Analysis of W-AHCAL data

Angela Lucaci-Timoce
on behalf of the CALICE W-AHCAL team

Introduction

2010 data

- W-AHCAL: **30 layers**
- Energies: 1-10 GeV
- Mixed runs (e, π, μ, p) in CERN PS
- Dedicated muon runs
- Analysis status: see next slides

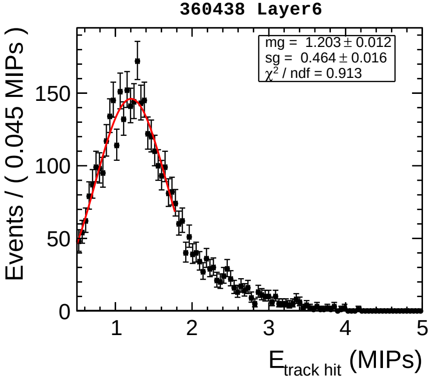
2011 data

- W-AHCAL: **38 layers**
- Energies: 10-300 GeV
- Mixed runs (e, π, μ, p, K) in CERN PS and SPS
- Dedicated muon runs, detector scans
- Analysis status:
  - Preliminary calibrations ready
  - Ongoing work to understand differences between data and Monte Carlo
- Results will be reported in future talks

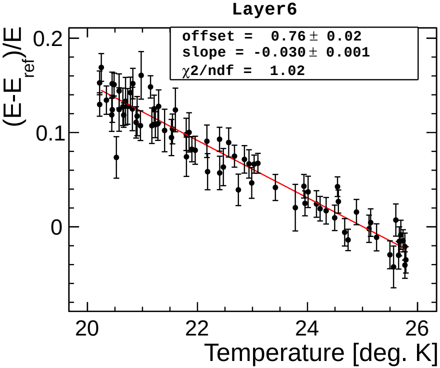
2010 MIP calibration and temperature correction

- Temperature dependence was studied using muon hits found by `PrimaryTrackFinder` (plus additional cuts for clean muon selection)
- Developed method to measure MIP slope layerwise

- Example fit for a given layer and a given run

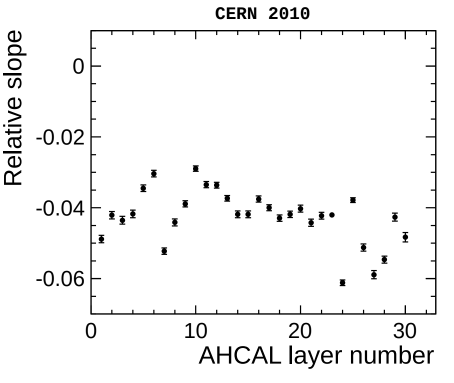


- Example: Measurement of MIP slope for layer 6



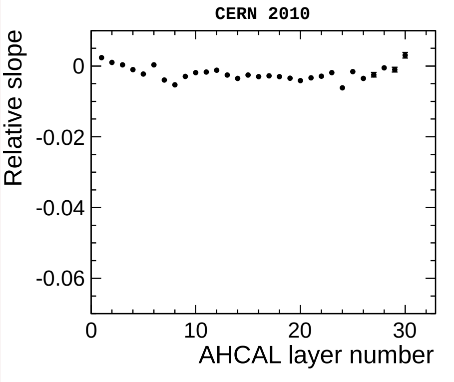
2010 MIP calibration and temperature correction

