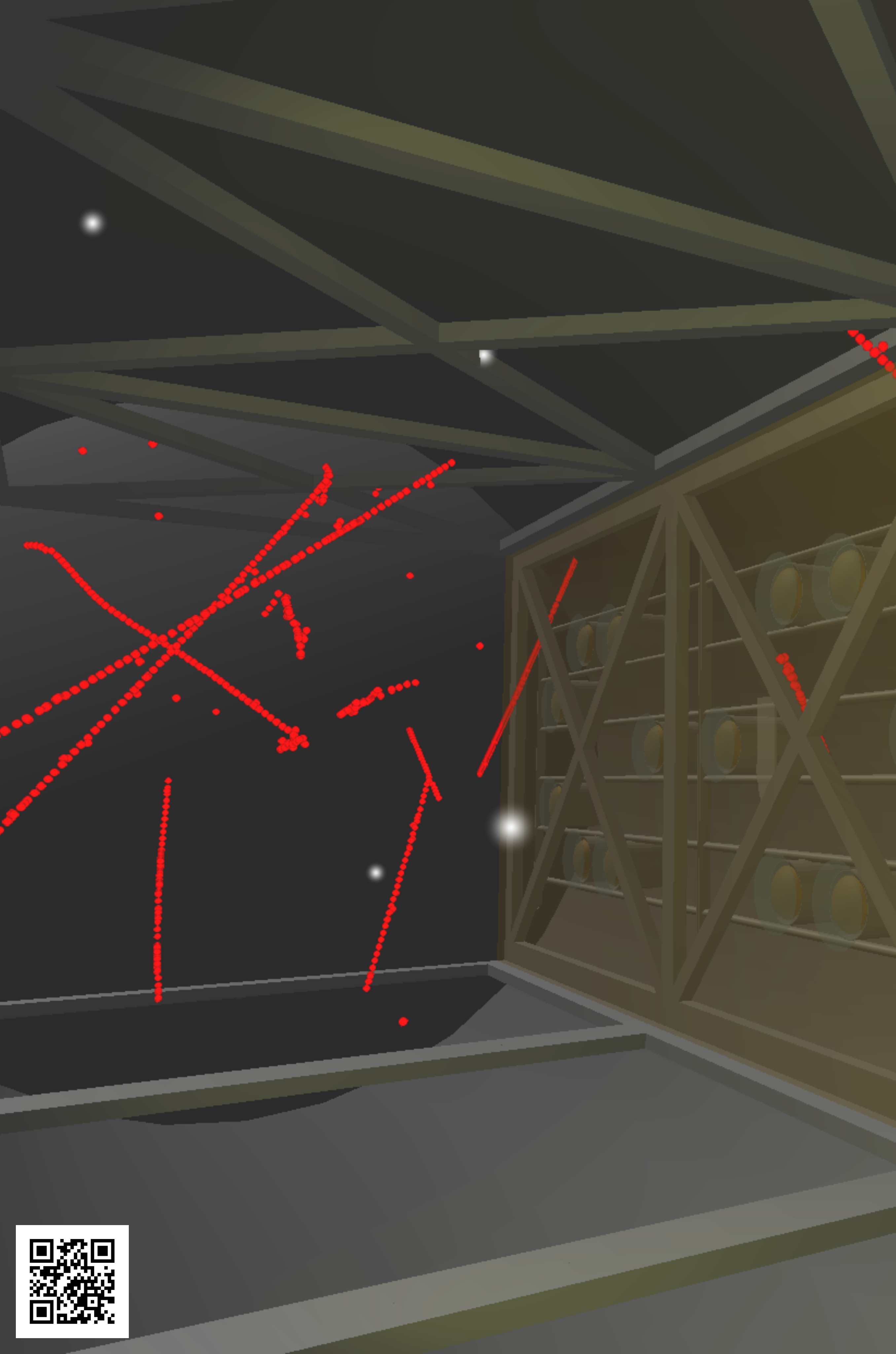


MicroBooNE Future Cross Section Measurements and Capabilities

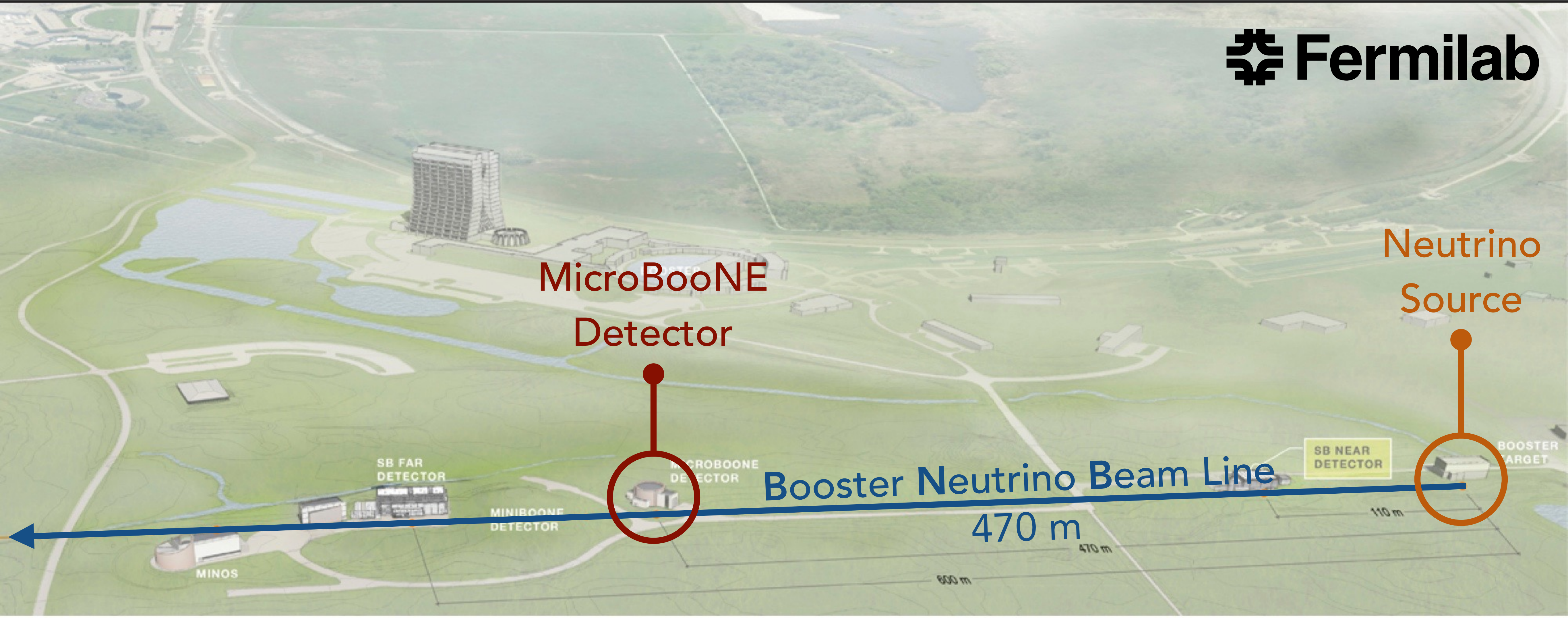
Marco Del Tutto

representing the MicroBooNE collaboration

Neutrino Cross Section Strategy Workshop (Nu-Print)

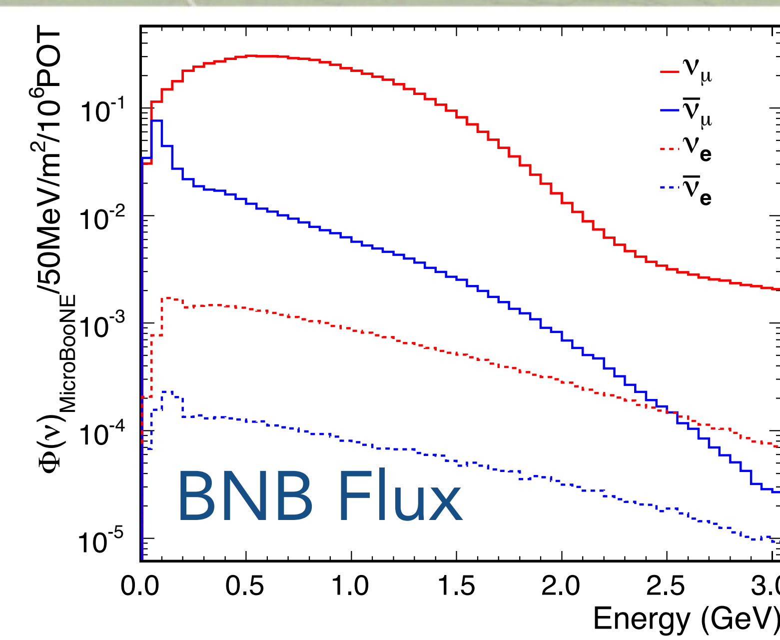
13th March 2018

The MicroBooNE Experiment



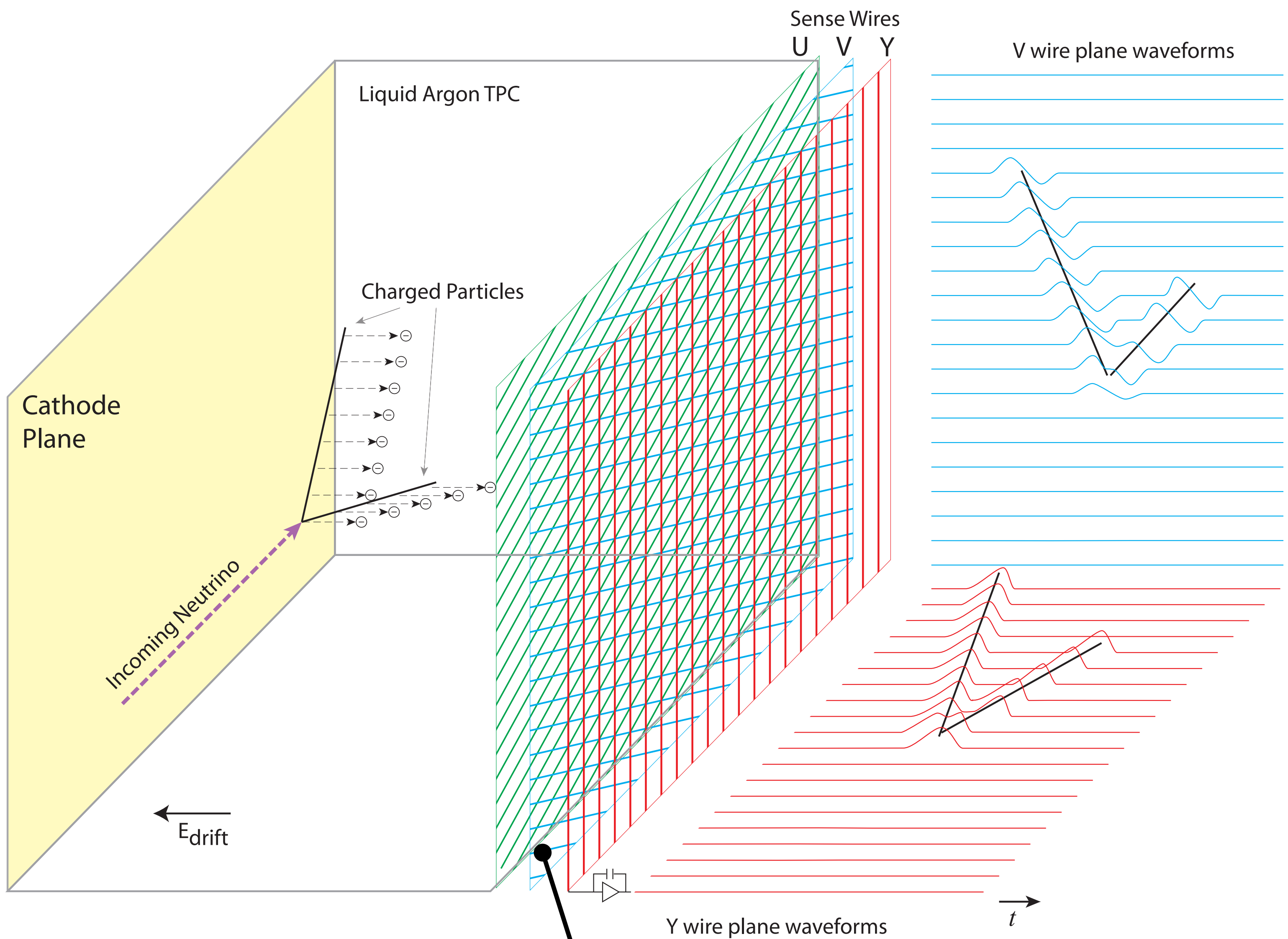
Goals of **MicroBooNE**:

- low-energy excess observed by MiniBooNE
- SBN search for sterile neutrinos with 5σ sensitivity
- ν-Ar cross section measurements
- R&D for future LArTPC experiments

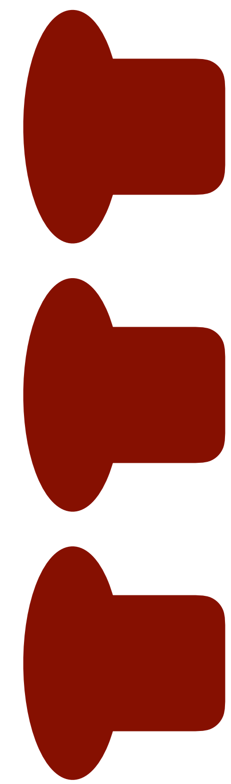


The MicroBooNE Detector

A liquid argon time projection chamber



8192 wires (3 mm pitch)



32 8″

Cryogenic

PMTs

PMT time resolution: O(10 ns)

TPC spatial resolution: 3 mm

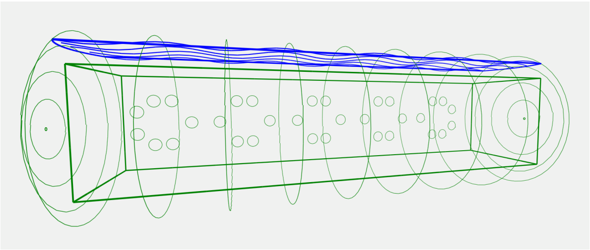
MicroBooNE Timeline

TPC in Cryostat

December 2013

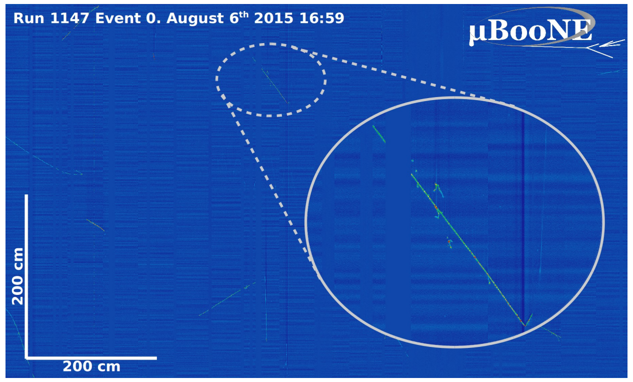
Moved to LArTF

June 2014



Filled with LAr

July 2015



First Cosmic Track

August 2015

First Neutrino Beam

October 2015

- **2015** First Neutrino Interactions Observed with the MicroBooNE LAr TPC (public note n1002)
- **2017** Design and Construction of the MicroBooNE Detector (JINST 12, P02017)
- Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber (JINST 12, P03011)
- Determination of Muon Momentum in the MicroBooNE LAr TPC Using an Improved Model of Multiple Coulomb Scattering (JINST 12 P10010)
- Michel Electron Reconstruction Using Cosmic Ray Data from the MicroBooNE LAr TPC (JINST 12, P09014)
- Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC (JINST 12, P08003)
- Measurement of Cosmic Ray Reconstruction Efficiencies in the MicroBooNE LAr TPC Using a Small External Cosmic Ray Counter (JINST 12, P12030)
- **2018** The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector (Eur. Phys. J. C.)

