

Towards measuring high-energy cosmic rays with SKA-Low

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for the SKA High Energy Cosmic Particles working group

Nederlandse Astronomen Conferentie

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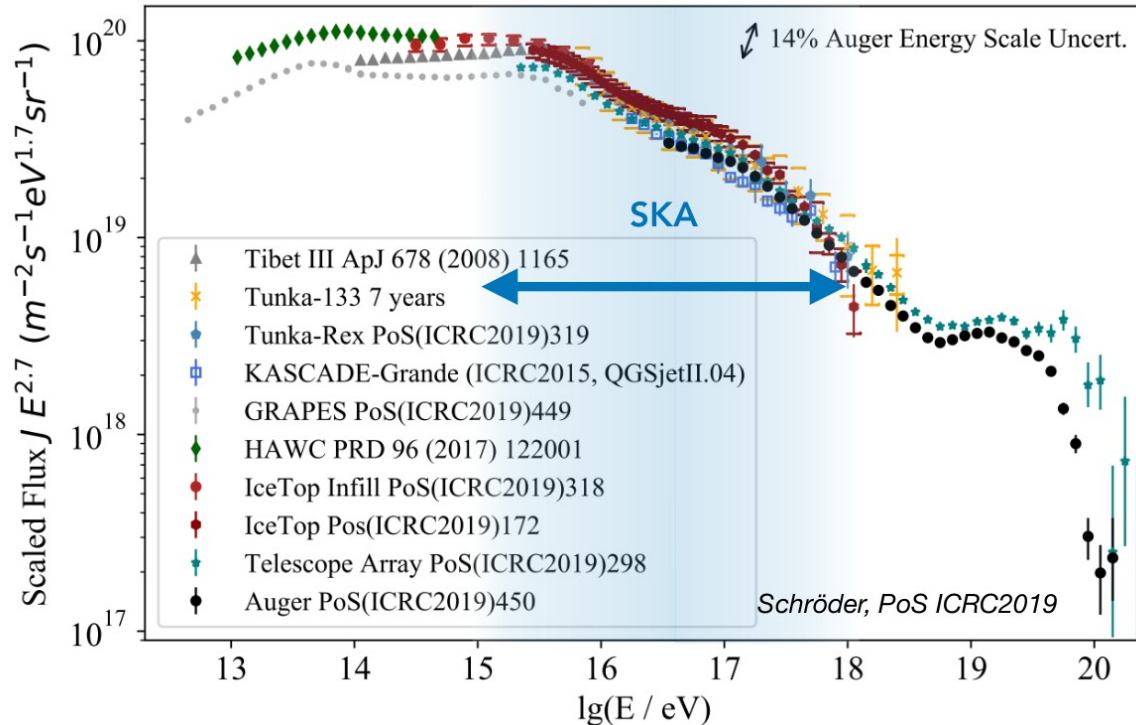
Radboud Universiteit



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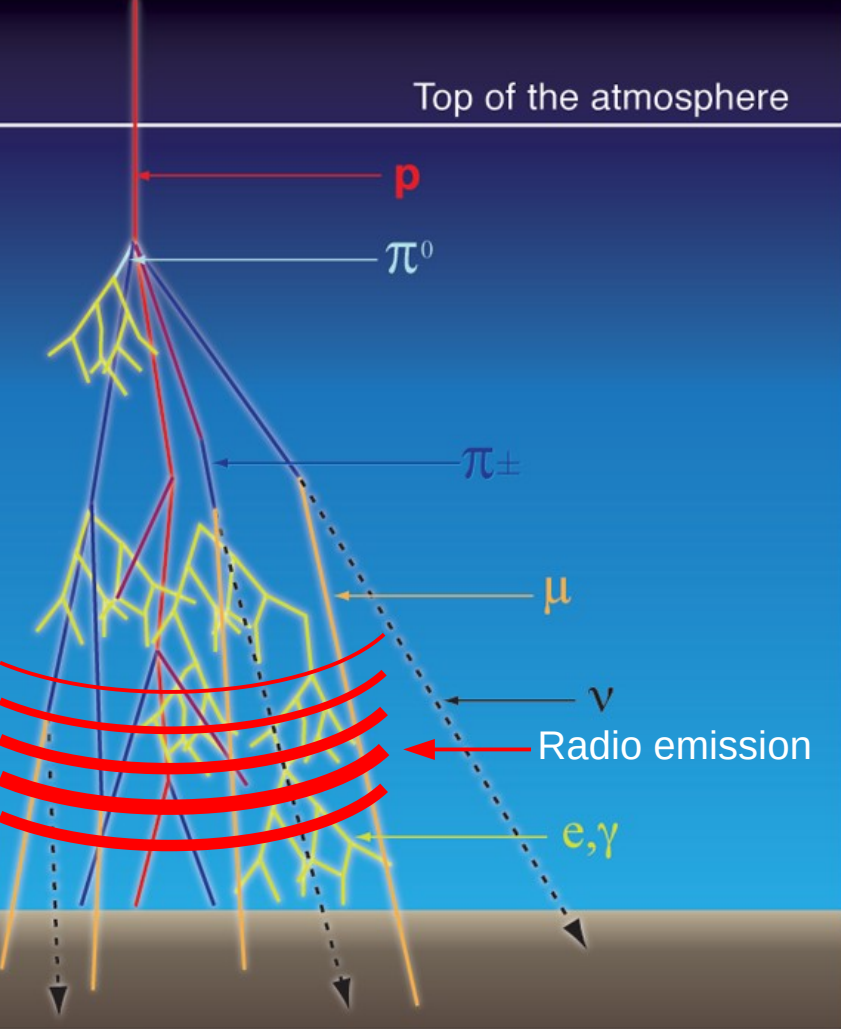
High-energy cosmic rays



- Energy 10^{15} to 10^{18} eV
- Produced by e.g. supernova remnants, up to about 10^{16} eV or active galactic nuclei, giant lobes etc., up to the highest energies.

