Planar Dual Readout Calorimetry Studies : Progress Report

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Outline

- Motivation
- Basic Idea of the Analysis
- Results (Energy Resolution) for various configurations for:
  - Single Pions
  - Jets
- Conclusions/Ongoing Work

Motivation:

- In total absorption calorimeters :

  - For e^+,e^- and γ's the total energy of the incoming particle is converted into detectable kinetic energy of electrons.

  - Hadrons break nuclei and liberate nucleons/nuclear fragments. Even if the kinetic energy of the resulting nucleons is measured, **the significant fraction of energy is lost to overcome the binding energy.** Fluctuations of the number of broken nuclei dominates fluctuations of the observed energy.

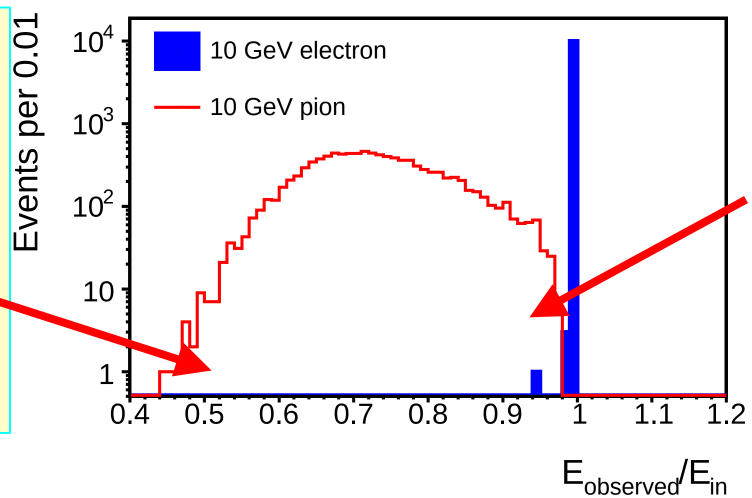
Excellent energy resolution for electrons/photons

Relatively poor energy resolution for hadrons (constant with energy, $e/\pi > 1$)

Large number of broken nuclei:

- Large number of slow neutrons

- Small fraction of energy in a form of π^0's



Very few broken nuclei:

- Small number of slow neutrons

- Large fraction of energy in a form of π^0's

Basic Idea of the Analysis

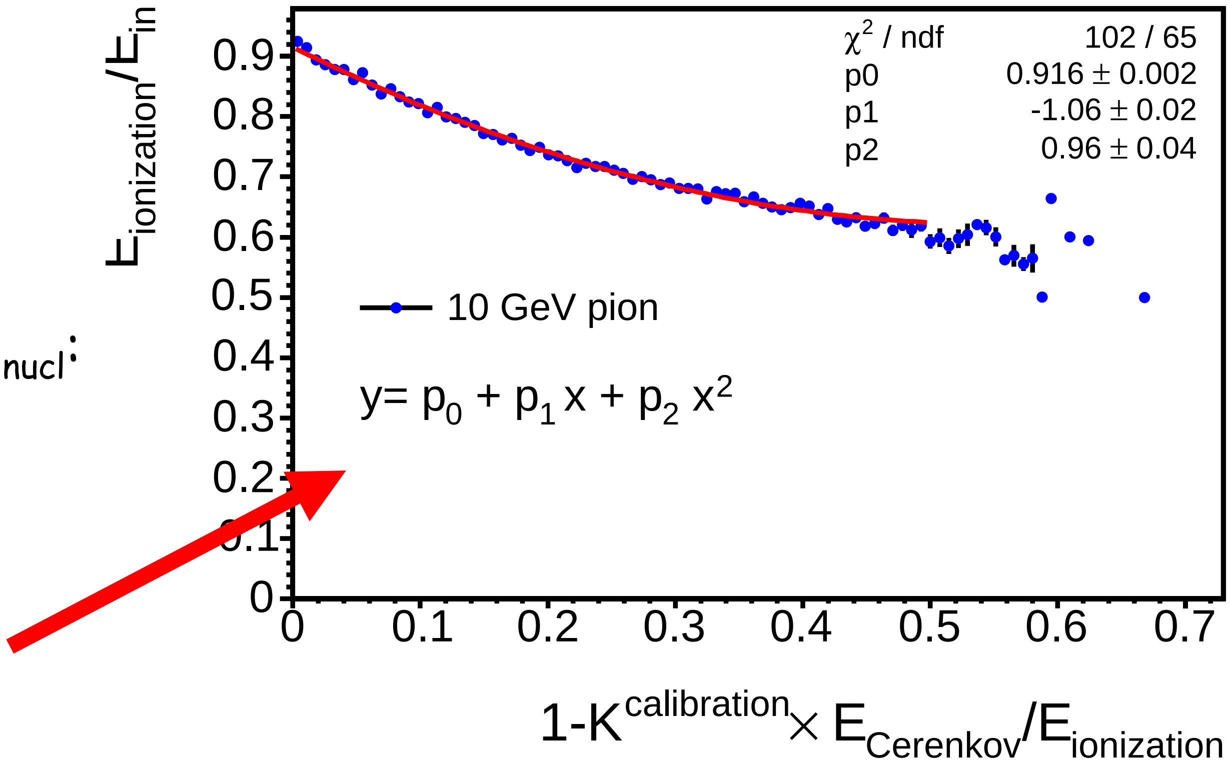
Compensation principle:

$E_{in} = E_{obs} + k*N_{nucl}$

Possible estimators of N_{nucl}:

1) $N_{nucl} \sim N_{slow\ neutrons}$

2) $N_{nucl} \sim (1-E_{em}/E_{tot})$



Cherenkov-assisted hadron calorimetry: $E_{em}/E_{tot} \sim E_{Cerenkov}/E_{ionization}$

-'EM' shower => Relativistic electrons => Large amount of Cerenkov light

- Hadronic shower => Most particles below the Cerenkov threshold

Basic Idea of the Analysis: "Calibration Procedure"

- Calibration using electrons :
  - Using the response of Calorimeter to electrons, we calculate the ratio of the total deposited energy due to ionization E_{ion} to the total deposited energy due to Cherenkov radiation $E_{Cer.}$:

$$K_e = E_{Ion.}/E_{Cer.} \qquad (1)$$

- Calibration using Pions :
  - Then, using the response of Calorimeter to pions we calculate the function " f " such that:

$$E_{Ion}/E_p = f(1 - E_{Cer.} \times K_e/E_{Ion.}) \qquad (2)$$

where E_p is the incident energy of the pion.

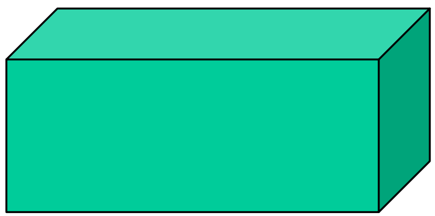
Basic Idea of the Analysis : Final Correction

- After obtaining (from the previous step):
  - $K_e = E_{Ion.} / E_{Cer.}$ **(1)**
  - $E_{ion.}/E_p = f(1 - E_{Cer.} \times K_e/E_{ion.})$ **(2)**
- We calculate the Jet energy, E_P :

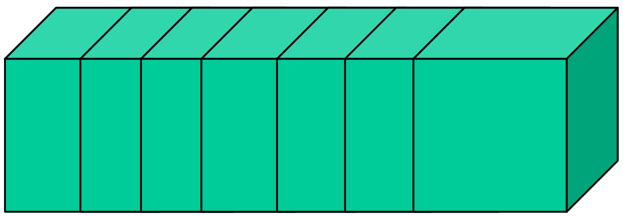
$$E_P = E_{Ion} / f\,(1 - E_{Cer.} \times K_e/E_{Ion}) \qquad \textbf{(3)}$$

Program of Studies (software)

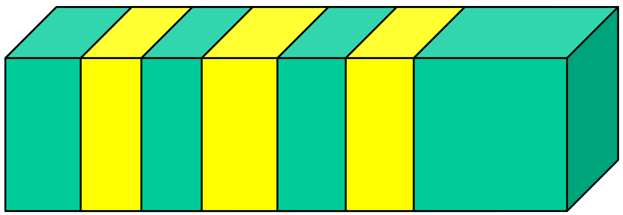
Systematic step-by-step approach



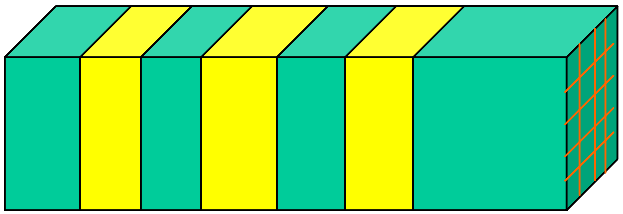
Large homogeneous calorimeter



Longitudinally segmented calorimeter (same material)

