Shower Moments: A compact Representation of Shower shapes

Parallel 6-A: Transition region/shower shape

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Approach

- To study shower shapes we usually make a profile of the energy distribution as a function of L or R
- Difficult to express in a compact form the dimension of the shower
- Depends on how the divisions in L and R are defined
- A different approach can be used to express these quantities in a "read-out" independent way
- Based on an idea from ATLAS EME calorimeters

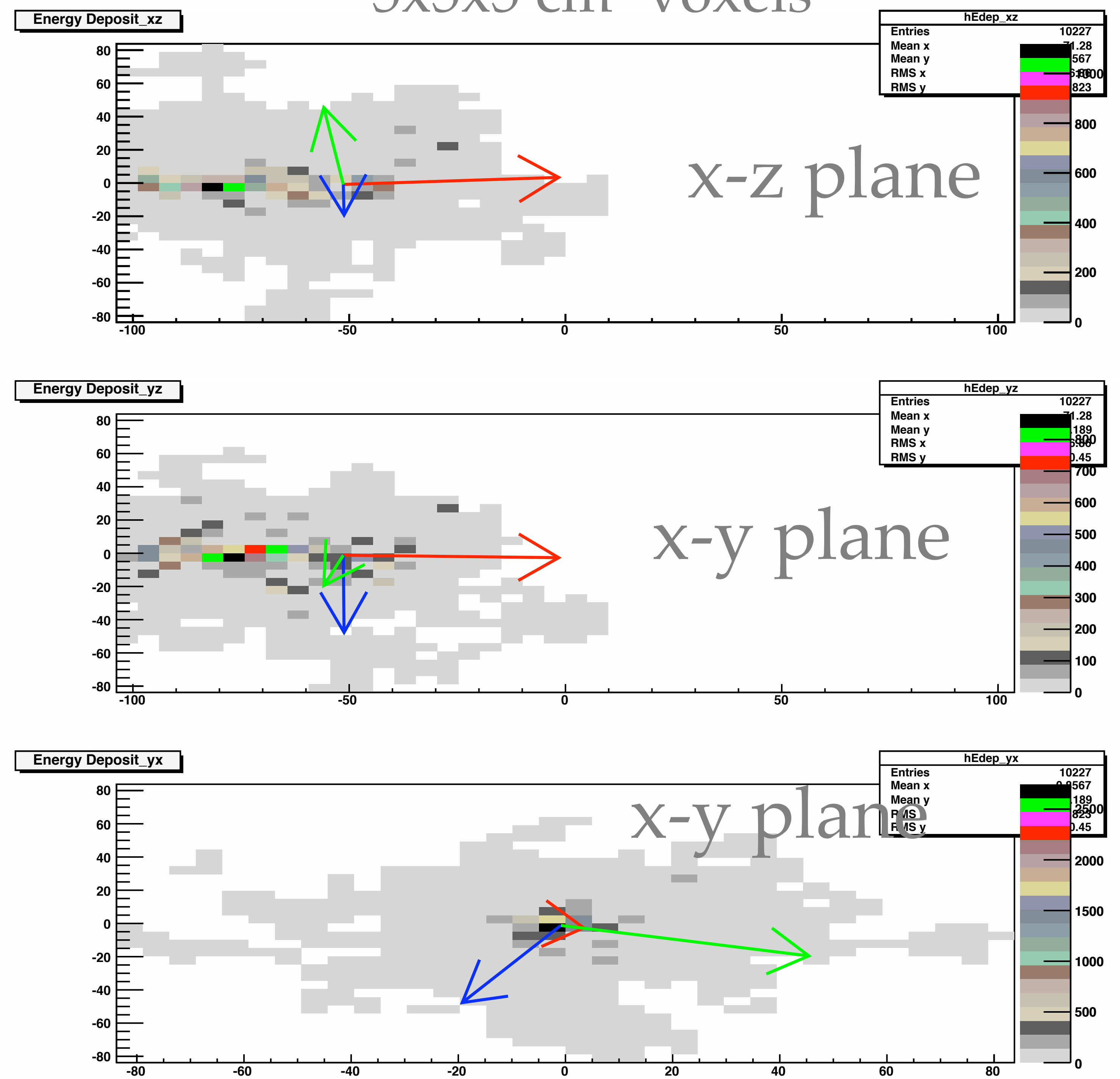
Definitions

- Step 1: define an appropriate segmentation of the calorimeter (ReadOut) **voxels**, define Edep for each voxel
- Step 2: measure, for each voxel **O**: an observable that can be defined for each voxel (e.g. position, energy density, ...)
- Step 3: for each shower define the *n-th* order moment in **O** as:

