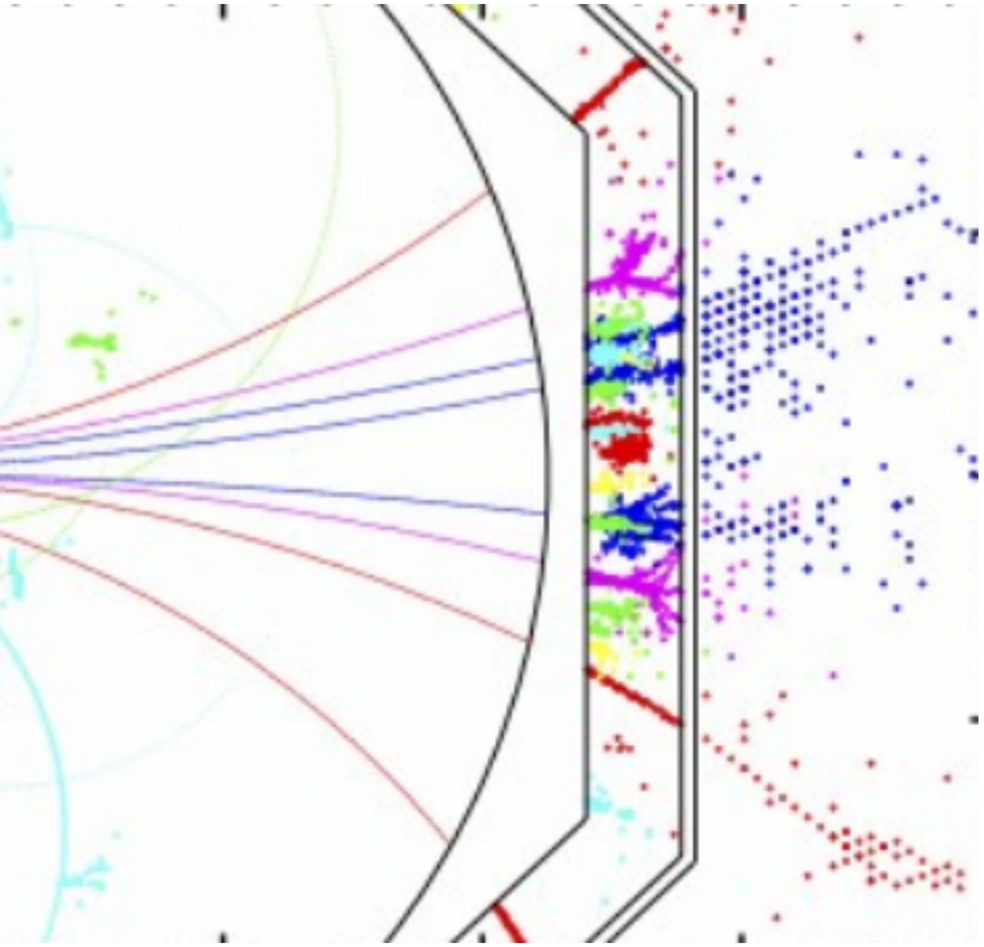
Advanced Techniques in Calorimetry

IMPRS Colloquium - 02.12.16

Christian Graf

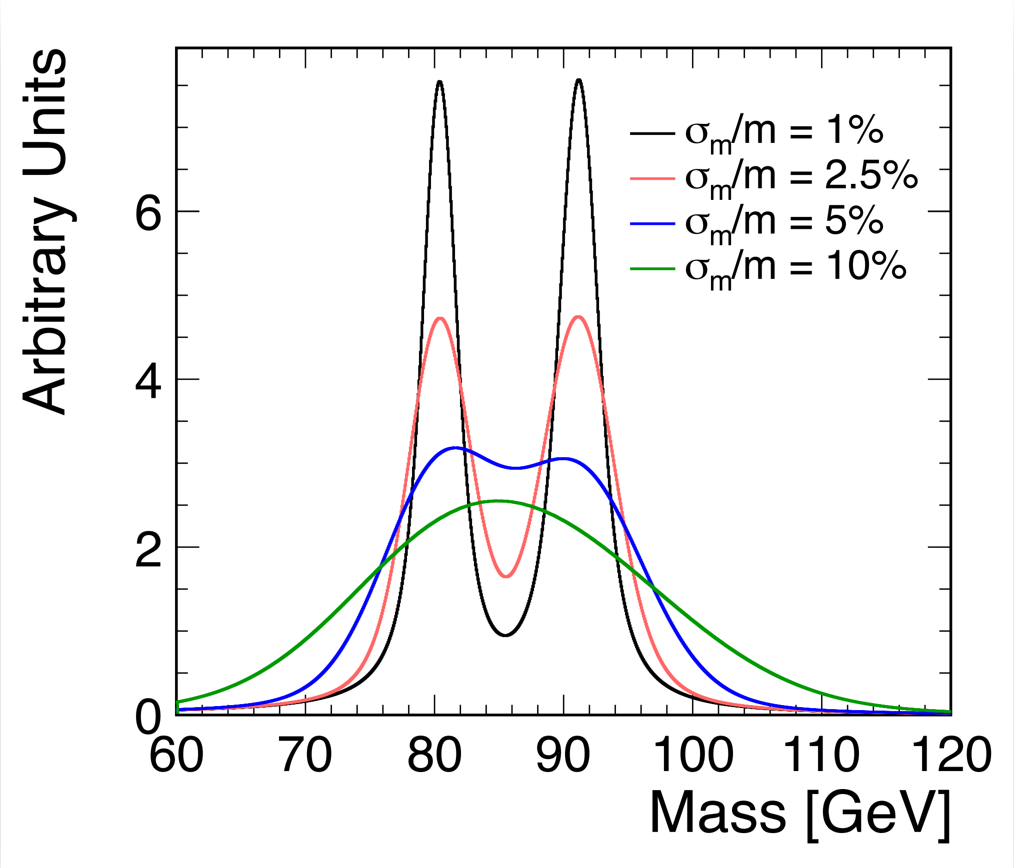
Outline


[M. Thompson]

- Improve jet energy resolution
- Particle Flow Algorithm
- Particle Flow based detector design
- Software Compensation

