Energy Resolution Study

for a prototype of the CALICE SiW-ECAL

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Simulation Data

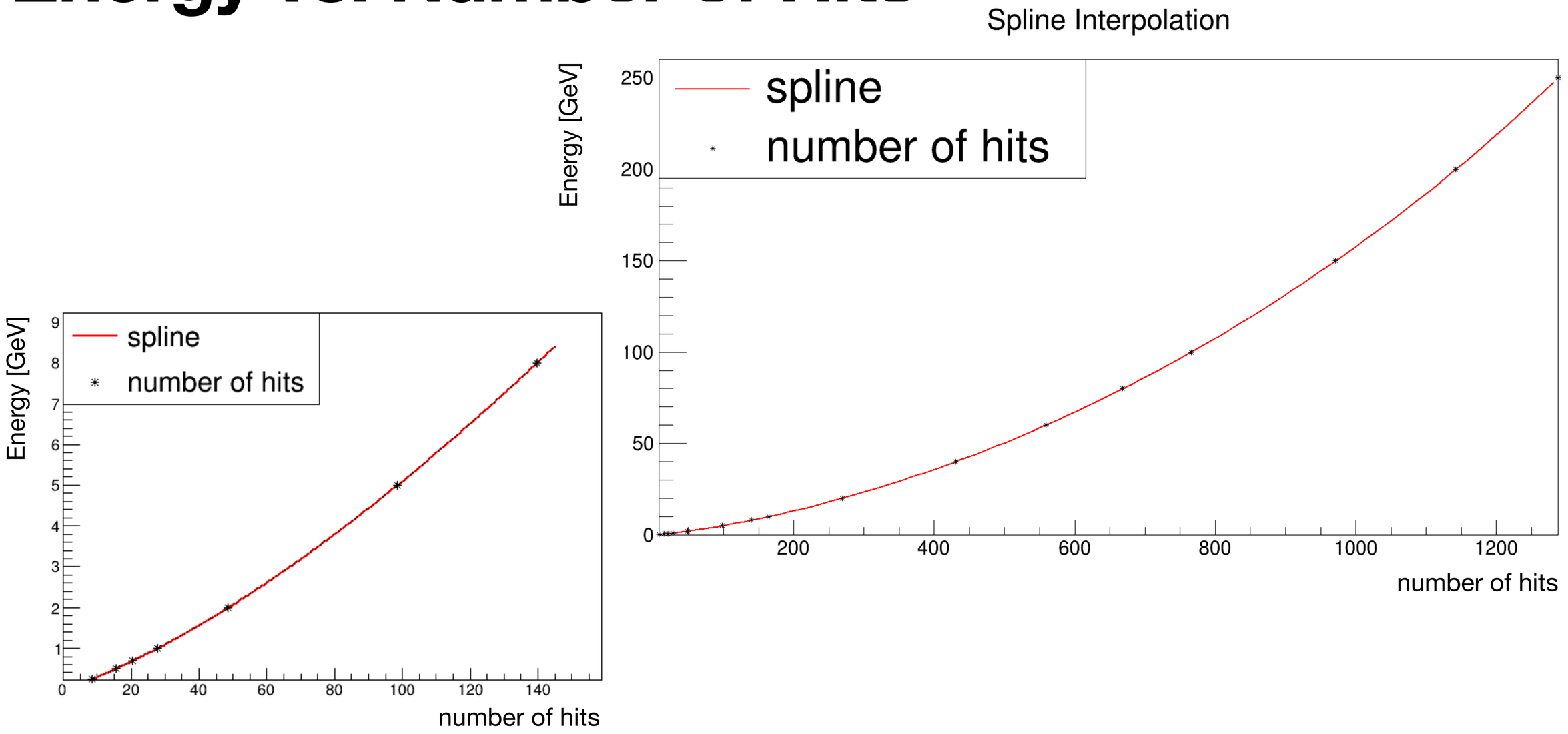
- SiW-ECAL with 15 layers and thicknesses:
  -> W [mm]: {4.2, 4.2, 4.2, 4.2, 4.2, 4.2, 4.2, 4.2, 5.6, 5.6, 5.6, 5.6, 5.6, 5.6, 5.6}
  -> Si [µm]: {650, 650, 650, 650, 500, 500, 500, 500, 500, 500, 320, 320, 320, 320, 320}
- based on CALICE prototype from TB in June 2022 at CERN
- simulated events at 16 energy points from 0.25 GeV to 250 GeV
- 5000 events for each energy
- without digitisation

Method for Energy Calculation

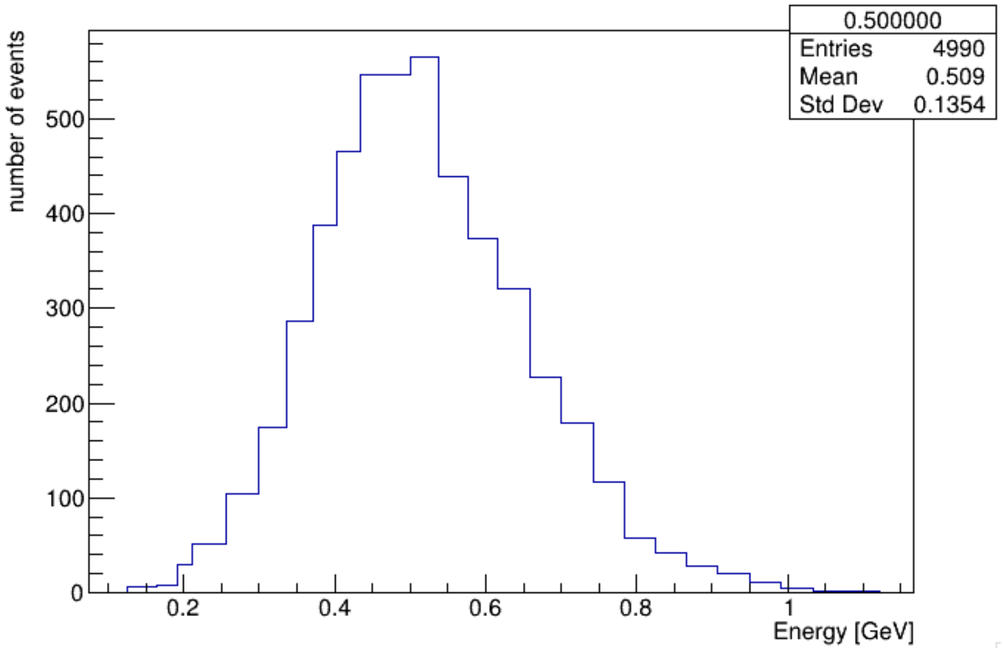
1. Use a quantity to obtain first proxy (*p*) of energy (mean over all events):
   - number of hits per event
   - sum of energy deposited per event
   - weighted sum of energy deposited per event (W thickness / W + Si thickness)
   - weighted number of hits per event (W thickness)
2. Plot input energy vs. proxy and make spline interpolation -> gives energy as function of proxy *E*(*p*)
3. Transform distribution *p* to distribution *E*(*p*)

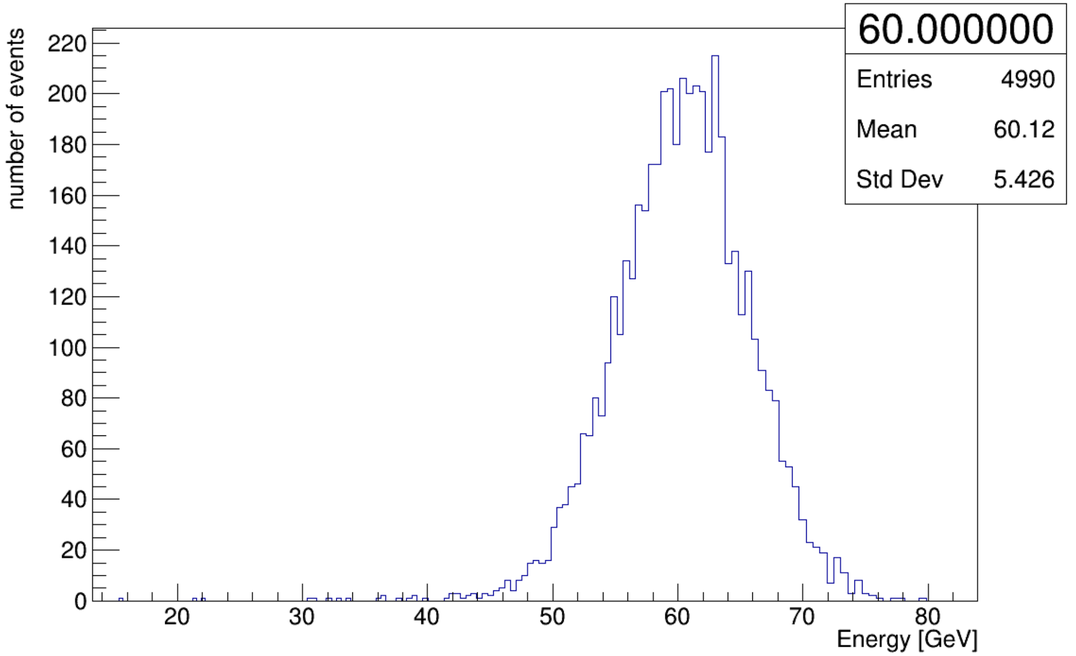
Energies calibrated in mips considering the Si thickness

Energy vs. Number of Hits



Transferred Distributions





Method for Energy Calculation

4. Calculate energy from energy distribution with different methods:

- mean
- gamma function
  -> asymmetric distributions
- gaussian fit
- gaussian fit within 2 sigmas
- median
- RMS68 -> mean of the central 68%
- RMS90 -> mean of the central 90%

$$\gamma(x, A, x_0, \sigma_0) = A \exp\left(-\left(\frac{x_0}{\sigma_0}\right)^2 \left(\frac{x-x_0}{x_0} - \ln\left(\frac{x}{x_0}\right)\right)\right)$$

