Track Efficiency & Trident & WAB Rates & Shapes

Mathew Graham
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Track Efficiency: What is it?

- Term "track efficiency" can be a little nebulous…ideally, it is the efficiency for the tracking algorithm to find a track when:
  - you have a charge particle
  - it goes through (deposits energy) in the right layers…in our case at least 5x2 of the modules
- In MC, this is easy since we know The Truth…
- Not so in data, so "track efficiency" can get mixed up with "acceptance" and "physics"

Track Efficiency: Why do we miss a track?

- Charged tracks that hit the ECal, and be part of a pairs trigger, can fail tracking for a convolution of a few reasons :
  - ***acceptance:*** the ECal can see some tracks that don't go through enough layers (or miss one-of-two stereo layers in a module)
  - ***SVT hit reconstruction inefficiency:*** there is an at-trigger-time decision made to read out SVT hits based on their ADC-vs-sample structure; we also fit this and extract t0 and the amplitude; either of these steps can be inefficiency, particularly at high occupancy
  - ***track finding inefficiency:*** even if the hits are all there (and correctly made into stereo pairs), there are loose selections made in the stages of track finding which can cause you to miss a track
  - ***track reconstruction/matching inefficiency:*** particularly if incorrect hits are assigned to a "found track" the reconstructed trajectory can be so wrong as not to match to the cluster

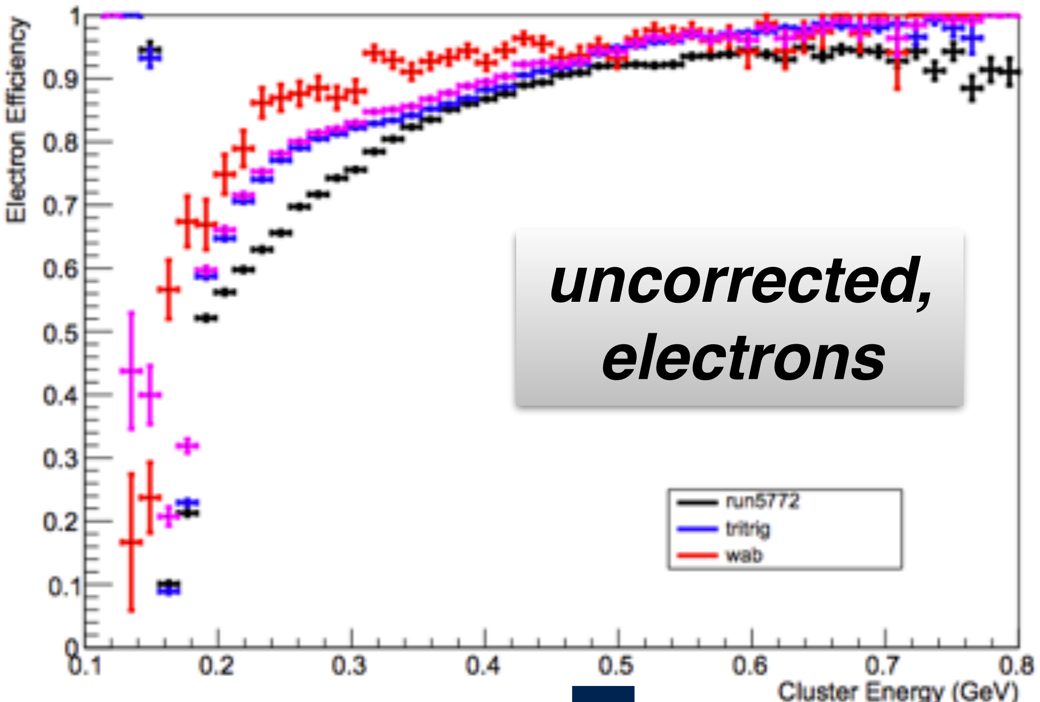
Track Efficiency: What do we do…

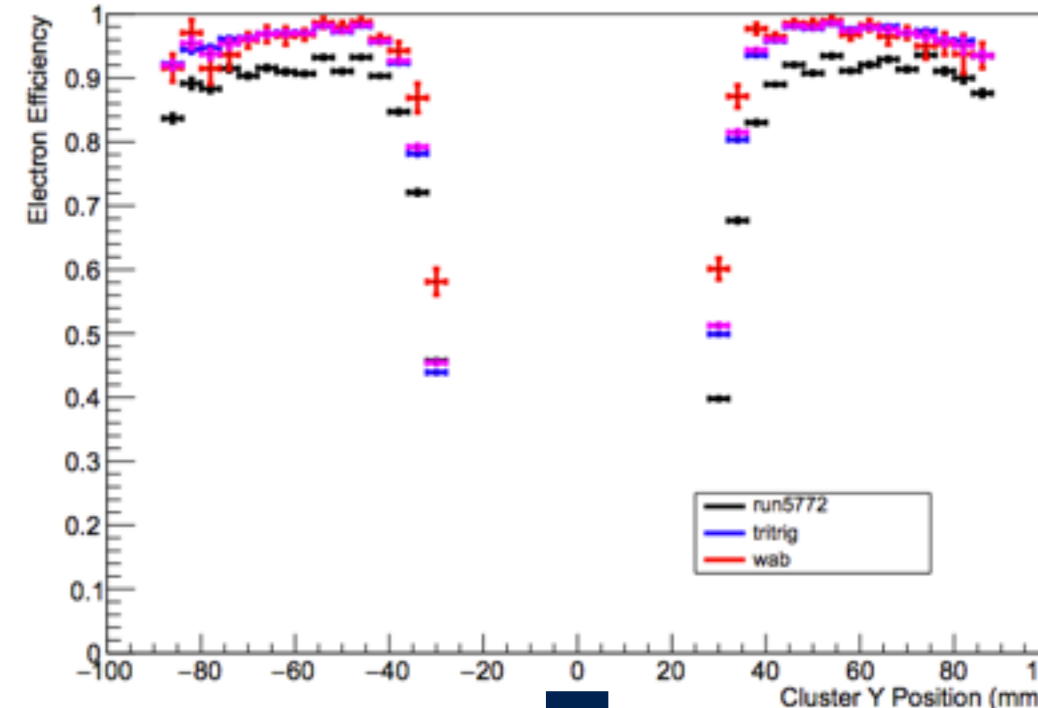
- "you have a charge particle"
  - In my case, I try to identify "e^+e^- events" by looking at the 2 clusters ECal and requiring 1 track associated with a cluster…then see if the other cluster has a track associated with it (tag & probe).
    - "physics" complicates things! WAB→γe^- … minor effect on tag=positron, probe=electron, but massive issue for tag=electron, probe=positron
- "it goes through (deposits energy) in the right layers…in our case at least 5x2 of the modules"
    - bag it…look at the ratios of data/MC efficiencies, which will encompass any "acceptance" differences (plus lots of other stuff)
- Since we use the ECal to define the tag & probe, we have to use ECal variables to define data/MC corrections…
  - there are really only 3: cluster energy & X, Y positions…cluster energy & cluster X are correlated (for charged track, bend in the B-field), so use 2D cluster energy vs cluster Y to do corrections

Track Efficiency, Killing & Weighting

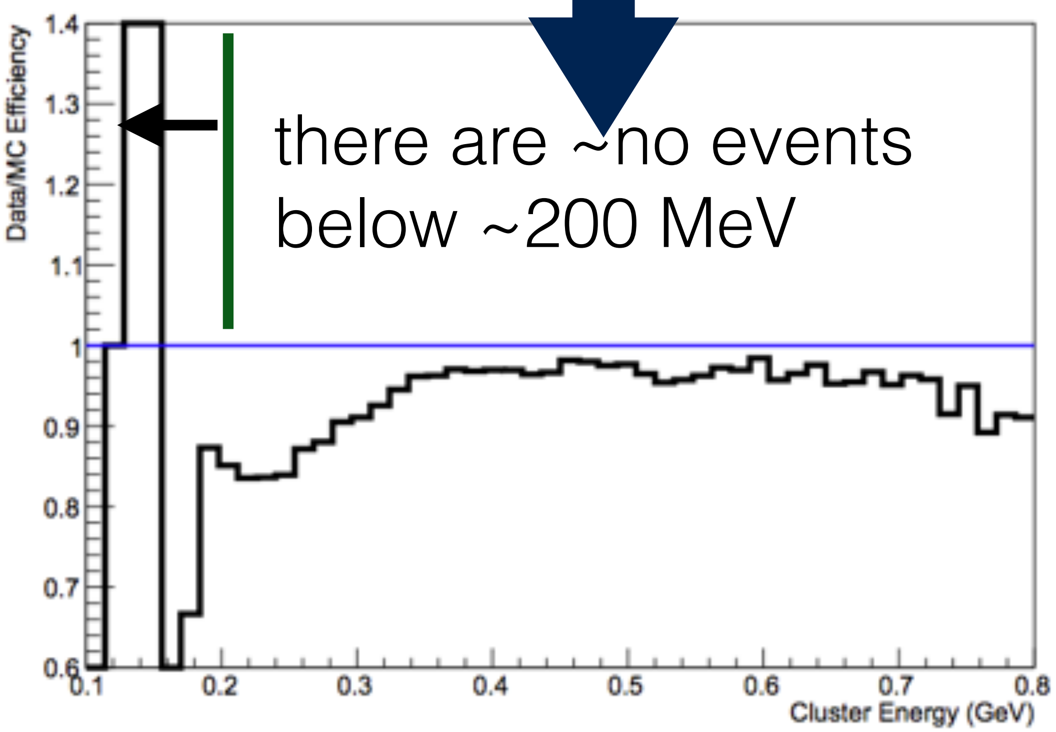
- Track efficiency from 2-prong events:
  - Select 2-cluster events that are top/bottom & left/right
  - tag (denominator) with matched track on one side (electron or positron); probe (numerator) also has matched track on other side
    - cuts on relative cluster time (±2ns), ECal coplanarity (~180^{o})
- For MC efficiency, use wab-beam/tri-beam weighted averages
  - small effect on electron efficiency..
  - crucial (and source of big uncertainty) for positron efficiency
- Track killing: based on measured ratio of data/MC efficiencies in a bin (e.g. momentum), reject a track
- Track weighting: based on measured ratio of data/MC efficiencies in a bin, weigh the event

Track Efficiency: tag=positron, probe=electron

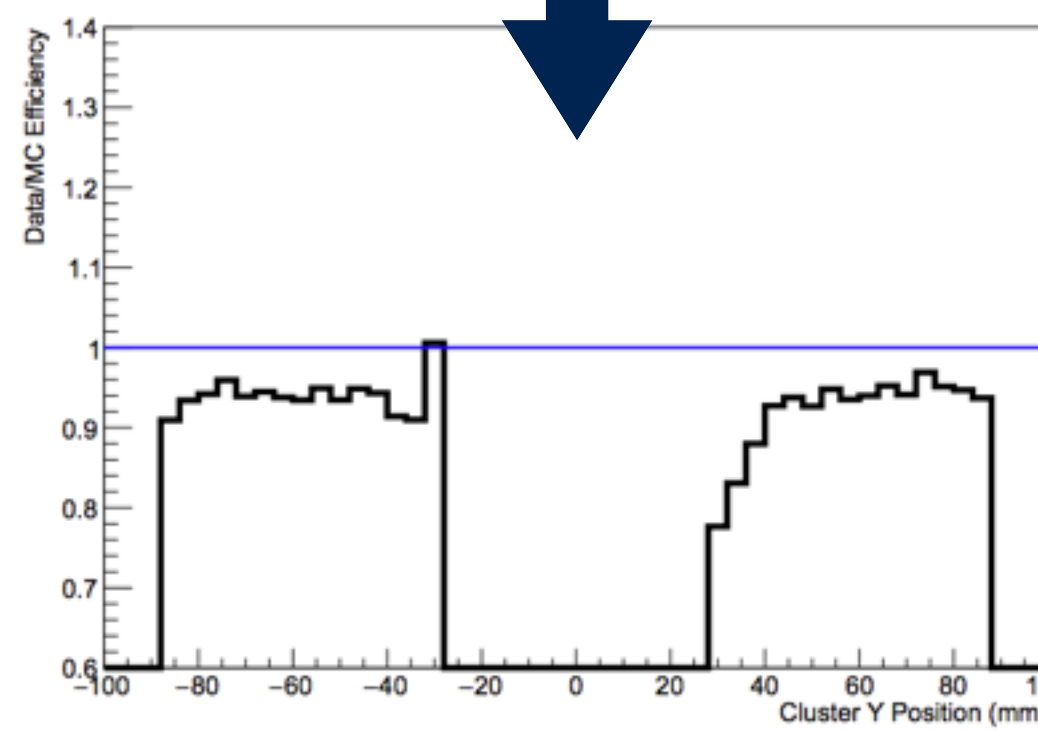


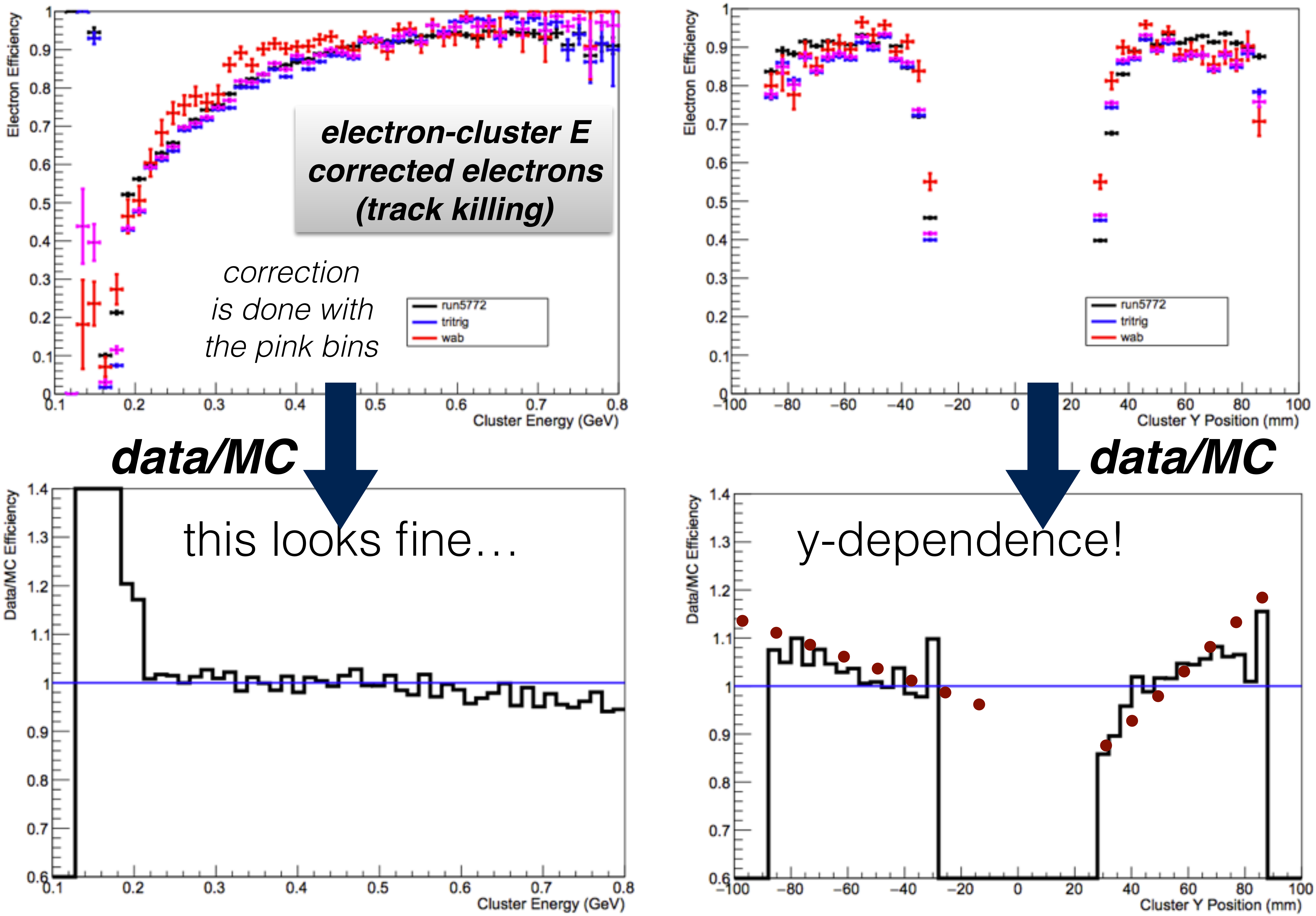


data/MC

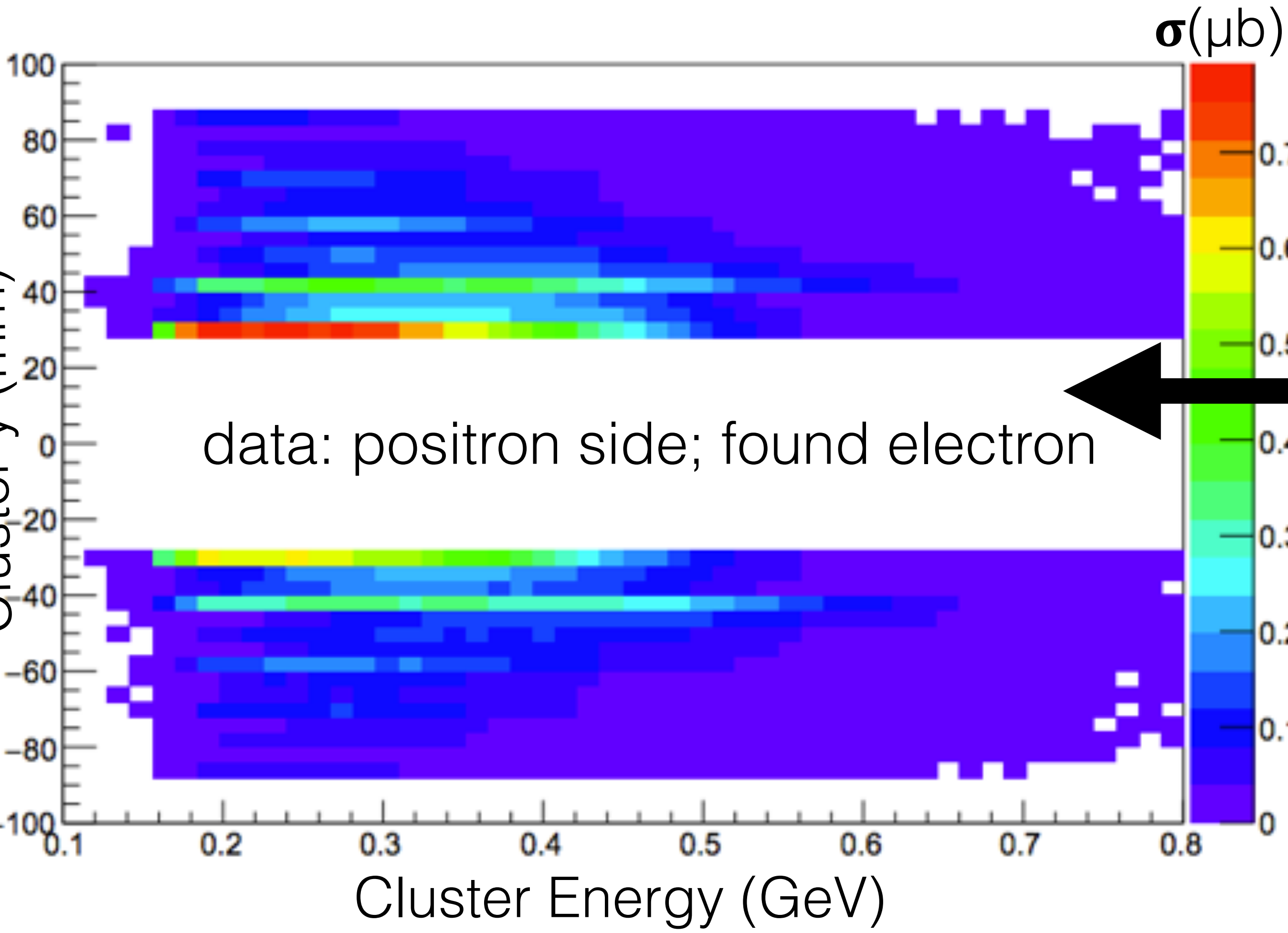


data/MC



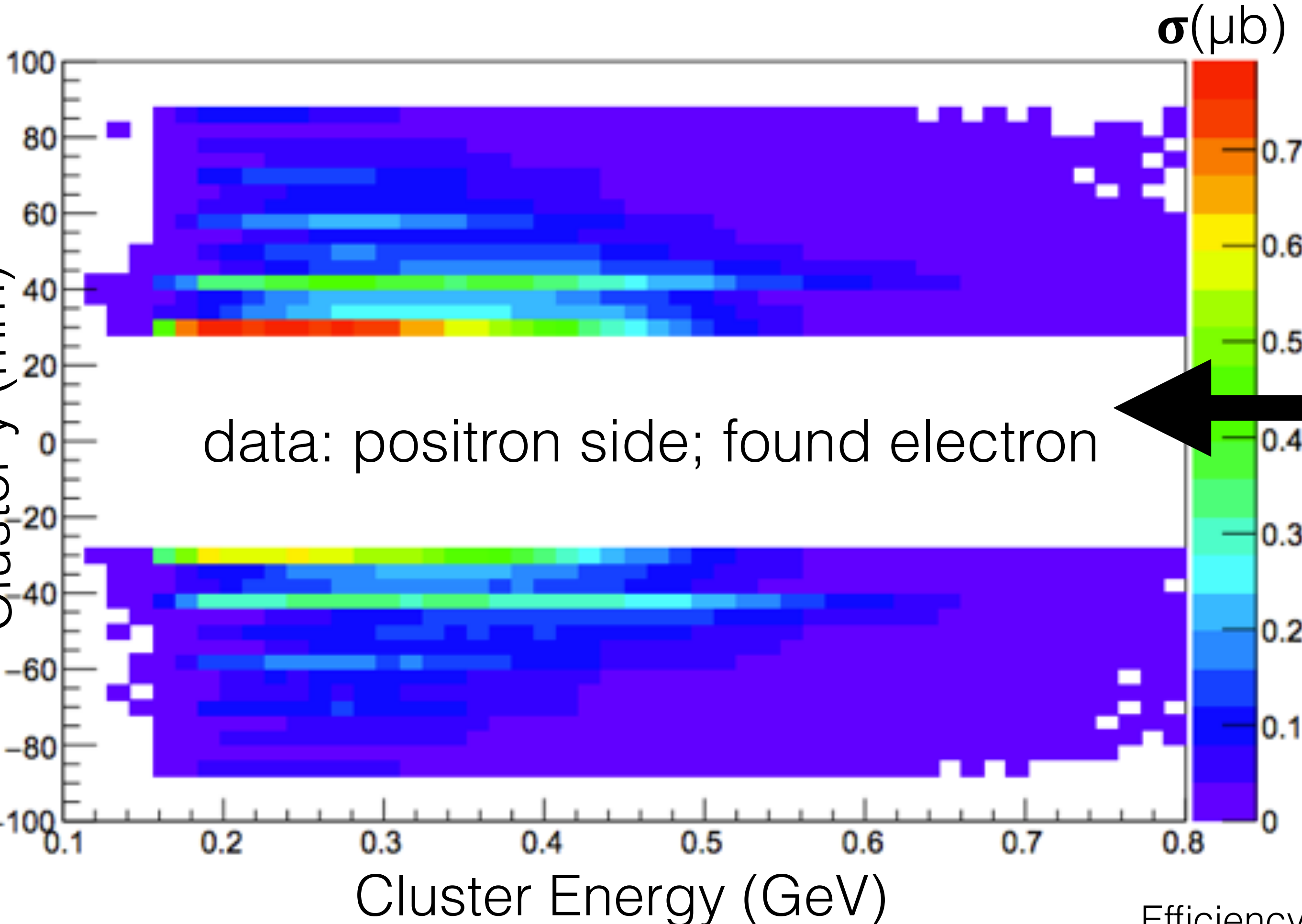


electron-cluster E
corrected electrons
(track killing)
correction
is done with
the pink bins
run5772
tritrig
wab
Electron Efficiency
Cluster Energy (GeV)
Cluster Y Position (mm)
data/MC
data/MC
this looks fine…
y-dependence!
Data/MC Efficiency
Cluster Energy (GeV)
Cluster Y Position (mm)



