Energy Resolution of LDC01 and LDC01Sc Model

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- **Introduction**
- **Energy resolution for photon**
- **Energy resolution for hadron**
- **Summary**

Introduction

- **MOKKA 5.5, GEANT 4.8.0 and LC Physics List**

- **LDC detector**
  - **LDC01: RPC digital HCAL (DHCAL)**
  - **LDC01Sc: Scintillator tile analogue HCAL (AHCAL)**
  - **Ecal @ LDC01 & LDC01Sc:**
    - **20 layers 2.1 mm W**
    - **10 layers 4.2 mm W**

- **We study the energy response by hits**
  - **Ecal:** $E_{ecal} = \sum_{i=1,20} E_i^{hit} + 2.0 * \sum_{i=21,30} E_i^{hit}$
  - **Analogue HCAL:** $E_{hcal} = \sum E_i^{hit}$
  - **Digital HCAL:** $E_{hcal} = a * N_{hit} + b * N_{hit}^2$
  - **Hadrons:** $E_{tot} = E_{ecal} + weight * E_{hcal}$

Introduction

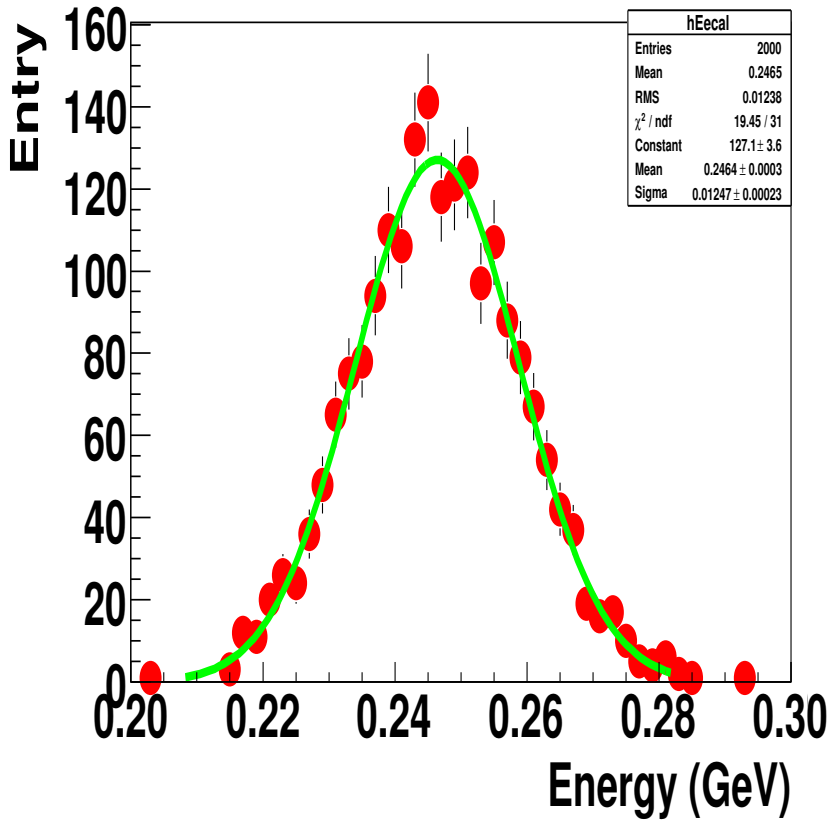
- **Hit selection**
  - **Ecal: hit energy $E_{hit} > 0.6 * 0.00016$ GeV**
  - **Analogue HCAL: hit energy $E_{hit} > 0.3 * 10^{-3}$ GeV**
  - **Digital Hcal: hit energy $E_{hit} > 0.3 * 10^{-6}$ GeV**

- **Simulated event samples**
  - **Single particle per event: photon, neutron, π^+, K_L^0, anti-neutron**
  - **photon: 2000 events from 0.25 to 300 GeV**
  - **hadrons: 10000 events from 2.0 to 100 GeV**
  - **All particles with $\cos(\theta) = 0.0$ and random ϕ in [0, 2.0*π]; 10.0 GeV neutron and π^+ with $\cos(\theta) = 0.1, \cdots, 0.9$ and random ϕ in [0, 2.0*π]**

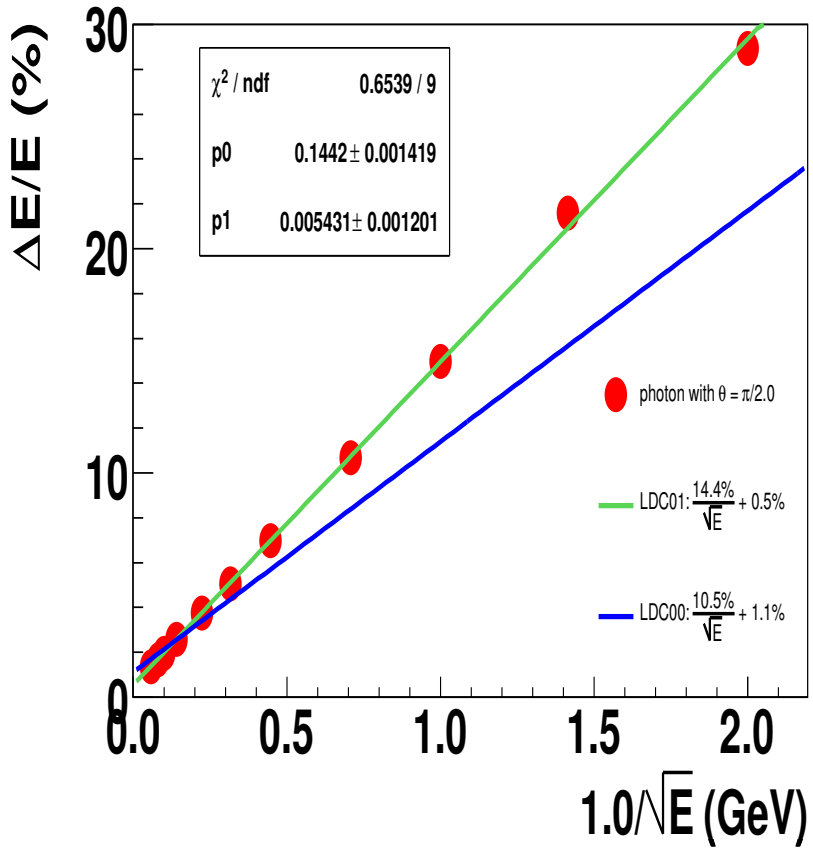
- **Hadrons: scaled energy $\rightarrow$ compare different hadrons on the same scale**

Particle	Neutron	Anti-neutron	K_L^0	π^+
Energy	$E_n - mass$	$E_{\bar{n}} + mass$	$E_{K_L^0}$	E_{π^+}

