# DUNE Near Detectors

Hongyue Duyang
University of South Carolina
On Behalf of the DUNE Collaboration

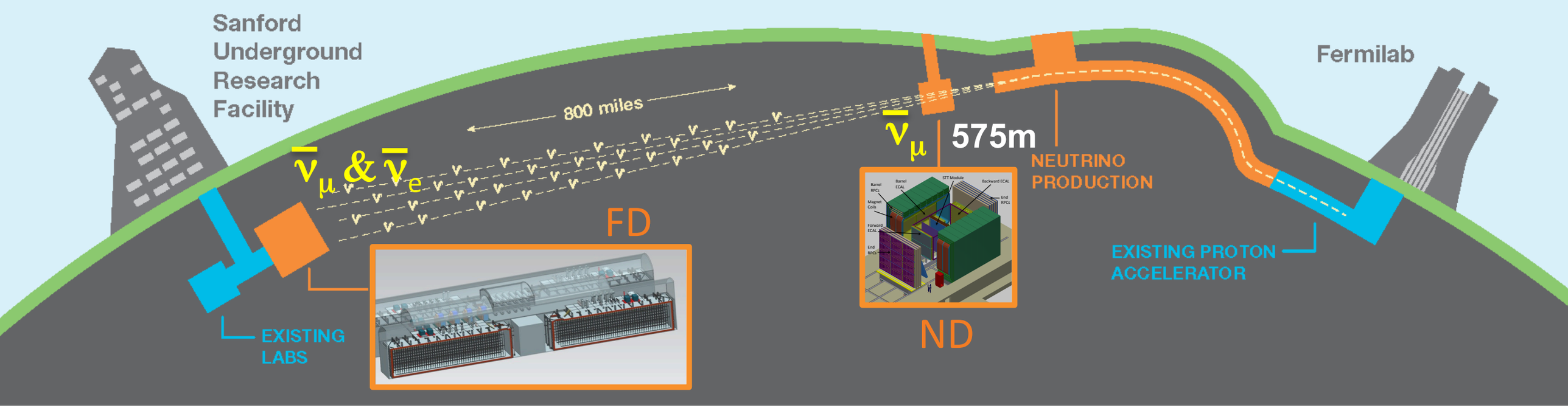
NUFACT 2016, 08/26/2016
Quy Nhon, Vietnam

# Overview

- DUNE Near detector roles.
- Near detector options under study.
- Near detector constraint on oscillation systematics.
- Physics in the near detector itself.

# Near Detectors for DUNE

- DUNE is a long-baseline neutrino experiment aiming to solve mass hierarchy and CP-violation by measuring $\nu_\mu$ to $\nu_e$/$\bar{\nu}_\mu$ to $\bar{\nu}_e$ oscillation in one single experiment.
- A capable near detector is crucial for DUNE to fulfill its scientific goal.



# Near Detector Roles

- Constrain the systematics for oscillation measurement.
  - Measure spectra of all four species of neutrinos: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$
  - Measure the absolute and relative flux: FD/ND($E_\nu$)
  - Constrain & Model nuclear effects: $\nu/\bar{\nu}$-Ar
  - Quantify differences between neutrino and antineutrino: energy scale, event topology, cross-section, etc.
  - Constrain Background: $\pi^0/\pi^+/\pi^-$/etc.

- Precision measurement for neutrino interaction:
  - Cross sections: Inclusive and exclusive.
  - Electroweak and isospin physics

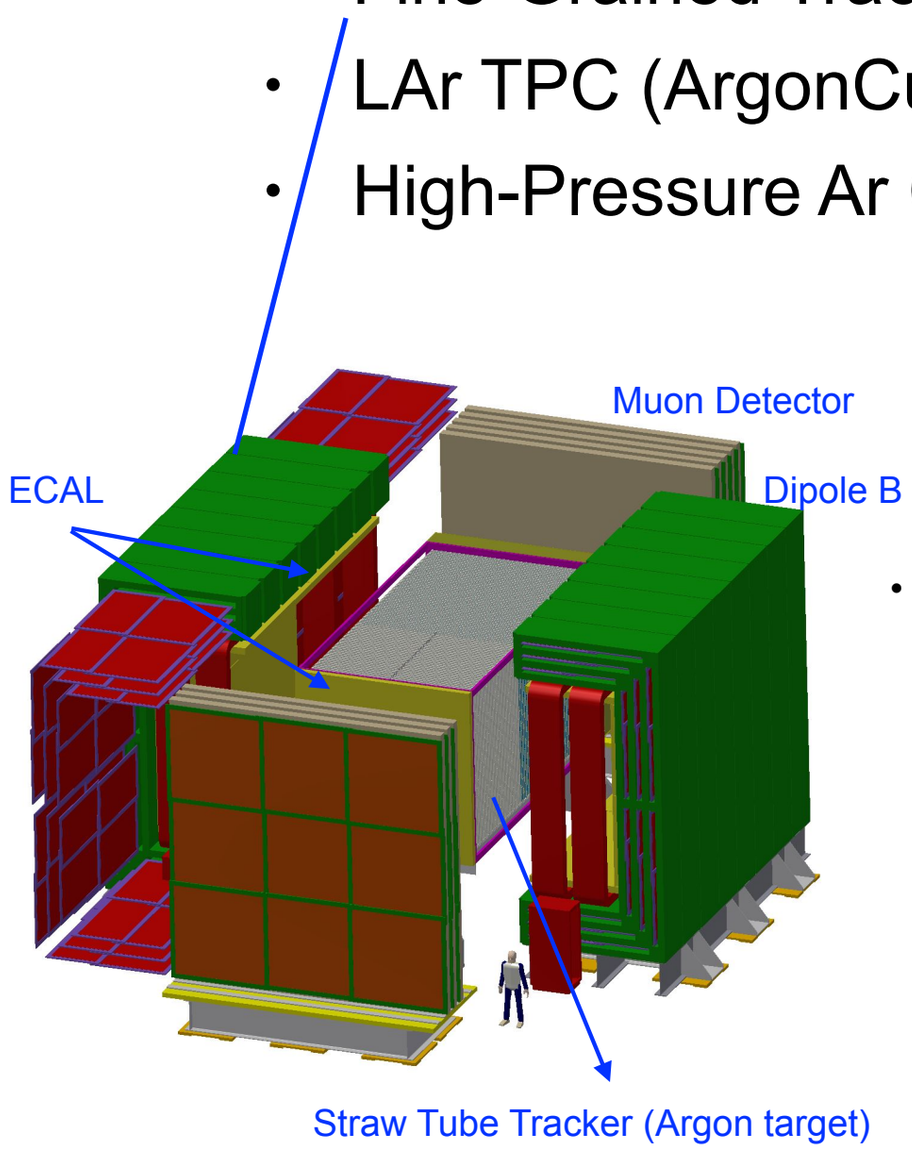
- Search for new Physics: sterile neutrinos, light Dark Matter candidates, etc.

# Near Detector Options

- Currently we have 3 ND options under study:
  - Fine-Grained Tracker (CDR reference design)
  - LAr TPC (ArgonCube)
  - High-Pressure Ar Gas TPC

# Near Detector Options

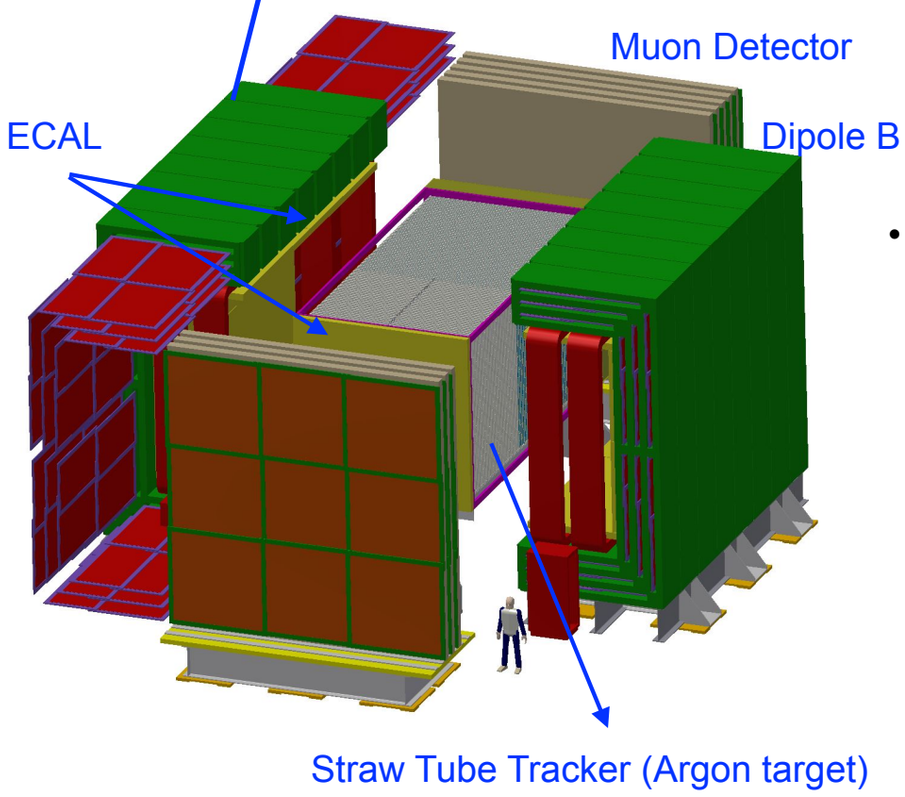
- Currently we have 3 ND options under study:
  - Fine-Grained Tracker (CDR reference design)
  - LAr TPC (ArgonCube)
  - High-Pressure Ar Gas TPC

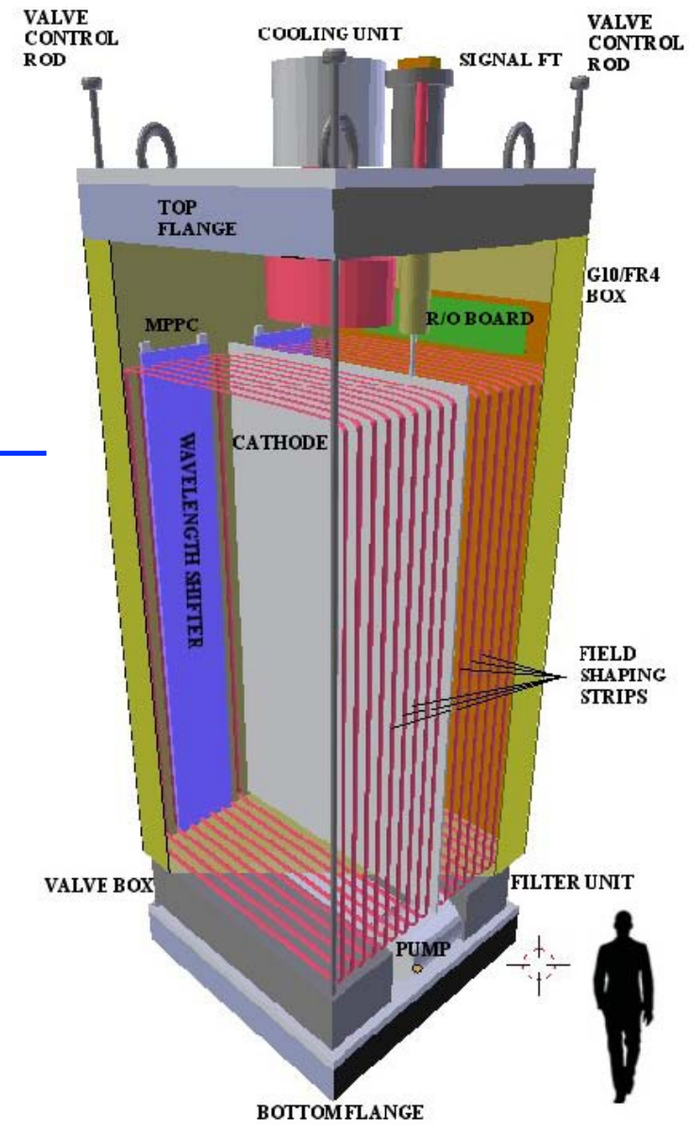



- **(the focus of this talk)**

# Near Detector Options

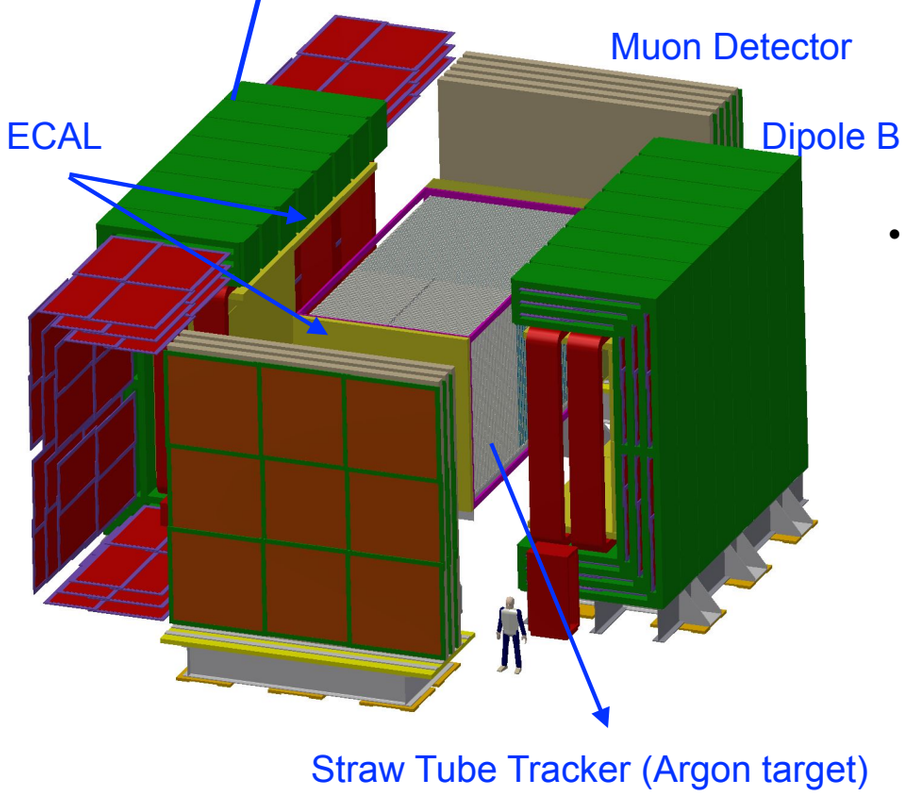
- Currently we have 3 ND options under study:
  - Fine-Grained Tracker (CDR reference design)
  - LAr TPC (ArgonCube)
  - High-Pressure Ar Gas TPC

