

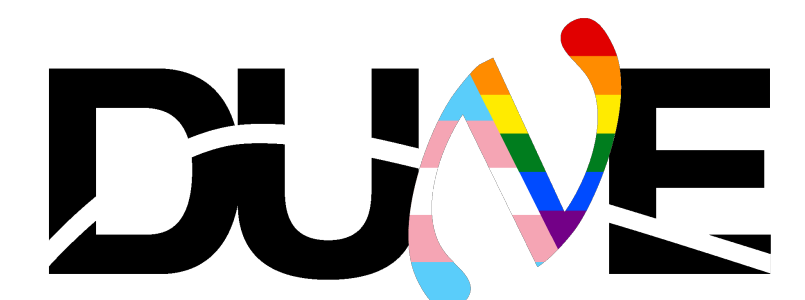
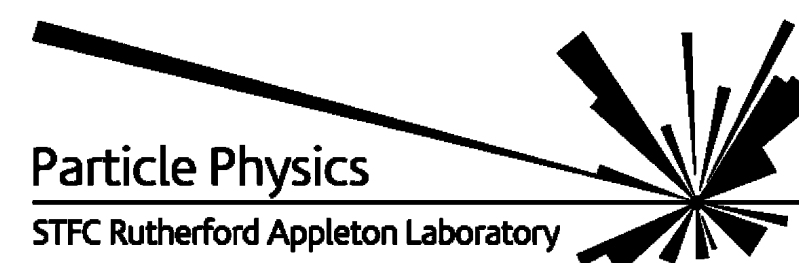
# A Magnetised High-Pressure Gaseous Argon TPC for the DUNE Near Detector

NuPhys 2023

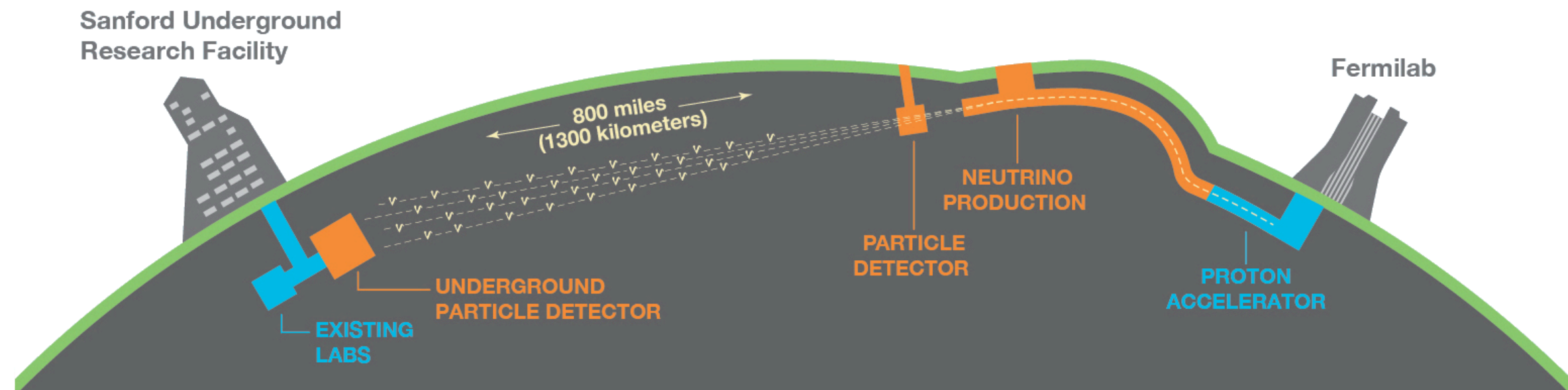
King's College London

18.12.2023

Francisco Martínez López  
for the DUNE collaboration  
[f.martinezlopez@qmul.ac.uk](mailto:f.martinezlopez@qmul.ac.uk)



