Stony Brook University

Study on liquid argon TPC with B-field

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Introduction

- From last collaboration meeting, it seems that the default design for LAr is without B-field.

- What can we gain if we have B-field applied to LAr tank?

- I always assume LAr tank in front of some tracker/FGD.

- I always assume perfect detector response.

Liquid Argon w/ Mag. Field

- Main purposes for events inside liquid argon are:
    1. separate nu and nubar.
    2. Help energy reconstruction.

In this talk:

- muon: B-field helps with nu/nubar separation and energy reco.

- electron: nu/nubar separation is hard as Brems happens quickly.
  B-filed also hardly helps with energy reco.

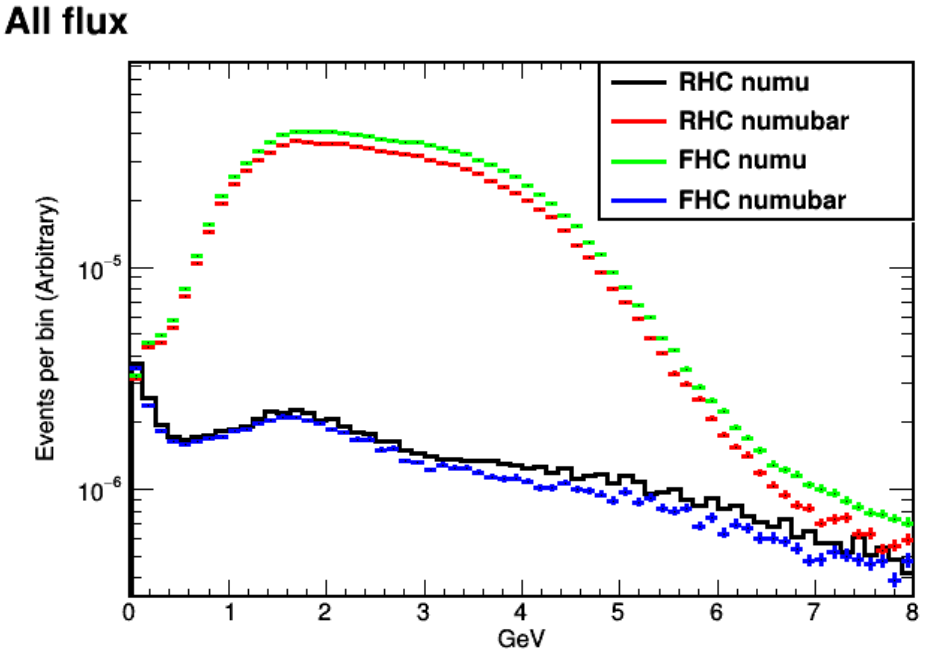
Future:

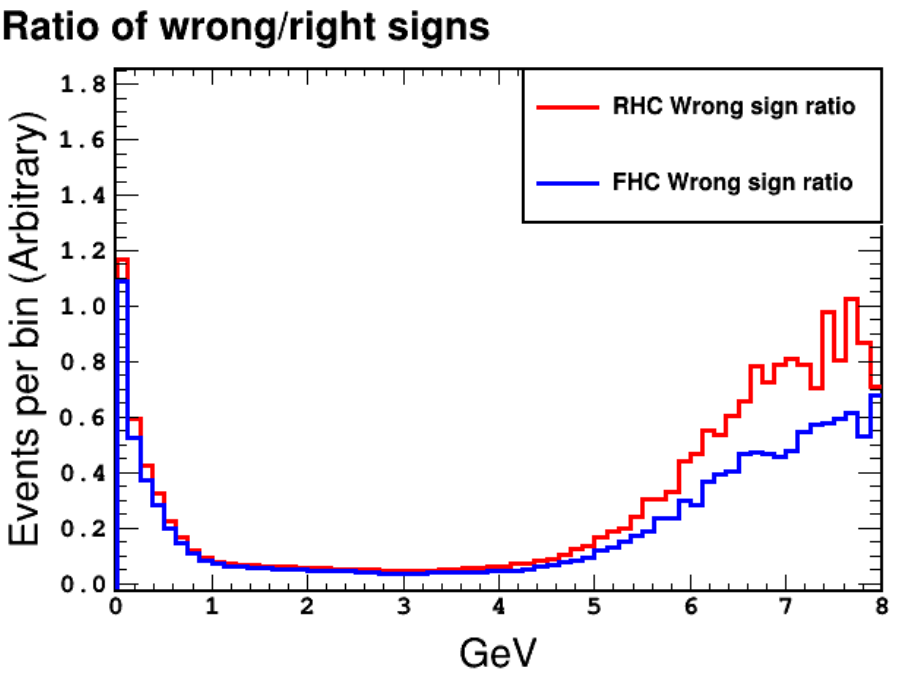
- Charged pion: Important. Muon can be dealed in the downstream detector
  While charged pion much more likely be contained in Lar.
- pi0 : no impact.
- proton?

DUNE flux

Reference flux from arxiv.1606.09550
With real rates overlayed

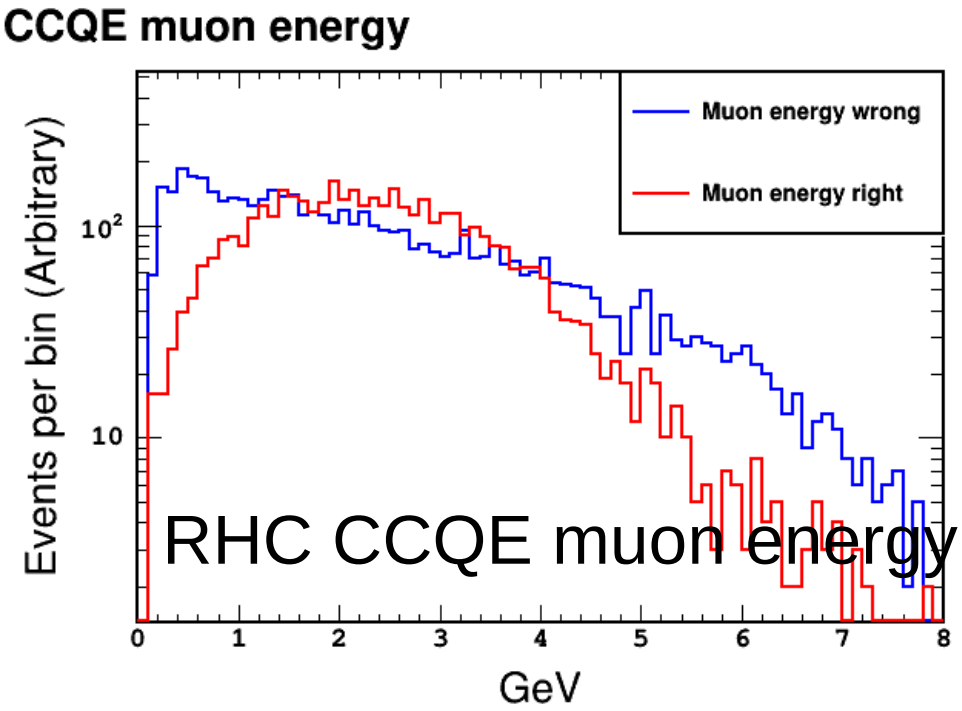
Wrong sign ratio for RHC and FHC

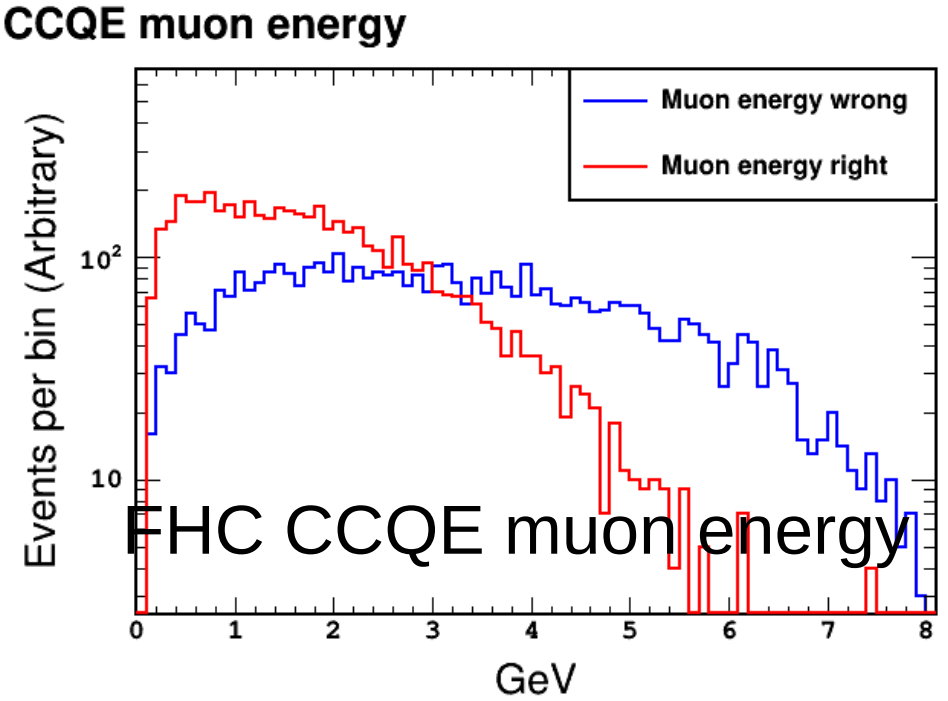




DUNE flux

- With GENIE, I generate same numbers neutrino interactions for FHC and RHC, nu and nubar.
- After that, I select only CCQE envents.



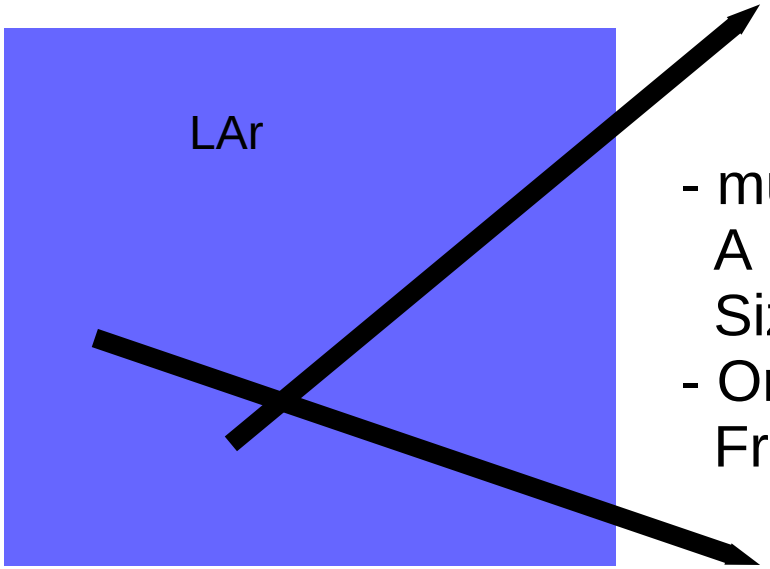


Muon in Liquid Argon

- How much energy can be contained in Liquid Argon? i.e. without B-field, we would lose nu-nubar separation up to what energy?
- Muon helps with E-reco.

Muon Energy deposit in LAr

10,000 muon events based on DUNE flux and GENIE are generated in simulation to study the energy deposit in a simple Lar tank.

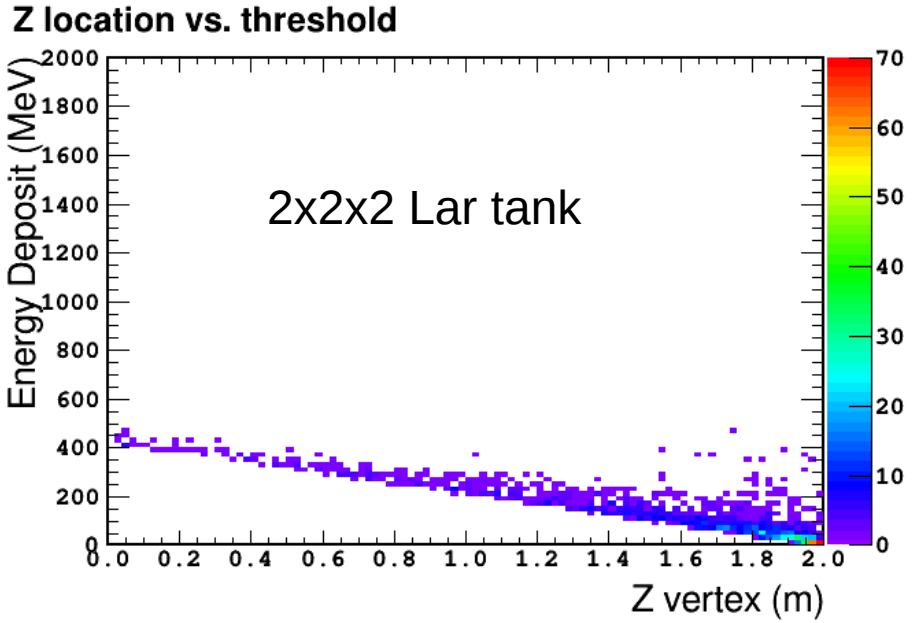


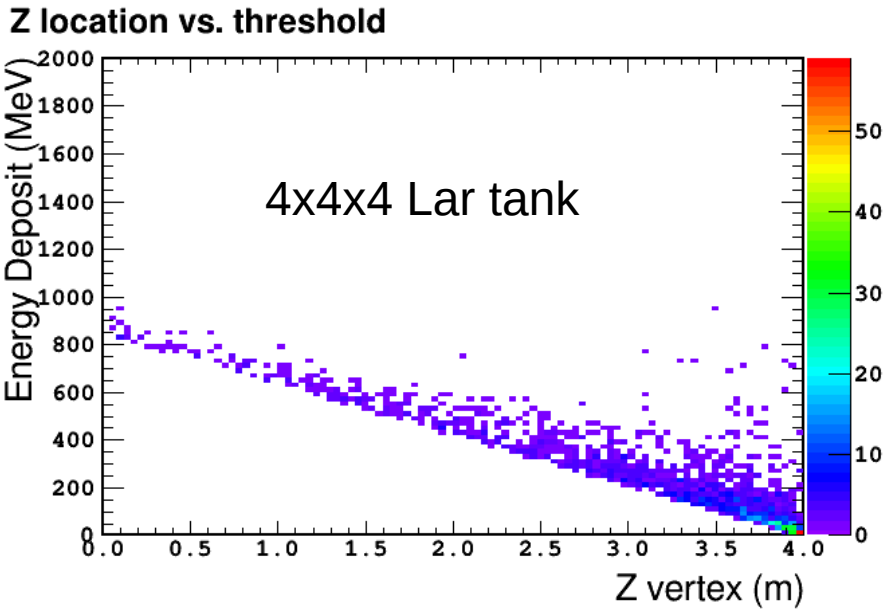
- muons generated at random place inside A Lar cube with radom directions. Size varies.
- Only look into muons that going out From the downstream cross-section.

- Muon energies are from GENIE CCQE with DUNE flux(arxiv.1606.09550).

Muon Energy deposit in Lar

10,000 muon events are generated in simulation to study the energy deposit in a simple Lar tank.



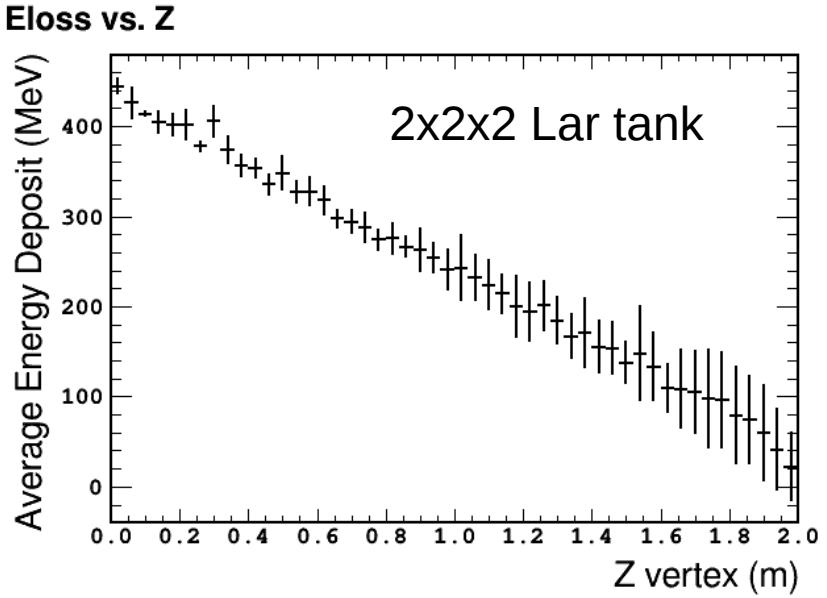


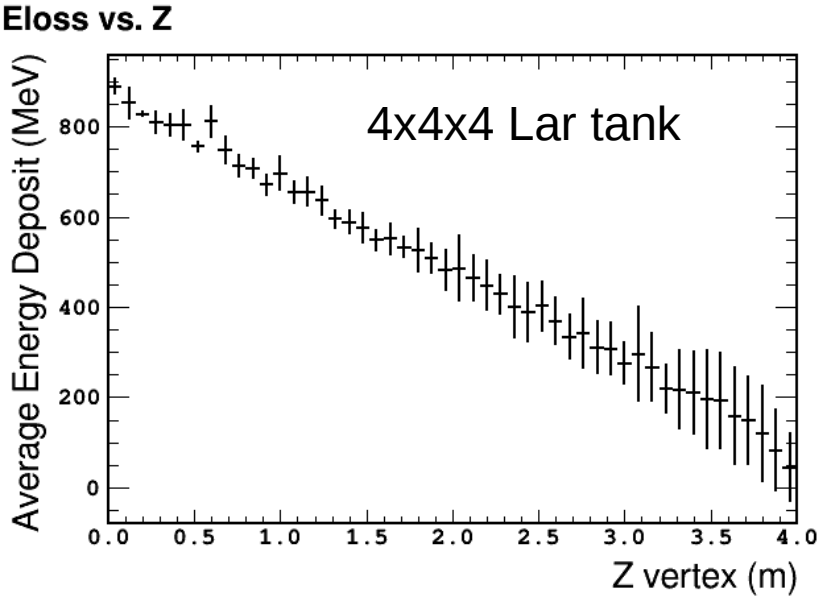
- As detector size increases, the nu and nubar separation thresold is increasing, if muons going downstream.
- 3x3x3 case is in the backup slides.

