

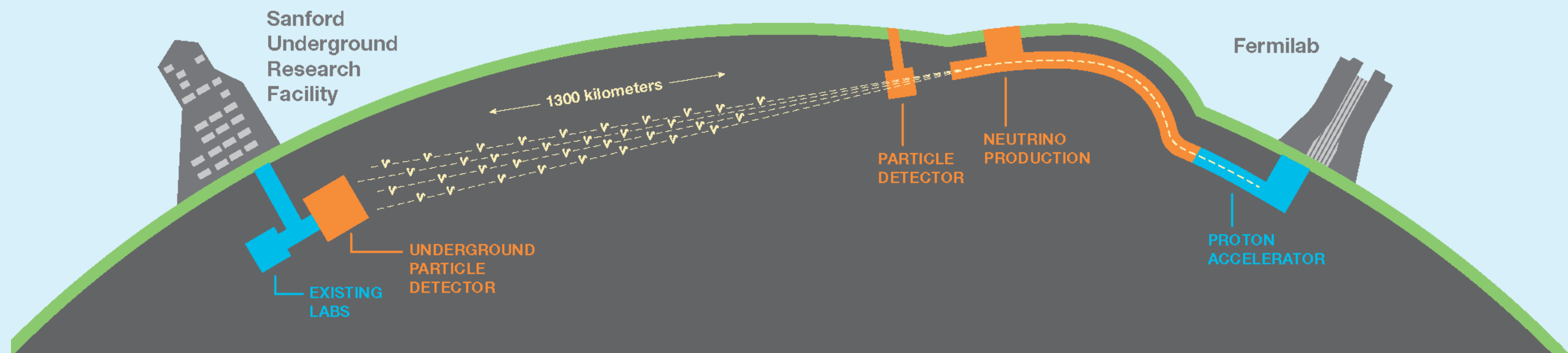
DUNE ND-GAr light collection: introduction and overview

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The Deep Underground Neutrino Experiment is a next-generation long-baseline oscillation experiment between Fermilab (Illinois) and the Sanford Underground Research Facility (South Dakota) consisting of

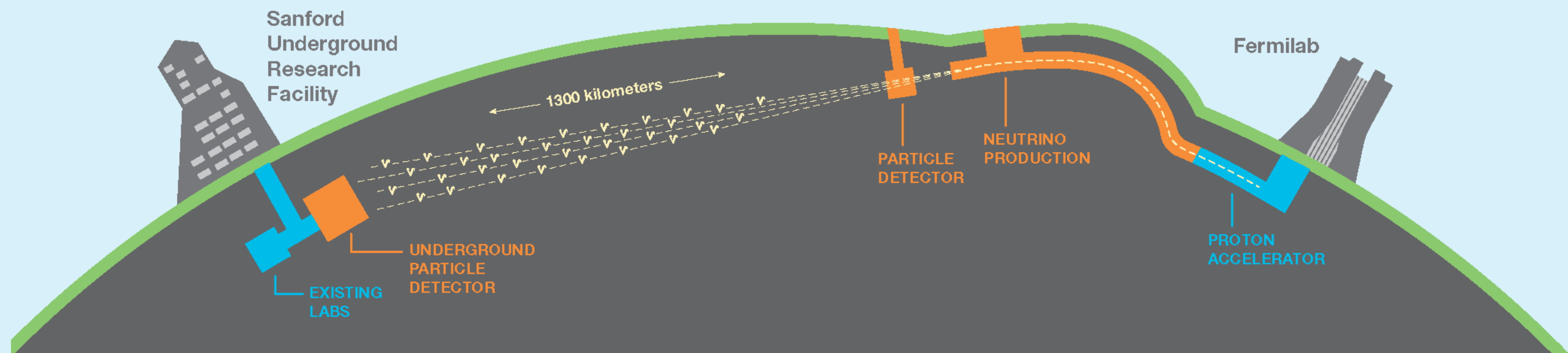
- a new MW-scale neutrino beamline (LBNF);
- a 40-kilotonne (fiducial) liquid argon far detector (FD);
- a high-resolution, high-rate near detector (ND).





The primary science program of DUNE includes

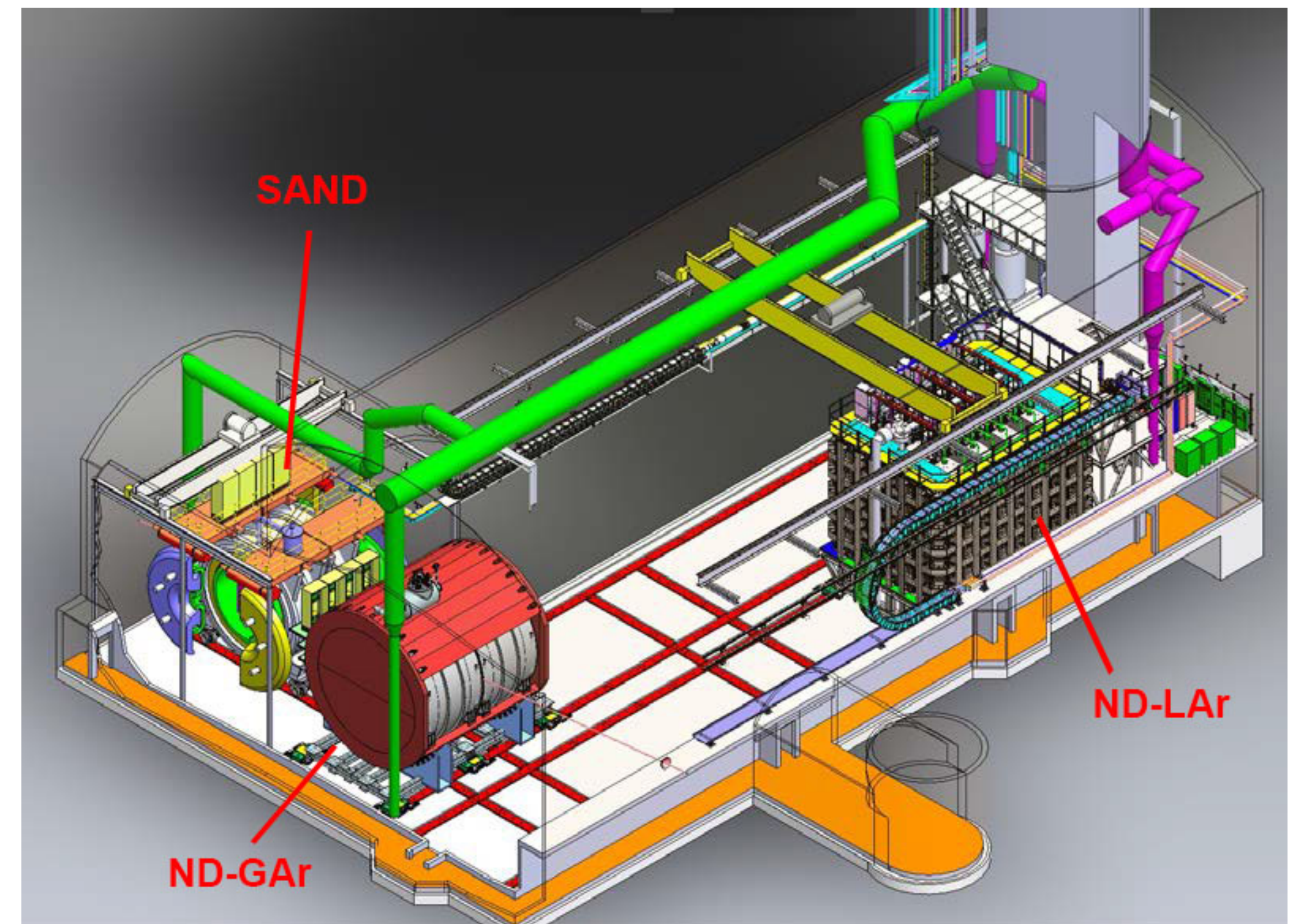
- The study of long-baseline neutrino oscillations (neutrino mass ordering, CP violation, precision measurement of flavour mixing);
- Neutrino astrophysics (e.g. core-collapse supernovae);
- BSM physics searches (e.g. nucleon decay, sterile neutrinos or dark sector).



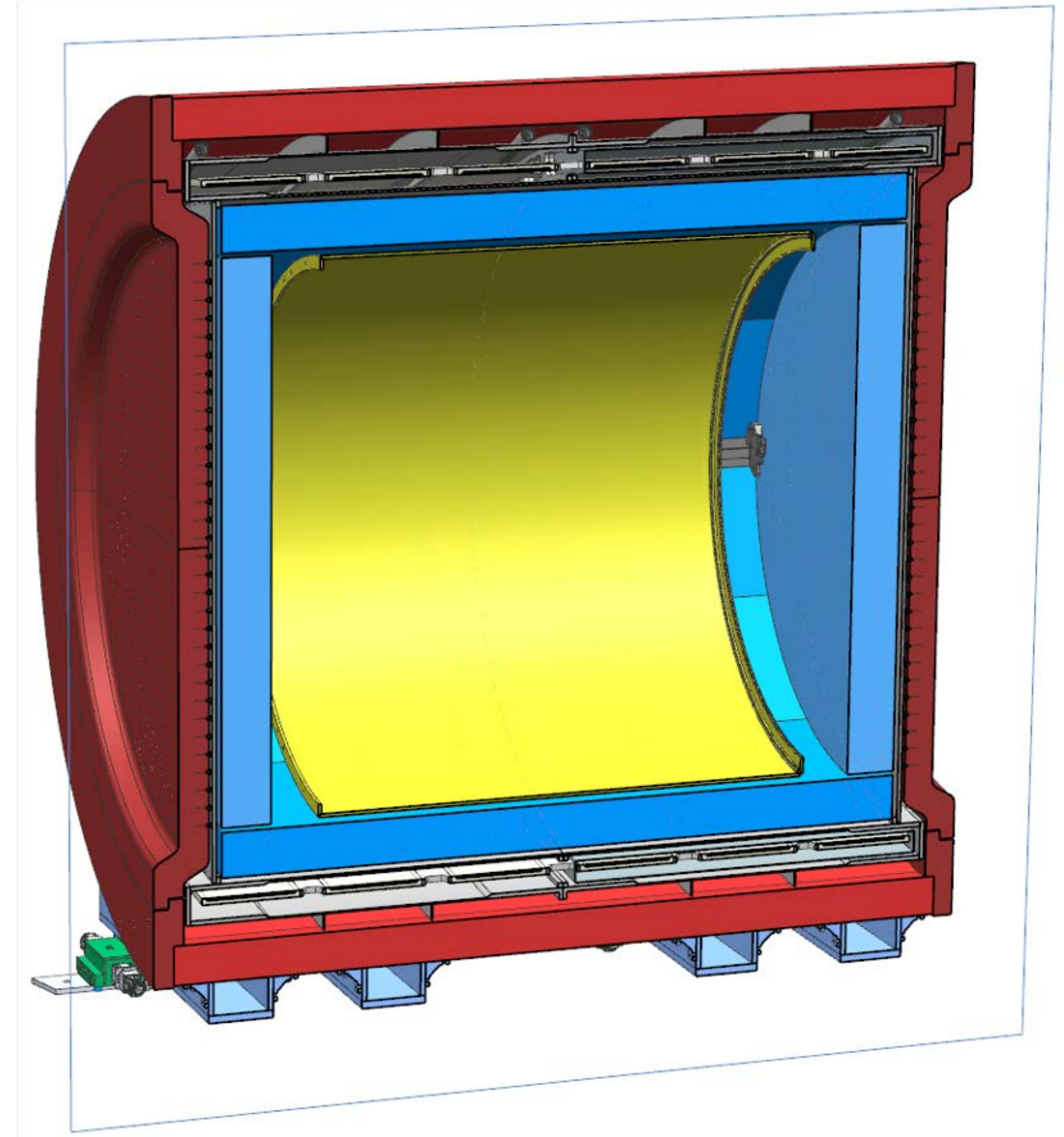
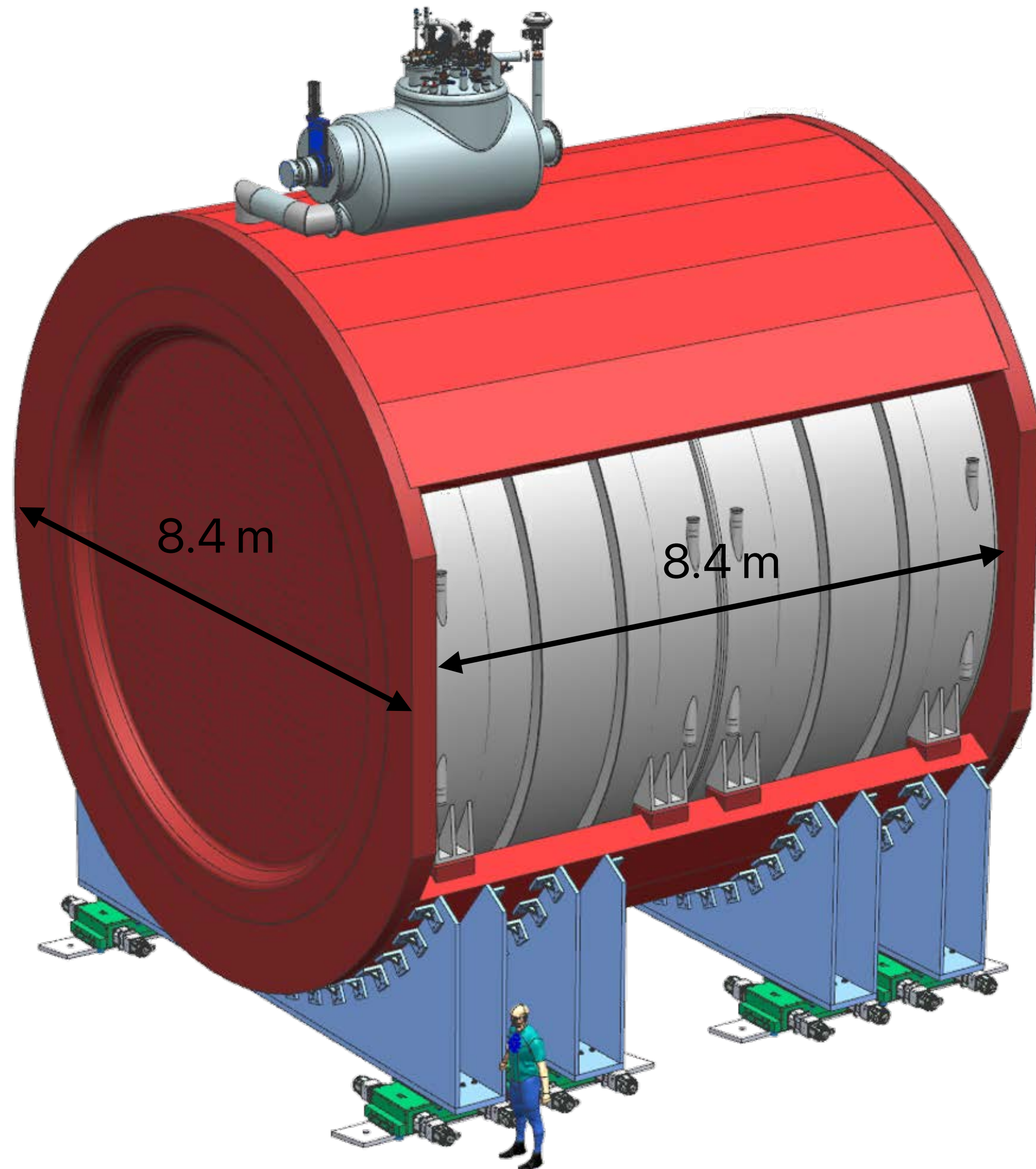
DUNE Near Detector

