Mass composition and cross-section from the shape of cosmic ray shower longitudinal profiles

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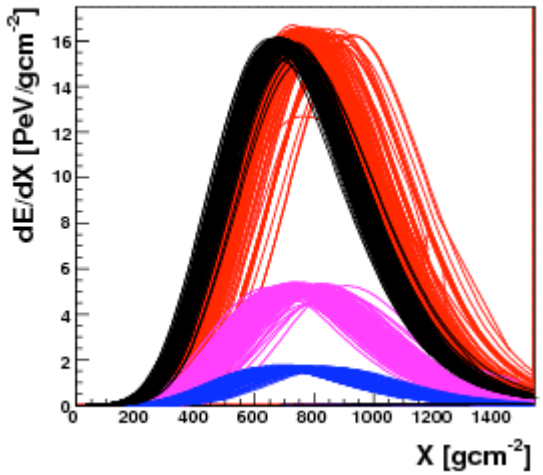
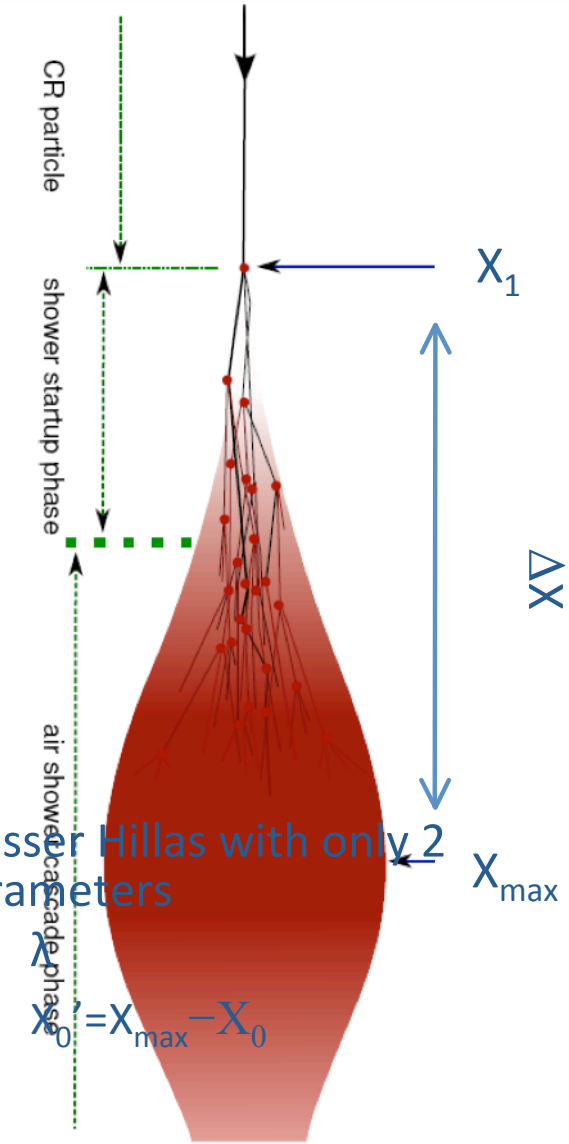
Universal Shower Profile



$$N = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X_0}{\lambda}} e^{\frac{X_{max}-X}{\lambda}}$$

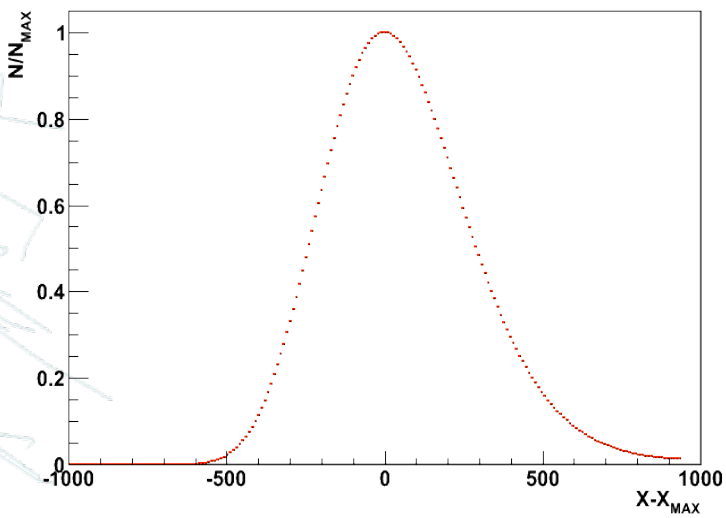
- Longitudinal profile
  - Usual shower observables
    - Nmax (Energy)
    - Xmax (Composition)
  - Information from the shape parameters (X_0,λ)??



