Geometric Efficiency Correction – Method and implementation with the PRISM framework

October 4th, 2024

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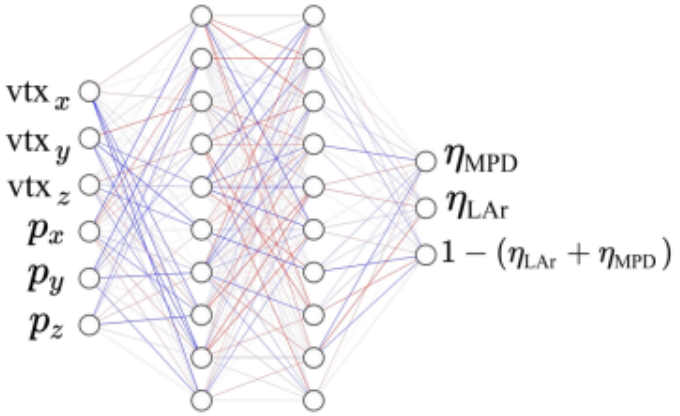
Disclaimer: Presented results are heavily based on Flynn Guo's work

Methods

Hadronic containment efficiency

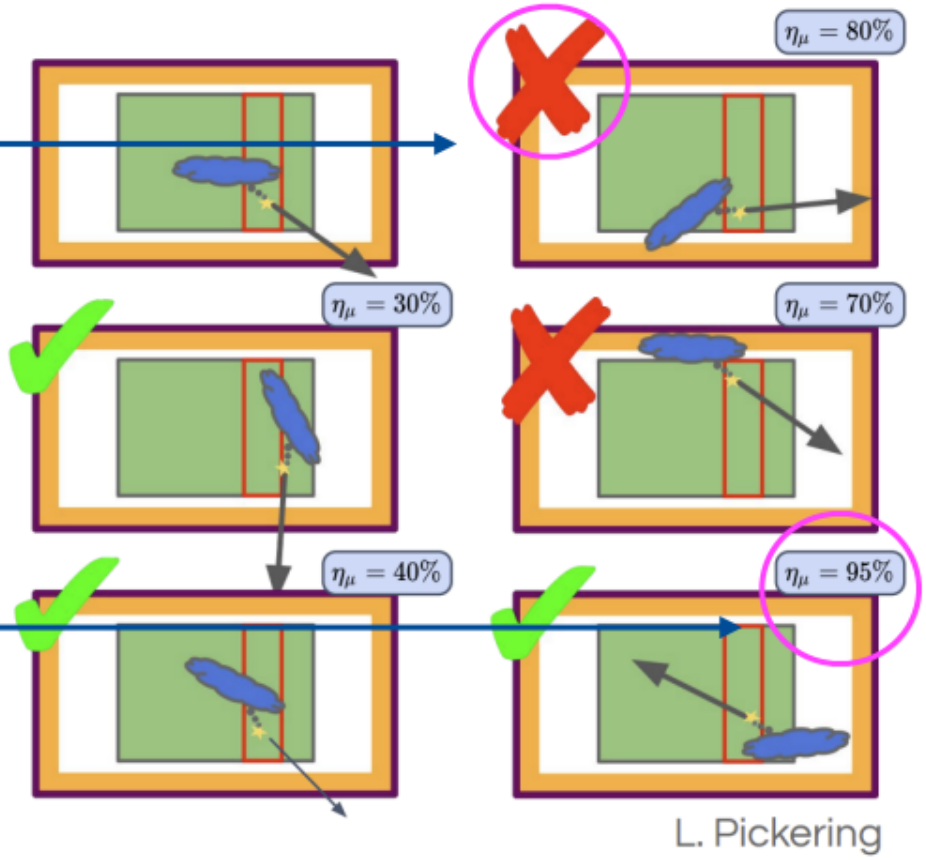
Pass or **fail** the hadronic veto cut in ND-LAr

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**

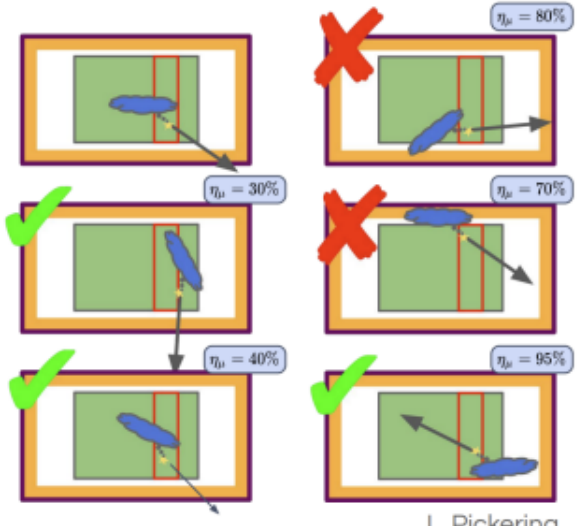
$$\eta = \frac{0\times0.8+1\times0.3+0\times0.70+1\times0.4+1\times0.95}{5} = 33\%$$

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)



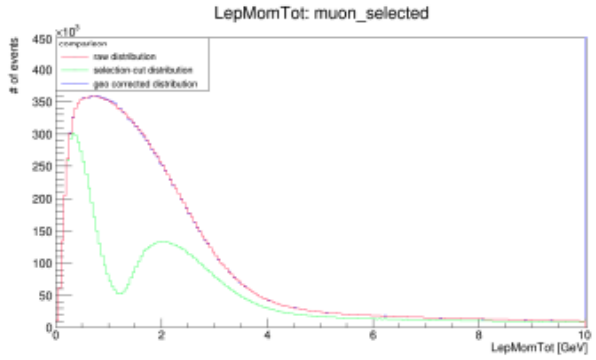
$$\eta = \frac{0\times0.8+1\times0.3+0\times0.70+1\times0.4+1\times0.95}{5} = 33\%$$

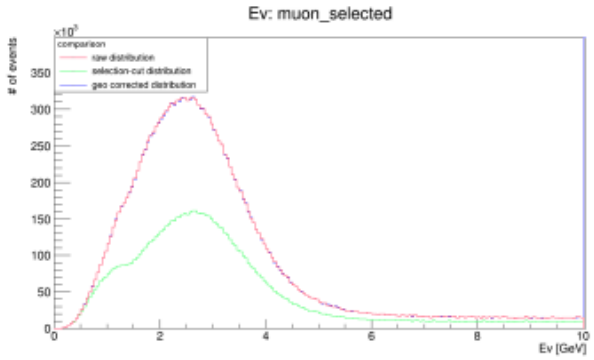
Geo-corrected:

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: $\frac{1}{33\,\%}$.

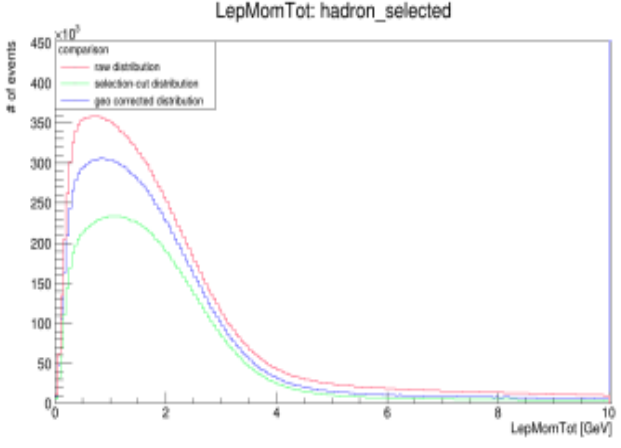
Results: Muon and Hadrons at ND

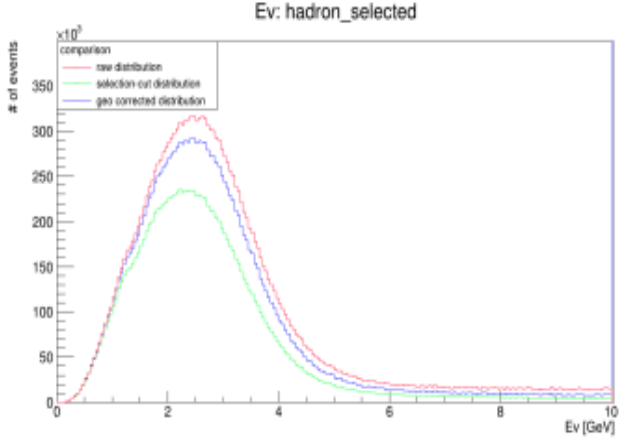
Muon_selected (On-axis)





Hadron_selected (On-axis)





Initial idea: Correct ND events

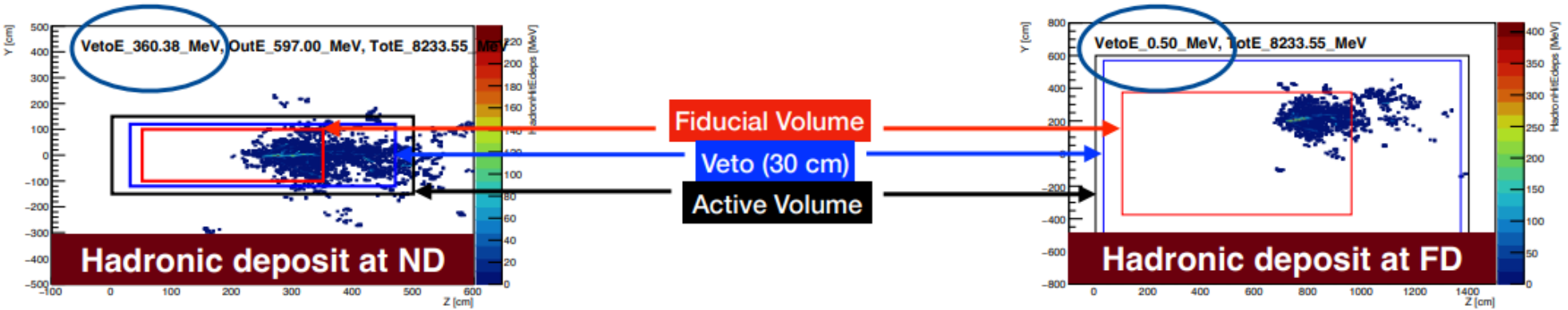
- Geo-corrected and raw distributions coincide with each other
  → **Geometric efficiency correction works well for muons**

