Deciphering the quantum behaviour of neutrinos with DUNE - PRISM

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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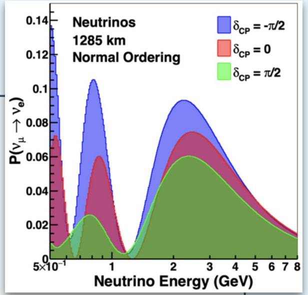
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia
LIP

Cristóvão Vilela
on behalf of the **DUNE Collaboration**

DEEP UNDERGROUND NEUTRINO EXPERIMENT



Long-baseline physics goals

- Determine the neutrino mass ordering.
- Search for ~~CP~~ and measure δ_{CP}.
- Determine the octant of θ_{23}.
- Test the 3-flavour model.

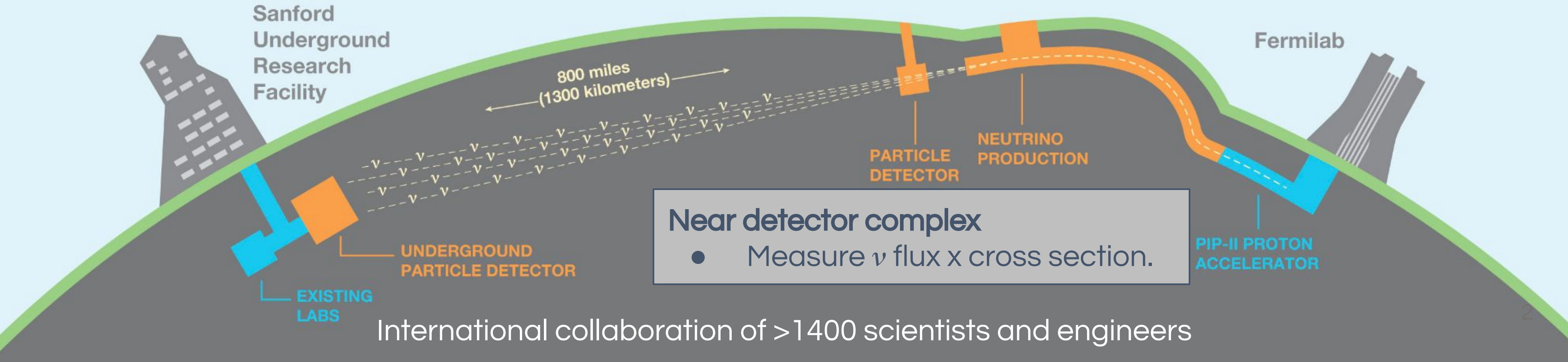
\+ **Astrophysics** : core-collapse supernovae; solar neutrinos.
\+ **BSM**: dark matter searches; nucleon decay; heavy neutral leptons, ...

Far detector

- Modular with 40 kton fiducial mass.
- Two LArTPC technologies:
  - Horizontal drift with wire readout.
  - Vertical drift with PCB readout.

LBNF beamline

- 2 MW wideband neutrino beam
- High flux between oscillation maximum and minimum.
- Coverage of the second maximum.

