# Optimizing DHCAL single particle energy resolution

Lei Xia
Argonne National Laboratory

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# Introduction

- Single particle energy resolution of a traditional calorimeter can be optimized by hardware/software compensation
  - Equalize EM and Hadronic responses -> e/h ~ 1
- The DHCAL is quite a unique/different device
  - Non-linear response for EM shower
    - Measured energy of a 10 GeV photon E(10)
      E(10) ≠ E(5) + E(5) ≠ E(2) + E(2) + E(2) + E(2) + E(2)
    - Correction can be applied for single EM showers
    - No obvious way to correct for pi0's generated in hadronic showers
  - Hadronic response close to linear
    -> Ratio of EM to hadronic response changes with energy
  - Software compensation not likely to be very successful without first taking care of the non-linearity of the EM response

# Linearizing the EM response I

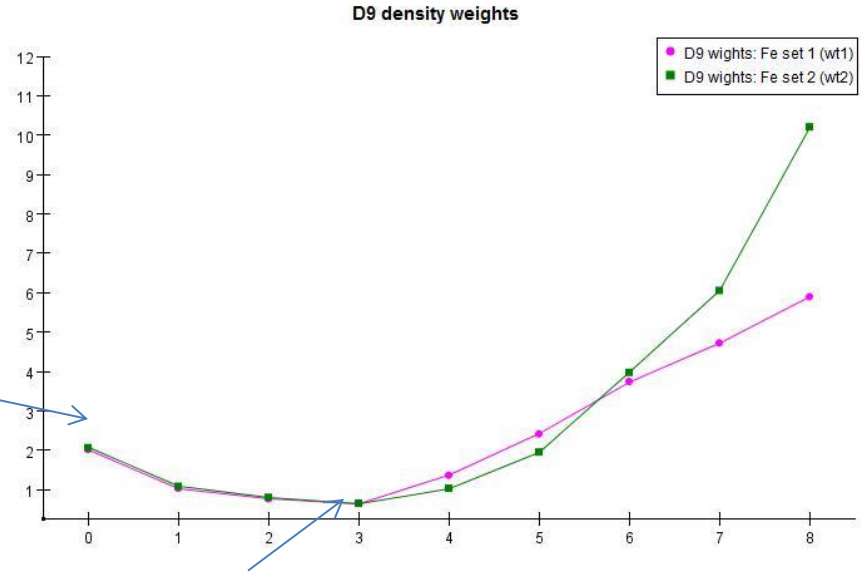
- The non-linear response of EM showers is due to finite readout pad size → multiple particles hitting same pad → saturation
- Need ways to account for multiple particles on the same pad
  - Assumption: Hit density (hit fraction in a given local space) is related to the local particle density

(Density weighted calibration proved good correlation between hit density and local particle density)

  - Start with simple hit density definition
    - d9: number of hits in the surrounding 3pad x 3pad area, centered on the hit being studied (d9 = 0 – 8)
  - Start with MC simulation for Fe absorber setup
    - RPC response: RPC_sim_4 (single exponential) – not the best…
    - Positron sample: 2, 4, 6, 8, 10, 12, 16, 20, 25, 32, 40, 60 (GeV)
    - Pion sample: 2, 4, 6, 8, 10, 12, 16, 20, 25, 32, 40, 60, 80, 100 (GeV)

# Linearizing the EM response II

- Chose two sets of positron energy points, adjust weights for each D9 bin to achieve linear response
  - Set I (wt1): 2, 6, 10, 16, 25 (GeV)
  - Set II (wt2): 2, 6, 16, 32, 60 (GeV)
  - Target response:  14.74 hits/GeV  (arbitrary)



