Test Beam 2024
Pion beam analysis

Andrea Pareti - 18/03/2025

General information

From DRAGO simulation studies:

chi = 0.35 to optimise response linearity

Using expected containment = [0.865, 0.87, 0.875, 0.88, 0.885, 0.89]

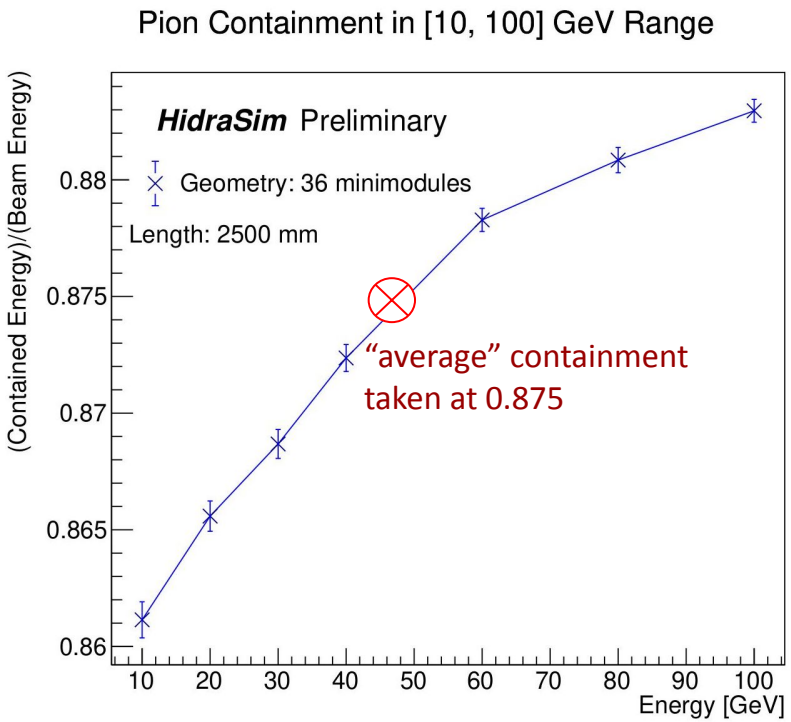
Simulation from last July, being updated with TB actual setup
Some simulations with pion beams already run, analysis ongoing

Using “newHV” runs = ["1000", "0967", "0966", "0965", "0963", "0962"]

Since contained energy inside calorimeter changes by a factor > 2% in our test beam range, simulation expected containment is used to account for this effect
Otherwise non-linearity is guaranteed

$$E_{DR} = \frac{1}{C_{AVG}} \frac{S - \chi C}{1 - \chi}$$

Average pion energy deposited inside DRAGO prototype, with respect to beam (truth) energy

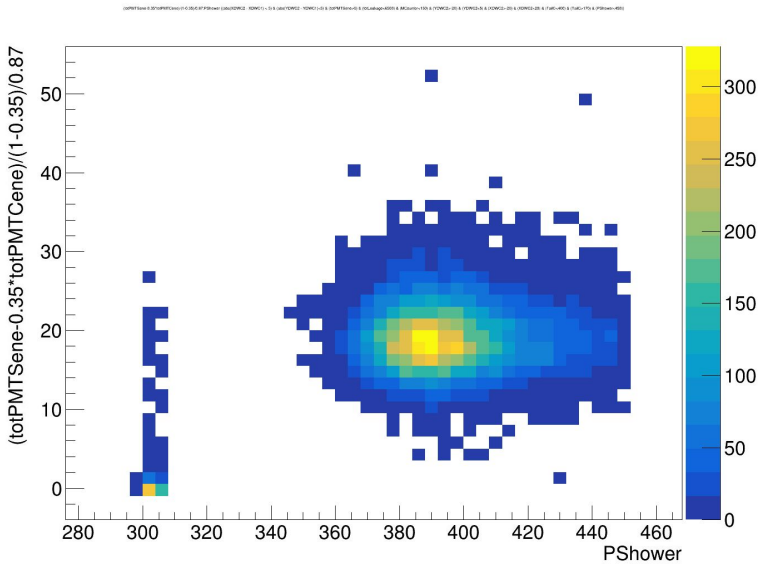


Pion Selection

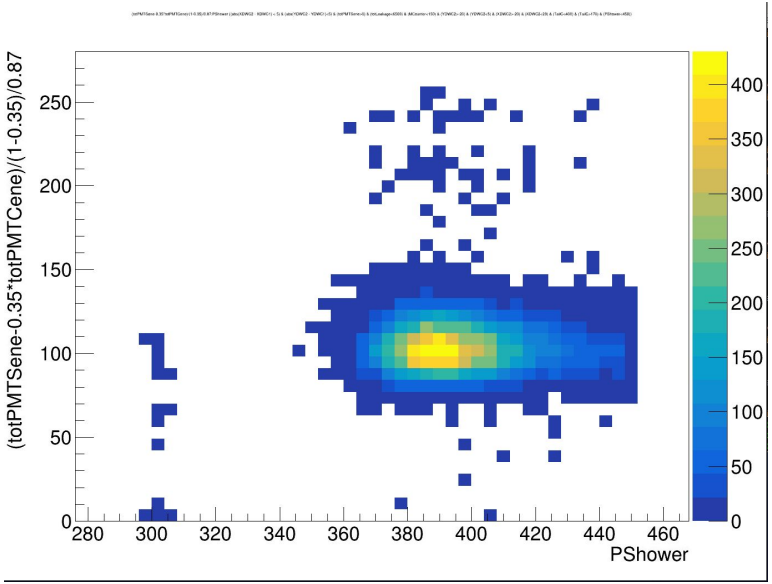
On X axis, variable used in the cut
On Y axis, reconstructed energy through dual-readout formula

```
myCut = "(abs(XDWC2 - XDWC1) < 5) & (abs(YDWC2 - YDWC1)<5) & (totPMTSene>0) & (PShower<450) &
(TailC<400) & (TailC>170) & (totLeakage<6500) & (MCounter<160) & (PShower>350) & (YDWC2>-20) &
(YDWC2<5) & (XDWC2>-20) & (XDWC2<20)"
```

Reco E Vs PreShower, 20 GeV pions



Reco E Vs PreShower, 100 GeV pions



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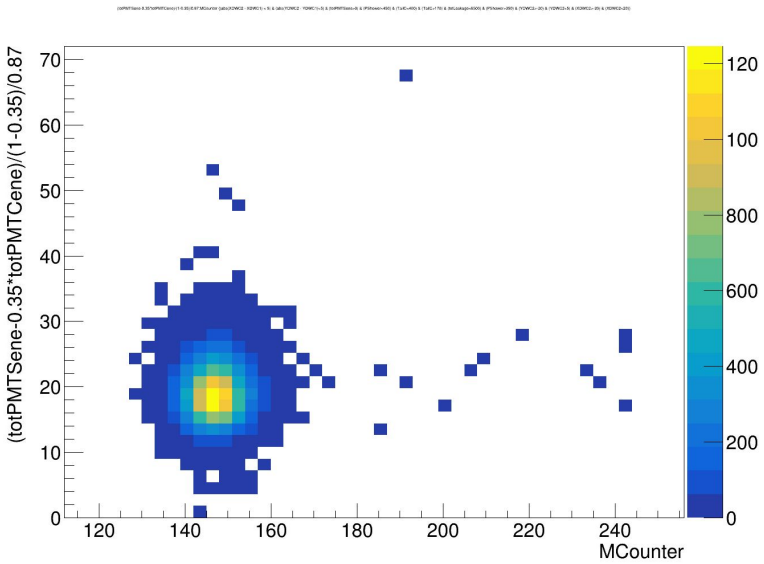
Reco E Vs MCounter, 20 GeV pions



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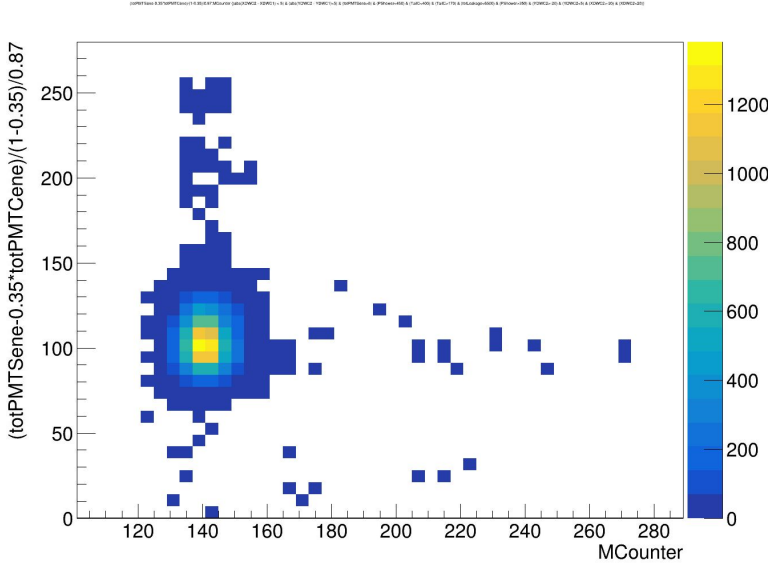

