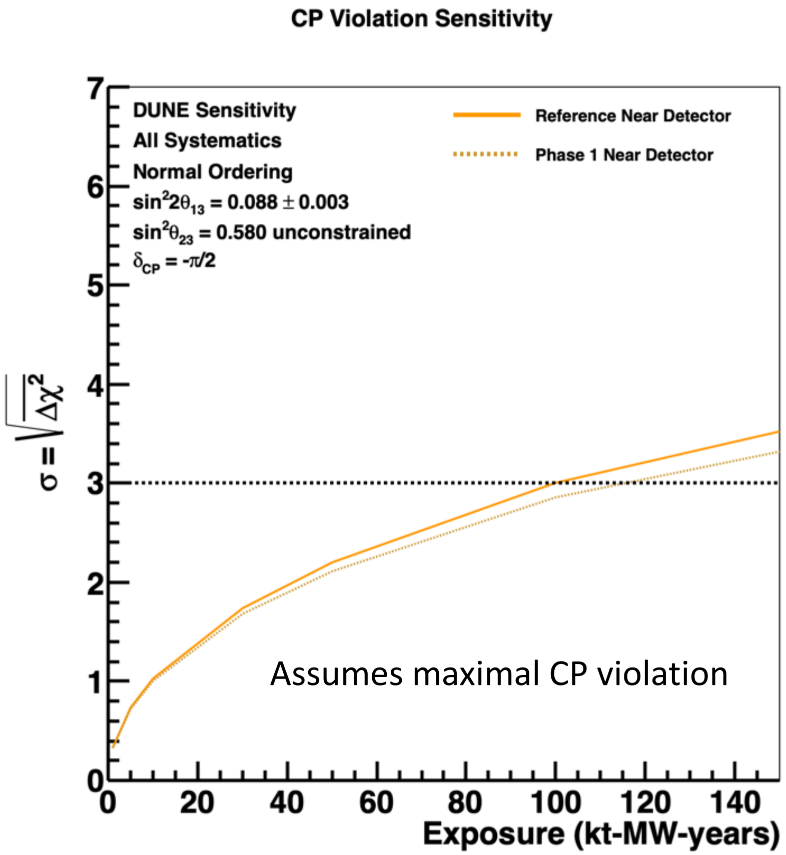
ND-GAr R&D

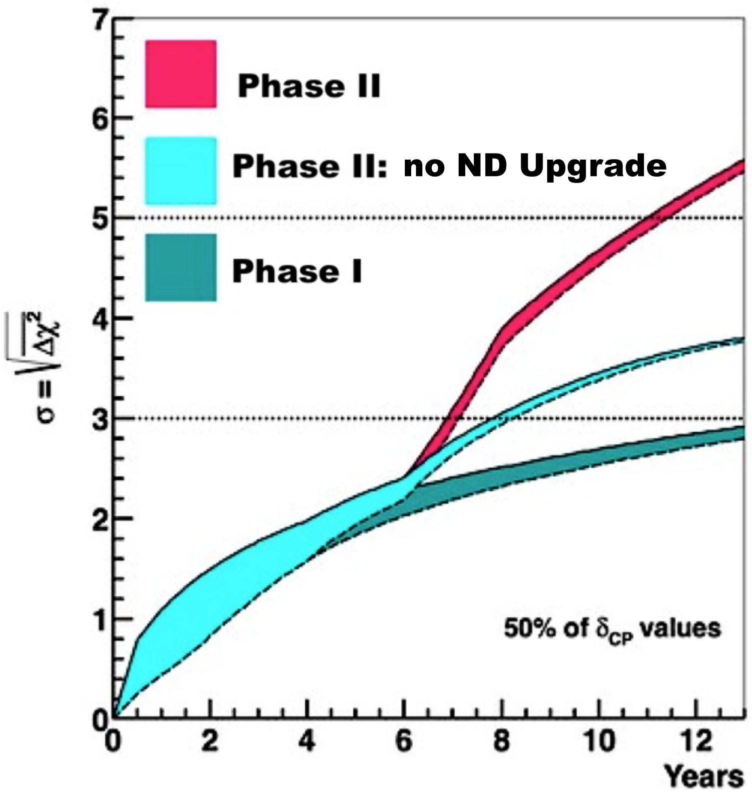
Jennifer Raaf (Fermilab)