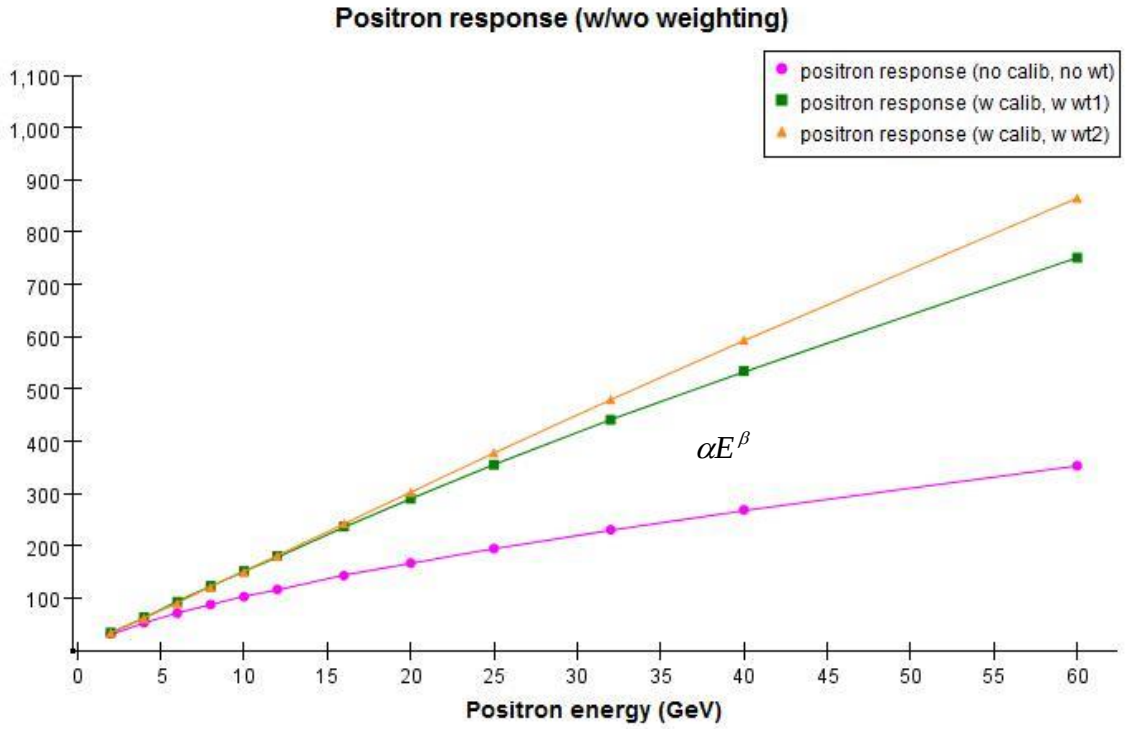

High weights for isolated hits

Very high weight for high density bins: **correction for saturation**

Low weights for medium density: mostly due to hit multiplicity ~ 1.6

**Everything as expected**

# Positron response after weighting




$16.687 \times E^{0.966}$

$20.240 \times E^{0.885}$

$20.866 \times E^{0.692}$

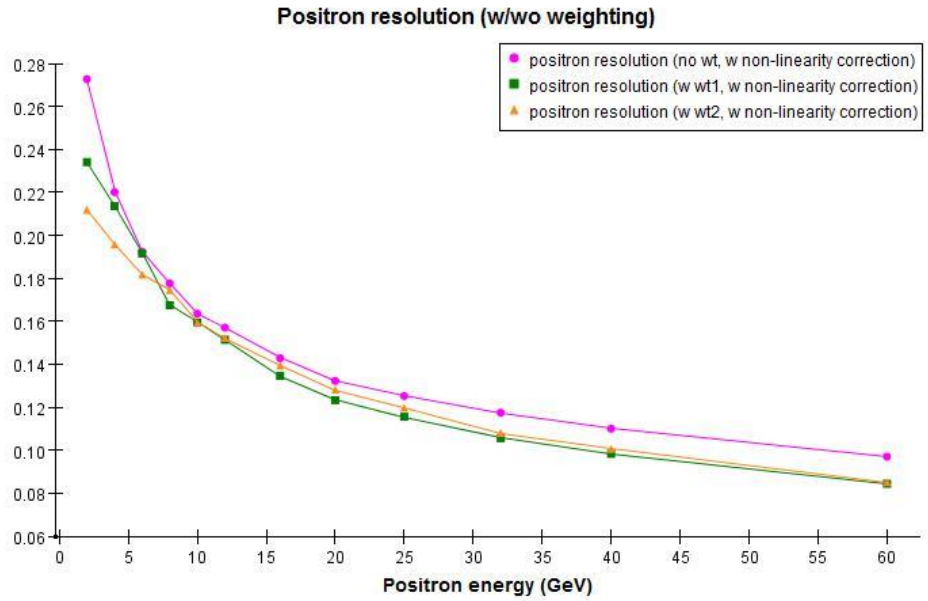
Fits to power law $\alpha \mathrm{E}^{\beta}$

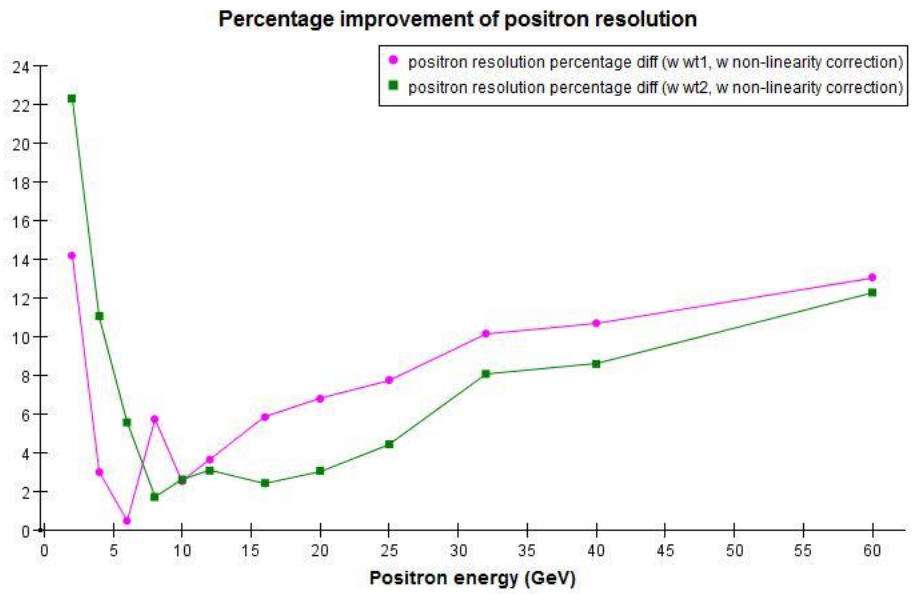
($\beta$=1 means **linear)**

**Things are exactly as expected:**

- Linearity significantly improved
- wt2 gives better linearity in larger energy range than wt1

