SBN Oscillation Physics with SPINE

SBN SPINE workshop

September 29, 2025 to October 3, 2025 at Columbia University, Nevis Laboratories

Dante Totani - CSU

Oct. 2nd 2025

Short Baseline Neutrino Anomalies

Short Baseline Anomalies

Experimental anomalies have been reported over the past 20 years from a variety of experiments studying neutrinos at short baselines (less than 1 km).

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)

ν_e appearance (LSND, MiniBooNE, MiniBooNE)

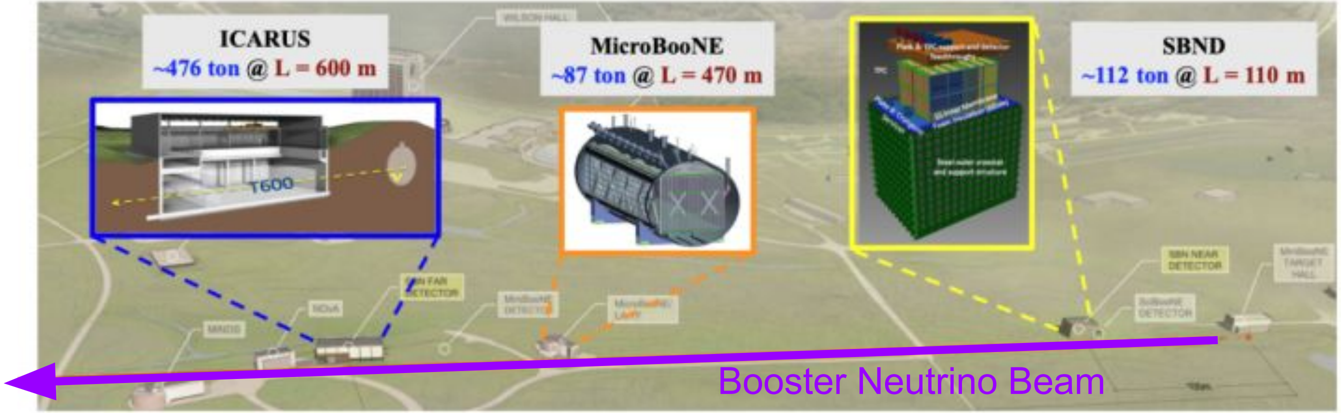
ν_e disappearance (GALLEX/SAGE, Reactors)

Common interpretation is as evidence for one or more additional, mostly “sterile” neutrino states driving oscillations at $\Delta m^2 \sim 1 eV^2$ and a relatively small $\sin^2 2\theta$.

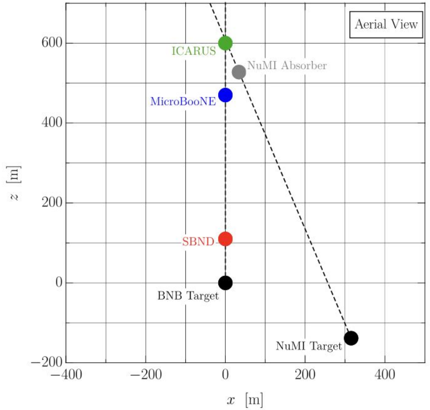
Confirmation of the sterile neutrino hypothesis would be a major discovery, opening a window onto a particle sector not accessible through SM interactions. A definitive null result would settle a long-standing open question in neutrino physics with possible implications for future neutrino oscillation experiments.

SBN program at Fermilab

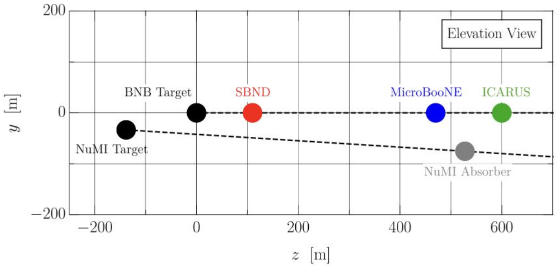
SBN program at Fermilab



BNB and NuMI

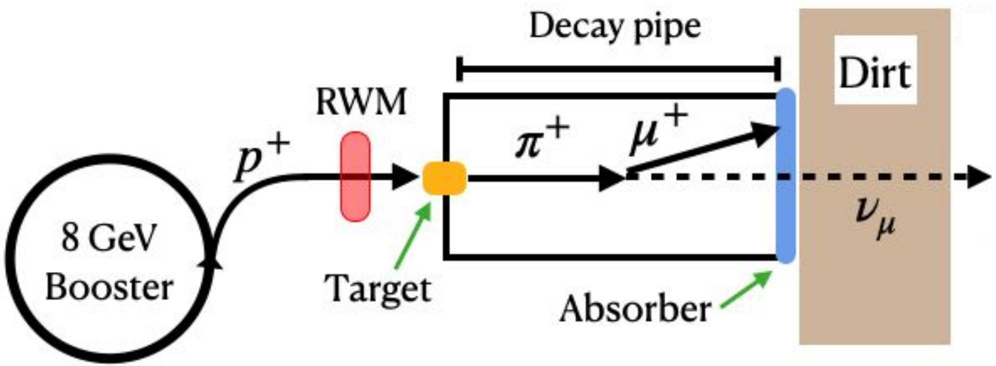


Detector	Active LAr Mass	Dist.from BNB Target	Angle w.r.t. BNB	Dist.from NuMI Target	Angle w.r.t. NuMI
SBND:	112 tons	110 m	0 rad	401 m	0.53 rad
MicroBooNE:	87 tons	470 m	0 rad	685 m	0.14 rad
ICARUS:	476 tons	600 m	0 rad	803 m	0.097 rad



https://arxiv.org/pdf/1909.11670

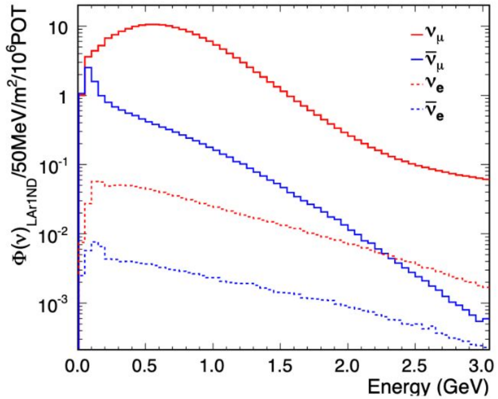
Booster Neutrino Beam (BNB)



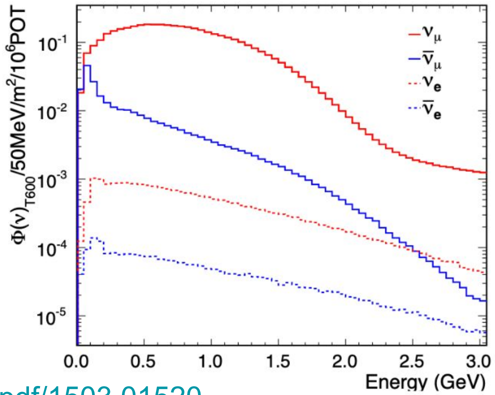
- 8 GeV protons from Booster
  - Up to 5.3 Hz repetition rate
  - 5 x 10^{12} protons per pulse, 1.6 μs spil
  - ⟨E_ν ⟩~700 MeV

- SBN Detector interaction rares:
  - SBND: 0.25 Hz ν, 0.03 Hz cosmic
  - ICARUS: 0.03 Hz ν, 0.14 Hz cosmic

BNB **ν** flux at SBND



BNB **ν** flux at ICARUS



https://arxiv.org/pdf/1503.01520

Physic goals of the SBN program

The 3 detector setup of the SBN program allows for a sensitive search of the Δm^2 regions highlighted by anomalies in the above experiments.

Baseline of 600 m and the BNB ν energy ~700 MeV

$$\frac{\langle L_\nu \rangle}{\langle E_\nu \rangle} \sim \frac{600\,\mathrm{m}}{700\,\mathrm{MeV}} \sim \mathcal{O}\left(1 \frac{\mathrm{km}}{\mathrm{GeV}}\right)$$

⇨ Boost in the sensitivity for oscillations at $\Delta m^2 \sim 1 eV^2$

(Δm^2 in [0.1-10] eV^2)

The basis of the search is ν_μ disappearance and ν_e appearance assuming a 3 + 1 sterile neutrino model.

Physic goals of the SBN program

In a 3 + 1 sterile neutrino model with: $\Delta m^2_{41} \gg \left|\Delta m^2_{32}\right|, \Delta m^2_{21}$
oscillations at short-baseline experiments can be well described by a two-flavor vacuum oscillation formula,

$$P_{\nu_\alpha \to \nu_\beta} = \delta_{\alpha\beta} - 4\left|U_{\alpha\beta}\right|^2\left(\delta_{\alpha\beta} - \left|U_{\alpha\beta}\right|^2\right)\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

Each oscillation channels $\nu_\alpha \to \nu_\beta$ is driven by a effective mixing angle: $\theta_{\alpha\beta}$

$\nu_\mu \to \nu_e$ ⟶ $\sin^2(2\theta_{\mu e}) = 4\left|U_{\mu 4}\right|^2\left|U_{e4}\right|^2$ ⟶ (LSND, MiniBooNE)

$\nu_e \to \nu_e$ ⟶ $\sin^2(2\theta_{ee}) = 4\left|U_{e4}\right|^2\left(1 - \left|U_{e4}\right|^2\right)$ ⟶ (reactor, gallium)

$\nu_\mu \to \nu_\mu$ ⟶ $\sin^2(2\theta_{\mu\mu}) = 4\left|U_{\mu 4}\right|^2\left(1 - \left|U_{\mu 4}\right|^2\right)$ ⟶ (no anomalies observed)

Physic goals of the SBN program

The key aspect of SBN that is ONLY enabled with multiple detectors is that ν_e appearance cannot occur in without ν_μ disappearance

$$P^{3+1}_{\nu_\mu\to\nu_\mu} = 1-\sin^2(2\theta_{\mu\mu})\ \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

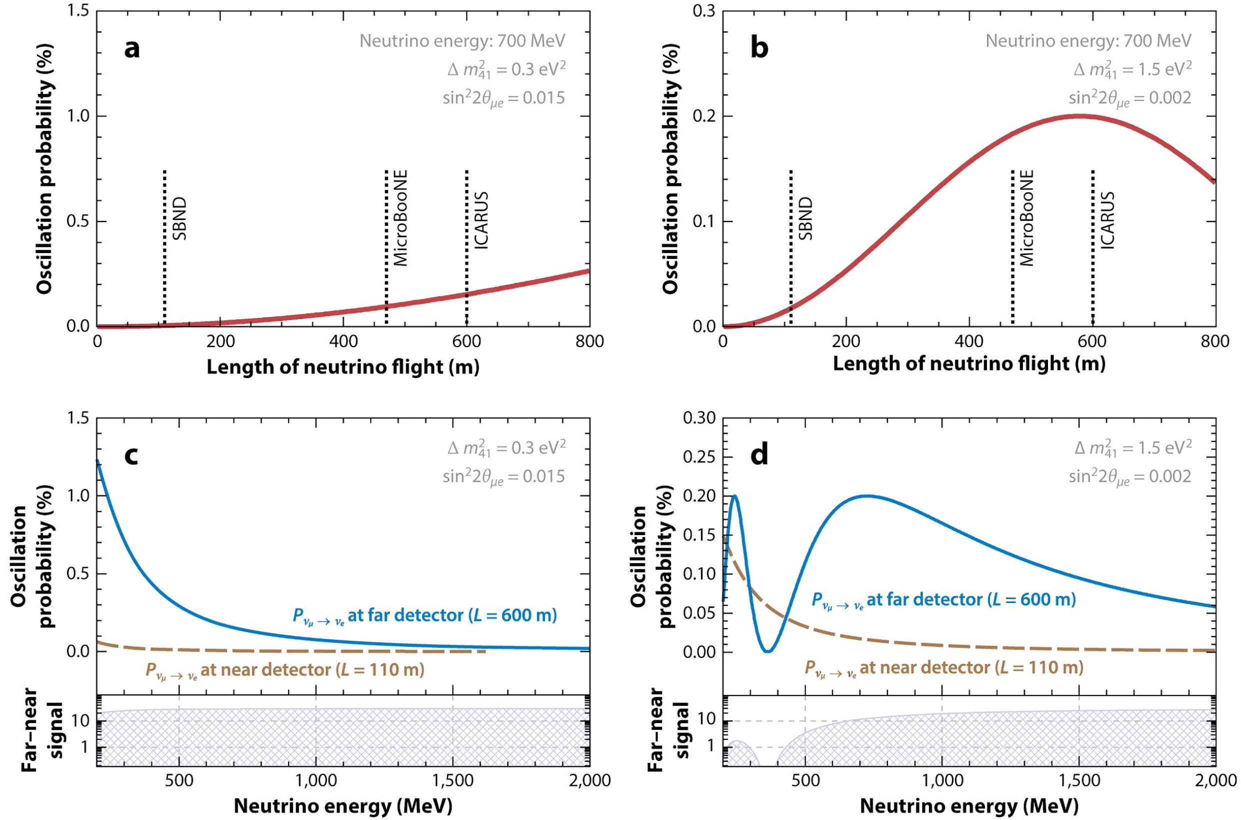
$$P^{3+1}_{\nu_\mu\to\nu_e} = \sin^2(2\theta_{\mu e})\ \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$P^{3+1}_{\nu_e\to\nu_e} = 1-\sin^2(2\theta_{ee})\ \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

The parameters dependence can be used to overconstrain the parameter space by observing ν_e appearance together with ν_μ disappearance (and ν_e disappearance).

