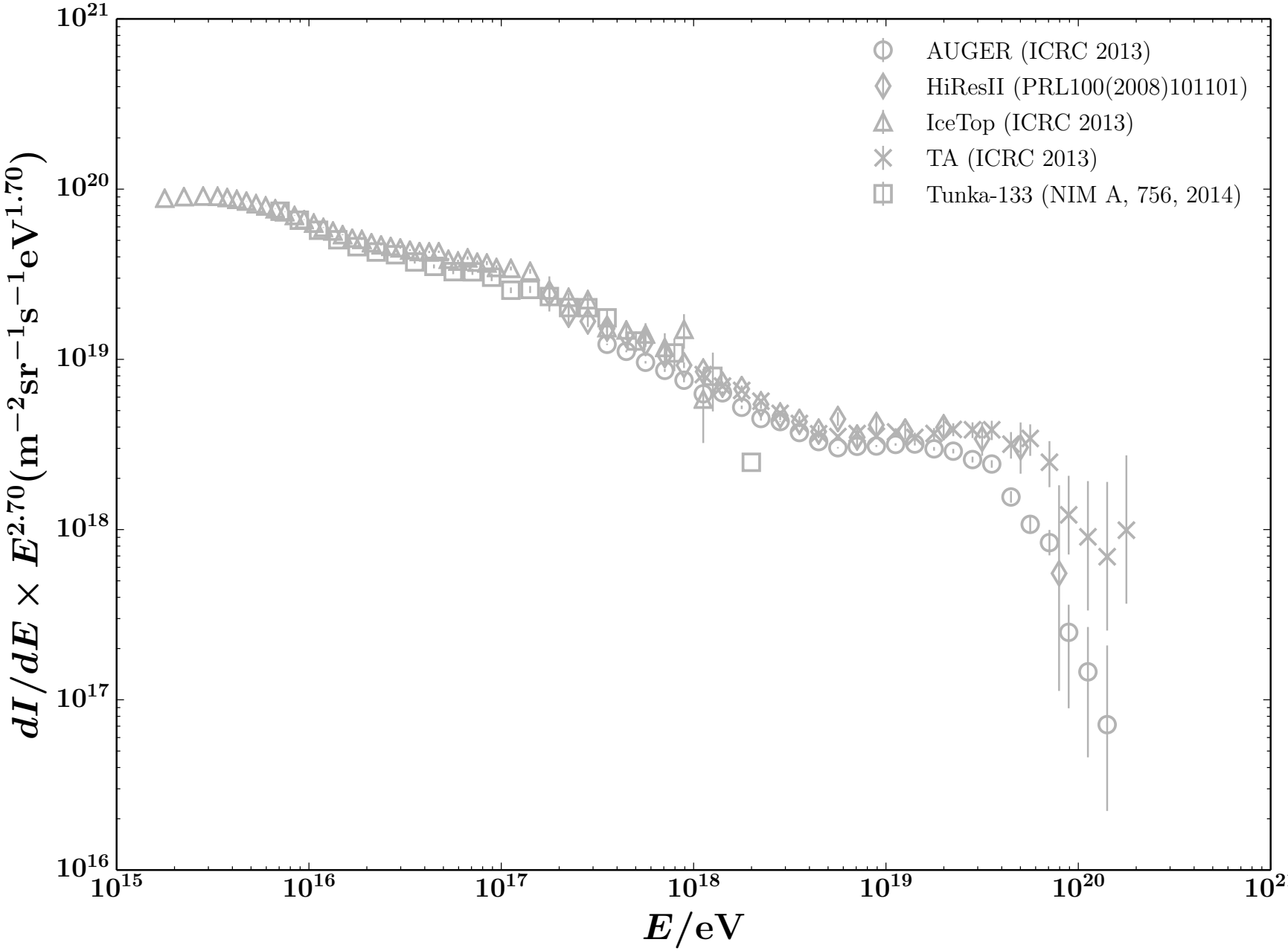
KASCADE/-Grande

Review, Recent Results, Future Endeavors

Sven Schoo

Karlsruher Institut für Technologie - Institut für Kernphysik

14.10.2014


AUGER (ICRC 2013)
HiResII (PRL100(2008)101101)
IceTop (ICRC 2013)
TA (ICRC 2013)
Tunka-133 (NIM A, 756, 2014)
$dI/dE \times E^{2.70}(\mathrm{m^{-2}sr^{-1}s^{-1}eV^{1.70}})$
E/eV
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}

252 Detector Stations organized in 16 Clusters

observable: Nch

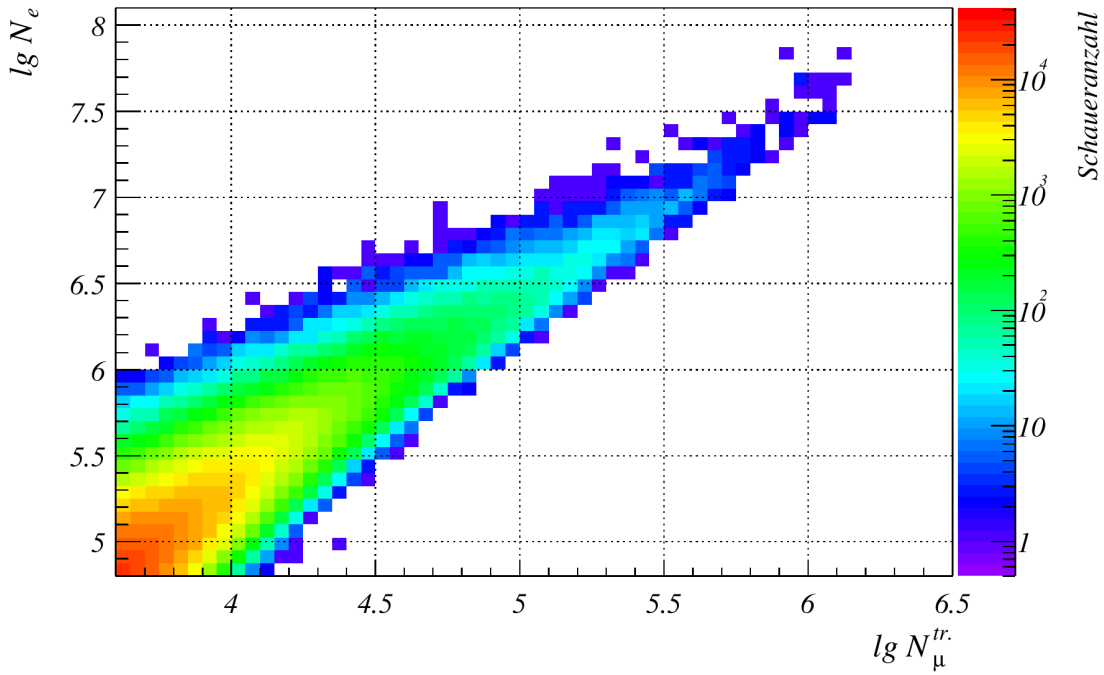
192 Detector Stations with shielded scintillators

