ND-GAr R&D

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The Phase-I ND (ND-LAr + TMS) is sufficient for early physics goals if $\delta_{CP}$ is $-\pi/2$

For high significance, and to meet P5 goals, a detector more capable than TMS is needed at the near site

- ND-GAr meets the requirements to enable $5\sigma$ CPV significance for a broad range of $\delta_{CP}$ values, and also enables an extensive BSM physics program
ND-GAr Overview

Cryogenic Feedcan
6, SC Magnet Coils

Argon Gas at 10 bar

Low Carbon Steel Yoke

Stayed Heads
ND-GAr Reference Design

- TPC based on ALICE TPC design
  - 5m diameter, central drift electrode with two 2.5m drift regions
  - MWPC-based charge readout chambers, new chambers for central region
- ECAL based on CALICE hadron calorimeter design
  - Scintillating layers with mix of tiles and strips, SiPM readout
- Superconducting solenoid based on JINR MPD design
  - 0.5 T central field
  - Solenoid vacuum vessel acts as the TPC pressure vessel to contain gas at 10 atm
  - Partial return yoke to allow LAr-exiting particles to enter ND-GAr
- Muon tagger
  - Active layer outside iron yoke to tag penetrating particles
Optimizing ND-GAr Design

• The ND-GAr reference design enables DUNE Phase-II physics
  • Measures $\nu$-Ar interactions with low thresholds and high resolution to improve systematics
  • Comprehensive BSM program

• Now that the timeline for this detector is part of Phase-II, later than originally envisioned, we have time to further refine the design
  • Ongoing R&D
  • Future R&D needed
  • Detector design optimization/finalization
Gas Mixture Studies

• Argon-based gas mixture to enable constraints of LAr systematics
  • Addition of molecular additive is essential for stable gain/HV operation
    • Minimize number of non-Ar interactions
    • Maintain good drift-diffusion characteristics
    • Achieve sufficient gas avalanche gain
  • Better if we can achieve stable operation without quenching all the light
    • Enables event/track time-tagging, with light collection system

\[ \nu \mu \]

Improved track-matching with ND-LAr

\[ \nu \]

(NC) Neutron reconstruction via TOF

\[ \nu \gamma \theta \]

(NC) Improved n, \( \gamma \) angular reconstruction & vertex assignment

\[ \nu x \]

Low energy nuclear physics and BSM
Gas Mixture Studies

- Noble gases scintillate in VUV range
- Photoelectric effect causes feedback/instability in wire chambers
- Typically, quencher gas added to gaseous detectors to eliminate scintillation and increase gas gain
- Consider a more modern approach, where dopant gas does more than quench the light
  - Initial work at IGFAE focuses on CF4
Gas Mixture & Light Collection

- Photosensor concept for cathode plane (current R&D work at IGFAE)
  - 125-150 modules, 256 tiles per module, 16 SiPMs per tile (~32k readout channels)
  - Requires active cooling to reduce dark rate to acceptable level for low E threshold and good timing resolution
- Other possibilities? Maybe LAPPDs? Metalenses?

Hamamatsu S13360-series
Readout Chambers

• Ongoing campaigns for ALICE IROC/OROC MWPC-based chamber characterization at a range of pressures and with various gas mixtures
• Next up: Charged particle test beam run at Fermilab this Fall
  • OROC with new readout electronics
Readout Chambers

• The readout must be optimized for
  • Long-term stability
  • High spatial resolution (for momentum reconstruction)
  • Fast time sampling (for reduced tracking threshold and improved PID)
  • High gain/sensitivity (for reduced energy threshold)

• Alternative ideas for TPC readout under consideration
  • TimePix optical readout (K. Mavrokoridis/ARIADNE, Liverpool)
    • Initial demonstration & testing in gaseous TPC (100mb CF4) w/dual THGEMs and Am-241 alpha source
    • https://iopscience.iop.org/article/10.1088/1748-0221/14/06/P06001
  • MicroMegas-based chambers
  • GEM-based chambers (T. Mohayai, FNAL New Initiatives R&D award)
    • https://detectors.fnal.gov/seeding-new-ideas/
Electronics & DAQ development

• Baseline design envisioned LArPix ASIC for front-end readout, but now considering other options
  • SAMPA ASIC (designed for ALICE TPC upgrade): Front-end card designed by U Pittsburgh, Fermilab & ICL, remainder of readout chain developed by ICL
  • To be used in upcoming test beam run w/DUNE DAQ