$$E_{cl} = \sum_{v \in \{voxels\}} E_v$$

$$< O^n > = \frac{1}{E_{cl}} \sum_{v \in \{voxels\}} E_v \times O^n_v$$

5x5x5 cm^3 voxels



Single π 20 GeV Fe-Sci calorimeter: beam along z axis

Shower Center And Shower Axis

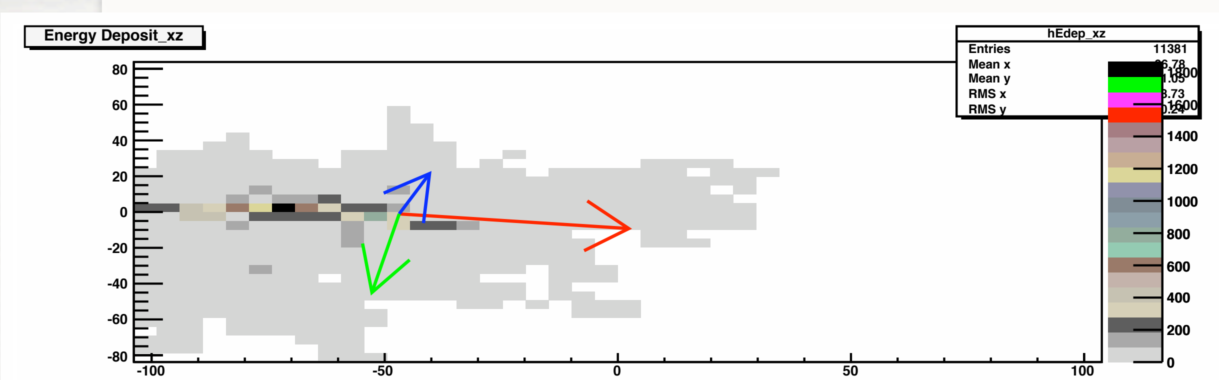
- It is useful to define the shower center: $\vec{C} = (<x>, <y>, <z>)$
- Let's also define the 3x3 matrix:

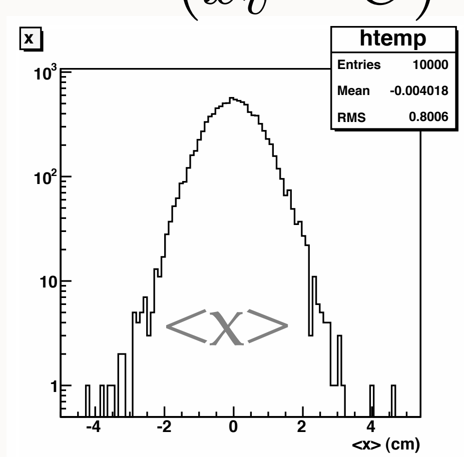
$$
\begin{aligned}
M_{i,j} &= \frac{1}{w} \sum_{v \in \{voxels\}} E_v^2 (i_v - <i>)(j_v - <j>) \\
i,j &\in \{x, y, z\} \\
w &= \sum_{w \in \{voxels\}}
\end{aligned}
$$

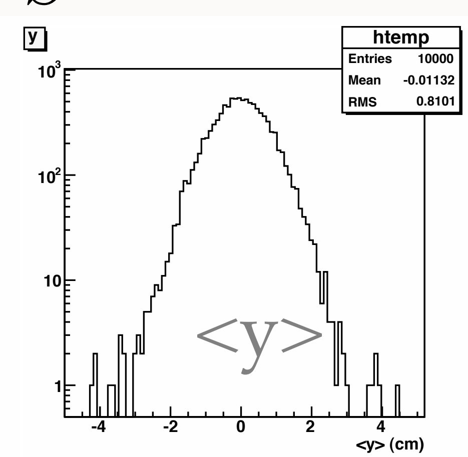
- The shower 3D axes are the eigenvectors of the symmetric matrix M (principal component analysis)
- The shower axis is the eigenvector that forms the smallest angle with respect to the (beam origin-shower center) vector (~z axis): $\vec{S}$
- For each voxel we define:

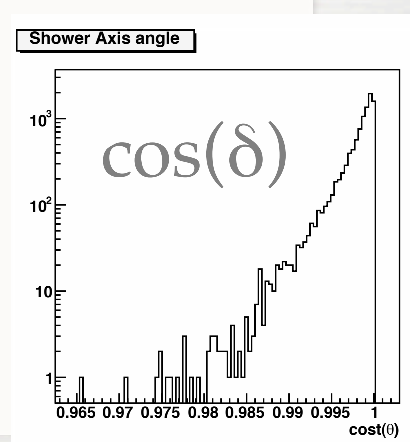
$$
\begin{aligned}
r_v &= |(\vec{x_v} - \vec{C}) \times \vec{S}| \\
\lambda_v &= (\vec{x_v} - \vec{C}) \cdot \vec{S}
\end{aligned}
$$

Position of the cell, w.r.t. shower center and axis







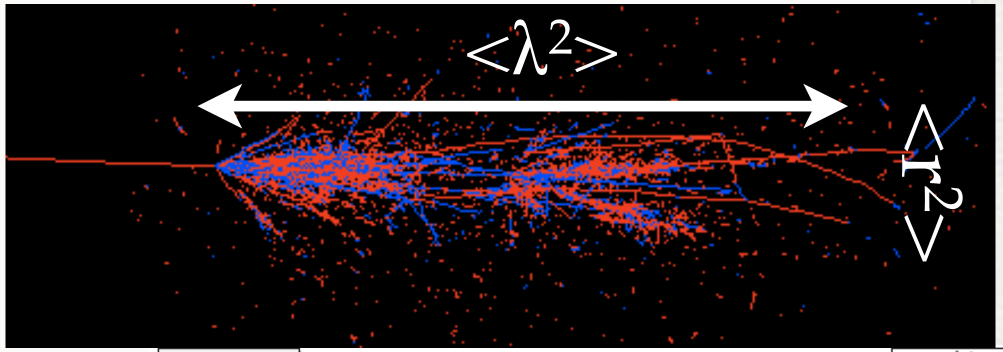


Shower Moments

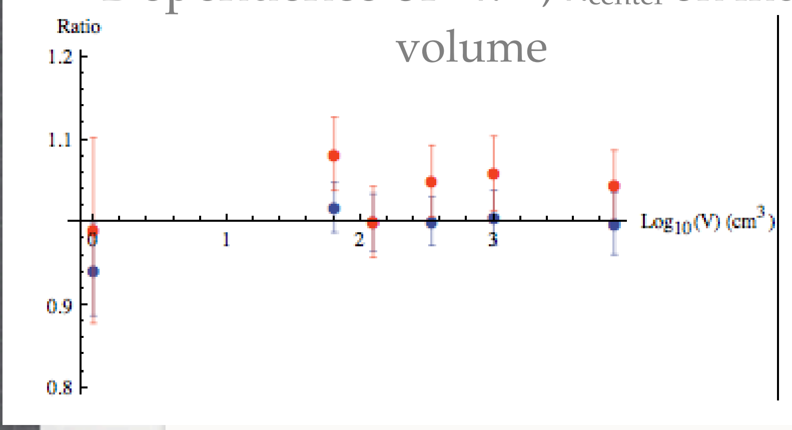
$$< \lambda^2 >= \frac{\sum_{cell} E_{cell}\lambda^2_{cell}}{\sum_{cell} E_{cell}}$$

$$< r^2 >= \frac{\sum_{cell} E_{cell} r^2_{cell}}{\sum_{cell} E_{cell}}$$

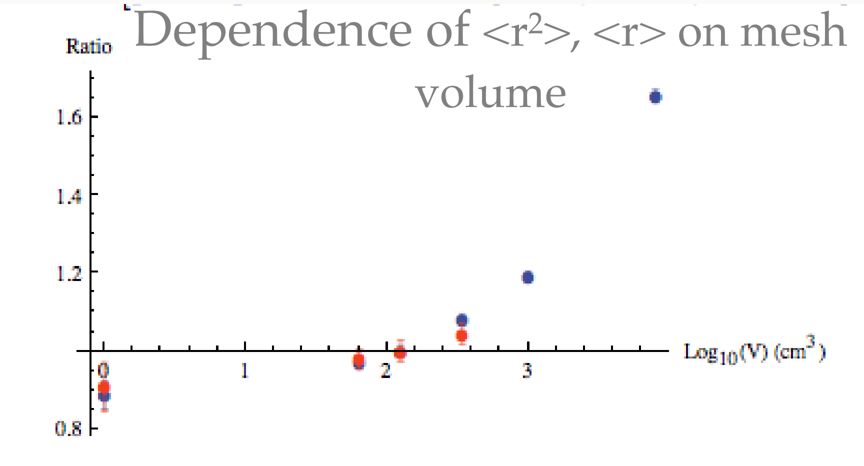
- For each shower calculate some moments:
  - $<r^2>$, $<\lambda^2>$, λ_{center} ($<z>$-FrontFace)
  - Reduce dependence on mesh dimension