Seattle Snowmass Summer Meeting

July 20, 2022

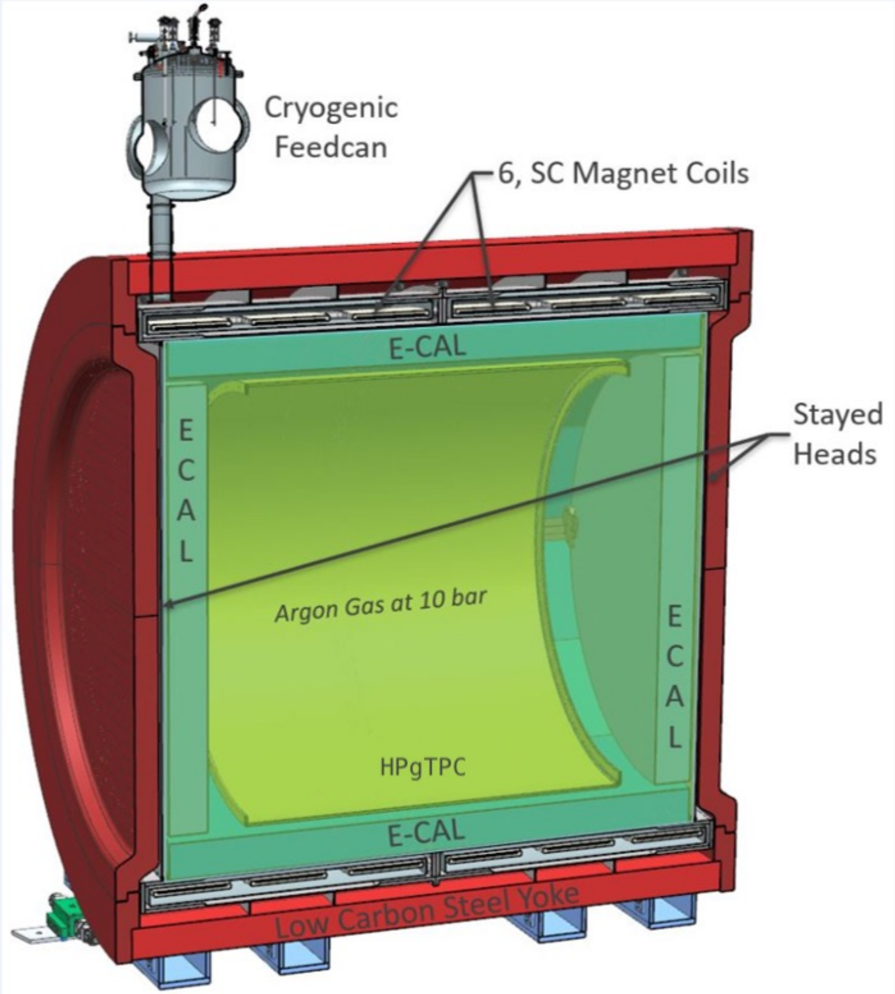
DUNE Phase-II Near Detector

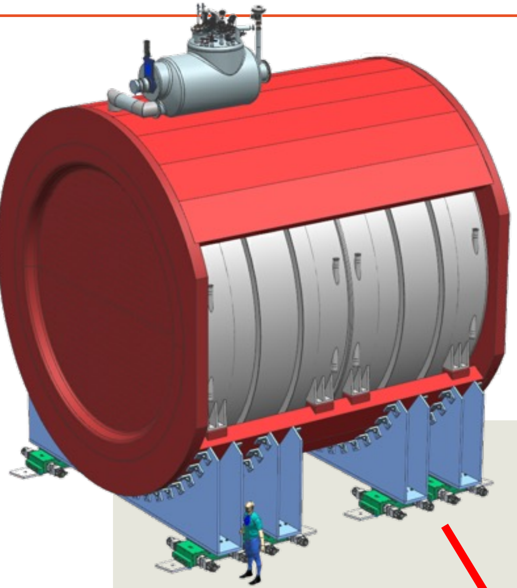


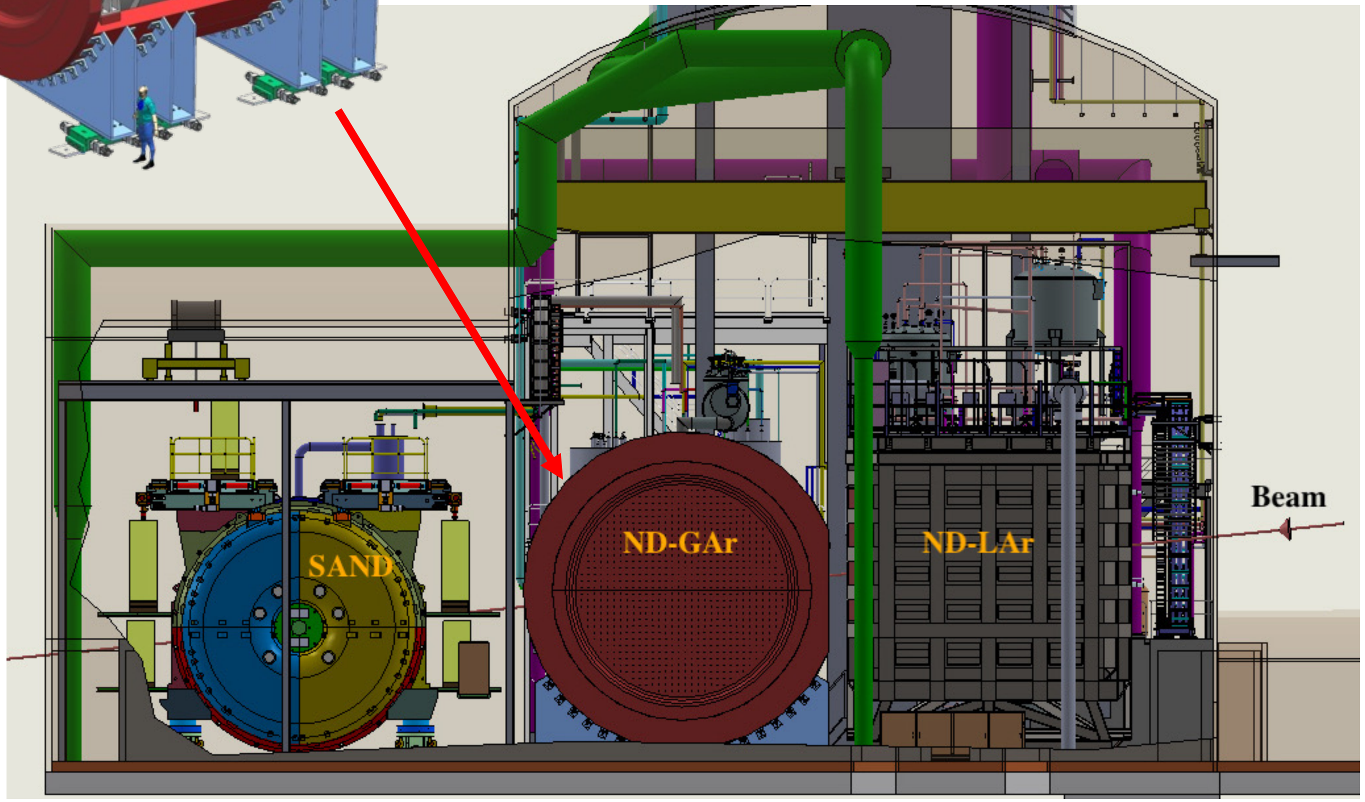


- The Phase-I ND (ND-LAr + TMS) is sufficient for early physics goals if δ_{CP} is $-\pi/2$
- For high significance, and to meet P5 goals, a detector more capable than TMS is needed at the near site
  - ND-GAr meets the requirements to enable 5$\boldsymbol{\sigma}$ CPV significance for a broad range of δ_{CP} values, and also enables an extensive BSM physics program

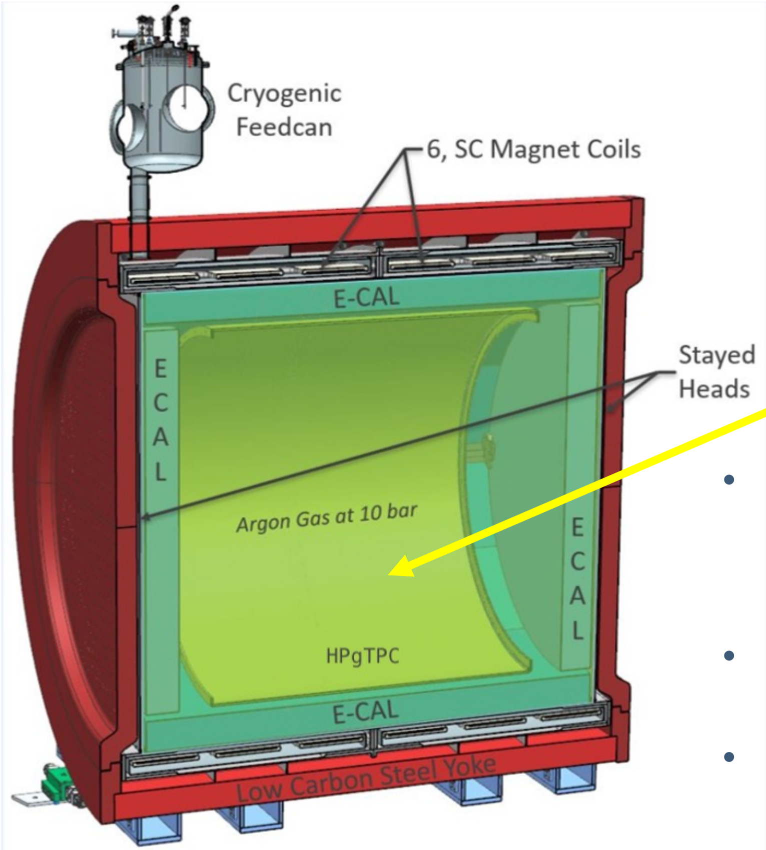
ND-GAr Overview

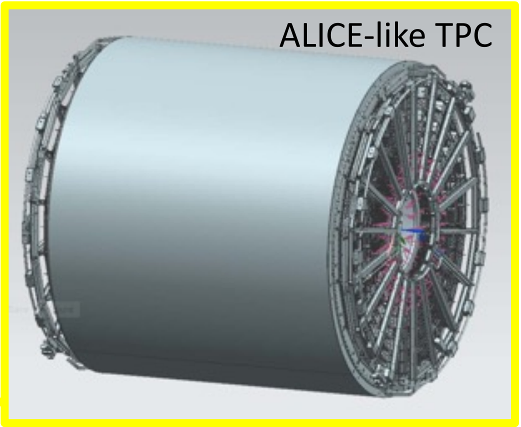


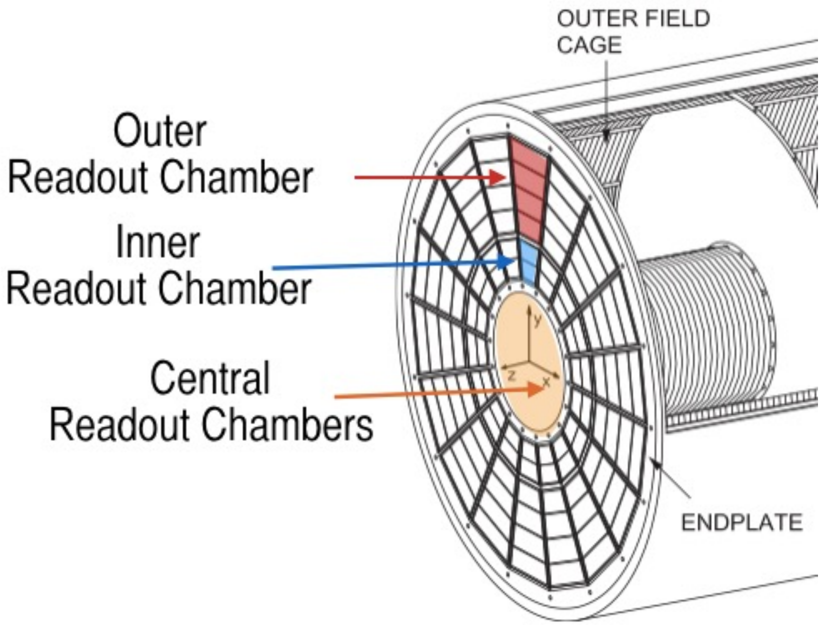




ND-GAr Reference Design

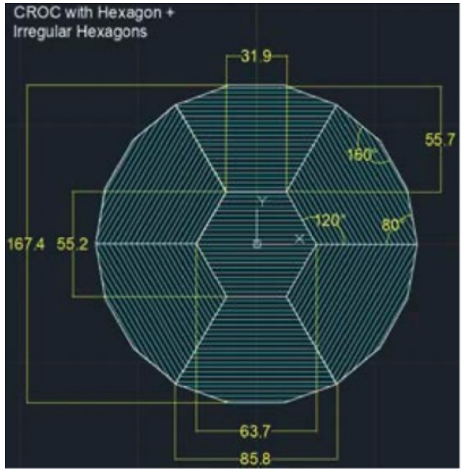






- TPC based on ALICE TPC design
  - 5m diameter, central drift electrode with two 2.5m drift regions
  - MWPC-based charge readout chambers, new chambers for central region
- ECAL based on CALICE hadron calorimeter design
  - Scintillating layers with mix of tiles and strips, SiPM readout
- Superconducting 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

Possible configuration of Central Readout Chambers

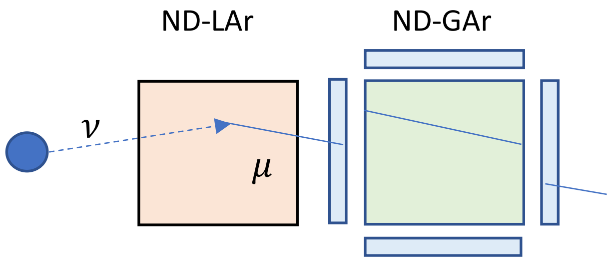


Optimizing ND-GAr Design

- The ND-GAr reference design enables DUNE Phase-II physics
  - Measures ν-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

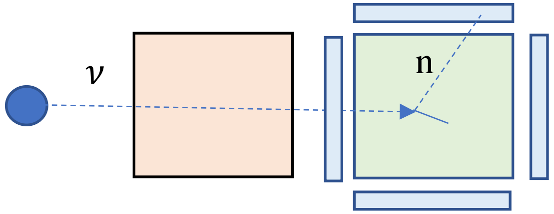
Gas Mixture Studies

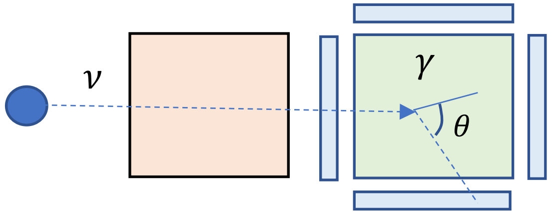
- Argon-based gas mixture to enable constraints of LAr systematics
  - Addition of molecular additive is essential for stable gain/HV operation
    - Minimize number of non-Ar interactions
    - Maintain good drift-diffusion characteristics
    - Achieve sufficient gas avalanche gain
  - Better if we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



