Geometric Efficiency Correction – Method and implementation with the PRISM framework

November 13th, 2024

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Geometric efficiency correction: hadronic component

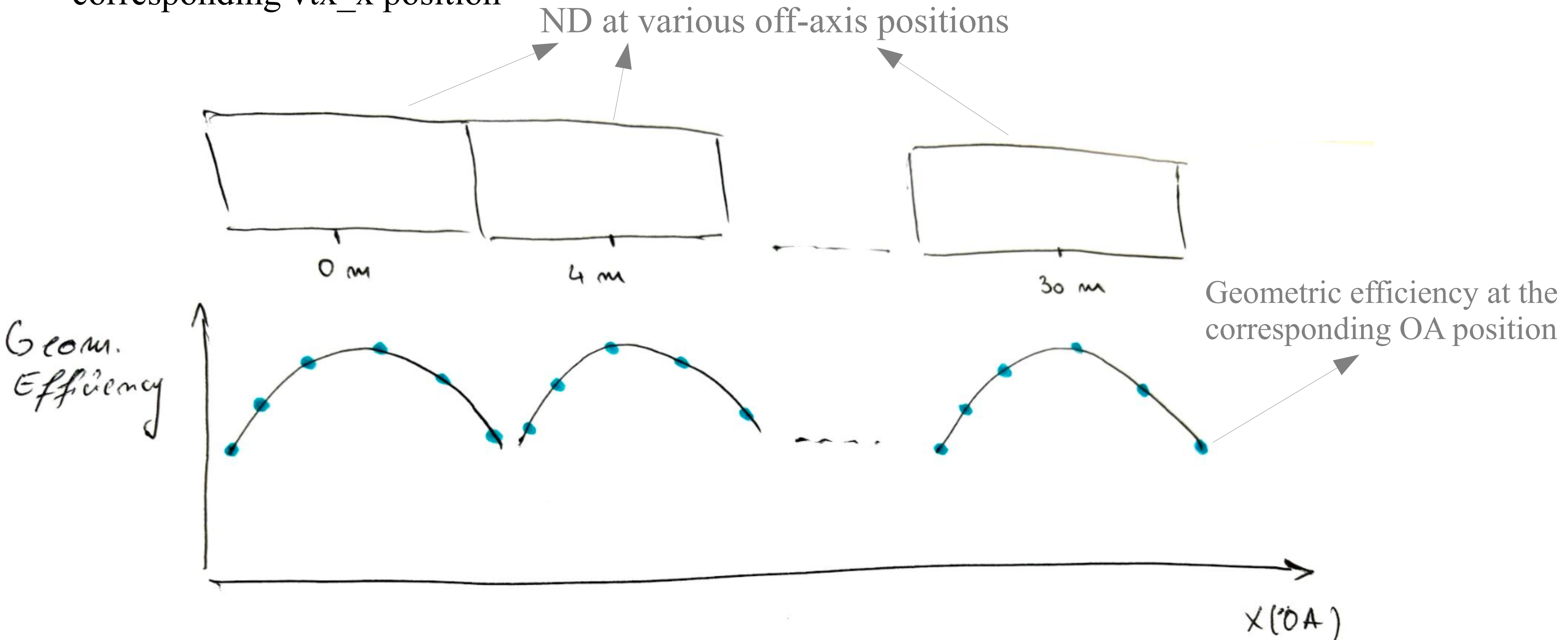
1. take a FD event from FD CAF(with the hadronic energy deposit in FD)
2. translate the FD event to ND (account for Earth curvature)
3. at the ND: move the event to the beam center (in front of the beam)
   – choose different detector positions off-axis (rotation of the event in the ND from on axis to 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) 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)
         5. calculate the geometric 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

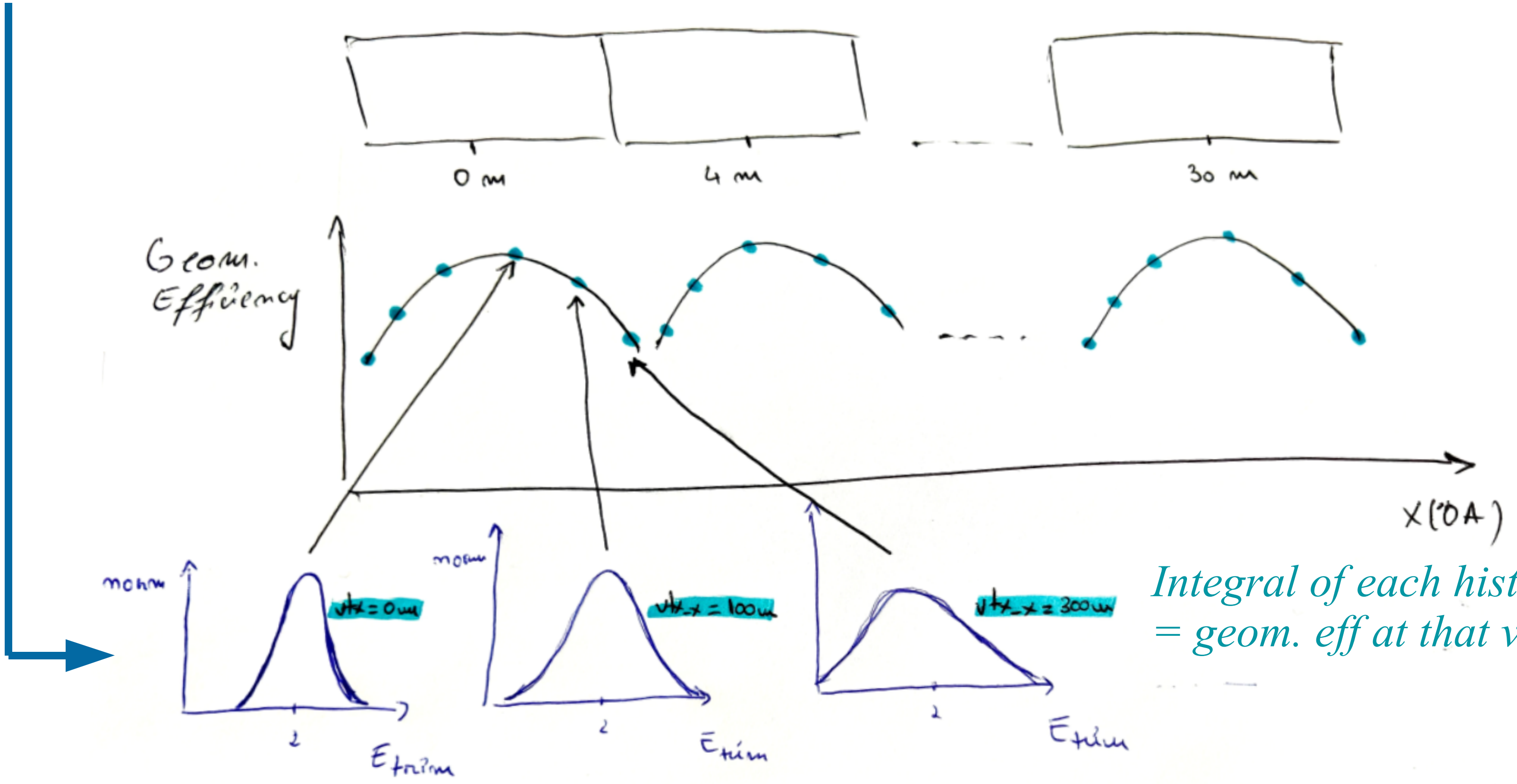
Geometric Efficiency within PRISM framework

- This procedure would apply to each individual FD Event: assume **1 FD Event** with FD Total hadronic energy
  → we have the geometric efficiency of each FD event at the ND for each off-axis position and corresponding vtx_x position



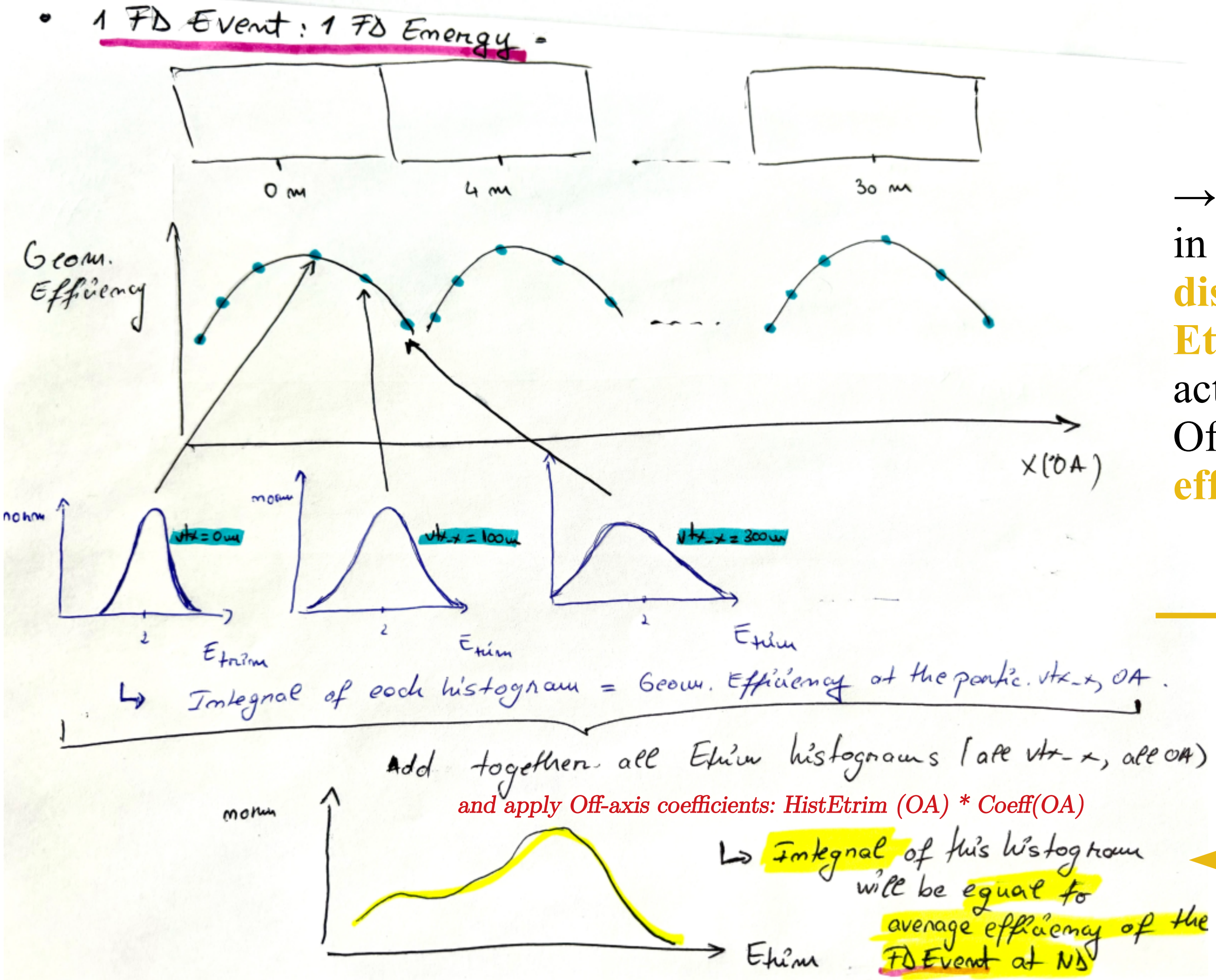
Geometric Efficiency within PRISM framework

- 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

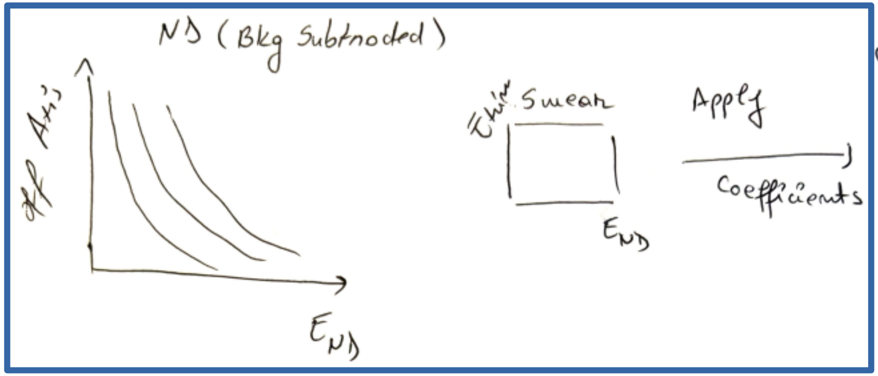


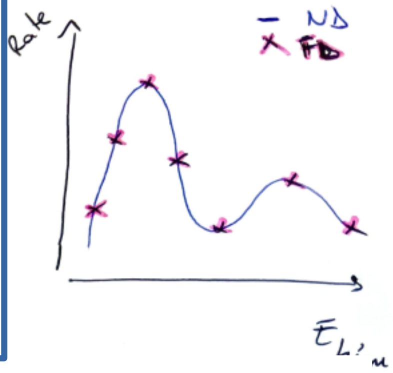
→ combine the histograms vs Etrim in order to get a **general distribution of the FD event vs Etrim** (energy deposited in the ND active volume) resulted from all Off-axis and vtx_x position and **efficiency corrected**

