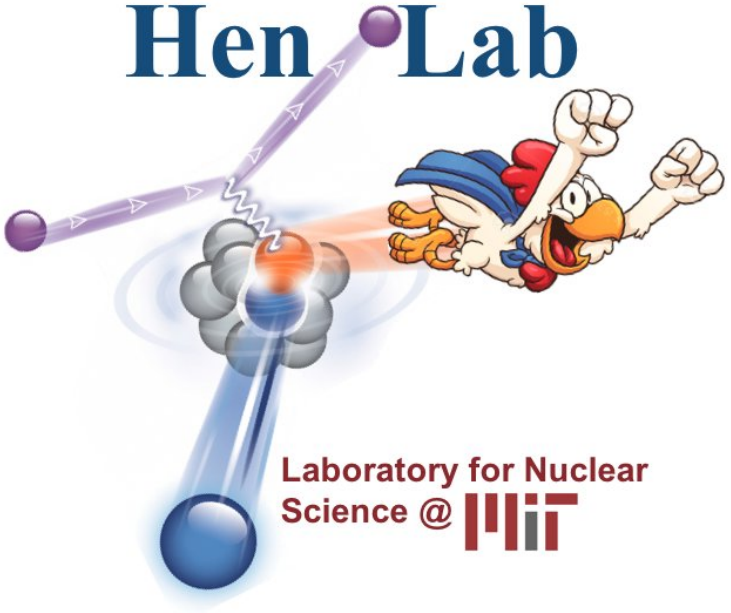
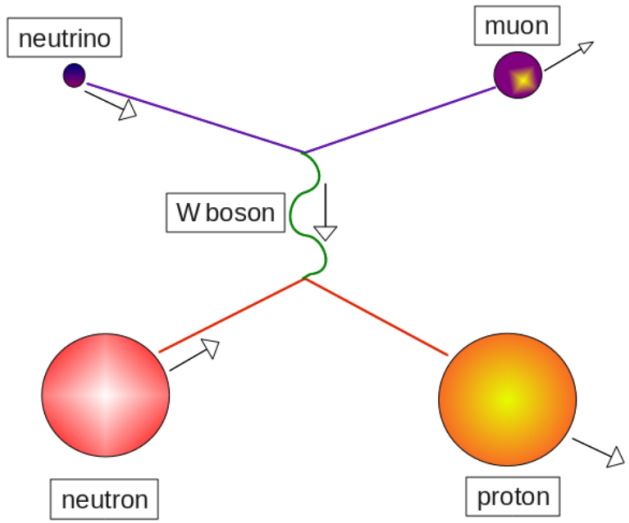
Progress towards the extraction of exclusive ν_μ-^{40}Ar CCQE–like cross–sections using the MicroBooNE LArTPC detector

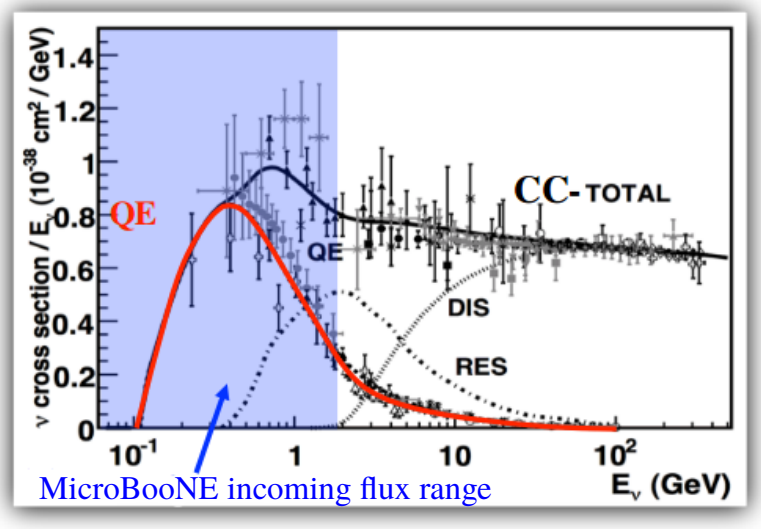


A.Papadopoulou
On behalf of the MicroBooNE Collaboration
June 10, 2019

Motivation

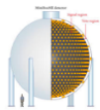
Charged Current Quasi–Elastic (CCQE) Interaction Channel





- Dominant interaction at low energies
- Studies of neutrino energy reconstruction
- Allows high precision oscillation studies

Existing Data

Experiment	Target	μ-dependence	p-dependence
SciBooNE	^{12}C	$d\sigma/dE_\nu$ doi: 10.1063/1.3661556	
MiniBooNE Detector 	^{12}C	$d^2\sigma/dP_\mu d\cos\theta_\mu$ Phys Rev D88 (2013)	
T2K	^{12}C, ^{16}O	$d\sigma/d\theta_\mu$ Phys Rev D92 (2015) $d^2\sigma/dP_\mu d\cos\theta_\mu$ PhysRevD.98.0124004	$d^2\sigma/dP_p d\cos\theta_p$ arXiv:1802.05078 [hep-ex]
MINERvA 	^{12}C, ^{56}Fe, ^{208}Pb	$d^2\sigma/dP_\parallel dP_T$ Phys Rev D97.052002	$d^2\sigma/dQ^2_p$ Phys Rev Lett 119 (2017)

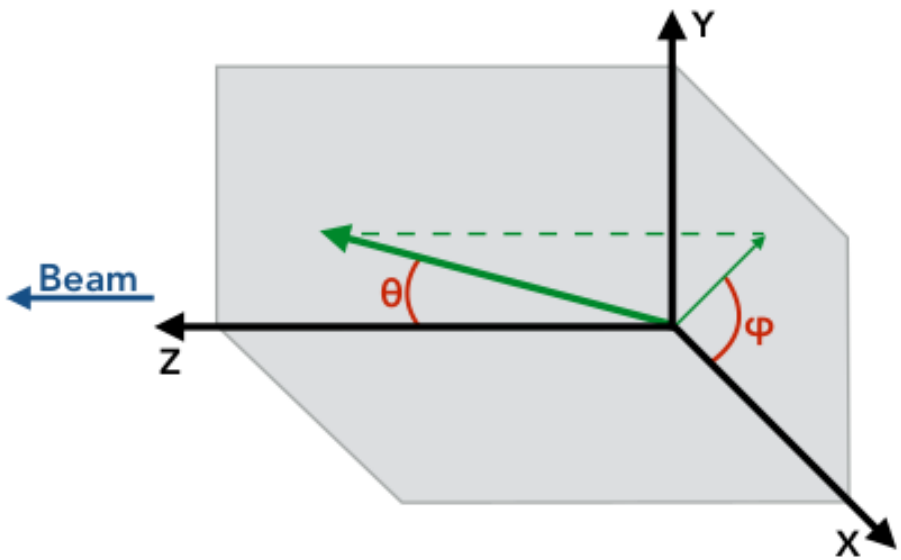
- Extracted cross–sections on ^{12}C, ^{16}O, ^{56}Fe, ^{208}Pb
  - None on ^{40}Ar (heavy asymmetric nucleus, building nucleus of LArTPC detectors)

