Geometric Efficiency Correction – Method and implementation with the PRISM framework

October 16th, 2024

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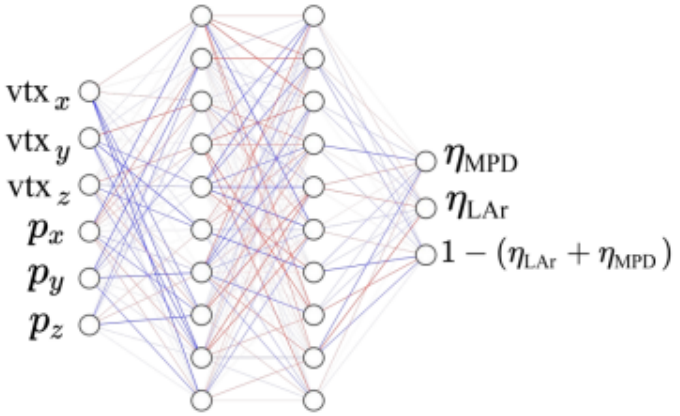
Disclaimer: Presented results are heavily based on Flynn Guo's work

Methods

Hadronic containment efficiency

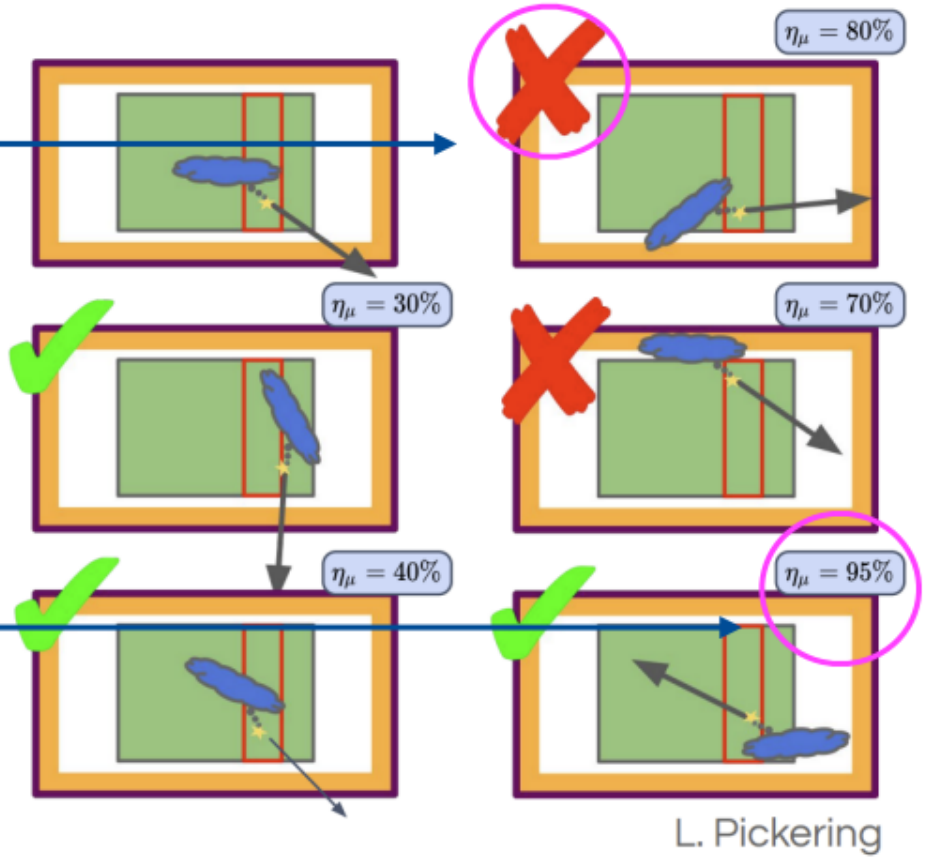
Pass or **fail** the hadronic veto cut in ND-LAr

Muon selection efficiency



$\mu \xrightarrow{\textit{Nerual Network}}$ Probability

See talk by C. Vilela for more details on NN



L. Pickering

Combined efficiency

Combine both to get an **event-level efficiency**

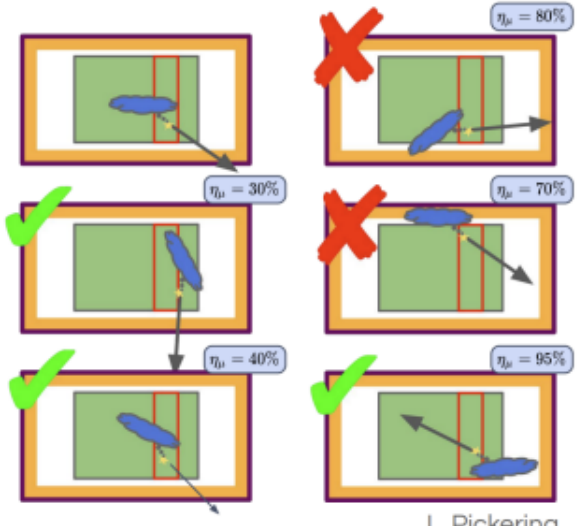
$$\eta = \frac{0\times0.8+1\times0.3+0\times0.70+1\times0.4+1\times0.95}{5} = 33\%$$

Methods

ND event selection

- Raw: all CC ND events w/ ND FV cut & ND dead region cut
- Selected: raw events w/ selected μ & selected hadronic deposits
- Geo-corrected: selected events weighted by $\frac{1}{geoeff}$

✳ ($geoeff$: geometric efficiency of ND event)



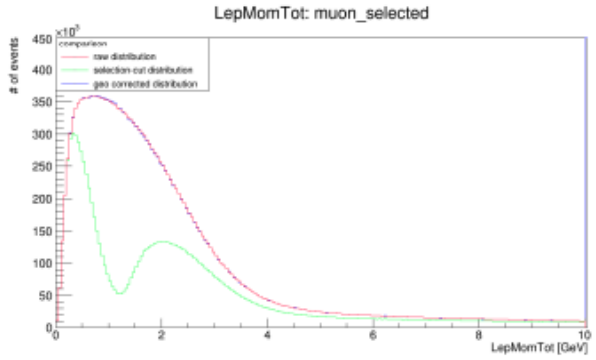
$$\eta = \frac{0\times0.8+1\times0.3+0\times0.70+1\times0.4+1\times0.95}{5} = 33\%$$

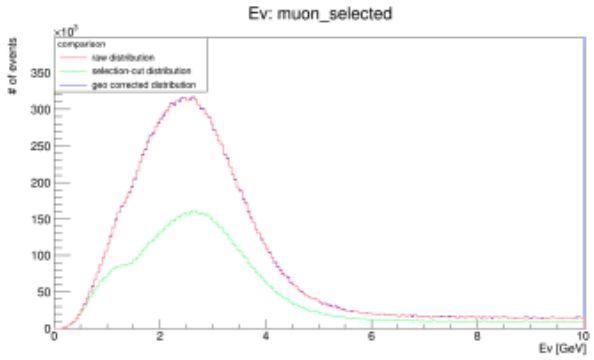
Geo-corrected:

For this specific selected ND event on the left, its event-level combined geometric efficiency η is $33\,\%$, so we correct this event by applying a weight: $\frac{1}{33\,\%}$.

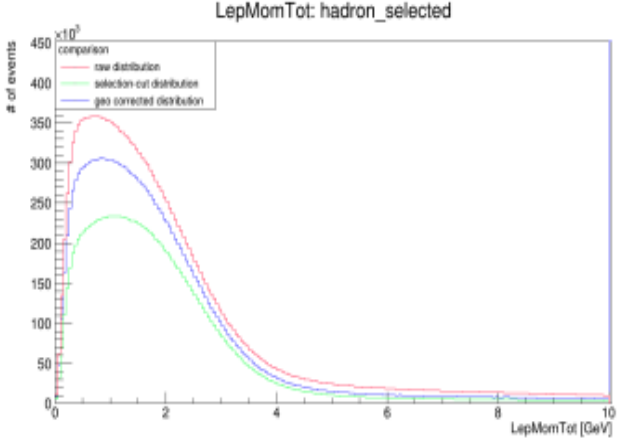
Results: Muon and Hadrons at ND

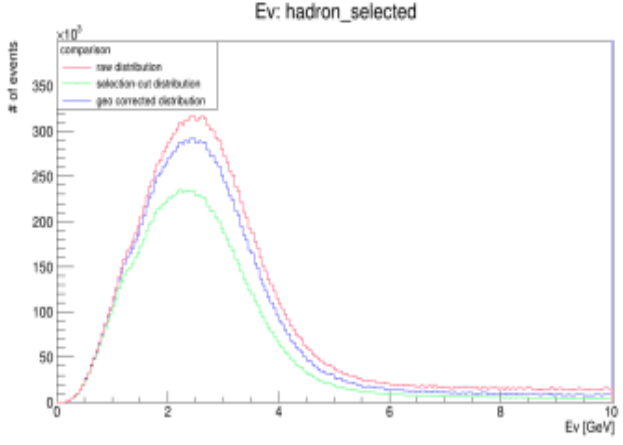
Muon_selected (On-axis)





Hadron_selected (On-axis)





Initial idea: Correct ND events

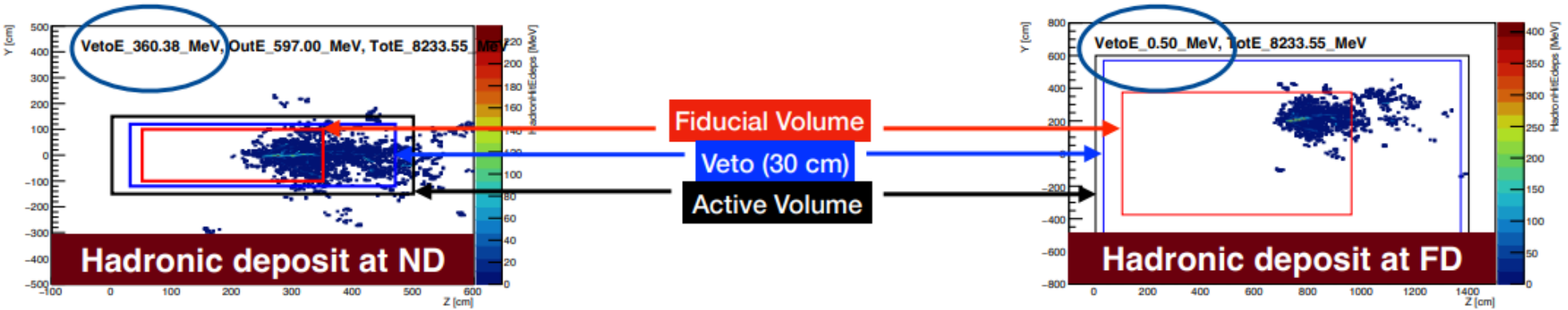
- Geo-corrected and raw distributions coincide with each other
  → **Geometric efficiency correction works well for muons**

- Discrepancy between geo-corrected and raw distributions coincide with each other → **Geometric efficiency correction can't perfectly correct for ND selected hadrons**

  – events with high hadronic energy deposits would never be selected at ND

FD Events at ND

Some events w/ large hadronic showers cannot be selected at the ND due to the limited size of ND-LAr, but it can be selected at FD



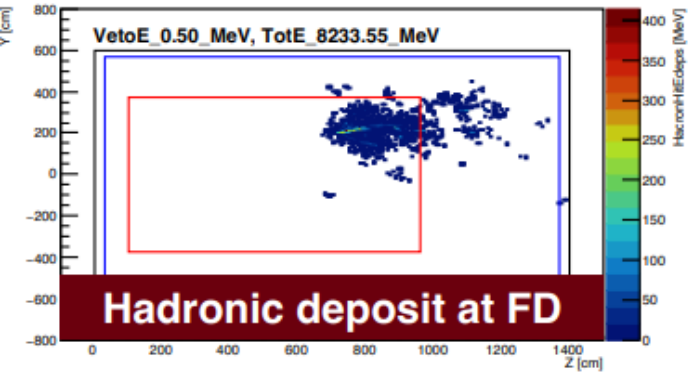
Veto Energy > 30MeV
Can't be selected

Veto Energy < 30MeV
Can be selected

- **Need to determine the geometric efficiency of FD events at ND**

FD Events at ND

FD event

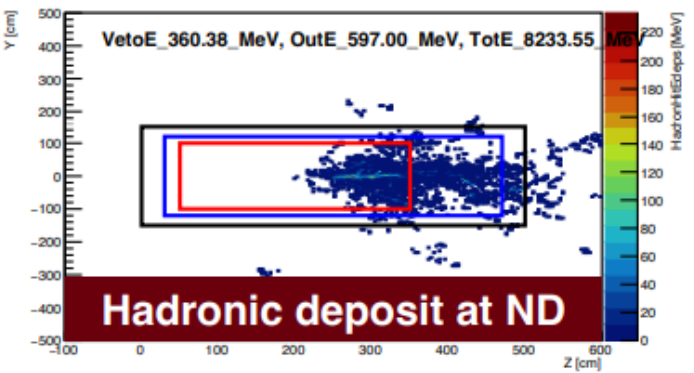


- Choose CC FD events w/ FD FV&vetoE cut
- Earth curvature transformation

↓ Move to ND

- Same method on random throws as we did for ND events
  - Rotate about the beam axis
  - Translate throughout the off-axis

FD event at ND



Pass or **fail** the hadronic veto cut in ND-LAr

Train a neural network to get the **probability**

Hadronic containment efficiency

Muon selection efficiency

Combined event-level efficiency for FD events at ND

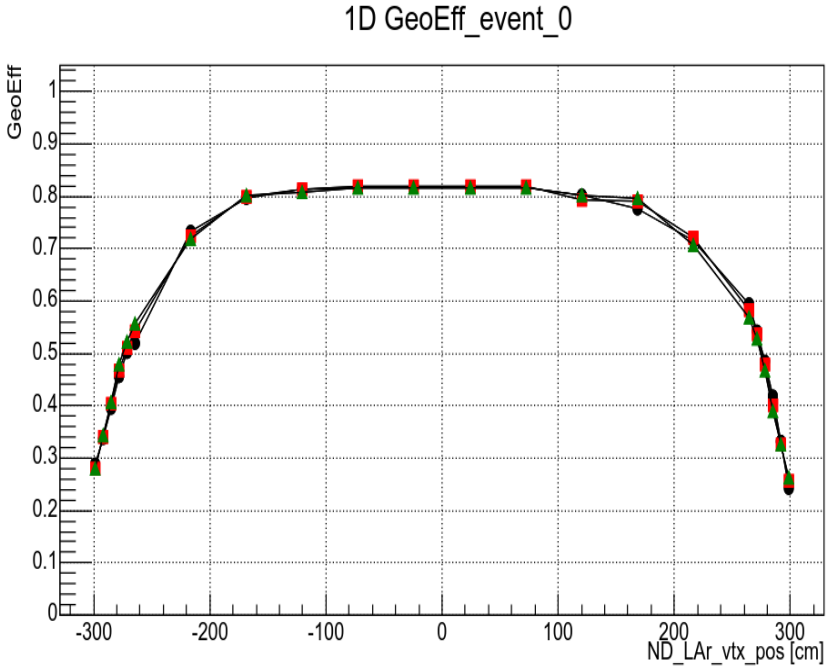
Geometric efficiency correction: hadronic component

1. take a FD event from FD CAF(with the hadronic energy deposit in FD)
2. translate the FD event to ND (account for Earth curvature)
3. at the ND: move the event to the beam center (in front of the beam)
   – choose different detector off-axis positions
   for each off-axis position:
   – move the event at different ND vtx_x positions (72 x_vtx positions);
   – for each x_vtx position:
   4. rotation of the ND event from on axis to off axis
   5. generate random throws of the event (at ND) at different vtx_y, vtx_z position with different rotations (vtx_x position is fixed)
   – for each throw: evaluate if the event passes the veto cut (Ehad < 30 MeV in the veto region)
   6. calculate the geometric efficiency of the FD event at the ND

→ same procedure is applied for muons

Final result: geometric efficiency (hadron containment only within the next slides) of each FD Event vs ND vtx_x position

Geometric Efficiency: Results (from Flynn's code)



This is the FD efficiency of 1 event (FD energy = 755.65 MeV) at the ND

– calculated after 4096 throws in Y, Z + rotations

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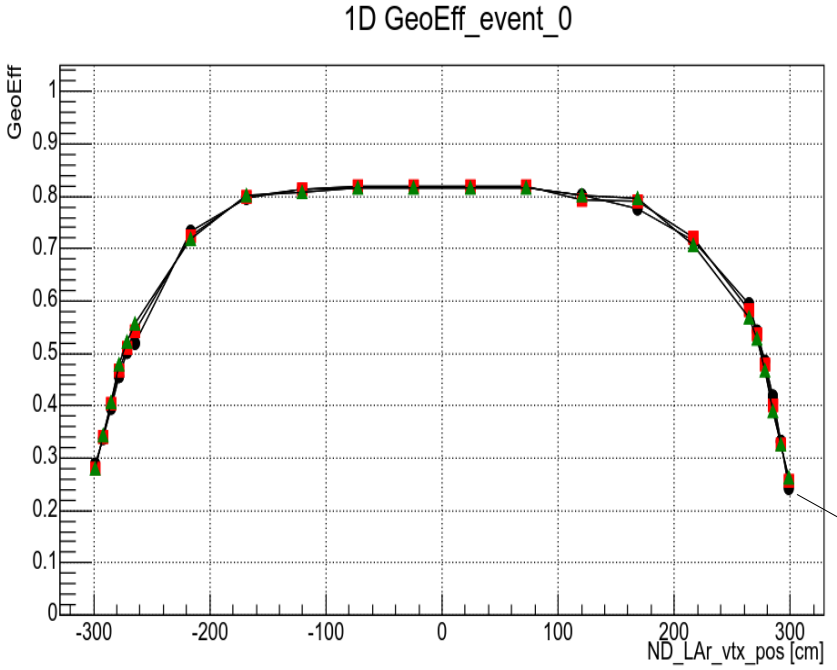

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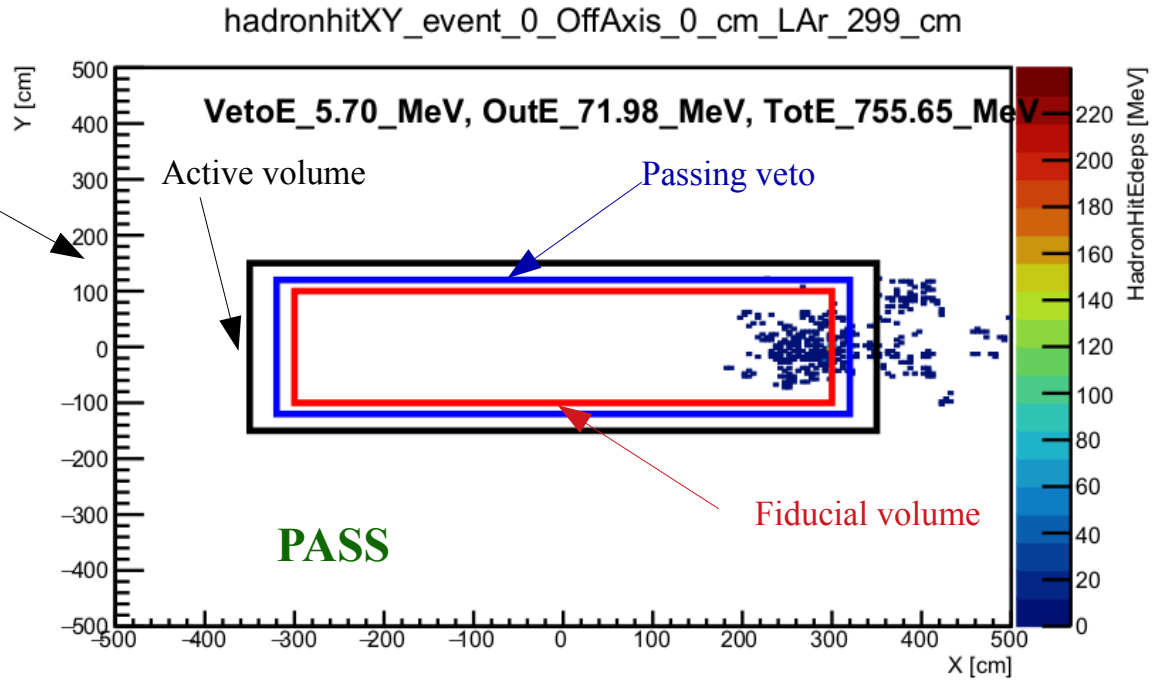
Event visualization at the ND

