HPTPC DESIGN STUDIES FOR DUNE

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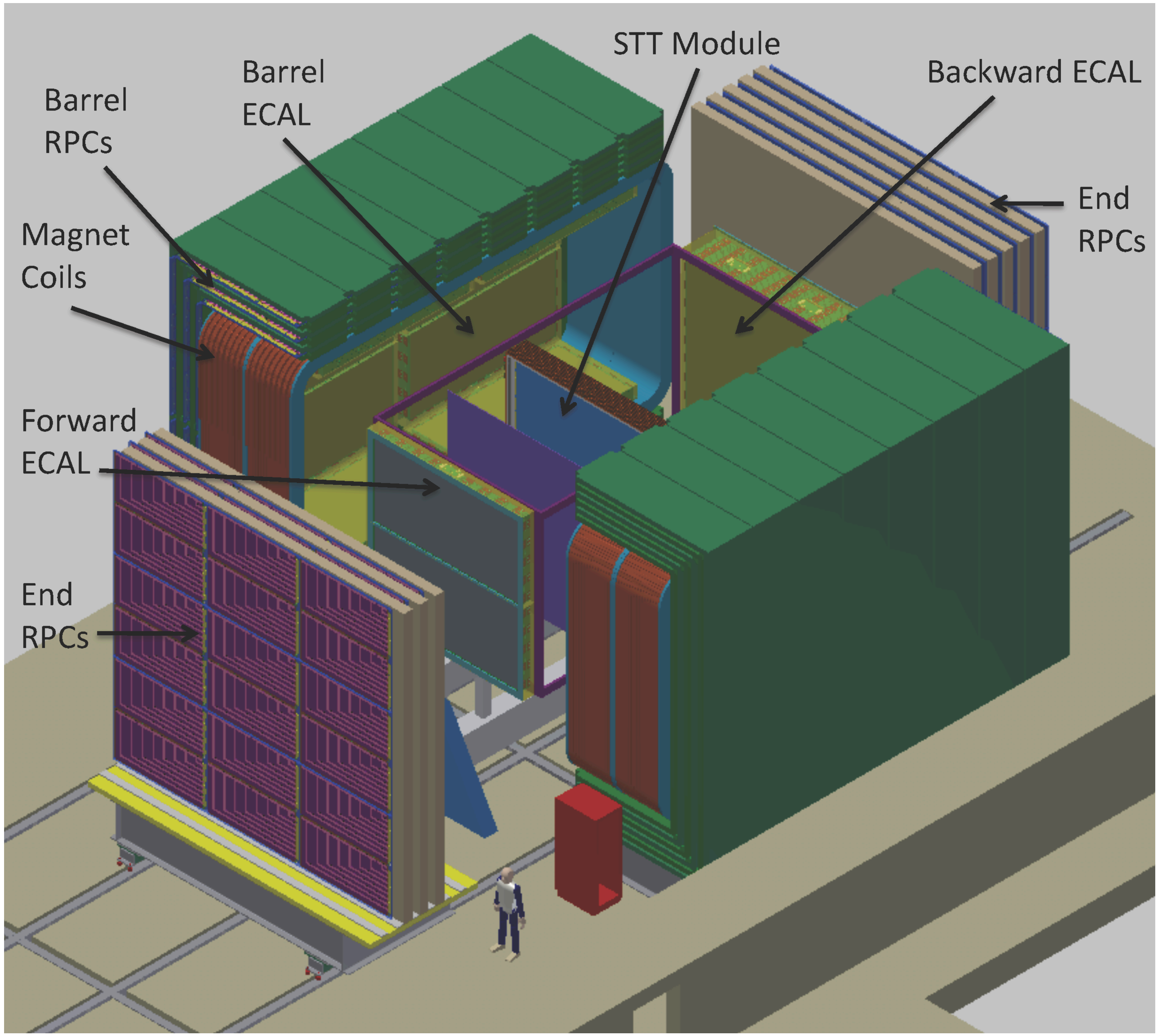
University of Oxford

Workshop on Neutrino Near Detectors based on Gas TPCs — CERN, 9th Nov 2016

DUNE'S NEAR DETECTOR REFERENCE DESIGN



(arXiv:1601.02984)

NEAR DETECTOR OPTIMIZATION TASK FORCE

The task force was charged to

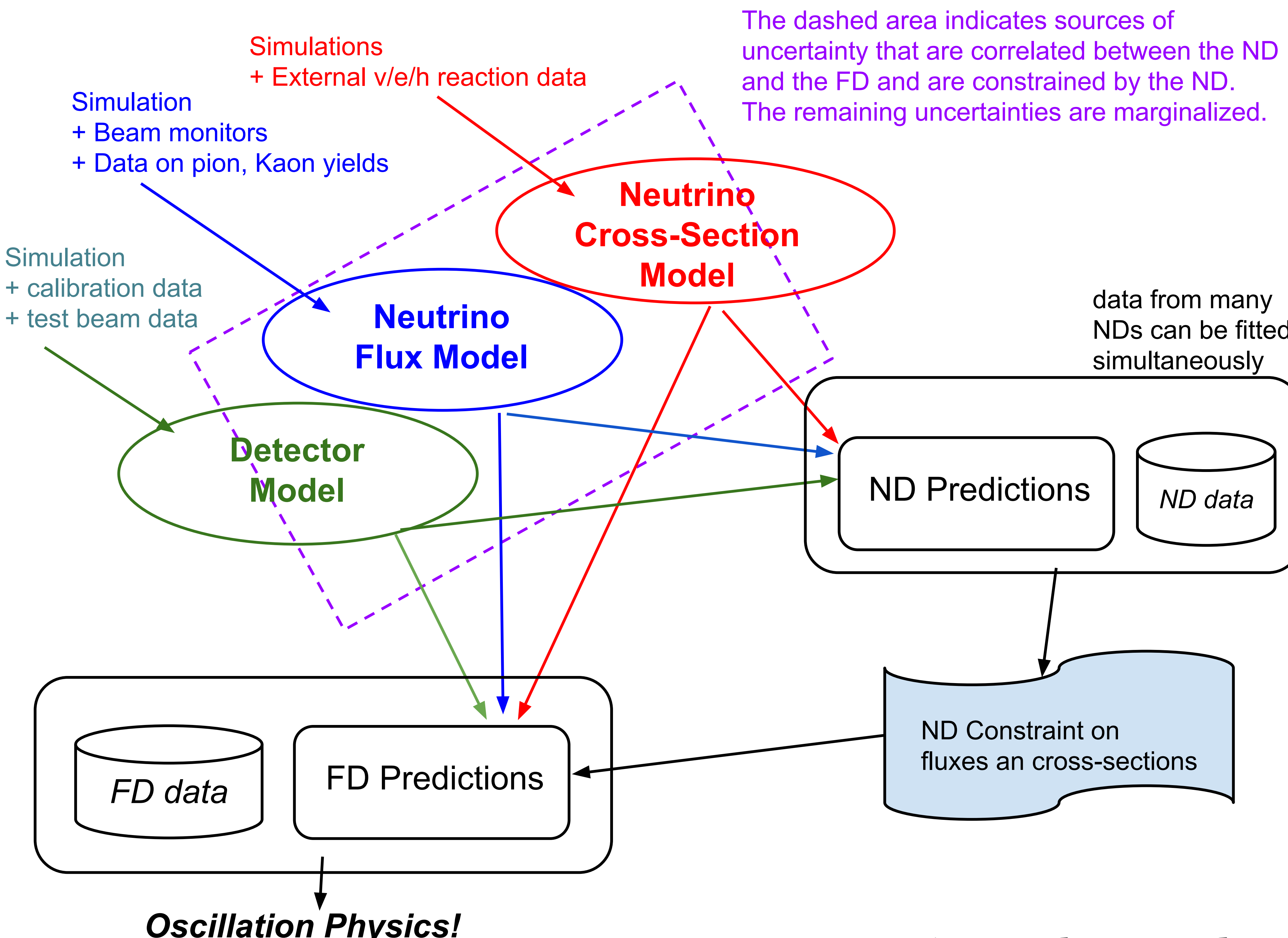
- Develop GEANT4 simulations of the reference design near detector and possible alternatives;

- Perform a full end-to-end simulation connecting the measurements in the near detector to the far detector systematics using, for example, the VALOR framework;

- Evaluate the potential benefits of augmenting the reference design with
  - a liquid argon TPC
  - and the use of a high-pressure gaseous TPC;

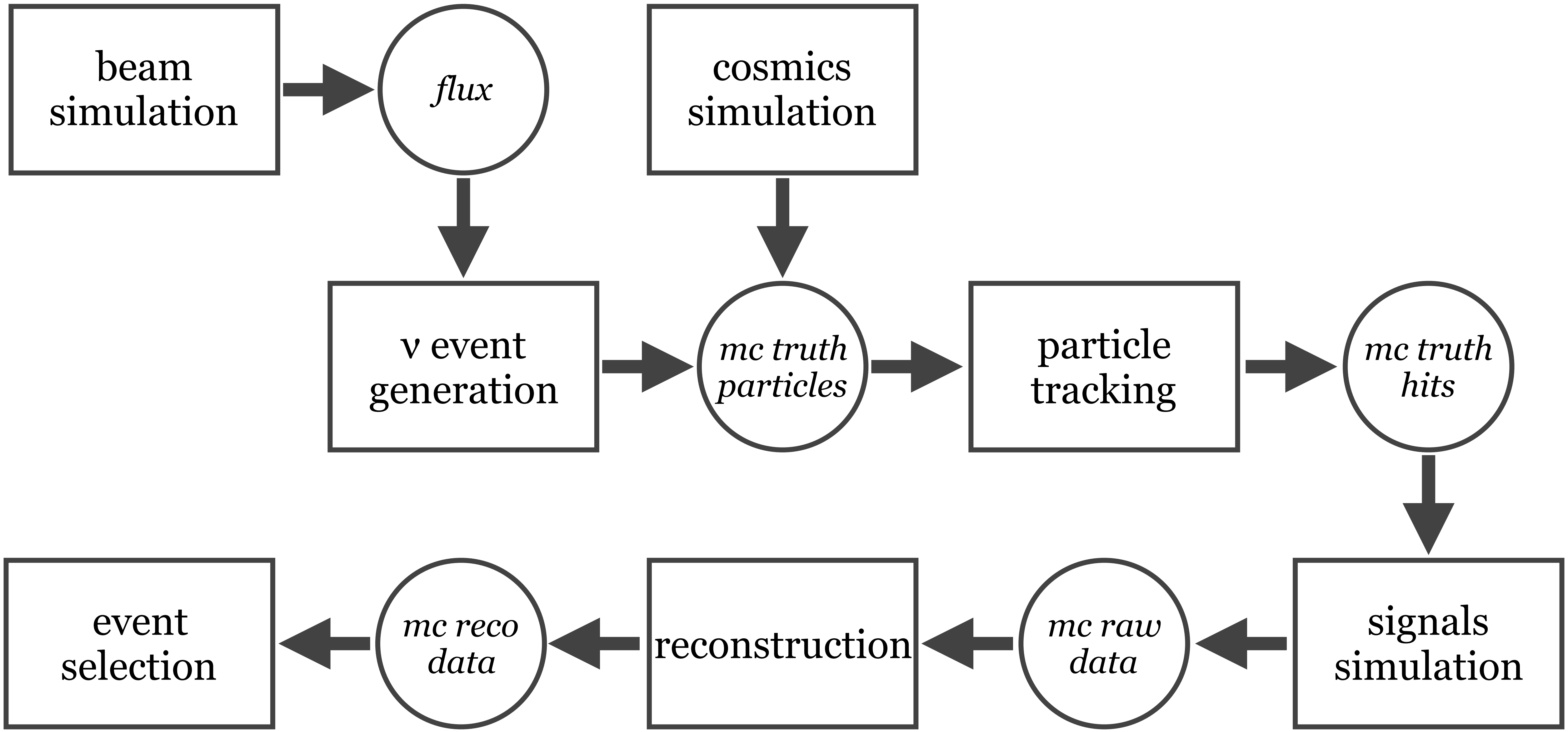
- Produce a first report on their findings to the DUNE Technical Board by September 2016 and a final report by March 2017.

NEAR DETECTOR OPTIMIZATION TASK FORCE

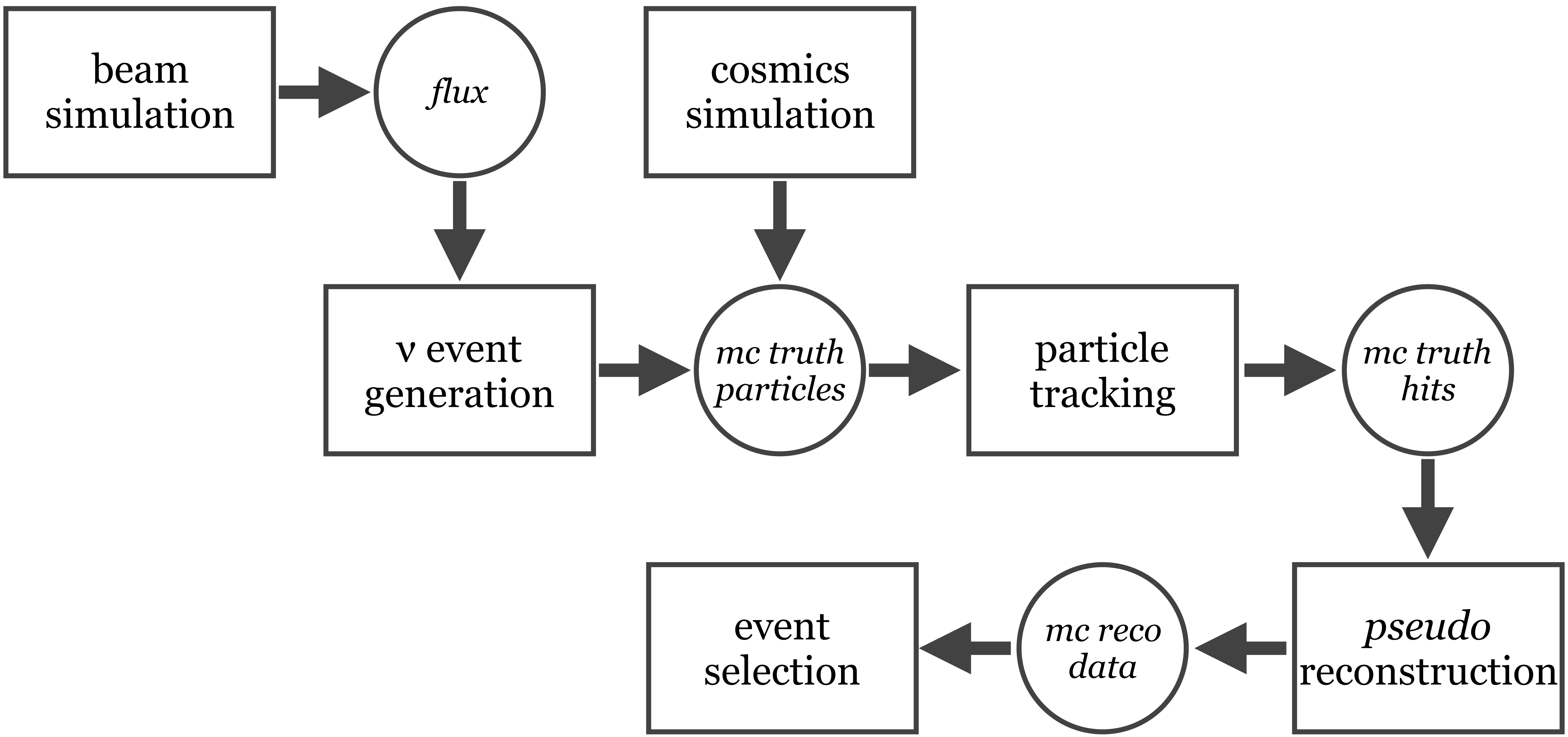


(Figure by C. Andreopoulos)