- 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



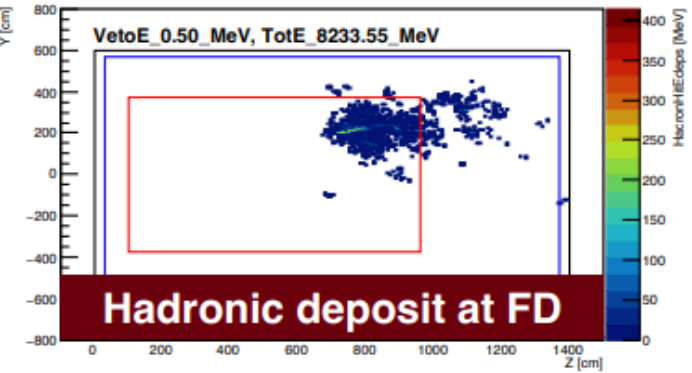
Veto Energy > 30MeV
Can't be selected

Veto Energy < 30MeV
Can be selected

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

FD Events at ND

FD event

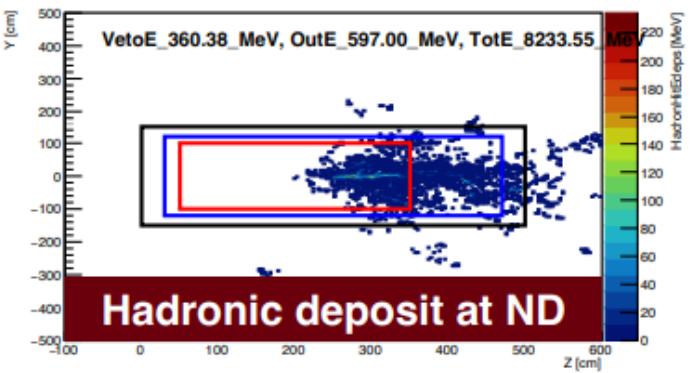


- Choose CC FD events w/ FD FV&vetoE cut
- Earth curvature transformation

↓ 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

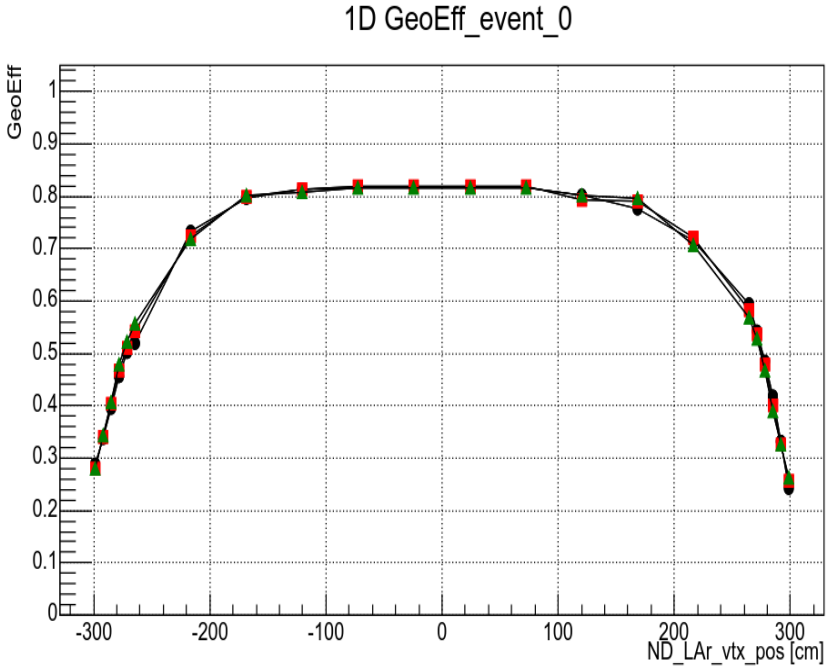
Geometric efficiency correction: hadronic component

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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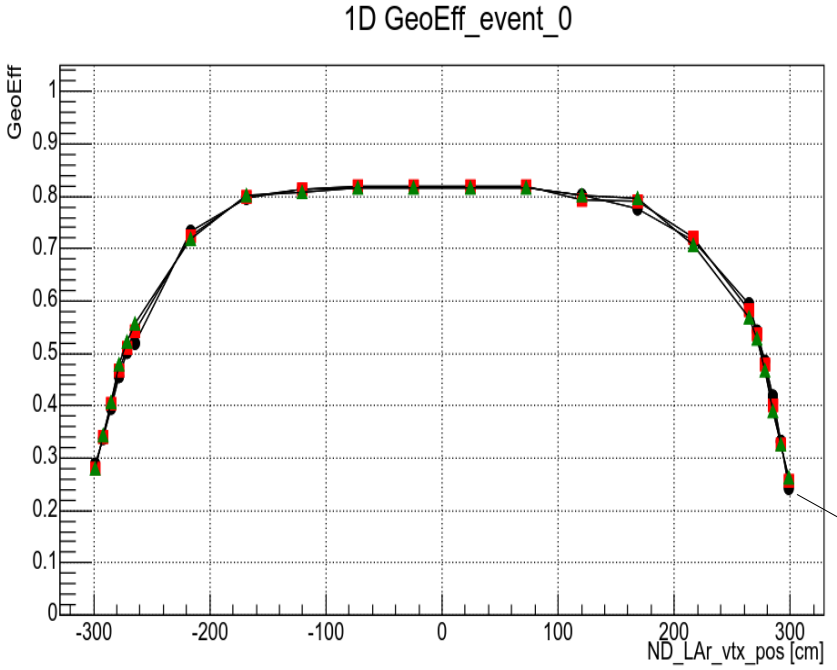

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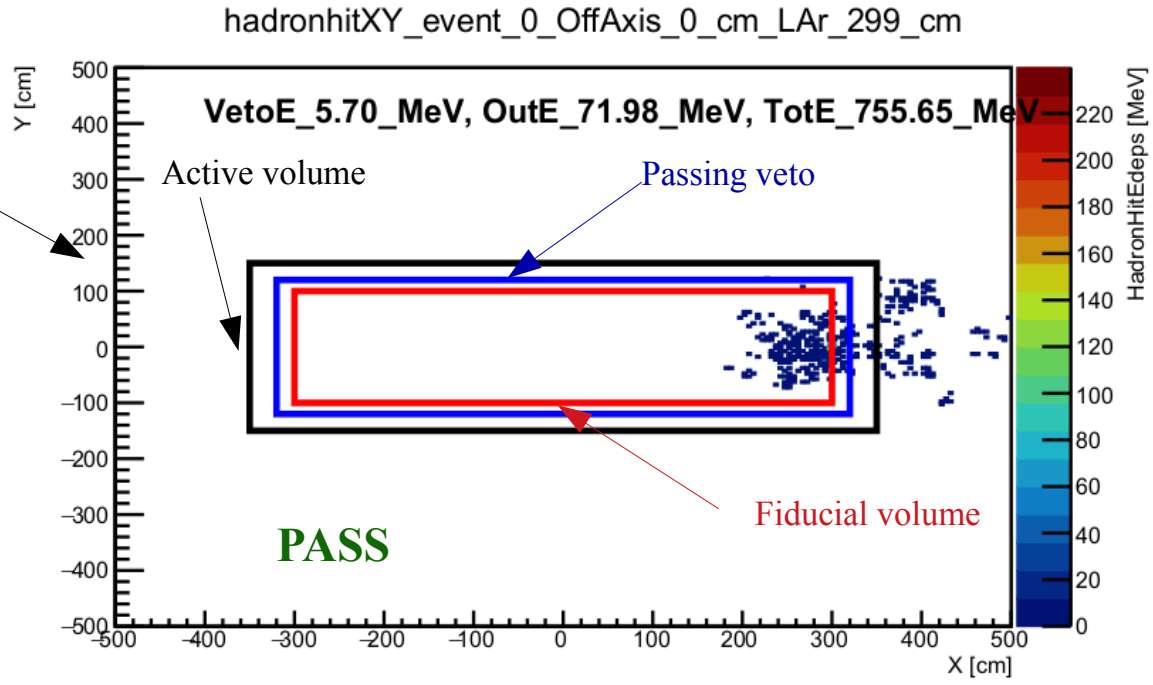
Event visualization at the ND

– before the throws



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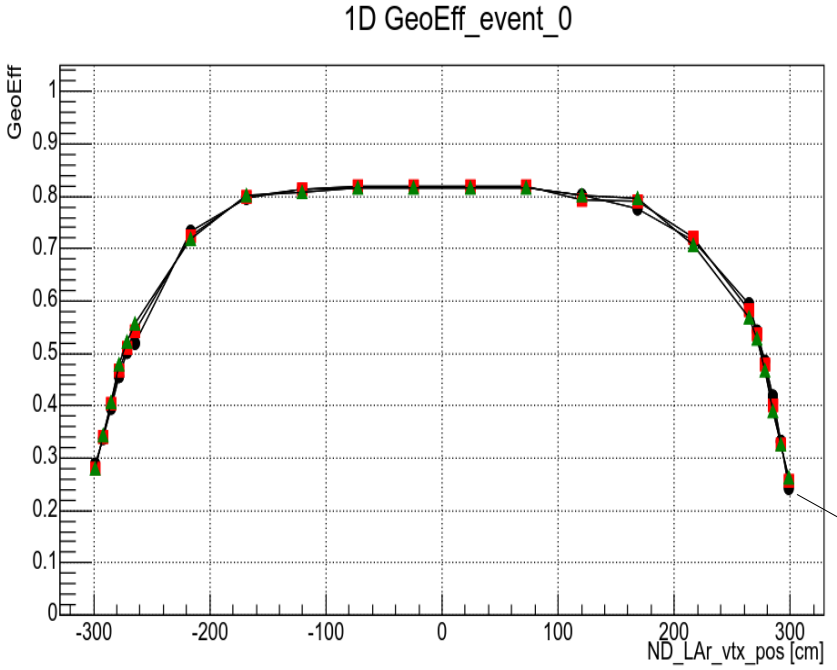

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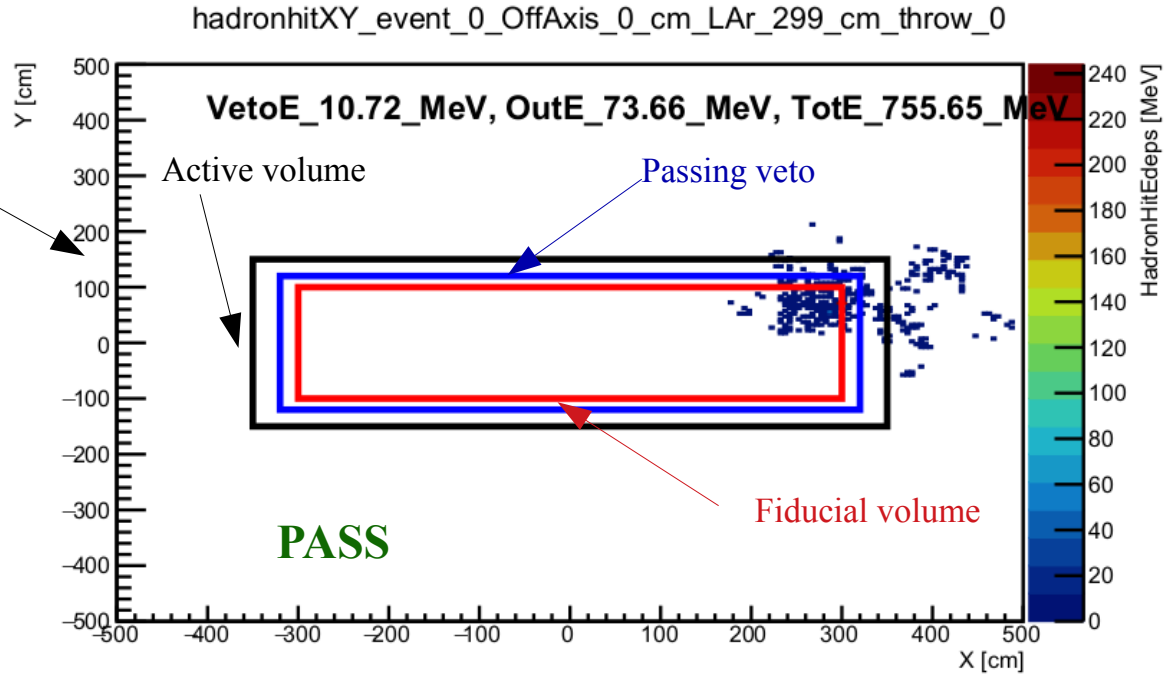
Event visualization at the ND