Muon Energy deposit in Lar

10,000 muon events are generated in simulation to study the energy deposit in a simple Lar tank.

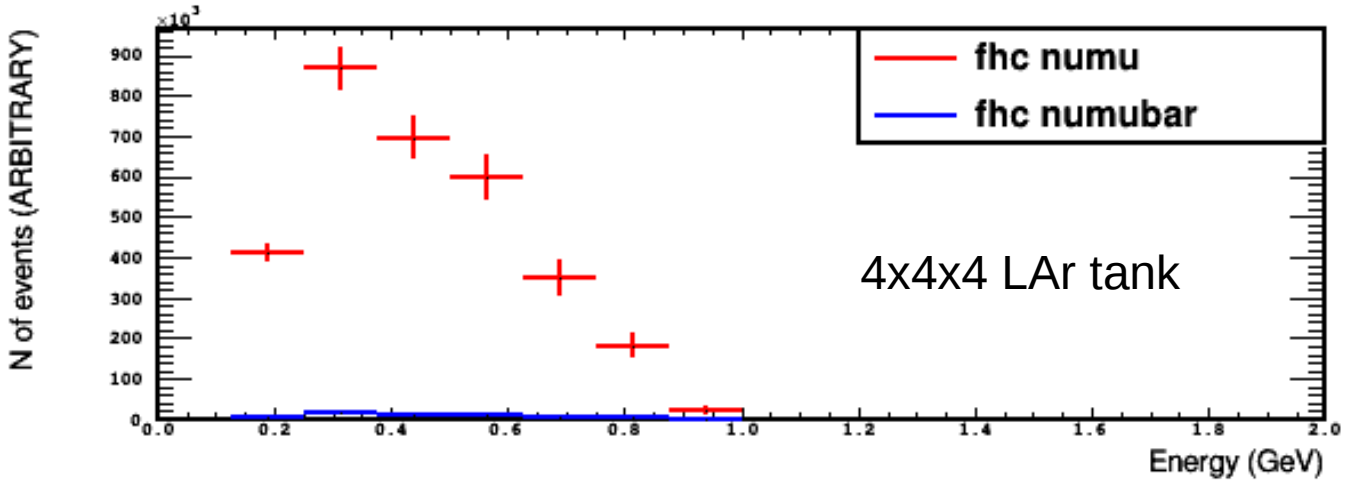
Average energy deposit values of previous page.

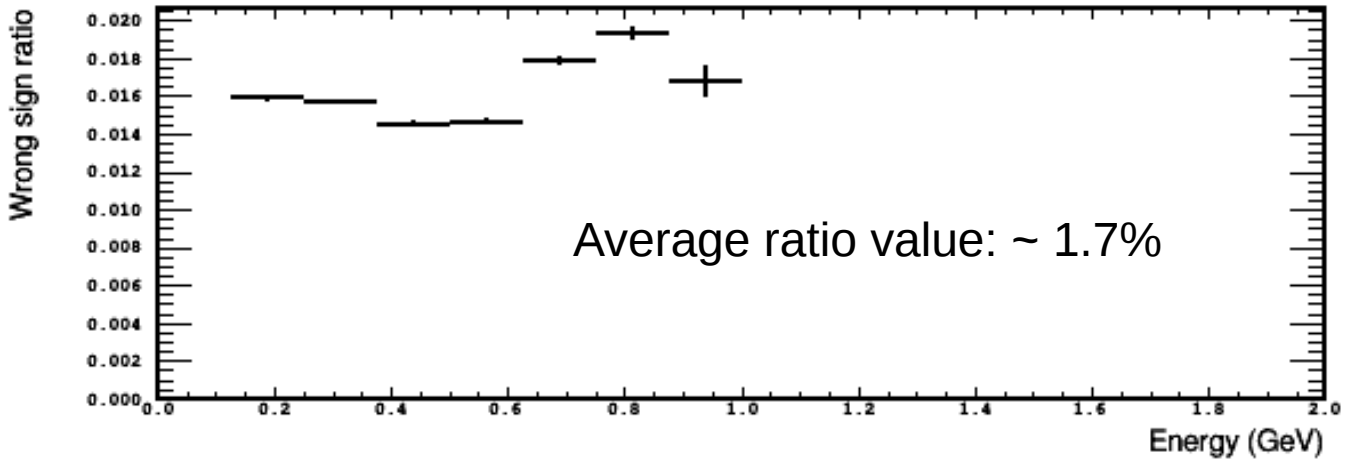




FHC Wrong sign nu ratio in LAr without B-field

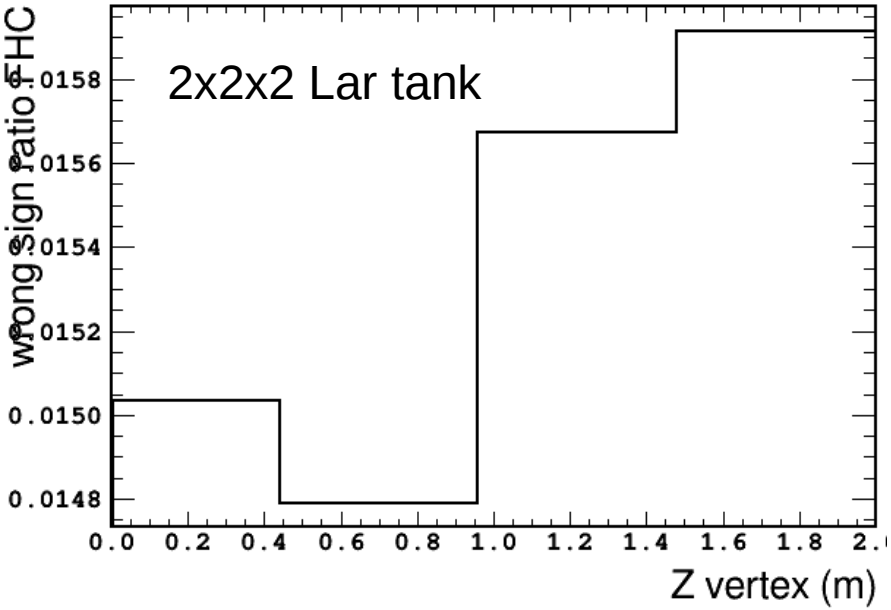
- All events that are contained inside LAr tank are taken into account.
- Flux, again is based on arxiv.1606.09550

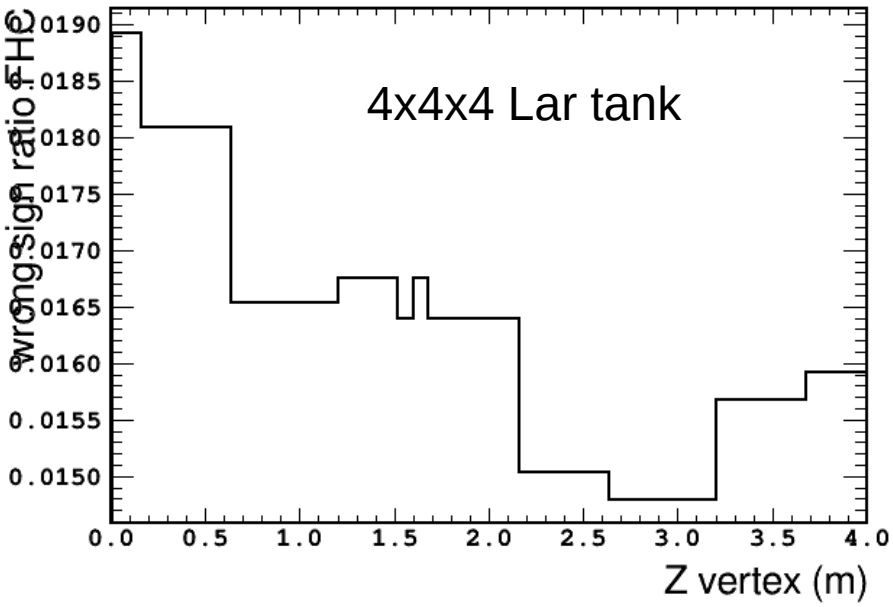




FHC Wrong sign ratio in LAr without B-field

- All events that cannot go out of the Lar tank are taken into account.
- Flux, again is based on arxiv.1606.09550

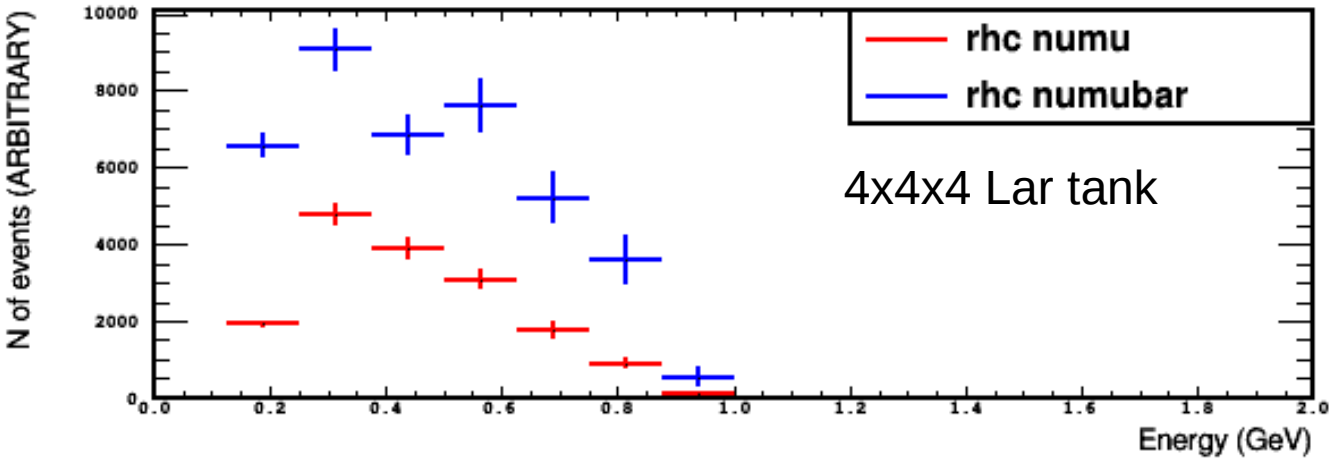


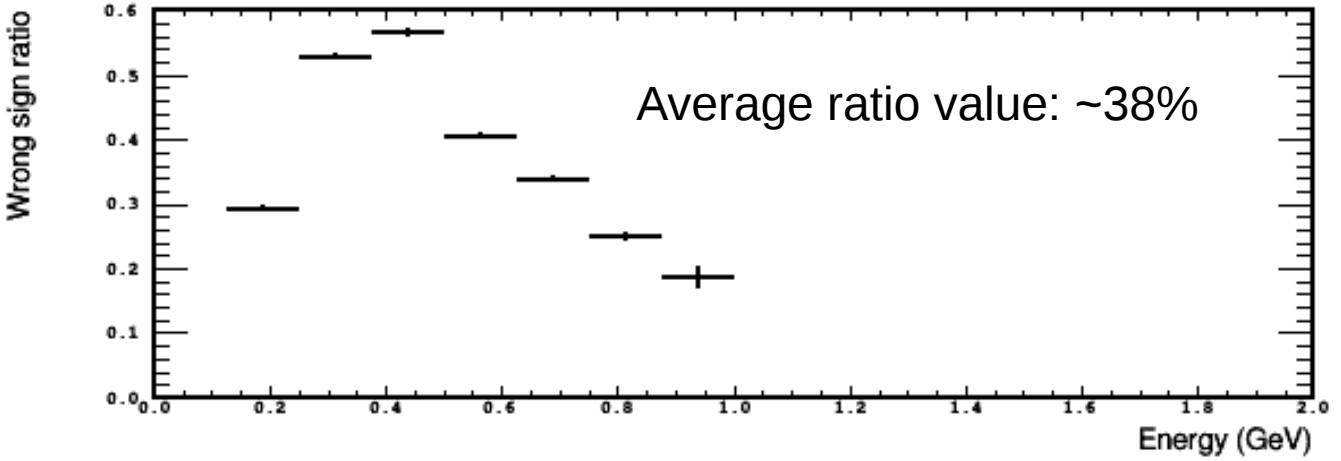


- For FHC, in energy below ~400 MeV, we may have wrong sign ratio of ~1-2%

RHC Wrong sign nu ratio in LAr without B-field

- All events that cannot go out of the Lar tank are taken into account.
- Flux, again is based on arxiv.1606.09550





RHC Wrong sign nu ratio in LAr without B-field

- All events that cannot go out of the Lar tank are taken into account.
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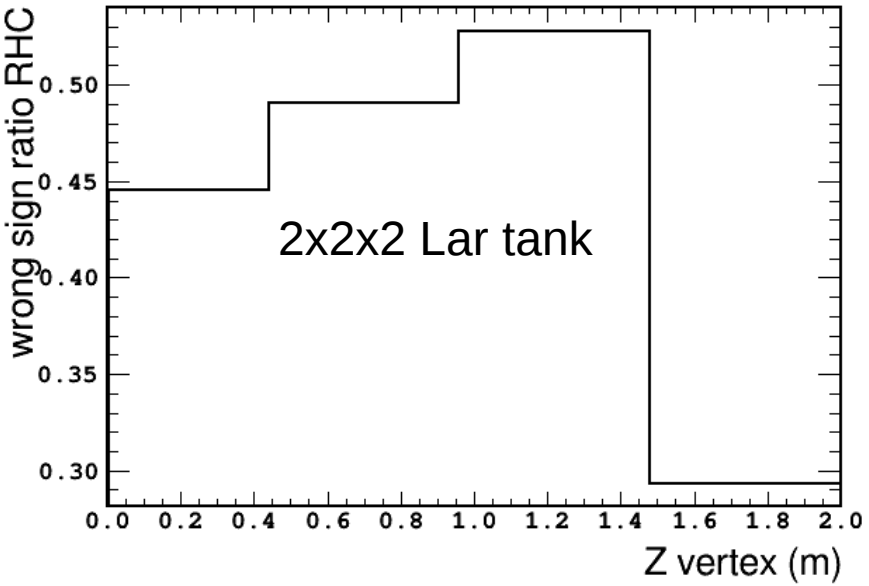
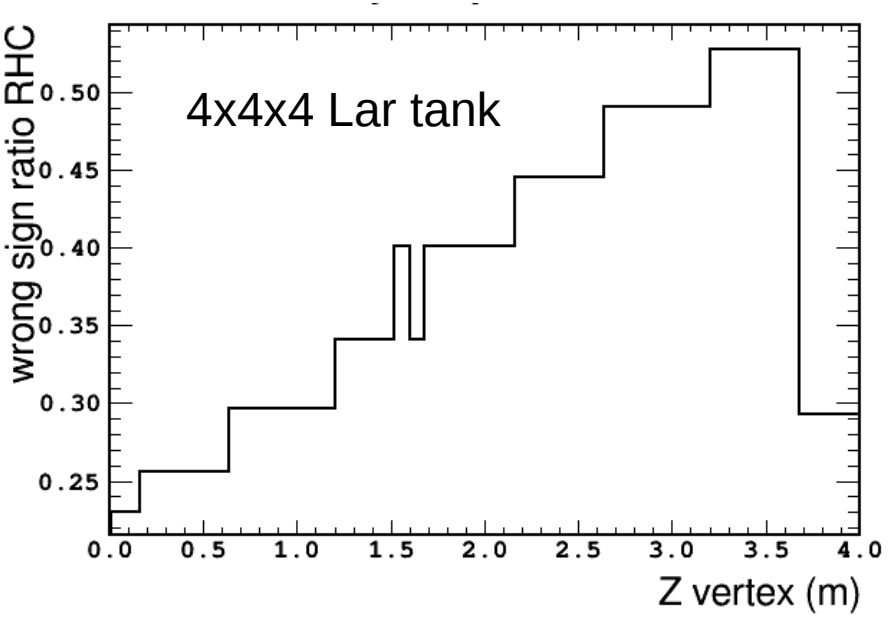


