Performance of CDF Calorimeter Simulation for Tevatron Run II

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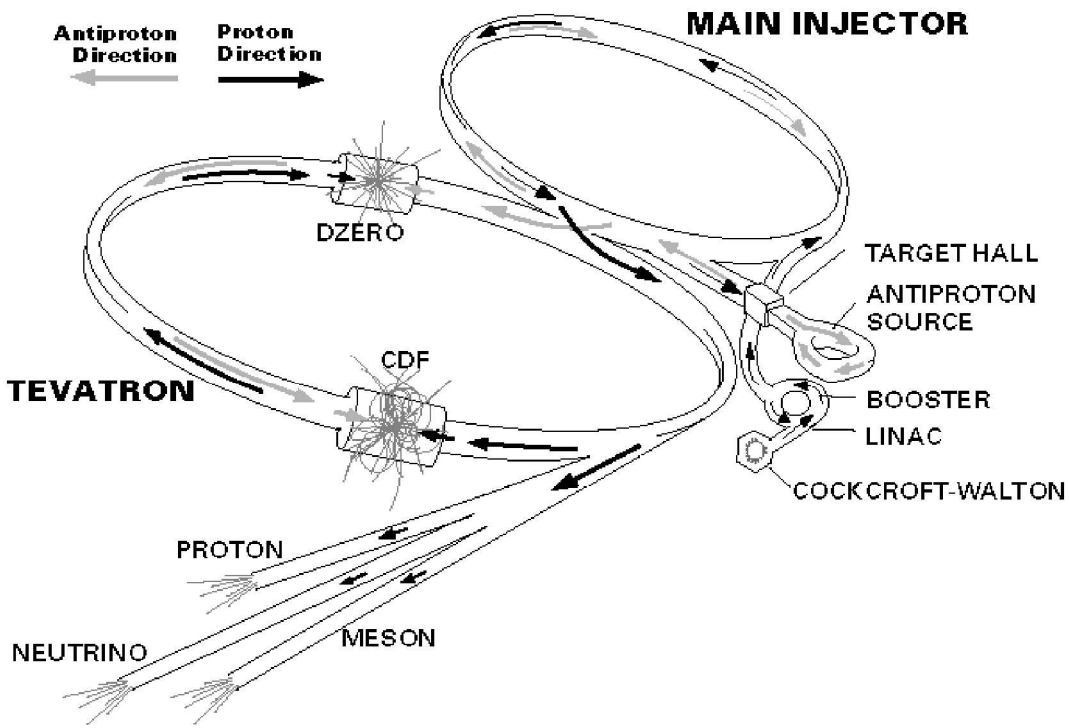
on behalf of the CDF collaboration

- CDF II upgrade
- The Gflash package: principles & interfacing
- Tuning procedure on data & results
- Conclusions

Tevatron upgrade



- Run I (ended Feb. 1996)
  - 3.5 μsec bunch spacing
  - $\sqrt{s}$ = 1.8 TeV
  - Luminosity > 10^{31} cm^{-2} s^{-1}
  - integrated 100 pb^{-1}

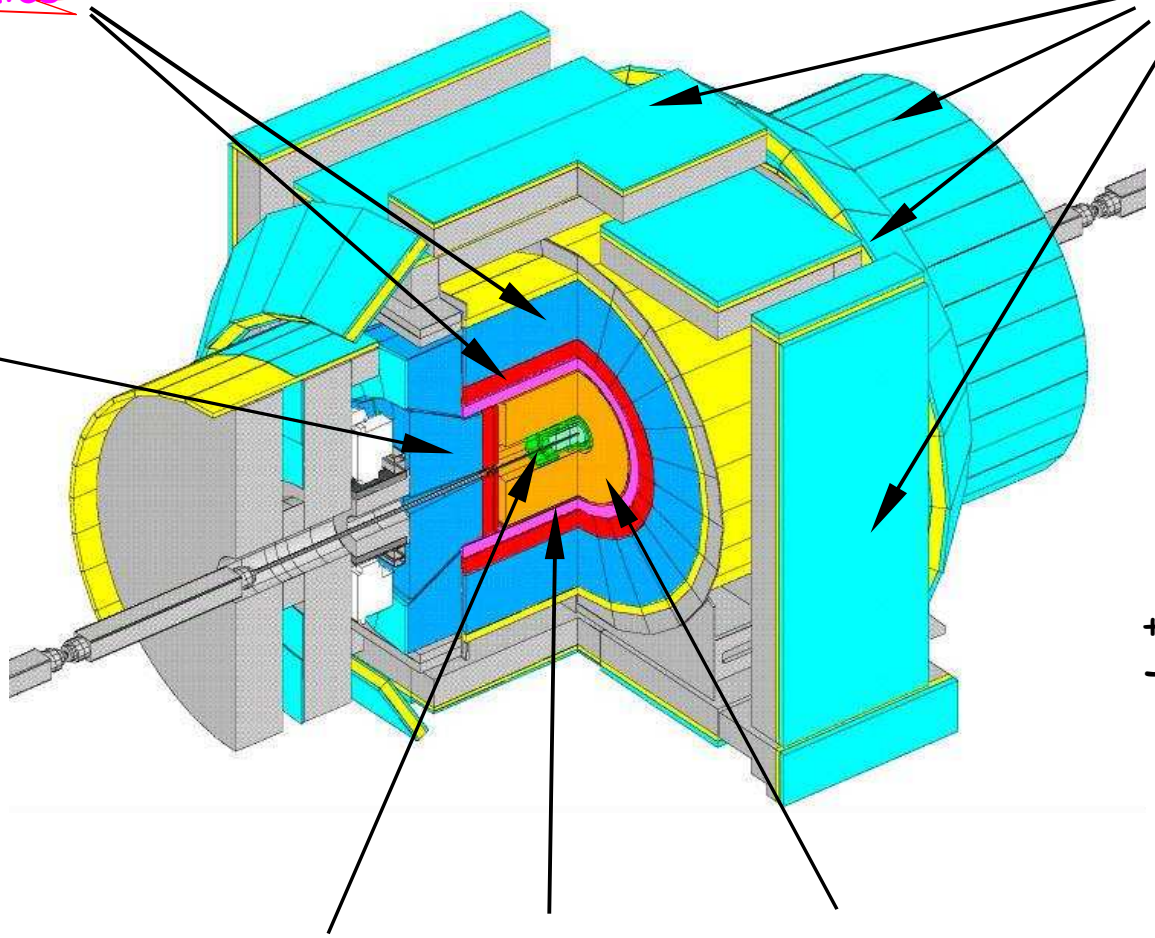
- Run II Upgrades
  - ➪ 5×10^{32} cm^{-2} s^{-1}
  - ➪ $\sqrt{s}$ = 1.96 TeV
  - Main Injector (2002):

    initial goal 3×10^{31} $cm^{-2} s^{-1}$
  - Recycler (2002):

    recover antiprotons
  - Bunches
    - Initially 36x36 at 396 ns
    - Ultimately 132ns
  - ➪ $\int L$ (2002) ~ 300 pb^{-1}

☞ commissionning effort going on ...

