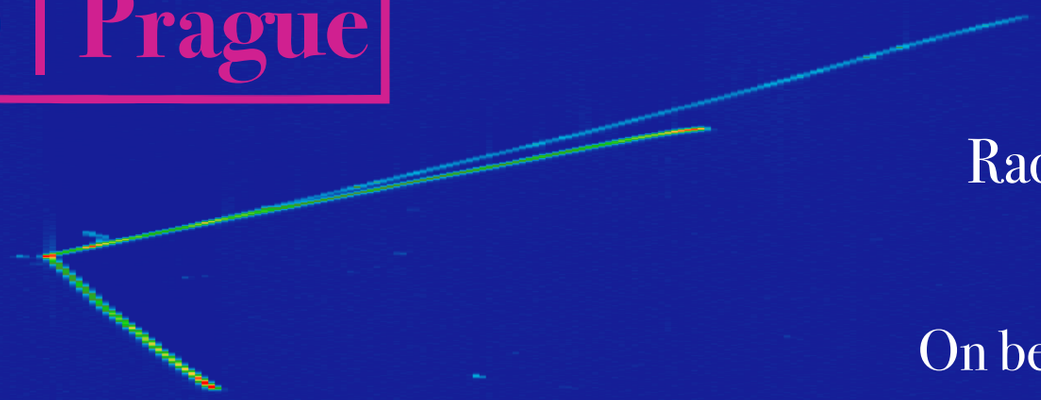
Recent Cross-section Measurements from MicroBooNE

ICHEP2020 | Prague



Raquel Castillo Fernández, Fermilab
28th July 2020

On behalf of the MicroBooNE Collaboration

MicroBooNE @ICHEP2020

Neutrino Physics Session

- *Recent cross-section measurements from MicroBooNE* (this talk)
- *Neutral current π^0 rate measurement with the MicroBooNE detector*. **Mark Ross-Lonergan** (today)
- *Charged-current electron neutrino measurement with the MicroBooNE detector*. **Wouter Van De Pontseele** (today)
- *Search for a low-energy excess with MicroBooNE.* **David Caratelli** (today)

Searches Beyond the Standard Model Session

- *Search for heavy neutral leptons decaying into muon-pion pairs in the MicroBooNE detecto*r. **Owen Goodwin** (today)
- *Searches for long-lived particle decays in MicroBooNE.* **Pawel Guzowski** (29th July)
- *Neutron-antineutron oscillation search with MicroBooNE and DUNE*. **Yeon-Jae Jwa** (31rst July)

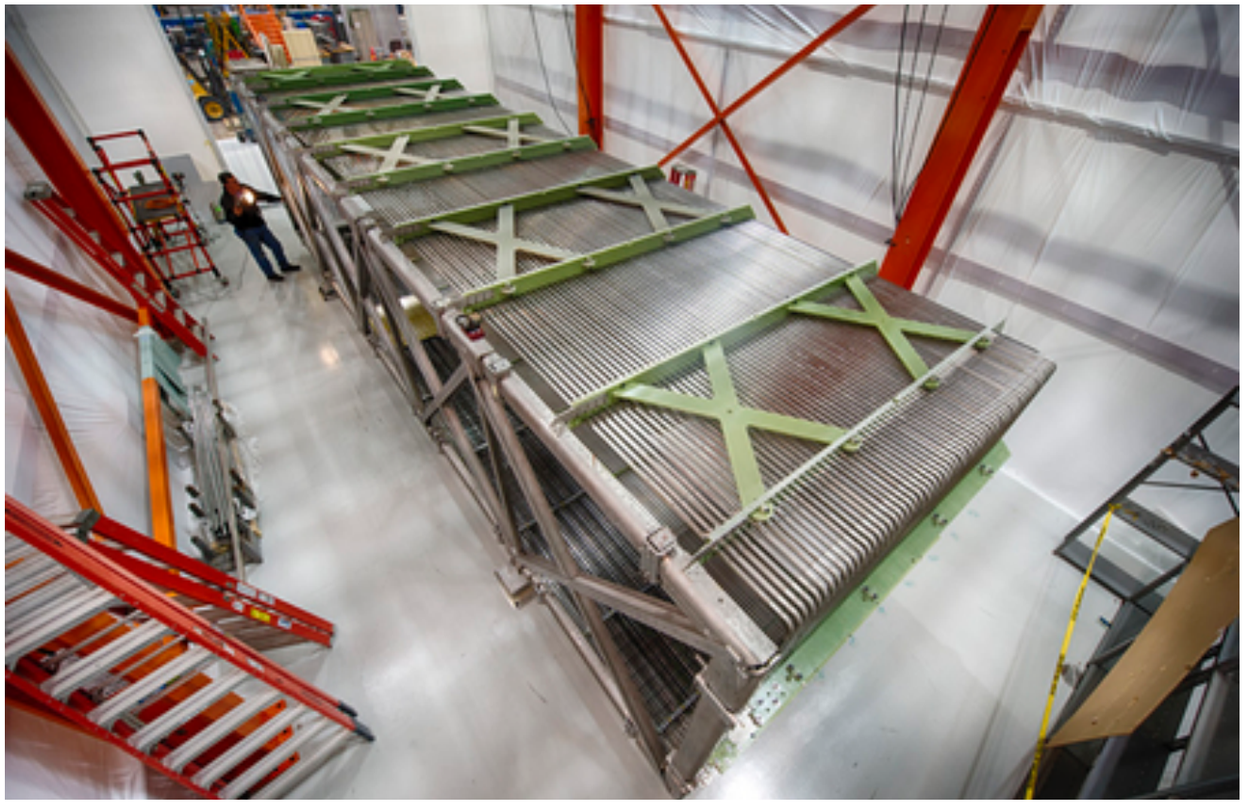
Operation, Performance and Upgrade of Present Detectors Session

- *The MicroBooNE Experiment.* **Ralitsa Sharankova** (today)

MicroBooNE

- Investigate the LSND/MiniBooNE anomaly: **electron/γ?** (see David Caratelli's talk)
- **Measure first low-energy ν-Ar scattering cross sections (this session)**
- **R&D** for future long baseline experiment: Deep Underground Neutrino Experiment (DUNE) (see Ralitsa Sharankova's talk)
- First phase of the **Short Baseline Neutrino (SBN)** program at Fermilab

First big LArTPC operating in the USA
First automatic reconstruction in LArTPC
Largest ν-argon data
Longest LArTPC operating in the world



Same location and beam (BNB) as MiniBooNE .

- Almost pure ν_μ beam (0.5% intrinsic ν_e contamination)
- Located on-axis from ν source @470m

Excellent **signal from background** and additional **rare processes** **(see Owen Goodwin, Yeon-Jae Jwa and Pawel Guzowski's talks)**.

LArTPC

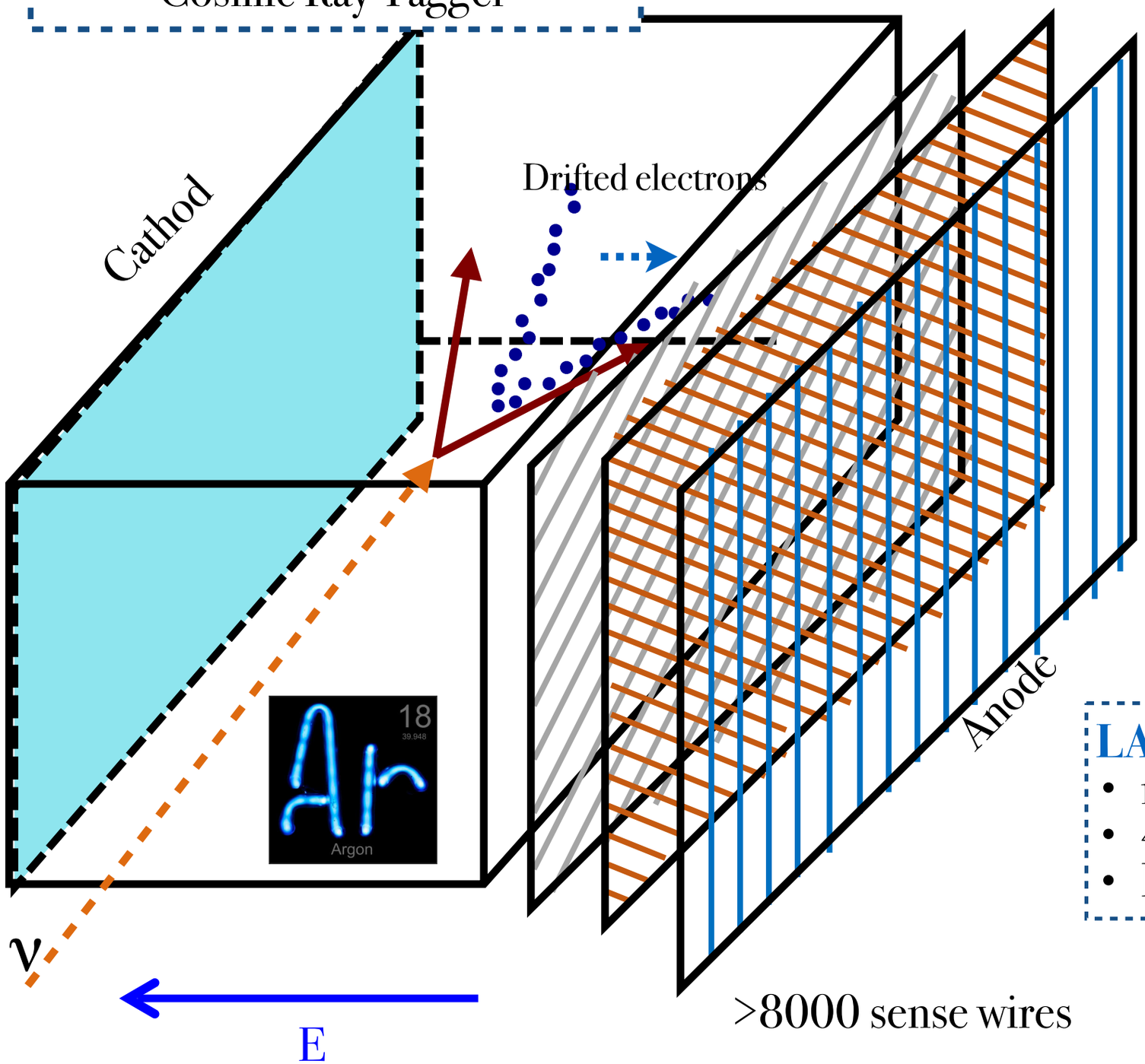
See Ralitsa Sharankova's talk

Inside the cryostat:
- **LArTPC**
- Photon detector system

Outside the cryostat
- Cosmic Ray Tagger

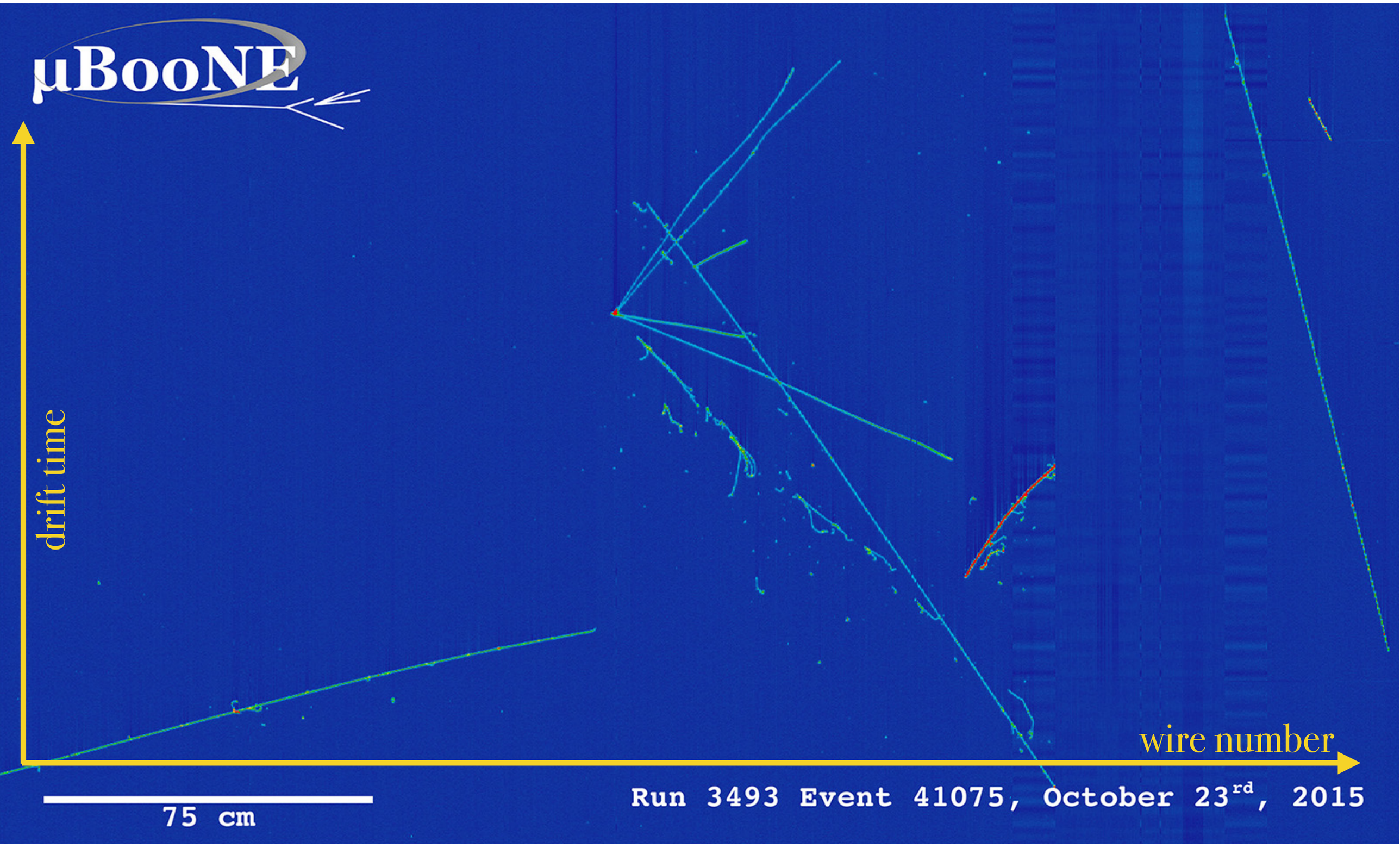
JINST 12, P02017 (2017)

- 170 tons of liquid argon
  - **86 tons of active mass**
- Non-evacuated liquid argon fill
- **Cold** (in LAr) **front-end electronics**
- Near-surface operation (cosmic rays are our biggest background)
- **UV laser calibration system**

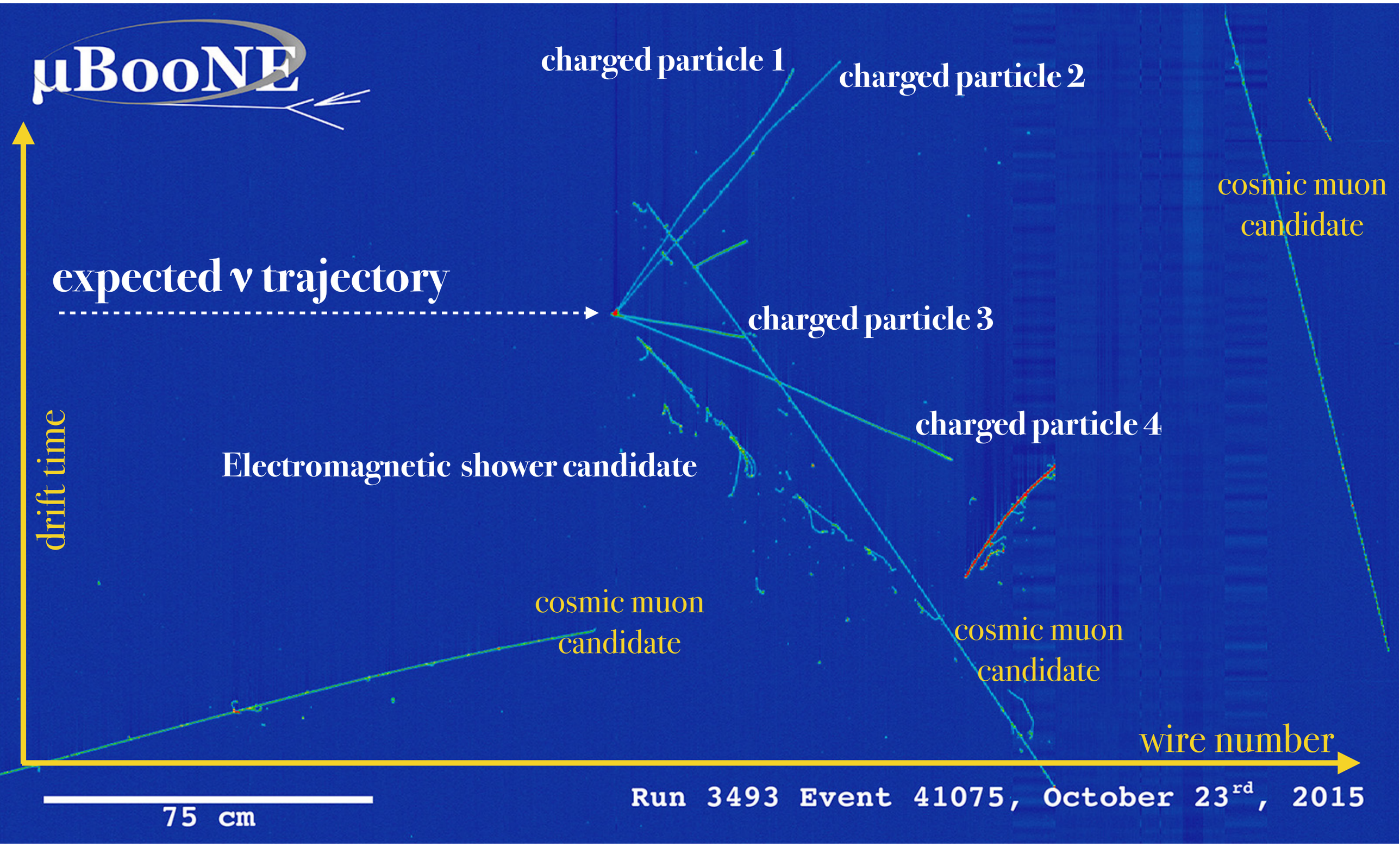


LArTPC = Topology + Calorimeter
- mm-scale resolution
- 4π angular coverage
- Protons visible from few 10s of MeV in KE