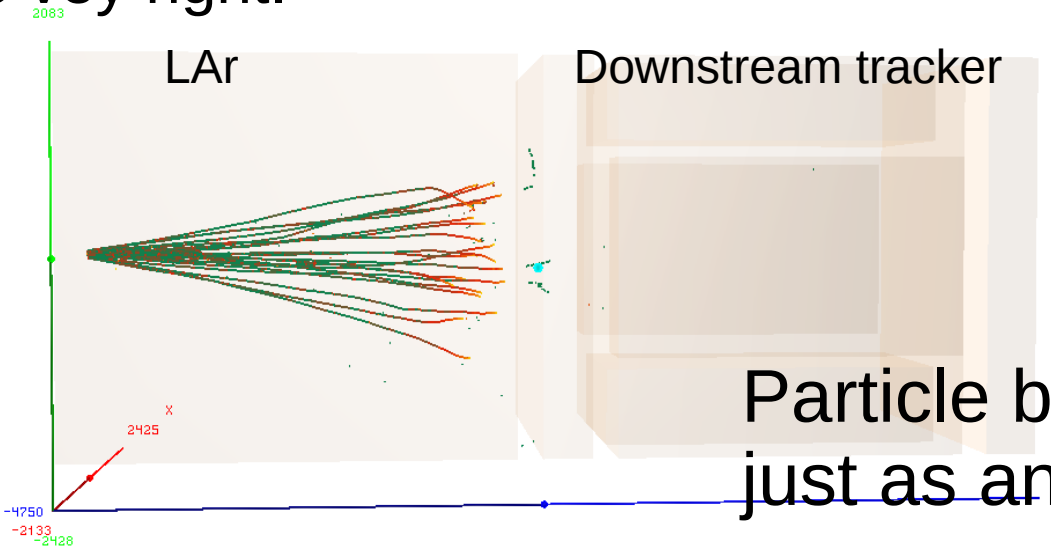


- For RHC, in energy below ~400 MeV, we may have wrong sign ratio of ~30-40%

Muon in Liquid Argon

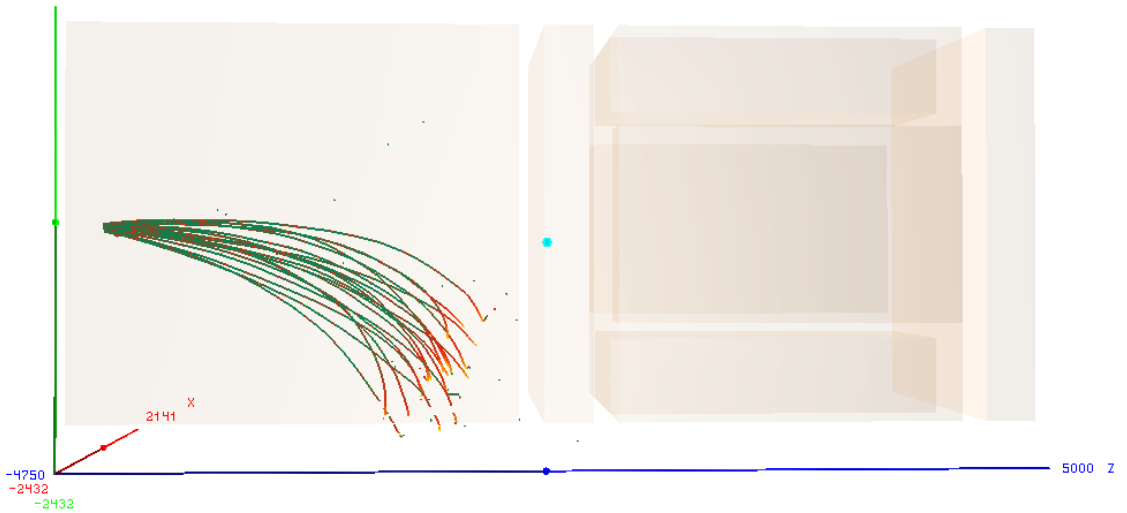
Now I am playing another game,
Shooting muon particle guns towards downstream direction from the very left to the vey right.

1 GeV muon
Without B-field



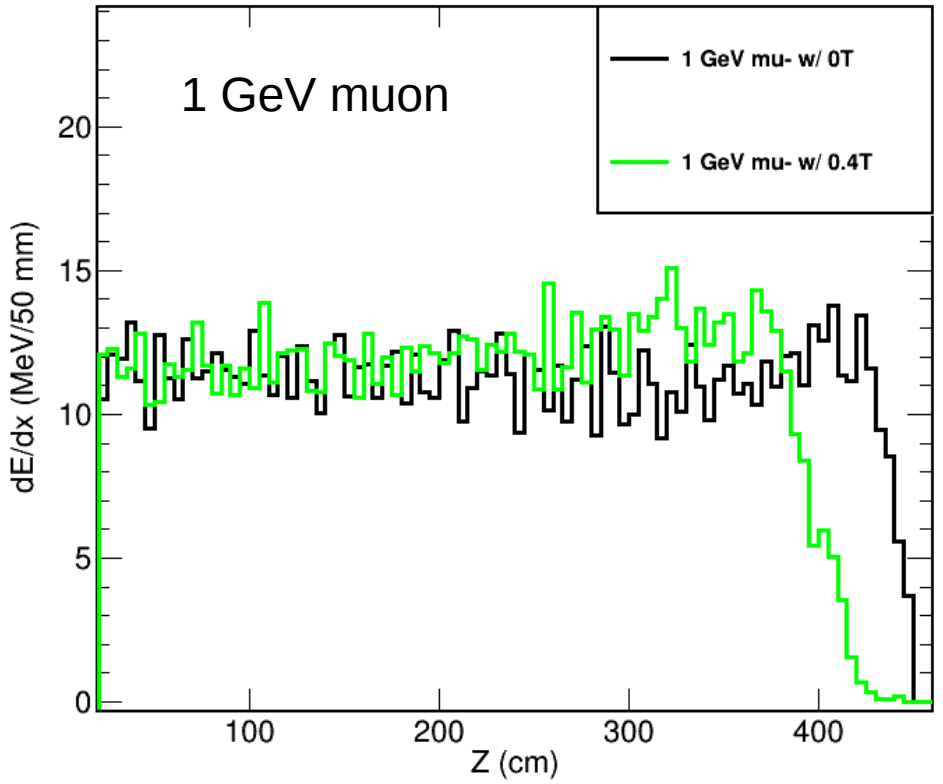
Particle burst
just as an example

1 GeV muon
With 0.4 T B-field



Muon dE/dx in Liquid Argon

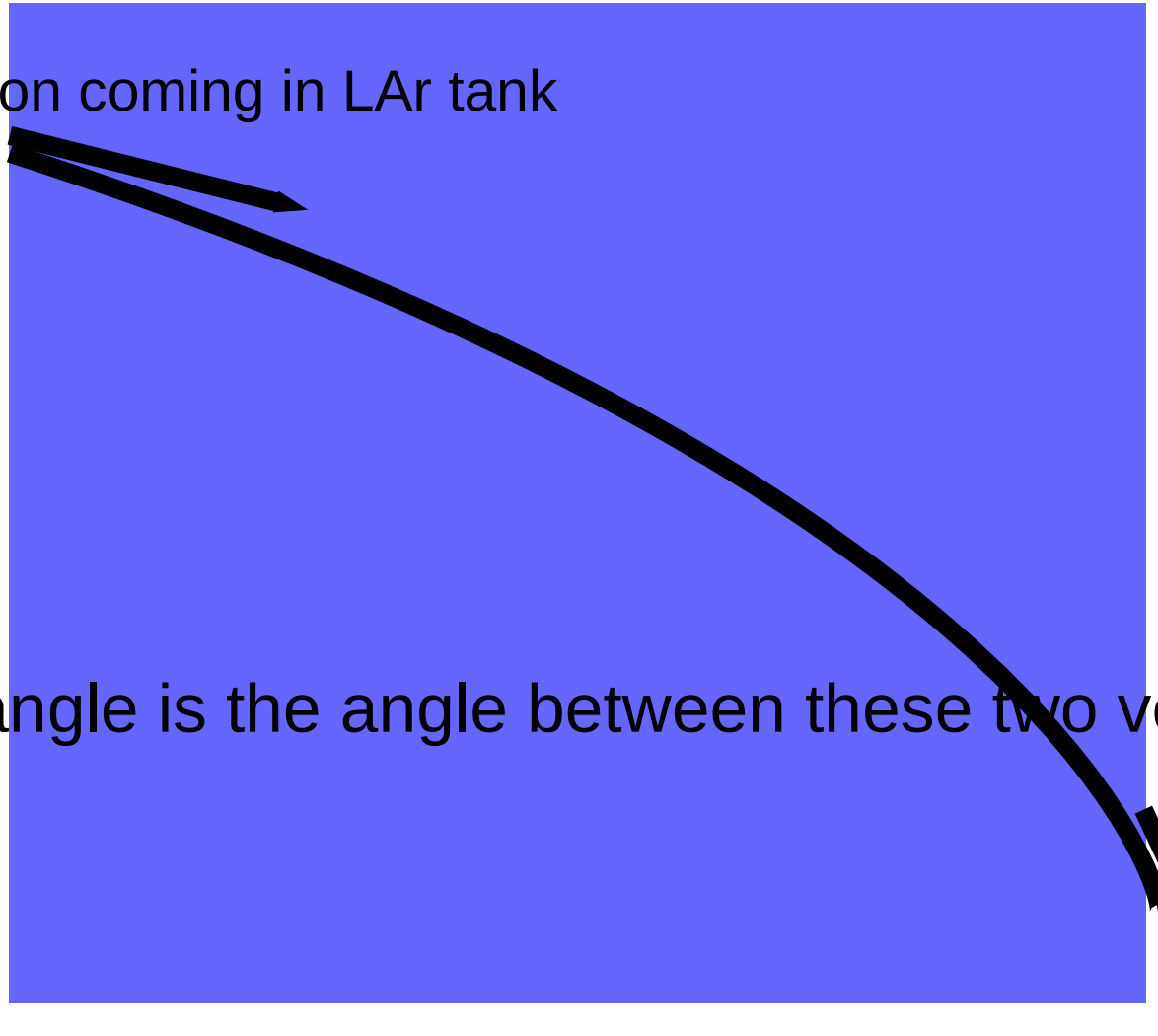
Averge dE/dx based on 1,000 events



- 2 and 3 GeV Cases are Also checked With similar Conclusion.

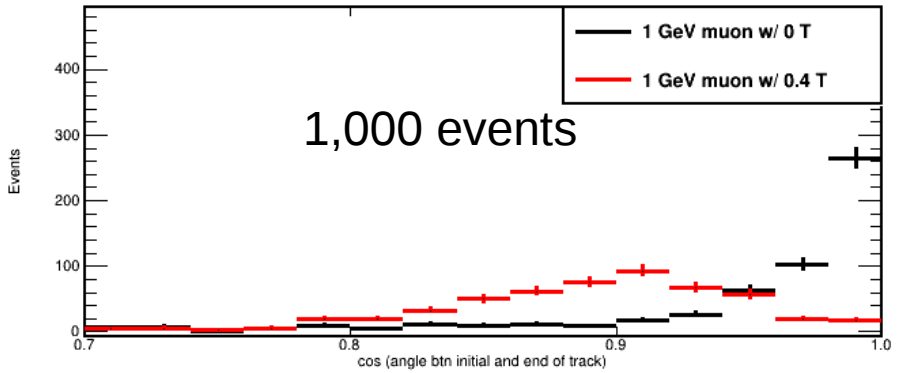
B-field dos not affect the muon dE/dx significantly.
B-field does not spoil the dE/dx informaiton significantly.

Muon (in-out) angle in Liquid Argon



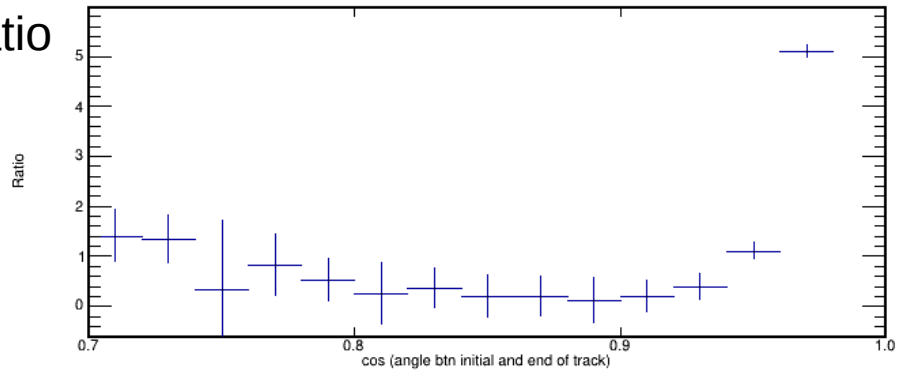
Bending angle is the angle between these two vectors

Bended muon angle in Liquid Argon



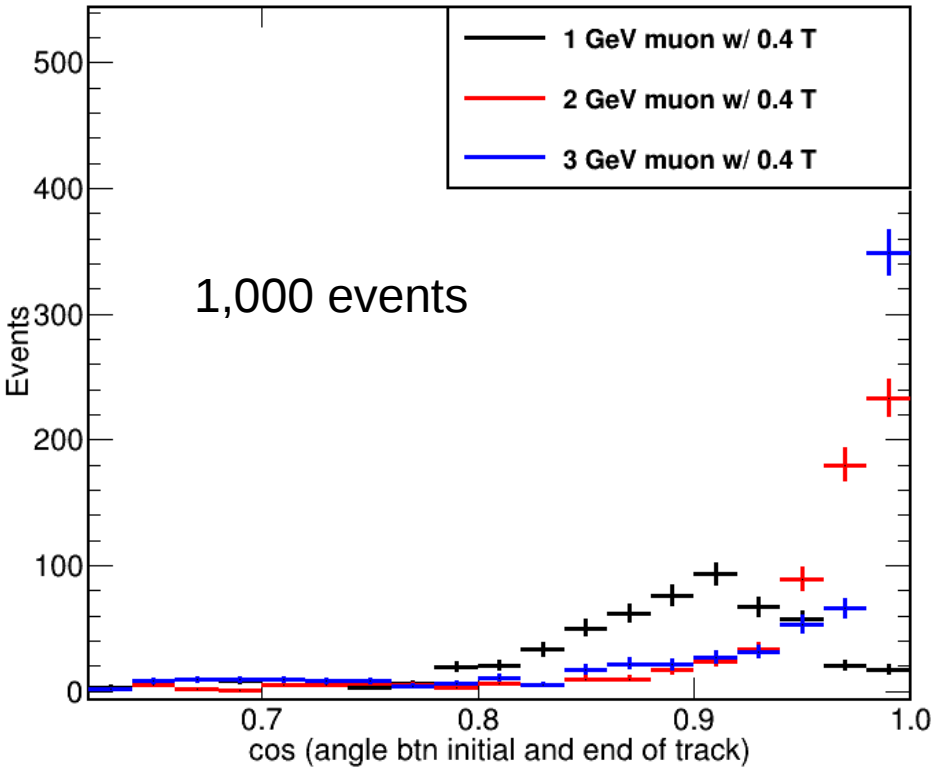
Cos (bended angle)

Ratio



Cos (bended angle)

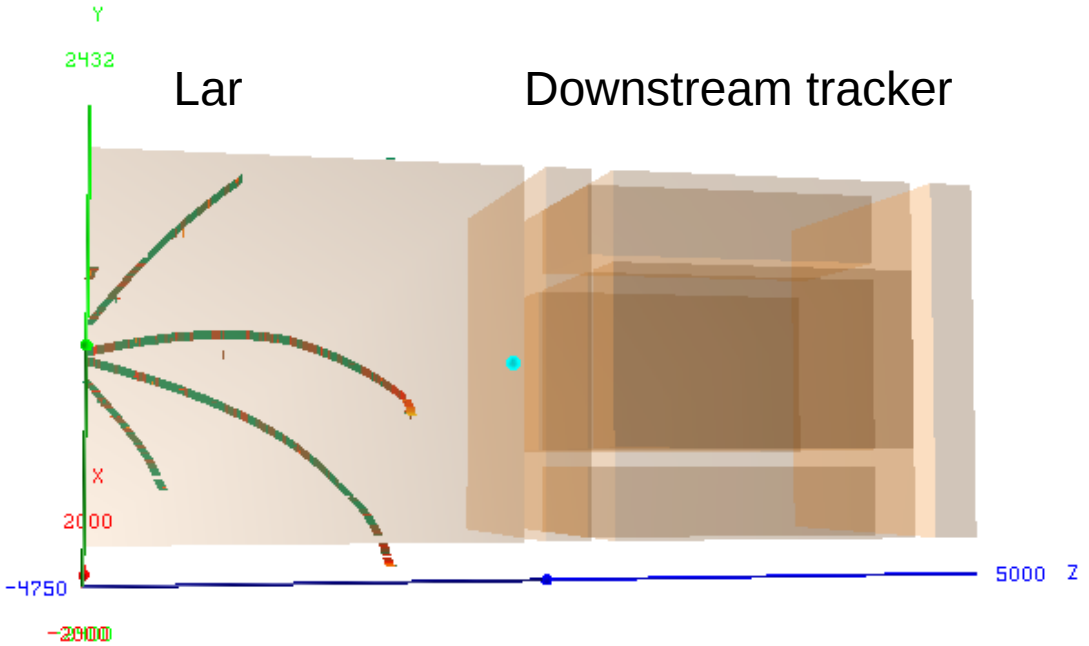
We see difference between the cases
W/ and w/o B-field.



B-field can help with the muon momentum reco.
Below ~2-3 GeV based on the bending angle.
- If we use full curve infomation,
  I guess the resolution will be better.