Energy resolution for photon

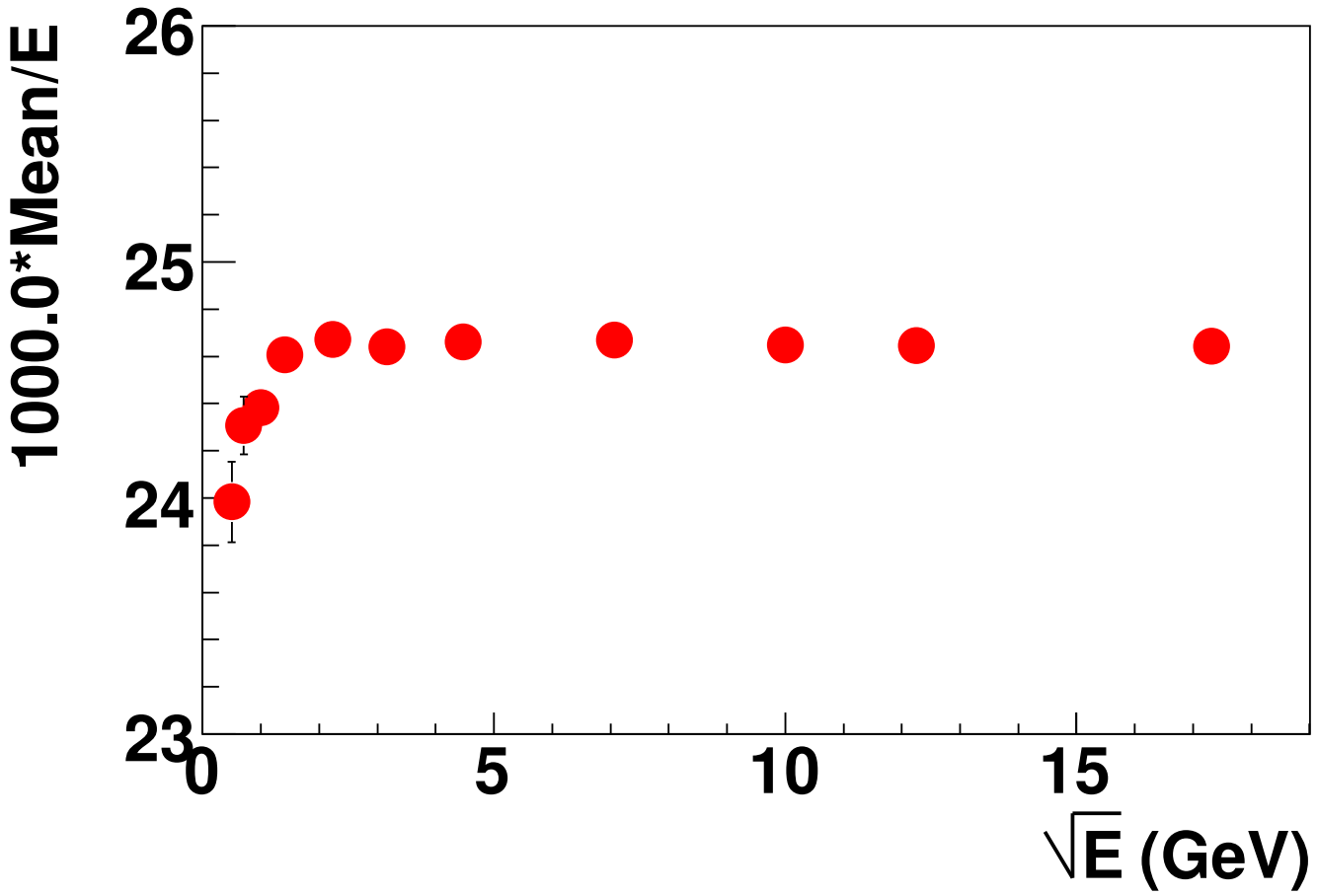


- **Gaussian fit: peak ± 3.0 * RMS**



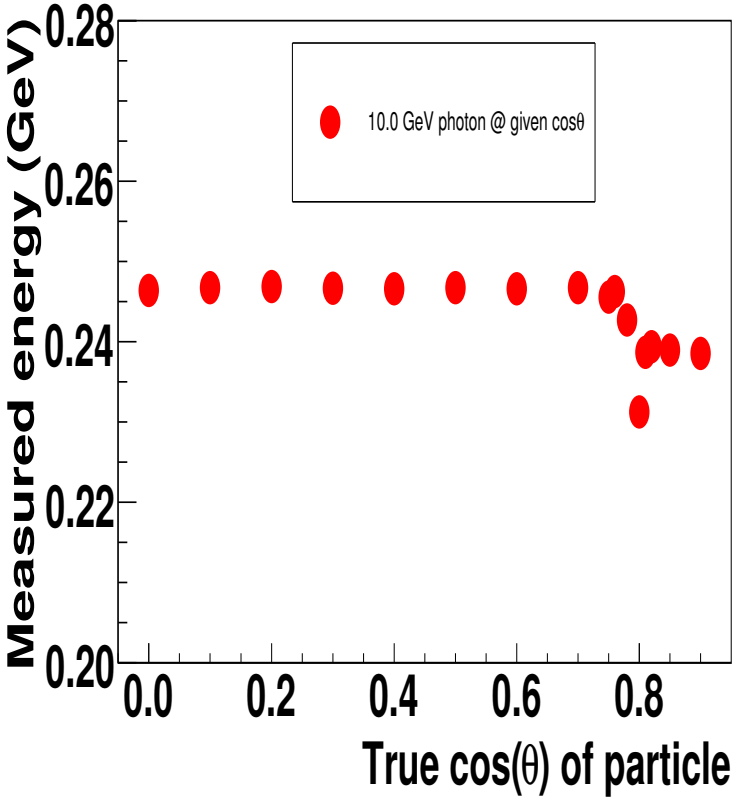
- **Photon resolution of LDC01 is worse than that of LDC00.**

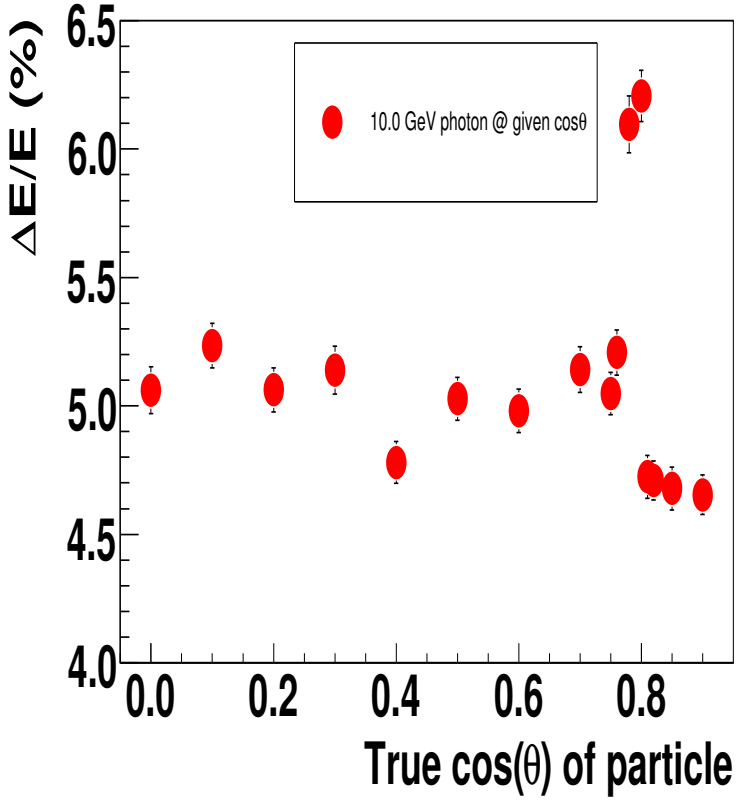
Linearity for photon



- **linearity: $\sim$ 2%, better linearity at energy $>$ 5.0 GeV**

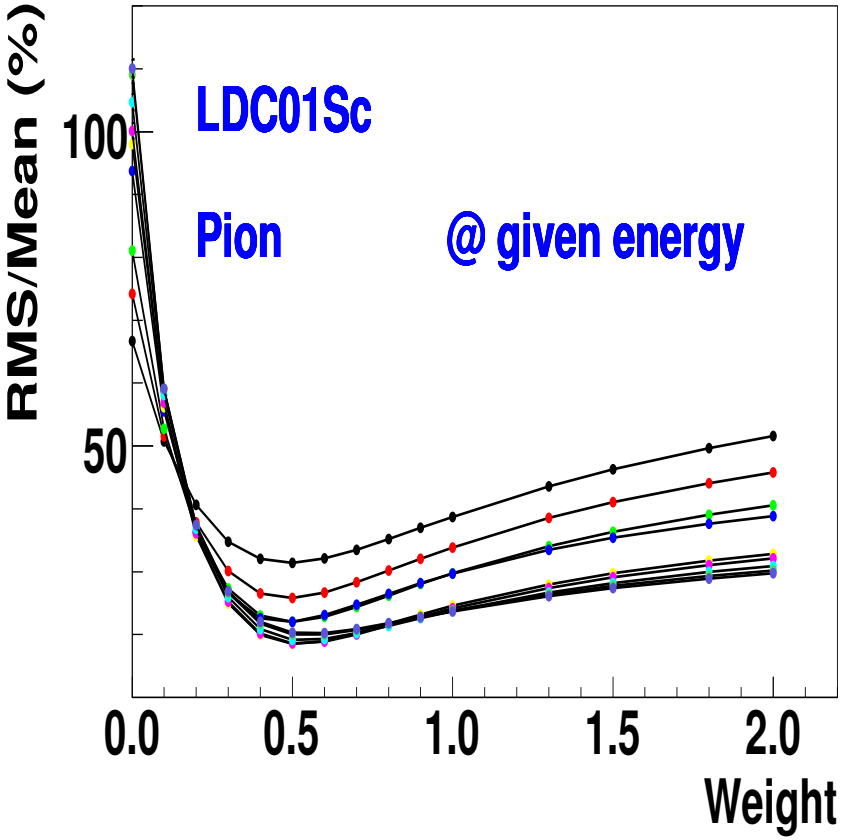
Energy response and resolution vs. θ for photon

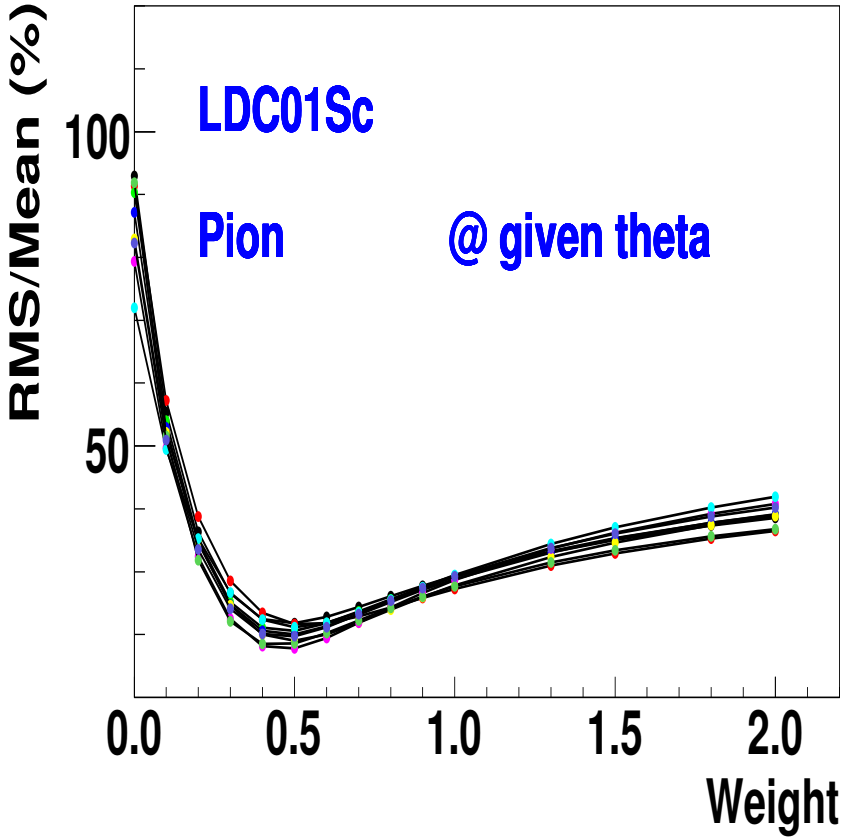




- **Energy response and resolution are uniform for $|\cos(\theta)| < 0.75$.**
- **Barrel and end-cap overlap $|\cos(\theta)| \sim 0.80$: spike; End-cap region: lower energy response and better energy resolution**

