Improving Neutrino Interaction Modeling with Electron Scattering Measurements in LDMX

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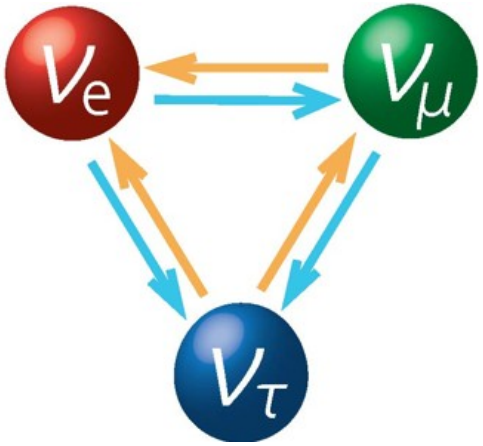
New Perspectives

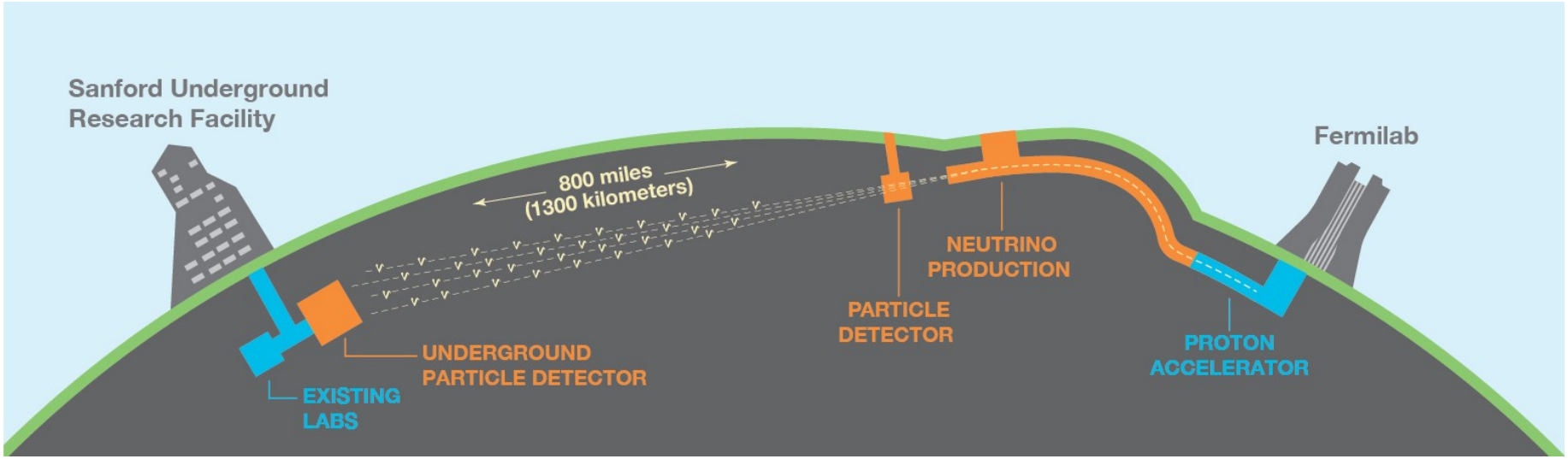
16 August 2021

Neutrino Oscillations



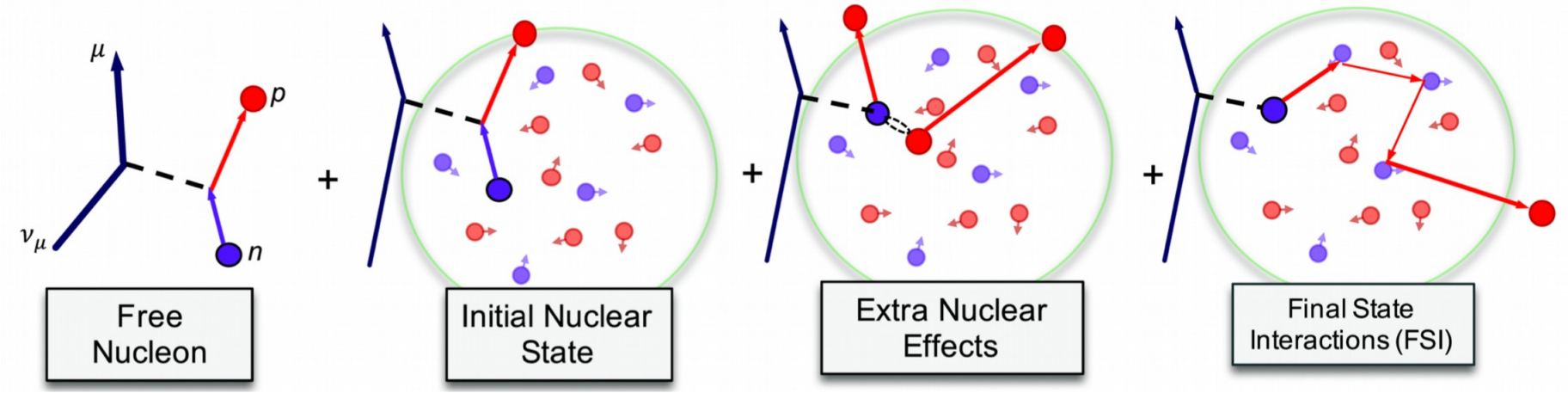
csulb.edu

- Deep Underground Neutrino Experiment (DUNE)
- Probability of neutrino flavor varies as it propagates
  - Flavors: ν_e, ν_μ, ν_τ
- Further understand neutrino's role in universe and matter/antimatter asymmetry