B-field makes muon acceptance rate higher

1 GeV muon
With 0.4 T B-field



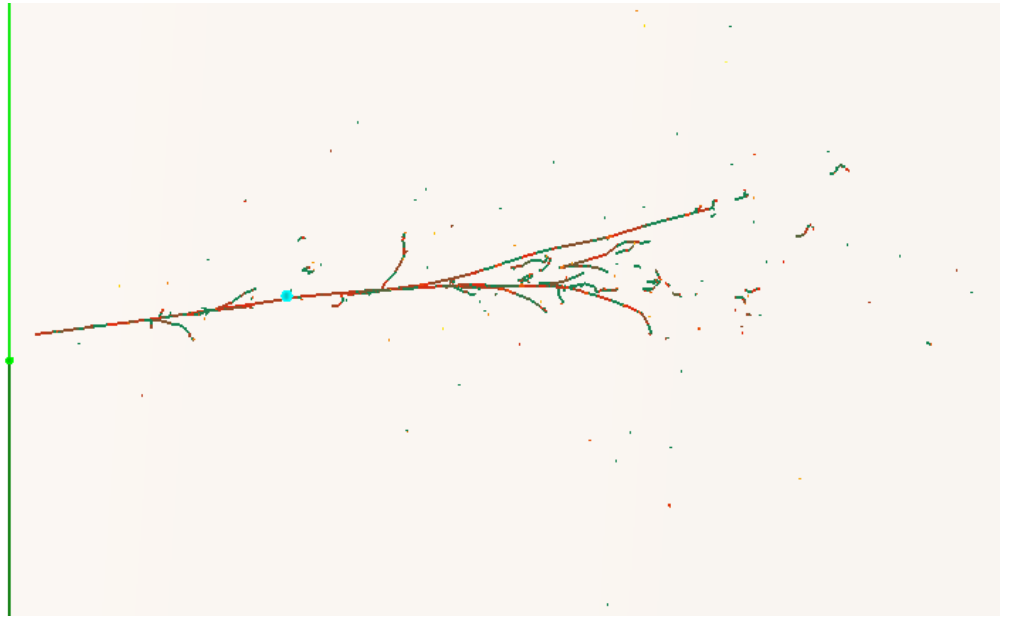
They are all possibly saved. One could do E-reco. With bending.

After neutrino interaction, regardless haronic part, fraction of CCQE muons that would go out through the side faces is: ~20%.

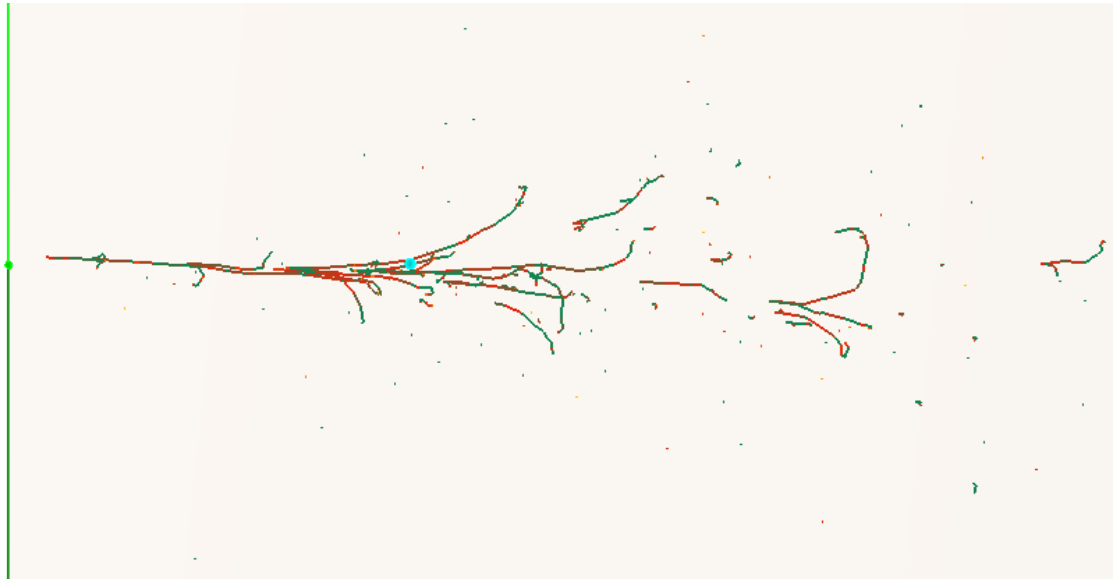
Electron in Liquid Argon

Electron in Liquid Argon

1 GeV electron
Without B-field



1 GeV electron
With 0.4 T B-field



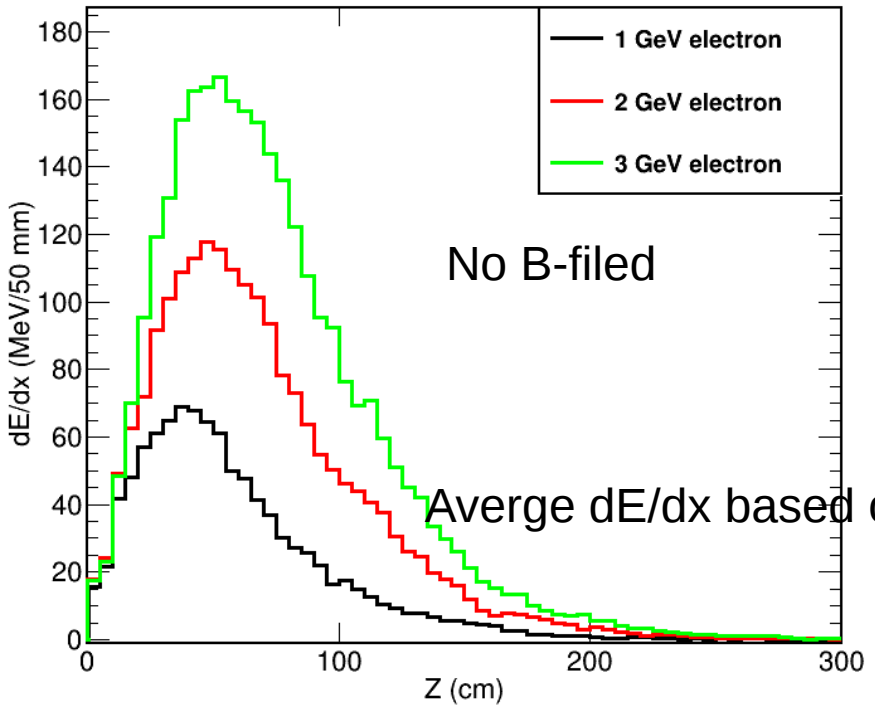
Electron in Liquid Argon

- Would B-field affect the direction informaiton of neutrino-electron scattering?
- Would B-fied help the sign determination? (similar to above)
- How well is the electron energy reconstruction including the B-field bending?

Energy reco in LAr with dE/dx

Comparison of 1, 2 and 3 GeV w/o B-filed.

Both rate and shape can be used
To do the energy reco.

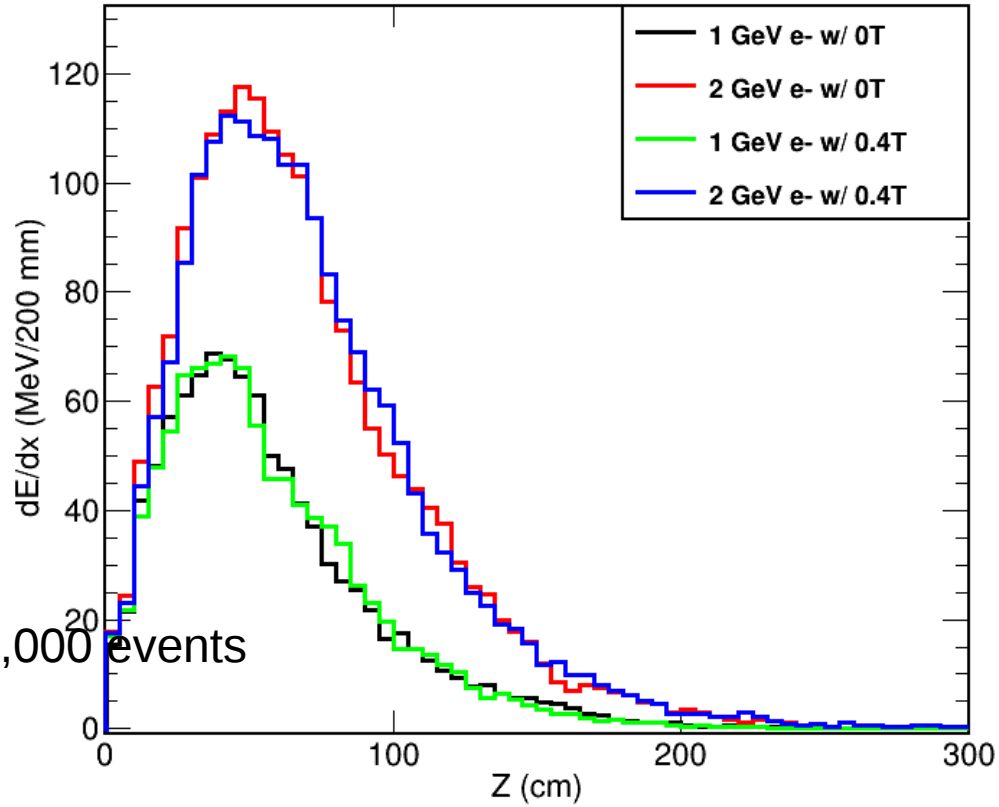


No B-filed

Averge dE/dx based on 1,000 events

Brems happens in ~10-20 cm.

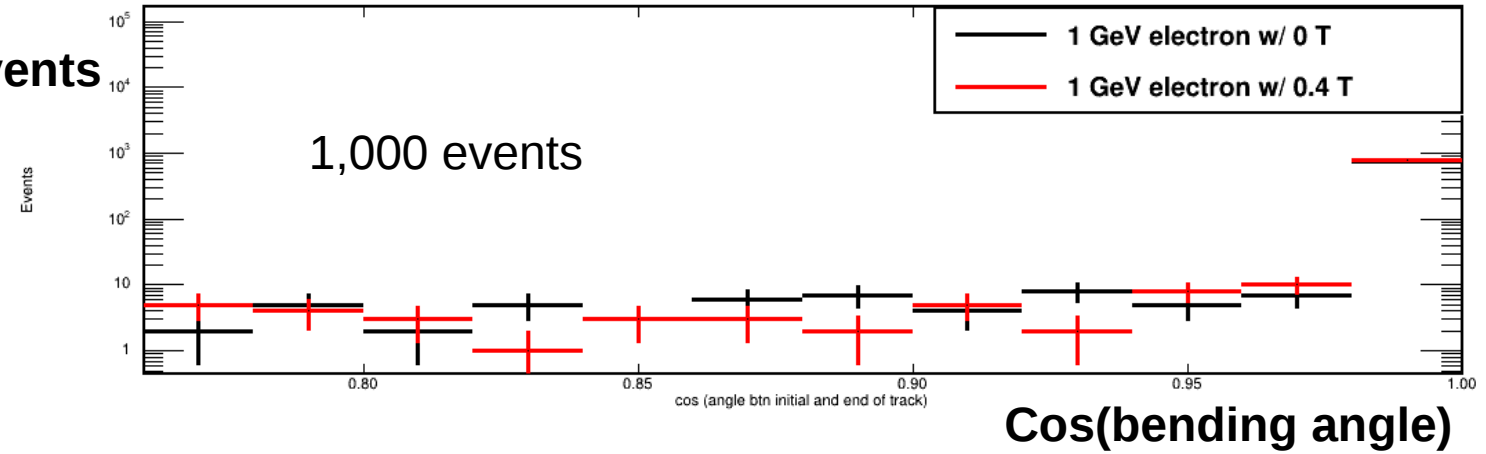
Comparison of 1 and 2 GeV w/ and w/o B-filed



Hard to tell the difference between cases
W/ and w/o B-filed

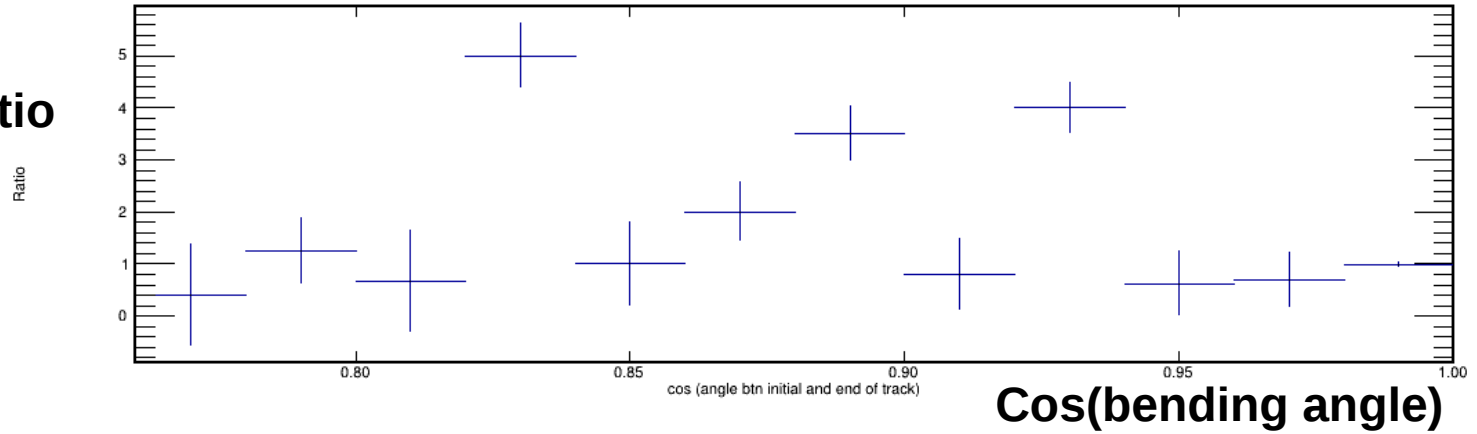
Before Brems, angle btn initial and end directions w/ and w/o B-field

Events



Cos(bending angle)

Ratio



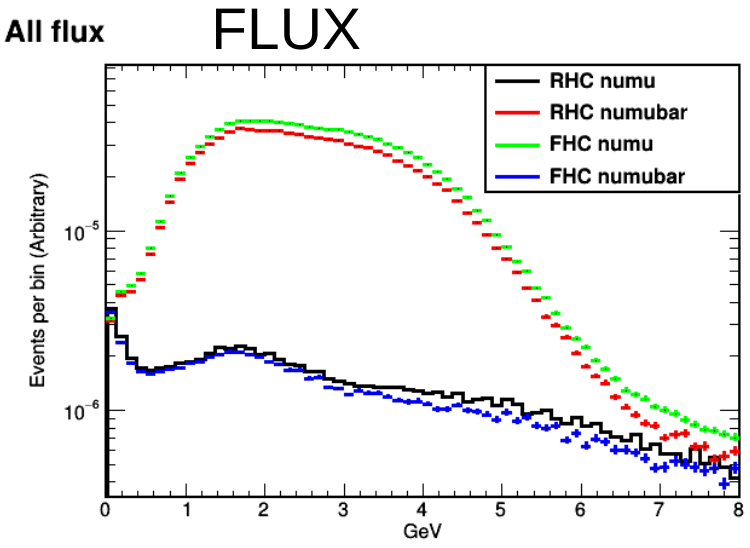
Cos(bending angle)

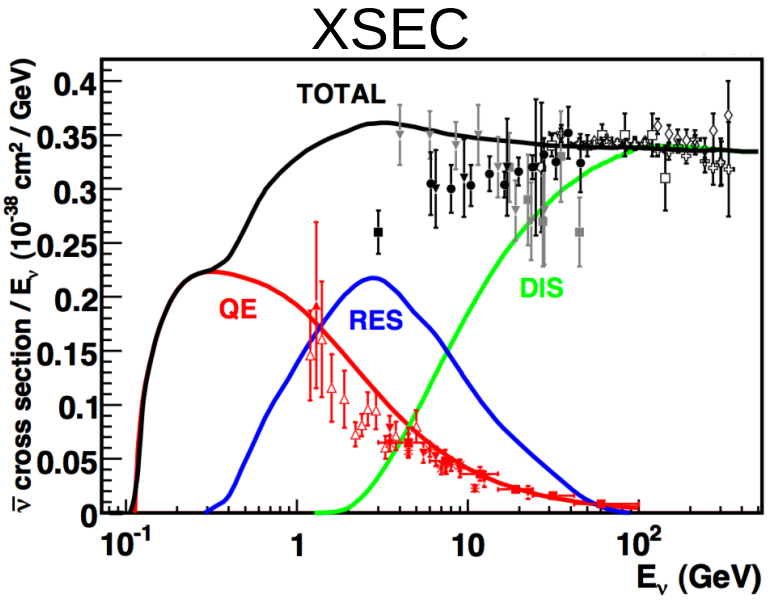
- 2 and 3 GeV Cases are Also checked With similar Conclusion.

- For electron w/ B-field, multiple scattering dominates over Lorentz force bend.
- We could do neutrino-electron scattering with B-field as good as without that.

Few words on charged pion in Liquid Argon (CC res.)

- We could investigate how to deal with charged pions.
- Radiation length is ~60 cm, so how much the B-field bending may help with the E-reco.?





