

Vorlesung 8:

Noch immer: Indirekte Messung kosmischer Strahlung

Detektorfelder und Messmethoden

- Teilchendetektoren
- nicht-abbildende optische Detektoren
- Beispiele: KASCADE, TUNKA

Messergebnisse und offene Fragen

- Knie im Energiespektrum
- Unsicherheiten bei der Dateninterpretation

Kalorimetrische Messung von Schauern mit Fluoreszenzlicht

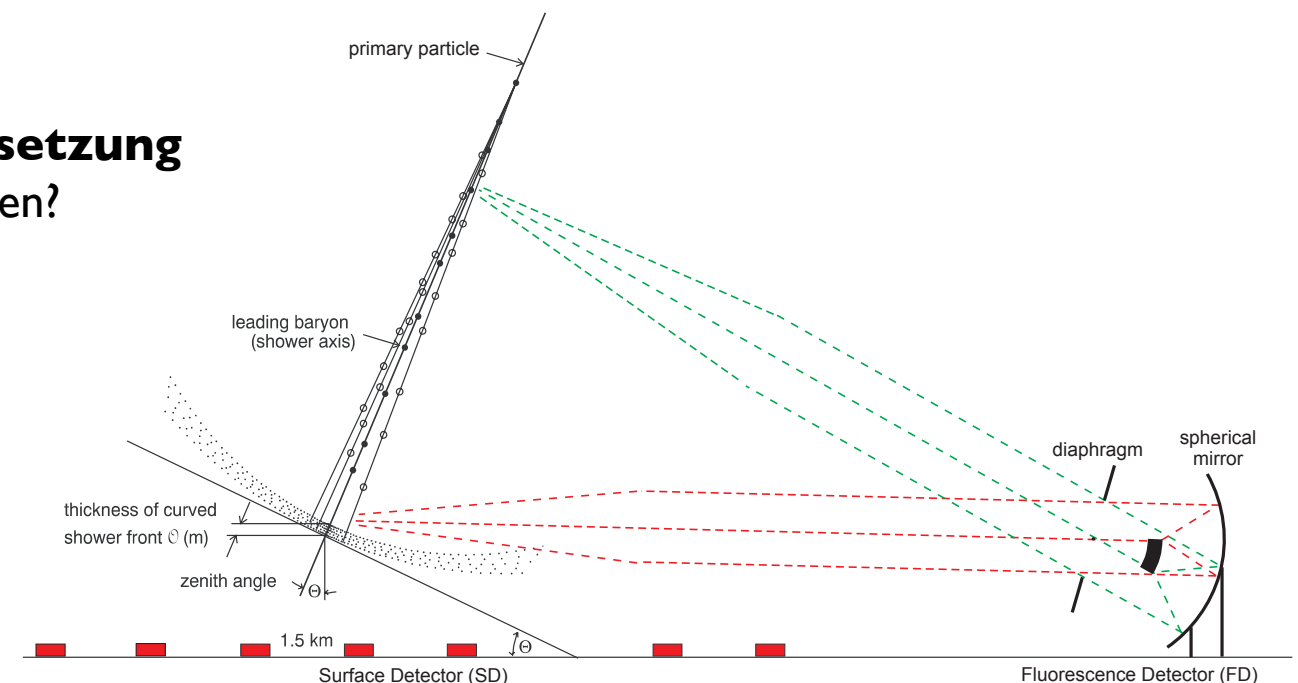
- Prozess der Fluoreszenzemission in Luft
- Korrektur für nicht nachgewiesene Energie

Beispiel: das Pierre Auger-Observatorium

- Aufbau und Schauernachweismethoden
- Methode der Hybrid-Messung

Daten zum Primärfluss und der Elementzusammensetzung

- Knöchel (Ankle) im Fluss: Übergang zu extragalaktischen Quellen?
- Tiefe des Schauermaximums und Interpretation



Vorlesung und Übungen : Daten

Vorlesung: Dienstags

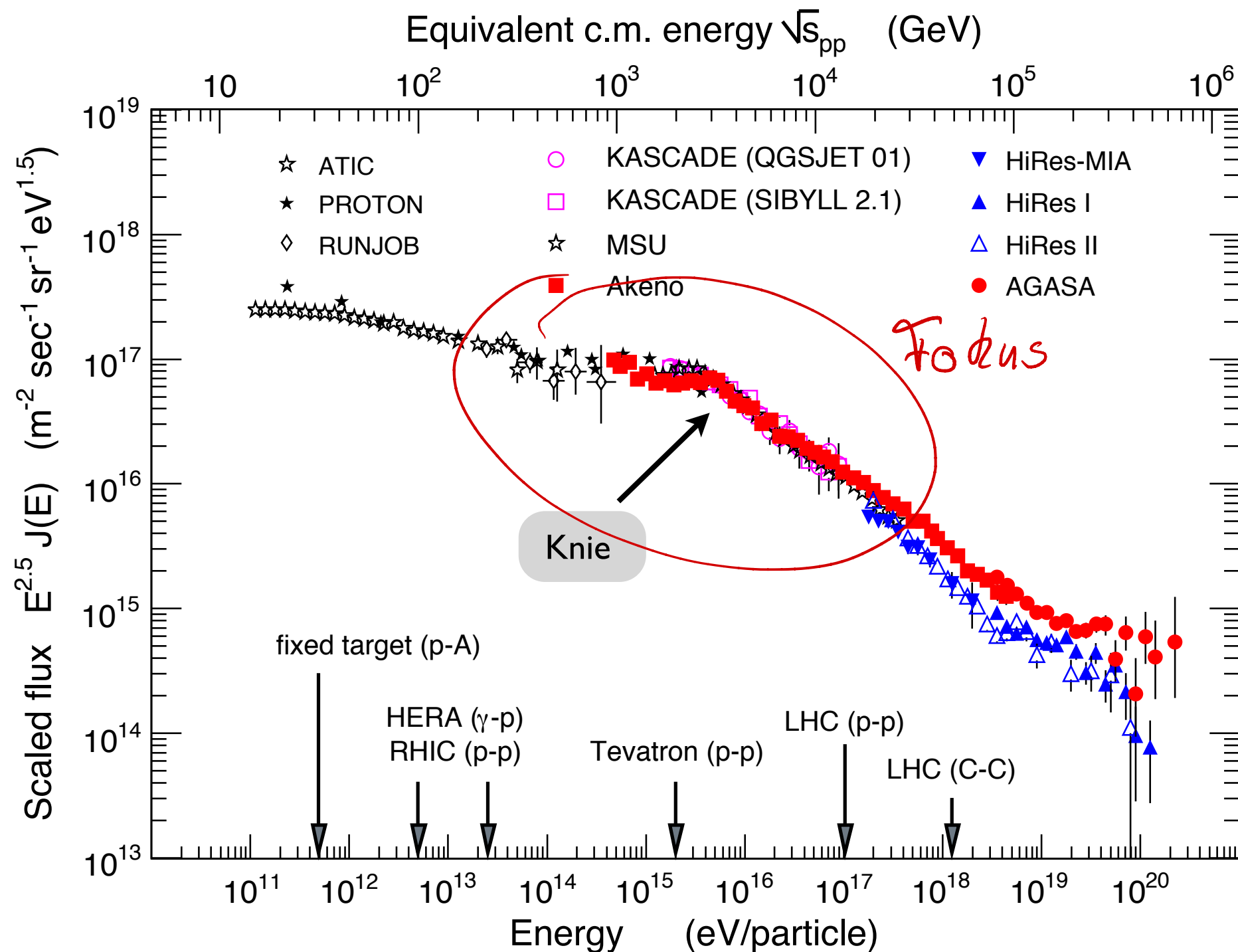
~~3. Nov. 2020~~
~~10. Nov. 2020~~
~~17. Nov. 2020~~
~~24. Nov. 2020~~
~~1. Dez. 2020~~
~~8. Dez. 2020~~
~~15. Dez. 2020~~
~~22. Dez. 2020~~
12. Jan. 2021
19. Jan. 2021
26. Jan. 2021
2. Feb. 2021
9. Feb. 2021
16. Feb. 2021

Übungen

gehalten von Max Stadelmaier

~~19.11.2020 - Blatt 1~~
~~03.12.2020 - Blatt 2~~
~~17.12.2020 - Blatt 3~~
14.01.2021 - Blatt 4
28.01.2021 - Blatt 5
11.02.2021 - Präsentation
18.02.2021 - Präsentation

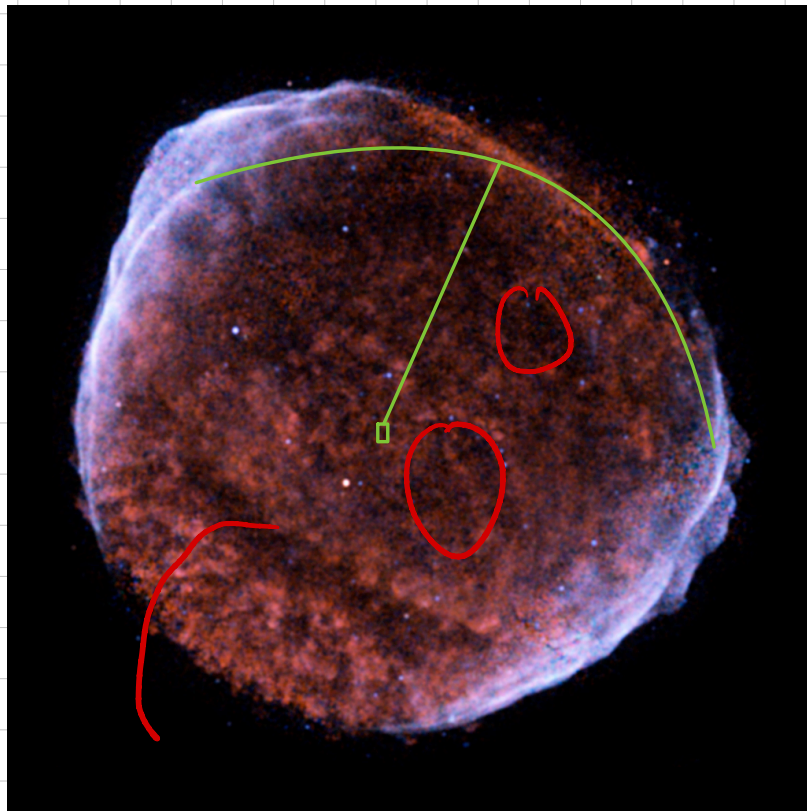
Das Knie im Fluss der Kosmischen Strahlung



Was ist Ursache
des Knies?

Magnetische Steifigkeit und Quellen

SN-Überrest 1006



Teilchen mit hoher Energie werden nicht so effizient beschleunigt

$$R_L \simeq 1 \text{ pc} \left(\frac{E}{10^{15} \text{ eV}} \right) \left(\frac{1 \mu\text{G}}{ZB} \right)$$

Hypothese: höher energetische Teilchen verlassen die Beschleunigungsregion (Quelle)

Rigidität (magnetische Steifigkeit)

$$\vec{F}_L = \vec{F}_Z \quad F_Z = q \cdot \vec{v} \times \vec{B} ; F_Z = \frac{m v^2}{r}$$

Magnetische Steifigkeit

$\Rightarrow$

$$R = B \cdot \rho = \frac{\gamma \cdot m \cdot v_{\perp}}{q}$$

Objekt-eigenschaft

Teilcheneigenschaft

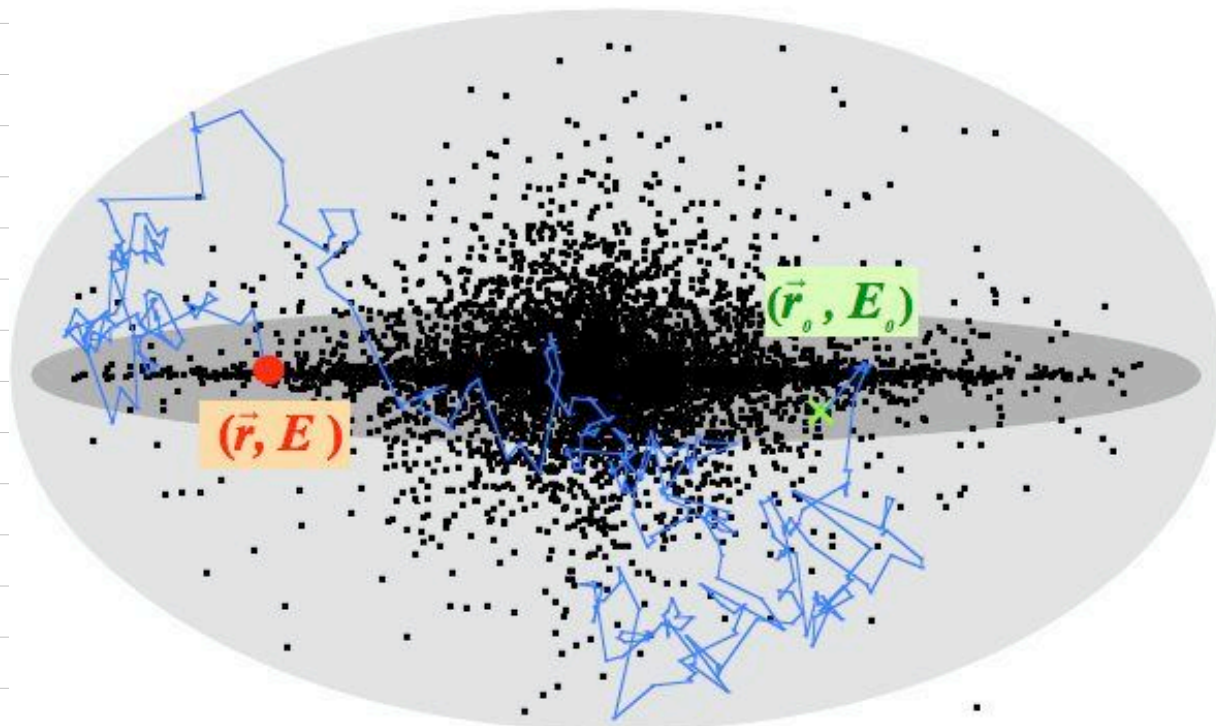
$$R_{\max} = \frac{p}{e \cdot Z} \approx \frac{\bar{E}}{e Z}$$

$$\bar{E}_{\max}^p = R_{\max}$$

$$\bar{E}_{\max}^A = Z \cdot \bar{E}_{\max}^p$$

Magnetische Steifigkeit und Ausbreitung

Magnetfeld nur unzureichend bekannt,
 $B = 3 \mu\text{G} = 30 \text{ nT}$ in der Nähe des
 Sonnensystems



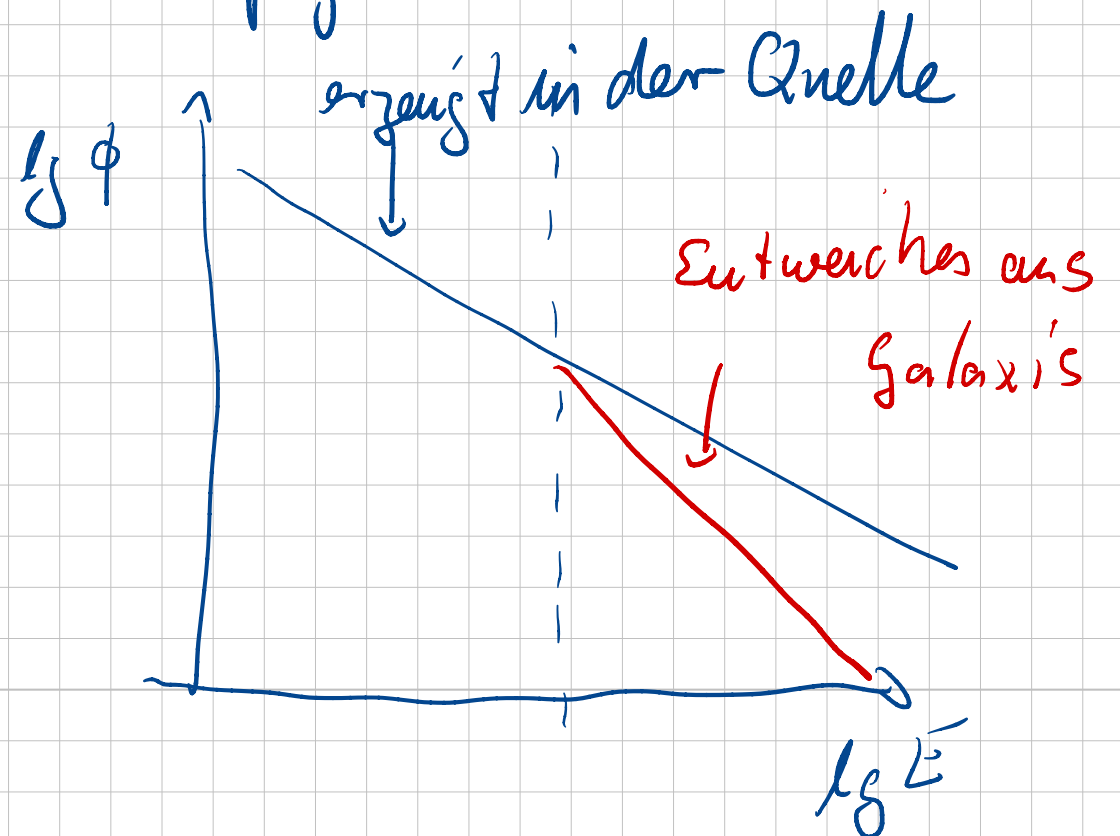
Teilchen mit hoher Energie entweichen
 schneller aus der Galaxie

„Leaky Box“-Modell
 $\Rightarrow$ Diffusionsgleichung

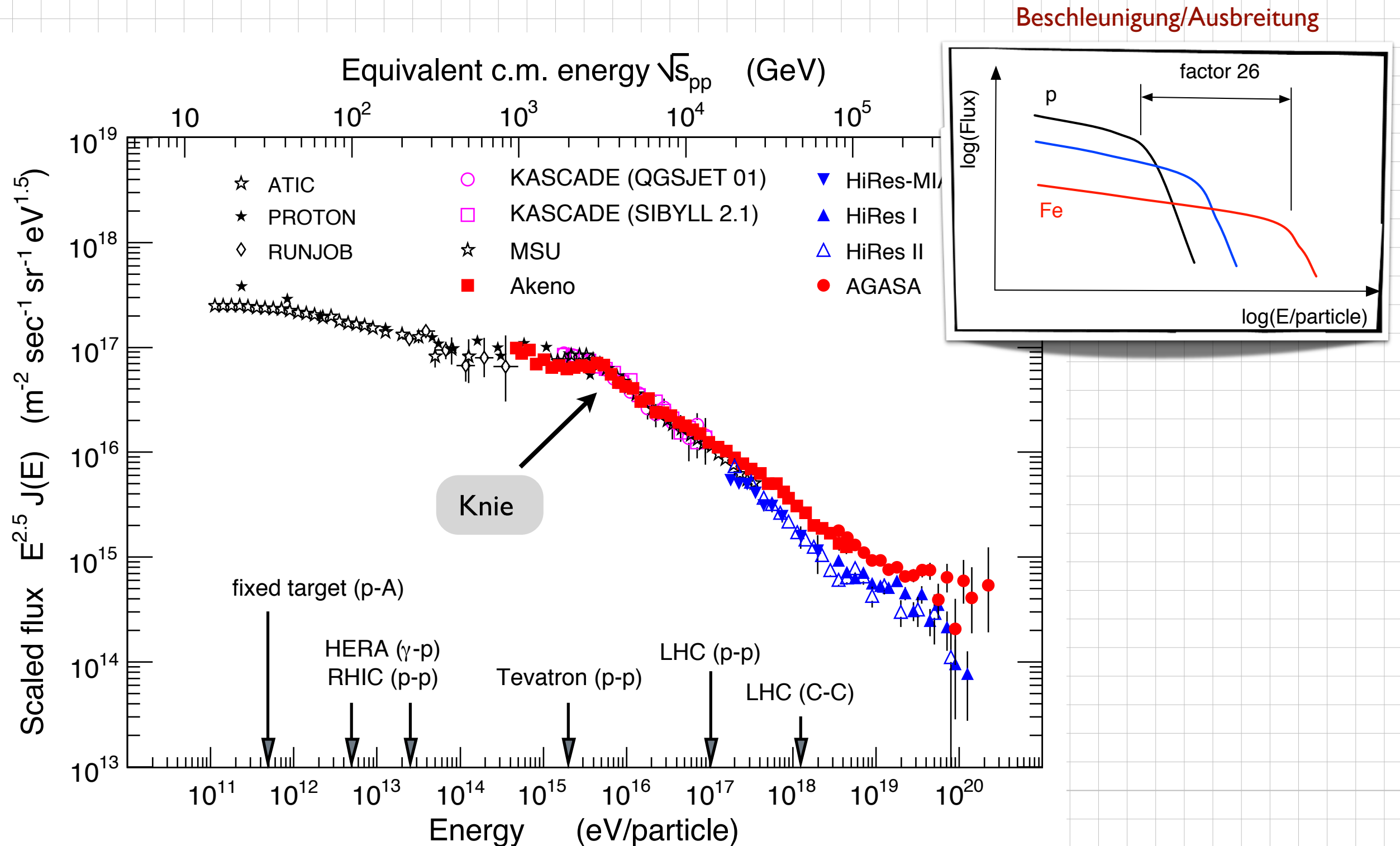
Hypothese: Entweichen aus Galaxis

Beobachtungsgröße:

$E_{\text{kin}} = E_{\text{max}}$ skaliert mit der
 Ladungszahl Z

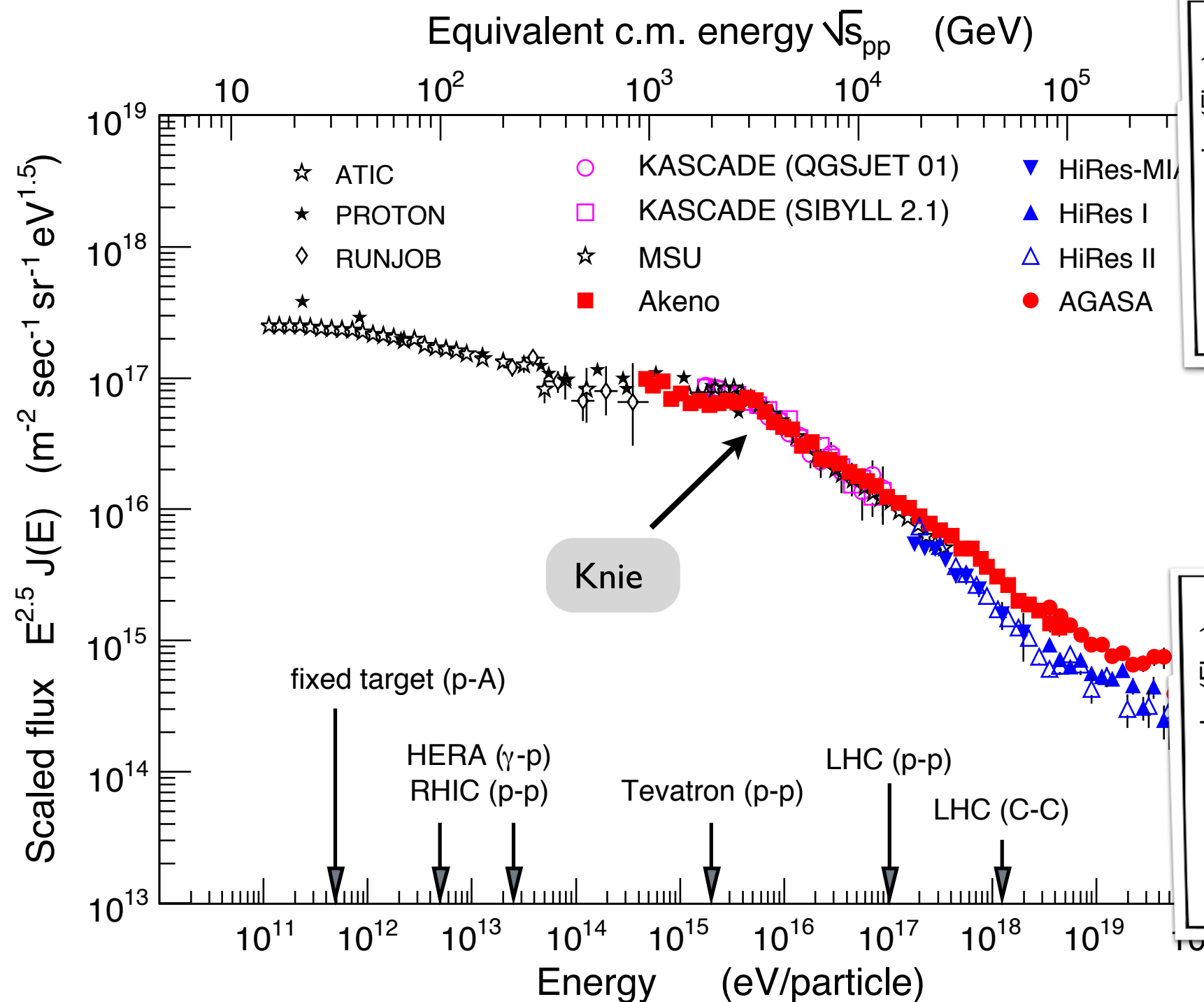


Das Knie im Fluss der Kosmischen Strahlung

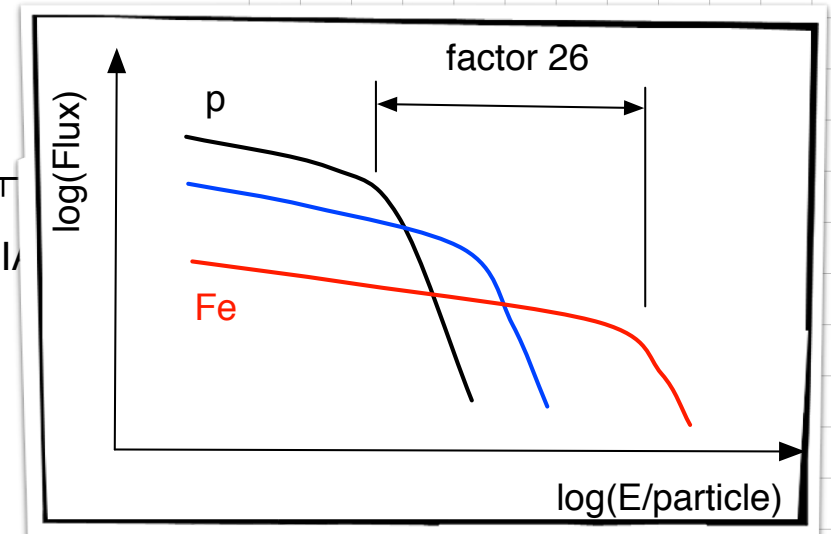


Exotische Modelle für die Entstehung des Knies

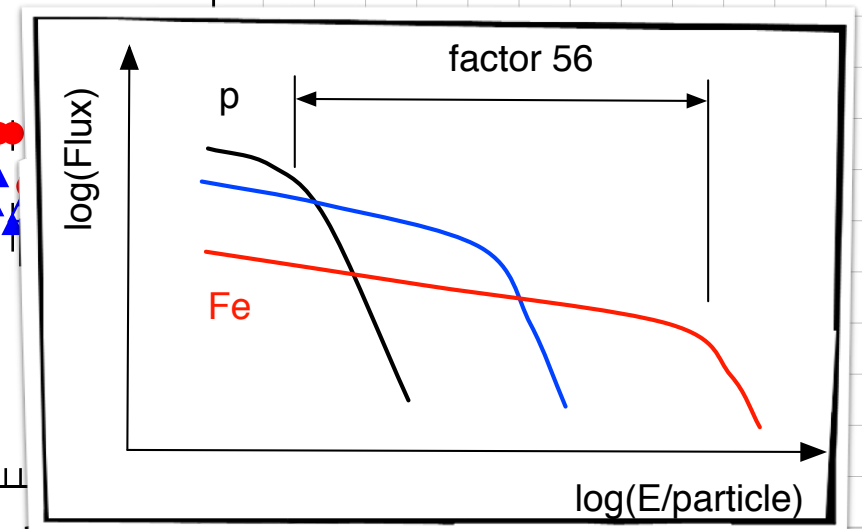
Das Knie im Fluss der Kosmischen Strahlung