Particle Reconstruction & Identification



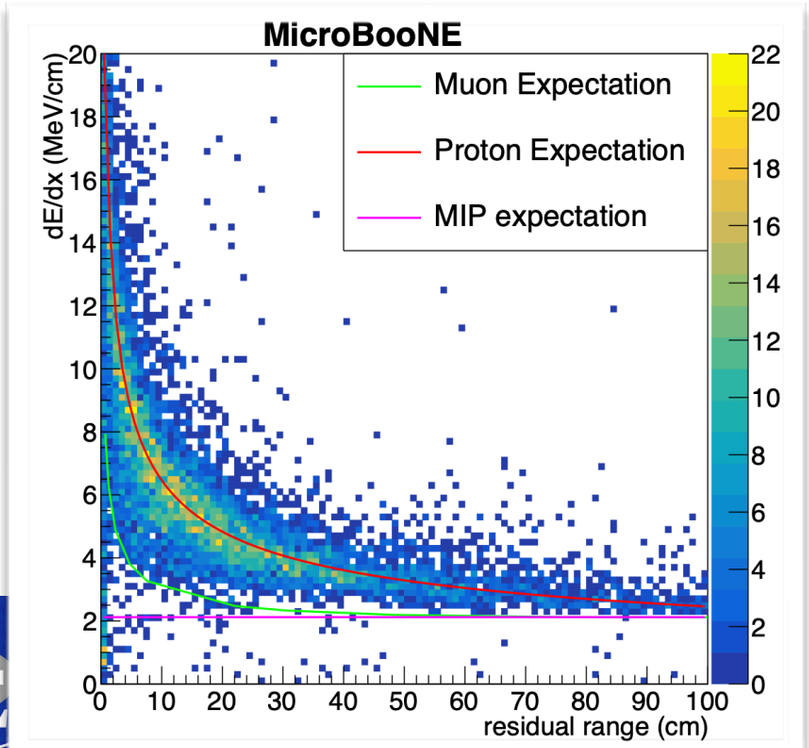
Particle Reconstruction & Identification

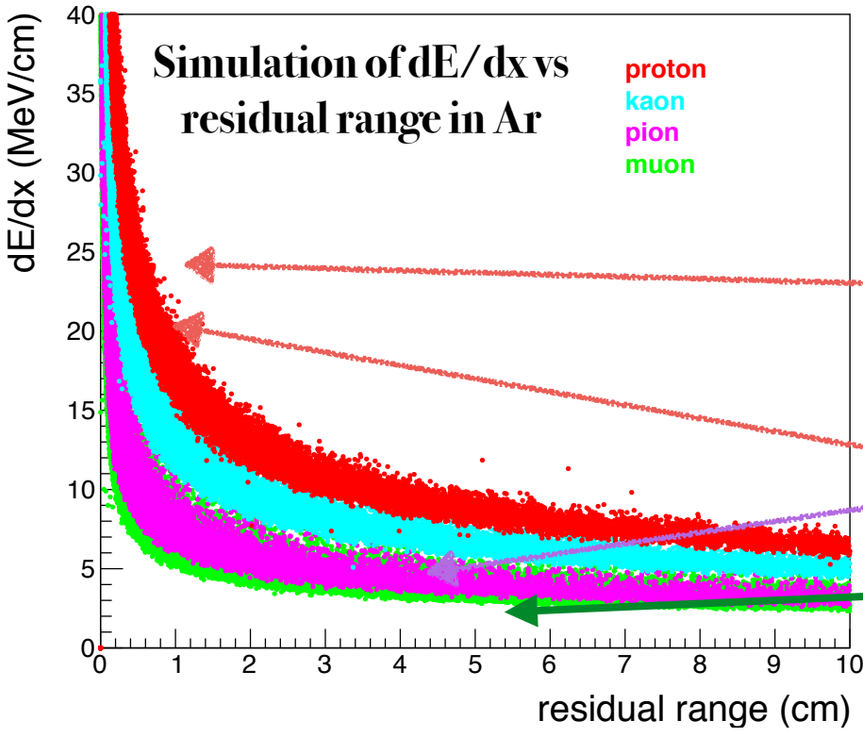


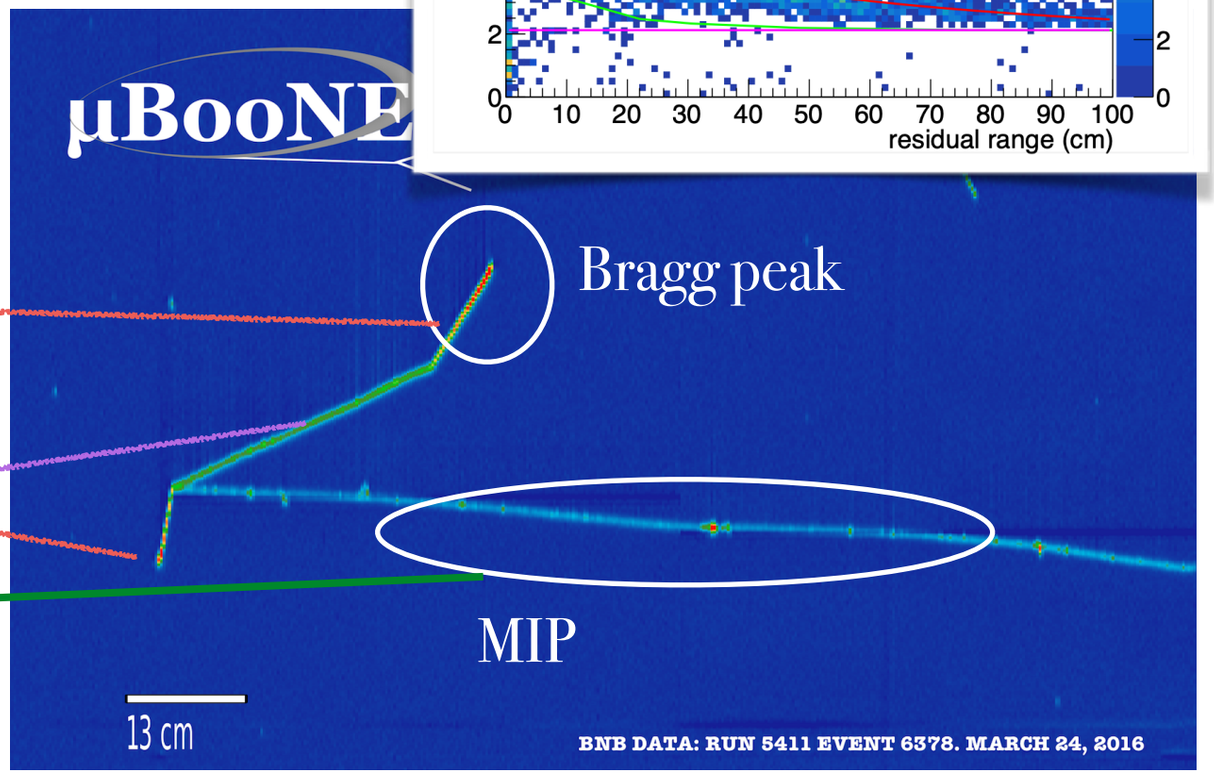
Particle Reconstruction & Identification

Lowest particle energy threshold (protons observed @47MeV KE) with respect to current ν accelerator-based experiments.
Observation of proton multiplicity.

JINST 15, P03022 (2020)

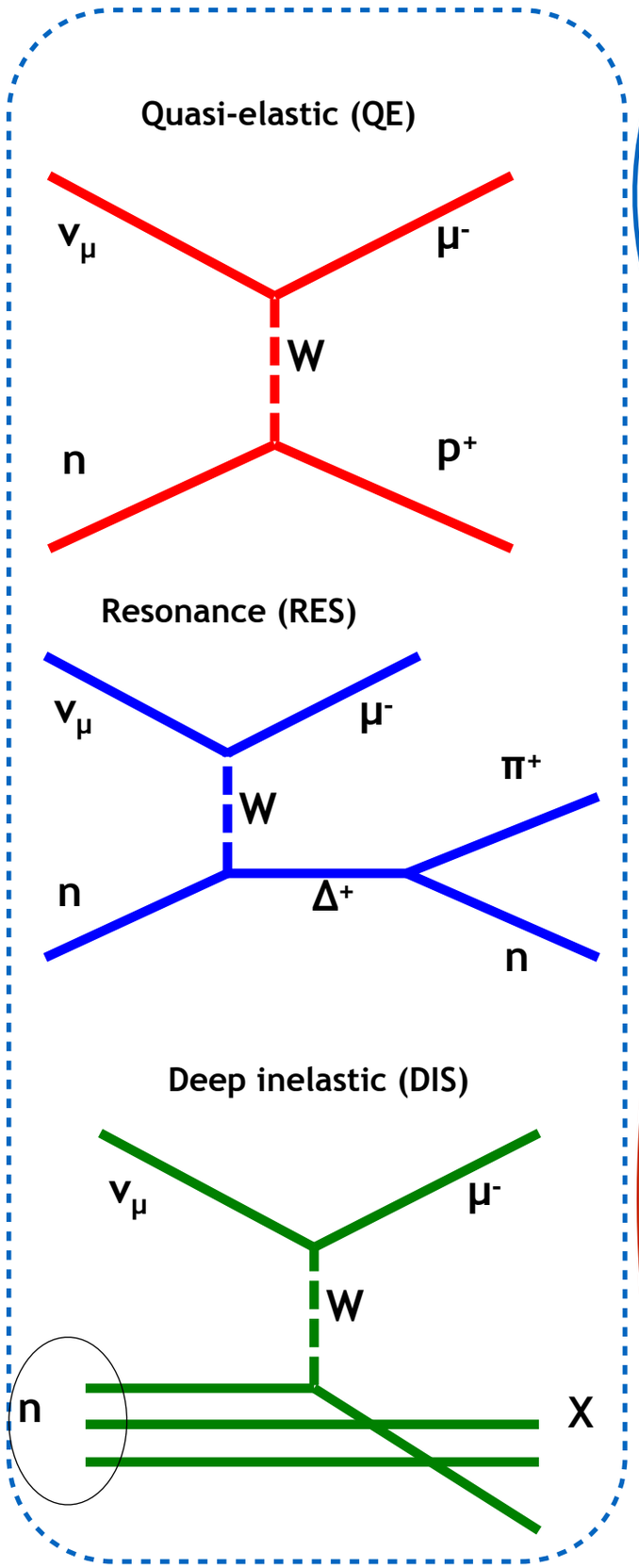


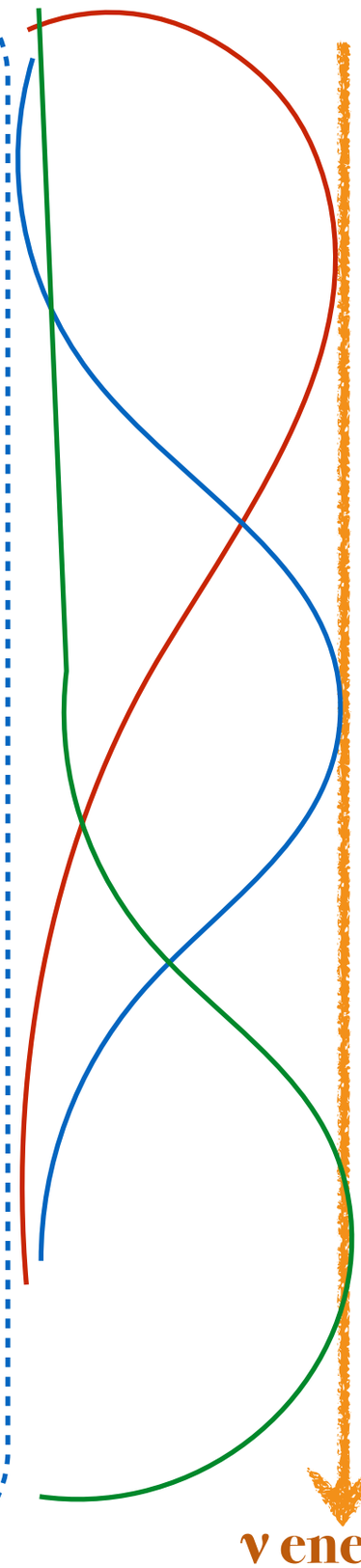




- **Energy loss** by ionization per distance traveled: dE/dx
- **residual range**: distance from a particle trajectory point to the last trajectory point.

Why ν-nucleus scattering matters?





Oscillated — Produced

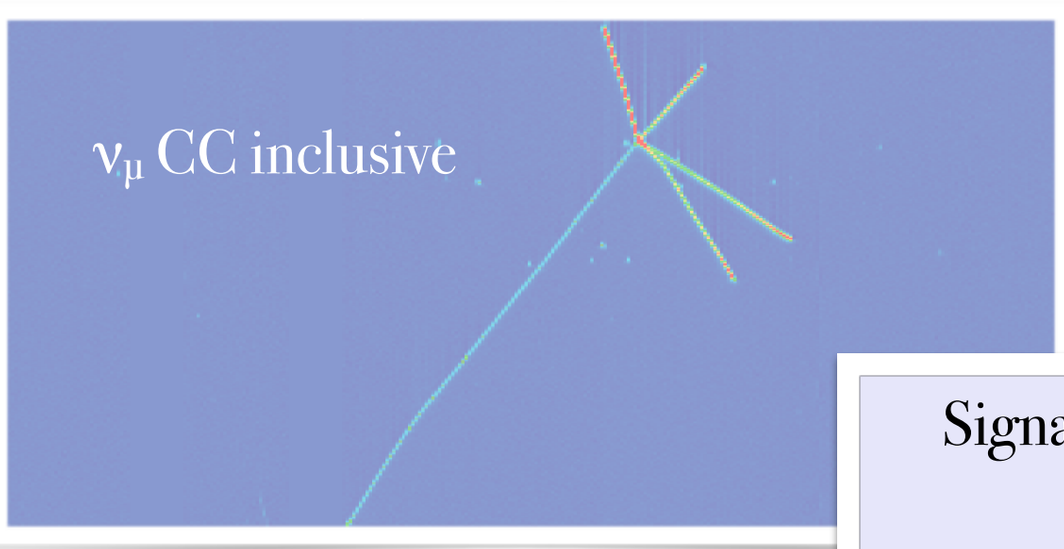
$$N_{det}(E_\nu, osc) \sim P_{osc}(E_\nu, prod) \times \phi(E_\nu, prod) \times \sigma(E_\nu, prod) - N_{bkg}(E_\nu)$$

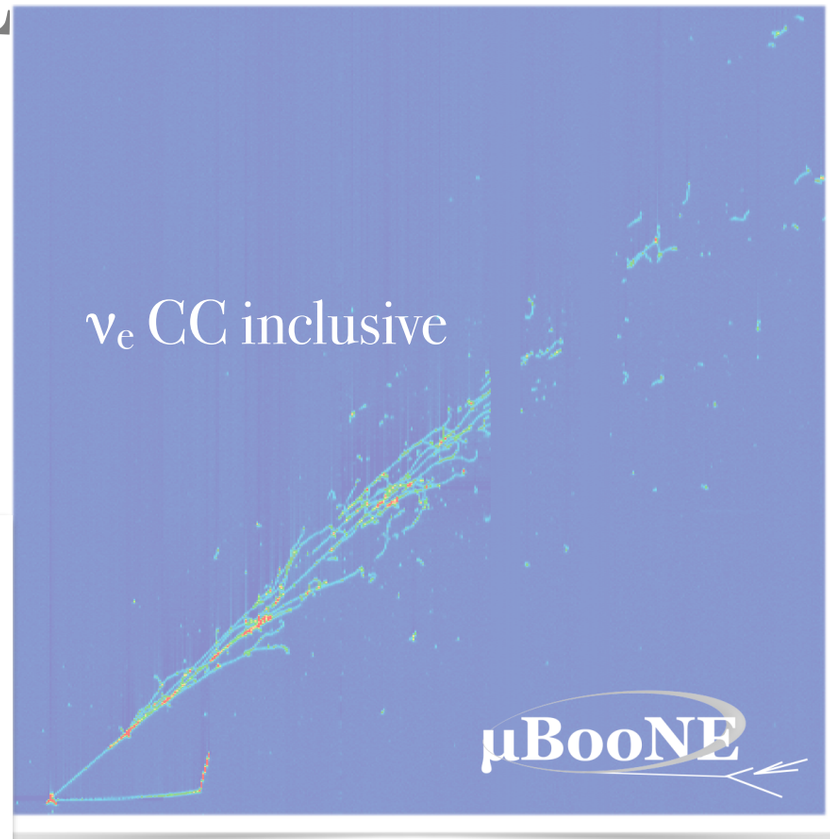
- **E_ν not an observable**. Calculated from observed final state particle kinematics.
- Need to measure **$\sigma(E_\nu, prod)$** as precise as possible!
- For background estimation need all flavors and interactions

Other interactions, as meson ex-change current (MEC), have more complex overlap in neutrino energy with other interactions.

We have very little knowledge of ν cross sections, very few data, even less in argon.

ν-argon scattering @MicroBooNE





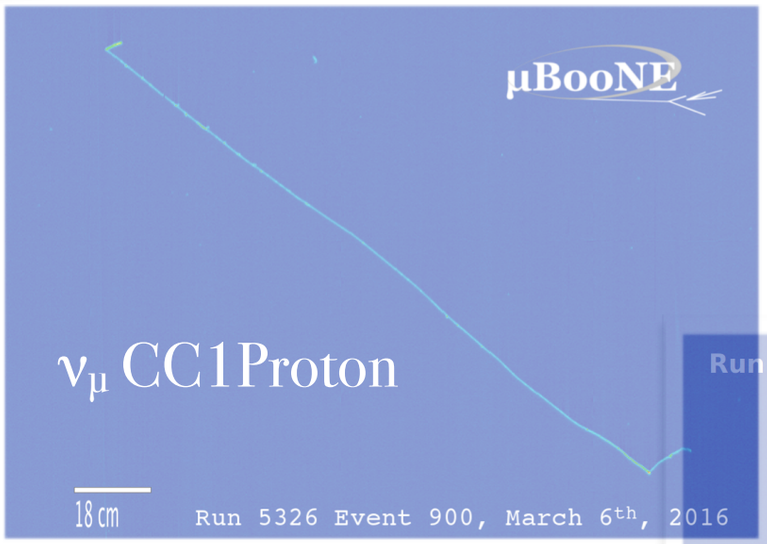
Signals for low energy excess searches:

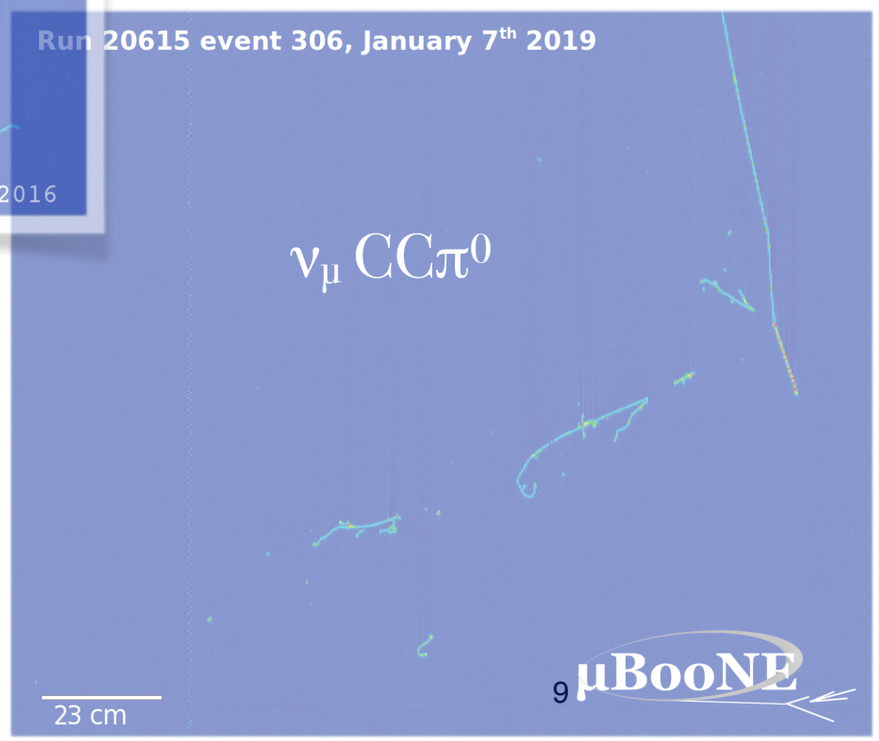
ν_e CC1Proton

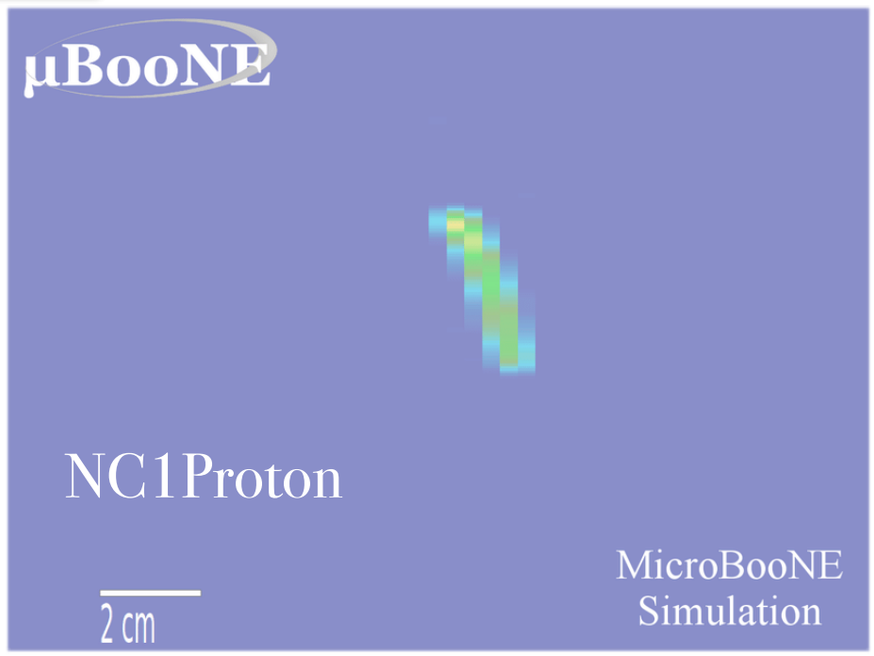
ν_e CCNProton

NCγ

NCπ^0

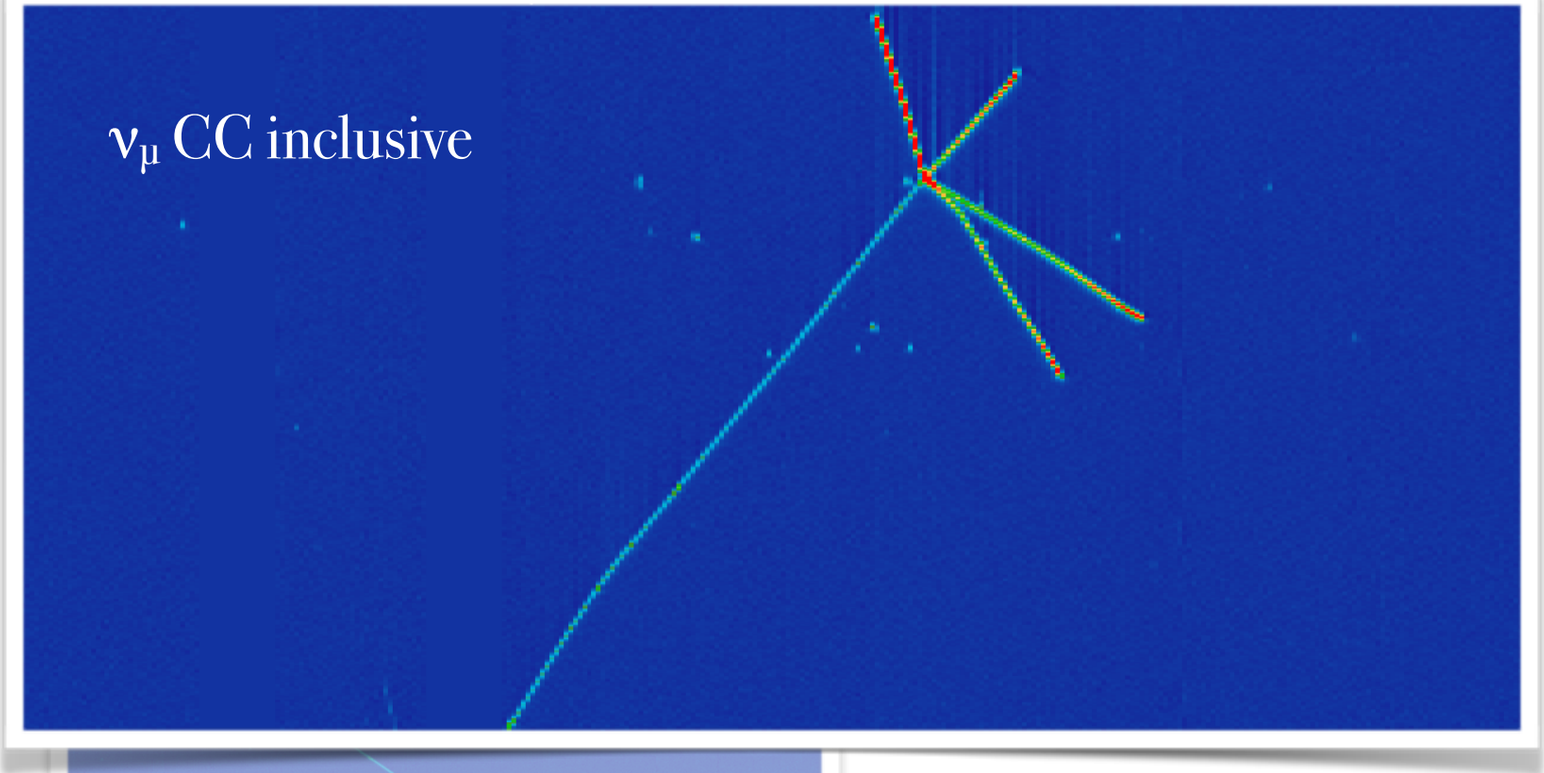


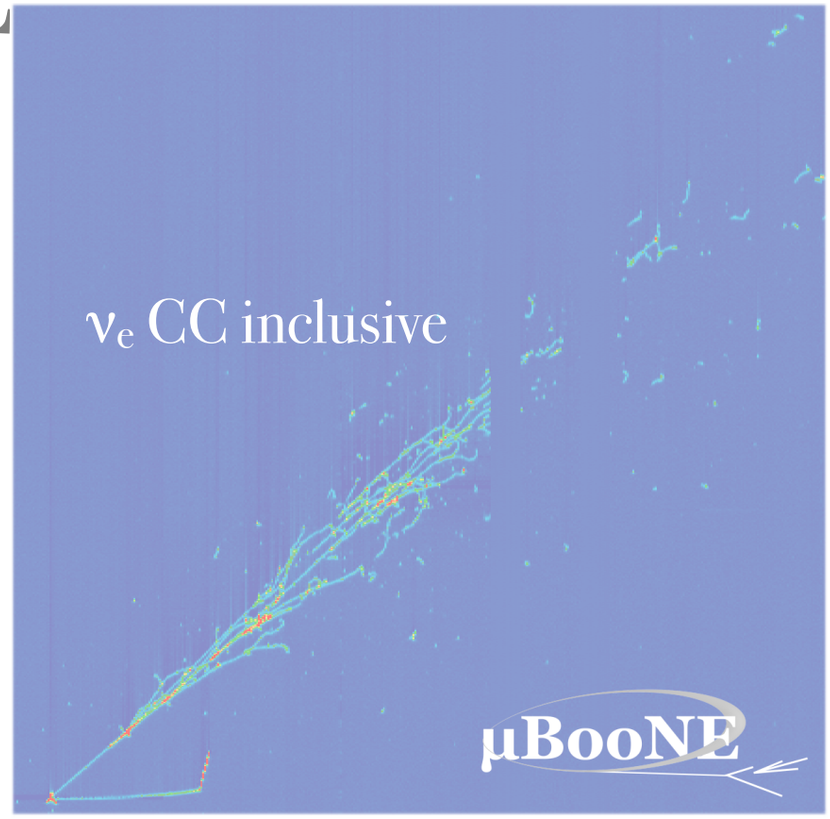


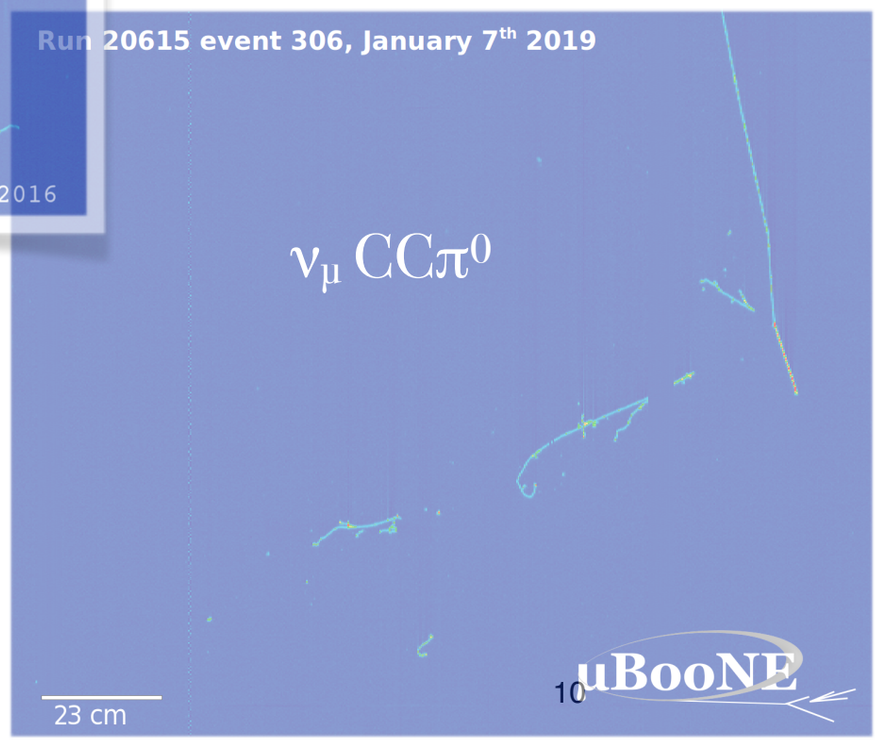


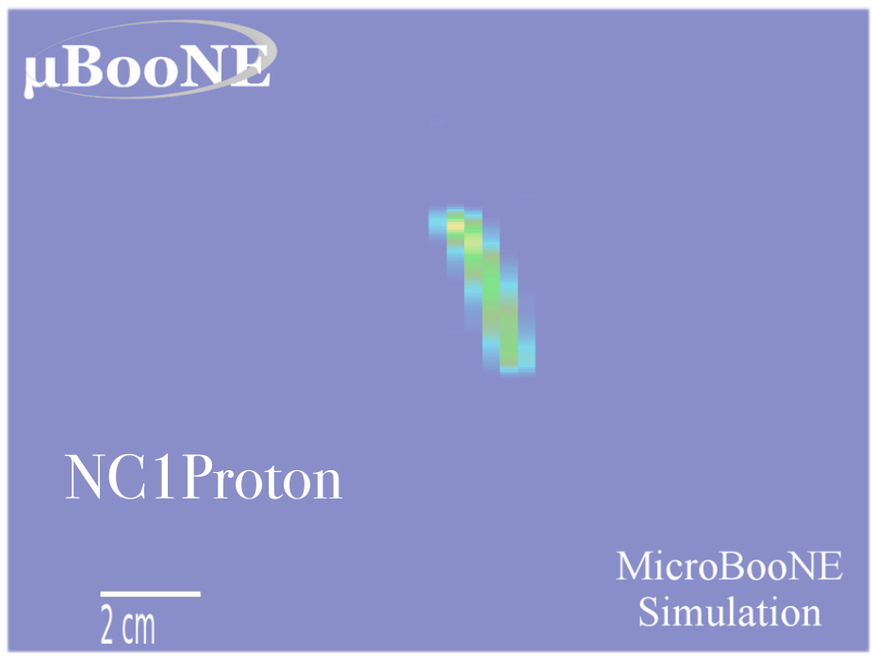
Raquel Castillo Fernández, FNAL

ν-argon scattering @MicroBooNE





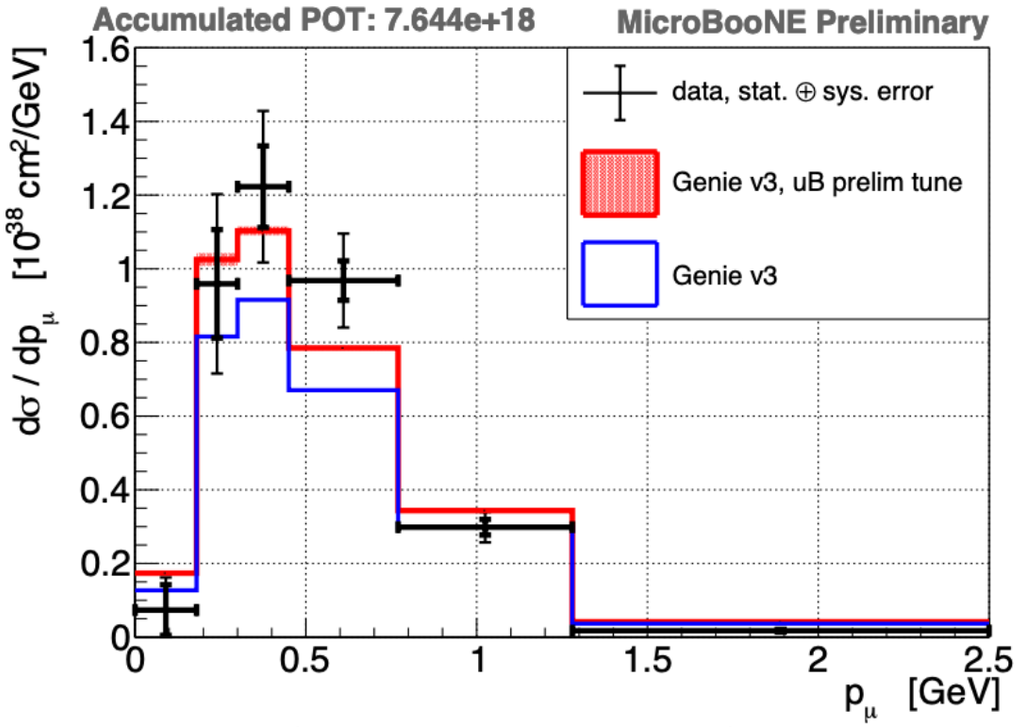


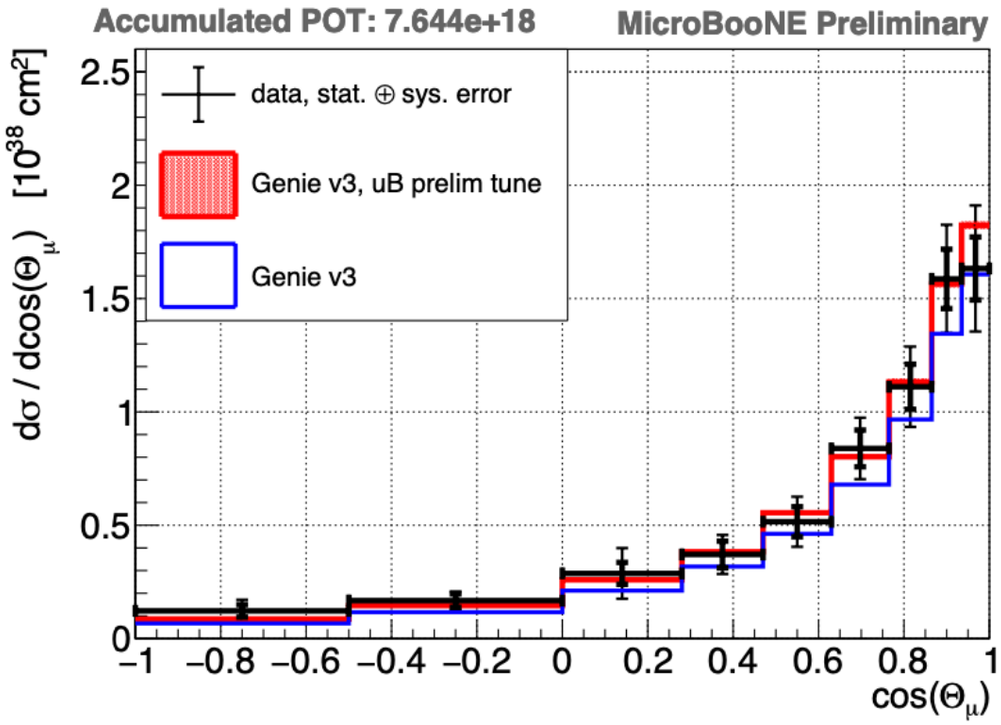


Raquel Castillo Fernández, FNAL

ν_μ CC inclusive $\nu_\mu + A \rightarrow \mu^- + A' + X$

2020 result: ν_μ CC single-differential cross section in argon.





