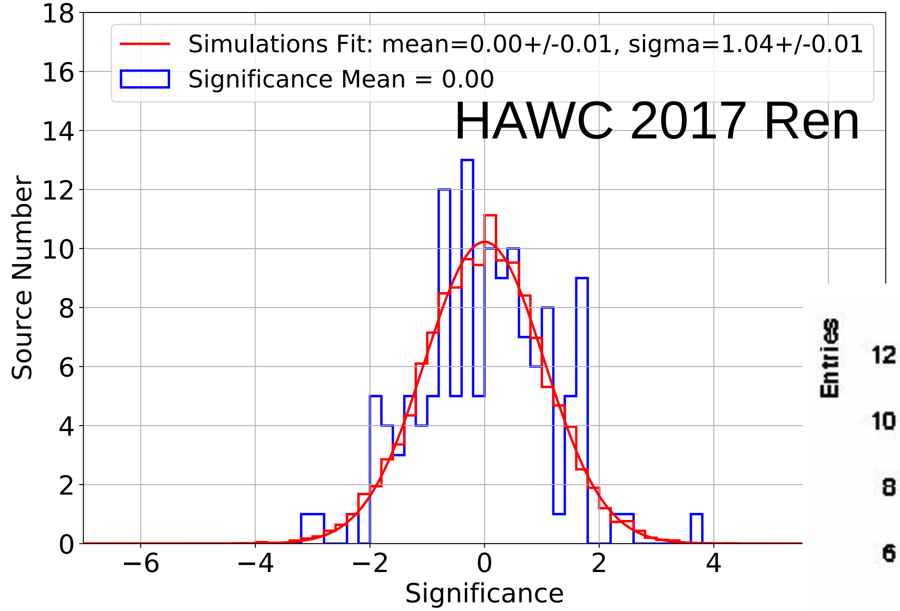
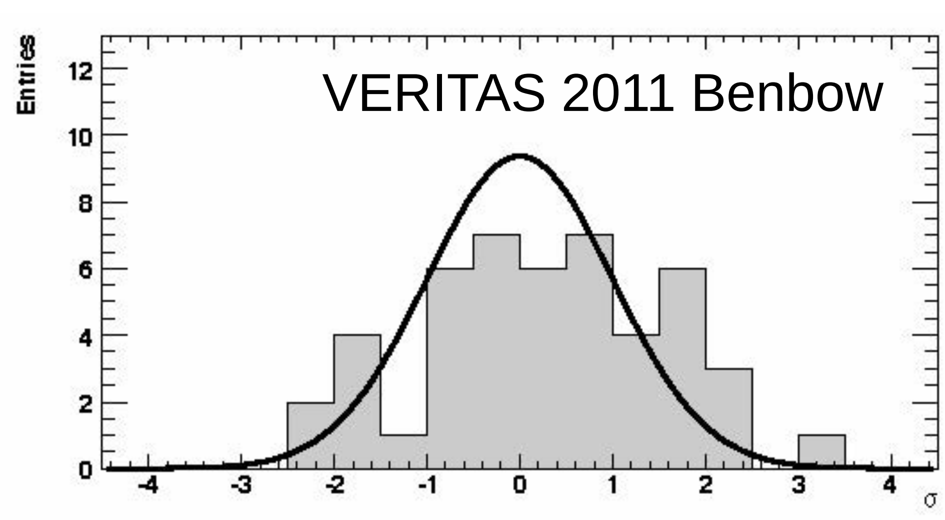
Lessons learned from <1 TeV Simulations

(Motivated by directed surveys of AGNs)





John Matthews (+ R. Lauer, Z. Ren), Physics and Astronomy, UNM
HAWC Collaboration meeting:
Cocoyoc, Mexico, Oct 29 ~ Nov 1, 2017

Overview … IF we are allowed to dream!

HAWC works quite well for events > 1 TeV

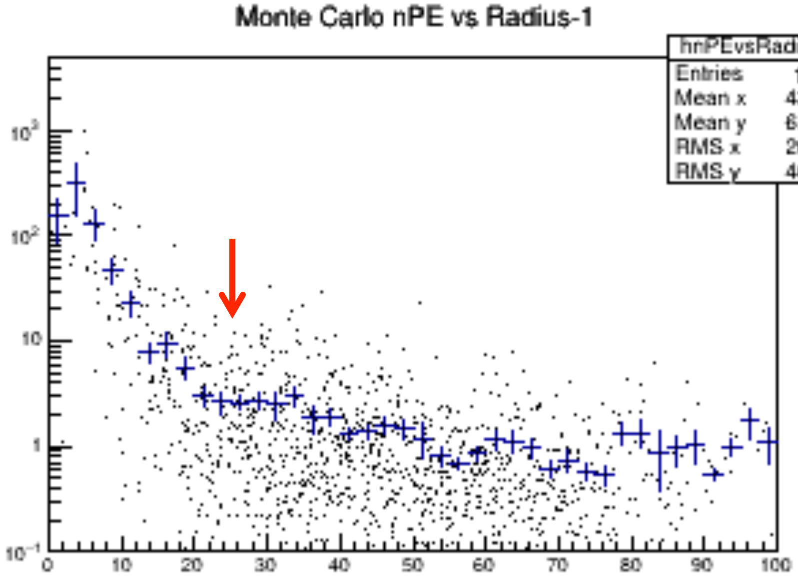
What might we do to improve HAWC performance for showers with energies < 1 TeV? (For example it would be nice to observe more than 2 AGNs …)

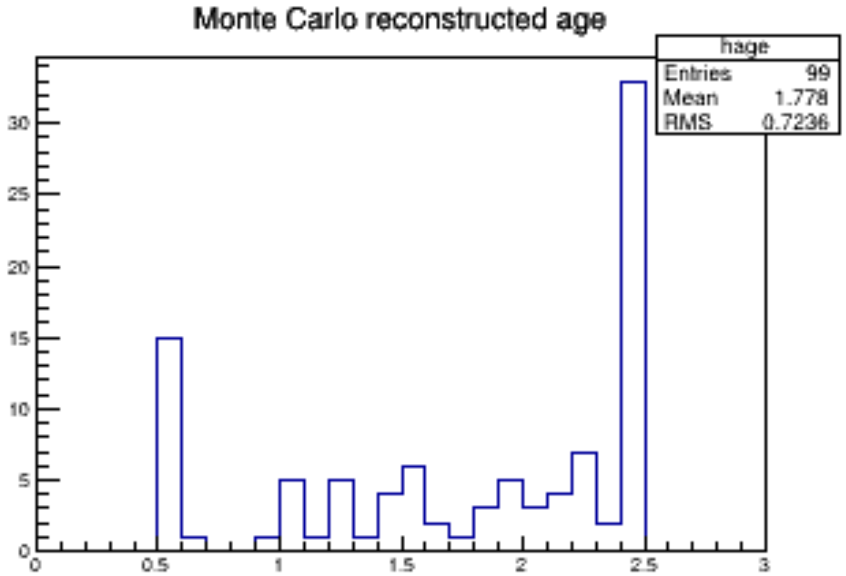
Components considered:

- Increase area of *low-energy* array (to reduce edge effects)
- Increase elevation (to help *low-energy* shower particles reach the array)
- Increase tank sensitivity (so when there are tank *signals we* record them)

Increase area of *low-energy* array

Remember that HAWC tanks provide a calorimetric measurement of the shower. For *low-energy* showers most of the signal is within ~25m of the core:



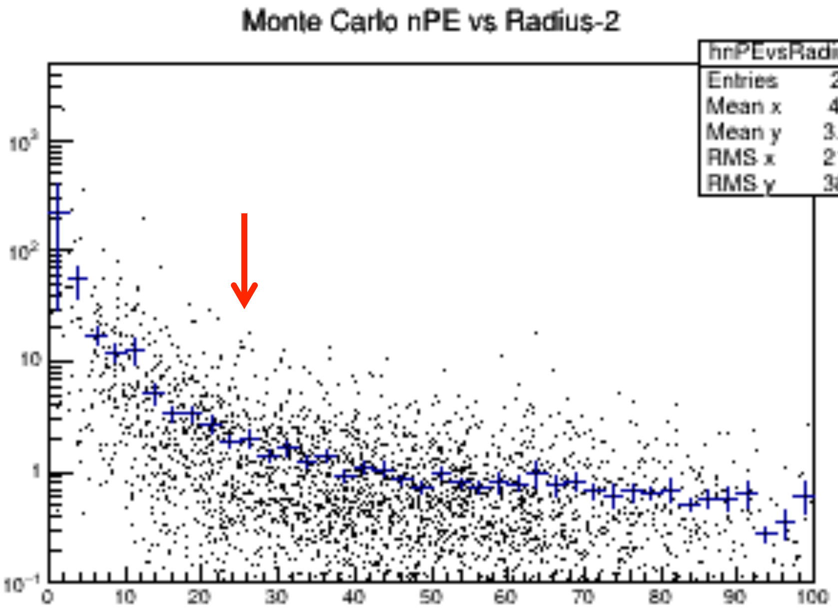


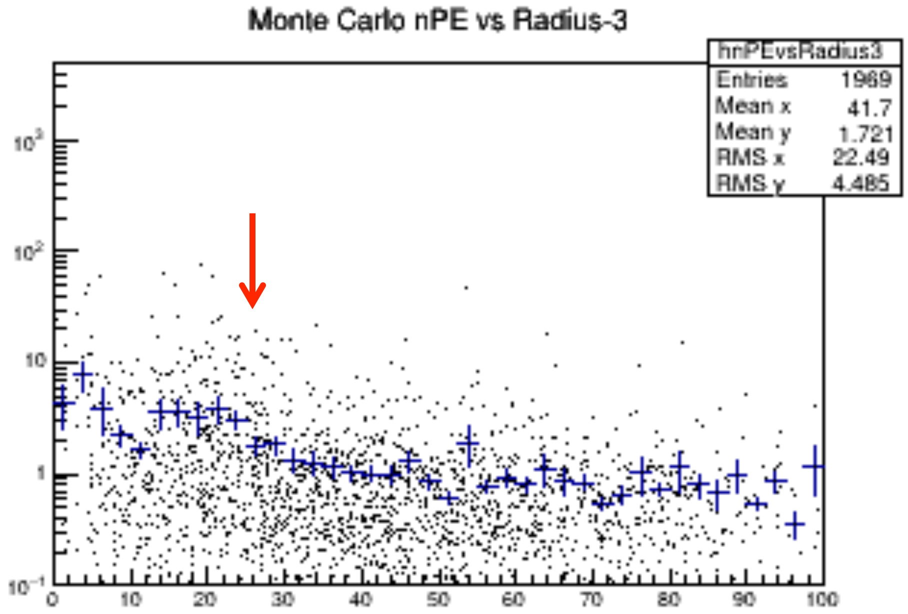
Left: nPE versus distance (m) from core for gamma showers with 500 GeV < E < 2000 GeV and zenith < 26° and core in center of array and GamCore *age* = 0.5 (fit limit)

Right: GamCore reconstructed shower *age* distribution

Increase area of *low-energy* array

Remember that HAWC tanks provide a calorimetric measurement of the shower. For *low-energy* showers most of the signal is within ~25m of the core (and about 1/3rd of the showers have *no* core):





Left: nPE versus distance (m) from core for gamma showers with 500 GeV < E < 2000 GeV and zenith < 26^{o} and core in center of array and GamCore *age* = 1 ~ 2

Right: nPE for showers with GamCore *age* = 2.5 (fit limit)

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Increase area of *low-energy* array

Thus showers, and particularly *low-energy* showers, are negatively impacted when their core is within ~25m of the edge of the array. Cf John M. – Gamma Coreness Data and Algorithms talk, Sept 26, 2016 [see Backup figures in talk]

This negative impact decreases as the dimensions of the *low-energy* array are increased; for example:

- Effective area = $(150m – 2x25m)^2$ = 0.44 x $(150m)^2$ (I)
- Effective area = $(300m – 2x25m)^2$ = 0.69 x $(300m)^2$ (II)

ratio (II)/(I) = 6.25 VS 4.0

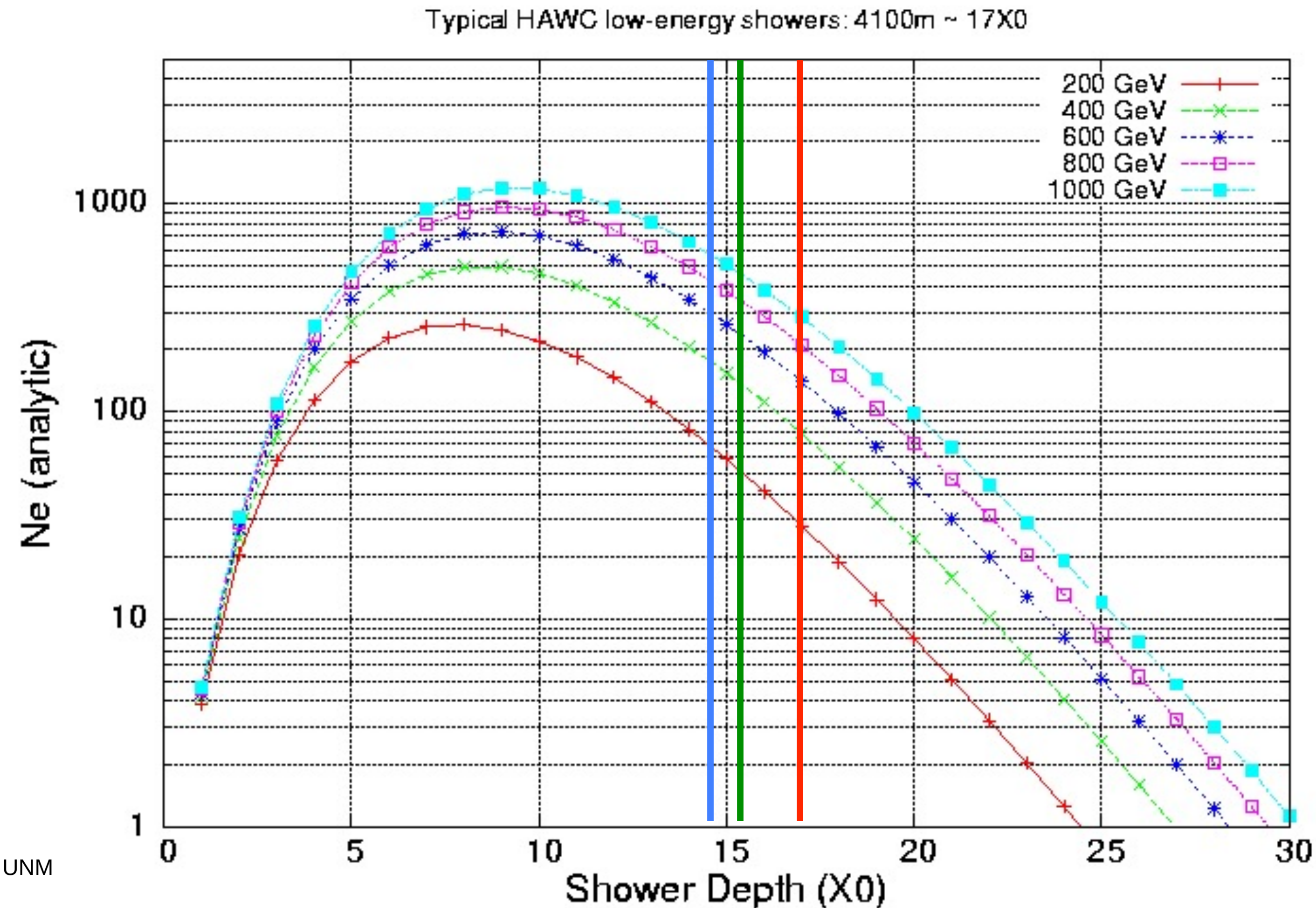
So bigger is (much) better!

