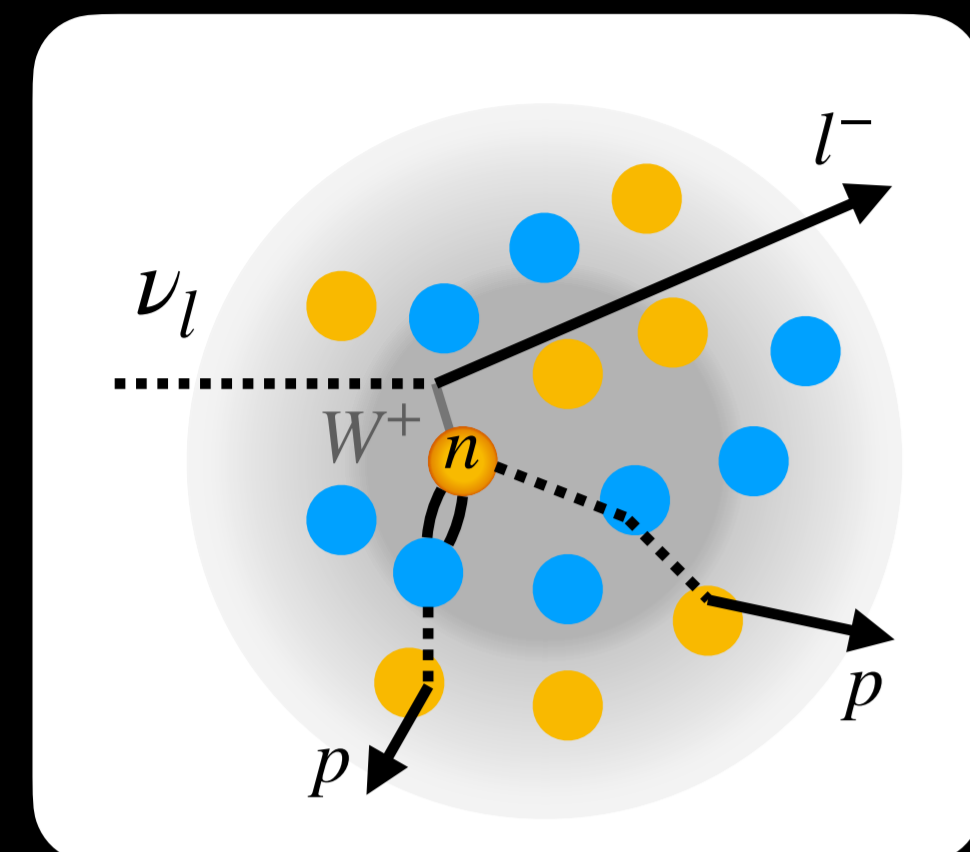


## Motivation

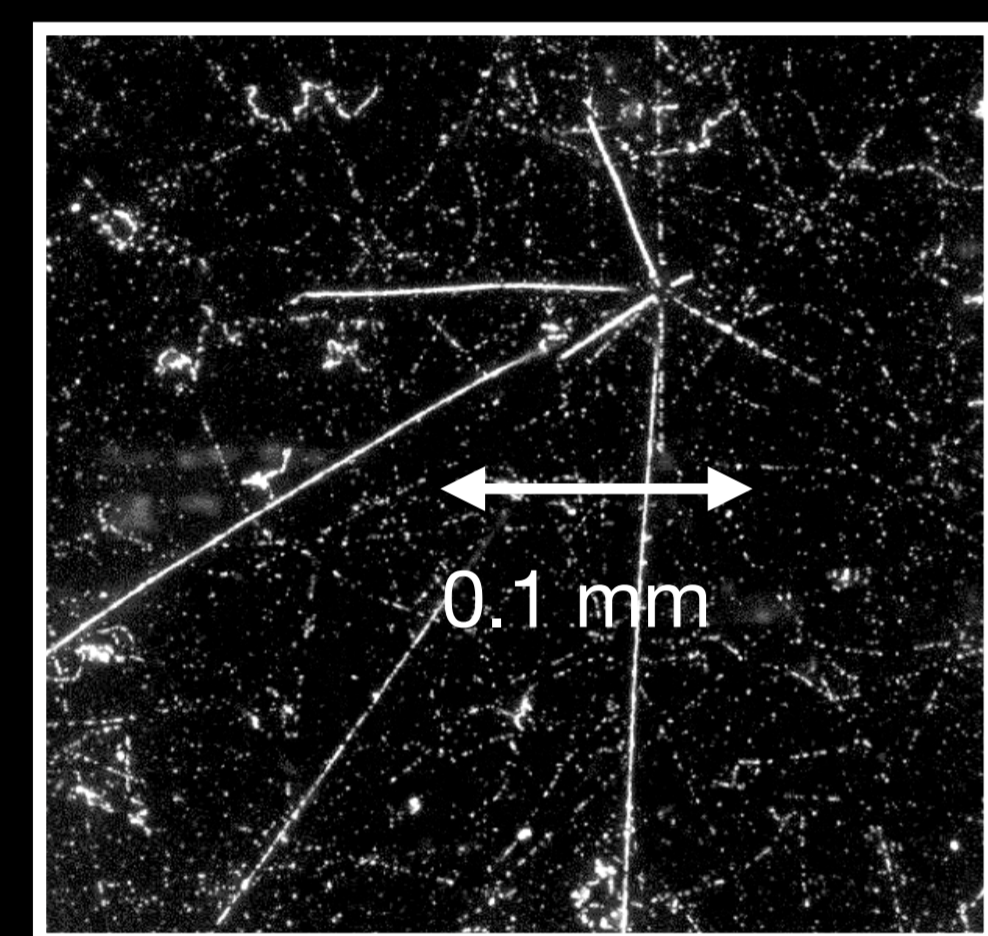
Predicting  $\nu$  energy profile crucial for long-baseline oscillation experiments targeting the test of leptonic CP violation