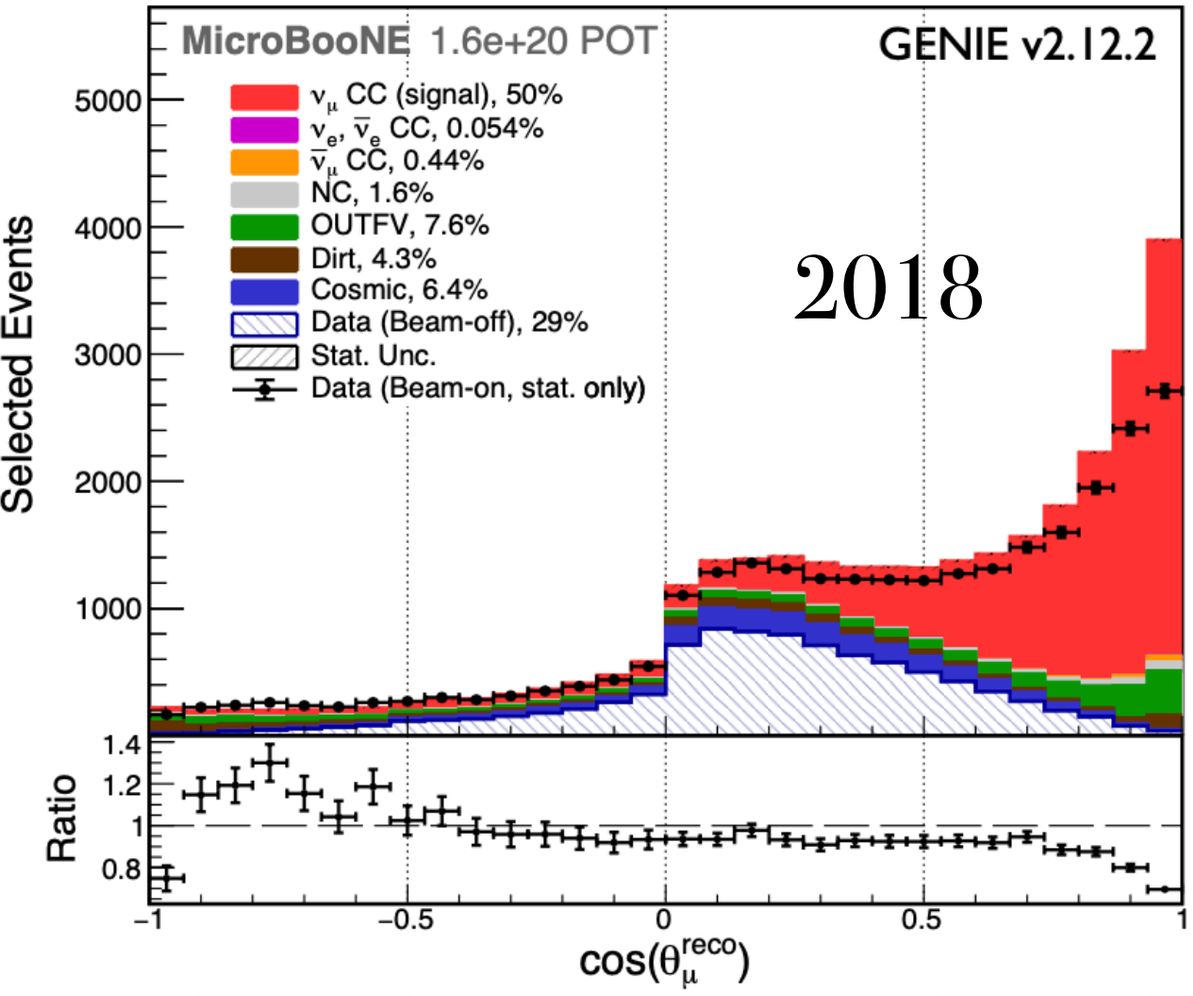
Source	Uncertainty in 2018	Uncertainty in 2020
Detector response	16.2%	3.3%
Cross section	3.9%	2.7%
Flux	12.4%	10.5%
Dirt background	10.9%	3.3%
Cosmic ray background	4.2%	N/A
POT	2.0%	2.0%
Total syst. Error	23.8%	12.1%
Statistics	1.4%	3.8%
Total	23.8%	12.7%

MICROBOONE-NOTE-1069-PUB

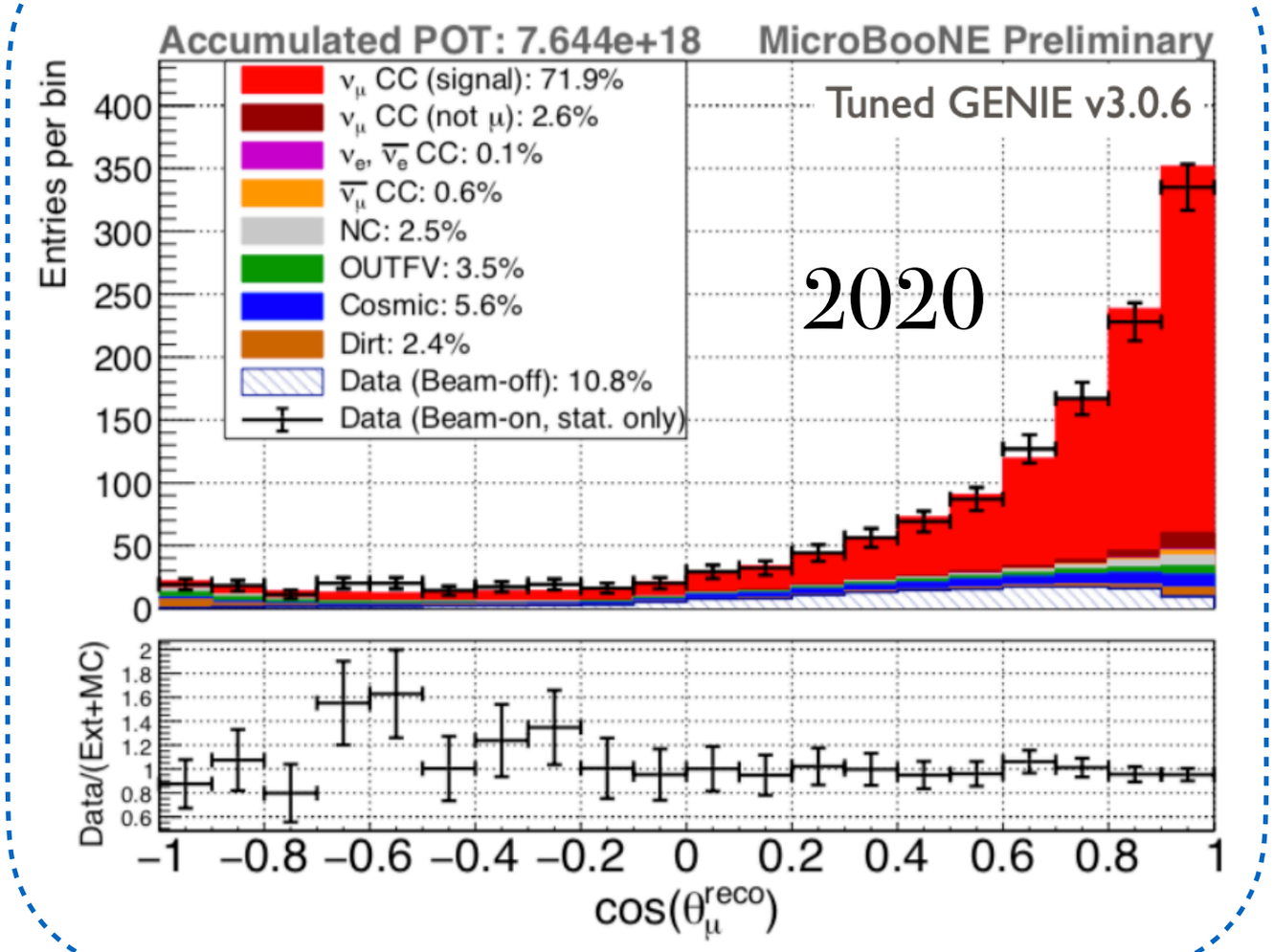
Exceptional campaign to model&calibrate the detector and understand argon properties pays back!

ν_μ CC inclusive $\nu_\mu + A \rightarrow \mu^- + A' + X$

Improved background removal, and detector modeling&calibration. Updated MC with additional tuning of CCQE and CCMEC to T2K CC0π data. 72% purity (50% in 2018 results, PRL 123, 131801).

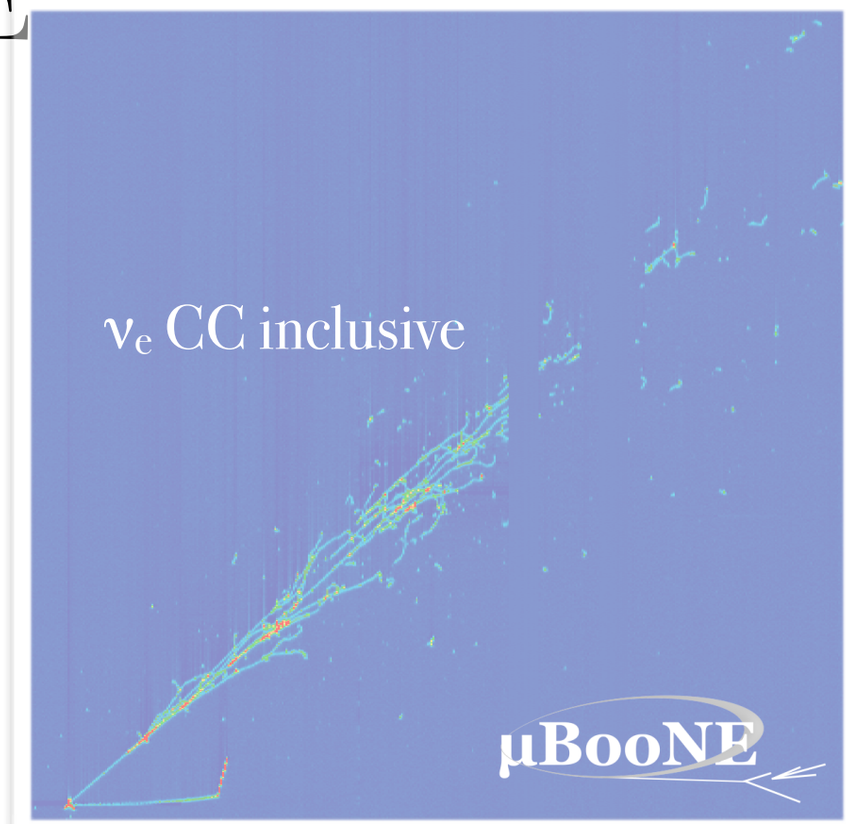


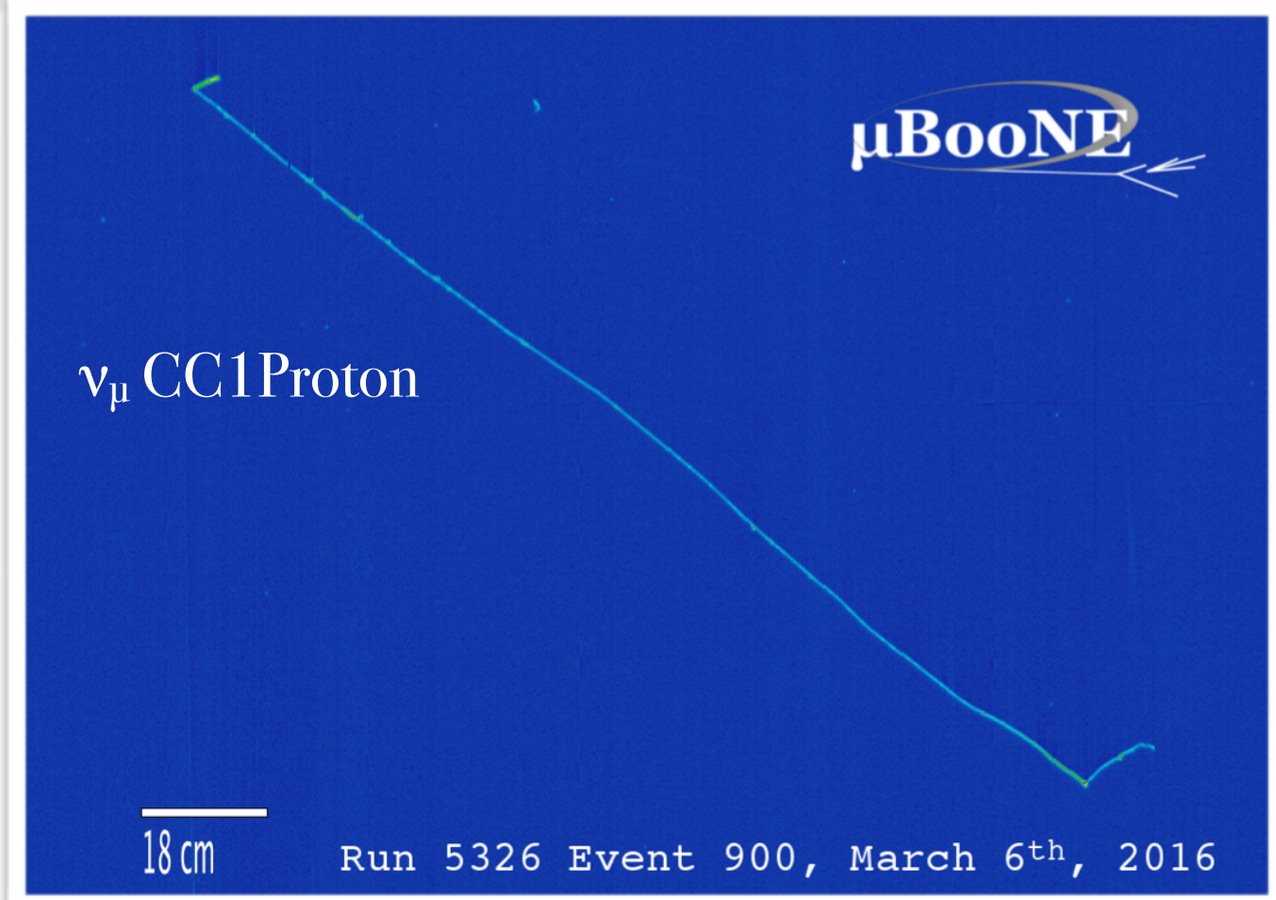
MICROBOONE-NOTE-1069-PUB

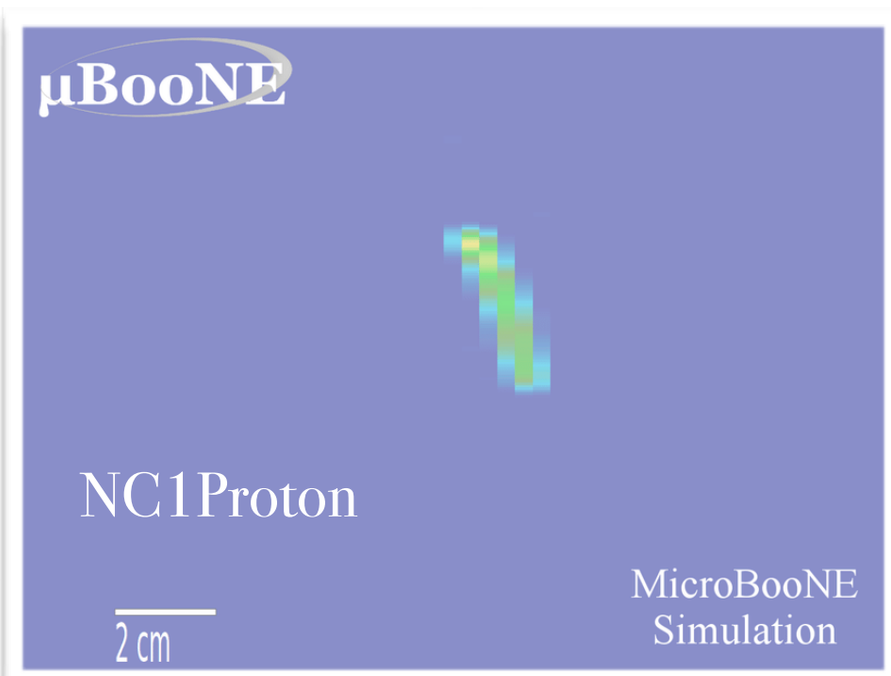


Similar under-prediction at backward-going particles (could indicate resonances/DIS, MC not been tuned for those, or angular acceptance of T2K for the tuning). Forward-going region shows better agreement, due to tuned scattering model and the detector modeling/calibration improvements.

ν-argon scattering @MicroBooNE







ν_μ CC1Proton $\nu_\mu + A \rightarrow \mu^- + A' + p$

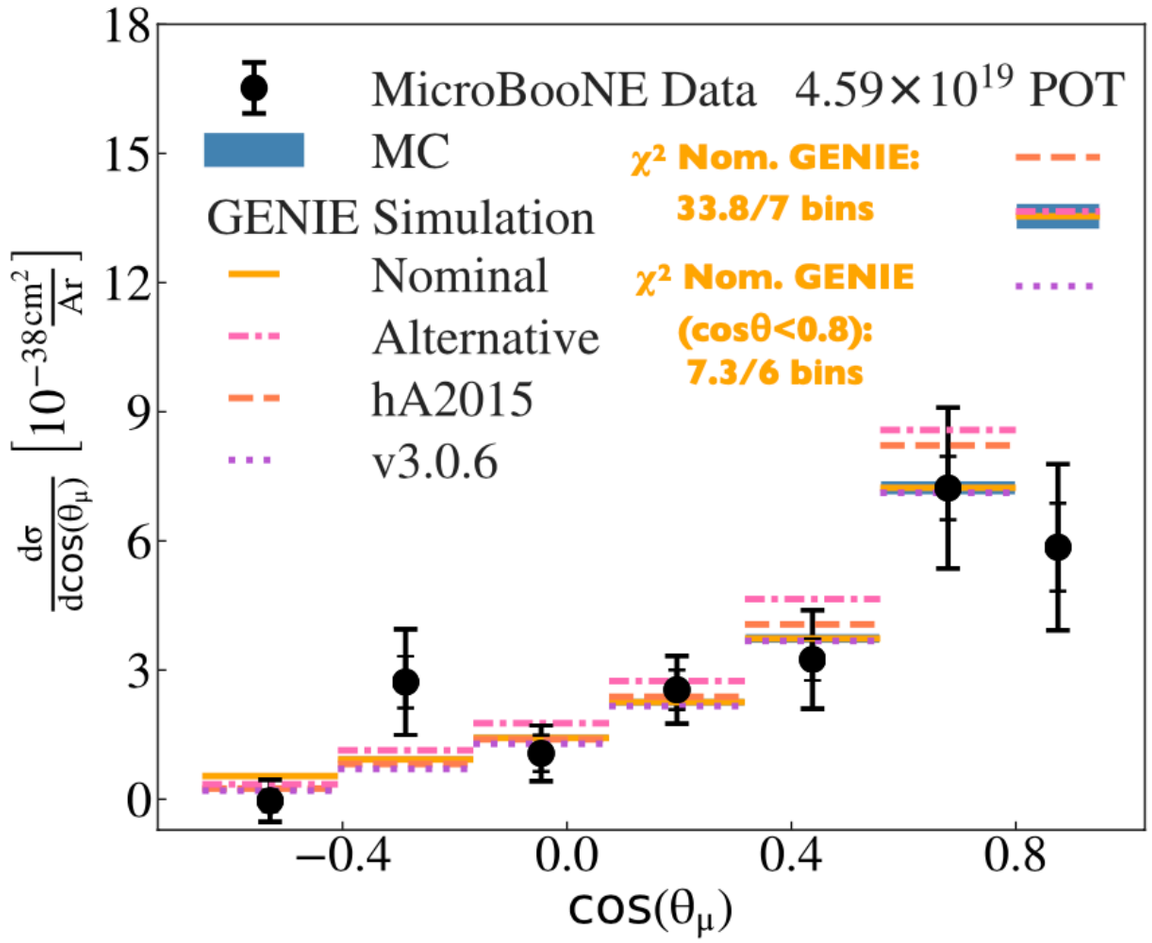
Signal: **1 muon (p_μ>100 MeV/c), 1 proton (p_p>300 MeV/c) leaving the nucleus** with additional kinematical cuts to enhance CCQE contribution according GENIE → ~84% CC1p0π (~81% CCQE) purity, ~20% efficiency.

arXiv:2006.00108

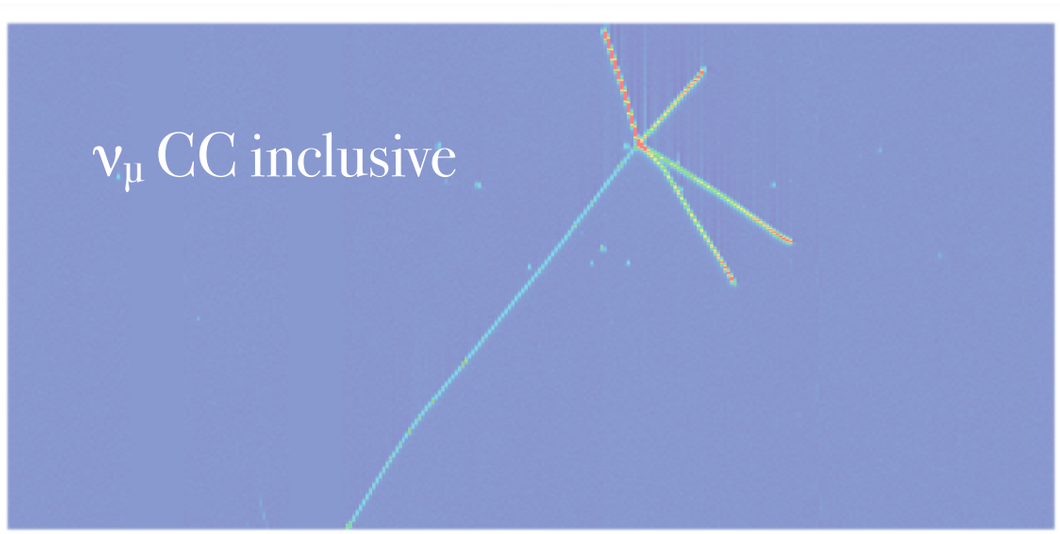
General good agreement with GENIE **except for the most forward-going muon bin**.

