Developing the Reconstruction of a Magnetised Gaseous Argon TPC for the DUNE Near Detector

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Deep Underground Neutrino Experiment

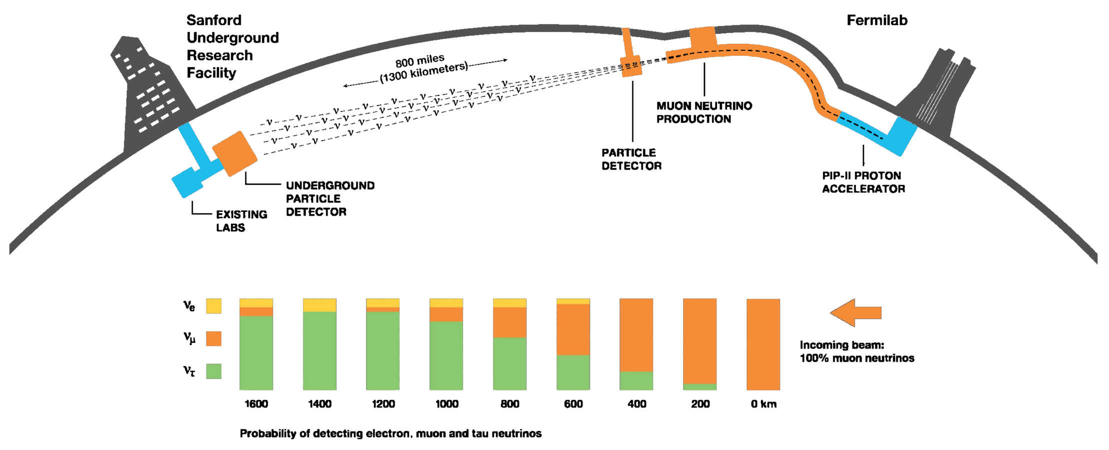

Figure 1: Schematic of the DUNE experiment [1].

- DUNE is a next-generation **long-baseline neutrino experiment**.
  - Near detector (ND) complex placed at Fermilab.
  - **70-kt liquid argon far detector** (FD) 1300 km away in South Dakota.
- **Neutrino oscillation physics** from accelerator-produced neutrino beam.
- Rare events like **supernova neutrinos**, potential **nucleon decays** and other **BSM** phenomena.