Conclusion

- B-field helps low energy muon sign separation.
  - low energy wrong sign BG contained without B-field.

    30-40% for RHC and 1-2% for FHC
- B-field helps muon energy reco.
  - we might a larger sample of muons (~20% for CCQE at least).
- B-field has no significant impact on electron.
- Next is B-field on pion study.

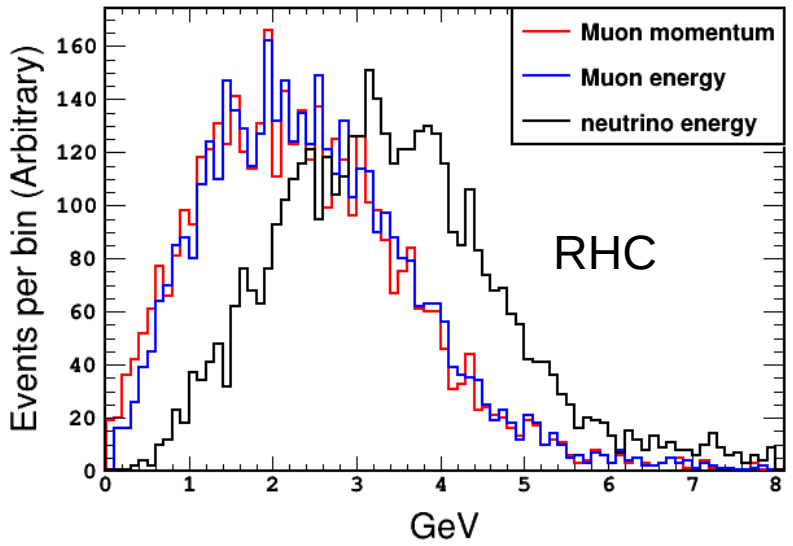
Backup

...

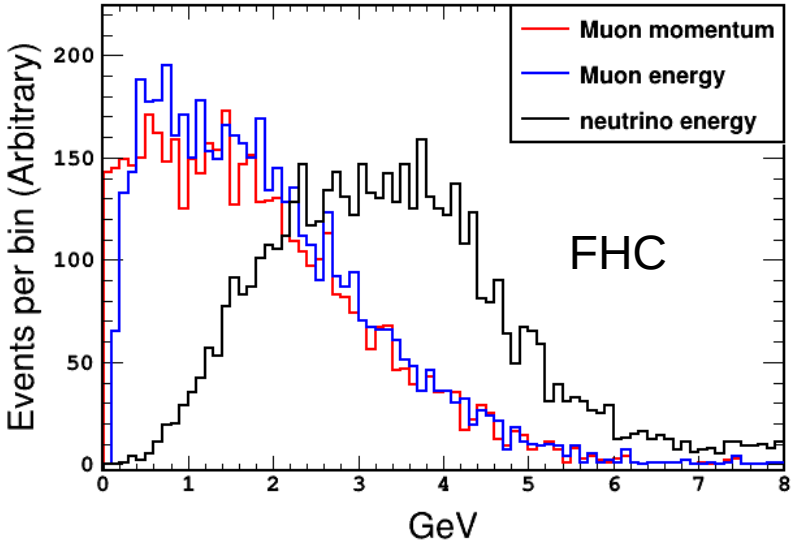
DUNE flux

Select only CCQE events from GENIE.

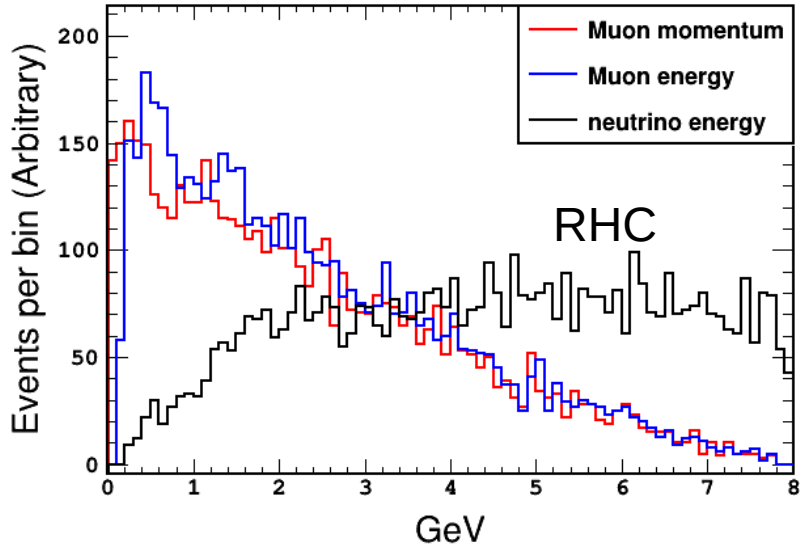
CCQE Right



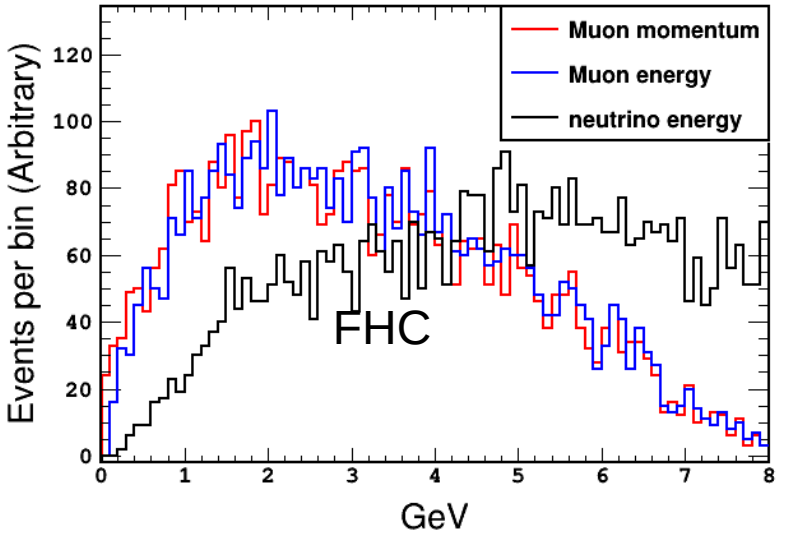
CCQE Right



CCQE Wrong

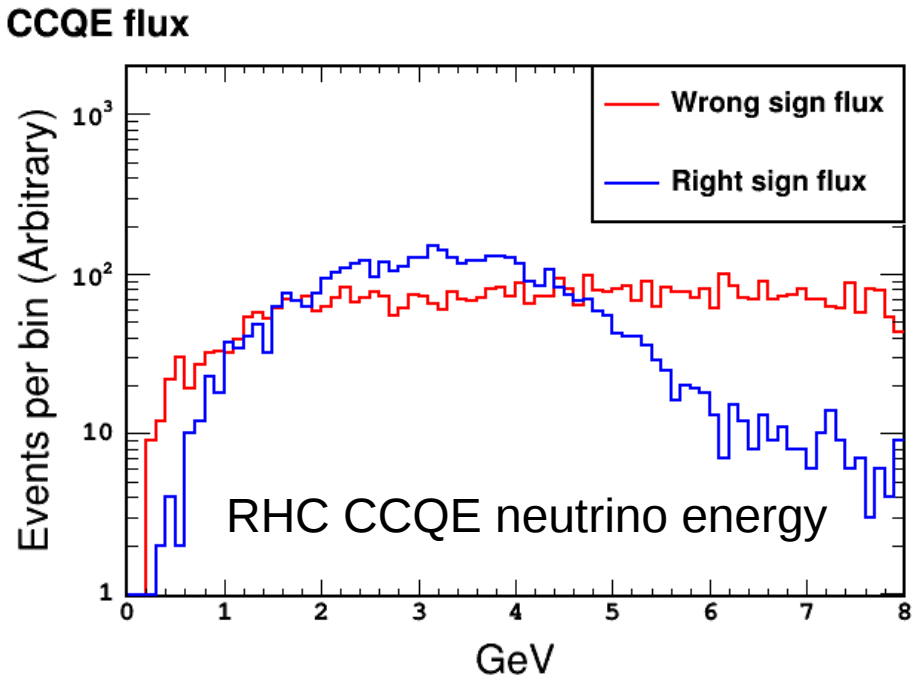


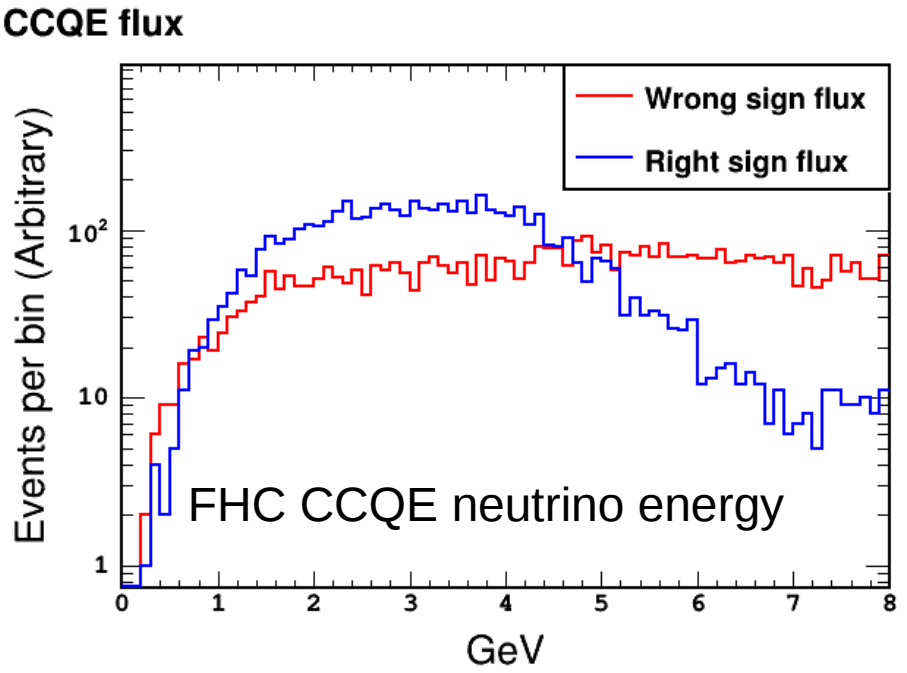
CCQE Wrong



DUNE flux

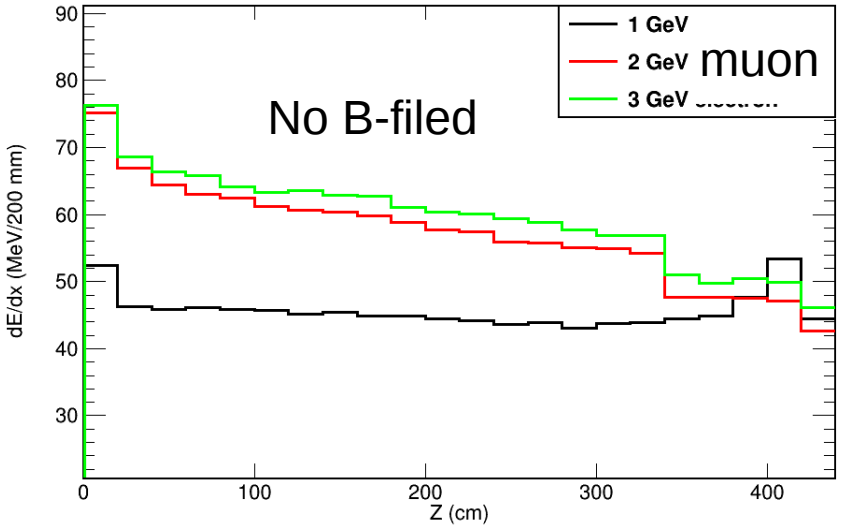
Select only CCQE events from GENIE, shape only.
Rates are from Xsec only, not scaled by flux.



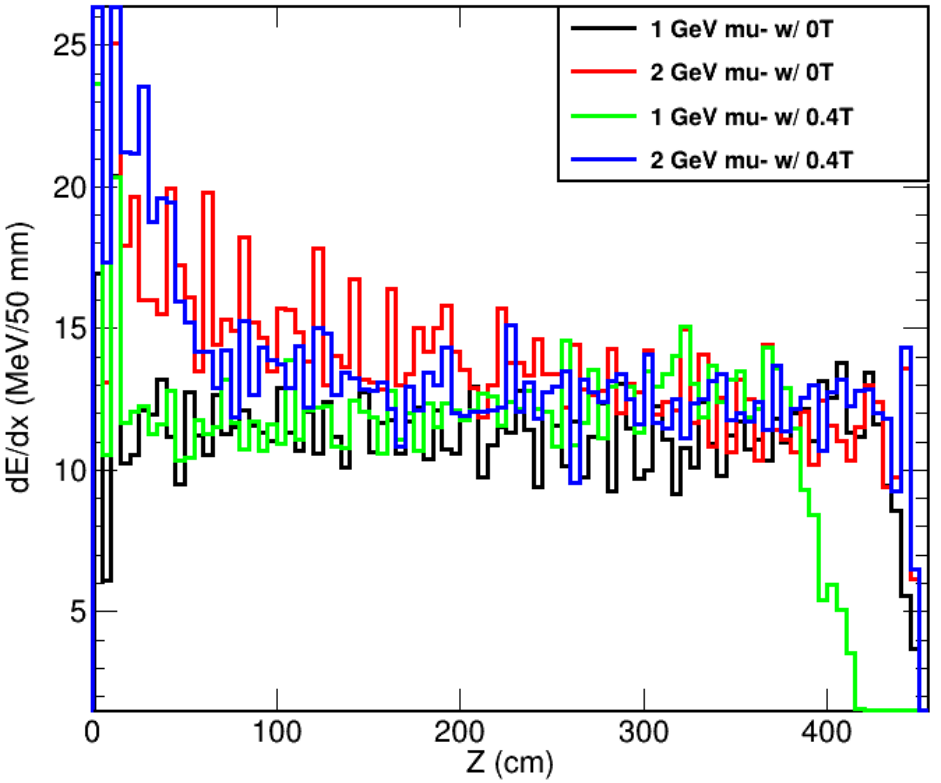


Muon dE/dx in Liquid Argon

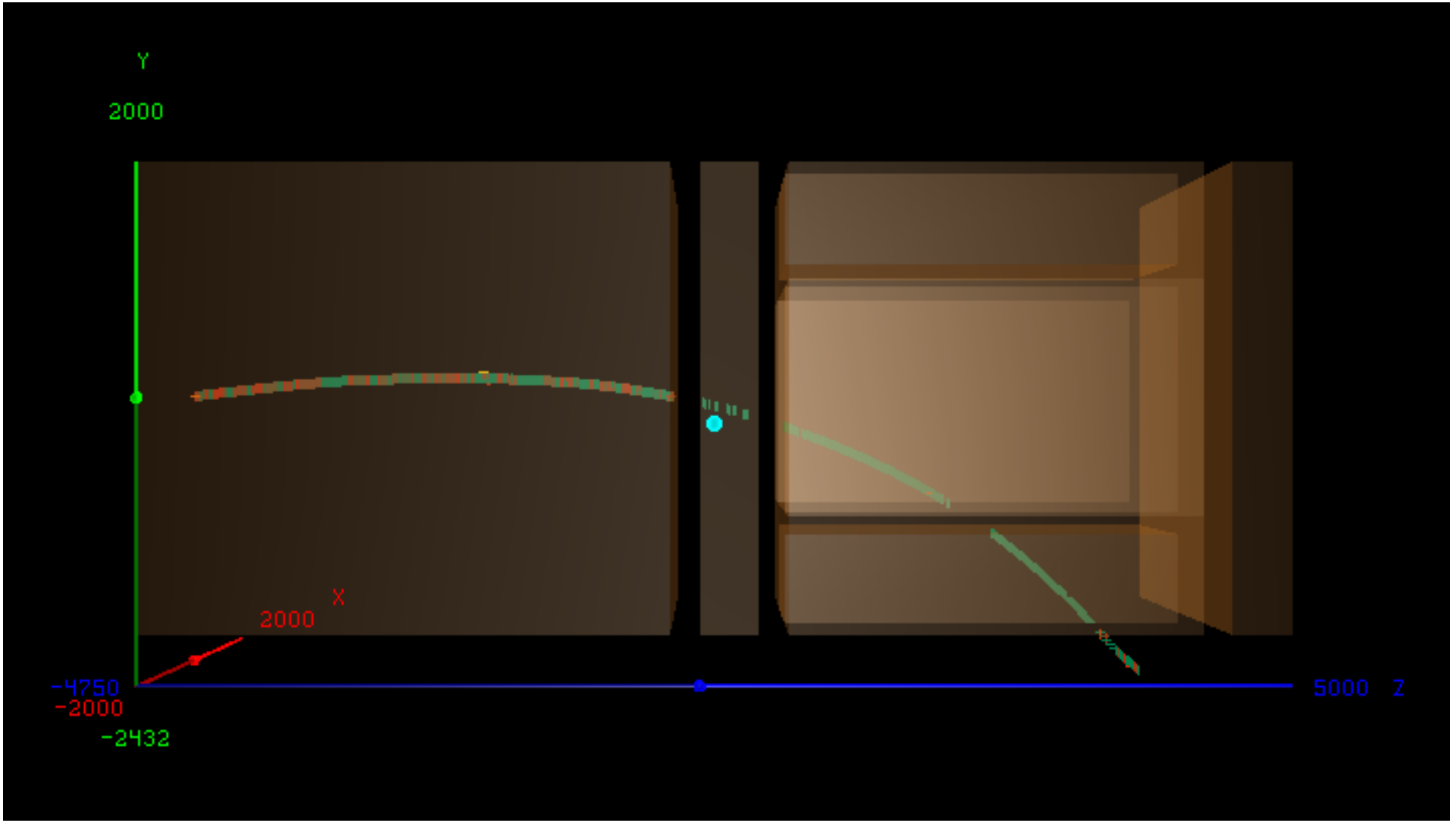
Averge dE/dx based on 1,000 events



Muon dE/dx may be directly used for Energy reco.