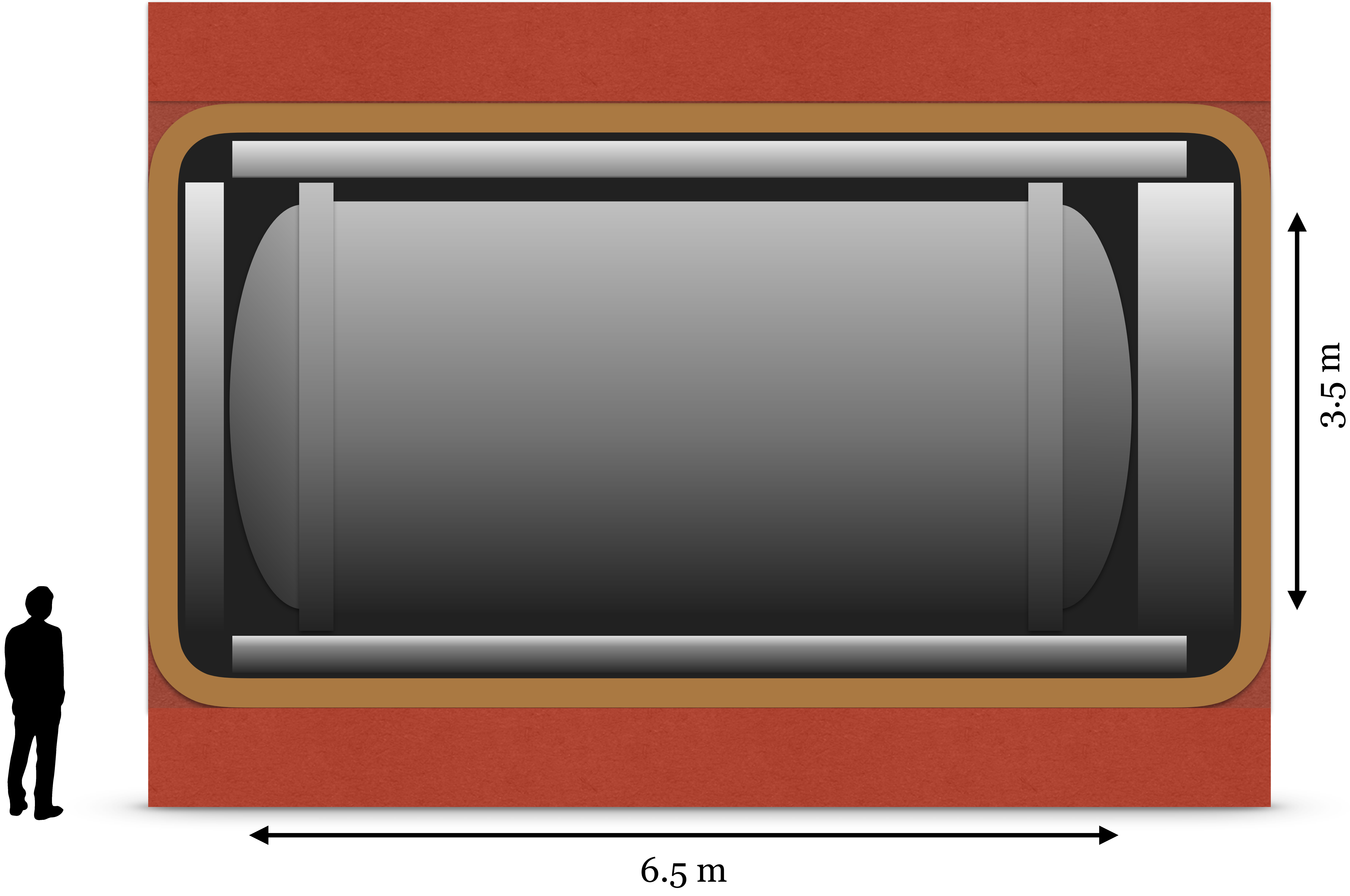
SIMULATION WORKFLOW



SIMULATION WORKFLOW



ARGON GAS TPC — DETECTOR CONCEPT



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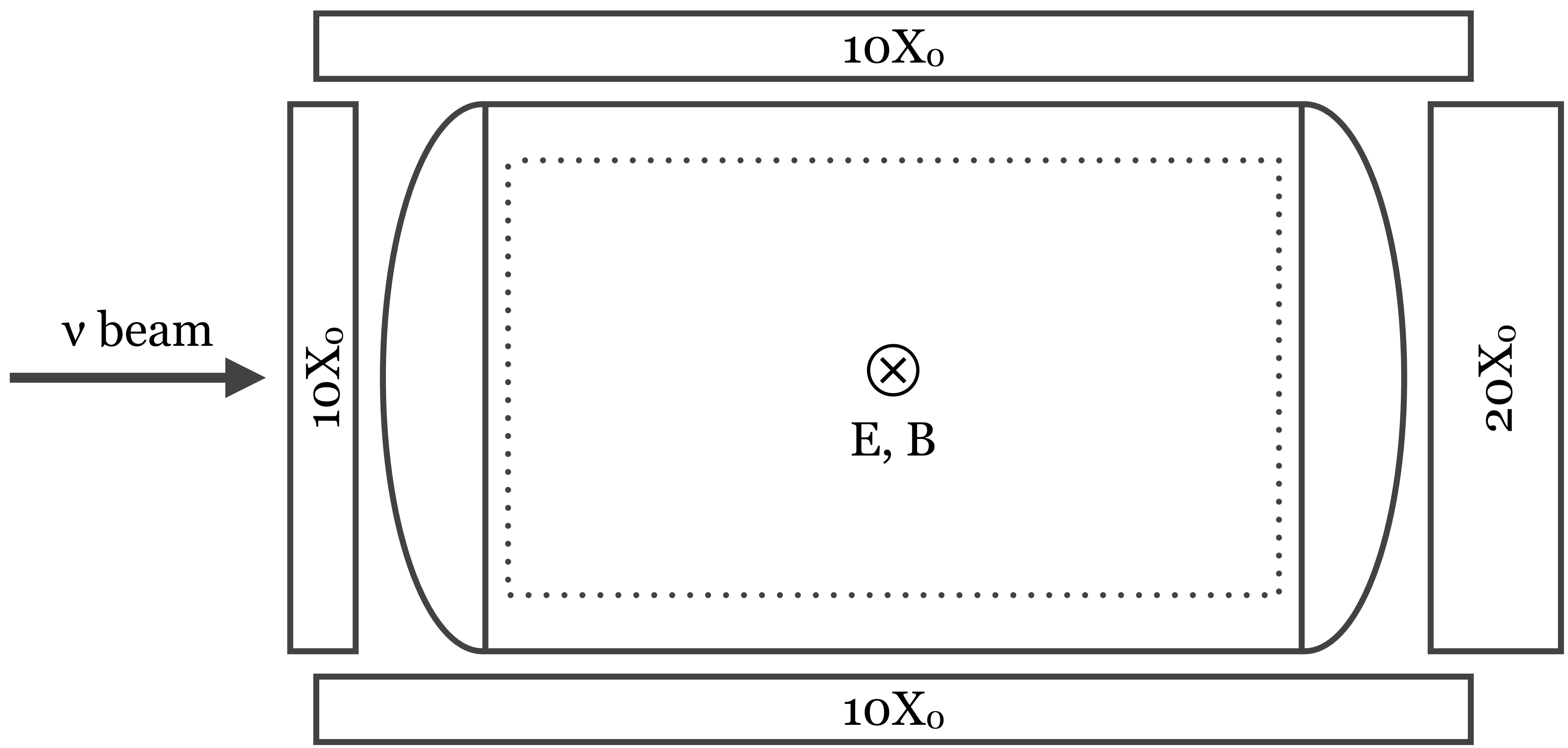

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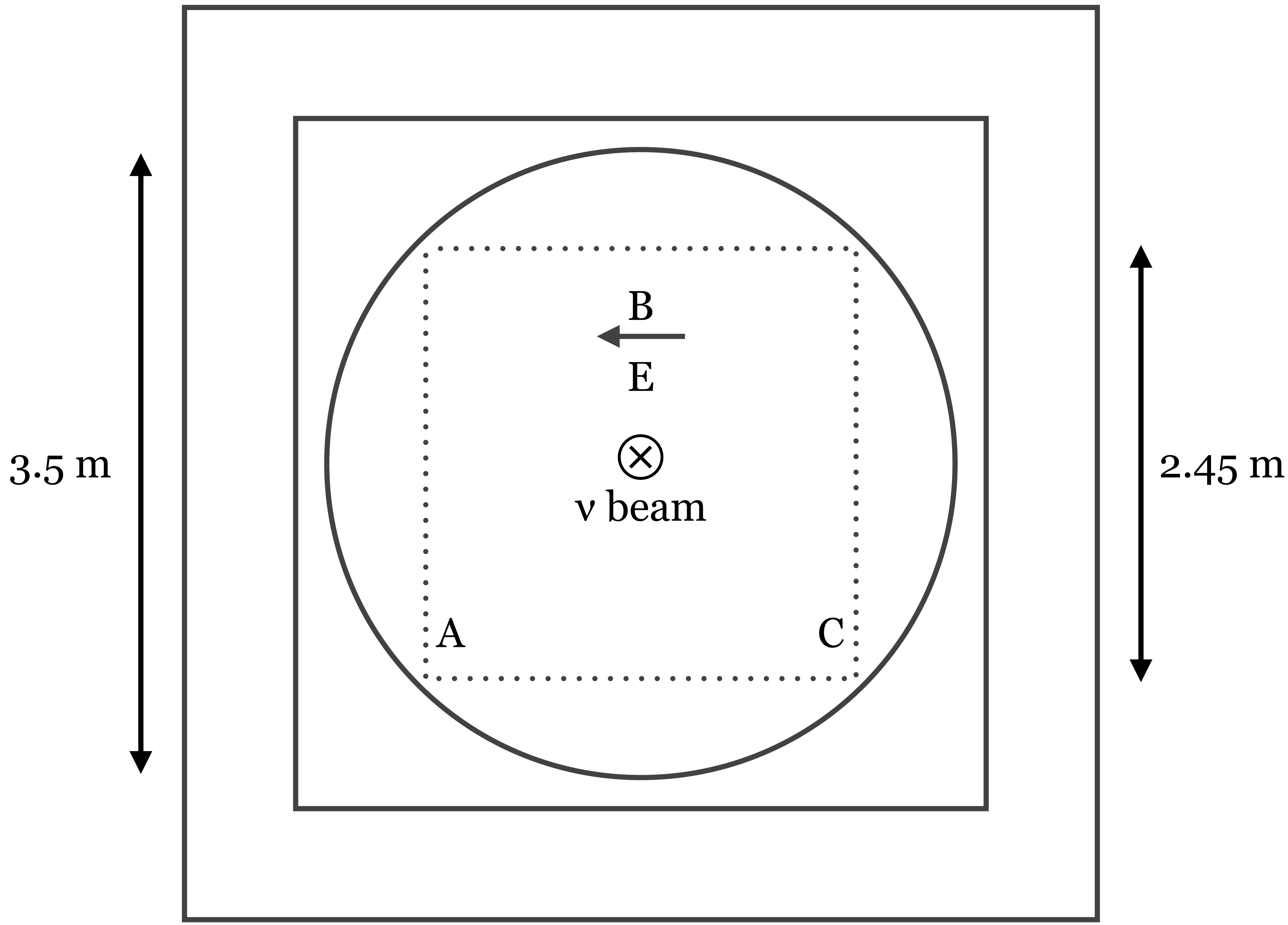
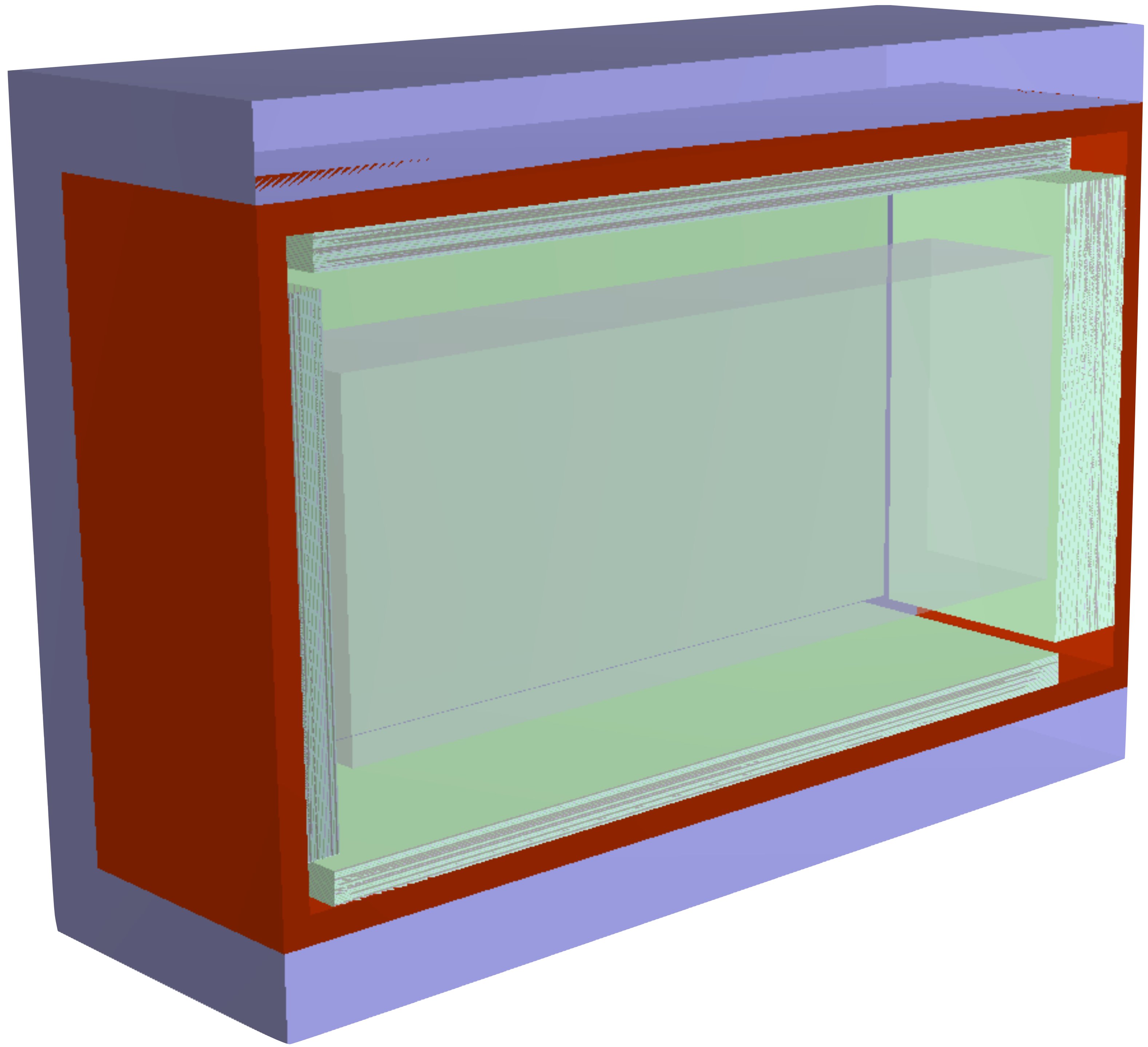


ARGON GAS TPC – SIMULATION GEOMETRY



TARGET MASS & OPERATIONAL PRESSURE

- FGT contains 112 kg of argon (passive targets) and 377 kg of calcium.
    - Expected statistics: O(1M) CC events in neutrino mode per year; O(0.3M) CC events in antineutrino mode.

