BROOKHAVEN NATIONAL LABORATORY

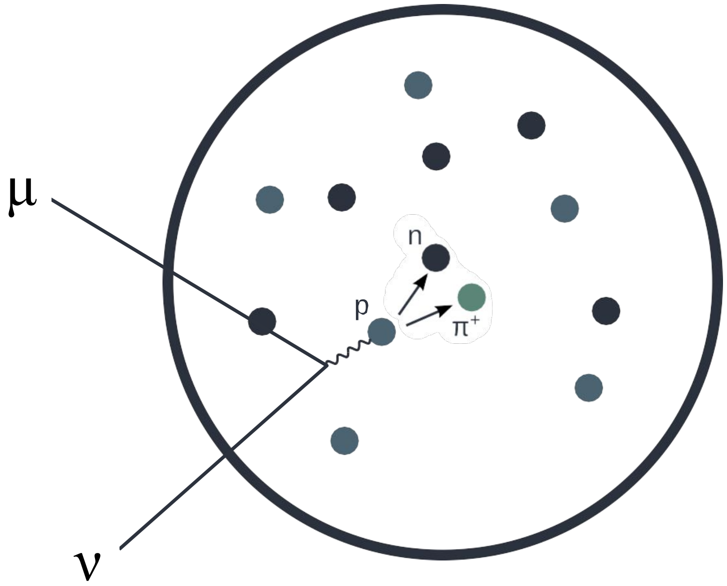
Neutrino Interaction Physics & the DUNE Near Detector

Mateus F. Carneiro on behalf of the DUNE Collaboration

Why is it important to measure Cross Sections?

Knowledge of **neutrino-nucleus scattering cross sections** is crucial to the global neutrino physics program

We may understand neutrino-nuclei interactions but we still have a long way to understand the **nuclear effects** that define what we see in our detectors



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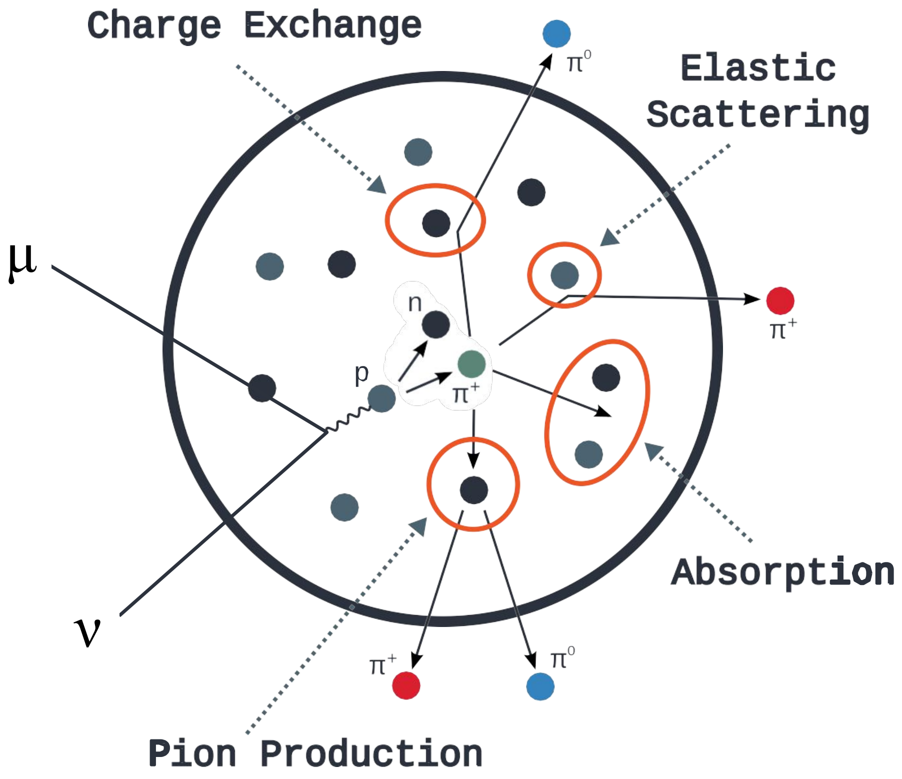
Final State Interactions (FSI) and other **nuclear effects** make different interaction channels have the **same final topology**



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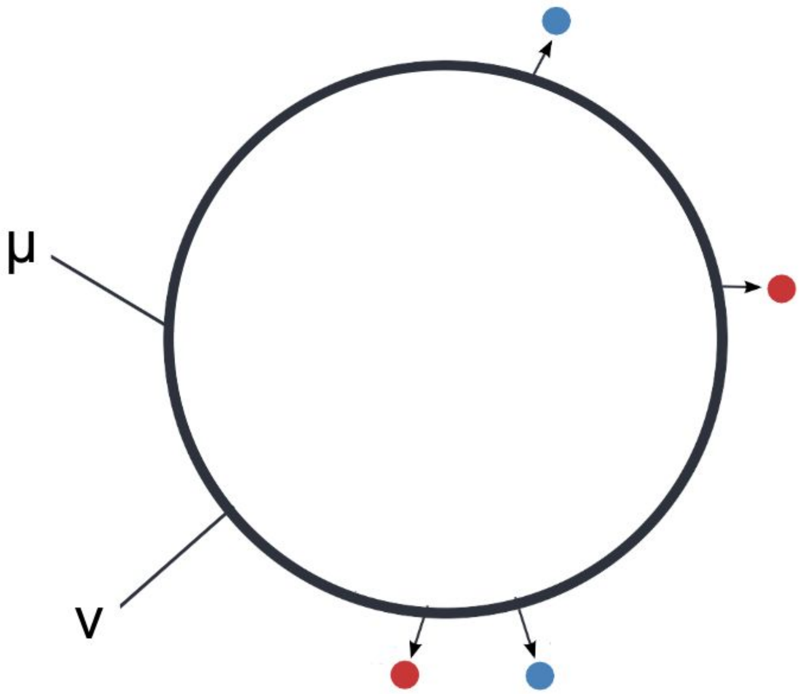
Most detector are made with heavy nuclei



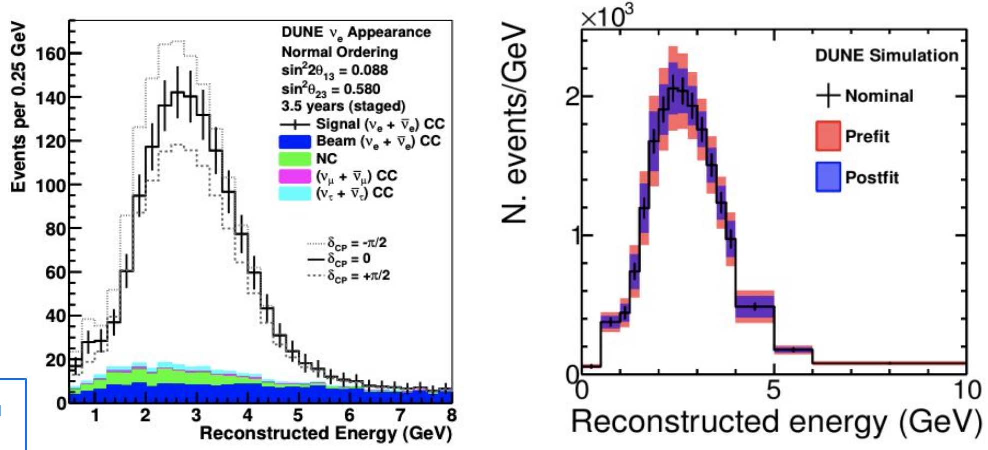
Effects in Neutrino Oscillation Systematics

