ND Geometric Efficiency – PRISM Implementation Update

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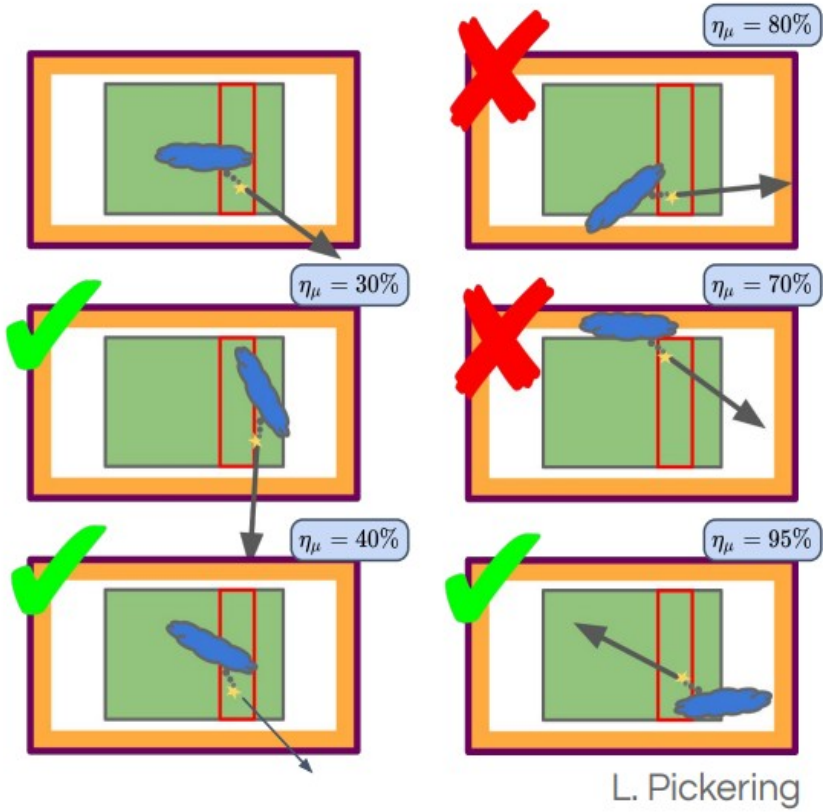
Data-driven Efficiency

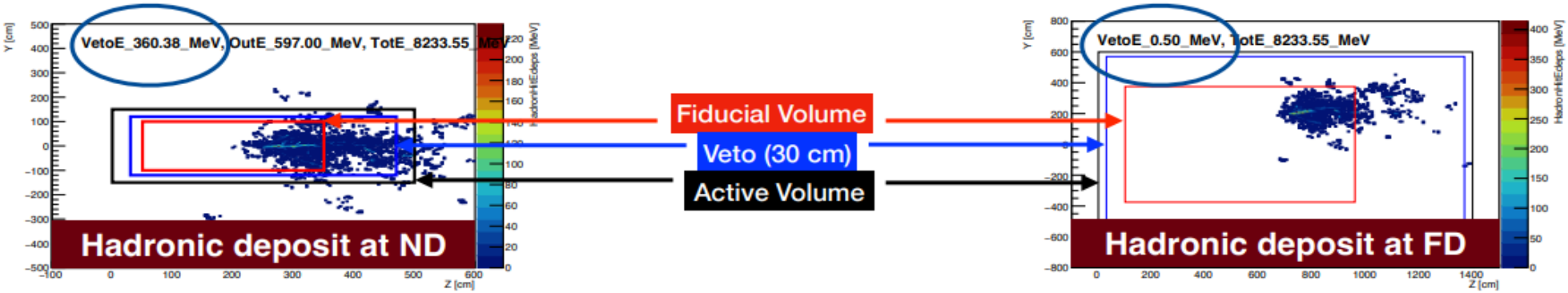
- Use symmetries of neutrino interactions in ArgonCube:
  – **translations** in LAr volume and **rotations** around the beam axis
- Method:
  – for a selected ND event, rotate and translate the 3D **hadronic energy deposits** and **muon positions** and **momentum** vectors N times (cover any possible configuration of the event within the ND)
  - For the **hadronic** part:
    – count how many times (out of N throws) the event passes the hadronic containment (veto) cut
    – take the ratio to the total number of throws (Npass / N) to get the geometric **hadron containment efficiency**
  - For the **muon** part:
    – use a **neural network** (C. Vilela) to estimate **muon selection efficiency** for a given translation and rotation



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

FD Events at the 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

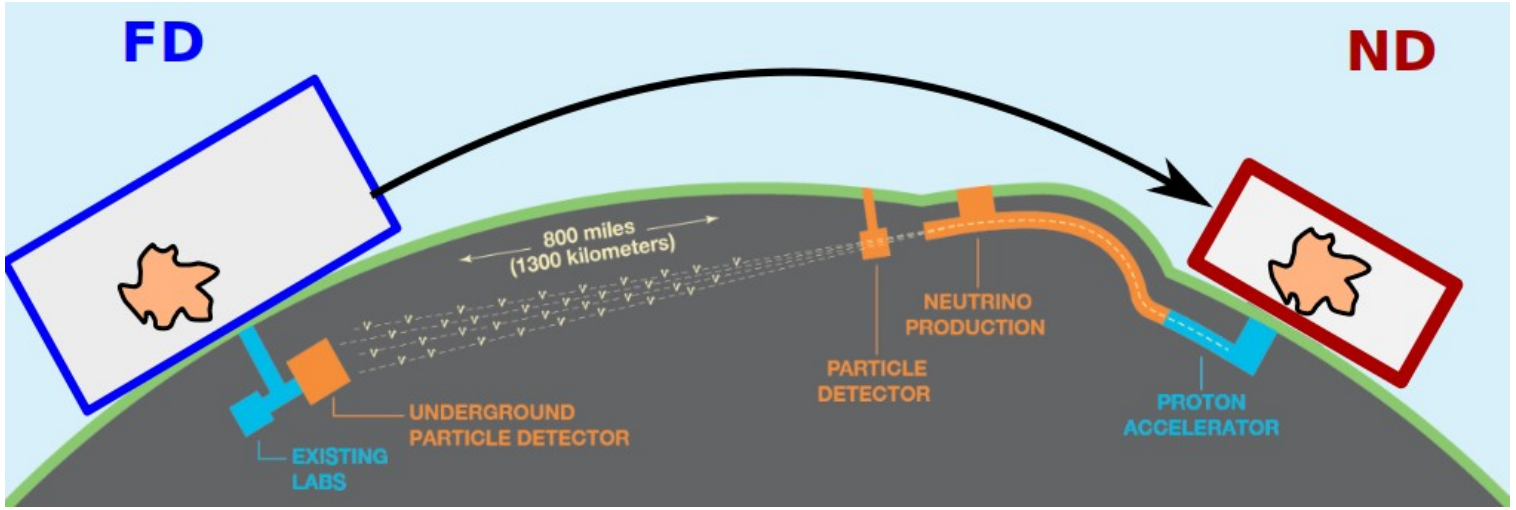


Veto Energy > 30MeV
Can't be selected

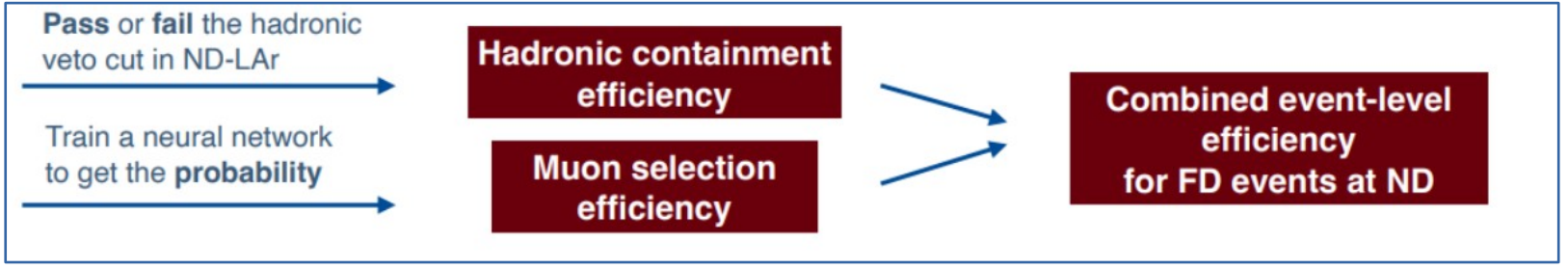
Veto Energy < 30MeV
Can be selected

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

FD Events at the ND

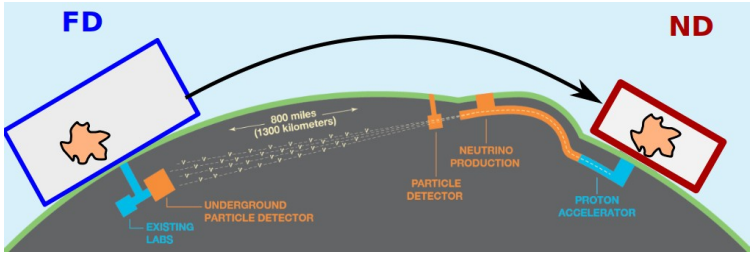


- choose CC FD events with FD FV & vetoE cut
- move these events to the ND (Earth curvature)
- same method: N throws of the event in the ND (rotations + translations)



FD Events at the ND: 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 positions off-axis** (rotation of the event in the ND from on axis to off-axis)



For each detector position:

– move the event at **different ND vtx_x positions** (72 x_vtx positions);

For each x_vtx position:

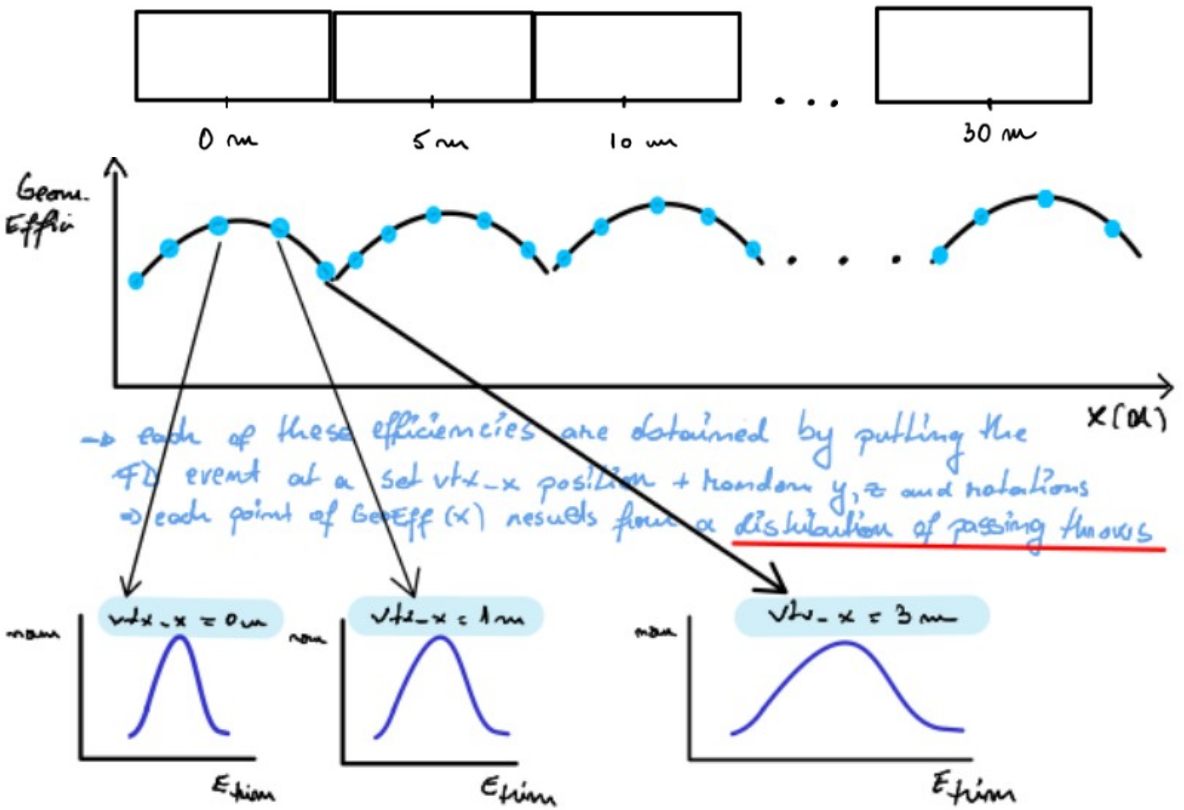
4. generate **random throws** of the event (at ND): translation at different vtx_y, vtx_z position + rotations (vtx_x position is fixed)
   – for each throw: evaluate if the event passes the **hadronic containment** cut (Ehad < 30 MeV in the veto region)
5. calculate the geometric hadron containment efficiency of the FD event at the ND :
   Efficiency (vtx_x) for different detector positions

→ *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 at several detector positions**

Geometric Efficiency within PRISM framework

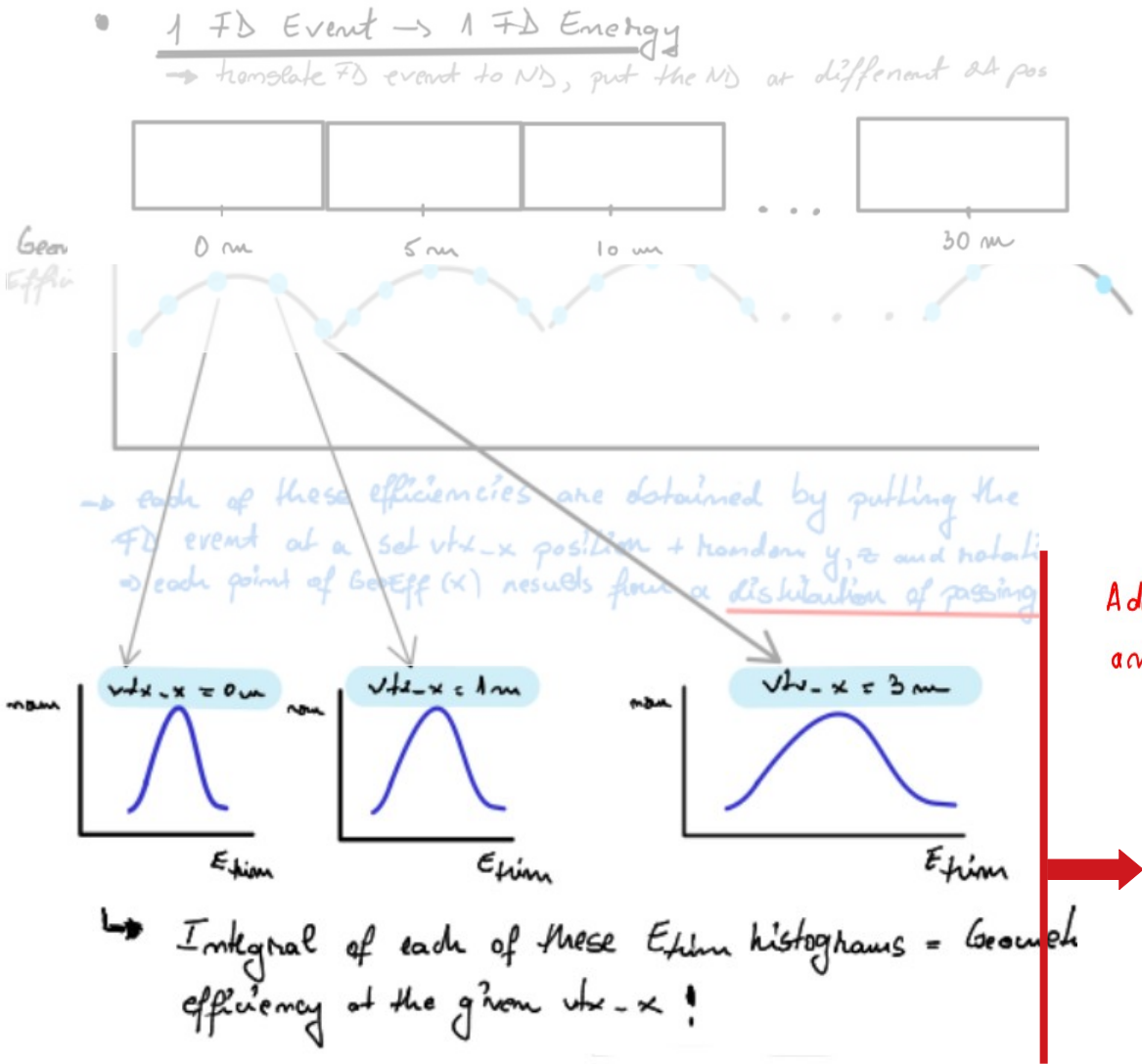
- 1 FD Event → 1 FD Energy
  - → translate FD event to ND, put the ND at different x pos