- To provide similar statistics (assuming a ~50% passive/active volume ratio), 1 tonne of argon needed for GArTPC:
    - 5 bar, 300 K: 125 m^3
    - 10 bar, 300 K: 62 m^3
    - 15 bar, 300 K: 41 m^3

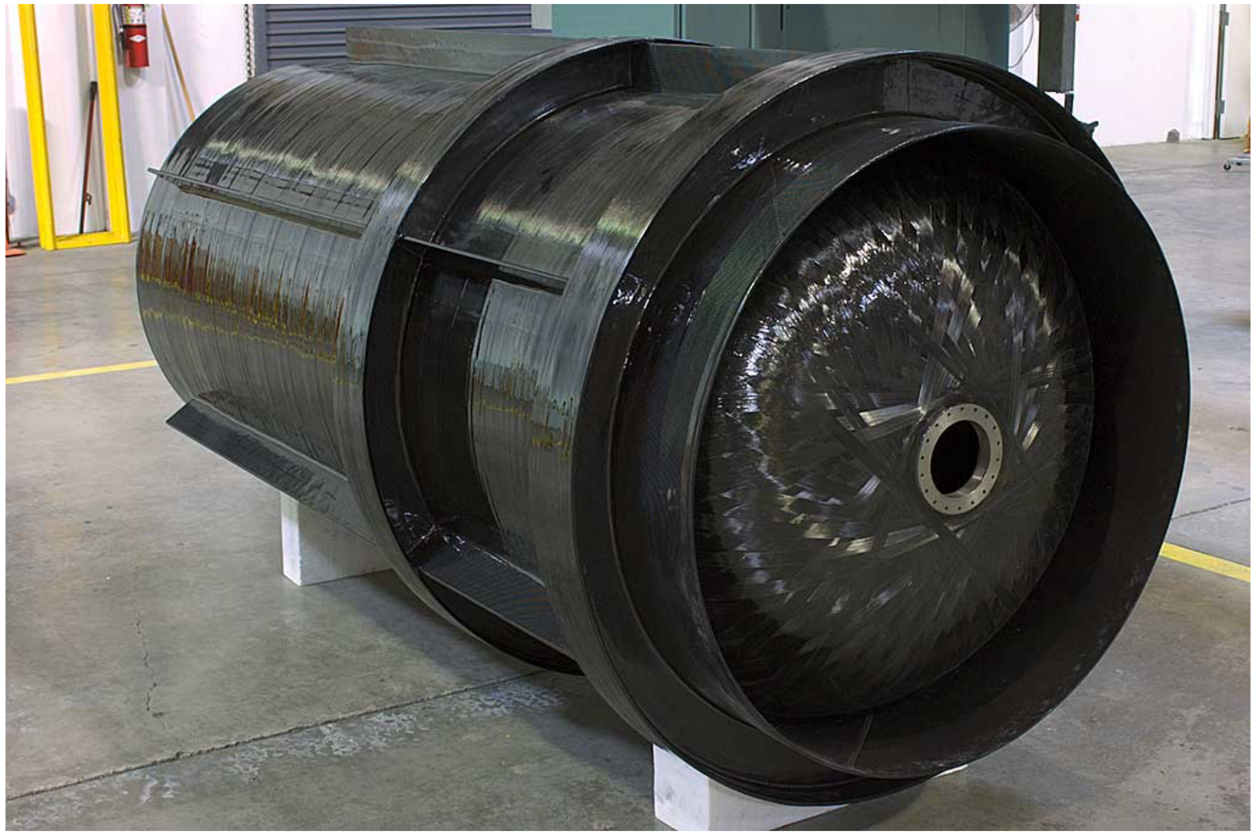
- Vessel dimensions for **10 bar** match approximately those of the FGT's straw-tube tracker, and that pressure seems also more manageable for charge readout.

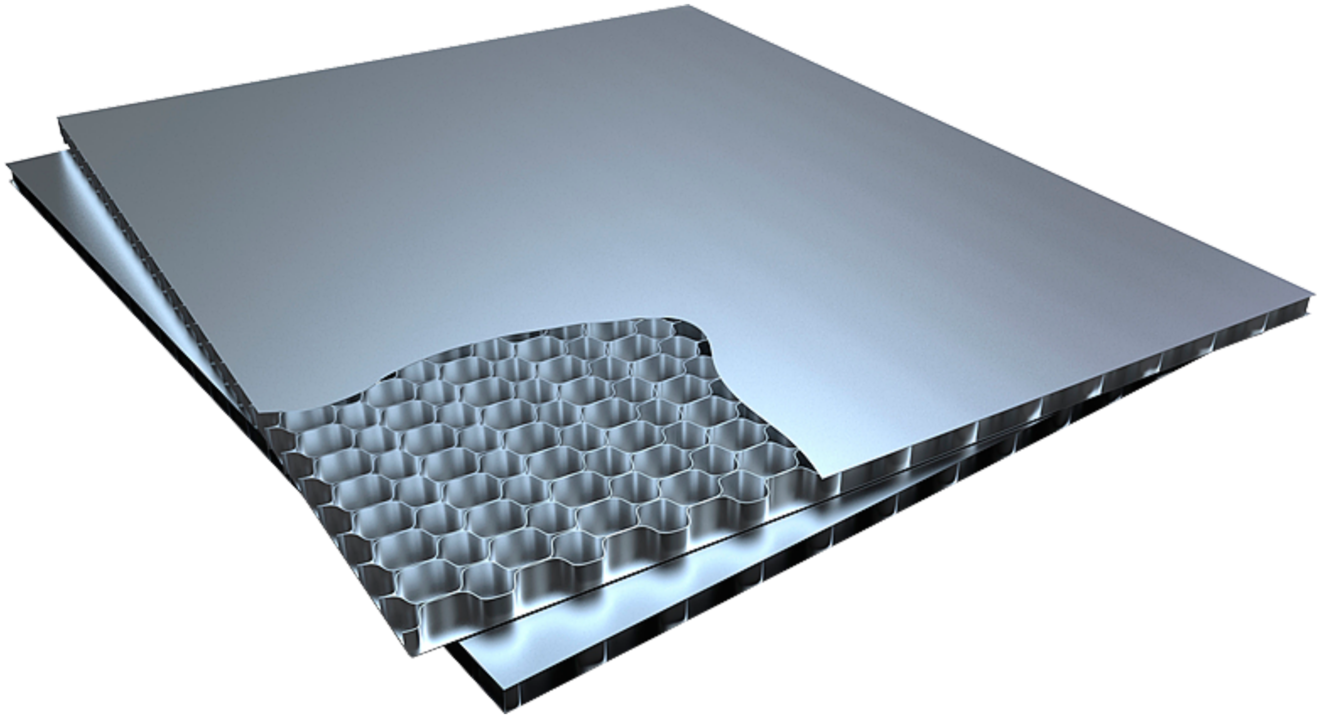
PRESSURE VESSEL

- Titanium alloy UNS-R56323
  - Wall thickness: barrel, 9 mm (0.25X_0); endcaps, 17 mm (0.5X_0).
  - Mass: ~13 tonnes.
- Stainless steel 304L
  - Wall thickness: barrel, 15 mm (1X_0); endcaps, 27 mm (2X_0).
  - Mass: ~20 tonnes.

Calculations by S. Cárcel (IFIC, Valencia) following ASME code and assuming torispherical endcaps.

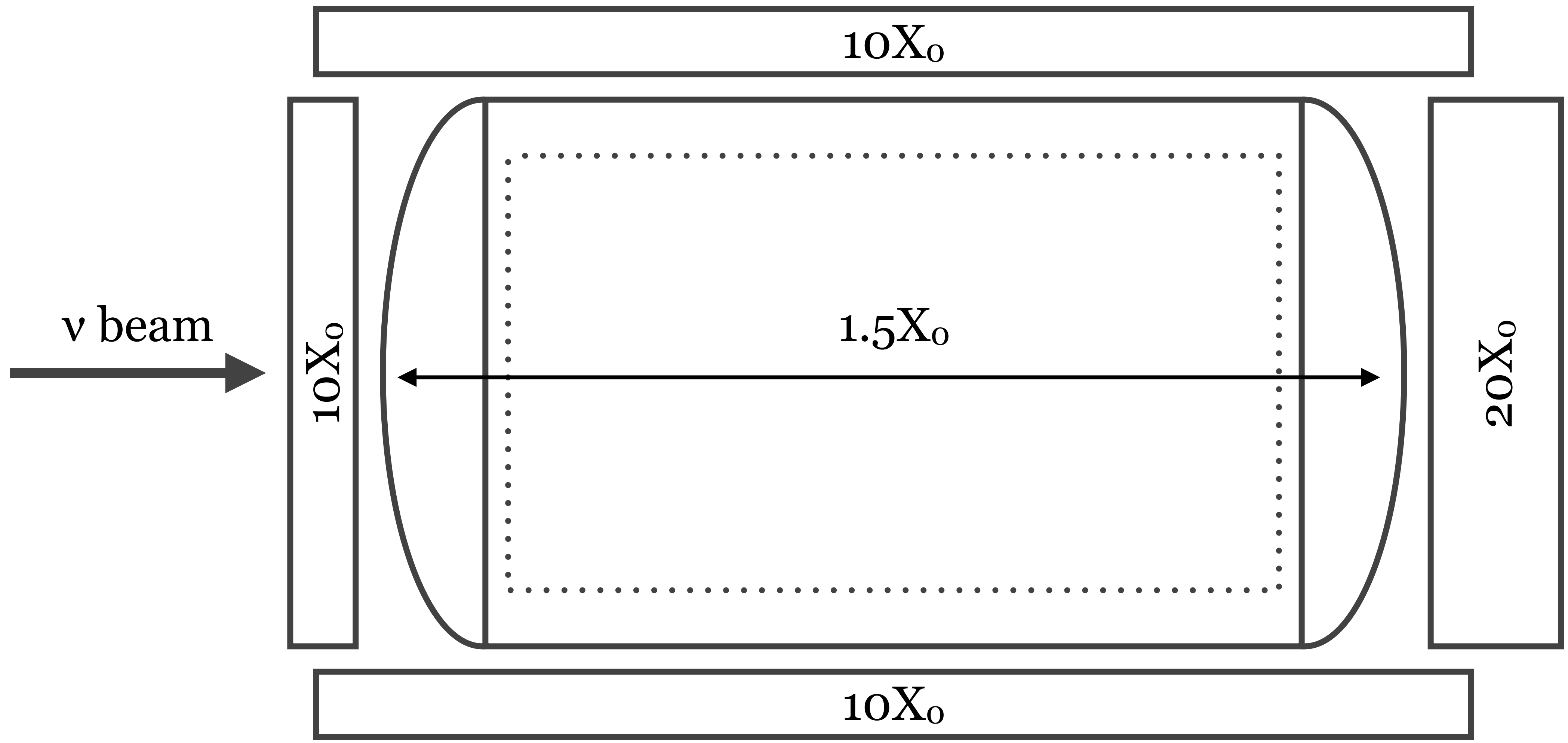
PRESSURE VESSEL





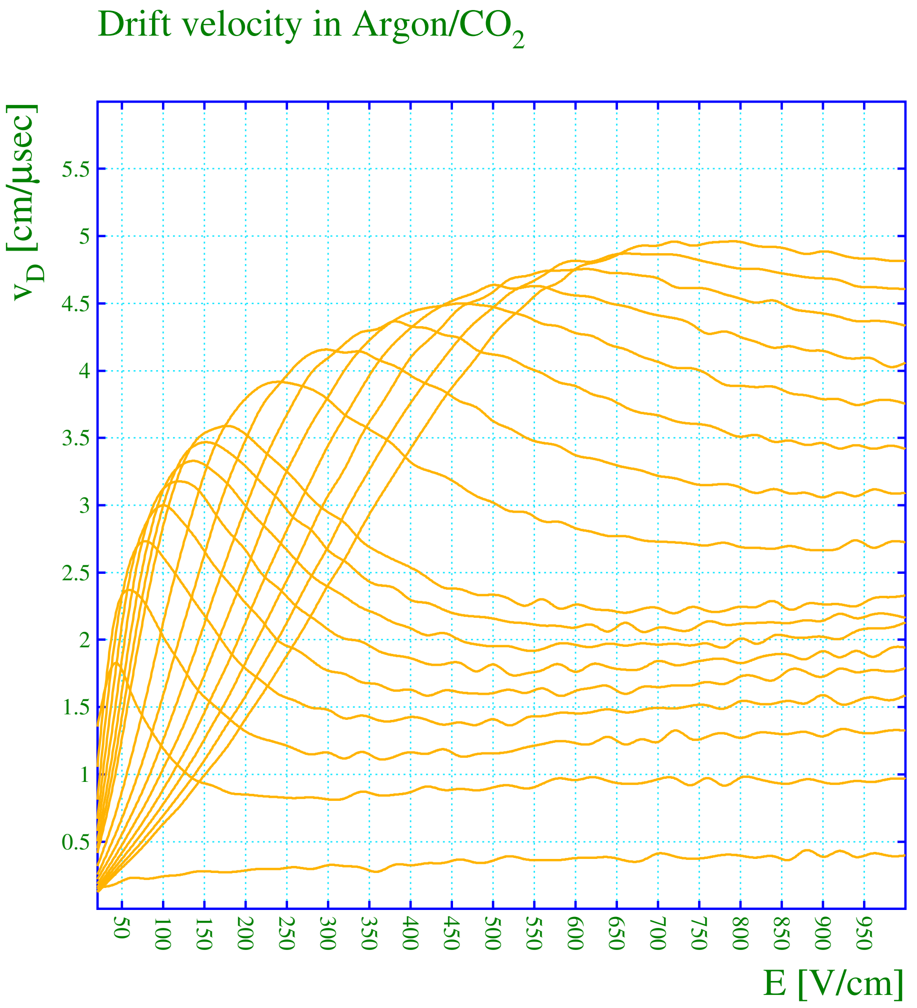
Possible lighter alternatives: composite materials or aluminium honeycomb?

