Photons: Energy Resolution and Linearity

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Silicon Detector Calorimetry Meeting
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Analysis

- Can we use simulations to design a detector with good response to photons?
- Start by investigating the intrinsic detector characteristics:
  - Energy linearity
  - Energy resolution
- Analyze the response to single photons.

Simple Geant4 study

- Generate simple sampling calorimeters composed of tungsten-silicon sandwiches.
- Create stacks sufficiently large to contain the full particle showers.
- Vary thicknesses of tungsten and silicon to study the impact on the energy resolution.
- Simulate the response to single photons of varying energy.
- Plot resolution as a function of tungsten and silicon thickness.

Resolution as fn(d_W, d_{Si})

- Generate 400 points in 20 x 20 grid.
- Resolution fits well to the plane:

  h(x,y) = a*x + b*y + c

  x is the silicon thickness in microns

  y is the tungsten thickness in mm

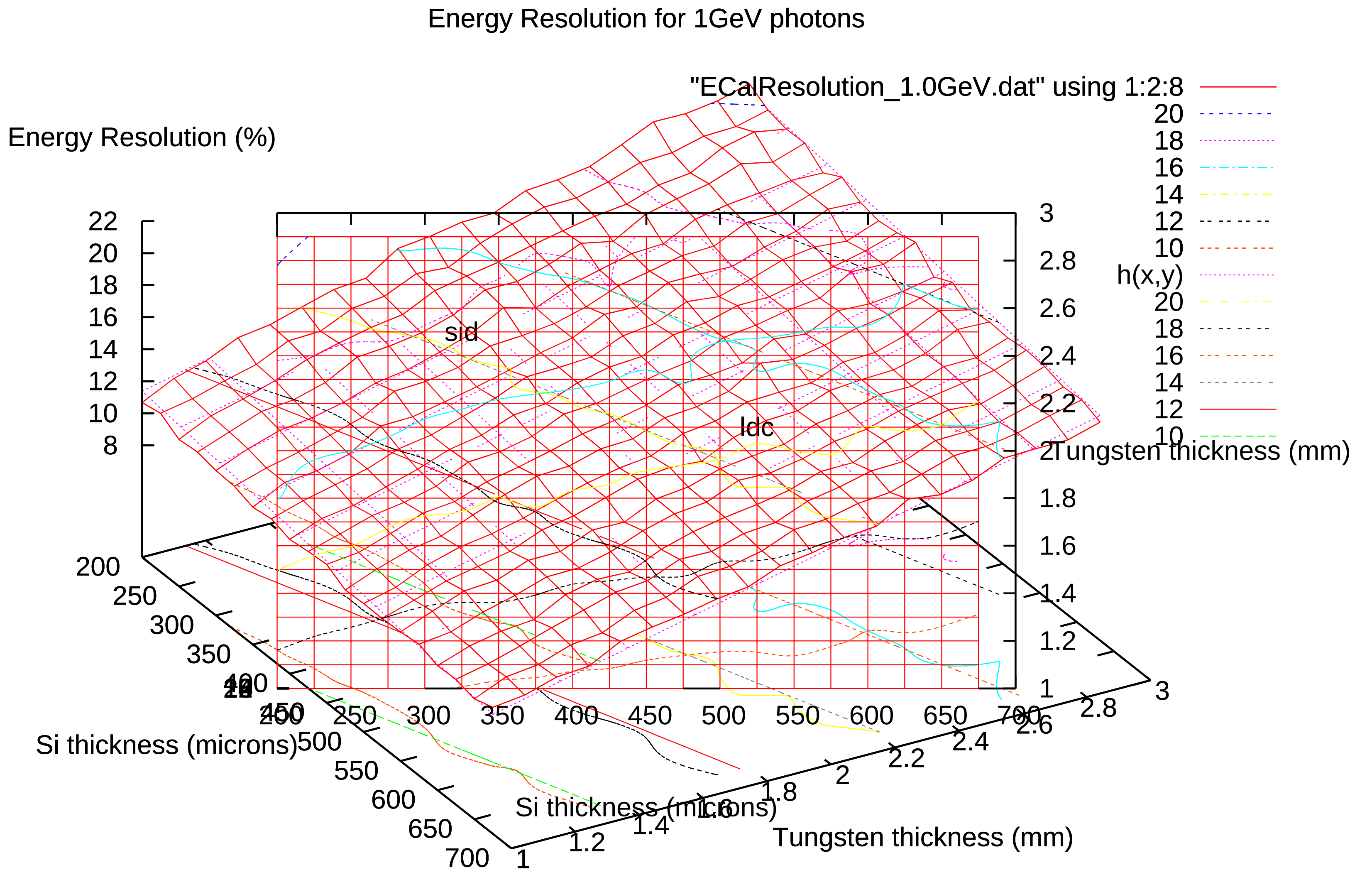
  h is the energy resolution in %
- With parameters:

  a = -0.00614792 +/- 0.0001221 (1.986%)

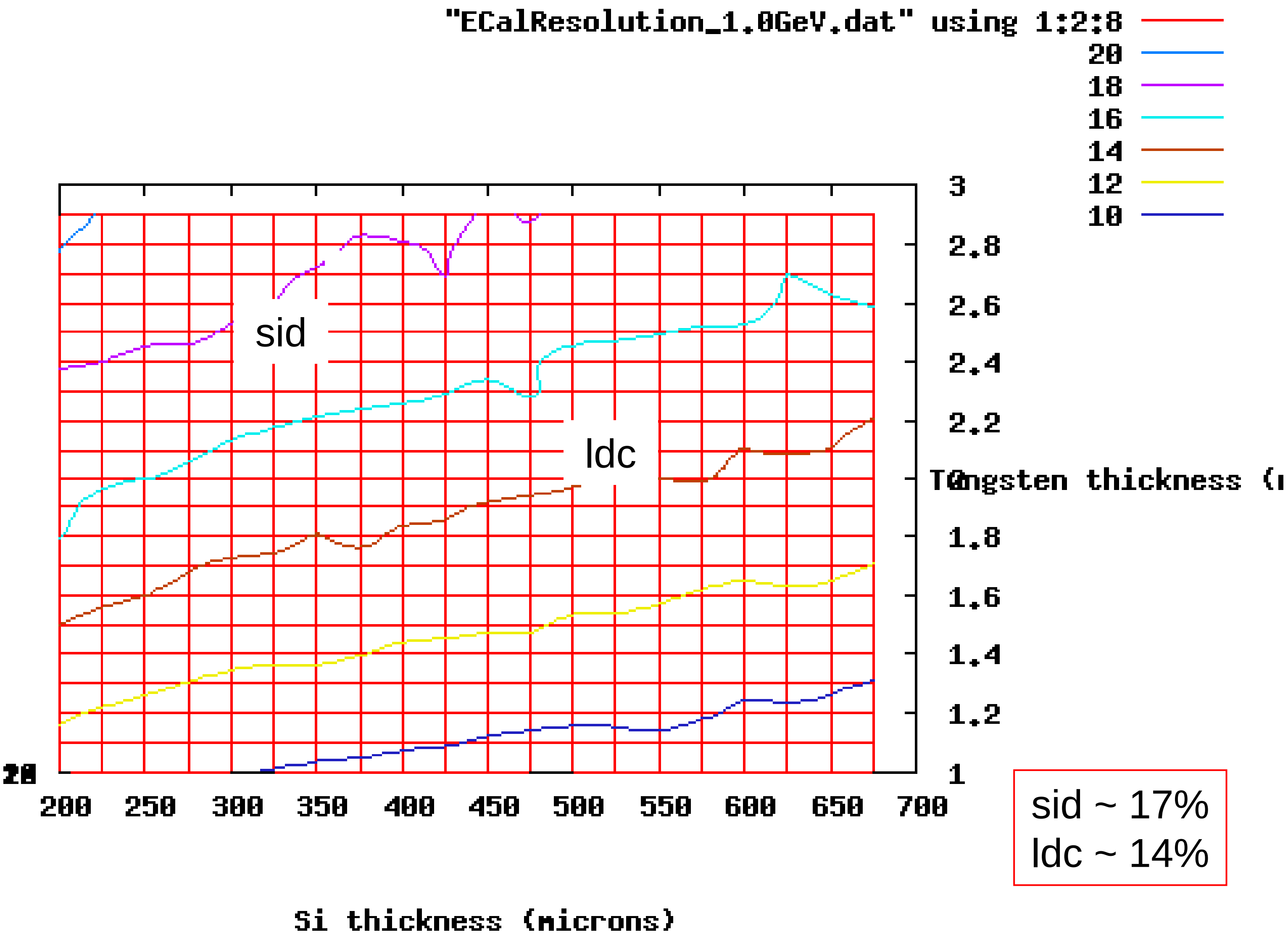
  b = 4.57985 +/- 0.03052 (0.6665%)

