Imperial College London

First Study of Neutrino-Nucleus Cross Section Measurements at the nuSTORM Facility

Marvin Pfaff

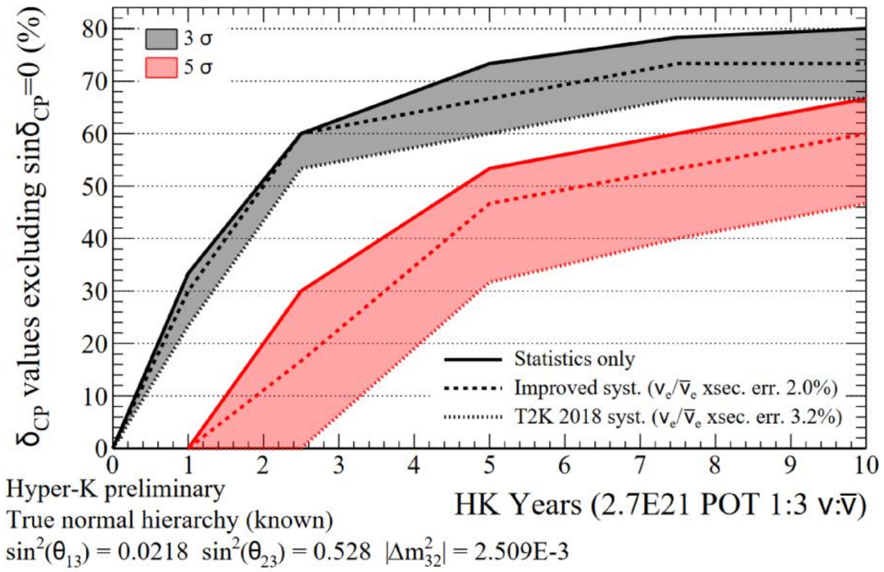
Imperial College London

Motivation

- ν-A interactions are still poorly understood and many open questions remain even in ν-N interactions
- Future generation of oscillation experiments will enter the precision era
  → no longer statistics limited
- One of the biggest uncertainties for the long-baseline experiments will be neutrino-nucleus cross section uncertatinties
  → these experiments will rely on good knowledge of these interactions & reliable modeling to maximise sensitivity and avoid biases

→ Dedicated high-precision cross-section measurements are needed

Scott, ICHEP 2020



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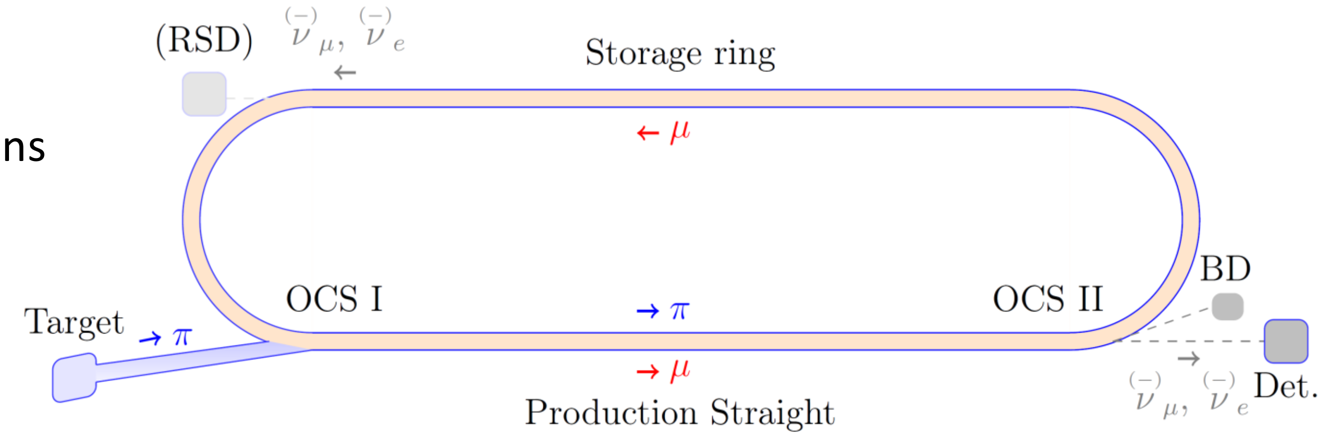


