DUNE PHASE II NEAR DETECTOR

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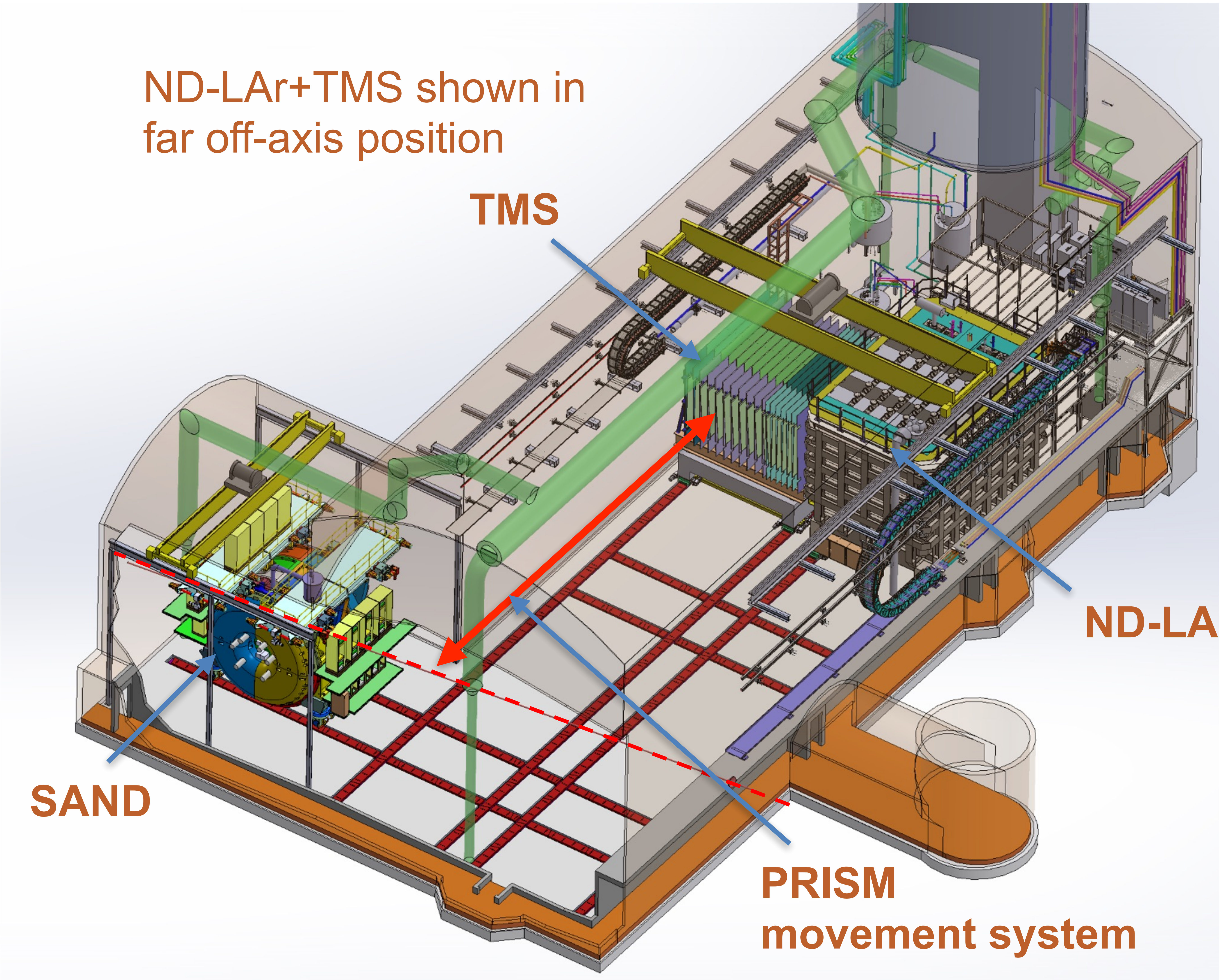
RECAP: PHASE I NEAR DETECTOR



- **ND-LAr + TMS with PRISM movement**
  - **ND-LAr:** 7 x 5 array of modular 1x1x3 m^3 LArTPCs with pixel readout
  - **TMS:** Magnetized steel range stack for measuring muon momentum/sign from ν_μ CC interactions in ND-LAr
  - **DUNE-PRISM: ND-LAr** + **TMS** move up to 28.5 m off-axis
- **SAND:**
  - On-axis magnetized neutrino detector with LAr target (GRAIN), tracking (STT), and calorimeter (ECAL)

See S. Zeller’s talk

PHYSICS IMPACT: LONG-BASELINE PHYSICS

- Significant uncertainty in modeling of final state of $\nu-$Ar interactions
  - Modeling dependence needs to be resolved by detailed measurements of the $\nu-$Ar final state
    - Due to limitations discussed later, LAr-based detectors have limited ability to tune/verify this modeling
    - **Does not impact Phase I physics goals, e.g. mass ordering, maximal CP violation scenario.**
- For more ambitious goals with larger exposure (~few hundred kt-MW-years), these systematics start become important
  - e.g., sensitivity to CP violation induced by a large range of δ_{CP}, ultimate precision on δ_{CP}
- This motivates a detector that
  - Performs full and detailed reconstruction of $\nu-$Ar interactions to verify the modeling
  - **Complements ND-LAr's role in directly connecting to Far Detector observables.**

CONSIDERATIONS FOR PHASE II

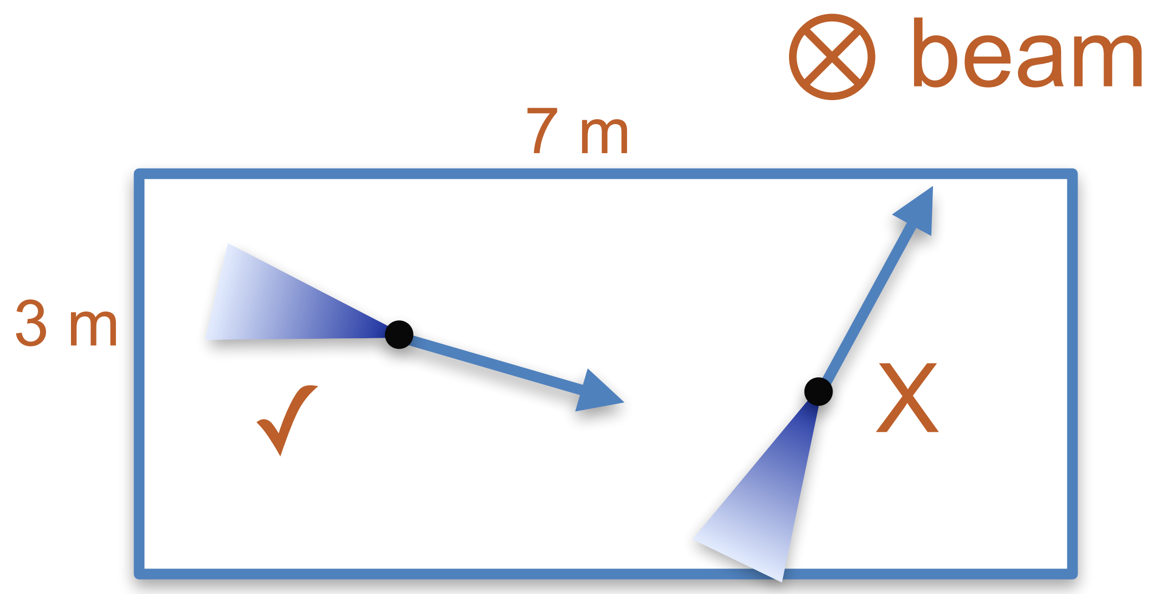
- Intrinsic features of LAr-based neutrino detection:
  - Tracking thresholds: 1 cm range in LAr corresponds to ~30 MeV KE for protons
  - Secondary interactions: pions/nucleons interact and produce secondary particles
  - Sign selection: limited ability to distinguish $\pi^{\pm}$ by, e.g. $\pi \rightarrow \mu \rightarrow e$ tagging
  - Scaleability: Powerful tracking calorimetry capabilities on kton scale.
- These:
  - Limit the ability of LAr-based detectors to resolve the final state of a ν-Ar interaction.
  - Apply for nearly any large LAr-based detector
- Limitations specific to the ND-LAr+TMS design
  - Tracking calorimetry reconstruction requires containment of particles
    - Activity from neutrino interactions span O(m)
  - Size limitations from hall →non-uniform acceptance
    - Acceptance corrections needed to extrapolate to ~uniform acceptance of far detector
- Motivates a "More Capable Near Detector" (MCND) to overcome limitations of the Phase I ND
  - ***An ND component that is functionally identical to the FD (e.g. LArTPC) remains essential regardless***

