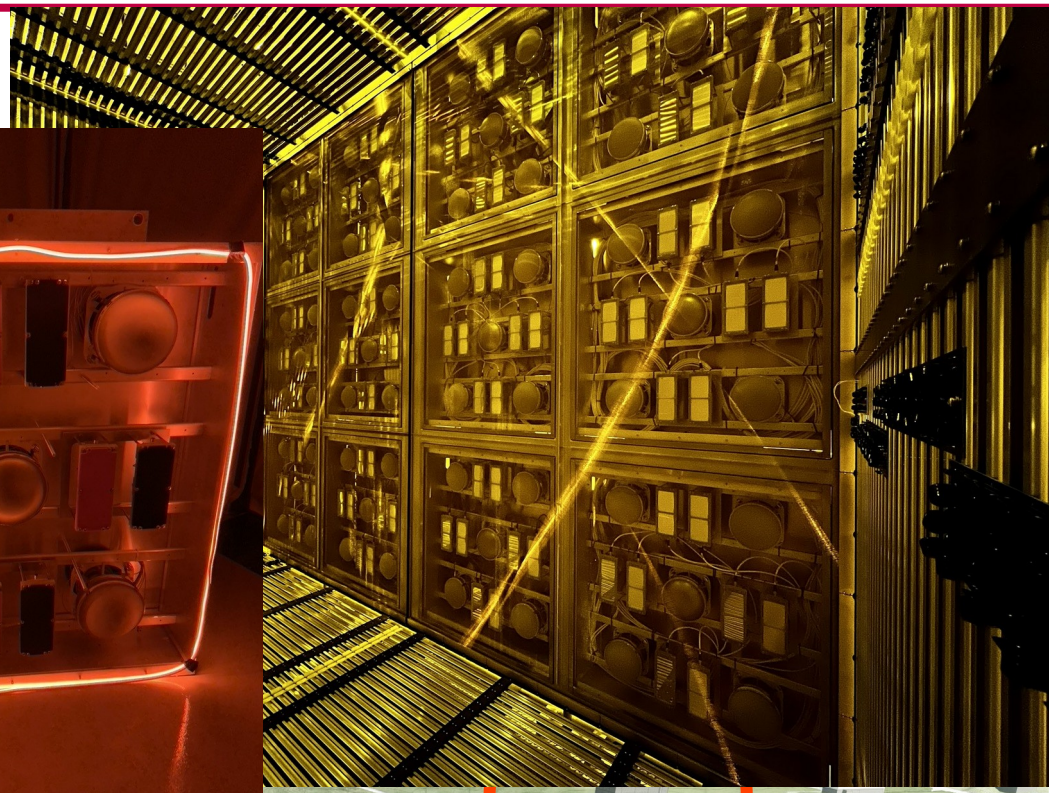
Some visible-sensitive



SBND

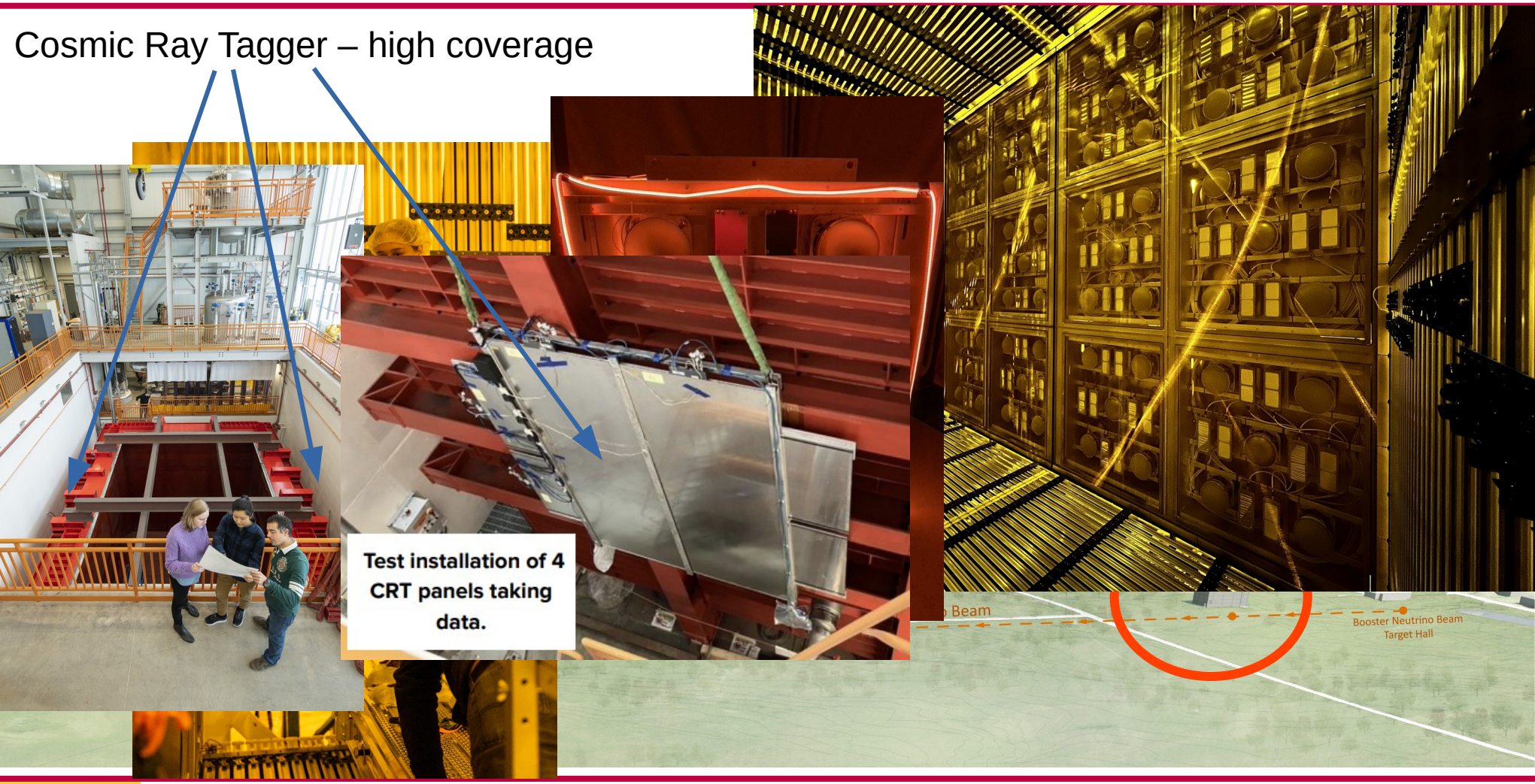
Wavelength-shifting reflective foils





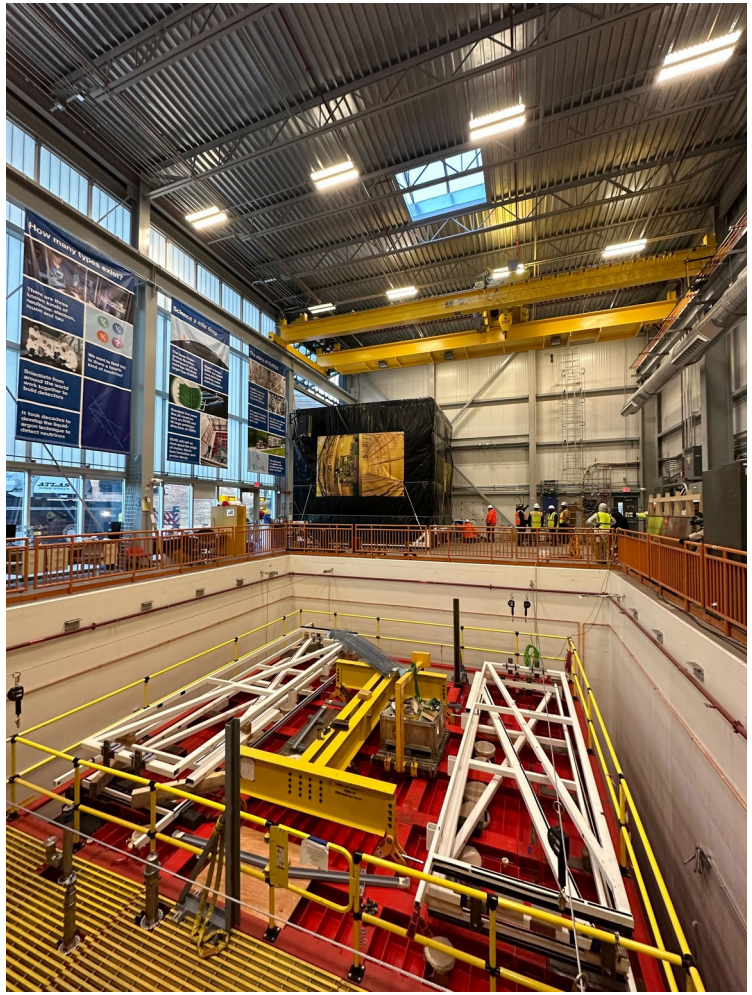
SBND

Cosmic Ray Tagger – high coverage



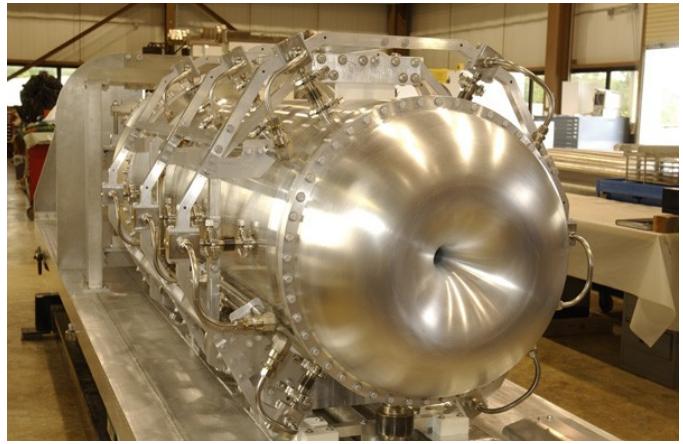
SBND status

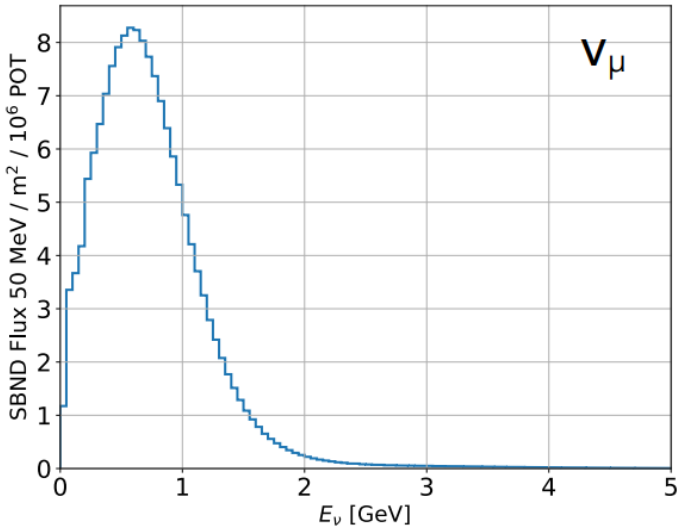
