# LAr acceptance vs. detector size
# How big should the TPC be?

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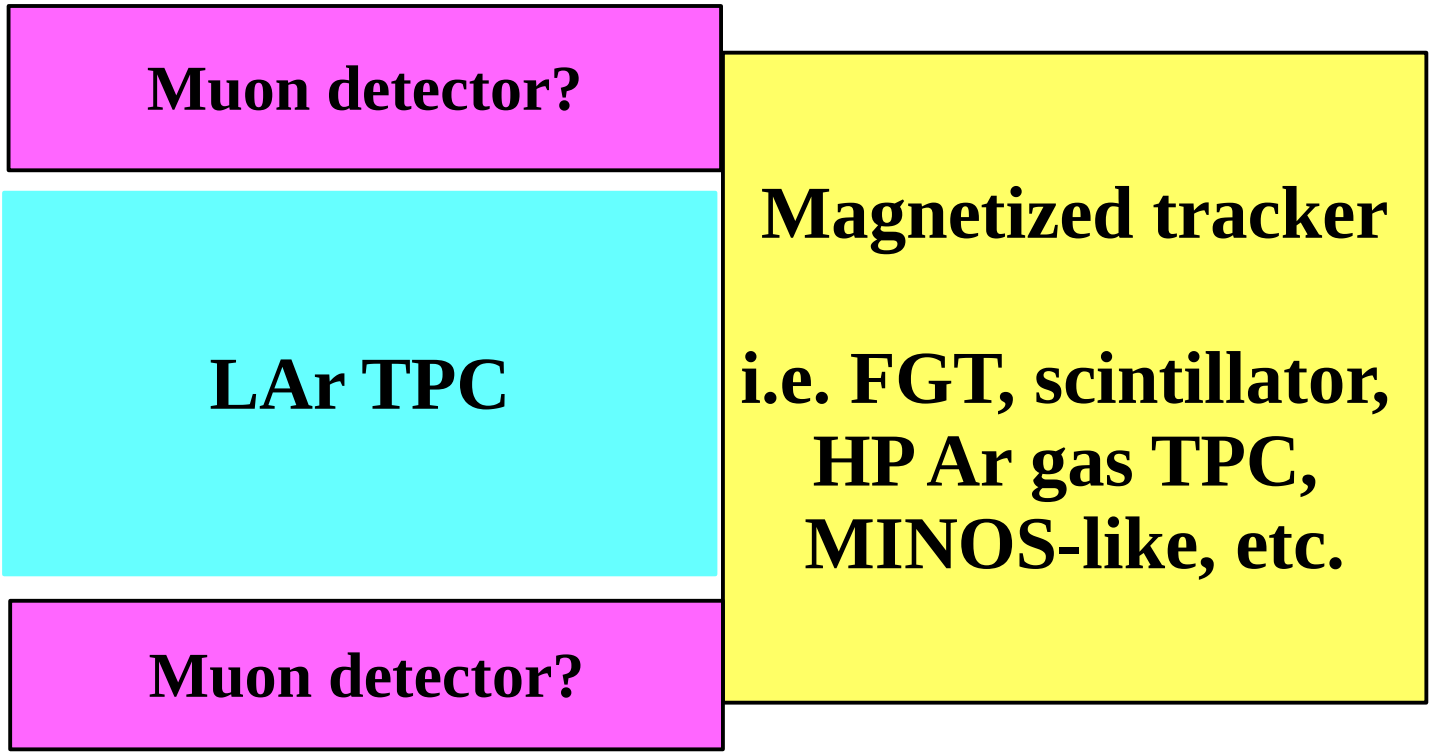
DUNE ND workshop
9 June, 2017

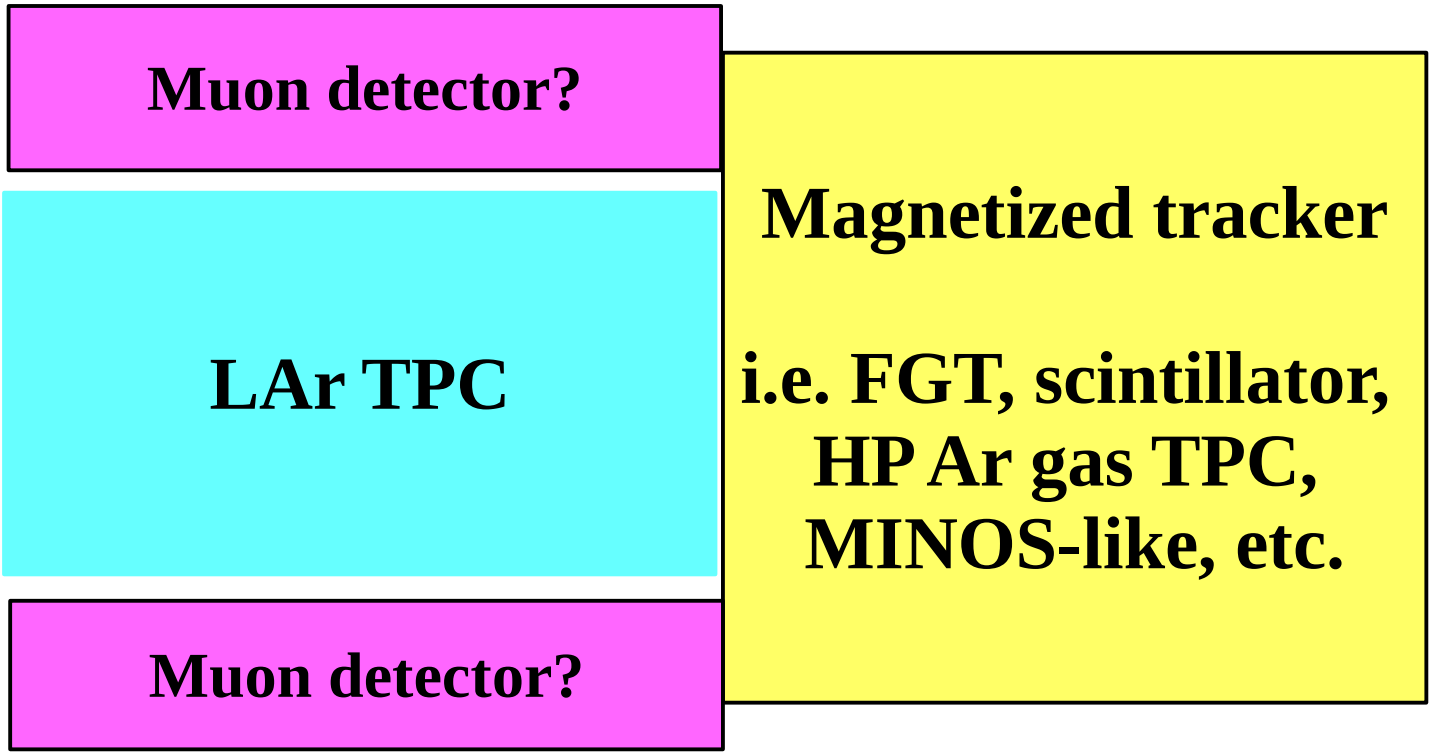

# Hybrid detector




Conclusion from last meeting:

