Cosmic-ray measurements by reconstructing longitudinal shower profiles for the Cherenkov Telescope Array

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on behalf of the CTA Consortium

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Outline

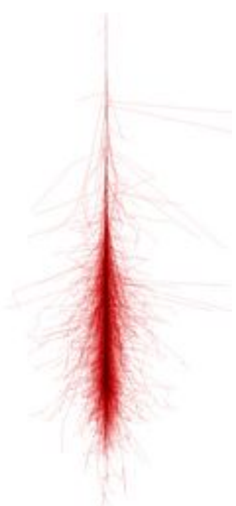
- Shower profile and shower maximum
- Reconstruction of particle shower longitudinal profile
- The Cherenkov Telescope Array
- Preliminary results
- Conclusions

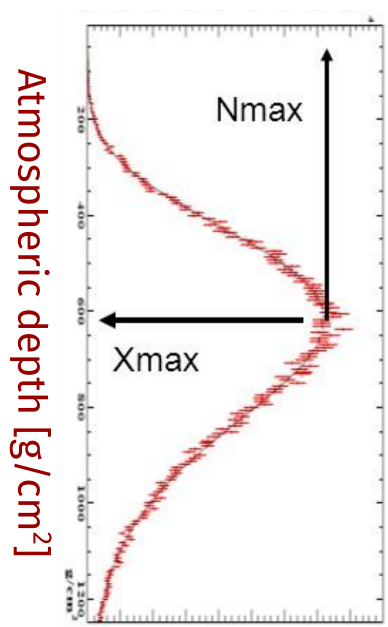
Scientific motivations

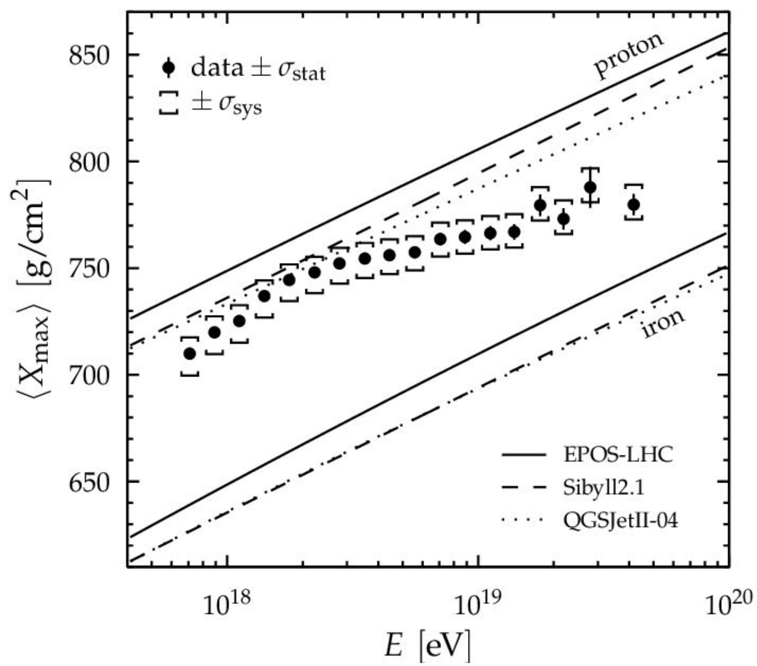
Develop an analysis chain that allow CTA to be also a cosmic-ray experiment by reconstructing:

- Particle shower longitudinal profile
- Shower maximum (Xmax)