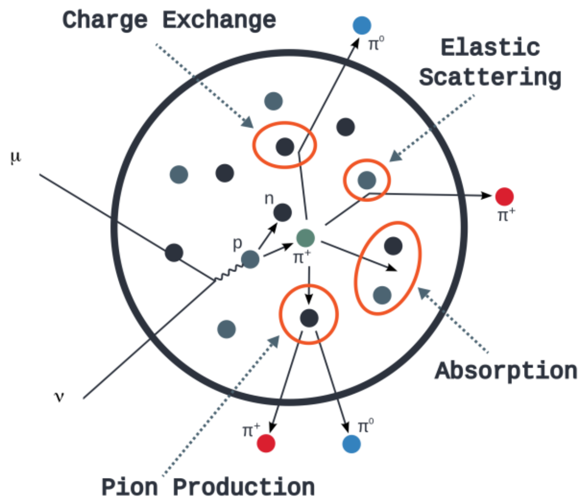
- nuSTORM will provide a uniquely well-defined neutrino beam with unprecedented precision and can therefore conduct high-precision neutrino measurements
- Tunable beam momenta allow to study at different neutrino energies and disentangle different nuclear effects
- By precisely measuring ν-N and ν-A cross sections, nuSTORM will allow these experiments to break their *flux × cross section* ambiguity

- First study of neutrino-nucleus cross section measurement at nuSTORM conducted using Transverse Kinematic Imbalance (TKI)

Neutrino-Nucleus Interactions

- Many nuclear effects can impact the initial state interaction and kinematics (e.g. Fermi motion, short-term correlations, etc.)
- Furthermore, outgoing particles can be impacted by final state interactions (FSI)
- All of these impact the kinematic distributions of the final state particles and therefore the disentanglement between energy uncertainties and nuclear effects

→ Need to look at energy independent observables, here: transverse observables (TKI)

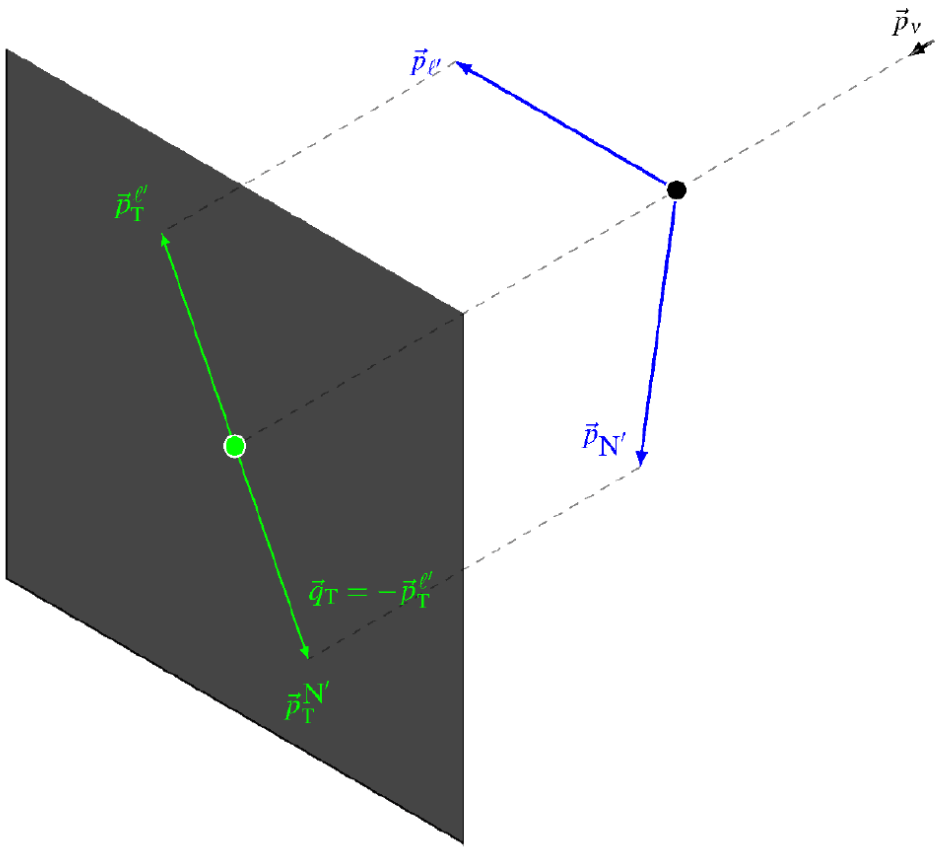


Transverse Kinematic Imbalance

- Transverse Kinematic Imbalance (TKI) introduces set of energy-independent variables quantifying the momentum imbalance in the transverse plane

  → allows study of nuclear effects in both, the initial and final state independent of nucleon model uncertainties (to first order)