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}

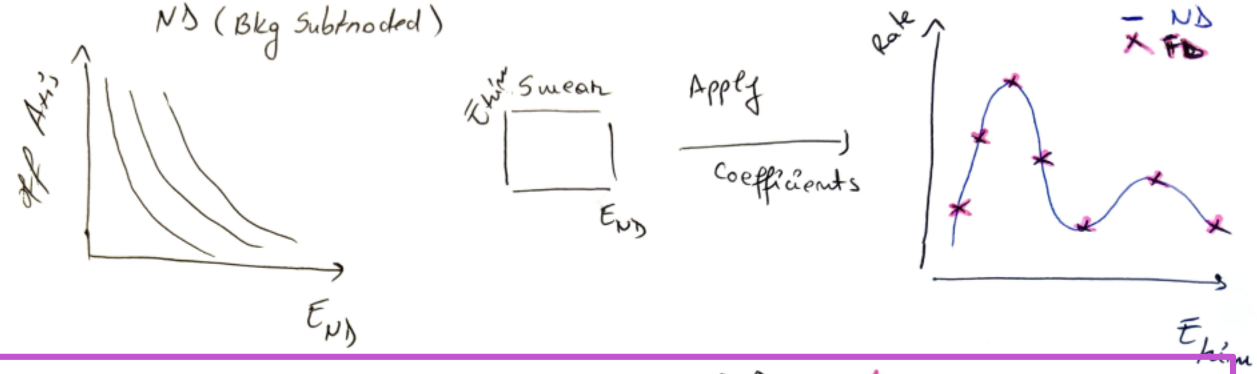
2. Smear ND data to Etrim

3. Apply OA coeficients

PRISM linear combination

Geometric Efficiency within PRISM framework

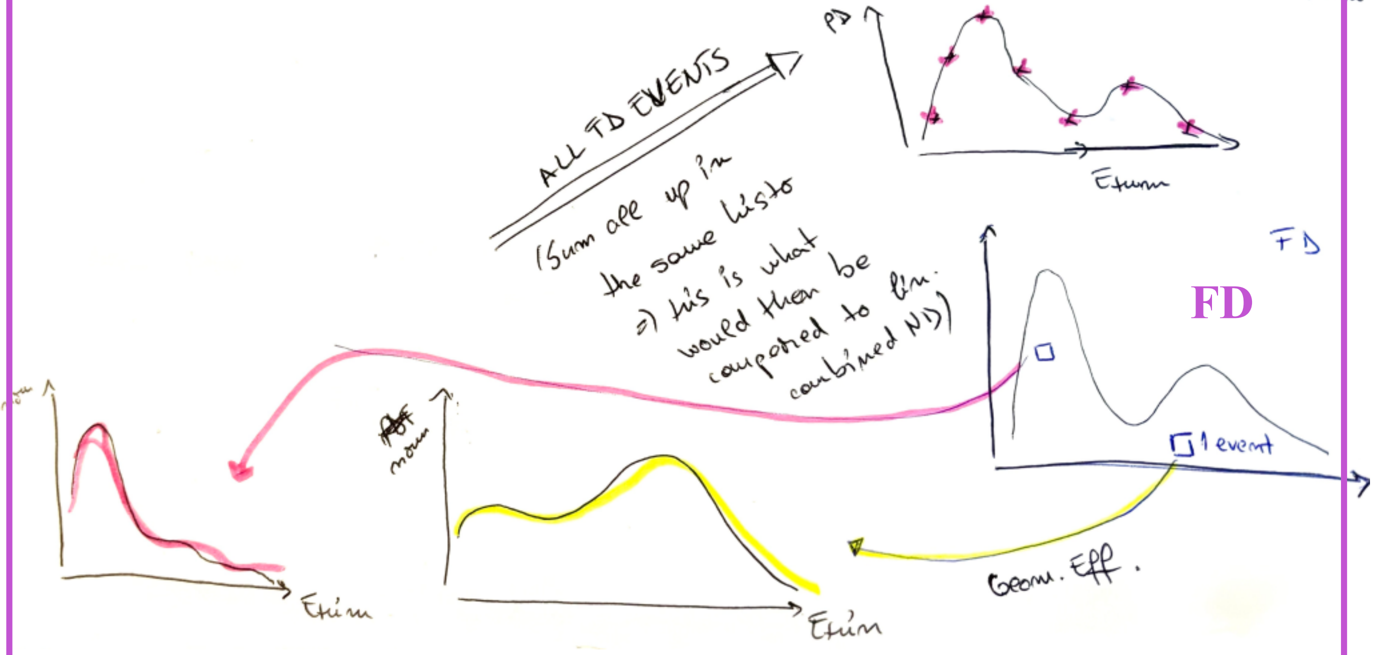
ND



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

FD

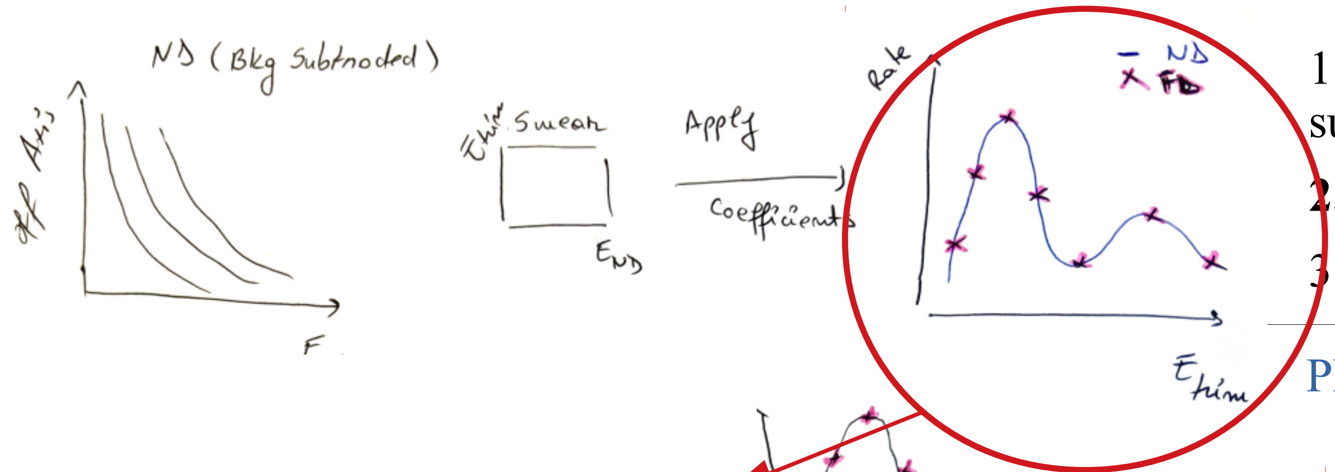


1. Start with FD oscillated spectrum (FD tot hadronic Energy)
2. For each FD event → geometric efficiency correction (Etrim)
3. FD events (efficiency corrected) distribution vs Etrim

Efficiency corrected FD oscillated spectrum

Geometric Efficiency within PRISM framework

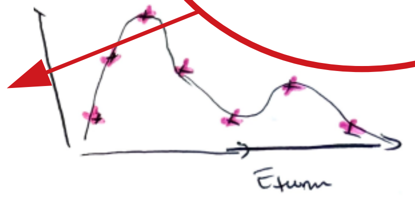
ND



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

Compare Linear combination with OscillatedFD Events corrected for their efficiency at ND



1. Start with FD oscillated spectrum (FD tot hadronic Energy)
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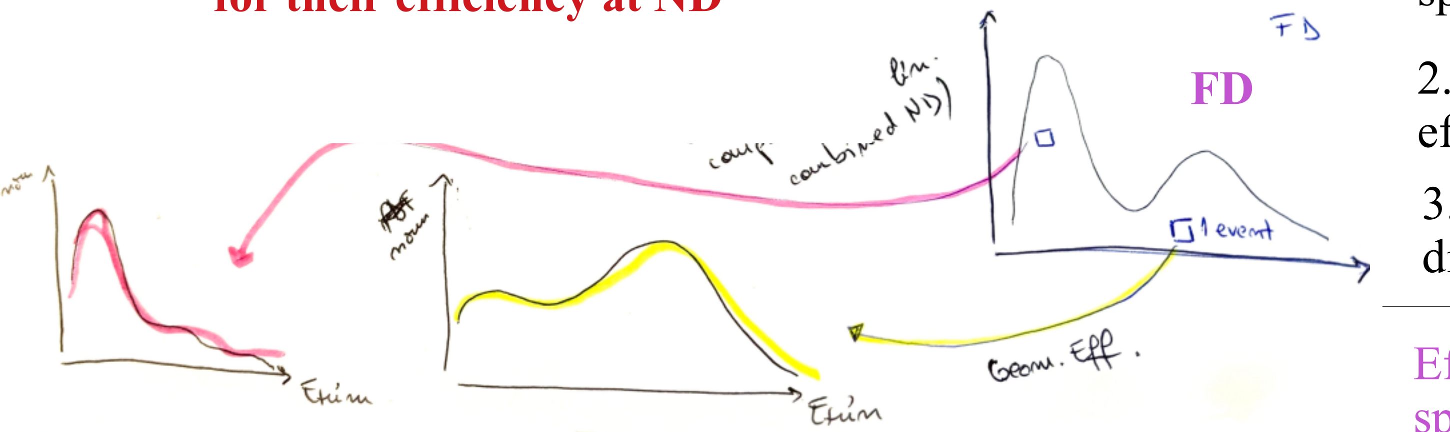
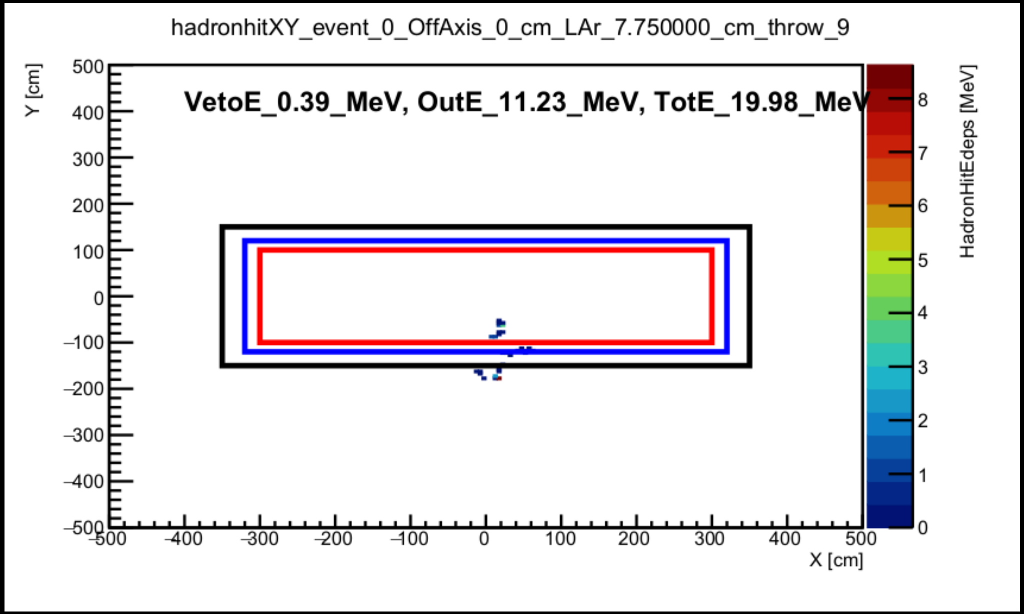
3. FD events (efficiency corrected) distribution vs Etrim

Efficiency corrected FD oscillated spectrum



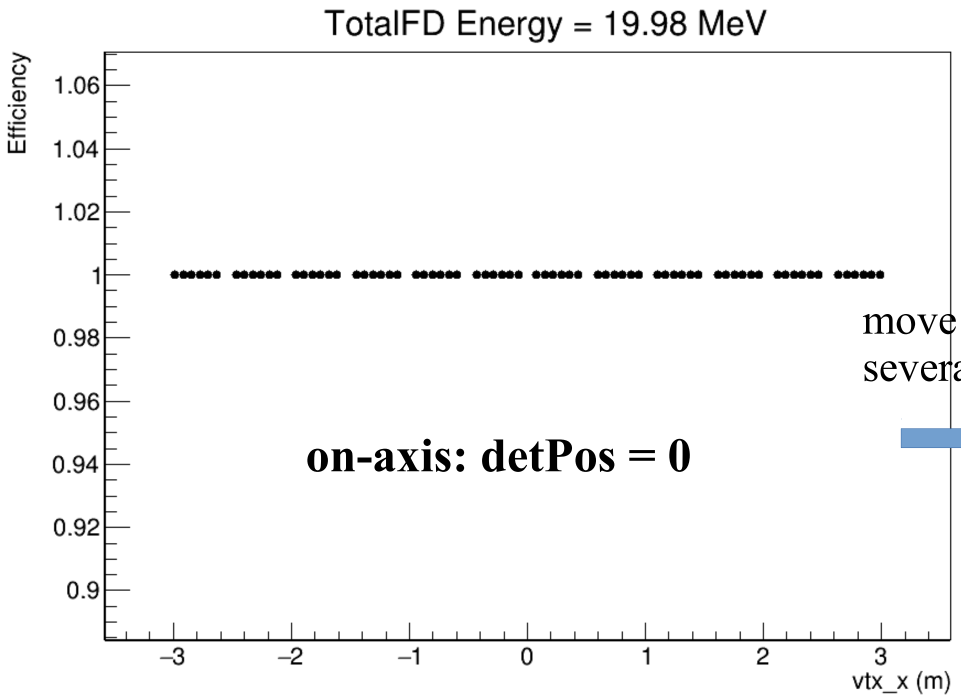
1. Look at the trimmed energy distribution of a FD event with very low total hadronic energy at the FD (efficiency = 1 at every point in vtx X)