– before the throws



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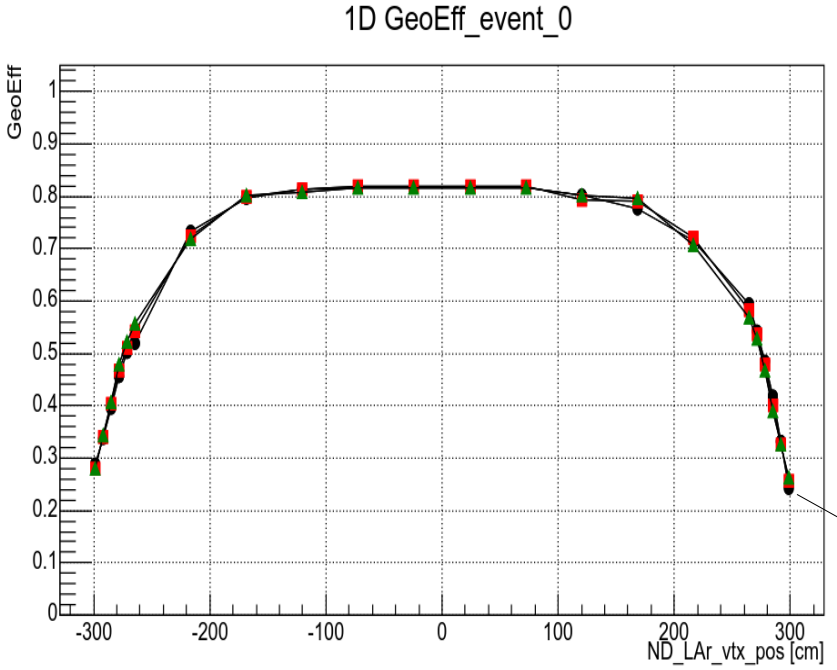

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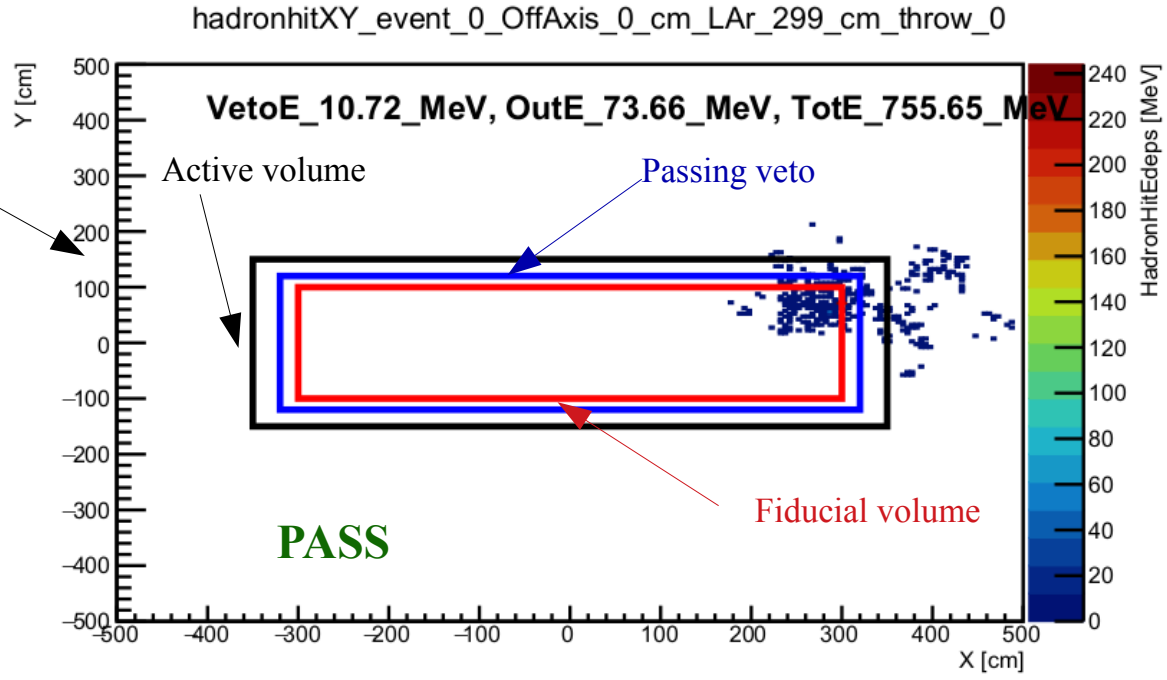

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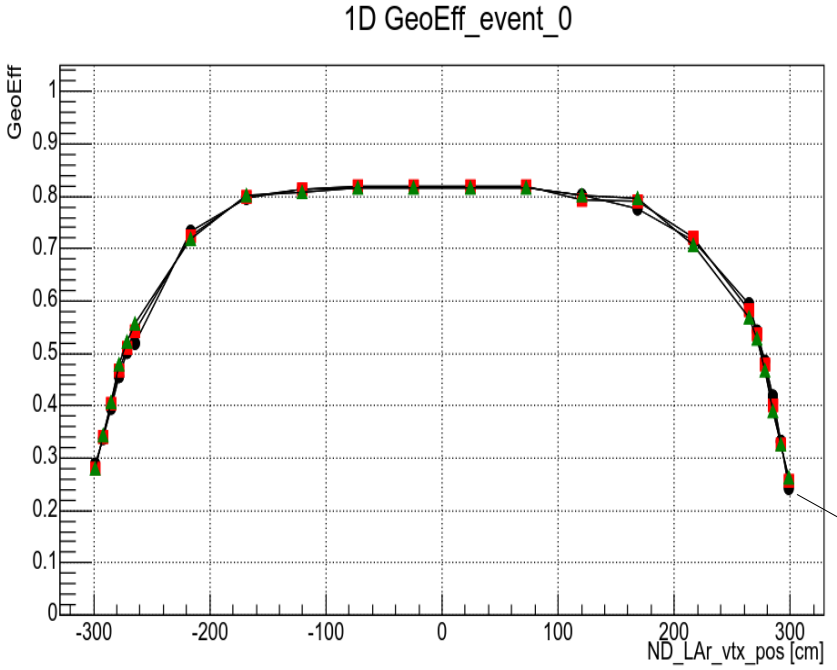

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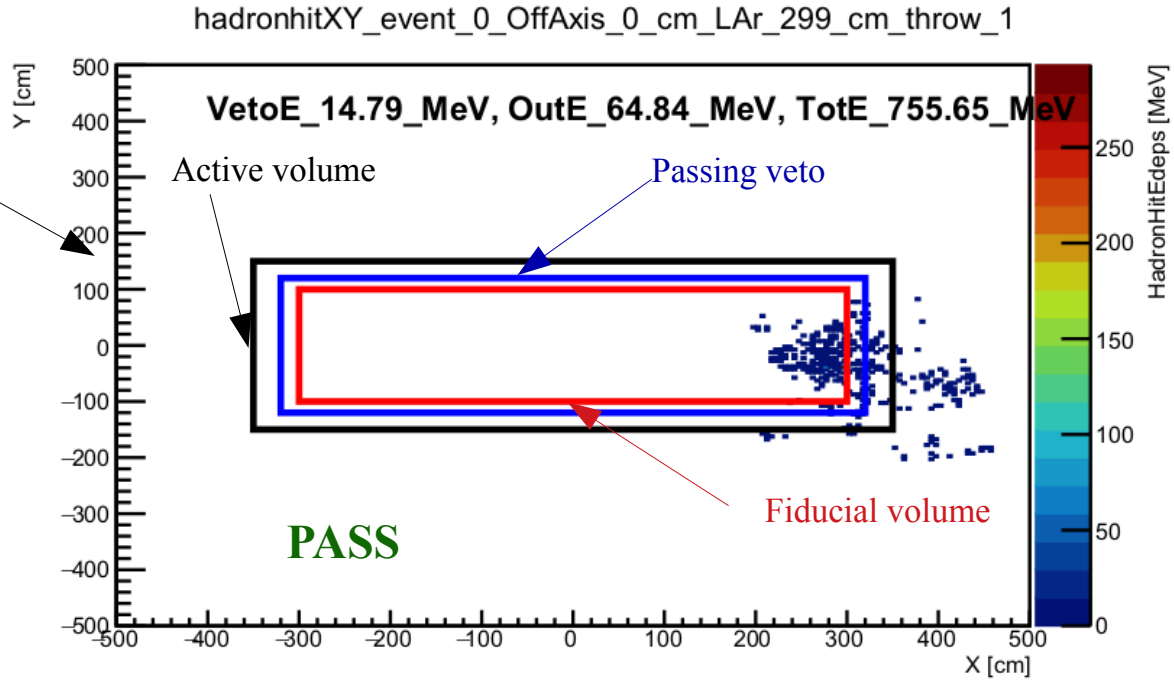
– after another throw



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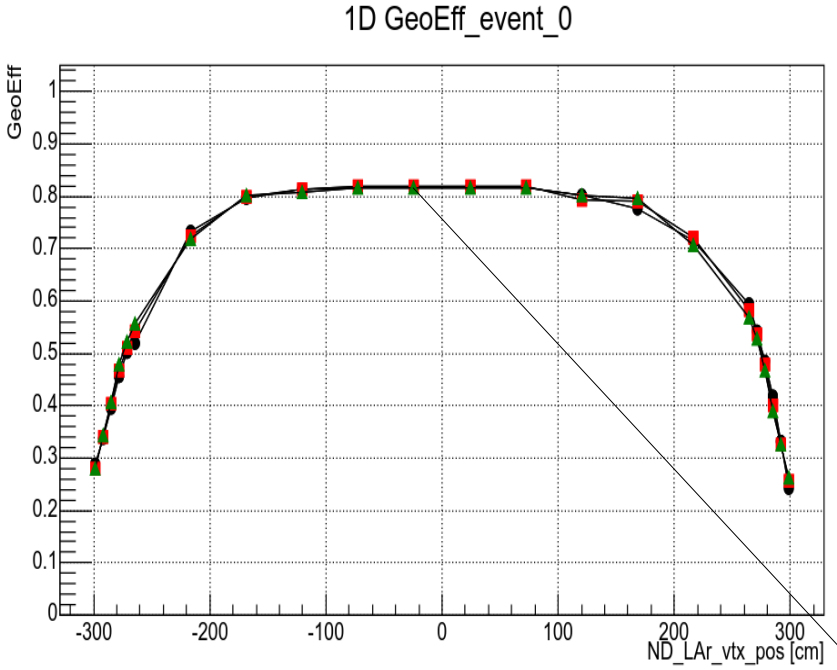

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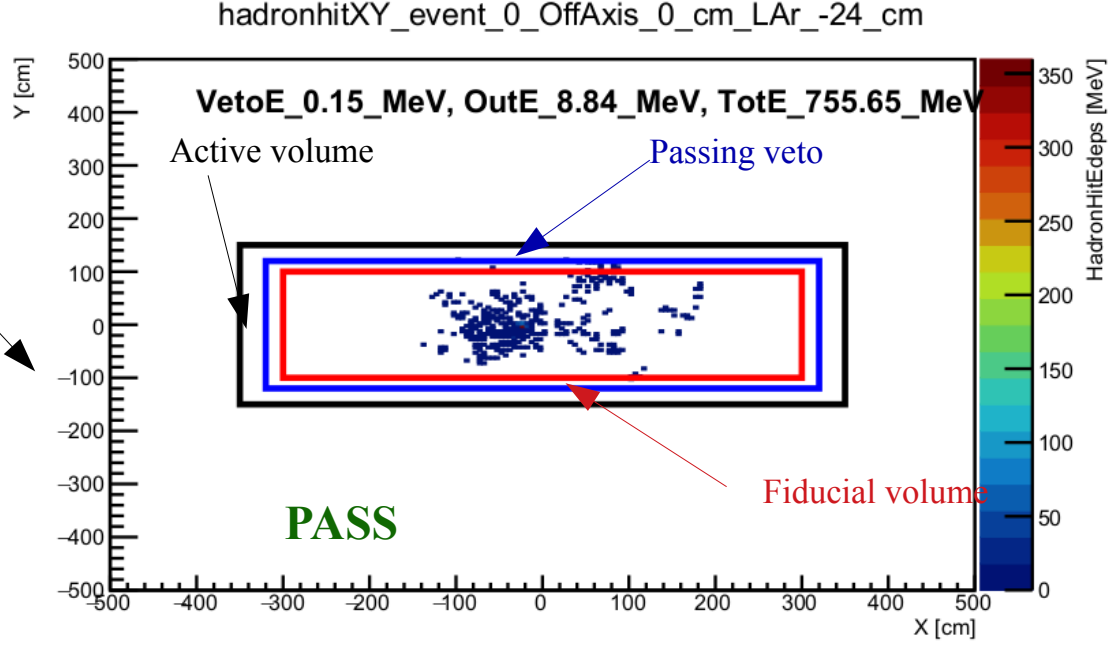

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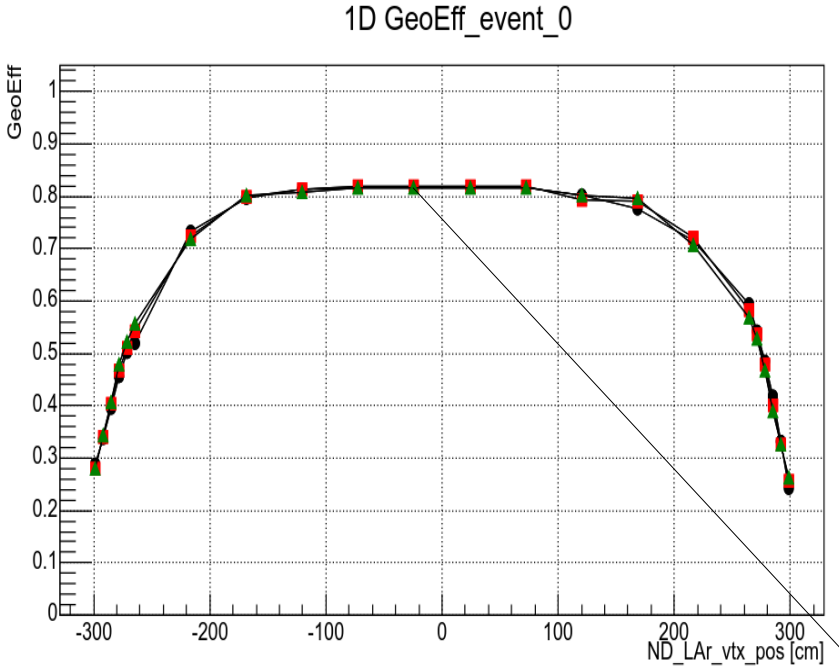

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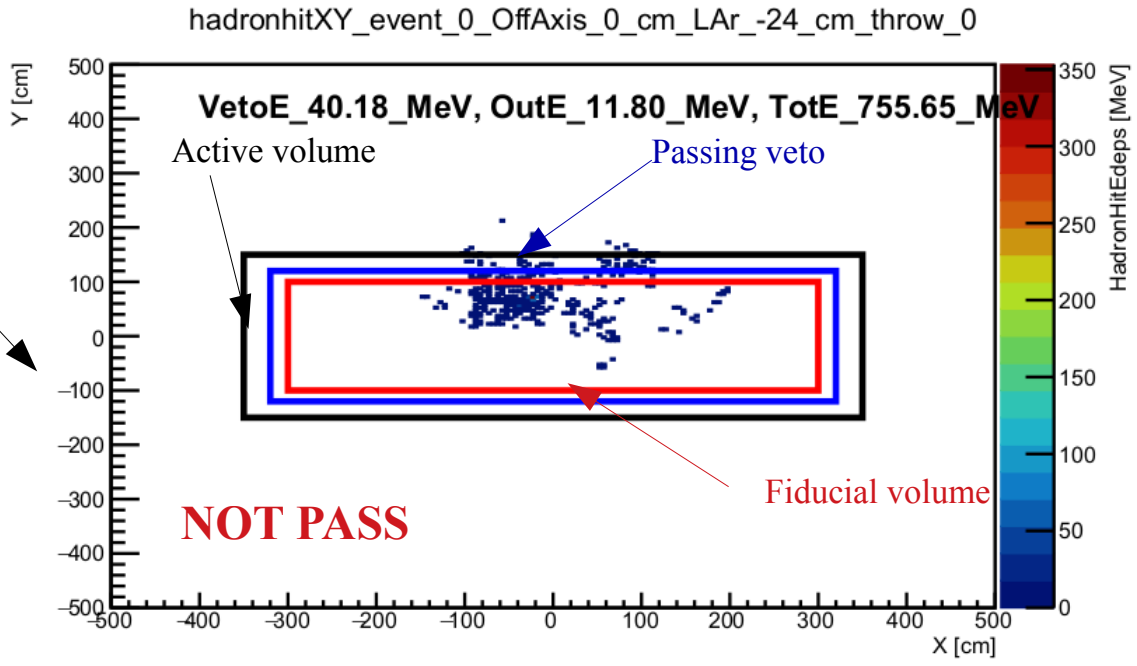
Event visualization at the ND

– after 1 throw



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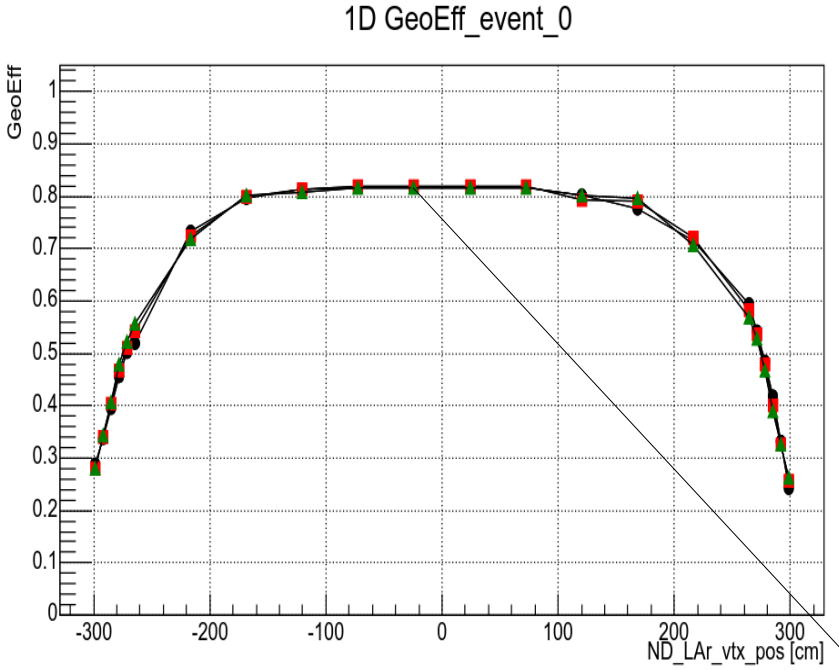

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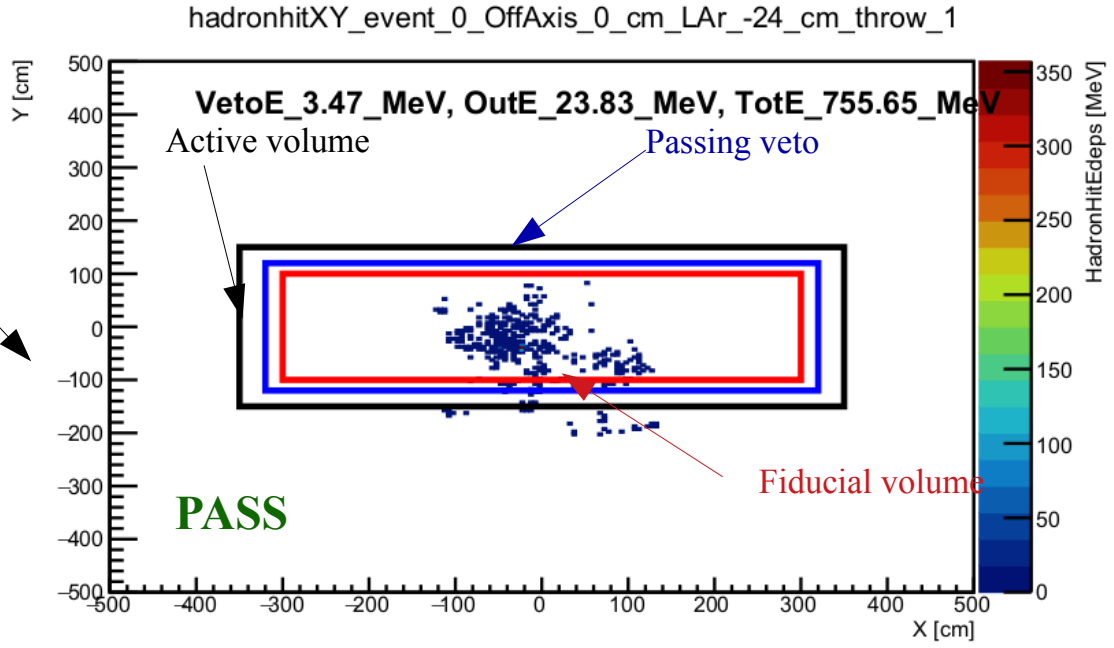
Event visualization at the ND