NOTE: BNB is not a pure ν_μ, a disappearance of the BNB ν_e component need to be take into account.

SBN Near and Far detectors



Machado PAN, et al. 2019.
Annu. Rev. Nucl. Part. Sci. 69:363–87

The locations of the near and far detectors are optimized for maximal sensitivity in the most relevant ranges of oscillation parameters.

(a,b) $\nu_\mu \to \nu_e$ oscillation probability for a 700 MeV neutrino as a function of the baseline for two different benchmark points in a 3+1 sterile neutrino scenario.

(c,d) $\nu_\mu \to \nu_e$ oscillation probabilities, at 110 m and 600 m, as a function of the neutrino energy for the same benchmark points.

(Bottom) The far–near ratio of appearance probabilities.

https://doi.org/10.1146/annurev-nucl-101917-020949

SBN Near and Far detectors

- Multiple detectors using the same technology enables sensitive searches for ν_e appearance and ν_μ disappearance within the same experiment.
  - Correlations between detectors (same beam and detection technique) allow for cancellations in systematic uncertainties on backgrounds
- Direct probe of ν_e disappearance using a neutrino beam rather than lower energy (MeV) reactor antineutrinos
  - ICARUS will use ν_e disappearance from NuMI as part of 3+1 neutrino model investigation

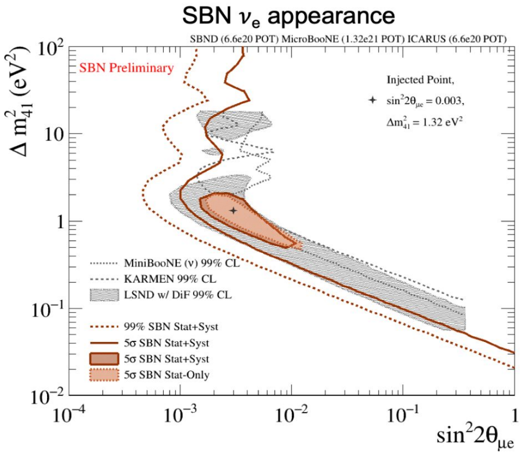
BND (Near, ~110 m)

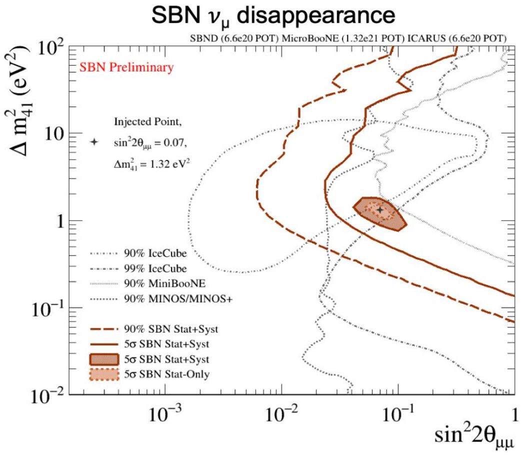
- Primary role: **flux + cross-section precision, systematics control.**
- Measures un-oscillated BNB flux (ν_μ, ν_e).
- World's highest-statistics ***ν***–Ar cross-section data (~7M ν_μ, ~50k ν_e in 3 yrs).
- Provides flux & cross-section constraints → reduces systematics.

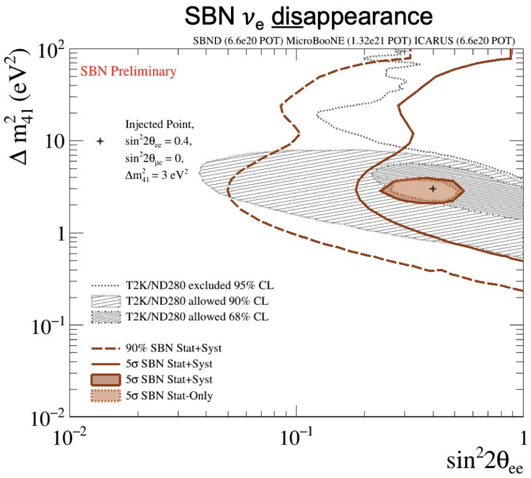
ICARUS (Far, ~600 m)

- Primary role: **oscillation sensitivity + higher-energy cross sections.**
- Observes oscillated spectrum (ν_μ disappearance, ν_e appearance).
- Precision ***ν***–Ar cross sections using NuMI off-axis (~300k ν_μ, ~10k ν_e per year).
- Directly tests sterile neutrino models via ν_e/ν_μ disappearance.

SBND + ICARUS sterile oscillation sensitivity





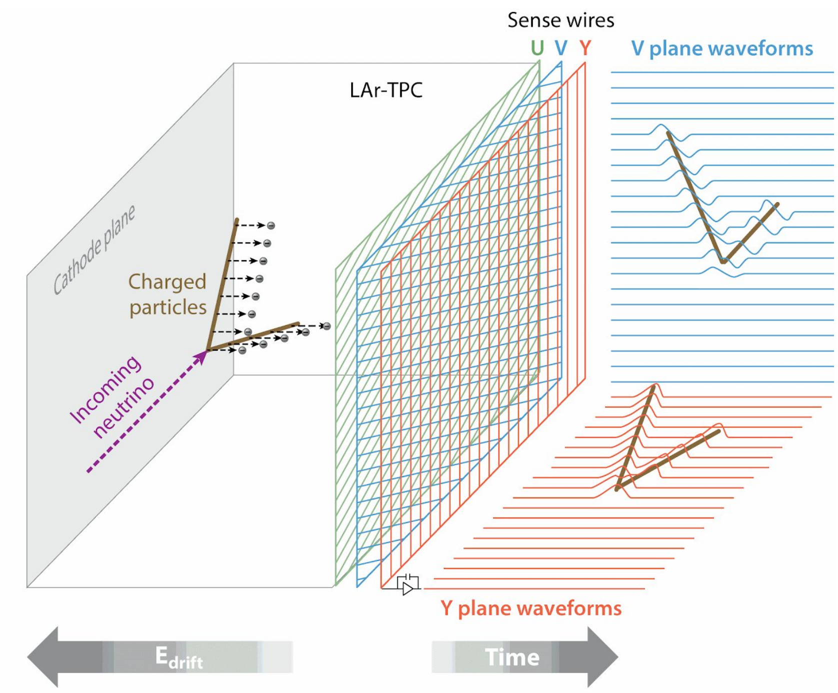


- Address conclusively the LSND and MiniBooNE anomalies.
- SBND will measure the ν_e and ν_μ components of the BNB with large statistics.
- ICARUS will search for an excess of ν_e and a deficit of ν_μ using SBND's measurement as reference.

SBND+ICARUS will be able to explore the LSND-favored region with 5σ and will covers almost the full allowed LSND-MiniBooNE region with 5σ.

From the *ν* interaction to the oscillation parameters

Liquid Argon TPC



Massive and homogeneous target, excellent tracking and calorimetric capabilities.

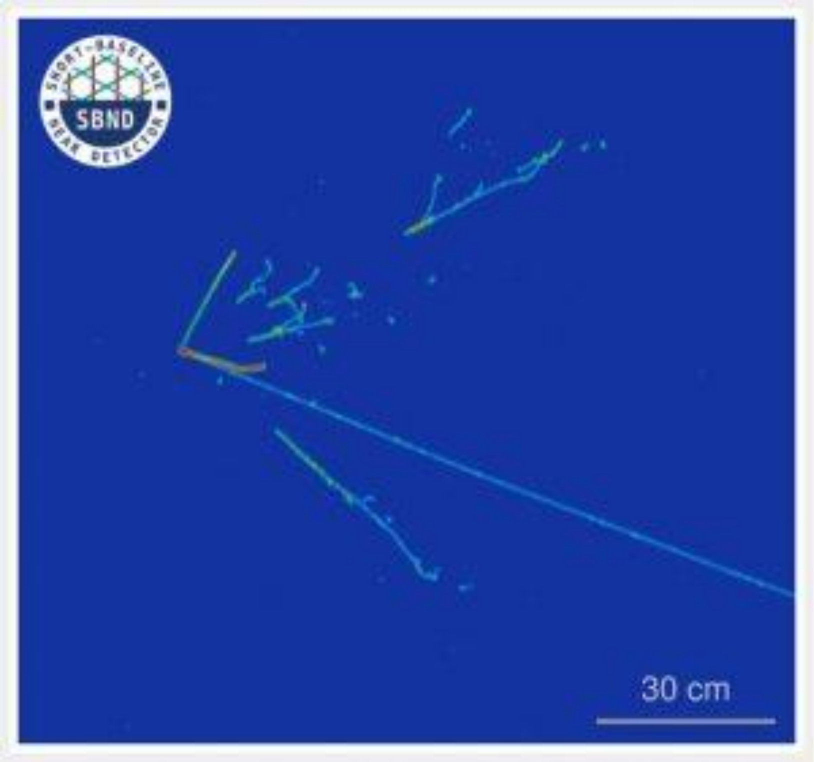
Ionisation electrons:

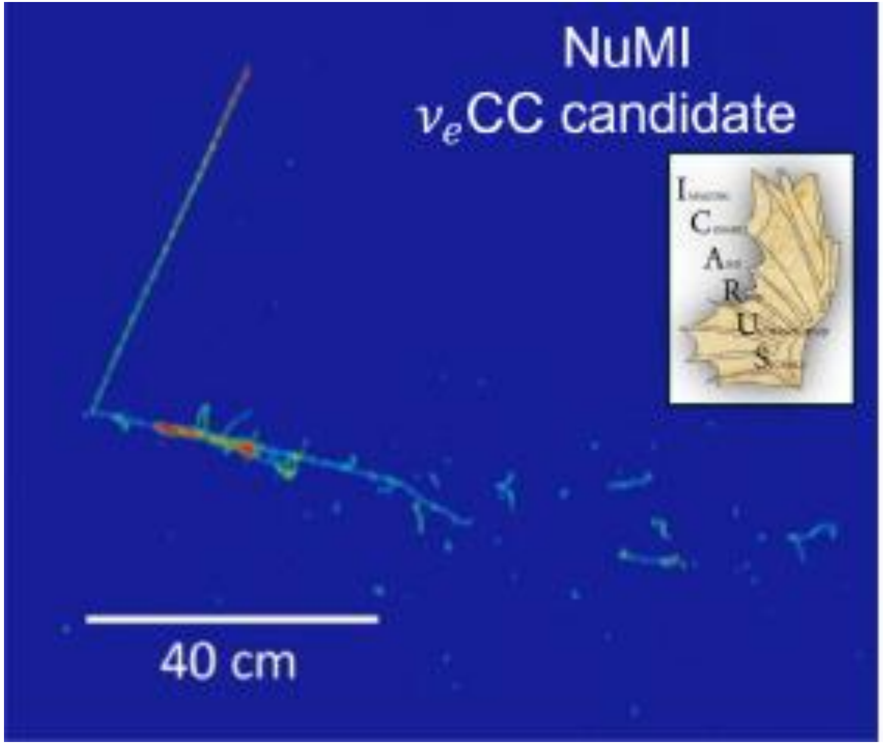
- ~ 42000 e/MeV
- Drift toward wire planes inducing a signal.
- Response time = drift time (~ ms)
- 3D image reconstruction by combining coordinates on different wire planes at the same drift time