  c = 8.02729 +/- 0.08189 (1.02%)

Resolution as fn(d_W, d_{Si})



Resolution as fn(d_W, d_{Si})



sid ~ 17%
ldc ~ 14%

Full Simulation Detectors

- acme0605
  - 20 layers of .271cm W (Dens25), 320μm Si
  - 10 layers of .543cm W (Dens25), 320μm Si
  - HCal: .75cm W, .5cm scintillator
- acme0605_30layerecal
  - 30 layers of .271cm W (Dens25), 320μm Si
- acme0605_40layerecal
  - 40 layers of .271cm W (Dens25), 320μm Si
- acme0605_steel_scint
  - 20 layers of .271cm W (Dens25), 320μm Si
  - 10 layers of .543cm W (Dens25), 320μm Si
  - HCal: 2.0cm Steel, .5cm scintillator

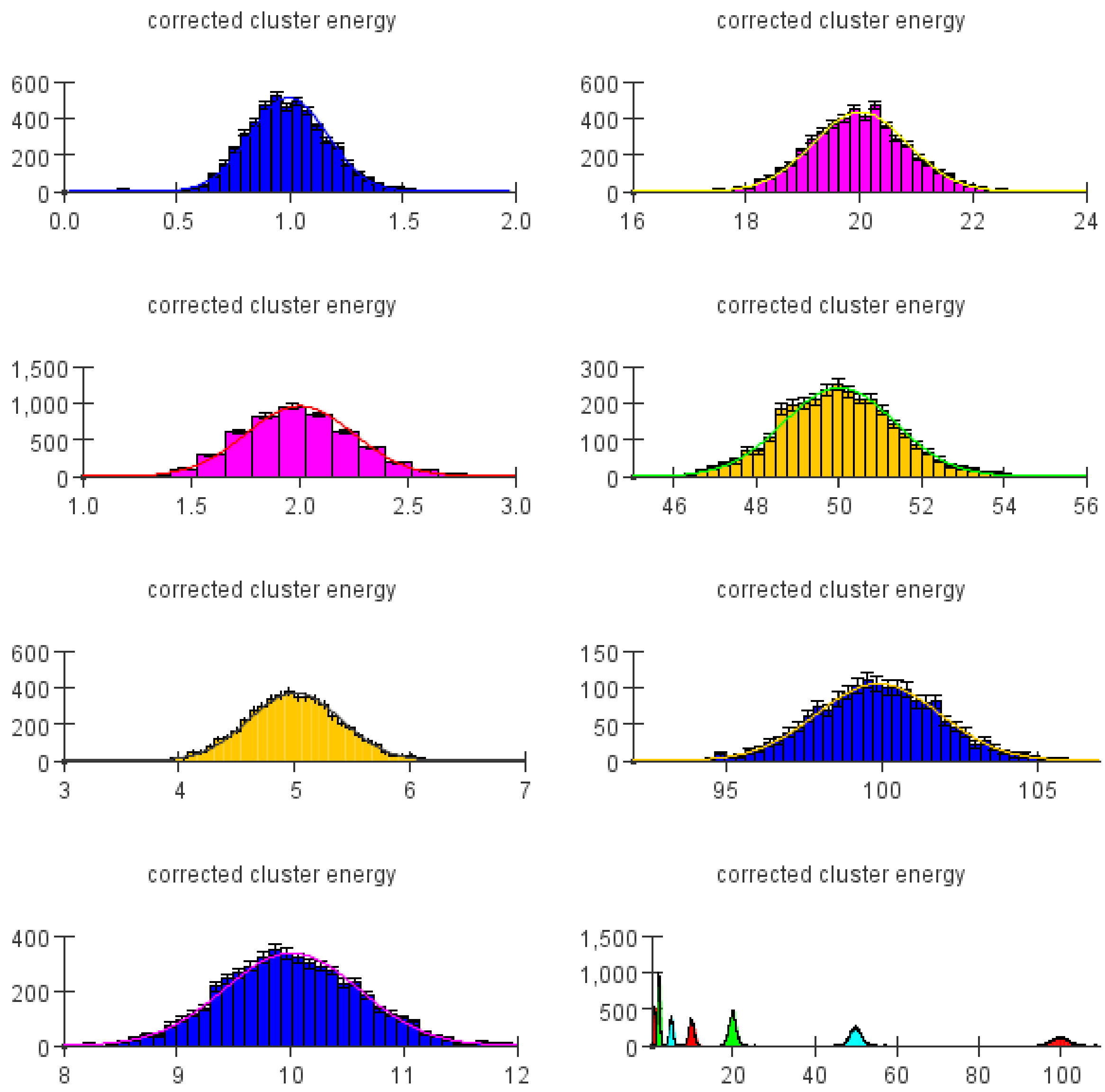
Full Simulation Data Samples

- Generated single particle events with photons at $\theta = 90°$ to the beam line, $0 < \varphi < 2\pi$.
- Discrete energies: 1, 2, 5, 10, 20, 50, 100 GeV
- Also looked at 250 and 500 GeV samples.
- Apply conservative fixed-cone clustering algorithm to clean up obvious outliers.