$\nu$  “2p2h” interaction on “two” correlated nucleons

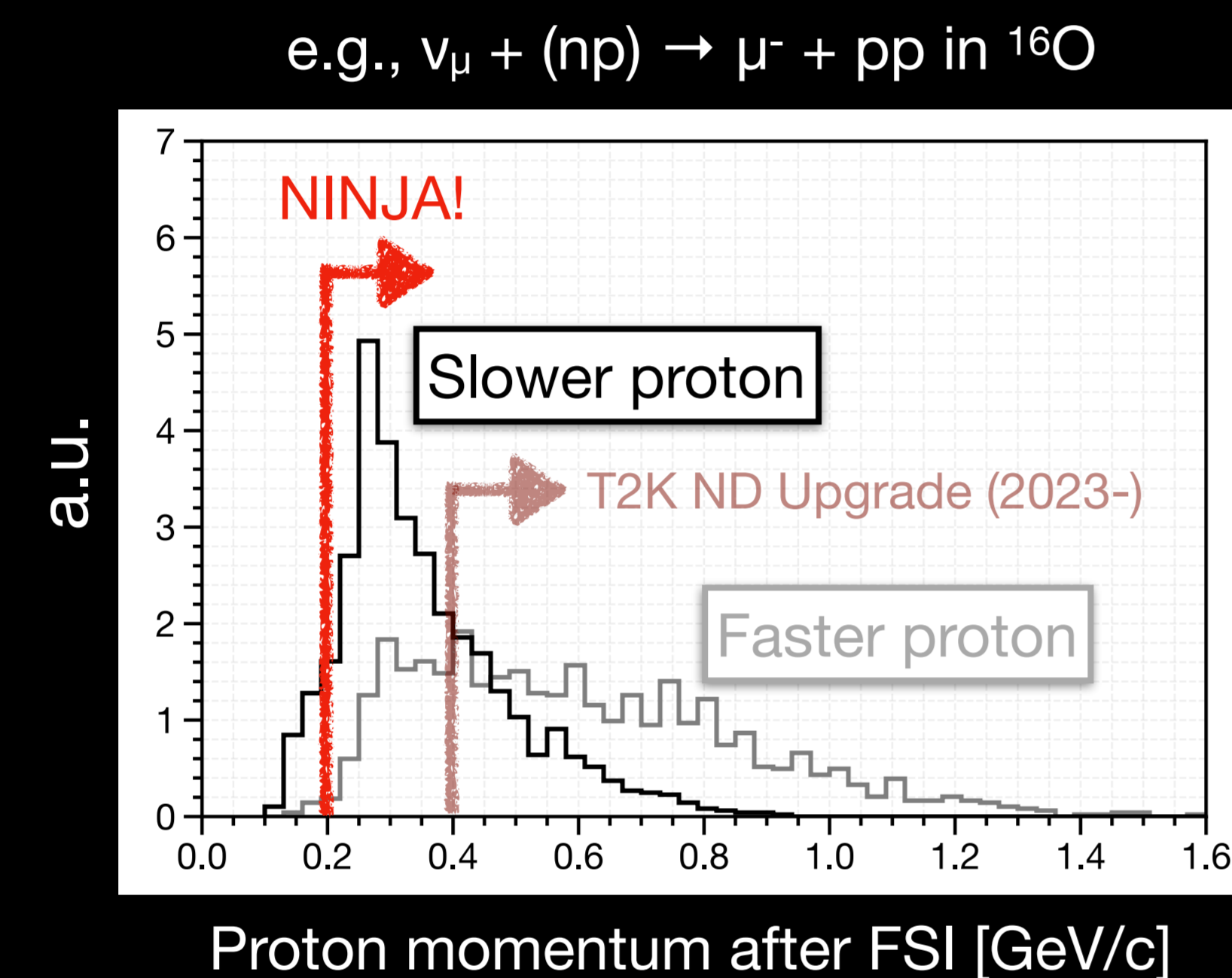
Channels like “2p2h” cause significant bias and also carry large xsec uncertainty, but measurement of nucleons challenging, especially with water targets

Nuclear emulsion gel (silver halide + gelatin) provides sub- $\mu\text{m}$  precision tracking medium, and can track protons down to  $\sim 200$  MeV/c, close to nucleon Fermi momentum



$\nu_\mu$  CC final-states on nuclear emulsion film

“Water target + Emulsion films” can provide valuable proton kinematics in  $\nu_\mu$ - $^{16}\text{O}$  CC interactions, important for water-based Hyper-Kamiokande