"After the constraint from the ND is applied, cross section uncertainties currently comprise 30-50% of the systematic budget on the most important oscillation parameter measurements"
Jeremy Wolcott, for the NOvA Collaboration
(NuFACT 2018) arXiv:1812.05653v1

Cross sections and interaction models are **directly used to reconstruct Neutrino energy**, affecting the **event rate** in different stages of the process of measuring oscillation parameters

XSec systematics are often the **largest contribution to the error summary** of neutrino oscillation experiments

The **current level of precision** we have in the ongoing neutrino oscillation program is a **problem for the measurements** we plan to do

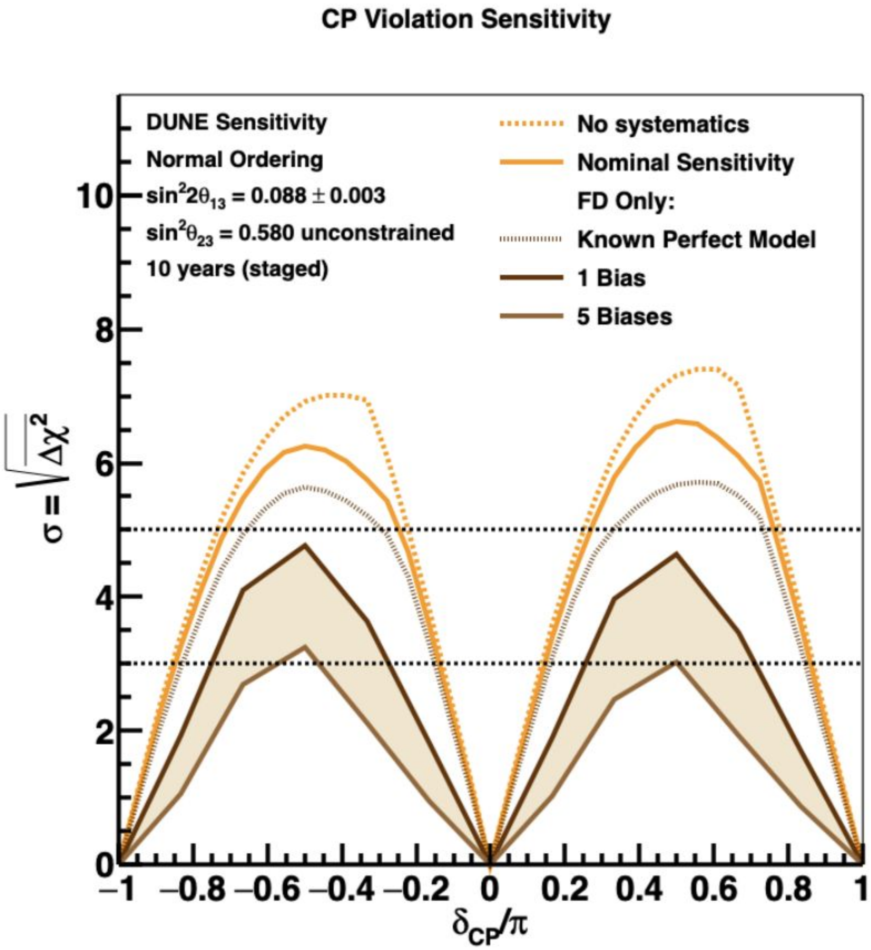


DEEP UNDERGROUND NEUTRINO EXPERIMENT

Effect on CP Violation Sensitivities

Nuclear models also play a big role in CP Violation Sensitivity

For this **sensitivity we are dependent on the event generator assumptions** of the cross section, but what if those assumptions are wrong?



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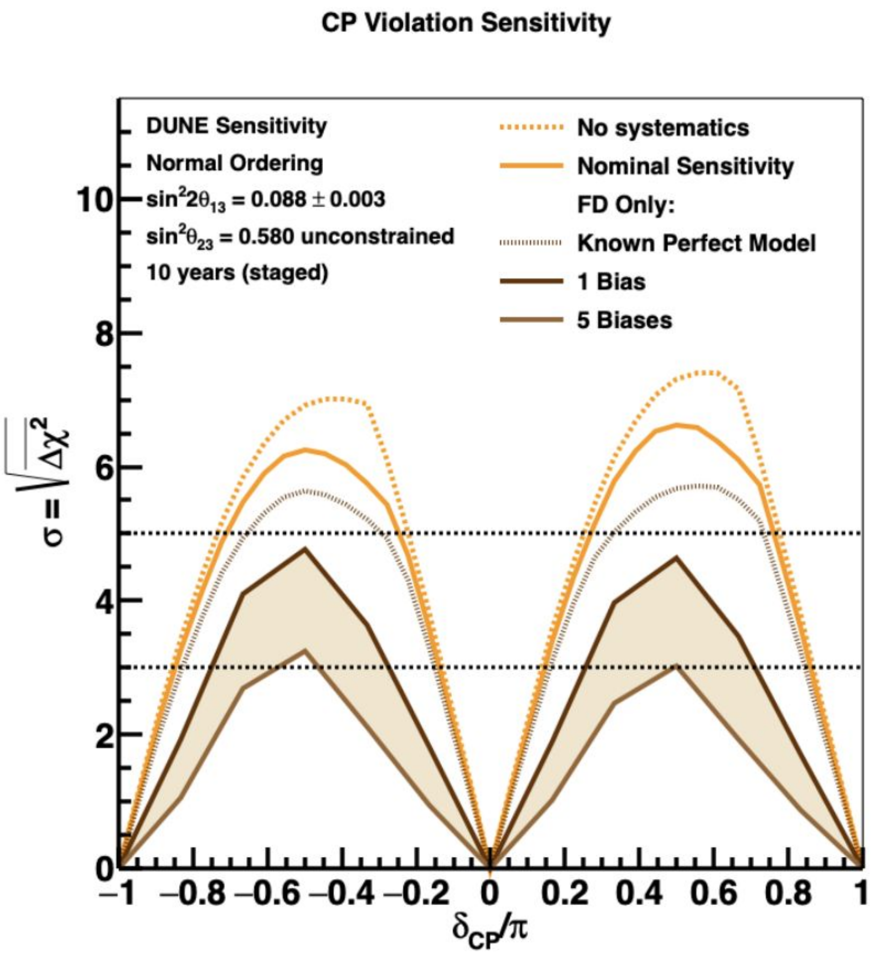
- **Sensitivity using GENIE**