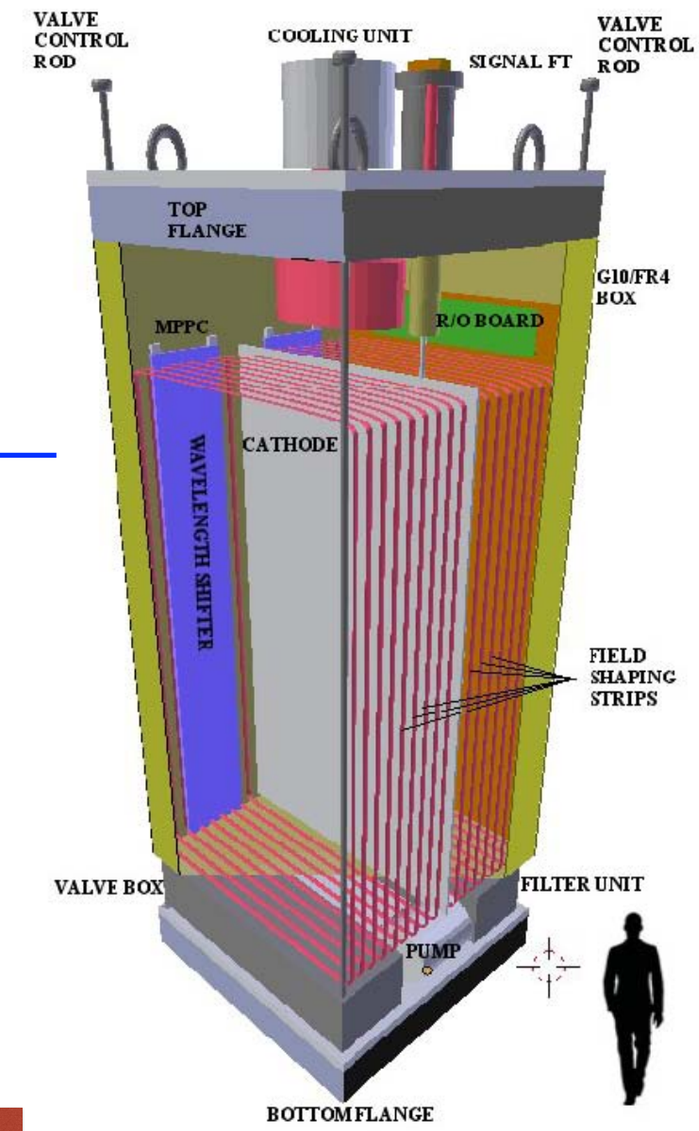


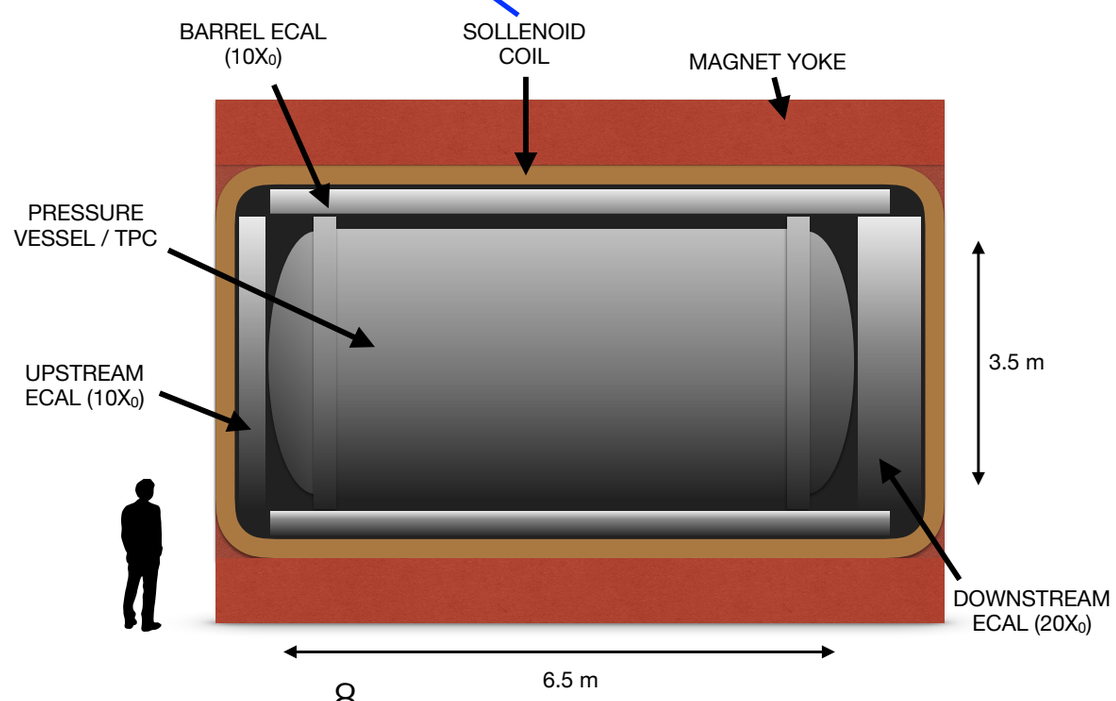



# Near Detector Options

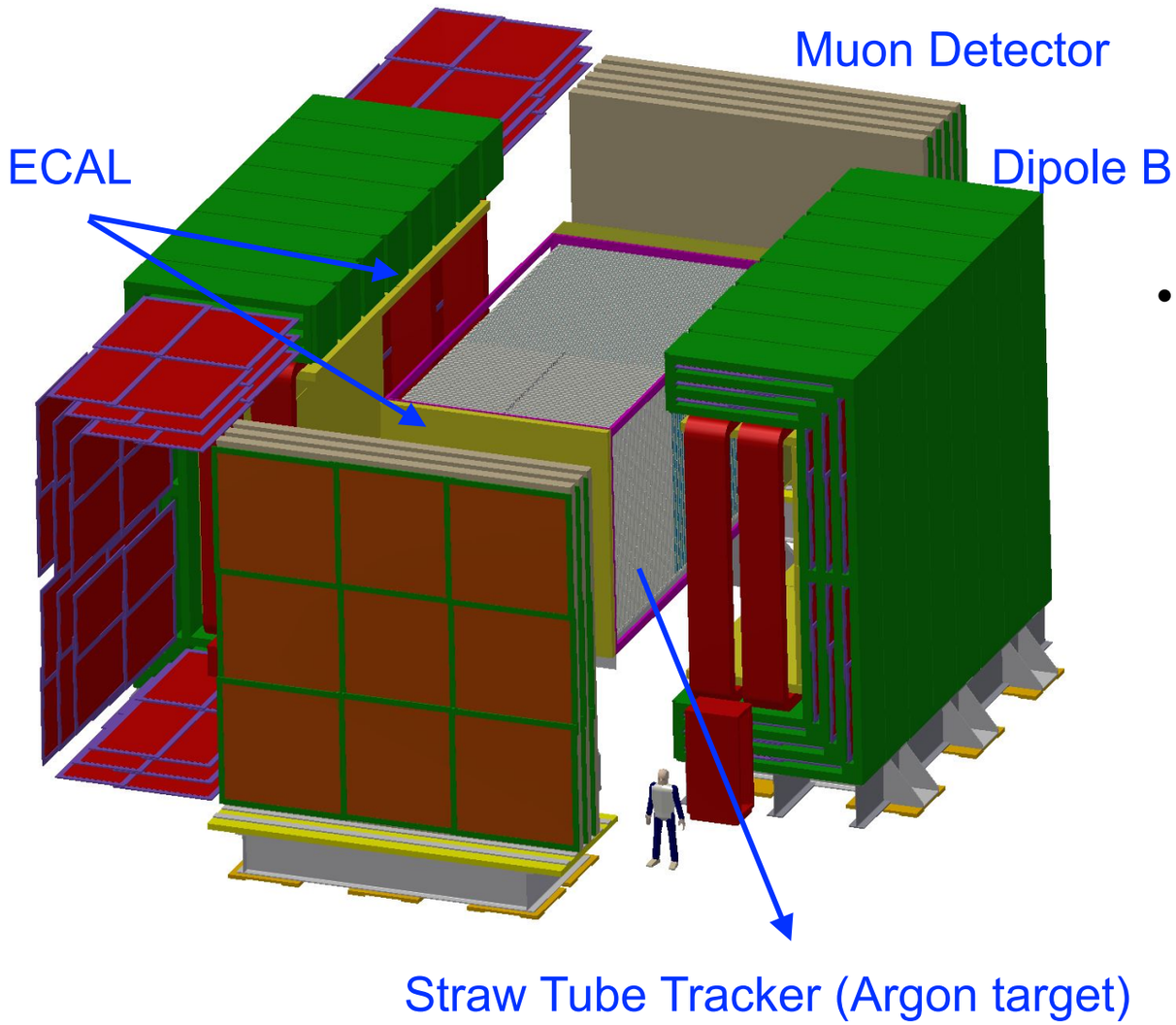
- Currently we have 3 ND options under study:
  - Fine-Grained Tracker (CDR reference design)
  - LAr TPC (ArgonCube)
  - High-Pressure Ar Gas TPC



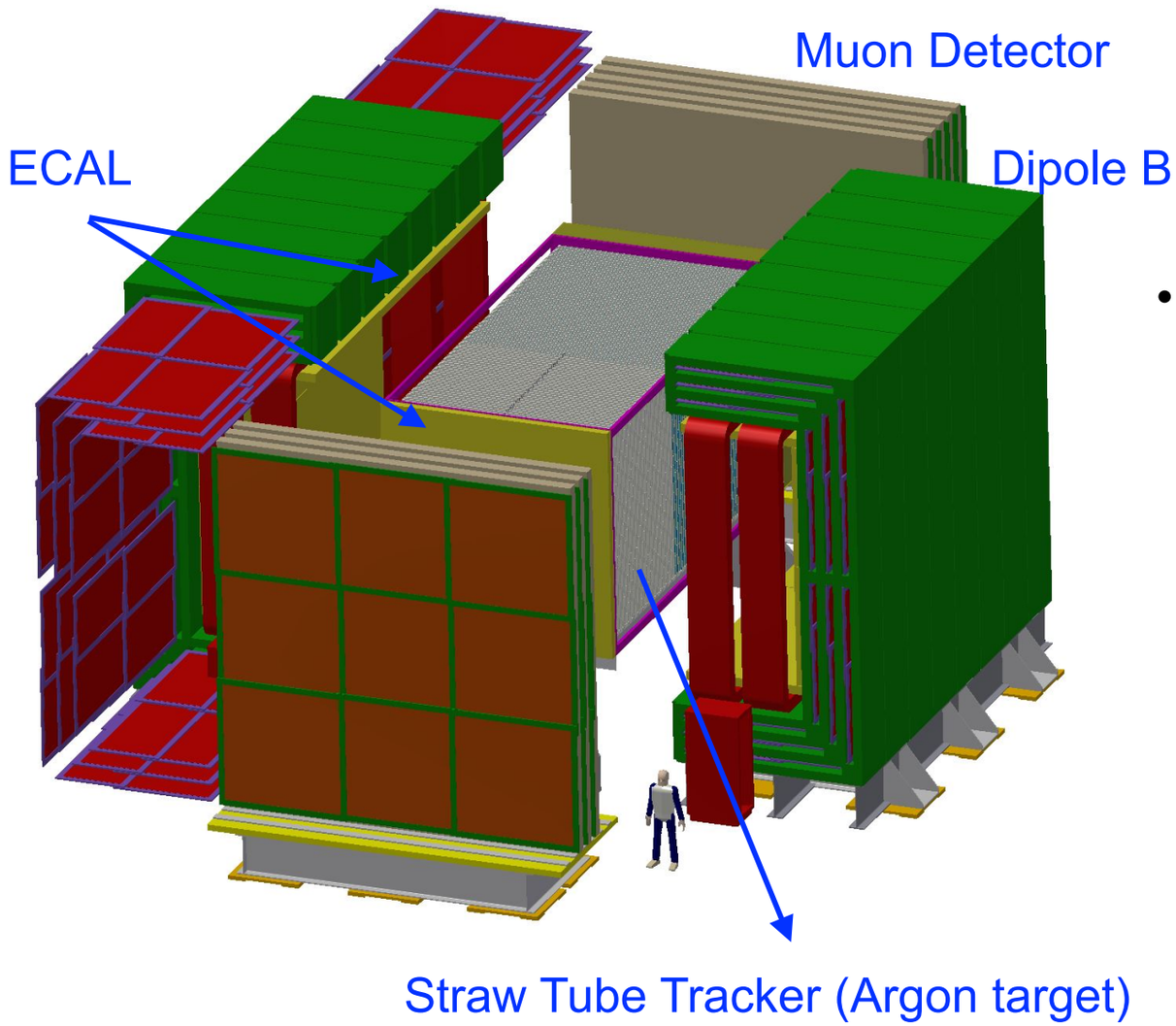
# Fine-Grained Tracker (FGT)




| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

- ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
- Dipole magnetic field (B = 0.4 T).
- 4$\pi$ ECAL coverage.
- 4$\pi$ MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

# Fine-Grained Tracker (FGT)

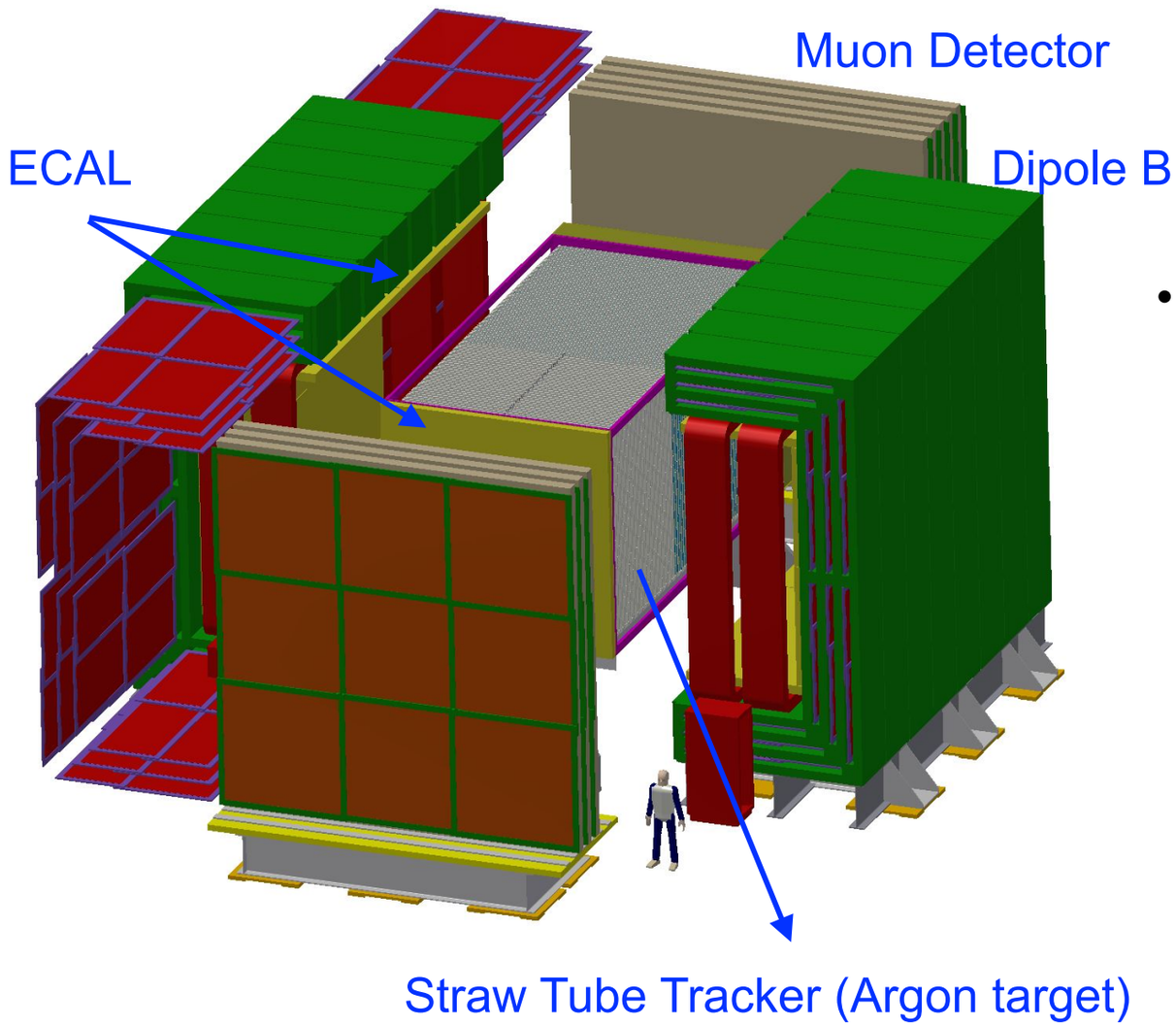



| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

- • ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
  - Dipole magnetic field (B = 0.4 T).
  - 4π ECAL coverage.
  - 4π MuID (RPC) in dipole and up/downstream.
  - Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

**Low-density good for tracking leptons and hadrons.**

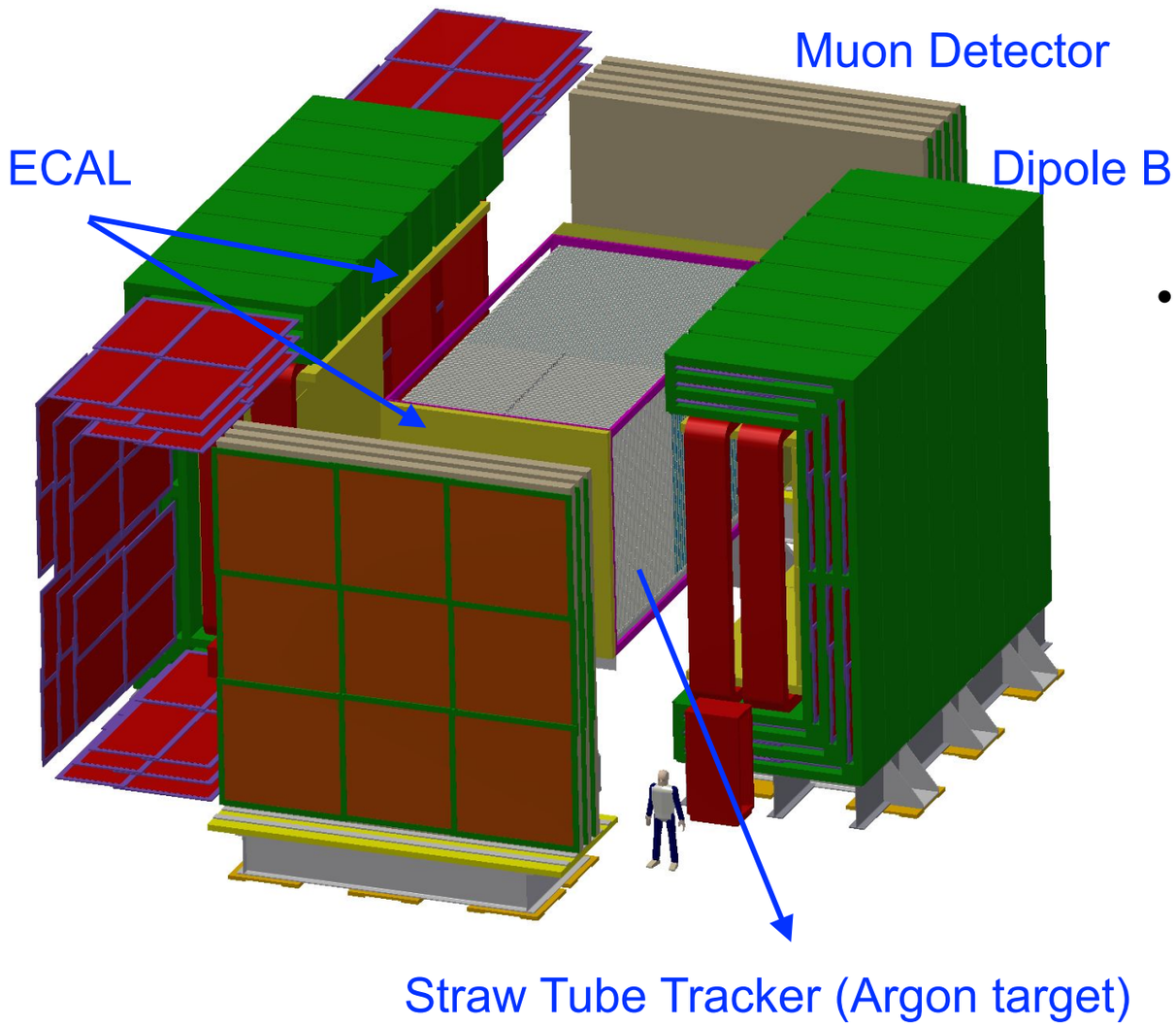
# Fine-Grained Tracker (FGT)




| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

- ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
- Dipole magnetic field (B = 0.4 T). **Measure charge: $\nu$ vs $\bar{\nu}$**
- 4$\pi$ ECAL coverage.
- 4$\pi$ MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

# Fine-Grained Tracker (FGT)

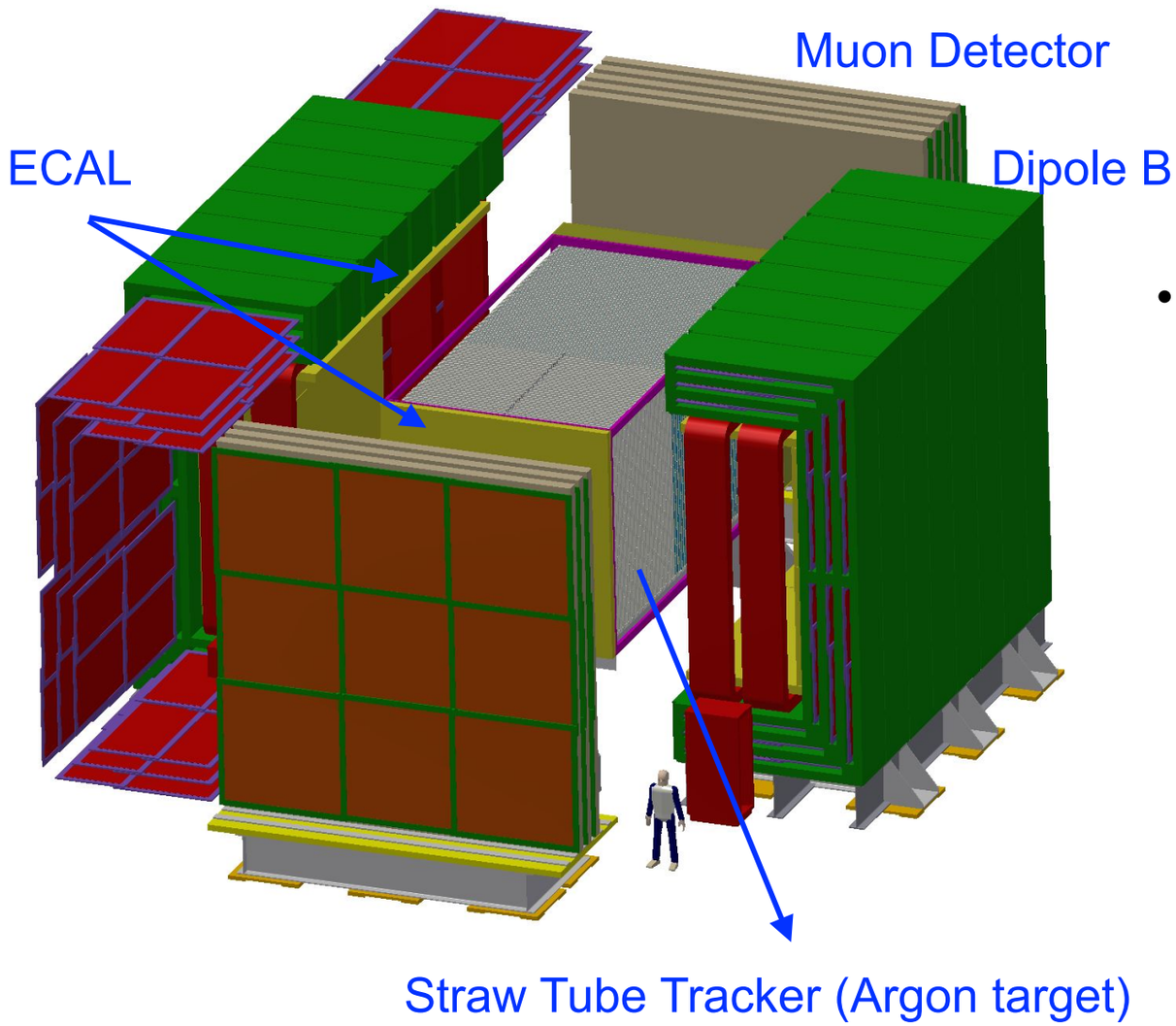



| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

- ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
- Dipole magnetic field (B = 0.4 T).
- 4$\pi$ ECAL coverage.
- 4$\pi$ MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