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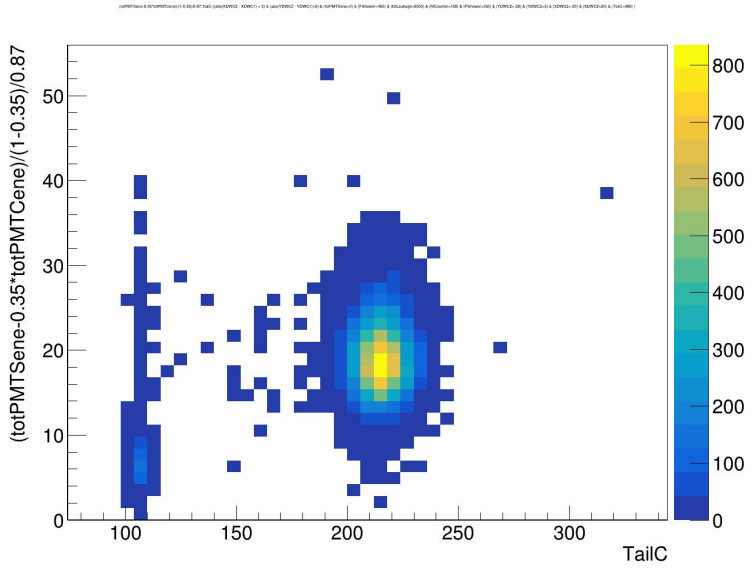
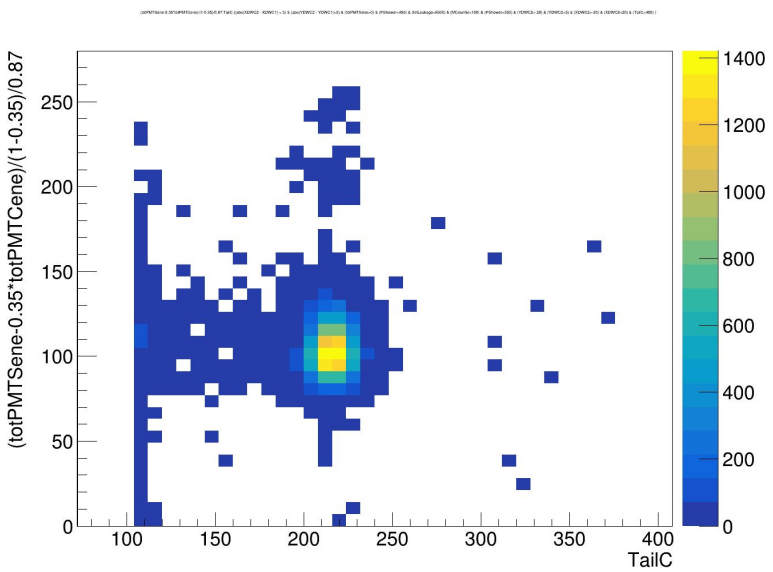
```

Reco E Vs TailC, 20 GeV pions



Reco E Vs TailC, 100 GeV pions



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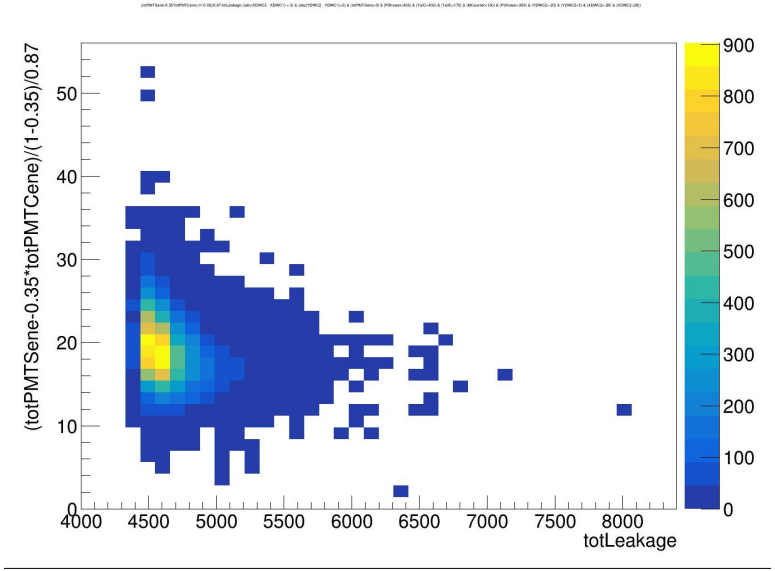
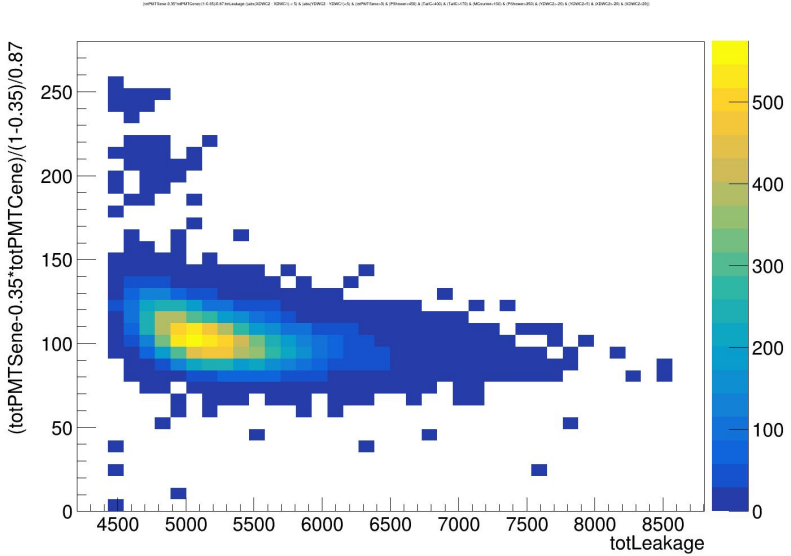
Reco E Vs totLeakage, 20 GeV pions

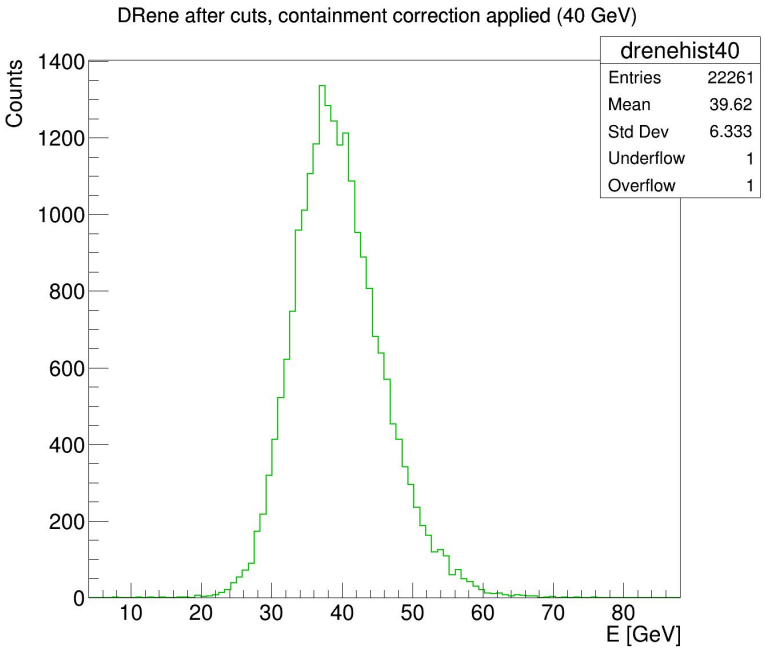


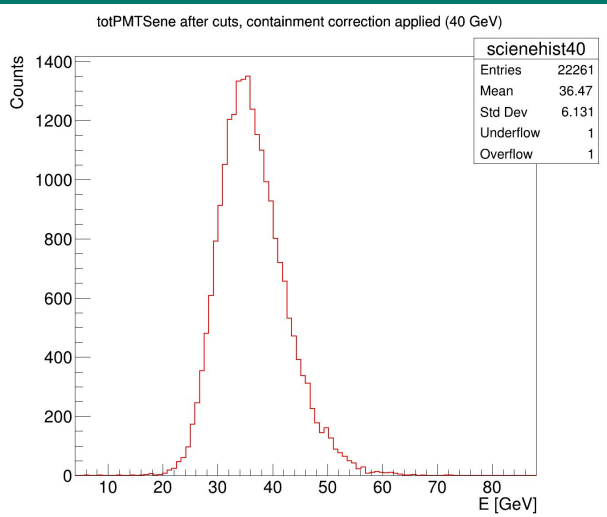
Reco E Vs totLeakage, 100 GeV pions



Pion Selection

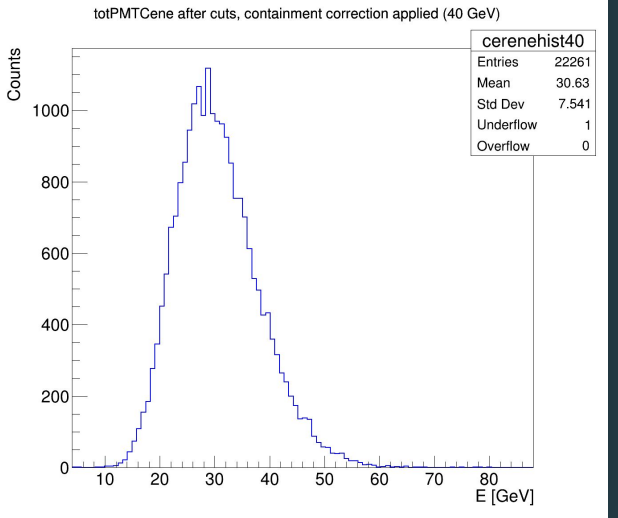
Reco Energy through dual-readout





S channel

C channel



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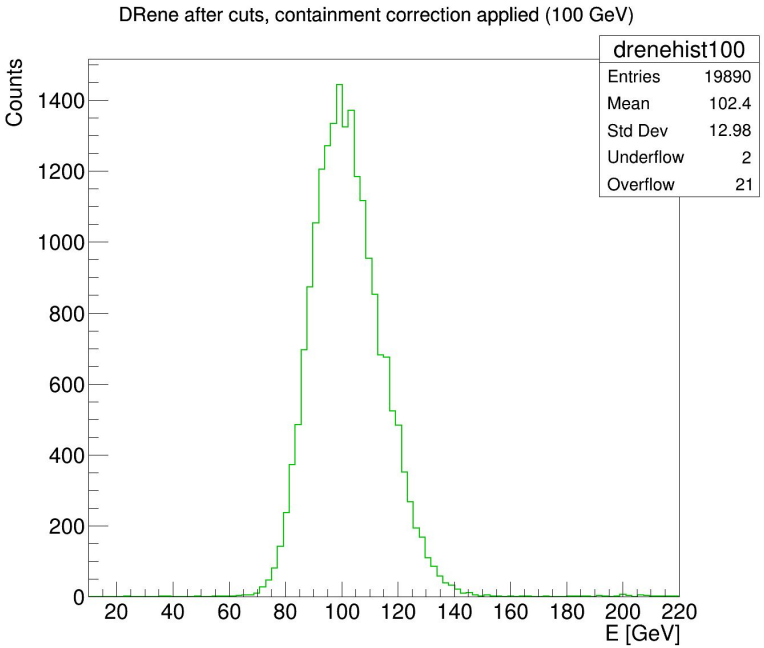

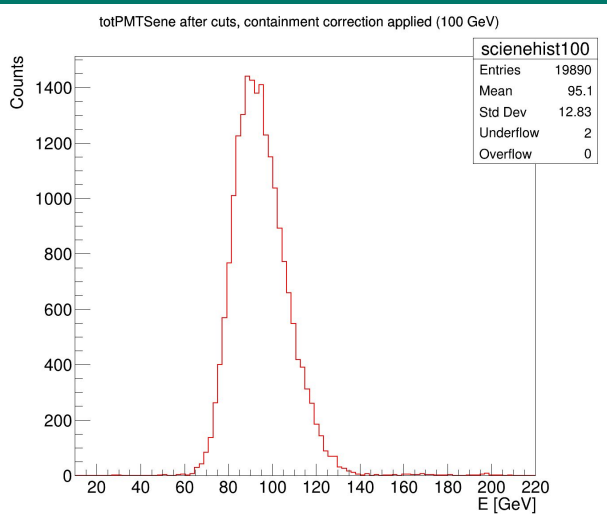

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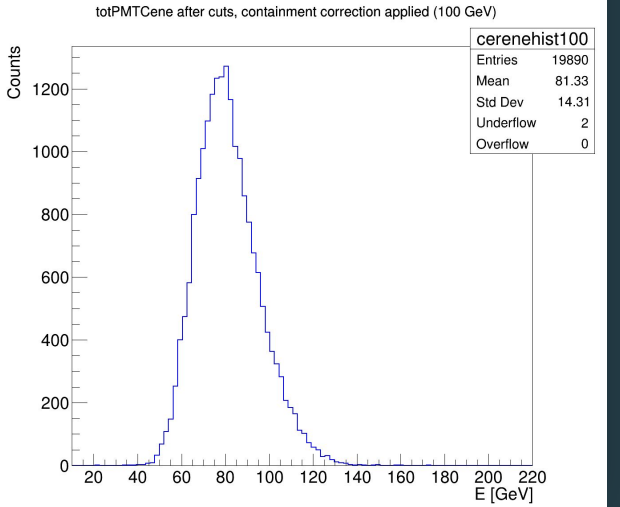
C channel



Energy dependences

Two main factors impacting energy response:

- Low energy tail -> due to leakage fluctuations
- High energy tail -> light attenuation in optical fibres

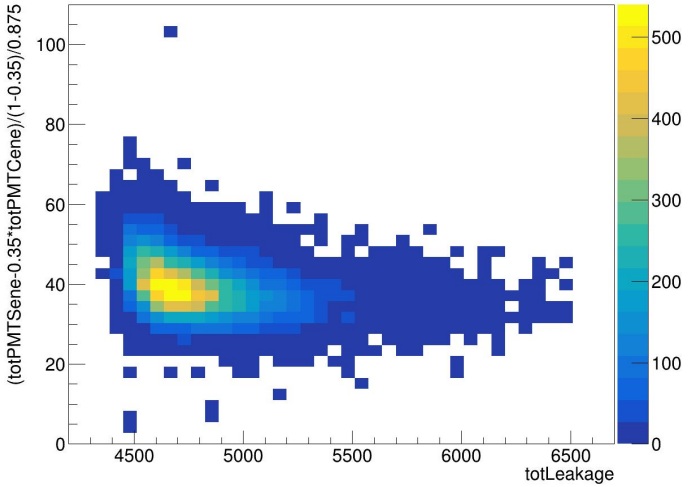
(hadron showers developing deeper in the calorimeter are less attenuated)

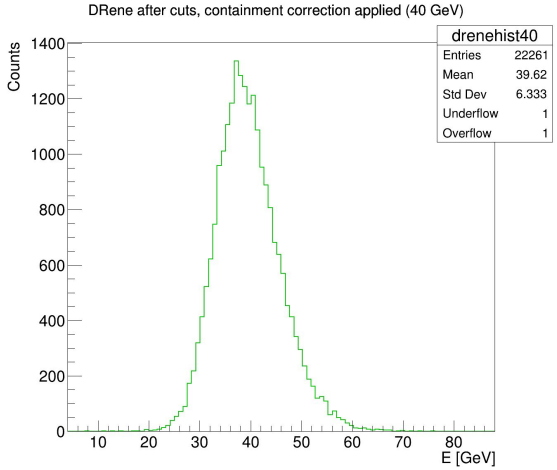
Steps to try reducing high-energy tail contribution:
Before adding timing information to data trees (thanks Iacopo!)
we had no information about shower development position

Use “asymmetry” variable (which was already implemented for electron beam analysis), reasoning in following slides

After timing was included, tried different approaches to exploit it