Apply coefficients – Assume Efficiency is same at all OA positions

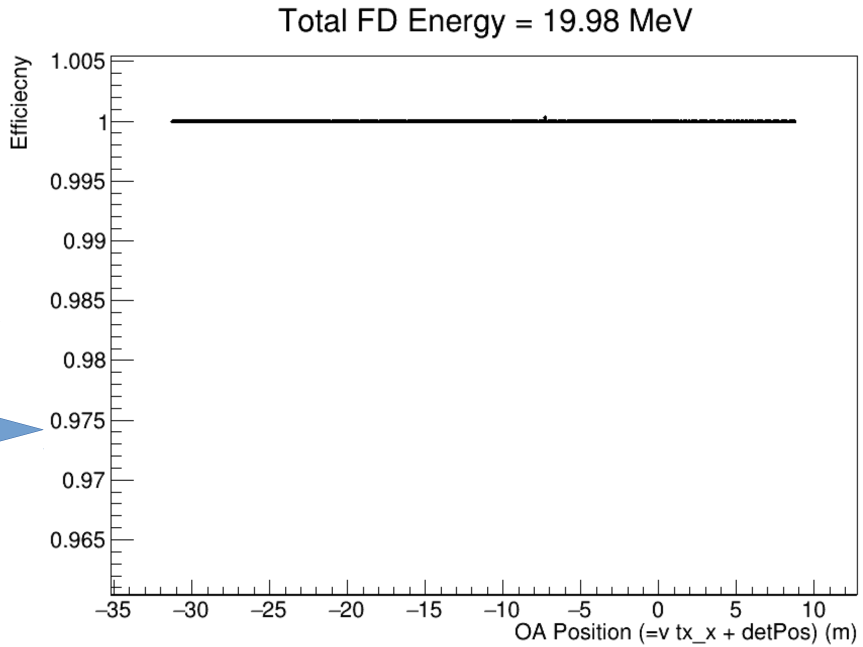
– assume FD Efficiency is same at all detector positions (for now)

– start with an event with Efficiency = 1 everywhere → cross-check the method works



on-axis: detPos = 0

move detector at several detPos

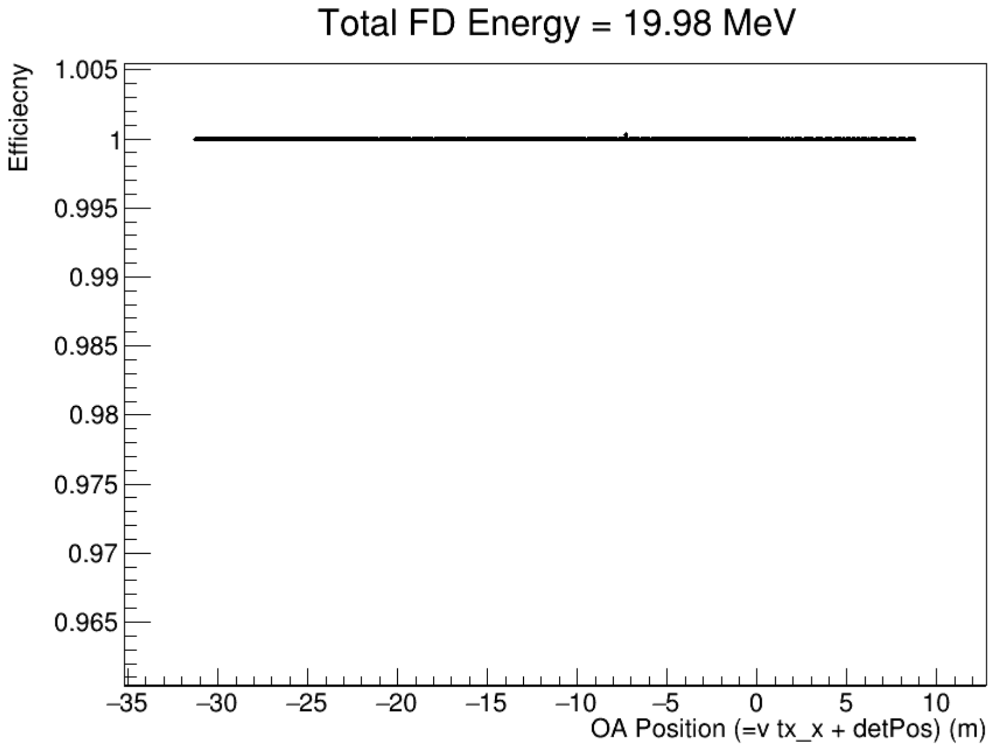


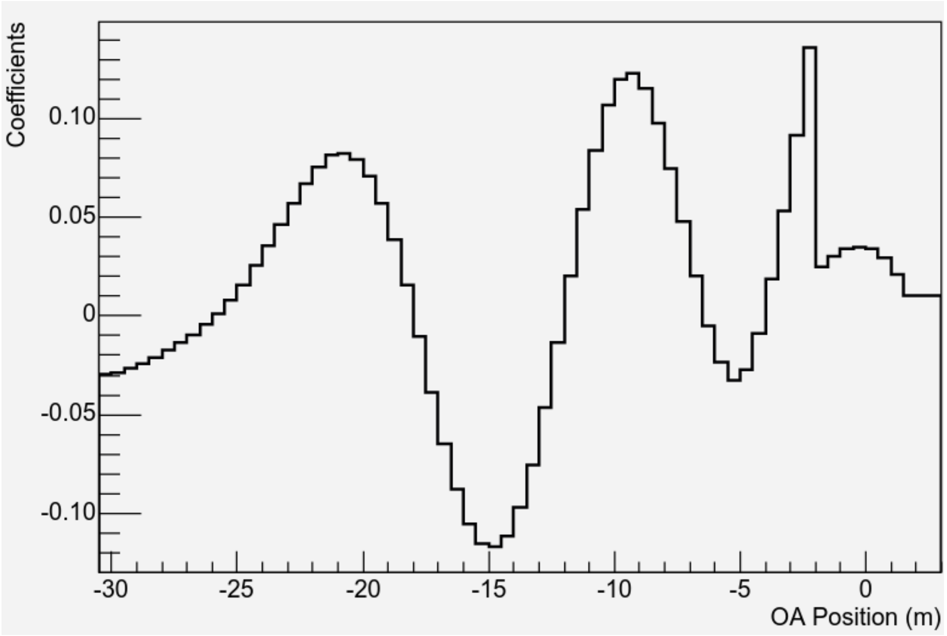
- now have nDetPos * nvtxX Etrim histograms

Apply coefficients – Assume Efficiency is same at all detector positions

– assume FD Efficiency is same at all detector positions (for now)

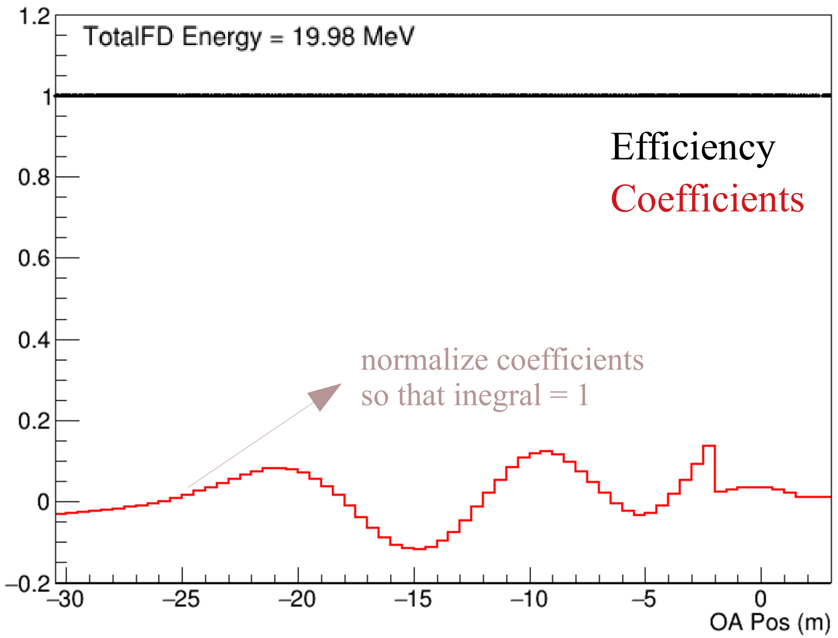
– need to apply the off-axis coefficients (Efficiency of 1 FD event when moved in the ND and rotated + translated at different vtxX positions and different detPos of the ND) to the translated FD event

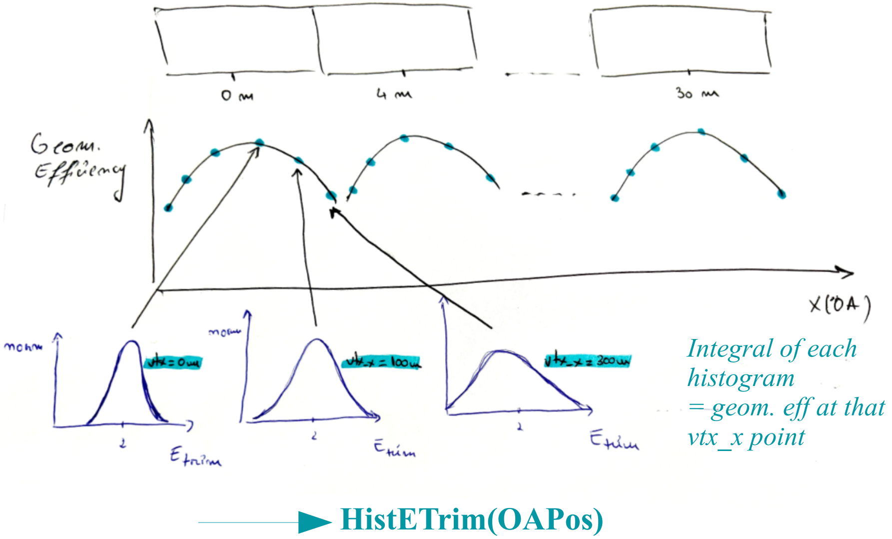




– integral = 1 (do not account for different FD and ND fluxes $1/L^2$ in the normalization factor)

Apply coefficients – Assume Efficiency is same at all detector positions



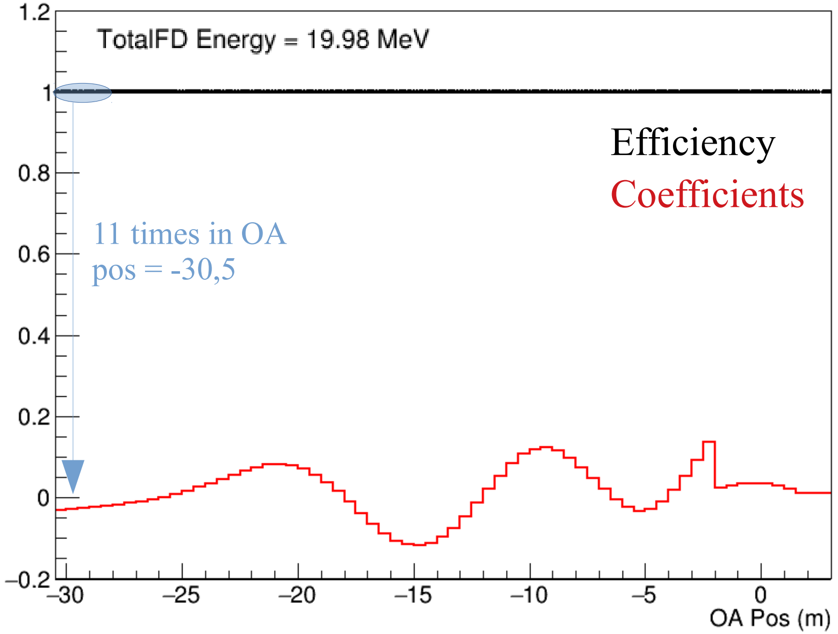


– now have nDetPos * nvtxX Etrim histograms (1 Etrim histo for each black dot)

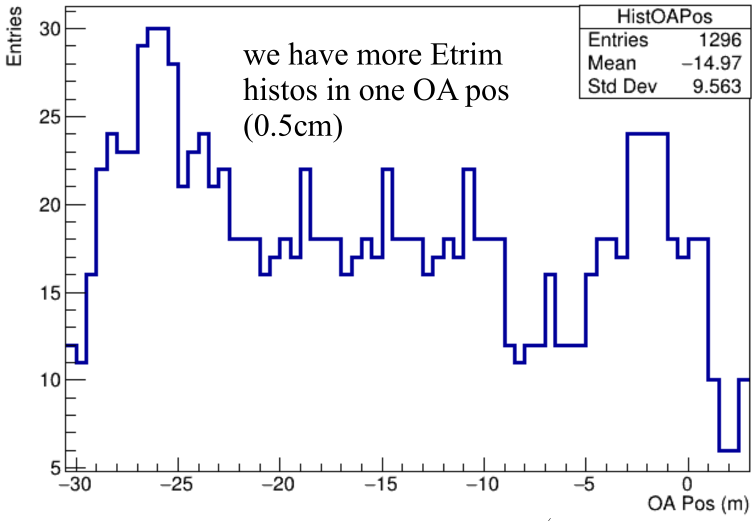
– final Etrim distribution of 1 FD Event:

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

Apply coefficients – Assume Efficiency is same at all OA positions




```
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};
```



– now have nDetPos * nvtxX Etrim histograms (1 Etrim histo for each black dot)

– final Etrim distribution of 1 FD Event:

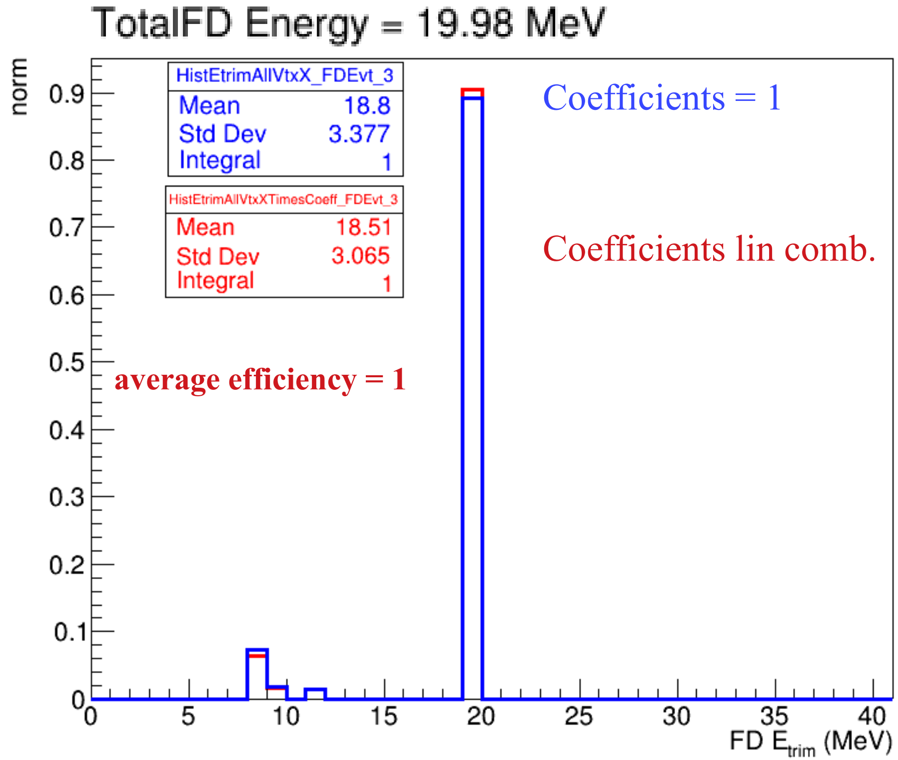
$$HistEtrimFinal = \sum_{OAPos} HistEtrim(OAPos) \times Coefficients(OAPos) \,/\, NEtrim(OAPos)$$

– for an event which has efficiency = 1 everywhere (at all OA positions) the resulting integral of HistEtrimFinal histogram has to always be 1 **as long as the detector is moved at enough positions** (covering all OA pos in the coefficients)

Apply coefficients – Assume Efficiency is same at all OA positions

Distribution of FD Event as seen by ND vs Etrim

(integral = average efficiency of FD event at the ND)

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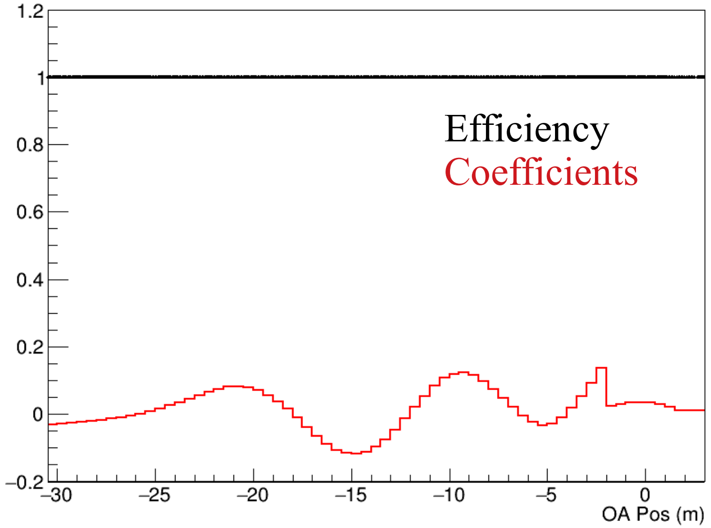
```

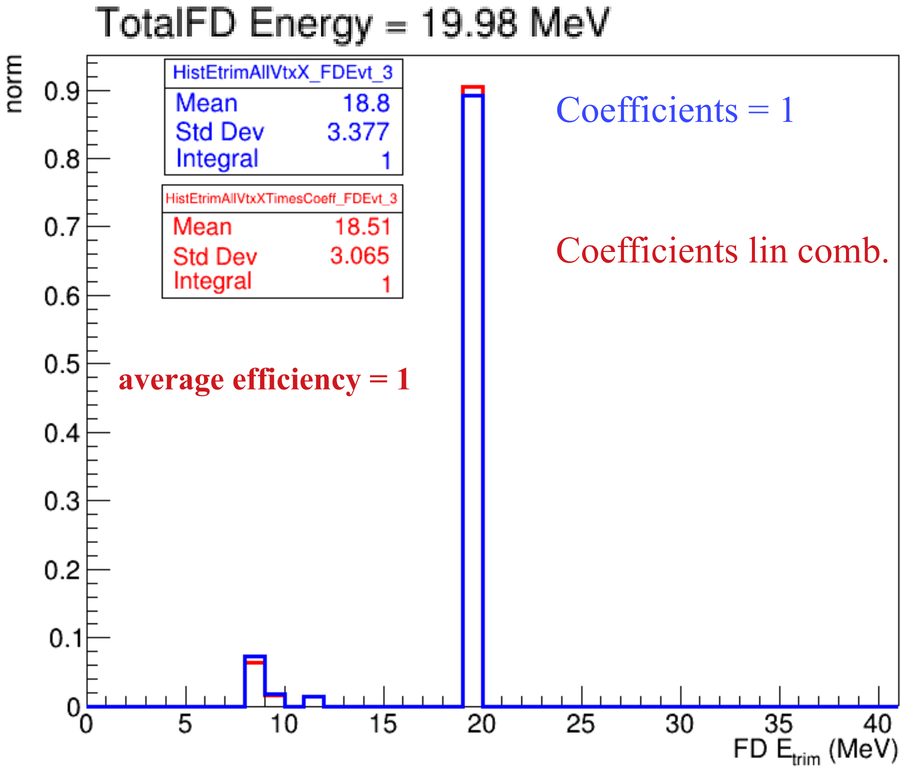


$$HistEtrimFinal = \sum_{OAPos} HistEtrim(OAPos) \times Coefficients(OAPos) \,/\, NEtrim(OAPos)$$

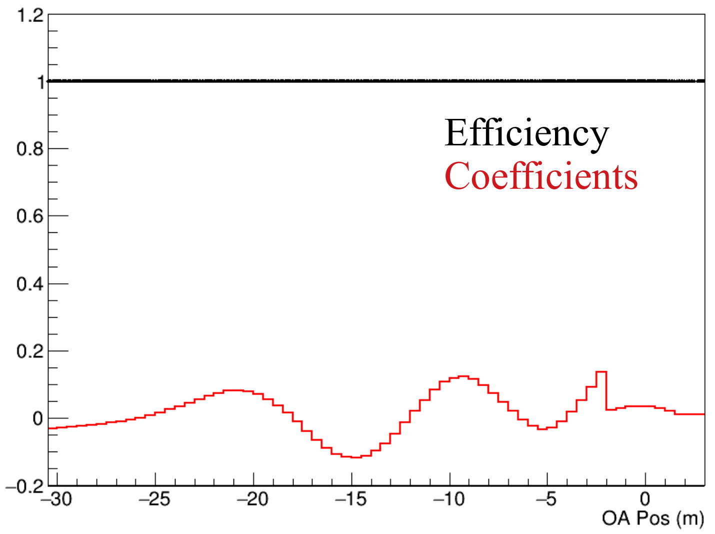
Apply coefficients – Assume Efficiency is same at all OA positions

Distribution of FD Event as seen by ND vs Etrim

(integral = average efficiency of FD event at the ND)



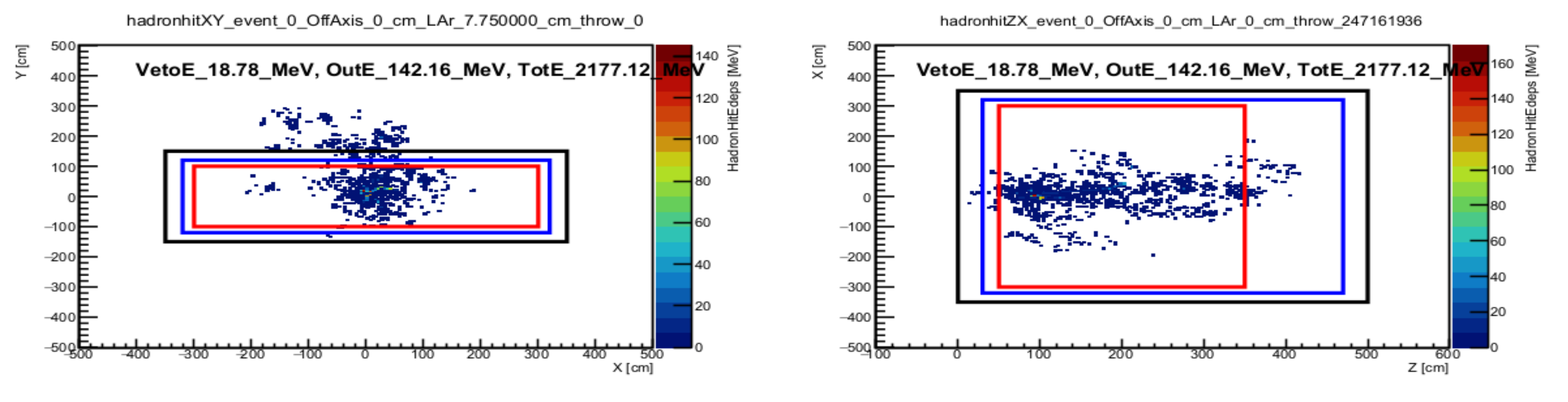