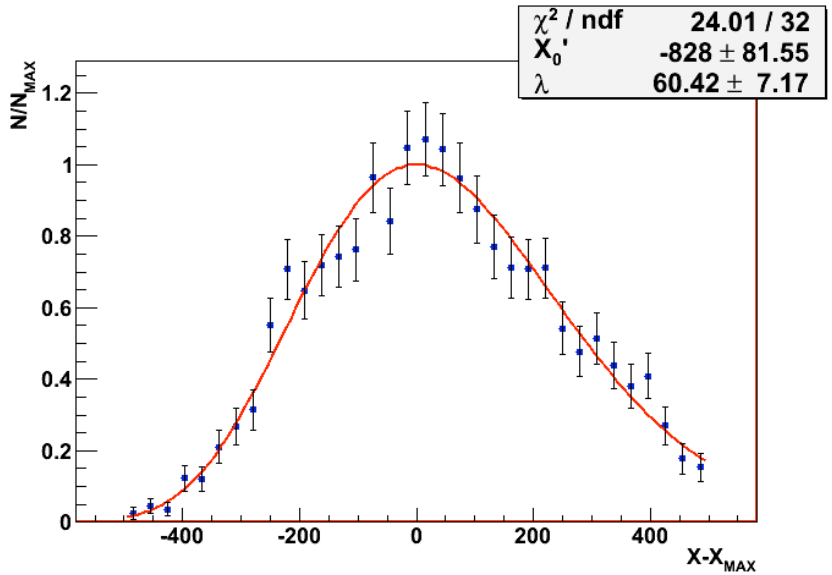
- Gaisser Hillas with only 2 parameters
  - λ
  - $X_0' = X_{max} - X_0$

Gaisser-Hillas shape parameters

Ideal longitudinal profile

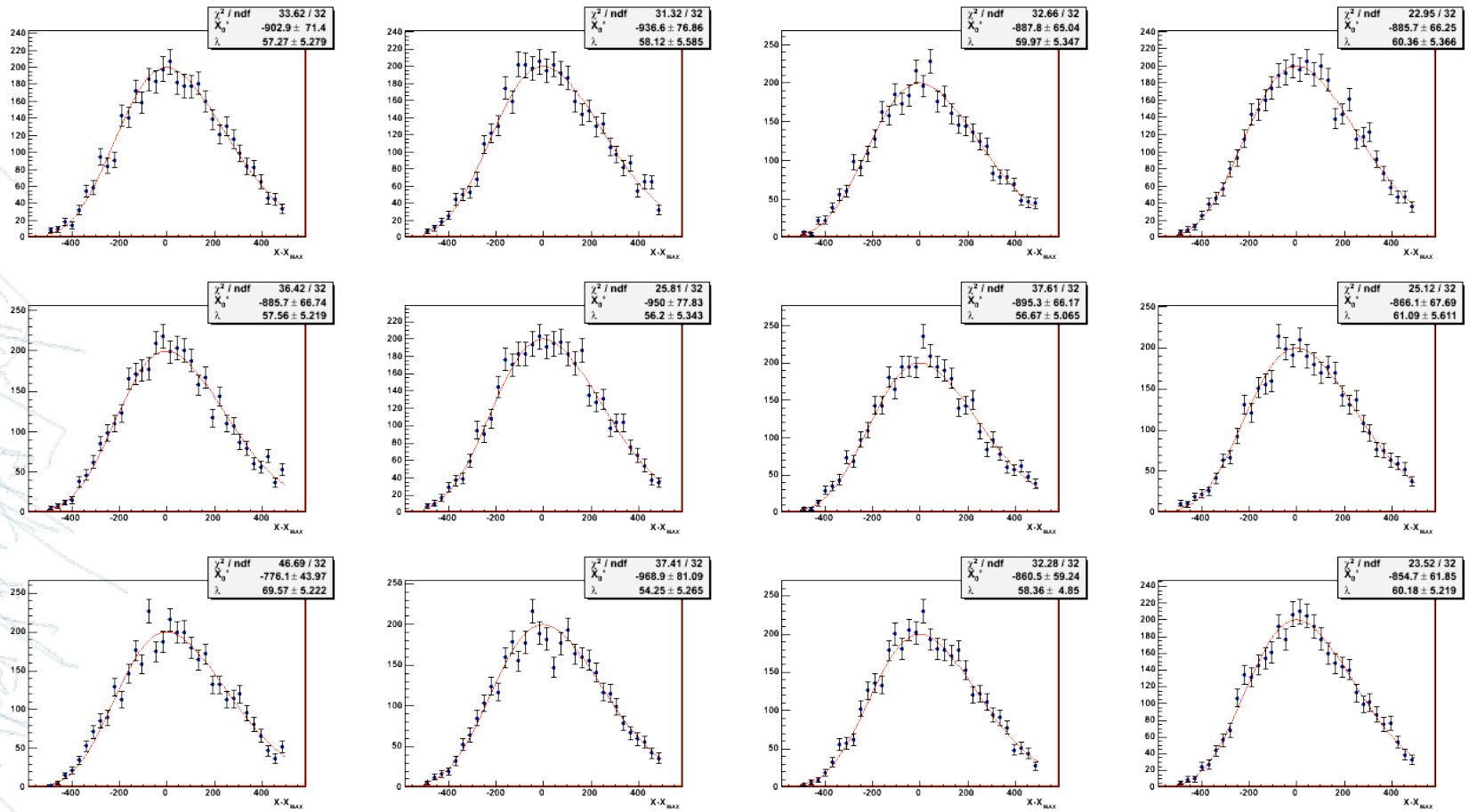


"Real" profile
(N_{max}=200 photons)