– after 1 throw



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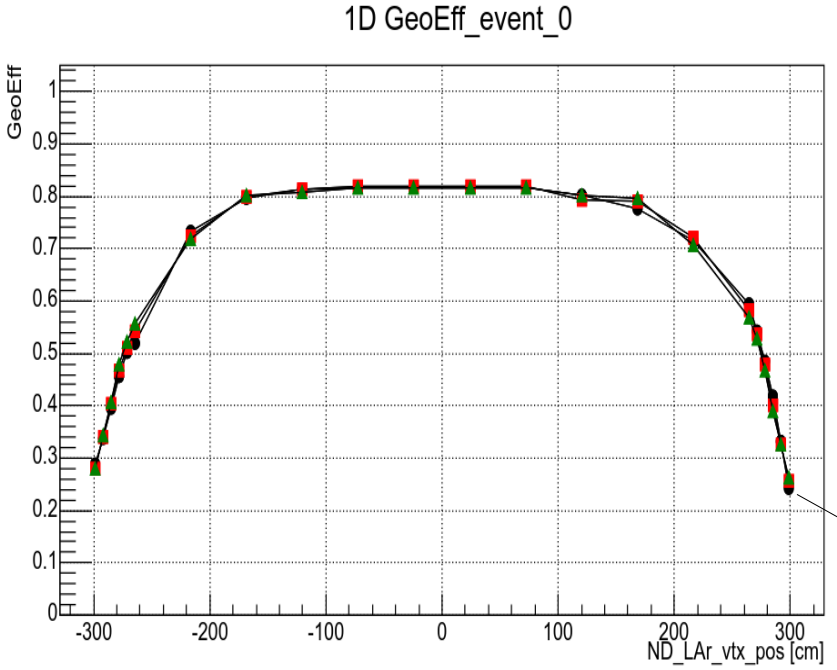

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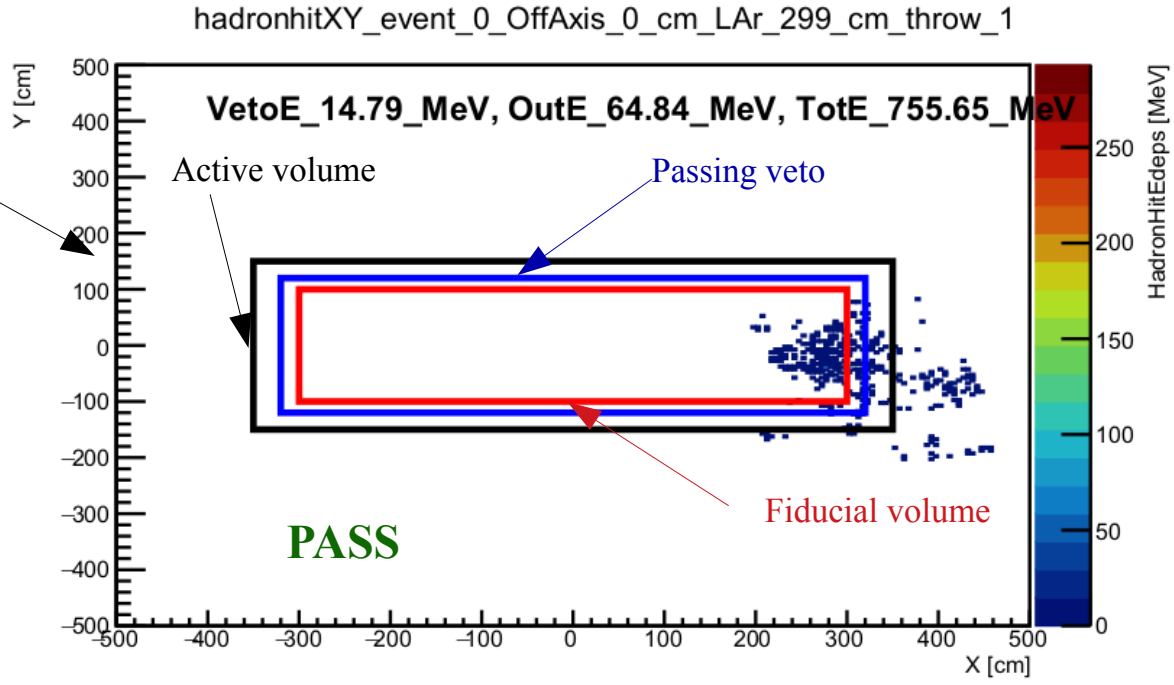
Event visualization at the ND

– after another throw



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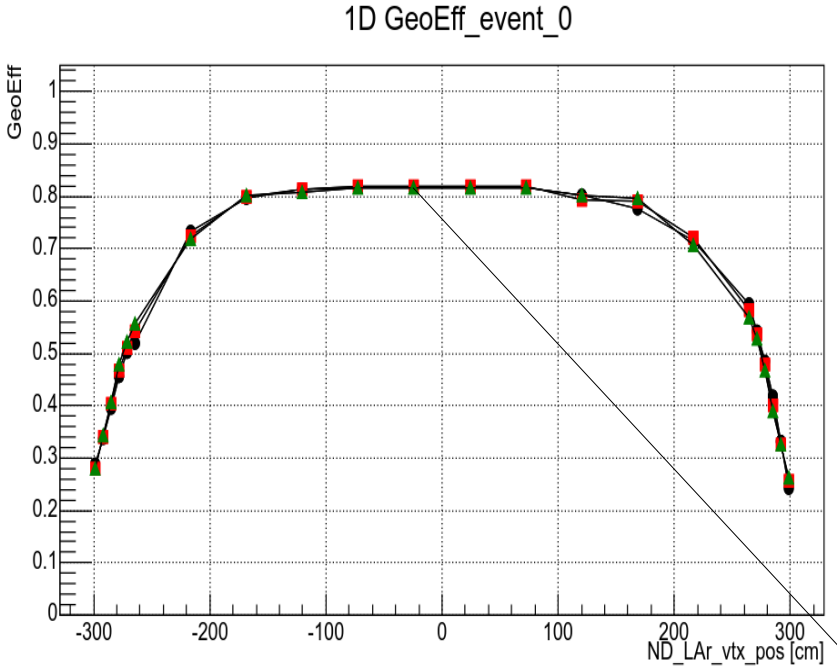

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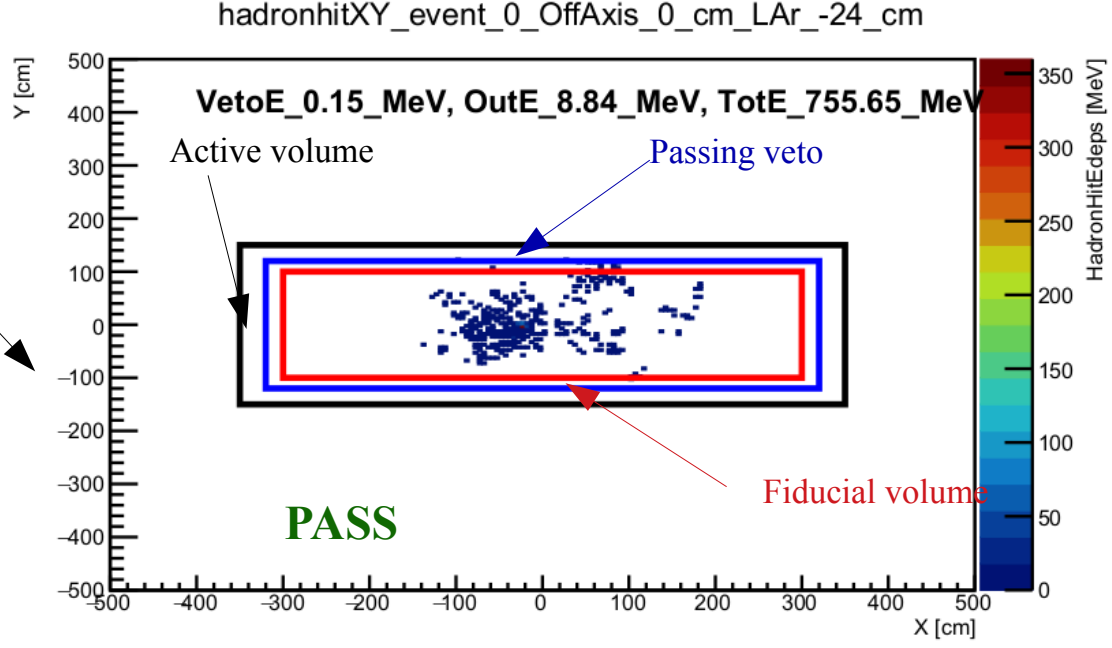

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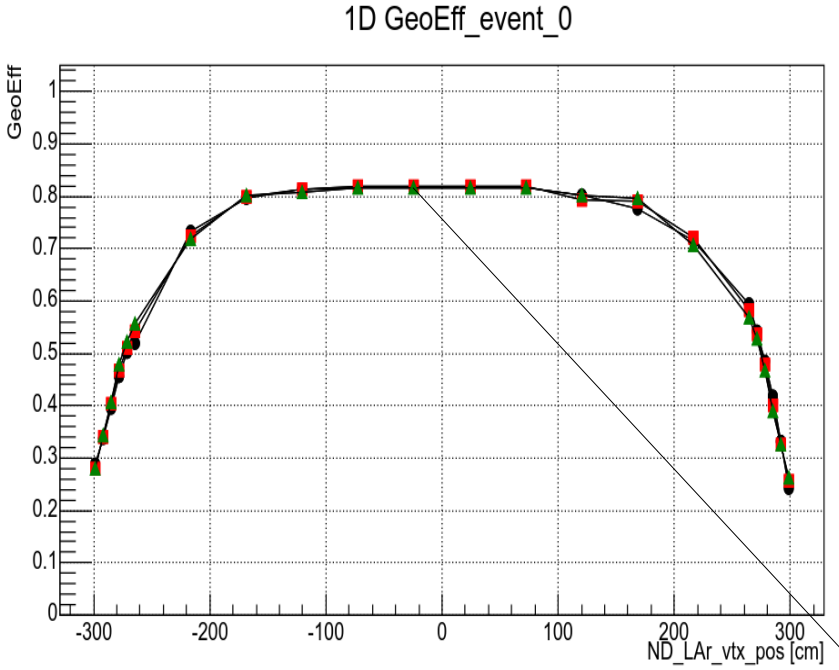