**Full phase space measurement**

# Fine-Grained Tracker (FGT)

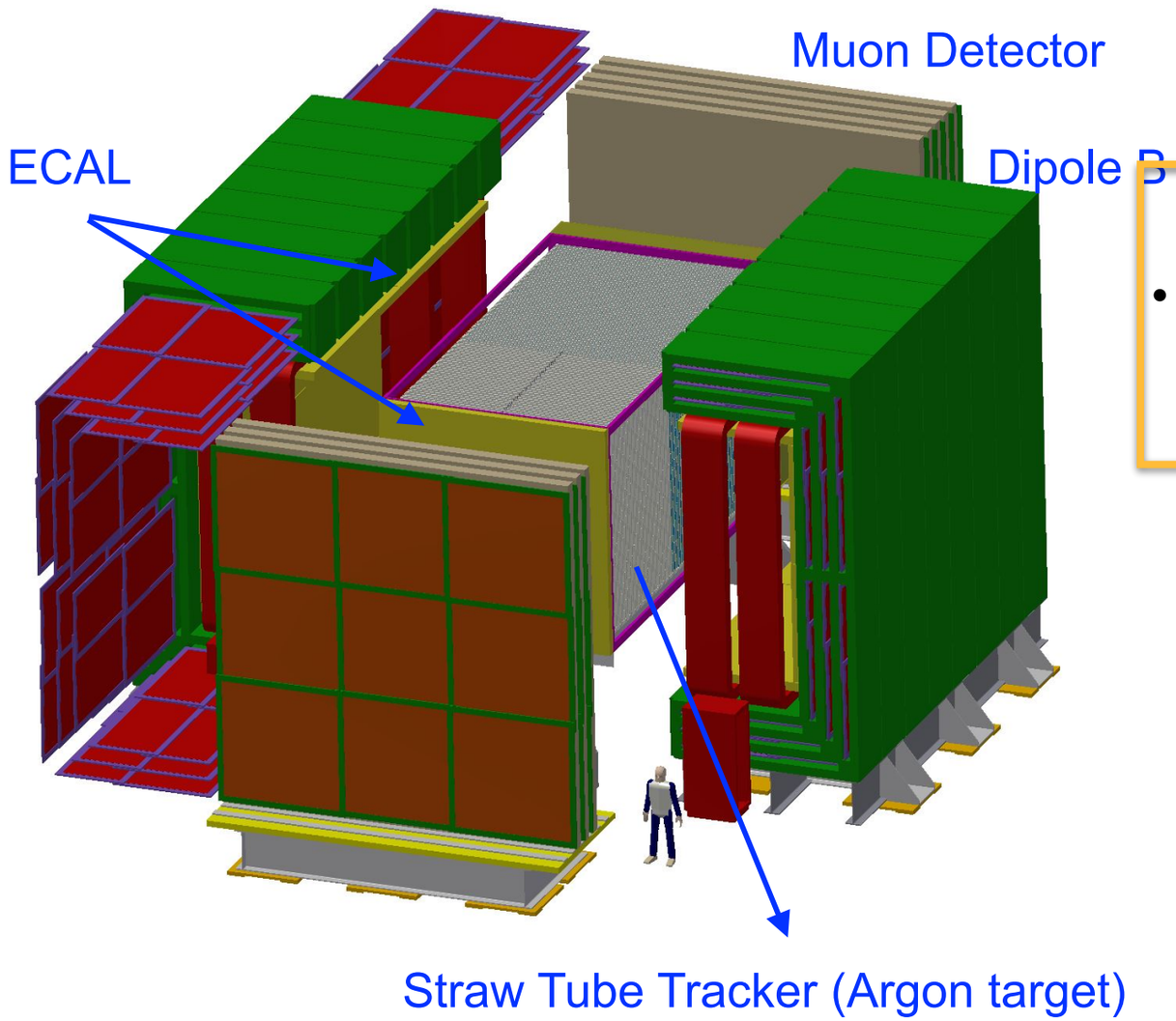



| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

- ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
- Dipole magnetic field (B = 0.4 T).
- 4π ECAL coverage.
- 4π MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

**Nuclear effect study**

# Fine-Grained Tracker (FGT)

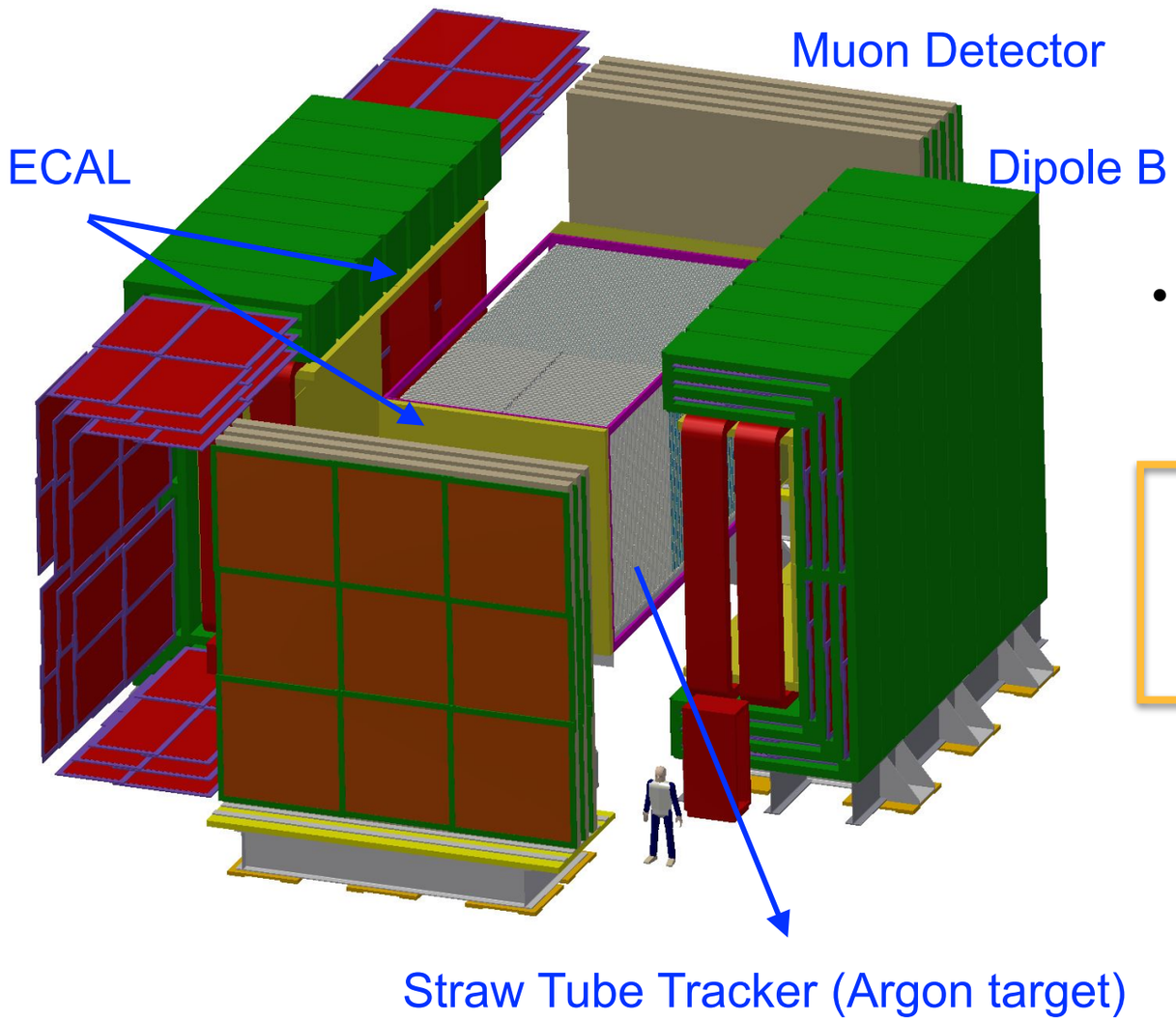



| | |
|---|---|
| Radiator[illegible] ons<br>Other N[illegible] tons | |
| Vertex Resolution<br>Angular Resolution | 0.1 mm<br>2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$<br>( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID<br>$\nu_e/\bar{\nu}_e$ ID<br>$\pi^-$ .vs. $\pi^+$ ID<br>$\pi^+$ .vs. *proton* .vs. $K^+$ | Yes<br>Yes<br>Yes<br>Yes |
| NC$\pi^0$/CCe Rejection<br>NC$\gamma$/CCe Rejection<br>CC$\mu$/CCe Rejection | 0.1%<br>0.2%<br>0.01% |

**High Resolution**

- • ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, $X_0 \simeq 6$m).
- Dipole magnetic field (B = 0.4 T).
- 4π ECAL coverage.
- 4π MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

# Fine-Grained Tracker (FGT)

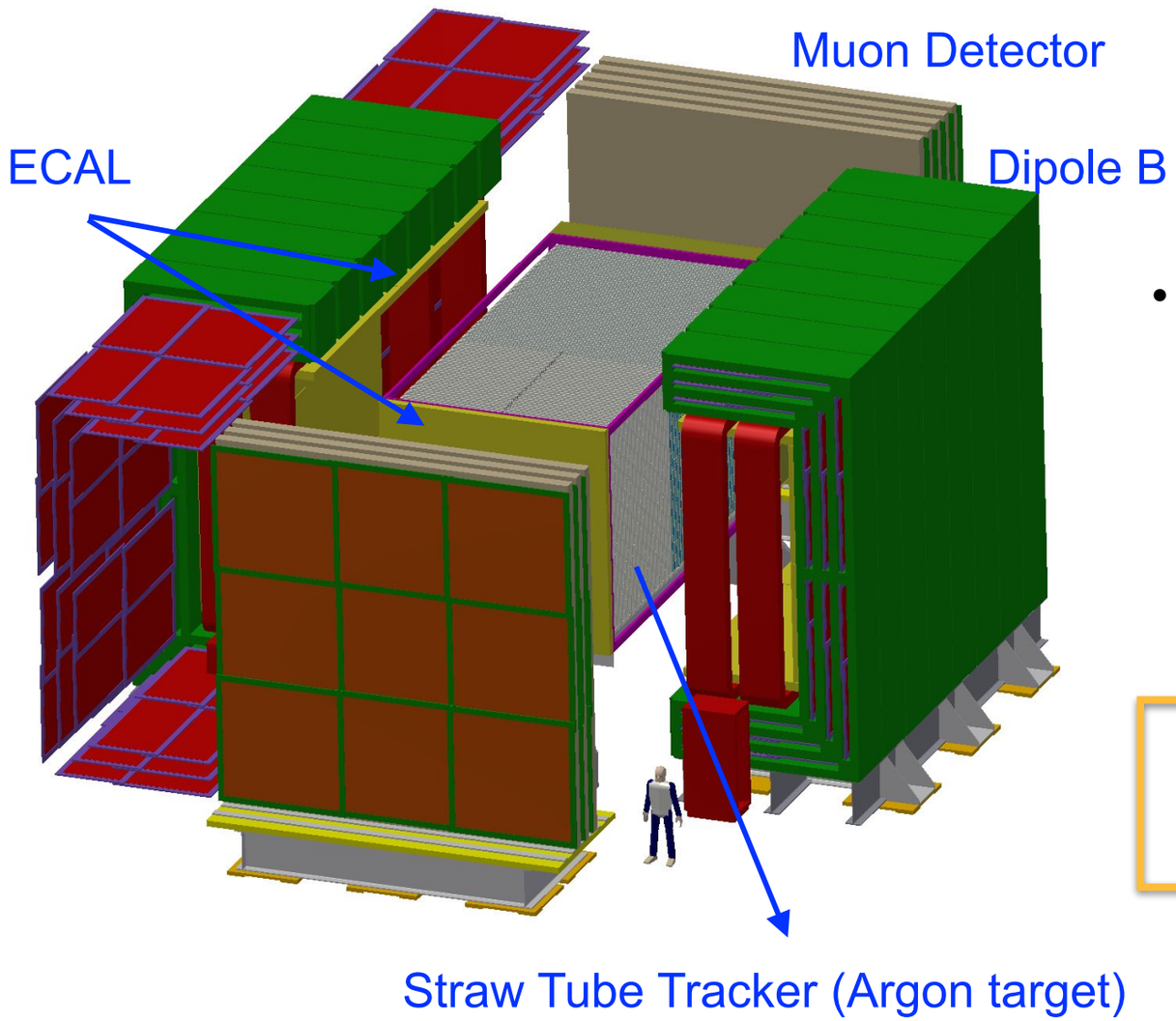



| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ [illegible] | $6\%/\sqrt{E}$ |
| $E_\mu$ [illegible] | [illegible] |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi^-$ .vs. $\pi^+$ ID | Yes |
| $\pi^+$ .vs. *proton* .vs. $K^+$ | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

**Particle Identification**

- • ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, X0≃6m).
  - Dipole magnetic field (B = 0.4 T).
  - 4π ECAL coverage.
  - 4π MuID (RPC) in dipole and up/downstream.
  - Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

# Fine-Grained Tracker (FGT)

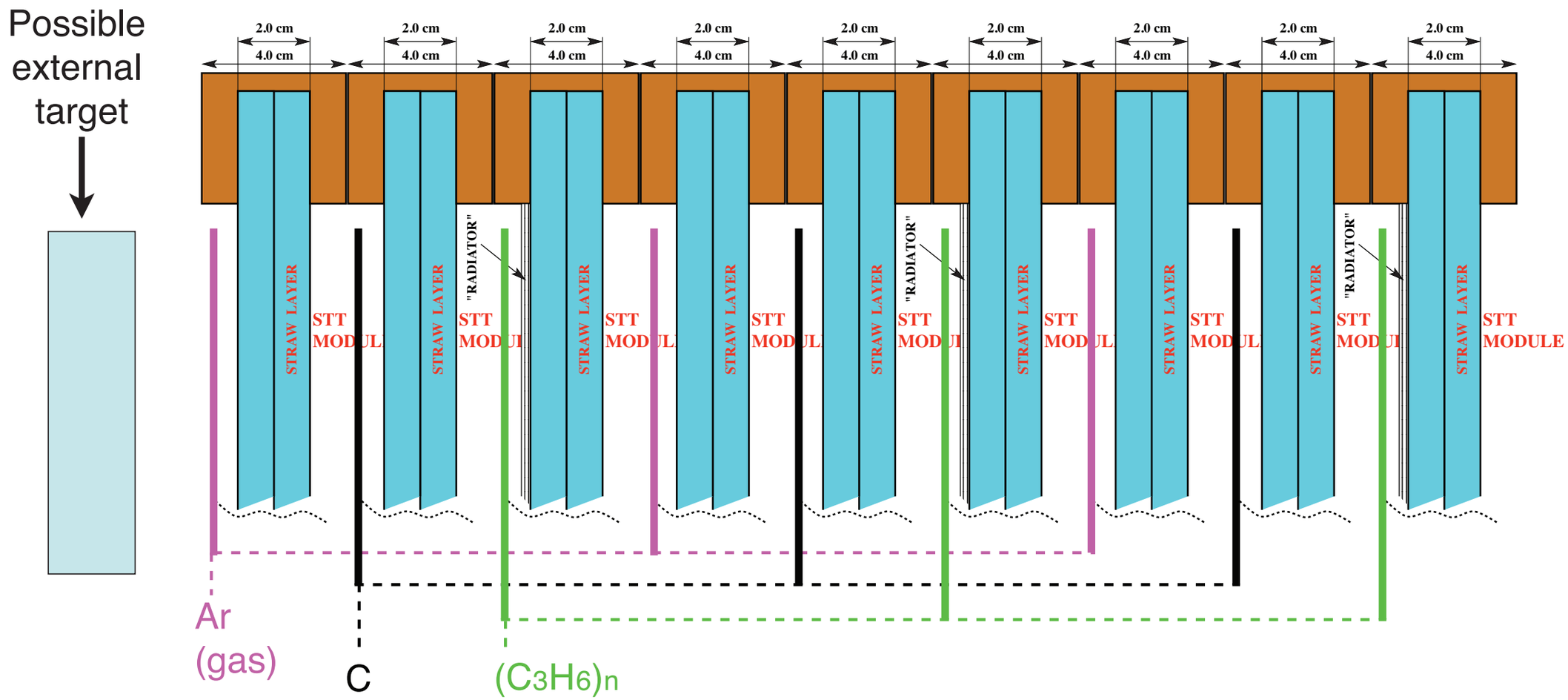



| | |
|---|---|
| Radiator (Target) Mass | 7 tons |
| Other Nuclear Target Mass | 1–2 tons |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | $6\%/\sqrt{E}$ ( 4% at 3 GeV) |
| $E_\mu$ Resolution | 3.5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| $\pi$ | |
| $\pi$ | |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

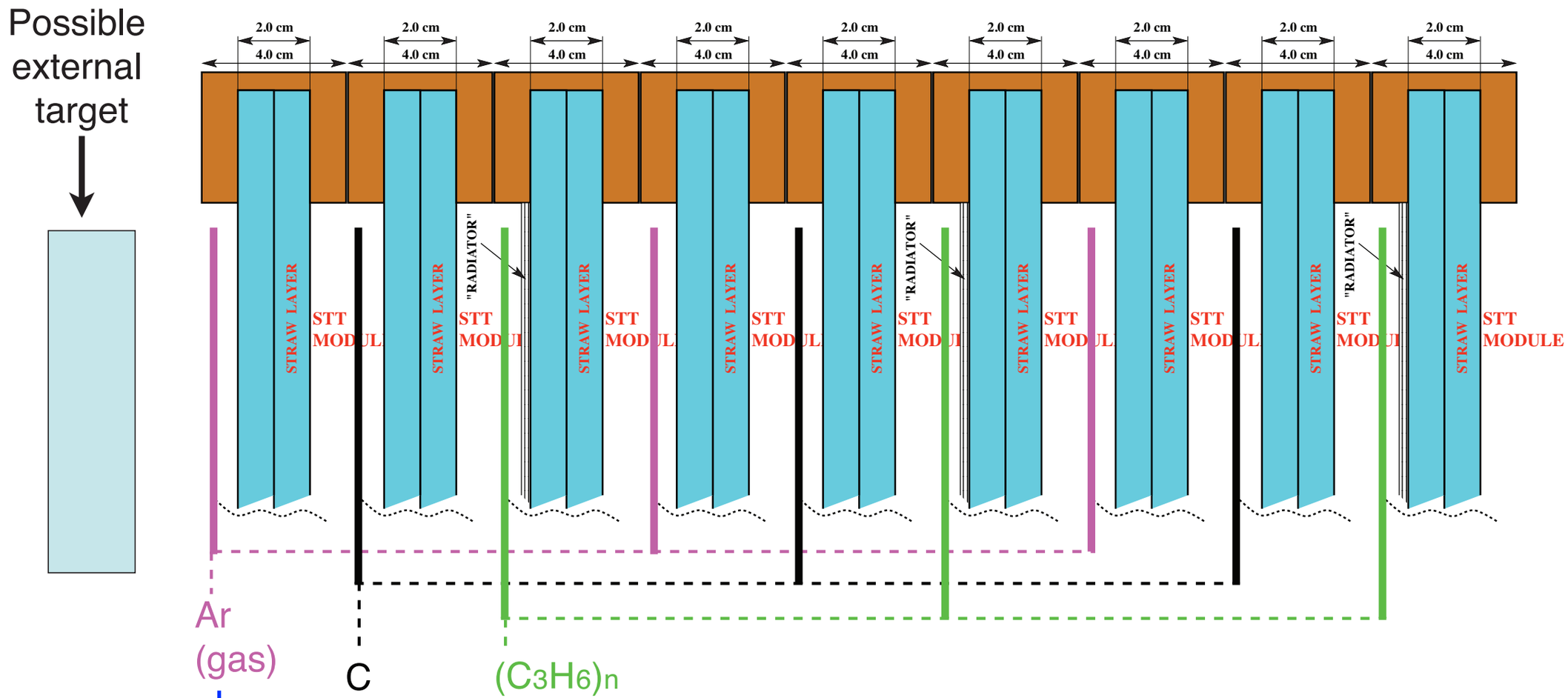
**Background Rejection**

- ~3.5m×3.5m×6.5m Straw Tube Tracker (STT) ($\rho \simeq 0.1$ g/cm$^3$, X0≃6m).
- Dipole magnetic field (B = 0.4 T).
- 4π ECAL coverage.
- 4π MuID (RPC) in dipole and up/downstream.
- Pressurized $^{40}$Ar target ≃ ×10 FD statistics, and $^{40}$Ca target.