# Positron resolution after weighting



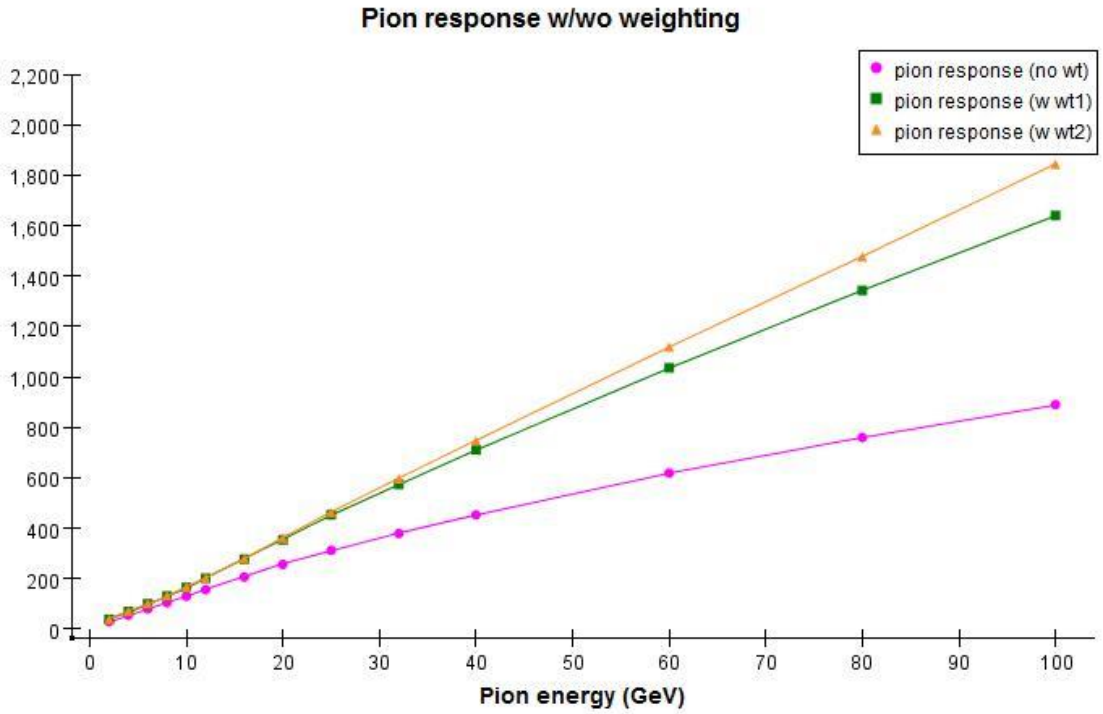

Non-linearity correction is included (this is very important!)

Positron energy resolution modestly improved (2 – 11%)

Not much difference between wt1 and wt2

- All energy resolutions were calculated from full-range Gaussian fit
- Fit at low energies are not very reliable

# Pion response




$17.690 \times E^{1.010}$

$20.500 \times E^{0.954}$

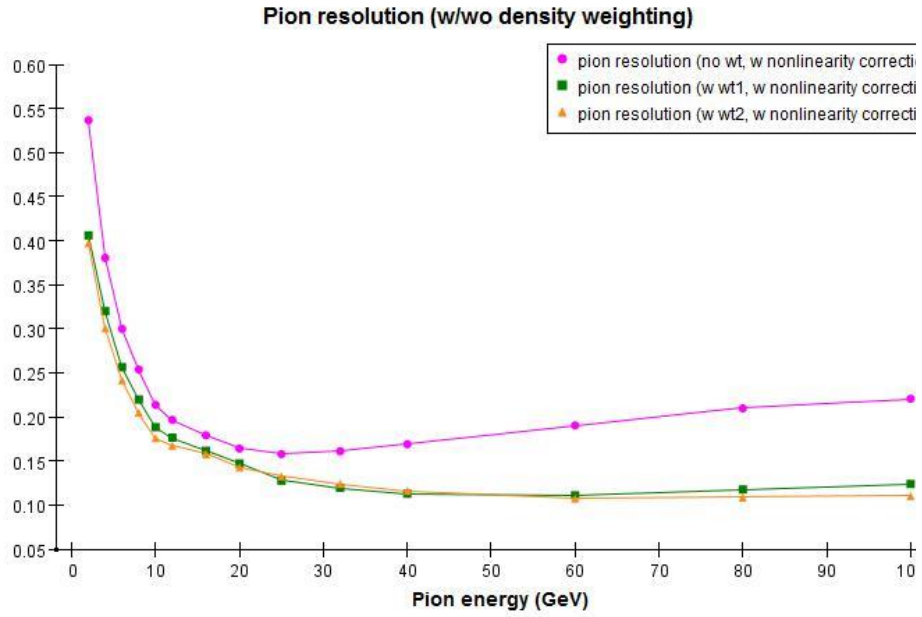
$22.918 \times E^{0.799}$

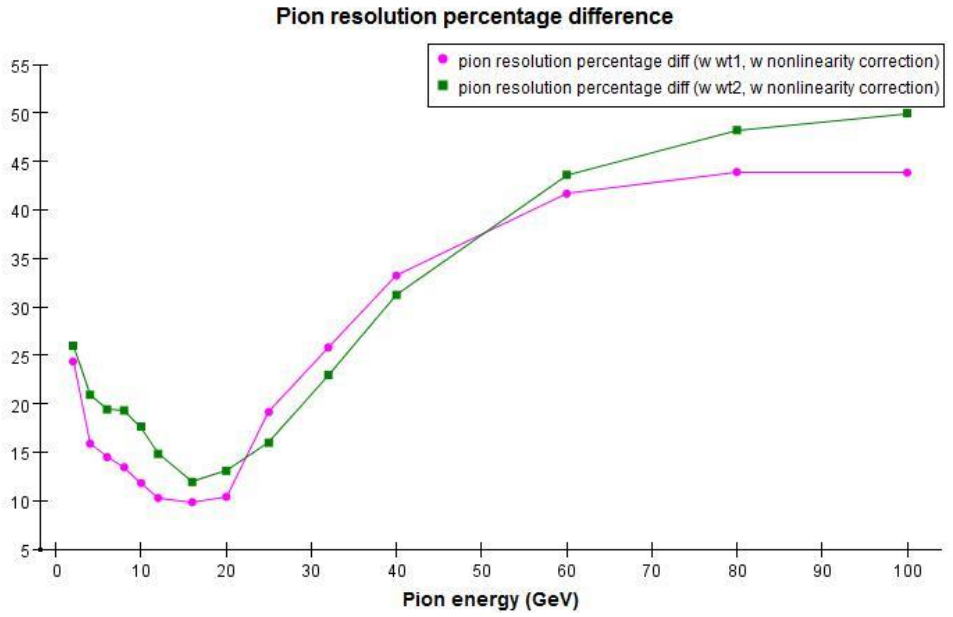
Pion linearity (no weighting) is much worse than in data (most likely due to inaccurate positron simulation)