Objective

μBooNE	^{40}Ar	$d\sigma/dP_\mu$, $d\sigma/d\cos\theta_\mu$, $d\sigma/d\varphi_\mu$	$d\sigma/dP_p$, $d\sigma/d\cos\theta_p$, $d\sigma/d\varphi_p$

First extraction

of exclusive ν_μ-^{40}Ar CCQE–like differential cross–sections using the MicroBooNE detector



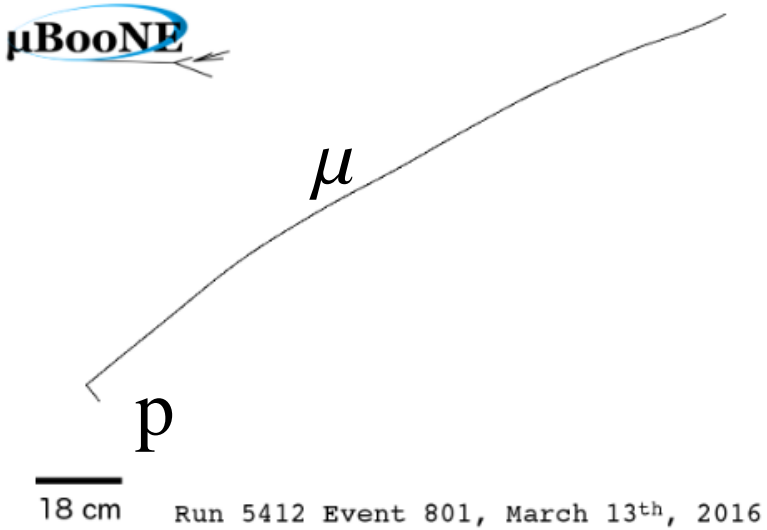
θ: angle w.r.t. the beam line

φ: angle around the beam line

Signal Definition

Vertex of 2 tracks

- 1 muon ($\geq$ 100 MeV/c)
- 1 proton ($\geq$ 300 MeV/c)
- No π^0, no $\pi^{\pm}$ ($\geq$ 70 MeV/c)

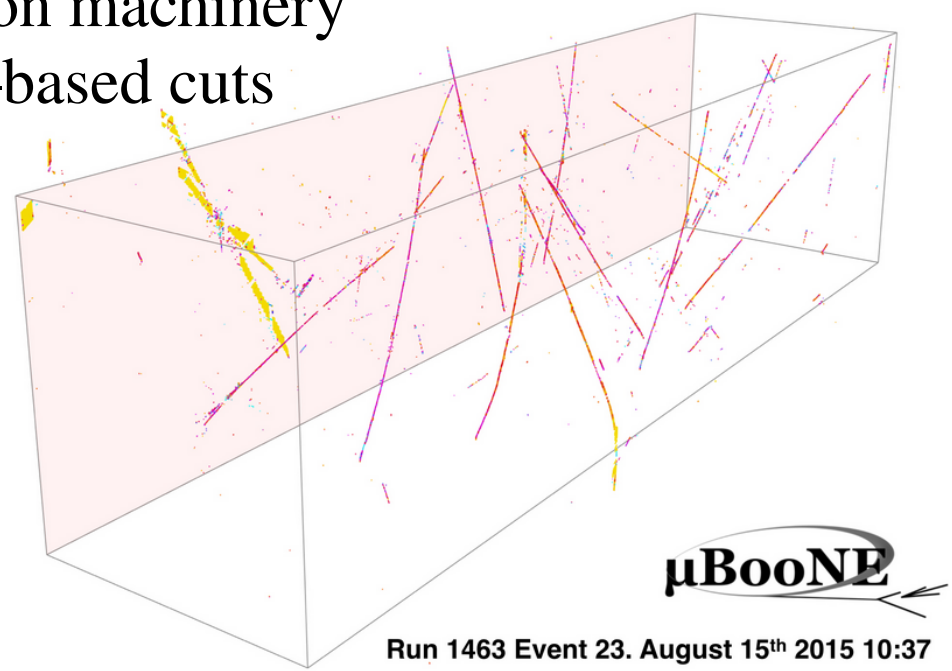


*We allow any number of e, γ, n
and charged hadrons below these thresholds,
which can be further lowered

Cosmic Background Rejection

- MicroBooNE is a surface detector dominated by cosmics
  - 1 ν interaction in $\sim$ 500 events
  - After trigger application,
    1 ν interaction in $\sim$ 10 events