Increase elevation

As HAWC is a ground array, low energy showers need to reach the array to be measured.   So take the array to the showers …

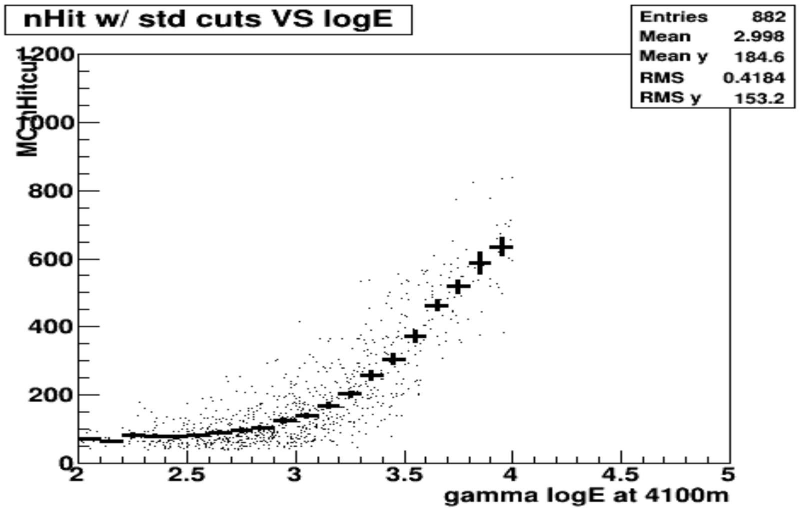
4100m ~ 17.0 X_0, 4800m ~ 15.5 X_0, and 5200m ~ 14.7 X_0

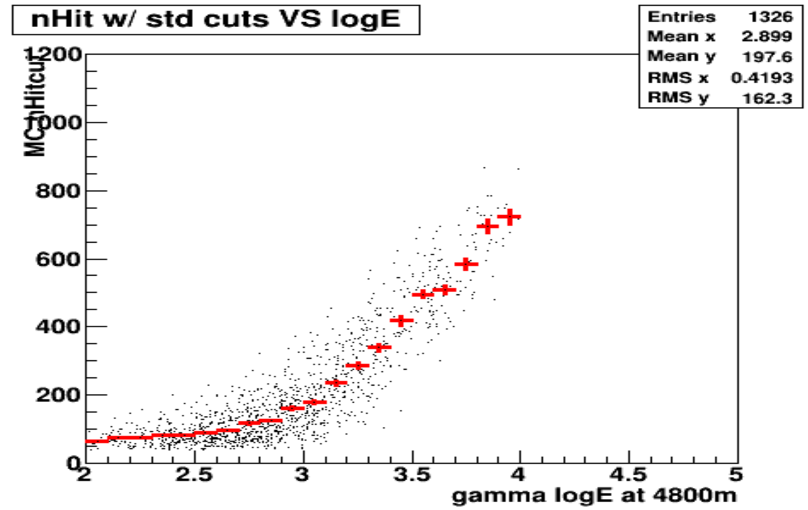
For the same N_e: 5200m should decrease HAWC *threshold* by ~2x

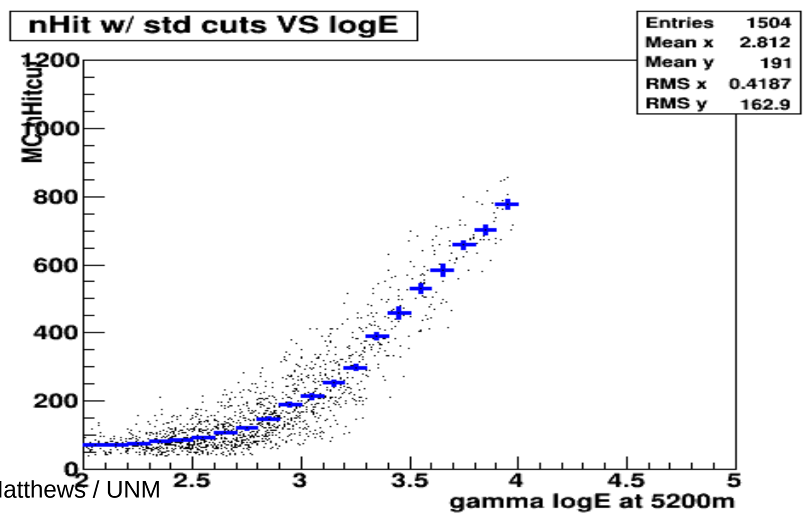


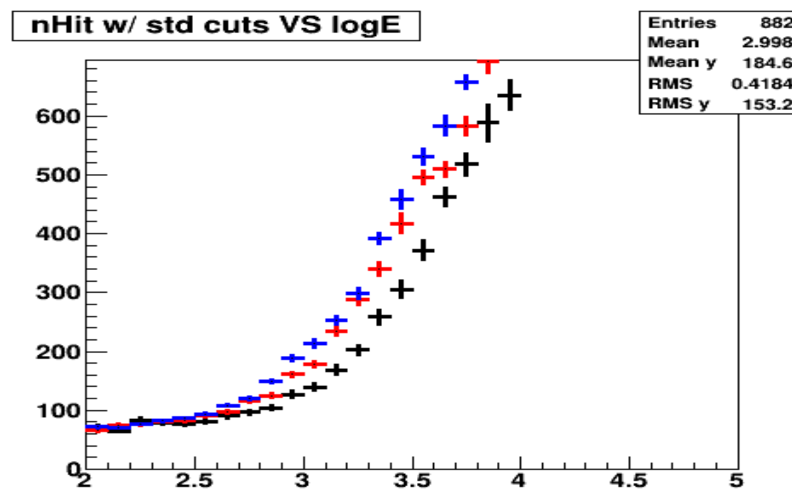
Increase elevation

Plot of **nHit** versus log10E(GeV) at 4100m, 4800m and 5200m for gamma showers with cores well within the (standard) HAWC array, zenith angle < 26º, and w/ *standard* (but no G/H) cuts:



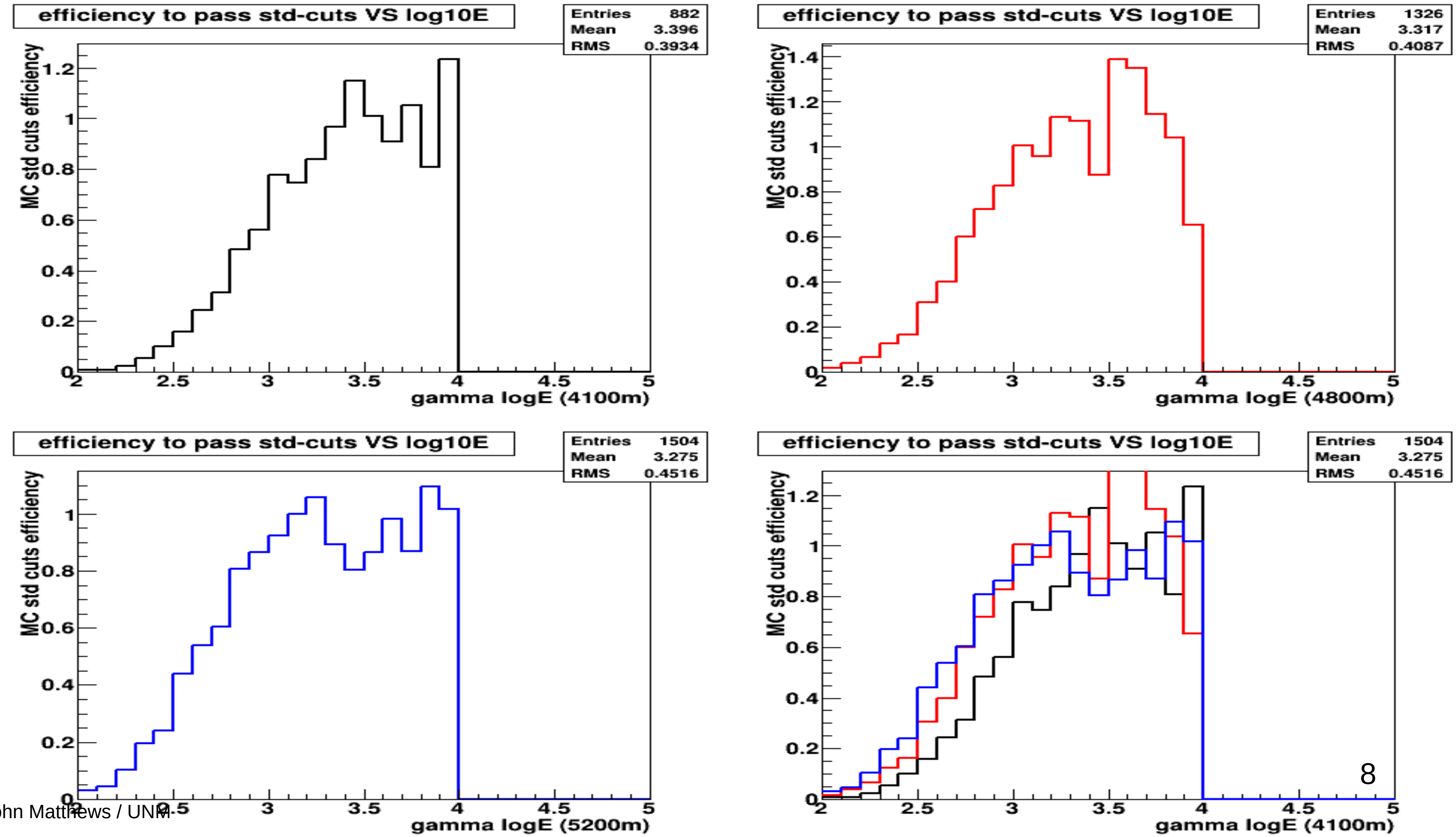






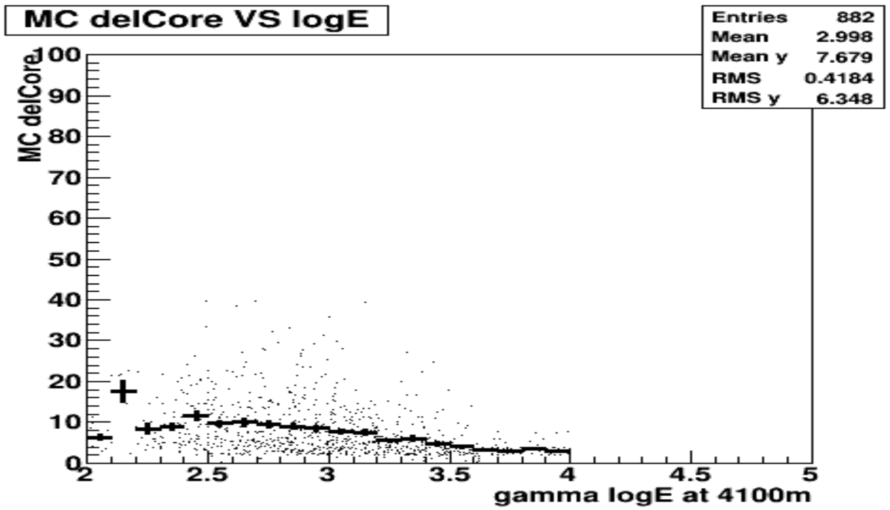
Increase elevation

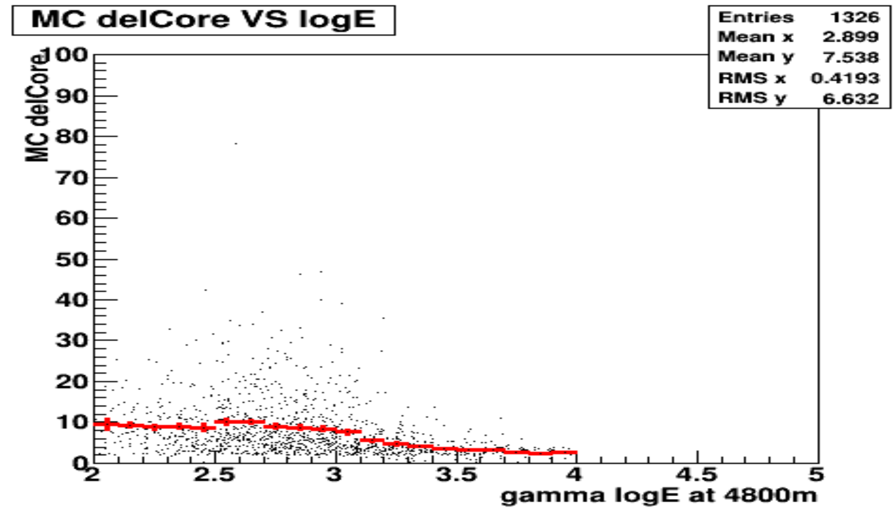
Plot of HAWC **efficiency** (to pass *standard* (but no G/H) cuts) versus log10E(GeV) at 4100m, 4800m and 5200m. A decrease in HAWC's energy *threshold* by ~2x would be a shift of -0.3 in log10E.