# Fine-Grained Tracker Nuclear Target

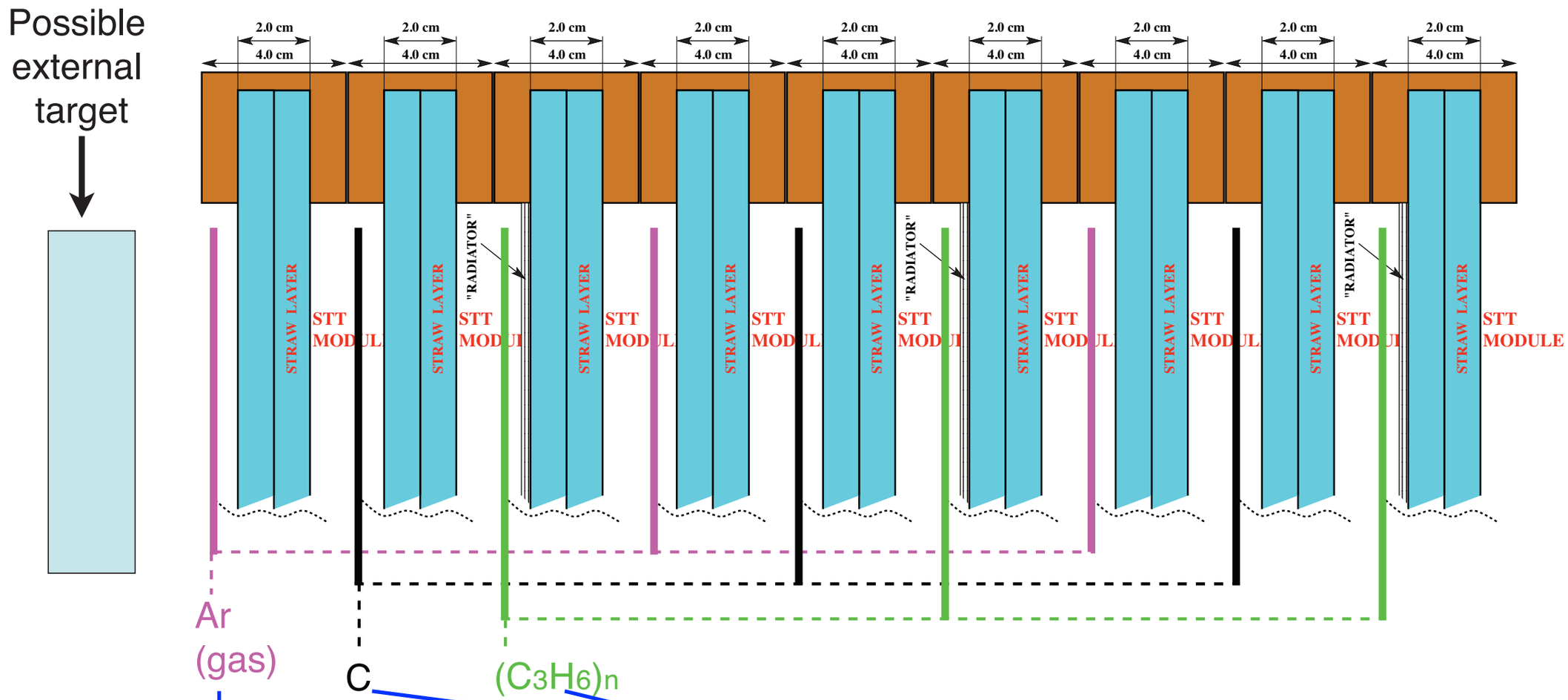


# Fine-Grained Tracker Nuclear Target




- Pressurized Ar gas and solid Ca target provide detailed understanding of the FD A = 40 target

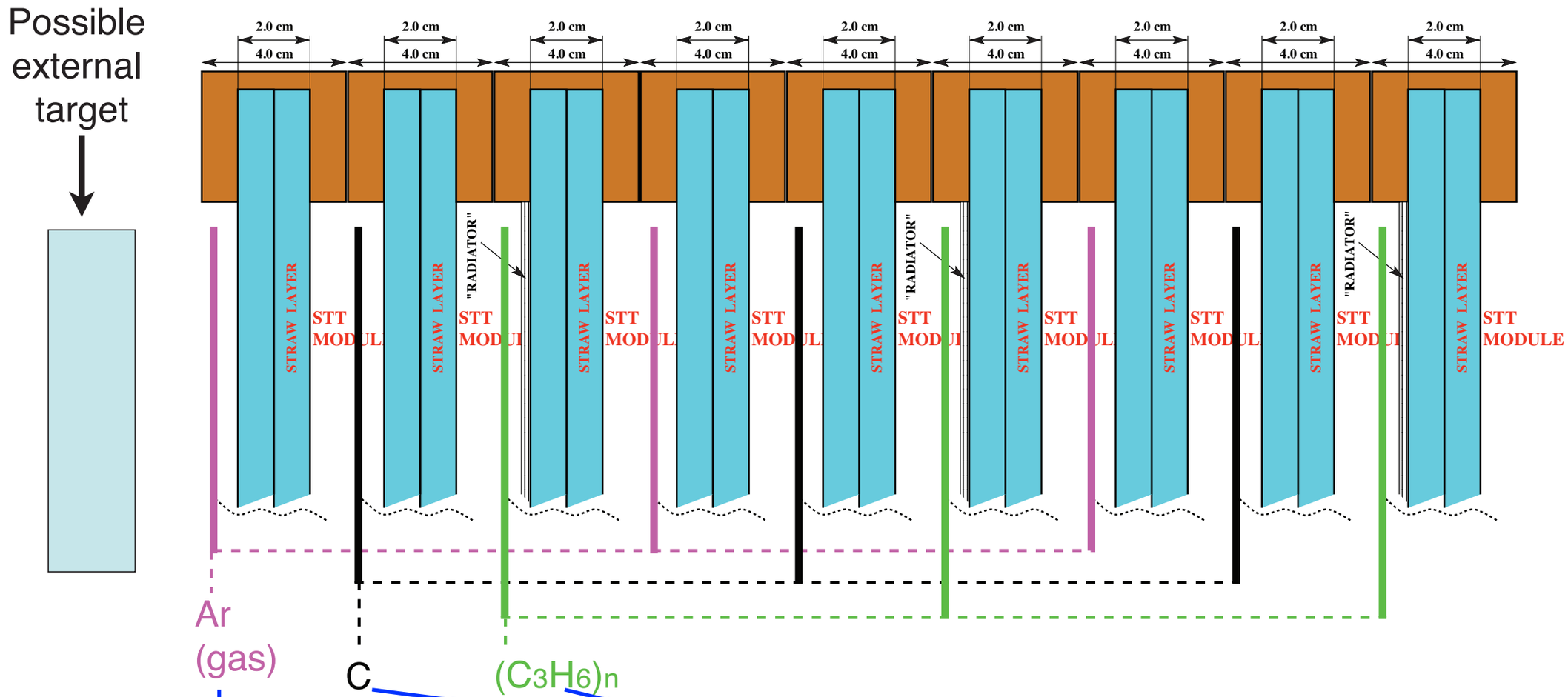
# Fine-Grained Tracker Nuclear Target




Subtraction of C from $(C_3H_6)_n$ provides free proton target

- Pressurized Ar gas and solid Ca target provide detailed understanding of the FD A = 40 target

# Fine-Grained Tracker Nuclear Target

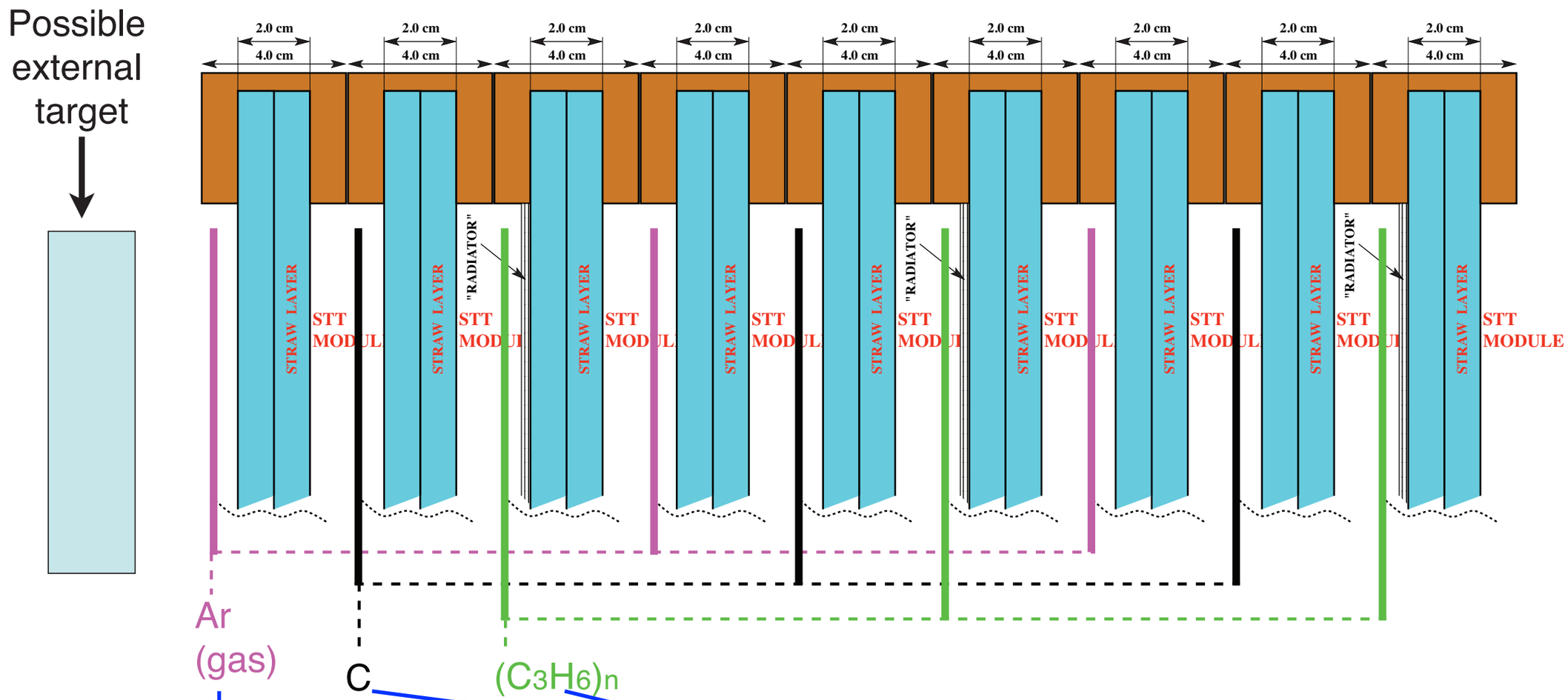



Subtraction of C from $(C_3H_6)_n$ provides free proton target

- Pressurized Ar gas and solid Ca target provide detailed understanding of the FD A = 40 target

Additional nuclear target to understand nuclear models

# Fine-Grained Tracker Nuclear Target




Subtraction of C from $(C_3H_6)_n$ provides free proton target

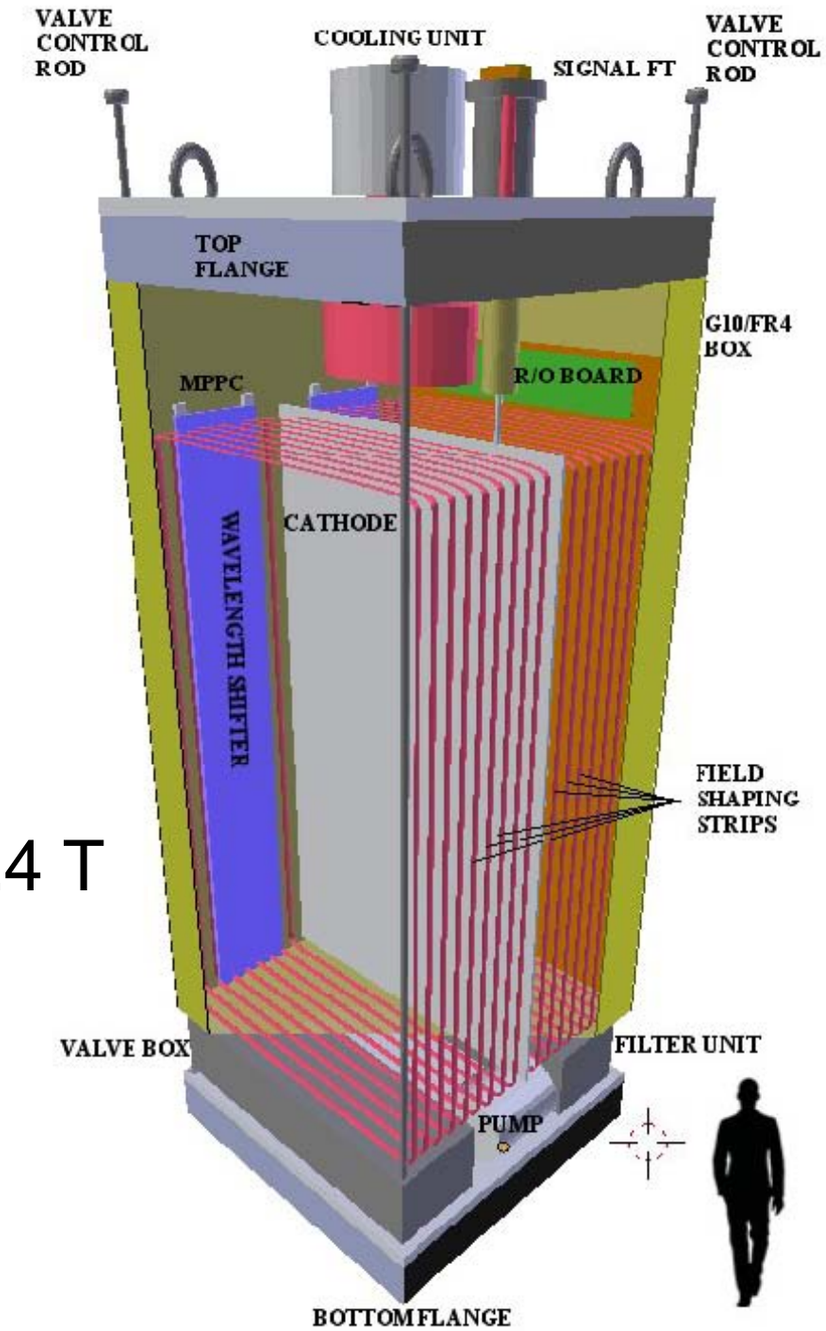
- Pressurized Ar gas and solid Ca target provide detailed understanding of the FD A = 40 target

Additional nuclear target to understand nuclear models

Separation from excellent vertex (~ 100μm) and angular (< 2 mrad) resolution

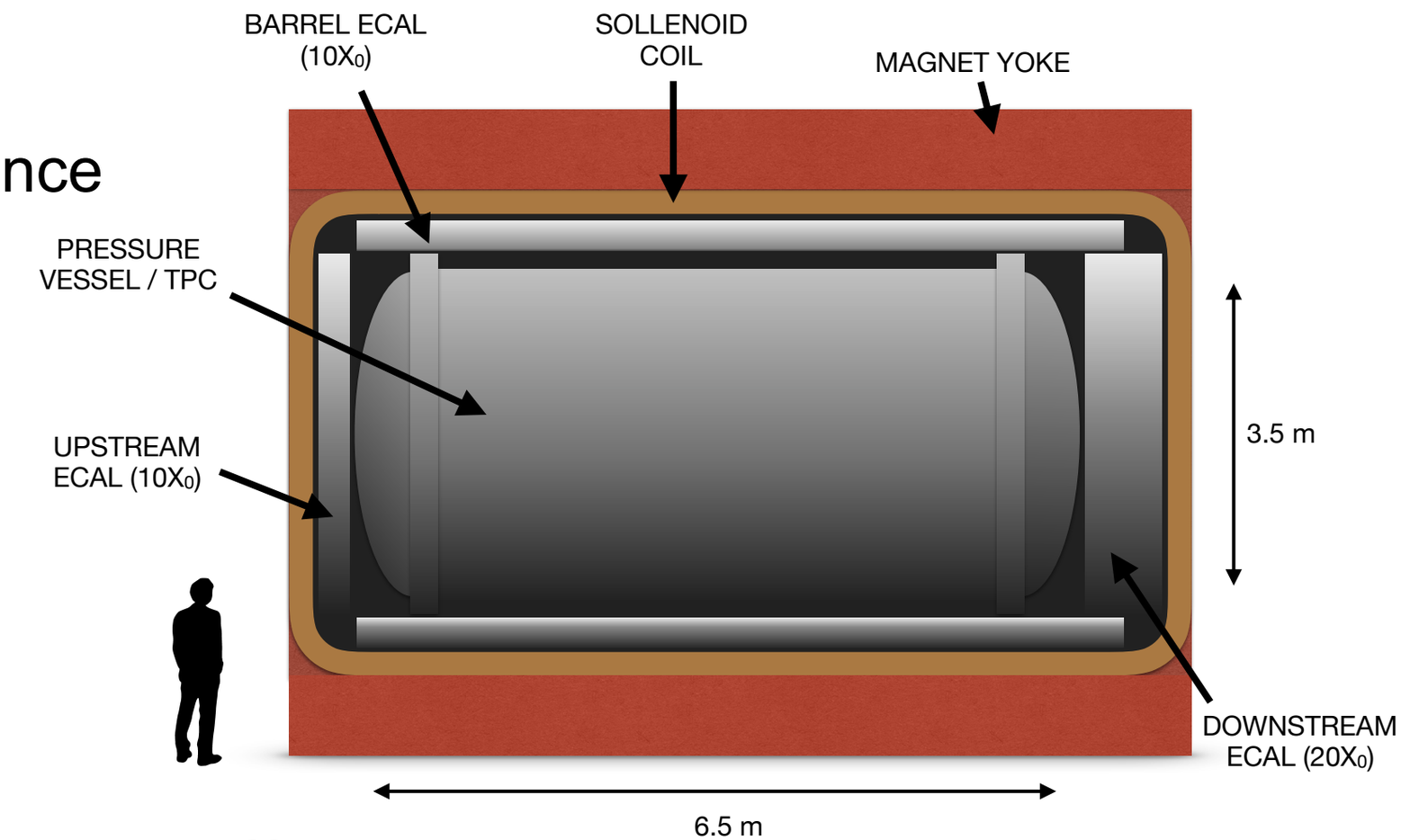
# LArTPC ArgonCube

- Similar LAr TPC as the DUNE FD, same target.
- Novel implementation of LAR TPC technology
  - Modularity and scalability
  - Pixelized charge readout: high rate capability.
  - Can be magnetized : compatible with 0.4 T field