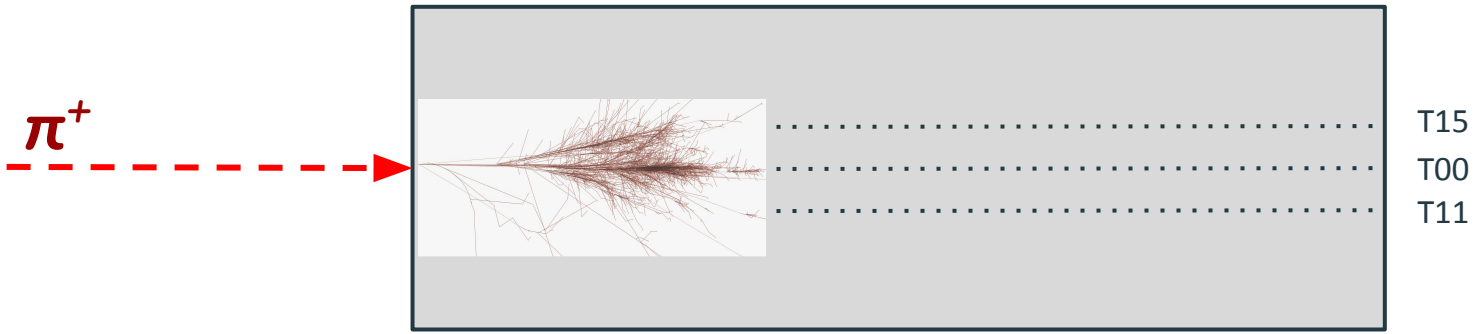
Reco E Vs totLeakage, 40 GeV pions





Calorimeter not tilted

On average, same amount of energy deposited in rows above and below the central one
(independent on longitudinal position of shower development starting point)



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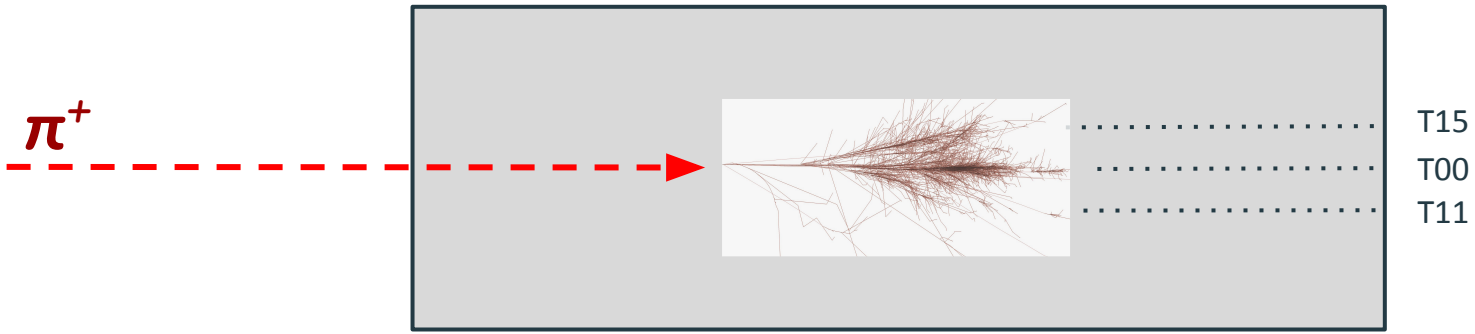
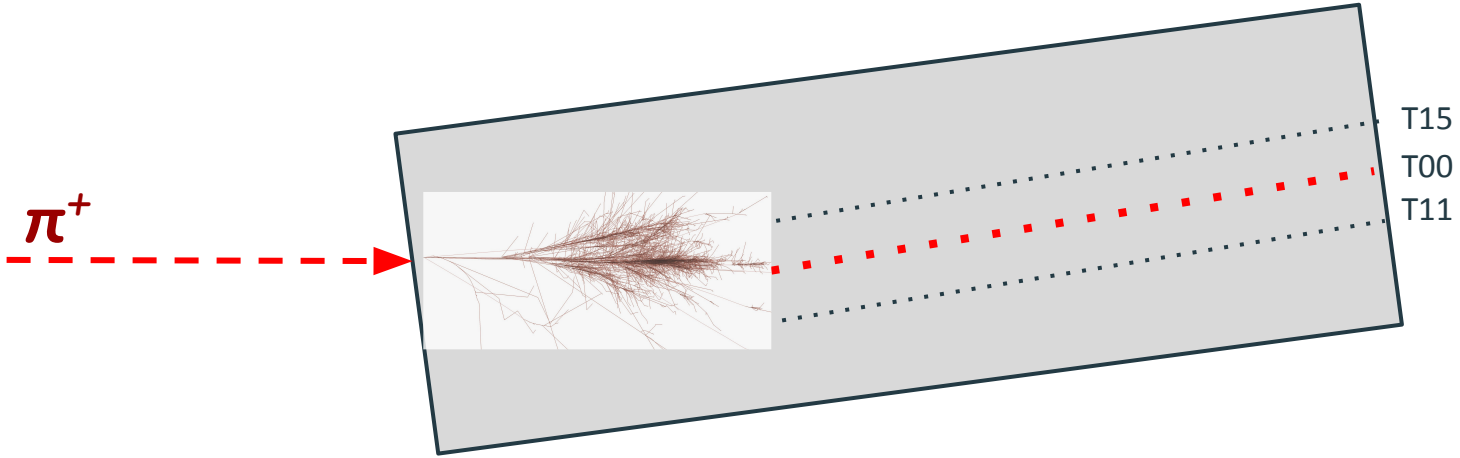


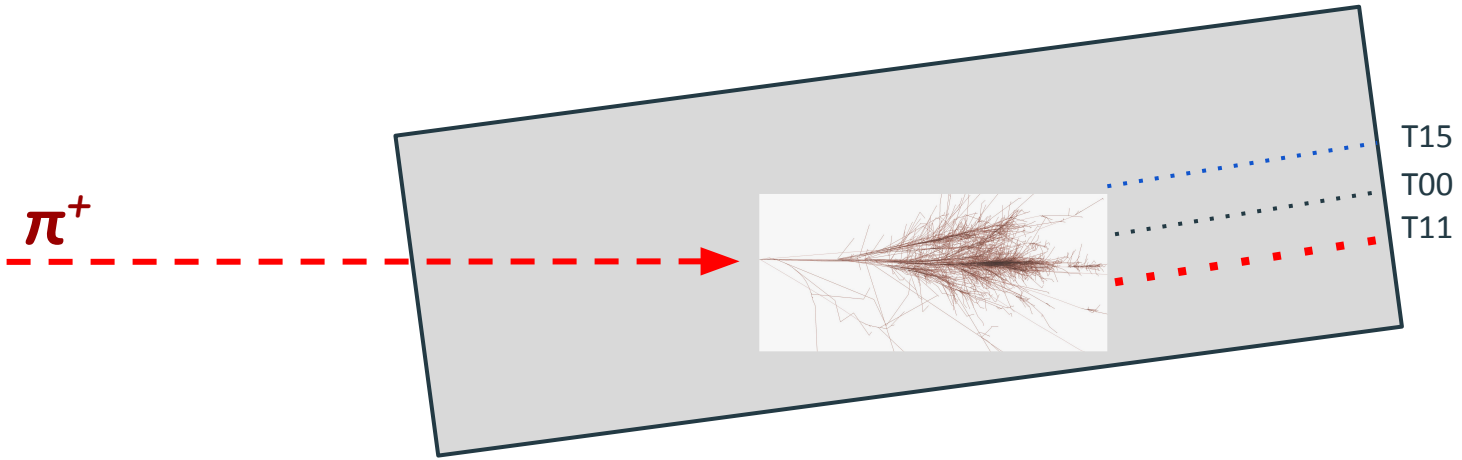
Calorimeter tilted

For early-initiating showers (hence, similar attenuation with respect to electromagnetic ones) still similar energy deposit in rows above and below central one



Calorimeter tilted

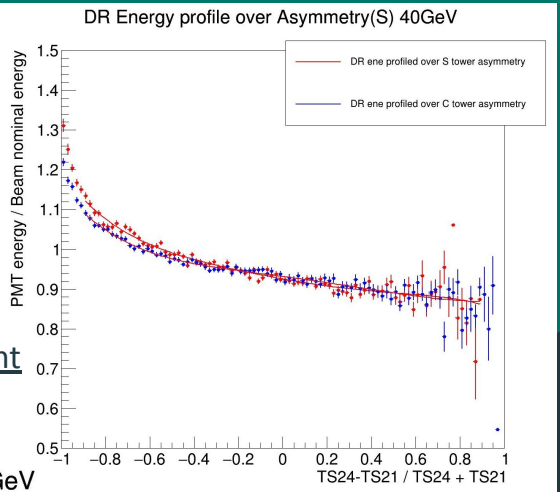
For late-initiating showers (less attenuated signal) lower towers read higher energy with respect to higher ones (on average)
-> more asymmetrical

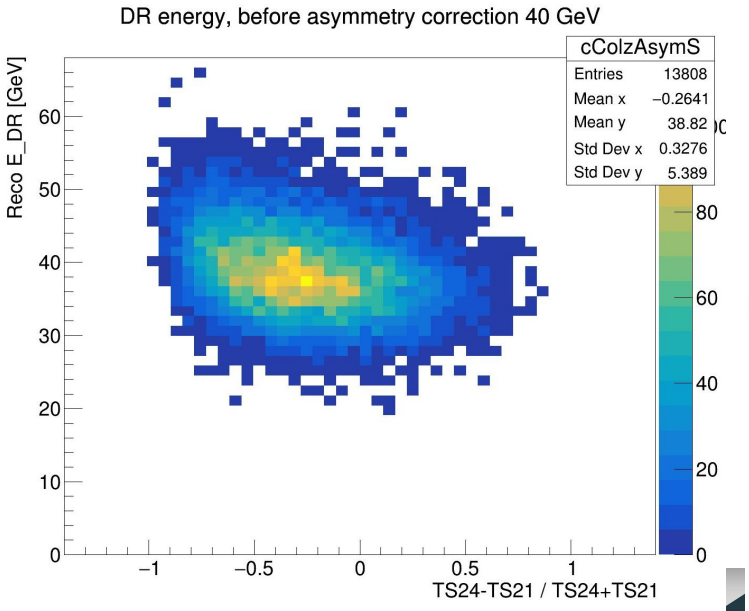


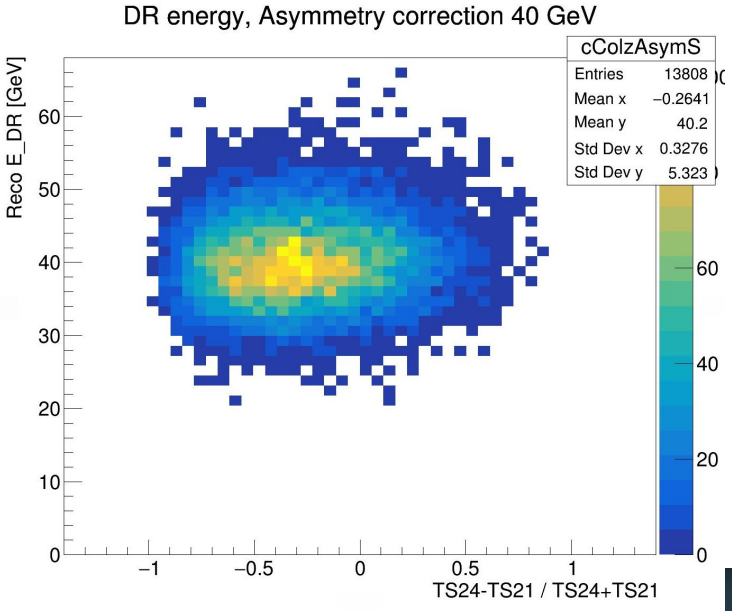
On pion energy correction

Observed better results using ring2 towers instead of T11 and T15
Also tried sums of (T23+T24+T25) and (T20+T21+T22), no significant improvement

Fit asym = (TS24-TS21)/(TS24+TS21) with 5deg polynomial, for only one energy working point
For any point, $\mathbf{E_{DR} = E_{DR}/fS_{40GeV}(asym)}$







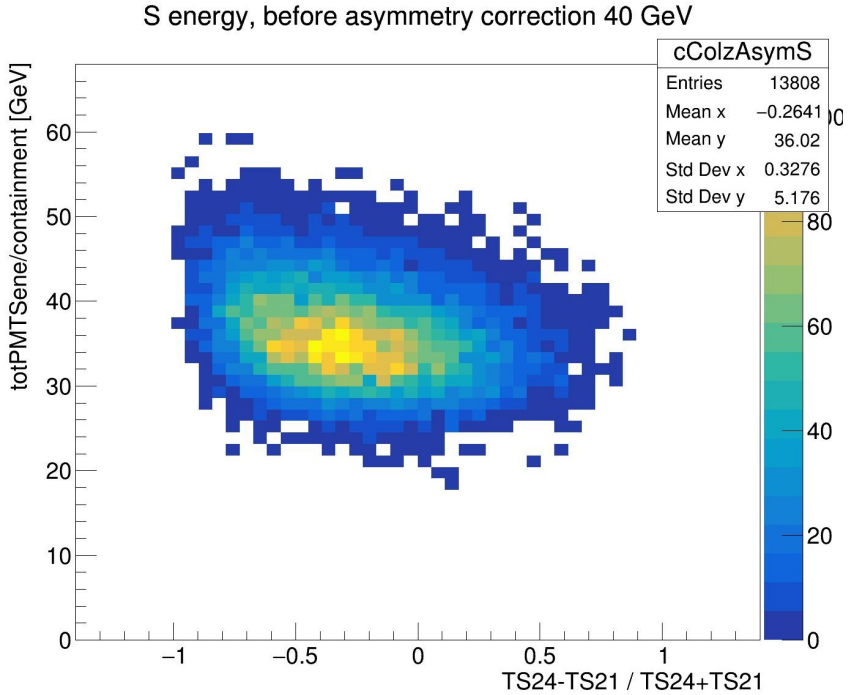
Profile of recoE/nominalE with respect to asymmetry variable

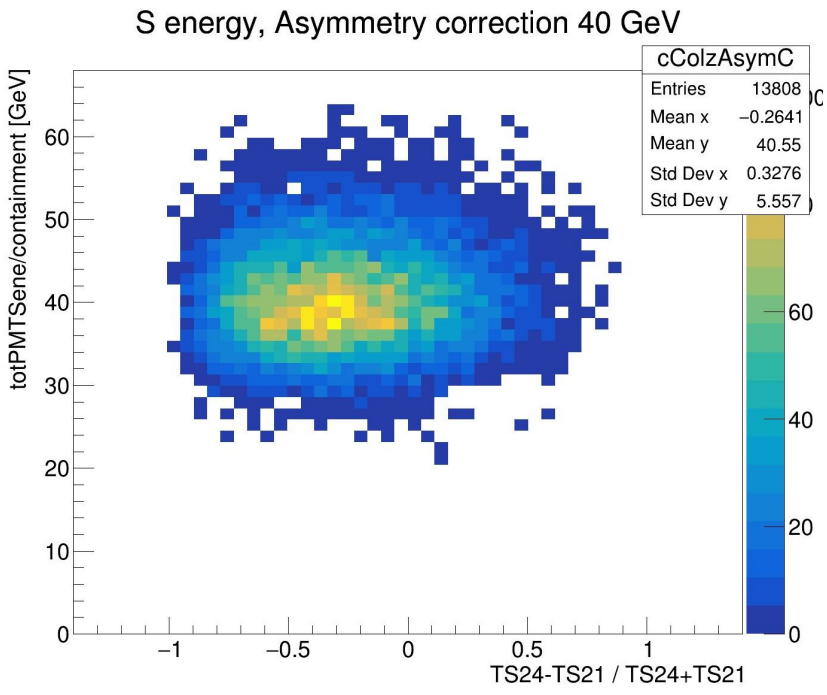
On pion energy correction

Note that using truth beam energy for this correction forces S and C energies around the correct energy value