Scintillation Light:

- λ = 128 nm scintillation light
- 24000 γ/MeV @ 500V/cm
- Response time O(1 ns)

ν interaction in SBND and ICARUS

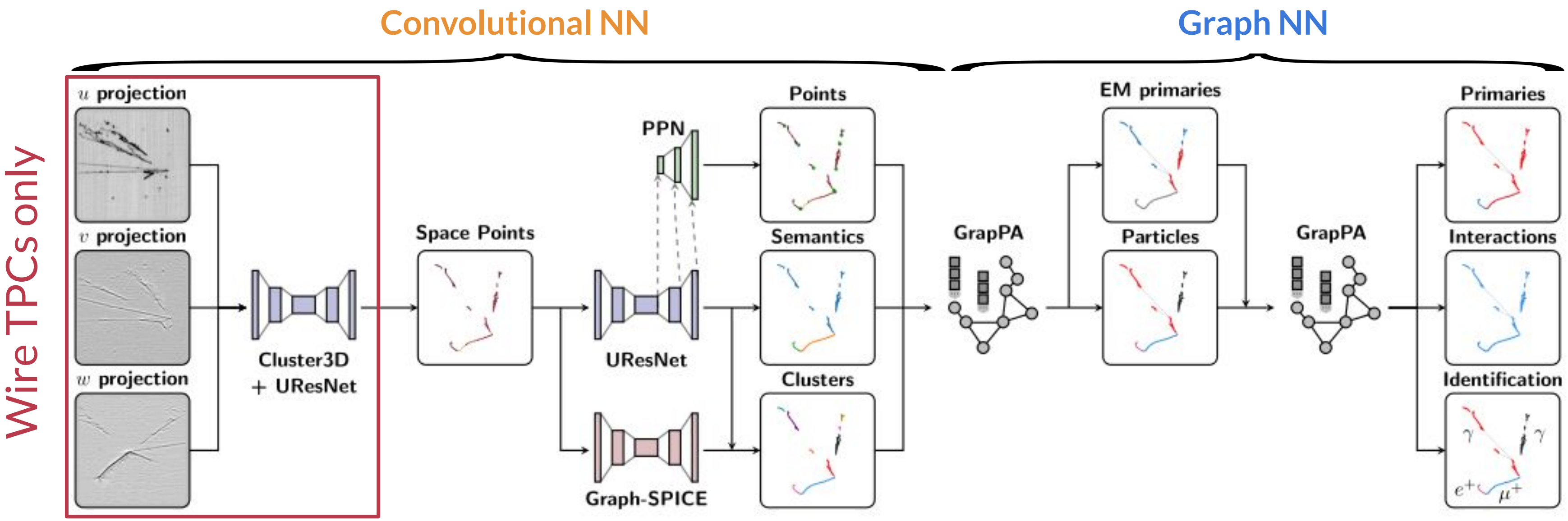




SPINE - Scalable Particle Imaging with Neural Embeddings

UResNet for pixel feature extraction, **GrapPA** for superstructure formation

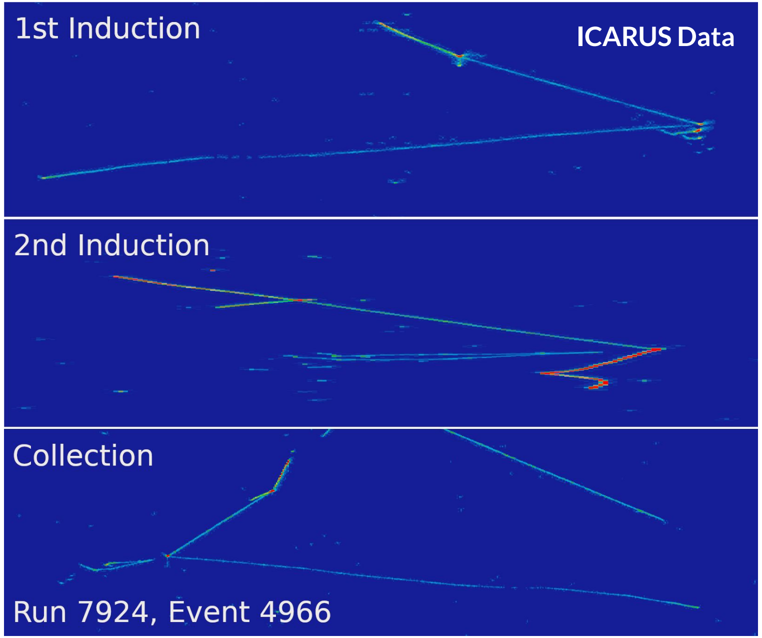
See François' slides https://indico.nevis.columbia.edu/event/11/contributions/99/

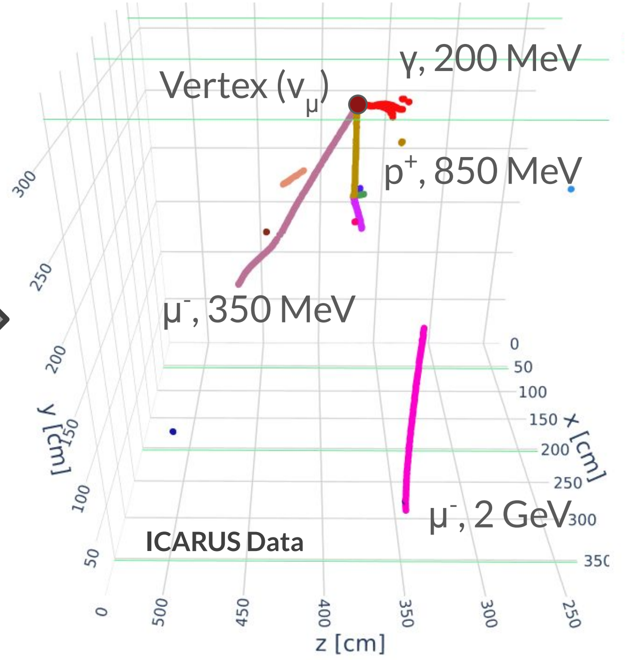


Paper: arXiv:2102.01033

SPINE: end-to-end reconstruction chain

SPINE provides an end-to-end reconstruction chain of particles and interactions in the TPC, demonstrating significantly improved performance compared to other approaches.





From François' slides https://indico.nevis.columbia.edu/event/11/contributions/99/

MEDULLA: new analysis framework and plotting tool

https://github.com/justinjmueller/medulla/tree/feature/medulla

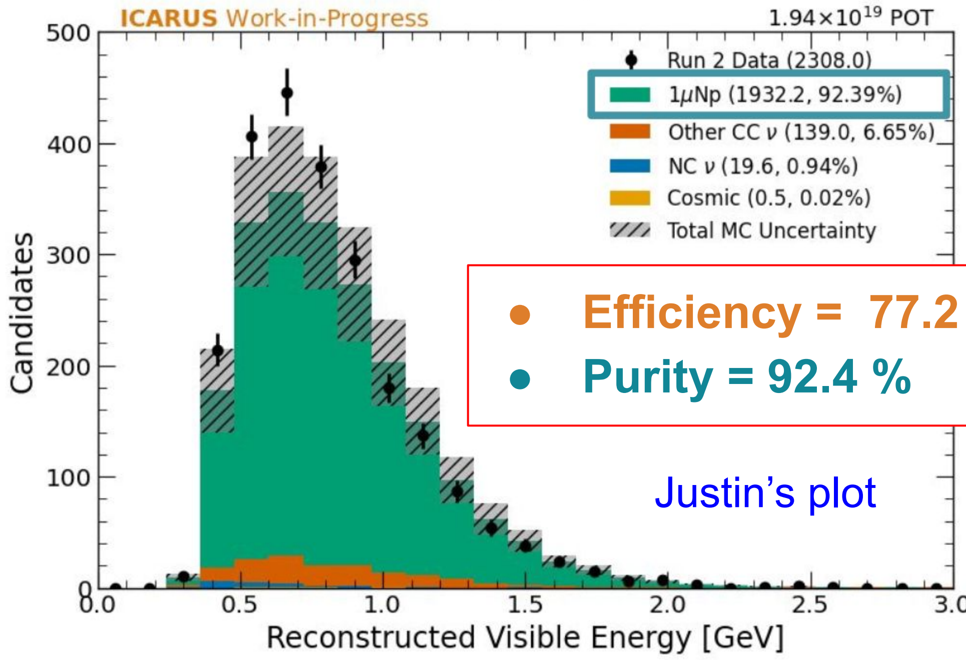
- Modular, event-driven C++ framework for:
  - Physics analysis
  - Systematic uncertainty evaluation
  - Plotting
- Companion layer to **SPINE** reconstruction
- Declarative config interface for quick setup

Key features are simplicity and portability from one experiment to another:

- Set path → input flat CAF files (from SPINE)
- Define selection → cuts
- Choose output variables → branch

Run with executable maintained by SPINE team.

ICARUS 1μNp CC0π



- **Efficiency = 77.2 %**
- **Purity = 92.4 %**

Justin's plot

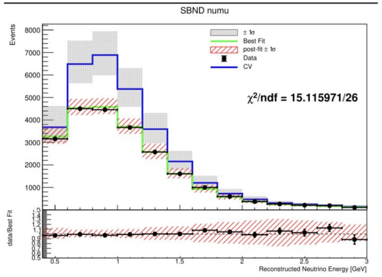
PROfit: Global Fitting Framework

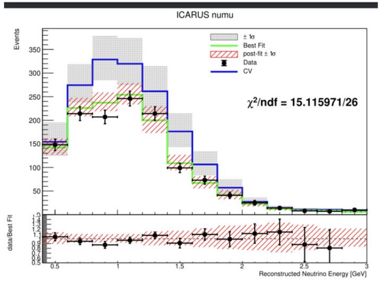
https://github.com/markrosslonergan/Elephant_Vanishes/wiki

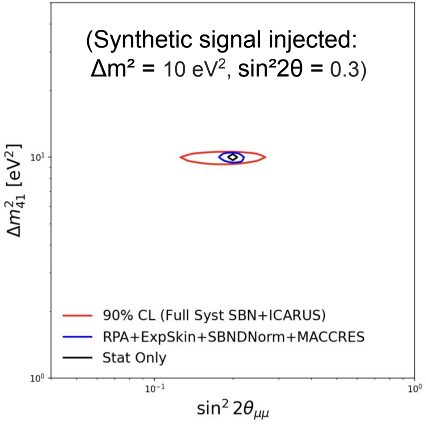
- Tool for **oscillation and cross-section fits**
- Integrates **MC inputs, systematics, and correlations**
- Supports **profiling and 2D parameter scans**
- Enables **signal injection** and “what-if” studies
- Portable across **SBND, ICARUS, MicroBooNE, DUNE**

Perform Δχ² scans in oscillation parameters:

- Confidence regions in (Δm², sin²2θ)
- Impact of systematic models
- Data/MC agreement with full uncertainty propagation







Laying the groundwork toward SBN-wide analyses!

Proposed analysis and new ideas

Multiple channels analysis

The excellent SPINE performances allows to select independent channels to perform separate analysis.
GENIE can provide a estimated event rates for many channels in SBND and ICARUS:

ν_μ CC Channels

- **CC Inclusive**
- **CC 0π**
  - **μ + 0p**
  - **μ + 1p**
  - **μ + 2p**
  - **μ + ≥3p**
- **CC 1π±**
- **CC ≥2π±**
- **CC ≥1π^0**

ν_μ NC Channels

- **NC Inclusive**
- **NC 0π**
- **NC 1π±**
- **NC ≥2π±**
- **NC ≥1π^0**

ν_e Channels

- **ν_e CC Inclusive**
- **ν_e NC Inclusive**

Rare Channels

- **Hyperon Λ^0 Production**
- **Hyperon Σ^+ Production**
- **ν–e Scattering (ν + e → ν + e)**

High statistics:

- wide range of νμ CC and NC channels → precision cross-section studies.

Oscillation sensitivity:

- νμ disappearance (robust, high-statistics test).
- νμ → νe appearance (sensitive to LSND/MiniBooNE anomalies).

Rare processes accessible:

- hyperon production, ν–e scattering.

Systematics control:

- multiple topologies and final states constrain nuclear models.