Four complementary elements:

- **ND-LAr:** 50t liquid argon TPC.
- **ND-GAr:** magnetized 1t high-pressure gaseous argon TPC + ECAL + muon catcher.
- **PRISM:** ND-LAr + ND-GAr move for exposure to off-axis fluxes.
- **SAND:** on-axis magnetized tracker for beam monitoring.



DUNE ND-GAr



DUNE ND-GAr

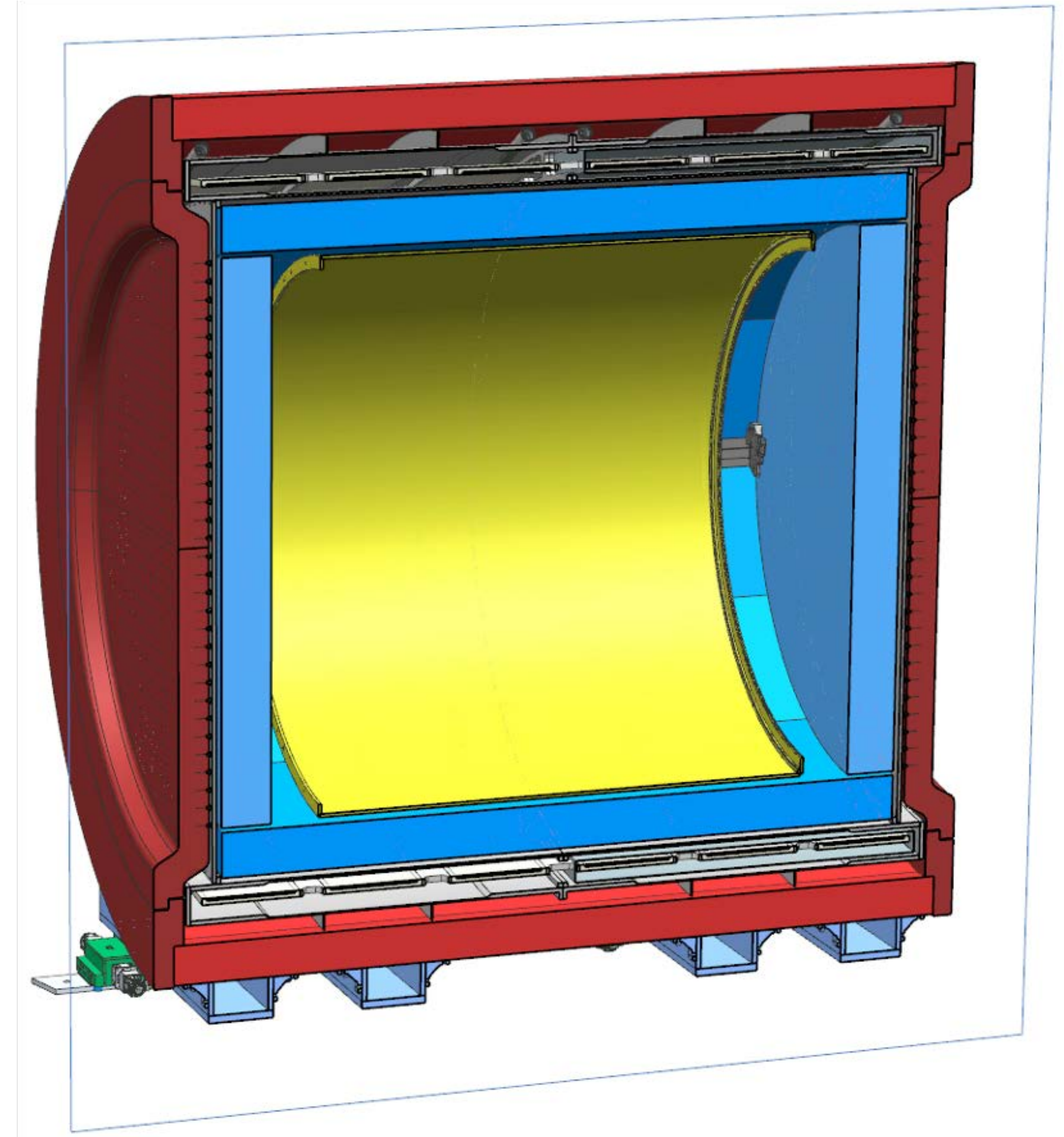
Cryostat contains

- Vacuum region for 6 superconducting coils;
- Pressurized GAr region that contains the TPC and ECAL.

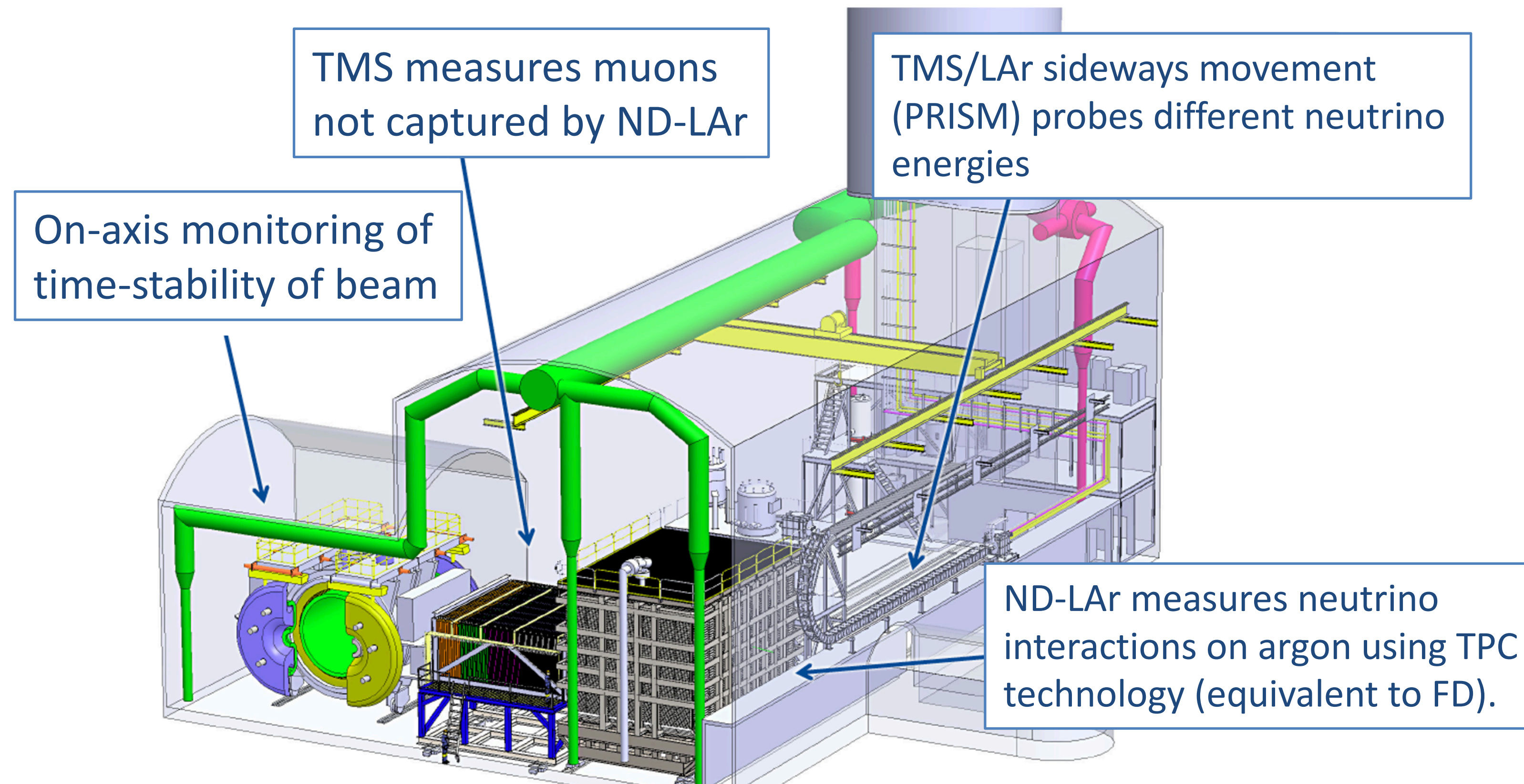
Stayed pressure vessel heads:

- A stayed head has braces ("stays") that allow a flat head to handle the internal pressure load.
- The 12-inch-thick iron yoke end flanges act as the strongback for each stayed head.

The entire detector is mounted on 8200-ton Hilman Rollers.



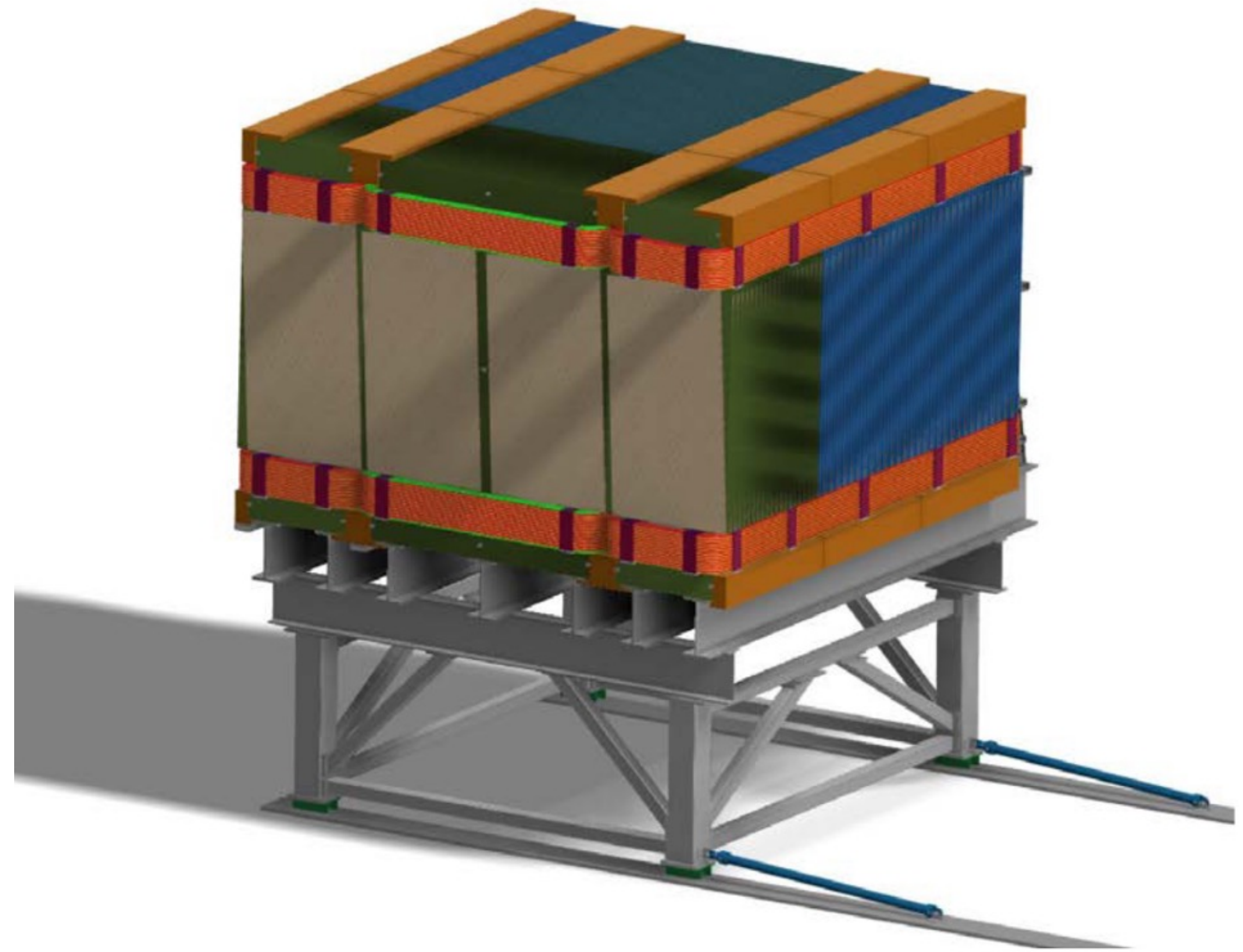
DUNE Day-1 ND



- Beyond Day-1: Replace TMS with ND-GAr (gas argon TPC) that will allow us to constrain interaction models.
- There is significant interest from international partners to support ND-GAr, but requires additional commitment to fund ND-GAr magnet.