- Moved TPC and PDS to detector building two weeks ago (see https://www.youtube.com/watch?v=w65vNO5XpUM)
- Cryostat complete
- CRT tested and ready for installation
- Final installation expected to be complete summer 2023



The Booster Neutrino Beam

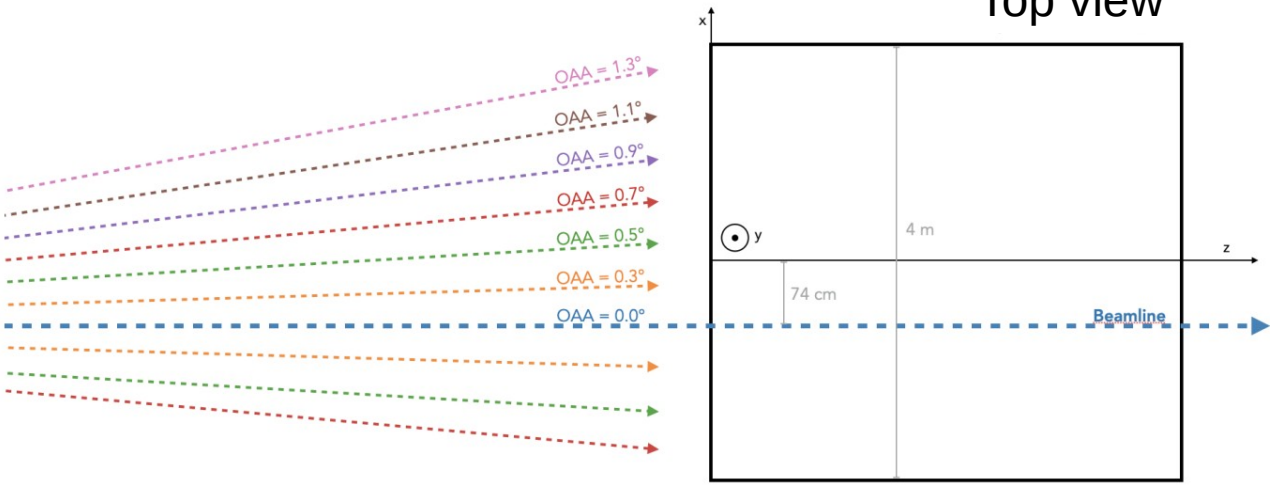
- 8GeV Proton Beam
- Berillium target
- Single focusing horn
- On-axis flux peak 600MeV
- 99.5% muon flavour



