A preliminary ν_μ CC 0π event selection in SBND

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On behalf of the SBND collaboration

New Perspectives, Fermilab
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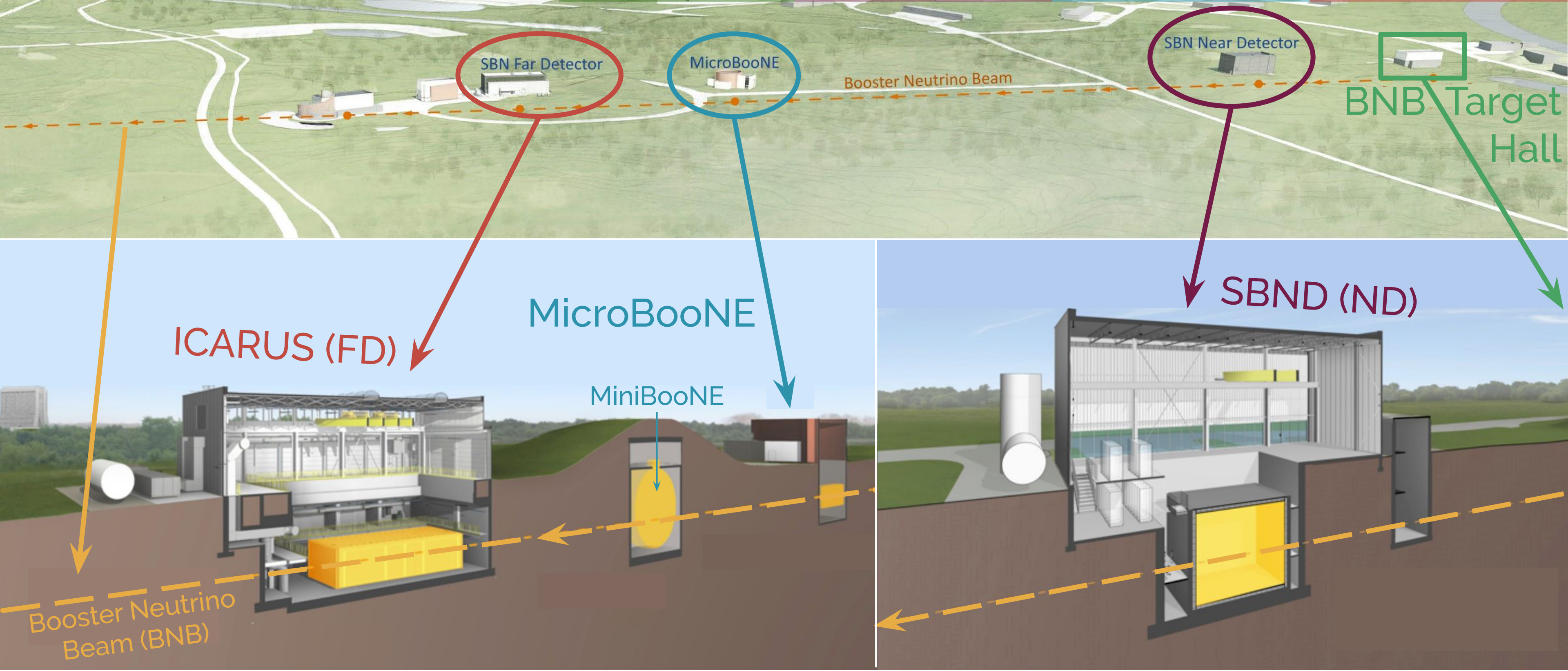
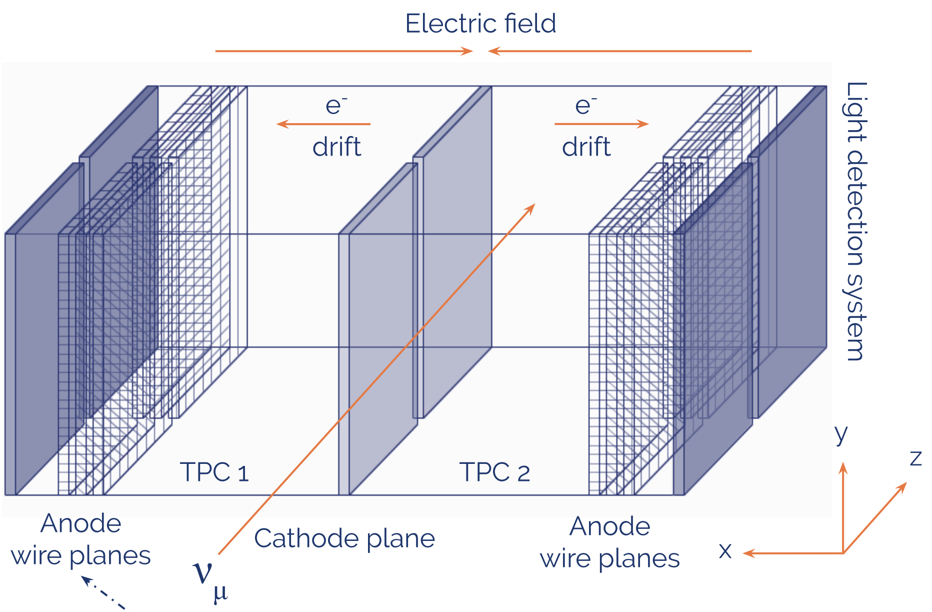
The SBN Program