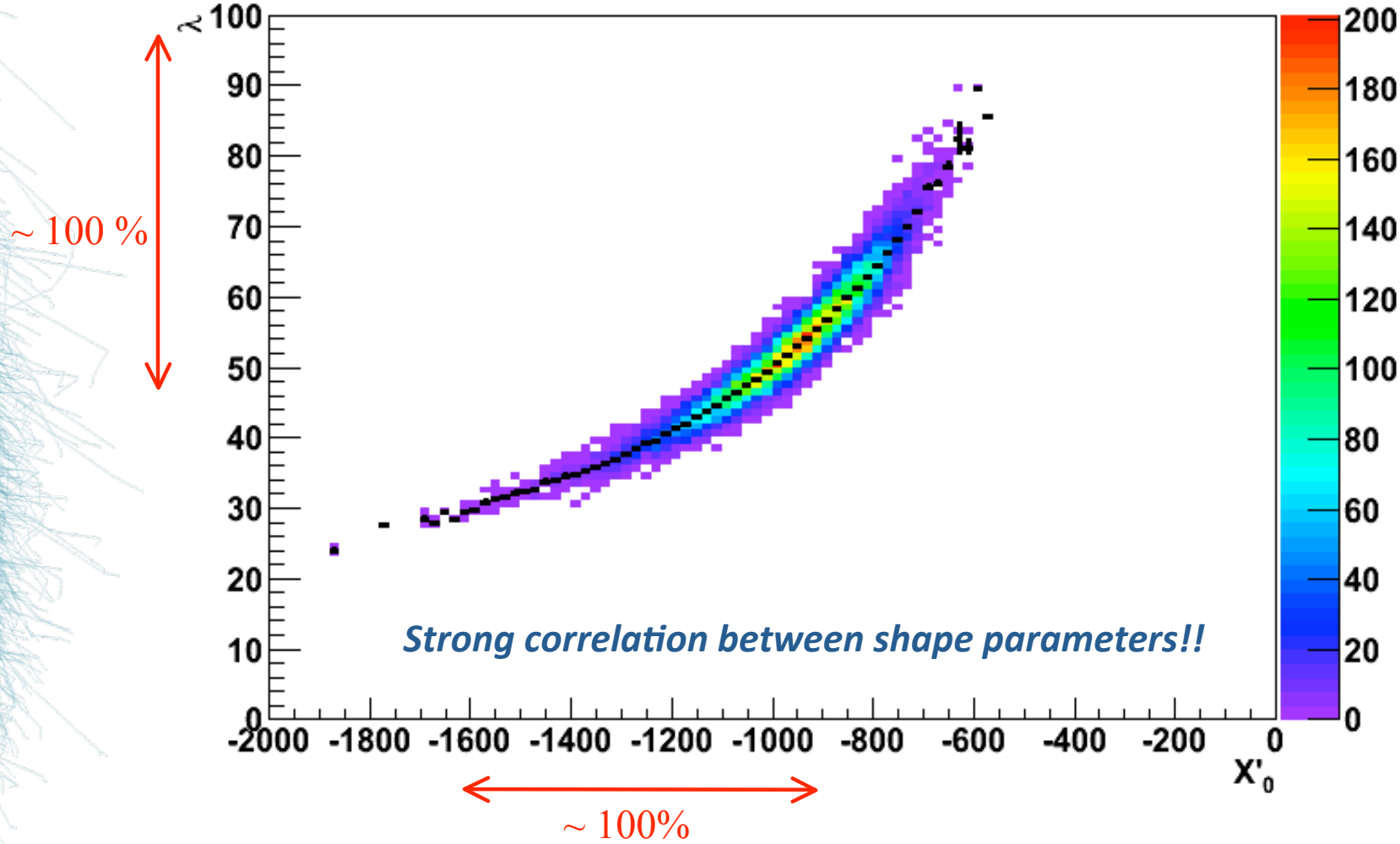
Fit using a Gaisser-Hillas function (λ,X_0')