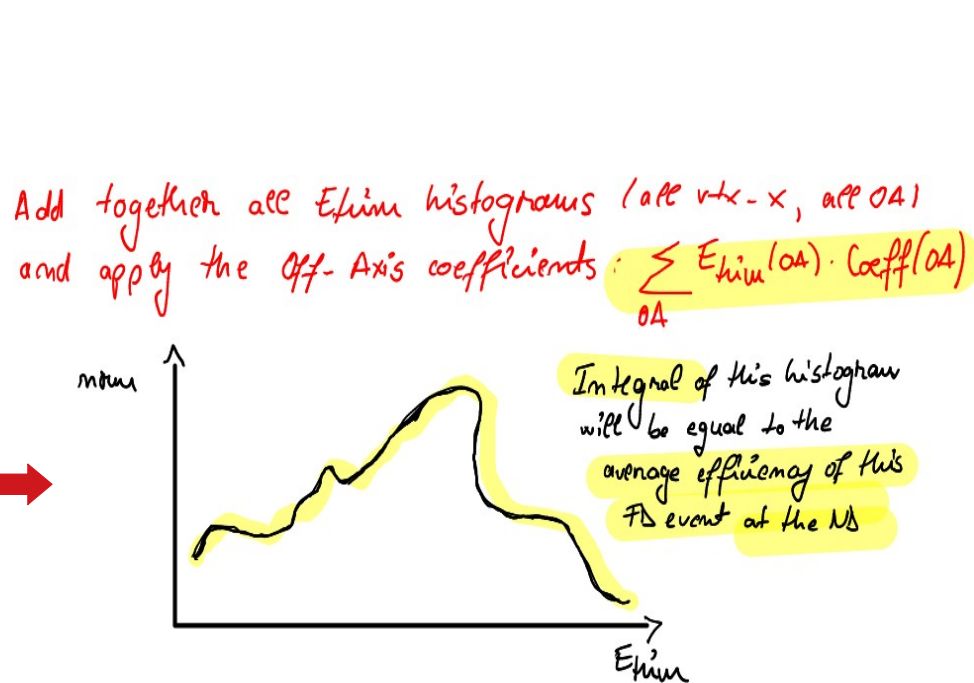
→ each of these efficiencies are obtained by putting the FD event at a set vtx_x position + random y, z and rotations
→ each point of GeoEff (x) results from a distribution of passing muons

→ Integral of each of these Etrue histograms = Geometric efficiency at the given vtx_x !

Geometric Efficiency within PRISM framework



- To get the **average geometric efficiency of a FD event at the ND:** add all Etrim histograms and linearly combine them



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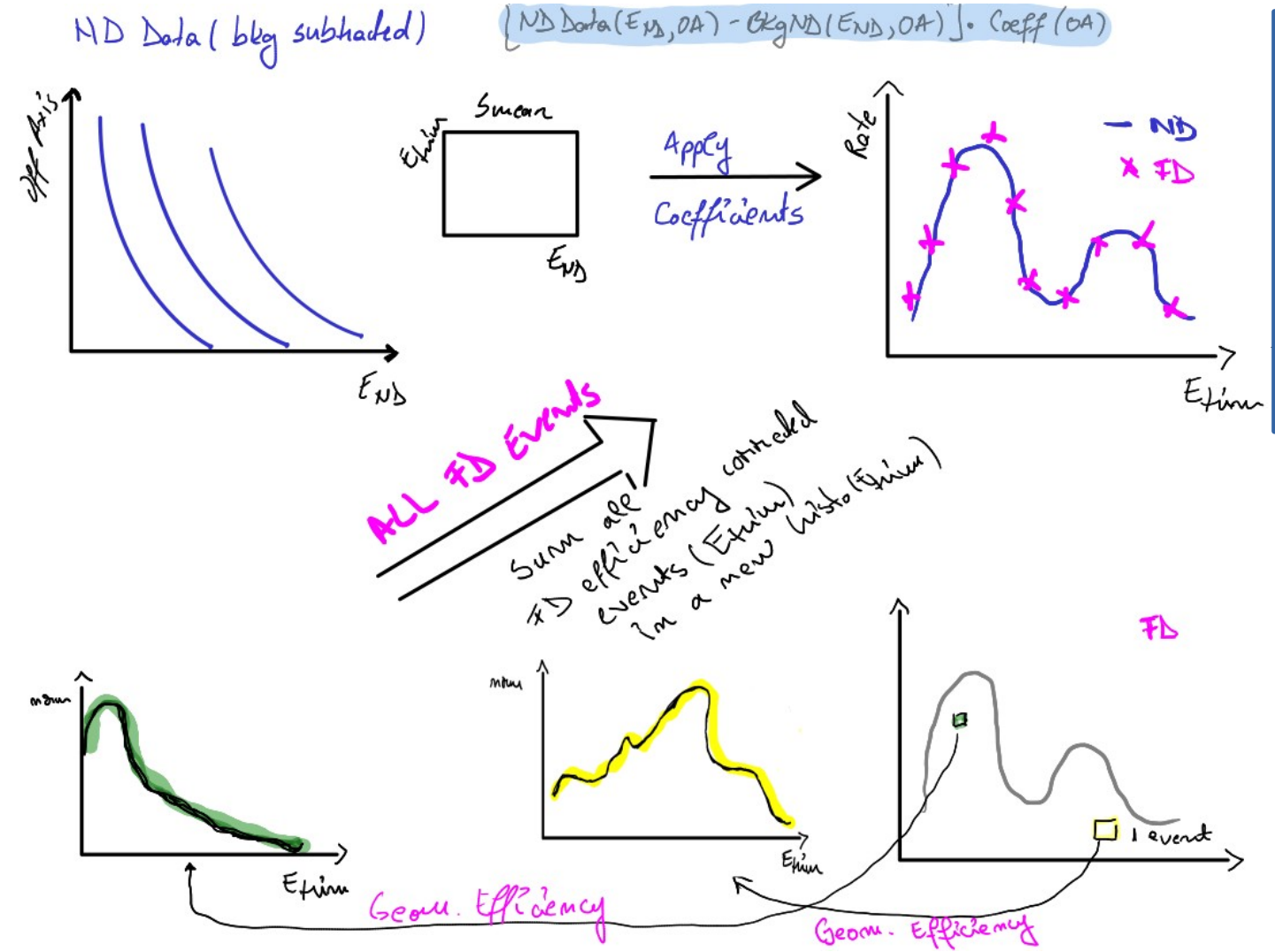


1. Start with ND data (bkg subtracted) vs OA vs E_{ND}
2. Smear ND data to Etrim
3. Apply OA coeficients

*** no efficiency correction: work with data (selected) events only**

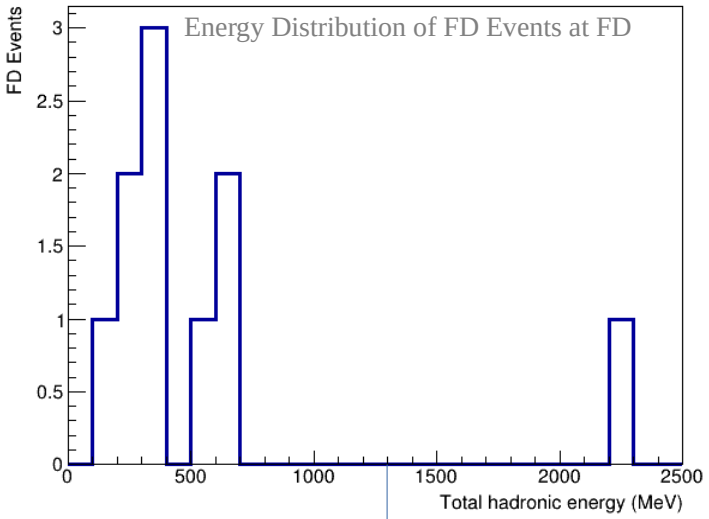
PRISM linear combination

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

Distribution of FD Events (eff. corrected) as seen by ND vs Etrim

More FD Events – accumulate statistics

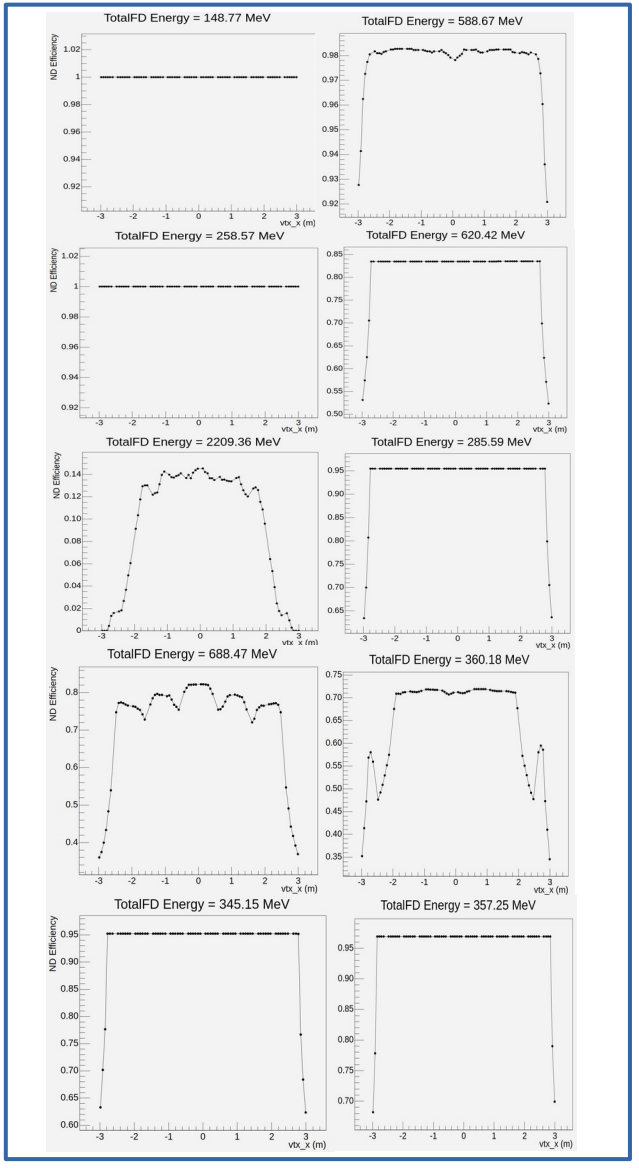
- 1 ntuple – 100 simulated FD Events → 10 events selected and translated to the ND



Selection Cuts:
– event has to have muon/hadronic energy deposits
– CC events
– muon as final state lepton
– event vertex inside FD FV

Translated to ND (Earth curvature) + placed at different vtx_x positions in ND & random throws in each vtx_x

→ **Efficiency of each event vs vtx_x**



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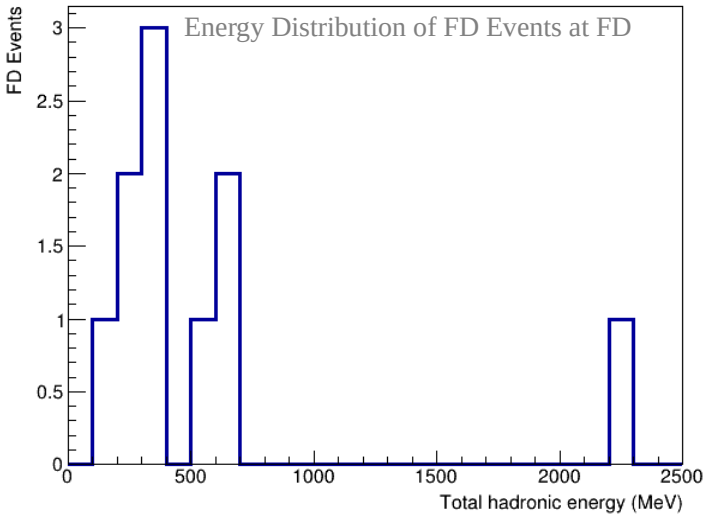

Selection Cuts:
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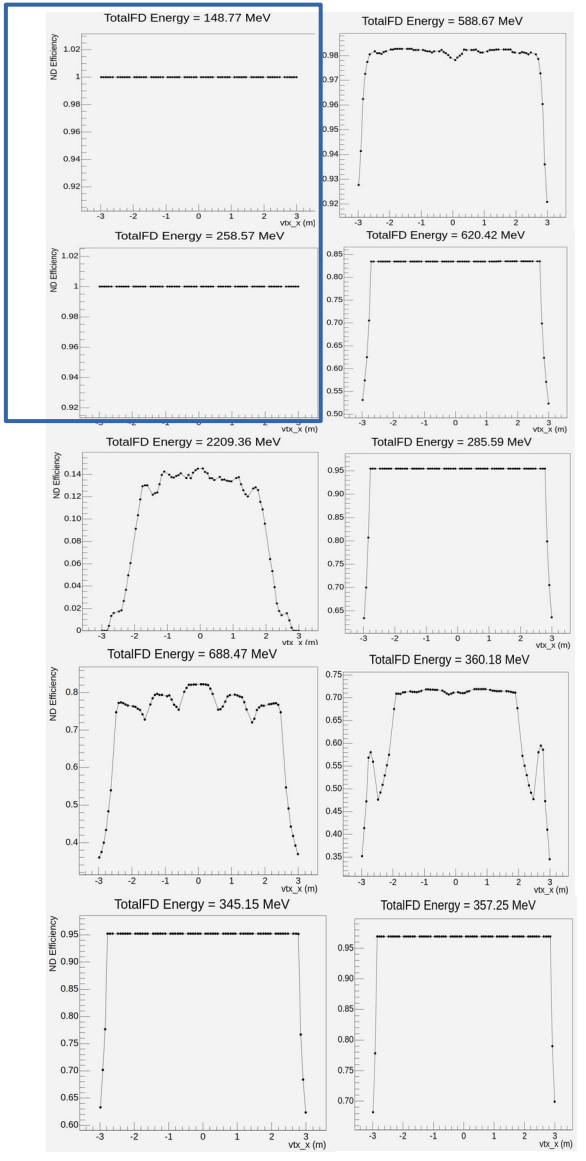
- Highest ND efficiency for lowest FD energy events
  – high FD energy events have in general a wider / more spread hadronic signature → ND volume is smaller than FD volume