$$X_{max} \propto \ln\left(\frac{E_0}{A}\right)$$







Gaisser-Hillas function

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

Pierre Auger Collaboration - 2014

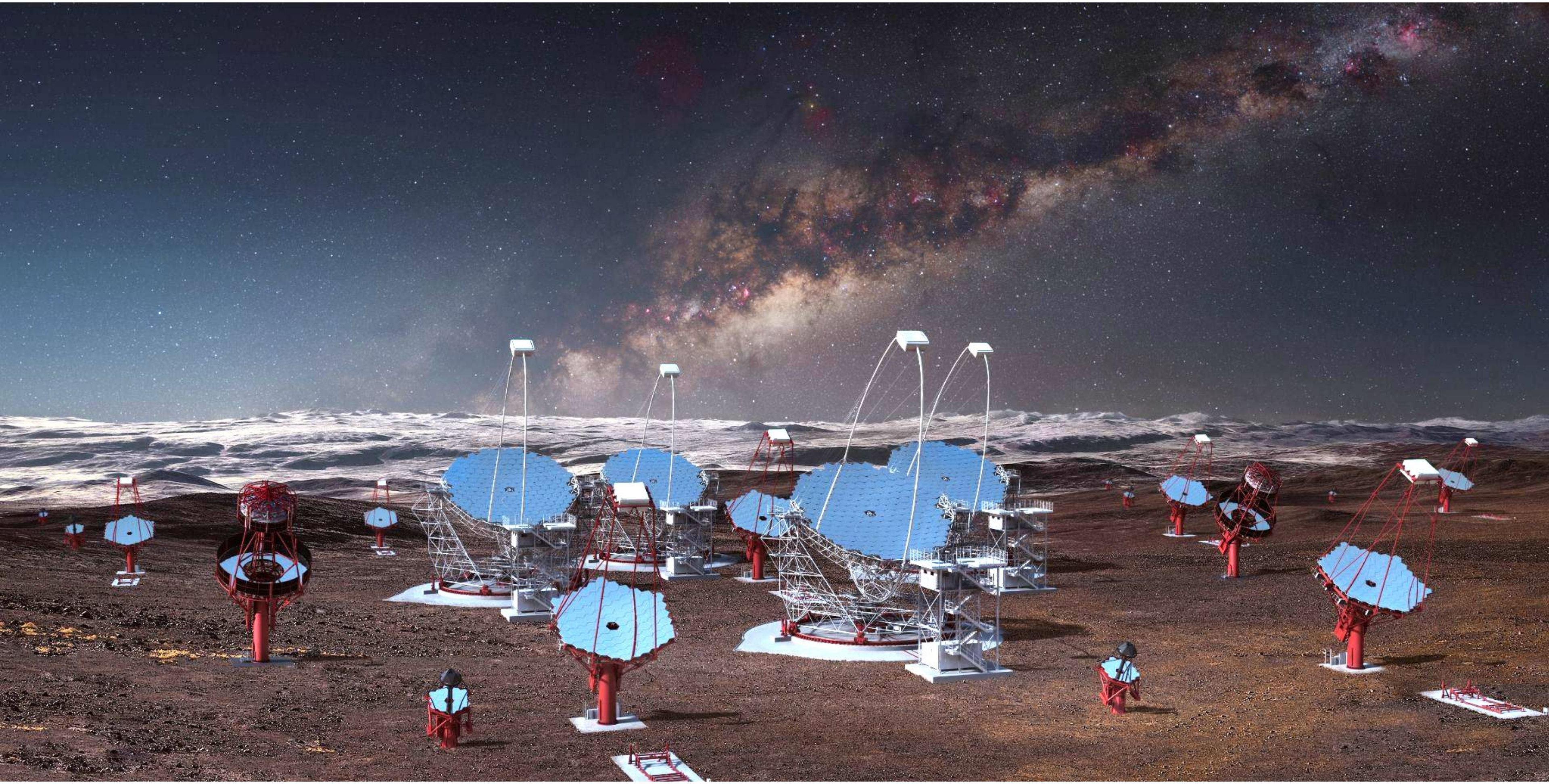
Scientific motivations

- Current methods to measure Xmax with ground-based observatories:
  - Likelihood fitting (e.g. HESS, resolution 30 g/cm^2 below 1 TeV)
  - Machine learning techniques (e.g. CTA)
  - Reconstruction of the shower profile from the fluorescence light (e.g. Pierre Auger Experiment, resolution 15 g/cm^2)

- **Objective**: reconstruct the shower profile from the Cherenkov light and get the Xmax

Credit: Otger Ballester (IFAE)

Cherenkov Telescope Array



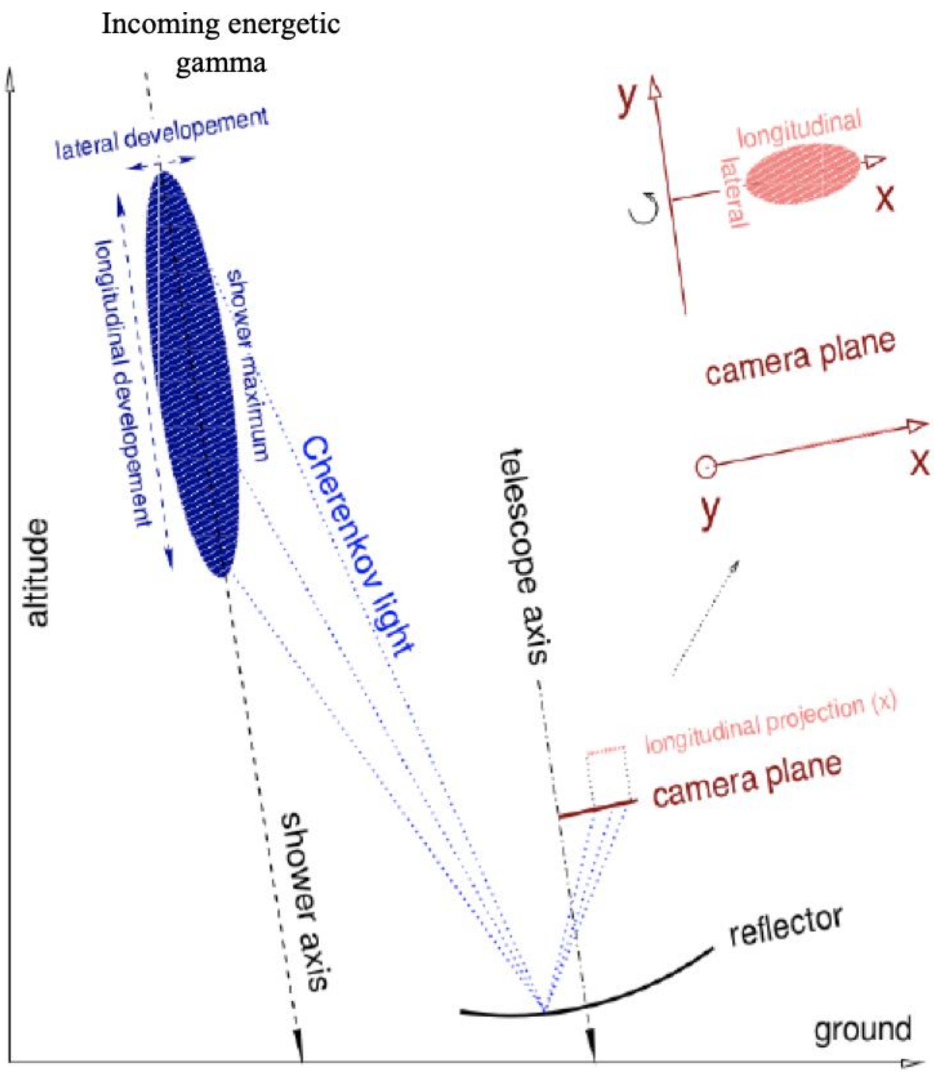
Cherenkov Telescope Array

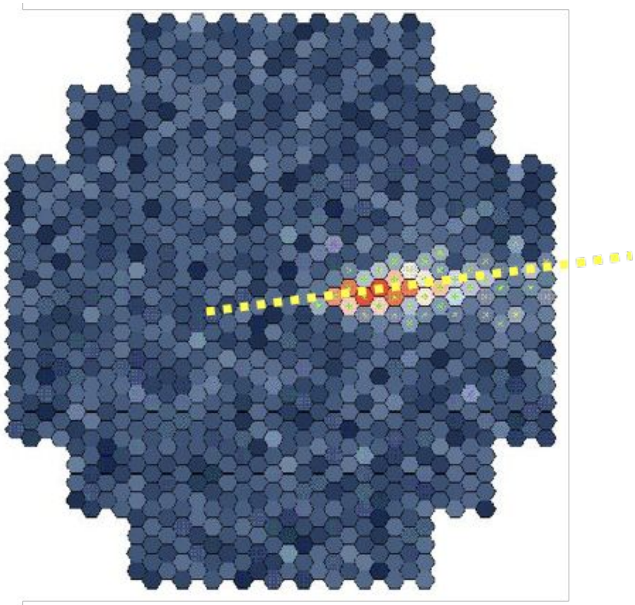
- CTA will be the world's largest ground-based gamma ray observatory for energies from 20 GeV to 300 TeV:
  - 5-10 x more sensitive
  - 5 x better angular resolution
  - 2.5 x larger field of view
- CTA telescope technology:
  - Small-sized for multi TeV
  - Medium-sized for TeV
  - Large-sized for GeV

cherenkov telescope array

Reconstruction of the particle shower longitudinal profile

How can we reconstruct the particle shower longitudinal profile?