LAr:

Density: ~1.4 g/cm^3

dE/dx (MIP): ~3 MeV/cm

L^{π}_{INT}: ~70 cm



MOTIVATION/REQUIREMENTS

- This motivates a neutrino detector that is:
  - An argon-based tracker
    - match far detector, avoid A extrapolation
  - Low density → gaseous, sufficient Ar target mass → High pressure
    - Lower tracking thresholds: 1 cm range corresponds to 2 MeV KE proton
    - Minimal secondary interactions: interaction lengths > 10 m
  - Magnetized → magnetic spectrometry
    - Momentum estimation by curvature → 4π acceptance
    - Sign selection
- Additional essential components:
  - Calorimetry surrounding the tracking for neutral (γ, n) reconstruction
  - Muon detection systems

LAr:

Density:	~1.4 g/cm^3
dE/dx (MIP):	~3 MeV/cm
L^{π}_{INT}:	~70 cm

10 B GAr:

Density:	~0.016 g/cm^3
dE/dx (MIP):	~0.025 MeV/cm
L^{π}_{INT}:	~6 x10^4 cm

Interactions/year at 1.2 MW for 1 ton (~60 m^3) of Ar

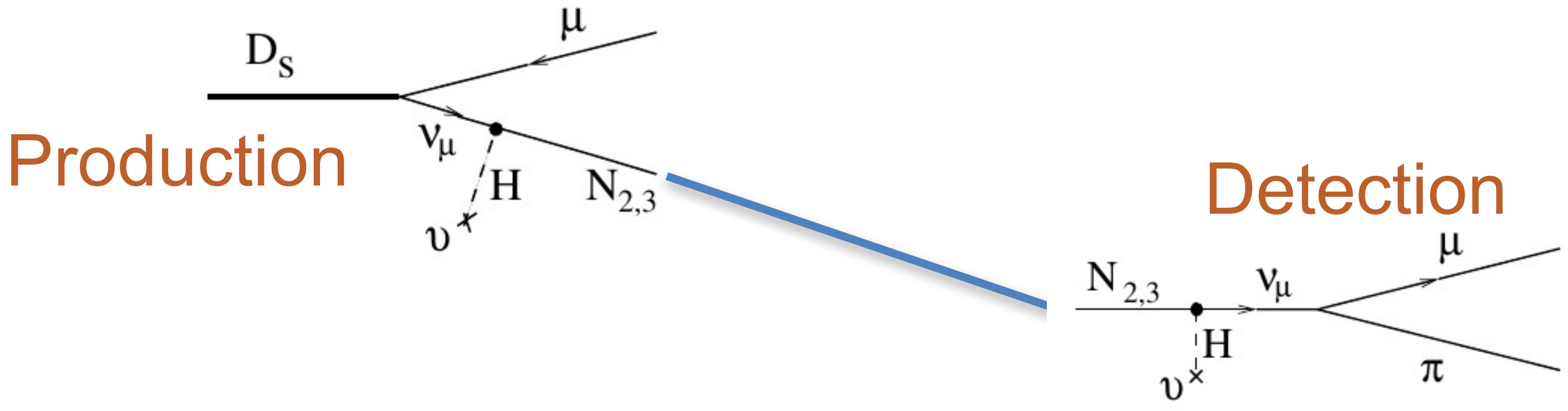
1.6M ν_μ charged current

30K ν_e charged current

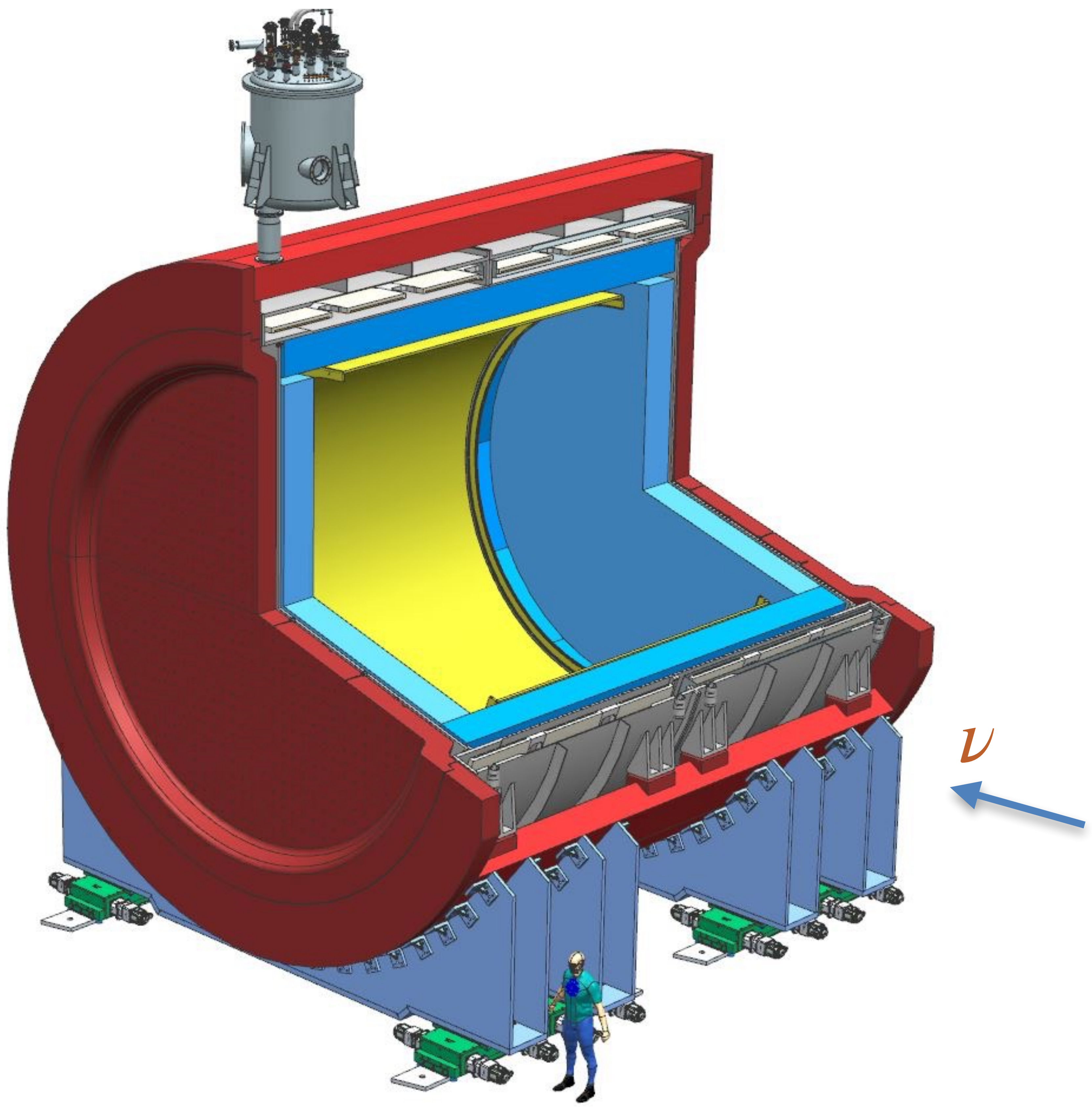
Such a detector would allow full characterization of the final state of ν-Ar interactions