Lu *et al.* Phys. Rev. C **94**, 015503 (2016)



static and free nucleon target

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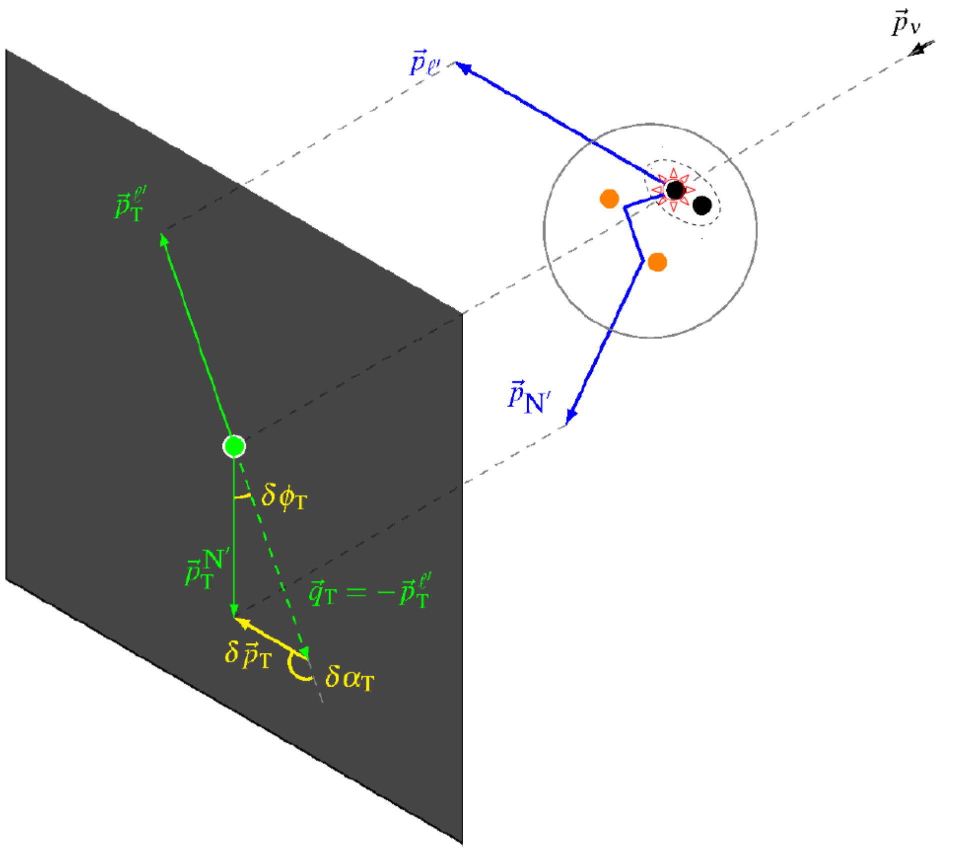
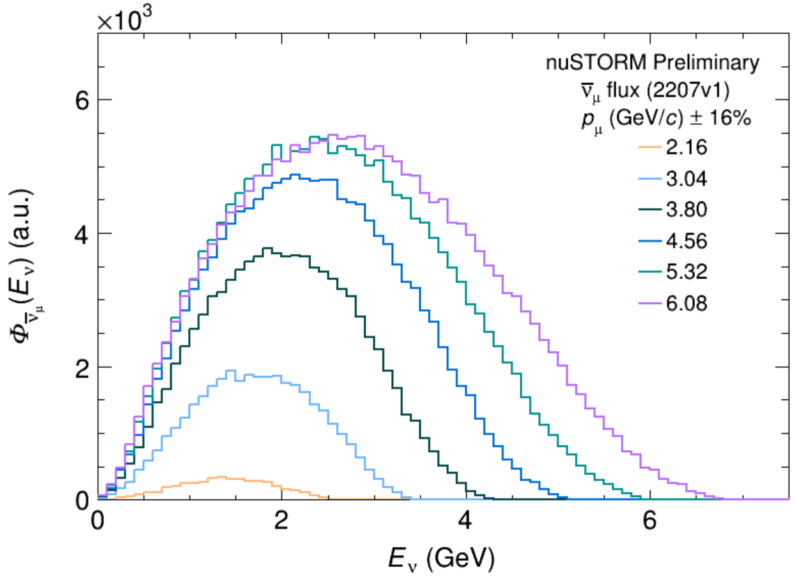