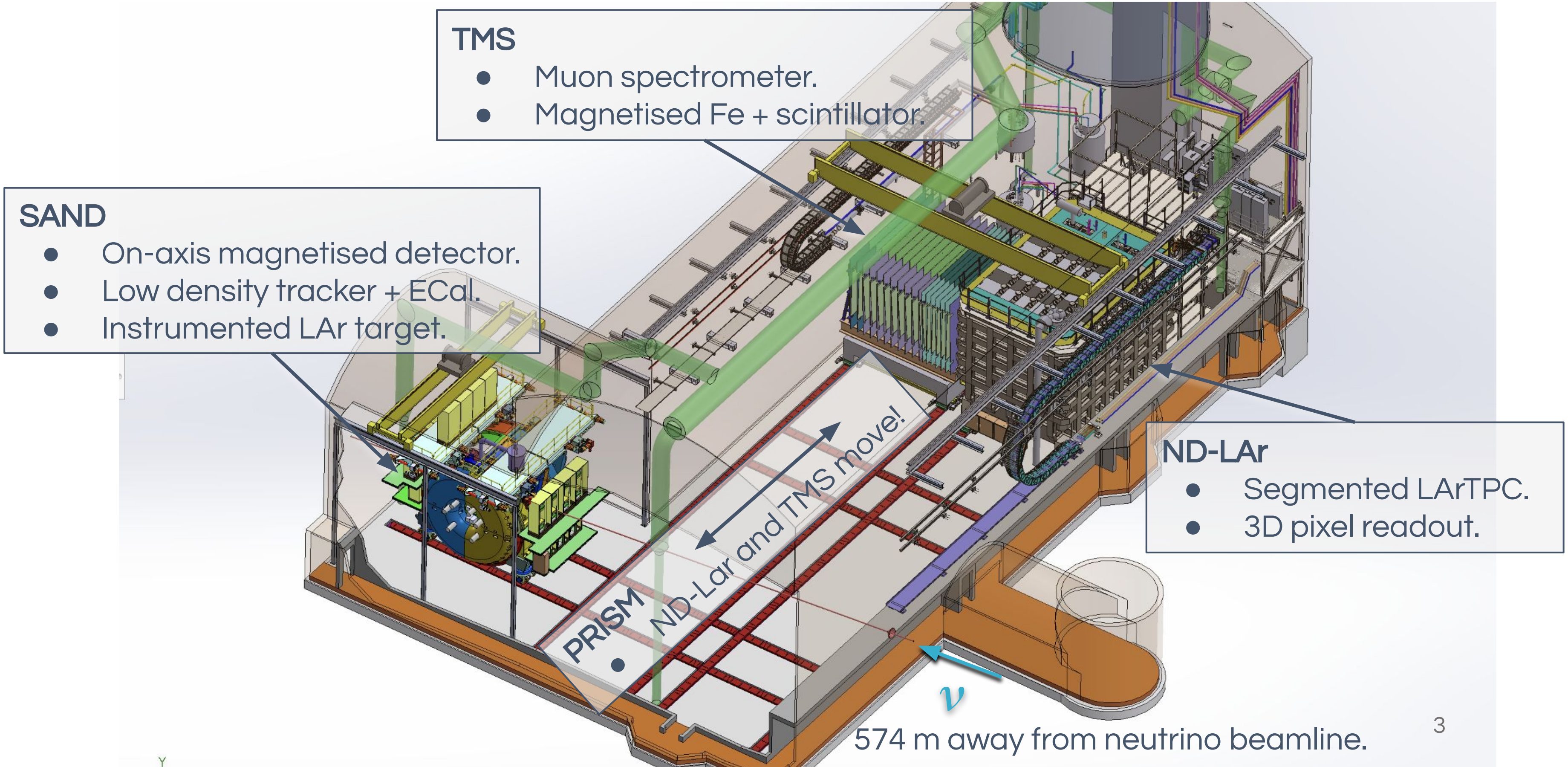


Near detector complex

- Measure ν flux x cross section.

International collaboration of >1400 scientists and engineers

The DUNE near detector complex



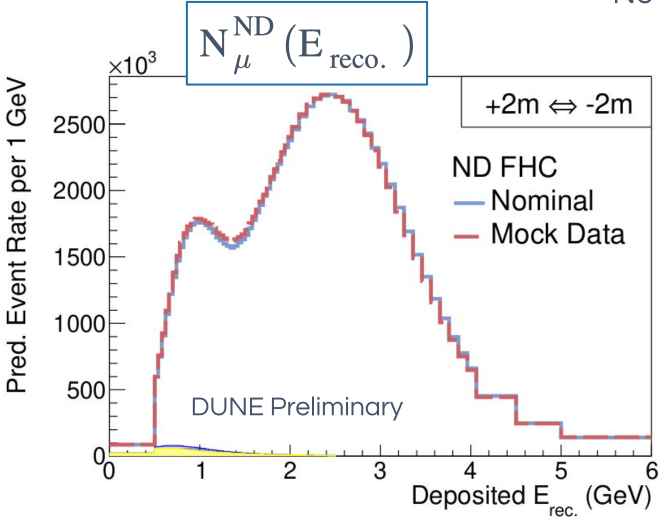
Understanding **bias** in ν oscillation experiments