Before T correction



- Average slope: -4.3%/K

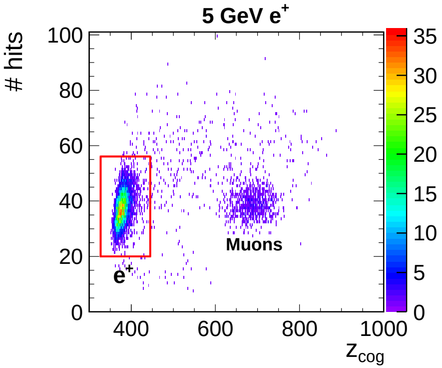
After T correction

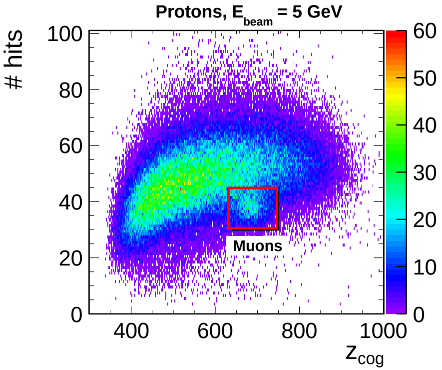


- Average slope: -0.2%/K
- Spread: $\pm$0.5%

Data selection

- First step: use Cherenkov information for particle identification
- Remaining muons (and noise) reduced by simultaneous cut on number of hits and on $z_{cog} = \sum E_i z_i / \sum E_i$
- Works for $E \geq 3$ GeV; for lower energies (in the hadron case) need more refined methods





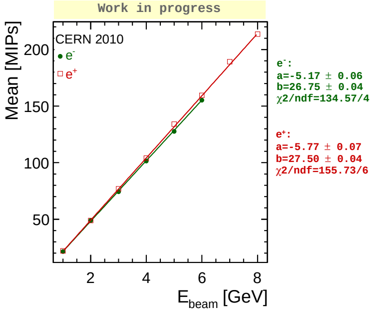
Comparison of Fe- and W-AHCAL

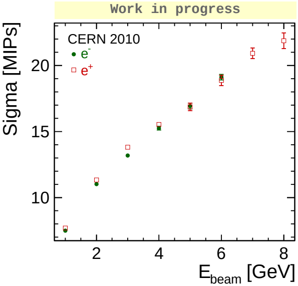
- Fe-AHCAL: one layer = $(16+2+2)$ mm Fe $\sim 1.1\ X_0$, $\sim 0.1\ \lambda_I$
- W-AHCAL: one layer = 10 mm W +4.5 mm Fe $\sim 3.1\ X_0$, $\sim 0.1\ \lambda_I$
  $\Rightarrow$ expect 'worse' electromagnetic resolution

e^+/e^- data

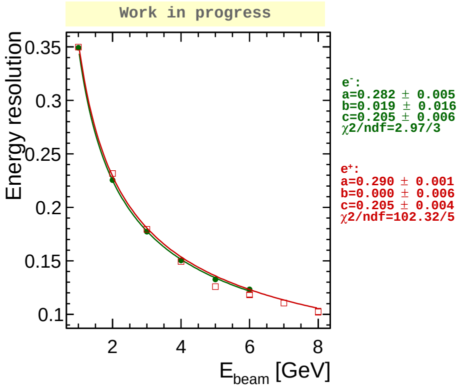
- Fraction of $e^\pm$ particles in the beam decreases with energy
  $\Rightarrow$ show only up to 8 GeV for e^+(a few hundreds of events)
- e^- runs at 7 and 8 GeV not included (data not clean)

Electromagnetic energy resolution





- $$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$



- Preliminary results only
- Noise term to be fixed
- Systematics to be added

Electromagnetic energy resolution

Comparison with other detectors: e^+

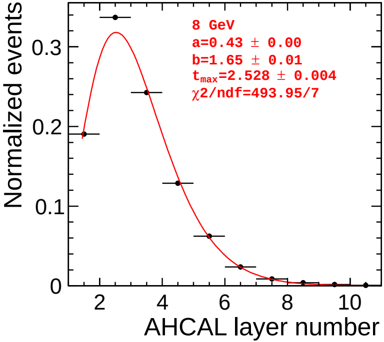
- Fe-AHCAL: arXiv:1012.4343 Gaussian fit in a $\pm 2\,\sigma$ range
- DHCAL: CAN-032 Gaussian fits over full range
- W-AHCAL: Novosibirsk fits over full range see example fits in backup slide