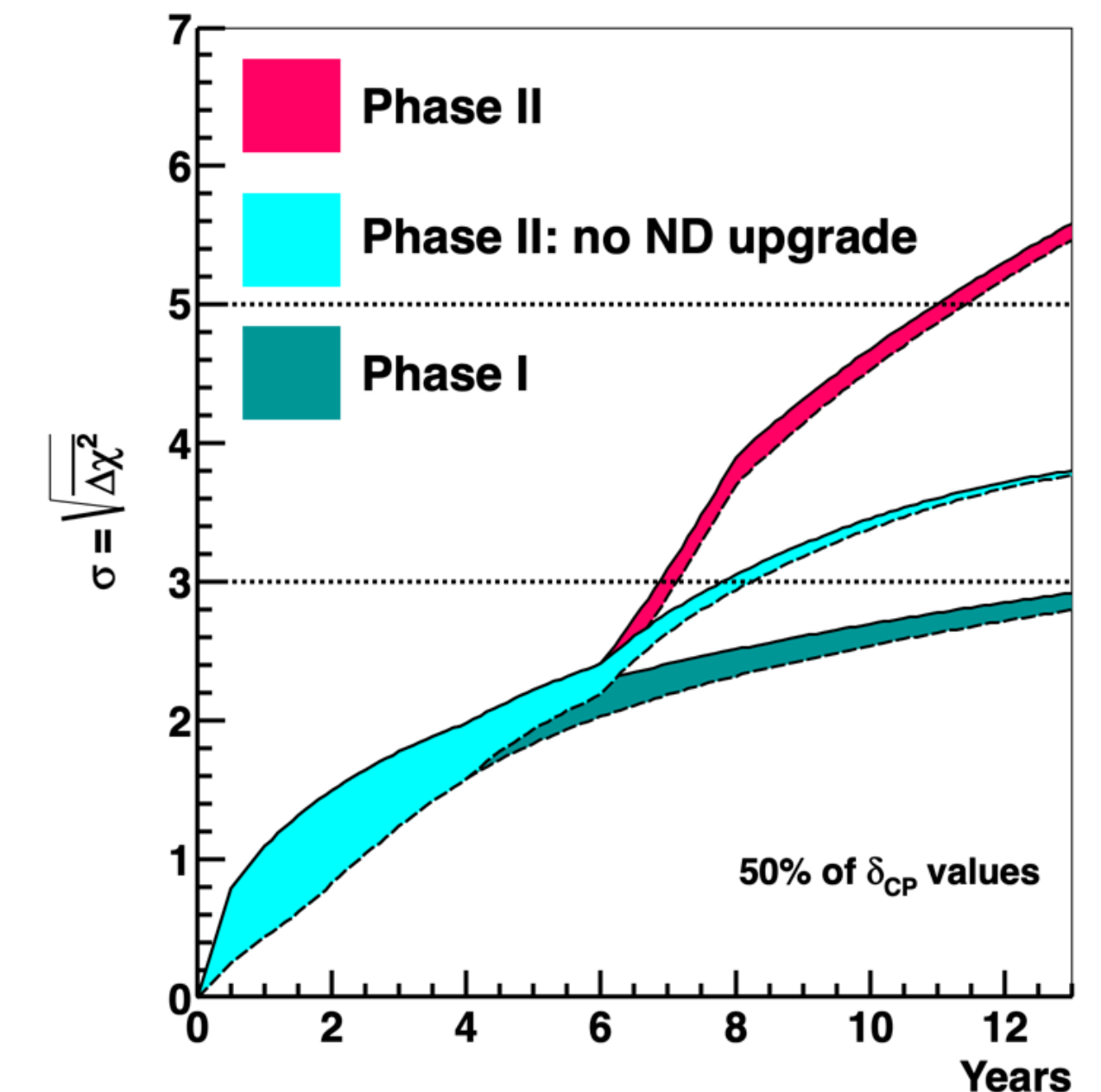
# Deep Underground Neutrino Experiment



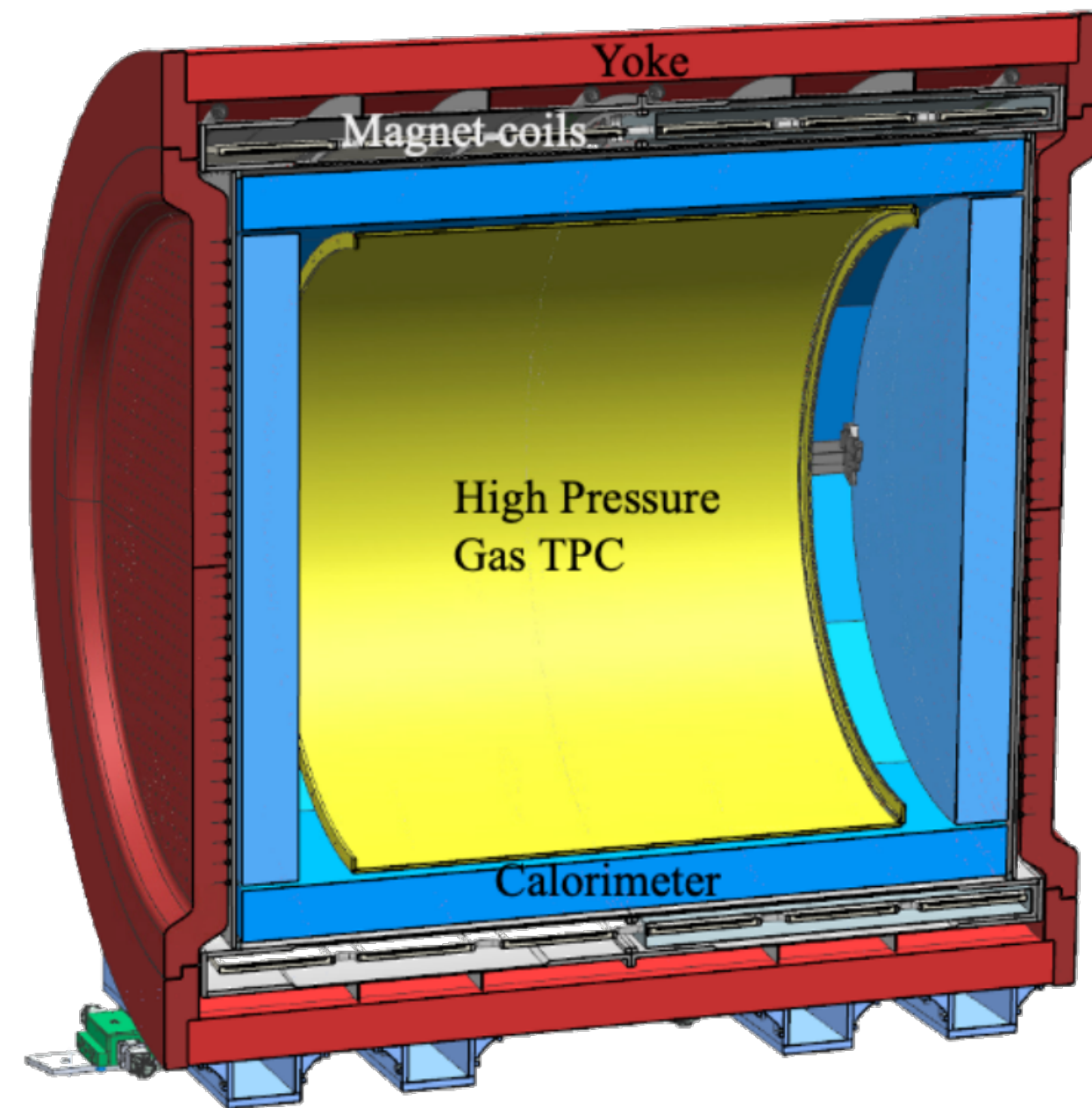
- Determine the **neutrino mass hierarchy**.
- Measure the value of the **leptonic CP violation**.
- Perform **precision measurements** of the three-flavour model.