dunescience.org

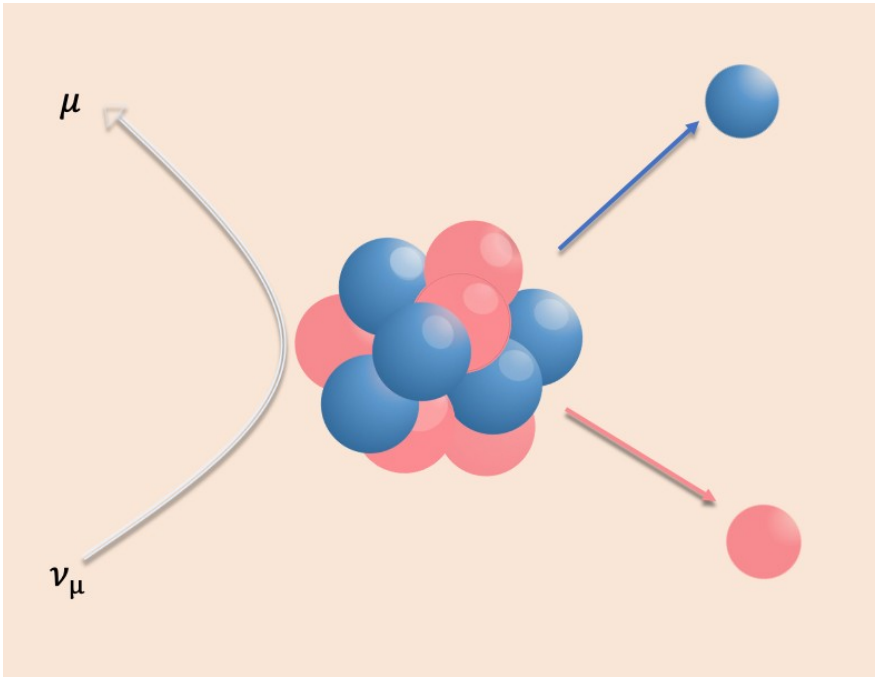
Neutrino Nucleus Interaction



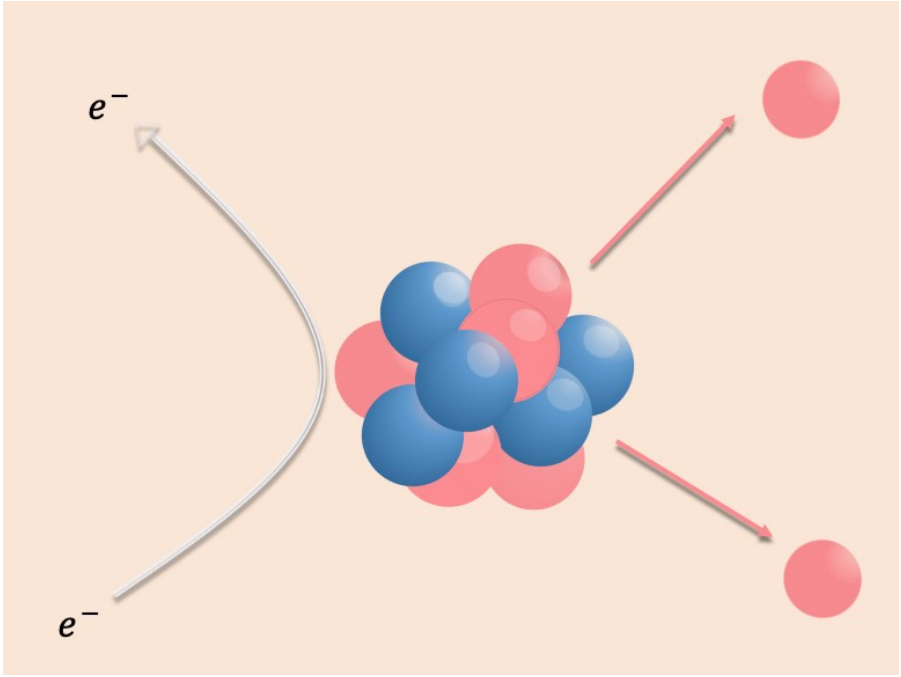
C.Wilkinson, 2020

Analogous Electron Nucleus Interaction

- Nuclear physics similarities
- Known incoming electron energy and angle
- Focus on FSI
  - Energy loss of propagating particles, hadronic interactions



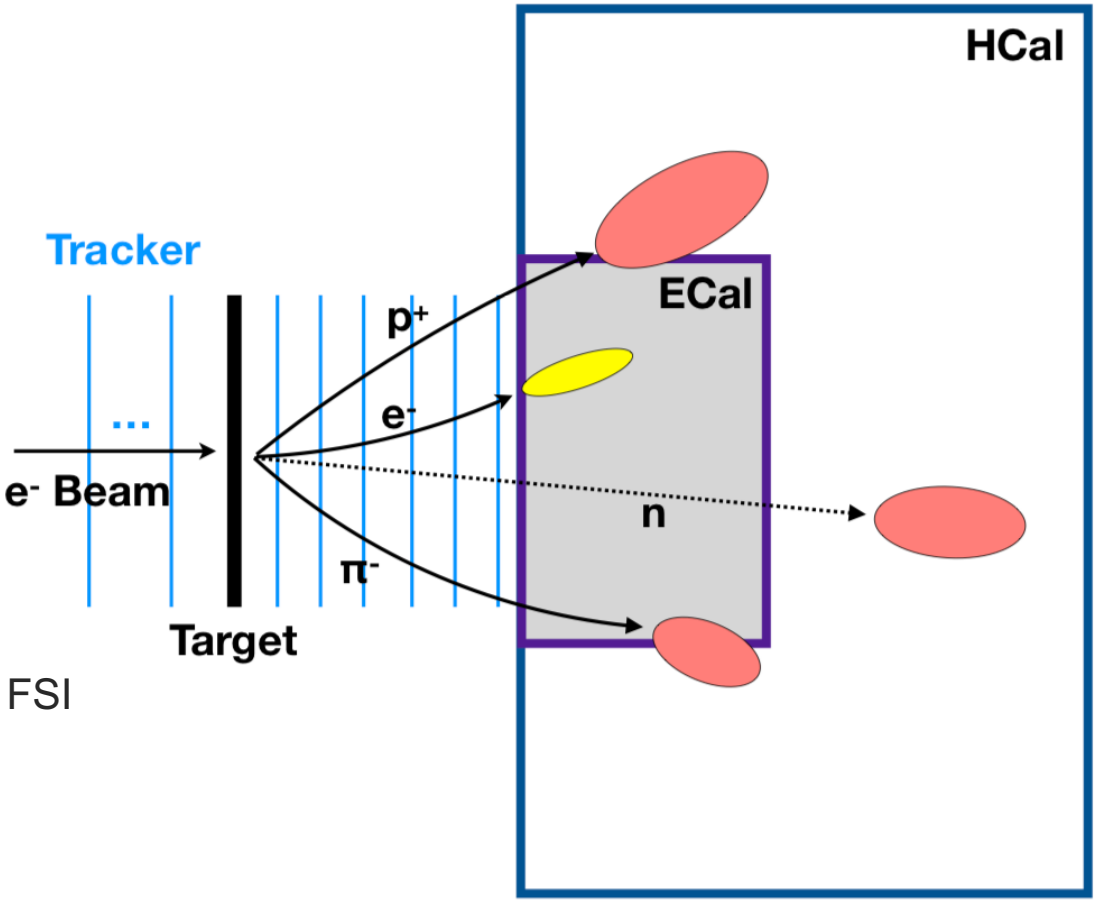
Neutrino nucleus interaction



Electron nucleus interaction

Light Dark Matter eXperiment (LDMX)