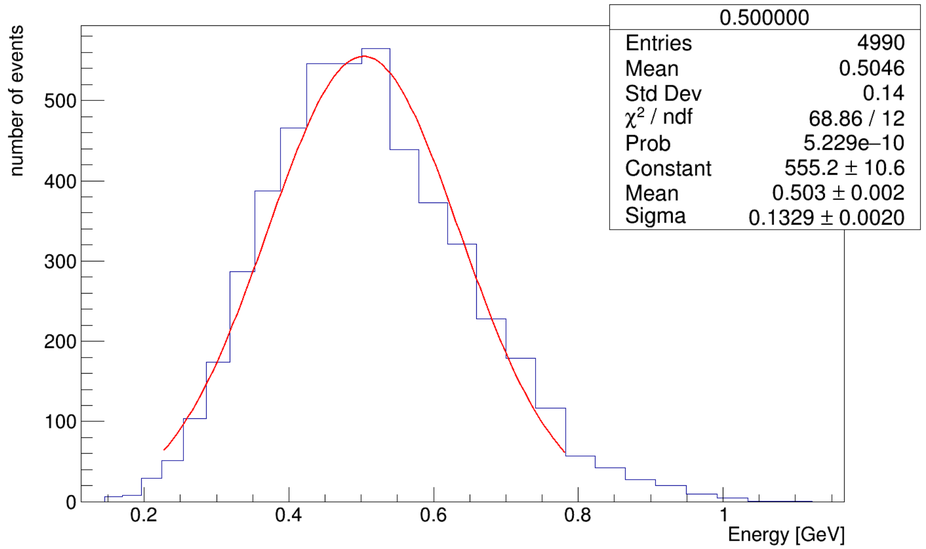
$$\mu_x = x_0 + \frac{\sigma_0^2}{x_0}, \sigma_x = \sigma_0 \sqrt{1 + \frac{\sigma_0^2}{x_0^2}}$$

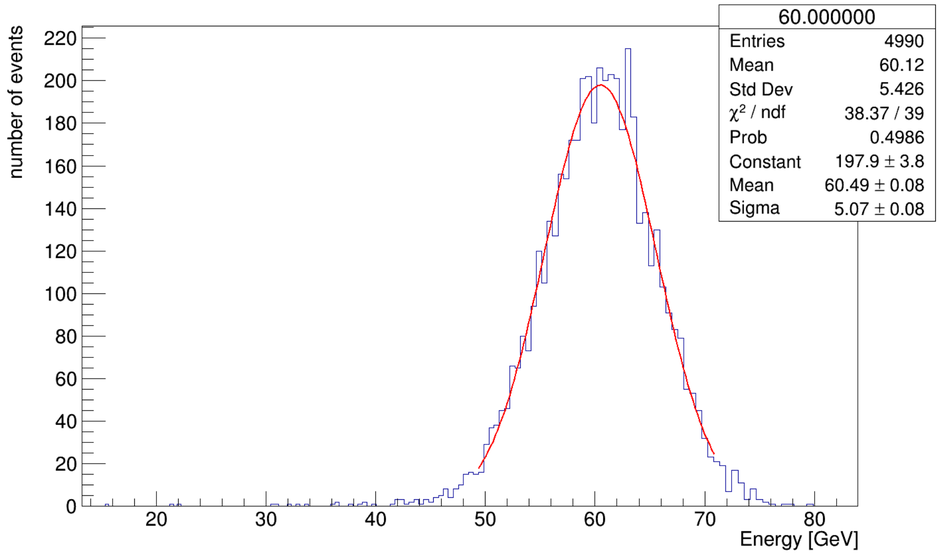
$$g(x, \mu_x, \sigma_x) = \frac{A}{\sigma_x} \exp\left(-\frac{1}{2} \frac{(x-\mu_x)^2}{\sigma_x^2}\right)$$

Thanks to Kamil Zembaczyński!

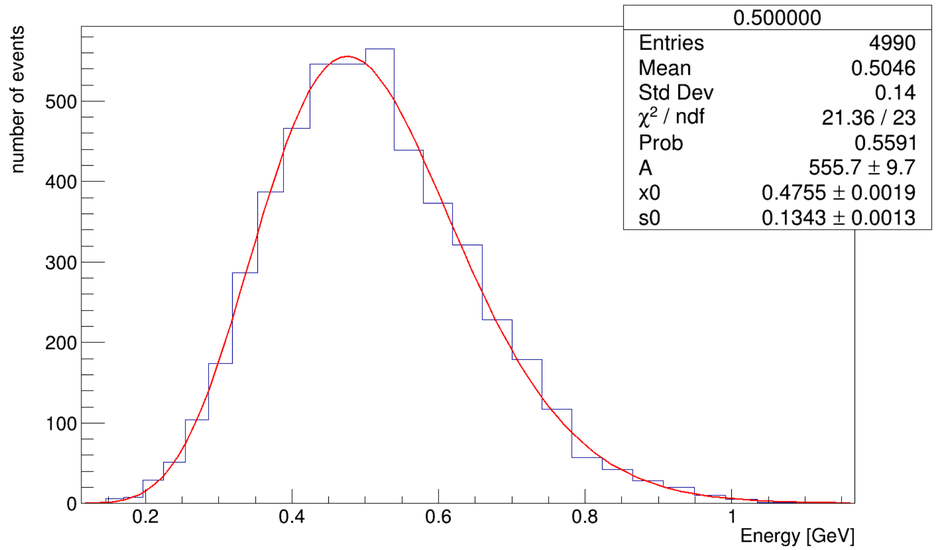
Transferred Distributions with fits

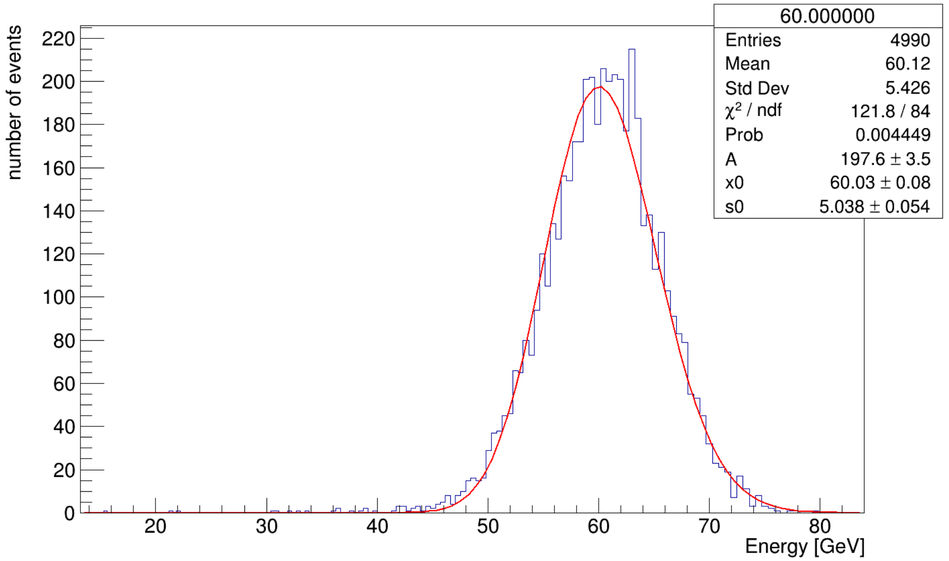
gauss(2σ)