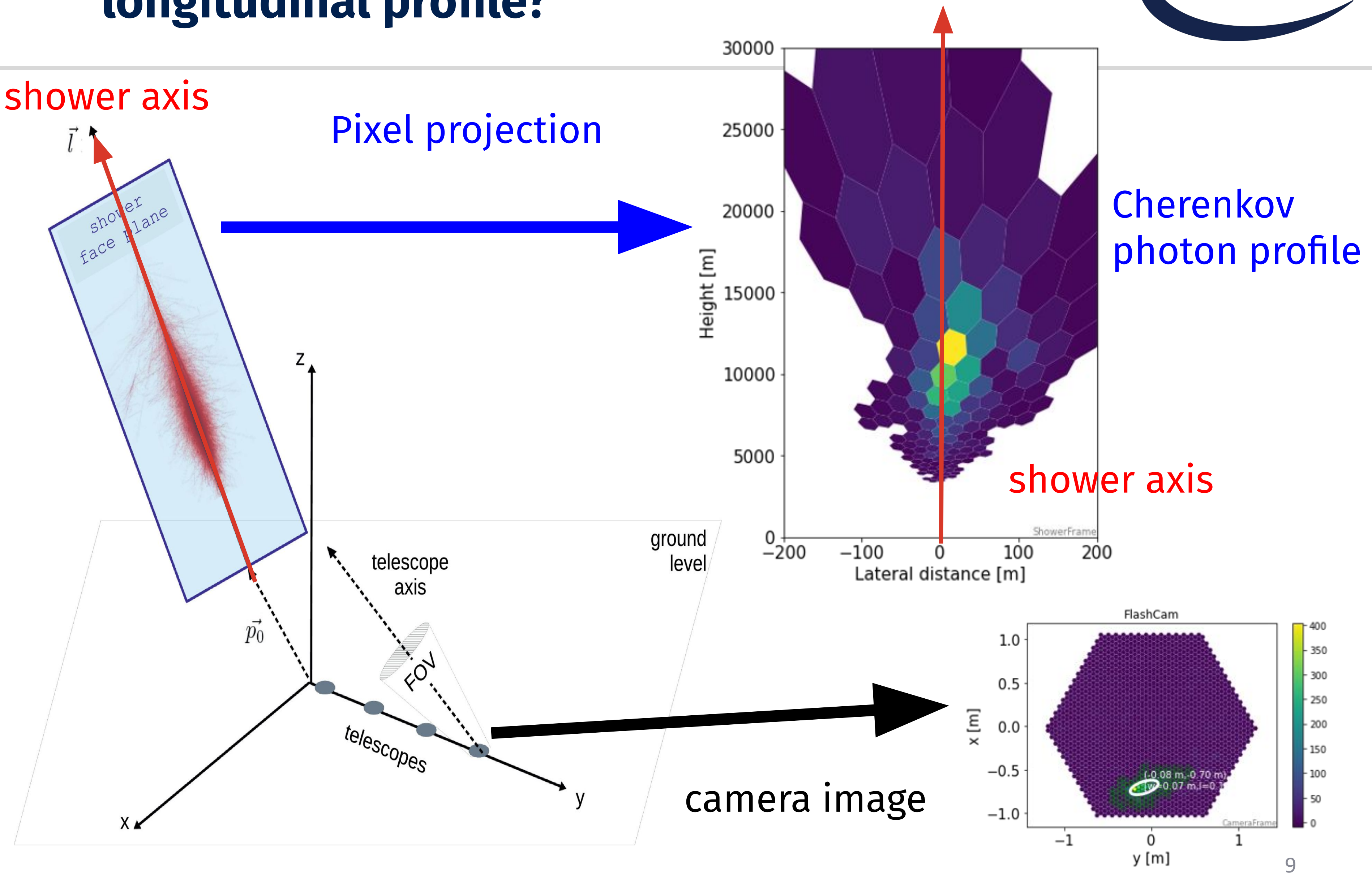




- Direction of the image is related to the direction of the shower of the gamma

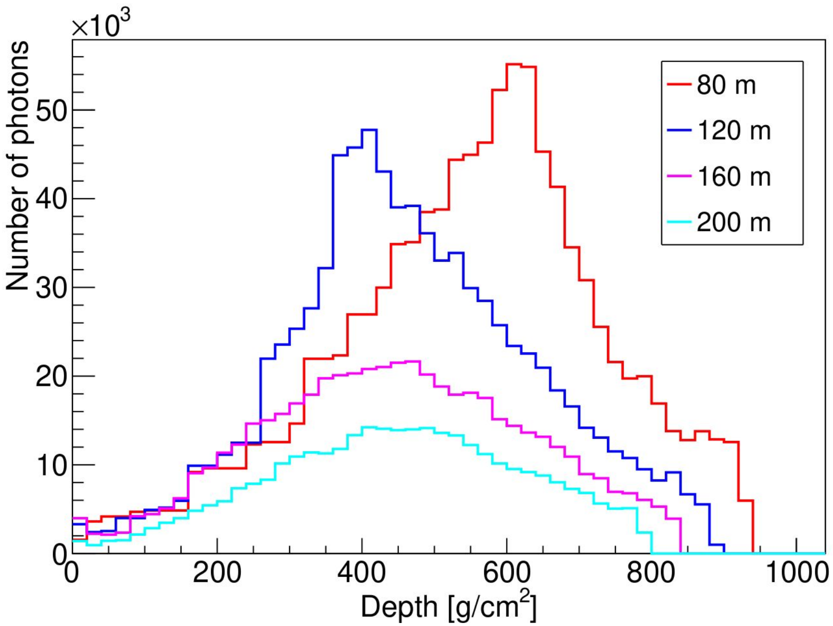
Slide credit: Mathieu de Naurois

How can we reconstruct the particle shower longitudinal profile?



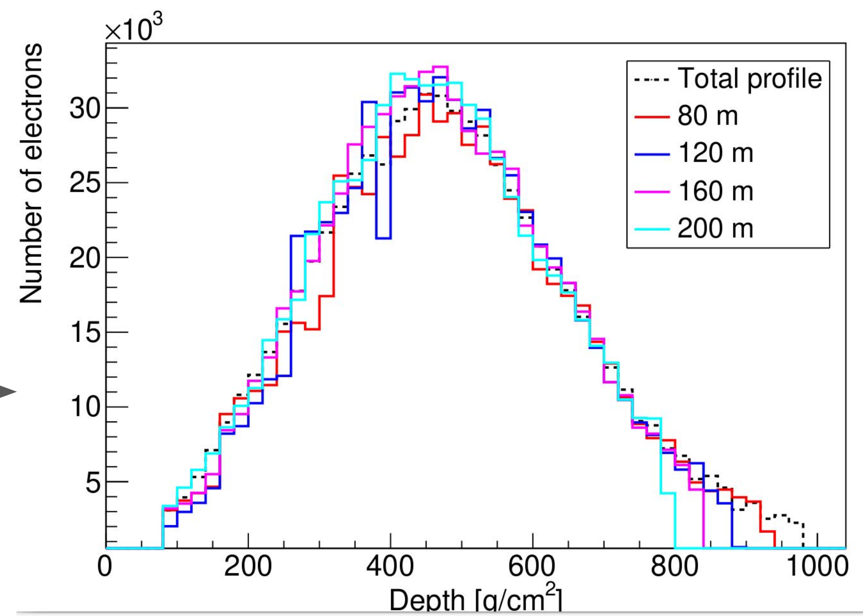
How can we reconstruct the particle shower longitudinal profile?