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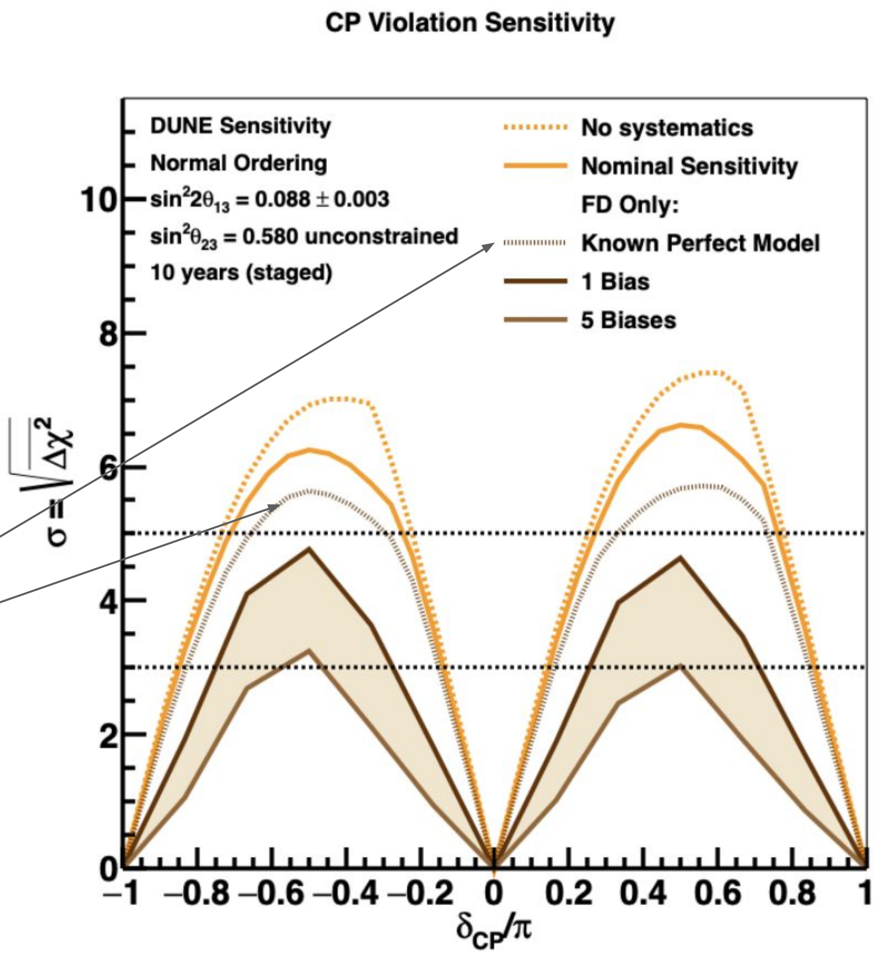

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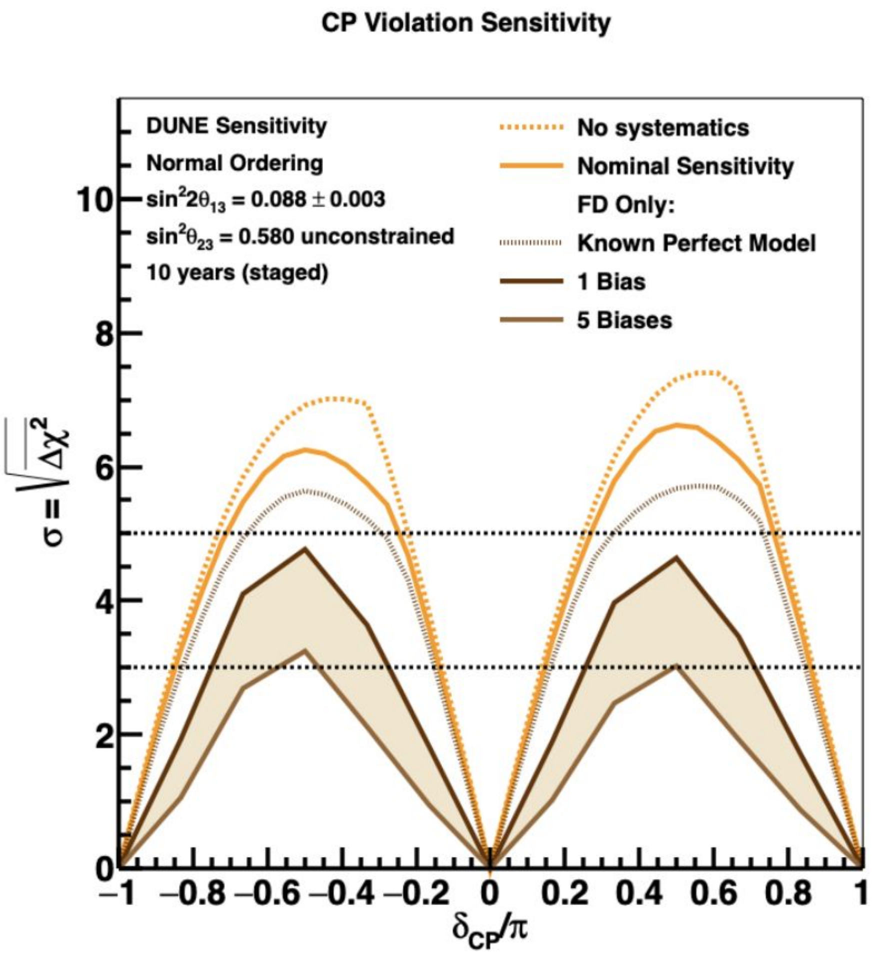
- **Then we use a different (but plausible) model and input it as fake data**



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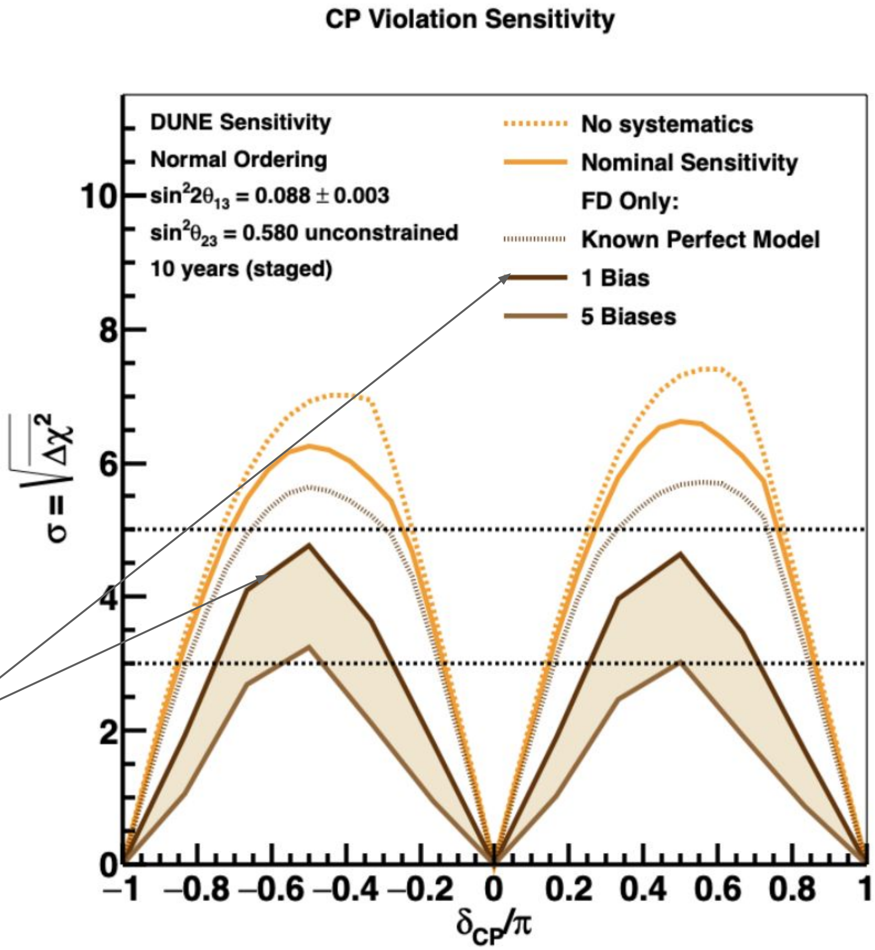

