The ECAL for the DUNE Near Detector

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

BMBF Scintillator Verbund Meeting
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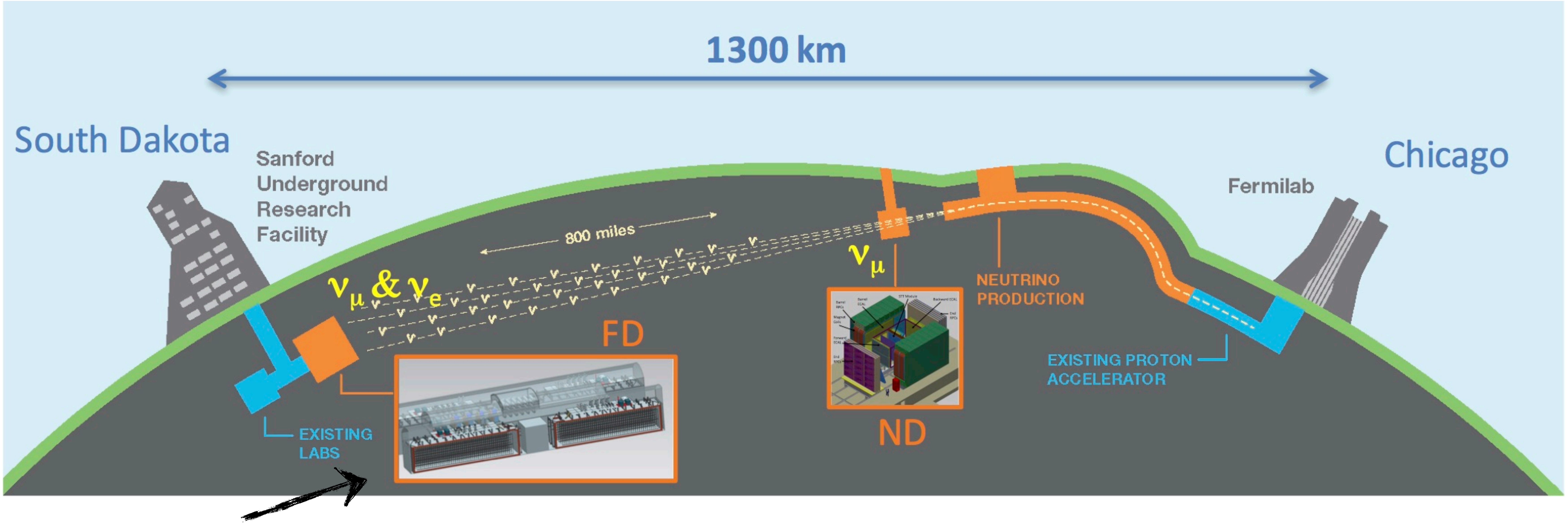
MAX-PLANCK-INSTITUT FÜR PHYSIK

Outline

- DUNE & the Near Detector
- ECAL Requirements & Conceptual Design
- ECAL Performance Examples: Photons, Neutrons
- Engineering & R&D Questions

The DUNE Experiment

Overall Layout



LBNF:

A broadband on-axis neutrino beam with high power:

1.2 MW from day 1 - upgrade possibility to > 2 MW

Far detector to measure oscillated neutrinos:

4 x 10 kT fiducial volume LAr TPC

1300 km baseline, covers 1st and 2nd oscillation max.

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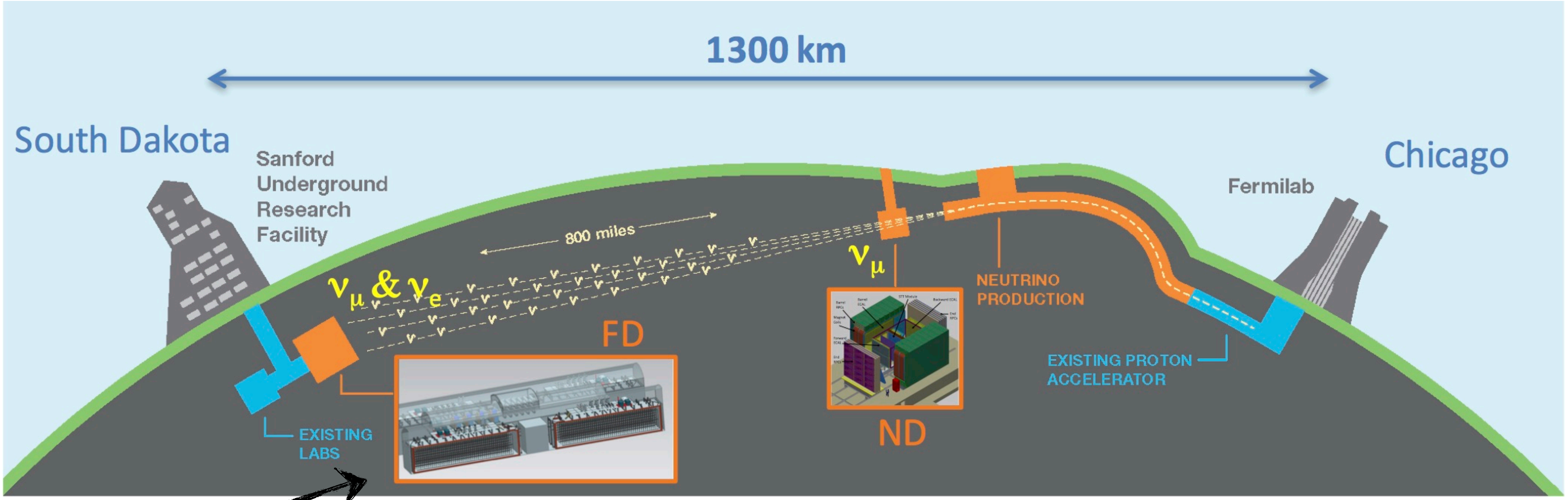

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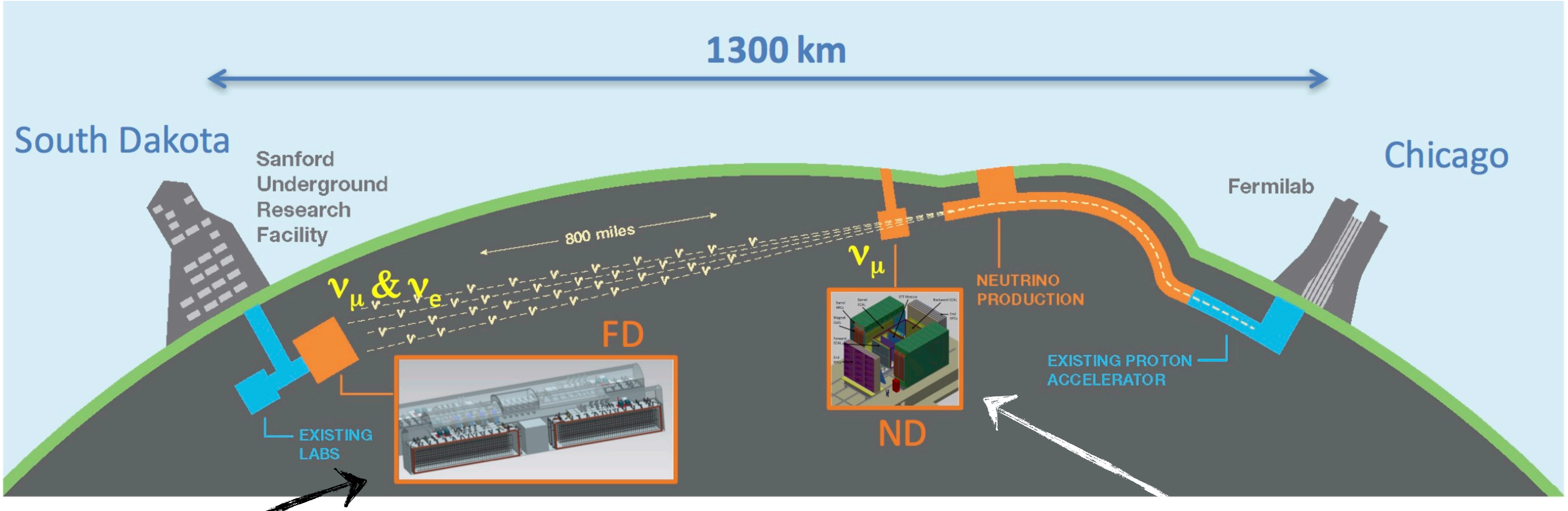

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Near detector to constrain un-oscillated flux and to perform a rich, high statistics non-oscillation program

hybrid detector system: LAr + multipurpose detector system

575 m from production target

- Conceptual design established

The Role of the Near Detector

Overarching performance goals

O0: Predict the neutrino spectrum at the FD: The Near Detector (ND) must measure neutrino events as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy event spectra from the ND to the FD.

O0.1	**Measure interactions on argon**	Measure neutrino interactions on argon, determine the neutrino flavor, and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	**Measure the neutrino energy**	Reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution.
O0.3	**Constrain the xsec model**	Measure neutrino cross-sections in order to constrain the cross section model used in the oscillation analysis.
O0.4	**Measure neutrino flux**	Measure neutrino fluxes as a function of flavor and neutrino energy.
O0.5	**Obtain data with different neutrino fluxes**	Measure neutrino interactions in different beam fluxes in order to disentangle flux and cross sections and verify the beam model. **(PRISM)**
O0.6	**Monitor the neutrino beam**	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales.