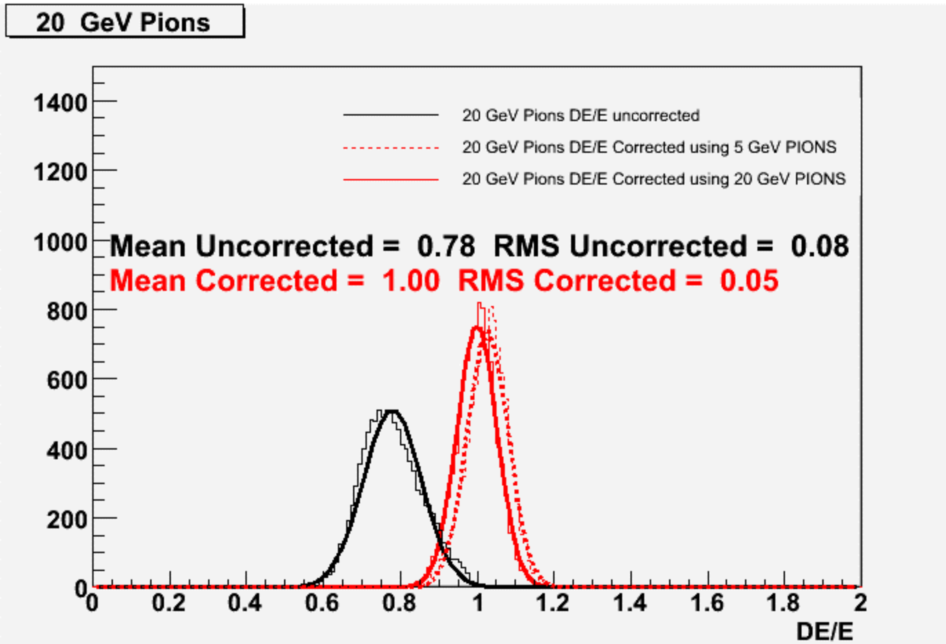


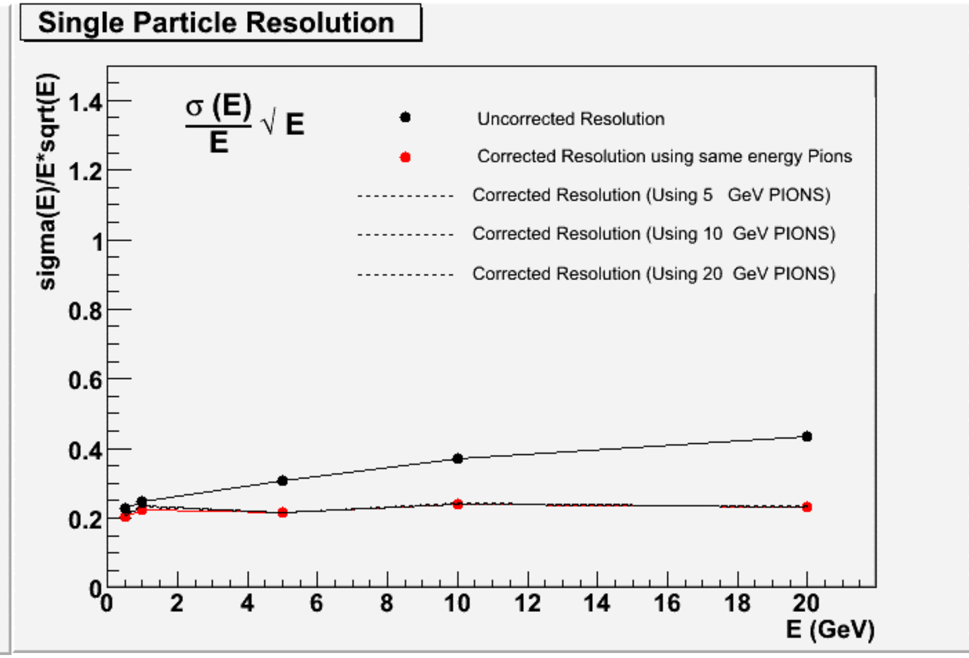
Longitudinally segmented calorimeter (different materials)



Transversely and longitudinally segmented calorimeter (different materials)

Results : Homogenous Detector
Single Particle Case (Proof of Principle)