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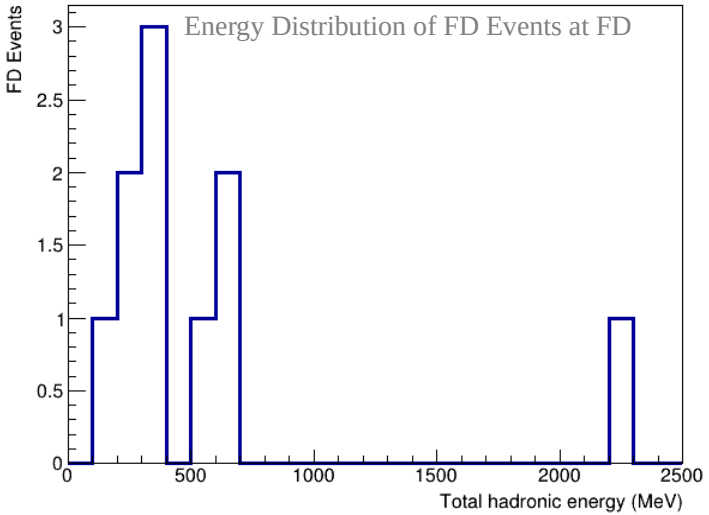

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- Highest ND efficiency for lowest FD energy events
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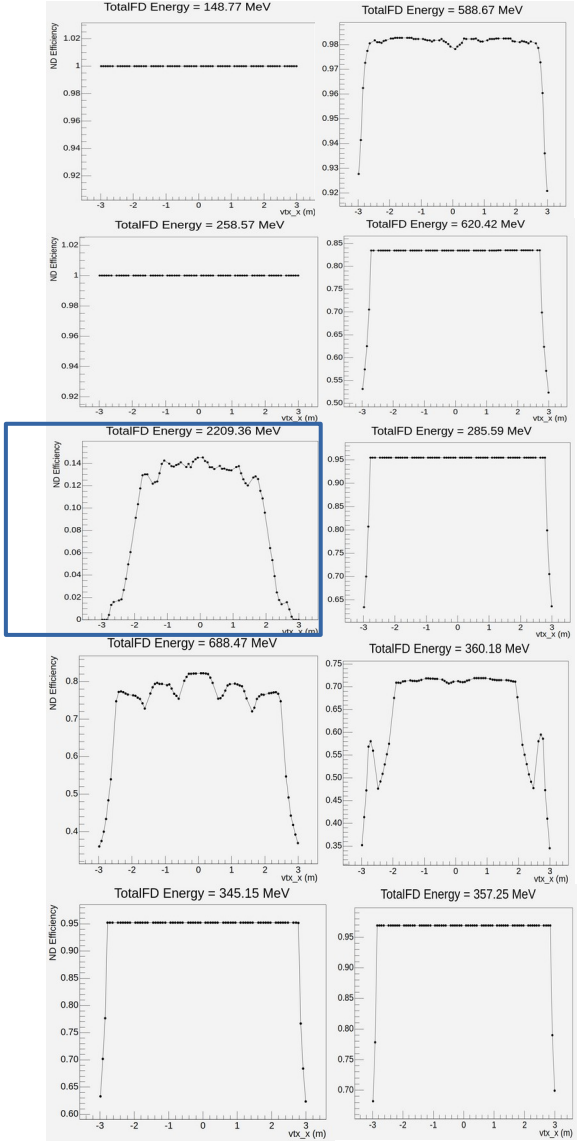
- Much lower ND efficiency (14%) for a FD event with total hadronic energy ~ 2 GeV
  - a 2 GeV FD event would only be seen 14% of the times in the ND



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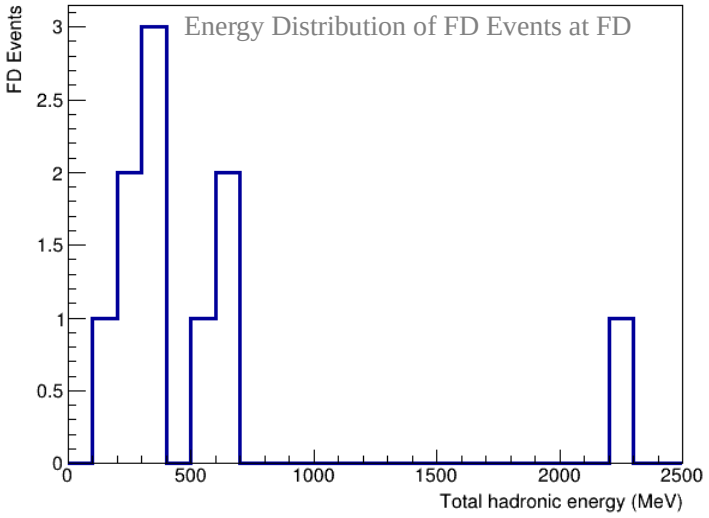

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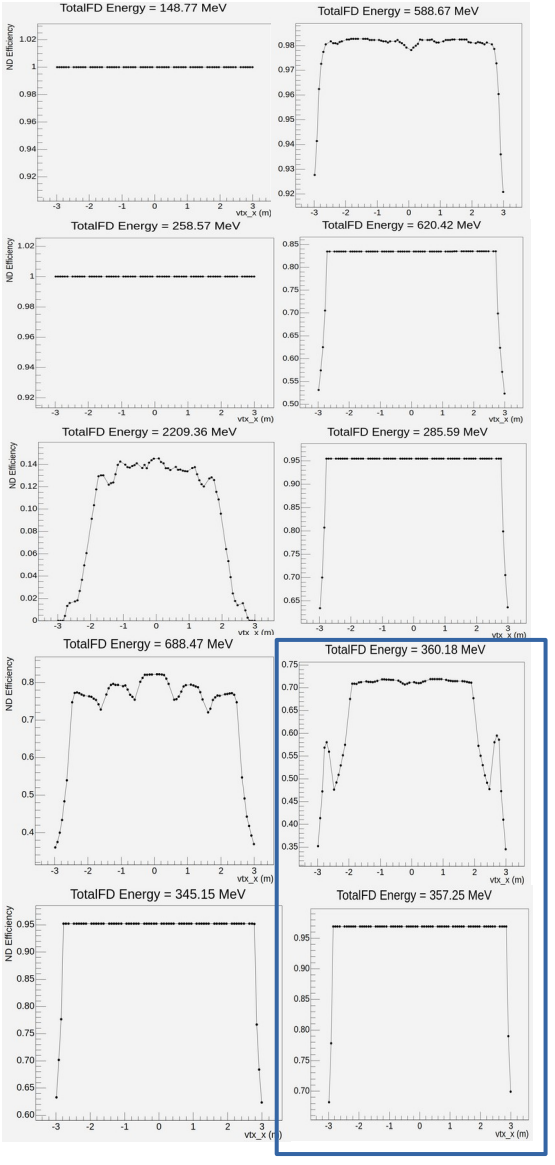
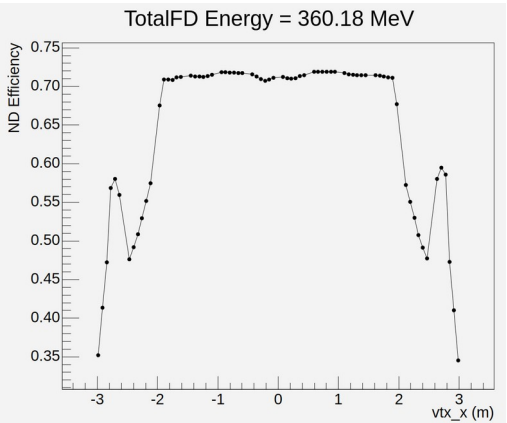
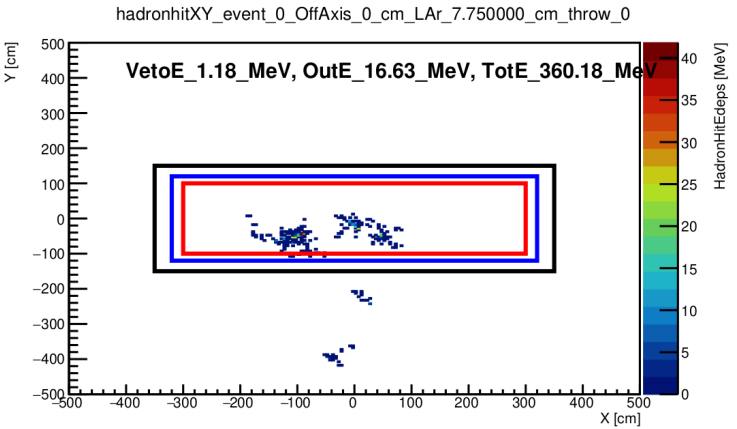
- **Most important: hadronic signature and spread**
  – similar total hadronic energies can have different “deposits” in the detector → different ND efficiencies

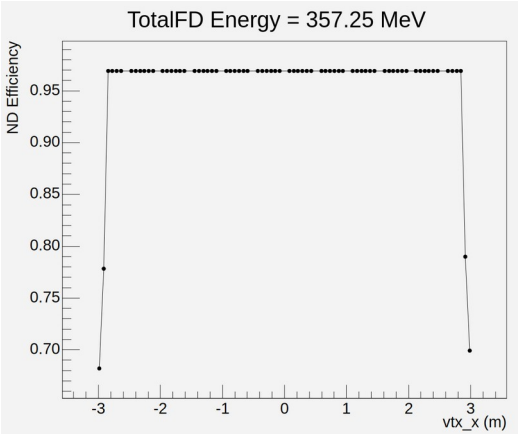


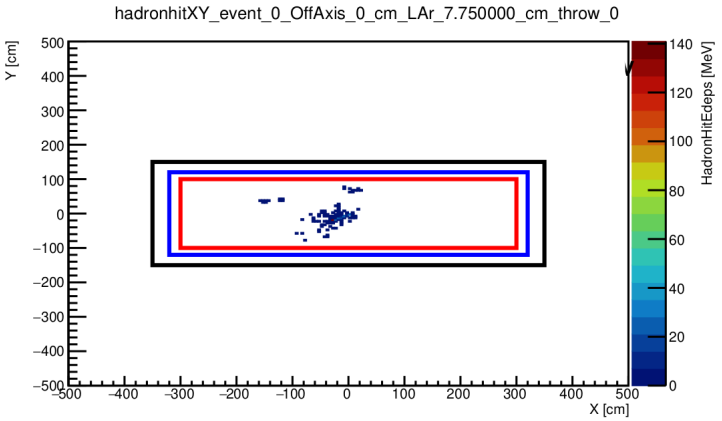
FD Events with similar total energies but different hadronic signatures

- very similar total FD energy but significantly different ND efficiencies .. why?



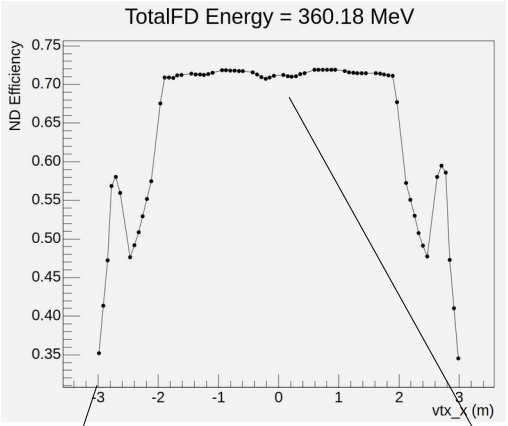


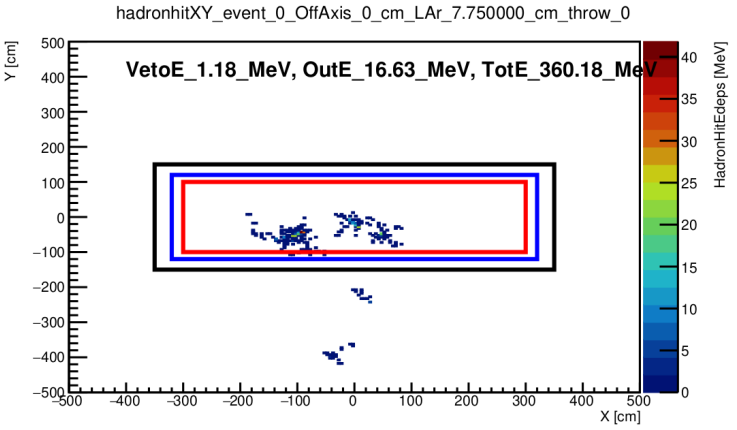


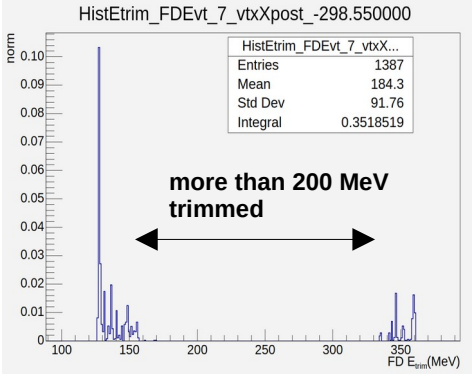


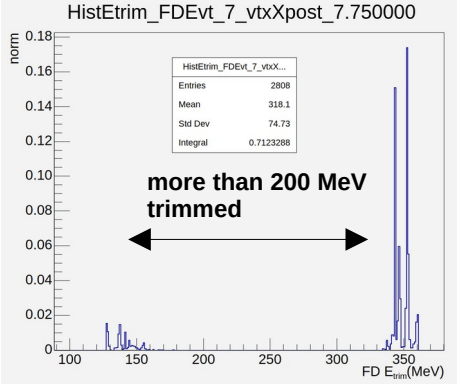
- Hadron signature of this event is very “spread” → much higher chances that the event won’t pass the veto cut + more trimmed energy

FD Event with low FD hadronic energy and wide hadronic signature



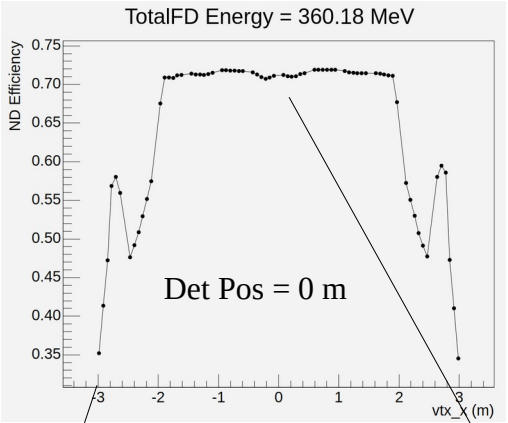


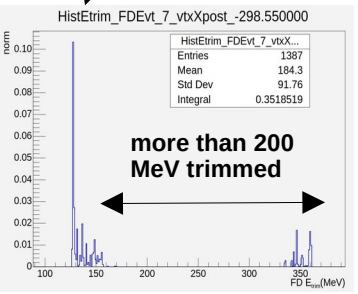


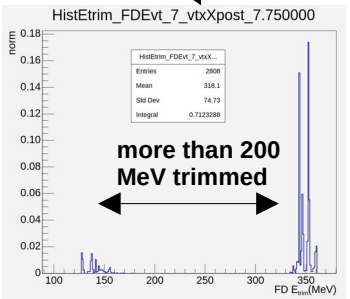


– most passing throws at low Etrim for events at the edge

FD Event with low FD hadronic energy and wide hadronic signature

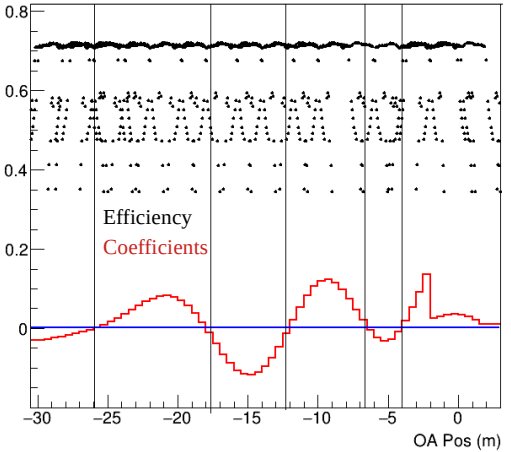






– most passing throws at low Etrim for events at the edge

Add together all Etrim histos and apply the OA coefficients (assume same ND efficiency at all detector postions)