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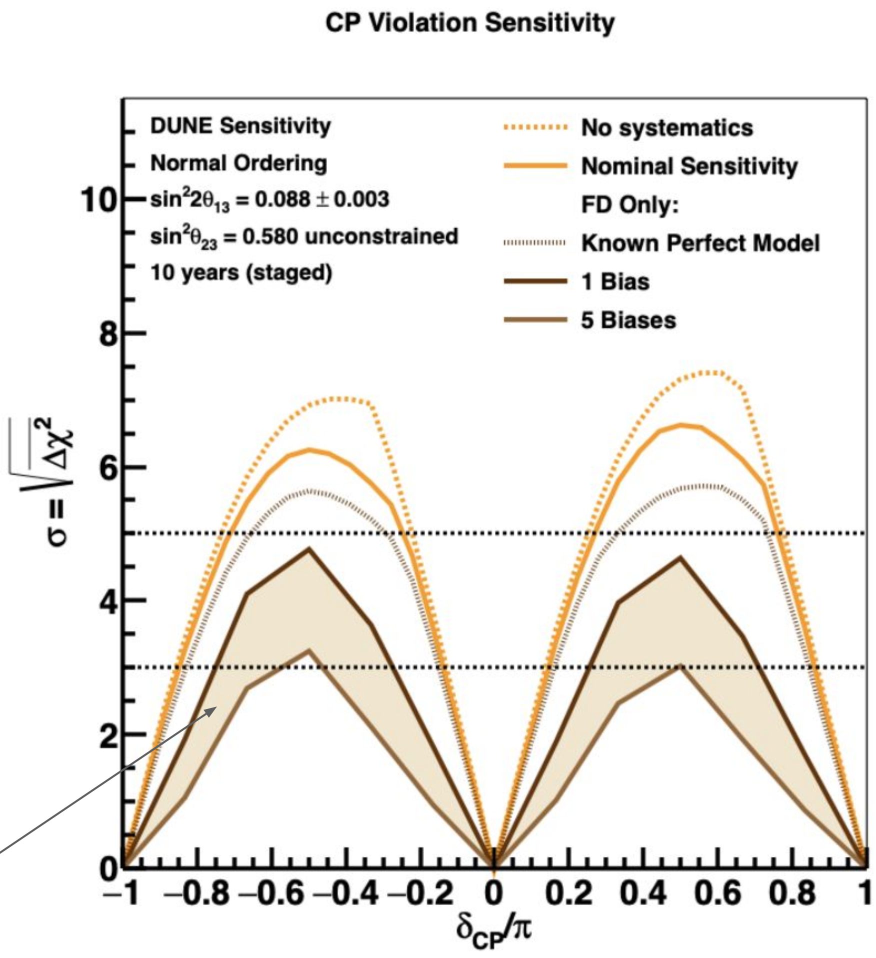
These are not the only possible viable models, more uncertainties due to **model bias** will need to be included, **reducing sensitivity even further**



The DUNE ND Complex

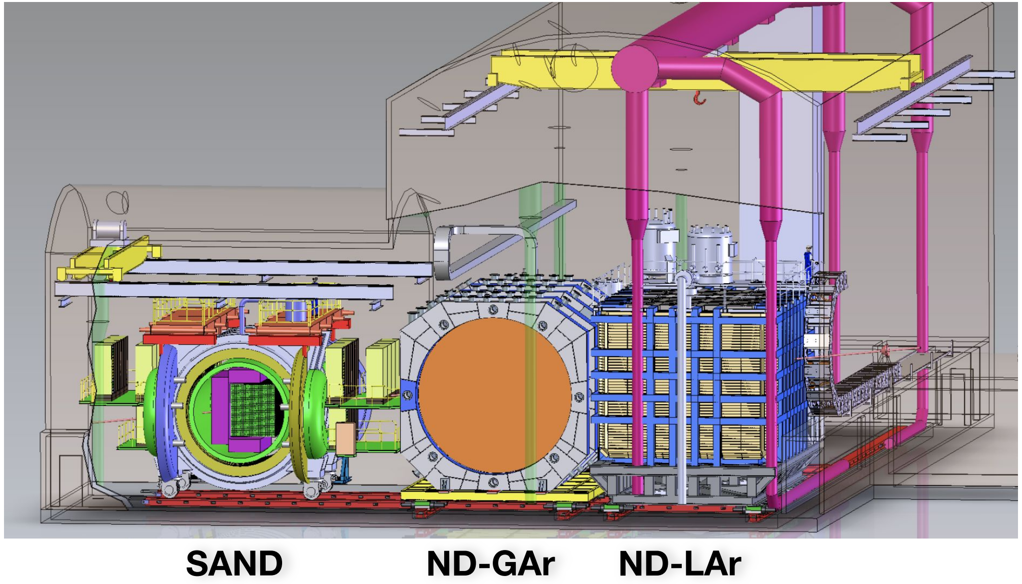
3 subsystems:

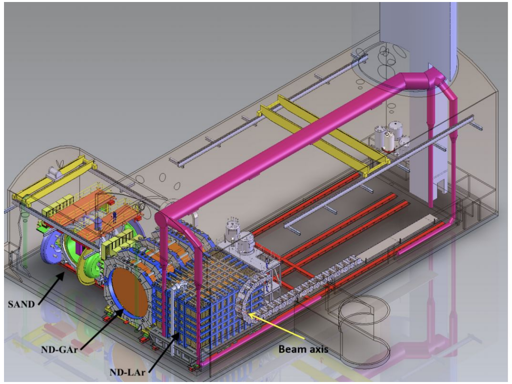
ND-LAr: modular, pixelated LArTPC
Primary target, similar to FD

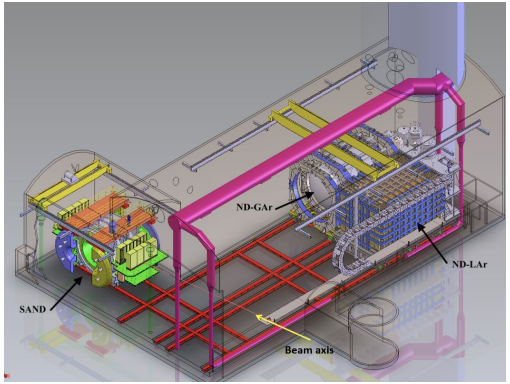
ND-GAr: high-pressure GArTPC surrounded by
ECAL and magnet
muon spectometer
Constraint nuclear interaction model,

SAND: tracker surrounded by ECAL and magnet
On-axis monitor of beam spectrum

ND-LAr/ND-GAr can move off-axis
(**DUNE-PRISM**)







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Status of the DUNE near detector

31 Jul 2020, 11:30
15m
virtual conference

Talk | 13. Detectors for Futur... | Detectors for Future Facil...

Speaker

Patrick Dunne (Imperial college)

Description

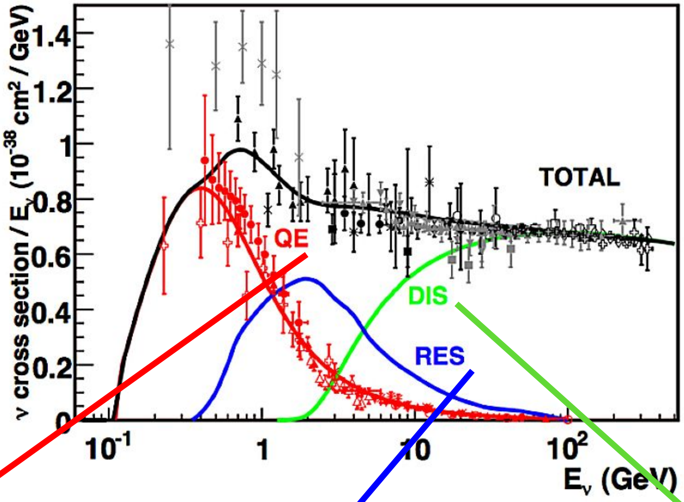
DUNE is a long-baseline neutrino oscillation experiment that will take data in a wideband neutrino beam at Fermilab in the latter half of the 2020s. The experiment is planning to build a very capable near detector to facilitate the high precision extraction of oscillation parameters. Part of the mission of the near detector is to acquire powerful data sets that can be used to constrain the fits used in the oscillation analyses and improve the neutrino interaction model. In this talk, the status of the DUNE near detector design is reviewed.