	SBND	MicroBooNE	ICARUS
Baseline [m]	110	470	600
Argon mass [t]	112	89	476



The Short Baseline Near Detector, SBND

- Liquid argon time projection chamber
  - 112 tonnes of liquid argon
  - 4 x 4 x 5 m^3
  - 110 m from the neutrino source
- 500 V/cm electric field across the TPC
  - Neutrinos interact and ionise the argon
  - Field drifts ionisation electrons towards one of the anode plane assemblies (APAs)
- 2 electron drift volumes
  - Connected at the centre by the cathode plane assembly
- All TPC components are now at Fermilab!
  - Installation will begin this year
  - Running by the beginning of 2021



2 of our APAs have been unpacked and aligned, the second 2 are here at Fermilab, awaiting the same

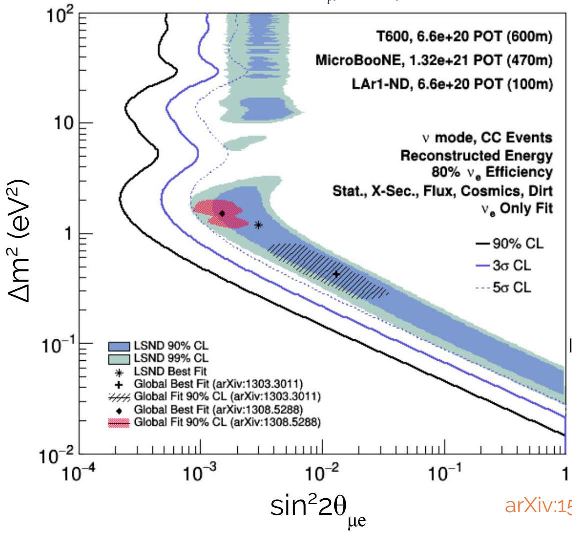
The physics program of SBND

- Near detector in the SBN oscillation analysis
  - Characterise the initial flux of the neutrinos
  - Confirm or rule out the existence of light sterile neutrinos

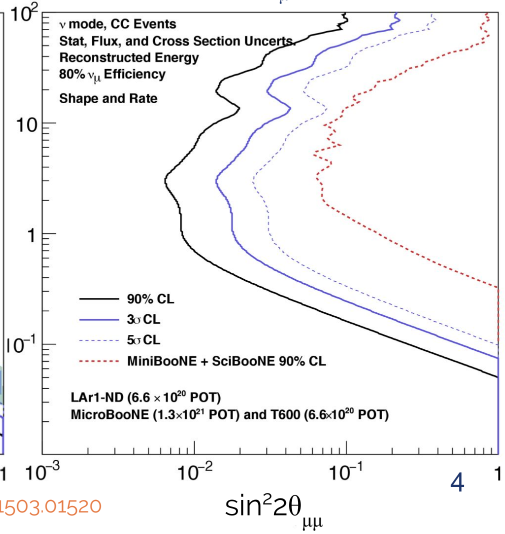
- Unprecedentedly high statistics
  - ~ 7,000,000 ν_μ events over 3 years
  - ~20 times µBooNE, ~10 times ICARUS

- Will make high-precision cross-section measurements of neutrino interactions with argon nuclei at ~1 GeV

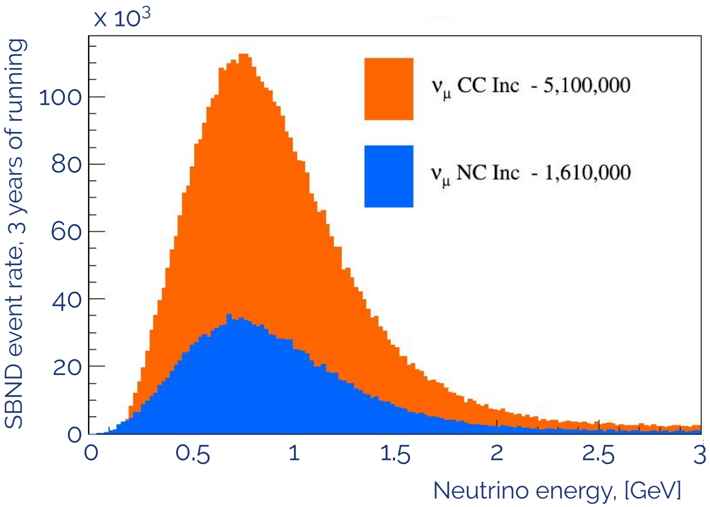
SBN sensitivity to $\nu_\mu \rightarrow \nu_e$ oscillations