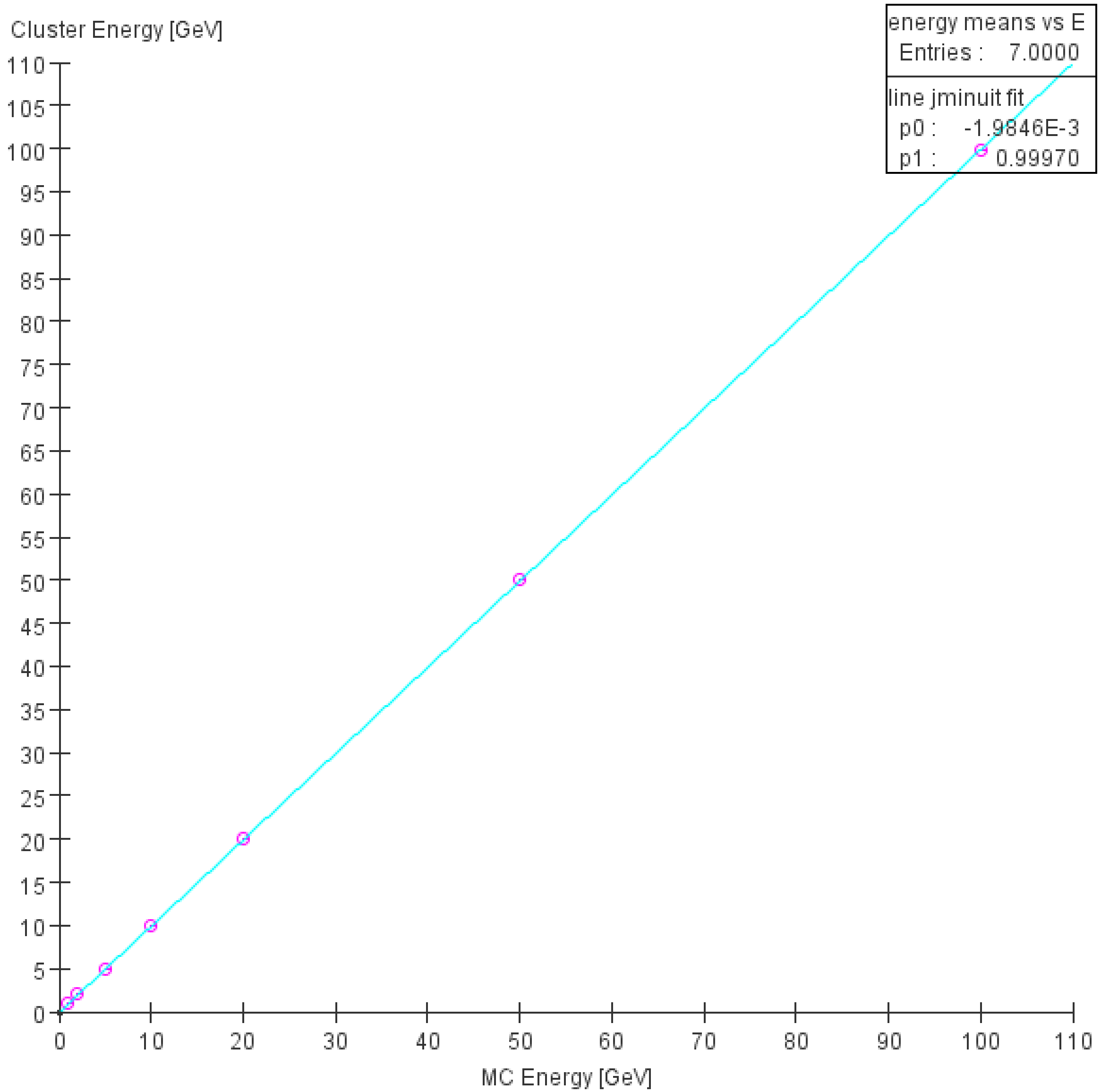
Results

- Sampling fractions can be obtained for all the detector designs which provide a linear response for photons with energies between 1 and 100 GeV.
- The energy resolution is only slightly affected by the EM calorimeter designs:
  - acme0605: 17.1%
  - acme0605_40layerecal: 16.9%
  - acme0605_30layerecal: 17.2%
  - acme0605_steel_scint: 17.7%