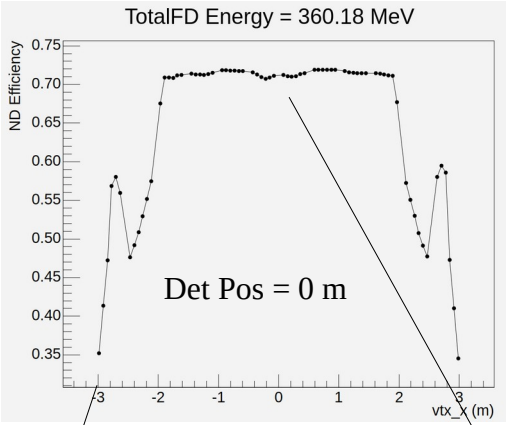


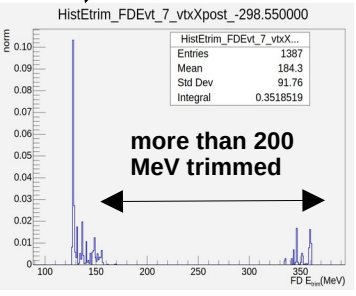

```
nDetPosVector = {0, -1.75, -2, -4, 5.75,
-8, -9.75, -12, -13.75, -16, -17.75, -20,
-21.75, -24, -25.75, -26.25, -28, -
28.25};
```

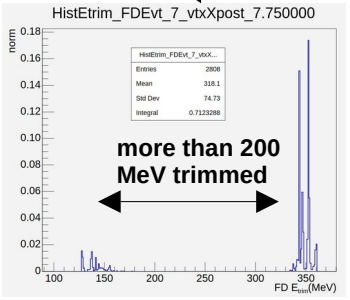
– det positions chosen same as those for the ND CAFs (OA Pos = detPos + vtx_x)

$$HistEtrimFinal = \sum_{OAPos} HistEtrim(OAPos) \times Coefficients(OAPos) \,/\, NEtrim(OAPos)$$

FD Event with low FD hadronic energy and wide hadronic signature







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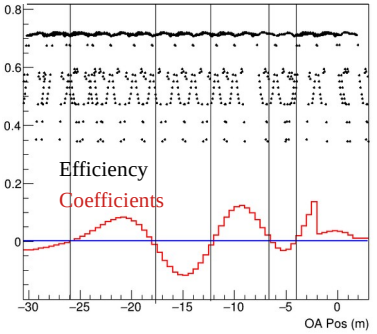
Add together all Etrim histos and apply the OA coefficients (assume same ND efficiency at all detector postions)

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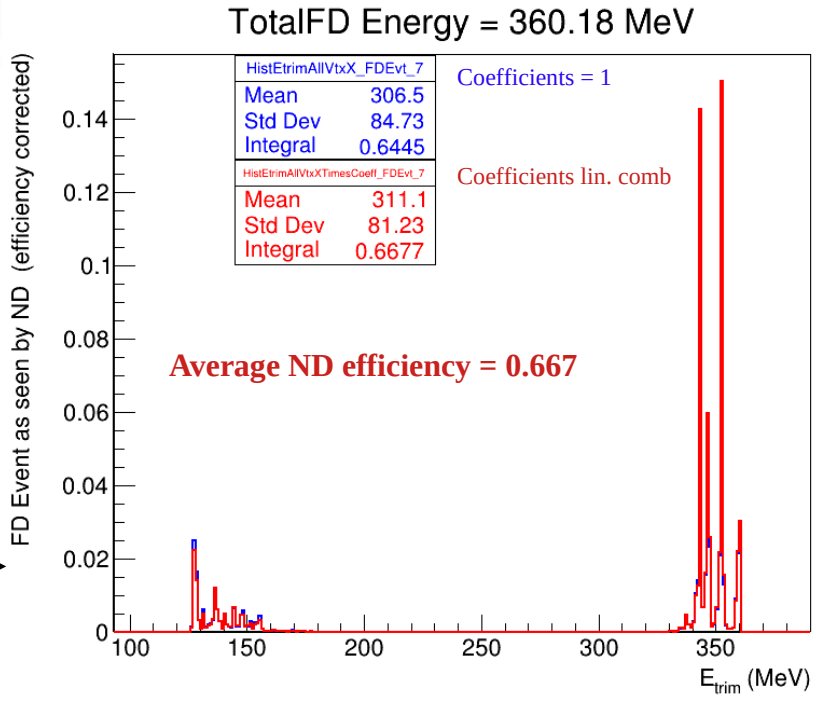
$$HistEtrimFinal = \sum_{OAPos} HistEtrim(OAPos) \times Coefficients(OAPos) \,/\, NEtrim(OAPos)$$

Distribution of FD event as seen by the ND vs trim energy (energy deposited inside the ND active volume)

y-axis = fraction of 1 FD event seen in the ND



Distribution of all FD events as seen in the ND (efficiency corrected)

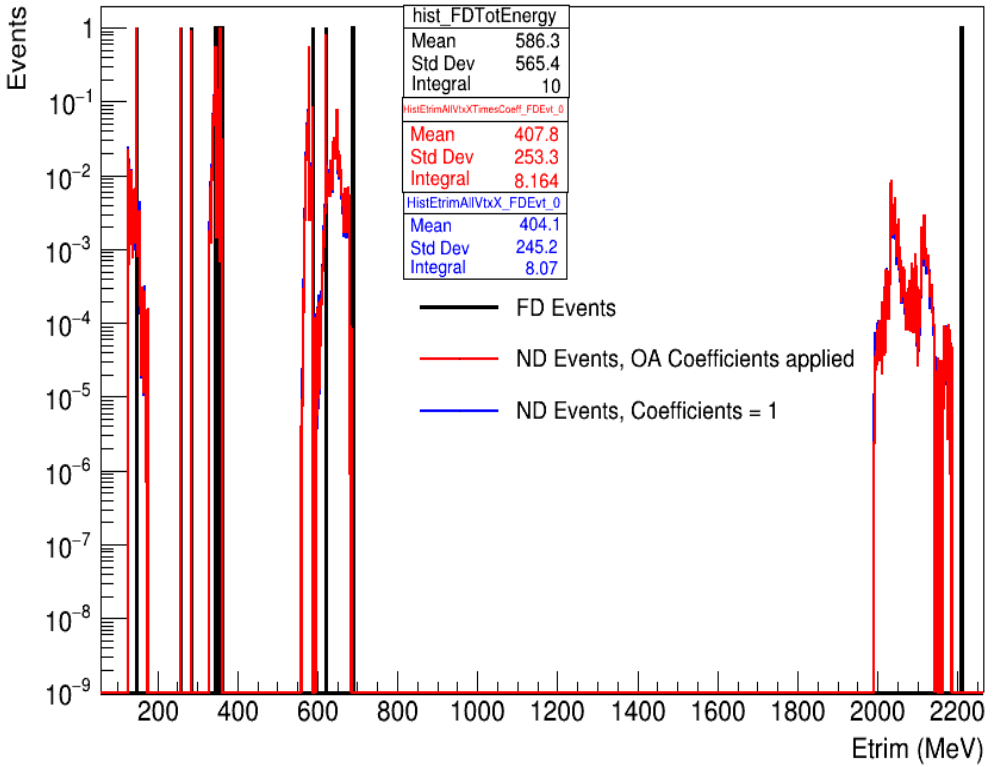
- 10 FD events selected and translated to the ND
  - → calculate the final ND Etrim distribution for each of the events and add them together to see their distribution in the ND
    - – detector position sampling same as the ND CAFs

– 10 events in FD

– 8.164 events seen in the ND

* highest FD total energy = 2.2 GeV
– expecting way less events seen by the ND for higher energy events

ND Events distribution of FD Events as seen in the ND (efficiency corrected)



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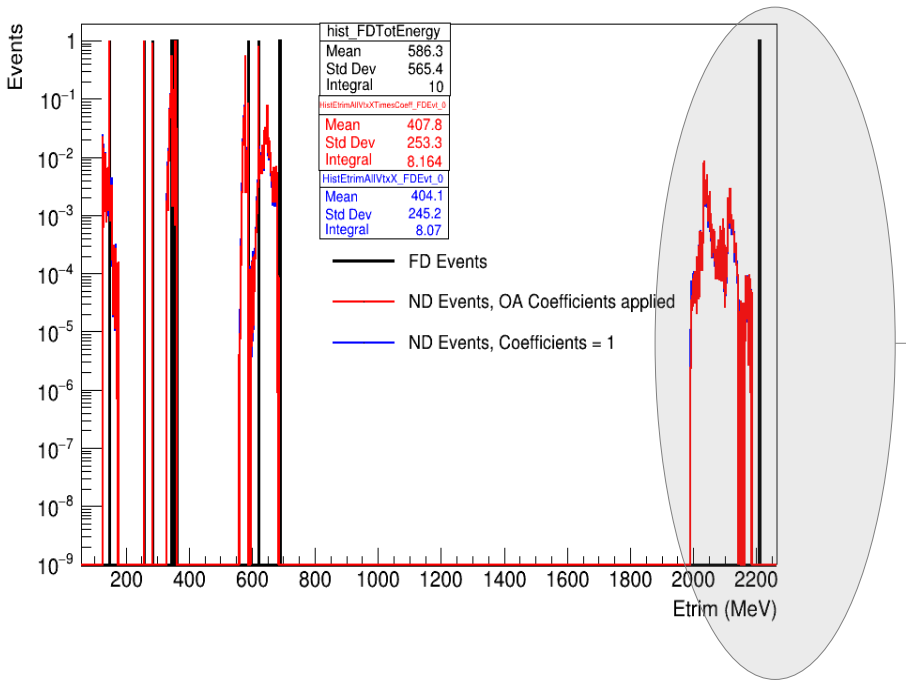
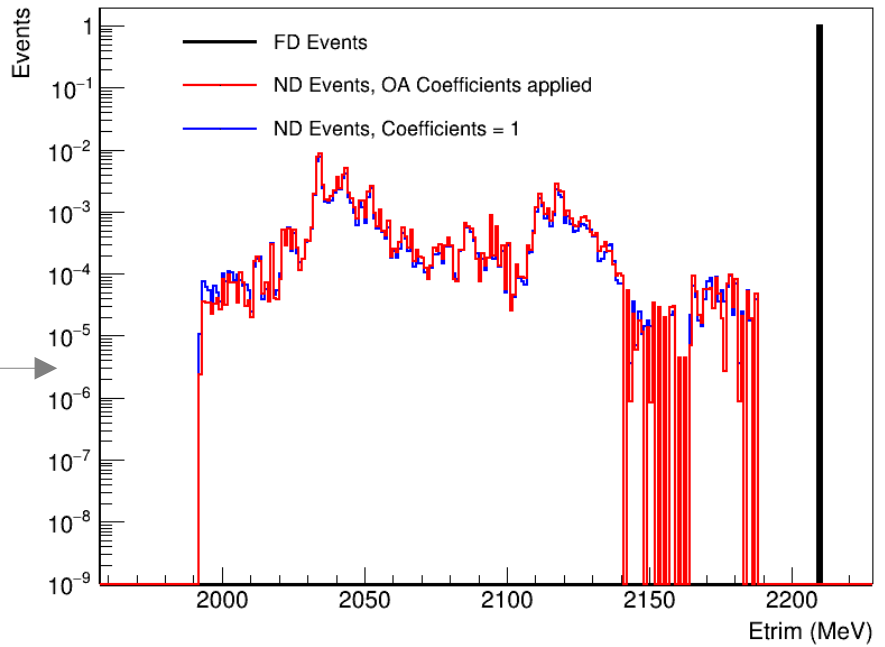


zoom-in



1 FD Event (2209.36 MeV) seen as 0.107 (0.09) events in the ND covering more than 200 MeV in Etrim

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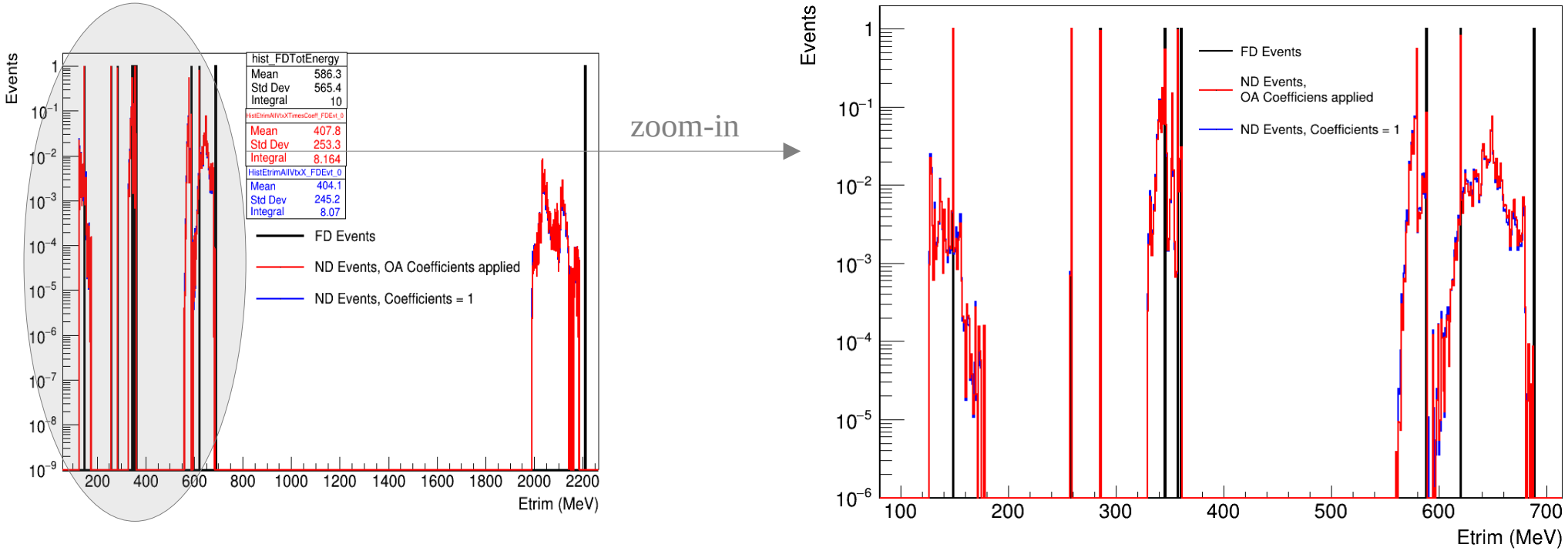

- Not enough statistics yet to nicely cover the entire energy spectrum but getting there :)

Distribution of all FD events as seen in the ND (efficiency corrected)

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– detector position sampling same as the ND CAFs