ARGON GAS TPC – DETECTOR CONCEPT



X_0 (Ar) = 19.55 g/cm² –> 6.3 m @ 10 bar (16.11 kg/m³): ~0.5 X_0
X_0 (Ti) = 3.6 cm –> 1.7 cm (x2) = ~0.5 X_0 (x2)

TPC PERFORMANCE: GAS & READOUT



Small concentrations (<1%) of quenchers (CO_2, CF_4, CH_4, isobutane…) can increase drift velocity by a factor of ~5 and reduce diffusion by a factor of ~5–10 with respect to pure argon.

Readout will provide point resolutions better than 1 mm and two-track separation of about 15 to 20 mm.

TPC PERFORMANCE: MOMENTUM MEASUREMENT

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma_T\, p_T}{0.3\, B\, L^2} \sqrt{\frac{720}{N+4}} + \frac{0.05}{B\, L} \sqrt{\frac{1.43\, L}{X_0}}$$

$$\sigma_\theta = \frac{\sigma_L}{L} \sqrt{\frac{12\,(N-1)}{N\,(N+1)}} + \frac{0.015}{\sqrt{3}\, p} \sqrt{\frac{L}{X_0}}$$

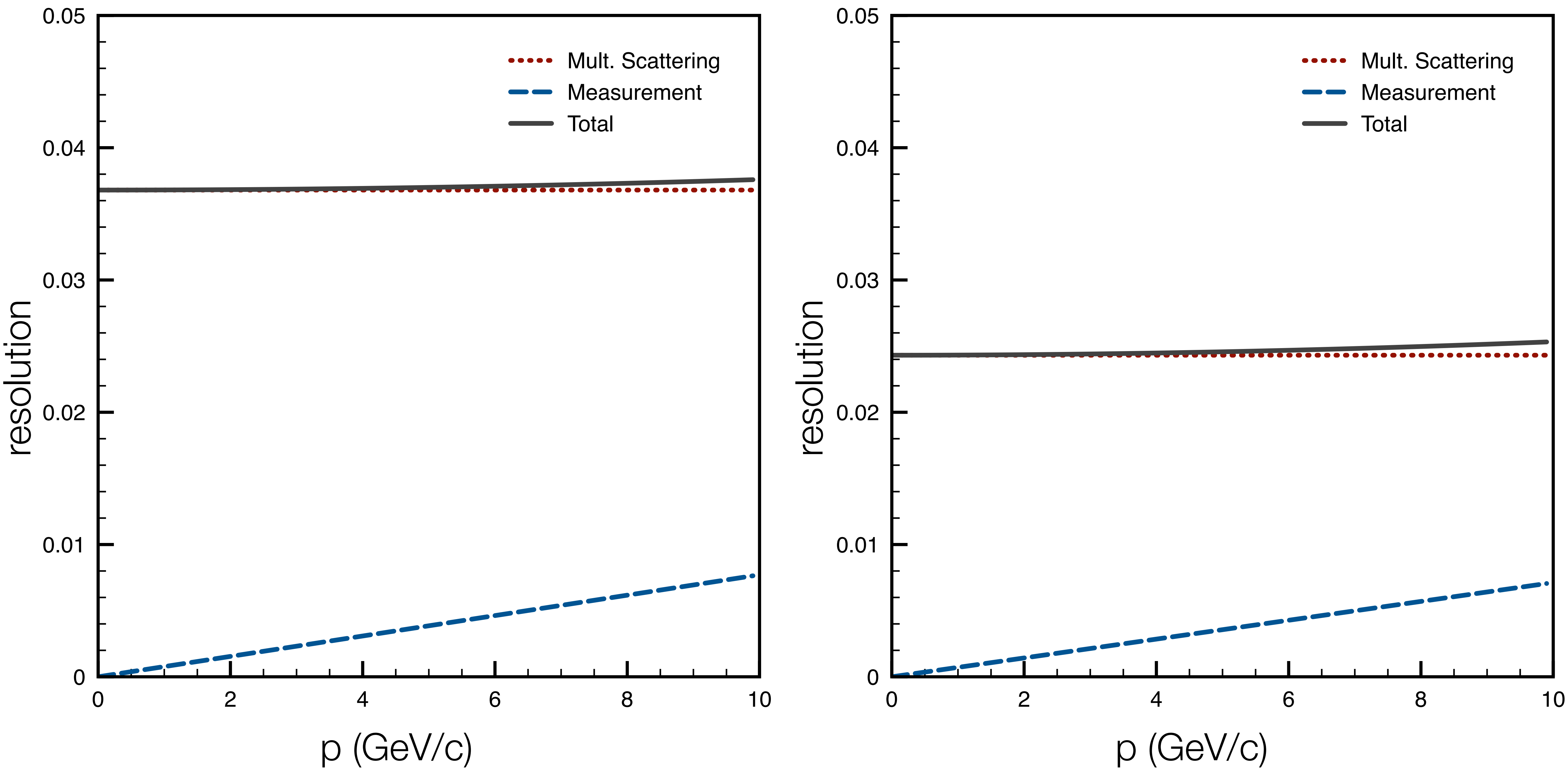
measurement terms

$$(p_T = p\, \sin\theta)$$

scattering terms

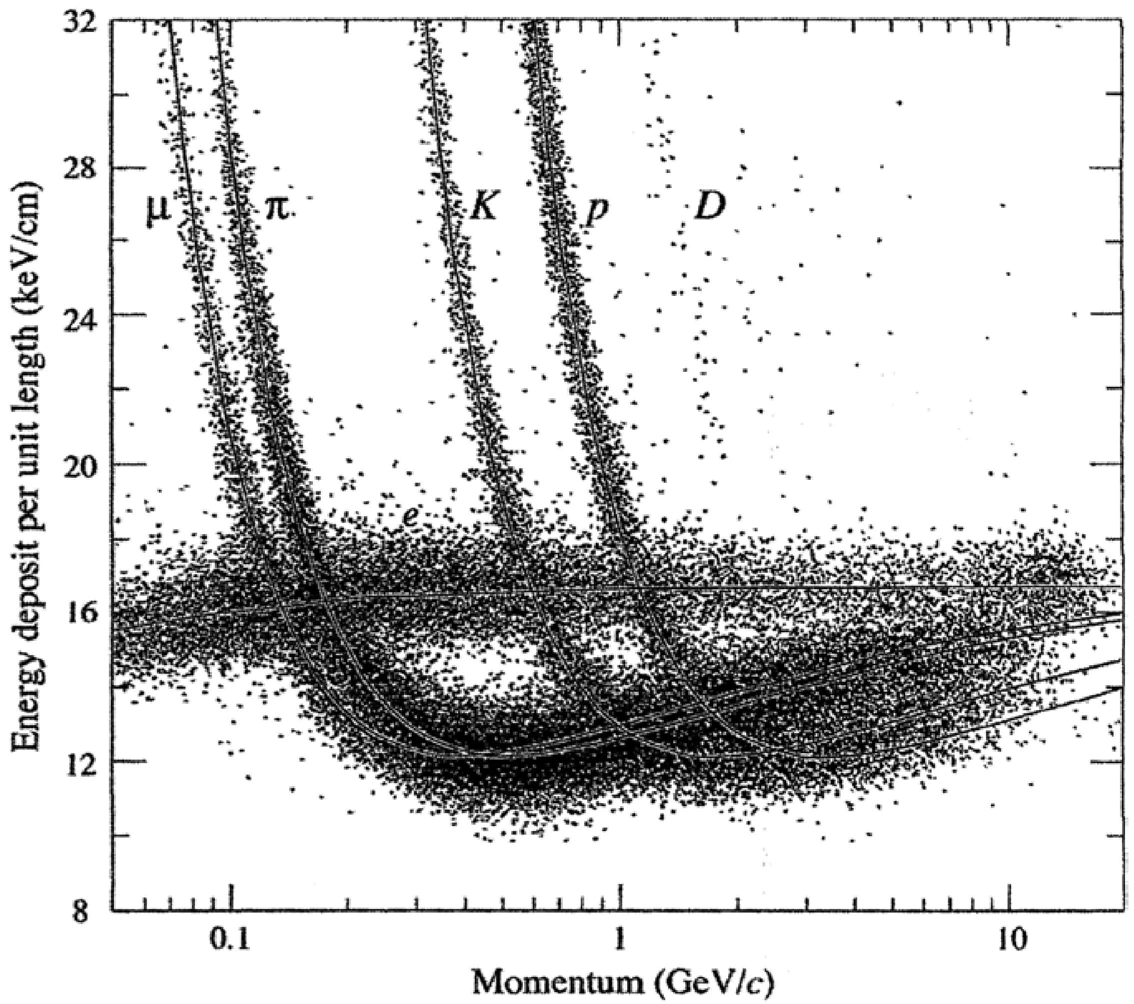
(σ: point resolution; p: momentum; B: magnetic field;
L: track length; N: no. of measurements; X_0: radiation length)

TPC PERFORMANCE: MOMENTUM MEASUREMENT

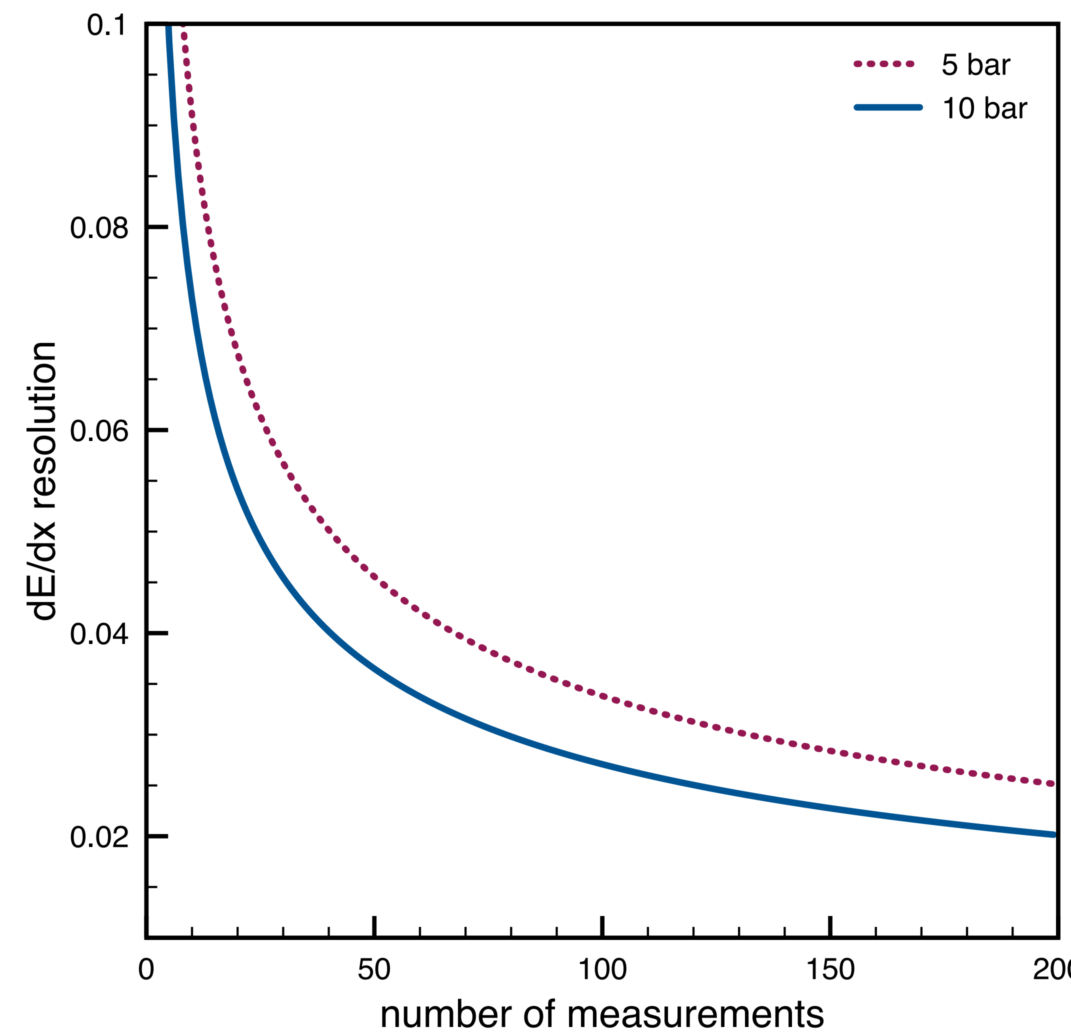


Predicted momentum resolution for forward-going, long tracks (3 m) in FGT and GArTPC.