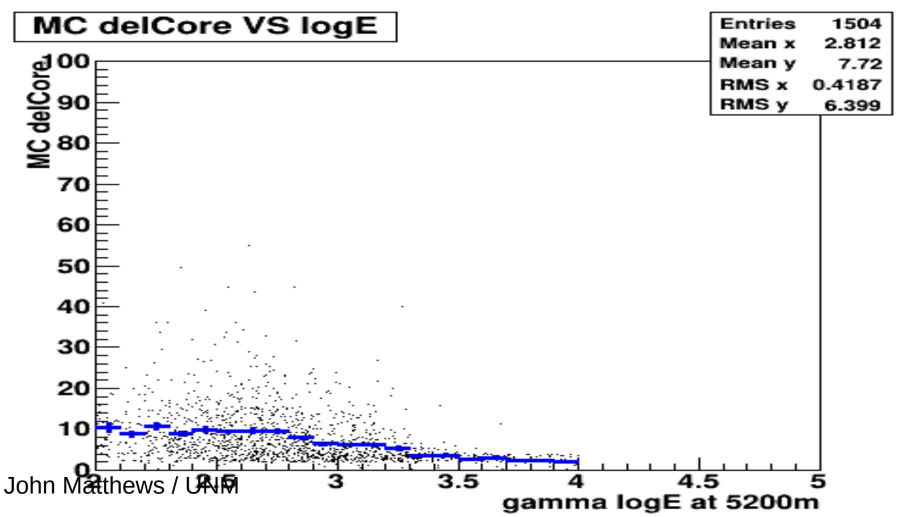


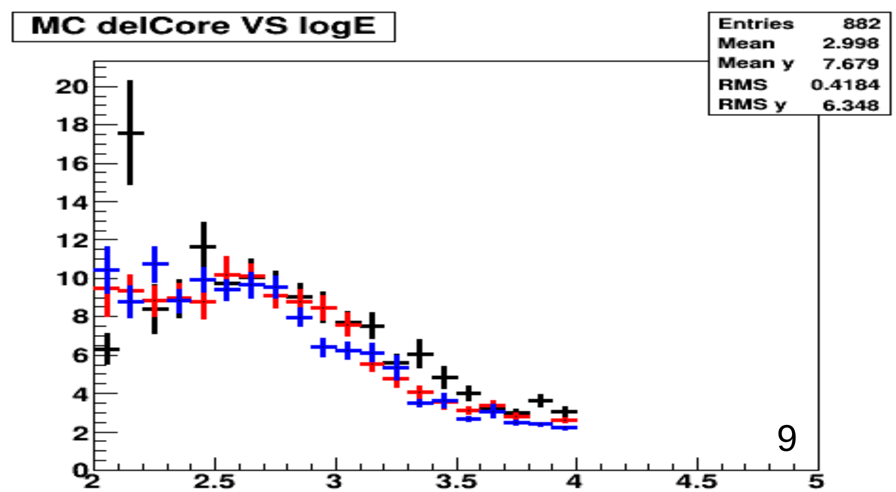
Increase elevation

Plot of **delCore(m)** versus log10E(GeV) at 4100m, 4800m and 5200m for gamma showers. The delCore distributions show only a small dependence on HAWC elevation.



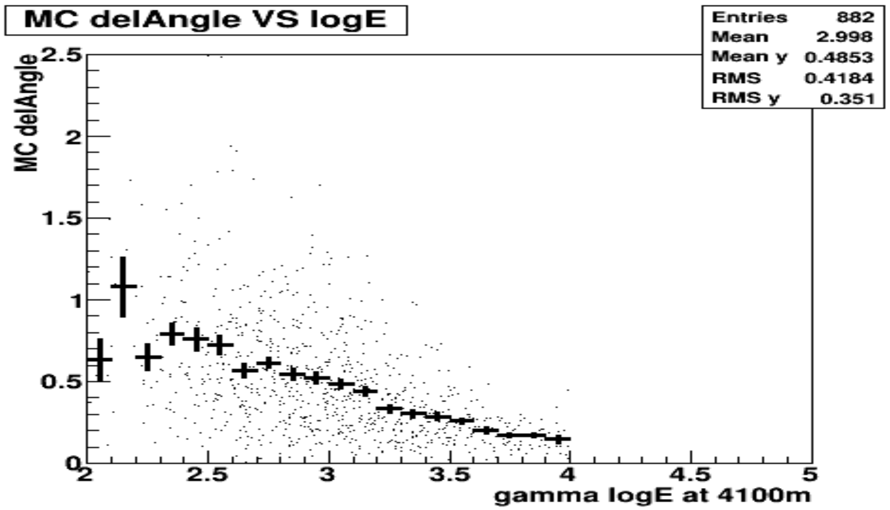


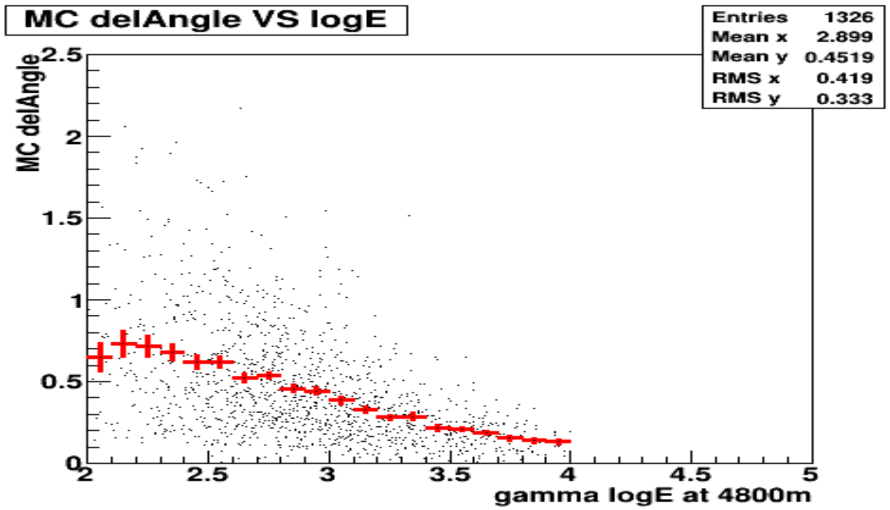


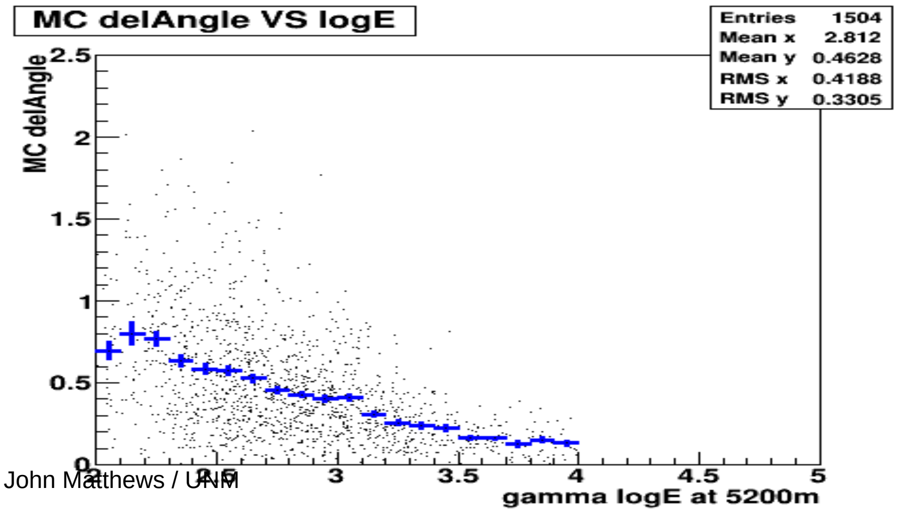


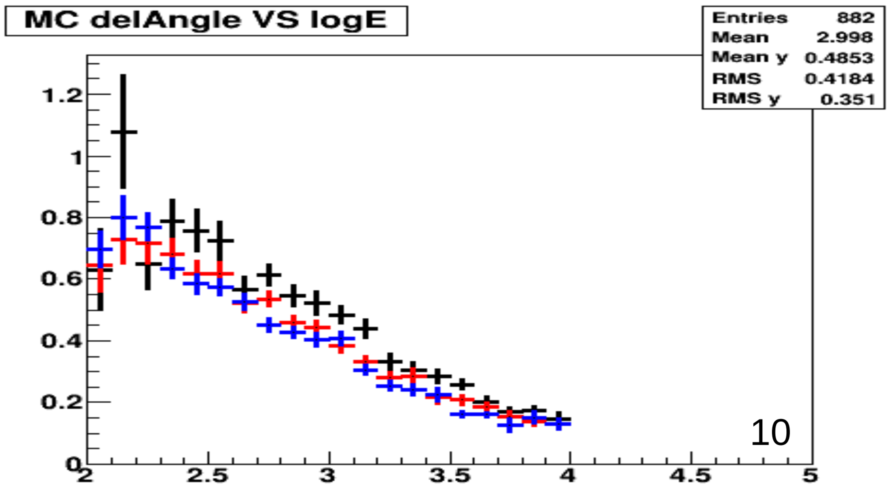
Increase elevation

Plot of **delAngle(º)** versus log10E(GeV) at 4100m, 4800m and 5200m for gamma showers. Even with fixed nHit thresholds, the **delAngle** resolution decreases (improves) with increasing elevation









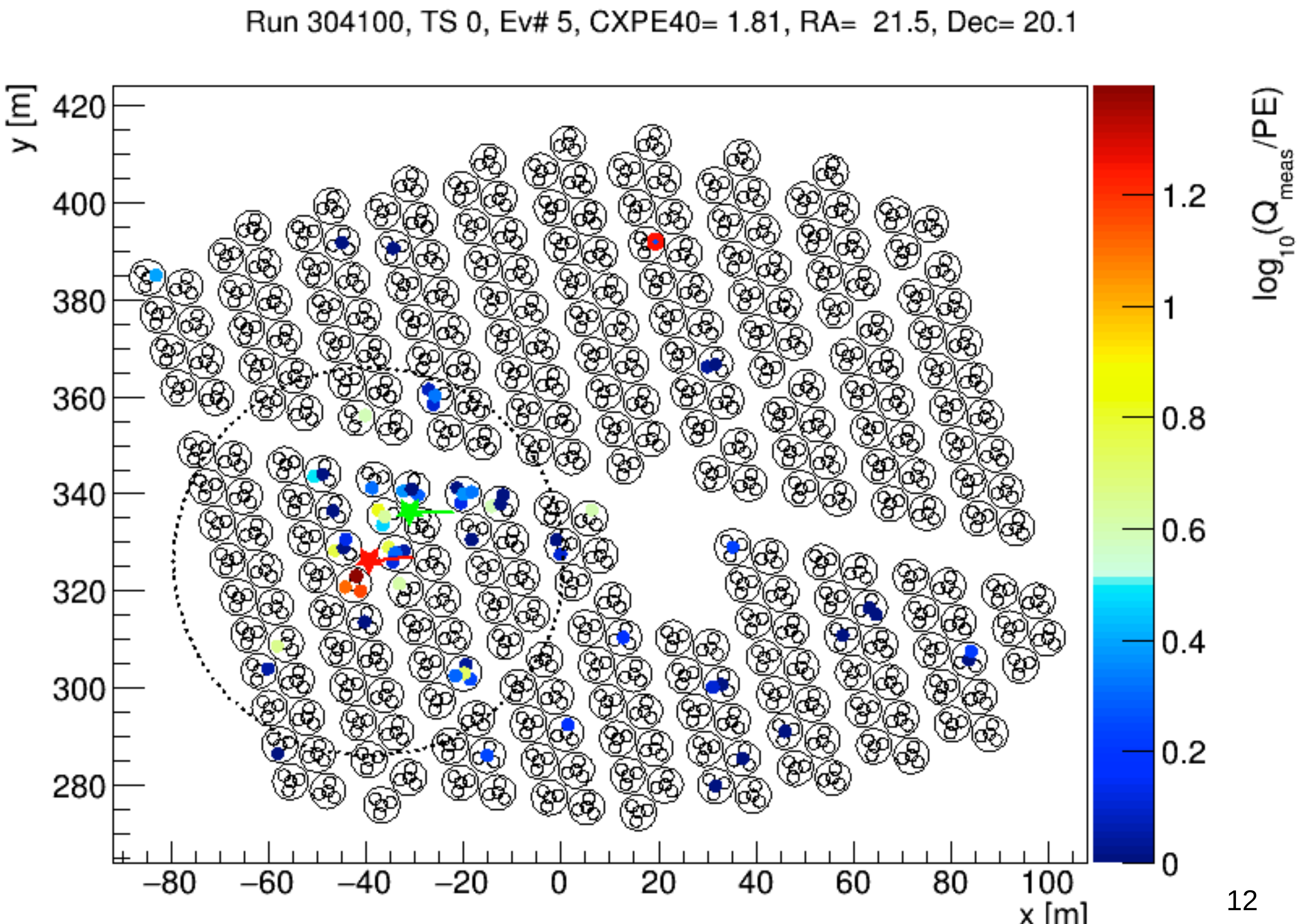
Increase tank sensitivity

HAWC tanks have a bottom area of ~ $41.85m^2$ instrumented by ~$0.148m^2$ of PMTs. So we have instrumented ~0.35% of the bottom tank surface.