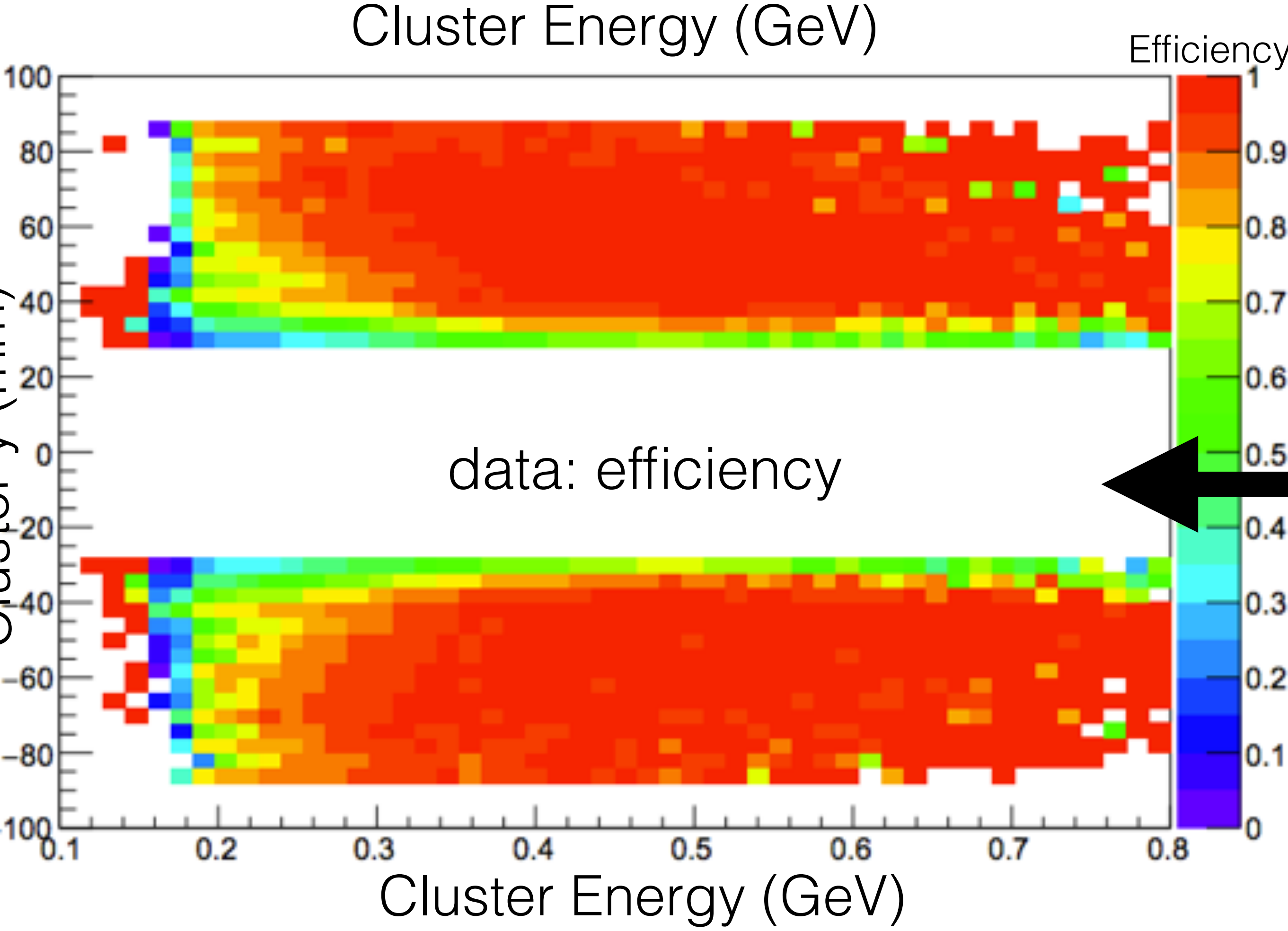
Cluster Y vs Cluster Energy

- electron side
- positron track found
- run 5772…

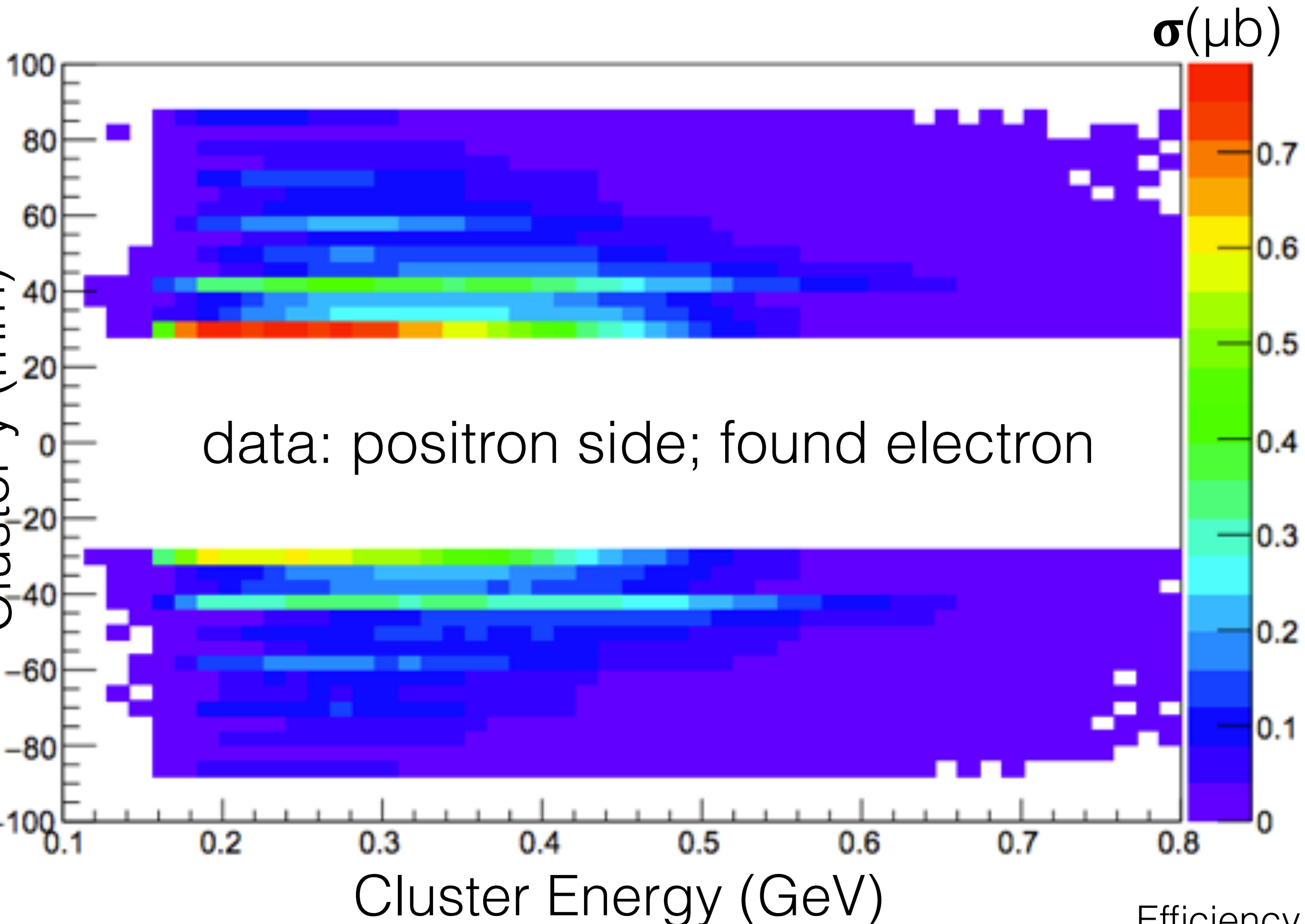


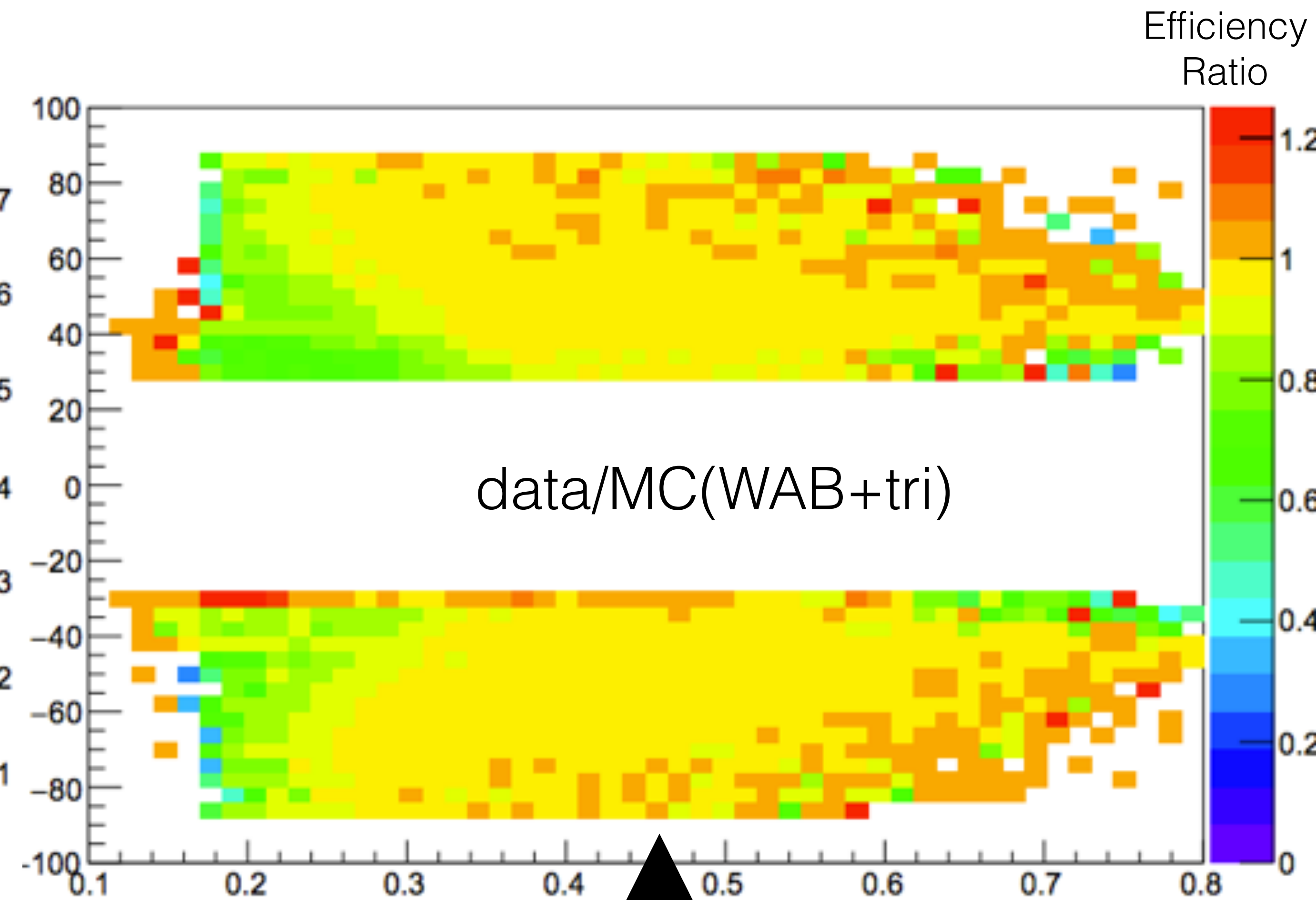
Cluster Y vs Cluster Energy

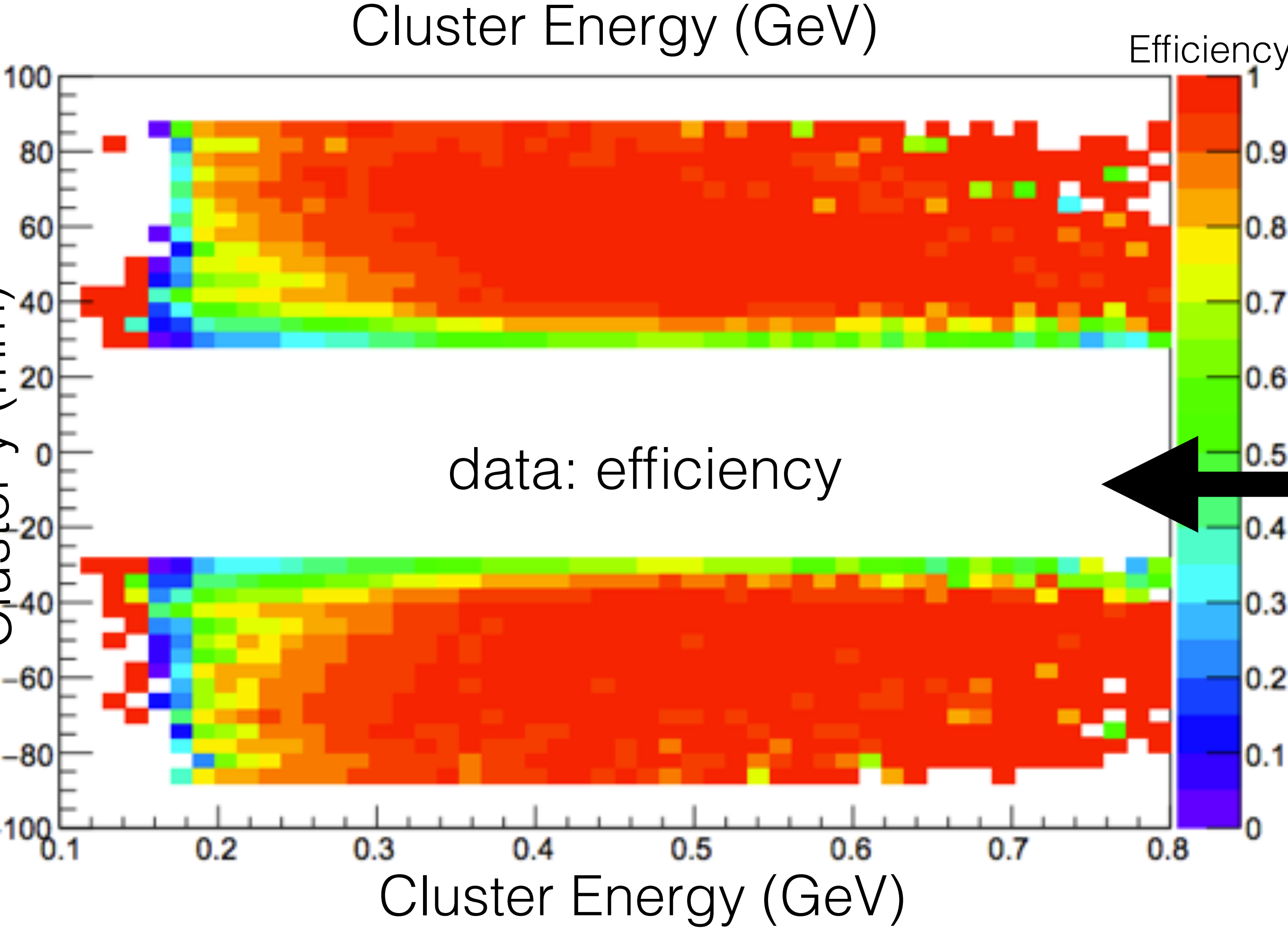
- electron side
- positron track found
- run 5772…



Electron track efficiency (data)

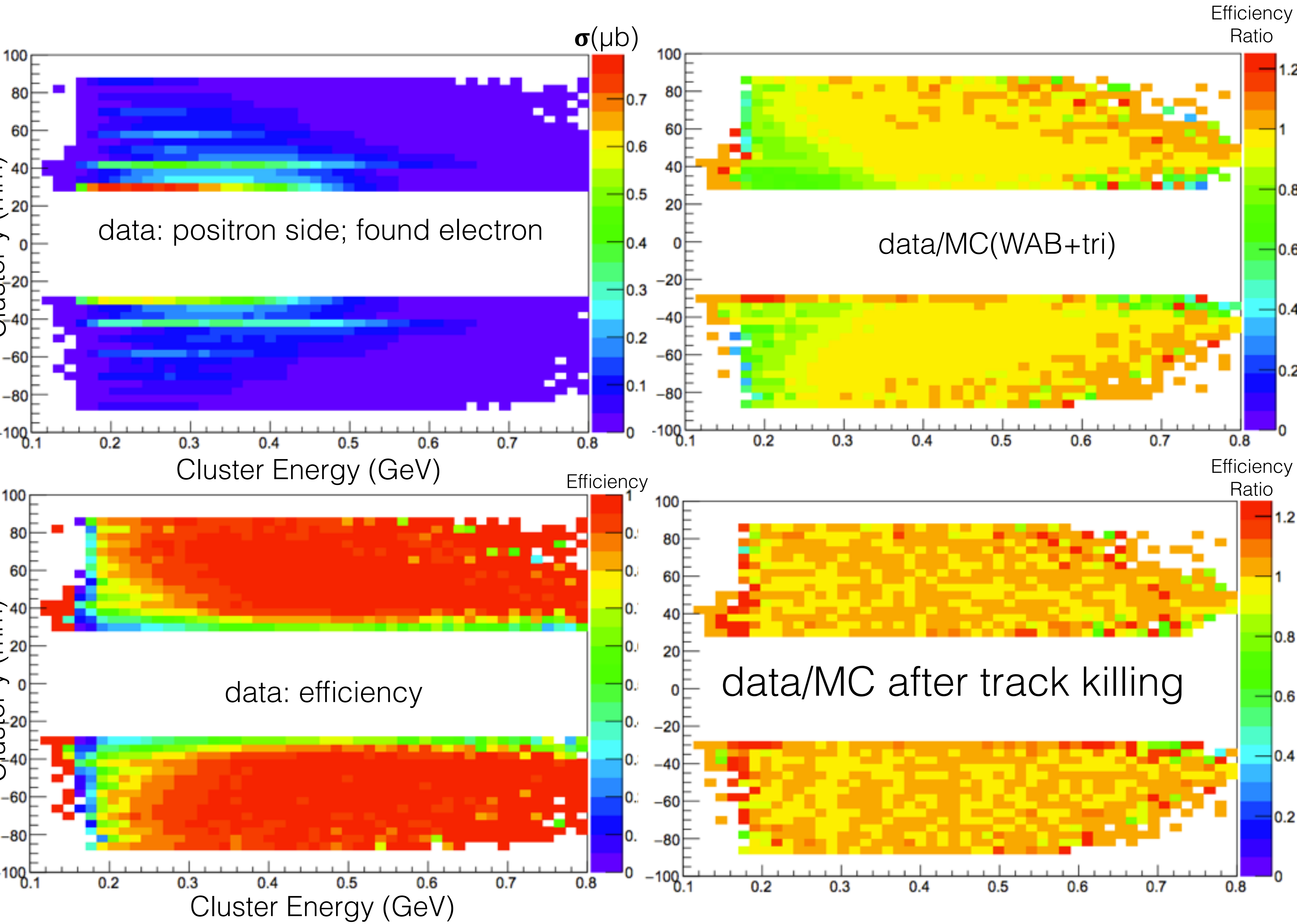




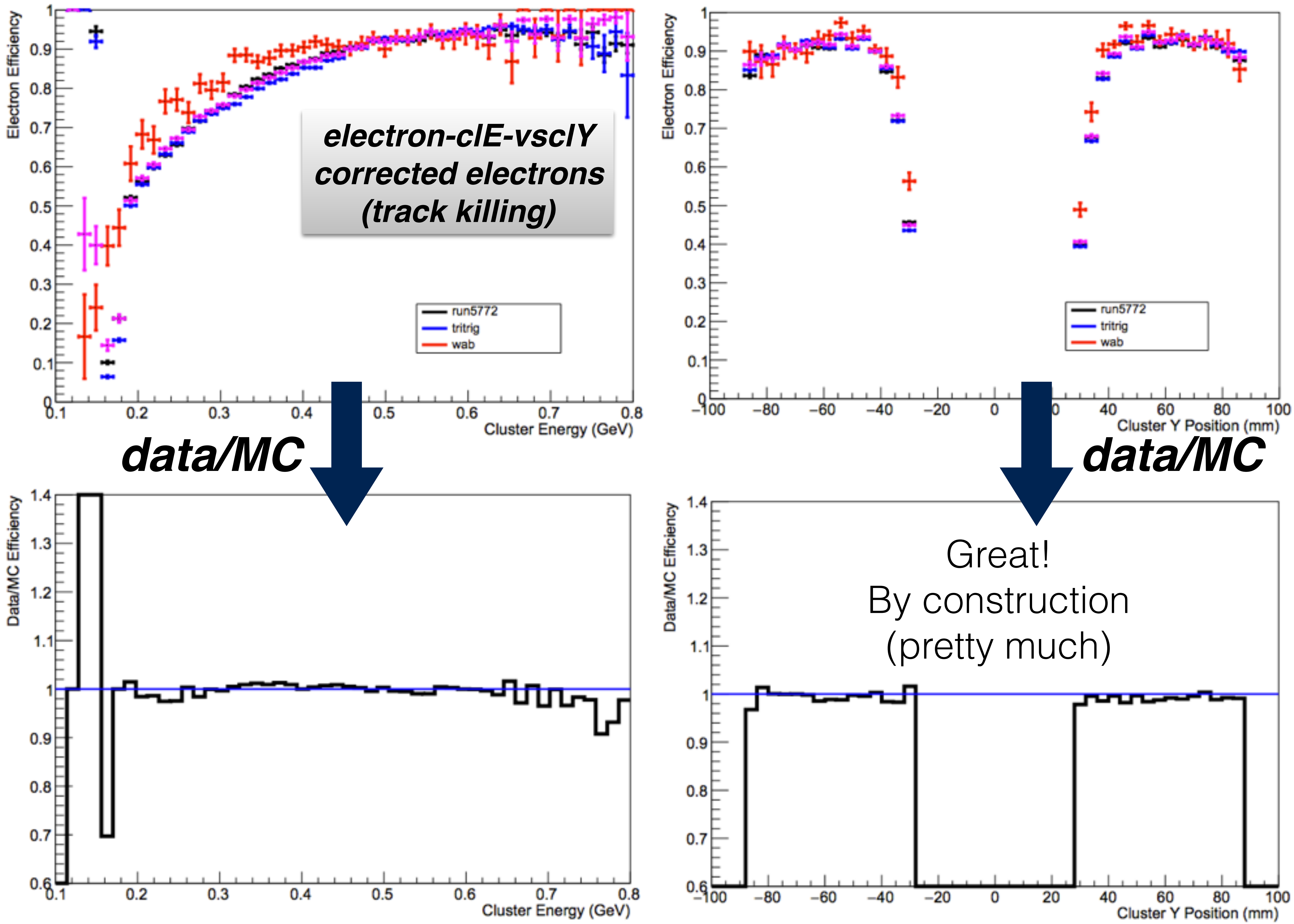


Ratio of electron track efficiency = data/MC

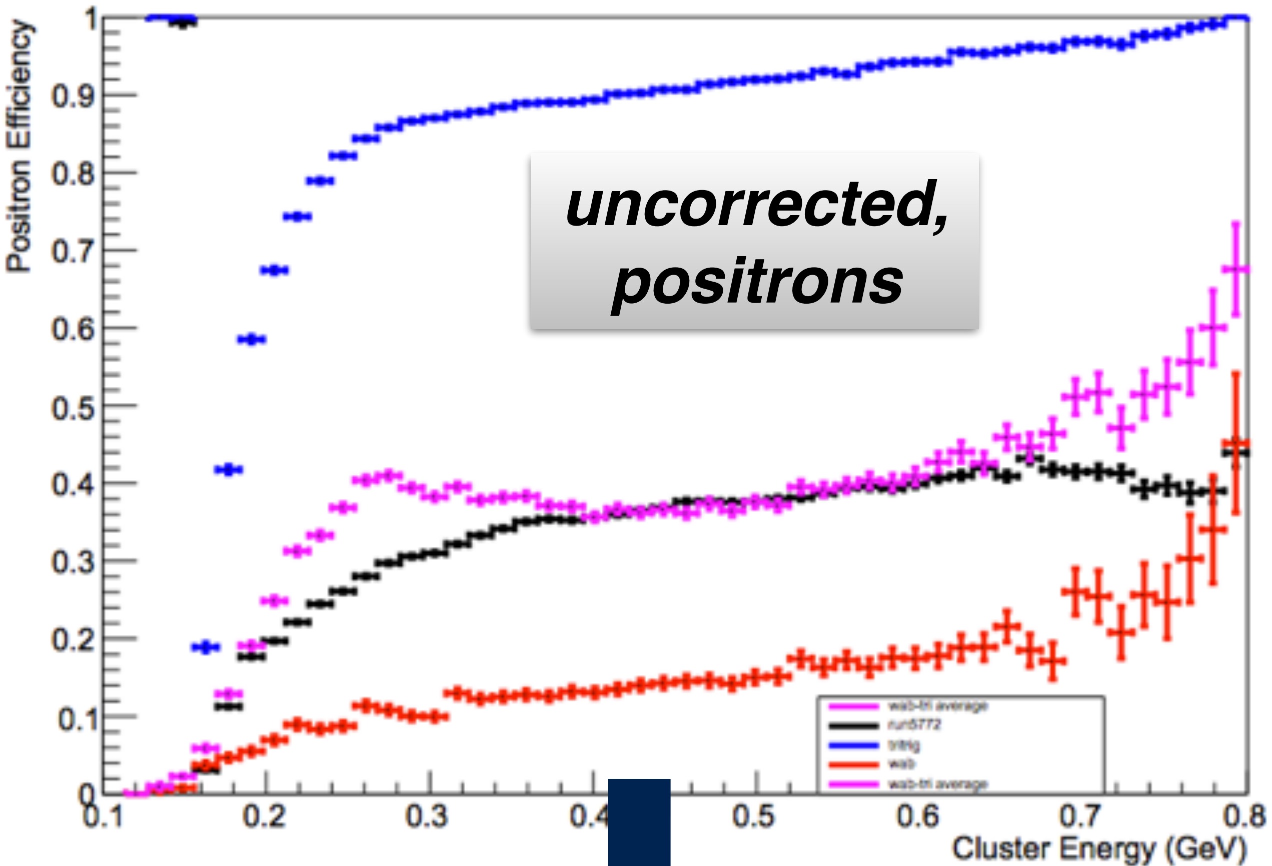
Electron track efficiency (data)

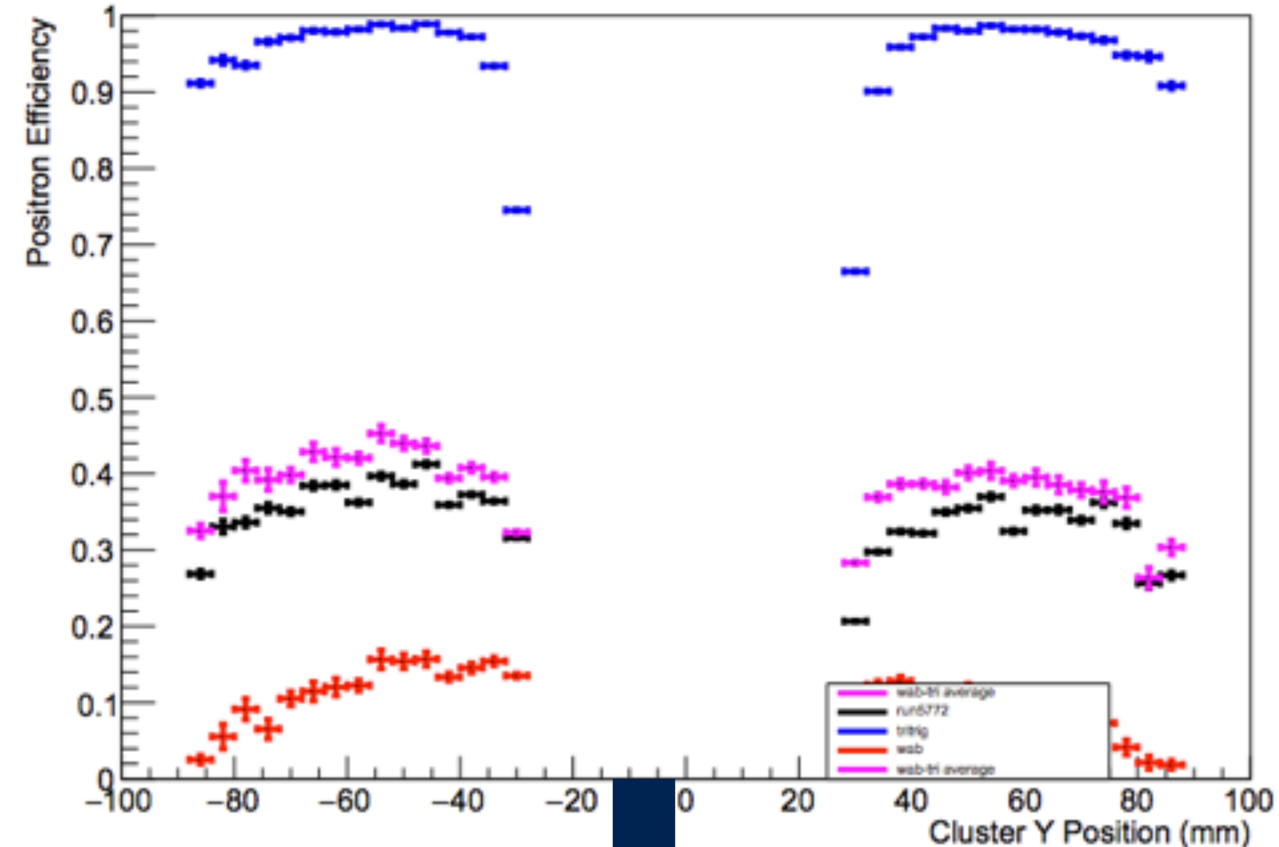


σ(μb)
data: positron side; found electron
Cluster Energy (GeV)
Efficiency Ratio
data/MC(WAB+tri)
Efficiency
data: efficiency
Cluster Energy (GeV)
Efficiency Ratio
data/MC after track killing