See http://microboone.fnal.gov

The MicroBooNE Experiment

One of MicroBooNE goal is ν-Ar cross section measurements. This is important for the neutrino oscillation program:

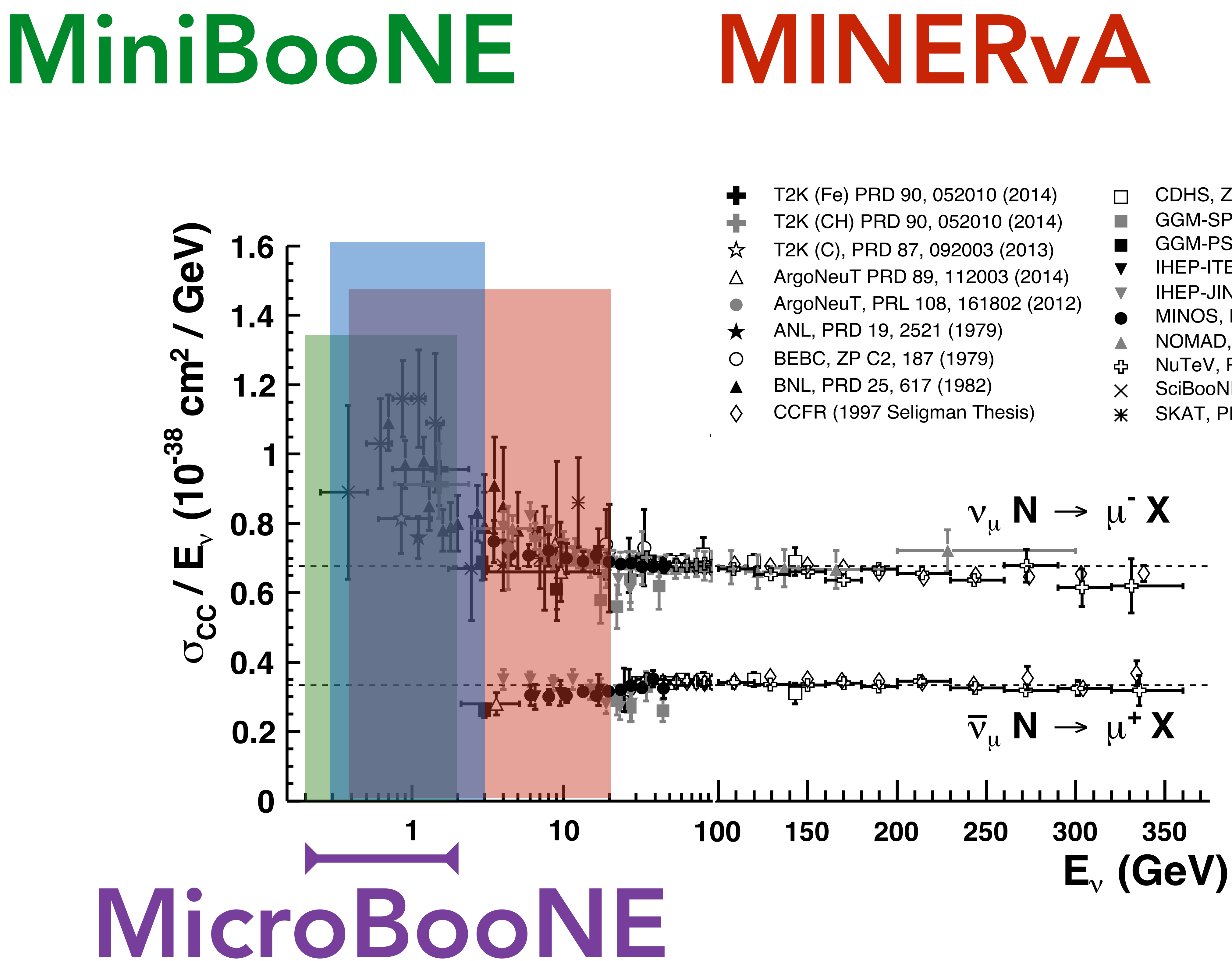
- Precision measurements of neutrino oscillation parameters.
- DUNE far detector is LArTPC. MicroBooNE can give direct cross section constraint (particularly in low energy region) for DUNE oscillation precision measurement.

Cross section measurements will help to:

- ν_μ measurement will allow to constrain ν_e
- $CC\pi^0$ will allow to study shower reconstruction for ν_e search
- proton studies will allow to constrain nuclear effects
- ν_e events in NuM will allow to constrain systematics in BNB

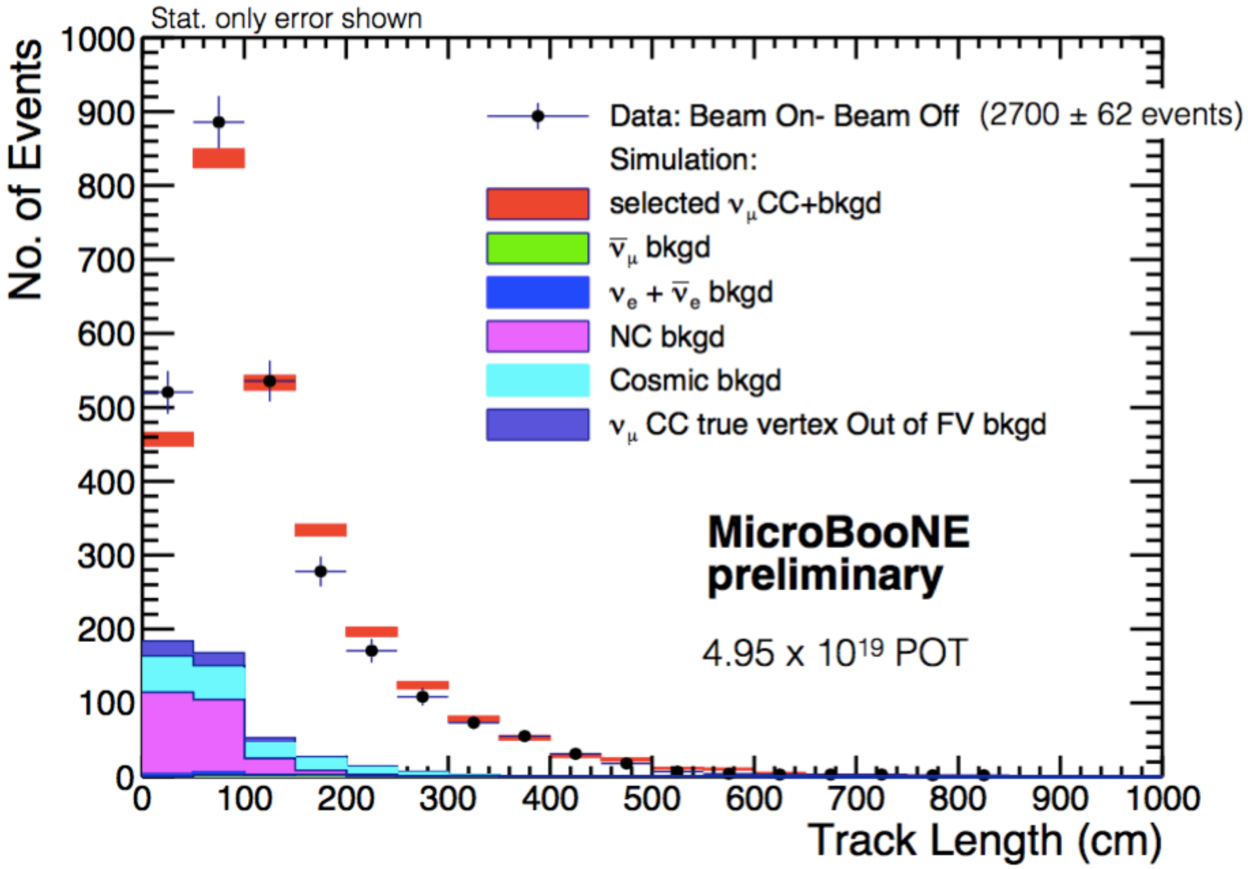
See Andy Furmanski's talk from yesterday

The MicroBooNE Experiment



Current Status

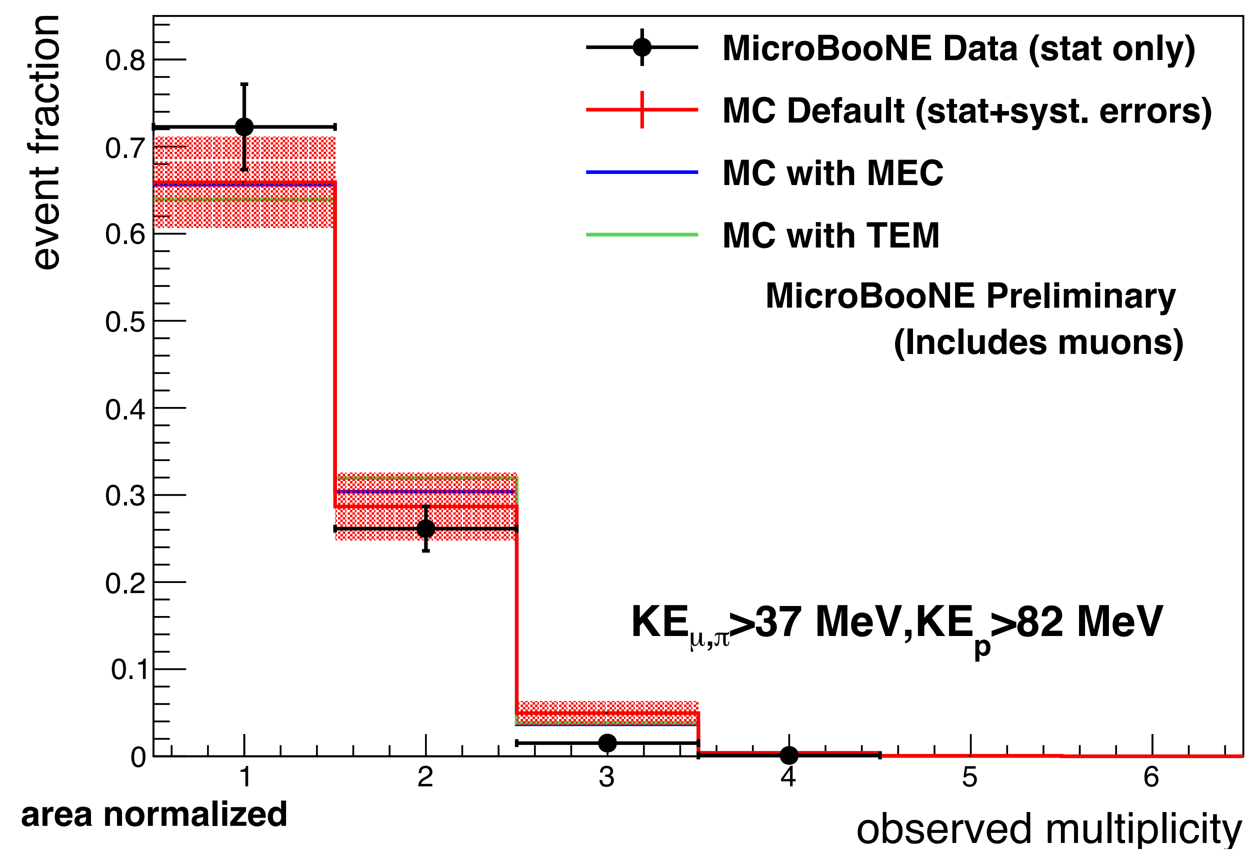
ν_μ CC Inclusive Distributions



MICROBOONE-NOTE-1010-PUB

- Simulation scaled to same number of events as data
- Cosmic background subtracted
- 3 months of data taking

ν_μ CC inclusive Track Multiplicity



MICROBOONE-NOTE-1024-PUB

- Observed multiplicity after event selection
- No efficiency correction
- Muon is included in the multiplicity count
- First time such a distribution has been measured in argon