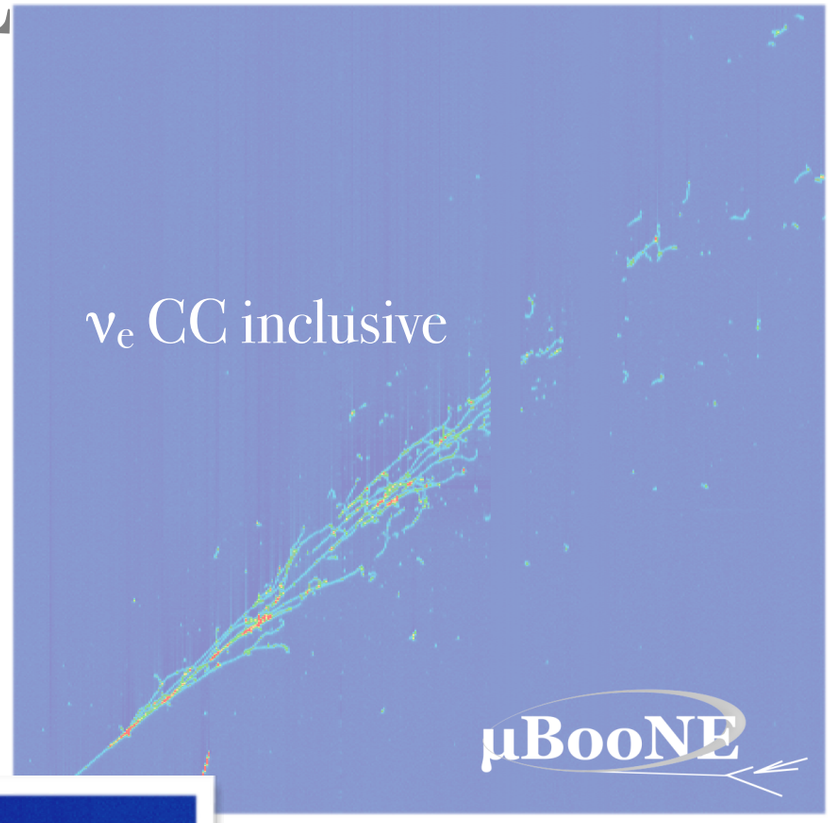
Measurement does not include CCQE events without protons leaving the nucleus, which may be more challenging for the MC.

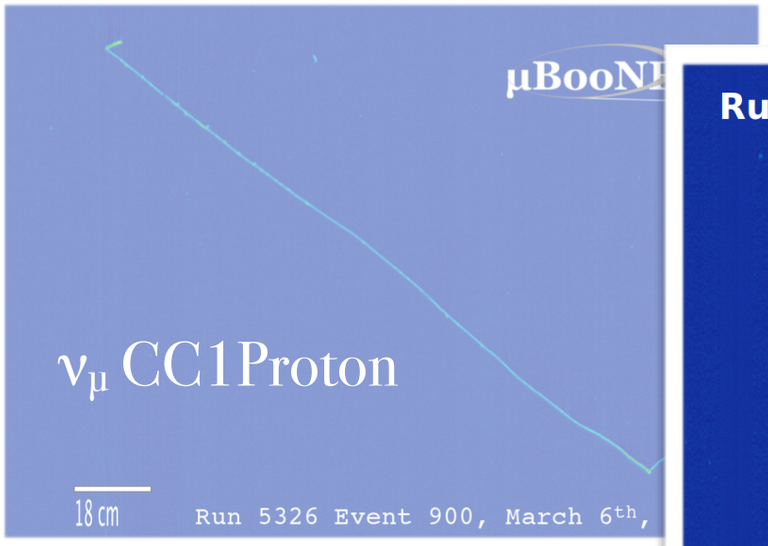
Enhancing CCQE including more topologies would help to understand the mis-modeling and to compare to other experiments.

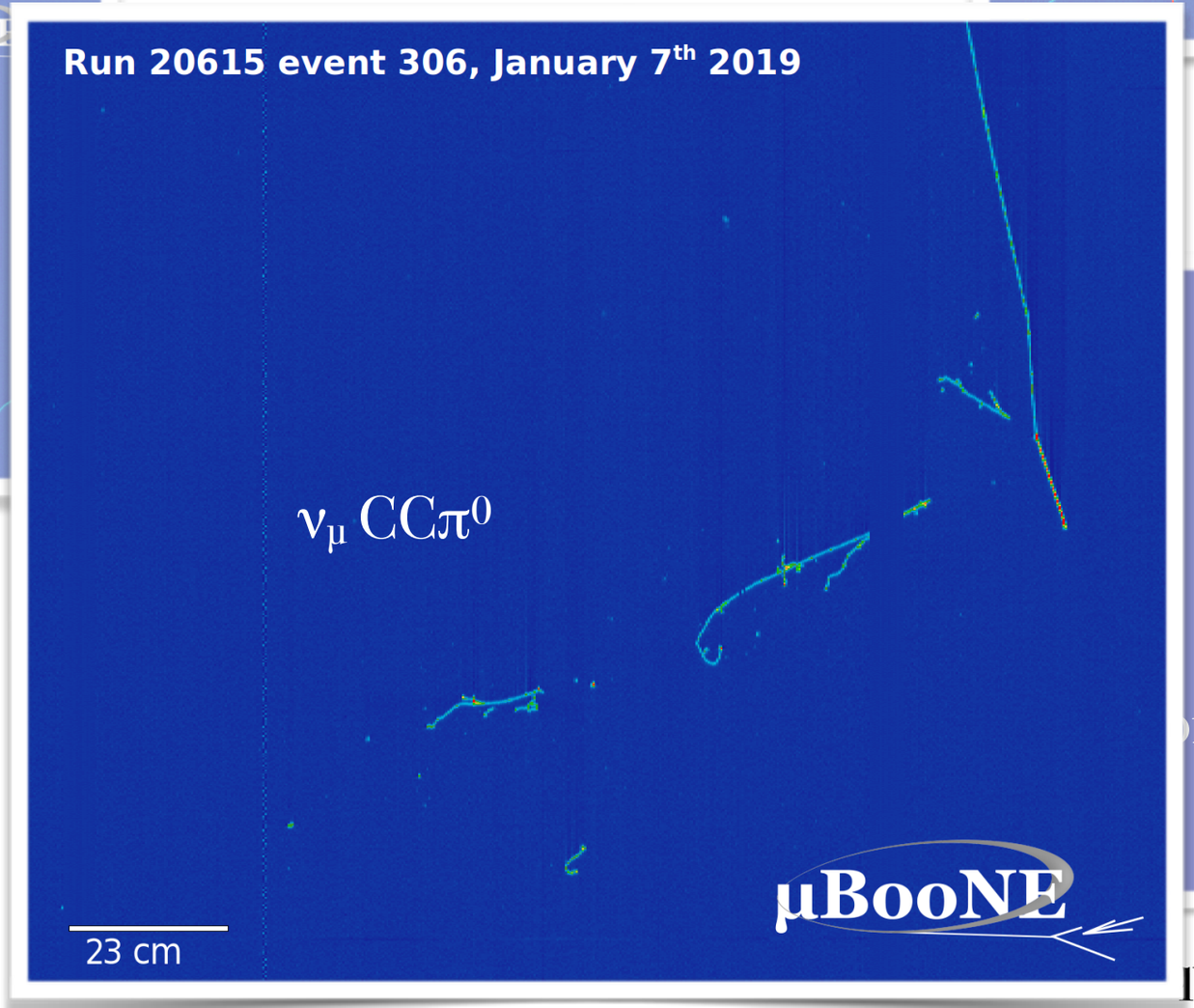


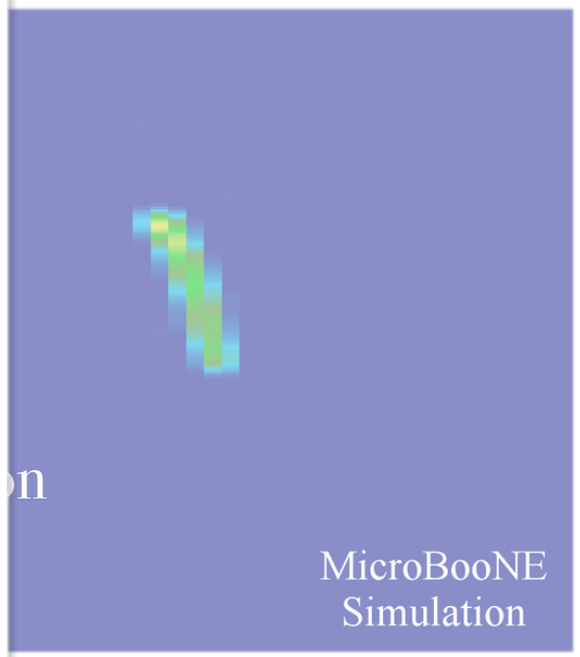
ν-argon scattering @MicroBooNE









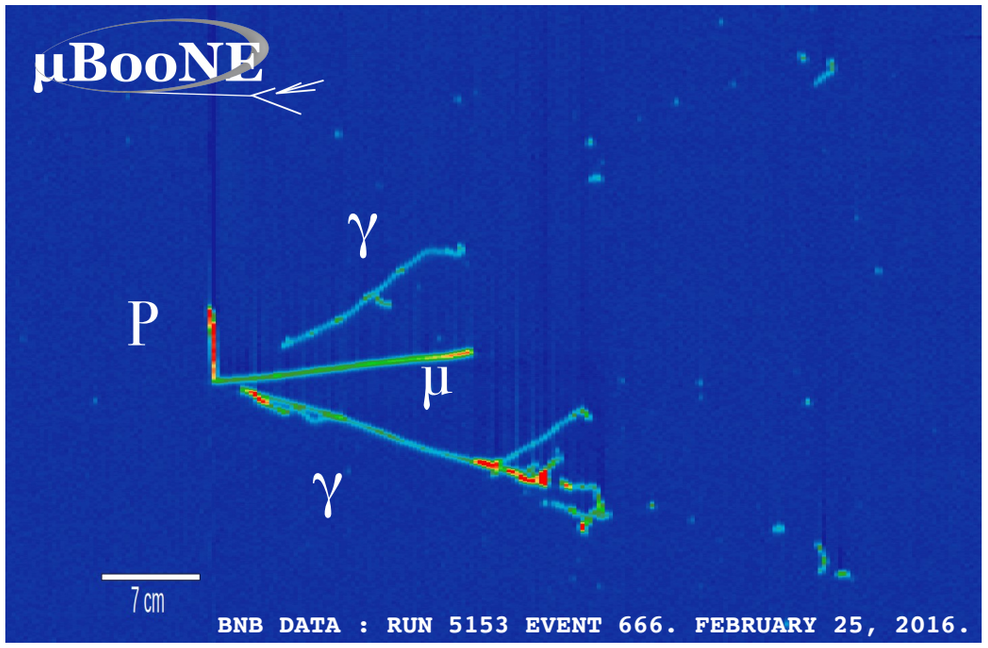


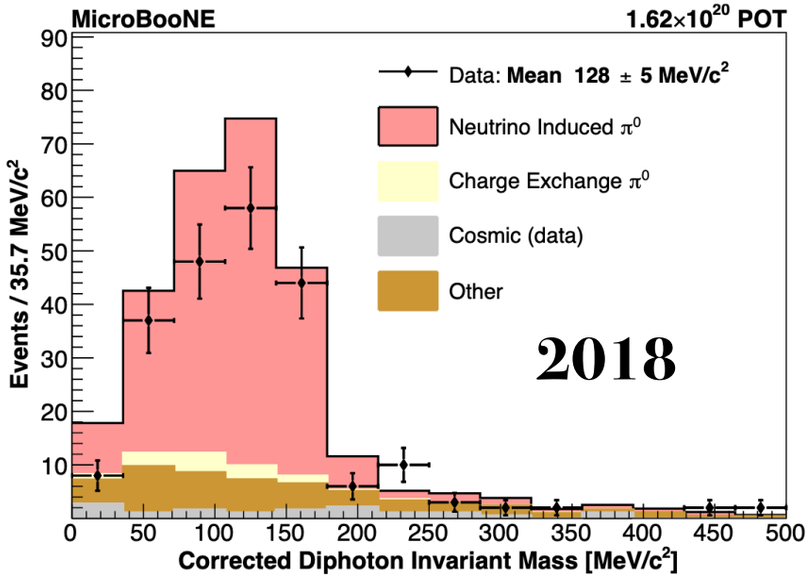
uel Castillo Fernández, FNAL

ν_μ CCπ^0

$\nu_\mu + A \rightarrow \mu^- + A' + \pi^0$

- Constraint our main background in anomaly searches, to reduce model dependencies.
- Not abundant experimental data.
- Good sample to improve shower reconstruction in LArTPC.

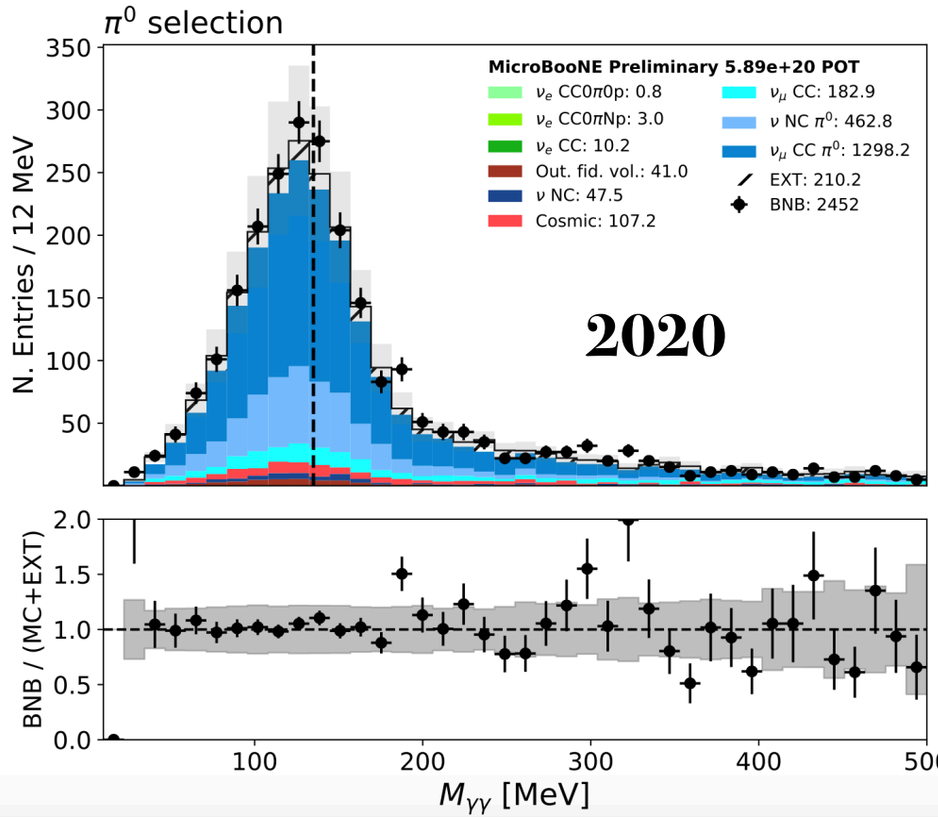




$$\langle\sigma\rangle_\Phi = 1.9 \pm 0.2\ (\text{stat}) \pm 0.6\ (\text{syst}) \times 10^{-38}\ \frac{\text{cm}^2}{\text{Ar}}.$$

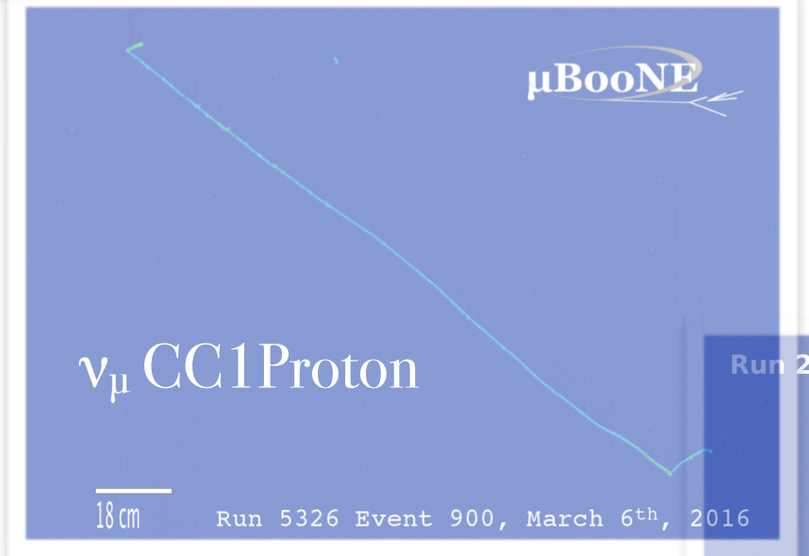
Phys. Rev. D99, 091102(R) (2019)

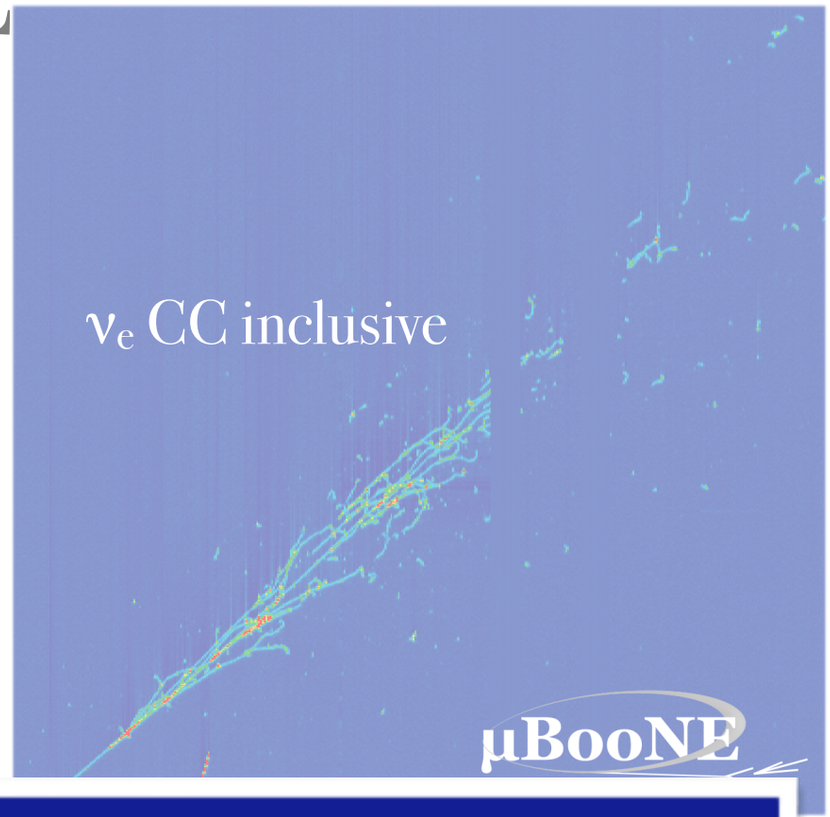
Spoiler alert:
we have the largest
NCπ^0 sample on
argon in the world!