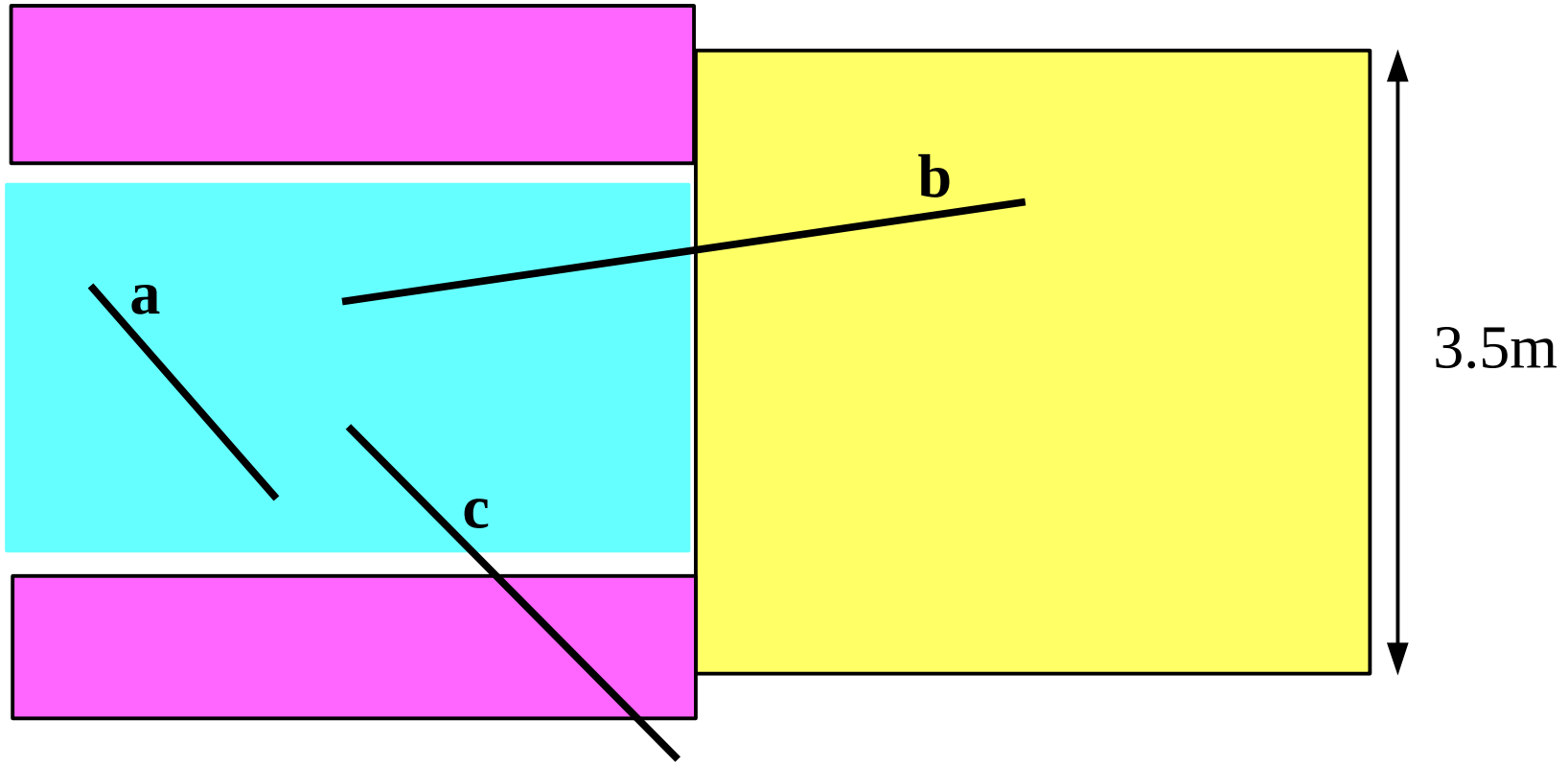
ND will look something like this

# LAr TPC size



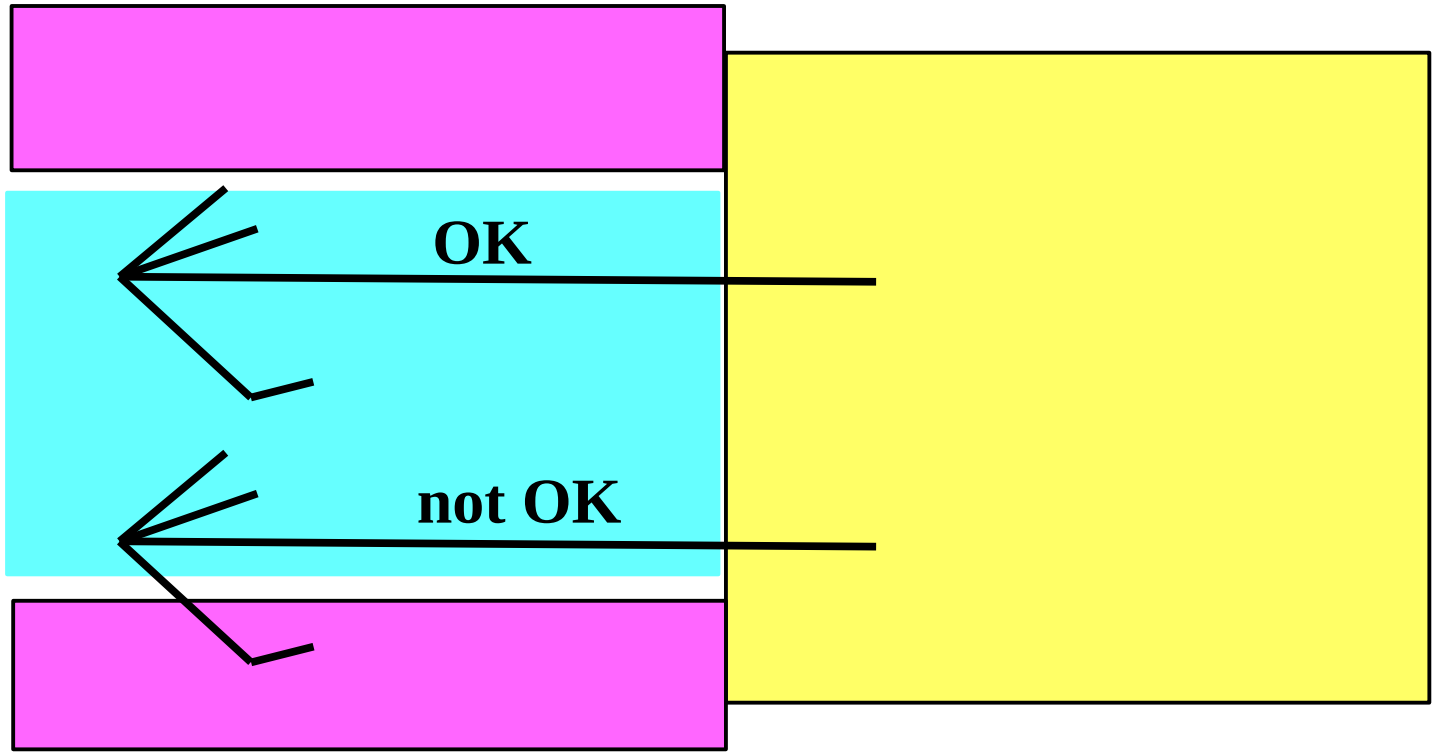

LAr TPC size is driven by containment
Goal: 4π acceptance like FD
What is the size requirement? Are side muon detectors required?

# Define muon acceptance



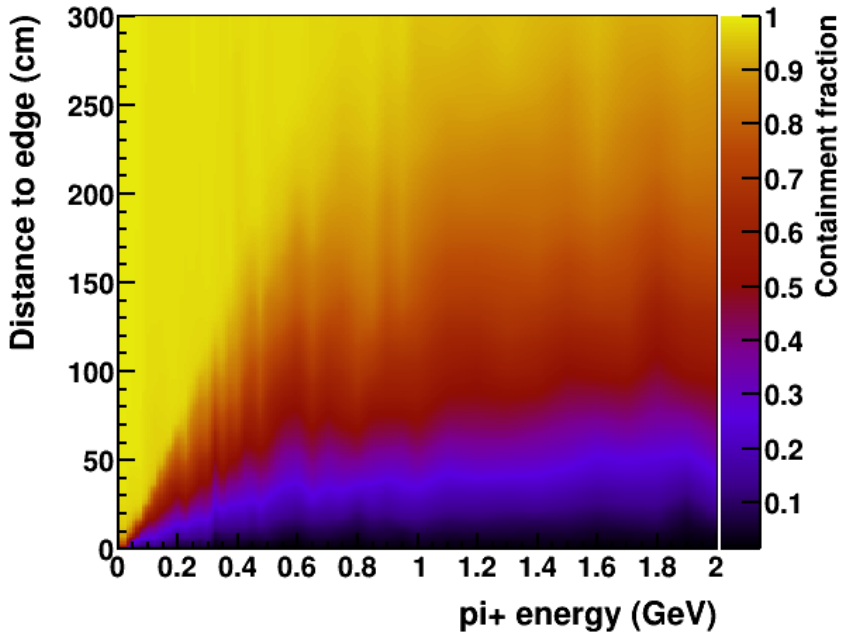

Muon is “accepted” if the muon is a) contained in LAr, b) exits rear of LAr (into magnetized region), or c) exits side of LAr (if muon detectors present)
2.23 MeV/cm assumed, based on G4 simulation

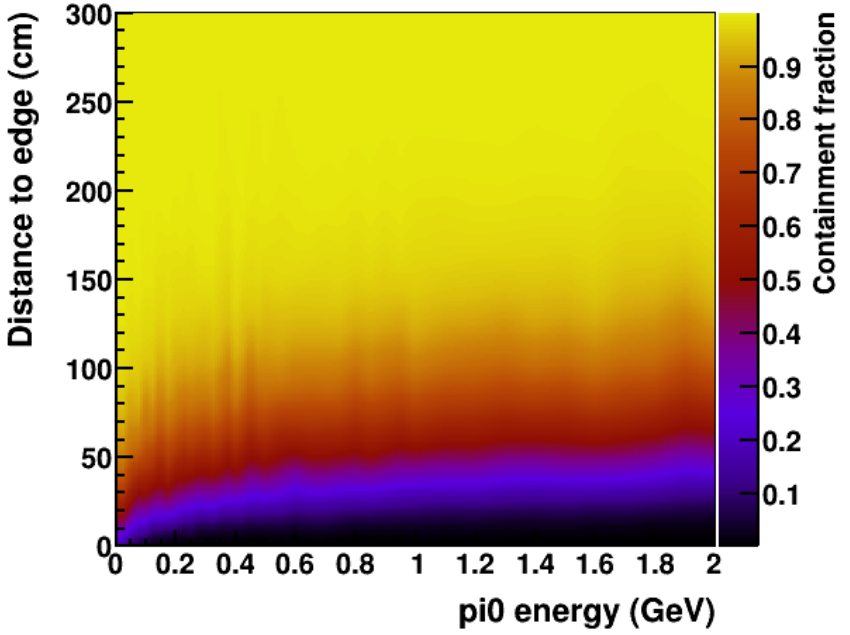
# Define hadron acceptance




Hadron system is “accepted” if 95% of hadronic energy is contained in LAr, **excluding neutrons**

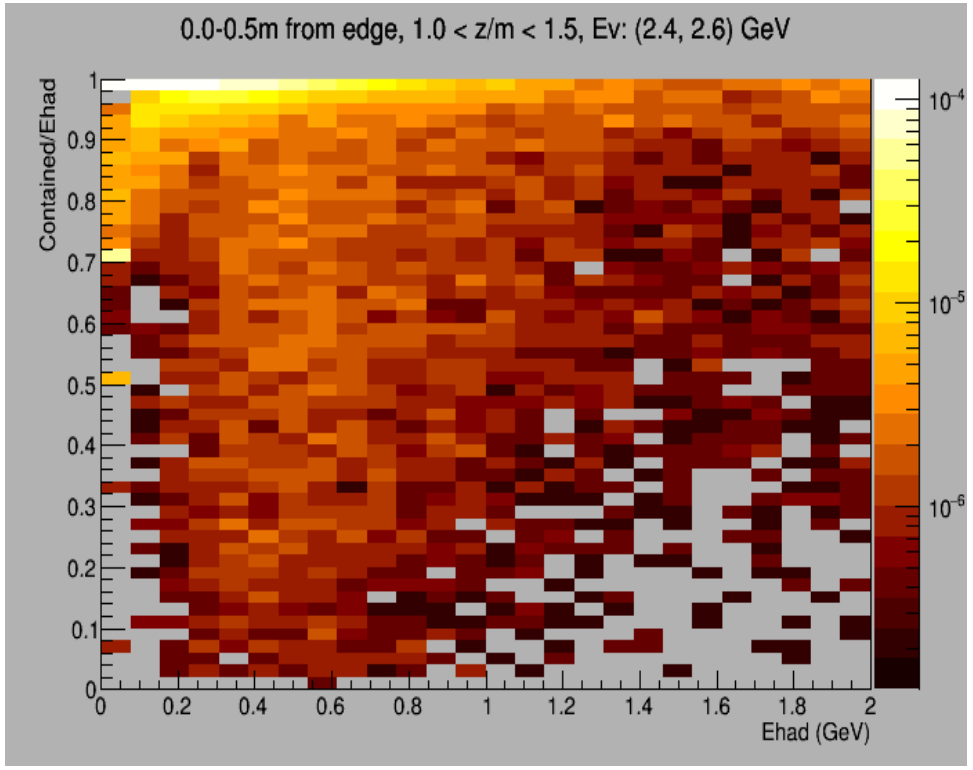
# Hadron simulation

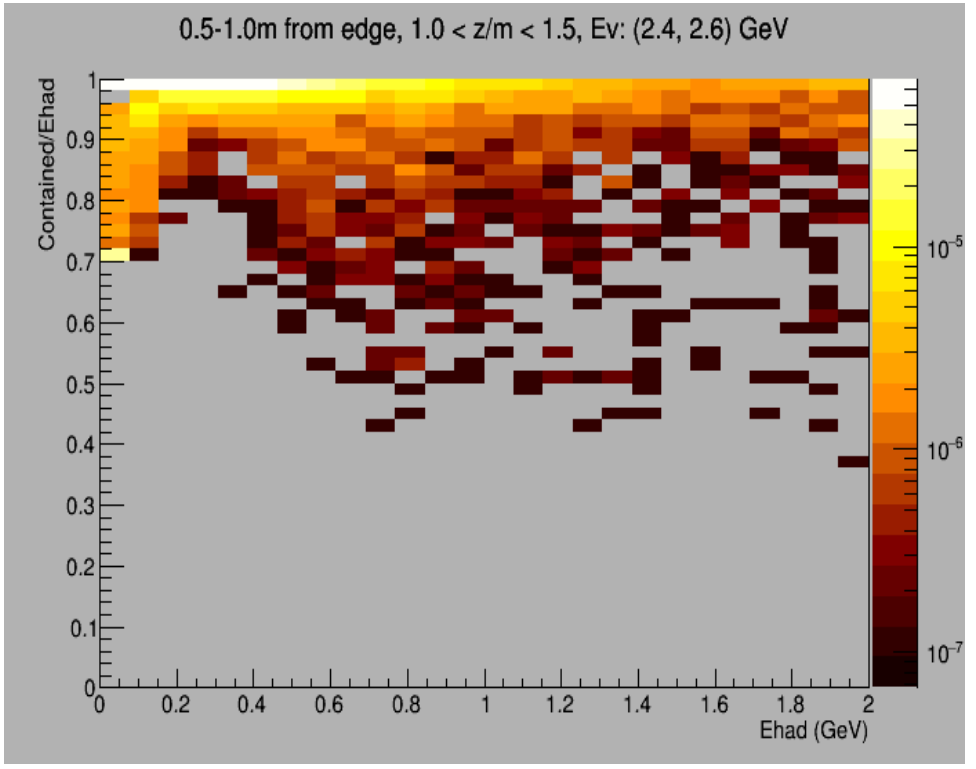



- Simulate hadrons of different initial energies in Geant4
- Profile visible energy (including from products of interactions in LAr) vs. distance
- Determine containment fraction vs. distance and energy
- Depends on model for distribution of hadronic energy

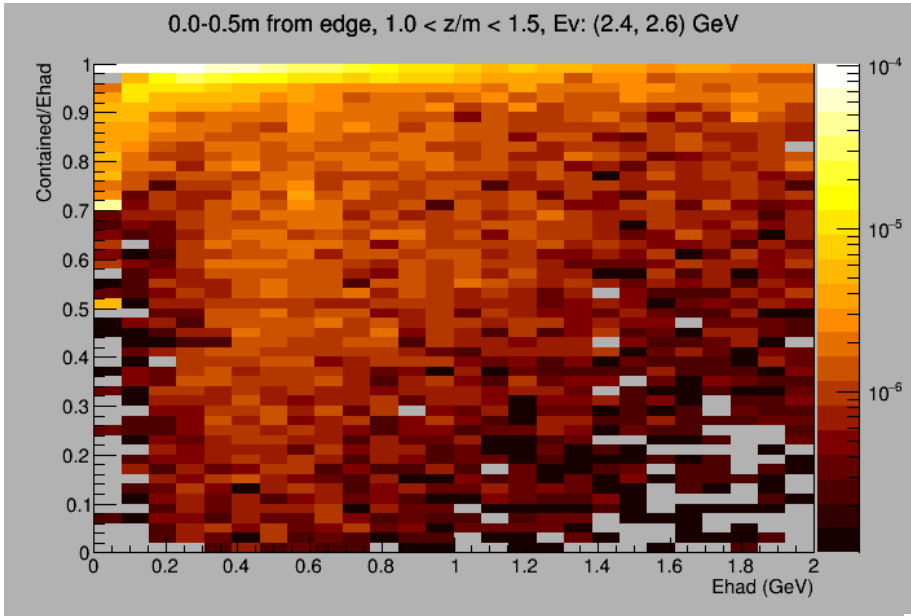
# FHC 2x2x4m TPC (23 tons)