TPC PERFORMANCE: PARTICLE ID



PEP-4 TPC (~3%)

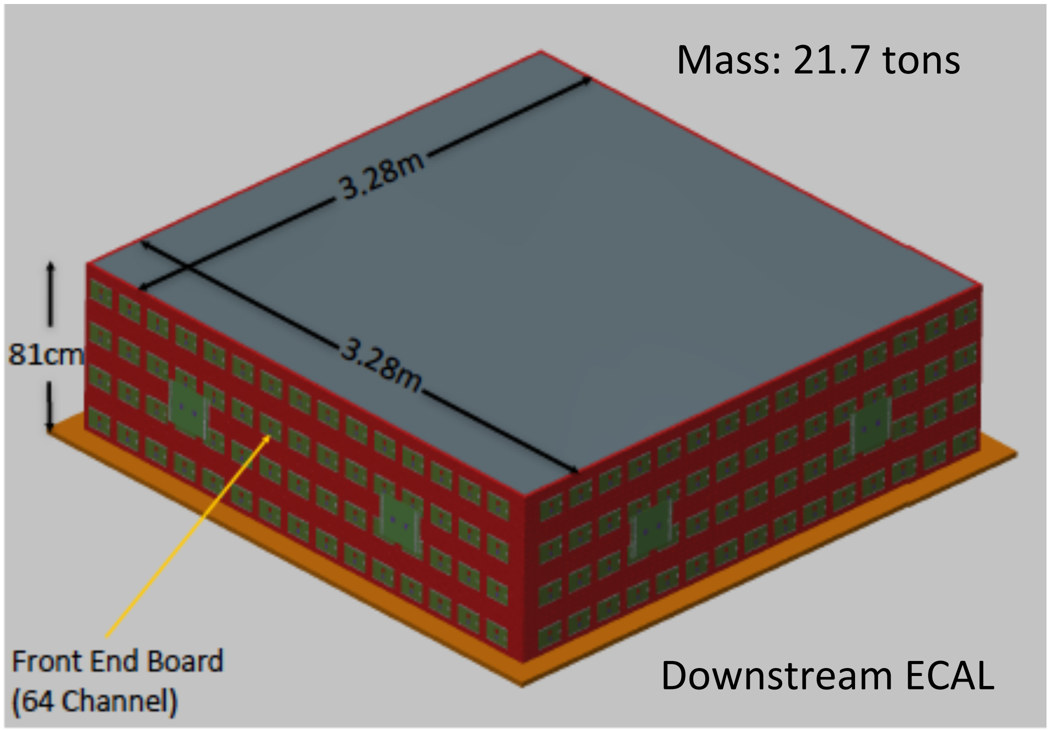


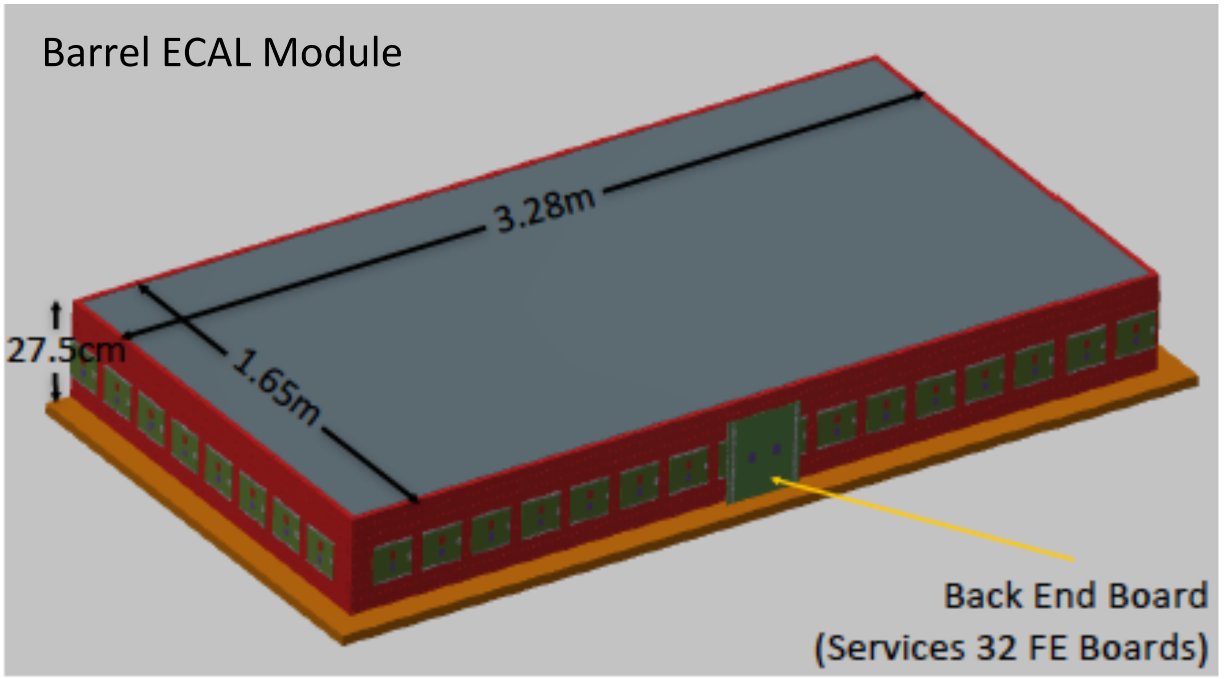
$$\sigma(\mathrm{d}E/\mathrm{d}x) = 0.41\, N^{-0.43}\, (t\, P)^{-0.32}$$

Good separation of pions, kaons and protons. Separation of muons, pions and electrons can be improved with measurements in ECAL and muon-ID systems.

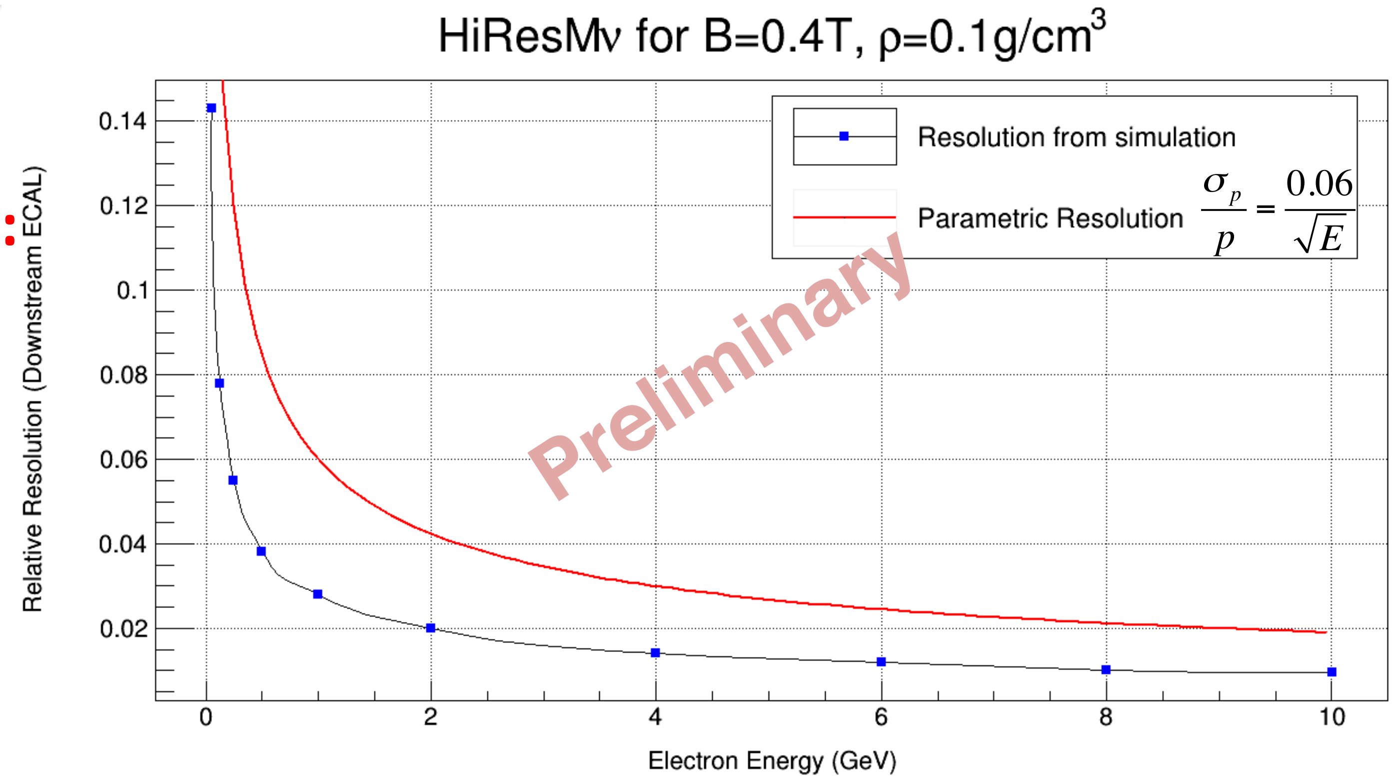
THE ELECTROMAGNETIC CALORIMETERS

- Reconstruction of e^+/e^-, γ with accuracy comparable to μ^+/μ^- and FD
  - Containment of > 90% of shower energy; energy resolution < $6\%/\sqrt{E}$ (GeV)
- Sampling electromagnetic calorimeter with Pb absorbers and alternating horizontal and vertical (XYXYXY…) 3.2 m x 2.5 cm x 1 cm plastic scintillator bars readout at both ends by 1 mm diameter extruded WLS fibers and SiPMs.
  - Downstream ECAL: 60 layers with 1.75 mm Pb plates. **20 X_0**.
  - Barrel ECAL: Will surround the sides of the STT. 18 layers with 3.5 mm of Pb. **10 X_0**.
  - Upstream ECAL: 18 layers with 3.5 mm Pb. **10 X_0**.



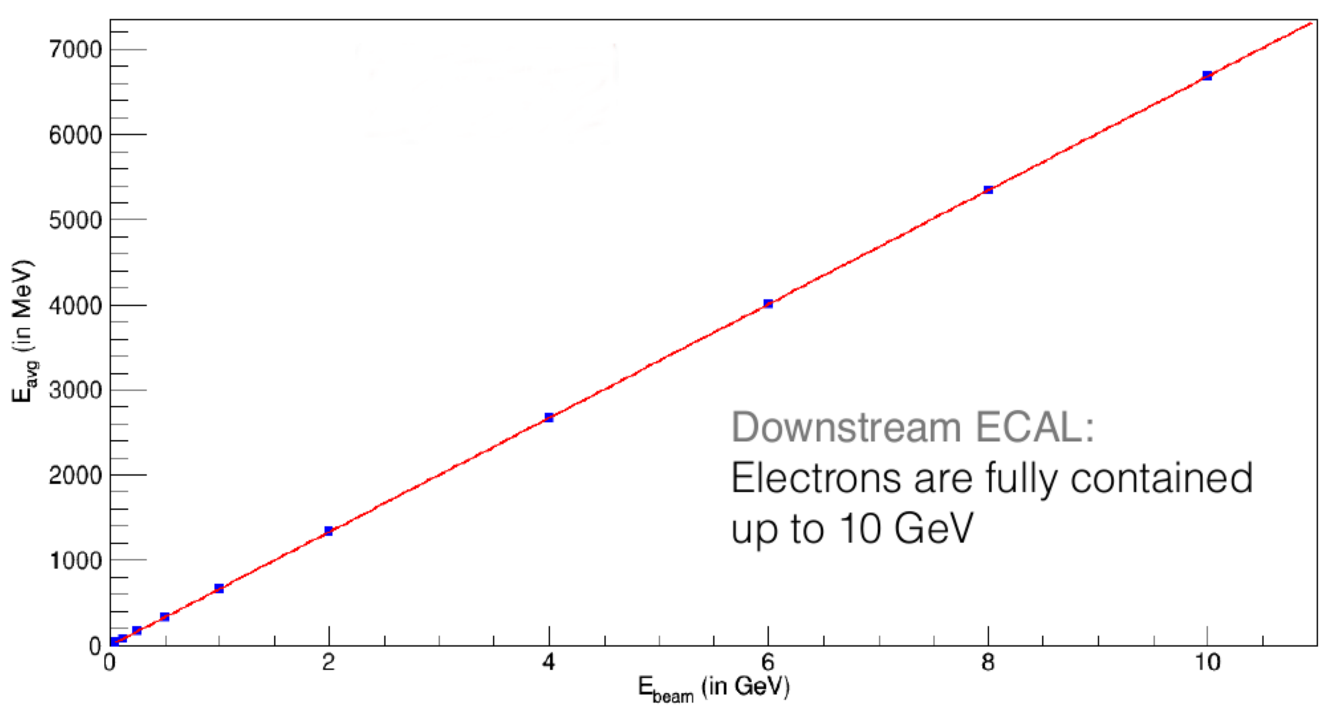


THE ELECTROMAGNETIC CALORIMETERS



Downstream ECAL Energy Resolution:

6% could be conservative: simulation does not include electronics noise, detector inefficiency.



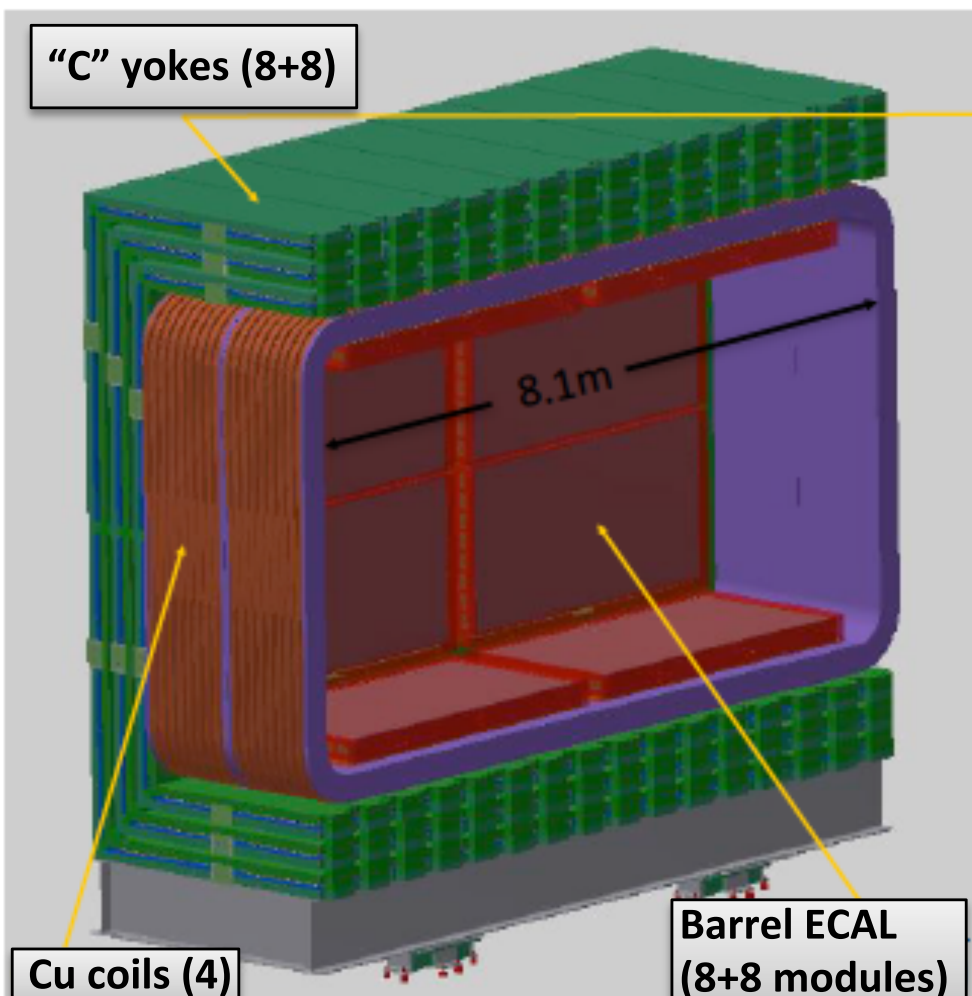
Downstream ECAL Linear Energy Response:

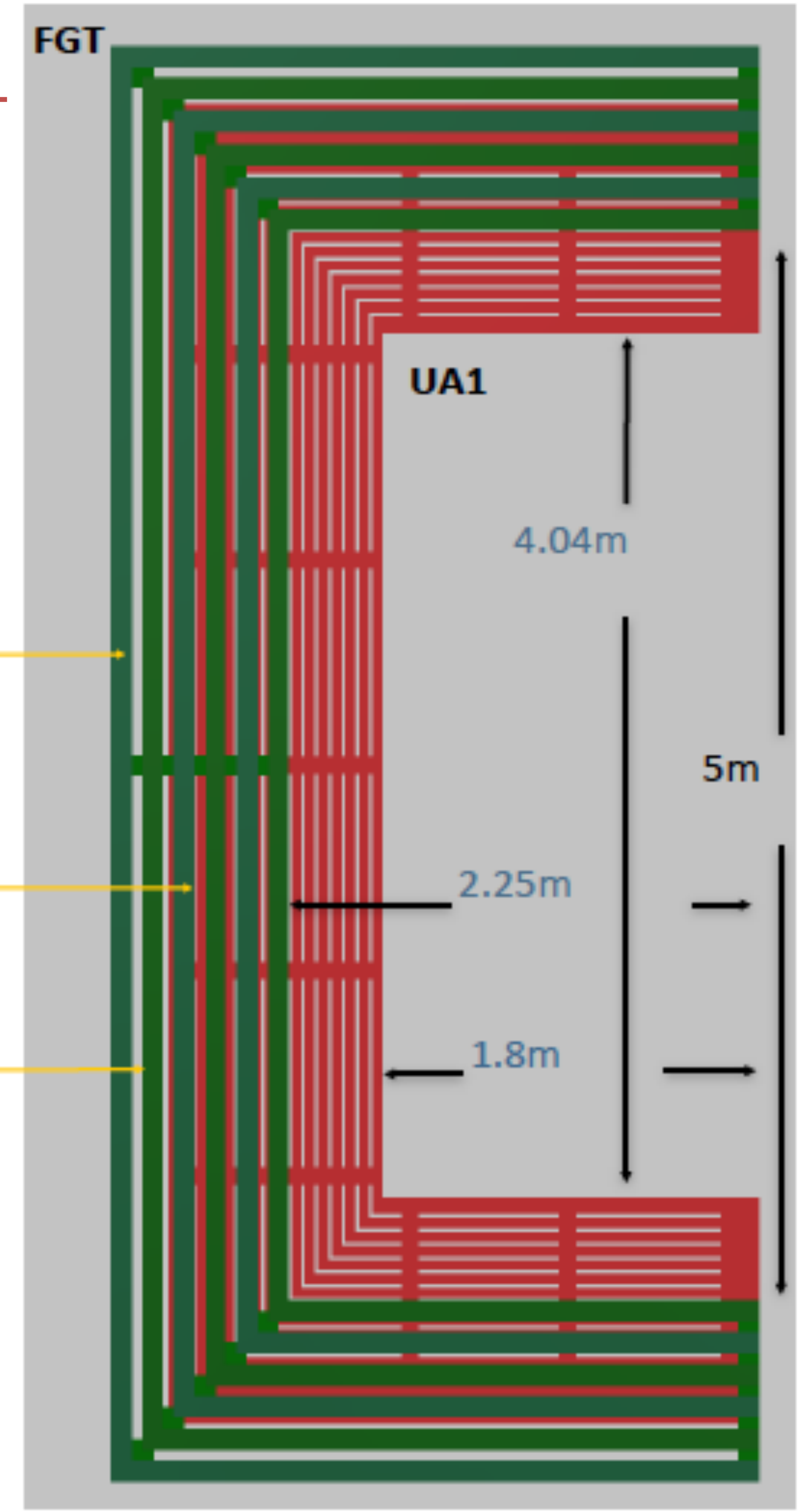
0.06/√E is valid at least up to 10 GeV

IIT Guwahati

THE DIPOLE MAGNET

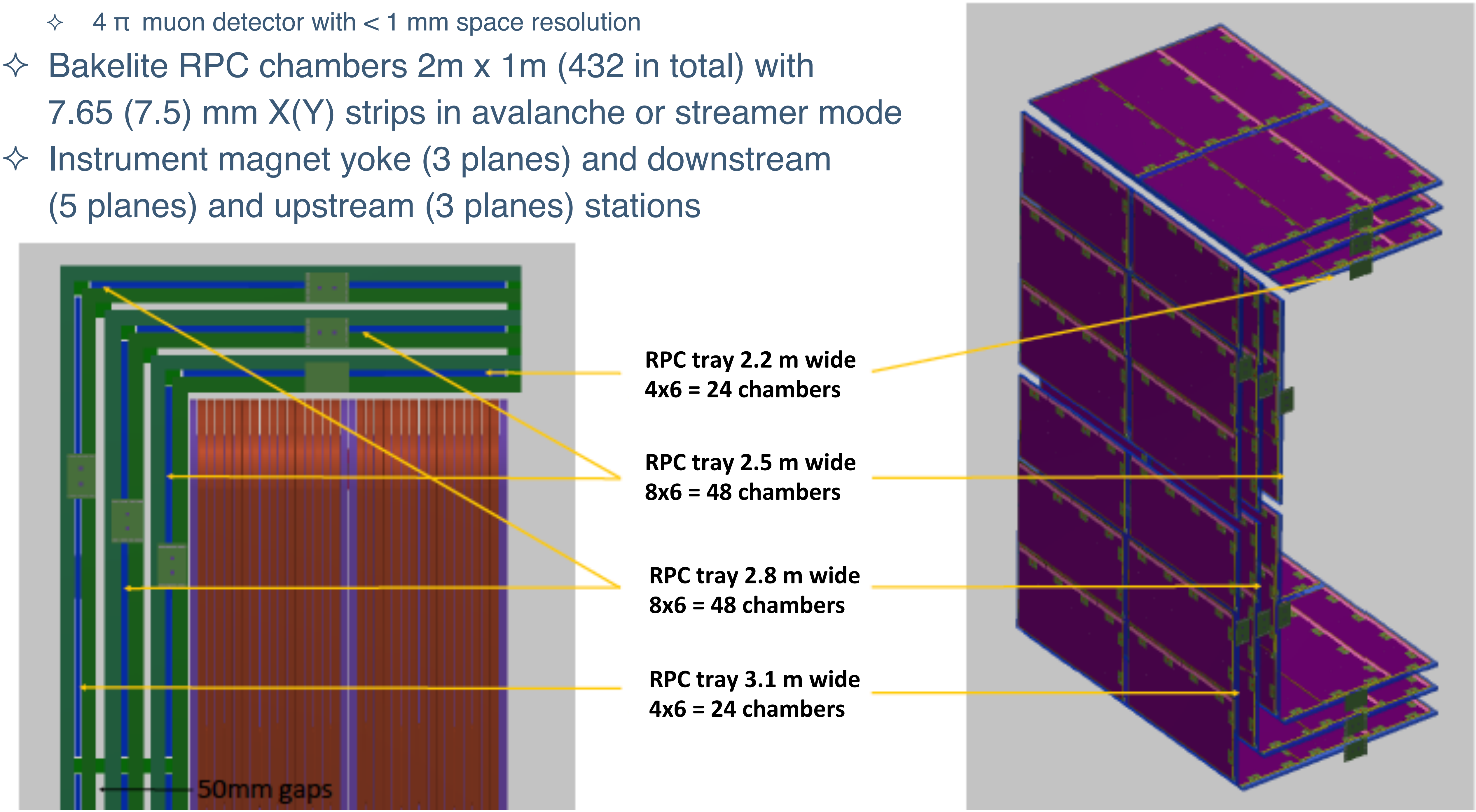
- Design based on UA1/NOMAD/T2K magnet
- Magnetic volume: 4.5 m x 4.5 m x 8.1 m, nominal B = 0.4T
- Return yoke with 8+8 “C” section:
  - 6 x 100 mm steel plates, 50 mm gaps (960 tons)
- 4 vertical Cu coils (168 tons) made of 8 double pancake
- Power requirement for nominal field 2.43 MW, water flow for coil cooling: 20 l/s





THE DIPOLE MAGNET: MUON-ID DETECTORS

- Require to measure absolute and relative ν_μ and $\bar{\nu}_\mu$ spectra separately
  - Identify muons exiting the tracking volume
  - 4 π muon detector with < 1 mm space resolution
- Bakelite RPC chambers 2m x 1m (432 in total) with 7.65 (7.5) mm X(Y) strips in avalanche or streamer mode
- Instrument magnet yoke (3 planes) and downstream (5 planes) and upstream (3 planes) stations



ALTERNATIVE DESIGNS FOR THE MAGNET

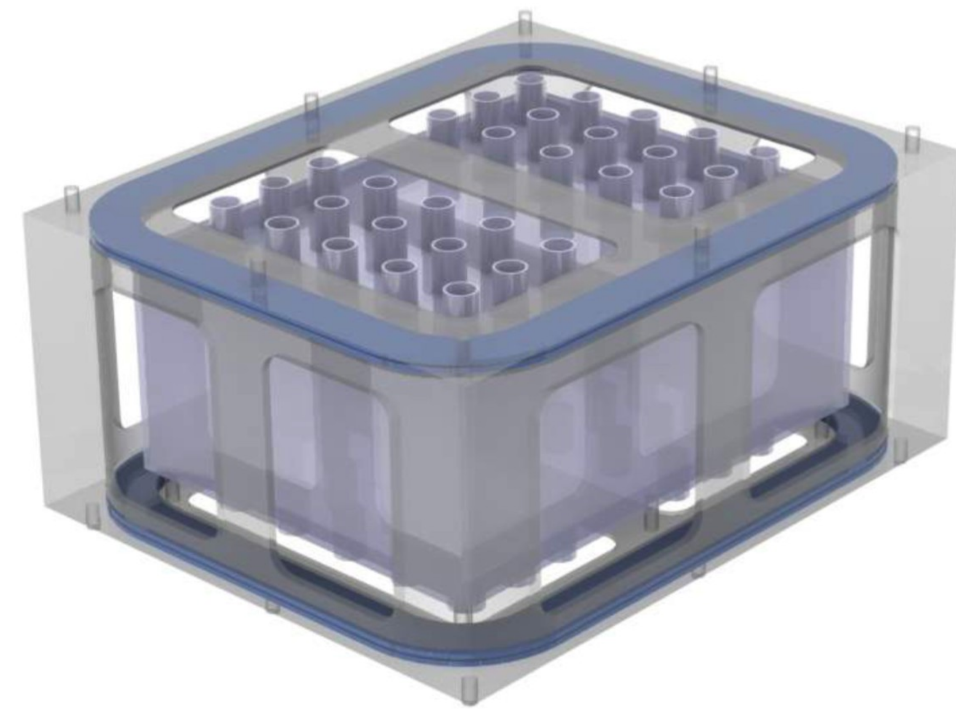
We propose to make use of the 2014 CERN engineering study for magnetizing ICARUS (12 x 9 x 5 m^3) . CERN are experienced and confident in this technology.

Helmholtz coils based on ATLAS toroidal magnets can achieve 1 T at centre.

Helmholtz coil minimizes material in beam direction. While allowing access to the modules. With no need for a return yoke.

Cryostat walls can form magnet support structure.

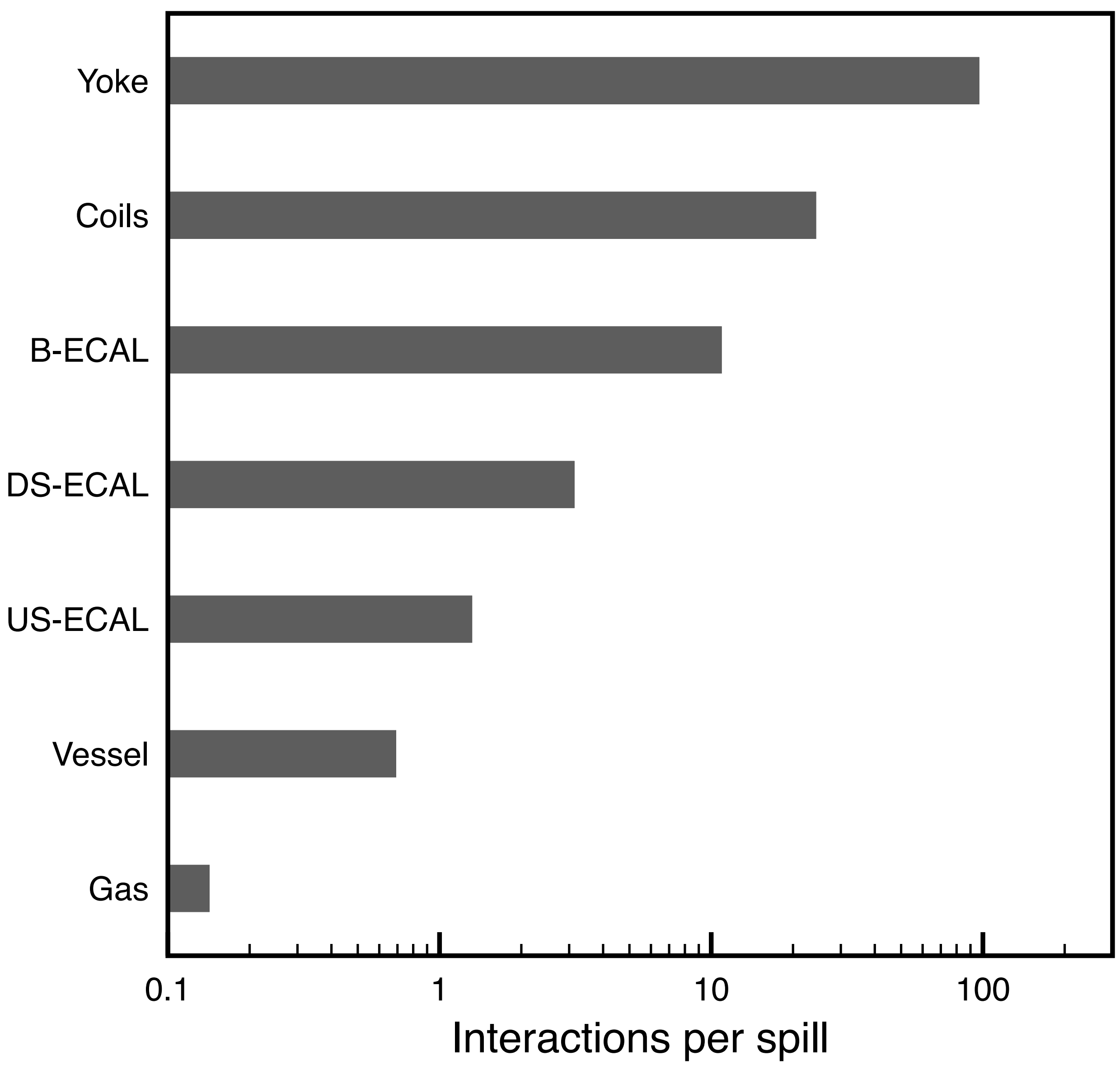
1 T B-field can deflect a 5 GeV $\mu^{+/-}$ by 13 cm after 4 m.