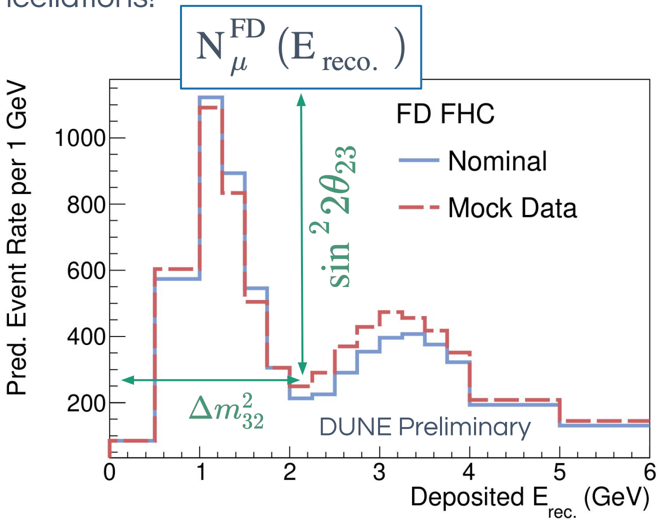
What we observe

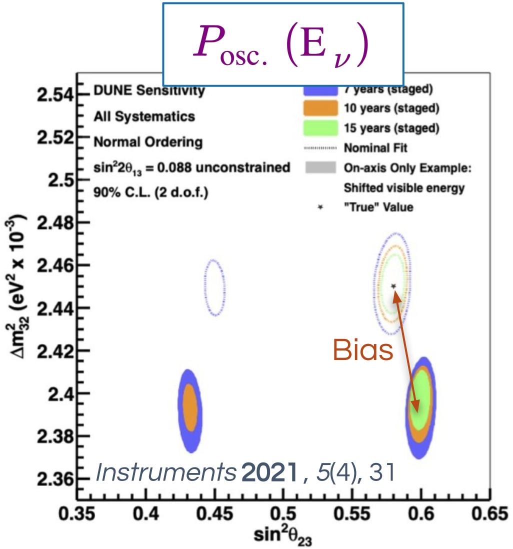
$$\frac{N^{FD}_{e,\mu}(E_{reco.})}{N^{ND}_{\mu}(E_{reco.})} = \frac{\int dE_\nu \, R^{FD}(E_\nu, E_{reco.})\, \phi_{\nu_\mu}(E_\nu)\, \sigma_{\nu_{e,\mu}}(E_\nu)\, P_{osc.}(E_\nu)}{\int dE_\nu \, R^{ND}(E_\nu, E_{reco.})\, \phi_{\nu_\mu}(E_\nu)\, \sigma_{\nu_\mu}(E_\nu)}$$

What we want to know

No cancellations!

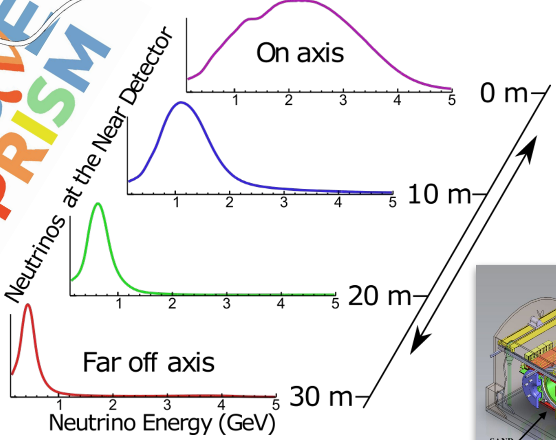


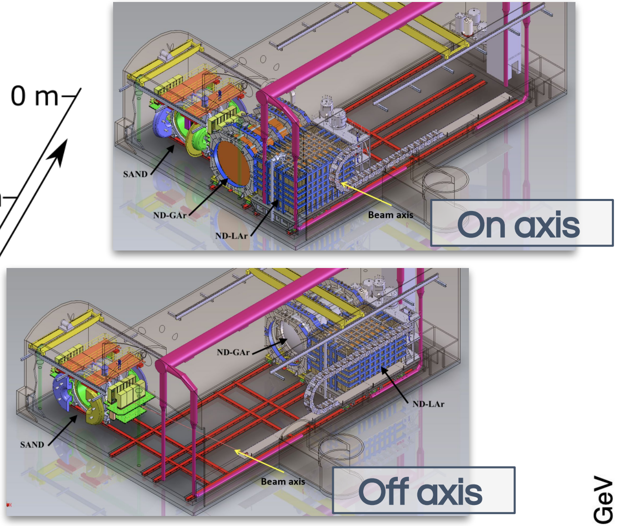


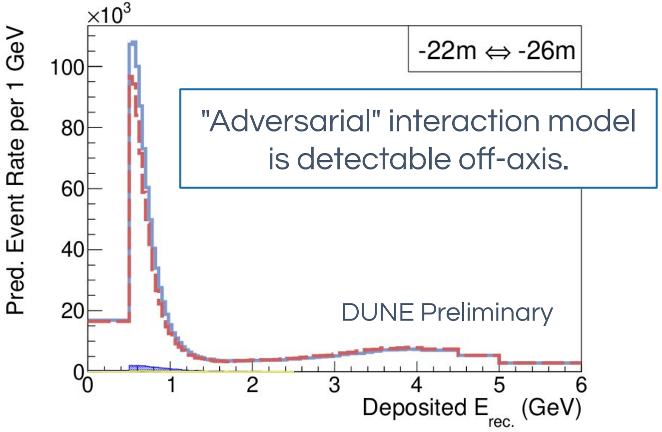


- Use machine learning to generate **mock data** with "adversarial" interaction model, where **20% of the protons'** energy is instead carried by **unseen** neutrons.
- Mis-modeling is **invisible** in **on-axis** near detector.
- Produces **biased** oscillation measurements when far detector mock data is fitted with nominal model.