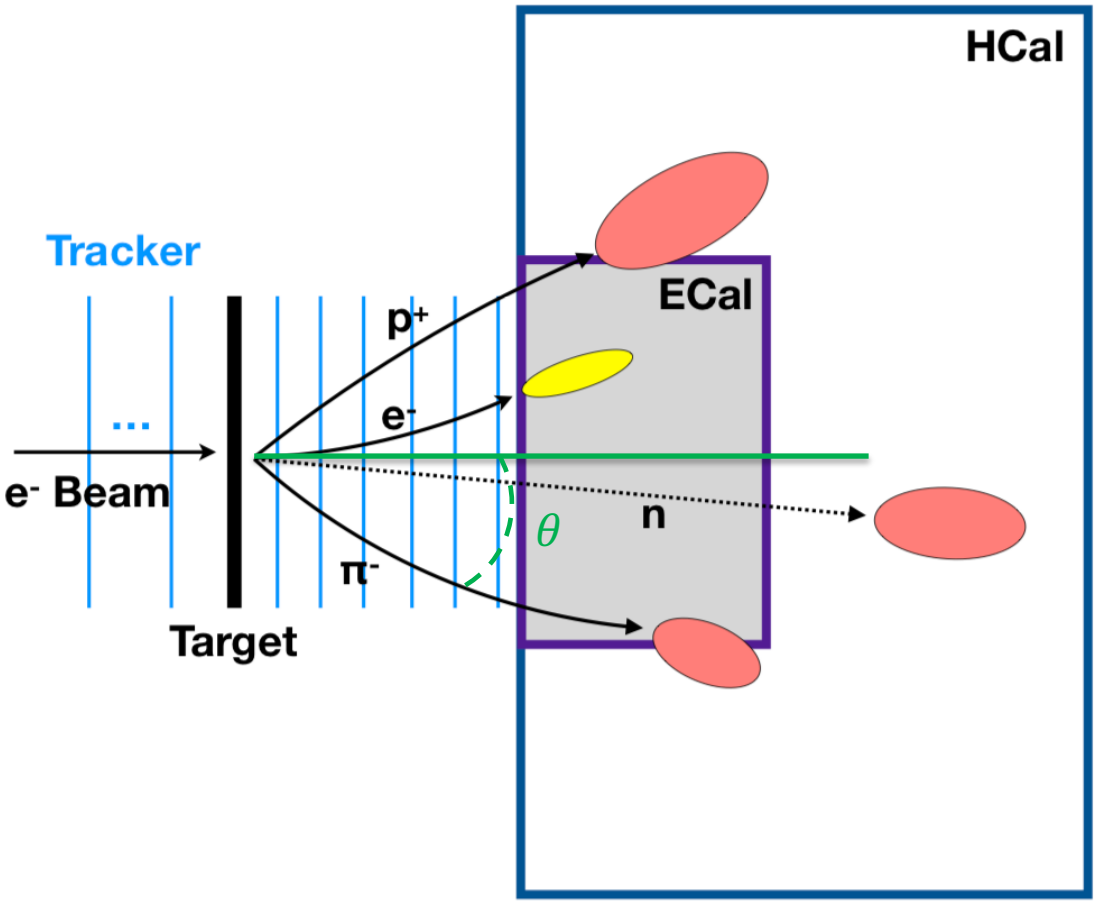
- Dark matter detection in largely unexplored region
  - 0.5 MeV to 0.5 GeV
- 4-GeV electron beam, precision tracker, electromagnetic and hadronic calorimeters
- Electron nucleus scattering for FSI reconstruction
- Design study phase



A. Ankowski et al., 2020

Light Dark Matter eXperiment (LDMX)

- Outgoing lepton p_T > 400 MeV
- Outgoing kinetic energy > 60 MeV
- Outgoing particle
  $-40° < \cos(\theta) < 40°$



A. Ankowski et al., 2020

GENIE Event Generator

- Software library producing simulated electron/neutrino nucleus interactions
- Probing different FSI model uncertainties
  - Fractional Charge Exchange [FrCEx]
  - Fractional Absorption [FrAbs]
  - Fractional Inelastic Collisions [FrInel]
  - Fractional Pion Production [FrPiProd]
- FSI parameters varied at level of 1σ uncertainty

FrCEx_N:
$p \rightarrow n + p$

FrAbs_N:
$p \rightarrow 21n + 21p$

FrInel_N:
$n \rightarrow 2n$

FrPiProd_N:
$n \rightarrow \pi^- + n + p$

FrCEx_pi:
$\pi^+ \rightarrow \pi^0 + p$

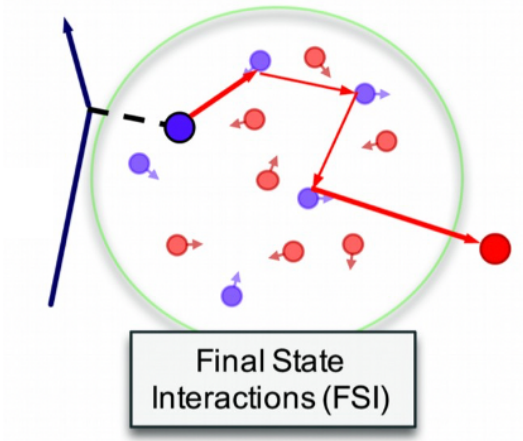
FrAbs_pi:
$\pi^+ \rightarrow n + p$

FrInel_pi:
$\pi^+ \rightarrow \pi^+ + p$

FrPiProd_pi:
$\pi^+ \rightarrow 2\pi^0 + p$

UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT

ie-mc.org.



Potential Observables and Chi Squared

Observable: measurable kinematic quantity in LDMX

- Effective Observables $[\frac{\chi^2}{dof} > 1]$
  - Kinetic energy by particle
  - Leading particle kinetic energy
  - Multiplicity
  - $\cos(\theta)$
  - Leading particle $\cos(\theta)$

  → **OUTGOING HADRON**

- Ineffective Observables $[\frac{\chi^2}{dof} \leq 1]$
  - Total kinetic energy
  - Kinetic energy sum by event

  → **OUTGOING HADRON**

  - $\cos(\theta)$
  - Energy
  - Kinetic Energy
  - Momentum

  → **OUTGOING LEPTON**

Chi Squared

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

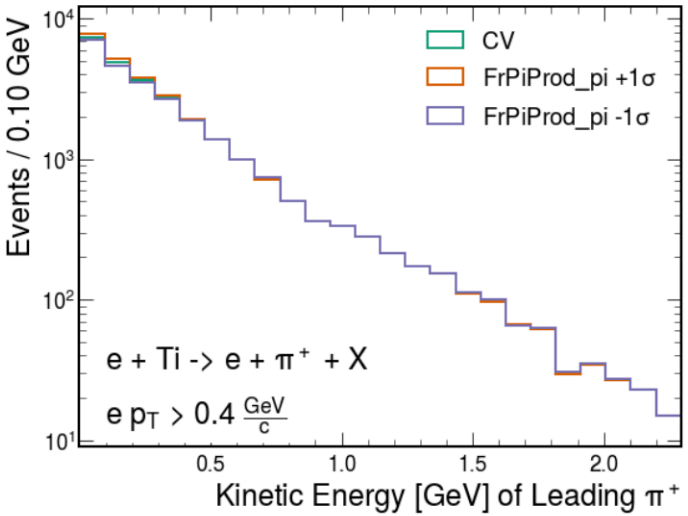
Reduced Chi Squared: $\frac{\chi^2}{dof}$