Beschleunigung/Ausbreitung



Teilchenphysik



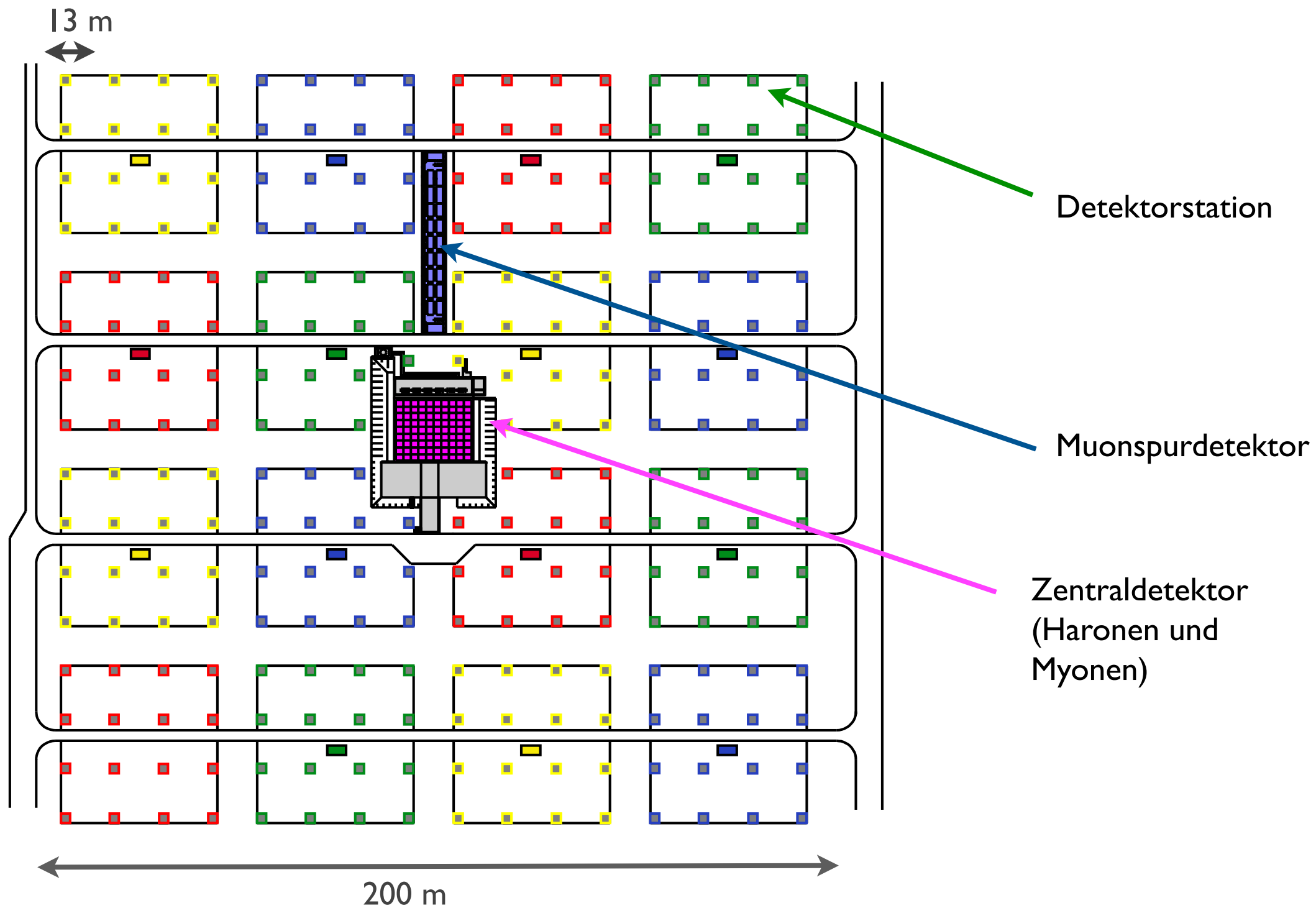
KARlsruhe Shower Core and Array DETector

gleichzeitige Messung der

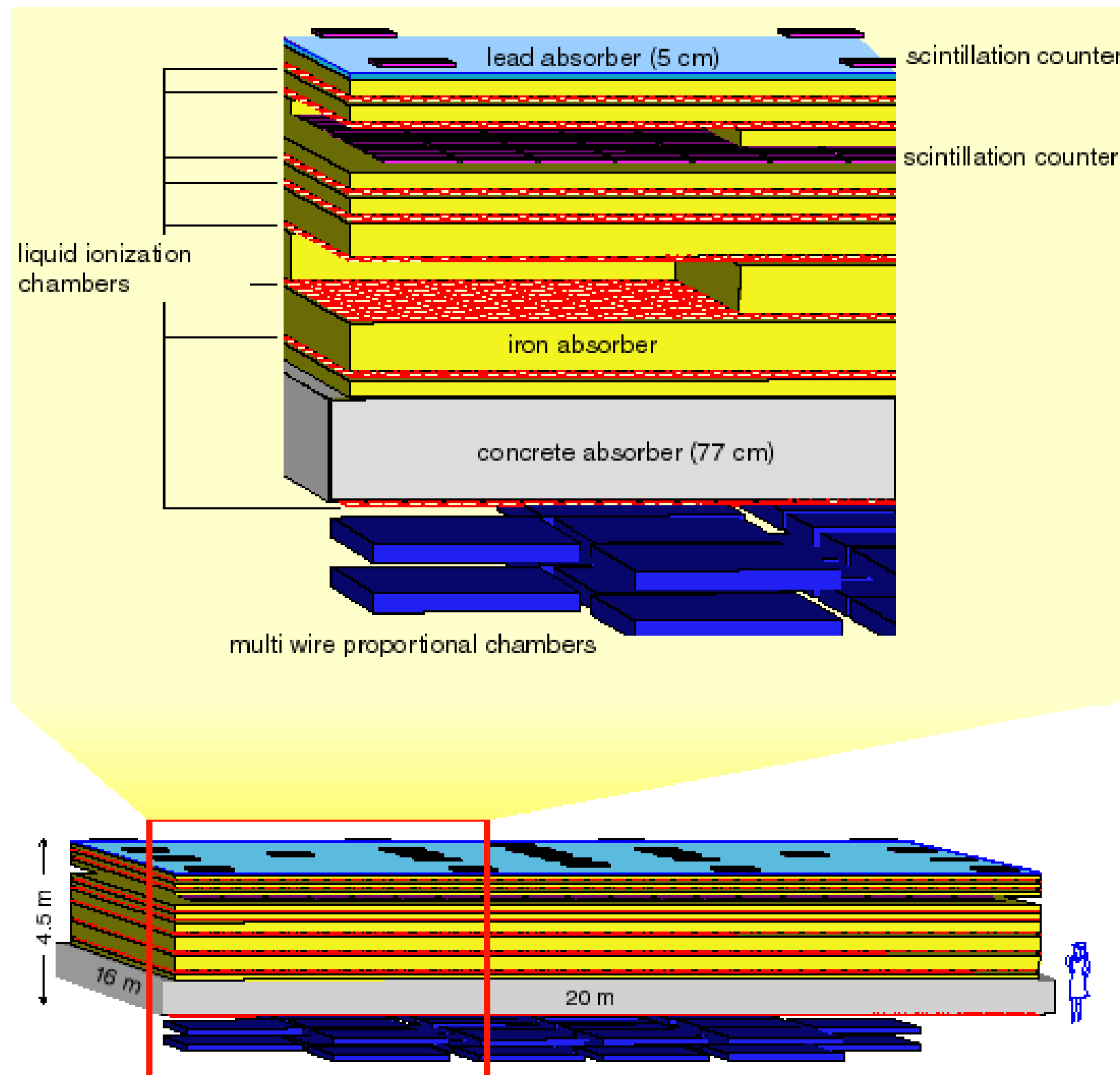
- elektromagnetischen,
 - myonischen
 - und hadronischen
- Schauerkomponenten



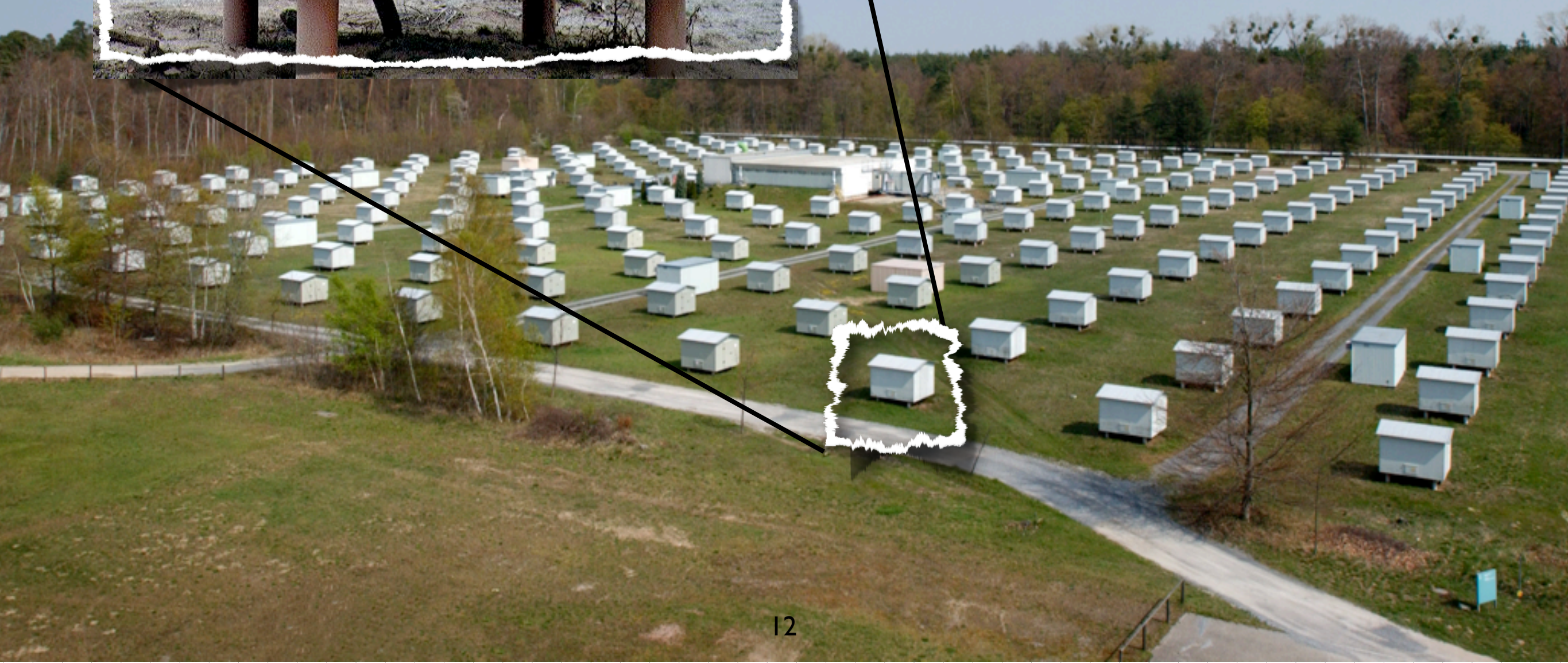
KASCADE Luftschauerdetektor



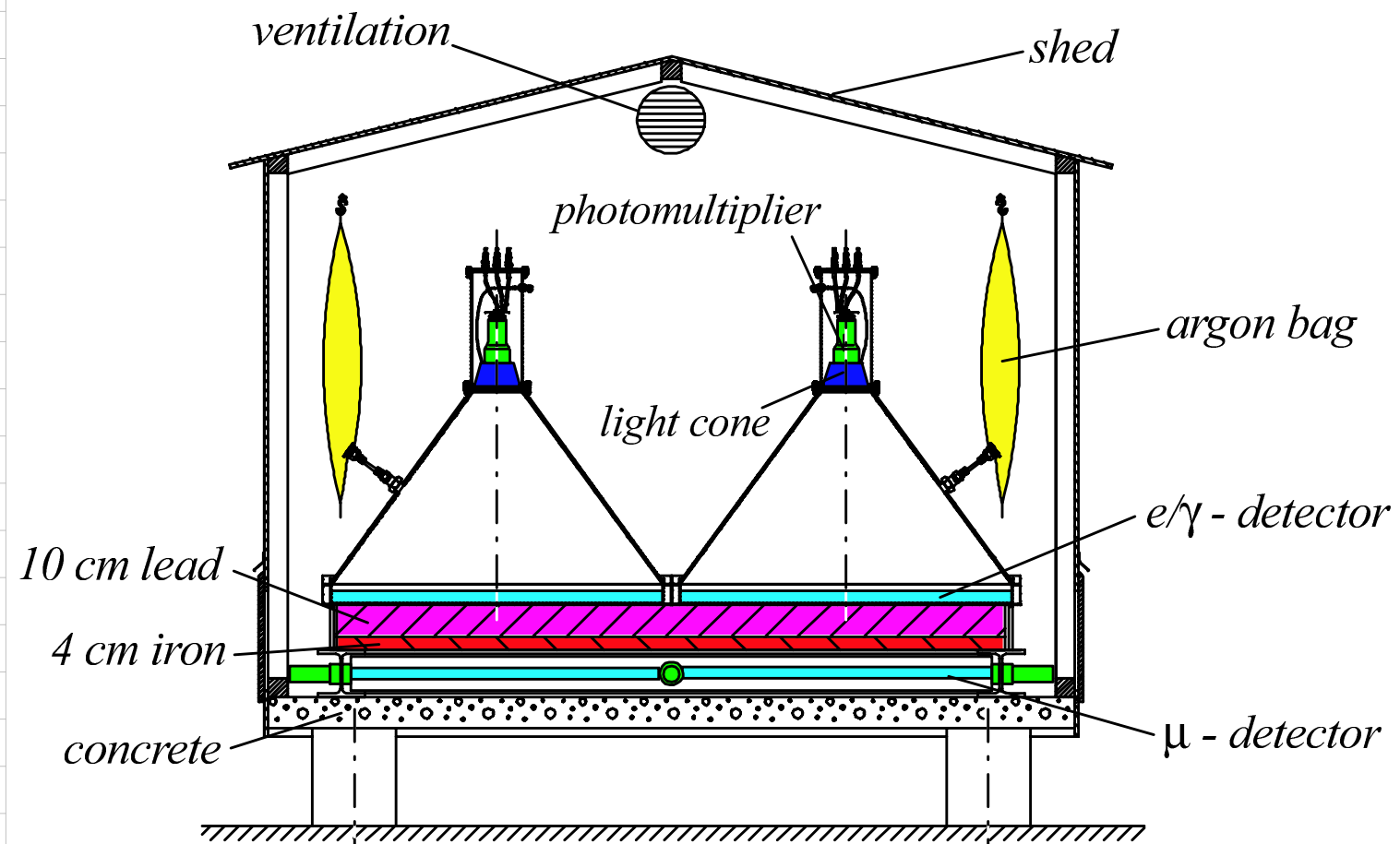
Der Zentraldetektor



Detektorstation



Prinzip der Elektron- und Myonmessung



Datenanalyse

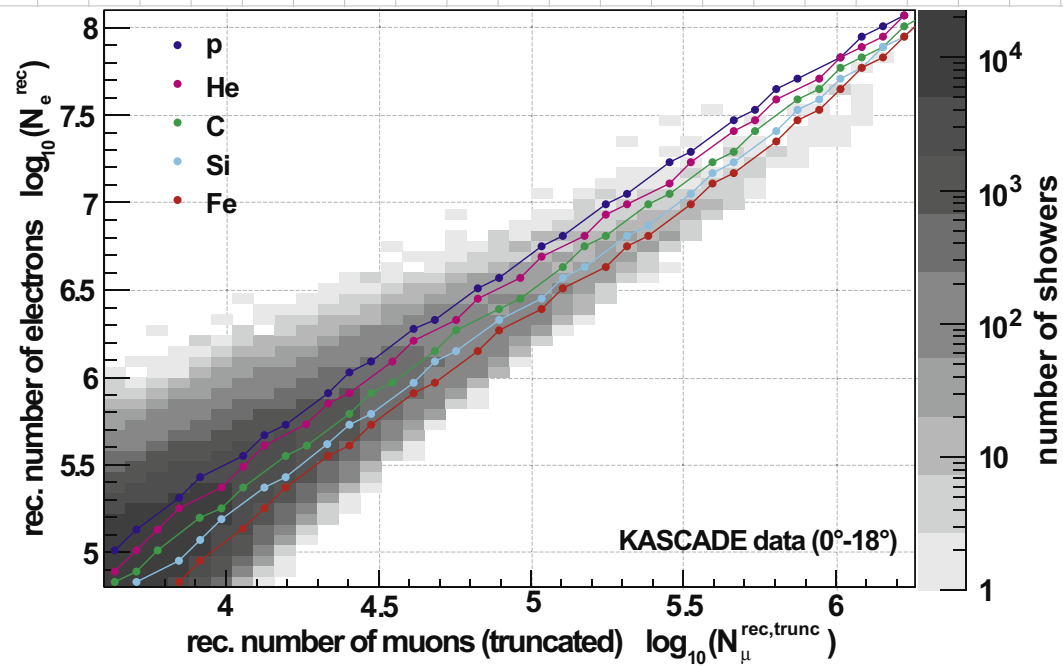
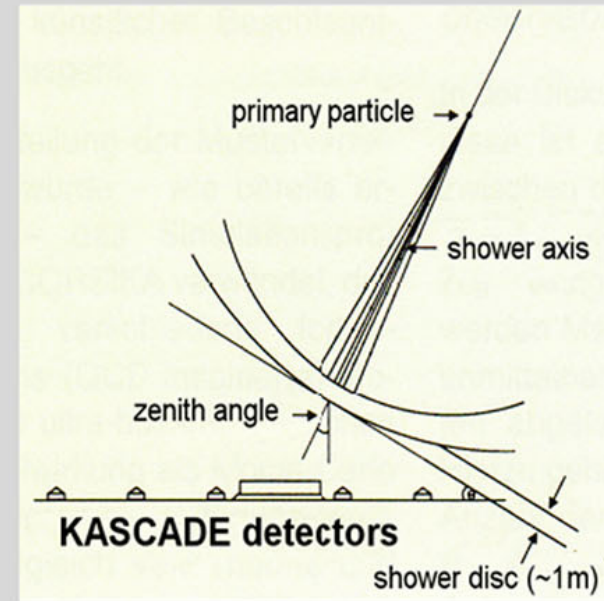


Fig. 13. Most probable values for the five considered nuclei according to the calculated response matrix (based on the interaction models QGSJET-II-02 [12,13] and FLUKA 2002.4 [14–16]). Additionally, the measured two-dimensional size spectrum (the data used) is depicted.