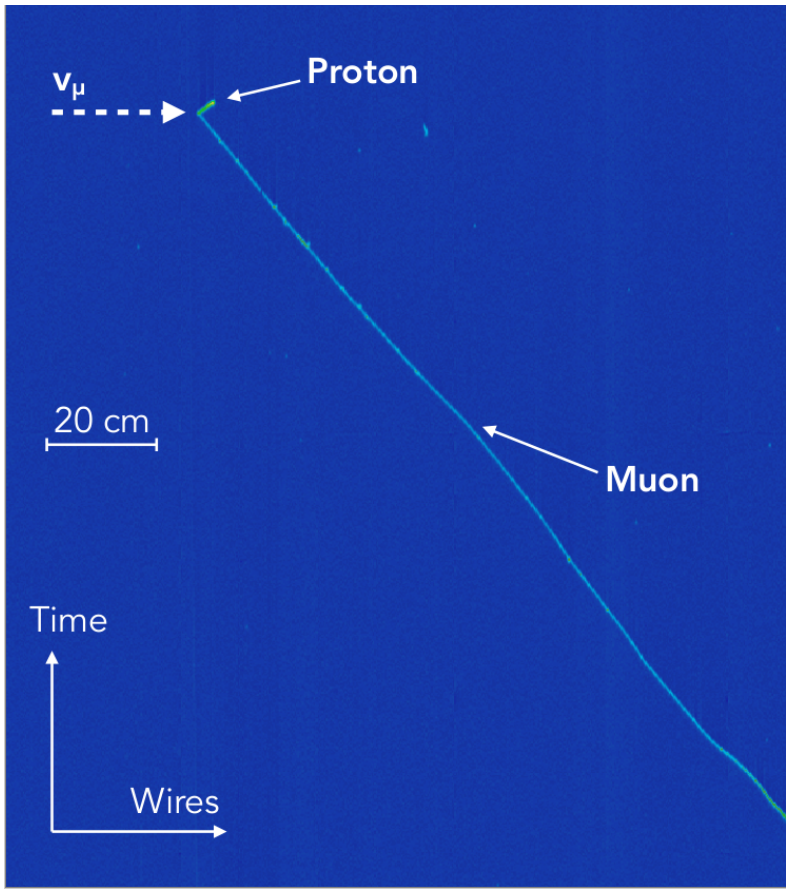
- Development of cosmic rejection machinery using detector and kinematics–based cuts
  - arXiv:1812.05679



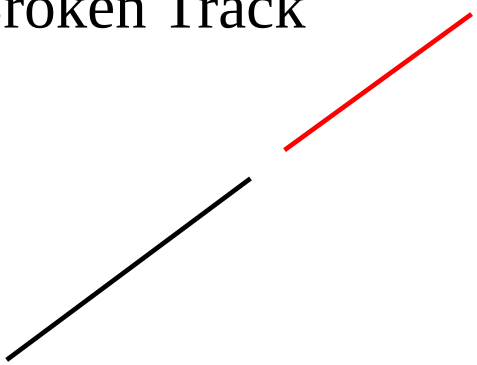
Cosmic Background Rejection

Detector–based cuts

- Energy deposition profile
- Track length
- Scintillation light
- Collinearity



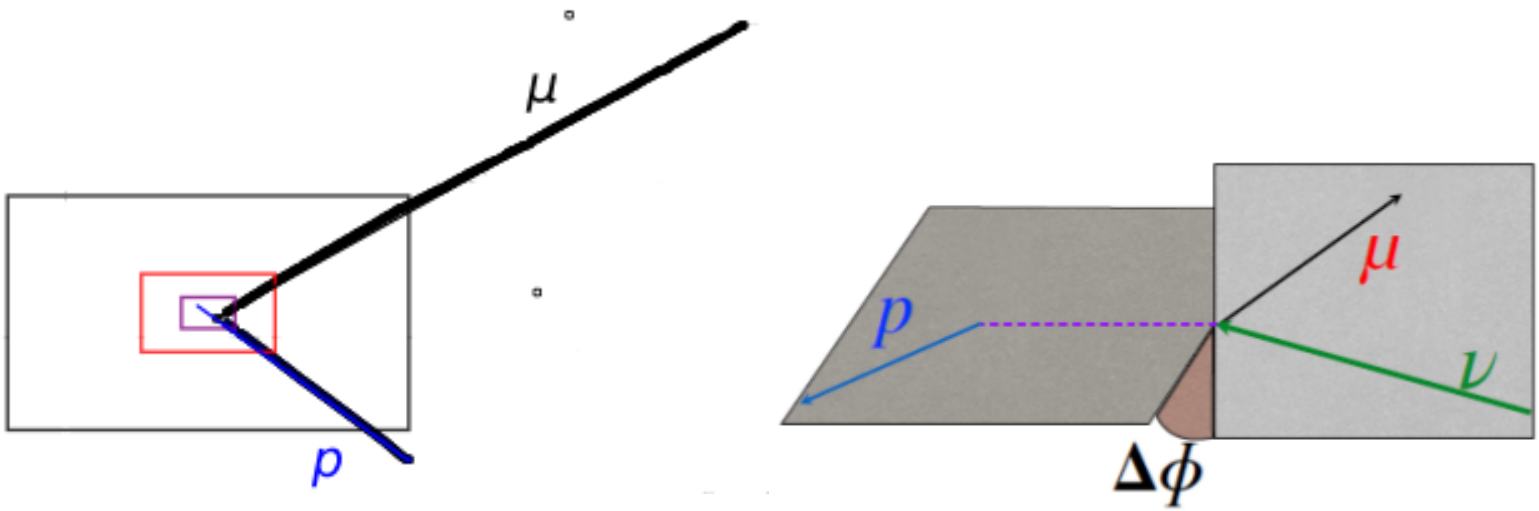
Broken Track



Cosmic Background Rejection

Kinematics–based cuts

- Vertex activity
- Coplanarity
- Transverse imbalance $\vec{P}^{\perp}_{miss} = (\vec{P}_{\mu} + \vec{P}_{p})^{\perp}$



Statistics

- Purity: 78.7 ± 1.1 %
- Efficiency: 15.5 ± 0.2 %

- # events measured: 462.0 ± (stat) 21.5*
- # events expected: 486.4 ± (stat) 5.0

Though low statistics,
first indication of **consistency** between data and simulation

* Using ~ 1 / 20 of the available data–sample

Cross–Section Extraction

- Select events in data sample
- Subtract cosmic related background
- Subtract MC beam related background

$$\left(\frac{d\sigma}{dp_\mu}\right)_n = \frac{N_n^{on} - N_n^{off} - B_n}{\eta_n^\mu \cdot \Phi_\nu \cdot N_{targets} \cdot \Delta_n^\mu}$$

*Same for the proton and other kinematic variables

Cross–Section Extraction

$$\left(\frac{d\sigma}{dp_\mu}\right)_n = \frac{N_n^{on} - N_n^{off} - B_n}{\eta_n^\mu \cdot \Phi_\nu \cdot N_{targets} \cdot \Delta_n^\mu}$$

N^{on} – # of events in beam-on data

N^{off} – # of events in beam-off data

} DATA

Cross–Section Extraction

$$\left(\frac{d\sigma}{dp_\mu}\right)_n = \frac{N_n^{on} - N_n^{off} - B_n}{\eta_n^\mu \cdot \Phi_\nu \cdot N_{targets} \cdot \Delta_n^\mu}$$