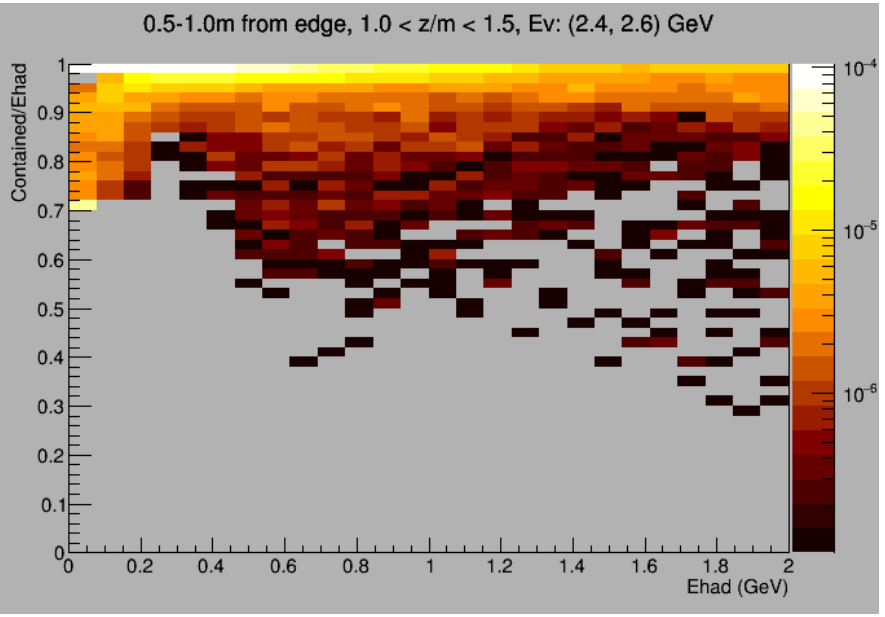


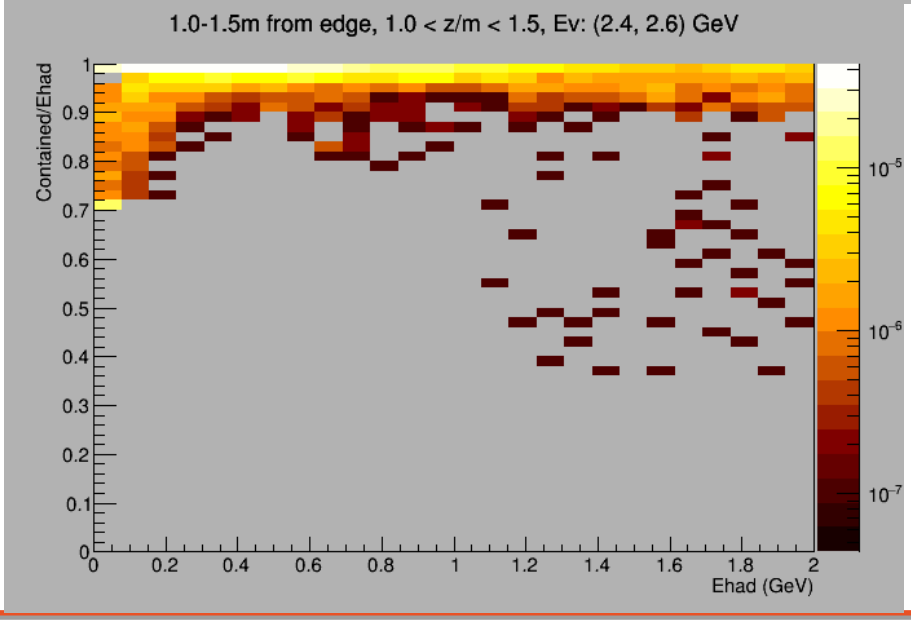




- Hadron containment fraction vs. $E_{had}$ (no neutrons)
- Central 1x1m (right), and outer 50cm (left)
- Good containment up to high $E_{had}$ for inner region

# FHC 3x3x4m TPC (50 tons)

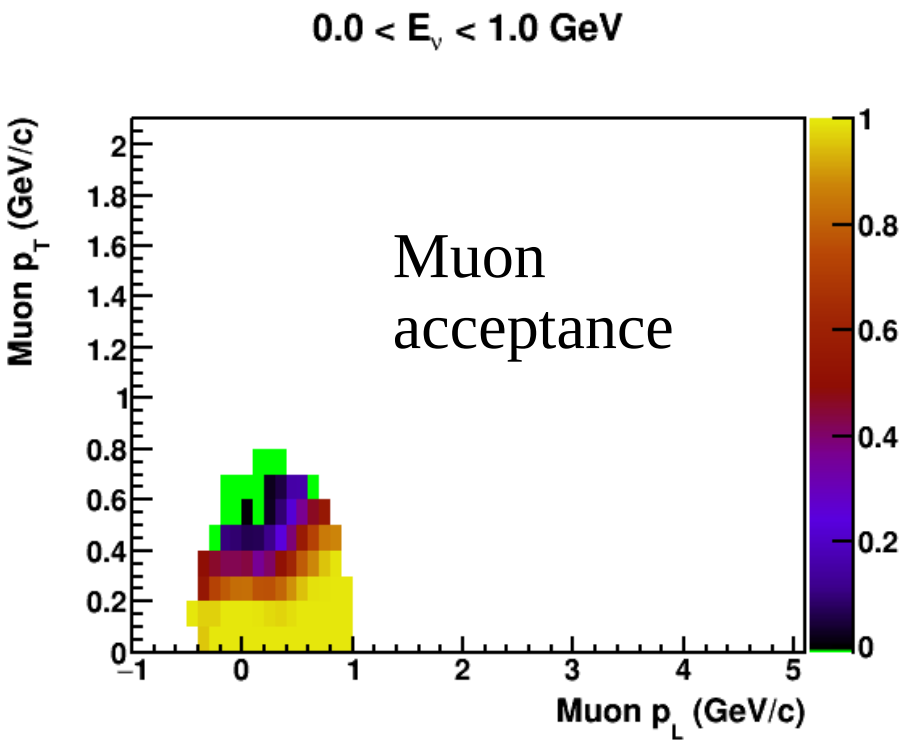


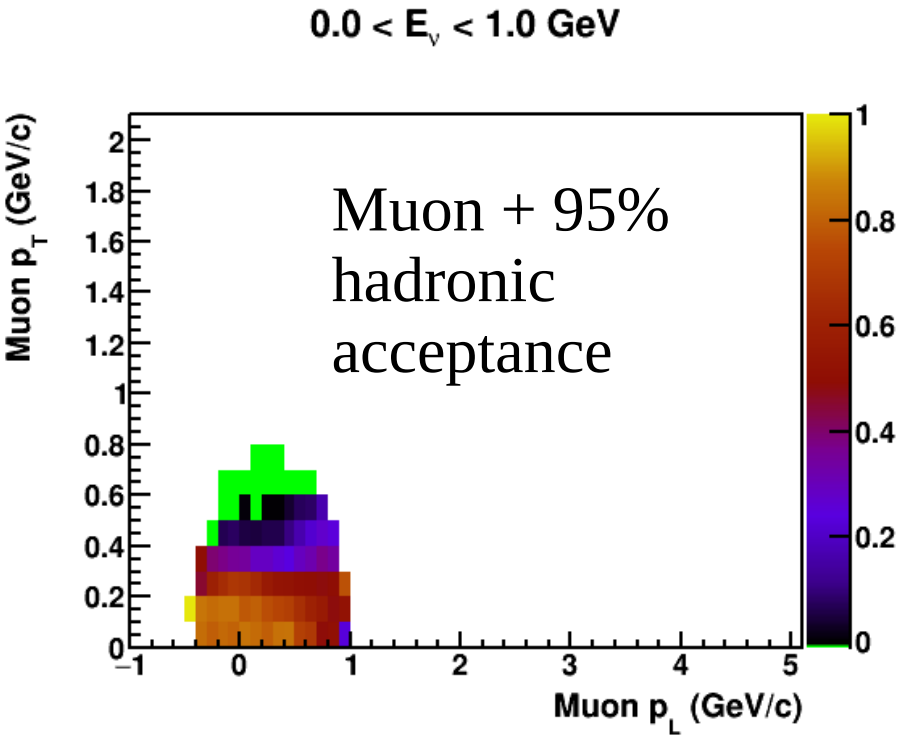




- Vertex <50cm from detector edge (top-left), 50-100cm from edge (top-right), and central 1m, 100-150cm from edge (left)

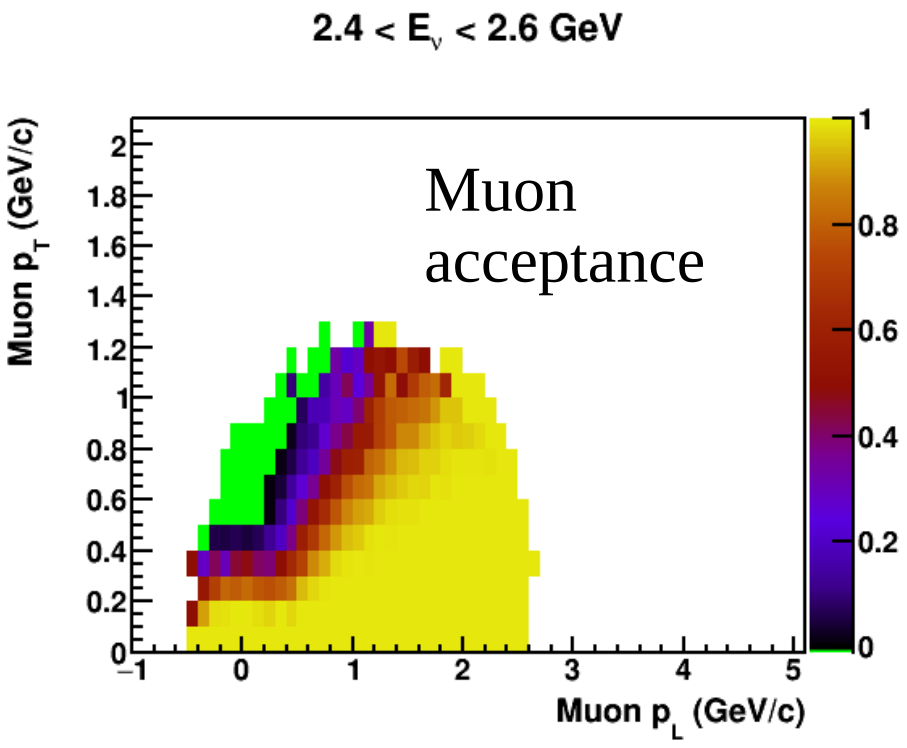
# FHC 2x2x4m TPC (23 tons)

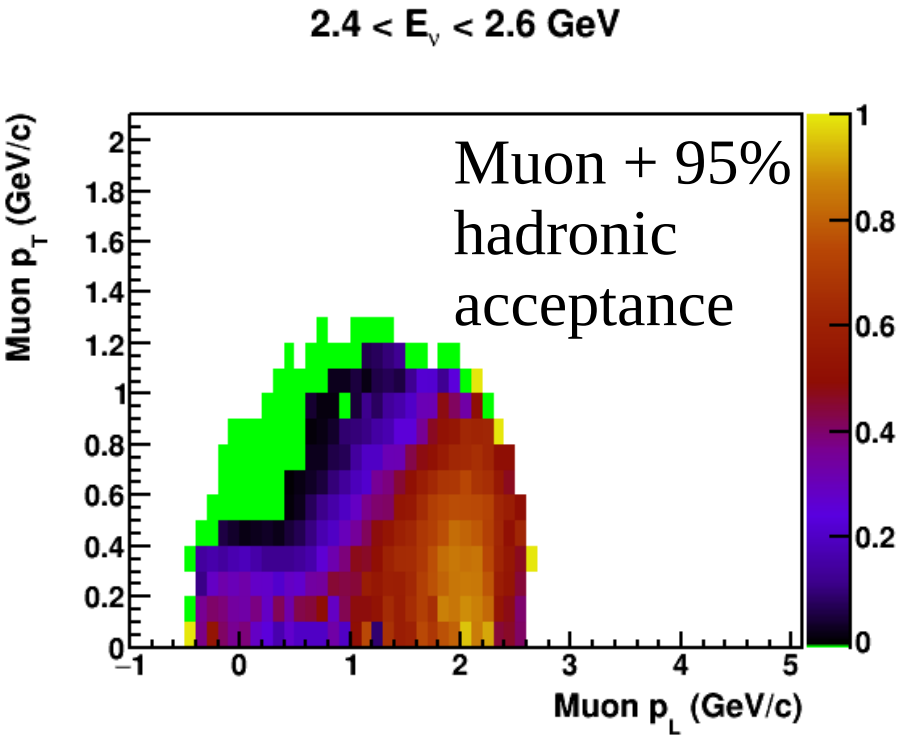



- Central fiducial volume events only (central 1x1x2 m)
- No side muon detectors
- Green = Zero acceptance, White = Zero cross section (GENIE)