Energy resolution for hadron: LDC01Sc

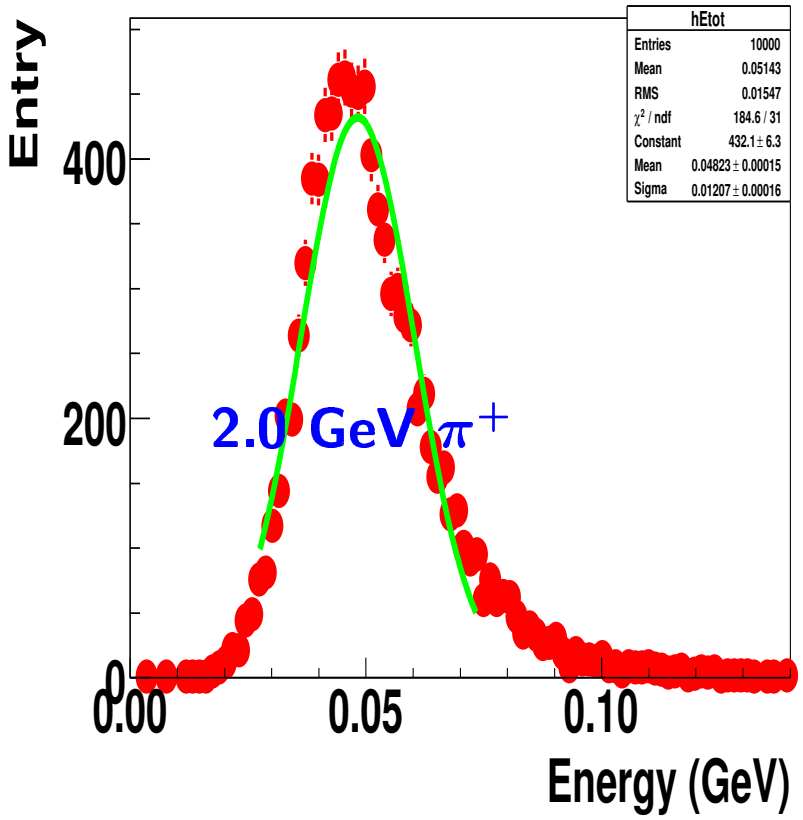


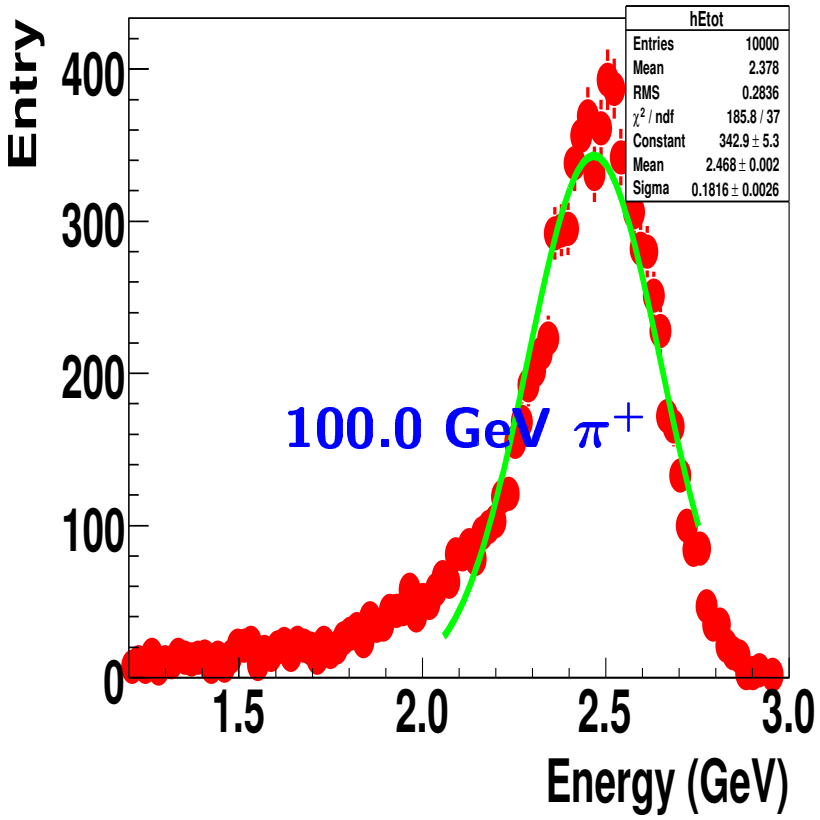


- π^+ with energy in [2, 100] GeV
- 10.0 GeV π^+ $\cos\theta$ in [0.1, 0.9]

- Neutron, anti-neutron and K_L^0 also support: $E_{tot} = E_{ecal} + 0.5 * E_{hcal}$

Energy resolution for hadron: LDC01Sc

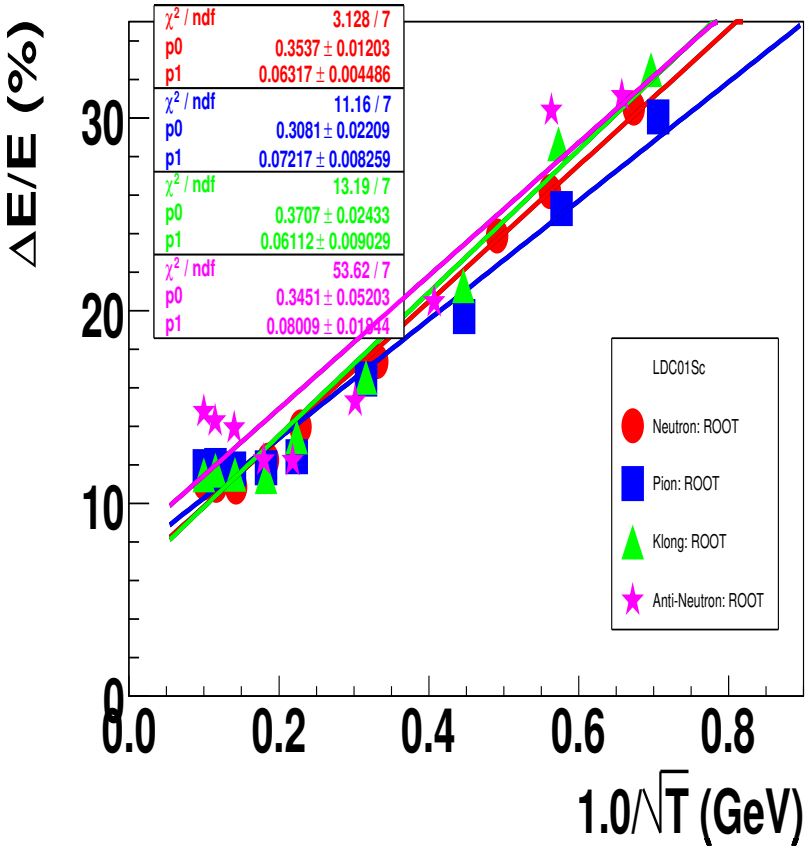




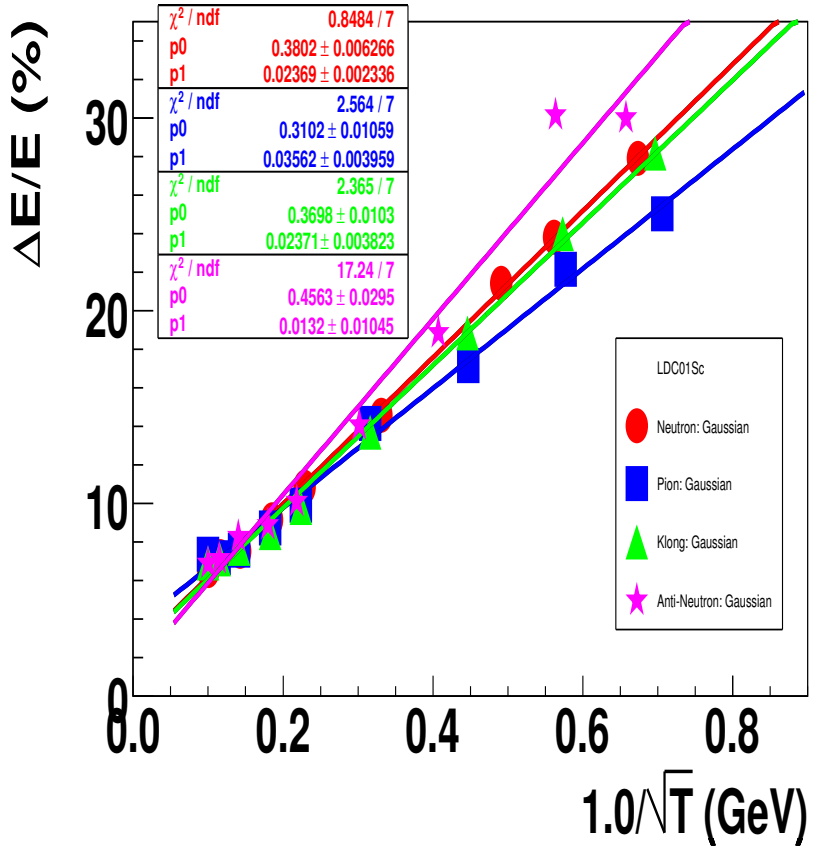
- **low tail: energy leakage; high tail: Landau tail**
- **Gaussian fitting for maximum region with $15\%/$ of peak value.**
- **Raw RMS & Mean by ROOT $\longrightarrow$ energy response and resolution**