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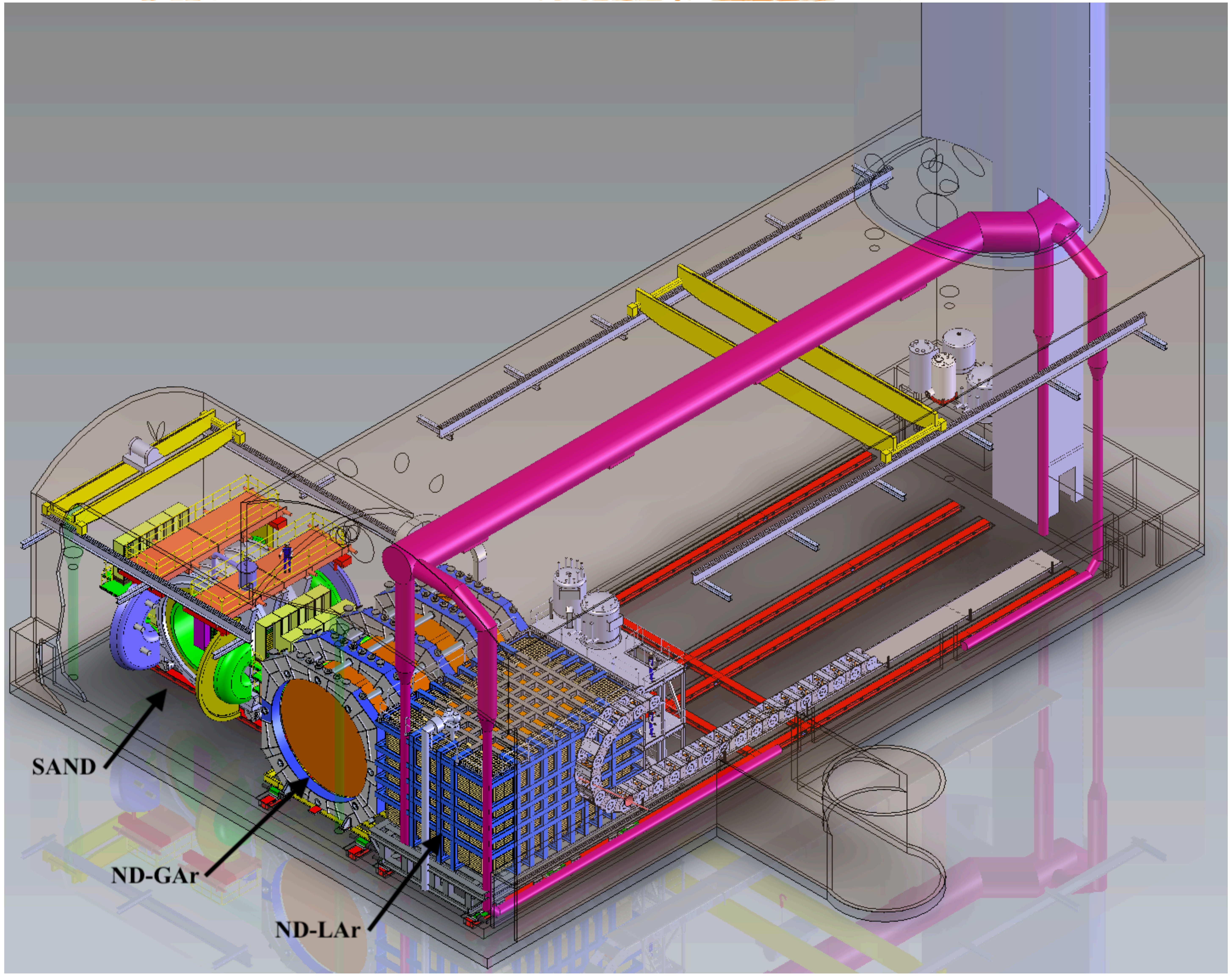
+ a rich set of stand-alone neutrino physics measurements: SM precision measurements, BSM searches

The DUNE ND Complex

Three separate detectors



The requirements for the ND define the overall design:

- A liquid Ar TPC with short drift length and pixelated readout
- A **Multi-Purpose Detector** with HPgTPC tracking + ECAL in a magnetic field
- An on-axis beam monitor with tracking target and magnetic field

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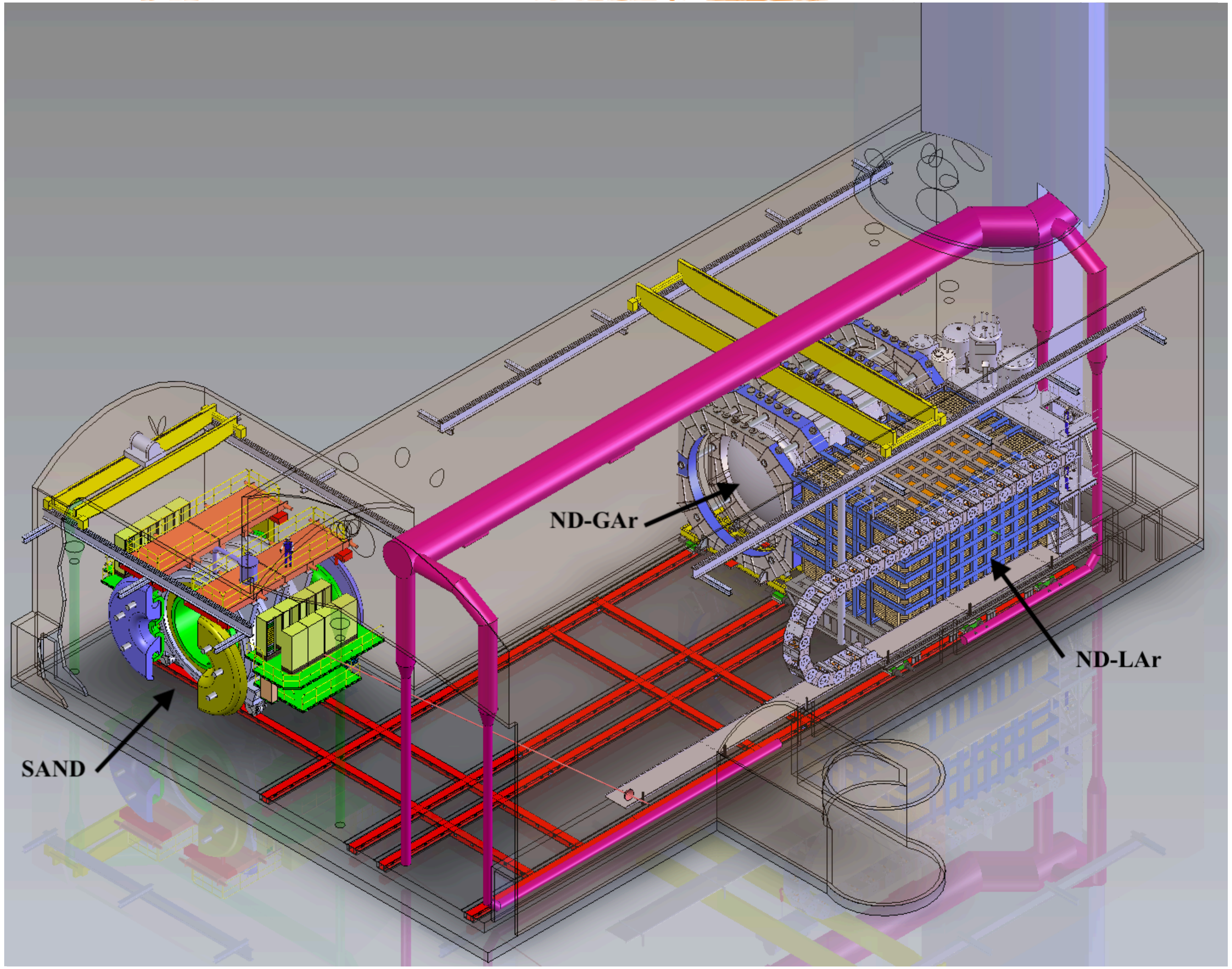

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- LAr and MPD can move off-axis to measure at different energies / ν spectra

MPD ECAL - Overall Concept

Motivation & Goals

- The MPD will make high-precision measurements of ν interactions on Ar
  - Requires full coverage and precise measurement of charged and neutral particles with low thresholds

- ECAL and HPgTPC complementing each other
  The ***ECAL*** has to provide:
  - Photon energy measurement
  - Neutral pion reconstruction
  - Particle identification (electron, muon, pion)
  - Determination of interaction time, muon tracking into and out of TPC
  - Ideally: Neutron detection and energy measurement
  - …

➯ Energy range from ~ 50 MeV to ~ 2 GeV: Small stochastic term crucial

➯ Requires position and angular resolution

➯ Requires longitudinal segmentation

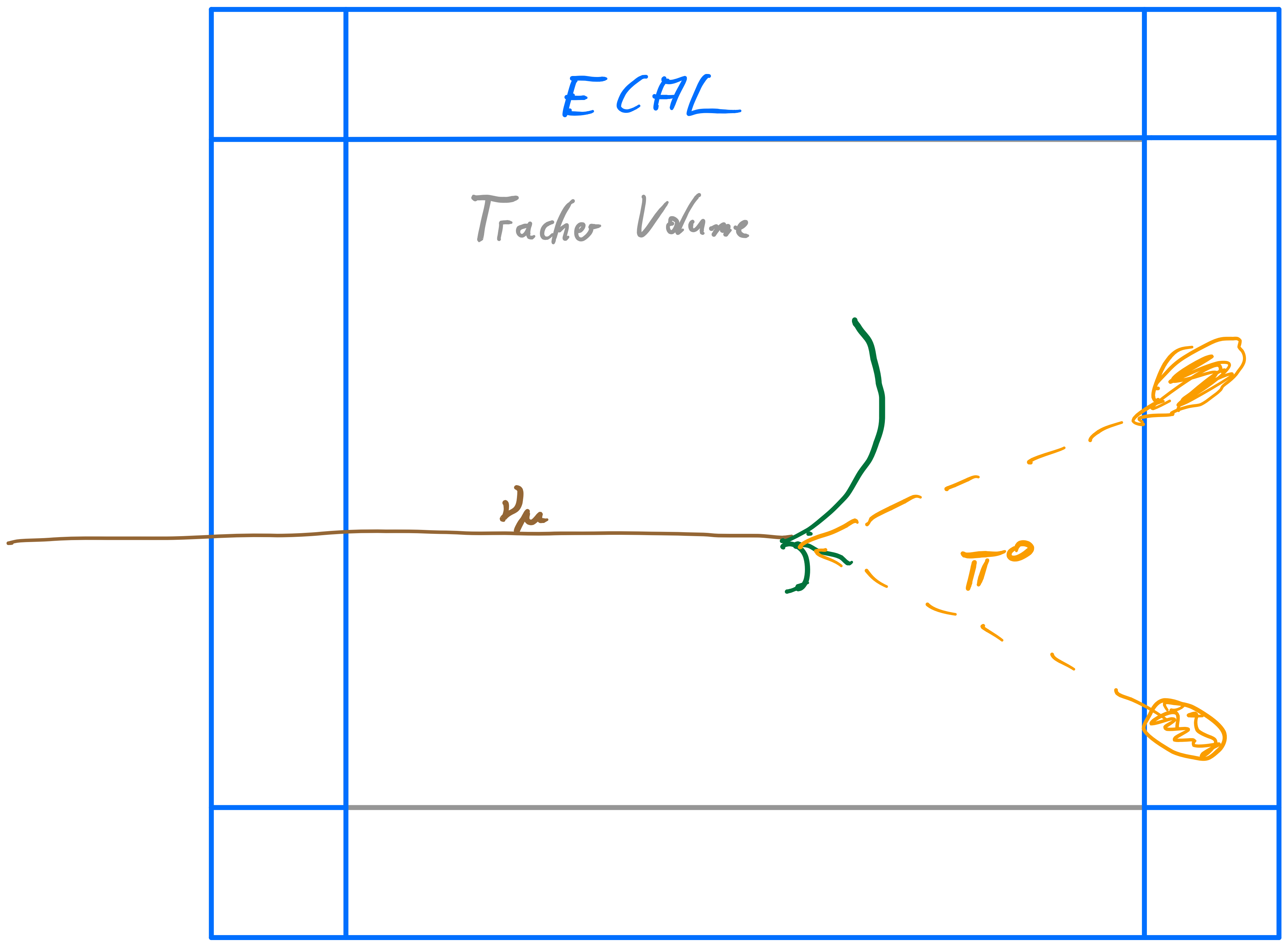
➯ Requires granularity and sub-ns time resolution

several 100k interaction/year on Ar in tracker
several 100M interactions/year in ECAL

