Energy Resolution and Particle Identification of the Dual-Readout Calorimeter

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IAS Program on High Energy Physics

1. The **electromagnetic** performance

2. The **hadronic** performance

3. **Particle identification** in the longitudinally unsegmented calorimeter

Main factors that degrade hadron energy resolution and how to improve the fluctuations

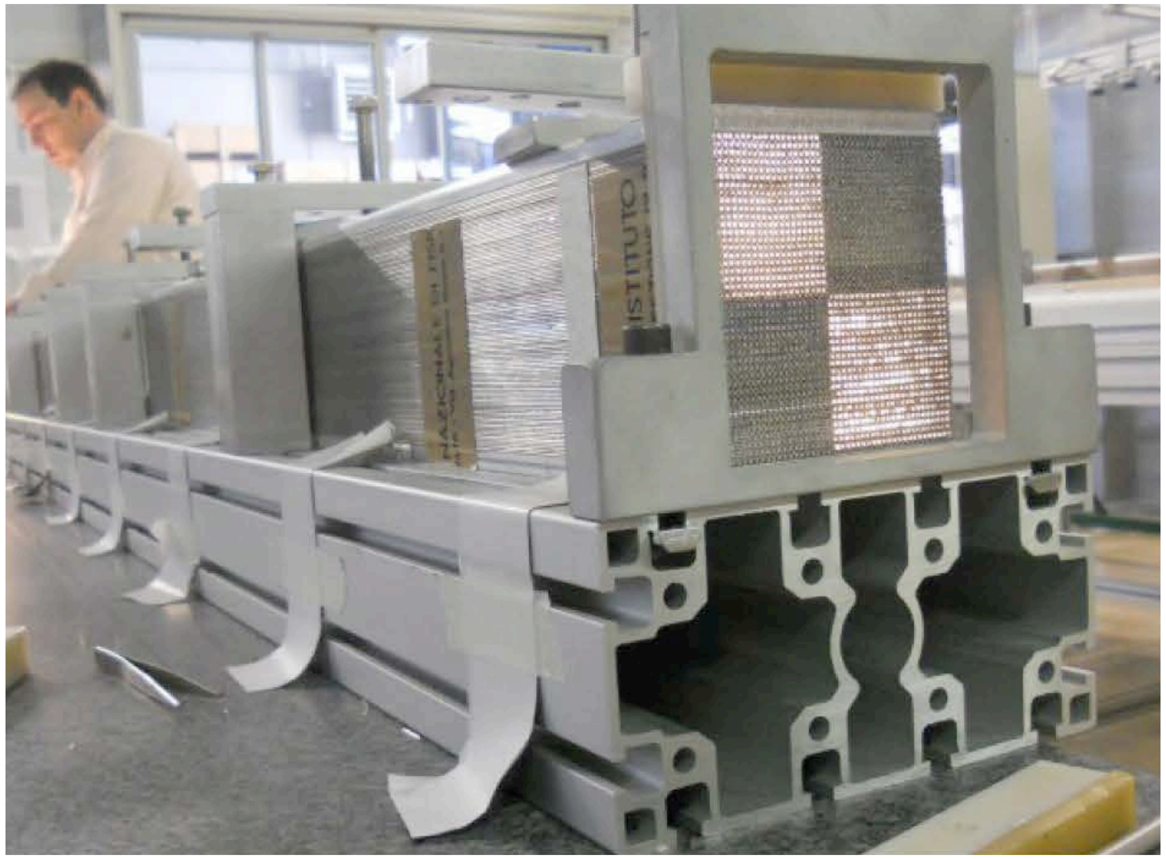
- **f_{em} fluctuations**
  - **Dominant fluctuation** in the hadron calorimeters
  - Eliminate by:
    - **measuring f_{em} event by event** using **Cerenkov light** (RD52 (DREAM))
- Fluctuations in nuclear binding energy loss
  - break-up of nuclei (“invisible”) → doesn't contribute to the calorimeter signal
  - correlation between the binding energy loss and the kinetic energy of neutrons
  - hydrogenous active material (The recoil protons from np→np)
- Stochastic fluctuations
  - sampling fluctuation, light yield
  - more fibers, high Numerical Aperature fiber, a good Q.E. of a light detector…

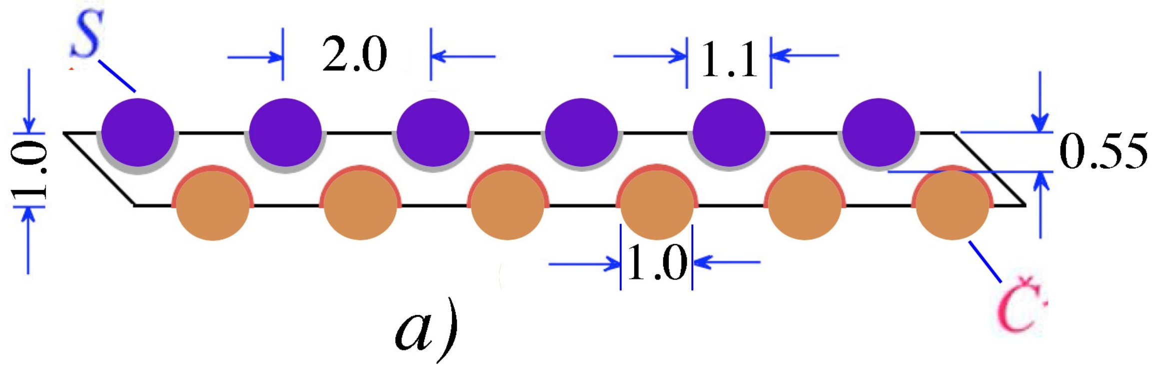
The RD52 Project

- Generic Calorimeter R&D
- H8 area of SPS at CERN
- High-quality energy measurements