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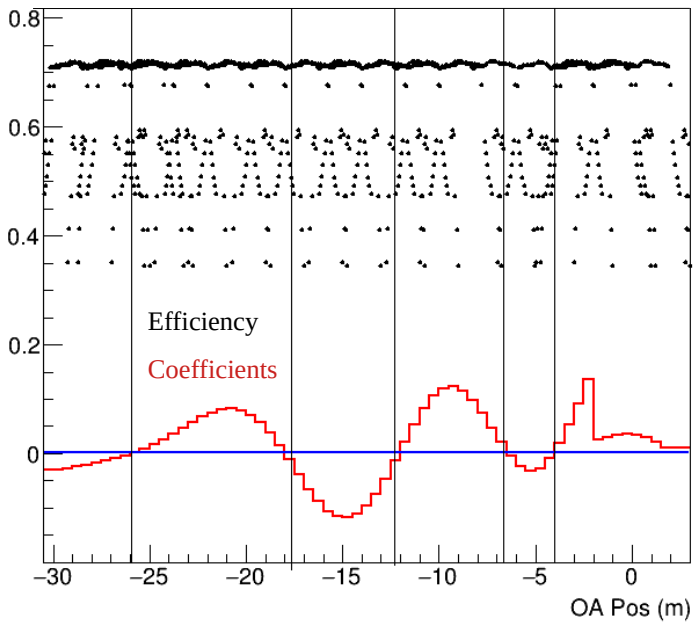
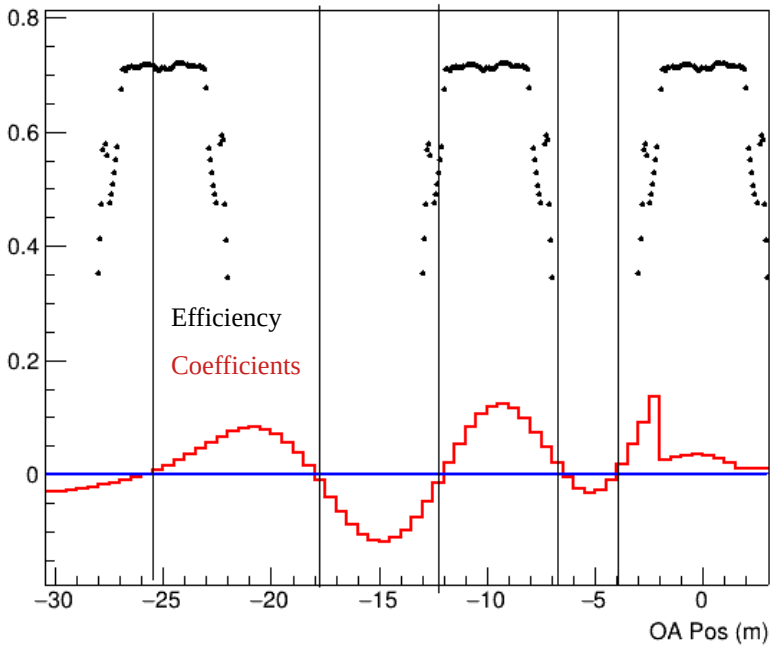
```

→ cover the entire OA position region



– detector position sampling mainly positive OA coeff region