observable: Nμ

KASCADE

Scintillator Array

KASCADE Analysis

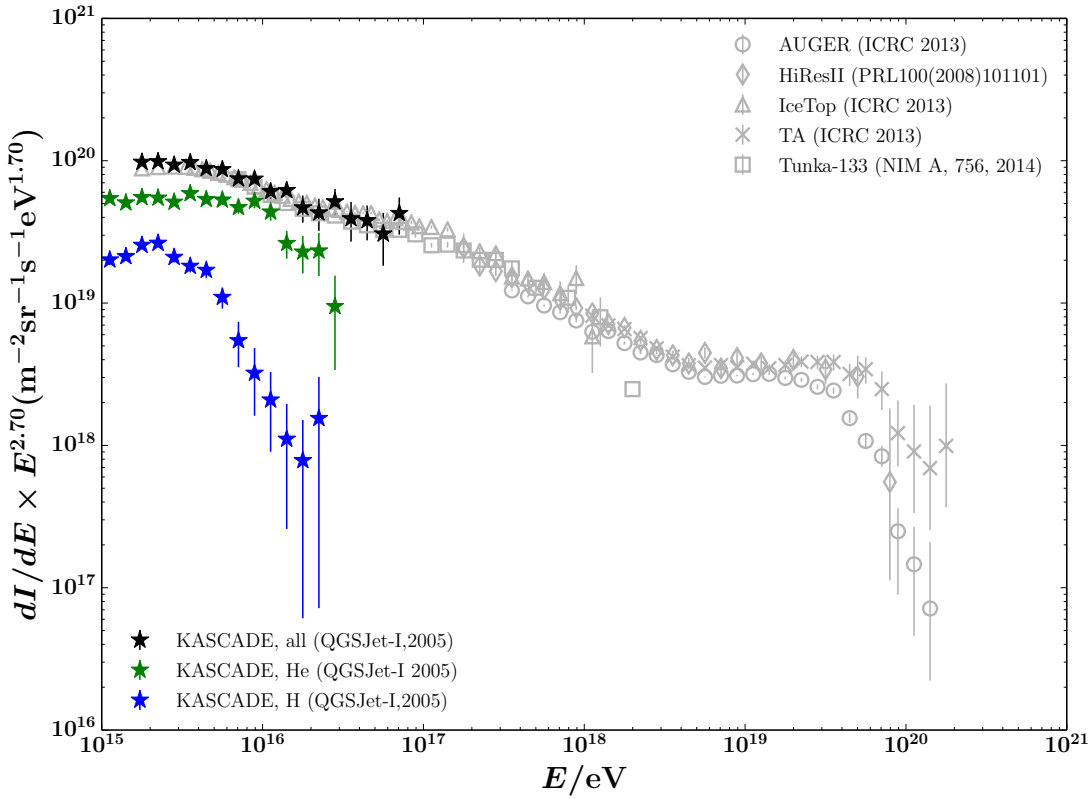


[doi: 10.1016/j.astropartphys.2005.04.001]

- $\frac{\mathrm{d}J}{\mathrm{d}\log_{10} N_\mathrm{e}\,\mathrm{d}\log_{10} N_\mu^\mathrm{tr}} = \Sigma_{n=1}^{N_\mathrm{nucl}} \int \frac{\mathrm{d}J}{\mathrm{d}\log_{10} E} p_\mathrm{n}(\log_{10} N_\mathrm{e}, \log_{10} N_\mu^\mathrm{tr} \mid \log_{10} E)\mathrm{d}\log_{10} E$
- p_n takes into account the probability...
  - that a nucleus n with an energy E induces EAS with $N_\mathrm{ch}^\mathrm{true}$ and N_μ^true
  - that the event gets triggered and properly reconstructed
  - that $N_\mathrm{ch}^\mathrm{true}$ and N_μ^true are reconstructed as the N_ch and N_μ of the cell i

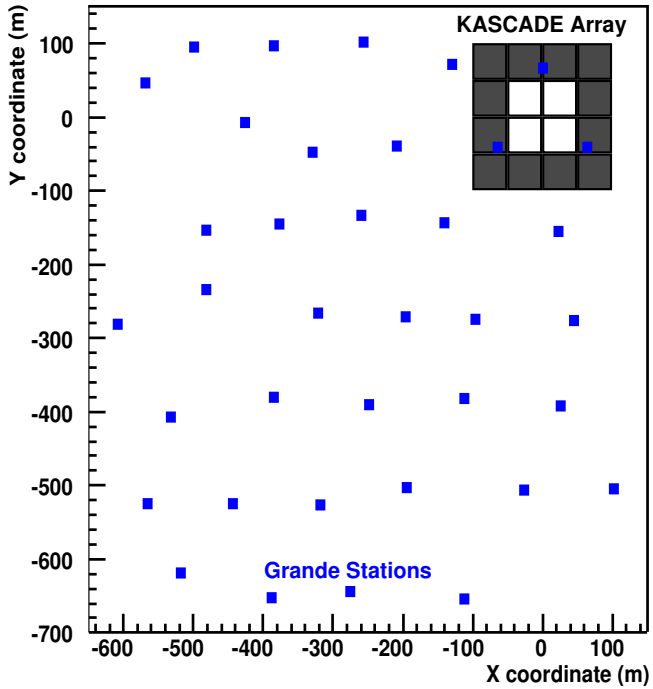
KASCADE Results (QGSJet-1)

- helium more abundant compared to proton (For QGSJet-1)
- proton knee: ∼2-3 PeV
- helium knee: ∼4-6 PeV? if yes, knee maybe Z-dependent
- helium knee: ∼8-12 PeV? if yes, knee maybe A-dependent
- take a look also at e.g. iron to get a clearer picture