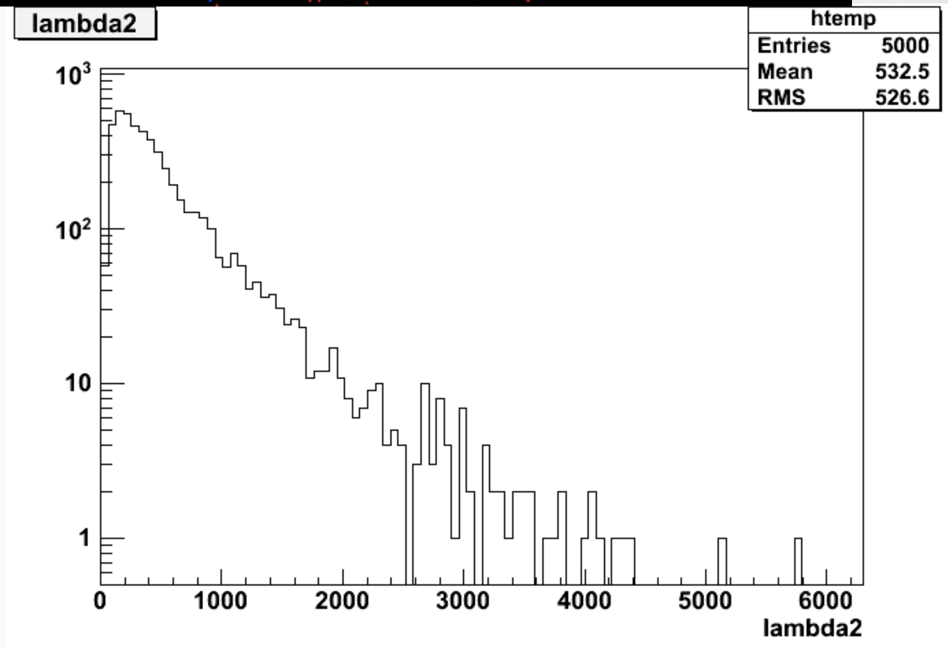


Dependence of $<\lambda^2>$, λ_{center} on mesh volume

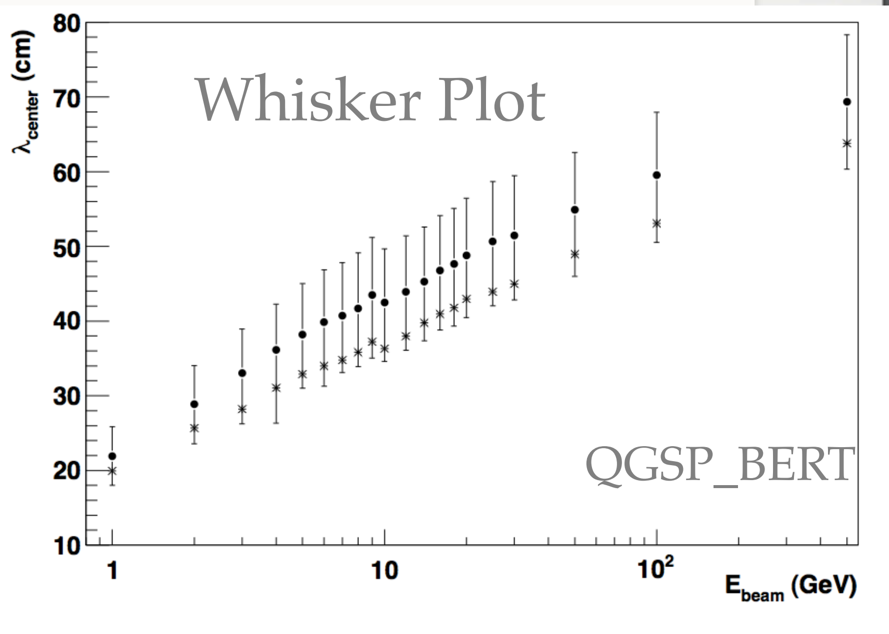


Dependence of $<r^2>$, $<r>$ on mesh volume



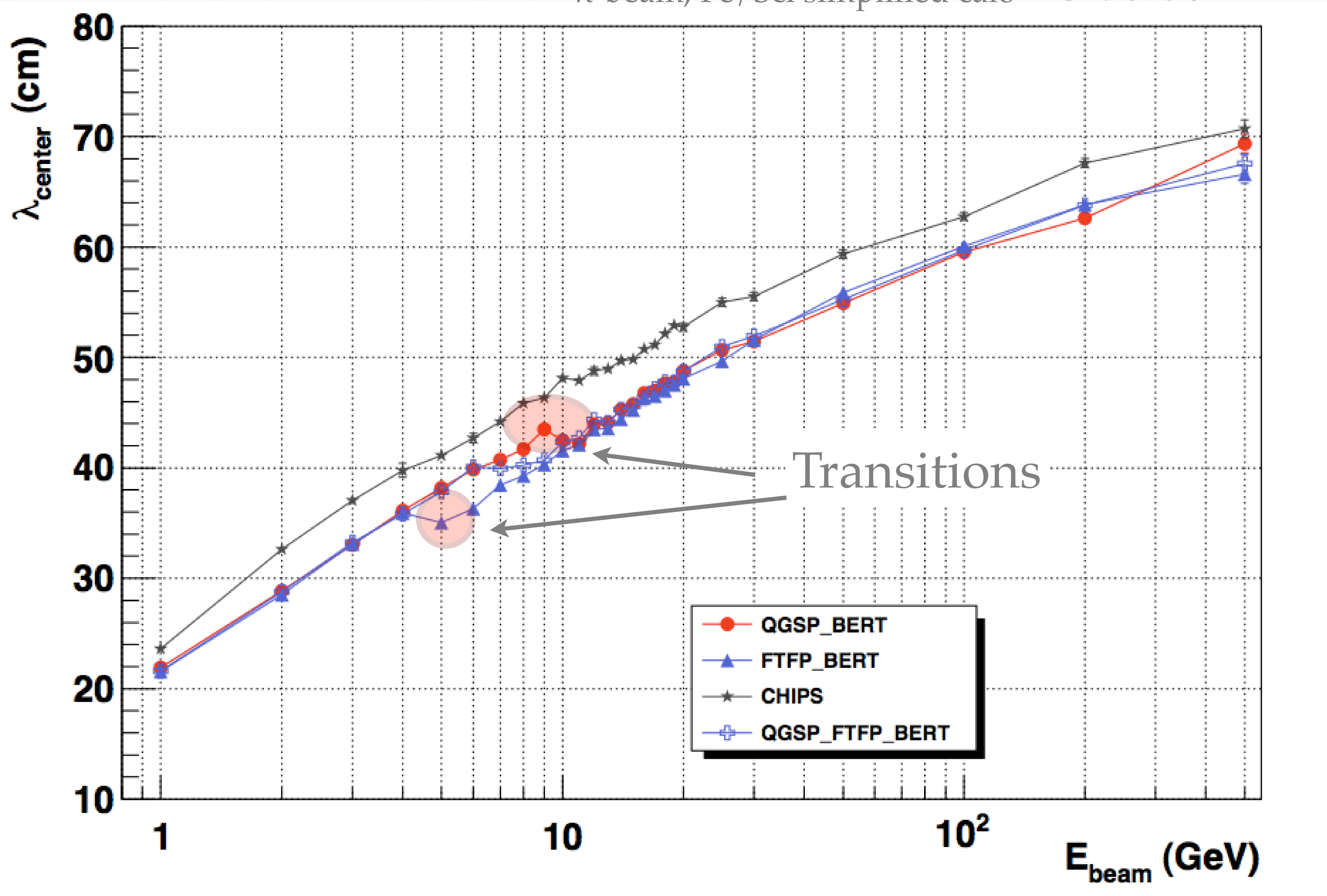


1. Distributions of shower moments have long tail
2. However the distributions are "well-behaved", i.e. their statistical quantities (mean, median, quantiles) are a smooth function of primary energy
3. Can summarize shower shapes in terms of e.g. Mean and Variance (or median quantiles, skeness and kurtosis,...)