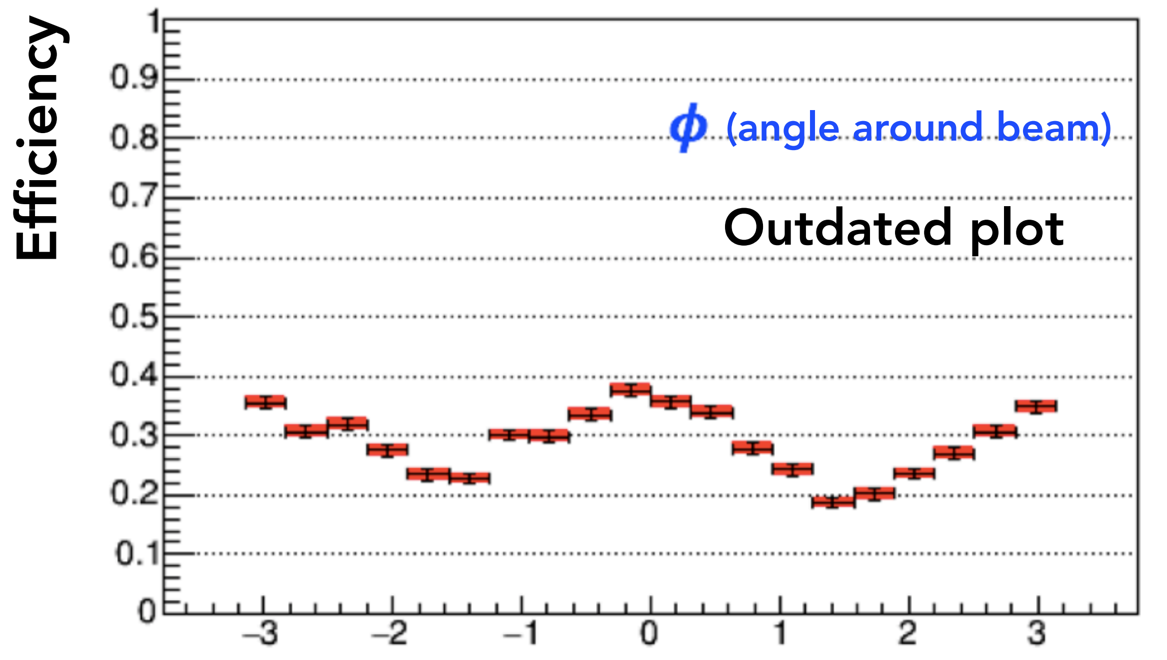
Outline of Future Measurements

1	**ν_μ CC inclusive differential cross section measurement**	• Least model dependent • Interesting physics measurement on argon, provides input for theory • Easy to compare with other experiment (clear signature) • Provides sample for more exclusive channels
2	**ν_μ CCπ^0 total cross section**	• For testing shower reconstruction performances and energy resolution • Good for characterising background for electron neutrino search • Provides a measurement of π^0 absorption which is much larger in argon that in carbon or water
3	**ν_μ CCNp (N>0) cross section**	• it will tell us about nuclear physics (initial and final state) • good to understand hadroning interactions (to measure nu energy for oscillations)
4	**ν_μ CC charged particle multiplicity**	• good to test several nuclear models • good to understand final state interactions: allows to test multiple things at once

See Andy Furmanski's talk from yesterday

(1) ν_μ CC Inclusive

A future measurement from MicroBooNE will be the ν_μ CC inclusive differential cross section in muon momentum and angle w.r.t. to the neutrino beam



Old efficiency plot (NEUTRINO2016)

Low efficiency and not flat (hard cosmic rejection)

Event selection now improved, new efficiency will be ~50%

Several improvements w.r.t. previously shown distributions:

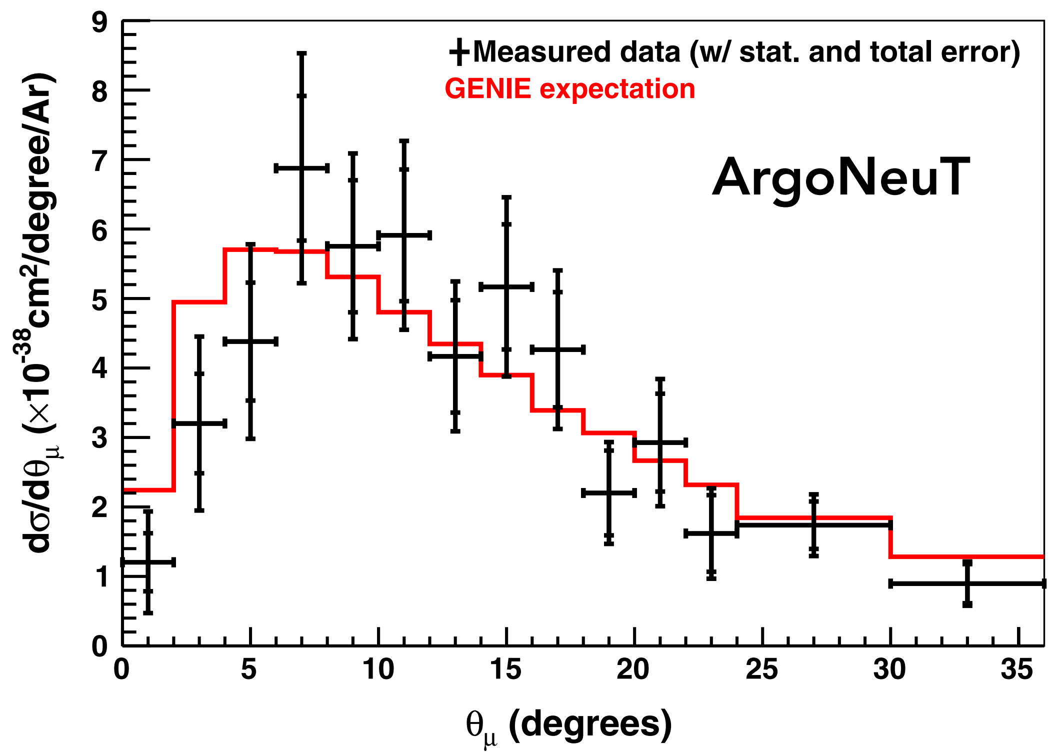
- improved use of the PMT system (flash to track matching)
- improved cosmic rejection (done by using light information, tracks that pierce the anode or the cathode, muons that stop in the TPC)
- use of the deposited charge profile on the wire for particle identification

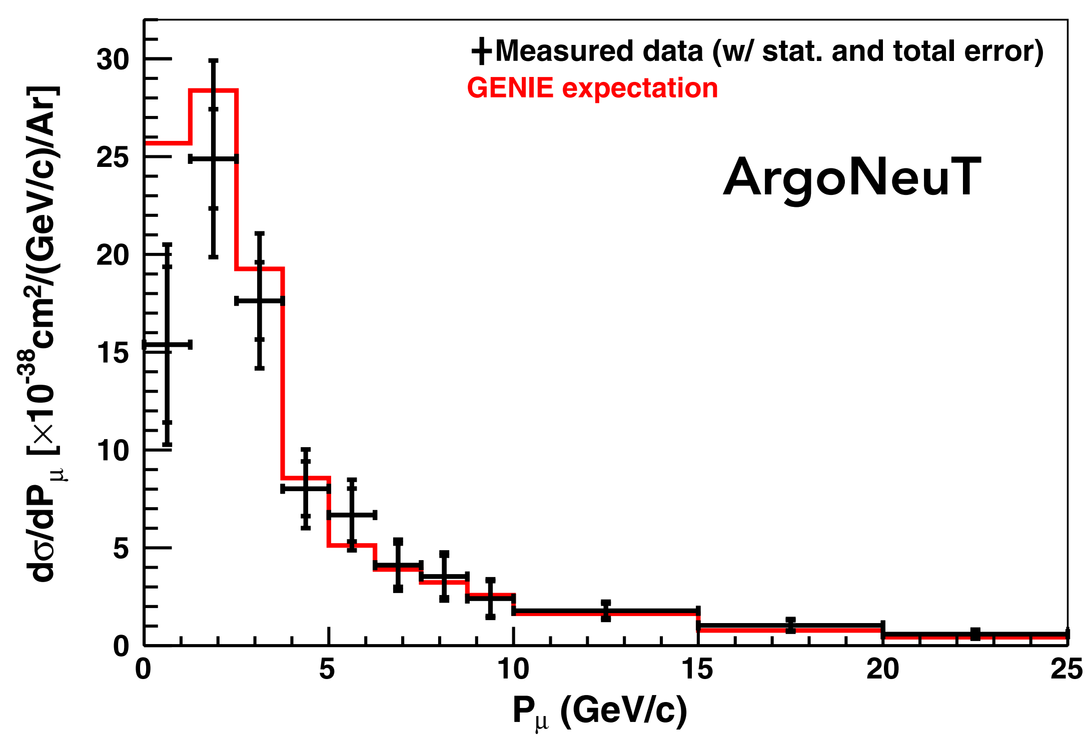
(1) ν_μ CC Inclusive

ArgoNeuT Results

Phys. Rev. Lett. 108, 161802 (2012)

ArgoNeuT has measured the inclusive muon neutrino charged current differential cross sections for the first time on argon

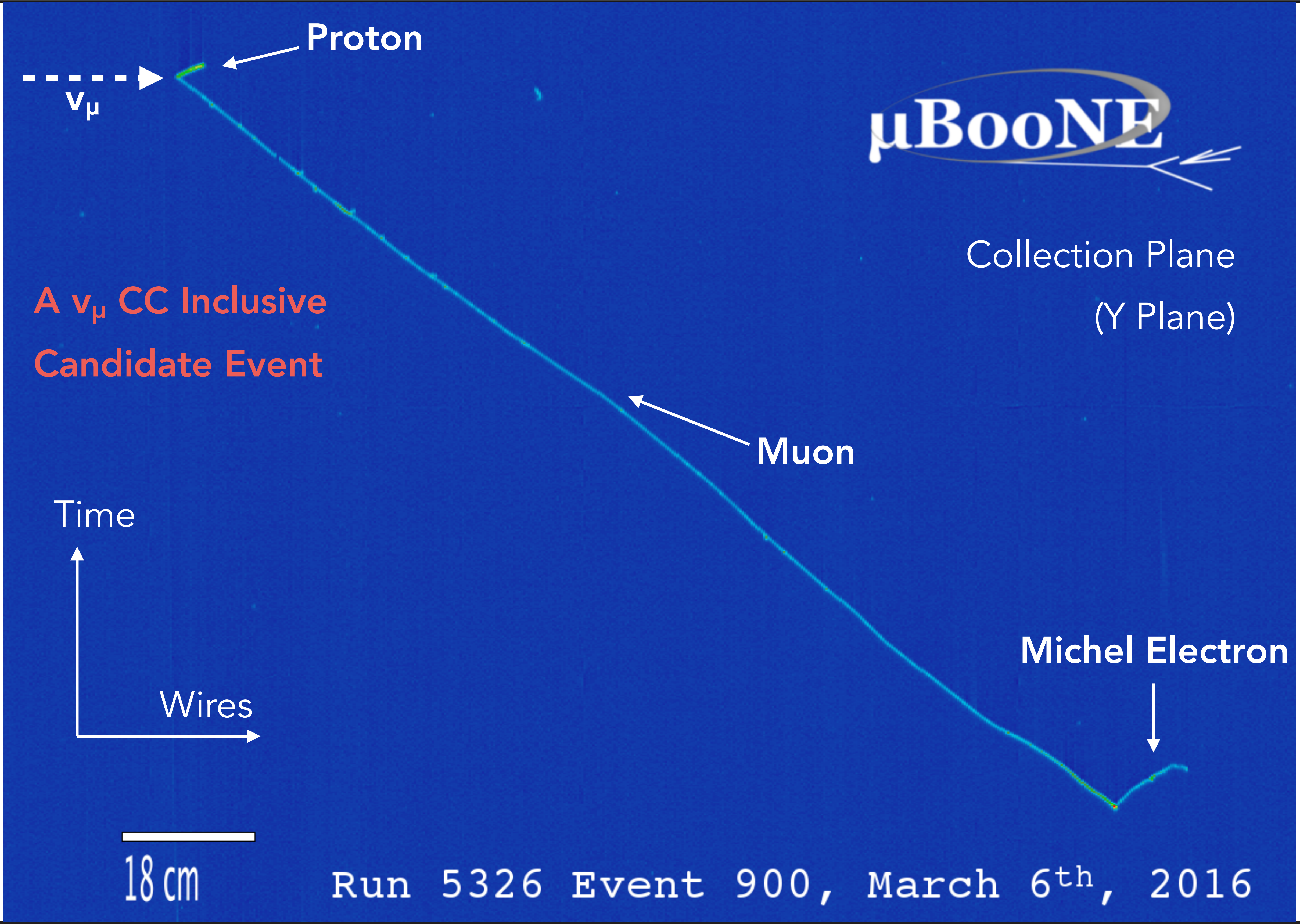




Future MicroBooNE measurement:

- different energy range
- higher statistics
- first to be performed in a fully automated way in LAr