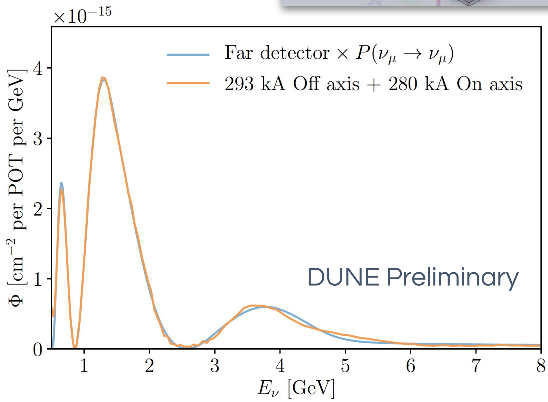
Precision Reaction- Independent Spectrum Measurement



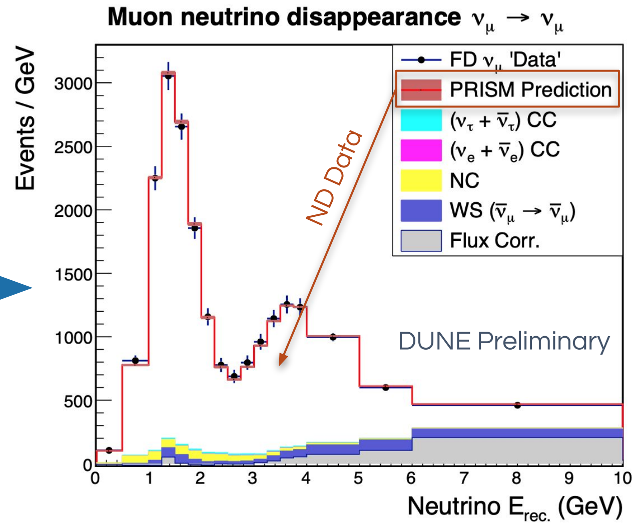




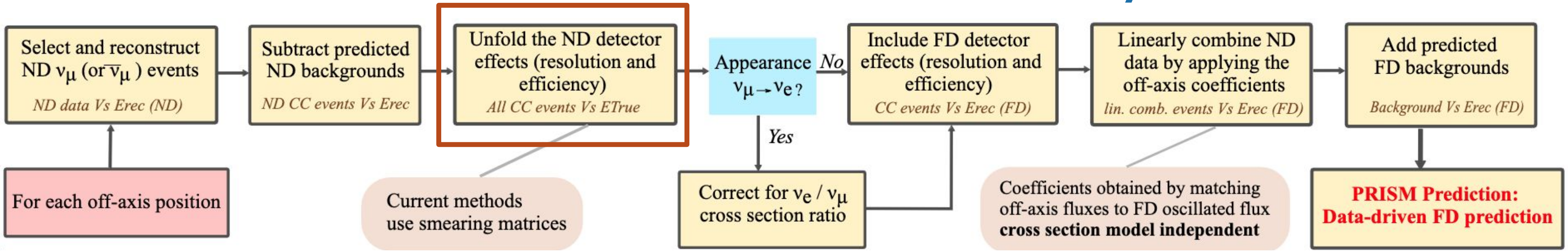
Combine DUNE-PRISM **fluxes**

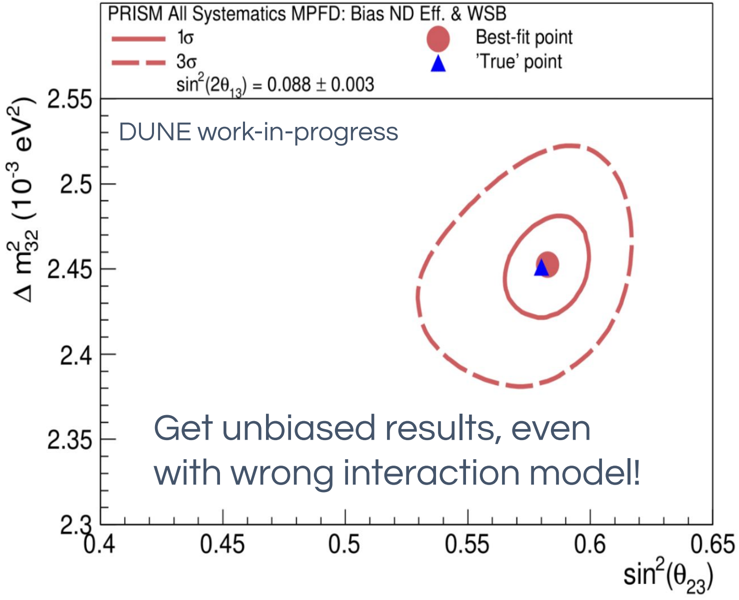


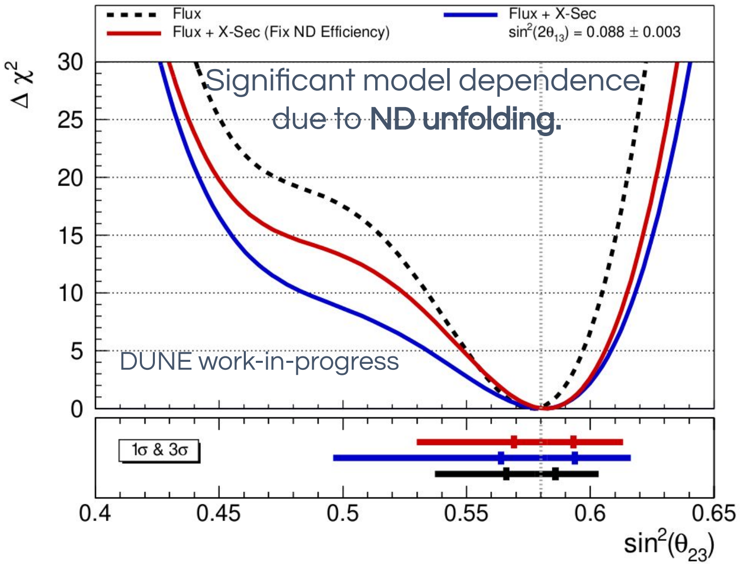
Combine DUNE-PRISM **data**



Data-driven oscillation analysis





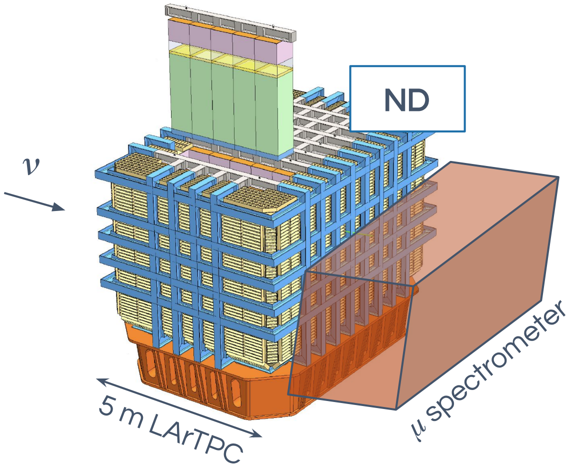


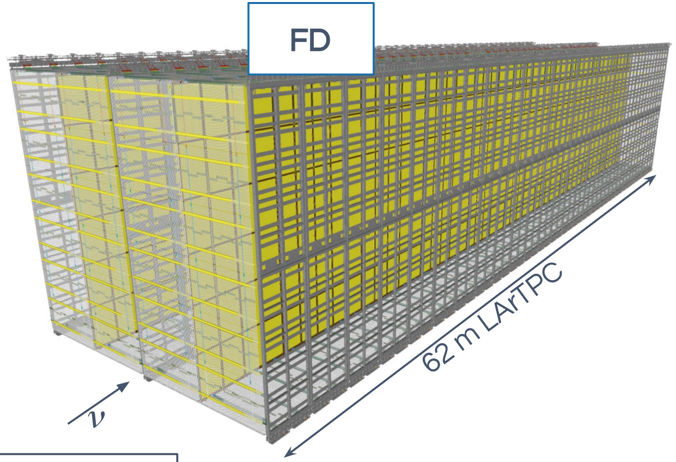
Detector response: near and far

67 ton LArTPC with 3D **pixel** read-out, **segmentation,** and downstream **muon spectrometer**

$R^{ND}(E_\nu, E_{reco.}) \neq R^{FD}(E_\nu, E_{reco.})$

10 kton LArTPC with 3 x 2D **wire/PCB strip** read-out and very large drift volumes





Muon energy measurement
- ND: by **range** (< 1 GeV) or **curvature** (> 1 GeV).
- FD: by **range**.

Hadron containment
- ND: covers the phase-space but **limited event-by-event**.
- FD: **good containment** event-by-event.

Charge read-out
- ND: pixels, some dead-space between modules.
- FD: wires, very little dead-space.