Improved track-matching with ND-LAr

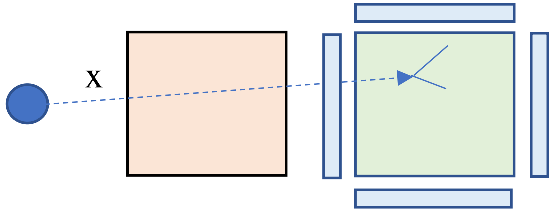
(NC) Neutron reconstruction via TOF



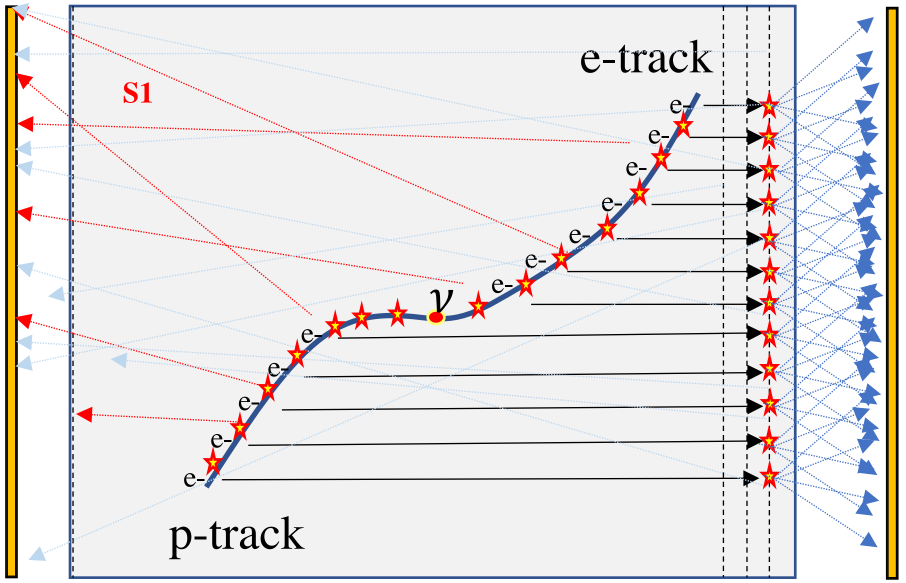


(NC) Improved n, γ angular reconstruction & vertex assignment

Low energy nuclear physics and BSM

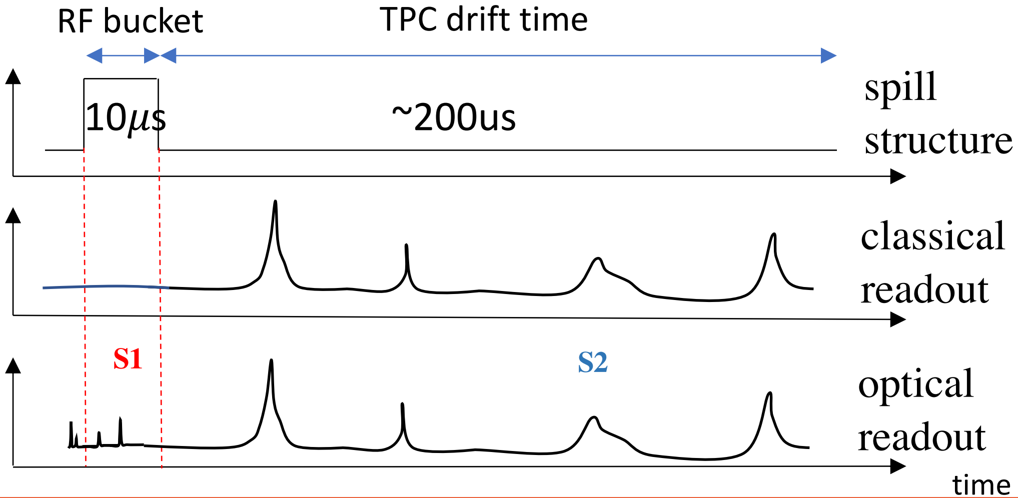


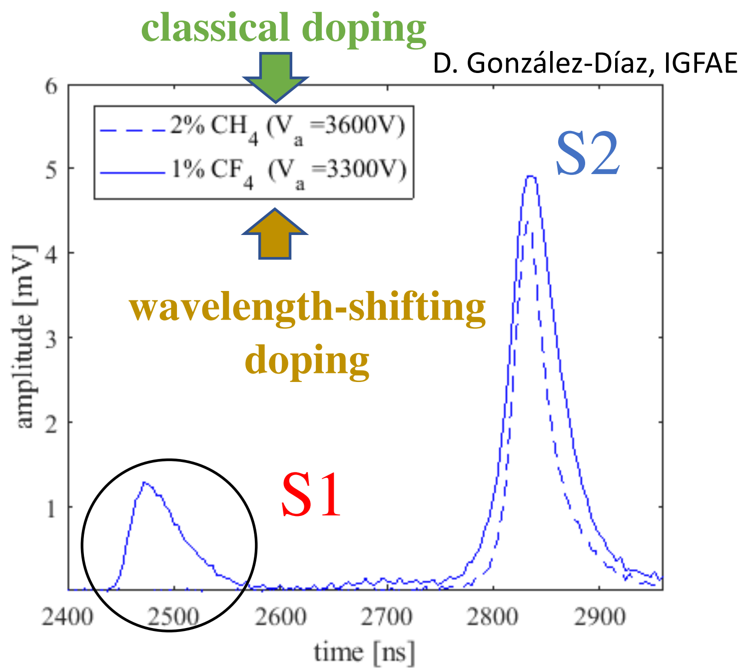
Gas Mixture Studies



Photosensor for primary scintillation (S1) → time stamping

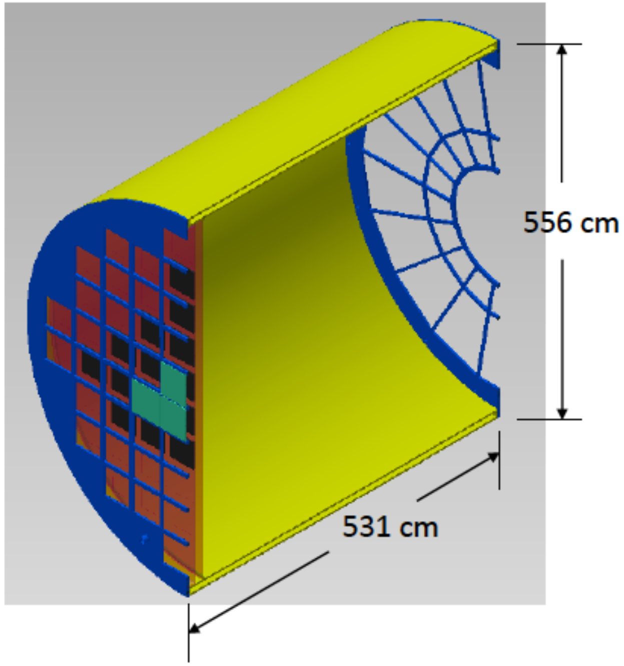
Charge readout or photosensor for secondary scintillation (S2) → 3D space sampling



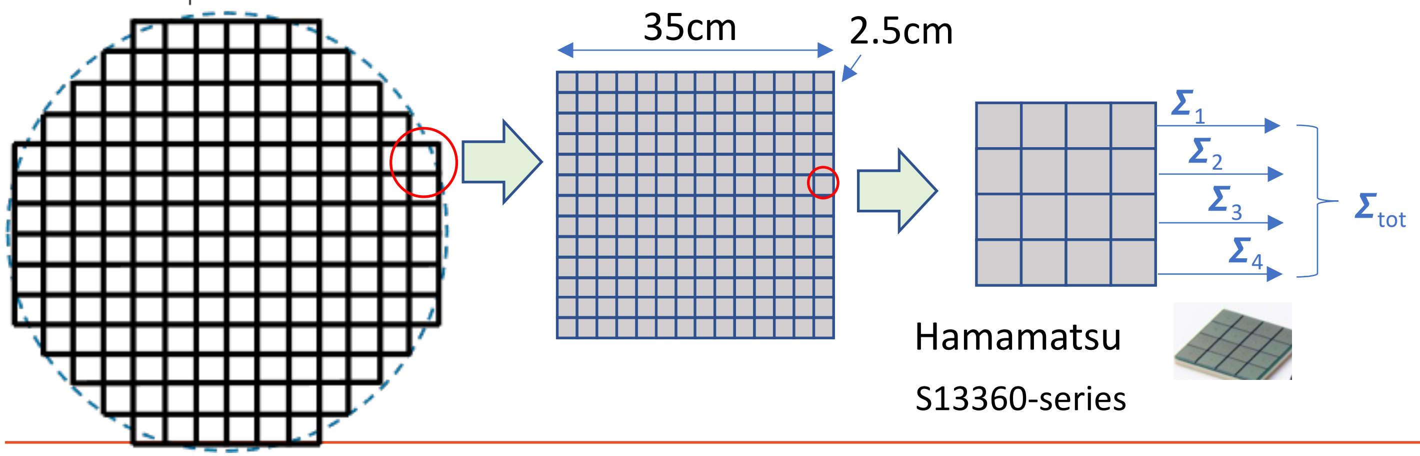


- Noble gases scintillate in VUV range
  - Photoelectric effect causes feedback/instability in wire chambers
- Typically, quencher gas added to gaseous detectors to eliminate scintillation and increase gas gain
- Consider a more modern approach, where dopant gas does more than quench the light
  - Initial work at IGFAE focuses on CF_4

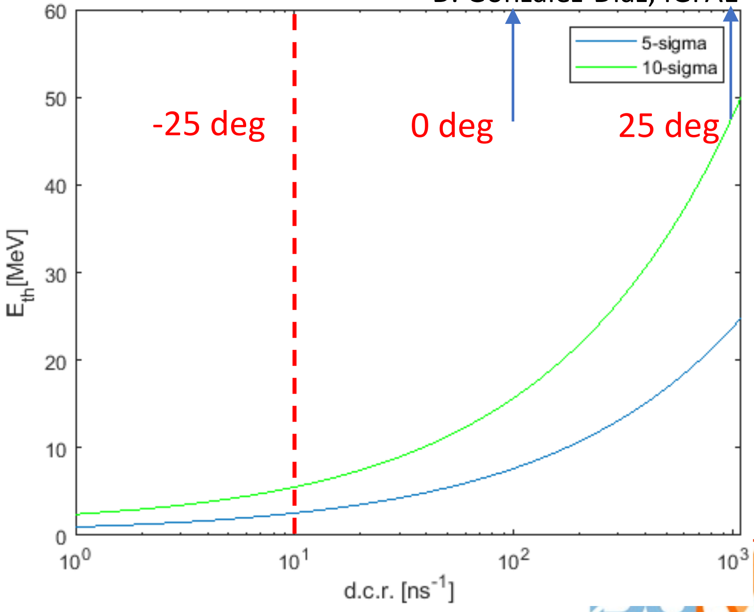
Gas Mixture & Light Collection



- 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?