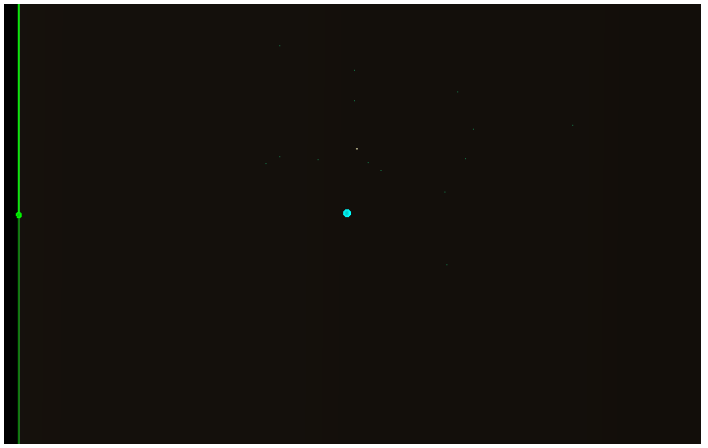
B-field dos not affect the muon dE/dx significantly.


Y
2000
X
2000
-4750
-2000
-2432
5000
Z

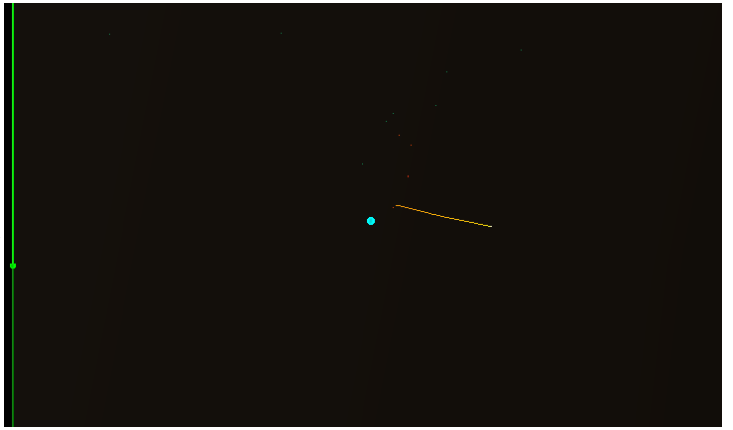
How do we deal with neutrons?

Just post few neutron displays in edep-sim. I don‘t know how to deal with neutron now.

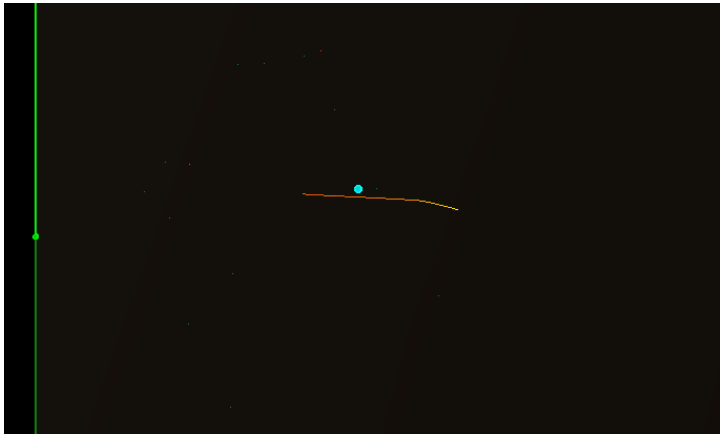
100 MeV



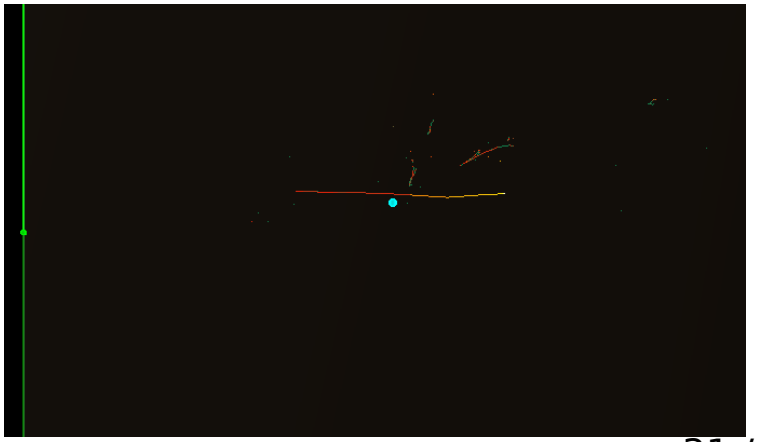
300 MeV



500 MeV

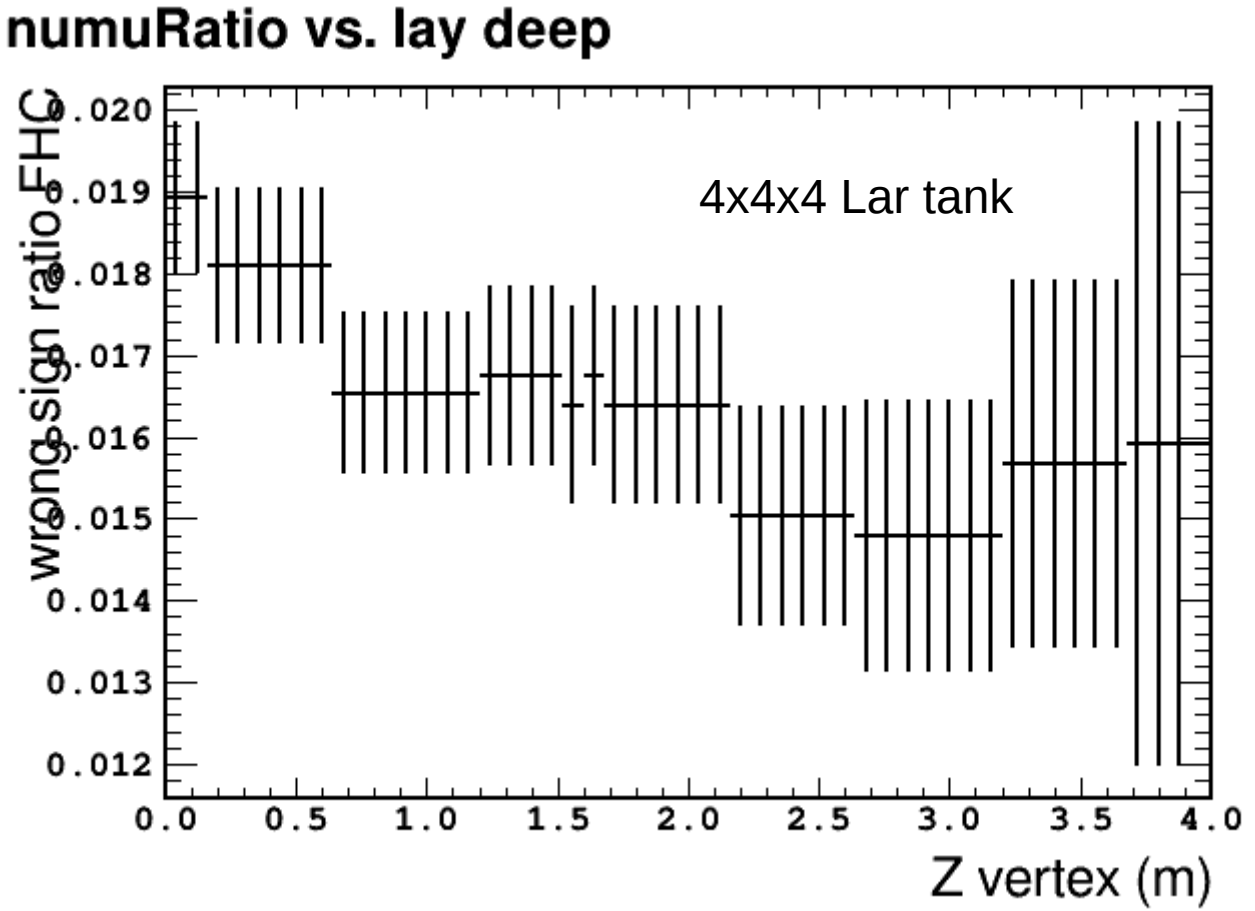


1 GeV



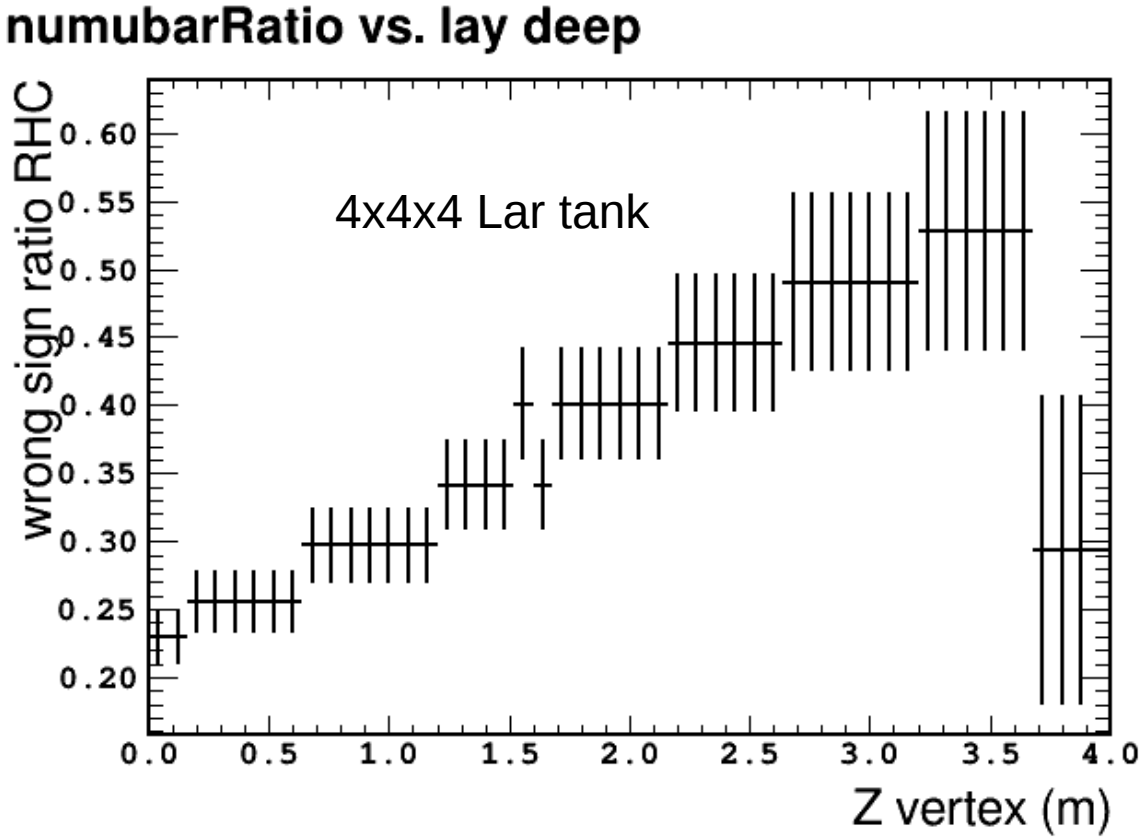
FHC Wrong sign nu ratio in LAr without B-field

- Dips are due to fluctuation.
- All events that cannot go out of the Lar tank are taken into account.
- The shape structure is due to the finite binning of neutrino flux.



RHC Wrong sign nu ratio in LAr without B-field

- Dips are due to fluctuation.
- All events that cannot go out of the Lar tank are taken into account.
- The shape structure is due to the finite binning of neutrino flux.



Simple study with LAr

- Muon in Lar : Energy deposit, Magnetic field impact
- Electron in Lar : Energy deposit, Magnetic field impact
- Neutron in Lar: don‘t know how to do

Question list

1. How to determine Brems starts?
2. neutron in T2K? Neuron in DUNE?
3. How T2K upgrade disentangle flux and Xsec?

Electron in Liquid Argon

1. Brems – Initial direction angle for electron
   - With and without magnetic field : Seems no difference?
2. track before Brems with Mag. field for electron
   - How well to reconstruct the momentum,
     do a 1, 2, 3 GeV angle comparison : no good?
   - Compare to Gamma : how well to separate
     gamma? → But this will be uncorrelated to FD : no good?
3. Without Mag. Field, how well E-reco.?
   - dE/dx vs. Z for 1 GeV, 2 GeV and 3 GeV
4. Direction resolution : to reconstruct nu energy?
5. Look at different particle, such as n, gamma..
   - Is there a chance to measure neutron?

Pion in T2K

- POD: dE/dx for CC1pi+, efficiency is super low due to 1. require exactly two tracks; 2. only downstream face. (no charge separtion based on technote.)
- Gas TPC: dE/dx for pion. Charged separated by magnetic field.
- FGD: dE/dx for pion. Charged separated by B-field.
- Good reading is T2K technote 136.

Pion in T2K

NEUT mode	Reaction	$\langle\sigma_{\nu_\mu}\rangle_\Phi$ on O $\left[\frac{\text{cm}^2}{\text{nucleon}}\right]$
11	$\nu_\mu + p \to \mu^- + p + \pi^+$	$1.22 \cdot 10^{-39}$
13	$\nu_\mu + n \to \mu^- + n + \pi^+$	$0.42 \cdot 10^{-39}$
16	$\nu_\mu + N \to \mu^- + N + \pi^+$	$0.12 \cdot 10^{-39}$
11, 13, 16		$1.76 \cdot 10^{-39}$

Table 2: NEUT predictions for the nucleon-level before-FSI ν_μ-induced CC1π^+ cross sections on oxygen calculated using MCP5E (Monte Carlo Production 5 Re-spin E) Runs 1 and 2 and 11b v3.2 flux tuning.

NEUT mode	Reaction name	Reaction
1	Charged-current quasi-elastic (CCQE)	$\nu + n \to l^- + p$
11	Resonant π^+ production	$\nu + p \to l^- + p + \pi^+$
12	Resonant π^0 production	$\nu + n \to l^- + p + \pi^0$
13	Resonant π^+ production	$\nu + n \to l^- + n + \pi^+$
16	Coherent π^+ production	$\nu + N \to l^- + N + \pi^+$
21	Multiple π production	$\nu + (n\|p) \to l^- + (n\|p) + \text{multi-}\pi$
22	Single η^0 from δ resonance	$\nu + n \to l^- + p + \eta^0$
23	Single K^+ from delta resonance	$\nu + n \to l^- + \Lambda + K^+$
26	Deep inelastic scattering	$\nu + (n\|p) \to l^- + (n\|p) + \text{mesons}$

Table 1: Charged current before-FSI NEUT interaction modes contributing to both signal and background. The rows are sorted in the order of increasing NEUT mode number.

Pion in T2K POD (CC1pi+)

N_w $(data)$	2703.00
B_w	1208.03
B_w^{sand}	2.50
ϵ_w	7.21%
p_w	50.79%
N_a $(data)$	2187.00
B_a	931.98
B_a^{sand}	3.85
ϵ_a	6.33%
p_a	50.97%

Table 11: Summary of event selection for both sub-selections. Numbers here are without any corrections. Quantities with subscript 'w' correspond water-in sample and 'a' to water-out (air) sample. N_w and N_a are the selected number of events in data. Other quantities are calculated using Monte Carlo simulation.

Pion in T2K FGD

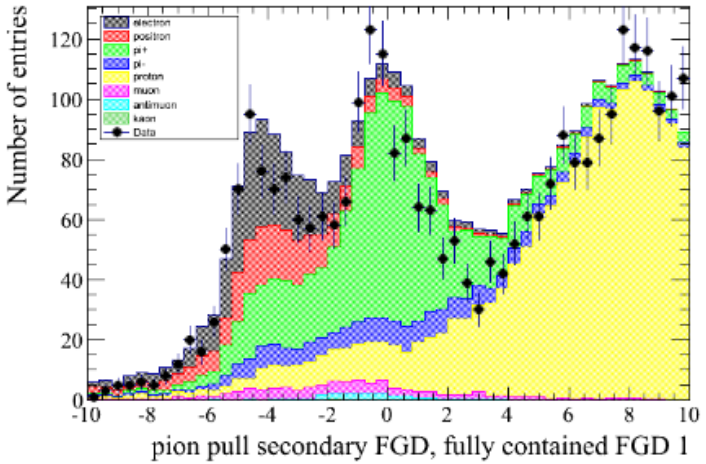


Figure 14: Pion pull distribution of the FGD-only tracks in the *CC* sample, without apply specific cuts to identify pions.