The CDF II detector



CDF II: calorimetry

Central (+wall) calorimeters
$|\eta|<1$ (1.32) :

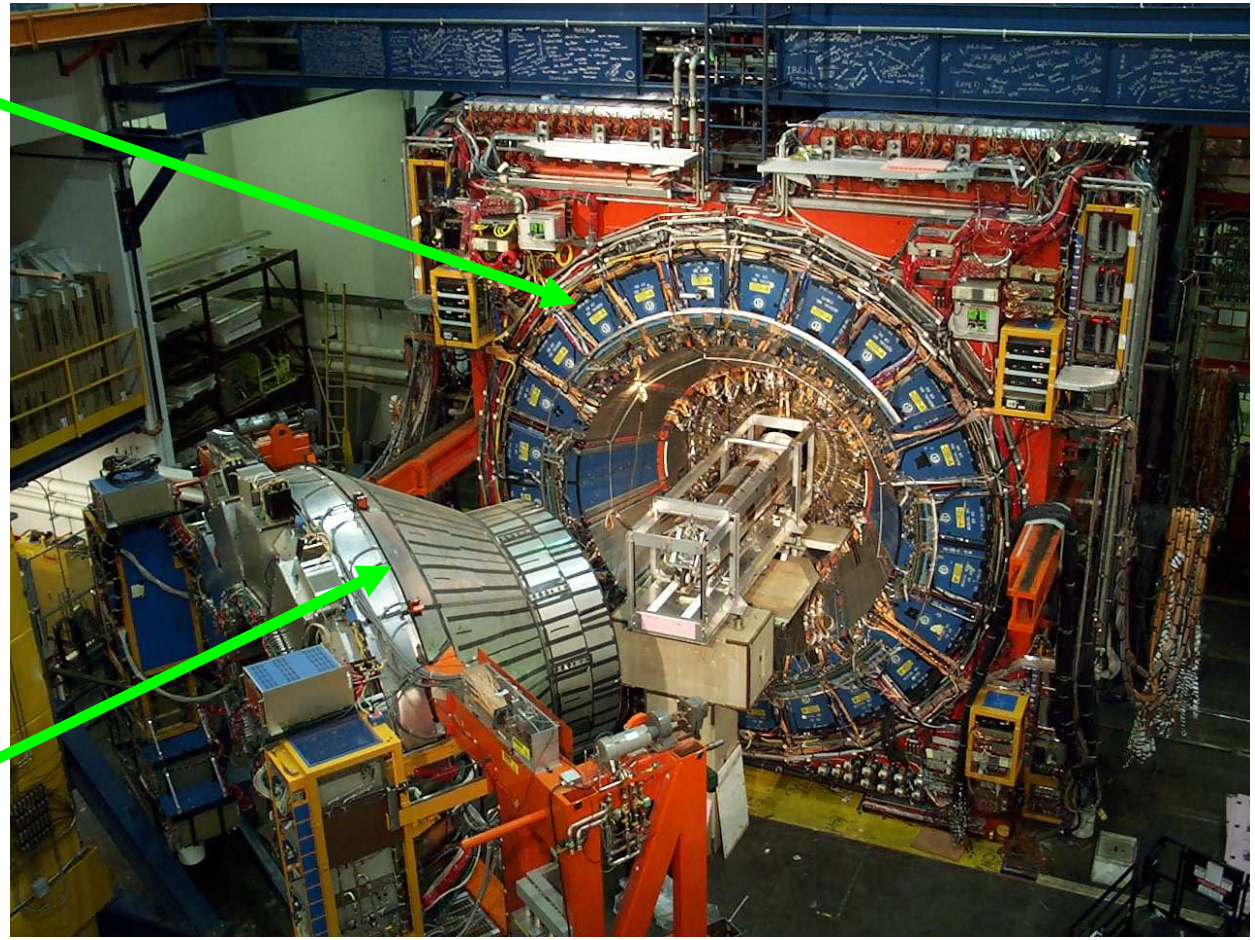
CEM $$\frac{\sigma}{E_T}=\frac{14\%}{\sqrt{E_T}}\oplus 2\%$$

CHA $$\frac{\sigma}{E_T}=\frac{50\%}{\sqrt{E_T}}\oplus 3\%$$

Plug (forward) calorimeter
$1.32<|\eta|<3.64$:

PEM $$\frac{\sigma}{E}=\frac{16\%}{\sqrt{E}}\oplus 1\%$$

PHA $$\frac{\sigma}{E}=\frac{70\%}{\sqrt{E}}\oplus 5\%$$



... all of Shashlik-type: $Pb_{EM}(Fe_{HAD})$ / Scintillator + WLS

Fast simulation of the showers

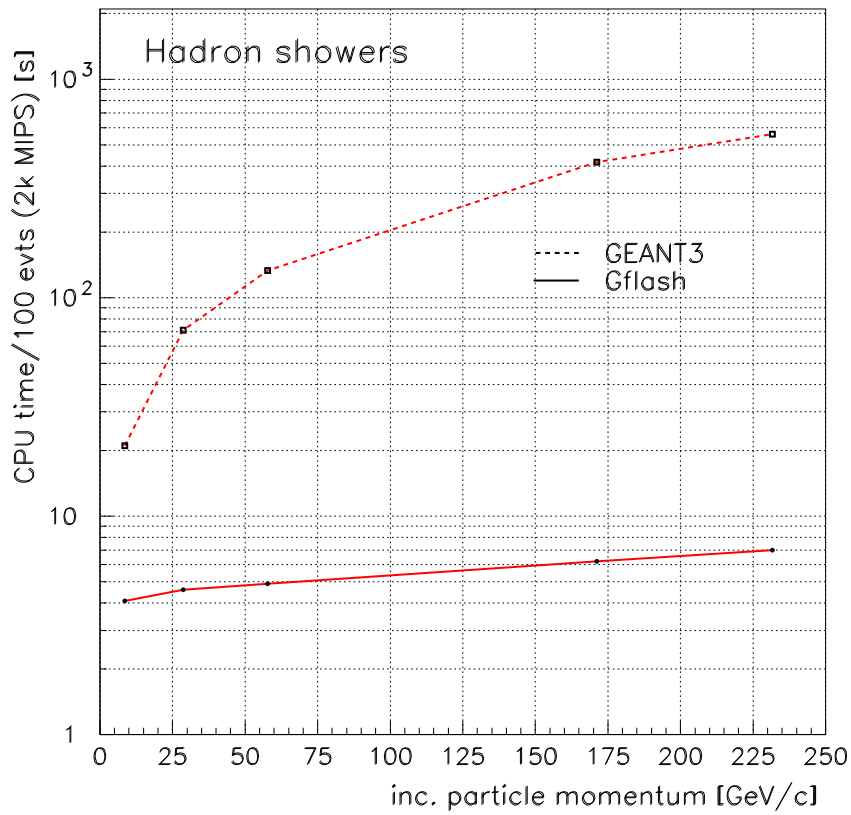
☞ Geant3-based offline detailed simulation ... ☞ top pairs @ 2 TeV @ 10^{32} cm^{-2} s^{-1} ?!?!