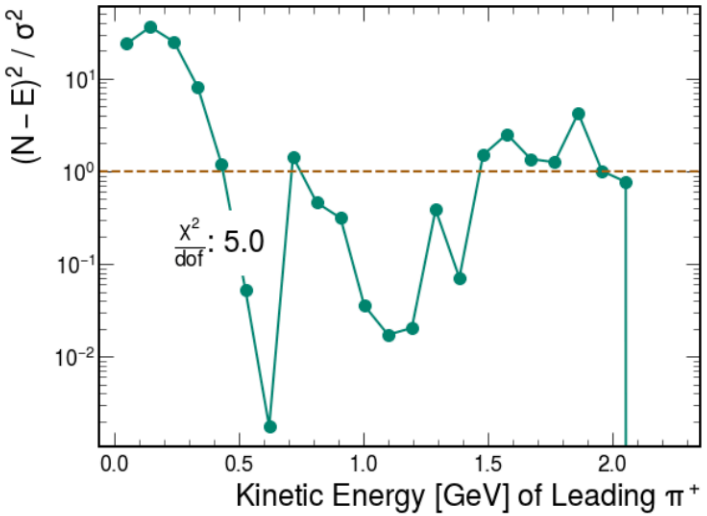
- O_i: Observed value (unweighted value)
- E_i : Expected value (weighted value)
- dof: Degrees of Freedom (# bins – 1)
- Assumed 1% uncertainty

Leading Kinetic Energy

Effective Observables [$\frac{\chi^2}{dof} > 1$]

Before Detector Cuts





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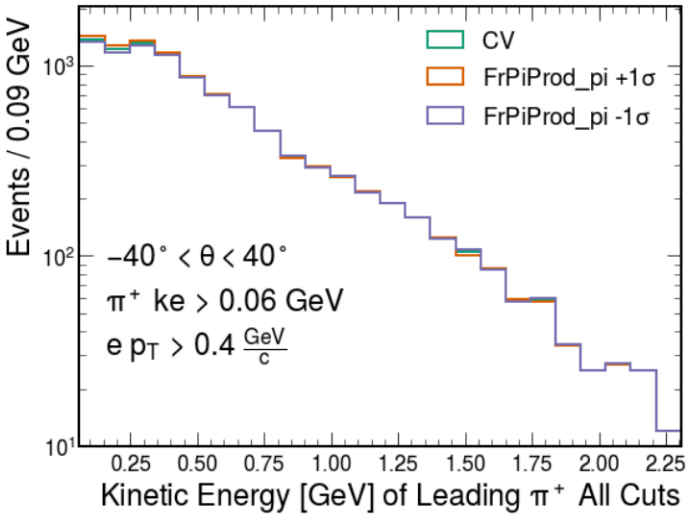
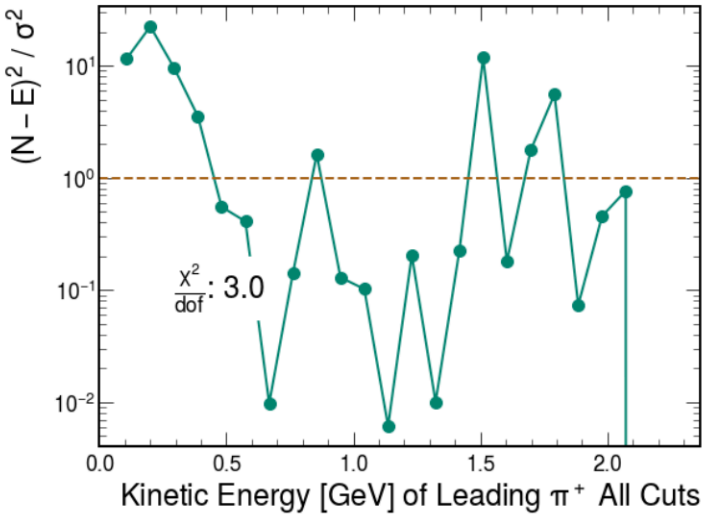


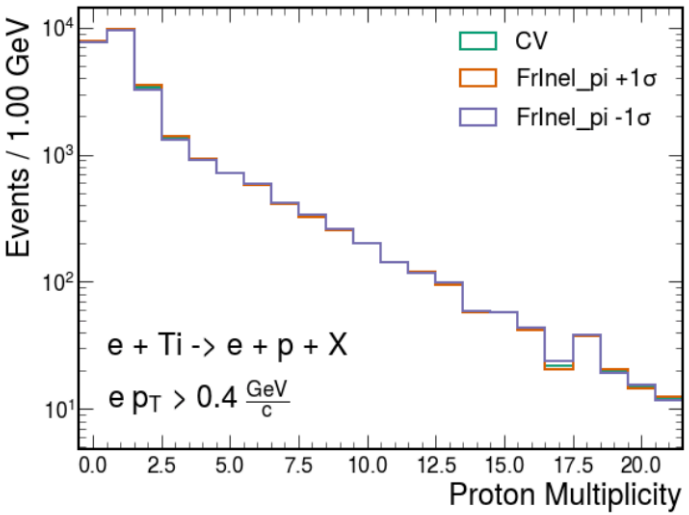


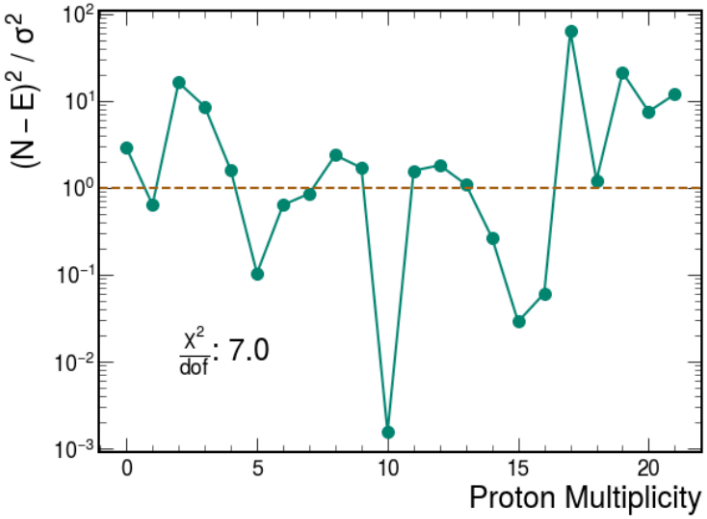
Fractional pion production in pions on outgoing leading π^+

Multiplicity

Effective Observables [$\frac{\chi^2}{dof} > 1$]

