DUNE Science Requiremetns for the ProtoDUNE-SP Detector Support

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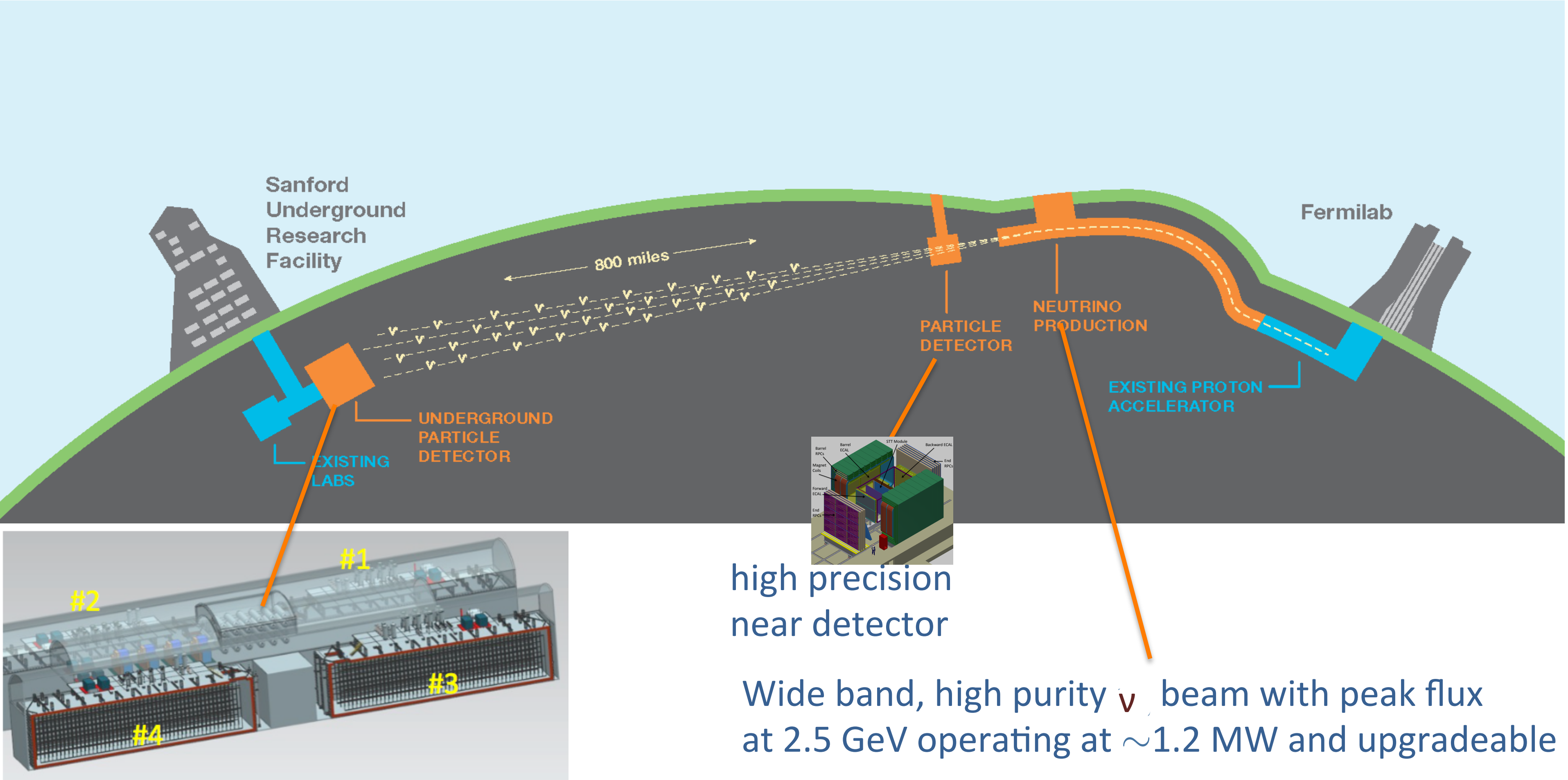
Detector Support Structure Design Review