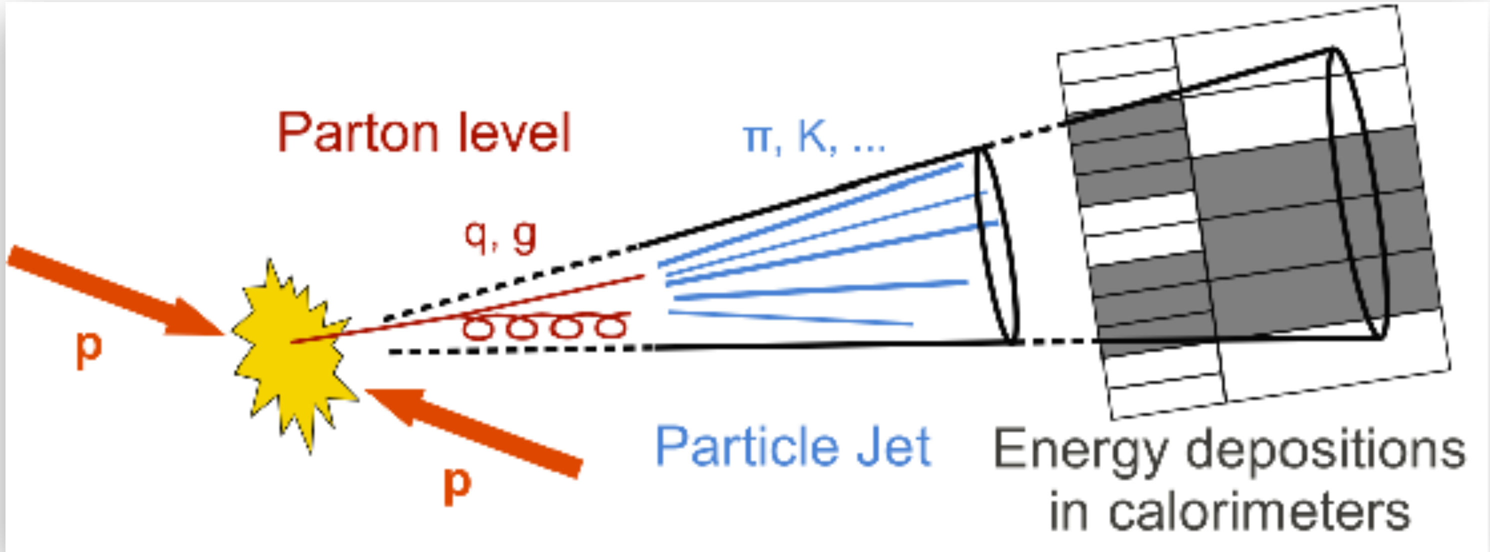
Separate W/Z peak

- Distinguish W -> 2jet and Z -> 2jet
- Important for e.g. Vector boson scattering
- Goal: Jet energy resolution 3.5% at 100GeV

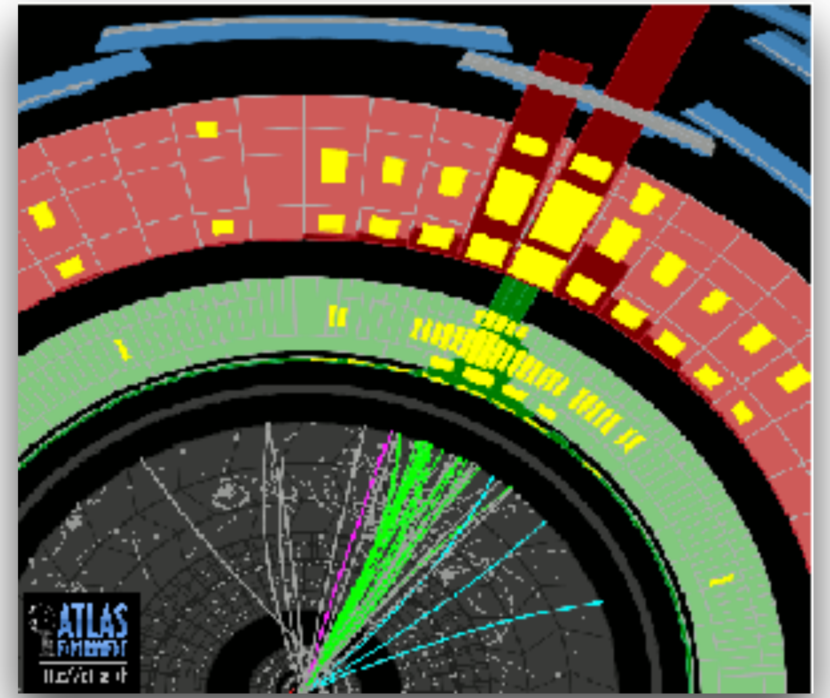


[CLIC - CDR]

Measuring Jet Energies



[CMS]

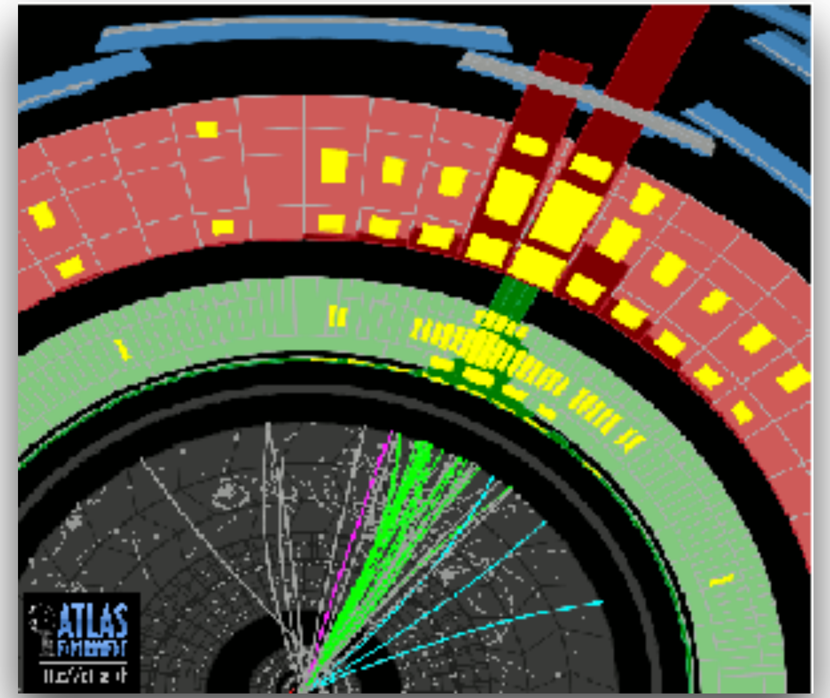


[arXiv:1112.6426]

- Classical approach:
  Add up all energy deposits in the hadronic and electromagnetic calorimeter

Jet Energy Resolution

Detector	Particles	ATLAS	CMS
Tracker	Electrons, Muons, Pions, …	$5*10^{-5}\,p_t$	$5*10^{-4}\,p_t$
Em Cal	Photons, Electrons, Pions, …	$10\% / \sqrt{E} \oplus 1\%$	$3\% / \sqrt{E} \oplus 1\%$
Had Cal	Neutrons, Pions, Kaons, …	$50\% / \sqrt{E} \oplus 3\%$	$100\% / \sqrt{E} \oplus 4\%$



[arXiv:1112.6426]

- Typical jet energy resolution: ~10% at 100GeV
- ~70% hadrons, ~30% electrons / photons

$$E_{\text{jet}} = E_{\text{em}} + E_{\text{had}}$$

$$(\sigma_{\text{jet}})^2 \approx 0.70(\sigma_{\text{Had}})^2 + 0.30(\sigma_{\text{EM}})^2 + (\sigma_{\text{loss}})^2$$

Jet Energy Resolution: How to improve?

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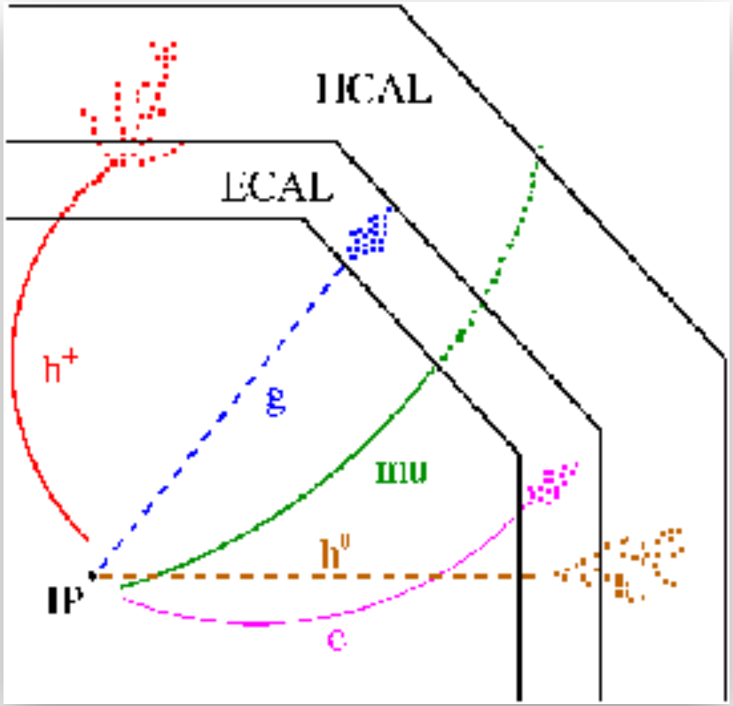