BEYOND THE STANDARD MODEL

- A detector with these capabilities is a powerful probe for BSM physics
  - Particularly for neutral particles (e.g neutral heavy leptons and axions)
    - produced in the beamline
    - decaying in the detector
  - Favorable signal/background for low density tracker:
    - Signals scale with volume
    - Background from neutrino interactions scale with mass
  - Reconstruction:
    - Clean kinematic reconstruction of decay products
    - Neutrino background rejection from recoil particles



ND-GAR:

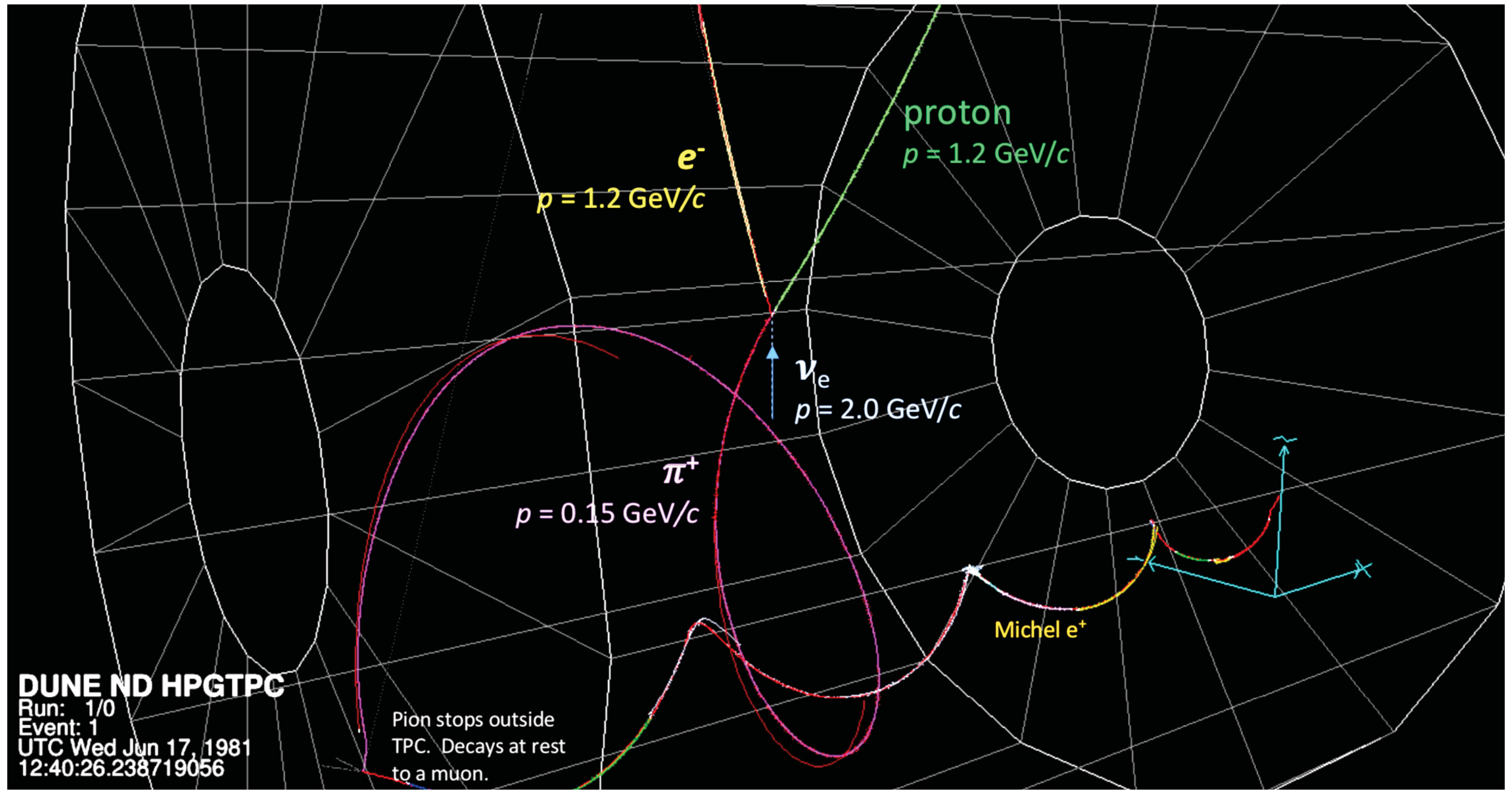


In the Phased approach, the Phase I TMS is replaced by the Phase II MCND

https://inspirehep.net/literature/1854065

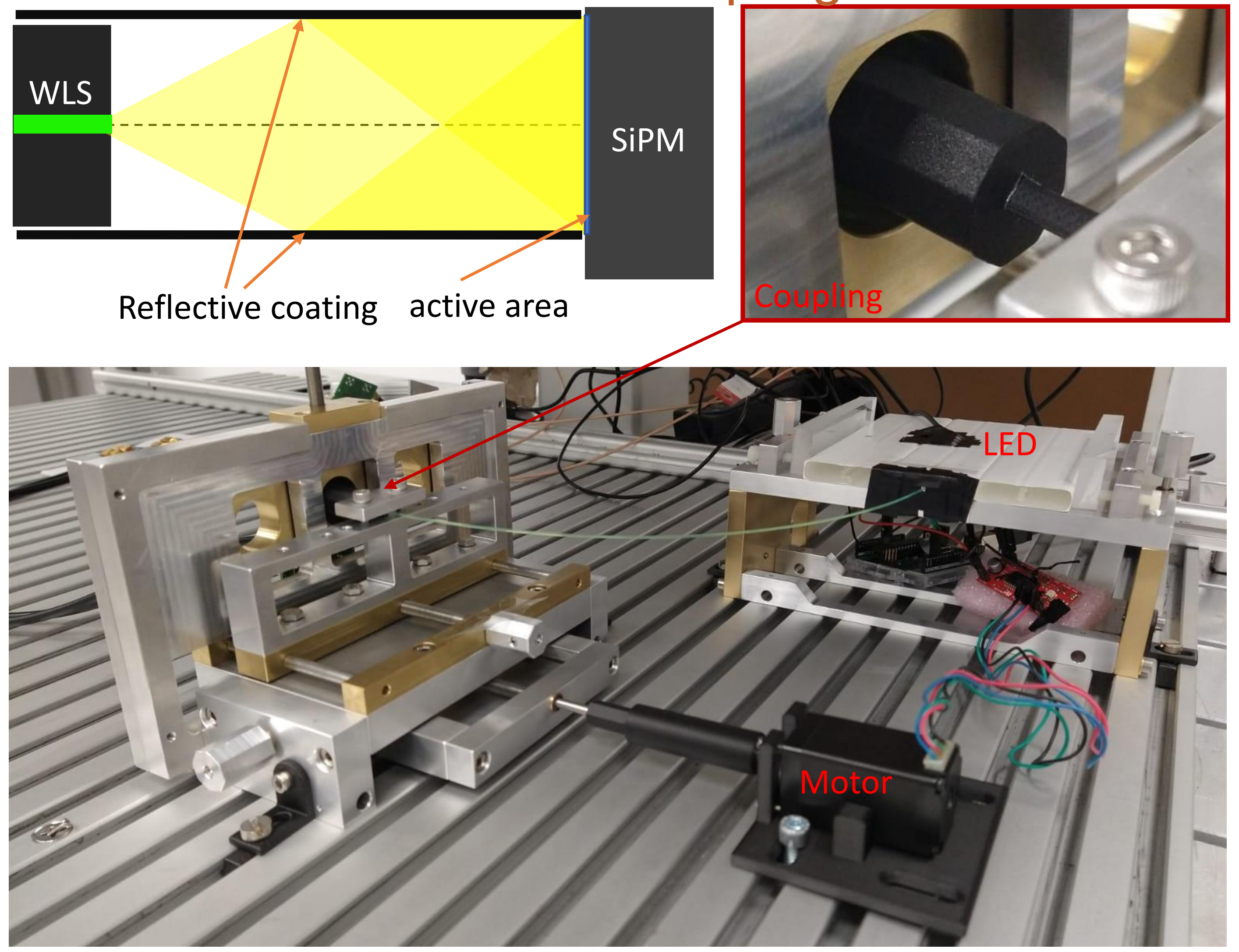
- Described in the DUNE Near Detector CDR
  - 0.5 Tesla superconducting solenoid with “partial yolk"
  - 10 bar high pressure argon gas TPC (HPgTPC)
    - 5 m diameter x 5 m length, O(1 ton) of argon target
    - Refurbished ALICE readout chambers
  - CALICE-inspired tile calorimetry system