– after another throw



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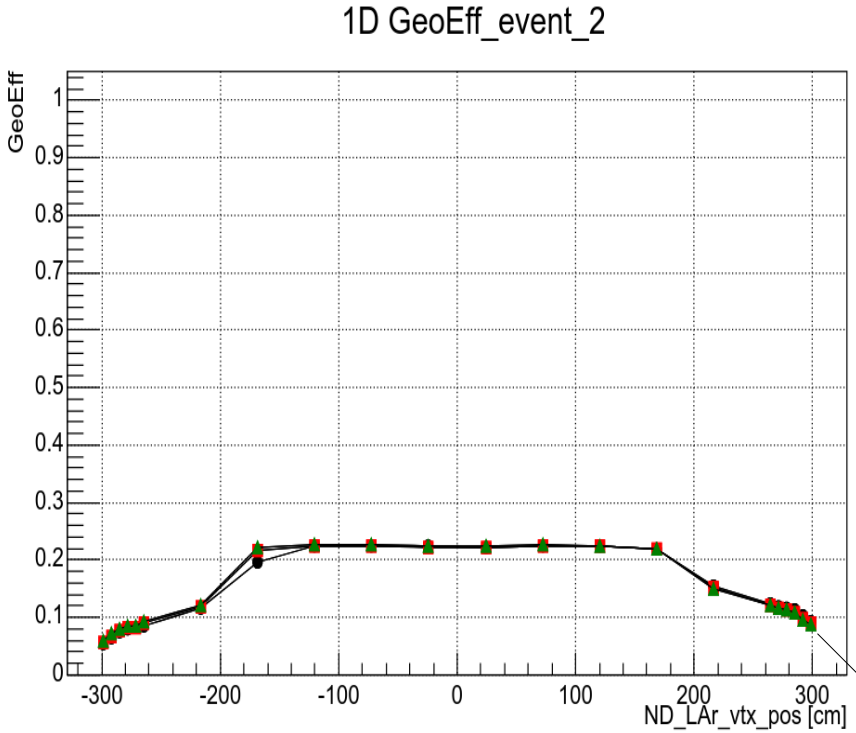
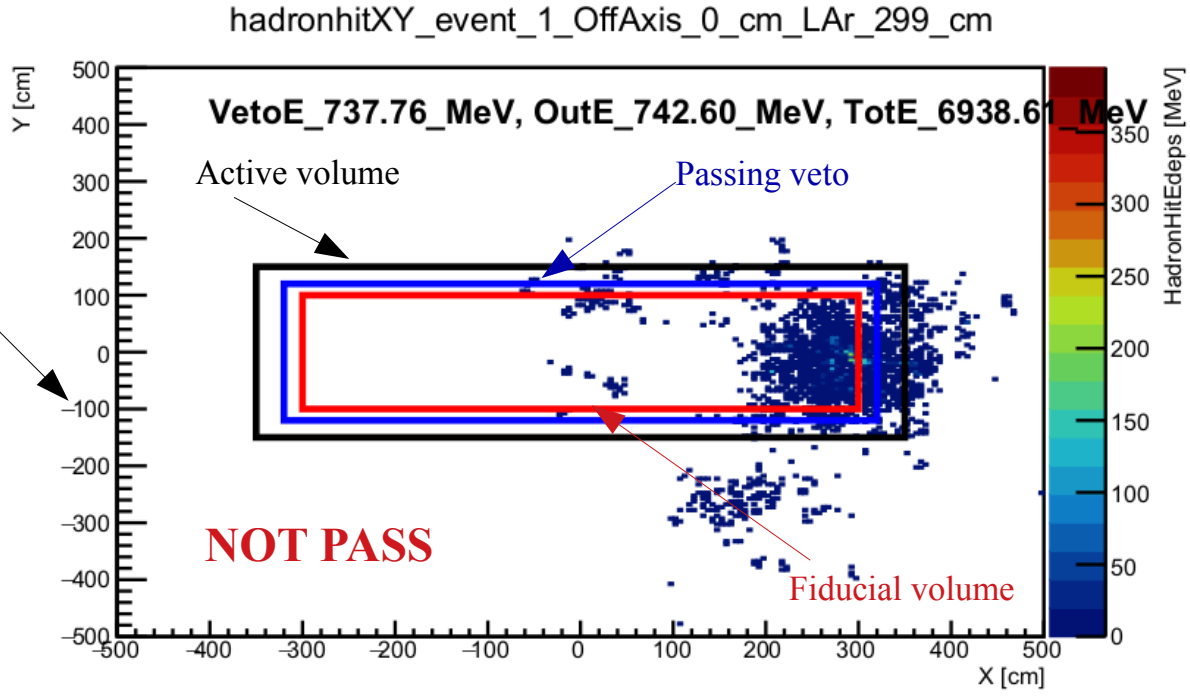


This is the FD efficiency of 1 event (FD energy = 6938.61 MeV) at the ND

– calculated after 4096 throws in Y, Z + rotations

Event visualization at the ND

– before throws



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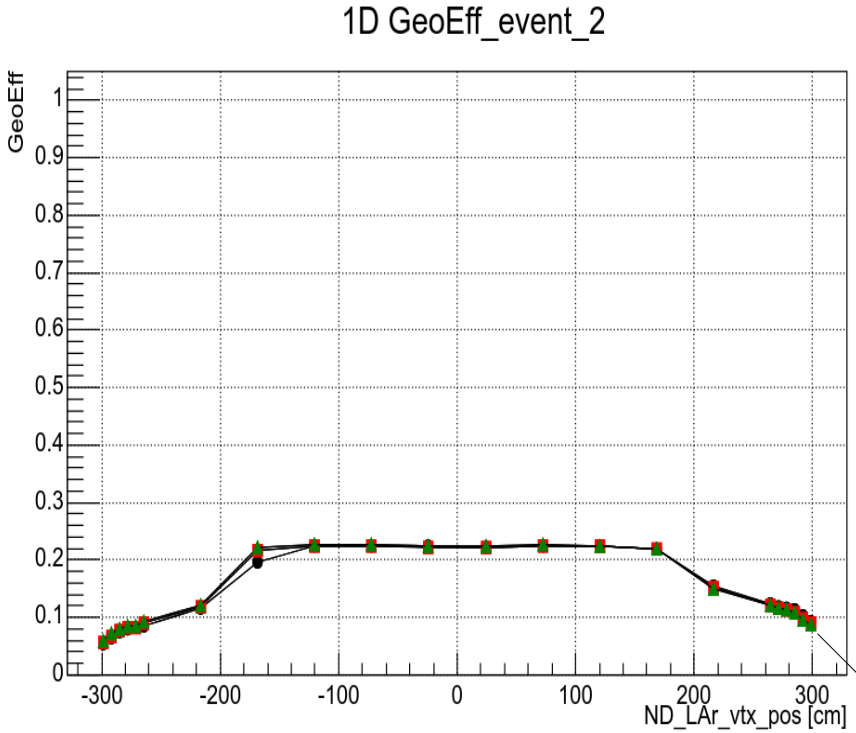

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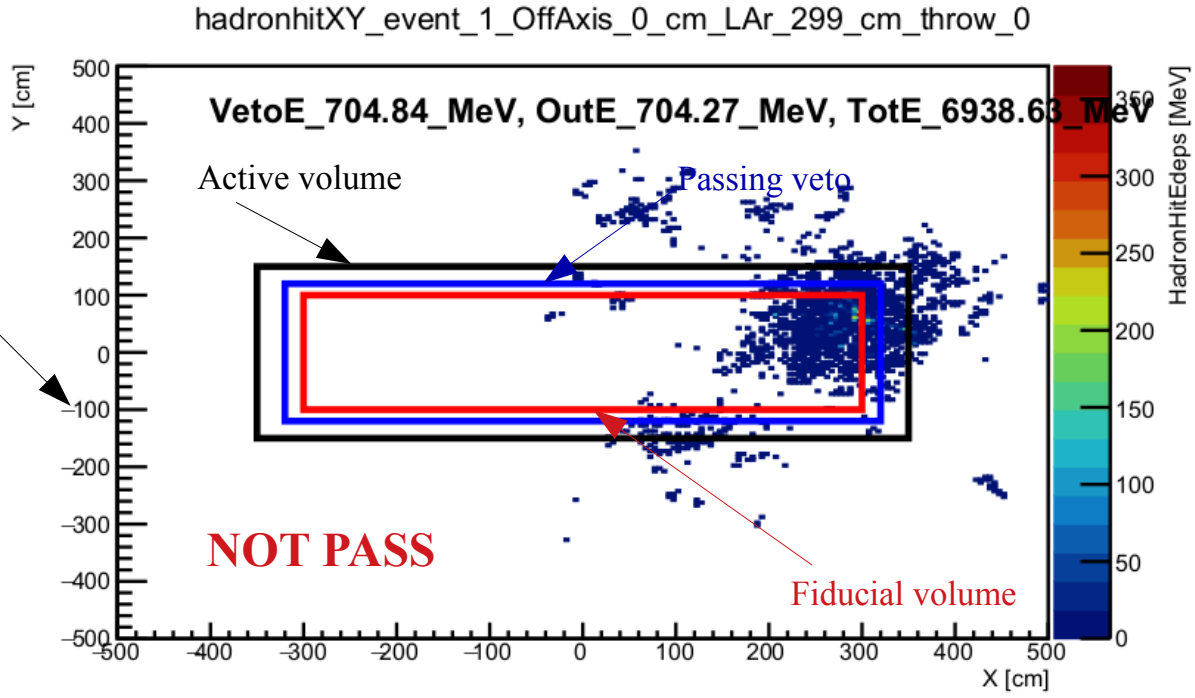
Event visualization at the ND

– after 1 throw



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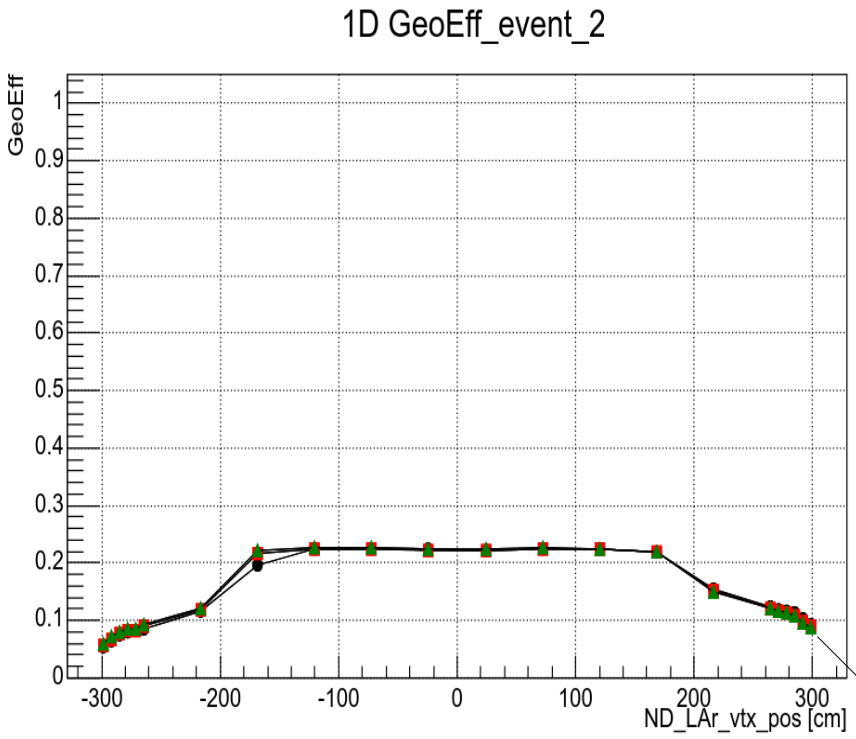
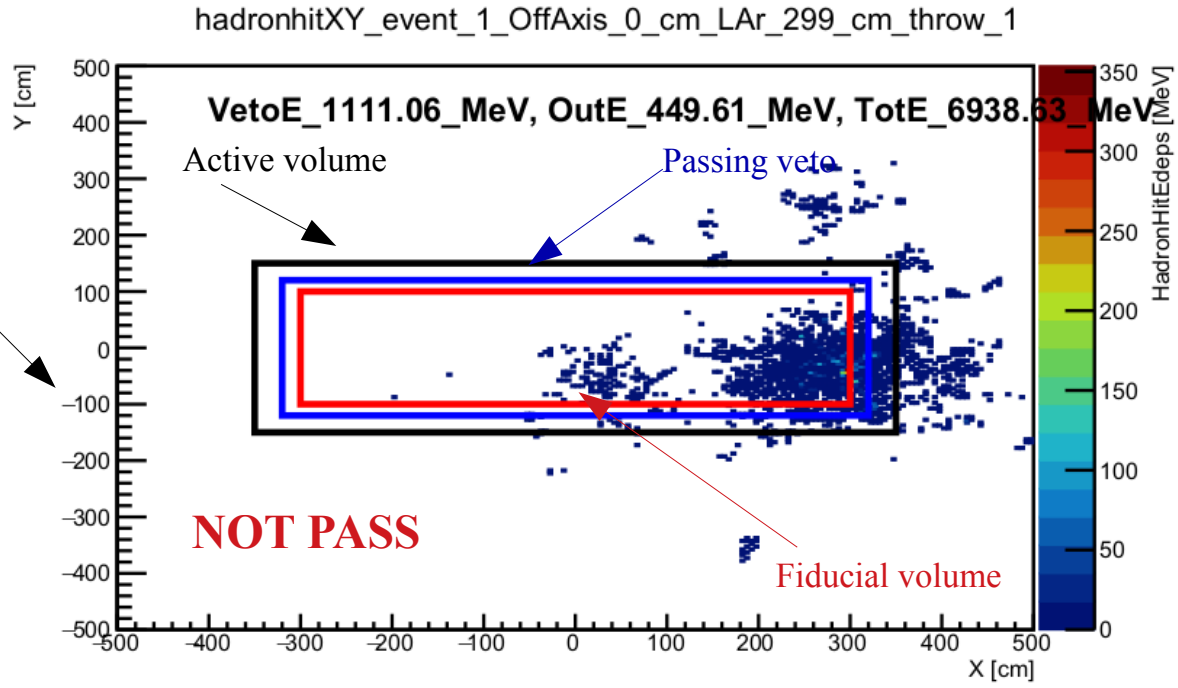


This is the FD efficiency of 1 event (FD energy = 6938.61 MeV) at the ND

– calculated after 4096 throws in Y, Z + rotations

Event visualization at the ND

– after another throw



Main Remarks

- Efficiency drops towards the edges of the x vtx within ND
- Not a significant effect for on / off-axis
- For high FD (hadronic) energy ND efficiency is significantly lower:

  – high energy showers have a “more spread” signature in the detector: easier to deposit more than 30 MeV within ND veto region

  – high energy events will have a higher fraction of “out Energy” (I.e energy deposited outside the ND active volume)

  – low energy events can be rotated / translated in many more ways without depositing 30 MeV within the veto region → FD low energy events are more likely (higher efficiency) to be seen at the ND

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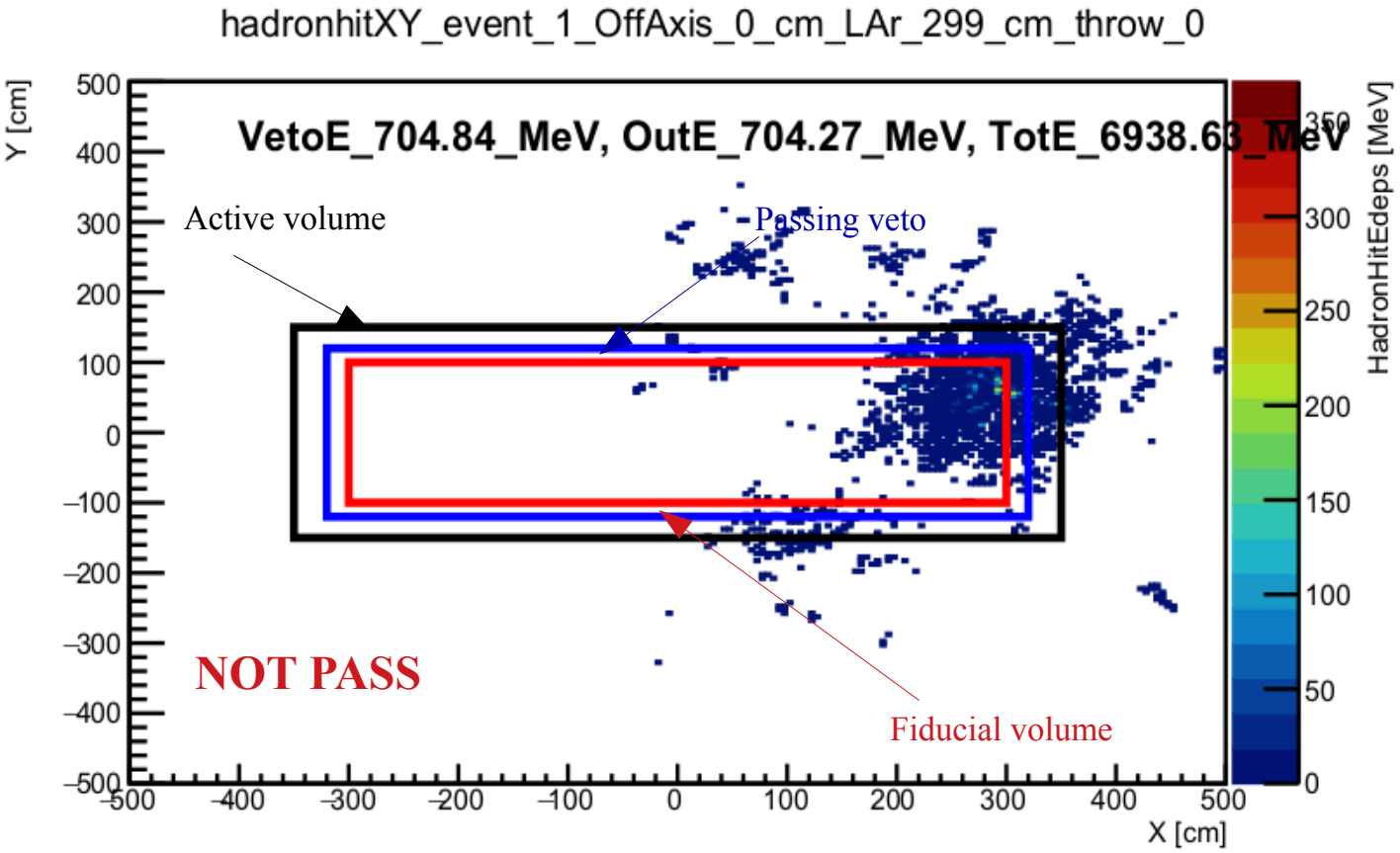
How do we implement / translate these results within the PRISM framework?

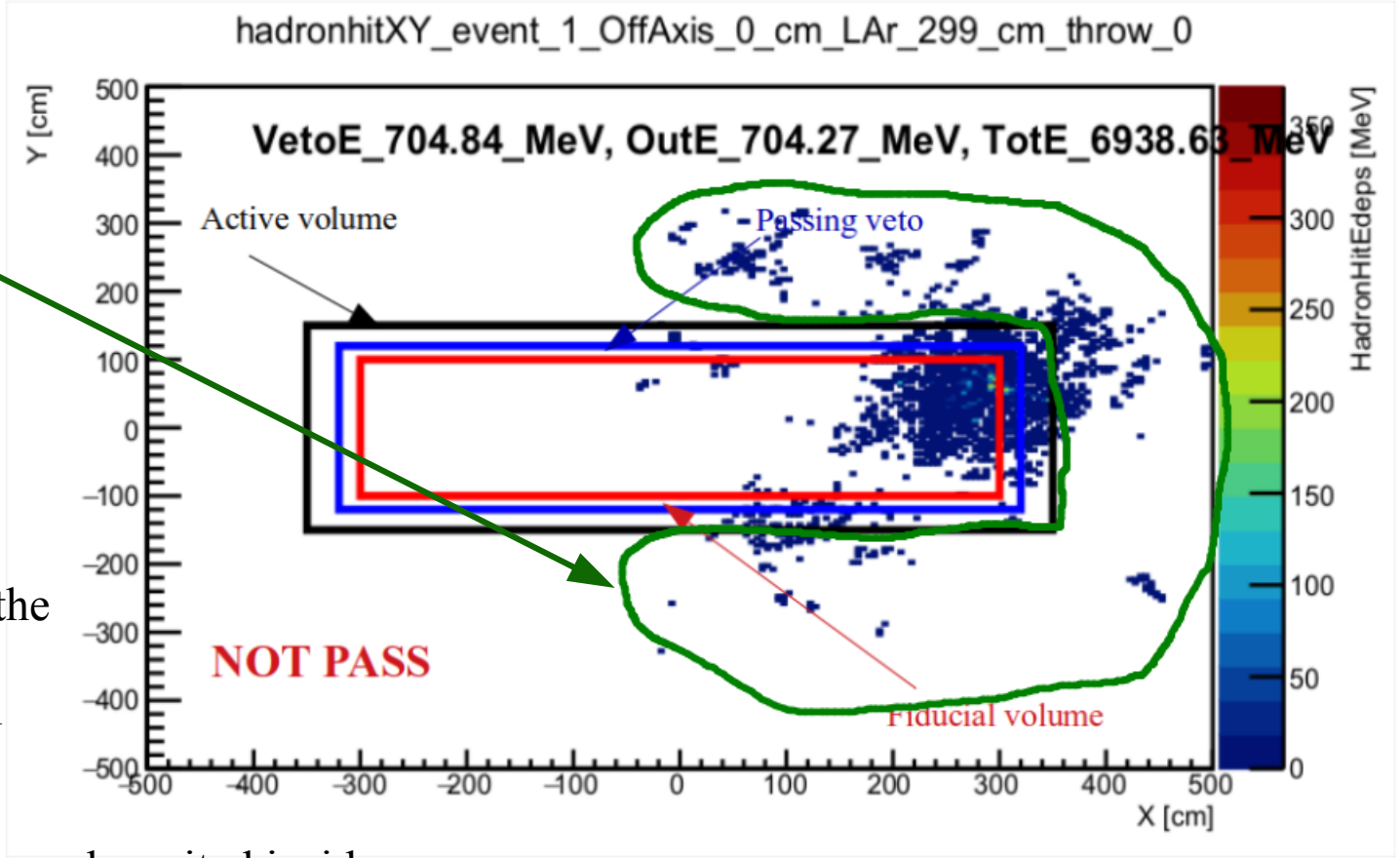
Trimmed Energy E_{trim}

- **tot_E** : FD hadronic energy
- **veto_E** : energy deposited in the ND veto region