Several realizations of the same ideal profile



Choose only fits with a good χ^2

Correlation between X_0' and λ

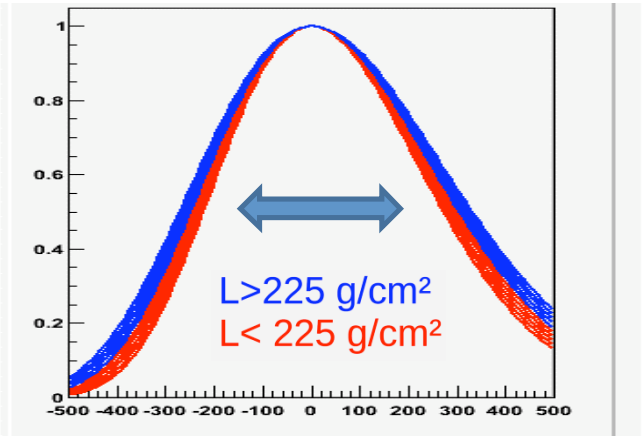


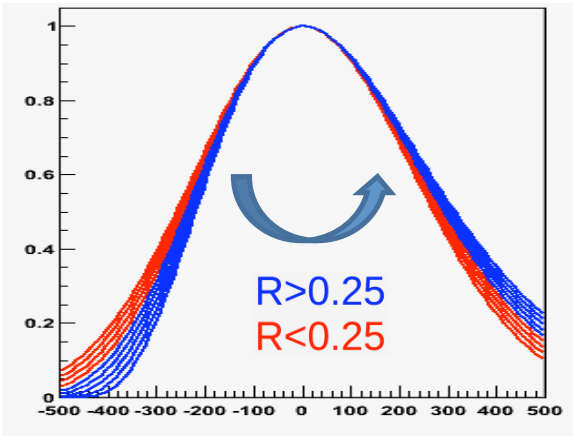
New parameterization

$$N' = \exp\left(-\frac{1}{2}\left(\frac{X'}{L}\right)^2\right) \prod_{n=3}^{\infty} \exp\left(-\frac{R^{n-2}}{n}\left(-\frac{X'}{L}\right)^n\right)$$

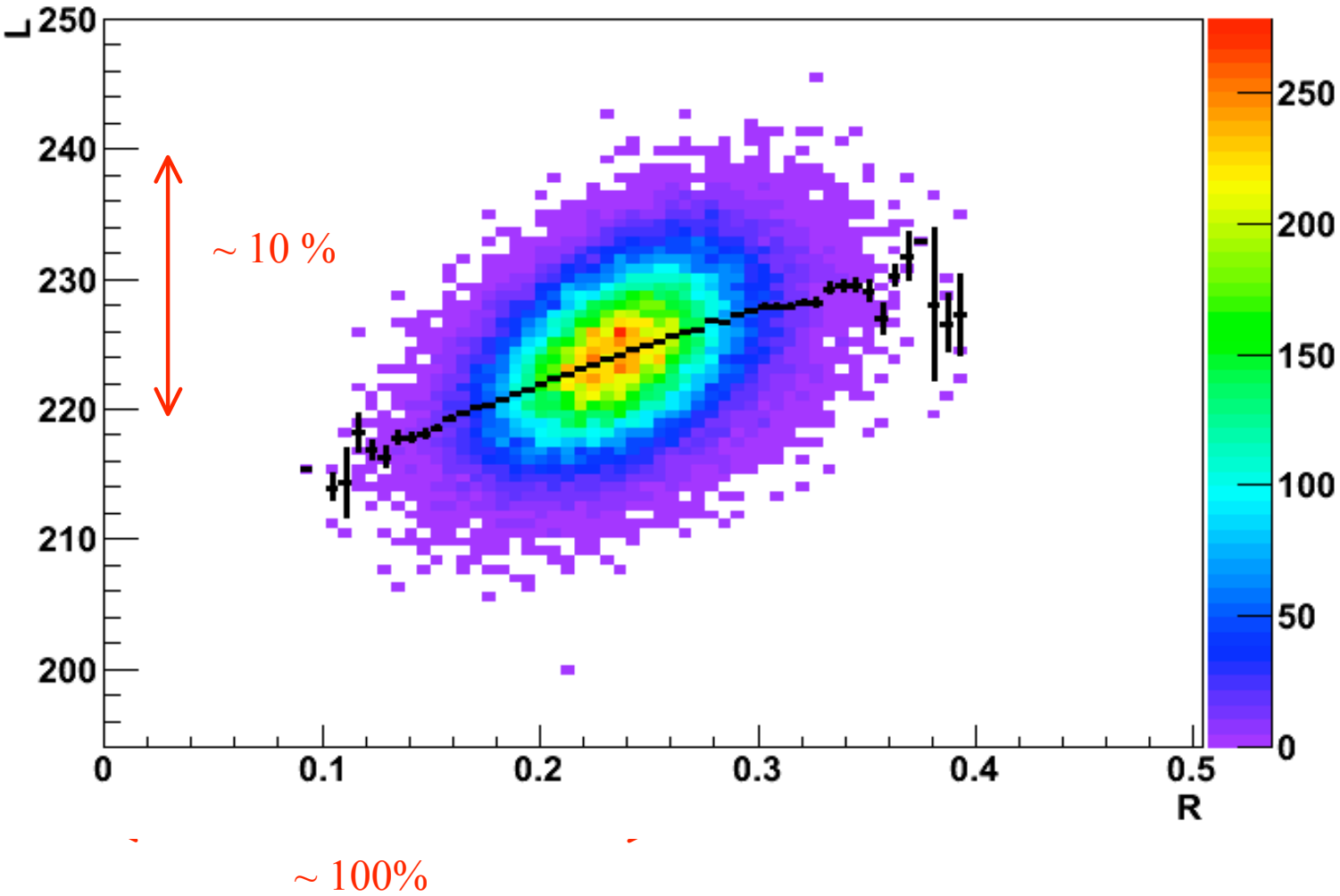
- $L^2 = \lambda \,.\, |X_0'|$
- L is proportional to the shower energy
- Could be fixed using $E_{e.m.}/N_{max}$ (approx. constant)

- $R^2 = \lambda \,/\, |X_0'|$
- R afects mostly the tails
- Should be sensitive to the speed of the shower development