η – effective detection efficiency (efficiencies & bin migration)

B – background processes

} MC

Cross–Section Extraction

$$\left(\frac{d\sigma}{dp_\mu}\right)_n = \frac{N_n^{on} - N_n^{off} - B_n}{\eta_n^\mu \cdot \Phi_\nu \cdot N_{targets} \cdot \Delta_n^\mu}$$

Φ_ν – neutrino integrated flux

$N_{targets}$ – number of nuclei

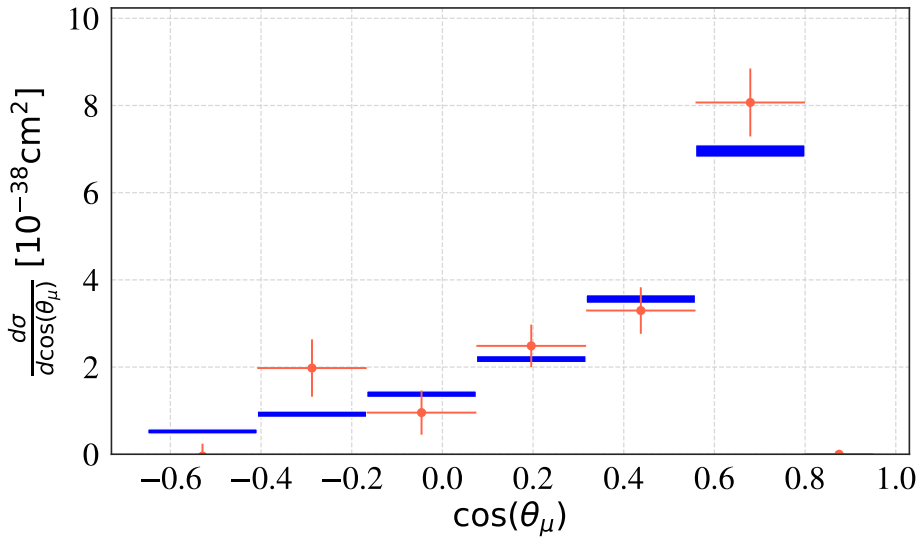
Δ – bin width

} Constants

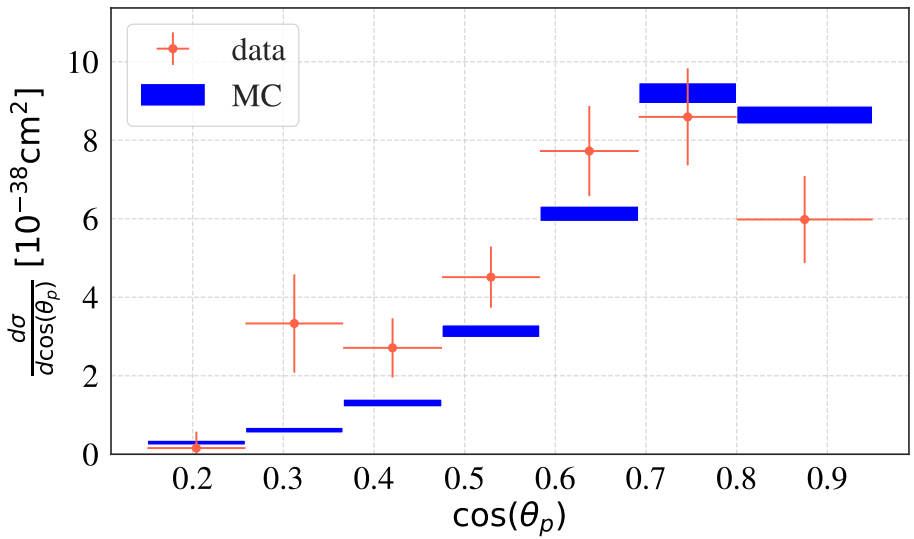
Differential Cross–Sections

Work In Progress

Muons



Protons



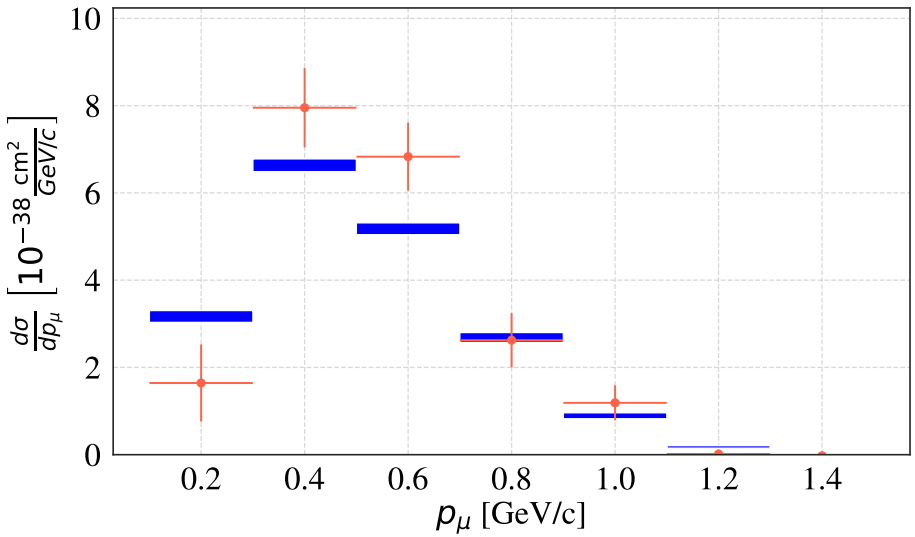
*Only statistical errors included