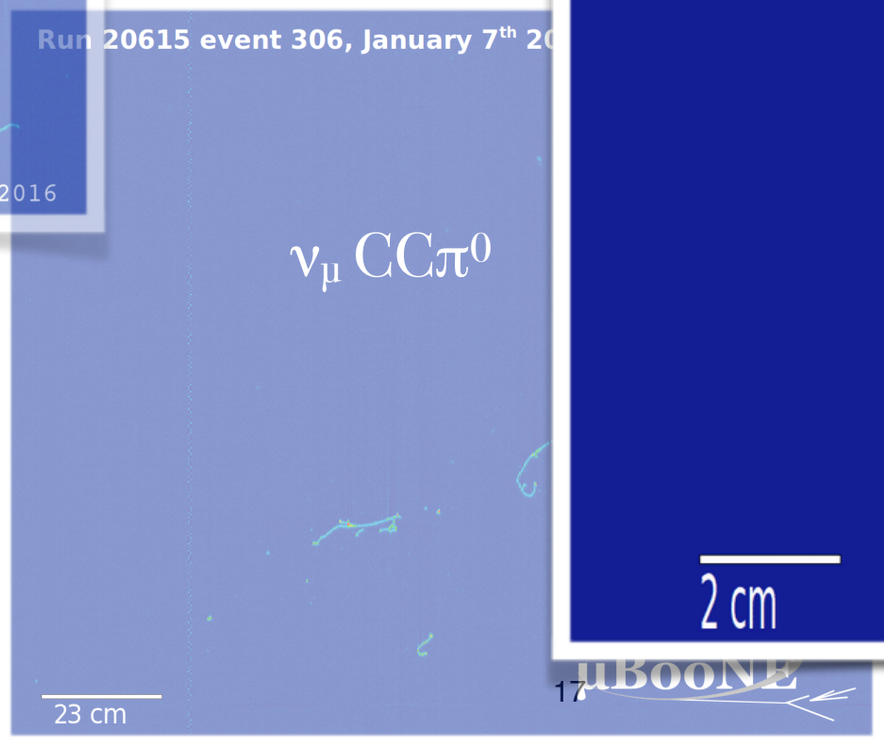


See Mark Ross-Lonergan (NCπ^0) and David Caratelli's (CCπ^0) talks!

ν-argon scattering @MicroBooNE







Raquel Castillo Fernández, FNAL

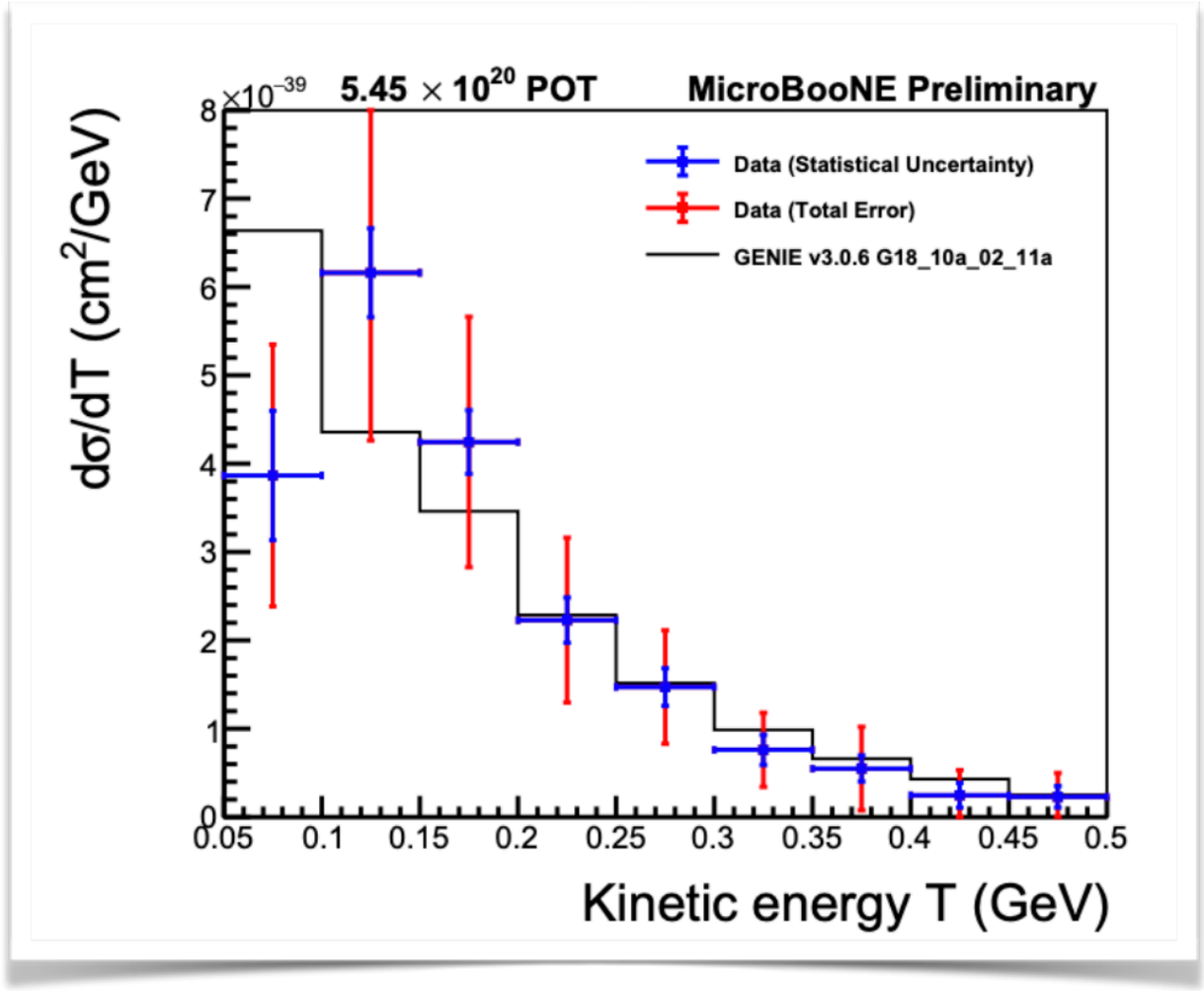
NC1Proton

$\nu + A \rightarrow A' + p$

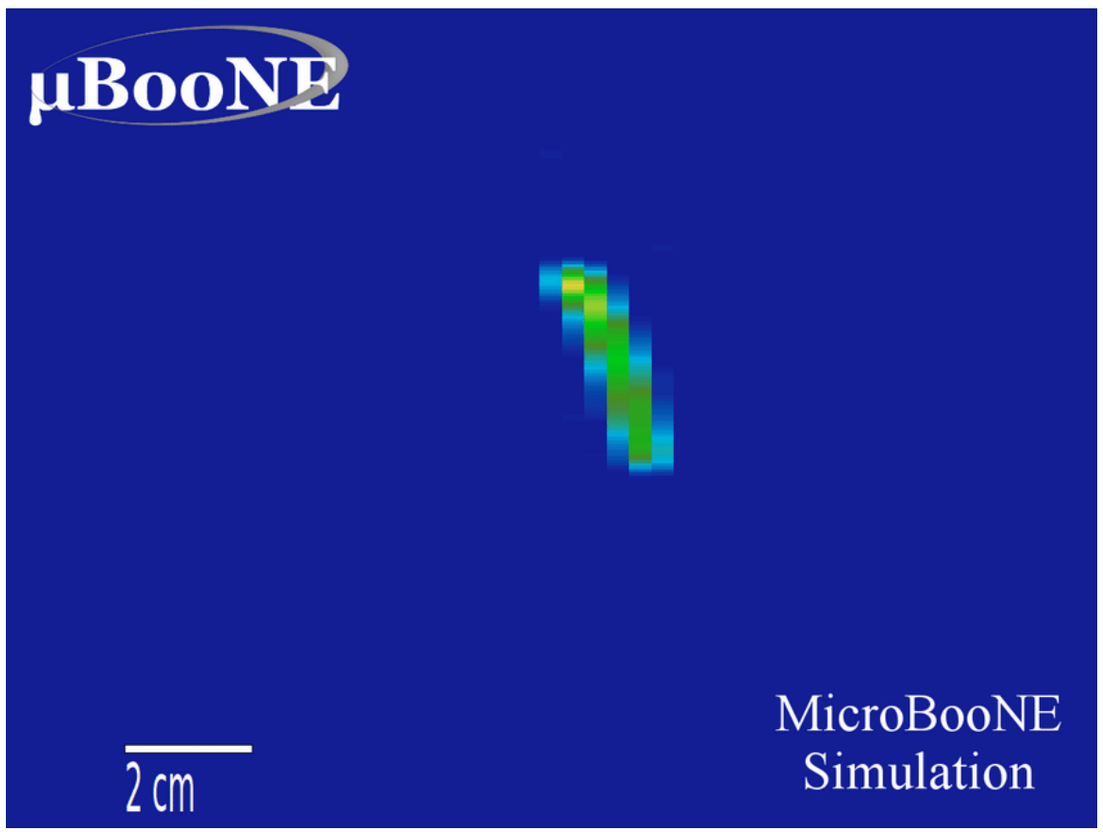
Challenge: **observing the presence of one proton only!** (non-trivial for surface detectors and to reconstruct the direction of the proton)

Low proton energy threshold reconstruction allows for low momentum transfer studies.

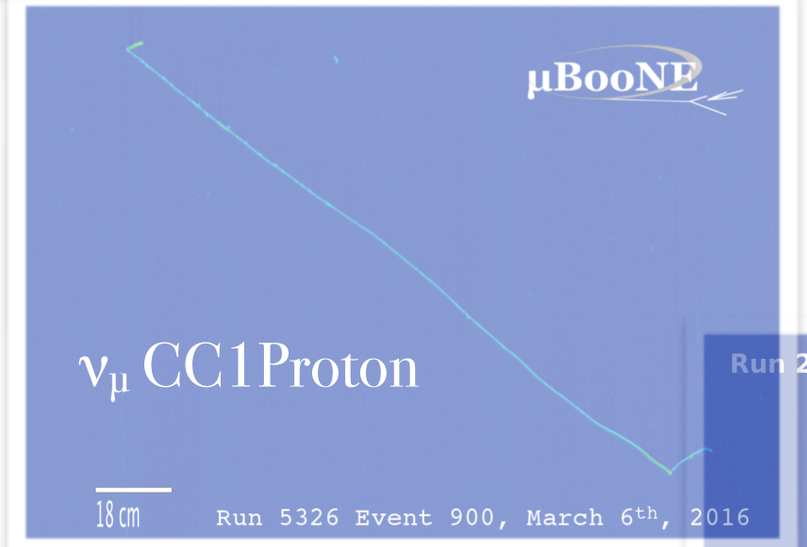
Measuring the cross section at low momentum transfer will help to **study the strange axial form factor.**

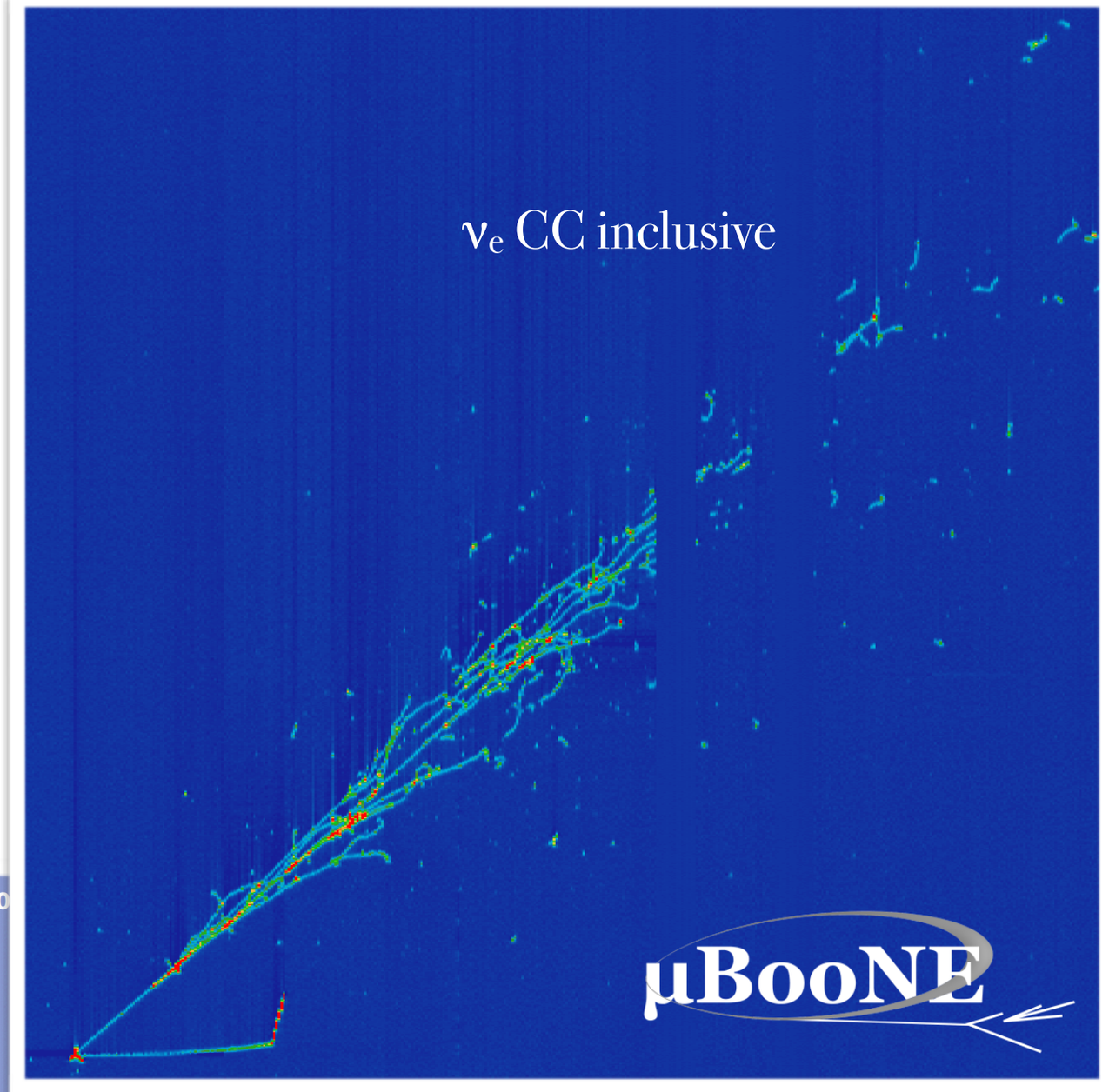


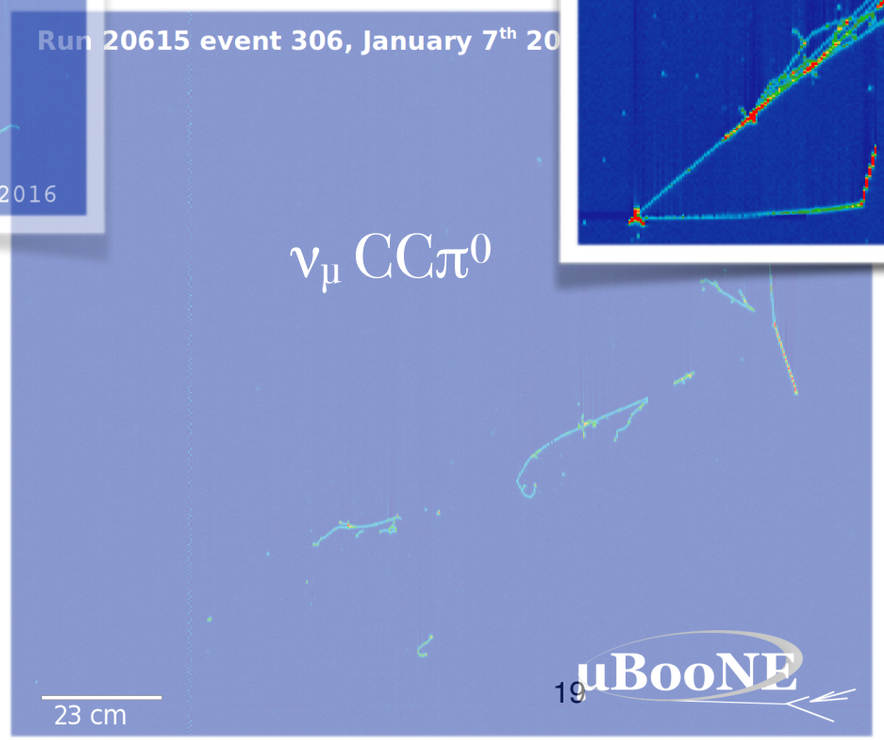
MICROBOONE-NOTE-1067-PUB



ν-argon scattering @MicroBooNE



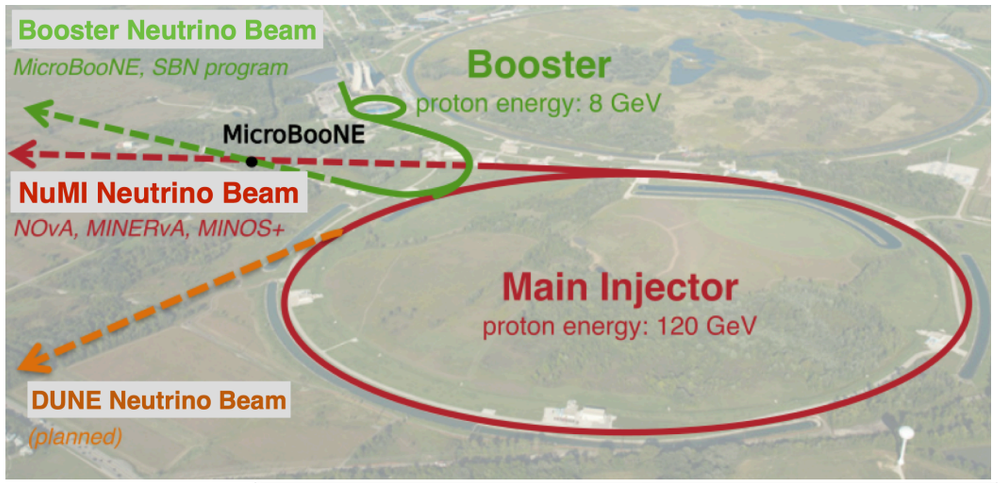


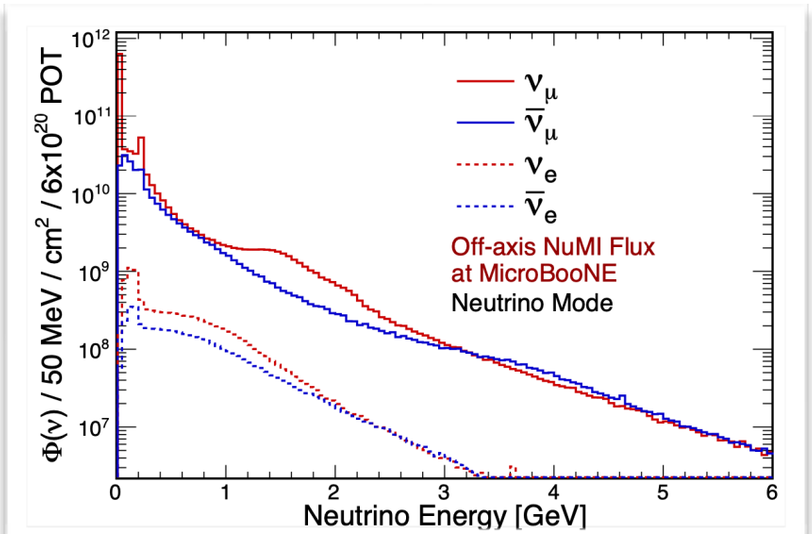


ν_e CC inclusive $\nu_e + A \rightarrow e^- + A' + X$

MicroBooNE receives two ν beams:

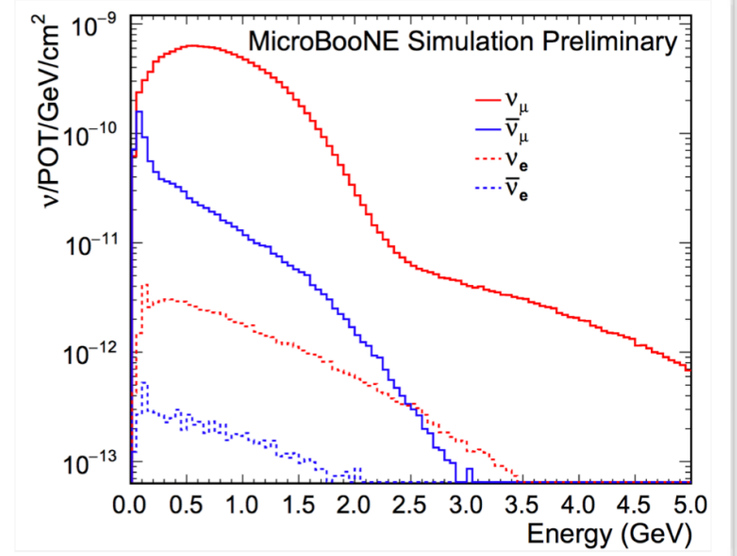
- BNB (on-axis): results covered today
- NuMI (off-axis ~6°)

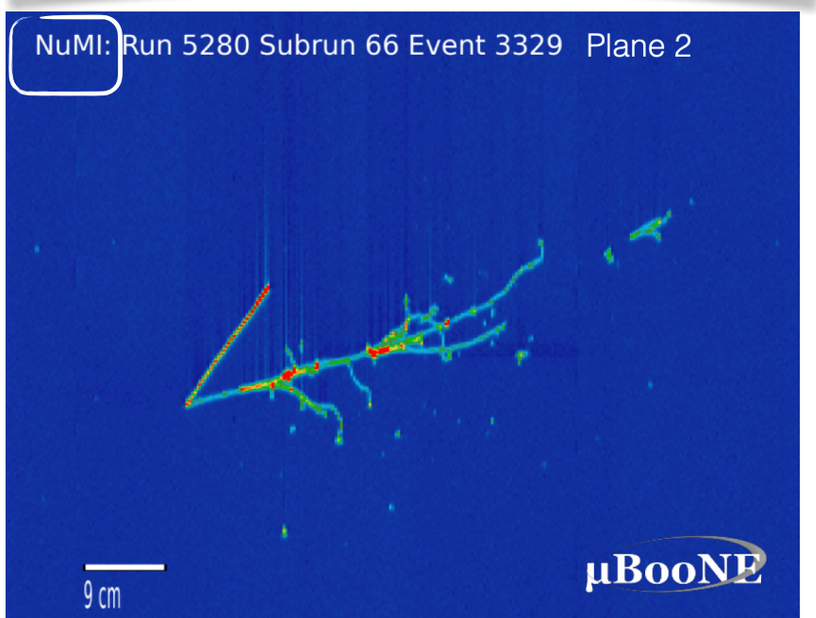




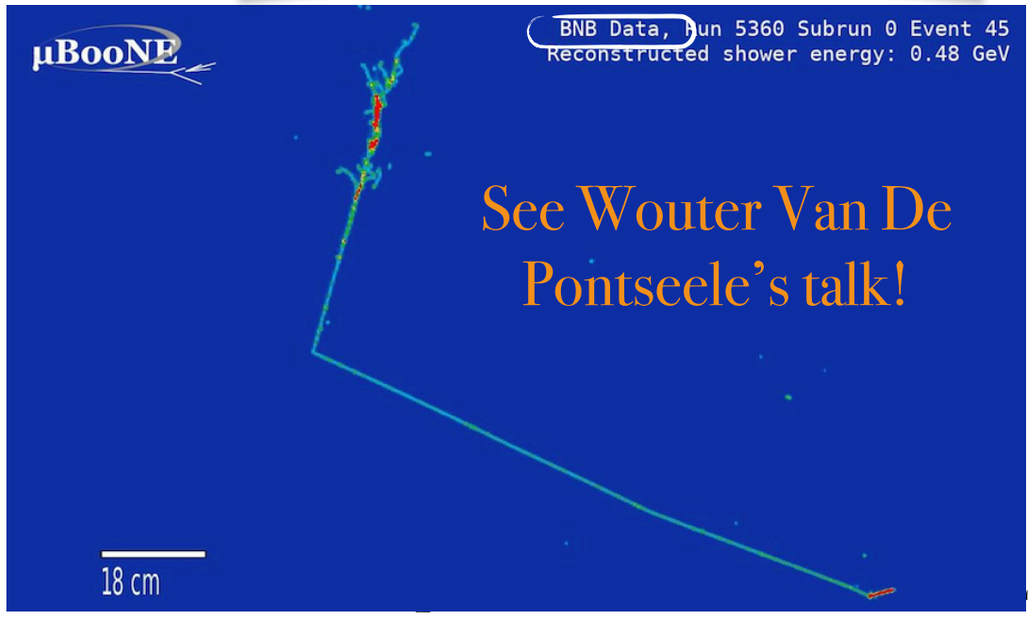
ν oscillation needs good understanding of ν_μ/ν_e and charged-current inclusive studies are key.

We measure two independent data with slightly different energy. This **approach is both, pioneering and exciting!**





Want to see (BNB) exclusive ν_e data? See David Caratelli's talk!



See Wouter Van De Pontseele's talk!

Uncovering unique signatures

More measurements coming soon:

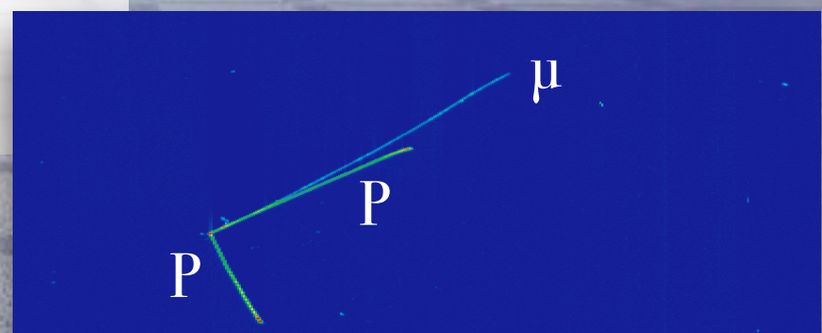
- ν_μ CC0π0p — Never measured, the most quasi-elastic
- ν_μ CC0πNp
- ν_μ CC0π2p
- ν_μ CC0π STV

} Exploring the nuclear structure

- ν_μ CC1π^+
- ν_μ CC-Coherent π^+

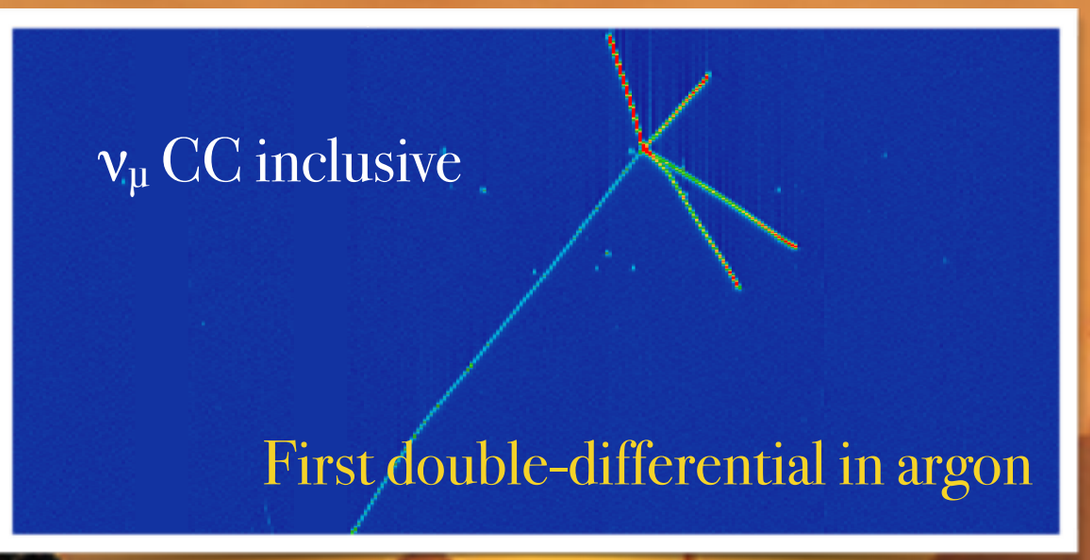
} Pion production

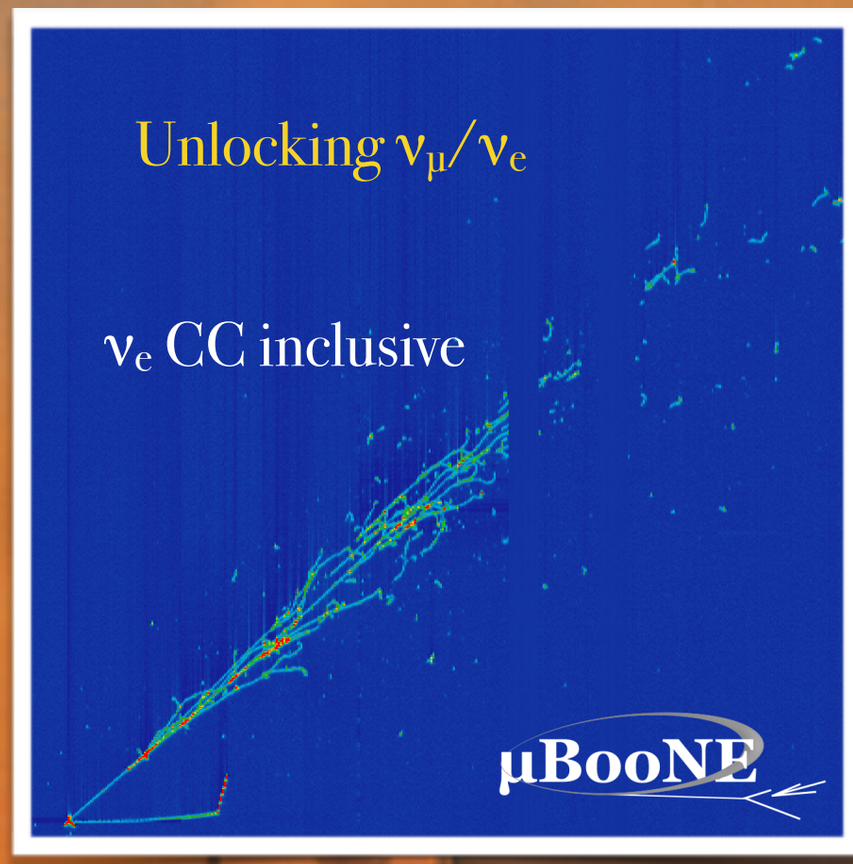
- ν_μ KDAR CC0π — Mono-energetic neutrinos
- ν_e CC0π1p — Constraining uncertainties in ν_e
- ν_μ CC1kaon$^+$ — Proton decay backgrounds