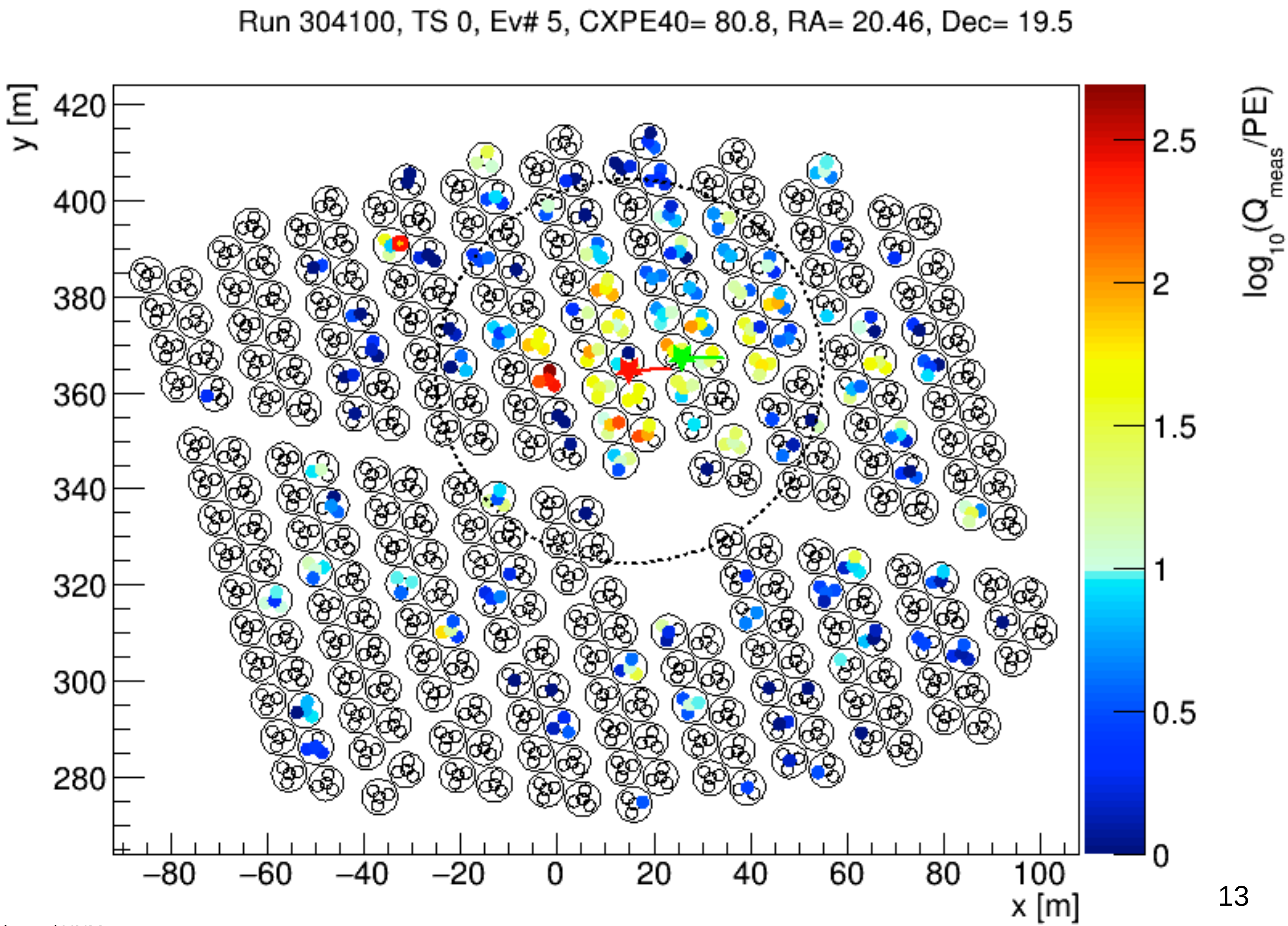
What if we increased this from 0.35% to say 8.84% (a factor of 25x increase)? To do this we simply scaled the dimensions of the 8" and 10" PMTs in the HAWC GEANT4 simulation by **5x** and then ran the standard HAWC simulation and reconstruction programs:

- First look at a few gamma showers on the HAWC display (all events were run with –splitter MultiPlaneFit option enabled)
- Making only a change in the minimum nHit to accept showers, how do the distributions of *e.g.* **nHit** w/ cuts, **delCore** and **delAngle** versus log10E compare to standard simulation results?

Std PMT event #5: 1.19 TeV

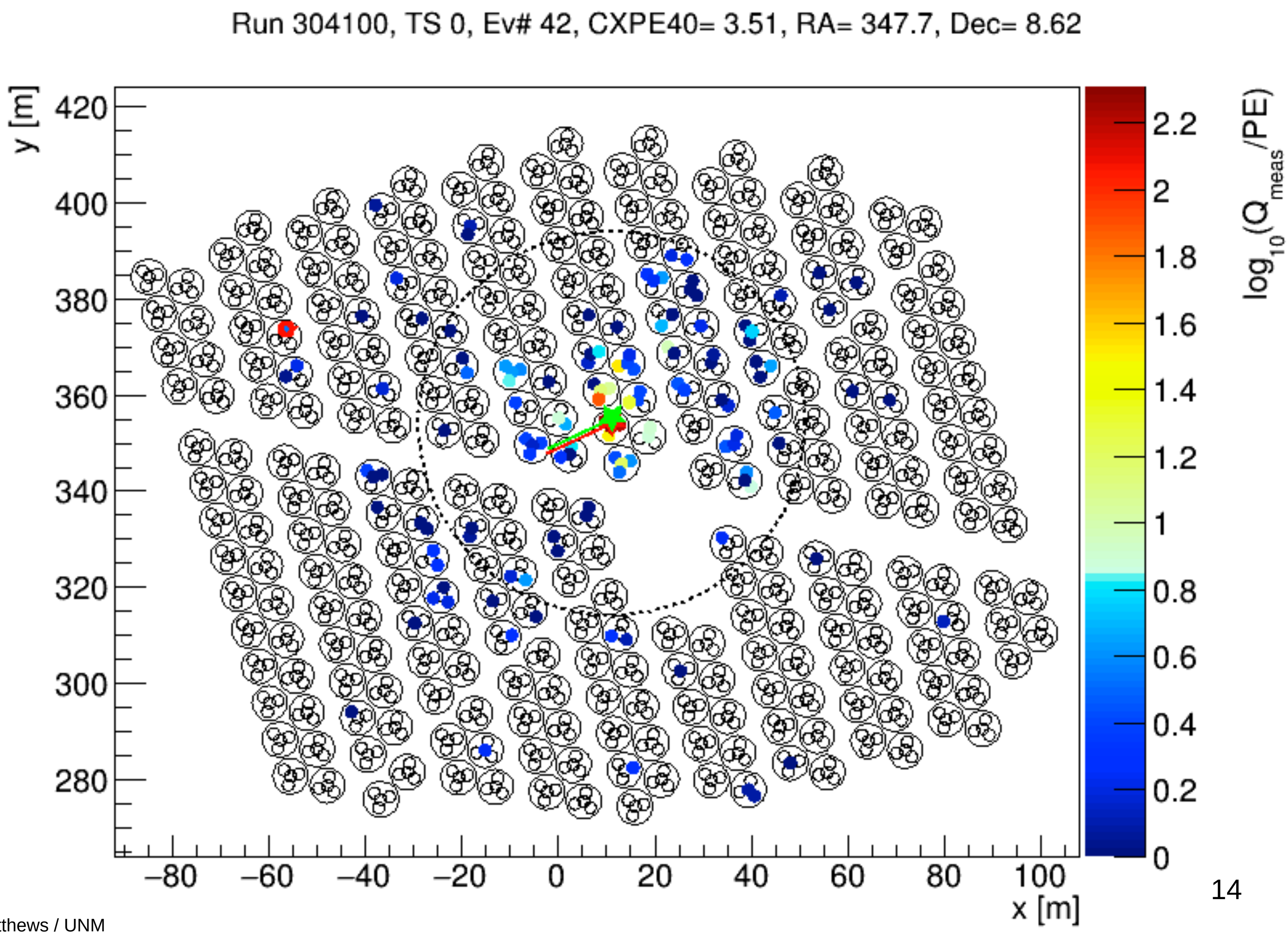


VeryLarge PMT event #5: 1.19 TeV [new CoreX, CoreY]



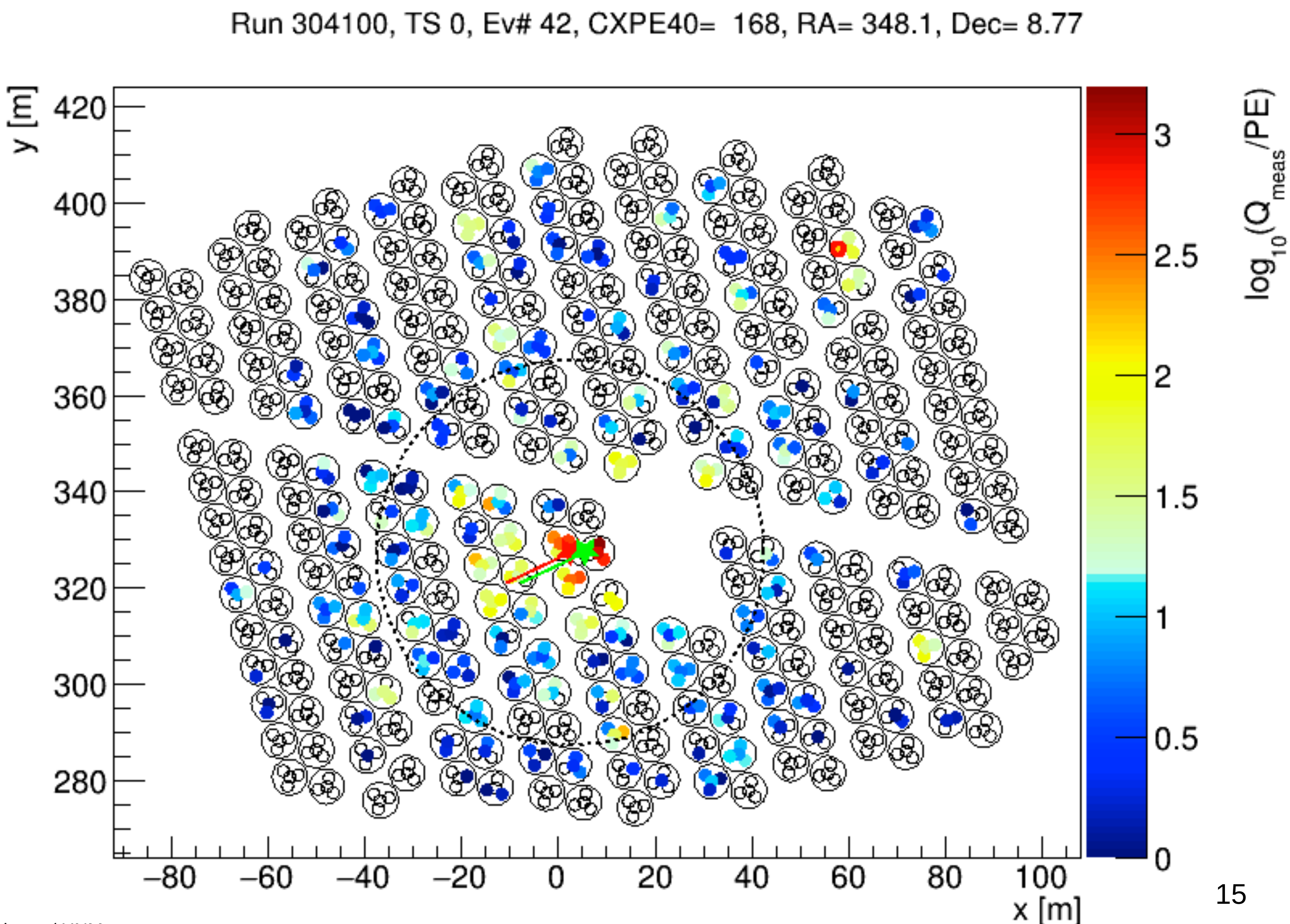
John Matthews / UNM

Std PMT event #42: 0.85 TeV



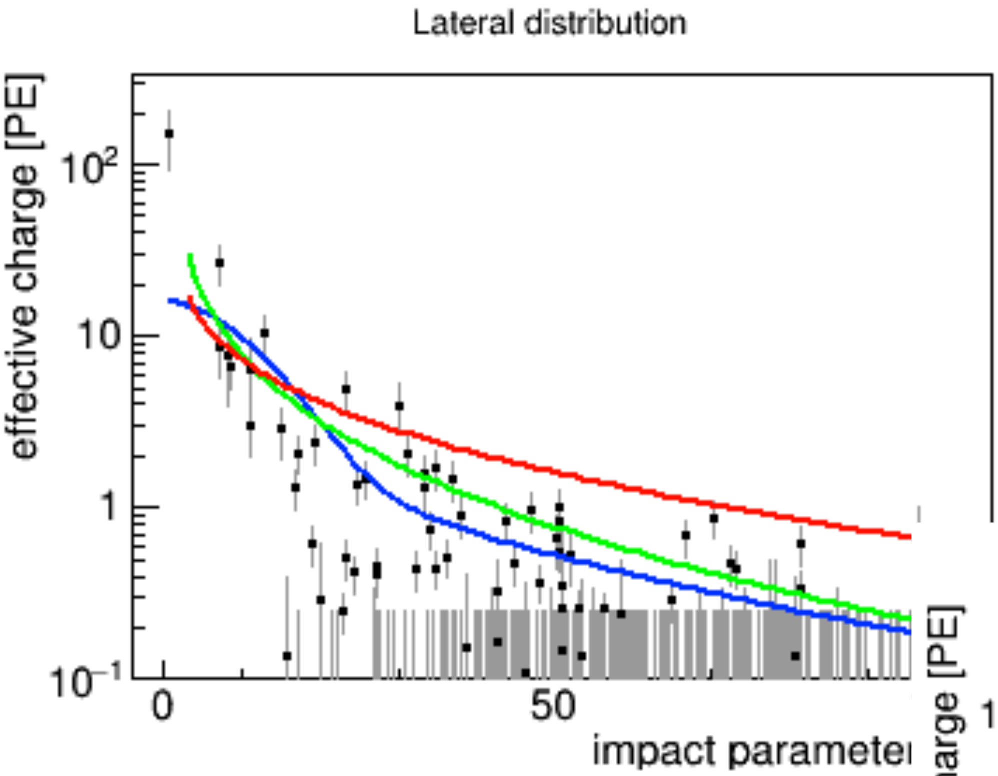
John Matthews / UNM

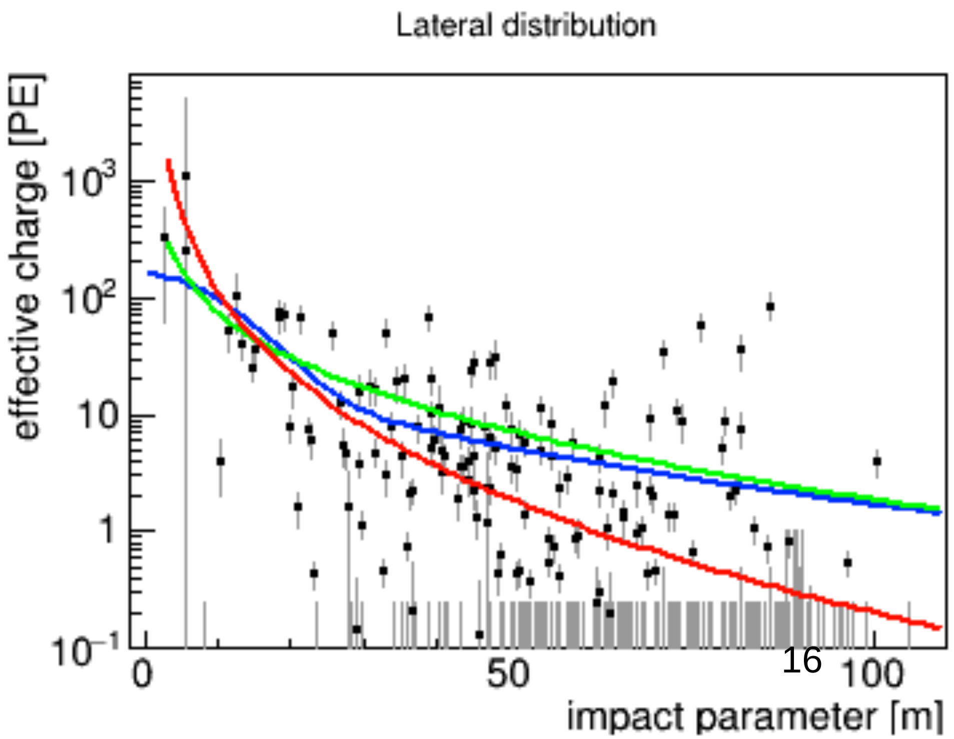
VeryLarge PMT event #42: 0.85 TeV [new CoreX, CoreY]