Main Performance Goals

And consequences for Calorimeter Concept

- Electromagnetic resolution: 6 %- 8% / Sqrt(E [GeV])
  - Drives sampling structure: Thin absorbers!
- π^0 reconstruction: Requires shower separation, position and angular resolution
  - Motivates highly granular readout



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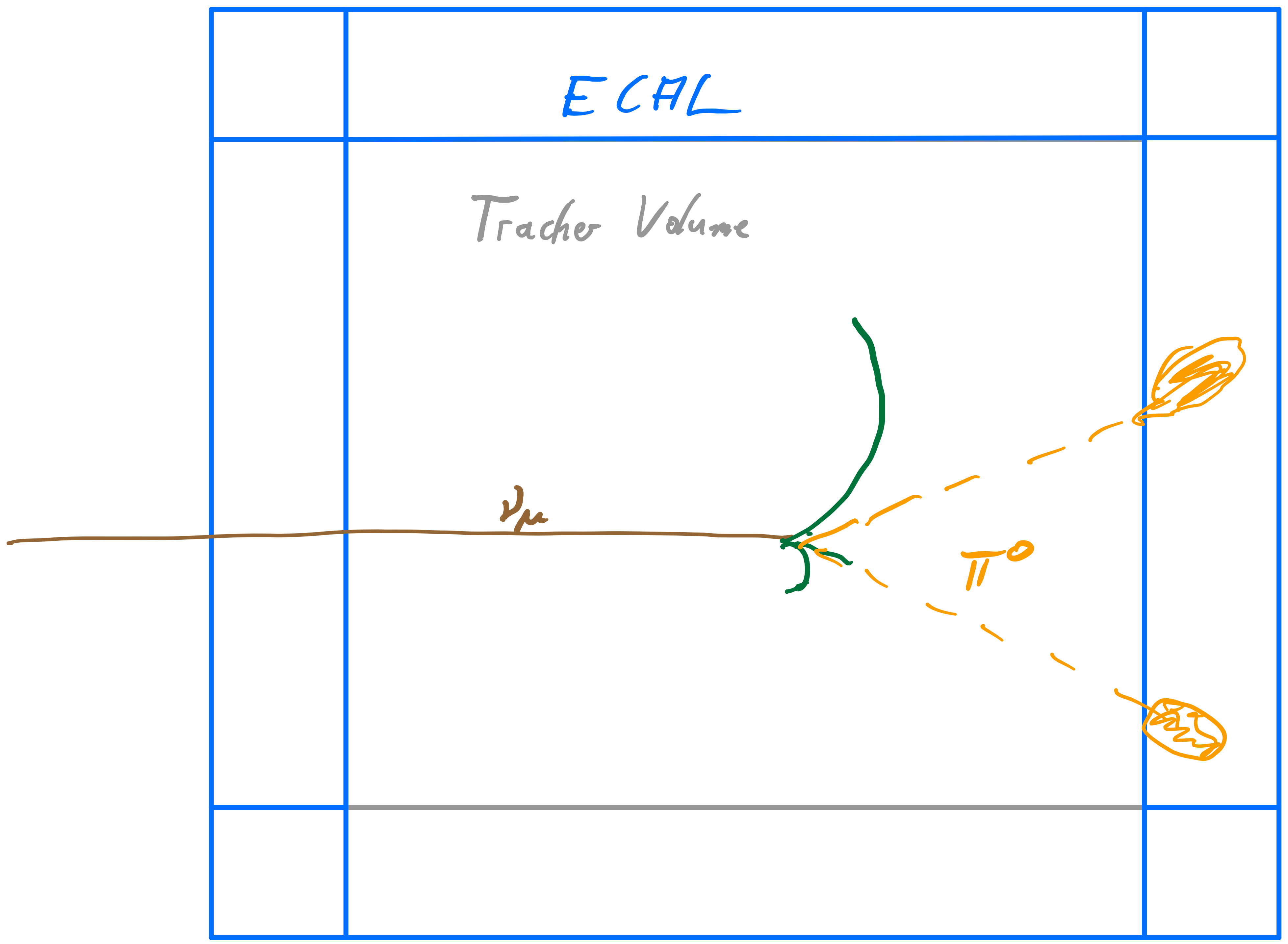
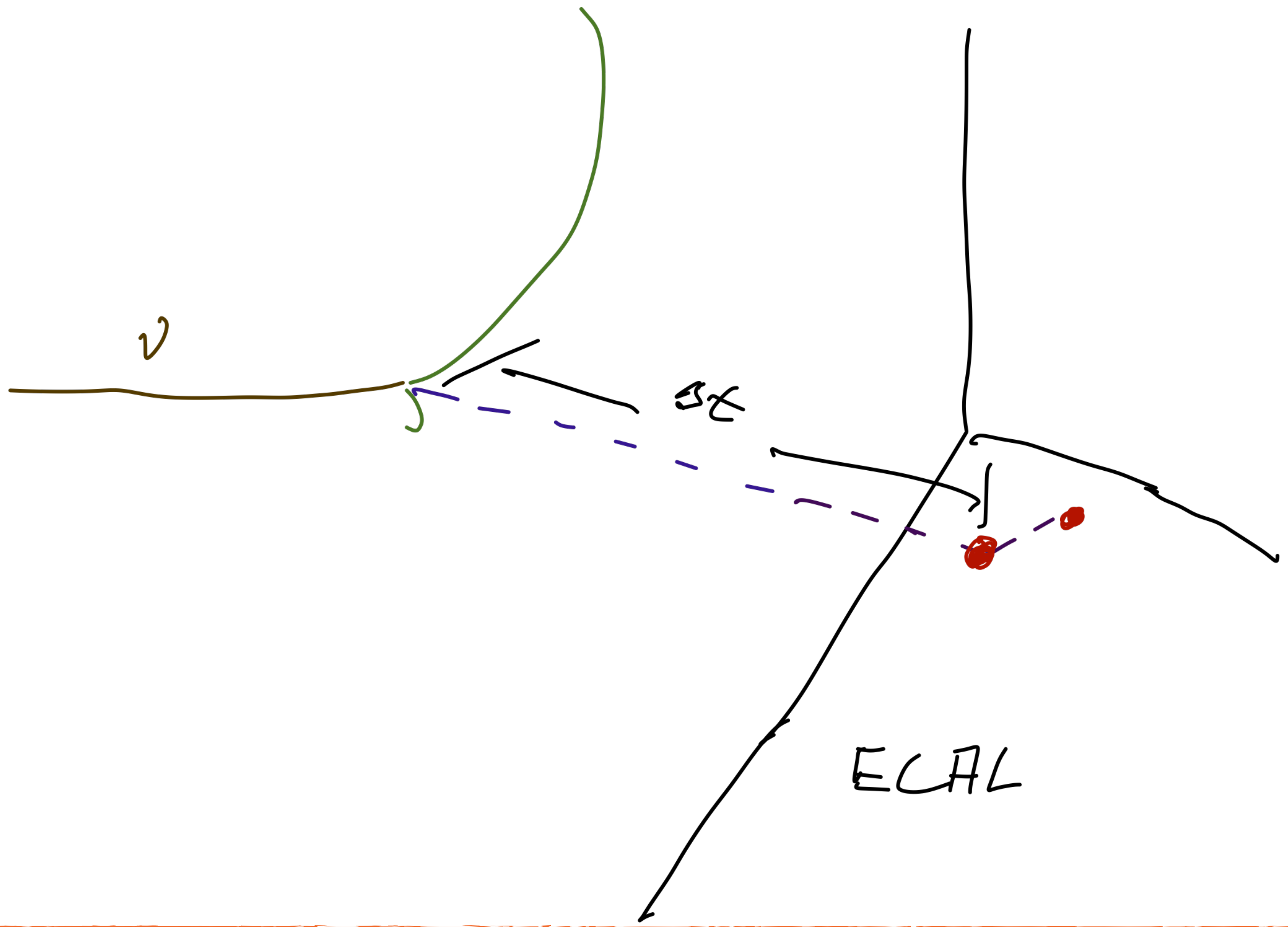


- Neutron reconstruction - a potential game-changer [still needs to be established in realistic environments!]
  - Requires timing on the few 100 ps - 1 ns level to enable energy measurement via time-of-flight



The Global Design - Developed for the ND CDR

Still subject to optimisation

- Need a calorimeter geometry that is fits the intrinsically planar geometry of the highly granular sampling structures, and matches the cylindrical HPTPC structure & pressure vessel:

  First approach: An *octagonal* structure
  NB: Also considering higher polygons (dodecagon, …) since this allows to have a deeper calorimeter while satisfying overall space constraints