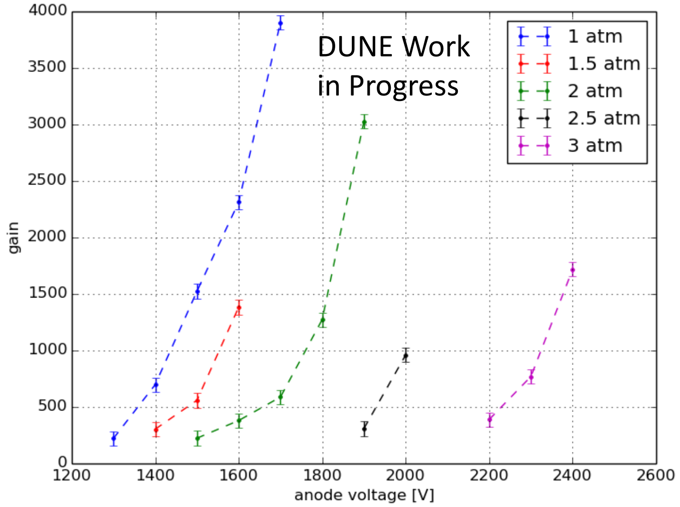
D. González-Díaz, IGFAE

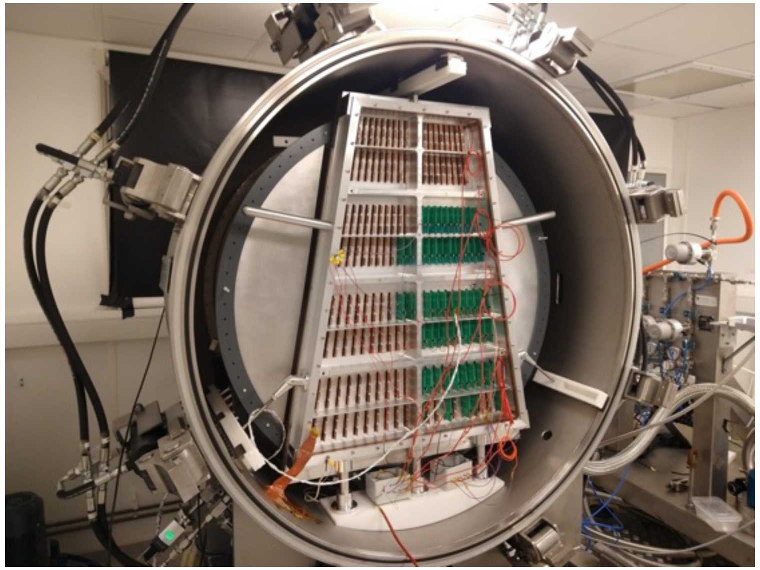


Readout Chambers

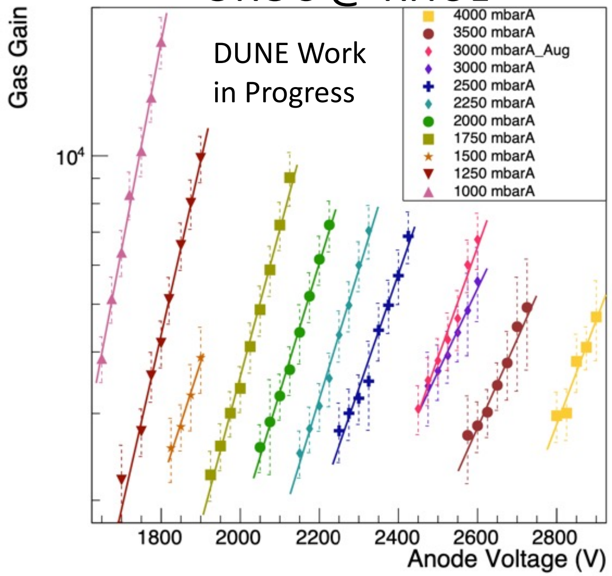
- Ongoing campaigns for ALICE IROC/OROC MWPC-based chamber characterization at a range of pressures and with various gas mixtures
- Next up: Charged particle test beam run at Fermilab this Fall
  - OROC with new readout electronics

IROC @ Fermilab





OROC @ RHUL

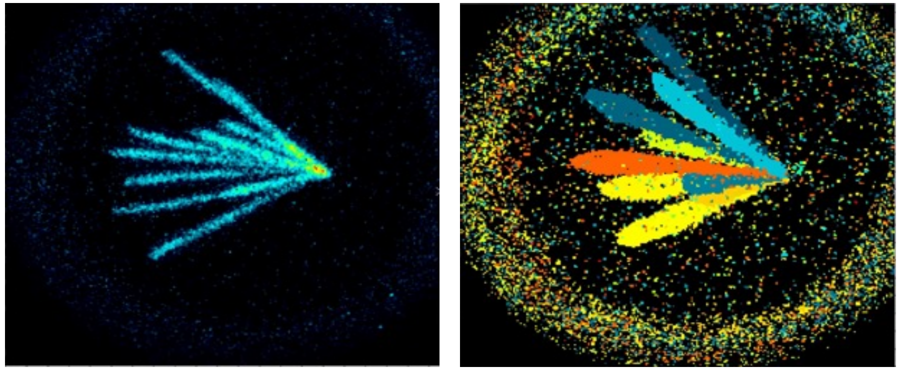


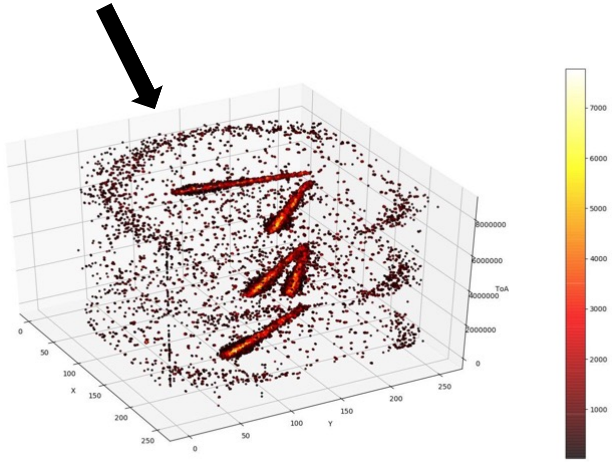
Readout Chambers

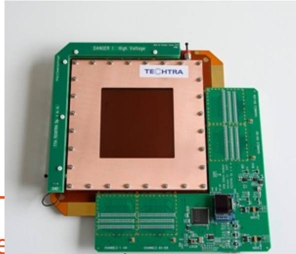
- The readout must be optimized for
  - Long-term stability
  - High spatial resolution (for momentum reconstruction)
  - Fast time sampling (for reduced tracking threshold and improved PID)
  - High gain/sensitivity (for reduced energy threshold)
- Alternative ideas for TPC readout under consideration
  - TimePix optical readout (K. Mavrokoridis/ARIADNE, Liverpool)
    - Initial demonstration & testing in gaseous TPC (100mb CF_4) 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/