John Matthews / UNM

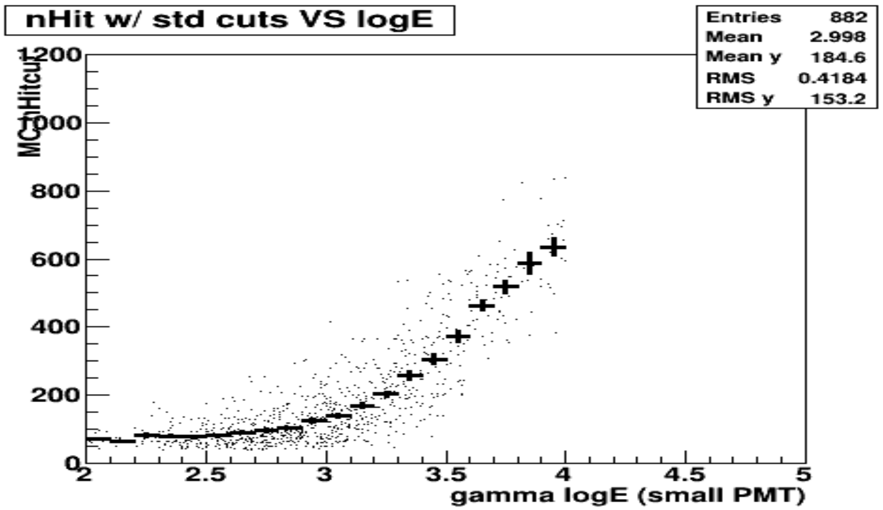
Std / VeryLarge PMT event #42: 0.85 TeV

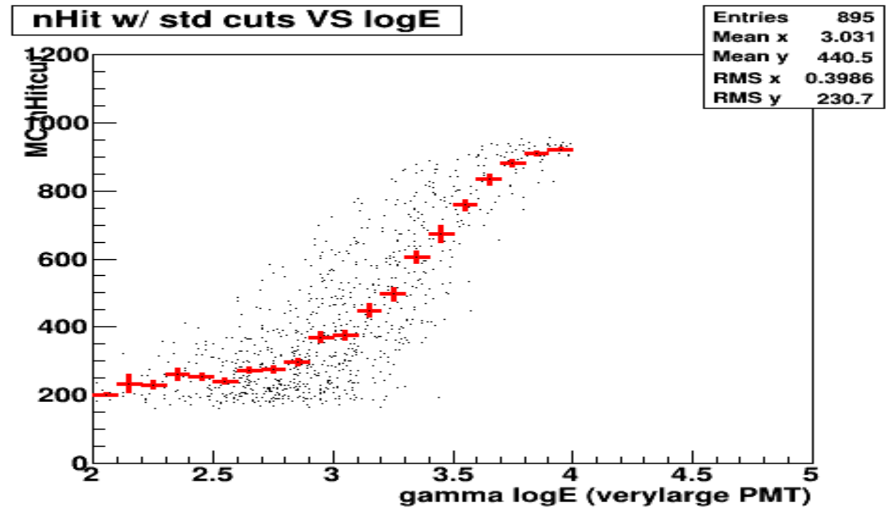


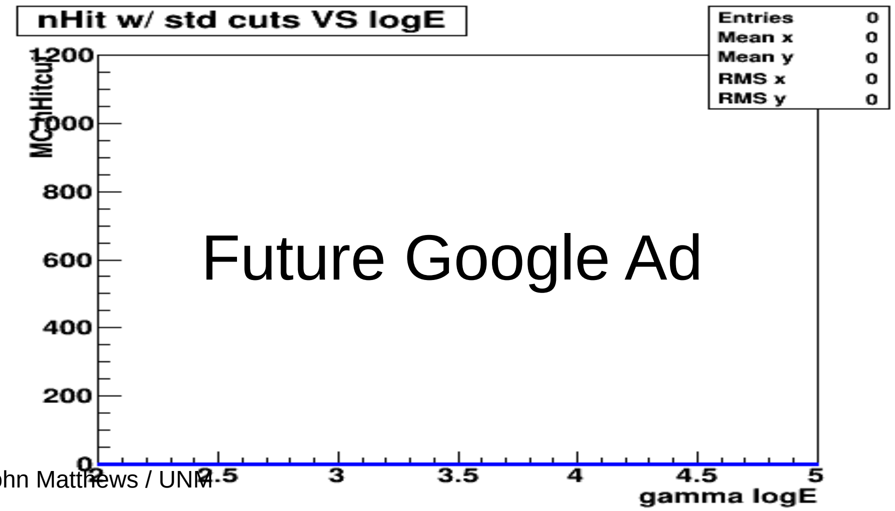


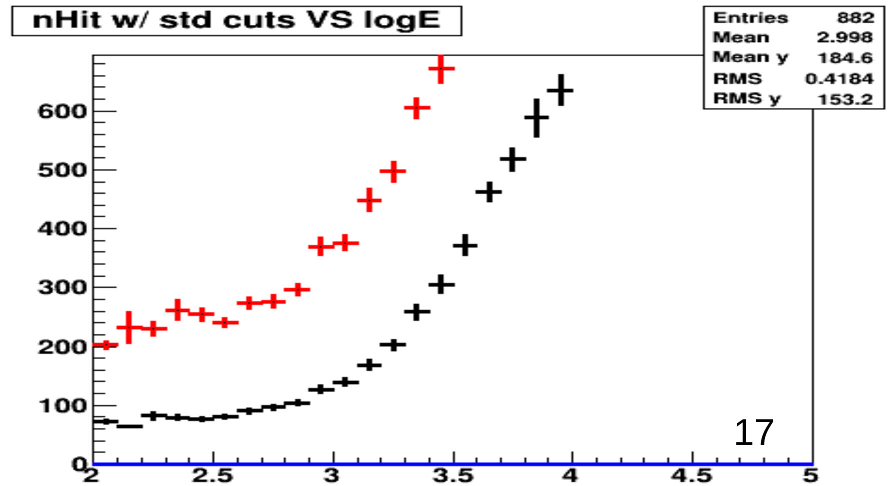
Increase tank sensitivity – (I)

Plot of **nHit** versus log10E(GeV) at 4100m for gamma showers with cores well within the (standard) HAWC array, zenith angle < 26º, and w/ *standard* (but no G/H) cuts for **normal** (*small*) and **5x** (*verylarge*) PMTs. For plots **(I)**, the nHit threshold with ***5x*** PMTs is increased by 3.5x to match **normal** PMT rates.



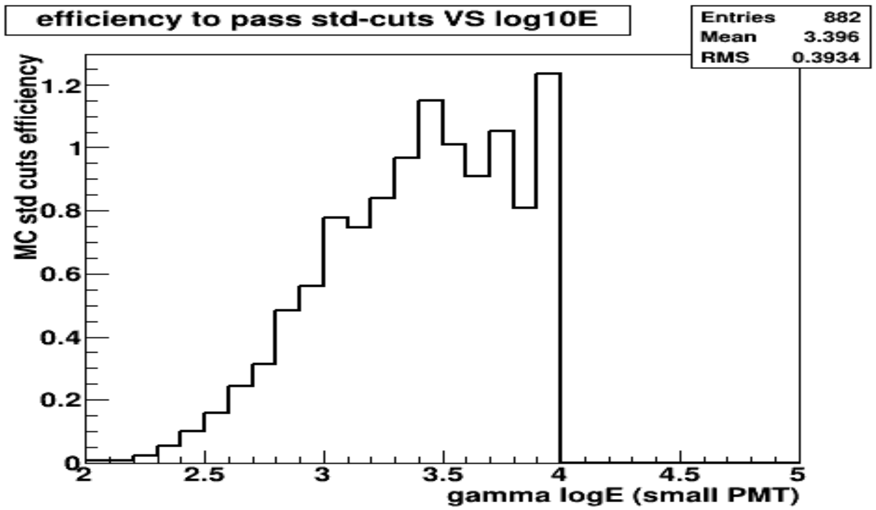


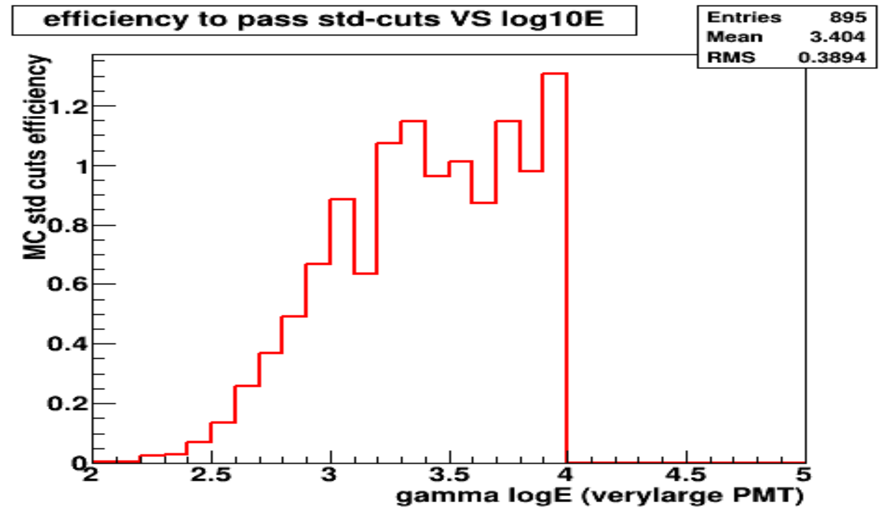


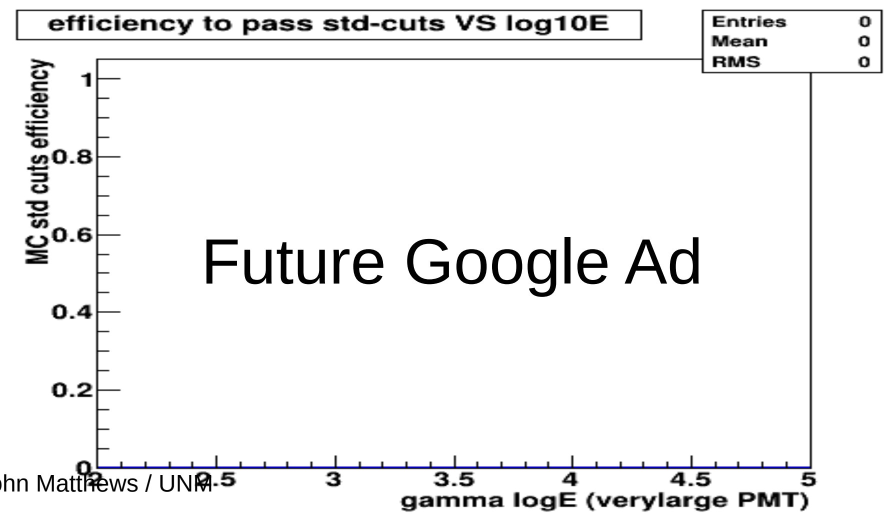


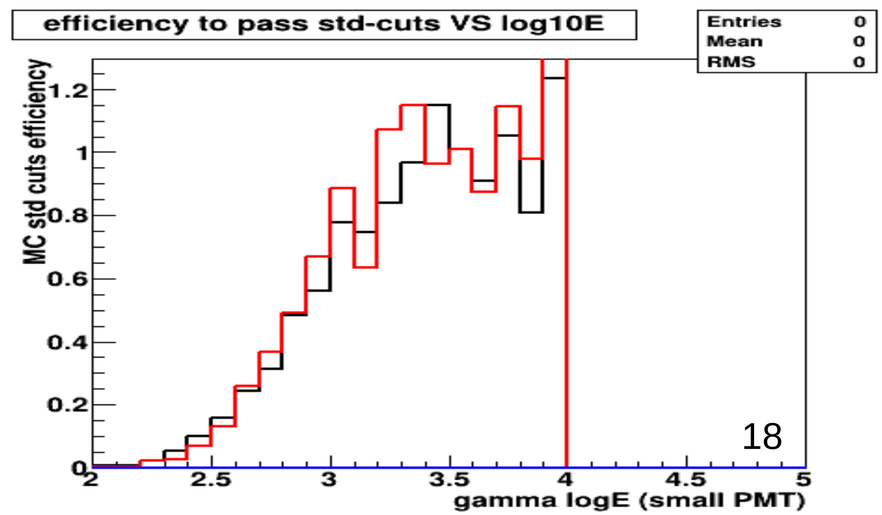
Increase tank sensitivity – (I)

Plot of HAWC **efficiency** (to pass *standard* (but no G/H) cuts) versus log10E(GeV) at 4100m for **normal** and **5x** PMTs. With this nHit threshold for **5x** PMTs, the energy threshold is unchanged.