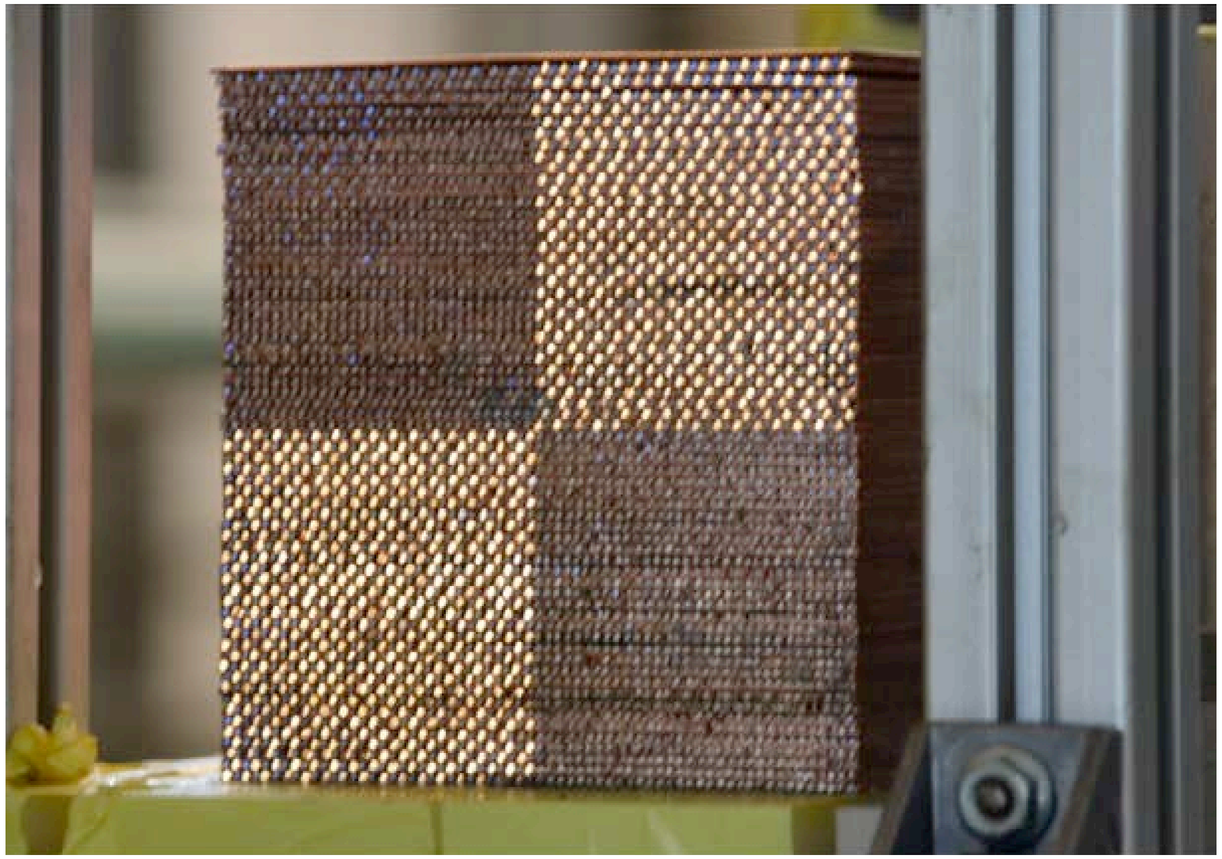
The structures of Pb and Cu modules

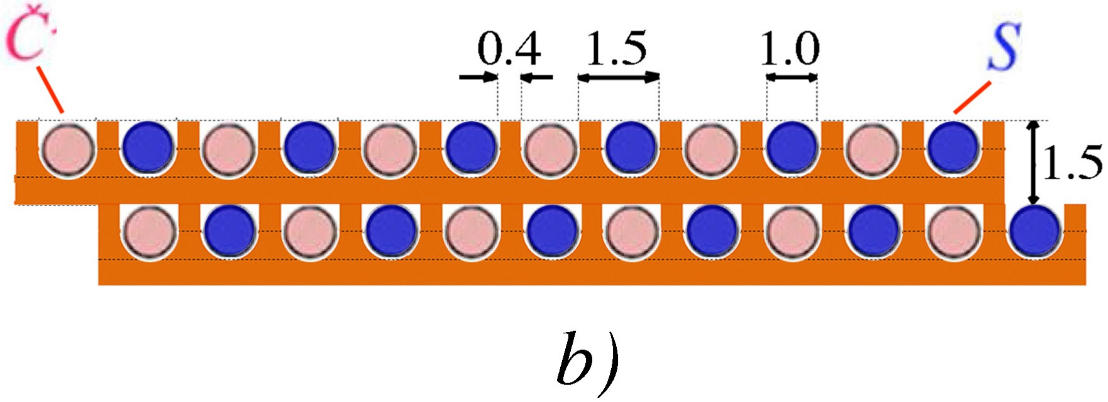
Pb



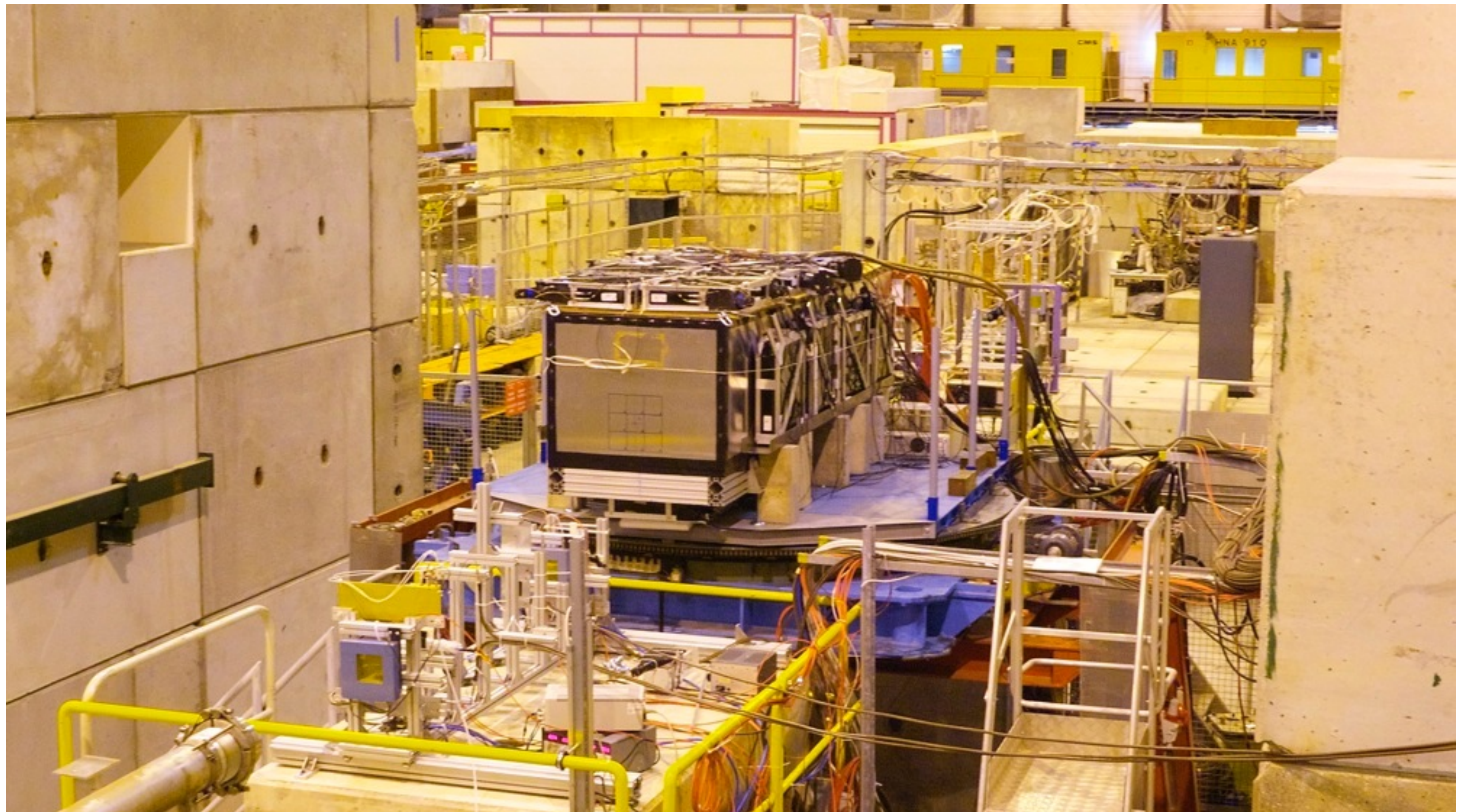


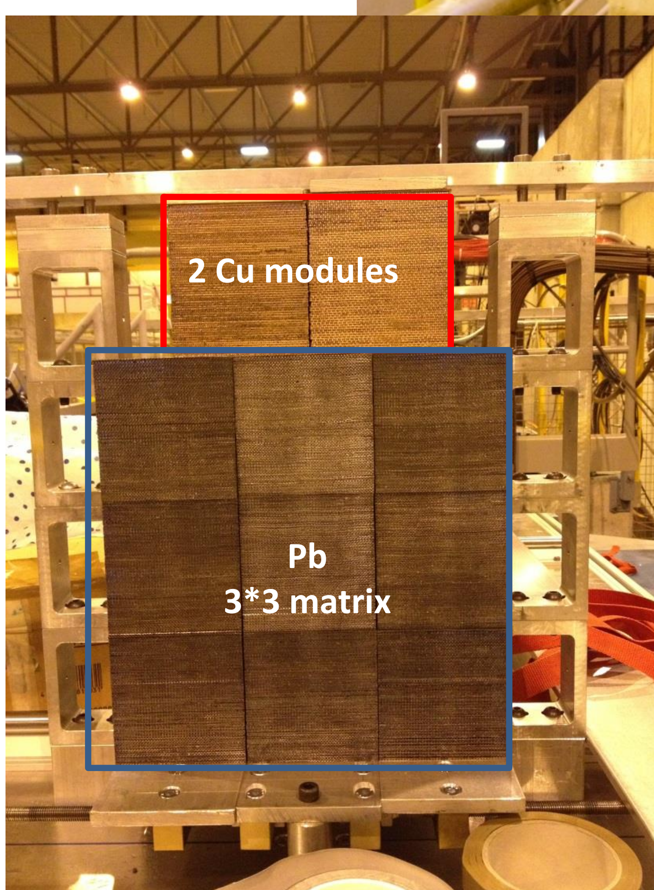
Cu

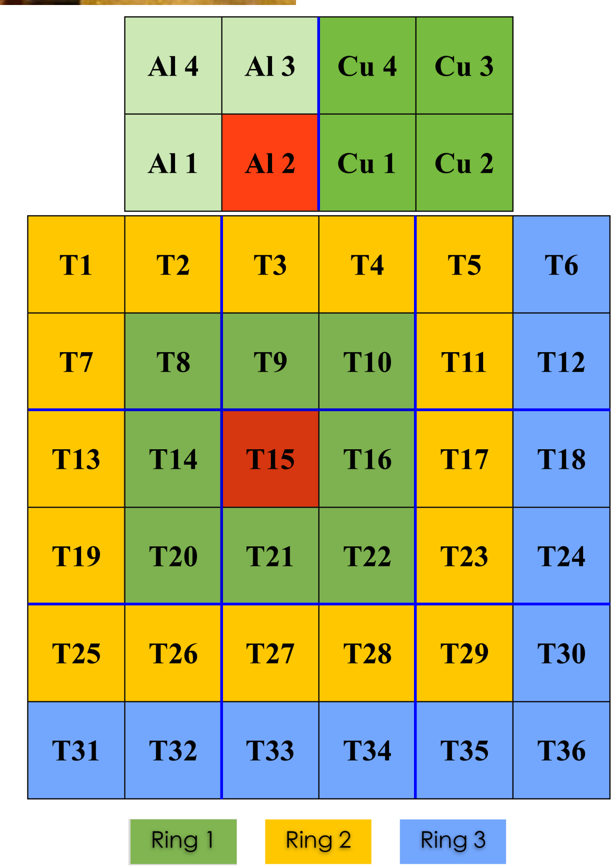




Test Beam with the RD52 calorimeters

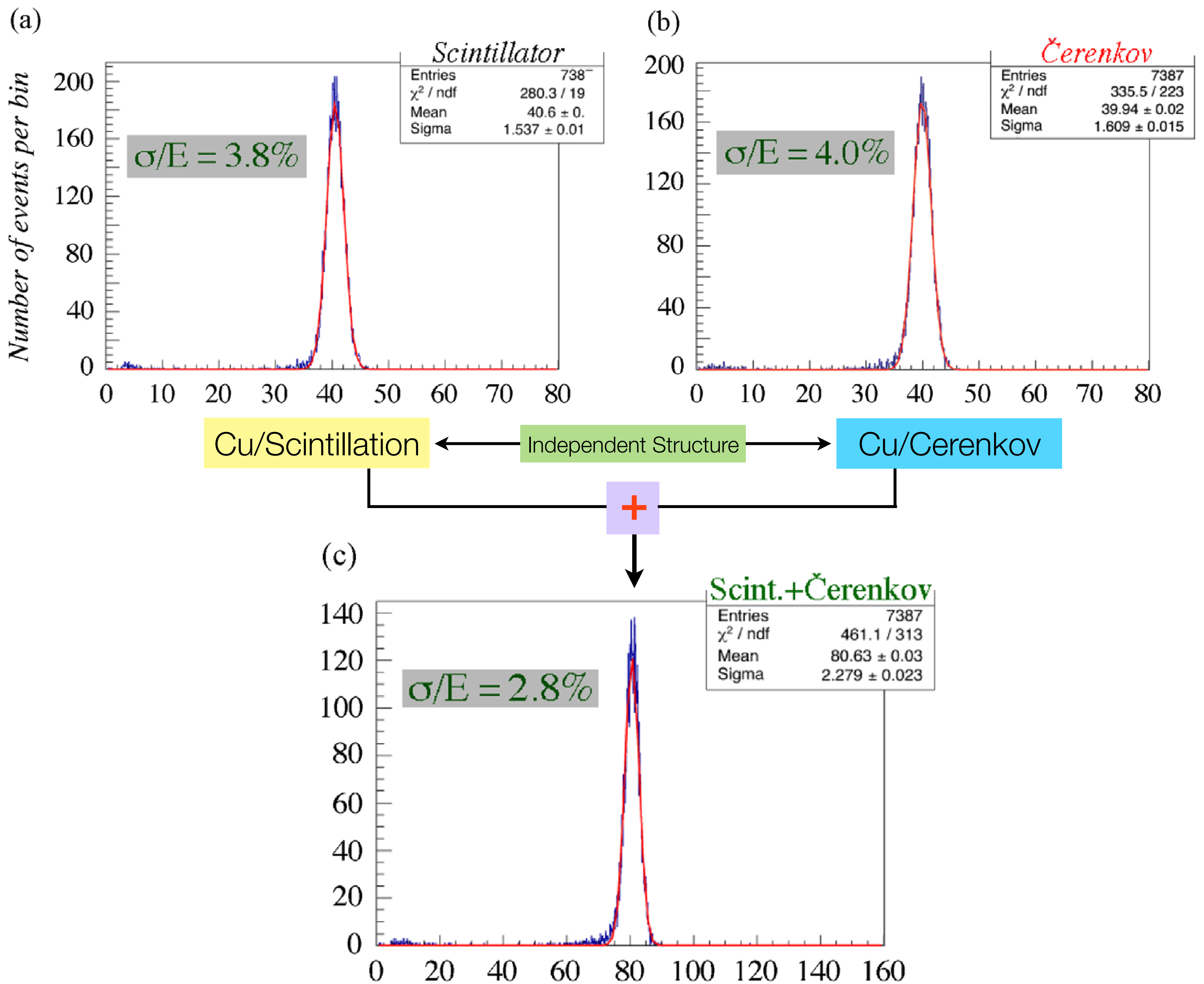




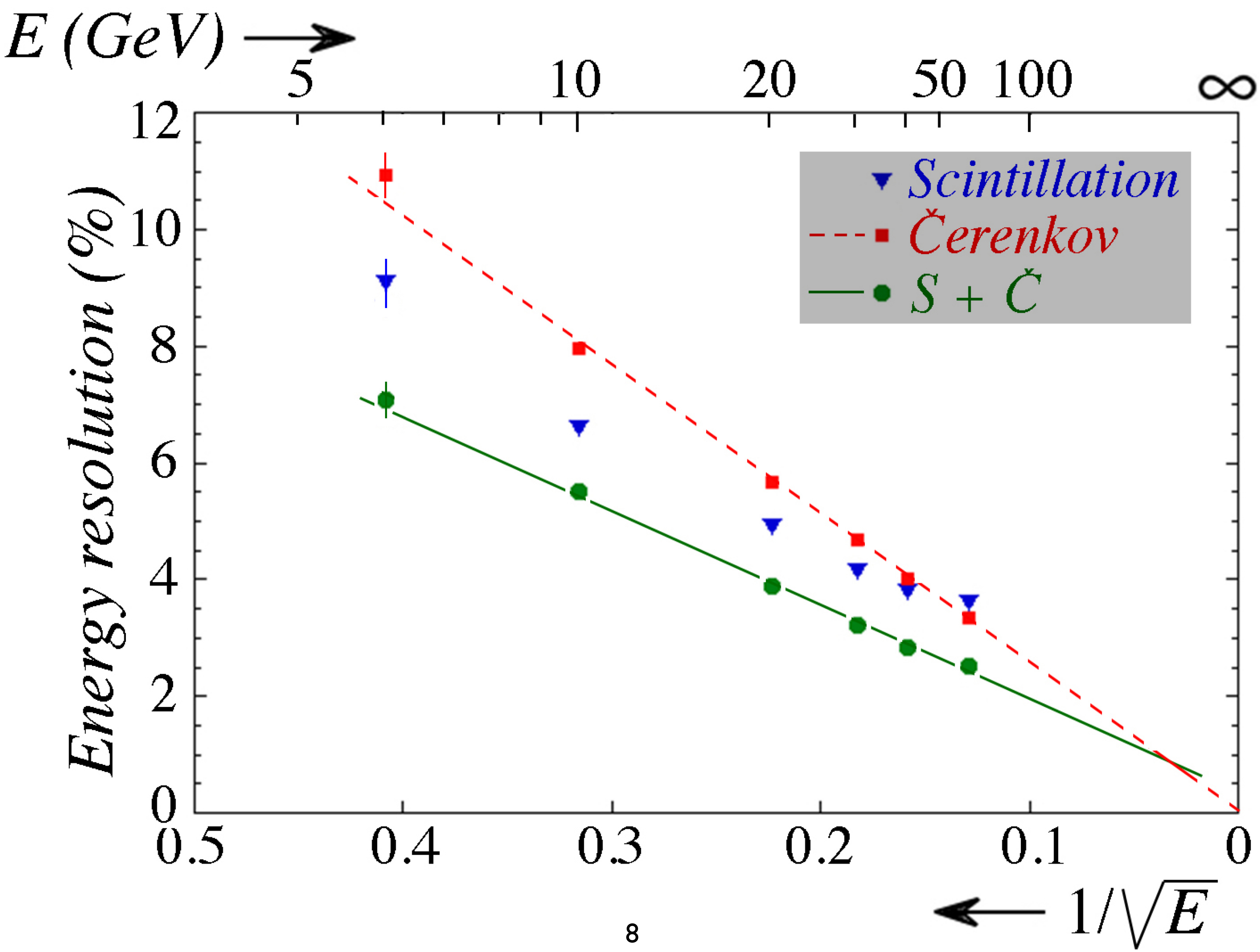


9 Pb modules (36 towers, 72 channels), 2 Cu modules (8 towers), 20 leakage counters (Plastic scintillator)

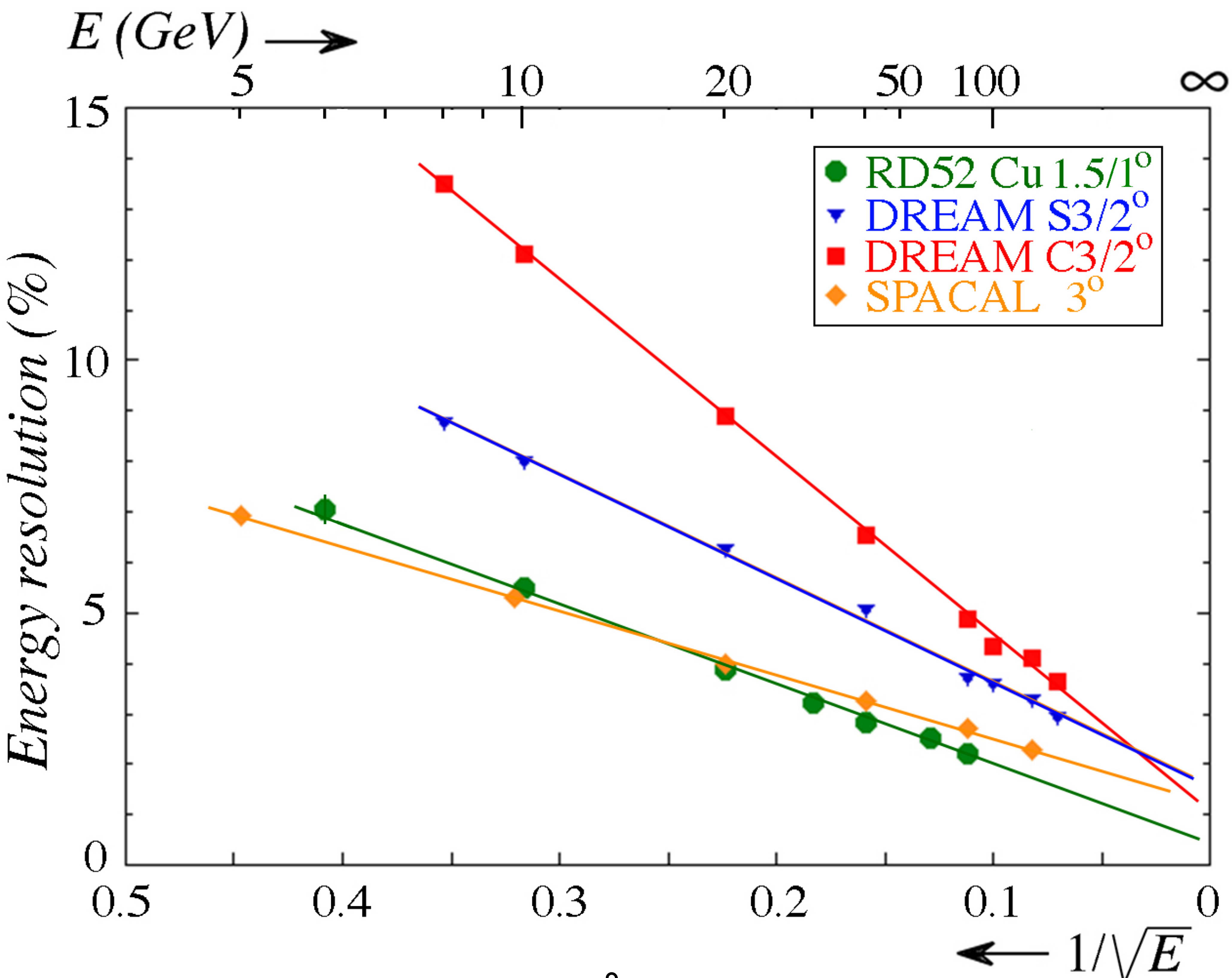
The electromagnetic performance for 40 GeV e^- (Cu/fiber)



The energy resolution for electrons (Cu/fiber)



Comparison of the electromagnetic energy resolution



The hadronic performance (Pb/fiber)

Dual-REAdout Method

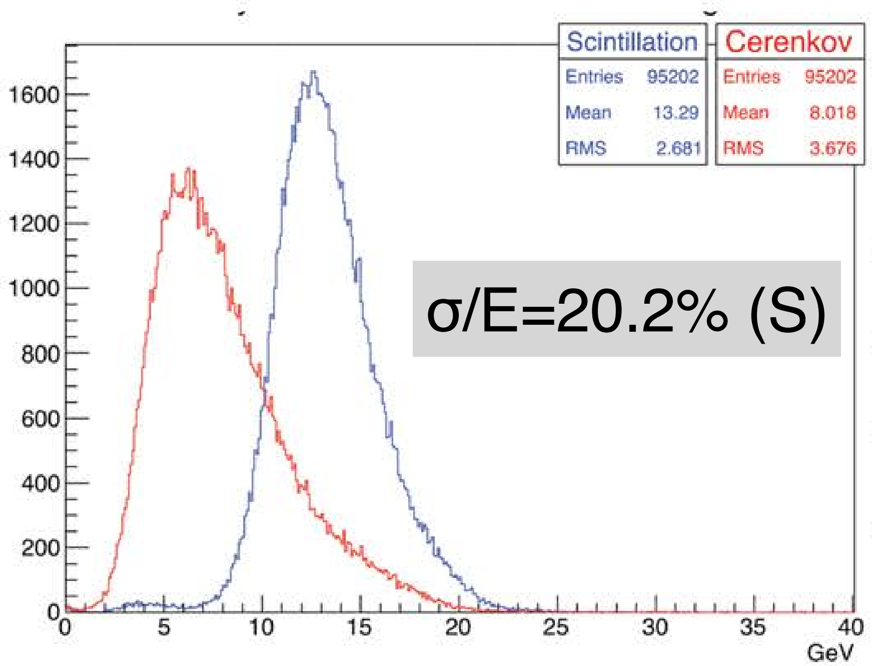
$$S = E\left[f_{\mathrm{em}} + \frac{1}{(e/h)_S}(1 - f_{\mathrm{em}})\right]$$

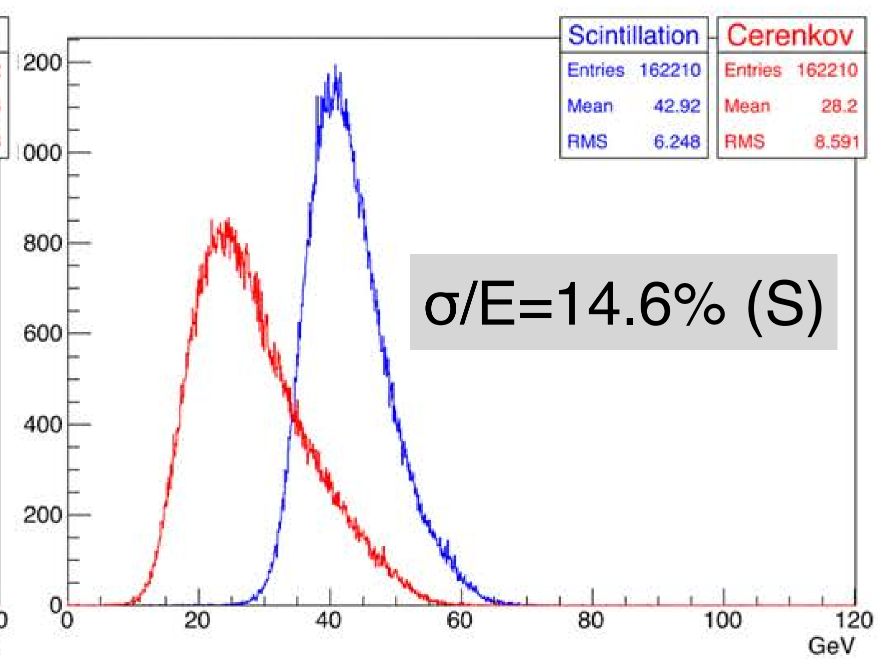
$$Q = E\left[f_{\mathrm{em}} + \frac{1}{(e/h)_Q}(1 - f_{\mathrm{em}})\right]$$