Trimmed Energy E_{trim}

- **tot_E** : FD hadronic energy
- **veto_E** : energy deposited in the ND veto region
- **outE**: energy deposited outside ND active volume
  - this is the energy that would never be detected / seen by the ND, but it is seen by the FD



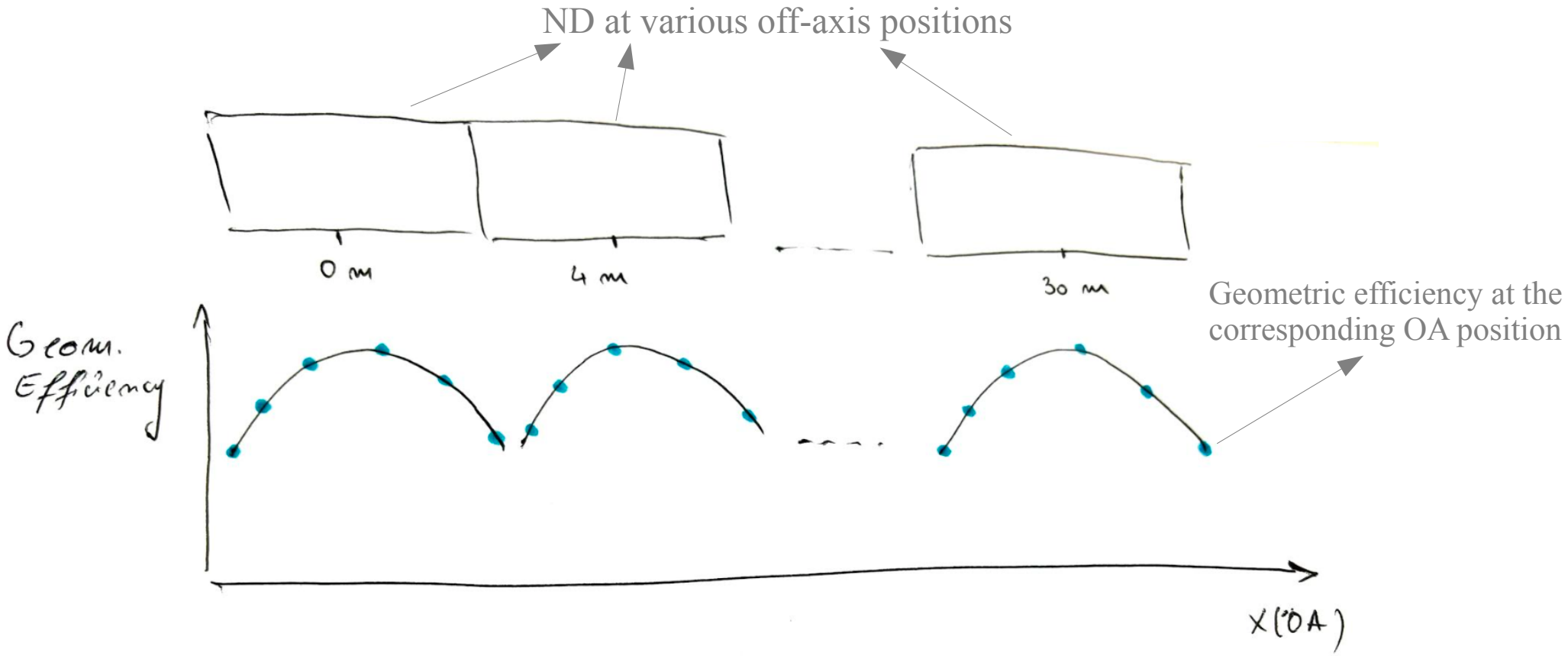
→ trim outside energy of the FD events
  - random throws with Etrim

→ get the trim energy: energy deposited inside ND Active volume
Etrim = totE - OutE

Geometric Efficiency within PRISM framework

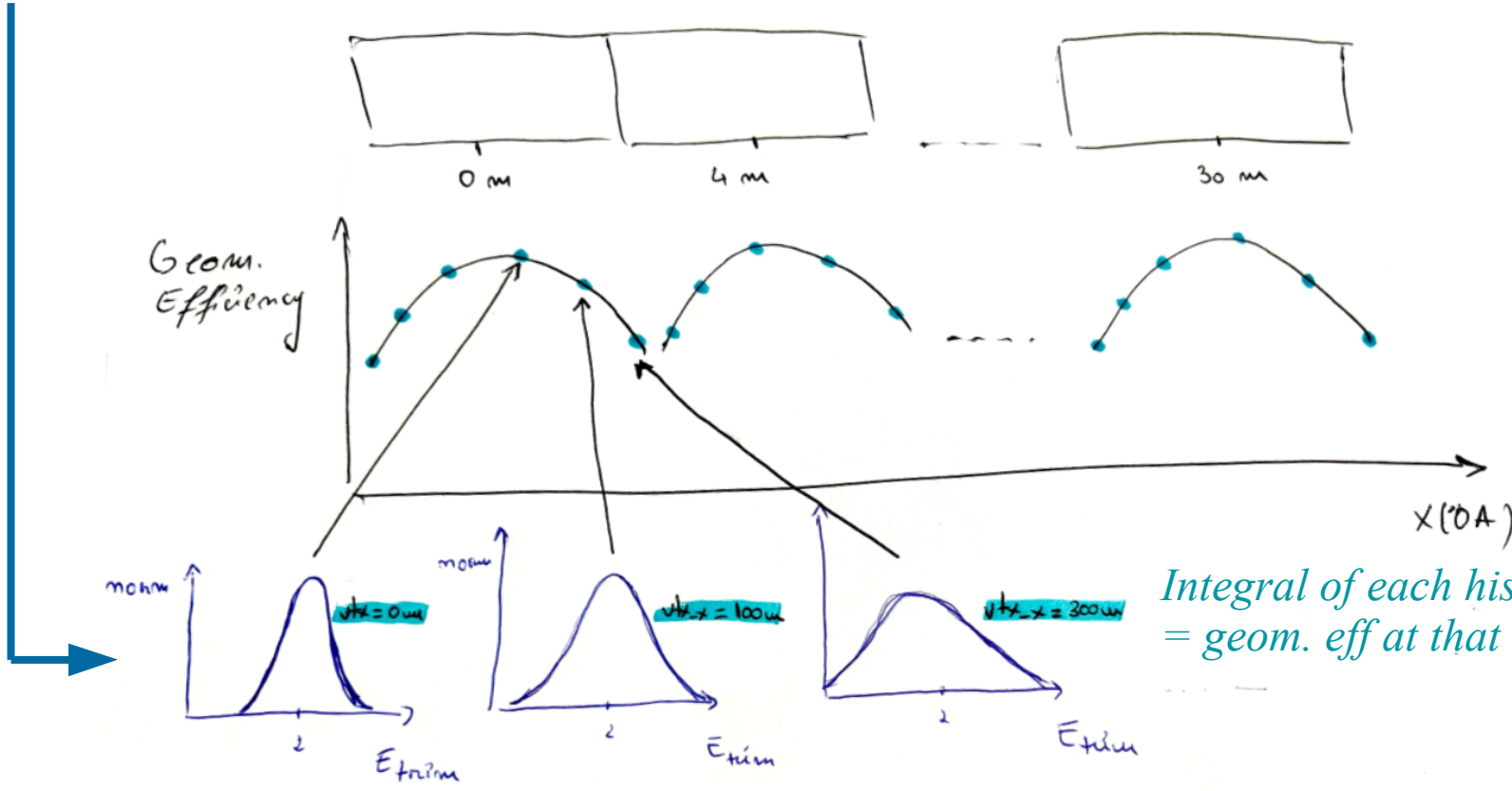
- This procedure would apply to each individual FD Event: Assume **1 FD Event** (FD Energy = 3 GeV)

  → we have the geometric efficiency of each FD event at the ND for each off-axis position and corresponding vtx_x position



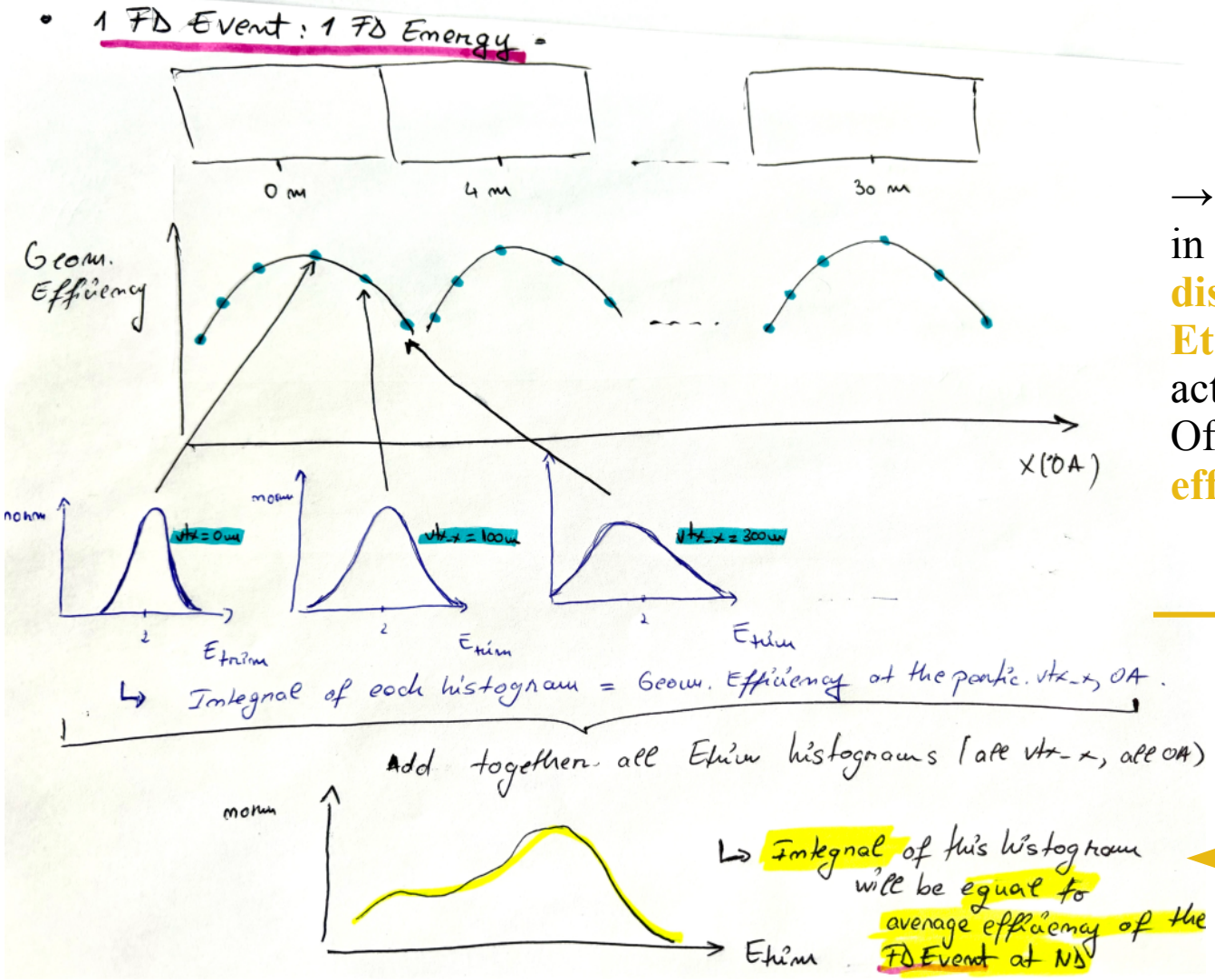
Geometric Efficiency within PRISM framework

- This procedure would apply to each individual FD Event: Assume **1 FD Event** (FD Energy = 3 GeV)
  – each exposure point results from N random throws in Y, Z → **events distribution** (from each throw) **in FD Etrim energy** (energy of the FD event deposited inside the ND active volume)



Integral of each histogram = geom. eff at that vtx_x point

Geometric Efficiency within PRISM framework

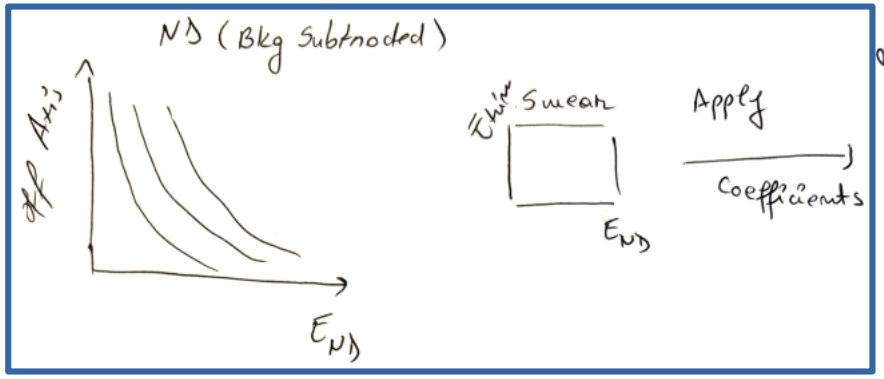


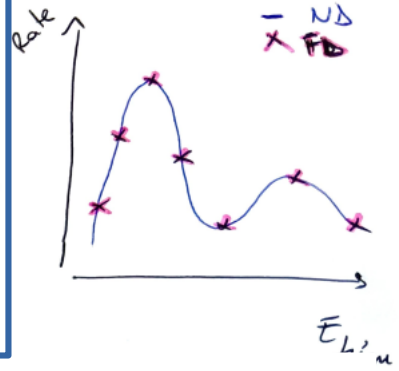
→ combine the histograms vs Etrim in order to get a **general distribution of the FD event vs Etrim** (energy deposited in the ND active volume) resulted from all Off-axis and vtx_x position and **efficiency corrected**

Integral of this histogram = average geom. eff of the FD event at the ND

Geometric Efficiency within PRISM framework

ND

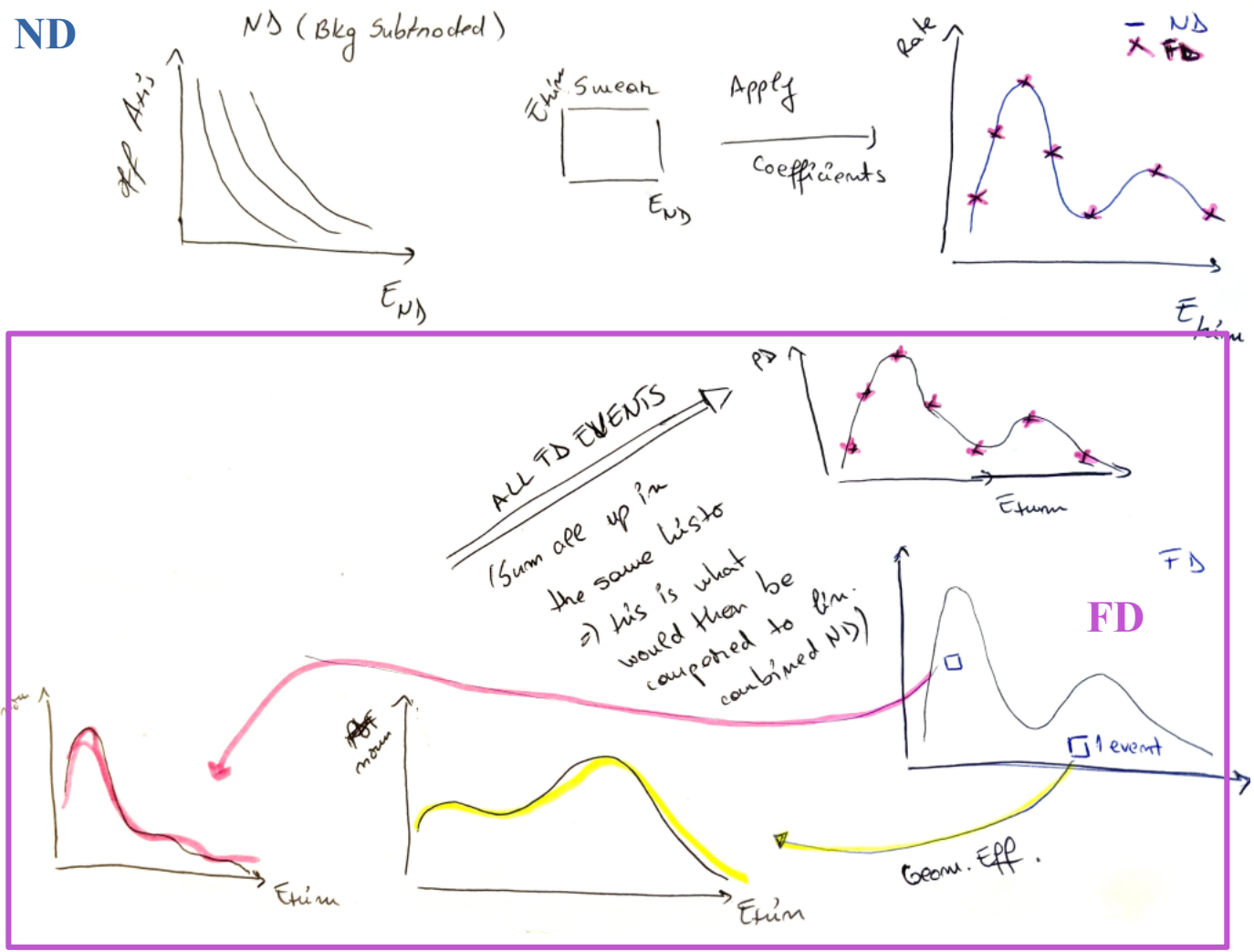




1. Start with ND data (bkg subtracted) vs OA vs E_{ND}
2. **Smear ND data to Etrim**
3. Apply OA coeficients

PRISM linear combination

Geometric Efficiency within PRISM framework



1. Start with ND data (bkg subtracted) vs OA vs E_{ND}
2. **Smear ND data to Etrim**
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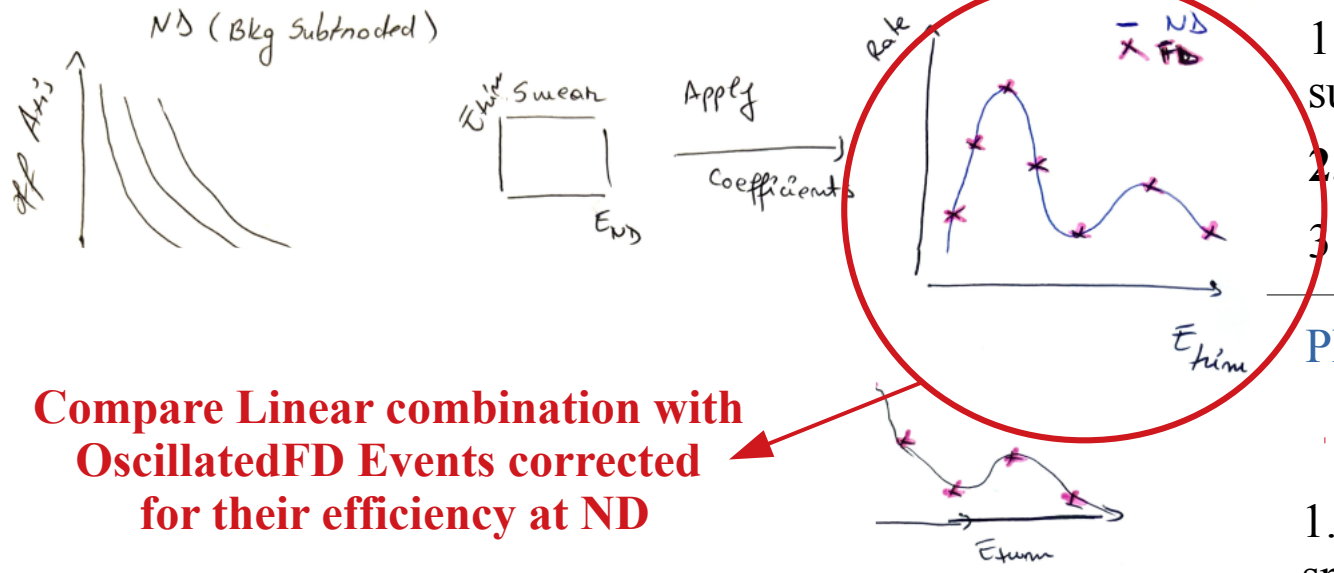
PRISM linear combination

1. Start with FD oscillated spectrum (FD tot hadronic Energy)
2. For each FD event → geometric efficiency correction (Etrim)
3. FD events (efficiency corrected) distribution vs Etrim