Workflow for KASCADE Measurement and Simulation Data

Measurements



- data acquisition
- event building
- event storage

Simulations

air shower simulation CORSIKA

Input

primary energy E
particle ID A
shower direction $\Theta, \Phi \dots$

high energy models

QGSjet
EPOS
Sibyll

low energy model

FLUKA

detector simulation
CRES
based on *GEANT 3*

data reconstruction using KRETA

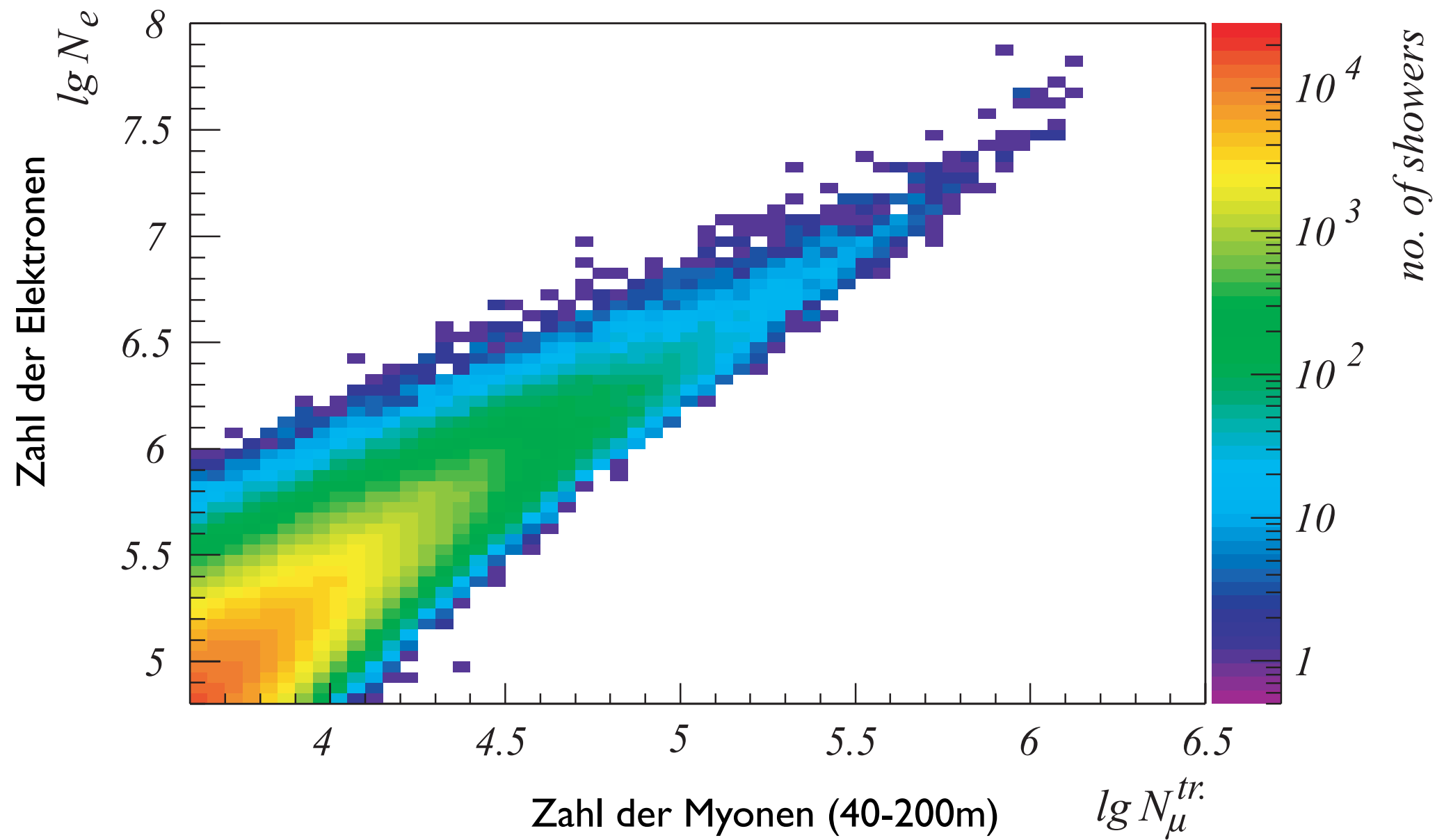
- data calibration and data correction
- reconstruction of EAS variables like N_e , N_μ , shower direction, core position, densities ..
- data storage in root files

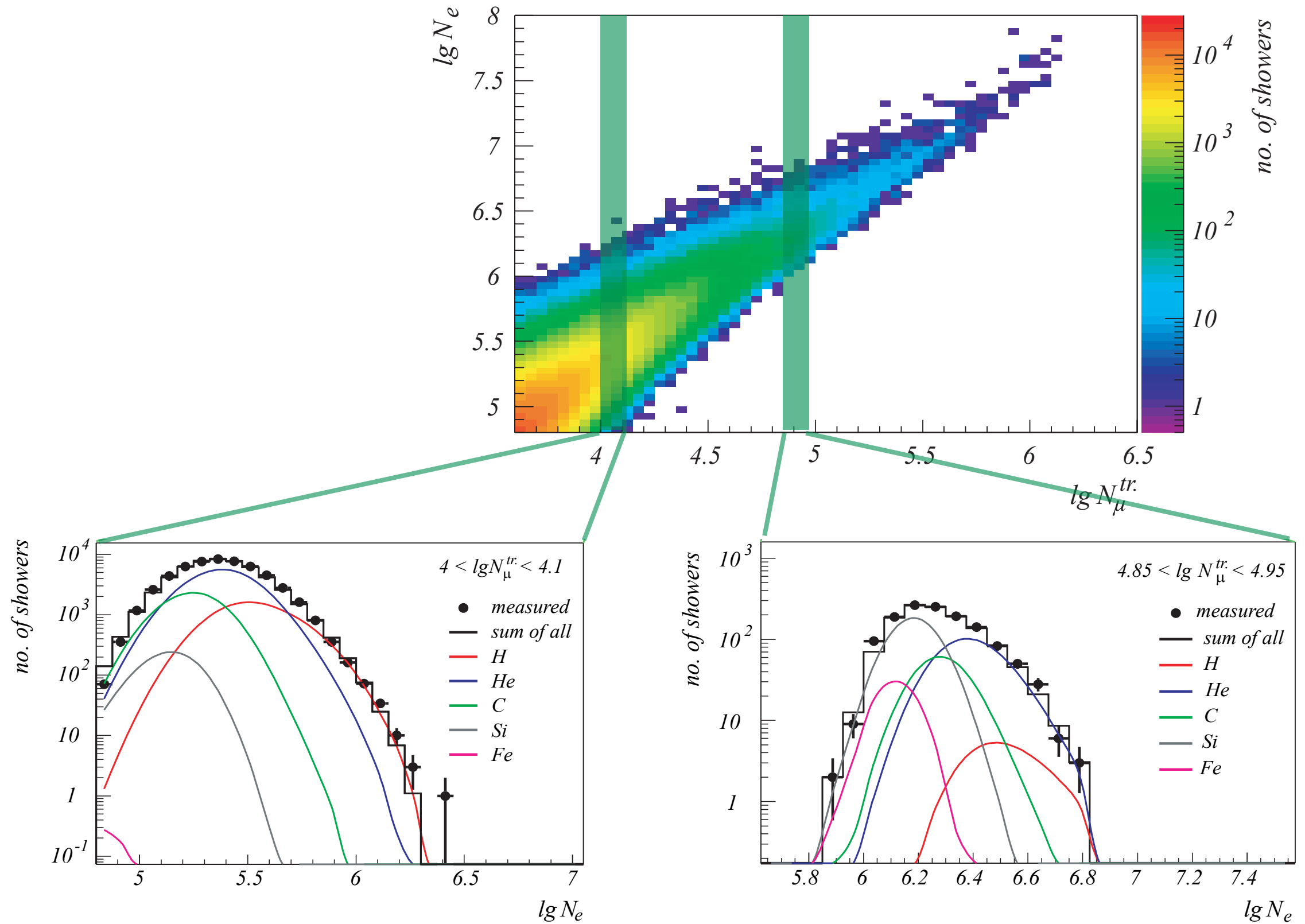
Data Analysis

compare measurements with distributions achieved from extensive air shower simulations

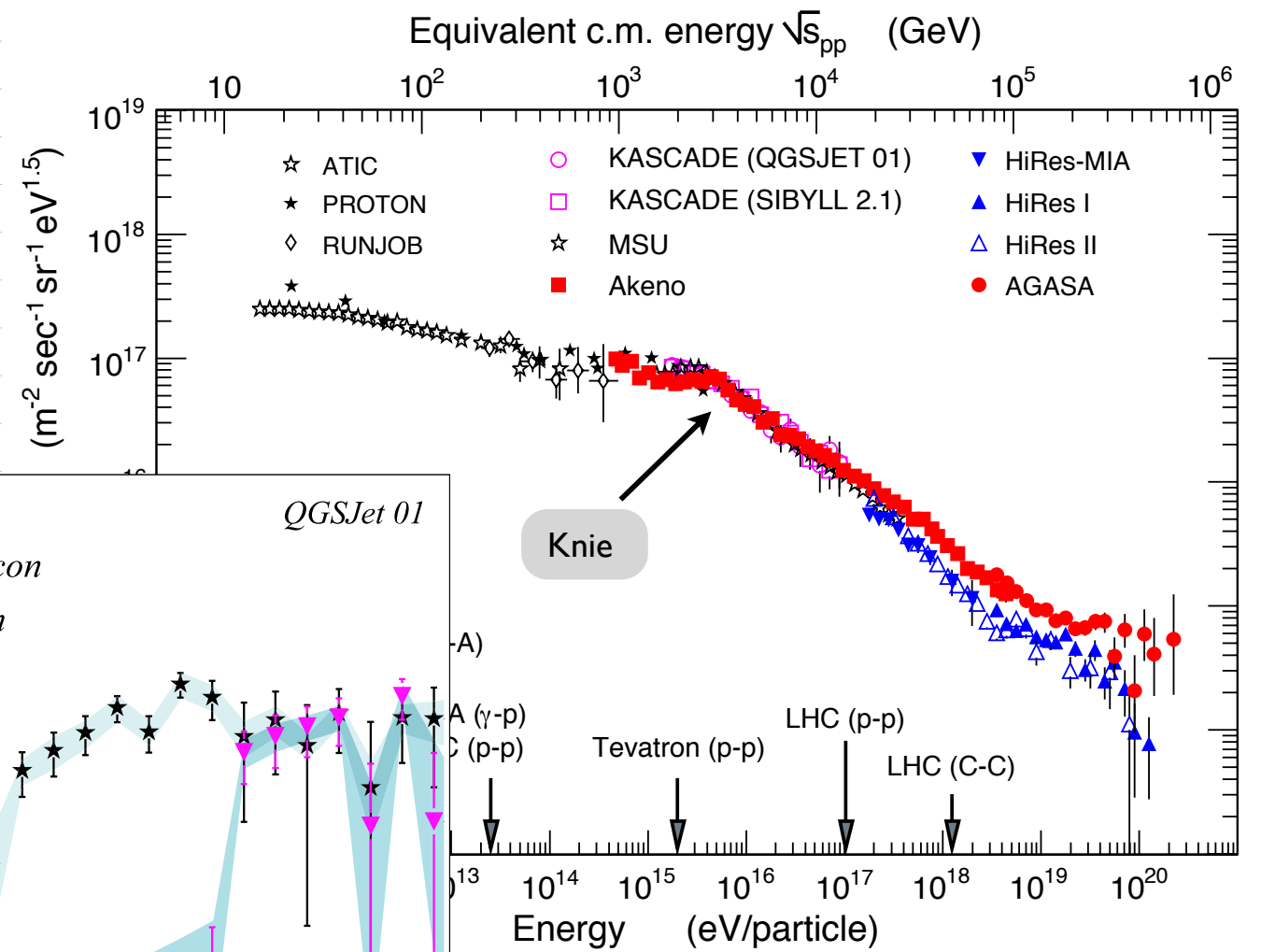
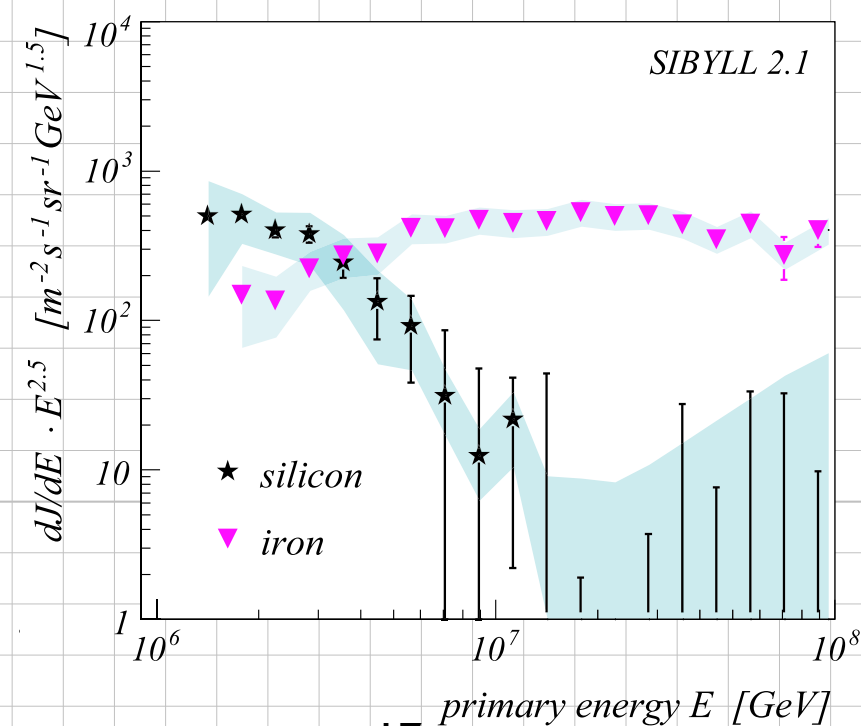
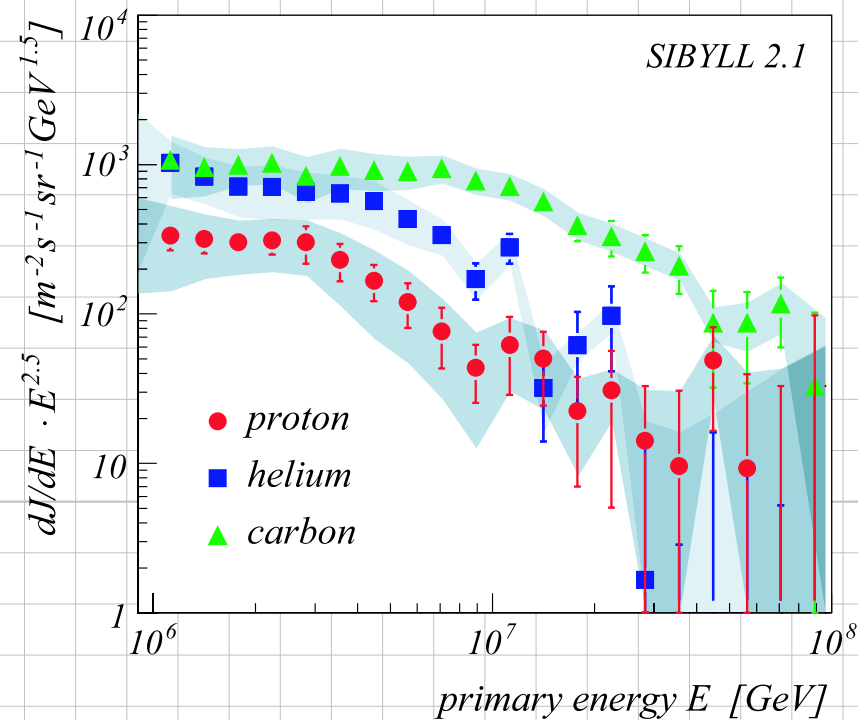
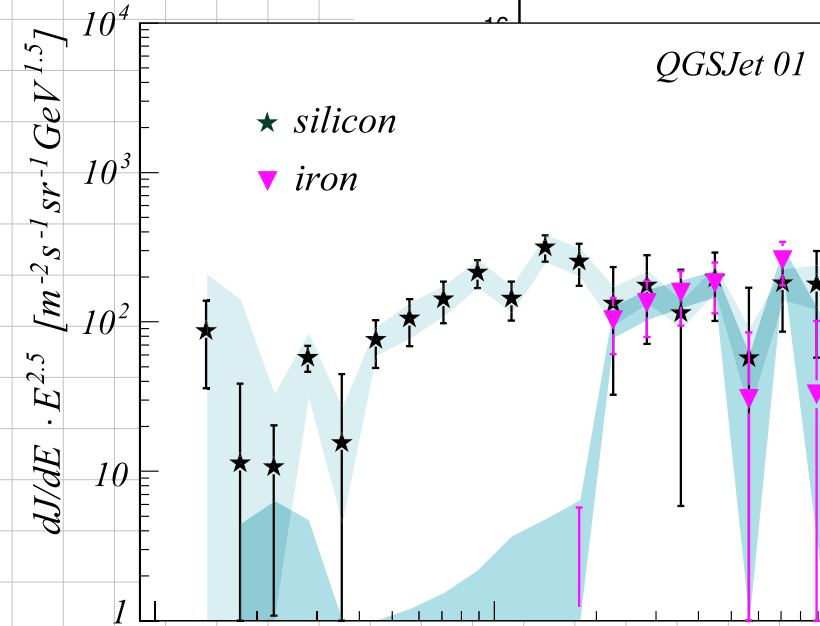
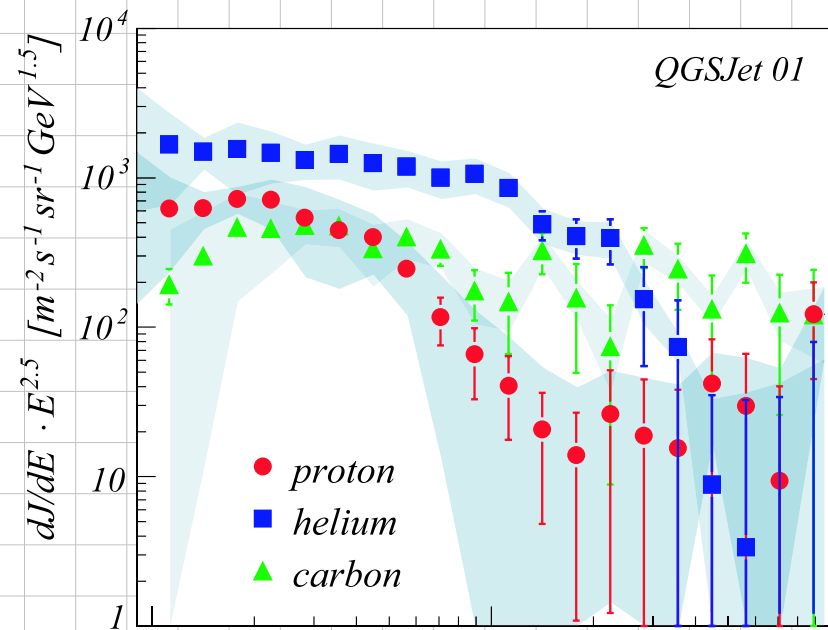
KASCADE: Elektron-Myon-Spektren

insgesamt 6.9×10^5 Ereignisse

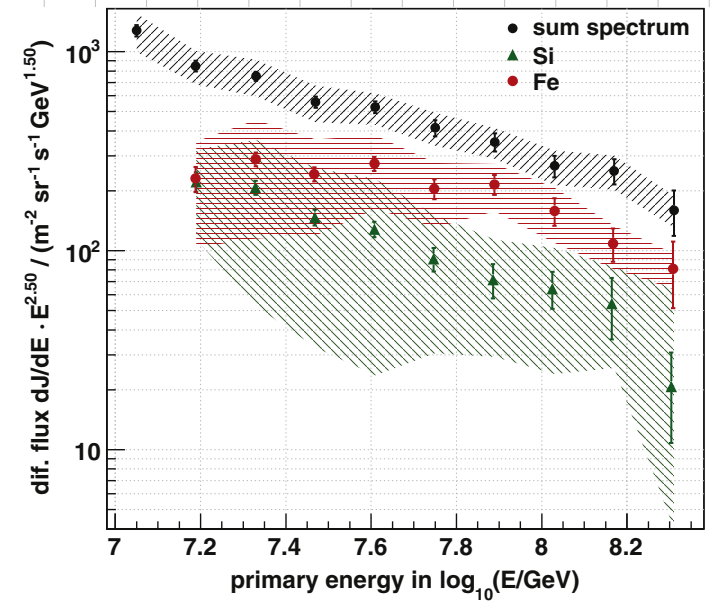
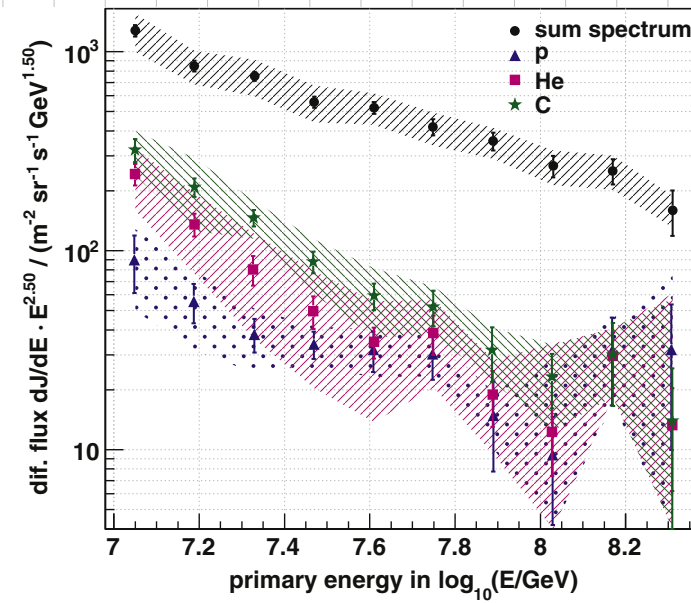
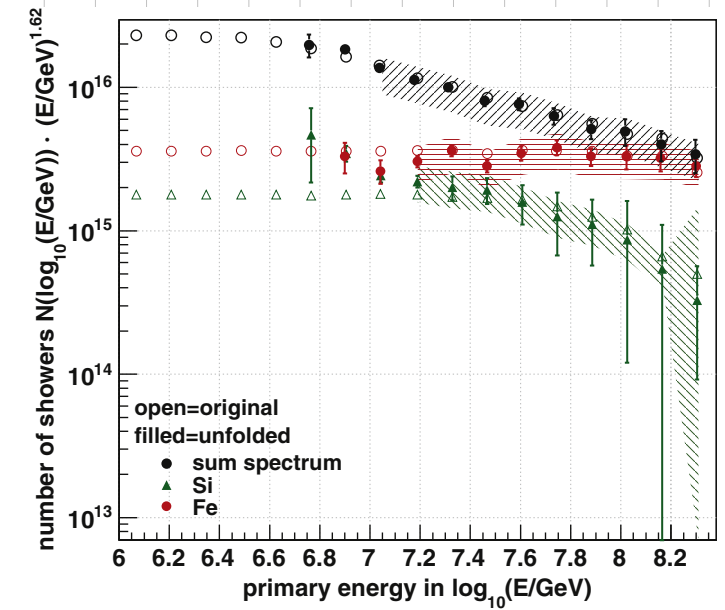
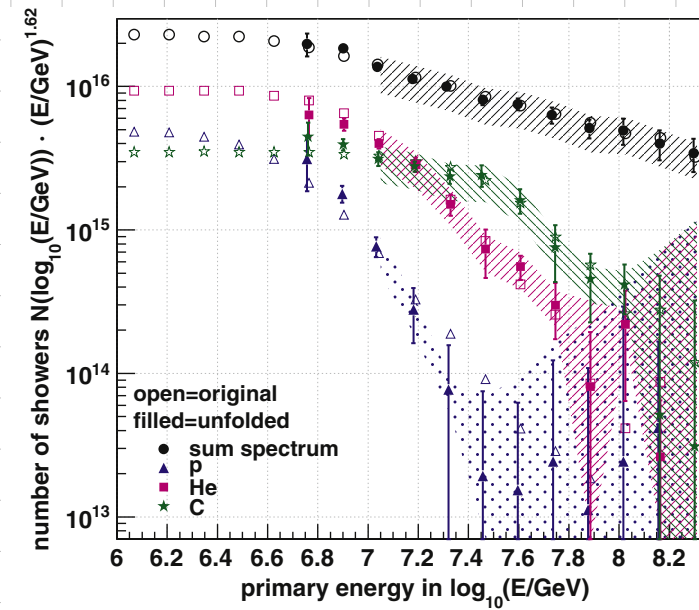
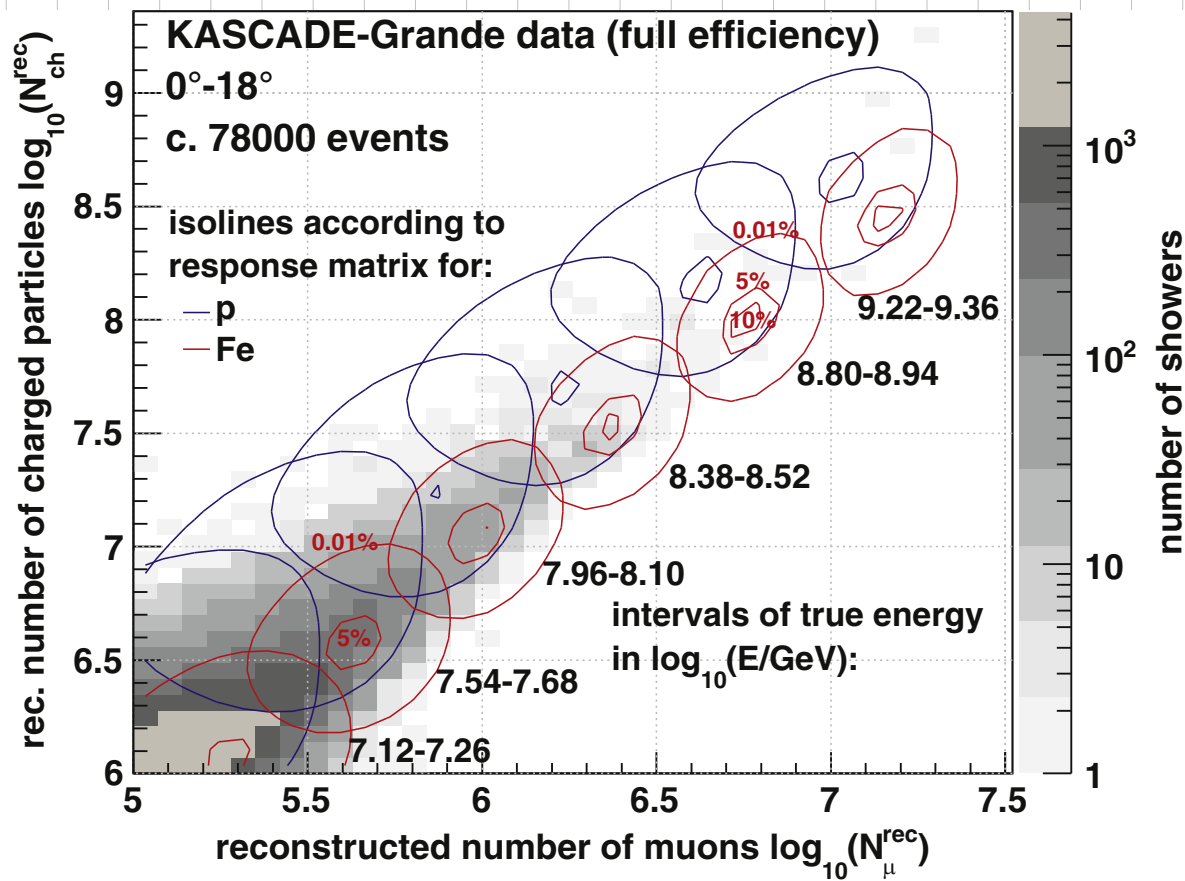