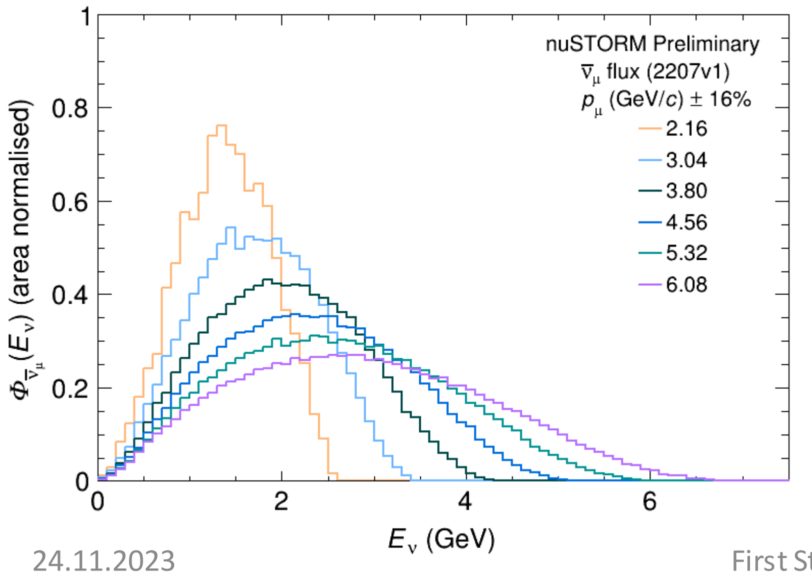
nuclear target w/ A > 1

nuSTORM Fluxes @ Nominal Detector

Total Flux



Area Normalised Flux

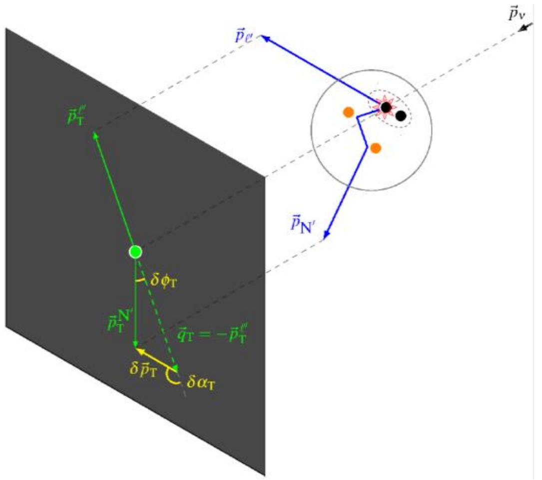


- This study focuses on ν_μ cross sections for different beam momenta using nuSIM version 2207v1

  → new nuSIM version available but flux shapes still identical

- Variation of beam momenta with $p_\mu^0 = 0.76 \times p_\pi^0$:
  - Total flux reduces drastically for lower p_μ^0
  - Integrated flux differs by factor of ~ 50 between $p_\mu^0 = 6.08\ \mathrm{GeV}/c$ and $p_\mu^0 = 2.16\ \mathrm{GeV}/c$
    → Longer run times for lower beam momentum settings or other counteractive measures needed
  - Flux shapes become narrower towards lower p_μ^0 and mean of spectra decrease