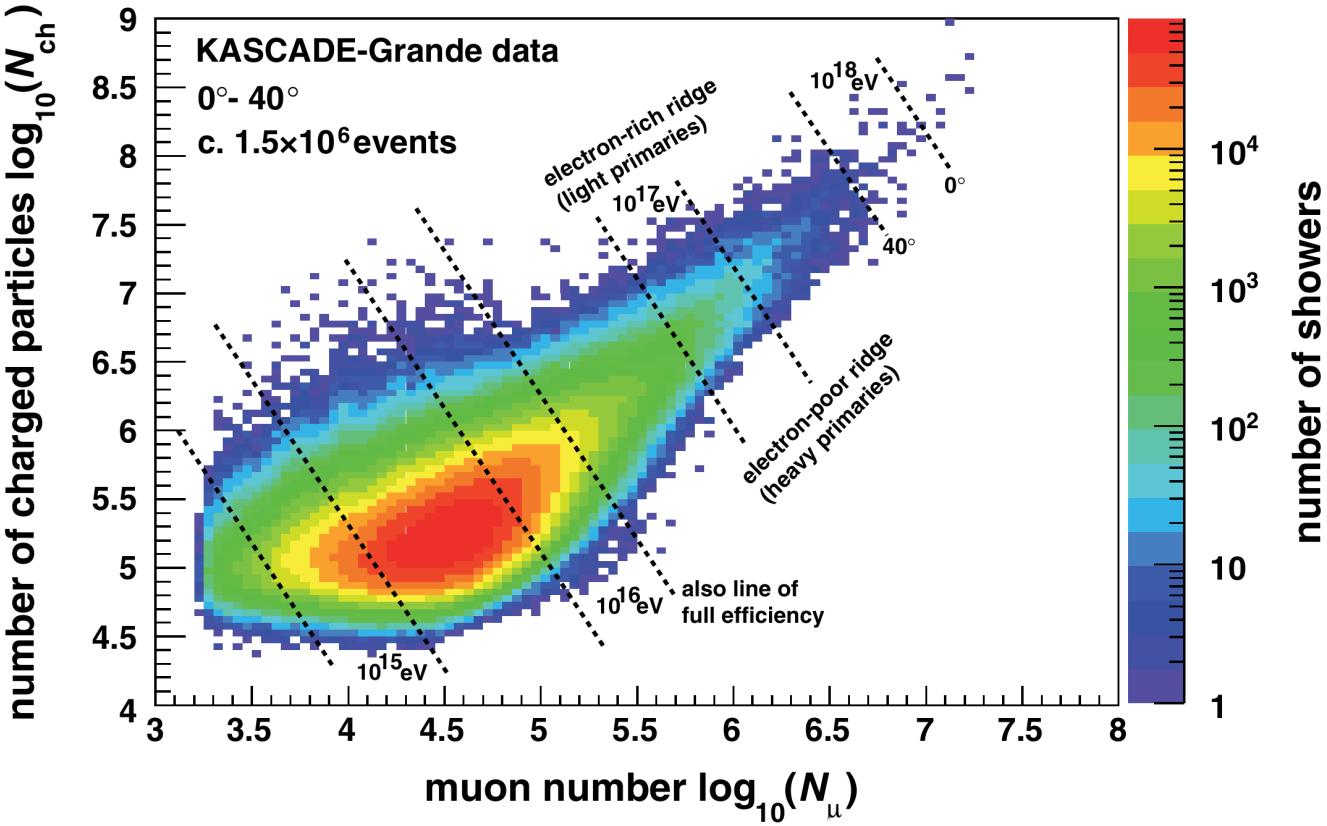
KASCADE-Grande Setup

- location: extension of the KASCADE-Array
- 37 additional stations (unshielded only)
- N_μ: derived using KASCADE
- area: $700 \times 700\,\mathrm{m}^2$
- spacing: $137\,\mathrm{m}$



[http://www-ik.fzk.de/KASCADE_home.html/]

2 dimensional shower size spectrum

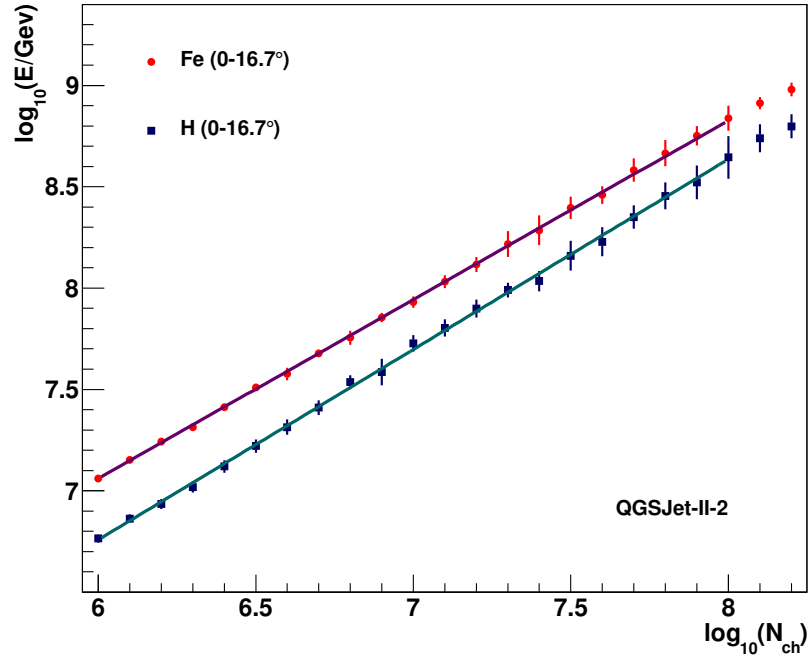


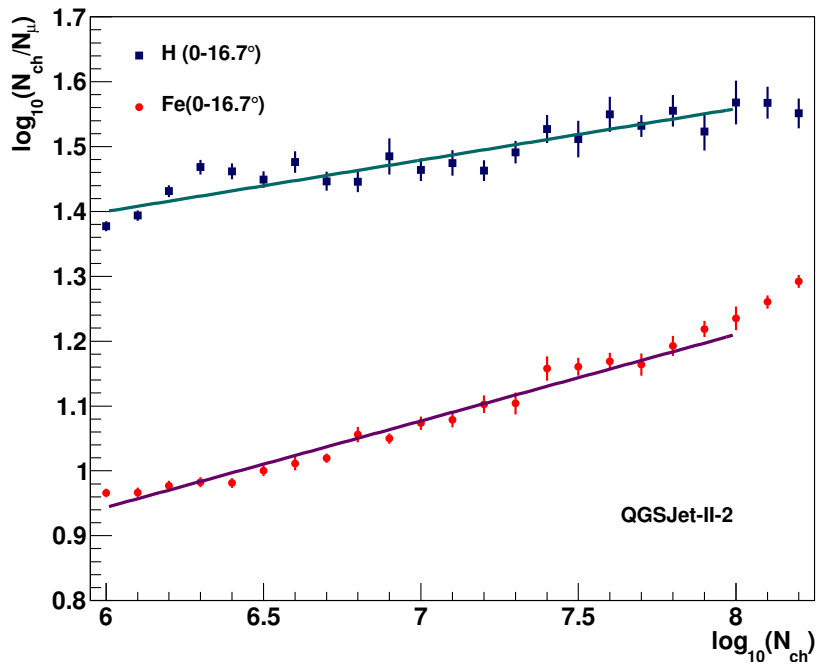
[doi: 10.1103/PhysRevLett.107.171104]

- again basis of the analysis
- lower statistics towards upper energy limit ($10^{18}\,\mathrm{eV}$) problematic for unfolding analysis $\rightarrow$ use different approach for the whole energy range
- used to separate events into mass groups