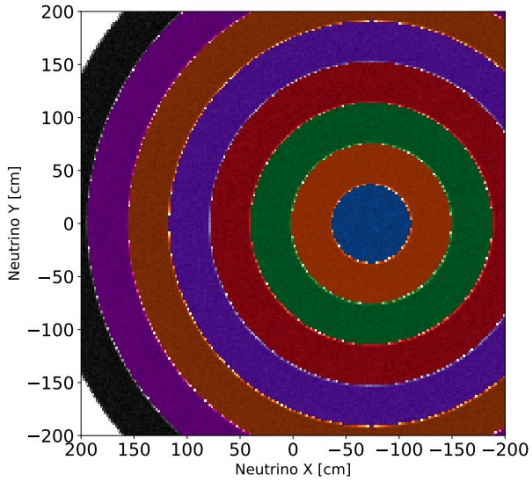


SBND-PRISM

Top view



Beam view



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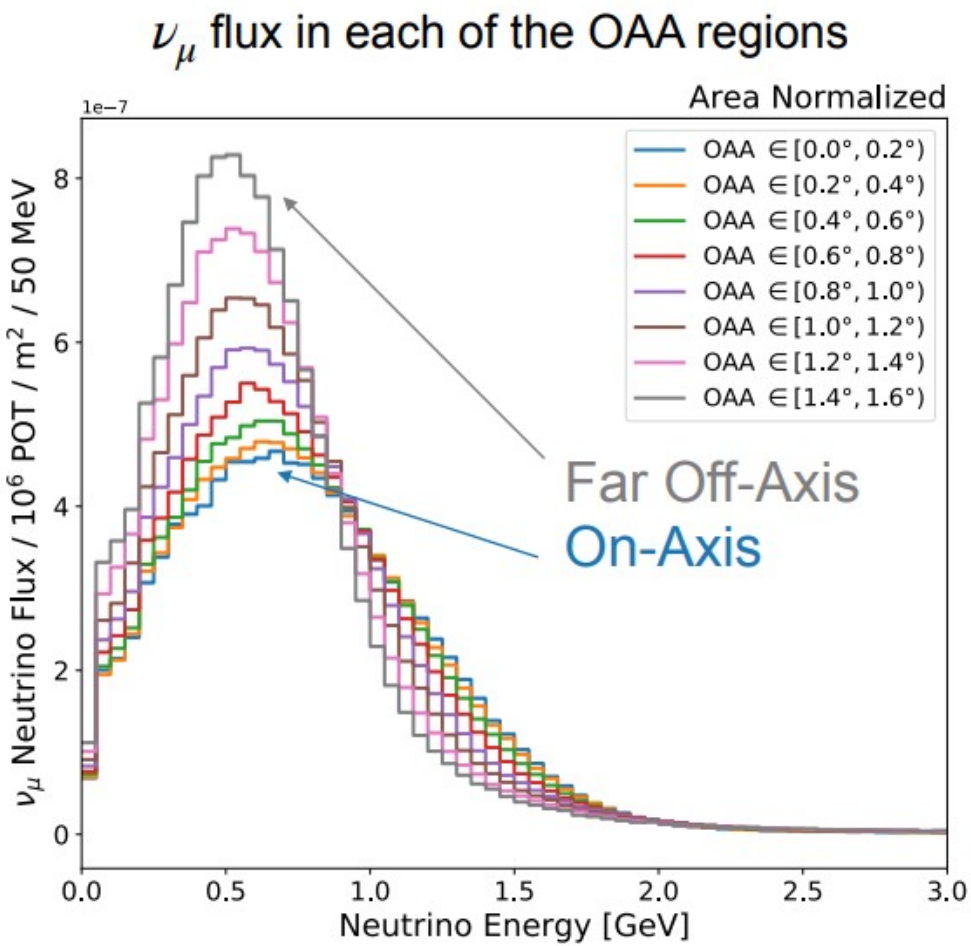

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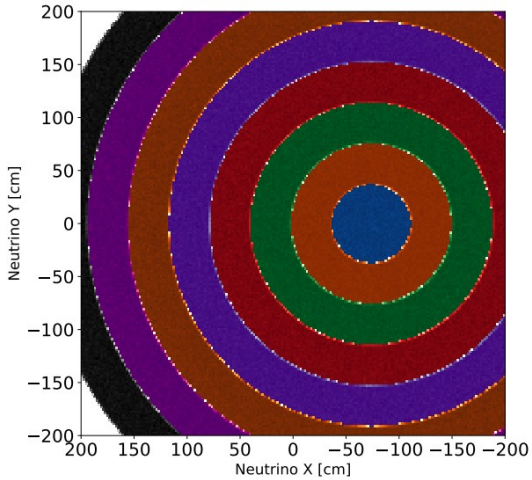
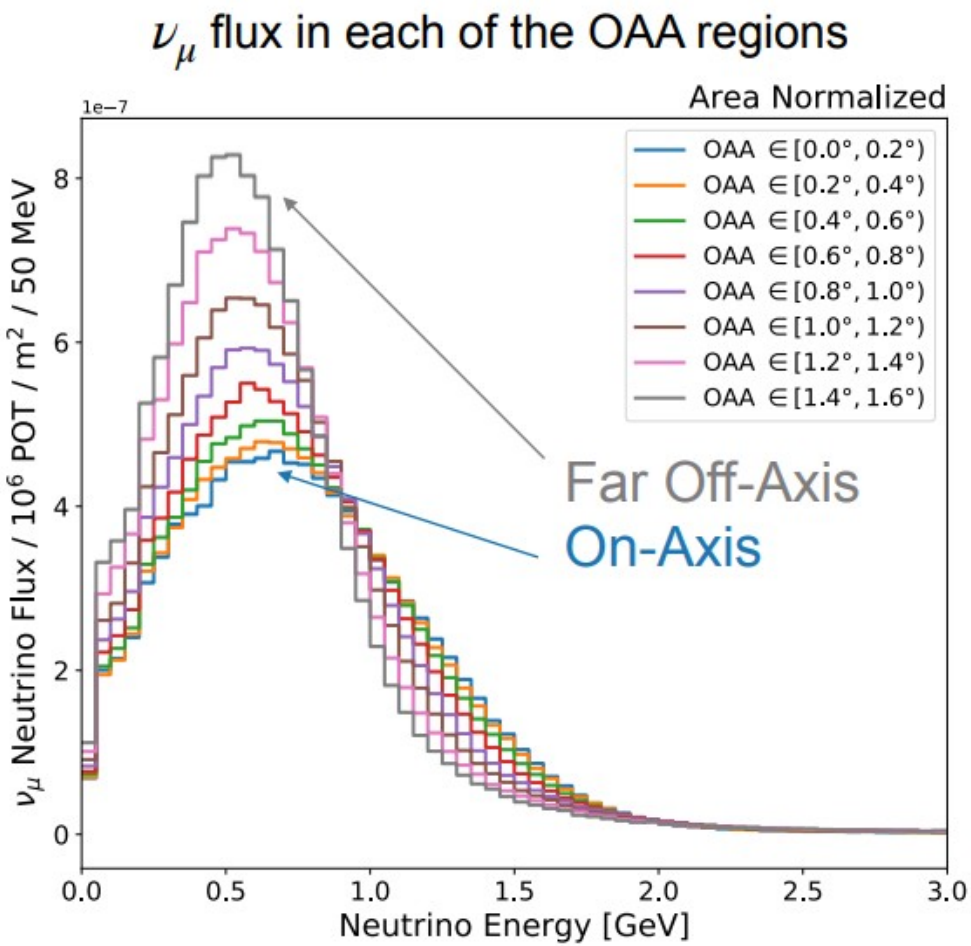