SBN sensitivity to $\nu_\mu \rightarrow \nu_x$ oscillations



arXiv:1503.01520



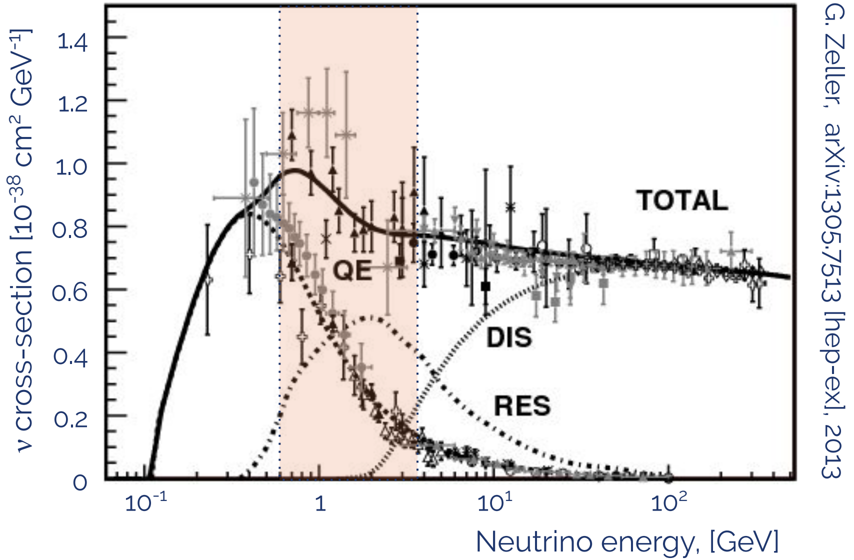
Cross-sections in the few-GeV energy range

- Neutrino interactions in the few GeV energy region are very interesting
  - Boundary between perturbative and non-perturbative regimes
    - QE, RES and DIS cross-over
  - Historically, very little data in this region

- Interactions on heavy nuclei are not yet well understood
  - Many unconstrained models exist

- Datasets from recent experiments are starting to help constrain these models
  - Such as MINERvA and MiniBooNE

Neutrino scattering cross-section data



SBND will provide data in this energy region with huge statistics giving us tighter constraints on these neutrino-nuclei models

ν_μ CC 0π in SBND

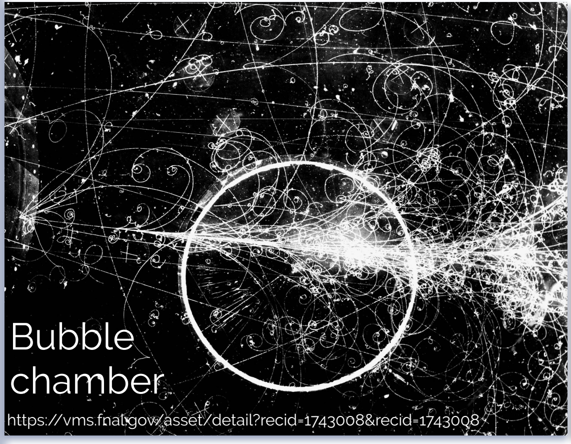
- LArTPC detector technology:
  - Bubble chamber resolution capability (~mm)
  - Automated event processing
  - Calorimetry

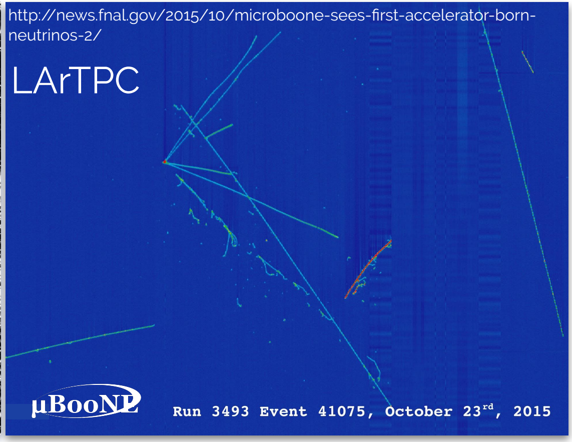
- Can distinguish individual particles in the final state of the neutrino interaction

- ν_μ CC 0π is the most simple and abundant final state in SBND:

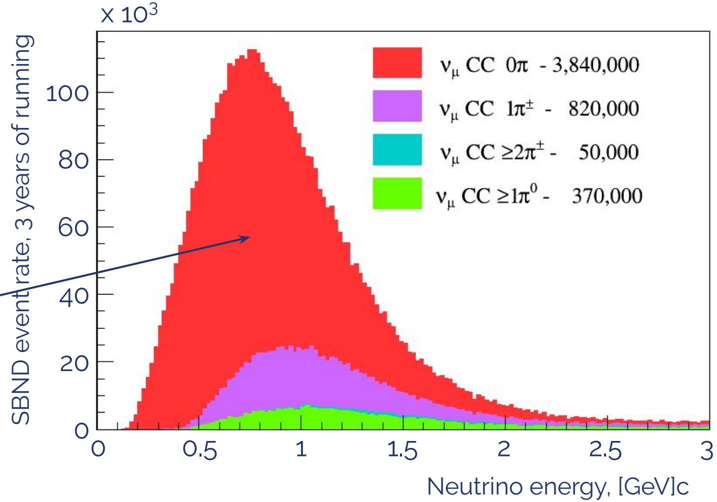
1 muon and any number of protons

- Expect to see ~4,000,000 ν_μ CC 0π events in 3 years

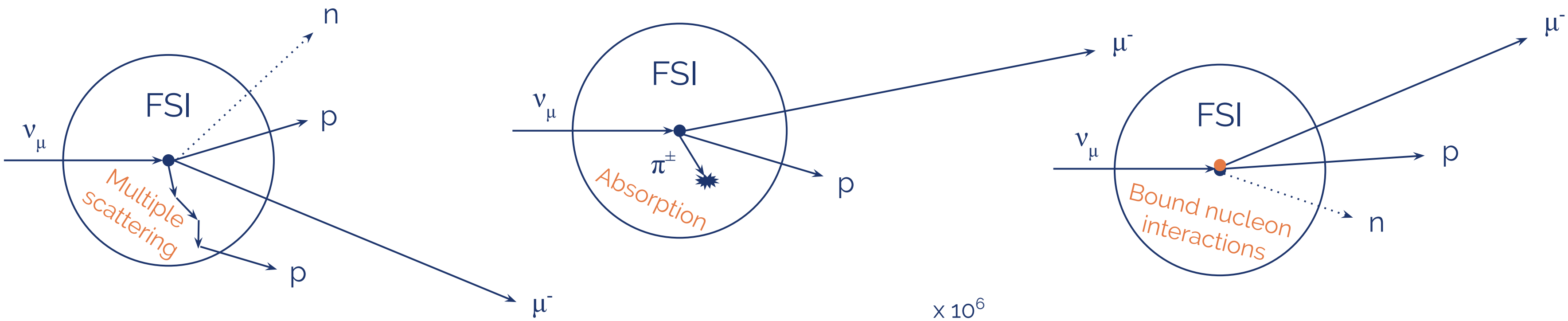




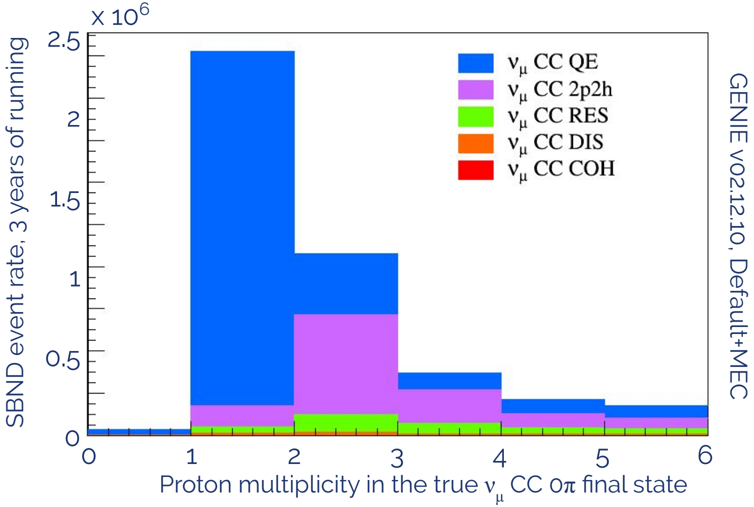
Final state charged current topologies in SBND



Using the ν_μ CC 0π final state in SBND

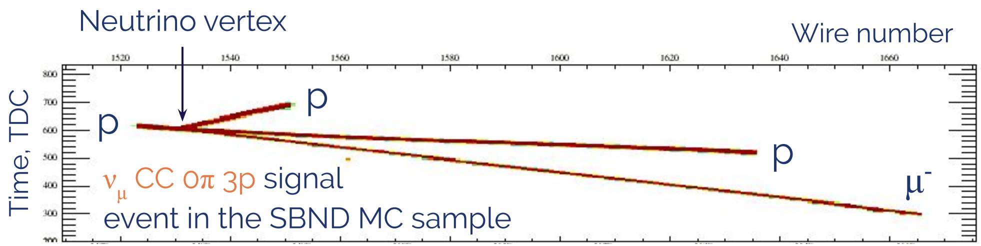


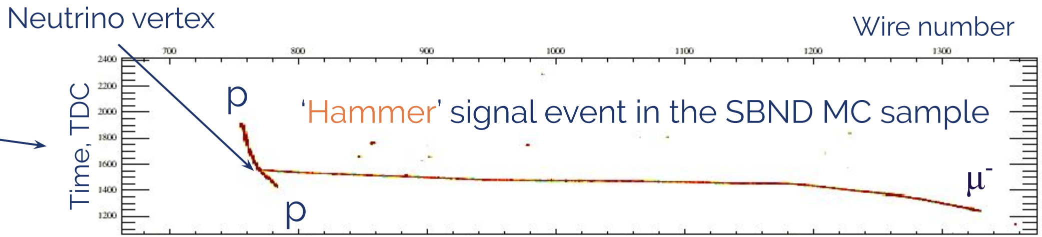
- Nuclear target neutrino experiments don't necessarily observe the products of the initial interaction which took place
- Can use exclusive final state topologies, such as ν_μ CC 0π, to discriminate between neutrino-argon interaction models
  - Distinguishing power in the proton multiplicity of the final state