Elementzusammensetzung im Energiebereich des Knies: KASCADE



KASCADE-Grande: Elementzusammensetzung



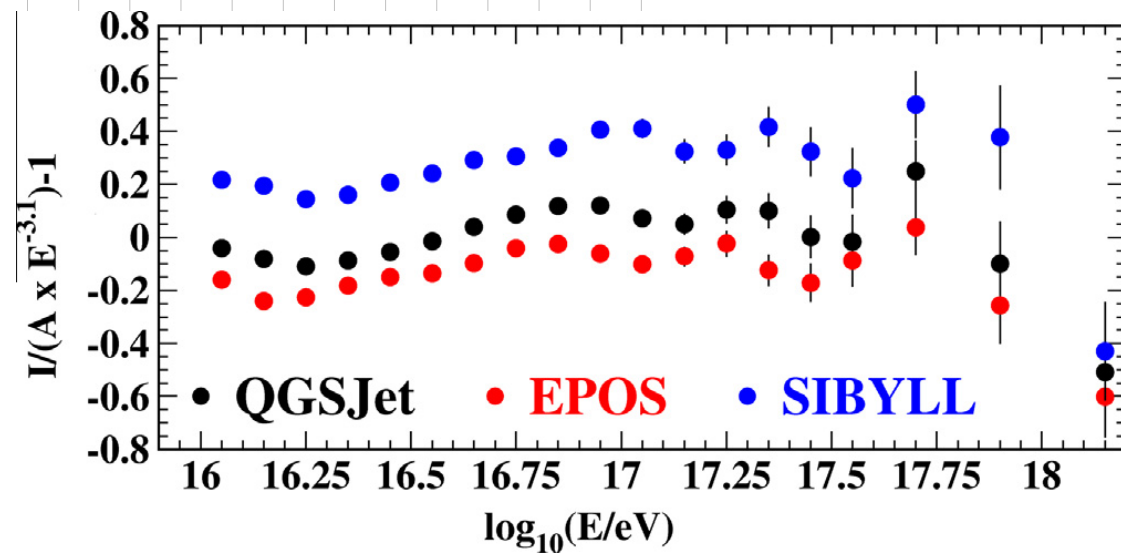
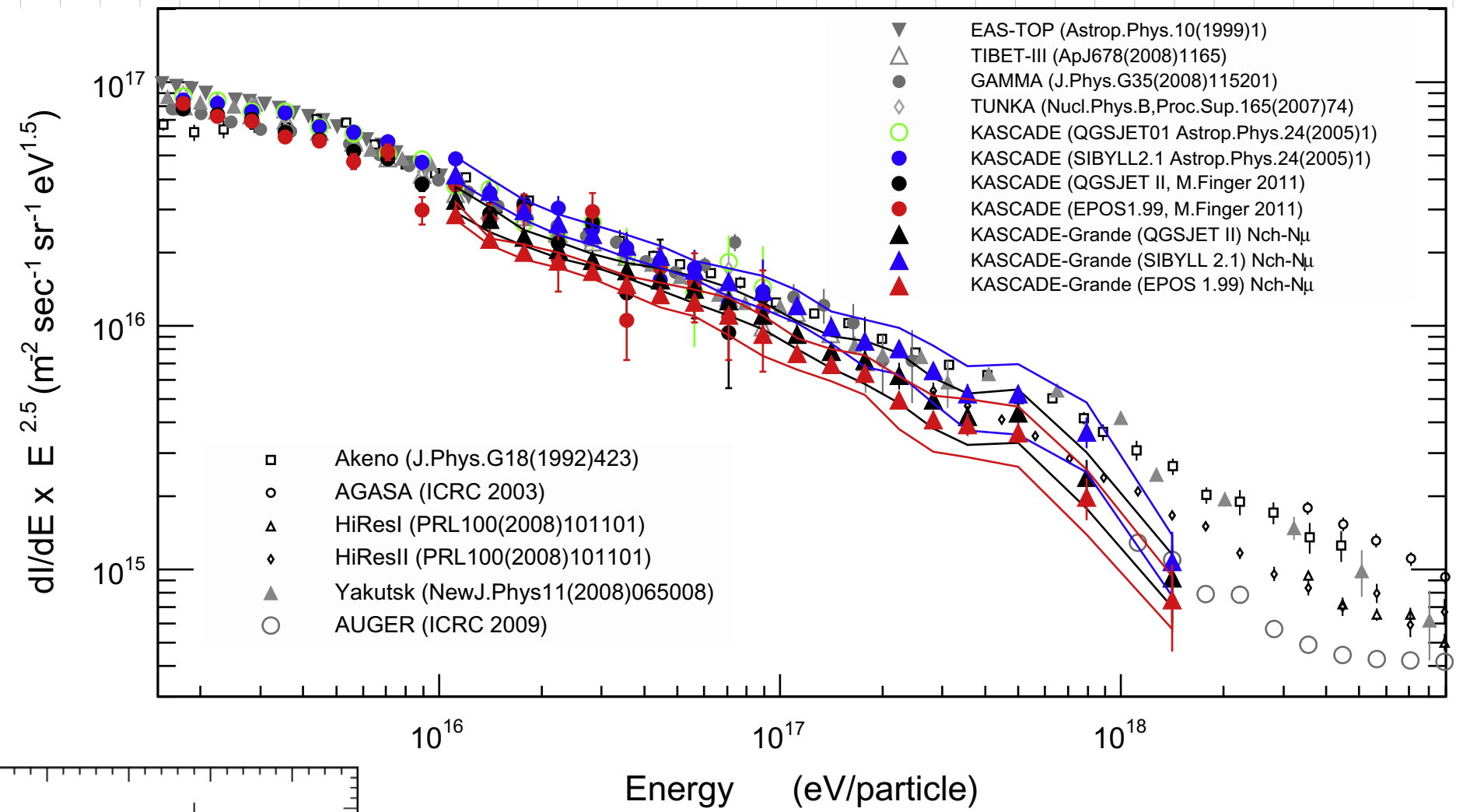
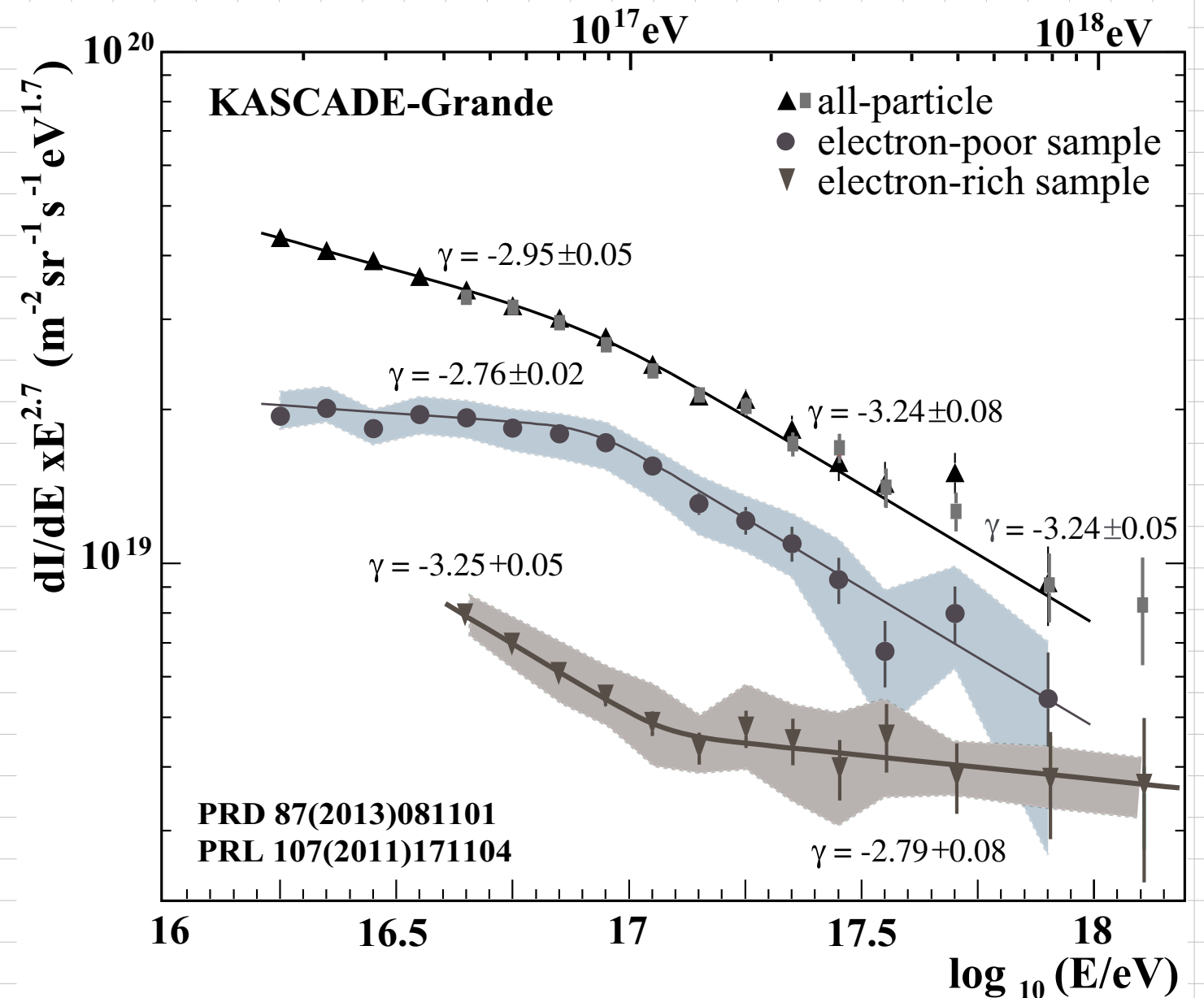
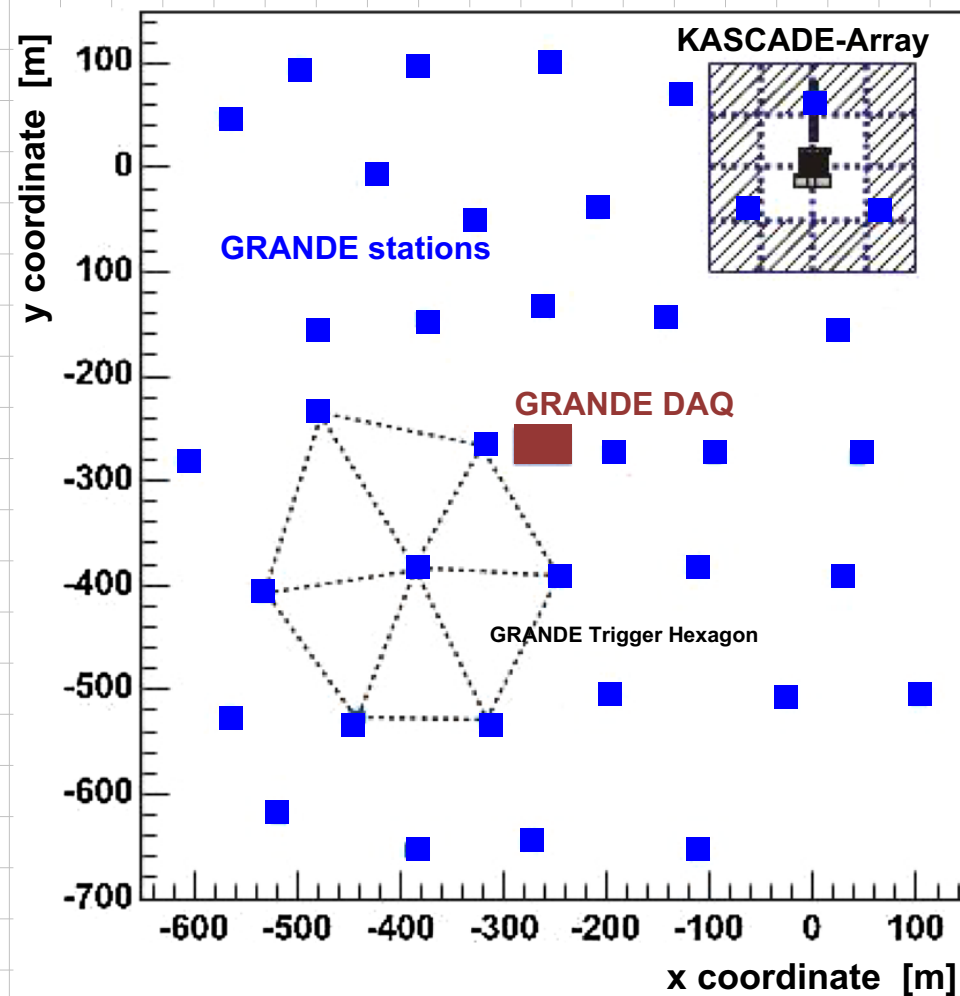


Fig. 6. The residual flux after multiplying the spectrum with a factor of $E^{3.1}$ where A is the normalization factor for QGSjet. Blue dots refer to SIBYLL, black to QGSjet and red to EPOS. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

Spektrum leichter und schwerer Teilchen gemessen mit KASCADE-Grande



Suche nach Photonen

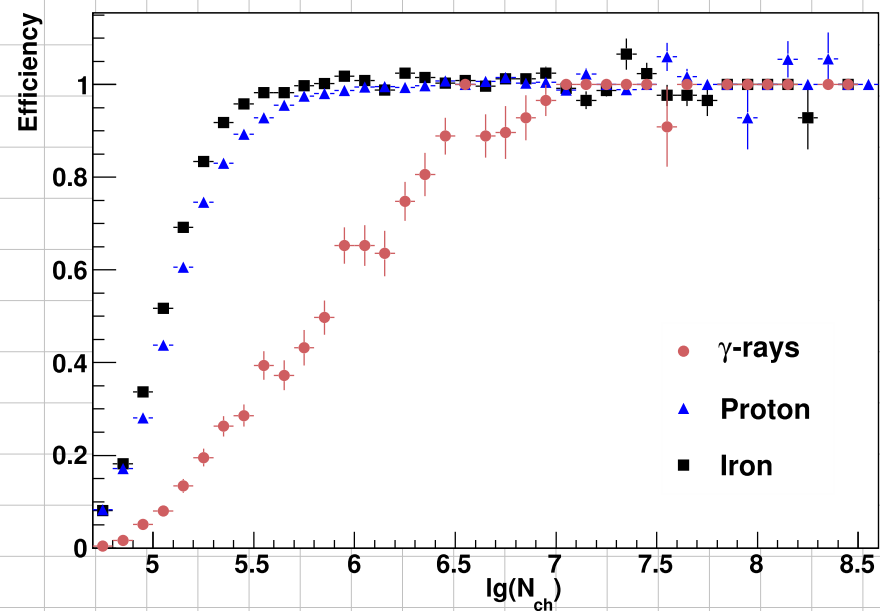
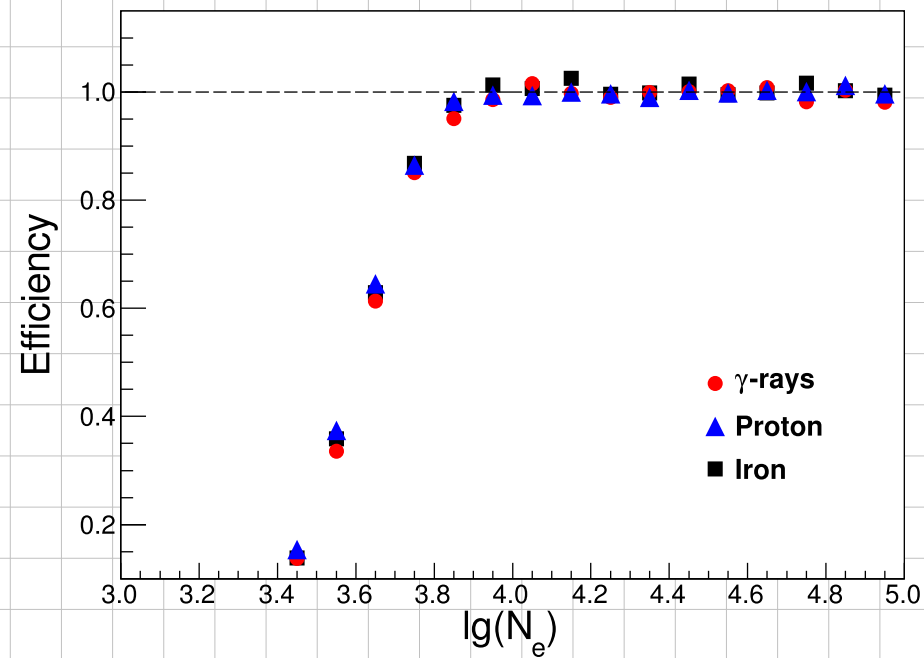


Figure 2. Trigger and reconstruction efficiency as a function of the number of electrons for KASCADE (top) and the number of charged particles for KASCADE-Grande (bottom) for air showers induced by photons, protons, and iron primaries.

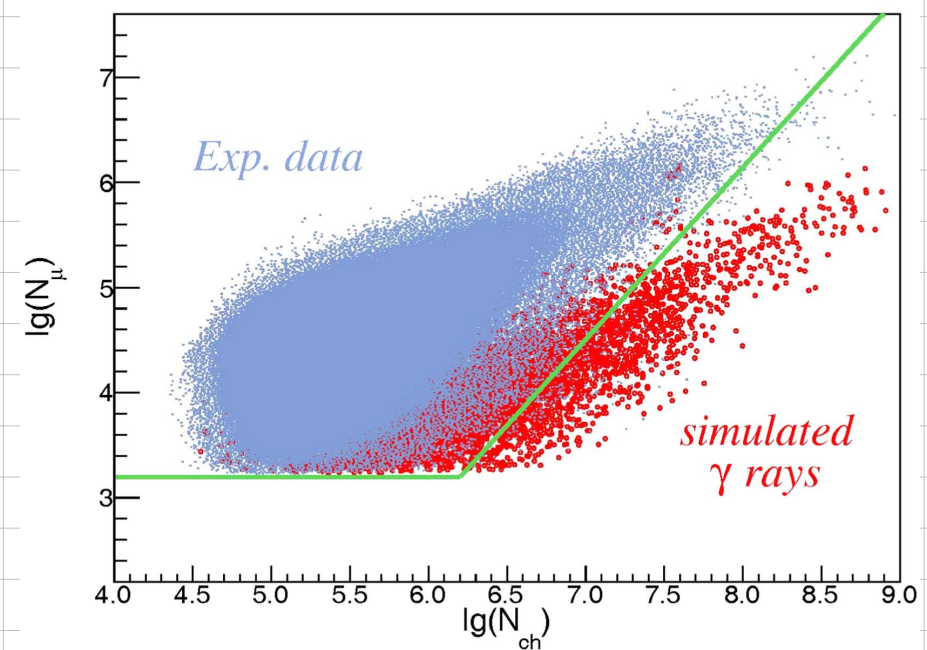
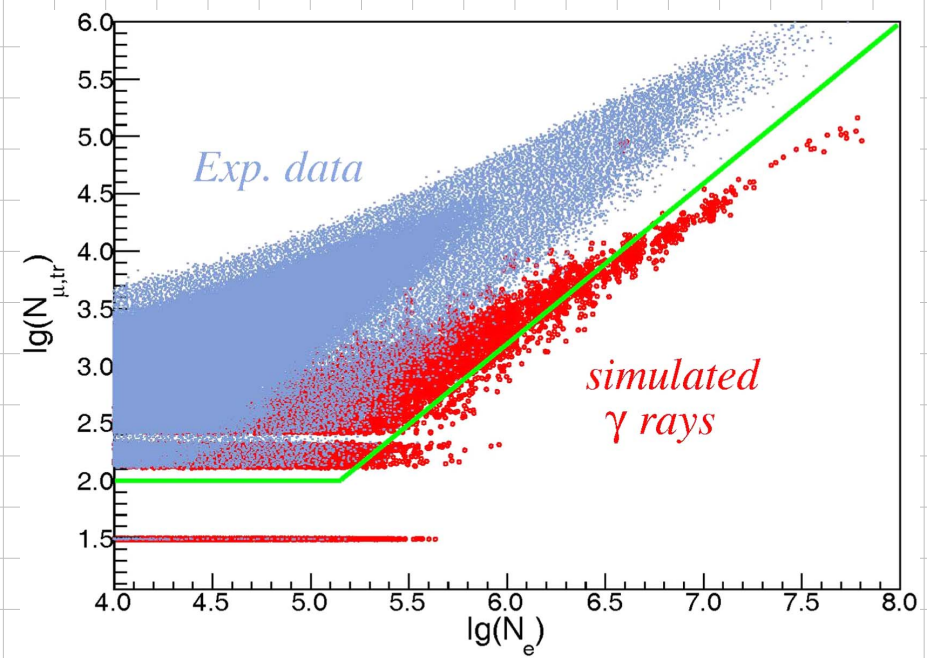


Figure 3. Scatter plot of the measured number of muons $\lg(N_{\mu,\text{tr}})$ vs. number of electrons $\lg(N_e)$ for KASCADE (top) and for number of muons $\lg(N_\mu)$ vs. number of charged particles $\lg(N_{\text{ch}})$ for KASCADE-Grande (bottom). In both cases simulated gamma-ray showers are superimposed. The lines indicate the selection criteria for the subset of the muon-poor showers.

Suche nach Photonen: Obere Grenzen an Photonenfluss

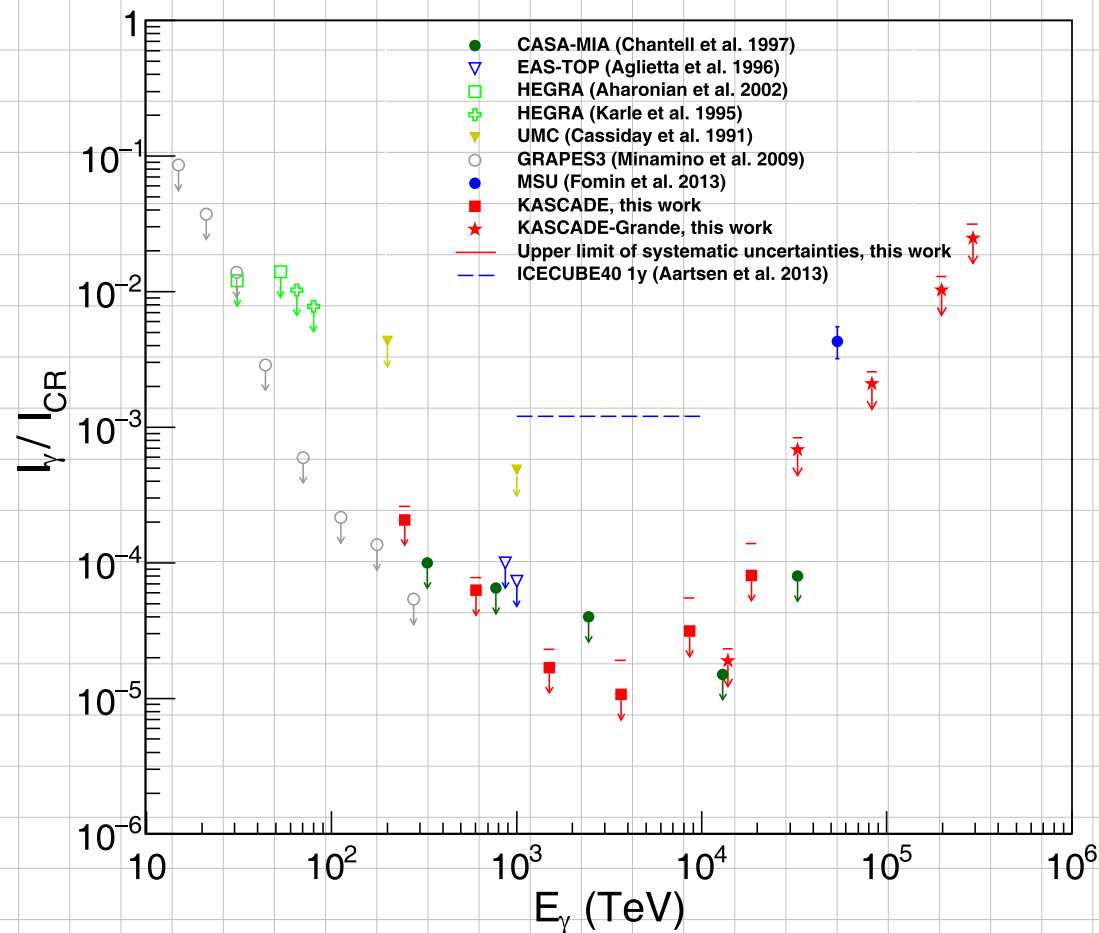


Figure 4. Measurements of the fraction of gamma-rays relative to cosmic rays in the energy range from 10^{13} to 10^{18} eV. The points with arrows represent upper limits from the CASA-MIA (90% C.L., Chantell et al. 1997), EAS-TOP (90% C.L., Aglietta et al. 1996), HEGRA (90% C.L., Karle et al. 1995; Aharonian et al. 2002), UMC (90% C.L., Matthews et al. 1991), GRAPES3 (90% C.L., Minamino et al. 2009), and IceCube (90% C.L., Aartsen et al. 2013), except the MSU (95% C.L., Fomin et al. 2013) experimental value. The red squares and stars represent the results from KASCADE (90% C.L.) and KASCADE-Grande (90% C.L.), respectively, with systematic uncertainties. Limits reported by the Tibet array (3–10 TeV, 90% C.L., Amenomori et al. 2002) and by Milagro (3.5–15 TeV, 90% C.L., Abdo et al. 2008) are out of this energy range.