## Track reconstruction

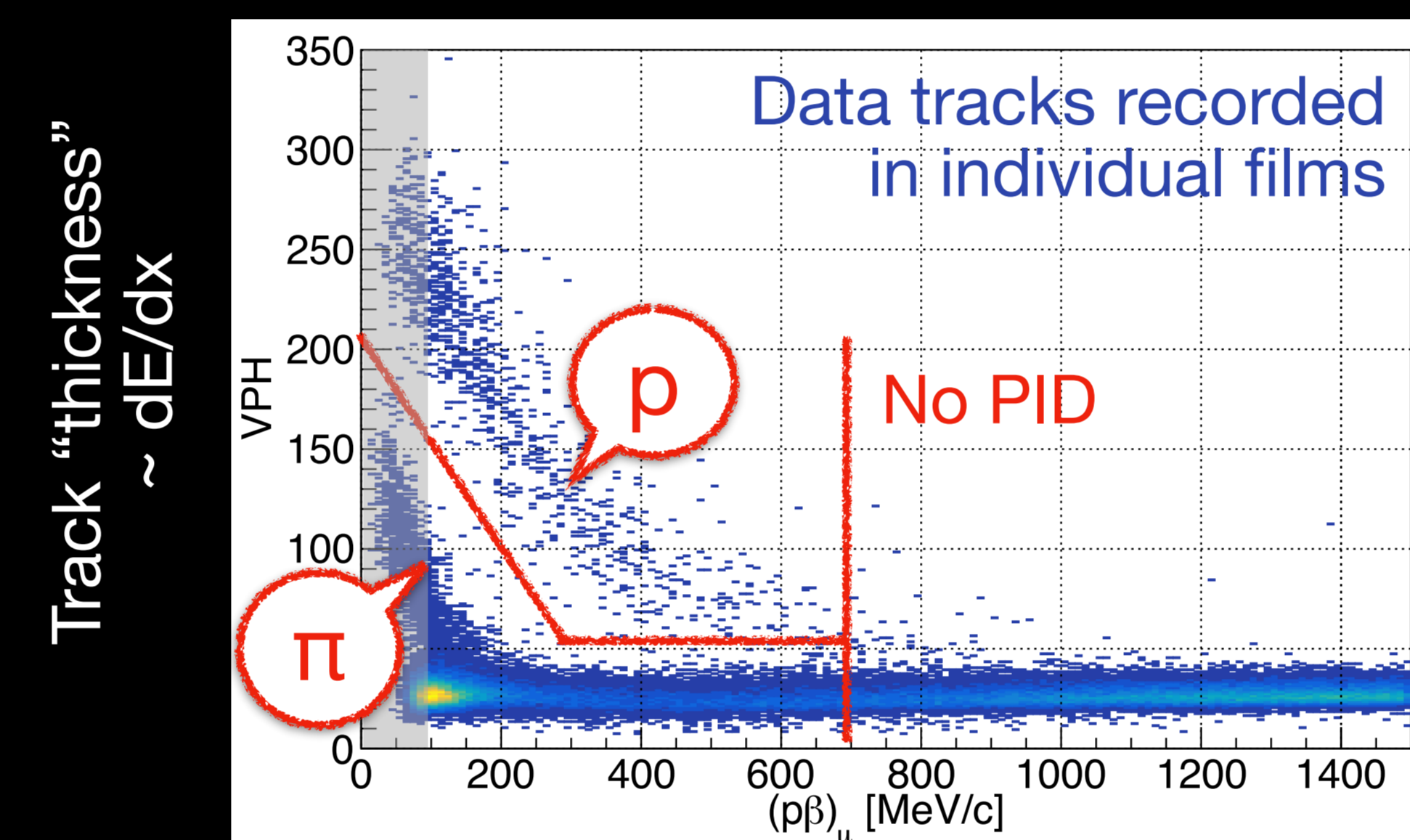
### Momentum reconstruction

Use RMS of Coulomb scattering angles  $\sim O(1)$  mrad, in 0.5 mm steel plate sandwiched btw two films

$$\text{Effective momentum } p\beta \approx 0.14 \times \frac{13.6 \text{ MeV/c}}{\theta_{\text{RMS}}}$$