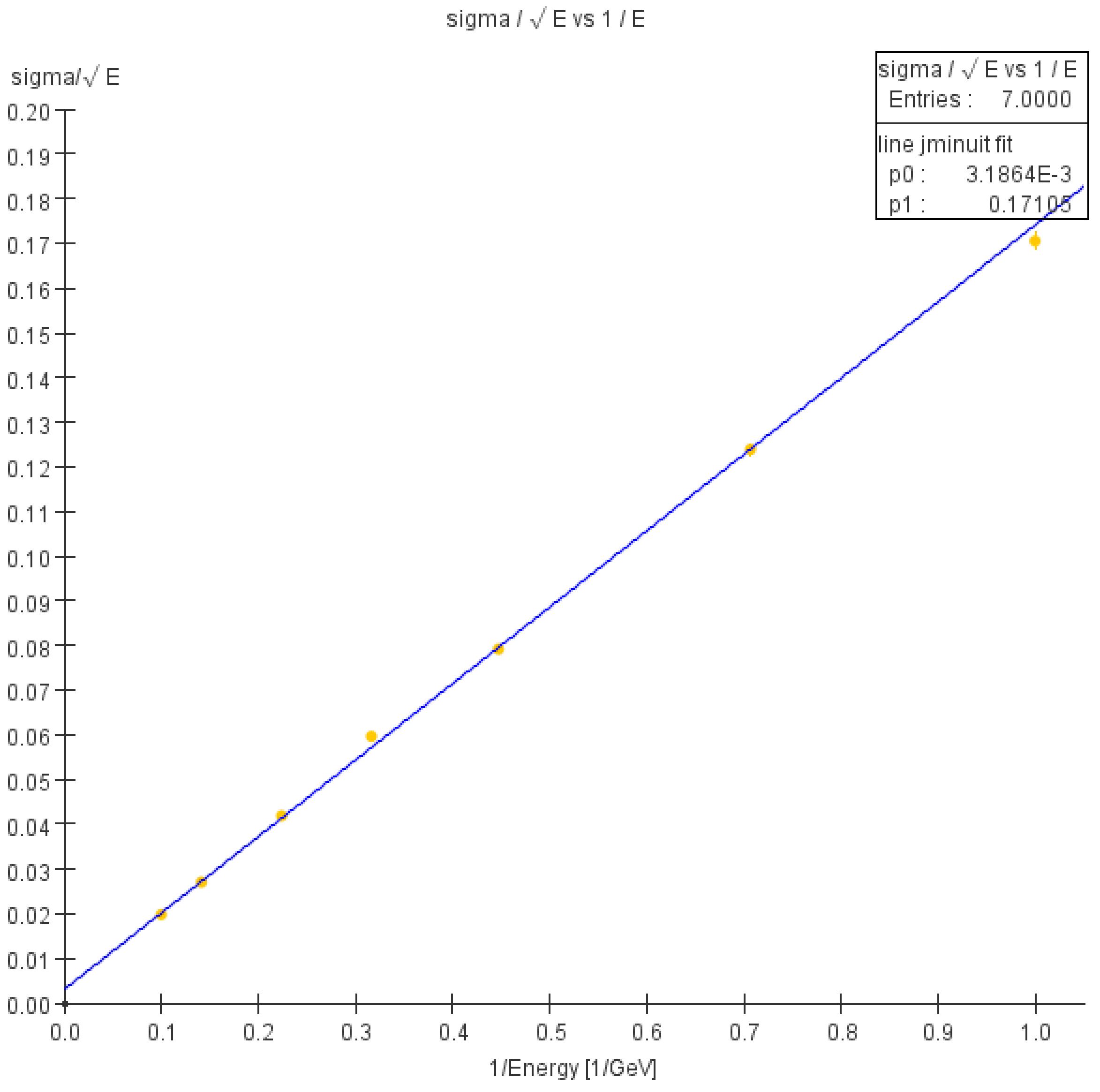
Plots: acme0605 Raw



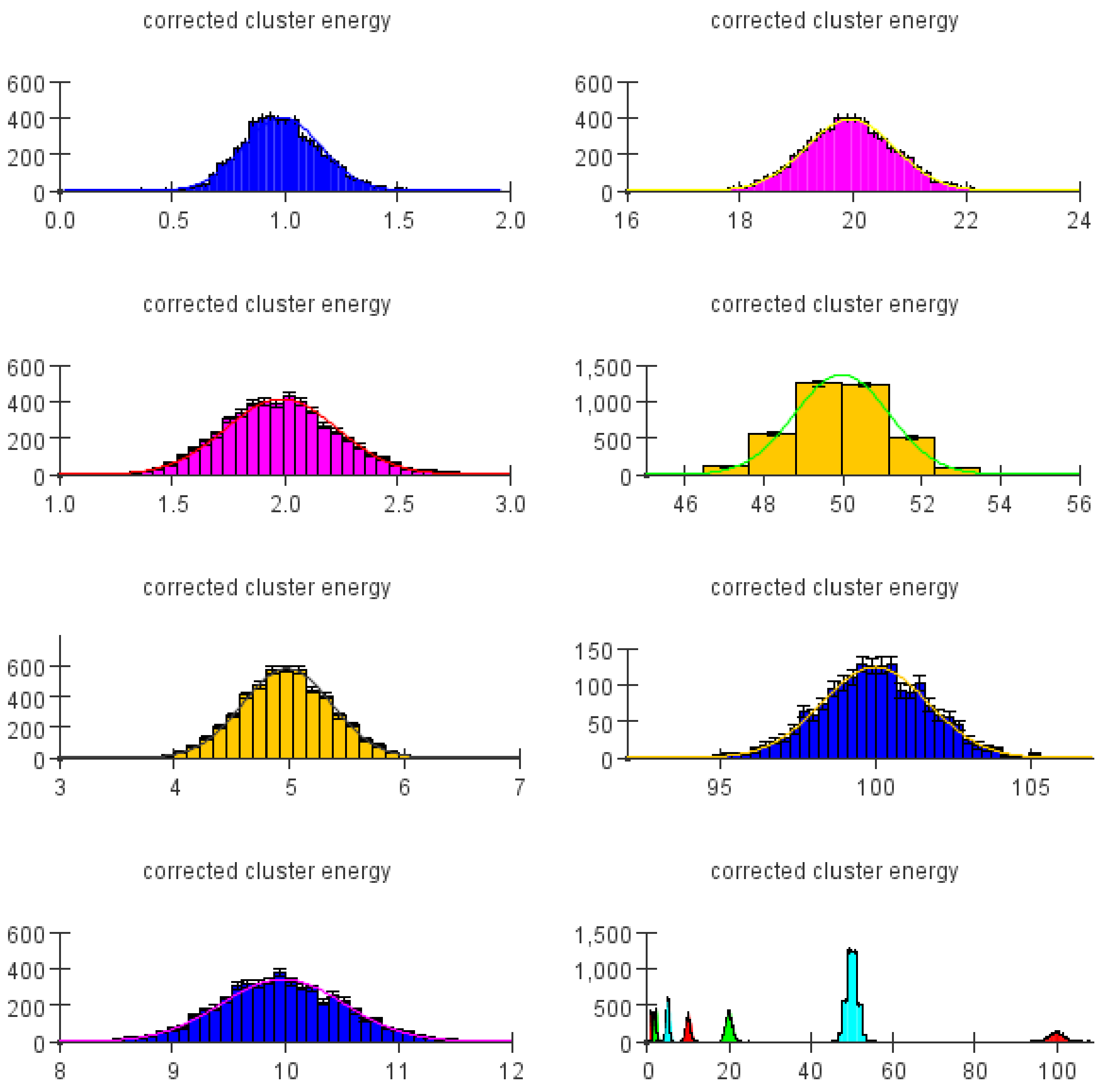
Plots: acme0605 Linearity



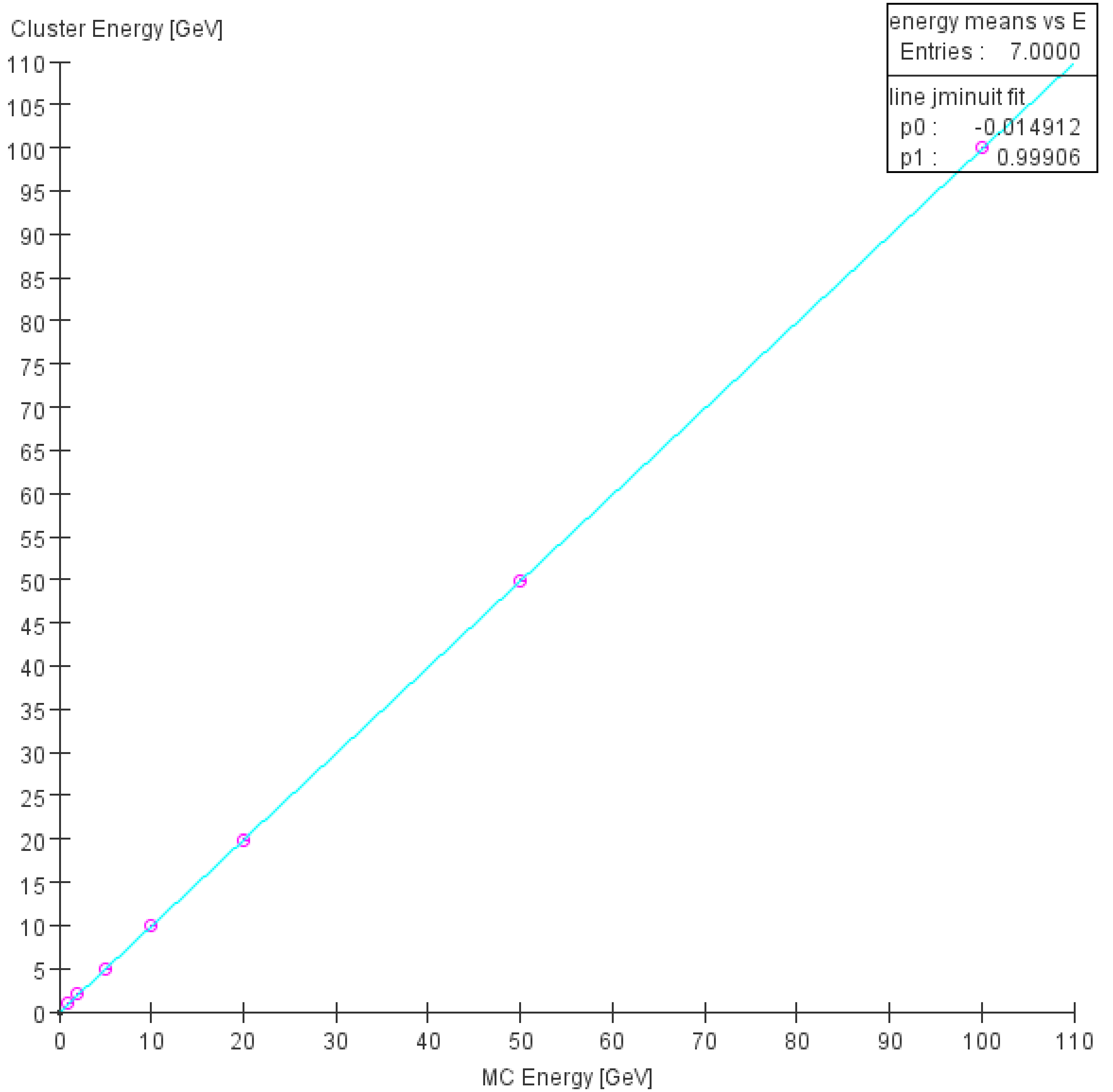
Plots: acme0605 Resolution



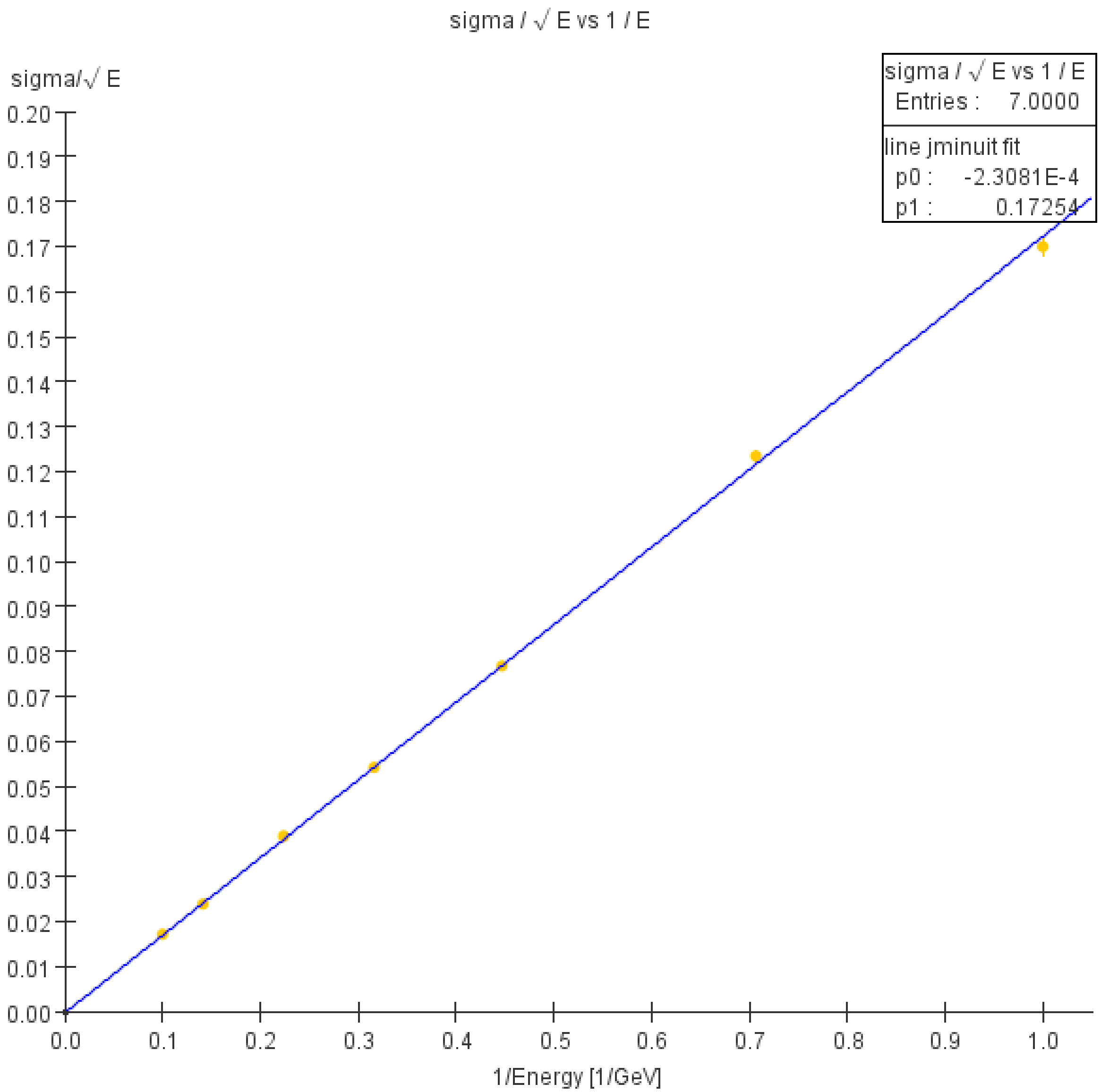
Plots: acme0605_30layerecal Raw



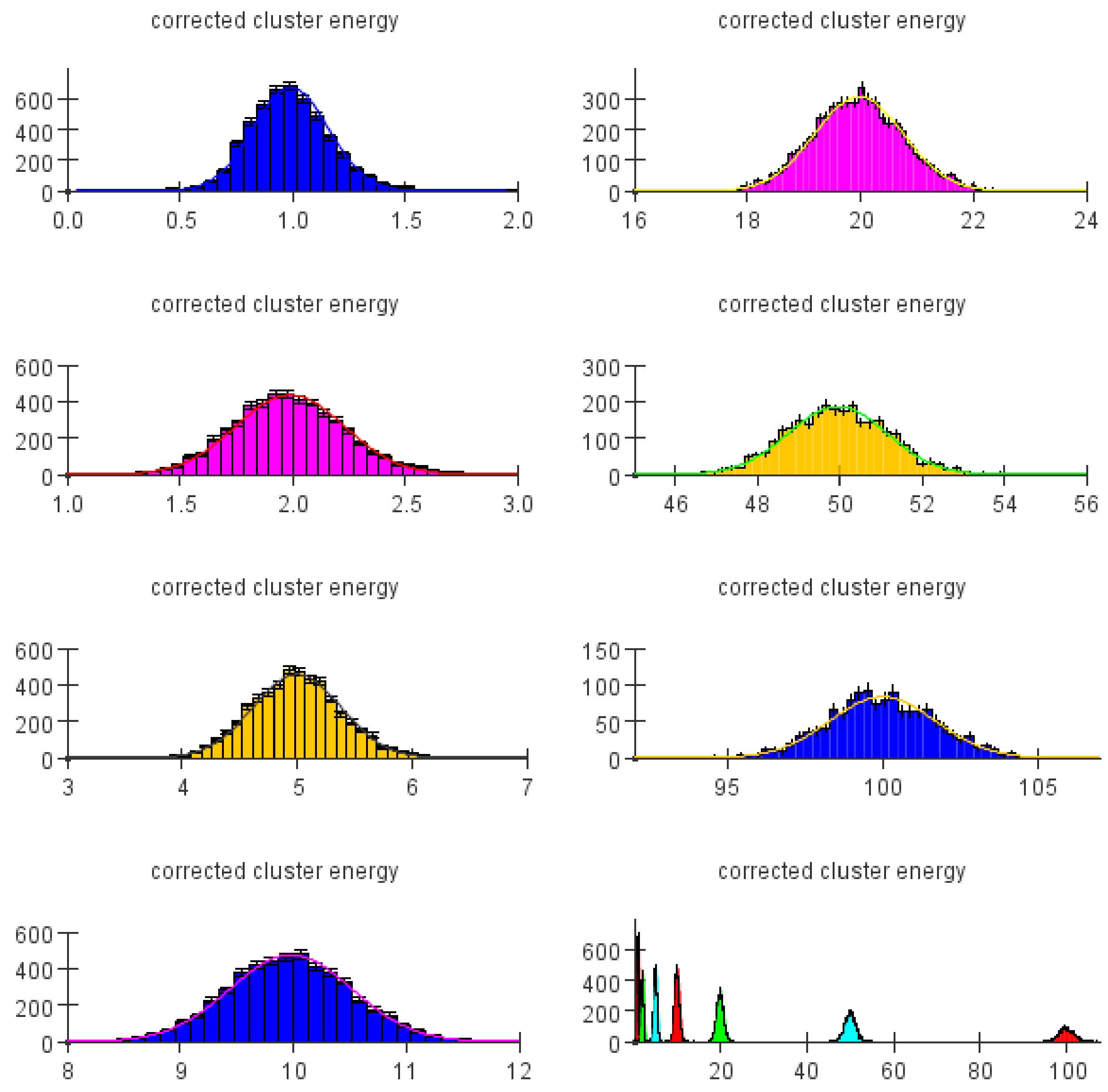