Before Detector Cuts





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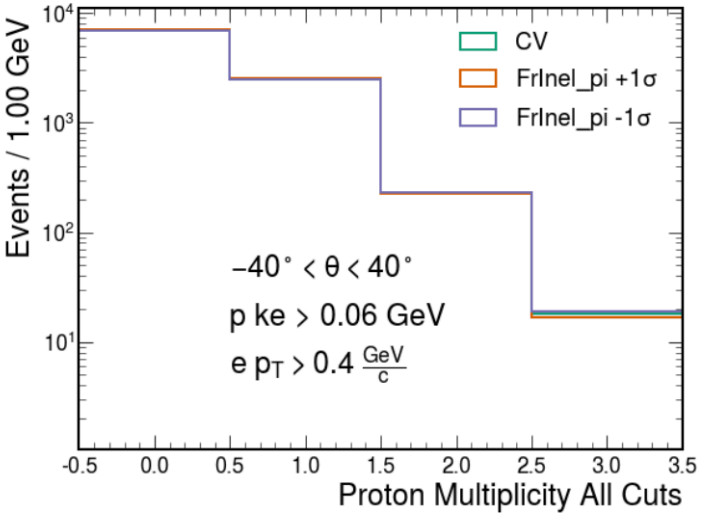
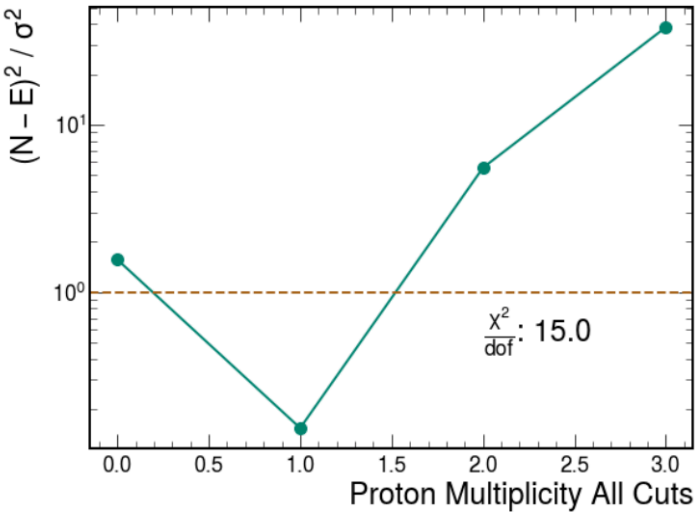


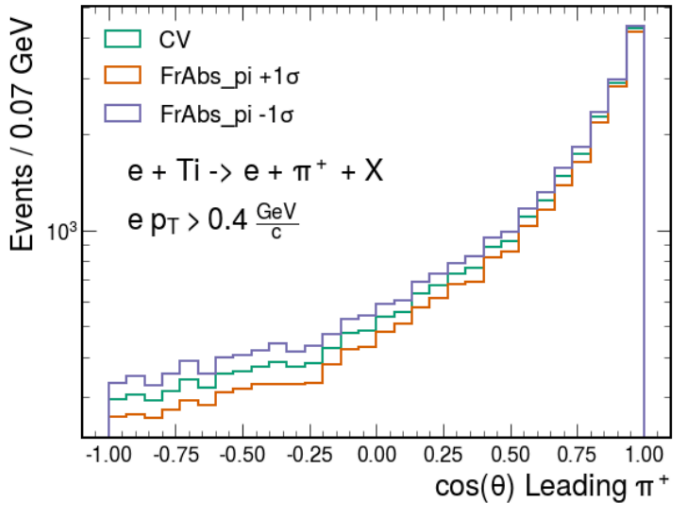


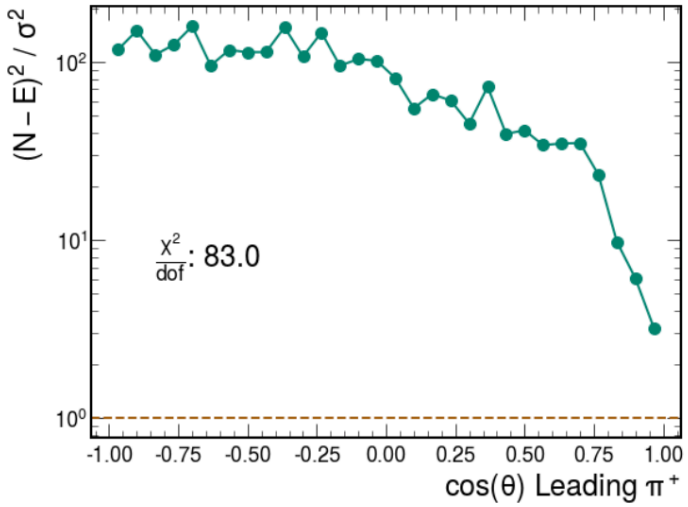
Fractional pion inelastic collision on multiplicity of all outgoing protons

Leading $cos(\theta)$

Effective Observables [$\frac{\chi^2}{dof} > 1$]

Before Detector Cuts





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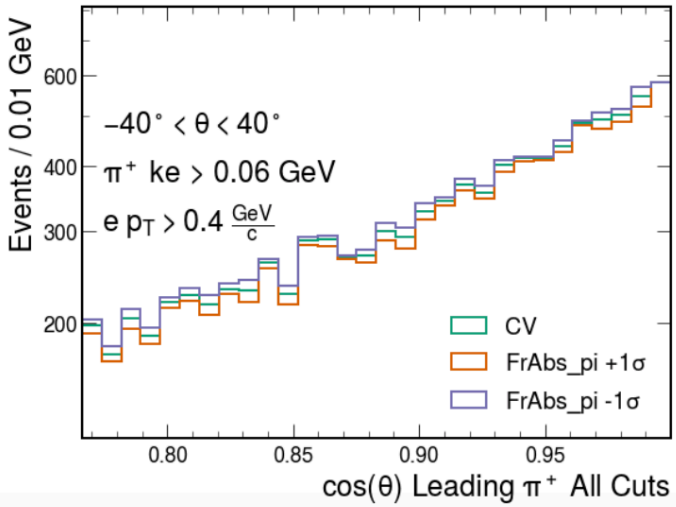
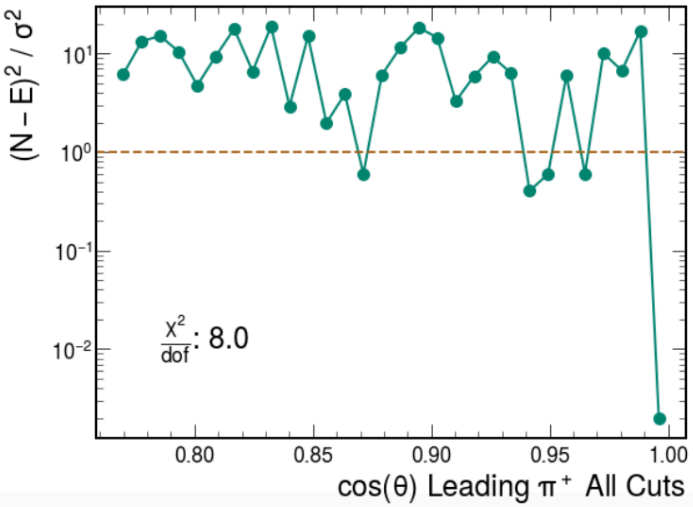