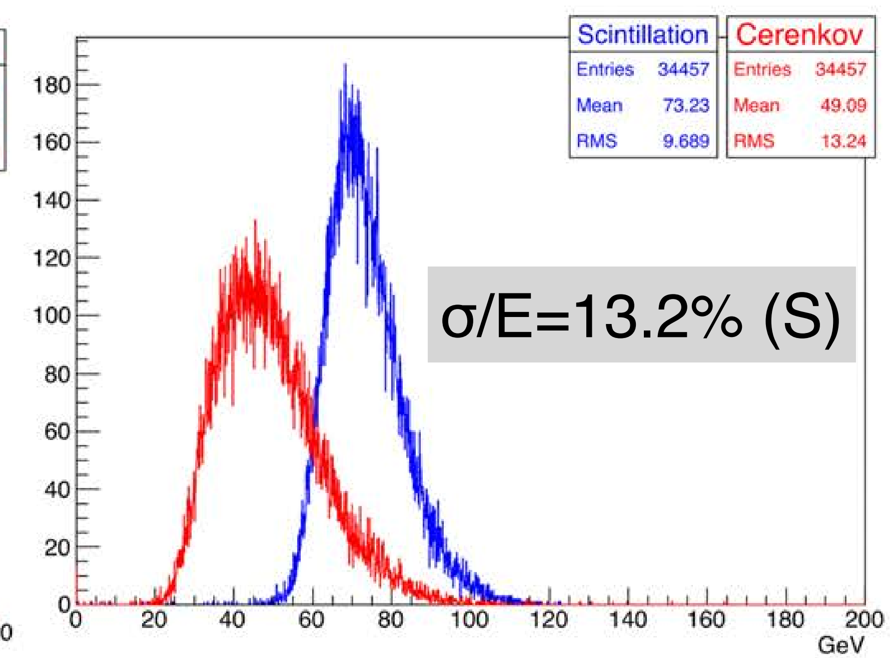
$$\boxed{E = \frac{S - \chi Q}{1 - \chi}}$$

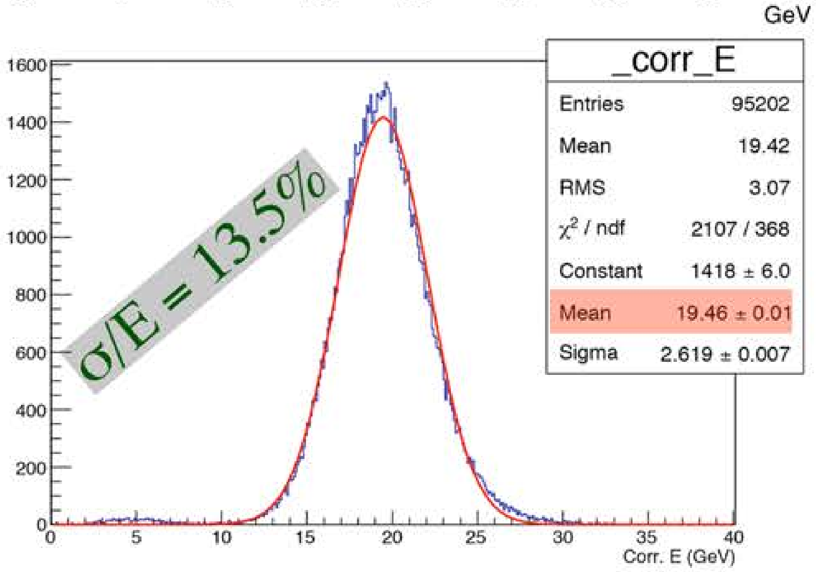
with $\chi = \frac{1 - (h/e)_S}{1 - (h/e)_Q} = 0.45$

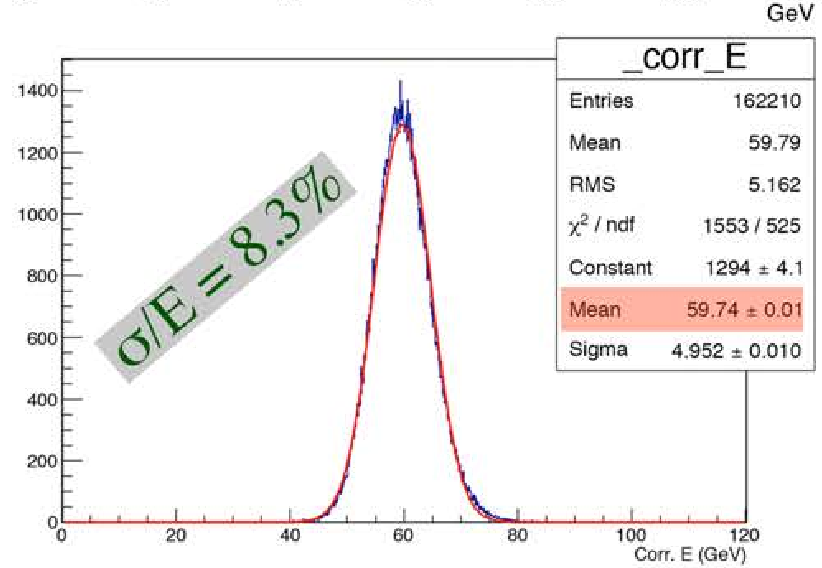
20 GeV π^-	60 GeV π^-	100 GeV π^-

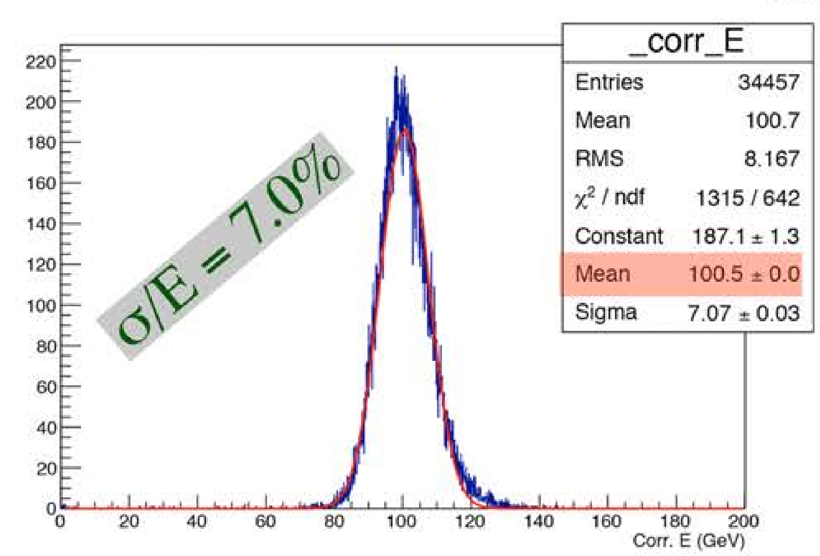








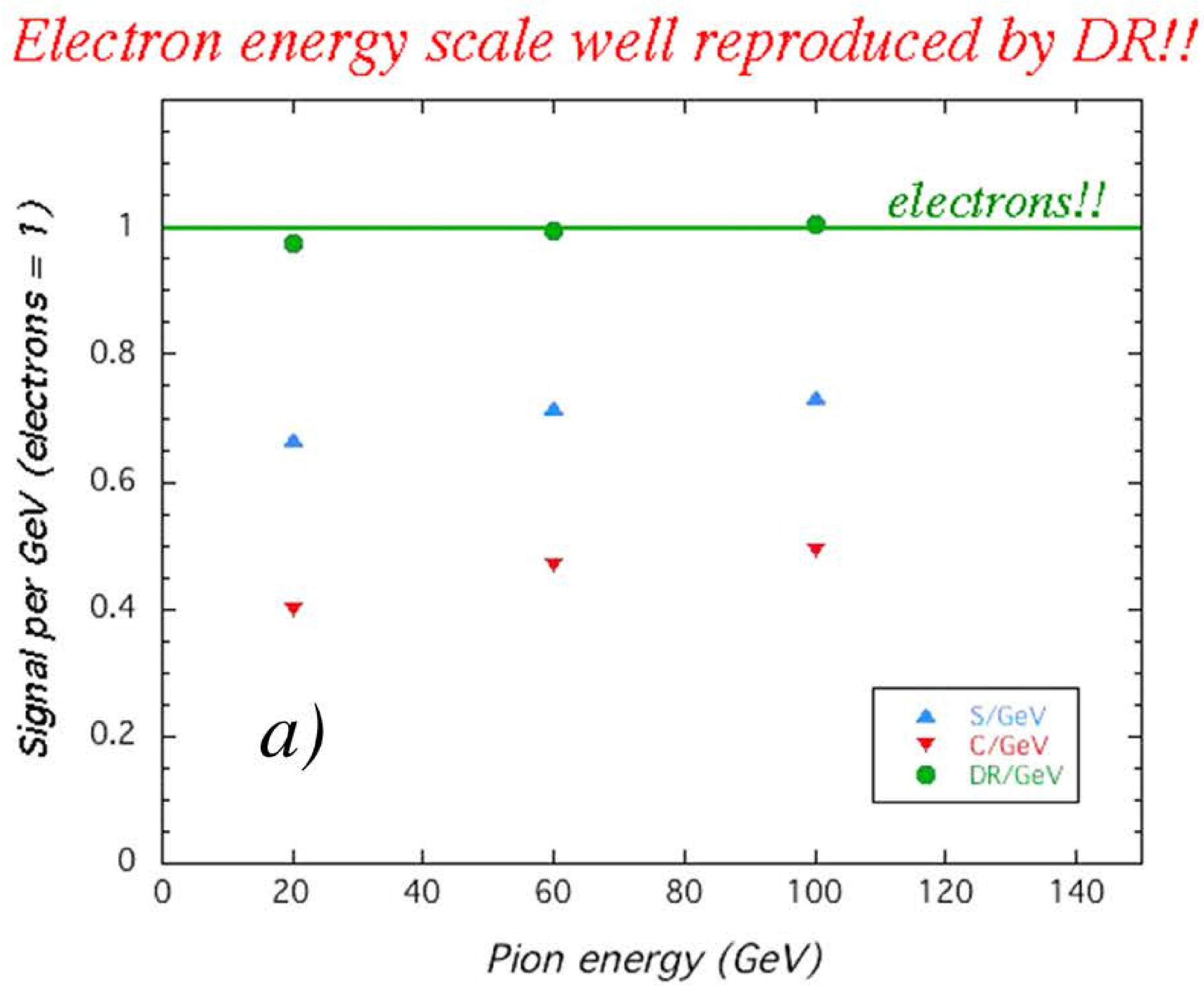


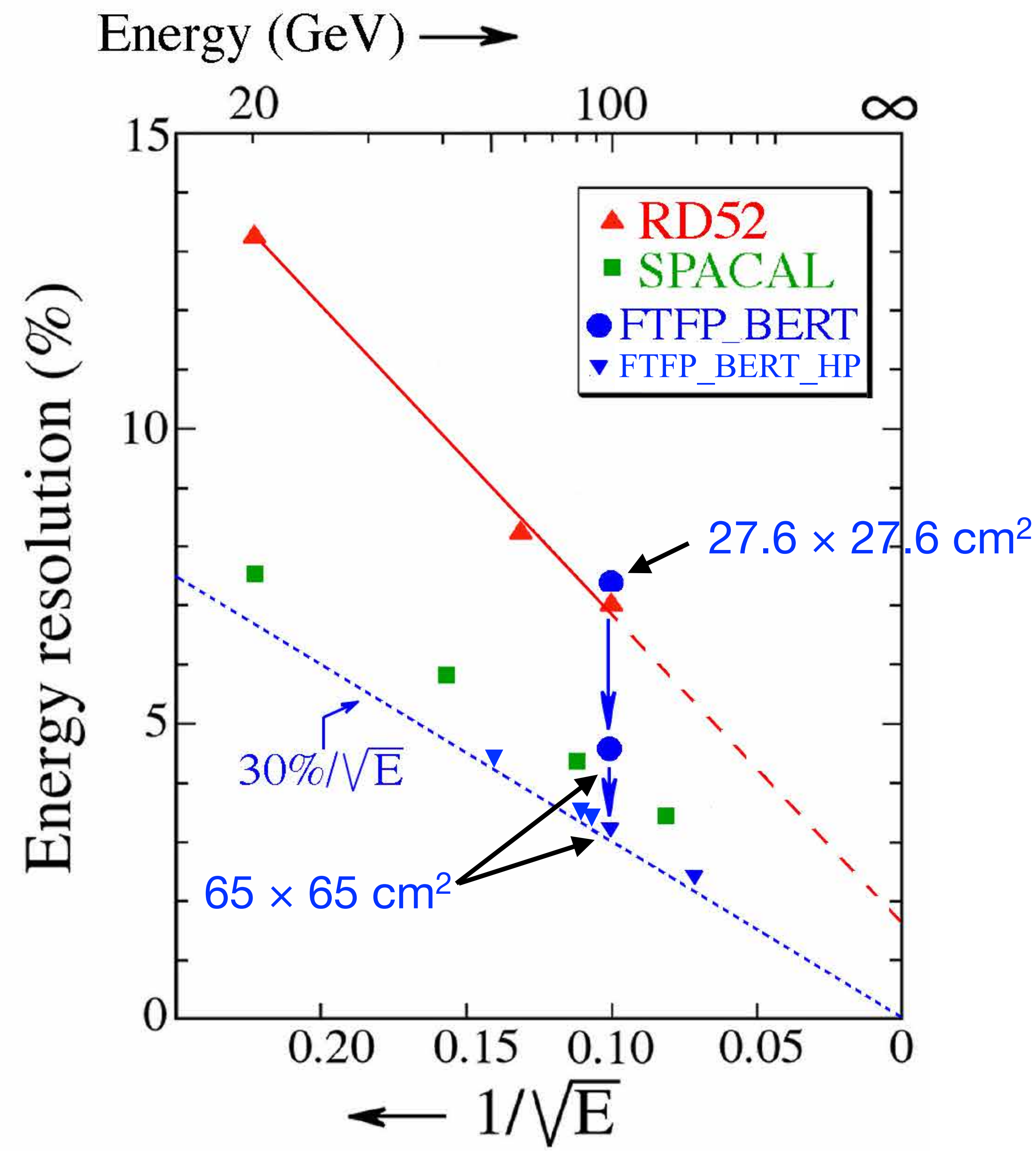


Single Pion (Pb/fiber)