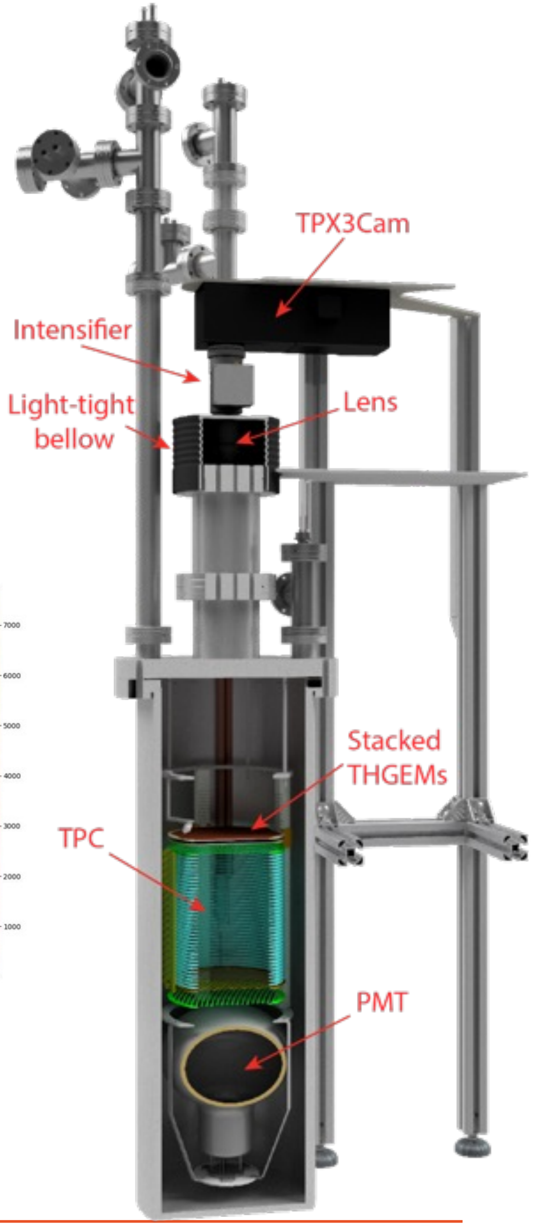
TPX3Cam

Time-over-Threshold Time-of-Arrival



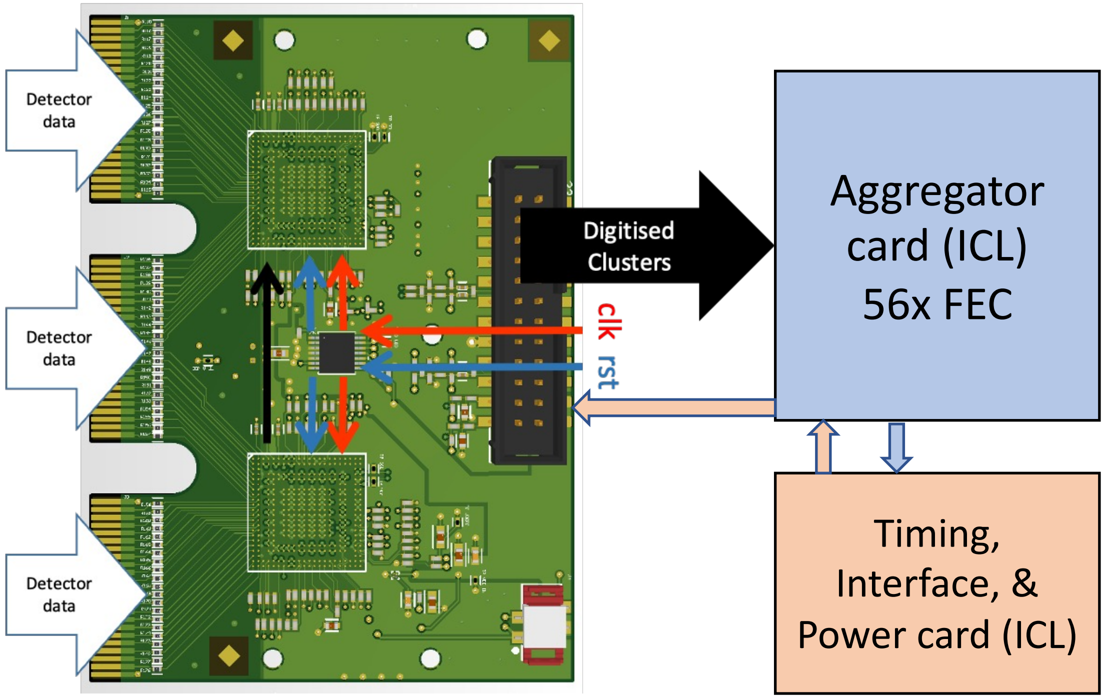






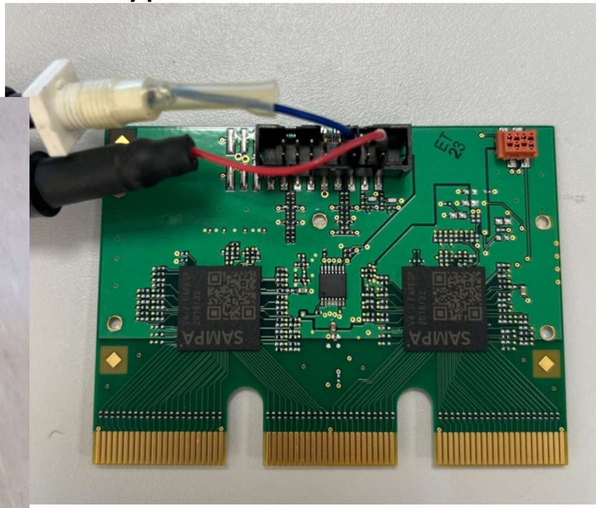
Electronics & DAQ development

- 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 TIP + Aggregator

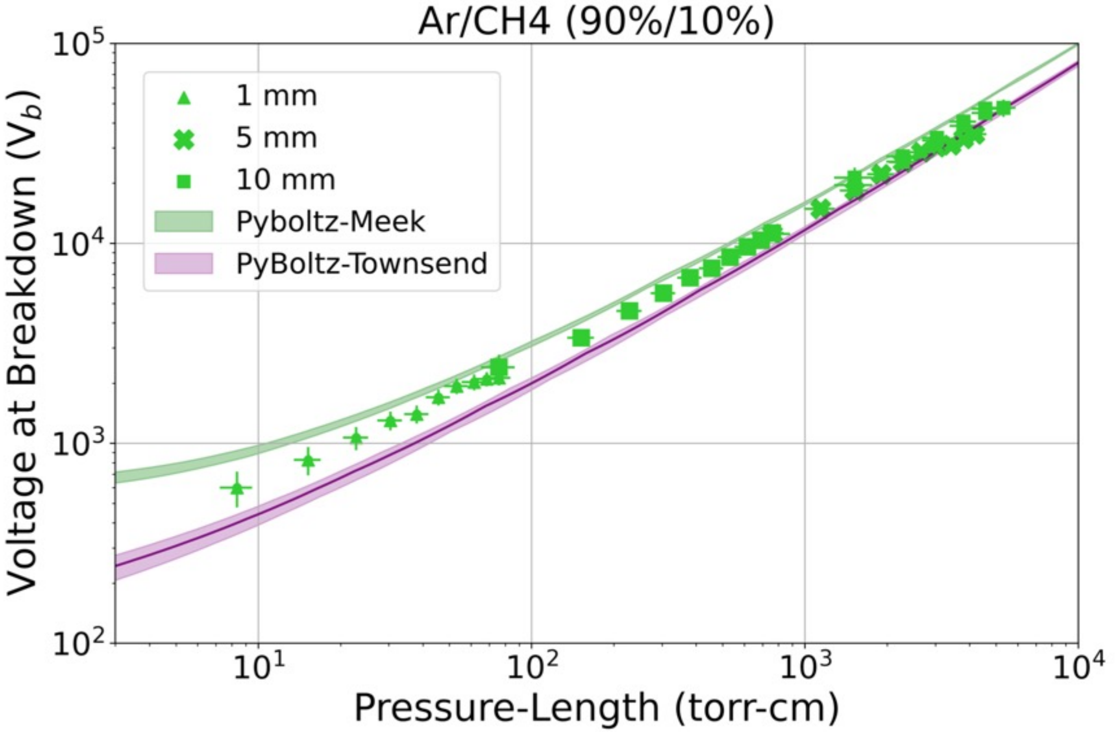
Prototype SAMPA front-end card



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 → 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)

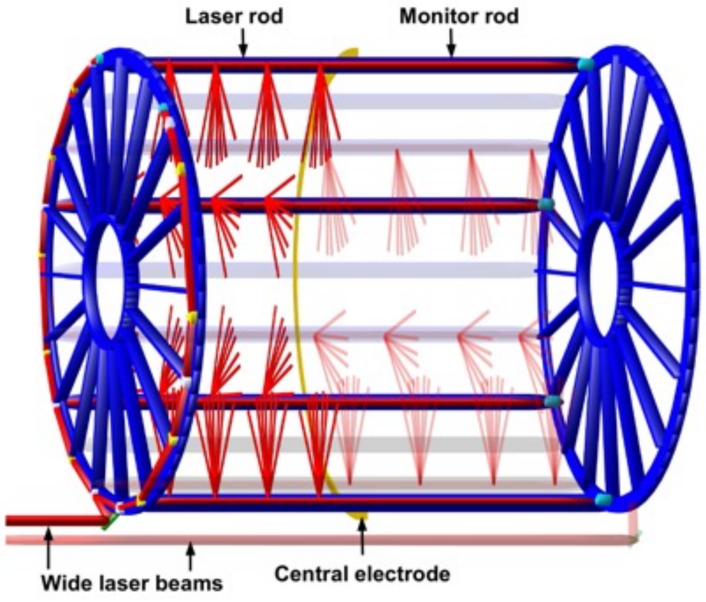
UTA: L. Norman et al. Eur. Phys. J. C 82, 52 (2022)



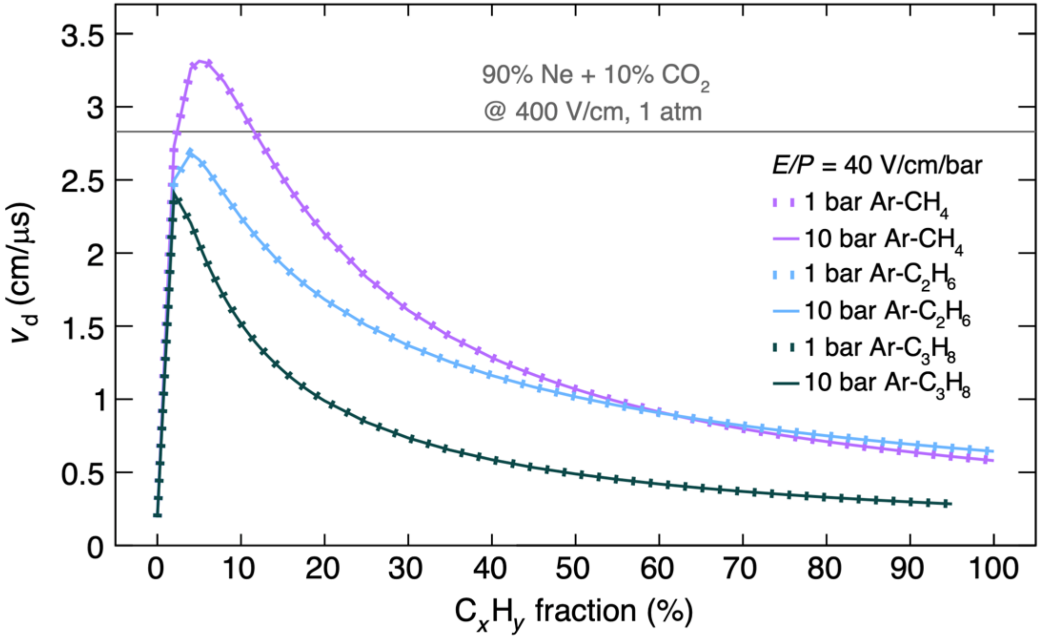
Projected Breakdown Voltage at 10 bar, 1 cm (kV)							
	Ar	Xe	Ar-CF_4	Ar-CH_4	Ar-CO_2	CO_2	CF_4
Townsend	**52.6**	**75.4**	61.7	63.9	68.6	129.5	179.7
Meek	69.9	98.9	72.1	80.3	87.3	**171.2**	**212.2**

Calibration

ALICE NIM A622:316-367 (2010)