Detector	a	b	c [GeV]	χ^2/ndf
W-AHCAL	$(29.0 \pm 0.1)\%$	$(0.0 \pm 0.6)\%$	0.205 ± 0.004	102.3/5
Fe-AHCAL	$(21.9 \pm 1.4)\%$	$(1.0 \pm 1.0)\%$	0.058 (fixed)	–
DHCAL	$(26.8 \pm 0.4)\%$	$(13.0 \pm 0.1)\%$	–	7.6/4

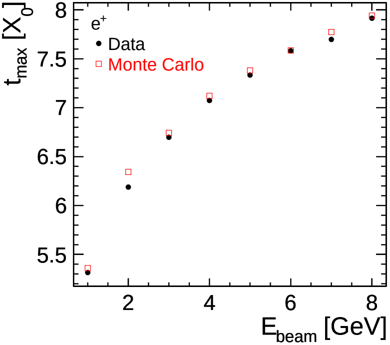
e^+: Data vs. Monte Carlo

- Fit longitudinal profile with: $\frac{\mathrm{d}E}{\mathrm{d}t} = a \cdot t^{t_{max} \cdot b} \cdot e^{-b \cdot t}$

- Example fit: 8 GeV e^+



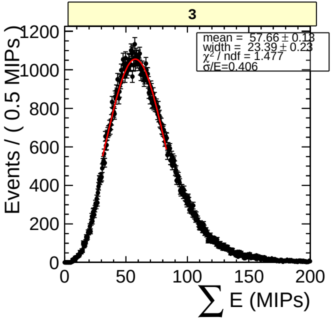
- Using 1 layer = 3.13 X_0



Hadron energy resolution

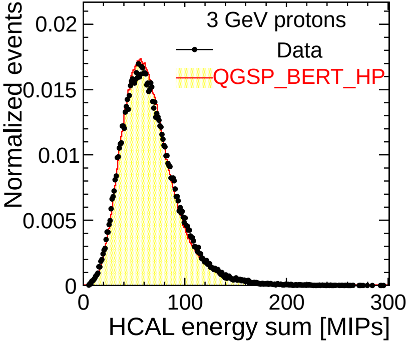
- Usually, energy resolution given by sigma of fit/mean of fit (e.g. Gaussian fit of central 70% statistics in the reconstructed energy distribution)
- Valid only for Gaussian distributions

- Example fit: 3 GeV protons



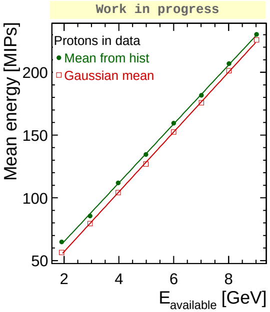
- But: Low energy distributions are non-Gaussian (due to fluctuations in the the electromagnetic fraction)
- Better: do not fit, but use RMS (takes tails into account) and mean of reconstructed energy

Shape of proton response



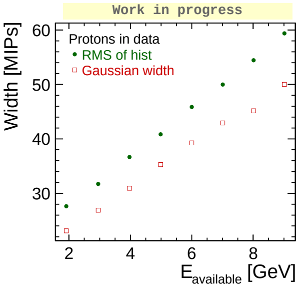
- High energy tail also described by Monte Carlo $\Rightarrow$ will use RMS to measure energy resolution
- Similar shape for pions