Efficiency corrected FD oscillated spectrum

Geometric Efficiency within PRISM framework

ND



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PRISM linear combination

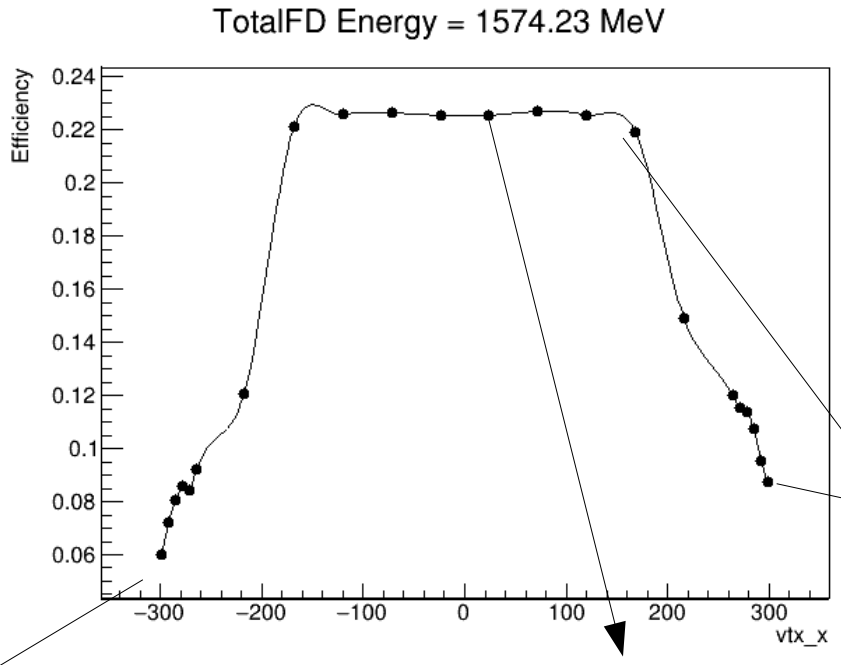
1. Start with FD oscillated spectrum (FD tot hadronic Energy)
2. For each FD event → geometric efficiency correction (Etrim)
3. FD events (efficiency corrected) distribution vs Etrim

Efficiency corrected FD oscillated spectrum

First Results: towards implementing the geometric efficiency correction withi PRISM

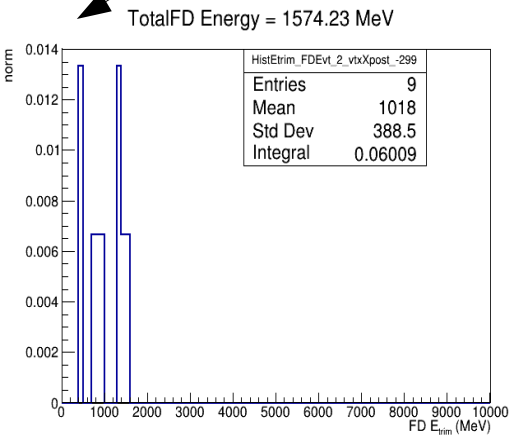
- first results: only 100 throws so far, just for visualization and understanding of the procedure
- soon to do the same from all throws → **in progress**
- need to **only keep the events that passed the throws** (not done in the following results)
  - saved the throws results and will soon have the final-end histograms (very memory consuming at the moment, need to improve this)
- very “raw” vtx_x position: not uniform across the detector

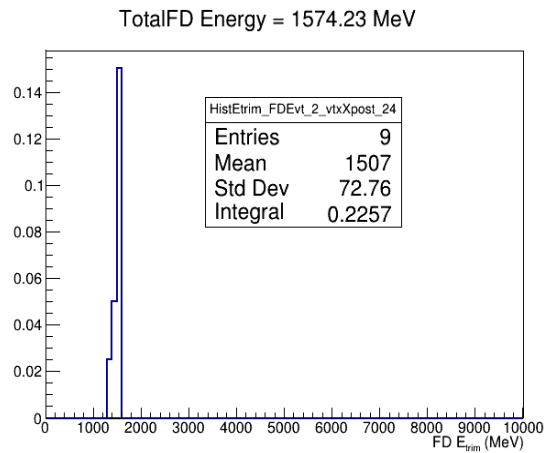
To be improved soon – just getting started :)

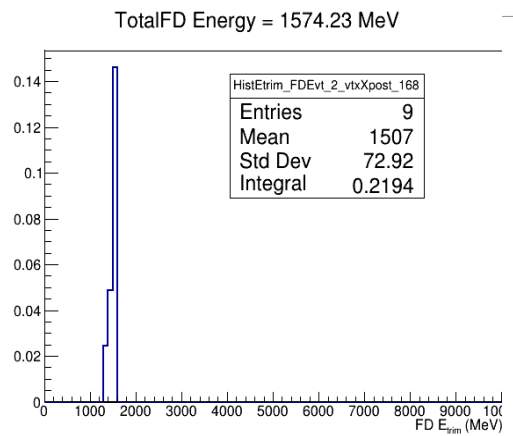


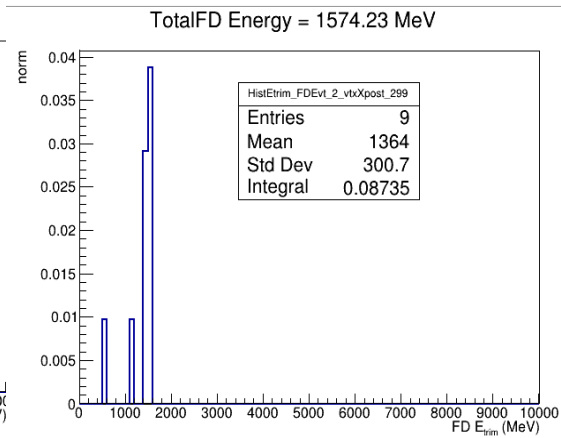
On-axis only : detector at 0 m

- for now only 100 throws → will get more throws ASAP
- Etrim: energy deposited inside ND active volume
  (= FD Energy – OutEnergy)
- Integral of each histogram corresponds to the efficiency at the given vtx_x position
  - **norm (y-axis) = Events * Eff / nthrows**

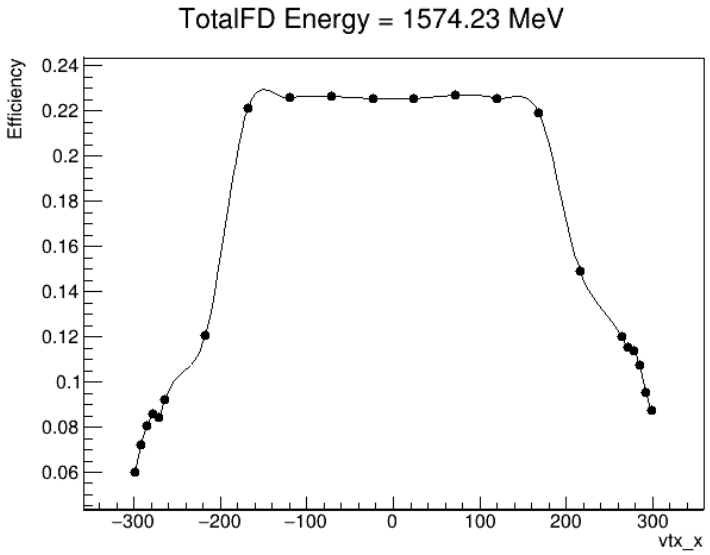




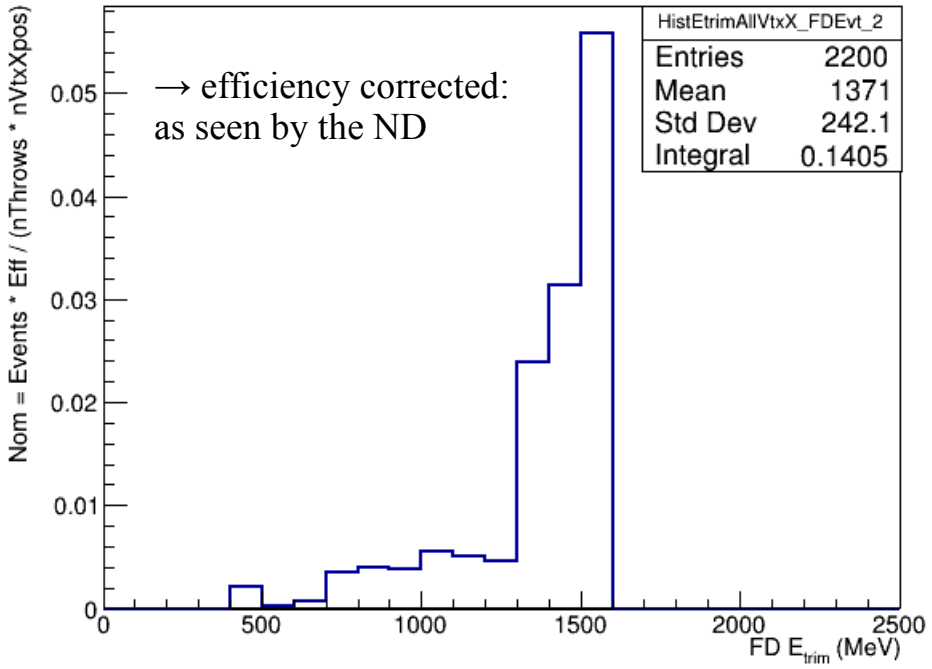




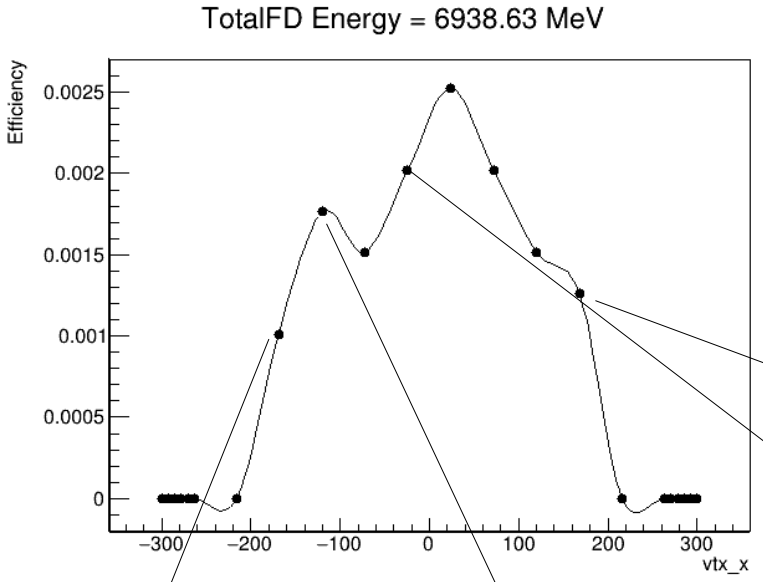
FD Events – efficiency corrected



Distribution of FD Event as seen by ND vs Etrim

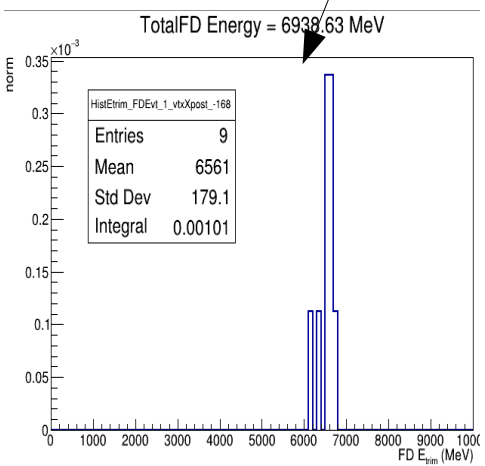


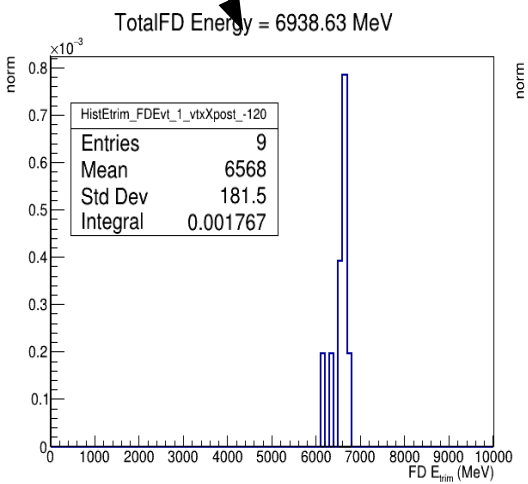
– **average efficiency** (E_{trim}) of FDEvt_2 (FD Energy = 1574.23 MeV) at ND is **0.1405**

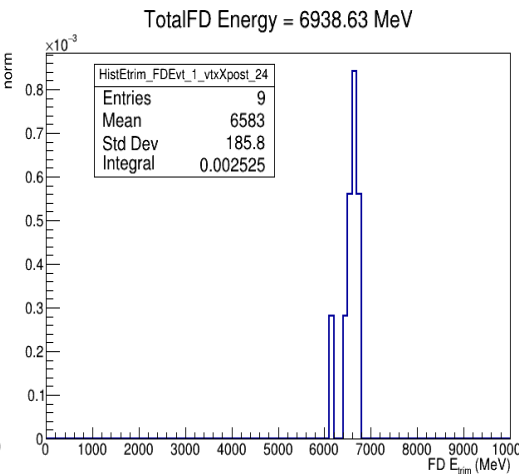


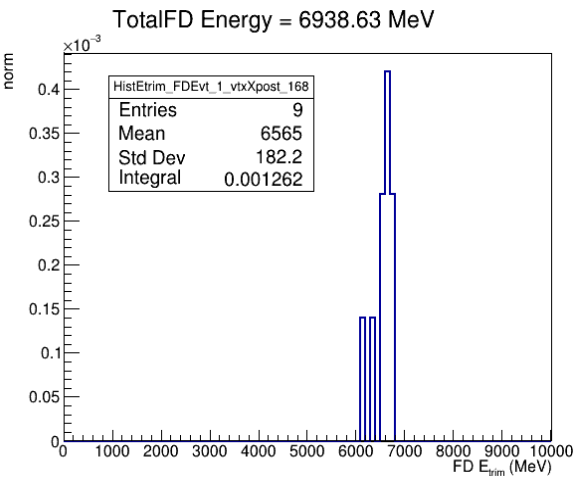
On-axis only : detector at 0 m

- for now only 100 throws → will get more throws ASAP
- Integral of each histogram corresponds to the efficiency at the given vtx_x position

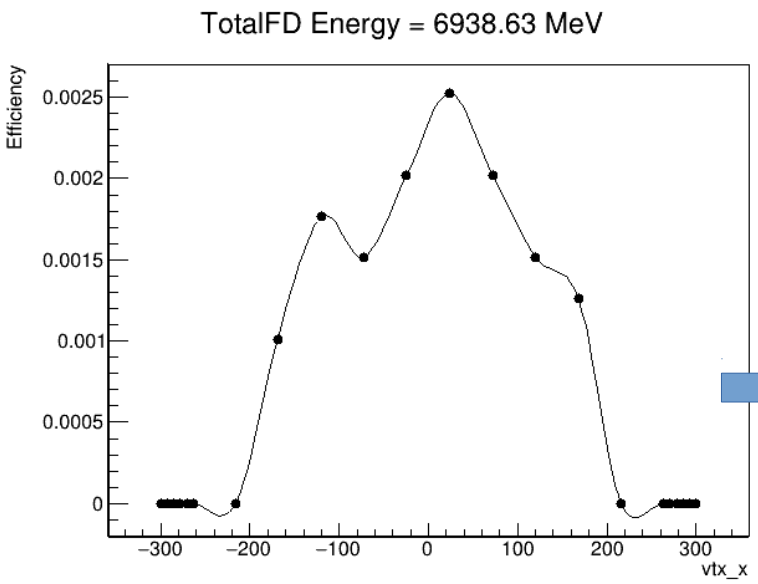




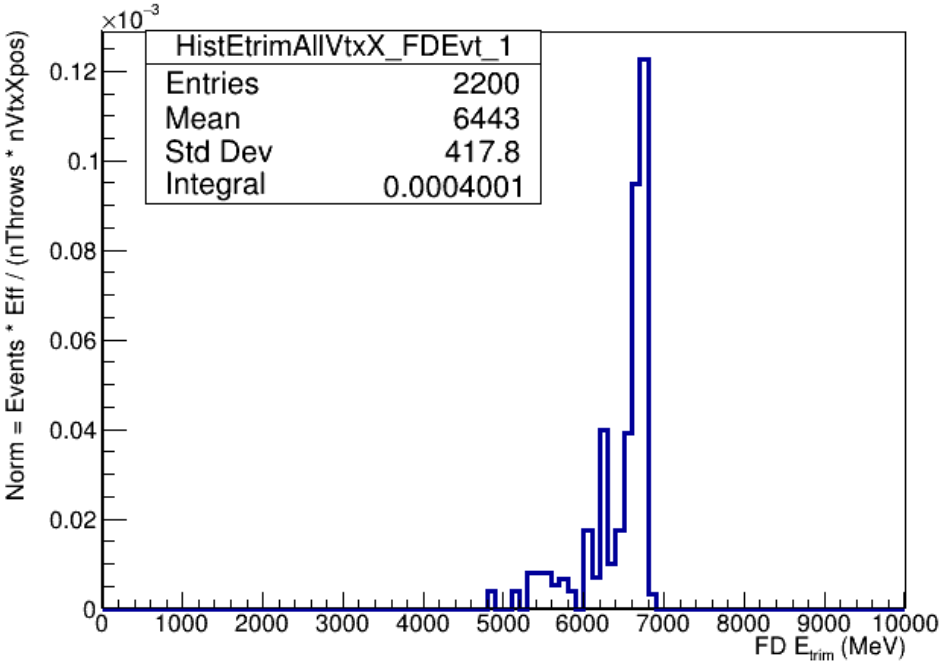




FD Events – efficiency corrected

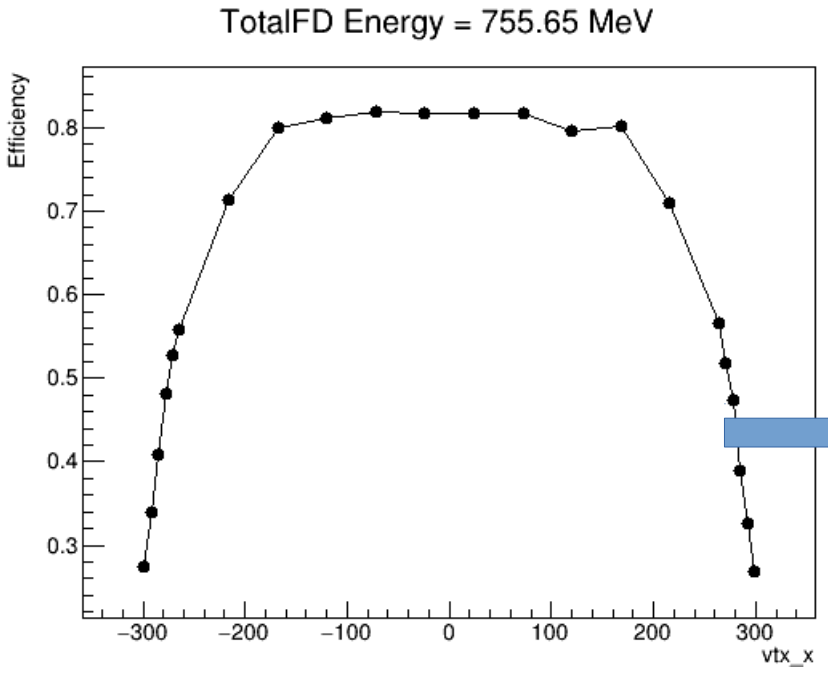


Distribution of FD Event as seen by ND vs Etrim

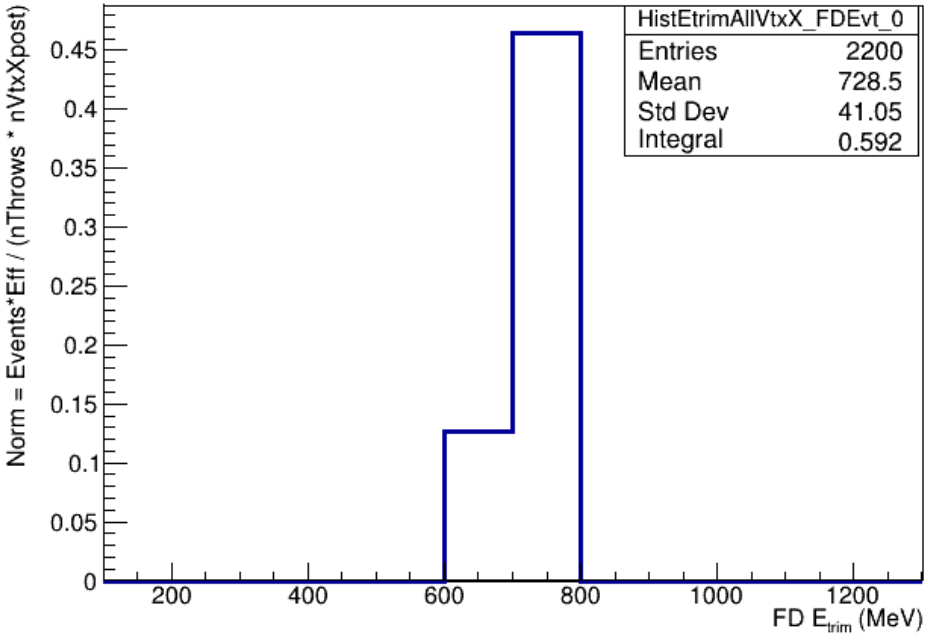


– **average efficiency** (E_{trim}) of FDEvt_2 (FD Energy = 6938.63 MeV) at ND is **0.0004**