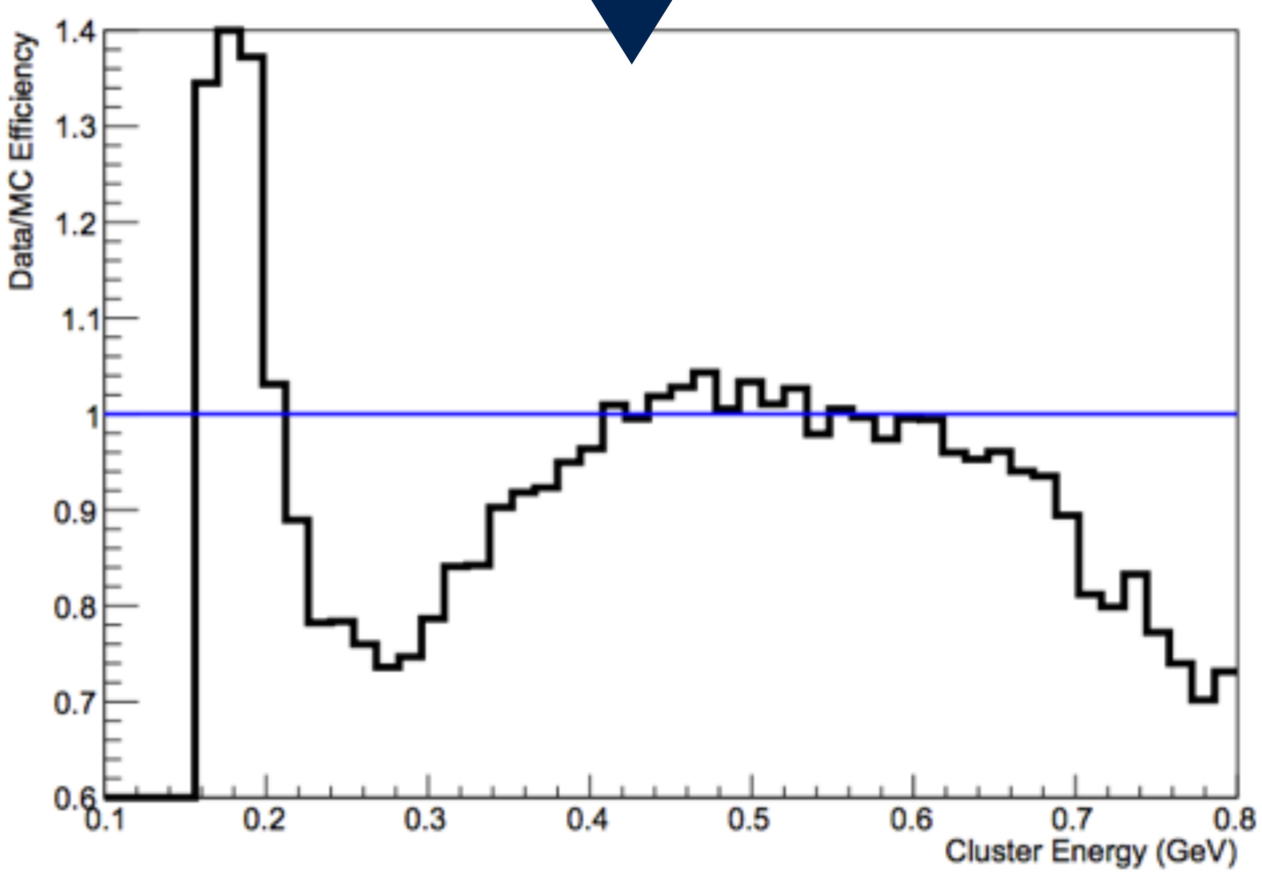
electron-clE-vsclY
corrected electrons
(track killing)
Electron Efficiency
Cluster Energy (GeV)
run5772
tritrig
wab
Electron Efficiency
Cluster Y Position (mm)
run5772
tritrig
wab
data/MC
data/MC
Data/MC Efficiency
Cluster Energy (GeV)
Great!
By construction
(pretty much)
Data/MC Efficiency
Cluster Y Position (mm)

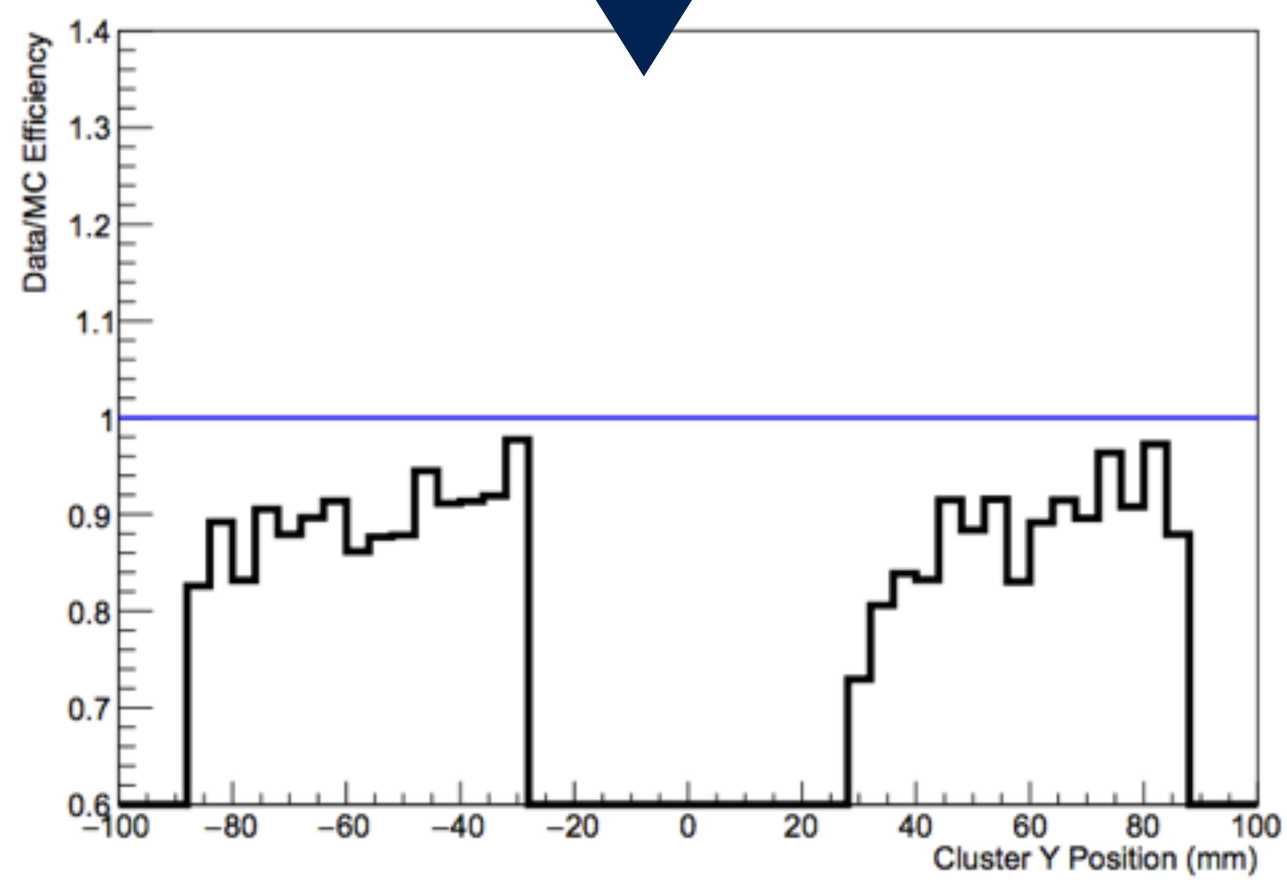


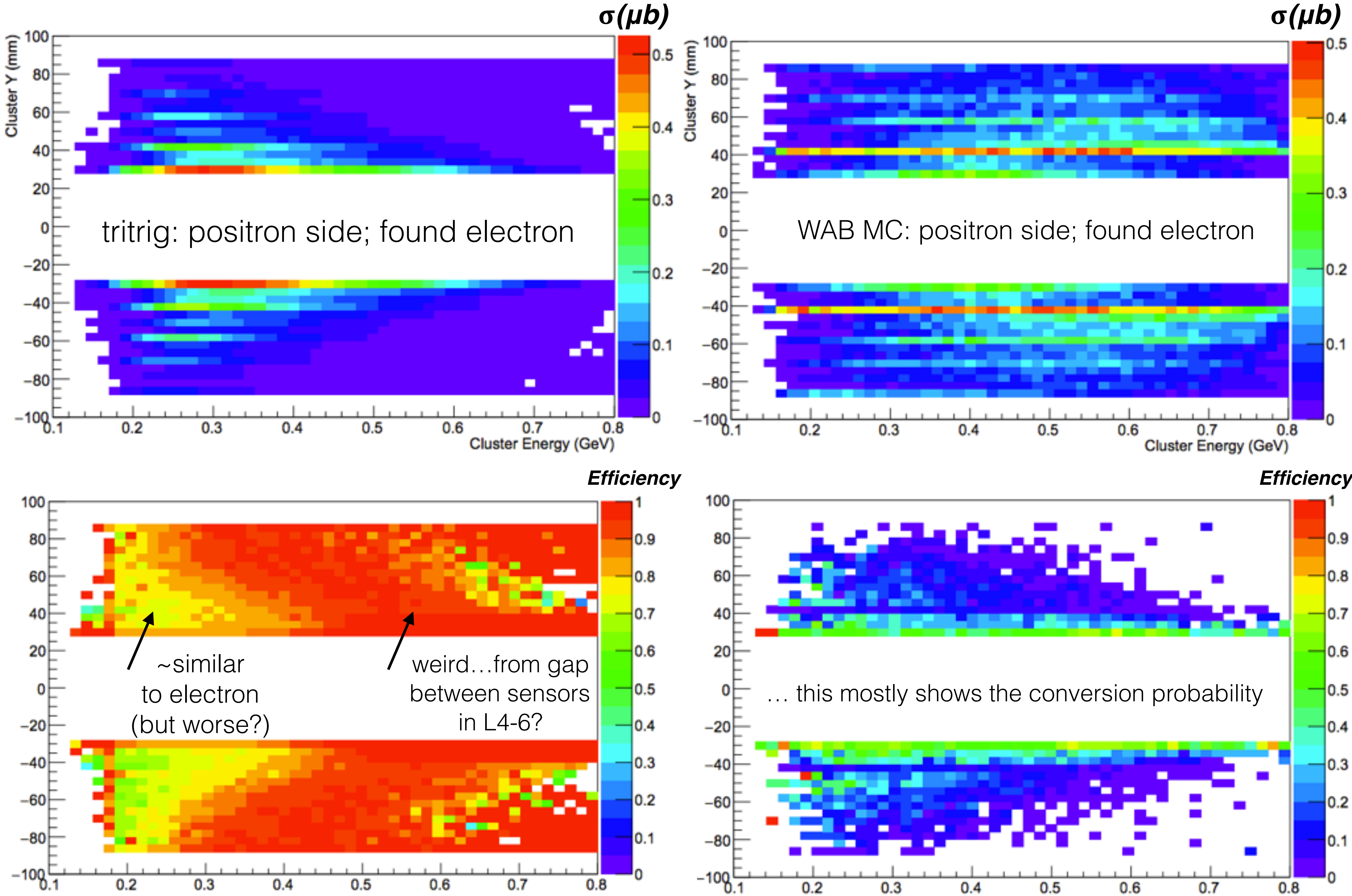


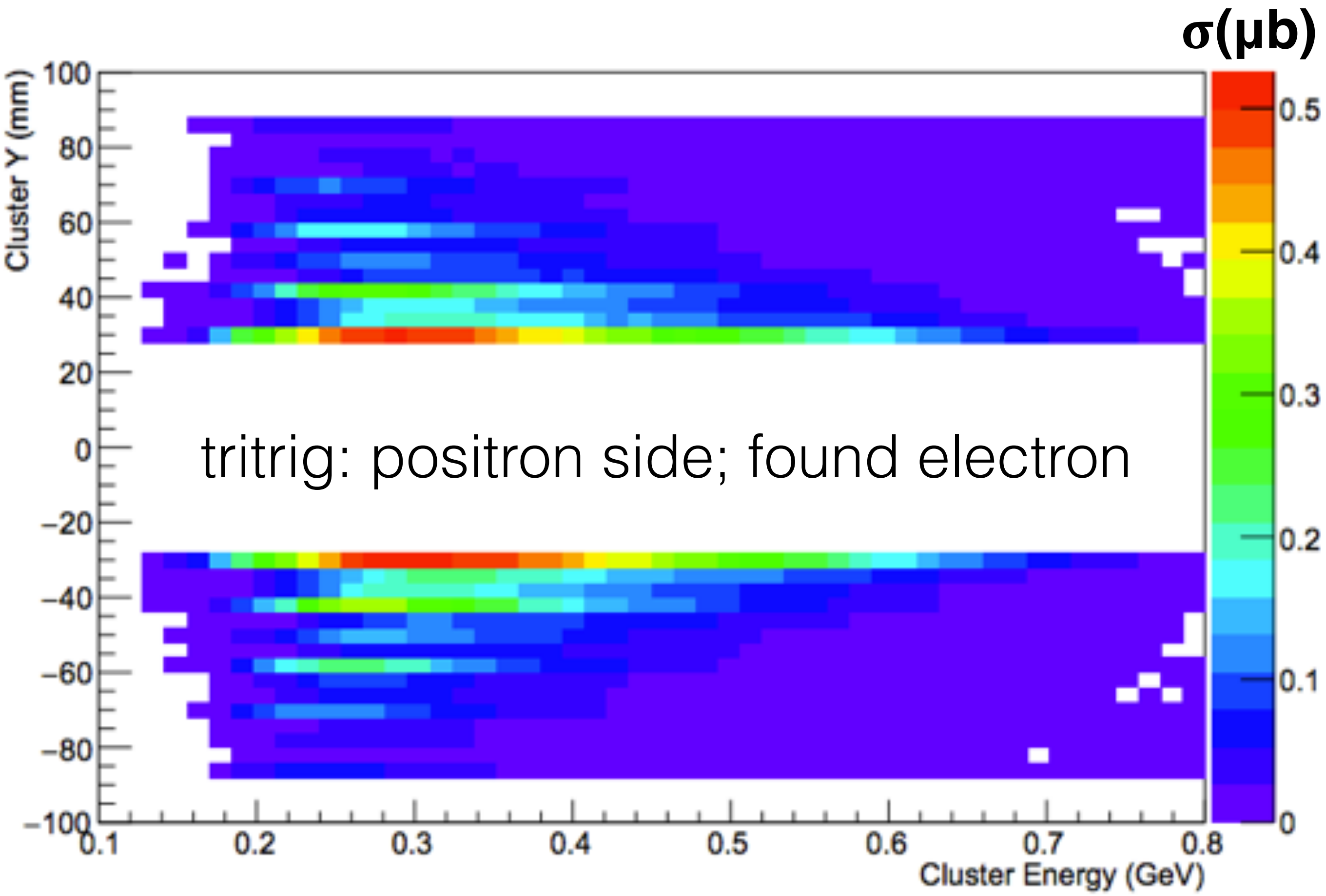
data/MC

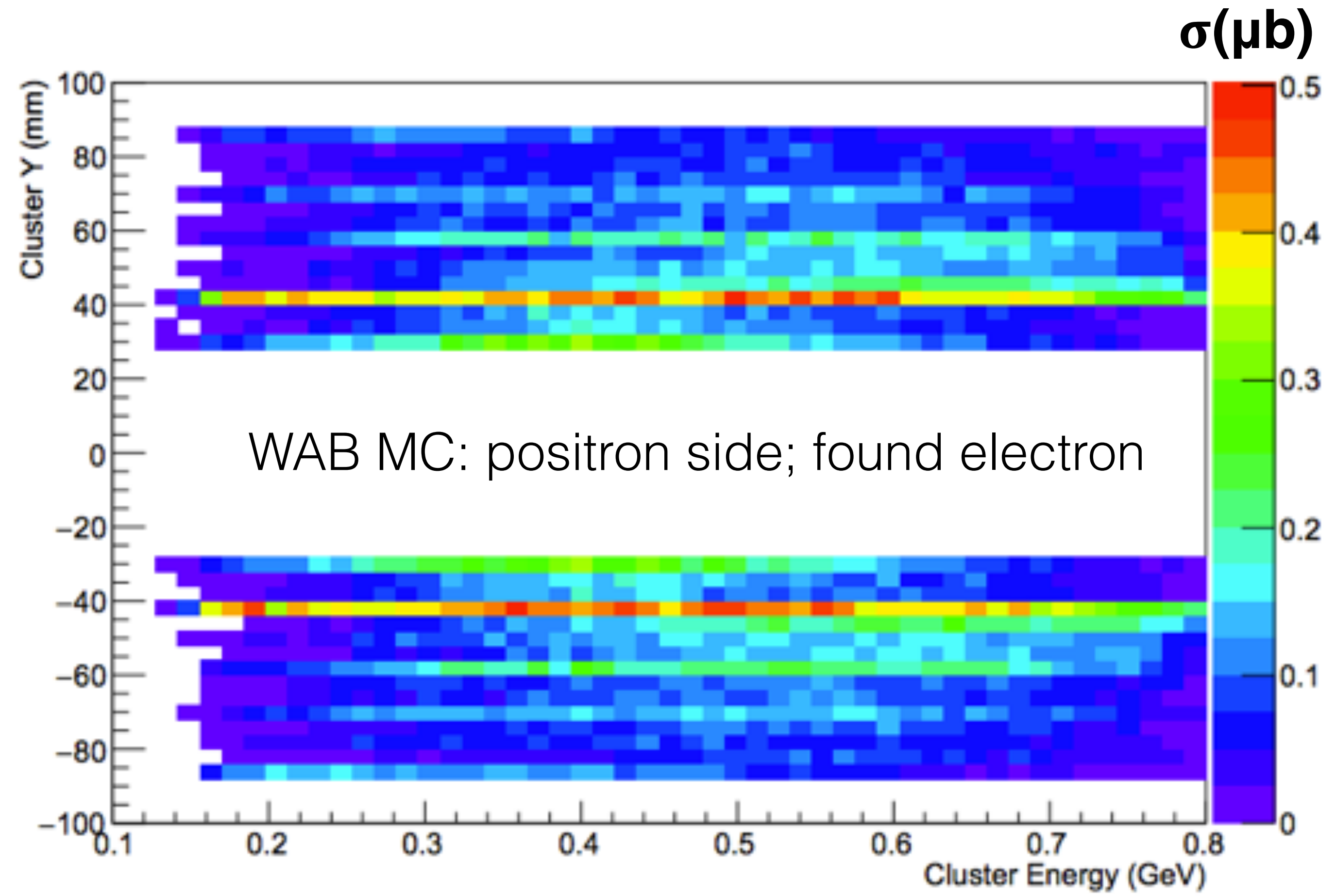
data/MC



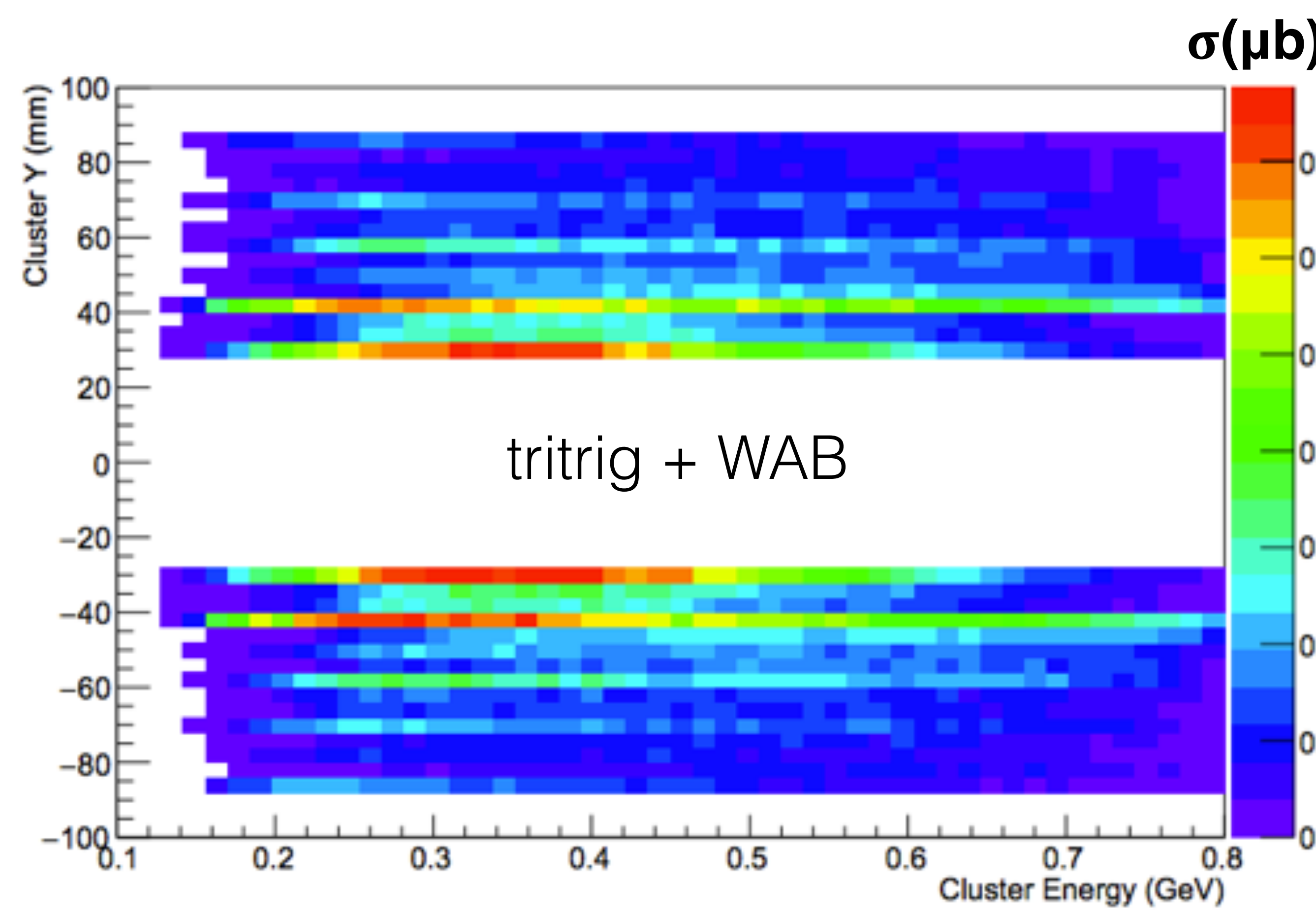


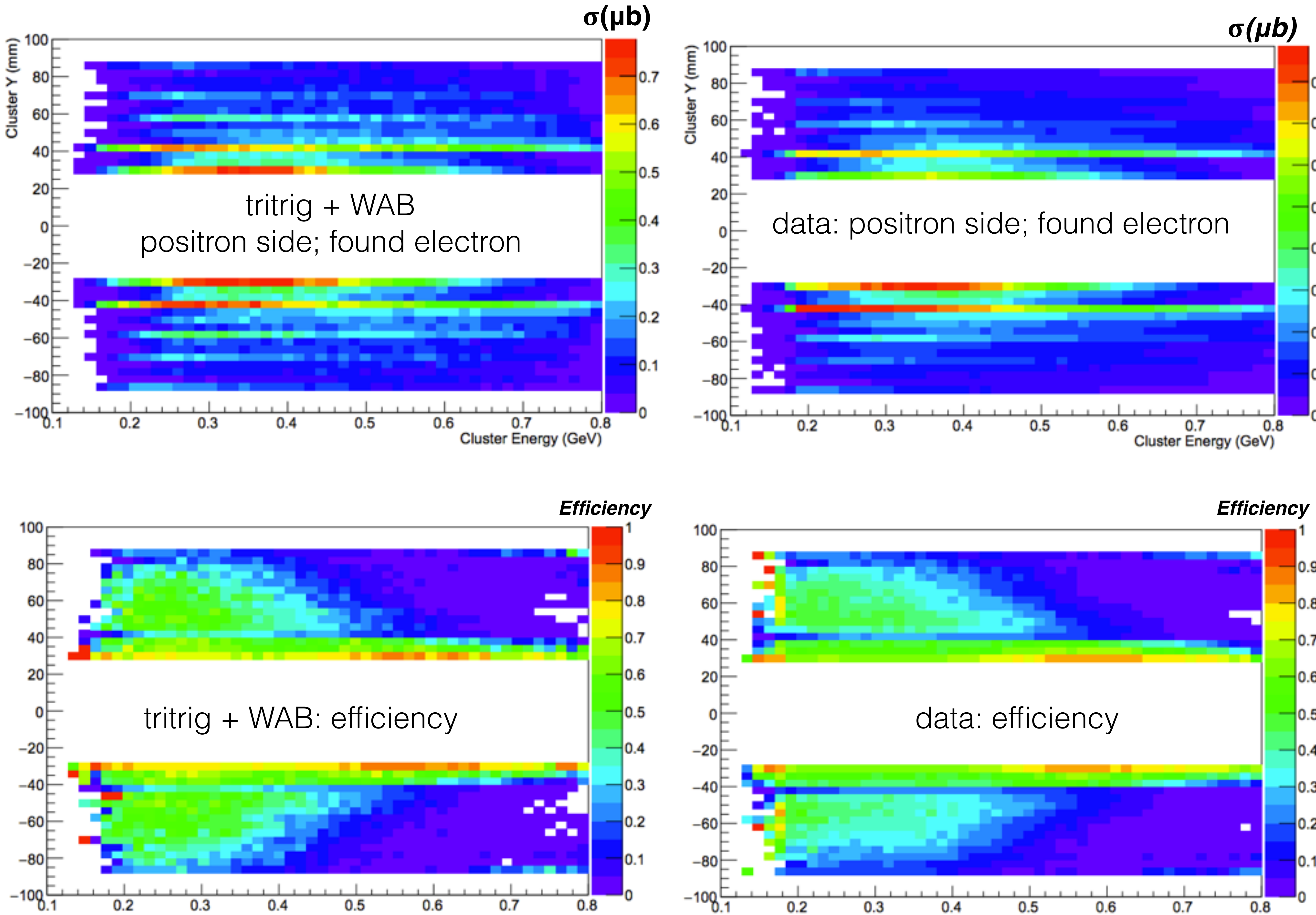

σ(μb)
Cluster Y (mm)
Cluster Energy (GeV)
tritrig: positron side; found electron
σ(μb)
Cluster Y (mm)
Cluster Energy (GeV)
WAB MC: positron side; found electron
Efficiency
~similar
to electron
(but worse?)
weird…from gap
between sensors
in L4-6?
Efficiency
… this mostly shows the conversion probability