Separating interaction channels by pion multiplicity in ND-GAr

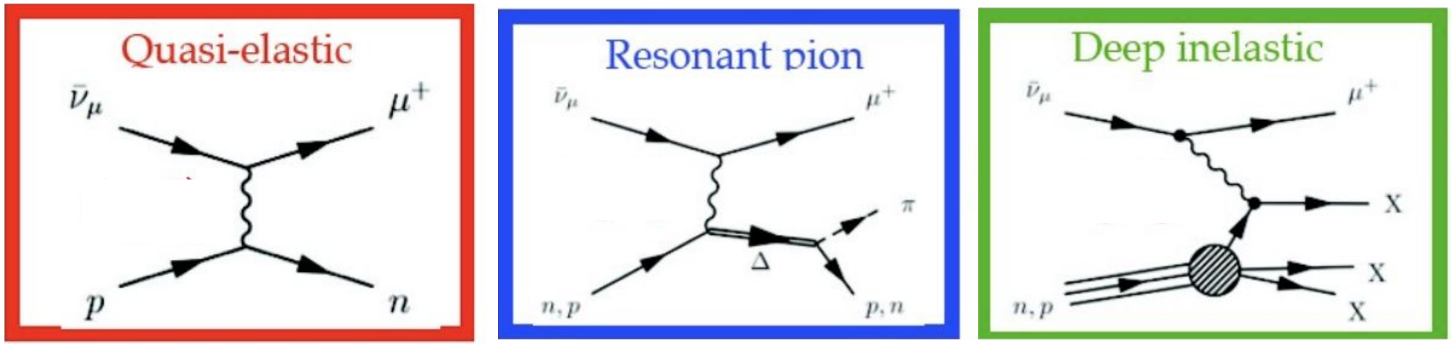
A rich spectrum of interaction types will take place in the near detectors

Simulation show the expected distribution of events in the **ND-GAr by pion multiplicity**

We **can't tell the initial interaction** channels



J.A. Formaggio and G.P. Zeller, Rev. Mod. Phys. 84 (2012)



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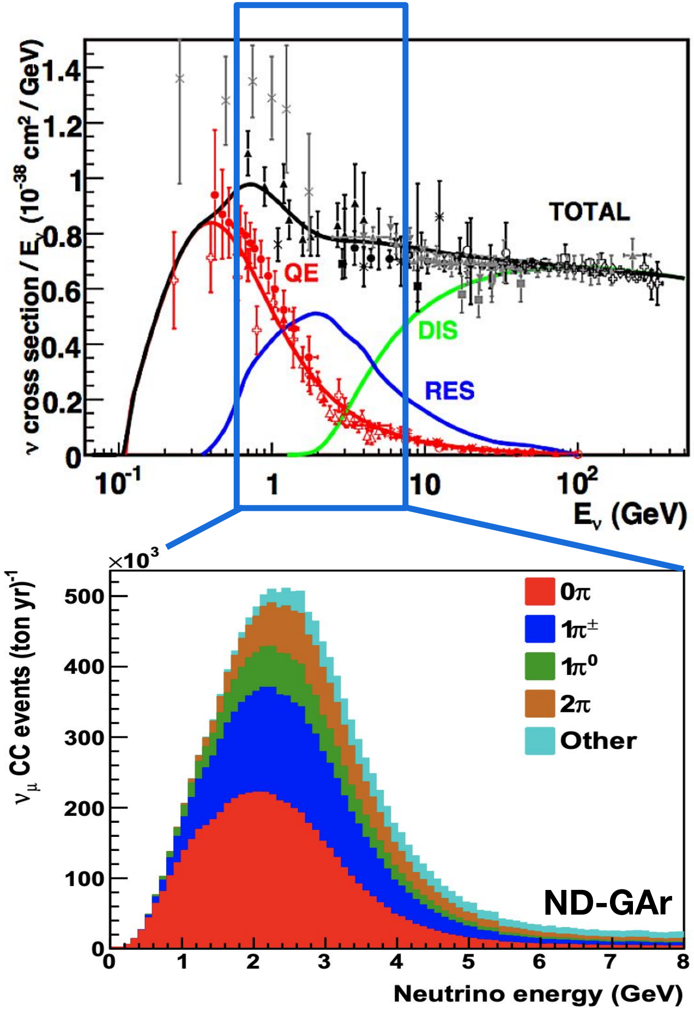

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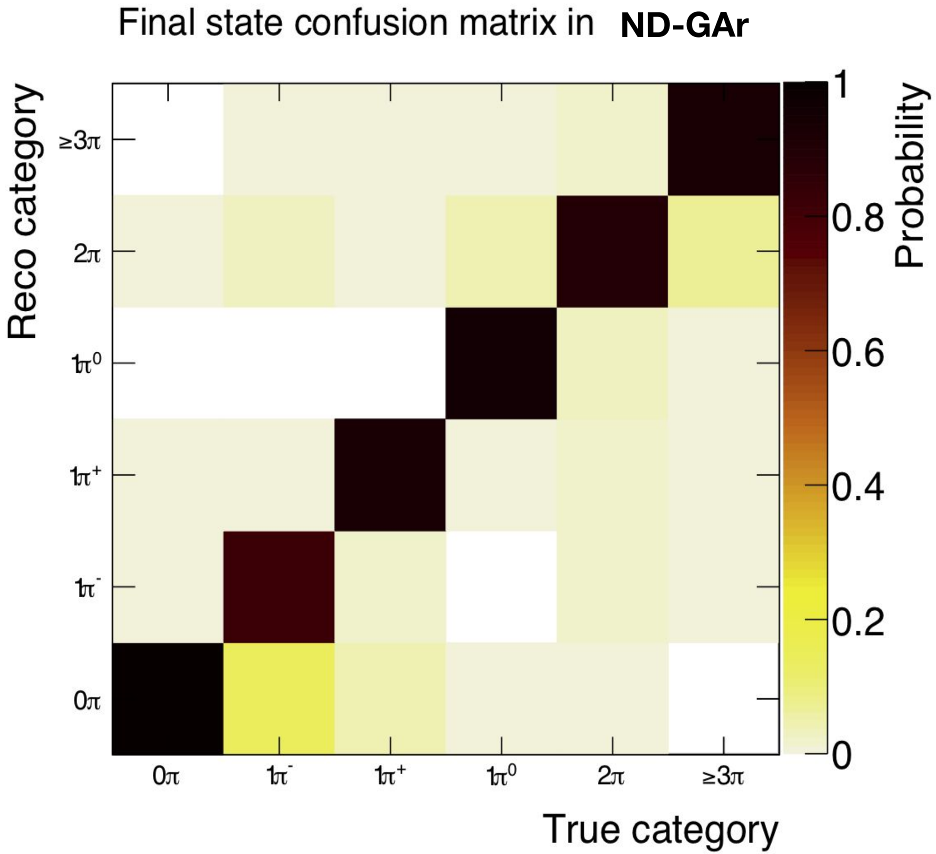