Same process also for S and C channels

For any point, $E_S = E_S/fS_{40GeV}(asym)$, $E_C = E_C/fS_{40GeV}(asym)$





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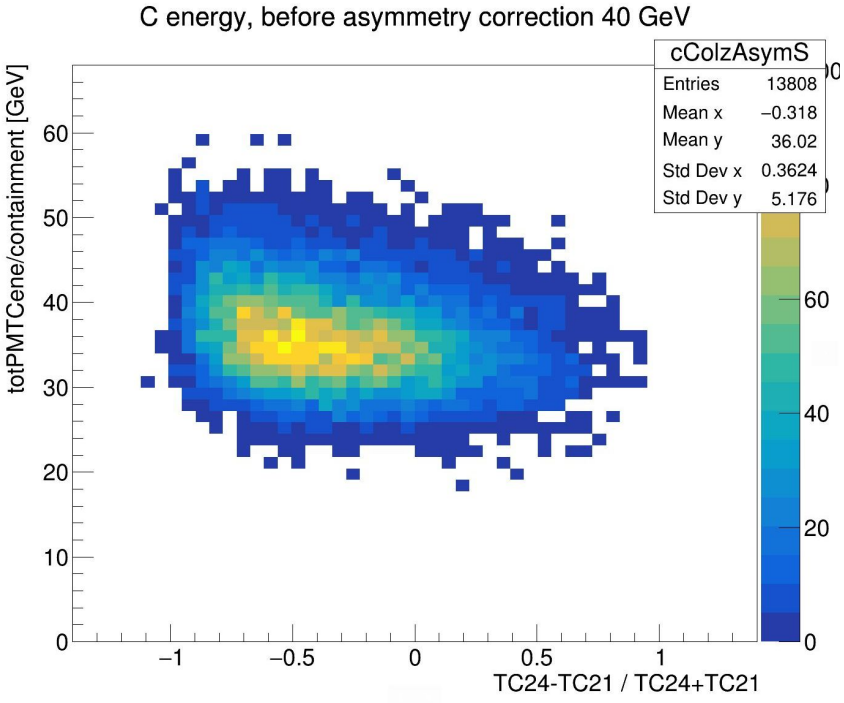
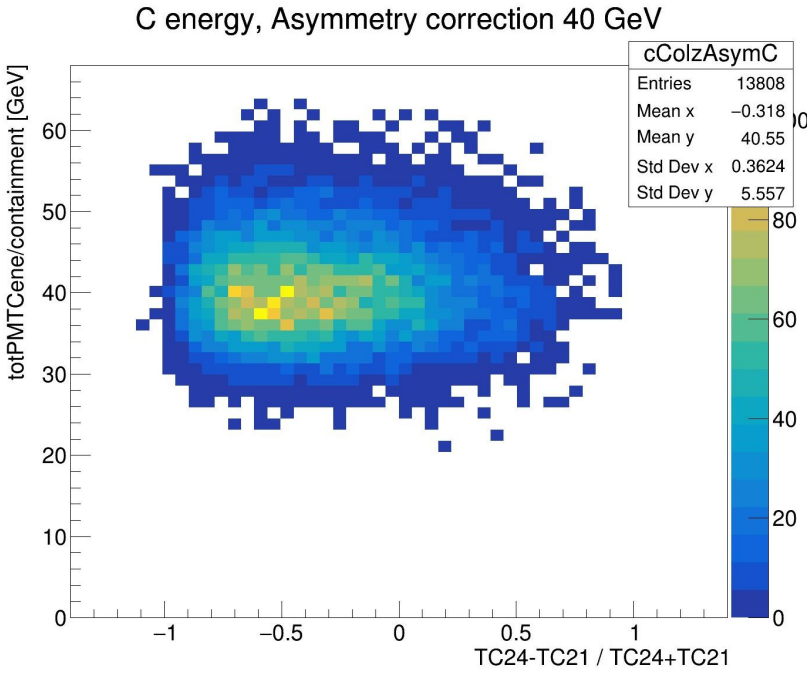
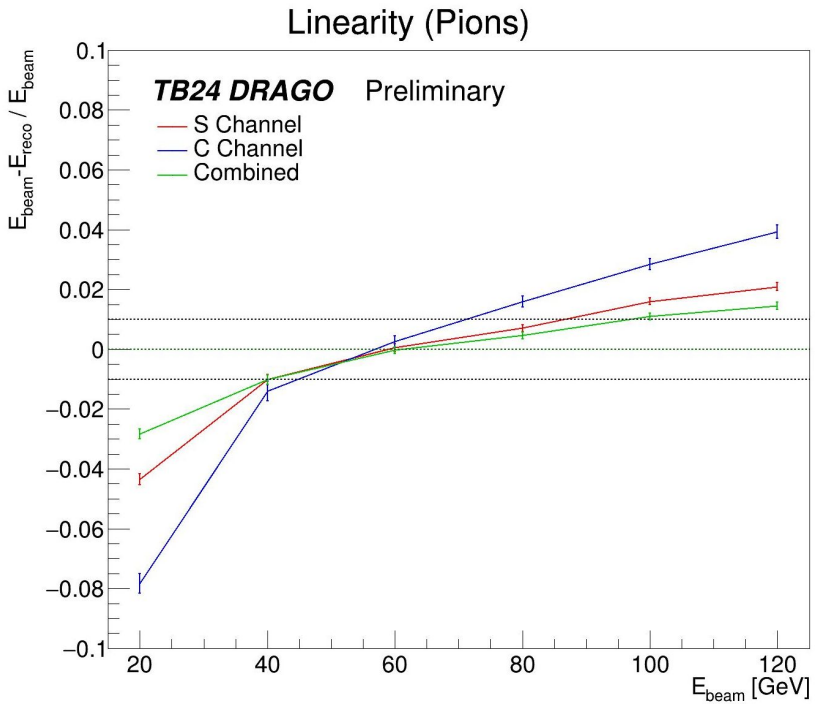
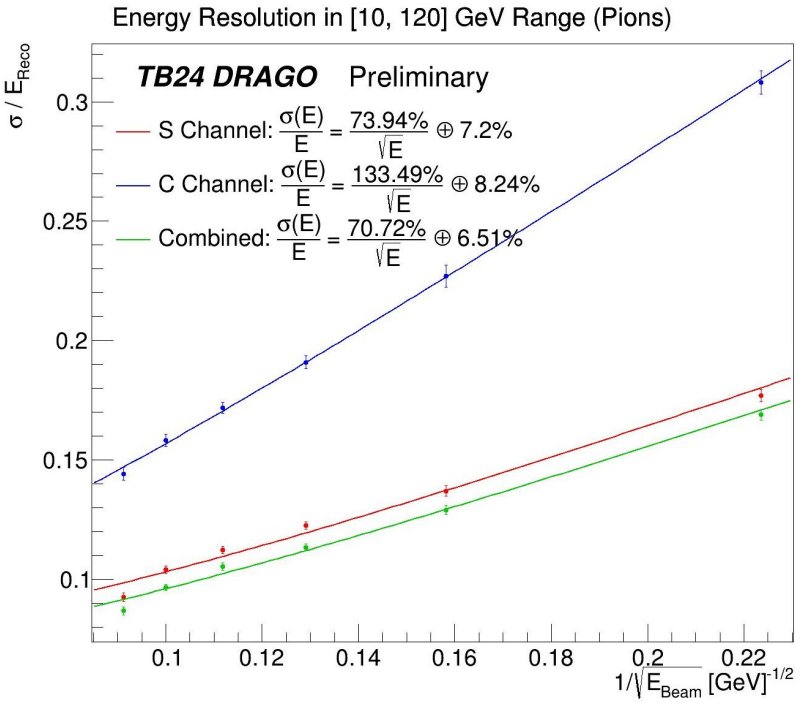




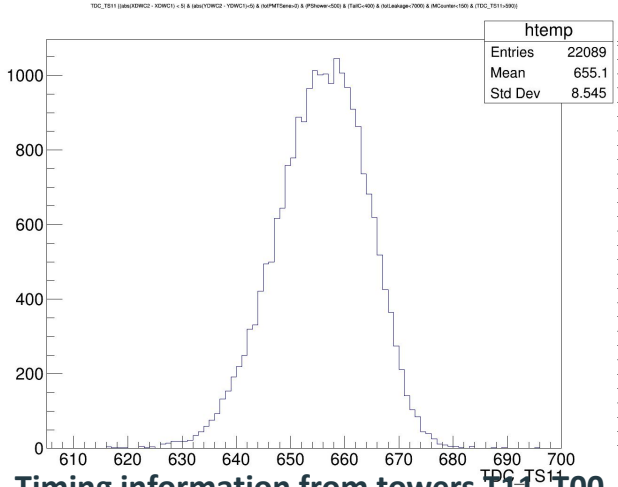
On pion energy correction

Using correction with asymmetry only

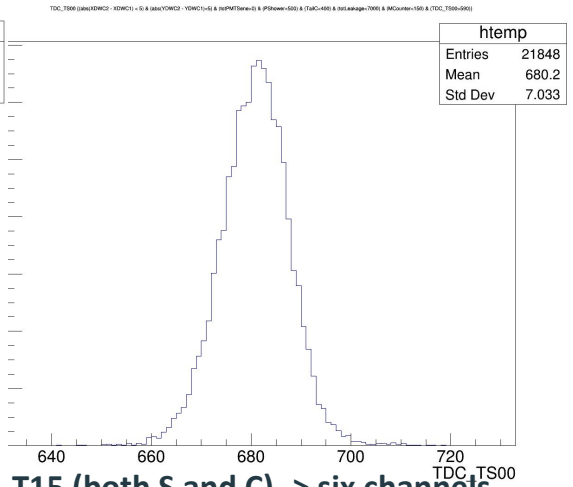




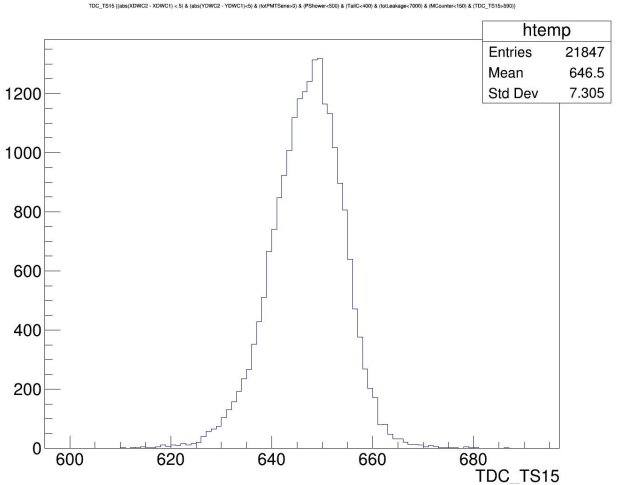
Tower 11



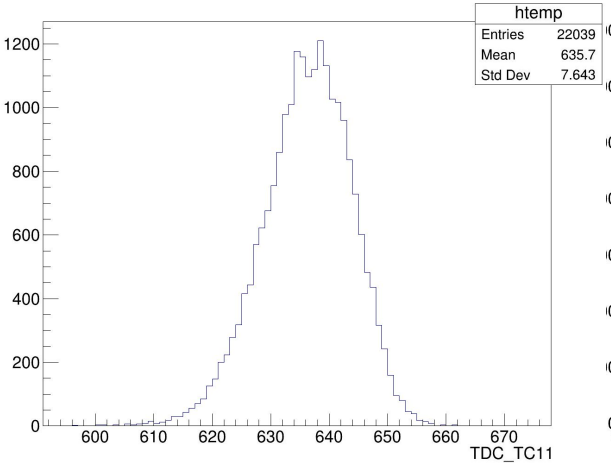
Tower 00

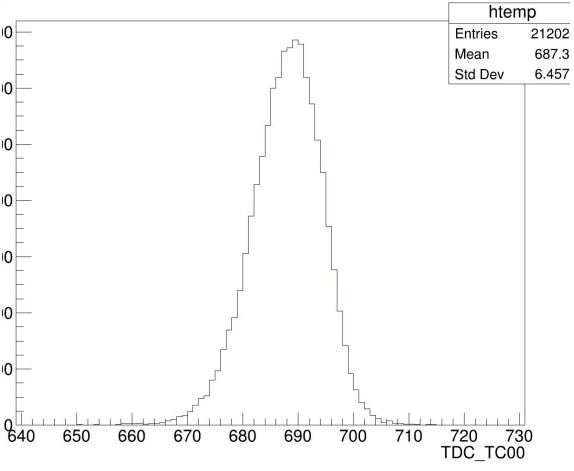


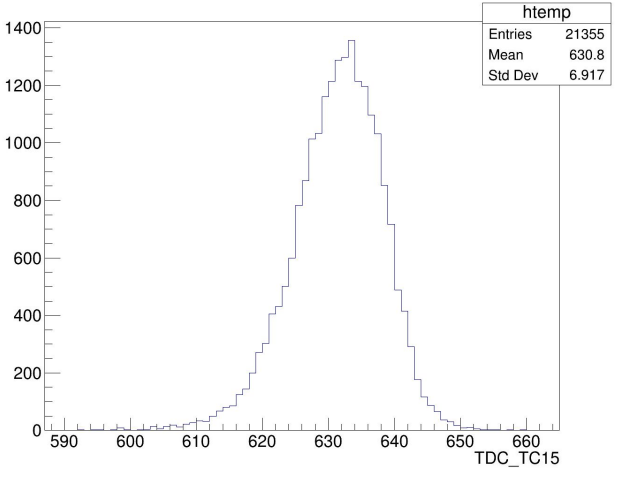
Tower 15



Timing information from towers T11, T00, T15 (both S and C) -> six channels







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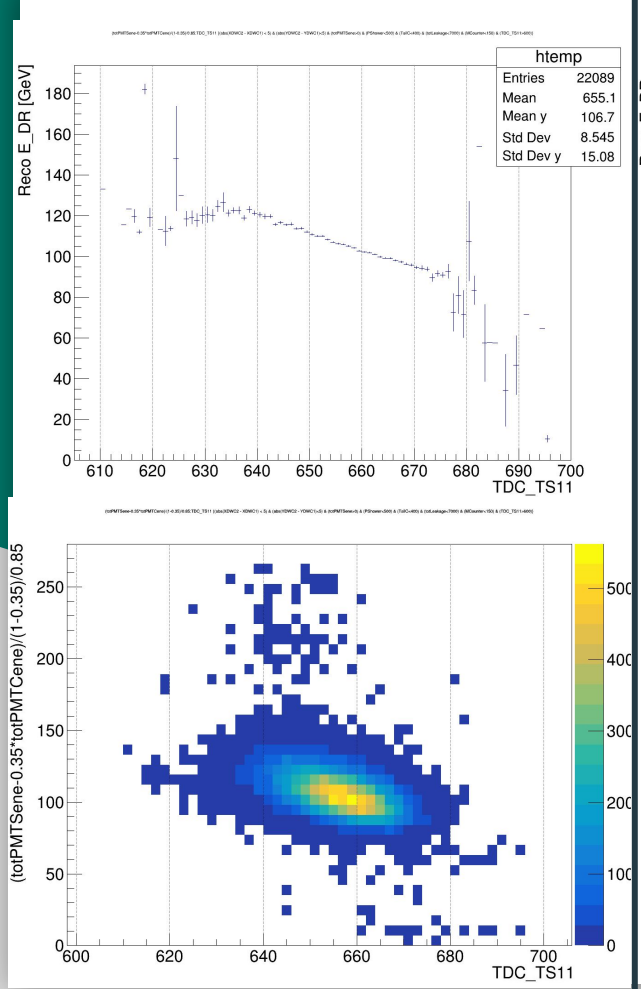
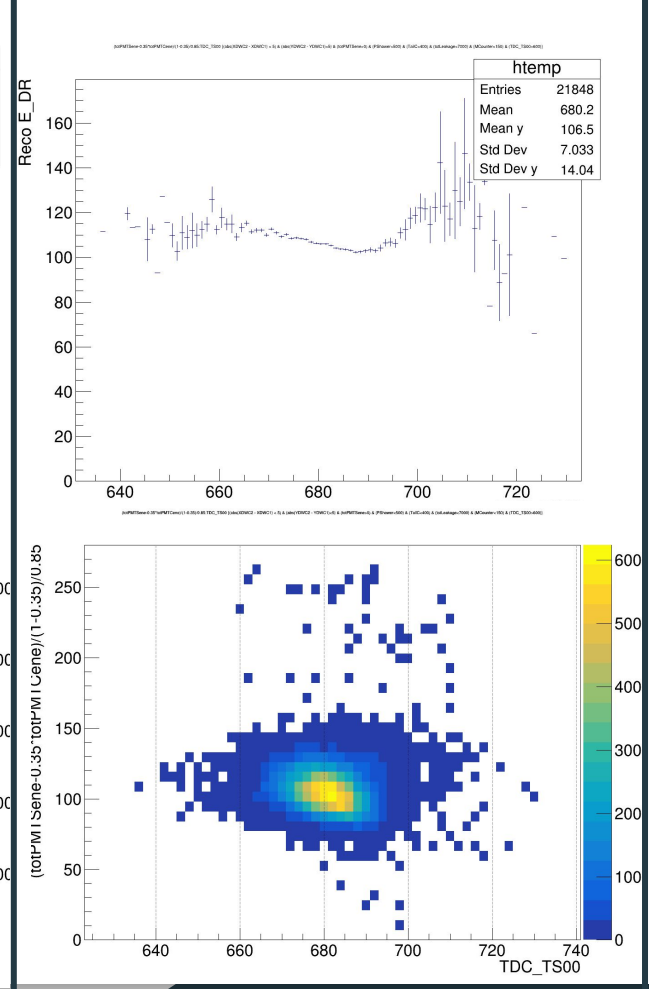
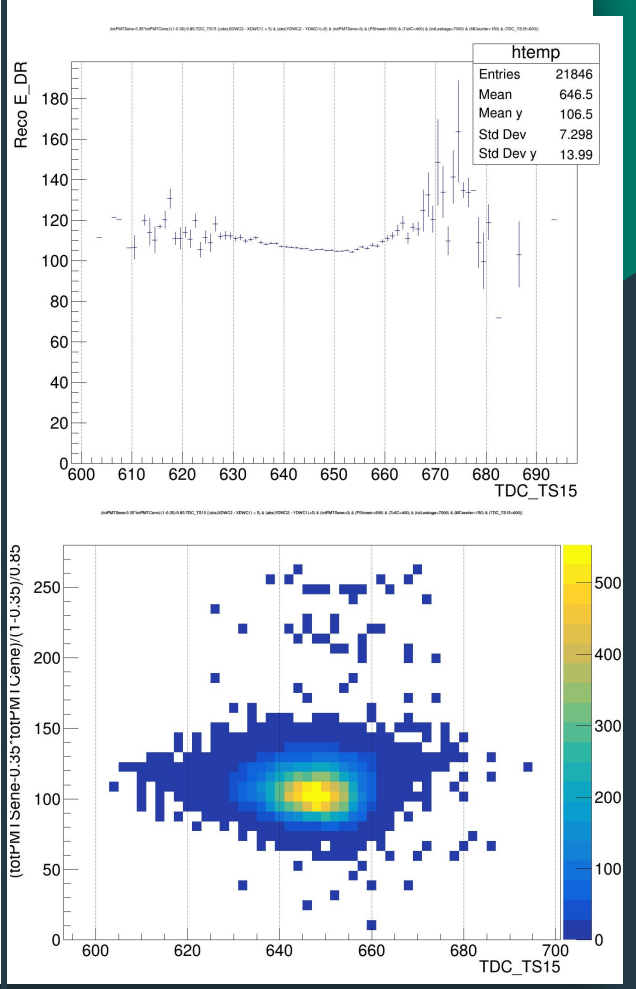


Tower 00



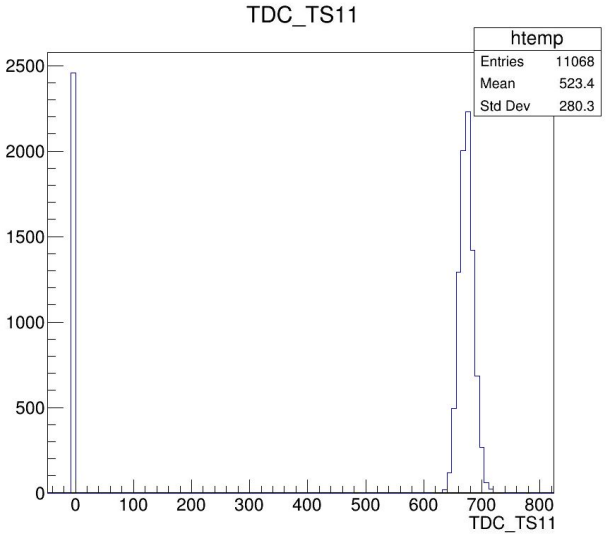
Tower 15



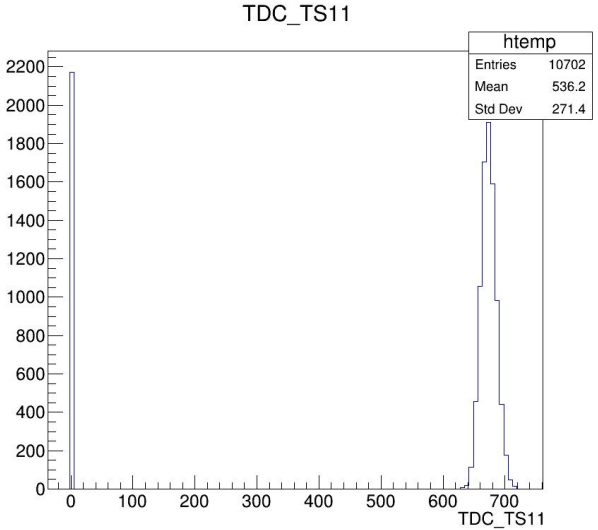
TDCs

Runs 0968, 0972 (20 GeV from pion energy scan) have large “pedestal” -> not sure what’s wrong
After cuts, quite low statistics
Run 1000 is good, but taken after time info was amplified -> offset for this energy sample on all TDCs

Run 0968, 20 GeV pions, before cuts



Run 0972, 20 GeV pions, before cuts



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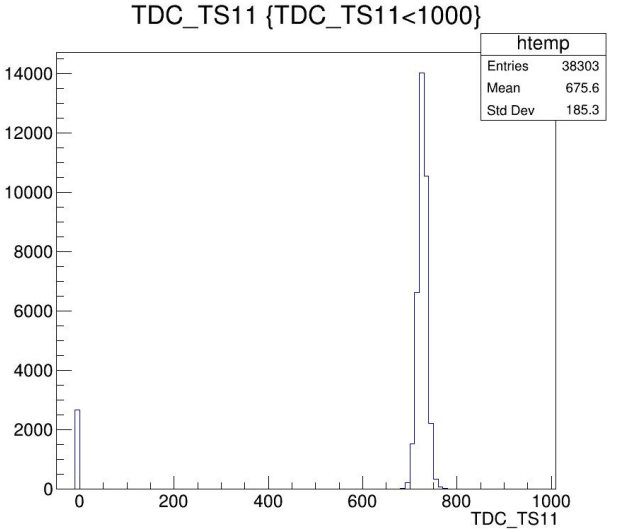
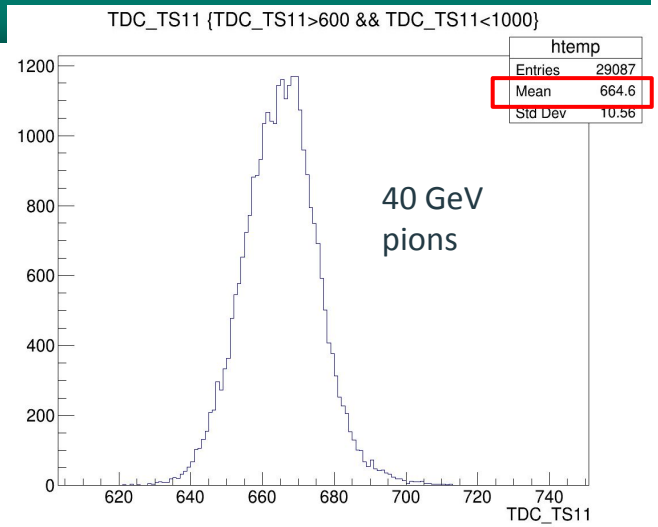