November 2016

The DUNE Experiment



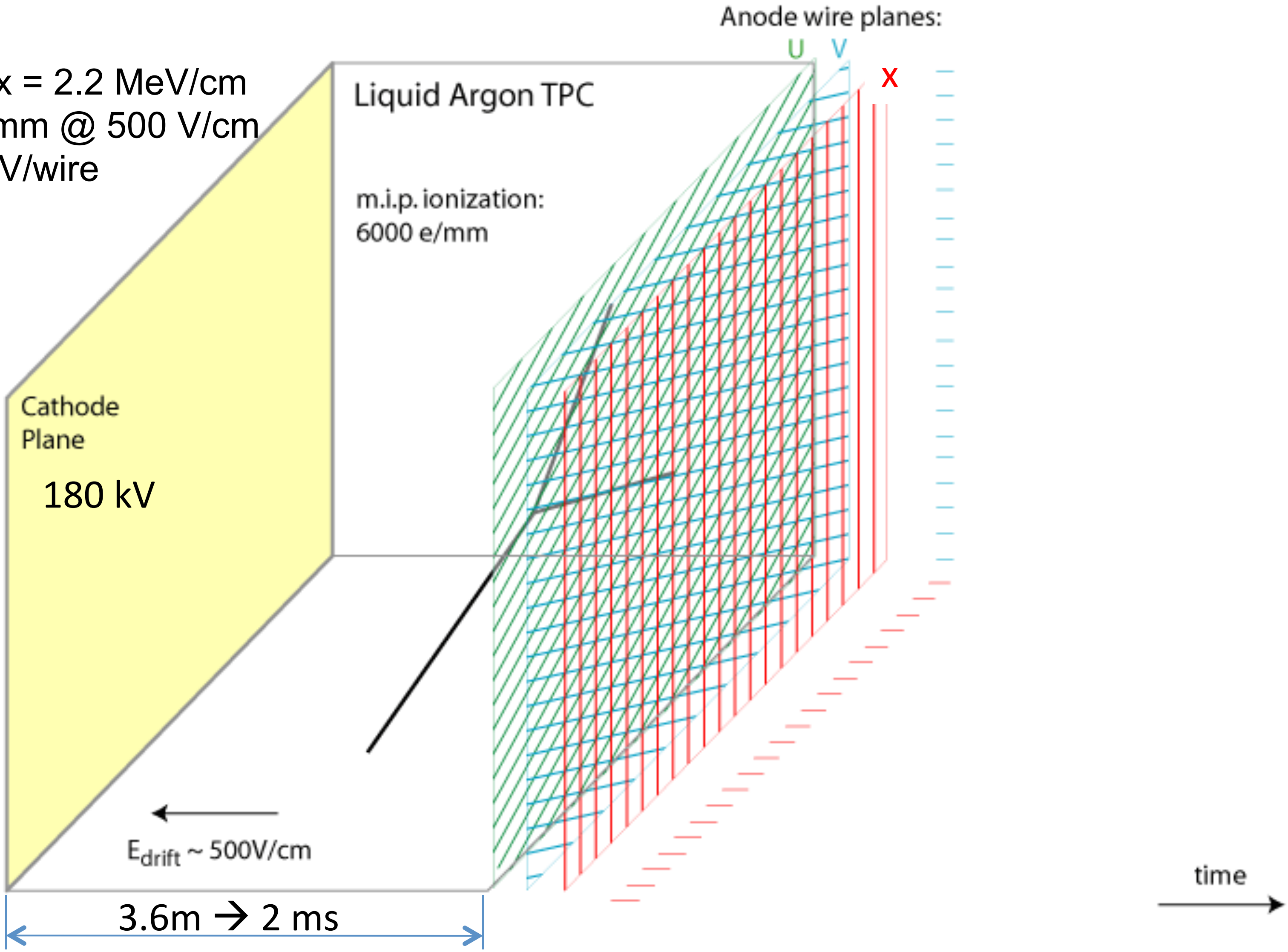
high precision near detector

Wide band, high purity ν beam with peak flux at 2.5 GeV operating at $\sim$1.2 MW and upgradeable

- four identical cryostats deep underground
- staged approach to four independent 10 kt LAr detector modules
- Single-phase and double-phase readout under consideration

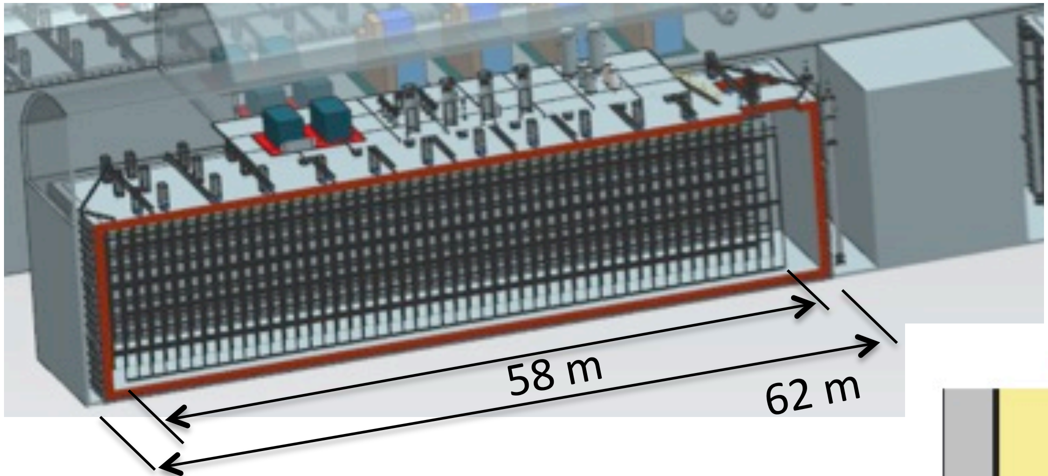
Time Projection Chamber (TPC) Operation

MIP dE/dx = 2.2 MeV/cm
→ ~ 1fC/mm @ 500 V/cm
→ ~1 MeV/wire



TPC design is modular.

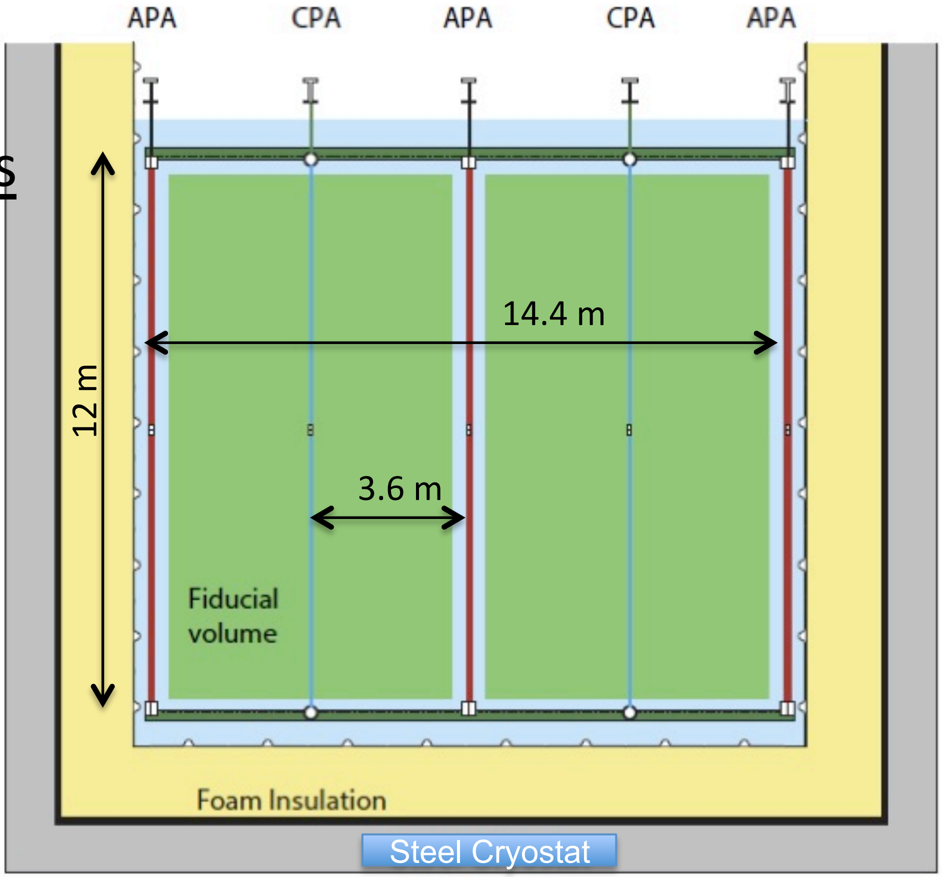
Single-Phase10 kt Detector Configuration