(1) ν_μ CC Inclusive

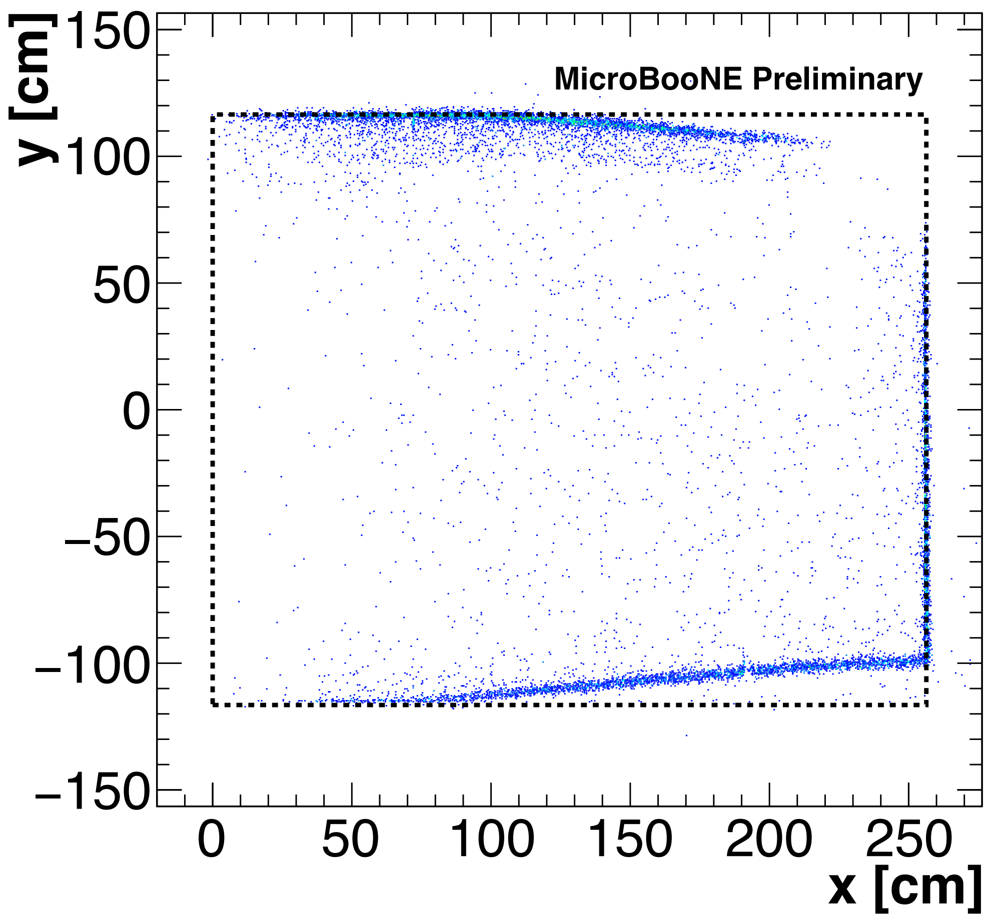


(1) ν_μ CC Inclusive

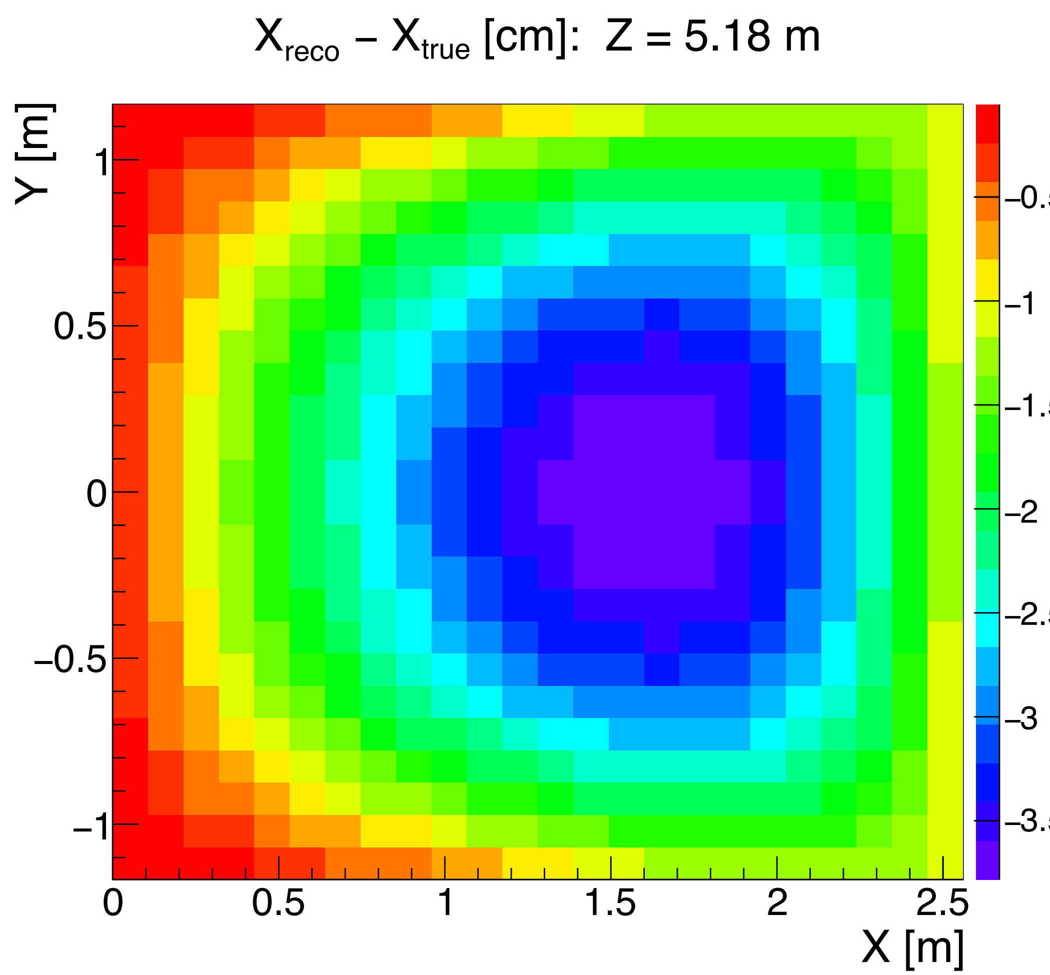
Cosmics are the major background

MICROBOONE-NOTE-1018-PUB

Space charge effect distorts the reconstructed positions, making it more difficult to tag cosmics simply based on their geometry



Start/end points of reconstructed cosmic muon tracks tagged by an external muon counter



Effect of space charge on the distortions in reconstructed position

(1) ν_μ CC Inclusive

Cosmics are the major background

Instruments 2017, 1(1), 2

We have installed a cosmic ray tagger (CRT) that will help to reject cosmics in future measurements

(1) ν_μ CC Inclusive

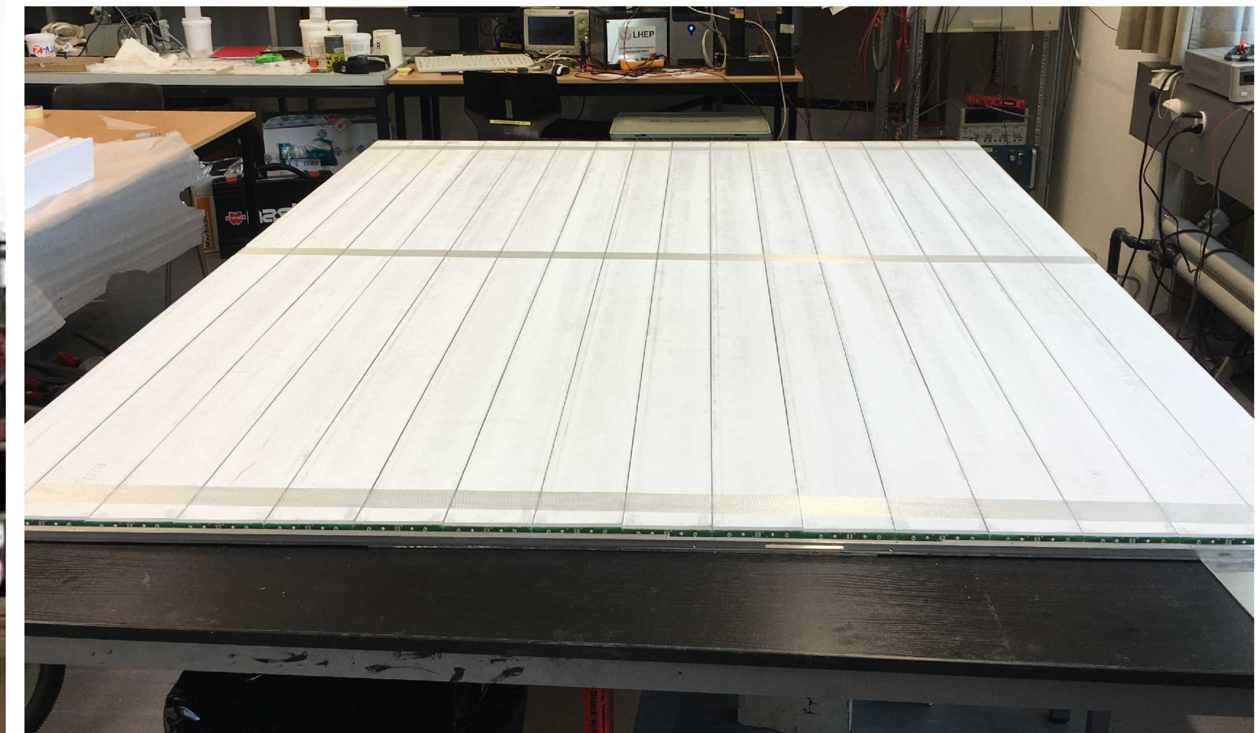
Cosmics are the major background

Instruments 2017, 1(1), 2

We have installed a cosmic ray tagger (CRT) that will help to reject cosmics in future measurements

- Scintillator-based tracking detector
- Spatial resolution:1.8 cm
- Timing resolution:1 ns
- Tagging efficiency measured to be greater than 95%

Scintillator strips



Multiple Coulomb Scattering

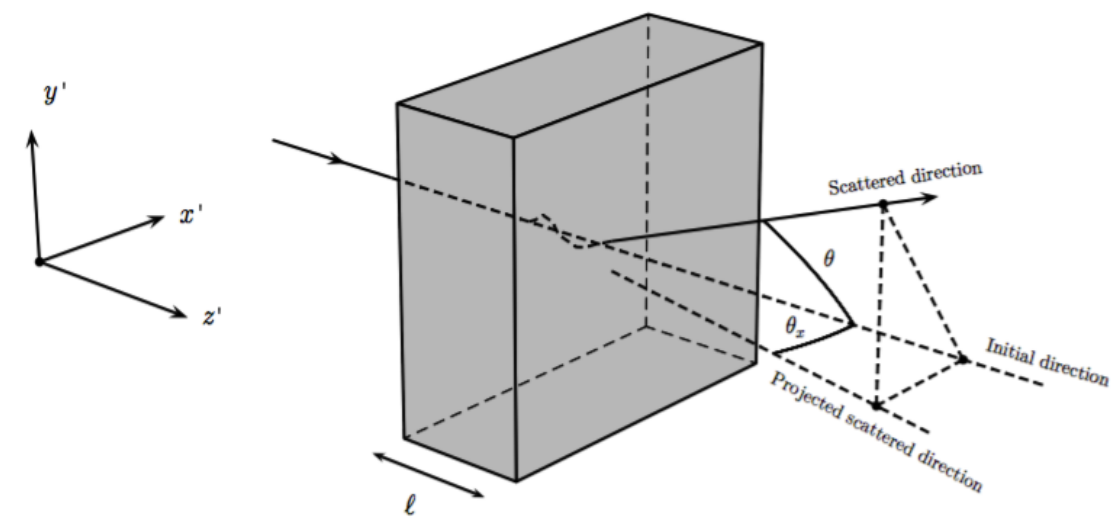
For track direction and particle momentum

JINST 12 P10010 (2017)

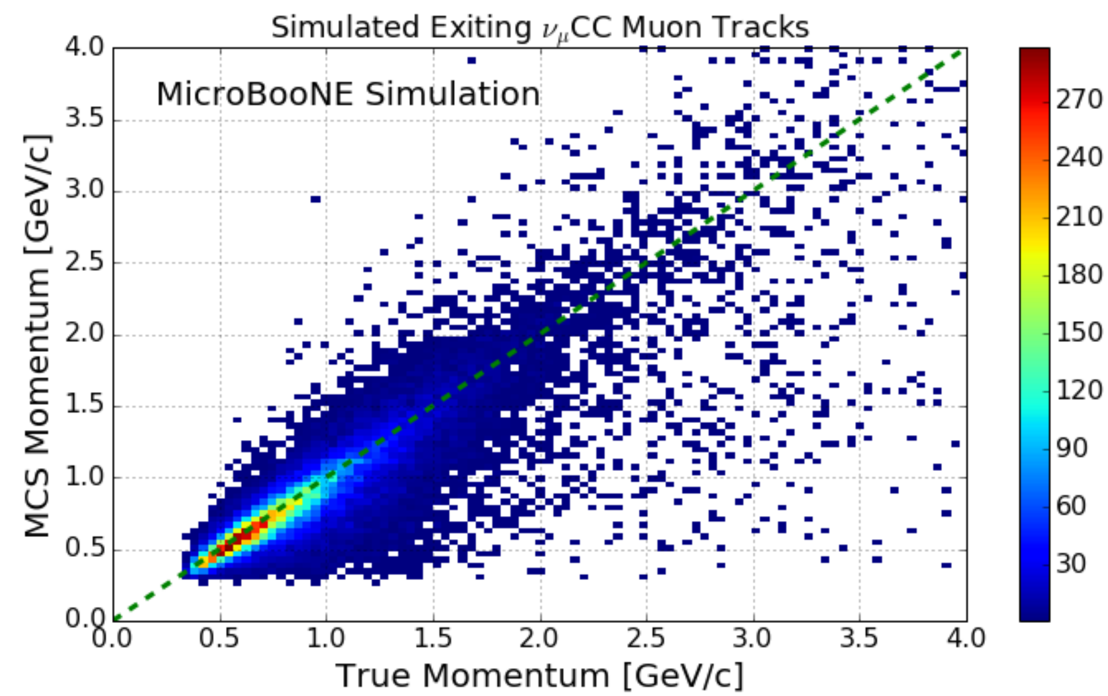
Charged particle's momentum can be measured via multiple Coulomb scattering (MCS)

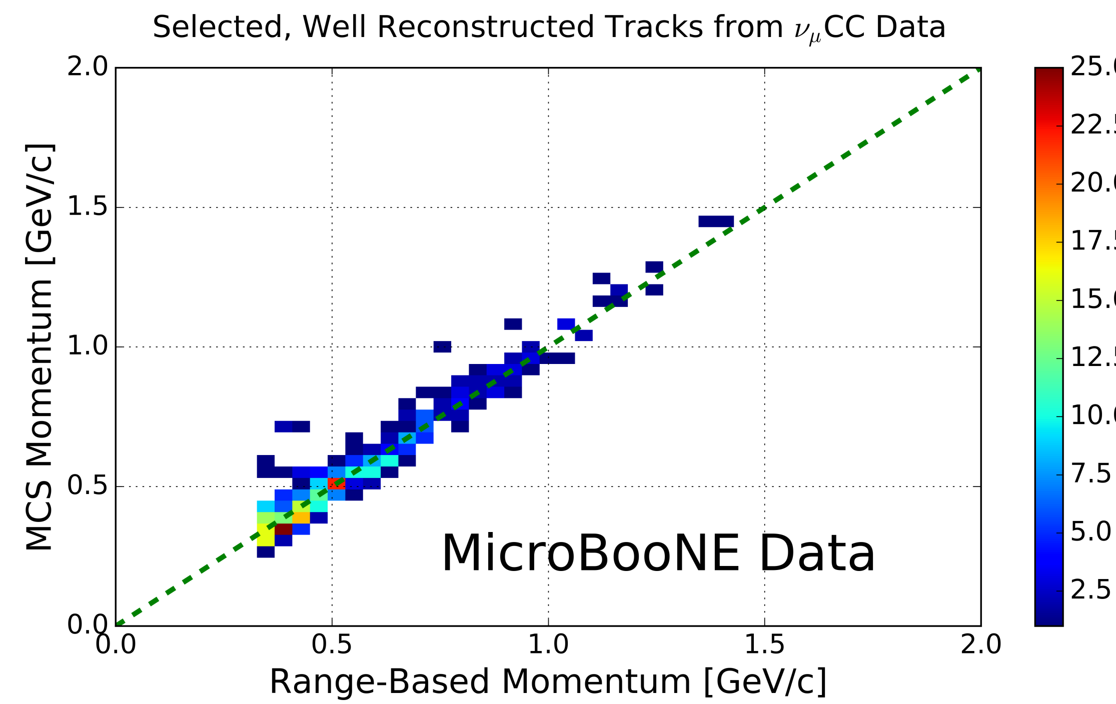
This method:

- does not require the full particle ionisation track to be contained inside of the detector volume (as required by range-based and calorimetric momentum reconstruction)
- can be applied to contained and exiting tracks