  - Instrumented magnet yolk for muon detection
- Interest from:
  - Germany (ECAL), India (magnet yolk, vessel), Italy (magnet coils), Spain (light detection, calibration, gas), UK (readout electronics, data acquisition), USA (readout chambers, ECAL)
- ND-GAr would also serves as the muon spectrometer for ND-LAr
  - Placed down-stream of ND-LAr to intercept exiting muons
  - ND-GAr would replace TMS in this role and will move via PRISM

ND-GAR: DESIGN/DEVELOPMENT

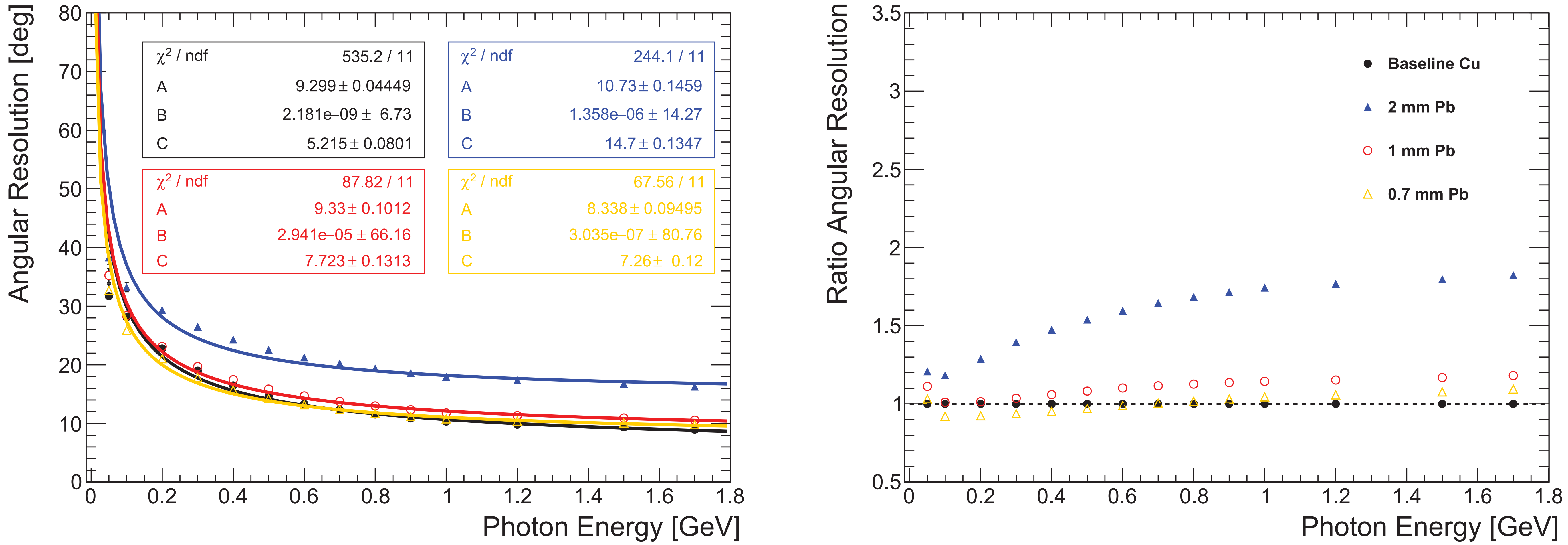


- Simulation and reconstruction studies
- Detector optimization
- Prototyping and test beam
- Snowmass white paper (https://arxiv.org/pdf/2203.06281.pdf)
  - “A Gaseous Argon-Based Near Detector to Enhance the Physics Capabilities of DUNE

ECAL
Fiber/SiPM coupling



TOAD (Test of Overpressure Argon Detector)
Beam test of readout chambers



ECAL radiator optimization

CALORIMETER:

- To compete the reconstruction of a ν-Ar interaction, a calorimeter is necessary
- “Current” plan calls for a “CALICE”-inspired tile/bar calorimeter