Energy resolution for hadron: LDC01Sc

- **By Raw RMS & Mean of ROOT**

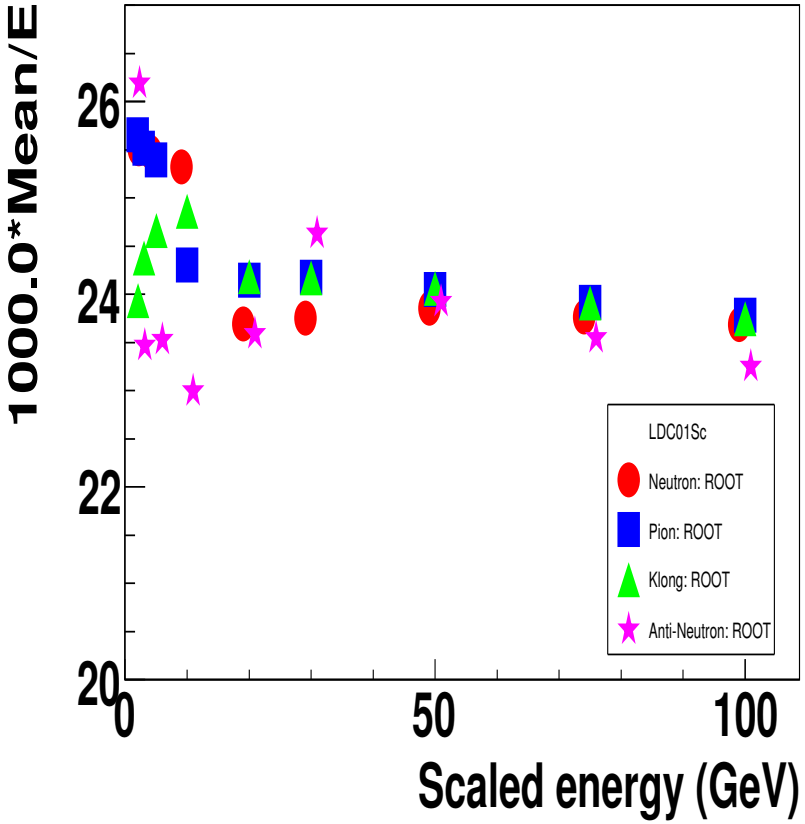


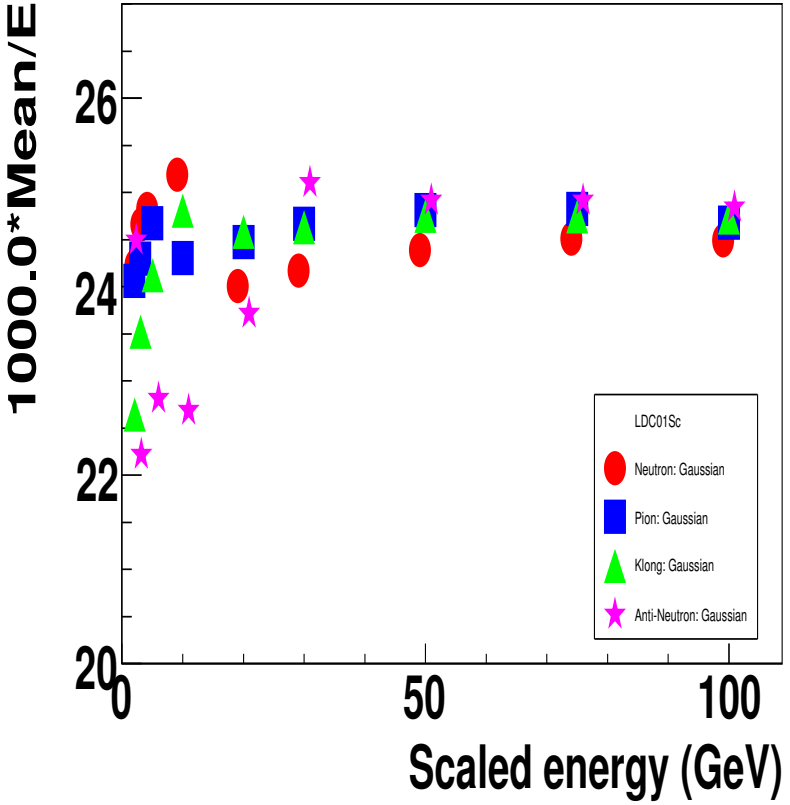
- **By Gaussian fitting**



- **Energy resolutions are about $(30-40)\%/\sqrt{T}+(1-7)\%$. Results by fitting and Root value are different due to non-Gaussian tail.**