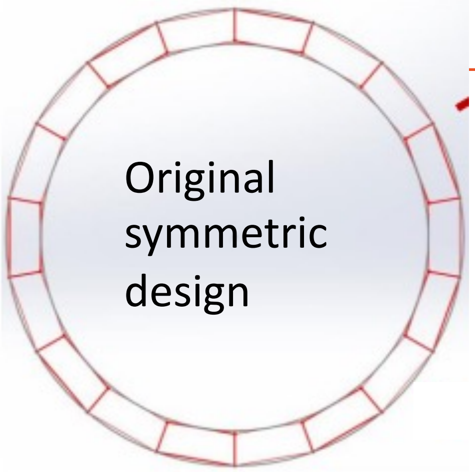


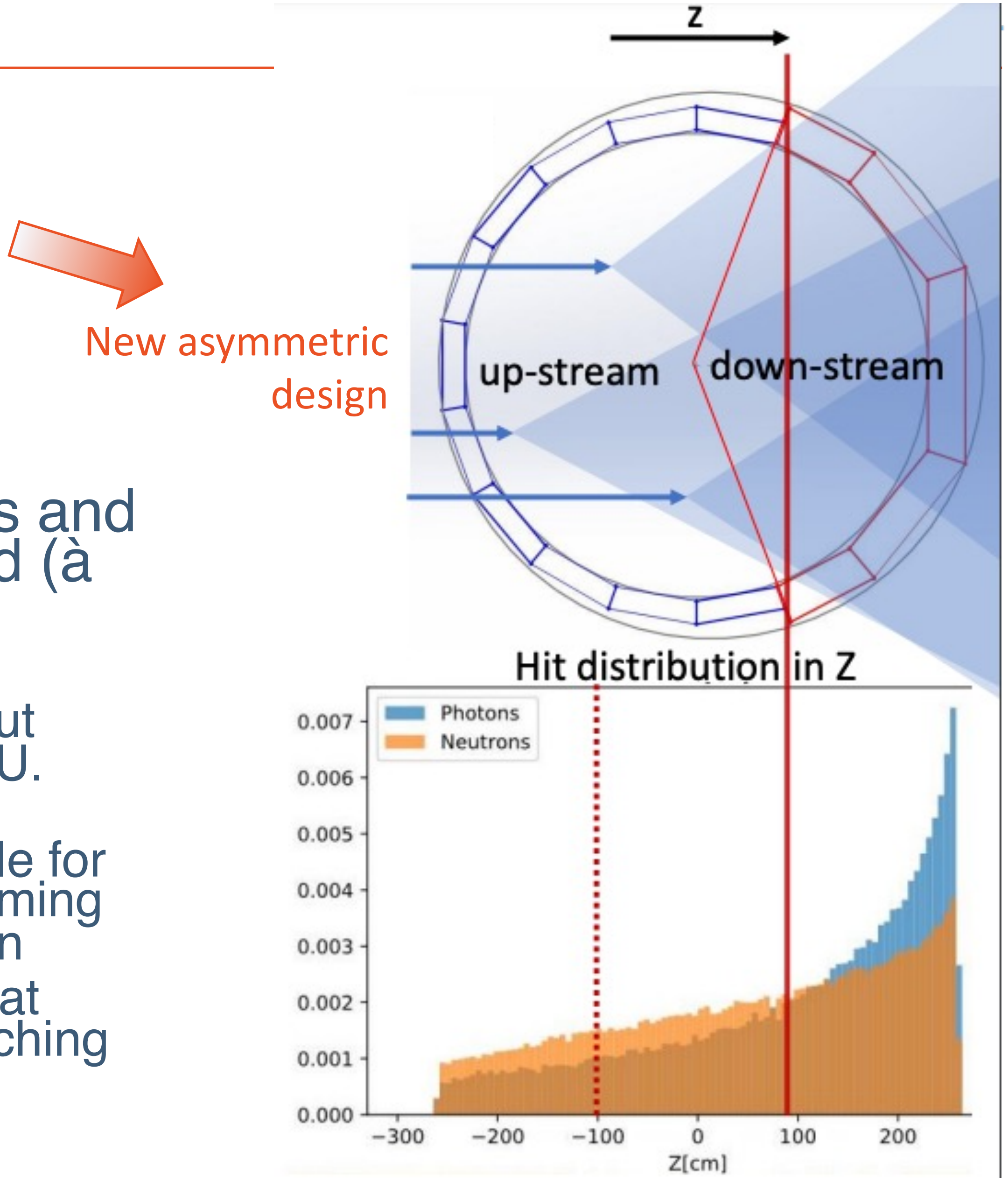
P. Hamacher-Baumann et al., Phys. Rev. D 102, 033005 (2020)



- 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





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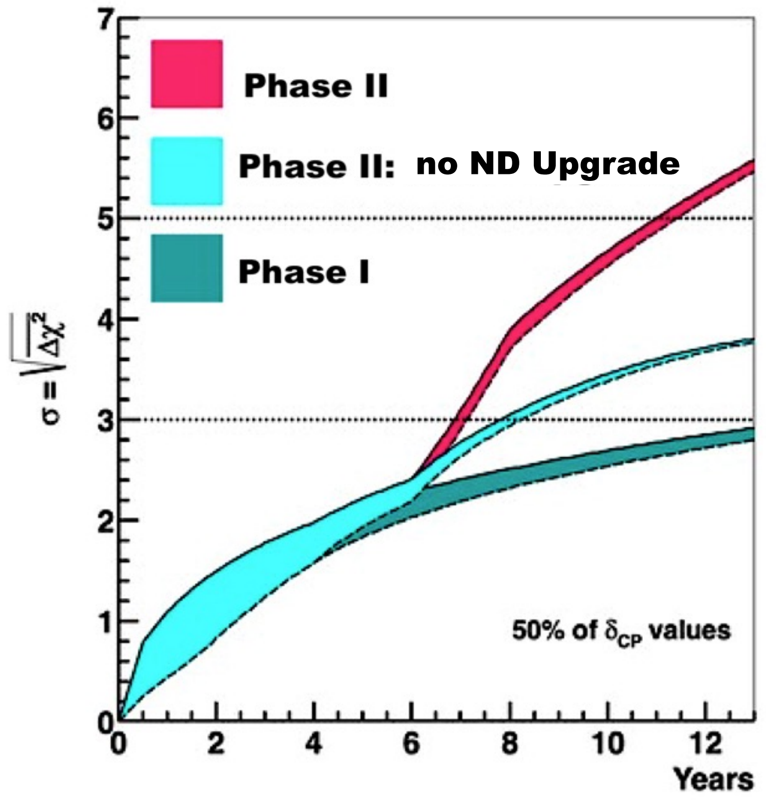
- General technology of plastic scintillator tiles and strips, read out by SiPMs, is well established (à la CALICE), but some ND-GAr specific design/optimization work remains
  - Optimization of absorber layers geometry, readout granularity, mechanical structure (in progress at U. Mainz)
  - Design of 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

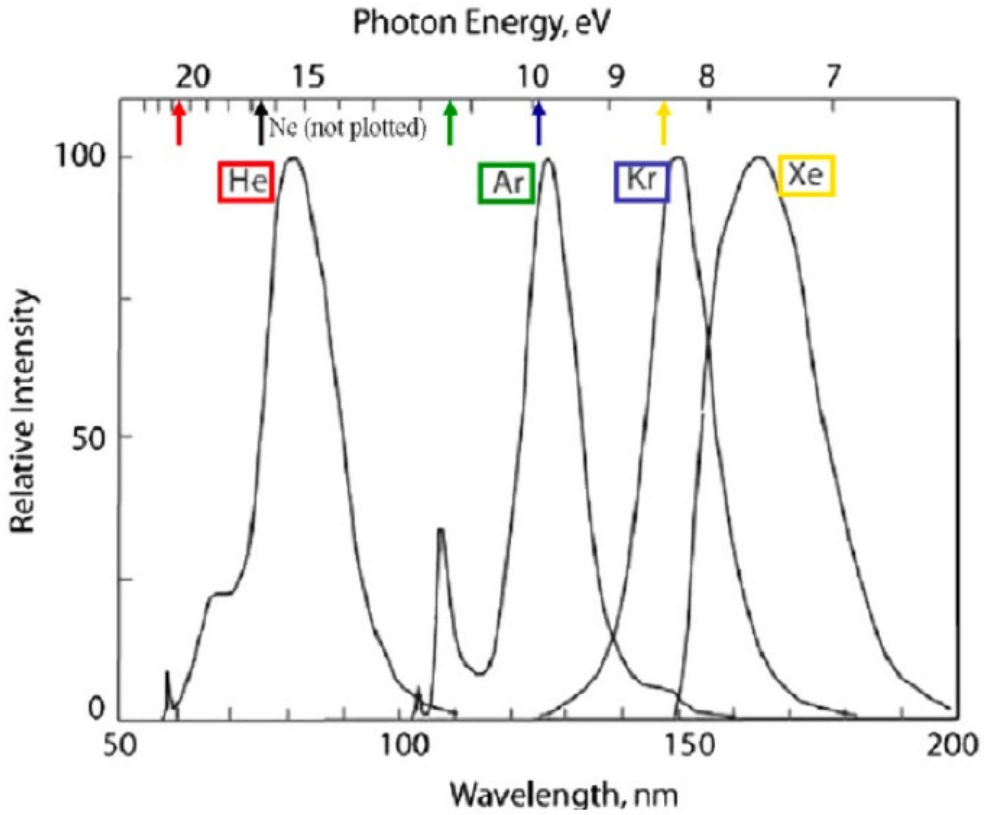
- An upgraded ND is essential for high-significance CP violation measurement
  - ND-GAr reference design meets these needs and enables DUNE Phase-II physics goals
- Detector design optimization can improve on that reference, and perhaps reduce costs?
- Several areas of active R&D
  - Gas mixture characteristics (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



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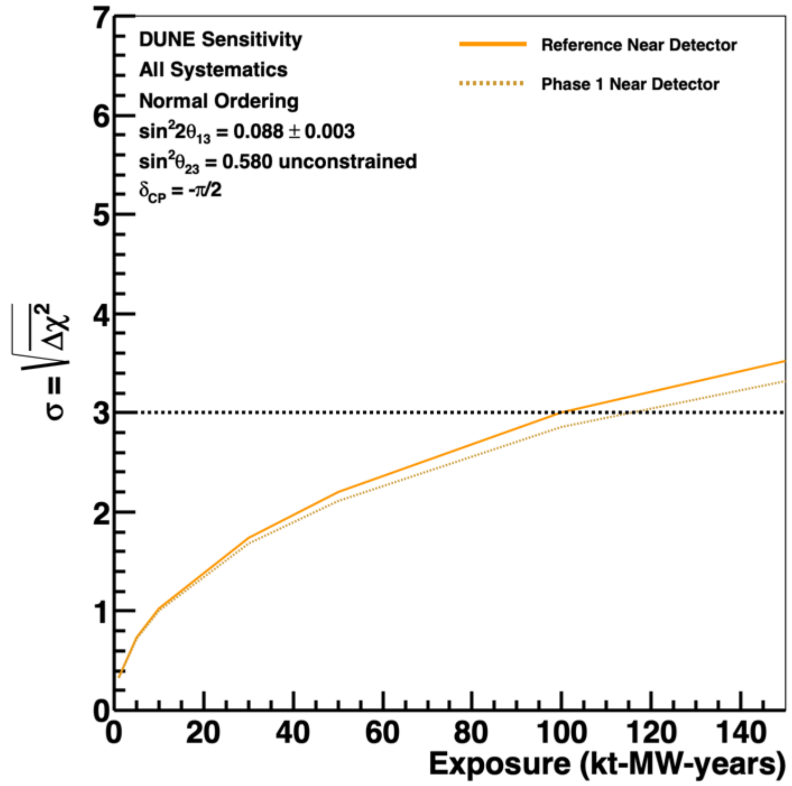
  - Photoelectric effect causes feedback/instability in wire chambers
- Typically, quencher gas added to gaseous detectors to eliminate scintillation and increase gas gain
- Consider a more modern approach, where dopant gas does more than quench the light
  - Initial work at IGFAE focuses on CF4