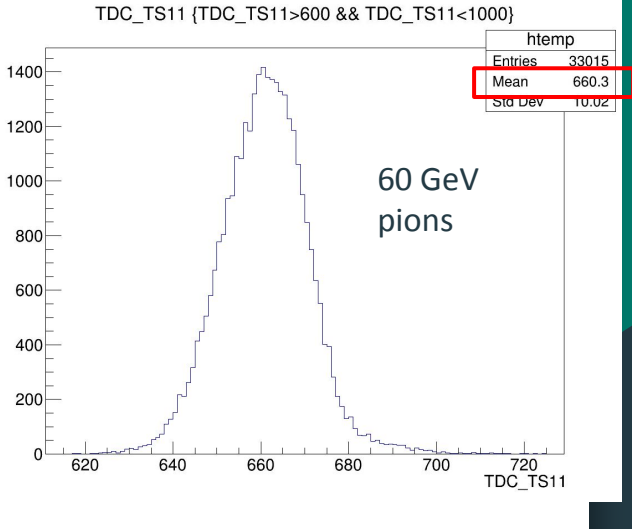
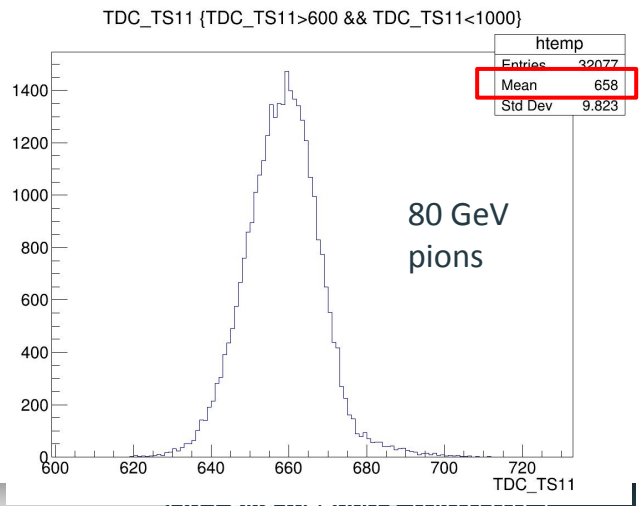


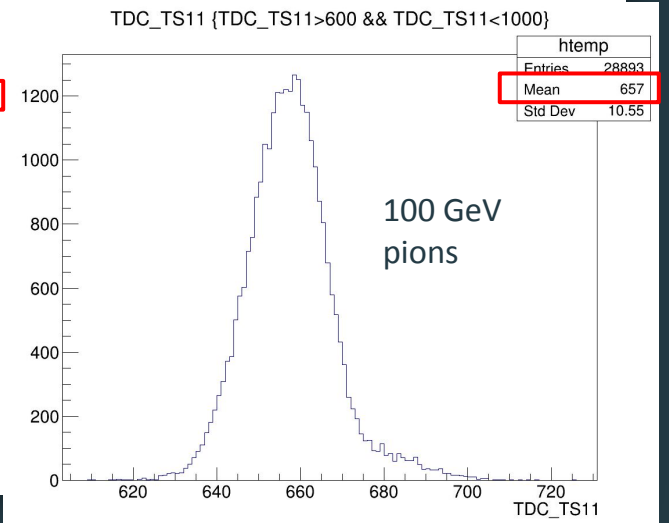
TDCs

Not clear how to shift TDC distribution with energy









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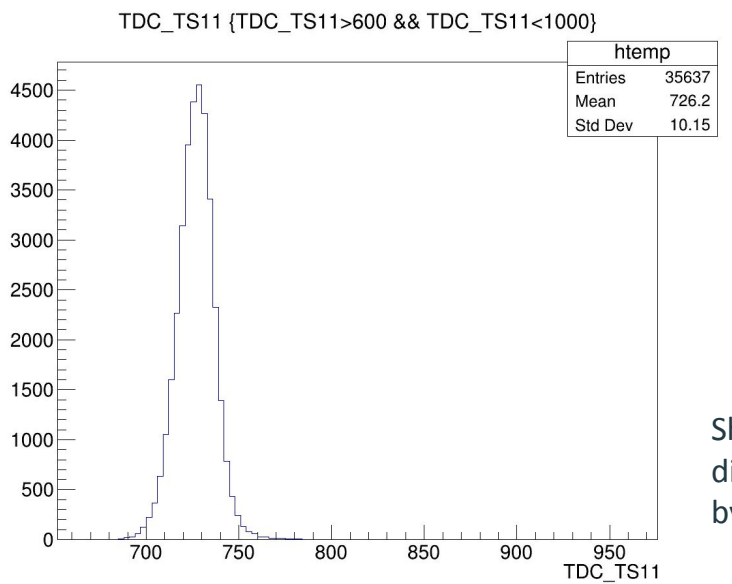
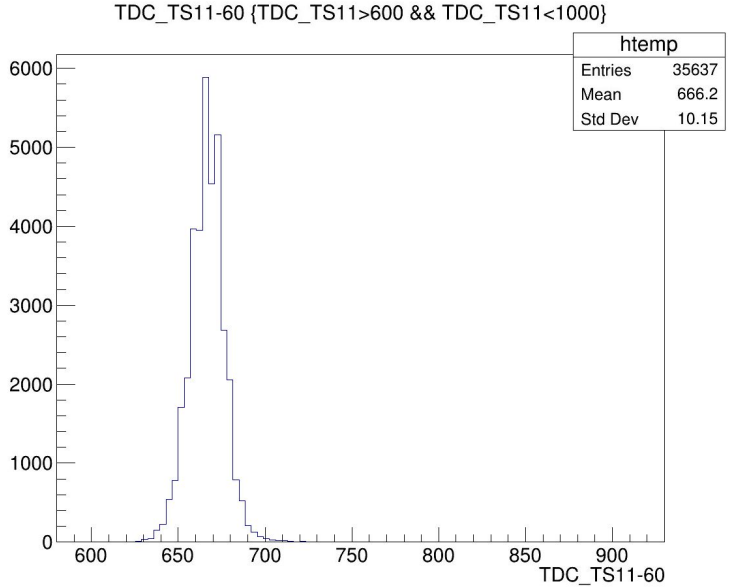
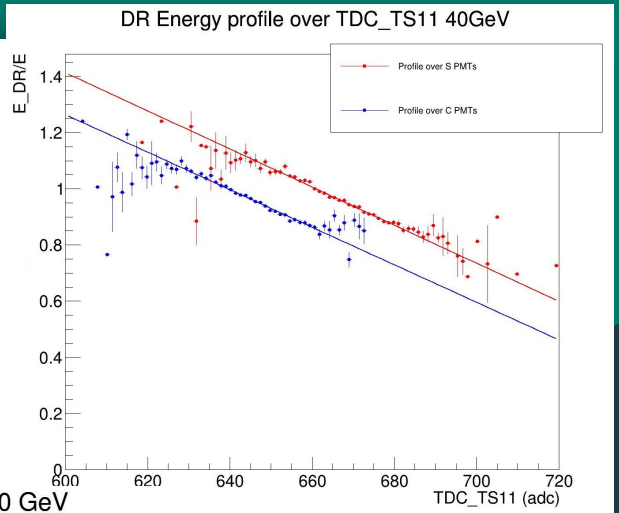


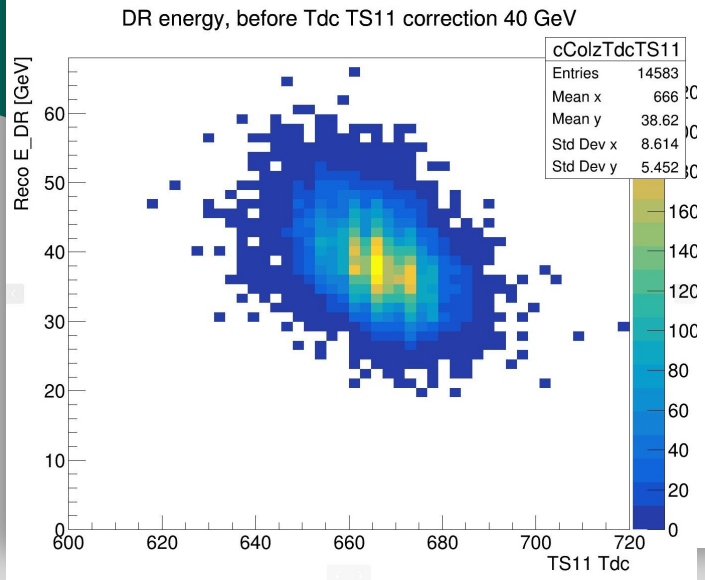
Shifting distribution by 60 tdcs

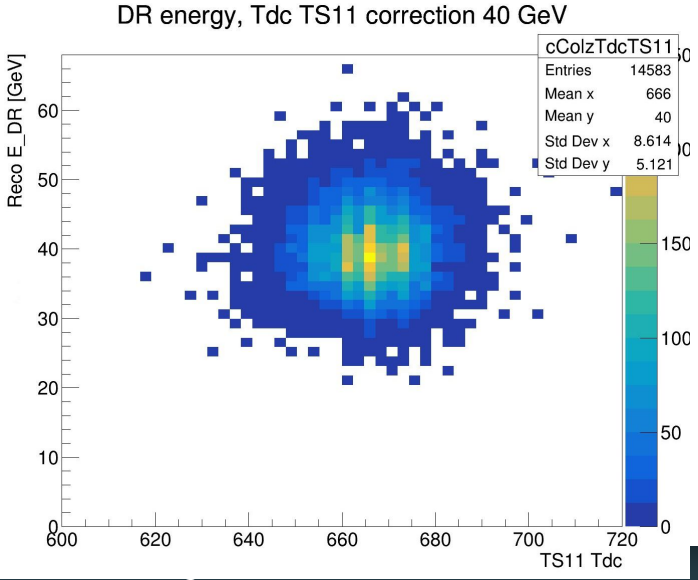


On pion energy corrections

Fit TDC_TS11 with 1deg polynomial
For any point, $E_{DR} = E_{DR}/fS_{40GeV}(asym)$

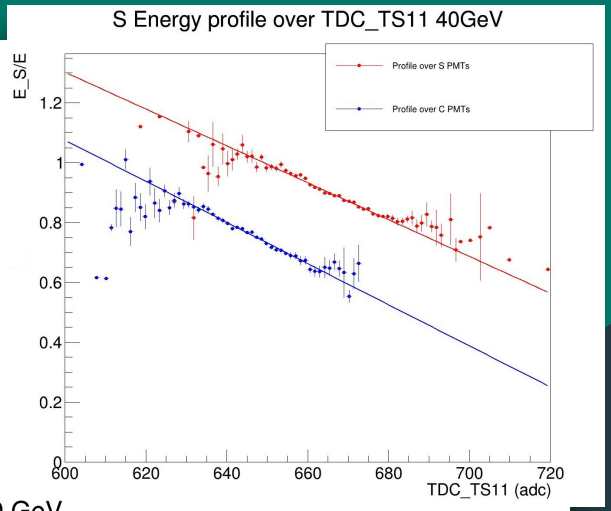


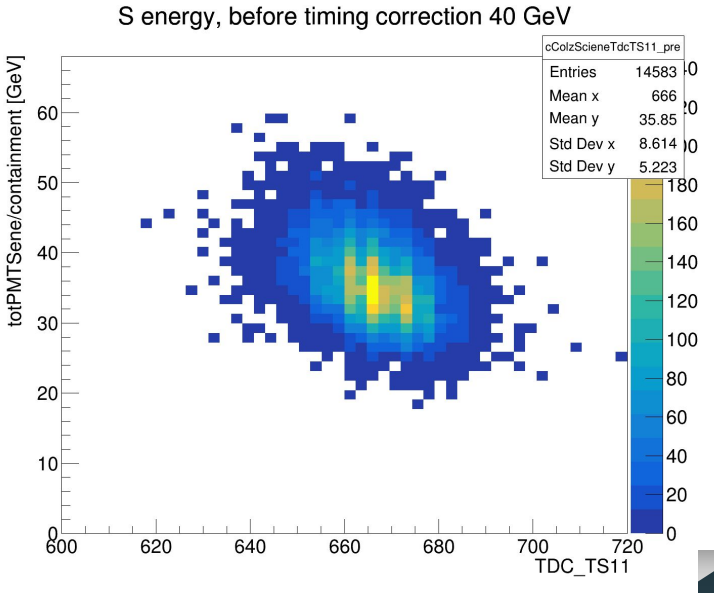


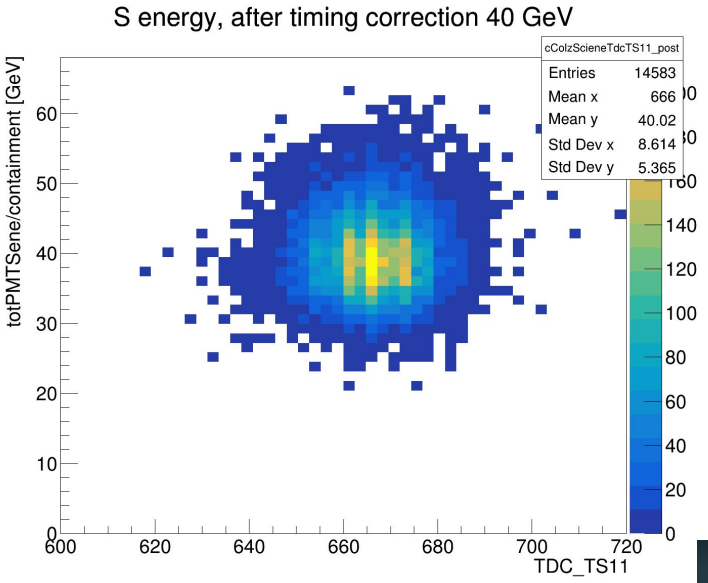


On pion energy corrections

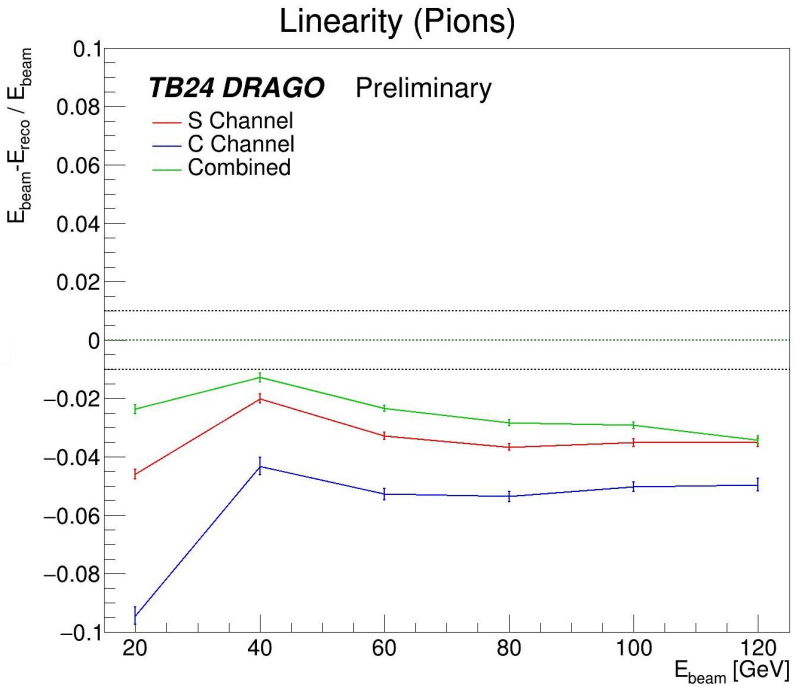
Fit TDC_TS11 with 1deg polynomial
For any point, $E_S = E_S/fS_{40GeV}(asym)$

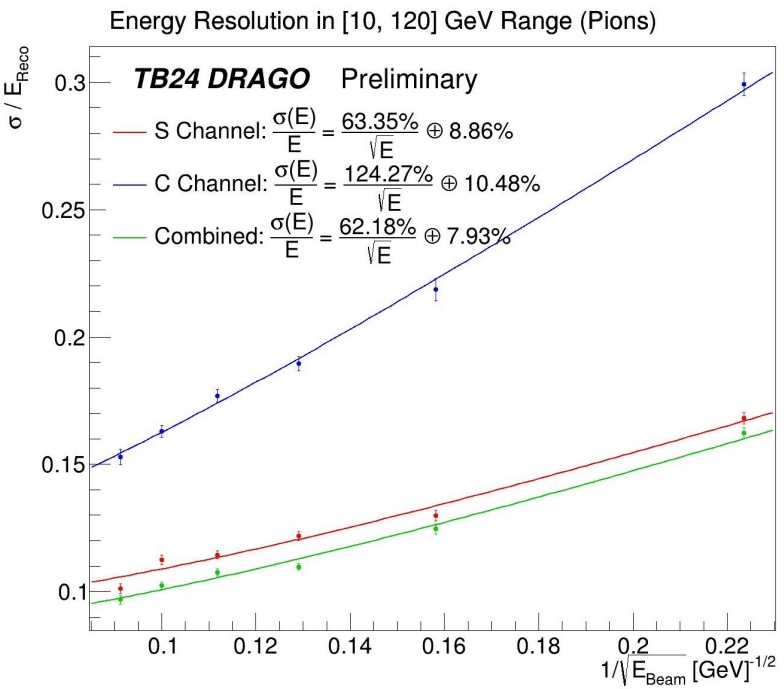






Using correction with timing only information



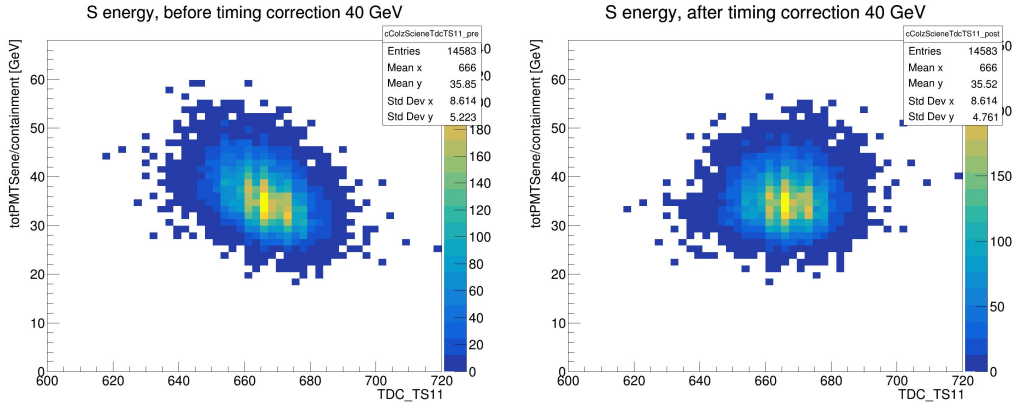


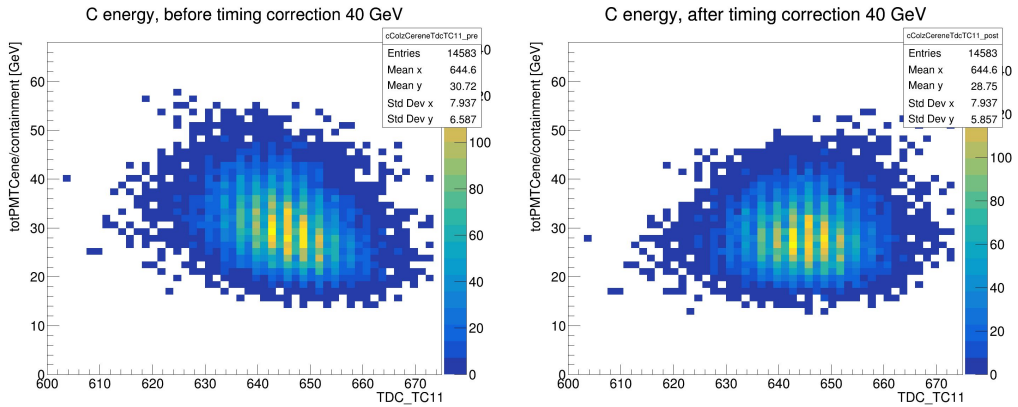
Also tried, but not shown here, tests with timing correction upon energy already corrected with asymmetry, and vice-versa
-> No significant improvement

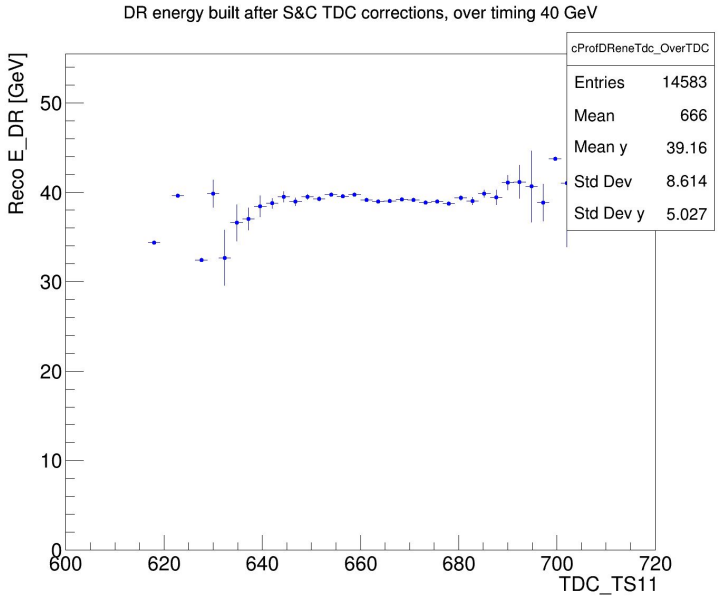
Second idea:

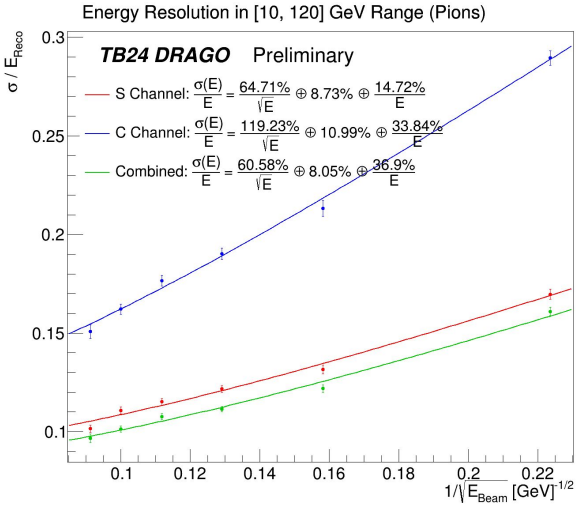
Use timing to correct S and C channels, and only later apply dual-readout formula

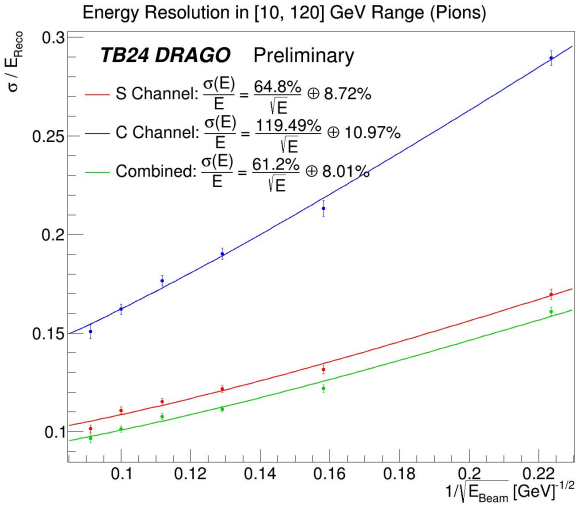
<u>This time, use most probable value instead of truth energy</u>