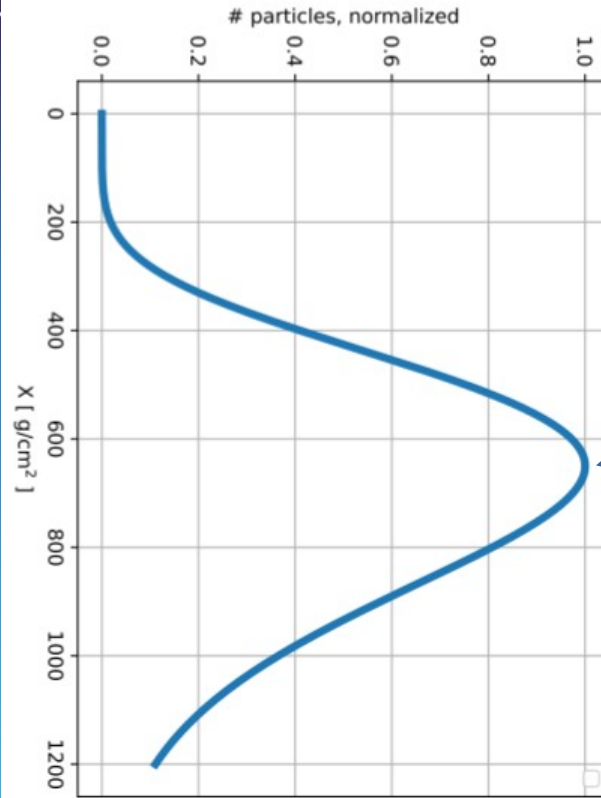
The Sun produces low-energy cosmic rays, $< \sim 1$ GeV

- Mass composition important



Extensive air showers

Longitudinal profile of number of particles

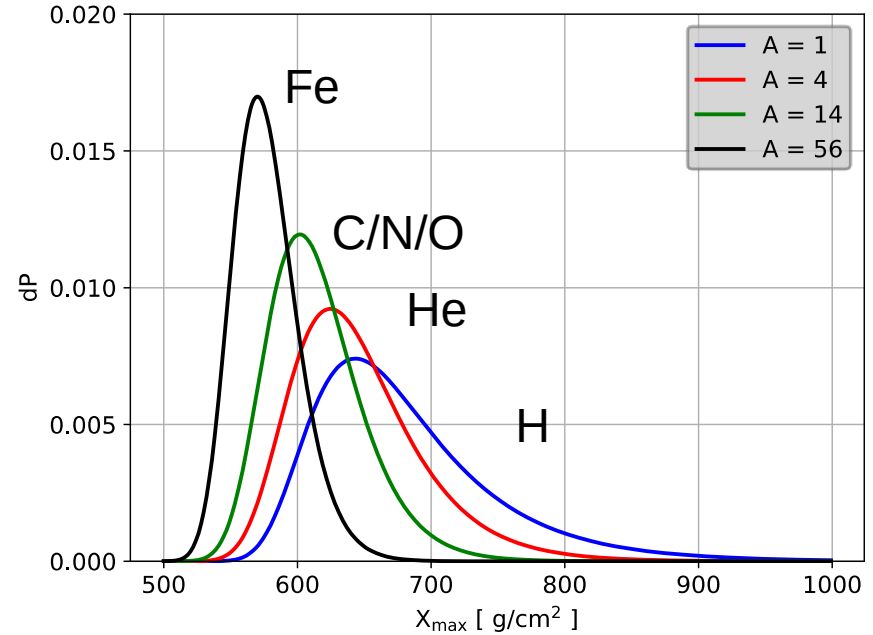
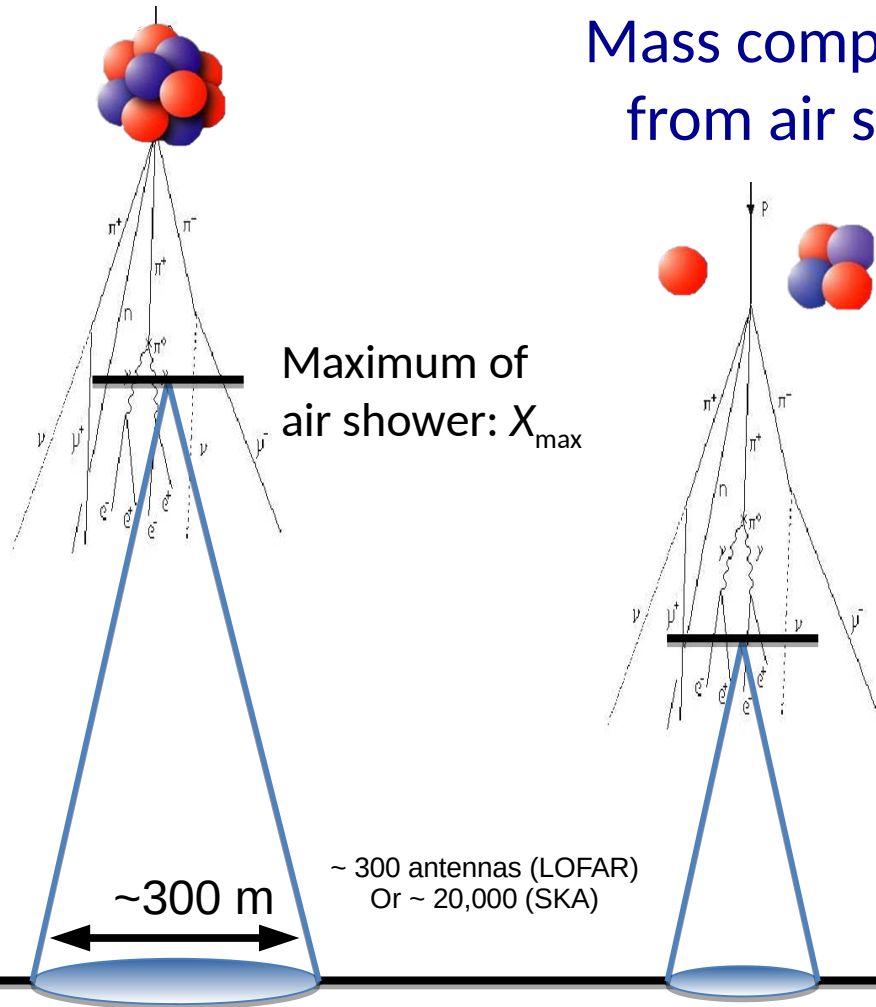