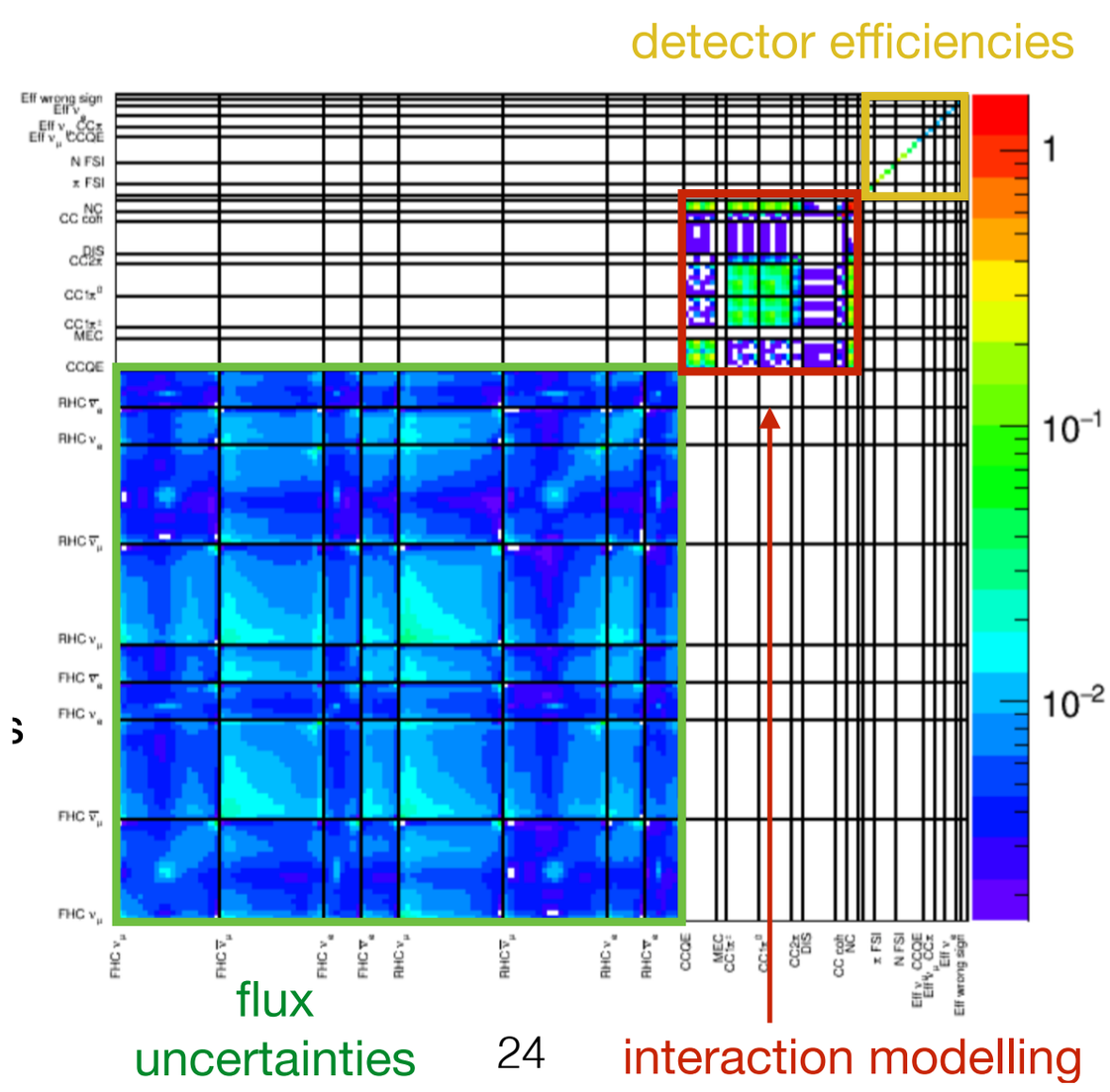
# High Pressure Ar Gas TPC

- HP Ar Gas: Same target as FD, low density, low thresholds.
- A dipole magnet of 0.4 T.
- A central large time projection chamber with about 1 tonne of argon pressurized at 10 bar.
- A pressure vessel that houses the TPC.
- An electromagnetic sampling calorimeter made of layers of lead and plastic scintillator.
- Good tracking performance and resolution



# Status

- A ND optimization task force formed.
- **GEANT4 simulation** of all 3 detector options complete.
- **Reconstruction** work in progress.
- Need detector uncertainties.
- The **VALOR** framework is used to study ND constraints on oscillation analysis.



# Near Detector Roles

- Constrain the systematics for oscillation measurement.
  - Measure spectra of all four species of neutrinos: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$
  - Measure the absolute and relative flux: FD/ND($E\nu$)
  - Constrain & Model nuclear effects: $\nu/\bar{\nu}$-Ar
  - Quantify differences between neutrino and antineutrino: energy scale, event topology, cross-section, etc.
  - Constrain Background: $\pi^0/\pi^+/\pi^-$/etc.

- Precision measurement for neutrino interaction:

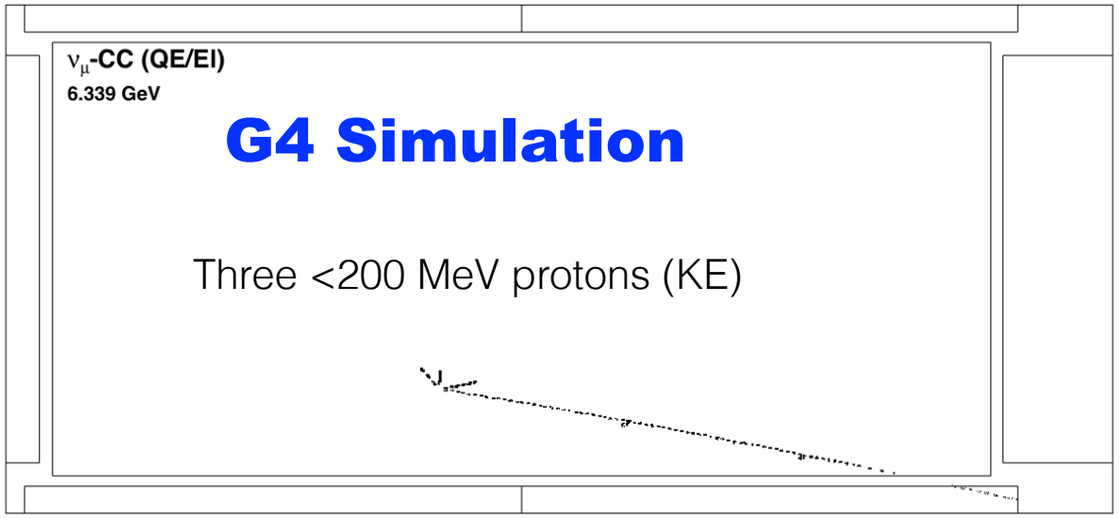
**In the following slides I am going to take FGT the reference design as an example to show the ND constraint on oscillation systematics and cross-section measurement.**

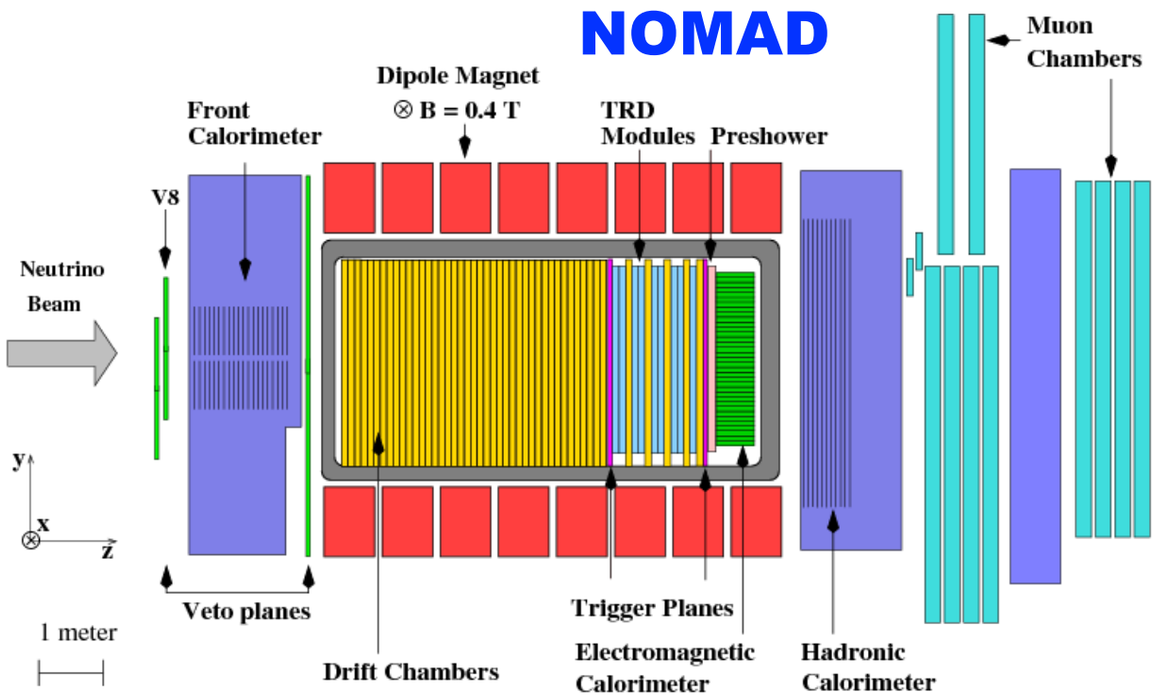
candidates, etc.

# FGT Study Strategy

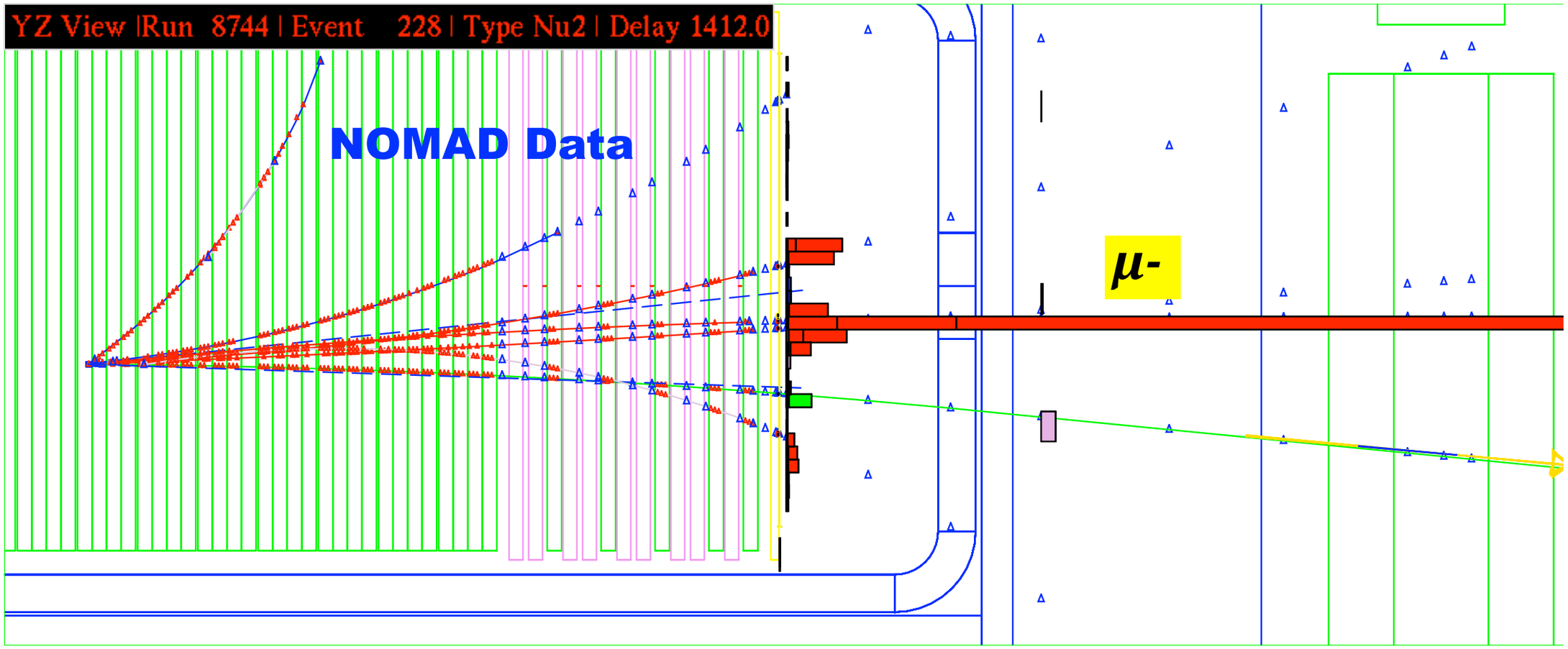
G4LBNE → GENIE → Detector response → Root Output

- **Fast MC** to do quick study of detector performance.
- Full **GEANT4 simulation** complete.
  - Based upon ART framework.
  - Working on reconstruction.
- **NOMAD data** to benchmark the ideas.
  - FGT concept is built upon the NOMAD detector, with better resolution, granularity, 4π Ecal & μID coverage & ~x100 higher statistics.



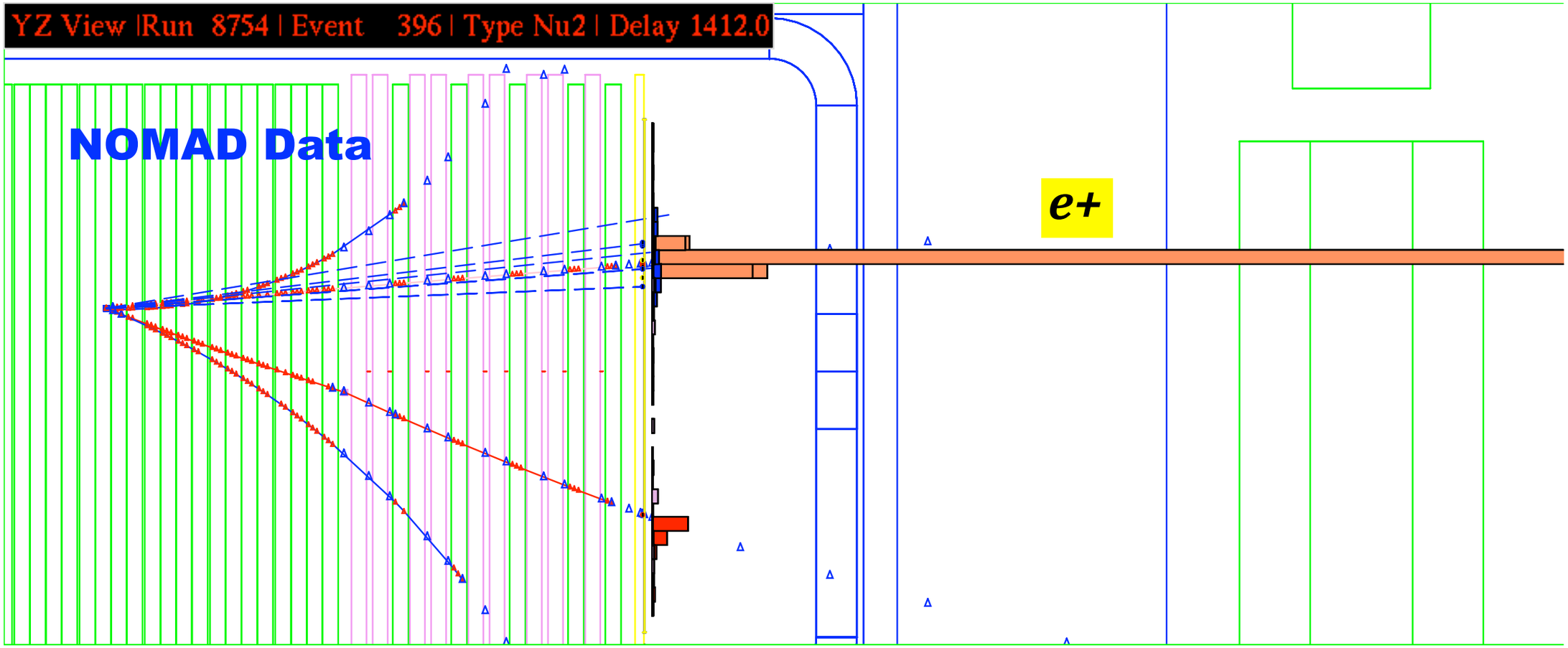



# $\nu_\mu$-CC Candidate




- Hadrons are tracks.
- Muon is kinematically separated from hadron vectors.

# $\nu_e$-CC Candidate

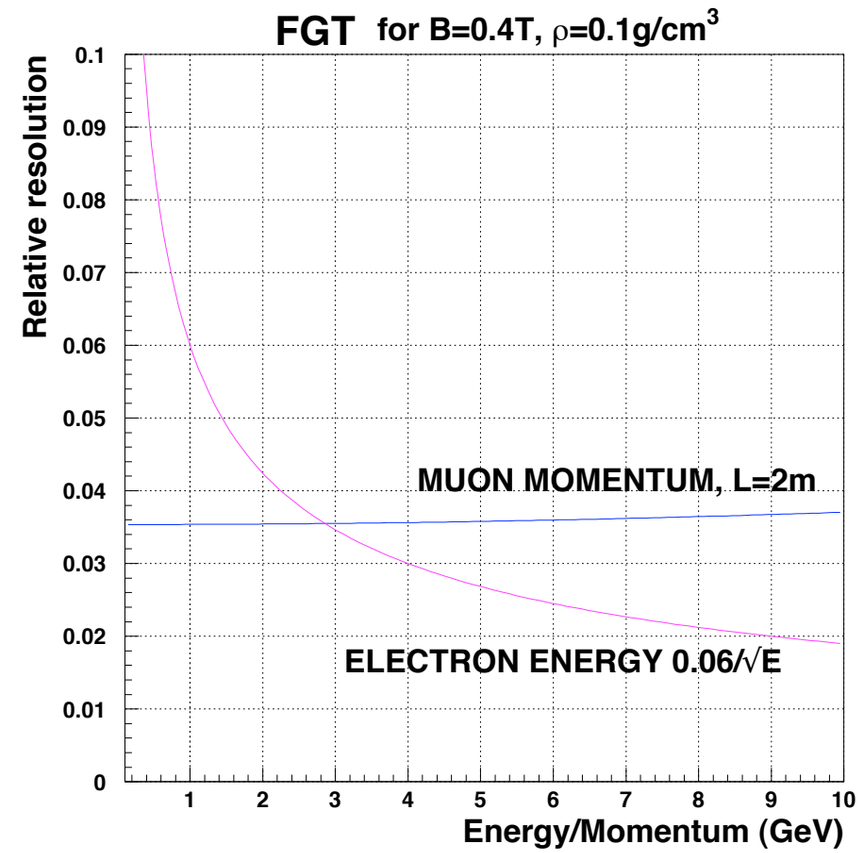



- Electrons are also tracks in FGT: high precision measurement:
  - Universality equivalence with muon from $\nu_\mu$.
- Dipole magnetic field allows distinguish e+ from e-:
  - Measure $\bar{\nu}_e$ content of the beam.