Proton energy resolution: RMS vs. Fit

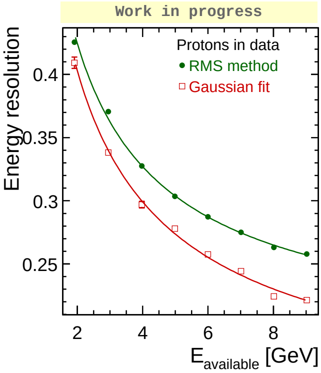


RMS:
a=18.18 ± 0.08
b=23.45 ± 0.01
χ2/ndf=1491.27/6

Fit:
a=9.33 ± 0.12
b=23.86 ± 0.02
χ2/ndf=362.63/6



- $$\frac{RMS\ (\sigma)}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

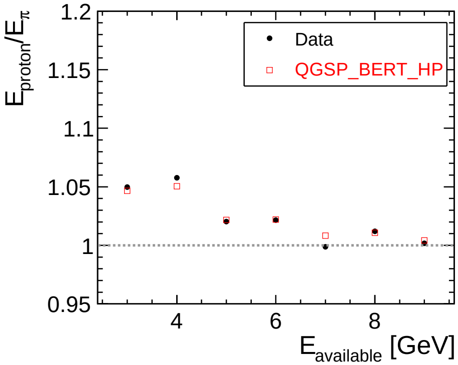


RMS method:
a=0.542 ± 0.001
b=0.183 ± 0.001
c=0.000 ± 0.004
χ2/ndf=148.01/5

Gaussian fit:
a=0.540 ± 0.004
b=0.128 ± 0.003
c=0.000 ± 0.015
χ2/ndf=31.93/5

Proton vs. pion response

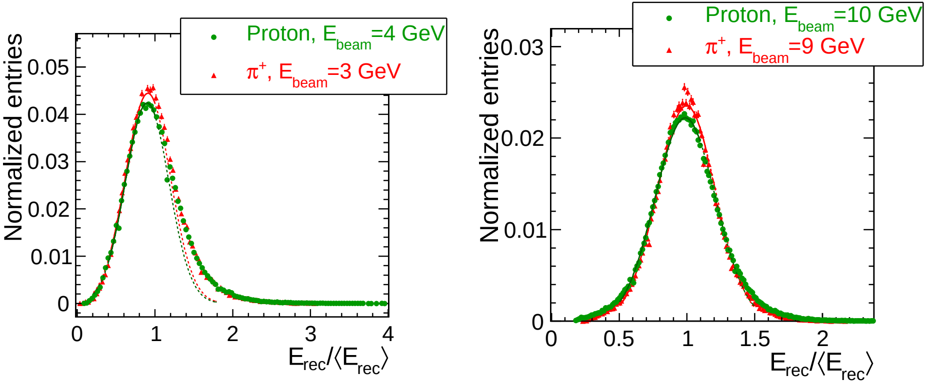
- In first order, expect the same response from all hadrons
- But:
  - Expect fraction of produced π^0 to be lower in proton showers than in pion showers (due to baryon number conservation) $\Rightarrow$ lower electromagnetic fraction
  - Hence, for an under-compensating calorimeter ($e/h > 1$) expect $E_{proton} < E_\pi$



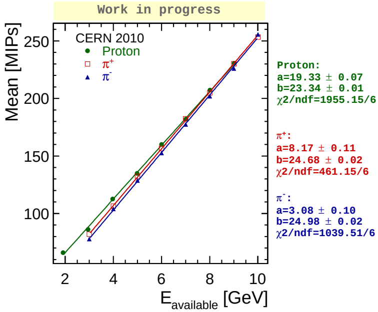
- In the studied low energy range, we see the opposite: $E_{proton} \geq E_\pi$ (both in data and in Monte Carlo)

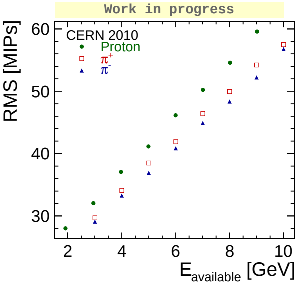
Proton vs. pion response

- Compare line shape asymmetry in proton and pion case by fitting the low energy part of the $E_{rec}/\langle E_{rec} \rangle$ distribution and extrapolating the fit to the high energy part (idea from ▸ Nucl. Instr. Meth. A 615 (2010) 158-181)
- Level of asymmetry similar in both cases, but pions have a narrower distribution ⇒ expect a better energy resolution for pions