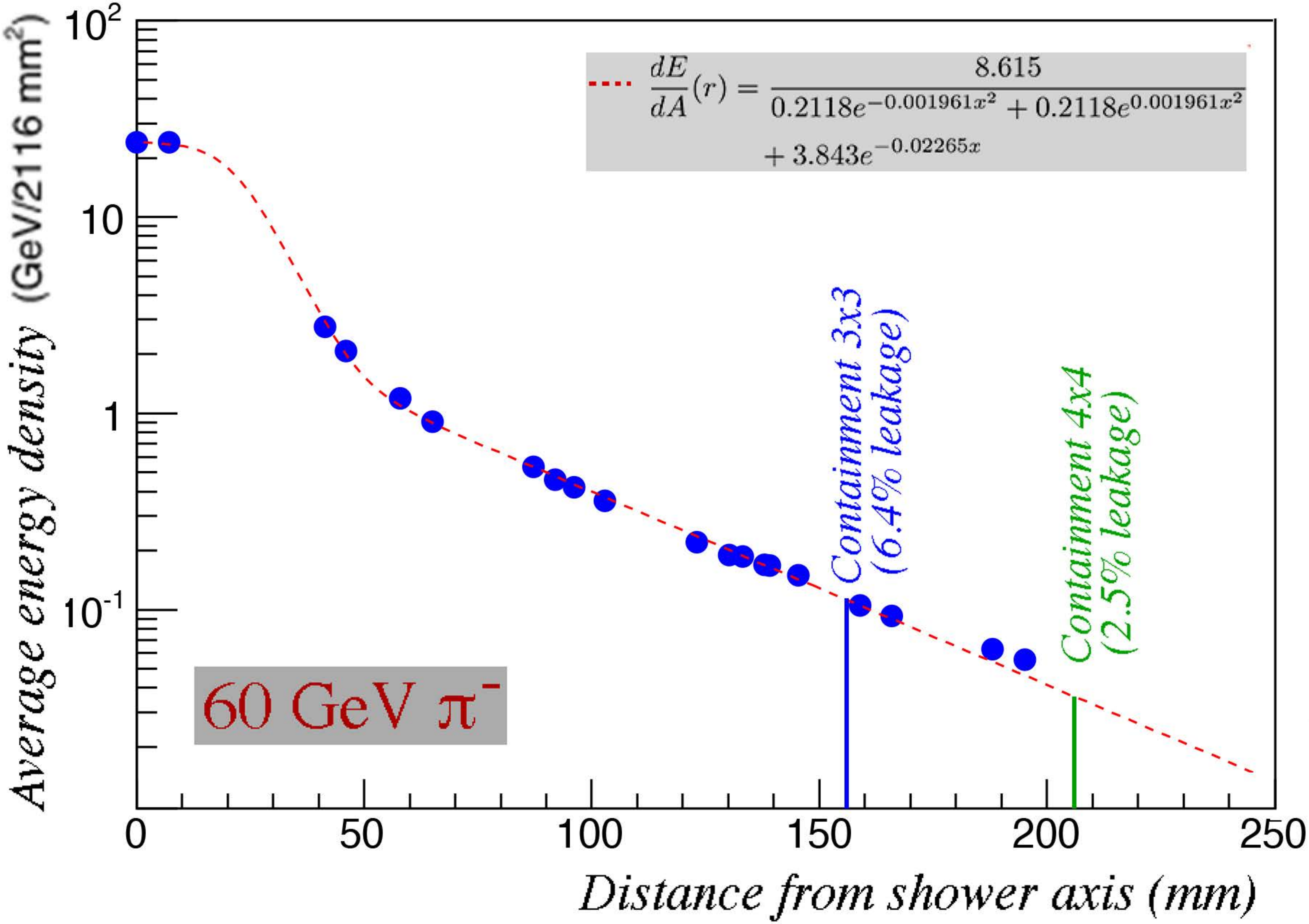
Calorimeter Response

Resolution

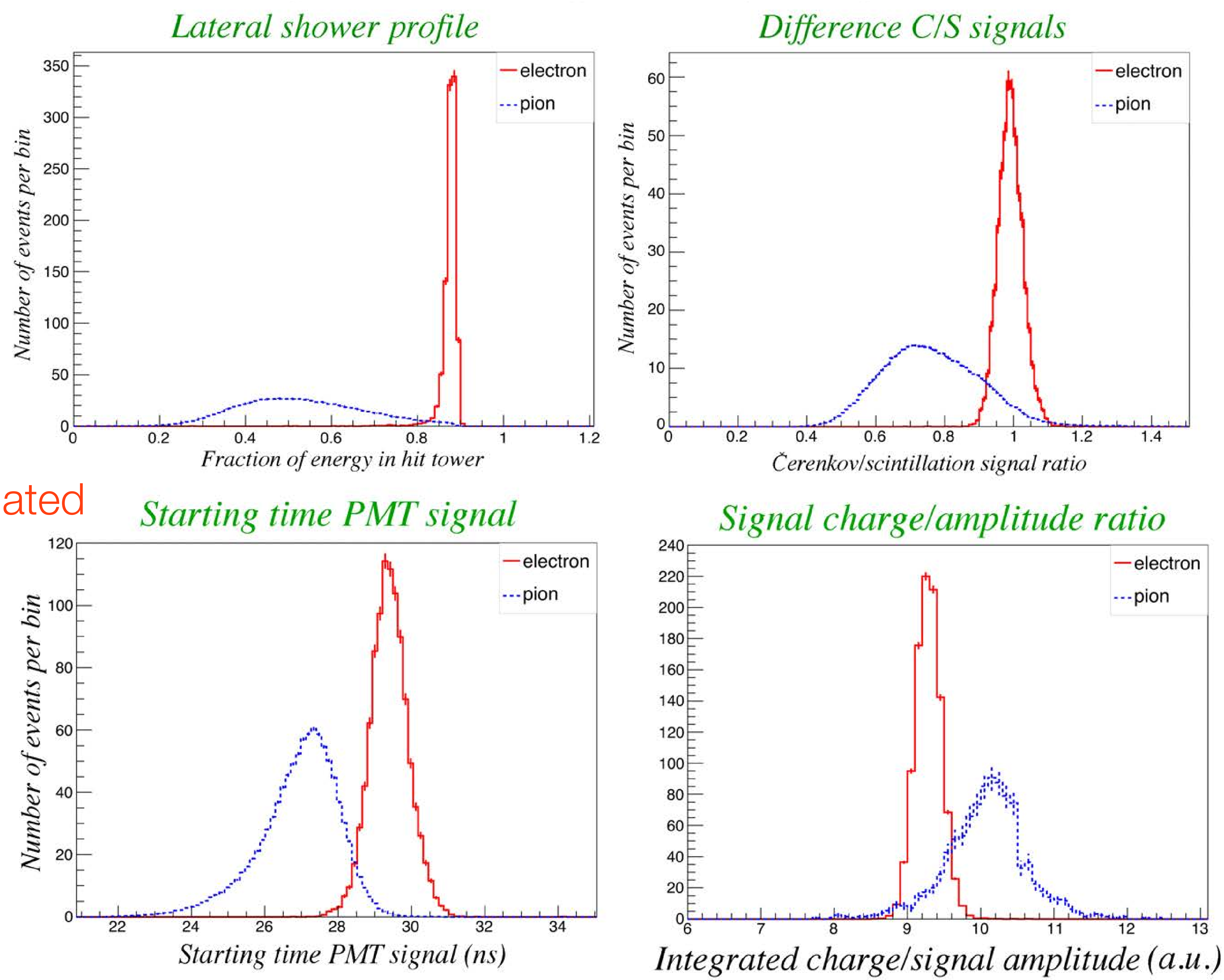




Radial shower profile (Pb/fiber)



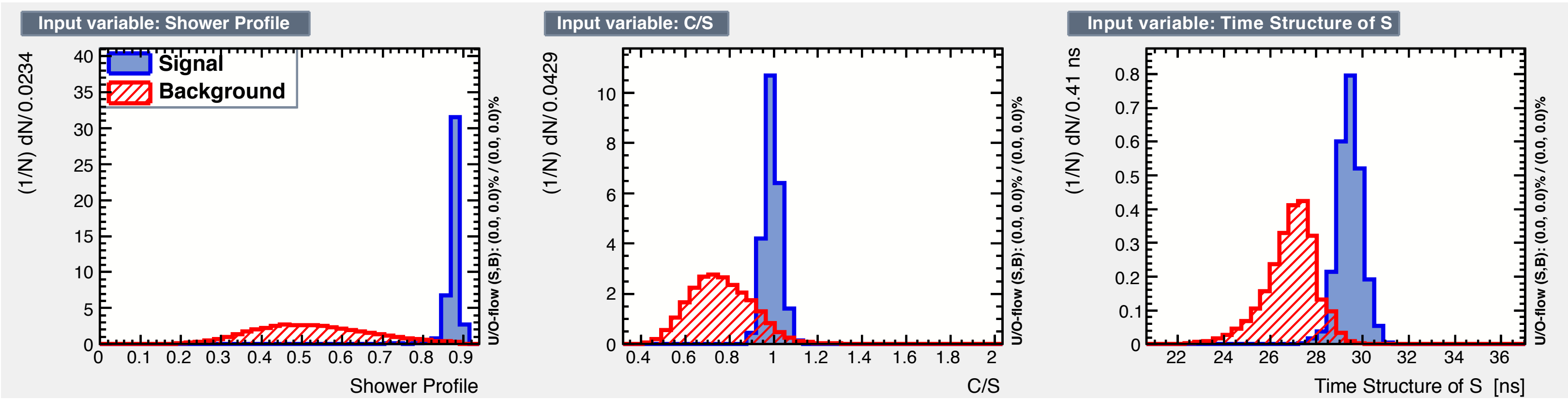
Particle ID (60 GeV)



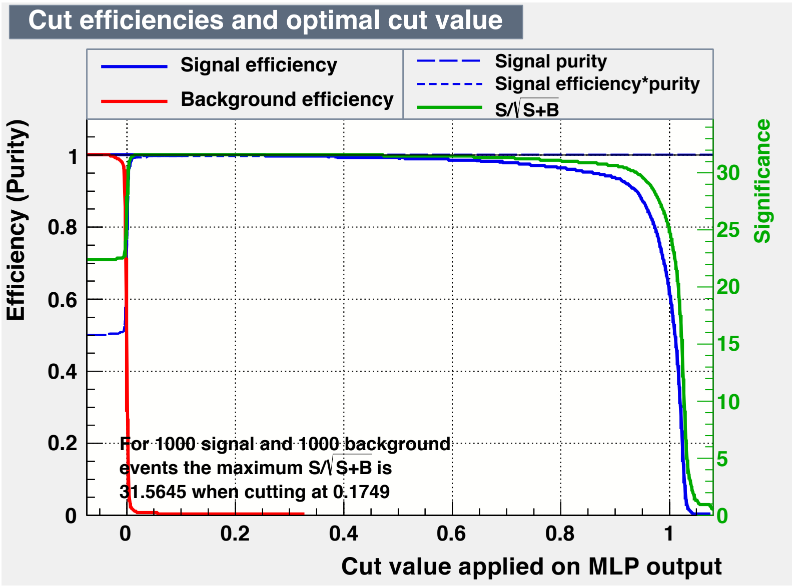
Uncorrelated

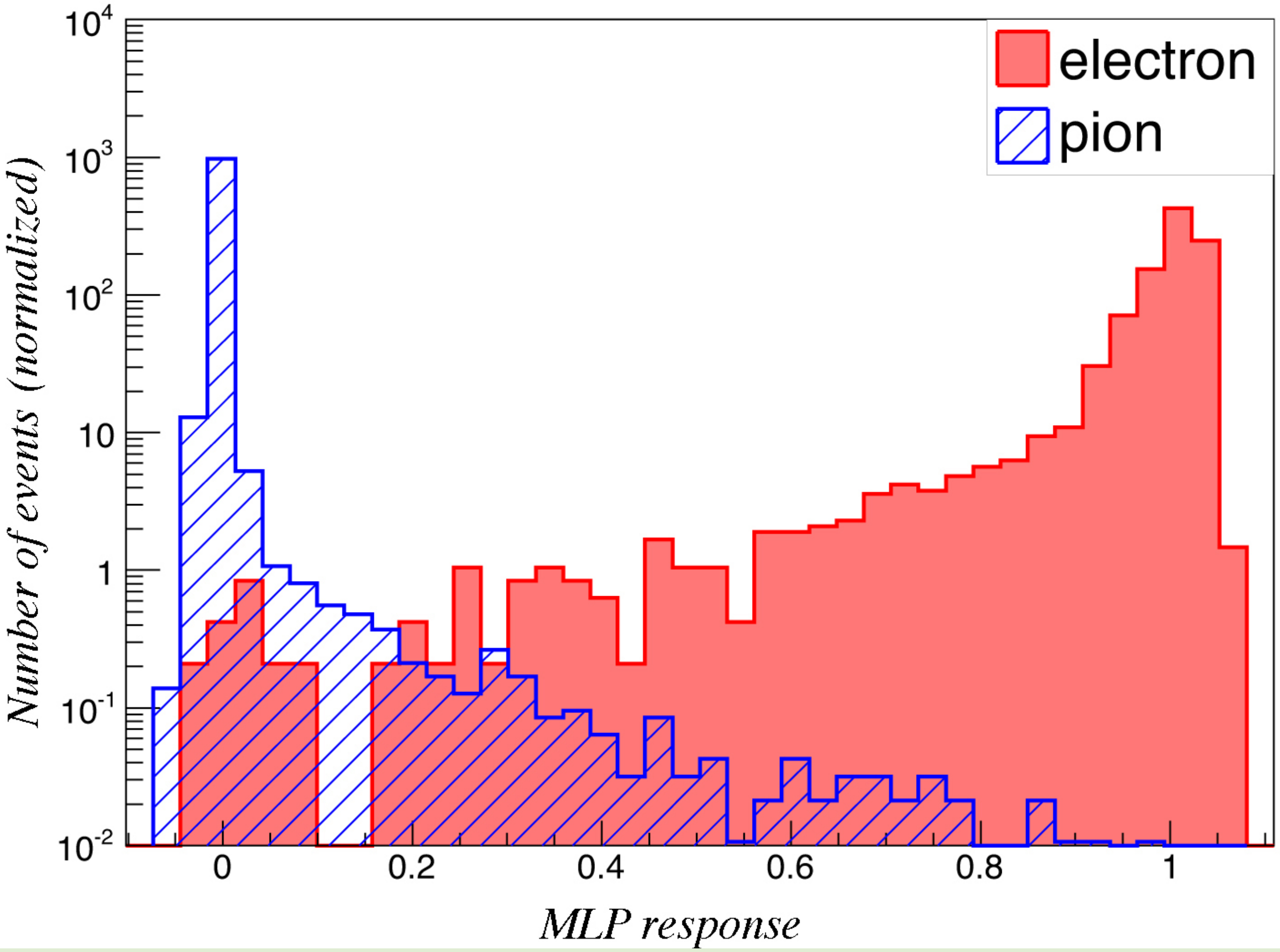
(Lateral shower profile > 0.7, t_S > 28.0 ns): 99.1 % electron ID, 0.5 % pion mis-ID

Input variables for 60 GeV e^- and π^-



Optimal cut





99.8 % electron ID, 0.2 % pion mis-ID for MLP > 0.17

Attractive Features
of the longitudinally unsegmented RD52 fiber calorimeter

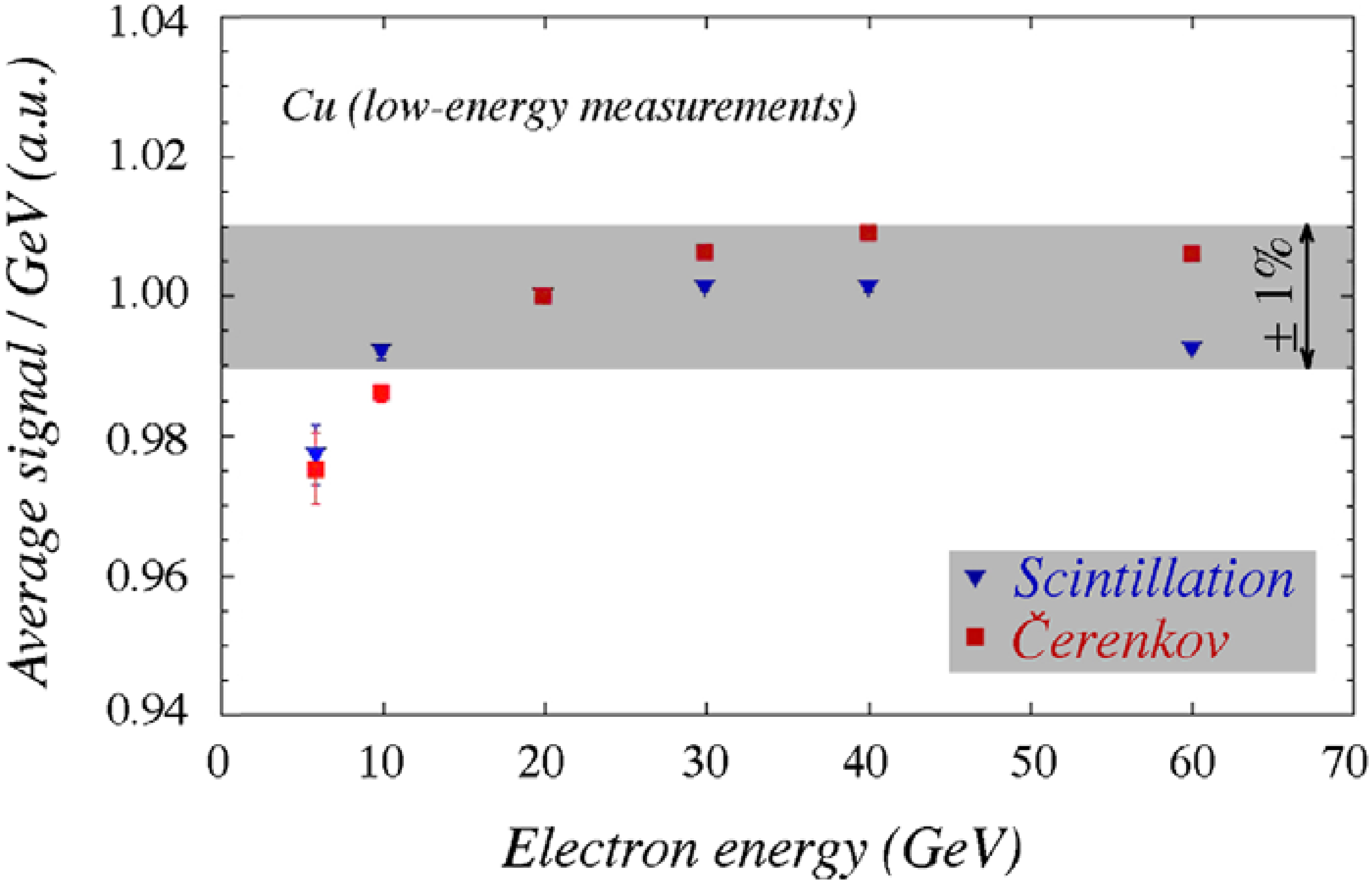
- Compact construction (no need em section)
- No intercalibration problem between em and hadronic calorimeters
- Easy calibration: calibration with electrons and that is all !!!