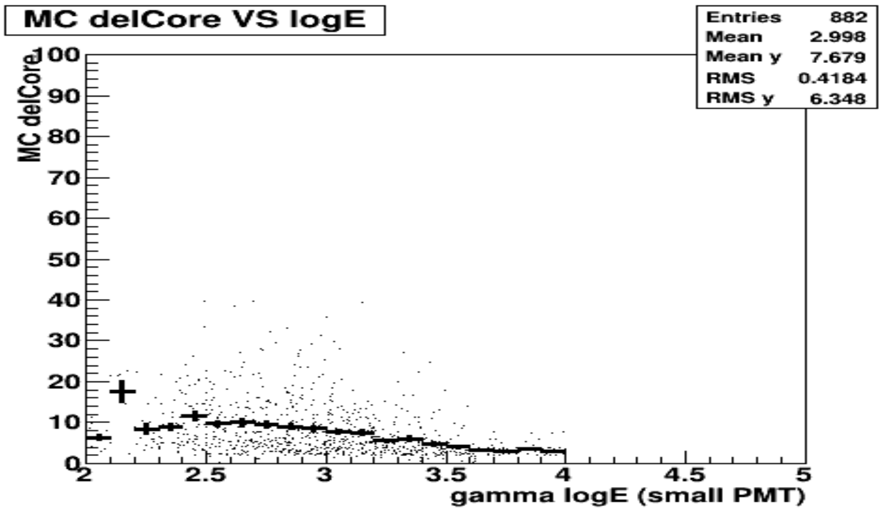


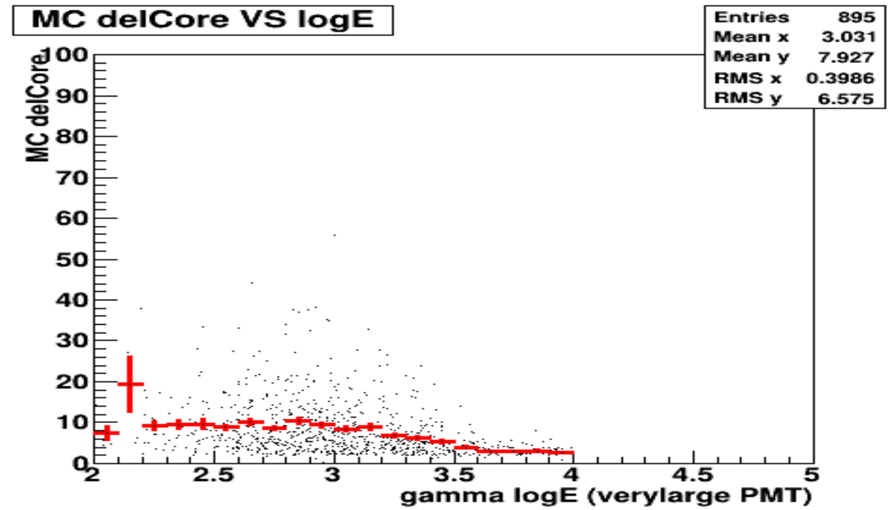


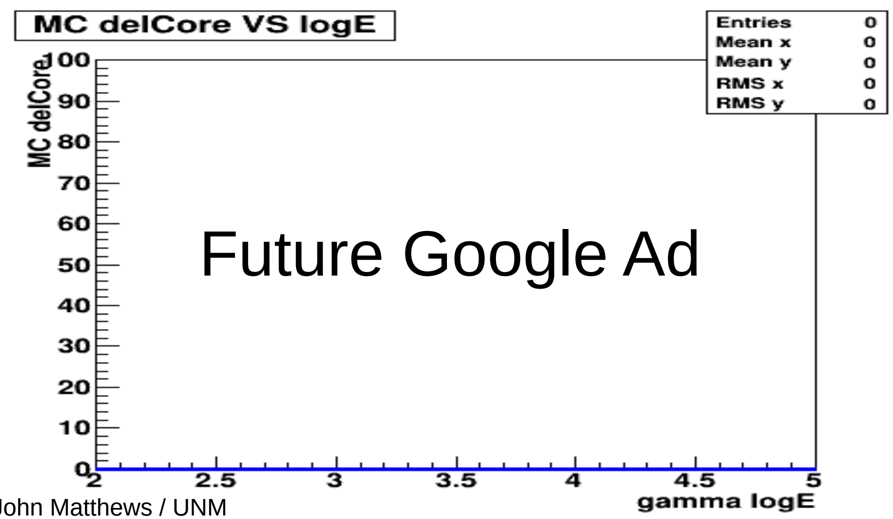


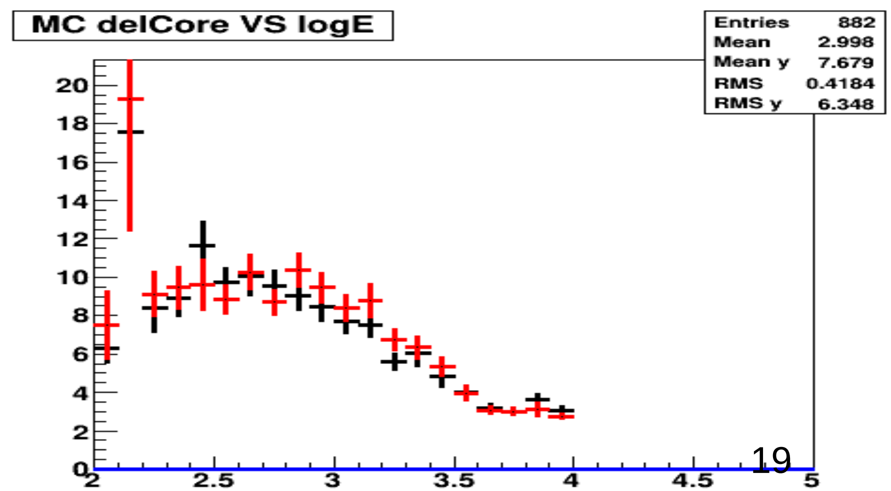
Increase tank sensitivity – (I)

Plot of **delCore(m)** versus log10E(GeV) at 4100m for **normal** and **5x** PMTs. The **delCore** distributions are curiously similar.



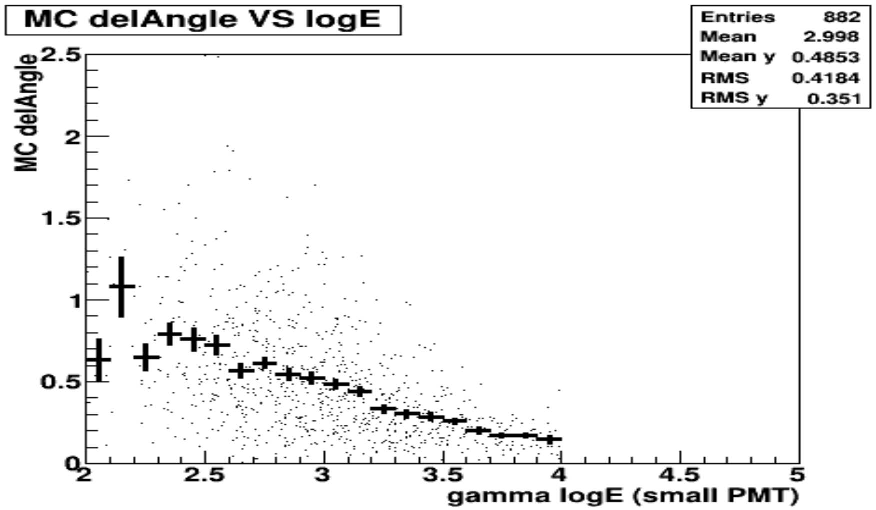


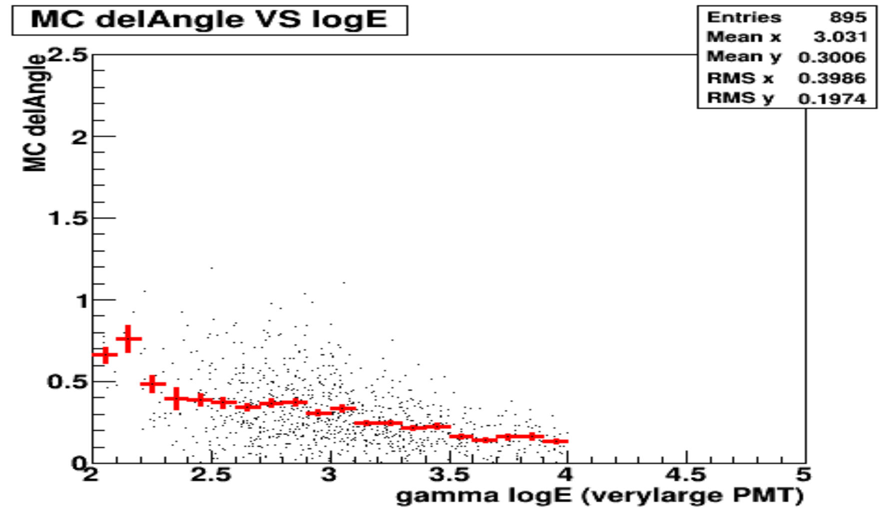


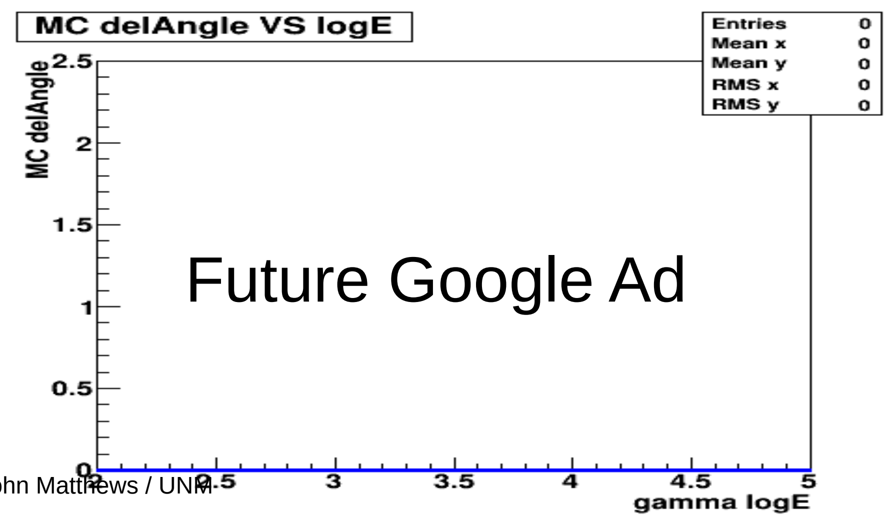


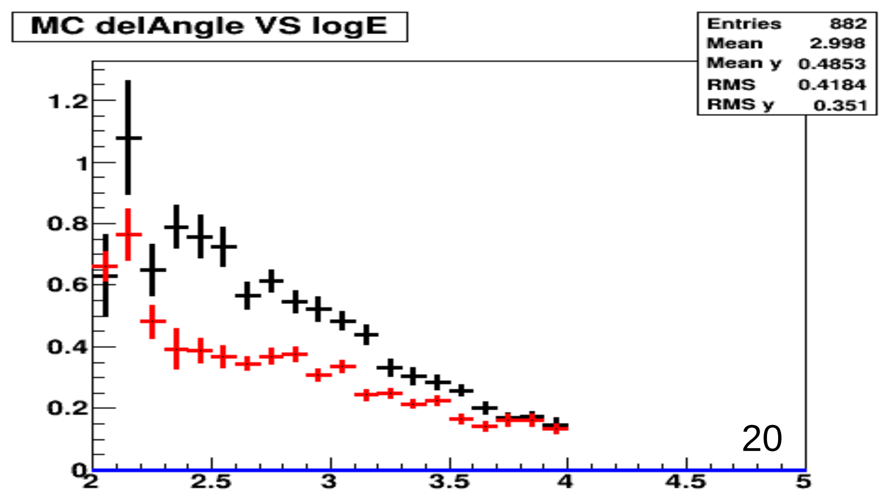
Increase tank sensitivity – (I)

Plot of **delAngle(º)** versus log10E(GeV) at 4100m for **normal** and **5x** PMTs. At low energies the angular resolution with ***5x*** PMTs appears to be significantly (~50%) reduced!