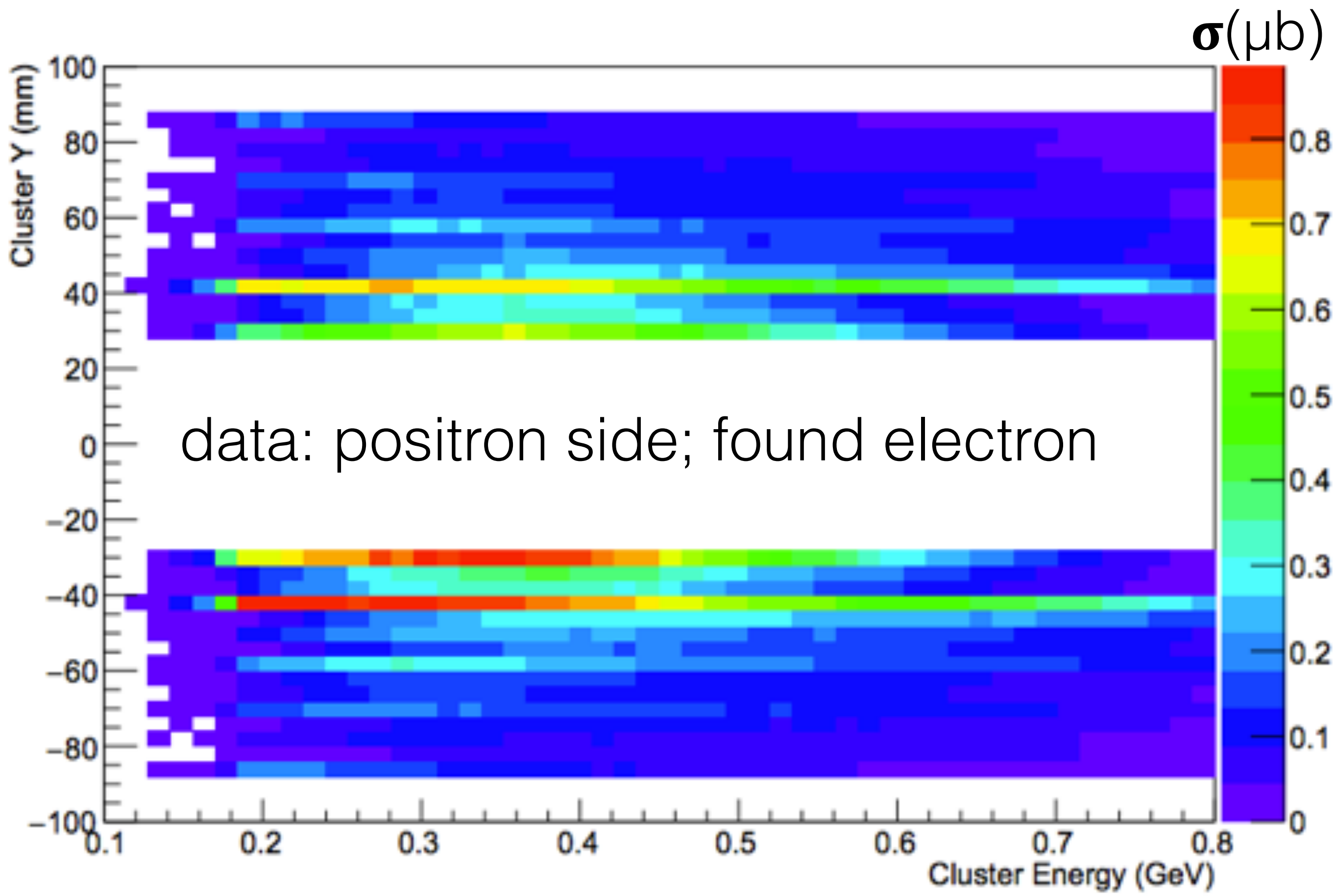


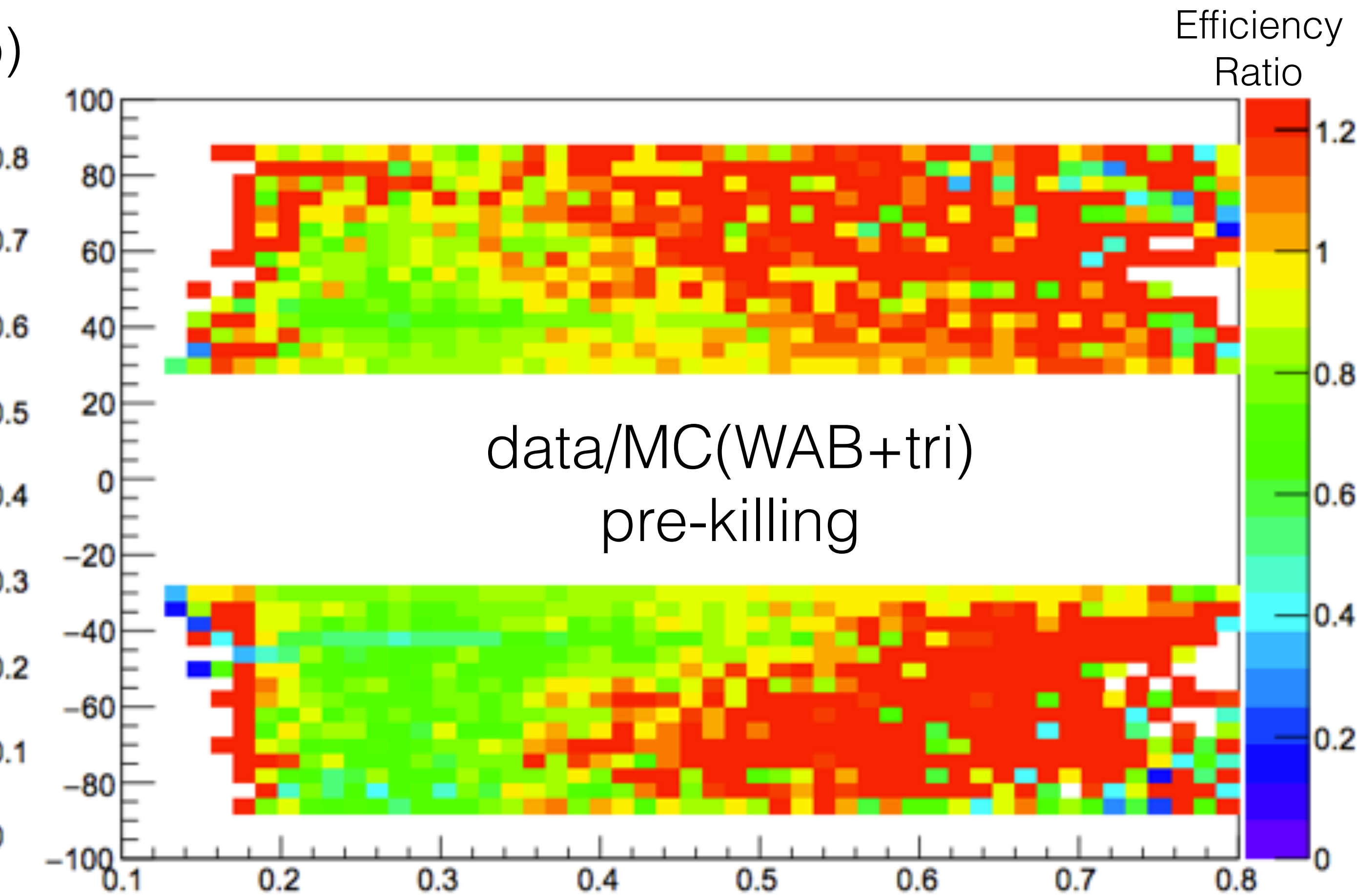
Combine based on expected proportions found in MC, correcting for alpha screwup…



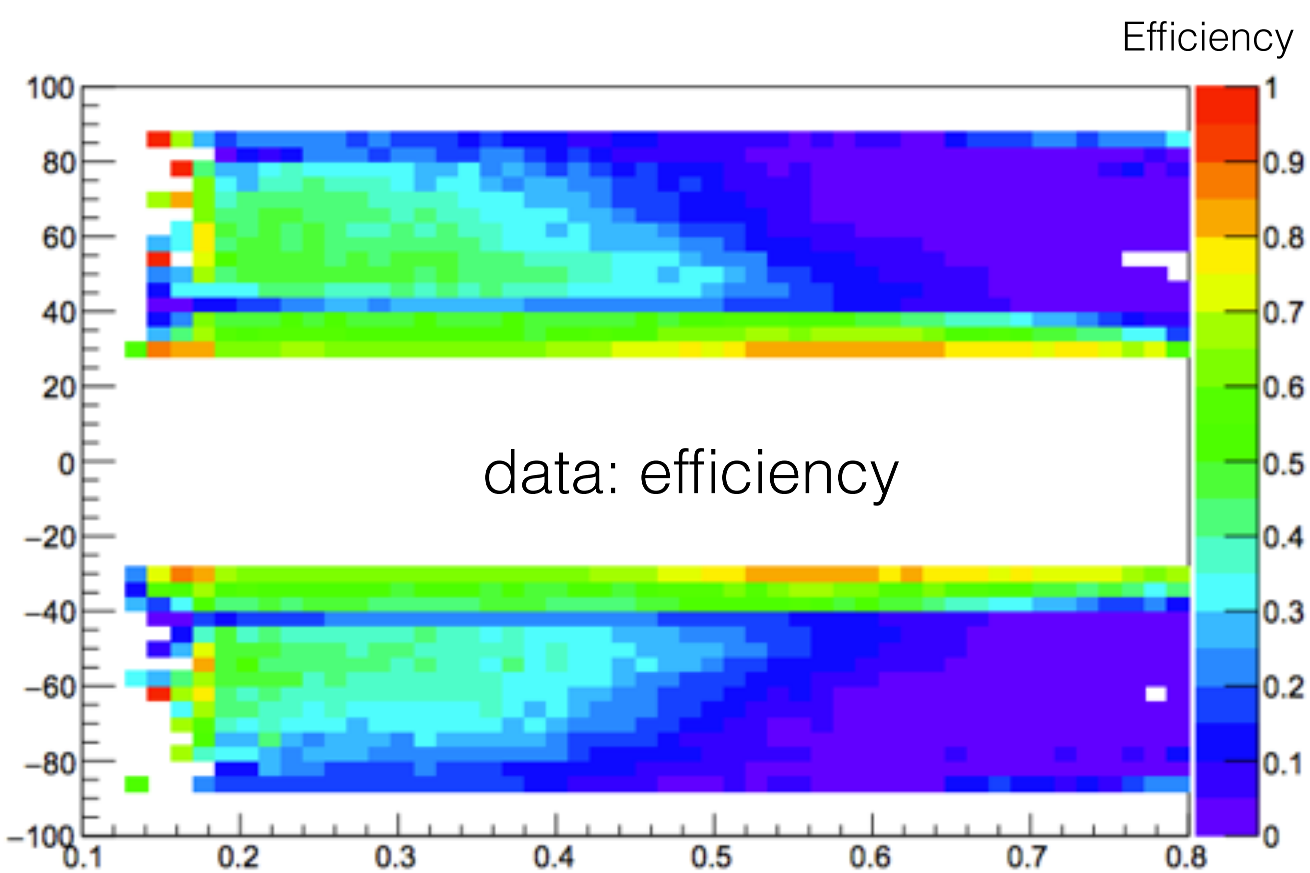


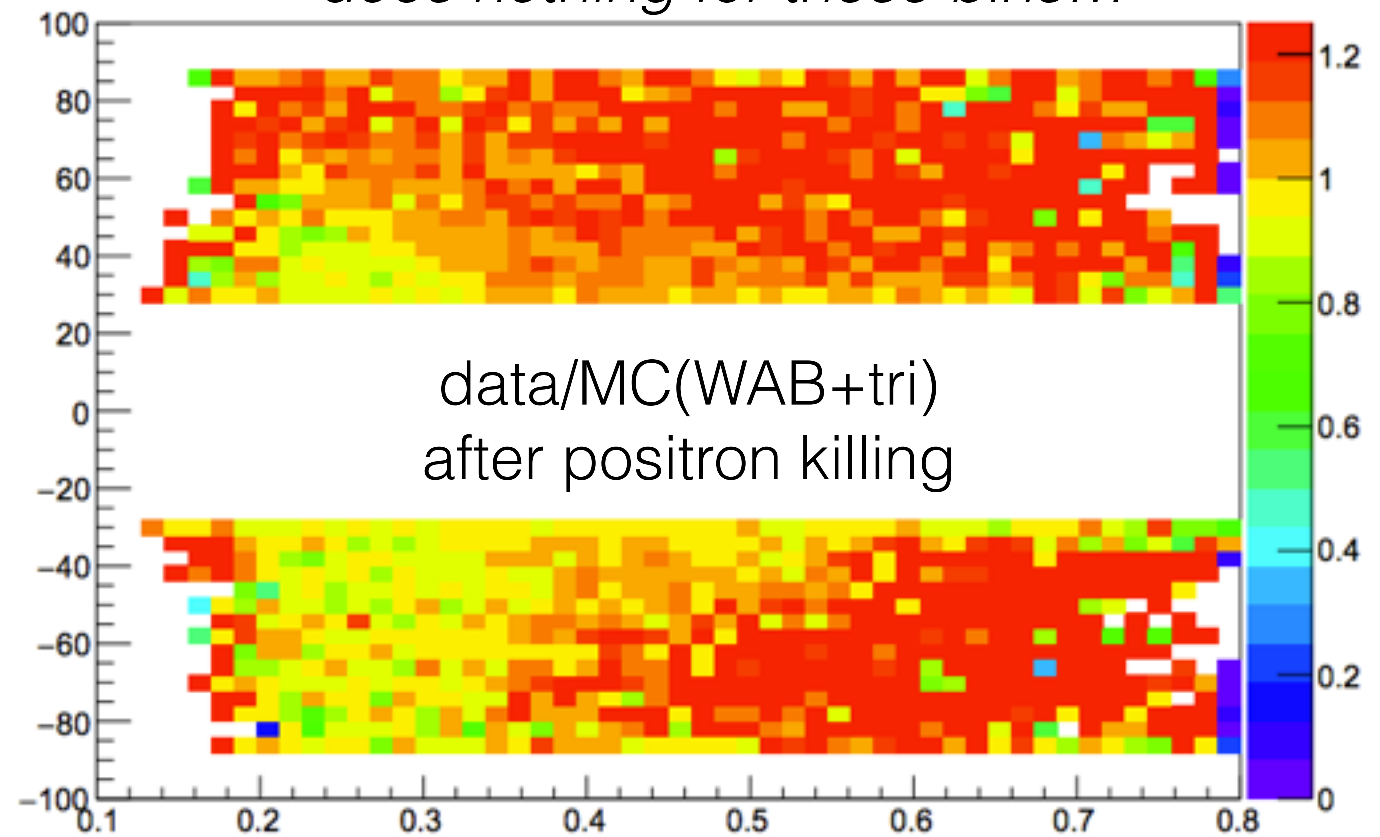
σ(μb)
Cluster Y (mm)
tritrig + WAB
positron side; found electron
Cluster Energy (GeV)
σ(μb)
Cluster Y (mm)
data: positron side; found electron
Cluster Energy (GeV)
Efficiency
tritrig + WAB: efficiency
Efficiency
data: efficiency

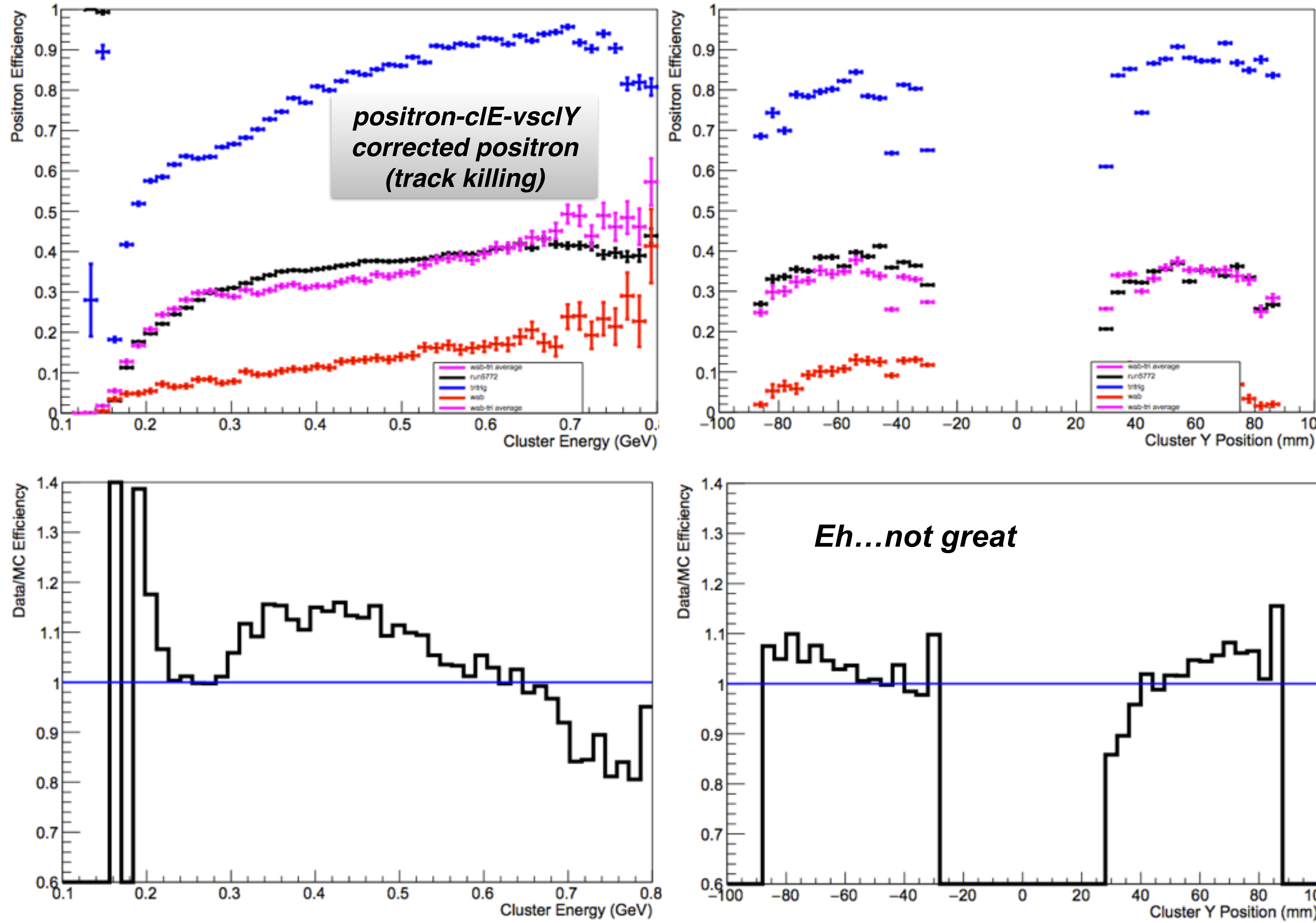




Lots of R>1.0…killing does nothing for these bins…






positron-clE-vsclY
corrected positron
(track killing)
Eh…not great
Positron Efficiency
Cluster Energy (GeV)
Cluster Y Position (mm)
Data/MC Efficiency
wab-tri average
run5772
tritrig
wab

Track Efficiency Summary

- As of today, my best recipe for correcting MC for differences in track efficiency is to use the electron cluster Y vs cluster E corrections for both electrons and positrons
  - I've tried using the positron correction (for positrons) as well and the difference isn't too huge…it does a decent job, but I trust the electron correction better (less WAB subtraction) so for now, stick with it
- There still is some cluster X dependence, even after correcting for Y vs E
  - this isn't crazy…X and E are not 100% correlated, the initial θ_x does matter some, particularly for low momentum
  - ideally, do a 3d (X,Y,E) correction but need more MC stats for this to be robust

Tridents and WABs

- I think it's really important to understand the WAB and trident rates and kinematic distributions
  - tridents are our main background and (radiative tridents/δm) is our signal!
  - WAB-γ conversions represent a significant background to A' search as well; understanding the non-converted rates help us believe the converted ones
- Primarily, this is a data-vs-MC comparison…at the end, there are lots of factors that can go wrong:
  - event generators (MadGraph)
  - detector simulation & geometry, and material models (slic)
  - readout simulation
  - detector conditions not simulated correctly (beam current, bad/dead channels, gains etc)
- We've already found+fixed lots of issues by looking at this stuff..
  - MadGraph4 vs MadGraph5, alpha is wrong in MG(!), WABs are a thing, our readout simulation needs work (though good stuff on ECal has been done!) …etc

WABs and Tridents: Event Selection

- preliminaries:
  - require pairs1 trigger
  - standard tracking…using all combinations of layers (no cut on L1L1, yet)
  - loop through FinalStateParticles list to find unique tracks
    - if 2 tracks share >2 hits, take track with more hits
      - if both tracks have same number of hits, pick one randomly
  - tracks must have:
    - ECal cluster match
    - $0.05 < p/E_{beam} < 0.8$
- For WABs:
  - require ECal-matched electron and unmatched ECal cluster in opposite halves
  - ECal cluster $|\Delta t| < 2$ns
  - ECal cluster coplanarity - $150^{o} \pm 15^{o}$
- For Tridents:
  - require ECal-matched electron and positron in opposite halves
  - ECal cluster $|\Delta t| < 2$ns

WABs and Tridents: Data Sets & Corrections

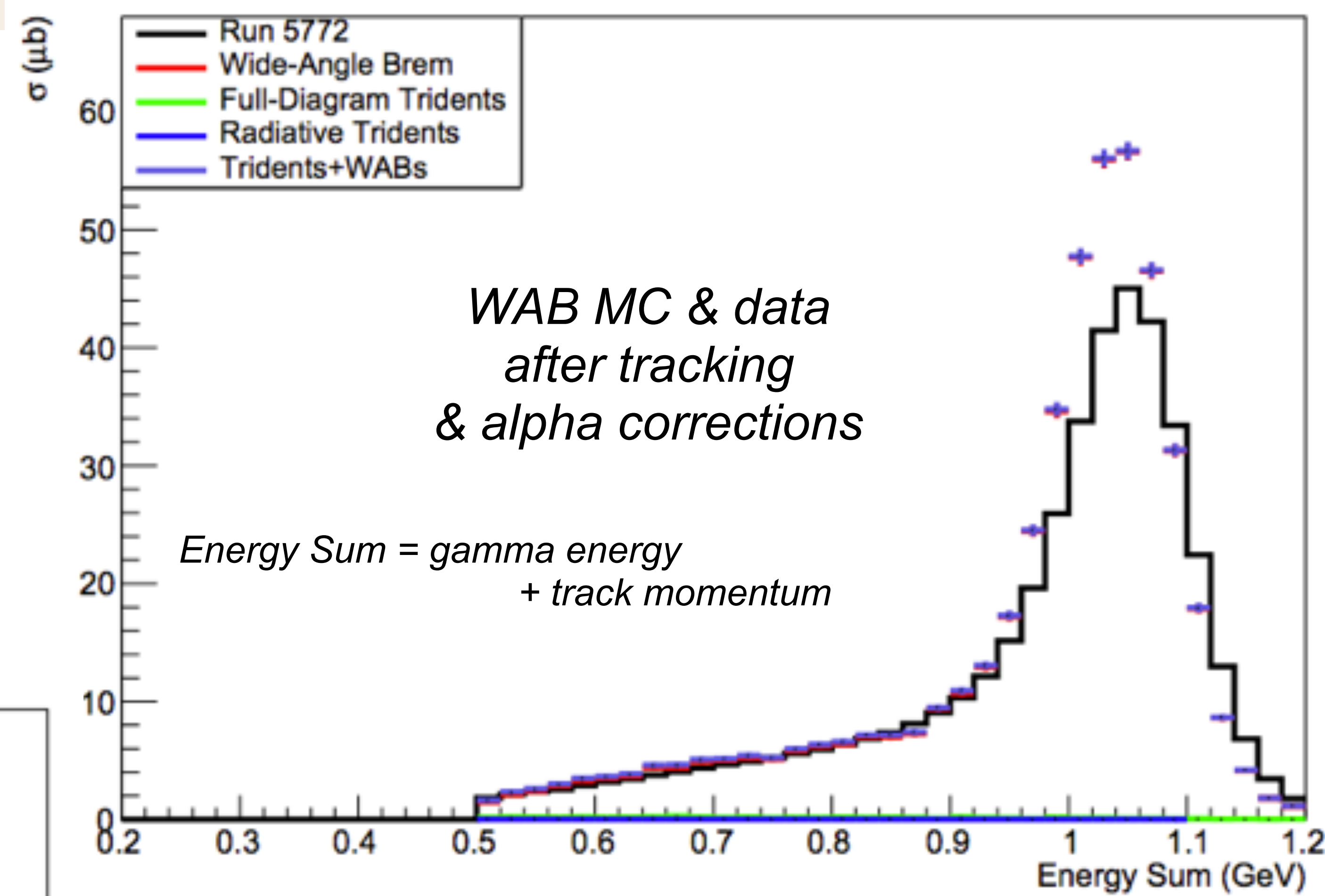
- data: run 5772 (unblind 10%)
- WAB-beam: MG4 WAB at the expected rate, overlaid with beam
  wabv3SF-egsv5-g4v1_100to1_HPS-EngRun2015-Nominal-v5-0-fieldmap_3.11-17Feb17
- Tri-beam: MG5 full diagram tridents at the expected rate, overlaid with beam
  triv2MG5-egsv5-g4v1_100to1_HPS-EngRun2015-Nominal-v5-0-fieldmap_3.11-17Feb17
- Radiative Tridents: MG5 radiative-only
  tridentsRADv3_MG5_noXchange_10to1_HPS-EngRun2015-Nominal-v5-0-fieldmap_3.11-20161225_pairs1

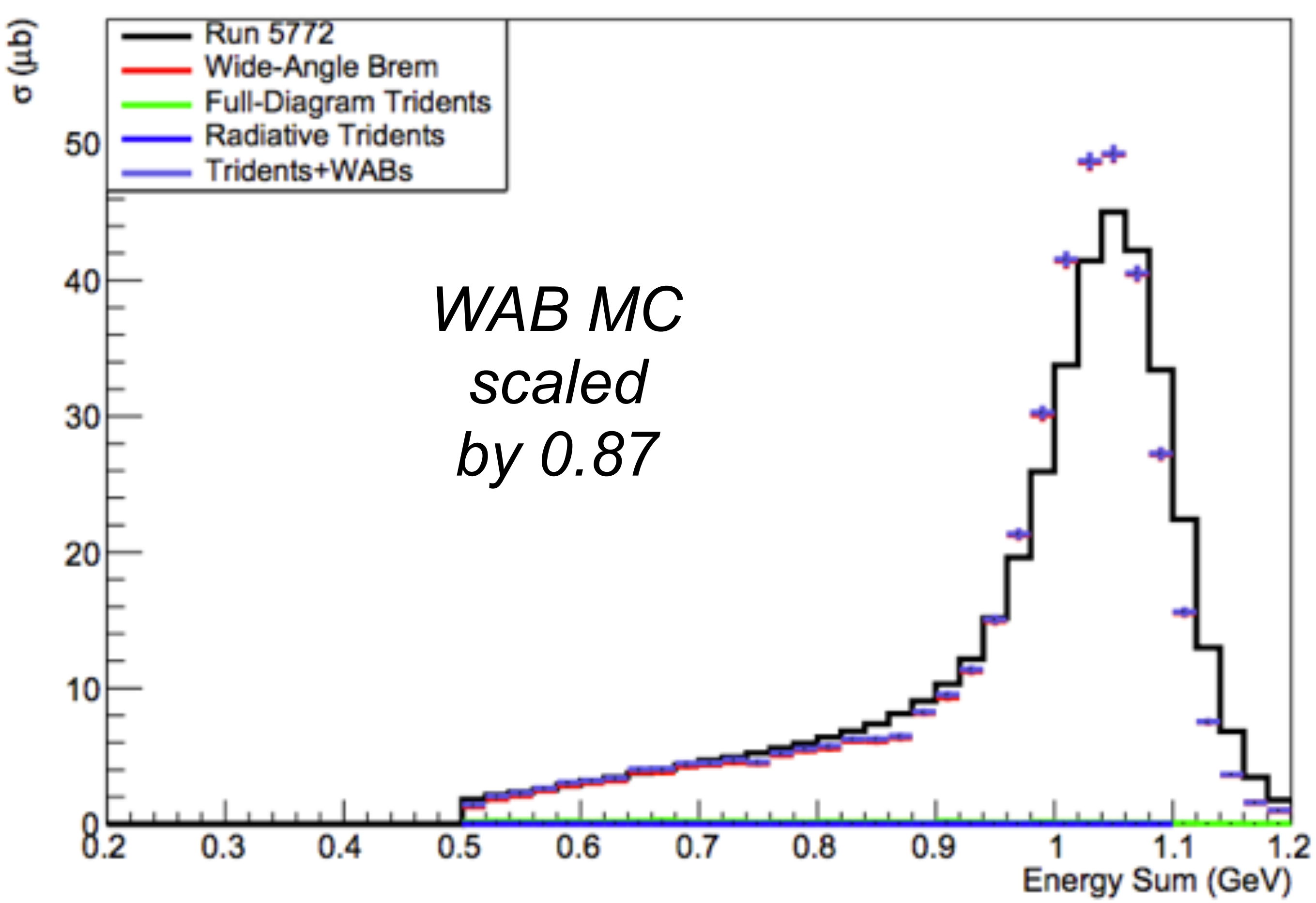
- track efficiency weighting to ***all*** tracks based on ***electron*** cluster E vs cluster Y correction
  - this reduces WAB ($e^-\gamma$) by 5% and tridents (e^+e^-) by 15%
- MG alpha error correction…0.81 for WABs, 0.76 for tridents
- WAB MC/data XS difference (see next slide)…0.87 for WABs

WAB → ɣe⁻

Try as I might, couldn't get WAB rates to agree 100%, so……..I fudge it. Scale the MC cross-section by 0.87 so that the peak rates match.