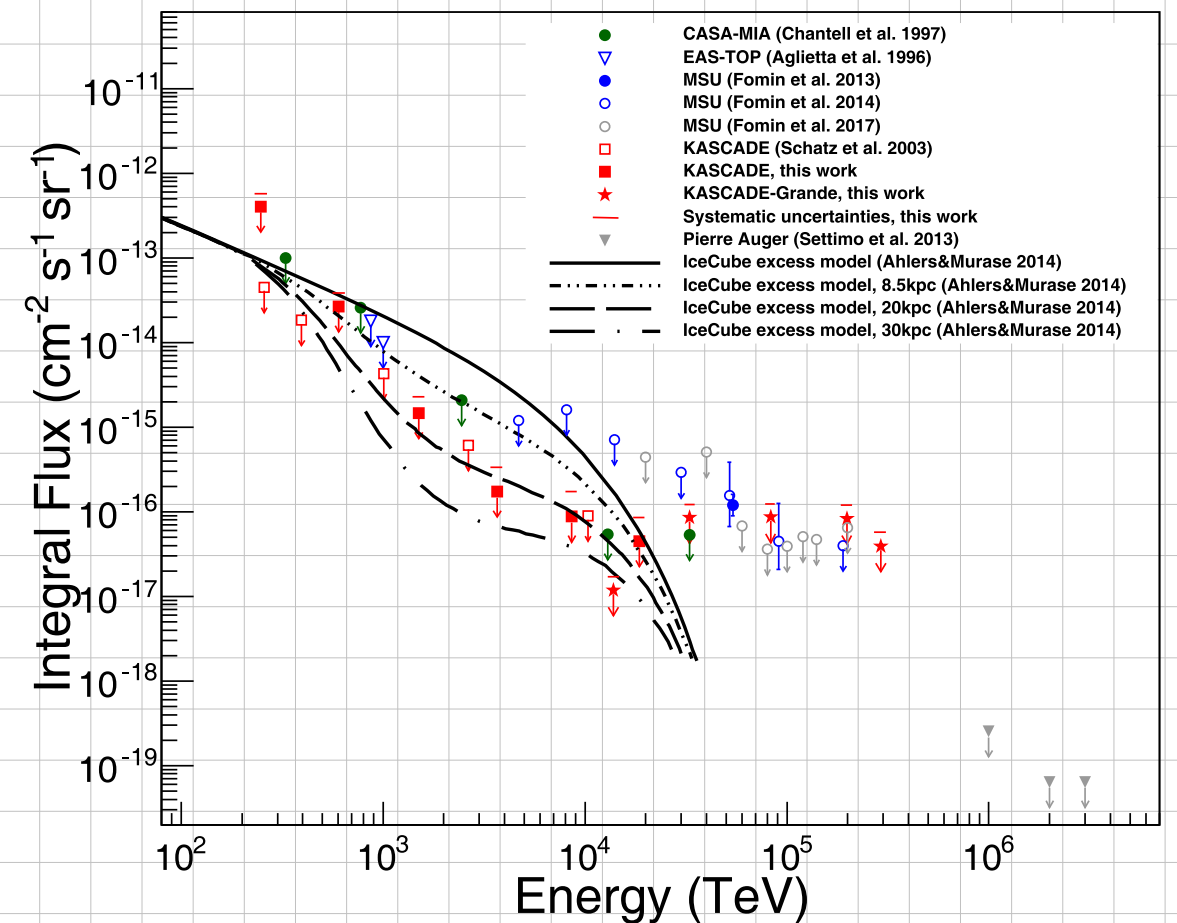
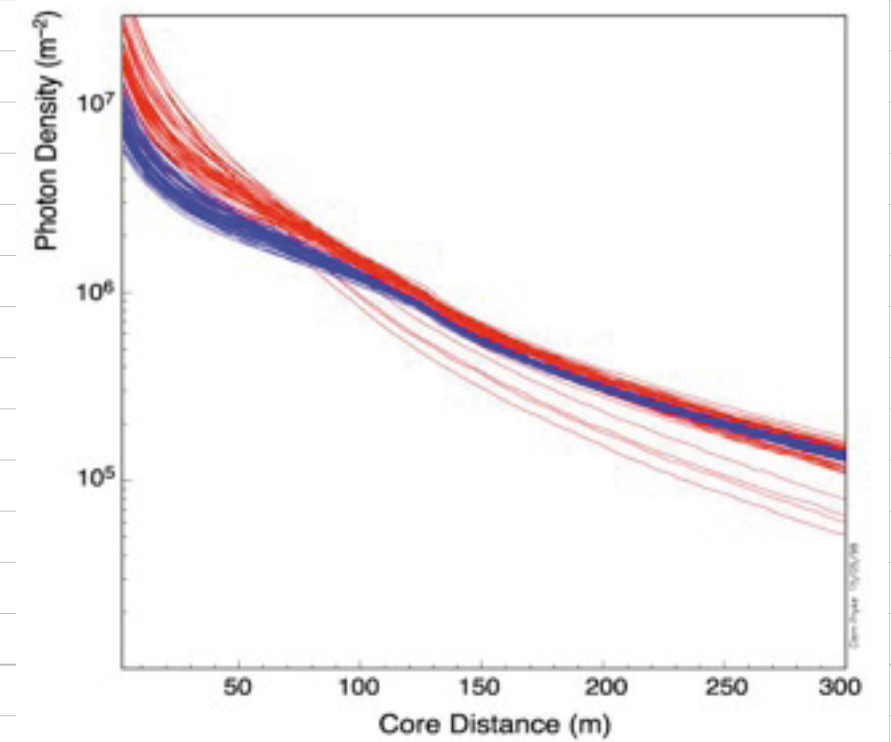
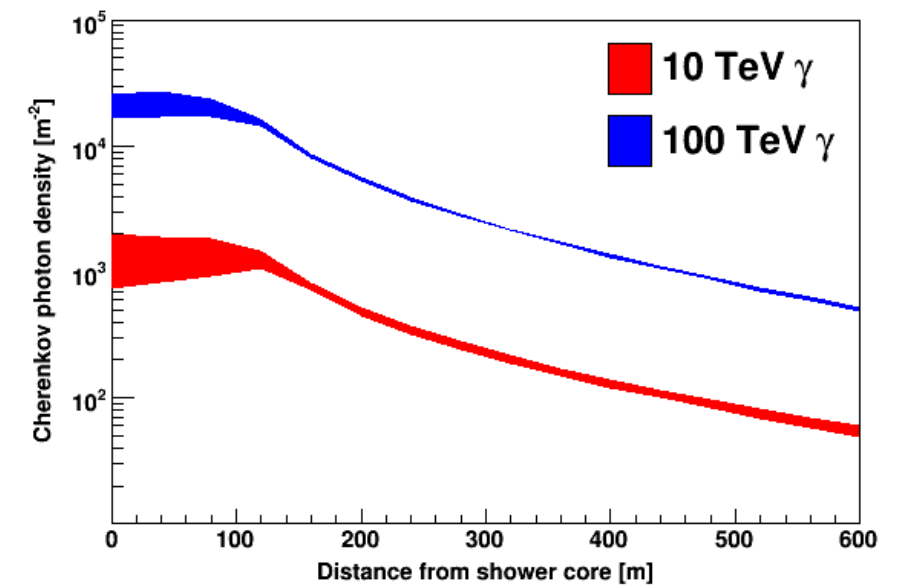
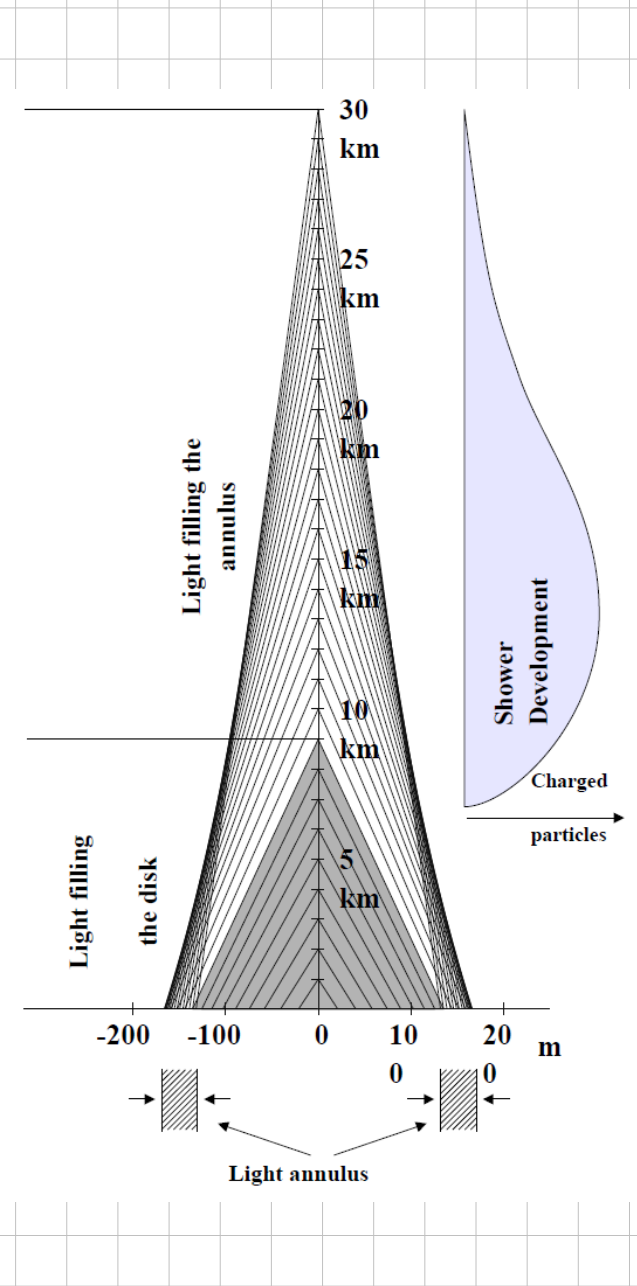
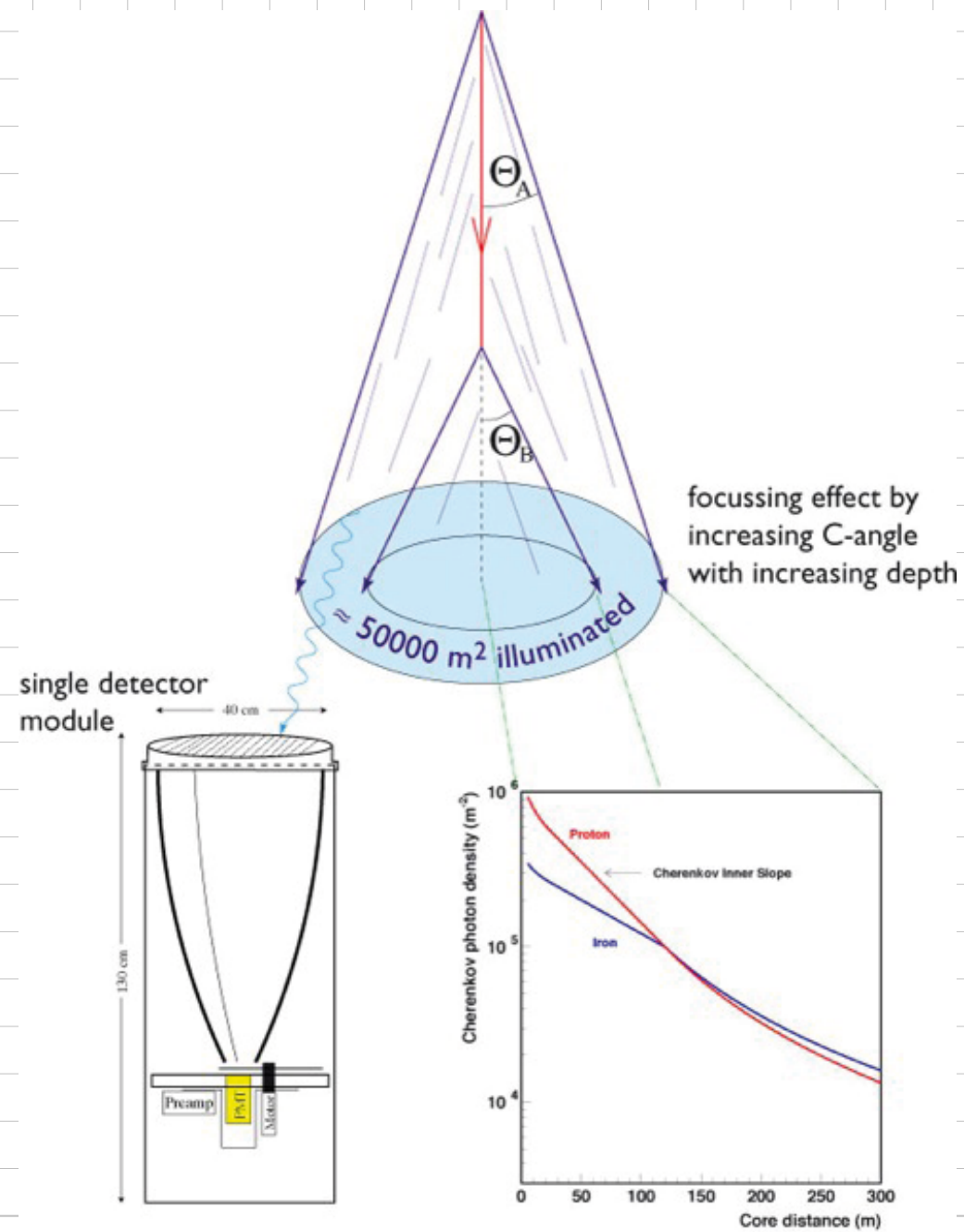
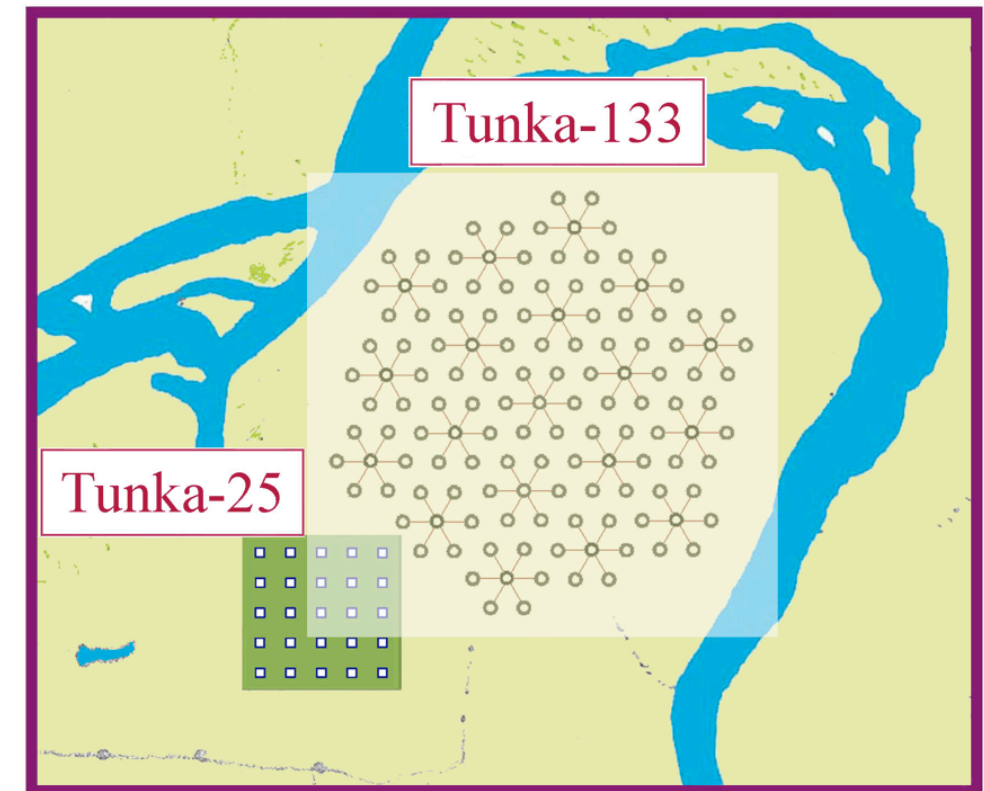
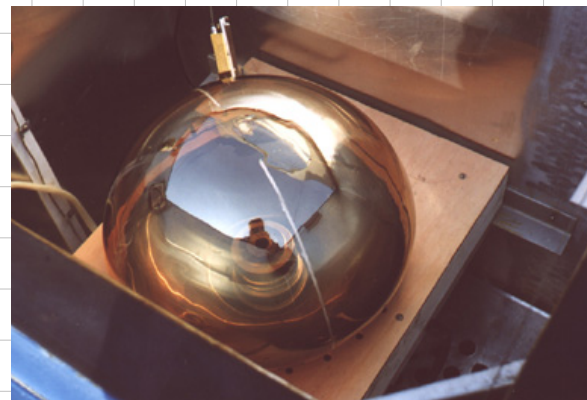
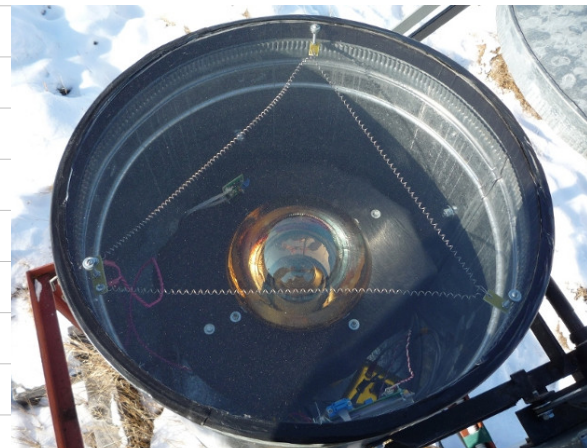


Figure 5. Comparison of integral flux of gamma-rays (including systematic uncertainties) with previous results and with theoretical curves using an IceCube excess model (Ahlers & Murase 2014). The lines are for the unattenuated flux (solid) and that from 8.5 kpc (distance from the Galactic center), 20 kpc, and 30 kpc, respectively. The high-energy points from the Pierre Auger Observatory are taken from Settimo (2013).

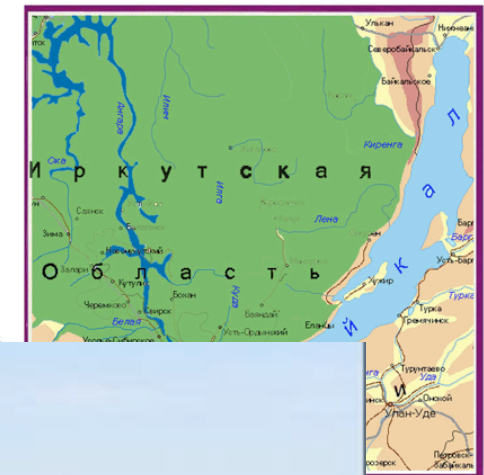
Schauermessung mit Cherenkovlicht



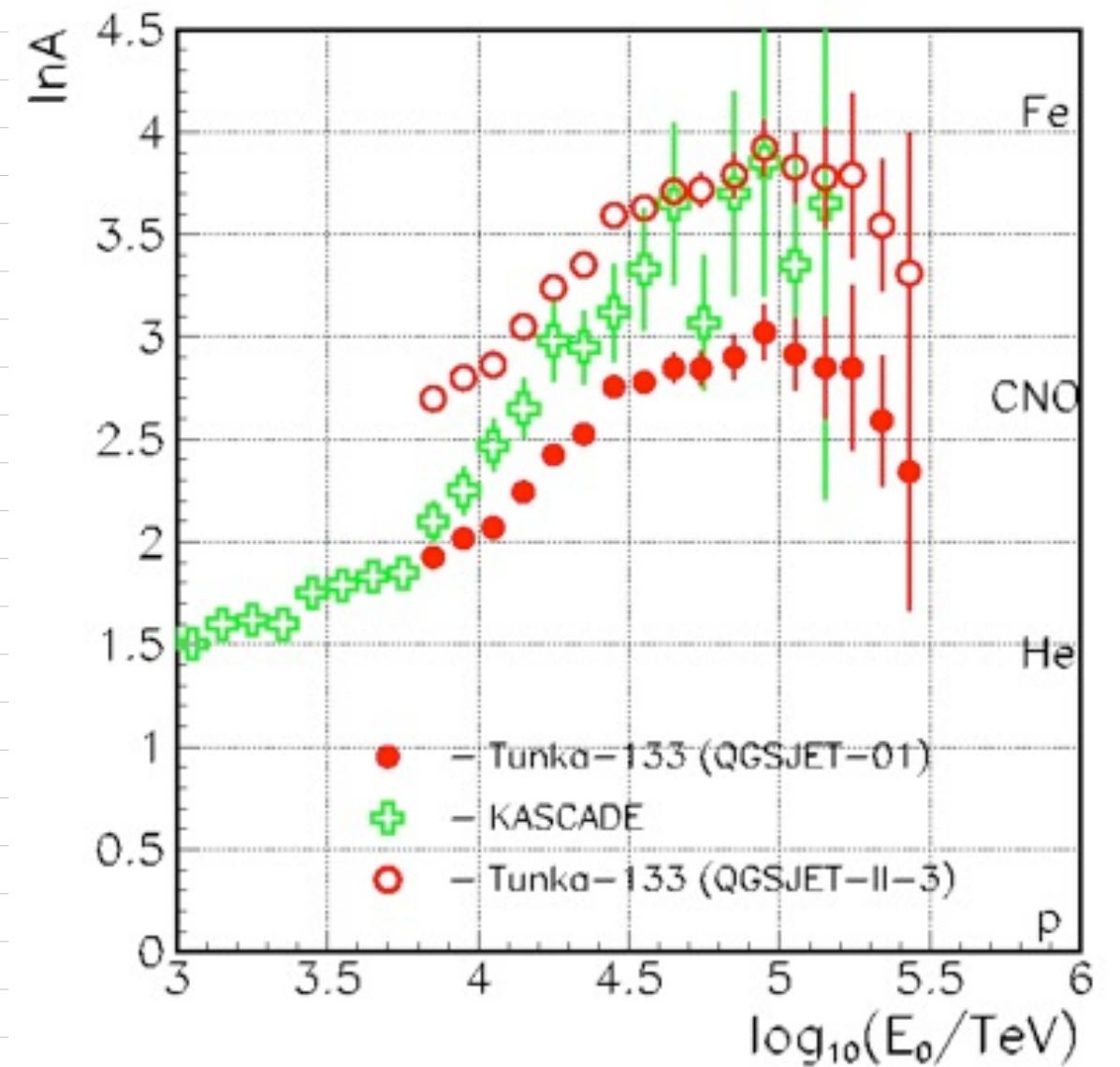
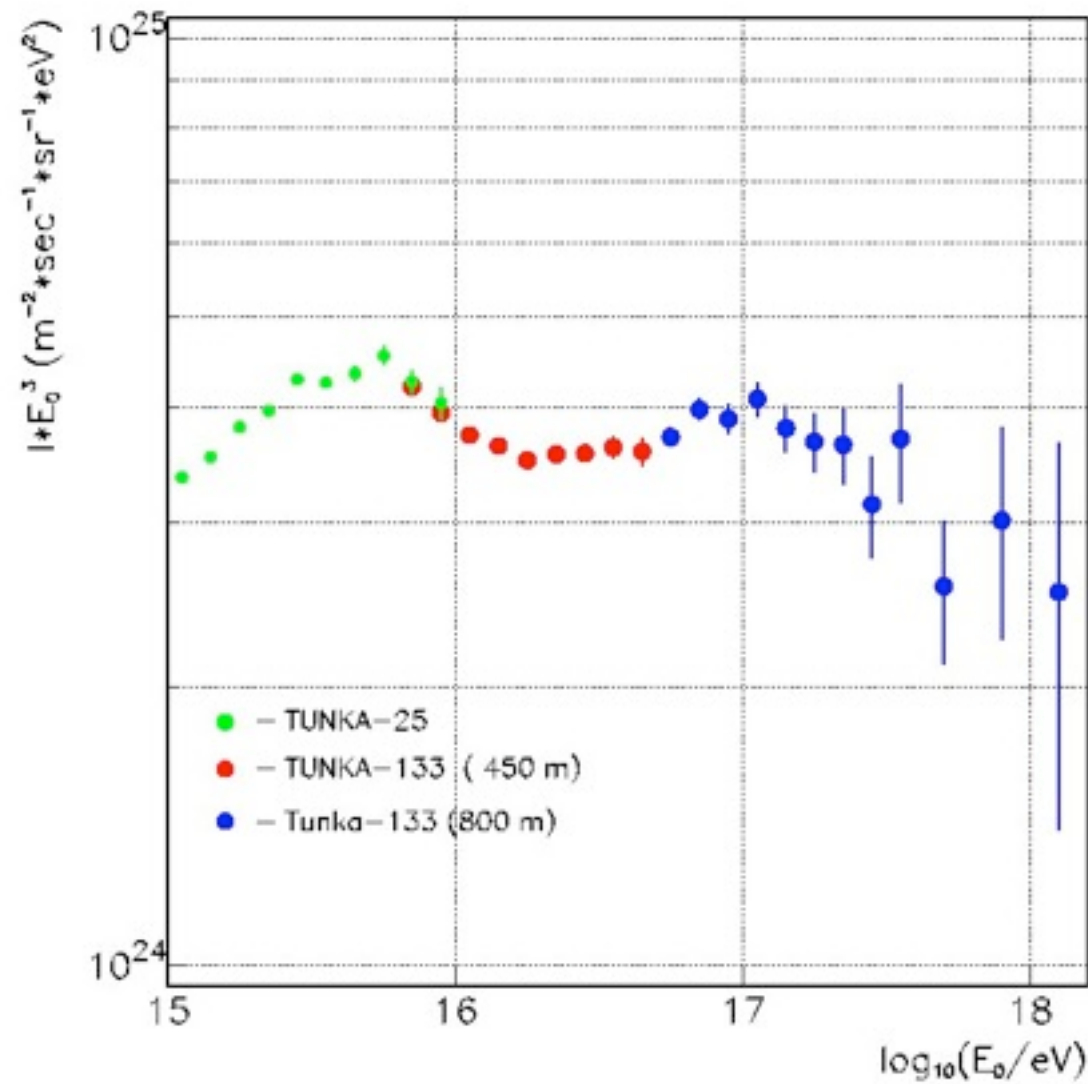
Beispiel: TUNKA-Detektorfeld