ν_μ CC 0π final state particles in SBND

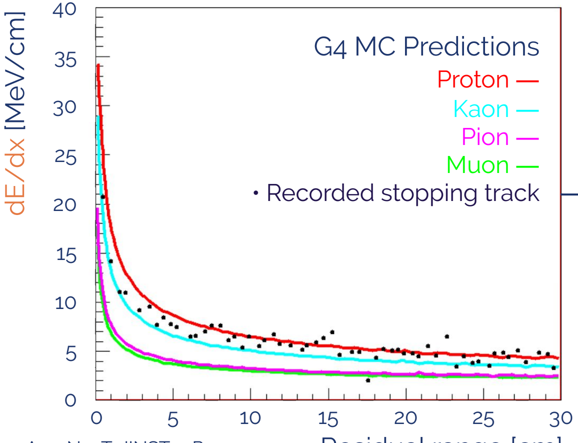
- Monte Carlo SBND ν_μ CC 0π events
- Resolution allows for straightforward particle identification by-eye
- Final states with interesting physical characteristics



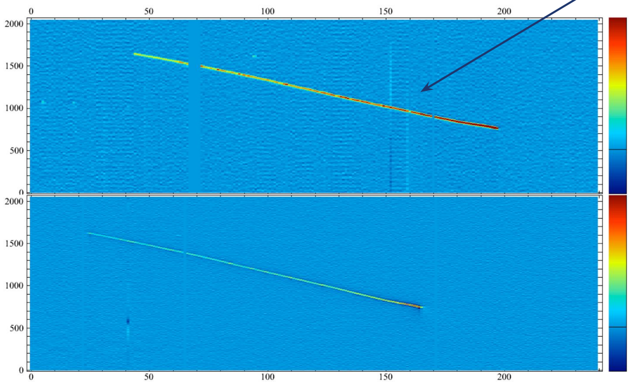


Need to ensure our software can reconstruct and select these events

Selecting ν-Ar interaction final state particles

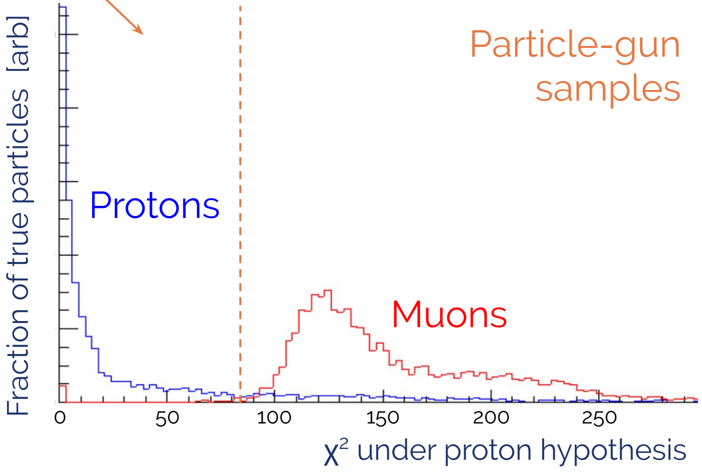


ArgoNeuT, JINST 7, P10019, 2012



- Use calorimetry to distinguish protons from muons & pions
- Use case: Fit the bragg peak of a reconstructed track to the theoretical peak under a certain particle hypothesis
- Fitting to the proton hypothesis has the strongest discrimination power

Protons are correctly distinguished from muons and pions 98% of the time when tested on a BNB sample!



Selecting ν-Ar interaction final state particles

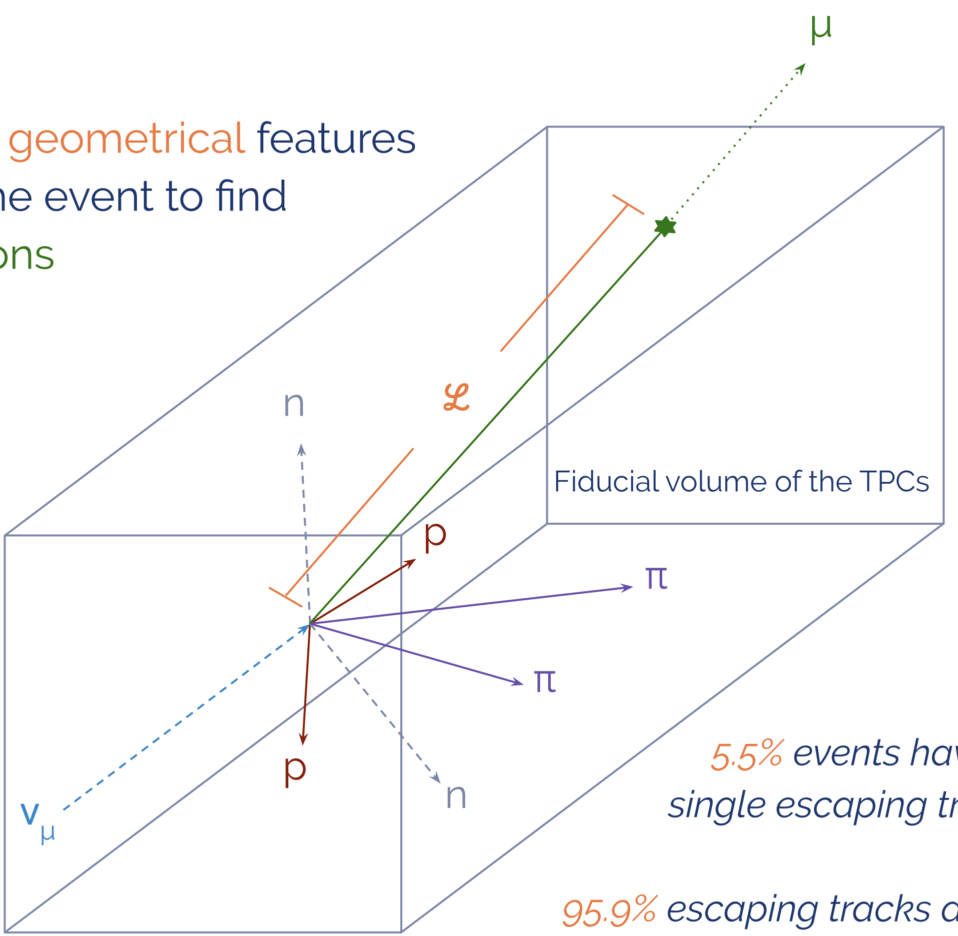
All tracks contained:

- Compare lengths of all particles to determine if a muon exists
- Longest ⇒ muon

Single track escapes:

- Check if the neutrino vertex is far from the exiting border
- Large ℒ ⇒ muon exits

Use geometrical features of the event to find muons



5.5% events have a single escaping track

95.9% escaping tracks are μ

Performance of the selection in SBND

Selected → ↓ True	ν_μ CC Inclusive	ν_μ CC 0π
ν_μ CC 0π	39,100	32,650
ν_μ CC 1π	8,386	3,218
ν_μ CC Other	658	70
ν_μ NC	2,967	2,130
Efficiency	92.0%	76.9%
Purity	94.2%	85.8%

Main sources of topological impurities:

Pion-proton mis-ID
8.5% in 0π

Incorrect-muon finding
5.6% in 0π, 5.8% in Inc.

Efficiency: Signal / Total true

Purity: Signal / Total selected

No external backgrounds (cosmic rays and dirt muons) included in the selection yet

Summary

- SBND will drastically increase the amount of neutrino interaction data on heavy nuclei in the few-GeV energy range

- The LArTPC detector technology allows us to observe final state particles at bubble chamber resolution
    - We can utilise particle selections to produce high-precision cross-section measurements on exclusive final state topologies
    - Oscillation measurements can also be made using exclusive final states to help constrain the interaction systematic uncertainties

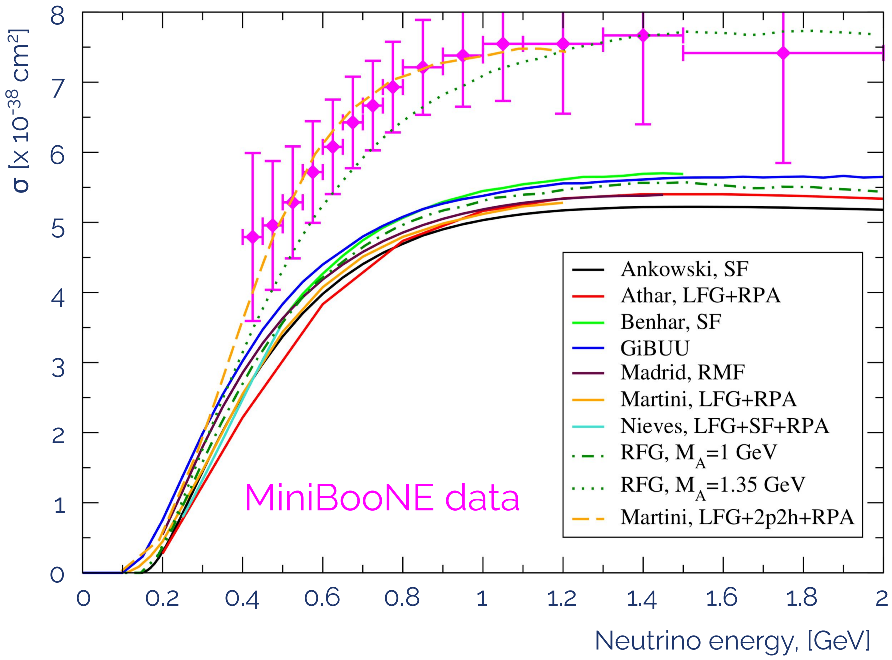
- Understanding neutrino interactions on argon will help future experiments like DUNE probe new and interesting physics