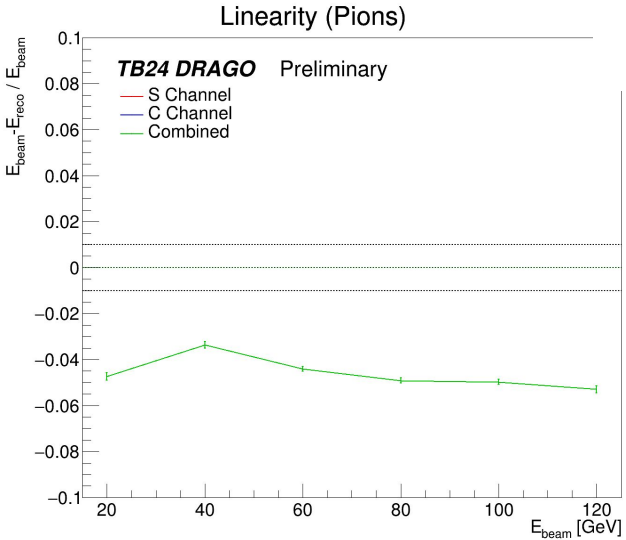




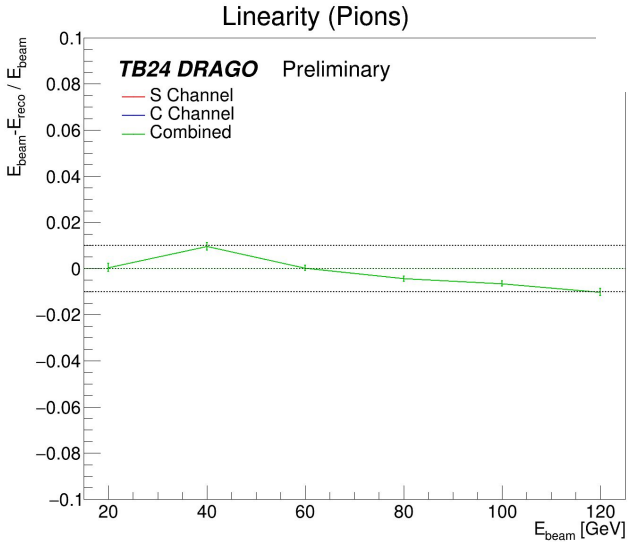


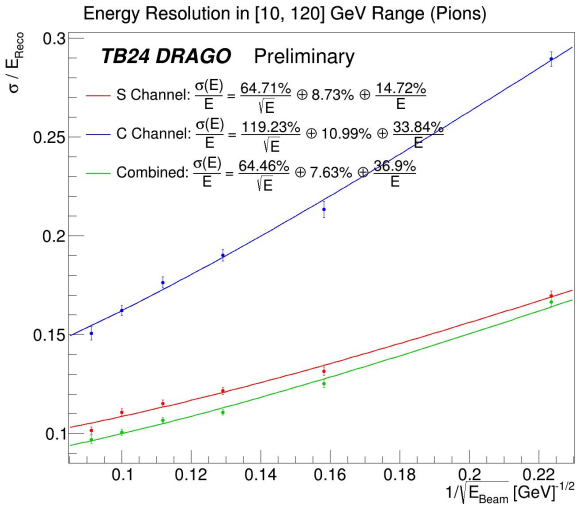

Energy Resolution in [10, 120] GeV Range (Pions)
TB24 DRAGO Preliminary
S Channel: σ(E)/E = 64.71%/√E ⊕ 8.73% ⊕ 14.72%/E
C Channel: σ(E)/E = 119.23%/√E ⊕ 10.99% ⊕ 33.84%/E
Combined: σ(E)/E = 60.58%/√E ⊕ 8.05% ⊕ 36.9%/E
σ / E_Reco
1/√E_Beam [GeV]^-1/2

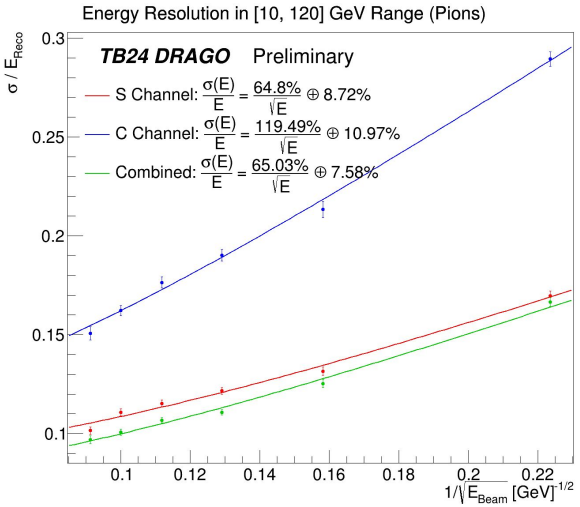

Energy Resolution in [10, 120] GeV Range (Pions)
TB24 DRAGO Preliminary
S Channel: σ(E)/E = 64.8%/√E ⊕ 8.72%
C Channel: σ(E)/E = 119.49%/√E ⊕ 10.97%
Combined: σ(E)/E = 61.2%/√E ⊕ 8.01%
σ / E_Reco
1/√E_Beam [GeV]^-1/2


Linearity (Pions)
TB24 DRAGO Preliminary
S Channel
C Channel
Combined
E_beam - E_reco / E_beam
E_beam [GeV]

chi = 0.35


Linearity (Pions)
TB24 DRAGO Preliminary
S Channel
C Channel
Combined
E_{beam}-E_{reco} / E_{beam}
E_{beam} [GeV]


Energy Resolution in [10, 120] GeV Range (Pions)
TB24 DRAGO Preliminary
S Channel: $\frac{\sigma(E)}{E} = \frac{64.71\%}{\sqrt{E}} \oplus 8.73\% \oplus \frac{14.72\%}{E}$
C Channel: $\frac{\sigma(E)}{E} = \frac{119.23\%}{\sqrt{E}} \oplus 10.99\% \oplus \frac{33.84\%}{E}$
Combined: $\frac{\sigma(E)}{E} = \frac{64.46\%}{\sqrt{E}} \oplus 7.63\% \oplus \frac{36.9\%}{E}$
σ / E_{Reco}
$1/\sqrt{E_{Beam}}$ [GeV]$^{-1/2}$


Energy Resolution in [10, 120] GeV Range (Pions)
TB24 DRAGO Preliminary
S Channel: $\frac{\sigma(E)}{E} = \frac{64.8\%}{\sqrt{E}} \oplus 8.72\%$
C Channel: $\frac{\sigma(E)}{E} = \frac{119.49\%}{\sqrt{E}} \oplus 10.97\%$