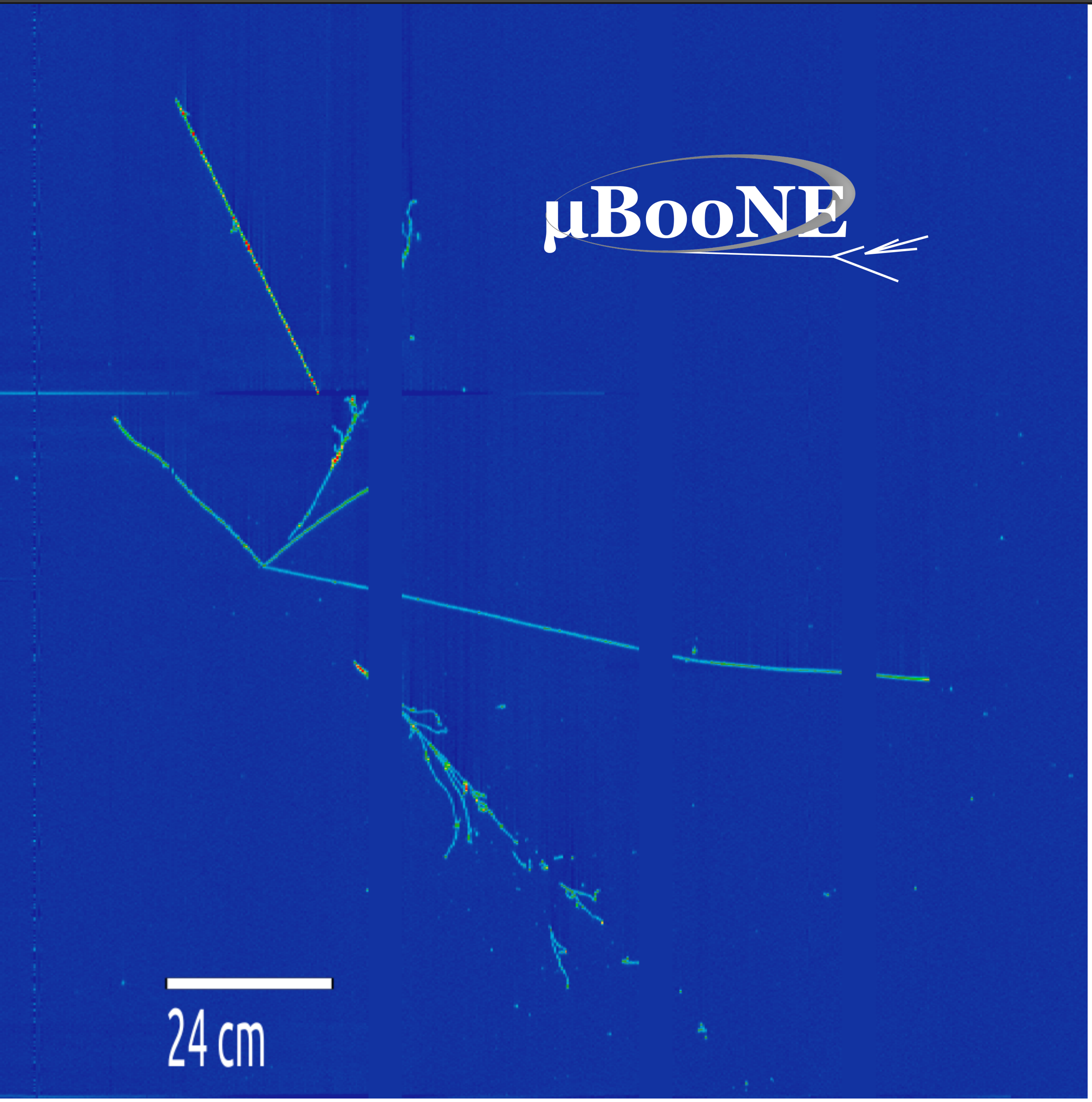


$$\sigma_o^{\mathrm{HL}} = \frac{S_2}{p\beta c} z \sqrt{\frac{\ell}{X_0}} \left[1 + \epsilon \times \ln\left(\frac{\ell}{X_0}\right) \right]$$





(2) ν_μ CCπ^0



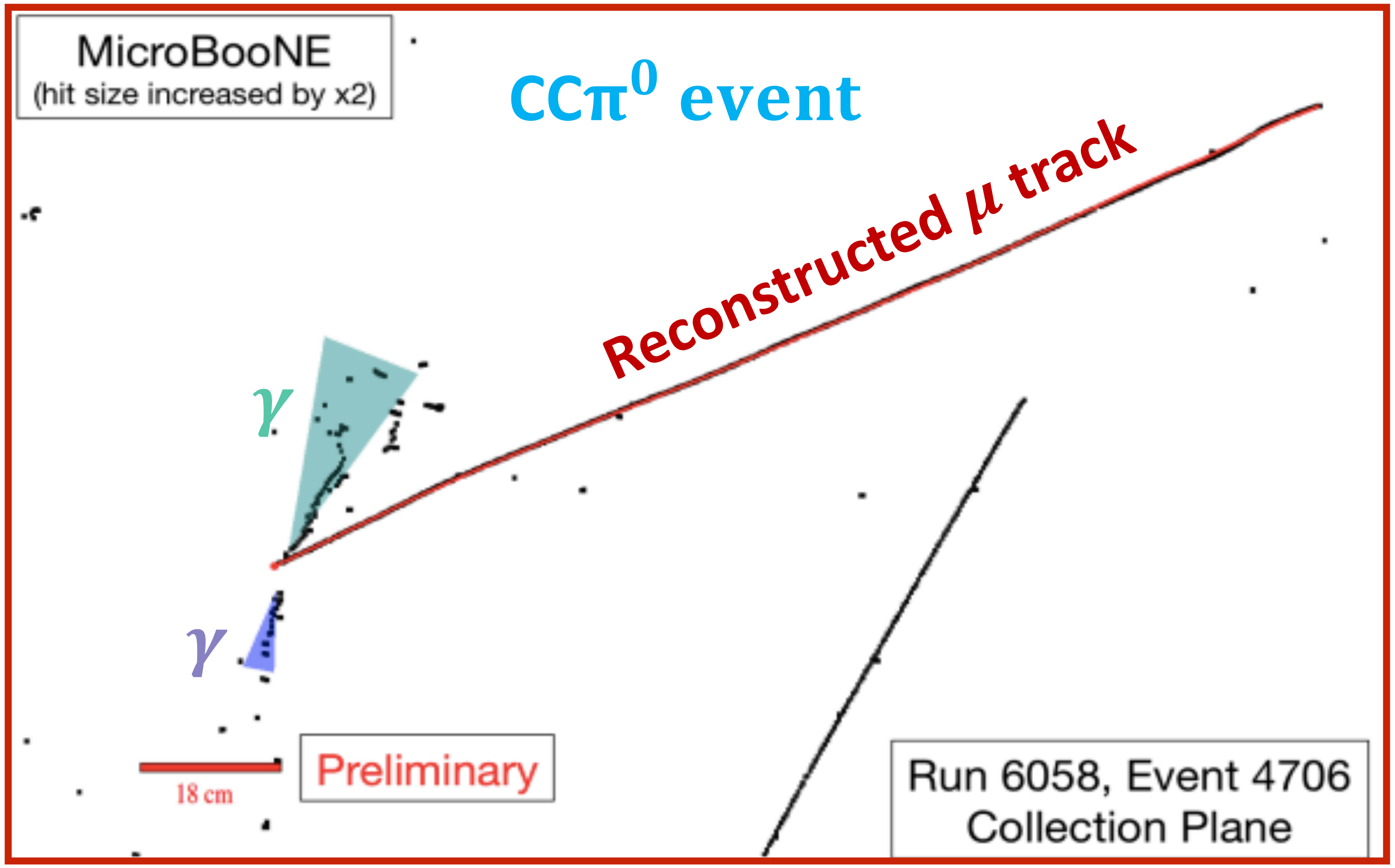
Importance of a π^0 sample

- gives us a data sample to test shower reconstruction performances and study energy resolution
- π^0 energy reconstruction is excellent validation of detector calibration
- characterise background for electron neutrino search (NCπ^0 expected to be a background for oscillation searches)
- provides a measurement of π^0 absorption which is much larger in argon that in carbon or water

Very challenging analysis - electromagnetic shower reconstruction is hard due to the difficulty of automatic clustering and pattern recognition.

MicroBooNE Public Note 1006

(2) ν_μ CCπ^0

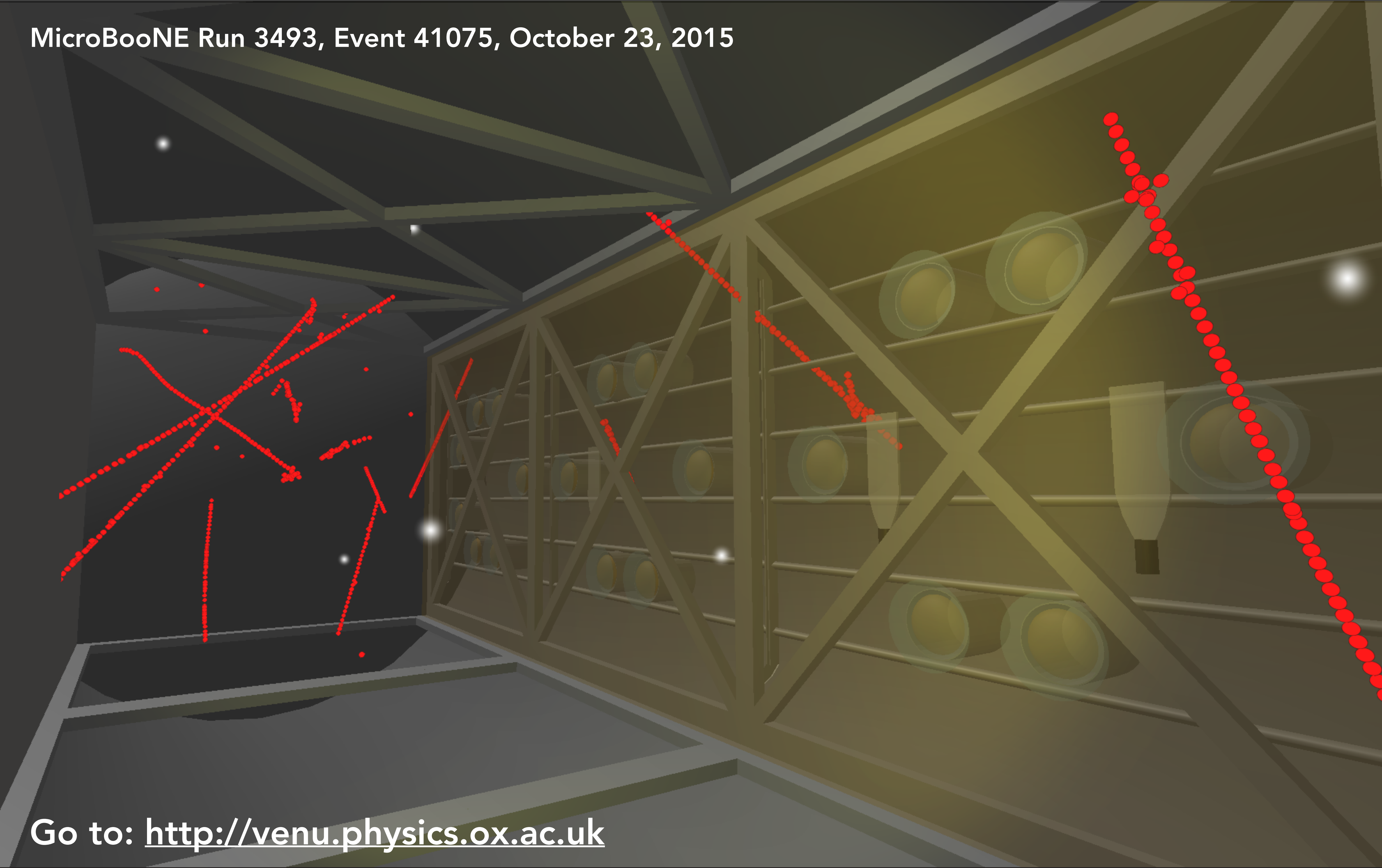


MicroBooNE has an event selection to identify π^0 events with two sub-samples: one based on a single shower tagged, and one based on both showers tagged coming from the π^0 decay.

First analysis (2018): will be the total cross section measurement of the ν_μ + Ar -> μ + π^0 + X

Further future: a differential cross section measurement will be performed

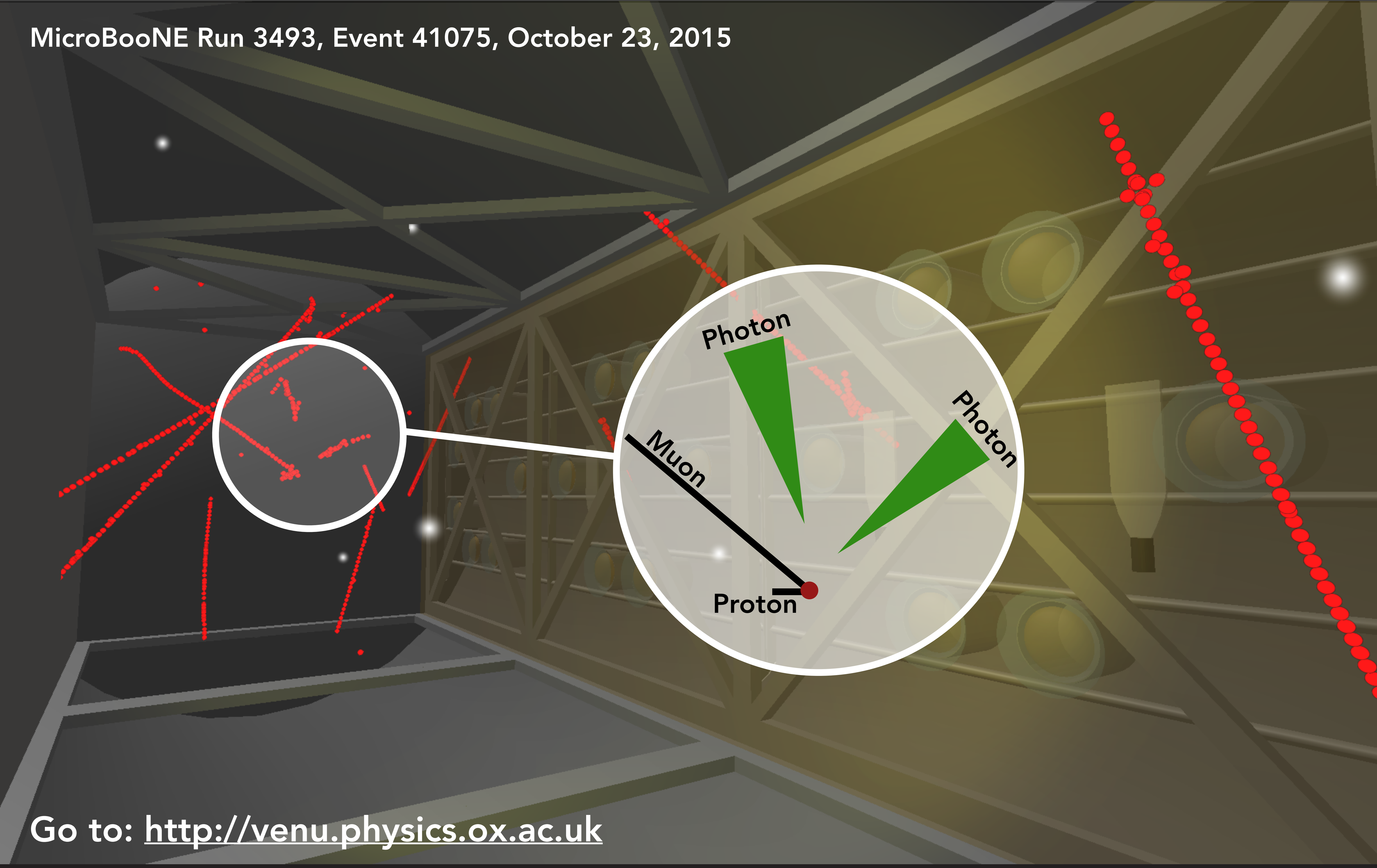
(2) ν_μ CCπ^0



Go to: http://venu.physics.ox.ac.uk

(2) ν_μ CCπ^0

MicroBooNE Run 3493, Event 41075, October 23, 2015



Go to: http://venu.physics.ox.ac.uk

(3) ν_μ CCNp

A future cross section measurement from MicroBooNE will be a ν_μ CC 0π with only **N protons** in the final state