Analyses underway with SPINE at SBND and ICARUS

ICARUS

1. BNB νμ selection (J. Mueller, D. Totani)
2. BNB νe selection (J. Xia, Y-J. Jwa)
3. BNB νμ CC/NC-π0 selection (G. Naumann, L. Kashur)
4. NuMI νe selection (D. Carber)
5. NuMI νμ selection (J. Gao)
6. NuMI anti νμ selection with Michels (D. Senadheera)
7. NuMI S→ee selection for Higgs portal scalars (G. Gurung)

SBND

1. BNB νμ selection (B. Carlson, D. Totani, J. Mueller)
2. BNB νe selection (N. Oza, C. Fan)
3. BNB νμ CC/NC-π0 selection (G. Naumann, R. LaZur, B. Weiss)

See slides from Mike Mooney (SBND CM, June 2025)
https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=41665
and Francois Drielsma (NEAT workshop, May 2025)
https://indico.global/event/13925/contributions/125640/

Suggestions and/or other ideas are welcome!!

SPINE first step in SBN selection:

Main oscillation analyses using SPINE planned:

- (1) ICARUS-only ν_μ disappearance analysis -> Final stage.
- (2) SBN-wide ν_μ disappearance analysis -> Starting now! (main topic of these slides)
- (3) SBN-wide ν_μ disappearance and ν_e appearance analysis -> Near future

First look at two prospective selections for a joint muon disappearance analysis (SBND + ICARUS):

- **1μ1p0π, 1μNp0π, νμ CC inclusive**

Other selections on the way for a joint analysis (under investigation now in SBND and ICARUS independently):

- νμ CC inclusive (B. Carlson, J. Mueller, D.Totani)
- νμ CC/NC-π0 (L. Kashur, G. Naumann, R. LaZur, B. Weiss)

Multiple selection options for 1μ1p and 1μNp:

Topology:

- ν_μCC -> 1μ and 0e required for all the cases
- 1p/Np -> at the least one p: 1p is a subset of Np (N>=1)
- 0π -> $0\pi^{\pm}$ and 0γ (-> $0\pi^0$)

TPC:

- Vertex in fiducial volume (FV)
- Contained/Not-contained (study both)

Scintillation Light (PMTs):

- Valid Flashmatch (required or not)
    - PMT timing -> under development
    - CRT match -> under development

4 cases analyzed for **1mu1p** and **1muNp** and both detectors

- Fiducial Volume
- -
- -

- Fiducial Volume
- Containment Cut
- -

- Fiducial Volume
- -
- Valid Flash Match

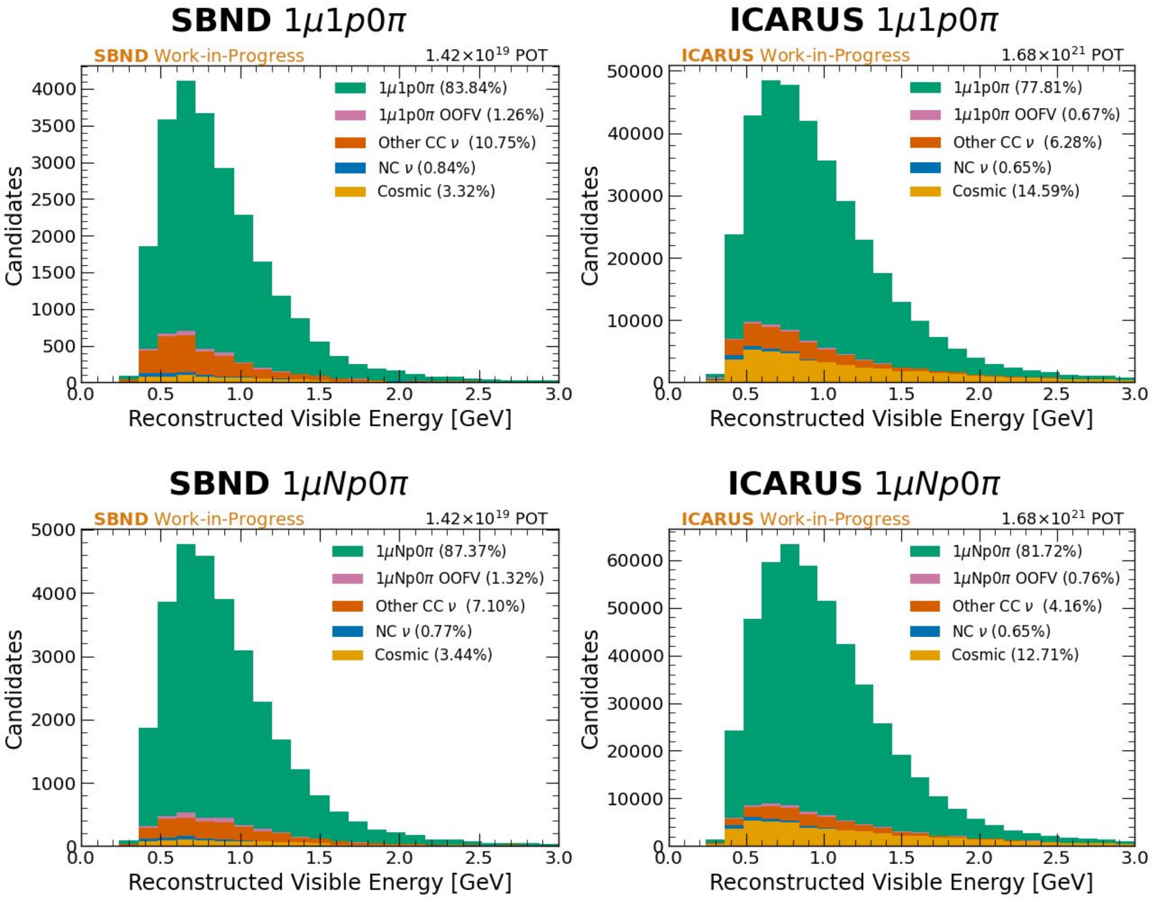
- Fiducial Volume
- Containment Cut
- Valid Flash Match

1μ1p and 1μNp:

Fiducial Volume only:

1µ1p0π	SBND	ICARUS
Efficiency	80.5%	81.0%
Purity	83.8%	77.8%
Cosmic	3.3%	14.6%

1µNp0π	SBND	ICARUS
Efficiency	74.4%	78.6%
Purity	87.4%	81.7%
Cosmic	3.4%	12.7%

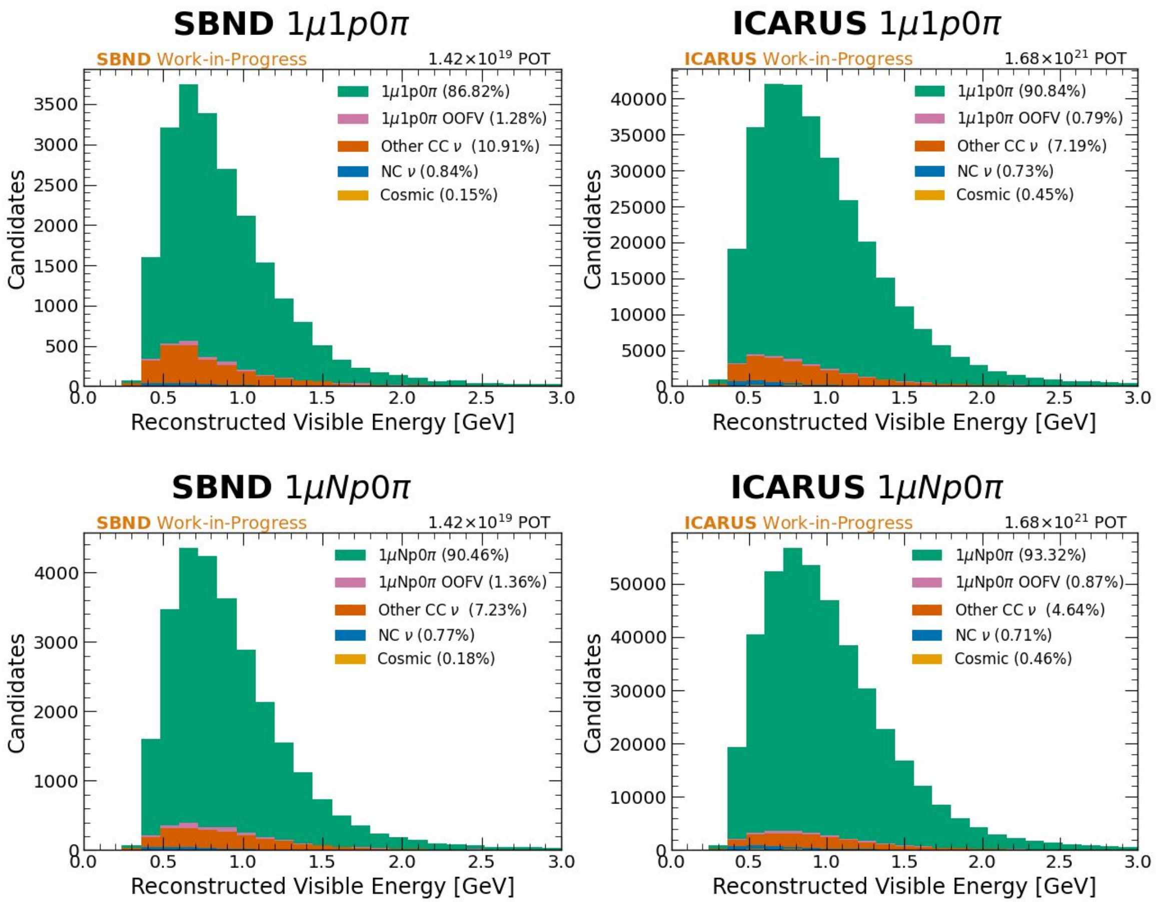


1μ1p and 1μNp:

Fiducial Volume + Flashmatch

1μ1p0π	SBND	ICARUS
Efficiency	75.8%	78.7%
Purity	86.8%	90.8%
Cosmic	0.1%	0.4%

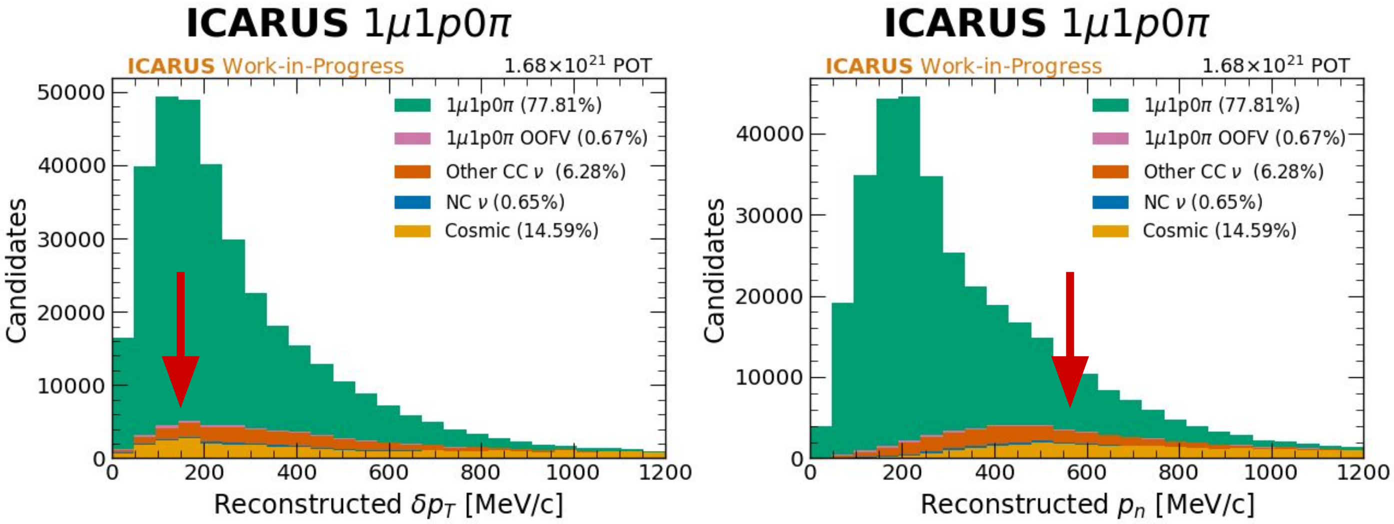
1μNp0π	SBND	ICARUS
Efficiency	70.3%	76.4%
Purity	90.5%	93.3%
Cosmic	0.2%	0.5%