Cherenkov profiles



?

Particle longitudinal profile



How to go from these Cherenkov profiles to the particle longitudinal profile**?**

Angular distribution of Cherenkov light

The shower profile is reconstructed considering the angular distribution of the Cherenkov light around the shower axis.

$$\Delta N_C(X_i) = f(\theta_{ij}, s_i, X_i)\ \Delta\theta_{ij}\ \Delta N_e(X_i)\ \Delta X$$

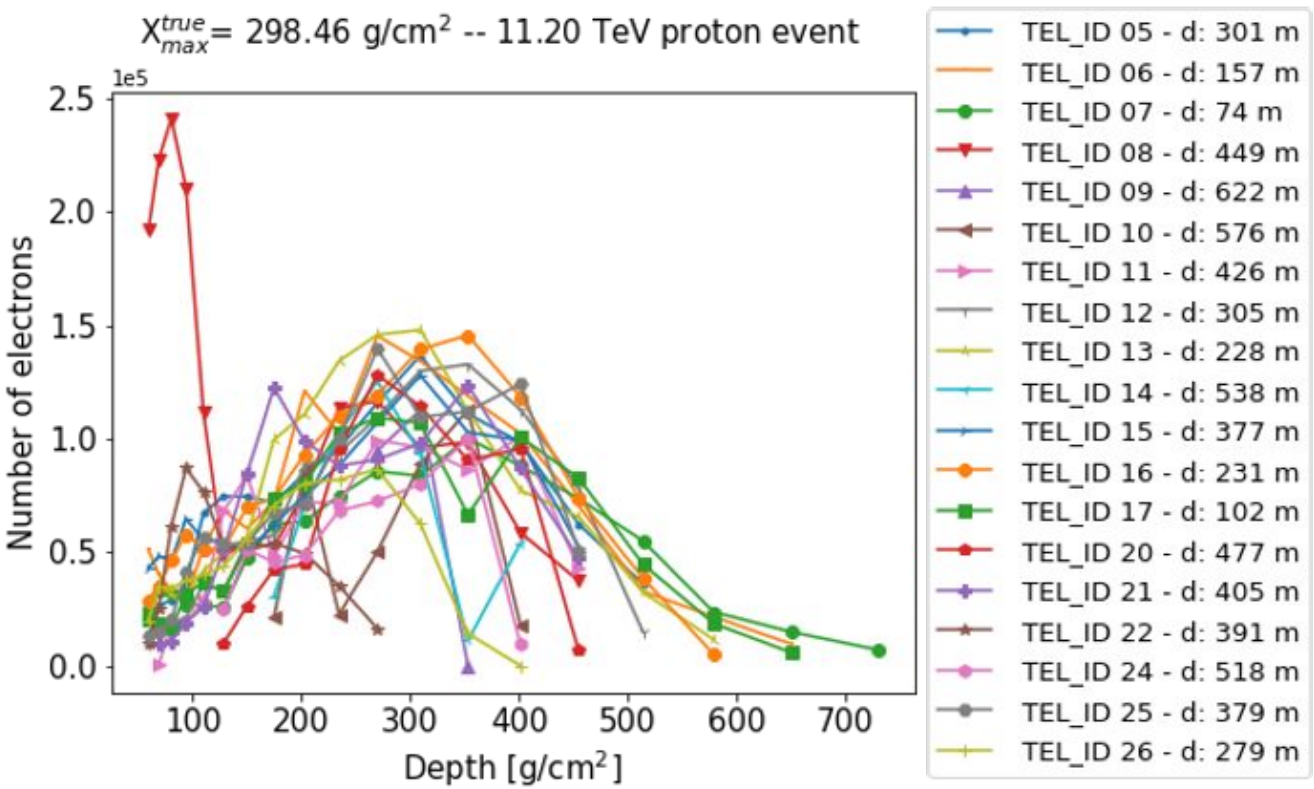
- $\Delta N_C(X_i)$ → Cherenkov photon profile
- $f(\theta_{ij}, s_i, X_i)$ → Cherenkov light angular distribution
- $\Delta N_e(X_i)$ → particle shower profile

Preliminary results

Simulated events

- CTA-South array configuration
- Telescopes: 25 Medium-Sized Telescopes (MST)
- Species and number of air showers used:
  - Proton: 3019 showers from 10 to 300 TeV
  - Iron: 4712 showers of specific energy bins of 10 TeV, 30 TeV, 50 TeV, 100 TeV and 300 TeV.
- Zenith angle: 20 degrees