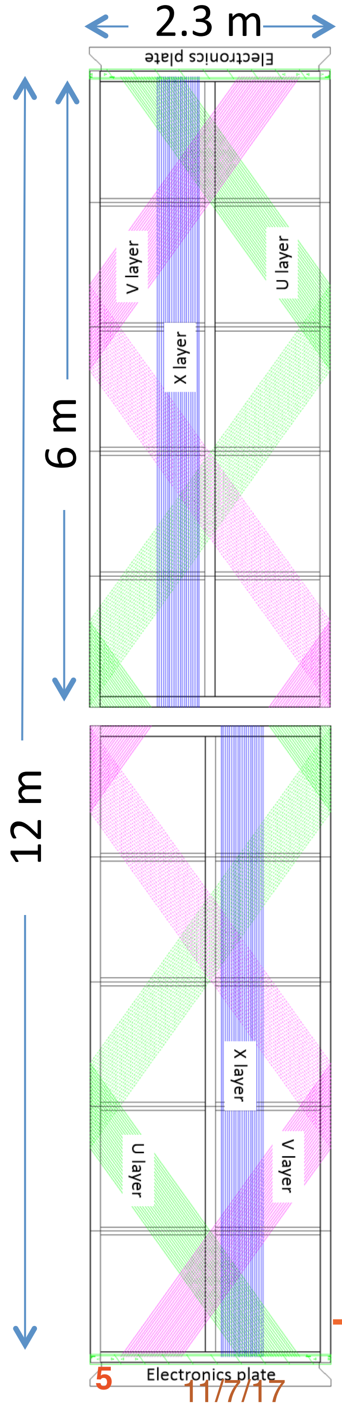


Liquid Argon Time projection chamber with both charge and optical readout.

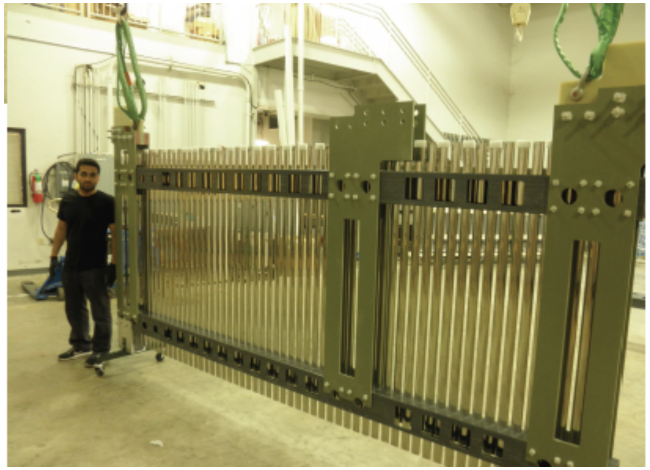
LAr Detector Module Characteristics

- 17.1/13.8/11.6 kt Total/Active/Fiducial mass
- 3 Anode Plane Assemblies (APA) wide (wire planes)
  - Cold electronics 384,000 channels
- Cathode planes (CPA) at 180kV
  - 3.6 m max drift length
- Photon detection for event interaction time determination for underground physics