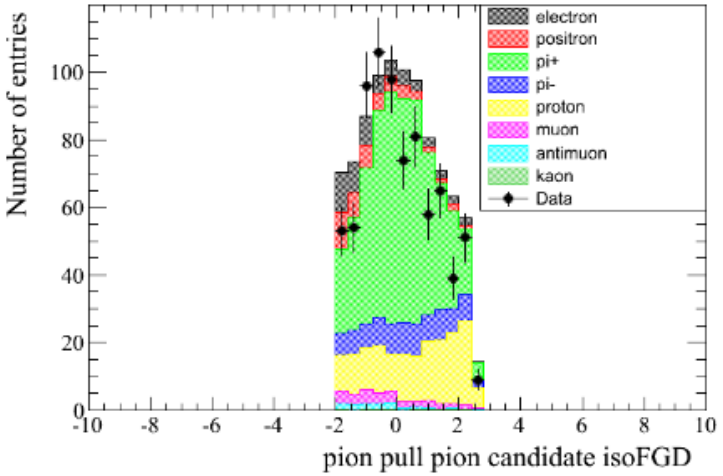


Figure 15: Pion pull distribution of the selected positive pions in the FGD-only tracks for the CC sample.

Pion in T2K FGD+TPC

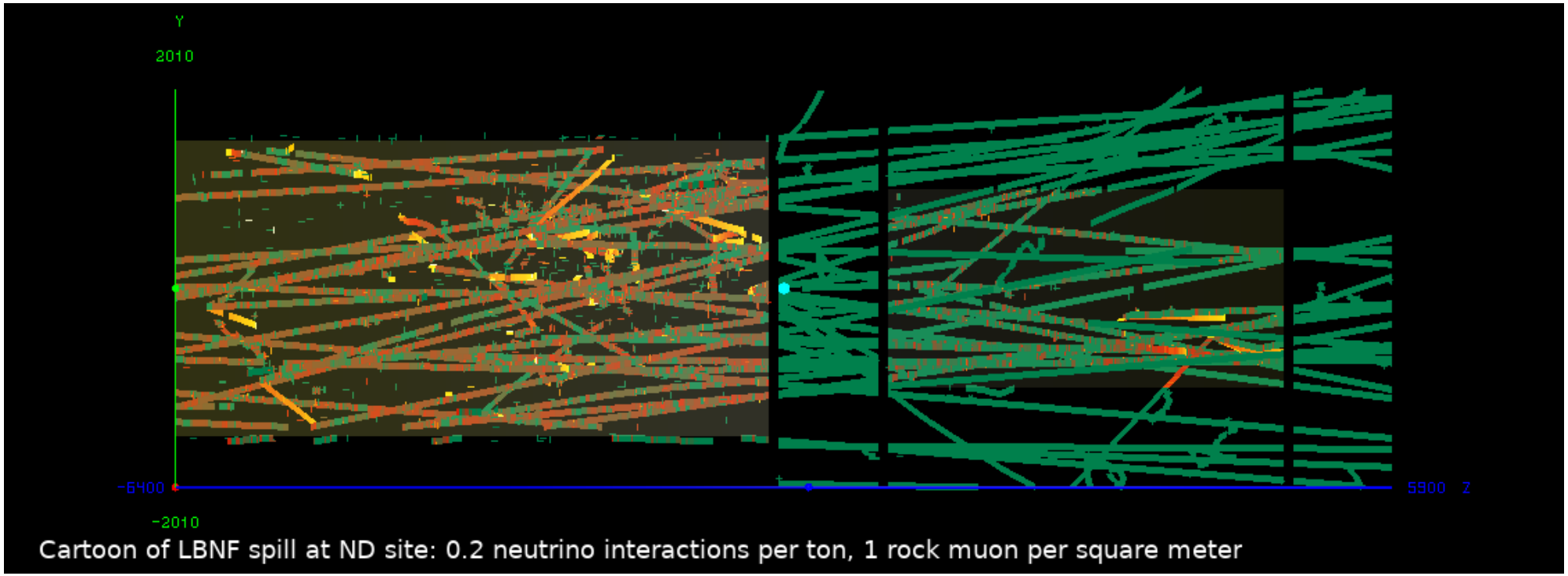
True particle	Fraction (%)
μ^-	89.8
μ^+	0.36
e^-	0.44
e^+	0.08
π^-	7.5
π^+	1.3
p	0.44
$other$	0.1

Table 4: Composition for the CC-inclusive sample, according to the particle type selected as muon candidate.

Sample	Efficiency (%)
CC-0-Pion	47.81
CC-1-Pion	28.37
CC-Other	29.71

Table 5: Efficiency per each sample. The efficiency is defined as the number of events in the given sample, where the true category matches the selected category, over the number of events generated in the FGD1 FV with true category corresponding to the category of the selected sample.

Pile-up per spill



Cartoon of LBNF spill at ND site: 0.2 neutrino interactions per ton, 1 rock muon per square meter

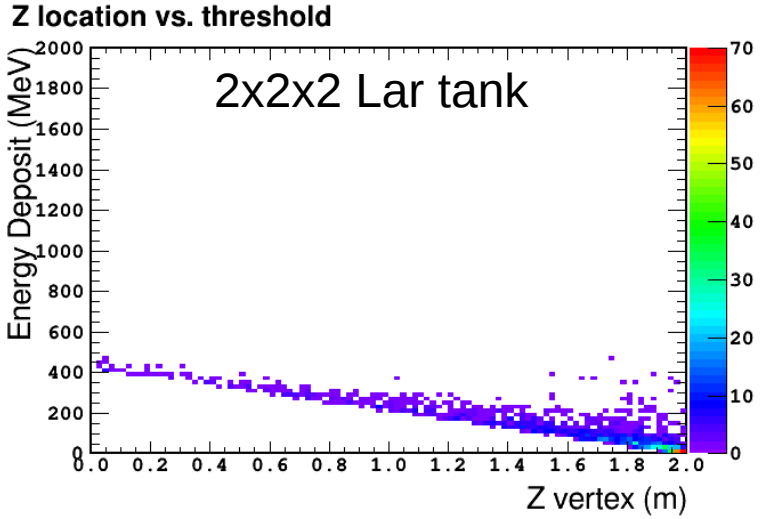
Disclaimer

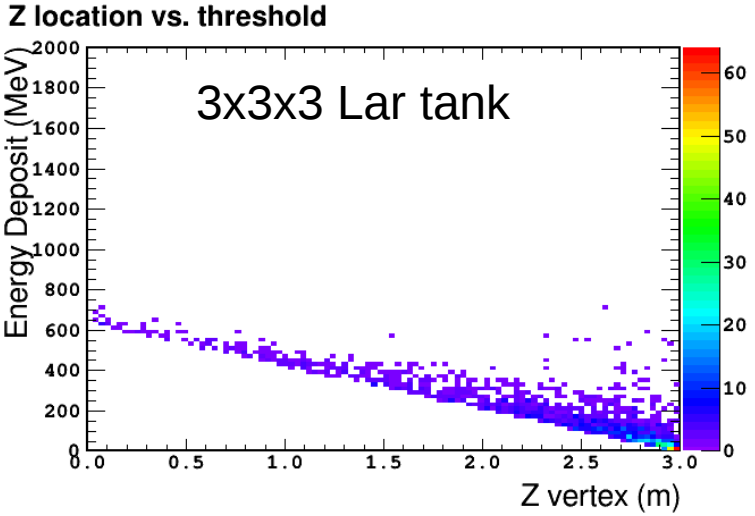
- All results and conclusions are based on true information.
  No reconstruction has been applied yet.

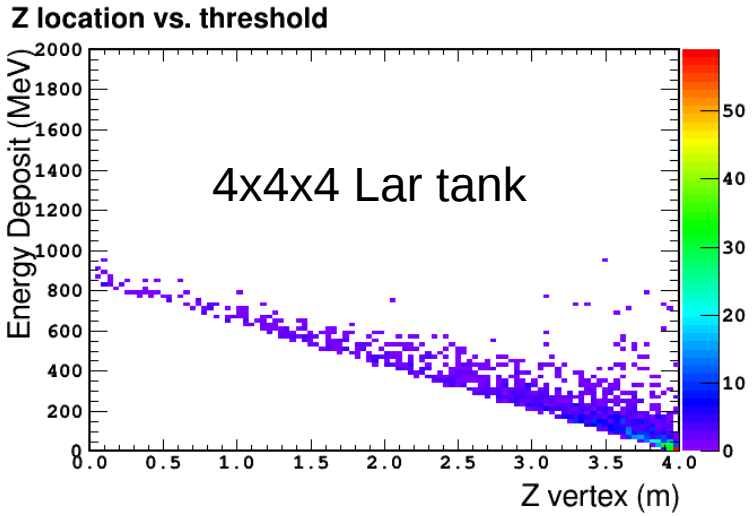
- I am using the tools of dunendggd and dune-ndx(G4), which
  Were introduced by Jose yesterday.

Muon Energy deposit in Lar

10,000 muon events are generated in simulation to study the energy deposit in a simple Lar tank.







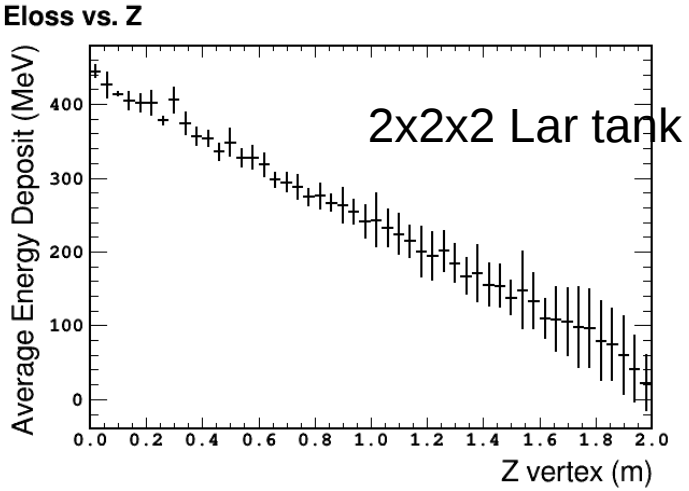
- As detector size increases, the nu and nubar Separation thresold is increasing, if muons going Downstream.

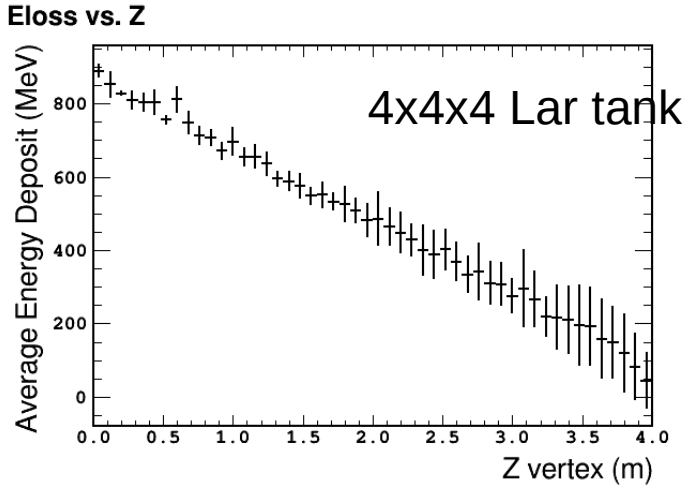
DO TWO CASES

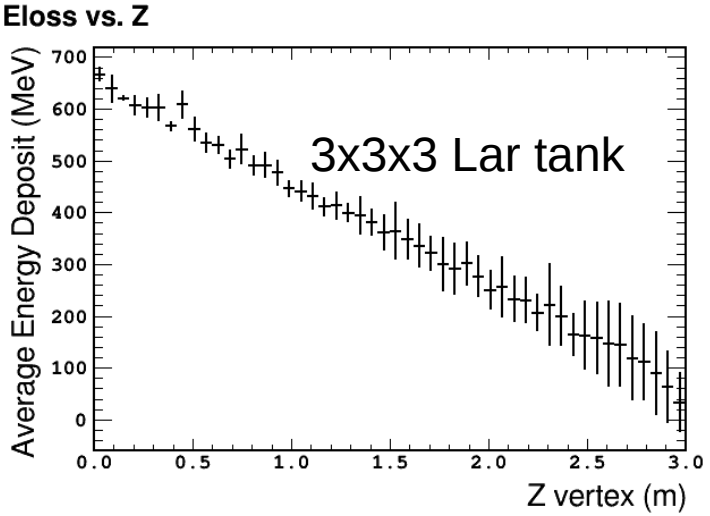
Muon Energy deposit in Lar

10,000 muon events are generated in simulation to study the energy deposit in a simple Lar tank.

Average energy deposit values of previous page.

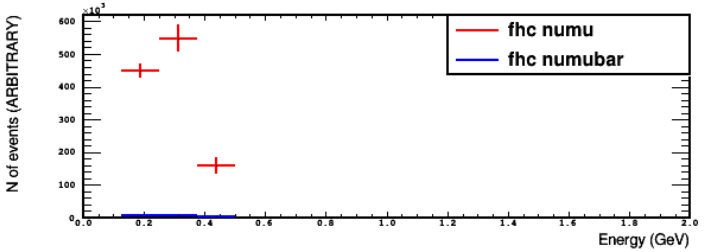


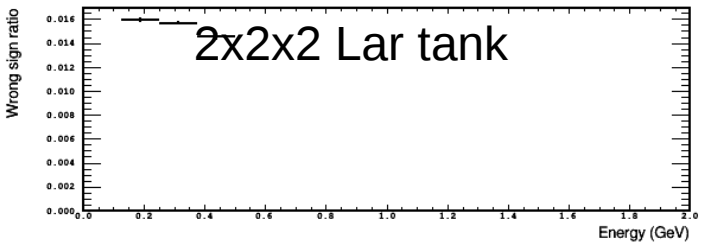


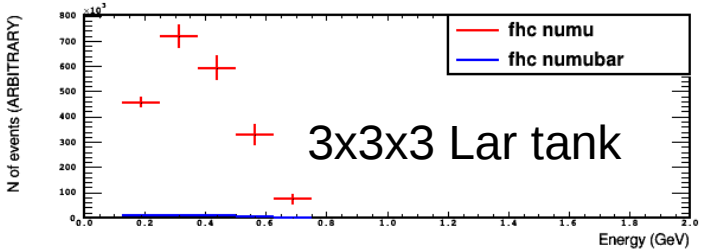


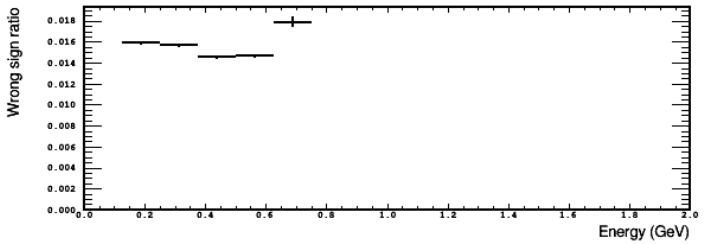
FHC Wrong sign nu ratio in LAr without B-field

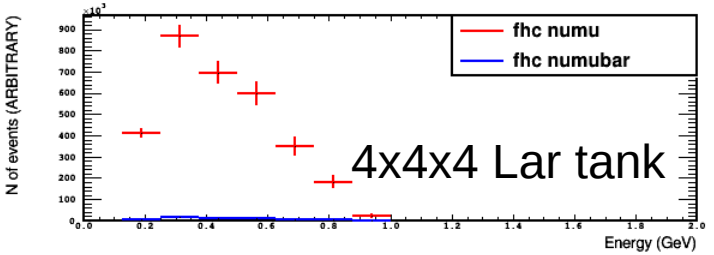
- All events that cannot go out of the Lar tank are taken into account.
- Flux, again is based on arxiv.1606.09550

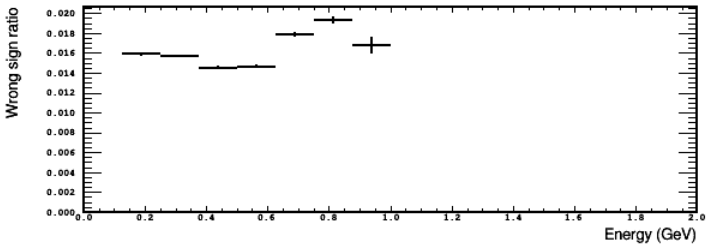












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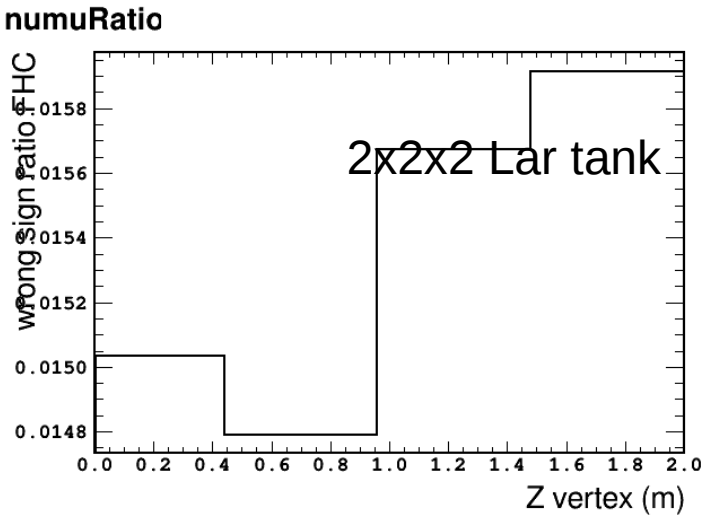