Combined: $\frac{\sigma(E)}{E} = \frac{65.03\%}{\sqrt{E}} \oplus 7.58\%$
σ / E_{Reco}
$1/\sqrt{E_{Beam}}$ [GeV]$^{-1/2}$

chi = 0.44

Electron equalisation runs

In order to understand the large spread of reconstructed energy in pion runs, turned back to the electron equalisation/calibration procedure
When shooting electrons in T00, only very low energies are seen in external towers

Equalisation runs at 20 GeV with “oldHV” settings on T00
Energy Scan runs taken with “newHV” settings on T00

Here, baseline reference for all plots are obtained from run 0766 -> new HV, 20 GeV electrons
Scans are done on all equalisation runs (eq run on T00 is 0745)

Electron equalisation runs

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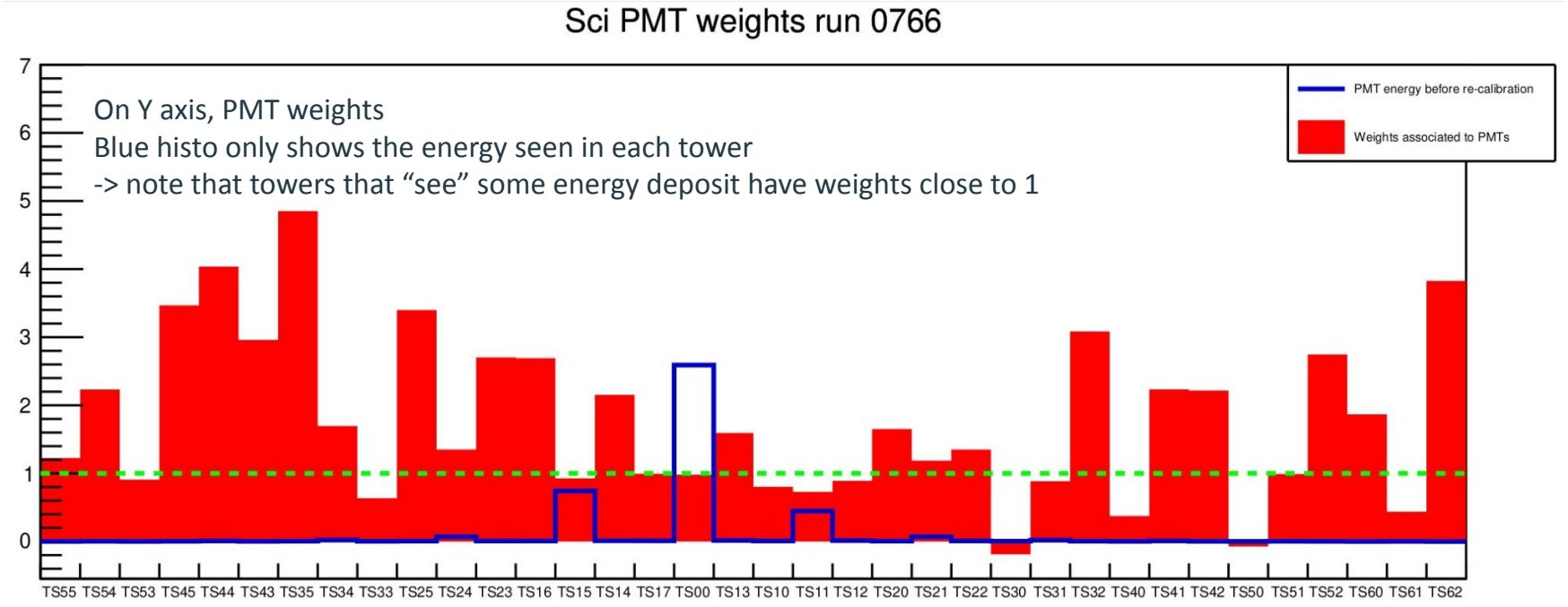

Electron equalisation runs

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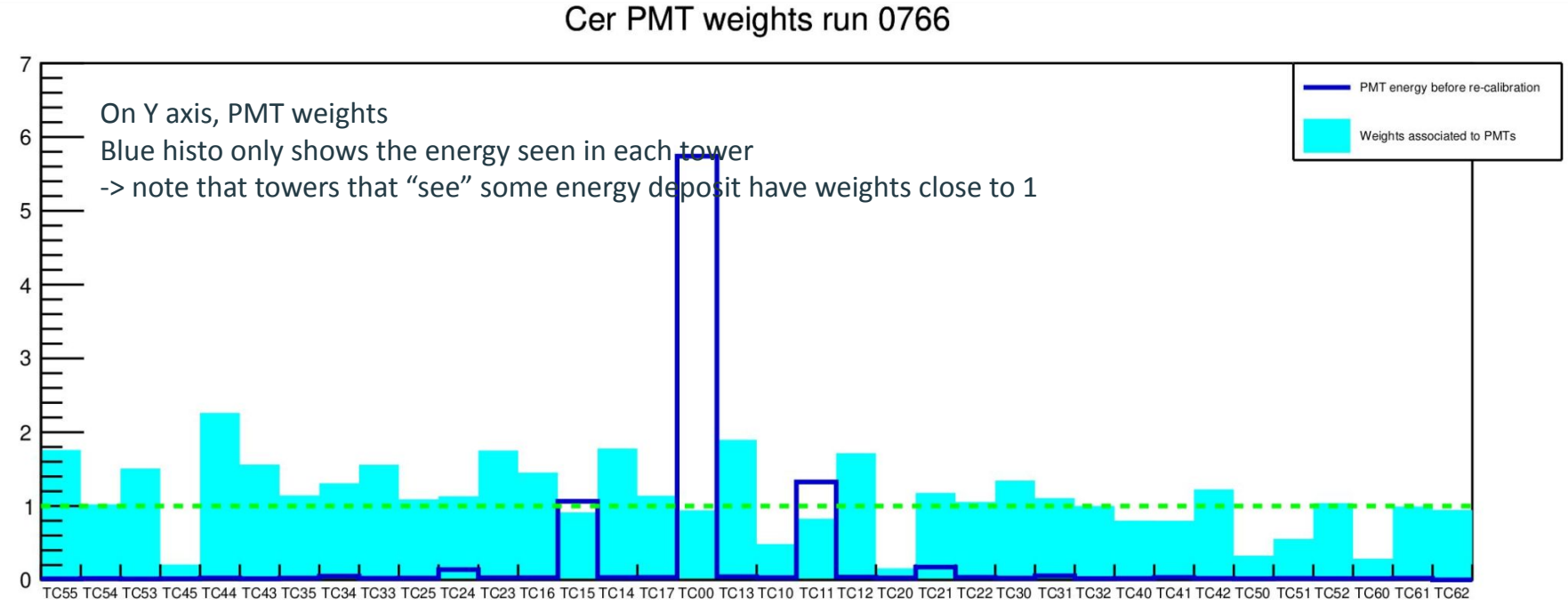
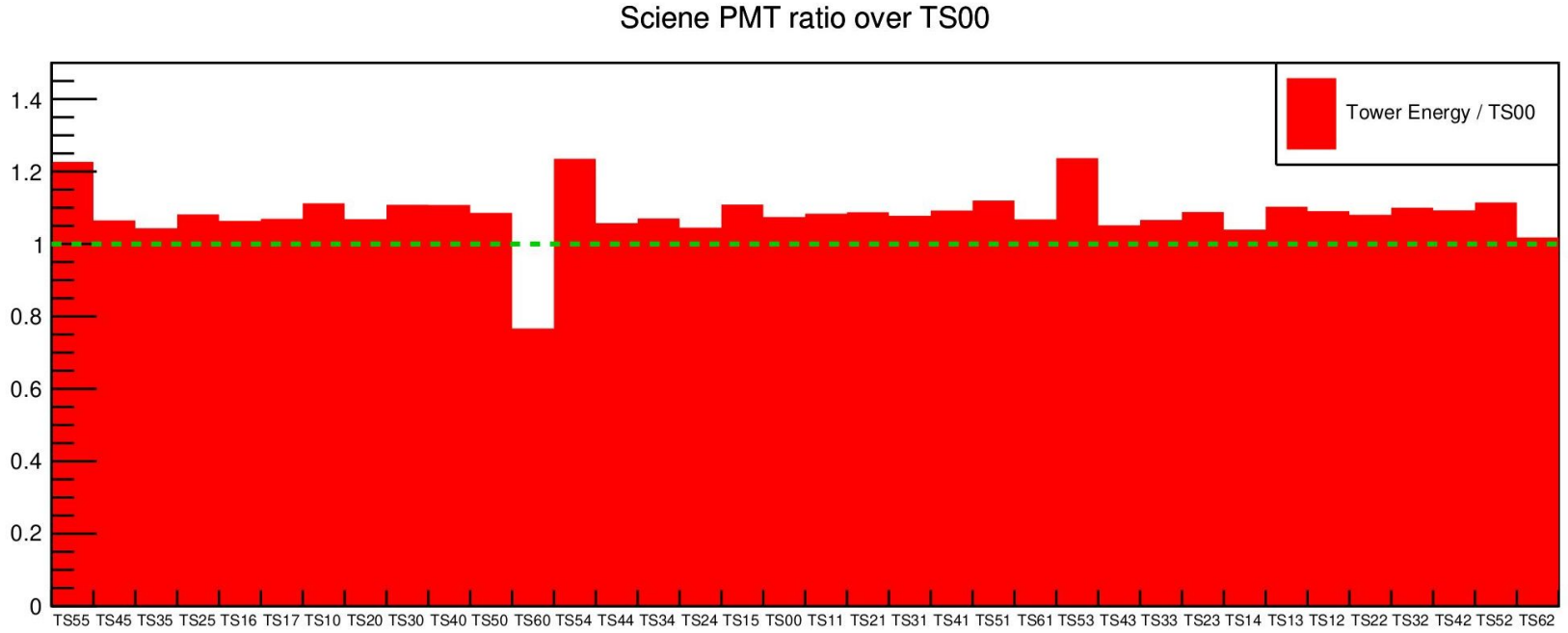


Electron equalisation runs

Following plots show comparisons of variables seen in equalisation runs and the ones in run 0766 used for electron energy linearity and resolution extraction

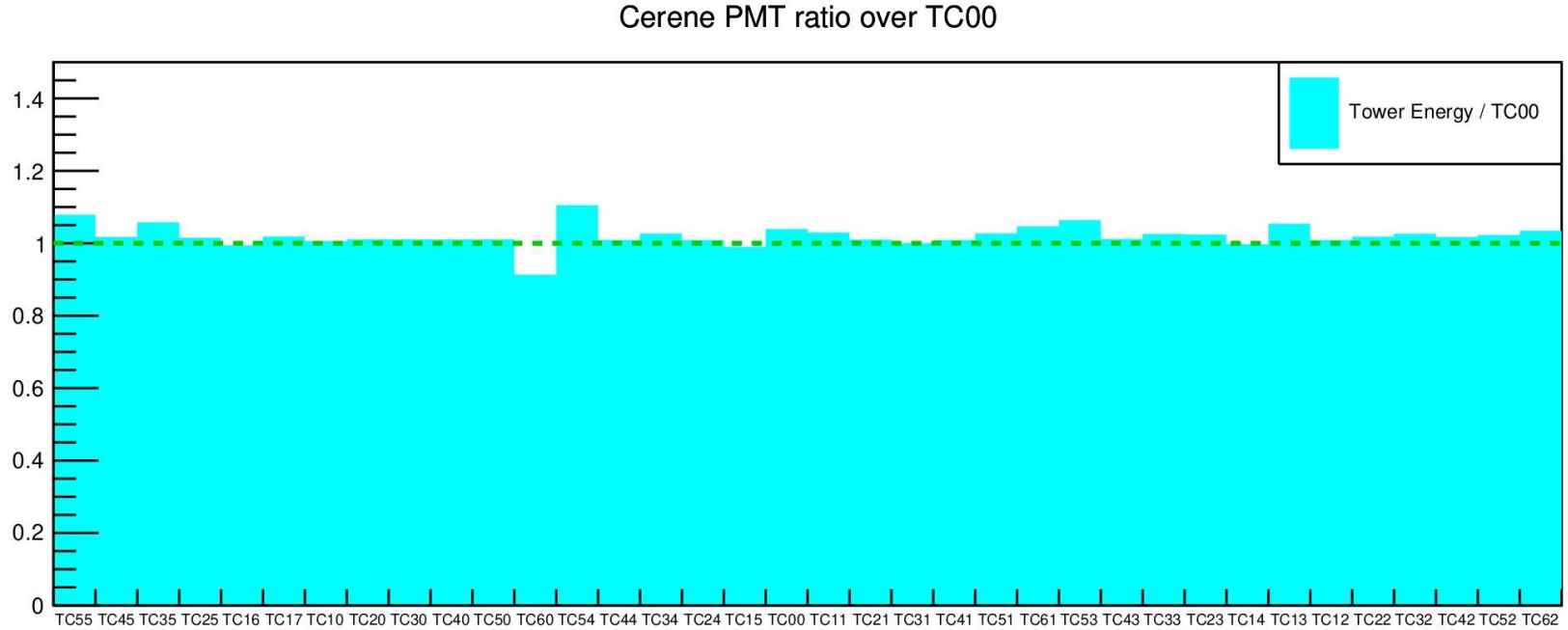
Showing tower where we are shooting in eq. run over T00 in run 0766



Electron equalisation runs

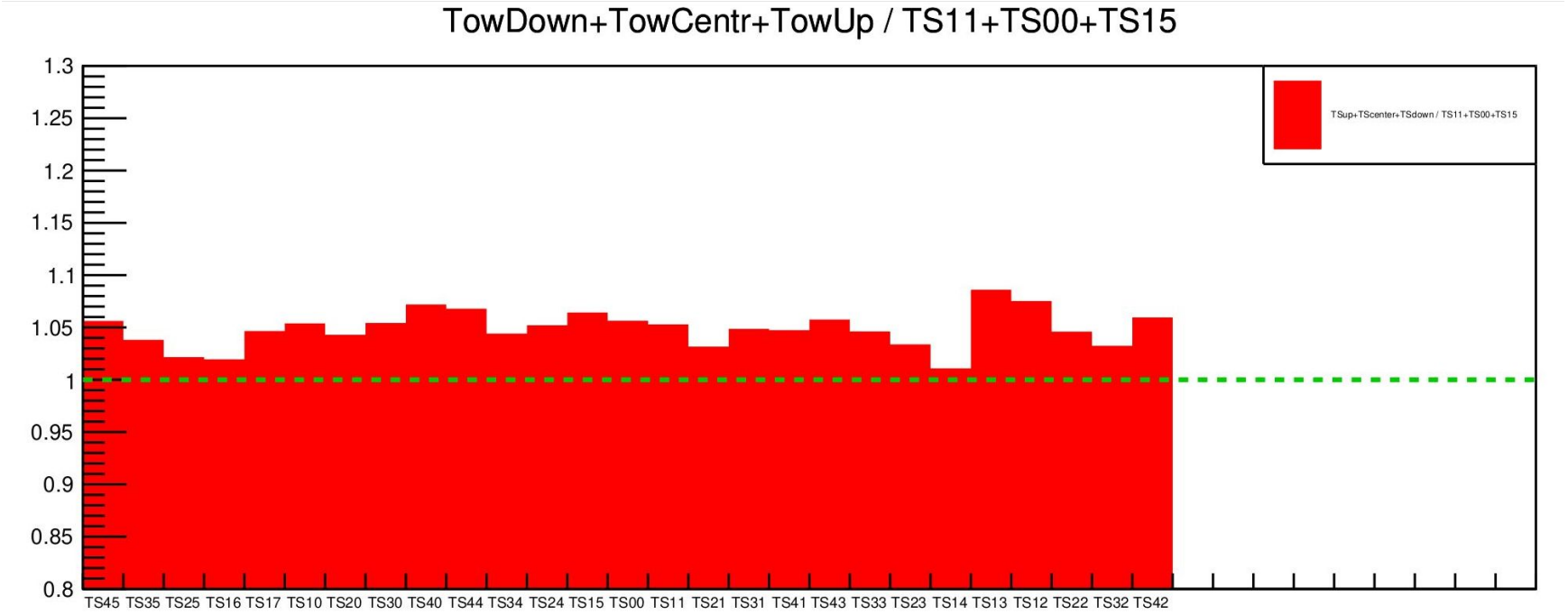
Following plots show comparisons of variables seen in equalisation runs and the ones in run 0766 used for electron energy linearity and resolution extraction

Showing tower where we are shooting in eq. run over T00 in run 0766