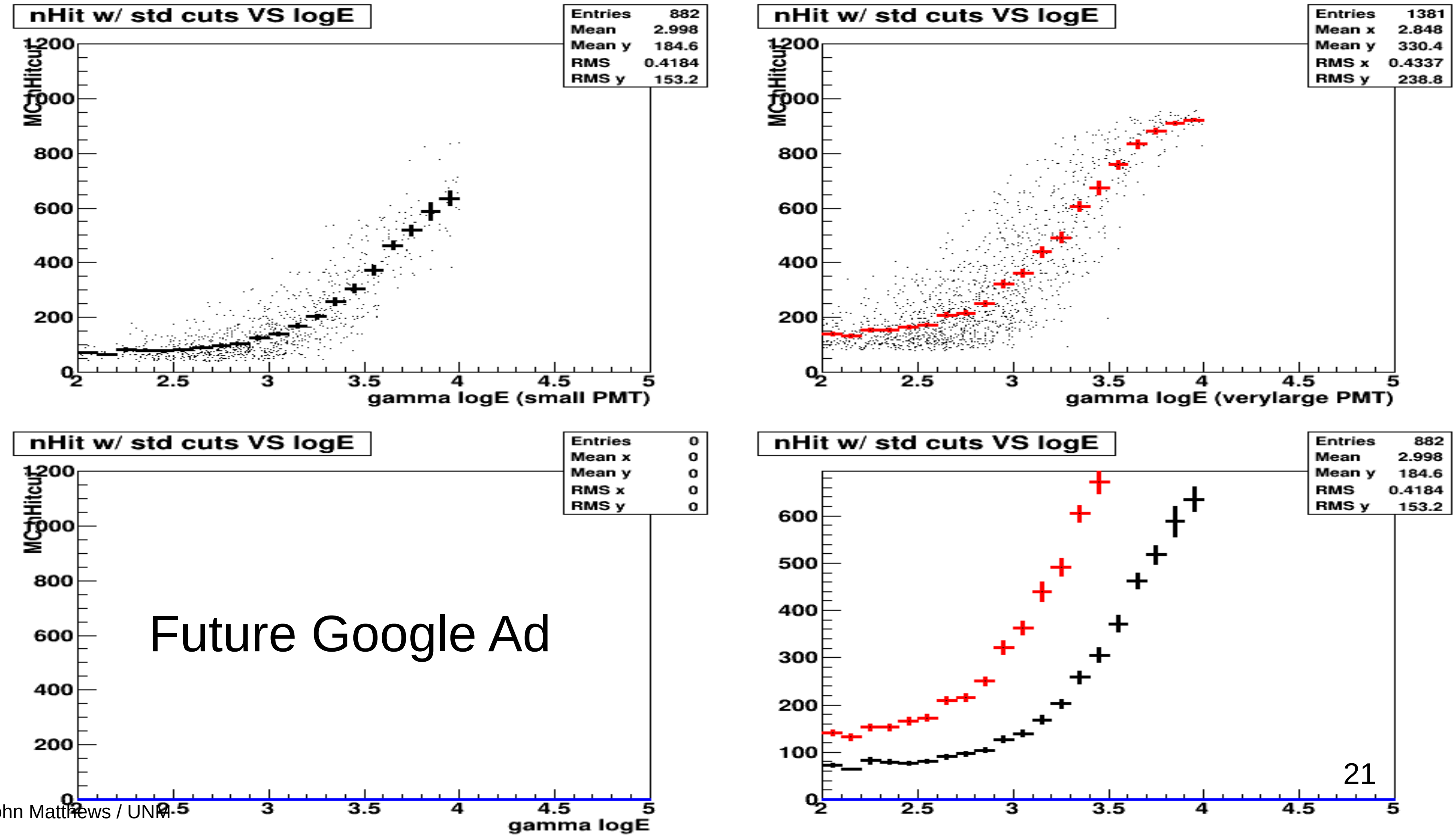






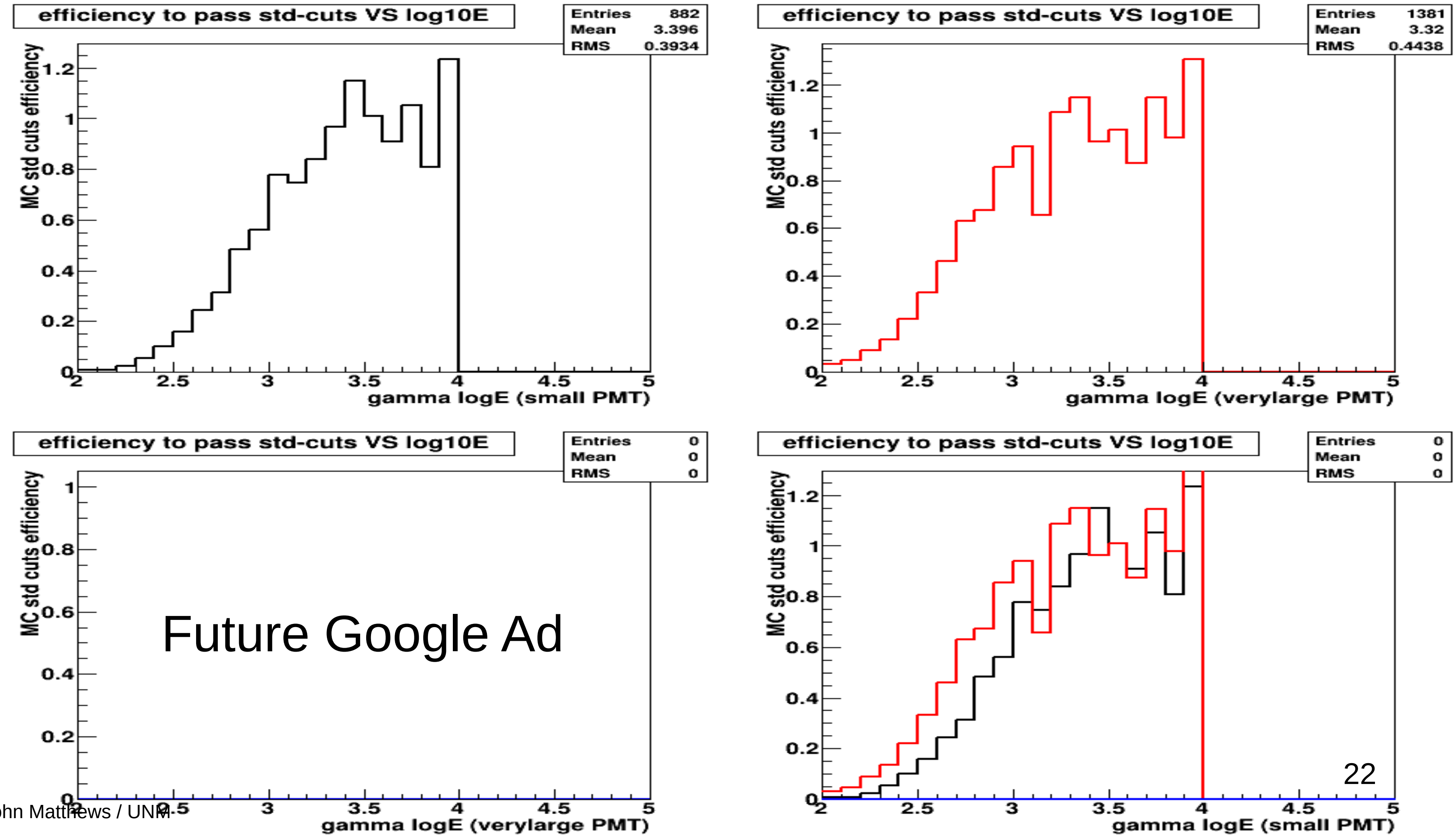
Increase tank sensitivity – (II)

Plot of **nHit** versus log10E(GeV) at 4100m for gamma showers with cores well within the (standard) HAWC array, zenith angle < 26º, and w/ *standard* (but no G/H) cuts for **normal** (*small*) and **5x** (*verylarge*) PMTs. For plots **(II)**, the nHit threshold with ***5x*** PMTs is increased now by 1.75x.



Increase tank sensitivity – (II)

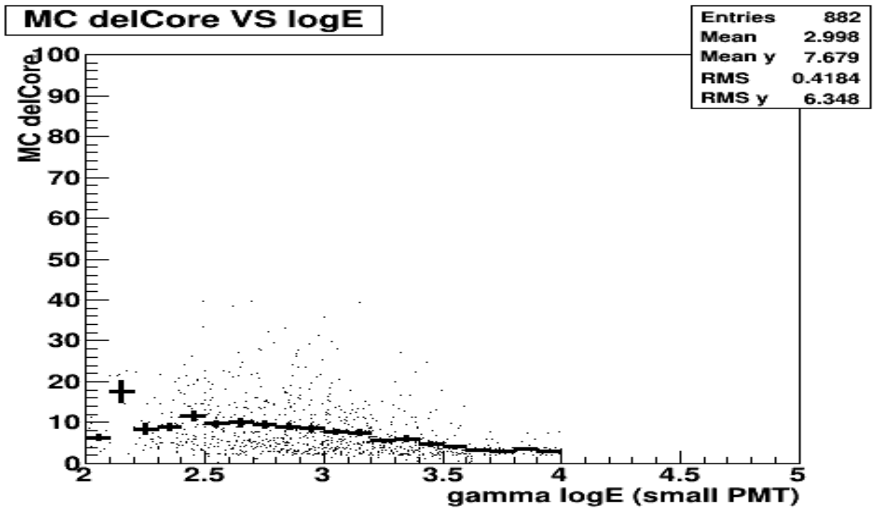
Plot of HAWC **efficiency** (to pass *standard* (but no G/H) cuts) versus log10E(GeV) at 4100m for **normal** and **5x** PMTs. With loosened (*i.e.* reduced nHit) threshold, the energy threshold with ***5x*** PMTs decreases!

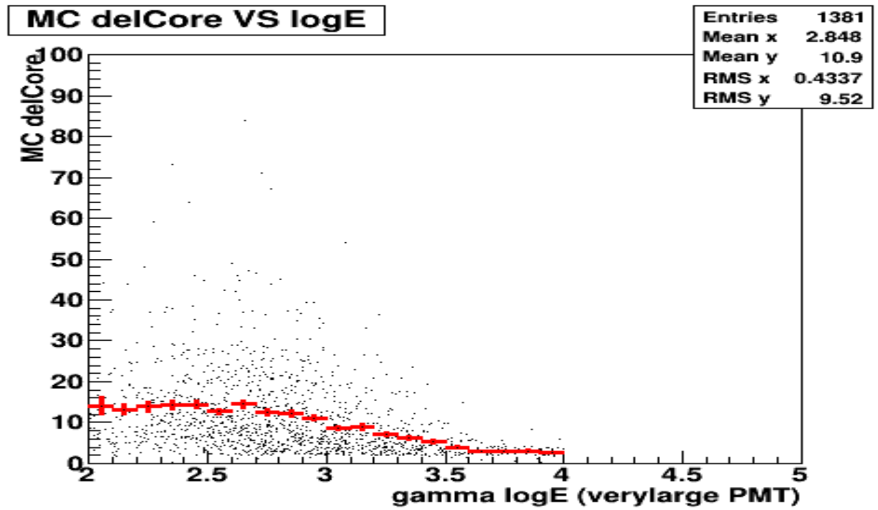


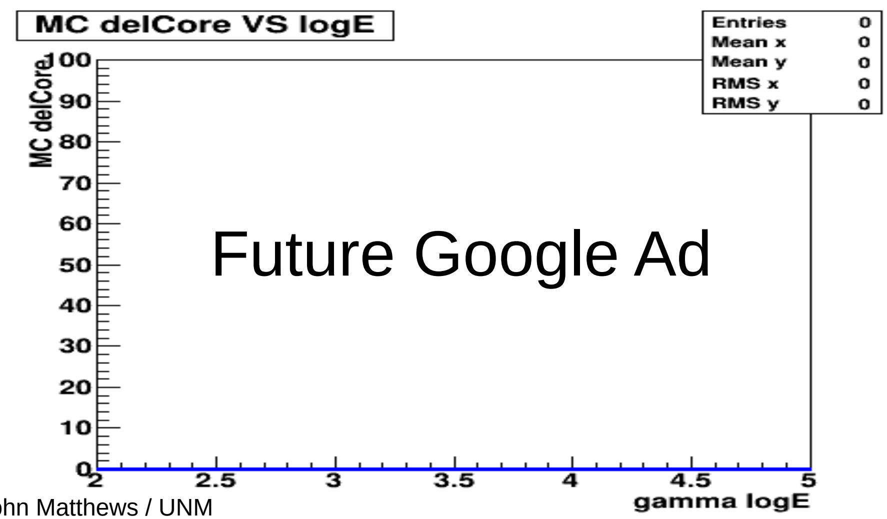
Increase tank sensitivity – (II)

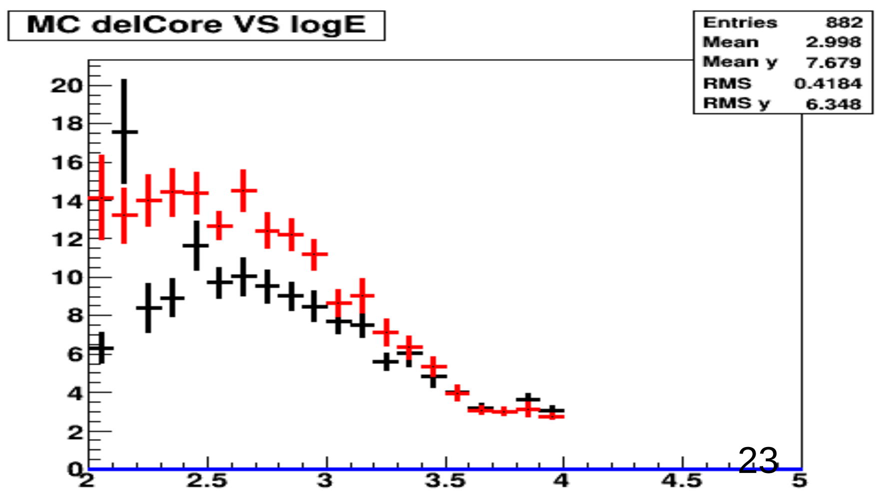
Plot of **delCore(m)** versus log10E(GeV) at 4100m for **normal** and **5x** PMTs.

With loosened (*i.e.* reduced nHit) threshold, the **delCore** resolution with ***5x*** PMTs degrades.



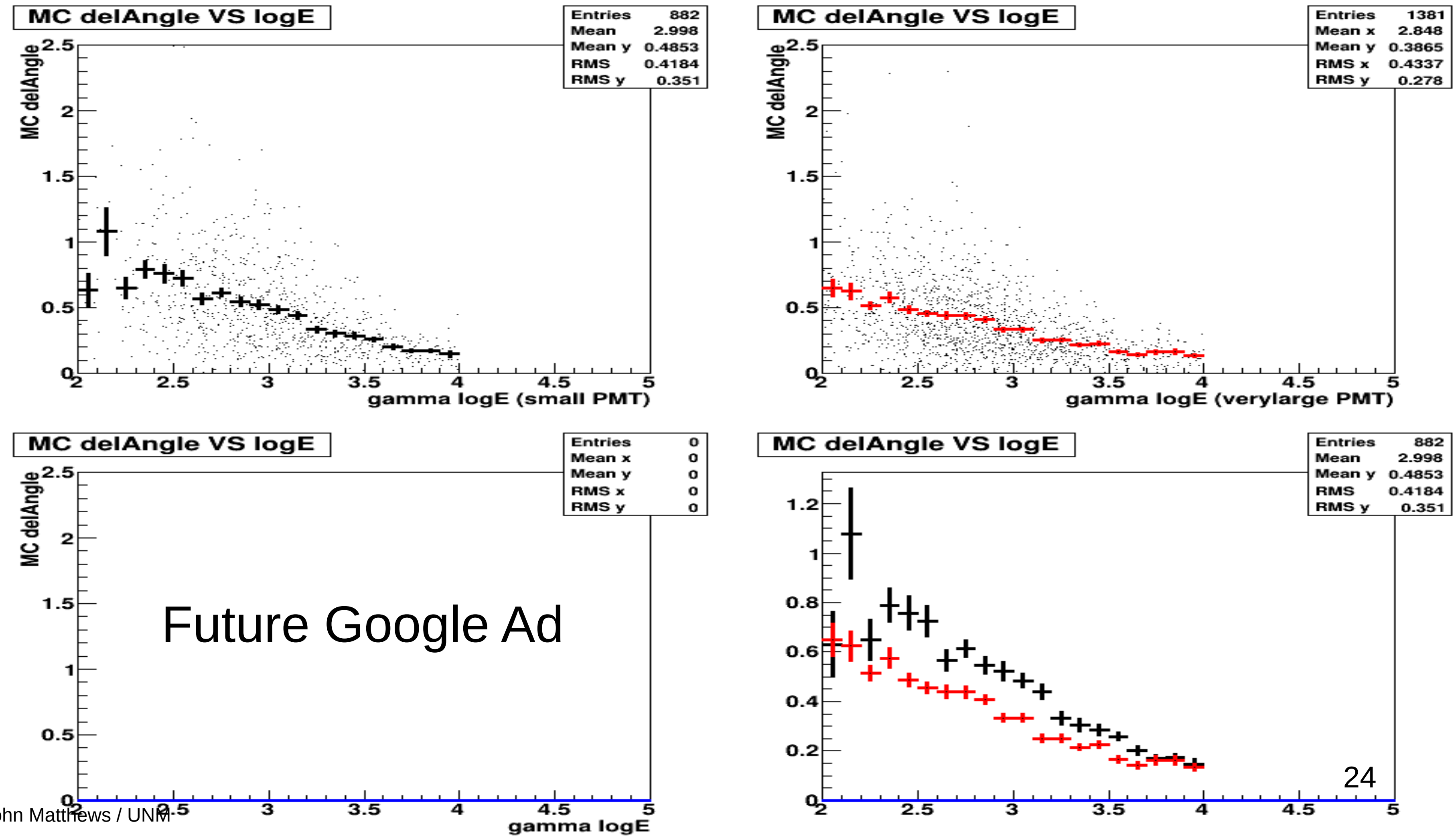






Increase tank sensitivity – (II)

Plot of **delAngle(º)** versus log10E(GeV) at 4100m for **normal** and **5x** PMTs. Interestingly the critical angular resolution with ***5x*** PMTs may still be better (*i.e.* reduced) versus **normal** PMTs.