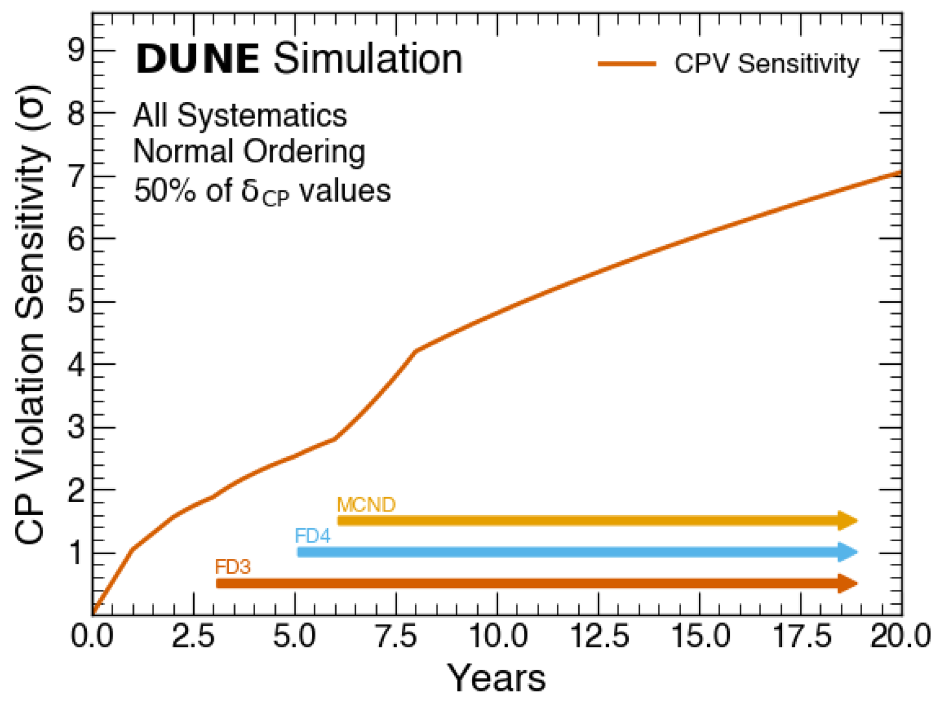

Figure 2: Sensitivity to CP violation for 50% of δ_{CP} values as a function of time [1].

- DUNE will be built using a **staged approach**.
- A **more capable ND** is **needed** in order to reach the ultimate physics goals of DUNE.

Why a Near Detector?

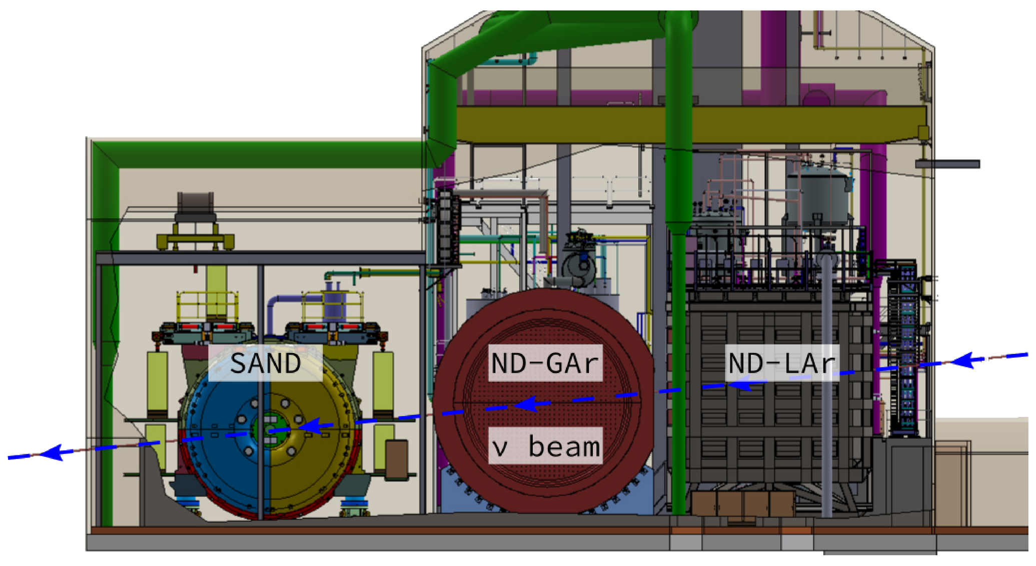

Figure 3: Representation of the ND hall in Phase II, showing its different subcomponents [2].

- Constrain **systematic uncertainties** for the oscillation program.
- Provide continuous **monitoring** of the beam.
- Opportunities for **neutrino interaction cross sections** and **BSM physics** measurements.

ND-GAr concept

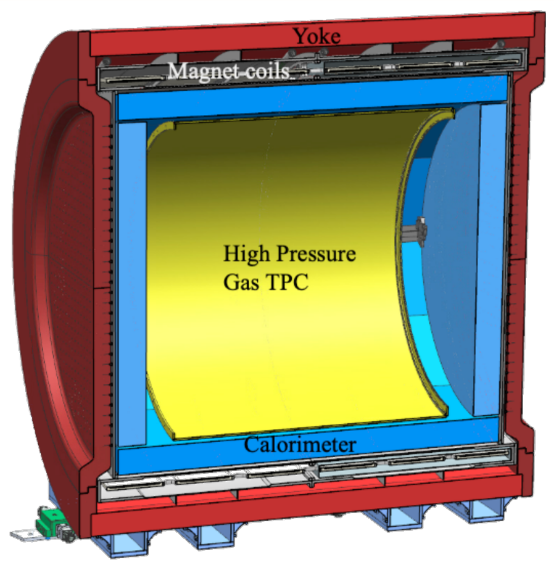

Figure 4: Cross section of the ND-GAr geometry, showing the HPgTPC, ECal and magnet.