Summary

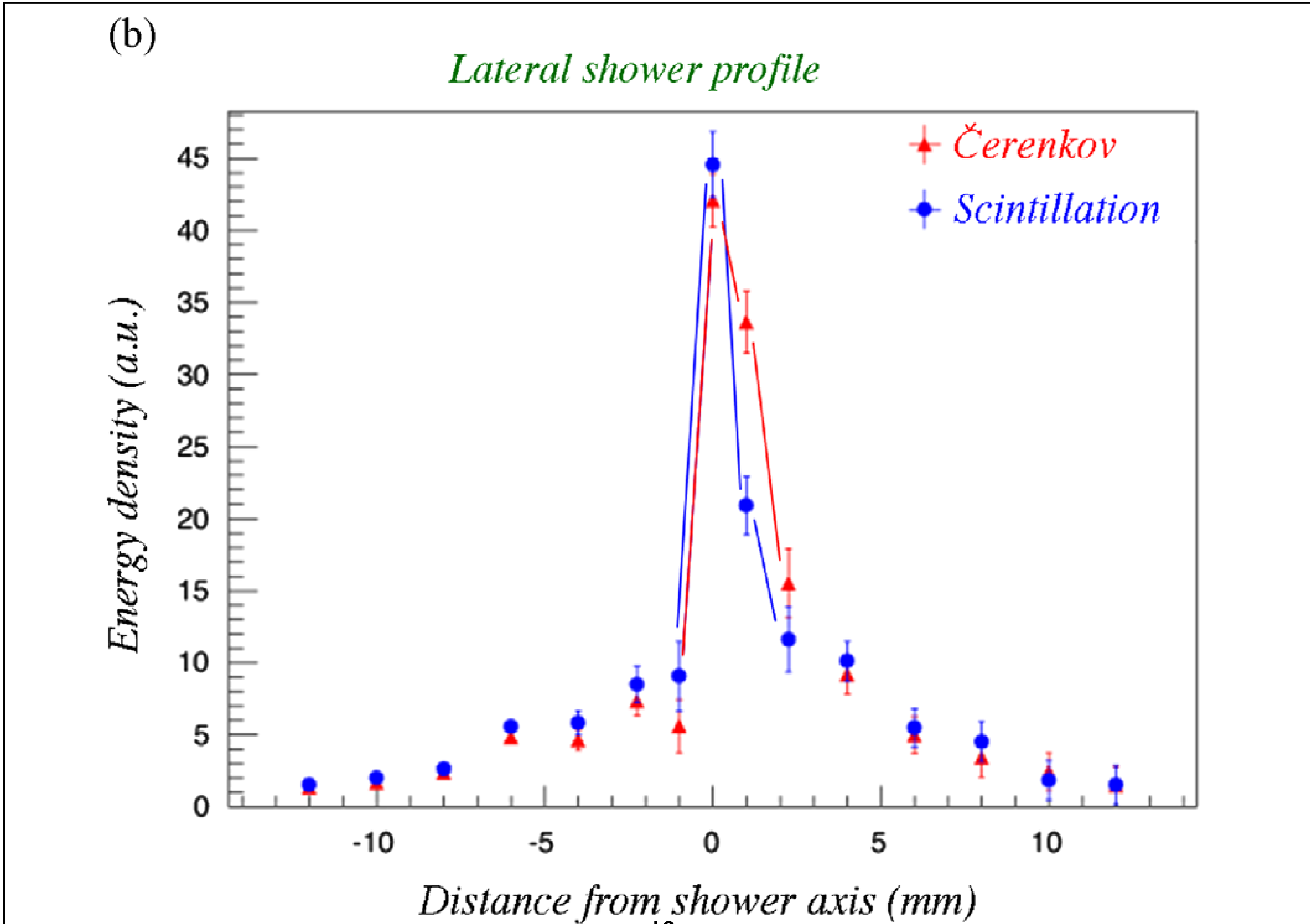
- The Cu/fiber calorimeter has better em energy resolution than the prototype DREAM and SPACAL (E > 20 GeV) **[NIM A 735 (2014) 130]**
- Pions have the same calorimeter response as electrons
- The RD52 calorimeter has linear response to electron and pion
- The longitudinally unsegmented fiber calorimeter offers excellent electron/pion identification **[NIM A 735 (2014) 120]**

Backup

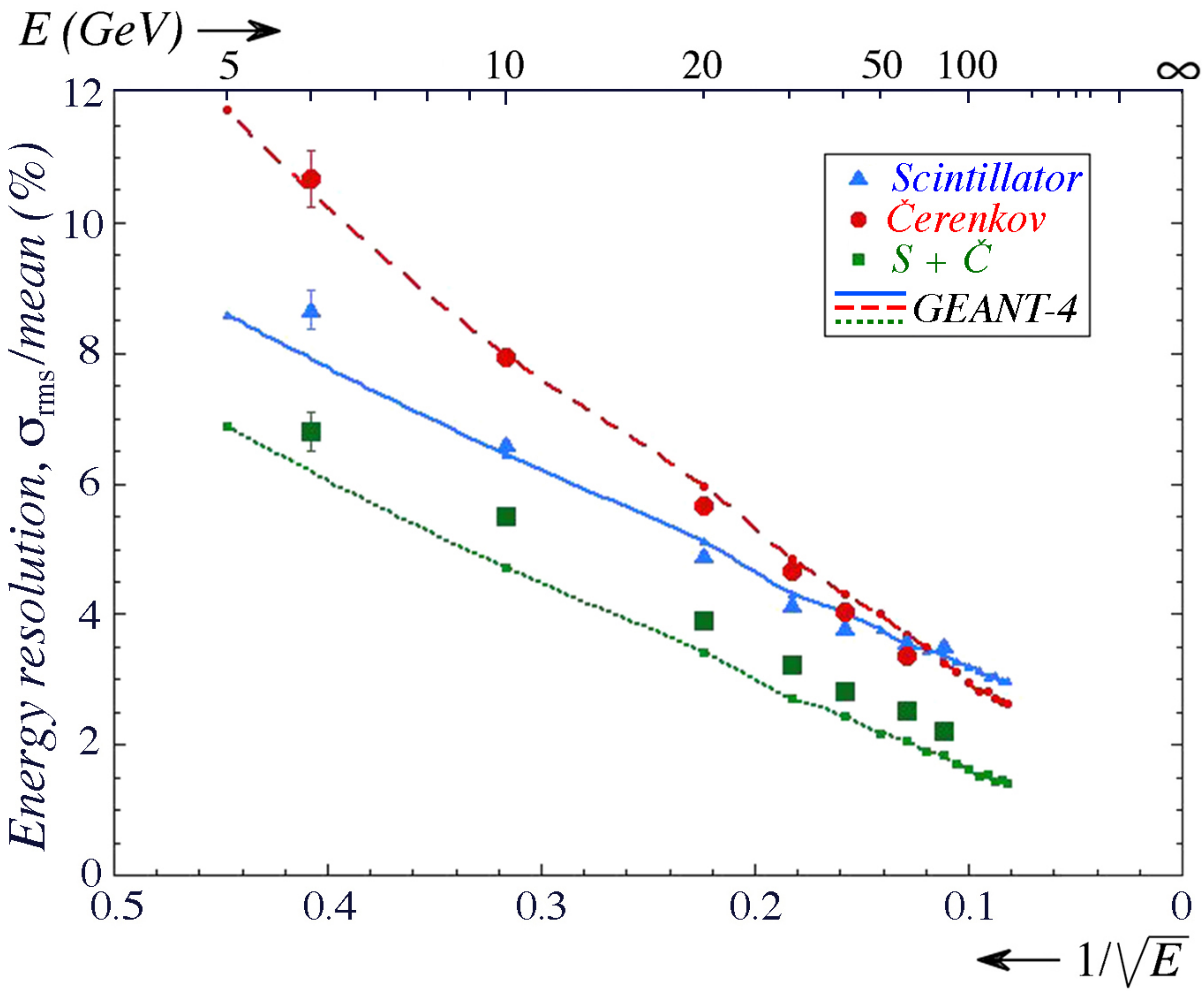
Linearity (Cu/fiber)



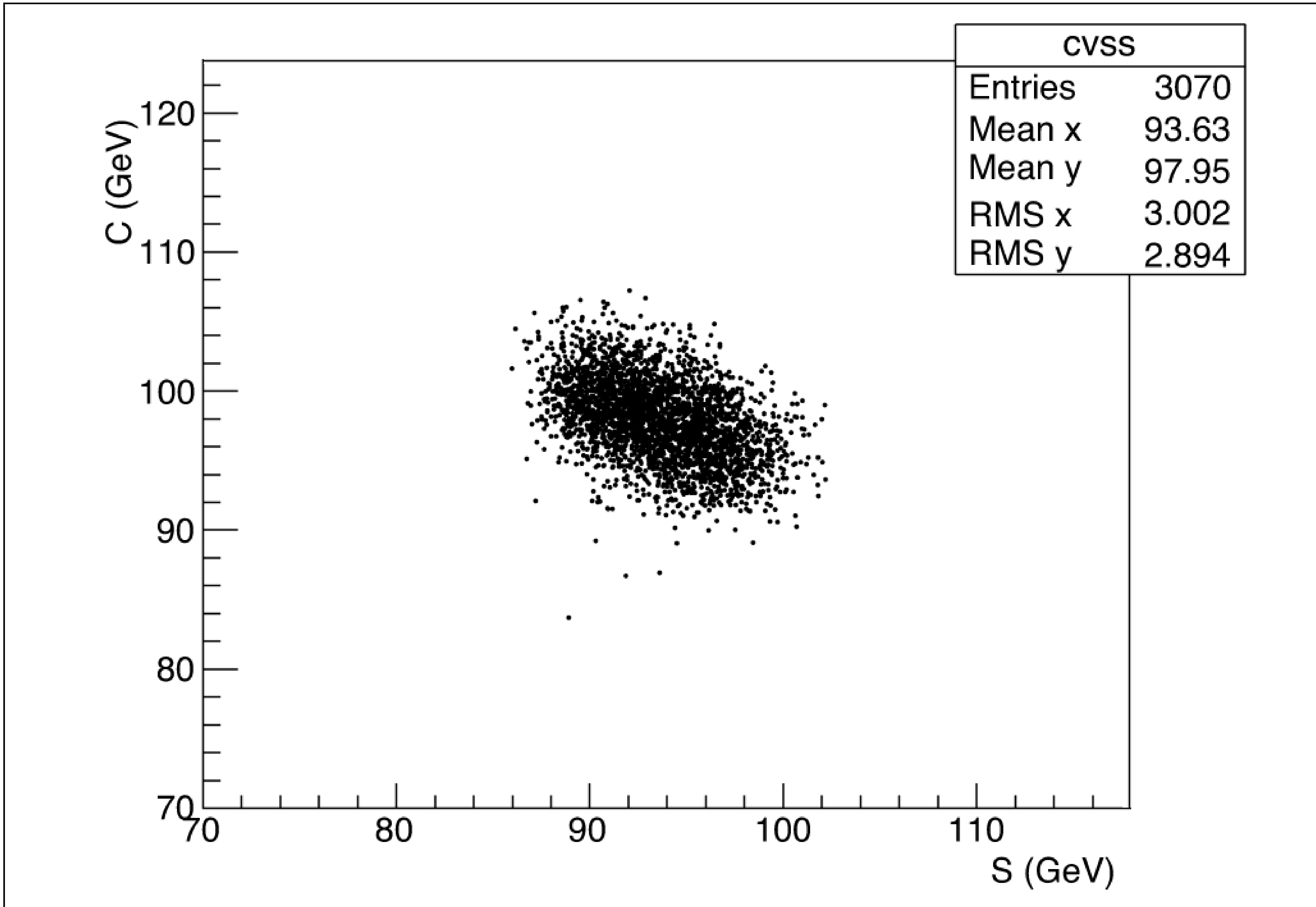
Lateral shower profile of electrons



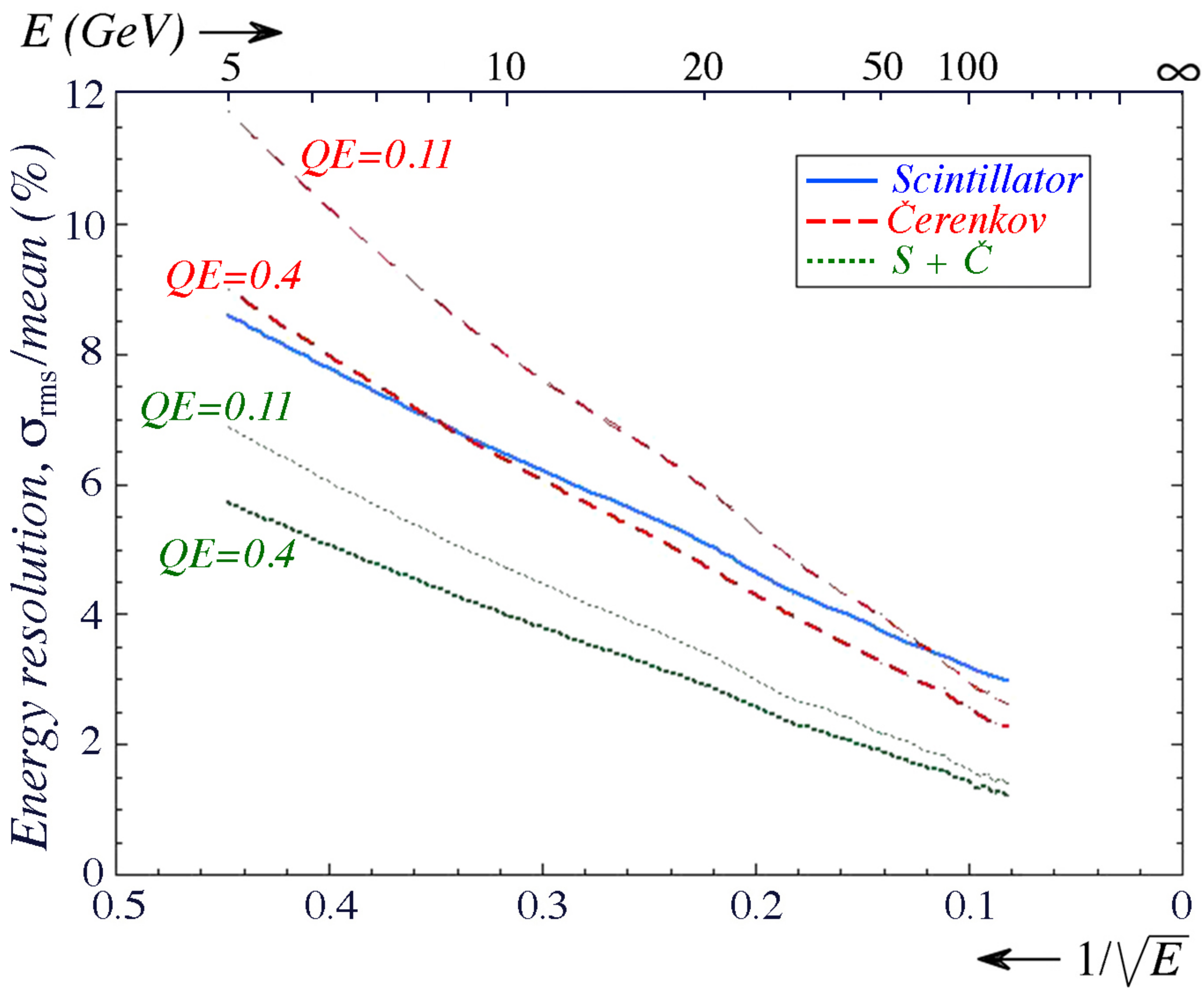
Comparison of Data and MC for the em resolution