Parameter	Phase I	Phase II
FD mass	20 kt fiducial	40 kt fiducial
Beam power	up to 1.2 MW	2.4 MW
ND config.	ND-LAr, TMS, SAND	ND-LAr, ND-GAr, SAND

- Phase I is sufficient for early physics goals.
- **Phase II is necessary** to reach the design sensitivity for  $\delta_{CP}$ .
- A **ND upgrade** is needed in order to reach the design sensitivity!

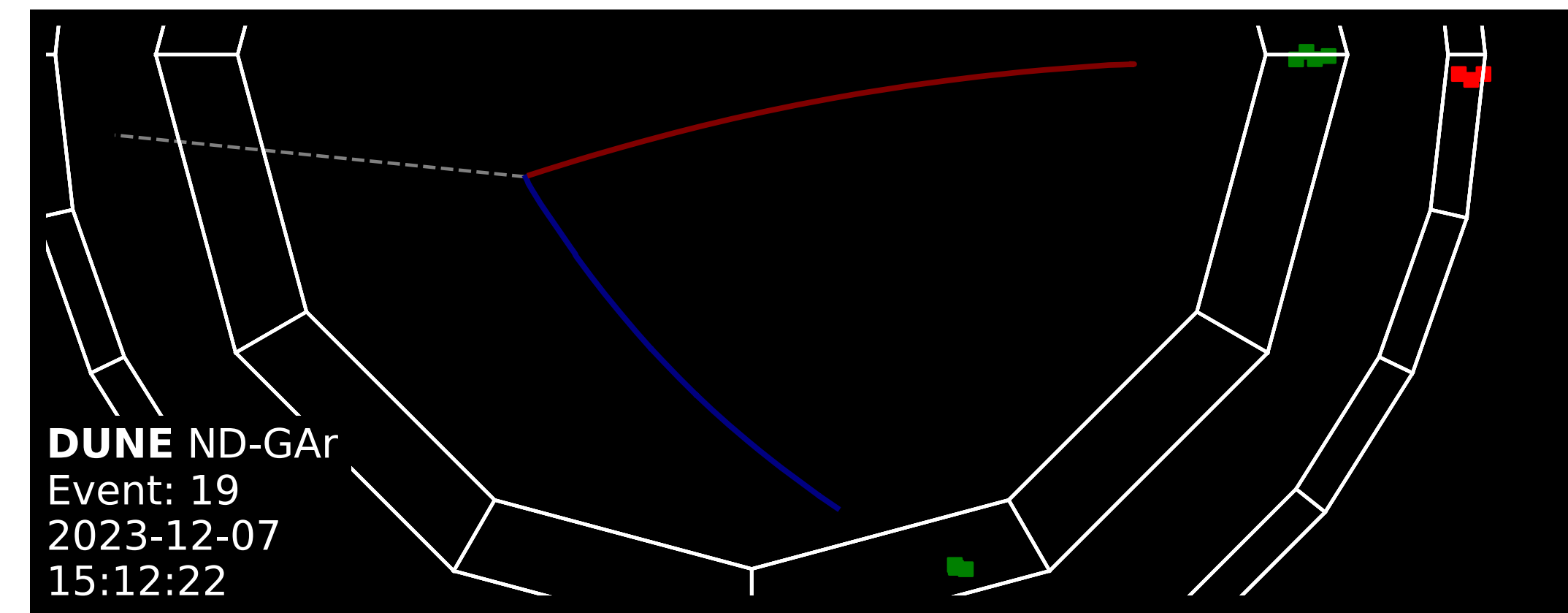


# ND-GAr concept



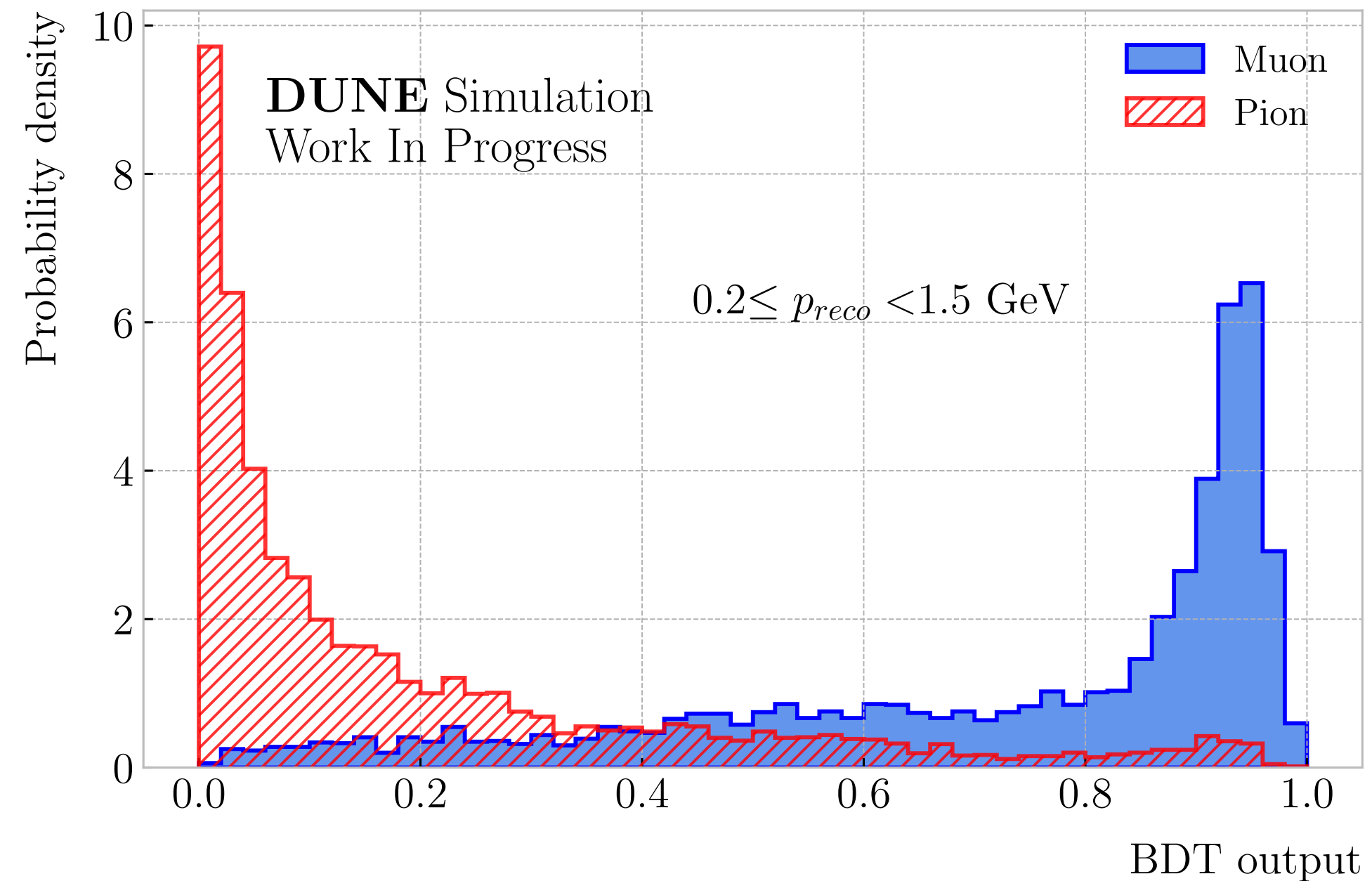
- ND-GAr is a magnetised high-pressure gaseous argon TPC, surrounded by an ECal and a muon tagger.
- The gaseous argon provides **lower tracking thresholds** and larger angular acceptance.
- The B field and the ECal allow for **particle identification** and **momentum and sign reconstruction**.

- *GArSoft* is ND-GAr's own **simulation and reconstruction toolkit**.
  - Simulates the readout of the TPC, ECal and muon detector.
  - Reconstructs tracks, vertices and ECal deposits.