Shower maximum
 X_{\max} varies with
 primary particle mass
 - on average
 - in distribution

X_{\max}

First few interactions
 are most important

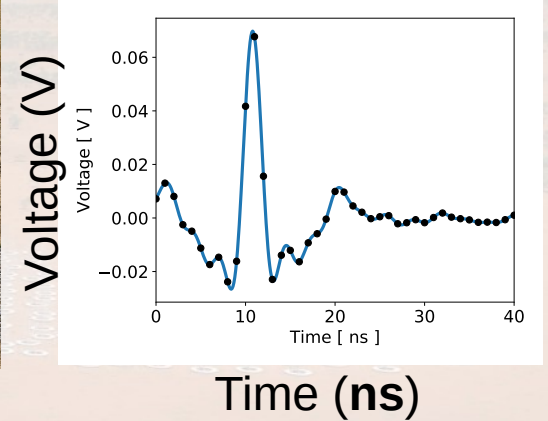
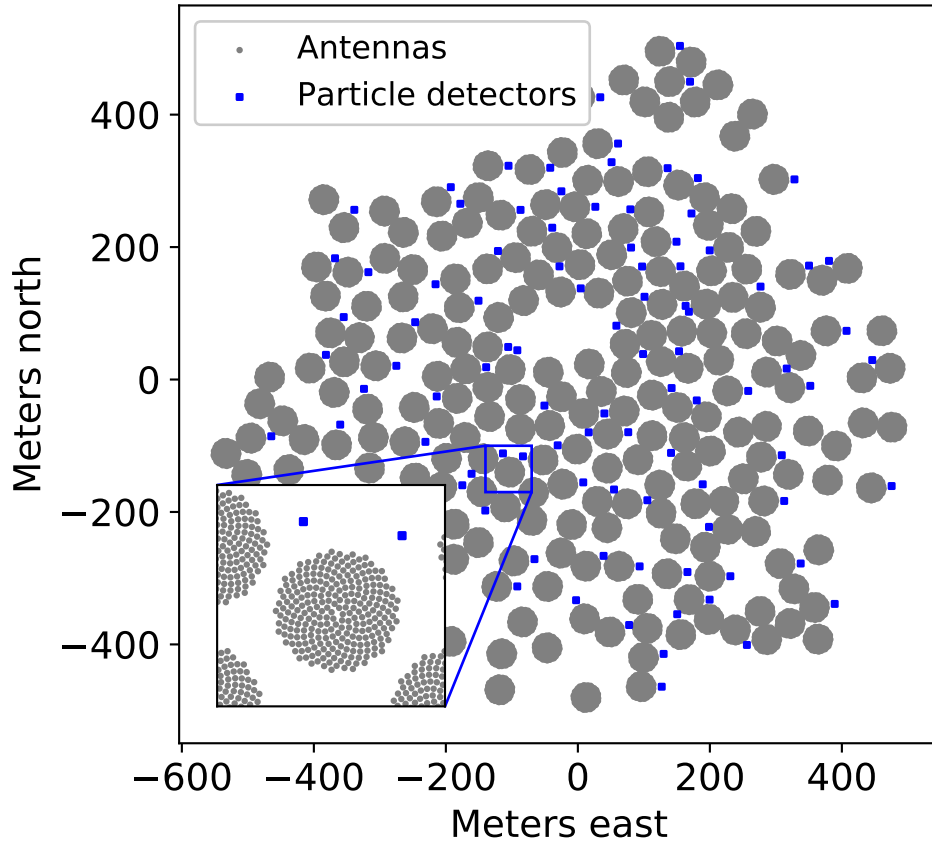
Mass composition of cosmic rays, from air shower maximum X_{\max}



Impression of the SKA-Low telescope



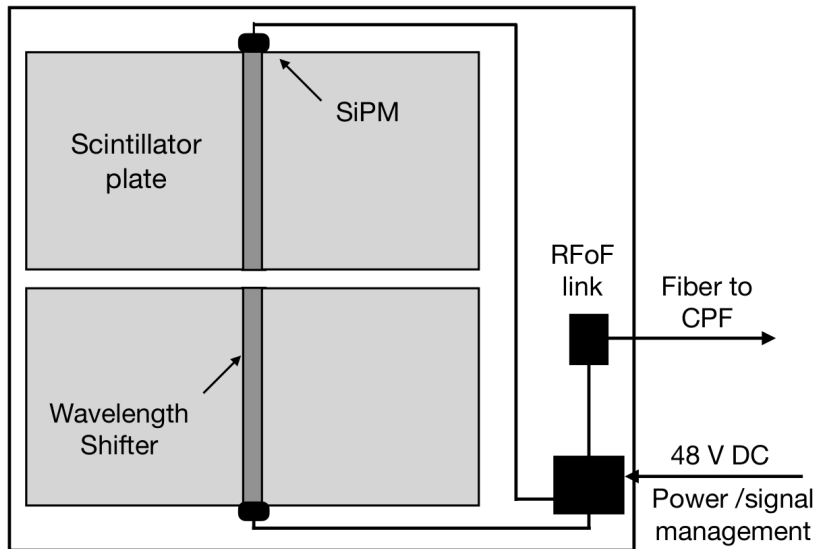
The layout of the SKA-Low core



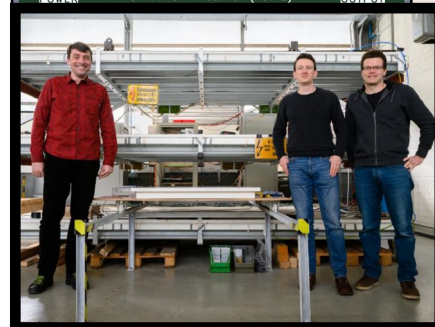
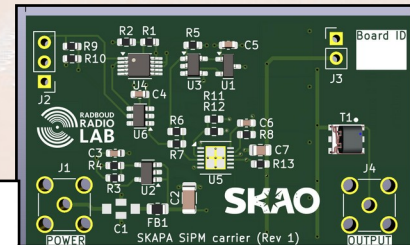
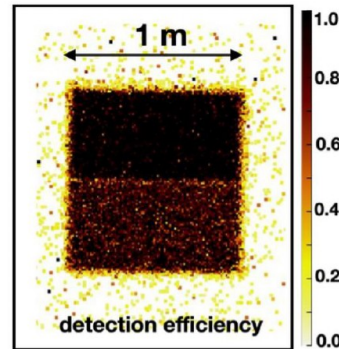
Particle detector
for triggering
(prototype MWA)