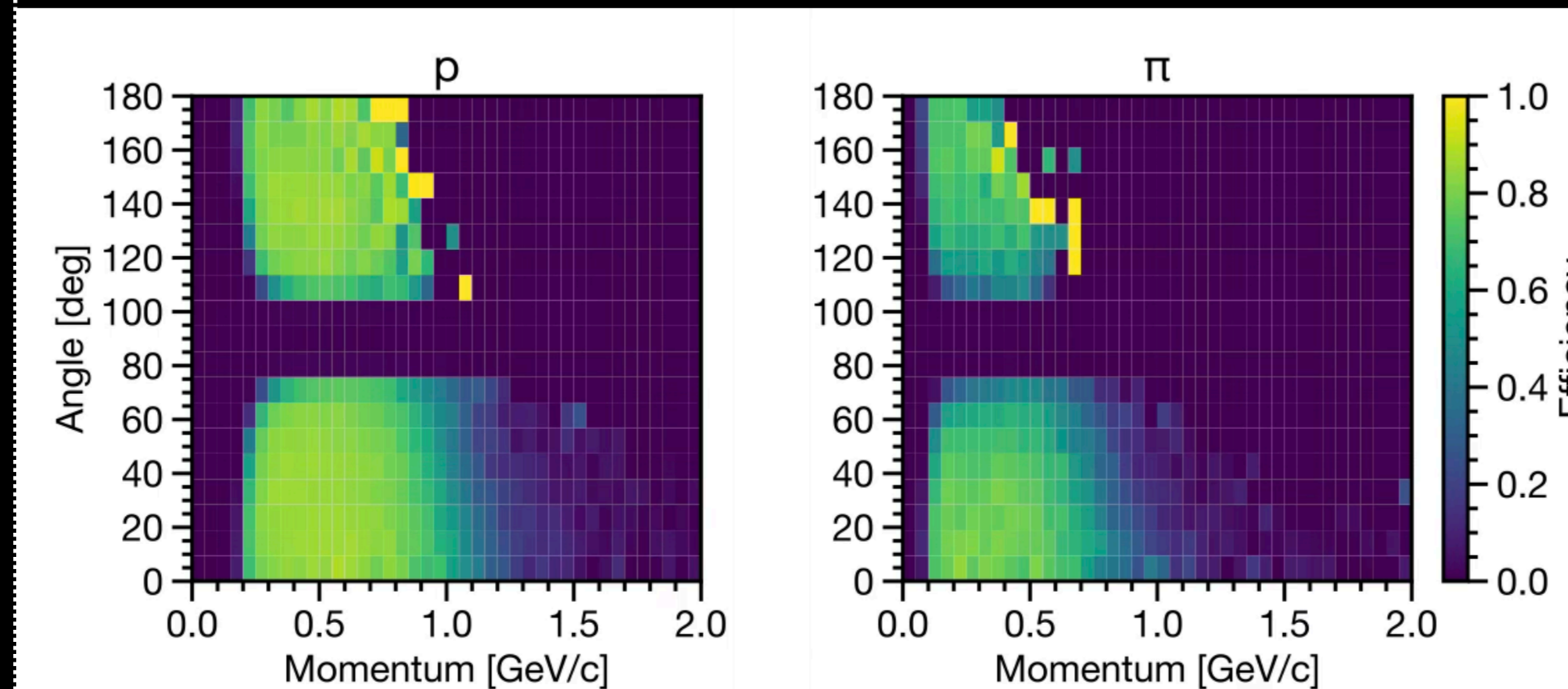
Highland formula + Correction for E loss along the track  
 $\sim 15\%$  uncertainty for  $\mu$  below 1 GeV/c [1]

### Hadron PID



Overall PID purity:  $\mu$  97%,  $p$  99%,  $\pi$  93%

### Hadron efficiency wrt kinematics ( $\nu$ MC)



Hadron angular acceptance restricted at 75-105°  
 Momentum limited to  $< 1$  GeV/c due to PID inefficiency