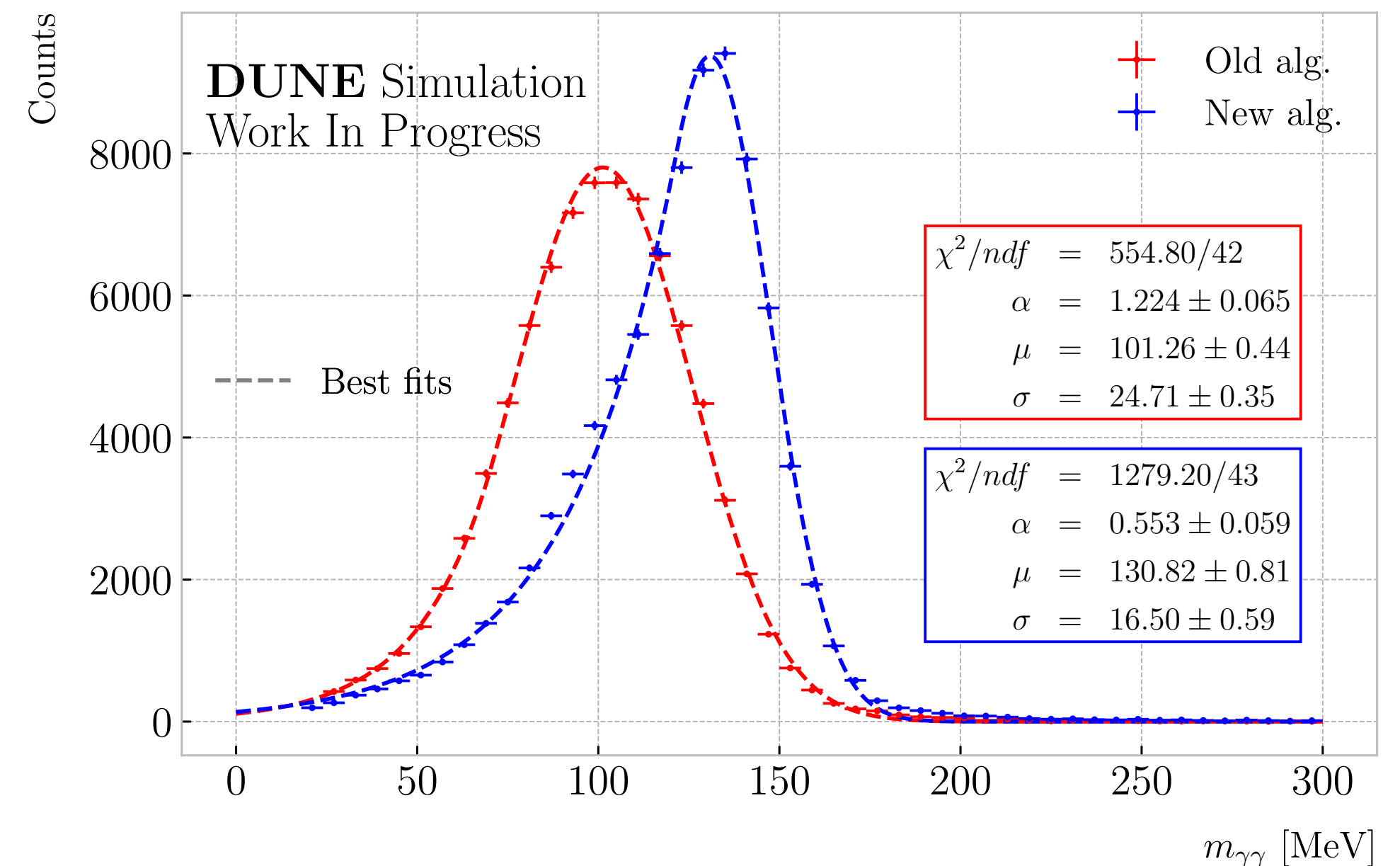
# Ongoing sim/reco work



- **Recent reconstruction improvements:**

- Studies on muon/pion separation using ECal.
- Improving ECal clustering for neutral pion reconstruction.