KASCADE-Grande Energy reconstruction

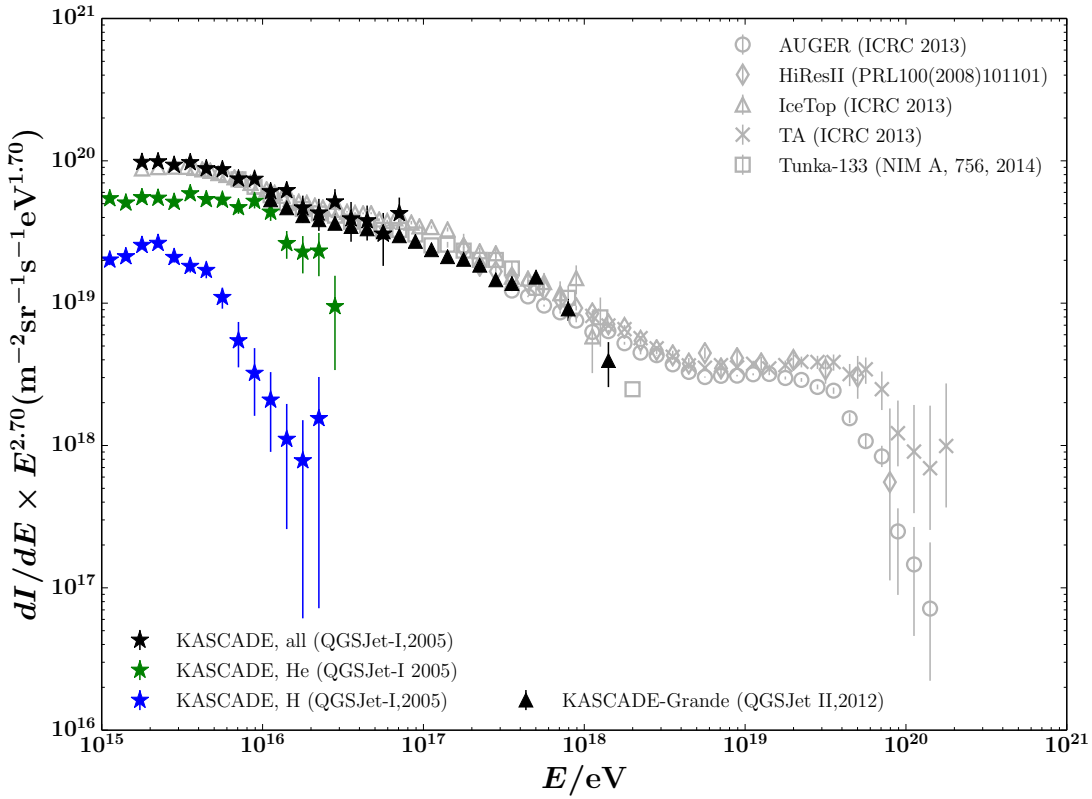
- N_{ch} is used to estimate the energy of an event.
- $\log_{10}(E/\mathrm{GeV}) = (a_{\mathrm{H}} + (a_{\mathrm{Fe}} - a_{\mathrm{H}}) \cdot k) \cdot \log_{10}(N_{\mathrm{ch}}) + b_{\mathrm{H}} + (b_{\mathrm{Fe}} - b_{\mathrm{H}}) \cdot k$
- k is used to correct the obtained energy for the mass dependence
- $k = \frac{log_{10}(N_{\mathrm{ch}}/N_{\mu}) - log_{10}(N_{\mathrm{ch}}/N_{\mu})_{\mathrm{H}}}{log_{10}(N_{\mathrm{ch}}/N_{\mu})_{\mathrm{Fe}} - log_{10}(N_{\mathrm{ch}}/N_{\mu})_{\mathrm{H}}}$
  proton: $k \to 0$,iron: $k \to 1$





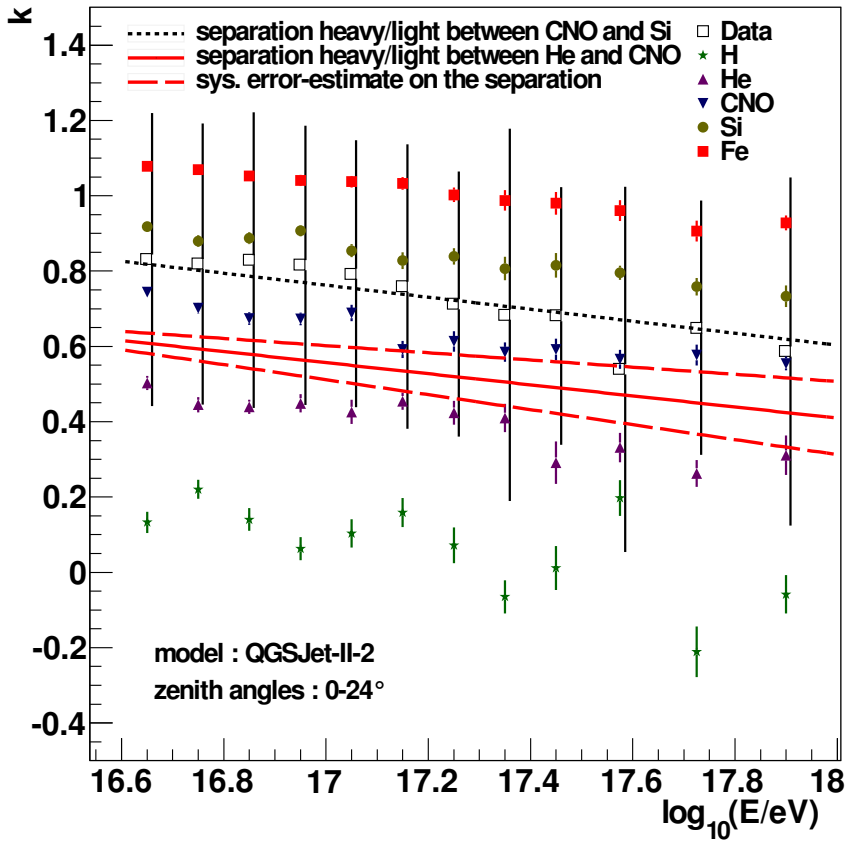
KASCADE-Grande All-Particle Spectrum

- all-particle spectra (K/KG) show same structures, but absolute flux different
- KG spectrum corrected for bin-to-bin migrations
- correction is of the order of a few percent
- all-particle spectrum does not follow single power law