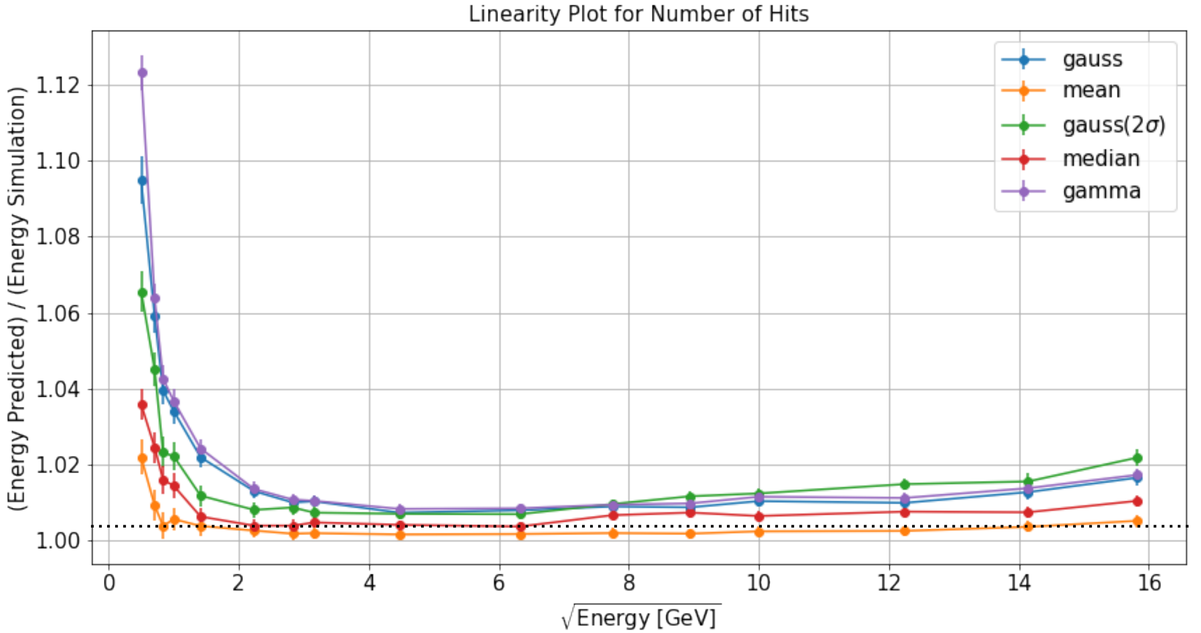
gamma





Linearity Number of Hits

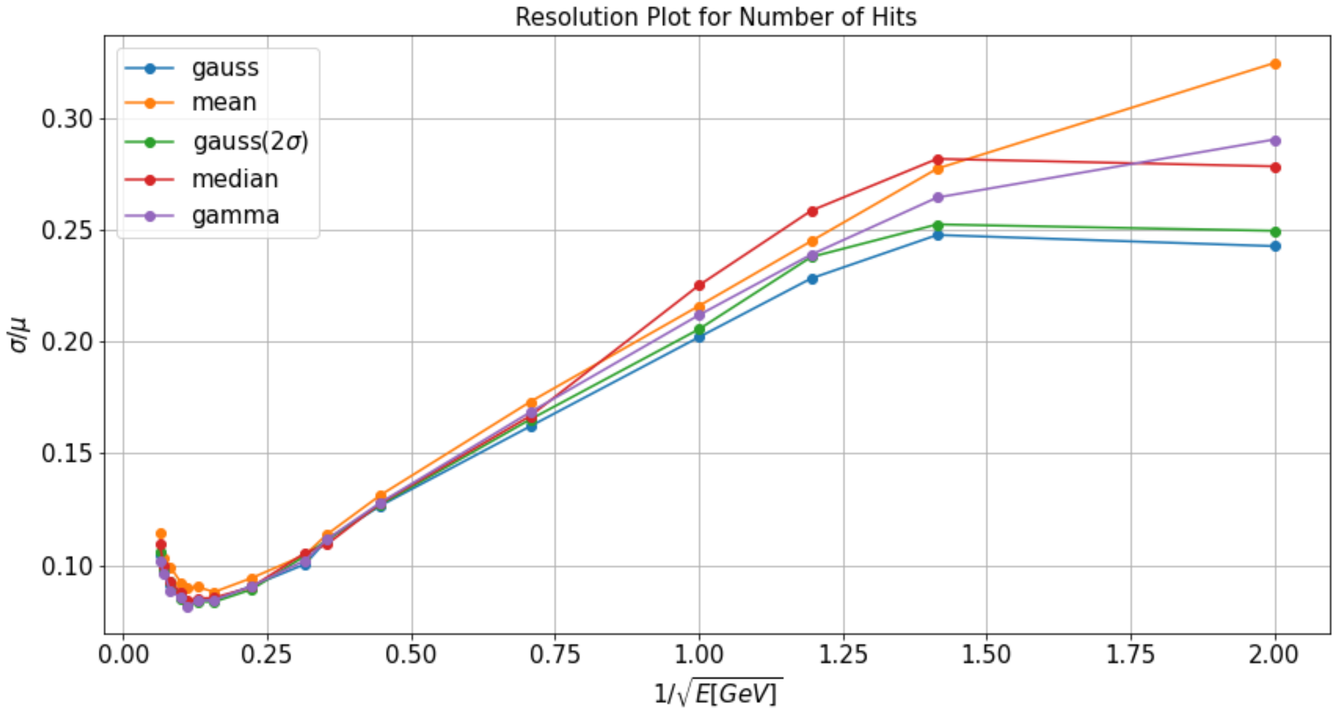
- without any weighting
- systematic bias
- higher non-linearity at low energies
  -> asymmetric distributions
- mean: non-linearity around 0.25%



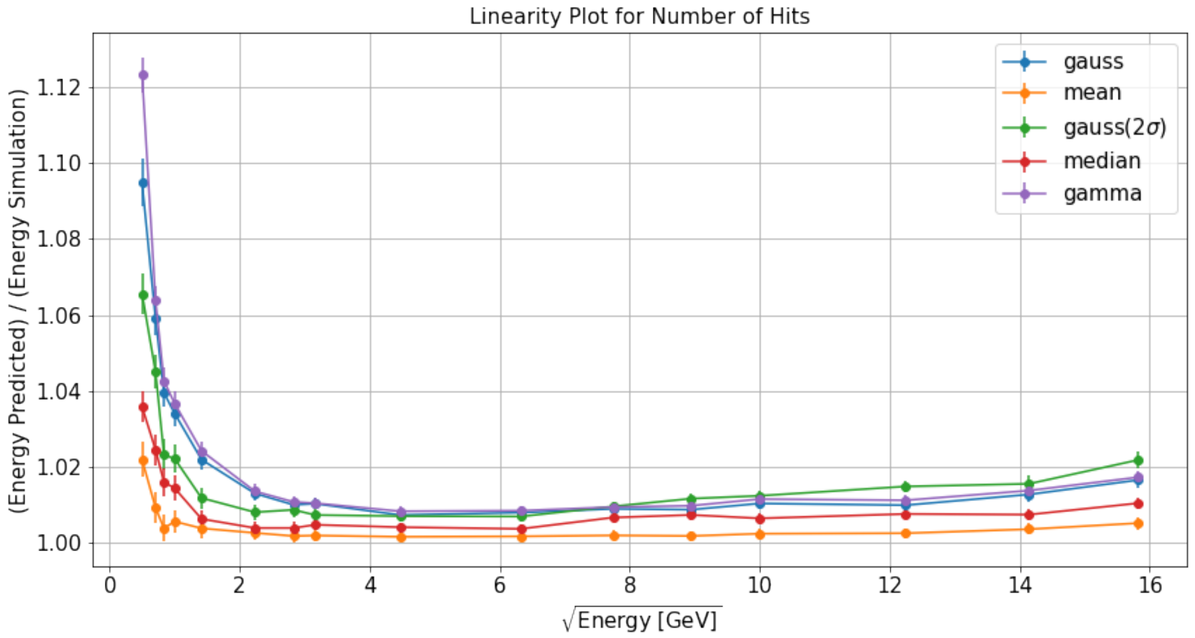
0.25%

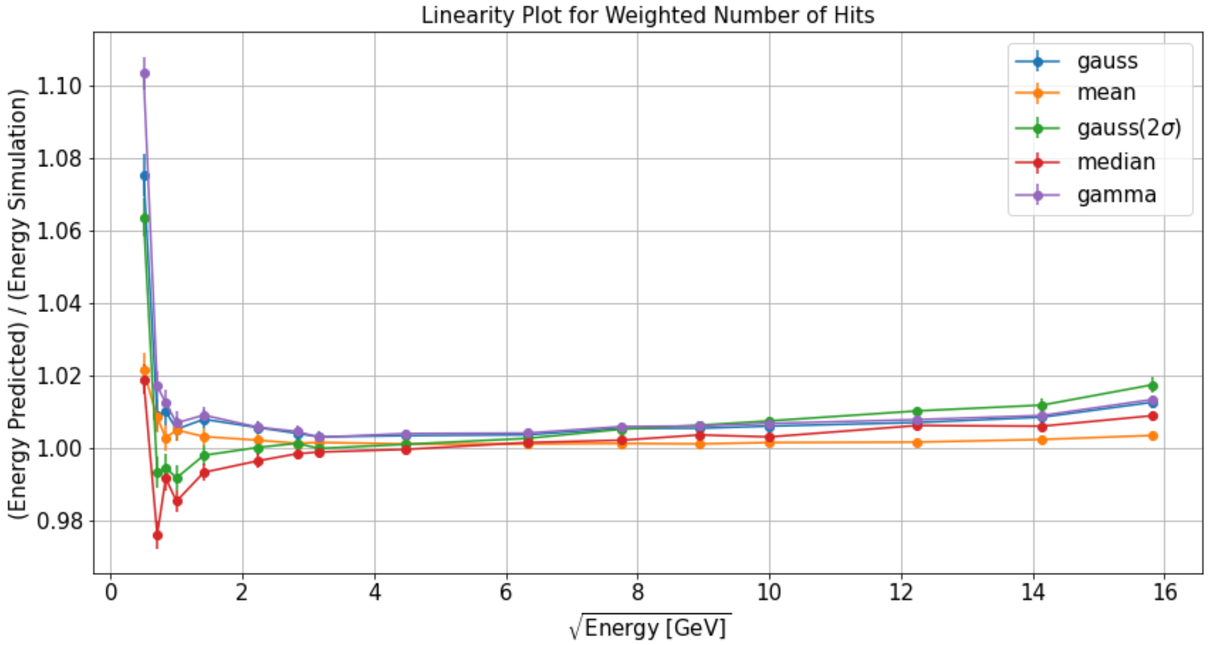
Resolution Number of Hits

- non-linear at low energy
  -> asymmetric distribution
- resolution deteriorates at high energies
  -> saturation