Particle detector development

- Particle detectors being developed in Karlsruhe (KIT), Radboud Radio Lab
- Fully funded for 120 detectors, by **FWO**, **NOVA**
- Very strict requirements on radio quietness!
- First field deployment tests: est. **late 2026**



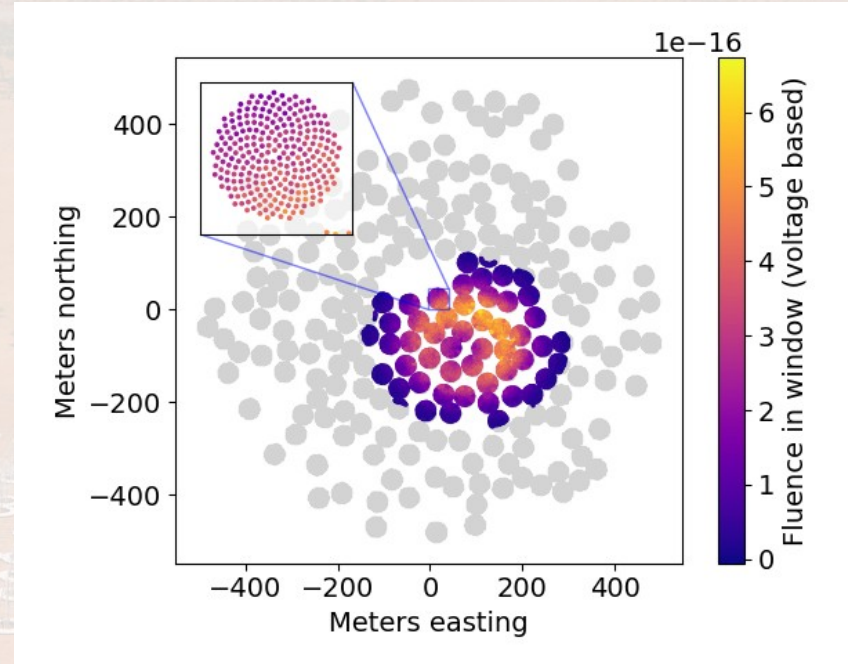
Figs by
K. Mulrey



Science objectives for CR measurements at SKA

Measure cosmic-ray 'radio footprint'
in unprecedented detail
SKA is unique here

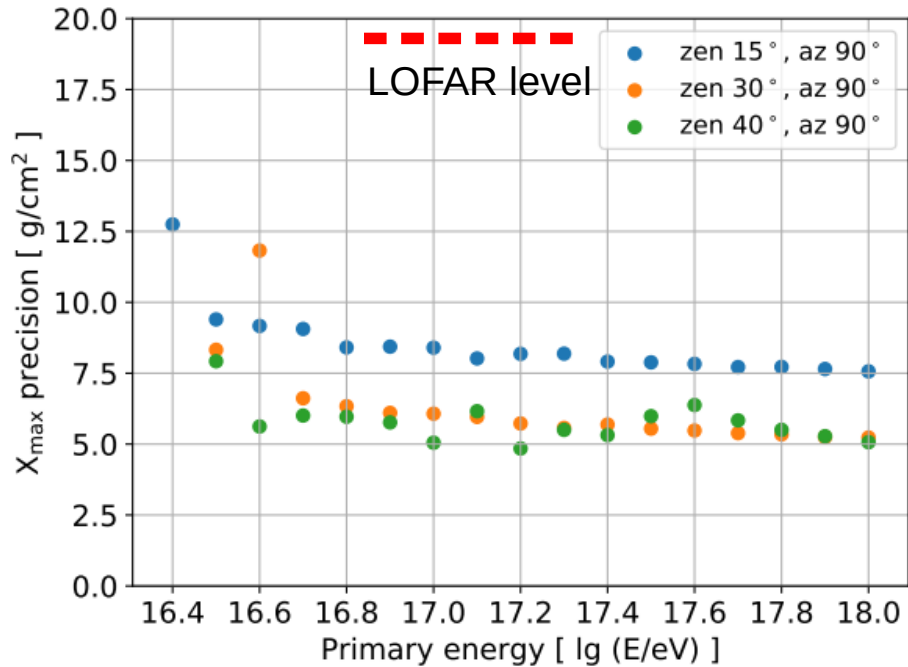
- **Mass composition** in highest energy range for Galactic sources
- **Hadronic physics**
- PeV Gamma rays?



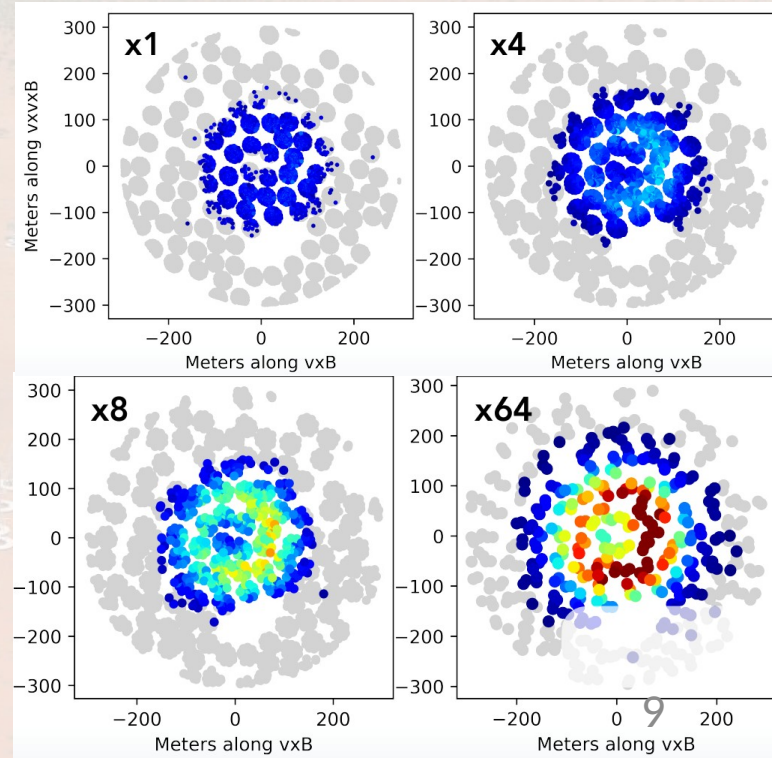
Corstanje et al., SKA Science Book, 2026;
Phys Rev D, 2025

