Using the CalDet results

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How we can use the CalDet results

- The basic idea is to provide the mip to GeV convertion

$$E_{eshower} = C_e \sum_i PH_i ; E_{hshower} = C_h \sum_i PH_i$$

- MINOS detectors are not-compensating calorimeters (e/h $\neq$ 1) which causes deviation from linearity in the hadronic response versus energy. It is necessary to know e/h for hadron energy reconstruction. CalDet will measure the e/h ratio

- Simulation of low energy hadron shower development in matter is one of the weakest links in the simulation. GHEISHA, FLUKA and GCALOR are known to have problems especially at low energies.

- Fine spatial granularity makes CalDet a very interesting tool to provide detailed information on showers originated by different particles

- CalDet data can correct/tune GEANT MC. The longitudinal and lateral development of the hadronic showers can be parametrized. These parameterizations can be fitted directly on the experimental test beam data and used as an alternative to the hadronic interactions packages

Finding e/h

- Part of the energy released in the developing hadronic cascade is transfered to the EM sector via $\pi^0 \rightarrow 2\gamma$. The mean transfer fraction $f_{\pi^0}(E)$ increases with energy

  $$C_\pi(E_\pi) = f_{\pi^0}(E_\pi) \times C_e + (1 - f_{\pi^0}(E_\pi)) \times C_h$$

  C_e – calibration constant for EM showers; C_h – calibration constant for "pure" hadronic showers; $C_\pi(E_\pi)$ – calibration constant for "real" hadronic showers;

- e/h is an intrinsic property of calorimeter and doesn't depend on the incident particle energy

- There are two parametrization of $f_{\pi^0}(E)$:

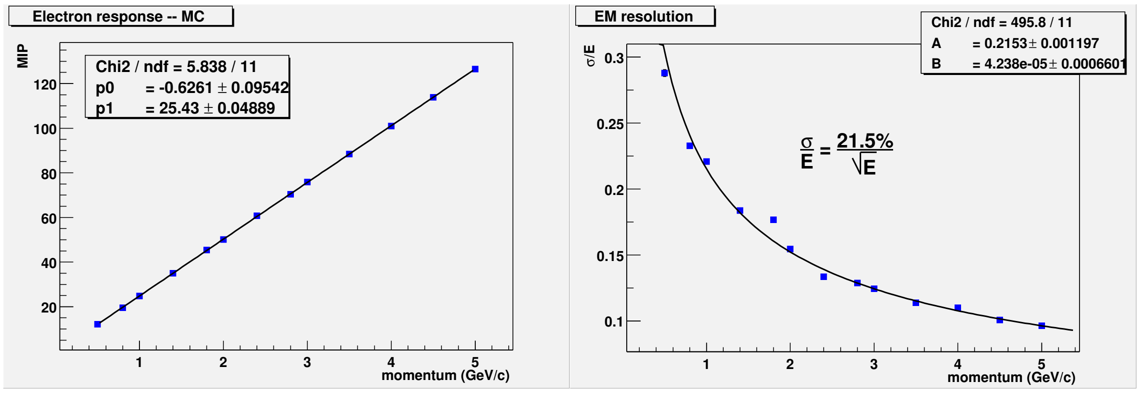
  $f_{\pi^0}(E) = 0.11 \times \ln(E)$ – Wigmans

  $f_{\pi^0}(E) = 1 - \left(\frac{E}{E_0}\right)^{m-1}$ – Groom
  where E_0 = 1 GeV