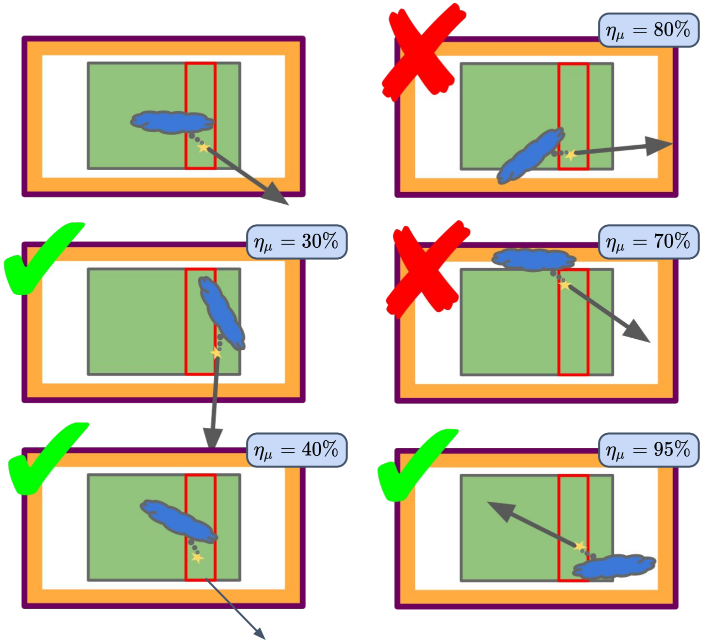
Data-driven ND efficiency

Hadron containment

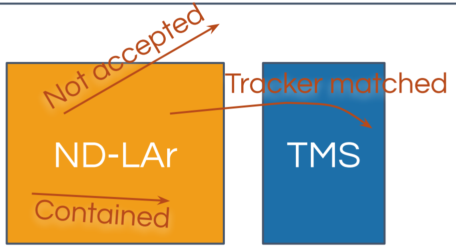
- Randomly rotate the event around the beam direction and translate within a slice of *x*.
- Count how often the event would fail the hadron containment criterion.

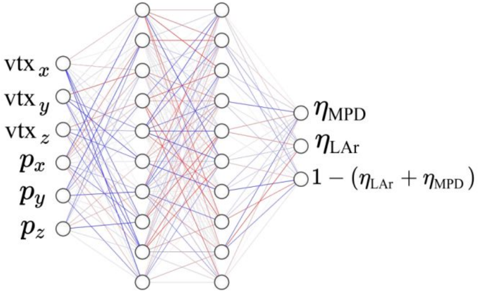
Muon acceptance

- Train a neural network to predict the probability of the muon being accepted, given the muon position and momentum.
- Use the neural network to calculate the muon acceptance probability for each random throw.