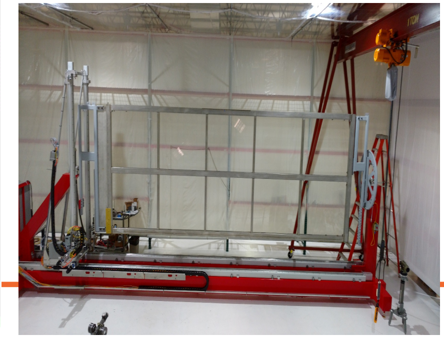


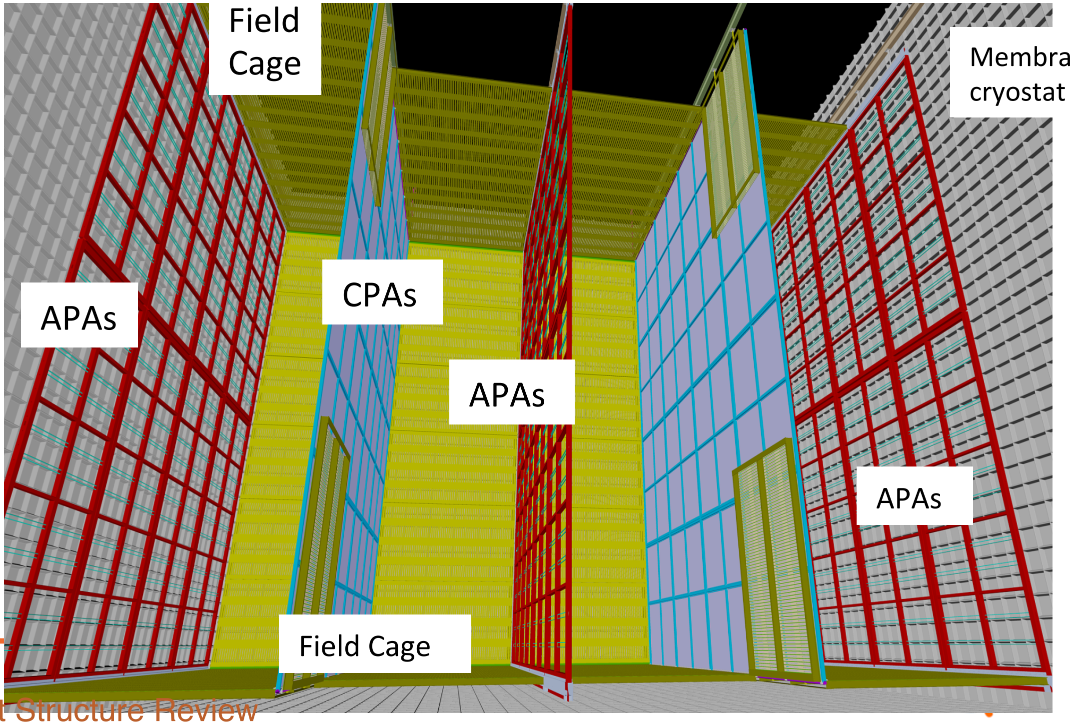


- Modular APAs - 2.3m by 6m
  - width limited by Ross shaft, and shipping
  - Length limited by wire capacitance and noise
- Cathode and field cage geometry fixed by APA and 3.6m drift → HV limitations and purity



End wall Field Cage Panel





ProtoDUNE Goals

- Engineering validation of the full-scale DUNE detector components.
  - Test the full scale detector elements under realistic (but high rate) conditions.
  - Use as close to final detector components as possible.
- Develop the construction and quality control process.
- Validate the interfaces between the detector elements and identify any revisions needed in final design.
- Validate the detector operation using cosmic rays.

Engineering validation

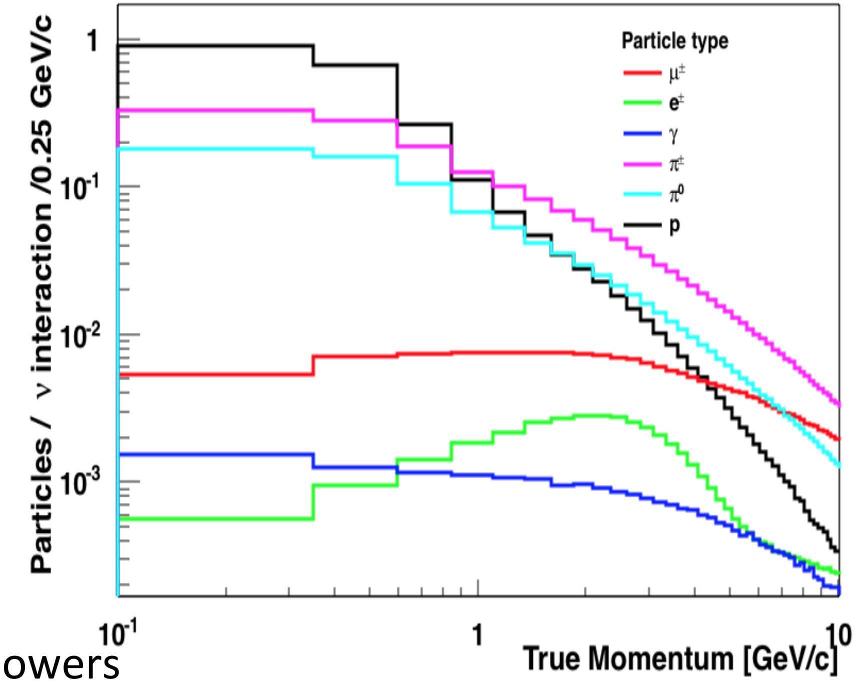
- Study the detector response to known charged particles.
- Improve the detector reconstruction and response model
- Validate the Monte Carlo Model accuracy