100 GeV electron

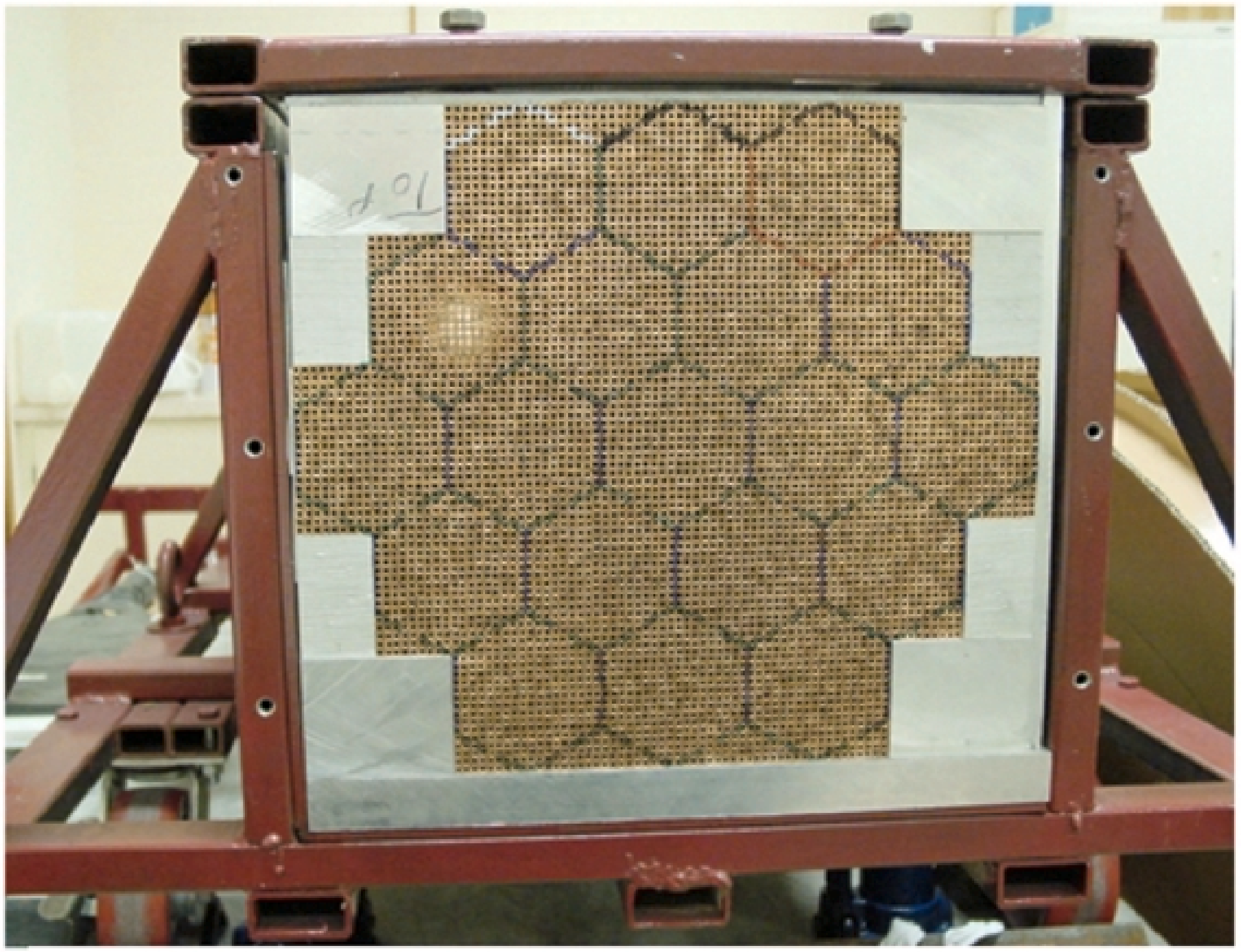


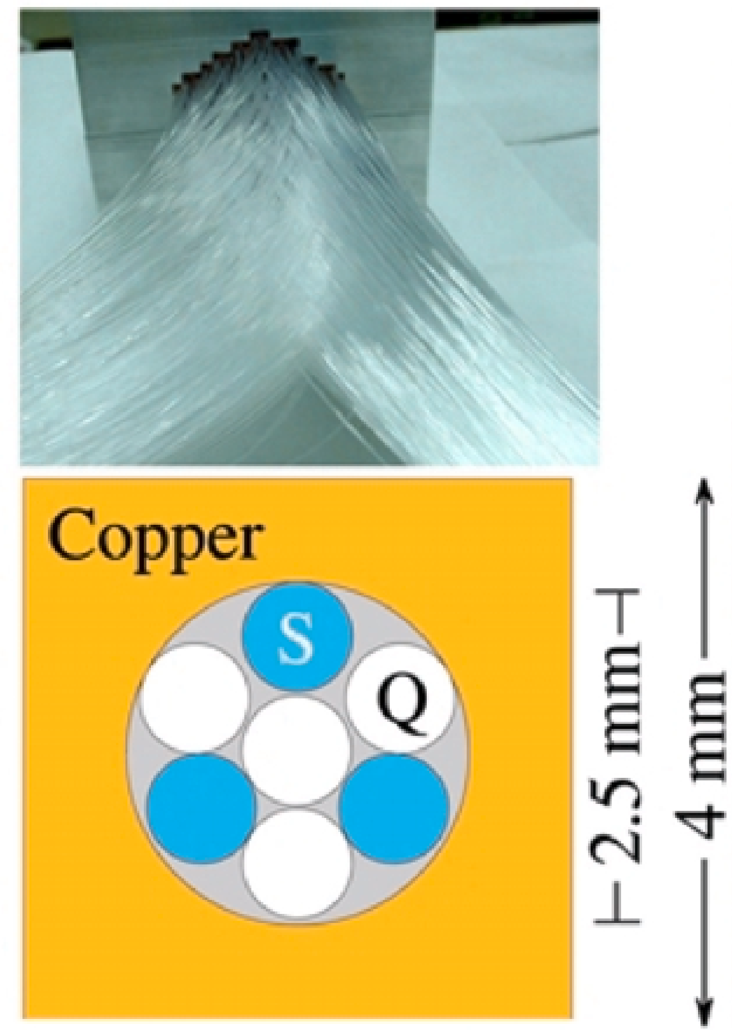
The prediction for the em performance by GEANT4



The Prototype DREAM Detector

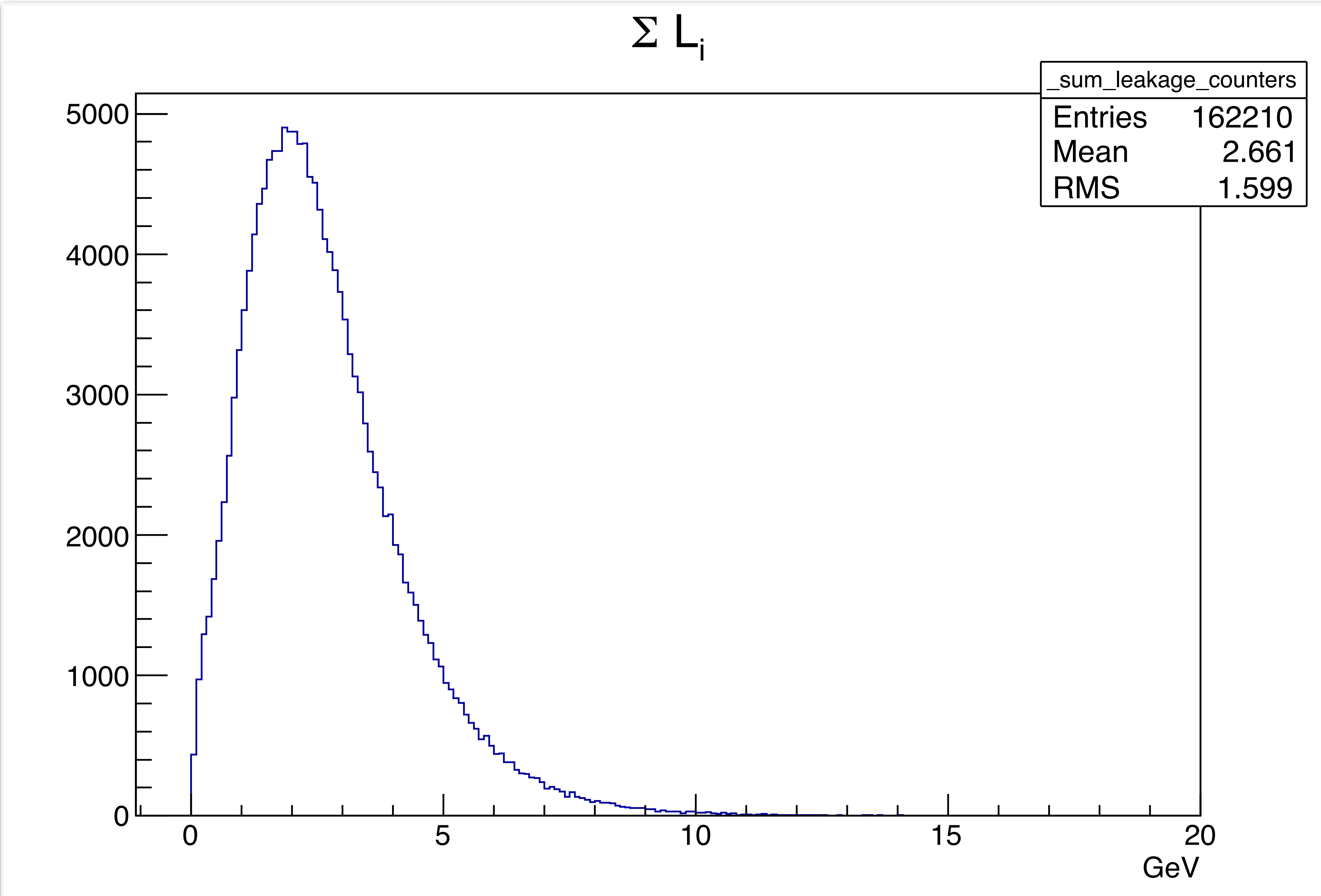
DREAM: Structure



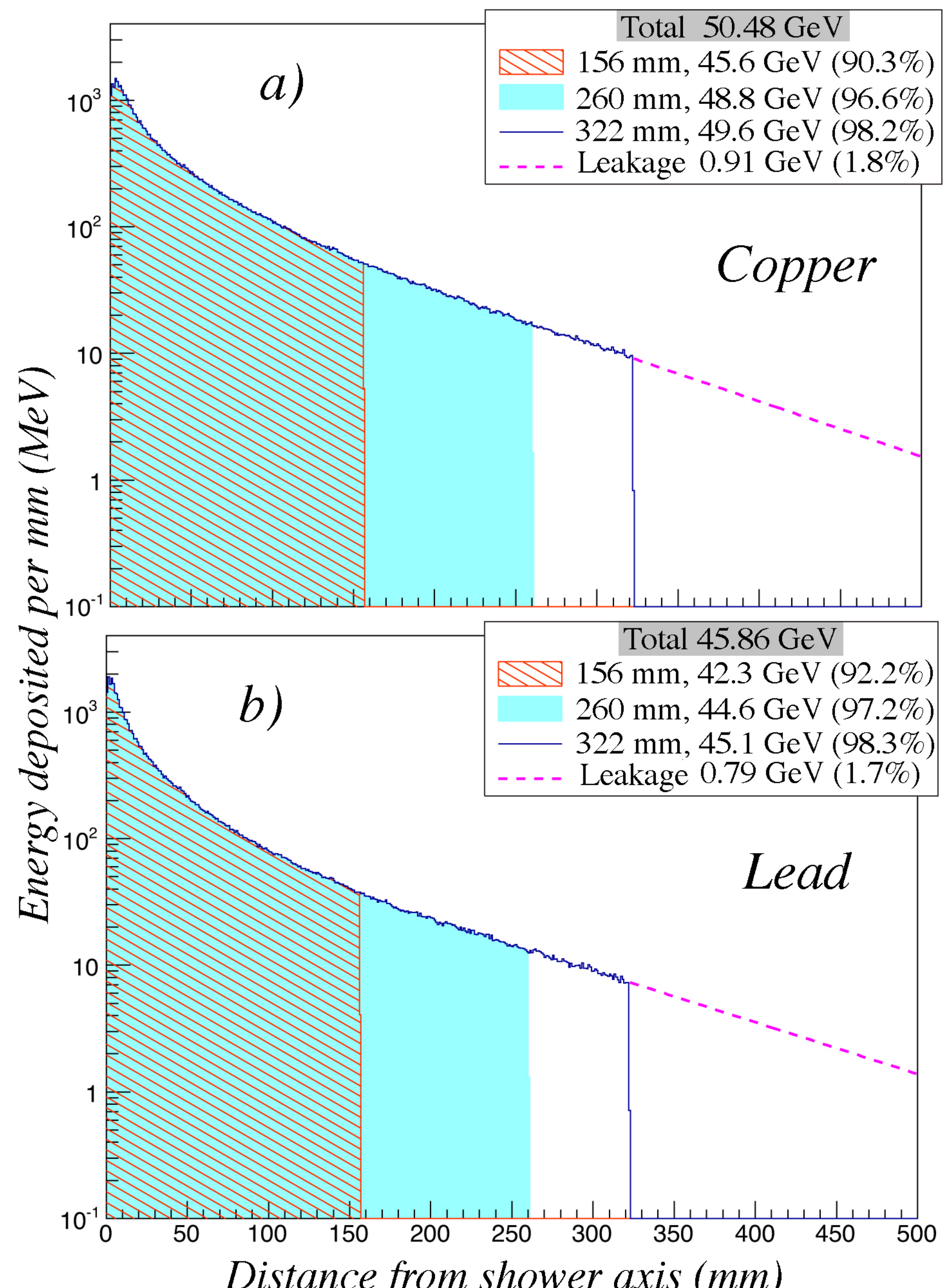


- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

Leakage Counters



Radial shower profile derived with 60 GeV pions and GEANT4



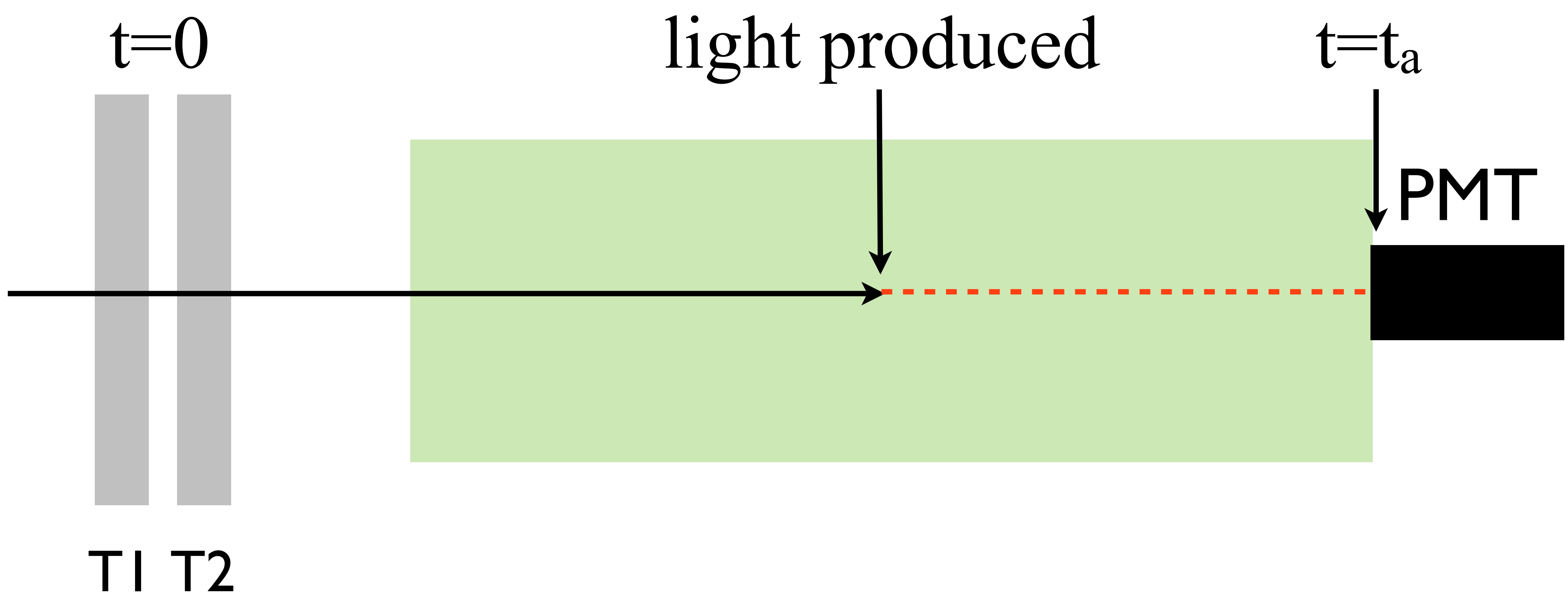
Particle ID

in the longitudinally un-segmented fiber calorimeter

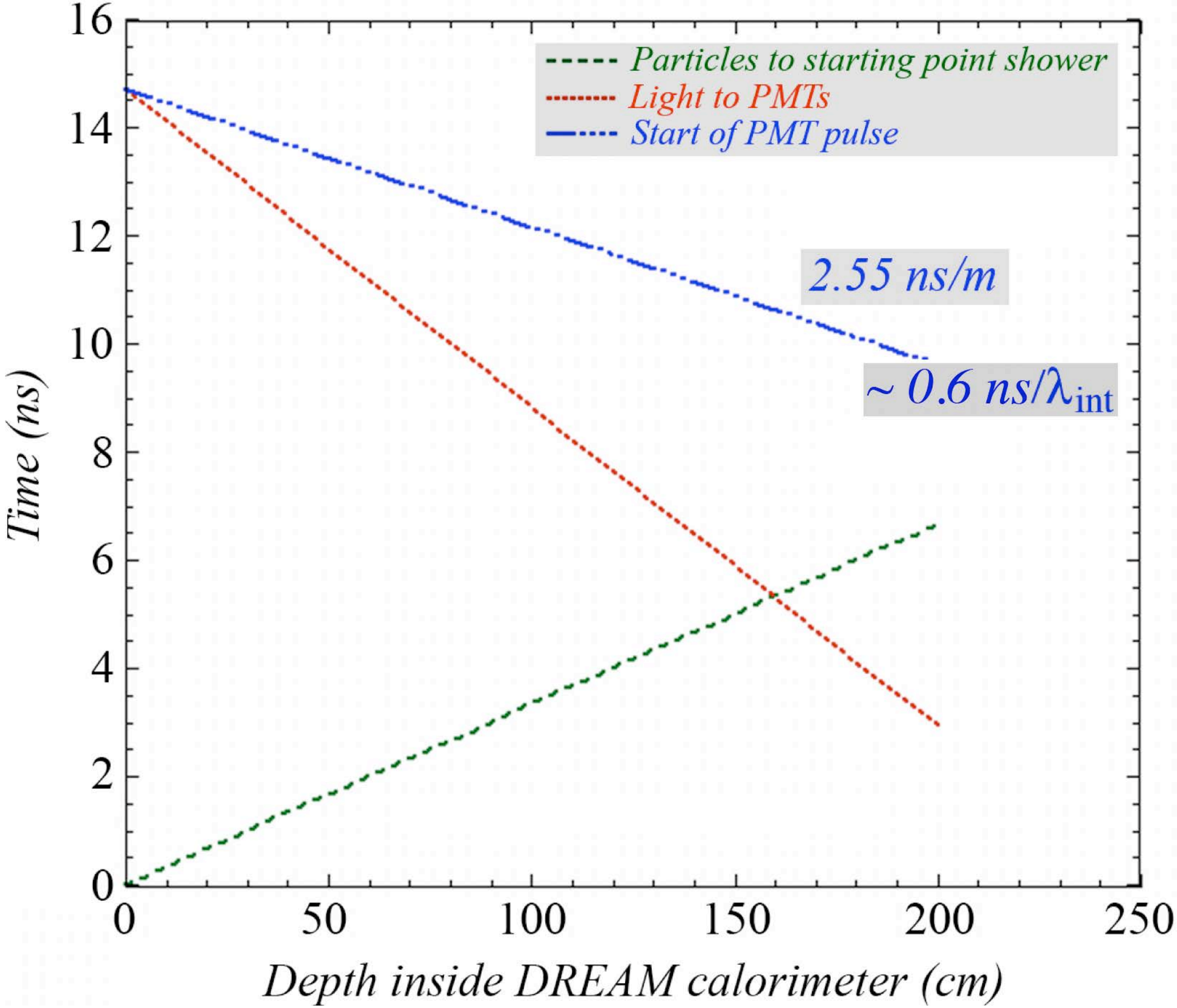
Distinguishable Features

	Electron	Pion	
Lateral shower profile (S15/∑S)	85%	40 - 50 %	Tower size: 1.6x1.6 R_M, 0.2x0.2 λ_{int}
C/S	1 (EM particles are relativistic)	Large fluctuations of the em component	
Start time of the PMT signals	The light is produced at: ~12 cm ($10X_0$) (on average)	The light is produced at: 60 cm (~2 λ_{int}) (on average)	Time between Trigger and the PMT signal
PMT Pulse (Int. charge/amp.)	relatively small and constant	Large fluctuations	The depth at which light is produced and the em comp. fluctuation