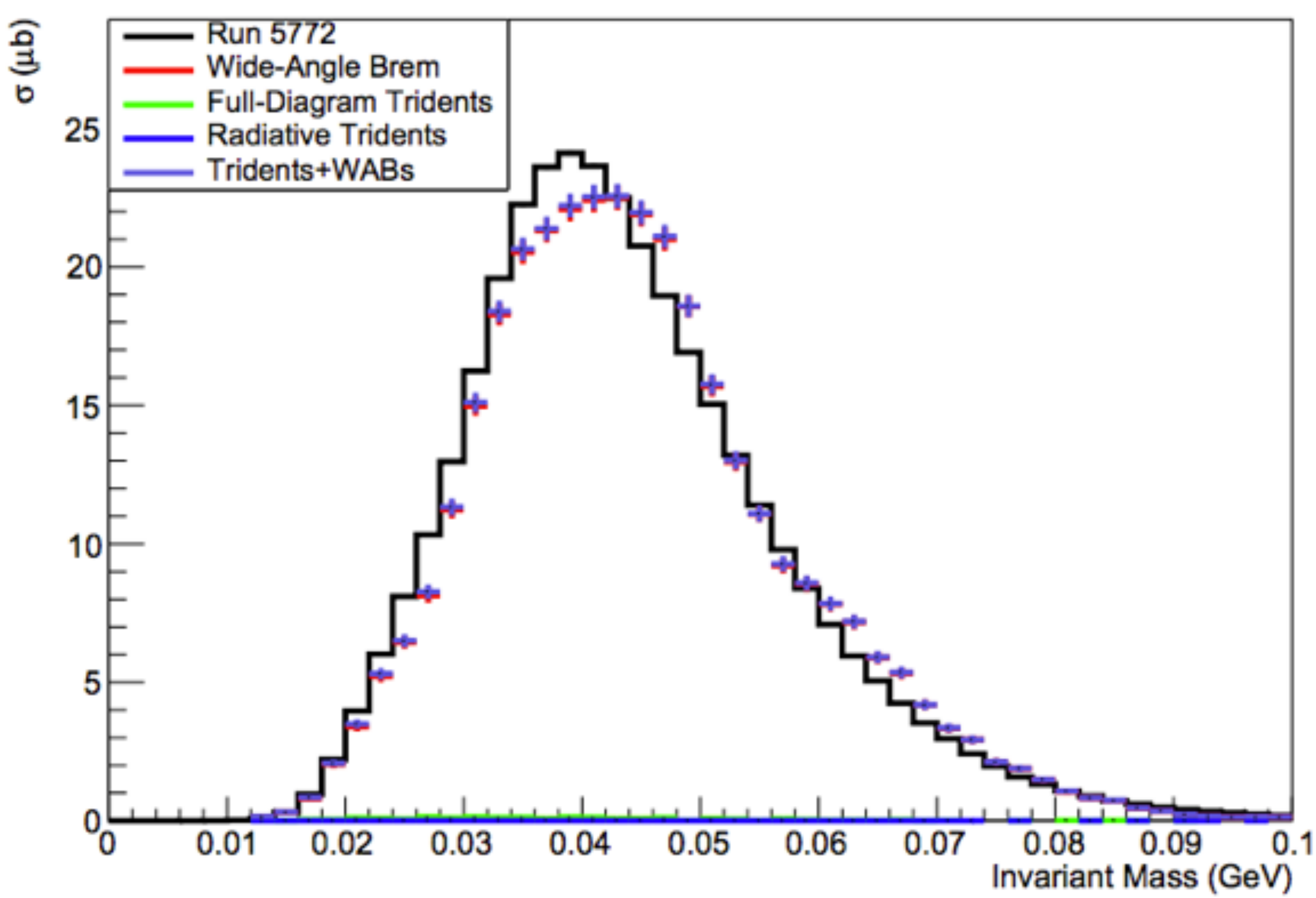
Note that data/MC peak mean/widths don't agree all that well. Some of it could be radiative effects (low-side tail)…





Scaling the WAB cross-section isn't the only (or correct?) thing to do. Other ways to loose WAB → ɣe⁻ events in MC (relative to data). *Maybe MC underestimates WAB-ɣ conversions?* Based on e^- e^+ shapes, this doesn't look likely.

WAB → γe⁻ Invariant Mass & Cross-section



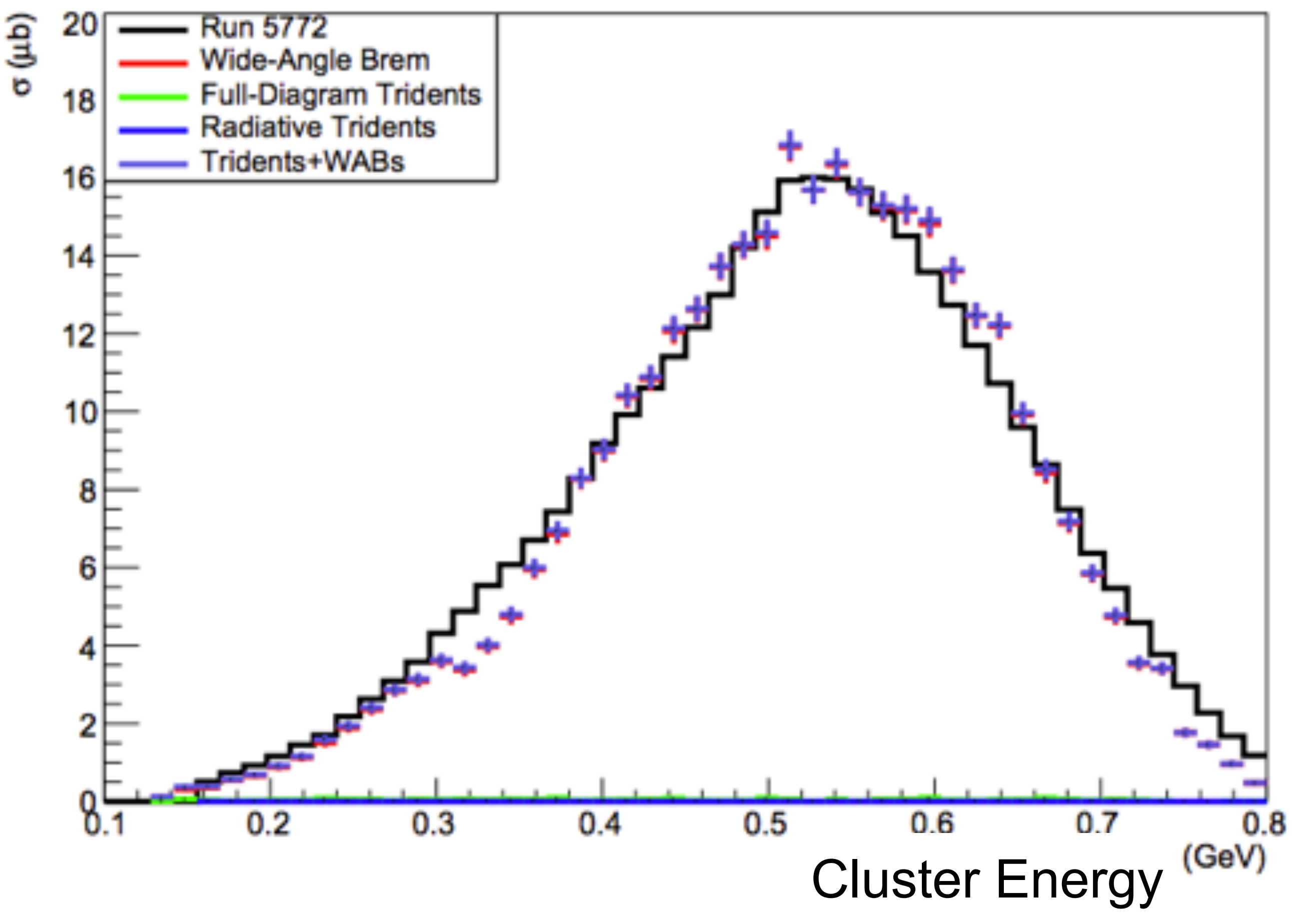
…for this plot (and the following), I've cut at ESum > 0.8*1.05 GeV.

Some of the ESum tail is clearly due to accidentals; this cut cleans them up

ESum>0.5	XS (μb)
Data	421.2
Full Tri	5.0
cWAB	407.9
total MC	412.9

ESum>0.85	XS (μb)
Data	350.8
Full Tri	1.8
WAB	343.6
total MC	345.4

WAB → ɣe⁻ Cluster Energy & Track Momentum

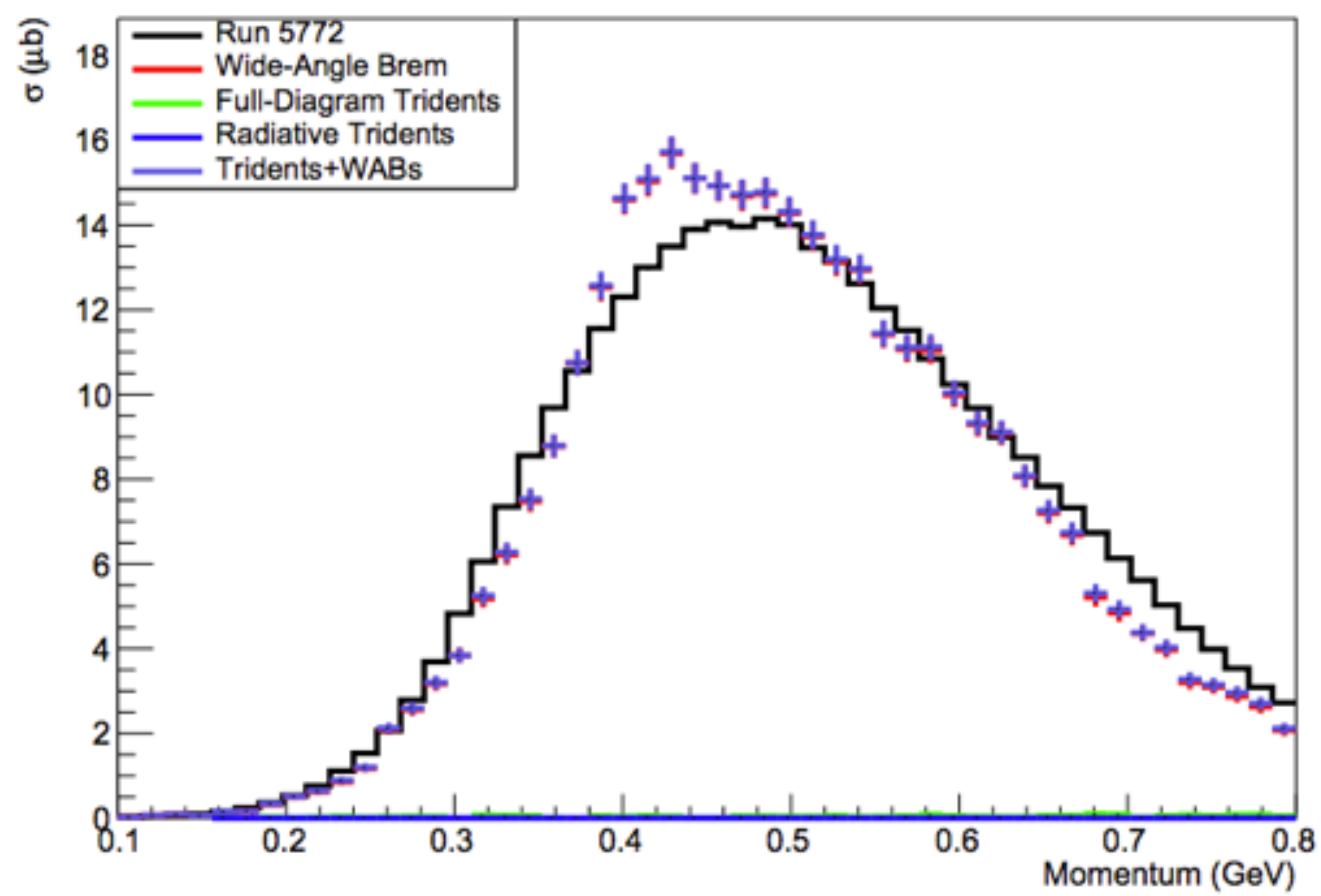


WAB→ ɣe⁻ is a really nice, clean sample and at $\mathcal{O}(1)$ we see really good agreement

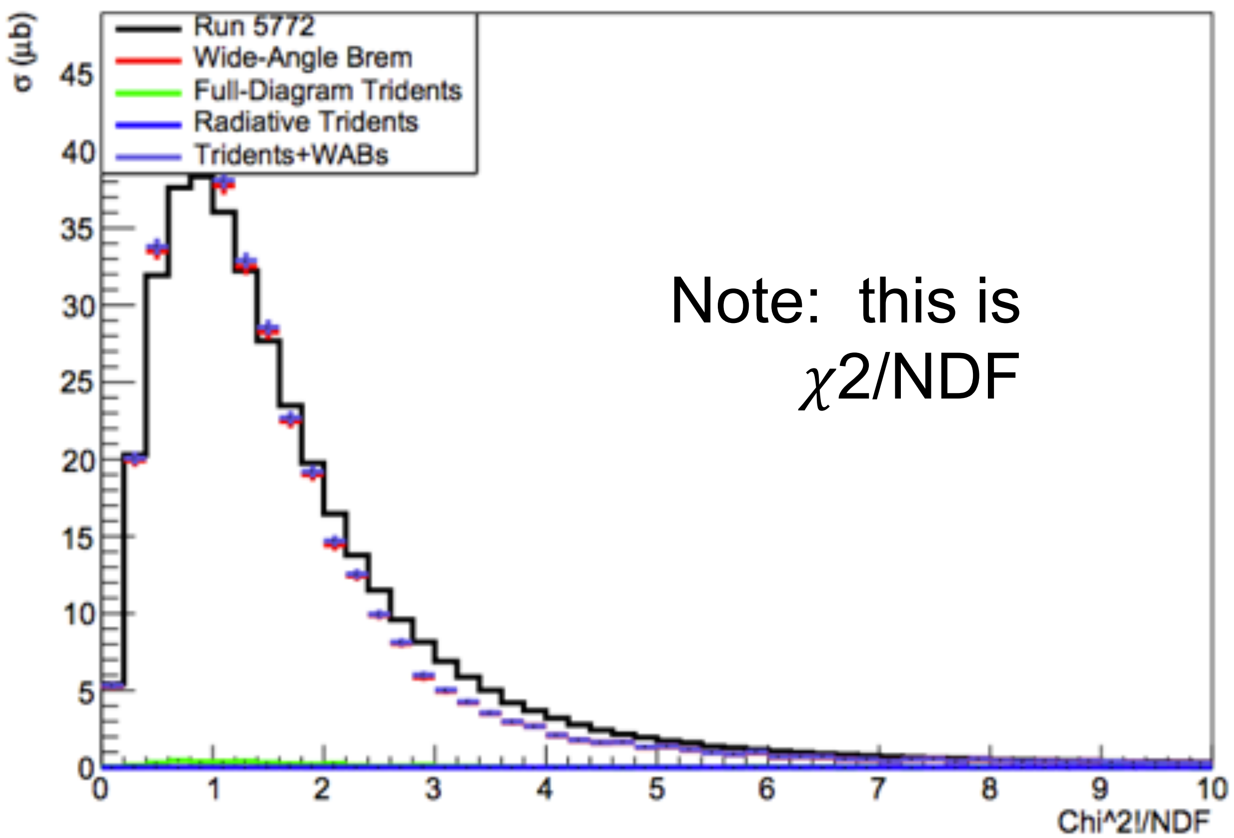
This is a big accomplishment!

If you look closely there are some trends here…data has some longer "tails" in both ɣ energy and e⁻ momentum.

Probably not due to resolution…more likely the higher ESum in data?



WAB Electron: track χ^2 and slope

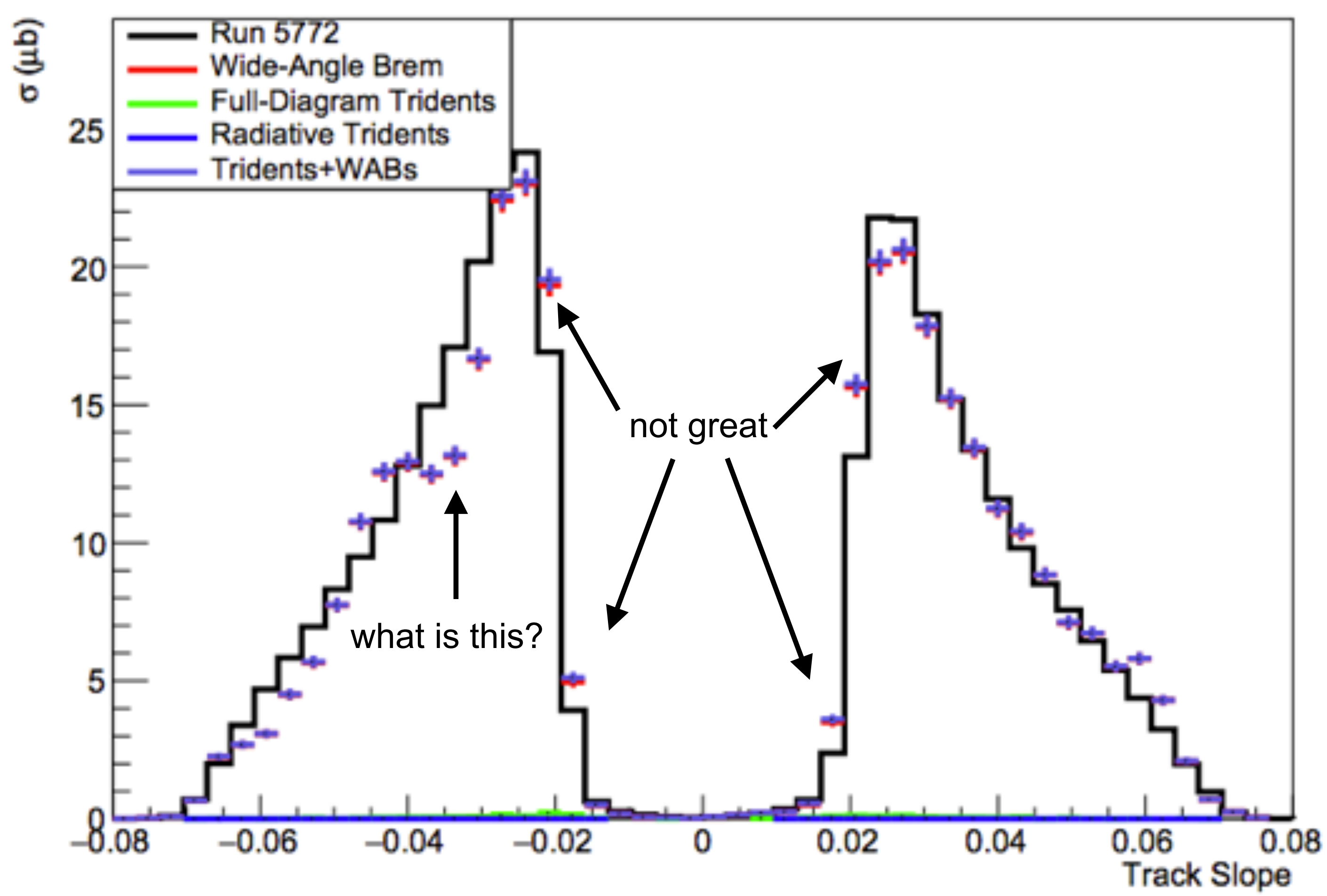


Note: this is χ2/NDF

χ^2 for electron track looks like we've seen before…slightly "worse" for data

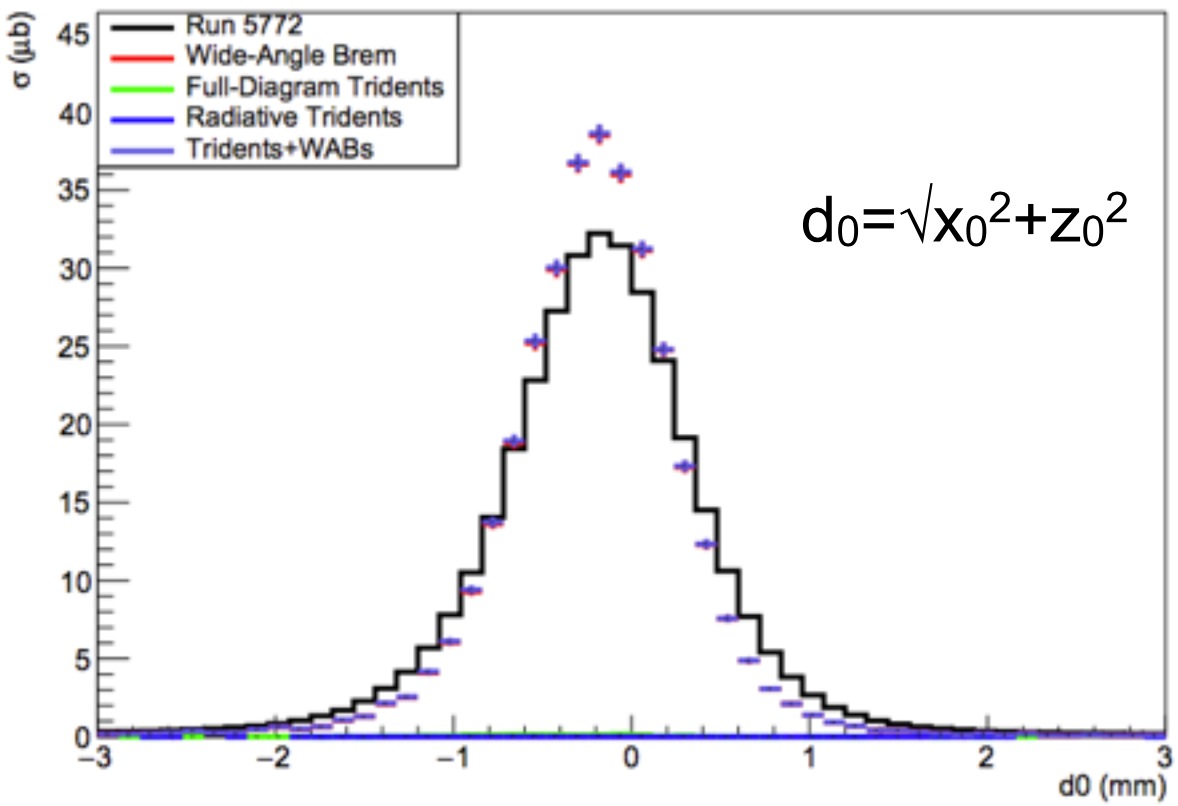
(though I still think this is damn good!)

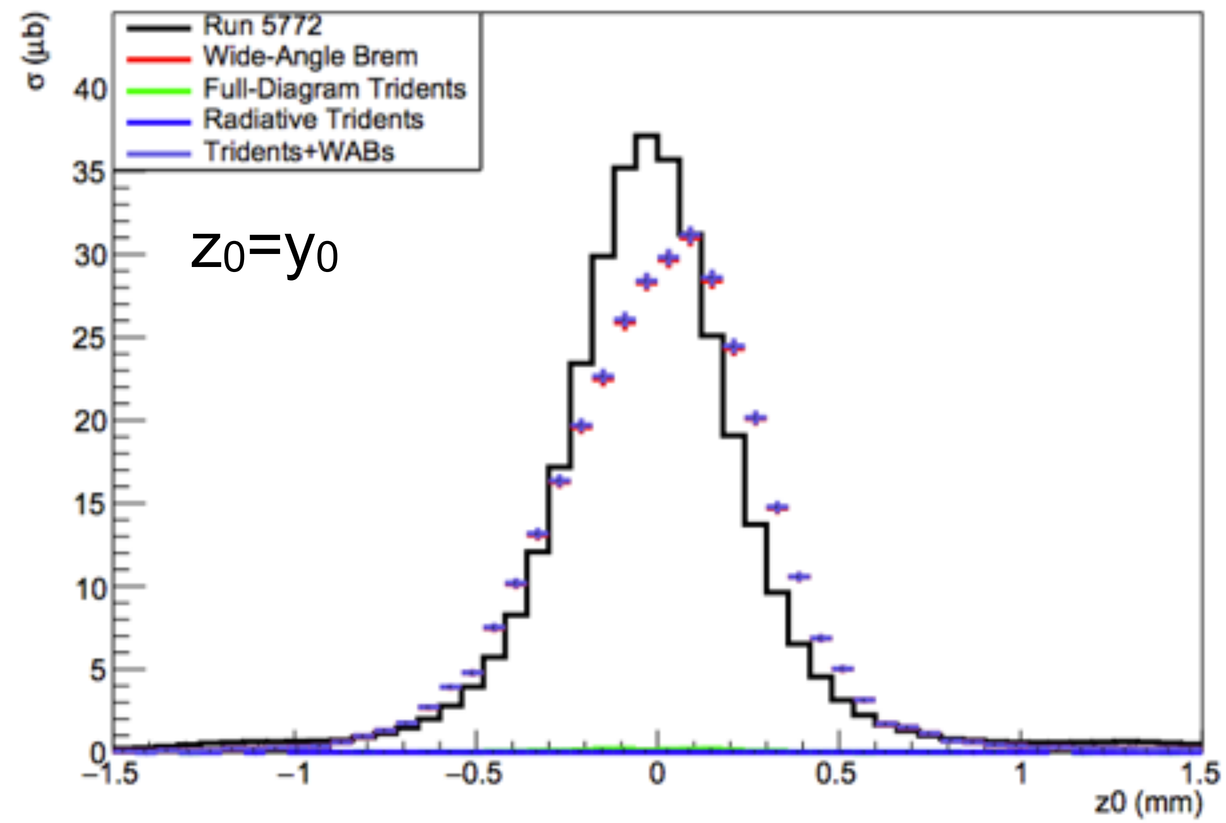
The track slope distribution is always one of the funny plots…I think it shows our small θ_y acceptance is a little off in MC. Geometry? ECal response of edge crystals?