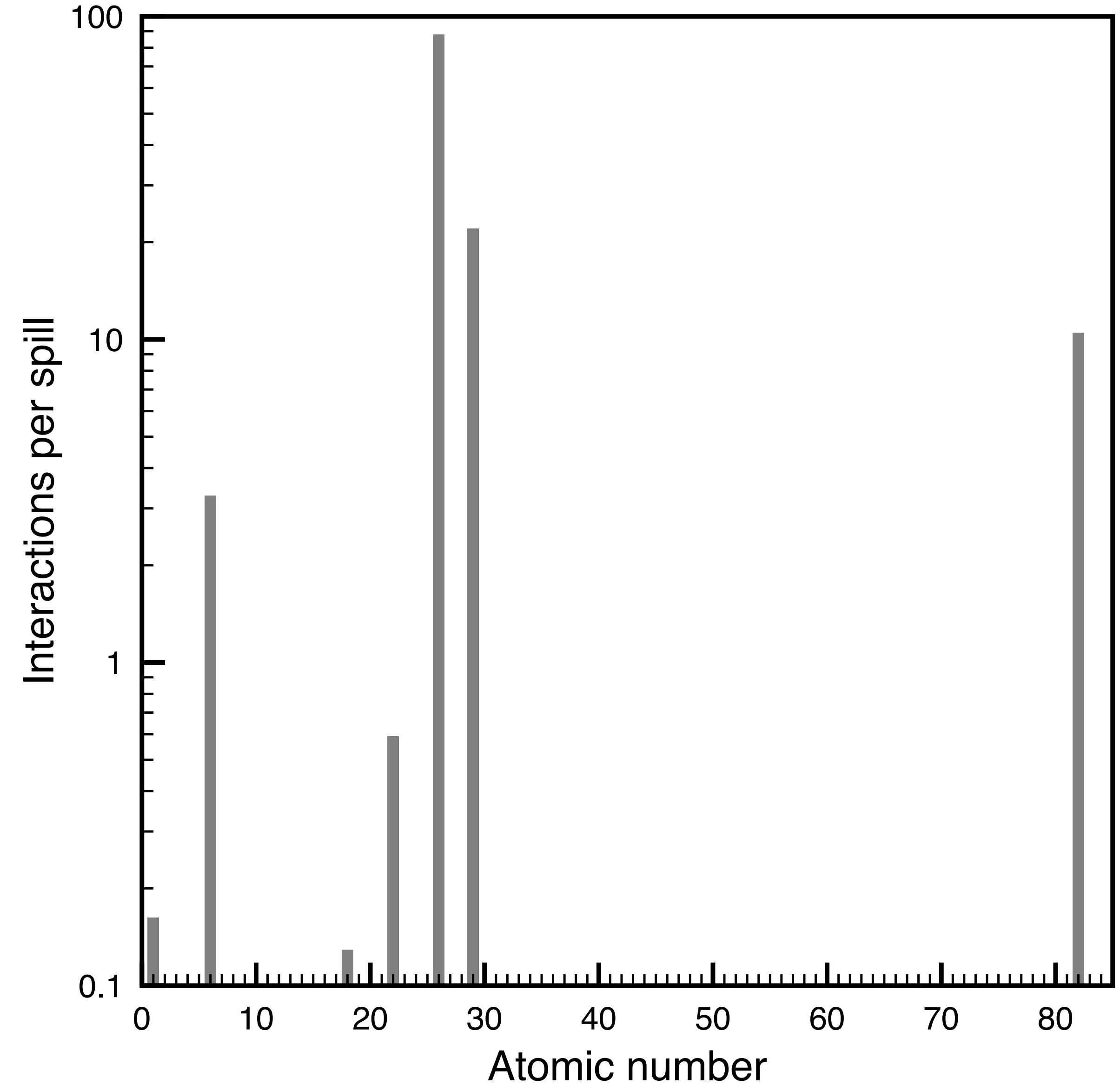


Double-racetrack Helmholtz magnet.
L.Y. van Dijk 2014

Slide by James Sinclair (Bern)

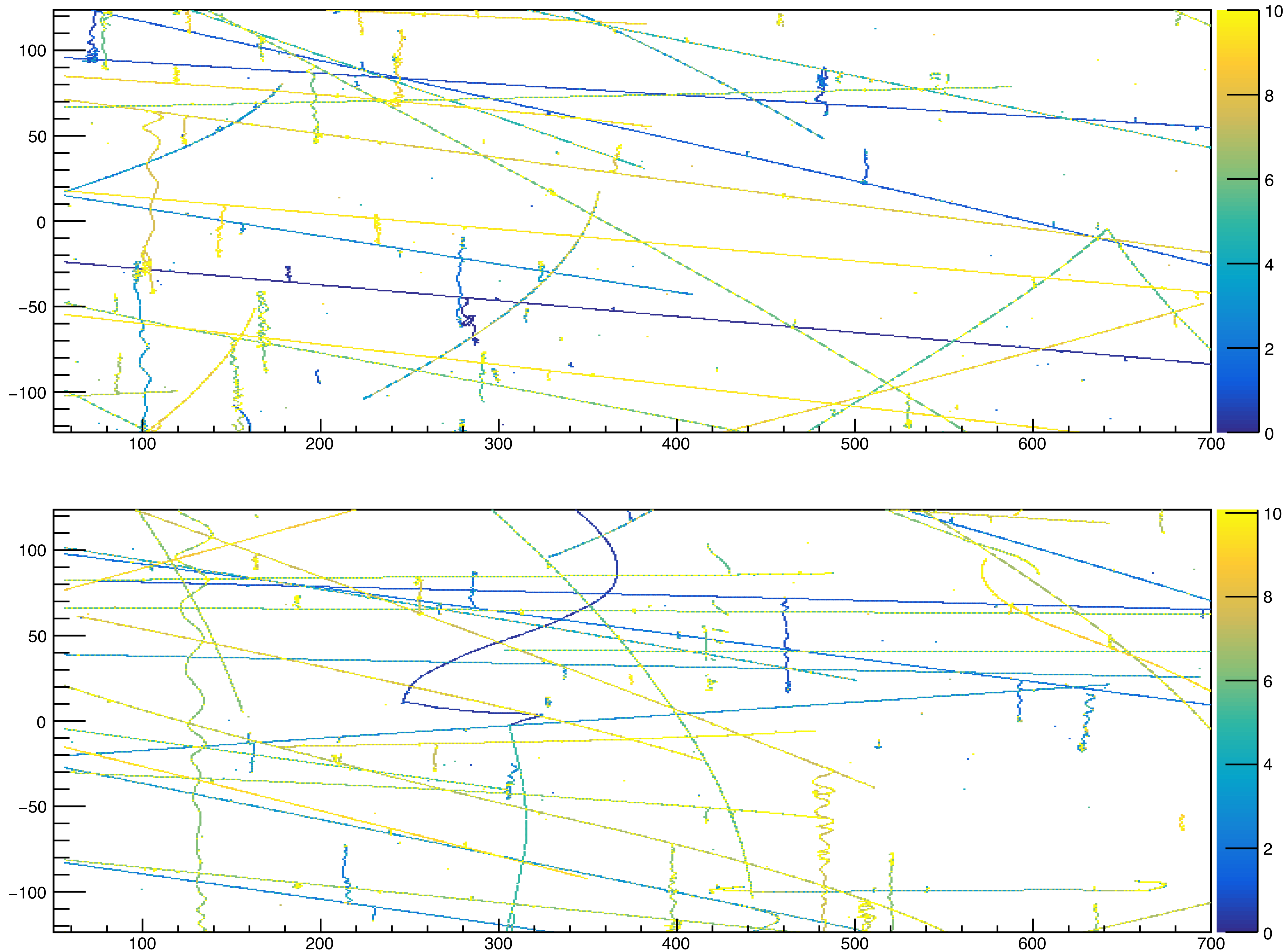
EVENT RATE





0.15 interactions per spill (7.5E13) and tonne of argon;
about 2M interactions per year (~1E21 POT).
3 orders of magnitude more interactions in other detector volumes.

EVENT RATE

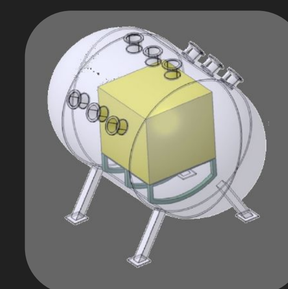


RECONSTRUCTION

TREx for DUNE

WARWICK
THE UNIVERSITY OF WARWICK

- Warwick Group is making an effort to use pre-existing recon expertise from T2K (Eddy Larkin from Warwick and others) and isolate the TREx package from nd280 software. Right now the entire pattern recognition code lives in a GitHub repository that Martin and Paula develop.
- For the imminent ND simulation production we hope to have TREx included alongside the mock reconstruction.
- In future it should be able to provide the task force with reconstructed input for sensitivity studies.



Schematics of a Pressure Vessel

TREx at work

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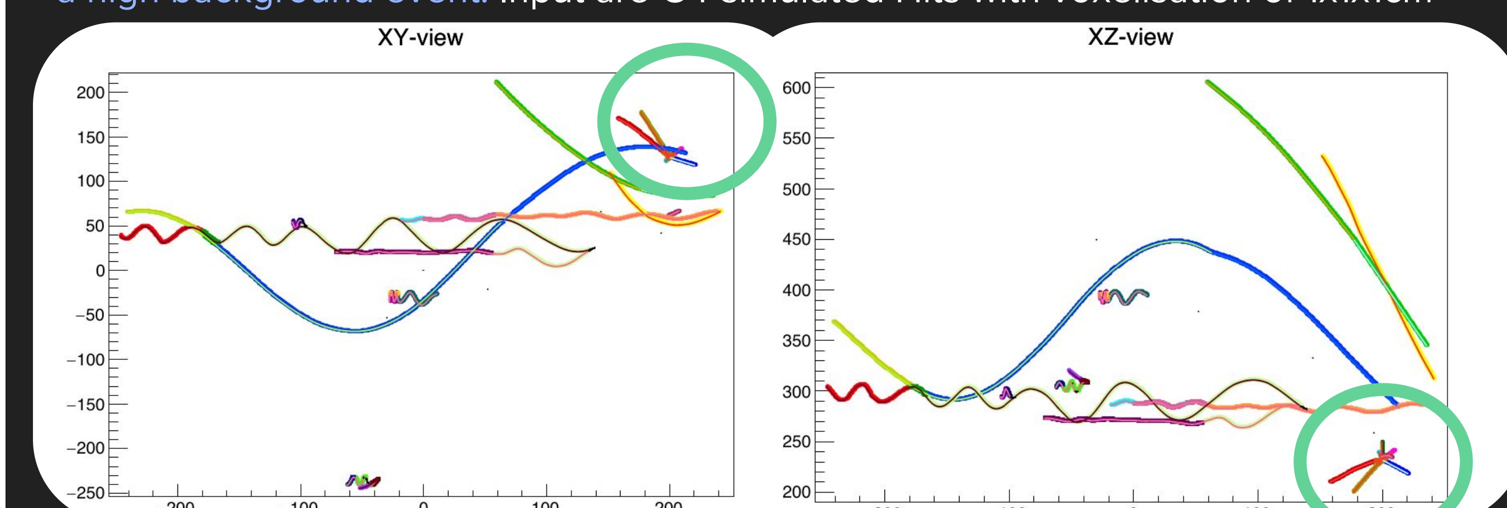
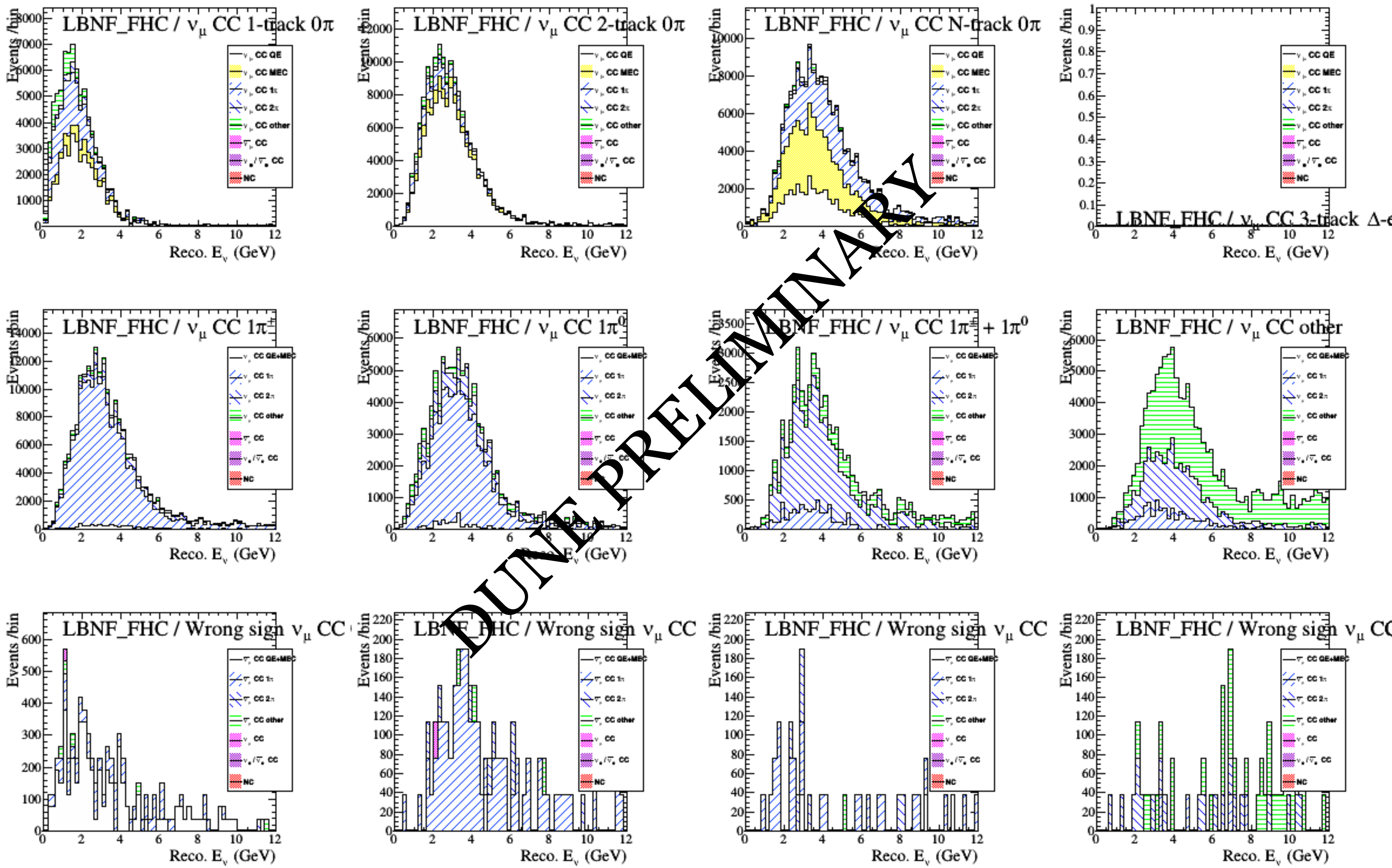
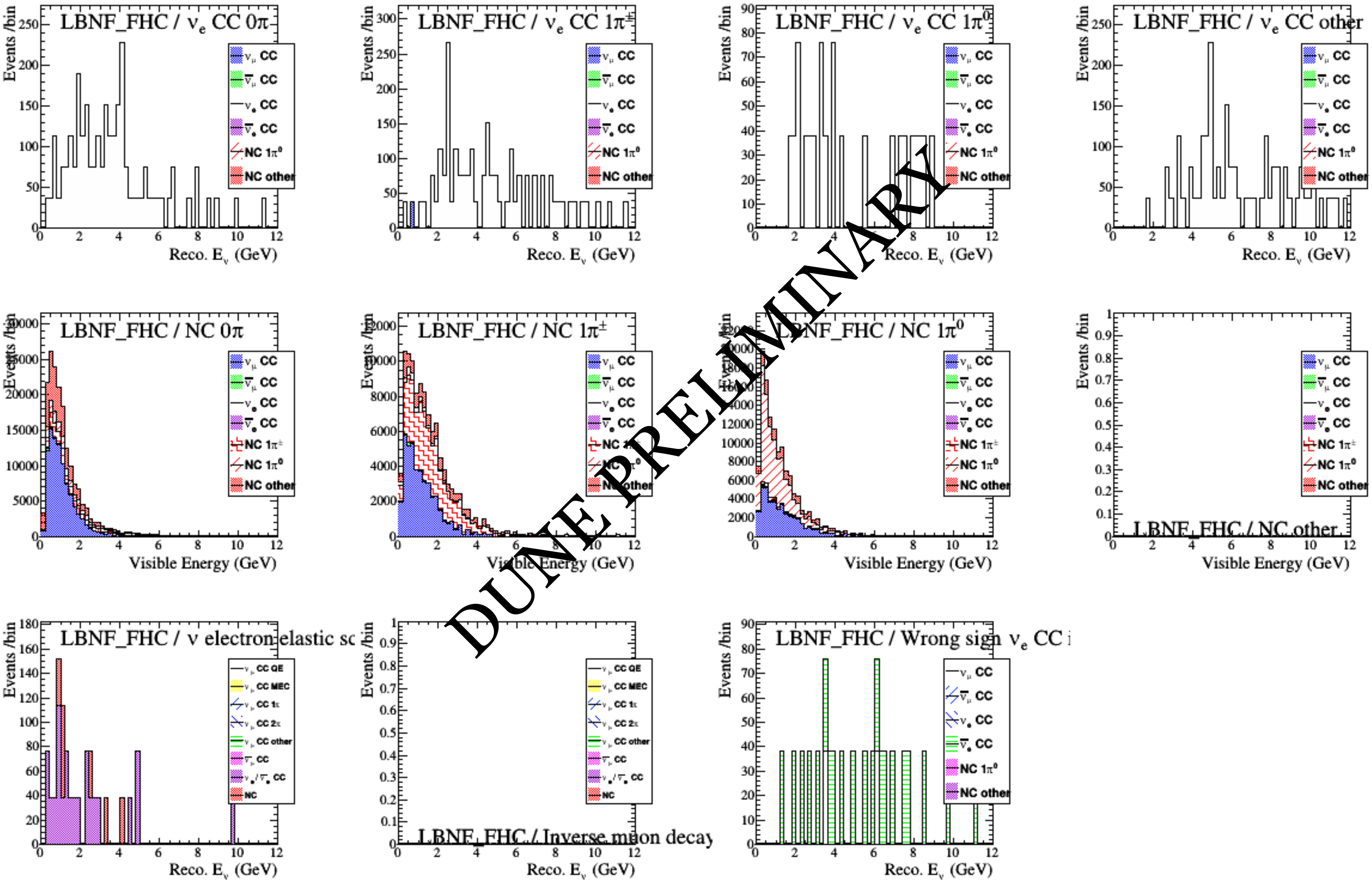
Do we think TREx is up to the task?