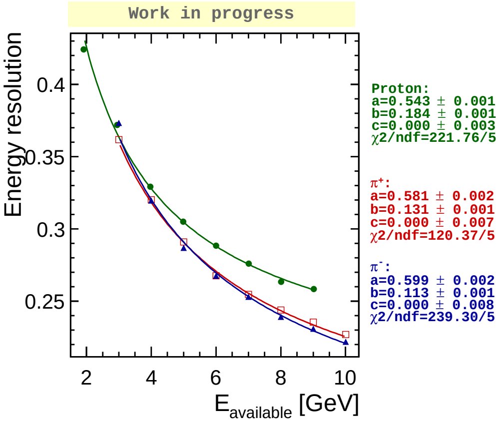


Hadronic energy resolution





- $$\frac{RMS}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$



- We get better energy resolution for protons: not yet understood

Pion energy resolution

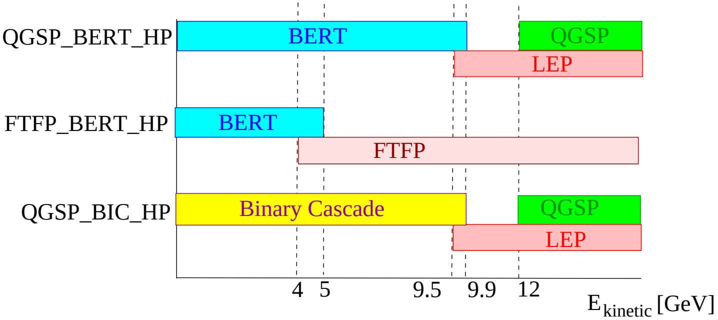
Comparison with other CALICE detectors

- Fe-AHCAL: ▸ CAN-035 Gaussian fits in a ±2 RMS range
- DHCAL: ▸ CAN-032 Gaussian fits over full range (of number of hits distributions)
- W-AHCAL: no fit, use RMS and mean of whole distribution

Detector	a	b	c [GeV]	χ^2/ndf
W-AHCAL	$(59.9 \pm 0.2)\%$	$(11.3 \pm 0.1)\%$	$(0.0 \pm 0.8)\%$	239.3/5
Fe-AHCAL	$(57.6 \pm 0.4)\%$	$(1.6 \pm 0.3)\%$	0.180 (fixed)	7.2
DHCAL	$(55.9 \pm 0.6)\%$	$(9.4 \pm 0.2)\%$	–	17.9/2

Comparison with GEANT4 models

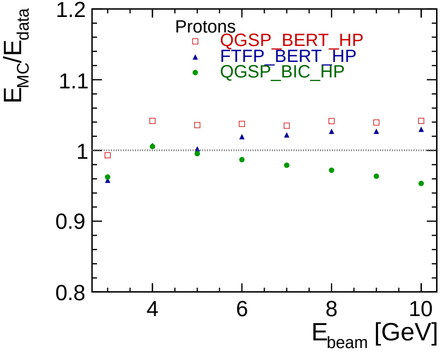
- Important for W-AHCAL: usage of data driven neutron package to transport neutrons below 20 MeV down to thermal energies (_HP)
- See detailed description ▸ GEANT4 web page



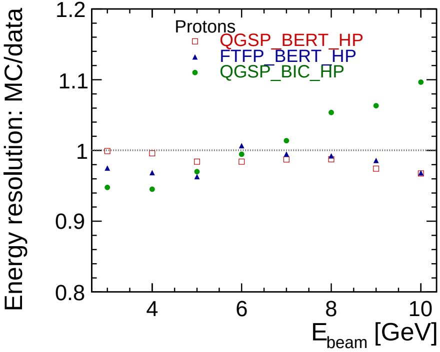
- FTFP_BERT_HP: not yet released, received directly from our GEANT4 colleagues (based on FRITIOF description of string excitation and fragmentation)

Protons: Data vs. Monte Carlo

- **Calorimeter response**: Agreement within 5%



- **Energy resolution**: Agreement within 10%

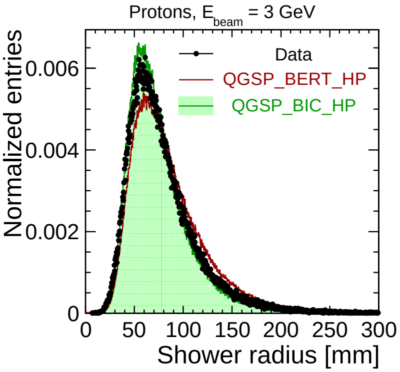


Protons: Data vs. Monte Carlo

- **Shower radius**:

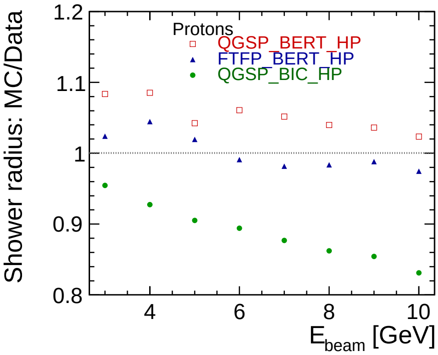
  $$radius = \sum E_i \cdot d_i / \sum E_i$$

  $$d_i = \sqrt{(x_i - x_{track})^2 + (y_i - y_{track})^2}$$



- Take the mean of distribution and plot agains beam energy

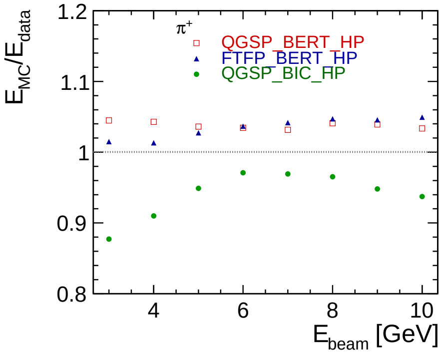
- Agreement within 10% for Bertini models, larger deviations for BIC model

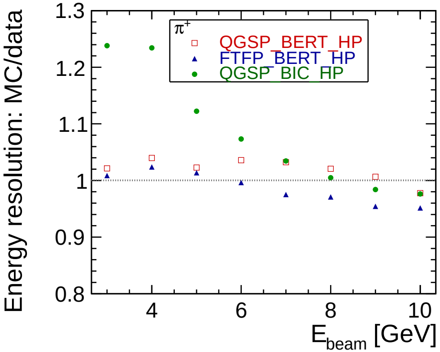


π^+: Data vs. Monte Carlo

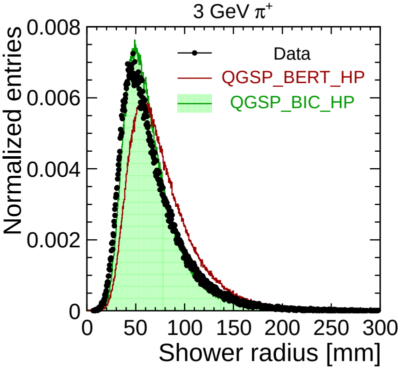
- **Calorimeter response**:
  Bertini models: agreement within 5%
  Binary cascade: worse, ratio varies with energy

- **Energy resolution**:
  Bertini models: agreement within 5%
  Binary cascade: worse, ratio varies with energy

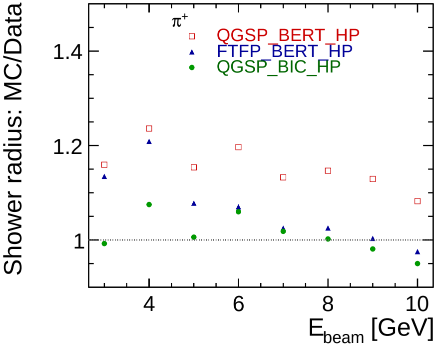




π^+: Data vs. Monte Carlo



- **Shower radius**:
  Binary cascade: agreement within 10%, worse for the other models



Summary

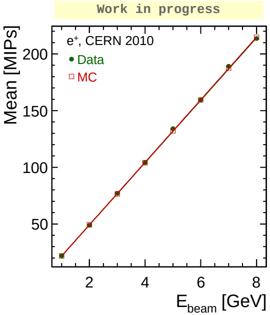
- Established procedure to measure MIP temperature slopes layerwise
  $\Rightarrow$ calibration ready
- Preliminary measurements of electromagnetic and hadronic energy resolution (systematics to come)
- First comparisons of hadronic shower models in W-AHCAL
  $\Rightarrow$ Discussions with GEANT4 colleagues started