Linearity fits are not as good as the positrons

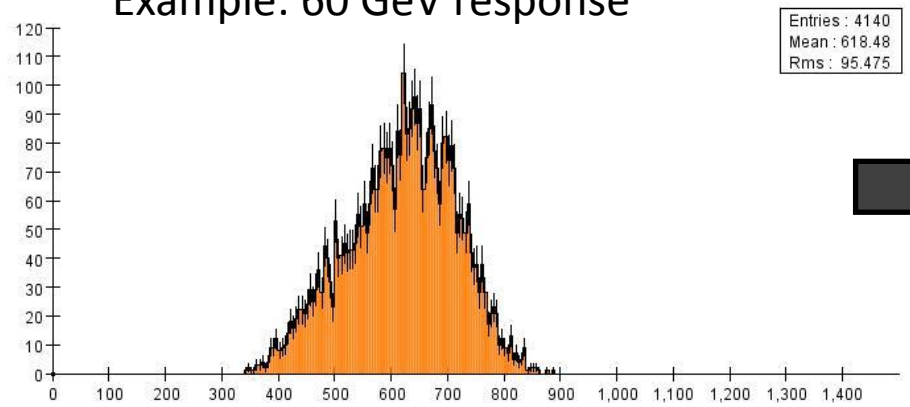
* Applied leakage cut: no more than 10 hits in tail catcher

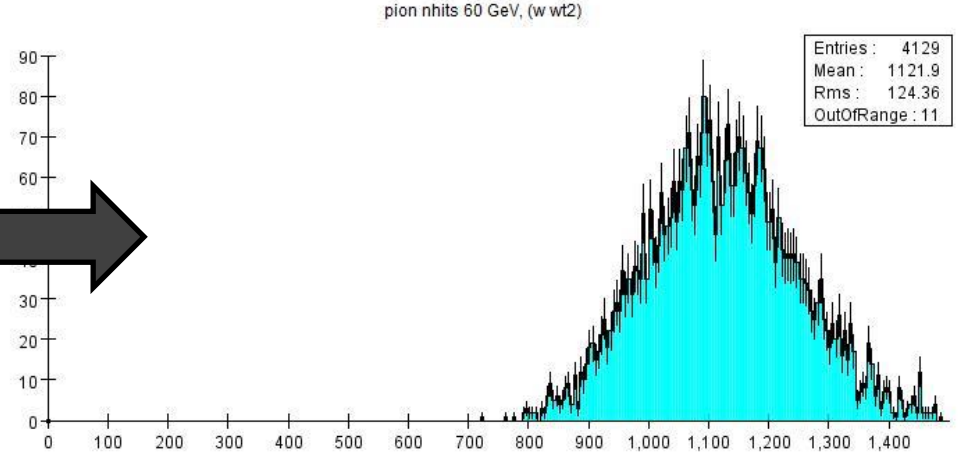
# Pion resolution




Example: 60 GeV response

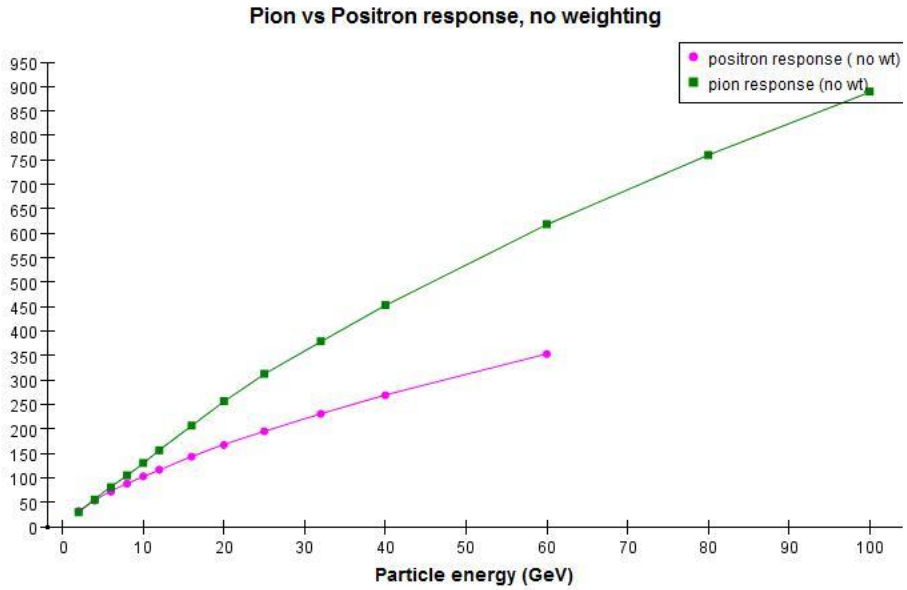


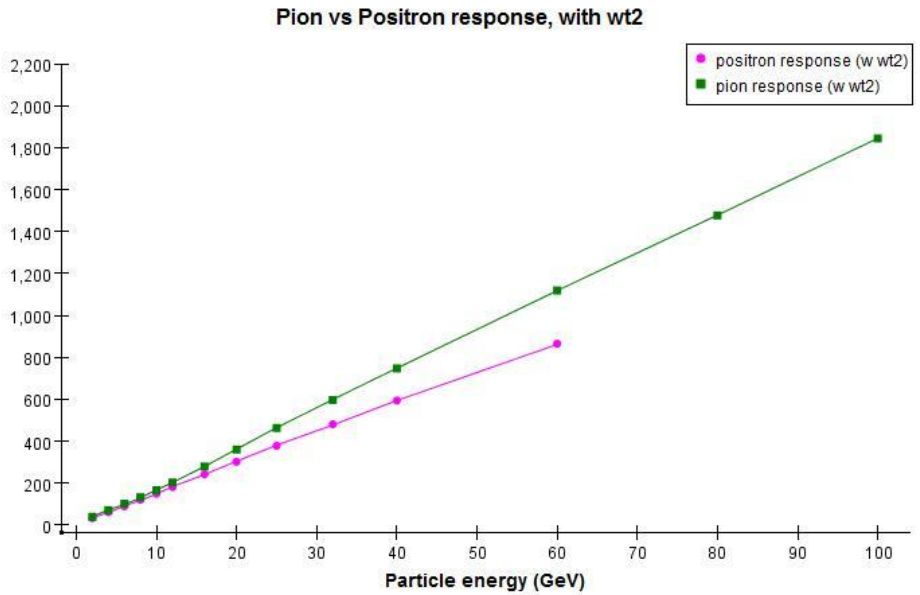

Pion resolution and linearity are both greatly improved in (not very good) simulation: 10 – 50%