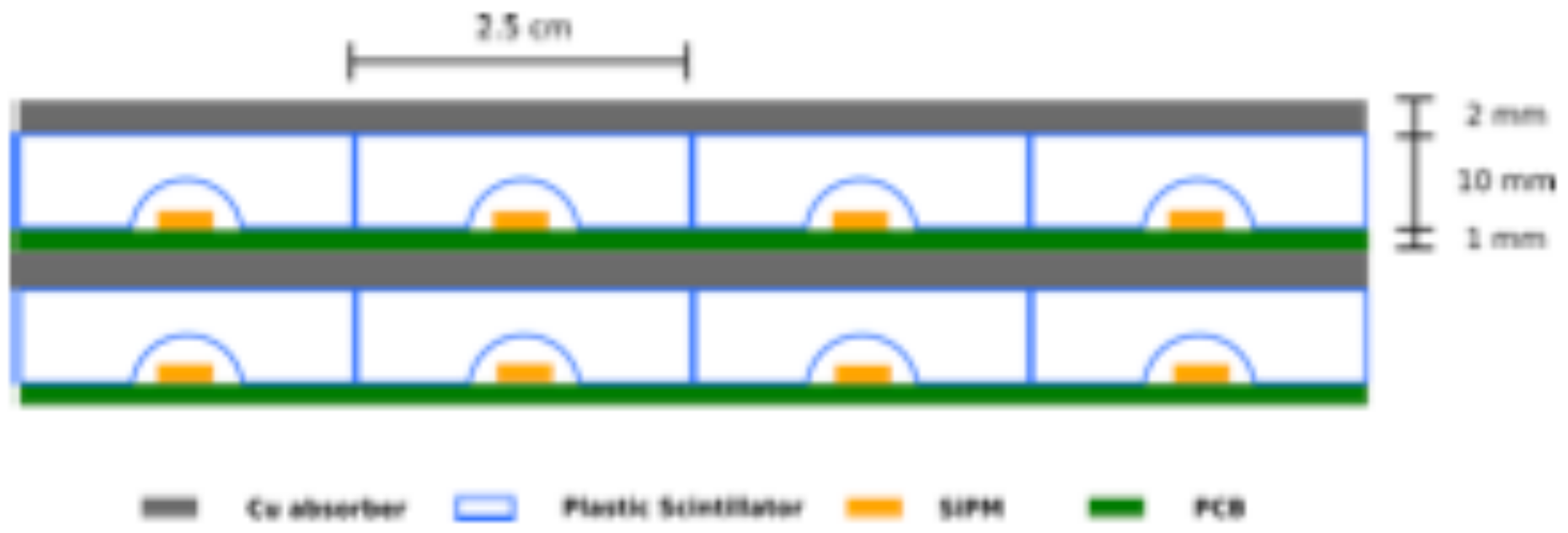
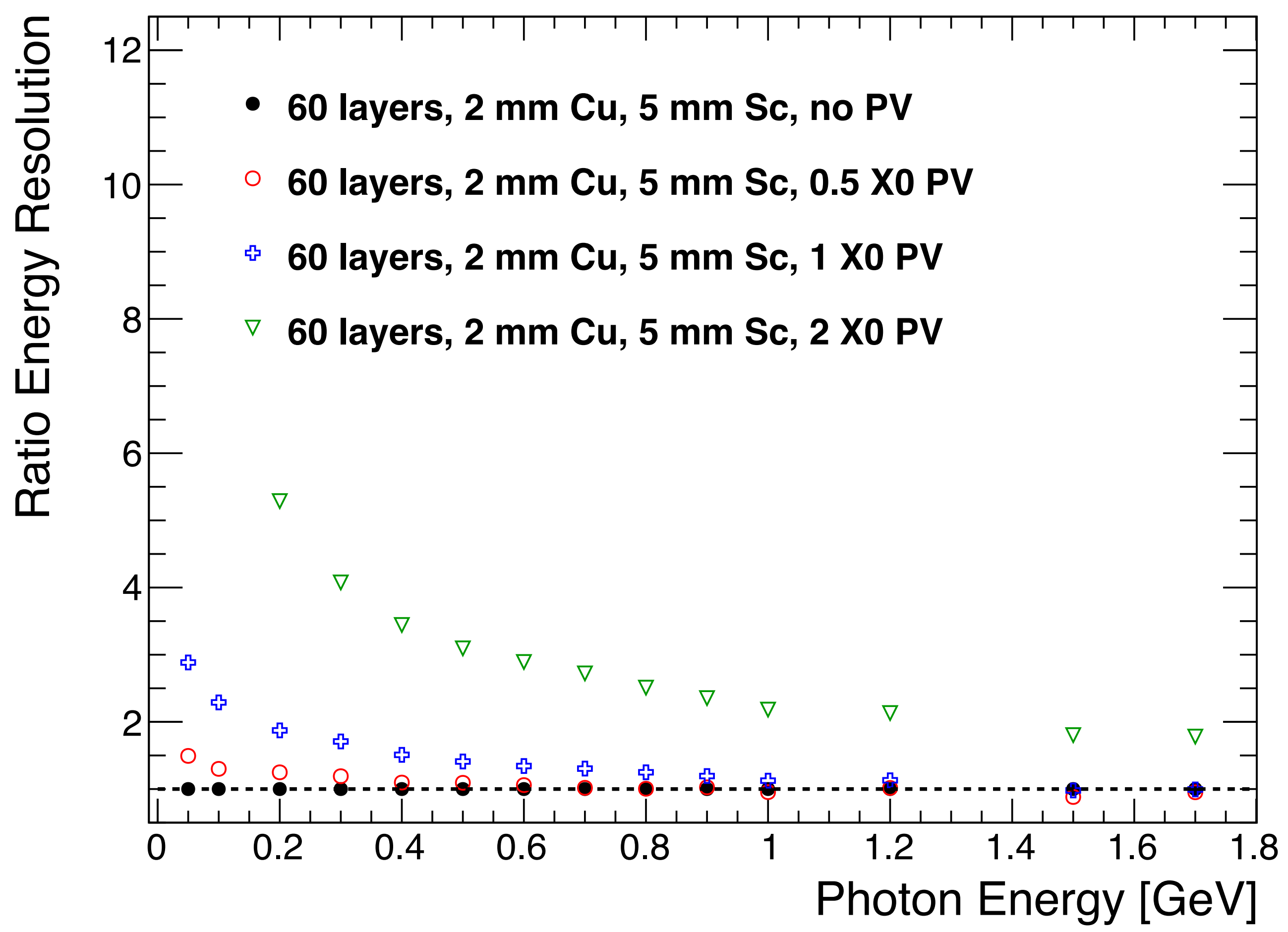
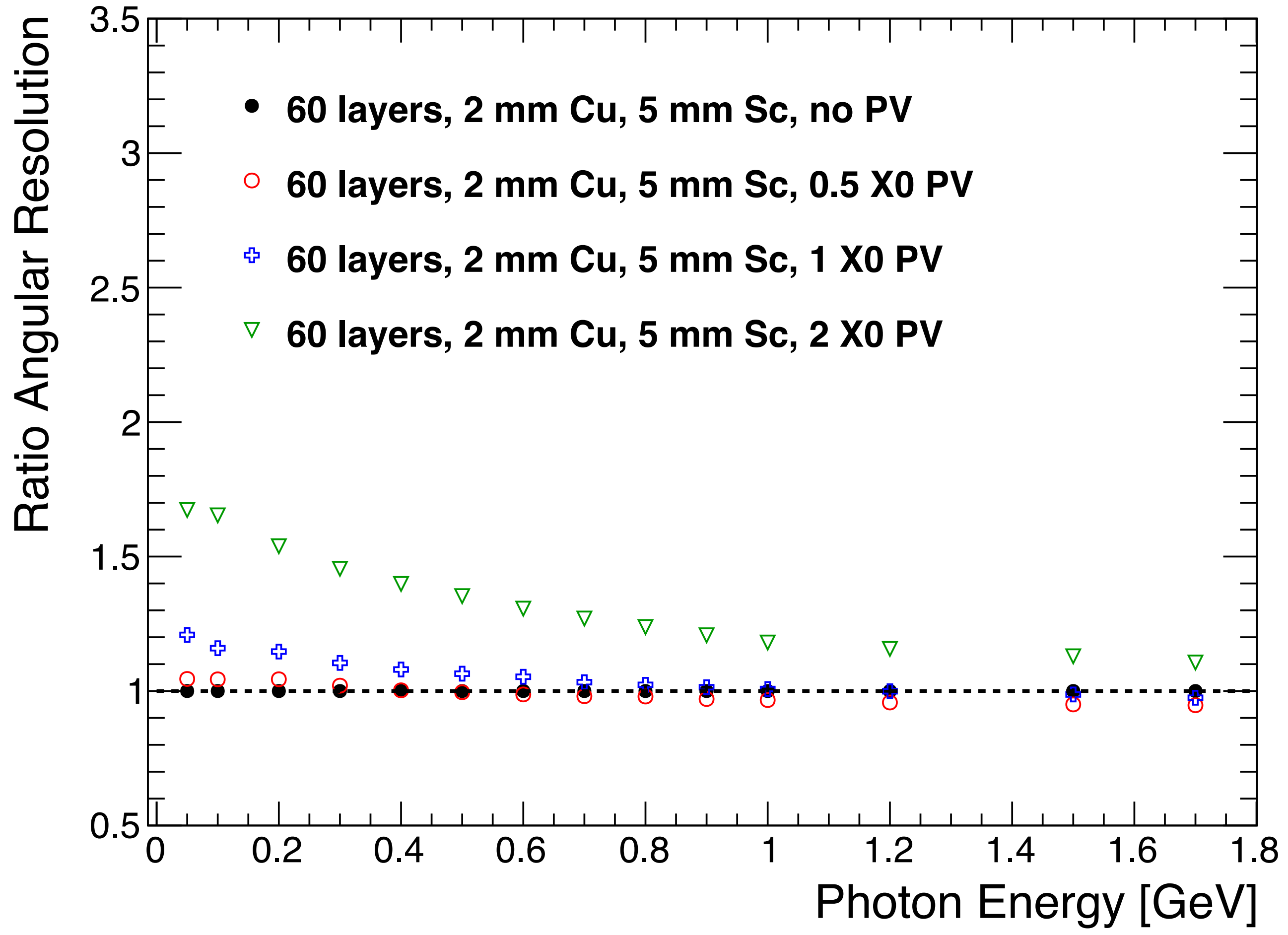