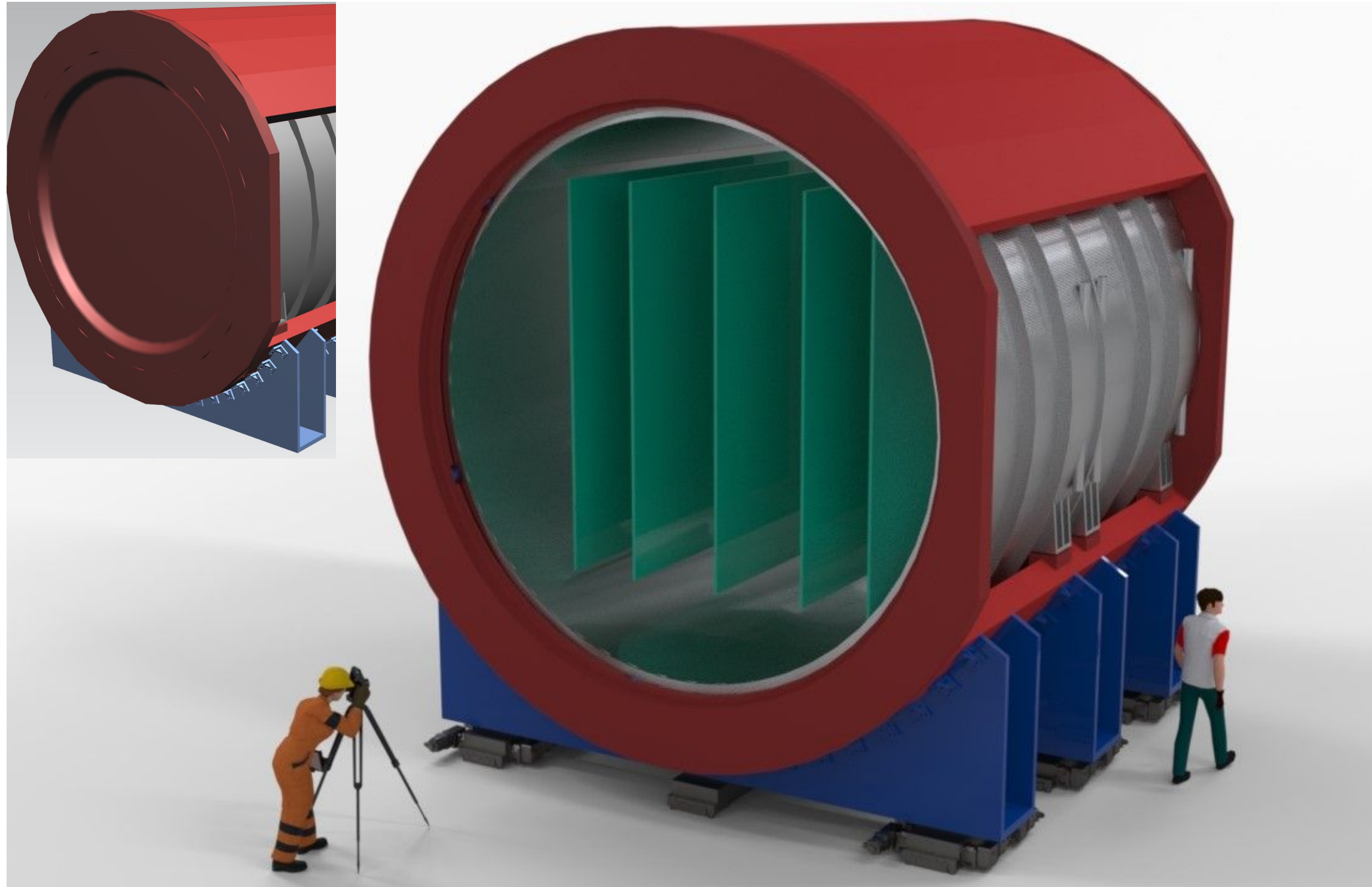
Temporary Muon Spectrometer (TMS)

- Magnetized range stack with 100 layers
- Located between SAND and ND-LAr
- Scintillator and steel
- Designed to measure muons ranging out from ND-LAr
- Entirely DUNE-US scope



7.4m wide x 5.0 m tall x 7m deep
~850 tons + base

ND-GAr Lite



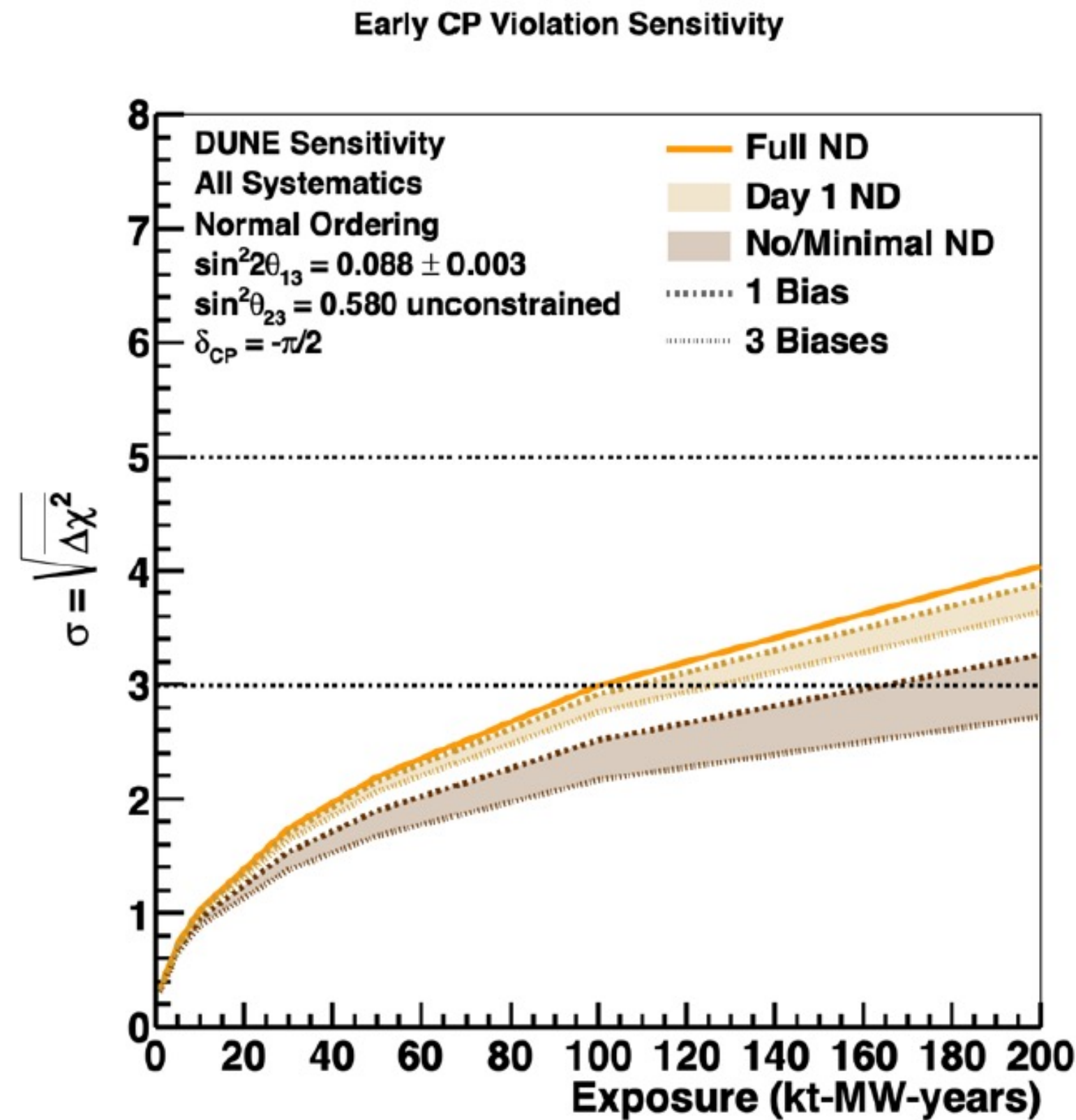
ND-GAr-Lite Design:

- Superconducting magnet including partial return-yoke (SPY design)
- Scintillator tracking planes
 - Nominal design of 5 tracking planes (6m W x 5m H)
 - Update of MINERvA
 - Similar electronics as SSRI
- ECAL modules could be added (but may degrade performance)
- “Window” in return-yoke to minimize energy loss for muons from ND-LAr

ND-GAr Physics Program

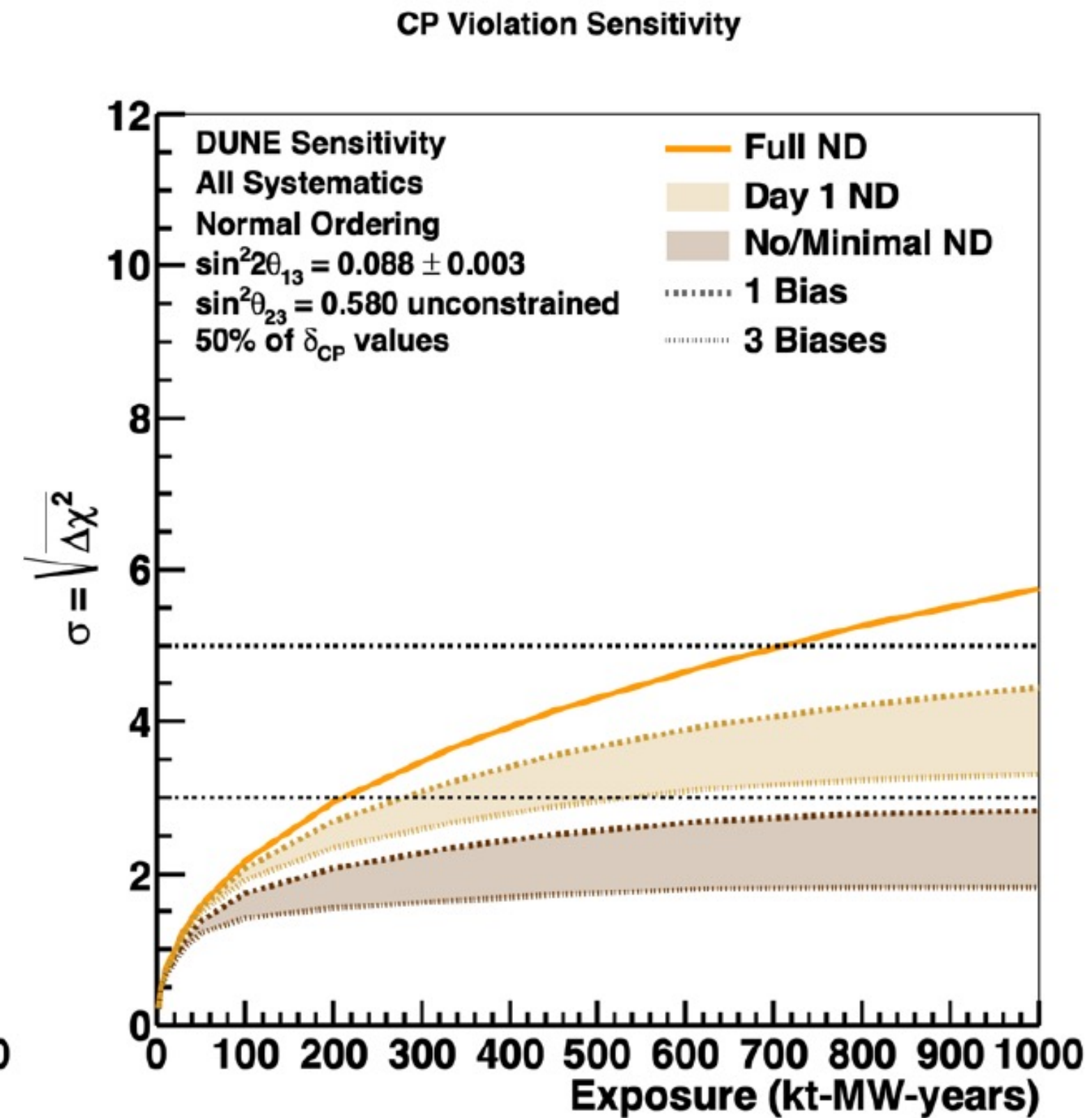
- Neutrino oscillations:
 - Measure muons exiting ND-LAr
 - Constrain systematic uncertainties on neutrino-Ar interactions
 - Precisely measure all components of neutrino flux.
 - Constrain ND-LAr detector response and selection efficiency.
- Neutrino interactions:
 - Exclusive interaction channels with greater resolution of vertex activity and fewer secondary interactions.
- Searches for physics beyond the Standard Model:
 - Heavy neutral leptons, neutrino tridents, dark matter, milli-charged particles...