51° 48' 35" N



Messergebnisse von TUNKA



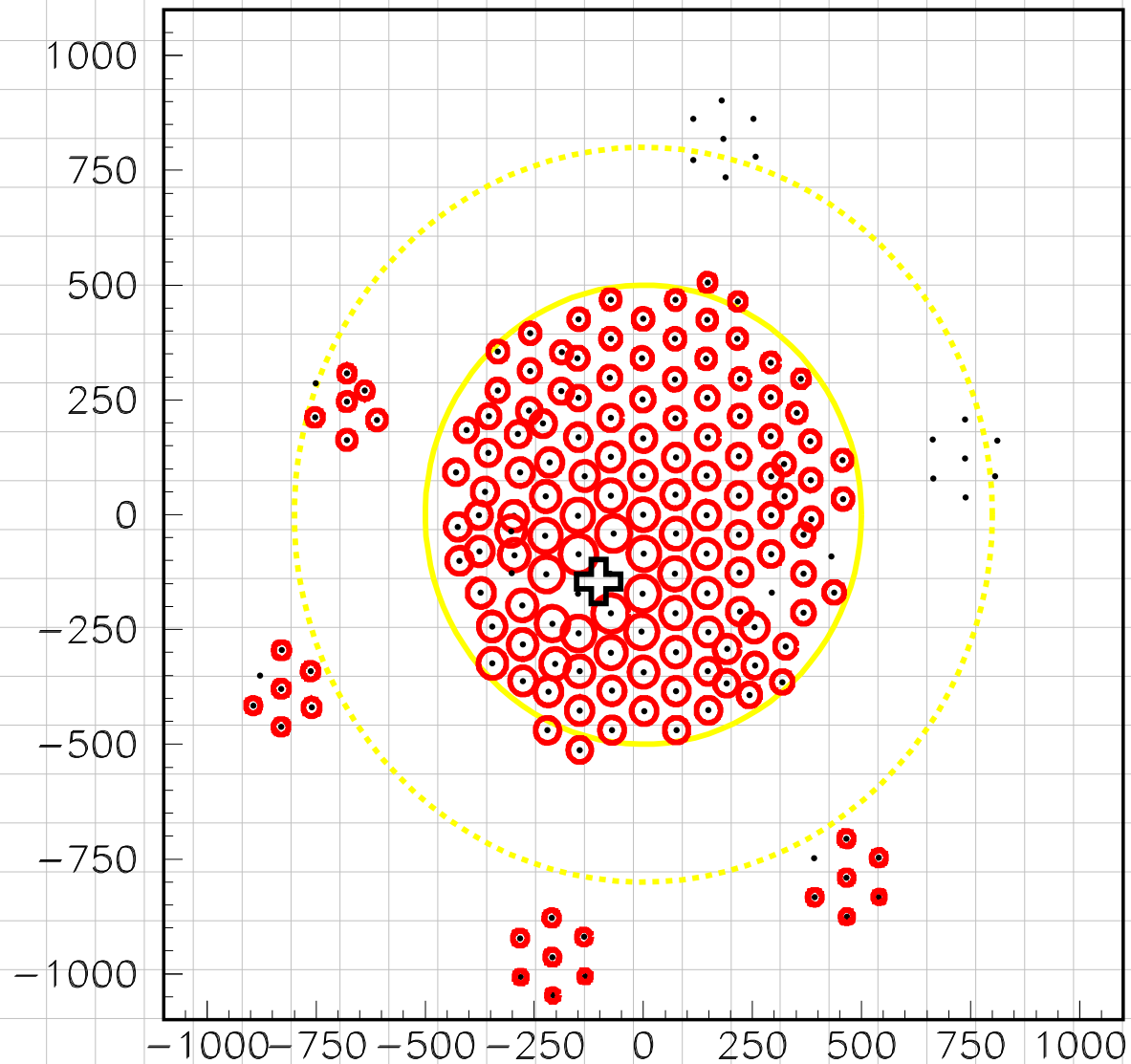


Fig. 6. An example of experimental EAS core reconstruction. The radius of each station circle is proportional to $\log Q_i$. The cross marks the reconstructed position of the shower core.

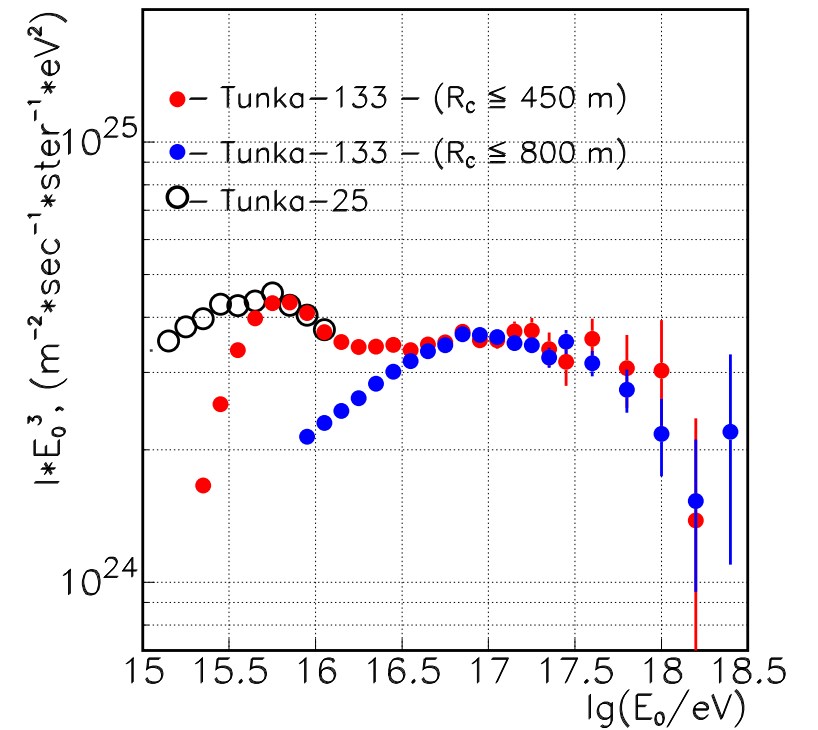


Fig. 11. Differential primary cosmic ray energy spectra for two collecting areas: $R_C \leq 450$ m and $R_C \leq 800$ m – before joining.

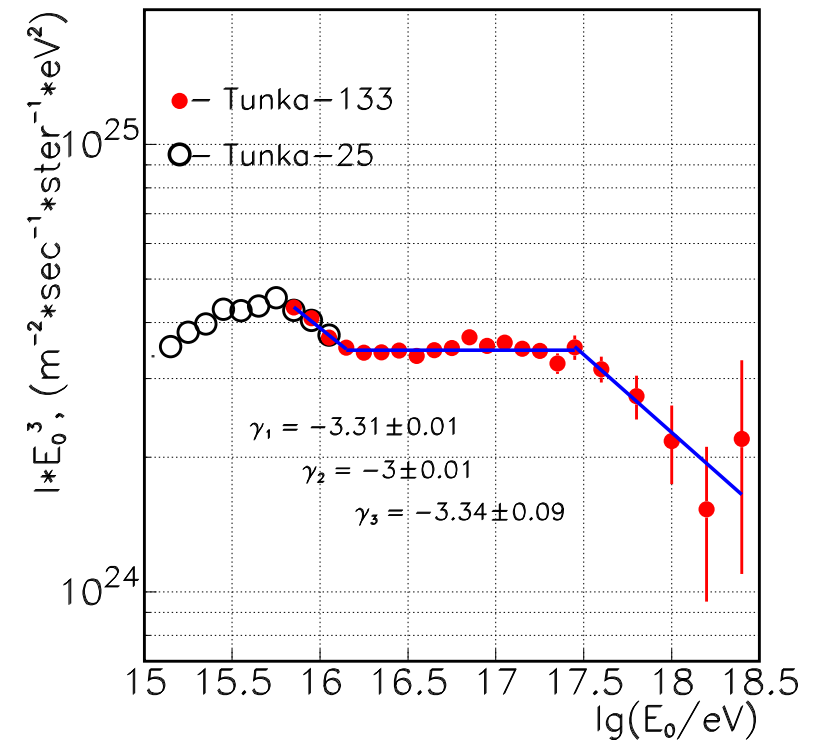


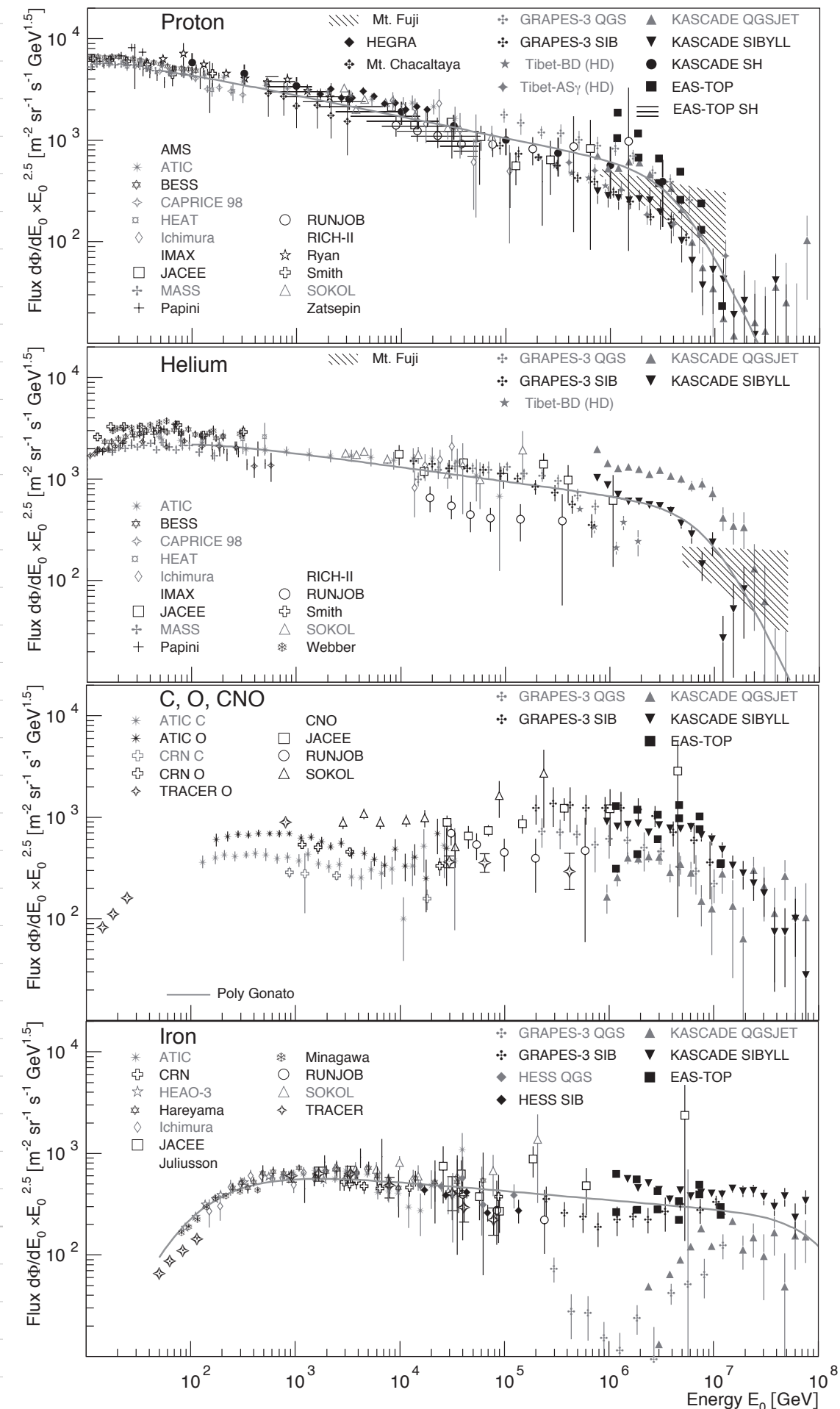
Fig. 14. Differential primary cosmic ray energy spectrum with a fit of a doubly broken power law.

Offene Fragen und Probleme

Leichte Elemente haben Knie im Spektrum bei niedriger Energie als schwere Elemente

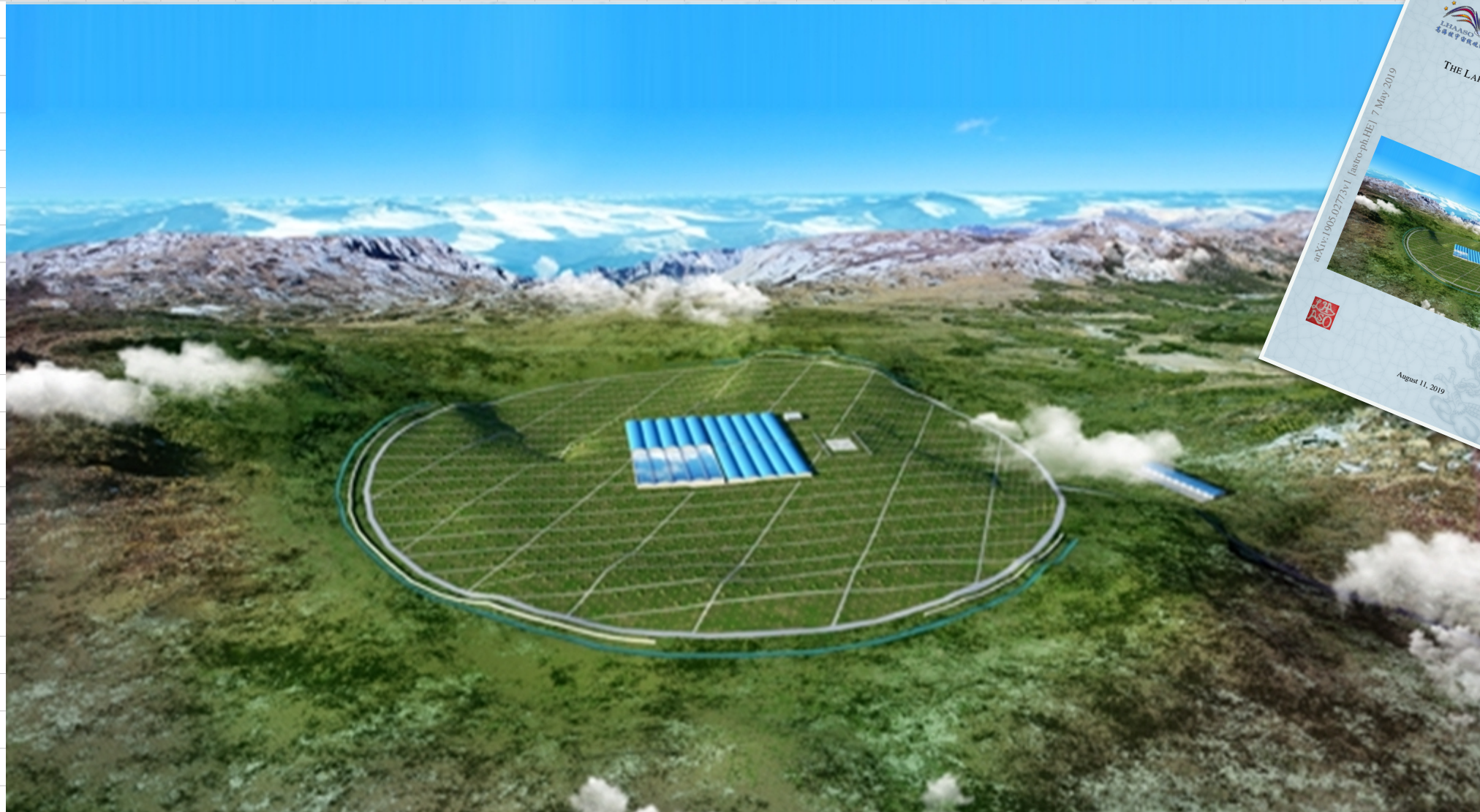
Gegenwärtig kann experimentell A- oder Z-Abhängigkeit nicht ausgeschlossen/bestätigt werden

Große systematische Unsicherheit durch Abhängigkeit von hadronischen Wechselwirkungsmodellen



LHAASO

The Large High Altitude Air Shower Observatory



Keywords: LHAASO, TeV gamma-ray astronomy, Cosmic Ray physics, Solar-heliospheric physics, Air showers, EAS arrays

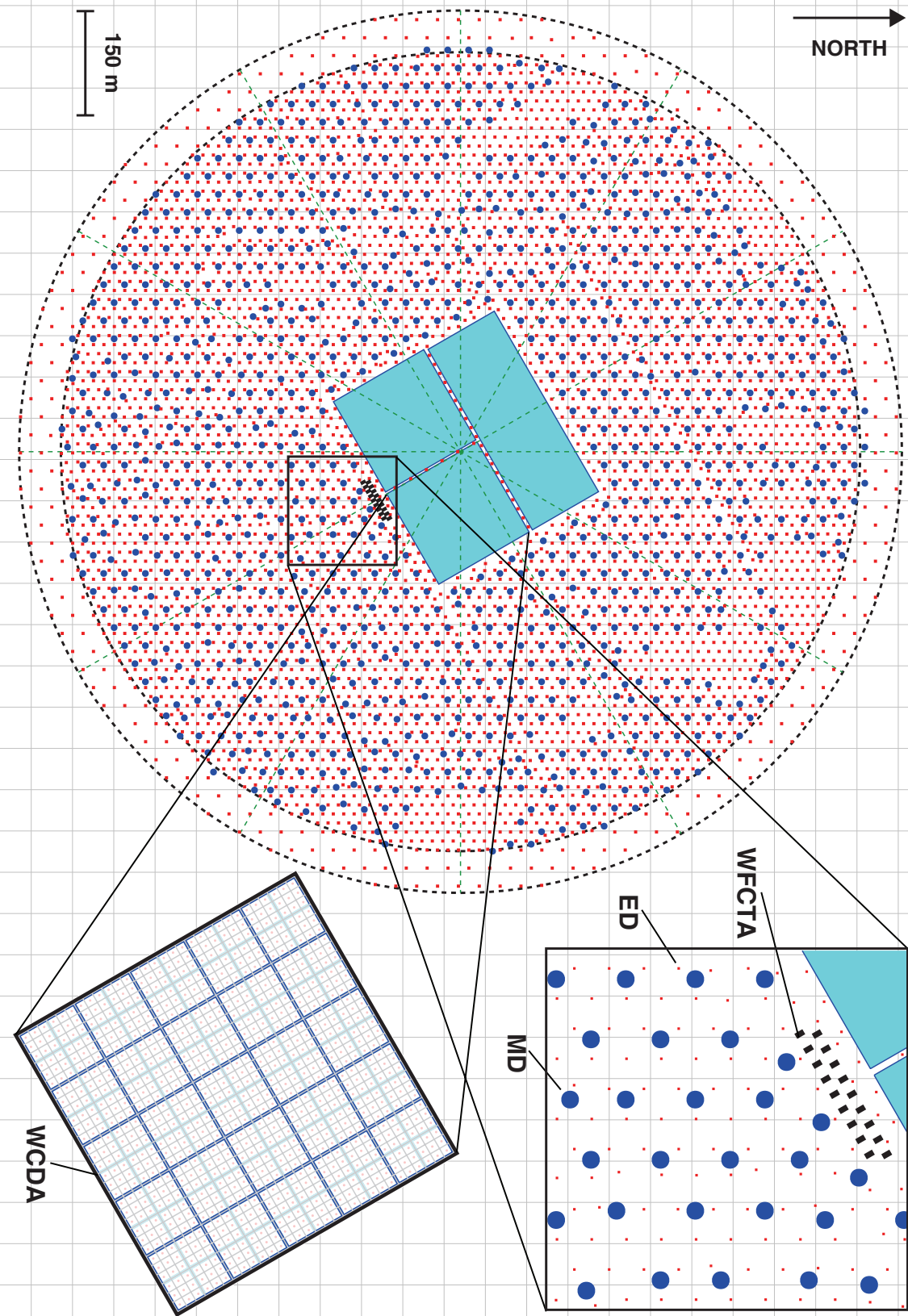


Figure 1: Layout of the LHAASO experiment. The insets show the details of one pond of the WCDA and of the KM2A array constituted by two overlapping arrays of electromagnetic particle detectors (ED) and of muon detectors (MD). The telescopes of the WFCTA, located at the edge of a pond, are also shown.

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Translate

First detector array put into use at China's new-generation cosmic ray observatory

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The three ponds of the Water Cherenkov Detector Array (WCDA). /IHEP

The first detector array at the Large High-Altitude Air Shower Observatory (LHAASO), sitting 4,410 meters above sea level, has been built and put into operation in the wilderness of Daocheng, southwest China's Sichuan Province.

According to the Institute of High Energy Physics (IHEP) under the Chinese Academy of Sciences (CAS), the water level at the No. 3 pond has reached the required standard, which means the construction of the Water Cherenkov Detector Array (WCDA) has been completed.

In the pond, water Cherenkov detectors are installed to form an array and are submerged in strictly purified water. Transparent pure water allows the detectors to clearly catch the signals generated by high-energy particles.