- Content of a „typical“ jet:
  - 62% charged particles
  - 27% photons
  - 10% neutral hadrons
  - 1% neutrinos

$$E_{\text{jet}} = E_{\text{em}} + E_{\text{had}}$$

Particle Flow

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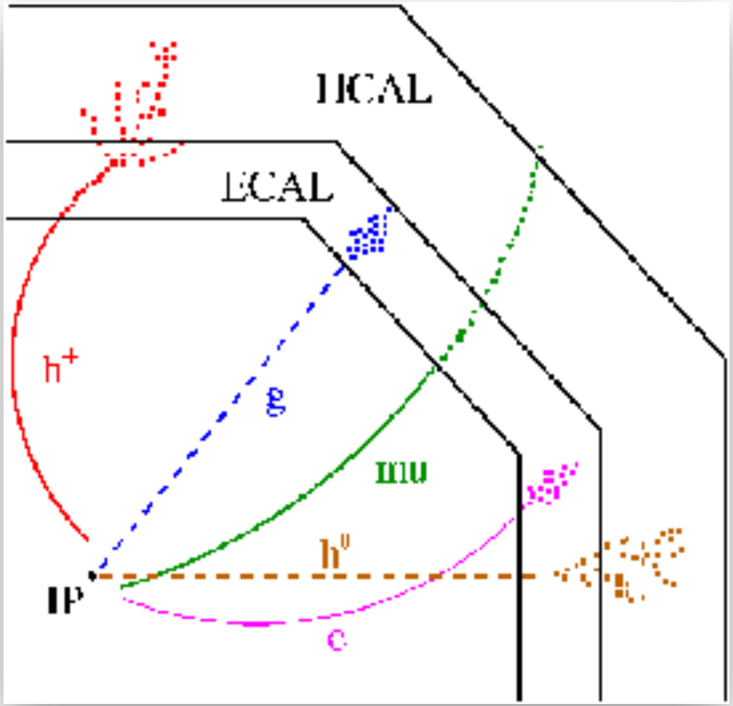
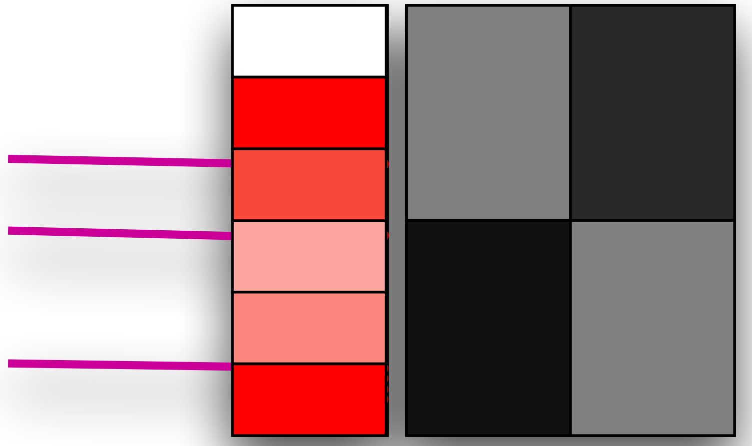


- Content of a „typical“ jet:
  - 62% charged particles —> Tracker
  - 27% photons —> Em Calorimeter
  - 10% neutral hadrons —> Had Calorimeter
  - 1% neutrinos
- Use sub-detector with the best energy resolution!

$$E_{\text{jet}} = E_{\text{em}} + E_{\text{had}} \longrightarrow E_{\text{jet}} = E_{\text{photon}} + E_{\text{n.had}} + E_{\text{tracks}}$$

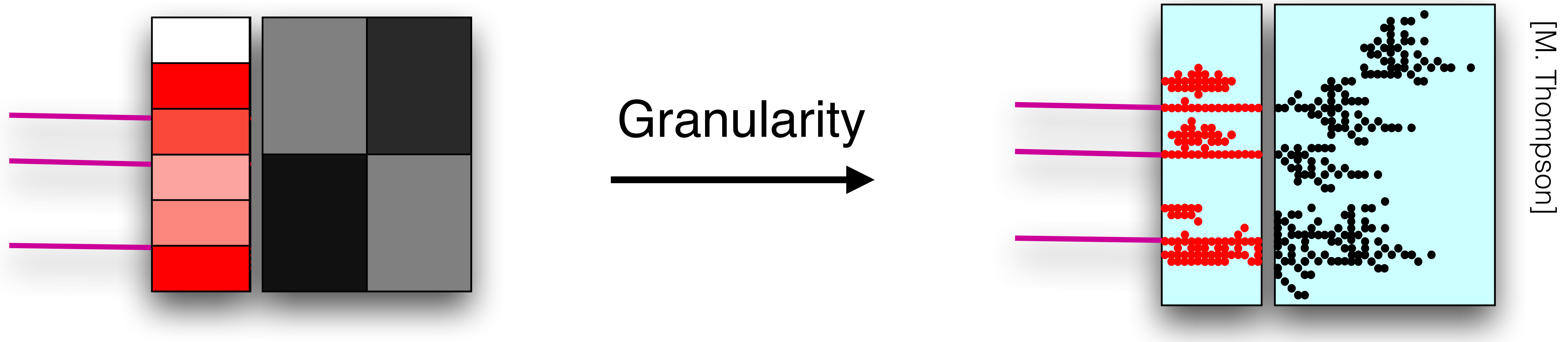
Particle Flow: Requirements



[M. Thompson]