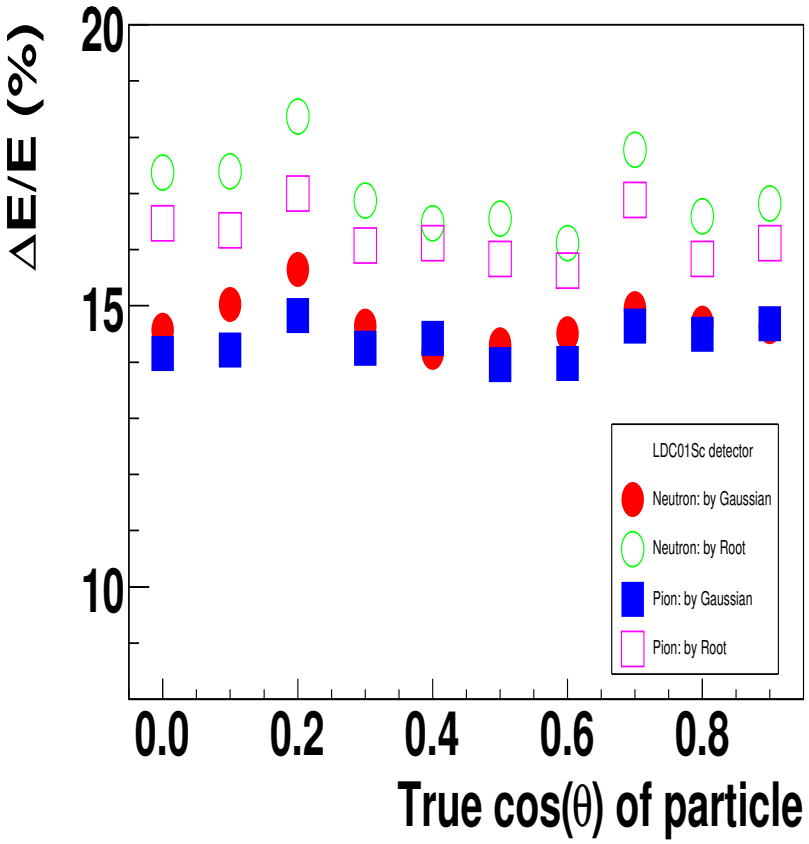
Linearity for hadron: LDC01Sc

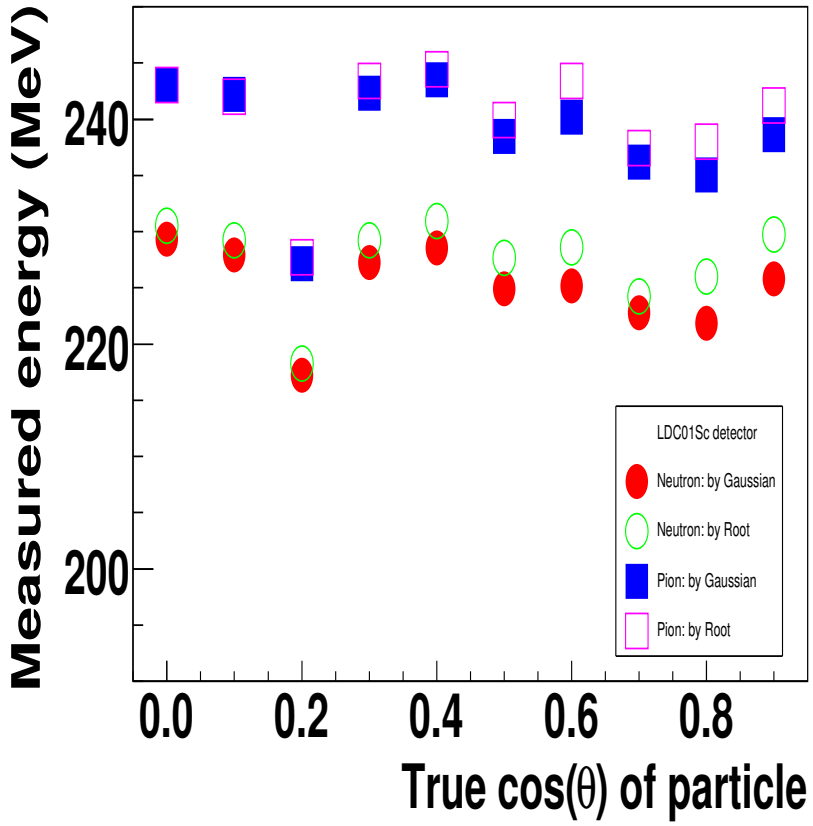




- **Linearity: $\sim$ 5% for Gaussian fitted values.**

Energy response and resolution vs. θ: LDC01Sc

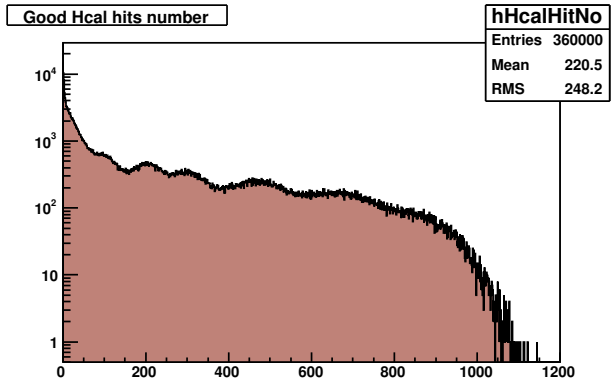


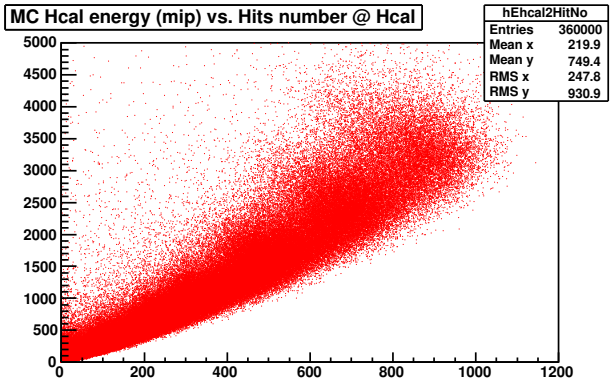


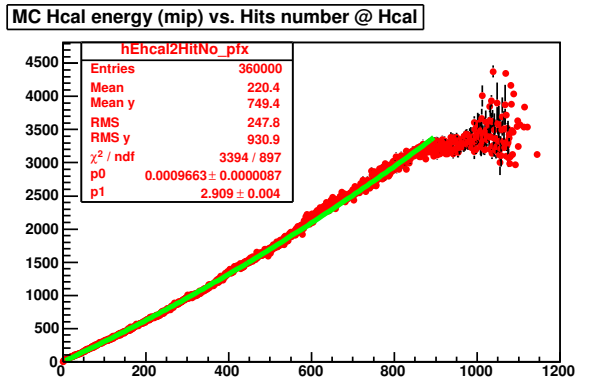
- **π^+ with energy in [2, 100] GeV**
- **10.0 GeV π^+ $\cos\theta$ in [0.1, 0.9]**

- **Energy response and resolution are uniform on θ for hadrons.**

Energy resolution for hadron: LDC01







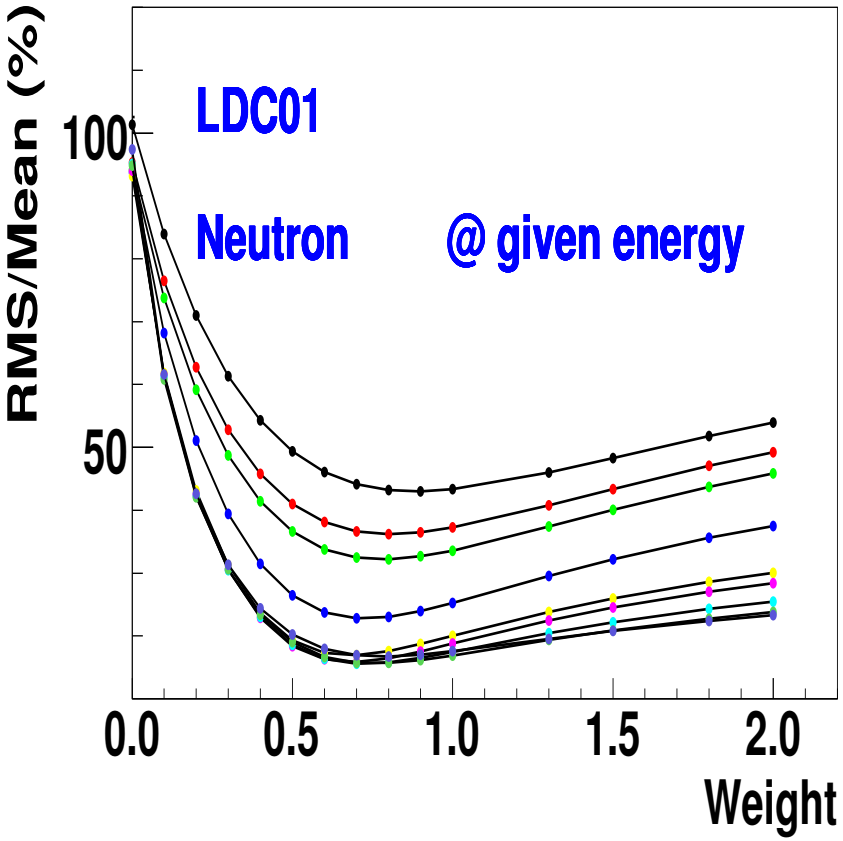
LDC01 detector

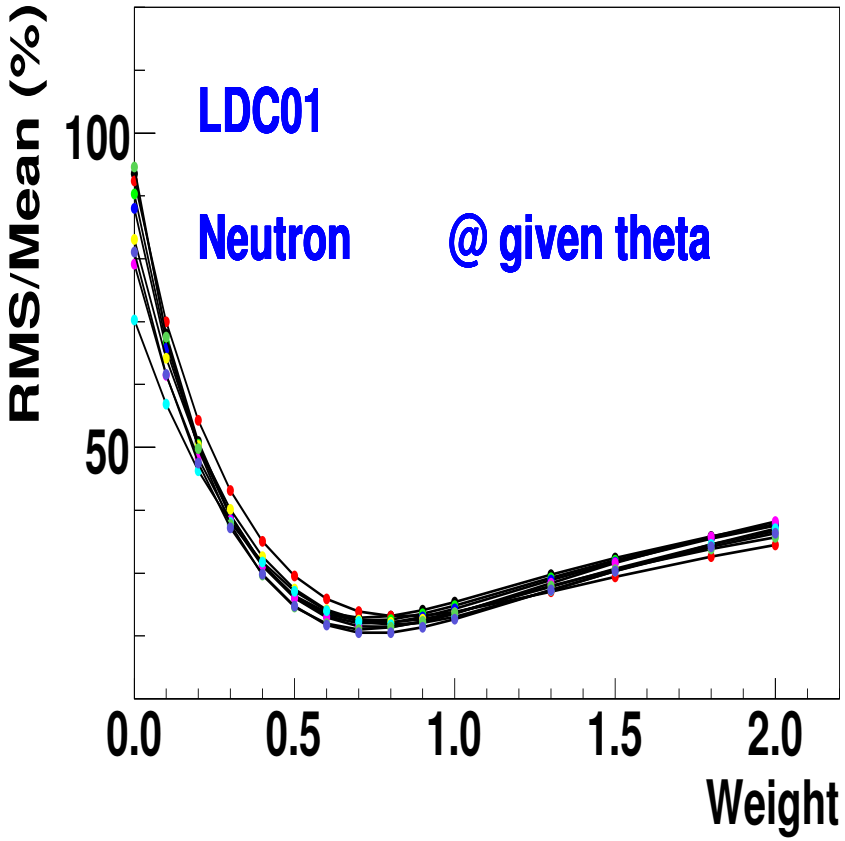
Hadron samples

fitting

- **Neutron, π^+, K_L^0 and anti-neutron samples with energy [2.0, 100.0] GeV**
- **Fitting: $E_{Hcal} = a * N_{hit} + b * N_{hit}^2$ (in MIPs)**