Prototype SAMPA front-end card

Prototype TIP + Aggregator

Aggregator card (ICL)
56x FEC

Timing, Interface, & Power card (ICL)
Field Cage & High Voltage

- Baseline ND-GAr design copies ALICE’s central drift electrode
  - Optimized design with a single drift volume (drift electrode at one end of cylinder) would simplify light collection system design, but has challenges
    - 5m drift requires higher voltage at the drift electrode \(\rightarrow\) breakdown voltage
    - More diffusion of drifted ionization electrons
- ND-GAr will be movable (PRISM concept)
  - Need a robust mechanical design for the field cage
  - Electrostatic and gas flow simulations (Indiana U)

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<tr>
<th>Projected Breakdown Voltage at 10 bar, 1 cm (kV)</th>
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<td>Townsend</td>
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<td>Meek</td>
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Calibration

- Laser calibration envisioned to monitor variations in drift velocity and inhomogeneities in drift field, and ExB effects
  - Can adequate signal amplitude be achieved in chosen high-pressure gas mix? If not, alternative calibration techniques must be developed.
- Perhaps other calibration techniques/systems to consider
  - Cosmics
  - Radioactive krypton injection
  - ?

Calorimeter

- General technology of plastic scintillator tiles and strips, read out by SiPMs, is well established (à la CALICE), but some ND-GAr specific design/optimization work remains
  - Optimization of absorber layers geometry, readout granularity, mechanical structure (in progress at U. Mainz)
  - Design of low-power front-end electronics suitable for high channel count, with few 100’s picosecond timing resolution, and maybe pulse shape discrimination
  - Study needed for specific scintillator materials that enhance neutron detection capabilities, and matching silicon-based photon sensors
Muon System

• Design depends on particulars of the calorimeter and the magnet
  • Current (very preliminary) design is a single layer of muon tagger outside iron yoke
    • Scintillator extrusions? RPCs? MicroMegas?
Summary

• An upgraded ND is essential for high-significance CP violation measurement
  • ND-GAr reference design meets these needs and enables DUNE Phase-II physics goals
• Detector design optimization can improve on that reference, and perhaps reduce costs?
• Several areas of active R&D
  • Gas mixture characteristics (scintillation light, diffusion, drift velocity, HV breakdown…)
  • Light collection system (SiPMs, LAPPDs, Metalenses,…)
  • Readout chambers (MWPC, GEM, MicroMegas, Optical readout, …)
  • Front-end readout electronics

Many opportunities for new groups to join these lines of research or bring their expertise from other areas to propose new ideas
Extra Slides
Gas Mixture Studies

- Noble gases scintillate in VUV range
  - Photoelectric effect causes feedback/instability in wire chambers
- Typically, quencher gas added to gaseous detectors to eliminate scintillation and increase gas gain
- Consider a more modern approach, where dopant gas does more than quench the light
  - Initial work at IGFAE focuses on CF4
• If CP violation is maximal, the Phase-I ND (ND-LAr + TMS) suffices
• If nature is not so kind, a detector more capable than TMS is needed at the near site
  • ND-GAr meets the requirements to enable $5\sigma$ CPV significance for a broad range of $\delta_{CP}$ values
Magnet design

- Superconducting coils with pressurized region containing HPgTPC and ECAL
  - Central field 0.5T, 2% uniformity
  - Stray fields: negligible in SAND, ~10G in ND-LAr FV
- Upstream window in return yoke to minimize material between ND-LAr and ND-GAr
- Major developments since last meeting:
  - Completed design document (DocDB 24430)
    - Includes technical specs & requirements, material budgets, FEAs, installation procedure
ECAL Modules

- Scintillator + Lead sandwich
  - 8 high-granularity tile layers (0.7 mm Pb + 6 mm scint)
  - 34 crossed strip layers (1.4 mm Pb + 10 mm scint)
  - Aluminum frame

- Tech transfer from CALICE and other experiments for readout
  - MPPC/fiber coupling for strips
  - Prototyping in progress at U. Mainz
ECAL Neutron/Photon Pulse Shape Discrimination

• Work in progress w/experimental test setup at Mainz

Distinguish between photons from $\pi^0$ and neutrons.

Neutron and photon-induced clusters are separated based on:
  ▪ Total number of hits in the cluster.
  ▪ Total energy of the cluster.
  ▪ Maximum hit energy.

Use difference in scintillation profiles to bring additional information:
  Pulse Shape Discrimination (PSD)

PSD techniques based on the difference in the long decay constants: compare total charge to charge in the tail.