# FHC 2x2x4m TPC (23 tons)

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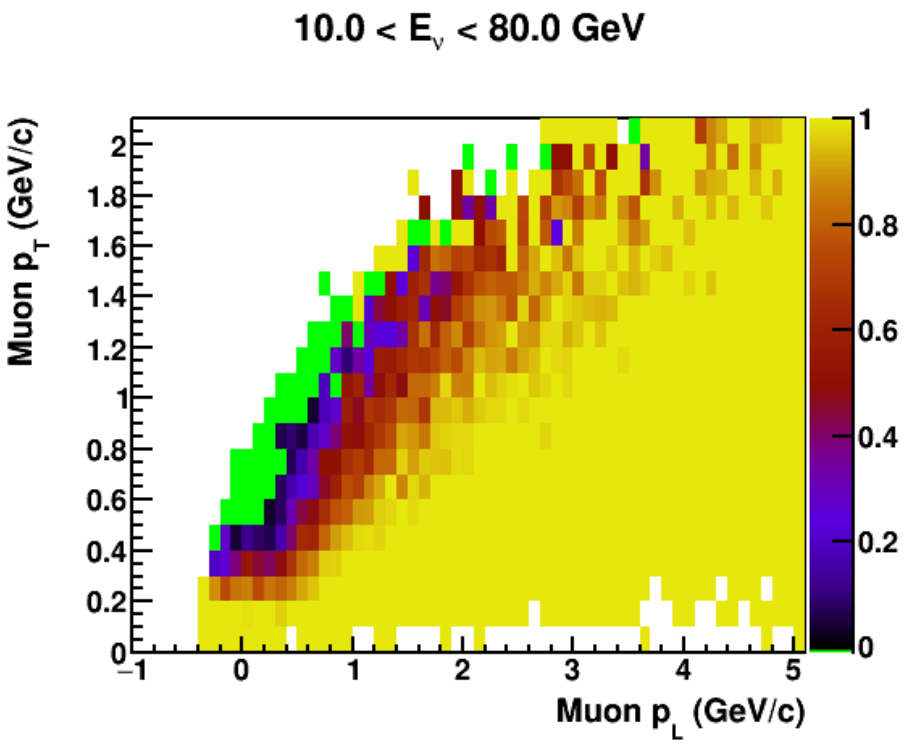
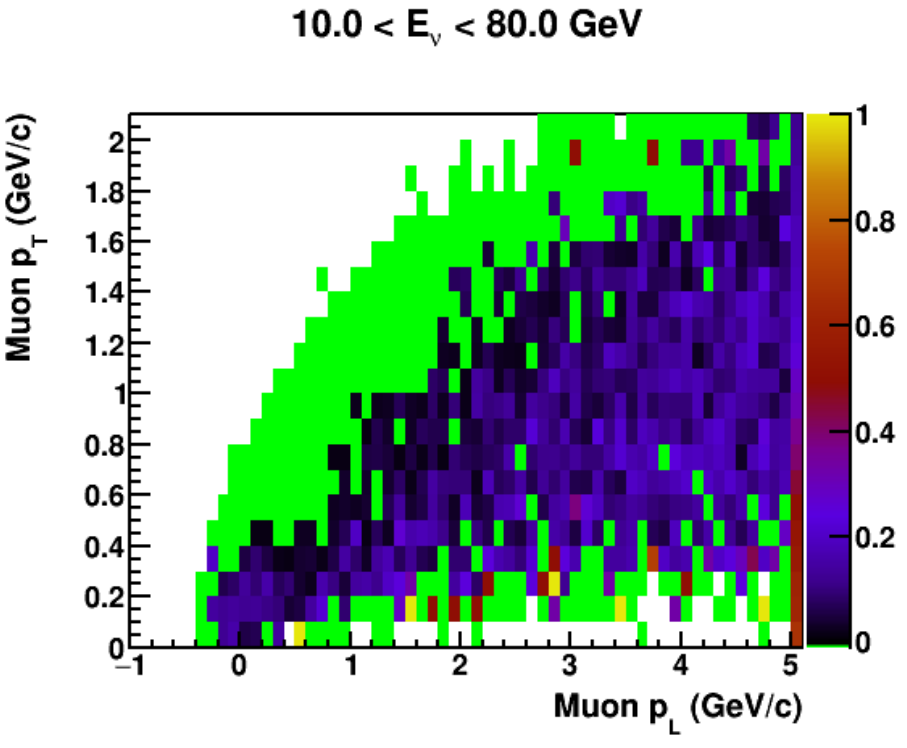
# FHC 2x2x4m TPC (23 tons)




- Central fiducial volume events only (central 1x1x2 m)
- No side muon detectors
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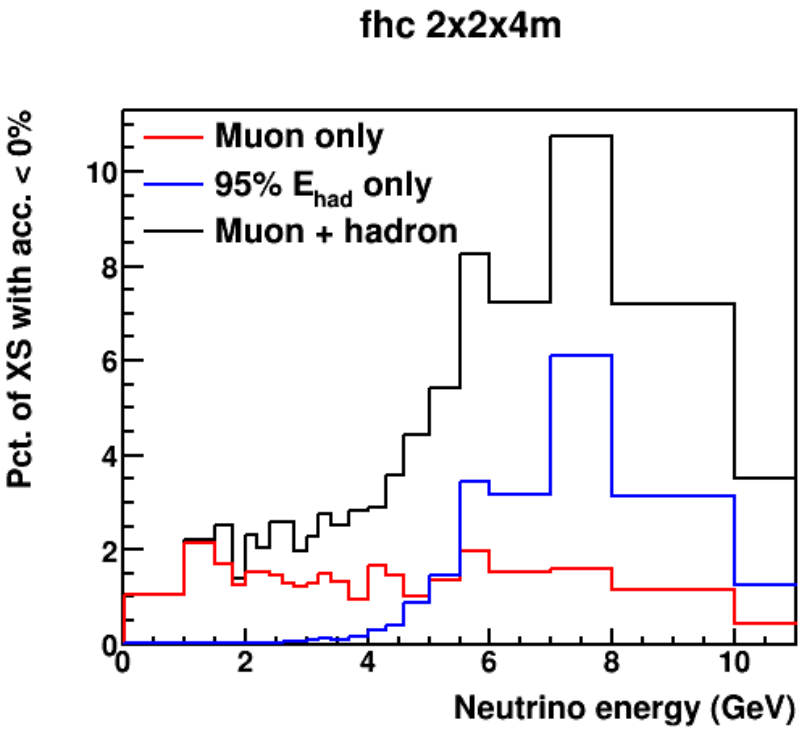
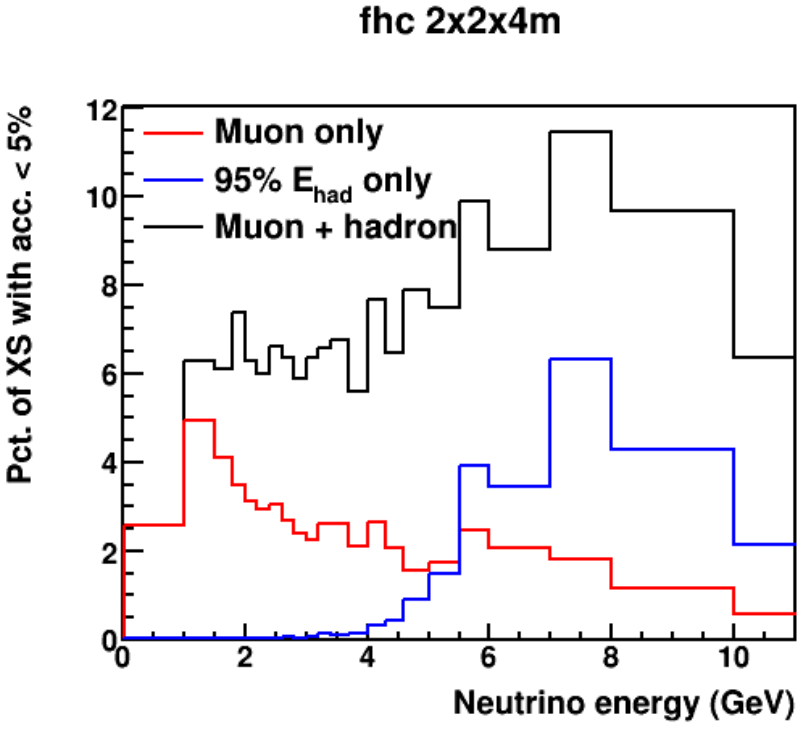
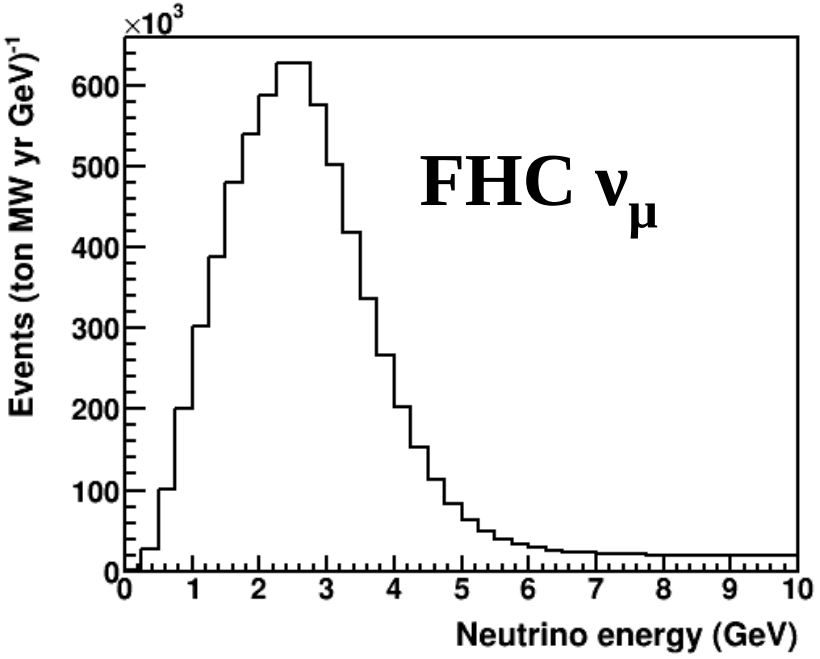
# Low-acceptance XS

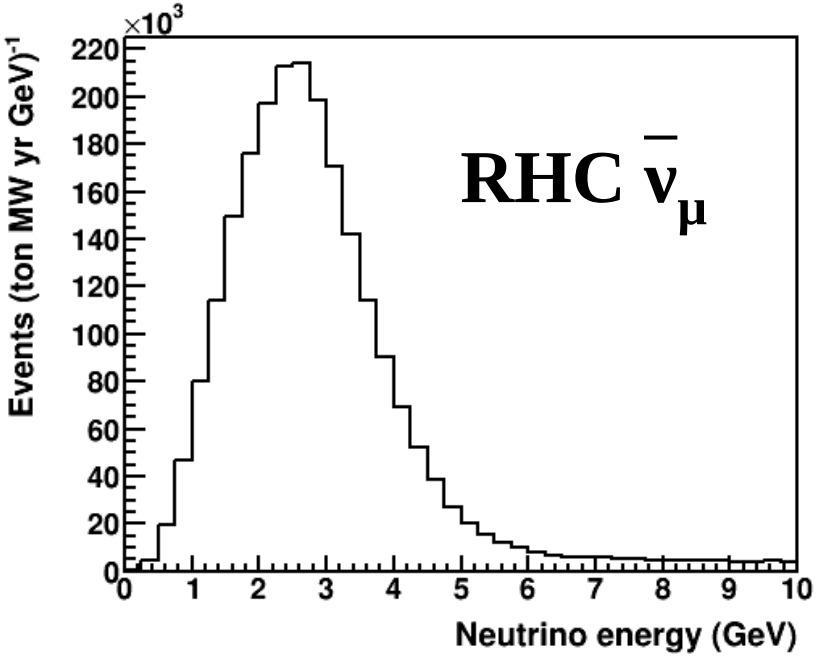



- For central 1x1x2m of 2x2x4m detector FHC
- Fraction of GENIE XS with zero acceptance (left) and <5% acceptance (right) vs. $E_\nu$