# e+/e- Measurement

## Electron Momentum:

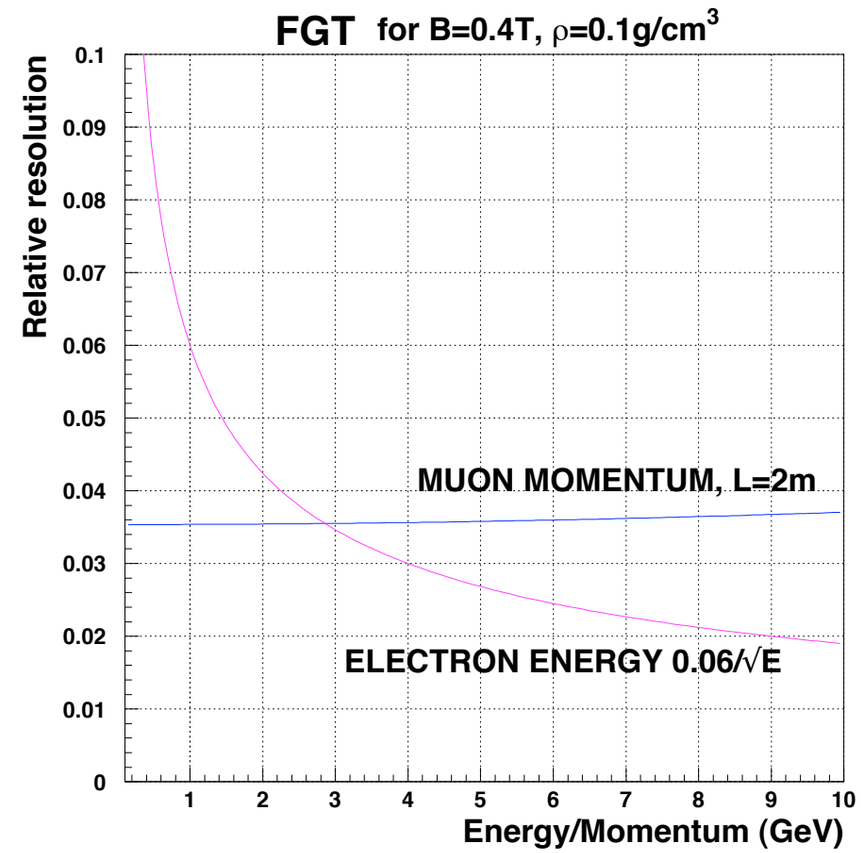
- **Curvature** in B field for momentum and charge (+/-) measurement.
- Track fit extrapolate to the vertex for direction measurement.
- **ECAL** for more precise energy measurement
- Momentum resolution **~ 3.5% (at ~3 GeV)**, from STT curvature + ECAL.

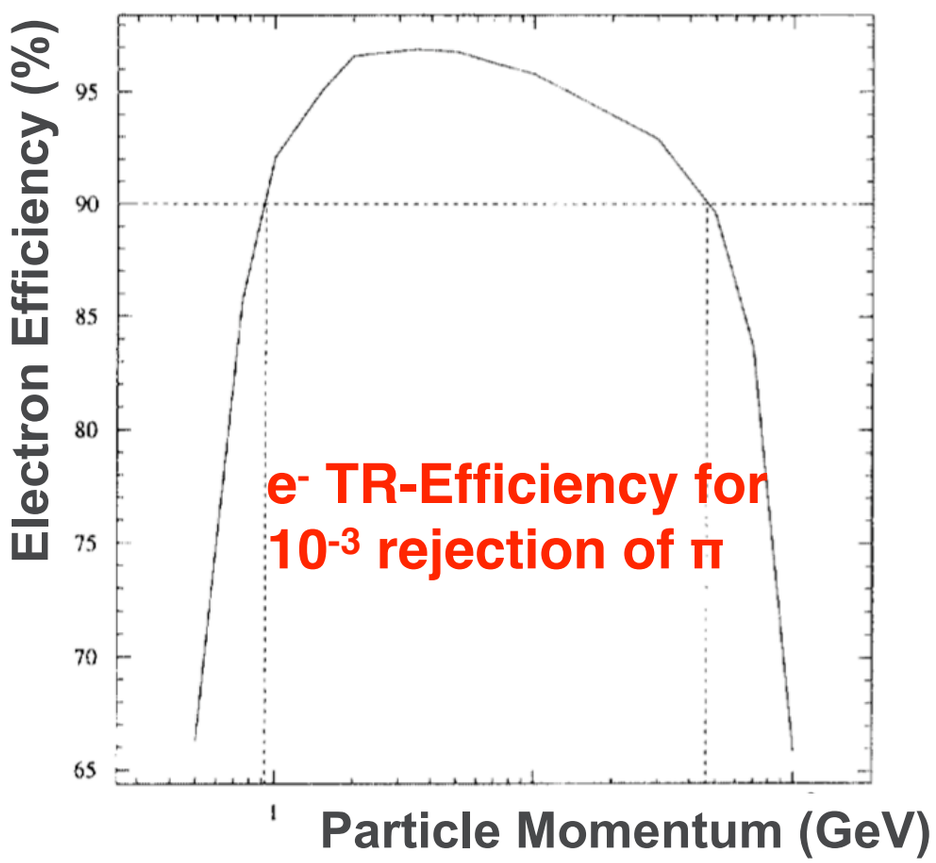


# e+/e- Measurement

## Electron Momentum:

- **Curvature** in B field for momentum and charge (+/-) measurement.
- Track fit extrapolate to the vertex for direction measurement.
- **ECAL** for more precise energy measurement
- Momentum resolution **~ 3.5% (at ~3 GeV)**, from STT curvature + ECAL.



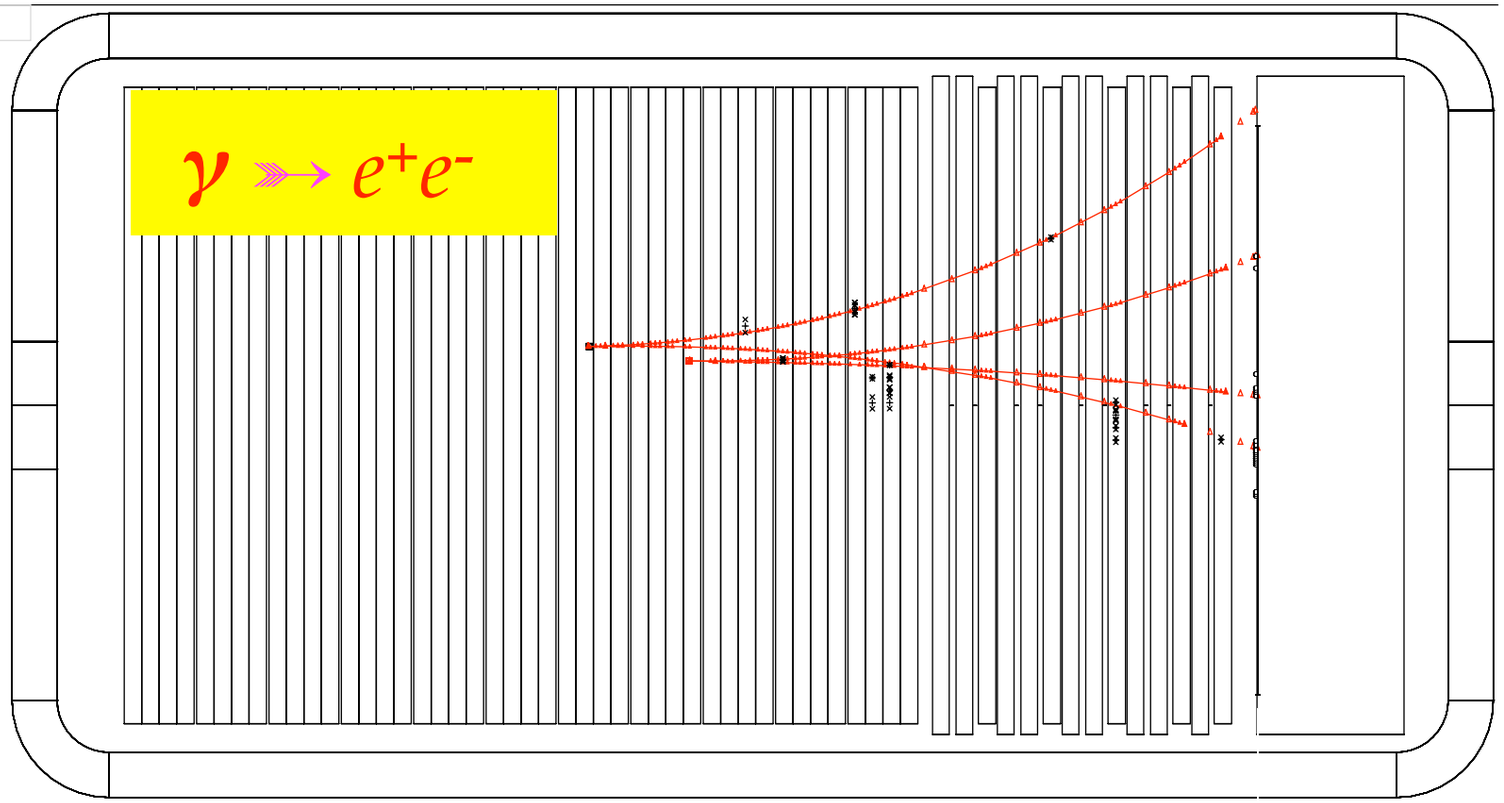



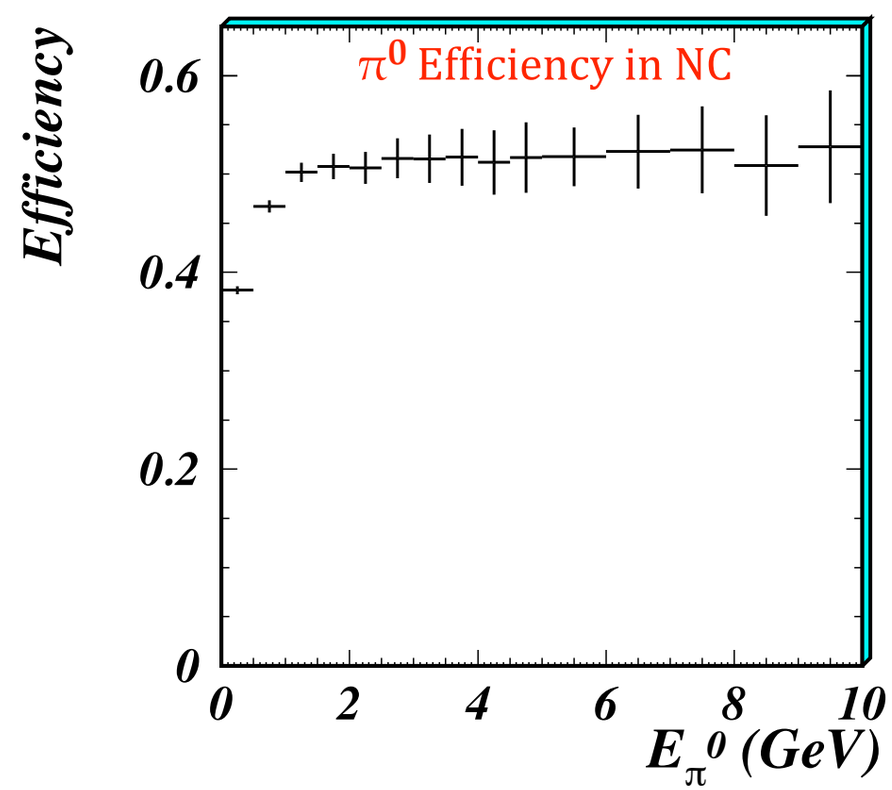

## Electron ID:

- **Transition radiation (TR)** measurement in STT
- **Energy deposition pattern (dE/dx)** in the ECAL.

# $\pi^0$ Reconstruction

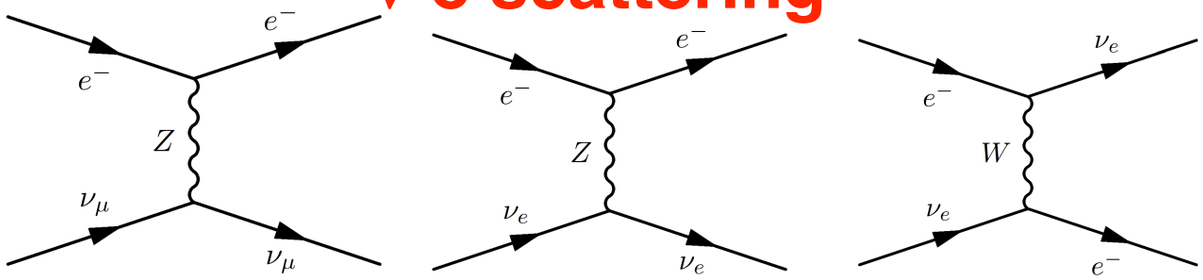
- $\pi^0$s are background to $\nu_e/\bar{\nu}_e$ appearance.
- FGT sees clean $\pi^0$ signatures:
  - 50% of the $\gamma$ convert in STT, away from the primary vertex.
- We can also use electrons $\gamma$-conversion to calibrate the electron measurement and identification.



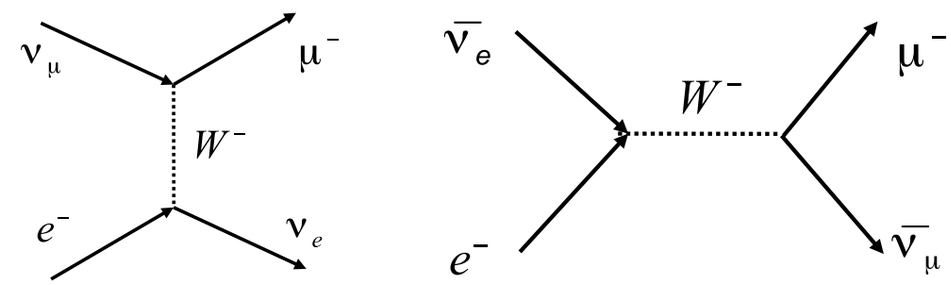



# Absolute Flux Measurement

**ν-e scattering**

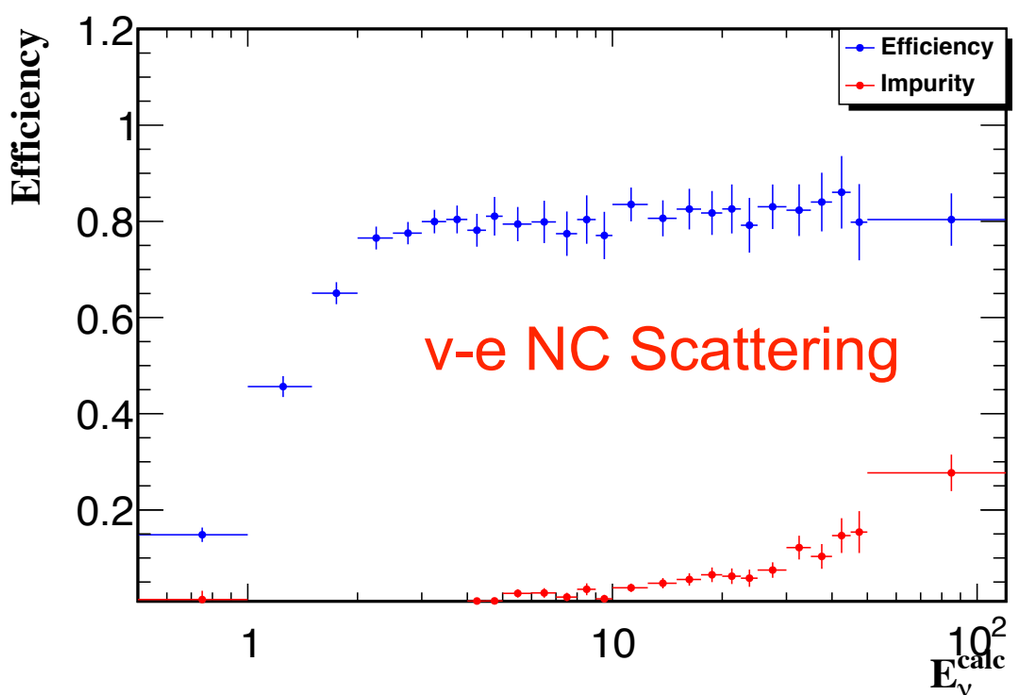


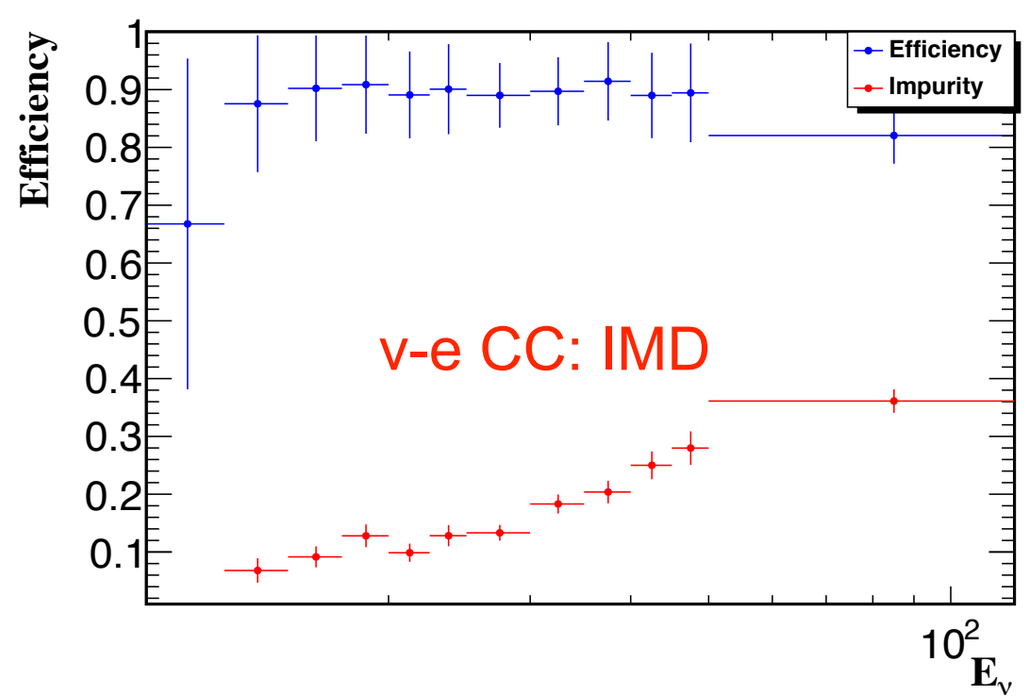

**IMD**




**Pure leptonic processes: small but very well known cross-sections.**

- Assuming 1.2 MW beam power, 5 tons ND fiducial mass, 5 years neutrino running we expect:
  - **~7.8k** $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$: **~2%** precision in 2.5~10 GeV.
  - **~4k** $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$: **~2.5%** precision in 11~50 GeV.