Vary energy dependence by scanning position in detector

All highly correlated

SBND-PRISM



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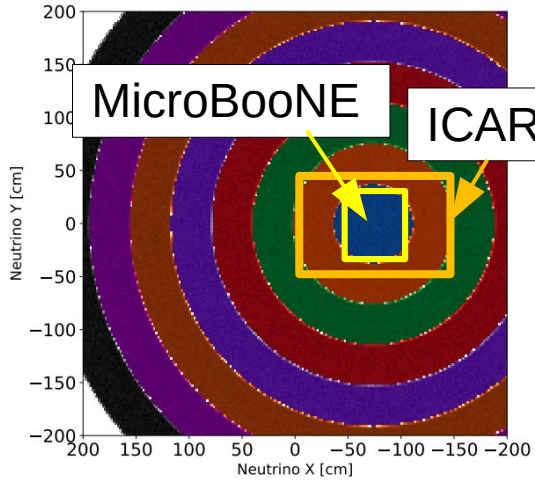


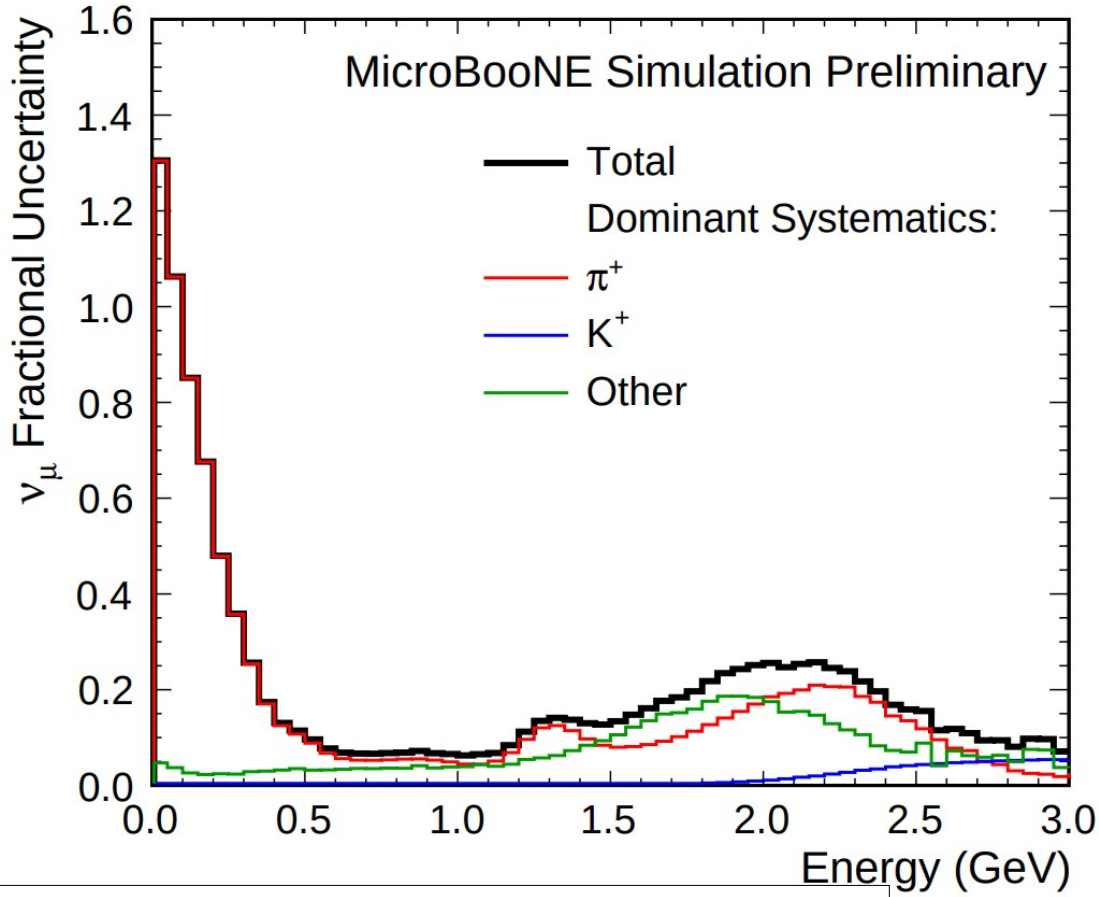
Vary energy dependence by scanning position in detector

All highly correlated

Flux Uncertainties - ν_μ

- Uncertainties very large at low energies
- Driven by lack of data for

  p+Be → π+X below 750MeV/c
- Expected to be limiting uncertainty in many analyses



N.B. Much of this is informed by experience from MiniBooNE and then MicroBooNE

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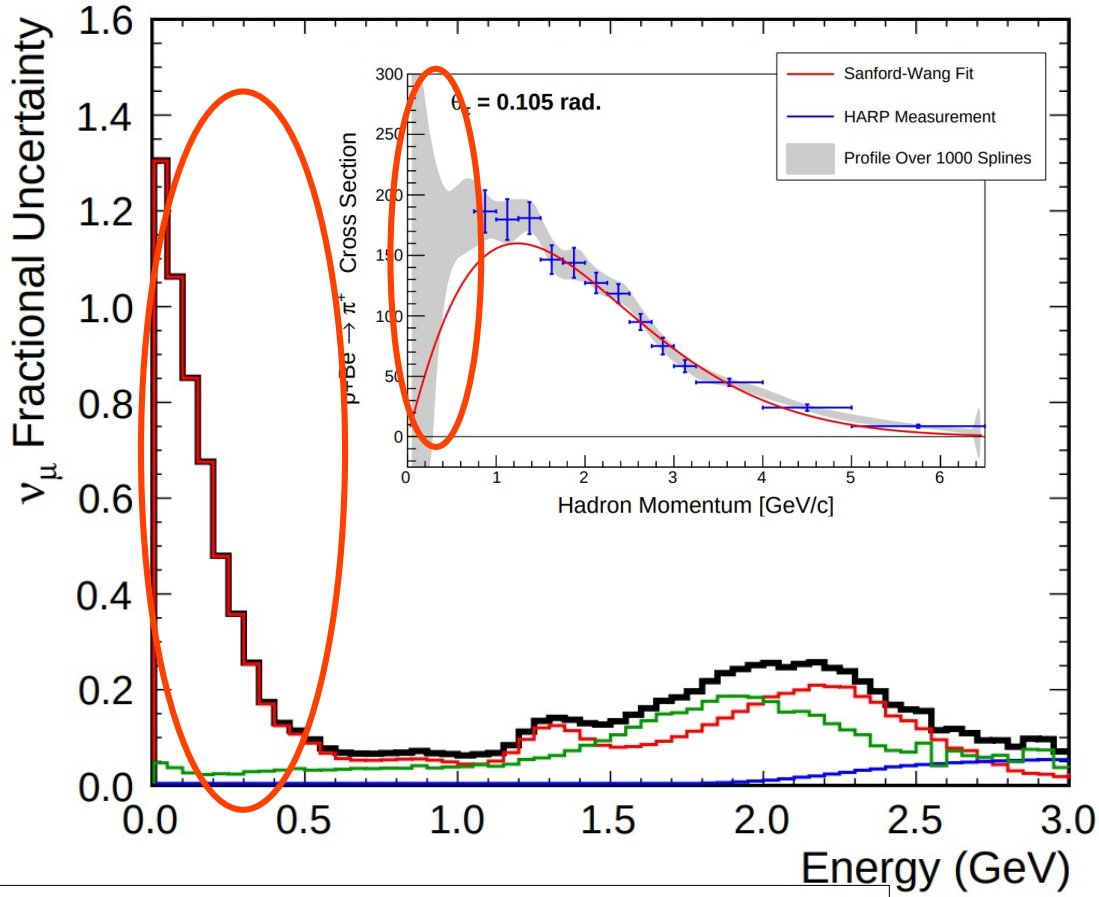