Example: reconstructed proton-initiated shower profile

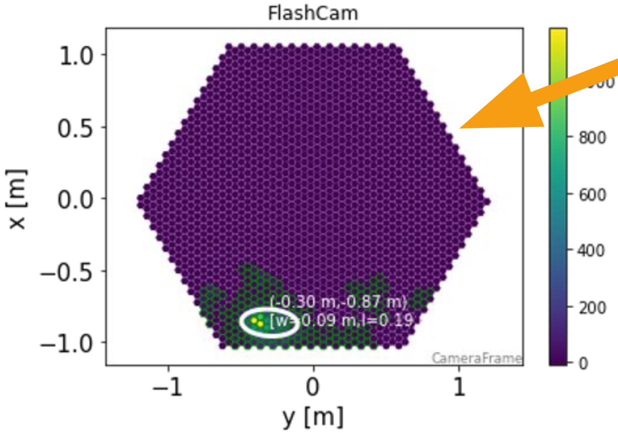


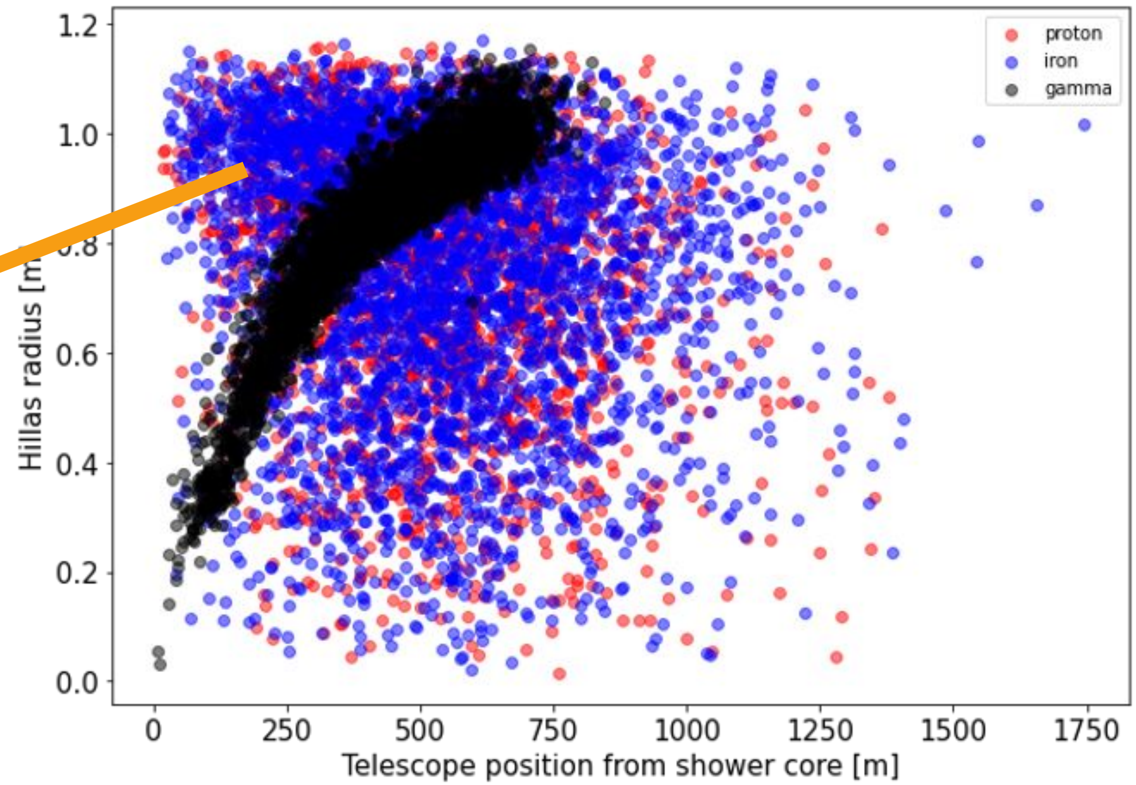
- Performing the reconstruction using all available telescopes results in a 'noisy' measurement.

- How can we identify telescopes which show the best profile?
  - (X_{max}^{rec} - X_{max}^{true}) vs variables

Quality cuts

- Number of triggered telescopes (MST)
- Number of islands in the camera image
- **Position of the ellipse's center**
- Telescope distance w.r.t shower core