Non–negligible differencies

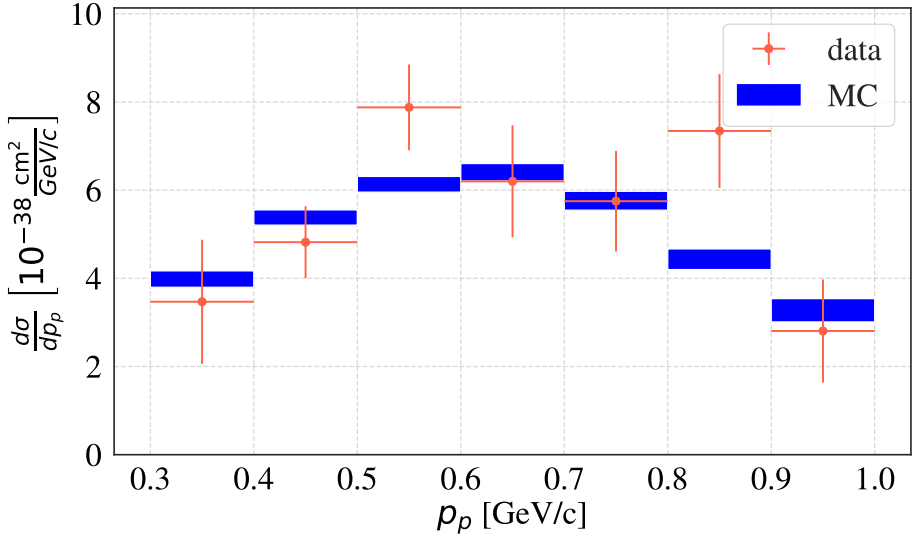
Differential Cross–Sections

Work In Progress

Muons



Protons*



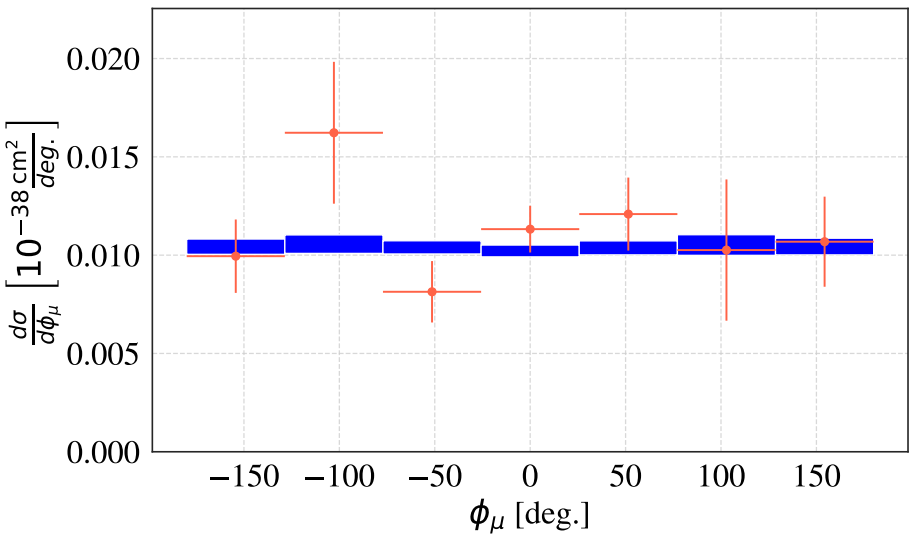
Non–negligible discrepancies

*First attempt to extract proton differential cross–sections at such low momenta

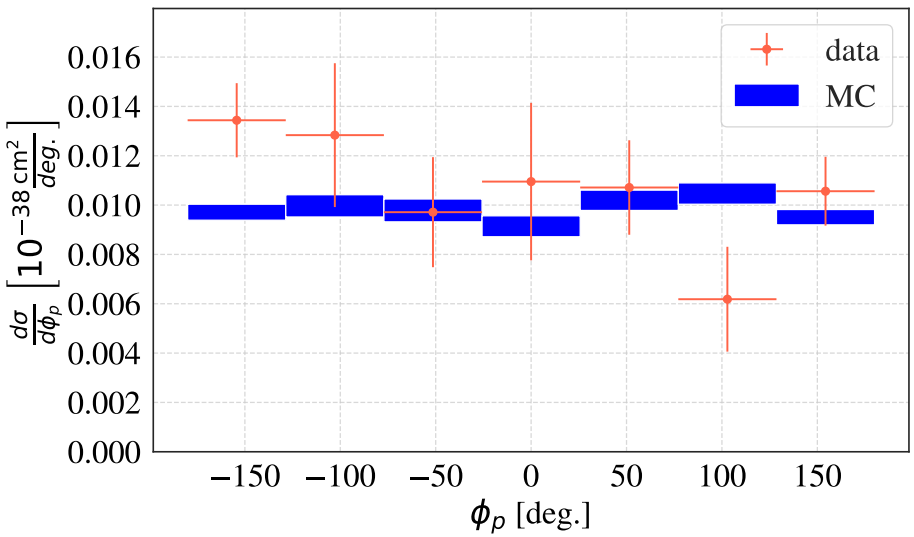
Differential Cross–Sections

Work In Progress

Muons



Protons



Sanity check

Uniform distributions in polar angle

Wrap Up & Future

☑ Progress towards first extraction of exclusive ν_μ-^{40}Ar CCQE–like differential cross–sections using data from the MicroBooNE LArTPC detector