Performance validation

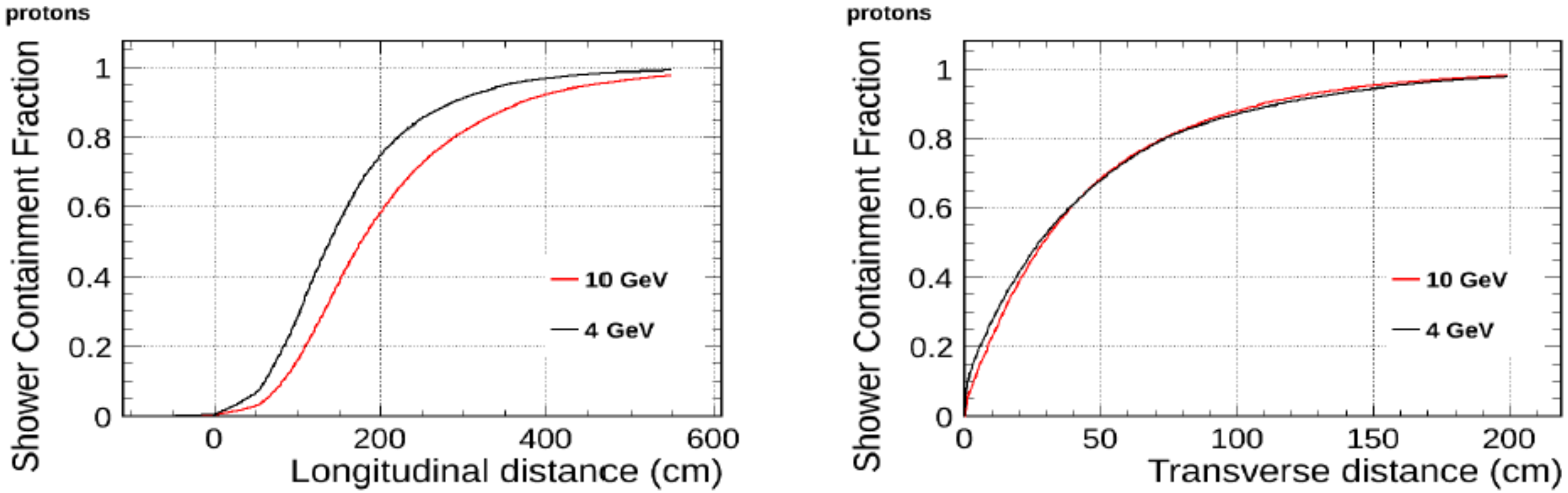
Desired ProtoDUNE-SP Data

- ProtoDUNE needs to be capable of measuring low energy pion, kaon, and electron showers well.
- The vertex reconstruction is critical for PID.
- Maximum hadronic shower size is 2m radius and 6m deep.
- A 3APA deep (6.9m) by two drift cell wide (7.2m) provides optimal coverage