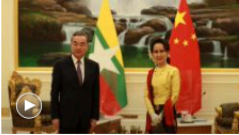
The WCDA, comprising three ponds, has 3,120 detector units and 6,240

TOP NEWS



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Asia 12:25, 11-Jan-2021



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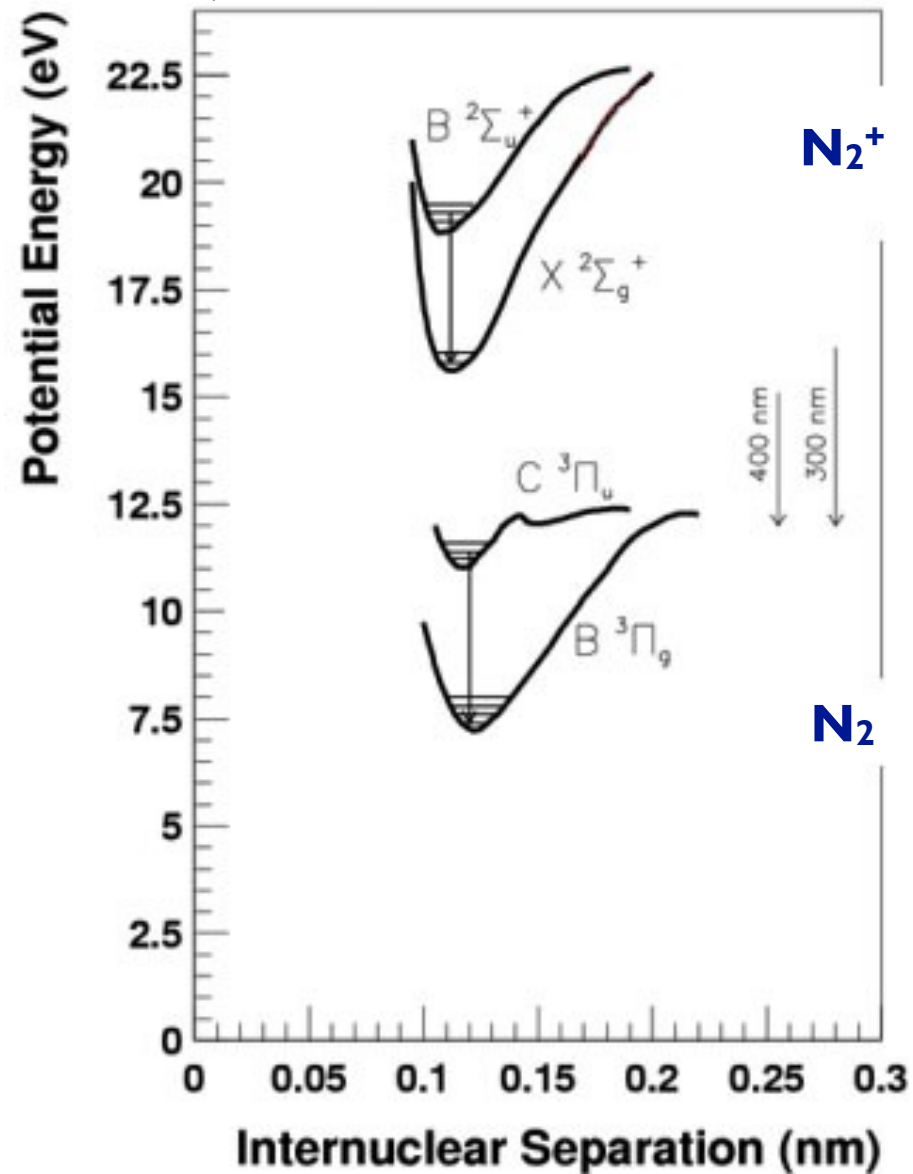
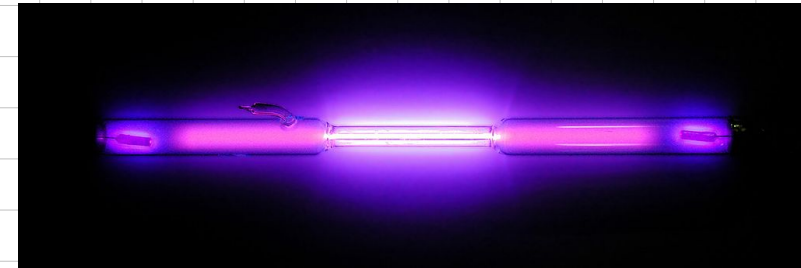
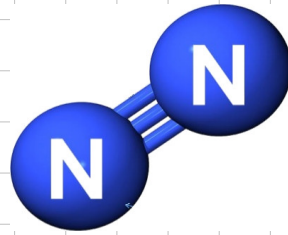
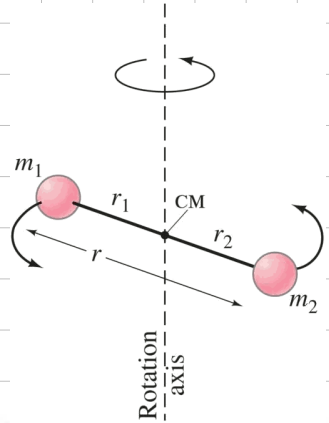
Live updates: U.S. Democrats ready for second Trump impeachment

According to Cao, the LHAASO project has drawn world attention. Some scientists and international research teams have expressed their desire for cooperation and joint observation with the LHAASO. Cao said foreign peers have been amazed at the speed of LHAASO's construction. It's not only a result of the scientists' efforts, but also that of the complete industrial production capacity of China. It's the embodiment of China's overall national strength.

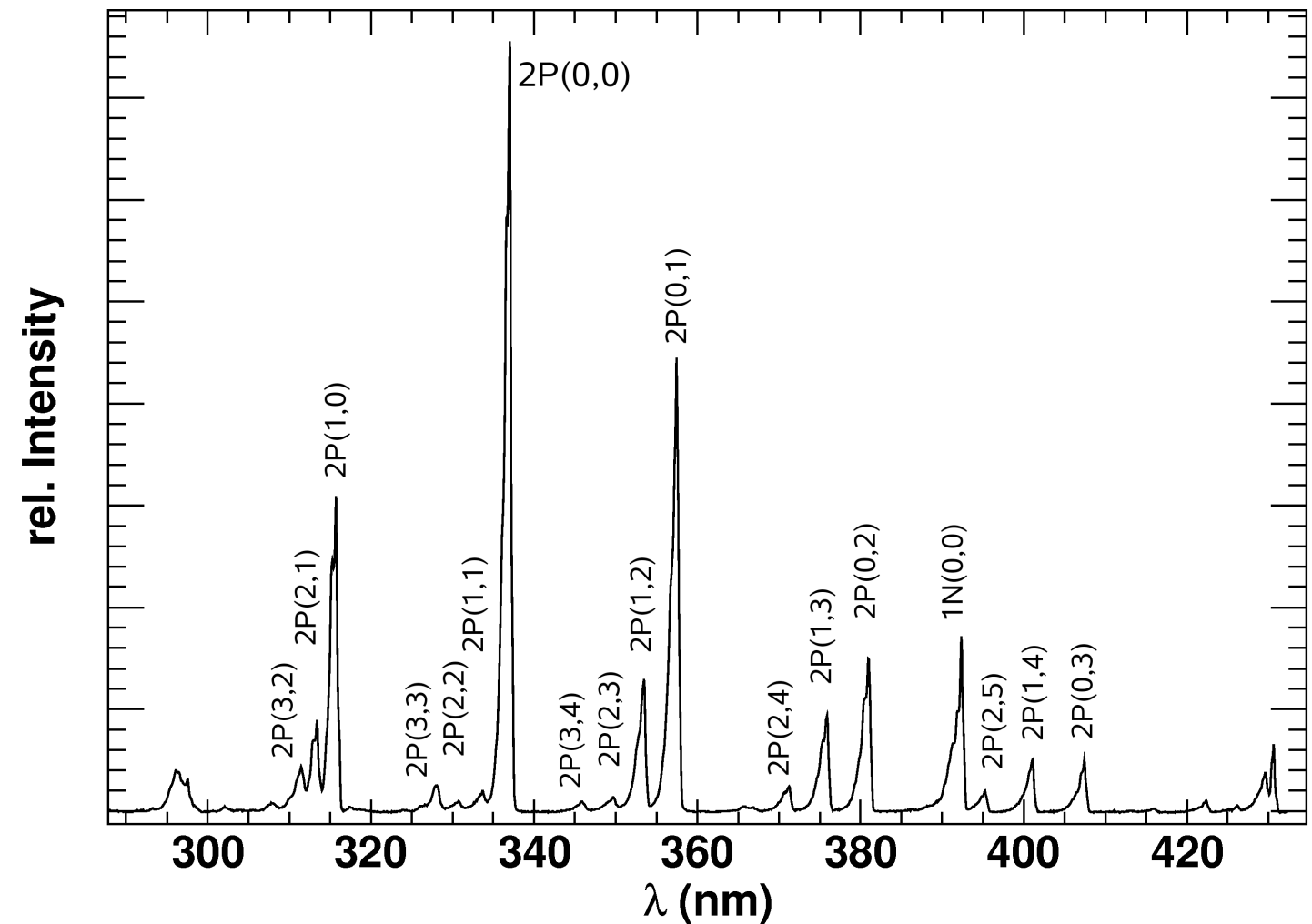
Source(s): Xinhua News Agency

<https://news.cgtn.com/news/2021-01-08/First-detector-array-built-at-China-s-advanced-cosmic-ray-observatory-WSjGjAjeuY/index.html>

Fluoreszenzlicht von Stickstoffmolekülen

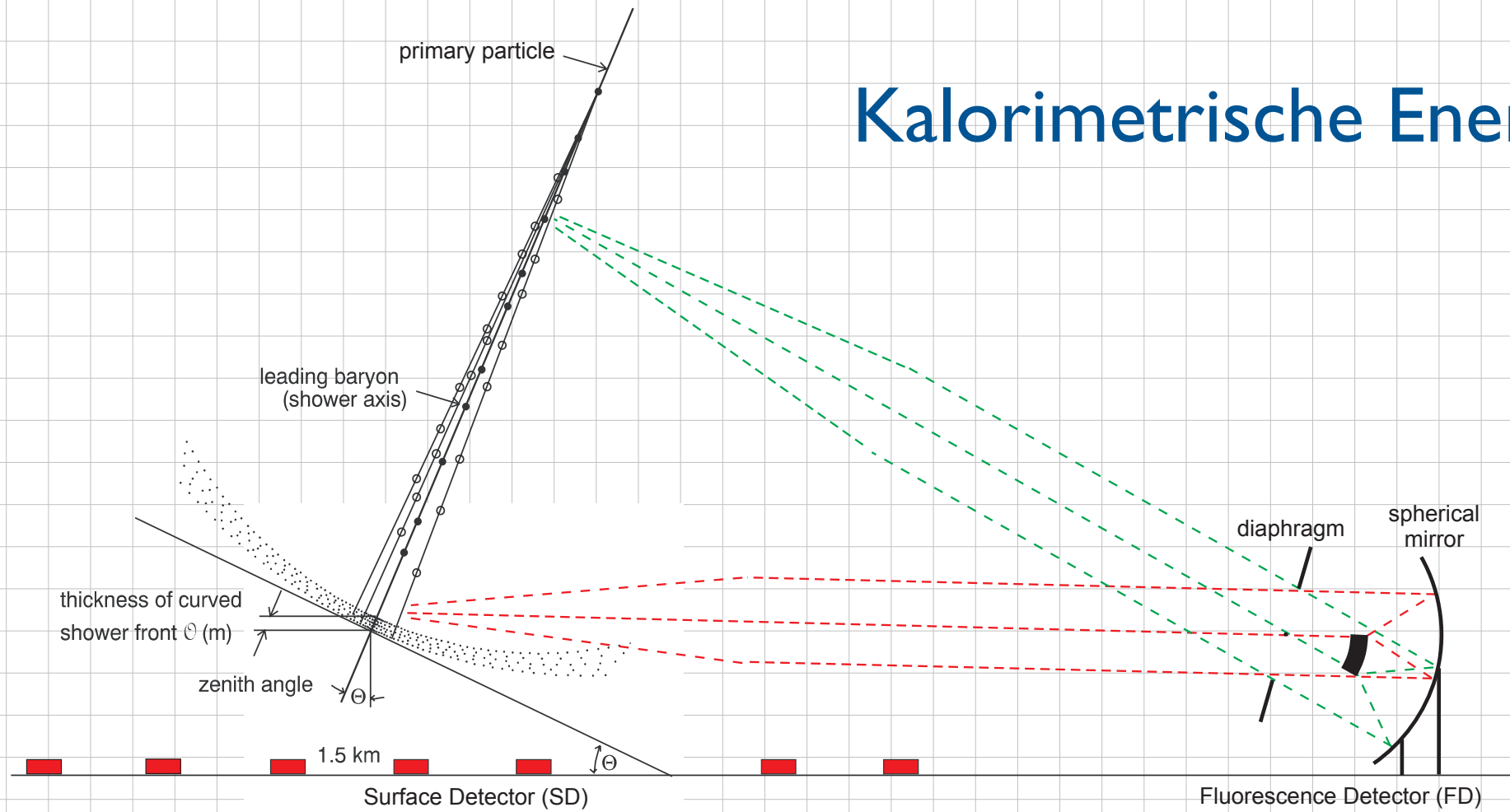


3-4 Photonen/m/Teilchen in 10km Höhe
entspricht einer 30 Watt-Glühlampe

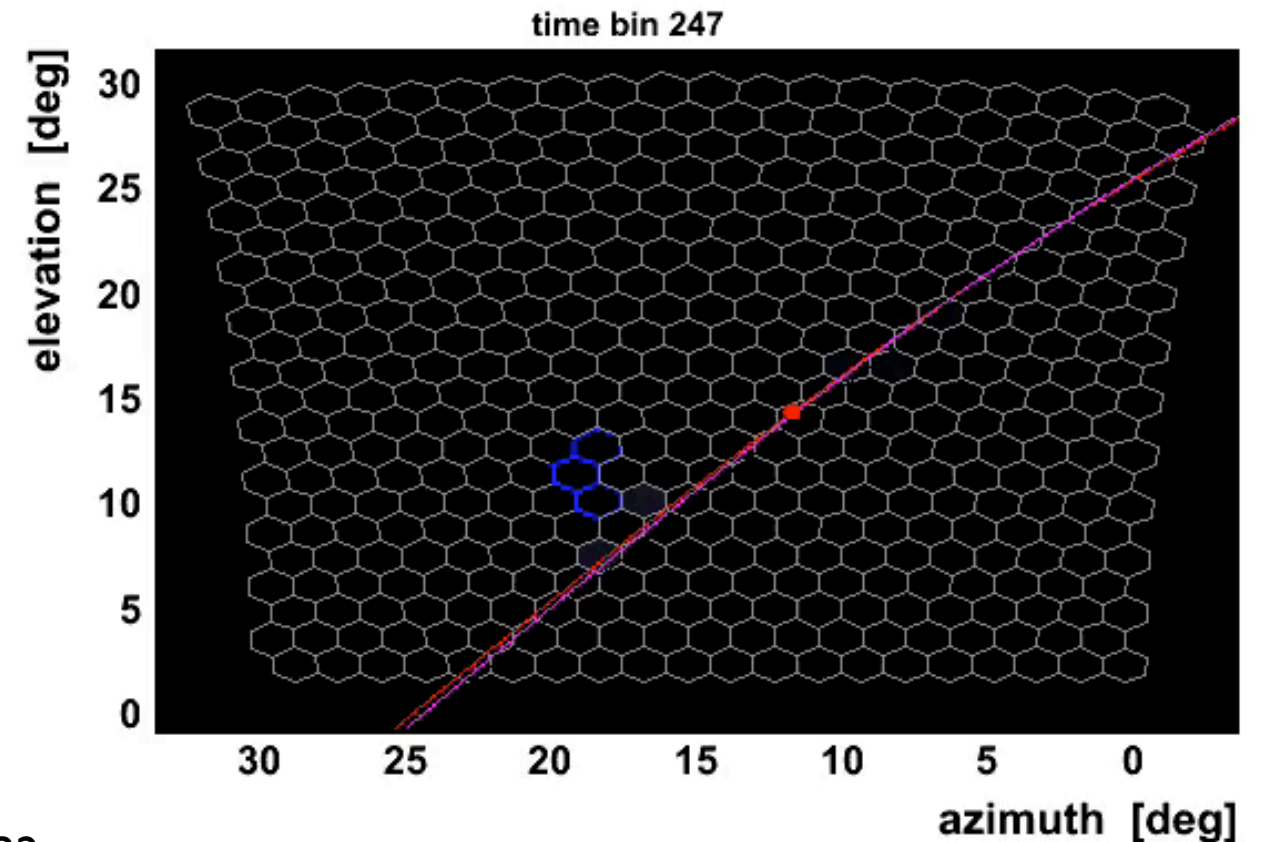
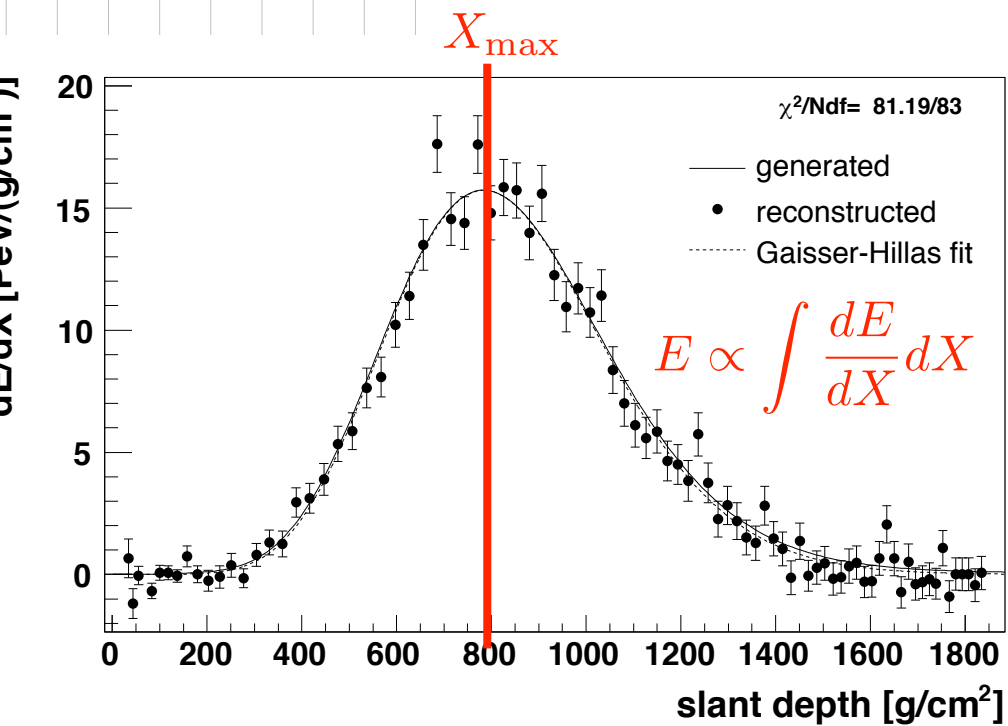


Lebensdauer des angeregten Zustands $\sim 10^{-8} \text{ s} = 10 \text{ ns}$
isotrope Emission, hauptsächlich im UV (300 - 400 nm)

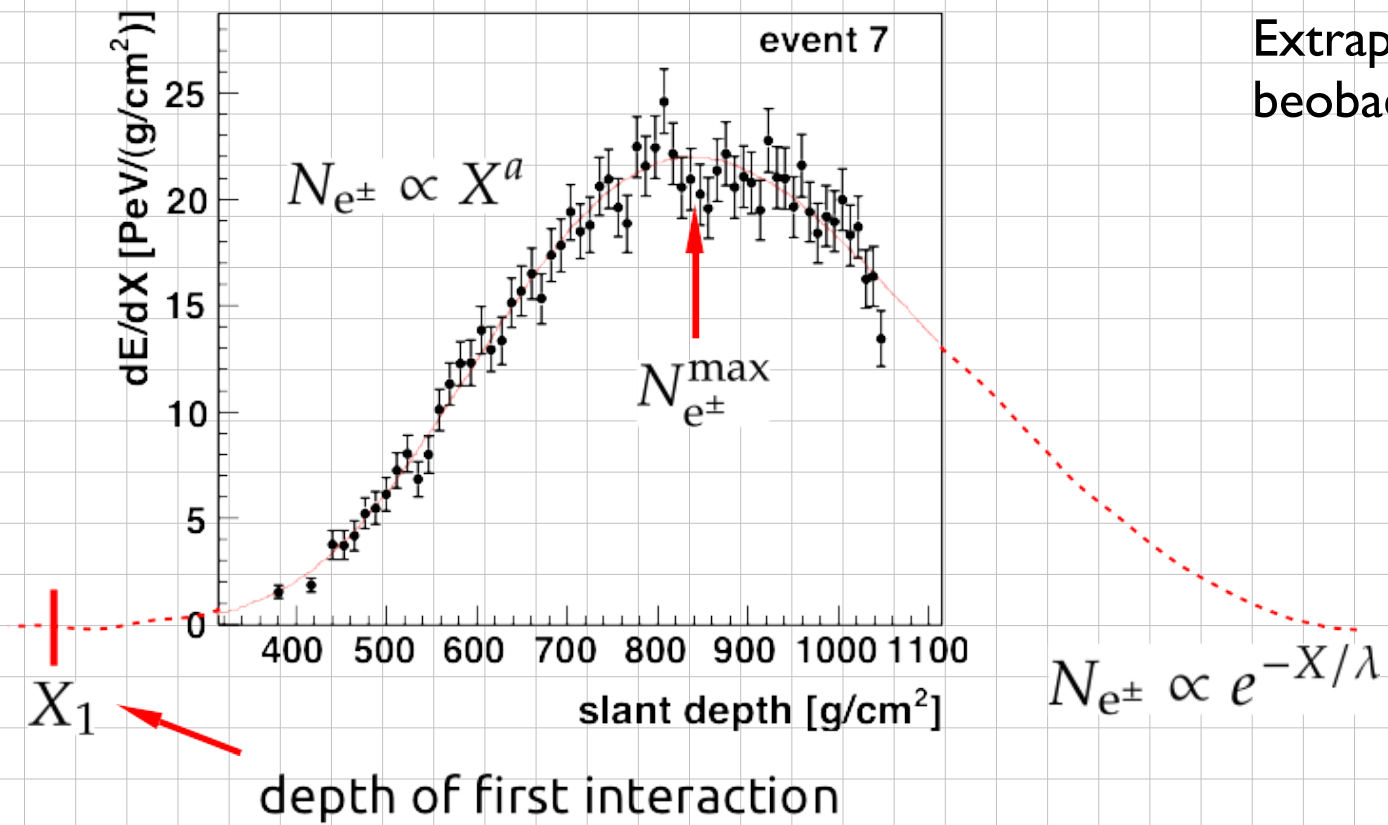
Kalorimetrische Energiemessung



Ionisationsenergieabgabe in Luft



Kalorimetrische Messung der Energie



Extrapolation in nicht direkt beobachtete Bereiche erforderlich

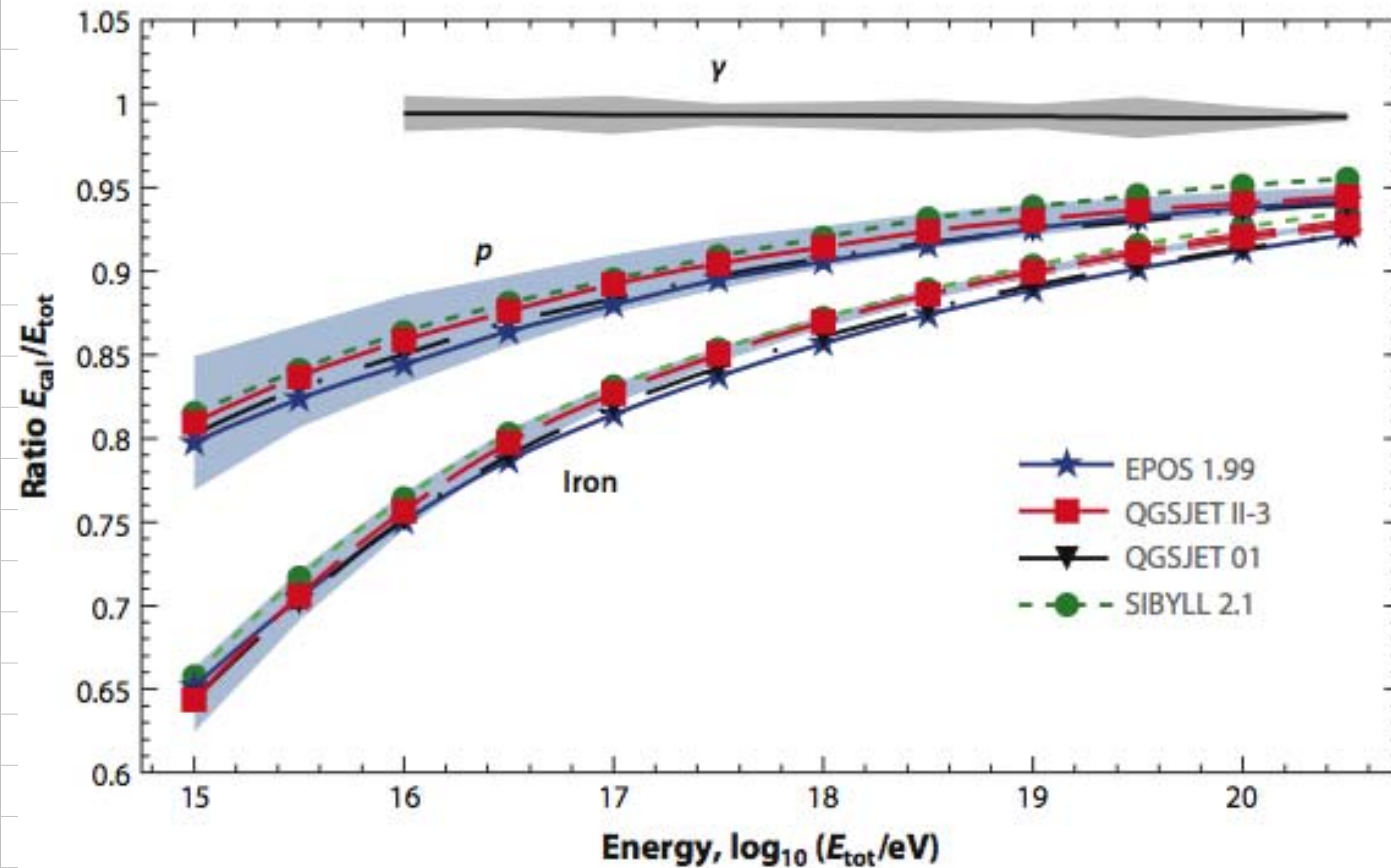
$$N_e(X) = N_{e,\text{max}} \left(\frac{X - X_1}{X_{\text{max}} - X_1} \right)^{\frac{X_{\text{max}} - X_1}{\Lambda}} \exp \left(\frac{X_{\text{max}} - X_1}{\Lambda} \right)$$

$$E_{\text{cal}} = \int_0^\infty \left(\frac{dE}{dX} \right)_{\text{measured}} dX \approx \langle \alpha_{\text{ion}} \rangle \left(\frac{dN_e}{dX} \right)_{\text{measured}} dX = E_{\text{em}}$$