FD Events – efficiency corrected



Distribution of FD Event as seen by ND vs Etrim



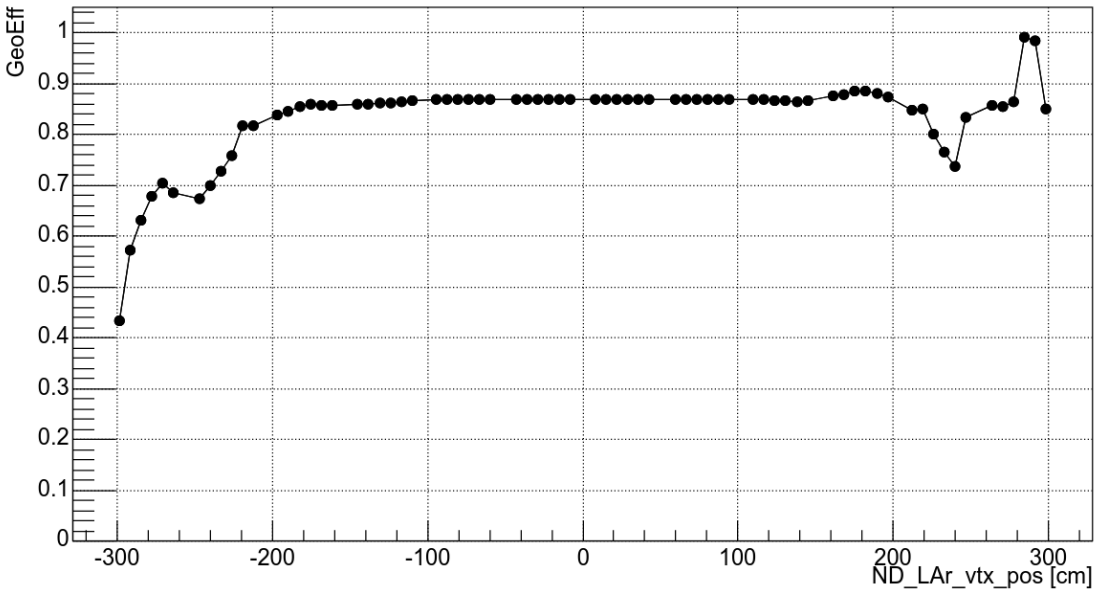
– **average efficiency** (E_{trim}) of FDEvt_0 (FD Energy = 755.65 MeV) at ND is **0.592**

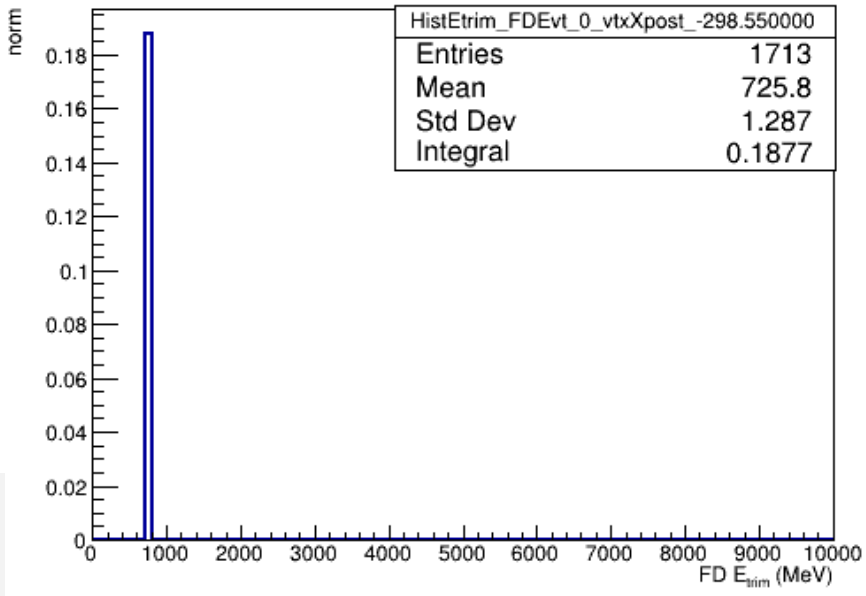
Where we are:

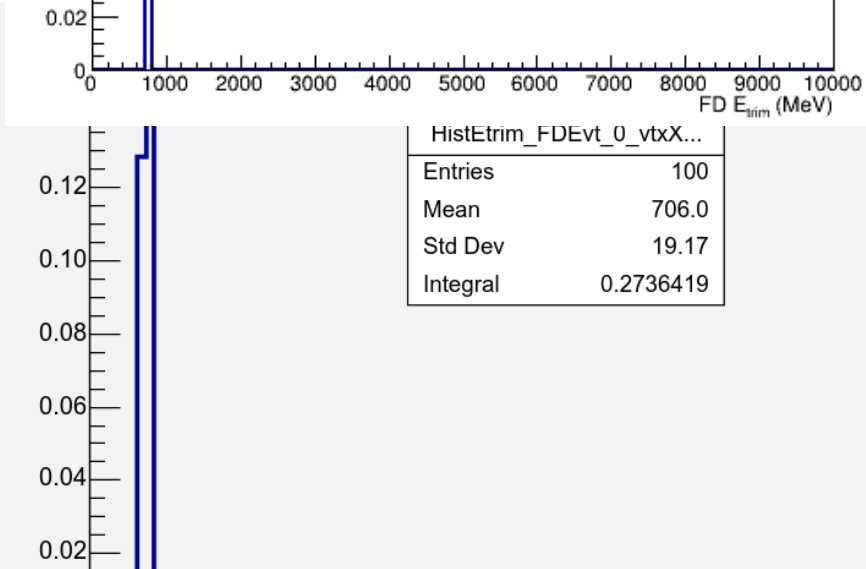
- plan on how to proceed to implement efficiency correction within the analysis
- can now access the throws result and create the histograms corresponding to all throws (4096) based on whether they pass the hadron containment (throw!=0) → this is rather memory consuming: nThrows & vtxXpos * nFDEvents
  - working on improving this, first results soon

TO DOs

- PRISM CAFs: we will eventually need same events from FD CAFs used within PRISM to be present in the CAFs used for geometric efficiency correction.. to be discussed more how to properly achieve this
- histograms for all throws and OA position of some “mockup” ntuples for the geometric efficiency correction → first results here more correct and complete results to come soon.

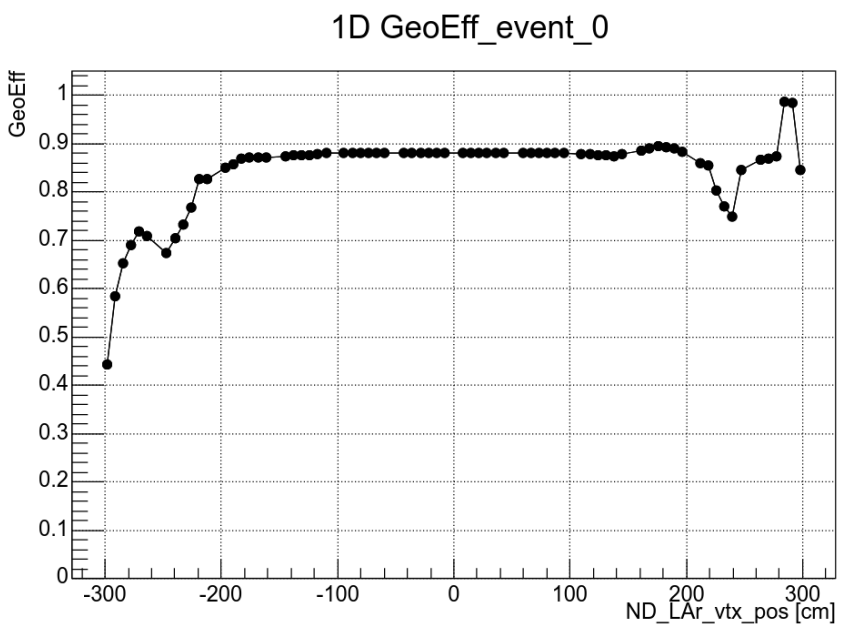

GeoEff
ND_LAr_vtx_pos [cm]

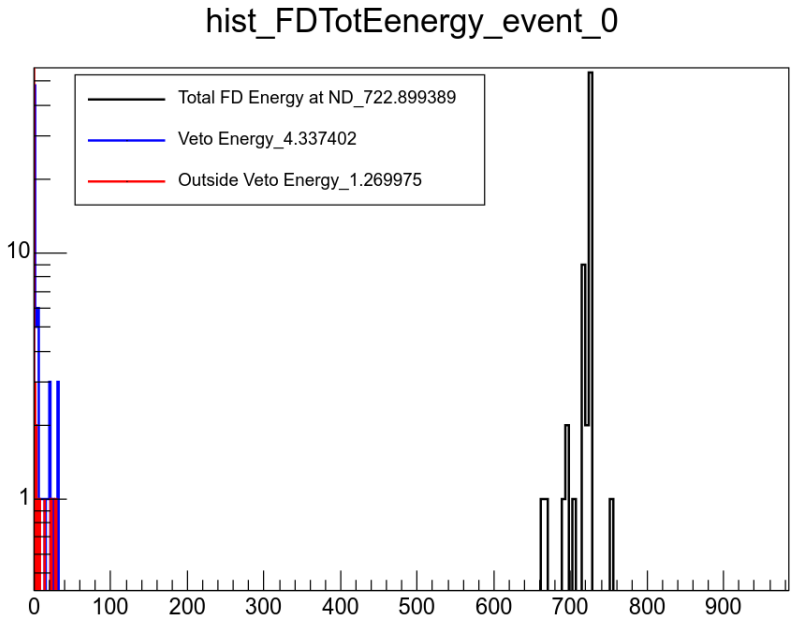

norm
HistEtrim_FDEvt_0_vtxXpost_-298.550000
Entries 1713
Mean 725.8
Std Dev 1.287
Integral 0.1877
FD E_trim (MeV)


HistEtrim_FDEvt_0_vtxX...
Entries 100
Mean 706.0
Std Dev 19.17
Integral 0.2736419

Geometric efficiency: stage 1 – hadronic energy with no FD trimmed events

- From main output file (runGeoEffFDSim.ccp):



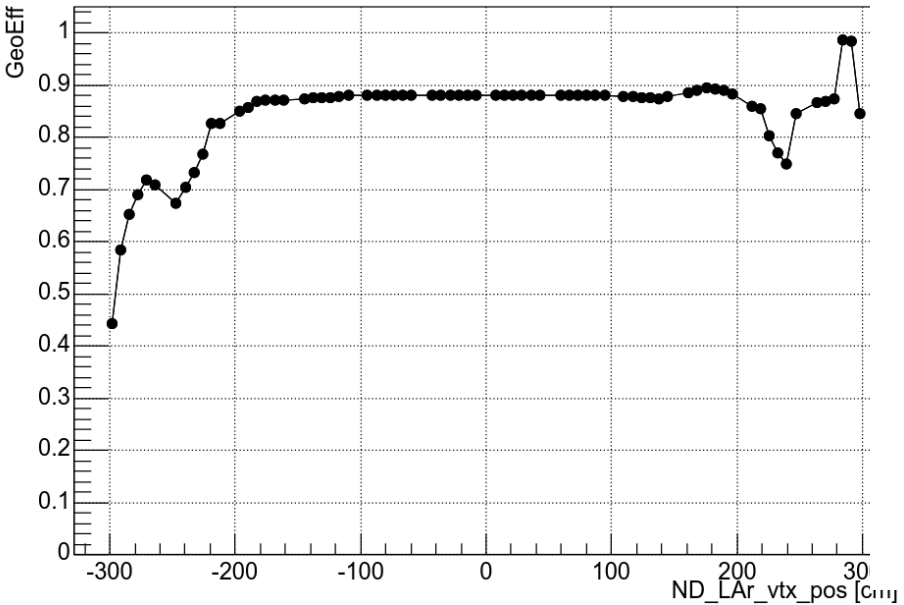


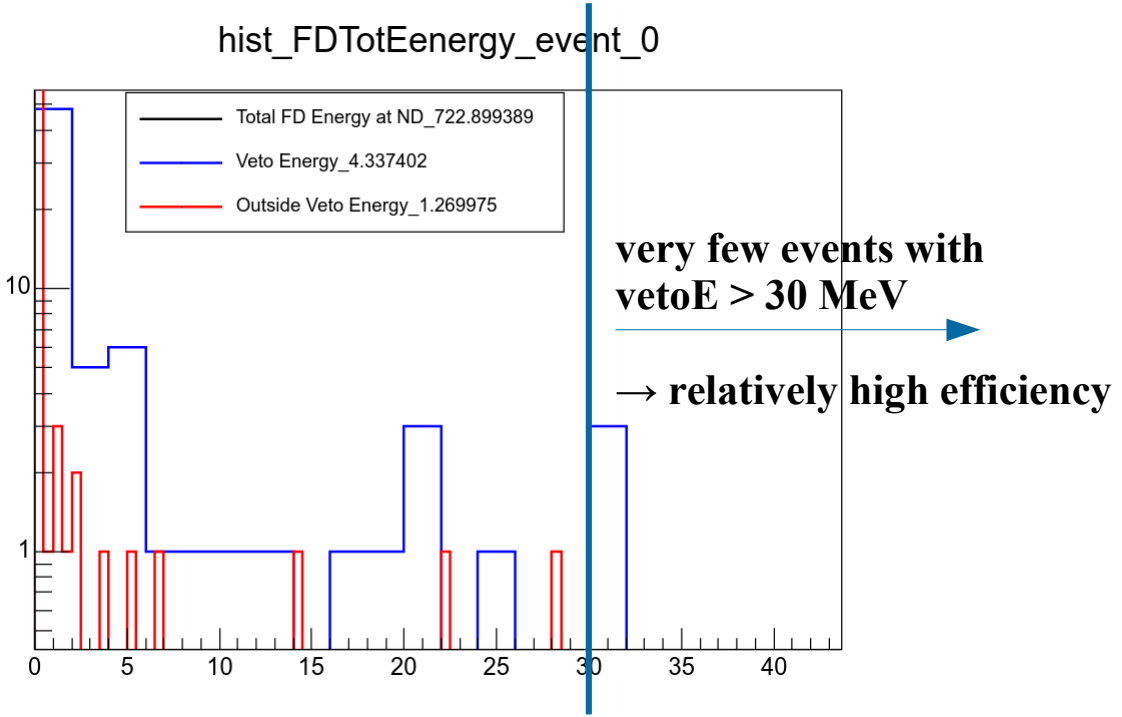
Total FD Energy = 722.89 MeV

Veto Energy = 4.33 MeV

- Energy deposited in ND FV = Total FD Energy – Veto Energy – Outside energy = 717.29 MeV
- FD Etrim = Total FD Energy – OutsideVetoEnergy? (= 721.62 MeV)

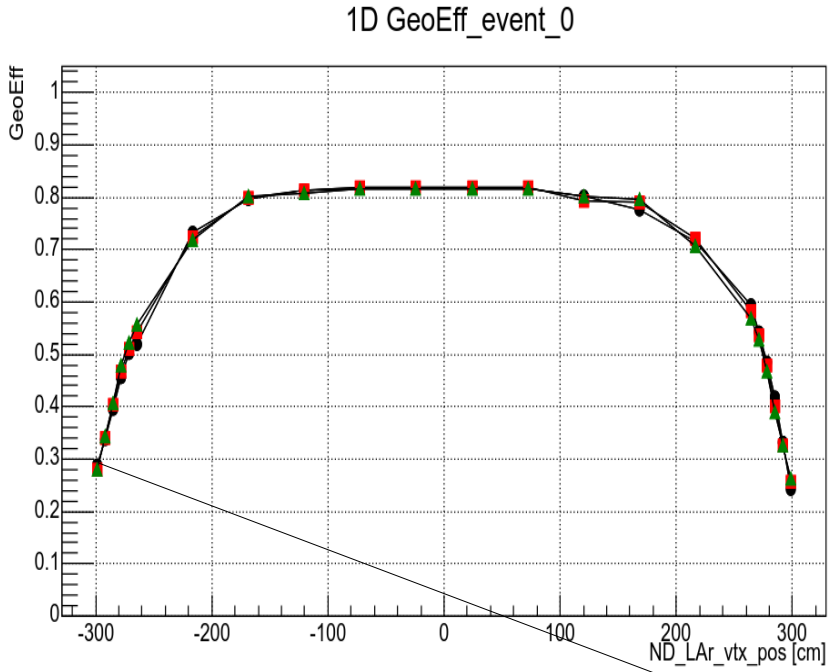
Geometric efficiency: stage 1 – hadronic energy with no FD trimmed events



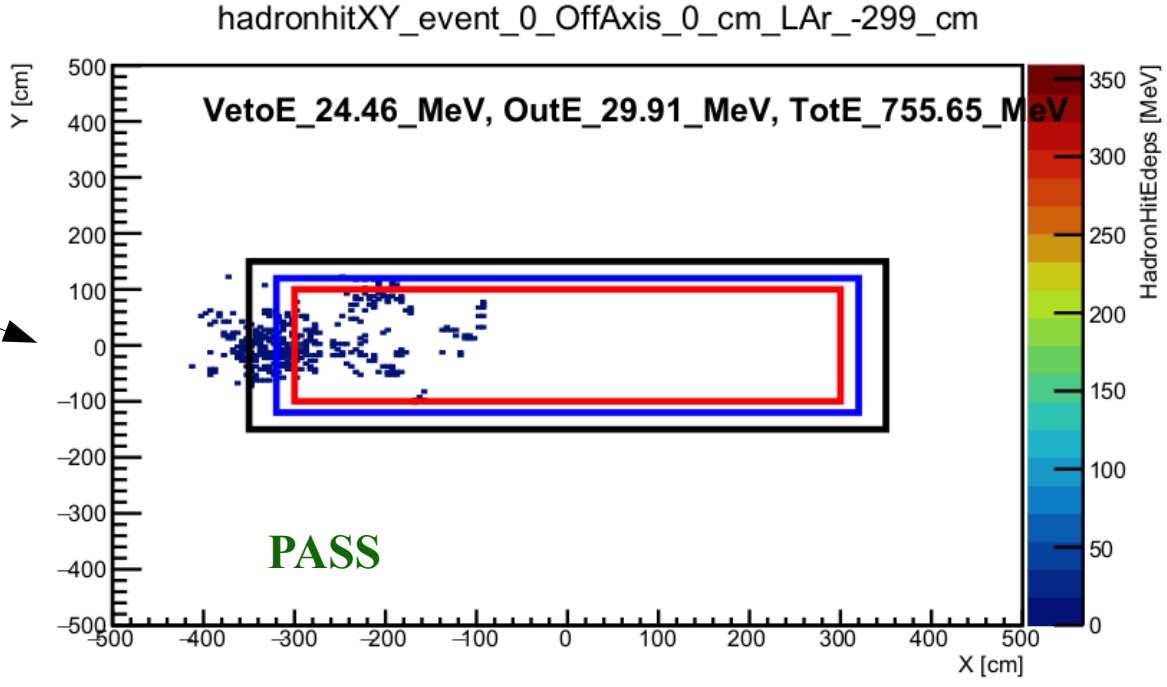


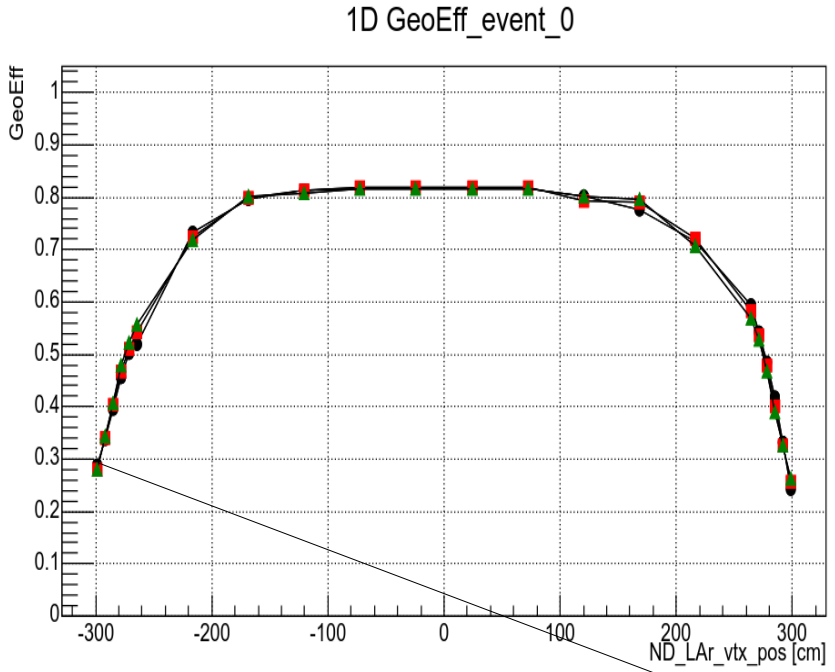
– FD Total energy corresponds to 1 FD Event: → will have 1 value of Total FD energy for each vtx_x