Summary

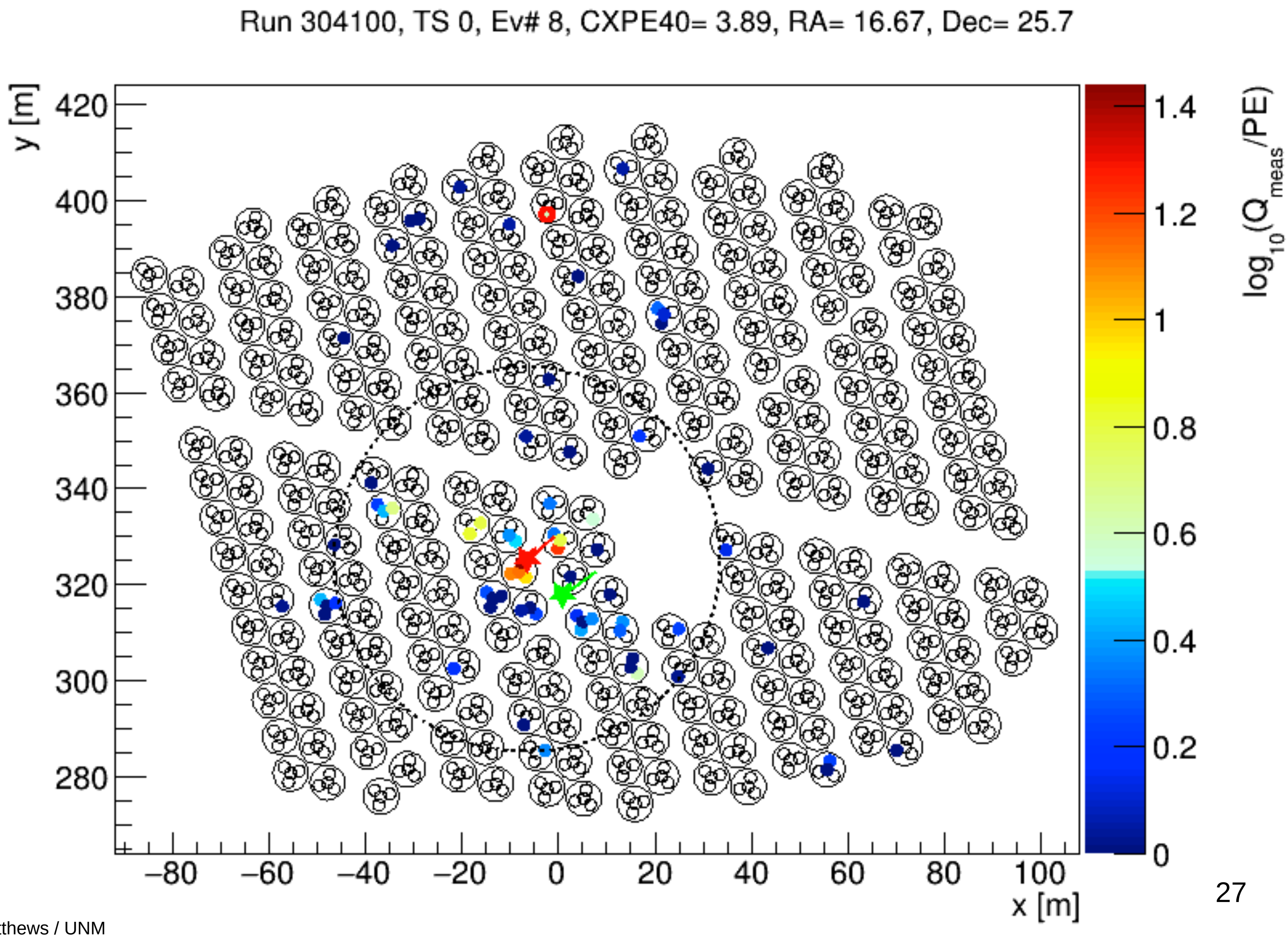
To improve HAWC performance for showers with energies < 1 TeV we considered 3 possible modifications:

- Increase area of *low-energy* array (to reduce edge effects)
  Toy simulation gain factor: ~sqrt(6.25)
- Increase elevation (to help *low-energy* shower particles reach the array). Toy simulation gain factor: $\sim 2^{(\mathbf{S.I.}-1)}$ / sqrt(similar factor for bkg w/ S.I.=2.5) --> $\sim 2^{(S.I.-1.75)}$
- Increase tank sensitivity (so when there are tank *signals we* record them). Toy simulation gain factor: ~(1/0.5) = 2
- Combining (optimistically) all 3 components, the toy simulation gain factor is ~10 (or more) … which is good as most TeVCat AGNs have measured flux < 0.1 Crab.

All 3 possible modifications will/would improve the performance for *low energy* showers. For *soft-spectrum* sources, such as (most) AGNs with **S.I.** > 3, going **high** is very important.

Backup material

Std PMT event #8: 0.50 TeV



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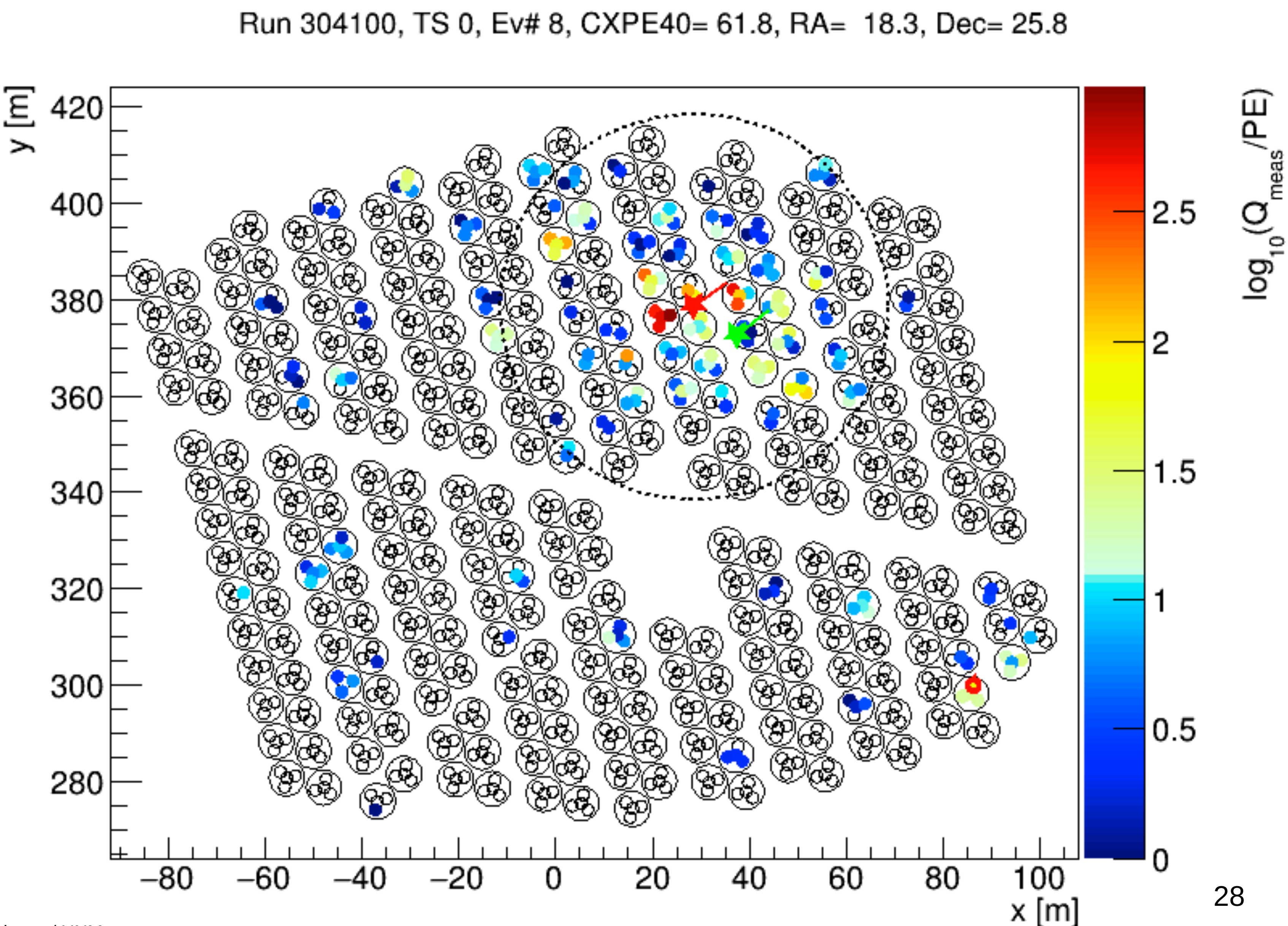
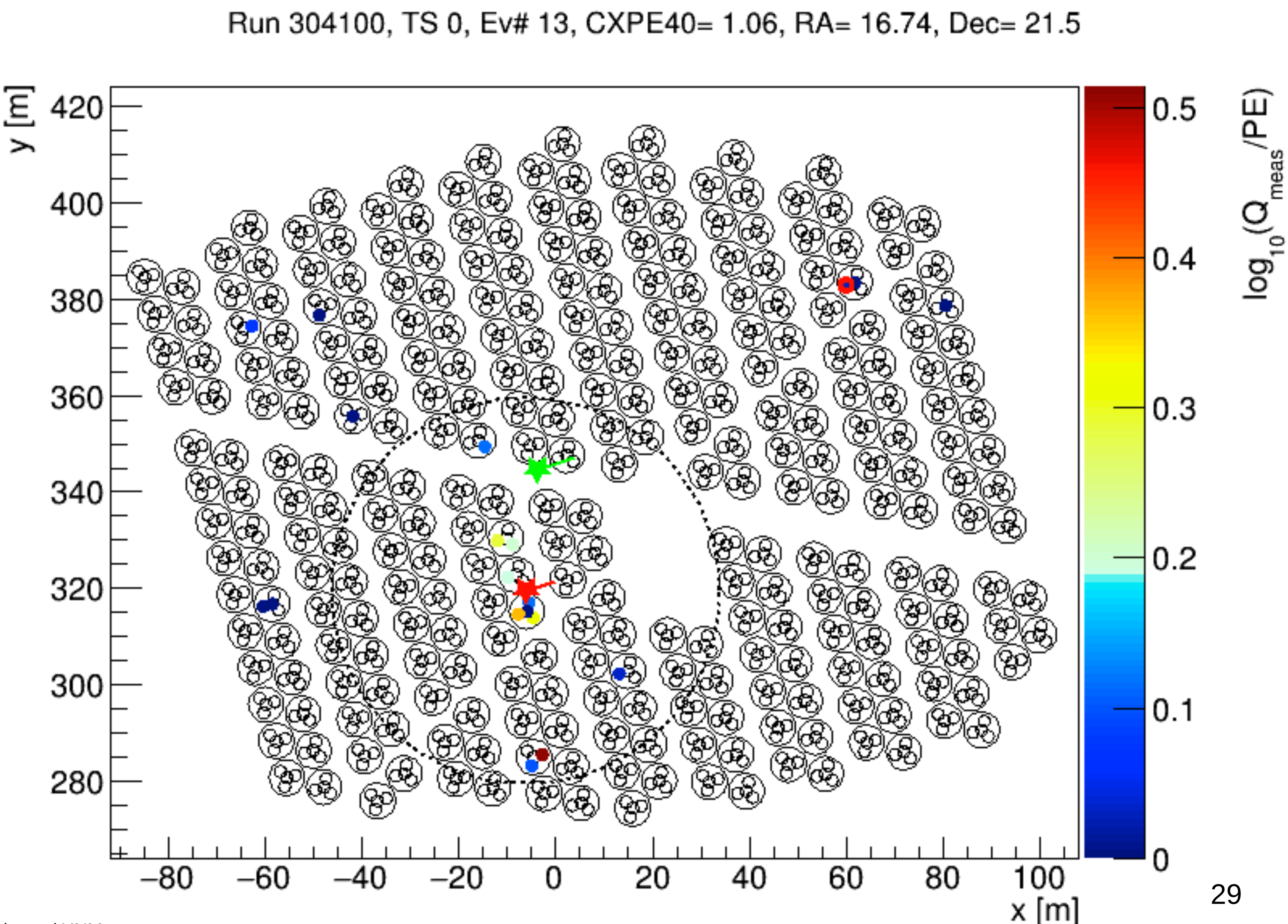
VeryLarge PMT event #8: 0.50 TeV [new CoreX, CoreY]



Std PMT event #13: 0.12 TeV



VeryLarge PMT event #13: 0.12 TeV [new CoreX, CoreY]