$$E_{\text{jet}} = E_{\text{photon}} + E_{\text{n.had}} + E_{\text{tracks}}$$

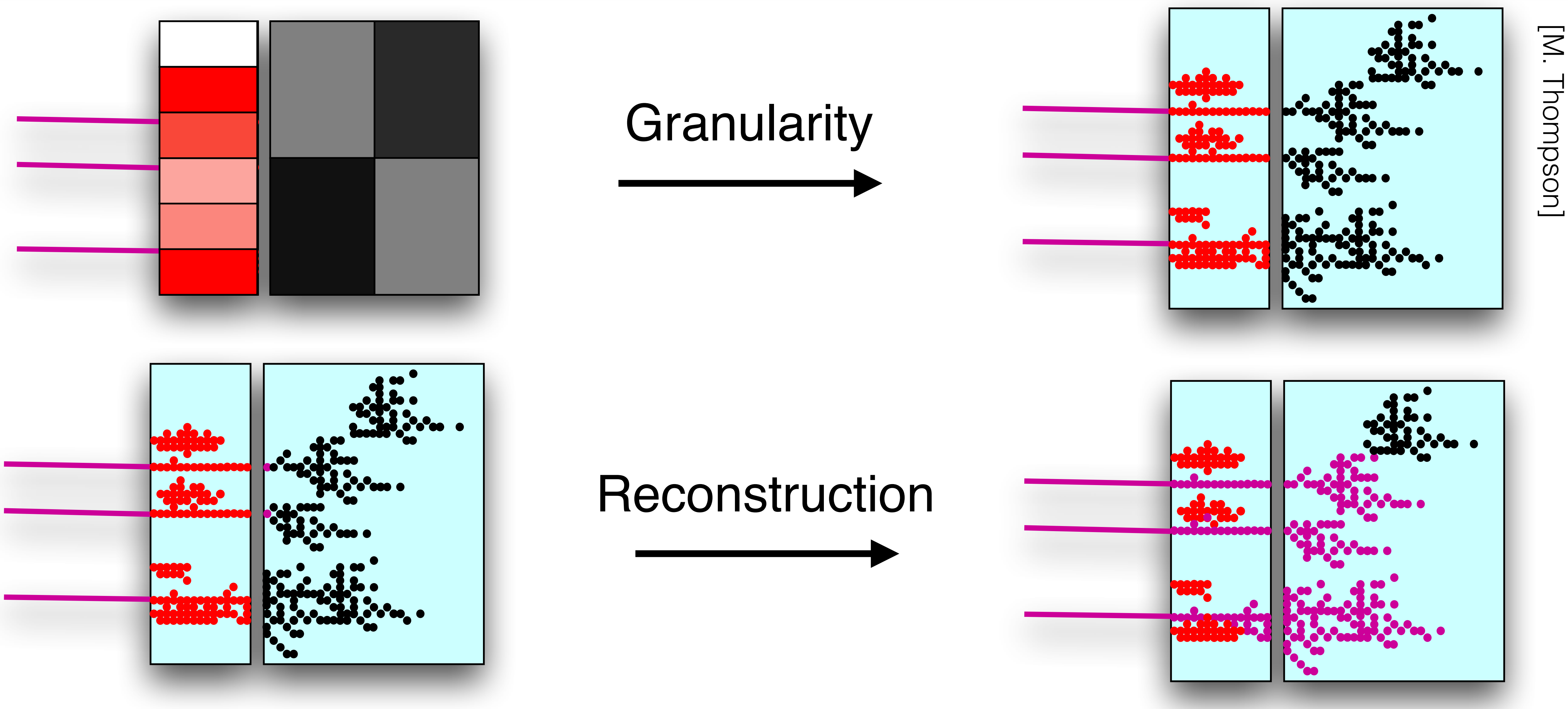
Particle Flow: Requirements



- Granularity is important.

$$E_{\text{jet}} = E_{\text{photon}} + E_{\text{n.had}} + E_{\text{tracks}}$$

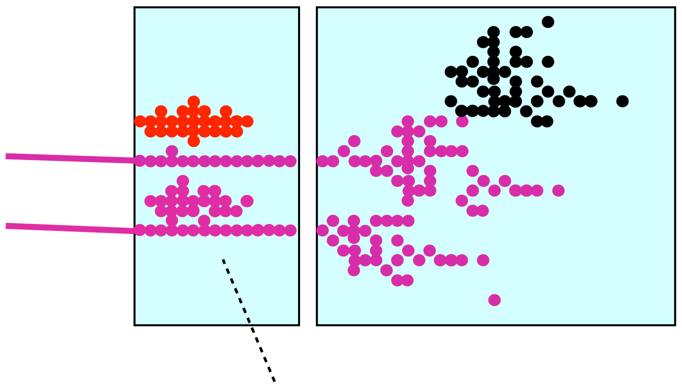
Particle Flow: Requirements



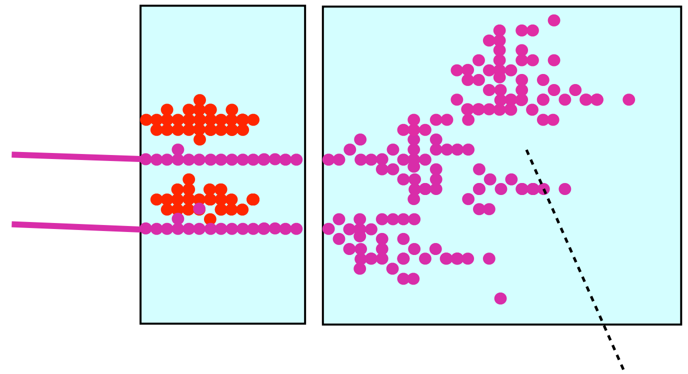
- Granularity is important.
- Problem: Confusion

$$E_{\text{jet}} = E_{\text{photon}} + E_{\text{n.had}} + E_{\text{tracks}}$$

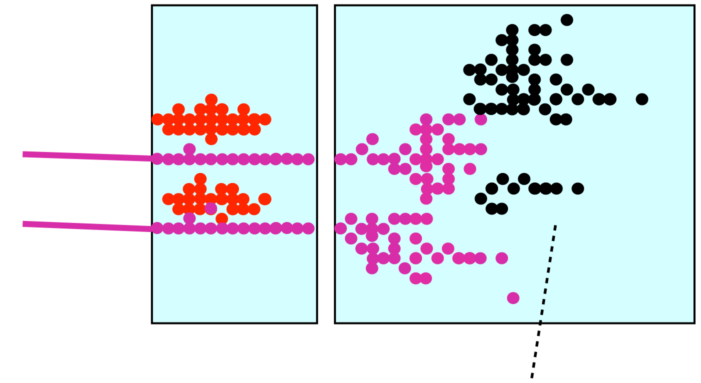
Particle Flow: Confusion



Failure to resolve photons



Failure to resolve neutral hadrons



Reconstruction of extra neutral hadrons

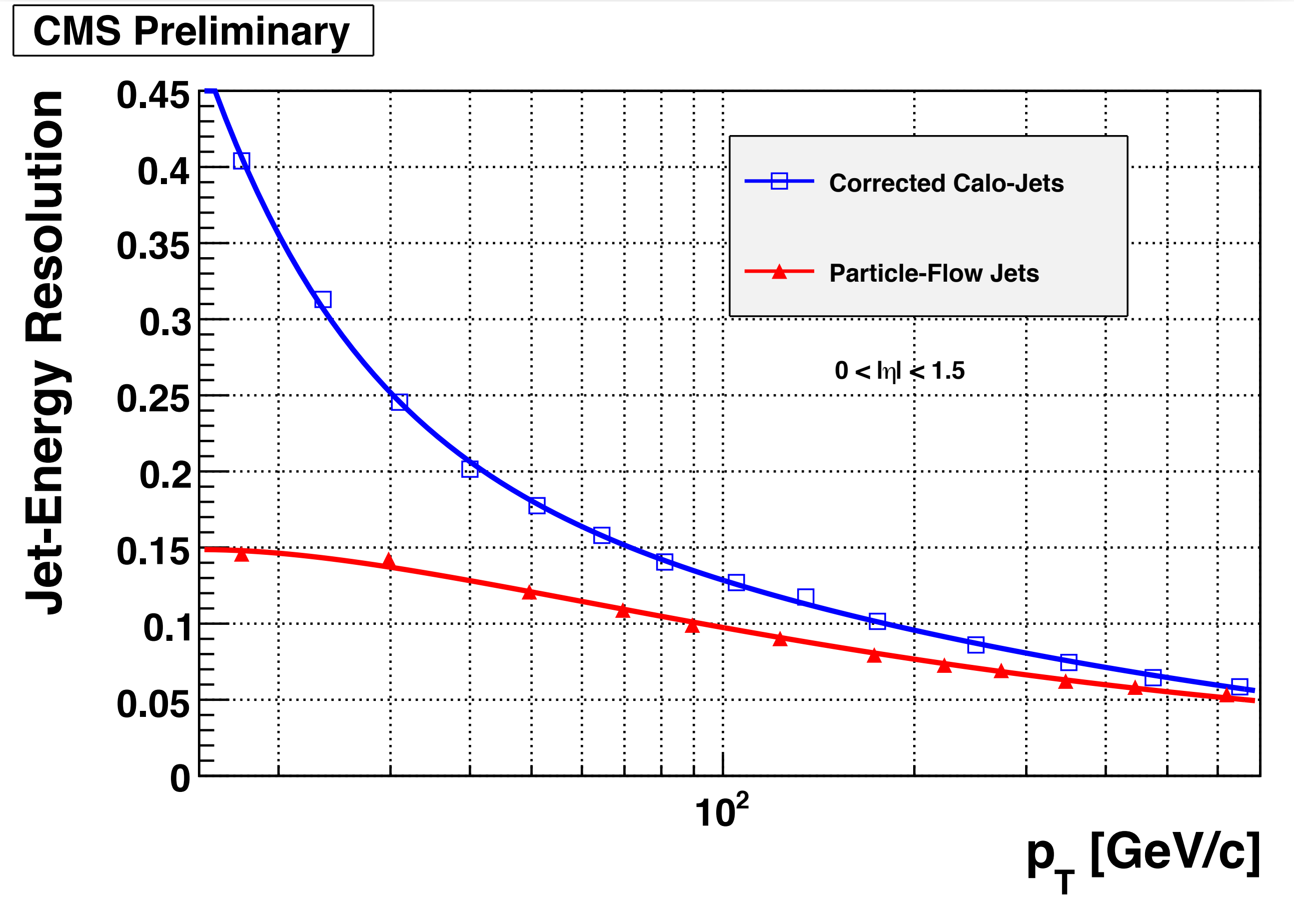
[M. Thompson]