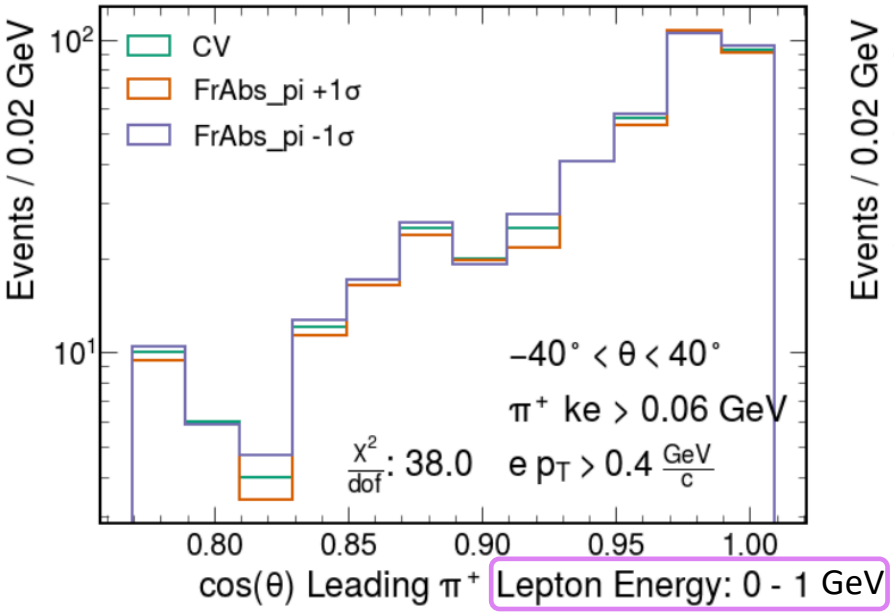
Fractional pion absorption on $\cos(\theta)$ of outgoing leading π^+

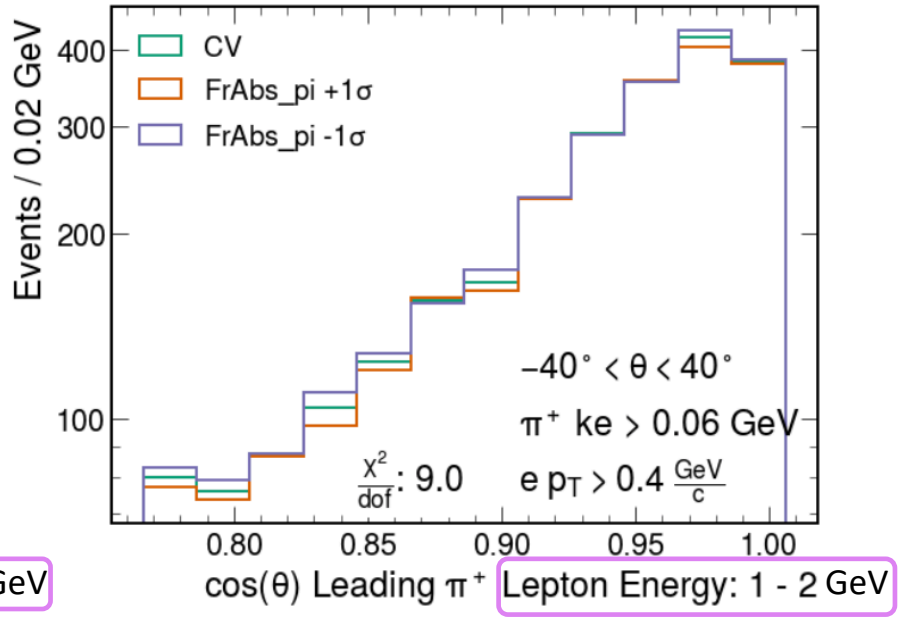
Further Distinctions with Lepton Kinematics

- Constrain FSI model uncertainties with lepton kinematics
  - Energy, momentum, $\cos(\theta)$

Effective Observables [$\frac{\chi^2}{dof} > 1$]

After Detector Cuts

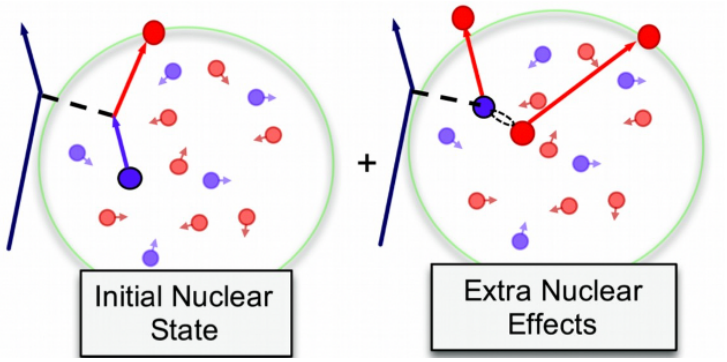


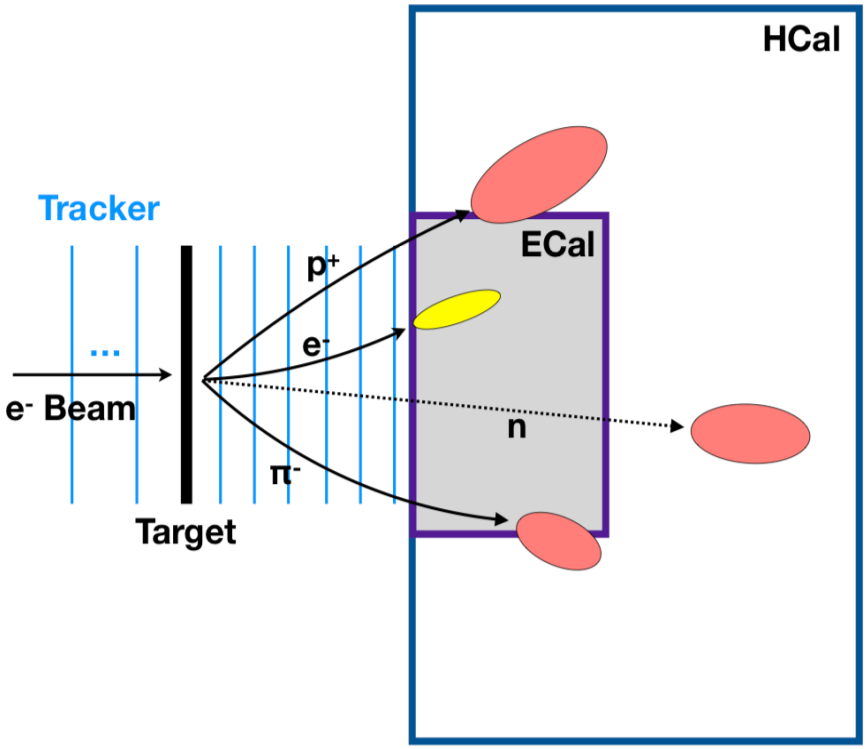


Fractional pion absorption on $\cos(\theta)$ of outgoing leading π^+

Next Steps

- Increased sample size
- Further probing of current FSI model parameters
  - More sophisticated lepton/hadron kinematics
- Different FSI model examination
- Non FSI model examination





A. Ankowski et al., 2020

- Integrate full LDMX simulation

Conclusion

Powerful LDMX detector ➔
Understand FSI of electron nucleus scattering ➔
Understand FSI of neutrino nucleus scattering ➔
Advanced neutrino detector sensitivity ➔
Increase understanding of universe composition