Motivation for ND-GAr



Impact for Maximal CP violation:

- 3 σ not much
- 5 σ : ~30% more exposure

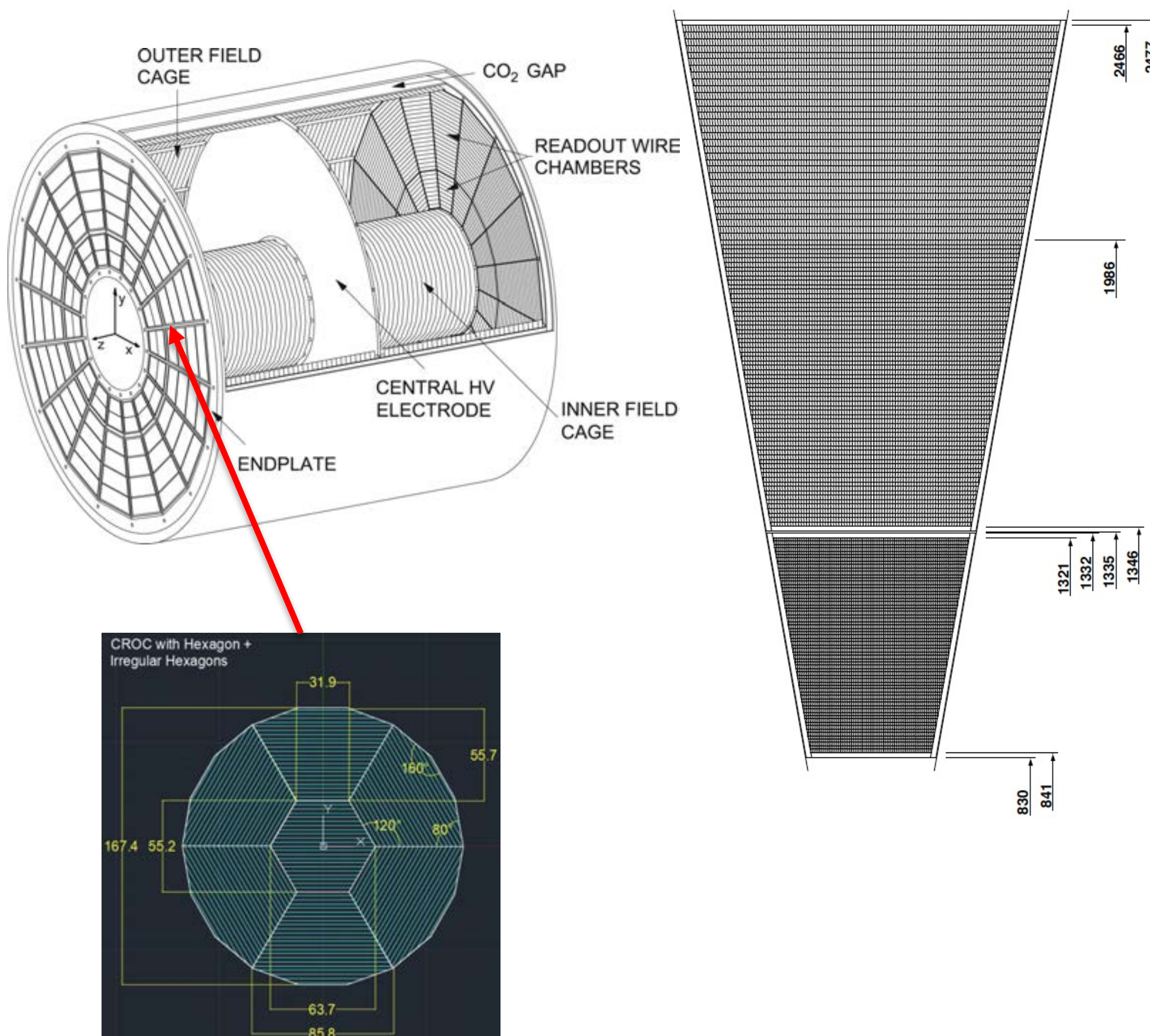


Impact on significance for 50% δ_{CP}

- Year 5: 3 σ requires significantly more exposure
- Year 10: 5 σ possibly never met

HPgTPC design (I)

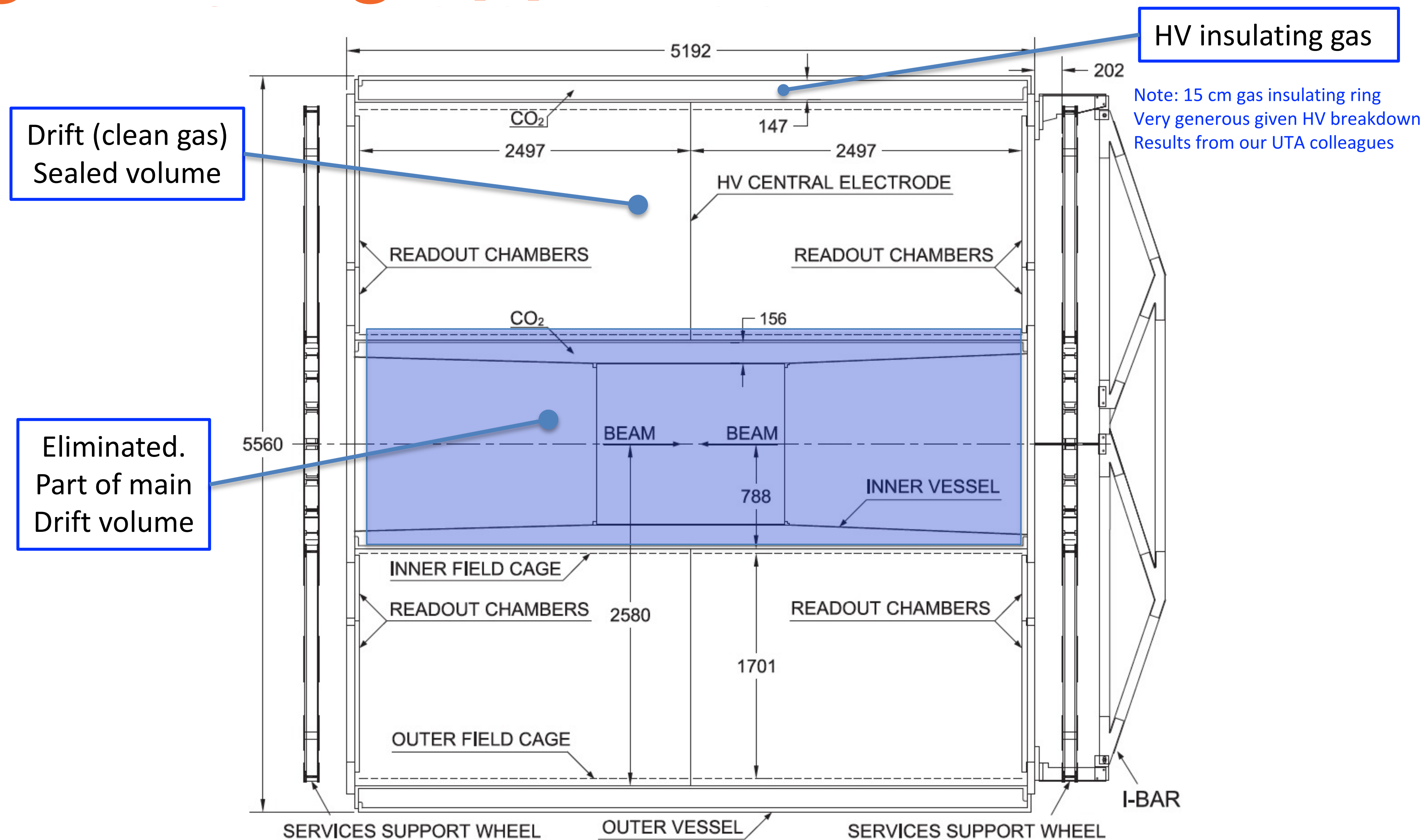
ALICE (18-fold symmetry)



Central readout chambers (2, new design)

- Pad readout ONLY. True 3D. No Wires
- Readout Pads (ALICE)
 - Inner chambers (36)
 - 4X7.5 mm² (5504/chamber)
 - Outer (36)
 - Inner rows: 6X10 mm² (5952/chamber)
 - Outer rows: 6X15 mm² (4032/chamber)
 - Total pads: ~554k
- Readout Pads (Central)
 - Still under study
 - Starting with 6X6 mm² pads as reference
 - ~125k
- Total channels: ~680k
 - Typical voxel occupancy/spill ~ 0.03%

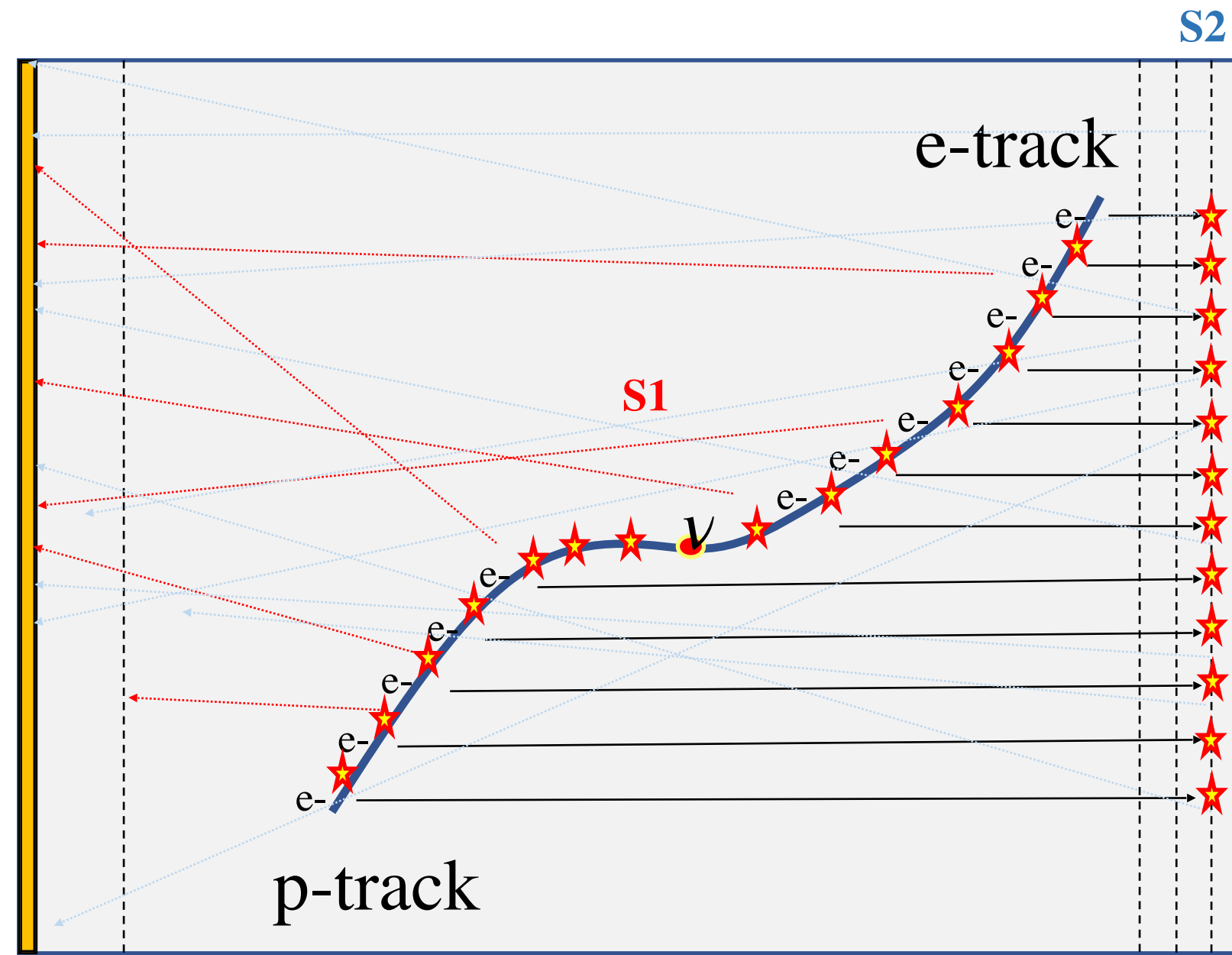
HPgTPC design (II)