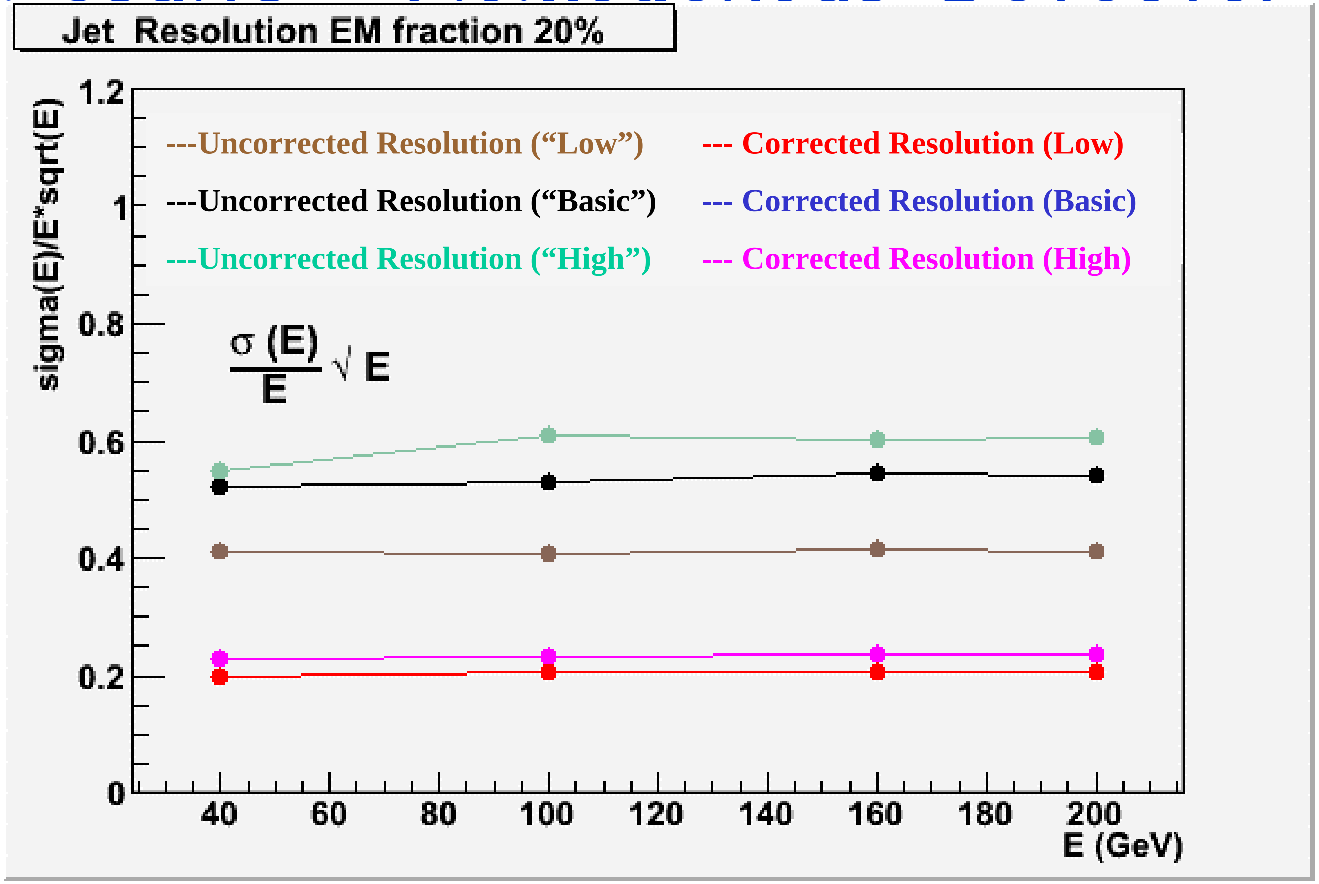


- ✓ Single particle energy resolution $\Delta E/E = 0.25/\sqrt{E}$
- ✓ Scales with energy like $1/\sqrt{E}$ (no constant term)
- ✓ Linear response
- ✓ Corrected pion shower energy = pion energy ("e/π"=1)
- ✓ Correction function independent of the actual shower energy

Results : Homogenous Detector and Jets

- Jets are "constructed" by merging the single particles. Various "Jet configurations" studied:
  - Jets composed of only 20 GeV pions ("High" case)
  - Jets composed of ("Basic" case)
    - 52% of 1 GeV pions,
    - 21% of 5 GeV pions,
    - 17% of 10 GeV pions
    - 10% of 20 GeV pions
  - Jets composed of only 5 GeV pions ("Low" case)
  - All of the above assuming an electromagnetic fraction of 0 and also of 0.2 (20%)
- The above "Jets" are used to obtain the energy resolution when the calibration using single particles is applied.