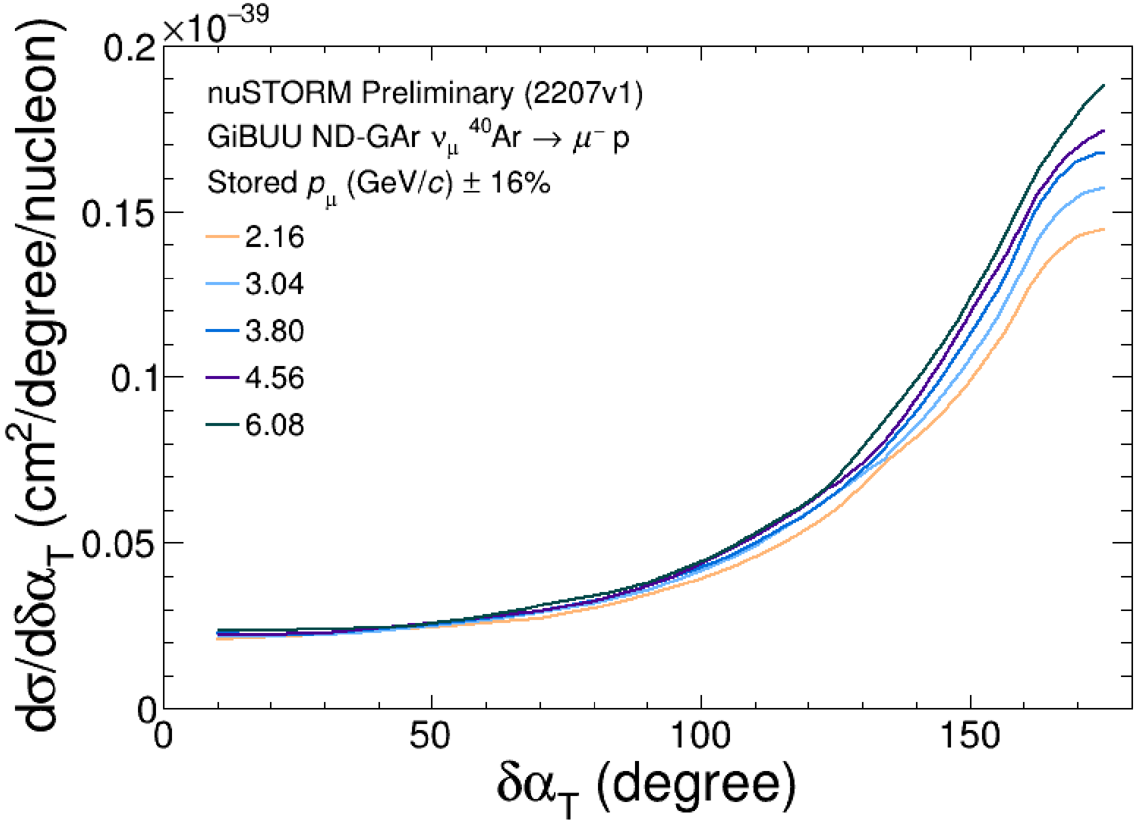
First nuSTORM Cross Section Study



Transverse boosting angle

Lu *et al.* Phys. Rev. C **94**, 015503 (2016)

Flux-averaged CC differential cross section



Assumptions:

- nuSTORM flux
- CCQE reactions
- Target nucleus: Ar
- High-pressure gaseous argon detector acceptance (e.g. DUNE ND-GAr)

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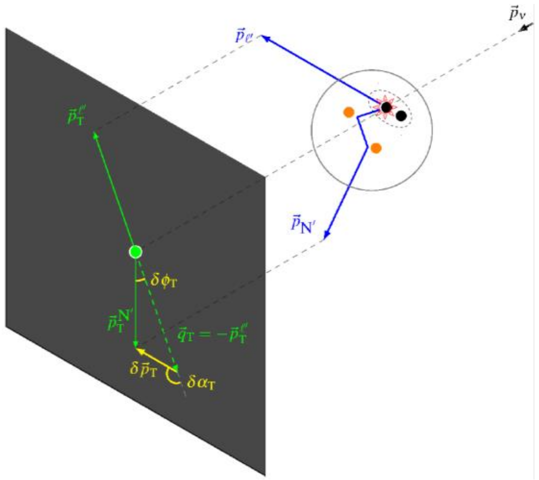

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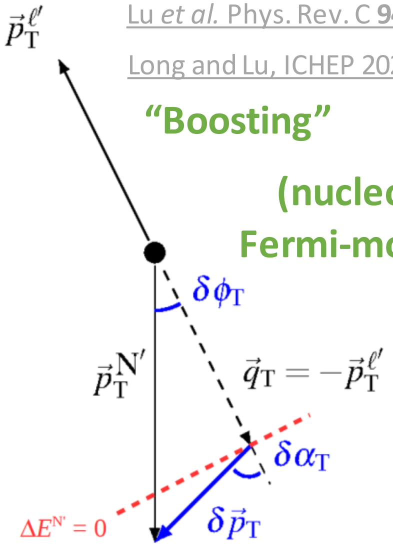
Long and Lu, ICHEP 2022



"Boosting"

(nucleonic + Fermi-motion)

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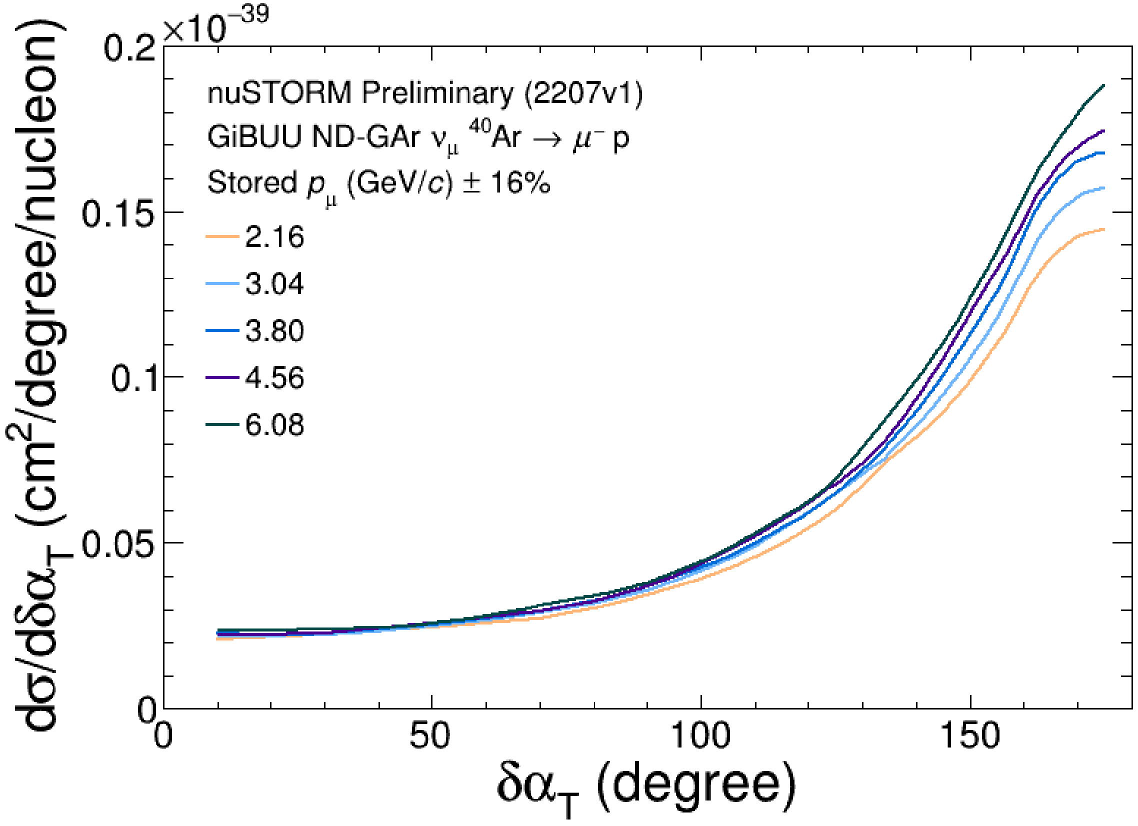