Particles produced in neutrino interactions at DUNE

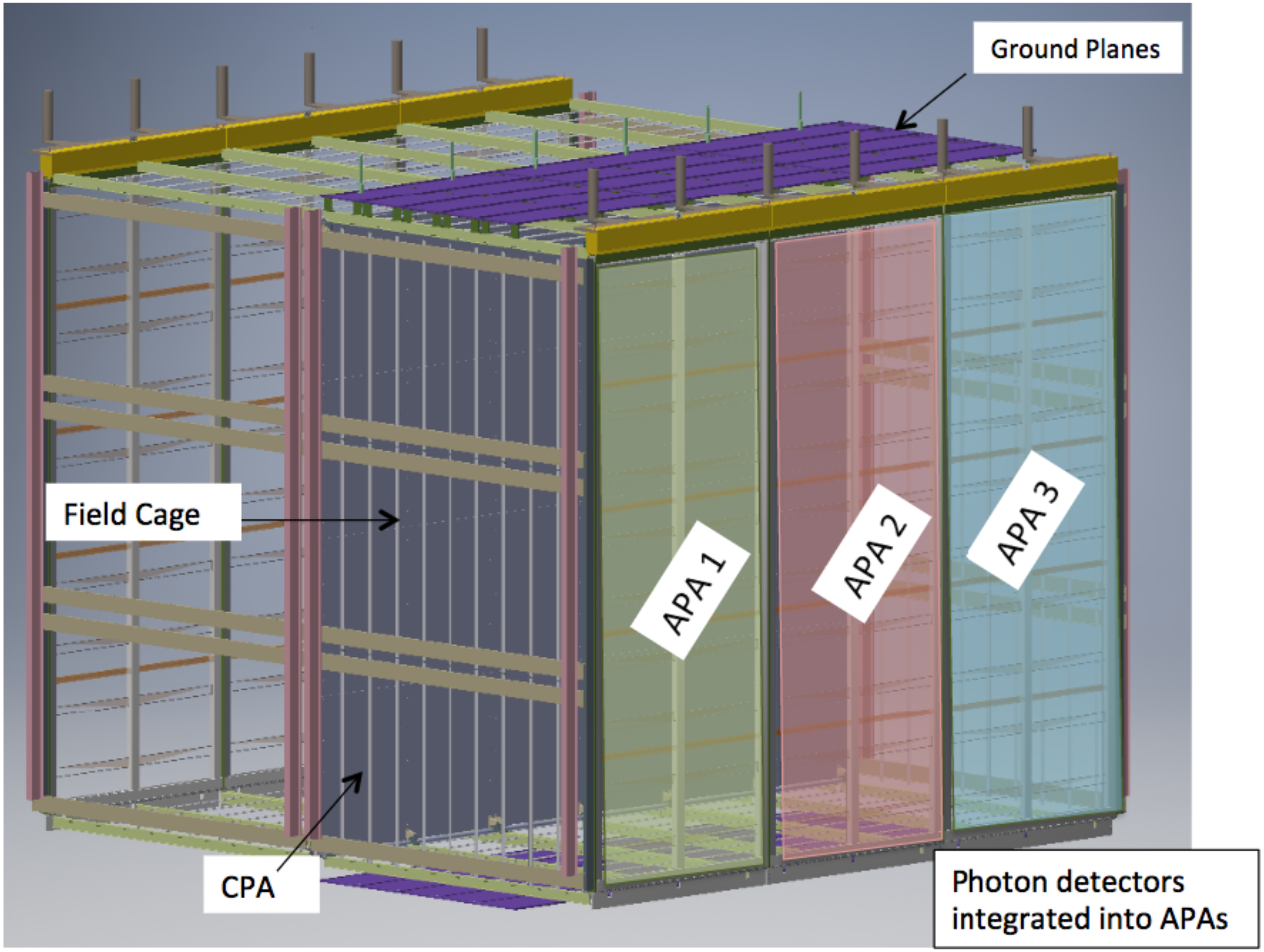


Largest complex event topology is from hadronic showers



ProtoDUNE-SP configuration

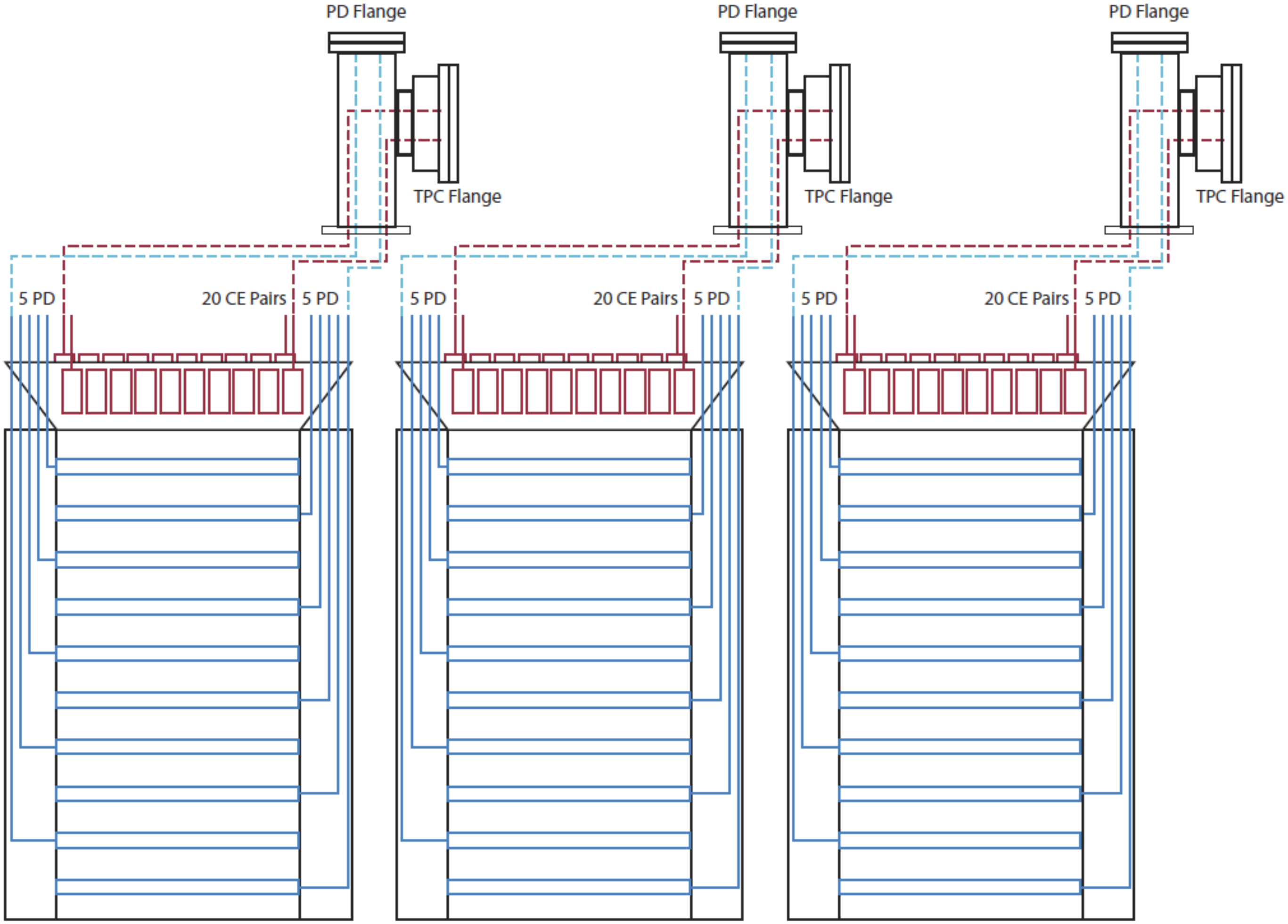
- 6 APA
- 6 CPA panels
- 6 top FC panels
- 6 bottom FC
- End wall FC
- 180kV HV



- Desire to reconfigure to 2.5m drift for future runs to reduce space charge effects (few CM distortions).
- The DSS dimensions are defined by the requirement to support the TPC.

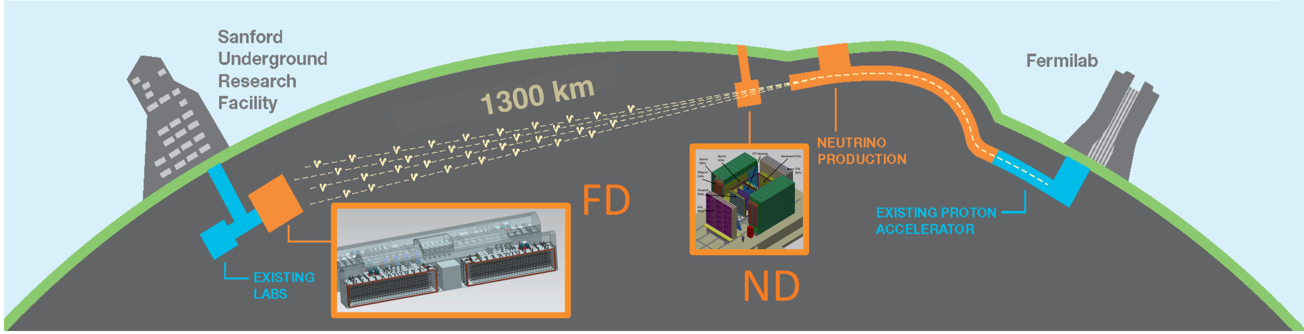
Grounding

- The single-phase TPC has no gain prior to charge collection so low noise design is critical.
- Proper grounding and shielding are vital.



- The detector support structure must be electrically isolated from the APA and electronics.
- The DSS must be electrically connected to the membrane at the penetrations..

Detector Mechanical Tolerances



- No absolute position accuracy required!
  - At 1300km the ν flux varies <1% over 1km
  - Requirements on the detector position are driven by engineering considerations and the cryostat interface.
- Detector volume needs to be known better than the 1% level.
  - DUNE will measure asymmetries so the volume is needed to normalize the data sets.