Results : Homogenous Detector and Jets

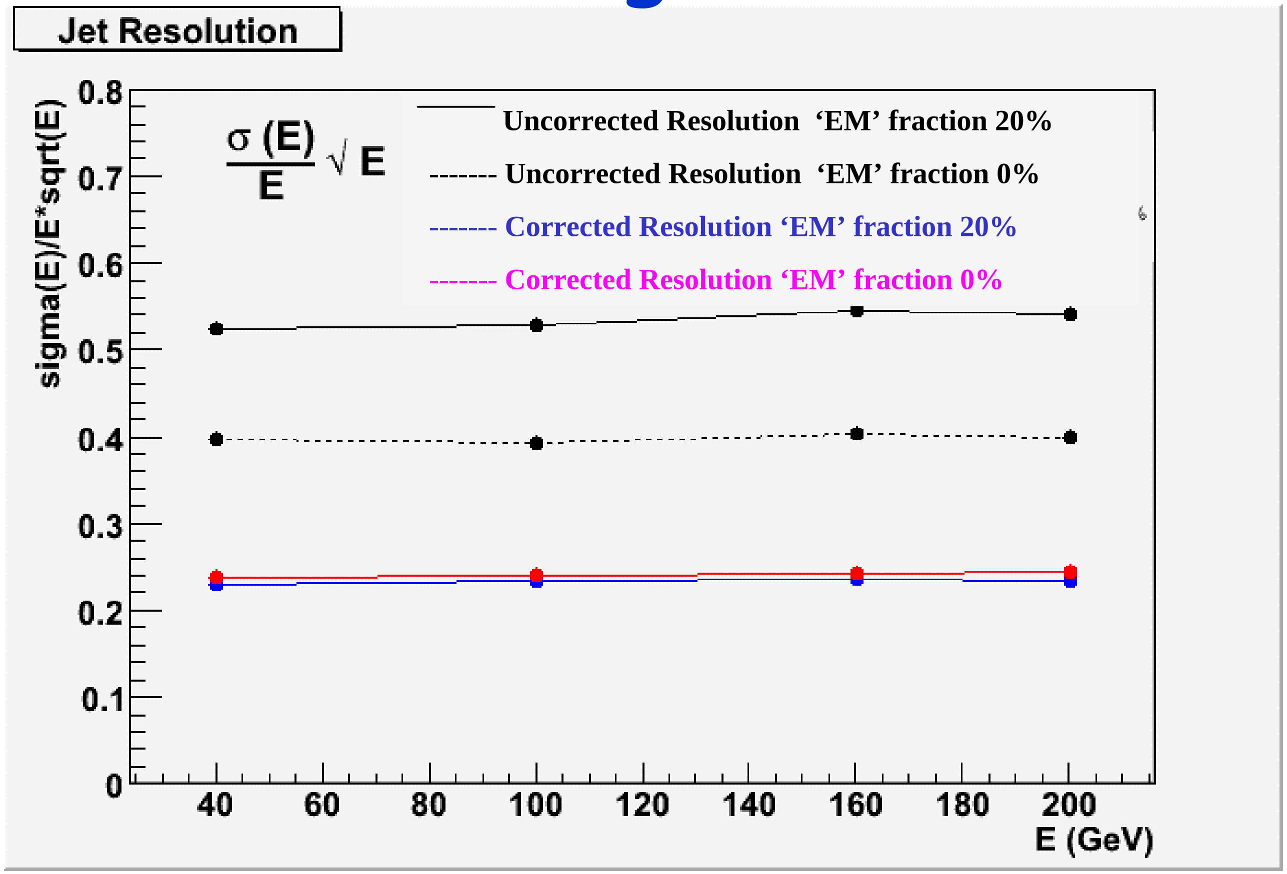


$$\frac{\Delta E}{E} \le \frac{0.25}{\sqrt{E}}$$

Jet fragmentation (in)dependence

- Resolution of Cerenkov-corrected energy measurement is nearly independent of the jet fragmentation
- Resolution (and the response) of the uncorrected energy measurement dependent on the jet composition

Results : Homogenous Detector and Jets



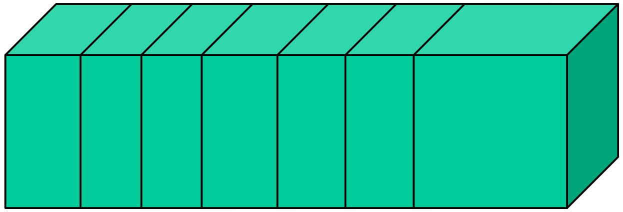
$$\frac{\Delta E}{E} \leq \frac{0.25}{\sqrt{E}}$$

Fluctuations of EM fraction of jets

- Do not contribute to the jet energy resolution for Cherenkov-corrected measurement
- Dominate the jet energy resolution in the uncorrected case

Longitudinally Segmented (Sampling) Calorimeter : Uniform Material

- Uniform medium: no ambiguities in sampling fraction definitions, no particle/energy dependence of sampling fractions.
- Lead glass as a material, 10000 layers 1 mm thick.
- Combinations of layers treated as 'Scintillator', 'Cerenkov' and 'structural' material.