Find/use fast modelling of the showers instead in calorimeters simulation:

* Gflash: developed by H1 coll., 1990s

  ☞ EM+HAD showers, longitudinal + lateral profiles

CPU time increase with E
* GEANT ... linear with E
* Gflash ..... as log(E)



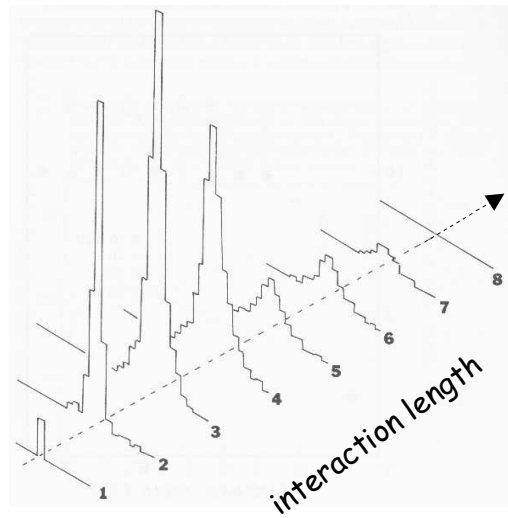
The Gflash package

- Single effective medium ⇨ fraction E_{vs} of deposited energy visible in active medium

k=e,had

$$dE_{vs}(\vec{r}) = E_{dp}\,\hat{m}\sum_k \frac{\hat{k}}{\hat{m}}\,c_k\,f_k(\vec{r})\,dV$$

response to MIP — response relative to MIP — rel. fraction e versus had



☞ parameters with energy dependence of the form a+b*ln E

~ calorimeter independent

- EM shower longitudinal profiles: gamma distribution $f(z) = \frac{x^{\alpha-1} e^{-x}}{\Gamma(\alpha)}, \quad x = \beta z [X_0]$

- Lateral profile: Ansatz $f(r) = \frac{2r R_0^2}{(r^2 + R_0^2)^2}$ ... for both EM and HAD showers

☞ parameter $R_0 = R_0$(E shower, depth)

☞ no azimuthal dependence

Correlations & sampling fluctuations

- Correlation between α, β taken into account

$$\begin{pmatrix}\alpha_i\\ \beta_i\end{pmatrix}=\begin{pmatrix}\mu_\alpha\\ \mu_\beta\end{pmatrix}+C\cdot\begin{pmatrix}rand\,1\\ rand\,2\end{pmatrix} \quad \text{with} \quad C=\begin{pmatrix}\sigma_\alpha & 0\\ 0 & \sigma_\beta\end{pmatrix}\cdot\begin{pmatrix}\rho_+ & \rho_-\\ \rho_+ & -\rho_-\end{pmatrix}$$

correlation: obtained from GEANT/data profiles (~ indep. of E)

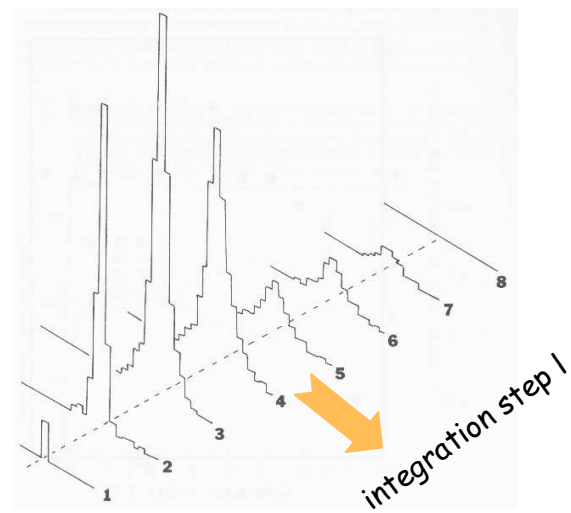
- Assuming energy resolution to be simulated is

$$\frac{\sigma_{dp}}{E_{dp}}=\frac{a}{\sqrt{E_{inc}}}$$

$$E_{spot}=a^2\cdot\frac{E_{dep}}{E_{inc}}$$

$$E_{dp}=\sum_l \underbrace{N_{spots(l)}}\cdot E_{spot}$$

Poissonian -> sampling fluctuations



- Distribute E spots according to lateral profile

- Go from deposited E to visible E: sampling fractions $\hat{m}$, $\frac{\hat{k}}{\hat{m}}$

Gflash: HAD showers

☞ Distinction between purely hadronic & π^0 components

HAD shower longitudinal profiles: 3 gamma distributions H, F, L

$$dE_{dp} = f_{dp} E_{inc} [c_h H(x) dx + c_f F(y) dy + c_l L(z) dz]$$

purely hadronic fraction

π^0 fraction produced in 1st inelastic interaction

π^0 fraction produced in further devel. of shower

☞ 3 classes of events:
H / H+F / H+F+L
... with relative prob. of occurence
(deduced from GEANT)

3 mean values f_k, α, β and 3 fluctuations σ_f, σ_α, σ_β per class (component)

$$(f_{k,} \alpha_{k,} \beta_{k,} \sigma_{f_k}, \sigma_{\alpha_k}, \sigma_{\beta_k})_3 \rightarrow (x_{i,} \sigma_i)_{i=1,9}$$