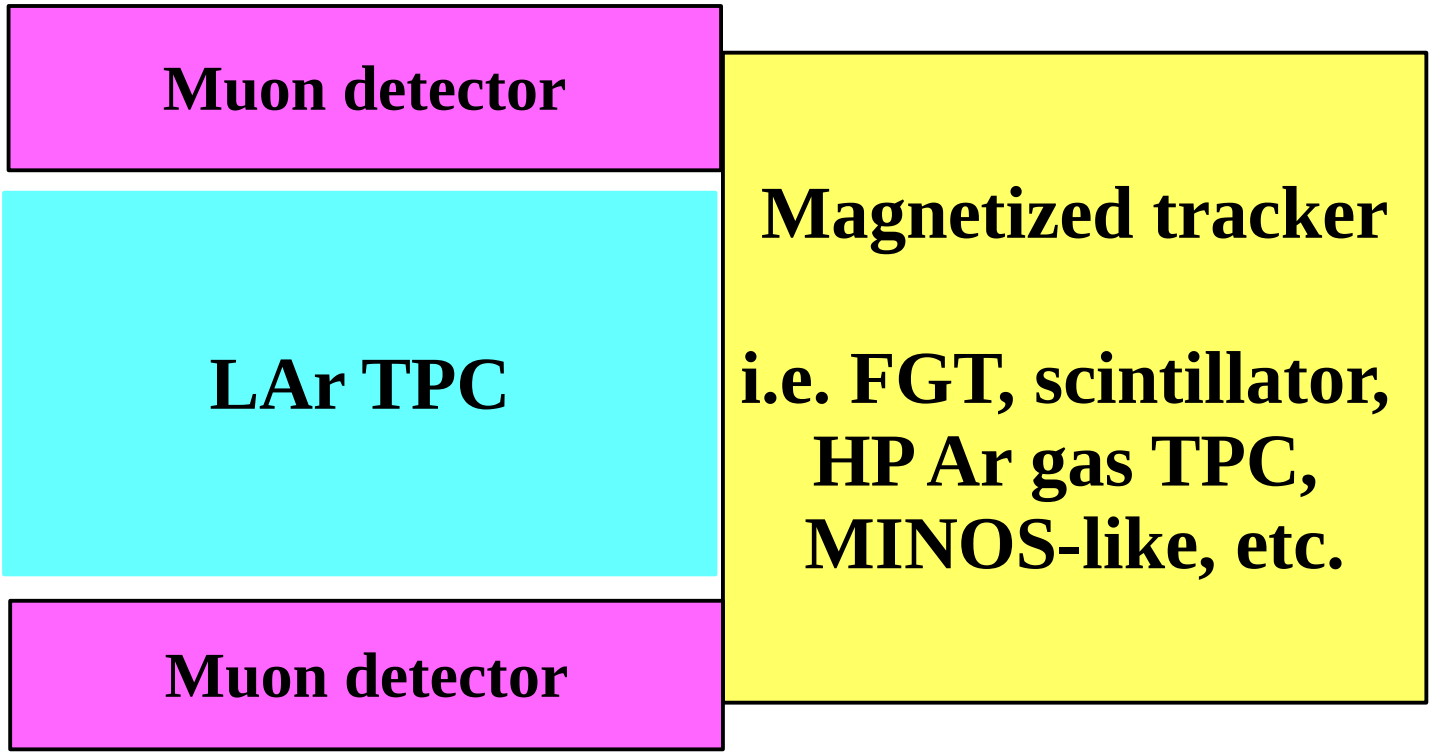
# Statistics for low acceptance




- 1.9M right-sign CC events/ton-yr FHC, 0.5M RHC
- 1% of XS is 6000 events/ton-yr-GeV in FHC peak, and 2200 in RHC peak
- Even with 1% acceptance, phase space with 1% XS will integrate 1000s events for a few 10s ton detector in a few years

# Add side MuID detectors

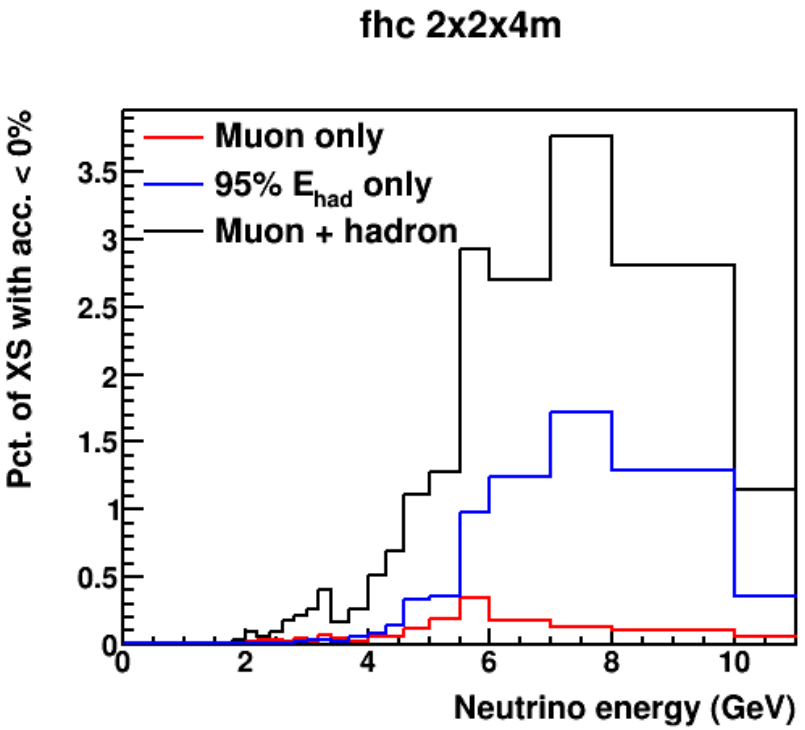


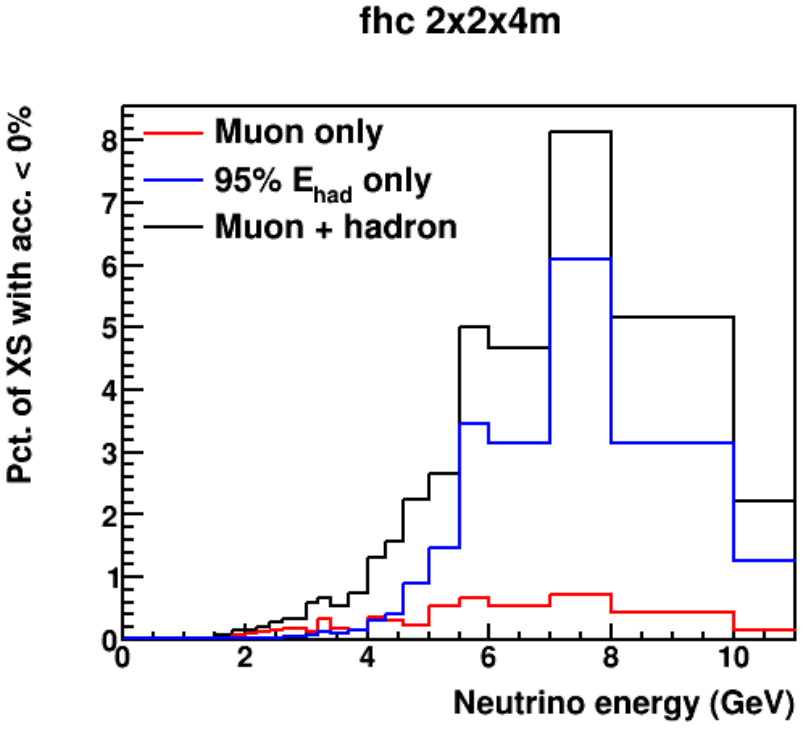

Accept muons if they stop in side μ detector of thickness X g/cm$^2$, assuming 2 MeV per g/cm$^2$, accounting for the muon angle

# Pros and cons of side muon detector

- Pros:
  - Extends μ acceptance, cheaper than making LAr TPC bigger
  - Fast timing – can get $t_0$ from side-exiting muons
- Cons:
  - Doesn't improve hadronic containment
  - Adds pile-up. Example: 32 tons of material to stop 200 MeV muon at 90º for 2x2x4m TPC
  - Probably impossible to ID charge of μ without magnet
- Possible solution: only put μID on one or two sides of TPC, use phi symmetry to sample muon kinematics

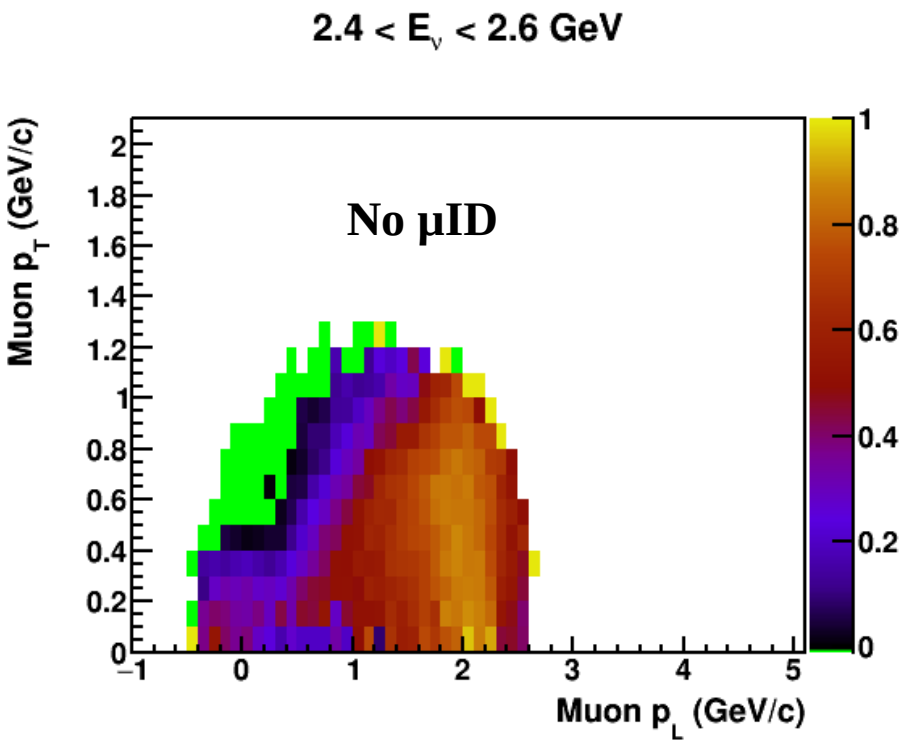
# With 200 g/cm² side μID

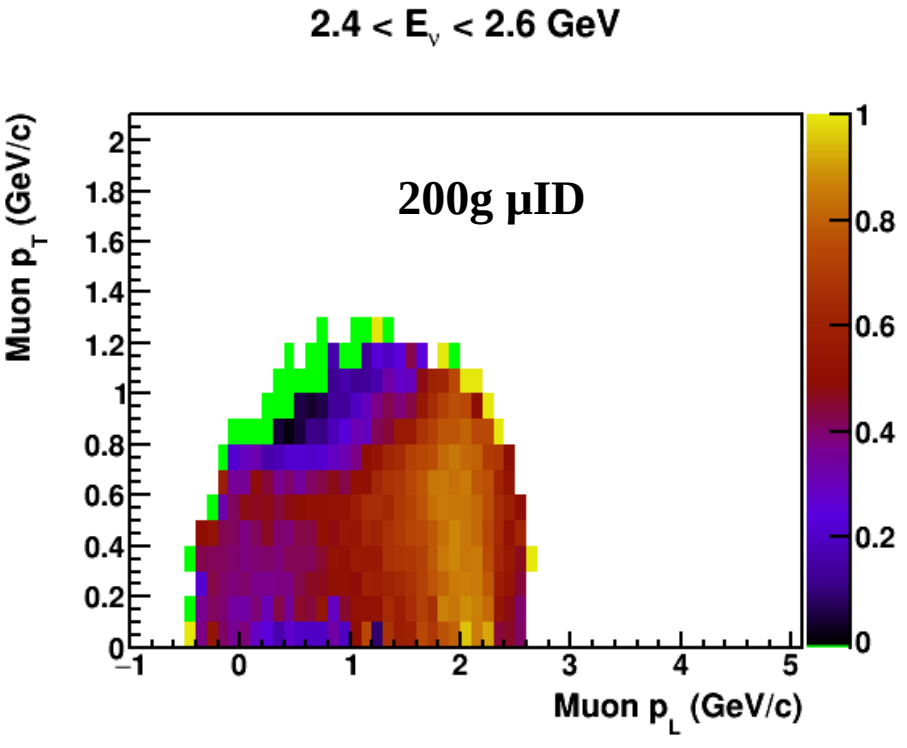



- Whole detector (left) and central 1x1x2 volume (right)
- <0.5% missing XS in oscillation region
- Essentially equivalent to 3x3x4m detector (1m of argon is 140 g/cm²)