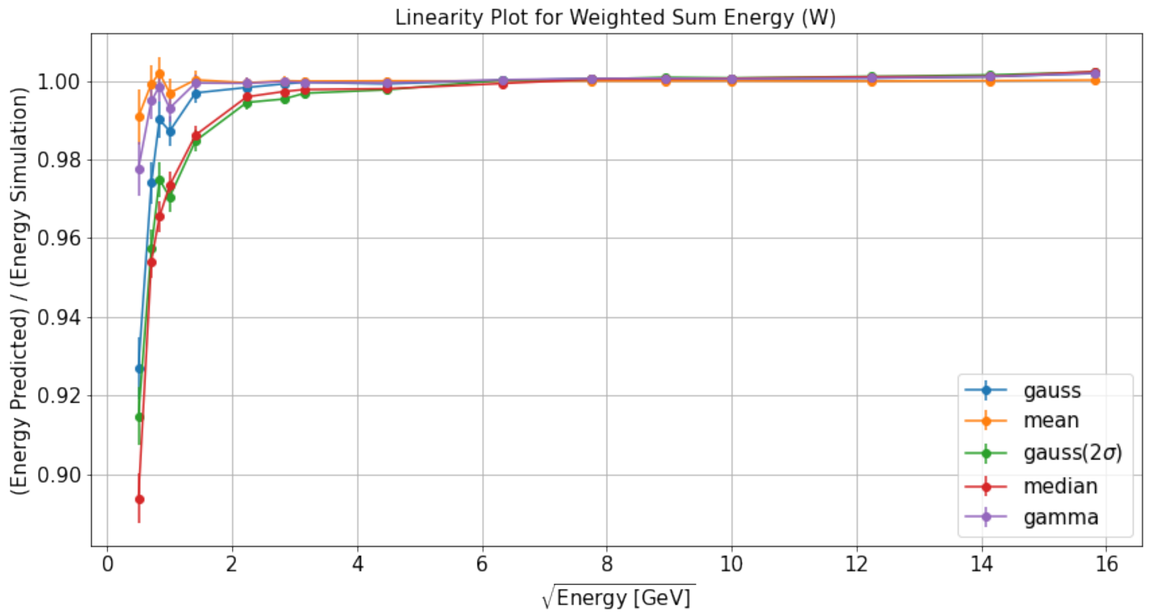
Linearity Weighted Number of Hits





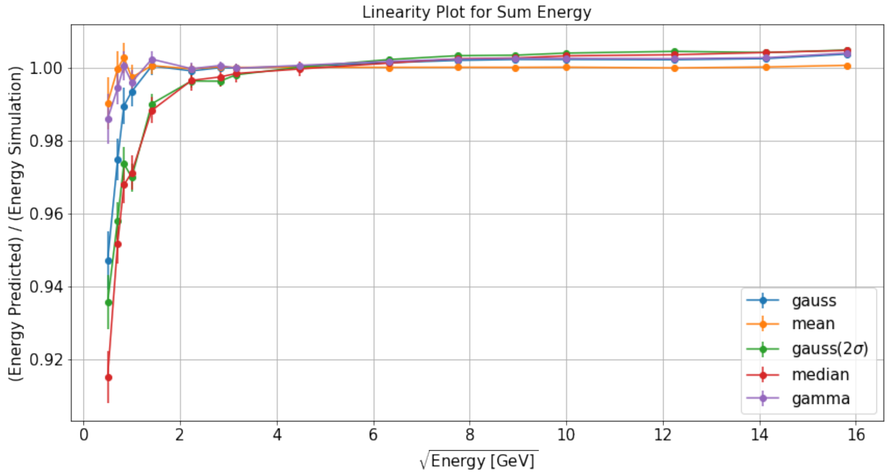
- linearity slightly improves
- systematic bias smaller for weighted number of hits

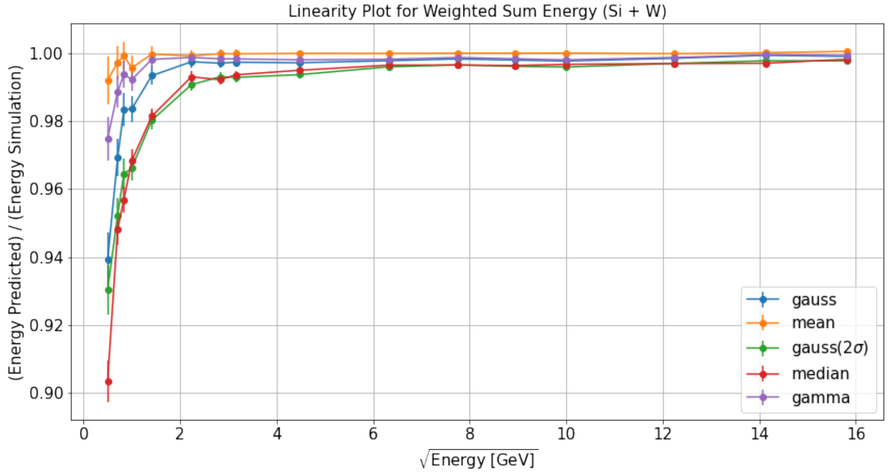
Linearity (Weighted) Sum Hit Energy



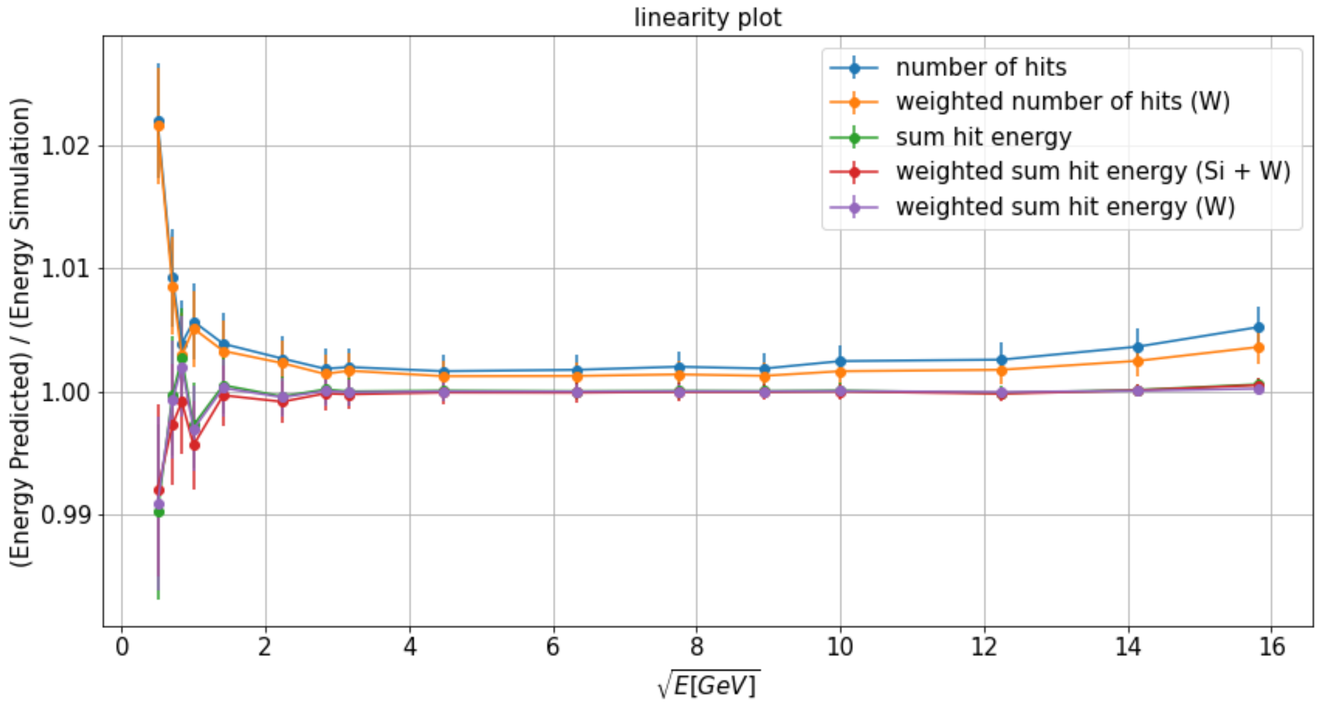
energy calibrated in mips to consider the different Si thicknesses

-> for mean and gaussian linearity approximately within 2%



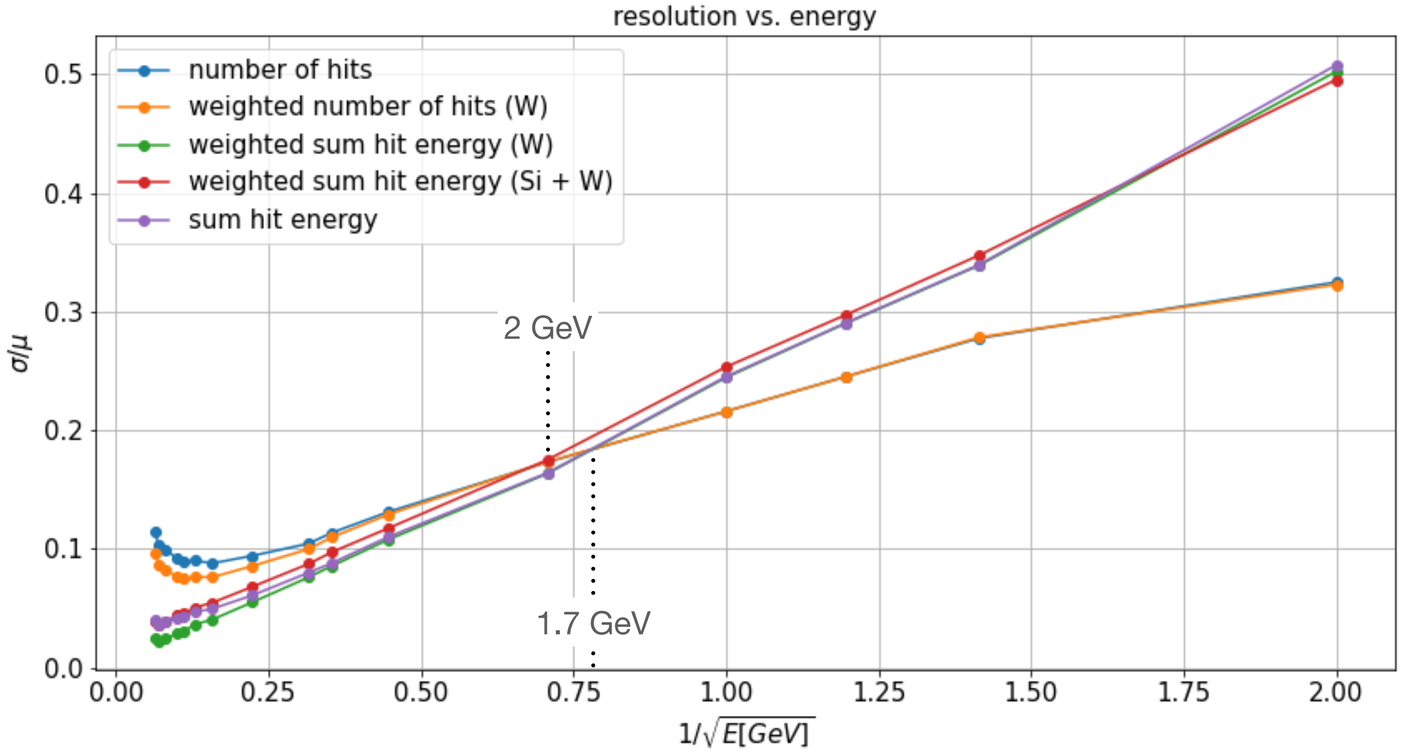


Linearity Comparison (mean)



- mean for every method
- (weighted) sum of hit energy has better linearity
- weighted number of hits has smaller bias
- for sum hit energy W weighting more linear than Si + W
- non-linearity mostly < 0.5%