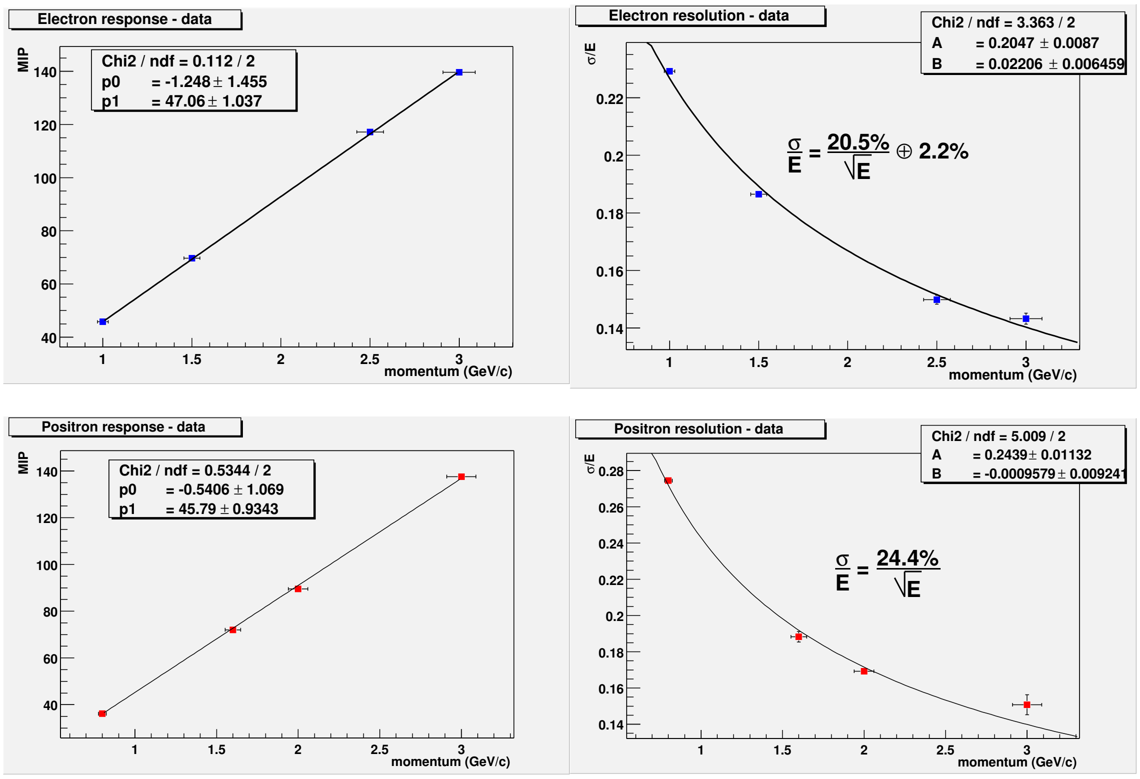
- Measuring the calorimeter response on the electrons and pions versus beam momentum one can extract e/h

EM response

- GEANT 3.21:

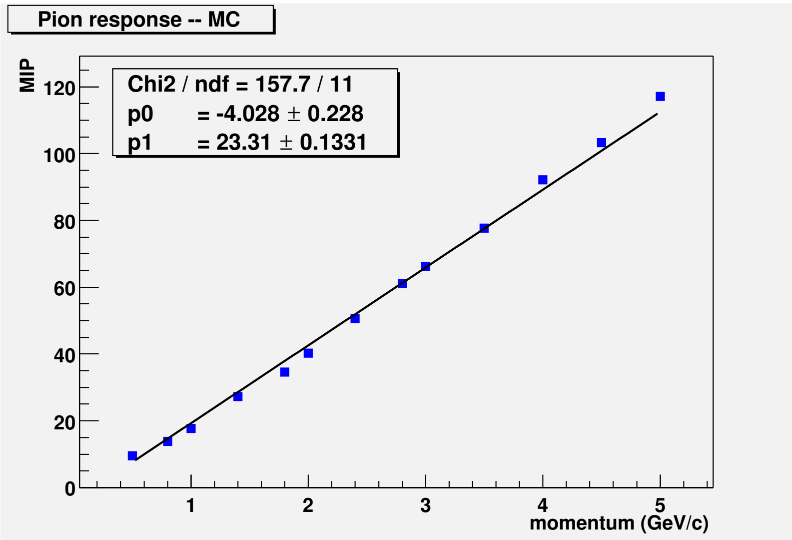


- Data (electrons and positrons):