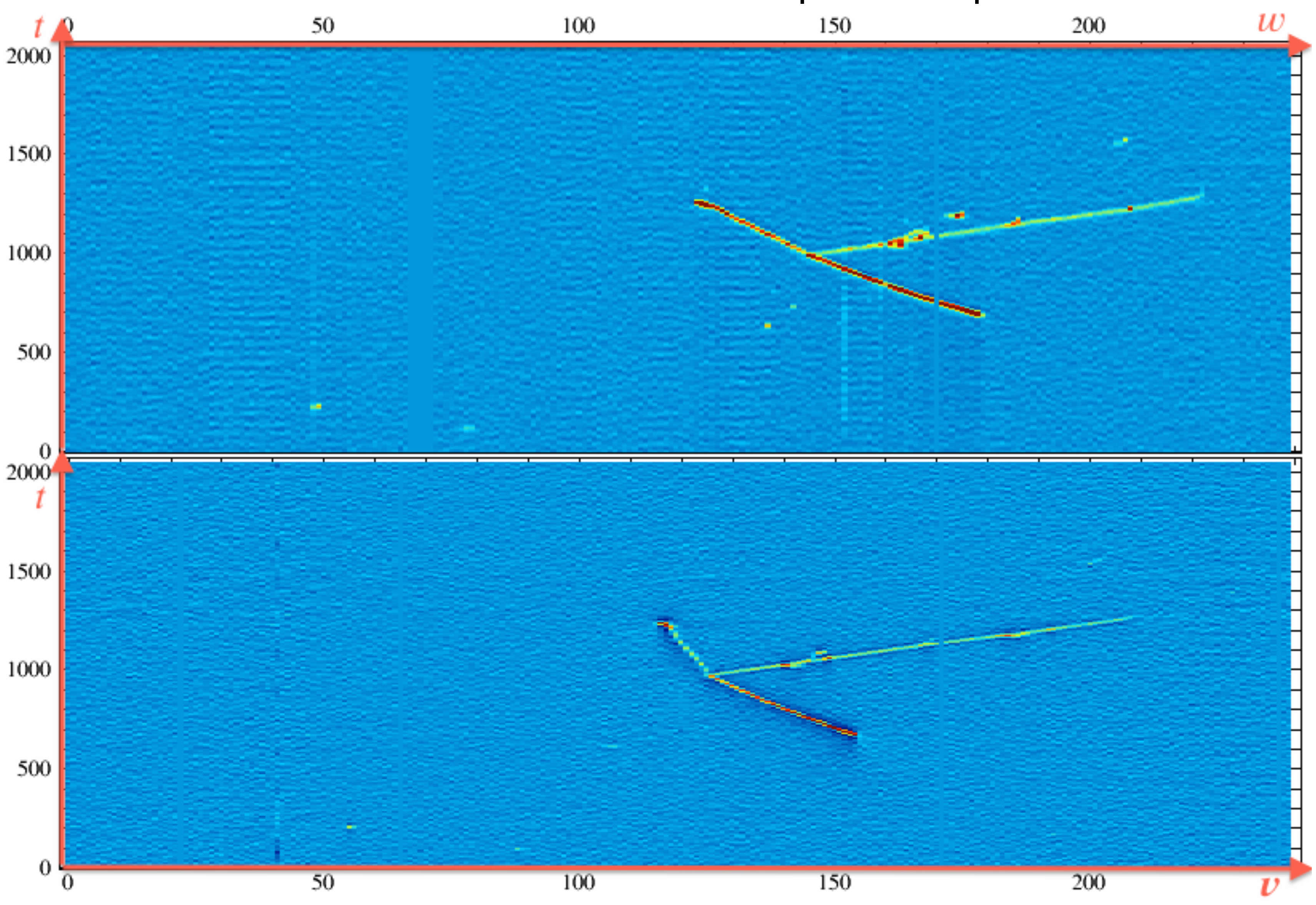
- this definition is closer to MiniBooNE and T2K's **CCQE** signal definitions (but we require one proton)
- it will tell us about **nuclear physics:**
    - final and initial state interactions
    - nucleon correlations

Observing the hadronic side of the interaction is going to be crucial for precision cross section and oscillation measurements because hadrons carry a significant fraction of the initial neutrino energy.

The thresholds of traditional experiments are around 100 MeV kinetic energy, for example in T2K (ARXIV:1802.05078) and MINERvA (JPSCP.12.010016). We can go down to lower thresholds with LArTPCs.

LArTPCs are excellent in detecting and identifying protons emerging from the interaction

A candidate back-to-back proton pairs



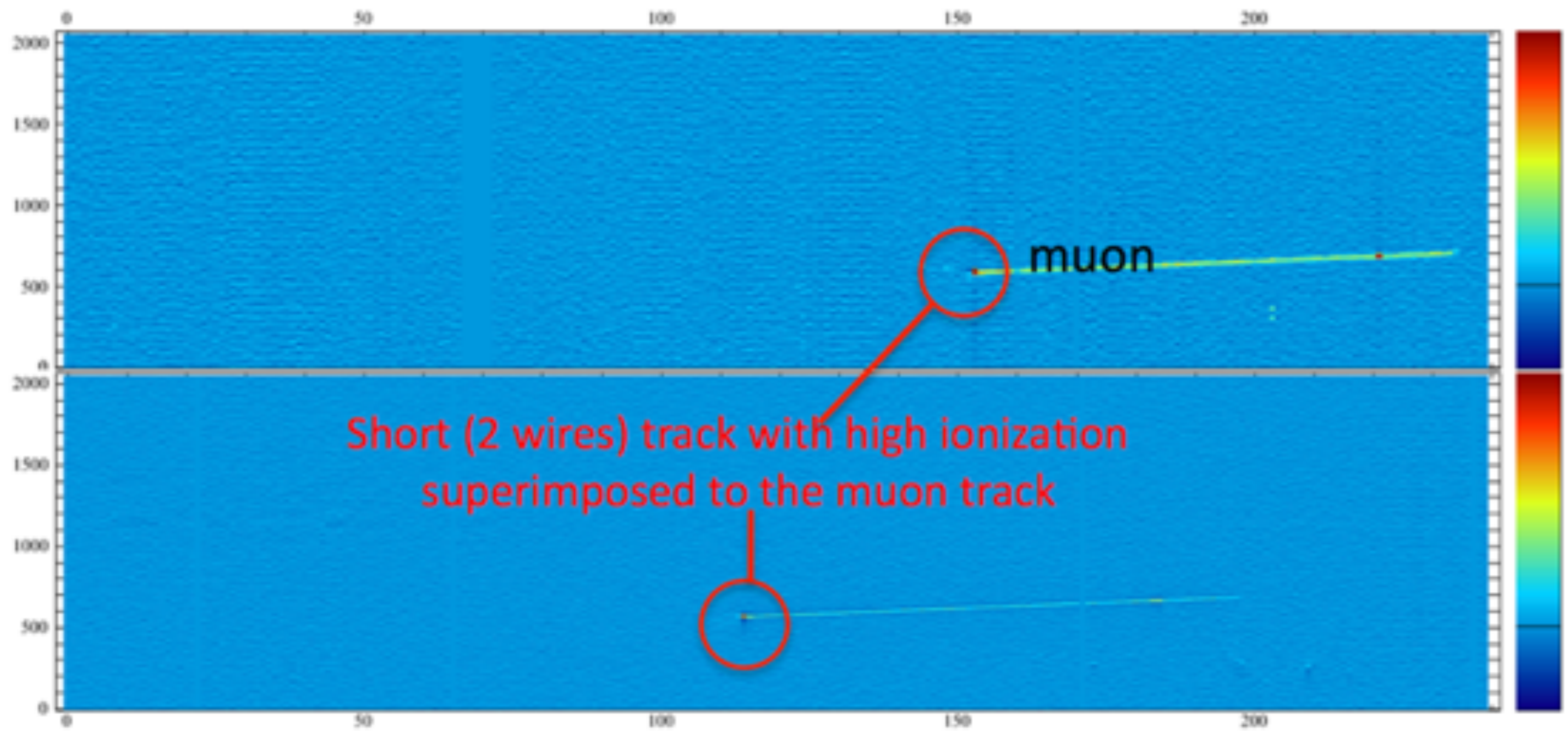
ArgoNeuT

Obtained a proton detection threshold of 21 MeV kinetic energy, relying partially on manual reconstruction

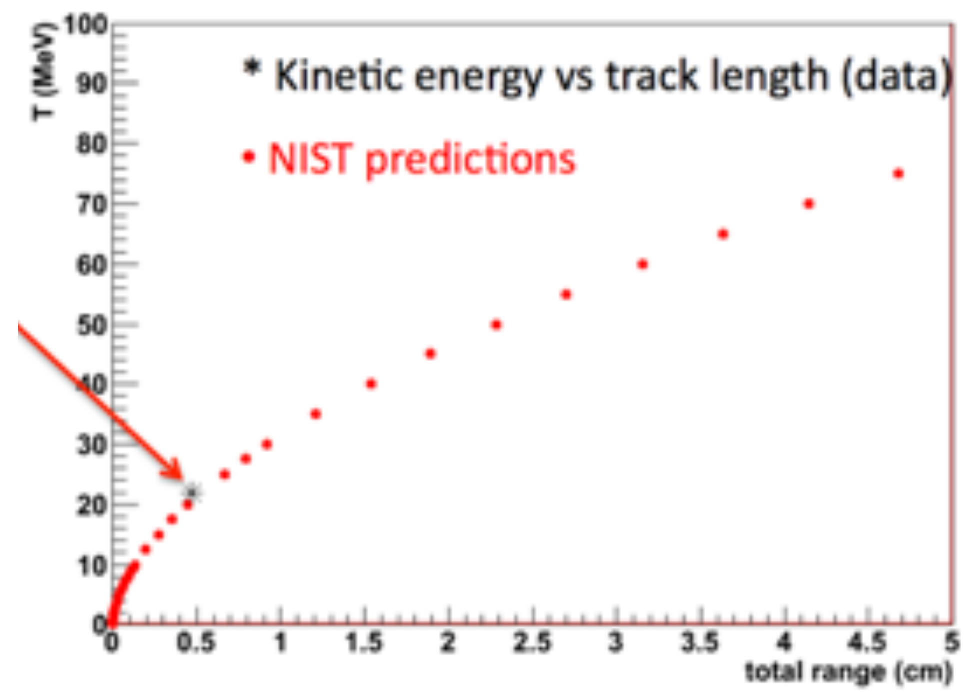
Phys. Rev. D 90, 012008

ArgoNeuT

LArTPCs are excellent in detecting and identifying protons emerging from the interaction



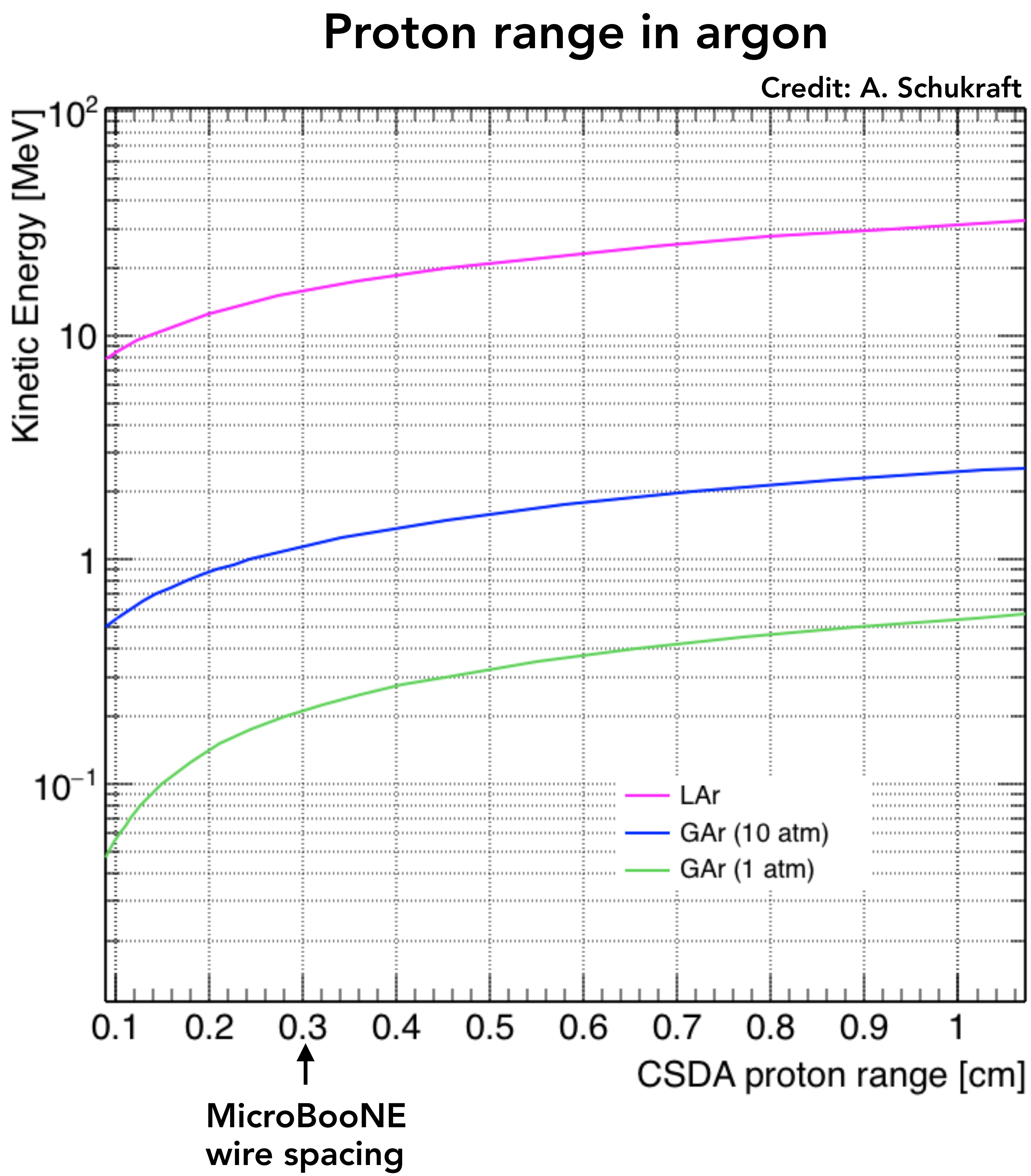
Credit: O. Palamara



- In this event, a proton could be identified that only touched two wires and was overlaid to the muon!
- It is possible to go back to waveform level and separate the charge in a waveform between two different particles.