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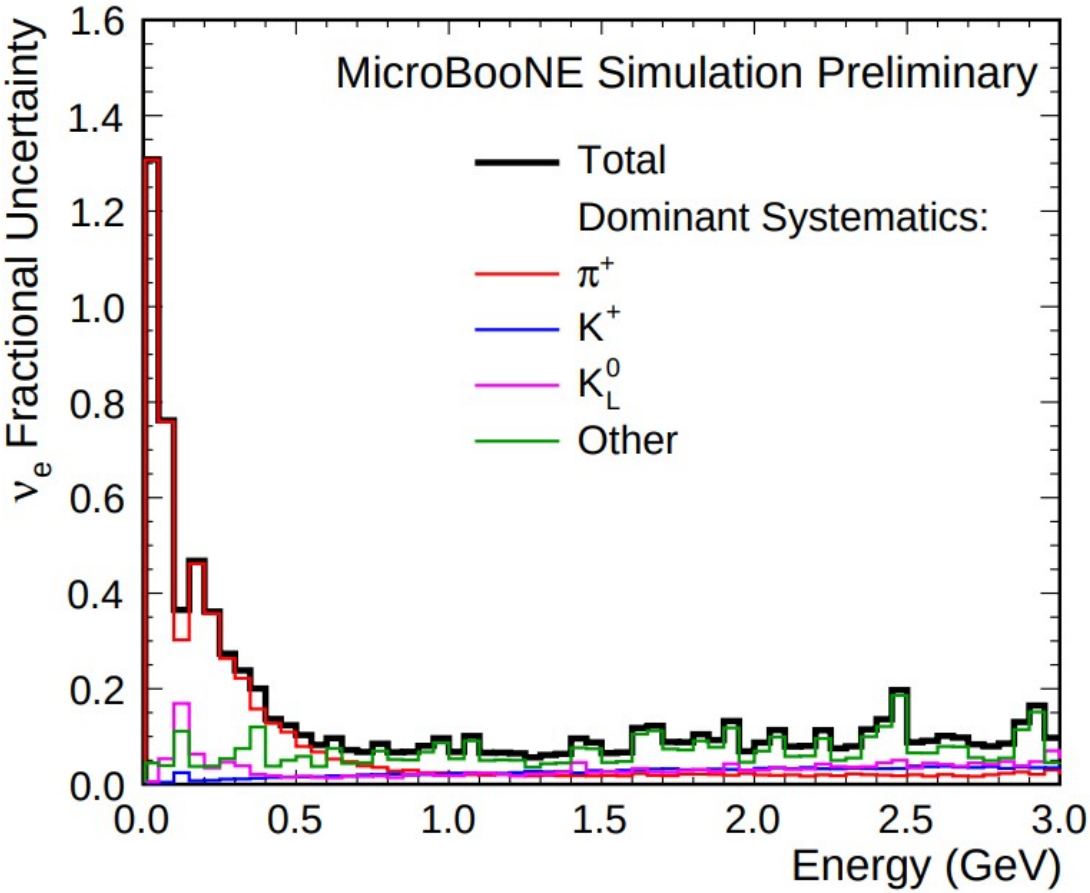
Flux Uncertainties - ν_e

- Kaon uncertainties make assumptions:
  - Feynman scaling from higher energy data
  - SciBooNE measurement of high-energy ν_μ
- Dedicated measurements would be much better!



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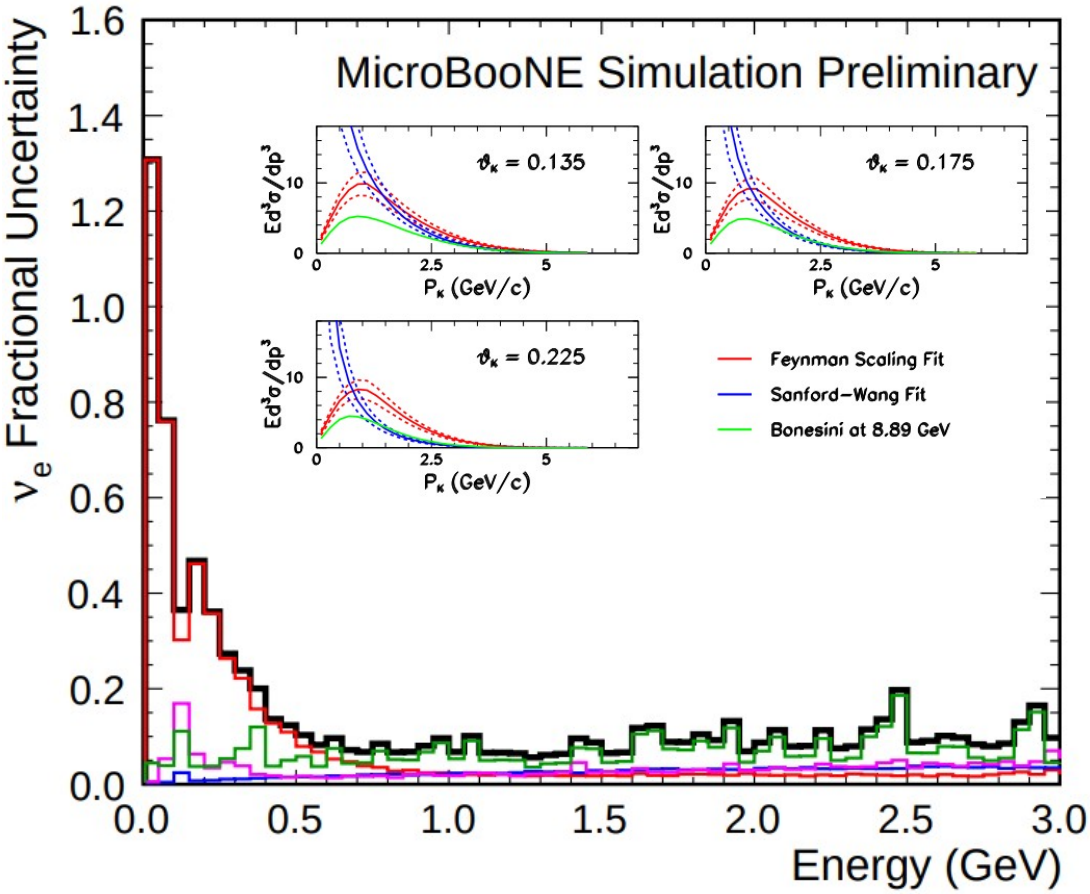
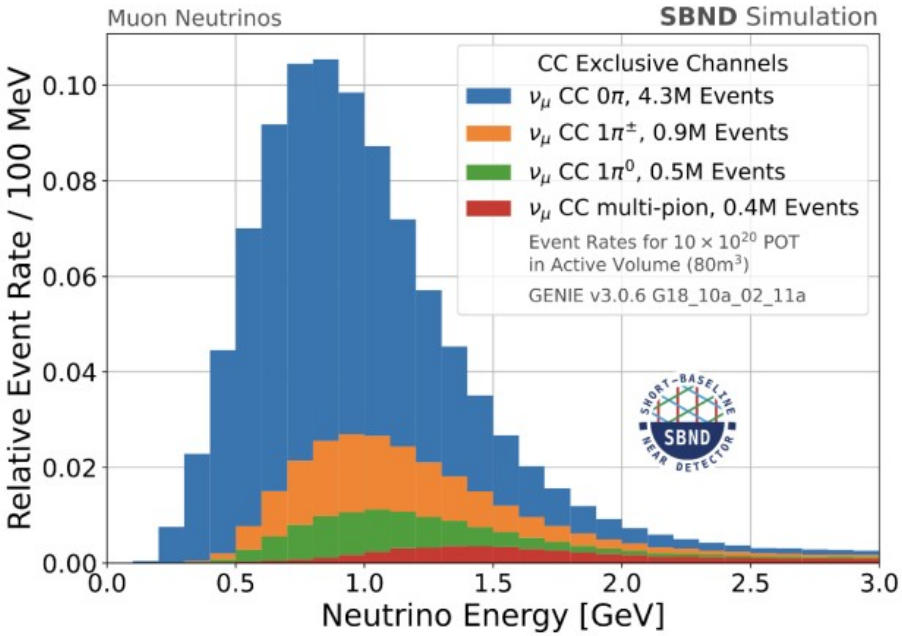