- ND-GAr is a magnetised high-pressure gaseous argon TPC, surrounded by an ECal and a muon tagger [3].
- The gaseous argon provides **lower tracking thresholds** and larger angular acceptance.
- The B field and the ECal allow for **particle identification** and **momentum and sign reconstruction**.
- HPgTPC design currently in progress.

Muon/pion separation in the ECal

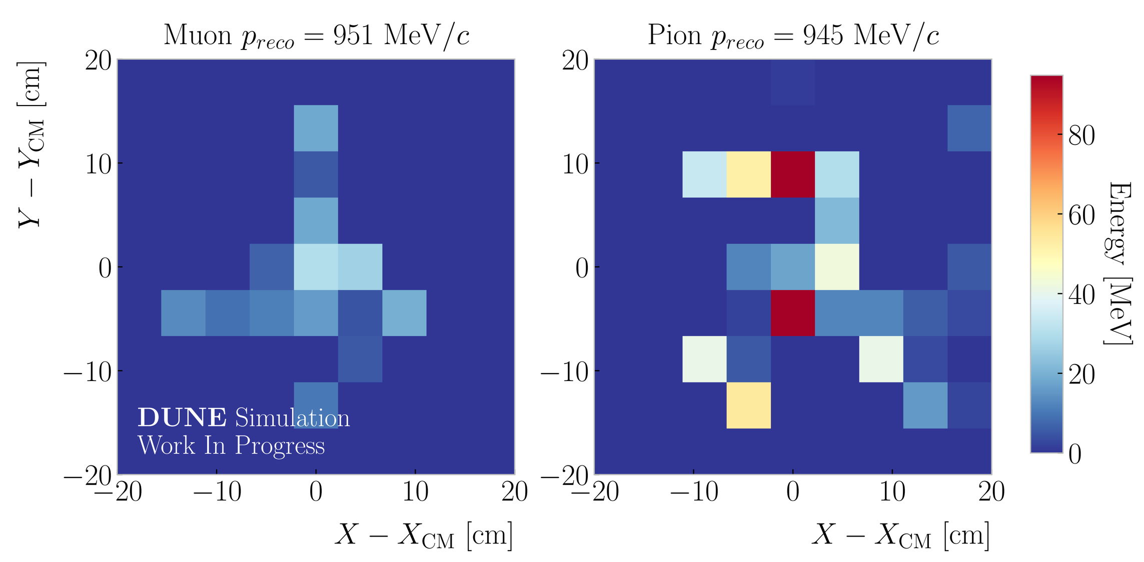

Figure 5: Distributions of energy deposits in the ECal for a muon (left) and a charged pion (right) with similar momentum.

- Hadronic **interactions in the ECal** significantly **different** from those of muons.
- Use **Boosted Decision Trees** (BDTs) trained on ECal features to separate muons from charged pions.
- We achieve an 80% muon purity in the relevant momentum range for ν_μ CC interactions.