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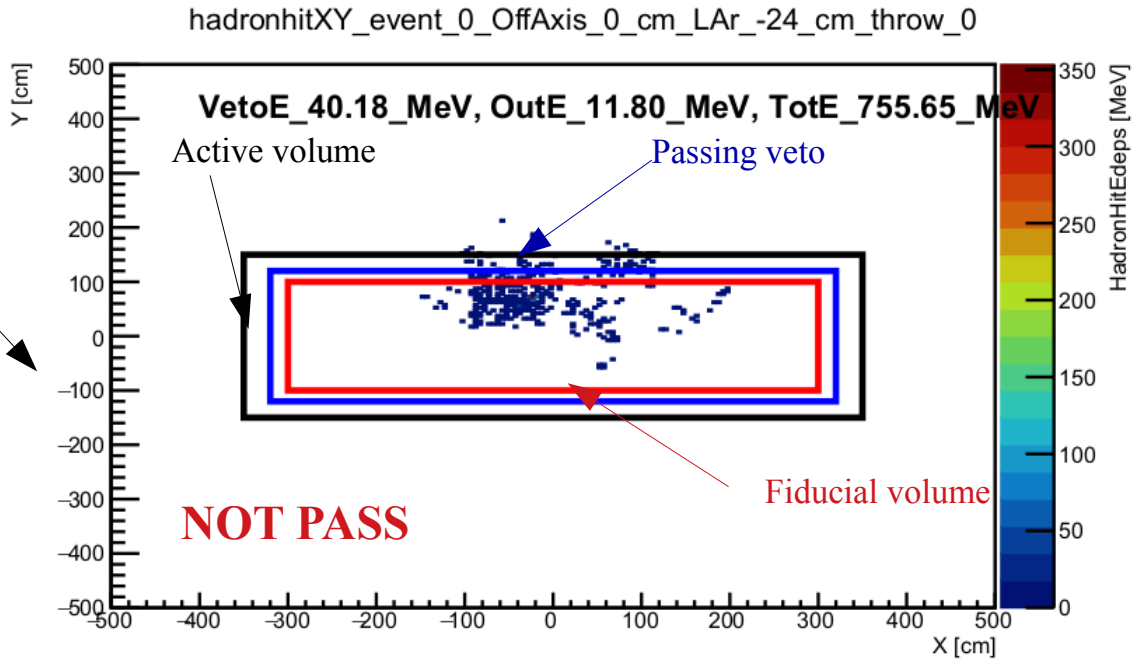
Event visualization at the ND

– after 1 throw



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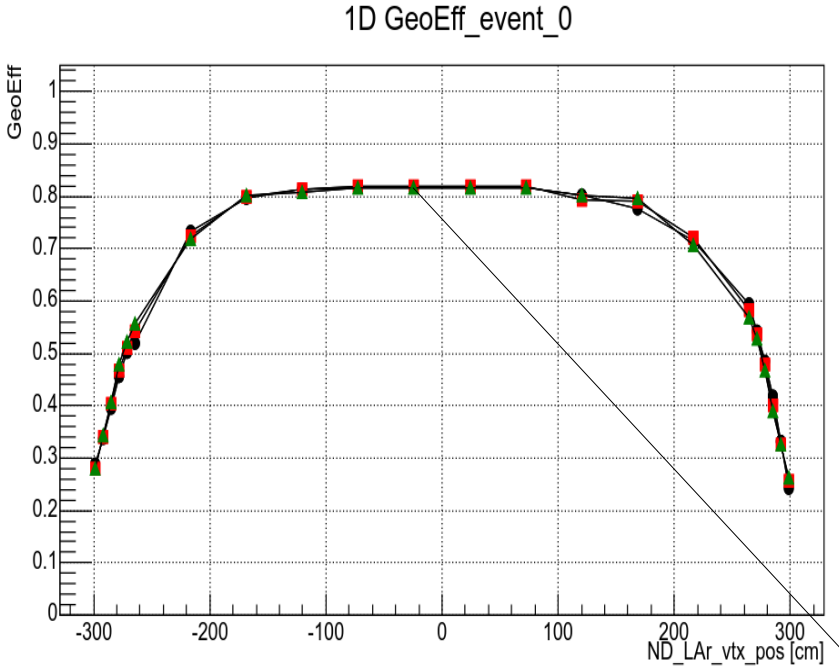

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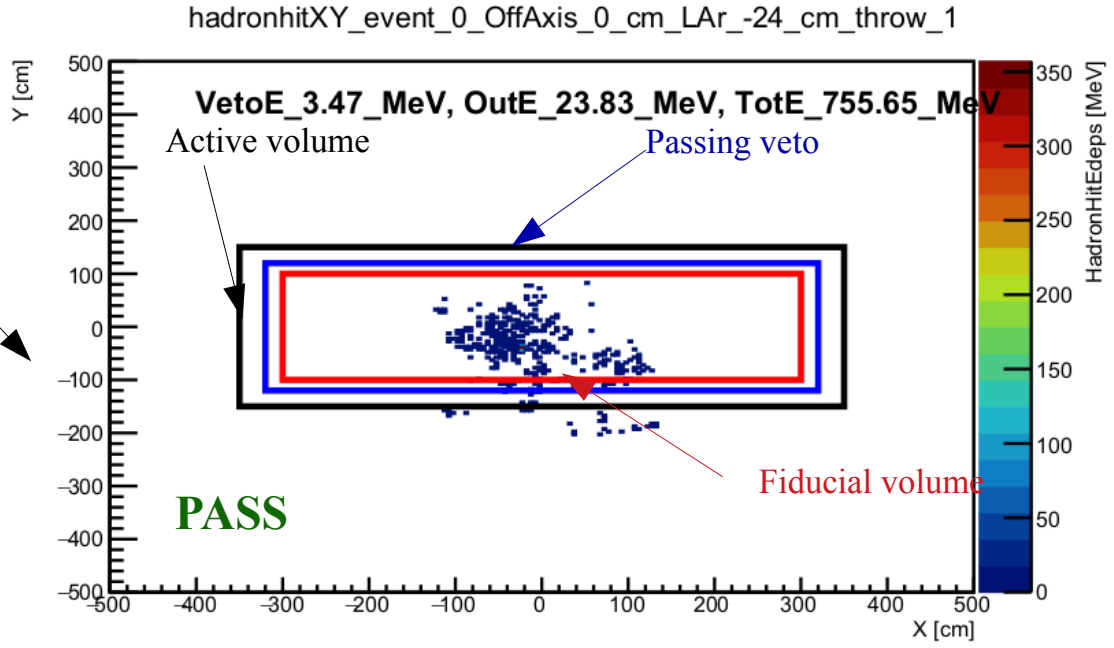
Event visualization at the ND

– after another throw



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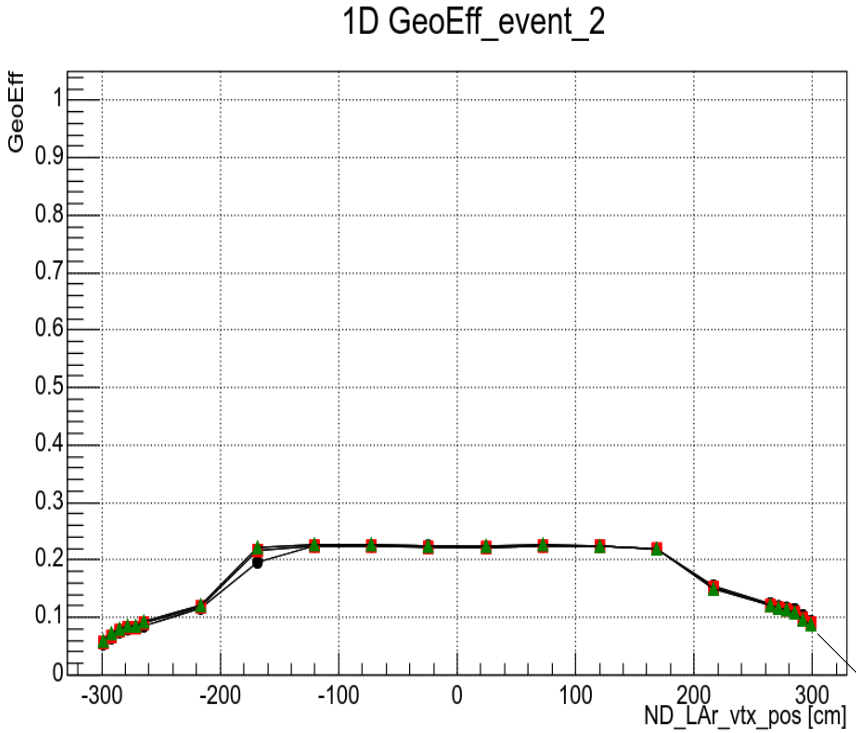
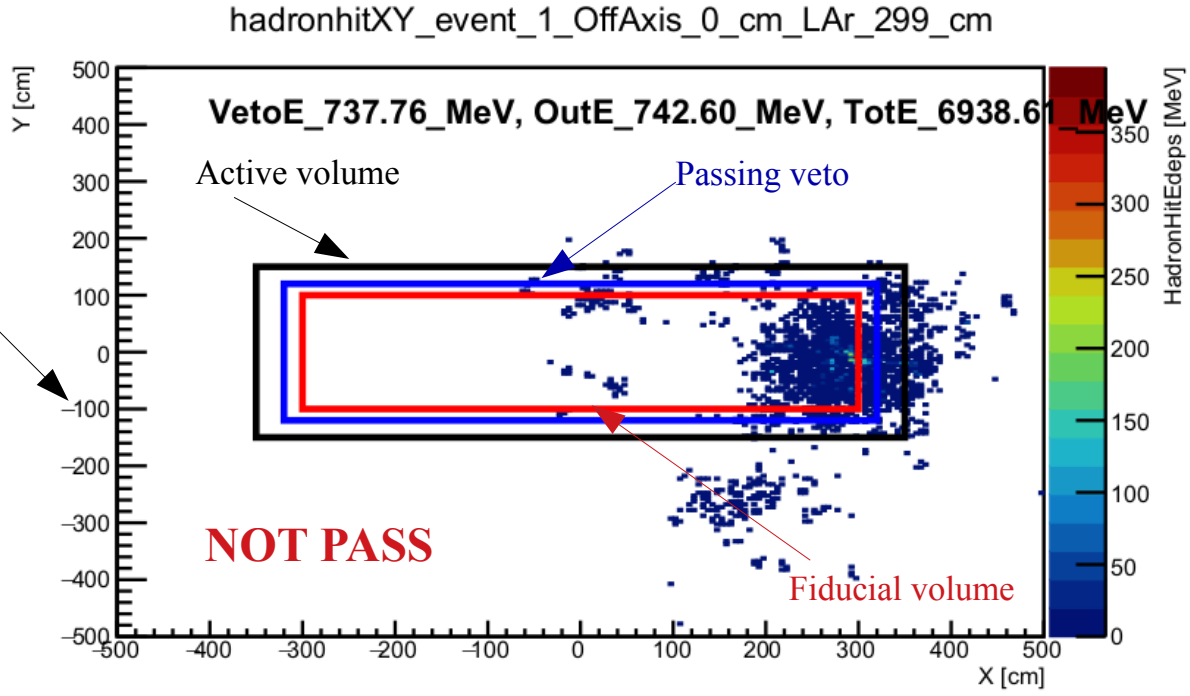


This is the FD efficiency of 1 event (FD energy = 6938.61 MeV) at the ND

– calculated after 4096 throws in Y, Z + rotations

Event visualization at the ND

– before throws



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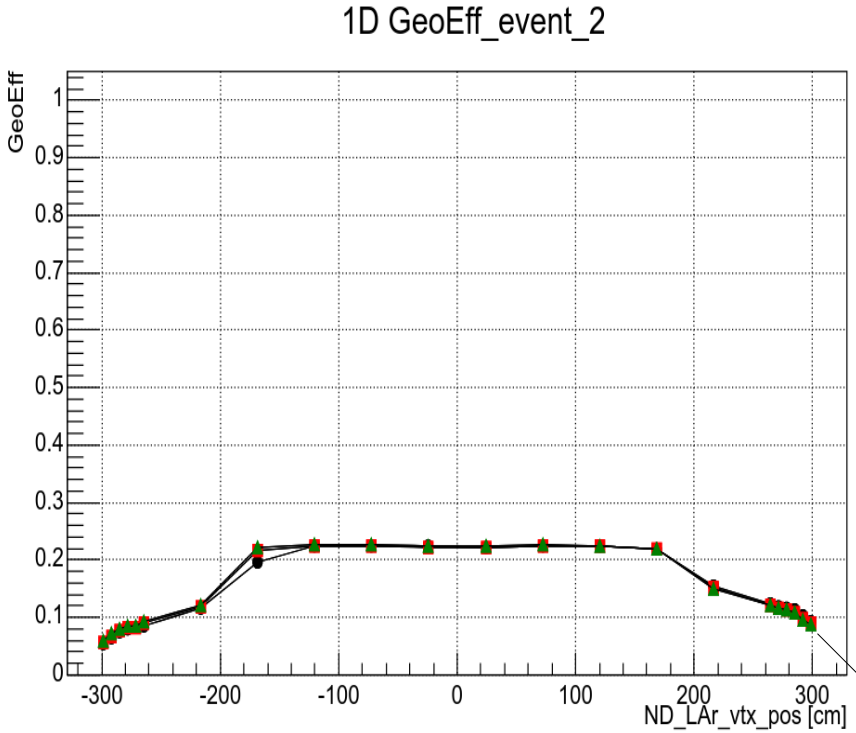