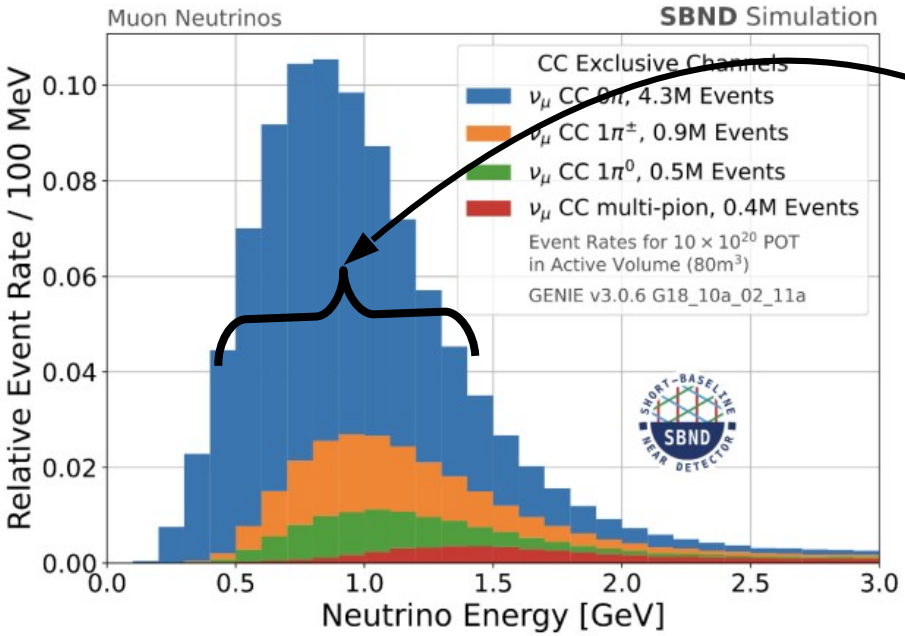
Impact on Cross Sections

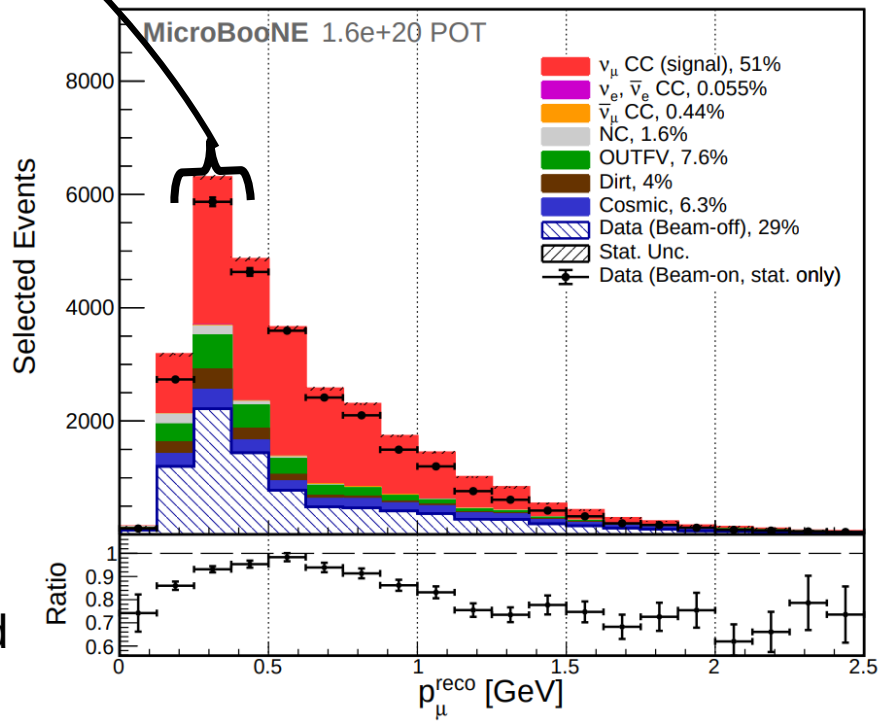


Flux uncertainties depend on neutrino energy

But we don’t measure neutrino energy directly

Impact on Cross Sections



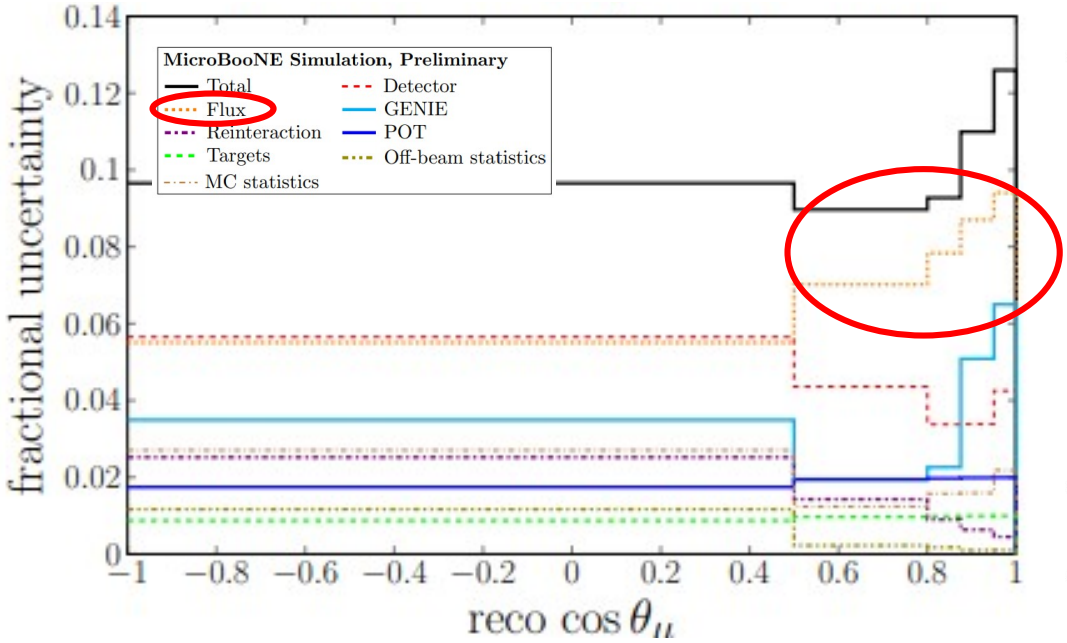


Each bin of muon momentum, contains many neutrino energies

Flux uncertainties become more complicated and convolved with interaction model

Impact on Cross Sections

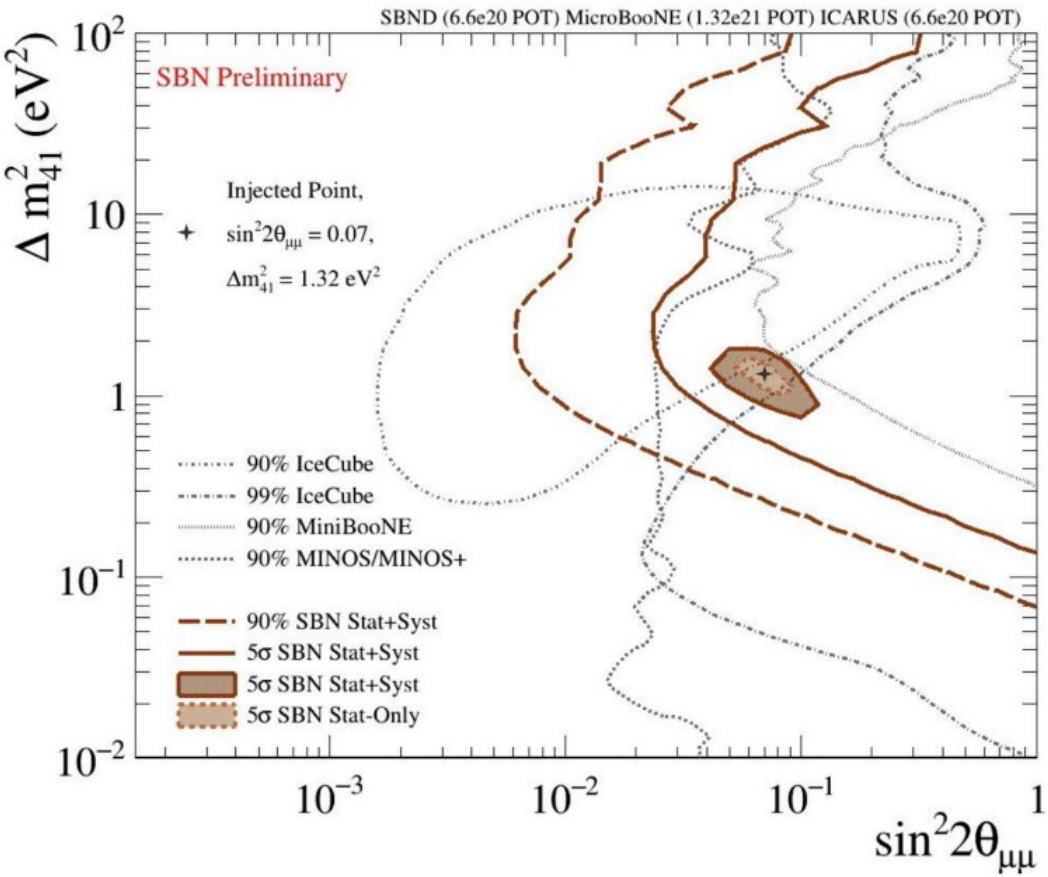
- Extremely high statistical precision expected
- Uncertainty on absolute cross section driven by flux
- Already dominates stats at MicroBooNE (30x lower event rate)



Process		No. Events	Events/ ton	Stat. Uncert.
	ν_μ Events (By Final State Topology)			
CC Inclusive		5,212,690	46,542	0.04%
CC 0 π	$\nu_\mu N \to \mu + Np$	3,551,830	31,713	0.05%
	· $\nu_\mu N \to \mu + 0p$	793,153	7,082	0.11%
	· $\nu_\mu N \to \mu + 1p$	2,027,830	18,106	0.07%
	· $\nu_\mu N \to \mu + 2p$	359,496	3,210	0.17%
	· $\nu_\mu N \to \mu + \geq 3p$	371,347	3,316	0.16%