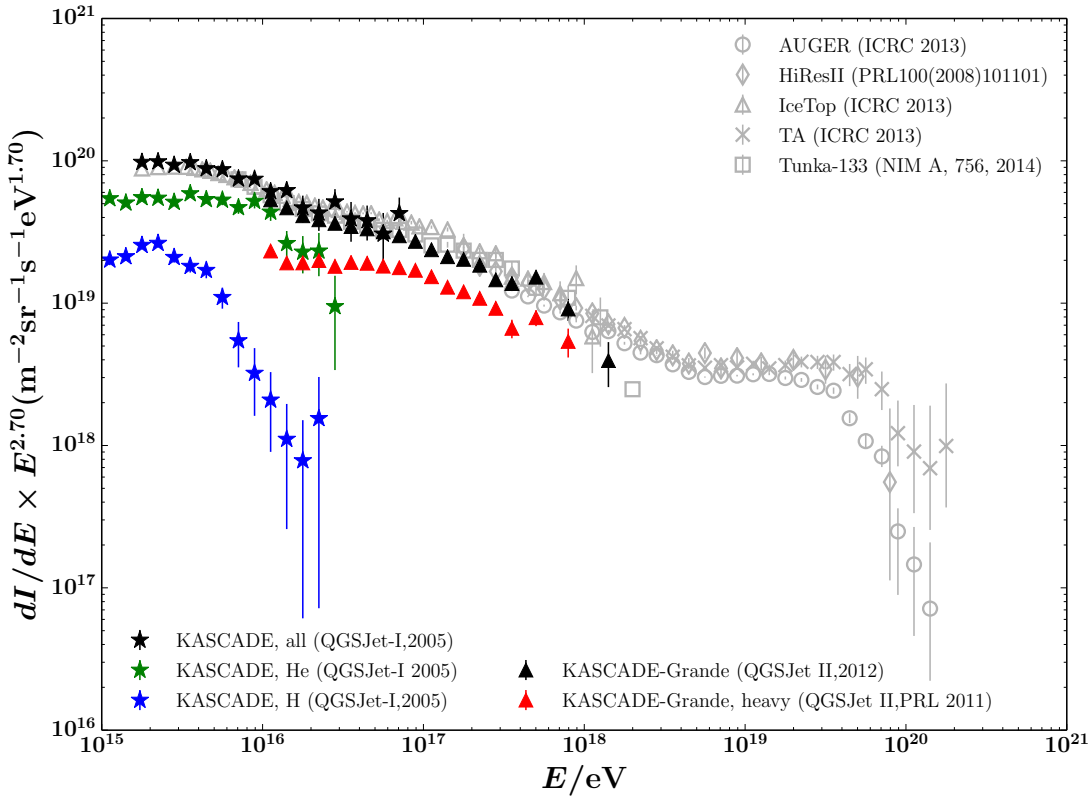
Separation into mass groups

- separation lines are fitted to mean k-values
- k-value(event) below separation line
  $\rightarrow$ light primary, else
  $\rightarrow$ heavy primary
- dotted line was used to put emphasis on the heavy component (search for a possible heavy knee)
- continuous line was used to put emphasis on the light component (search for a recovery of the light component)



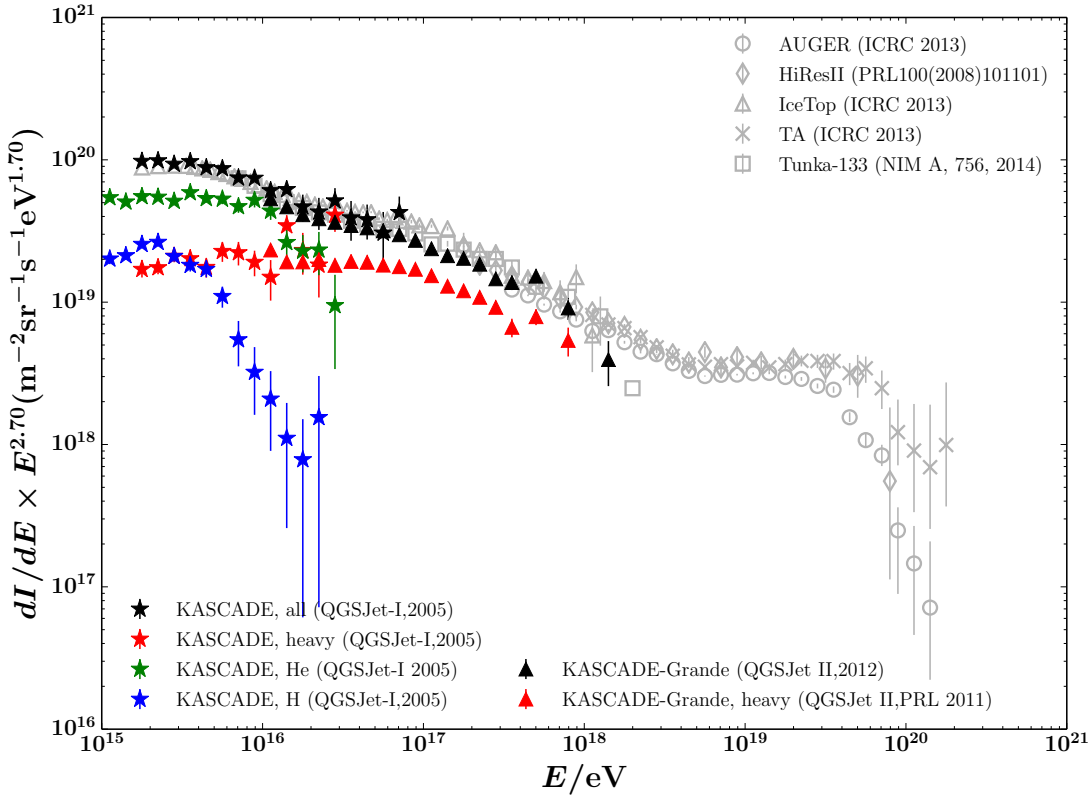
KASCADE-Grande The heavy knee

- heavy knee observed at $10^{16.92 \pm 0.04}\,\mathrm{eV}$
- indication for Z-dependent knee positions (Heavy == Iron?)
- significance: $3.5\,\sigma$