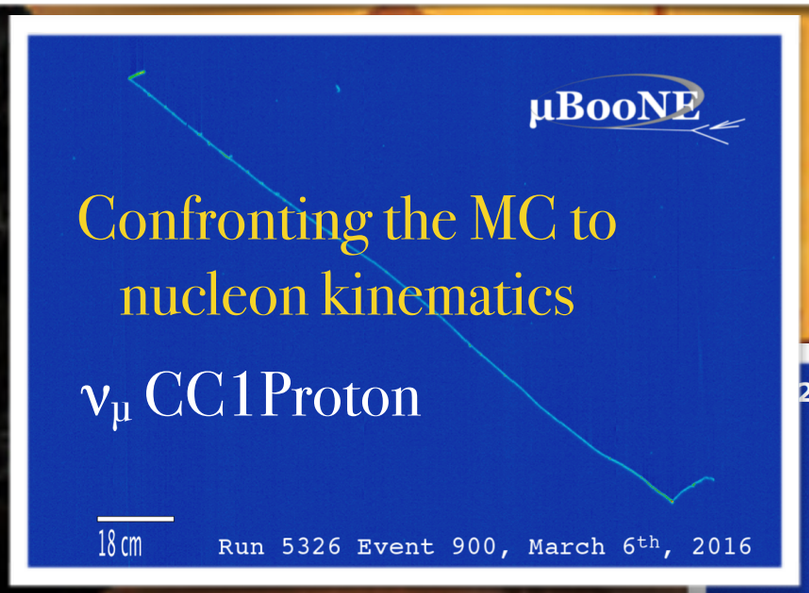


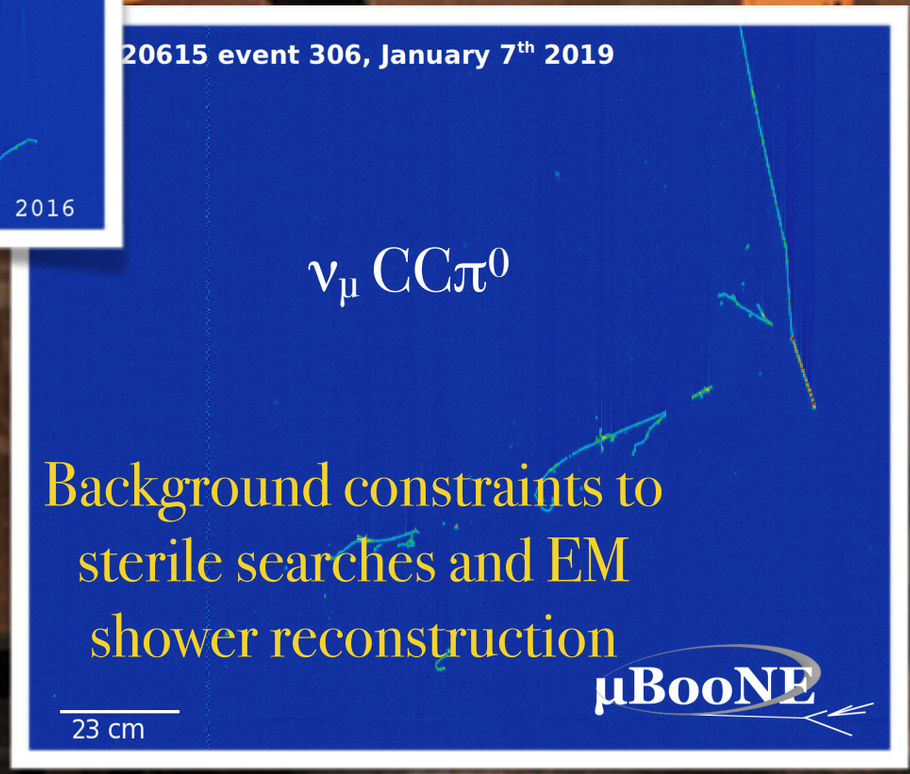
Raquel Castillo Fernández, FNAL

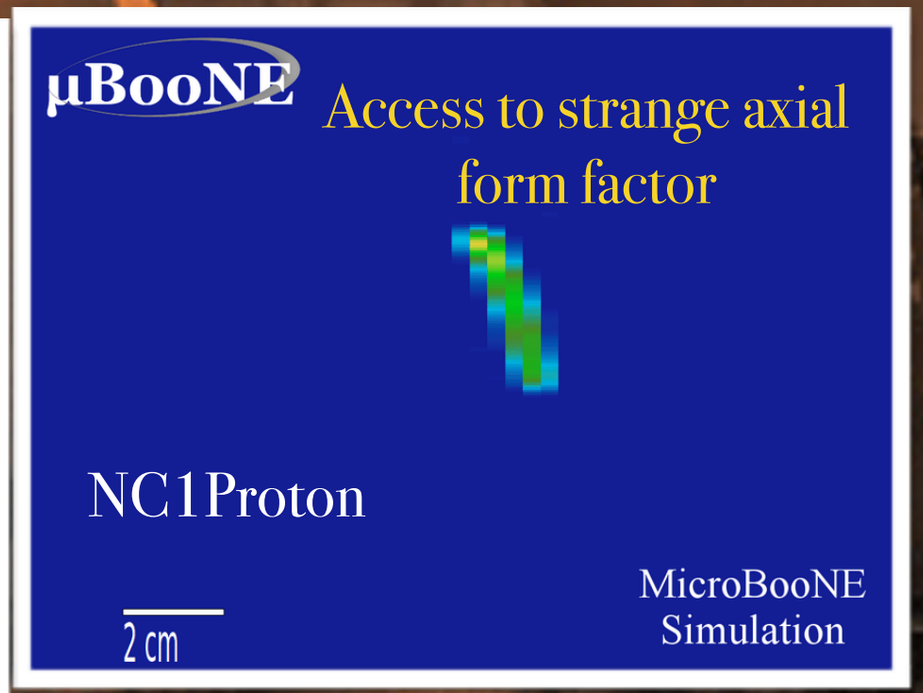
Summary











Raquel Castillo Fernández, FNAL

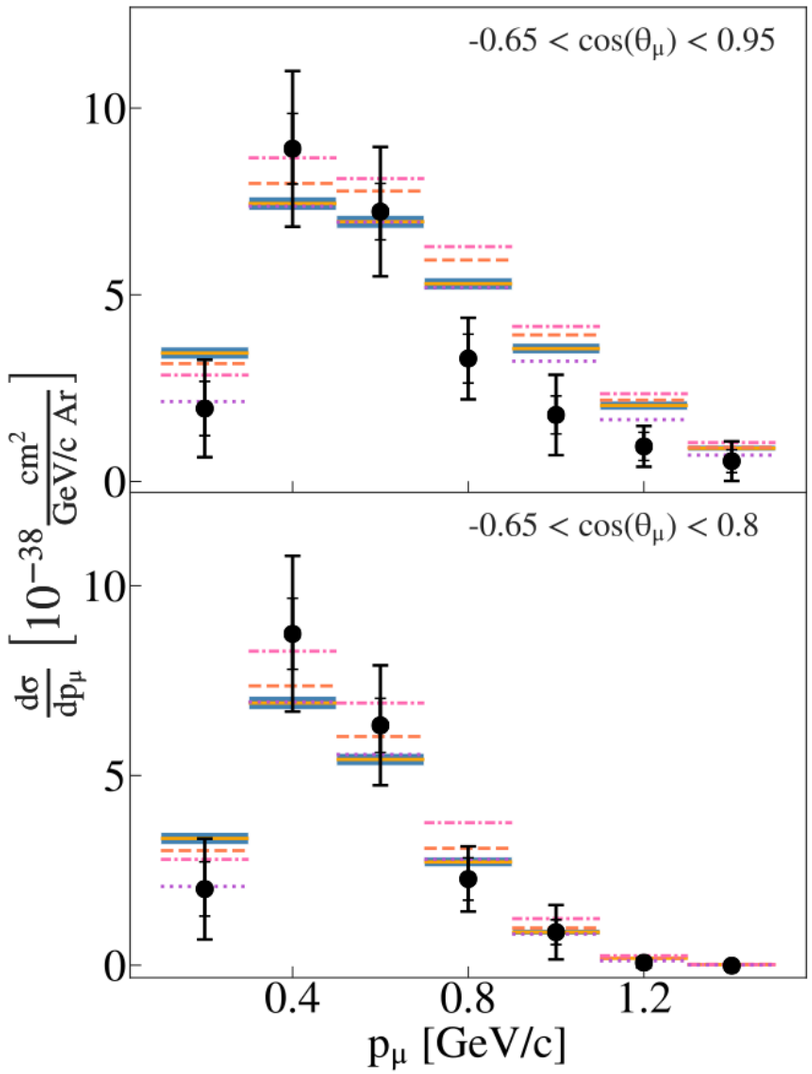
Thanks

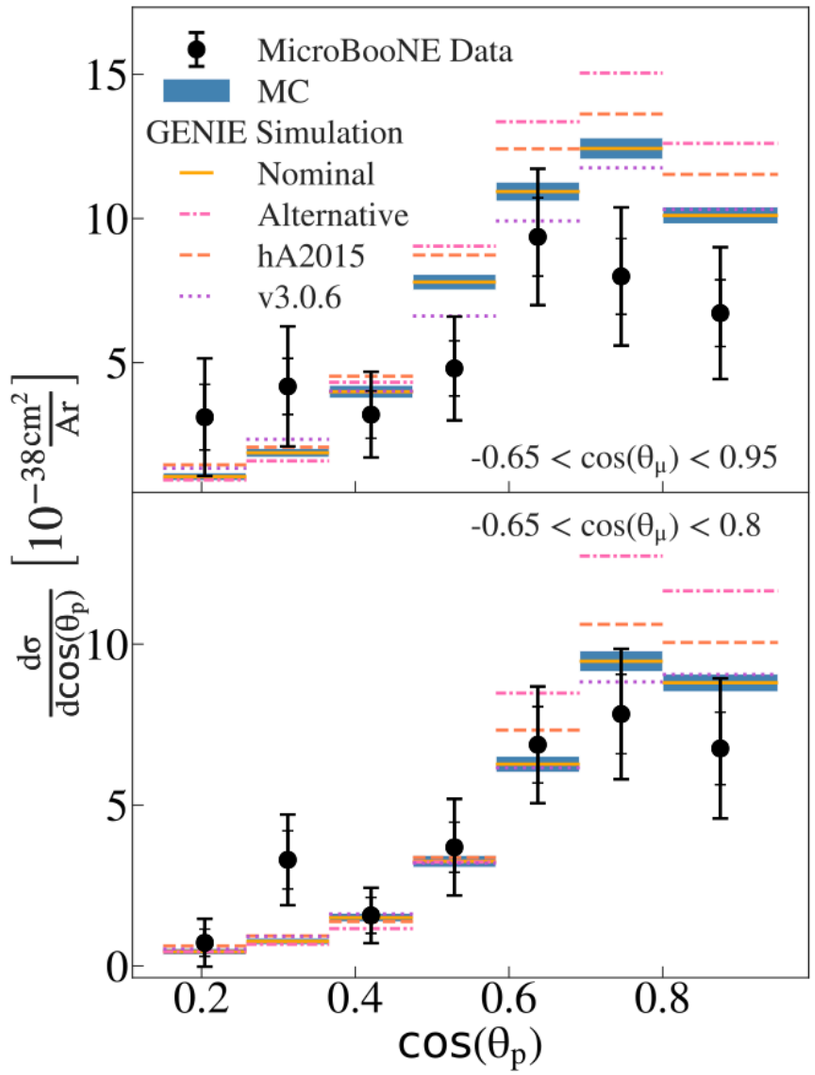
ν_μ CC1Proton

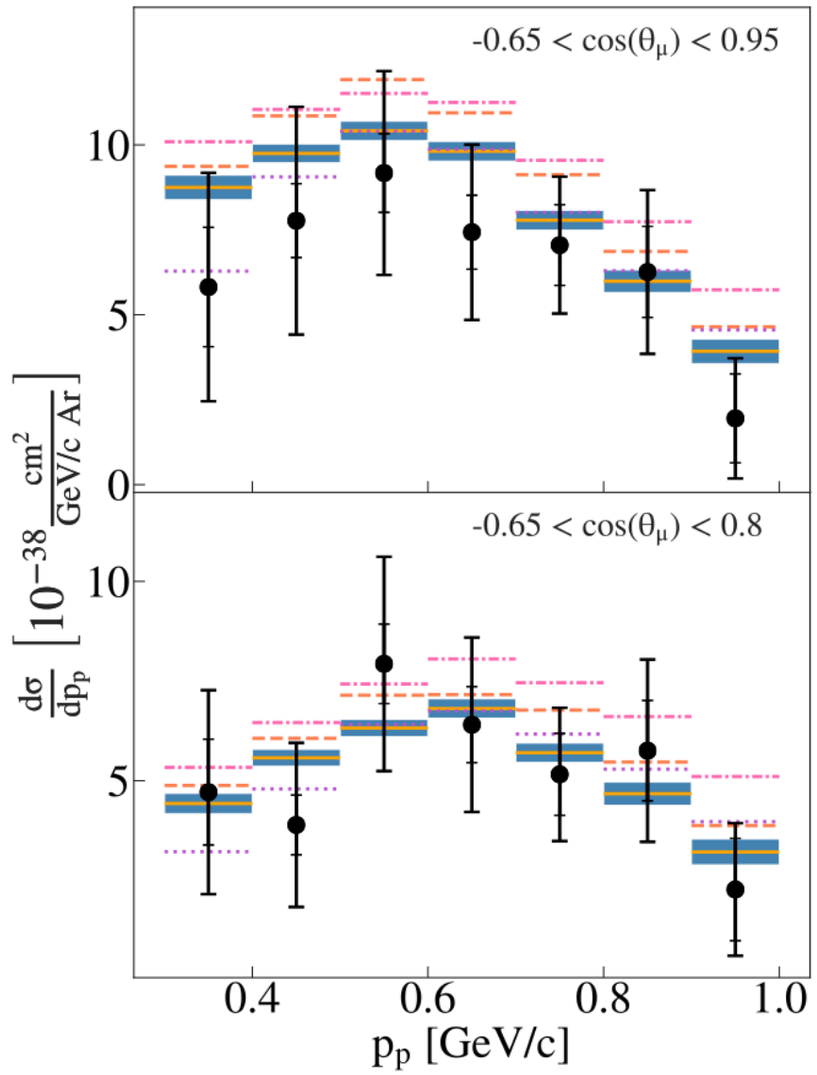
$\nu_\mu + A \rightarrow \mu^- + A' + p$

Differential cross section results excluding most forward-going muons. Observed reasonably good agreement.

arXiv:2006.00108



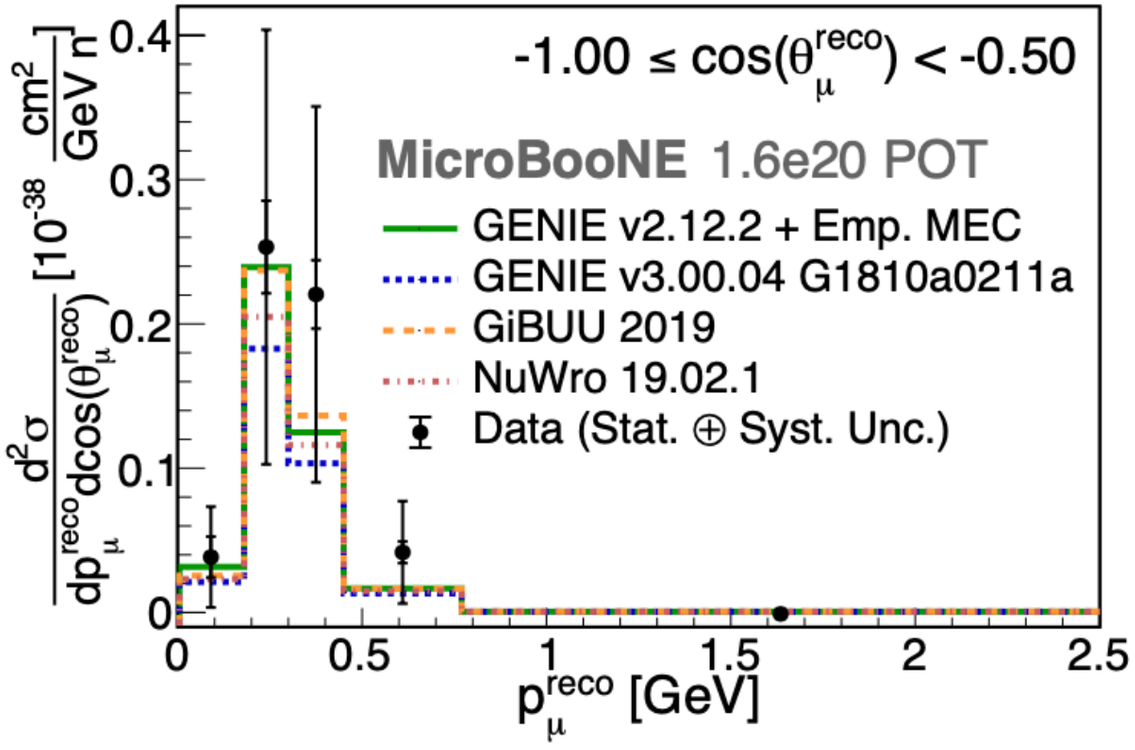


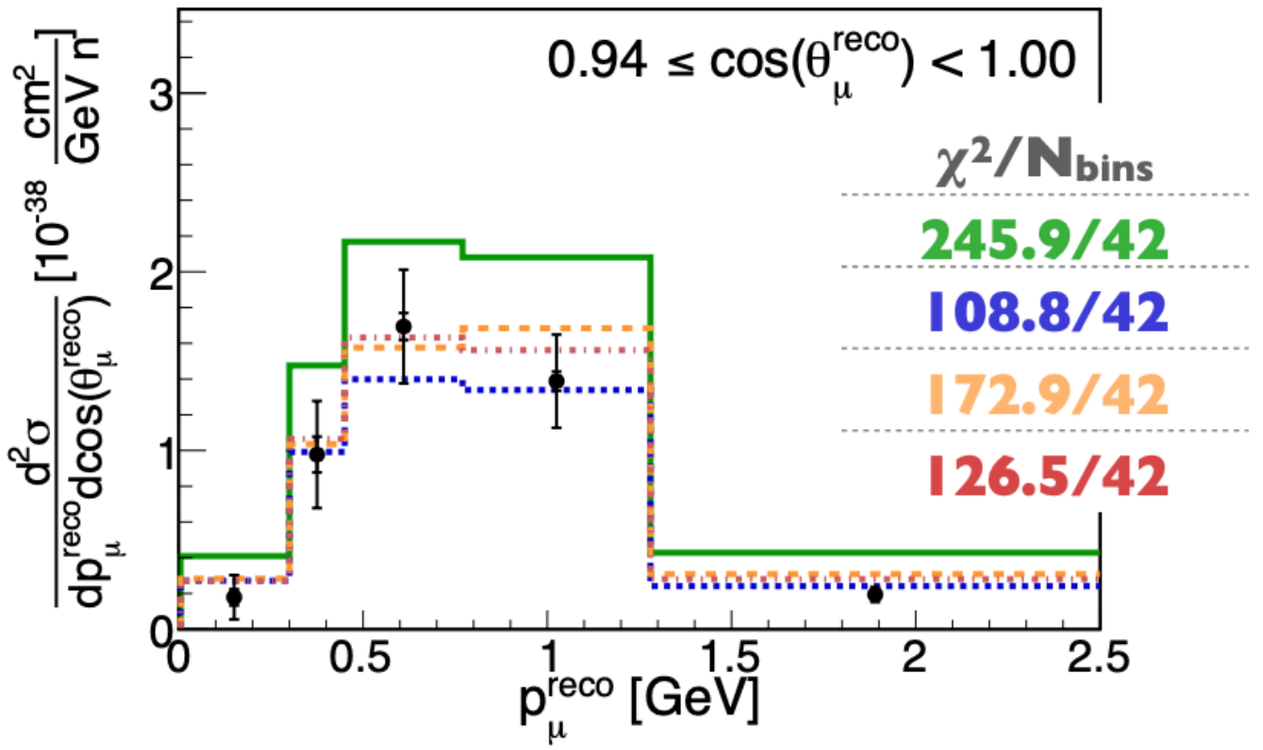


ν_μ CC inclusive $\nu_\mu + A \rightarrow \mu^- + A' + X$

2018 result: **first ν_μ CC double-differential cross section in argon**. Compared to several generators, all tuned previously to world neutrino scattering data (except GiBUU). Mis-modeling in several regions, particularly forward-going muons, could be explained by many competing mechanisms. 50% purity and big contribution of detector uncertainties.

Big effort to improve **detector modeling**, **signal processing**, **calibration** and other detector effects.





PRL 123, 131801 (2019)

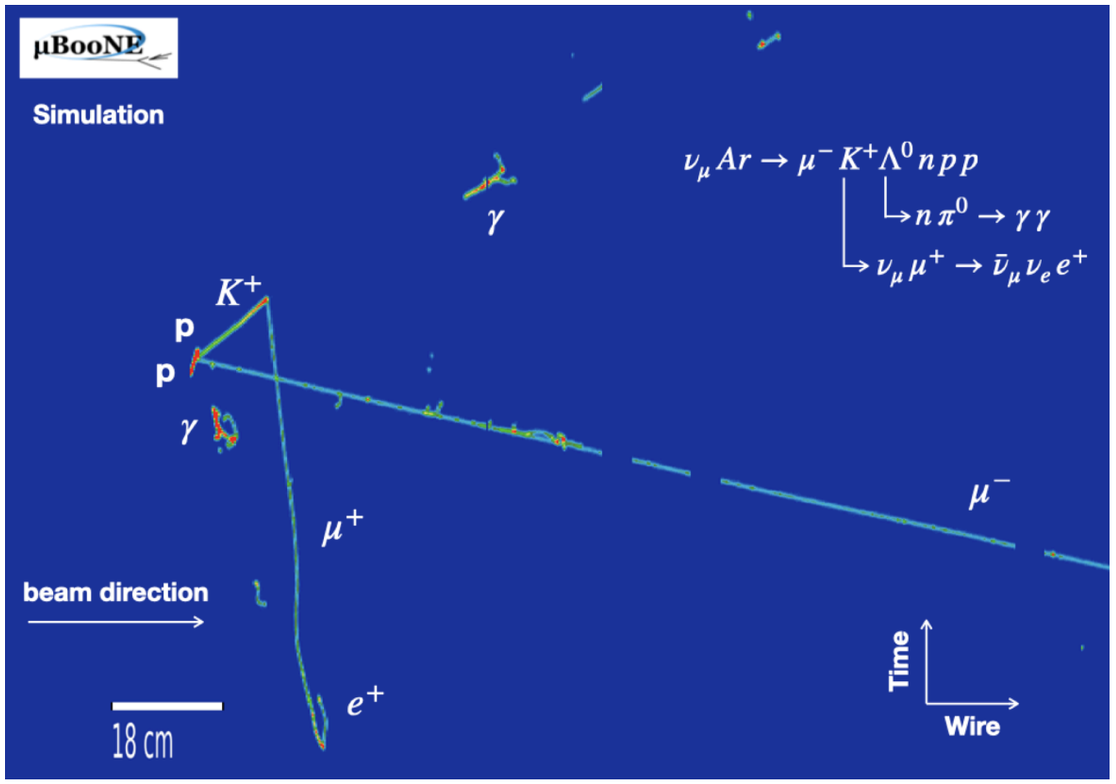
ν_μ CC single kaon

MICROBOONE-NOTE-1071-PUB

The ability to identify kaons, and those coming from neutrino interactions (in NC), will help to constraint one of the main backgrounds for some of the **proton decay searches**.

But also, neutrino-induced kaon production represents **genuine physics processes never studied before with such a precision**.

Opening data coming soon, stay tuned!



Cand. #	Interaction	K^+ cand. gen. particle	decay μ^+ cand. gen. particle
1	CC RES, ν_μ Ar $\to \mu^-$ Λ^0 K^+ n 2p	K^+	μ^+
2	CC RES, ν_μ Ar $\to \mu^-$ Λ^0 K^+	K^+	μ^+
3	CC DIS, ν_μ Ar $\to \mu^-$ Σ^+ K^+ π^+ π^-	K^+	μ^+
4	CC DIS, ν_μ Ar $\to \mu^-$ Σ^+ K^+ π^+ n	K^+	μ^+
5	CC RES, ν_μ Ar $\to \mu^-$ Σ^+ K^+ n	K^+	μ^+
6	CC DIS, ν_μ Ar $\to \mu^-$ Λ^0 K^+ p	K^+	μ^+
7	CC DIS, ν_μ Ar $\to \mu^-$ Λ^0 K^+ n p	K^+	μ^+
8	CC RES, ν_μ Ar $\to \mu^-$ Λ^0 K^+	K^+	μ^+
9	CC RES, ν_μ Ar $\to \mu^-$ π^+ p	proton	π^+
10	CC MEC, ν_μ Ar $\to \mu^-$ 2n 2p	proton	proton
11	CC RES, ν_μ Ar $\to \mu^-$ π^+ 3p 2n	proton	π^+
12	CC RES, ν_μ Ar $\to \mu^-$ π^+ π^- π^0 n p	proton	π^+

Signal