Precision of Xmax reconstruction

- Versus primary energy, with 1 in 4 antennas used
- Compare to $\sim 20 \text{ g/cm}^2$ precision with LOFAR

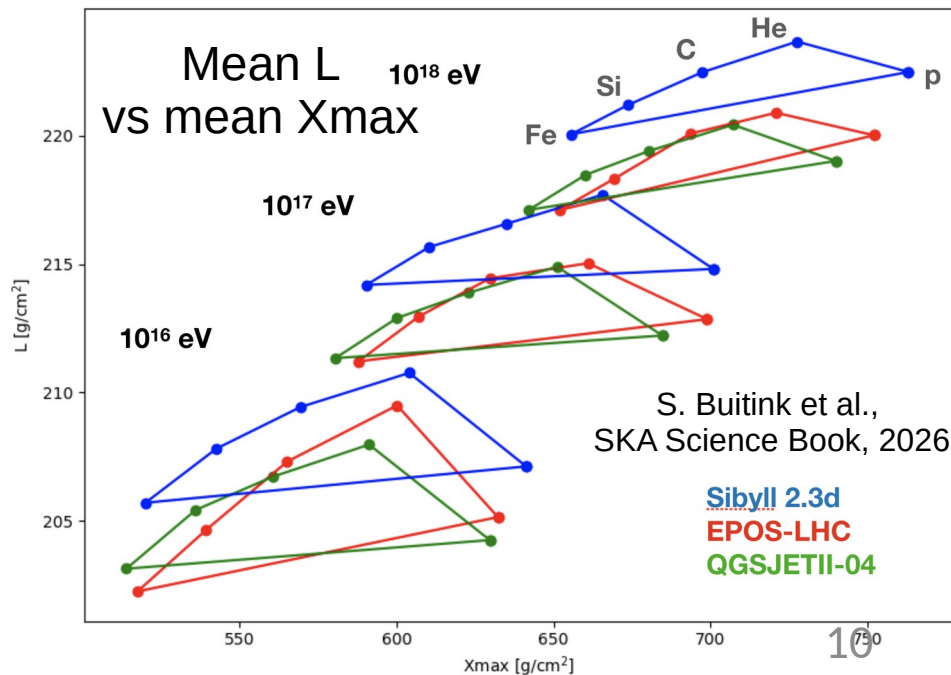
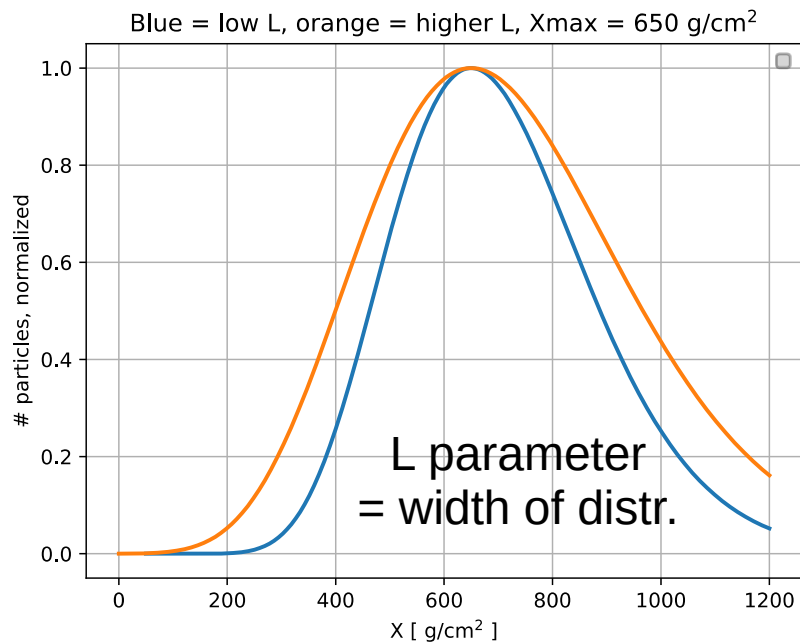


Beamforming: SNR improvement



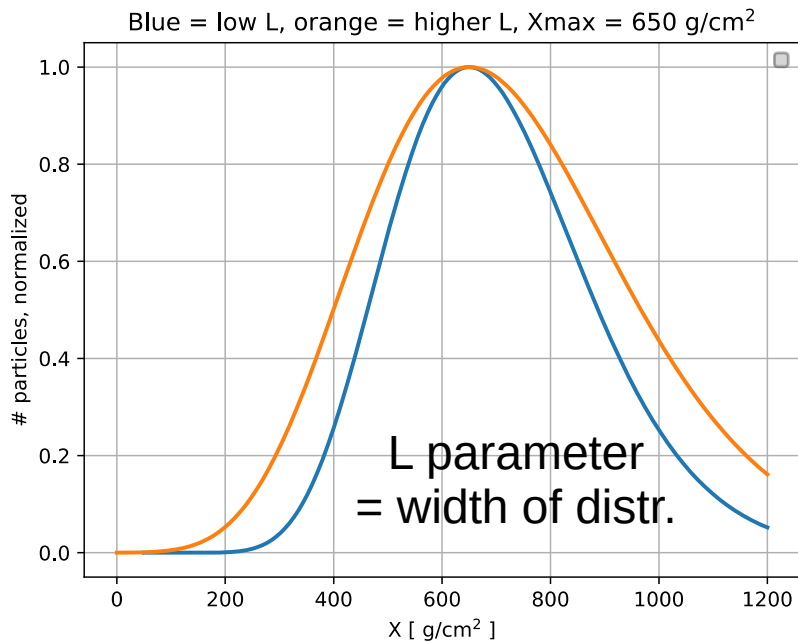
Beyond Xmax: longitudinal evolution

- Number of particles vs atmospheric depth
- Distribution of L-parameter (tails) help to separate hydrogen from helium