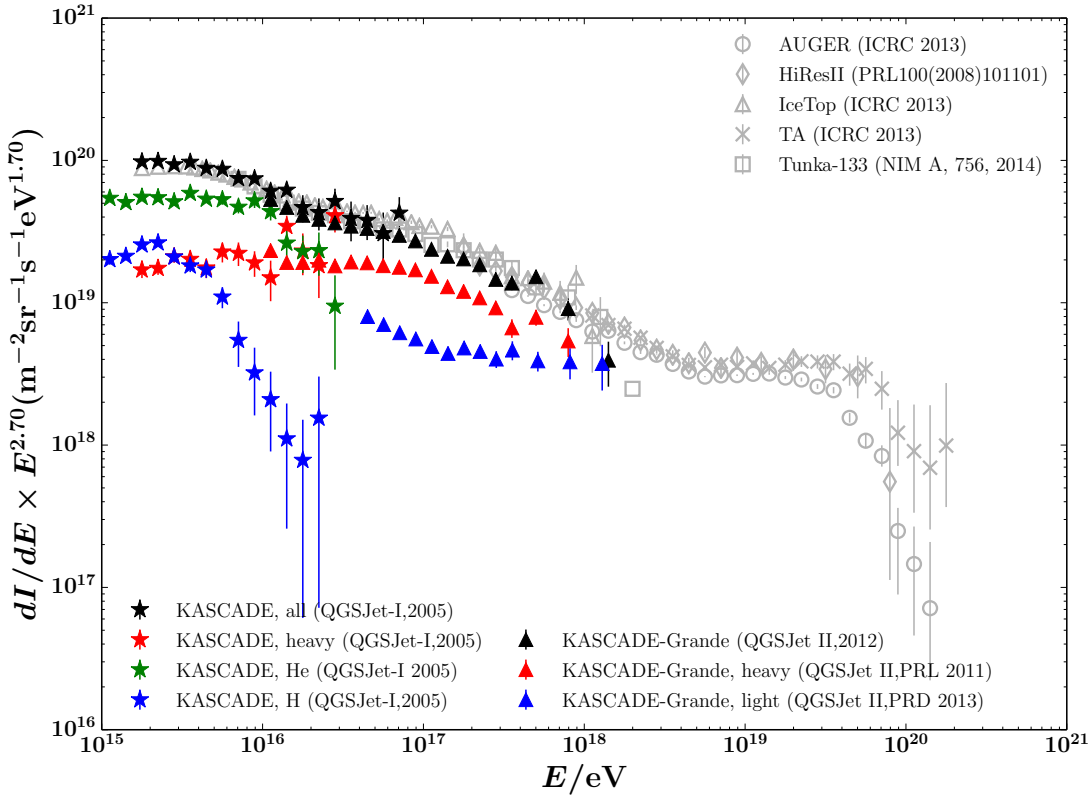
KASCADE-Grande The heavy knee

- heavy knee observed at $10^{16.92 \pm 0.04}\,\mathrm{eV}$
- indication for Z-dependent knee positions (Heavy == Iron?)
- significance: $3.5\,\sigma$
- KASCADE spectrum for heavy component connects to the one from KASCADE-Grande



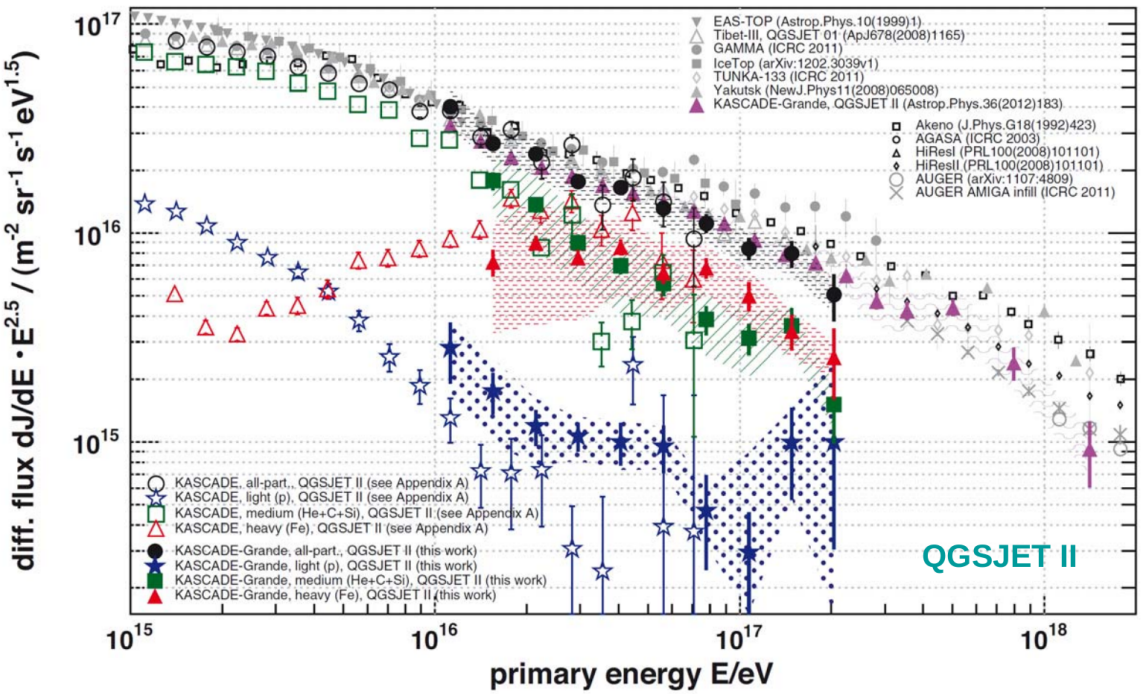
KASCADE-Grande The light ankle

- light ankle observed at $10^{17.08 \pm 0.08}\,\mathrm{eV}$
- same slopes of heavy/light spectra above/below feature
- possible transition from galactic to extragalactic origin starts at this energy?
- significance: $5.8\,\sigma$
- medium component not shown (e-poor + e-rich != all-particle)



KASCADE-Grande Unfolding

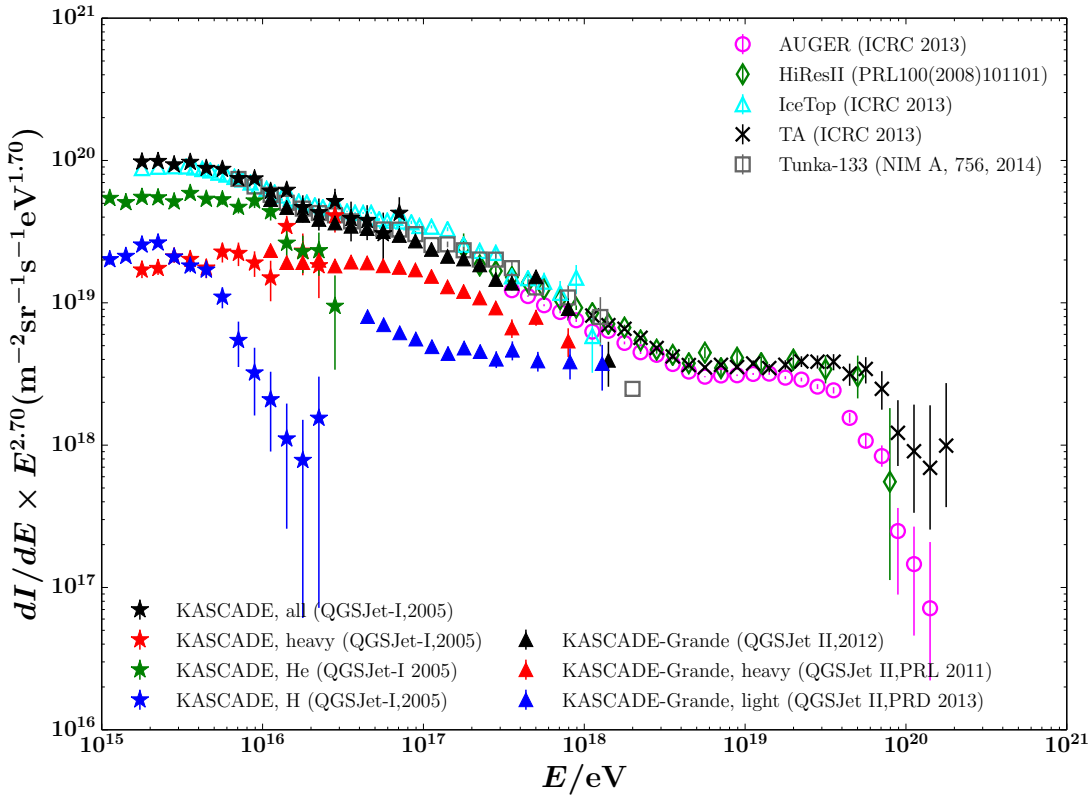
- compatible with the results of the other approach
- events with zenith angles below 18°
- using the same reconstruction procedure and hadr. interaction model, the absolute flux in agreement with KASCADE
- knee at $\sim 10^{16.9}\,\mathrm{eV}$ visible in iron spectrum.
- second bending in proton flux at $\sim 10^{16.5}\,\mathrm{eV}$?