Backup slides

Neutrino-nuclear interactions

CC QE on C_{12}

L. Alvarez-Ruso, arXiv:1012.3871 (Neutrino 2010)



- CC QE on free-nuclei is a theoretically well understood process

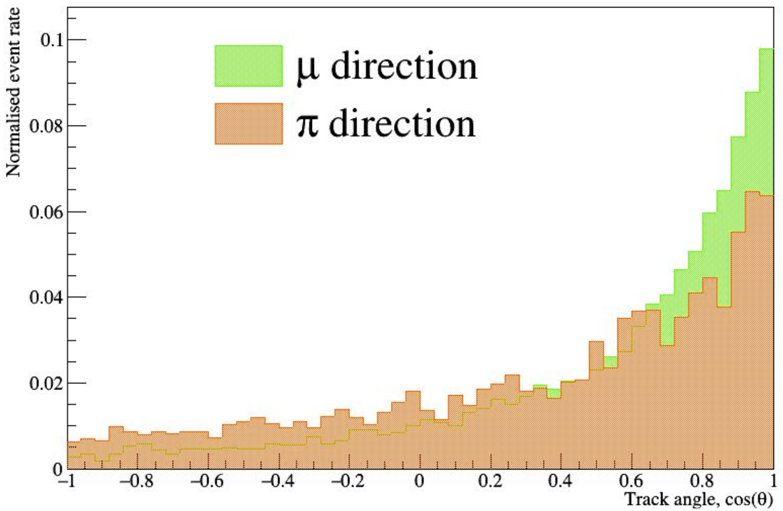
$$\nu_\mu + n \rightarrow \mu^- + p$$

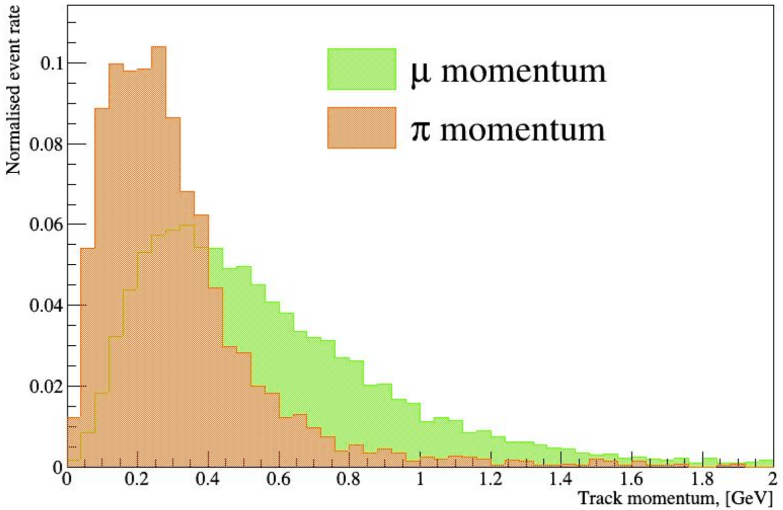
  - Models were built on neutrino interactions on free-nuclei
  - Don't work for interactions on nuclear targets
  - Experiments use nuclear targets!

- Experiments such as MiniBooNE saw an excess of events
  - Known as the quasi-elastic puzzle
  - The data is QE-like, not true QE
  - Tuning free model parameters & including the 2p-2h process helps fix this

μ vs. π: z-angle & momentum

- Took pions as the comparable particle since they rival the individuality of the muon's MIP property
- Looking at the characteristics of the true particles, does this support the theory that the muon is most likely to escape when the neutrino vertex is sufficiently far from the fiducial border?
- Since the muons tend to have higher momenta and are more forward going: Yes!