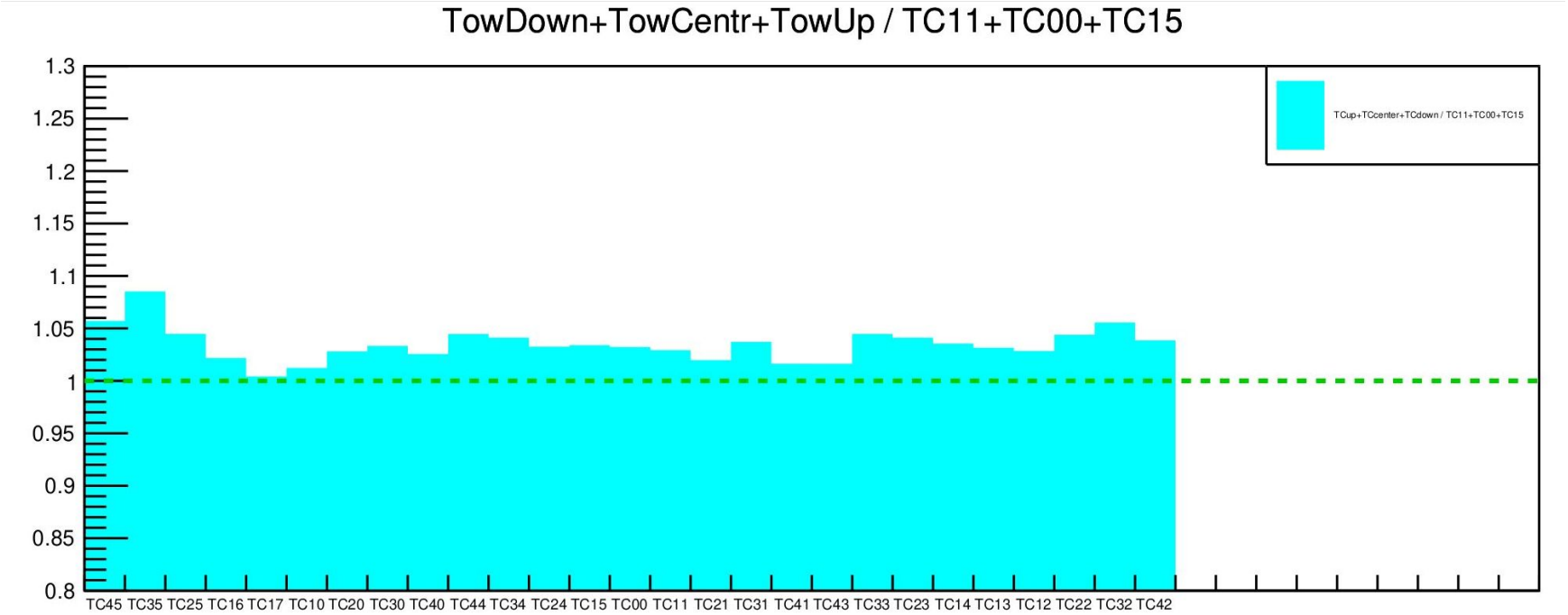
Electron equalisation runs

Showing sum of three towers (ratio with respect to T15+T00+T11 in run 0766)



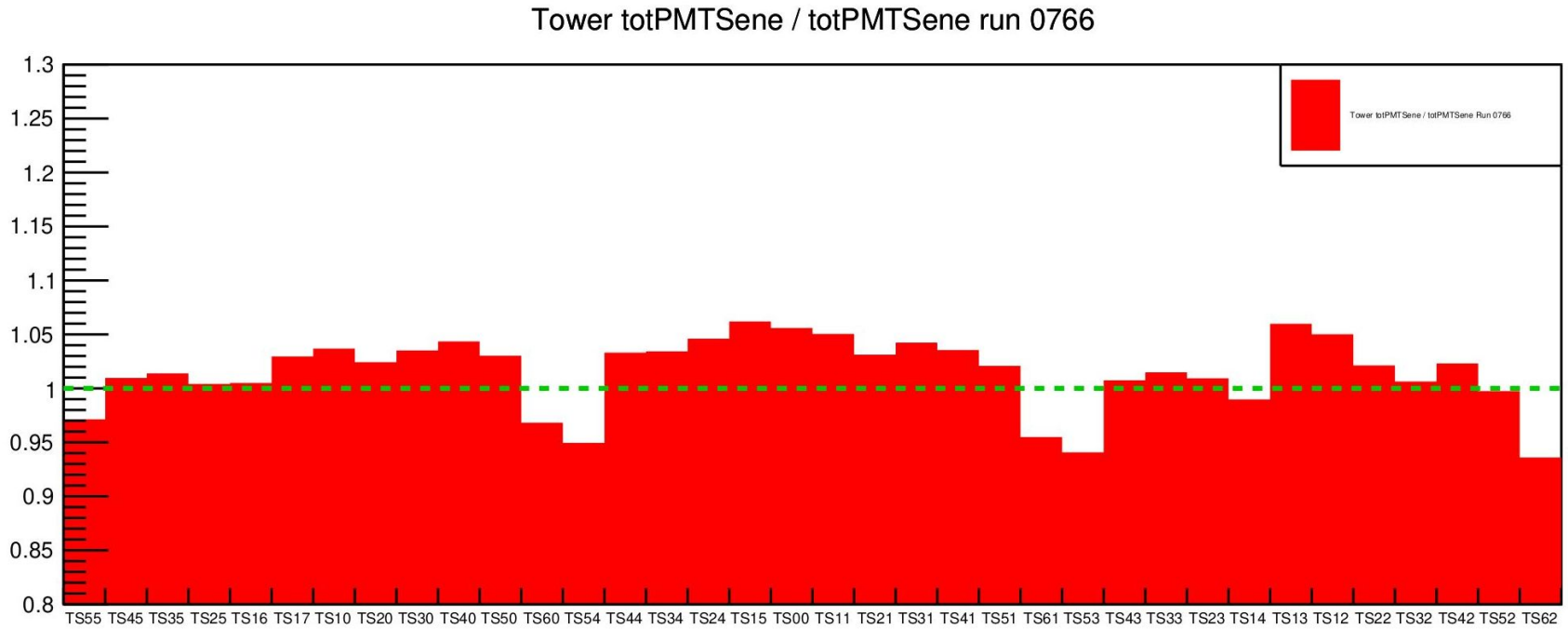
Electron equalisation runs

Showing sum of three towers (ratio with respect to T15+T00+T11 in run 0766)



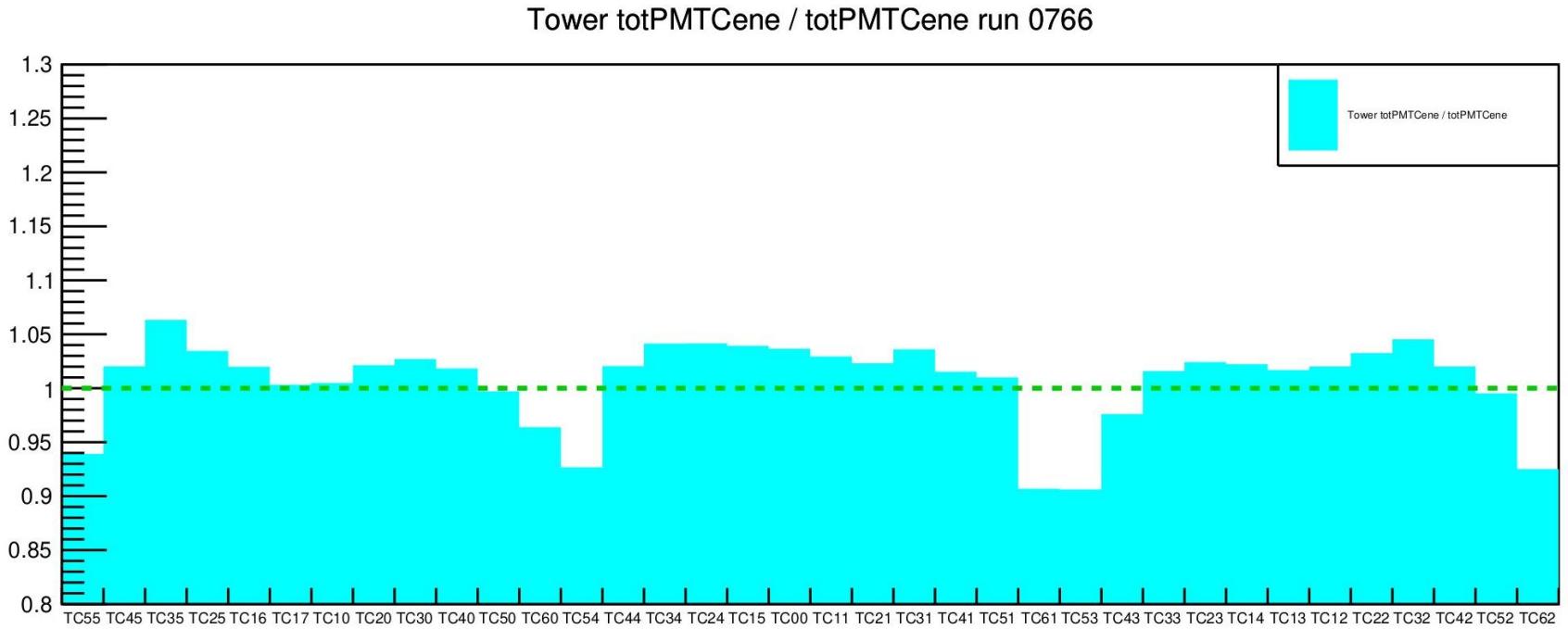
Electron equalisation runs

Showing tower above the one we are shooting at (ratio with respect to T15 in run 0766)



Electron equalisation runs

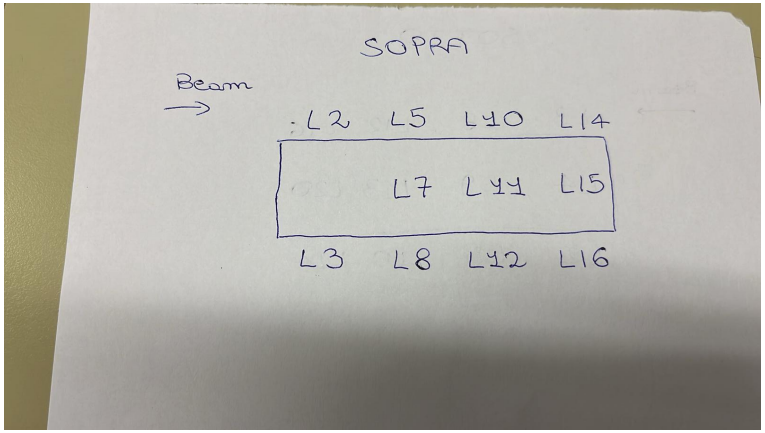
Showing tower above the one we are shooting at (ratio with respect to T15 in run 0766)

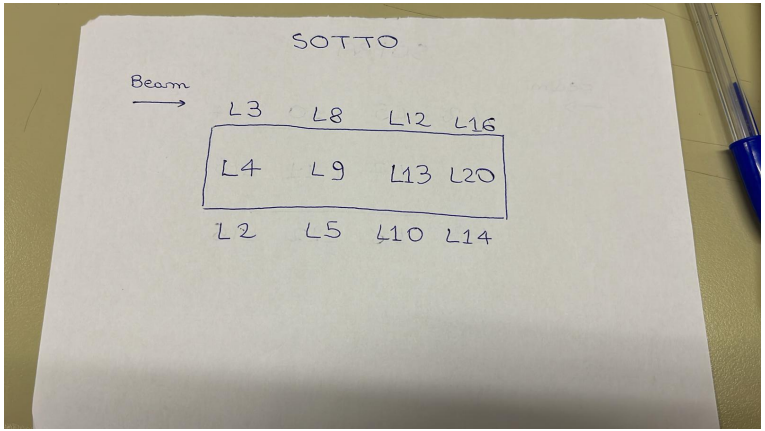


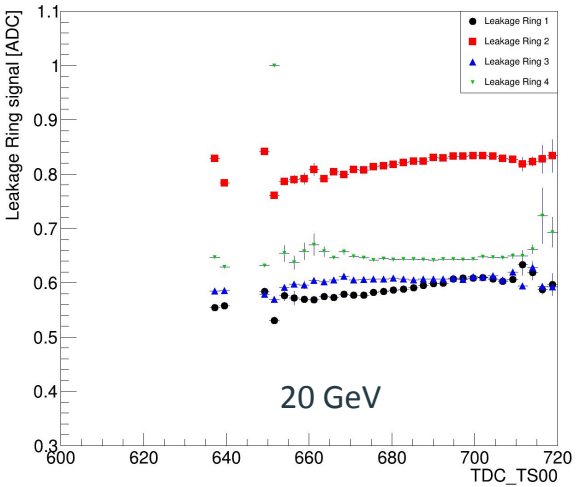
Leakage counter studies

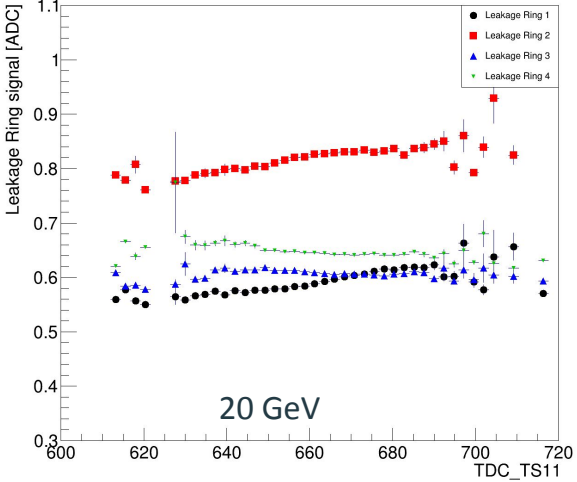
Compare “rings” of leakage counters with time info

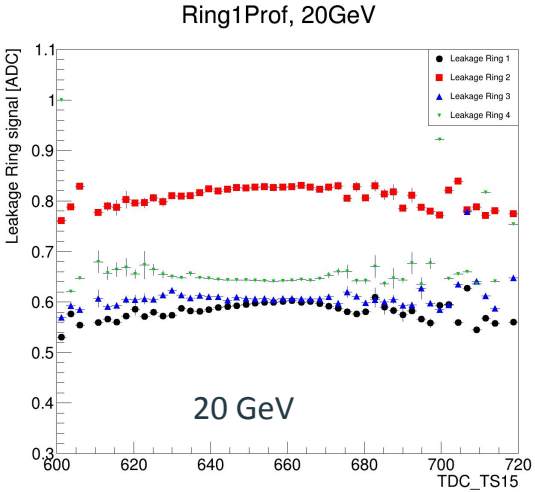
```
df["leakRing1"] = df["L02"]+df["L04"]+df["L03"]
df["leakRing2"] = df["L05"]+df["L07"]+df["L08"]+df["L09"]
df["leakRing3"] = df["L10"]+df["L11"]+df["L12"]+df["L13"]
df["leakRing4"] = df["L14"]+df["L15"]+df["L16"]+df["L20"]
```



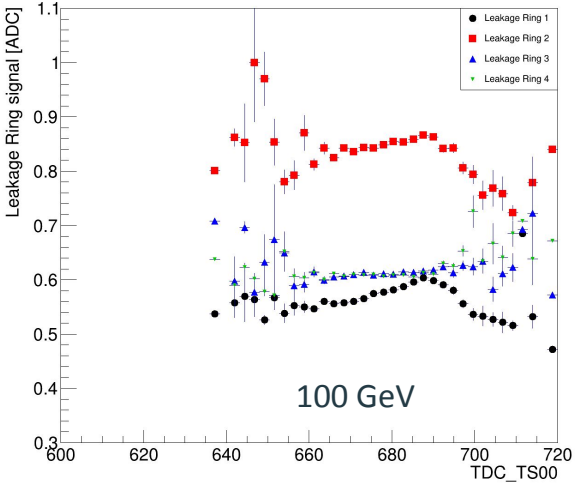


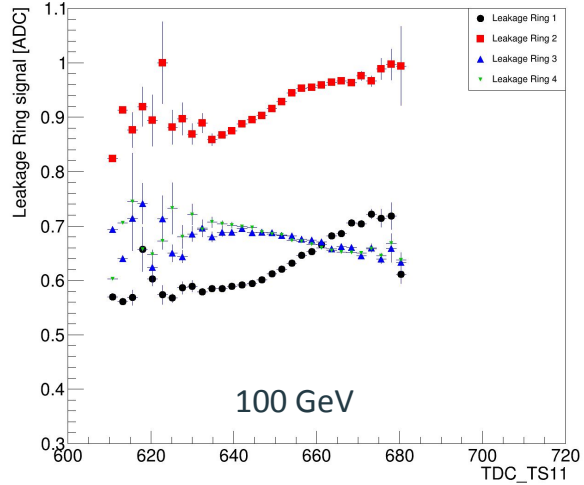


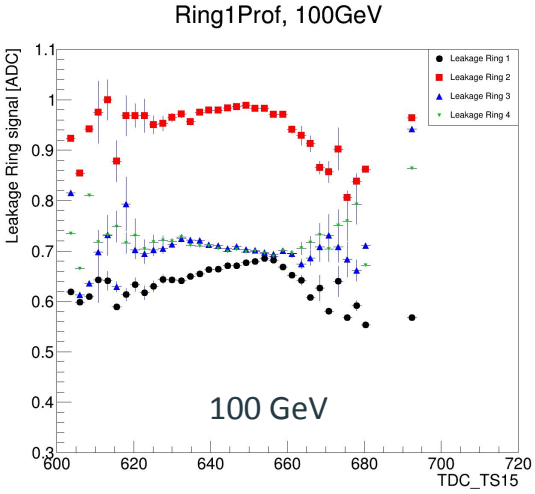


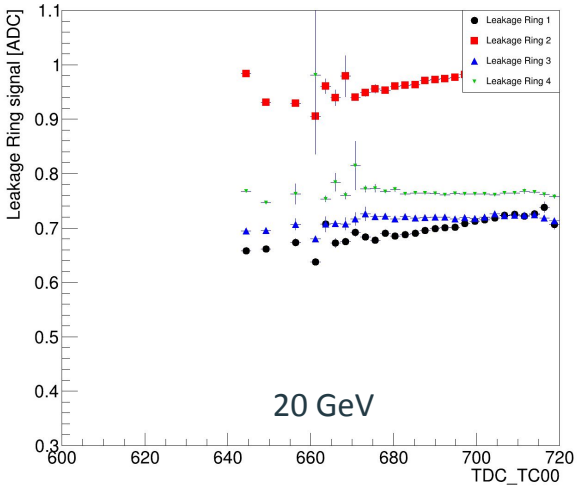


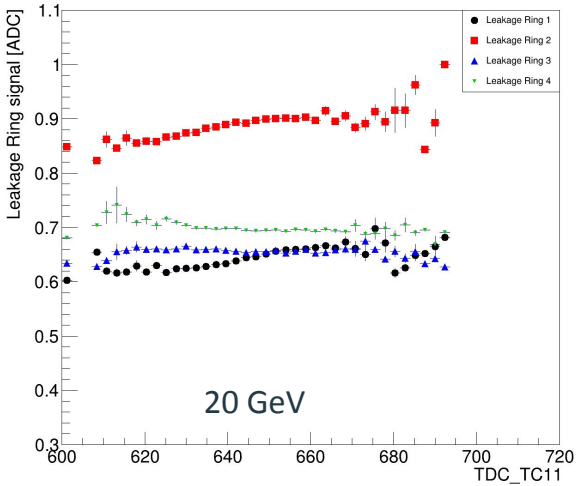
S towers TDCs

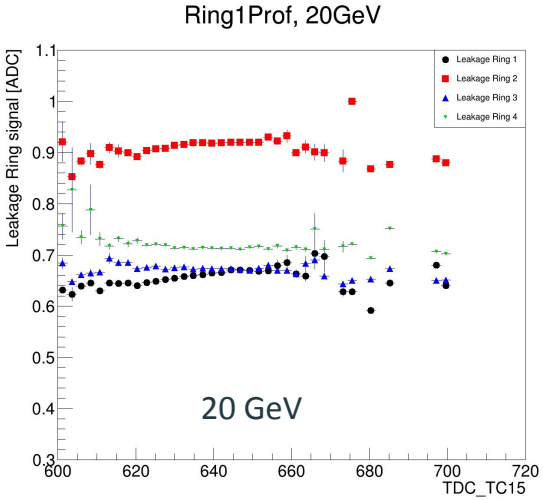




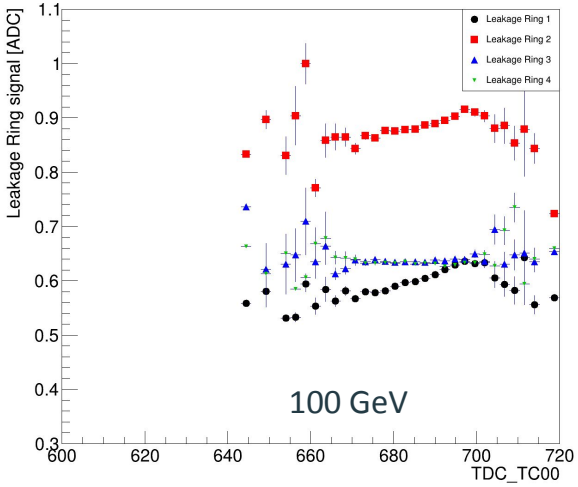


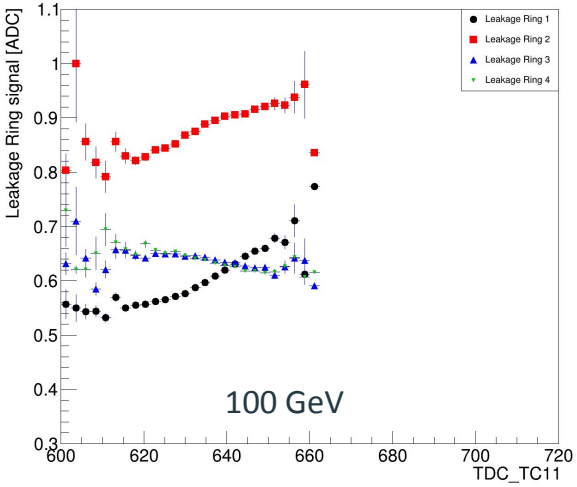


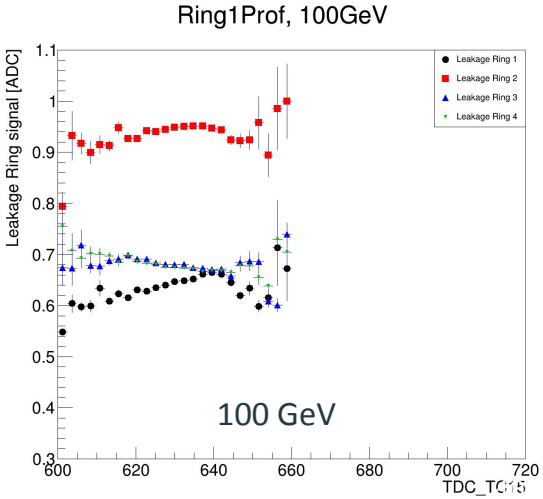




C towers TDCs







Backup