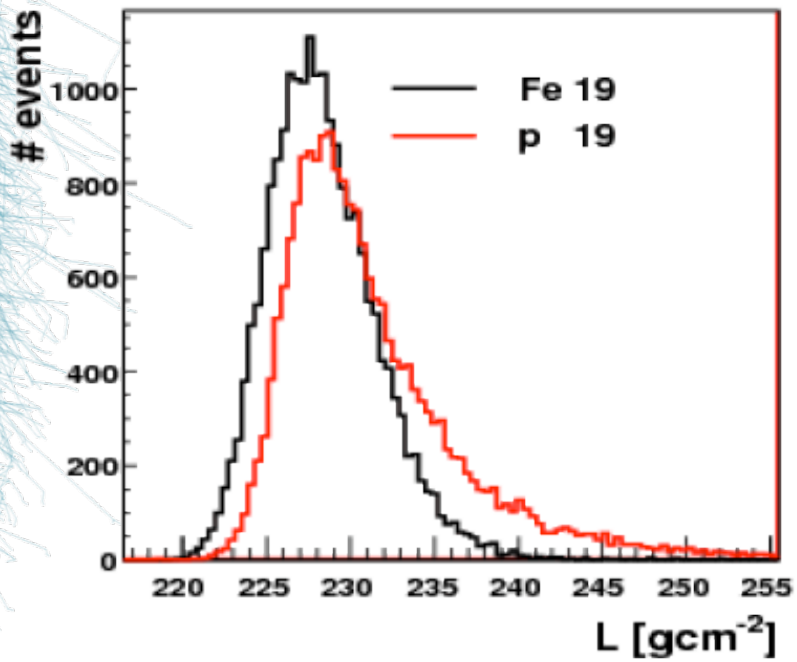


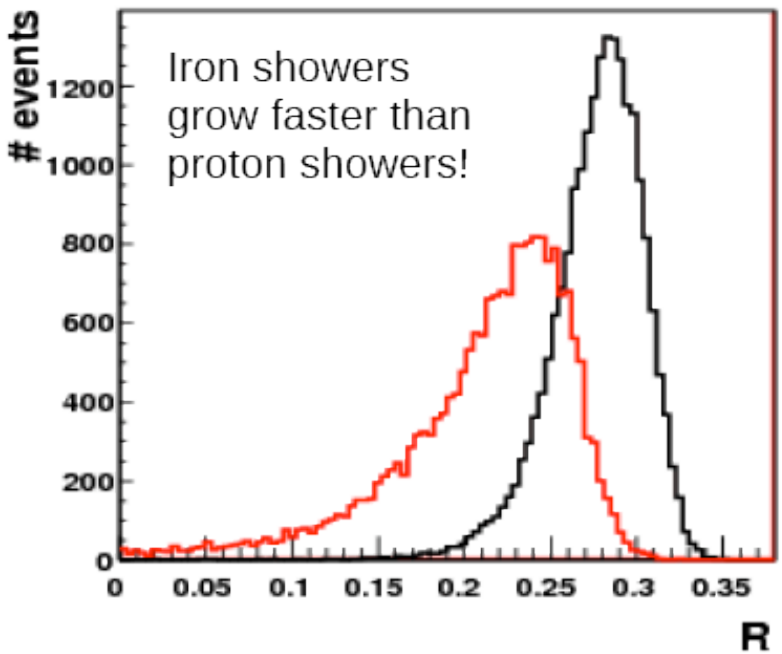
Correlation between L and R



L and R for proton and iron initiated showers

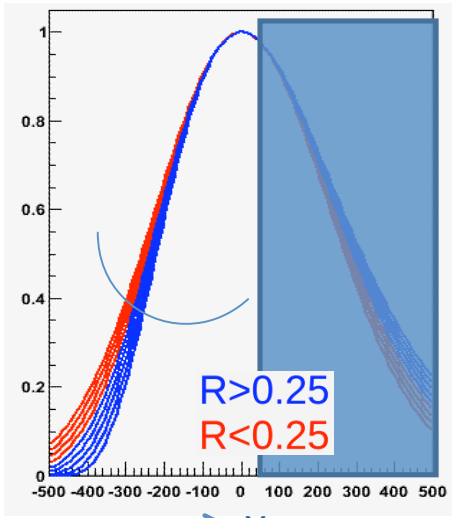
- L varies only ~ 5%
  - like Energy/N_{max}
  - can be fixed for shape analysis
- R can be used as a new composition variable!
  - independent of X_{max}





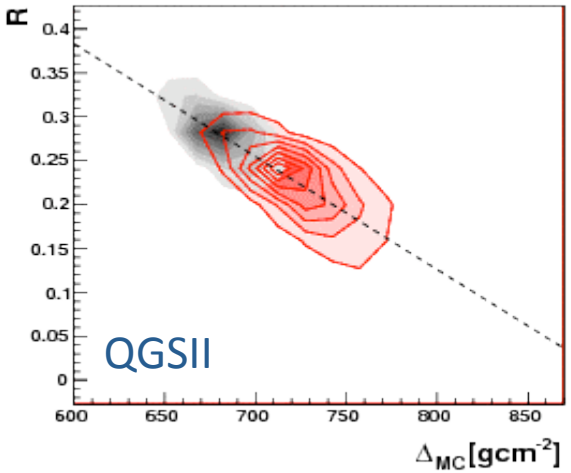
R is a measurement of $\Delta X = X_{max} - X_1$