CC 1 $\pi^{\pm}$	$\nu_\mu N \to \mu +$ nucleons $+ 1\pi^{\pm}$	1,161,610	10,372	0.09%
CC $\geq 2\pi^{\pm}$	$\nu_\mu N \to \mu +$ nucleons $+ \geq 2\pi^{\pm}$	97,929	874	0.32%
CC $\geq 1\pi^{0}$	$\nu_\mu N \to \mu +$ nucleons $+ \geq 1\pi^{0}$	497,963	4,446	0.14%
NC Inclusive		1,988,110	17,751	0.07%
NC 0 π	$\nu_\mu N \to$ nucleons	1,371,070	12,242	0.09%
NC 1 $\pi^{\pm}$	$\nu_\mu N \to$ nucleons $+ 1\pi^{\pm}$	260,924	2,330	0.20%
NC $\geq 2\pi^{\pm}$	$\nu_\mu N \to$ nucleons $+ \geq 2\pi^{\pm}$	31,940	285	0.56%
NC $\geq 1\pi^{0}$	$\nu_\mu N \to$ nucleons $+ \geq 1\pi^{0}$	358,443	3,200	0.17%
	ν_e Events			
CC Inclusive		36798	329	0.52%
NC Inclusive		14351	128	0.83%
Total ν_μ and ν_e Events		7,251,948	64,750	

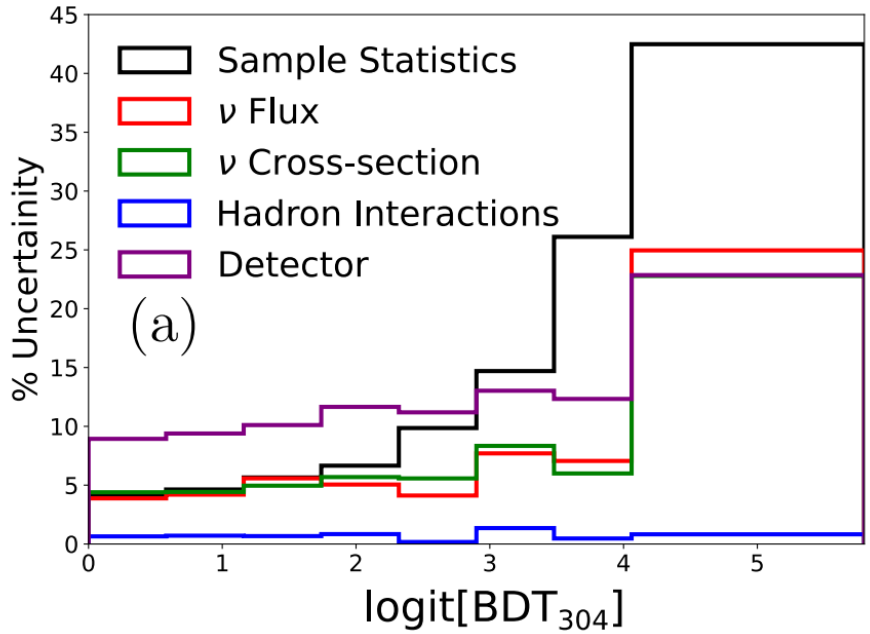
Impact on Oscillations

- At high sterile neutrino mass, oscillation peak is at SBND
- Estimate of event rate limited by flux uncertainties
  - And cross section uncertainties
- Becomes a “shape” measurement
- But the flux uncertainties also have a shape...