$$(\sigma_{\text{jet}})^2 \approx \underline{0.70(\sigma_{\text{Had}})^2} + 0.30(\sigma_{\text{EM}})^2 + (\sigma_{\text{loss}})^2$$

$$(\sigma_{\text{jet}})^2 \approx \underline{0.62(\sigma_{\text{tracks}})^2} + 0.27(\sigma_{\text{EM}})^2 + 0.10(\sigma_{\text{Had}})^2 + (\sigma_{\text{loss}})^2 + \underline{(\sigma_{\text{confusion}})^2}$$

- Granularity becomes more important than energy resolution

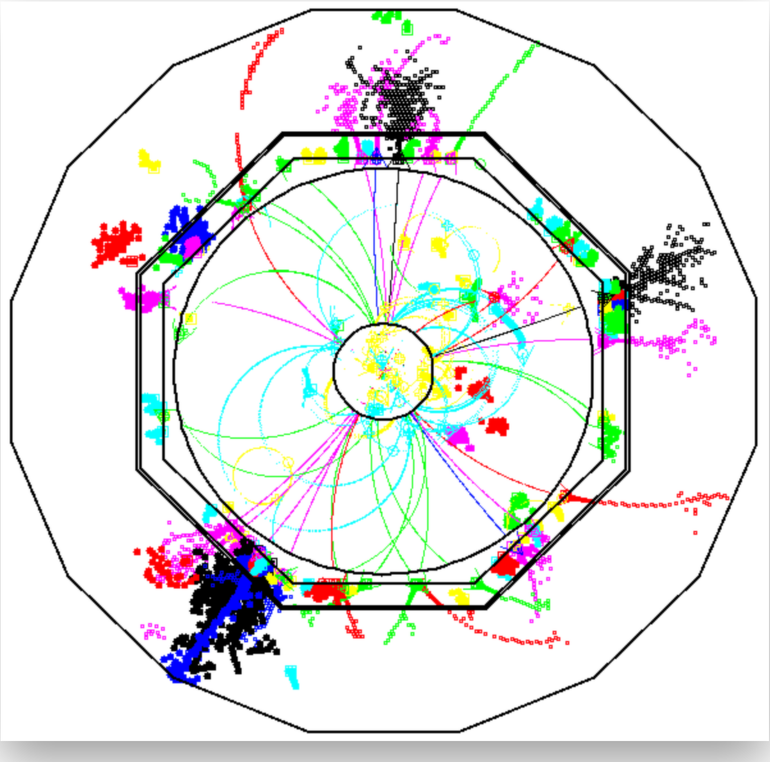
Particle Flow at CMS

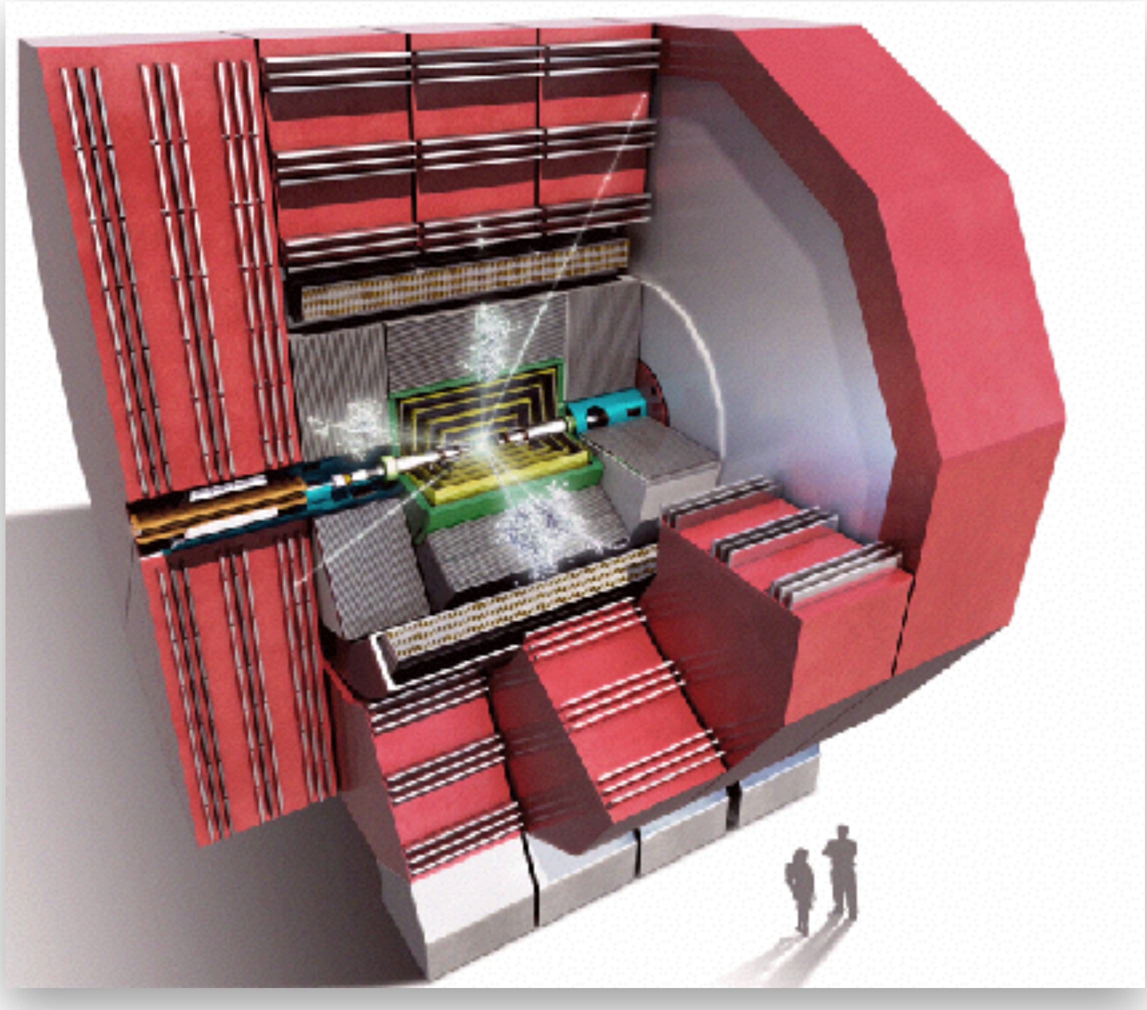


[arXiv:1401.8155]

- Particle Flow is in use in many experiments
- Good improvement in jet energy resolution at CMS
- We still want a better jet energy resolution