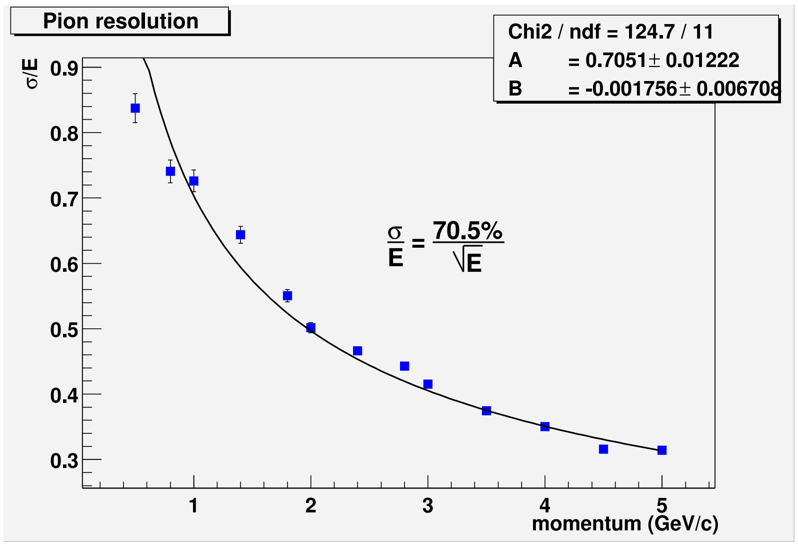


Pion response (MC)