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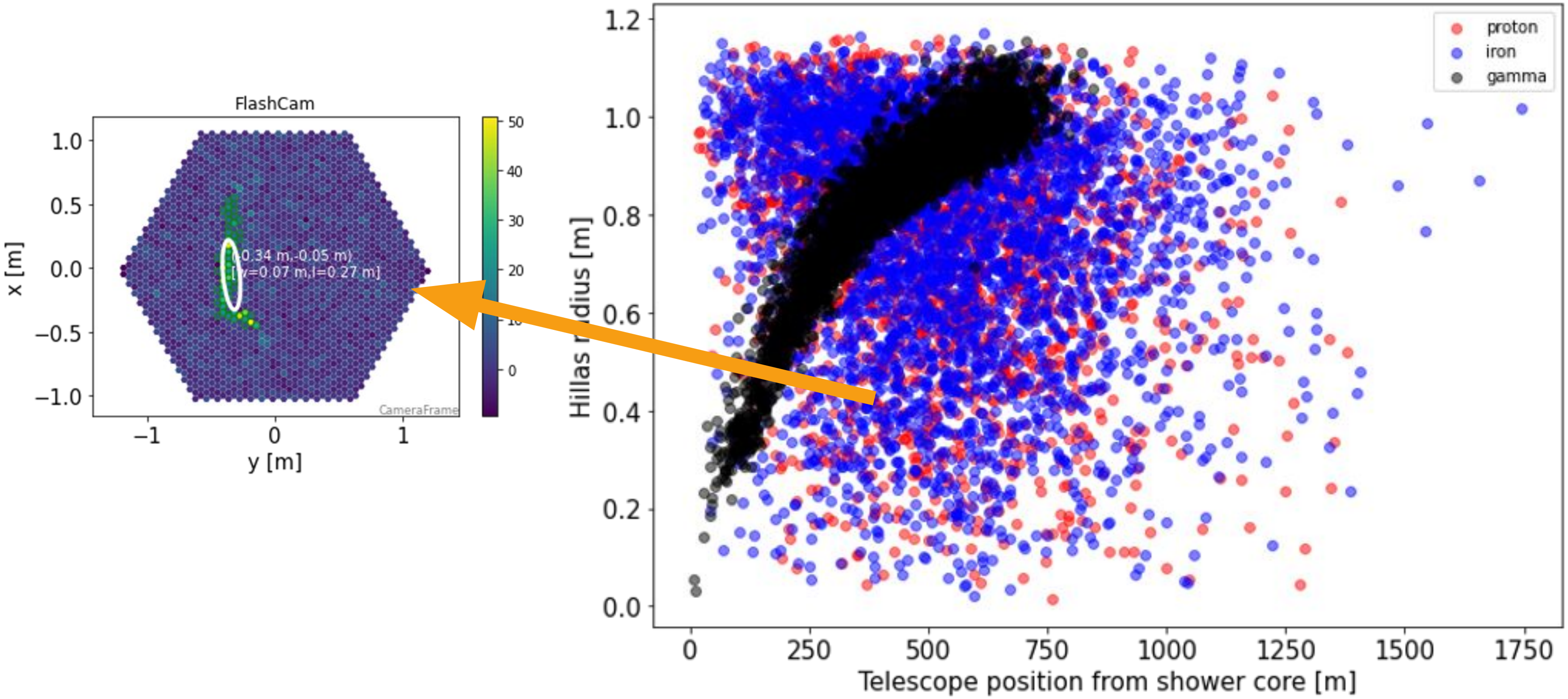
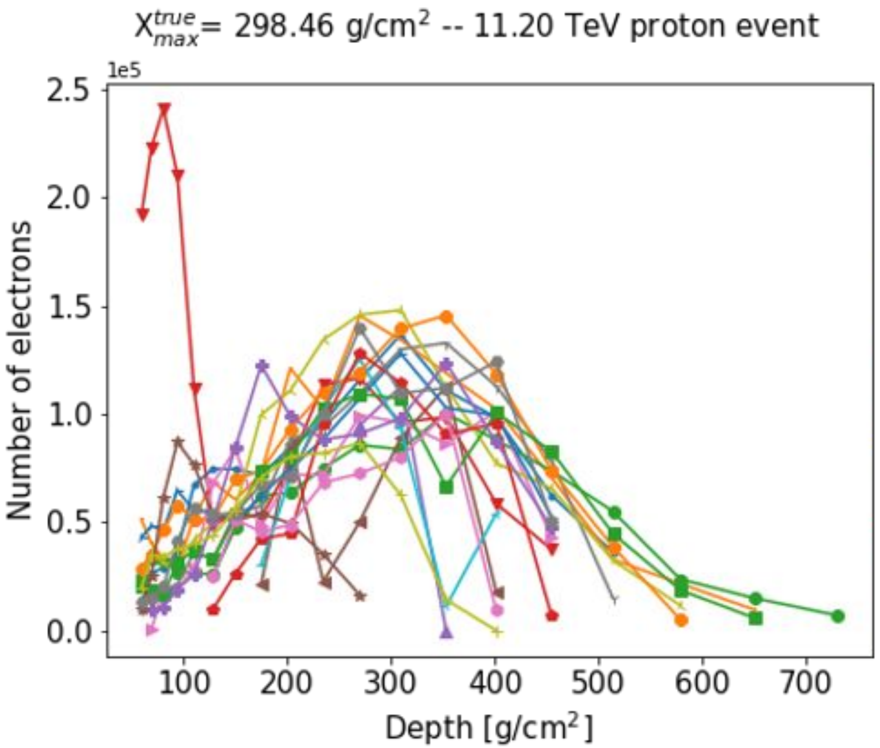
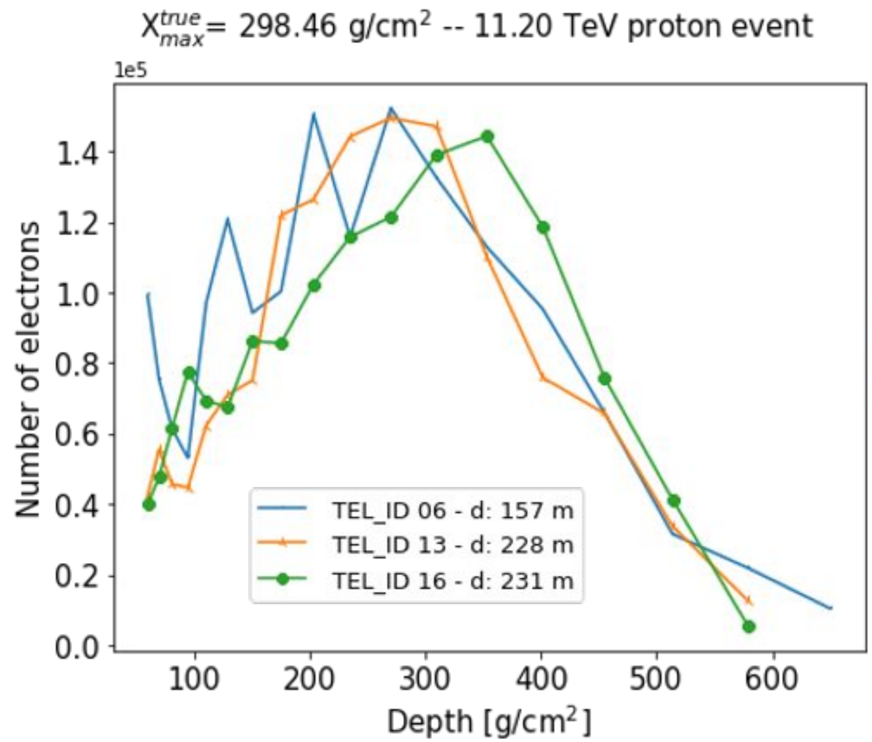


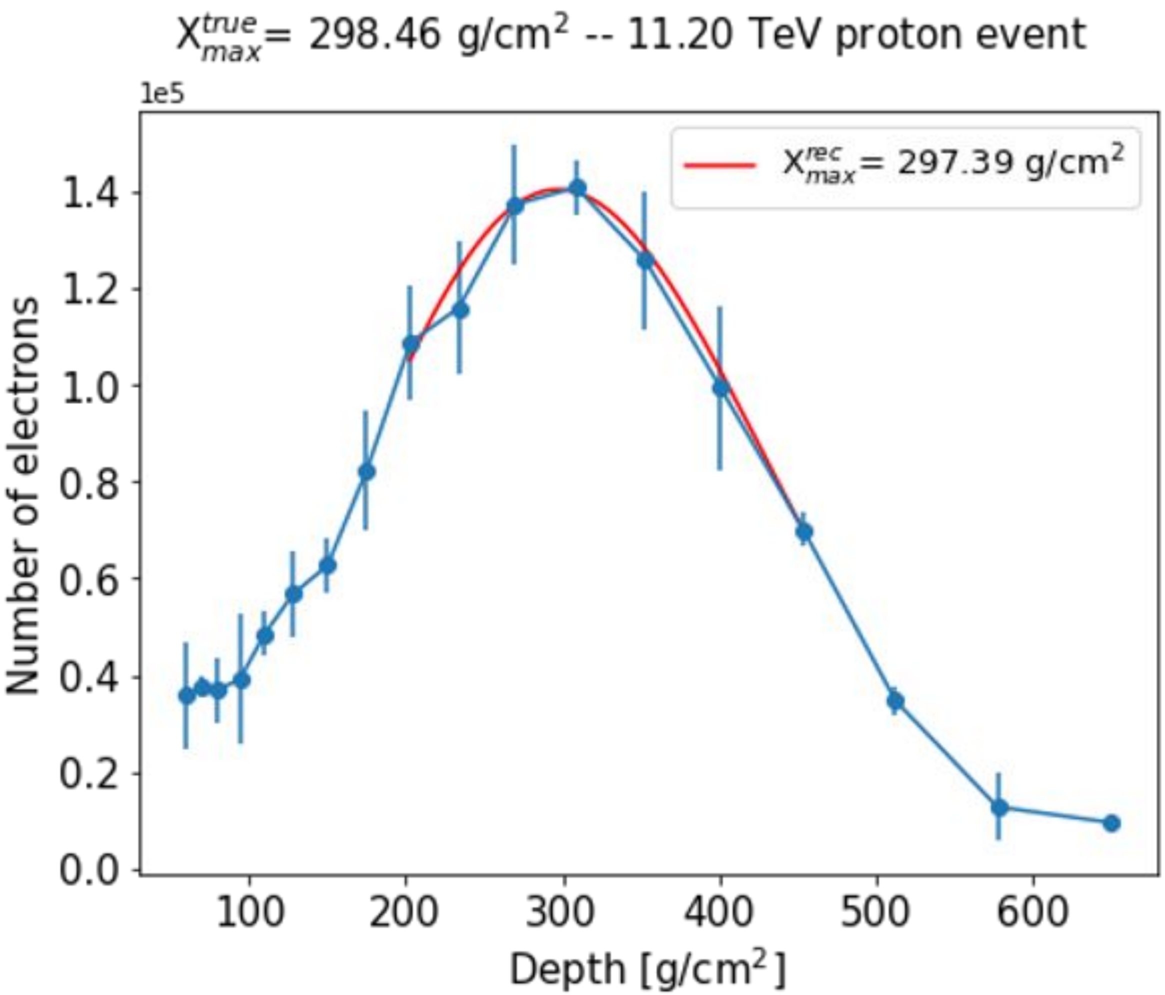
Example: reconstructed proton-initiated shower profile