Figure 50. Conceptual layout of the ECAL showing the absorber structure, scintillator tiles, SiPMs, and printed circuit boards (PCBs).





- Significant to optimization studies
- Results in a hybrid configuration of:
  - *high granularity*: 25 x 25 mm^2 tiles, 5 mm thick
  - *low granularity*: 40 x 5 mm^2 bars over full module length, crossed in alternating layers
  - 8 HG+52 LG downstream 6 HG + 54 LG in upstream
- Results in ~3 million channels

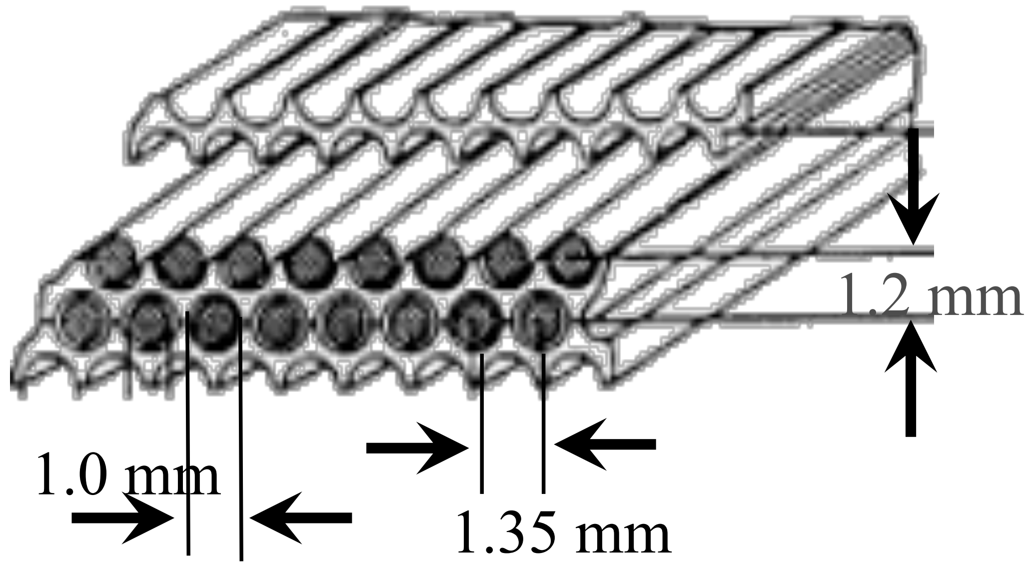
CHALLENGES/NEEDS

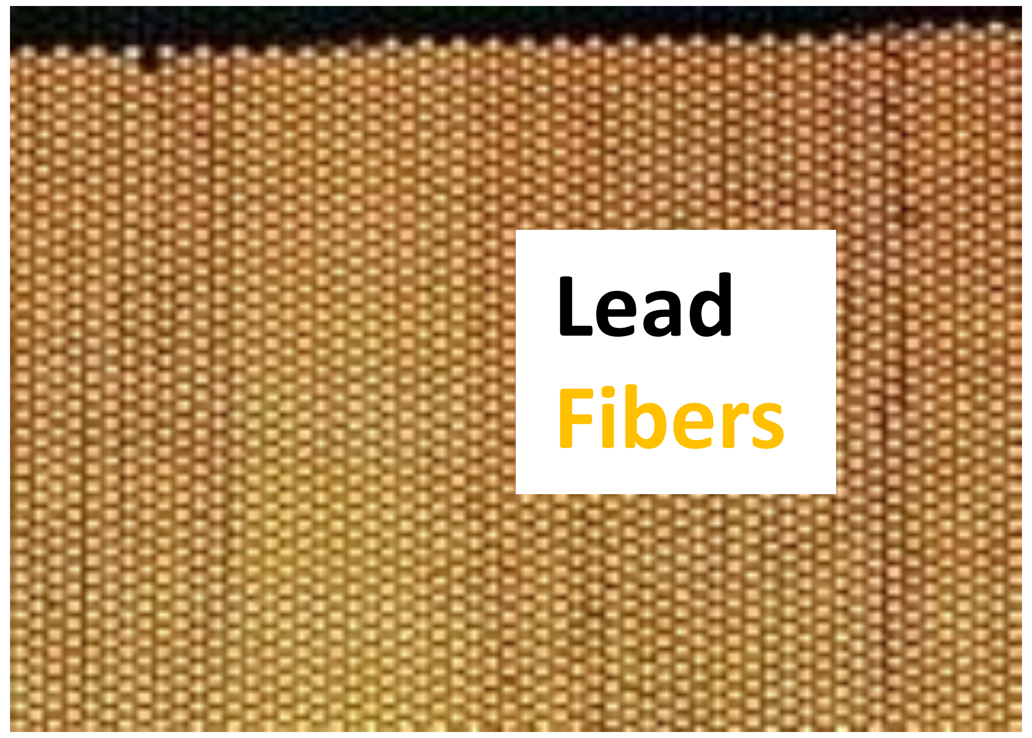
- Physics needs:
  - Reconstruction of e/γ across wide range of energies
    - [~10 MeV, few GeV] γ from π^0 decays
    - [~100 MeV, few GeV] e for ν_e events
    - Pointing in order to associate with neutrino vertex
  - μ/π separation from hadronic interactions
    - [~100 MeV, ~ 1 GeV]
  - Neutron reconstruction
    - [~10 MeV, ~few GeV]
  - Timing ≲10 ns