At higher energies, distributions become much more symmetric after weighting

# Pion vs. Positron response




Before weighting



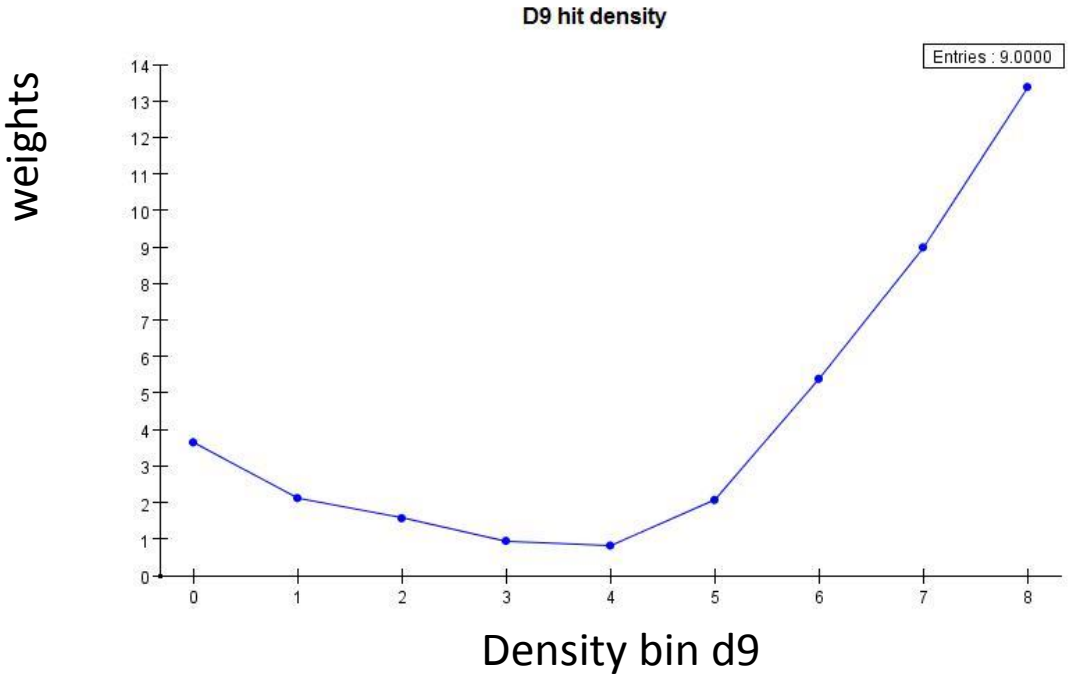

After weighting

Pion and Positron responses are brought closer by weighting, but not equal yet
(weighting changes both pion and positron responses)

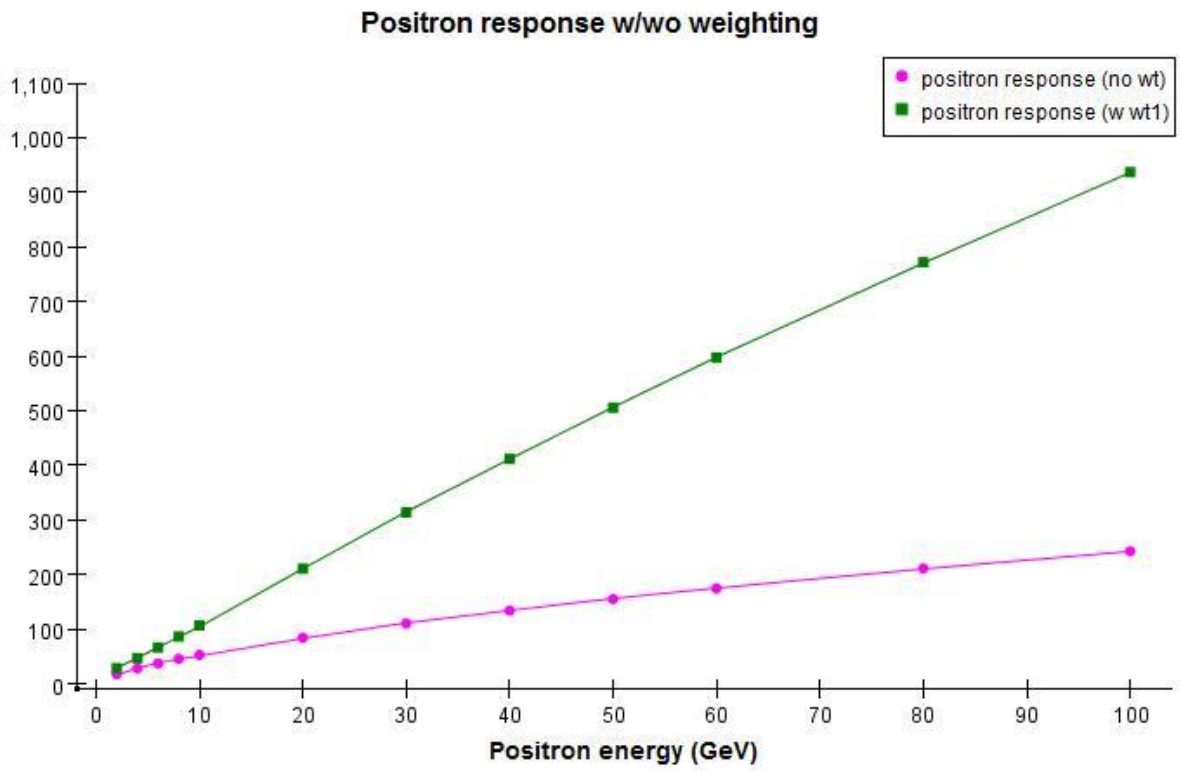
Room for software compensation: work in progress (pretty optimistic on further improvement)