Separating interaction channels by pion multiplicity in ND-GAr

A rich spectrum of interaction types will take place in the near detectors

Simulation show the expected distribution of events in the **ND-GAr by pion multiplicity**

We **can't tell the initial interaction** channels, but we can **identify the multiplicity** quite well and with **great statistics**

More recent MINERvA **high statistics** sample have 6 x 10^5 events

	Interaction Channel		Event Rate	
			ND-LAr	ND-GAr
CC	ν_μ		8.2×10^7	1.64×10^6
		0π	2.9×10^7	5.8×10^5
		$1\pi^\pm$	2.0×10^7	4.1×10^5
		$1\pi^0$	8.1×10^6	1.6×10^5
		2π	1.1×10^7	2.1×10^5
		3π	4.6×10^6	9.3×10^4
		other	9.2×10^6	1.8×10^5
	$\bar{\nu}_\mu$		3.6×10^6	7.1×10^4
	ν_e		1.45×10^6	2.8×10^4
NC			5.3×10^5	5.5×10^5
$\nu + e$			8.3×10^3	1.7×10^2

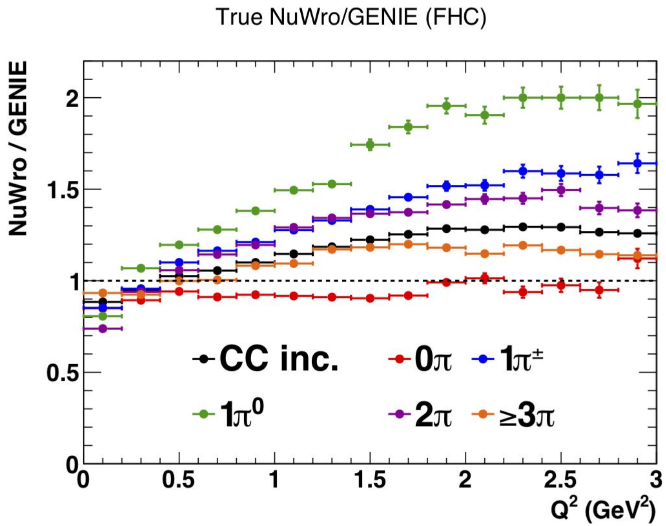
Events per year (1.1×1021 POT)

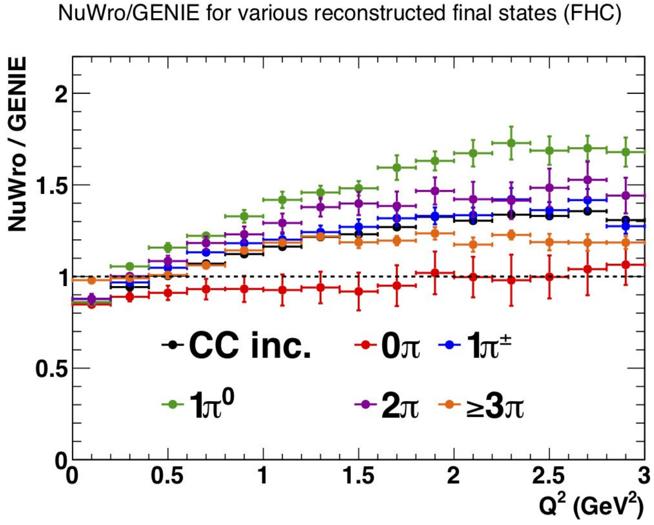
Separating interaction channels by pion multiplicity in ND-GAr

Each **exclusive samples depends** on various parameters that are heavily **dependent on the interaction model** used

Comparing **two different event generators** we can see the spread on predictions resulting from the different viable models

This gives insight to **select, optimize and tune models** using data to **address the bias** and achieve greater **precision**



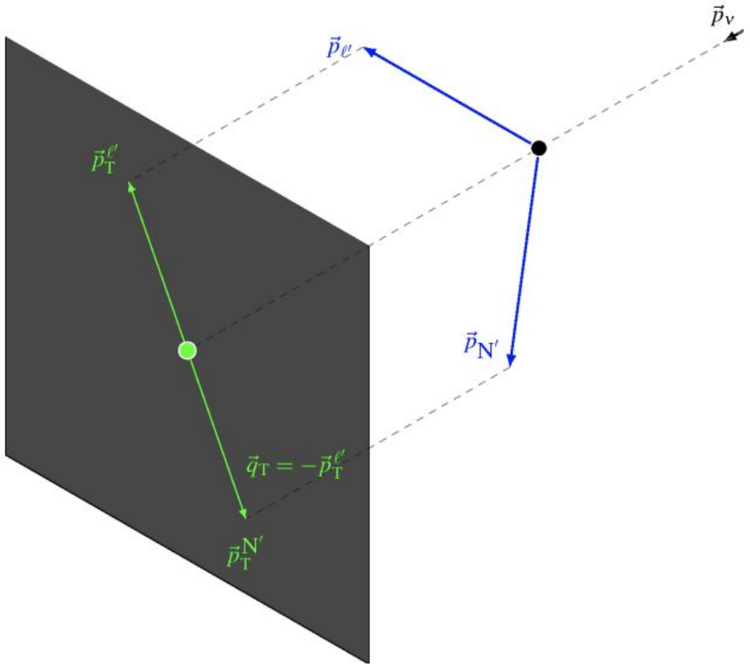


Investigating Nuclear Effects with Transverse Kinematic Imbalance

TKI is a technique that can use the kinematics of the detected particles to study **the motion of initial-state nucleons** in the nucleus and **FSI**

Considering a final state with only a muon and a proton:

- In a neutrino scattering with a **stationary particle** the **TKI would be zero**



Stationary nucleon target

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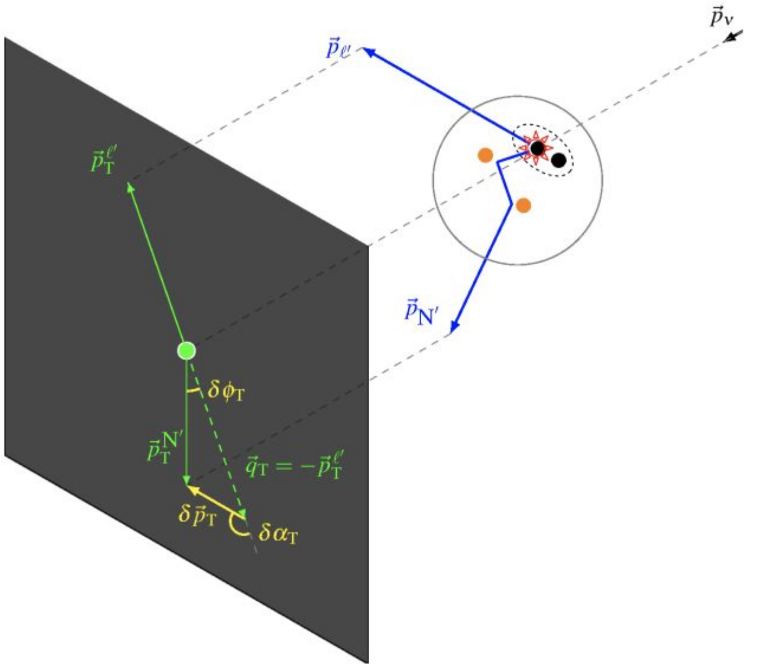
Considering a final state with only a muon and a proton:

- In a neutrino scattering with a **stationary particle** the **TKI would be zero**
- thus the **magnitude of the TKI** indicates the **initial momentum of the neutron**
- and the **direction** of the imbalance let us **measure FSI effects**



Nuclear target (A>1)