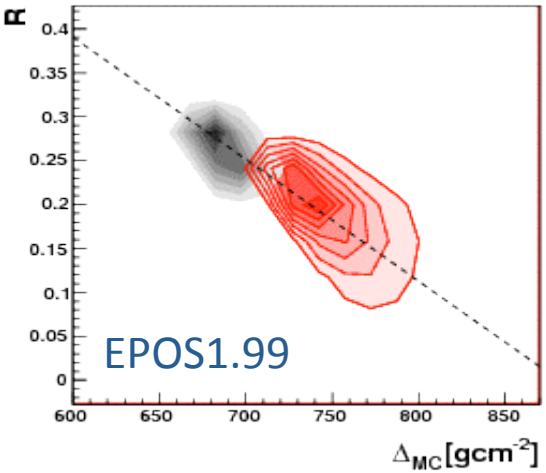
- R is sensitive to the shower development speed
  - High energy hadronic models
- R fit is performed in X'∈ [-400,100]
- L fixed to $E_{e.m.}/(2\pi)^{1/2} dE dX_{max}$
- ΔX is a linear function of R



$X_1 \longleftrightarrow X_{max}$

ΔX



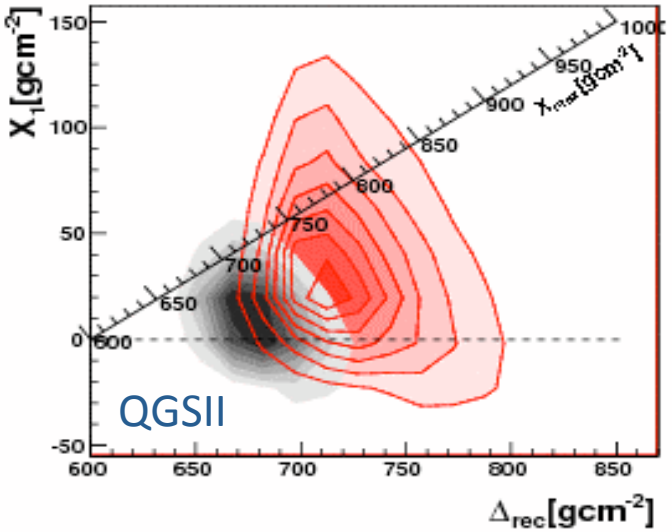


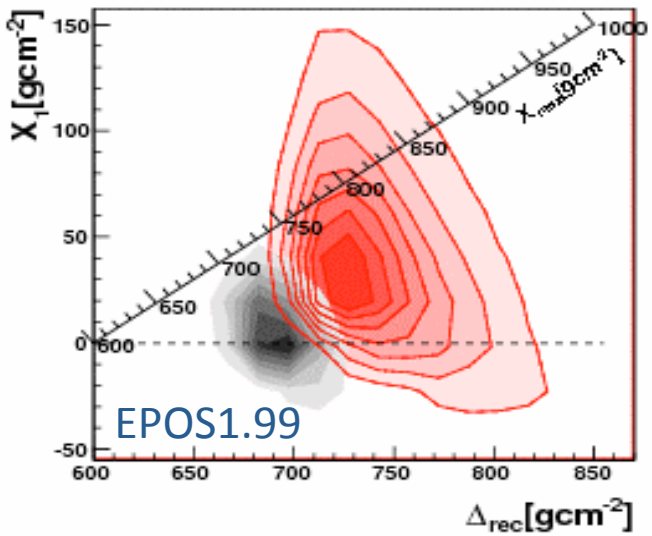
Proton

Iron

Accessing the first interaction

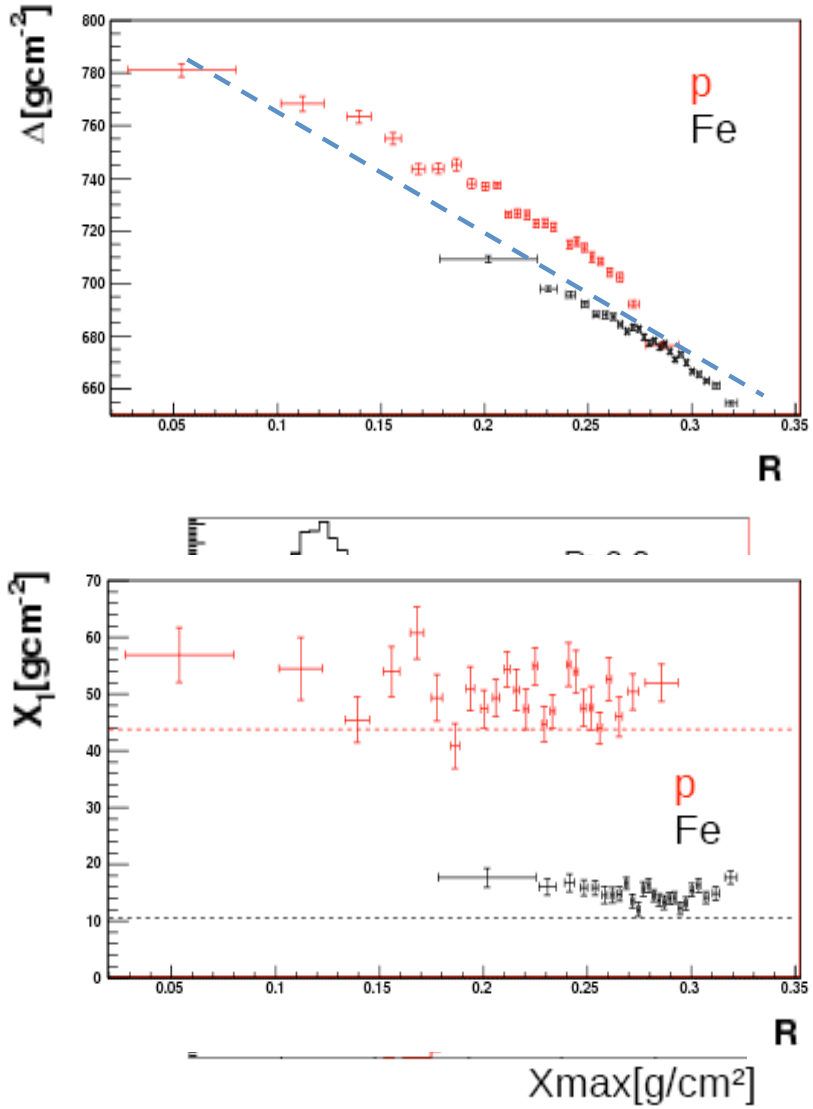
- First interaction (X_1) is not visible
- But can be measured using: $X_1 = X_{max} - \Delta X(R)$
  - In this case $\Delta X(R)$ is obtained from MC