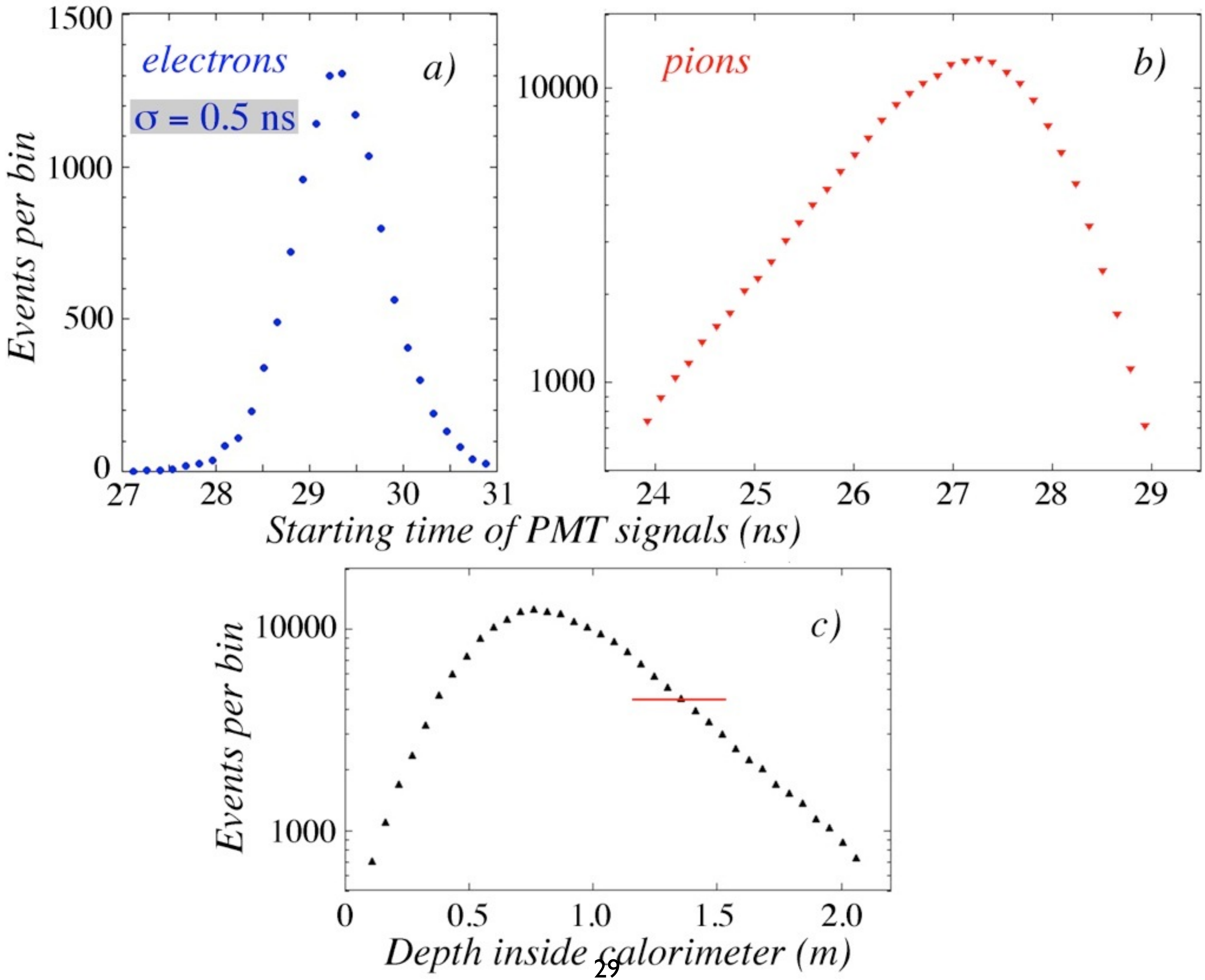
Starting Time of PMT Signals



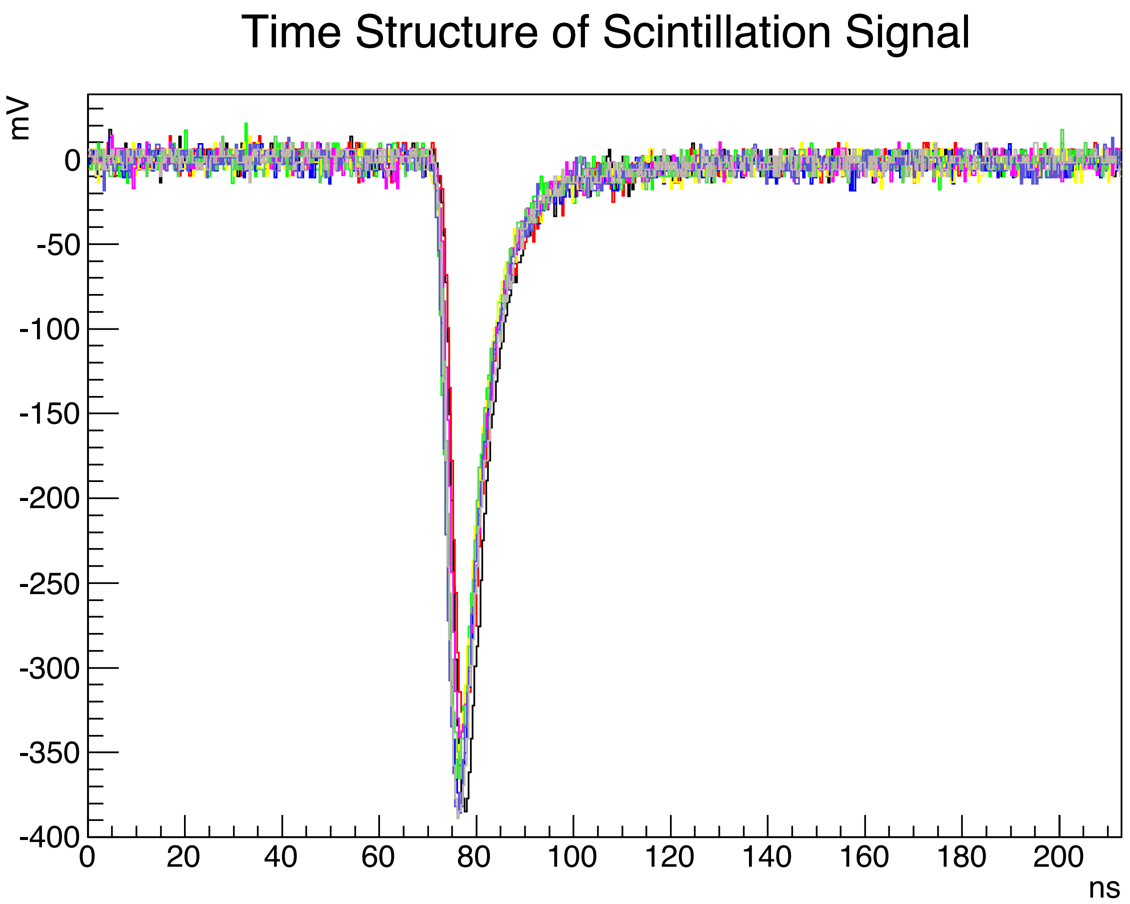
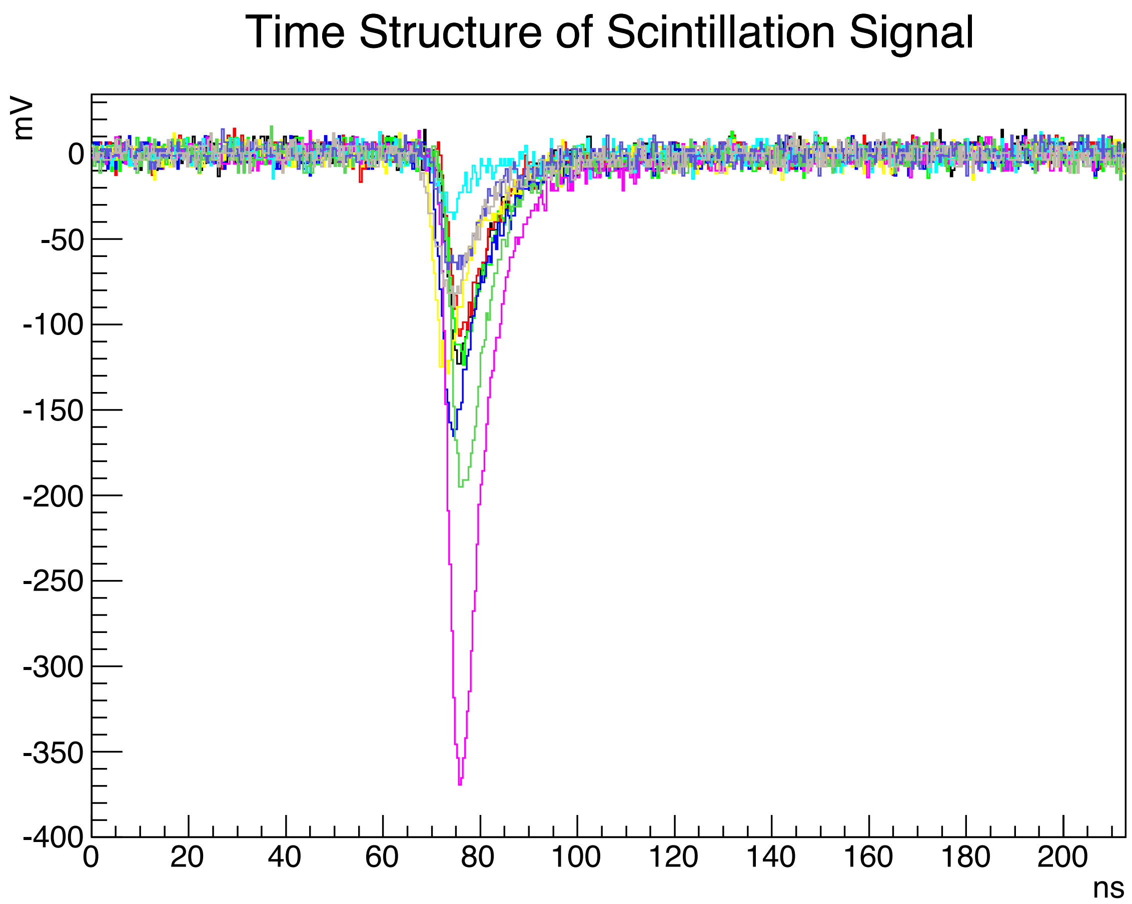
Depth of the light production and the starting point of the PMT signals



60 GeV electrons and pions

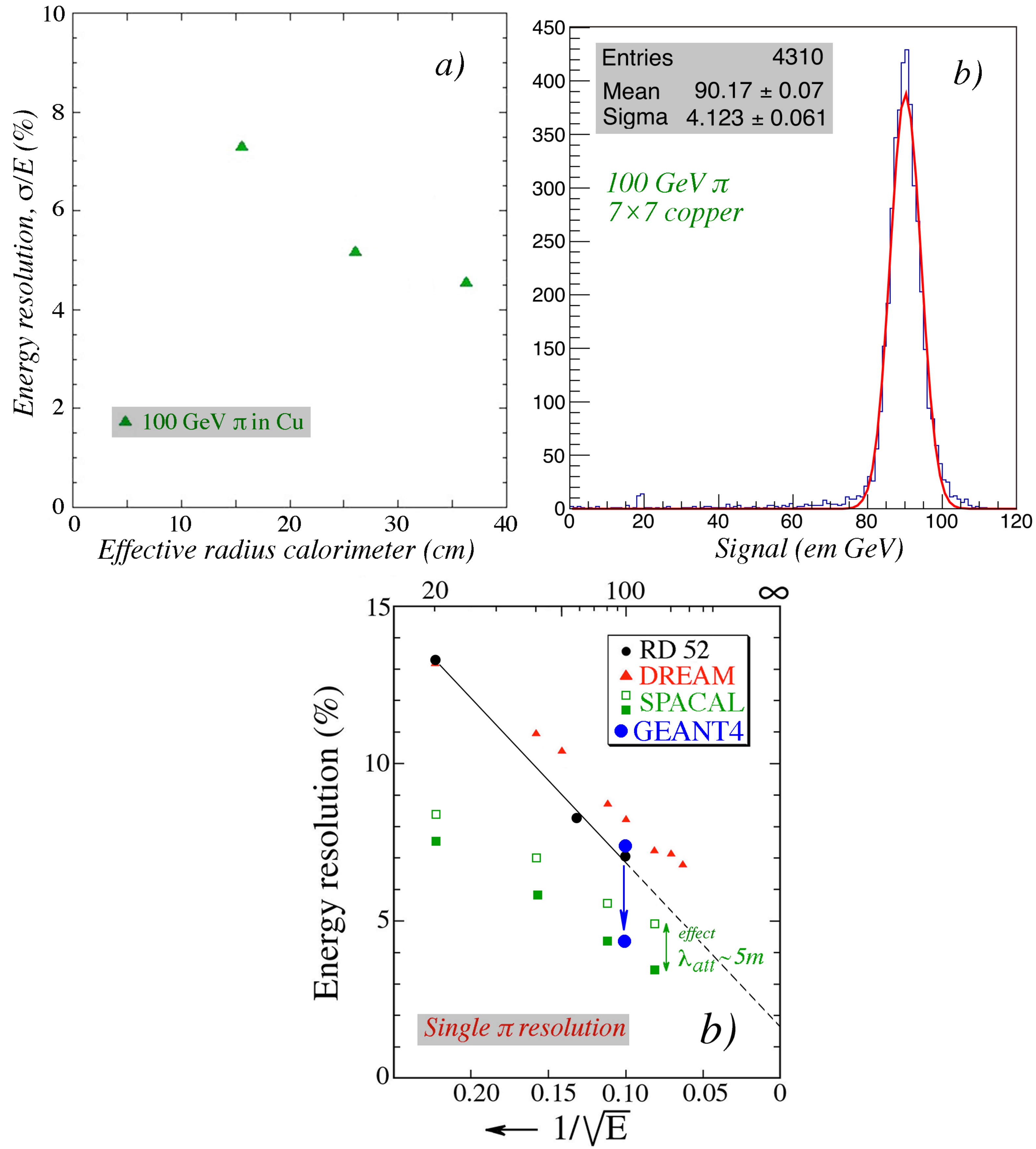


Time Structures of electrons and pions

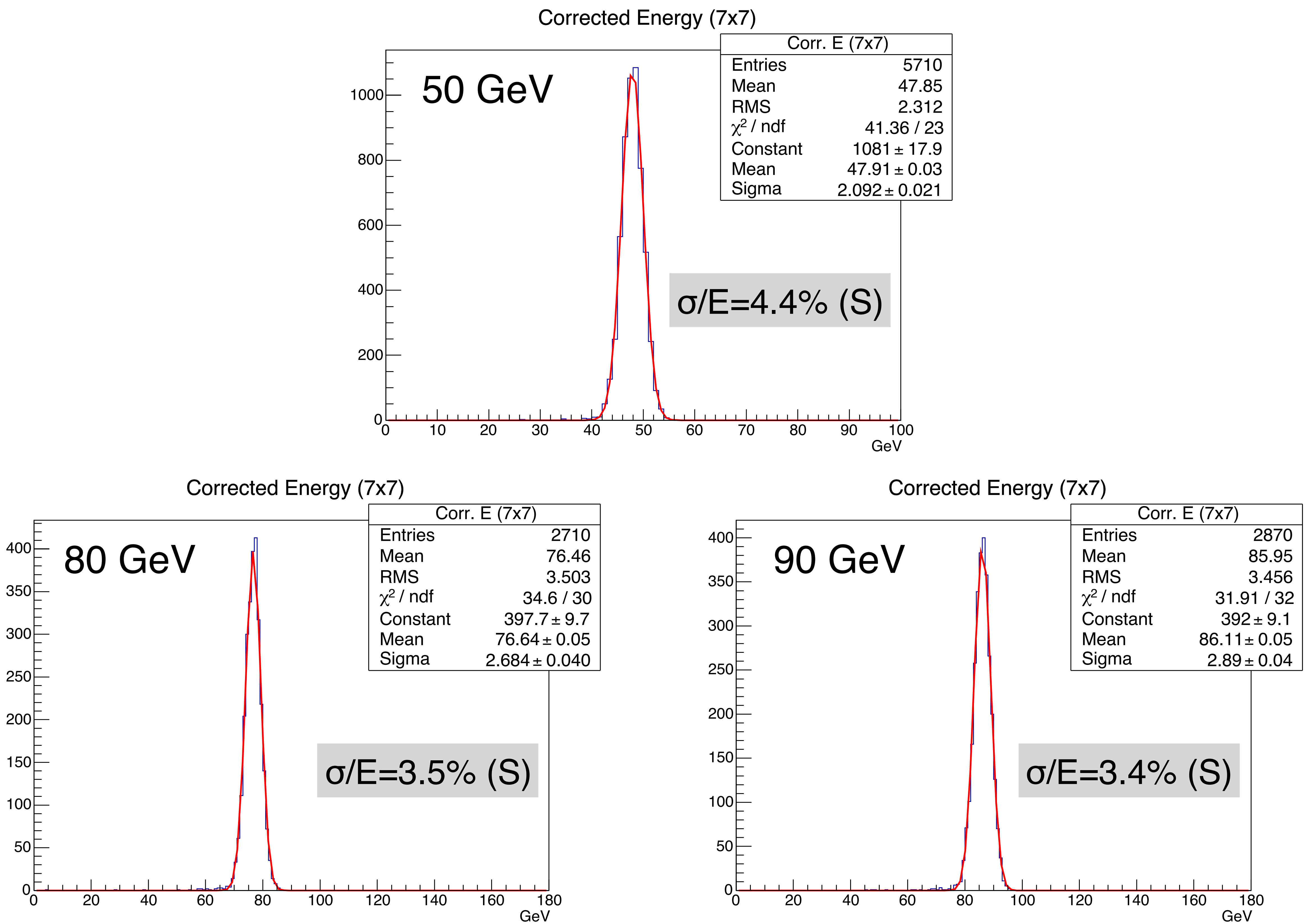
Electron (80 GeV)	Pion (80 GeV)
	