Nobelprize.org

References

T. Akesson et al. (LDMX), arXiv:1808.05219 (2018).

A. Ankowski et al., Phys. Rev. D 101, 053004 (2020).

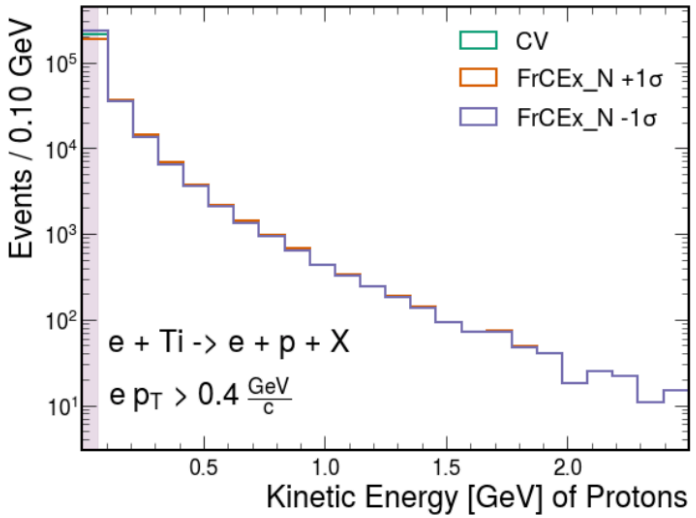
(v3.0.6) C. Andreopoulos et al., NIM A 614, 87 (2010).

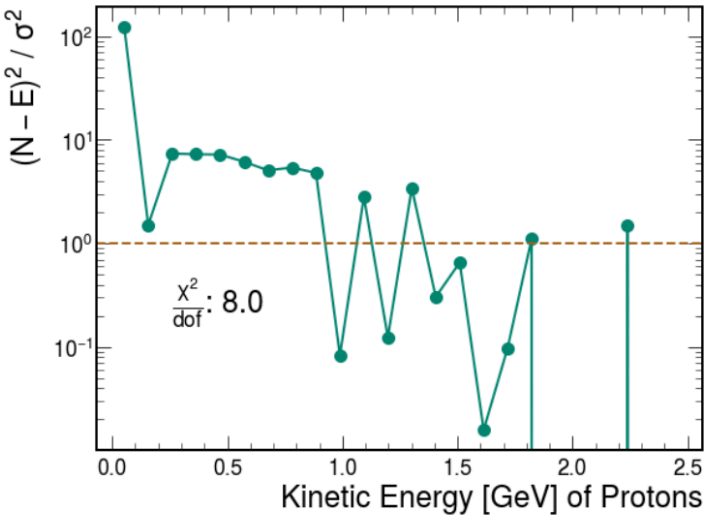
C. Andreopoulos, et al., arXiv:1510.05494 [hep-ph] (2015).

Kinetic Energy

Effective Observables [$\frac{\chi^2}{dof} > 1$]

Before Detector Cuts





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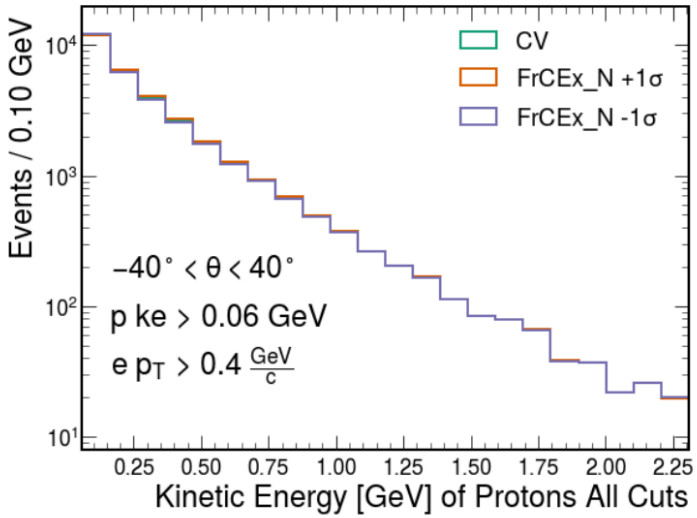
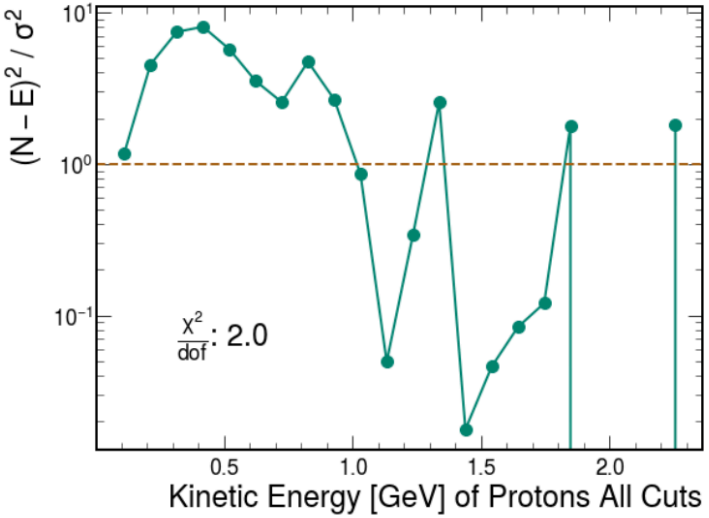


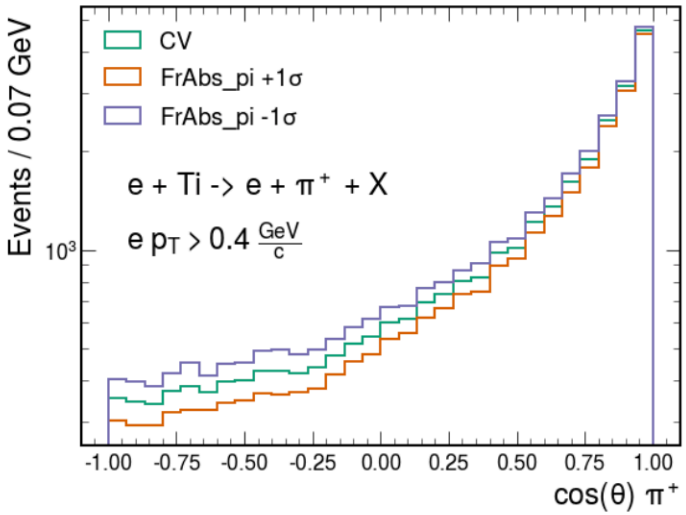


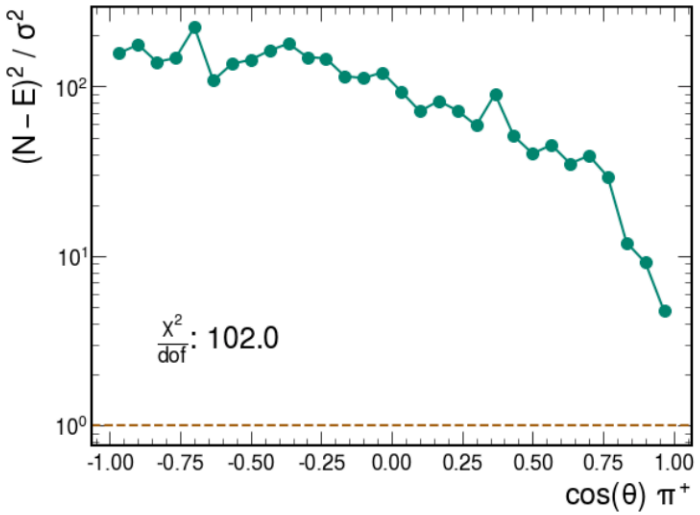
Fractional nucleon charge exchange on all outgoing protons