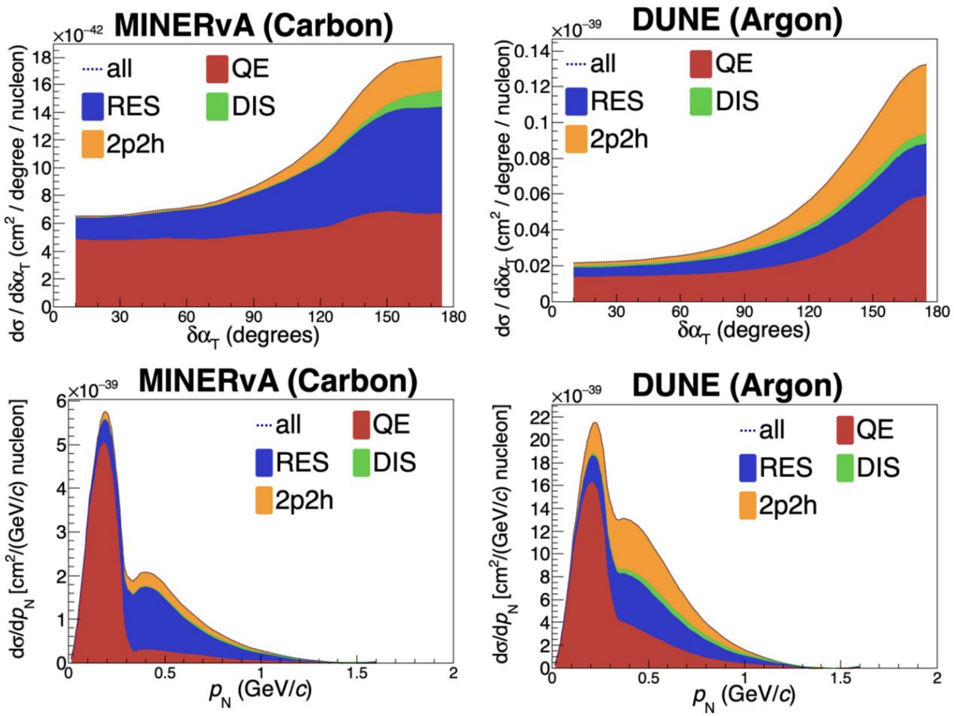
Fermi motion
Final-state interactions
Pion absorption
2p2h
...

Investigating Nuclear Effects with Transverse Kinematic Imbalance

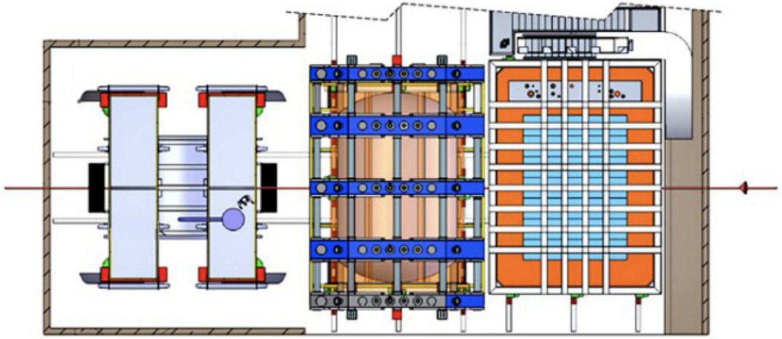
Applications of this technique in **MINERvA and T2K** showed good agreement with current implemented models but **not in the transition region** between Fermi motion and other nuclear effects

DUNE has a significantly **larger phase space**, with a **full angular acceptance**, and a great momentum acceptance

DUNE ND excellent particle identification will allow the use of TKI to investigate these effects in **argon,** shedding light on **A-dependence.**

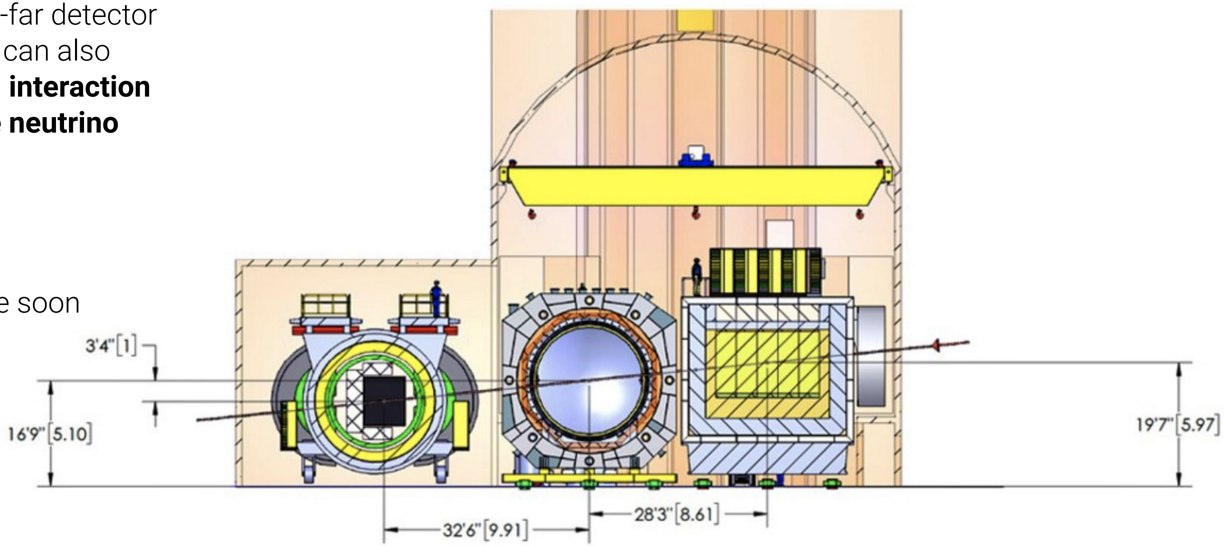


Summary



Knowing neutrino nucleus cross section is necessary for oscillation experiments.

The **DUNE ND** not only provides near-far detector ratios to constrain flux uncertainty, it can also measure cross sections to **constrain interaction models** using **argon** and in the **same neutrino beam** as the FD



DUNE ND CDR will be public available soon with many more details

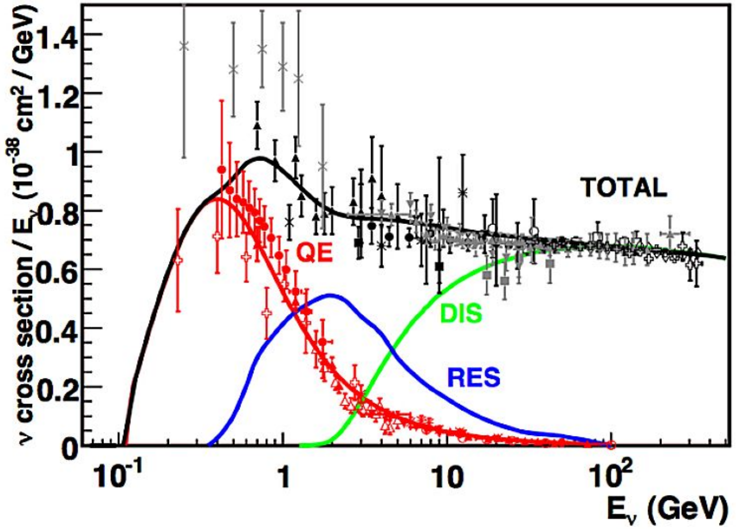
Thank you

Backup

Model validation

Each **generator has a different approach** to almost every interaction channel

Even when considering e**xclusive final topologies**, nuclear effects force us to take **every channel into account**