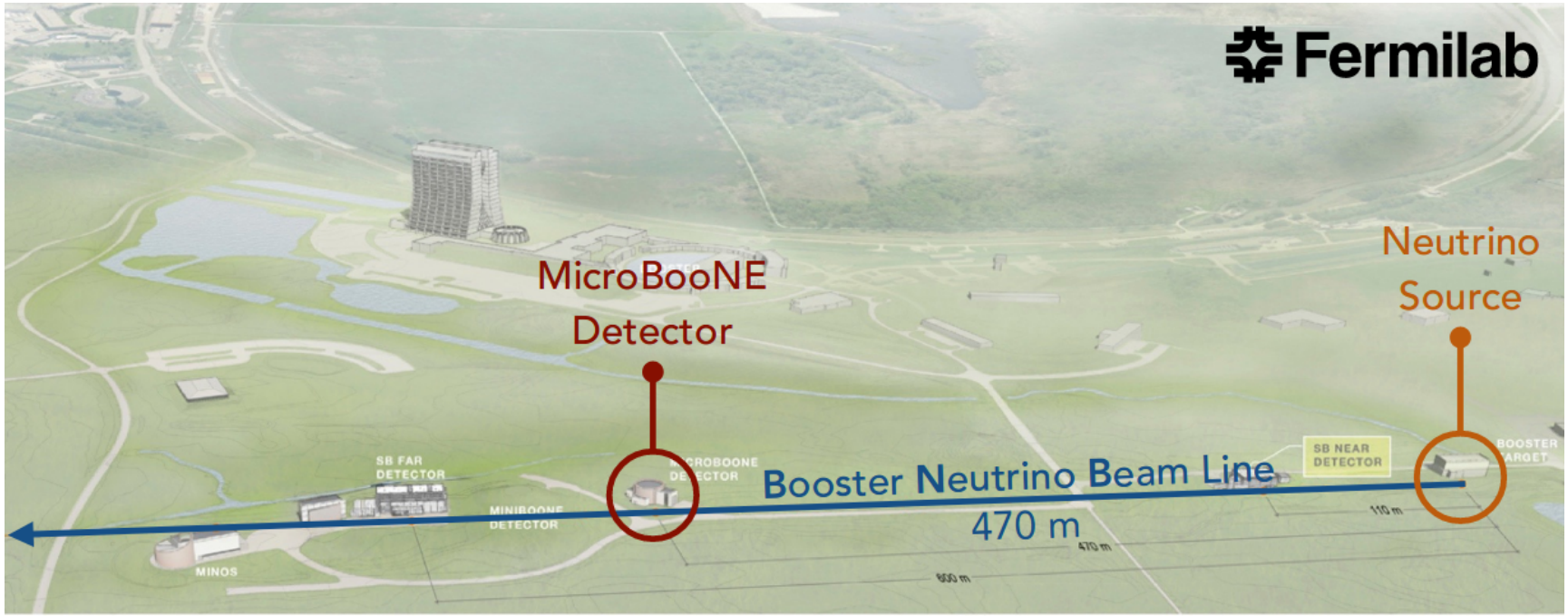
☑ Finalizing systematical studies

*Paper published in the near future

Thank you!

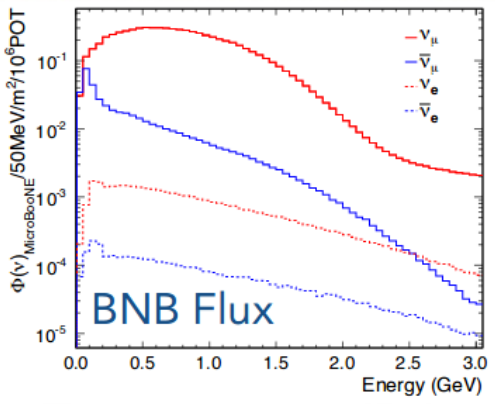
Backup Slides

The MicroBooNE Experiment

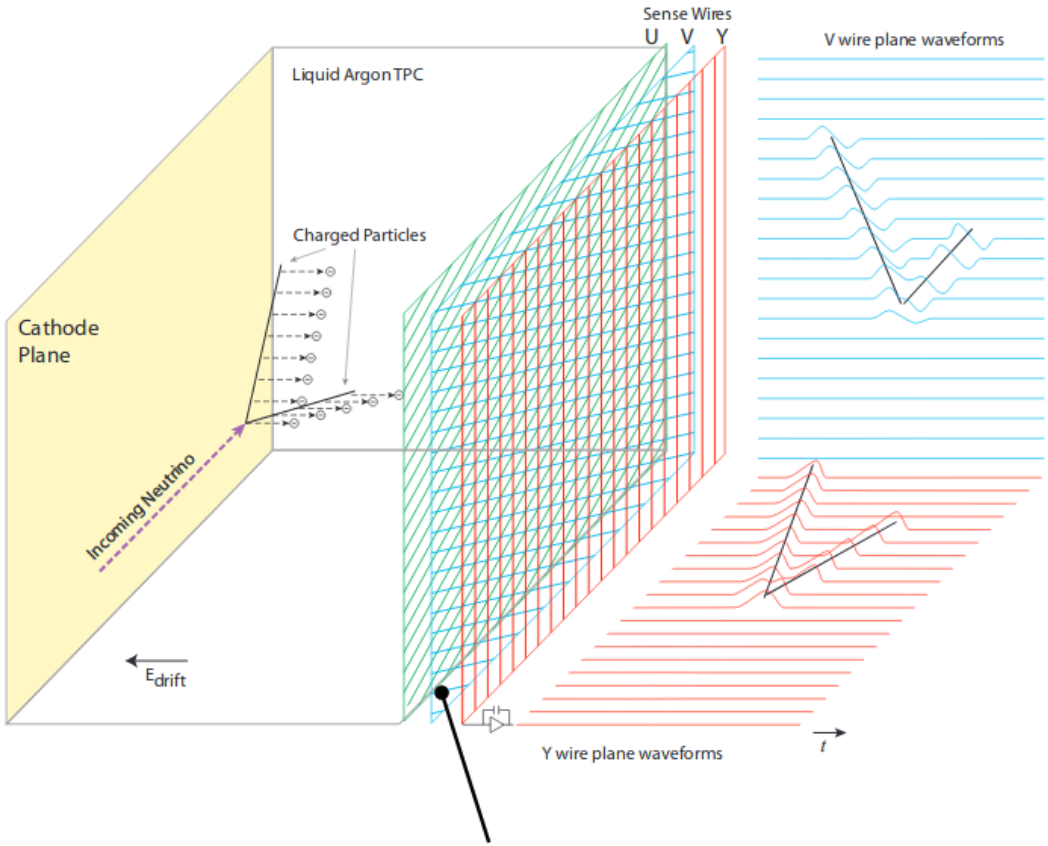


Goals of the **S**hort **B**aseline **N**eutrino program:

- low-energy excess observed by MiniBooNE
- sterile neutrinos
- cross section measurements
- R&D for future LArTPC experiments



The MicroBooNE Detector



8192 wires (3 mm pitch)

32 8″ Cryogenic PMTs

170 ton LArTPC (total mass)