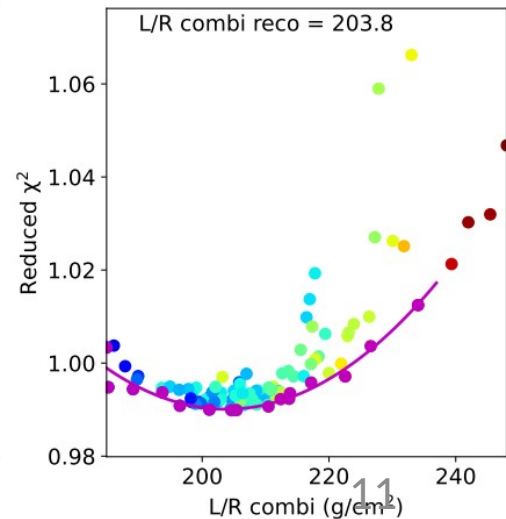
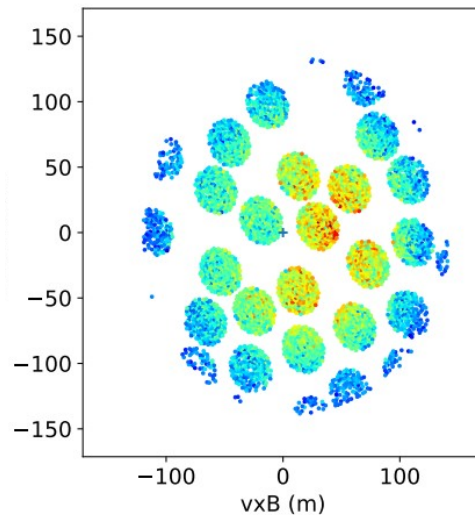


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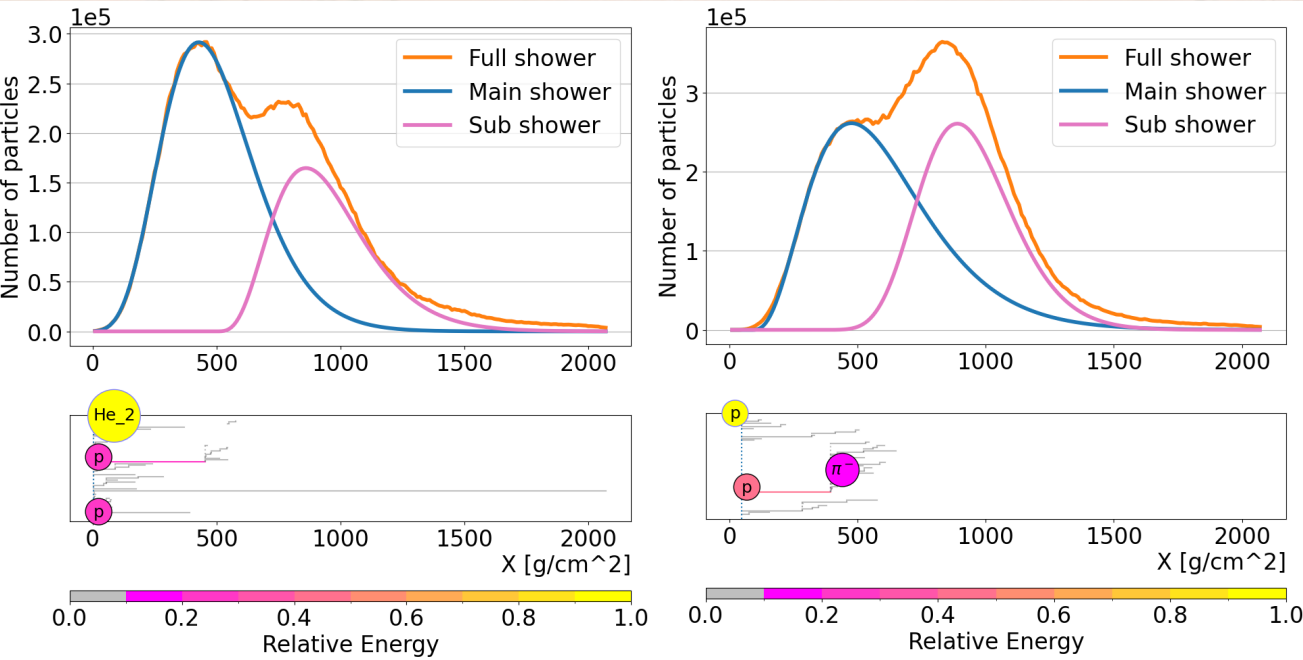
- Measurable at SKA



Hadronic physics from anomalous air showers

- Number of particles vs column depth in atmosphere
- A way to probe the first, highest-energy interactions