Plots: acme0605_30layerecal Linearity



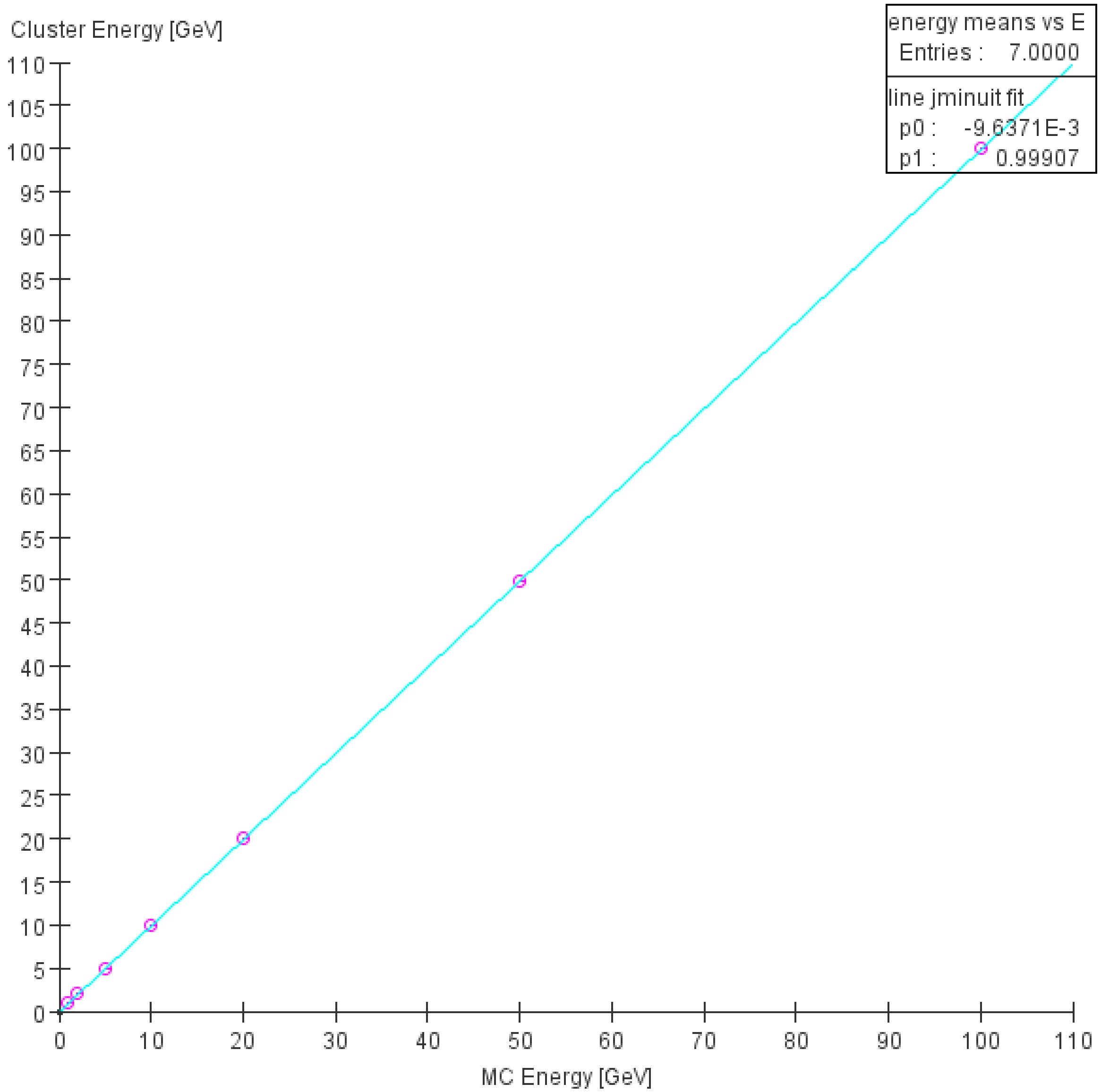
Plots: acme0605_30layerecal Resolution



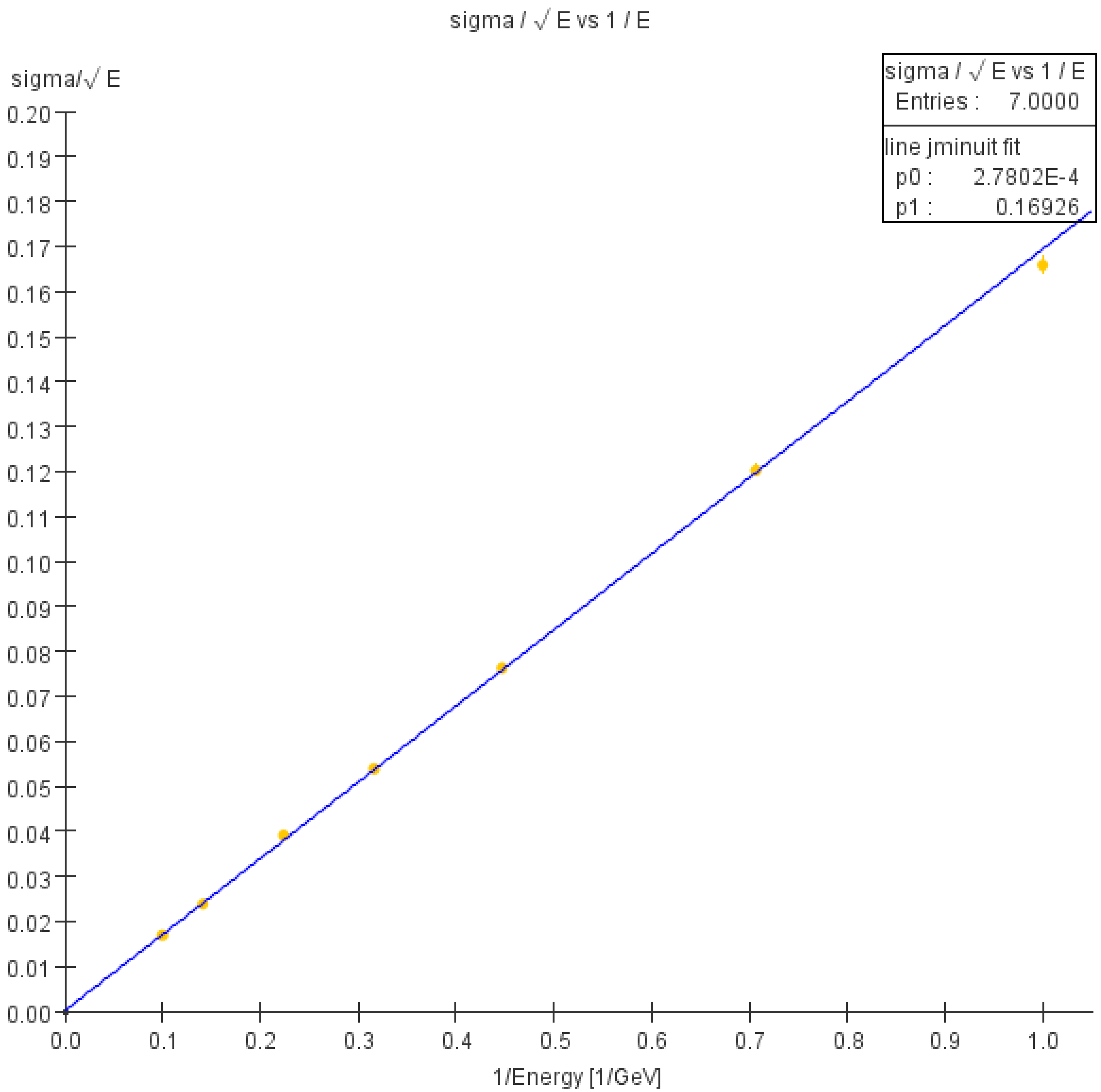
Plots: acme0605_40layerecal Raw



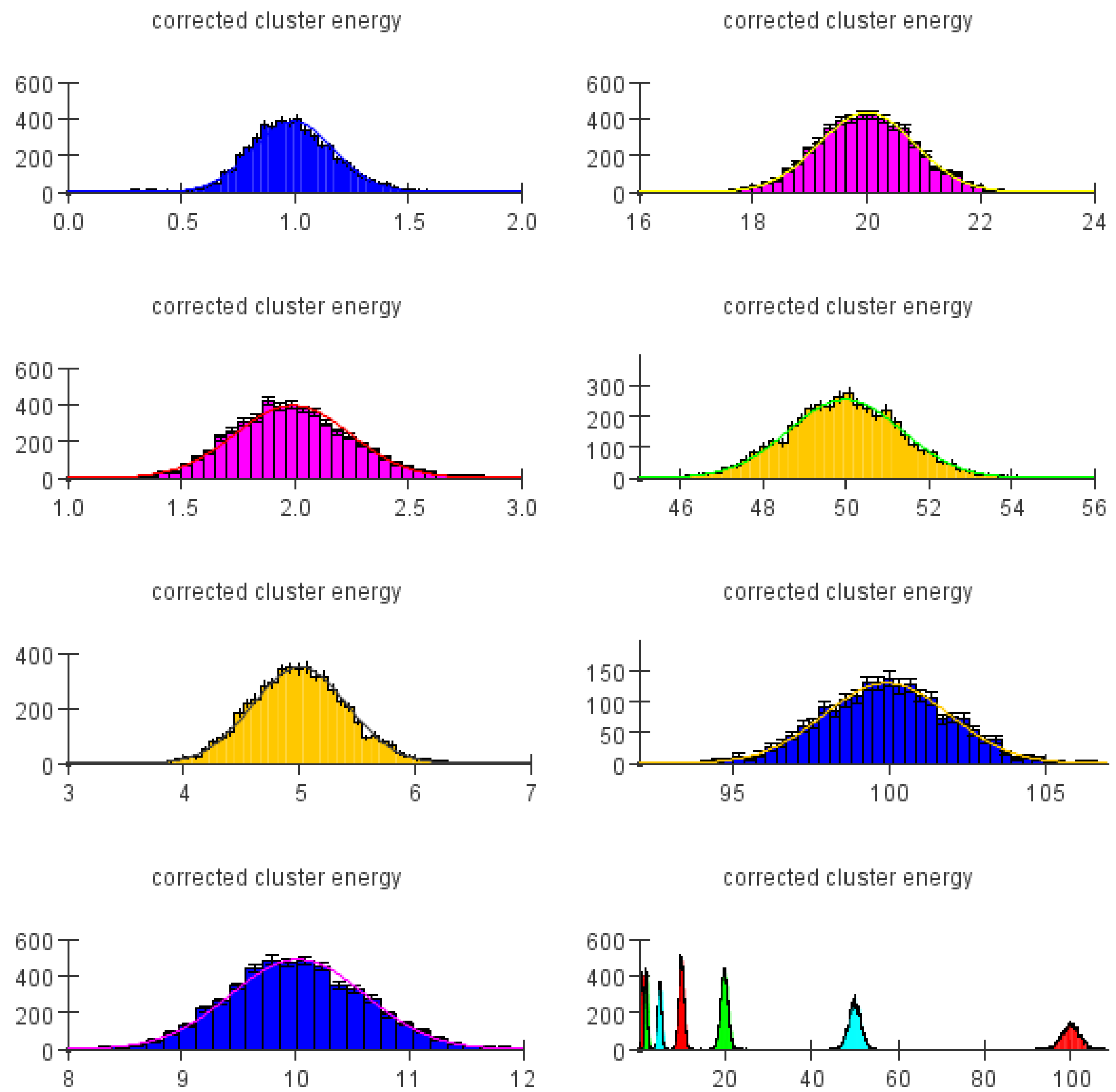
Plots: acme0605_40layerecal Linearity