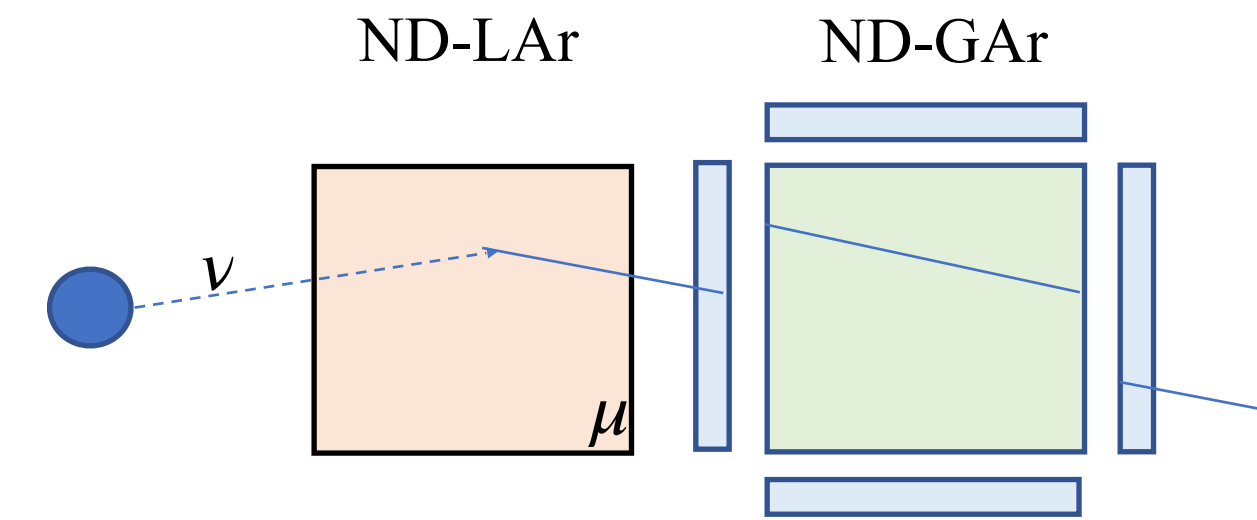
Why enabling optical readout in ND-GAr?

optical readout

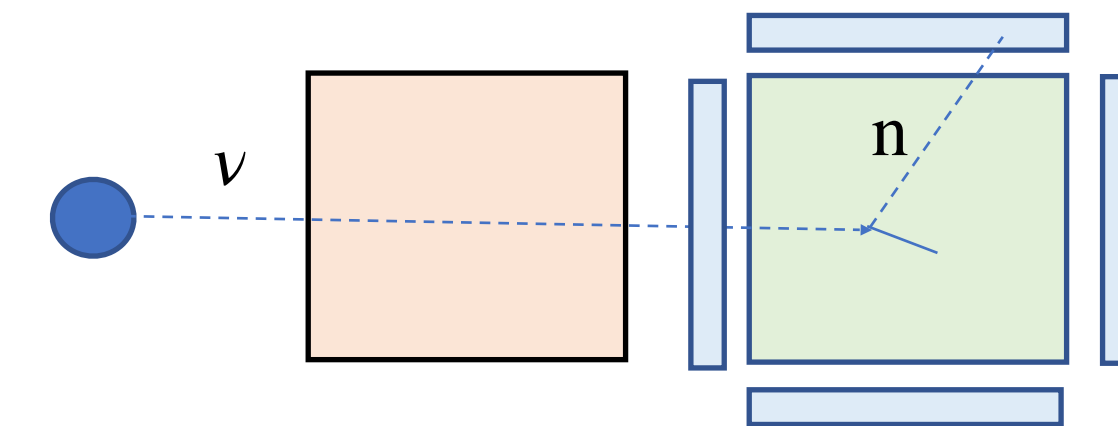
avalanche multiplication



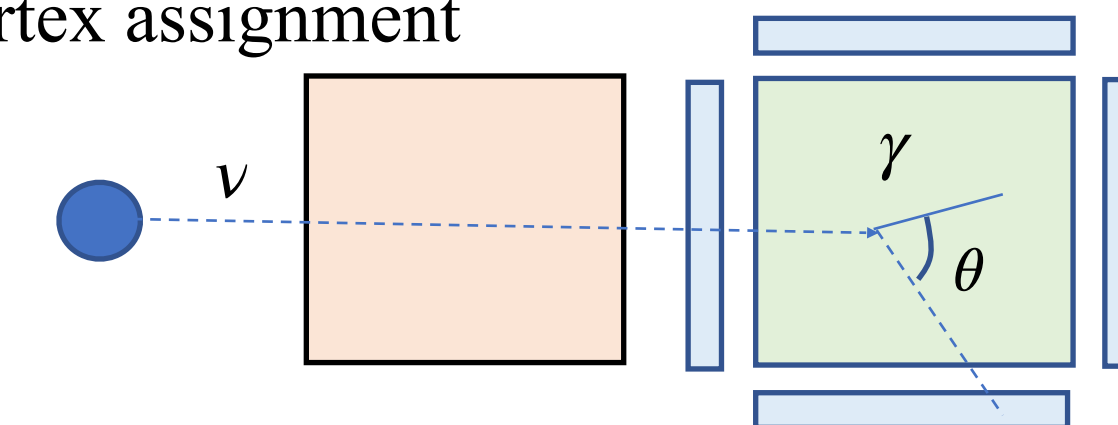
a) Improved track matching with ND-LAr



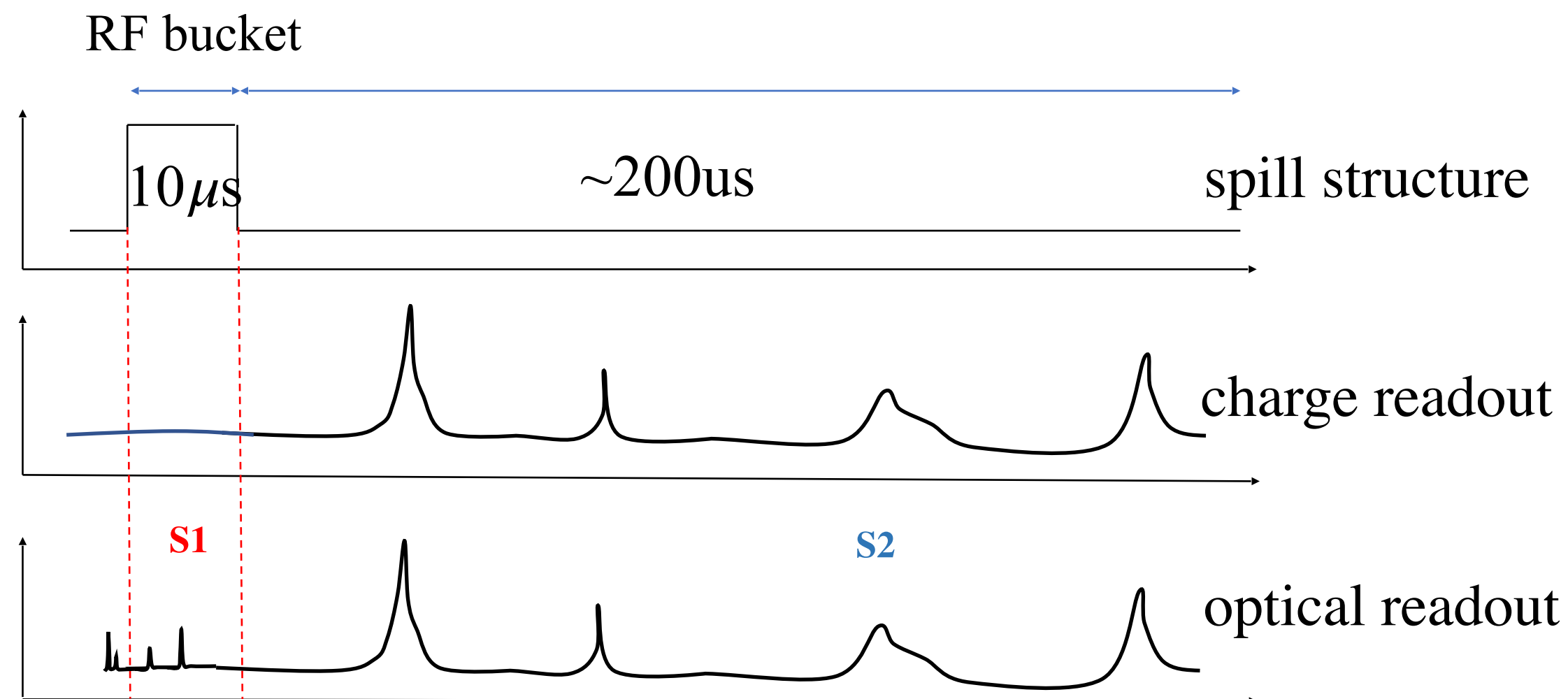
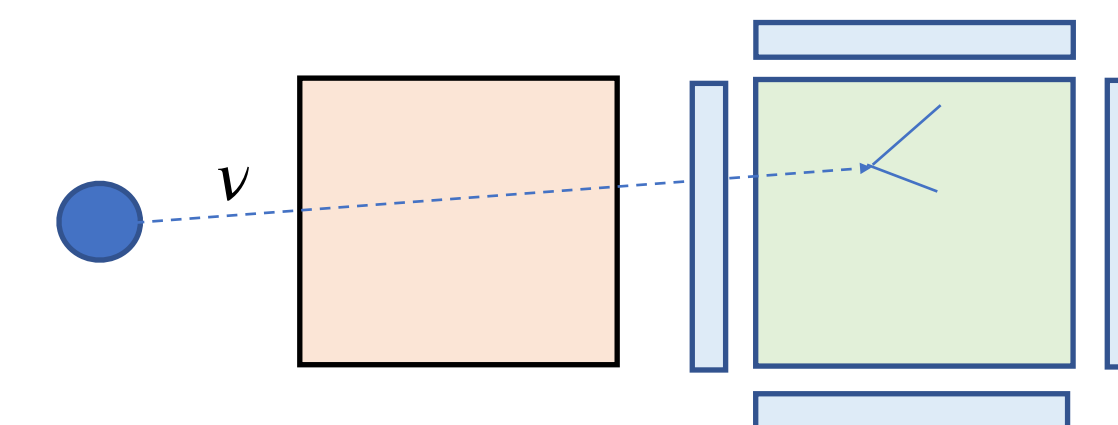
b) (n-c) Neutron reconstruction via ToF



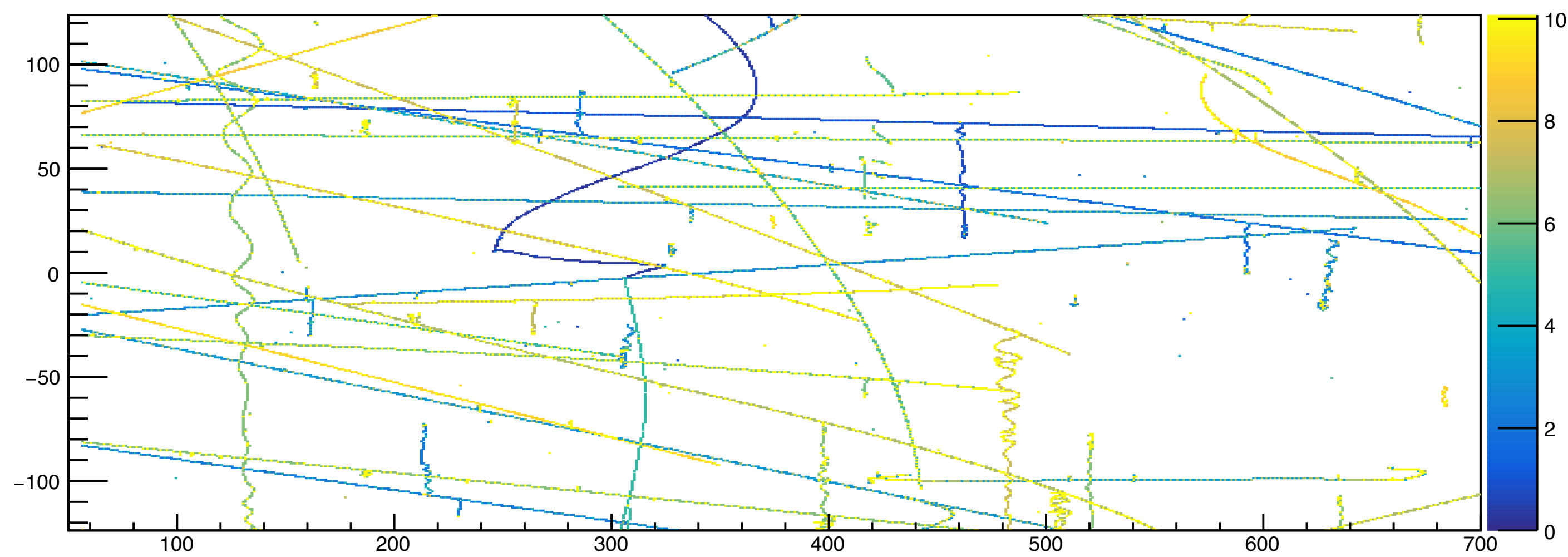
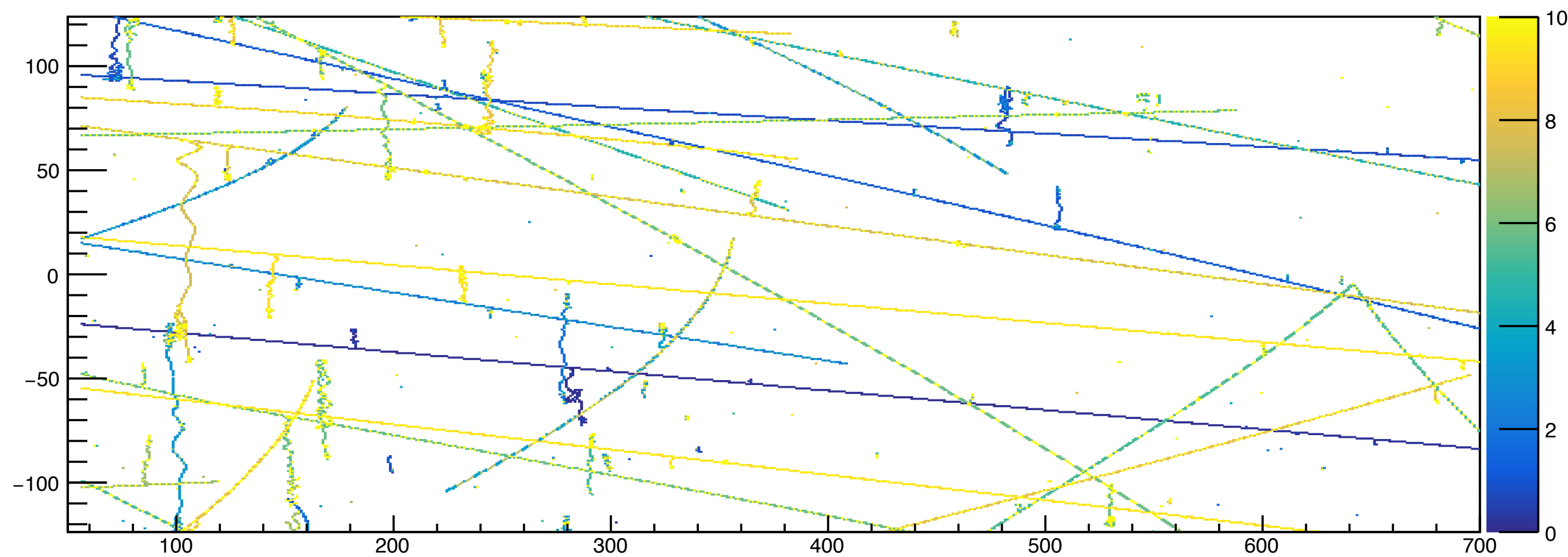
b') (n-c) Improved n, γ angular reconstruction, vertex assignment