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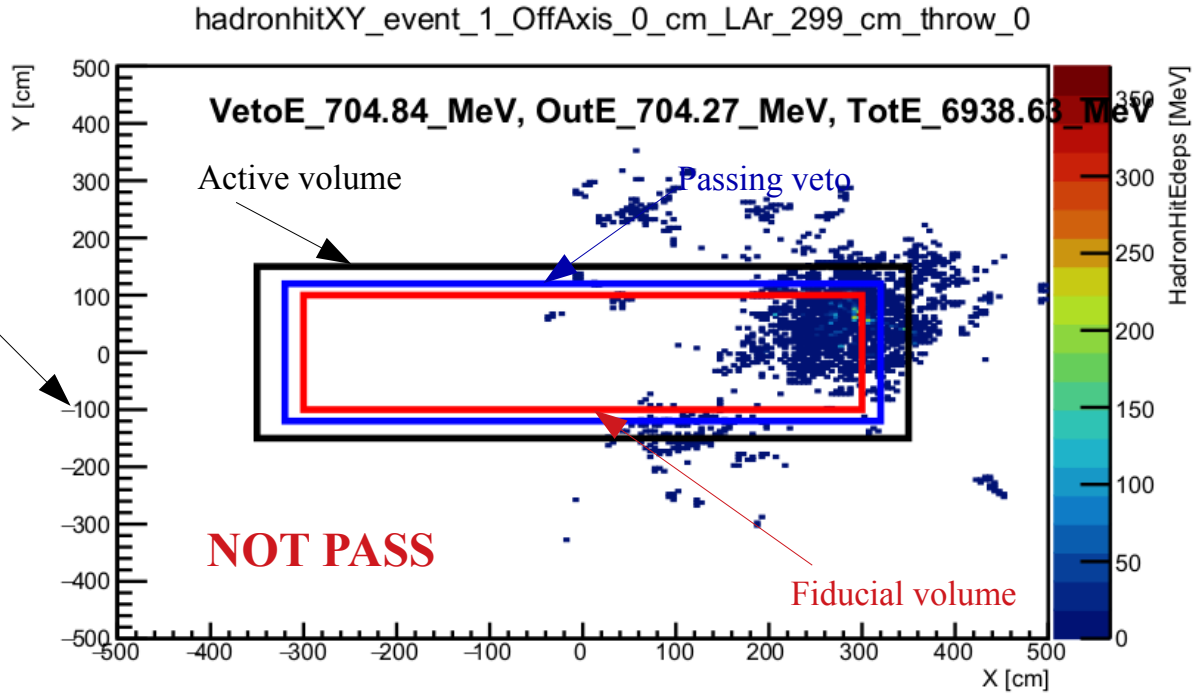
Event visualization at the ND

– after 1 throw



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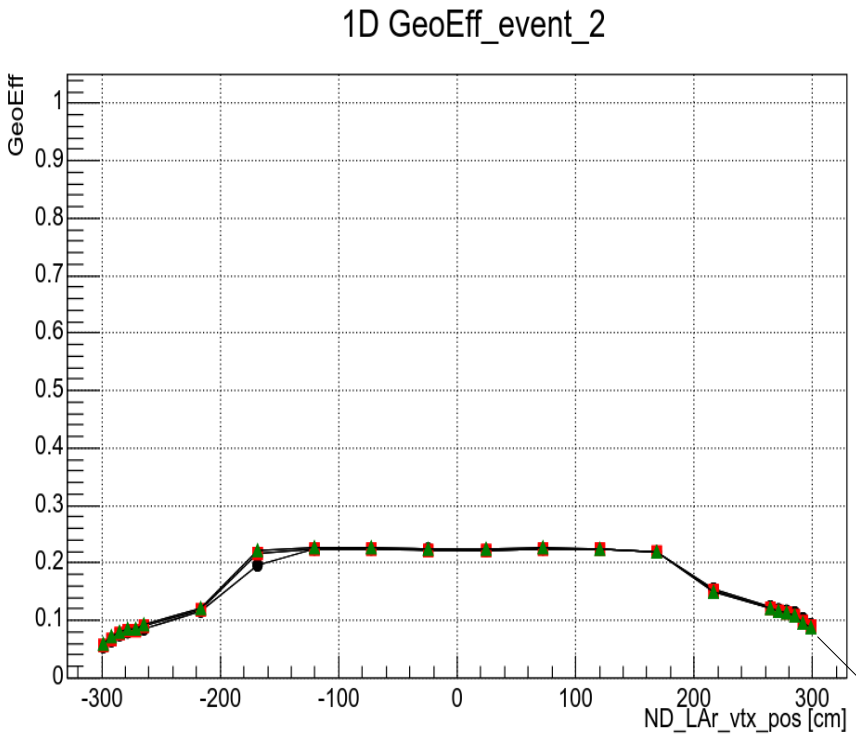
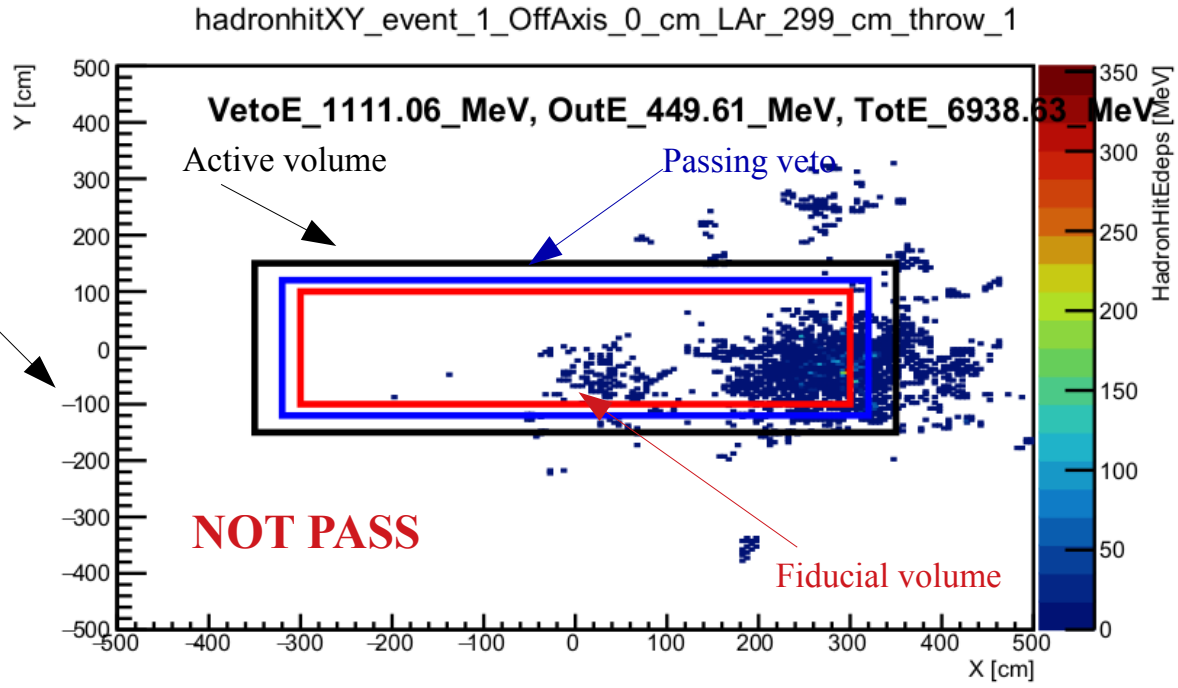


This is the FD efficiency of 1 event (FD energy = 6938.61 MeV) at the ND

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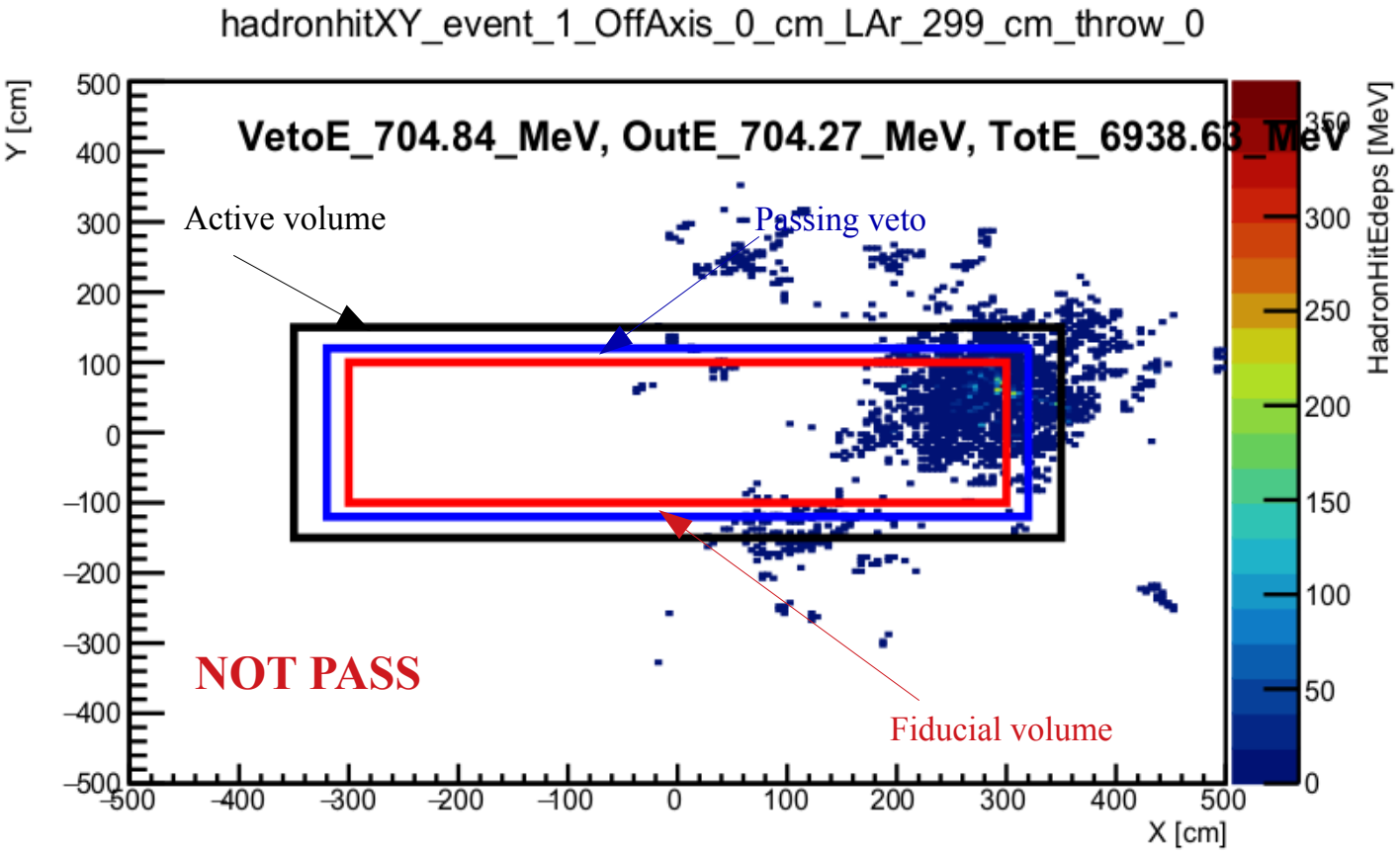
How do we implement / translate these results within the PRISM framework?