# More density weighting

- It seems that things work best with very different e/p responses and very non-linear EM response
- One obvious place is W-DHCAL data: studies using simulated events
  - Electron sample: 2, 4, 6, 8, 10, 20, 30, 40, 50, 60, 80, 100 (GeV)
  - Pion sample: 8, 10, 20, 30, 40, 50, 80, 100, 120, 150, 180, 300 (GeV)
  - Weights tuned with electron energy points: 4, 10, 30, 50, 80 (GeV)



# Electron response

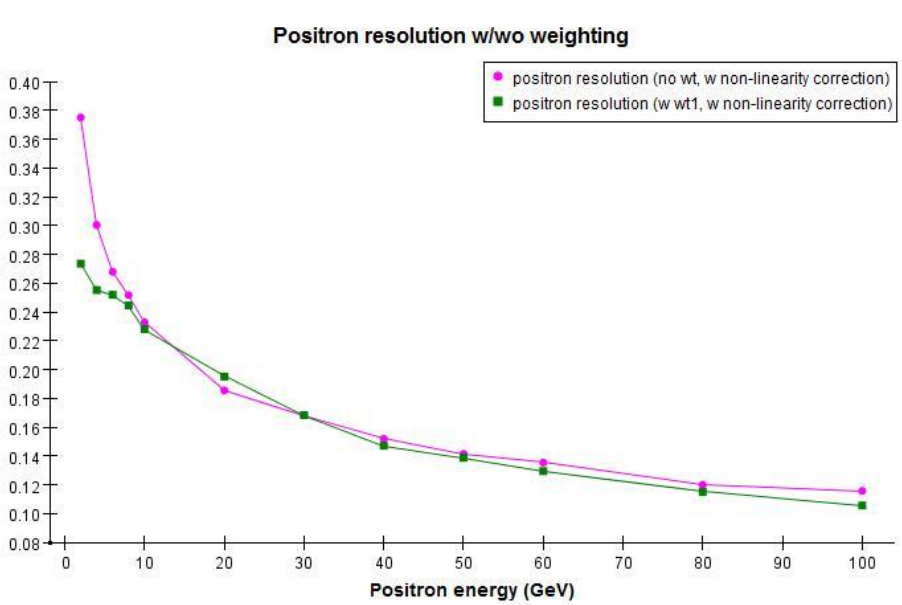


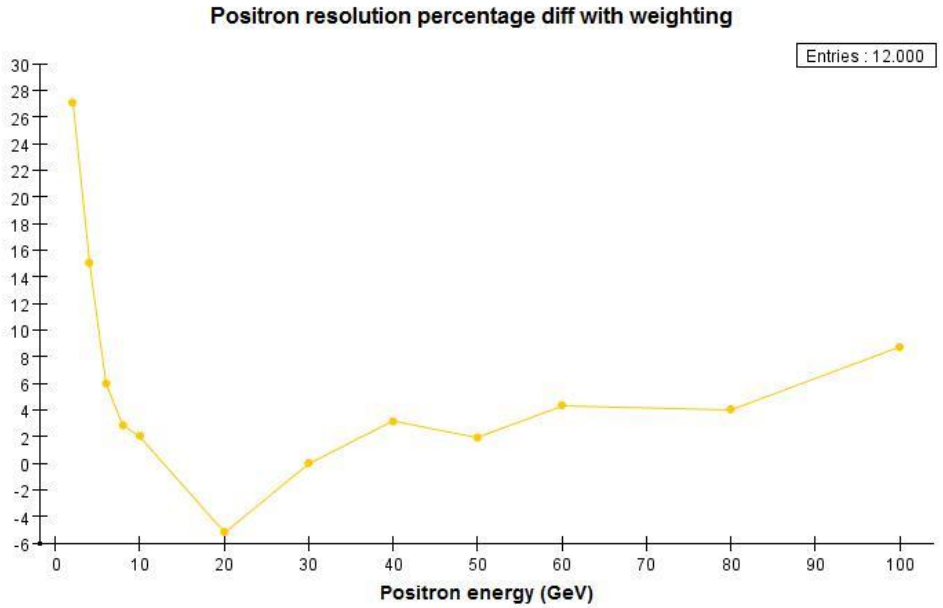

$13.780 \times E^{0.918}$

$11.522 \times E^{0.663}$

- Response is highly non-linear without weighting
- Weighting does a good job, as with the Fe-DHCAL (tuning target was 10 Hits/GeV, again, arbitrary)