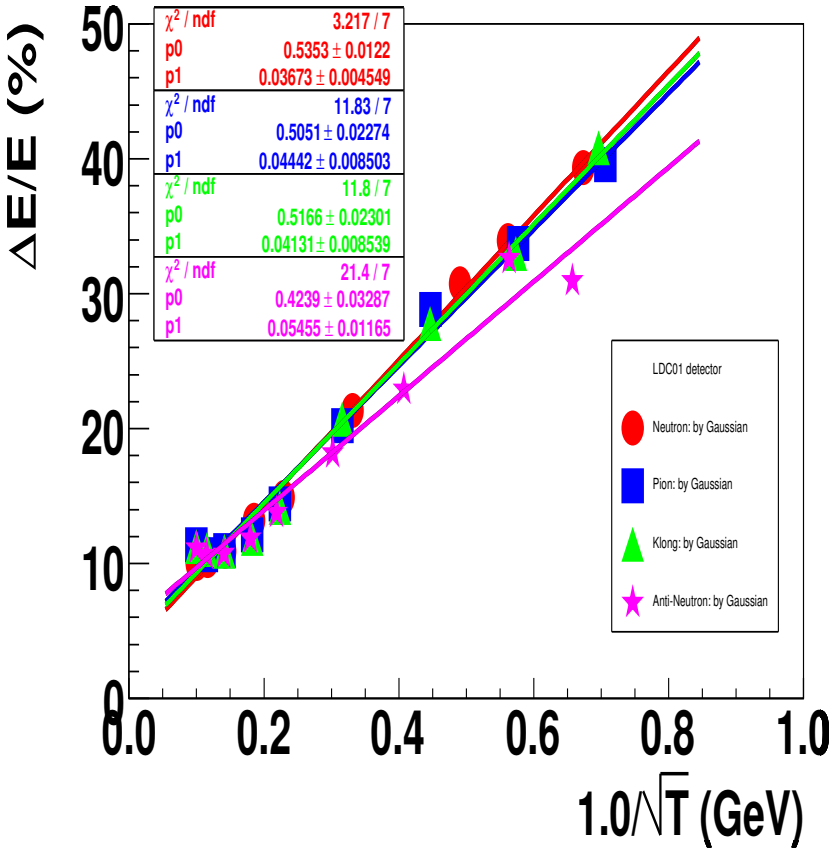
Energy resolution for hadron: LDC01

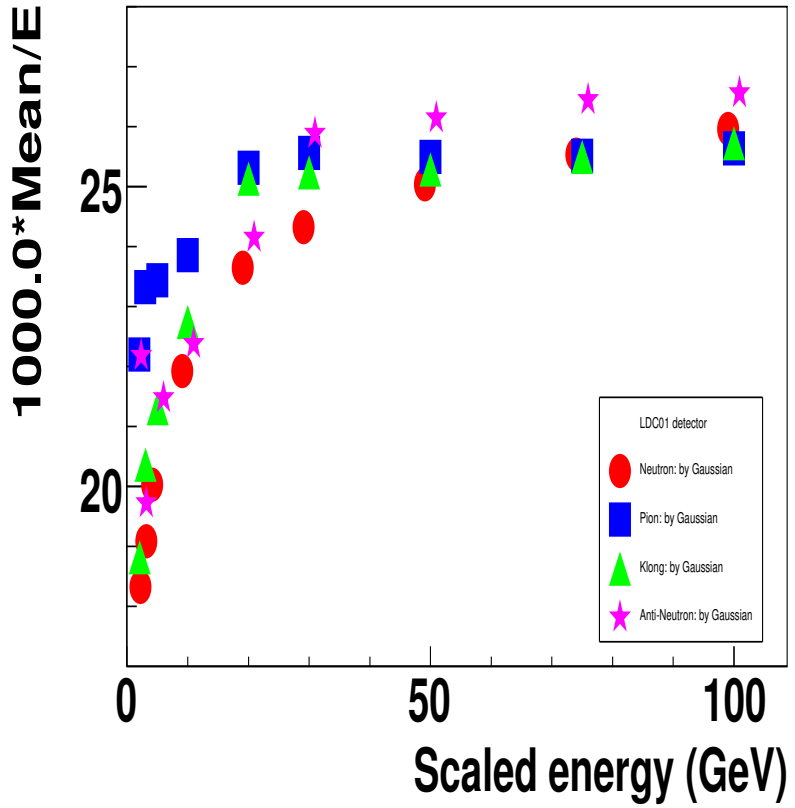




- **Neutron energy: [3, 100] GeV**
- **10.0GeV neutron $\cos\theta$: [0.1, 0.9]**
- **Best $E_{tot} = E_{ecal} + 0.8 * E_{hcal}$ for Neutron, acceptable for anti-neutron, K_L^0 and π^+.**

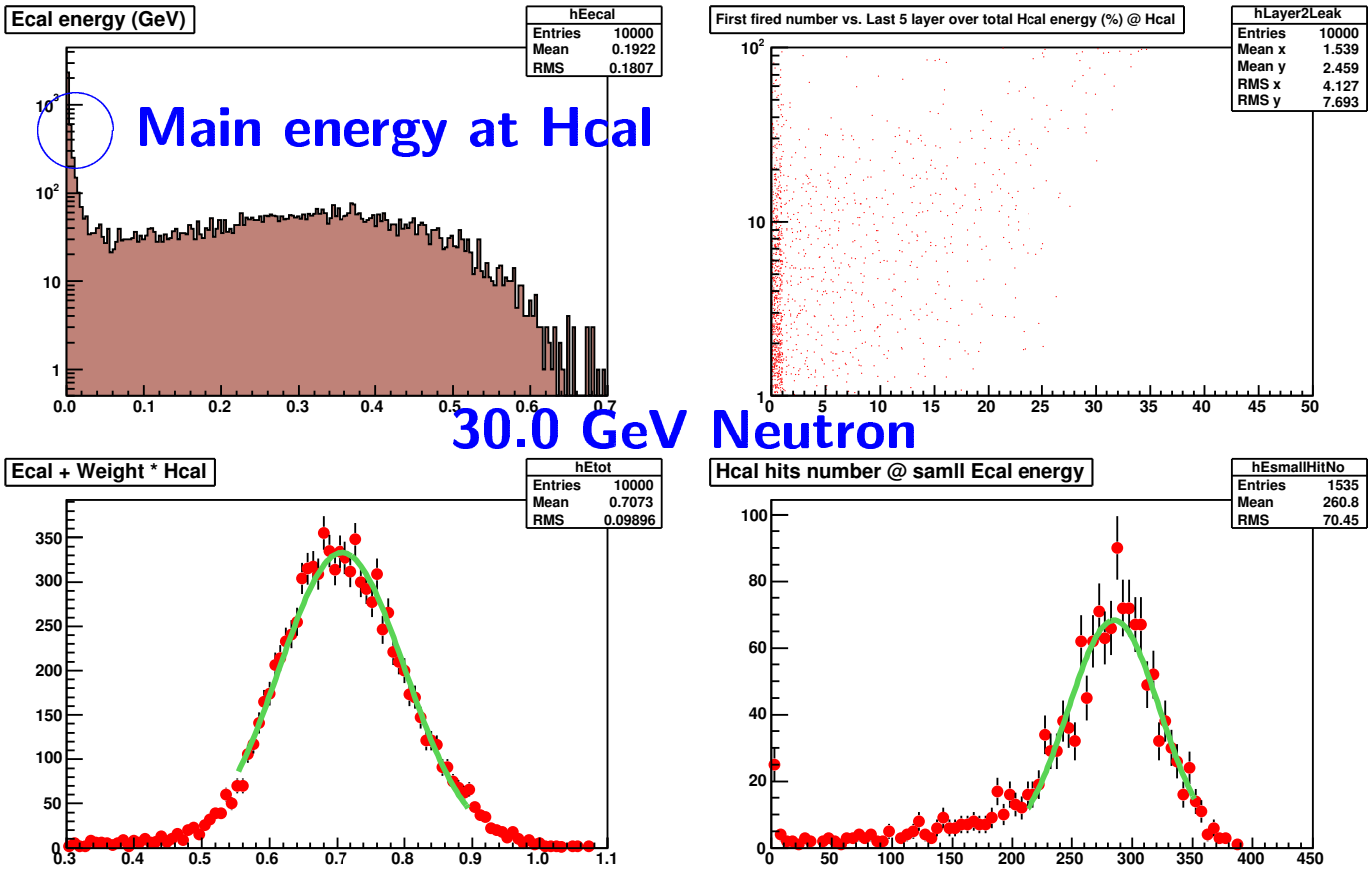
Energy resolution and Linearity for hadron: LDC01





- **Energy resolution are about $50\%/\sqrt{T}$ with constants in the range $3-5\%$. Energy resolutions are consistent except anti-neutron at low energy.**
- **Energy responses are consistent at high energy.**

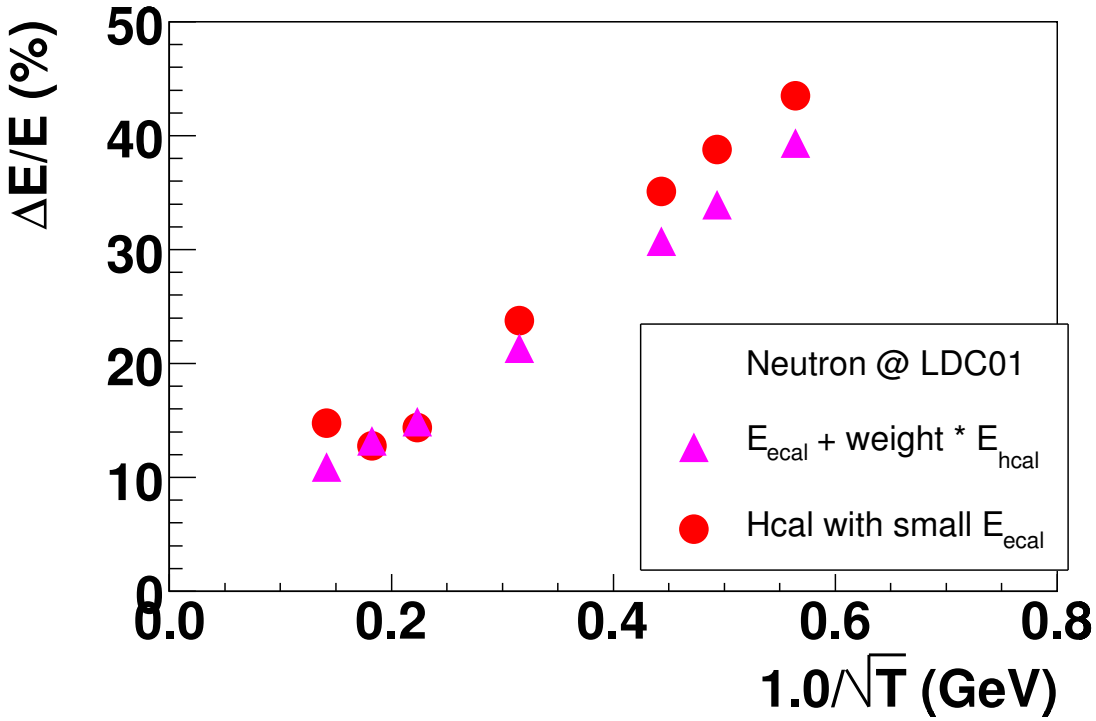
Hcal with small E_{ecal} method: LDC01



- **Hcal with small E_{ecal} method: Hcal-alone resolution**
  - **Gaussian fitting for the number of hits in Hcal**
  - **$E_{ecal}/E_{beam} < 5 \times 10^{-5}$**
  - **First fired layer number in Hcal < 20**