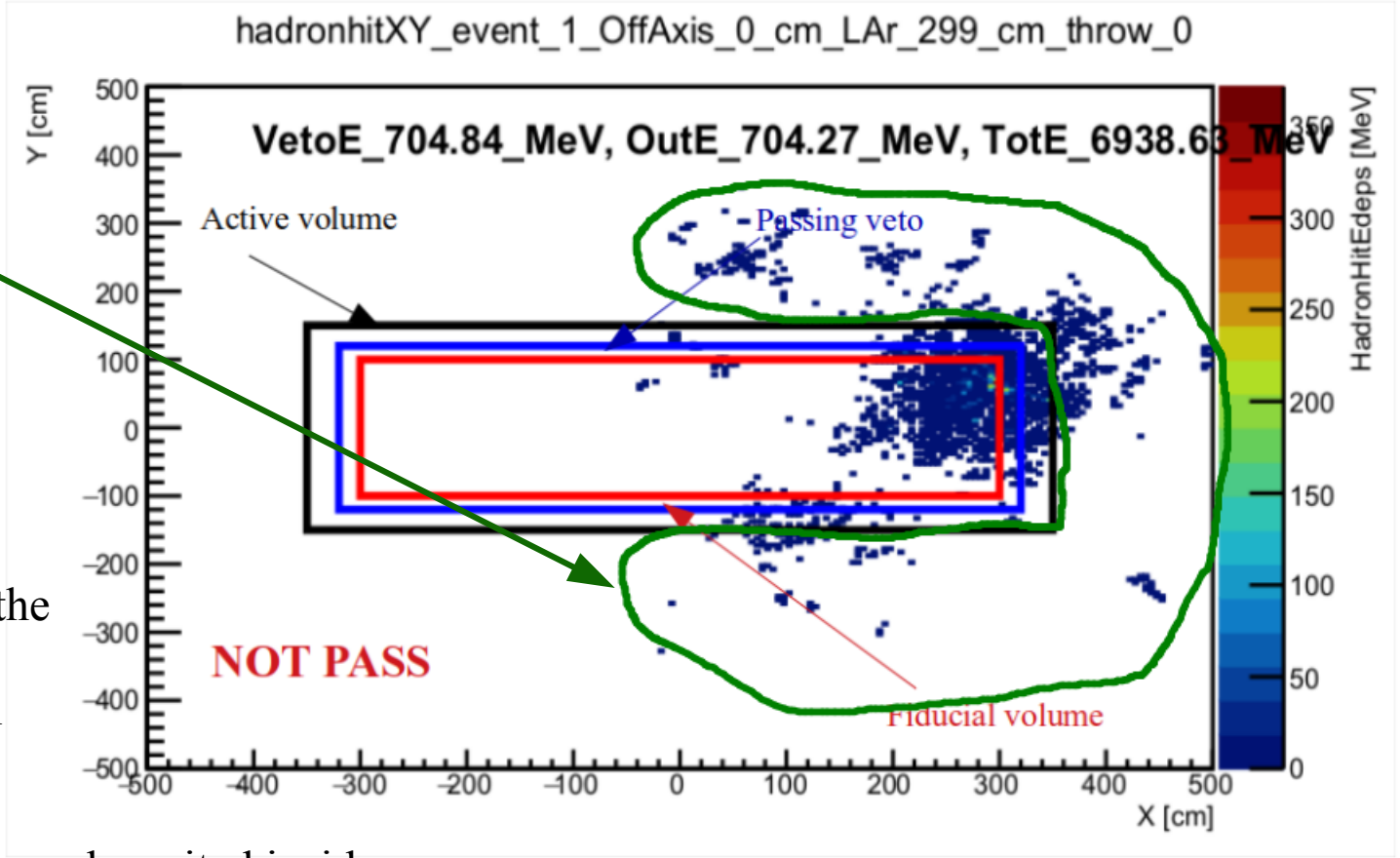
Trimmed Energy E_{trim}

- **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



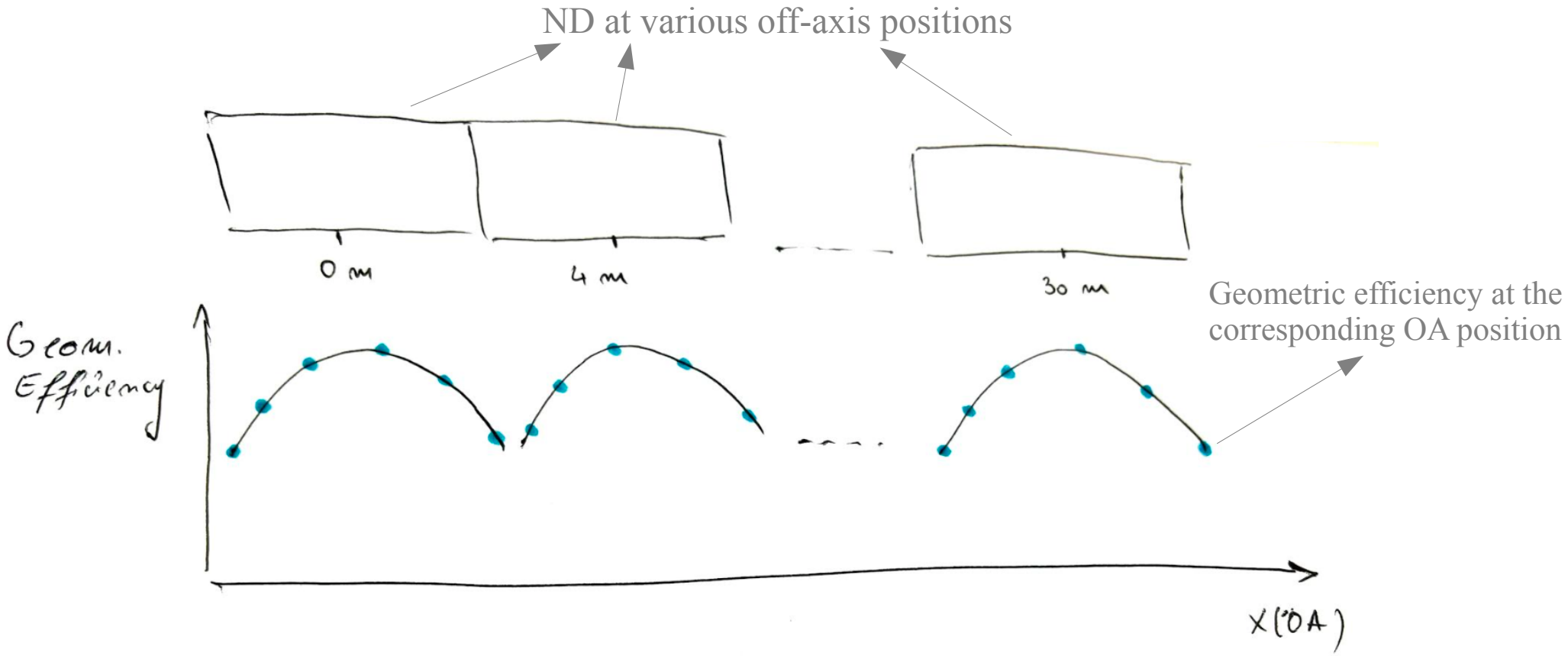
→ trim outside energy of the FD events
  - random throws with Etrim

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

Geometric Efficiency within PRISM framework

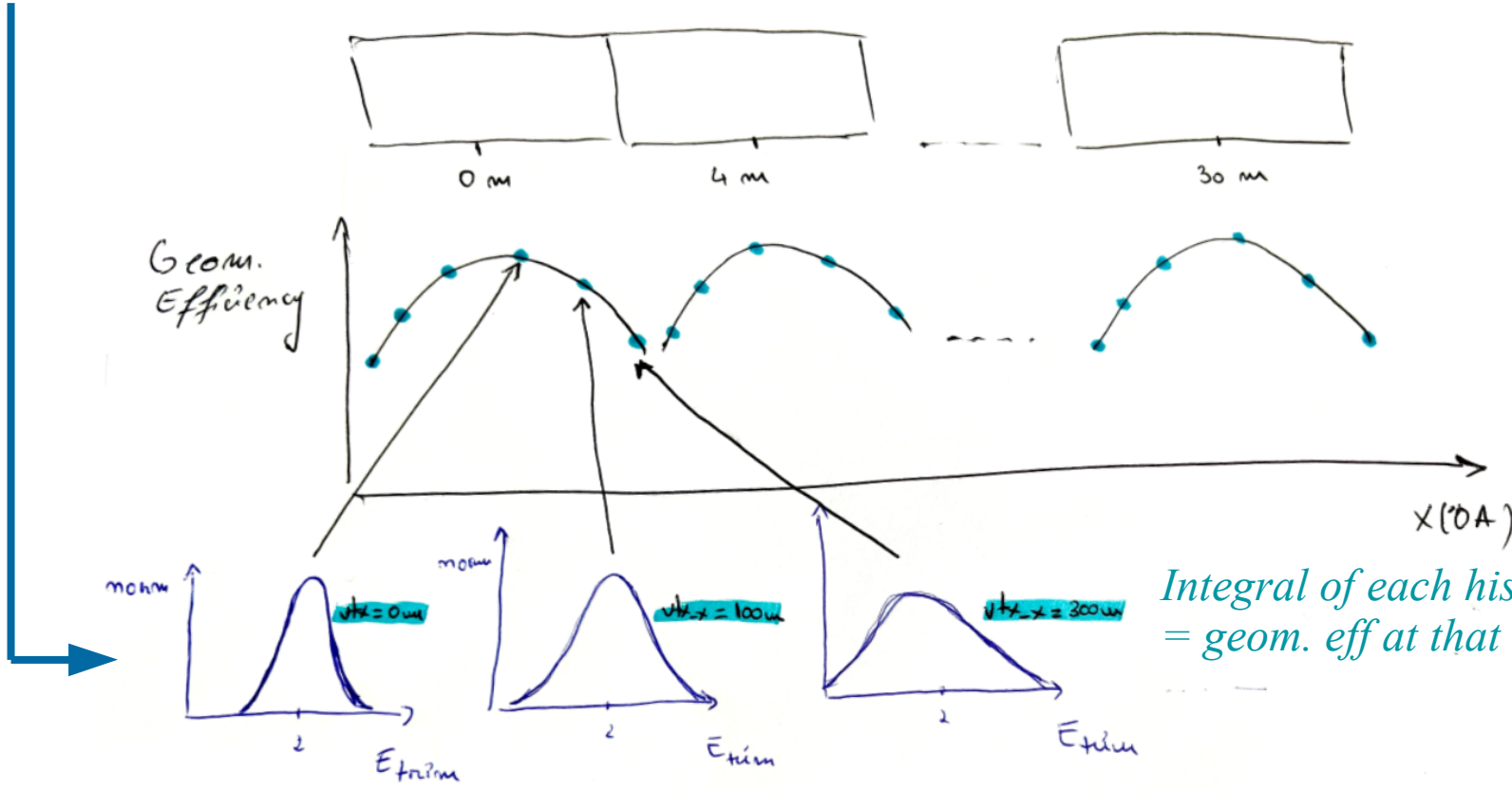
- This procedure would apply to each individual FD Event: Assume **1 FD Event** (FD Energy = 3 GeV)