– Veto Energy and Outside energy: will have some **energy distribution** / histograms f**or each vtx_x** (resulted from Nthrows)

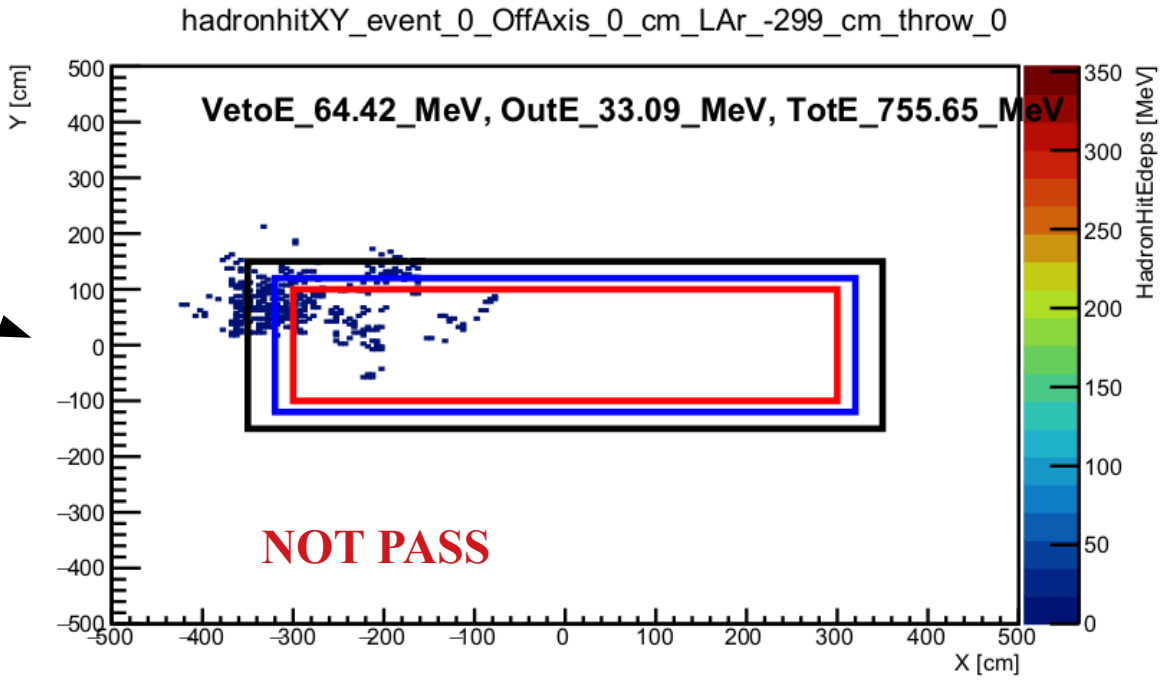


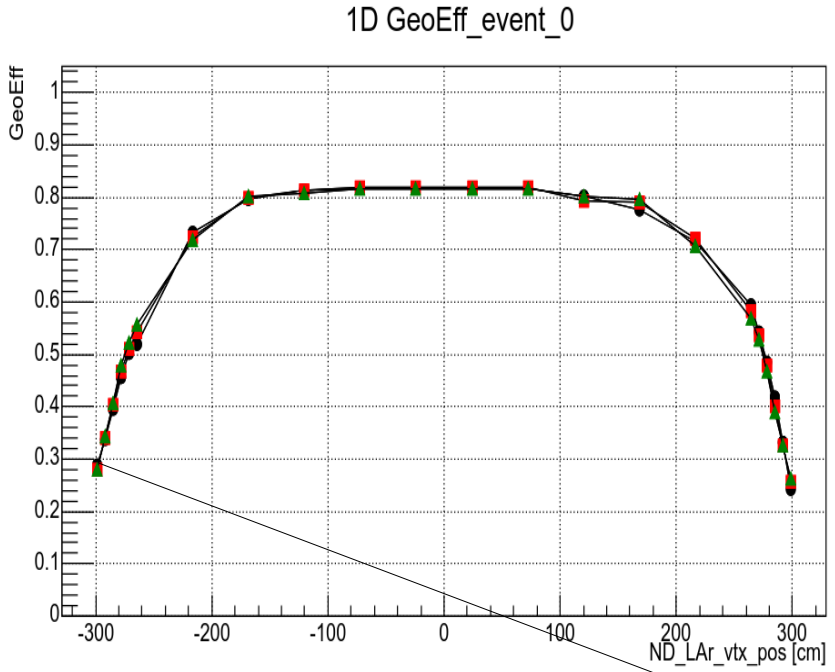
- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws



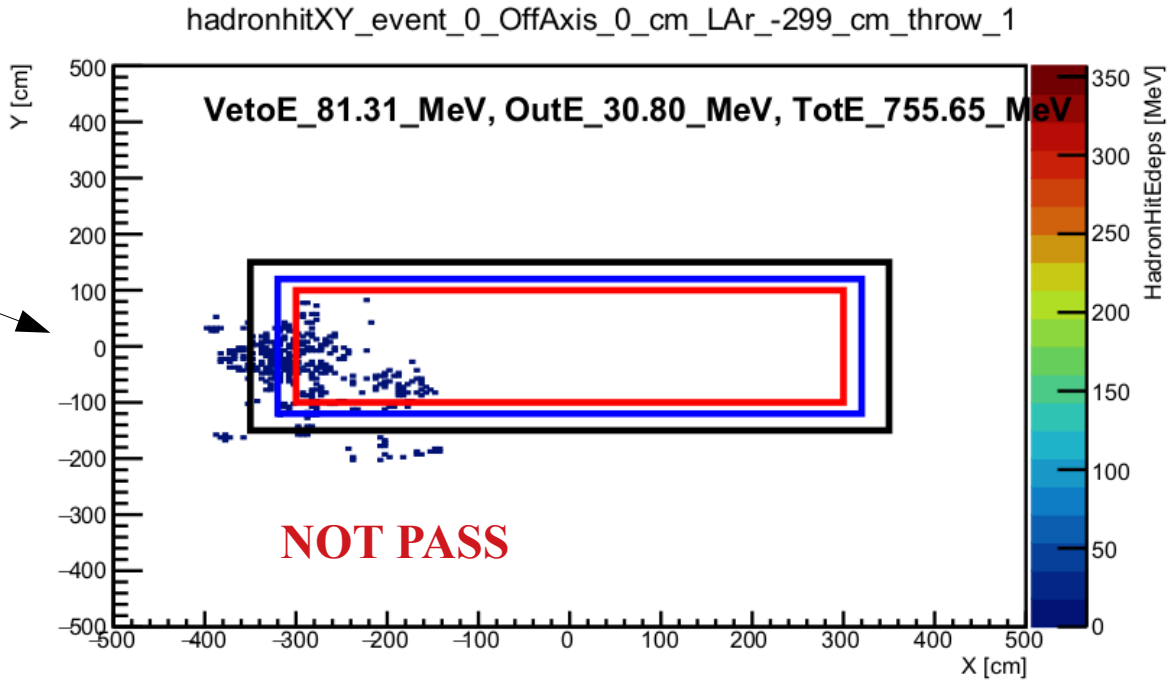


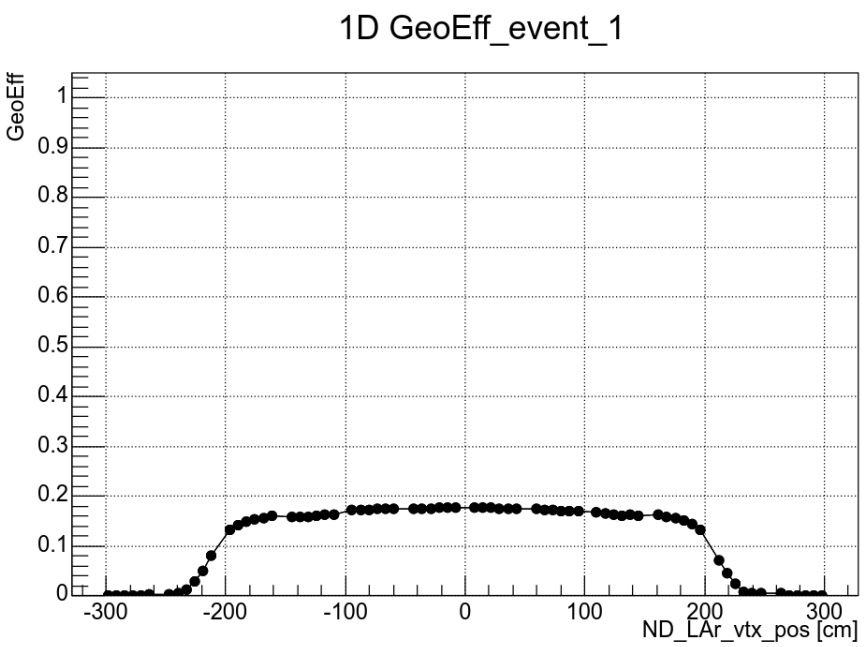
- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws

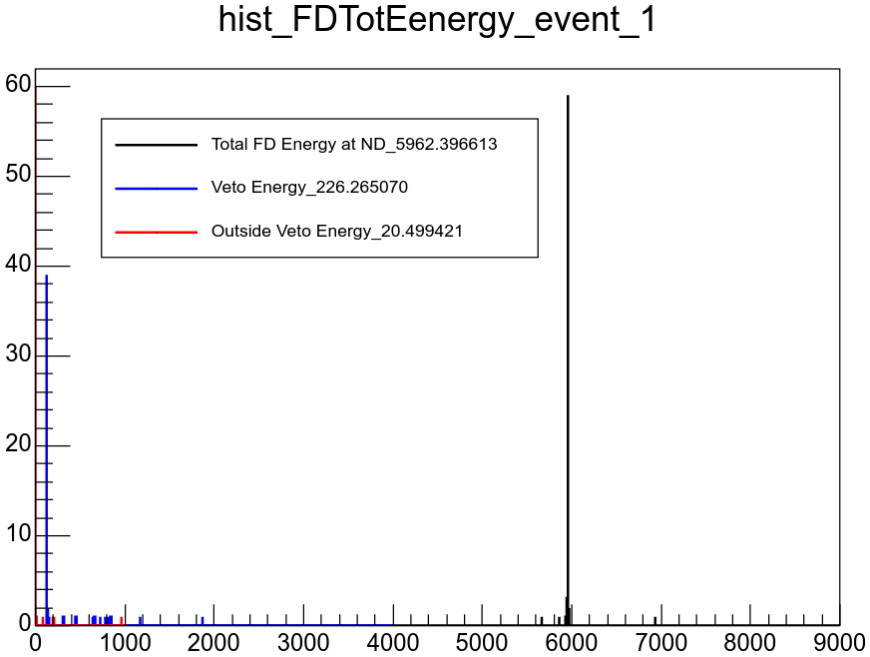




- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws



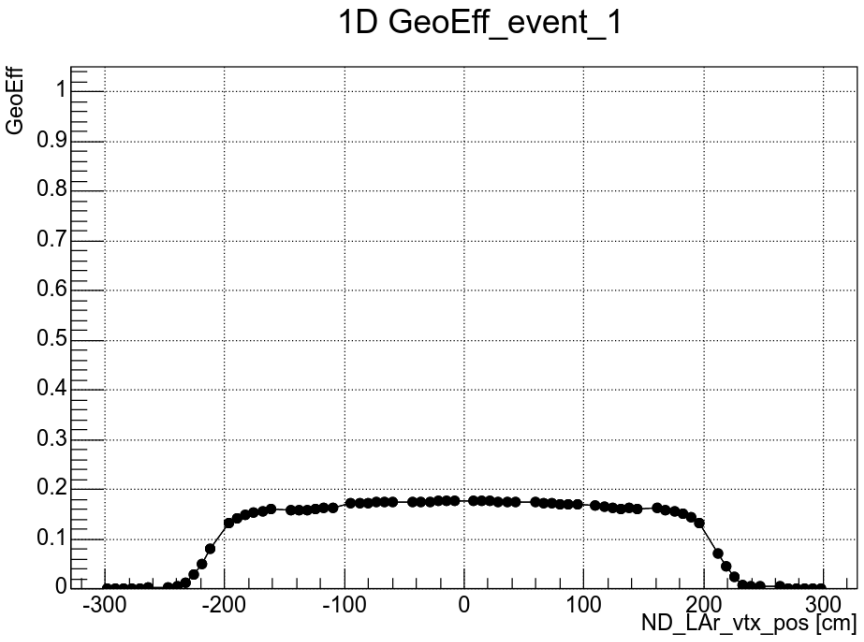


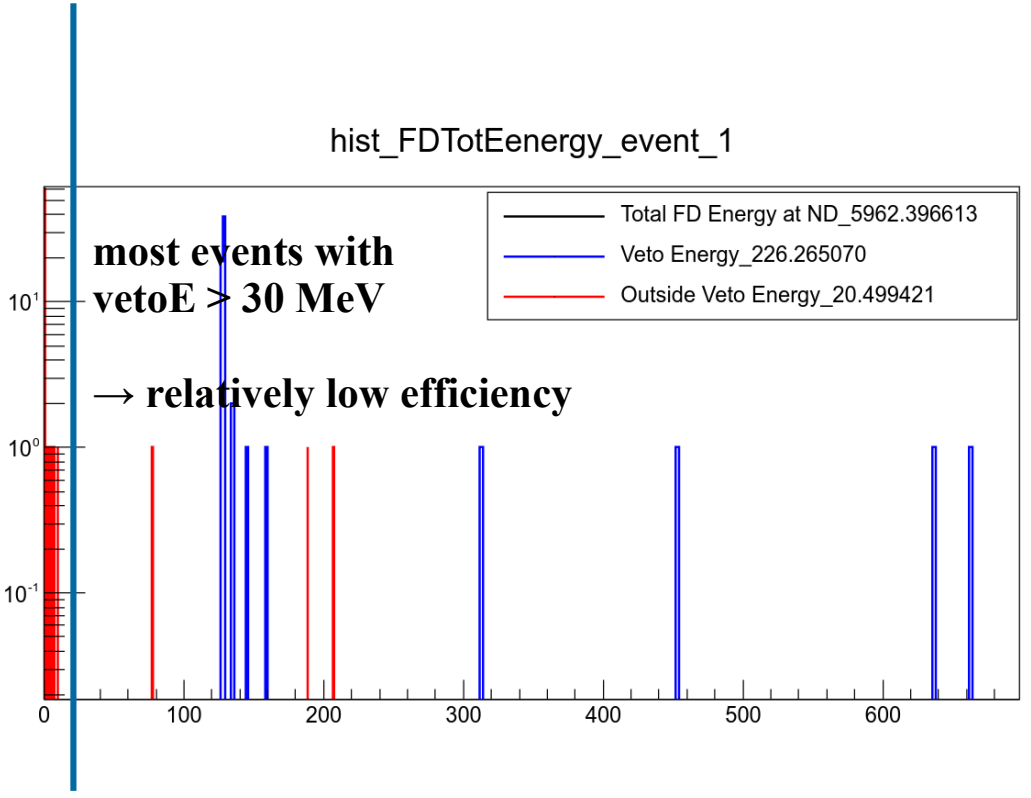


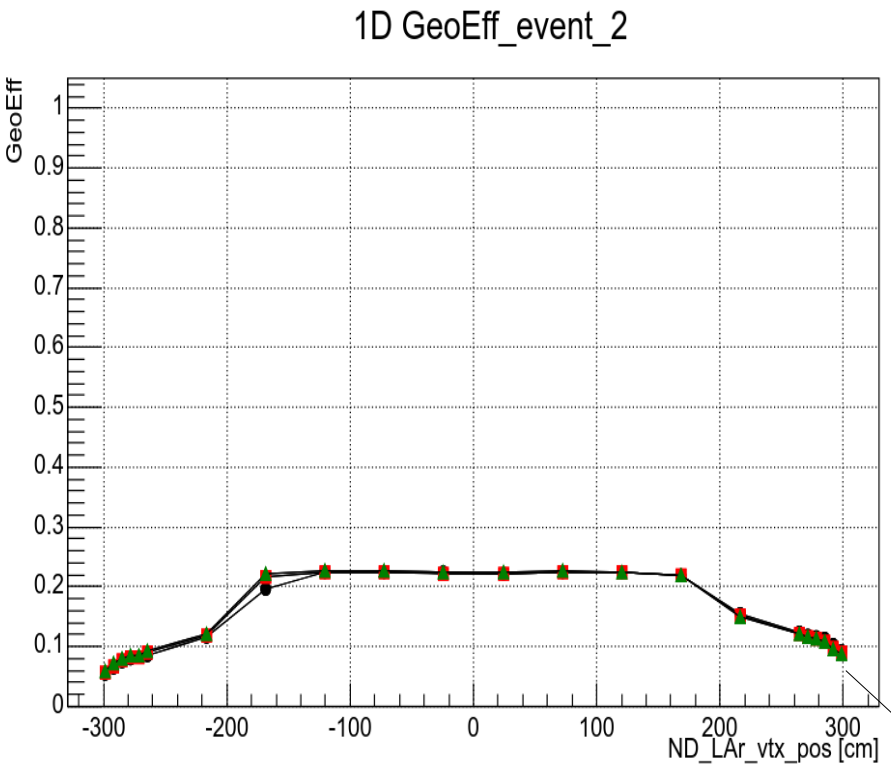
Total FD Energy = 5962.4 MeV

Veto Energy = 226.26 MeV

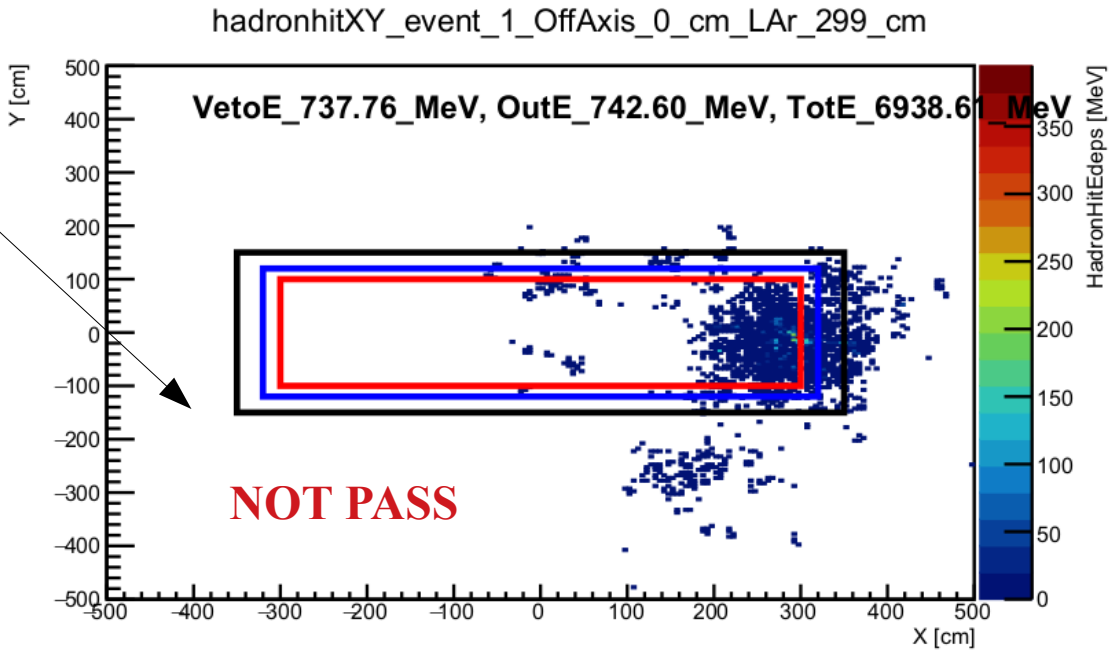
- Energy deposited in ND FV = Total FD Energy – Veto Energy – Outside energy = 5715.63 MeV
- FD Etrim = Total FD Energy – OutsideVetoEnergy?
  (= 5941.9 MeV)