Energy resolution for hadron: LDC01

- $E_{ecal} + weight * E_{hcal}$ **method:** $E_{Hcal} = a * N_{hit} + b * N_{hit}^2$ **fitting and weighting factor** $weight$
- **Hcal with small** E_{ecal} **method: Independent of** a, b **and weighting factor** $weight$**; more sensitive to energy leakage**



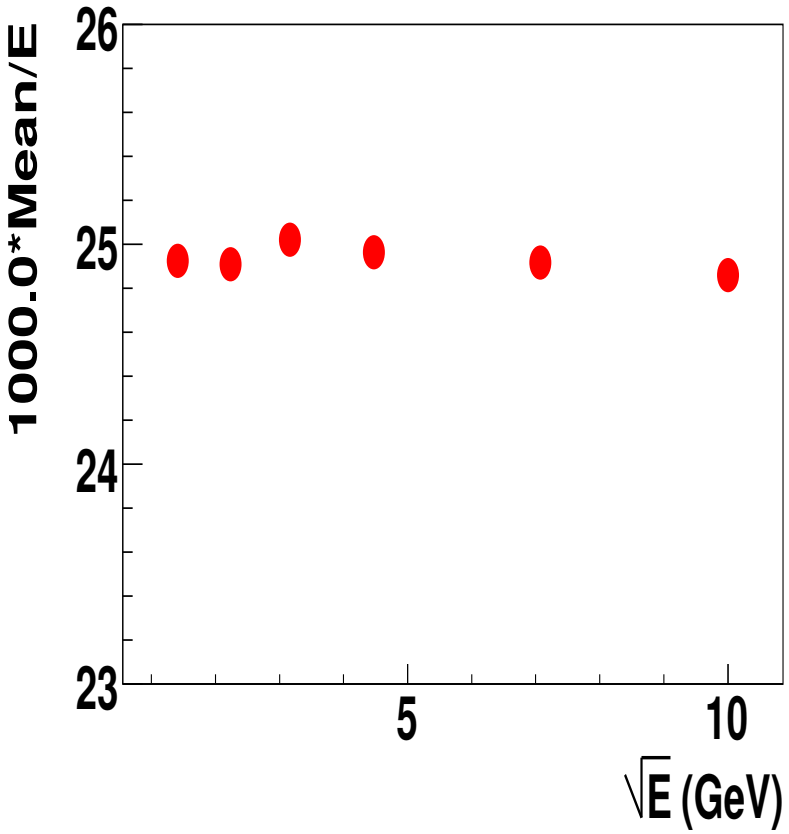
Summary and outlook

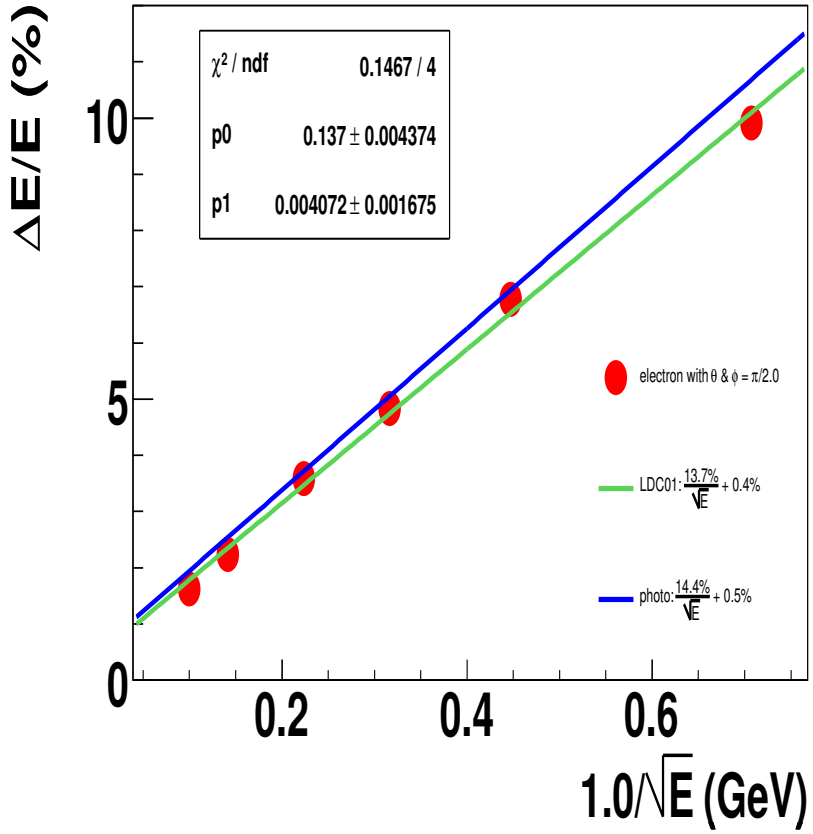
- **Photon energy resolution**
  - $14.4\%/\sqrt{E} + 0.5\%$
  - **Photon energy resolution of LDC01 is worse than that of LDC00**
- **Hadron energy resolution**
  - **Analogue Hcal:** $(30-40)\%/\sqrt{E} + (1-7)\%$
  - **Digital Hcal:** $\sim 50\%/\sqrt{E} + (3-5)\%$
  - **Anti-neutron at low energy: ???**
- **Energy resolution and energy response on the θ dependence**
- **Linearity for photon and hadrons**

Energy Resolution of LDC01 and LDC01Sc Model

Backup Slides

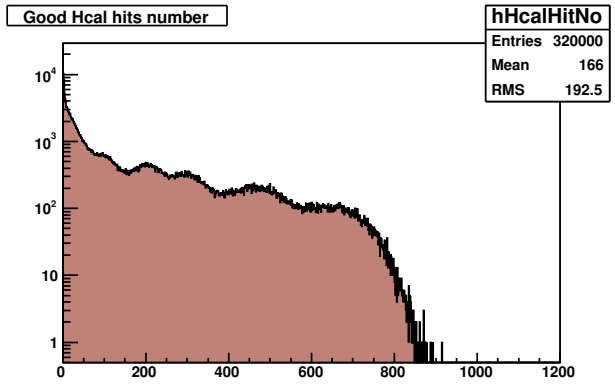
Energy resolution for electron: LDC01

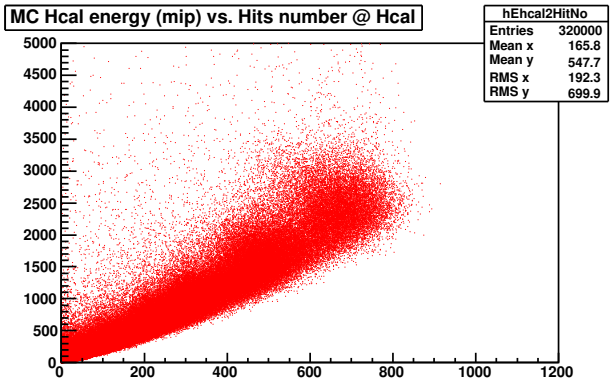


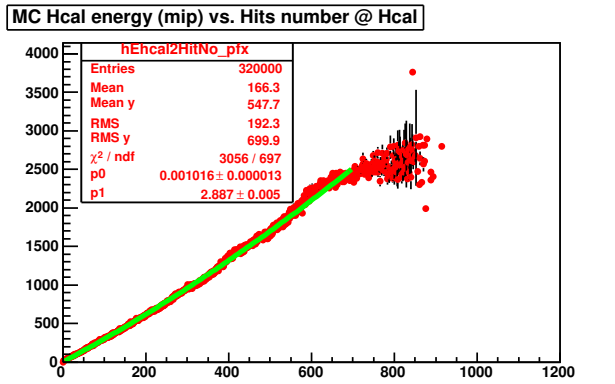


- **Mike's electron sample:** $13.7\%/\sqrt{E} + 0.4\%$
- **Photon energy resolution:** $14.4\%/\sqrt{E} + 0.5\%$