DUNE Phase-II Near Detector

CP Violation Sensitivity



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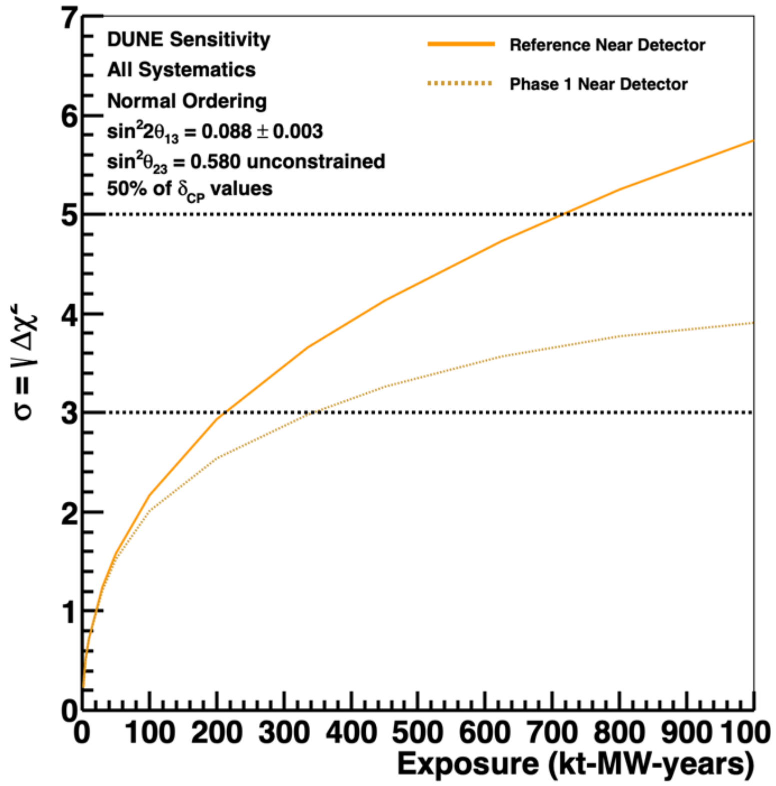
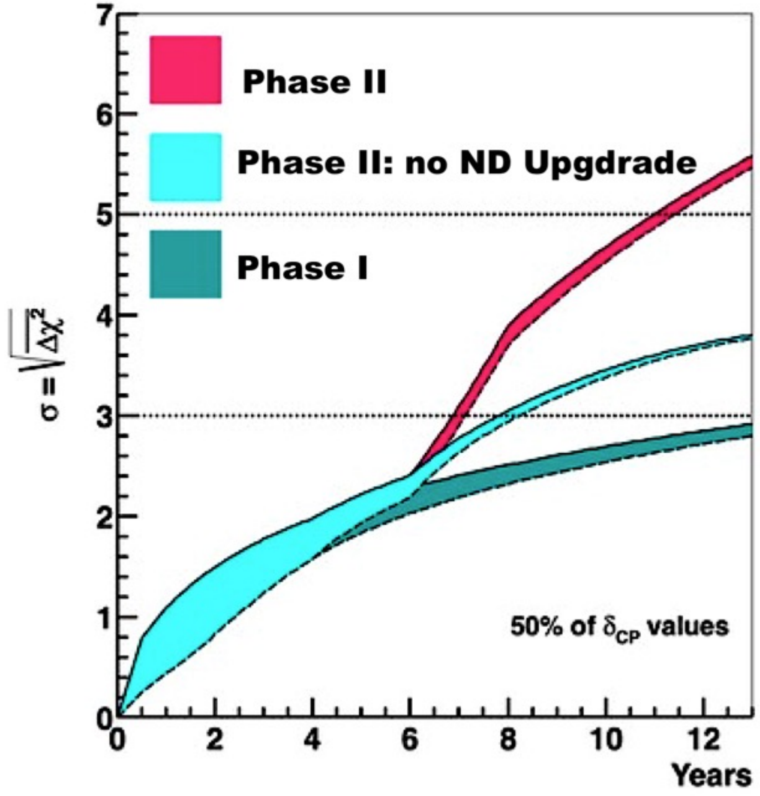


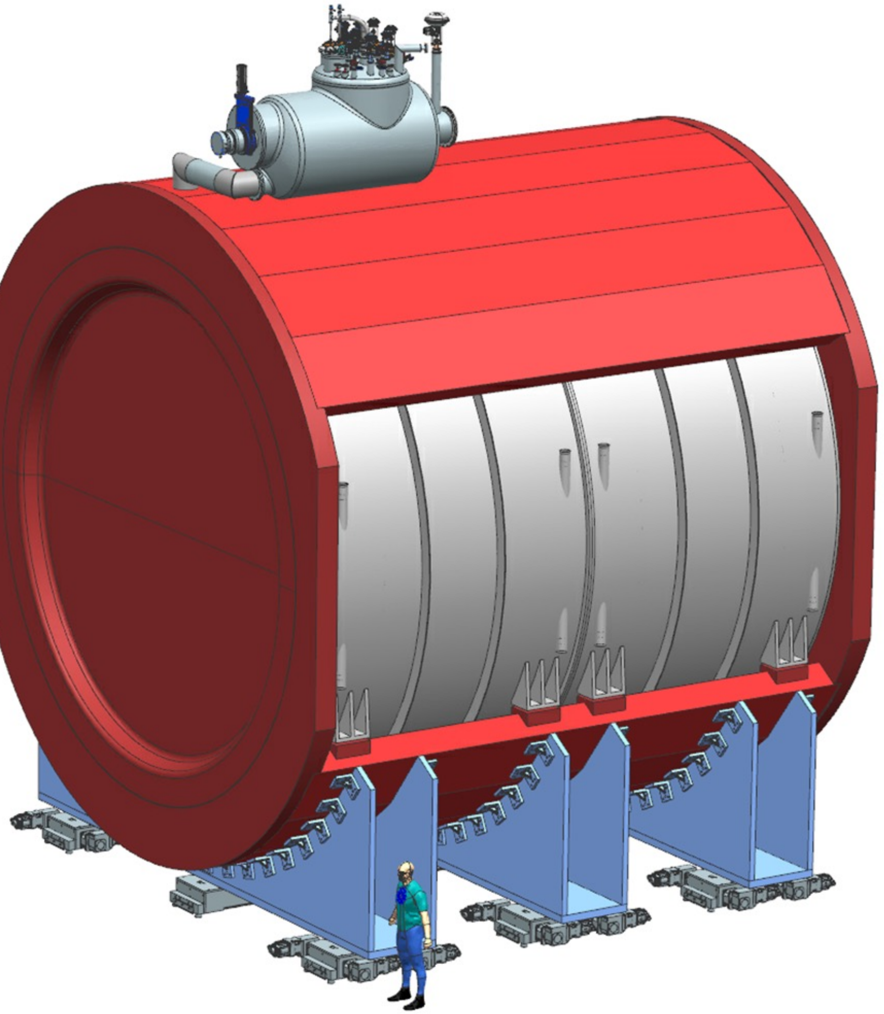


- If CP violation is maximal, the Phase-I ND (ND-LAr + TMS) suffices
- If nature is not so kind, a detector more capable than TMS is needed at the near site
  - ND-GAr meets the requirements to enable 5σ CPV significance for a broad range of δ_{CP} values

Magnet design

A. Bersani, A. Bross, et al.

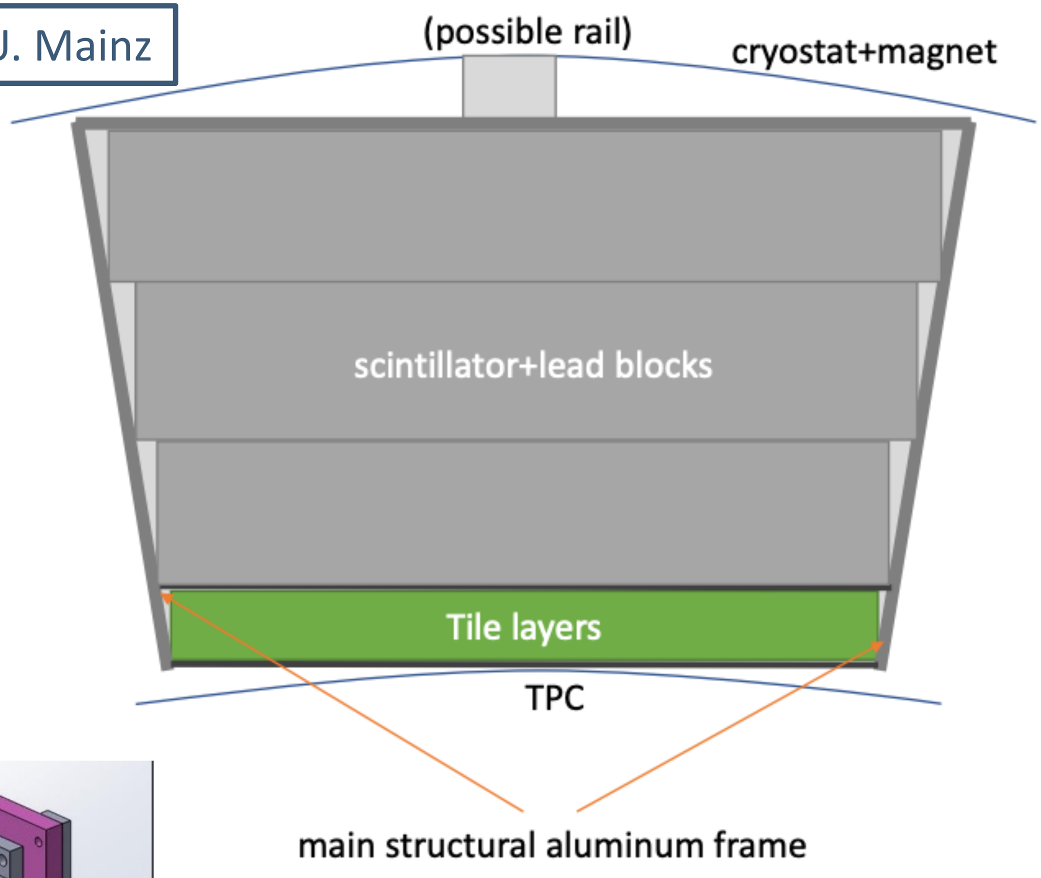
- Superconducting coils with pressurized region containing HPgTPC and ECAL
  - Central field 0.5T, 2% uniformity
  - Stray fields: negligible in SAND, ~10G in ND-LAr FV
- Upstream window in return yoke to minimize material between ND-LAr and ND-GAr
- Major developments since last meeting:
  - Completed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