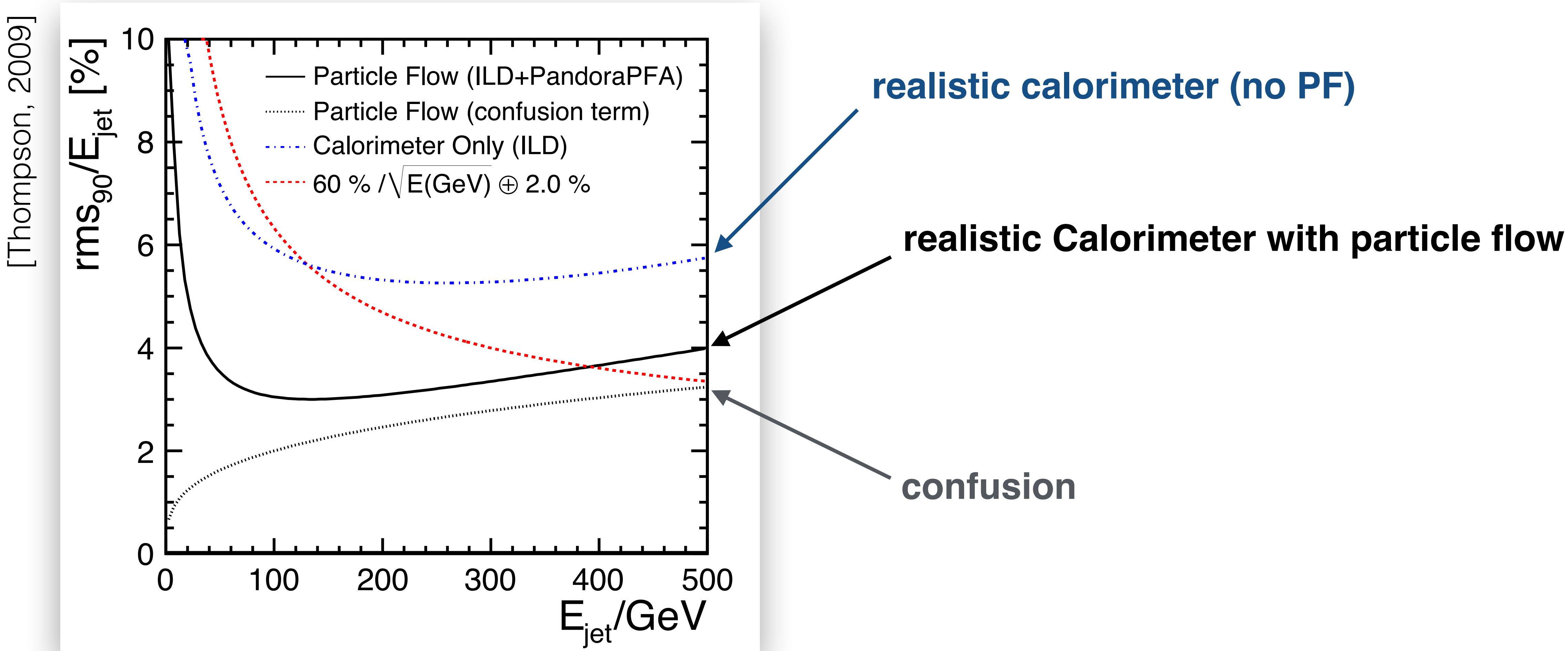
International Large Detector - ILD





- Design a detector that is optimized for particle flow:
- Highly granular calorimeter: ~10M channels
- As little material as possible in front of the calorimeters -> calorimeters inside the magnets
- Large magnetic field to separate charged from neutral particles

ILD Particle Flow Results

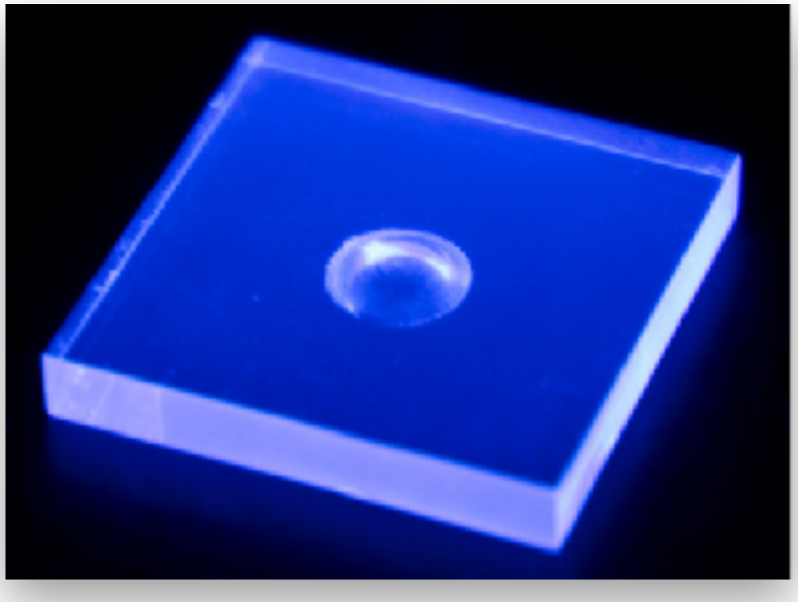


- ~3% Jet energy resolution only possible with particle flow
- confusion term dominates the resolution at higher energies

CALICE Prototypes

- Several options under discussion for building a hadronic calorimeter optimized for particle flow:
  - Digital: resistive plate chambers
  - Semidigital: resistive plate chambers
  - Analog: scintillators + SiPMs