```
nDetPosVector = {4,2, 0, -2, -4, -6, -8, -10, -12, -14, -16, -18, -20, -22, -24, -26, -28, -30, -32};
```



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

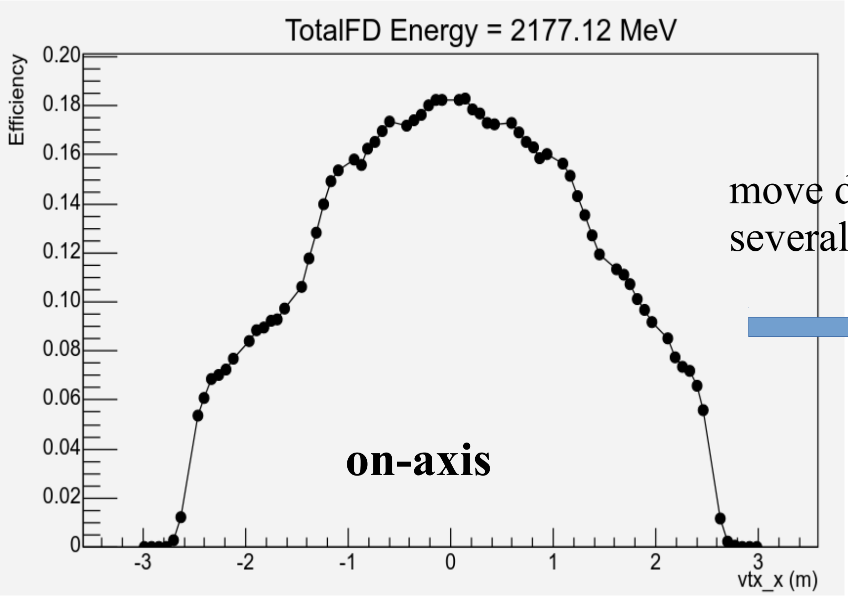
2. Look at the trimmed energy distribution and average efficiency at the ND of an "interesting" FD event:

– not very high FD hadronic energy but very wide hadronic signature in the detector (low ND Efficiency)

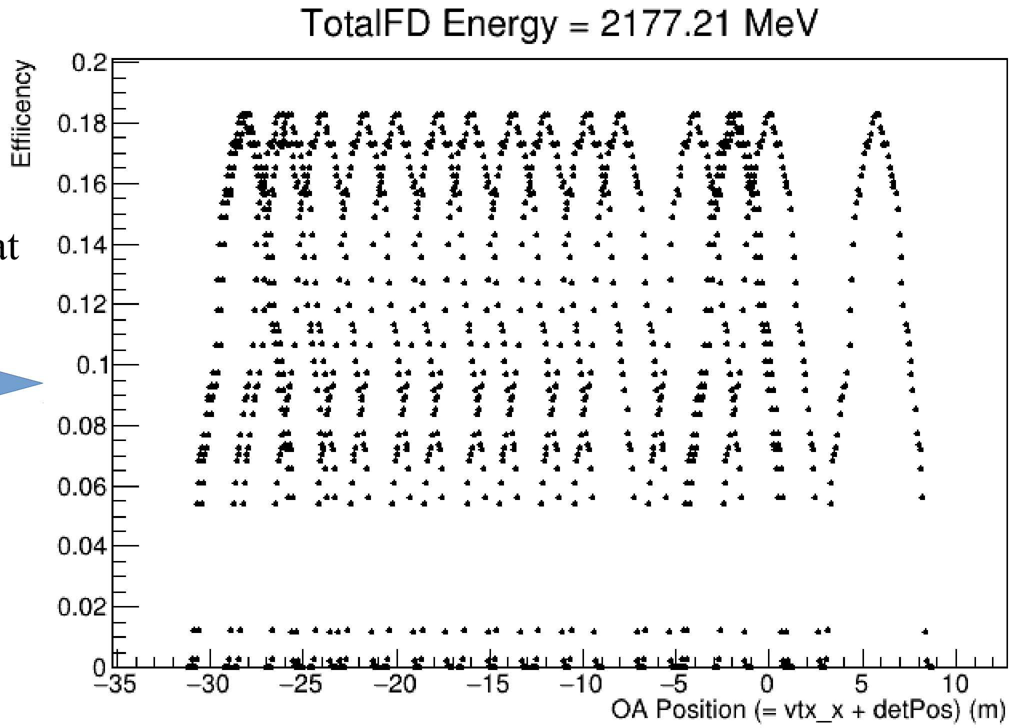


Apply coefficients – Assume Efficiency is same at all detector positions

– assume FD Efficiency is same at all detector positions (for now)



move detector at several detPos

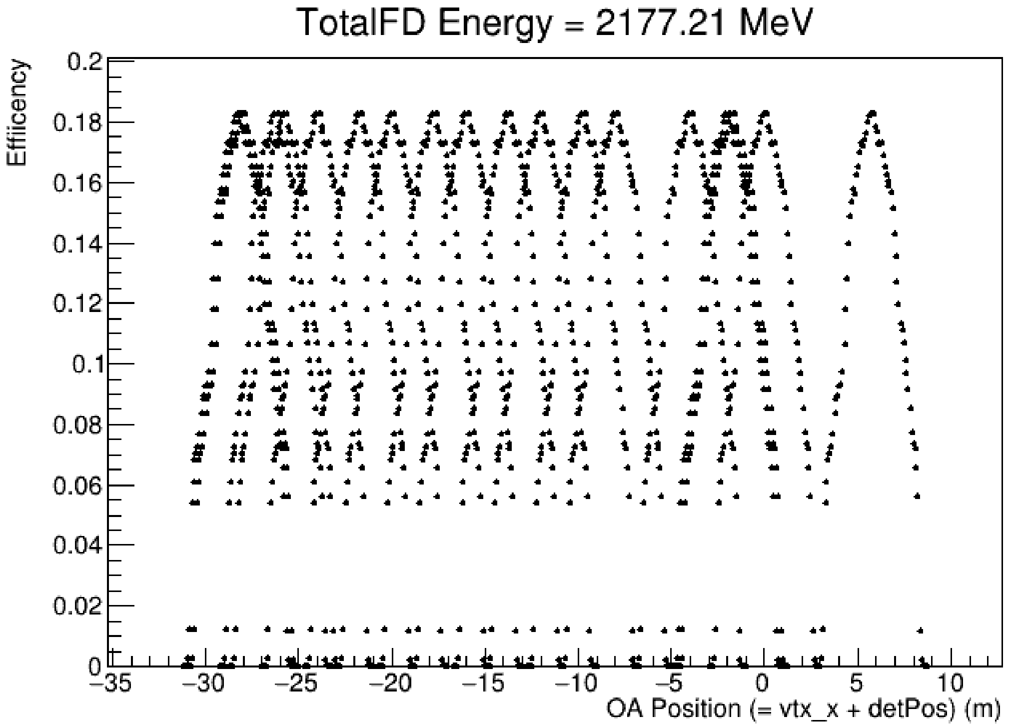


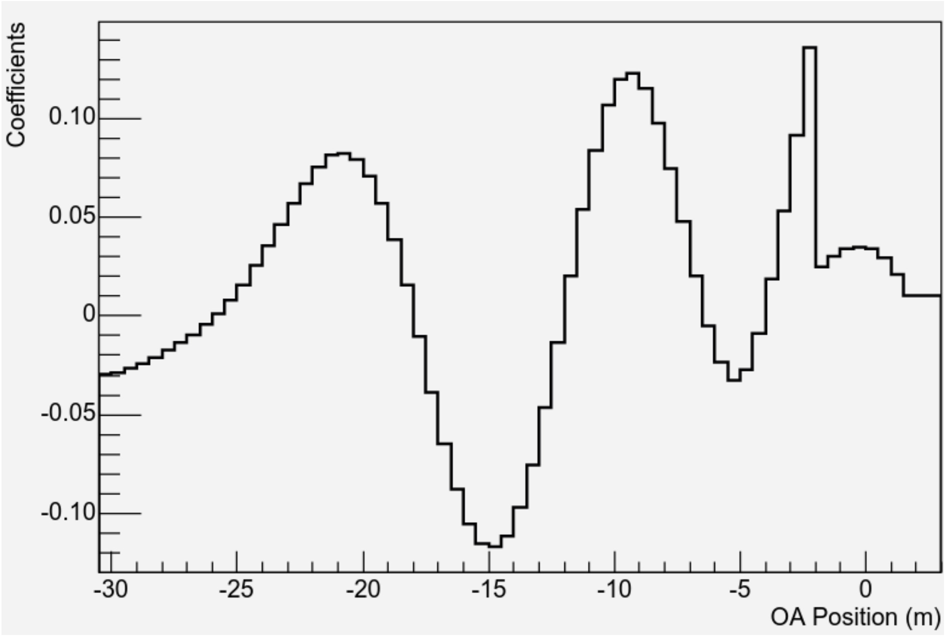
- now have nDetPos * nvtxX Etrim histograms

Apply coefficients – Assume Efficiency is same at all detector positions

– assume FD Efficiency is same at all detector positions (for now)

– need to apply the off-axis coefficients (Efficiency of 1 FD event when moved in the ND and rotated + translated at different vtxX positions and different detPos of the ND) to the translated FD event





– integral = 1 (do not account for different FD and ND fluxes $1/L^2$ in the normalization factor)

Apply coefficients – Assume Efficiency is same at all detector positions

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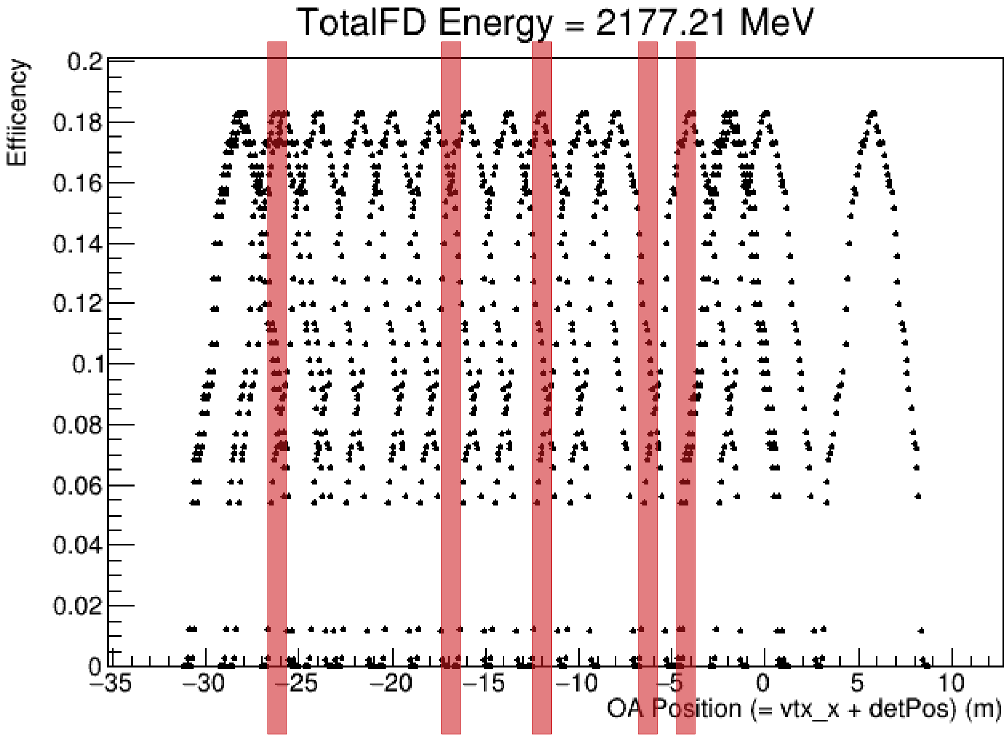
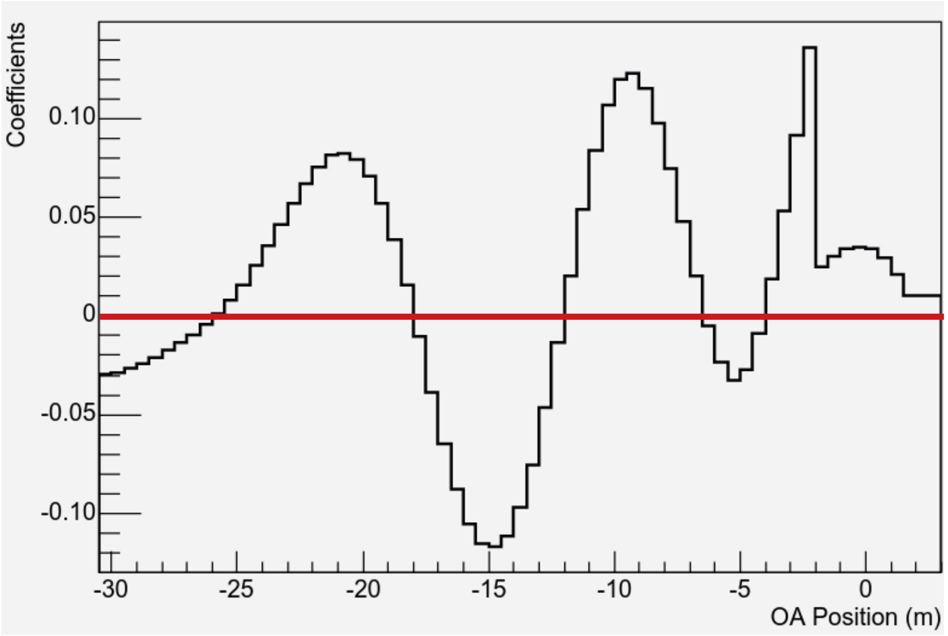
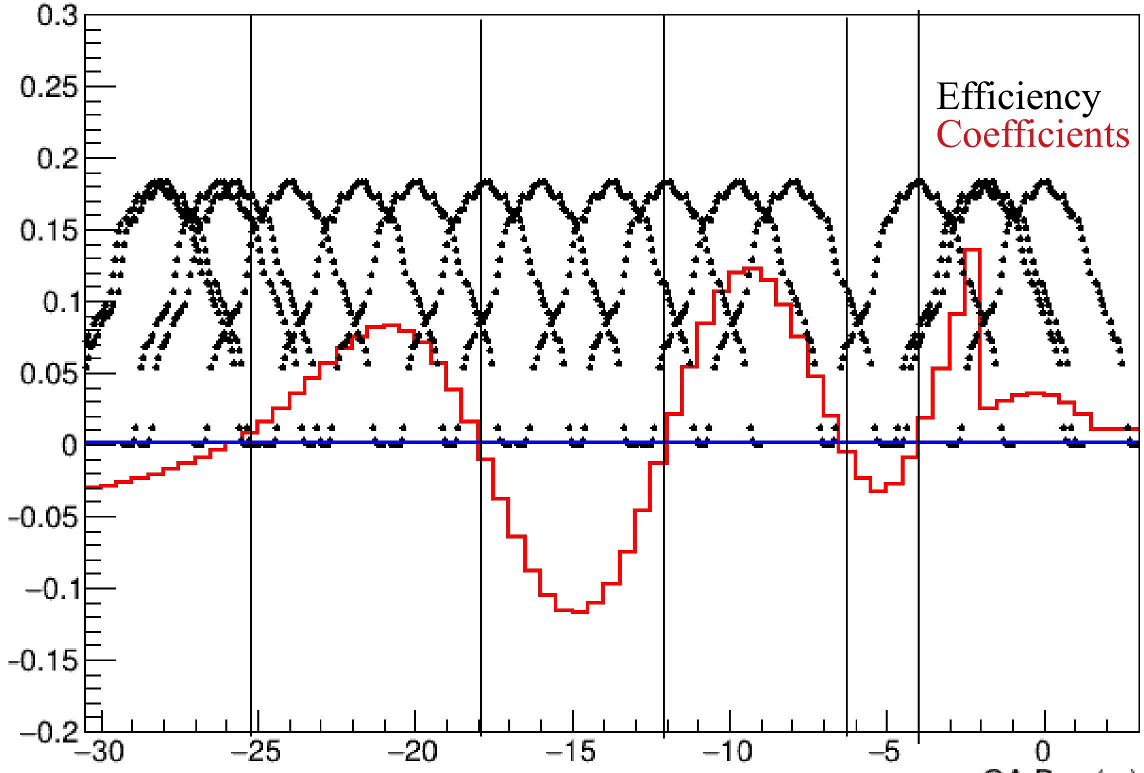
– need to apply the off-axis coefficients (Efficiency of 1 FD event when moved in the ND and rotated + translated at different vtxX positions and different detPos of the ND) to the translated FD event

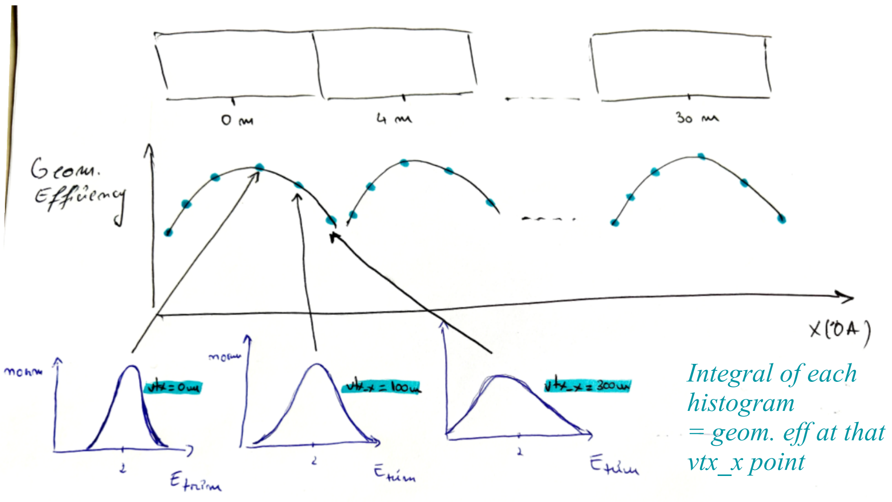




– integral = 1 (do not account for different FD and ND fluxes $1/L^2$ in the normalization factor)

Apply coefficients – Assume Efficiency is same at all detector positions



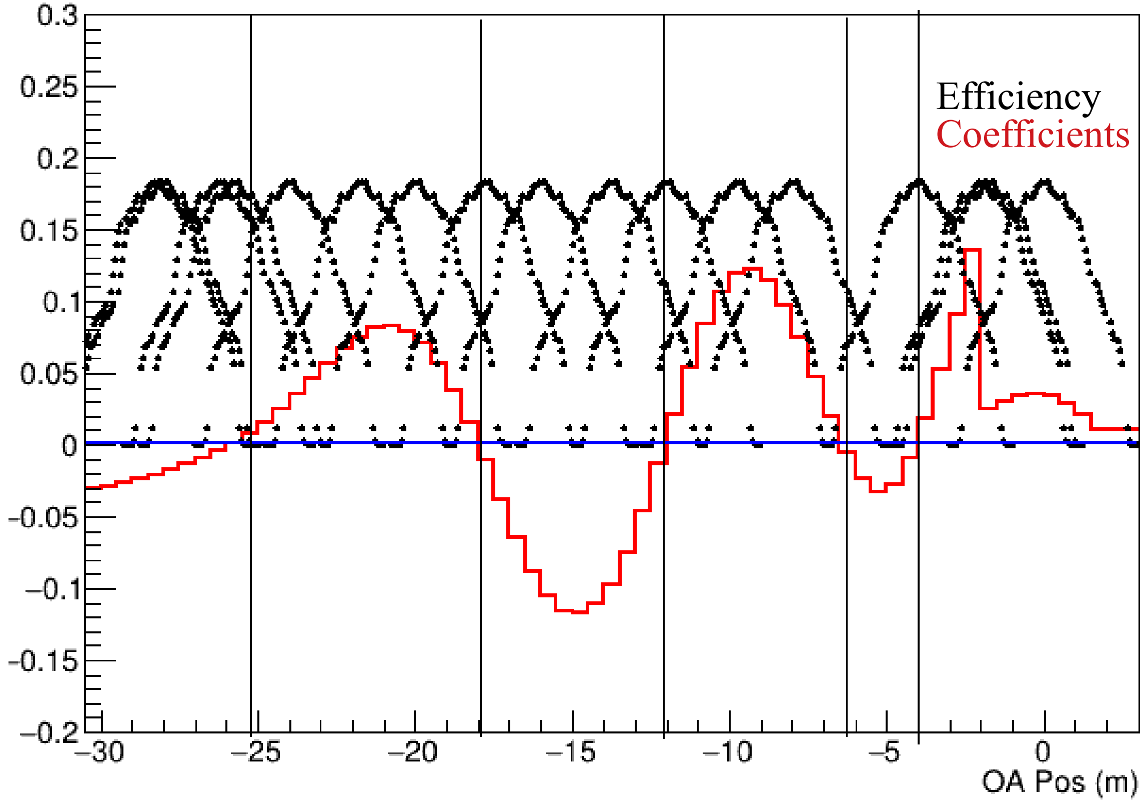


HistETrim(OAPos)

- now have nDetPos * nvtxX Etrim histograms (1 Etrim histo for each black dot)
- Final Etrim distribution of 1 FD Event:

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

Apply coefficients – Assume Efficiency is same at all detector positions

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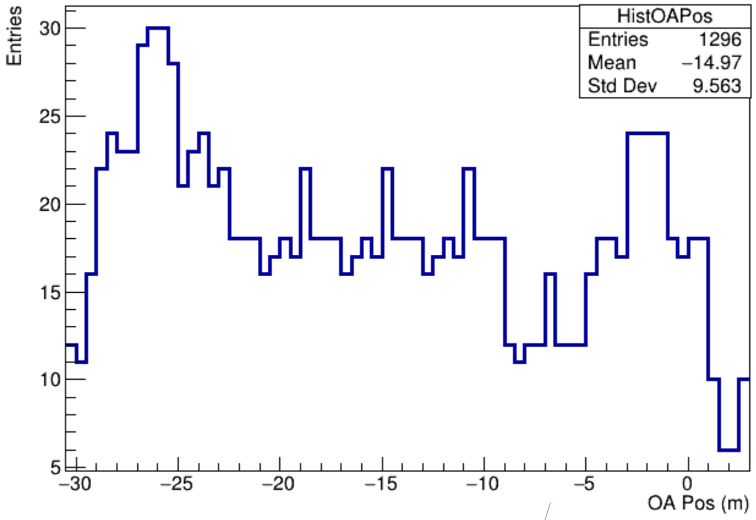
```