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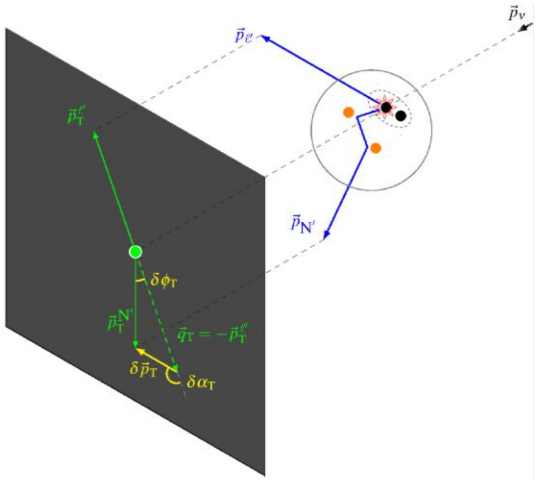

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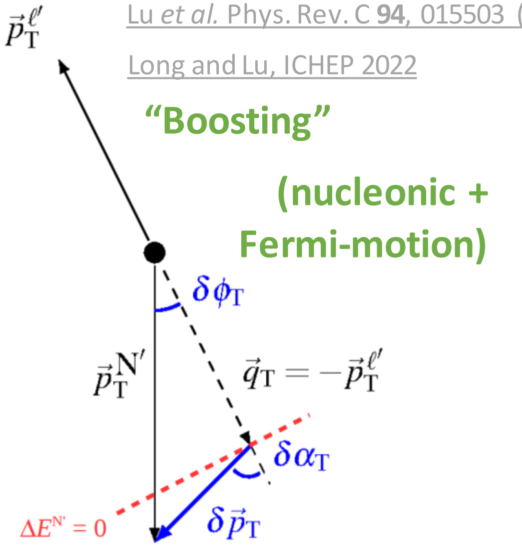