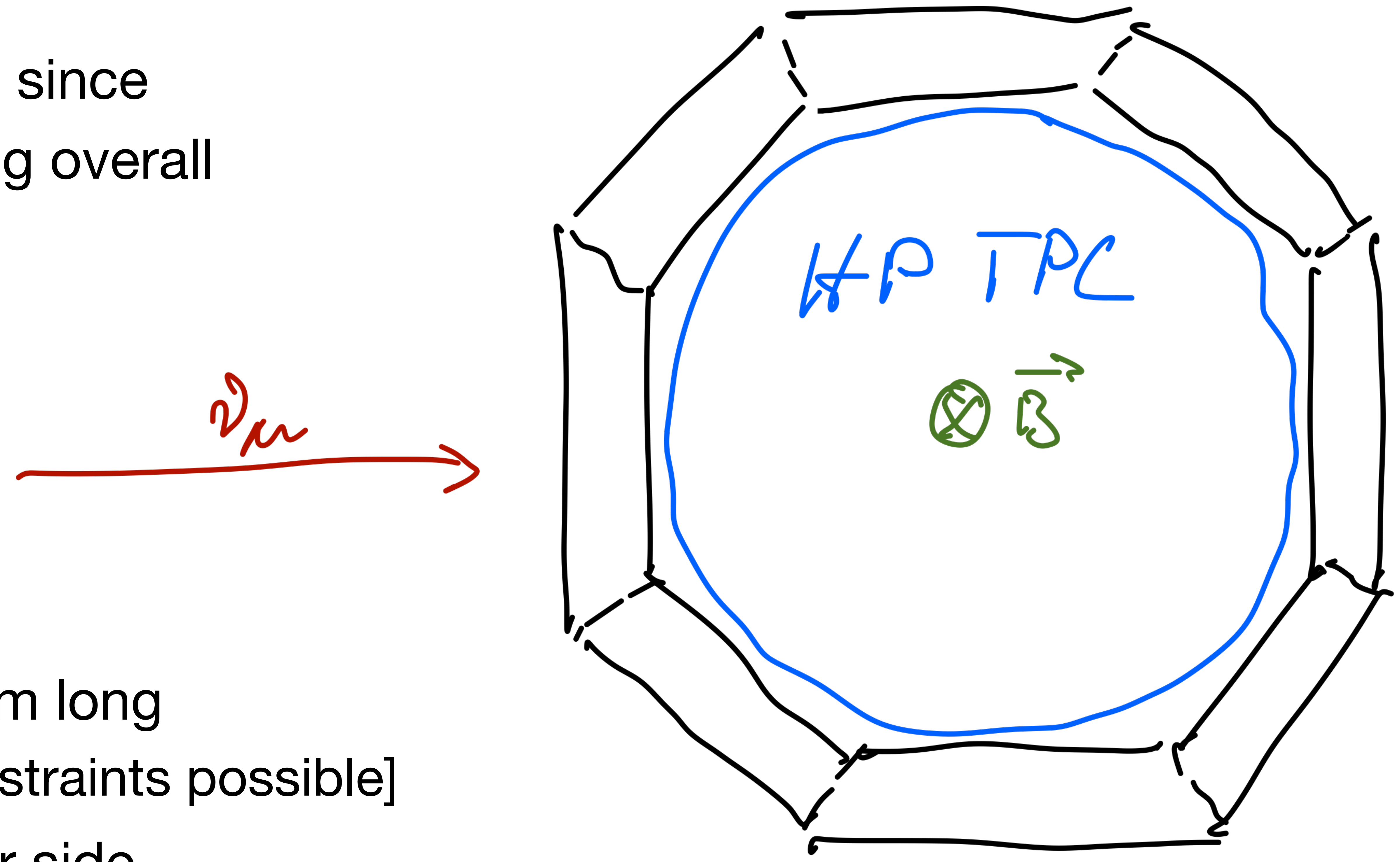
Magnetic field:

- parallel to drift direction (= cylinder axis)
- perpendicular to beam direction

For octagonal (CDR) layout:

Dimensions:

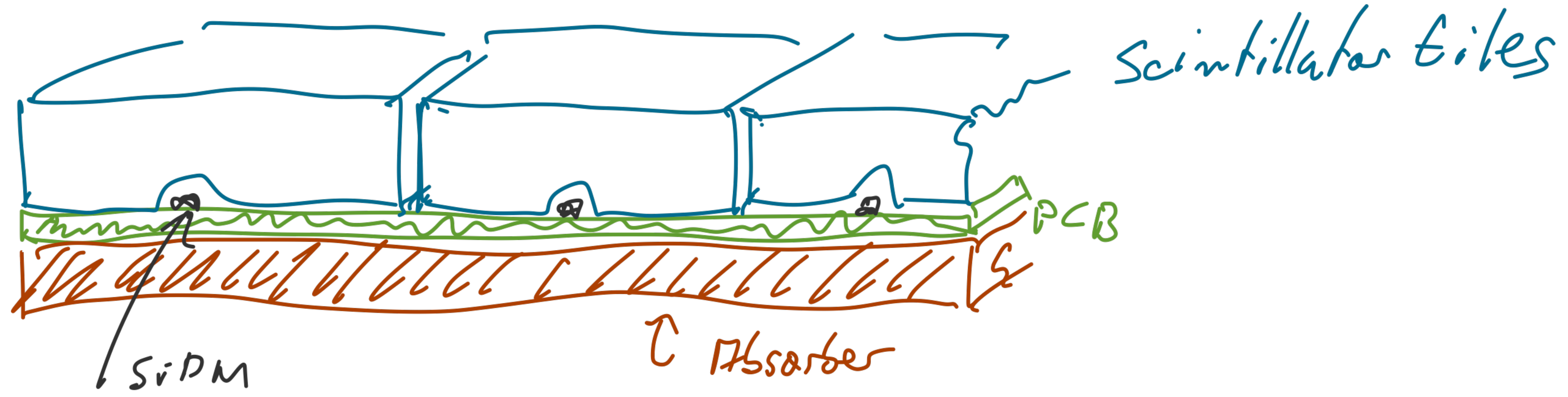
- Octagon side length: ~2.3 m (inner), ~2.6 m (outer)
- Barrel subdivided into 4 rings, each module ~ 1.46 m long
  [ad-hoc division - adjustments based on technical constraints possible]
- Endcaps subdividided into quarters - 4 modules per side



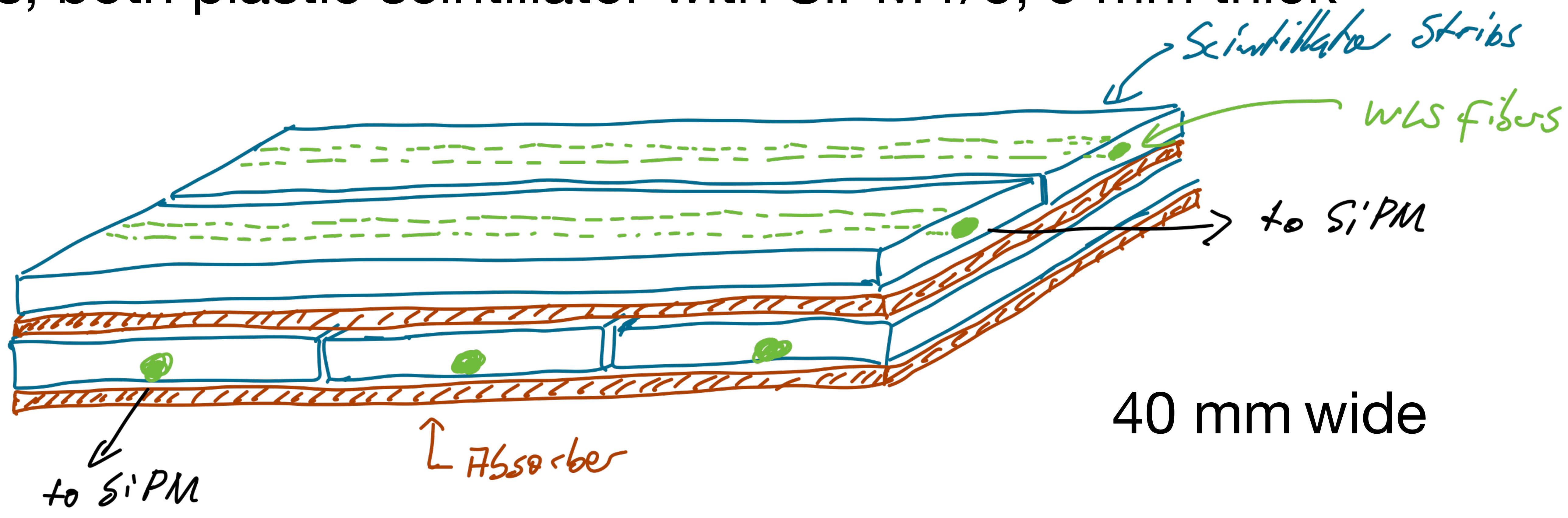
The Global Design - as used in CDR

Active Elements & Absorbers

- Thin absorbers to achieve high sampling fraction & small stochastic term: **2 mm Cu**
  - Cu chosen as for small ρ_M/X_0, moderate X_0 : more “pointy” showers than with Pb
    - Also investigating Stainless Steel / Pb sandwich: The best of both worlds?
  - Total calorimeter mass **300 t:** A significant source of background!
- Two levels of granularity in readout: Tiles and strips, both plastic scintillator with SiPM r/o, 5 mm thick