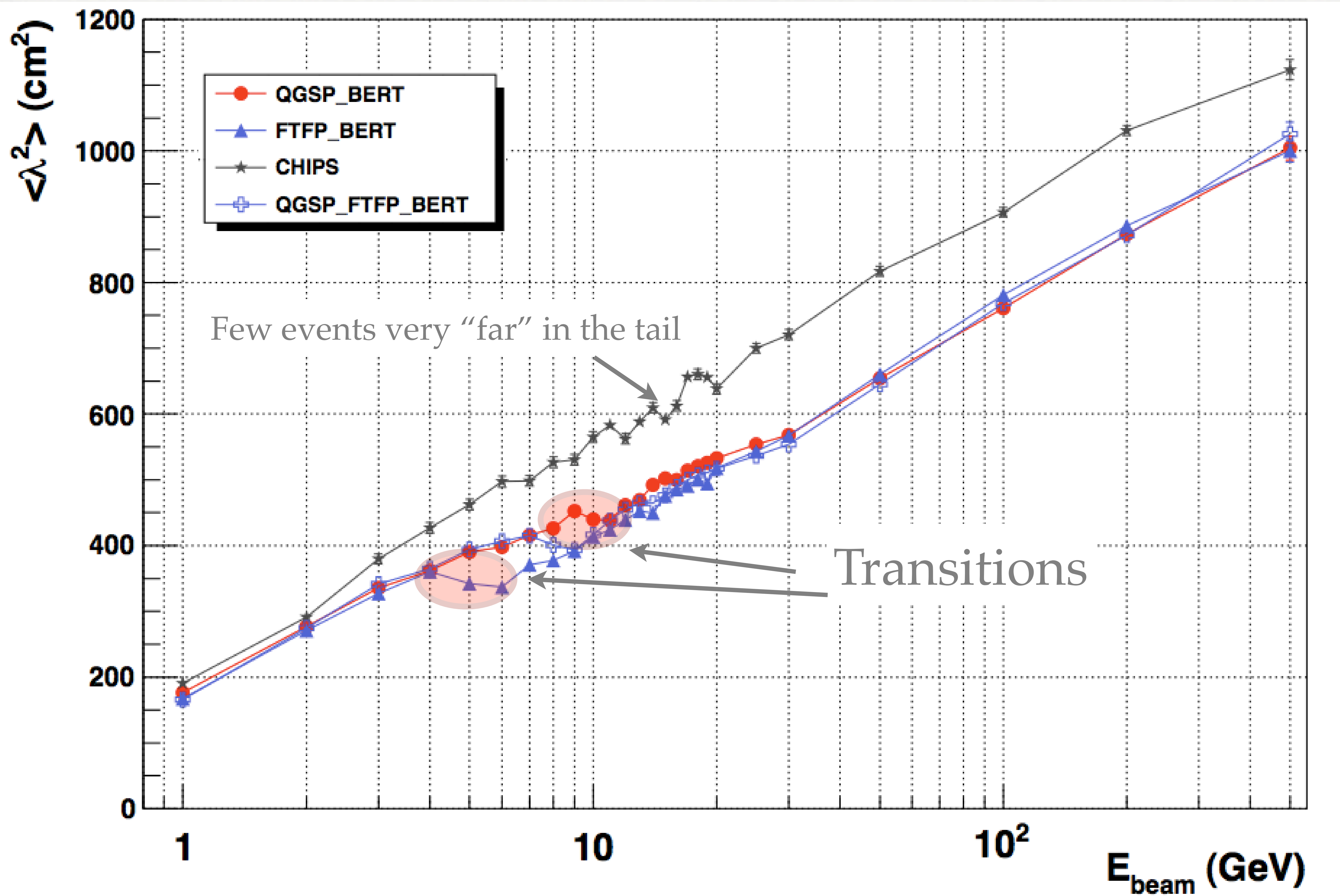
Shower Maximum depth

π^- beam, Fe/Sci simplified calo   G4 9.3.ref02



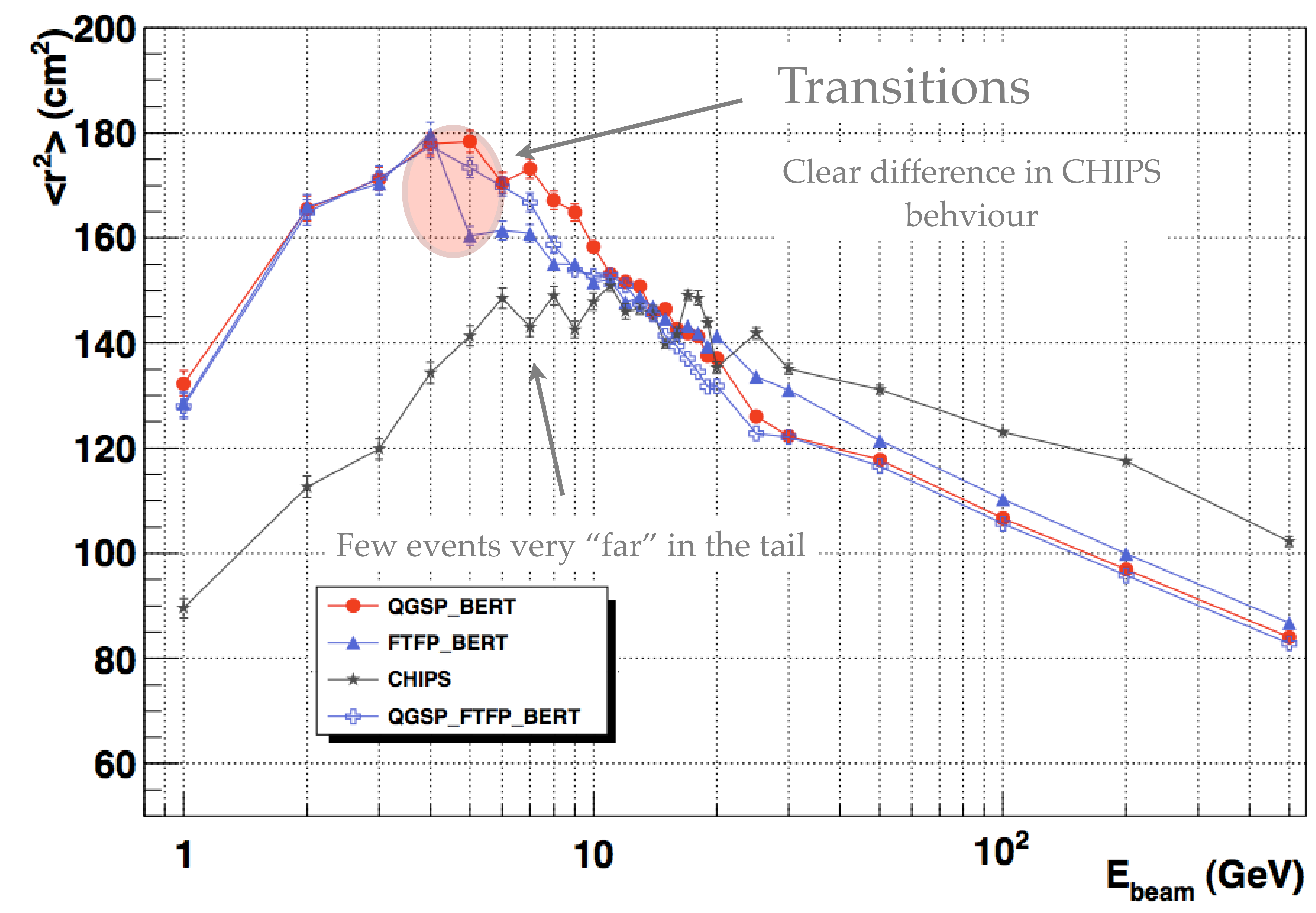
Shower "length"

π⁻ beam, Fe/Sci simplified calo   G4 9.3.ref02



Shower “width”

π⁻ beam, Fe/Sci simplified calo   G4 9.3.ref02



Conclusions

- We have developed a method to summarize shower shapes in a compact form (few numbers, 2-3 are enough: λ_{center} , $<\lambda>$, $<r^2>$)
- Weak dependence on “read-out” mesh size
- Some results:
  - FTFP/BERT transition (not seen in response, solved in recent ref. tags)
  - CHIPS fluctuations
- We are now calculating these quantities routinely and store results in a (very simple) DB