$$f_k = f_k(c_j)$$

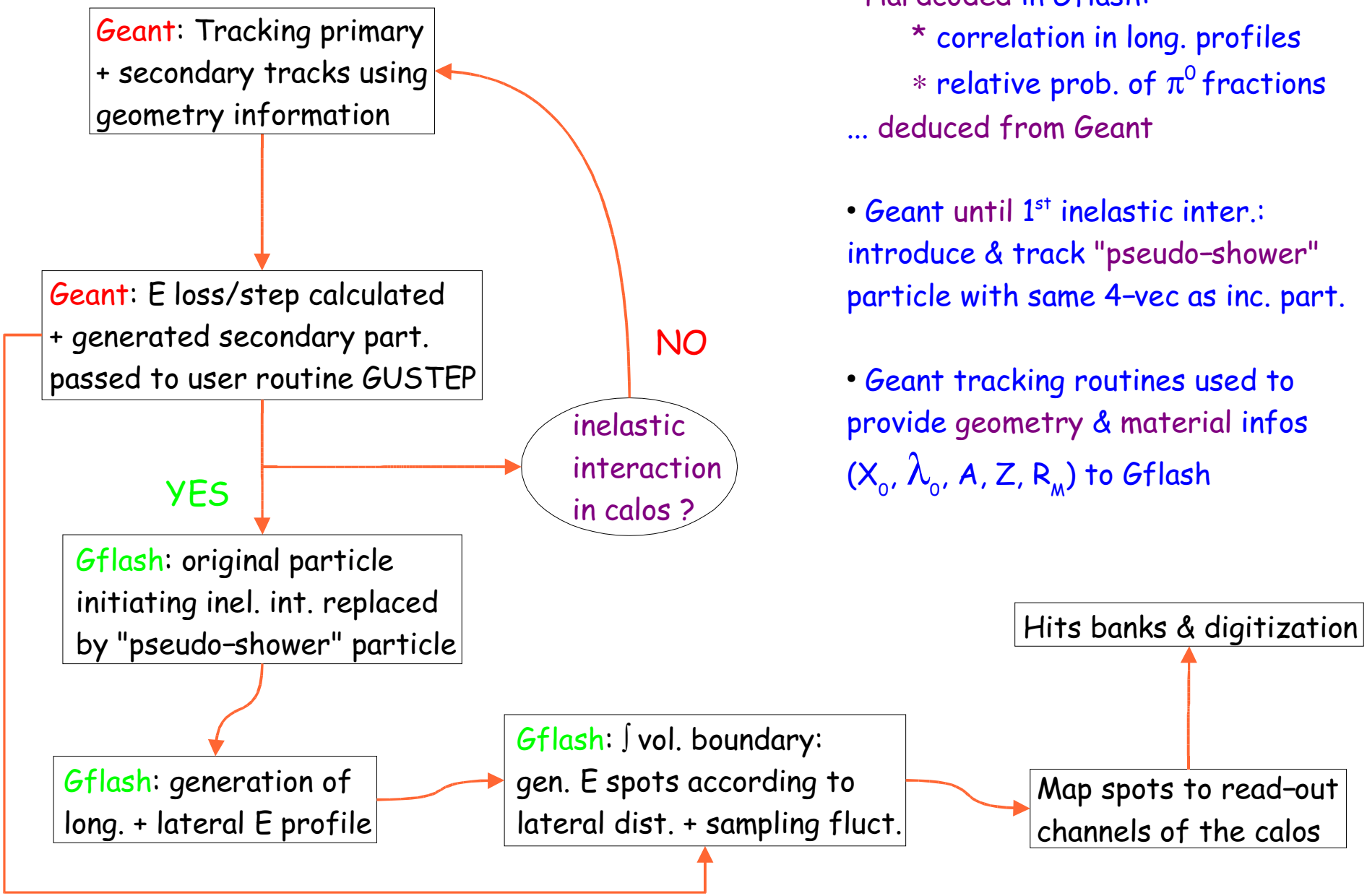
$$\vec{x} = \vec{\mu} + C\vec{z} \qquad \vec{\sigma} \rho \vec{\sigma}^T = CC^T$$

random numbers

correlation matrix

☞ parameters with energy dependence of the form a+b*ln E

Interface with Geant



- Hardcoded in Gflash:
  - * correlation in long. profiles
  - * relative prob. of π^0 fractions

... deduced from Geant

- Geant until 1st inelastic inter.: introduce & track "pseudo-shower" particle with same 4-vec as inc. part.

- Geant tracking routines used to provide geometry & material infos (X_0, λ_0, A, Z, R_M) to Gflash

Tuning Gflash with data

- Use calos test beam data: e,π ... ranging 8 < E < 250 GeV

- Tune Gflash

$$dE_{vs}(\vec{r}) = E_{dp}\,\hat{m}\sum_k \frac{\hat{k}}{\hat{m}} c_k f_k(\vec{r})\,dV$$

Results ... ☞

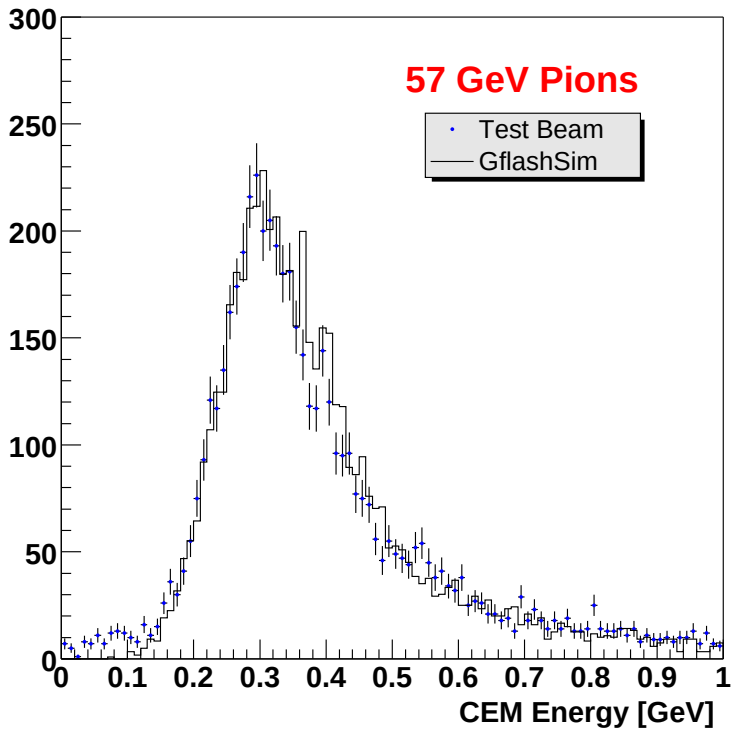
1. Adjust MIP peak
2. Set E scale: response relative to MIP
3. Adjust E dependence: $f_k = f_k(a + b\cdot\log E)$