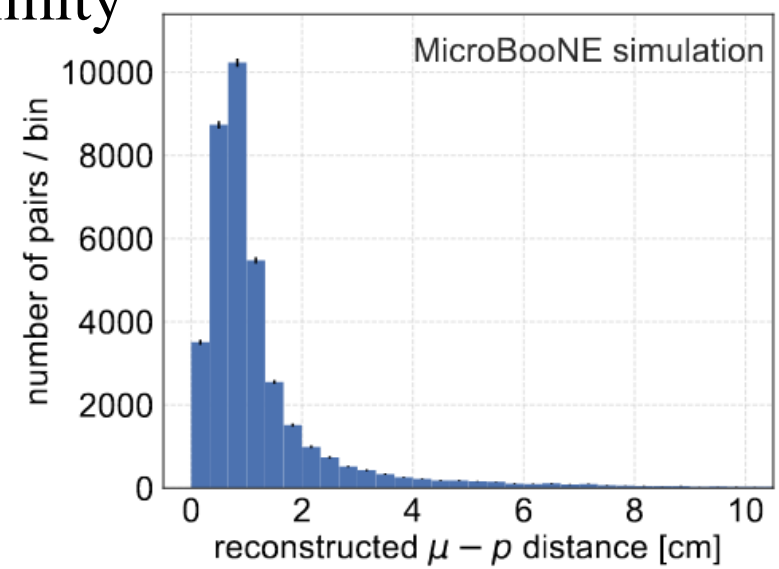
Pre–Selection

Hardware and Software Triggers

- 1 ν interaction in $\sim$ 1000 triggered events
- PMT trigger enriches this ratio to 1 ν interaction in $\sim$ 10 events

Collection of track pairs at close proximity

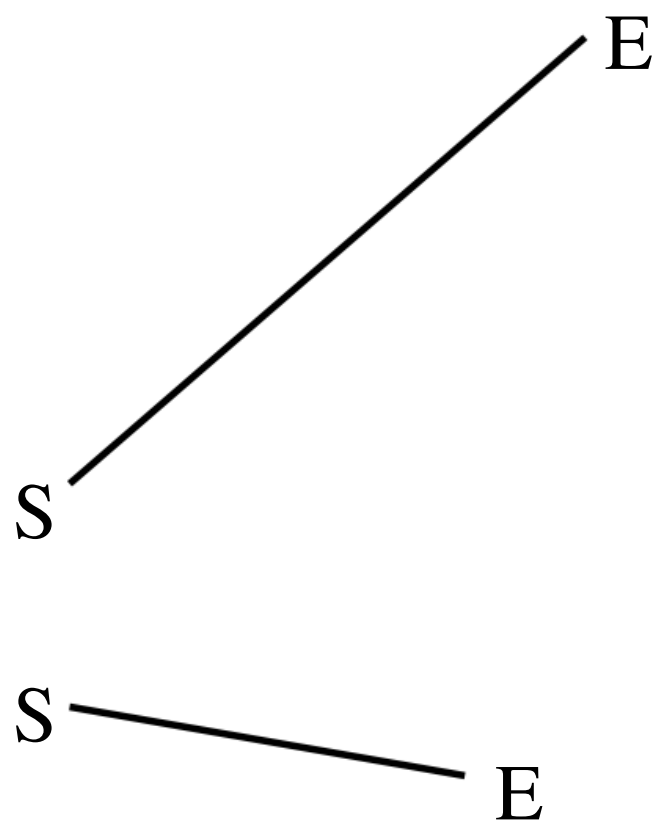
- arXiv:1812.05679



Pre–Selection

- Pairs of tracks at close proximity:

distance < 11 cm between any two edges (start-start, start-end, end-start, end-end)

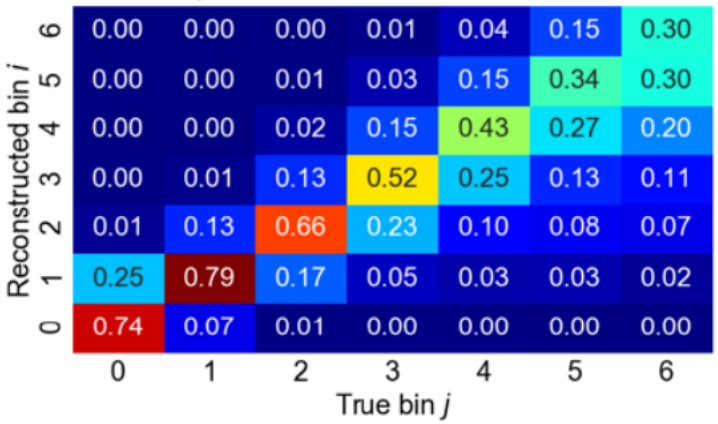


Statistics

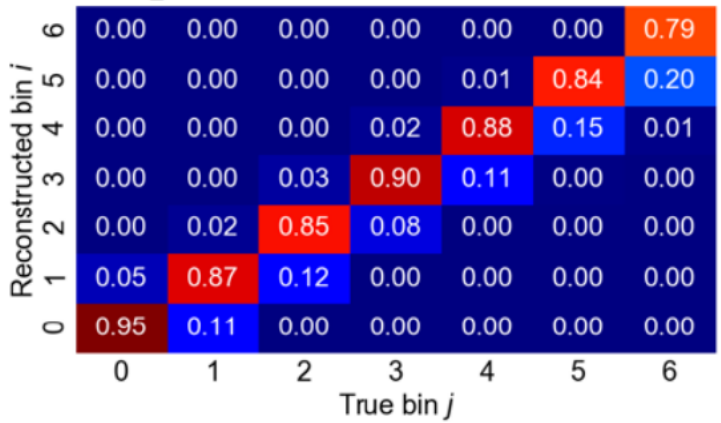
sample	number of events	beam–on equivalent
beam-on	462 ± 21.5	462.0 ± 21.5
beam-off	15 ± 3.9	10.6 ± 2.7
overlay	12120.0 ± 110.1	618.3 ± 5.6
$CC1pO\pi$	9533 ± 97.6	486.4 ± 5.0