- **Develop a robust PID algorithm.**
- **Produce samples divided in pion multiplicity.**
- **Run new samples through long-baseline analysis to understand impact of ND-GAr design choices.**



# A Magnetised High-Pressure Gaseous Argon TPC for the DUNE Near Detector



Francisco Martínez López for the DUNE Collaboration

Particle Physics Research Centre (QMUL), Particle Physics Department (RAL) and Southampton High Energy Physics (SOTON)

## DUNE

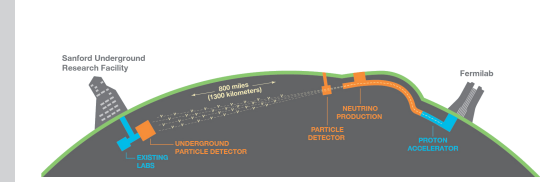


Figure 1: Schematic of the DUNE experiment [1].

- The Deep Underground Neutrino Experiment (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 the South Dakota.
- **Neutrino oscillation physics** from accelerator-produced neutrino beam.
- Rare events like **supernova neutrinos**, potential **nucleon decays** and other **BSM phenomena**.

## Neutrino oscillations at DUNE

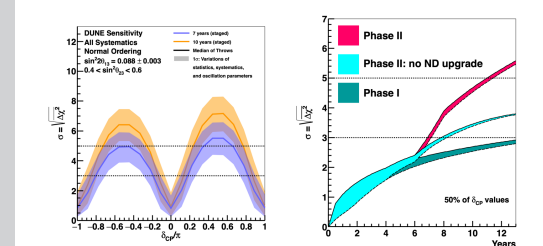


Figure 2: Left panel: sensitivity to leptonic CP violation as a function of the true value of  $\delta_{CP}$  for several exposures. Right panel: sensitivity to CP violation for 50% of  $\delta_{CP}$  values as a function of time in different scenarios [2].

- Determine the **neutrino mass hierarchy**.
- Measure the value of the **leptonic CP violation,  $\delta_{CP}$** .
- Perform **precision measurements** of the three-flavour model, like measuring  $\theta_{23}$  octant.

## Why a Near Detector?

- Constrain **systematic uncertainties** for the oscillation program.
- Provide continuous **monitoring** of the neutrino beam.
- Precision measurements of **neutrino interaction cross sections**.
- Plenty of **BSM opportunities** thanks to its privileged location.

## Staged approach

- DUNE will be built using a **staged approach**.
- Phase I is sufficient for early physics goals, like the determination of the mass ordering.
- **Phase II is necessary** to reach the design sensitivity for e.g.  $\delta_{CP}$ .
  - Among other things, a **ND upgrade** is needed.

Table 1: Summary of DUNE's two-phased plan [2].

Parameter	Phase I	Phase II
FD mass	20 kt fiducial	40 kt fiducial
Beam power	up to 1.2 MW	2.4 MW
ND config.	ND-LAr, TMS, SAND	ND-LAr, ND-GAr, SAND

## ND-GAr concept

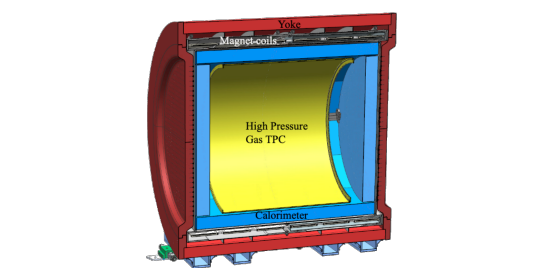


Figure 3: Cross section of the ND-GAr geometry, showing the HPgTPC, ECal and magnet.

- 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.
  - Gas electron multipliers (GEMs) are leading option.
- ECal design combines high-granularity tiles and cross scintillator strips.
- The superconducting magnet surrounds the entire detector, providing a uniform 0.5 T field.

## GArSoft

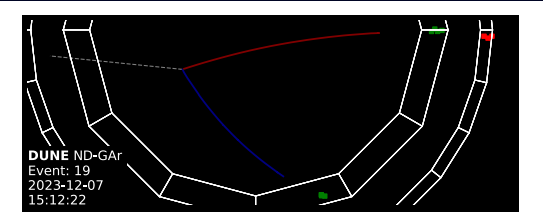


Figure 4: Example  $\nu_\mu$  CC QEL reconstructed event.