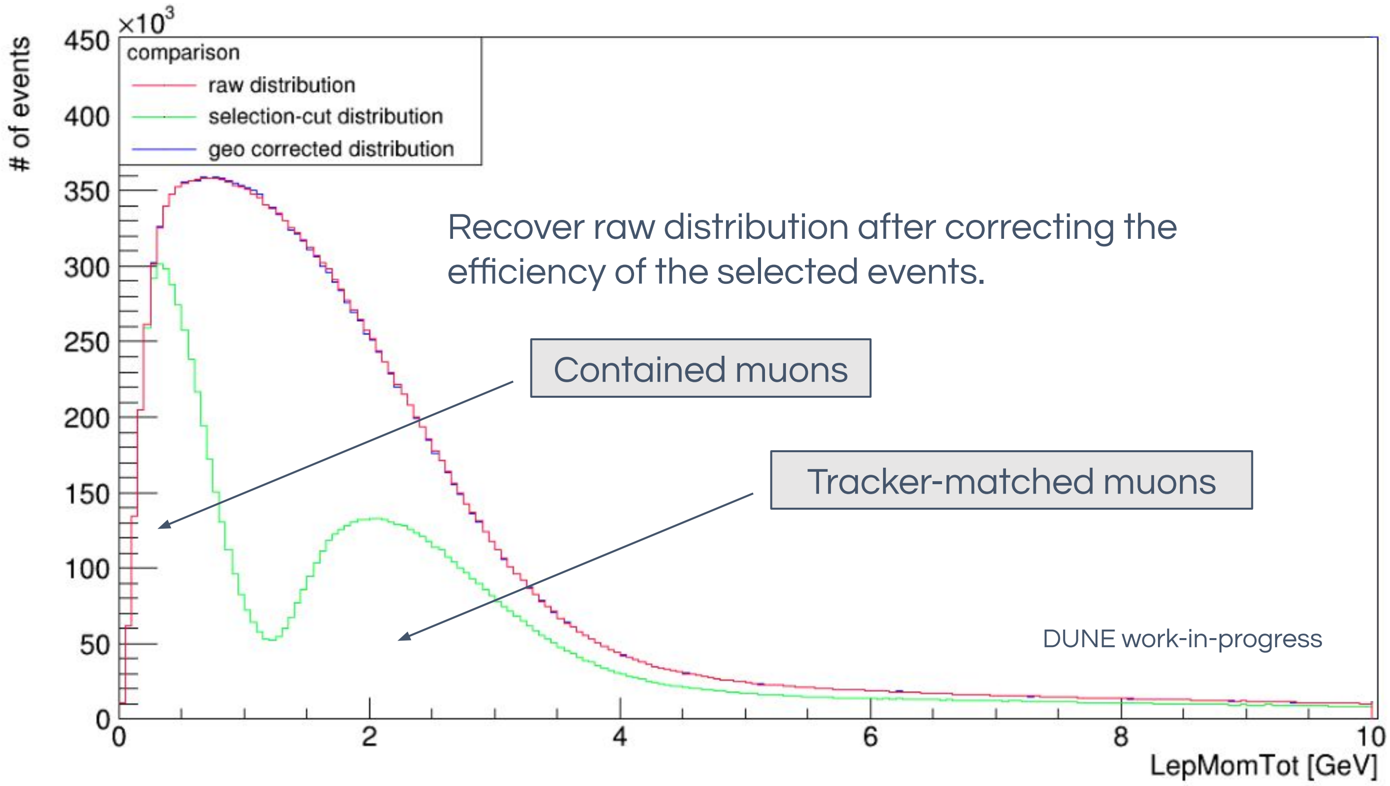


$$\eta = \frac{0\times0.8+1\times0.3+0\times0.70+1\times0.4+1\times0.95}{5} = 33\%$$