- X_{max} is the best composition variable by itself
- X_1 allows the extraction of the primary cross-section
- ΔX contains information about the subsequent shower development





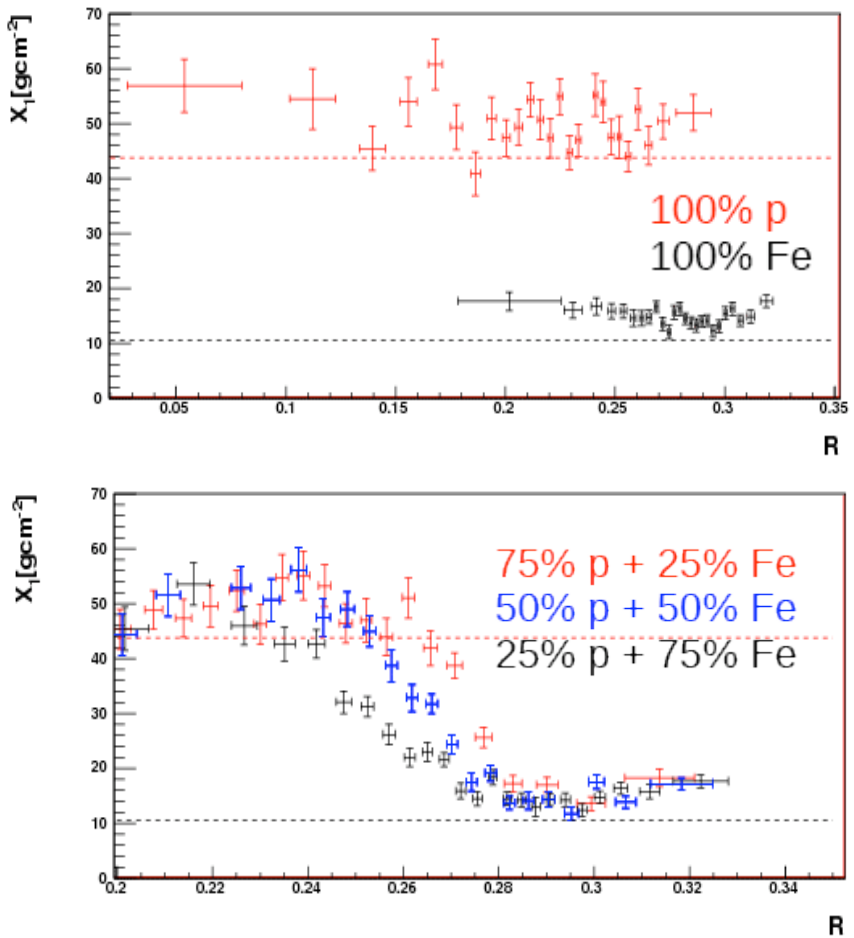
How to meausure <ΔX> and <X1>

- X_{max} distribution for each R slice fitted with
  - $\exp(X_1)$ +Gaussian(ΔX)
- ΔX depends on R
  - Effective calibration on data
  - Event-by-event analysis
- X_1 is constant in R for each primary
  - Effective cross section



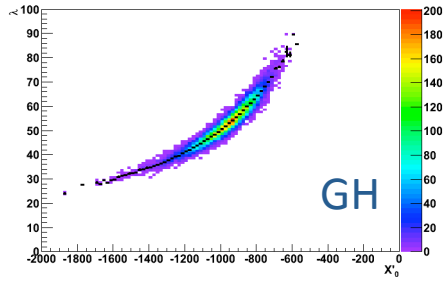
Fitting cross-section for mixed composition