- GHEISHA is used for hadronic interaction simulation

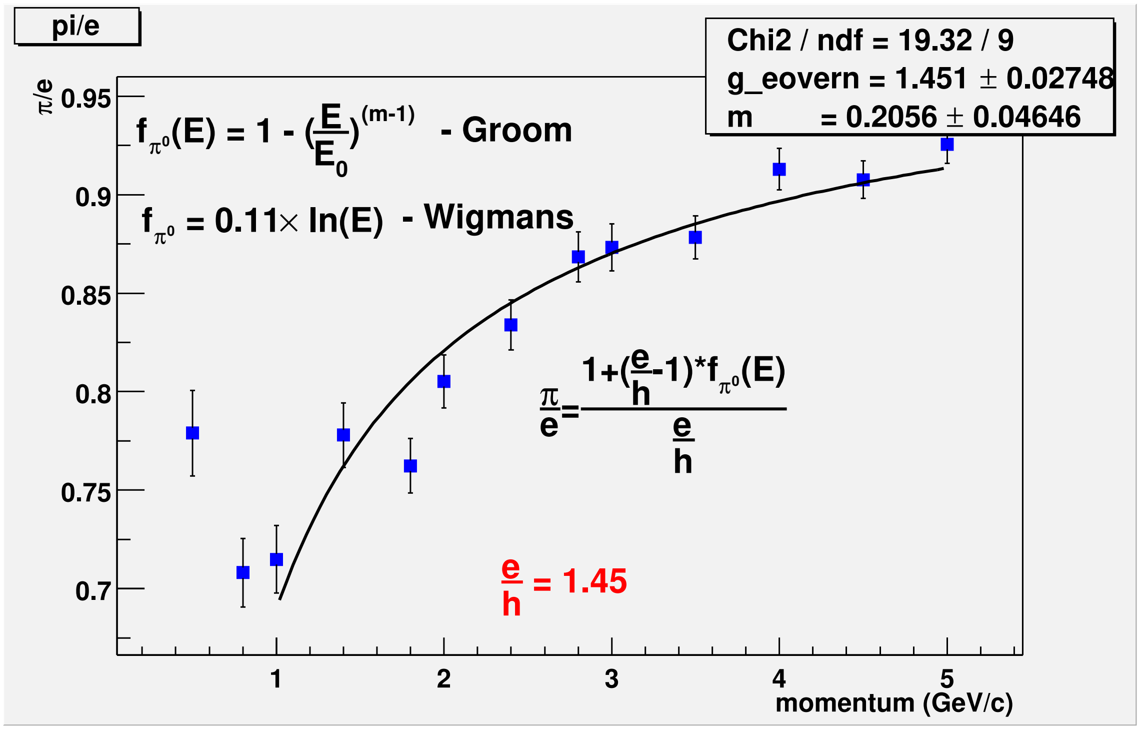


- Non-linearity in pion response due to f_{π^0} is evident



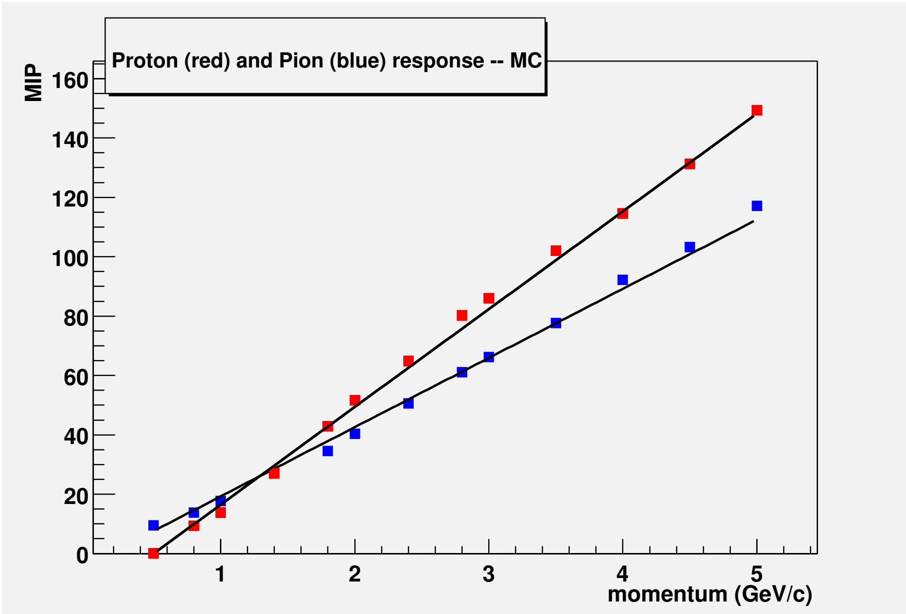
Extracting e/h

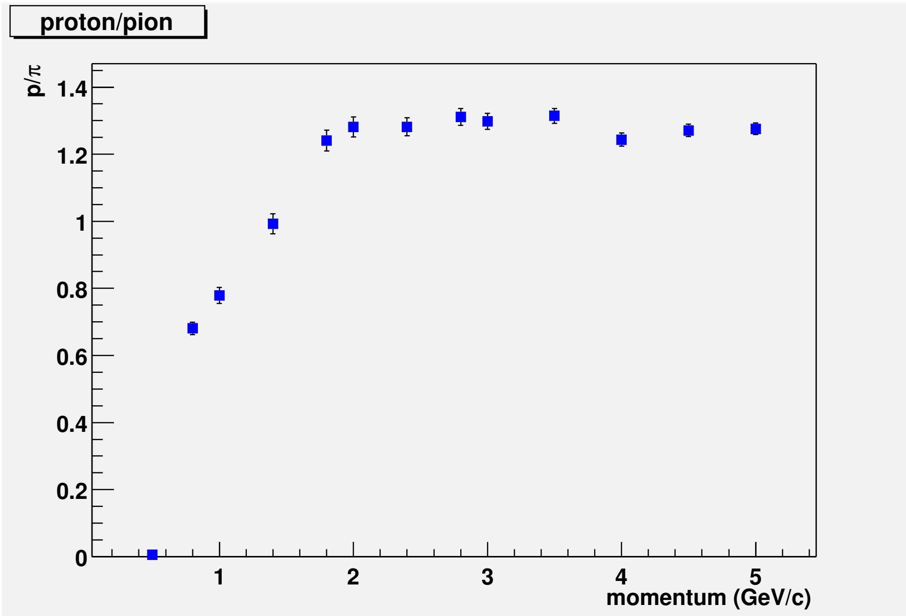
- To extract e/h one can fit $\frac{\pi}{e}(P_{beam})$ leaving e/h as a free parameter



Proton/Pion response

- The p/π ratio is not 1 as well. But MC gives somewhat ... unexpected: the calorimeter response to protons is higher than to pions for $P_{beam} \geq 1.5GeV$





MC based on hadronic shower parametrization (strategy)

- Why? Because hadronic interaction generators are not reliable at low energies
- Also, it is faster
- Use the real testbeam data to parametrize the average longitudinal and lateral development of the hadronic (and EM if needed) showers
- Once the average profile is parametrized the fluctuations around the average should be added to reproduce the test data in their statistical (i.e. event by event) behaviour

- Introduce fluctuations in the incident particle energy to reproduce the resolution of the calorimeter (simple and straightforward but not the only way)
- The shape of the longitudinal profile of the shower has to be submitted to fluctuations (event by event fluctuations of the hadronic shower length)

Hadronic shower parametrization

- Bock *et al.* parametrization for the longitudinal HS profile can be used

  $$\frac{\Delta E}{\Delta x} = k(\omega s^{a-1} e^{-bs} + (1-\omega) t^{c-1} e^{-dt})$$