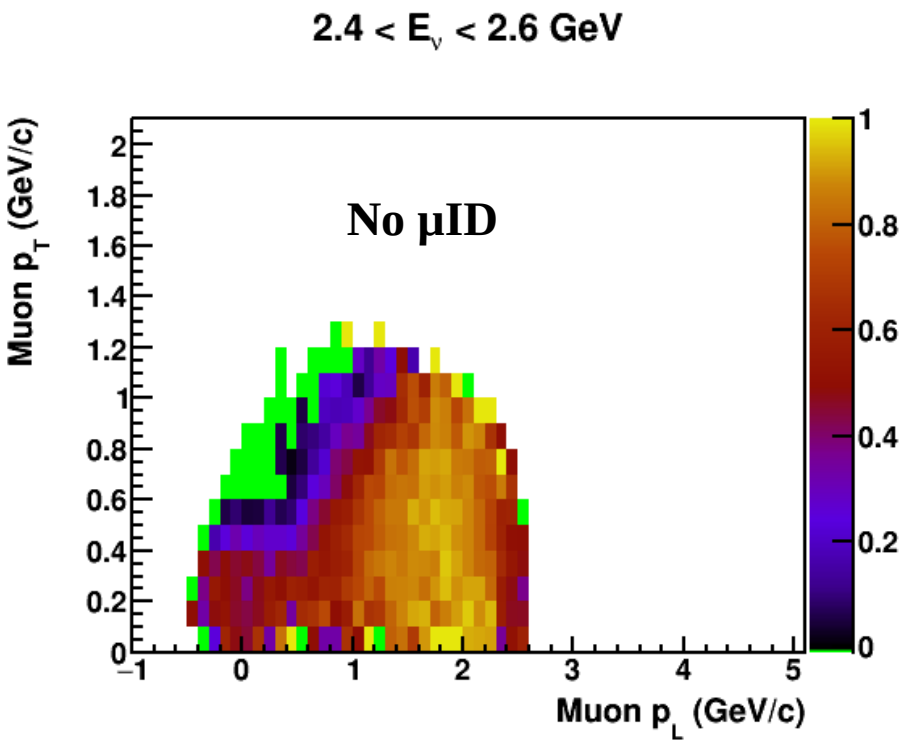
# Central region osc. peak

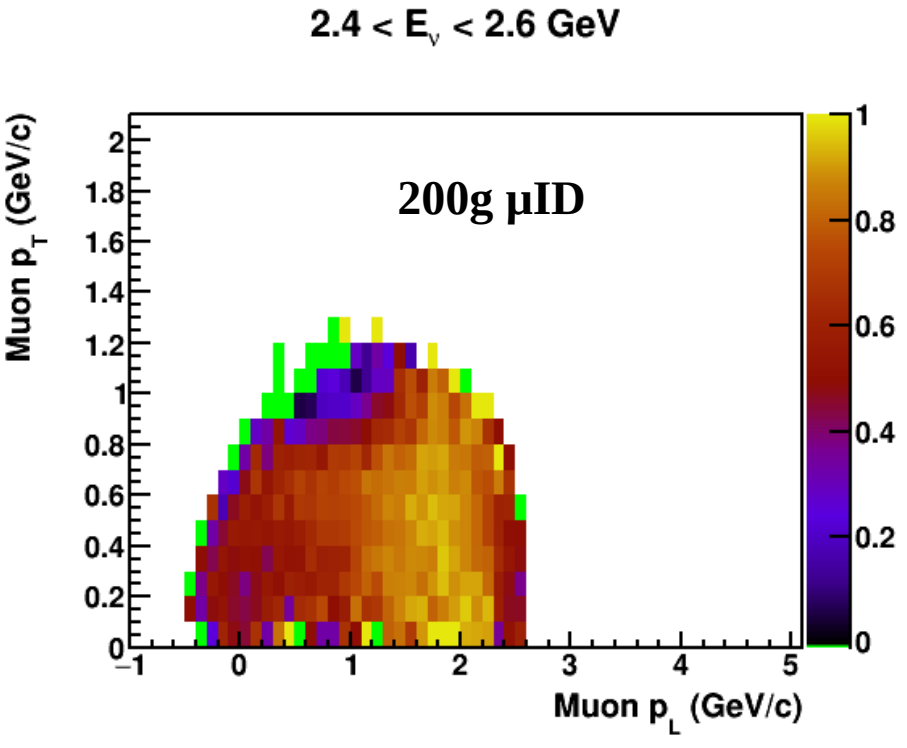



- Much better acceptance in high-pT region
- Central 1x1x2m region only, FHC

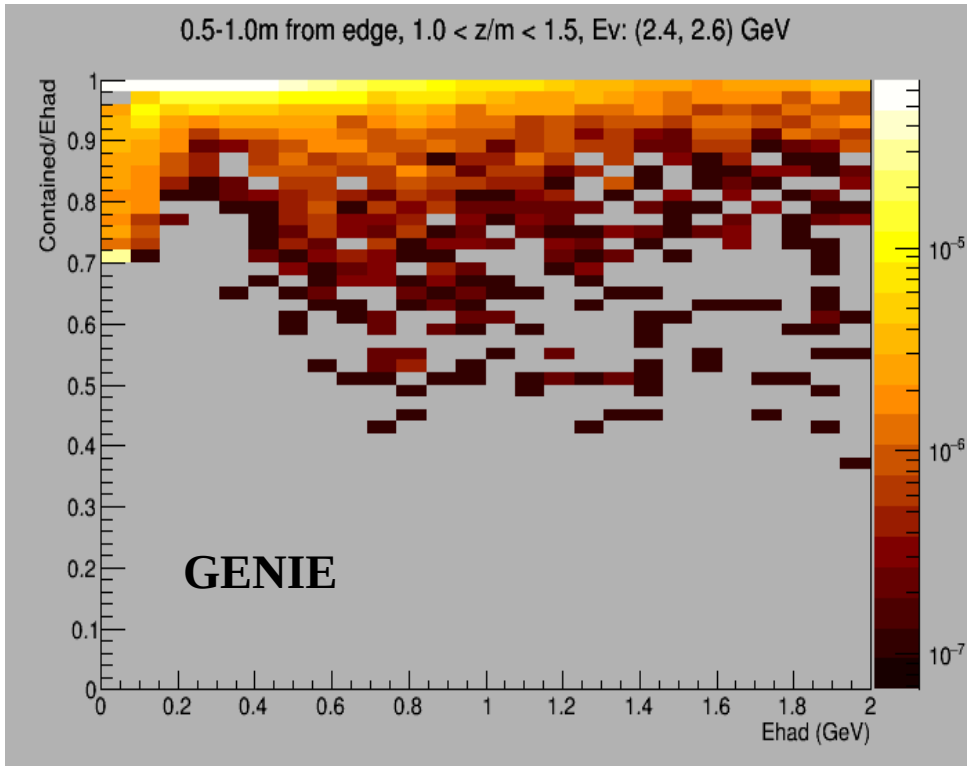
# 3x3x4m detector FHC

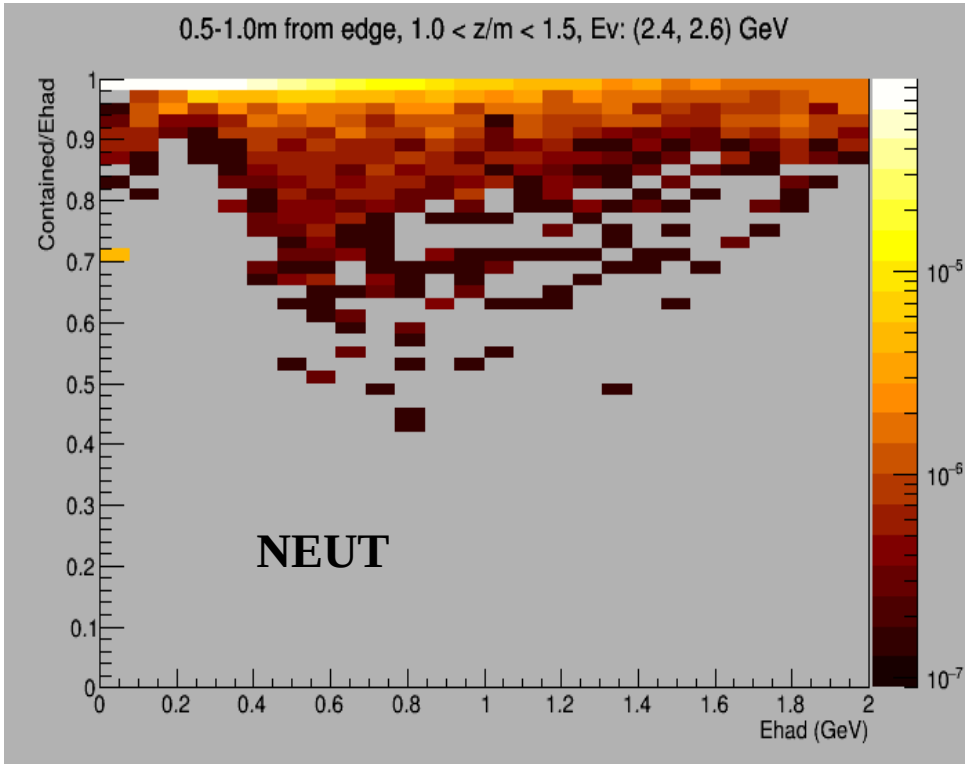



- 3x3x4m detector has really excellent acceptance with µID detector, but very little cross section coverage to be gained

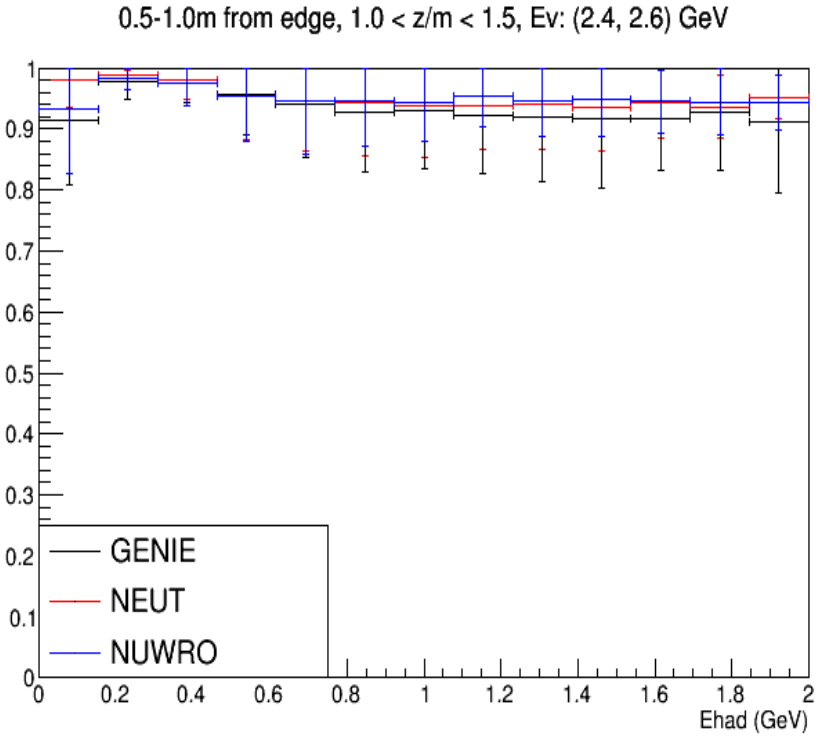
# Hadronic model dependence



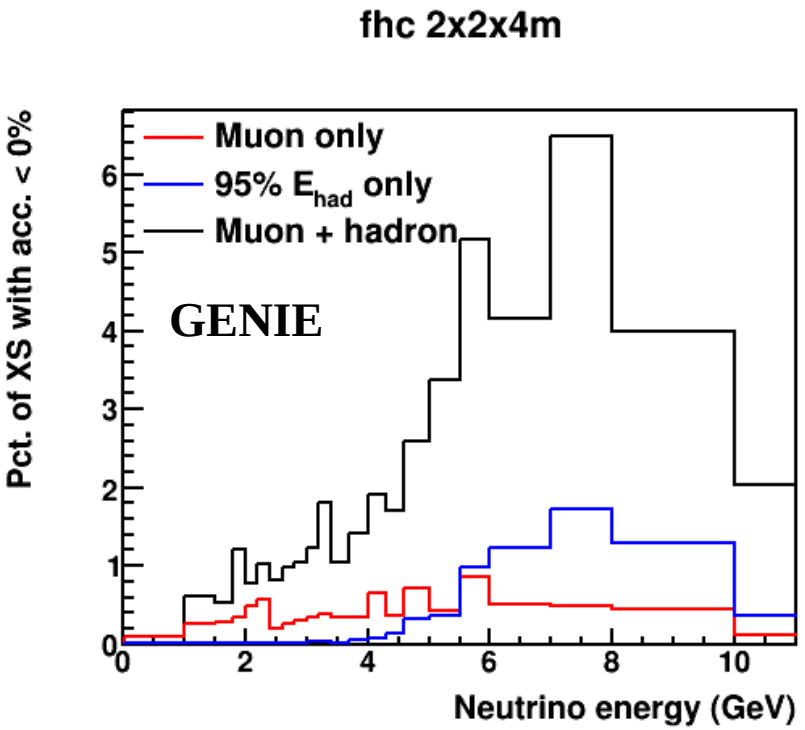

- 2x2x4 FHC no FV, no μID, inner 1x1m
- GENIE (left) and NEUT (right)
- Hadronic containment fraction vs. hadronic energy