Resolution Comparison (mean)

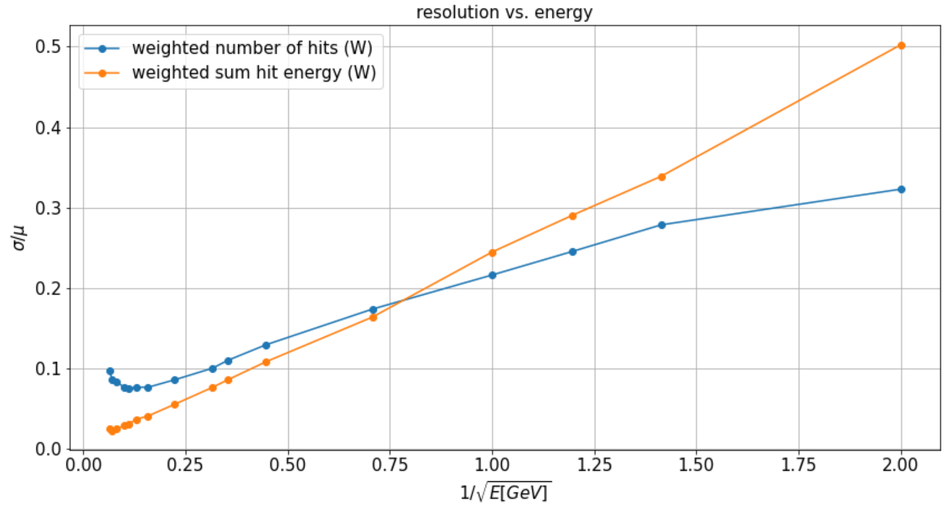


Combination of Methods

- energies < 1.7 GeV
  -> number of hits better resolution

- energies > 1.7 GeV
  -> summing hit energies better resolution

-> try to combine the two methods!

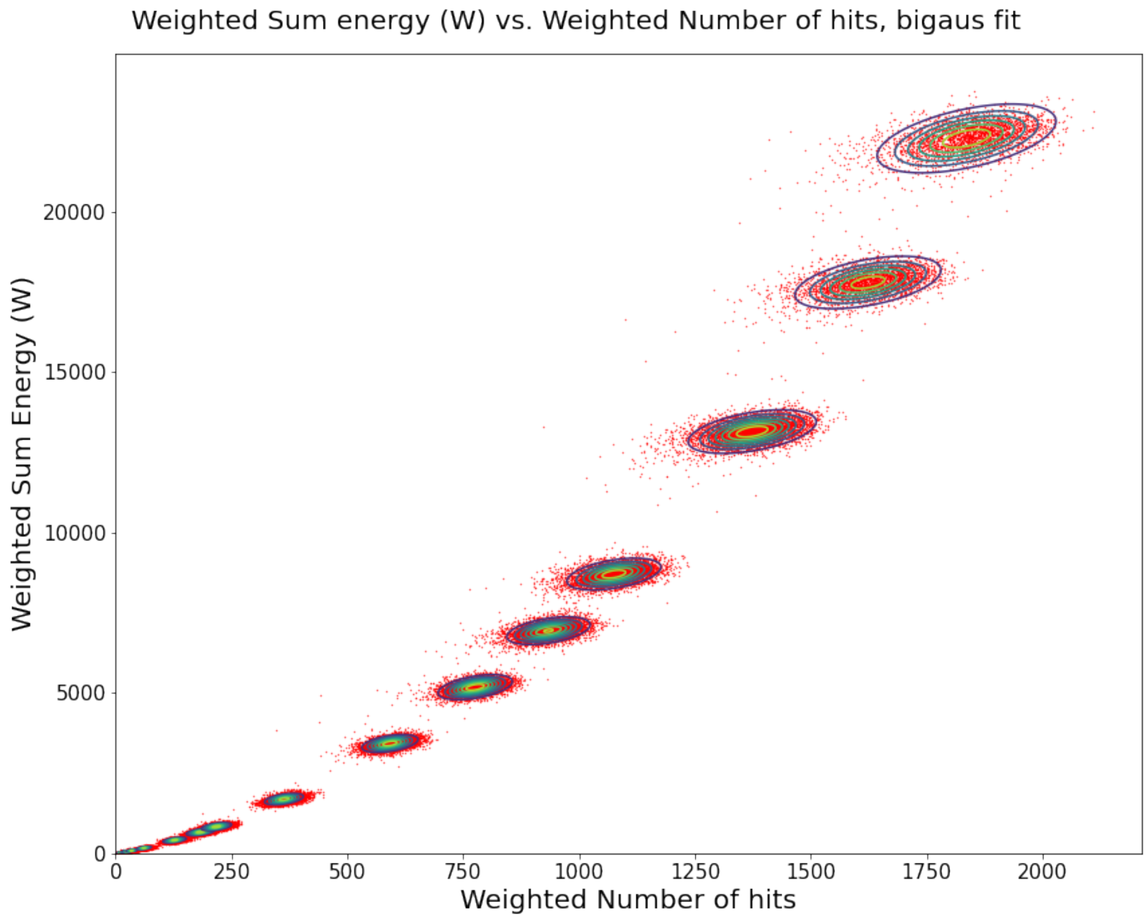


1. linear combination:
   -> α * E(weighted number of hits) + (1 - α) * E(weighted sum energy)

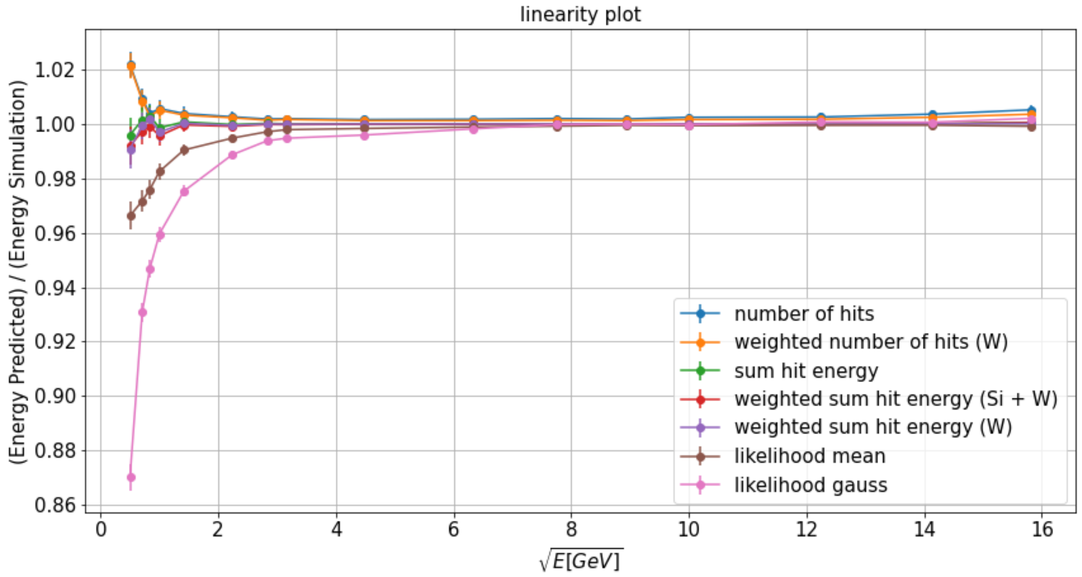
2. likelihood method: most probable value by combining the two

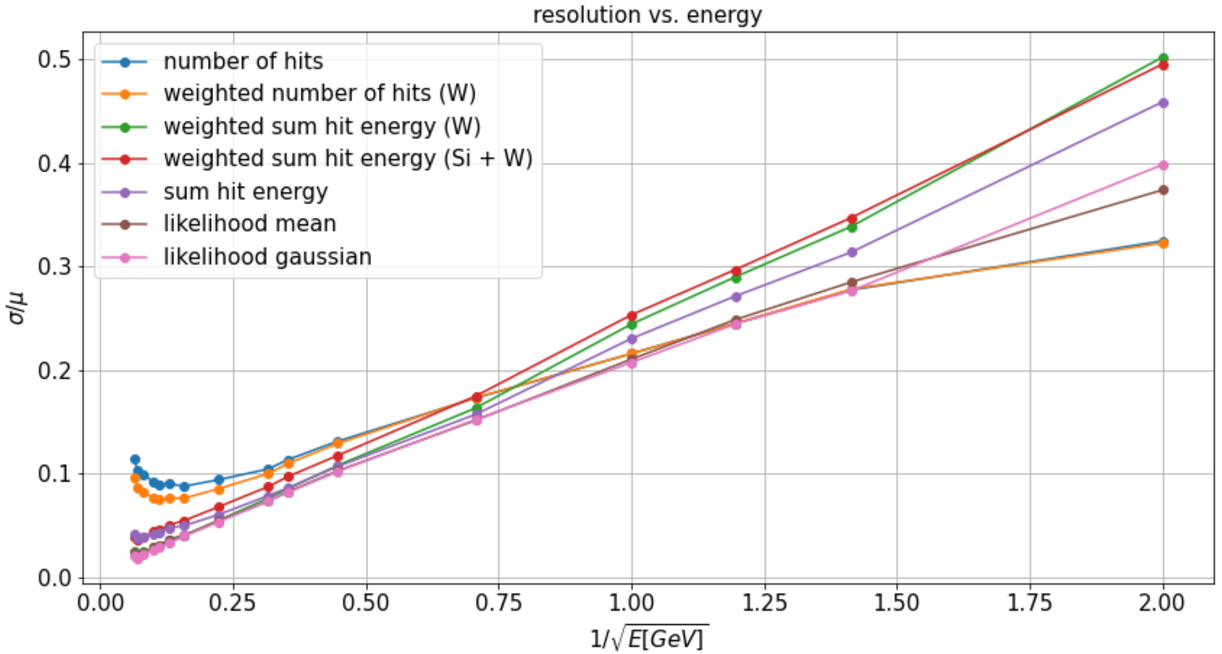
Likelihood Method

- Fit bivariate normal distribution to (weighted) number of hits vs. (weighted) sum hit energy
- Parametrise the fitting parameters as a function of energy
  -> use to „build“ new distributions
- for new point ((weighted) number of hits, (weighted) sum energy) find the distribution/energy it has the highest probability of belonging to