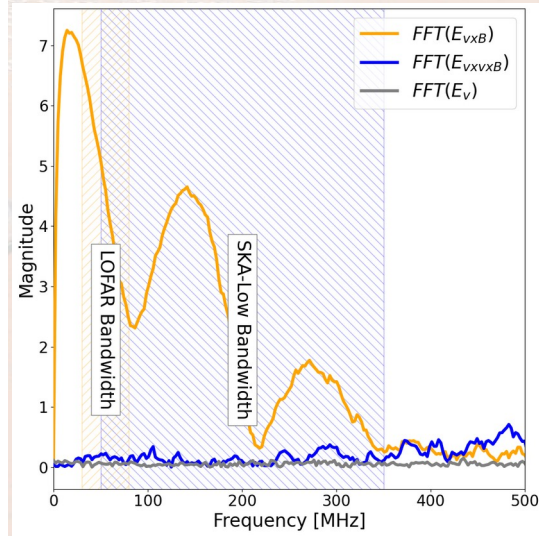
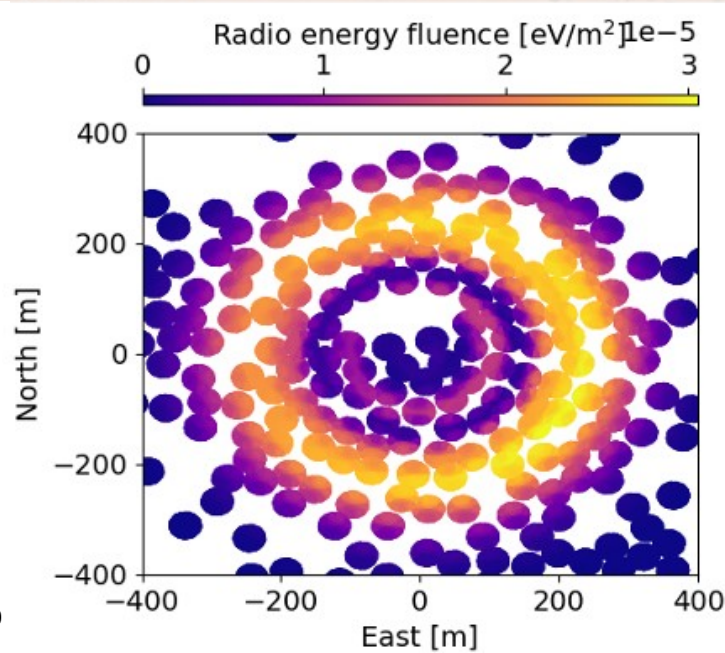
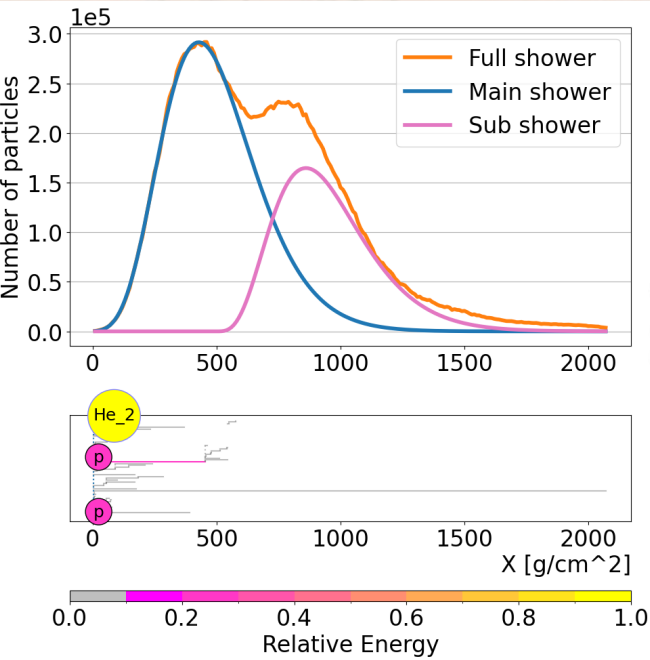
V. de Henau, S. Buitink et al., SKA Science Book, 2026



- “Double bumps” in 2% of showers at 10 PeV
- Mostly for hydrogen and helium
- Details differ for H vs He
 - Helps distinguish

Hadronic physics from anomalous air showers

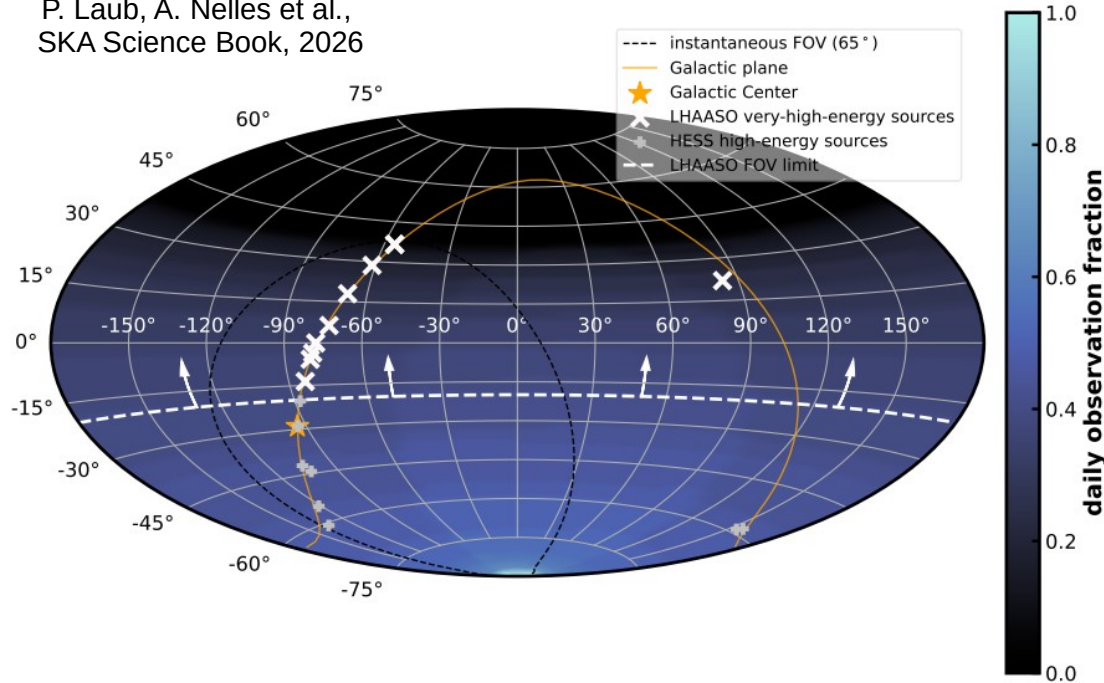
- Well measurable with SKA!
- Secondary shower clearly visible
- Statistics of distance 1st/2nd peak: hadronic cross-section