The charge-parity (CP) asymmetry is defined as

$$\mathcal{A}_{cp} = \frac{P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}{P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}$$

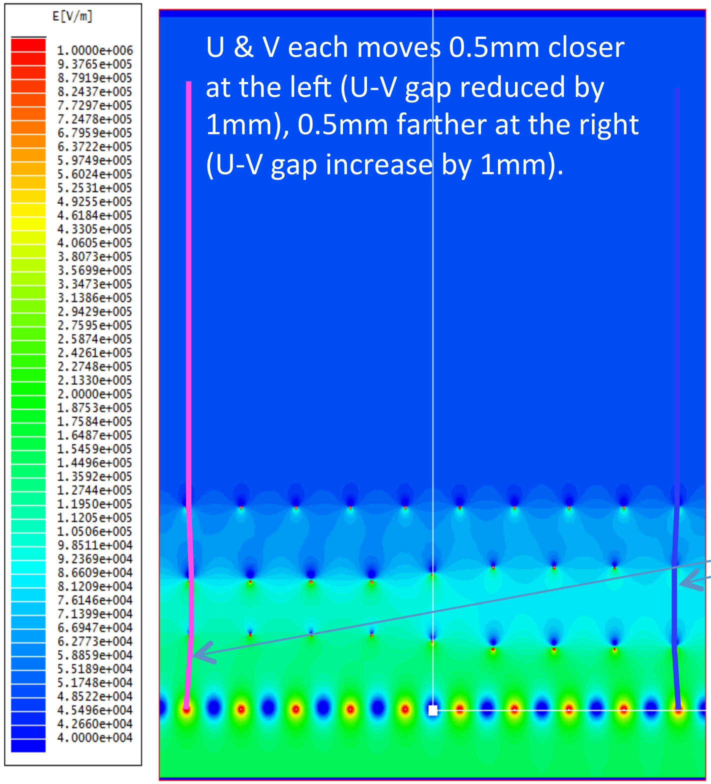
  - Detector motion under cooldown needs to be understood to insure the 1% precision in defining the fiducial volume.

APA plane mechanical distortions

- The induction planes must fulfill the transparency condition at > 99%.
  - Needed for both calorimetry and tracking.
- This defines the APA flatness specification.
- Field calculations show 0.5 mm wire displacement OK.
- APA distortion studies show that this corresponds to a +/-5mm tolerance on flatness.
- The detector support cannot distort the APA beyond the +/- 5 mm limit.

Nominal wire plane spacing: 3/16”
G & X wire pitch: 4.5mm
U & V wire pitch: 5mm

G and X planes remain at nominal position



U & V each moves 0.5mm closer at the left (U-V gap reduced by 1mm), 0.5mm farther at the right (U-V gap increase by 1mm).

Bo Yu

Impact of Mechanical Distortions on calorimetry

- If the wire planes are off by 1 cm, the drift distance will be changed by 1 cm over 3.6 m. The will change the nominal drift field 500 V/cm by 0.3%.

- The recombination (quenching) effect depends on electric field. Using the Birks correction:

$$\mathscr{R}_{\mathrm{ICARUS}} = \frac{A_B}{1 + k_B \cdot (dE/dx)/\mathscr{E}}$$

$$A_B = 0.800 \pm 0.003$$

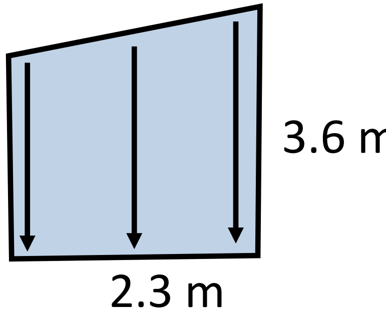
$$k_B = 0.0486 \pm 0.0006 \ \mathrm{kV/cm\ (g/cm^2/MeV)}$$

Amoruso, et al NIM A 523 (2004) 275

Changing the electric field by 0.3% will change the recombination factor by 0.05% for a MIP particle (2.1 MeV/cm) and by 0.15% for a HIP particle (10 MeV/cm). The changes are negligible for calorimetry reconstruction.

- Distortions of several cm would be permitted based on calorimetry

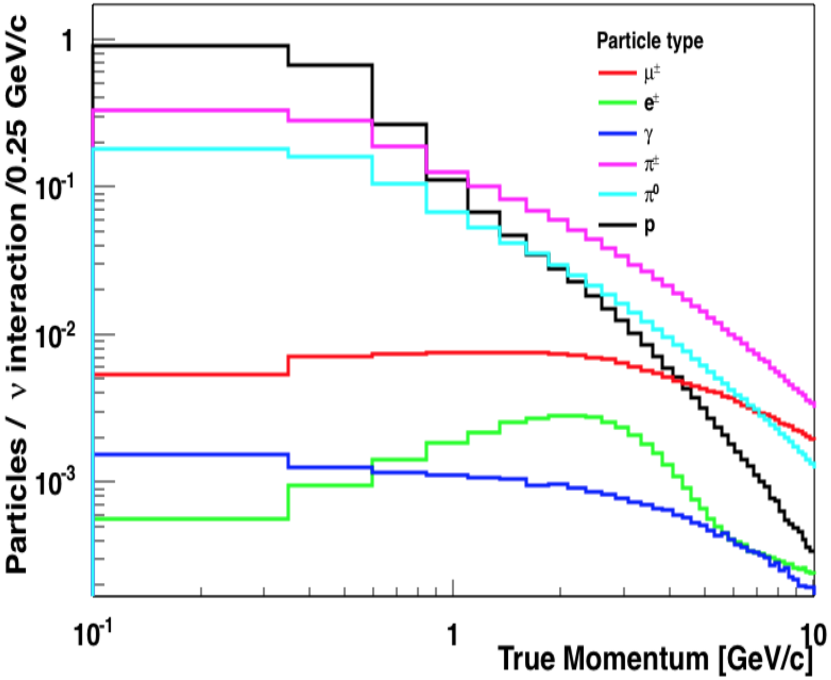
Impact on dE/dx from mechanical distortions



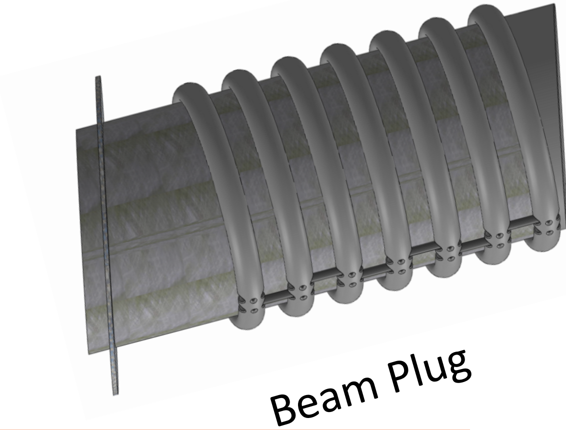
- Suppose the drift volume becomes a trapezoid instead of a rectangle due to distortion and the drift distance on one side is 1 cm longer than on the other side, the electric field is different by 0.3% between the two sides.