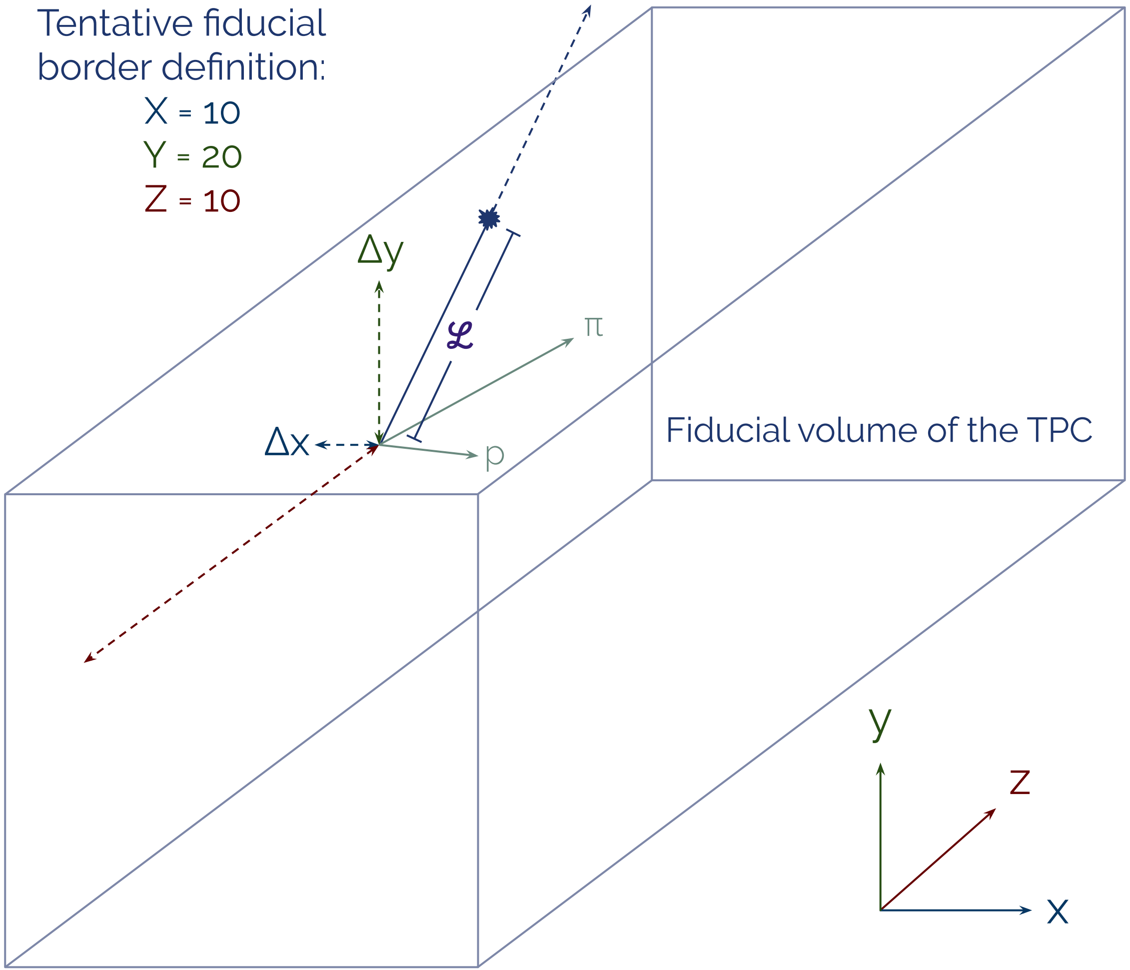




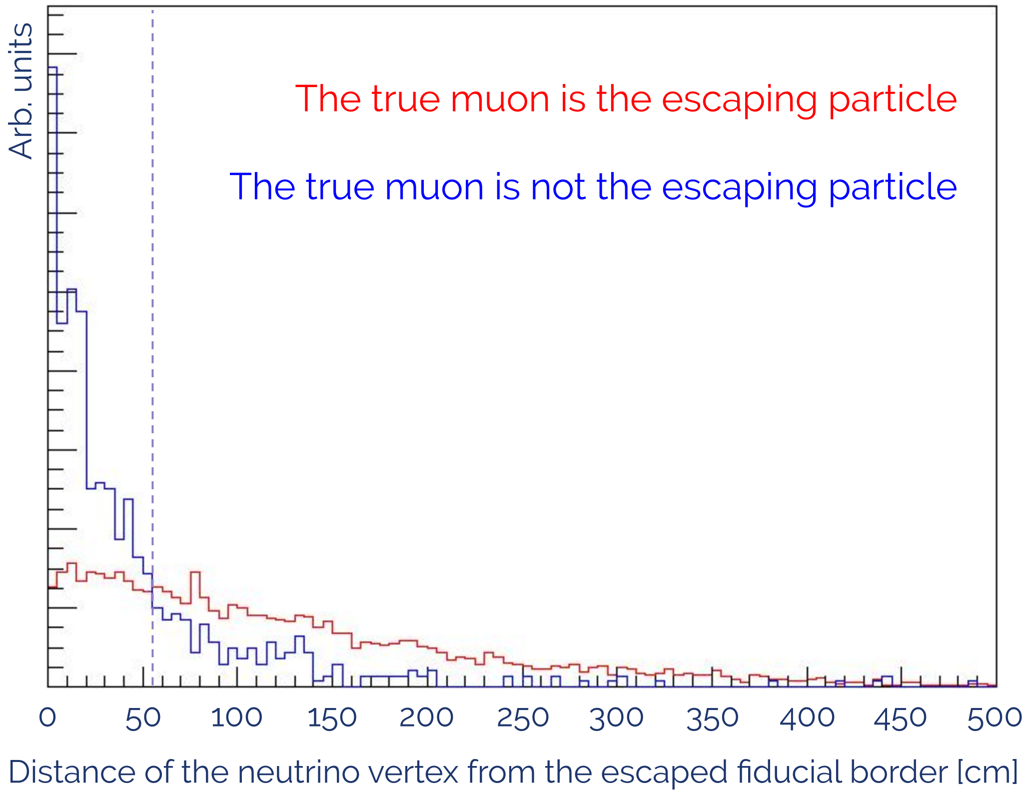
Finding escaping muons

- In an event with 1 escaping particle, we can use the TPC to determine if this particle is a muon
  - Using its properties as a MIP and the neutrino primary final state lepton

- If a particle exists and the neutrino interaction vertex is far from the border the particle exits from ($\mathscr{L}$ is large), ask if that particle is likely to be a muon



Escaping track rates



When the neutrino vertex is further than ~50 cm from the escaping fiducial border, the escaping track becomes significantly more likely to be a muon

Quantities within this sample

Total events with contained, reconstructed neutrino vertex	65,830
True vertex also contained	96.3%
Maximum 1 escaping track	99.9%
Exactly 1 escaping track	5.5%
Of these, only the true muon escapes	95.9%

Adding cosmics has reduced the 'free' muons to be 4.9% of the sample