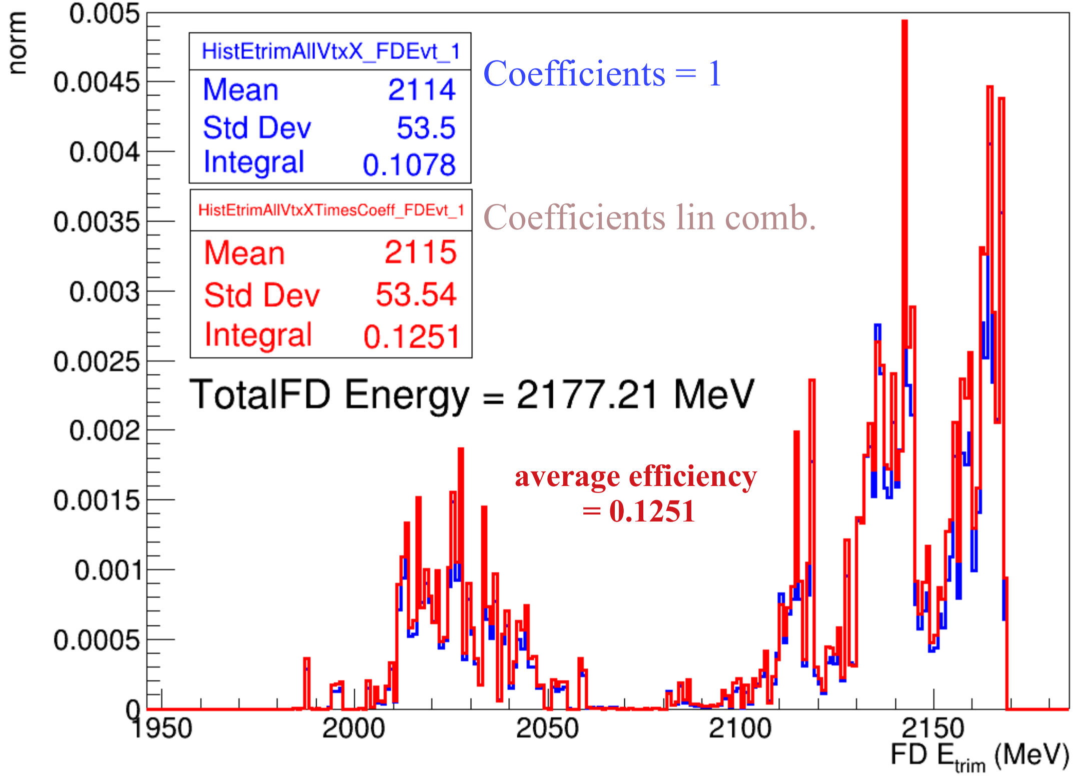
- now have nDetPos * nvtxX Etrim histograms (1 Etrim histo for each black dot)
- Final Etrim distribution of 1 FD Event:

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

Apply coefficients – Assume Efficiency is same at all detector positions

Distribution of FD Event as seen by ND vs Etrim

(integral = average efficiency of FD event at the ND)




```
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, -
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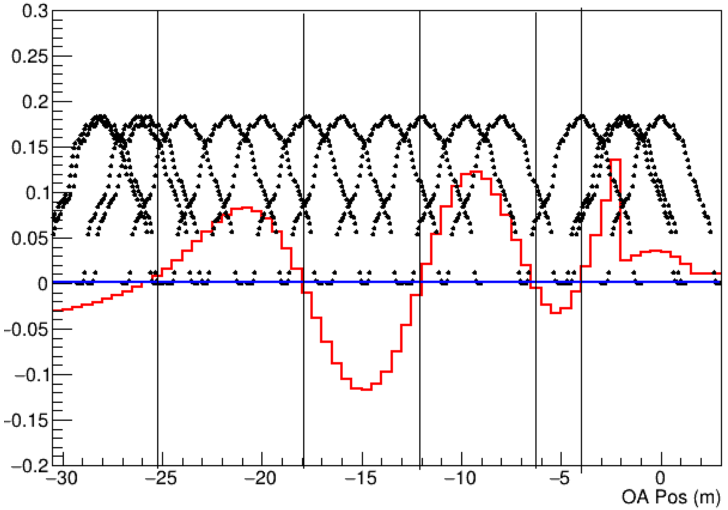


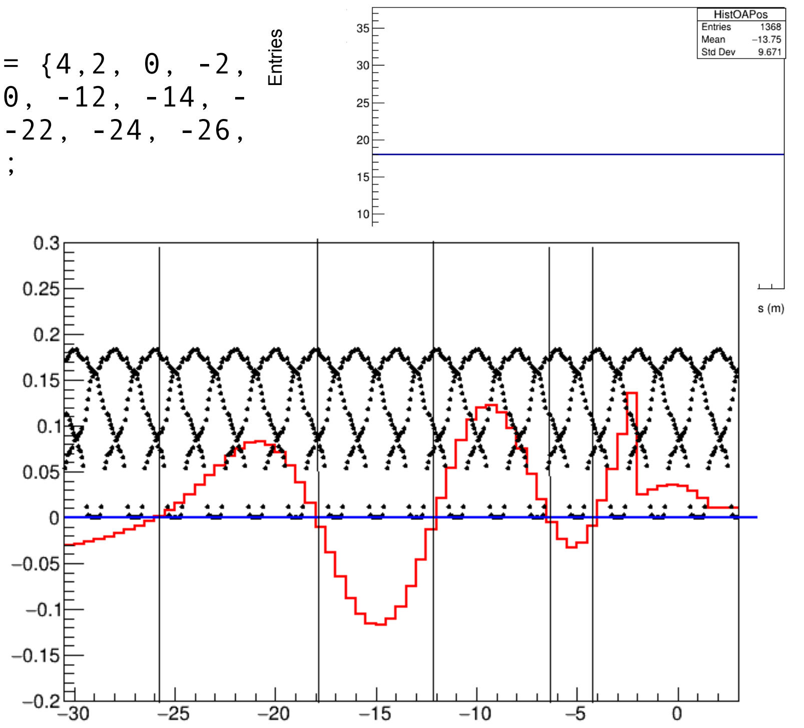
$$HistEtrimFinal = \sum_{OAPos} HistEtrim(OAPos) \times Coefficients(OAPos) \,/\, POT(OAPos)$$

Apply coefficients – Assume Efficiency is same at all detector positions

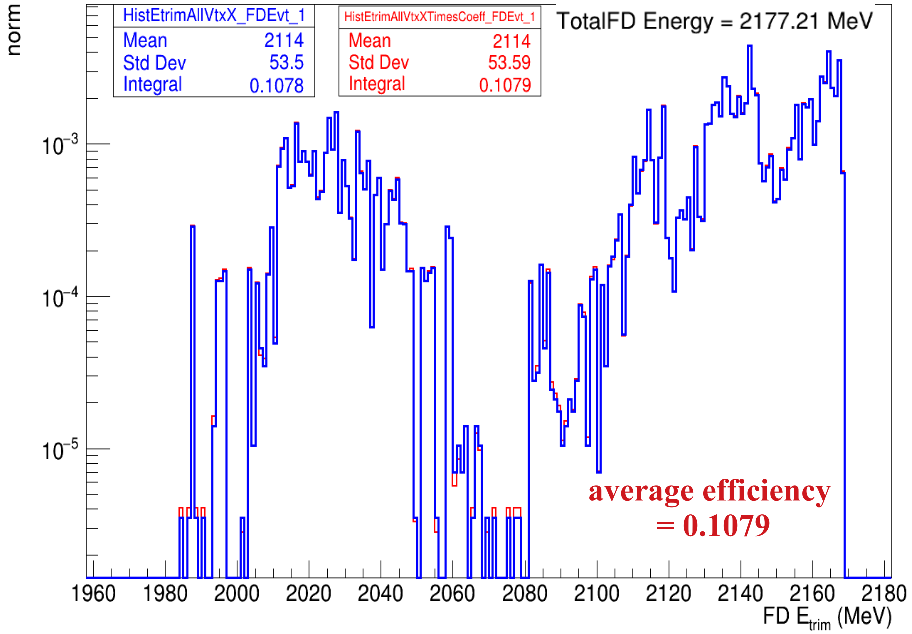
- choose different sampling of the detector positions

Flat distribution of Etrim histos in OA position