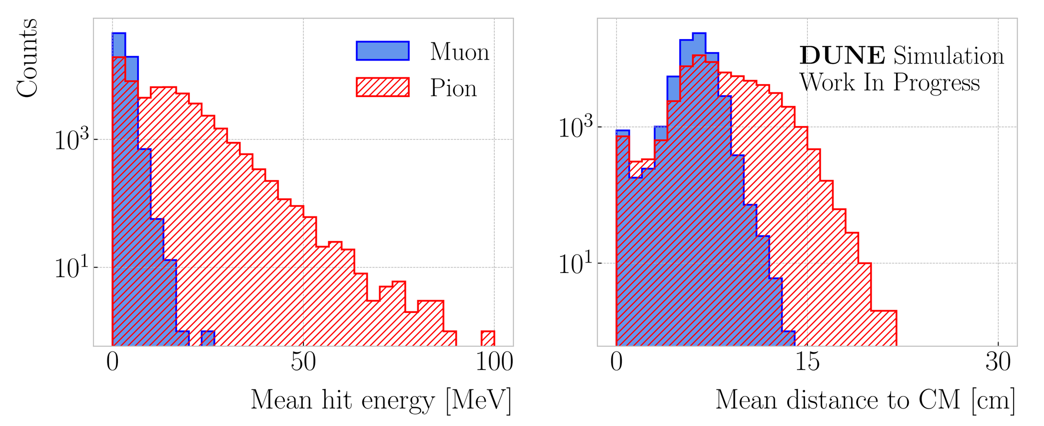

Figure 6: Feature distributions for muons and pions in the range $0.8 \leq p < 1.5$ GeV/c used for the BDT training.

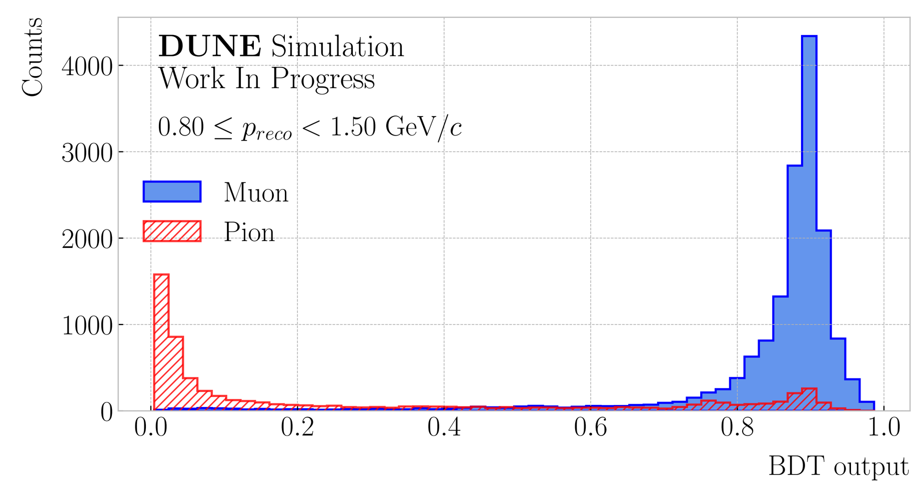

Figure 7: Predicted probabilities assigned by the BDT to true muons (blue) and charged pions (red).