WAB Electron: d0, z0, phi0

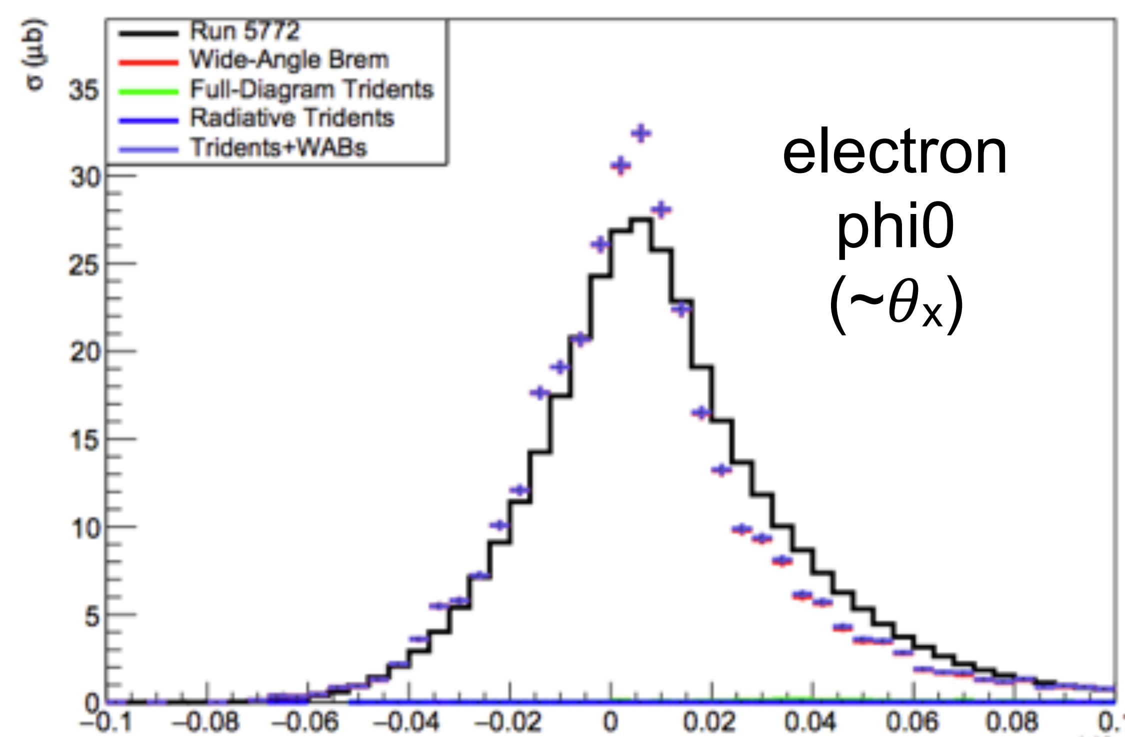
SLAC



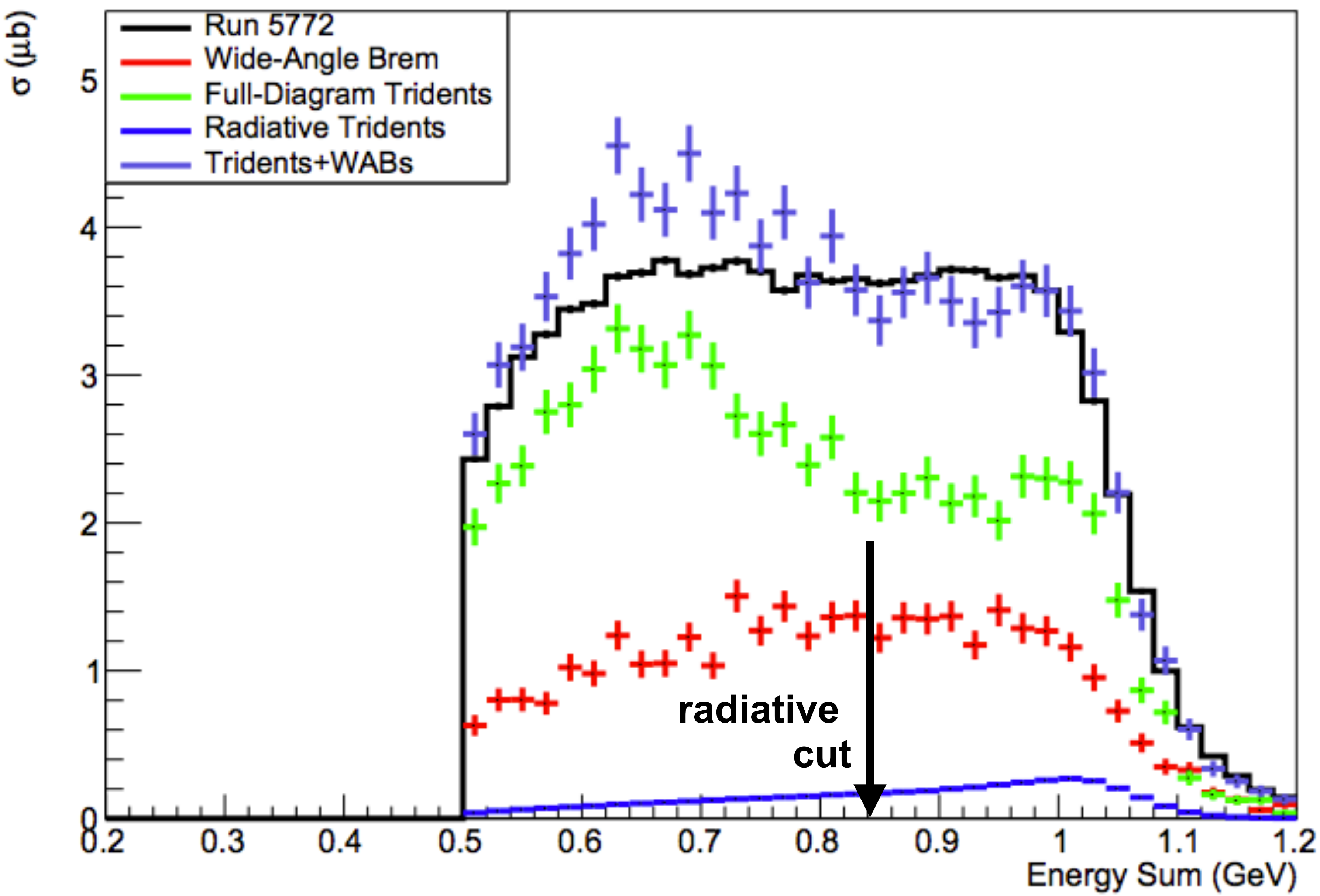


d0, z0 (in tracking frame) slightly broader in data than MC…
Alessandra has improved alignment that should improve this (and other things!)

phi0 (~θ_x) peaks at ~0.01! Shouldn't it be 0.03??
Acceptance vs P effect? It's a little puzzling…



Tridents and cWABs: Energy Sum & Rates

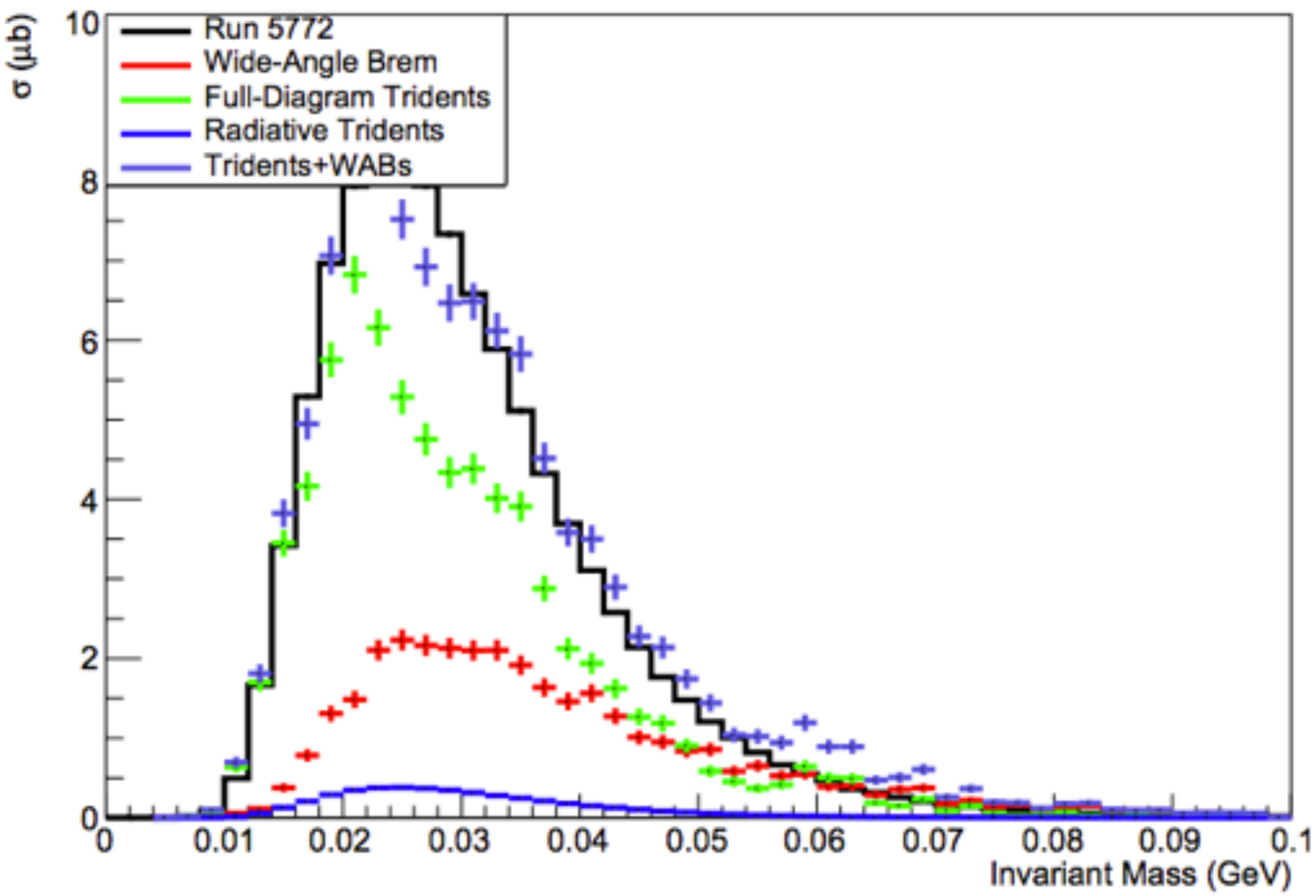


ESum>0.5	XS (μb)
Data	100.9
Full Tri	72.0
cWAB	33.7
total MC	105.7

ESum>0.85	XS (μb)
Data	41.7
Full Tri	25.7
cWAB	14.9
total MC	40.6
Radiative-only	2.7

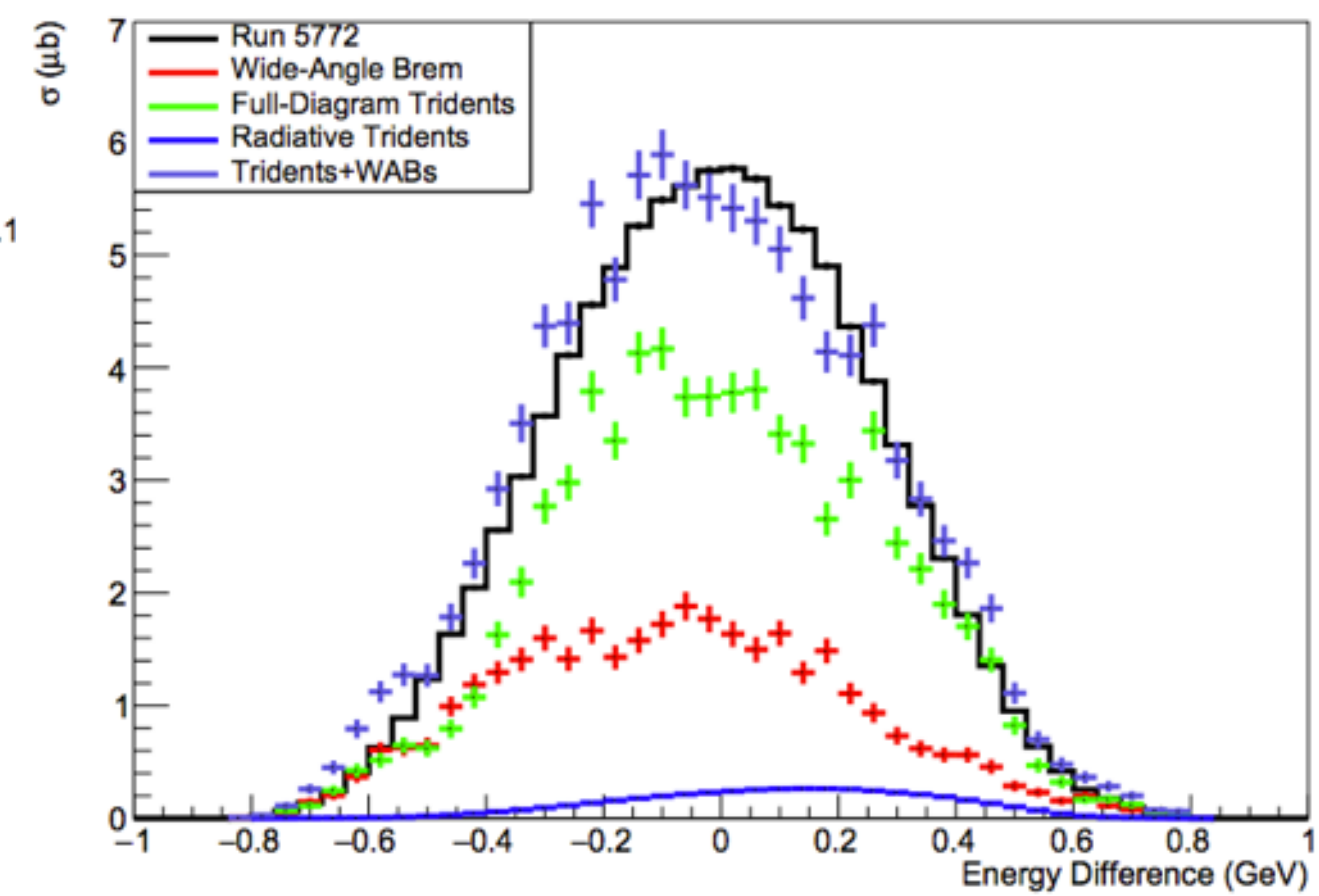
Good enough? (yes, Good enough for now)

Tridents and cWABs: Mass and Δp



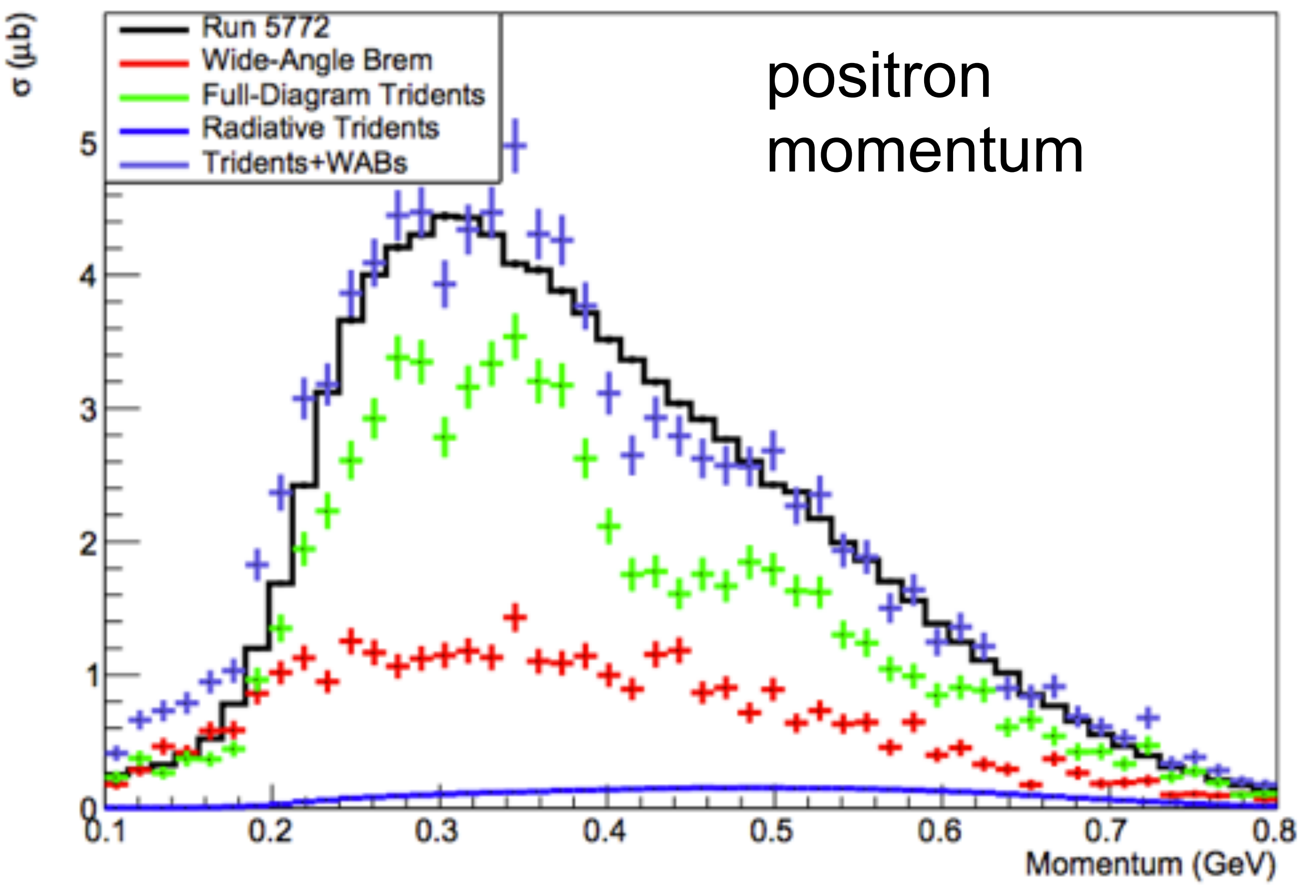
There are some weird structures in the MC…they show up in all of the plots.

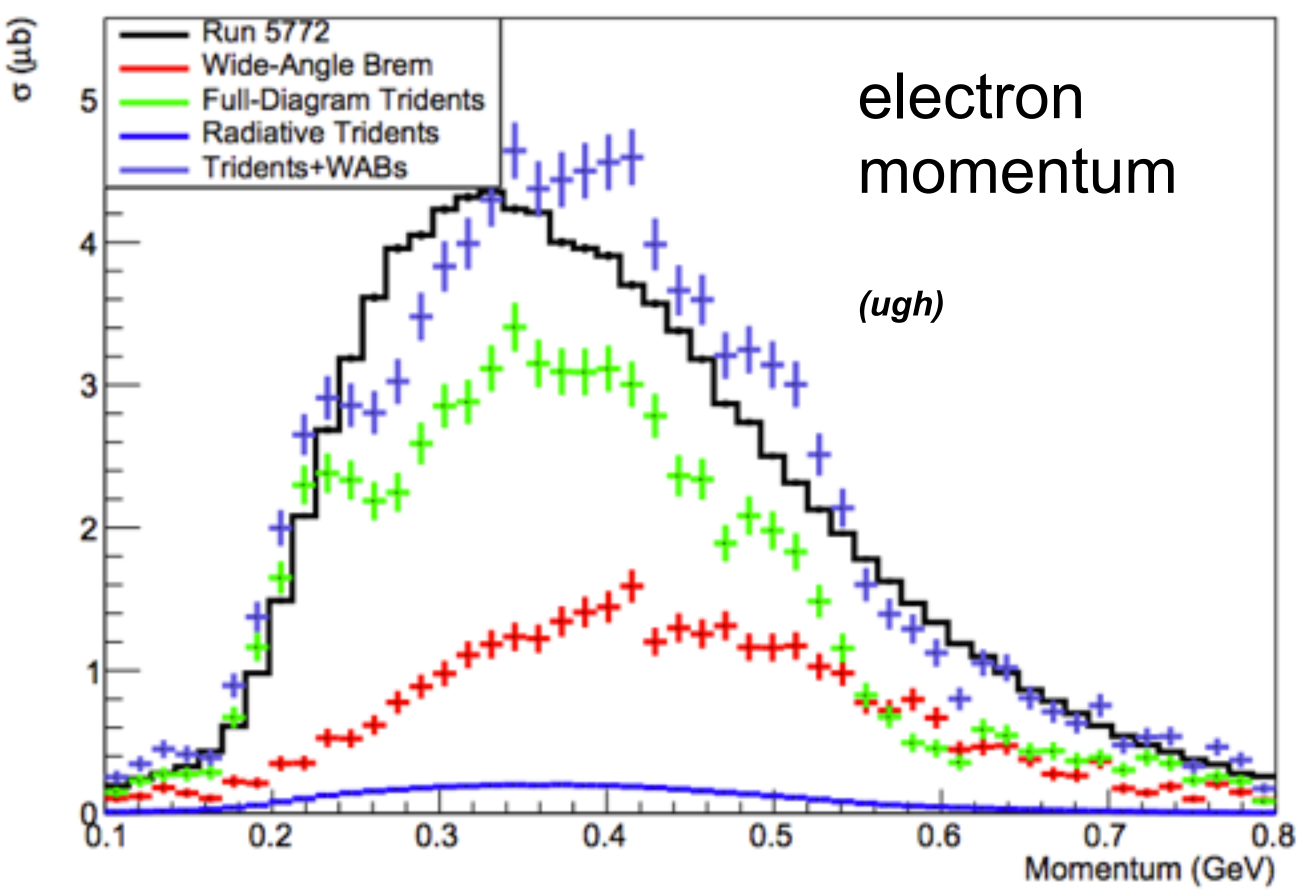
Obviously, need more MC stats…hopefully they go away?



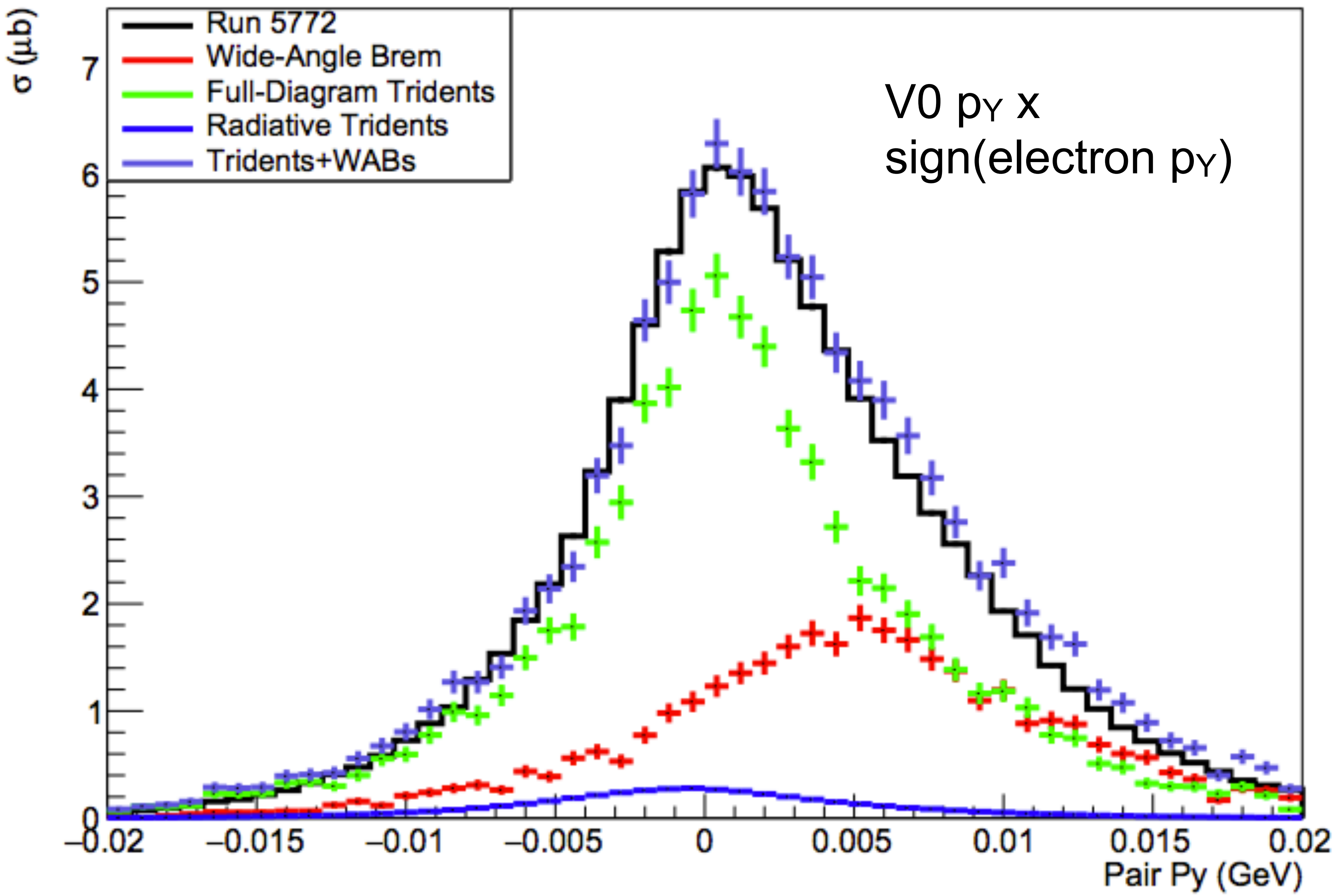
Even with these MC "hiccups", the shapes generally look ok…