```
nDetPosVector = {4,2, 0, -2, -4, -6, -8, -10, -12, -14, -16, -18, -20, -22, -24, -26, -28, -30, -32};
```



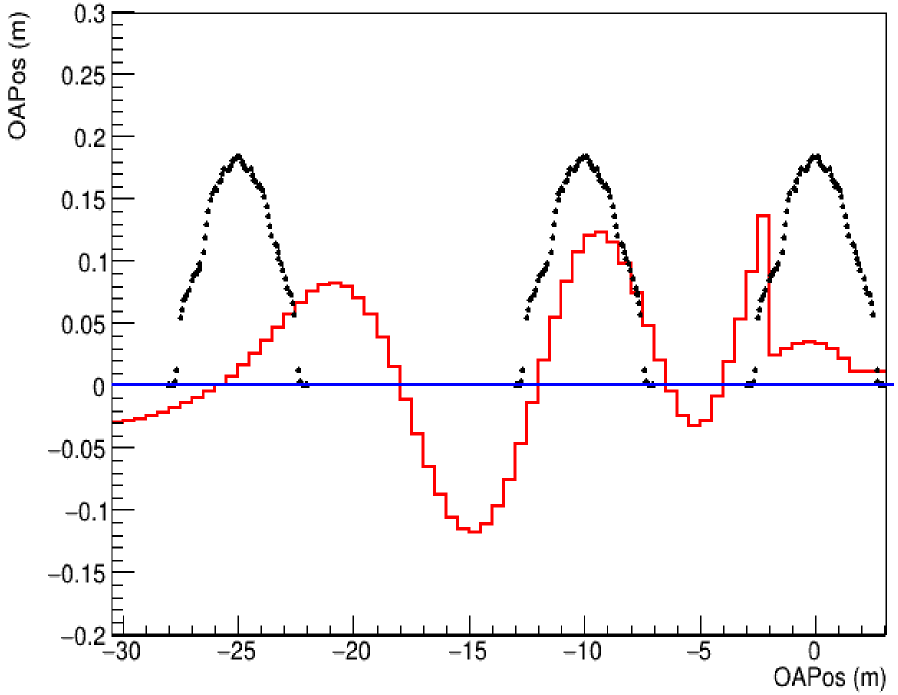
Distribution of FD Event as seen by ND vs Etrim

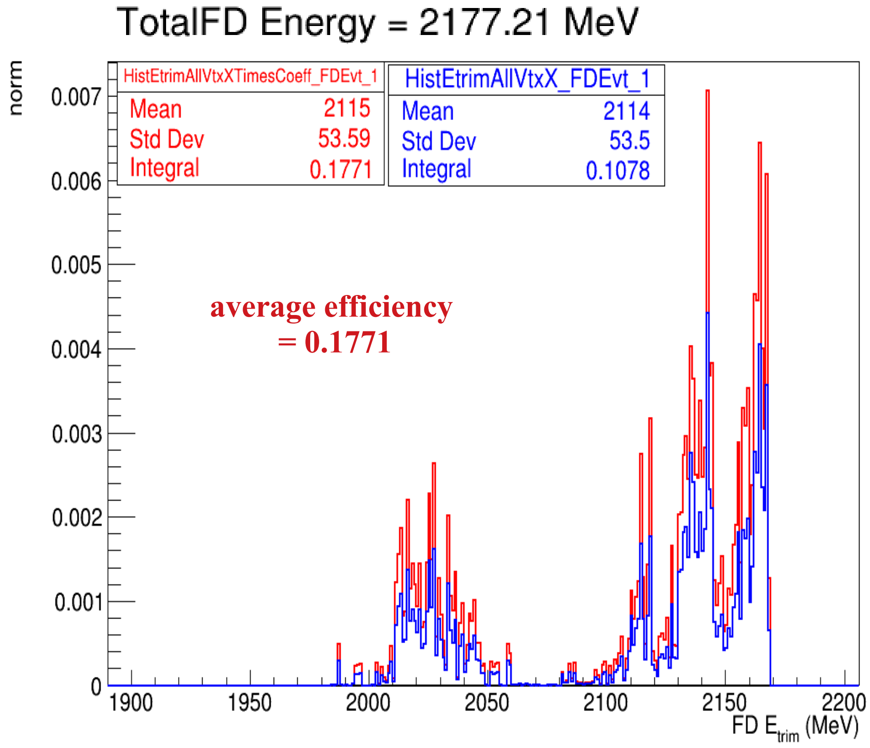


- average efficiency of a FD event at the ND depends on the chosen detector positions: if the efficiency maximum is going to be in a 0-coefficients region, as well as if only a certain region of the off-axis position is sampled (next slide)

Apply coefficients – Assume Efficiency is same at all detector positions

- sampling where coefficients are positive only results in a higher average efficiency of the FD event → favoring the "+" side

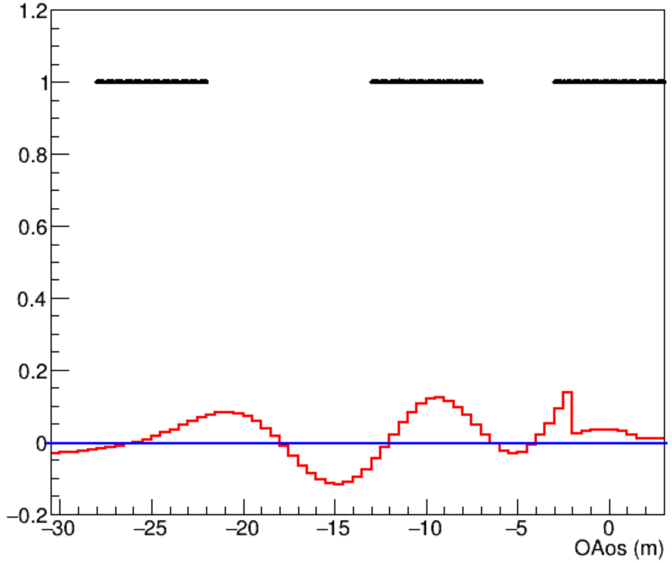


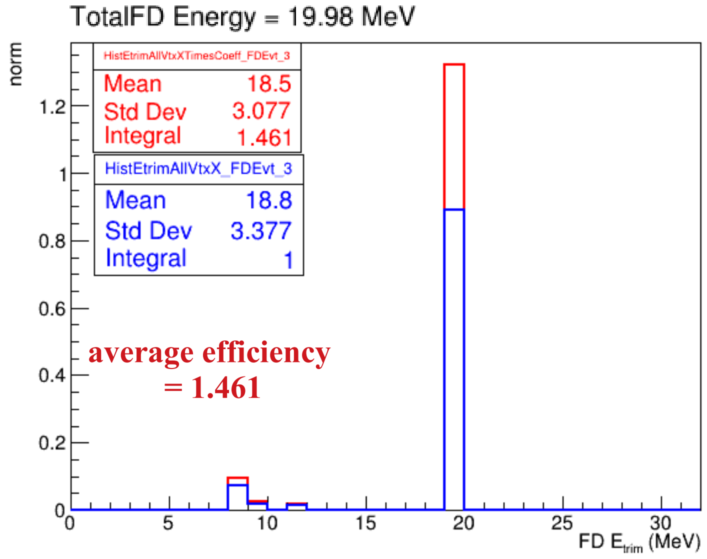


Apply coefficients – Assume Efficiency is same at all detector positions

- sampling where coefficients are positive only results in a higher average efficiency of the FD event → favoring the "+" side

- this scenario affects the efficiency = 1 case as well
  - – if all off axis positions are sampled, the efficiency = 1 case results in the same average efficiency of 1 (same shape across all OA positions)
  - – if only the "+" side is sampled, this results in an average efficiency > 1





Overview

So far...

- can properly access and save Etrim distribution of every passing throw
- linearly combine the Etrim distributions (off-axis coefficients scaling solved) and study the average efficiency of a FD event when translated to the ND for any given off-axis detector positions
  - – assumption for now is that we have the same efficiency at all detector positions
- POT scaling not taking into account yet → but pretty good idea how to further do this:

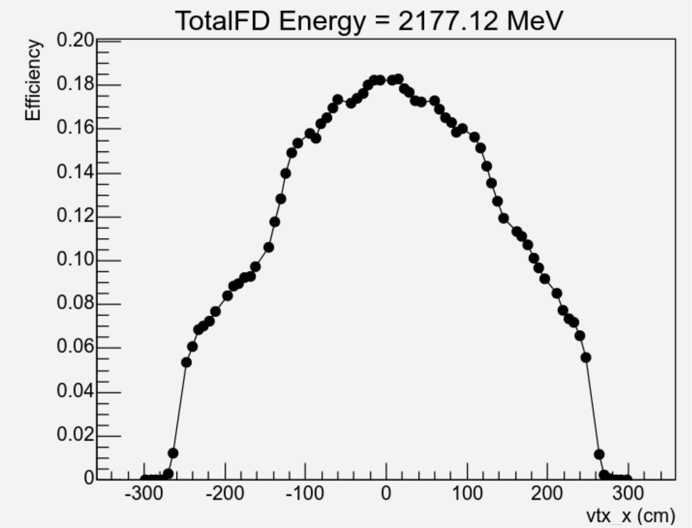
  1. scale Efficiency (detPos) to the POT (detPos) and then proceed with the linear combination

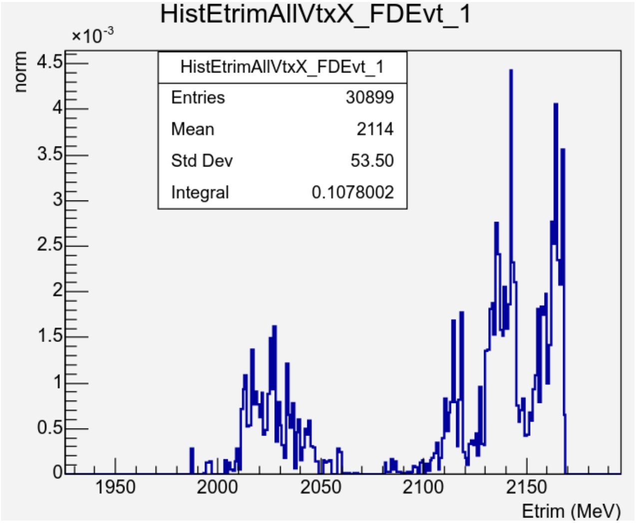
  2. continue as presented (no POT scaling for the FD events) and then 1/POT scale the ND events → final linearly combined FD efficiency corrected distribution will not be different depending on the POT run-plan (but the linearly combined ND distribution will be)

  → keep both options viable: try to do it both ways and cross-check the result stays the same