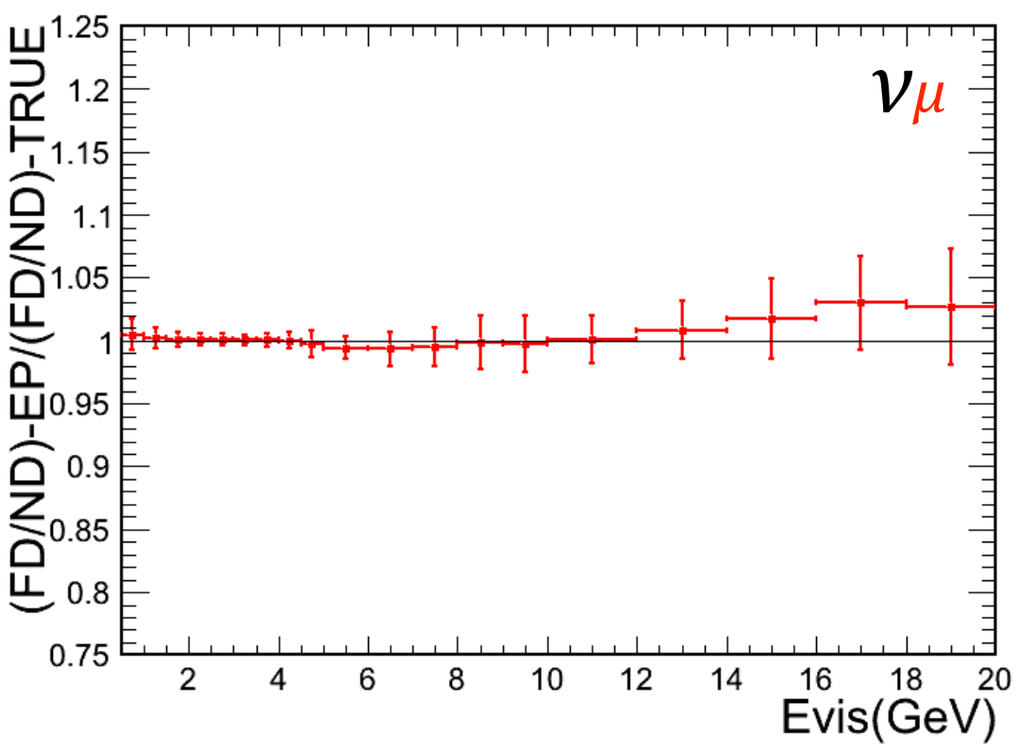



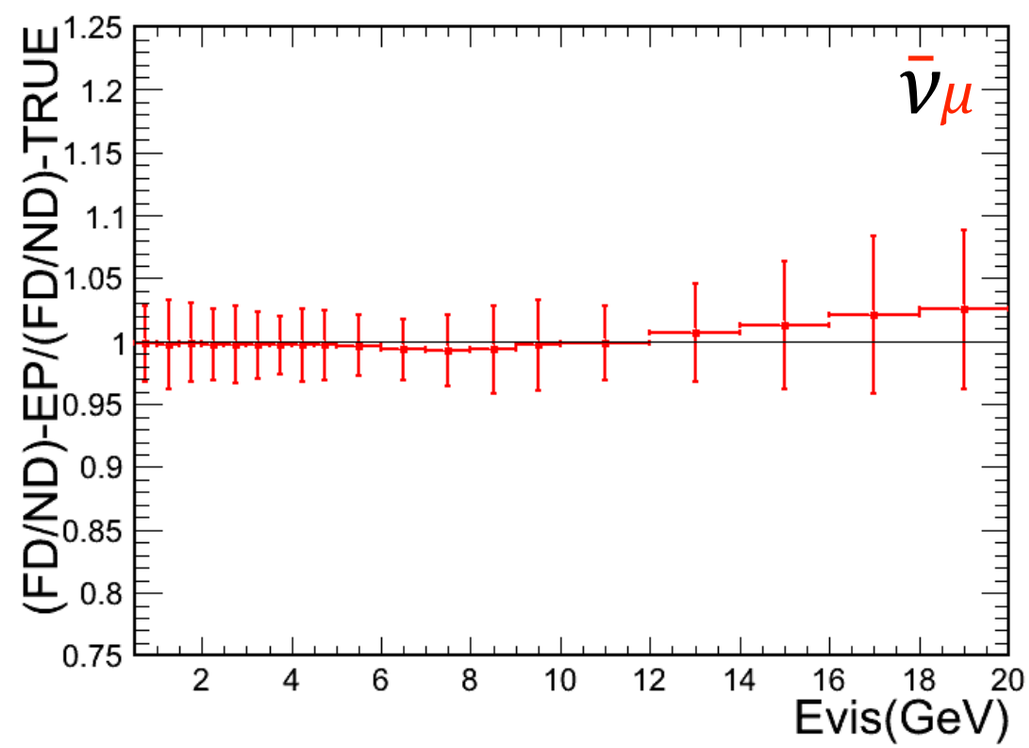
# Relative Flux Measurement

- **Low-ν method**: at low ν, the number of events in a given energy bin is proportional to the neutrino flux.

$$N(E)_{\nu<1} = k\Phi(E)f_c(\frac{\nu}{E_\nu})$$

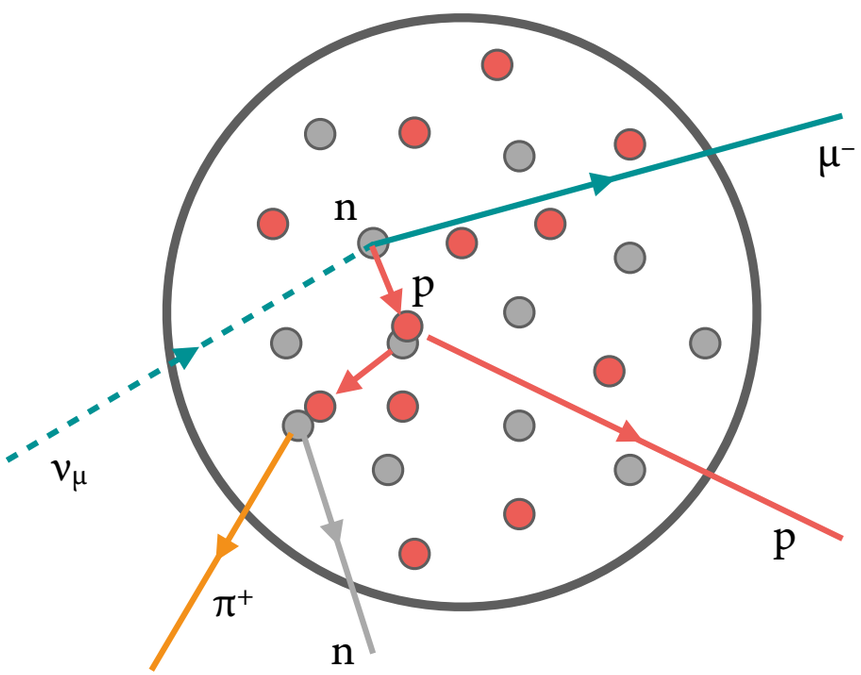
- Dominant uncertainty is muon energy scale and resolution.
- Use ND low-ν data to constrain beam hadron productions.
- Expect an FD/ND ratio at **1~2%** precision in 0.5~50 GeV

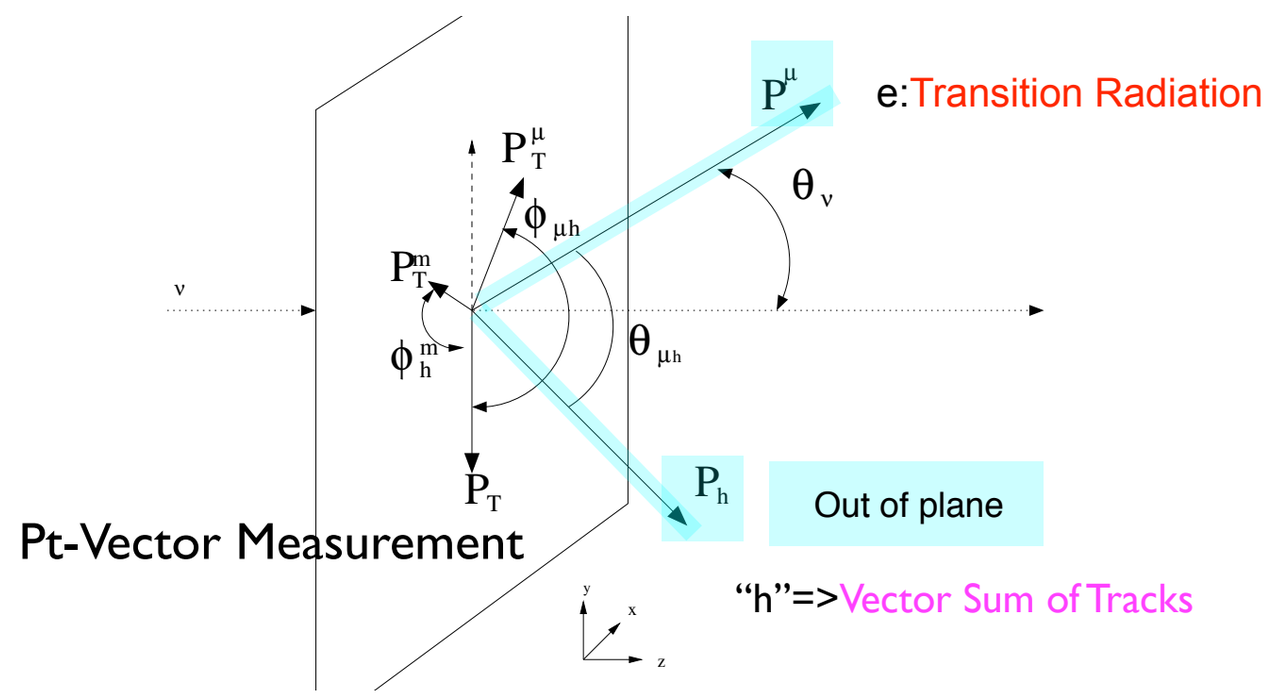


# Nuclear Effect on Energy Scale

- Neutrino energy scale are sensitive to nuclear effect, which can be different between neutrino and antineutrino.
- FGT measures both lepton and hadron momentums: calculate **missing $p_T$** to constrain nuclear effect.
- **Coherent-$\pi$** topology is identical between neutrino and antineutrino, with little nuclear effect.
- Additional constraint from **QE** and **Resonance** interactions.



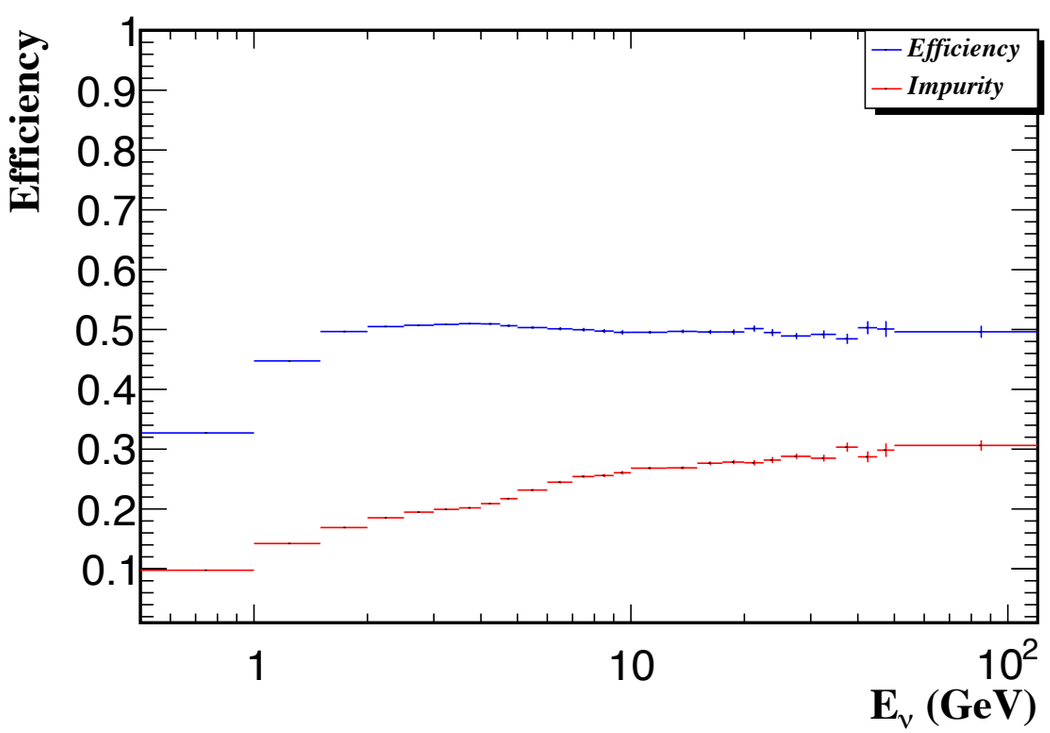

Missing-PT vector helps constrain the $E_\nu$-scale for CC

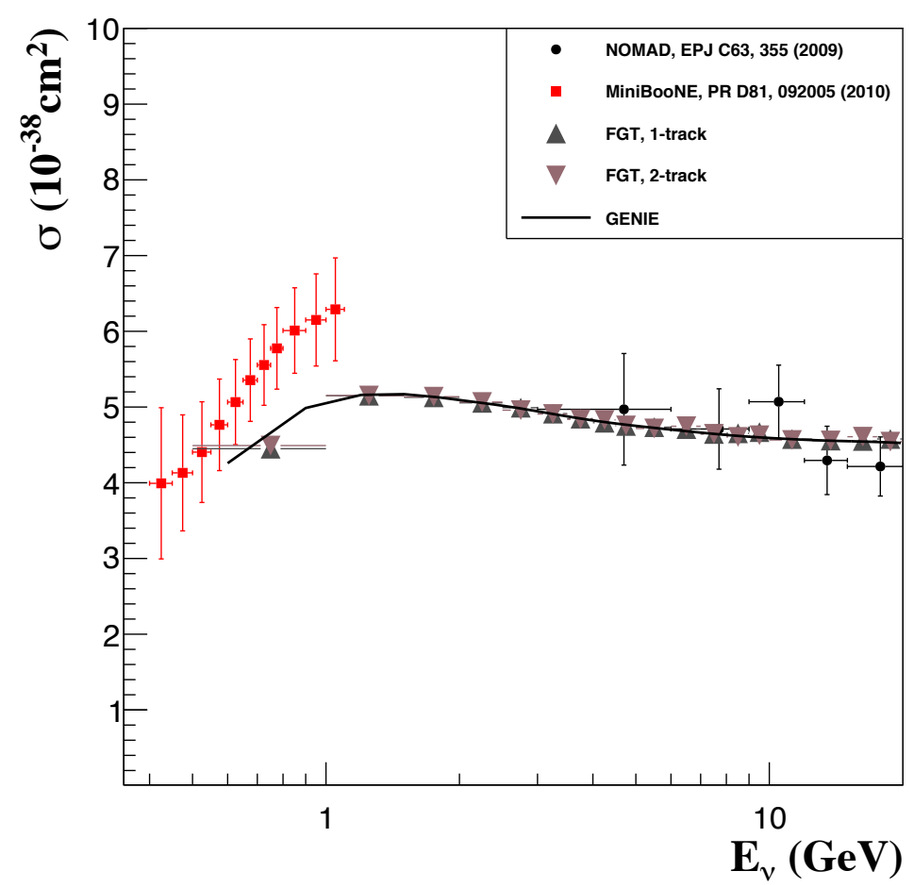
# Quasi-Elastic

- QE is an important channel in DUNE oscillation measurement.
  - 2-track or 1-track topology.
- Constrain nuclear effect by comparing $E_\nu$ calculated from muon momentum with total visible energy.

$$E_\nu^{\text{calc}} = \frac{2(M_n - E_B)E_\mu - (E_B^2 - 2M_nE_B + m_\mu^2 + \delta M^2)}{2[(M_n - E_B) - E_\mu + p_\mu \cos\theta_\mu]}$$

- Sensitivity study using fast MC shows signal **efficiency ~48%, purity ~76%**.



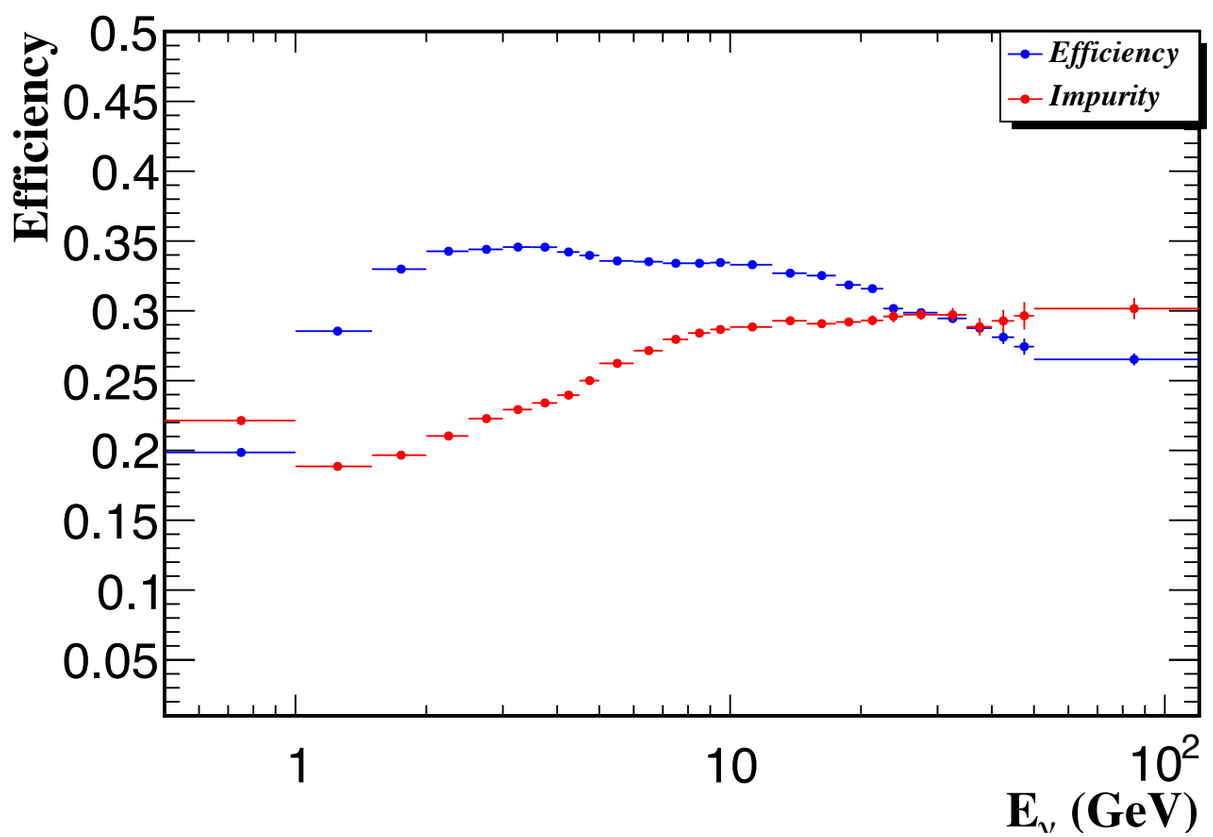



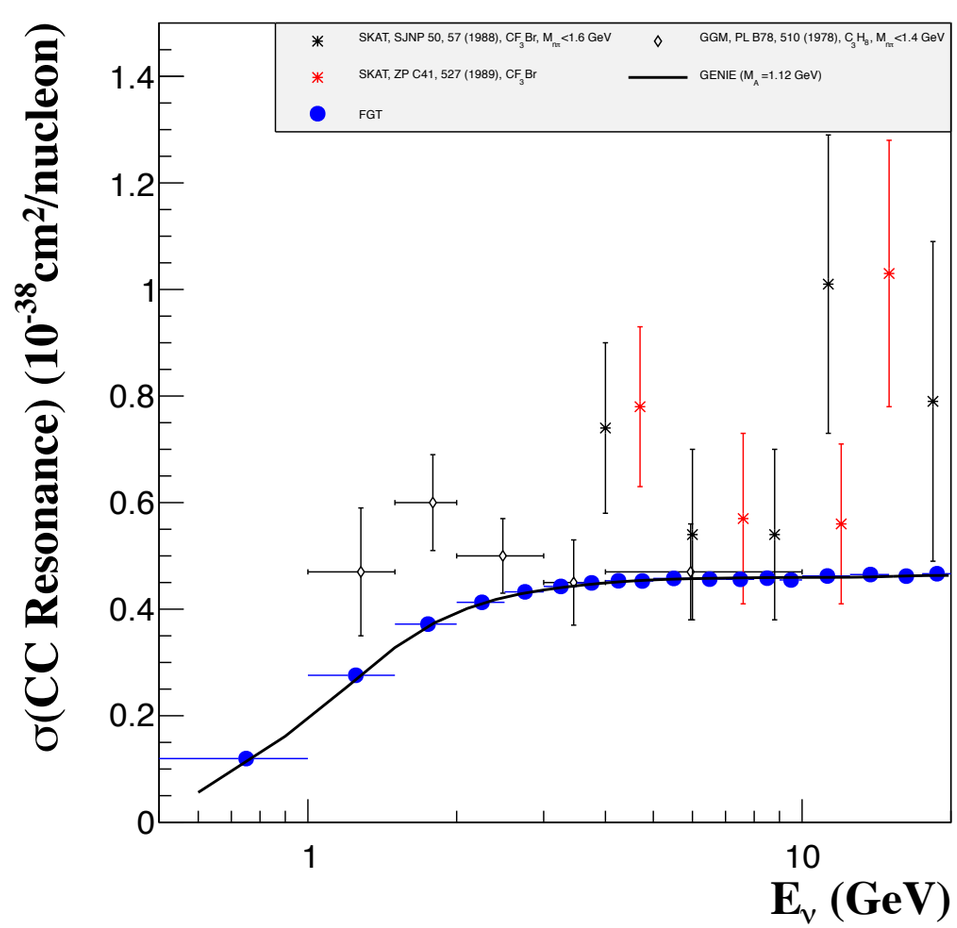
# Resonance

- Resonance will be the most abundant interaction in DUNE detectors.
- Also an independent handle to constrain nuclear effect by $E_\nu$ calculated from muon and pion momentum with total visible energy.

$$E_\nu = \frac{m_\mu^2 + m_\pi^2 - 2M_p(E_\mu + E_\pi) + 2p_\mu \cdot p_\pi}{2(E_\mu + E_\pi - |\mathbf{P}_\mu|\cos\theta_\mu - |\mathbf{P}_\pi|\cos\theta_\pi - M_p)},$$

- Sensitivity study using fast MC shows signal **efficiency ~33%, purity ~77%**.