c) Low energy nuclear physics and BSM



Motivation for T_0

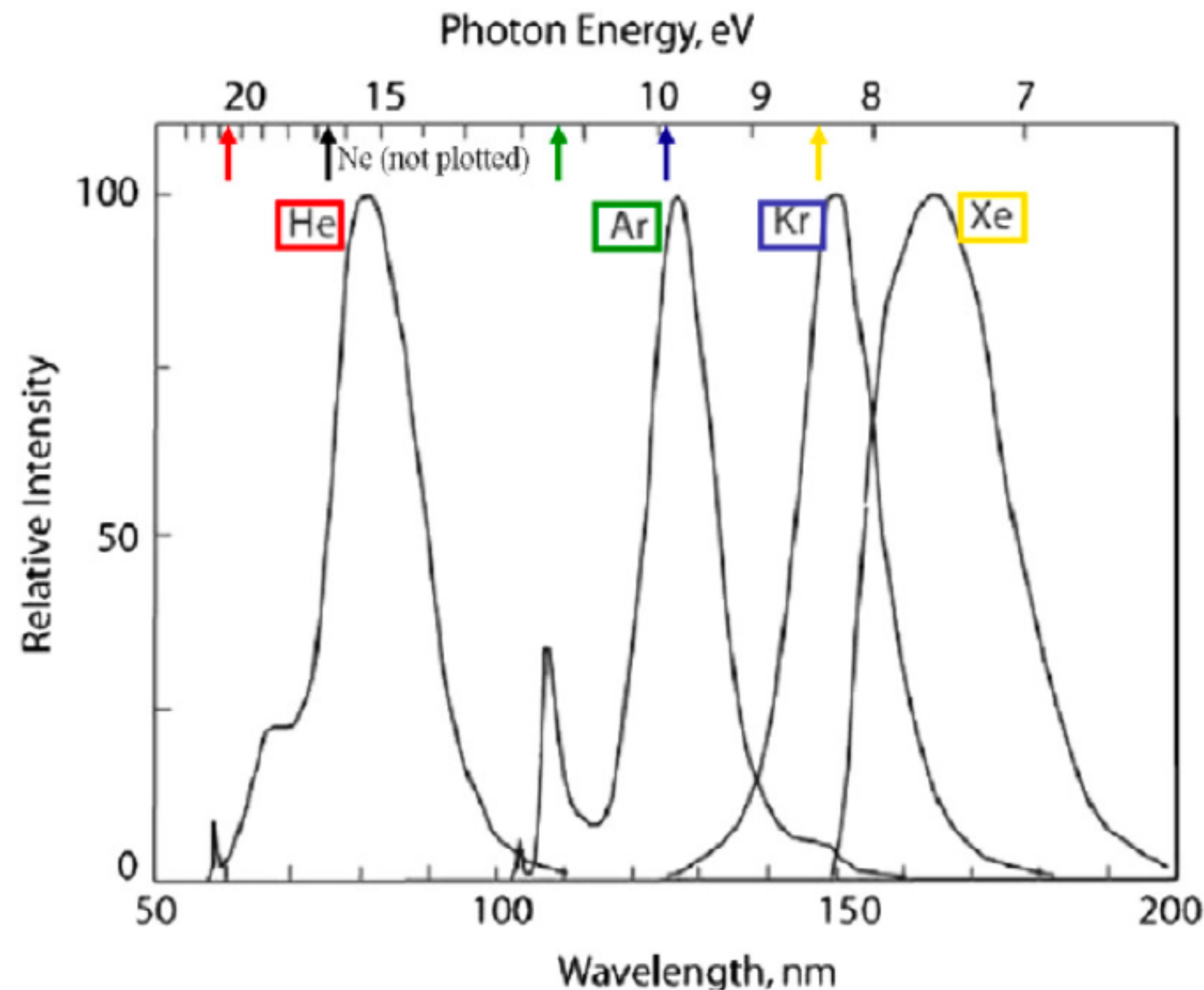


Motivation for T_0

- Complex TPC events with tens of interactions distributed along the 10 microseconds of the beam spill.
- Redundancy between scintillation and ECAL may help timing all interactions.
 - Particularly important for interactions circumscribed to TPC (e.g. neutral-current neutrino interactions or low-energy phenomena).

The technological challenge

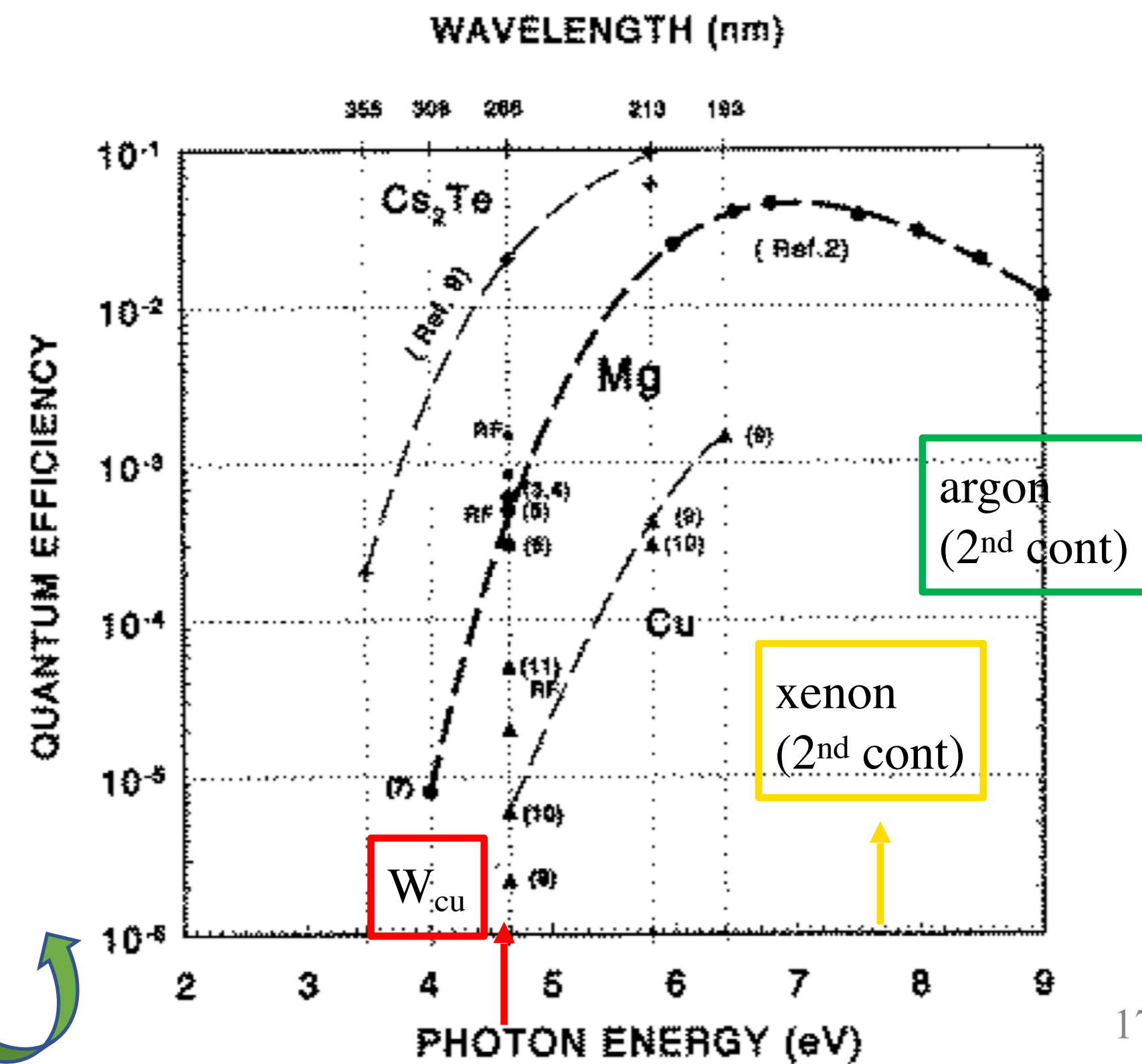
noble gases scintillate in the VUV (2nd continuum)



- Traditionally, quenchers are added to Ar (e.g., CH₄), to eliminate scintillation and increase MWPC gain.
- There are, however, more modern approaches, where the dopant does more than just quenching.