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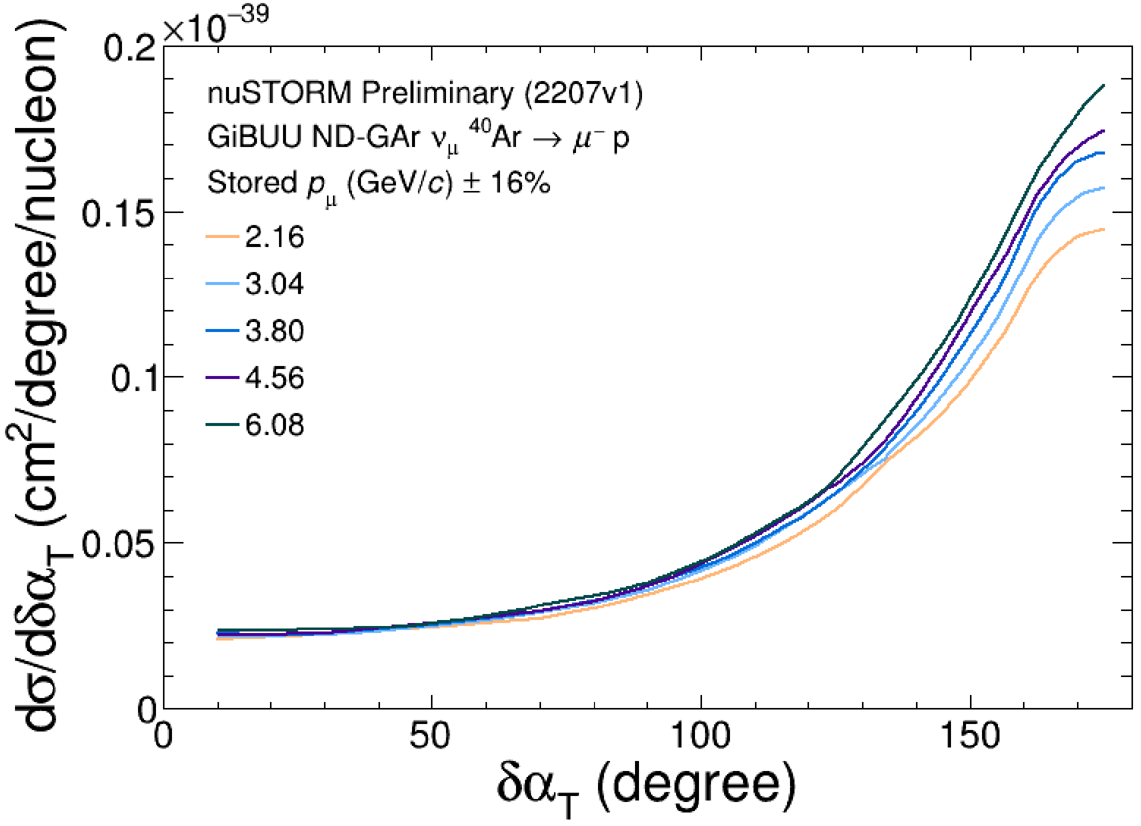

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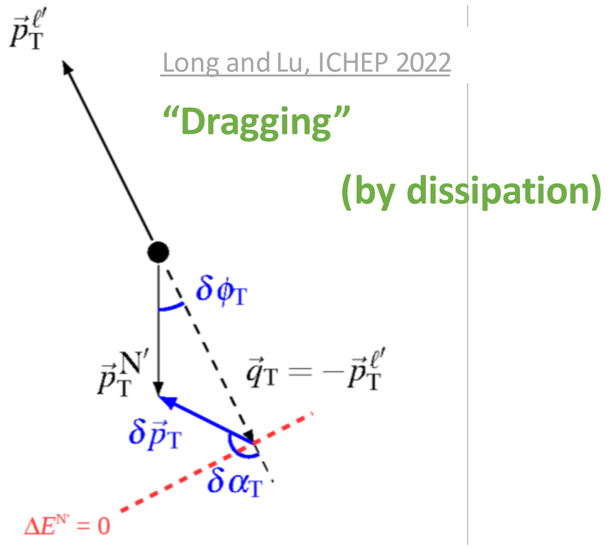

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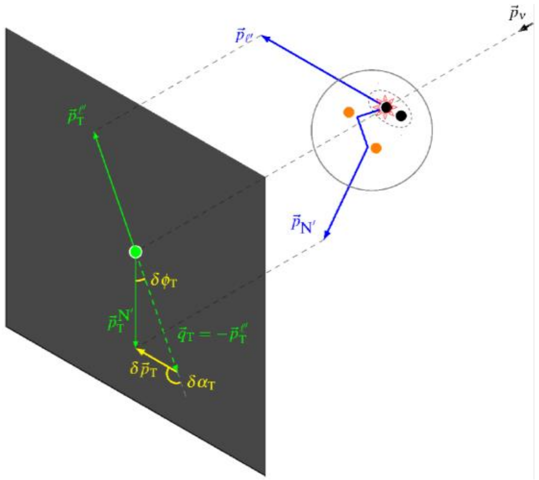

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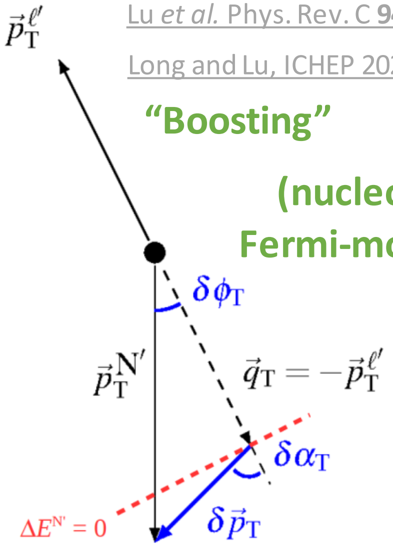