# Precision Measurements

- The DUNE Near Detector complex offers a generational advance in neutrino precision measurement program.

- Key ingredients are:
  - Very high resolution detectors capable of measuring absolute flux and quantifying nuclear effects,
  - High statistics.

- Examples:
  - Measurement of Adler sum-rule
  - Weak mixing angle in $\nu$-e and $\nu$-Quark scattering
  - Differential cross-section measurements of exclusive & inclusive processes with ~O*(3%)* precision
  - Isospin physics

# Search for New Physics

- The ability to identify/reconstruct :
  - (1) Leptons $e^+$, $e^-$, $\mu^+$, $\mu^-$ with high resolution
  - (2) Hadrons $\pi^0$, $\pi^-$, $\pi^+$, p, $K^0s$, $\Lambda$, etc. with high eff/purity
- Examples include search for :
  - High $\Delta m^2$ o(>0.5 $eV^2$) oscillation
  - Neutral heavy leptons
  - light dark-matter particles
- Rich physics with overall >100 topics

# Summary

- A capable near detector is crucial to DUNE to reach its scientific goal of determine mass hierarchy and CP-violation
- 3 ND options under study:
  - Fine-Grained Tracker (reference design)
  - Liquid Argon TPC, e.g. ArgonCube
  - High-Pressure Ar Gas TPC
- Clear plan of using ND to constrain systematic uncertainties for oscillation measurement:
  - Determine all four species of neutrino source: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e,$
  - Measure absolute and relative flux.
  - Measure backgrounds
  - Constrain nuclear effect.
  - A lot of work in progress.
- The near detector also has rich neutrino interaction physics and other physics topics by itself.

# Back Up Slides

# Relative Flux Measurement: Low-nu Method

S.R.Mishra, World Sci (1990):
Cross-section of hadron production using structure functions ($2xF_1$, $F_2$, $xF_3$):

$$\frac{d\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 ME}{\pi} \times \left[ \left(1 - y - \frac{Mxy}{2E}\right) F_2^{\nu(\bar{\nu})} + \frac{y^2}{2} 2xF_1^{\nu(\bar{\nu})} \pm y \left(1 - \frac{y}{2}\right) xF_3^{\nu(\bar{\nu})} \right]$$

Integrating over x:

$$\frac{d\sigma}{d\nu} = A \left(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}\right)$$

$$\begin{aligned} A &= \frac{G_F^2 M}{\pi} \int F_2(x) dx \\ B &= -\frac{G_F^2 M}{\pi} \int (F_2(x) \mp xF_3(x)) \\ C &= B - \frac{G_F^2 M}{\pi} \int F_2(x) R_{TERM} dx \end{aligned}$$

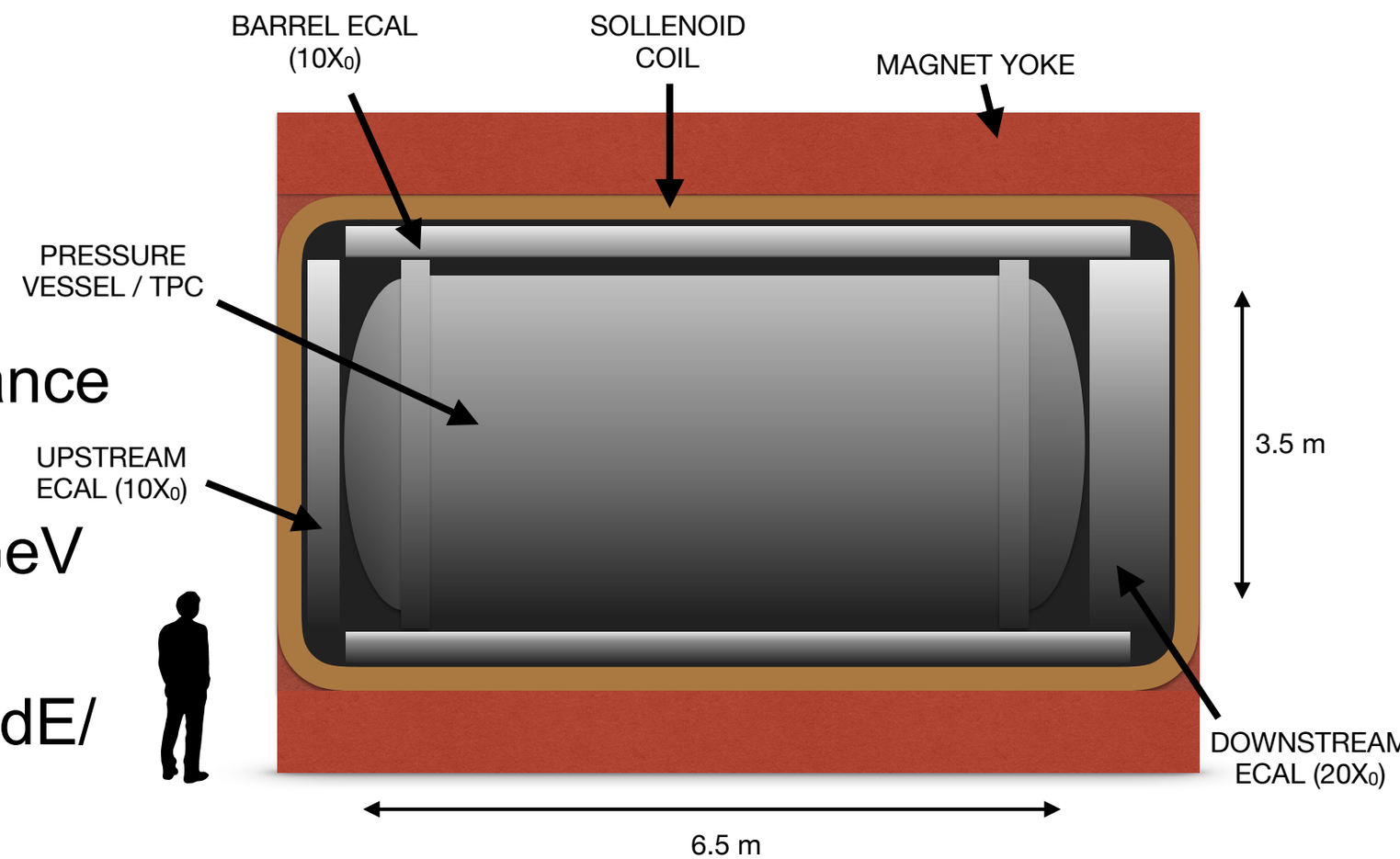
$$N(E)_{(\nu \leq 1)} = \Phi(E) \cdot A \int_0^1 \left(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}\right) d\nu$$

At low-$\nu$, the number of events in a given energy bin is proportional to the neutrino flux: $N(E)_{\nu<1} = k\Phi(E) f_c(\frac{\nu}{E_\nu})$

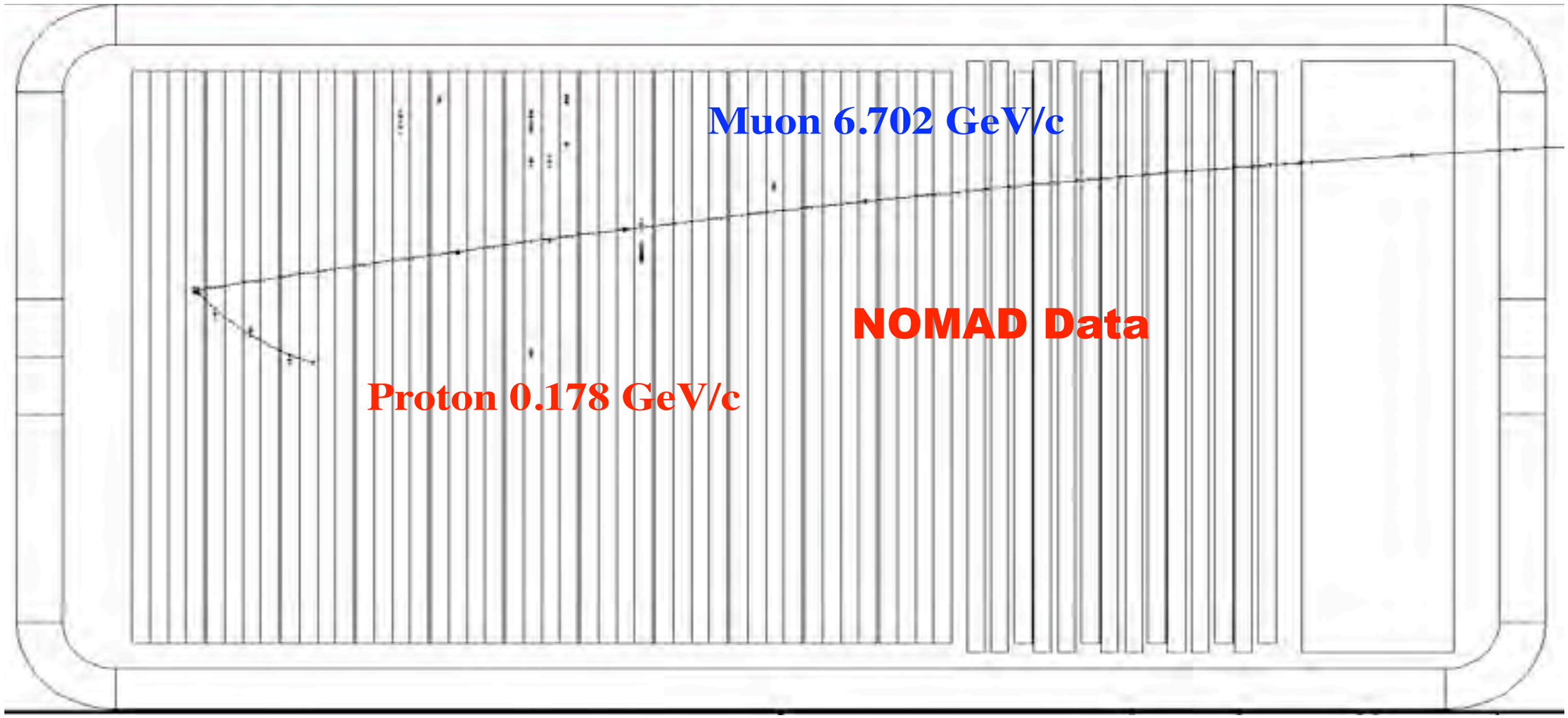
# Alternative Design: High Pressure Ar Gas TPC

- A dipole magnet of 0.4 T.
- A central large time projection chamber with about 1 tonne of argon pressurized at 10 bar.
- A pressure vessel that houses the TPC.
- An electromagnetic sampling calorimeter made of layers of lead and plastic scintillator.

- Low energy detection thresholds
- Excellent tracking performance
- high-resolution momentum measurement (<5% for 1 GeV tracks)
- Energy deposition pattern (dE/dx) in the ECAL.

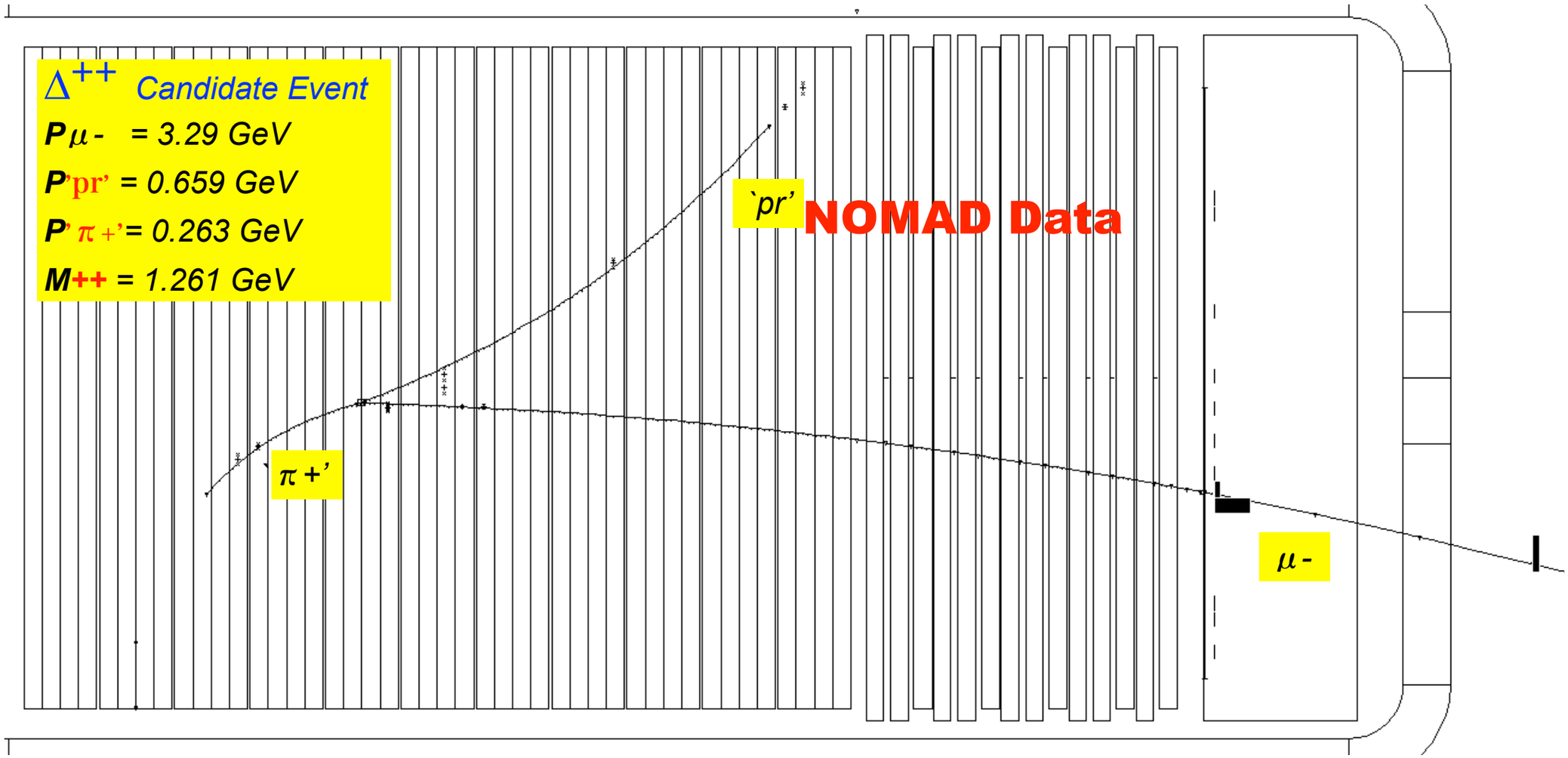


# QE in FGT




FGT will have $\sim \times$ 10 higher granularity vs NOMAD

# Resonance in FGT




FGT will have $\sim \times$ 10 higher granularity vs NOMAD

# Search for New Physics

- The ability to identify/reconstruct :
  - (1) Leptons $e^+$, $e^-$, $\mu^+$, $\mu^-$ with high resolution
  - (2) Hadrons $\pi^0$, $\pi^-$, $\pi^+$, p, $K^0_S$, $\Lambda$, etc. with high eff/purity

⇛ sensitive search for new physics

- Examples include search for :
  - High $\Delta m^2$ o(>0.5 $eV^2$)scillation
  - Neutral heavy leptons
  - light dark-matter particles
- Rich physics with overall >100 topics

# FGT vs NOMAD

**Improvement in resolution, granularity and 4π coverage**

| Sub-Detector | NOMAD | FGT | Improvement |
|---|---|---|---|
| Tracking | | $\times 6$ more hits in X-Y<br>$\times 2$ more hits along Z | $\times 2$ higher QE-Proton Eff.<br>$e^{\pm}$ down to 80 MeV<br>$\gamma$-Conv. Reconstruction |
| TR: Electron-ID | Downstream | Continuous | $\simeq \times 3$ $e^{\pm}$-Eff |
| Calorimetry<br>Segmentation<br><br>E-shower Resolution | Downstream<br>No Longitudinal<br>Transverse<br><br>$3\%/\sqrt{E}$ | $4\pi$ Coverage<br>Fine Longitudinal<br>Finer Transverse<br><br>$6\%/\sqrt{E}$ | Much better converage<br>$e^{\pm}/\pi$ Separation<br>Better miss-$P_T$<br>Powerful 'Dirt'-Veto<br>Poorer resolution |
| $\mu$-ID | Downstream<br>$P_\mu \geq 2.5$ GeV | $4\pi$ Coverage | $P_\mu$ down to 0.3 GeV |
| Trigger | Downstream<br>No Cal.Trigger | Continuous in STT<br>Calorimetric Trigger | $P$ down to 0.1 GeV<br>$E \simeq 0.3$ GeV |

# Status

- A ND optimization task force formed.
- **GEANT4 simulation** of all 3 detector options complete.
- **Reconstruction** work in progress.
- Need detector and beam uncertainties.
- The **VALOR** framework is used to study ND constraints on oscillation analysis.