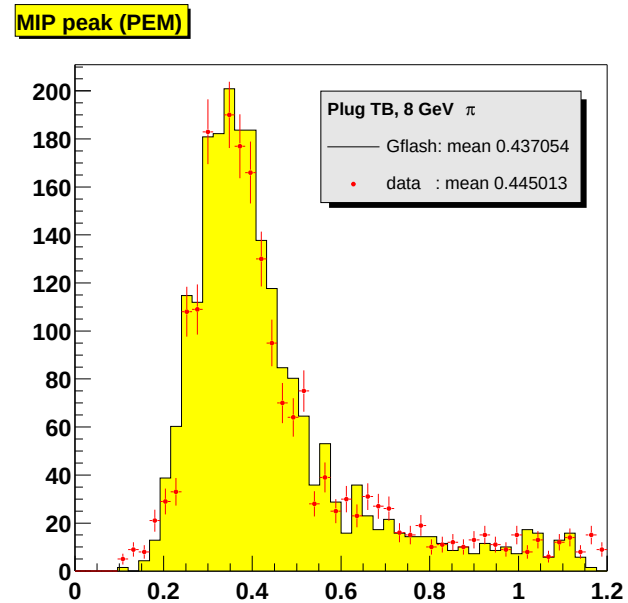
☞ linearity, resolution

Tuning Gflash: response to MIPs

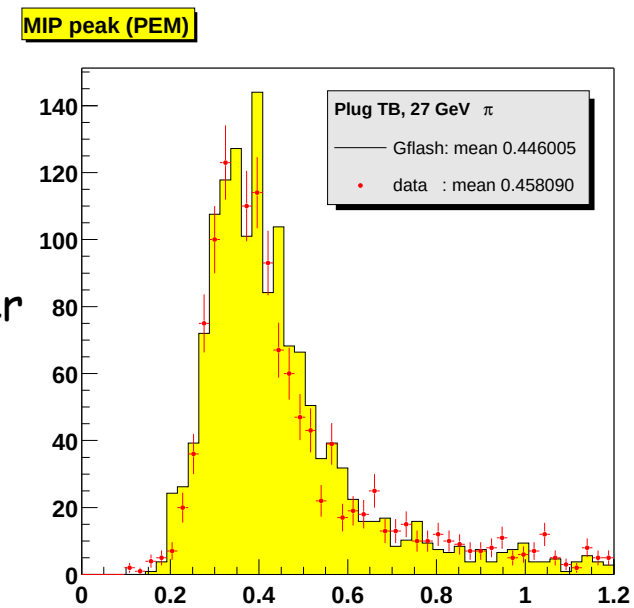
$$dE_{vs}(\vec{r}) = E_{dp}\,\hat{m}\sum_k \frac{\hat{k}}{\hat{m}} c_k f_k(\vec{r})\,dV$$

MIP peak in the central calorimeter:





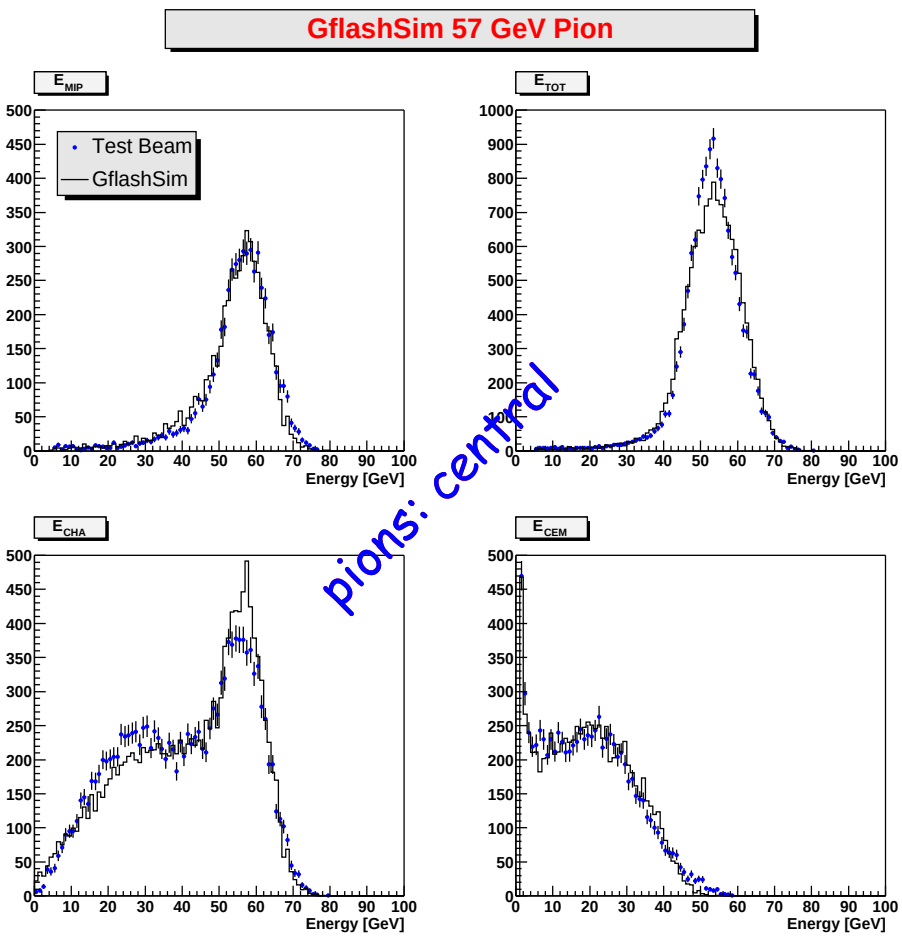
... and in the plug calorimeter

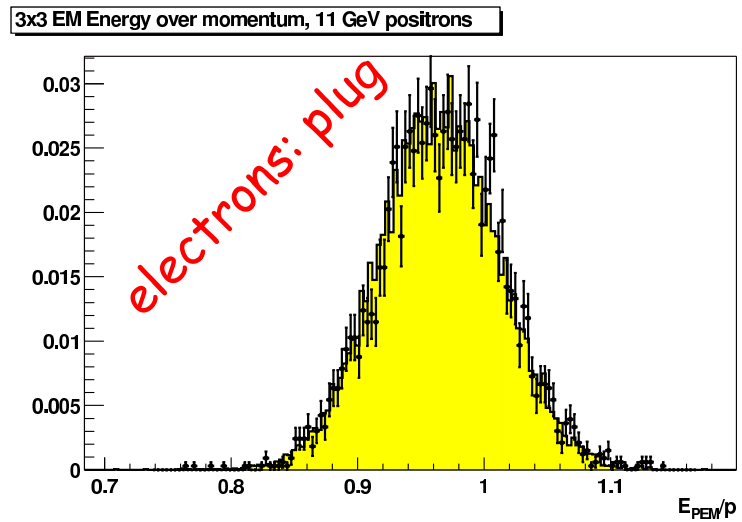


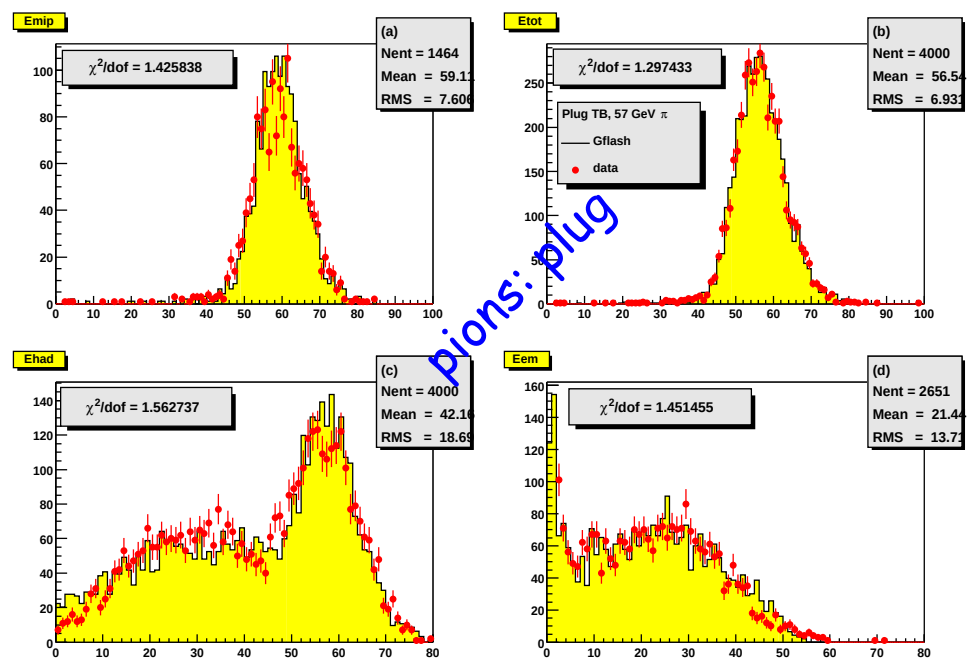
Response relative to MIPs …

$$dE_{vs}(\vec{r}) = E_{dp}\,\hat{m}\sum_k \frac{\hat{k}}{\hat{m}} c_k f_k(\vec{r})\,dV$$

fixed energy







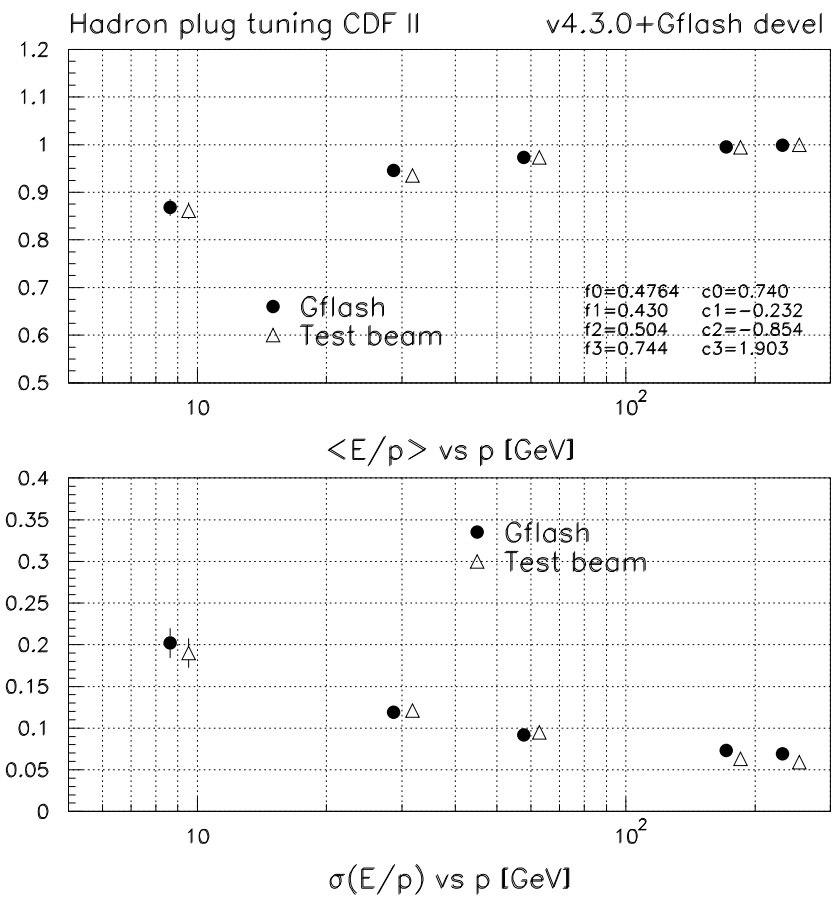
Energy dependence: linearity

$$f_k, \alpha, \beta = f_k(E), \alpha(E), \beta(E)$$

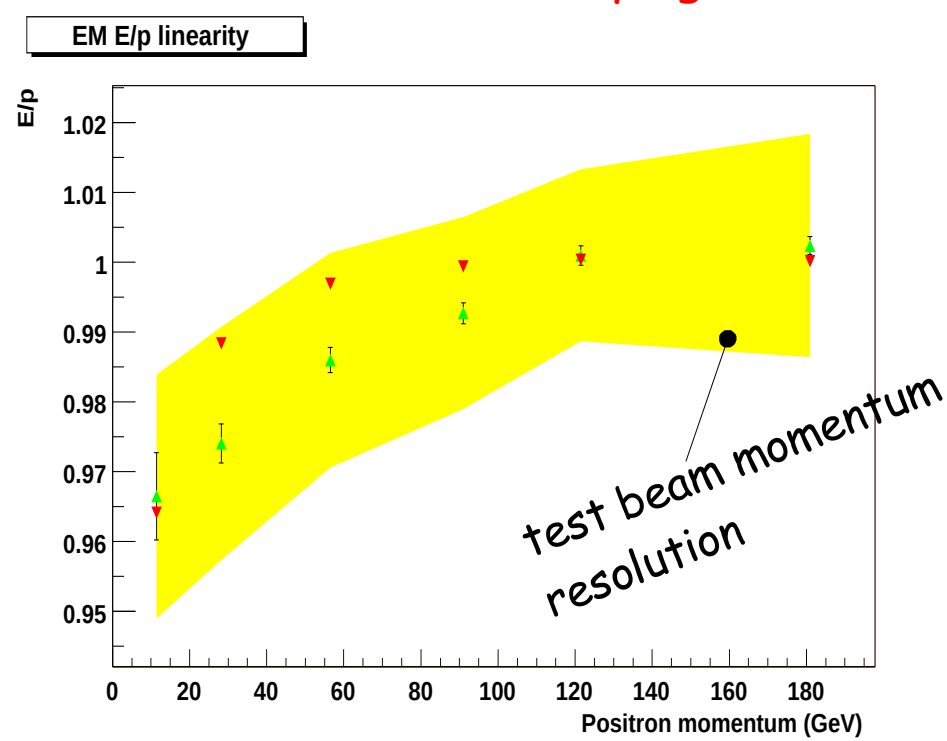
☞ parameters with energy dependence of the form a+b*ln E

... basically iterative ...