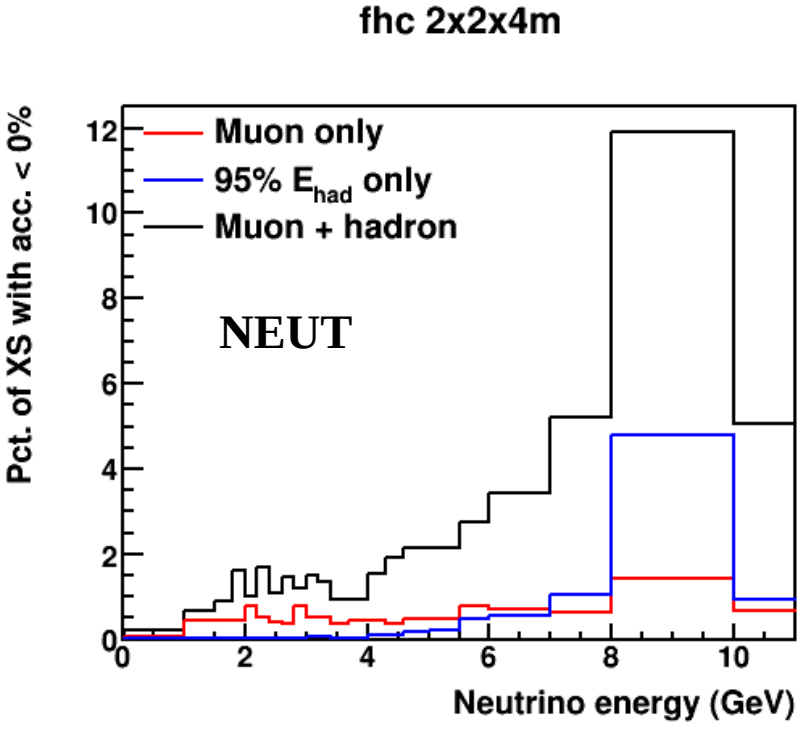
# Hadronic model dependence




- Profile of previous slide
- Similar mean hadronic containment in GENIE, NEUT, NuWro
- GENIE is generally wider, i.e. more events with poor containment

# GENIE vs. NEUT XS coverage




- 2x2x4 FHC no FV, no μID
- GENIE (left) and NEUT (right)
- Differences in hadronic side at higher neutrino energy

# Conclusions

- ~30 tons LAr TPC with side μID detectors has sufficient acceptance/containment up to ~4 GeV
  - Or ~50-60 tons w/o side μID
- Remaining questions:
  - What is the effect of missing ~10% of XS in the tail?
  - How many pile-up tracks are produced with μID?
  - Can we put μID on just one or two sides of detector? Only downstream part of detector?

# Backups

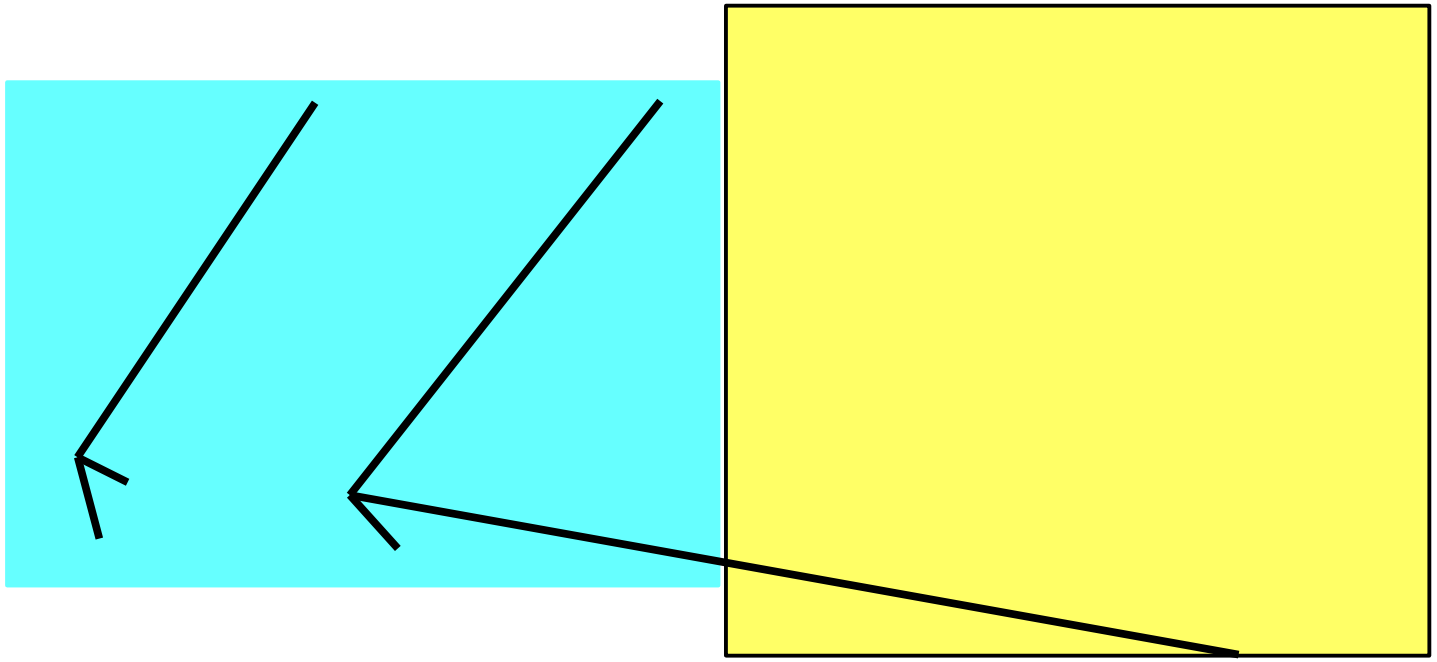
# Hadron simulation caveats

- Projects dE/dx into 1D particle by particle, neglecting transverse dimensions of shower of individual hadrons
- Really not good for low-energy $\pi^0$
- Full event-by-event Geant4 simulation is obviously preferable
  - To get good stats over all kinematics, need ~10M events
  - Full simulation would take ~1000s CPU days
  - Want to do this for many detector configurations
- Fast version good enough for first pass, not intended to be perfect

# Model dependence caveat

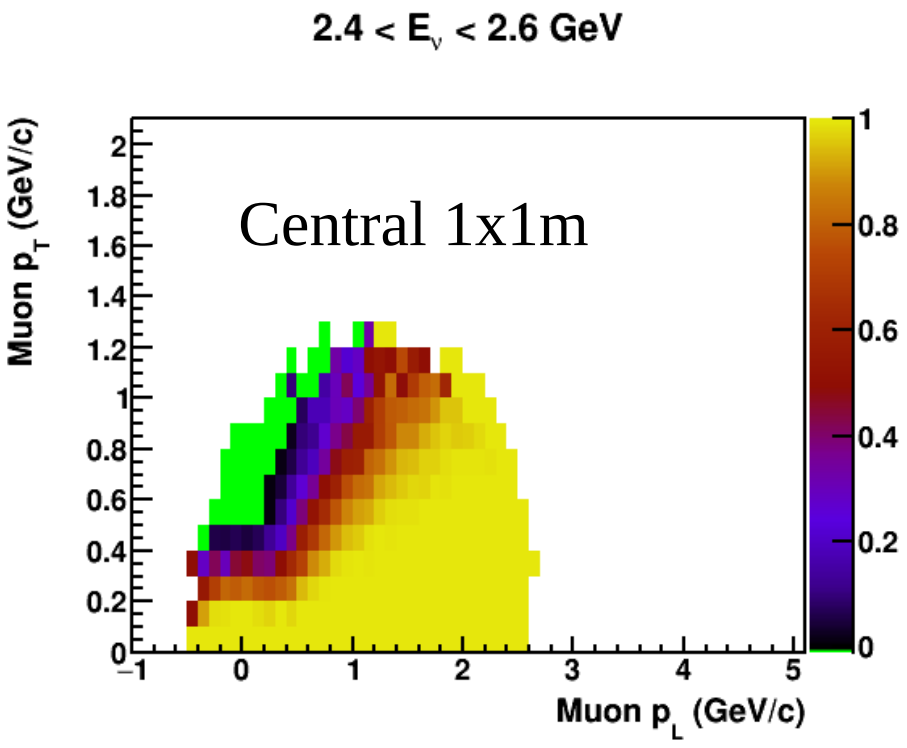
- Will show acceptance vs. muon kinematics in 2D
- Muon side is model-independent (depends only on Geant4 muon simulation)
- At fixed neutrino energy, total hadronic energy ν is fixed in a bin of muon momentum
- But the containment of that energy depends on the composition of the hadronic system
- Two things are model dependent:
  - Muon kinematics vs. neutrino energy
  - Hadron containment at fixed hadronic energy

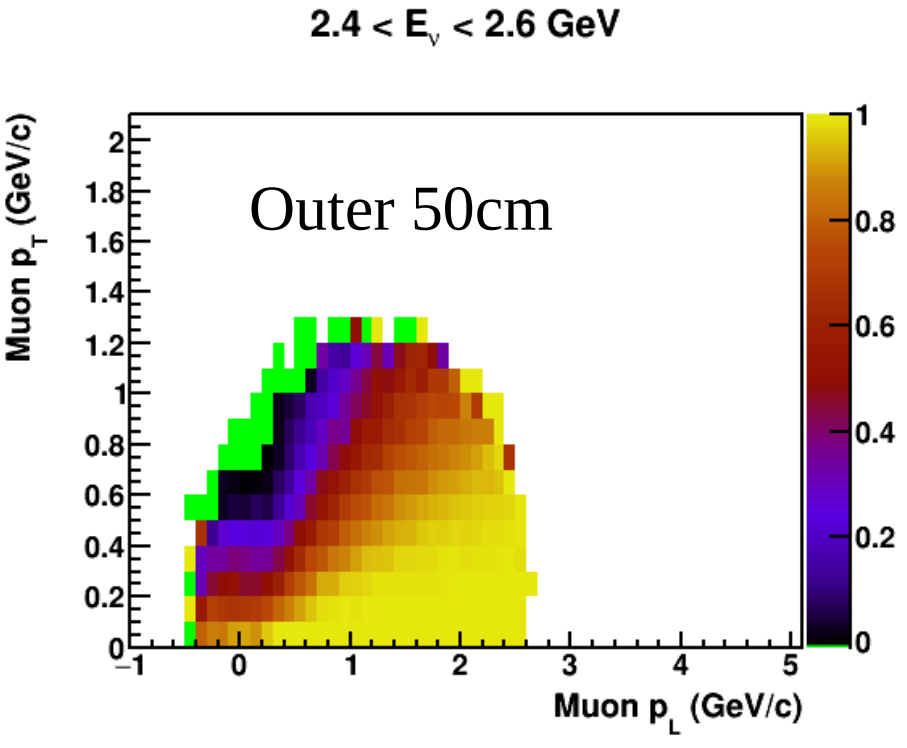
# Edge events



Acceptance is generally worse for vertices near the edges. Some event topologies have no acceptance in a central fiducial volume, but might be accepted when the vertex happens to be near the edge of the detector.