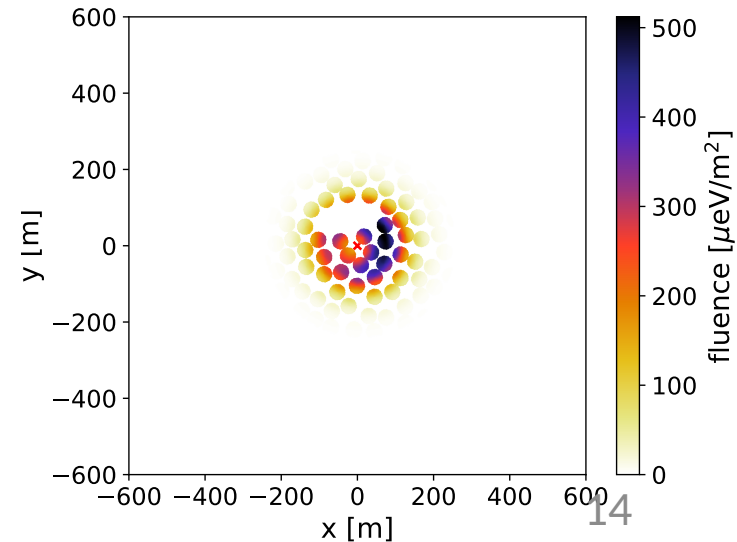
Detecting PeV gamma rays

- Gamma rays around 1 PeV have been detected with LHAASO
- Candidate sources are conveniently located in SKA-Low field of view

P. Laub, A. Nelles et al.,
SKA Science Book, 2026

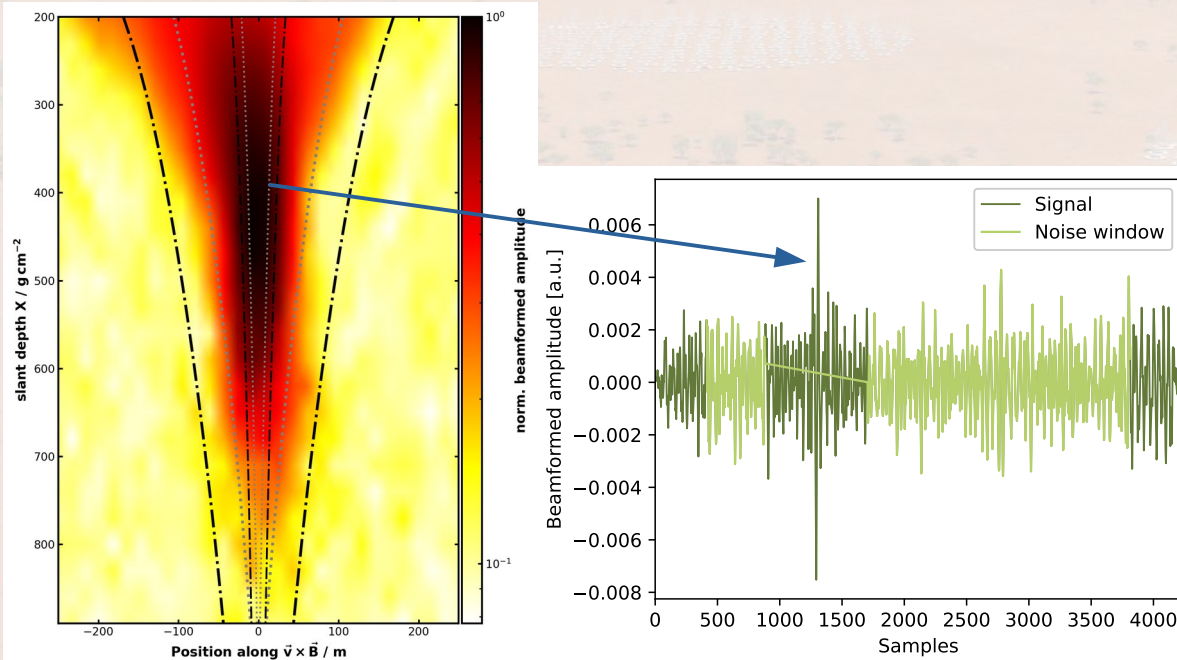


But: radio signals very weak

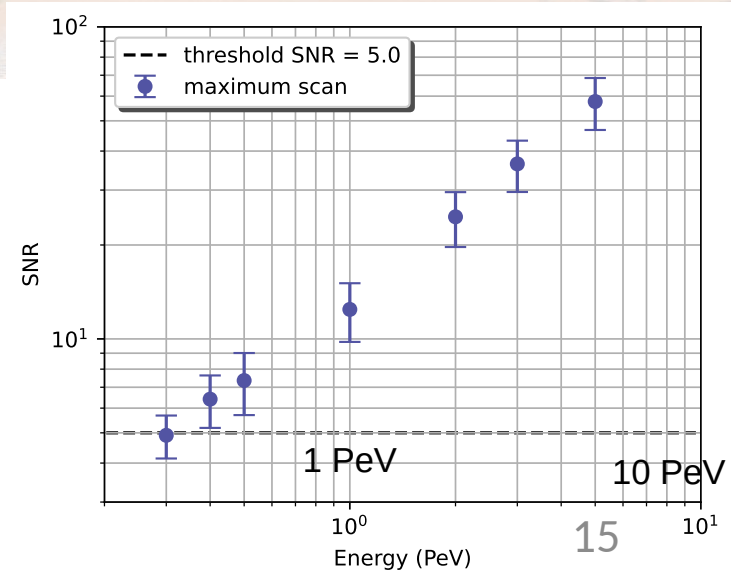


Detecting PeV gamma rays

- Using beamforming gets enough SNR down to 0.5 to 1 PeV
- Challenges: triggering (few particles on ground), many beams needed, distinguishing gammas from proton background (!)



SNR vs energy



Summary

- Improve the mass composition measurements
 - Highest detail ever, Xmax resolution < **8 g/cm²**
 - Extra, independent information from longitudinal distribution
 - Better **H / He** separation, astrophysically relevant
 - Extends to lower energy range, **10¹⁵ eV**
- Hadronic physics
 - Indirectly probe cross sections at energies > LHC
 - Test hadronic interaction models
 - Extra H / He / heavy separation from anomalous air showers
- Gamma ray detections?
 - Exciting, within possibility
 - Much work still needed, will also benefit CR detection