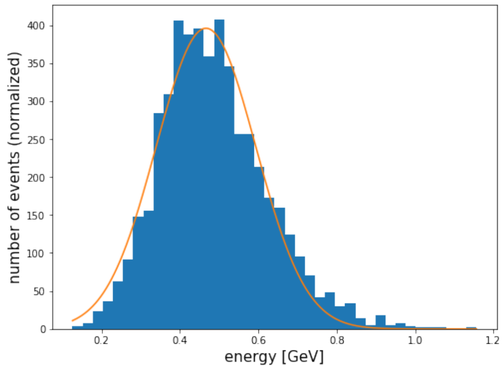


Results Likelihood Method

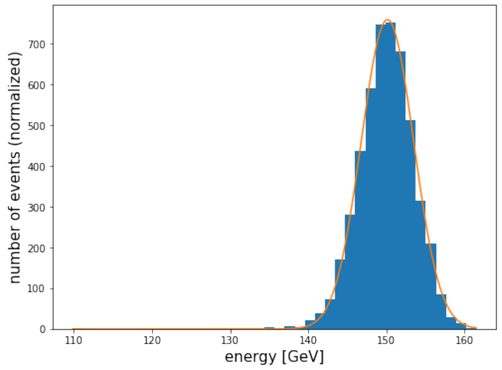




0.5 GeV

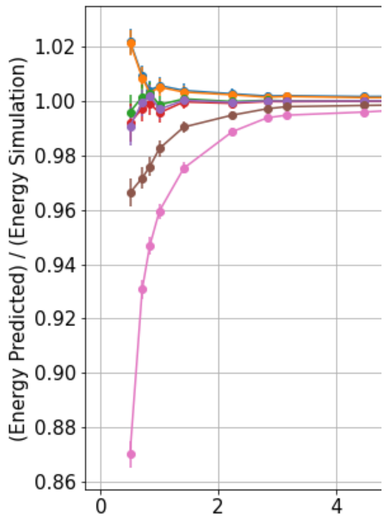


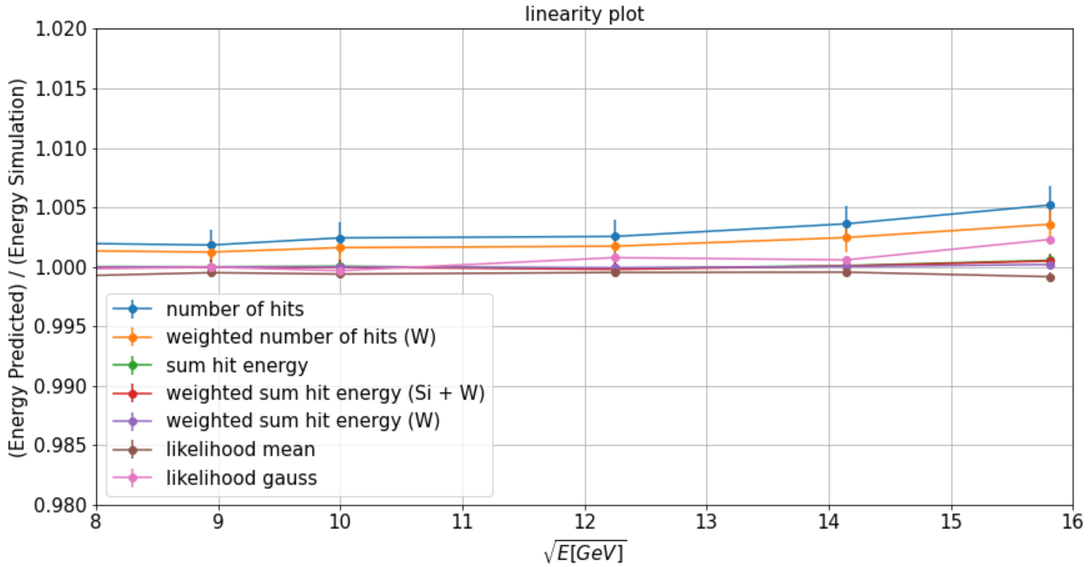
150 GeV

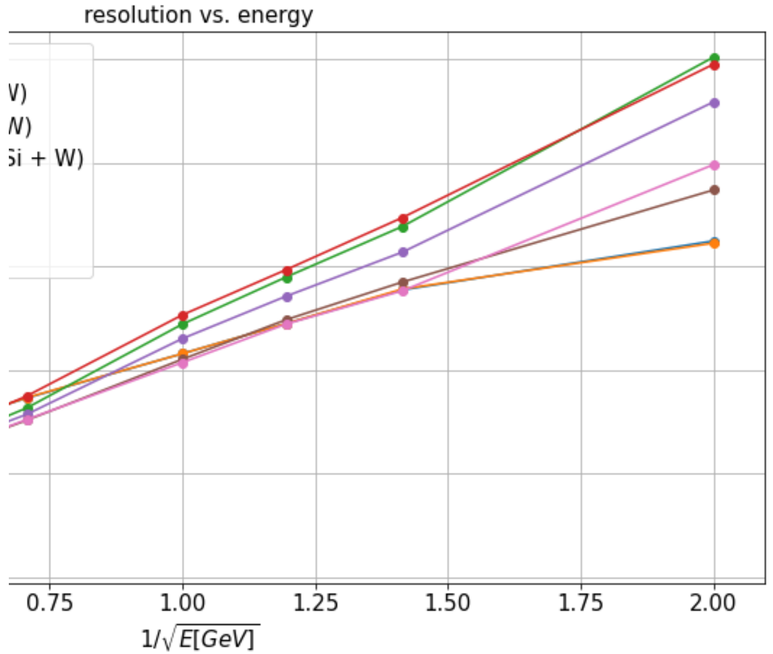


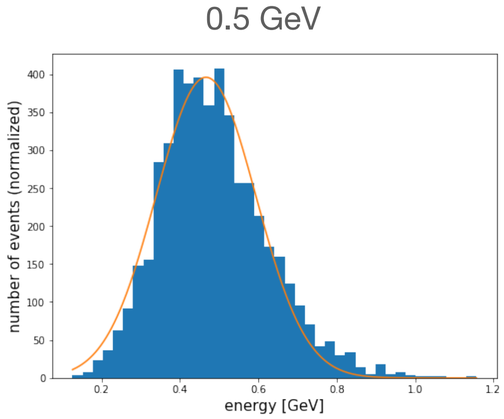
-> study in more detail, especially for lower energy range

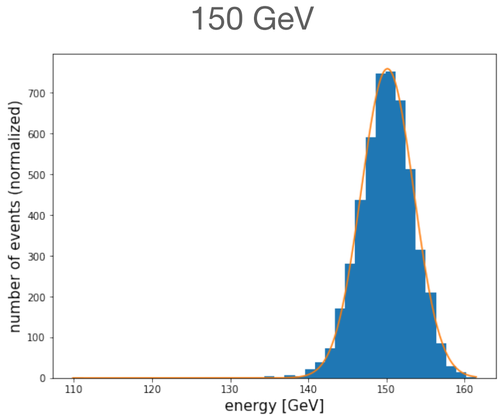
Results Likelihood Method











-> study in more detail, especially for lower energy range

Conclusion

- still preliminary results
- does not include digitisation
- can expect better resolution from counting hits a low energies
- expect better resolution from summing hit energies at high energies
- very low energy part (< 500 MeV) needs special consideration

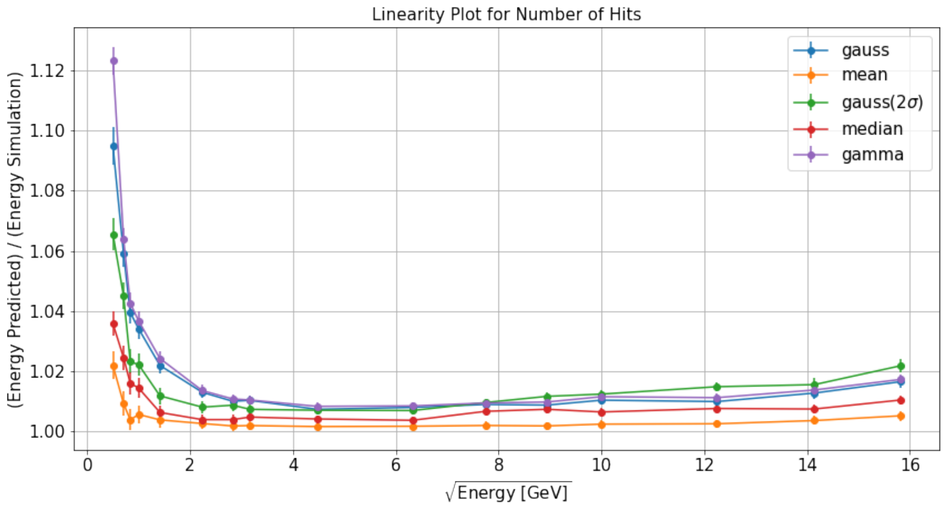
Next Steps

- study nonlinearity for lower energies in more detail
- find method for asymmetric distributions
- understand bias in linearity for number of hits
- study likelihood method in more detail, especially for lower energies
- compare linear method and likelihood method for combination