Hadronic resolutions for the different sizes of calorimeters predicted by GEANT4

Improvement in resolution when calorimeter enlarged (GEANT4)

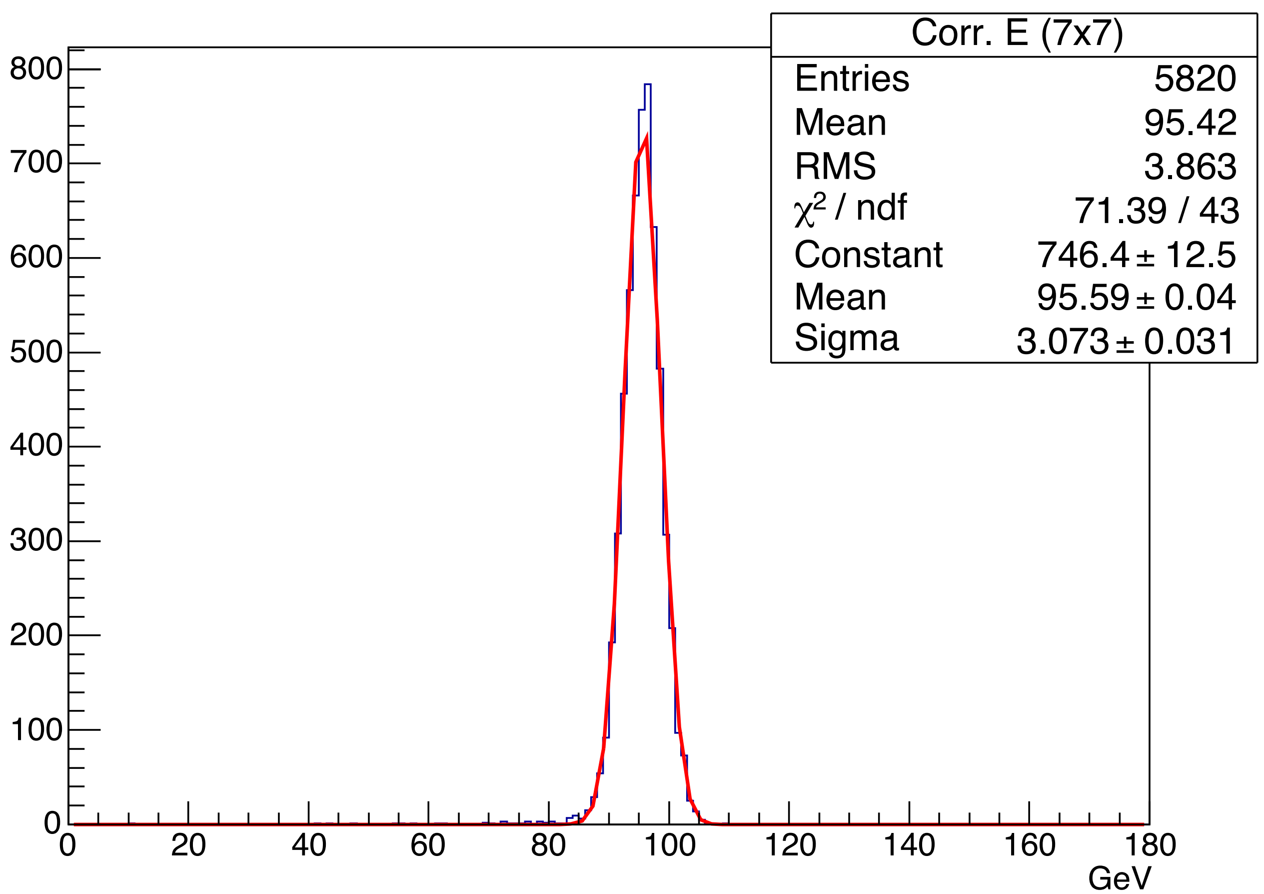


50 GeV, 80 GeV, and 90 GeV pions (GEANT 4 simulation)

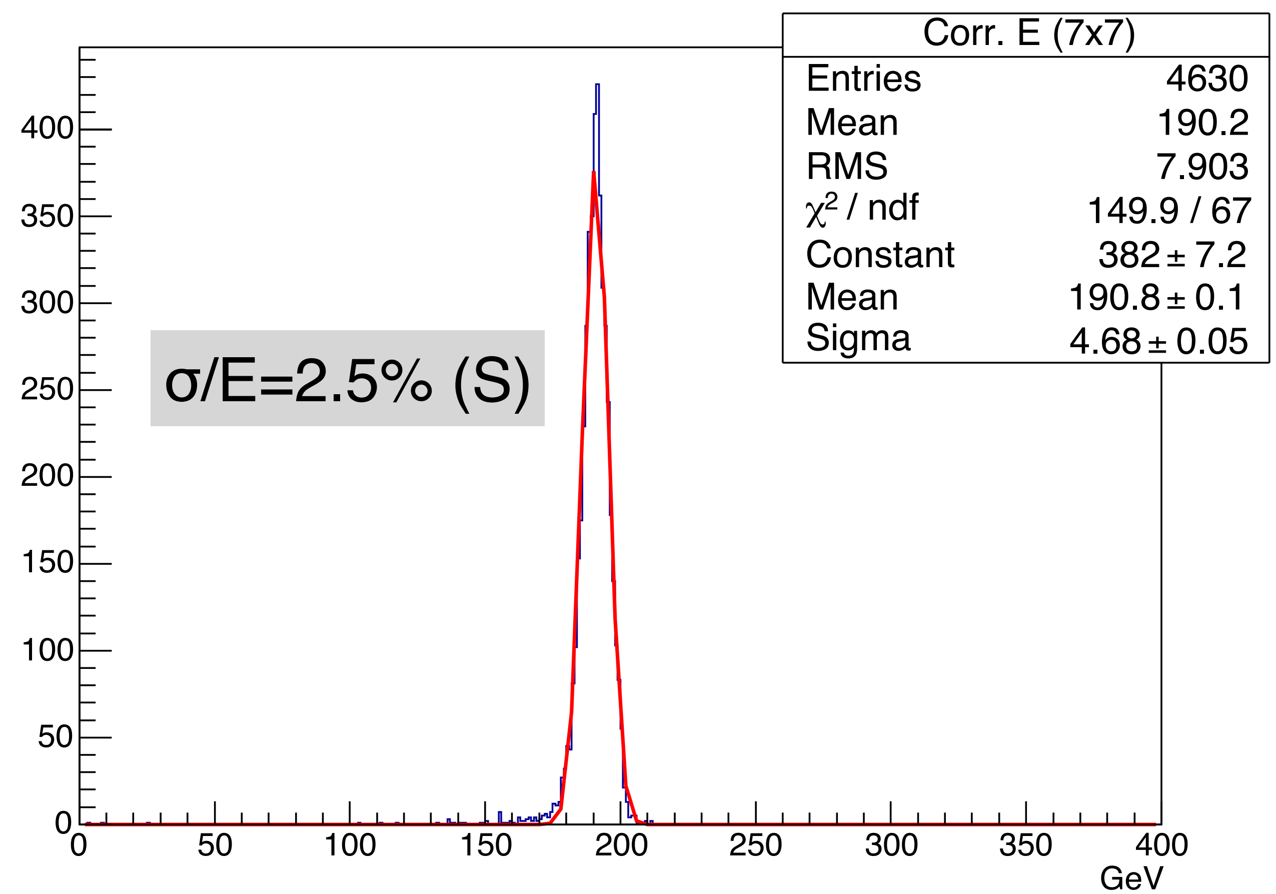


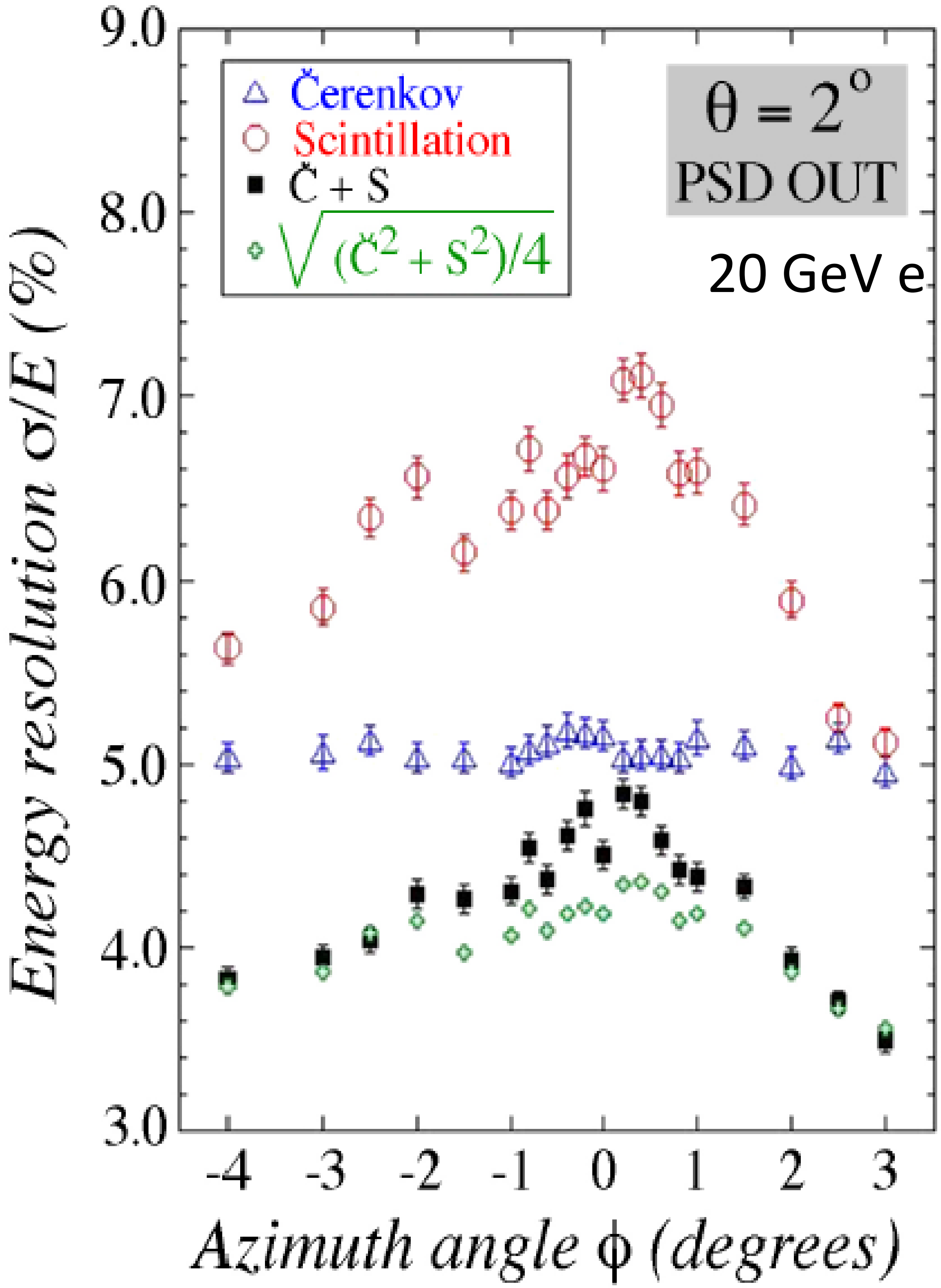
100 GeV and 200 GeV (GEANT 4 simulation)

100 GeV pions

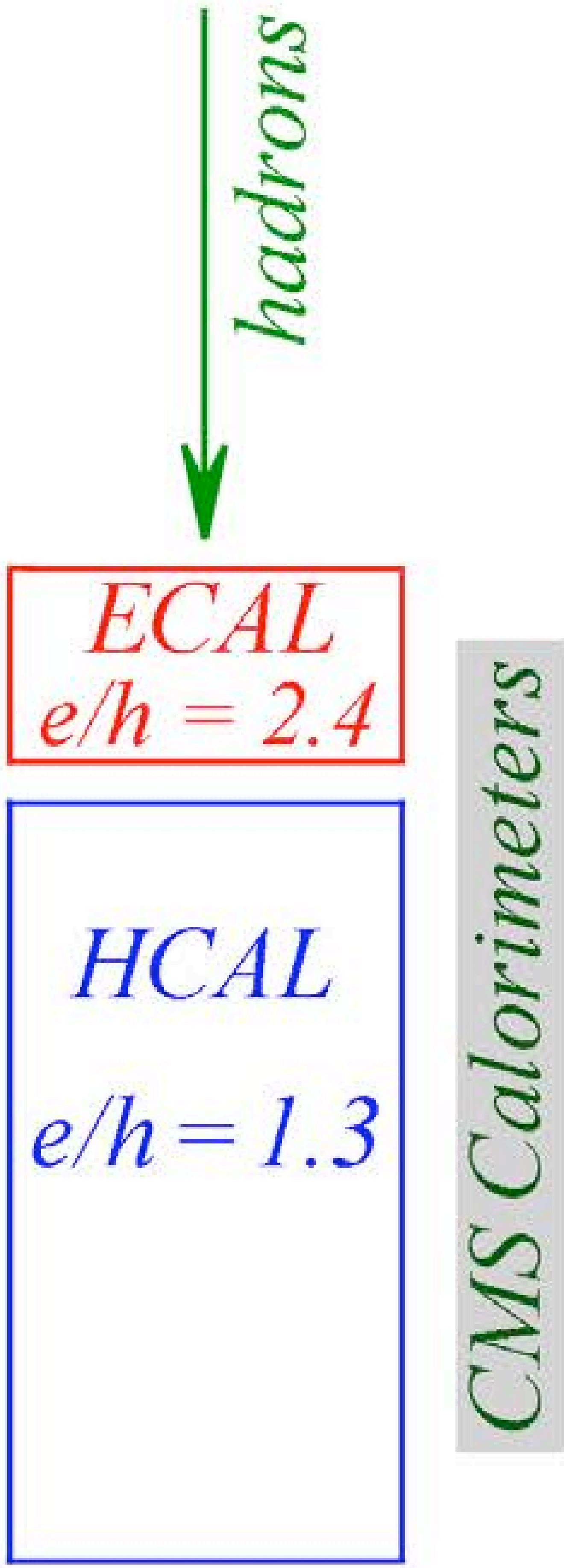


200 GeV pions




Čerenkov
Scintillation
Č + S
$\sqrt{(\check{C}^2 + S^2)/4}$
θ = 2°
PSD OUT
20 GeV e
Energy resolution σ/E (%)
Azimuth angle φ (degrees)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
-4
-3
-2
-1
0
1
2
3

Longitudinally Segmented Calorimeter



$$Q = \sum_{j=1}^{N} \left[E - A \sum_{i=1}^{n} S_{ij}^{\mathrm{em}} - B \sum_{i=1}^{n} S_{ij}^{\mathrm{had}} \right]^2$$

E: Beam Energy

$\sum S^{em}$: *the sum of all the signal in ECAL*

$\sum S^{had}$: *the sum of all the signal in HCAL*