$cos(\theta)$

Effective Observables [$\frac{\chi^2}{dof} > 1$]

Before Detector Cuts





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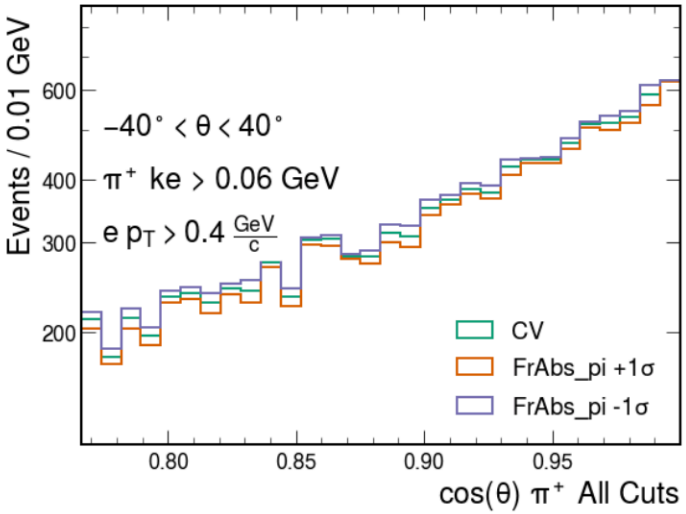

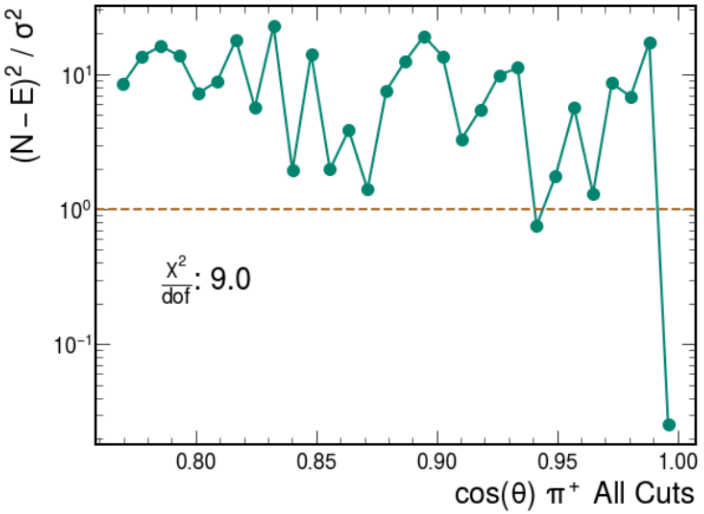

Fractional pion absorption on $cos\ (\theta)$ of all outgoing π^+

GENIE Weighting Check

Formation Zone coding error

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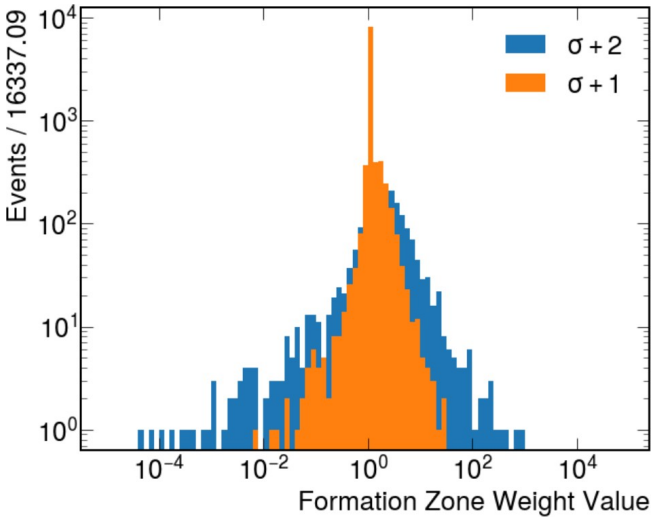
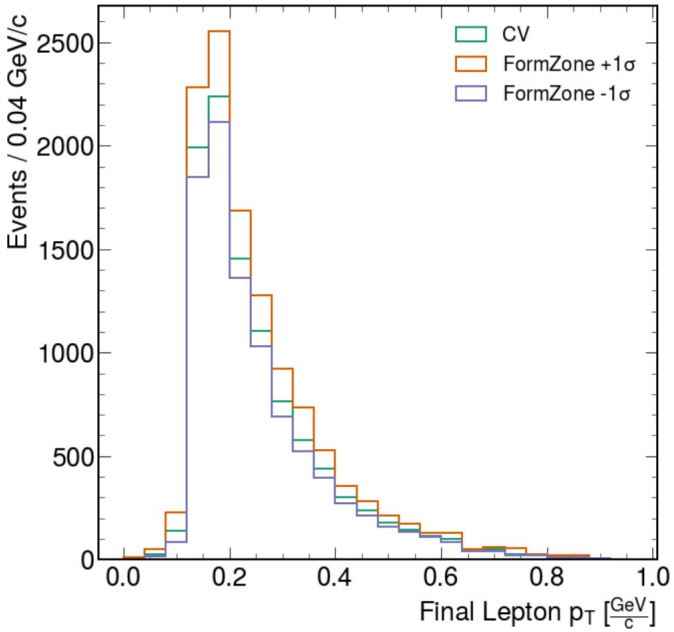
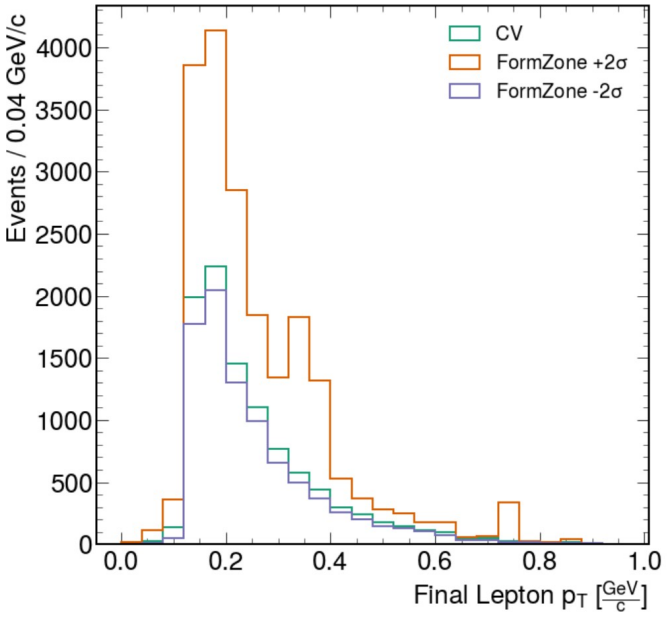
Focus on FSI weights







Fermilab