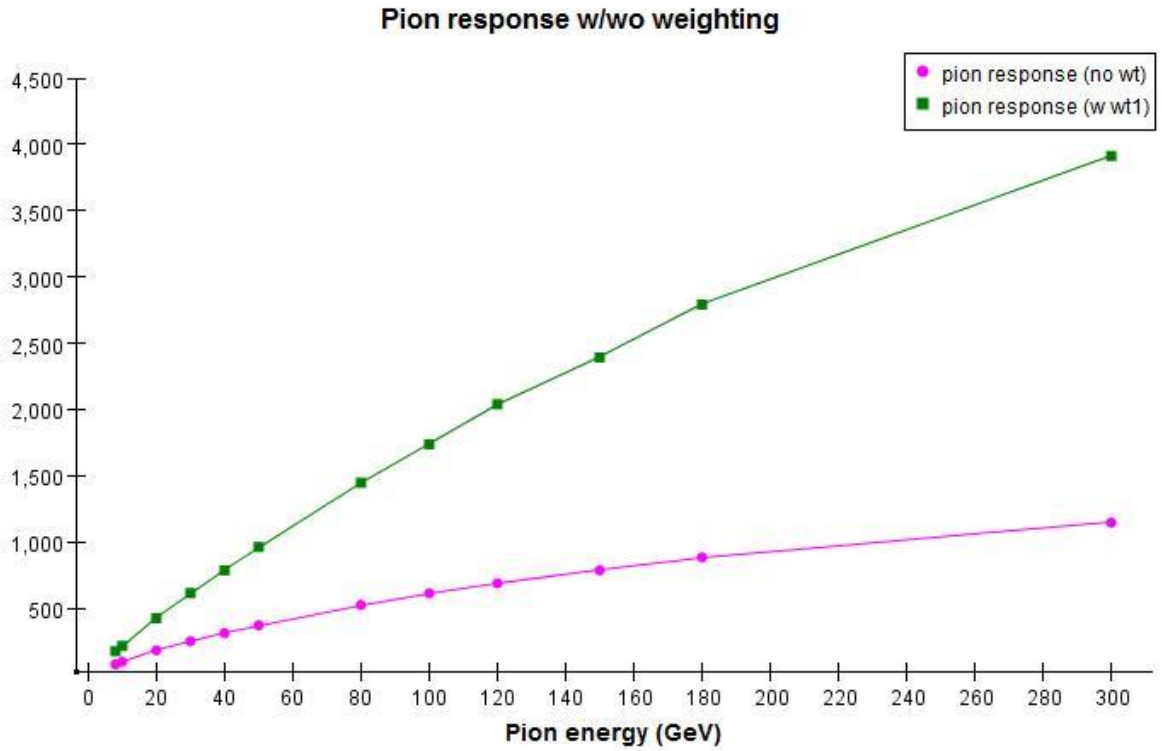
# Electron resolution




- As with the Fe-DHCAL, no significant improvement
- Fits at low energy points are not reliable

# Pion response

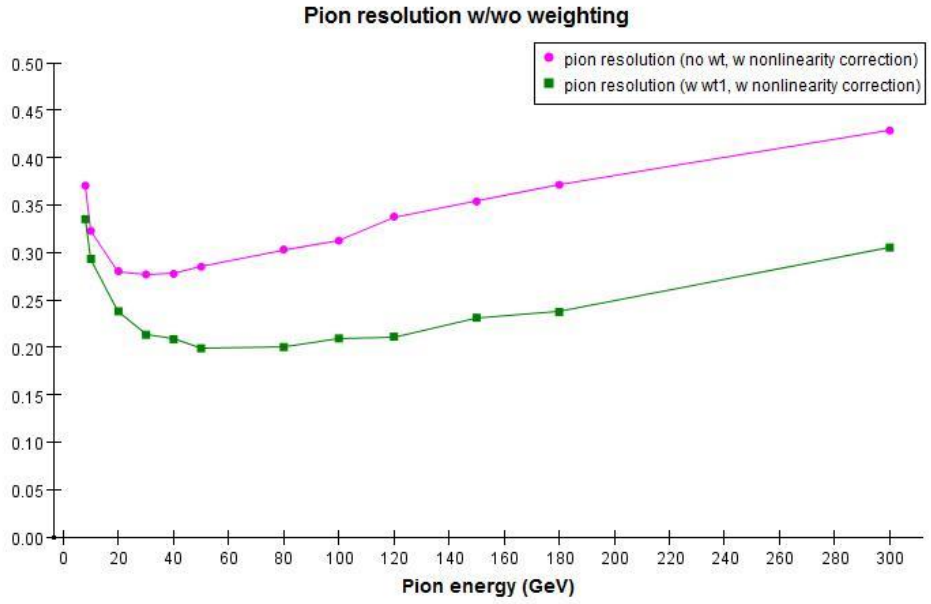


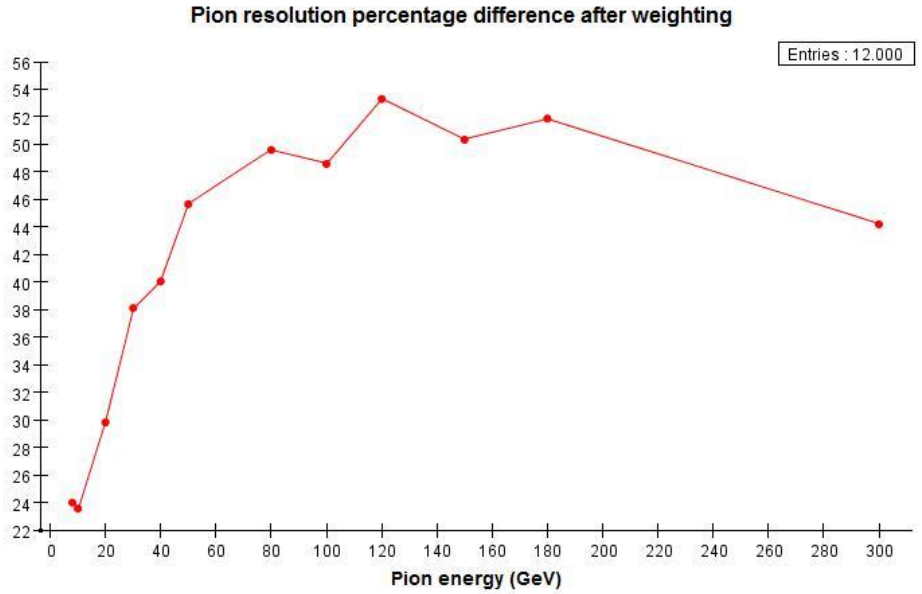

$35.520 \times E^{0.842}$

$22.826 \times E^{0.708}$

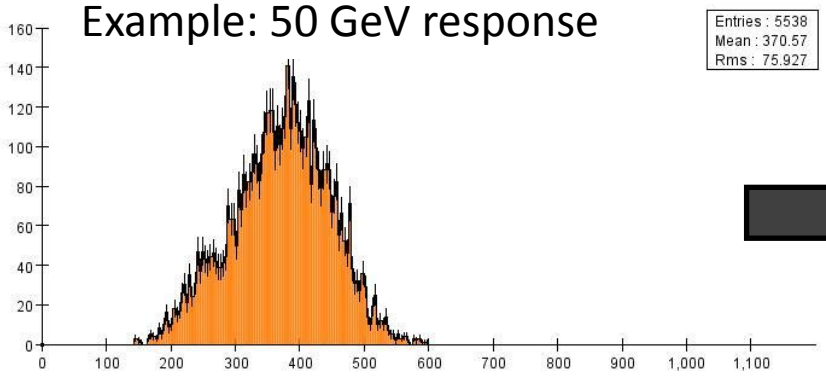
- As usual, fits are not great as compare to electron fits
- 300 GeV point systematically low → Excluded from fits
- All high energy points are low probably due to bias from leakage cut
- Fit parameters are also systematically low, probably due to the above reason
- Nevertheless, linearity did improve significantly