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



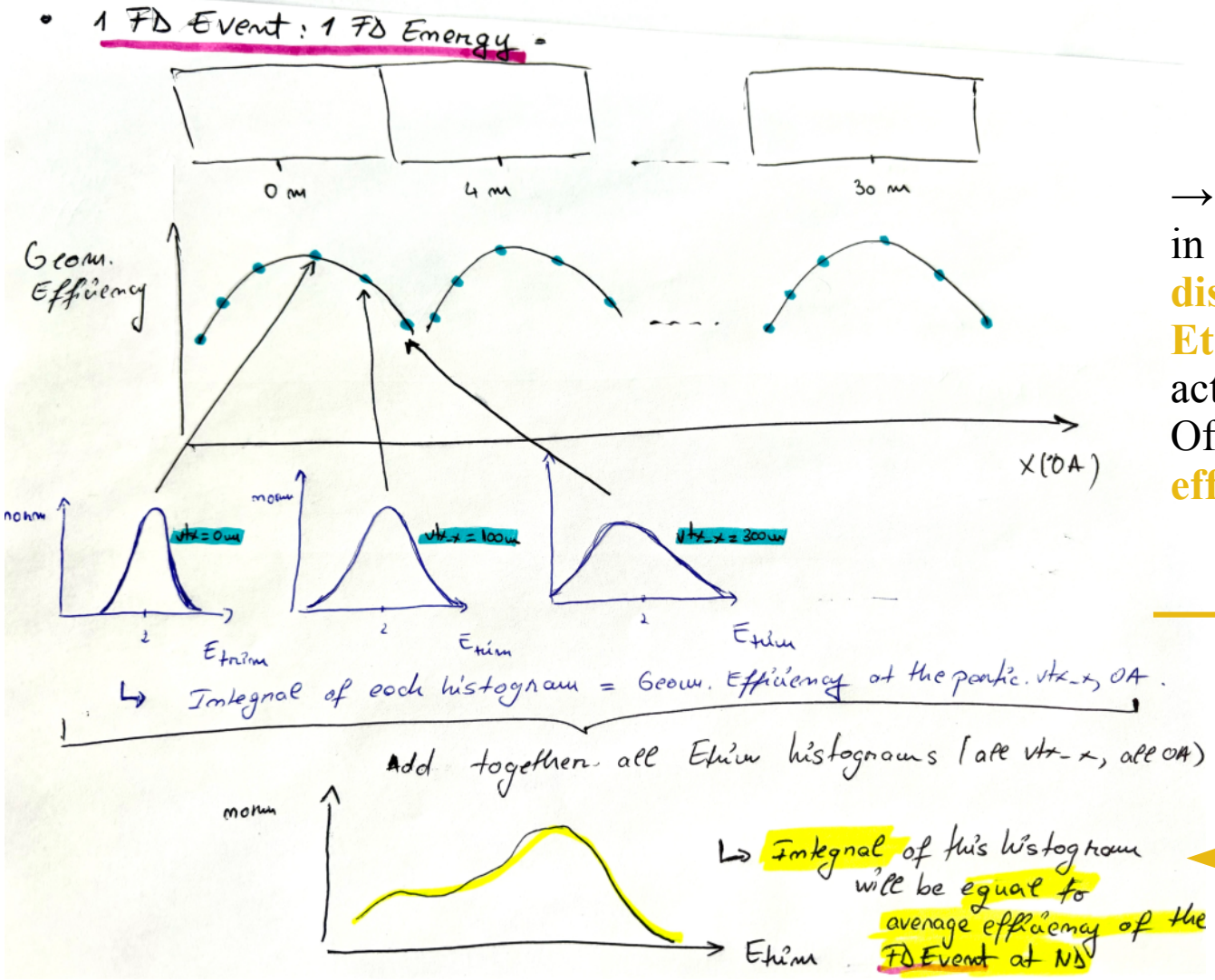
Geometric Efficiency within PRISM framework

- 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

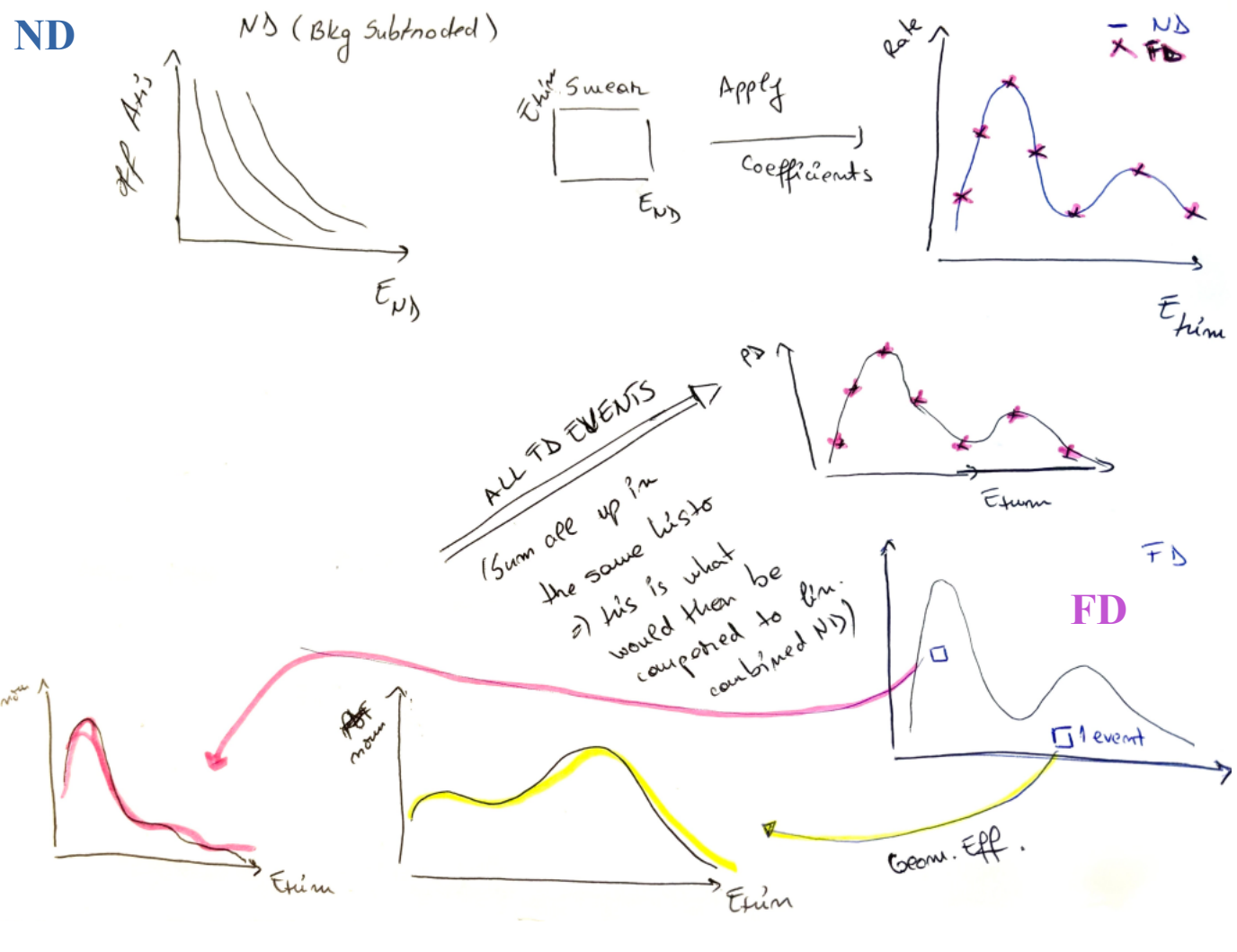
Geometric Efficiency within PRISM framework



→ 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



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

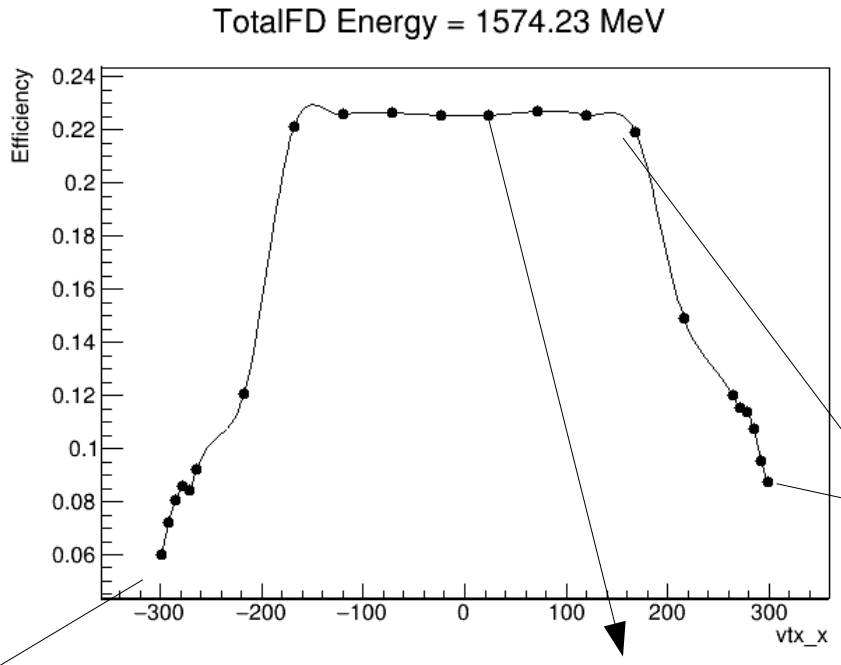
1. Start with FD oscillated spectrum (FD tot hadronic Energy)
2. For each FD event → geometric efficiency correction (Etrim)
3. FD events (efficiency corrected) distribution vs Etrim

Efficiency corrected FD oscillated spectrum

First Results: towards implementing the geometric efficiency correction withi PRISM

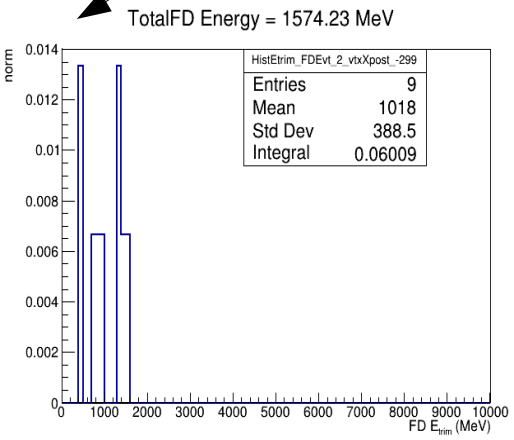
- first results: only 9 throws so far, just for visualization and understanding of the procedure
- soon to do the same from all throws
- need to only keep the events that passed the throws (not done in the following results)
- very “raw” vtx_x position: not uniform across the detector