δp_T vs. p_n → PROfit: 2D fit

A useful tool is the possibility to implement a simultaneous fit on two different variables improving sensitivity using variables where background and signals behave differently:

Transverse momentum: δp_T vs . Total missing momentum: p_n



1mu1p FV-only

cosmic background displacement between δp_T and p_n

Preliminary Sensitivity Studies of an SBN 1μNp Disappearance Search with SPINE

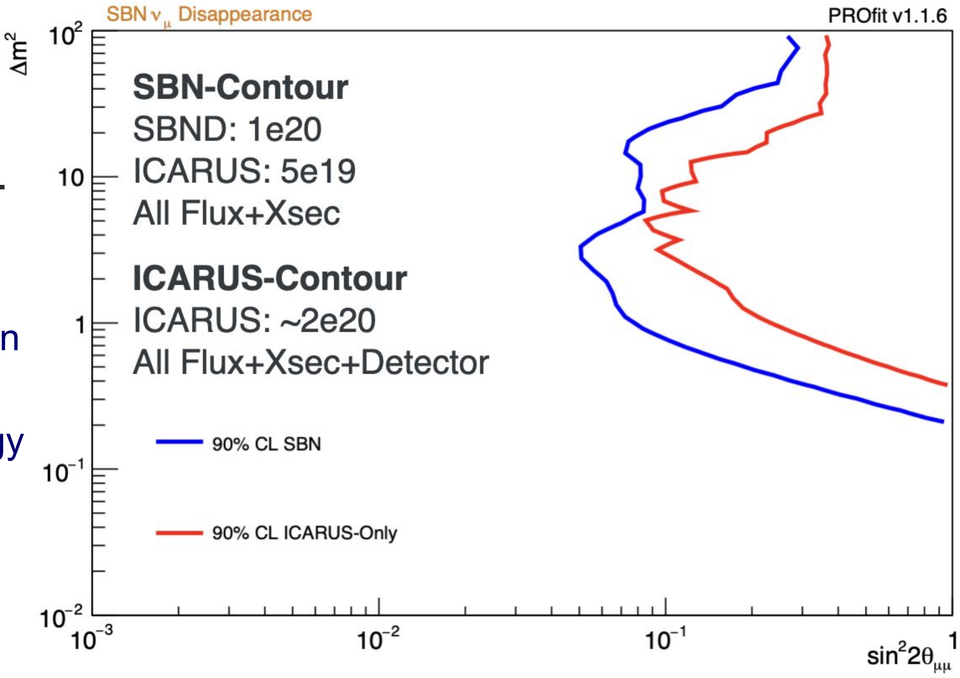
From Justin's talk at SBN Oscillation WG
https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=43417

- With SPINE, we already have a mature 1μ1p and 1μNp selection built for ICARUS

Moving forward to a SBN-wide sensitivity study.

Preliminary analysis snapshots:

- hypothetical source of additional cosmic rejection efficiency
- shrink the residual between reconstructed energy and true neutrino energy by some scale factor
- run the sensitivity calculation at multiple exposure values
- work in progress on systematic



Moving to ν_μCC inclusive:

TKI/GKI variables could provide signal/background discrimination in a 2D fit along with Visible Energy (reconstructed neutrino energy):

- Transverse momentum: δp_T
- Total missing momentum: p_n

See Ryan's slides (Dec 2024)
https://sbn-docdb.fnal.gov/cgi-bin/sso/RetrieveFile?docid=39380&filename=SBND%20Dec%20Collab%20Meeting%20-%20Oscillations%20w_%20SPINE%20V4.pdf&version=1

- Muon initial dE/dx
- Flash score

See Brinden's slides (SBND CM, June 2025)
https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=41650

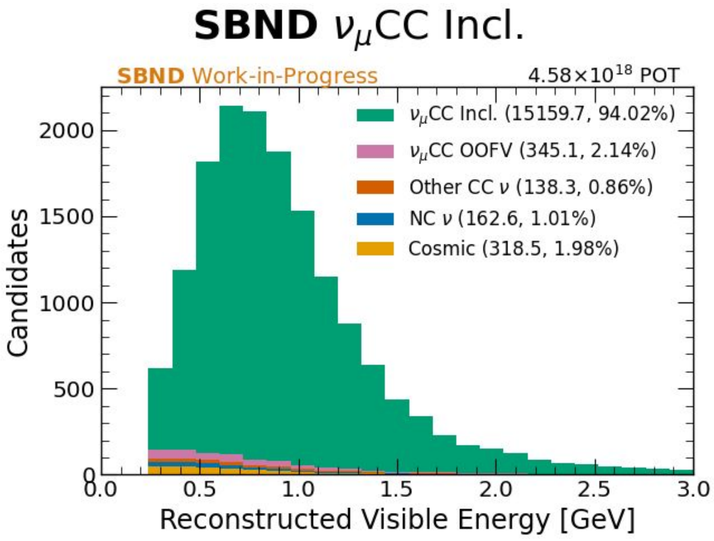
- Muon cathode offset
- Charge time containment
- Geometrical parameters
  - Neutrino vertex
  - Muon start/end point
  - Muon polar/azimuthal angle

Analysis ongoing

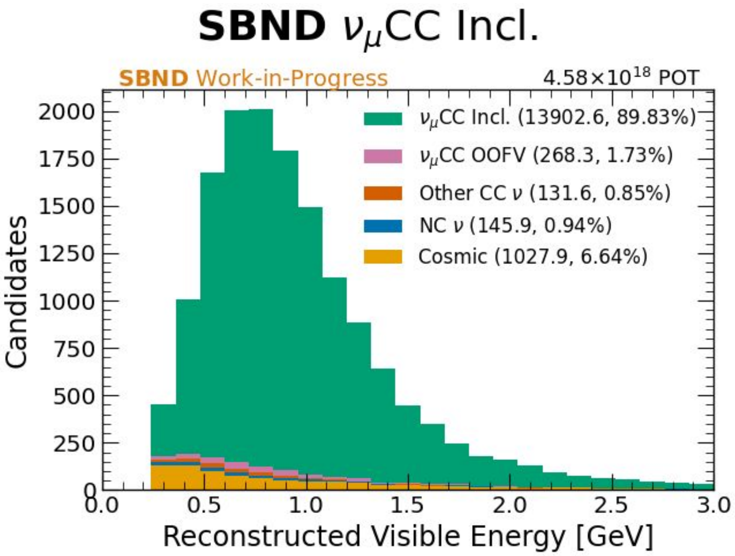
SBND ν_μCC inclusive: FV, with flashmatch vs TPC - geometric cuts

Applying some cuts on muon starting point and direction improve cosmic rejection in disfavor of uniformity, accompanied to TPC based cuts:
time containment cut + dedx [1,7] + cathode offset [-2,2]

Valid flashmatch



TPC /geometric cuts



Next steps:

- Flash Match provide a powerful tool for cosmics rejection, need to improve/validate data-MC comparison
- Selections cuts based on TPC variable (time containment cut, dedx, cathode offset) seems to improve cosmic rejection
  - Better characterization needed
  - Symmetric SBND/ICARUS approach (i.e. time containment cut still not available in ICARUS)
- Single μ CC selection large cosmic contamination:
  - Developing alternative cuts to reject cosmics
- Investigating other selections topologies:
  - Sensitivity studies using PROfit.

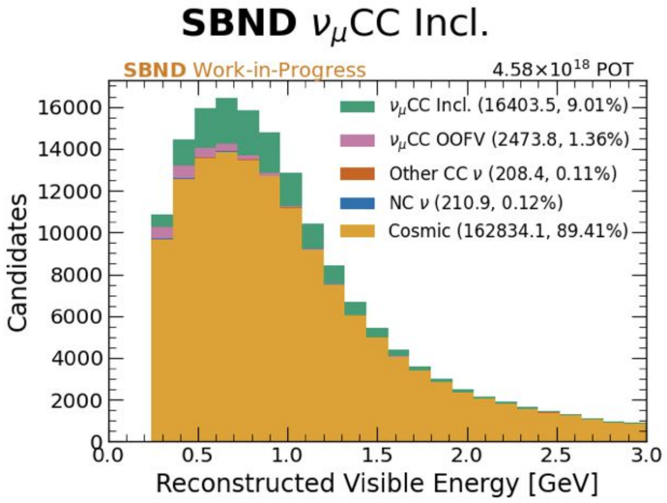
Backup slides

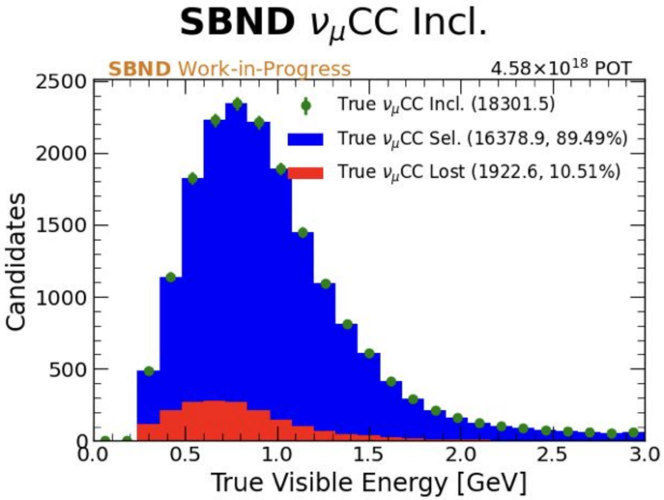
SBND ν_μCC inclusive: fiducial volume only

Selection: 1mu, 0e, in FV (no other cuts selections applied)

A huge amount of cosmics is present

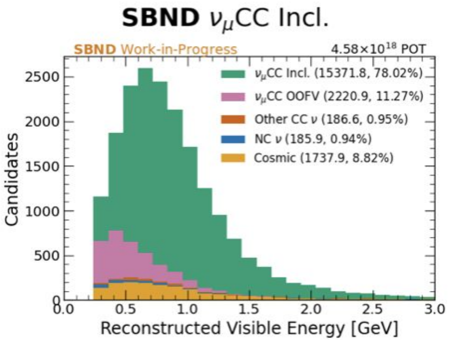
Efficiency on true numuCC =89.5%

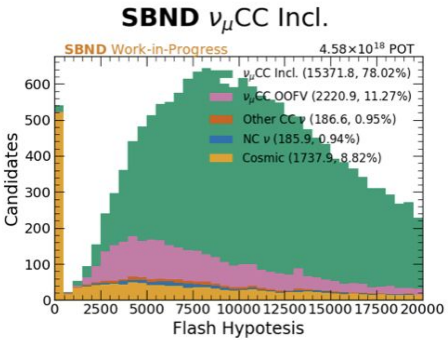


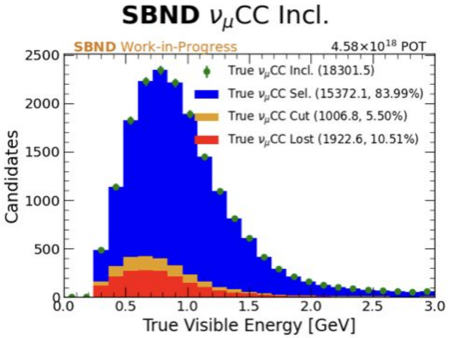


SBND ν_μCC inclusive: fiducial volume + scintillation light cuts

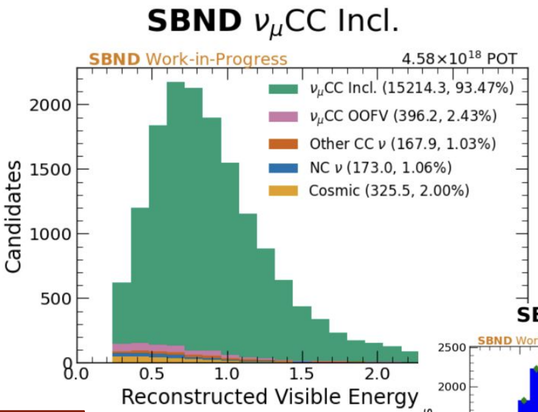
Selection: 1mu, 0e, in FV + reco valid flash match