```
nDetPosVector = {0., -10, -25};
```



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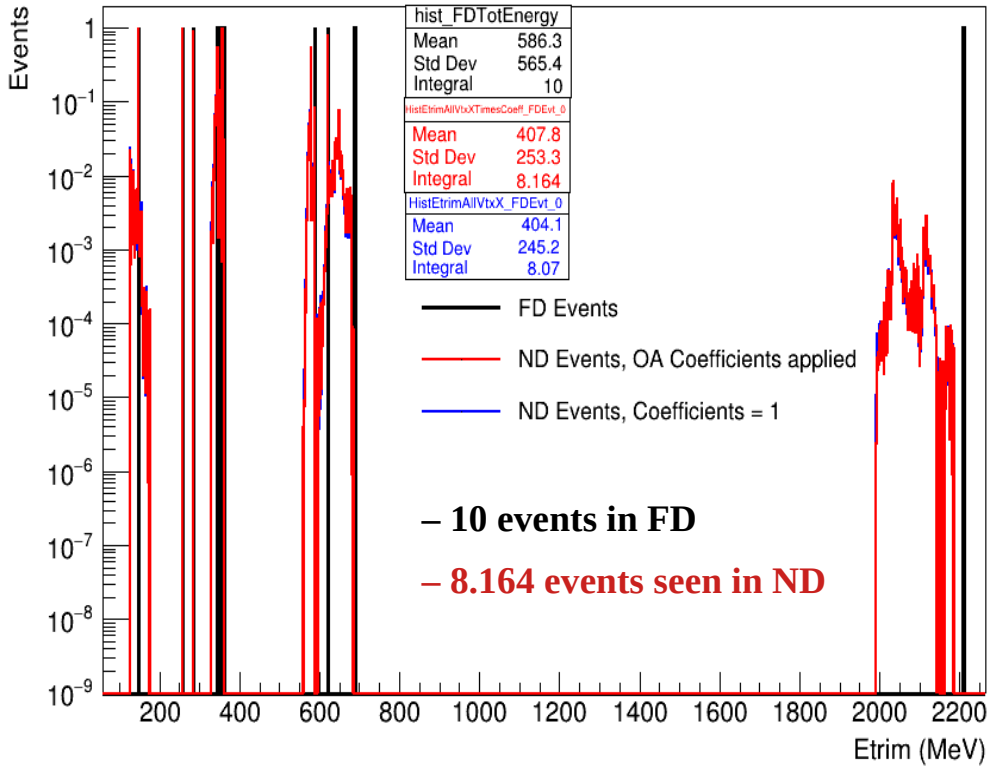

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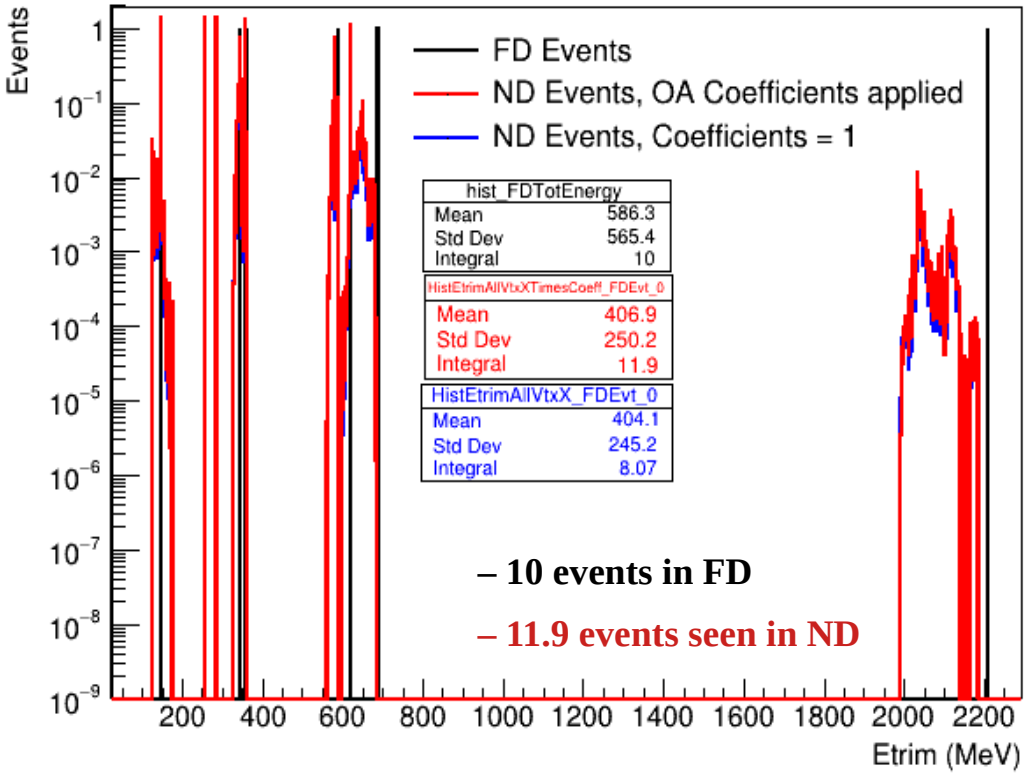

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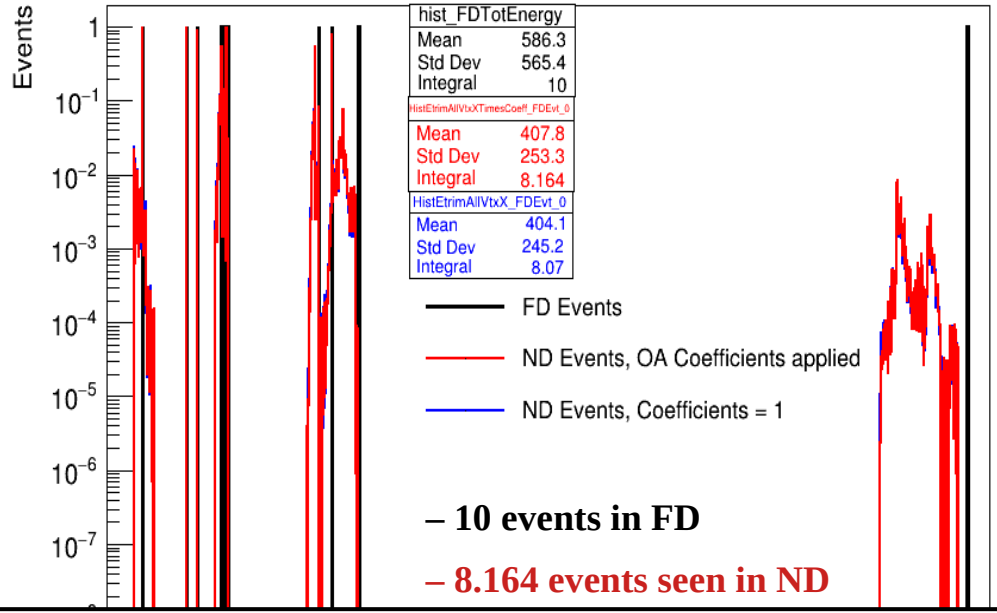
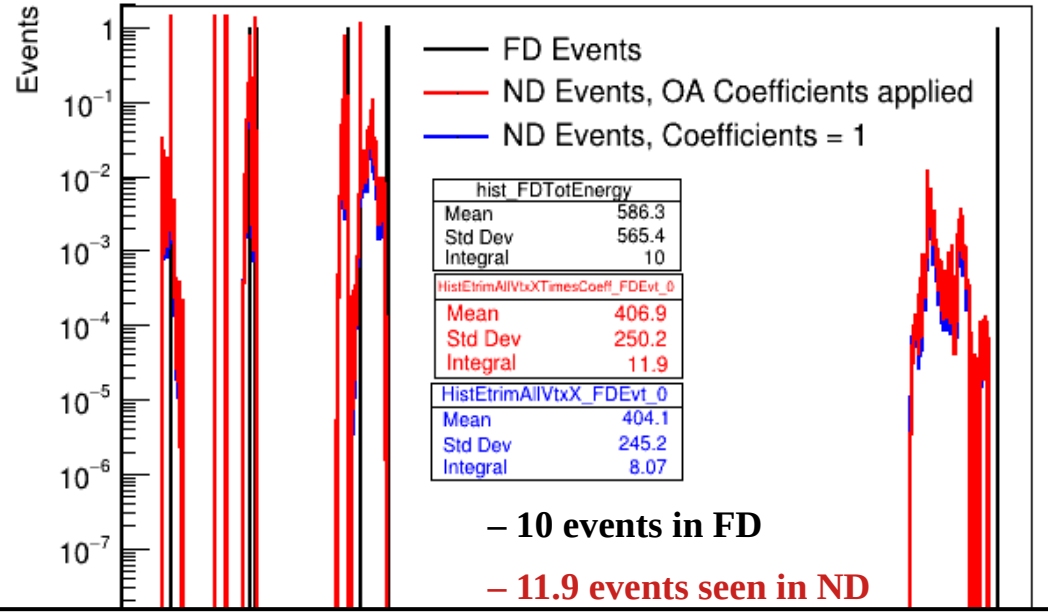
  → calculate the final ND Etrim distribution for each of the events and add them together to see their distribution in the ND

– detector position sampling same as the ND CAFs



– detector position sampling mainly positive OA coeff region



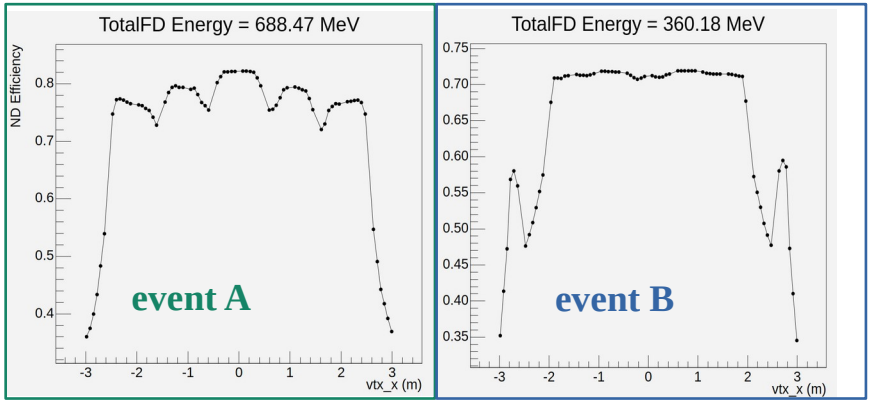
Detector positions sampling matters: sampling mainly the area where coefficients are positive (+) / negative (–) **will result in a higher /** lower **average efficiency of any given FD event**

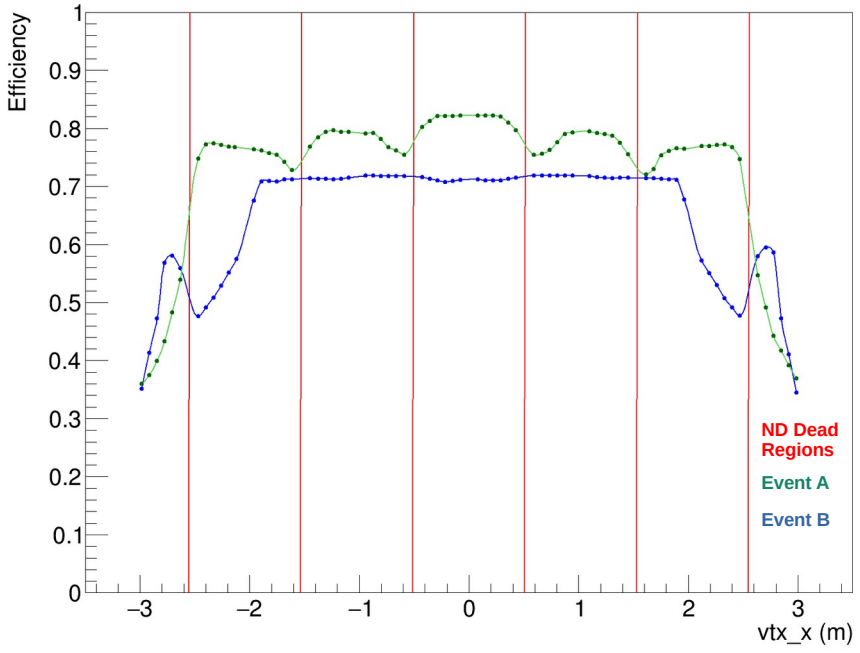
→ **would end up with more /** negative nr of **events in the ND than the total FD events we started with**

Questions from last discussion

1. Are the ND dead regions accounted for in the code?
   – YES
– event only thrown if in ND FV and not in dead region

2. What is happening with the 2 weird peaks in event B?

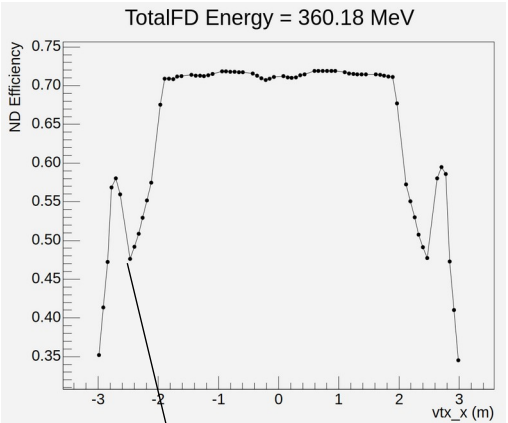


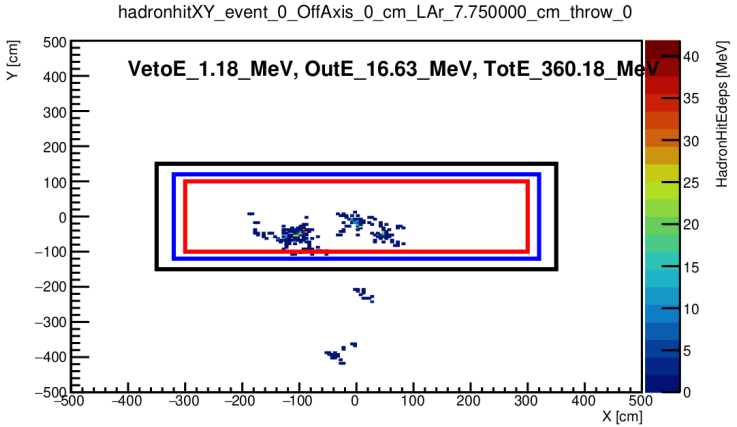


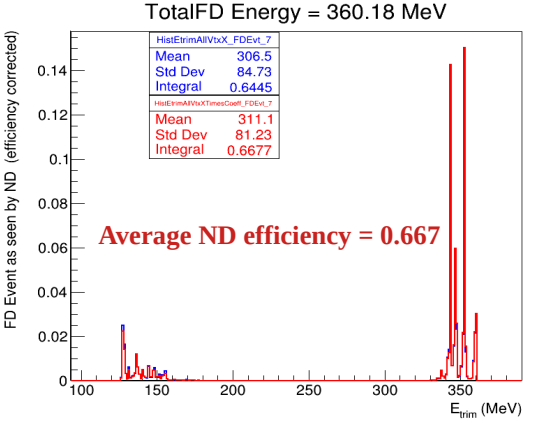
– multiple peak structure in event A is due to the ND dead regions: if neutrino vtx close to one of these regions → lower efficiency

– the 2 peaks in event B are however **not** due to the dead regions

FD Event with low FD hadronic energy and wide hadronic signature



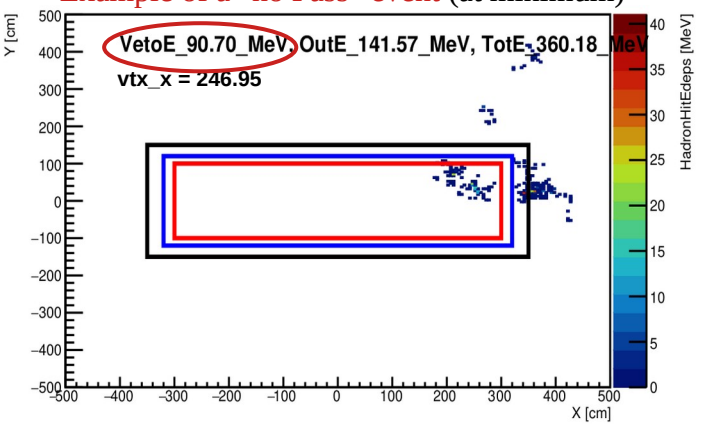




– wide hadronic signature → signficant fraction of total energy is trimmed (many event at low trim energy – 200 MeV gap)

– where are these peaks coming from?

Example of a “no Pass” event (at minimum)



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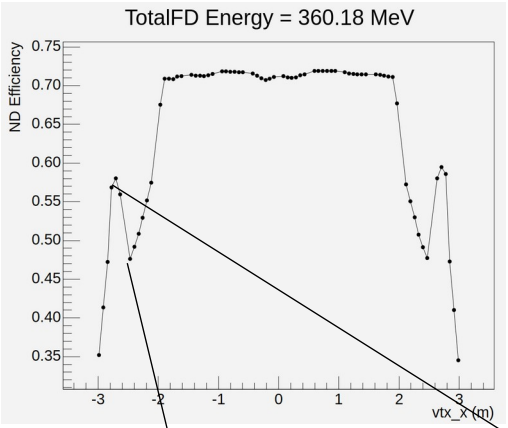

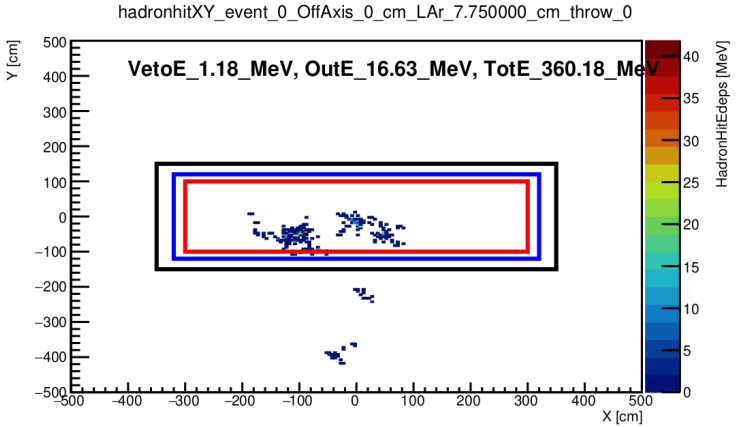

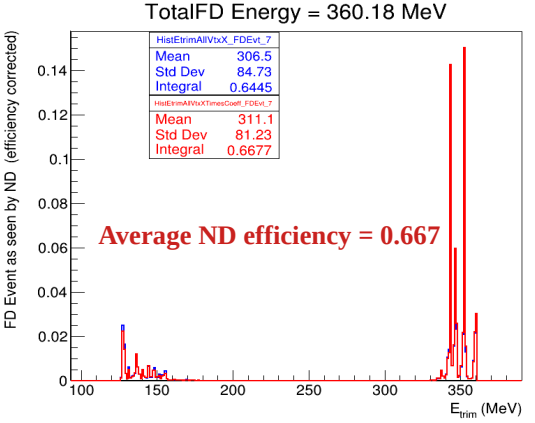

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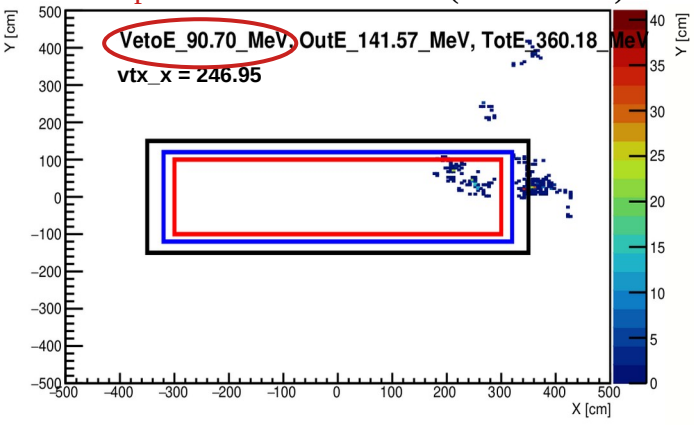
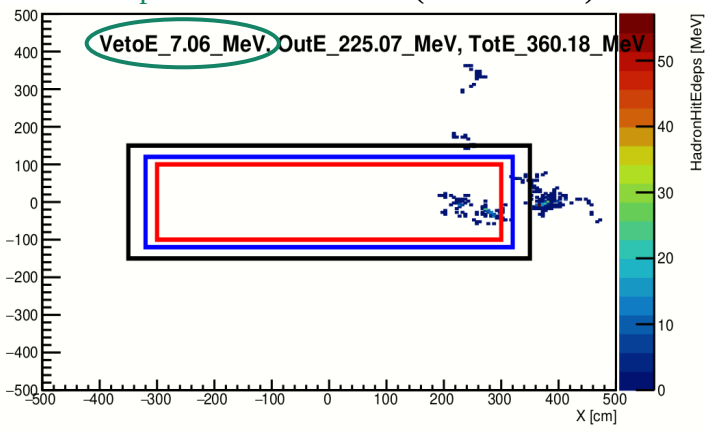
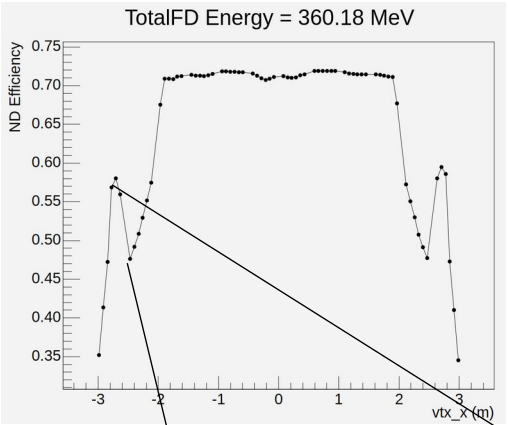
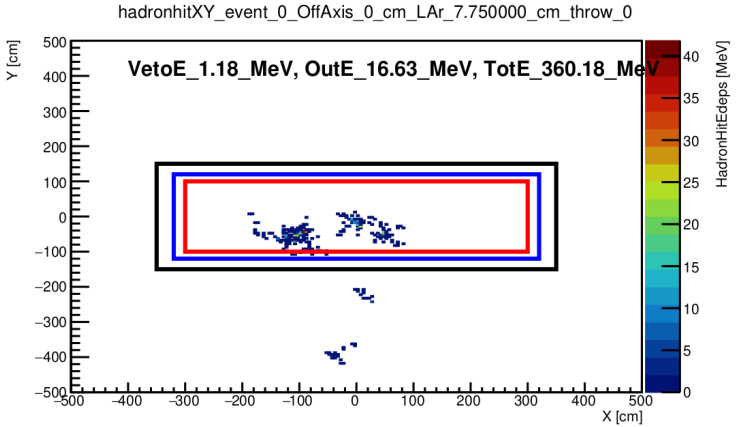


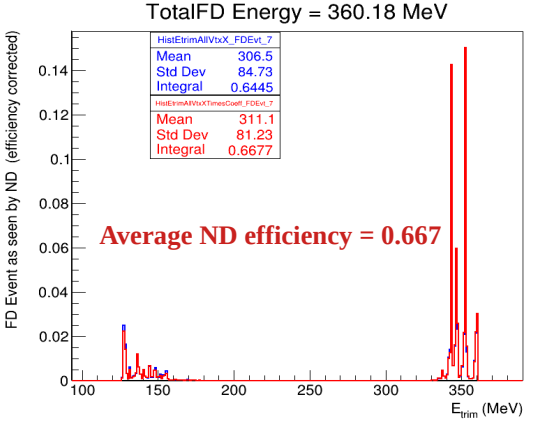
Example of a “Pass” event (at maximum)



FD Event with low FD hadronic energy and wide hadronic signature







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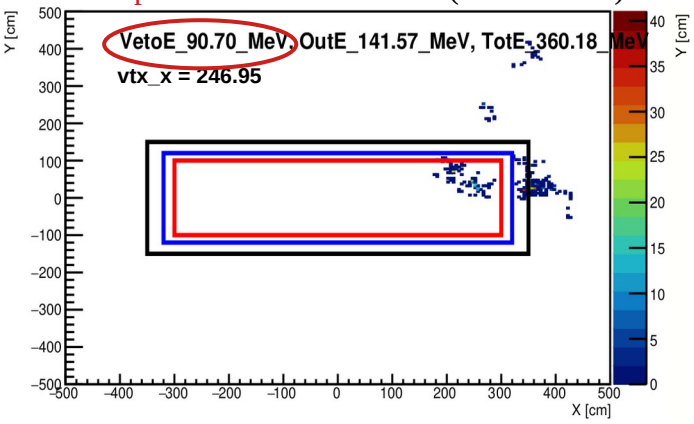

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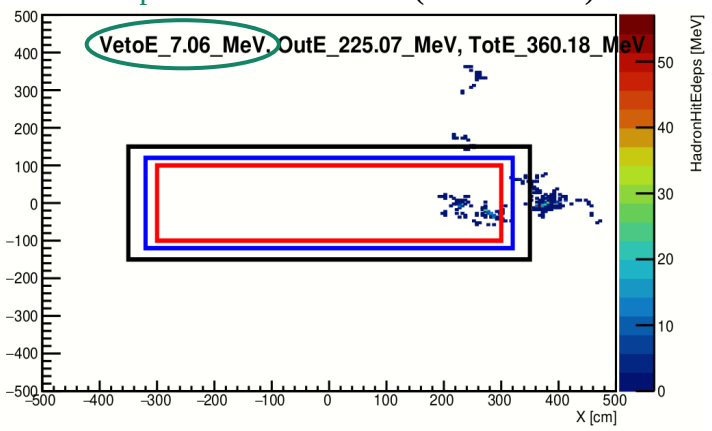


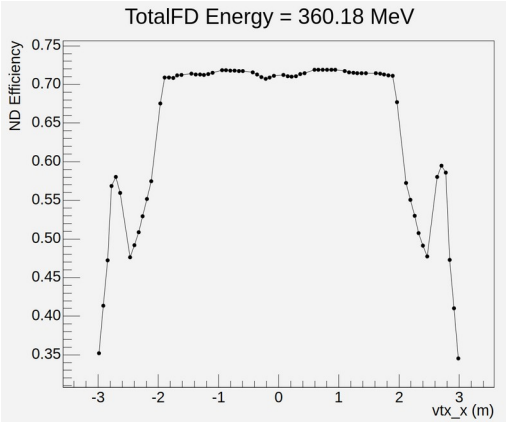
– the peak comes from the position of the **“gap” in the hadronic signature**:

– for a vtx_x = 246.95 the “second” part of the hadronic signature will deposit its energy in the veto region more often

– for a vtx_x = 270.55 the gap between the two main parts in the hadronic signature falls within the veto region → less energy deposited in the veto → more chances for the event to pass the throw

→ this should be mirrored in Etrim distributions