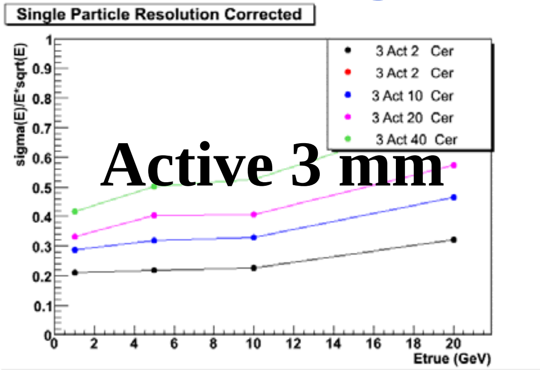
Longitudinally segmented calorimeter (same material)

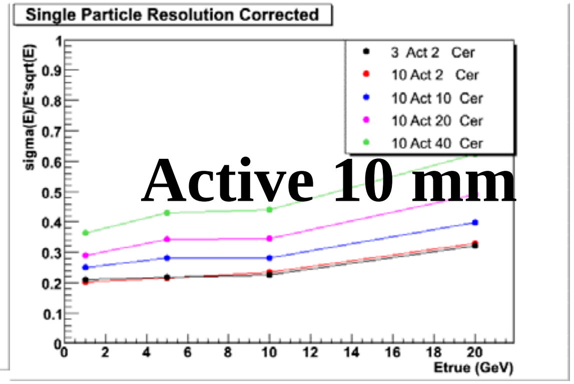
Longitudinally Segmented (Sampling) Calorimeter : Uniform Material cont'd

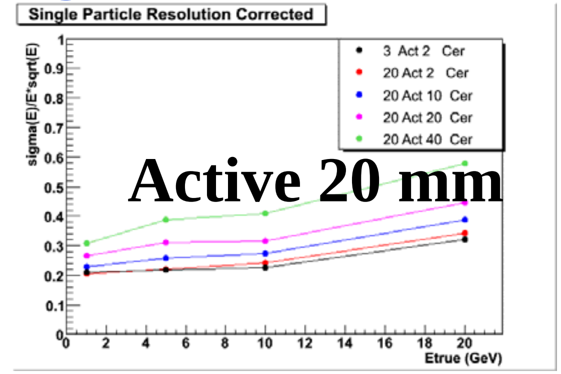
- Study the energy resolution of the segmented calorimeter as a function of :
  - *Sampling fraction and thickness of Active Layers*
  - *Sampling fraction and thickness of Cherenkov layers*

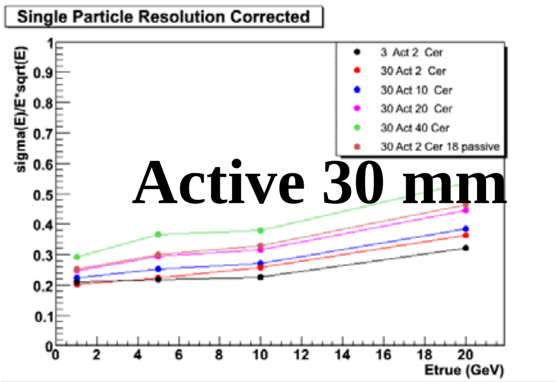
- Various "configurations" are studied (all combinations):
  - ***Active Layer of 3 , 10, 20 , 30 , 40 mm***
  - ***Cerenkov Layer of 2 , 10 , 20 , 40 mm***
  - ***One case of Active Layer 30 mm Cherenkov Layer 2mm Passive Layer 18 mm***

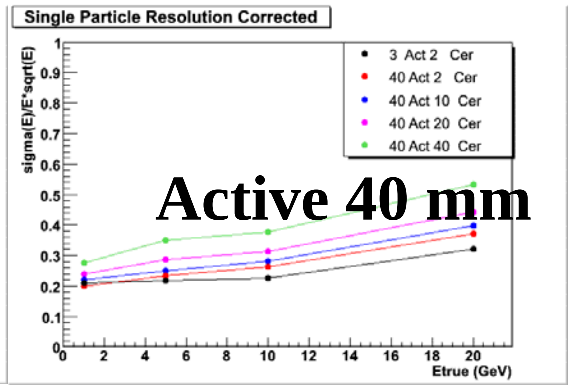
Results:Segmented Detector Single Particles