http://dx.doi.org/10.1016/j.astropartphys.2013.06.004

Comparison

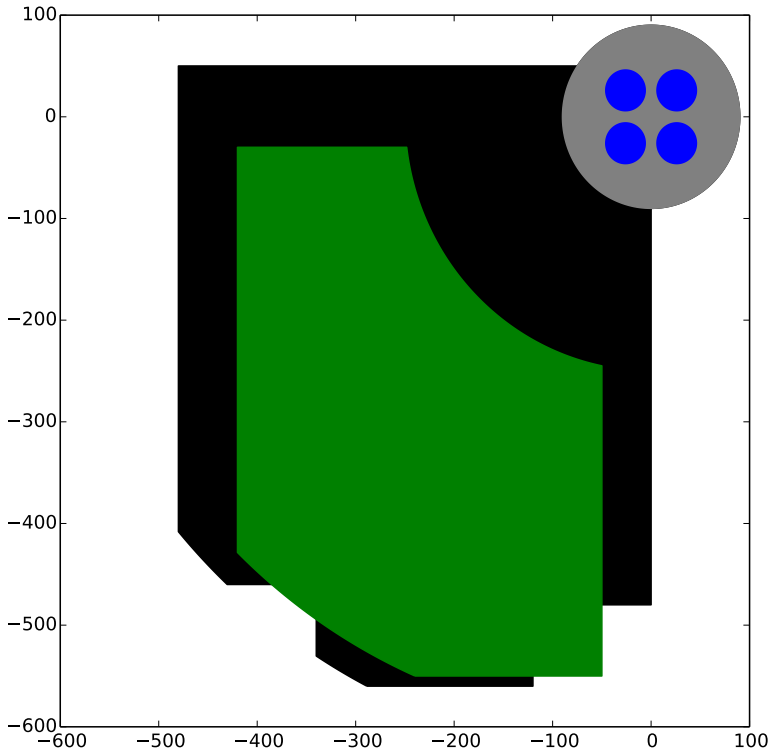
- absolute flux slightly different
- heavy mass spectra seem to fit reasonably well
- what is the composition of the light spectrum below and above the ankle-like feature?
- KASCADE He-flux may be too steep. Need another component? Should we expect another bending at around $10^{16.5}\,\mathrm{eV}$?
- galactic KASCADE proton flux is too low



- change of composition before and after the light ankle possible
- composition at higher energies needed, connection to direct measurements desirable

Combined Analysis

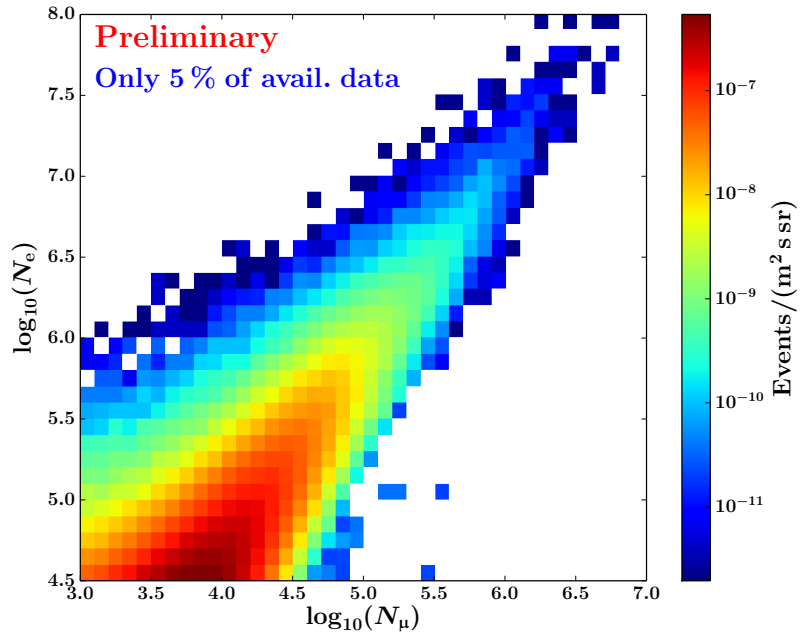
- Idea: Use e/γ detectors of both arrays together instead of separately
- Reconstruction of observables even more accurate
- The consistent reconstruction over the whole range eliminates systematic differences due to different reconstruction procedures
- Significant increase in number of events by increased measurement time and fiducial area
- Sub-KASCADE area might help to reach down to $10^{14}\,\mathrm{eV}$



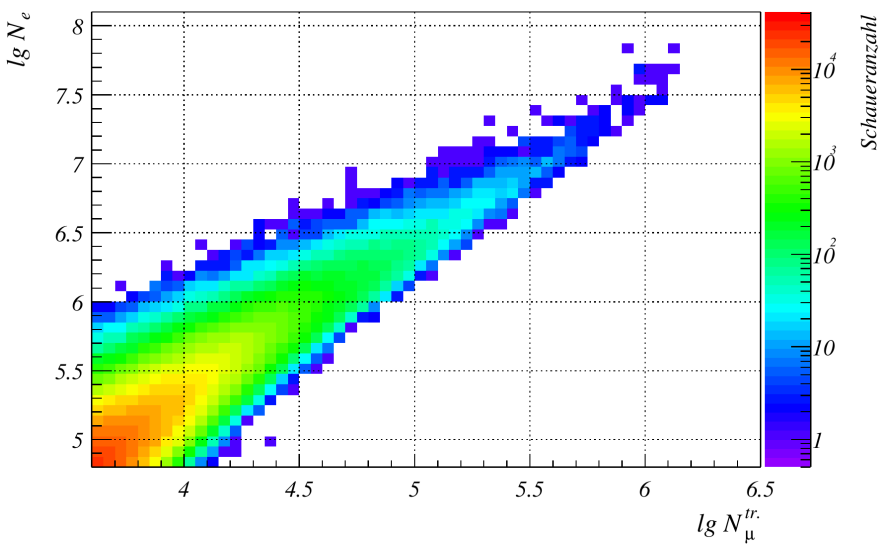
- Standard Area: $152202\,\mathrm{m}^2$
- KASCADE Area: $25447\,\mathrm{m}^2$
- Sub-KASCADE Area: $5027\,\mathrm{m}^2$
- Combined Area: $282057\,\mathrm{m}^2 (\sim 1.84 \times \mathrm{Std.\,Area})$