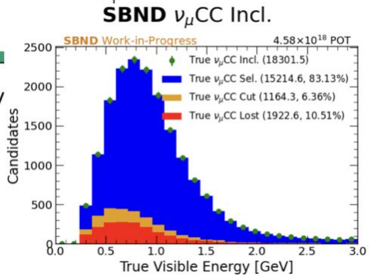






reco valid flash match + reco flash hypothesis <1000

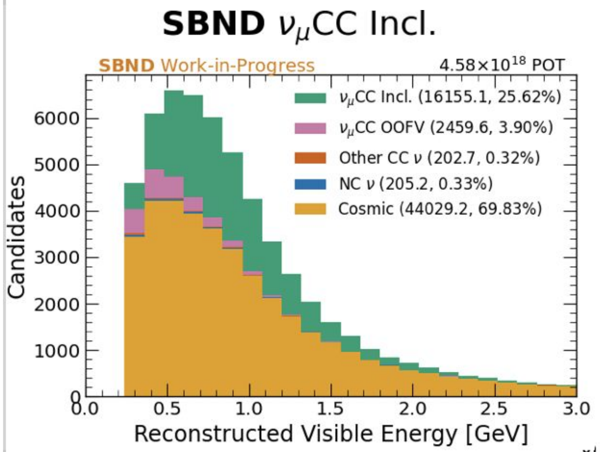




Based on Brinden's selection:
https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=41650

SBND ν_μCC inclusive: TPC only cuts

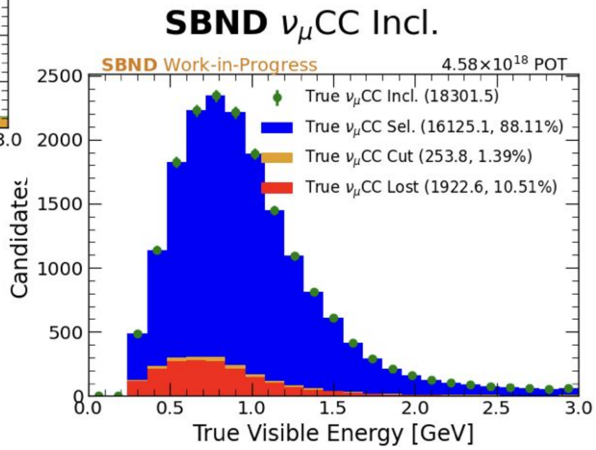
Selection: 1mu0eX, in FV + time containment cut + dedx [1,7] + cathode offset [-2,2]



2/3 of cosmic removed

Cosmic = sim + intime

Negligible loss of efficiency

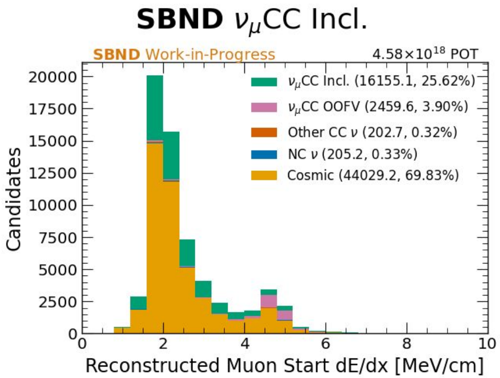


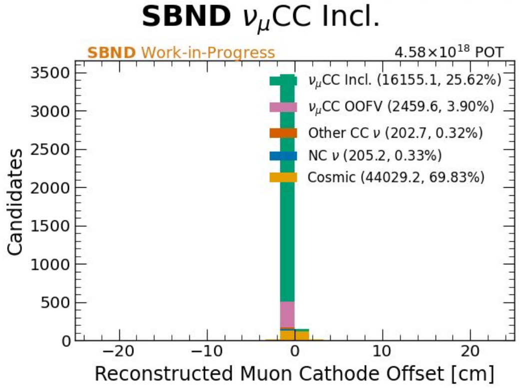
Multiple parameter under investigation.

⅔ of cosmic background removed but still large.

SBND ν_μCC inclusive: TPC only cuts

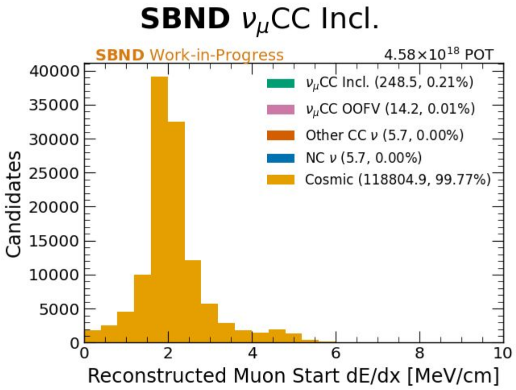
Selection: 1mu0eX, in FV + time containment cut + dedx [1,7] + cathode offset [-2,2]

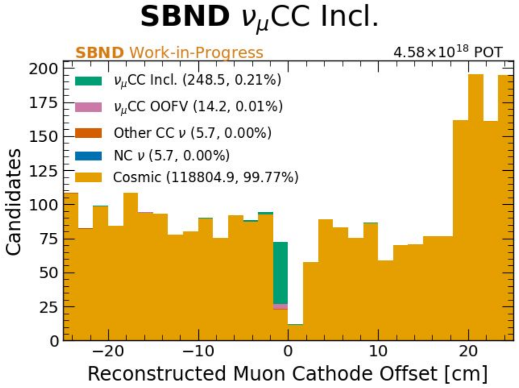




Selected Evts.

Evts. cut



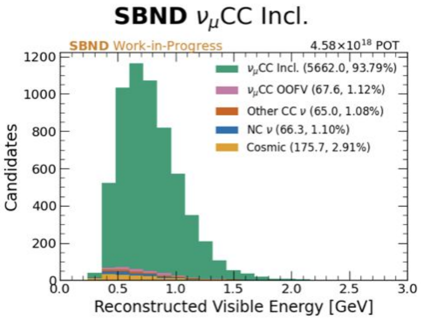


SBND ν_μCC inclusive channels split

Selection: 1mu0eX, in FV + time containment cut

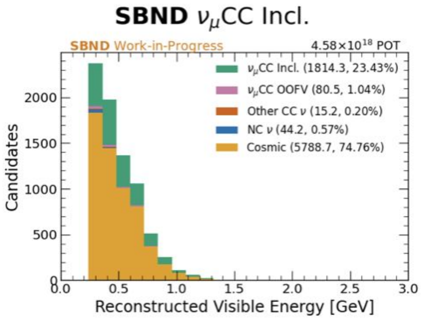
Split in 4 gourps: Cont./Not Cont and 1mu only/1mu +X

1muX Cont



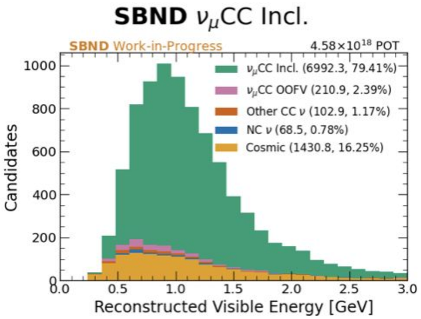
1mu only

Cont



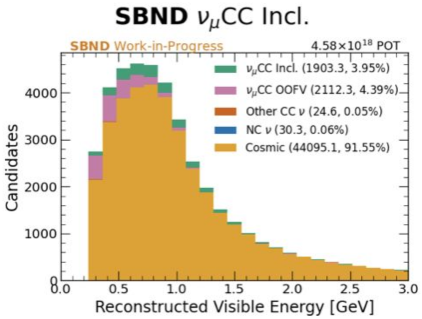
1muX

Not Cont.



1mu only

Not Cont.



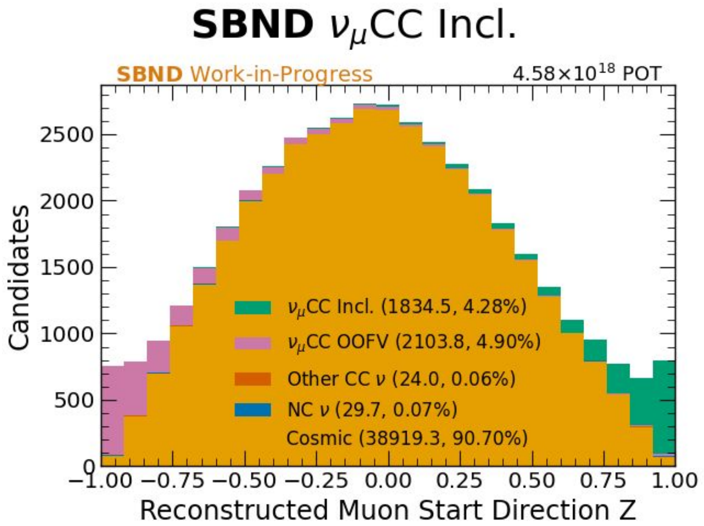
SBND ν_μCC: Sub channels proposed geometric cut

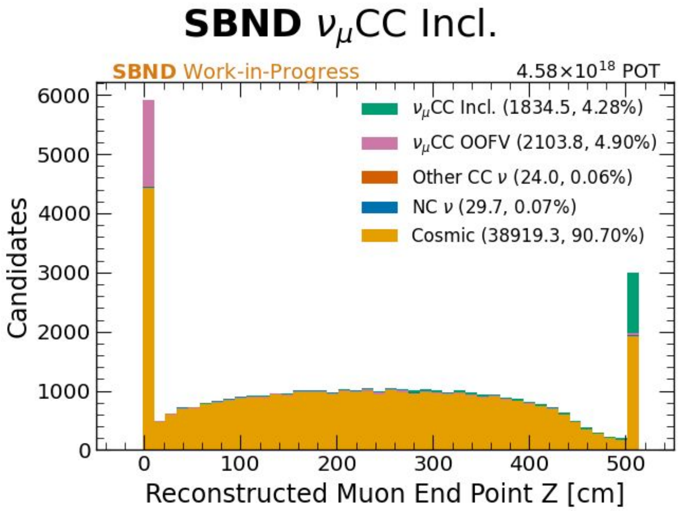
Specific sub-selections shows a huge amount of cosmic contamination.

Proposed approach:

- Split selection in sub categories
- Perform strong cuts on specific geometric variables showing peculiar distributions:

Selection: Single mu only, exiting TPC, in FV + time containment cut + dedx [1,7] + cathode offset [-2,2]

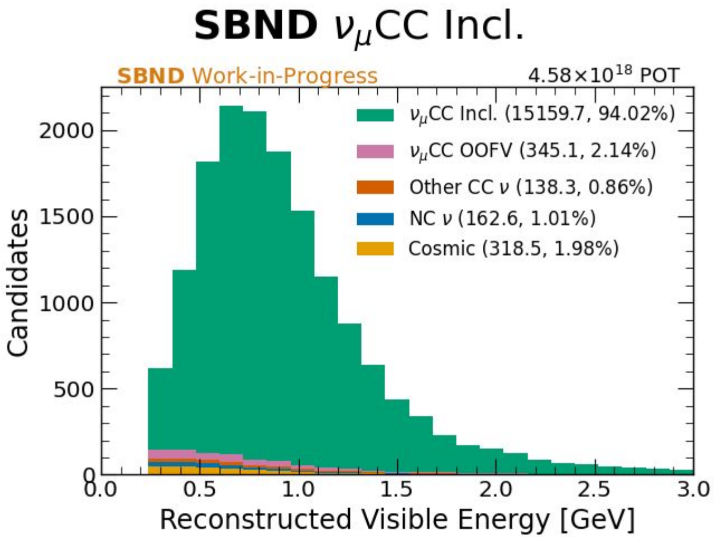




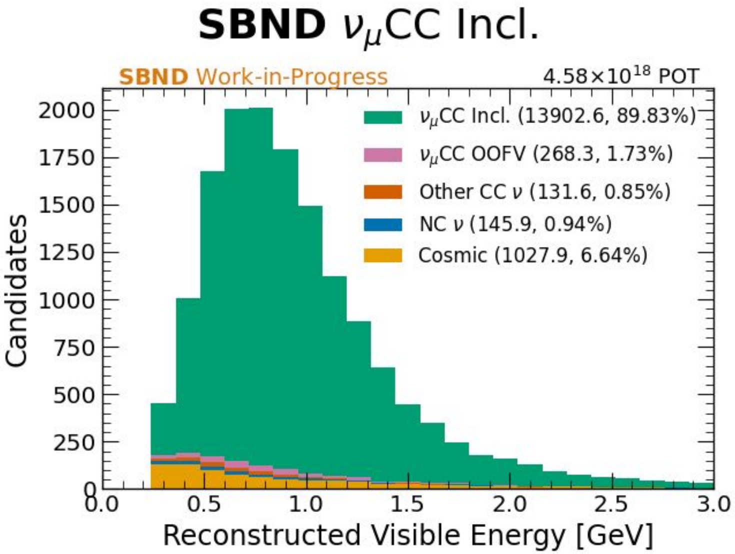
SBND ν_μCC inclusive: FV, with flashmatch vs TPC - geometric cuts