$$\sigma(E)/E \bullet \sqrt{E} \text{ vs } E$$

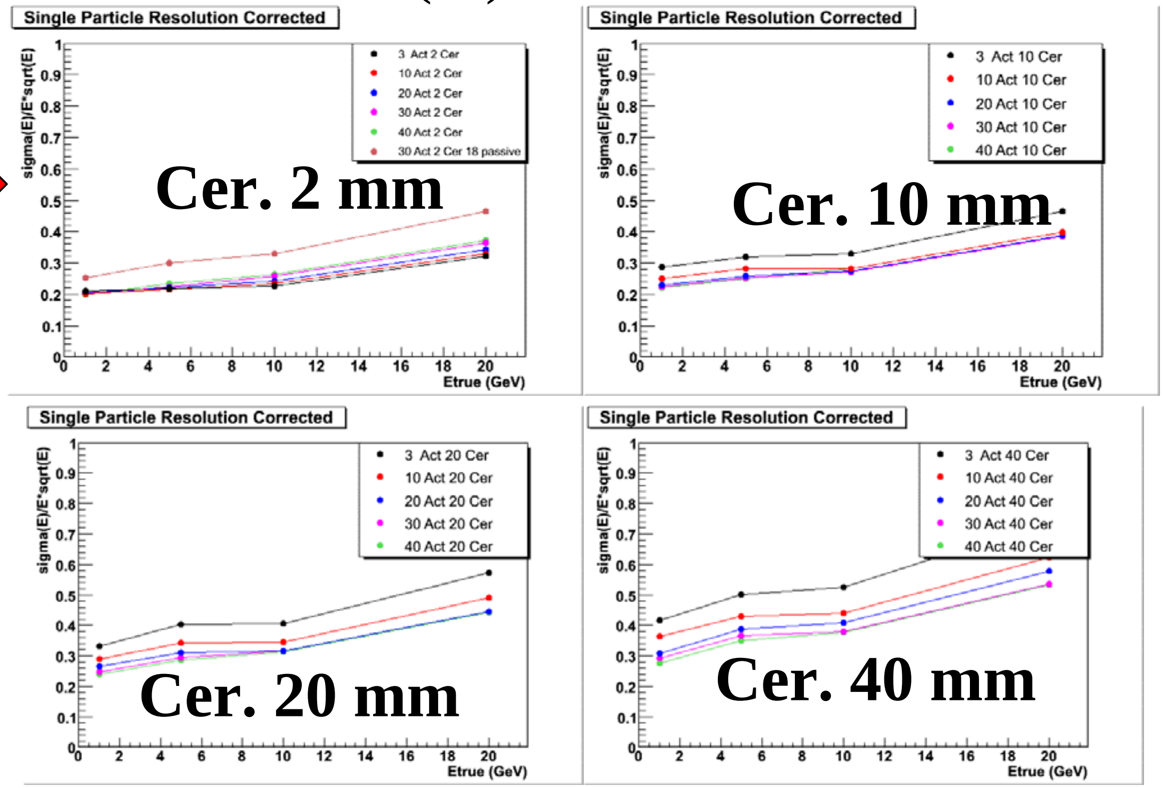
-Energy resolution improves , for all active layer thicknesses, when the Cherenkov layer thickness decreases.

-Energy resolution of the "3mm Active 2 mm Cerenkov" case as good as for a homogenous detector.

-The energy resolution of the "30mm Active 20 mm Cerenkov" case and the "30mm Active 2mm Cerenkov 18mm Passive" case are almost identical = > No additional information in terms of correlations between Cherenkov and Ionization light are contained after ~ the first 2 mm of the Cherenkov Layer.

Results:Segmented Detector Single Particles Cont'd

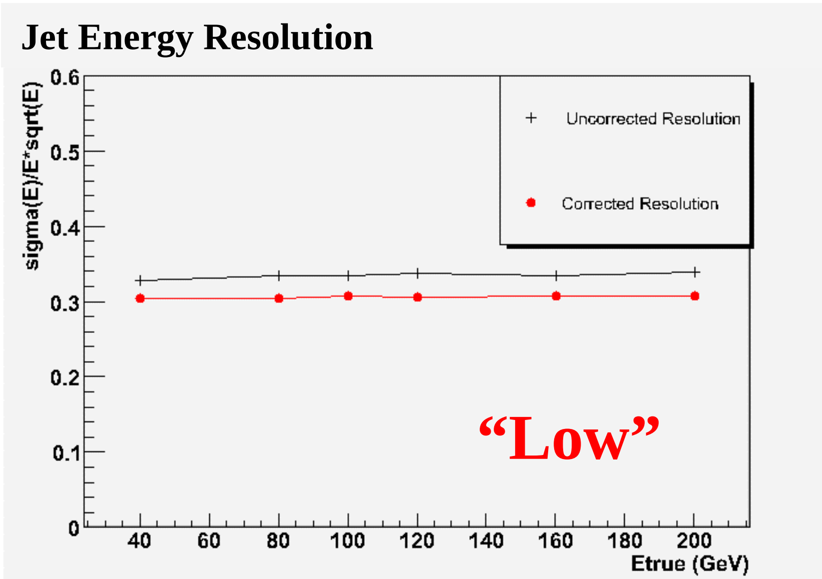
$$\sigma(E)/E \bullet \sqrt{E} \text{ vs } E$$