FD Event with low FD hadronic energy and wide hadronic signature



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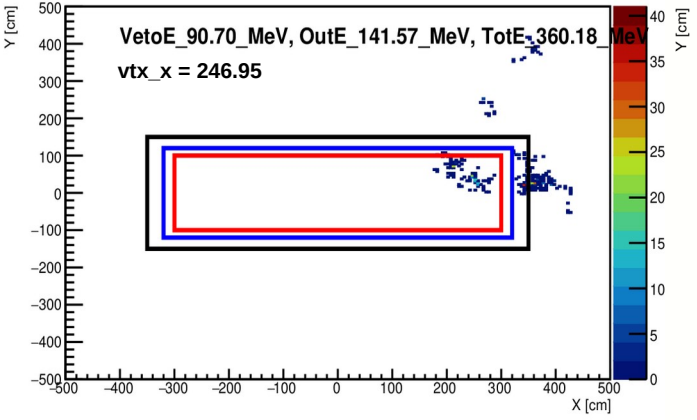

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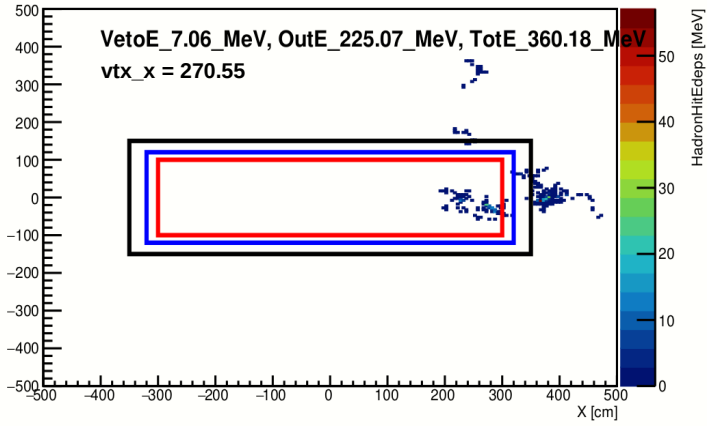

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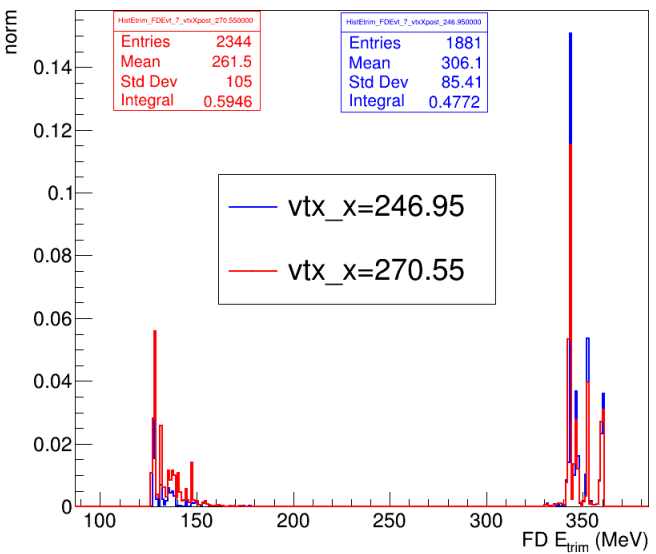
→ this should be **mirrored in Etrim distributions**

HistEtrim_FDEvt_7_vtxXpost_246.950000

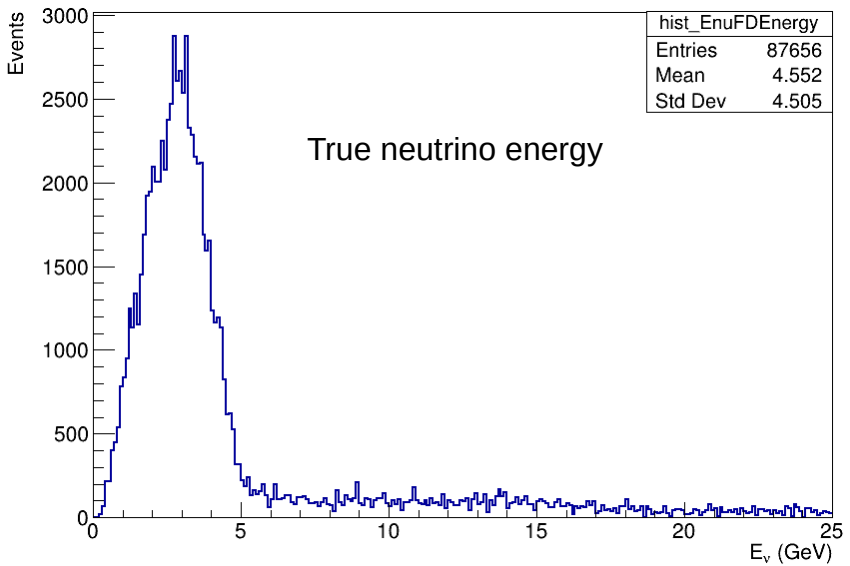


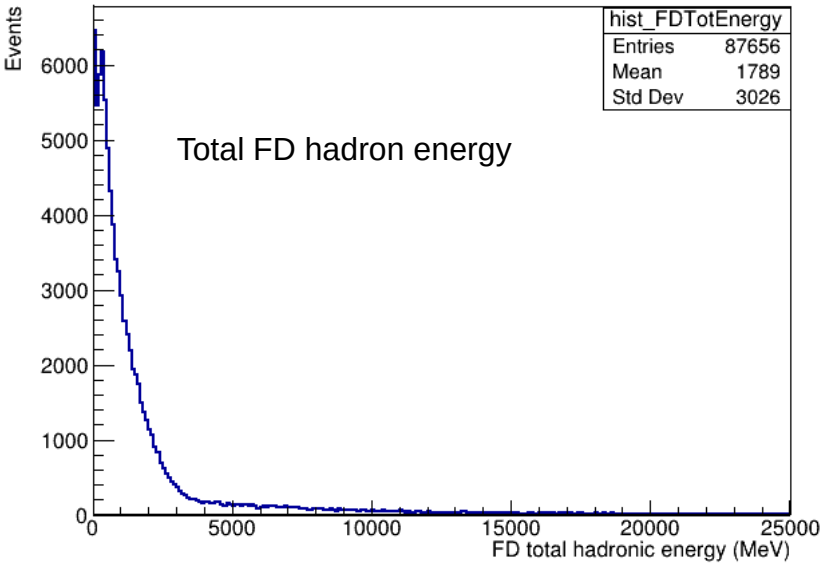
Average Etrim (= 261.5 MeV) for vtx_x = 270.55 smaller than average Etrim (=306.1) at vtx_x = 246.95
→ need to cut out more energy – (less energy in the ND active region) due to bigger hadronic deposit outside the active region

Geometric efficiency – first results with higher statistics

- 9070 ntuples (all ntuples created by Flynn) – 907 000 simulated FD Events
  → **87 656 events selected and translated to the ND** (~ 10 % of simulated FD events pass selection)

Selection Cuts:
– event has to have muon/hadronic energy deposits
– CC events
– muon as final state lepton
– event vertex inside FD FV

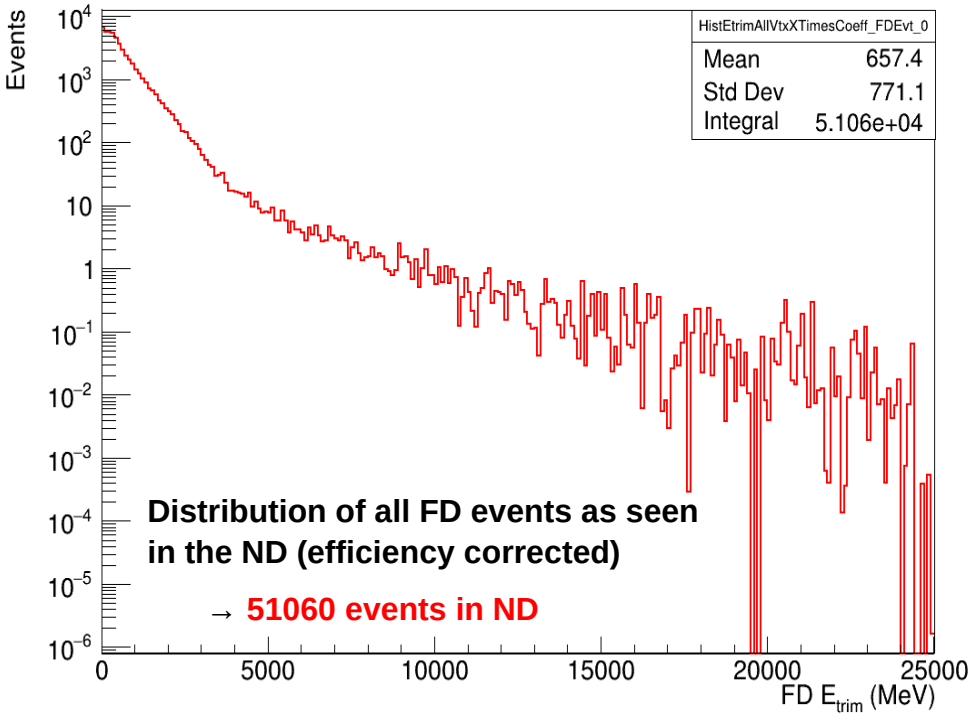


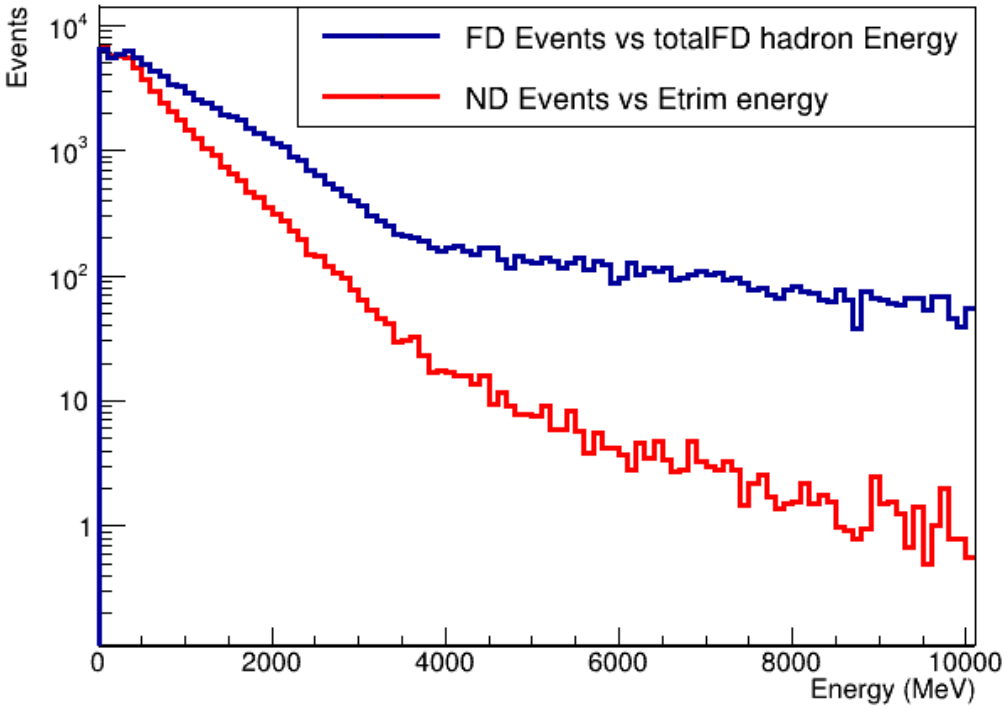


!!! Un-oscillated spectra..

Geometric efficiency – first results with higher statistics

- 87 656 events selected and translated to the ND





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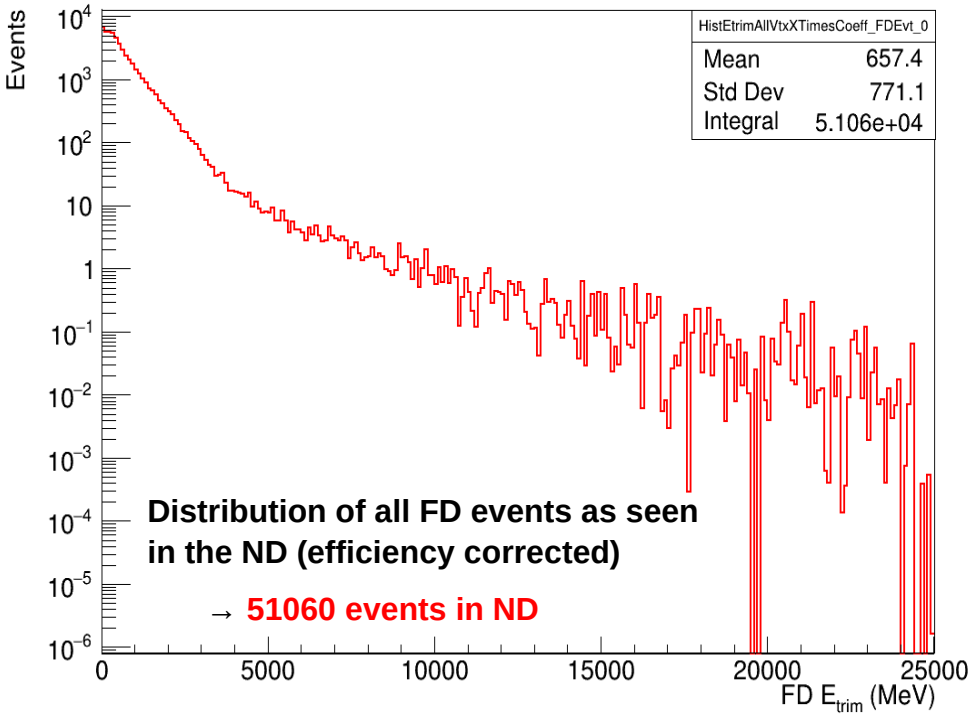
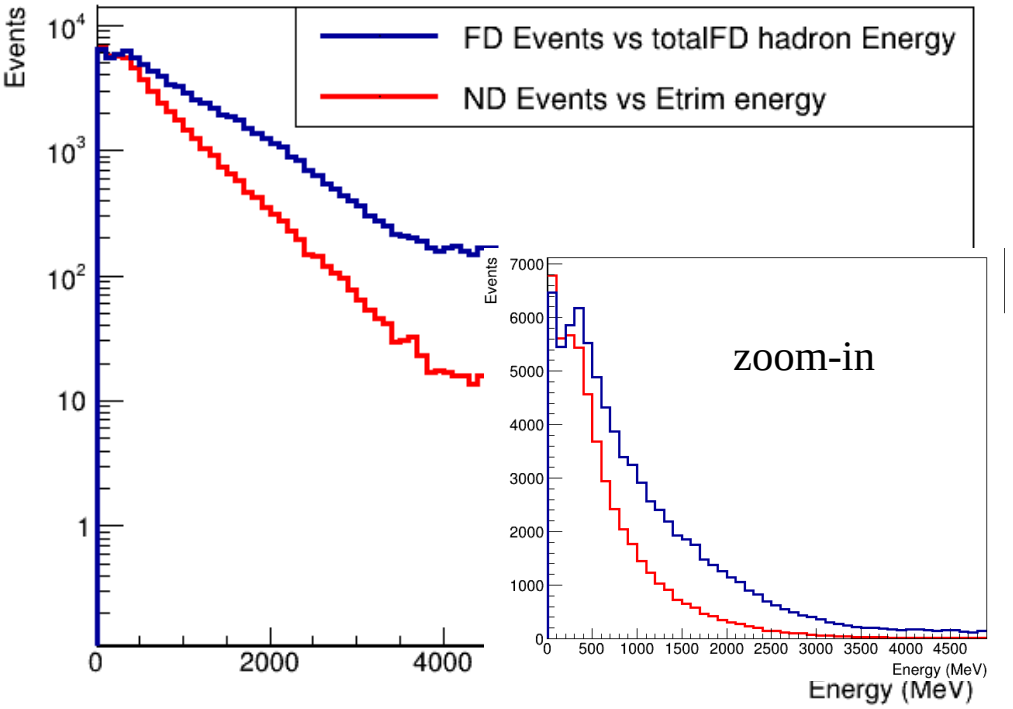
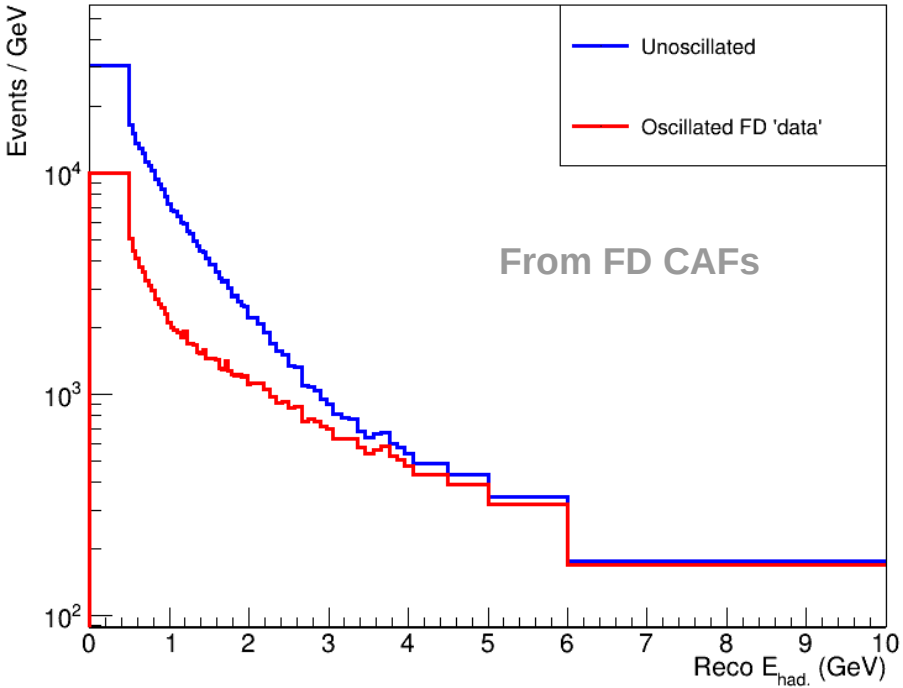




- Spectrum of FD Events in the ND (efficiency corrected) vs Etrim seems to be following the FD events spectrum vs total FD hadronic energy (less events at high FD energies and more at very low Etrim)
  - but it does not look oscillated at all..
- Neutrino spectra in the FD is unoscillated → **TODO:** try to re-weight / repeat the same study with NuFit4.0 param.

FD Spectrum vs Hadronic Energy

- Meanwhile: worth checking how the oscillated FD spectra vs Vis Had E (PRISM var) looks like



- FD oscillated spectrum in FD visible hadronic energy does not have an “obvious” oscillation shape

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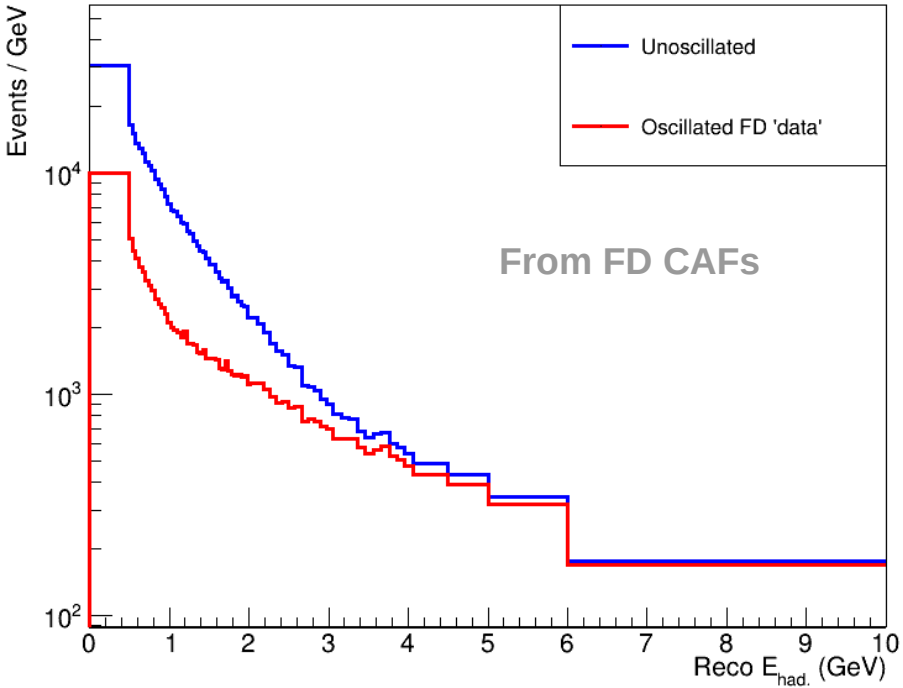
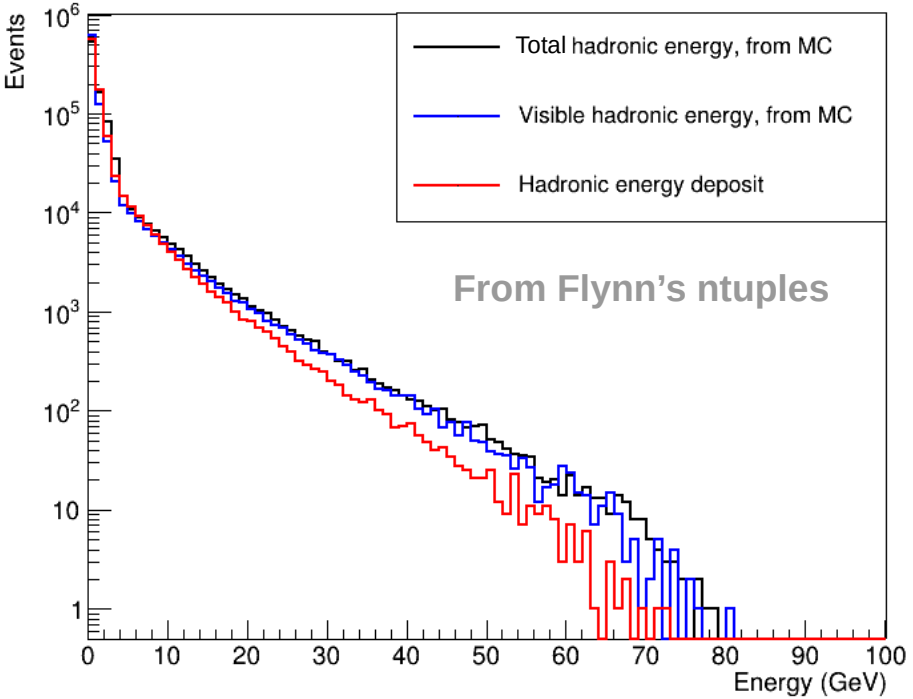


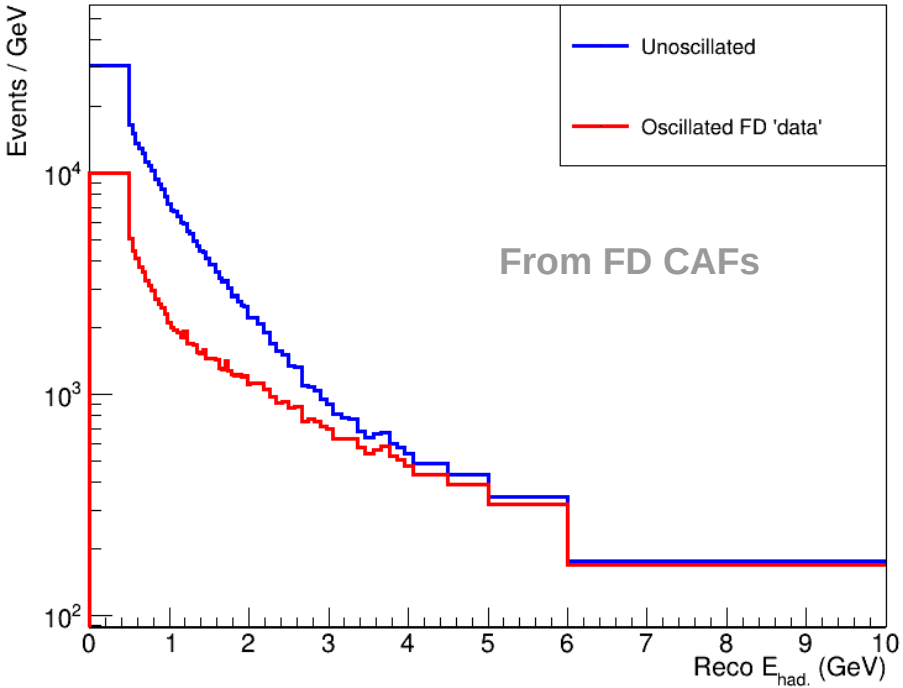


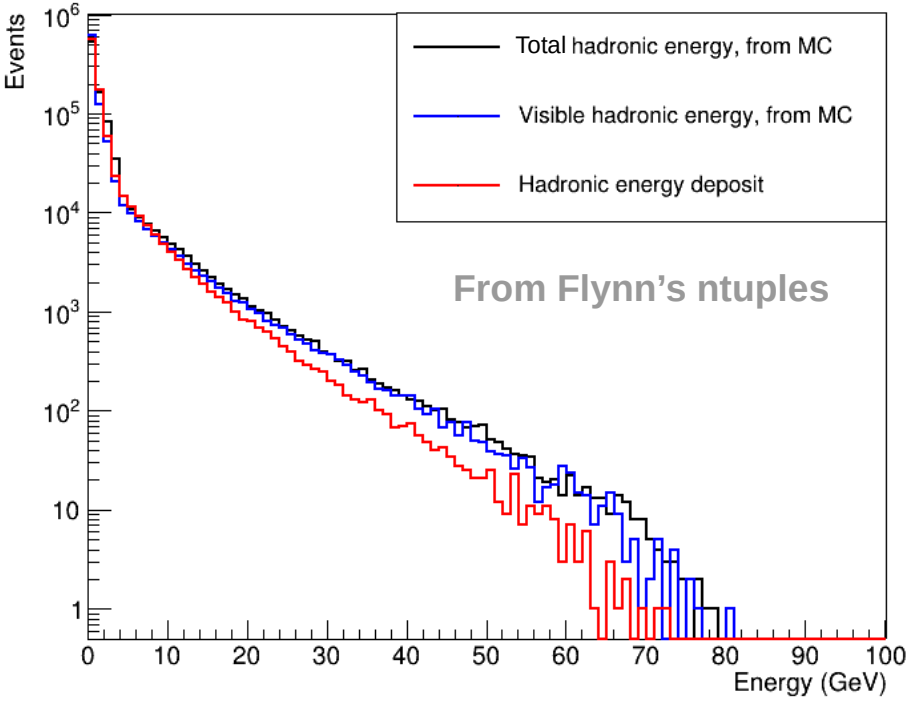
- FD oscillated spectrum in FD visible hadronic energy does not have an "obvious" oscillation shape

- We also don't work with the "visible hadronic energy" in the efficiency correction, but rather with the hadronic energy deposit → shape seems to be quite similar

FD Spectrum vs Hadronic Energy

- Meanwhile: worth checking how the oscillated FD spectra vs Vis Had E (PRISM var) looks like



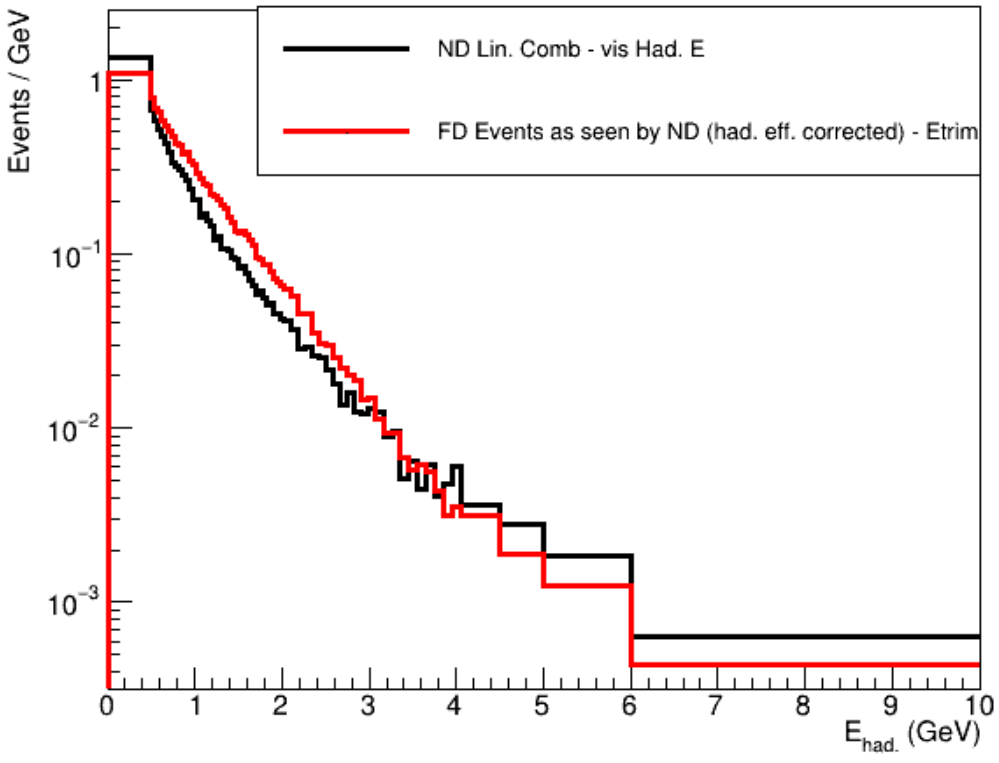


- FD oscillated spectrum in FD visible hadronic energy does not have an "obvious" oscillation shape → should we try to add the muon energy (AnaVar = Elep + visHadE == VisEreco) when we meet in the middle with the 2 predictions?