25 x 25 mm^2



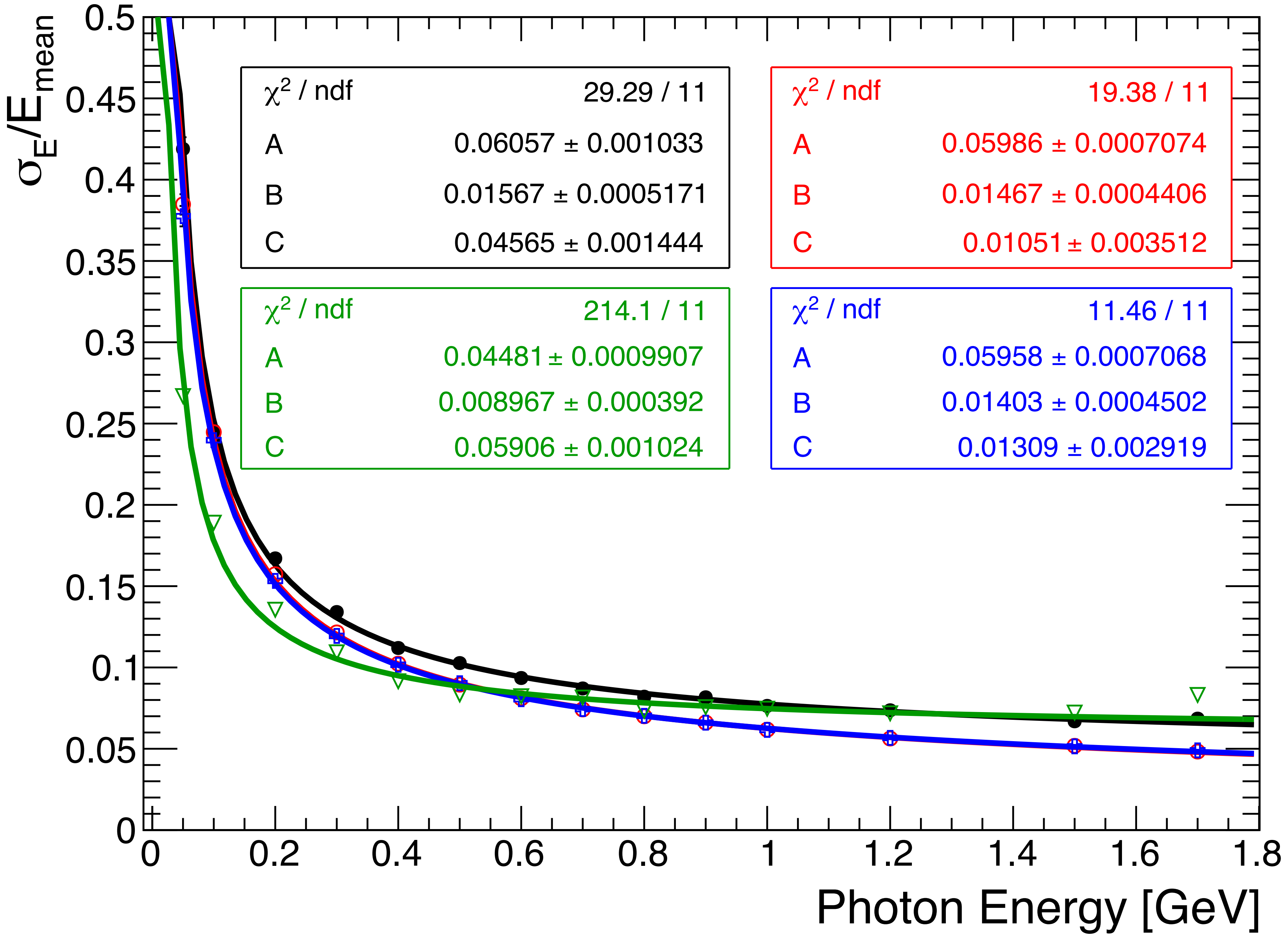
40 mm wide

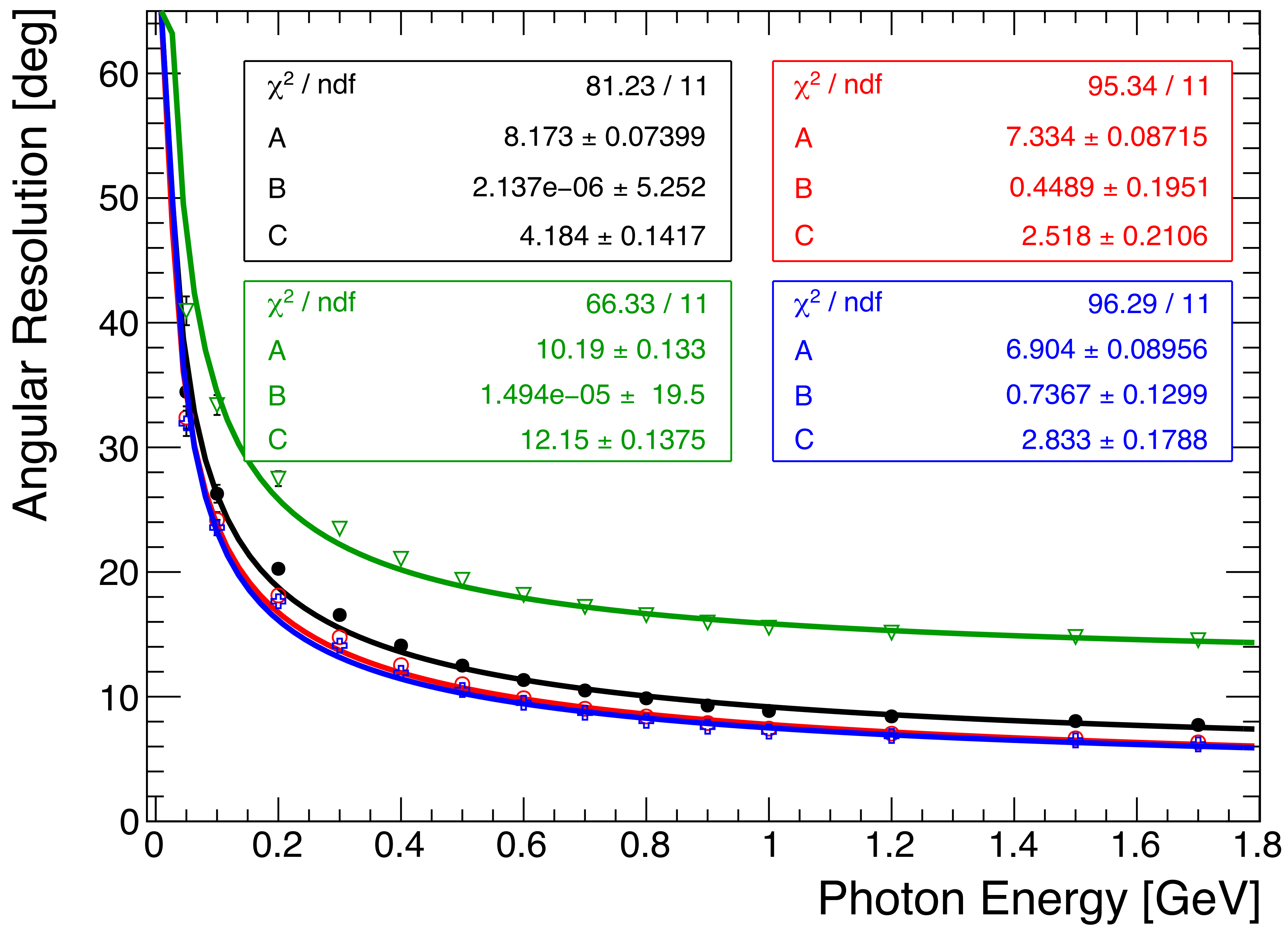
- High granularity only in first 8 (6) layers for 3 downstream (5 upstream) segments - to be optimized
- Assuming spatial resolution along strip via time difference in two-sided readout
  - Currently in simulations: 5 cm Gaussian σ for the cog of the energy distribution along strip (optimistic!)

ECAL Performance Impressions

Photons

- Energy and angular resolution for different geometries





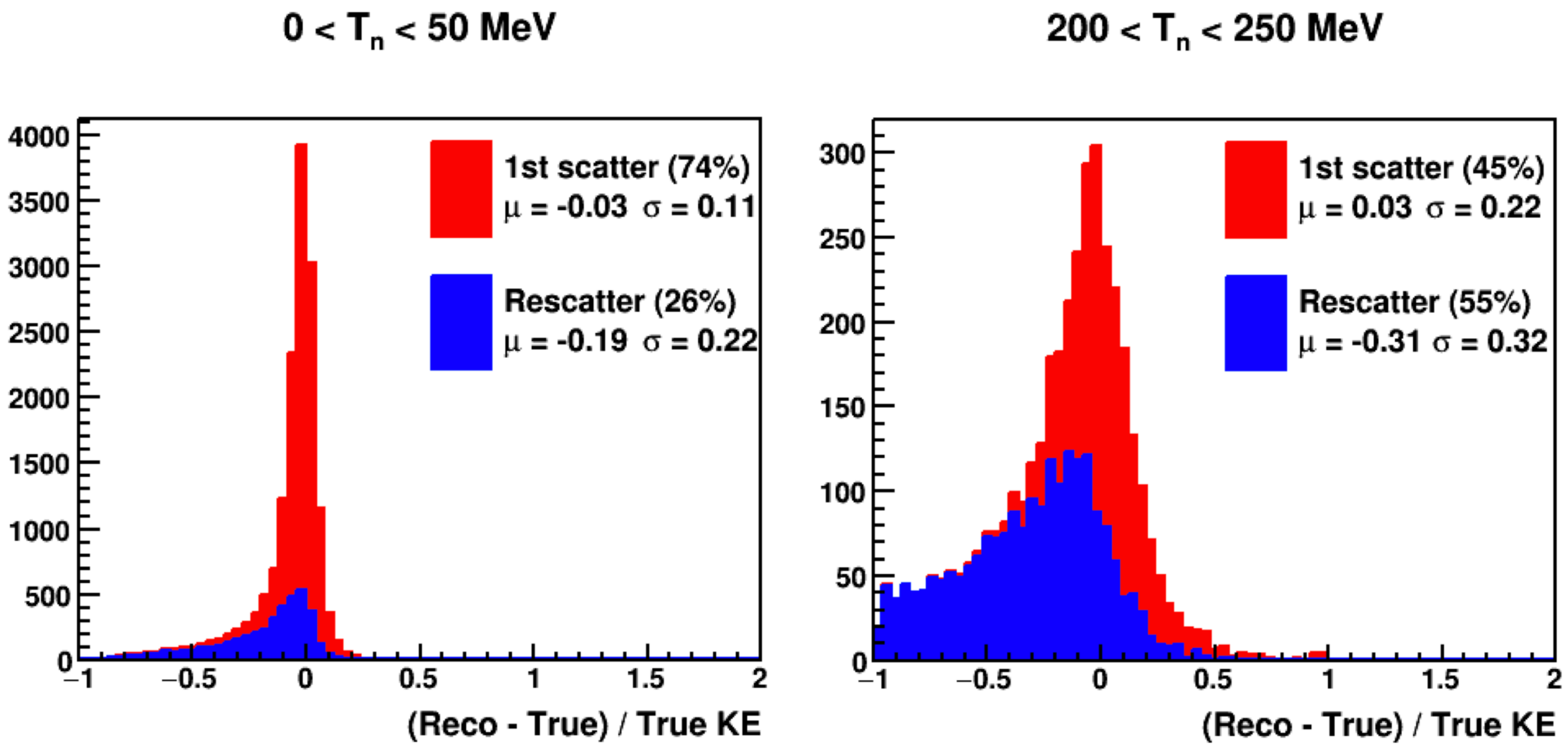
- **Octagonal ECAL, 60 layers, 2 mm Cu, 5 mm Sc**
- **Octagonal ECAL, 80 layers, 2 mm Cu, 5 mm Sc**
- **Dodecagonal ECAL, 80 layers, 2 mm Cu, 5 mm Sc**
- **Dodecagonal ECAL, 90 layers, 0.5 mm Pb, 3 mm Sc**

- Used to reconstruct neutral pions, including decay vertex position in HPgTPC volume with a few 10 cm accuracy

NB: Shower direction reconstruction not well-developed yet!

ECAL Performance Impressions

Neutrons



- Reconstructing kinetic energy from time of flight
  - requires identifying neutron scatters in plastic scintillator