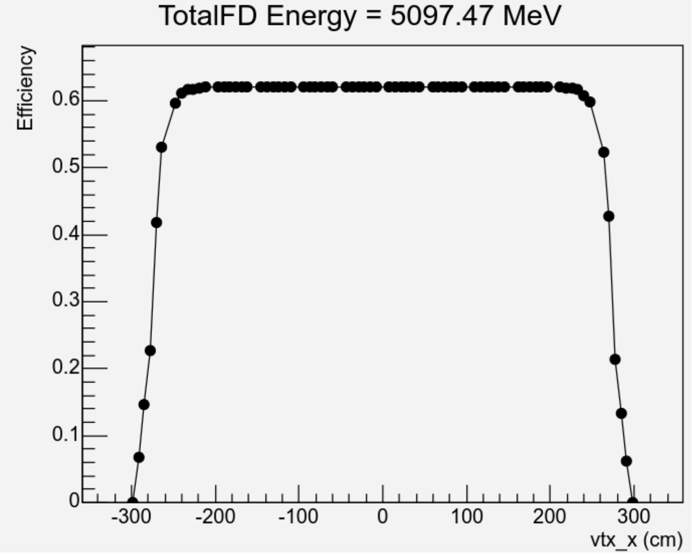
- first try (and success) to submit jobs on the cluster: statistically significant production + analysis to come soon (so far only looked at few FD events.. good enough for the state of art of the method but more events needed in the end)

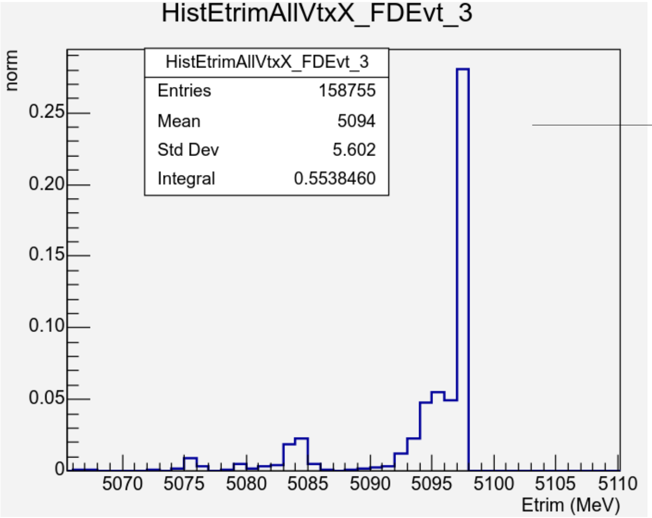
Interesting / Not intuitive events





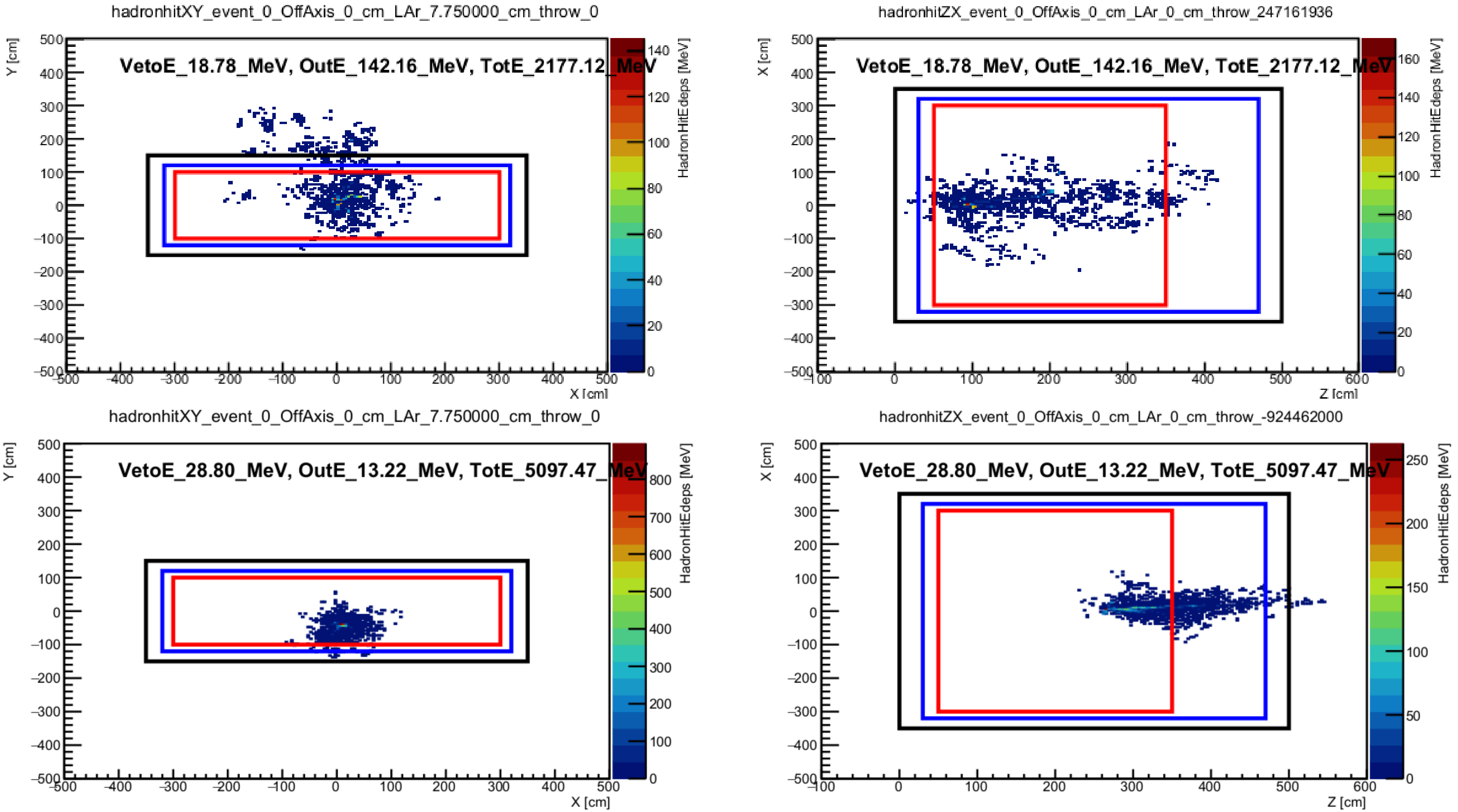
- why is there a lower efficiency for an event with 2.1 GeV at the FD than for an event with 5 GeV?



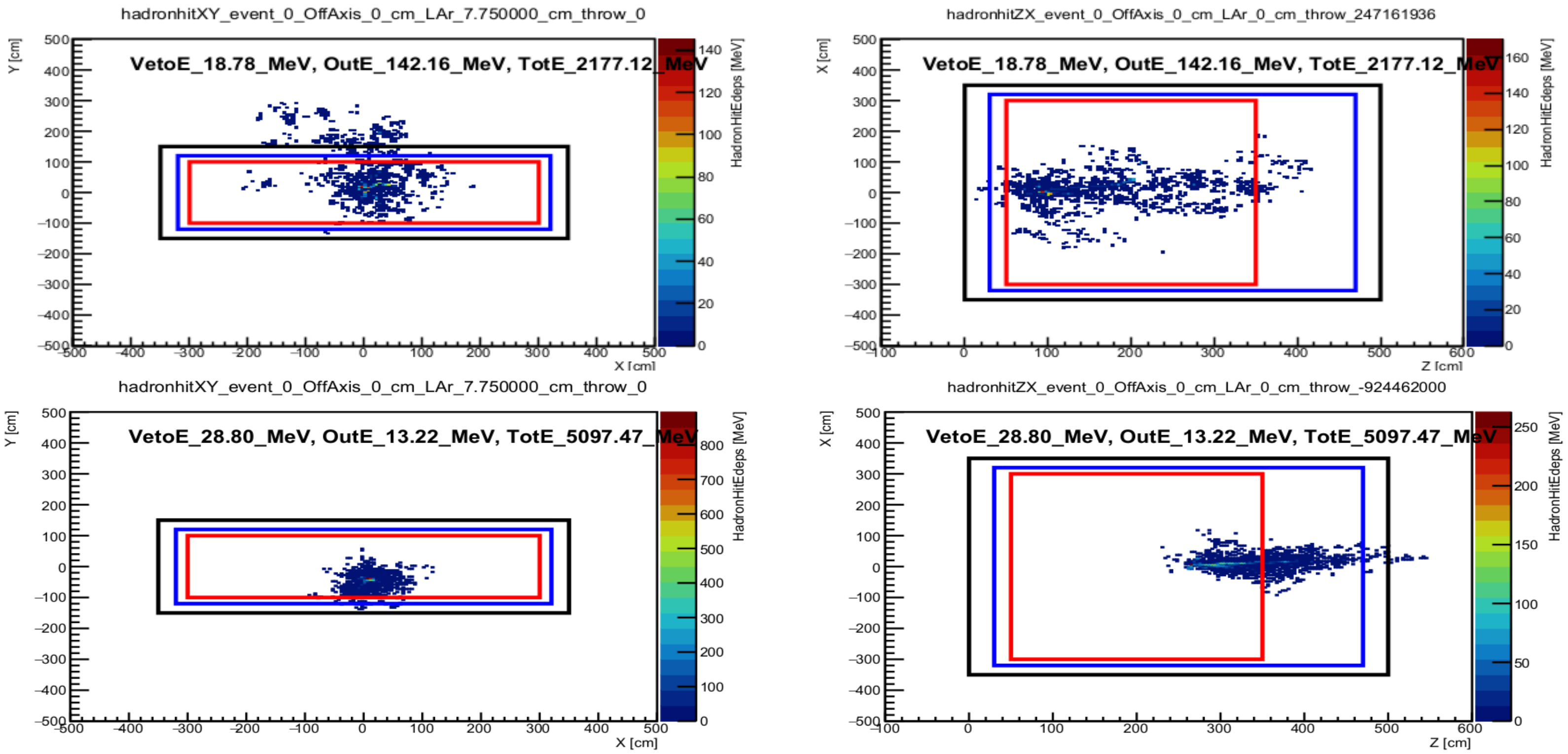


seems like this event is barely trimmed at all..

Interesting / Not intuitive events – hadron hits

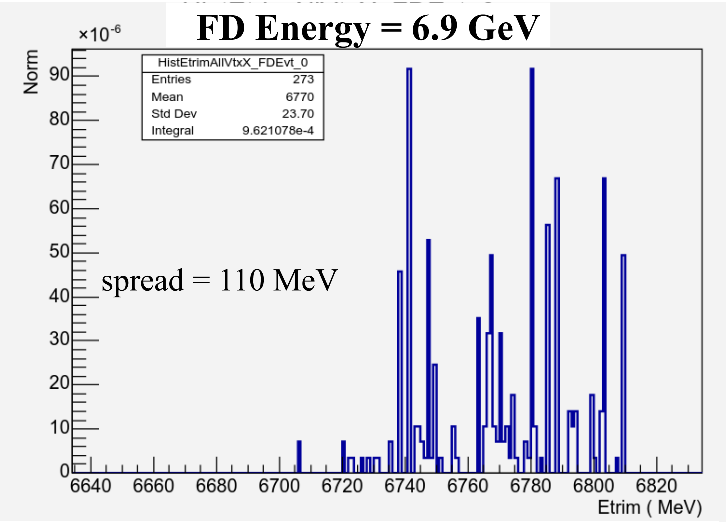


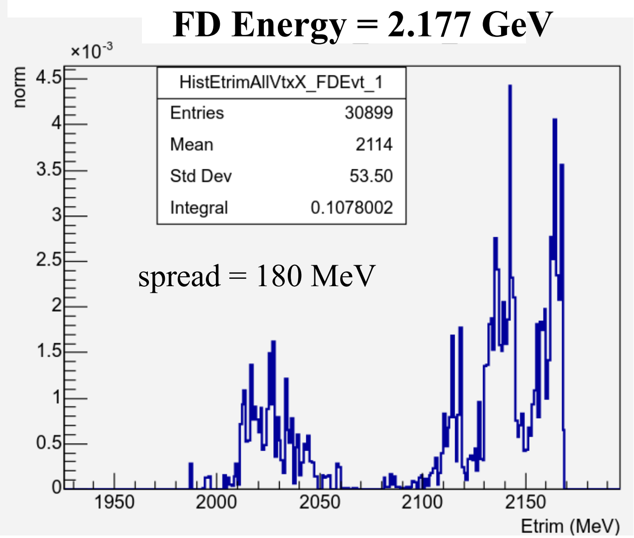
Interesting / Not intuitive events – hadron hits

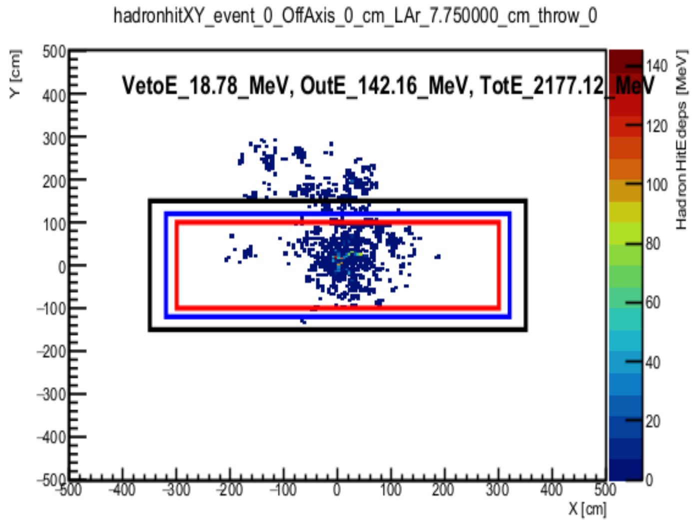


- lower energy event (2.1 GeV) has a more "spread" hadronic signature, while the 5 GeV event is pretty well contained / narrow
  - different primaries inducing the shower: – 2.1 GeV: 2 protons, 1pi0, 4 pi+/-
    – 5 GeV: 11 protons, 3 pi0, 0 pi+/-

Interesting / Not intuitive events





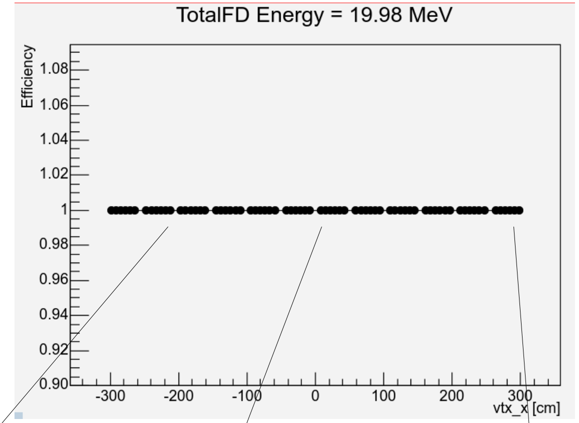


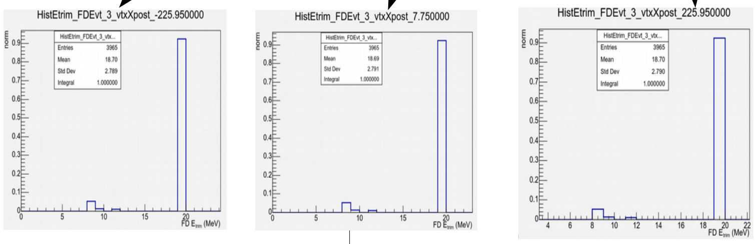
- looking not only for high FD energy events, but also for events with a spread hadronic energy deposit (more pi+/- and not so many p in the primaries) in order to see a very "split" Etrim distribution

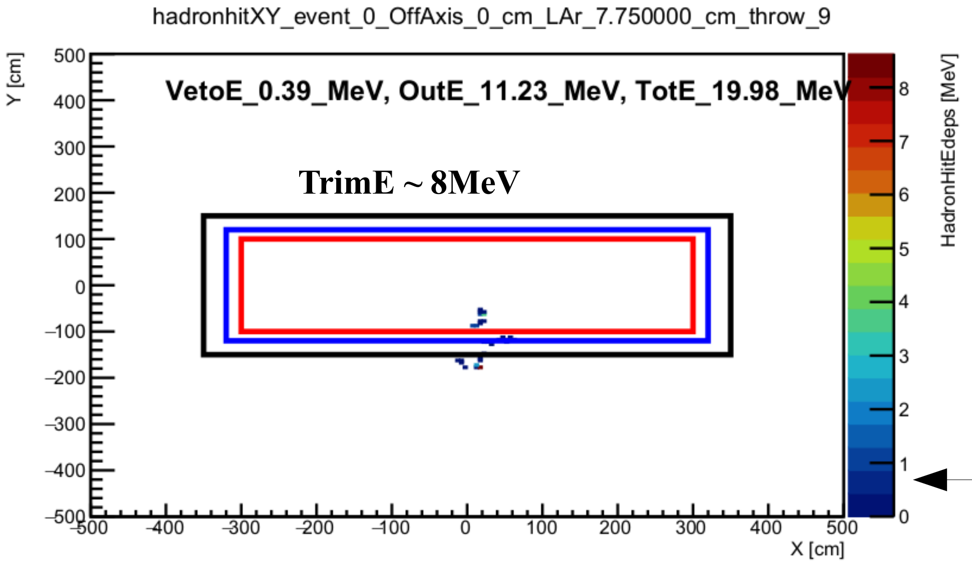
  → best type of event to show the usefulness of Etrim would be a high energy event with a very wide hadronic signature… (however those are not very likely to pass the throws) → need to start working with more events – soon :)

FD Events with low hadronic energy

- FD total hadron energy = 19.98 MeV → 100% efficiency at all vtx_x position in ND (can not deposit > 30 MeV in veto region)
  - **– why not perfect step function in Etrim?**
- the FD event is randomly thrown + rotated in Y and Z
  - – there are specific configurations in which for any given X position the event hadronic signature would not be in the ND active volume: extreme Y / Z positions + rotations







→ Given the **low hadronic energy**, this doesn't happen very often – **peak (almost step function) at Etrim = totE**