  $s = x/X_0$ – depth from shower origin in radiation lengths

  $t = x/\Lambda_{int}$ – depth from shower origin in interaction lengths

  a, b, c, d – shower shape parameters to be fitted

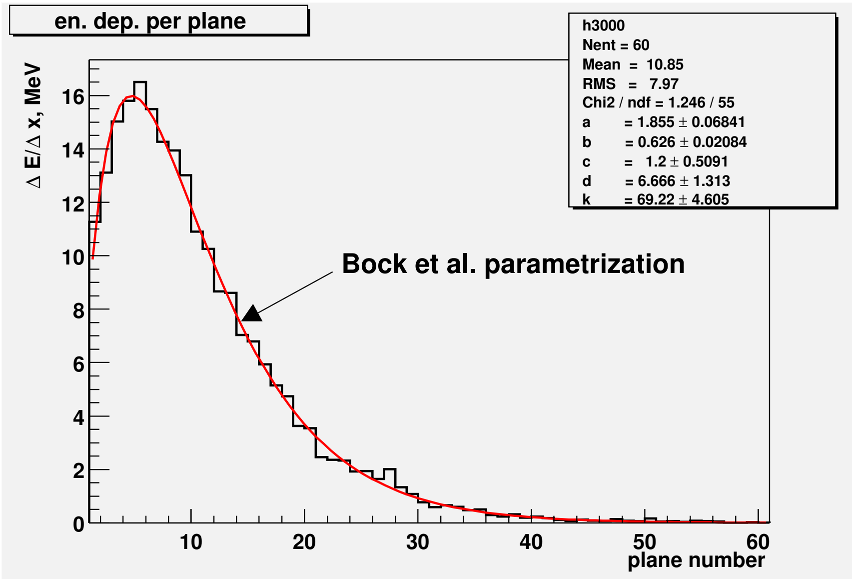
  ω, 1-ω – relative weight of the two curves giving respectively the pure EM part and the pure hadronic part of the shower

  k – normalization constant

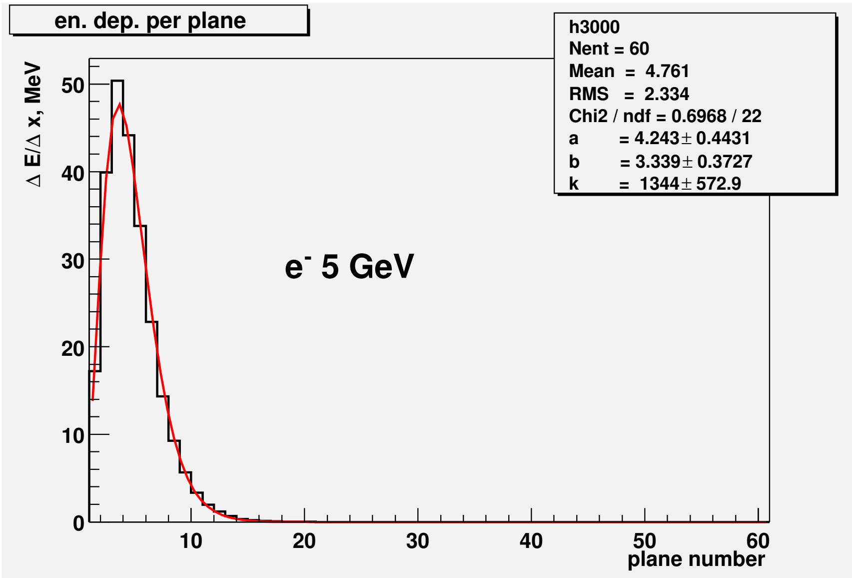
- By fitting this function to HS longitudinal profiles at different energies one can derive the energy dependence of the shape parameters (a, b, c, d)