Overall final-state tracking efficiency:  $p$  54%,  $\pi$  46%

## Looking at $\sim 2\%$ fraction of data

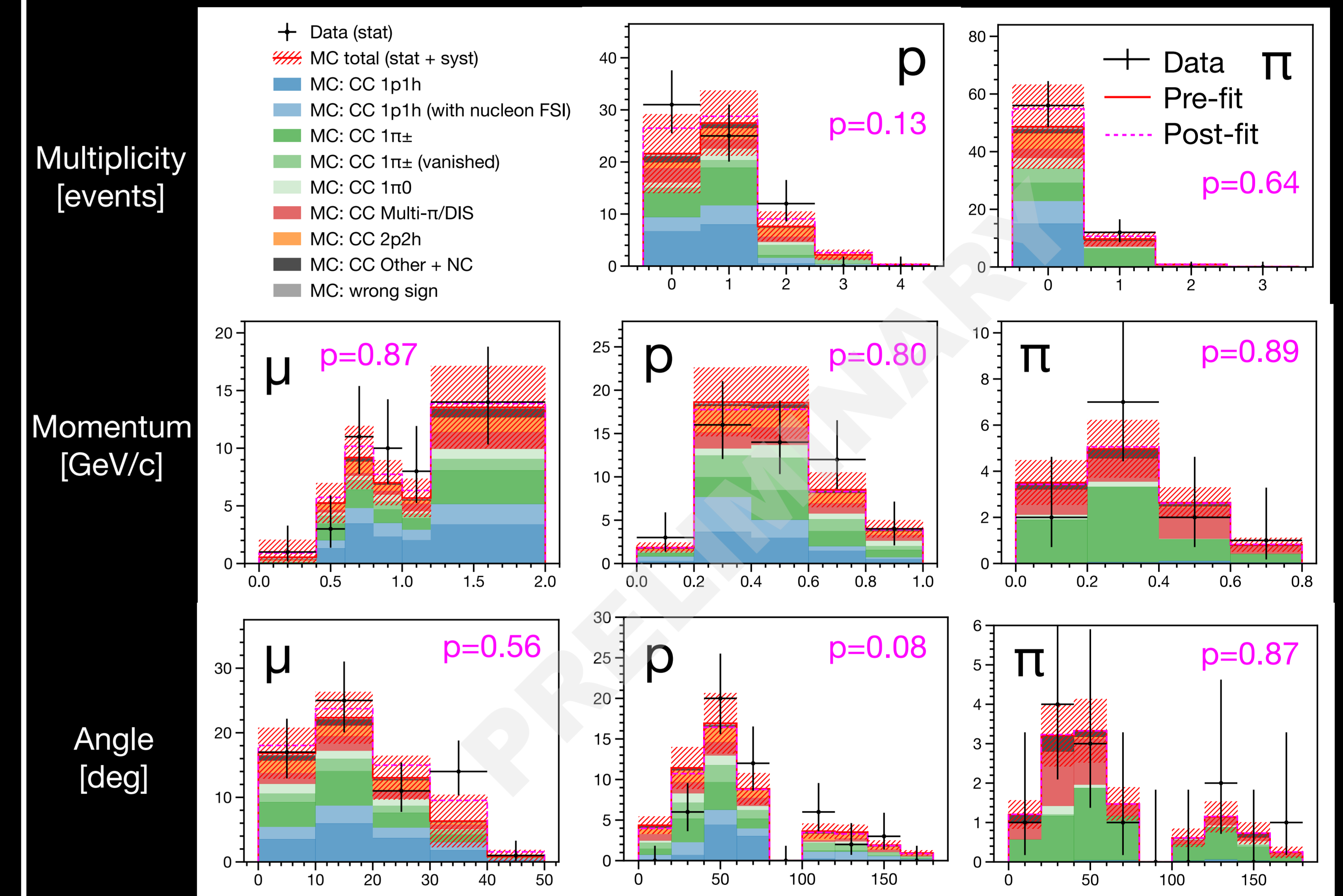
Reco-level  $\mu$ ,  $p$ ,  $\pi$  kinematics in 68 inclusive events ( $4.6 \times 10^{20}$  POT  $\nu_\mu$  exposure  $\times$  4 kg water)

Compared against NEUT 5.6.4 (T2K model configuration [2]) + Geant4.10.6.2 MC simulation

Syst covariance as nuisance parameters and fitted to data (p-value w MC toys)

- Stat  $\sim 20\%$ , Beam flux  $\sim 5\%$
- Interaction modeling 10-20%
- $\mu$  connection 5% ( $\theta_\mu < 20^\circ$ ) 15-60% ( $\theta_\mu > 20^\circ$ )
- Detector response  $\sim 10\%$  (multiplicity, angle)  $\sim 20\%$  (momentum)