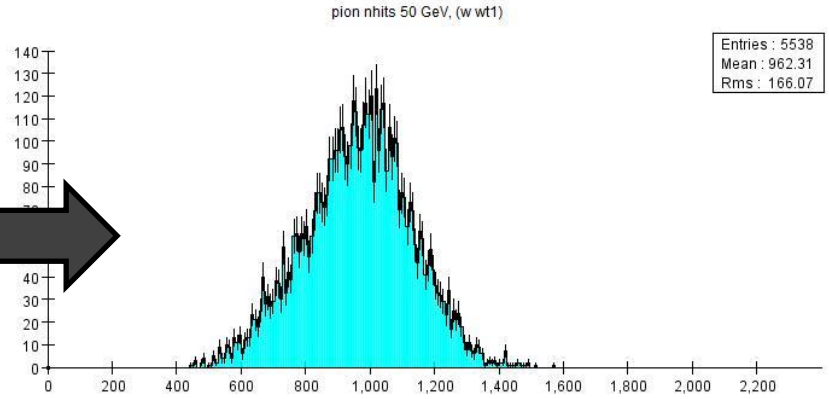
# Pion resolution



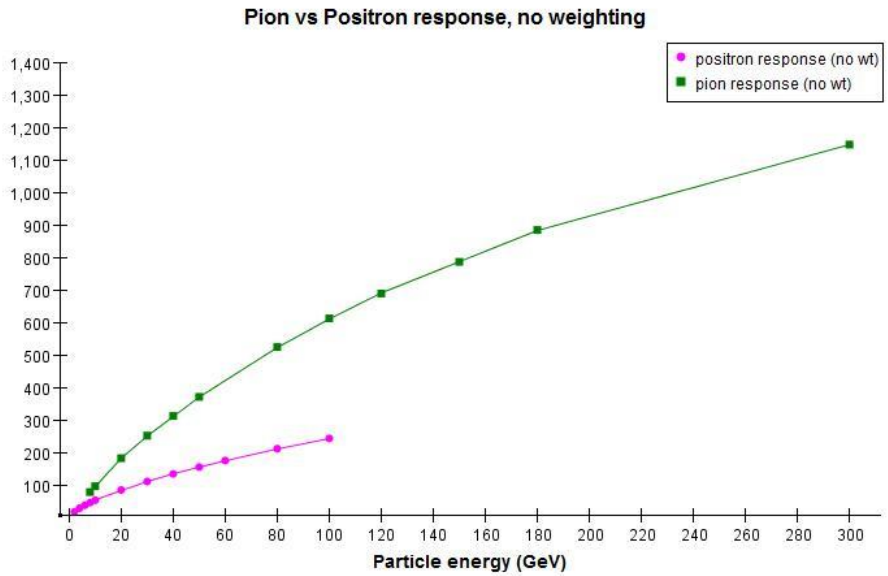

Example: 50 GeV response

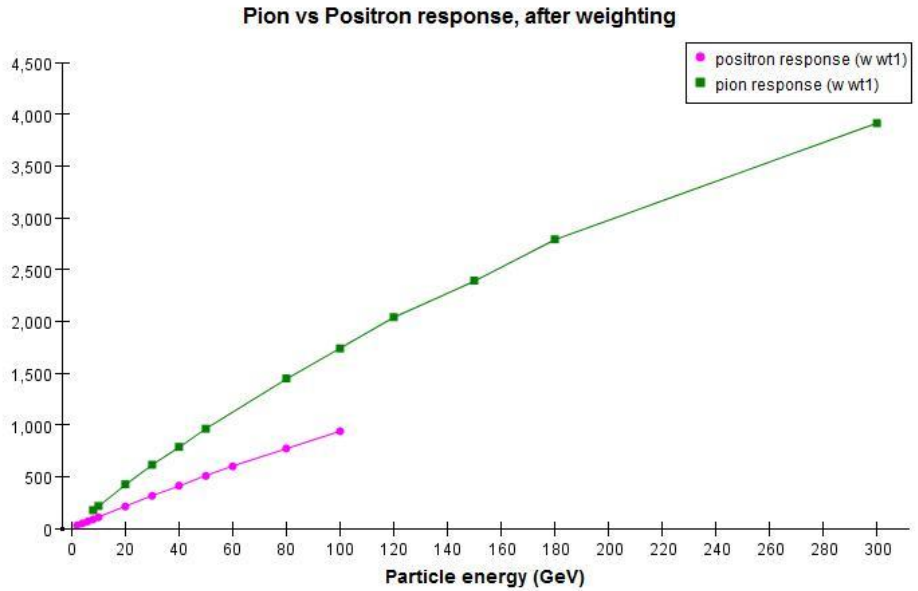



- Energy resolution greatly improved over large energy range: 24 – 54%
- Weighing improved distribution, but didn't totally remove low end tail

# Pion vs. electron responses




Before weighting

After weighting

- e/h improved with density weighting
- Difference is still very large → ideal test bed for software compensation

# Summary

- Density weighting is able to achieve close to linear EM shower response for DHCAL
- Using the same weights can improve linearity and energy resolution of pion showers
  - Significant (~ 25 - 50%) improvement observed with Fe-DHCAL and W-DHCAL simulation
  - Applying the same technique for test beam data is on-going, results will come soon
- Pion and EM shower response are still quite different after weighting
  - Chance for software compensation: work started
- Once we have the method to get optimized energy resolution for DHCAL, we should think of optimizing the DHCAL design itself…