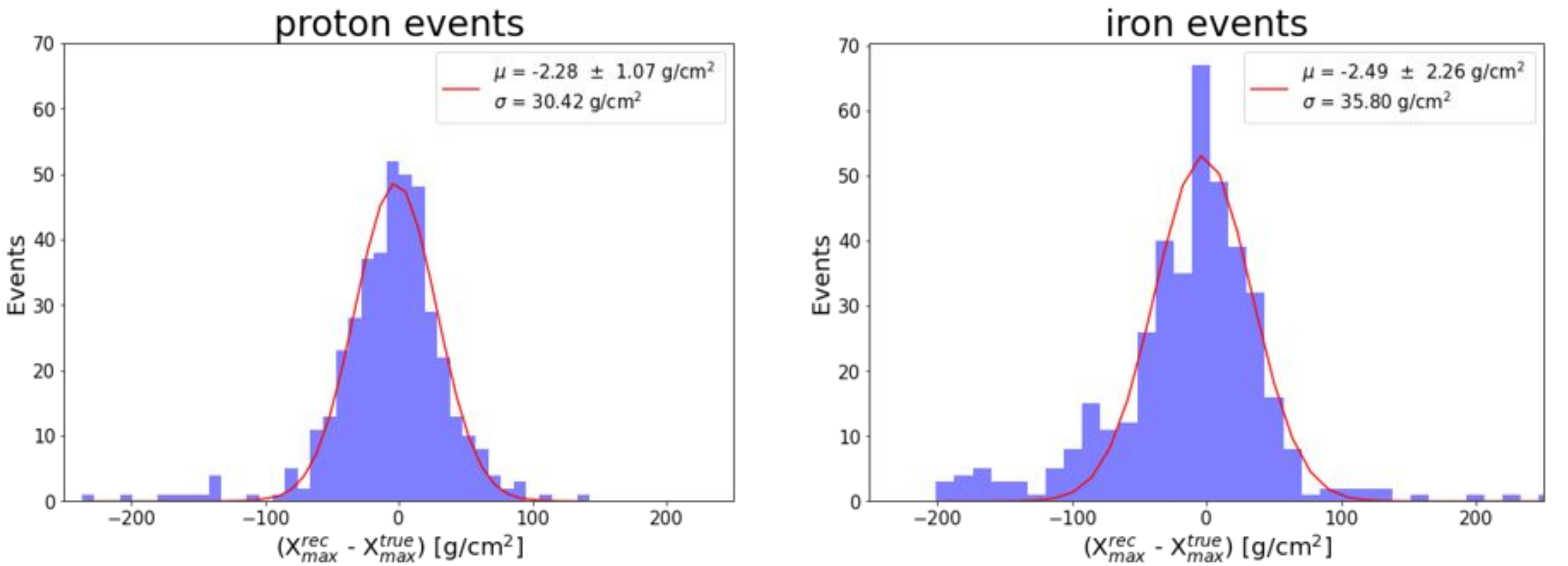
before quality cuts → after quality cuts

Example: reconstructed proton-initiated shower profile



- Average profile from three telescopes.
- Gaisser-Hillas function adjusted around the maximum
- Xmax rec matches with xmax simulated.

Resolution of the Xmax reconstructed



- Difference distribution between reconstructed and simulated Xmax for events in the energy range from 10 TeV to 300 TeV.
- Resolution of 30 g/cm^2 for proton-initiated showers and 35 g/cm^2 for iron-initiated showers.

Conclusions

- The synergy between CTA and cosmic-ray experiments could allow complementary cosmic-ray measurements.

- We studied a method to reconstruct the full shower profile using multiple telescopes for measurements of cosmic-ray observables like the Xmax with the CTA.