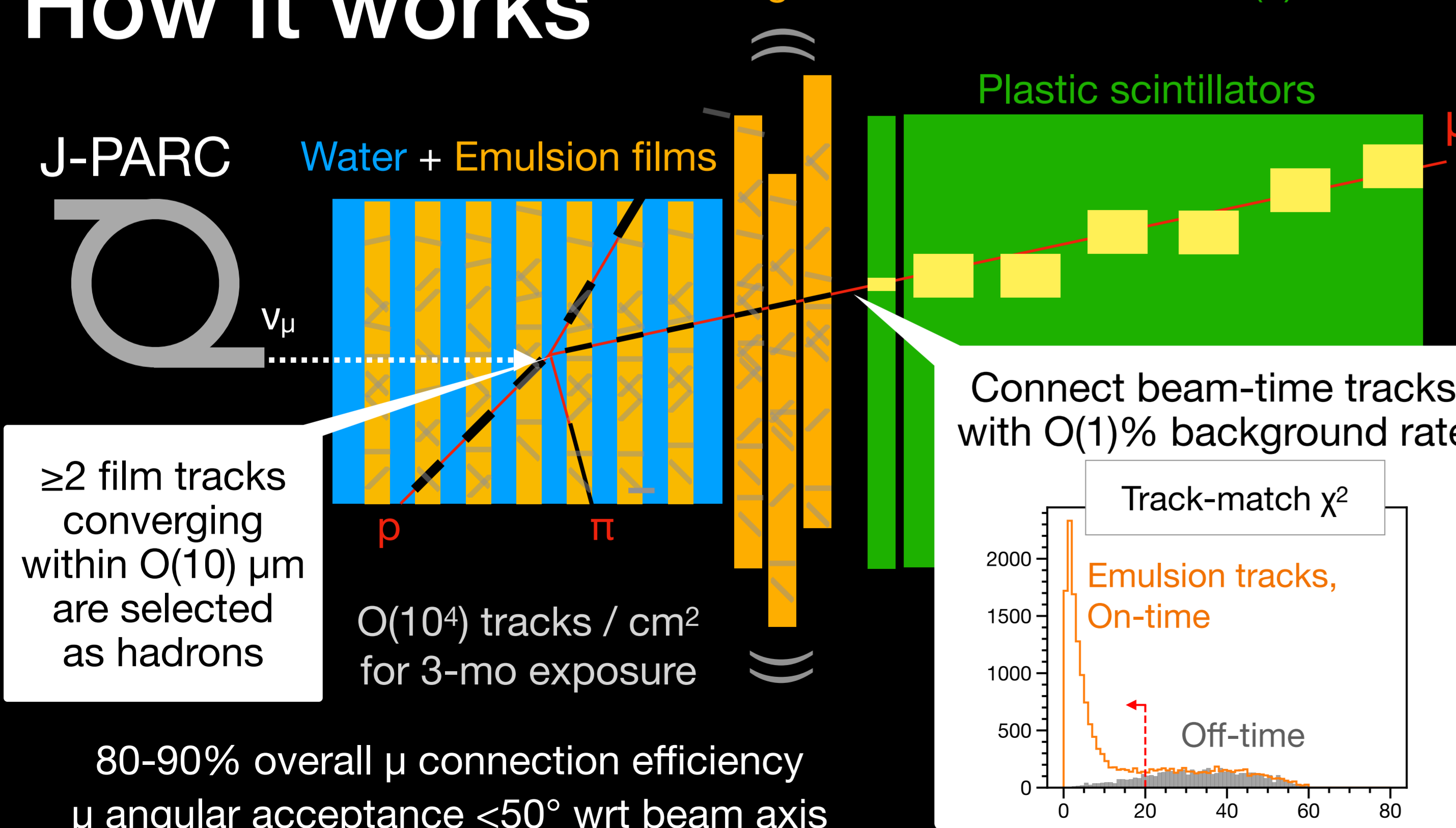
Minimized Binned Poisson  $\chi^2$  + Gaussian nuisance penalty POT normalized



Overall, individual distributions are in agreement with T2K model predictions within errors  
 We need to better model  $\mu$  connection efficiency and reduce momentum systematics

## How it works

Moving films + 2D tracker with  $O(1)$  mm res.



## Prospects with full data

Beam exposure completed on March 2026 and film processing/scanning ongoing.  
 By 2028-2029, we will be able to analyze  $\sim 300$   $\nu_\mu$  CC  $1\mu 2p0\pi$  events to test 2p2h models