Next

- 2010 data:
  - Finalize resolution response
  - Finish analysis note (CAN-036)
- 2011 data: still bits and pieces to fix

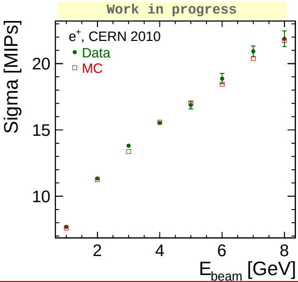
Backup slides

Energy resolution: e^+

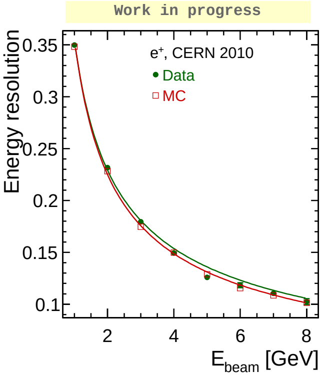


Data:
a=-5.77 ± 0.07
b=27.50 ± 0.04
χ2/ndf=155.73/6

MC:
a=-5.91 ± 0.03
b=27.59 ± 0.01
χ2/ndf=129.09/6



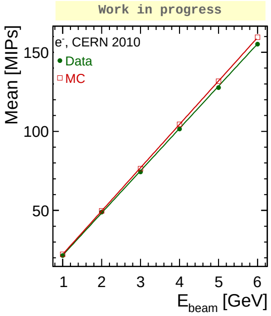
- $\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$



Data:
a=0.290 ± 0.001
b=0.000 ± 0.006
c=0.205 ± 0.004
χ2/ndf=102.3/5

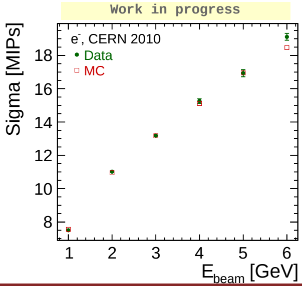
MC:
a=0.275 ± 0.000
b=0.000 ± 0.003
c=0.225 ± 0.001
χ2/ndf=247.8/5

Energy resolution: e^-

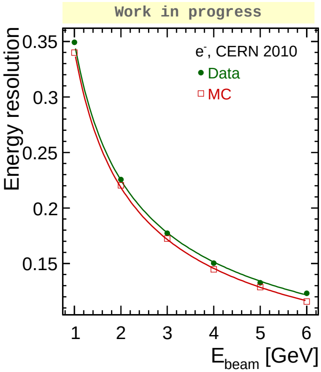


Data:
a=-5.17 ± 0.06
b=26.75 ± 0.04
χ2/ndf=134.57/4

MC:
a=-5.23 ± 0.04
b=27.41 ± 0.01
χ2/ndf=144.12/4



- $$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

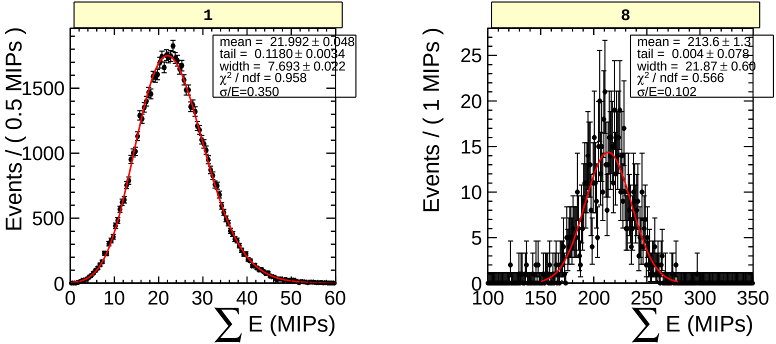


Data:
a=0.282 ± 0.005
b=0.019 ± 0.016
c=0.205 ± 0.006
χ2/ndf=3.0/3

MC:
a=0.272 ± 0.001
b=0.000 ± 0.004
c=0.207 ± 0.002
χ2/ndf=42.3/3

e^+ example fits

- Fit with **Novosibirsk** function: Gaussian with a tail



▸ Go back to talk