Proton identification

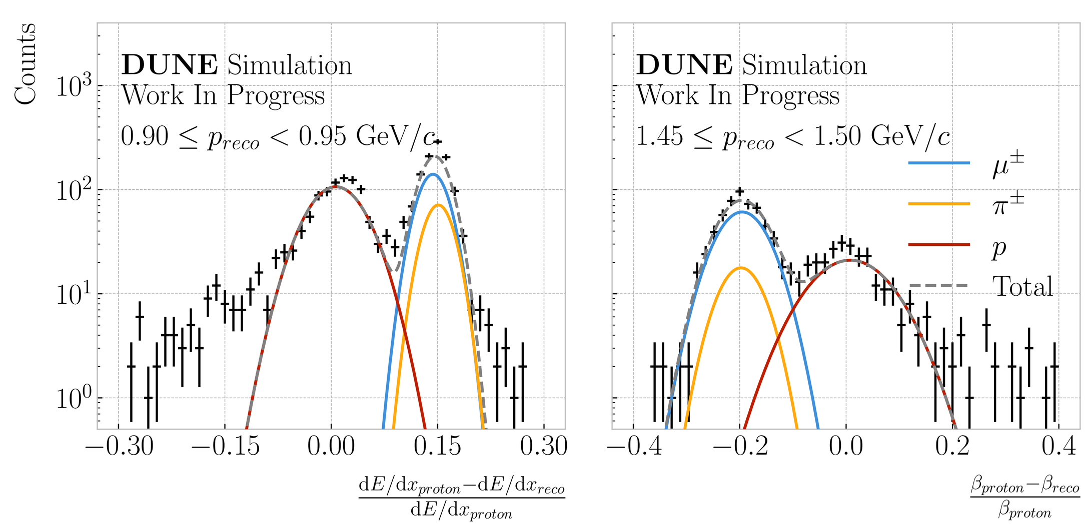

Figure 8: Distribution of dE/dx measured with the TPC (left) and β measured by time-of-flight with the ECal (right) for two different momentum bins.

- Measuring the **mean energy loss** with the TPC allows us to **identify protons** up to 1.5 GeV/c.
  - Use truncated mean to avoid fluctuations in the Landau tail.
- A **time-of-flight measurement** with the inner layers of the ECal can be used for PID at high momenta.
  - Using SiPMs with a time resolution under 500 ps allows for proton separation up to 3.0 GeV/c.

Event selection

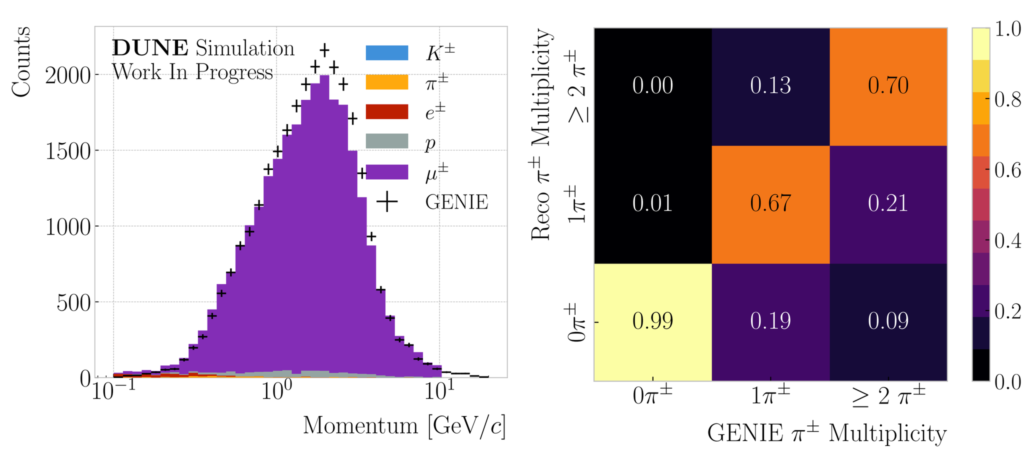

Figure 9: Left panel: reconstructed momentum distribution of selected primary muon candidates, broken down by true ID, and true primary muon momentum. Right panel: comparison between true and predicted charged pion multiplicities per event.

- The different PID approaches can be combined in order to cover all cases and energy ranges.
- The muon BDT score can be used to **identify the primary lepton** in ν_μ CC interaction inside the fiducial volume.
- Starting from the selected muon, we can **determine the number of charged pions** in the CC events.

Next steps

- Generate **Monte Carlo production** of events starting inside the HPgTPC volume, **with full reconstruction**, in both neutrino and antineutrino mode.
- Produce neutrino interaction **samples divided in pion multiplicity**: 0π, 1π and $\geq 2\pi$.
- Run new samples through long-baseline analysis to **understand impact of ND-GAr design** choices.

References

[1] DUNE collaboration, *DUNE Far Detector Technical Design Report, Volume I*, *JINST* **15** (2020) T08008.

[2] DUNE collaboration, *DUNE Near Detector Conceptual Design Report*, *Instruments* **5** (2021) 31.

[3] DUNE collaboration, *A Gaseous Argon-Based Near Detector to Enhance the Physics Capabilities of DUNE*, arXiv:2203.06281 [hep-ex].

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