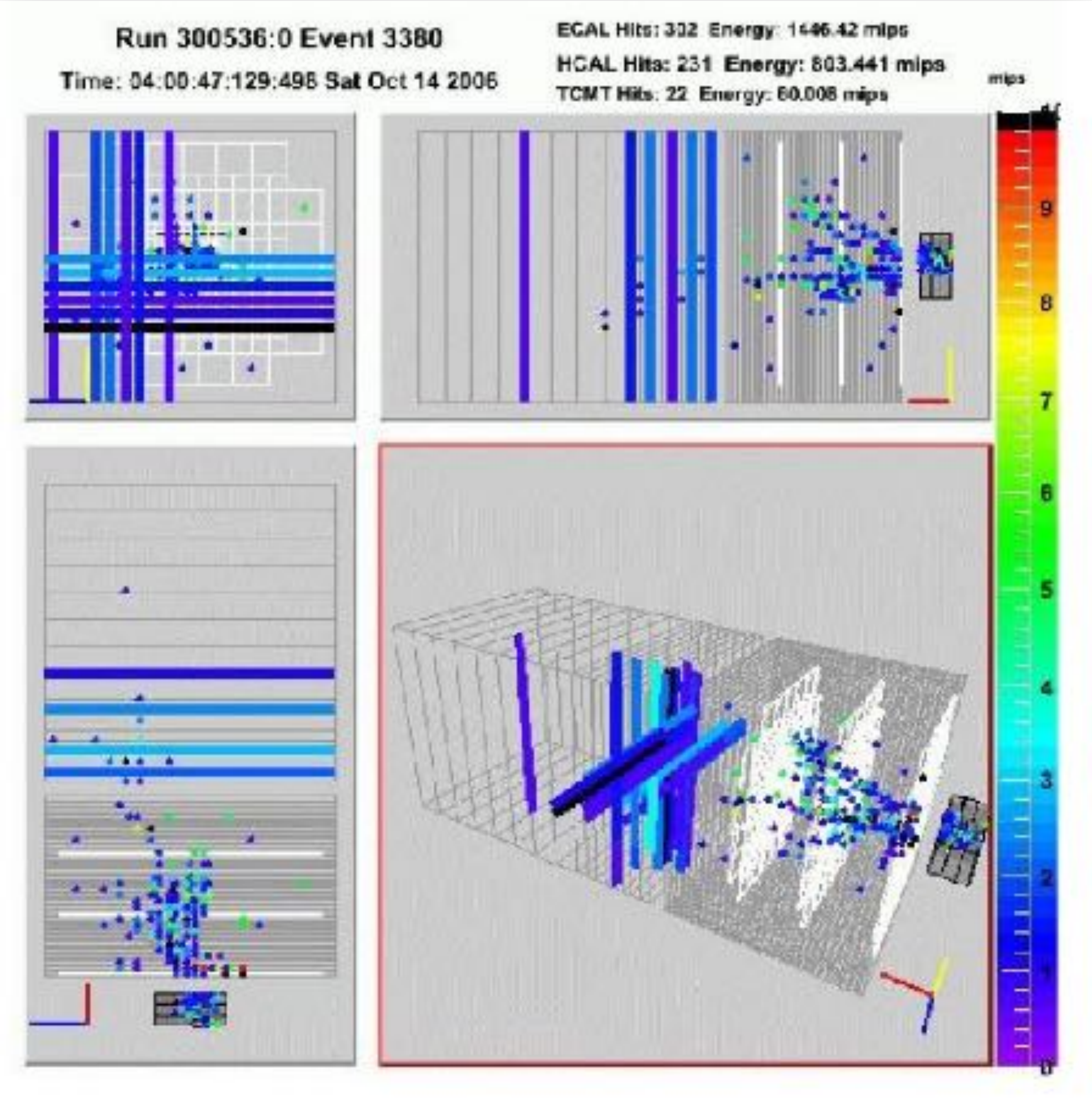
Analog Hadronic Calorimeter



[Hamamatsu]

- Sampling calorimeter based on scintillators and silicon photomultipliers (SiPMs) with steel/tungsten absorber.
- Particles produce light by ionization while traversing a scintillator.
- Produced light is proportional to the deposited energy of the particle
- Silicon photomultipliers transform the light into a measurable signal