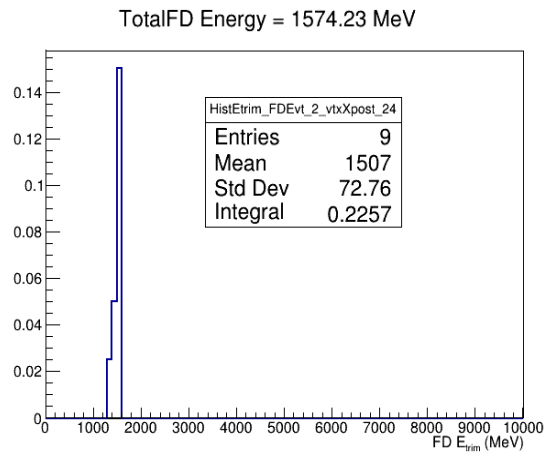
To be improved soon – just getting started :)

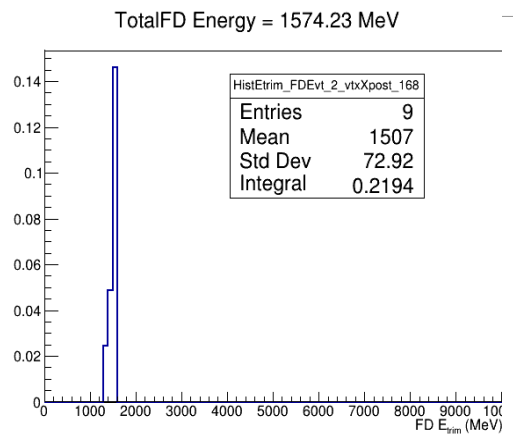


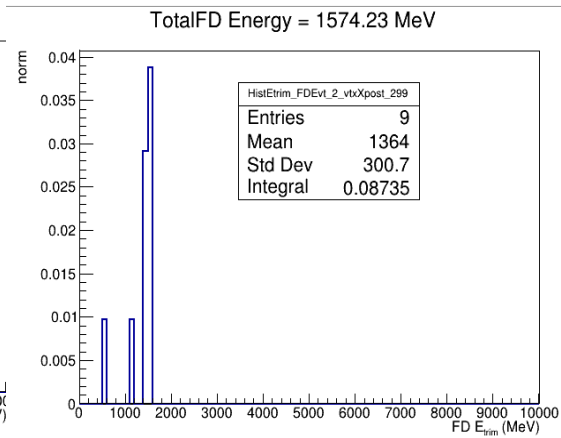
On-axis only : detector at 0 m

- for now only 9 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**

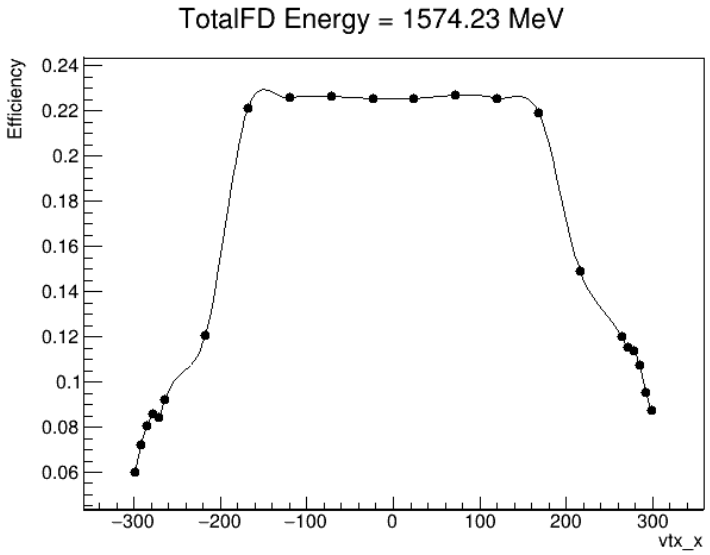




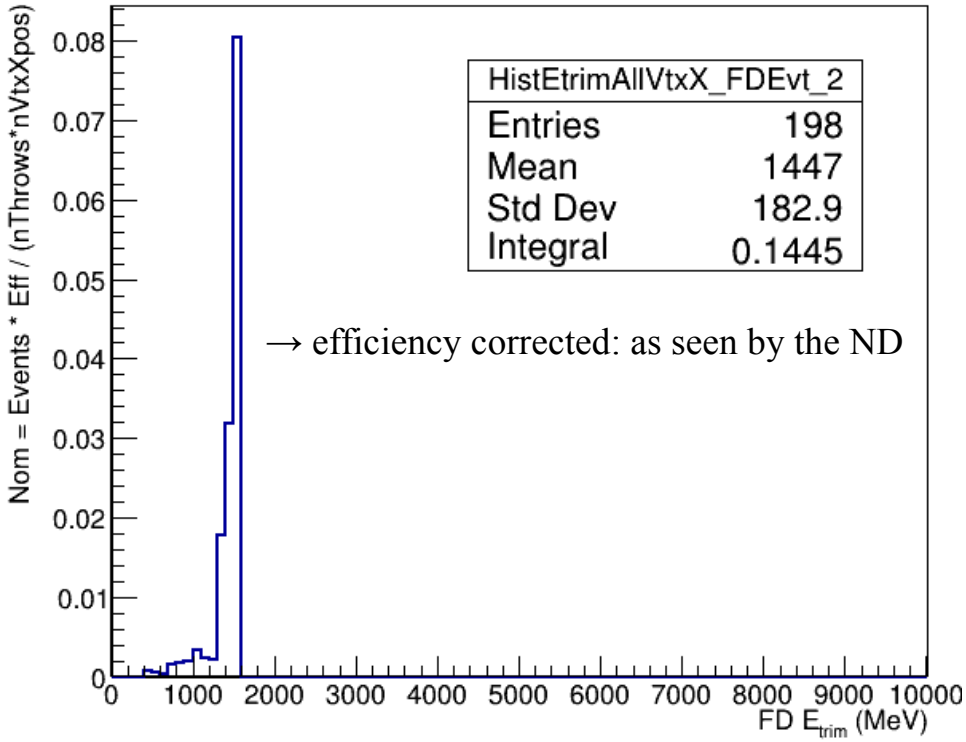




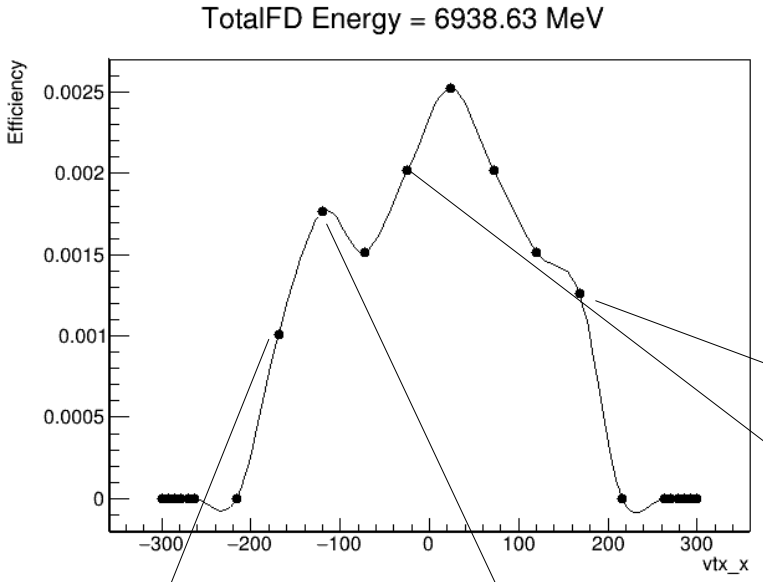
FD Events – efficiency corrected



Distribution of FD Event as seen by ND vs Etrim

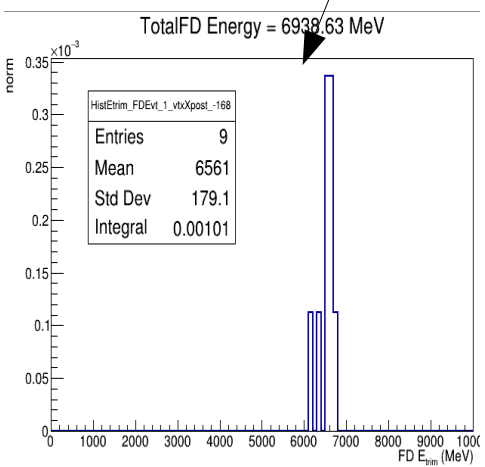


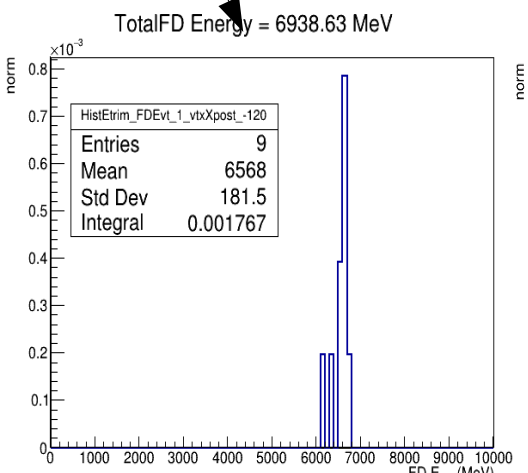
– **average efficiency** (E_{trim}) of FDEvt_2 (FD Energy = 1574.23 MeV) at ND is **0.1445**

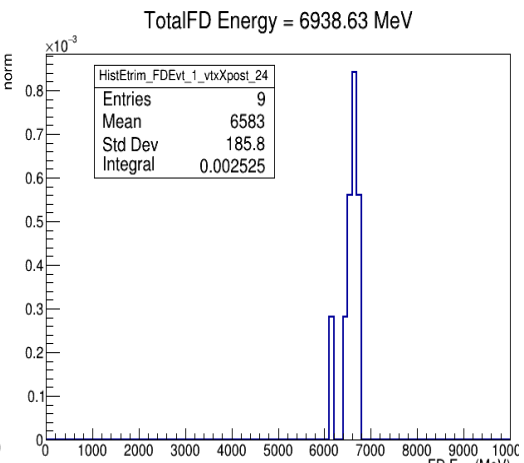


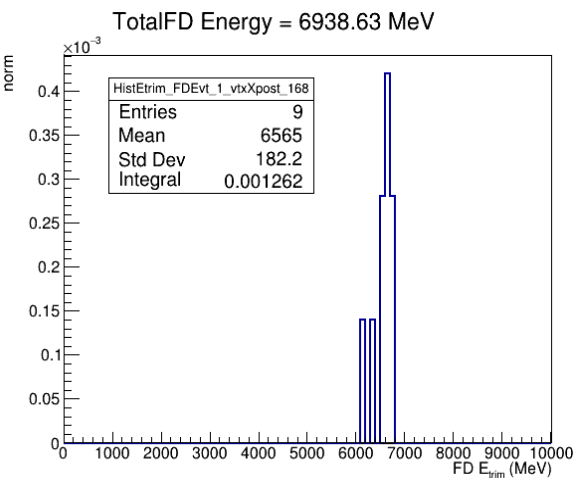
On-axis only : detector at 0 m

- for now only 9 throws → will get more throws ASAP
- Integral of each histogram corresponds to the efficiency at the given vtx_x position









TO DOs

- Near to Far: ND events vs Etrim
- PRISM CAFs: we 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

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