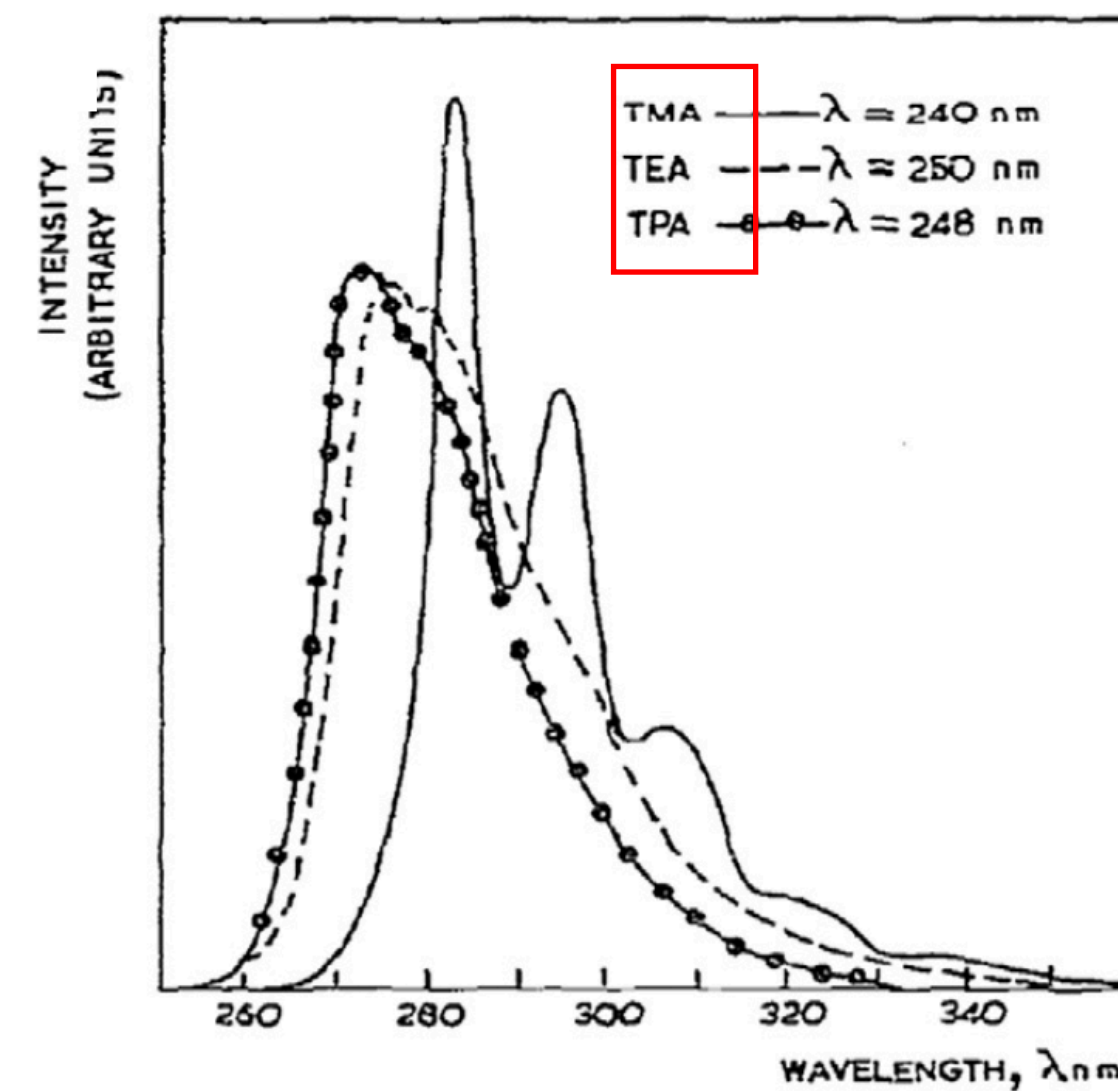
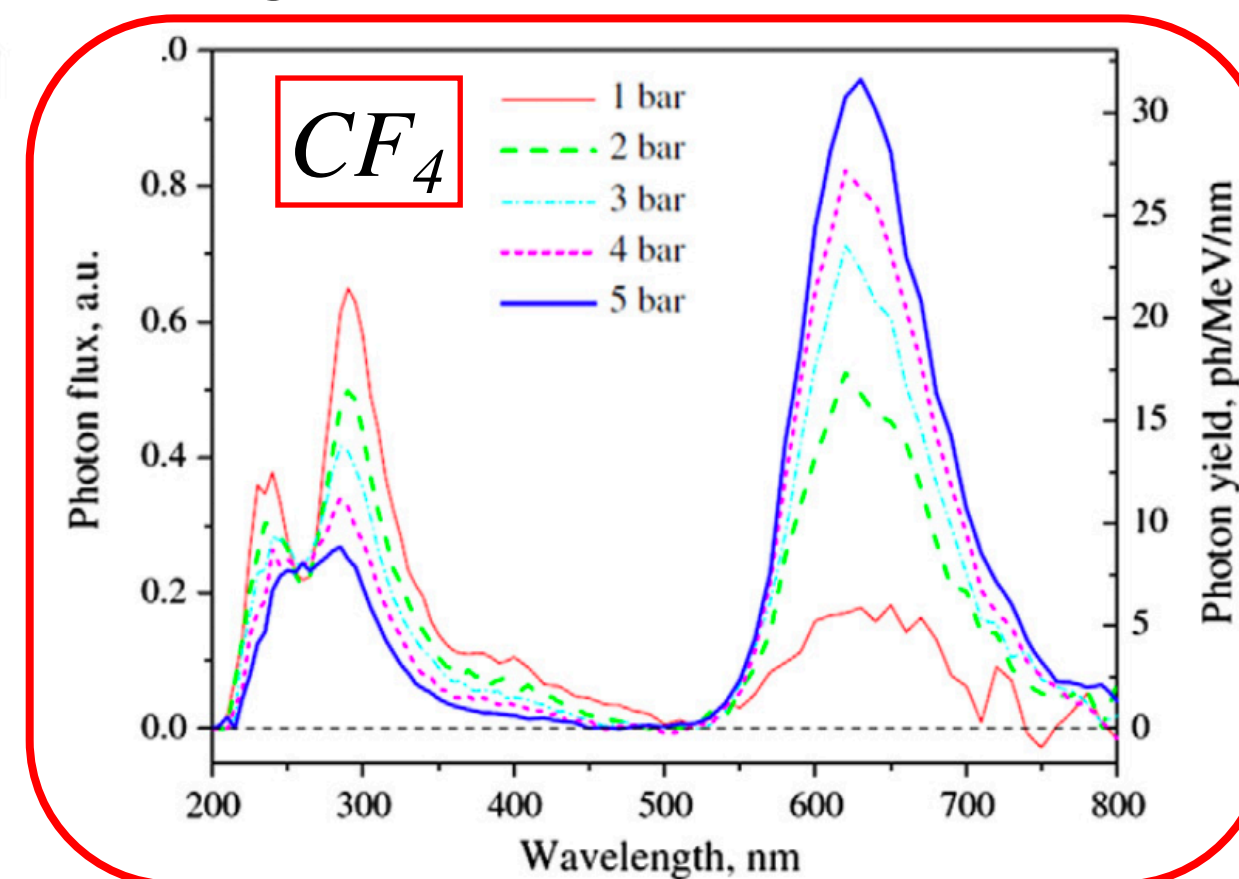
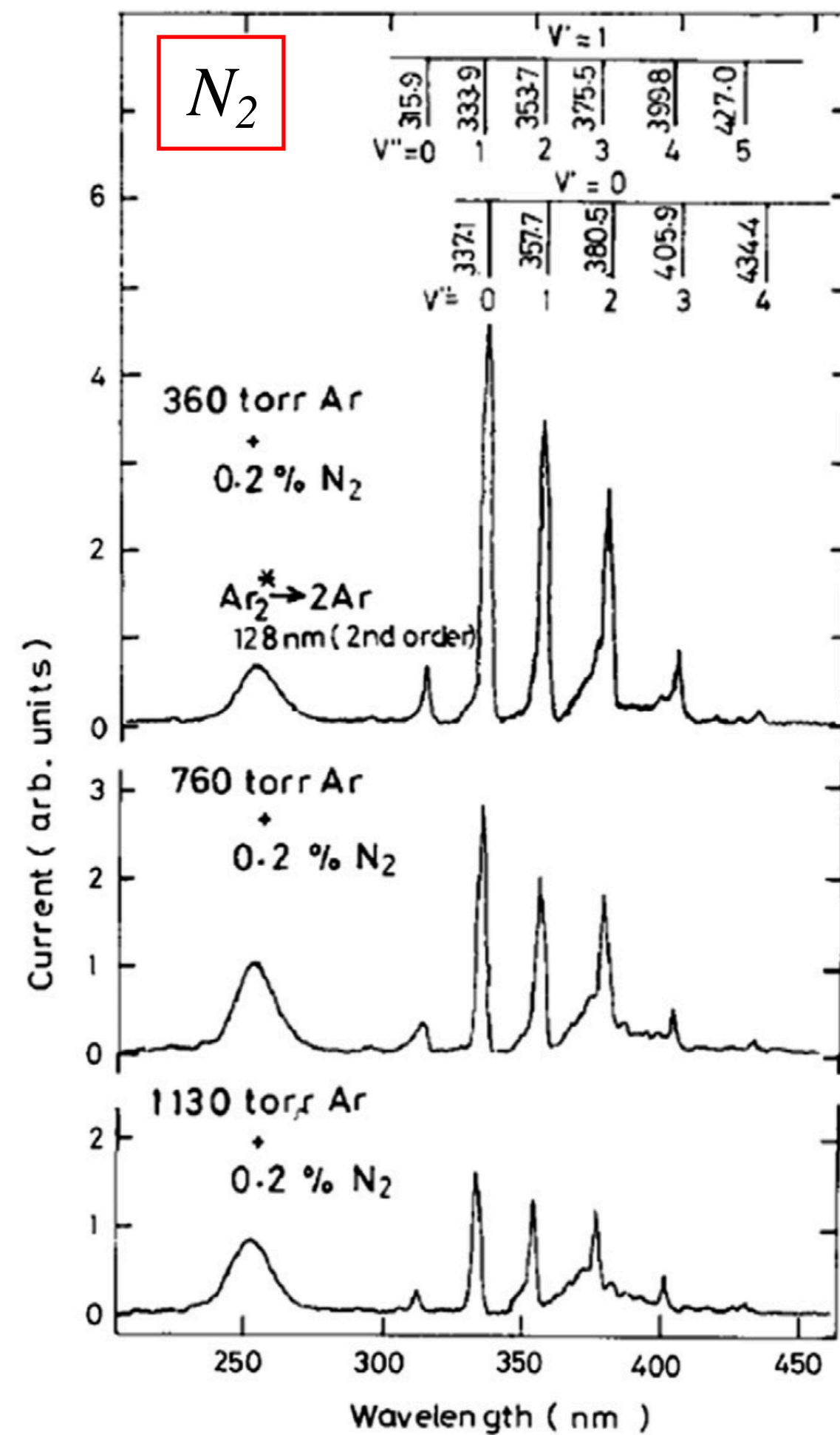
...and

photoelectric effect causes feedback in wire chambers!

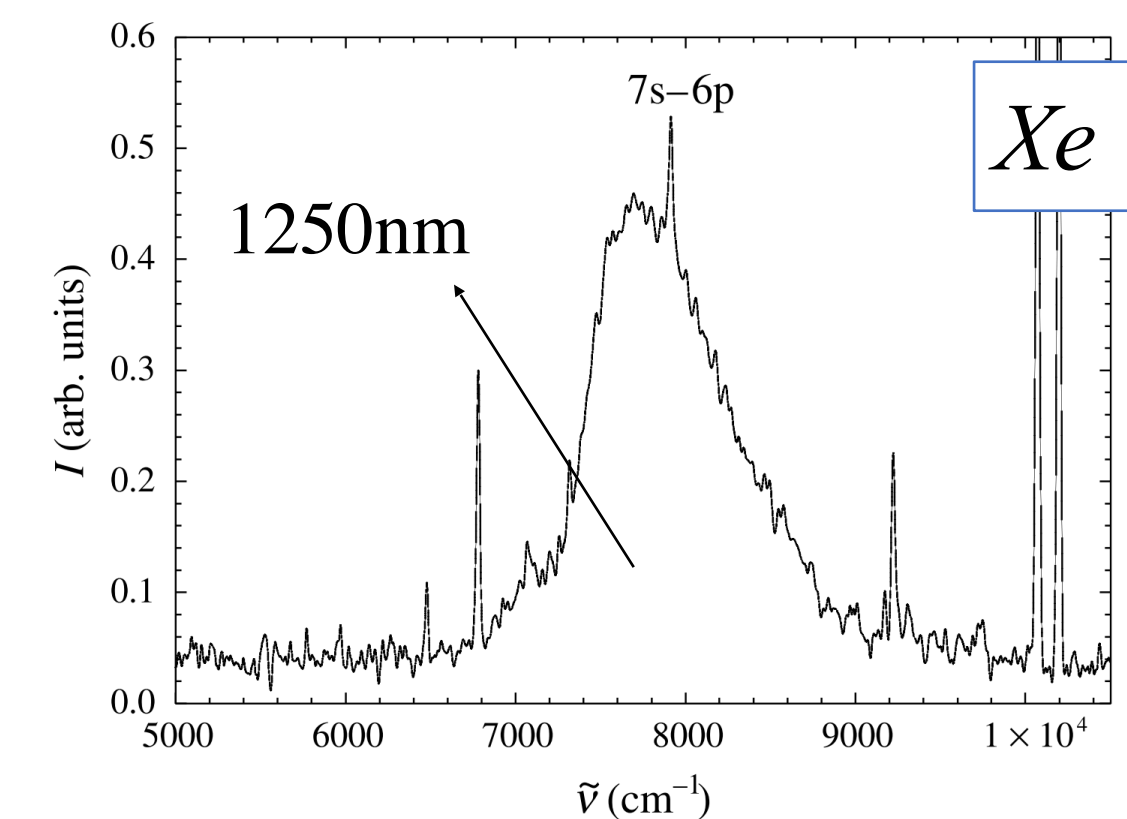
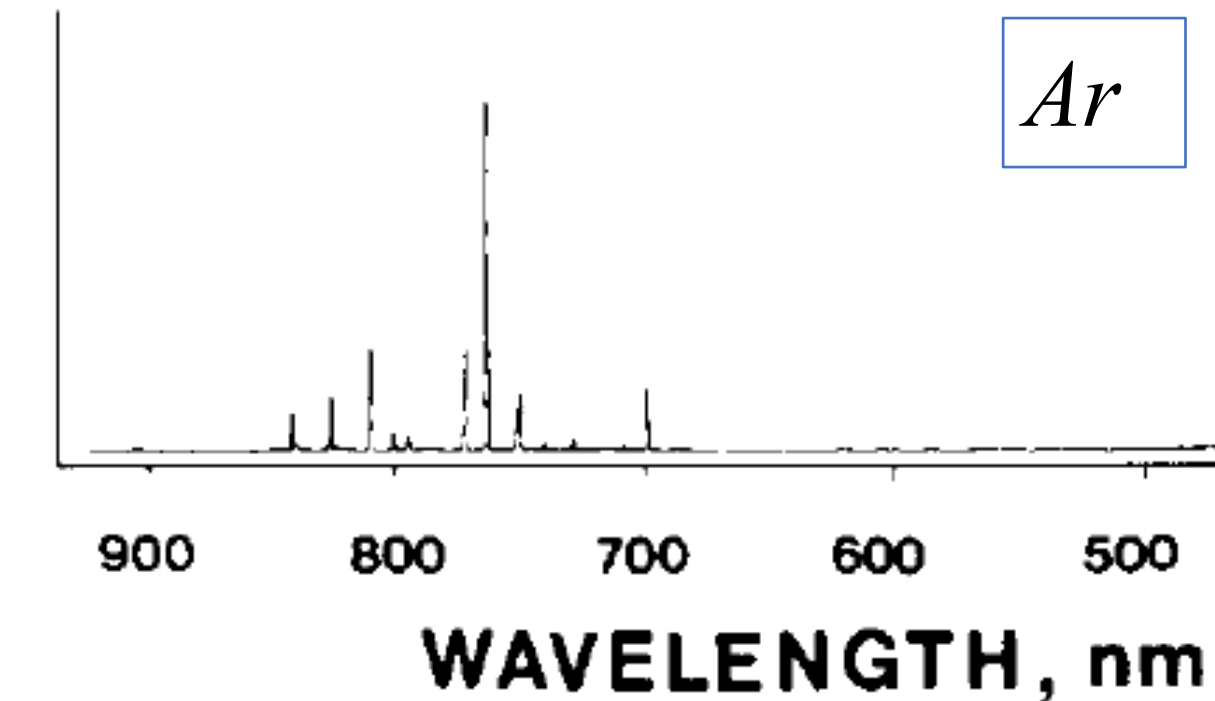
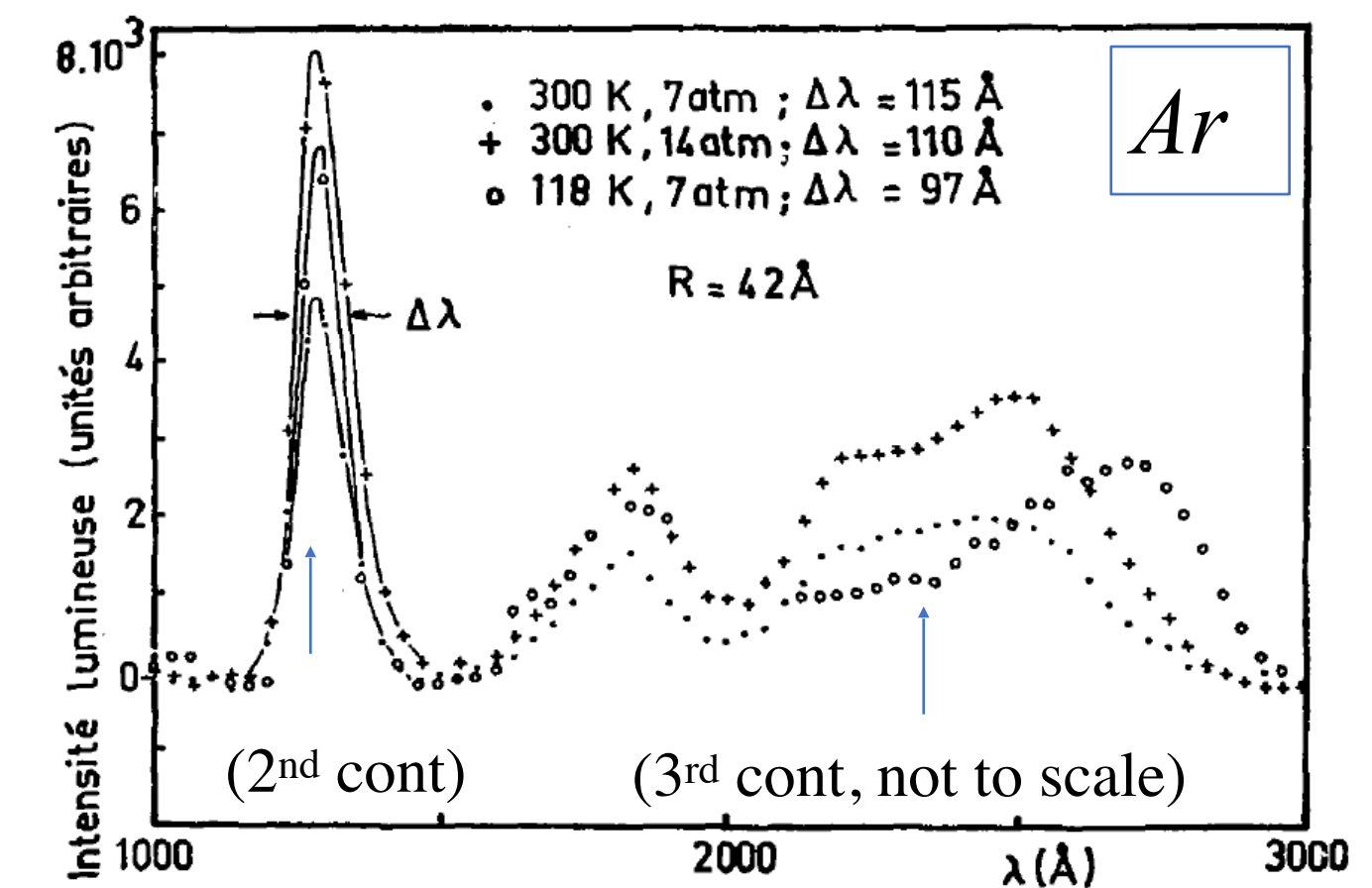