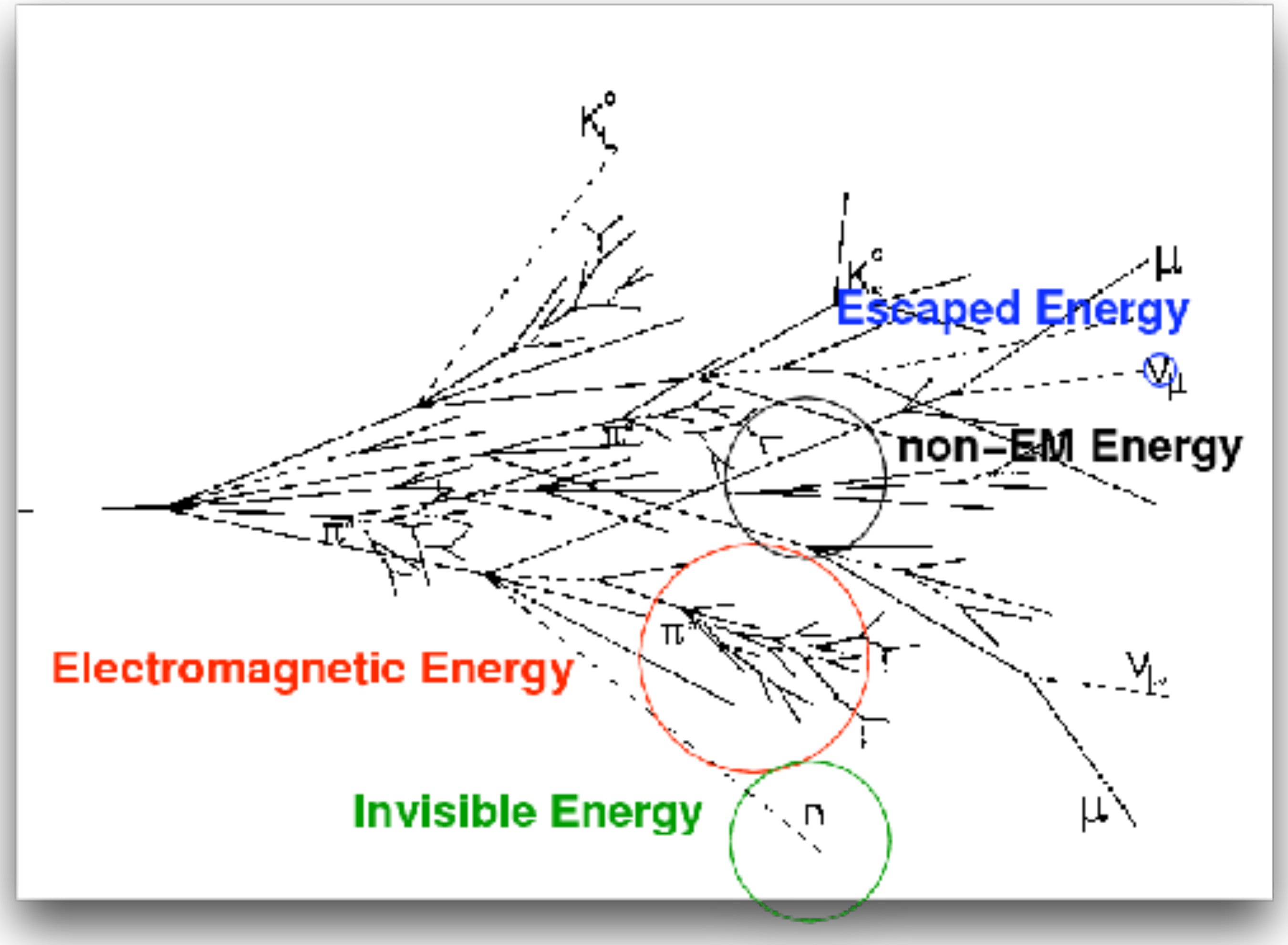
Analog Hadronic Calorimeter: Prototype



- Prototypes tested in various test beam campaigns

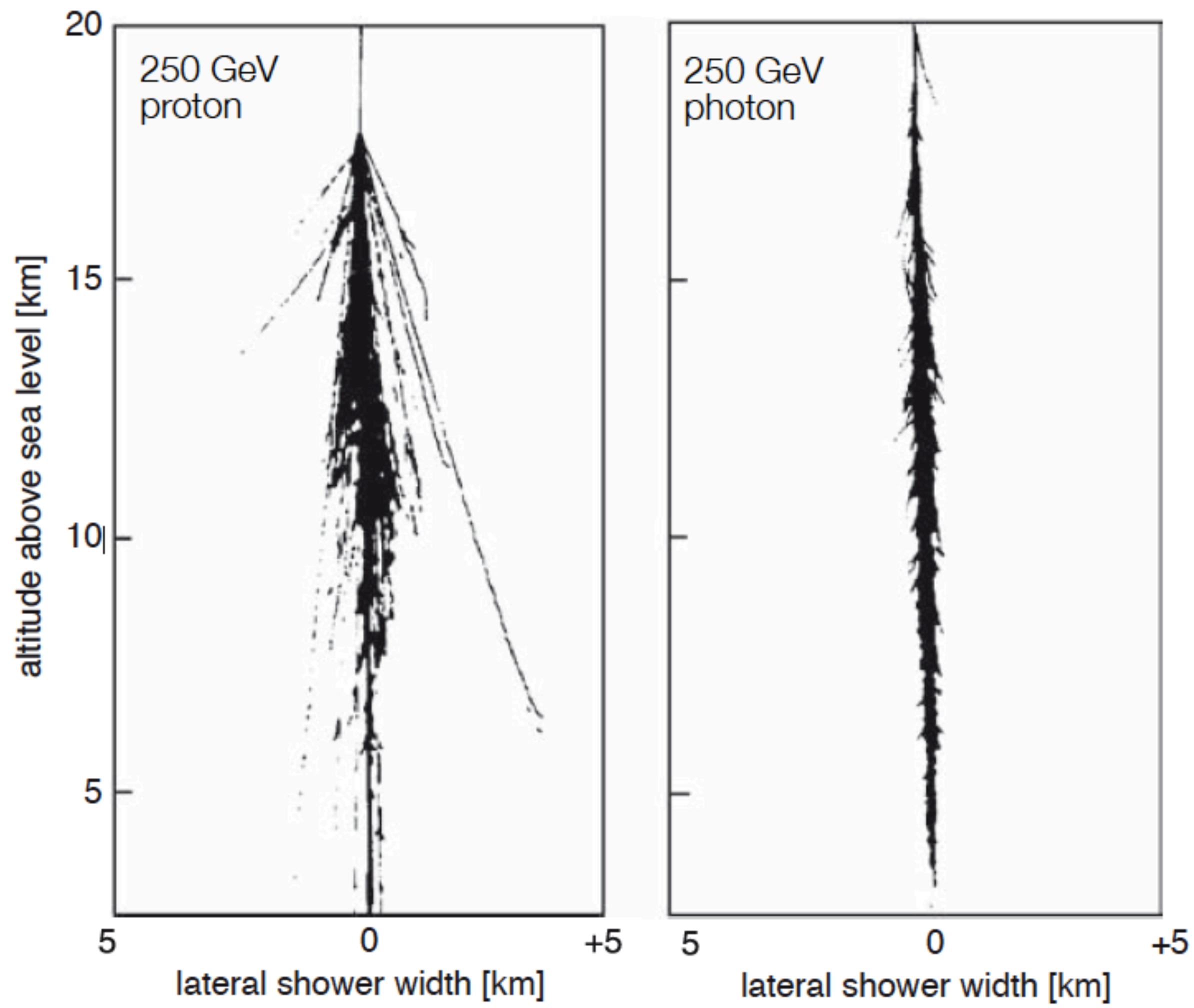
Hadronic Shower

- Different response from electromagnetic and hadronic showers: Fluctuation in fraction of electromagnetic part -> compensation



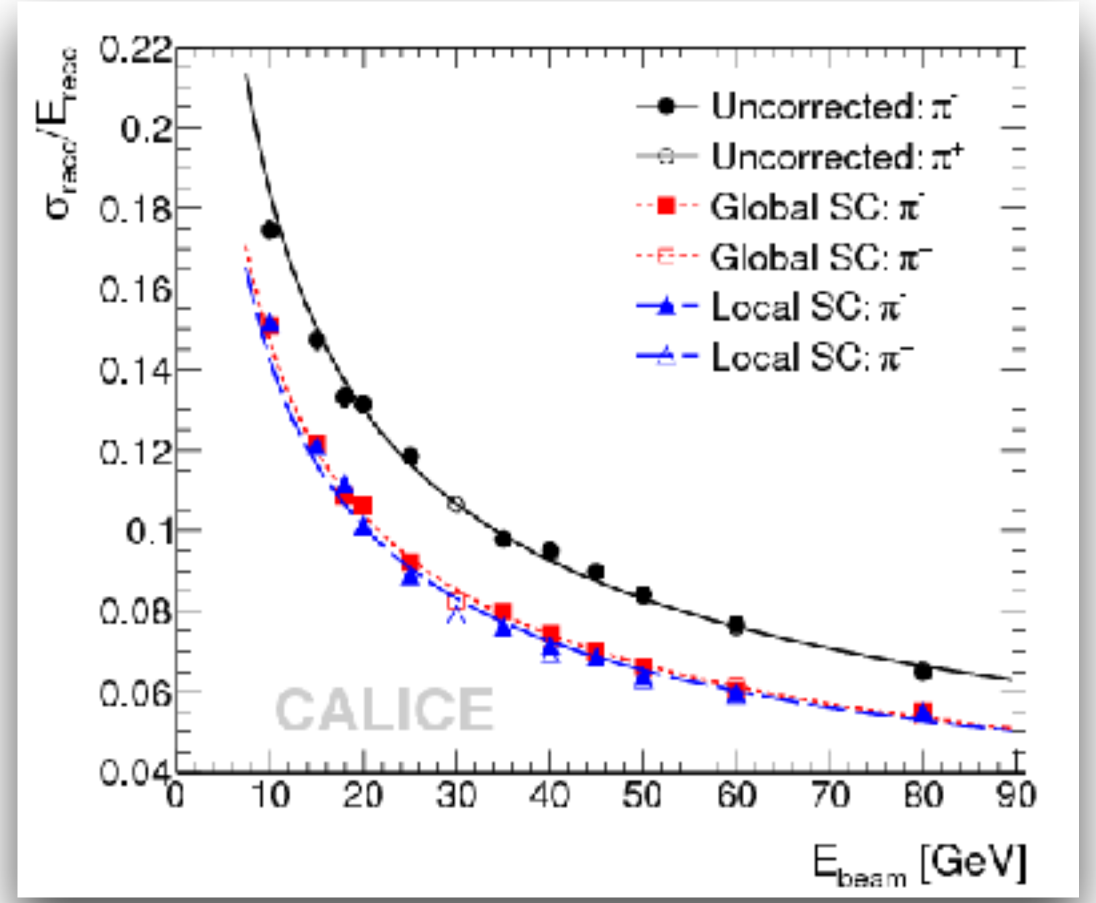
Software Compensation

- Another benefit of a highly granular calorimeter:
  Software compensation
- Calorimeters may be non-compensating: $e/\pi > 1$
- Details of a shower are observable in a highly granular calorimeter
- Em showers are more dense than hadronic showers
- Assign different weights with respect to the shower density



Simulated air showers

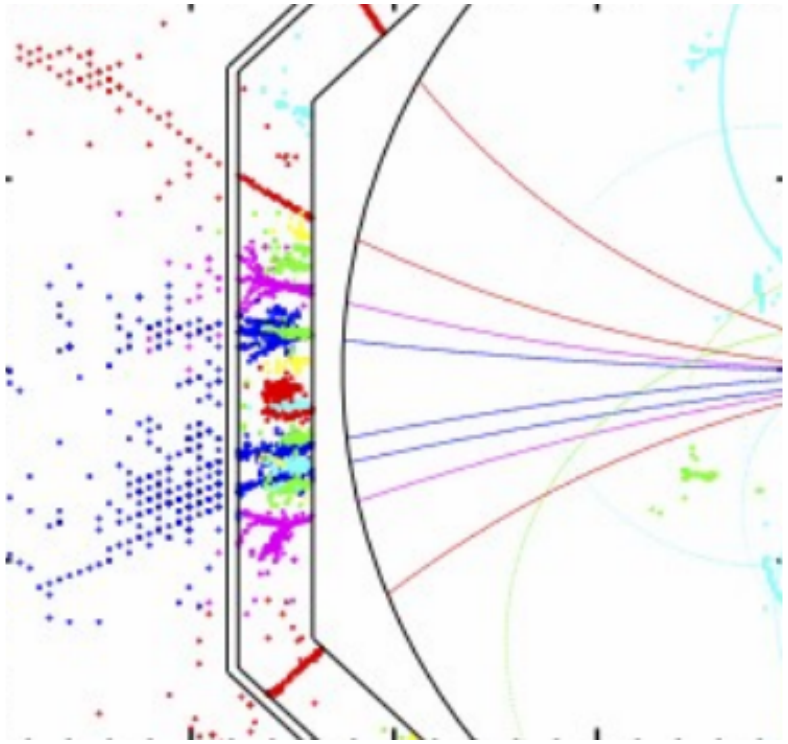
Software Compensation Results



[arXiv:1207.4210]

- Software compensation improves energy resolution!

Conclusion



[M. Thompson]

- Calorimetry moves towards high granularity
- Particle Flow: Use the best detector for each particle
- 3-4% Jet energy resolution achievable -> W/Z separation
- Exploit shower details to further increase energy resolution

The End

Thanks!