Challenges:

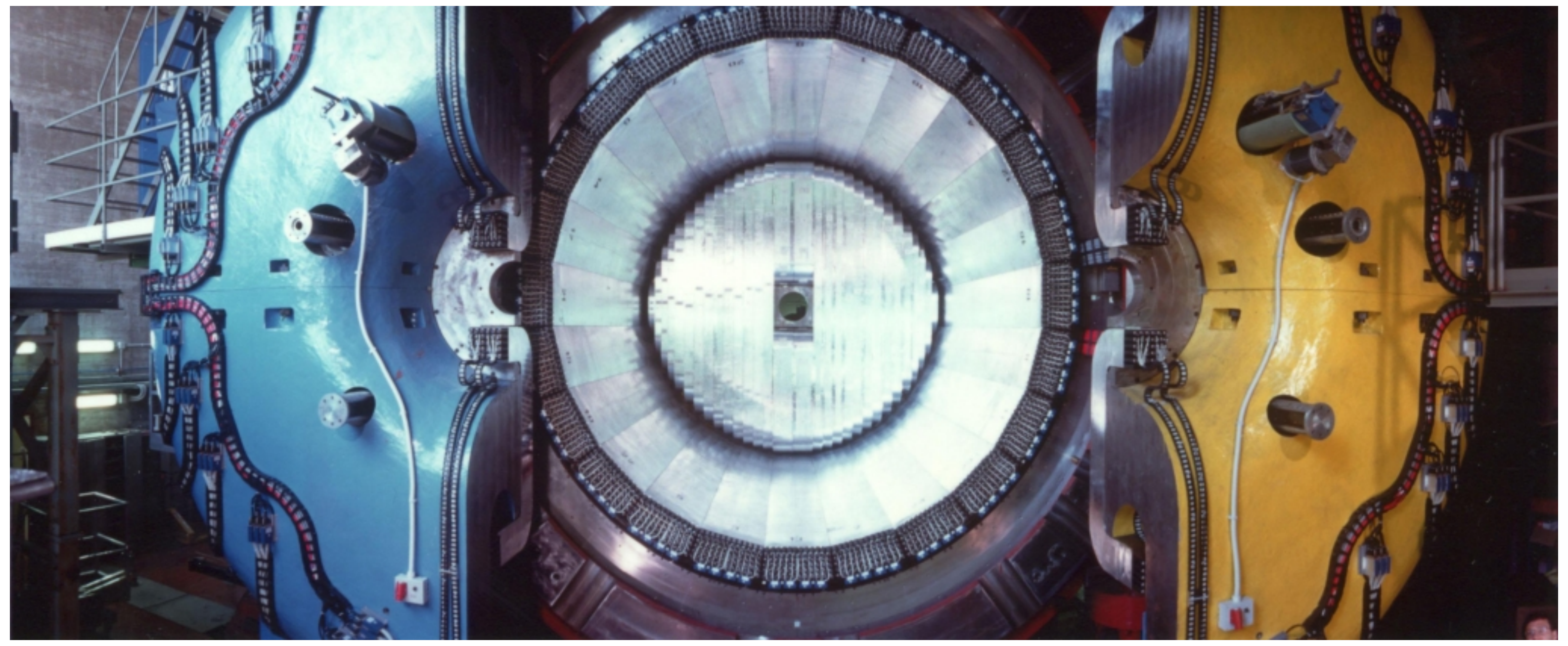
- Enormous amount of area
  - Barrel 5 m diameter x 5 m = ~400 m^2
- Thinness
  - Inside pressure vessel in order to minimize material
  - Sets overall size of vessel and solenoid
- Basically want everything (energy, sampling, timing)
  - But specific/quantitative requirements unknown . . . .