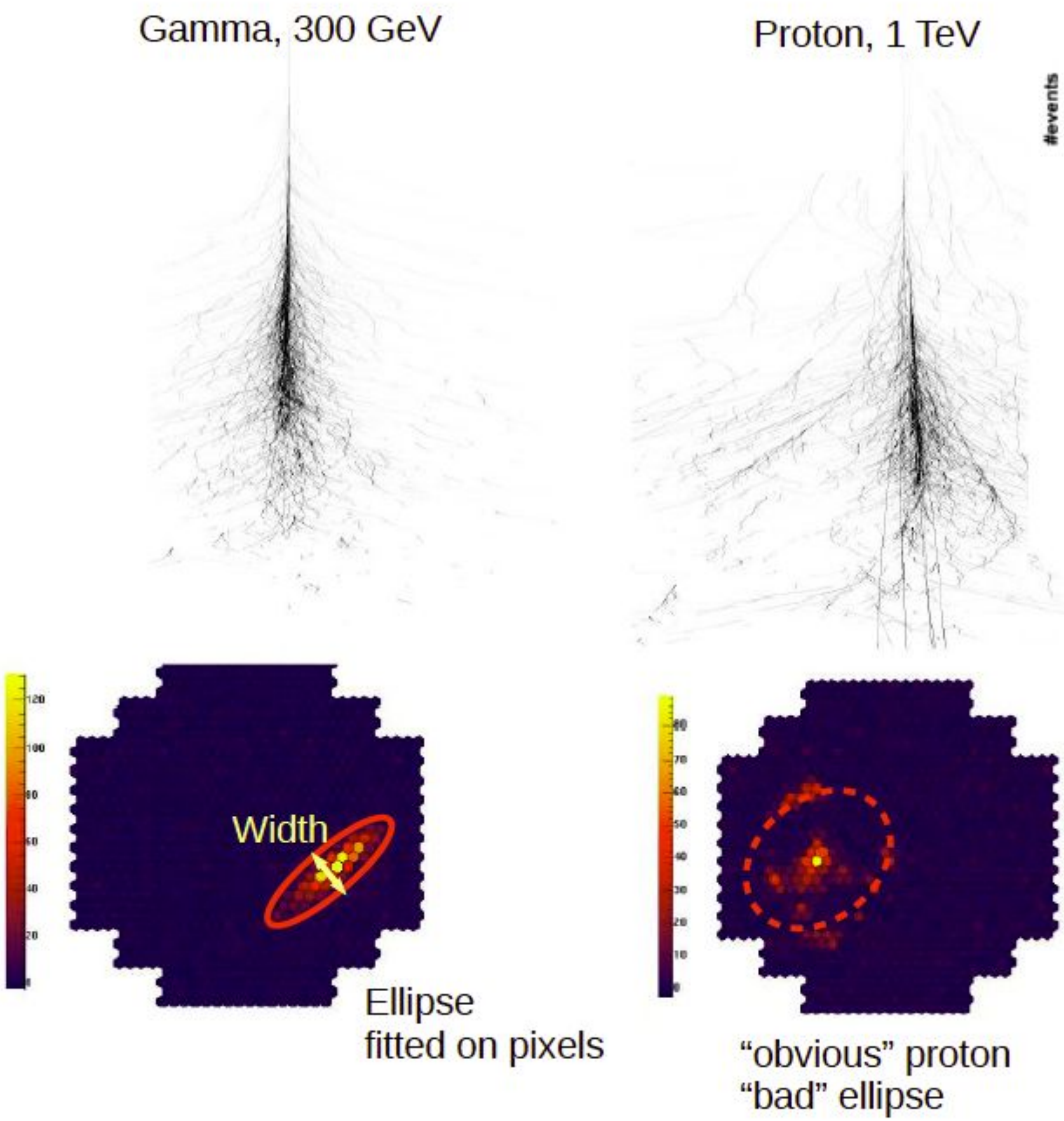
- Preliminary results on CTA simulated events show good Xmax resolutions from 10 TeV to 300 TeV:
  - 30 g/cm^2 for proton-initiated showers and
  - 35 g/cm^2 for iron-initiated showers,

  compared with previous methods such as likelihood fitting with resolution of 30 g/cm^2 below 1 TeV.

Thank you for your attention

Backup slides

Characteristics of cosmic and gamma ray air showers



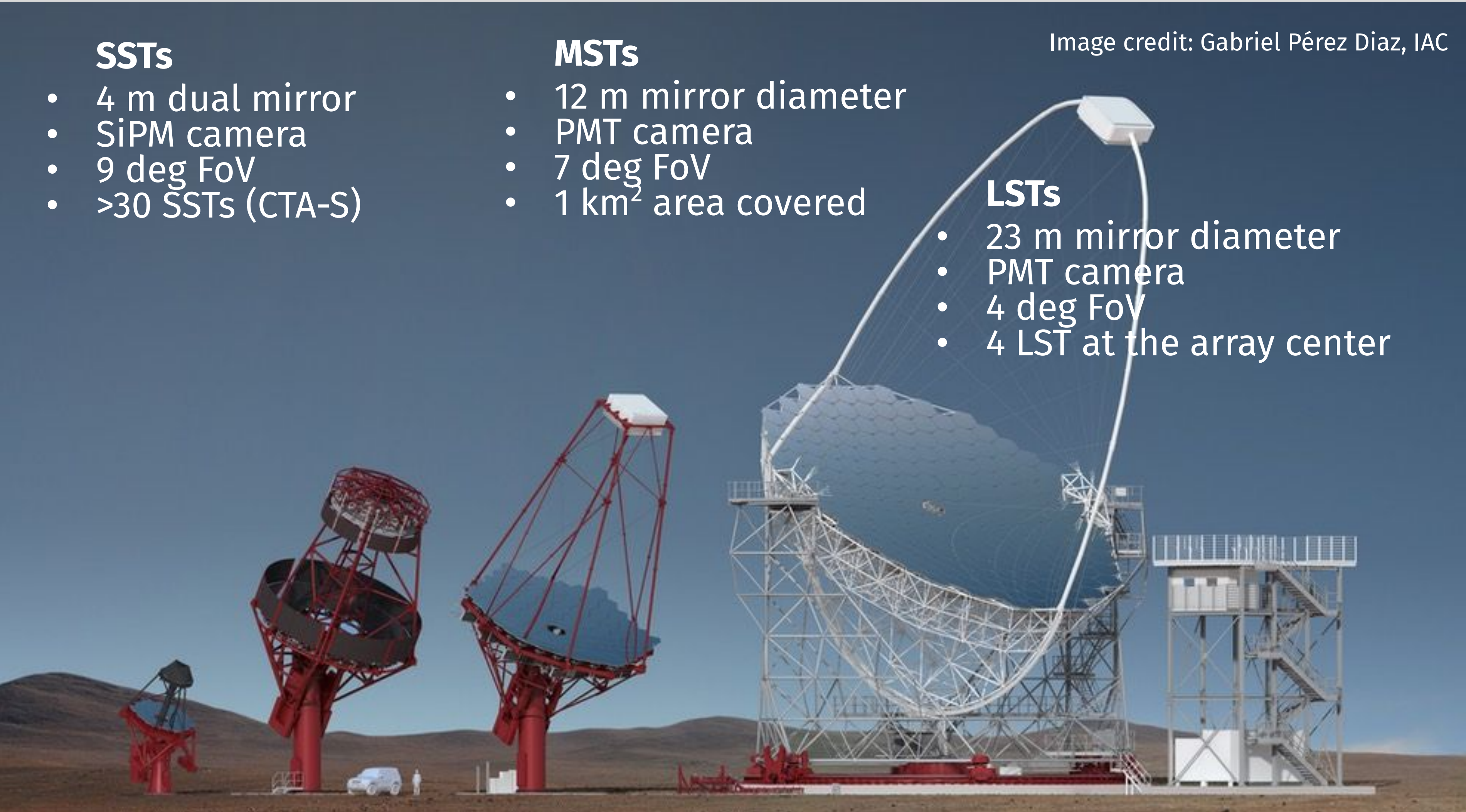
Slide credit: H. Costantini

CTA technology

SSTs
- 4 m dual mirror
- SiPM camera
- 9 deg FoV
- >30 SSTs (CTA-S)

MSTs
- 12 m mirror diameter
- PMT camera
- 7 deg FoV
- 1 km^2 area covered

LSTs
- 23 m mirror diameter
- PMT camera
- 4 deg FoV
- 4 LST at the array center



multi-TeV | TeV | GeV

Quality cuts

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