Gas interaction with a cleanly reconstructed vertex and correctly associated tracks in a high background event: Input are G4-simulated Hits with voxelisation of 1x1x1cm

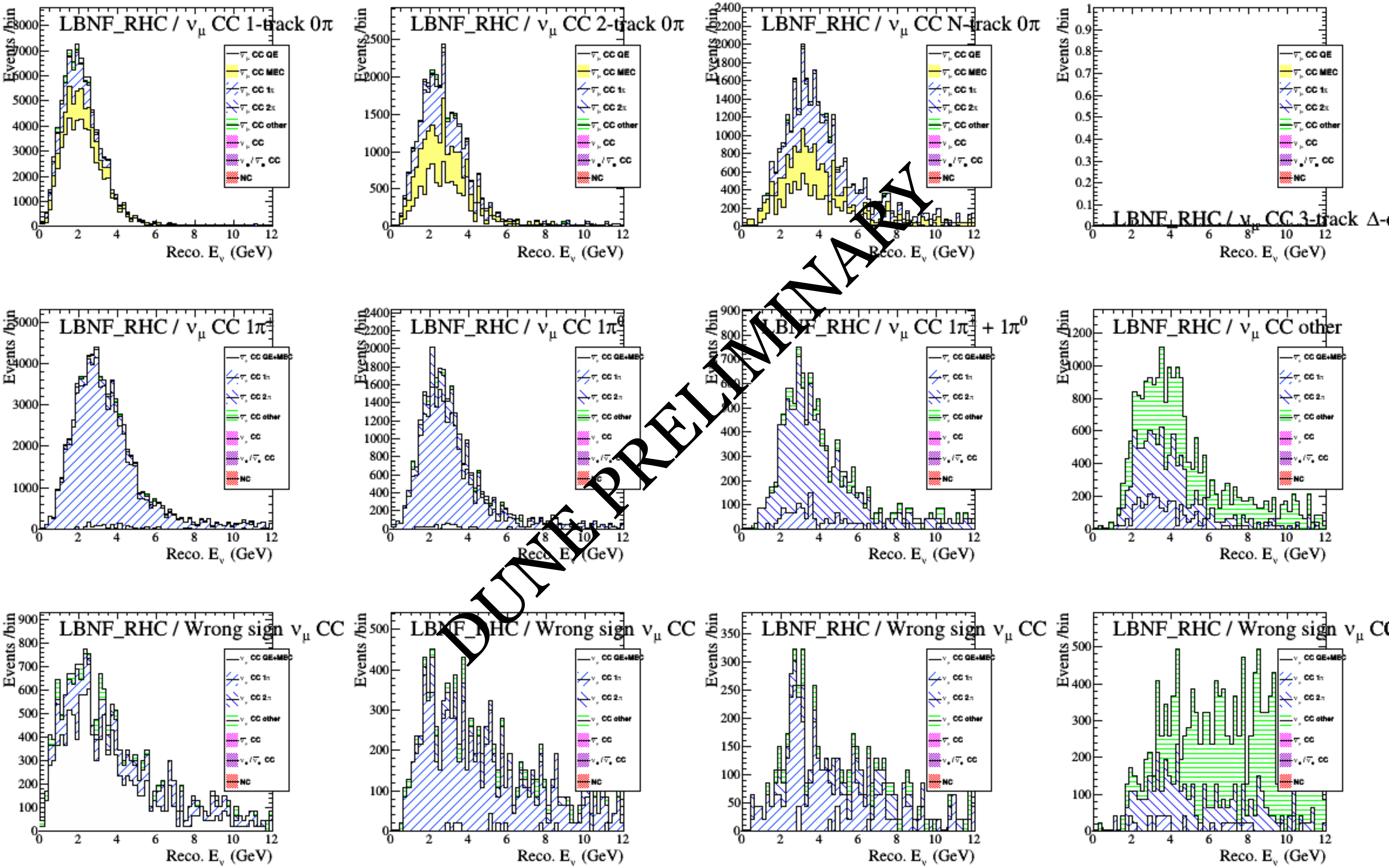


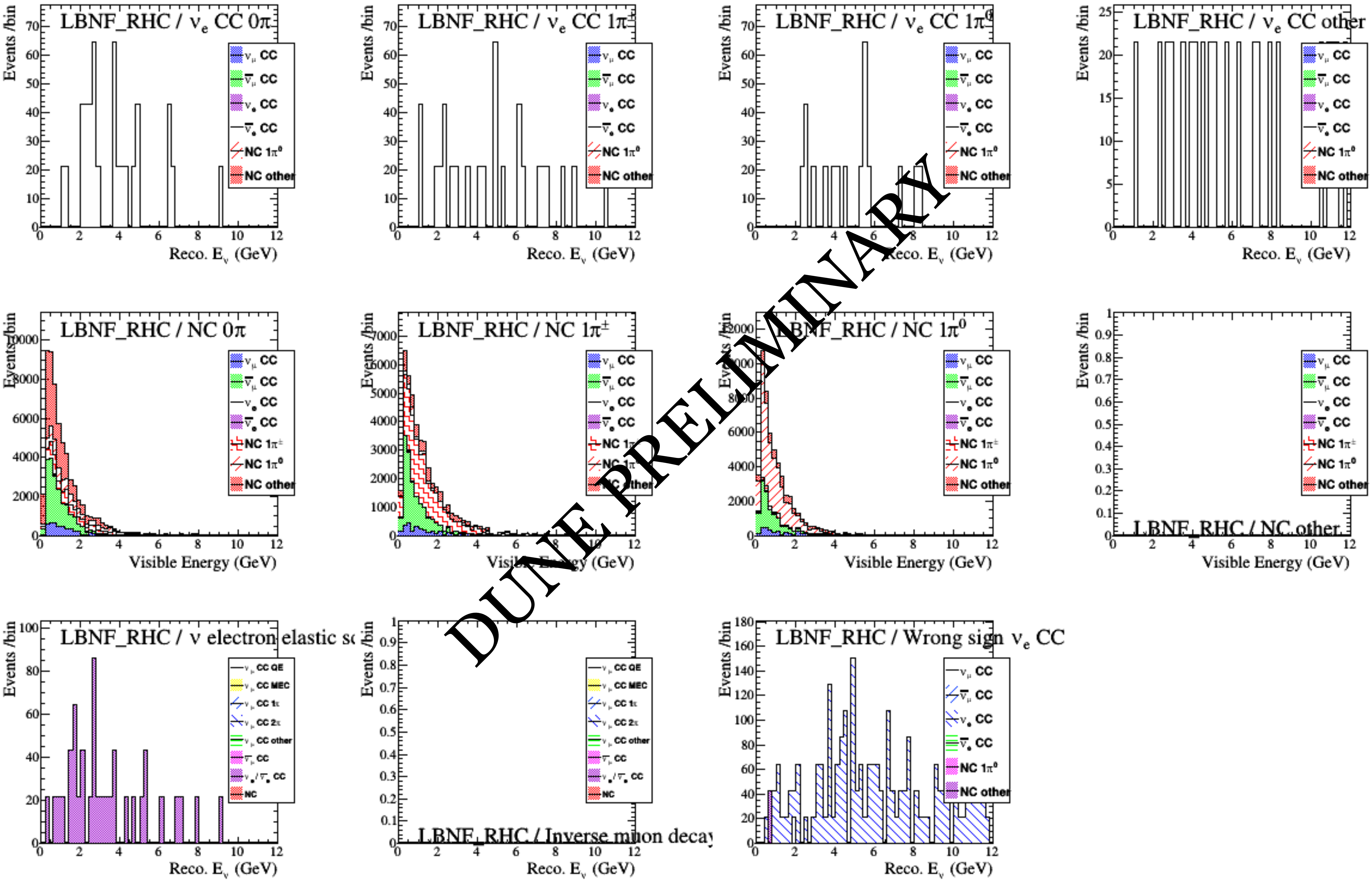
Slides by P. Denner and M. Haigh (Warwick)


LBNF_FHC / ν_μ CC 1-track 0π
LBNF_FHC / ν_μ CC 2-track 0π
LBNF_FHC / ν_μ CC N-track 0π
LBNF_FHC / ν_μ CC 3-track Δ-e
LBNF_FHC / ν_μ CC 1$\pi^\pm$
LBNF_FHC / ν_μ CC 1π^0
LBNF_FHC / ν_μ CC 1$\pi^\pm$ + 1π^0
LBNF_FHC / ν_μ CC other
LBNF_FHC / Wrong sign ν_μ CC
LBNF_FHC / Wrong sign ν_μ CC
LBNF_FHC / Wrong sign ν_μ CC
LBNF_FHC / Wrong sign ν_μ CC
ν_μ CC QE
ν_μ CC MEC
ν_μ CC QE+MEC
ν_μ CC 1π
ν_μ CC 2π
ν_μ CC other
$\bar{\nu}_\mu$ CC
ν_e / $\bar{\nu}_e$ CC
NC
Events /bin
Reco. E_ν (GeV)
DUNE PRELIMINARY



LBNF_FHC / νe CC 0π
LBNF_FHC / νe CC 1π±
LBNF_FHC / νe CC 1π0
LBNF_FHC / νe CC other
LBNF_FHC / NC 0π
LBNF_FHC / NC 1π±
LBNF_FHC / NC 1π0
LBNF_FHC / NC other
LBNF_FHC / ν electron elastic sc
LBNF_FHC / Inverse muon decay
LBNF_FHC / Wrong sign νe CC
Events /bin
Reco. Eν (GeV)
Visible Energy (GeV)
νμ CC
ν̄μ CC
νe CC
ν̄e CC
NC 1π±
NC 1π0
NC other
νμ CC QE
νμ CC MEC
νμ CC 1π
νμ CC 2π
νμ CC other
ν̄μ CC
νe / ν̄e CC
NC
DUNE PRELIMINARY


LBNF_RHC / ν_μ CC 1-track 0π
LBNF_RHC / ν_μ CC 2-track 0π
LBNF_RHC / ν_μ CC N-track 0π
LBNF_RHC / ν_μ CC 3-track Δ-
LBNF_RHC / ν_μ CC 1π
LBNF_RHC / ν_μ CC 1π^0
LBNF_RHC / ν_μ CC 1π + 1π^0
LBNF_RHC / ν_μ CC other
LBNF_RHC / Wrong sign ν_μ CC
LBNF_RHC / Wrong sign ν_μ CC
LBNF_RHC / Wrong sign ν_μ CC
LBNF_RHC / Wrong sign ν_μ C
Events /bin
Reco. E_ν (GeV)
$\bar{\nu}_\mu$ CC QE
$\bar{\nu}_\mu$ CC MEC
$\bar{\nu}_\mu$ CC 1π
$\bar{\nu}_\mu$ CC 2π
$\bar{\nu}_\mu$ CC other
ν_μ CC
ν_e / $\bar{\nu}_e$ CC
NC
$\bar{\nu}_\mu$ CC QE+MEC
DUNE PRELIMINARY


LBNF_RHC / νe CC 0π
LBNF_RHC / νe CC 1π±
LBNF_RHC / νe CC 1π0
LBNF_RHC / νe CC other
LBNF_RHC / NC 0π
LBNF_RHC / NC 1π±
LBNF_RHC / NC 1π0
LBNF_RHC / NC other
LBNF_RHC / ν electron elastic sc
LBNF_RHC / Inverse muon decay
LBNF_RHC / Wrong sign νe CC
Events /bin
Reco. Eν (GeV)
Visible Energy (GeV)
νμ CC
ν̄μ CC
νe CC
ν̄e CC
NC 1π±
NC 1π0
NC other
νμ CC QE
νμ CC MEC
νμ CC 1π
νμ CC 2π
νμ CC other
ν̄μ CC
νe / ν̄e CC
NC
DUNE PRELIMINARY

SUMMARY

- DUNE is performing a systematic comparison of different technological options for the near detector with CP violation sensitivity as figure of merit.
- Pressurized GArTPC among the options considered.
- Ongoing simulation study of baseline design.
- Hardware R&D projects coming soon in Europe and USA.