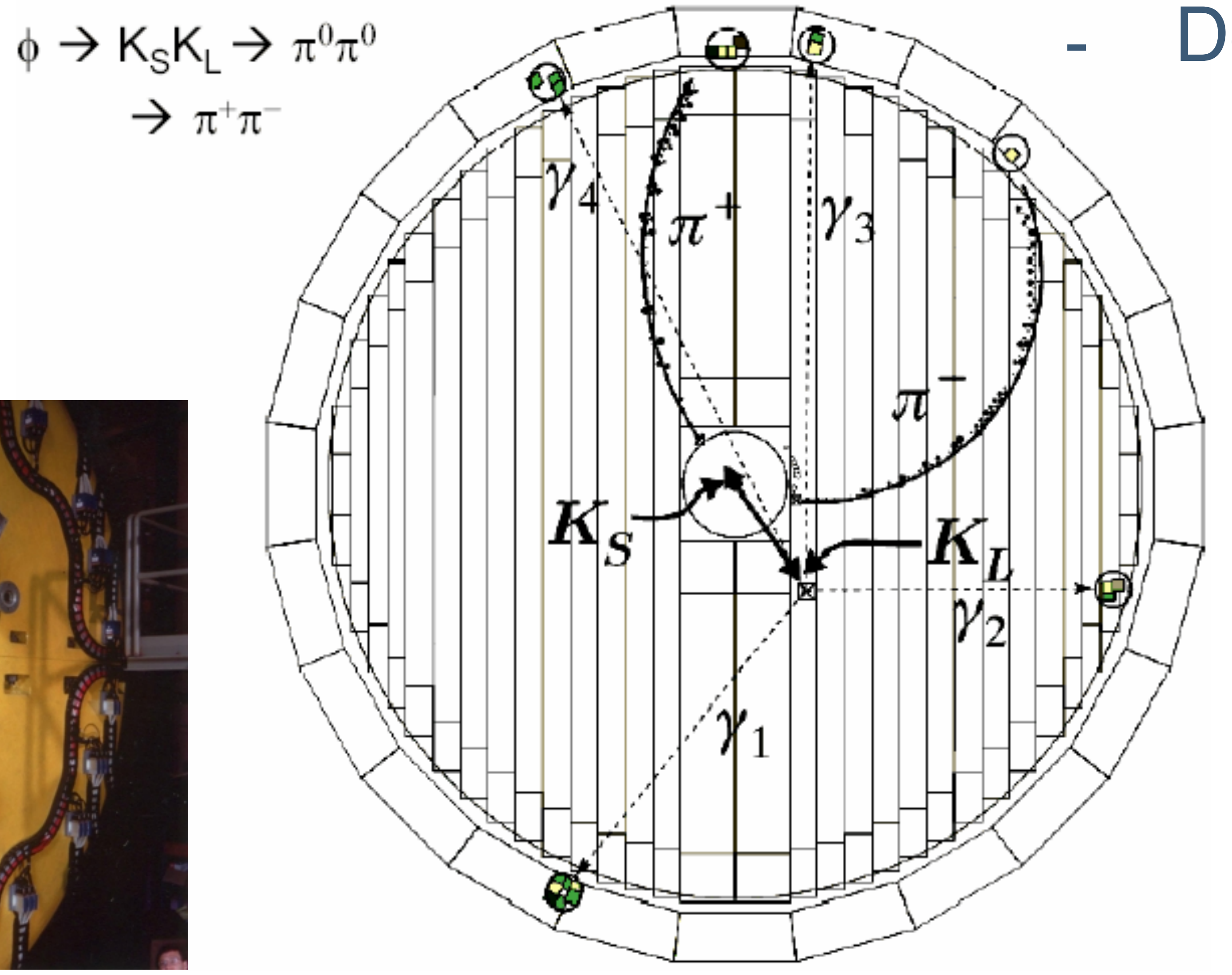
ALTERNATIVES





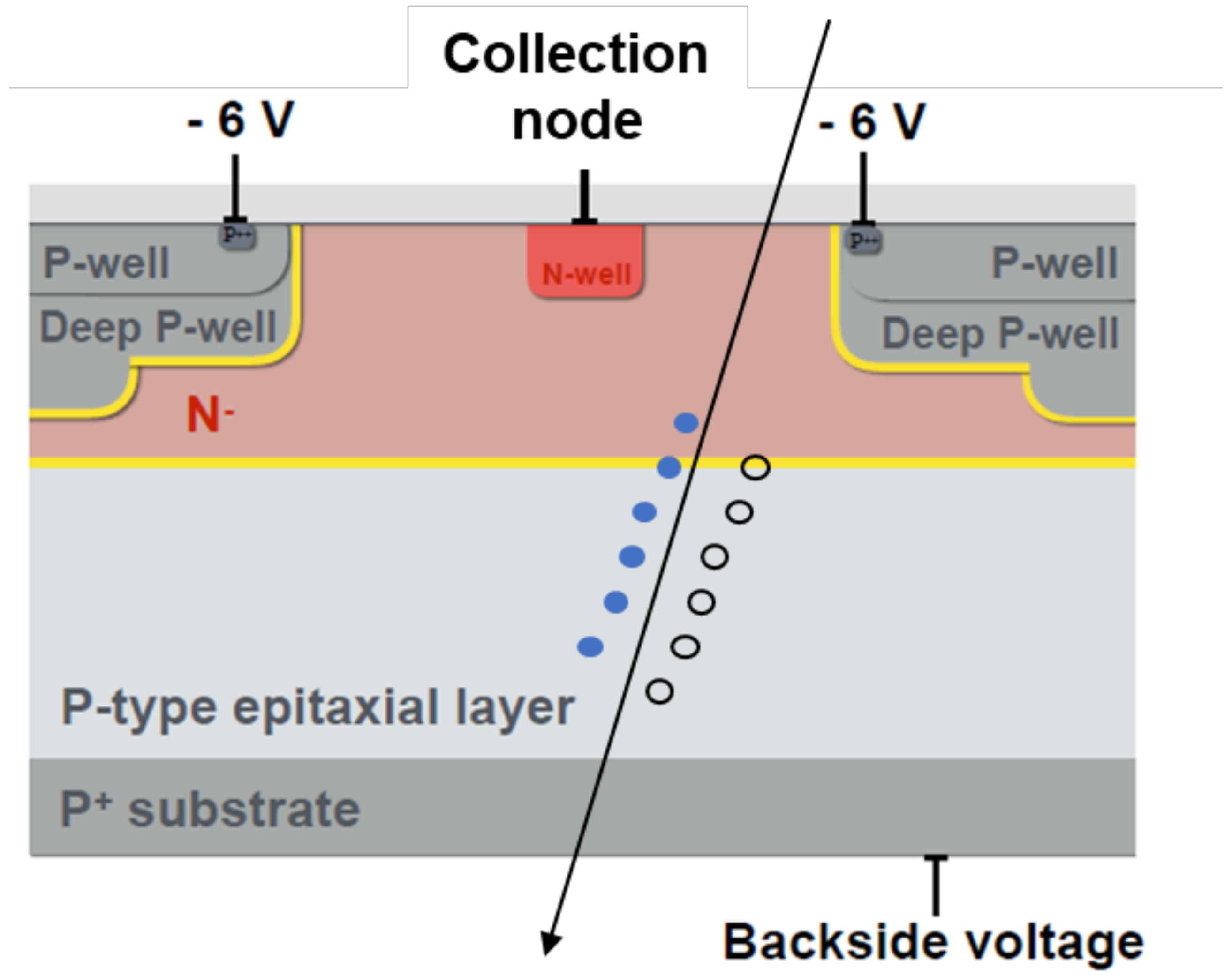
- Radiator/WLS matrix
  - KLOE, GLUEX





	Crystal	LAr	Plastic	Fiber	MAPS
Energy	Y	N?	Y	Y	Y
Pointing	N	Y	Y	Y	Y
μ/π	N?	Y	Y	Y	Y
Neutrons	N?	N?	Y	Y	Y

- CMOS Monolithic Active Pixel Sensor (MAPS
  - Fully integrated sensor, readout at ~10-100 μm scale
  - Highly scalable
  - Deployed at sPHENIX, future e^+e^- collider



COST AND PERFORMANCE OPTIMIZATION

- Is there a more systematic way to optimize the design?
  - Segmentation, radiator/sensitive layer thicknesses
  - Multiple targets (energy/angle resolution, neutron vs. EM)
- Cost optimization:
  - Current MAPS technology is far more than we need
  - Is there any cost savings if we have (far) less requirements
- Large calorimeters and their cost is a common issue with energy frontier

OBSERVATIONS:

- Solidify:
  - Physics case:
    - what is the “purpose” of MCND and what does it mean to adequately carry out its mission
    - our current case relies on a single case study: it is hard to see its generality or sufficiency.
  - Requirements:
    - Articulate what the detector needs to be able to do (measurements, capabilities, etc.)
      - What is necessary and sufficient for MCND to achieve its goals?
    - Can we incorporate BSM and νSM requirements?
  - Articulate needed added capabilities in relation to other detectors
    - Why is this detector needed in addition to the Phase I detectors?
    - What is the relation, say;
      - of νSM program in MCND vs. multi-target system in SAND?
      - BSM in MCND vs. SAND?
      - of LBL measurements in MCND vs. ND-LAr+TMS with PRISM?