Migration Matrices

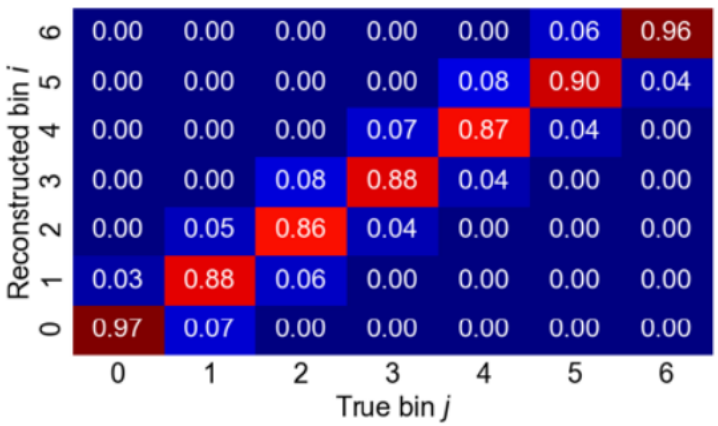
p_μ



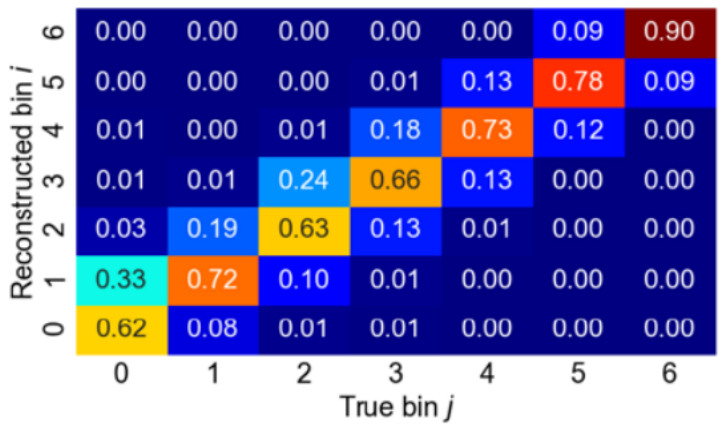
p_p



$\cos\theta_\mu$



$\cos\theta_p$



Effective Efficiency

$$\eta_n = \left(\frac{N_{\text{reconstructed}}\ (\text{reco.})}{N_{\text{generated}}\ (\text{truth})} \right)_n$$

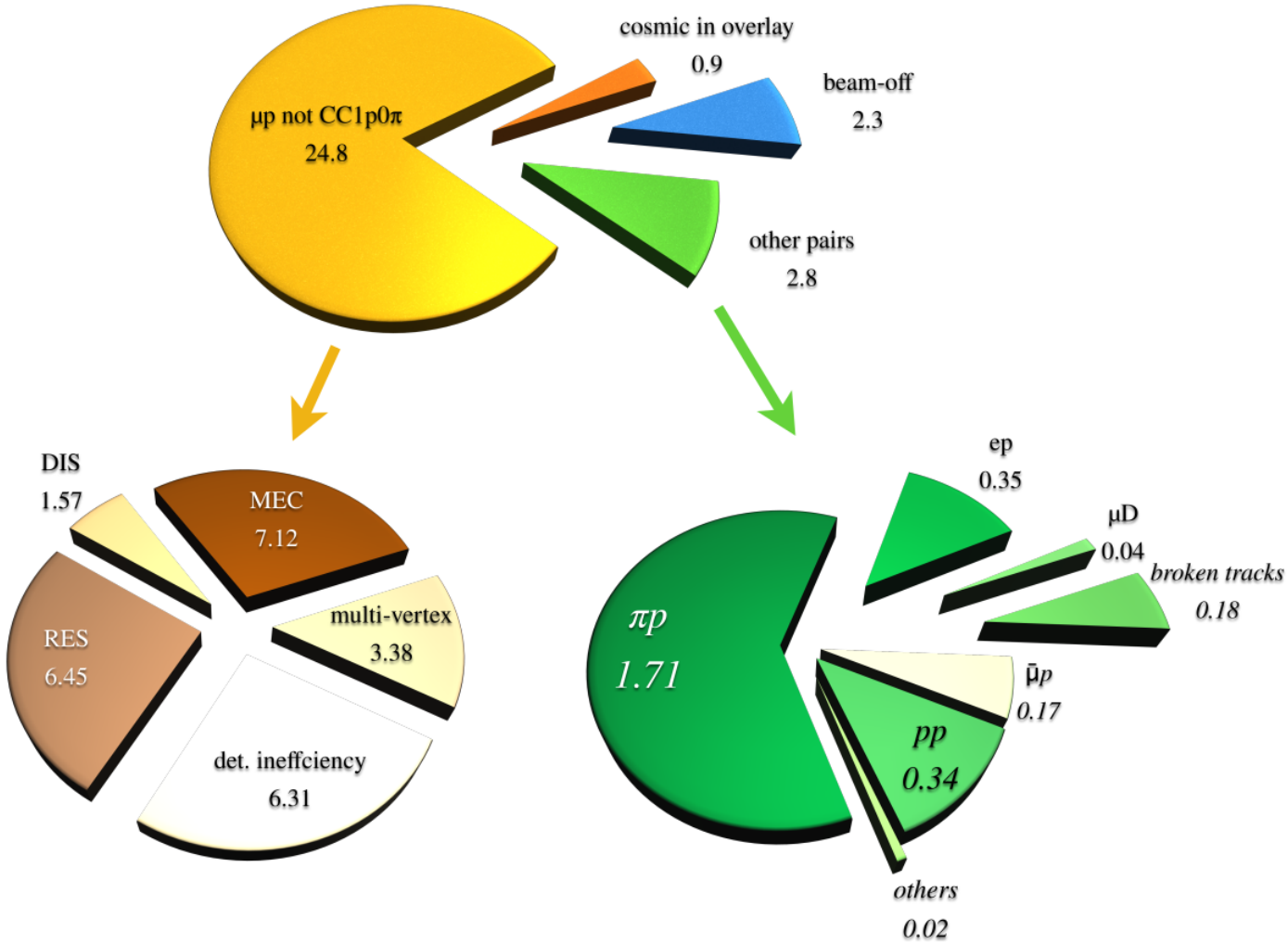
$$= \frac{N_{\text{rec}}\ (\text{gen. in bin } n)}{N_{\text{gen}}\ (\text{gen. in bin } n)}$$

standard efficiency

$$+ \frac{N_{\text{rec}}\ (\text{migrate into bin } n) - N_{\text{rec}}\ (\text{migrate outside bin } n)}{N_{\text{gen}}\ (\text{gen. in bin } n)}$$

efficiency + bin migration

Background


μp not CC1p0π
24.8
cosmic in overlay
0.9
beam-off
2.3
other pairs
2.8
DIS
1.57
MEC
7.12
RES
6.45
multi-vertex
3.38
det. ineffciency
6.31
ep
0.35
μD
0.04
broken tracks
0.18
πp
1.71
μ̄p
0.17
pp
0.34
others
0.02

Systematics

- ☑ Event selection cuts
- ☑ Beam flux
- ☑ POT
- ☑ Efficiencies due to correlations

- ☒ Detector modeling
- ☒ Event generator