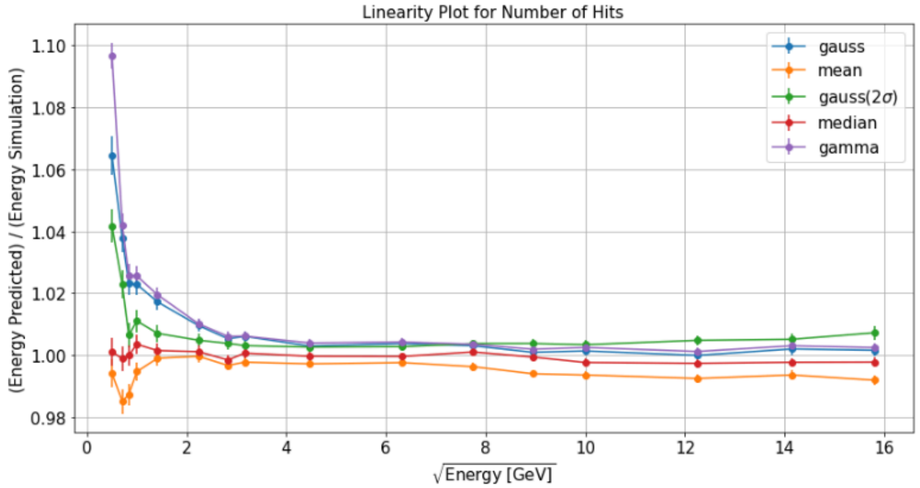
Backup

Comparison mean, gauss and gauss(2 sigma)