Energy resolution for hadron: LDC01







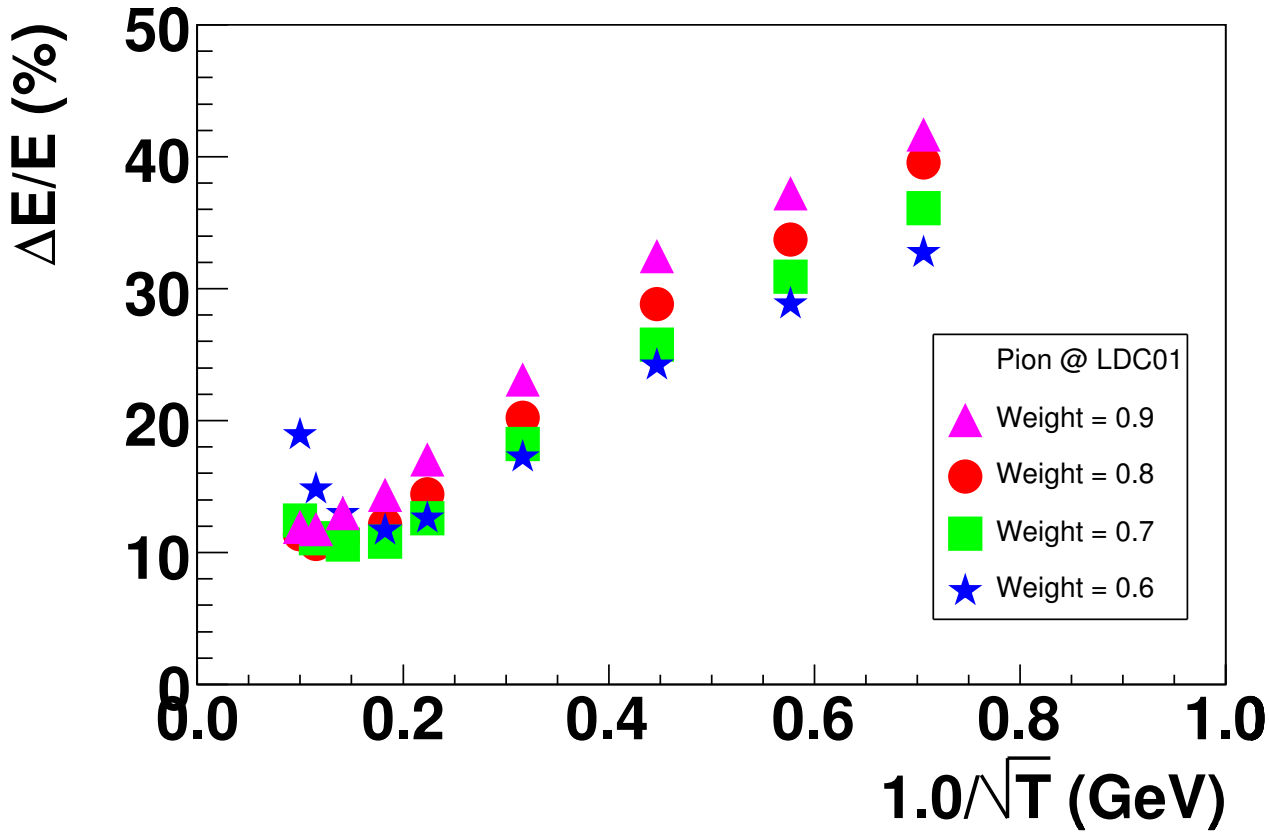
LDC01 detector

Hadron samples

fitting

- **Neutron, π^+, K_L^0 and anti-neutron samples with energy [2.0, 75.0] GeV**

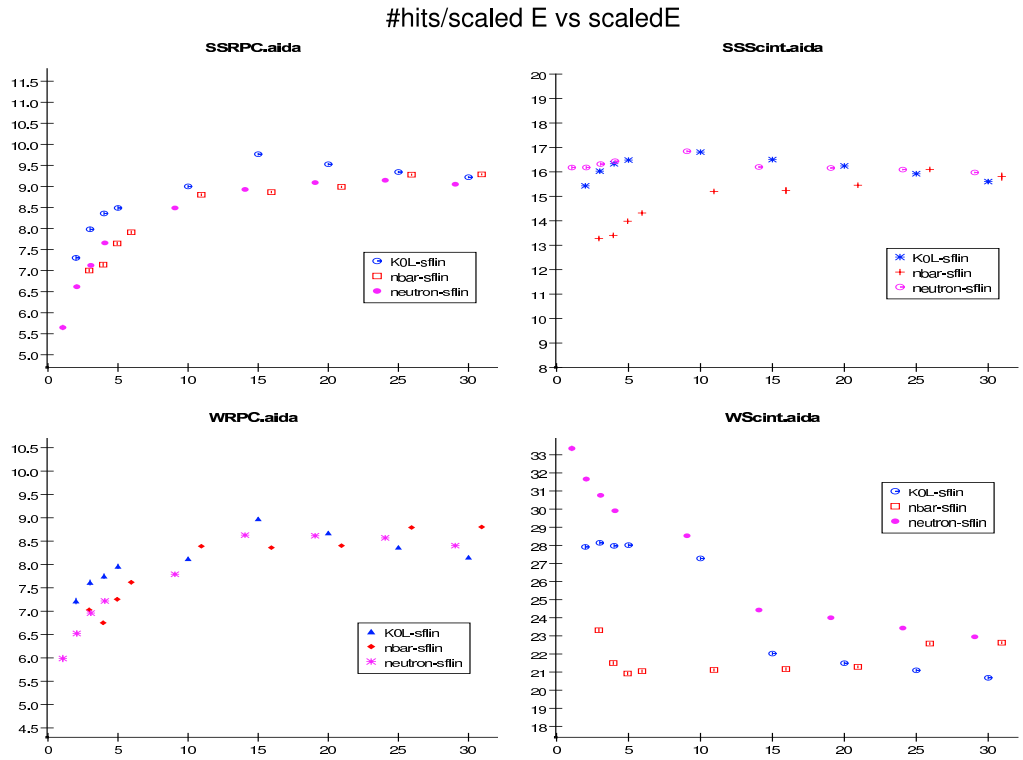
Energy resolution for hadron: LDC01



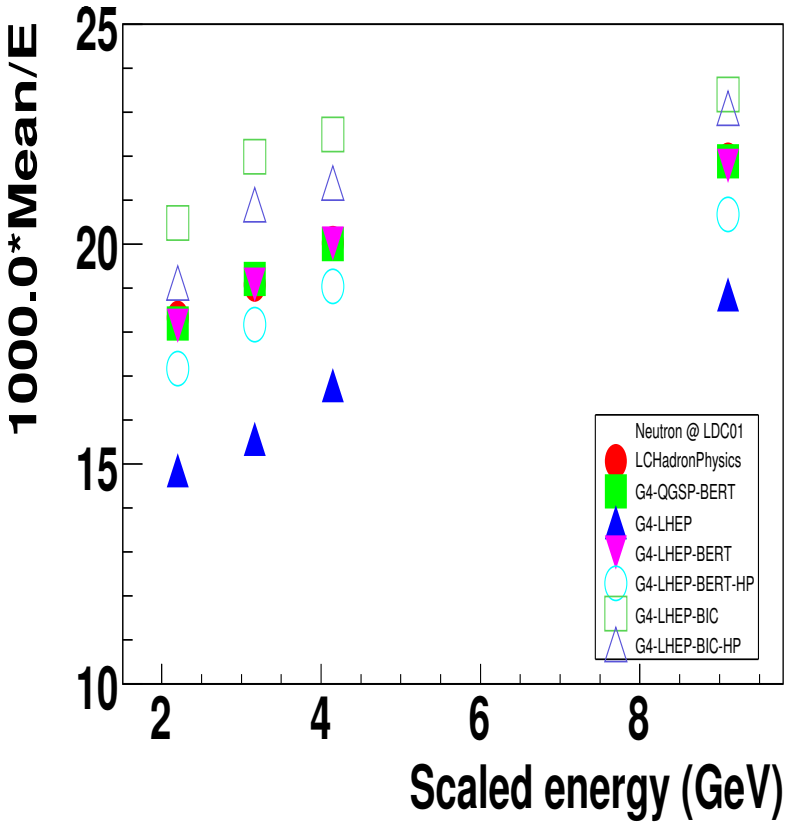
- π^+ **sample:** $E_{tot} = E_{ecal} + Weight * E_{hcal}$

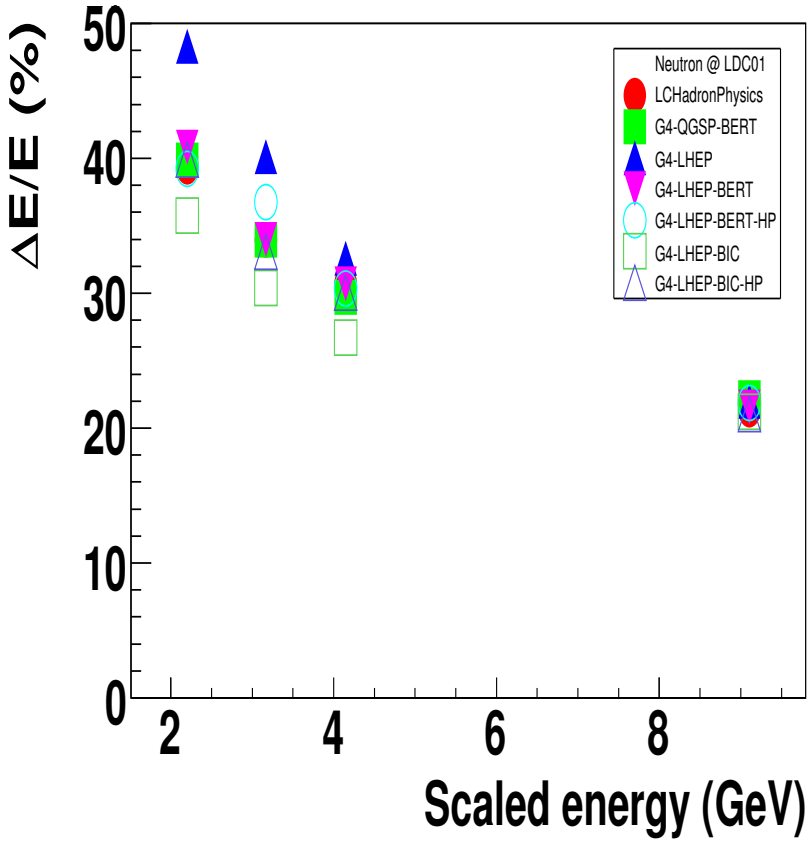
Energy response by SiD Model

- **Ron cassell's talk "Neutron hadron studies with isolated (semi) infinite calorimeters" at Detector simulation workshop ALCPG Jan 9-11, 2006**
- **1000 Hcal-alone for SiD model: LC Physics list with Geant4v7**



Neutron: Geant4.8.0 physics list





- $E_{ecal} + weight * E_{hcal}$ **method:** $E_{Hcal} = a * N_{hit} + b * N_{hit}^2$ **fitting and weighting factor** $weight$ $\longleftarrow$ **parameters decided by hadron samples with LC Physics List.**