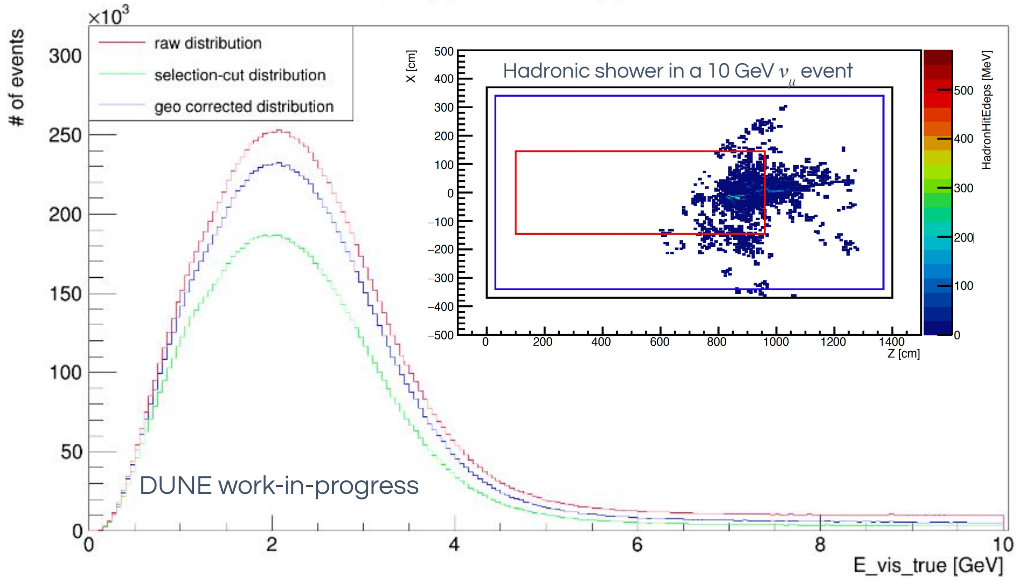


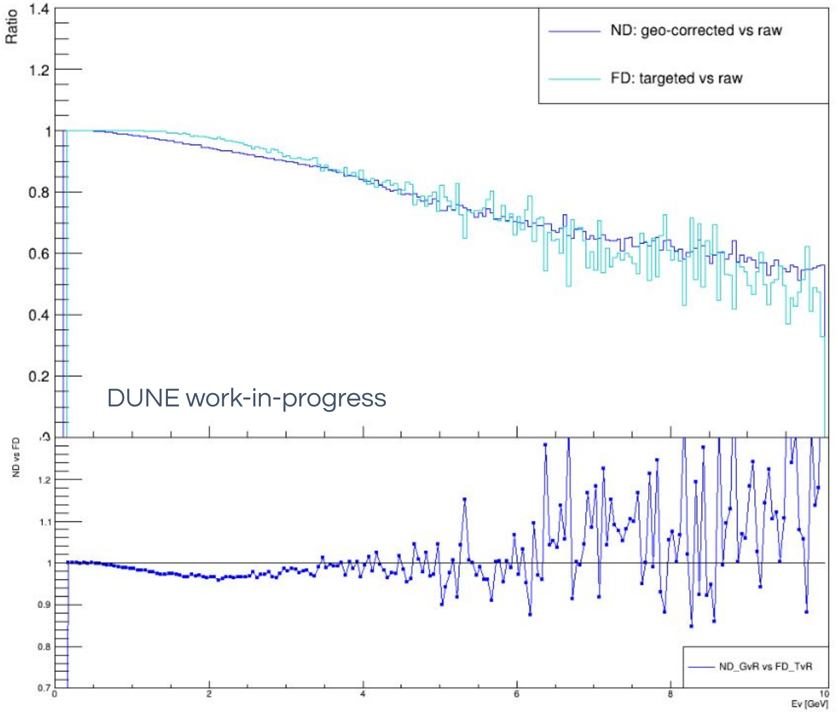


Data-driven muon efficiency correction



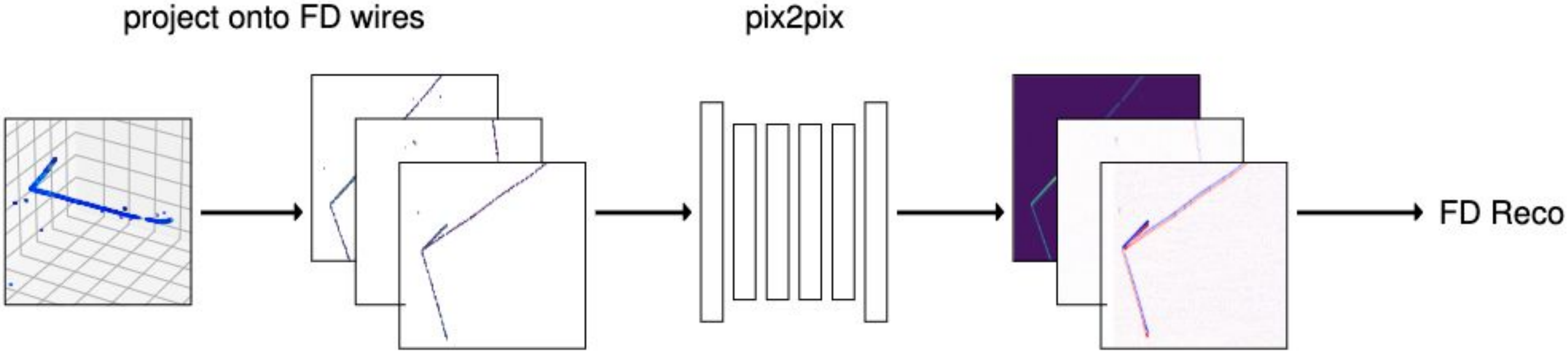
Data-driven hadron efficiency correction

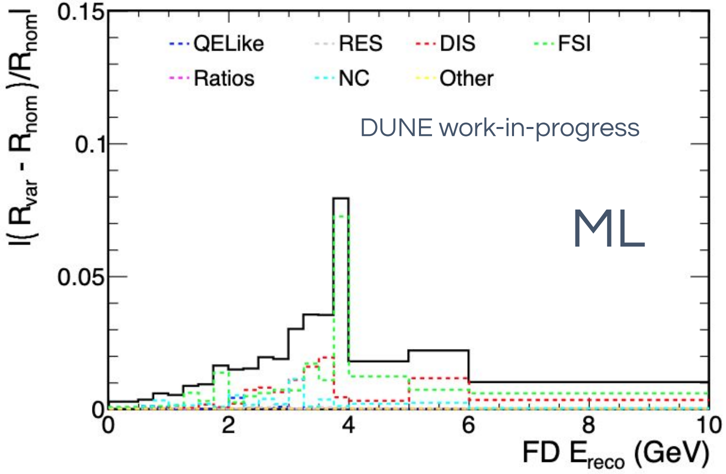


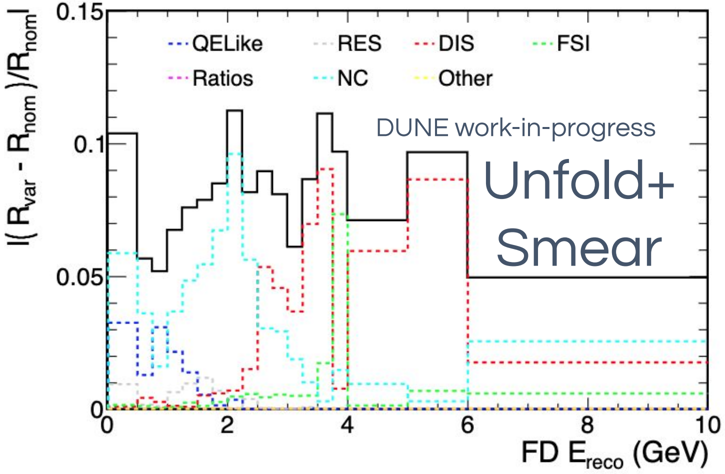


- Some events are too large to fit in the ND.
- Calculate the "ND efficiency" of FD events.
- Only use events with "ND efficiency" > 10%.
  - Efficiency correction has demonstrated a precision of 2%.
    - Further improvements are underway.

Learn the ND / FD read-out differences







Summary

- The **DUNE** experiment will unravel some of the neutrinos best-kept secrets.
- A moveable near detector, **DUNE-PRISM** , is part of the experiment's strategy to mitigate the impact of neutrino interaction model uncertainties on the physics measurements.
- A **data-driven** approach to neutrino oscillation has been developed.
  - **Data-driven efficiency corrections** are being developed, making use of advanced machine-learning techniques.