- First tests with about 5% of the avail. data look very promising.
- The recontruction using both arrays simultaneously works as expected.
- Next: process the whole dataset, apply energy-reconstruction procedures to combined data

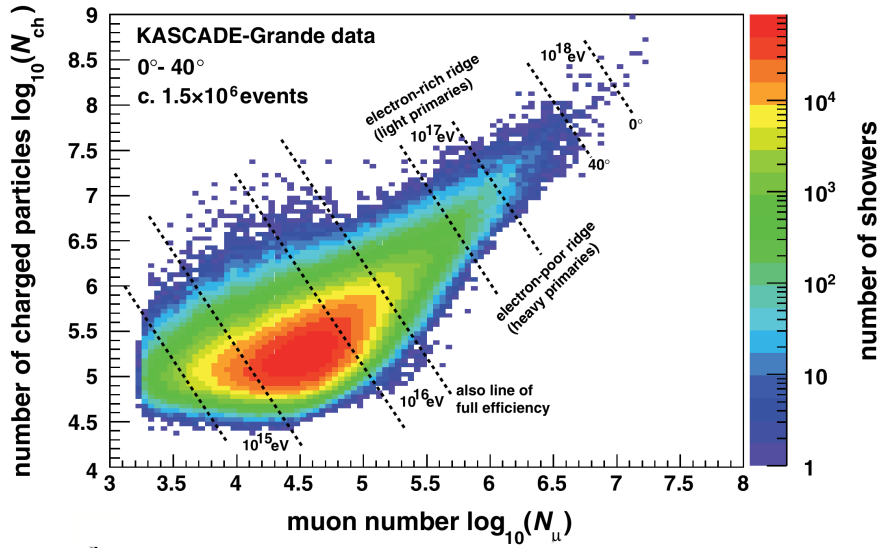
Combined



KASCADE

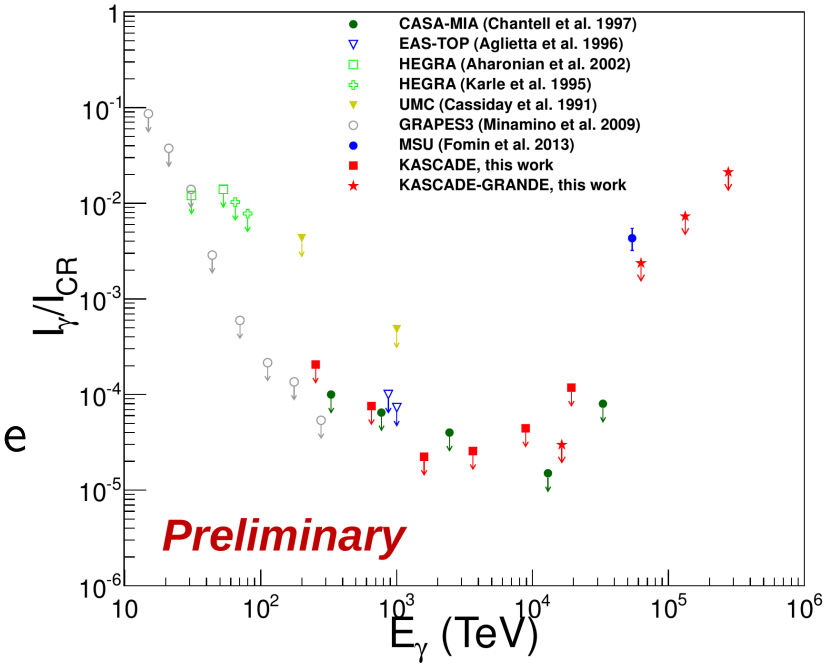


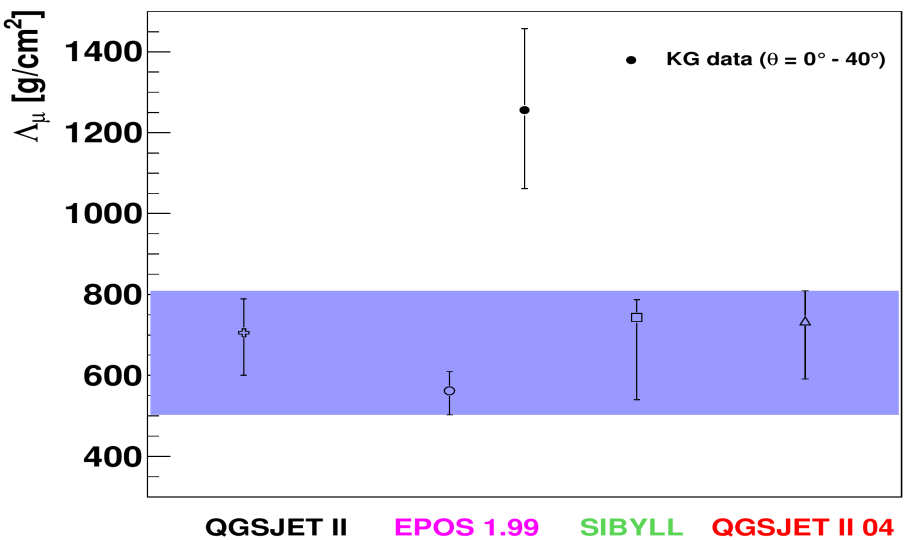
KASCADE-Grande

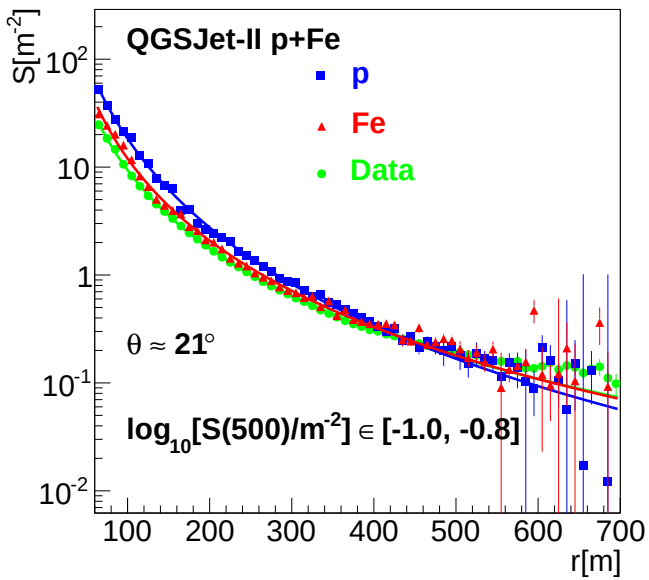


Not in this talk, Still important.

- New limits on diffuse gamma flux
- Current simulations do not fully describe data
- Papers are being prepared / are on the way







Dismantled, but still analysing/publishing data!