Tridents and cWABs: Track Momenta



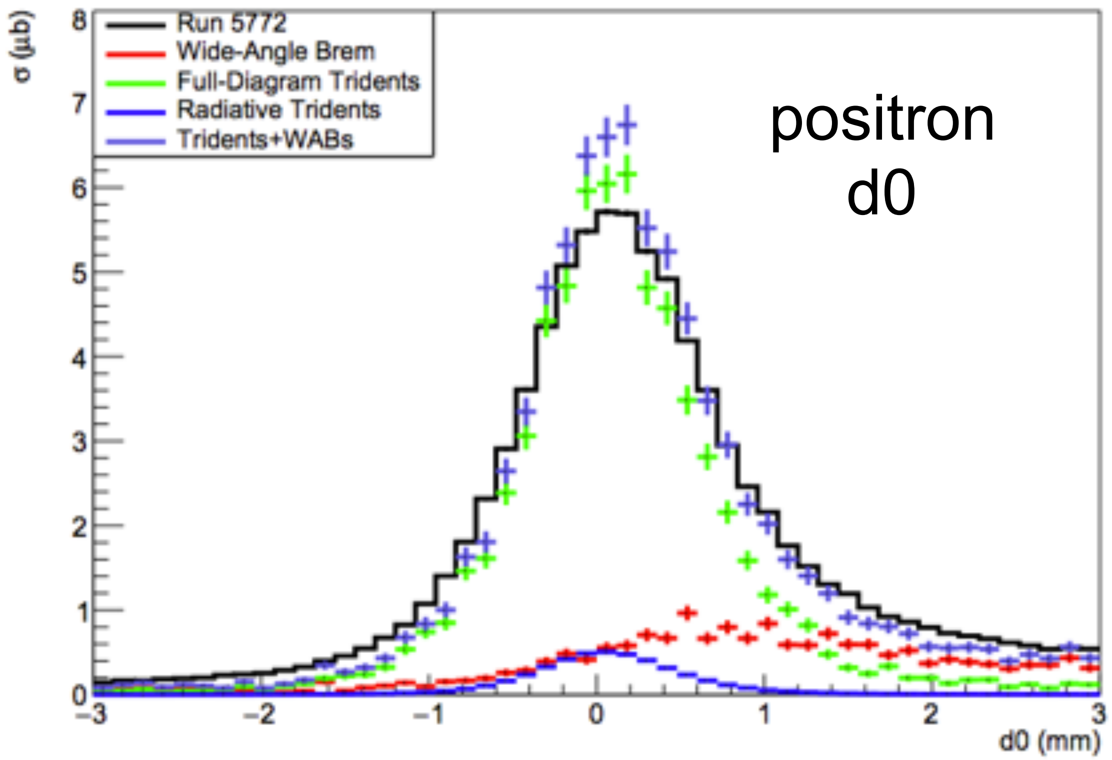


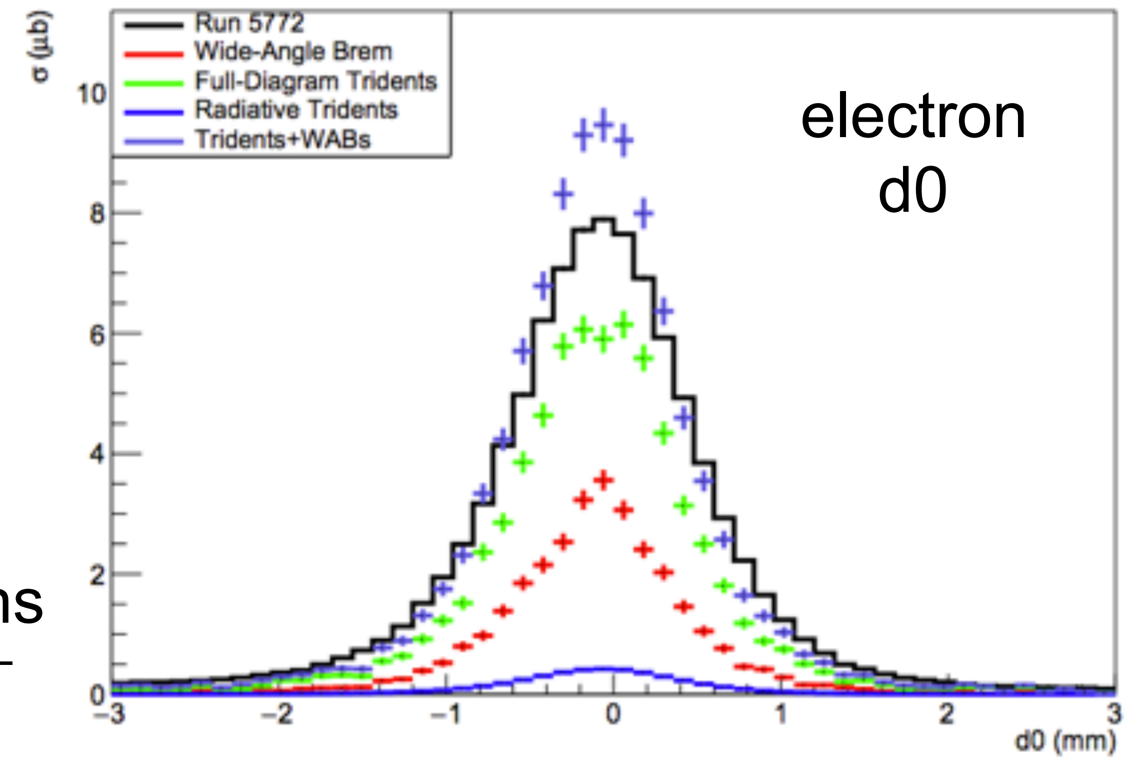
Tridents and cWABs: V0 pT



This is a variable where WABs look quite a bit different than tridents.
If you leave the WAB cross-section to it's nominal value the MC tail here is significantly high…***also evidence against increasing MC WAB conversion rate***.

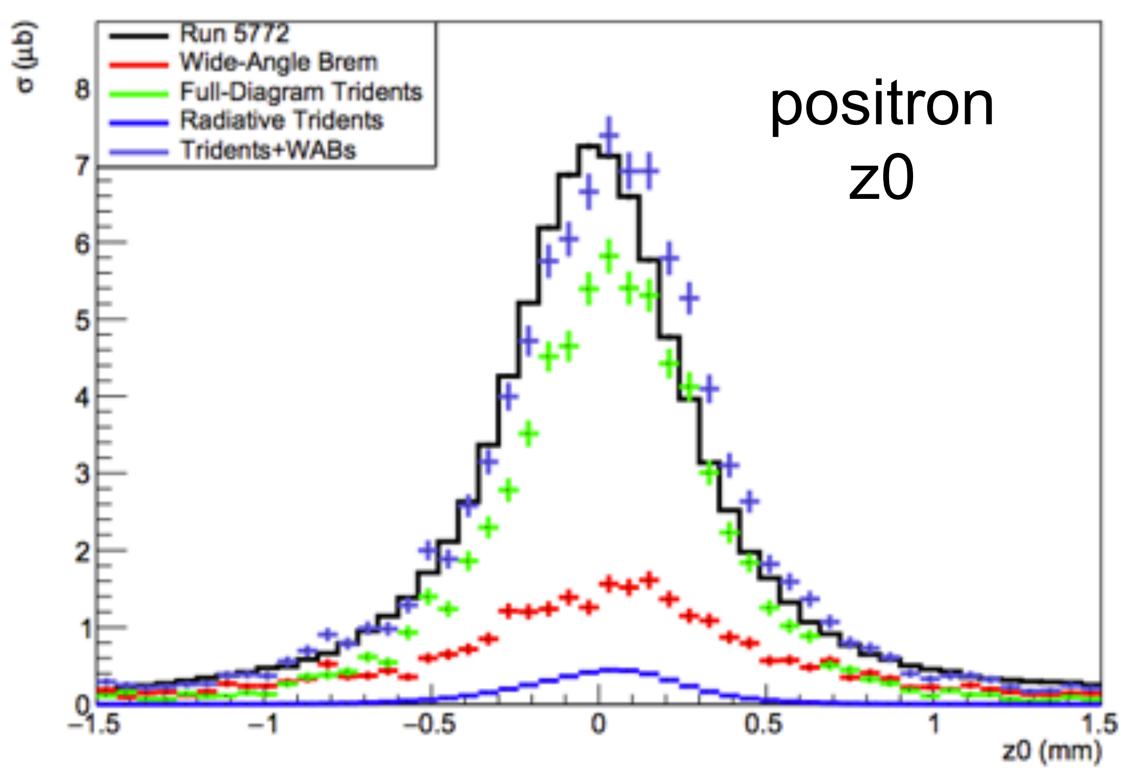
Tridents and cWABs: d0 & z0

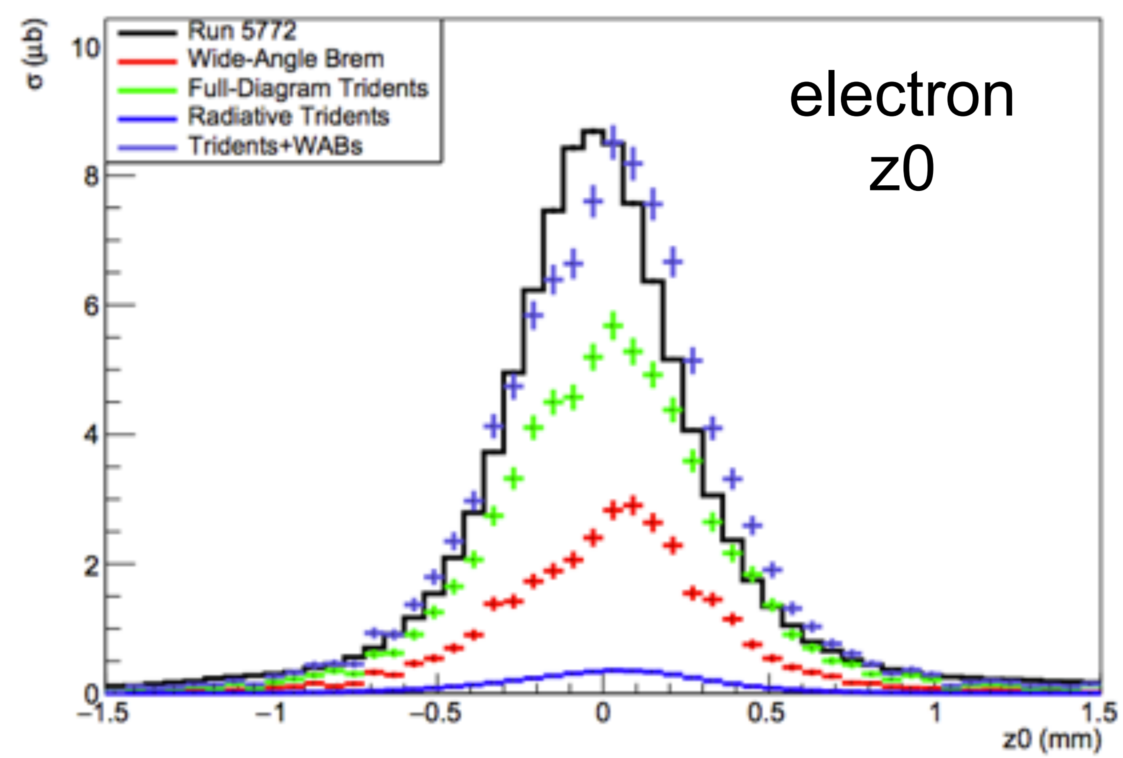




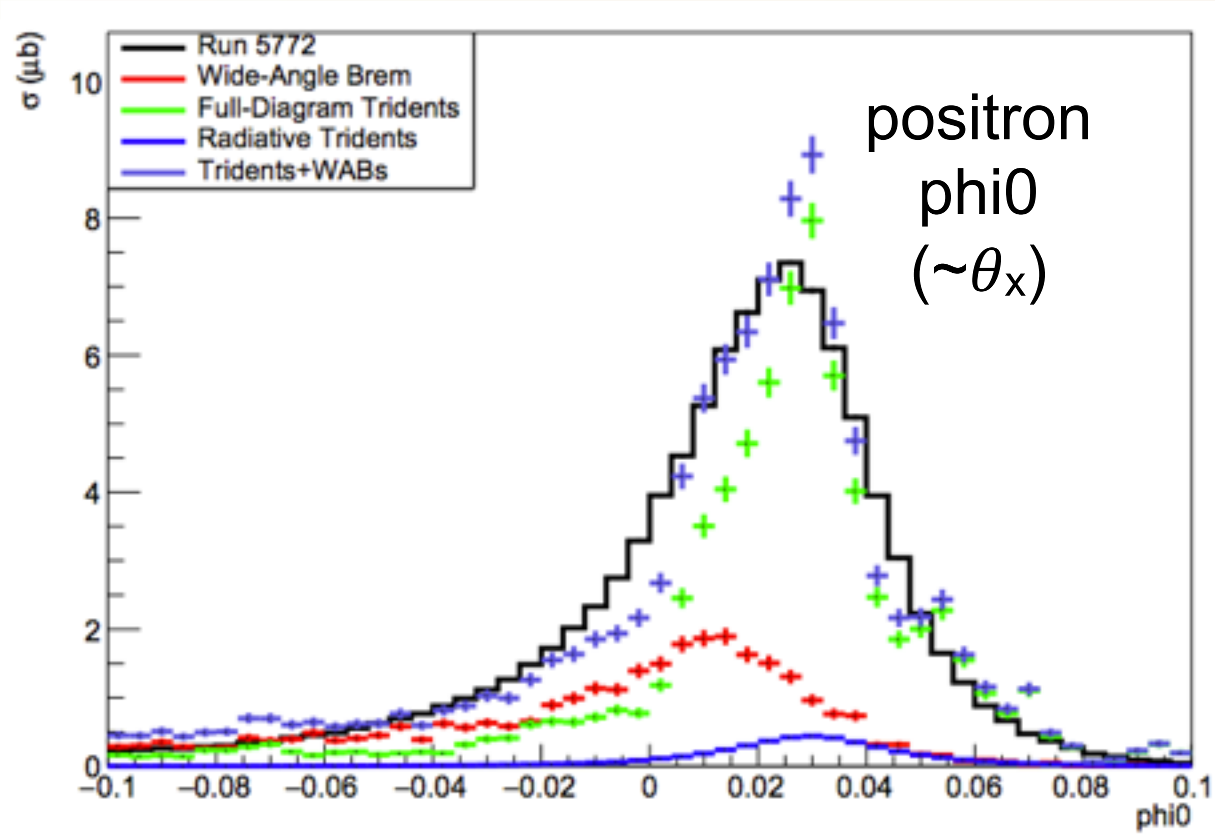
Similar patterns as WAB→ɣe⁻

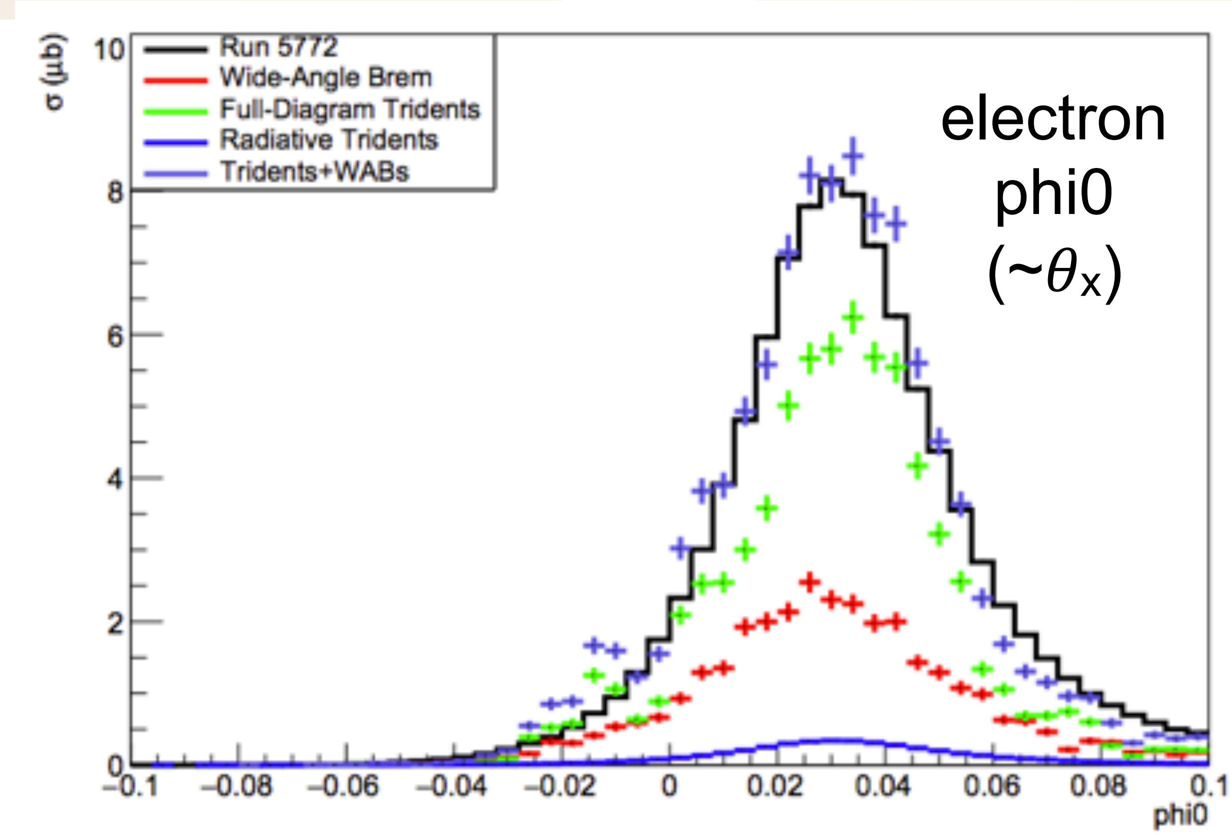
improved alignment will help!

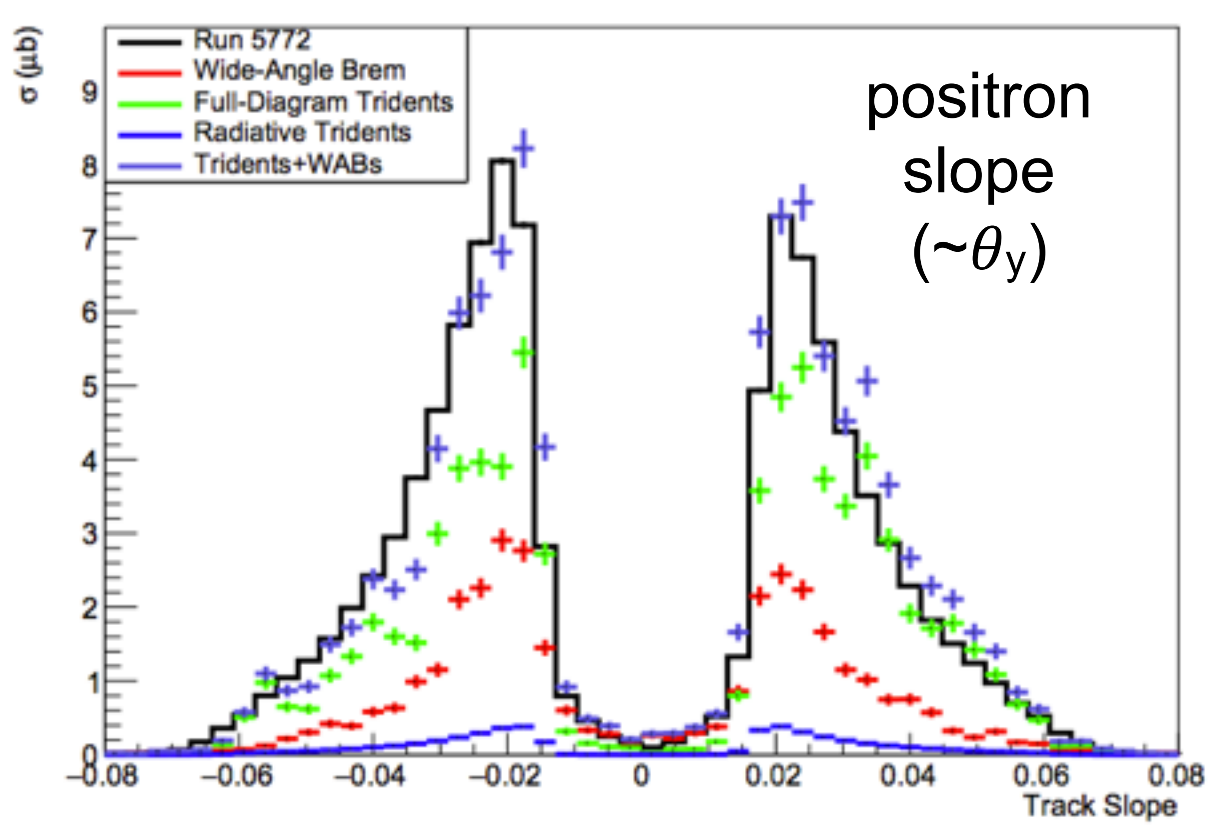


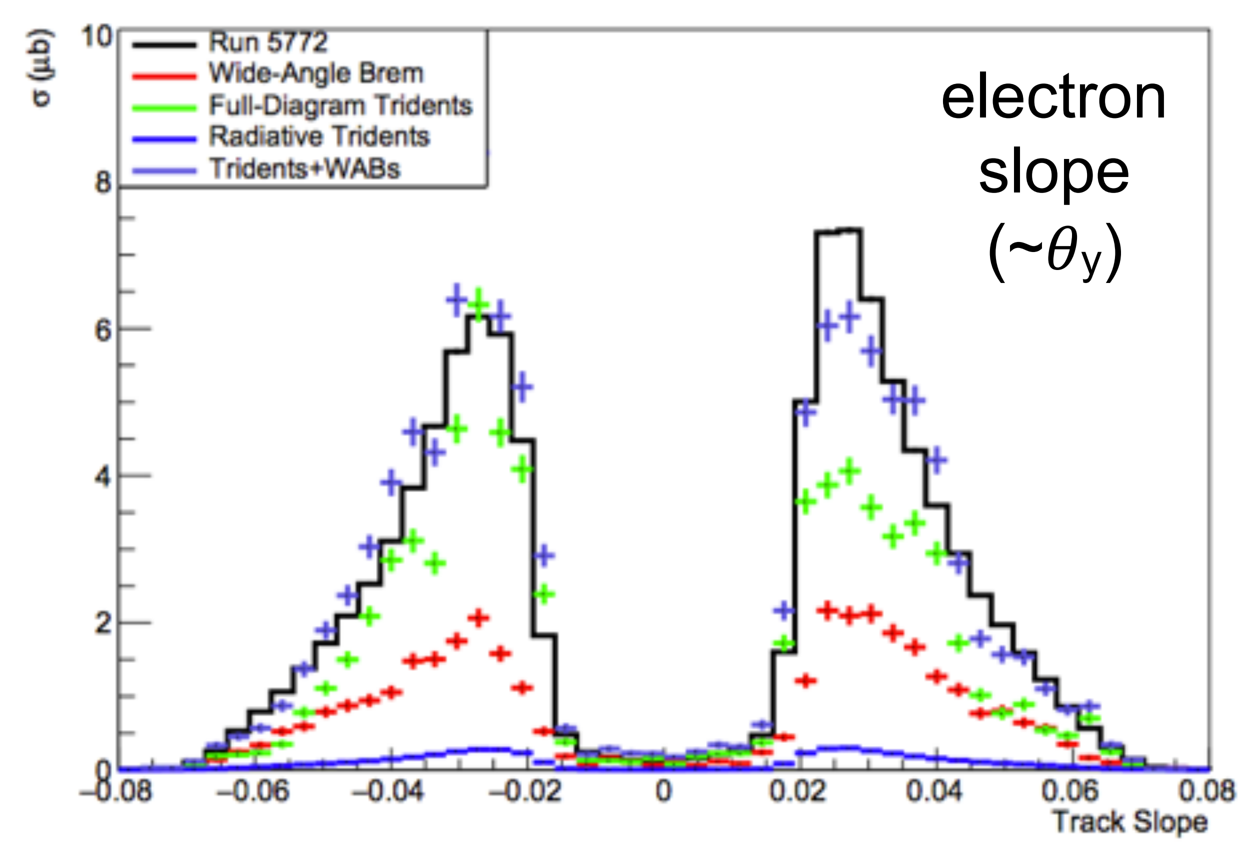


Tridents and cWABs: track slope and phi0









Layer 1 Hit Efficiency

- Everything I showed just now on WABs, cWABs and tridents combined tracks from all tracking strategies…didn't separate out tracks with first hit in L1 from first hit in L2 (which we know is a good discriminator between tridents and cWABs)
- When we do separate these out………..