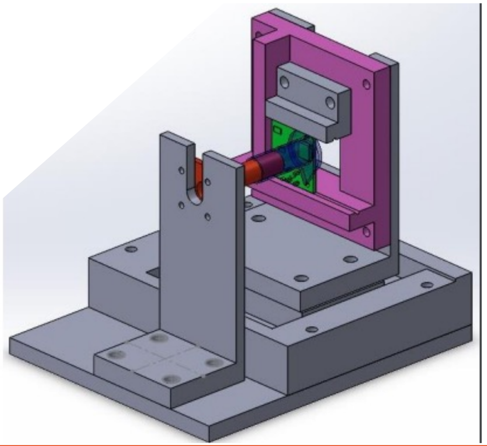


ECAL Modules

S. Ritter, U. Mainz

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





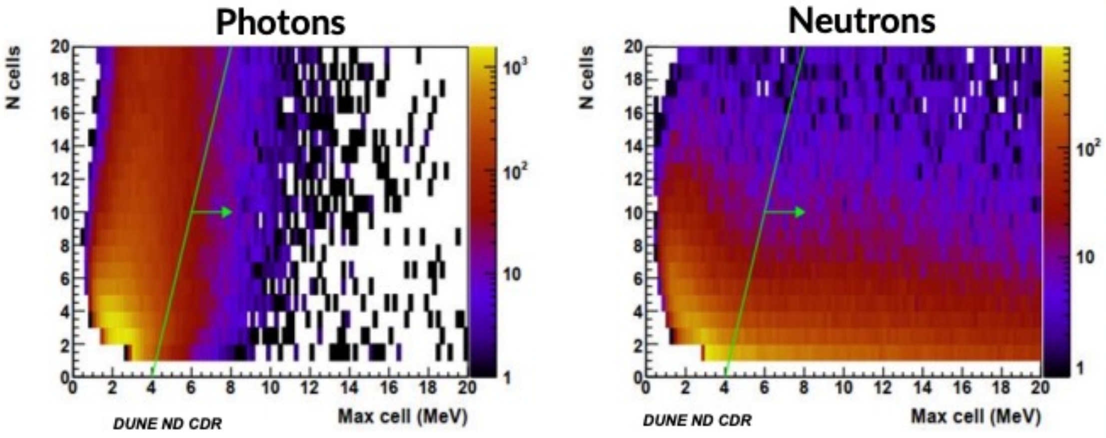
ECAL Neutron/Photon Pulse Shape Discrimination

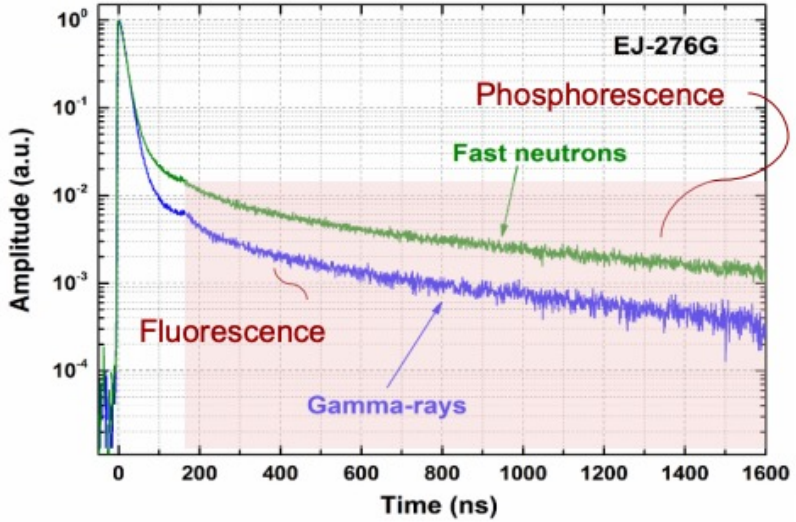
- Work in progress w/experimental test setup at Mainz

S. Ritter

Distinguish between photons from π^0 and neutrons.

Our project





Neutron and photon-induced clusters are separated based on:

- Total number of hits in the cluster.
- Total energy of the cluster.
- Maximum hit energy.

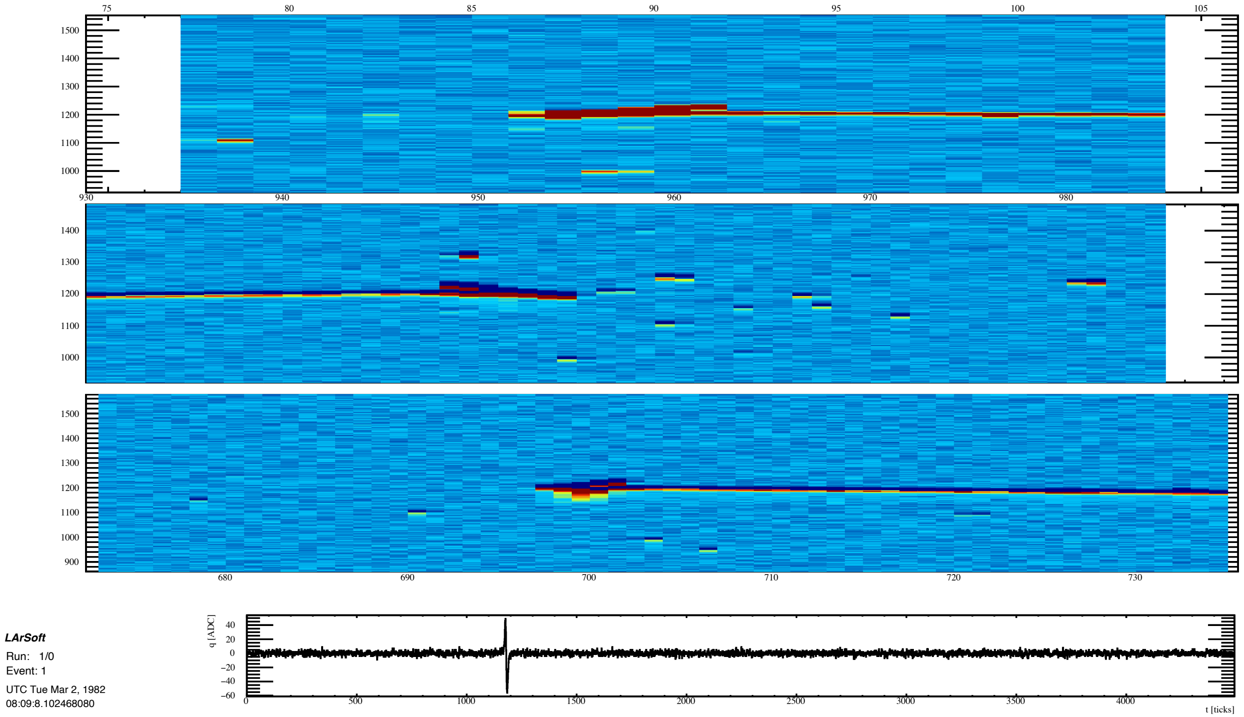
Use difference in scintillation profiles to bring additional information:

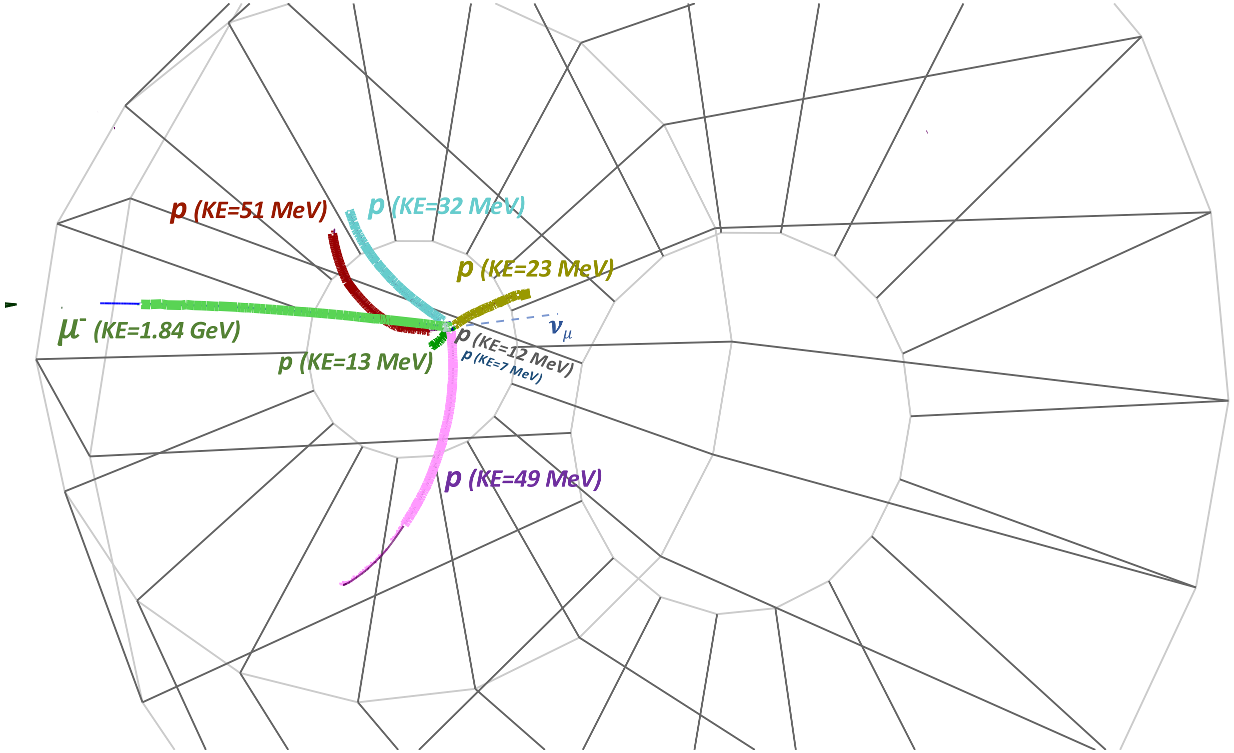
Pulse Shape Discrimination (PSD)

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

18 | 26.01.2022 | Sebastian Ritter I DUNE ND-GAr ECAL Concepts | JG|U

LAr vs. GAr: same neutrino event





- Neutrino interaction with 1 muon, 7 low energy protons, and 9 neutrons
- Lower density gaseous argon → particles travel further (and therefore easier to detect and reconstruct their tracks)