Applying some cuts on muon starting point and direction improve cosmic rejection in disfavor of uniformity

valid flashmatch

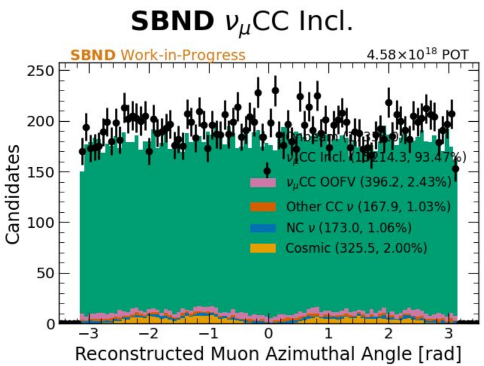


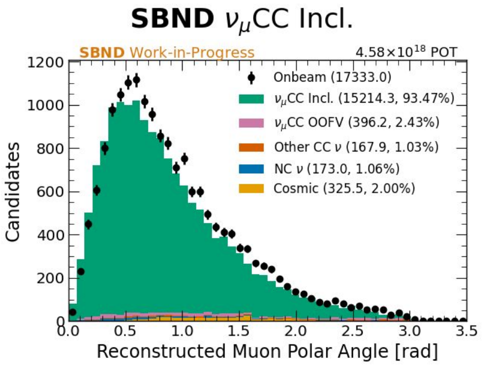
geometric cuts



SBND ν_μCC inclusive: FV, with flashmatch vs TPC - geometric cuts

valid flashmatch

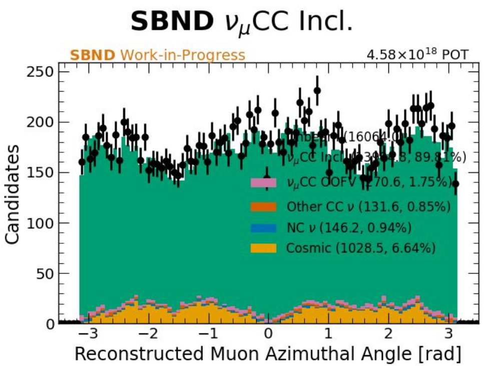


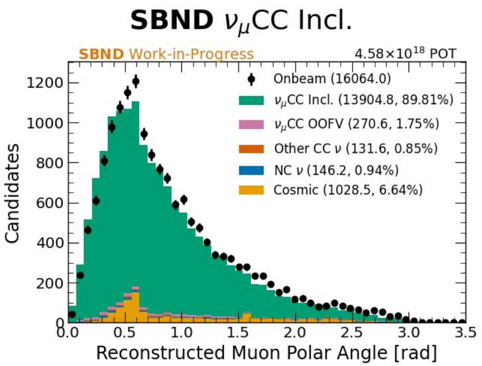


Muon polar and azimuthal angles are good parameter to check the bias introduced by cuts.

Flash match provide a powerful uniform cut w/o introducing major non-uniformity

geometric cuts





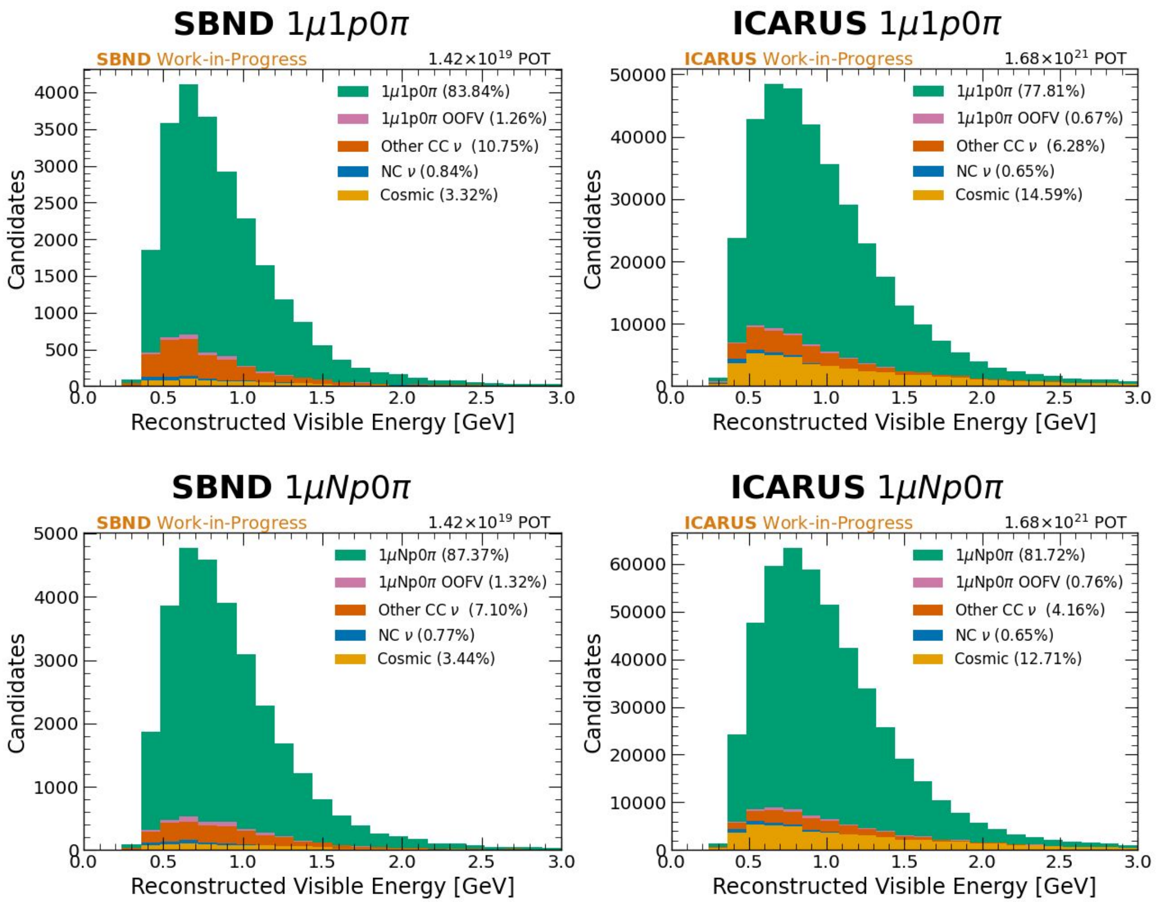
1μ1p and 1μNp:

Selection cut:

- Fiducial Volume

1μ1p0π	SBND	ICARUS
Efficiency	80.5%	81.0%
Purity	83.8%	77.8%
Cosmic	3.3%	14.6%

1μNp0π	SBND	ICARUS
Efficiency	74.4%	78.6%
Purity	87.4%	81.7%
Cosmic	3.4%	12.7%

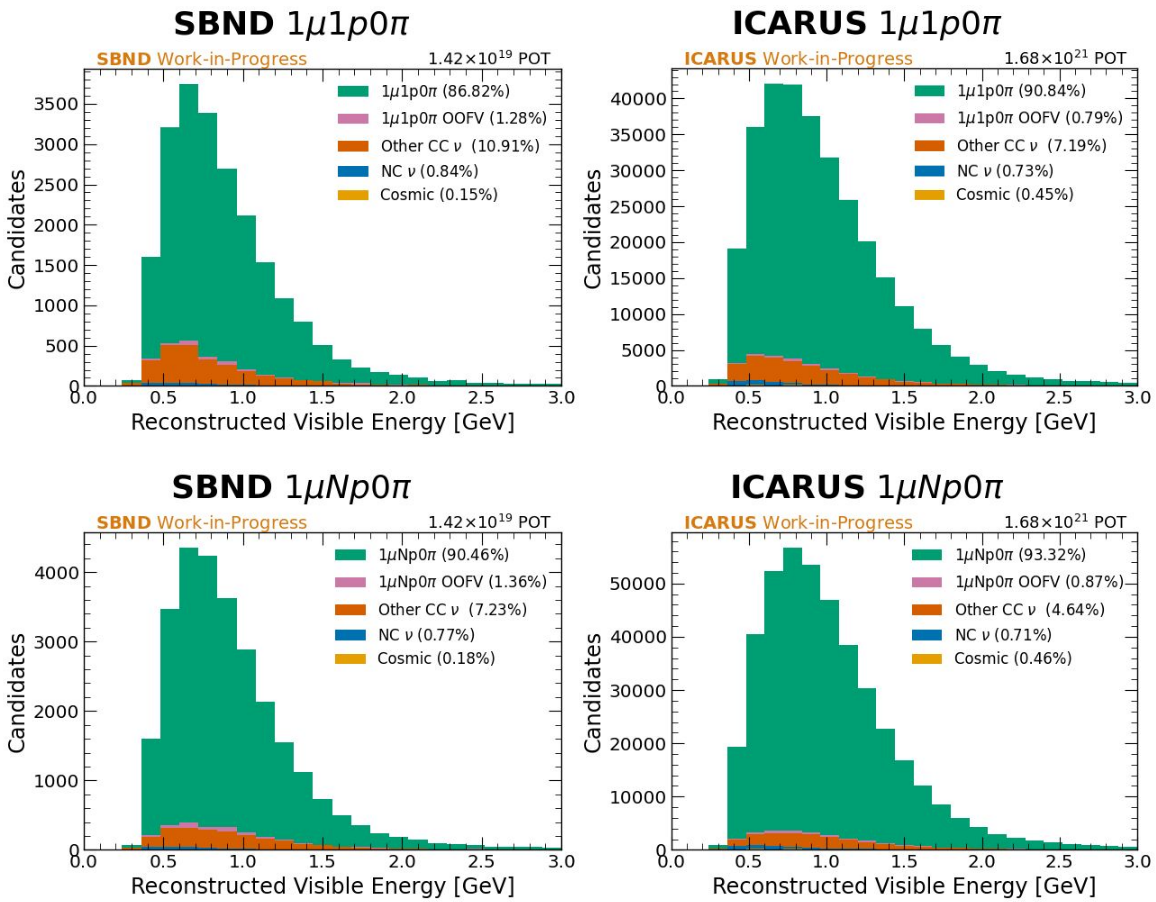


Selection cut:

- Fiducial Volume
- -
- Valid Flash Match

1μ1p0π	SBND	ICARUS
Efficiency	75.8%	78.7%
Purity	86.8%	90.8%
Cosmic	0.1%	0.4%

1μNp0π	SBND	ICARUS
Efficiency	70.3%	76.4%
Purity	90.5%	93.3%
Cosmic	0.2%	0.5%

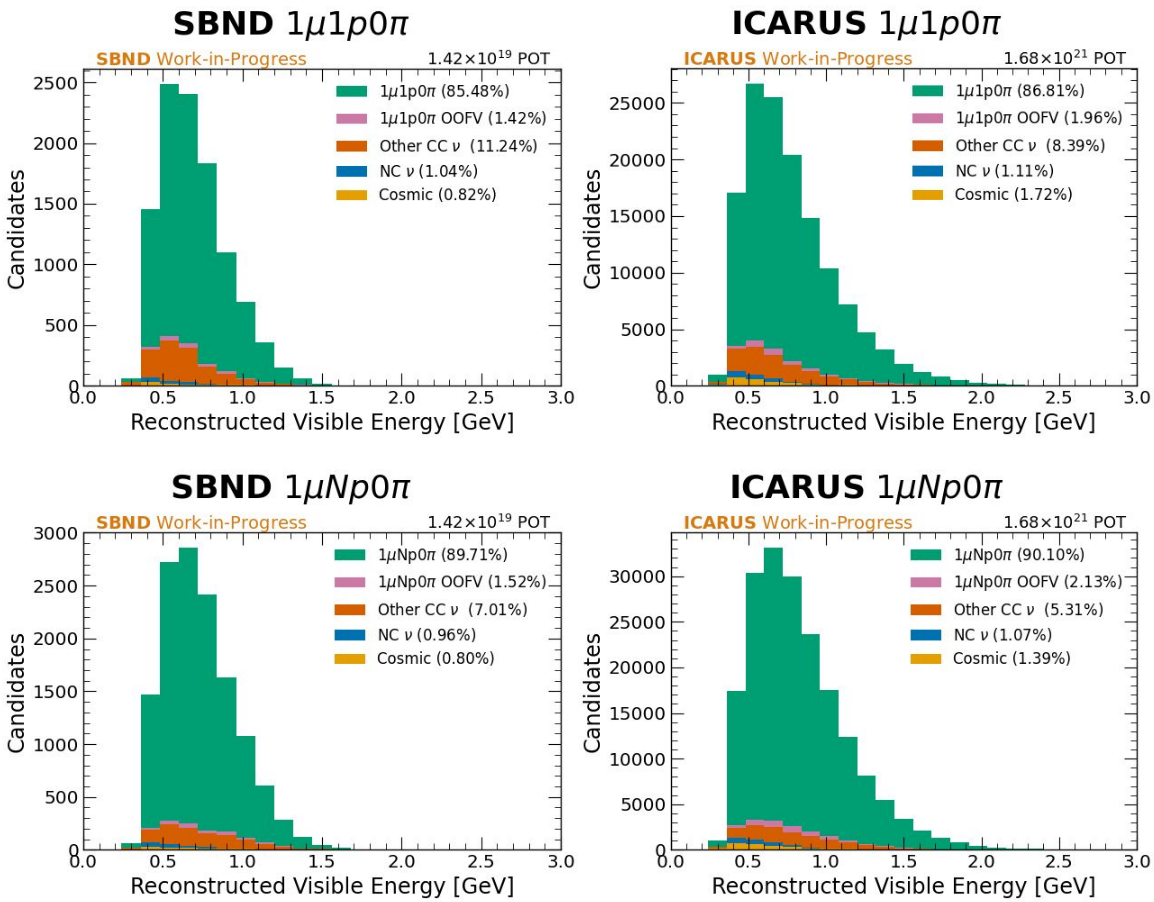


Selection cut:

- Fiducial Volume
- Containment Cut
- -

1μ1p0π	SBND	ICARUS
Efficiency	77.1%	77.1%
Purity	85.5%	86.8%
Cosmic	0.8%	1.7%

1μNp0π	SBND	ICARUS
Efficiency	70.3%	74.3%
Purity	89.7%	90.1%
Cosmic	0.8%	1.4%

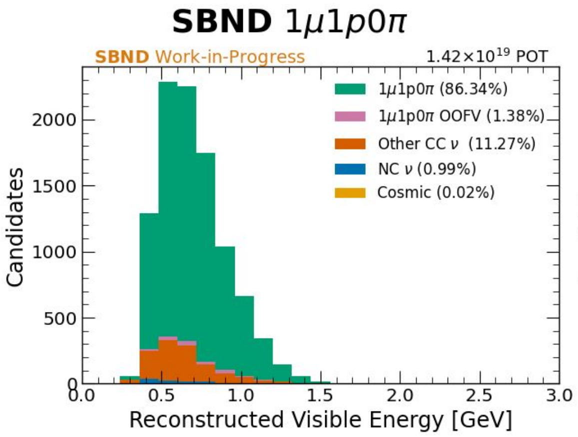


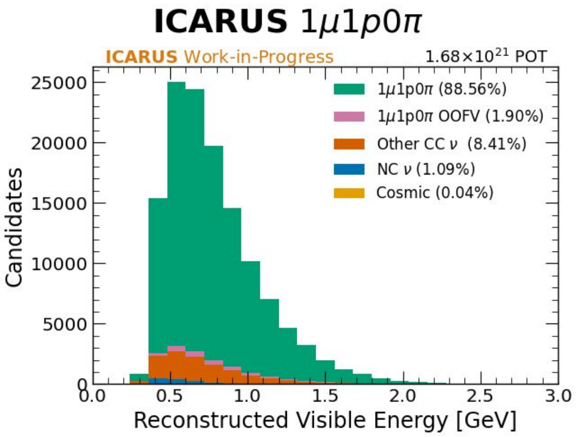
Selection cut:

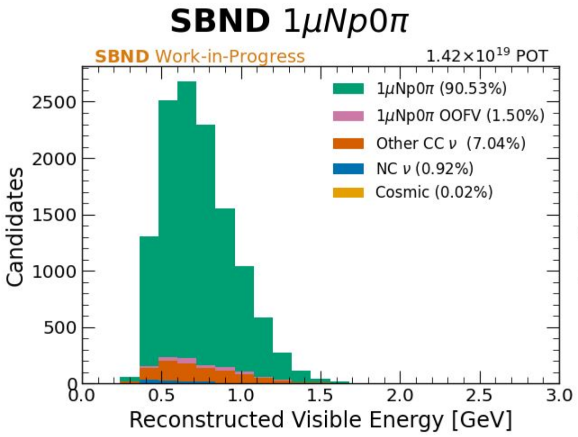
- Fiducial Volume
- Containment Cut
- Valid Flash Match

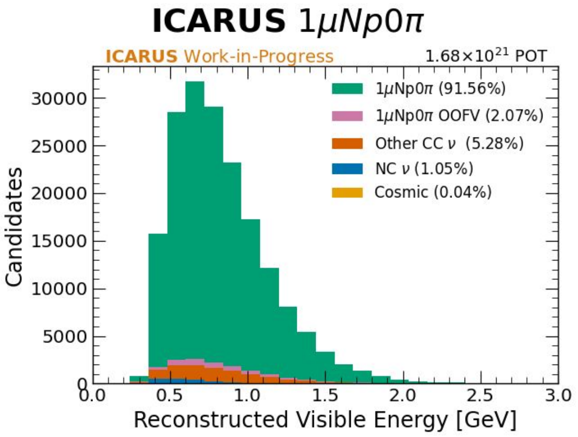
1μ1p0π	**SBND**	**ICARUS**
Efficiency	72.7%	75.2%
Purity	86.3%	88.6%
Cosmic	<0.1%	<0.1%

1μNp0π	**SBND**	**ICARUS**
Efficiency	66.6%	72.5%
Purity	90.5%	91.6%
Cosmic	<0.1%	<0.1%









Purity x Efficiency (PxE)

SBND 1μ1p0π FV	w/o flashmatch	with flashmatch
w/o containment	PxE = 0.67	PxE = 0.66
with containment	PxE = 0.66	PxE = 0.63

ICARUS 1μ1p0π FV	w/o flashmatch	with flashmatch
w/o containment	PxE = 0.63	PxE = 0.71
with containment	PxE = 0.67	PxE = 0.67

SBND 1μNp0π FV	w/o flashmatch	with flashmatch
w/o containment	PxE = 0.65	PxE = 0.63
with containment	PxE = 0.63	PxE = 0.60

ICARUS 1μNp0π FV	w/o flashmatch	with flashmatch
w/o containment	PxE = 0.64	PxE = 0.71
with containment	PxE = 0.67	PxE = 0.66

Preliminary Sensitivity Studies of an SBN 1μNp Disappearance Search with SPINE from Justin talk: https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=43417

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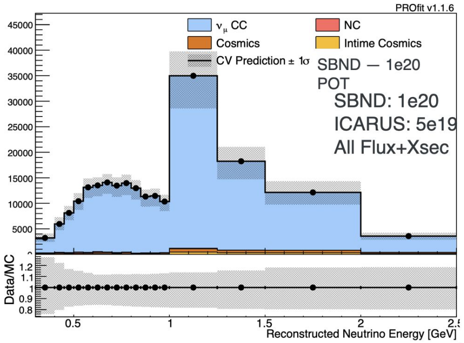

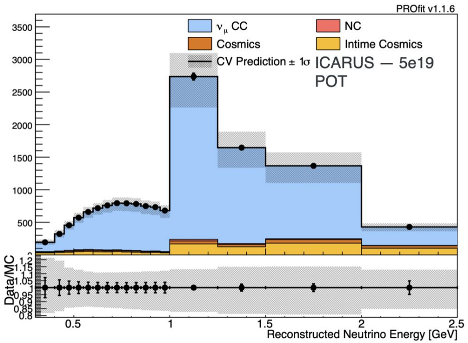

- Using a "default" binning scheme from the proposal that is not optimized

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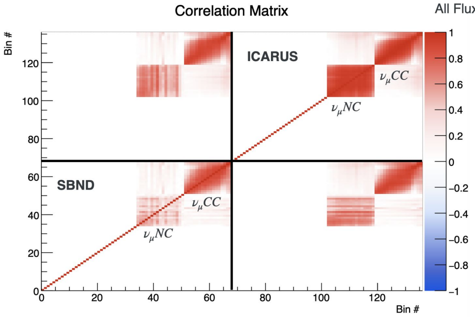
SBND: 1e20
ICARUS: 5e19
All Flux+Xsec



Fractional Uncertainties

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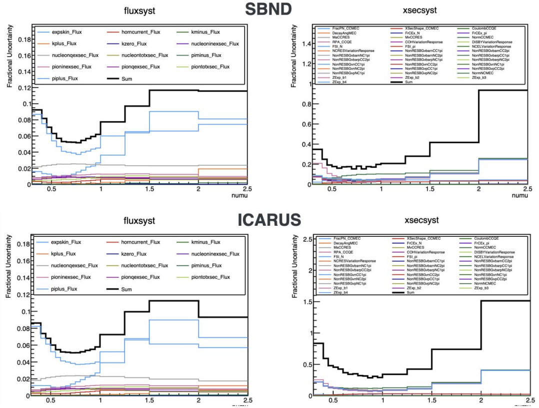
SBND: 1e20
ICARUS: 5e19
All Flux+Xsec

- Not a particularly pretty plot (there are only so many colors!), but it gives a sense of scale
- We can begin to resolve which systematics are important for this analysis
- Need to investigate some of the xsec systematics in ICARUS



Preliminary Sensitivity Studies of an SBN 1μNp Disappearance Search with SPINE from Justin talk: https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=43417

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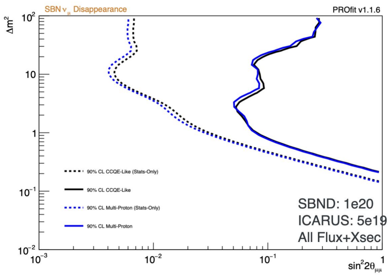
- How do $1\mu 1p0\pi$ and $1\mu Np0\pi$ compare as target final states?
- The multi-proton final state covers higher energies and increases statistics
  - Observed expected improvement in stats-only sensitivity
  - Slightly higher sensitivity at higher Δm^2 (higher energy signal)
- In the interest of time, I will focus on studies with the multi-proton final state from here



Impact of Energy Resolution

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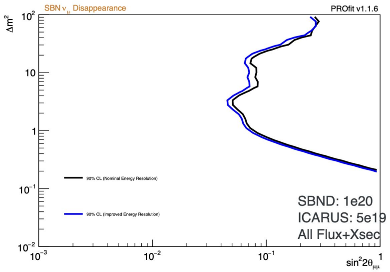
- Idea: shrink the residual between reconstructed energy and true neutrino energy by some scale factor (25% here)
- Answers the question: how much can energy resolution improve this result?

Noticeable sensitivity gain by improving energy reconstruction (not terribly surprising)



Impact of Cosmics

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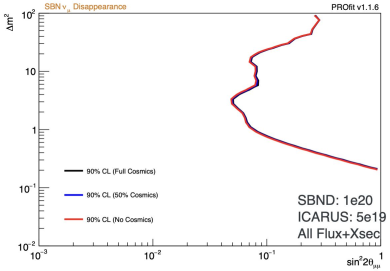
- Idea: mock-up a hypothetical source of additional cosmic rejection efficiency (flat reduction)
- Provides an idea of how important additional cosmic rejection is
- One important caveat: CORSIKA cosmics have no assessed systematic uncertainty

Negligible improvement in *this* channel from additional cosmic rejection



Different SBND Exposure Targets

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- What about statistics?
- Re-run the sensitivity calculation at a few choice exposure values:
  - 1e20 — "nominal"
  - 5e19 — an intermediate point
  - 5e18 — "fixed Dev. Sample" (SBND)
- The one plot I had time to remake with the correct ICARUS exposure (2e20 POT)

Already "maxed out" at 5e19, but some sensitivity improvement present beyond the development sample exposure