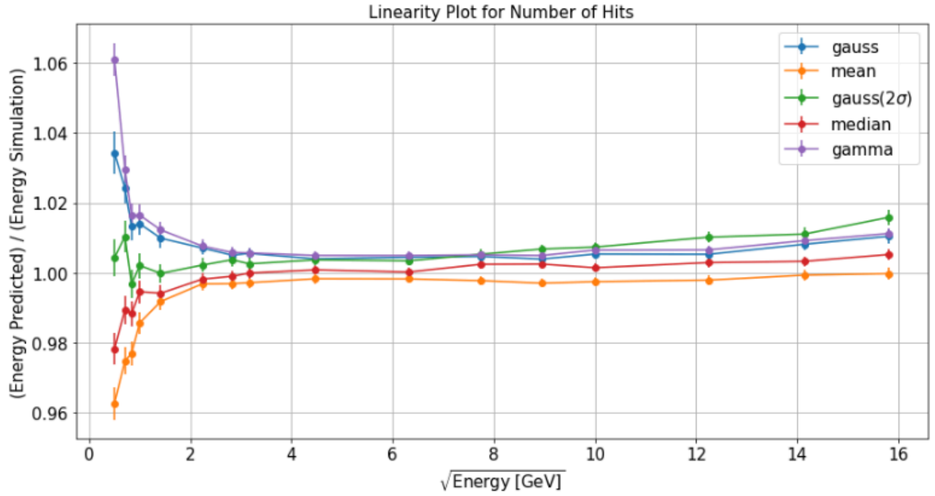
mean



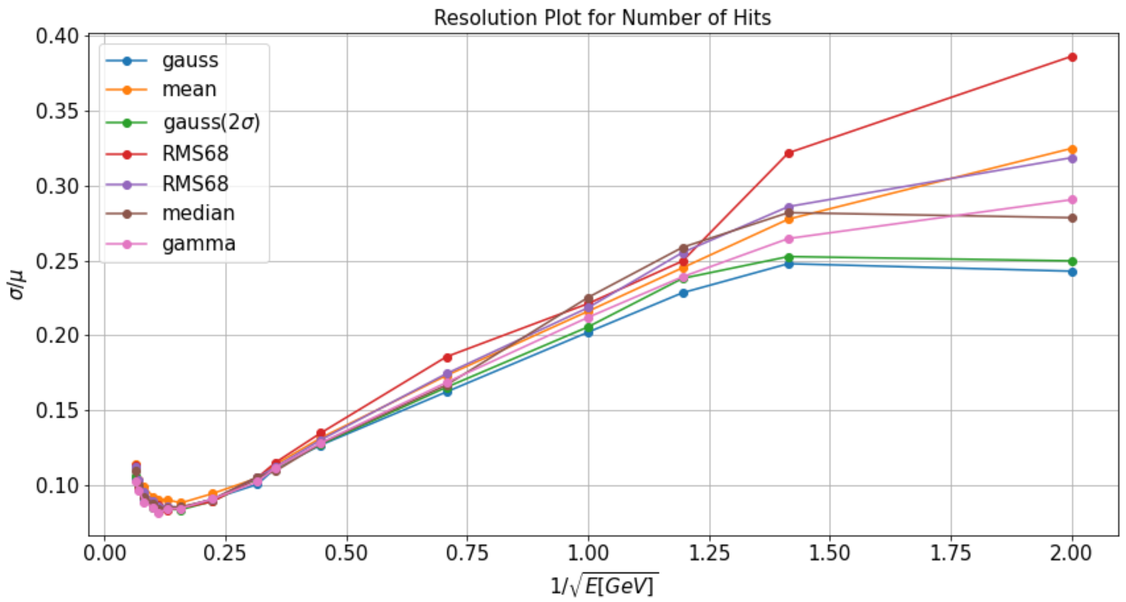
gauss within 2 sigmas

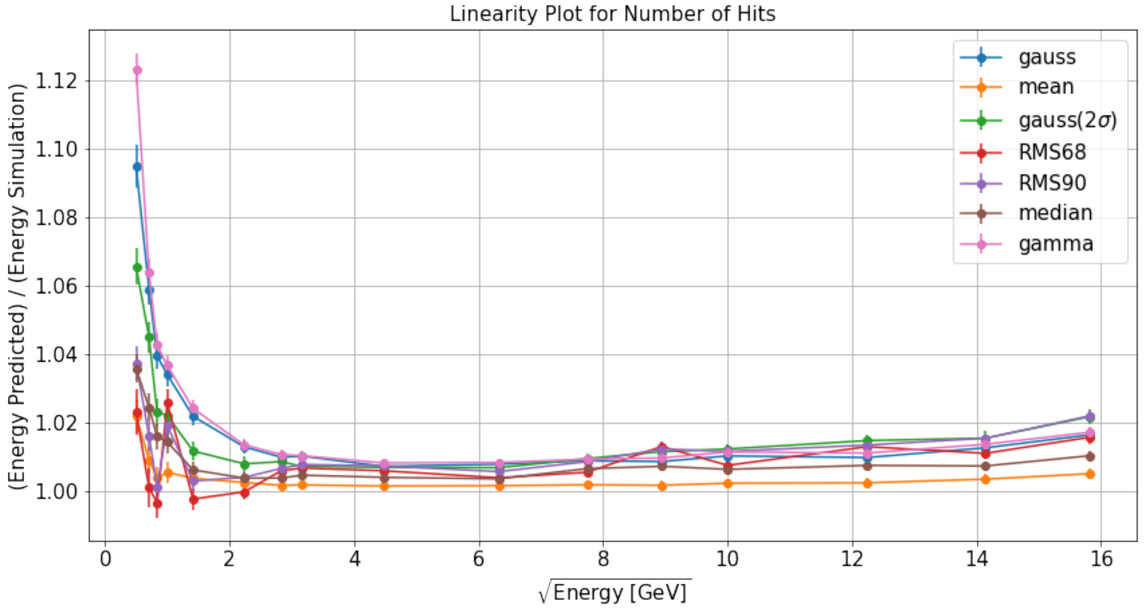


gauss

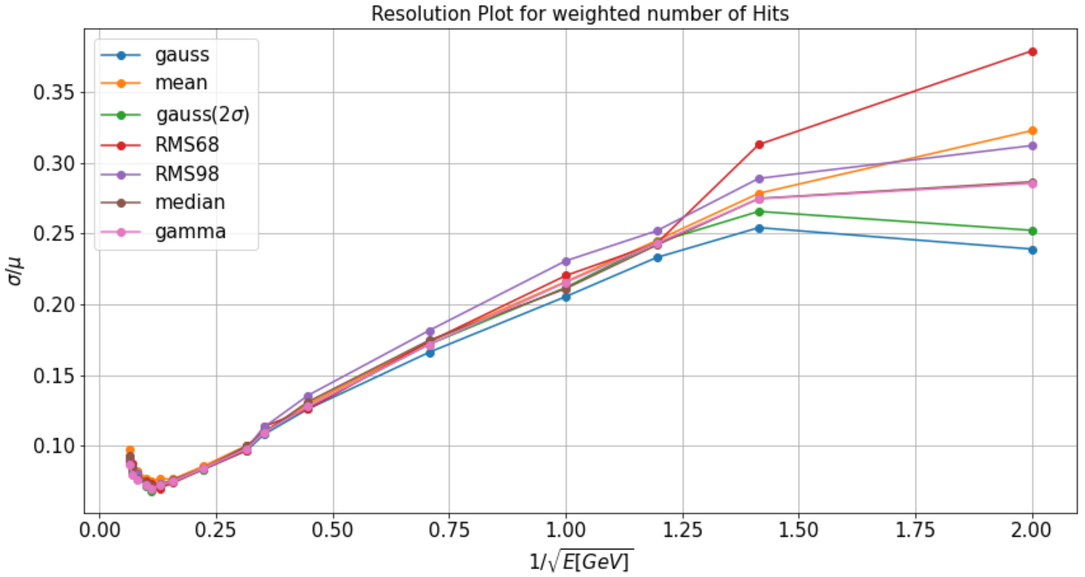


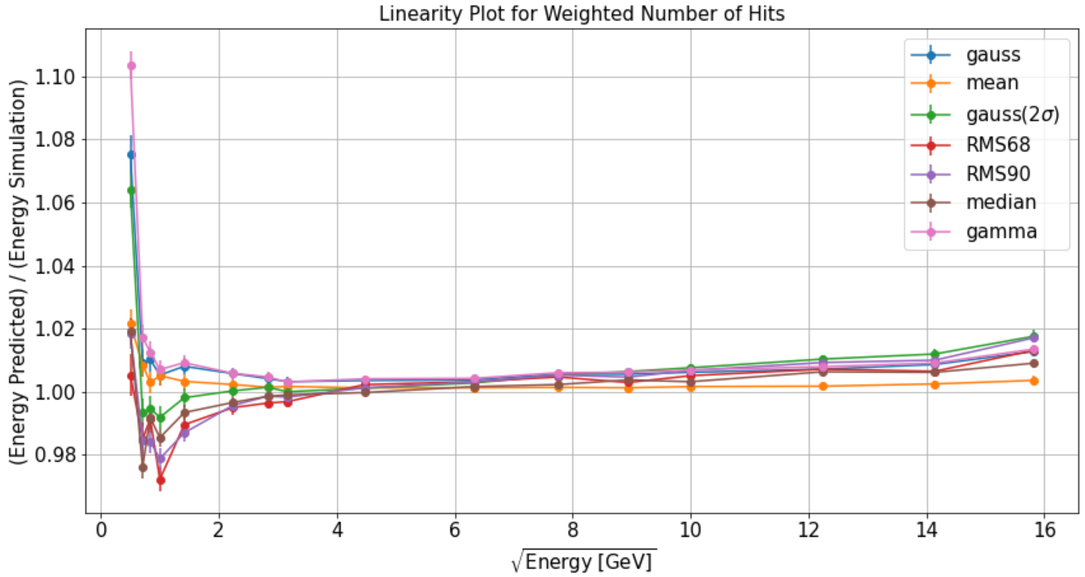
Linearity and Resolution number of hits



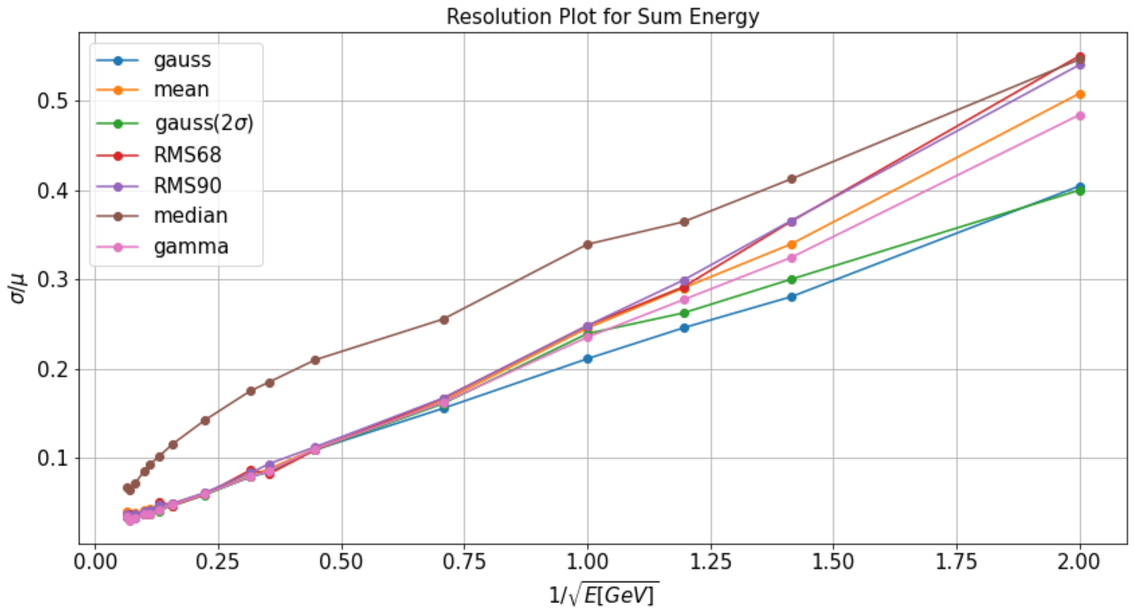


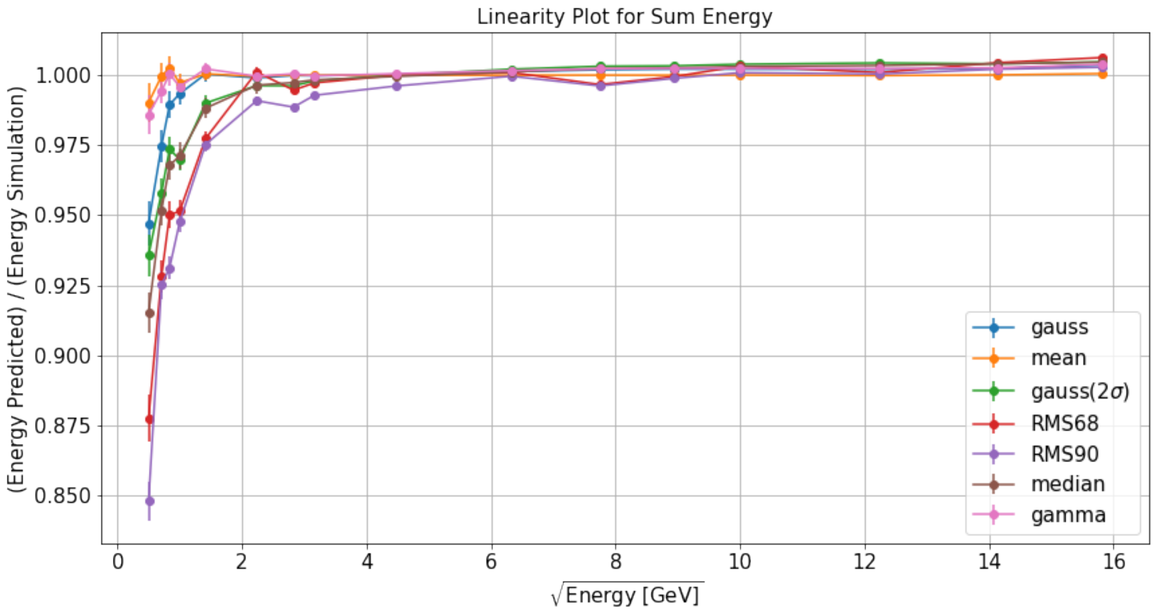
Linearity and Resolution weighted number of hits



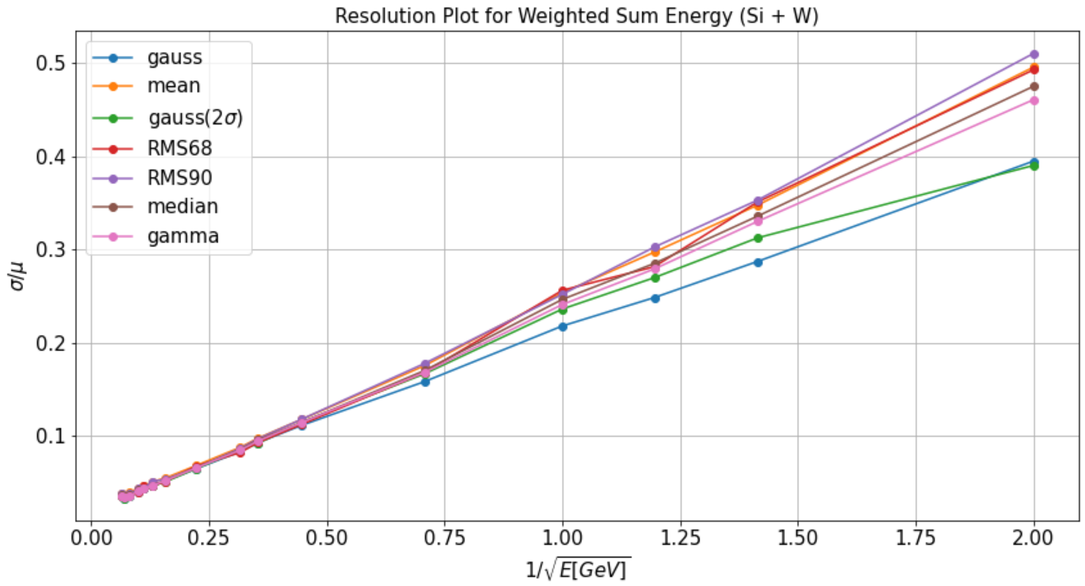


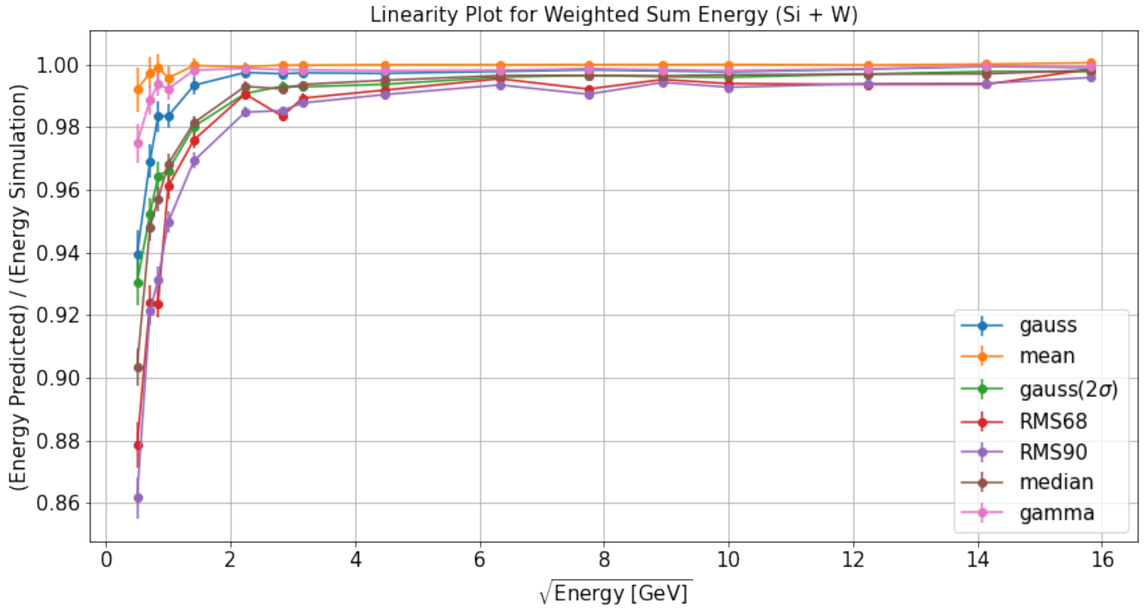
Linearity and Resolution sum hit energies





Linearity and Resolution weighted sum energy (Si + W)





Linearity and Resolution weighted sum energy (W)