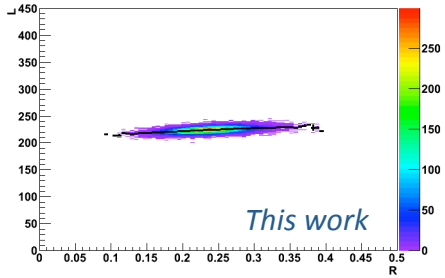
- Possibility to measure two cross-sections at the same energy
- Estimate different primary components concentration

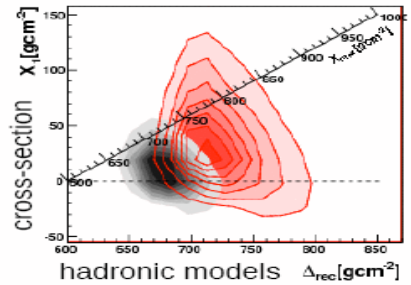


Conclusions

- New parameters for shower profiles shape
  - Gaussian(L).Distortion(R)
  - L is almost constant and related to the shower energy
  - R is a new primary mass composition variable
- R measures the speed of the shower development
  - R correlates with ΔX
    - Sensitivity to hadronic models
  - Measurement of $X_1 = X_{max} - \Delta X(R)$
    - Primary cross-section even with mixed compositions







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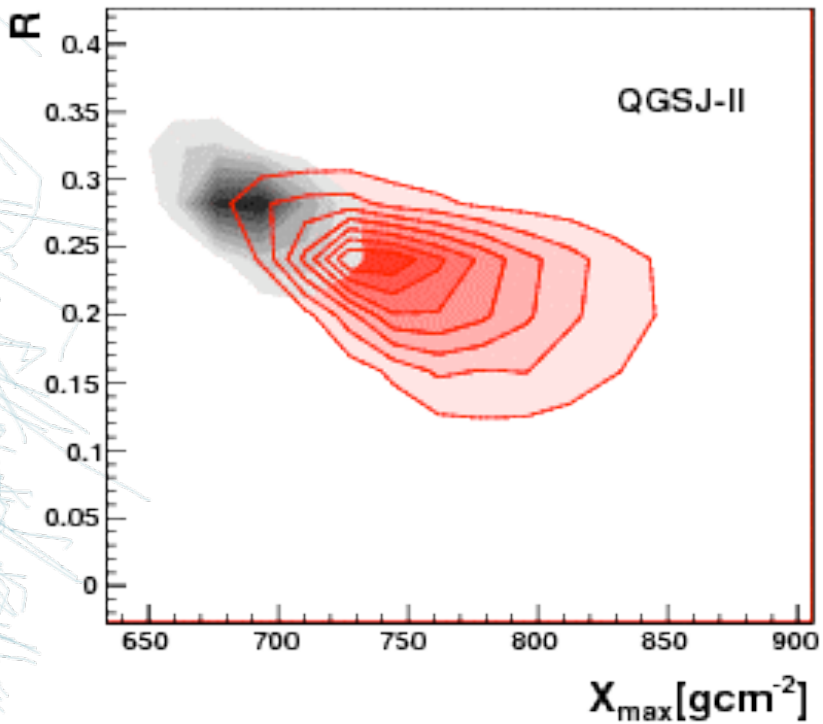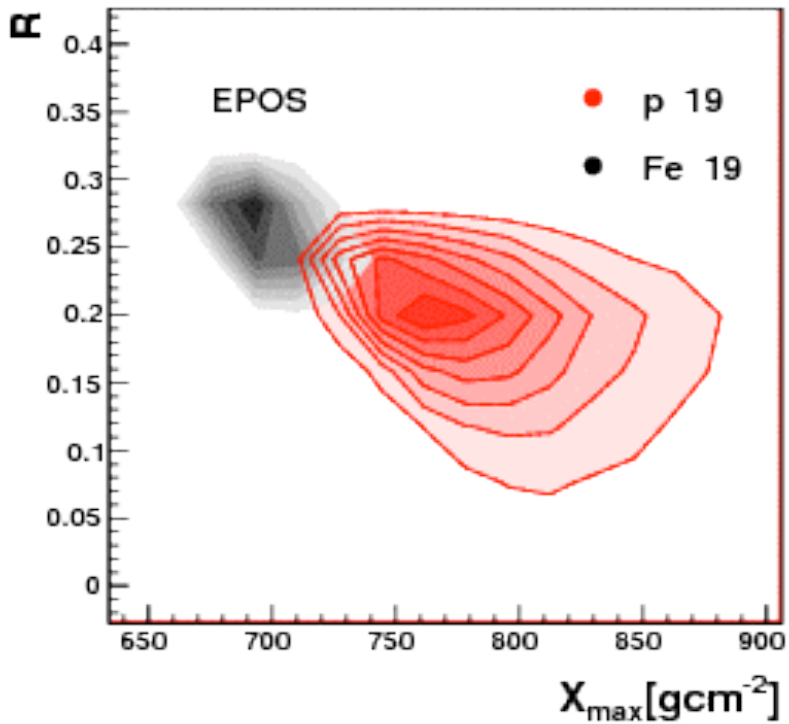
Constrain Hadronic models