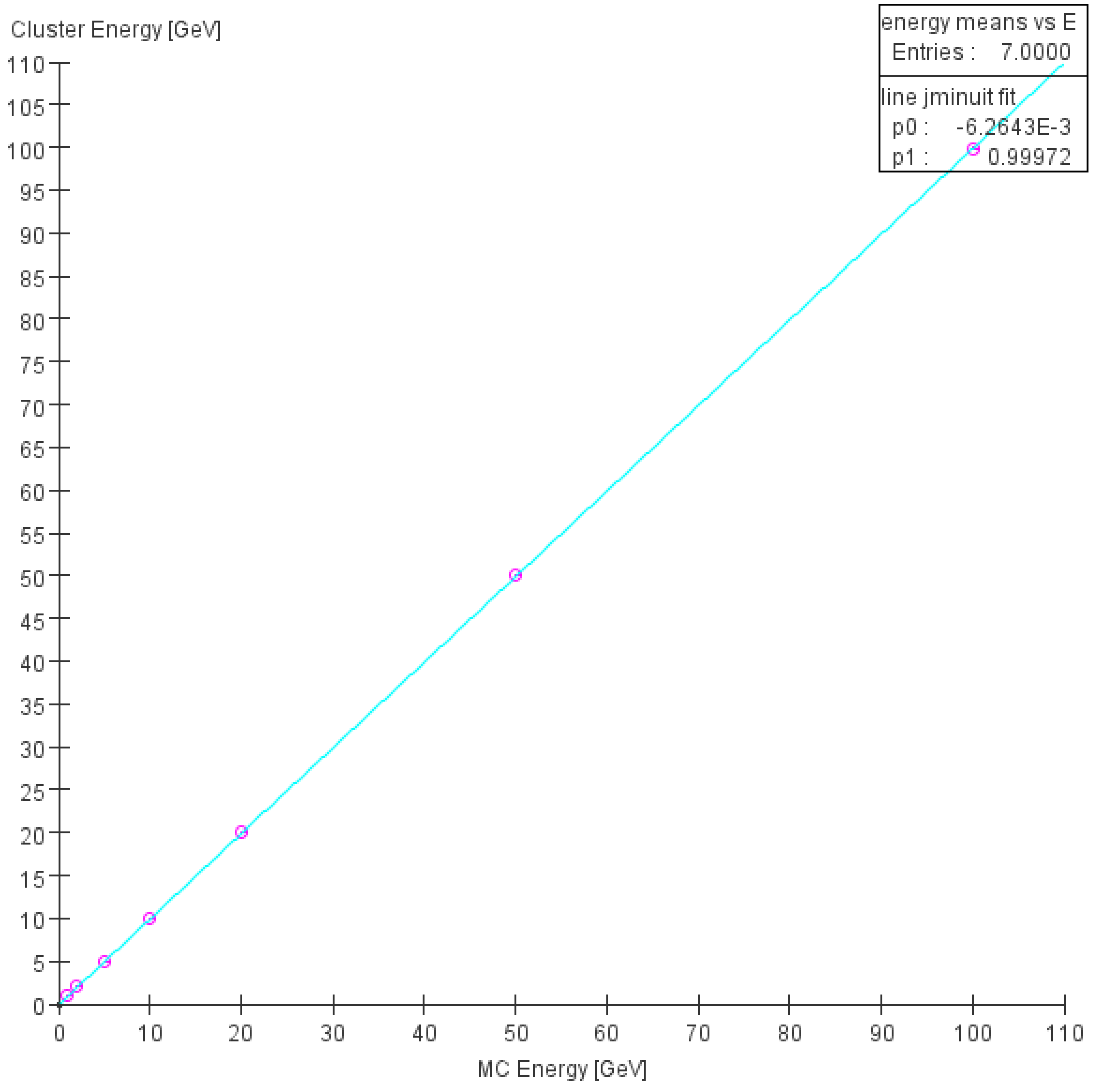
Plots: acme0605_40layerecal Resolution



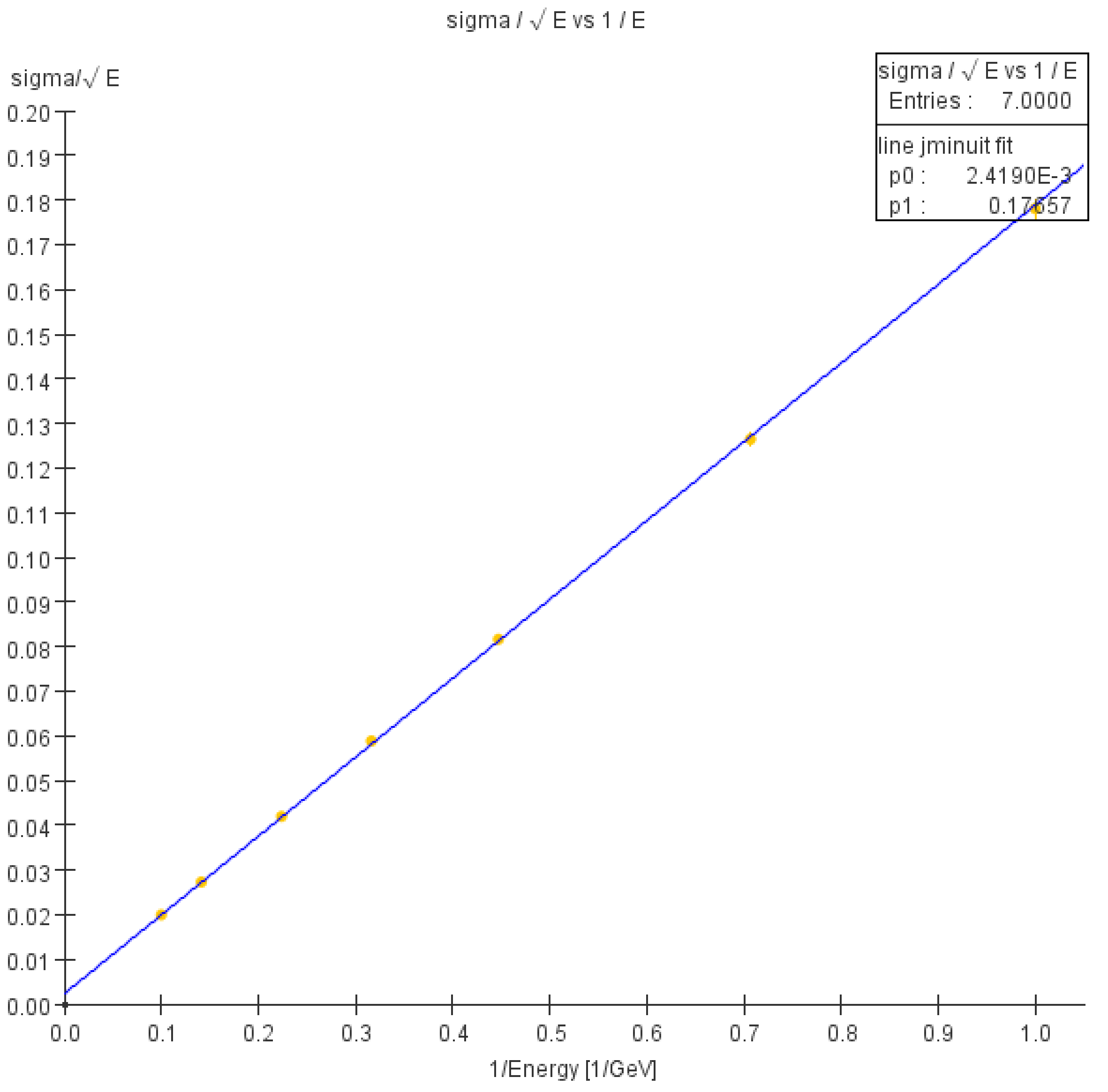
Plots: acme0605_steel_scint Raw



Plots: acme0605_steel_scint Linearity



Plots: acme0605_steel_scint Linearity



Summary

- The tools are available to design a system of calorimeters with good energy resolution and linearity of response to photons.
- A default set of sampling fractions can be determined which gives excellent linearity for photons with energies between 1 and 100 GeV.
- The energy resolution and linearity can be improved by introducing energy-dependent sampling fractions.
  - Physical reason for this is that the electromagnetic shower composition changes as a function of energy and longitudinal depth of the shower.
- The baseline silicon detector calorimeters provide an energy resolution of:

$$\sigma/E \sim 17\%/\sqrt{E} \text{ with} \sim 0 \text{ constant term.}$$