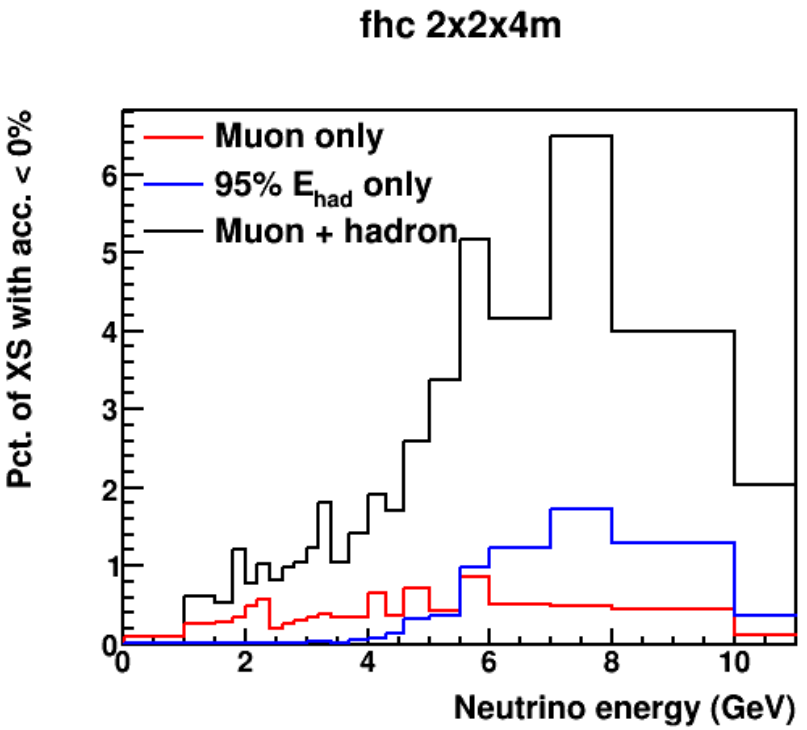
# Edge event acceptance

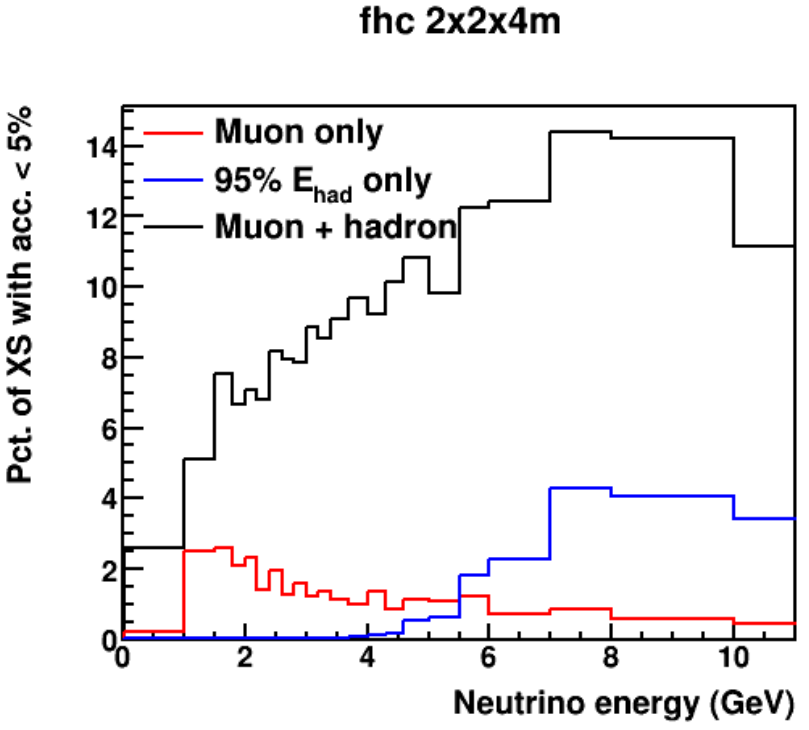



- Muon acceptance only, FHC, 2x2x4m detector, middle 2m in Z direction
- For high-$p_T$ muons, acceptance is better for events with vertices near the edge

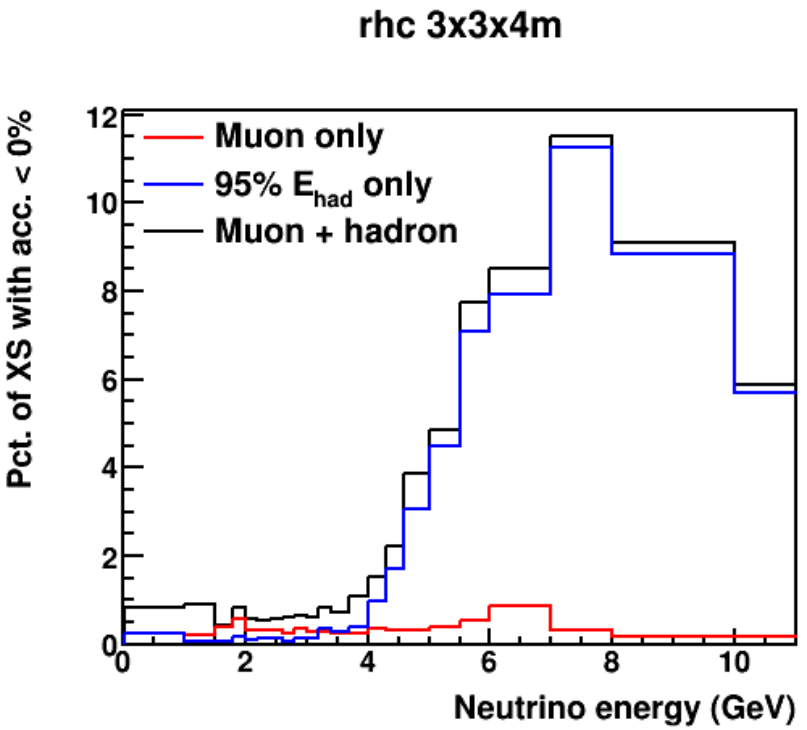
# Low-acceptance XS

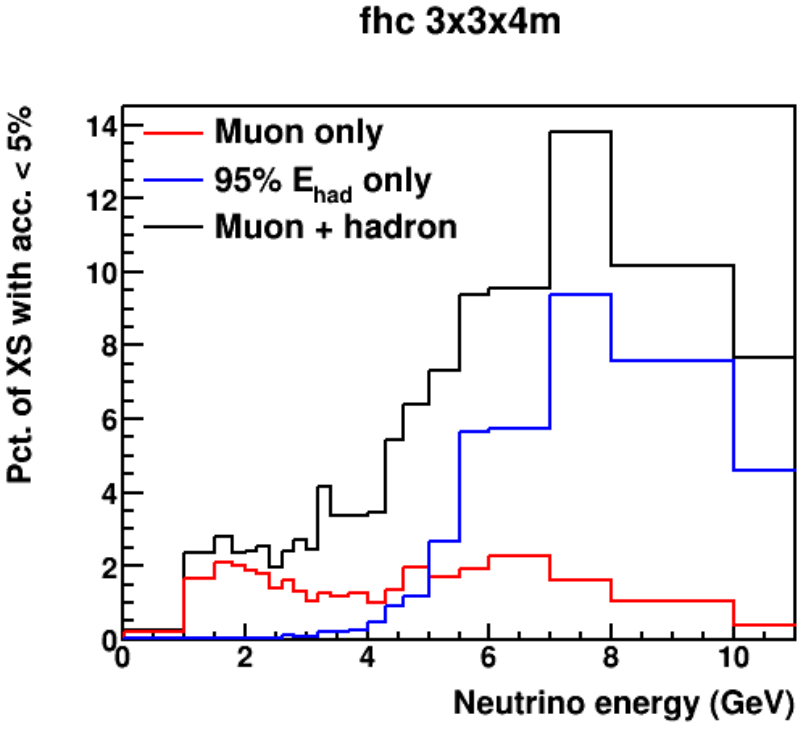



- For central 2m in z of 2x2x4m detector FHC (including outer events)
- Fraction of GENIE XS with zero acceptance (left) and <5% acceptance (right) vs. $E_\nu$

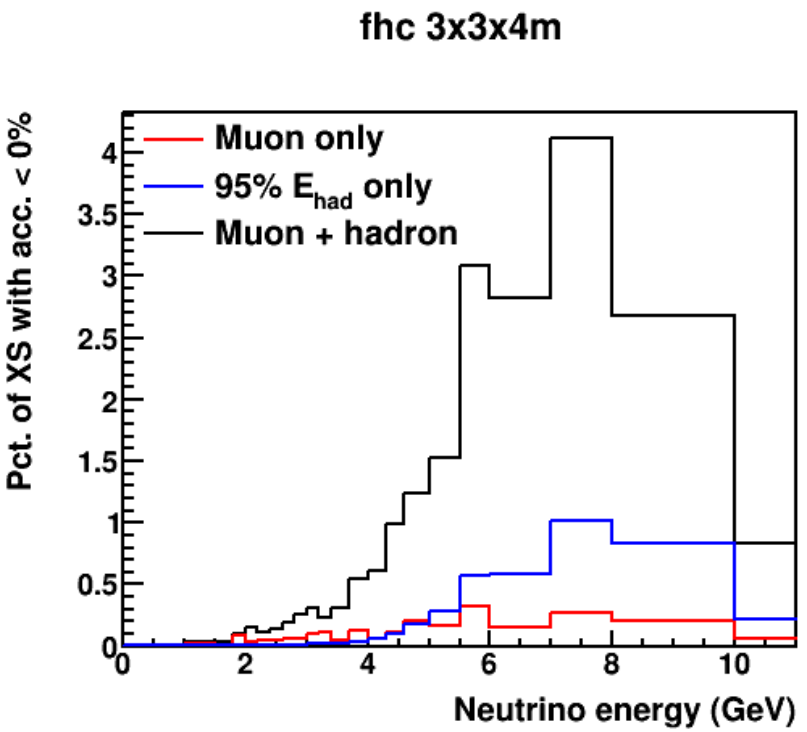
# 3x3x4m detector: central only

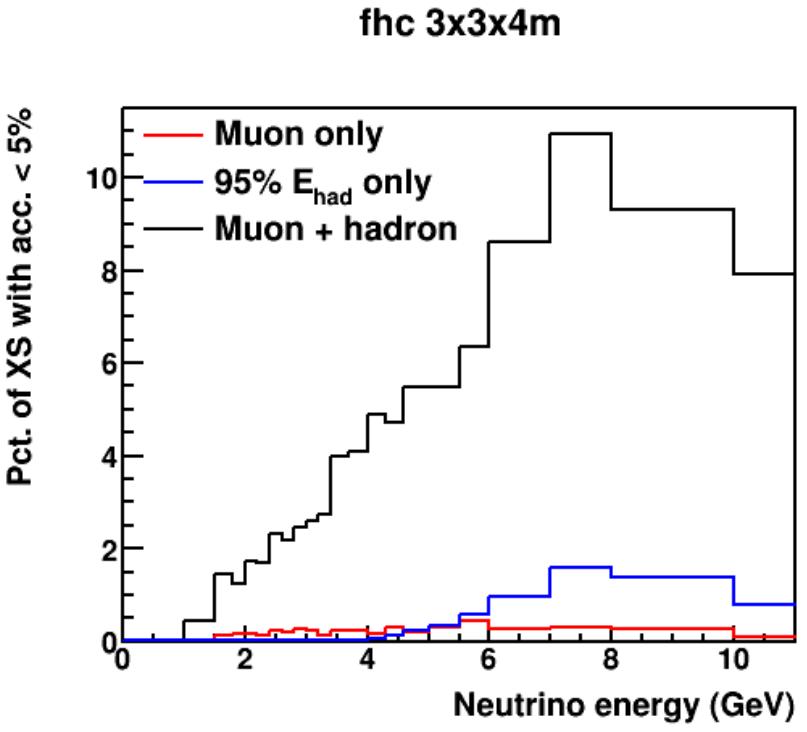



- central 1x1x2m of 3x3x4m detector, FHC
- Zero acceptance (left) and <5% acceptance (right)

# 3x3x4m detector: full




- 3x3x4m detector FHC, including edge events
- In oscillation region < 0.5% of XS has no acceptance