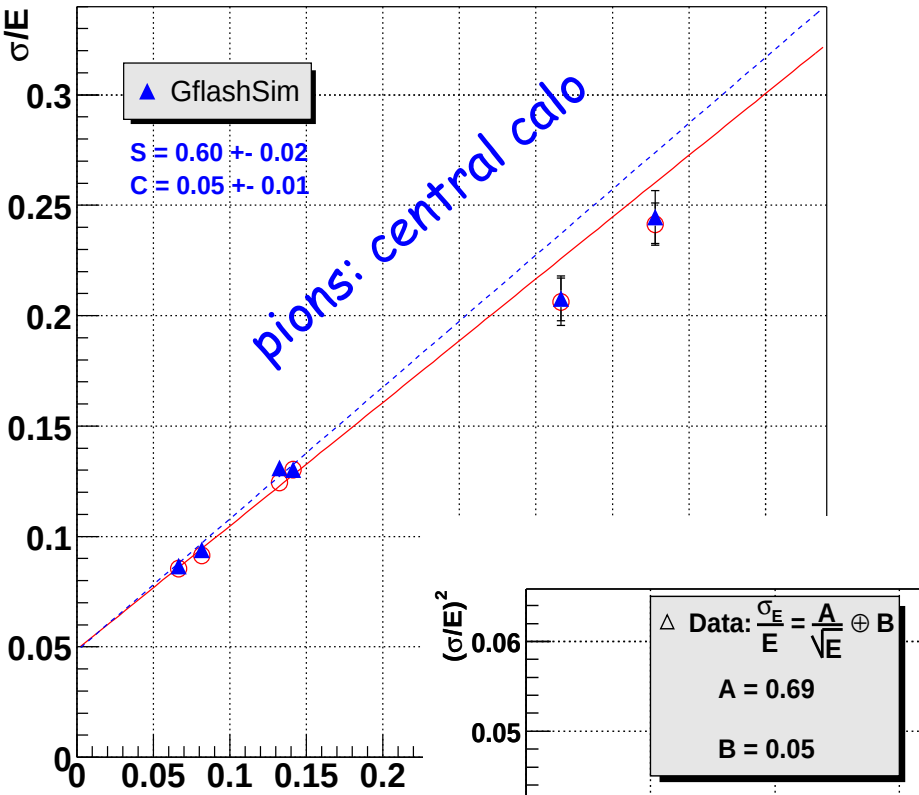
pions: plug calo

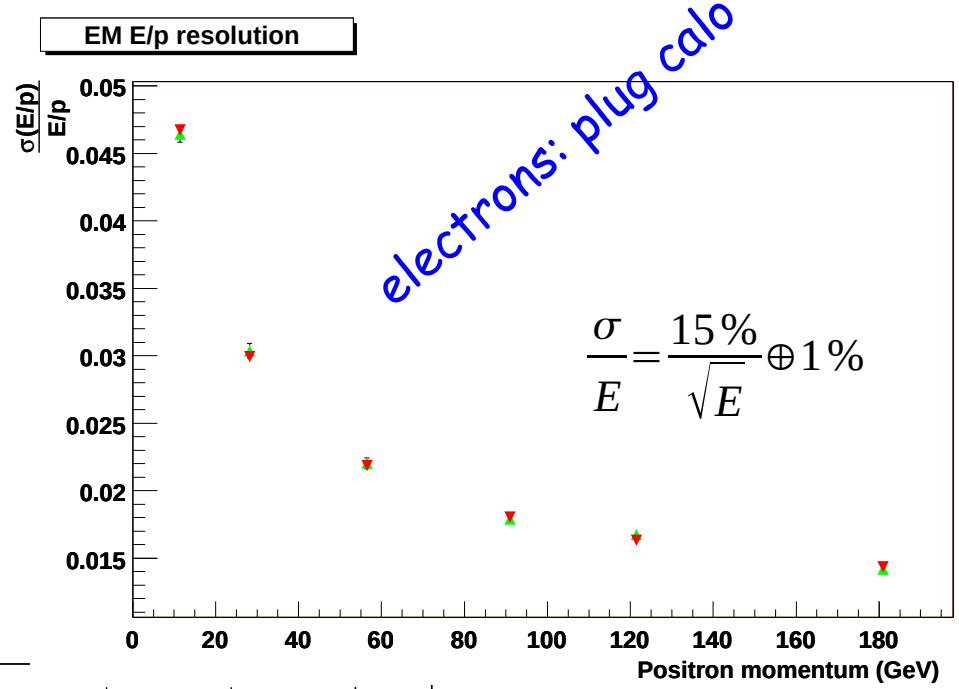


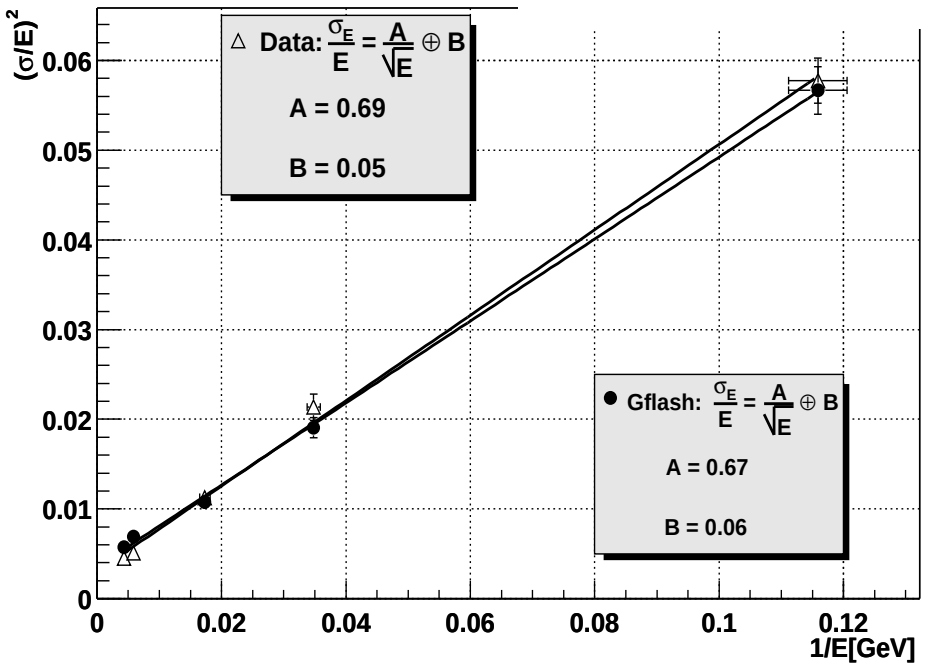
electrons: plug calo



Energy dependence: resolution





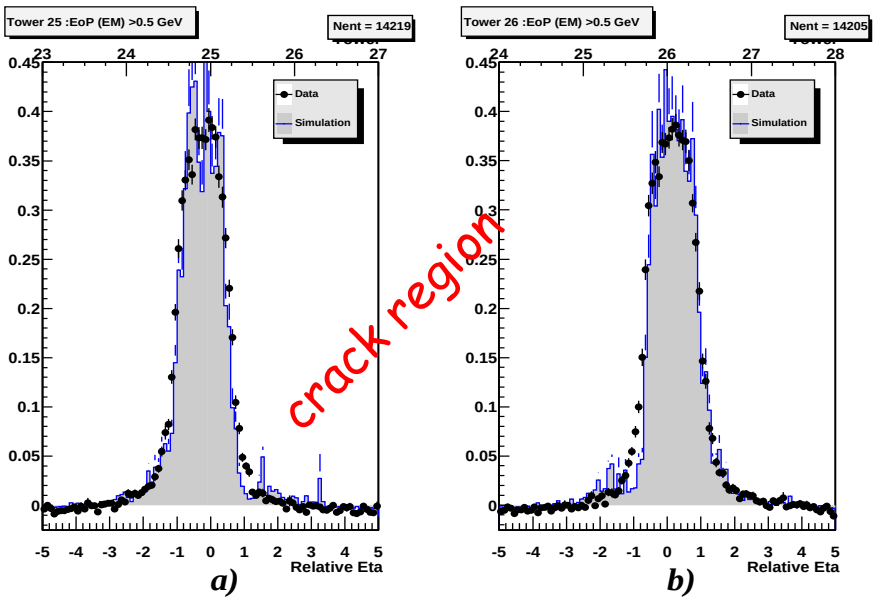


pions: plug calo

Tuning the lateral profile

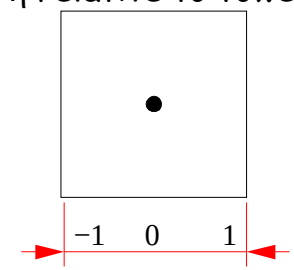
☞ using min.bias tracks in the central region: low E_T as yet ...

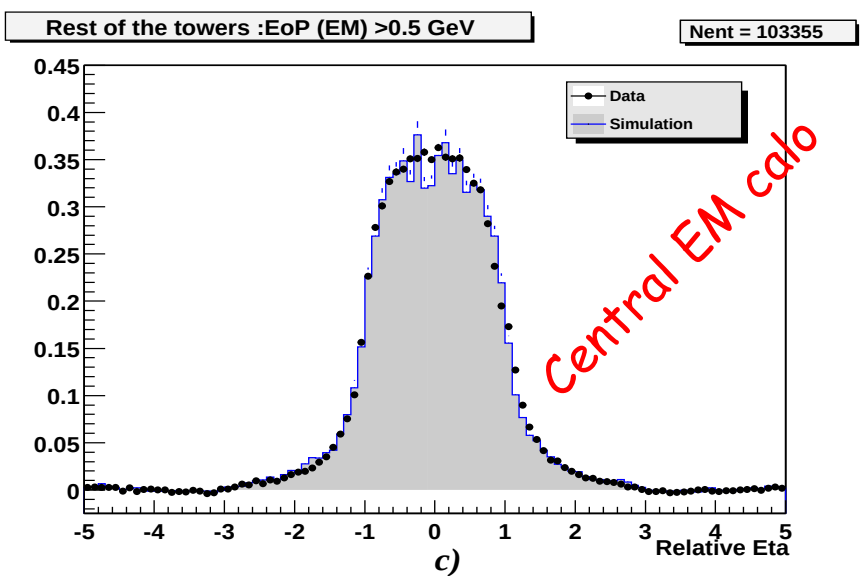
$0.5 < E_T < 2.5$ GeV range

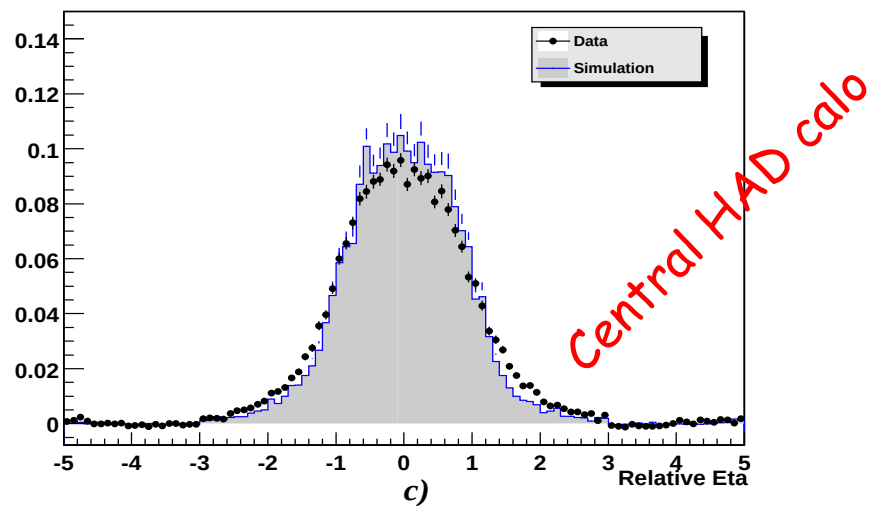


$$f(r) = \frac{2r\,R_0^2}{(r^2 + R_0^2)^2}$$

η relative to tower







Work in progress

- extend tuning using "in situ" tracks from minimum bias events: low E

- single particles —> jets:

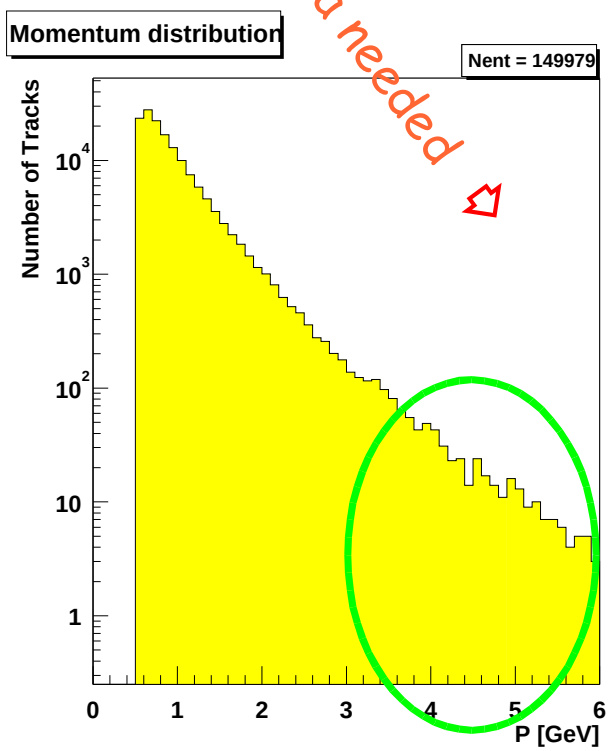
  ☞ jets modelled as convolution of single part.

  ★ systematics set by ... single part. response
  ★ ... + uncertainty on modelling fragmentation

  ☞ setting jets energy scale:

  ★ absolute E scale (e.g. central calos)
  ★ relative E scale in the rest of the det w.r.t. central -> correction function

more data needed



Outcomes & conclusions

- Parameterized EM & HAD showers using Gflash ...
  - over the full "4π" CDF calorimetry
  - over the range 8 < E < 250 GeV
- Keeping robustness ...
  - GEANT detailed geometry & material infos
  - no runaway of the parameterization: tuning by interpolation
- Gaining efficiency ...
  - ~O(100) gain in CPU time for simulation
- Next steps: extensive tuning at low E / jets ... going on