The short track behaves like a proton:
Length = 0.5 cm
K = 22 ± 3 MeV

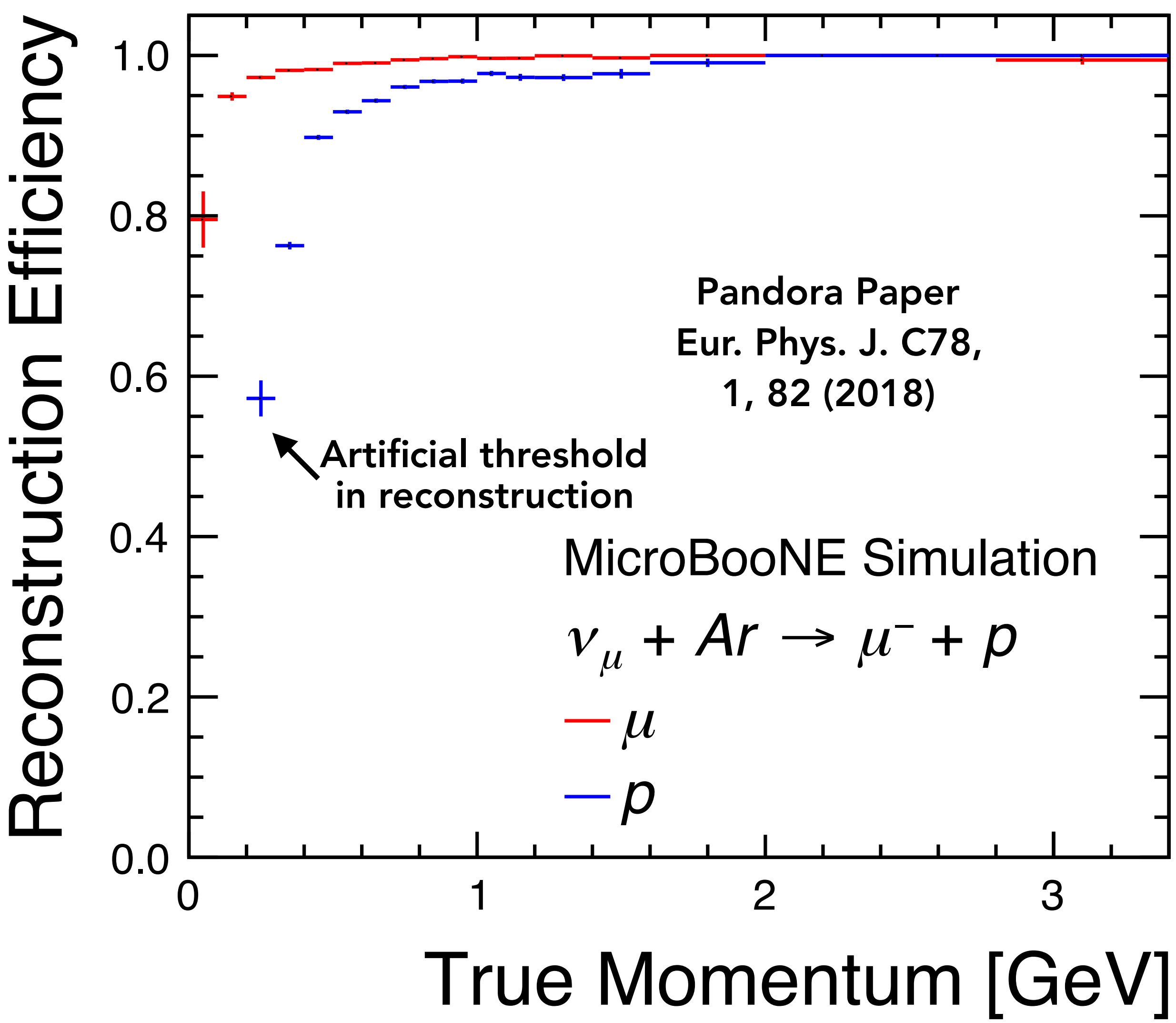
Proton Threshold at MicroBooNE

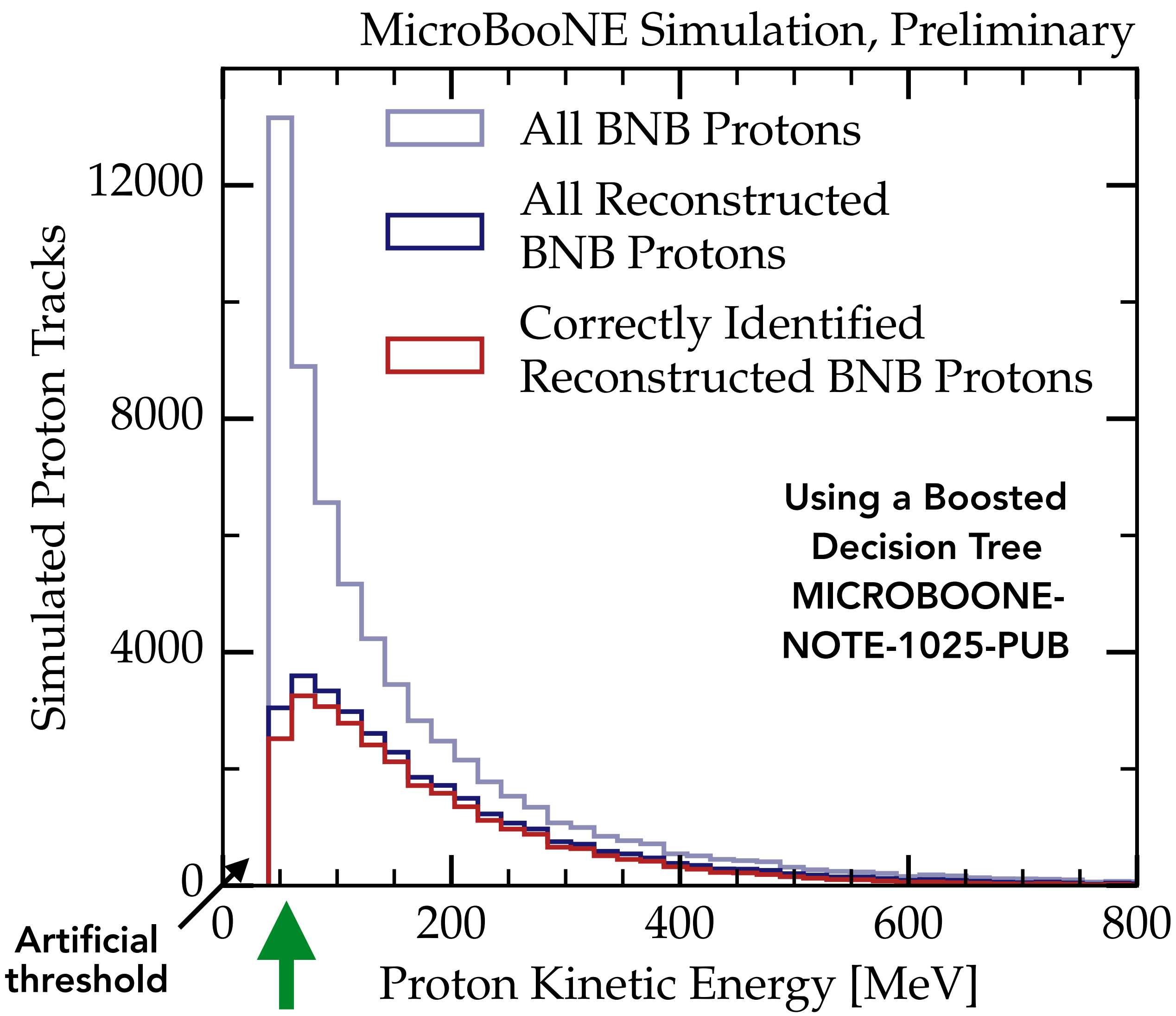


- Protons with less than K ~ 20 MeV don't get to the next wire (a wire spacing = 3 mm)
- Current efficiency for proton reconstruction is ~20% at K = 50 MeV, and ~< 1% at K = 20 MeV, though these numbers are not final and constant improvements are being made.

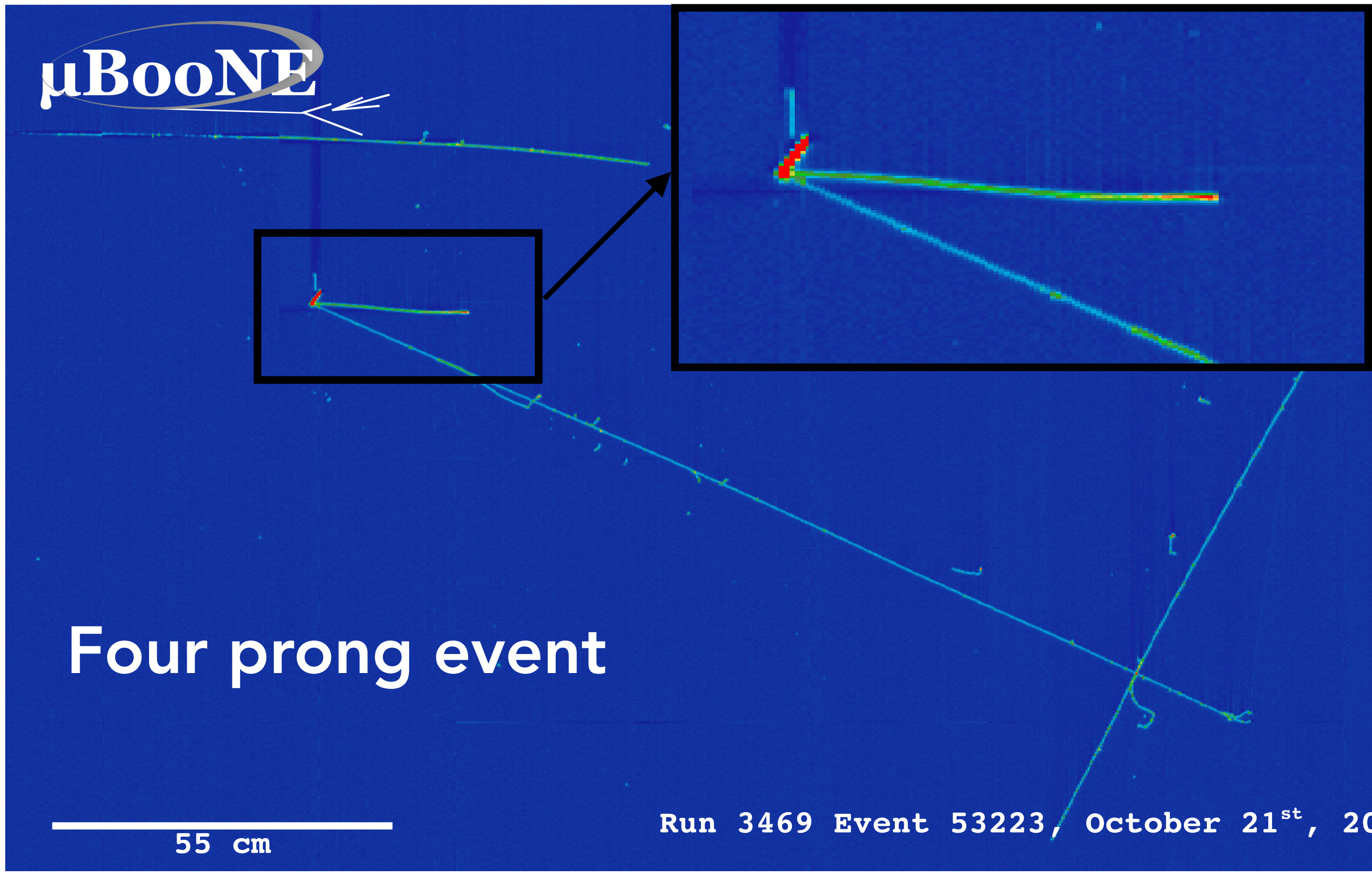
Proton Threshold at MicroBooNE

- First LArTPC experiment to use fully automated event reconstruction on all particles on neutrino interactions.
- Can achieve lower proton thresholds than previous experiments; we are now working on improving the **reconstruction** efficiency, **especially at low kinetic energy**