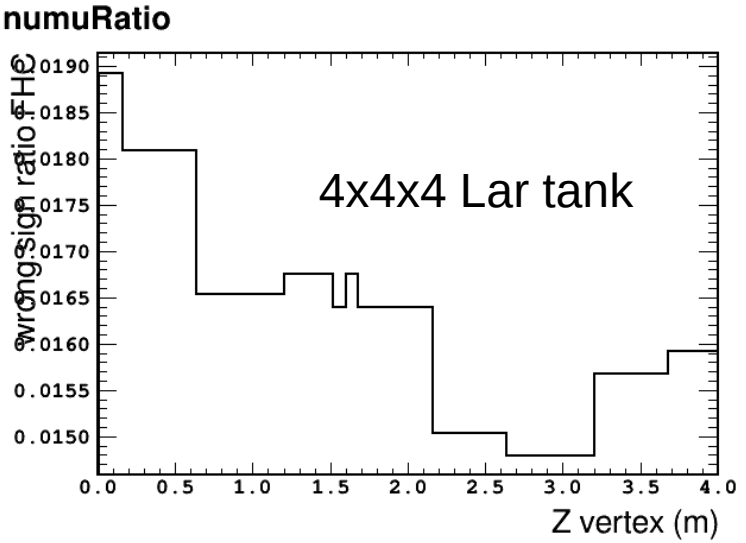

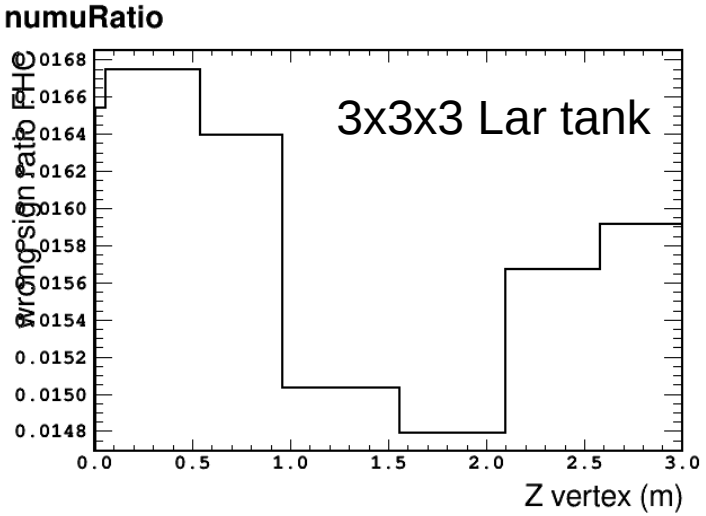

RHC Wrong sign nu ratio in LAr without B-field

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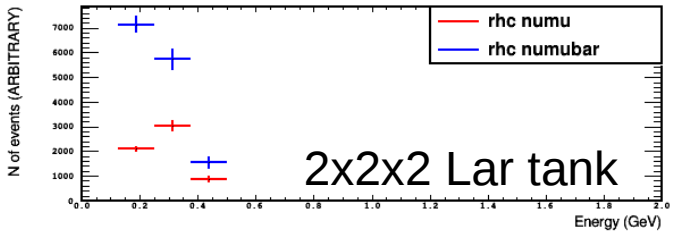
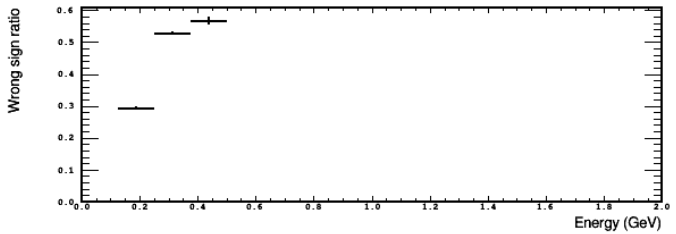
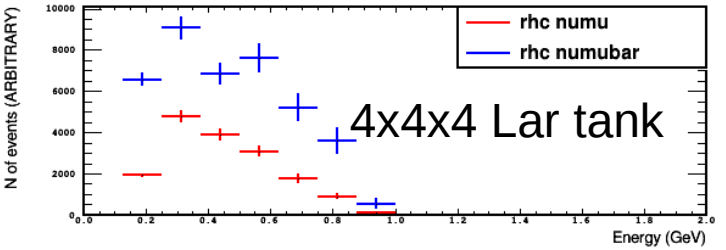
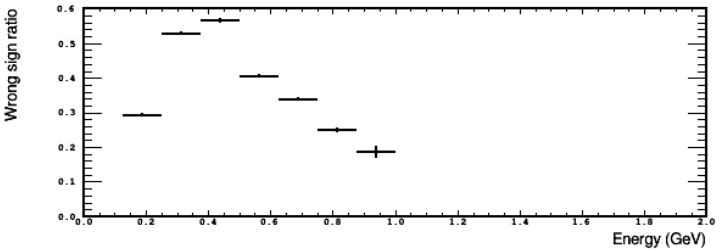
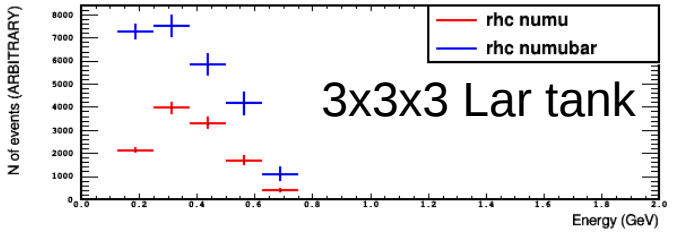
- Flux, again is based on arxiv.1606.09550

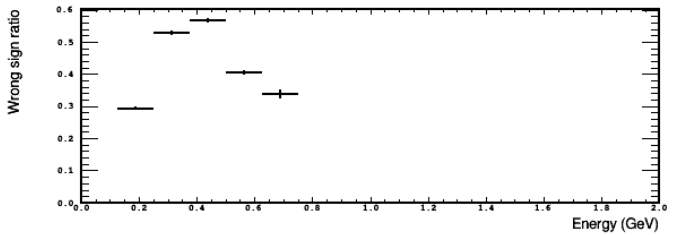












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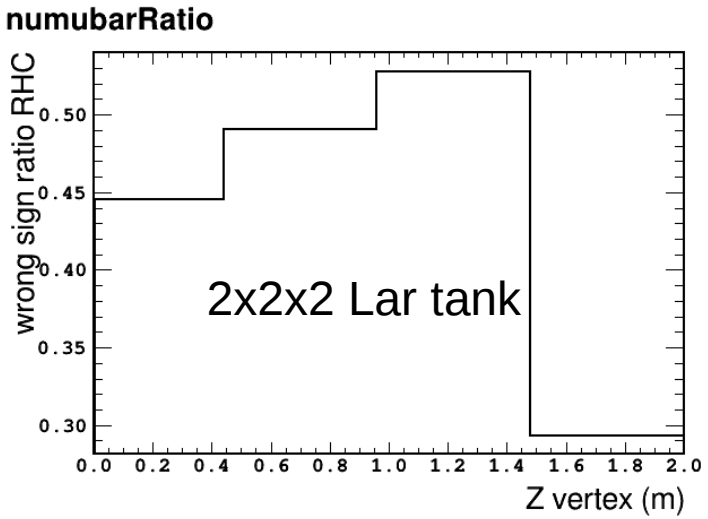
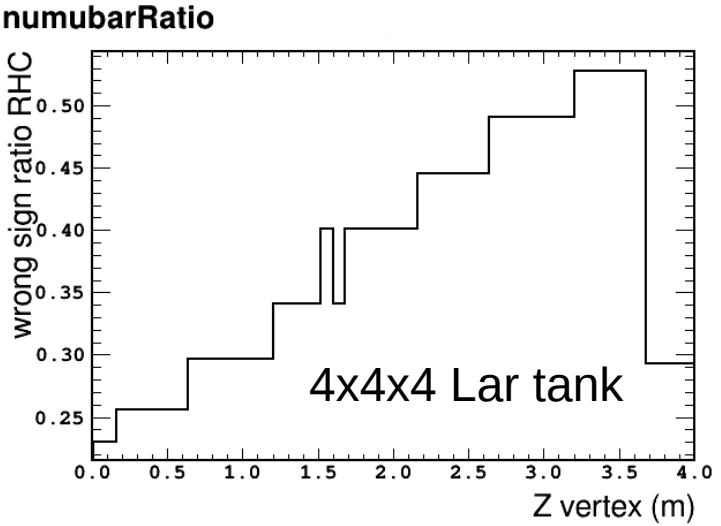
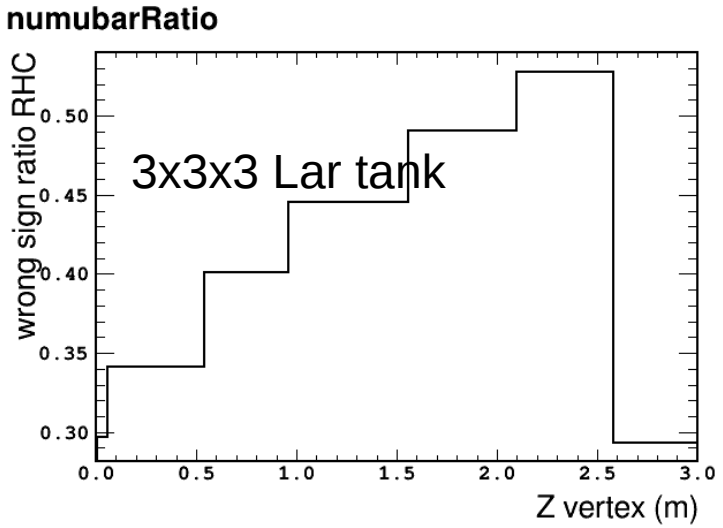
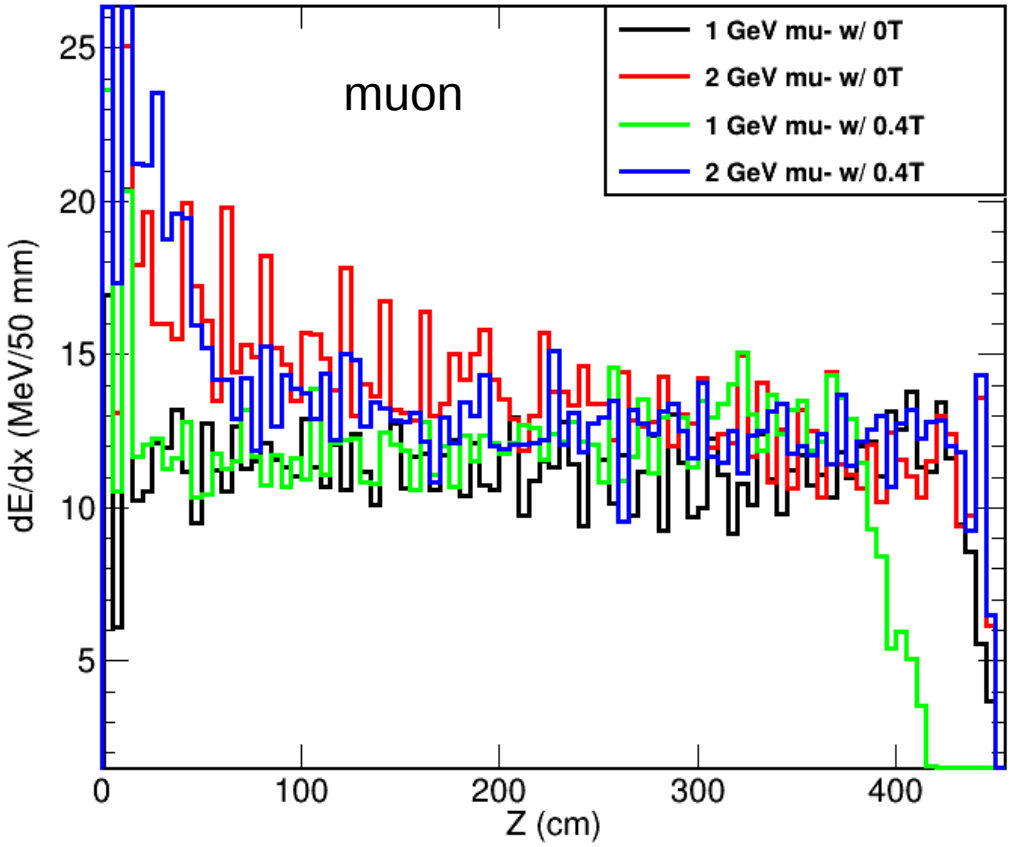






Muon dE/dx in Liquid Argon

Averge dE/dx based on 1,000 events

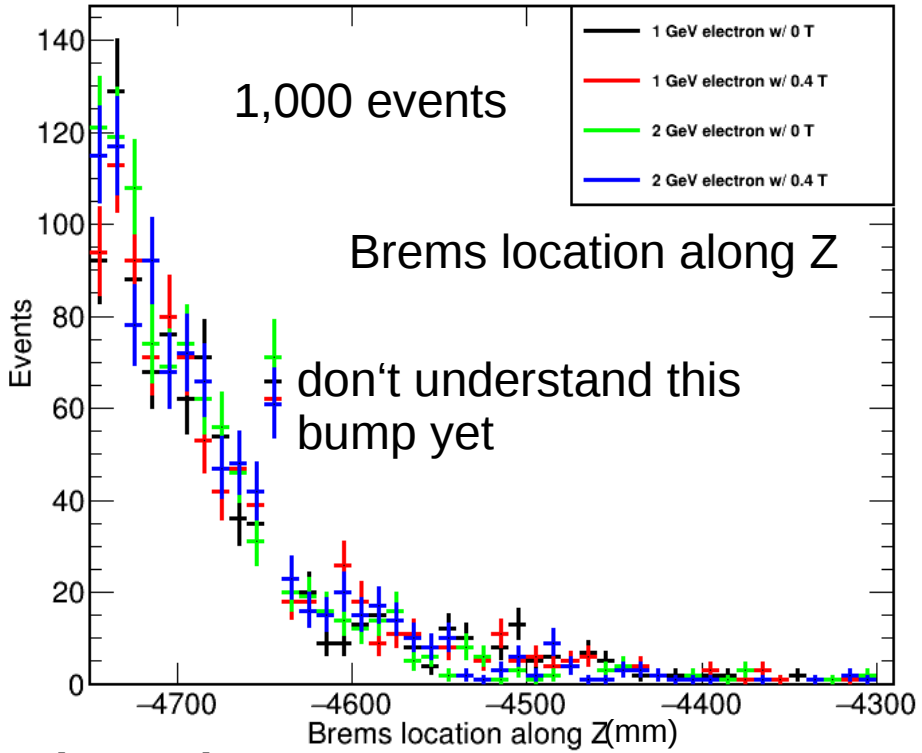


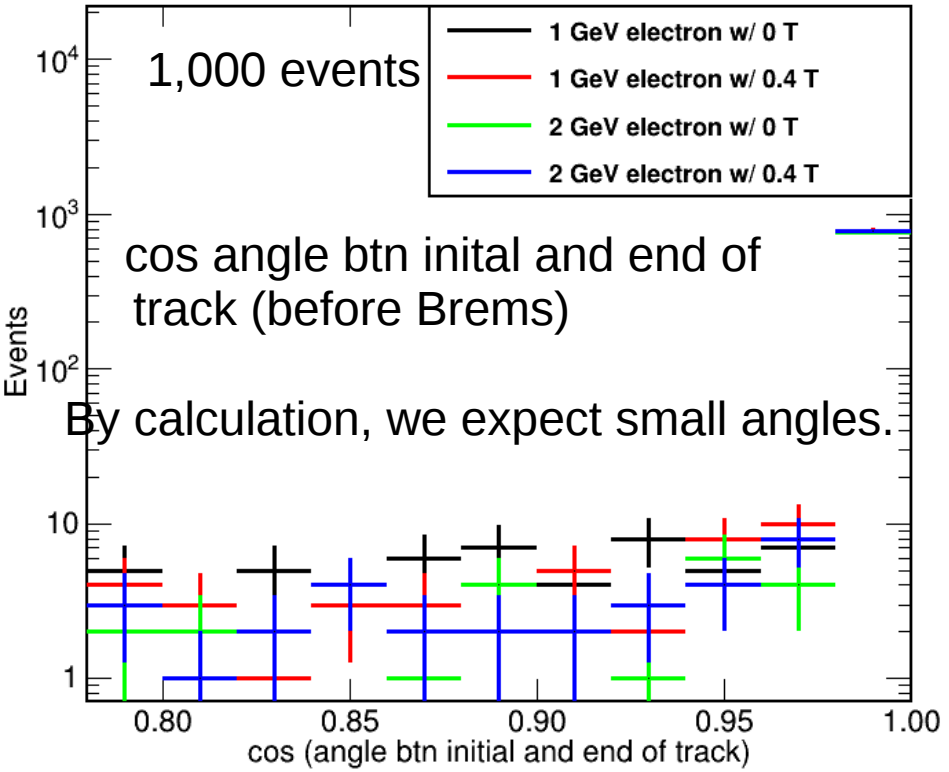
Separate is better?

B-field dos not affect the muon dE/dx significantly.
This is just to

Before Brems, angle btn initial and end directions w/ and w/o B-field

How to define a start of Brems: 1. gamma generated; 2. two branches exist
- Tested several criteria, above seems the best comparing to event display.





Starting point at -4750mm

- Brems distance for higher energy is smaller.
- For electron w/ B-field, multiple scattering dominates over Lorentz force bend.
- We could do neutrino-electron scattering with B-field as good as without that.