Impact on BSM searches

- BSM searches usually have neutrino backgrounds
- Neutrino flux uncertainties obviously matter
- Cross section uncertainties depend on flux uncertainties

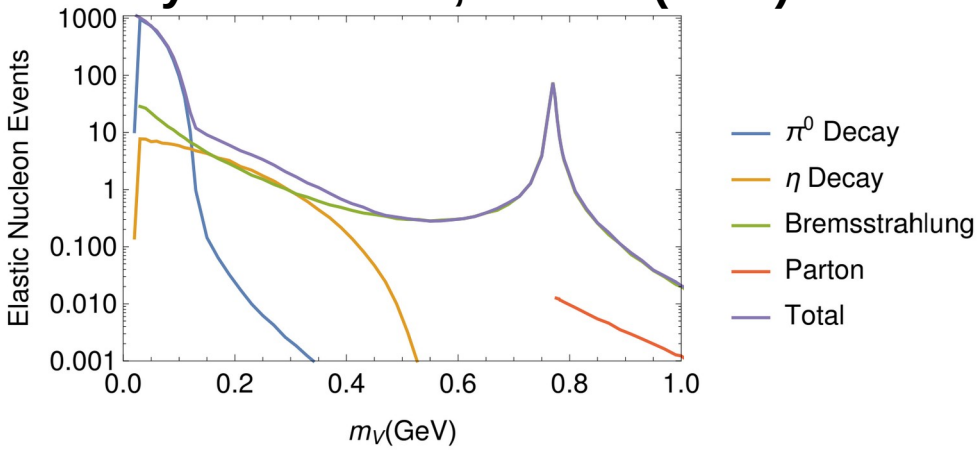


Phys. Rev. D 106, 092006 (2022)

Impacts on BSM searches

- Interpreting a **rate** limit as a **coupling** limit (or mixing, etc) requires **production process**
- Many models assume neutral meson decays
- π^0 and η production matter
- Other searches use KDAR from beam dump

Phys. Rev. D 95, 035006 (2017)



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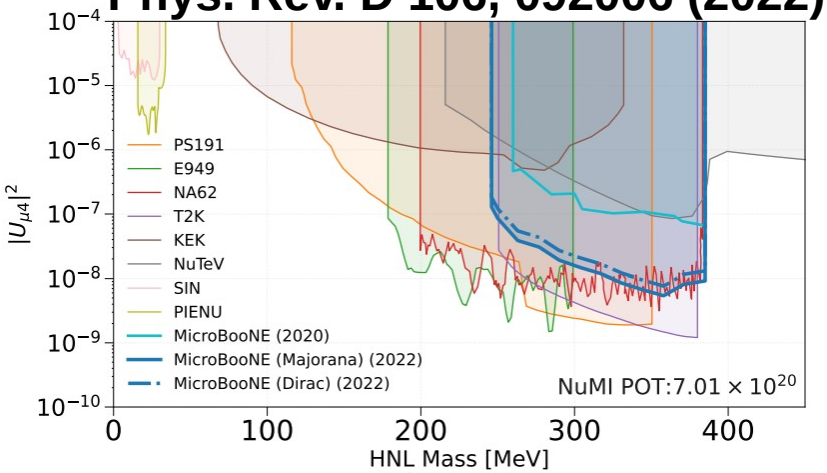
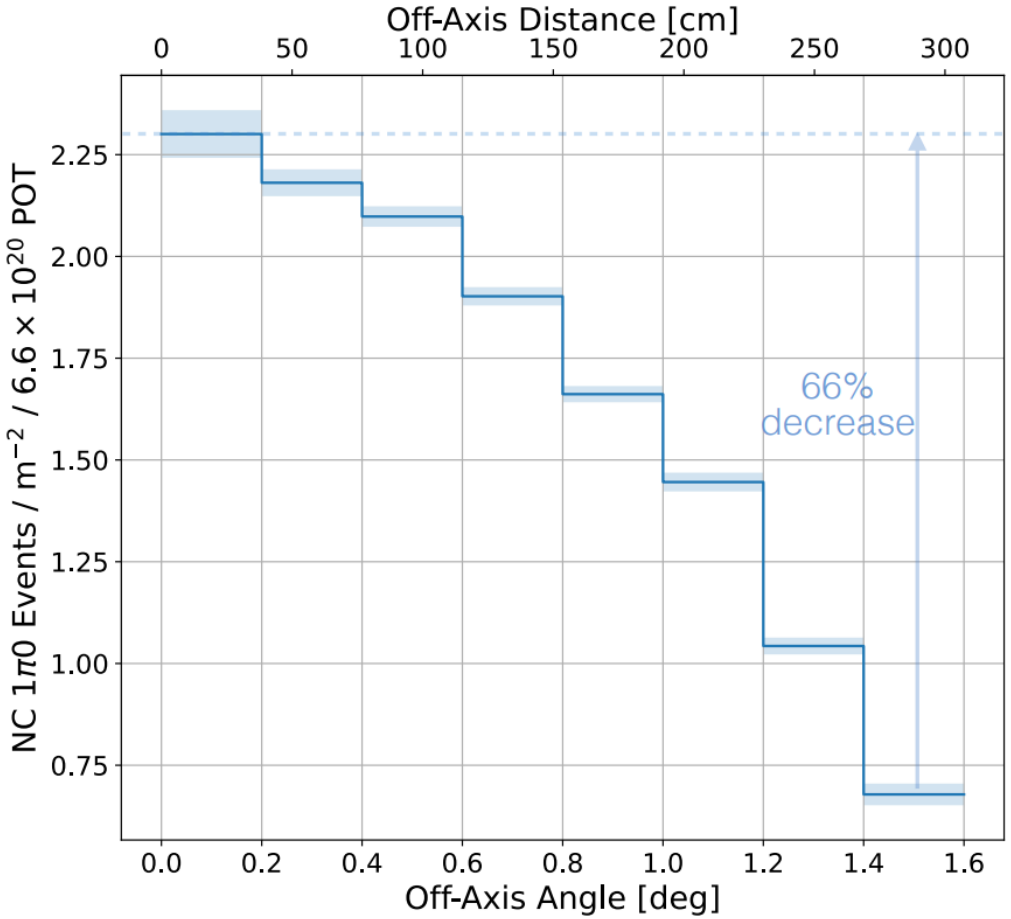


Using PRISM again

- Neutrino backgrounds vary with off-axis angle
  - Beam is focused
- BSM production through neutral mesons
  - Unfocused
- Natural constraint – signal and background have different shapes!



Conclusions

- SBND has a rich physics program
- Reduced flux uncertainties would improve most analyses
- Largest improvement would likely come from low-energy pion yield measurements

Thank You