Chris Marshall, DUNE CM 01/2020

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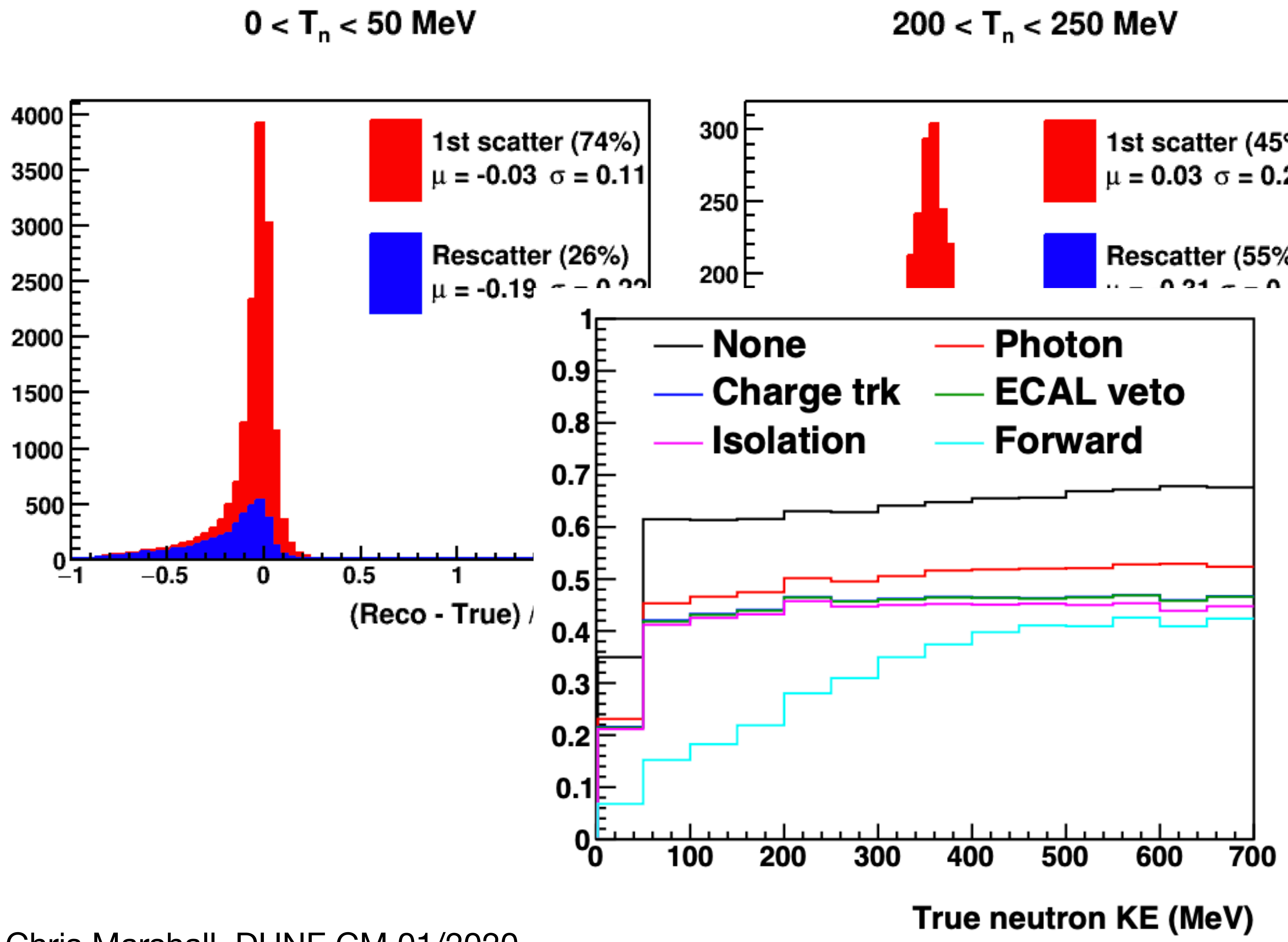

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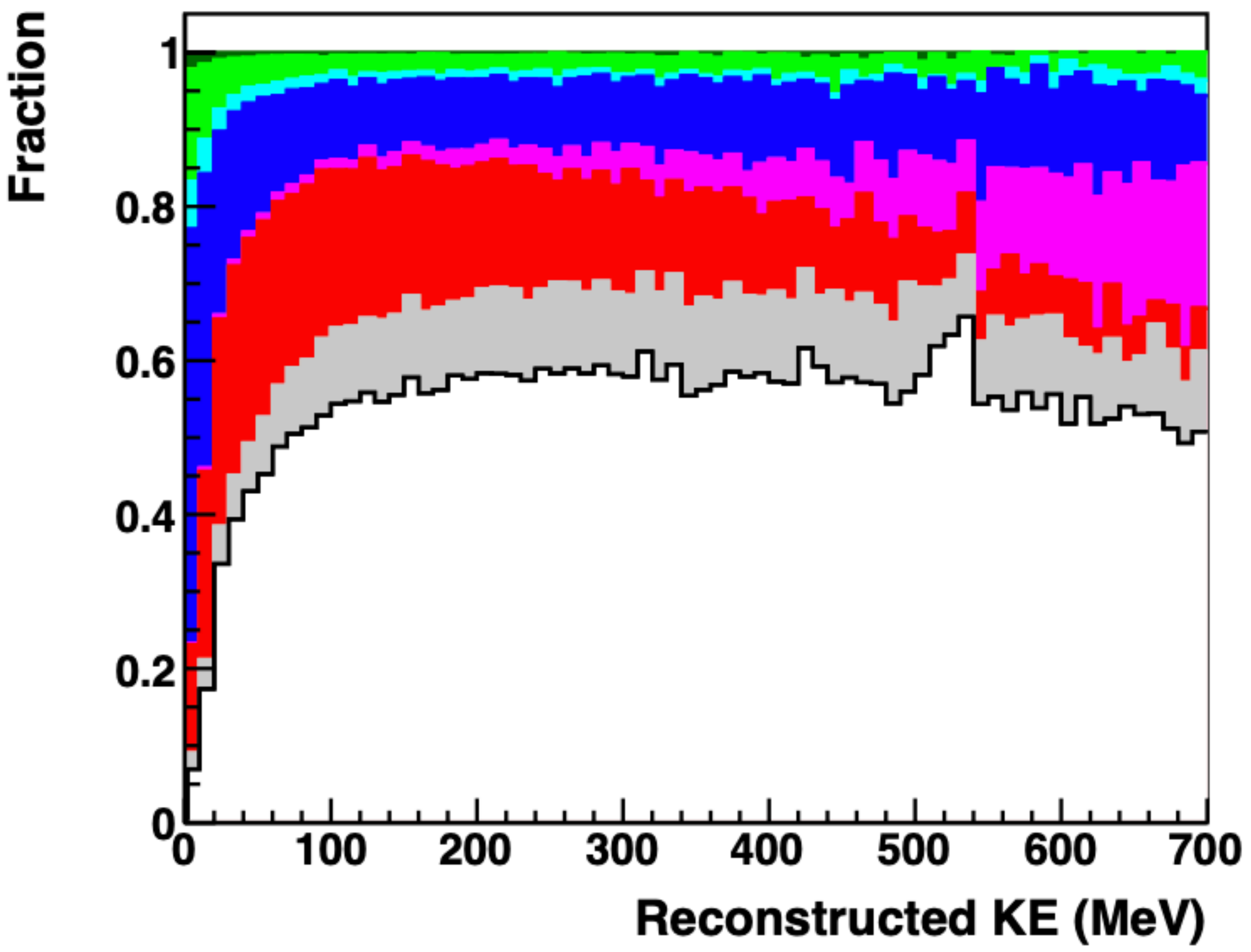

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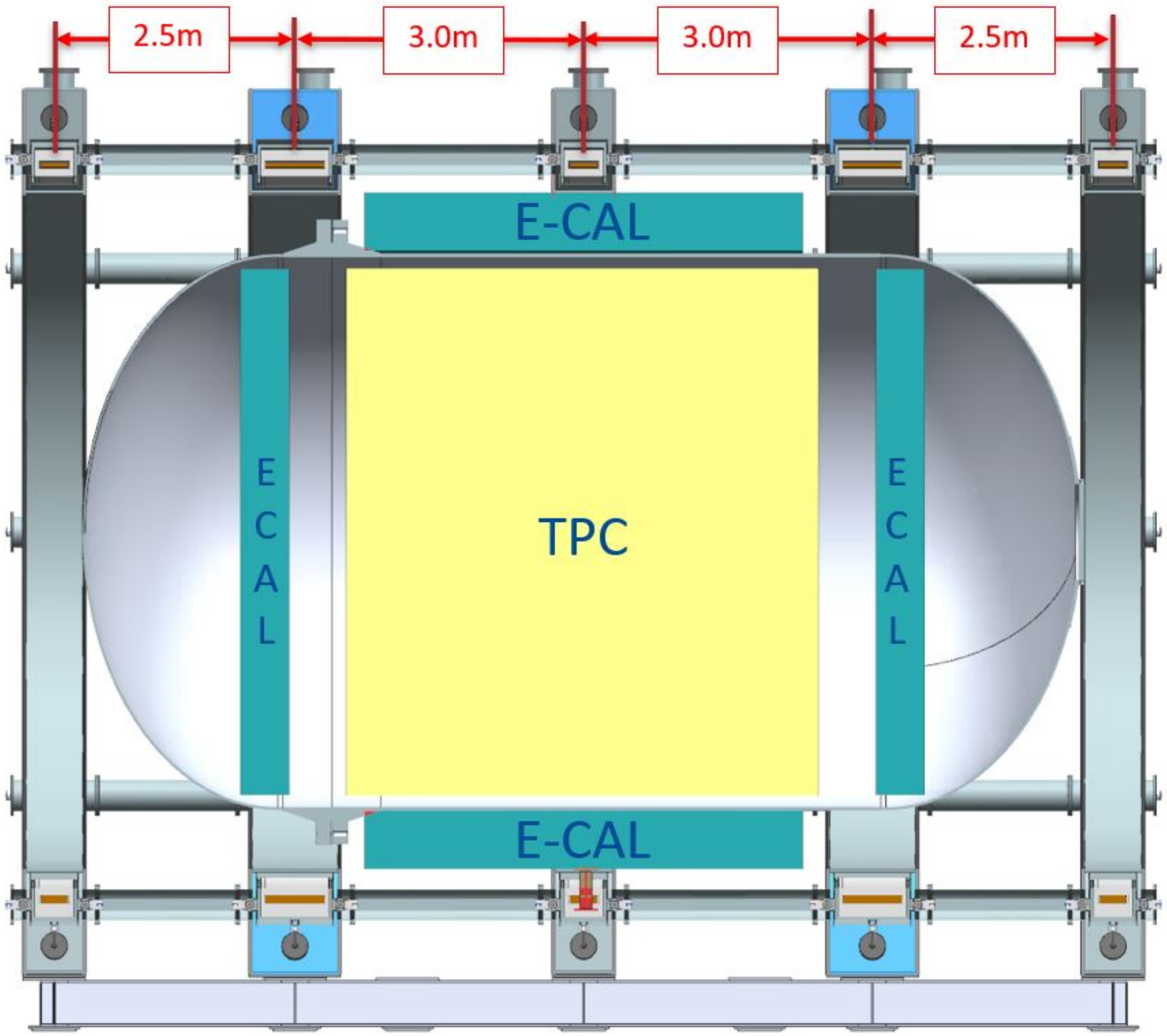
Integration of ECAL with Rest of MPD

Close connection to pressure vessel

- Still in early phase of development
  - Strong correlation with PV design
    - With dome-shaped ends, the PV will get very long: prohibitively large ECAL
    - With flat ends (currently under study), PV ends are too much material: no measurement left
  - ➩ Expect barrel outside PV, endcaps inside: Interesting integration issues!