Shower parametrization

- MC 5 GeV pions, ω was fixed at 0.3



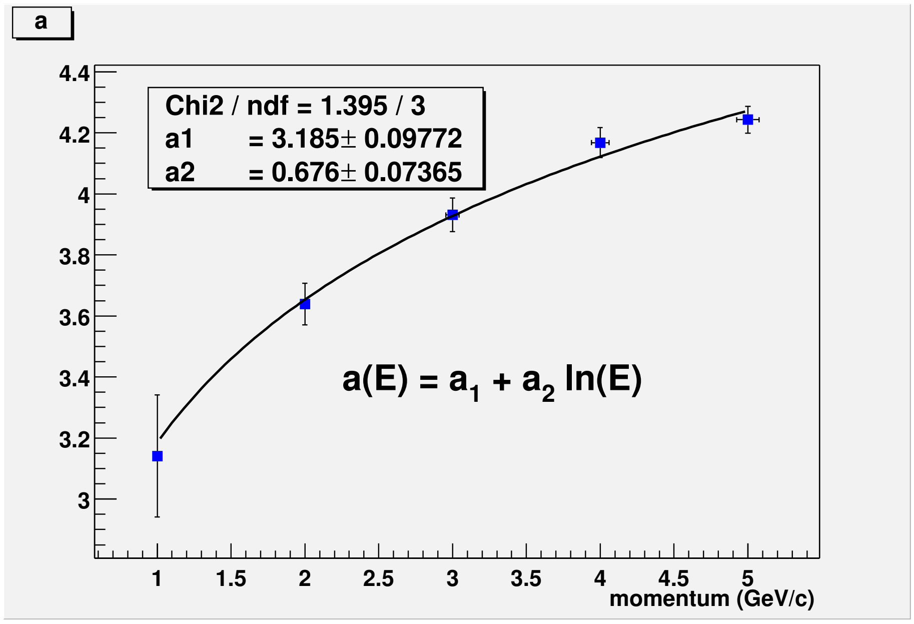
- The same parametrization (without hadronic term) can be applied to fit EM longitudinal shower profile

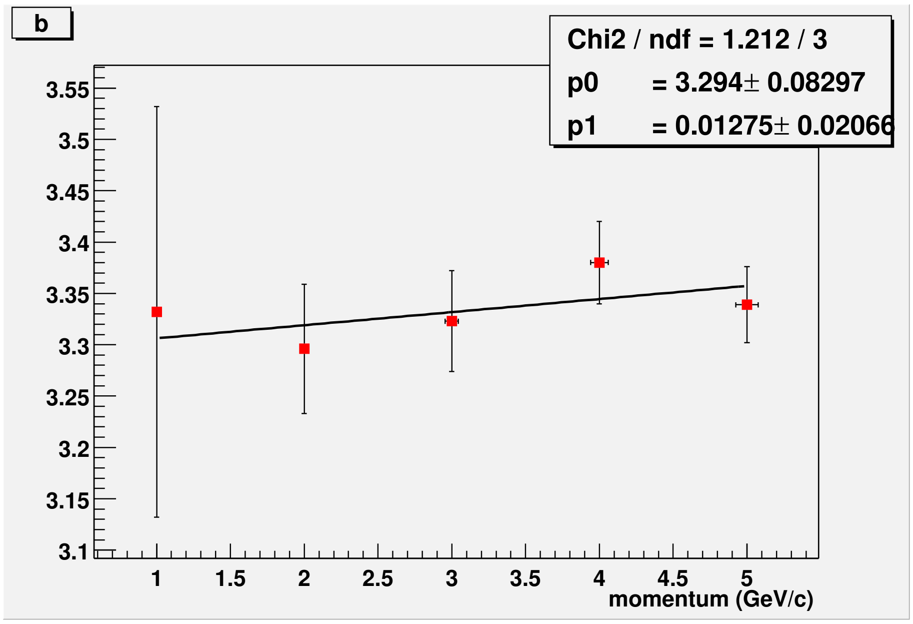


Shape parameters energy dependence

- MC of electrons (1, 2, 3, 4, 5 GeV) was used to find the energy dependence of the EM shower shape parameters a and b

$$\left(\frac{\Delta E}{\Delta x}\right)_{EM} = k(s^{a-1}e^{-bs})$$





How to introduce fluctuations (strategy)

- The resolution of the calorimeter is reproduced by introducing the fluctuations in the incident particle energy

- How to include longitudinal fluctuations?

$$\frac{\Delta E}{\Delta x} = k(\omega s^{a-1} e^{-bs} + (1-\omega) t^{c-1} e^{-dt})$$

\- Fix the a, b, c, d parameters at the mean values fitted previously and introduce two scale factors: EMSCALE and HDSCALE which multiply the space variable s and t respectively

\- The distribution of EMSCALE and HDSCALE is obtained from an *event by event fit to the real testbeam data*