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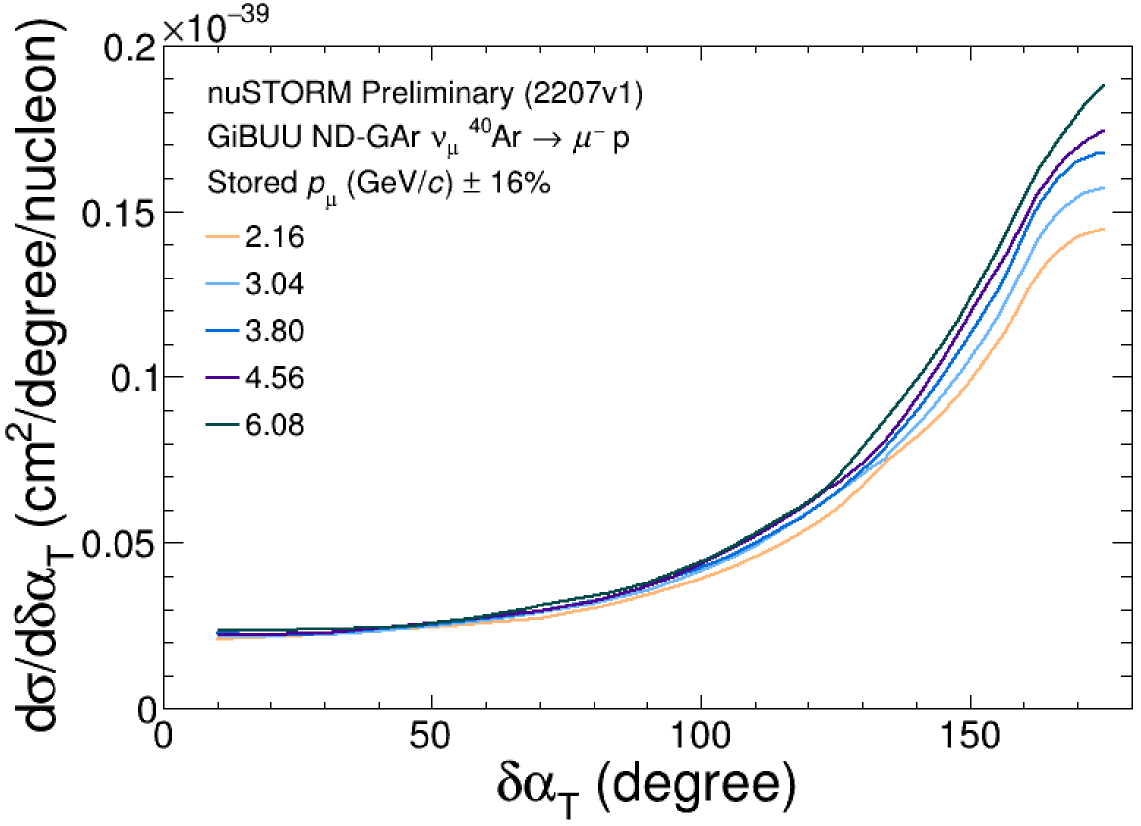

- Low $\delta\alpha_T$ region → flux calibration
- High $\delta\alpha_T$ region → constraints for nuclear models

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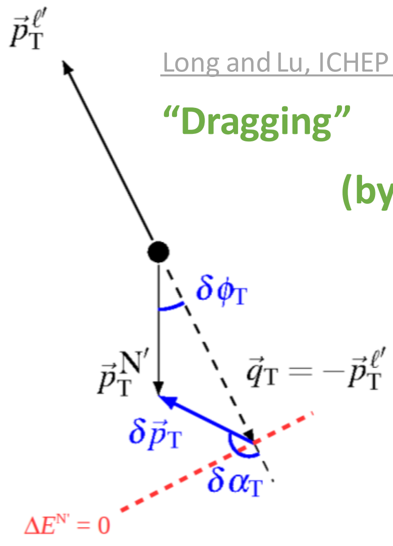

"Dragging"

(by dissipation)

Summary & Conclusion

- The *nuSTORM facility* will use a *novel approach to create neutrino beams* purely from muon decay allowing *lower systematic uncertainties*
- Poor understanding of nuclear structure and effects remains to date and future long-baseline accelerator neutrino experiments are reliant on good knowledge of these in order to maximise their physics potential and avoid biases

  → dedicated cross section measurements needed
- nuSTORM's unique characteristics are especially suited for precision ν-A and ν-N cross section measurements
- First nuSTORM cross section study conducted using nuSIM 2207v1 and TKI:
  - Studied for ν_μ and different beam momenta
  - indicated value of having unique feature of "tunable" beam

→ nuSTORM will be a unique tool to further our understanding of nuclear structure and effects and help next-generation long-baseline experiments to break *flux × cross section* ambiguity and reach their full physics potential