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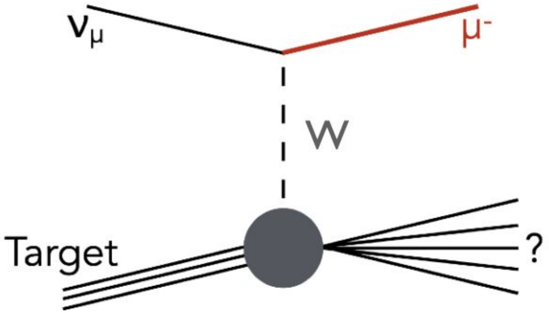
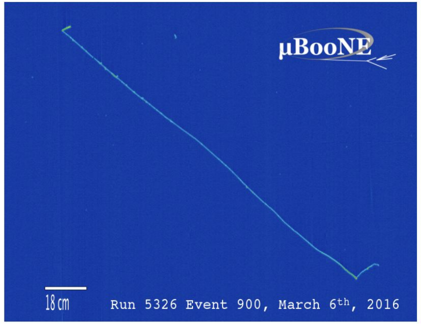


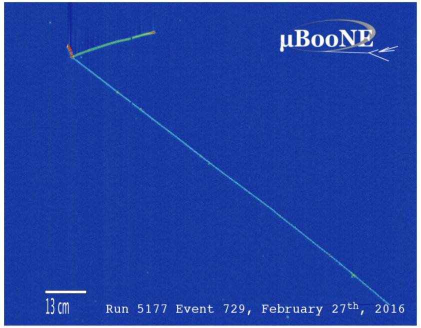
Generator	SBN Experiments	Resonance model	Coherent model	FSI model
NUANCE	MiniBooNE	Rein-Sehgal	Rein-Sehgal KNL-BRS	Cascade
GENIE	MicroBooNE T2K SBN (ND and FD)	Rein-Sehgal KNL-BRS	Rein-Sehgal Bergel-Sehgal	INTRANUKE/hA
NEUT	T2K	Graczyk-Sobczyk	Rein-Sehgal Bergel-Sehgal	Hybrid Oset et al. + exp. Based tune
NuWro	T2K MicroBooNE	Home-grown	Rein-Sehgal Bergel-Sehgal	Cascade

Particle Identification

$CC0\pi$



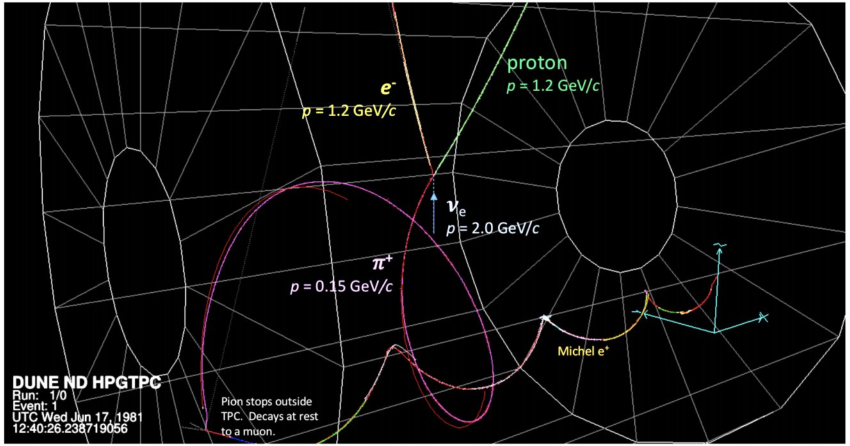
$CC1\pi^{\pm}$



Liquid argon TPCs like the **LAr-ND** are sensitive to different final-state hadron topologies and are excellent calorimeters.

While the magnetized **GAr-ND** can identify the muons that reach the detector and also use it's lower density for a even lower energy threshold

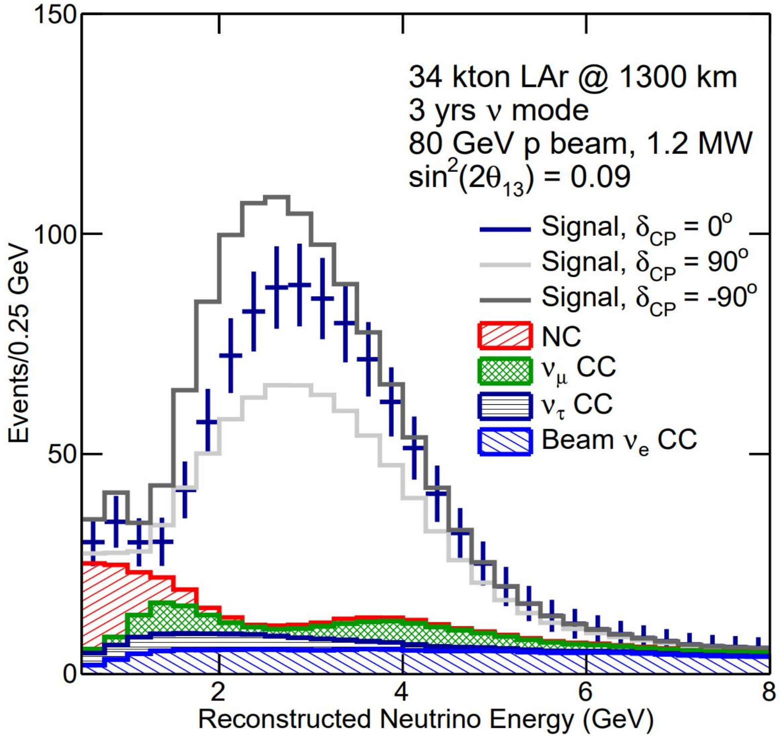
SAND have a great capacity to identify neutrons which can be very useful for the program



How do we find osc parameters?

1. reconstruct topology and energy in the Near Detector
2. use a **nuclear model** to infer the neutrino interaction energy
3. use geometry differences (and oscillation hypothesis) to predict FD flux
4. use the **nuclear model** and the estimated flux to reconstruct topology and energy in the Far Detector
5. compare mc and data and test your hypothesis

LBNE Collaboration
arXiv:1307.7335



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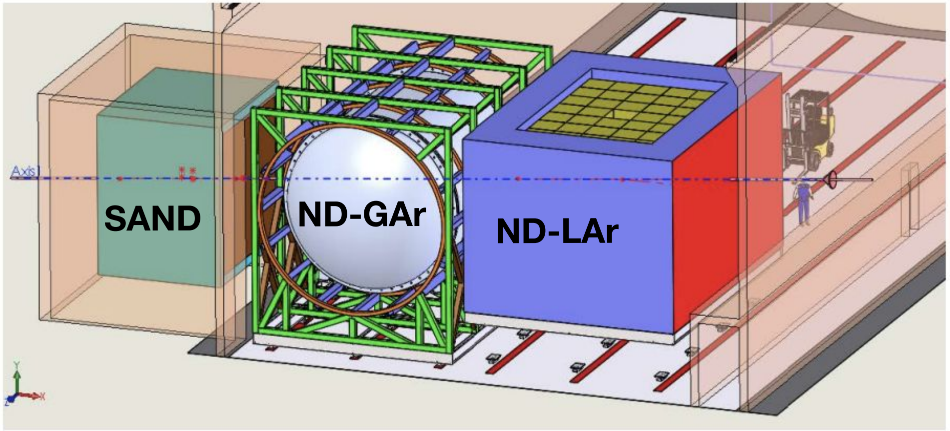

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