- **GArSoft** is ND-GAr's own **simulation and reconstruction toolkit**.
  - Interfaces with *GENIE* and *Geant4* for neutrino interaction and detector response models.
  - Simulates the readout of the TPC, ECal and muon detector.
  - Reconstructs tracks, vertices and ECal deposits.

## Tracking and energy loss

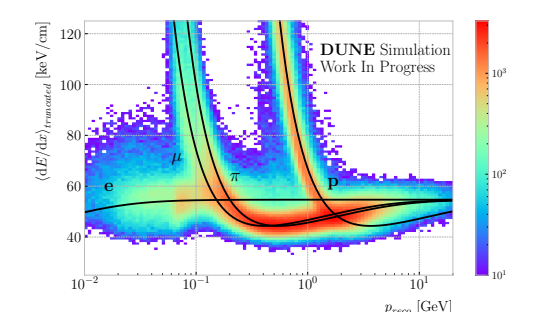


Figure 5: Reconstructed  $dE/dx$  spectrum versus momentum in the ND-GAr HPgTPC from  $\nu_\mu$  CC beam events.

- With an ALICE-inspired design we achieve:
  - **Momentum resolution** estimated to be **better than 2%** for a through-going muon sample.
  - **Resolution in energy loss** per unit length improves with pressure, **under 5%** in our conditions.

## Muon/pion identification

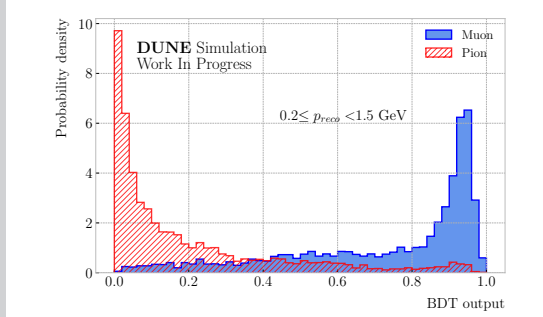


Figure 6: Distributions of the predicted probabilities assigned by the BDT to true muons (blue) and charged pions (red) from a test sample of  $\nu_\mu$  CC events.

- Combine TPC tracking and ECal to perform **muon/pion separation**.
- A BDT can identify what tracks produced **hadronic-like interactions** in the ECal, achieving an 80% muon purity.

## Neutral pion reconstruction

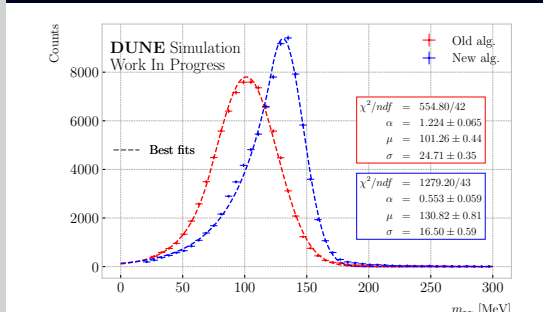


Figure 7: Reconstructed invariant mass distribution for photon pairs from single  $\pi^0$  events.

- The ECal can be used for **neutral particle reconstruction**.
- Currently working on **improving the clustering algorithm**.
  - Goal is to achieve a better neutral pion reconstruction.

## Next steps

- Use tracking and calorimetry to develop a **robust PID algorithm**.
- Evaluate impact of **improved reconstruction**.
- Produce neutrino interaction **samples divided in pion multiplicity**:  $0\pi$ ,  $1\pi$  and  $\geq 1\pi$ .
- 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 1, JINST 15 (2020) T08008 [2002.02967]*.  
 [2] DUNE collaboration, *Snowmass Neutrino Frontier: DUNE Physics Summary, 2203.06100*.  
 [3] DUNE collaboration, *A Gaseous Argon-Based Near Detector to Enhance the Physics Capabilities of DUNE, 2203.06281*.

# Come and take a look!

## Poster EX-11