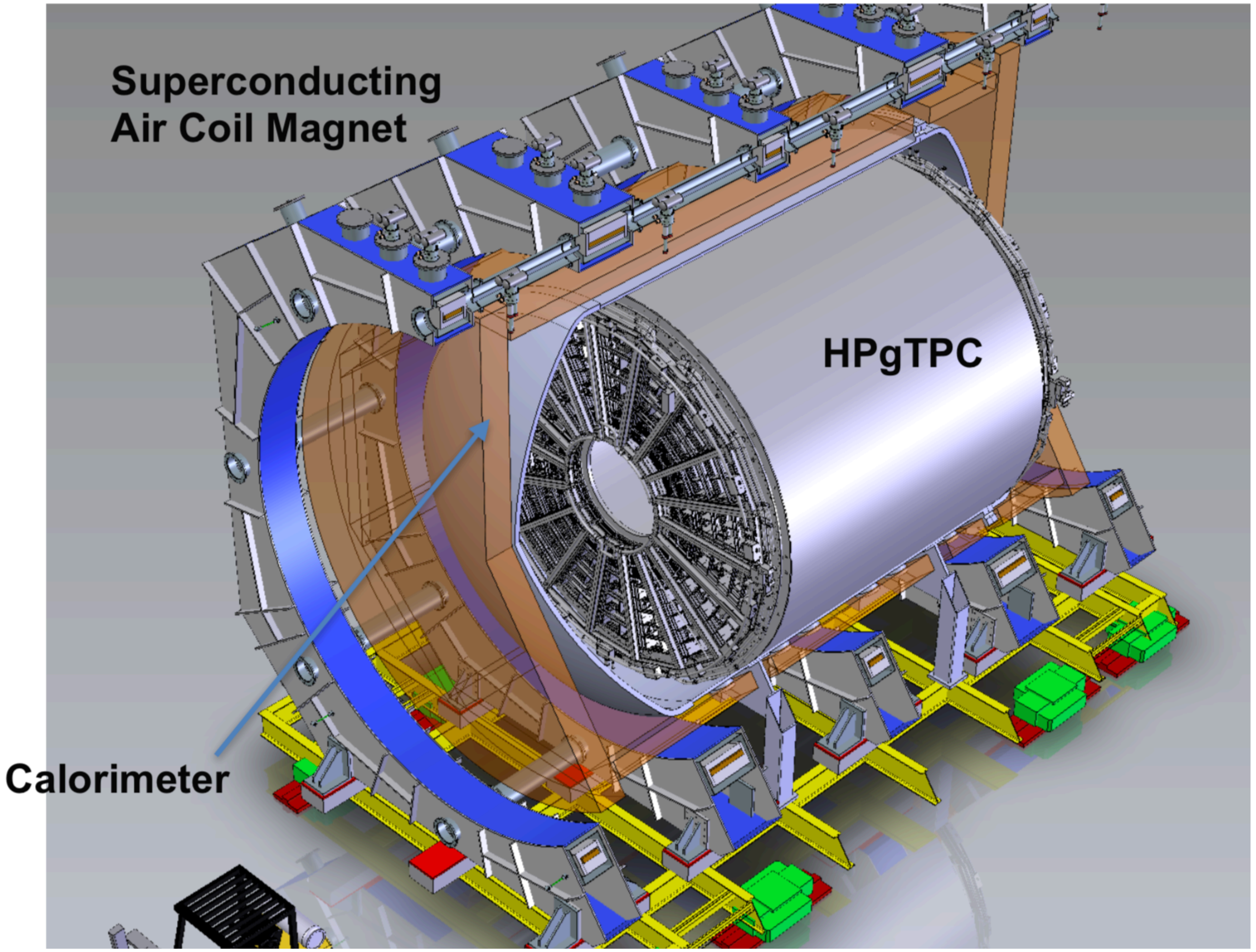
- Mechanical engineers at BARC working on PV will start into looking how to integrate ECAL into PV design - also needs some assumptions on ECAL structure / mechanics that are currently not more than educated guesses



The Boundary Conditions

A Large Detector

- The ECAL barrel surrounds the pressure vessel of the HPgTPC
  - Fiducial volume of TPC: 2.7 m radius, 5.5 m length
  - Inner dimensions of ECAL need to accommodate the PV - present assumptions (with endcaps inside PV):
    - ca. 2.8 m radius
    - ca. 6 m length



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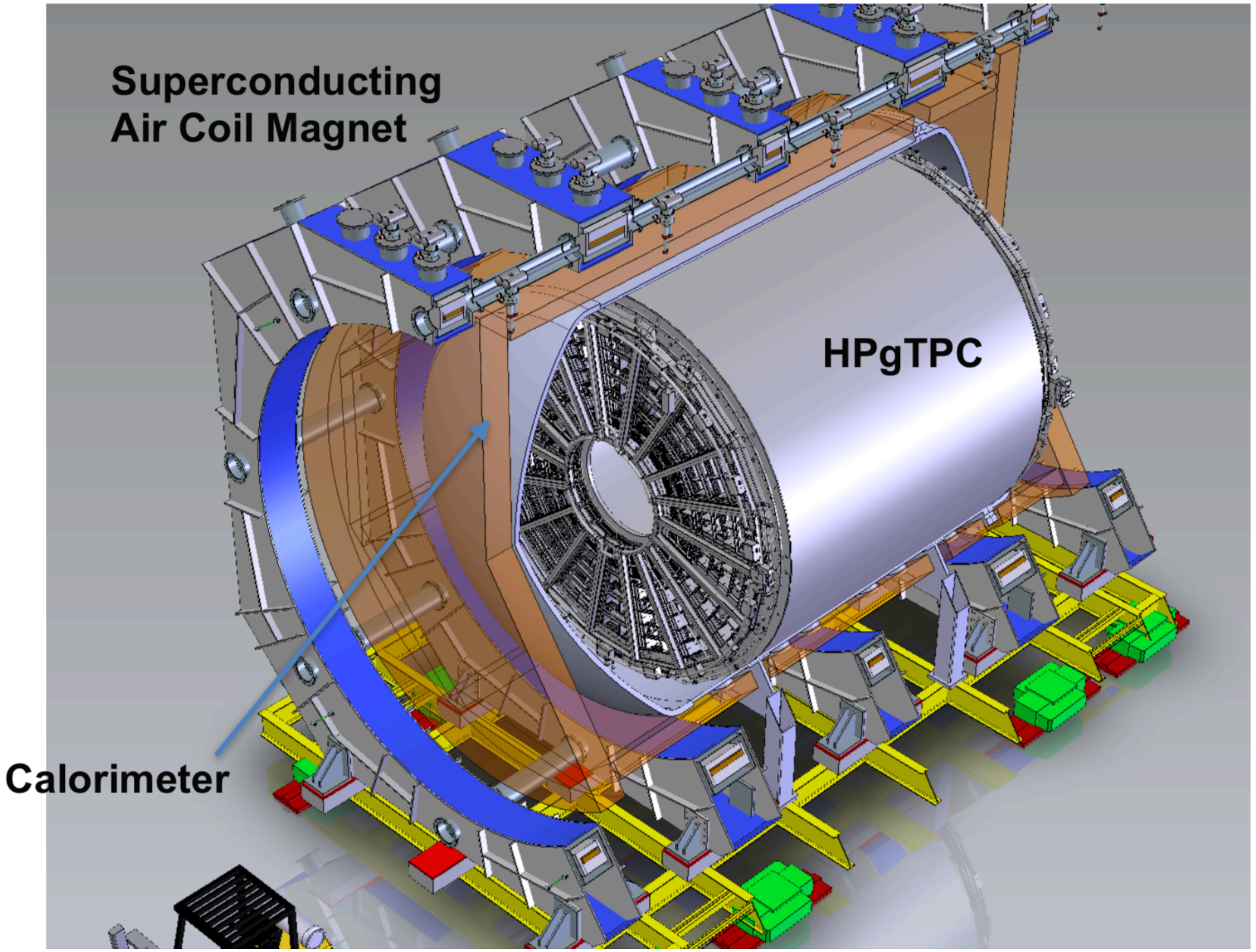
    that is a cylinder with a surface of 105.5 m^2, endcaps 2 x 24.4 m^2



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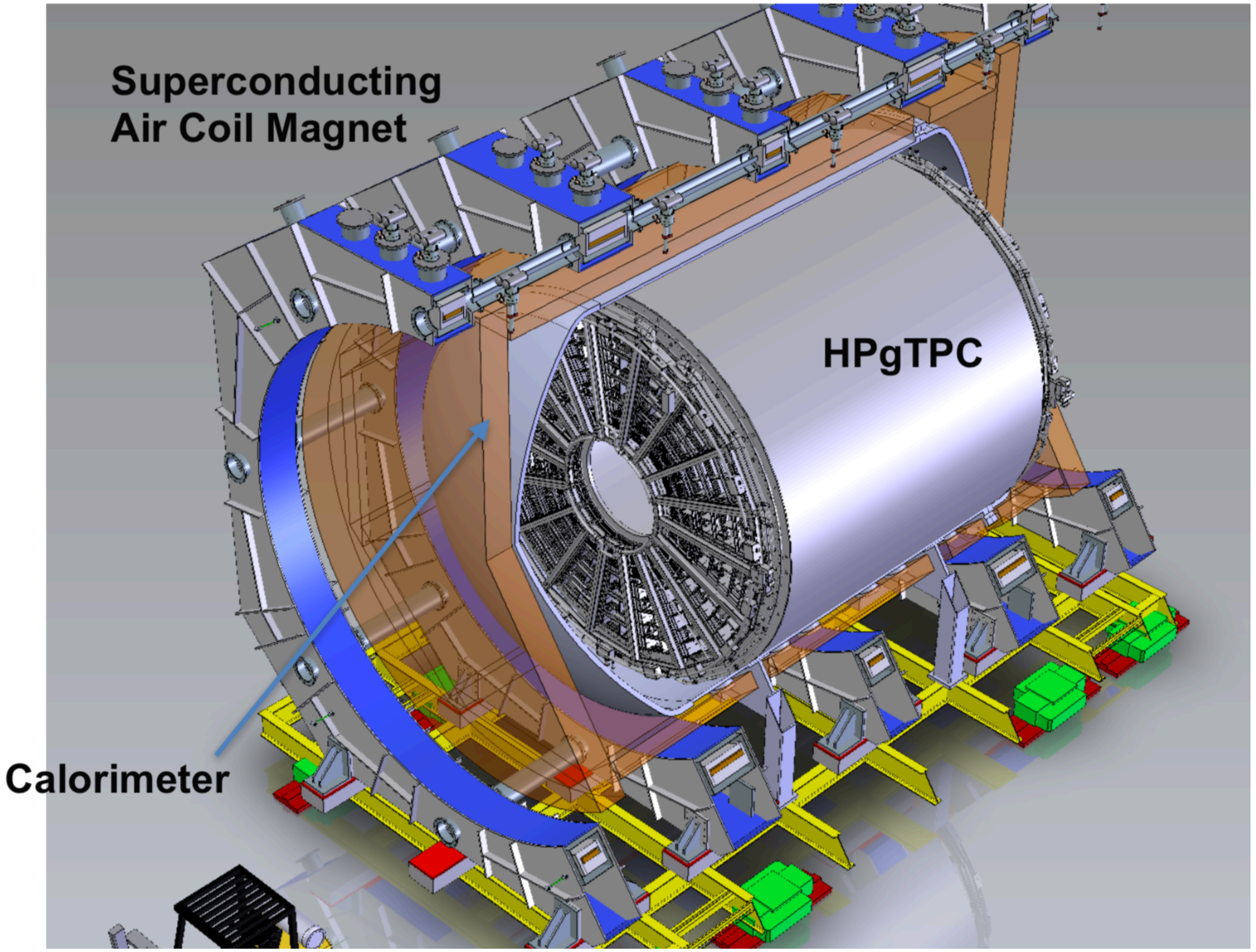
  As comparison:

  The CMS ECAL

  inner radius 1.3 m, inner length ~ 5.8 m



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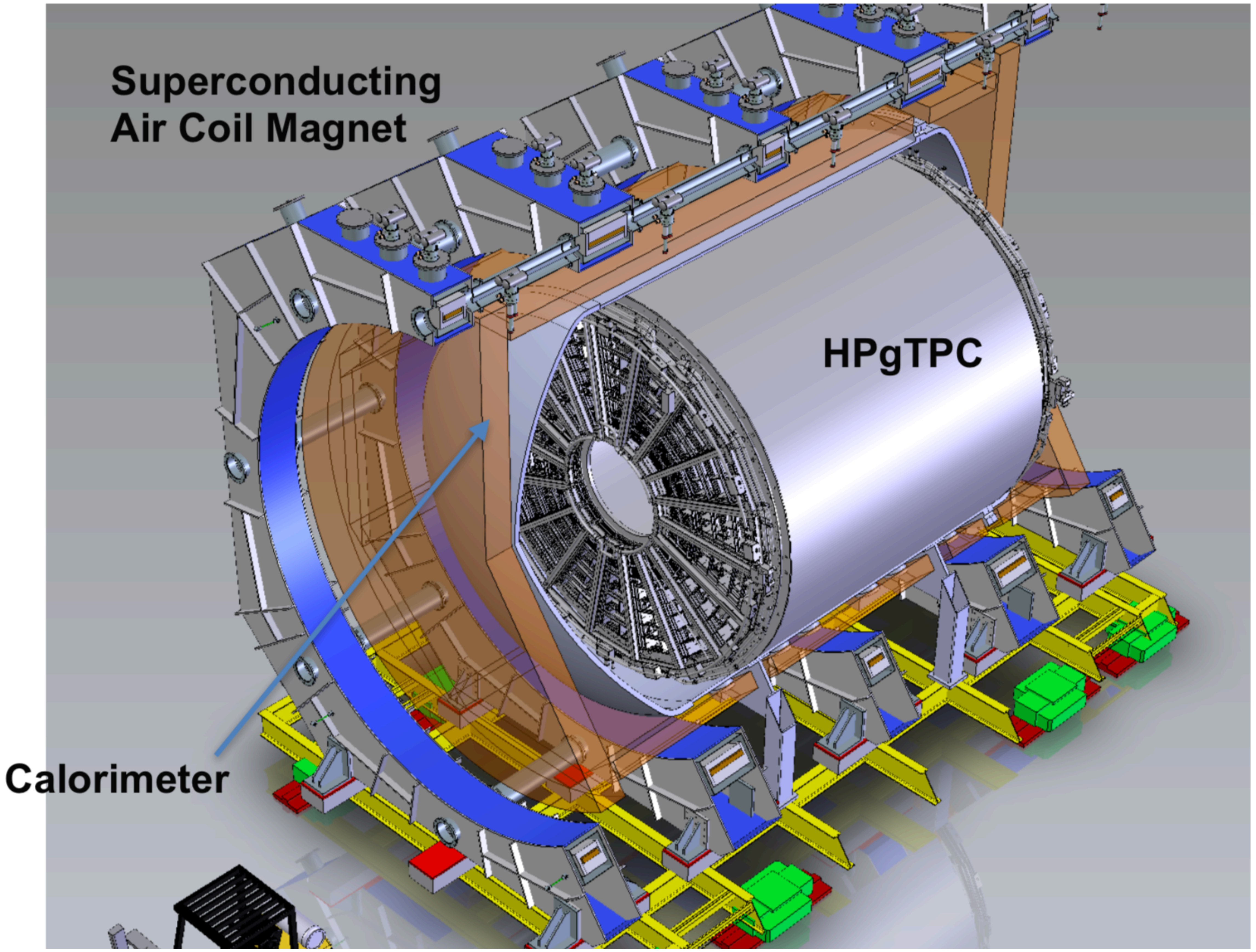


Scintillator tiles / strips with SiPM readout as active elements,

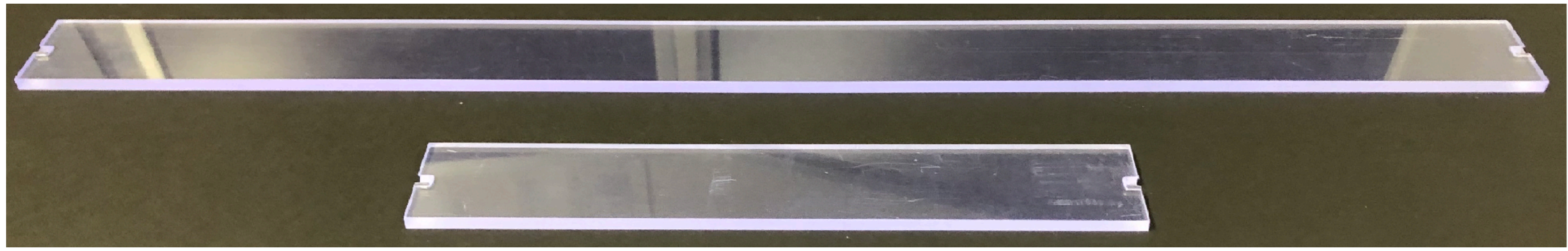
with long strips covering the bulk of the volume - depending on design:

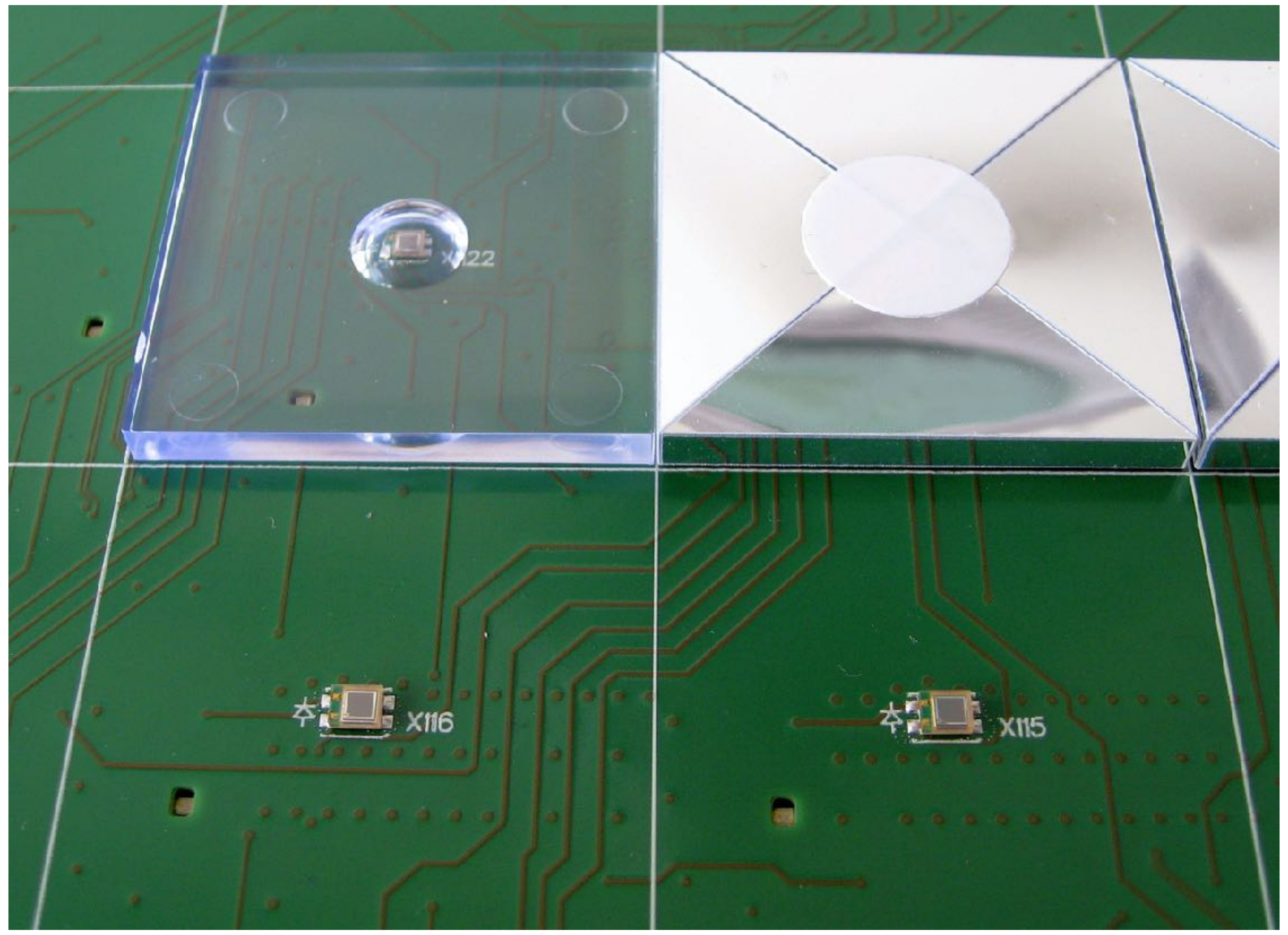
~ 400k - ~ 3M electronics channels

R&D Questions

On the way towards a TDR

- Optimising the detector design
  - Absorber material and layout
  - Active elements: Highly granular vs strip elements; strip readout technology, material,…
- Requires increased realism (and performance) in simulations, reconstruction
- In particular:
  - Response to neutrons:
    - Optimisation potential for plastic scintillators?
    - Realistic modelling in simulations?
    - Requirements on readout / granularity?
  - Timing: What is needed, what can be achieved?
  - …





Summary

… and a look ahead

- Have developed a concept for the electromagnetic calorimeter for the DUNE ND
  - Up to now essentially a “hobby project” - with very limited dedicated manpower
- Incorporates CALICE AHCAL developments and technologies - with modifications driven by performance goals and detector size

- Key performance goals
  - Stand-alone neutral pion reconstruction, including vertex reconstruction
  - Neutron reconstruction and energy measurement using time-of-flight

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- Next steps: Bringing the project “on the real axis”
  - Technical Design Report for DUNE Near Detector ~ end of 2021
  - Construction starting ~ 2024
  - First beam 2028 / 2029