- For a track near the cathode that is parallel to the wire planes, the reconstructed track would appear to have a smaller angle w.r.t the wire planes. The maximum change to dE/dx would be .01/2.3 = 0.4% due to this distortion. This is negligible for particle ID.

Material Budget in the ProtoDUNE-SP Beam

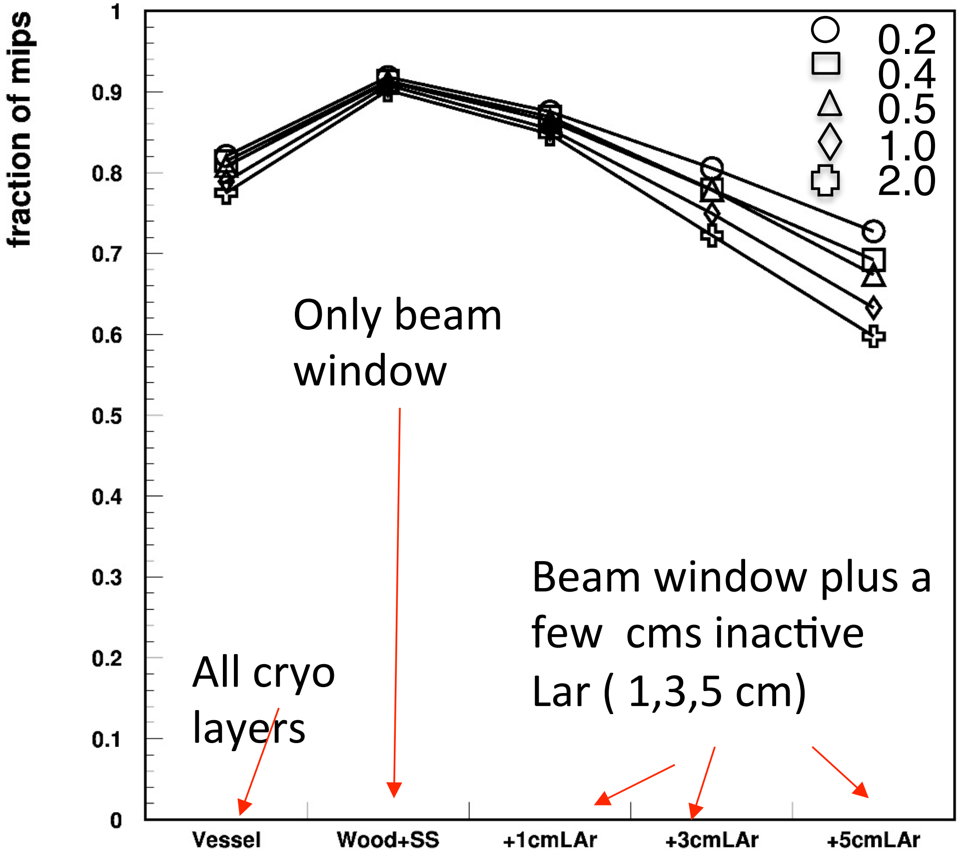


- Required Particles:
  - Hadrons starting 1 GeV/c , electrons from 0.5 GeV/c
  - Energy uncertainty <=1%
  - Minimize electron showering, for e/γ discrimination test
  - Avoid large scatterings, for “good” particle identification and checks of angular resolution/reconstruction
- Dead materials are an issue, especially if the composition/ thickness is not well defined.
- Reminder: without plug,
  - all electrons would shower before the active volume,
  - >=50% hadrons would interact in the passive layer
  - 1GeV un-collided protons would loose 36% of their energy



Effect of materials on electrons

Fraction of electrons that are still "minimum ionizing particles" after dead layers in various configurations ➔ study e/γ discrimination



Only beam window

All cryo layers

Beam window plus a few cms inactive Lar (1,3,5 cm)

- Different symbols: e^- initial momentum, within 0.2-2 GeV/c
- Beam window: 90% survive
- 5cm LAr: only 60-70 % survive as mip
- Also 3 cm is problematic

➡ Can tolerate ≈1 cm IF PRECISELY KNOWN

Hadrons, and summary

- For protons at 1GeV/c, every cm of inactive LAr adds 1.5% energy loss. ➔ few cms can be afforded IF PRECISELY KNOWN (better than 1-2 mm)
- For pions at 1 GeV/c, absolute energy loss is relatively less important, however
  - angular deflection becomes large, 20mrad rms for 5cm inac. LAr
  - Spread in energy loss 0.5% at 5 cm inactive LA
  - Also for pions safe limit is few cm, need knowledge

- **Combining electron and hadron requirements, acceptable Lar inactive layer is or the order of 1cm.**
- **Needed good knowledge of the actual thickness**

Contamination

- The electron lifetime needs to be longer than 3ms.
  - All materials in the cryostat need to be tested for electronegative impurities.
  - Materials in the gas ullage are especially important.
  - All materials need to be tested in the FNAL material test stand.

- As the outgassing rate grows exponentially with temperature all penetrations to the warm structure must be purged to prevent contaminates from entering the ullage space.

Summary

- The detector support dimensions are defined by the TPC dimensions based on the desired test beam data set.
  - The gap between the beam entry window and the beam plug should be on the order of ~1cm.
- The detector will be constructed from full-scale DUNE detector components.
- The DSS needs to be able to accommodate a shift from 3.6 to 2.5 m drift distance.
- The requirements from contamination and grounding are clear.
- The DSS must not appreciably distort the APA frames.
- Mechanical distortions of the TPC at the few cm level will not appreciably impact detector performance.