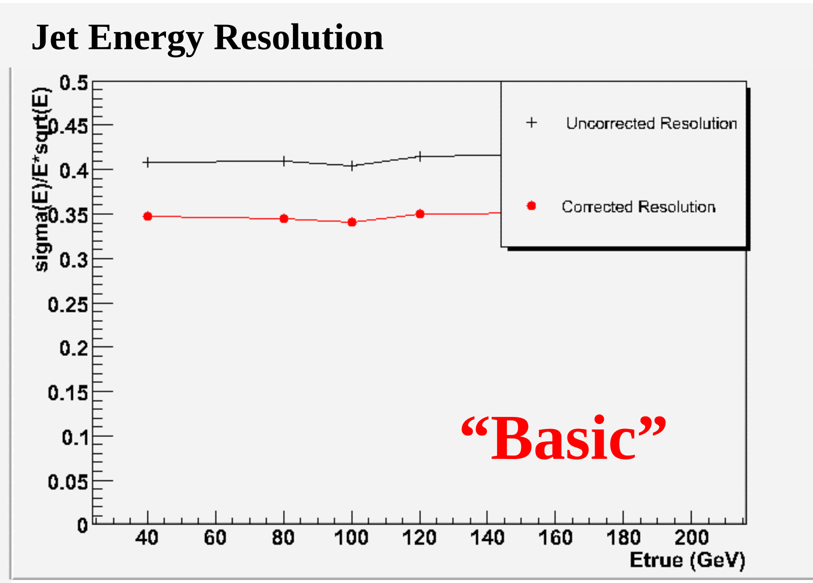


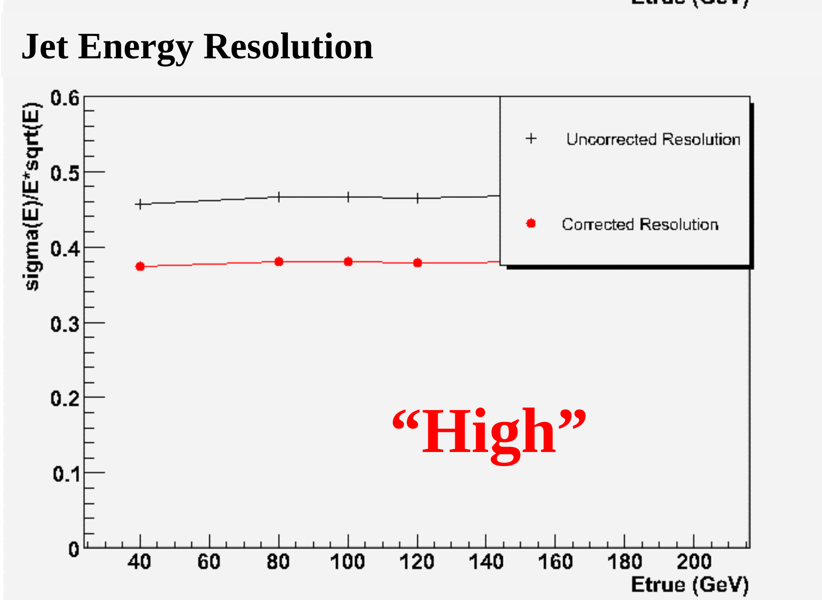
- The energy resolution improves , for all Cerenkov layer thicknesses, when the Active layer thickness increases.
- For the case of a 2 mm thick Cerenkov layer nearly any Active layer thickness give the same results

Results : Segmented Detector Jets

Choose "less optimal" perhaps "more realistic" configuration of :
30 mm Active 2mm Cherenkov 18 mm Passive Layers







$$\sigma(E)/E \bullet \sqrt{E} \text{ vs } E$$

$$\frac{\Delta E}{E} \leq \frac{35\%}{\sqrt{E}}$$

Possible advantages of Planar Calorimeter in Comparison with Fiber Based Dual Readout

- Very good energy resolution for electrons (using lead glass, nearly 100% sampling fraction), hence…
- Uniform calorimeter (the same structure for EM/Hadron section)
- Easy transverse and longitudinal segmentation
- High yield/detection efficiency of the Cherenkov photons

Summary

- We have shown preliminary results of the energy resolution for single particles and jets in a dual readout type calorimeter.

- The results indicate that for both the homogenous and the segmented case :

  - Energy resolution Scales with energy like $1/\sqrt{E}$ (no constant term)
  - The response is Linear
  - Corrected pion shower energy = pion energy ("e/π"=1)
  - Correction function independent of the actual shower energy

- The results indicate that for the homogenous case a single particle and jet energy resolution $\Delta E/E < 0.25/\sqrt{E}$ can be achieved, and for the segmented case a $\Delta E/E < 0.35/\sqrt{E}$ can be achieved.

Outlook

- Perform the same studies using a sampling calorimeter, uniform medium, where longitudinal and transverse segmentation is present and :
- *Try to explore if we can improve the Compensation Algorithm by using the local scintillation/Cherenkov ratio to correct the energy measurement of the 'hadronic' component.*

- Perform the same studies using different materials, like plastic scintillator or scintillating glass and :
- *Try to explore if the combination of neutron-based and Cherenkov-based compensation can improve the results further.*