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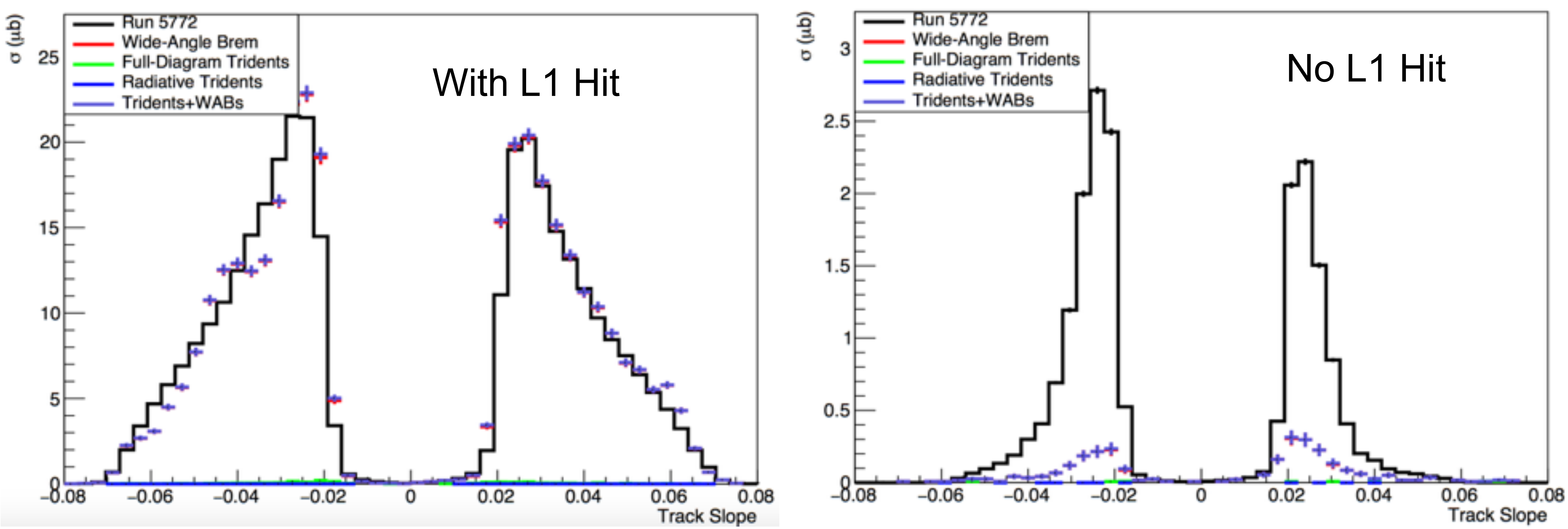
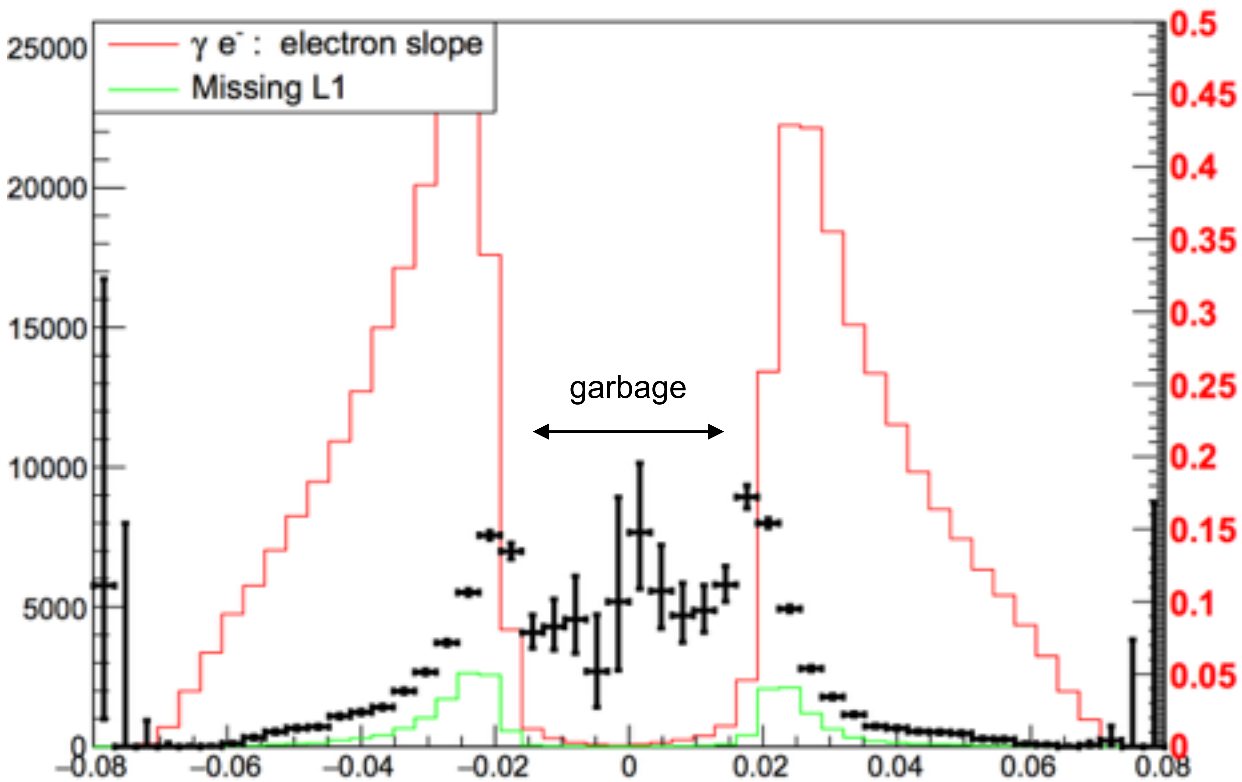
- When we do separate these out……….for WAB→γe^-…



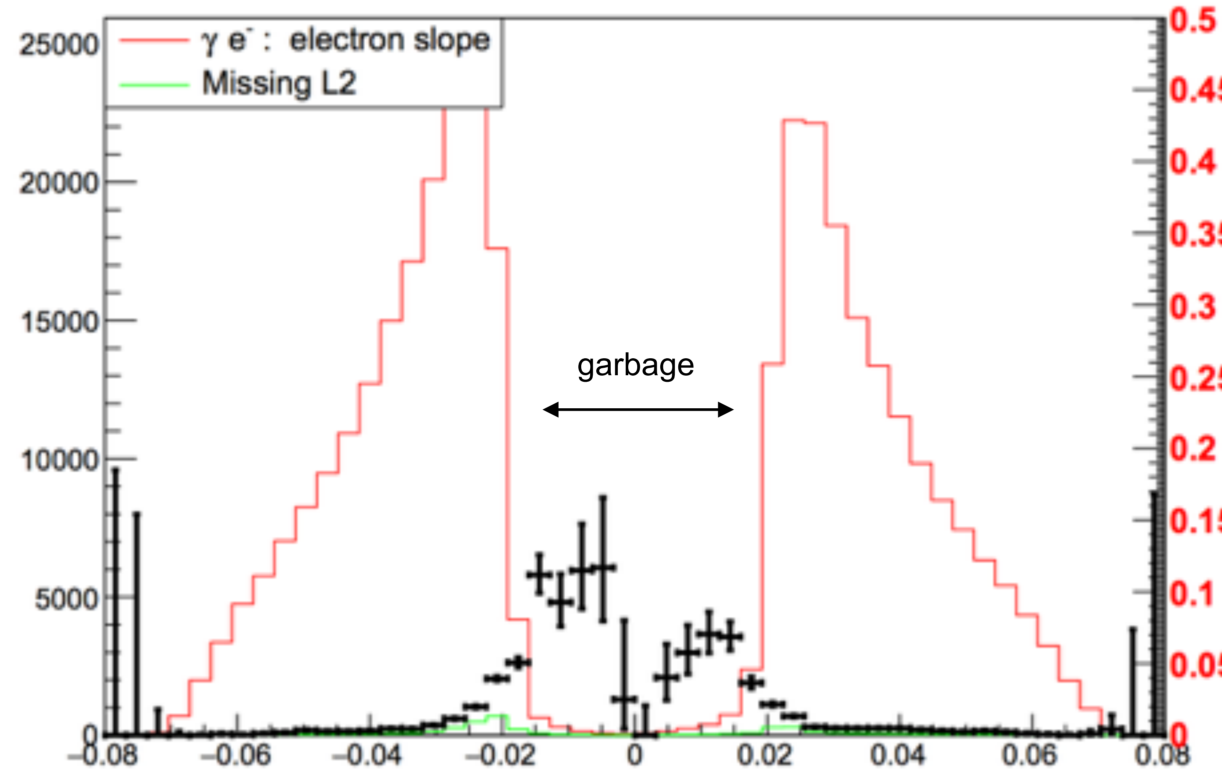
Layers 1 & 2 Hit Efficiency in Data

L1 Inefficiency



track slope (θ_y)

L2 Inefficiency



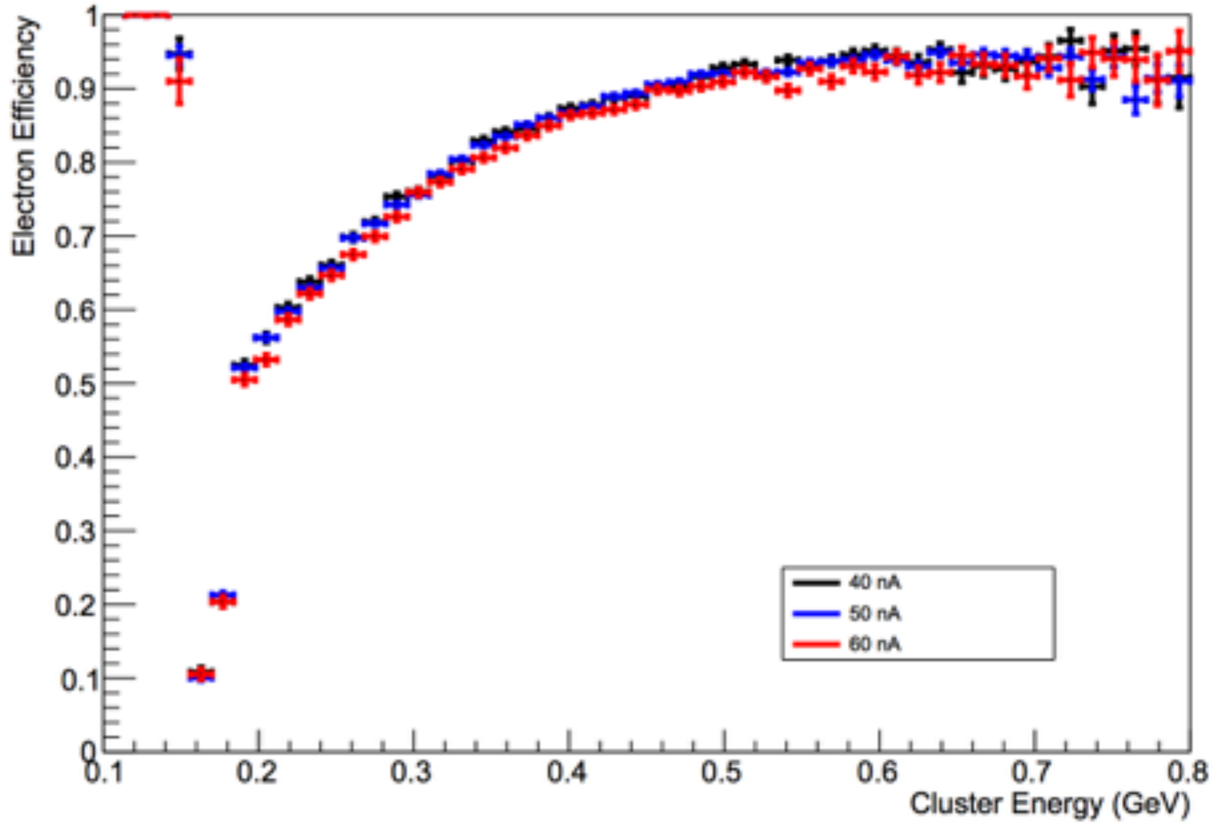
track slope (θ_y)

We've seen before that L1 has a larger SVT hit inefficiency before (Omar & MrSolt's studies)…this just shows it again. Inefficiency higher at small angle→closer to the sensor edge→higher occupancy→more overlapping hits. Figuring out how to either a) recover these hits in data; or b) simulate in the MC should be on the list…

The MC track efficiency corrections will "account" for this in that it will de-weight tracks with clusters at small Y.

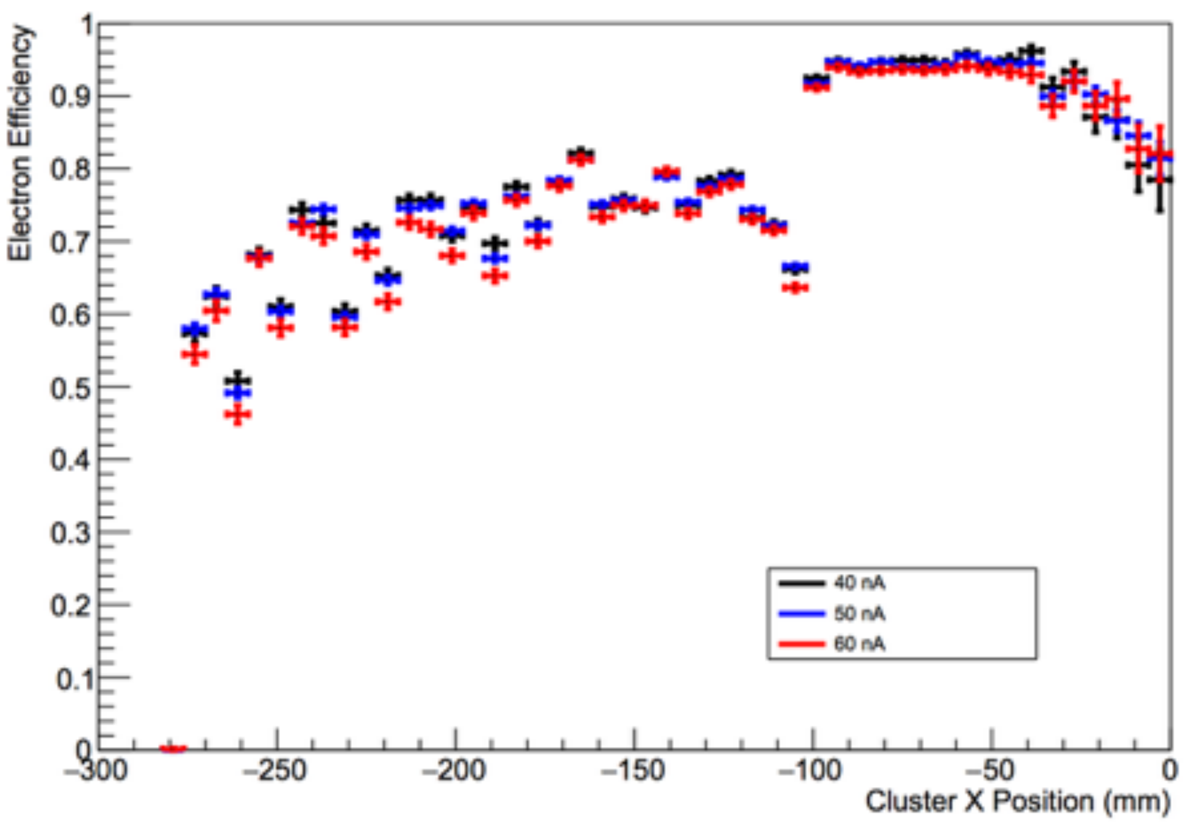
Beam current effects on track efficiency: Electrons

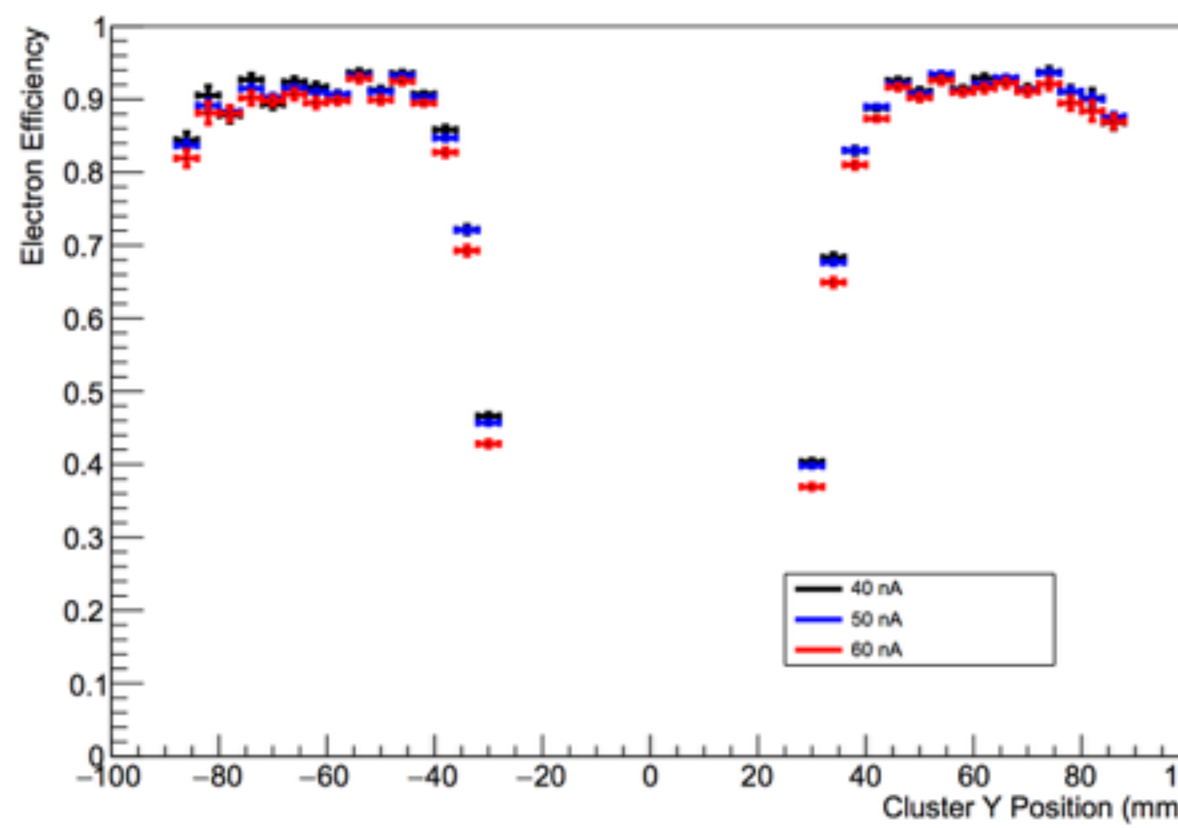
SLAC



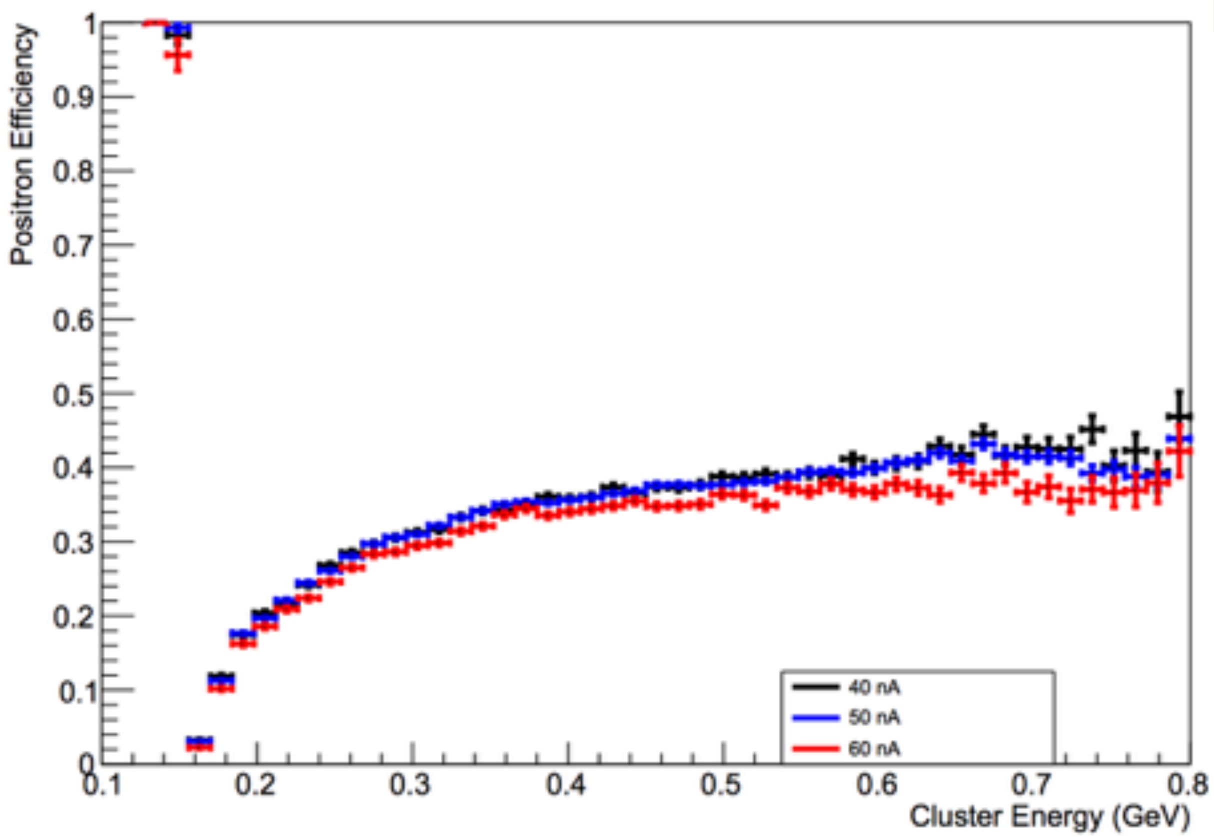
Data from 3 runs at different currents…
run 5754: 40 nA
run 5772: 50 nA ⟵ nominal current
run 5755: 60 nA

Definitely a small, current-dependent trend…
40 → 60 nA drops efficiency ~ a few percent, up to ~10% at very small θ_y





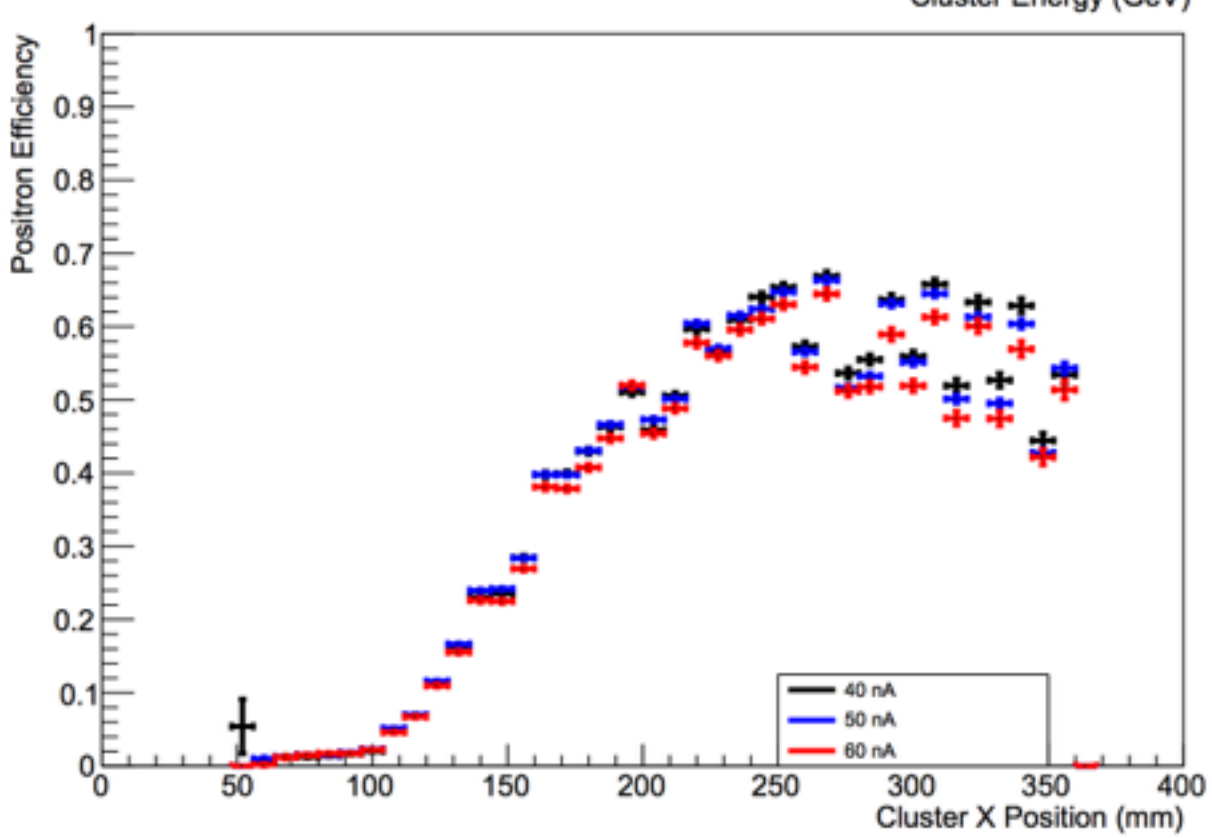
Beam current effects on track efficiency: Positrons

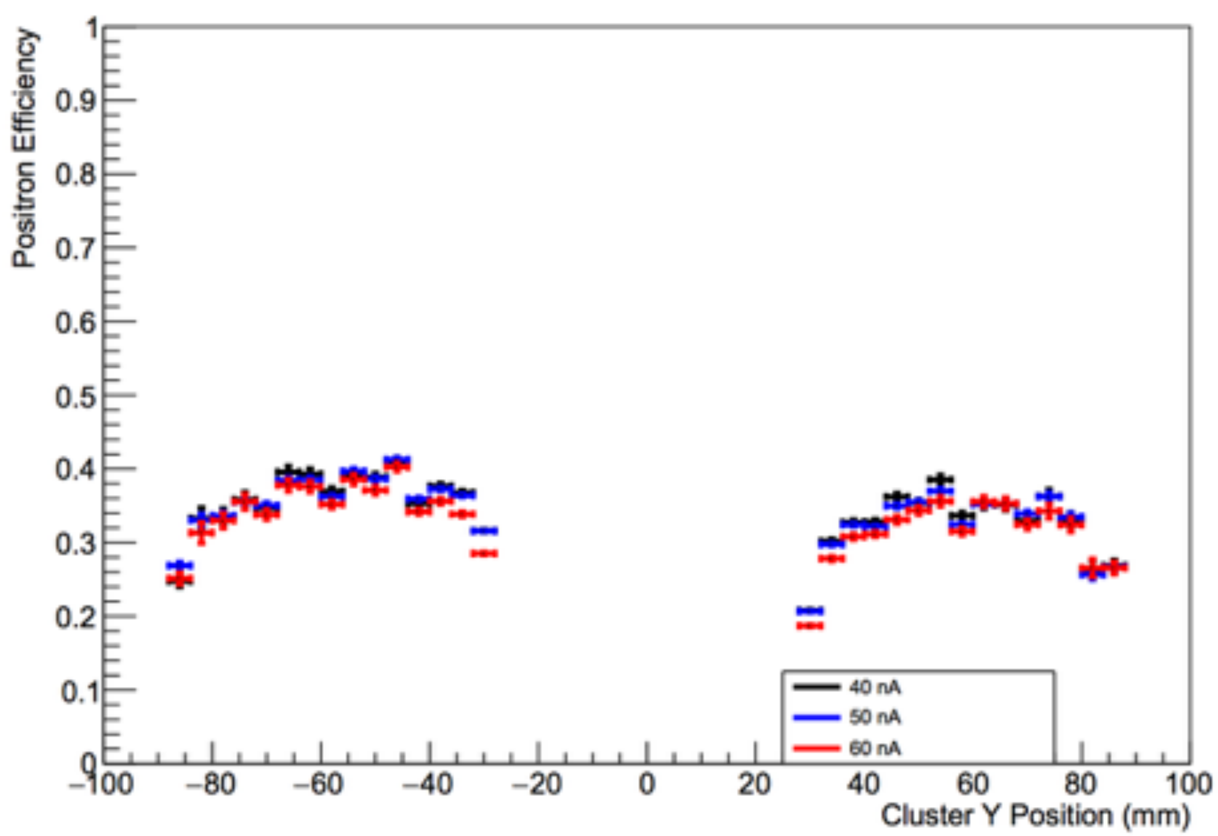


Data from 3 runs at different currents…
run 5754: 40 nA
run 5772: 50 nA ← nominal current
run 5755: 60 nA

Positron trend is somewhat stronger, though that may be due to more random $e^{-}\gamma$ contamination at higher rates…

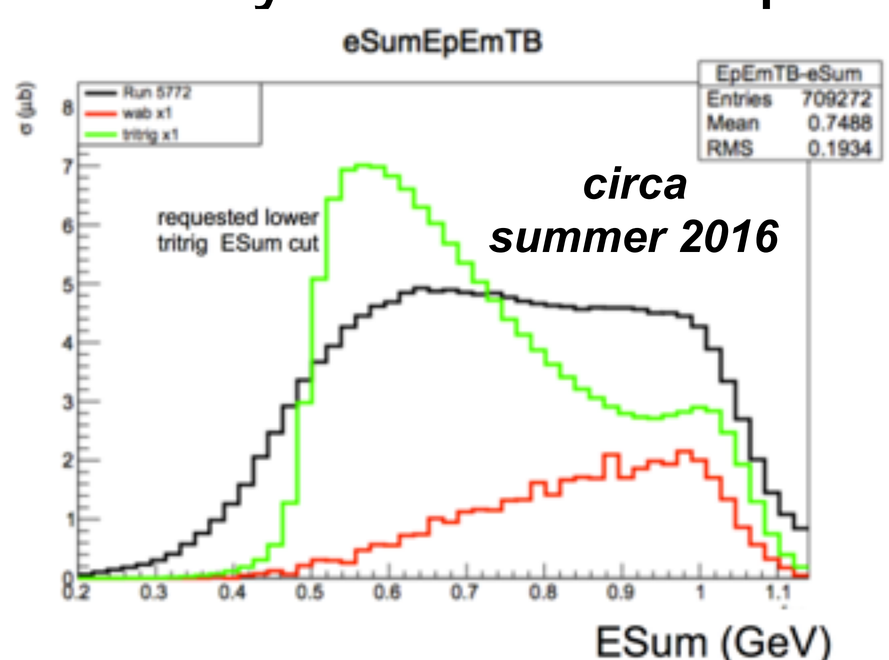
Either way, doesn't seem like a major concern…





Conclusions

- The *electron* efficiency and corrections are pretty well understood
  - going to a 3d correction (X,Y,E) would be an improvement
- The *positron* efficiency and corrections needs work
  - to first order, using electron correction is probably ~ok…better than nothing!
  - really need to use 3-prong events for this…but that's not easy either! See Holly's talk.
- The WAB-cWAB-trident picture has come together in the last year…"trident problem" is pretty much solved!!!(?)



- We've moved on from worrying about $\mathcal{O}(1)$ effects to worrying about $\mathcal{O}(0.1)$ effects… progress!