- Some common molecules known to display scintillation on their own, and some little-known noble gas emissions unmeasured in DUNE ND-GAr pressure conditions

common scintillating molecules



noble gases (Ar/Xe)

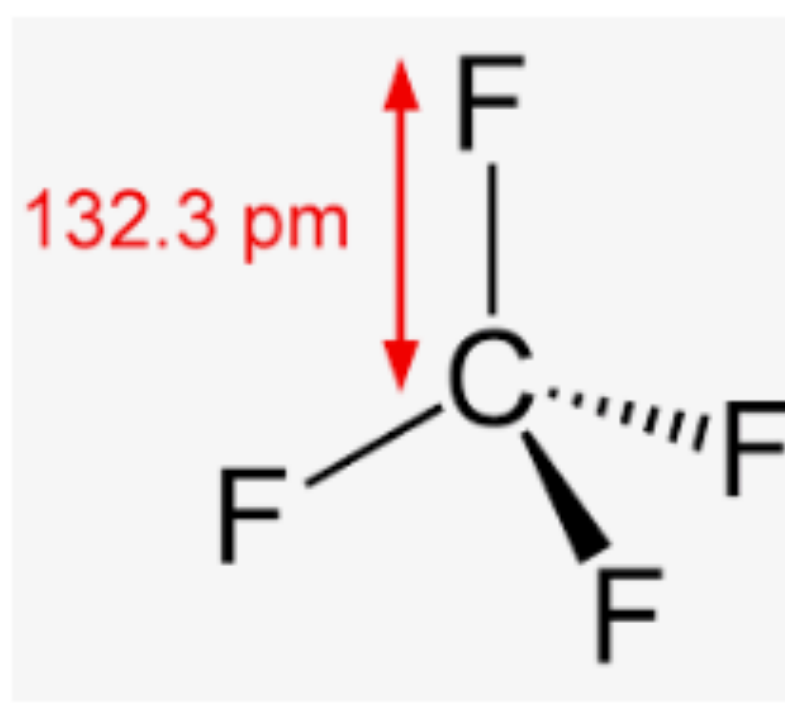
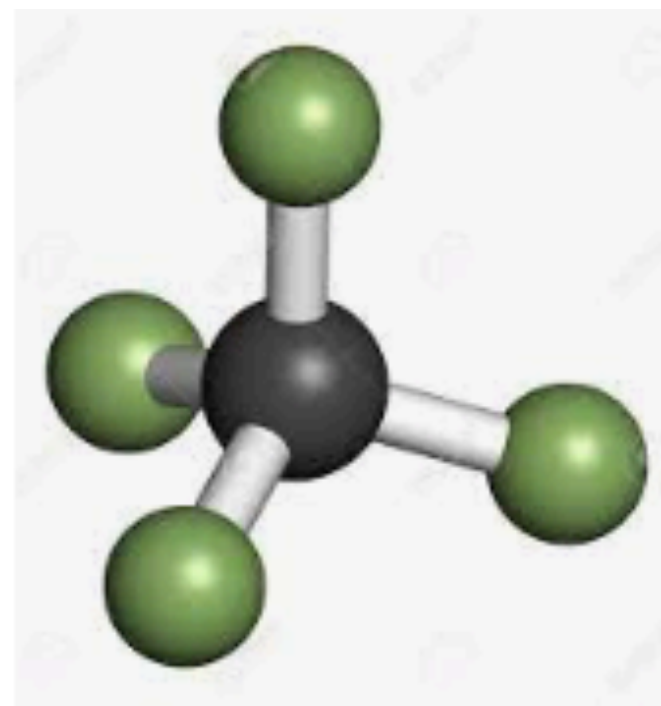


- question: do they produce wavelength-shifting in argon when used in low concentrations and at high pressures?

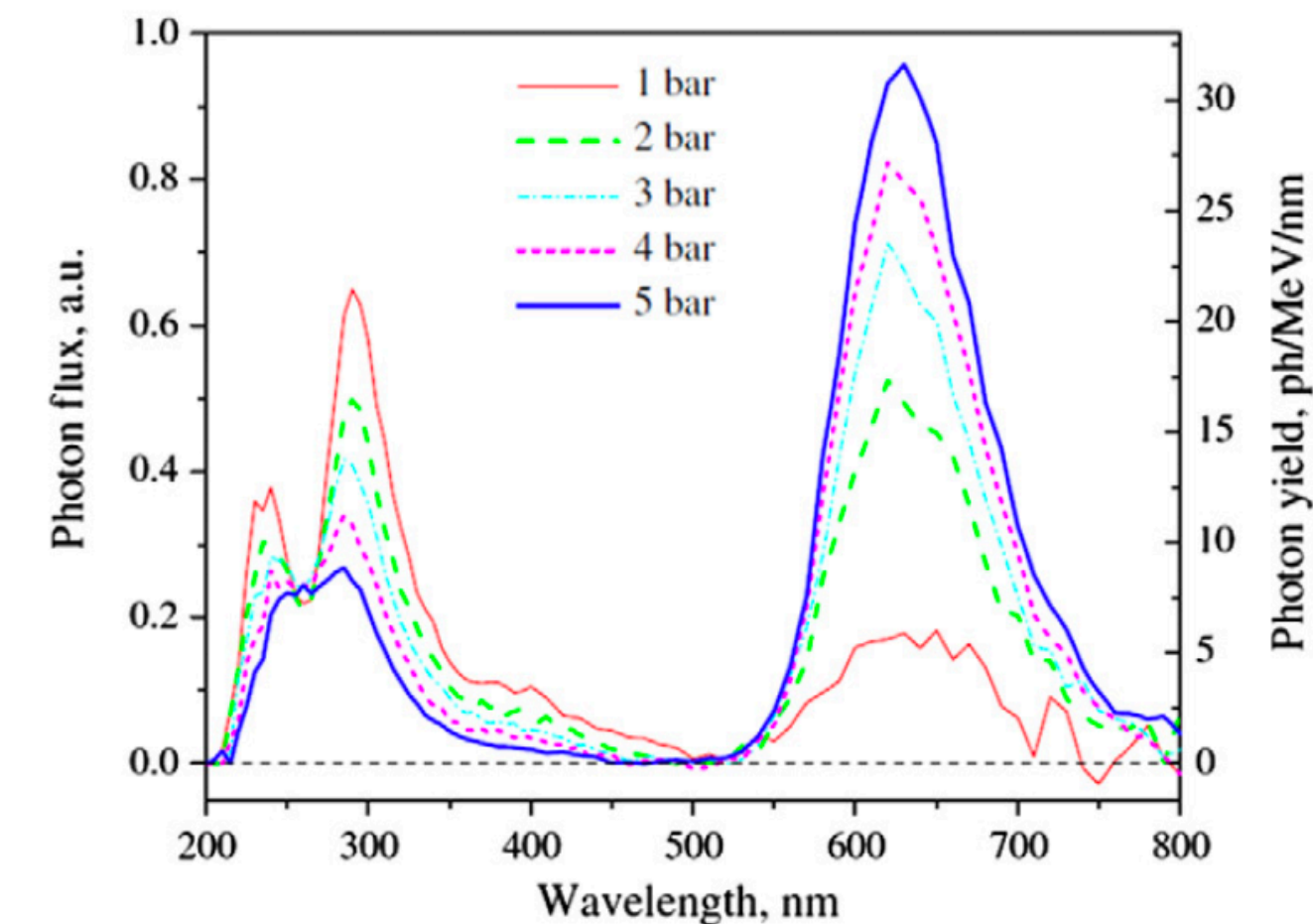
Shortlisting potential gas dopants

We focus on **CF₄** as a quencher/wavelength-shifting additive:

- Scintillation less harmful to MWPC operation than Ar one (600 nm vs 128 nm).
- Better scintillator and stronger electron cooler than N₂.
- Compatible with zircon-based cold getters (useful for operation in closed loop and at high pressure).
- Indirect evidence of wavelength-shifting, but light yields and time response unknown.
- Its visible (wavelength-shifted) scintillation is easy to handle and collect (e.g., with SiPMs).
- Earlier work in single wires shows good gain up to 10⁴.
- Transverse diffusion down to less than $\sigma_T = 1.6$ mm (1 m drift).
- At 1-2% volume fraction of CF₄ the mass fraction is 2.2-4.4%, below the default gas (P10).
- Free from attachment at typical drift fields.



scintillation spectrum



Outlook

- Candidate gas mixture has been established already based on measurements at IGFAE.
- Optical simulations show promising performance in terms of time resolution.
- Main challenge: relatively weak signal may result in high detection threshold.
 - Photon detectors must have (close to) single-photon sensitivity.
- Our objective is the development, towards the ND-GAr Technical Design Report, of a concept/design for the detection of primary scintillation.
 - In parallel, we should explore the physics that the system could give access to.