(4) ν_μ CC Particle Multiplicity

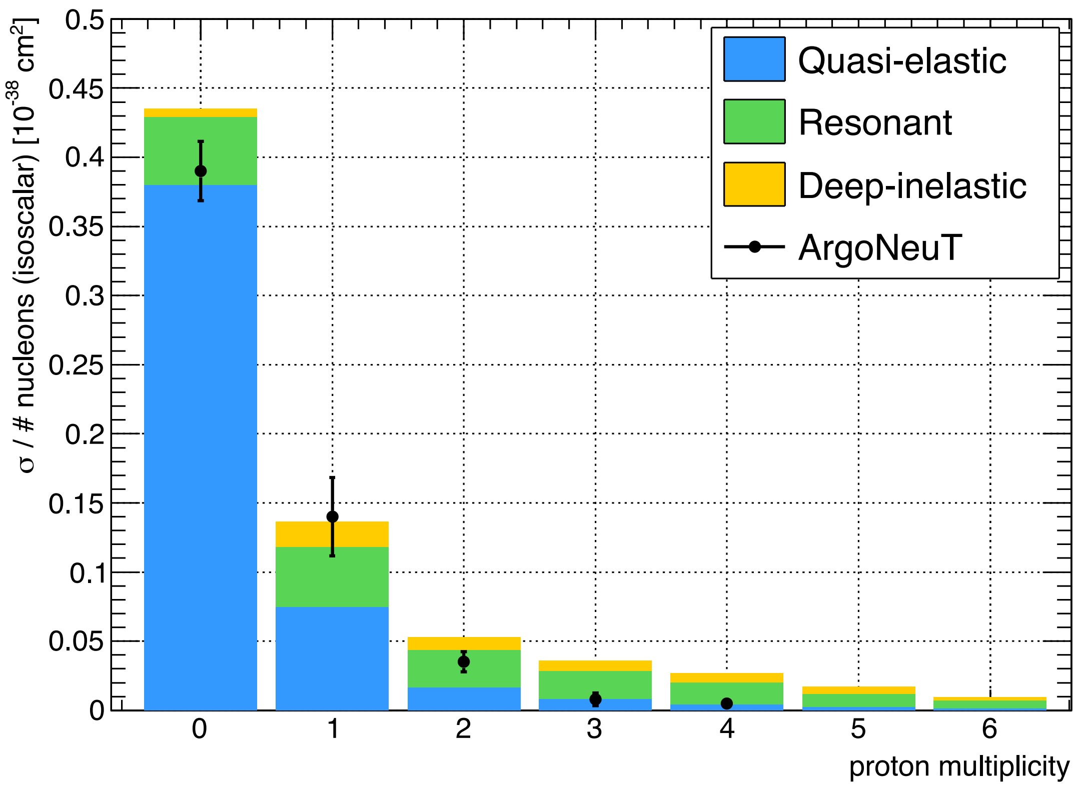


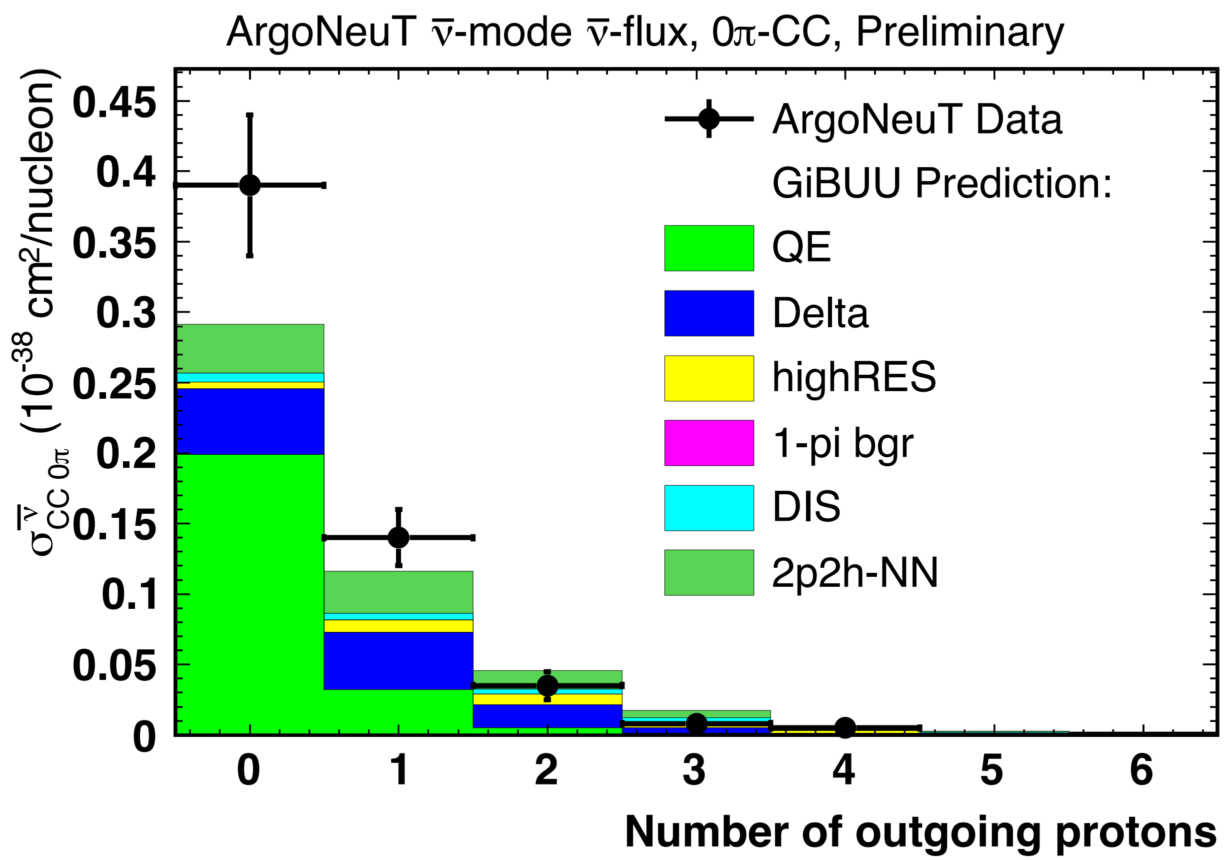
(4) ν_μ CC Particle Multiplicity

ArgoNeuT Results

JPS Conf. Proc. 12, 010017 (2016)

Anti-ν_μ CC0π cross section measurement



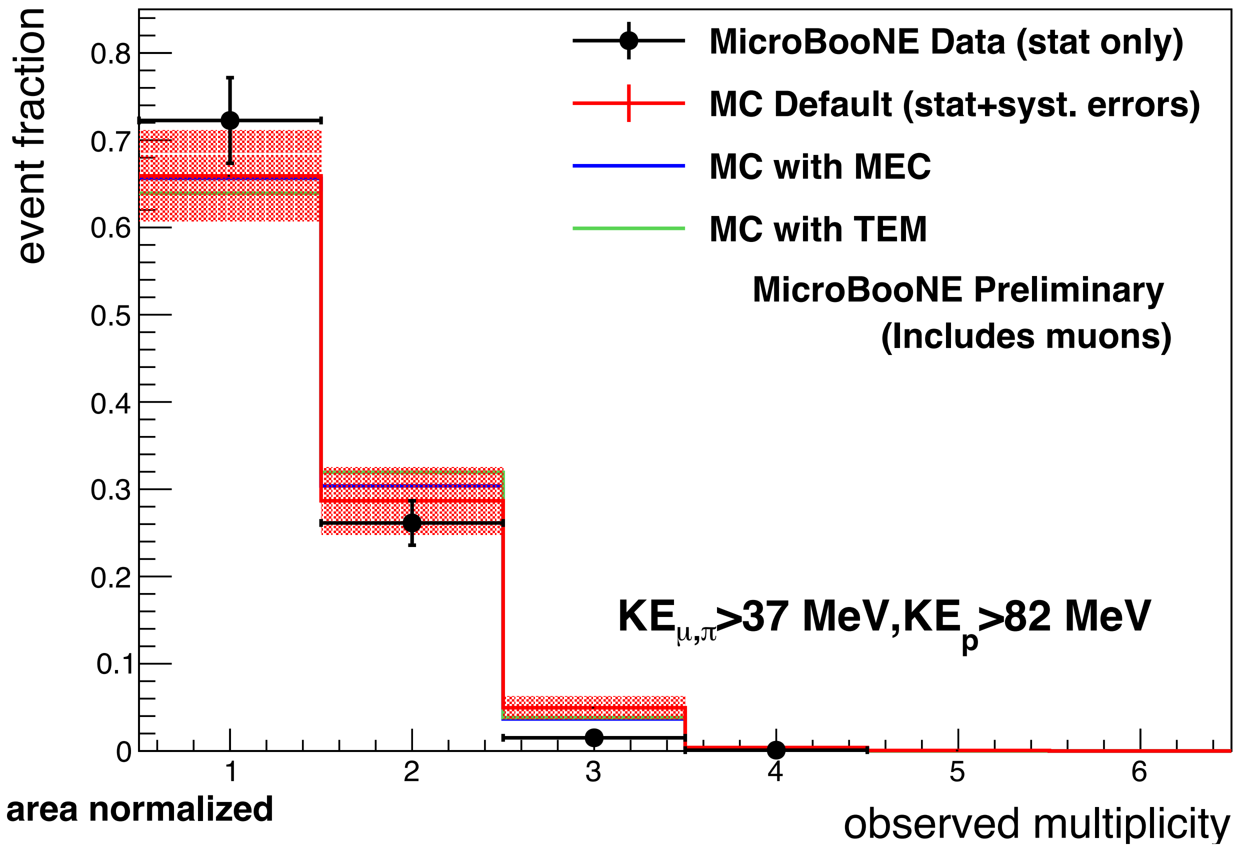


GENIE prediction is 22% higher than ArgoNeuT data

GiBUU prediction is 17% lower than ArgoNeuT data

(4) ν_μ CC Charged Particle Multiplicity

Observed charged multiplicity after event selection: intermediate step towards a cross section as a function of particle multiplicity



- No efficiency correction
- No background subtraction
- Muon is included in the multiplicity count
- Not the same as ArgoNeuT

Paper is in preparation

MicroBooNE Public Note 1024

Future:

- improve statistics, efficiency correction, background subtraction
- lower threshold per particle type
- cross section, as a function of particle multiplicity
- unfold, in order to get to true particle multiplicity

How to Present the Results

MicroBooNE goal is to show **cross section measurements** as a function of as many kinematic variables as possible, together with their correlation.

Upcoming analysis:

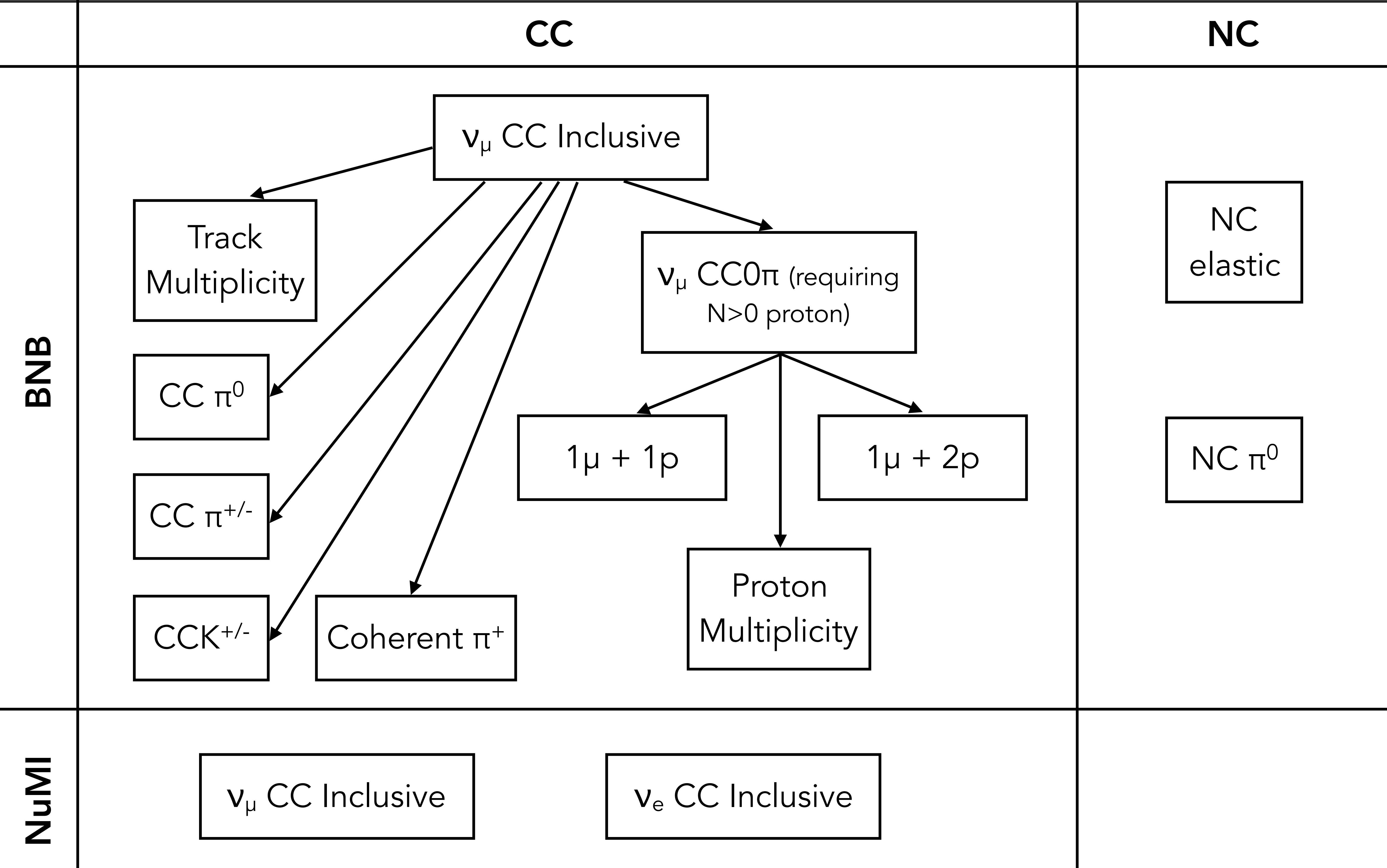
- will show cross section as a function of **muon momentum** and **angle**
- muon momentum will likely be estimated via **MCS**

We would like to present measurements that are as model independent as possible, and to present them to the community in a way that can be compared to theory and other experiments.

We recognise the inherent problems with unfolding, and considering forward folding techniques for our future results.

What is the best format to present forward folded data?

Next Plans for Cross Section Measurements



Conclusions

The next upcoming results will include

- ν_μ CC inclusive cross section measurement
- charged particle multiplicity
- ν_μ CC0πNp cross section measurement (N>0)
- ν_μ CCπ^0 total cross section measurement

Future results will include

- ν_μ CCπ^0 differential cross section measurements and π^0 kinematics
- ν_μ CC$\pi^{+/-}$ differential cross section measurements
- study of rare process (kaon production)
- study of coherent π^+ interactions
- others…

Back up

The MicroBooNE Detector

MicroBooNE cryostat lowered into the pit

Inside the detector: PMT system

Stainless steel wires

with gold coating

3 wire planes

8192 wires total