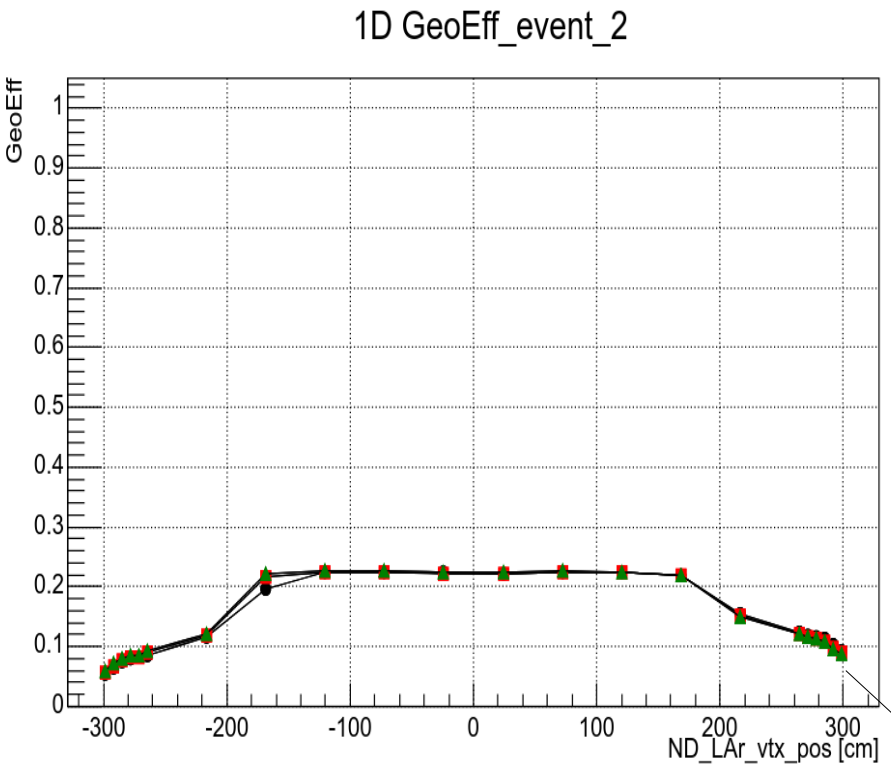

1D GeoEff_event_1
GeoEff
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-300
-200
-100
0
100
200
300
ND_LAr_vtx_pos [cm]


hist_FDTotEenergy_event_1
Total FD Energy at ND_5962.396613
Veto Energy_226.265070
Outside Veto Energy_20.499421
most events with
vetoE > 30 MeV
→ relatively low efficiency
10^1
10^0
10^{-1}
0
100
200
300
400
500
600



- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws





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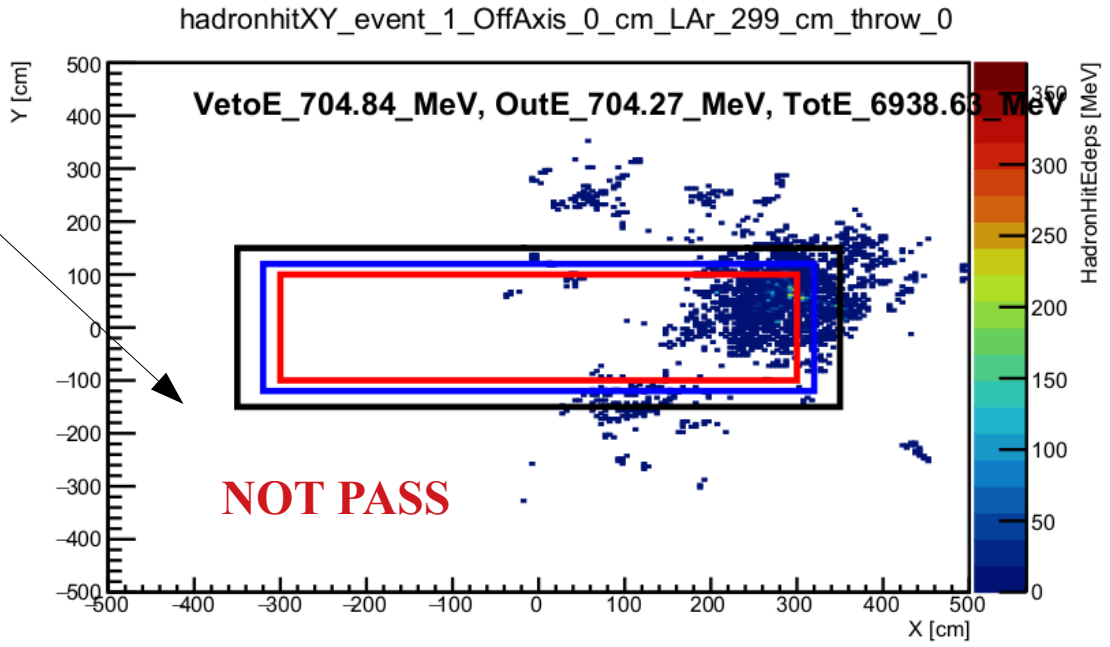
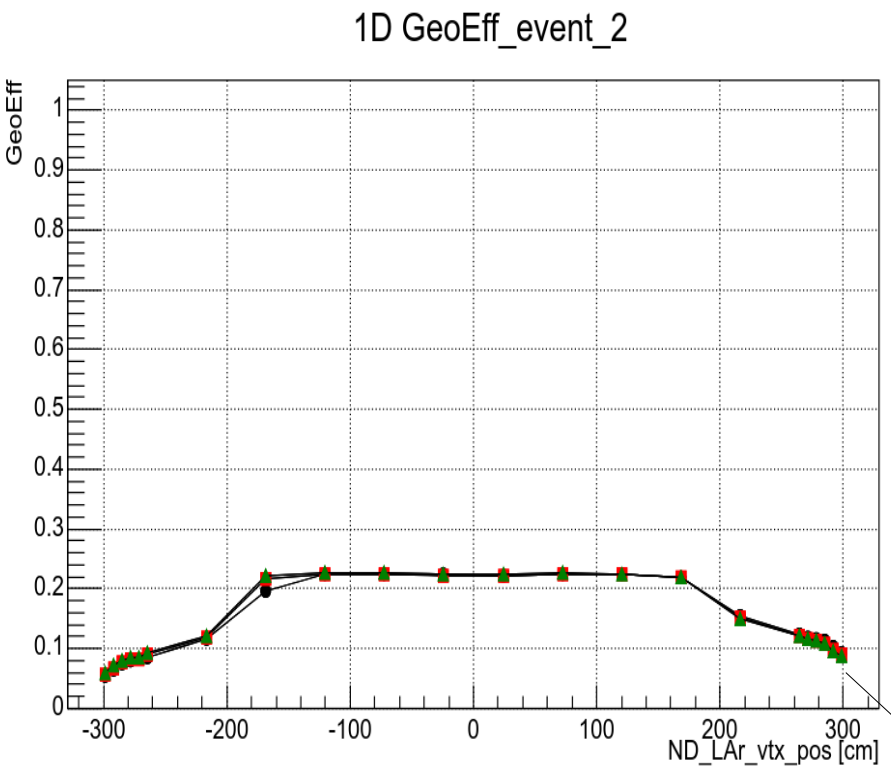
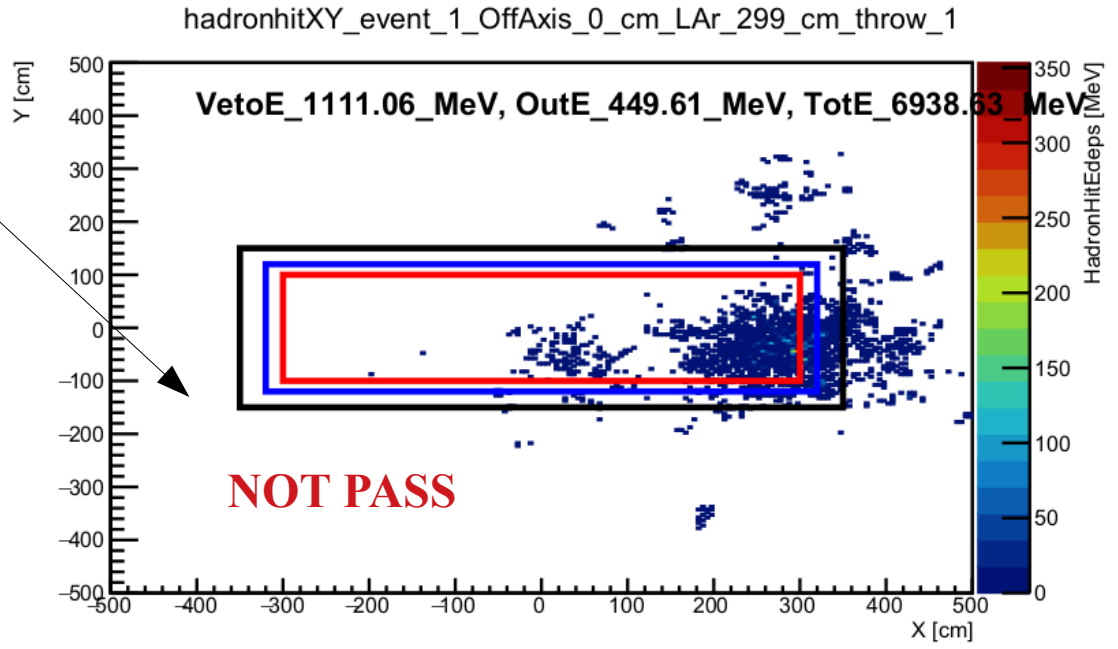
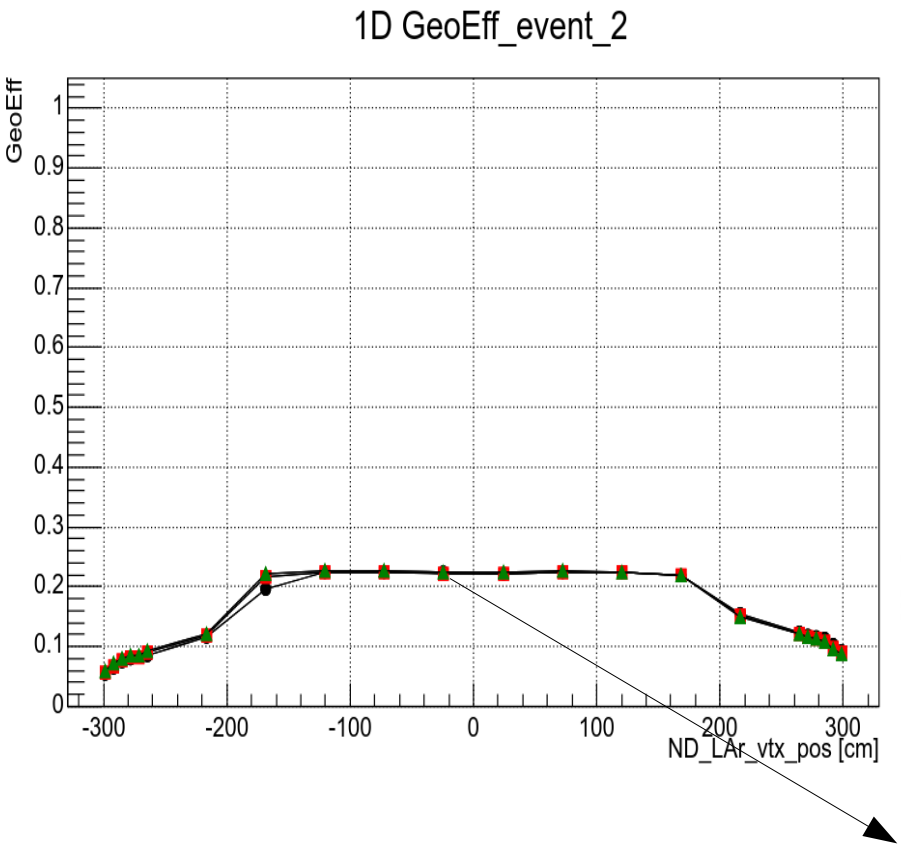
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws



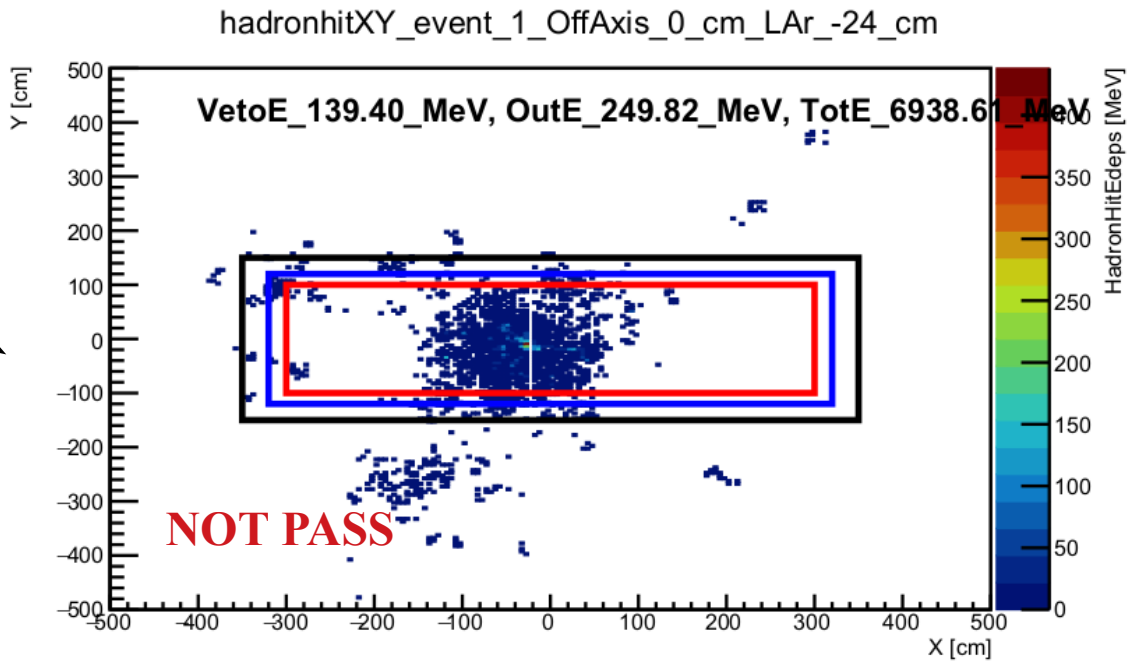


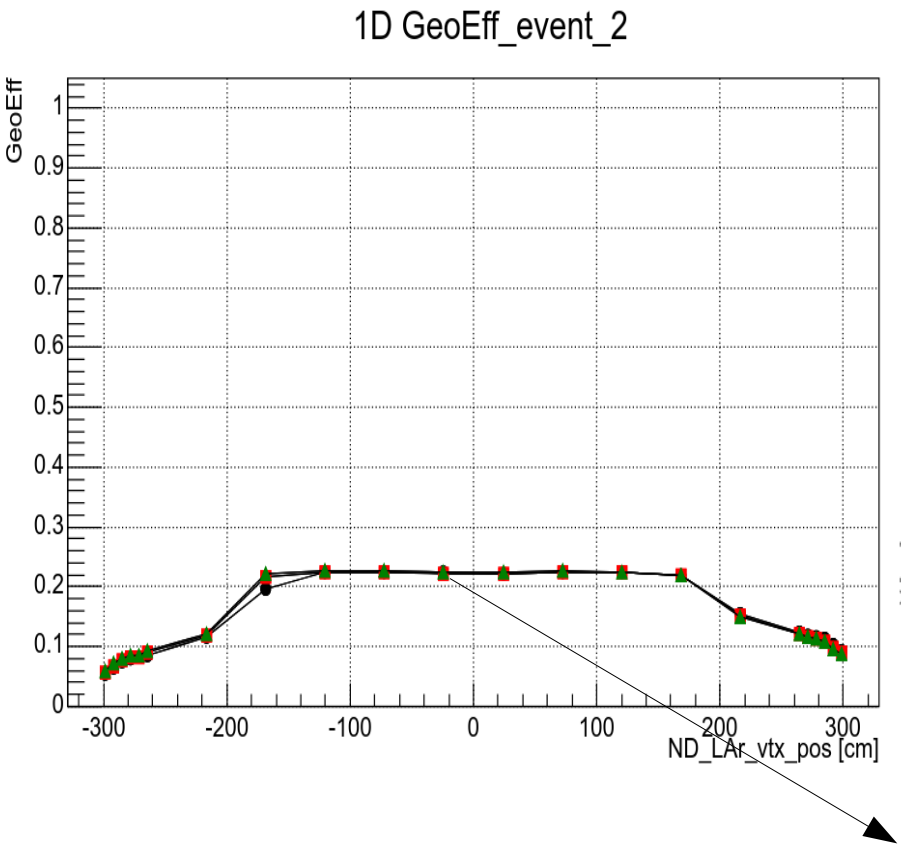
- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws



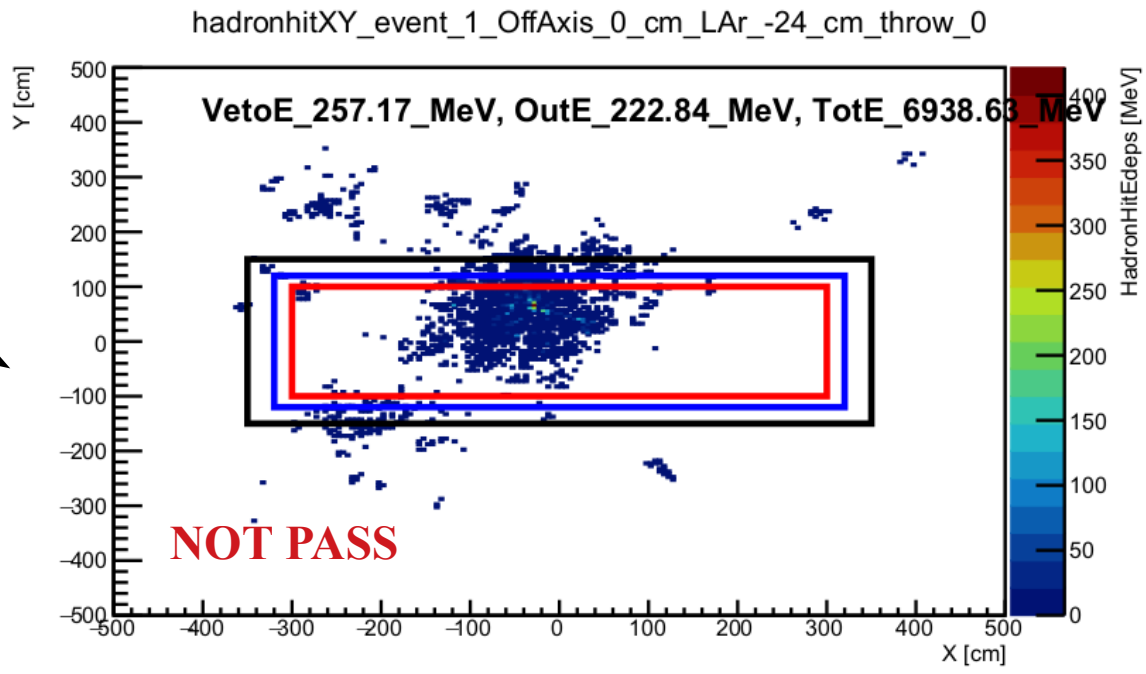


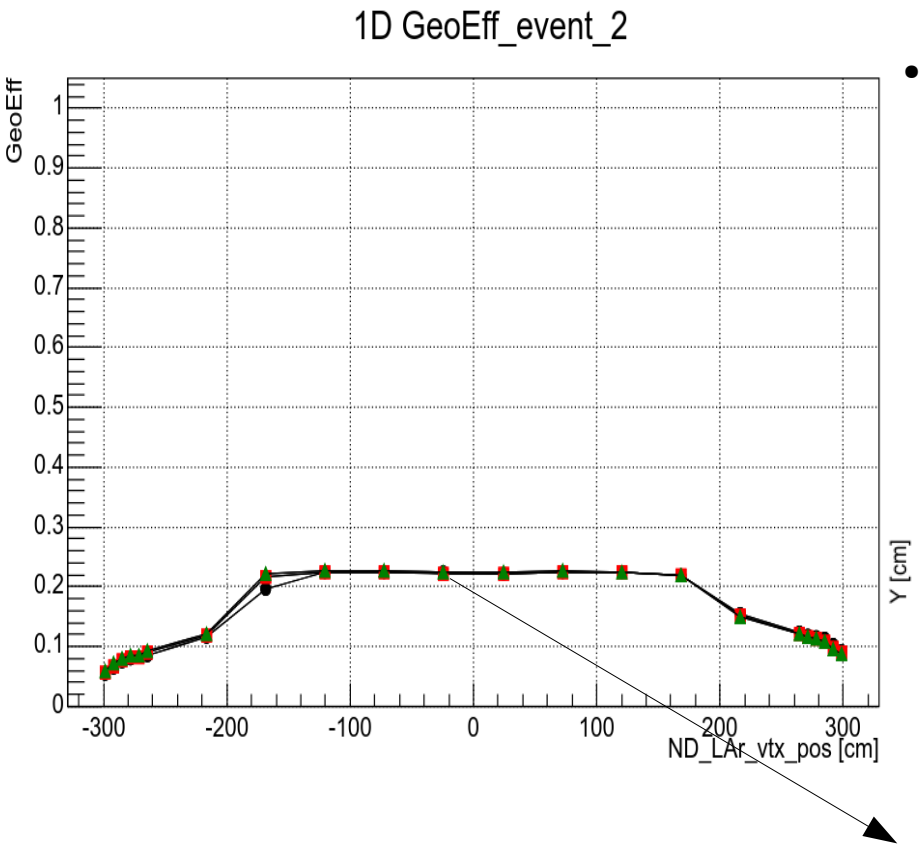
- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws





- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws





- This efficiency is calculated for each NDLAr_vtx_pos (x_vtx) and then thrown in y and z + rotations 4096 times
  → efficiency obtained from (event passing the throws) I.e for one value of efficiency at ND_LAr_vtx_pos we have additional 4096 throws