  – each event efficiency corrected (rotated + translated) has a fixed muon energy which we could further add to the final variable: **EvisTrim = Etrim + Emu**

Work in progress..

Geometric efficiency – first results with higher statistics



Still a lot to do, but:

– for now try to compare the non-oscillated spectrum (ntuples spectra is not oscillated → will have to oscillate it : TODO)

PRISM can work with predicting a non-oscillated FD spectra: different OA coeffs

– ND Linear Comb:
(NDData-Bkg) (visEHad, OA) * CoeffNoOsc(OA)

– FD Events as seen by ND (Etrim) : all FD events in Flynn's ntuples put in the ND, rotated +translated, and Coeff applied to Etrim histos

– NO muon efficiency correction: all events in red should be scaled down (or events in black scaled up)

– NO smearing between NDVisHadE and Etrim..

Where are we...

- Understanding all the efficiency shapes – efficiency vs vtxX – and different effects specific hadronic signatures would have on these efficiencies in the ND
- First statistics significant distribution of FD events translated and hadronic efficiency corrected in the ND as a function of the trim energy Etrim (hadronic energy deposited inside the ND active volume)
  - Method seems to be working well so far, no outliers / not understood behavior
- First **very raw** comparison between the linearly combined ND data – (ND – bkg) * Coeff – and the FD events as seen in the ND (had. Efficiency corrected)
  - Comparison for non-oscillated FD spectrum (OA coefficients calculated to predict FD NoOsc)
  - Similar energy dependency (considering we have different energy variables: visHadE vs Etrim and no muon efficiency applied yet)

Where are we...

- Understanding all the efficiency shapes – efficiency vs vtxX – and different effects specific hadronic signatures would have on these efficiencies in the ND
- First statistics significant distribution of FD events translated and hadronic efficiency corrected in the ND as a function of the trim energy Etrim (hadronic energy deposited inside the ND active volume)
- First **very raw** comparison between the linearly combined ND data – (ND – bkg) * Coeff – and the FD events as seen in the ND (had. Efficiency corrected)

TO DOs...

- Events distribution in the ND of the FD events (hadronic efficiency corrected) vs VisEtrim = Etrim + muEdep – should have an “oscillated” or “non-oscillated” shape that we are used to
  - Jobs submitted, should have the result in 1-2 days
- Re-weight ntuples to oscillated Enu spectrum using NuFit4.0 params – bit of thought on how to correctly do this but doable – maybe already some existent code that I am not aware of..?
- Short term : muon efficiency correct the ND data
  - [(NDdata – bkg)(OA, visE) * MuonEfficiency(visE)] * Coeff(OA)
- Long term: muon efficiency applied to FD events translated to ND (have all efficiencies applied to the translated FD events in ND)
- Some time next year: need a thorough discussion about the final FD CAFs + ntuples – need additional info (energy deposits) to the current FD CAFs in order to be able to translate them to the ND and geo. Eff. correct them ..