Korrektur der *unsichtbaren Energie*

Energiekorrekturfaktor für Fluoreszenzmessungen

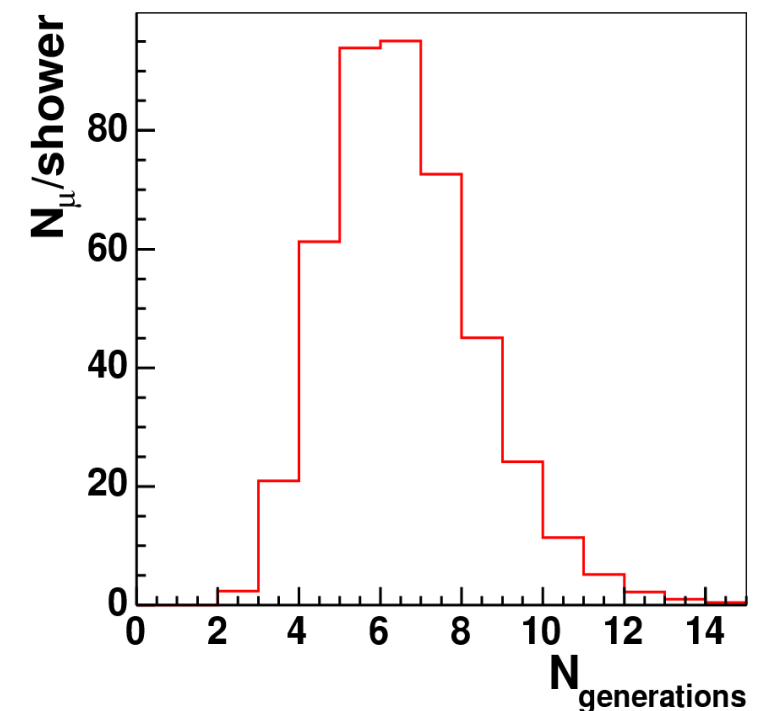
$$E_{\text{tot}} = f \cdot E_{\text{em}}$$



Modellabhängigkeit für rekonstruierte Energie klein

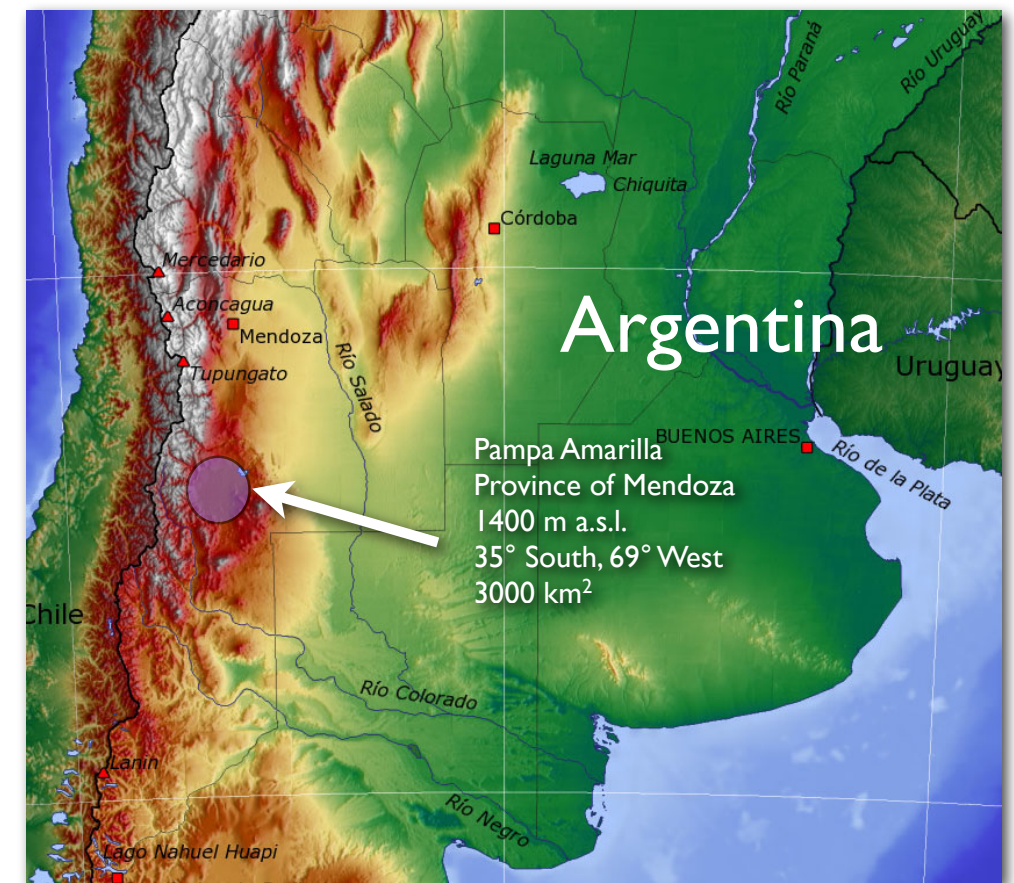
Protonenschauer, $E = 10^{15}$ eV

Number of generations (muons)

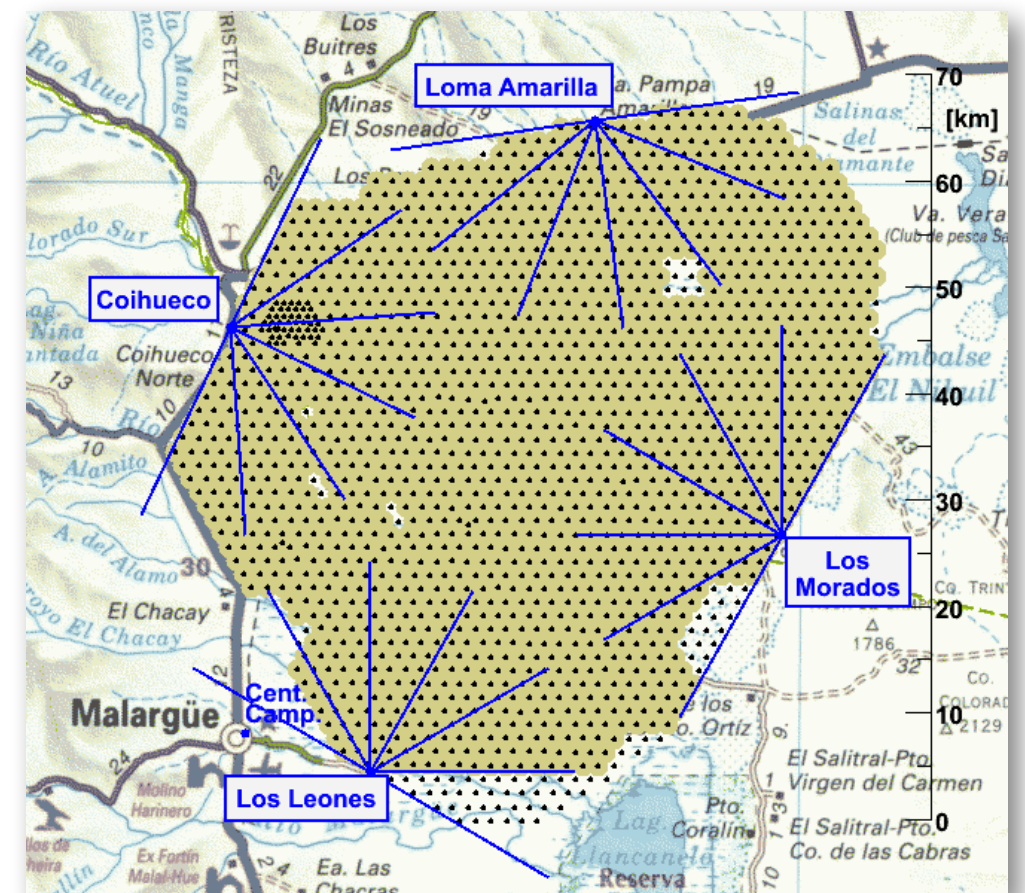


The Pierre Auger Observatory

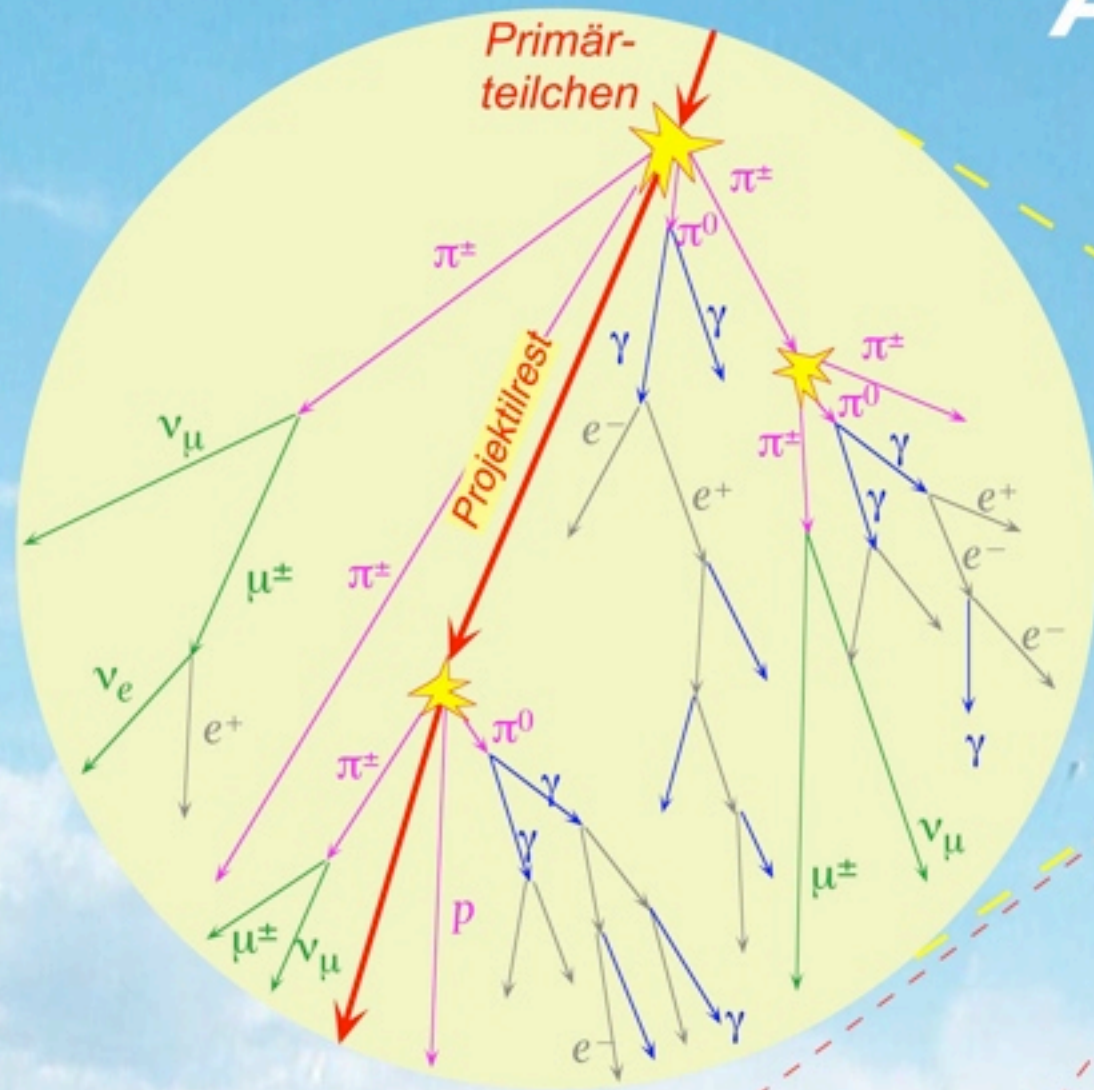
- Auger: >400 authors from 17 countries
- Southern site:
Hybrid detector near Malargüe/Argentina
- June 13th 2008 : 1660 tanks deployed
1637 with water
1603 totally equipped
- All 4 fluorescence buildings complete
each with 6 telescopes since February 2007
- 1st 4-fold on May 20th 2007



3



Ausgedehnte Luftschauder



Pierre Auger Observatorium:
 $10^{19} \text{ eV} < E < 10^{21++} \text{ eV}$

Primärteilchen

ca 8 km Höhe

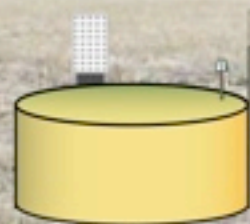
**Fluoreszenz-,
Cherenkov Licht**

**Elektronisches
Schmidt-Teleskop**

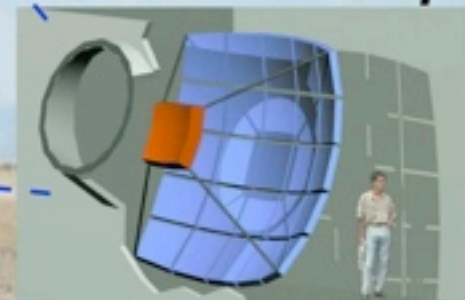
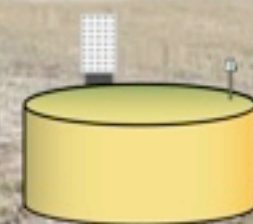
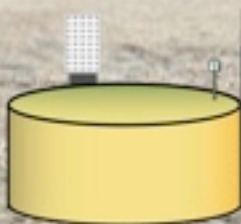
1 m Dicke

Trajektorie

$\gamma \approx c$

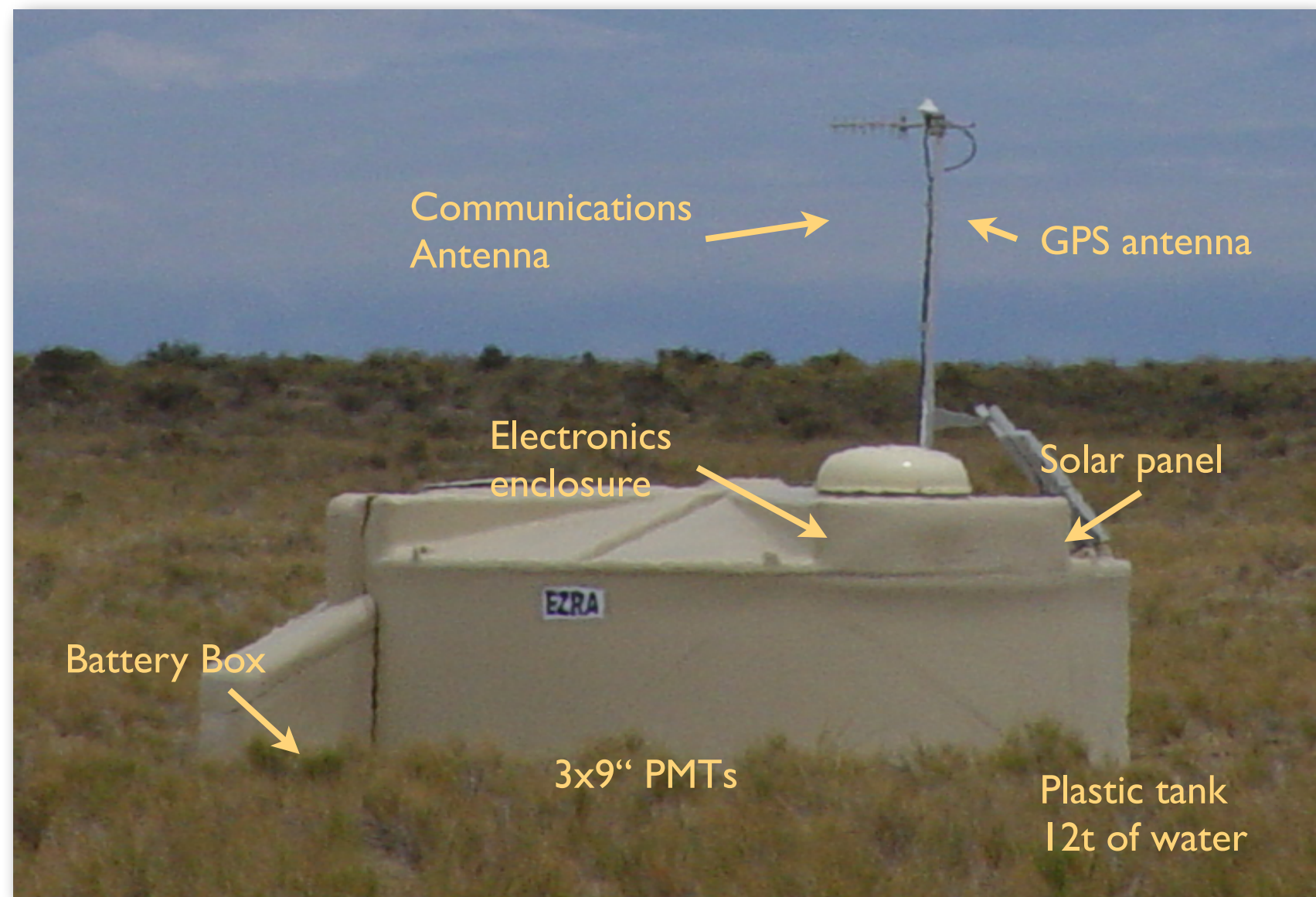


**Wasser-
Cherenkovdetektoren**

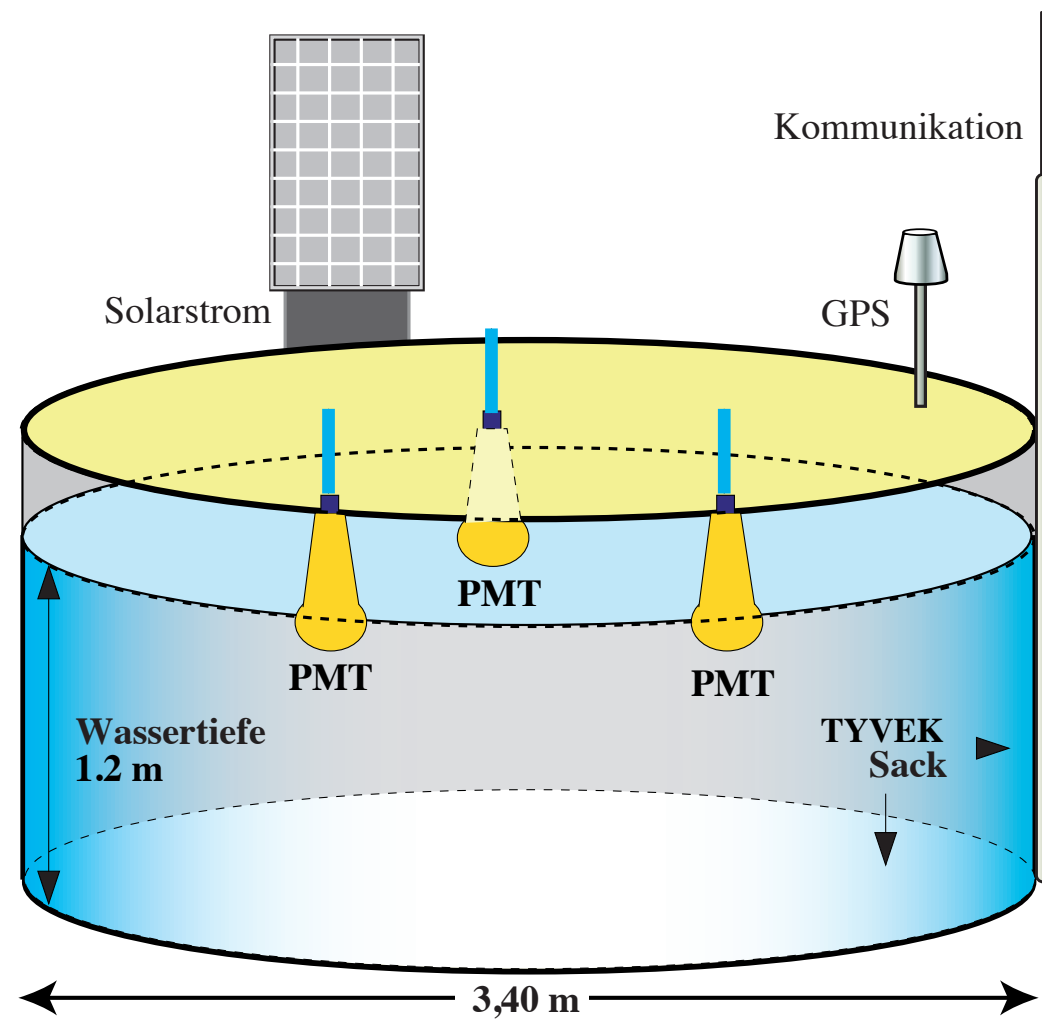


The surface detector

- 1600 Water Cherenkov tanks (1.2 m height, 10 m² area)
- 12,000 ltrs of purified Water
- Three 9" PMTs
- 40 MHz FADCs
- solar powered
- GPS based timing
- micro-wave communication

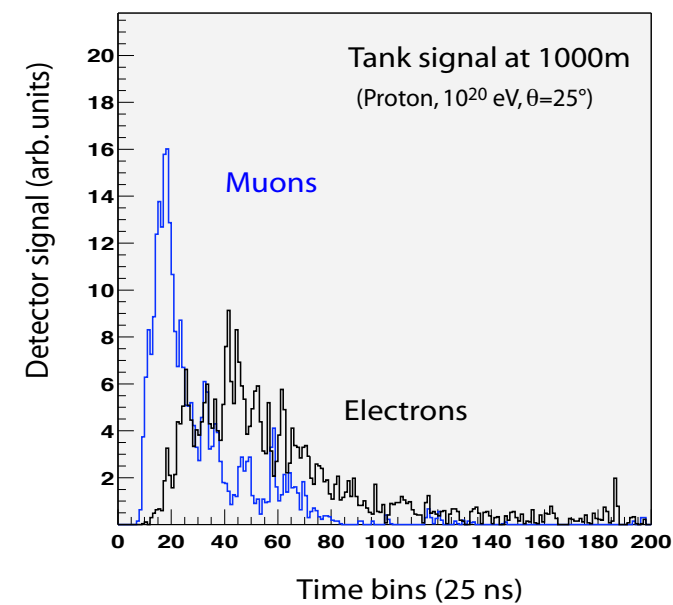
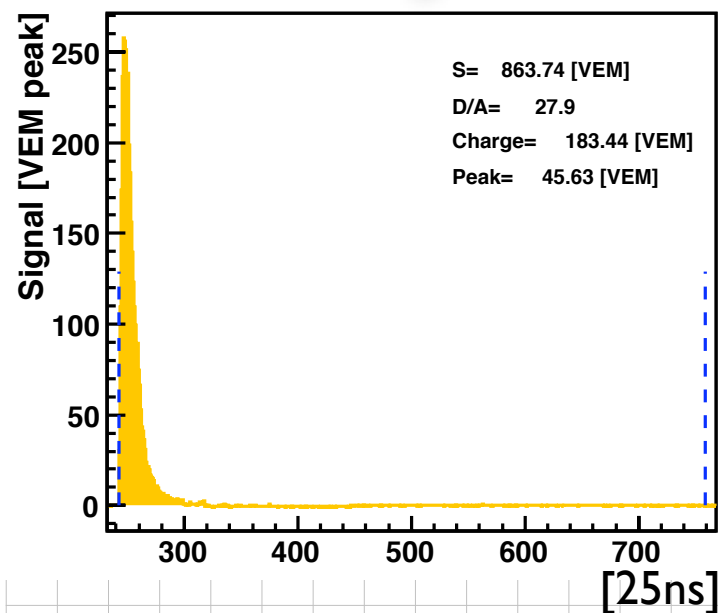
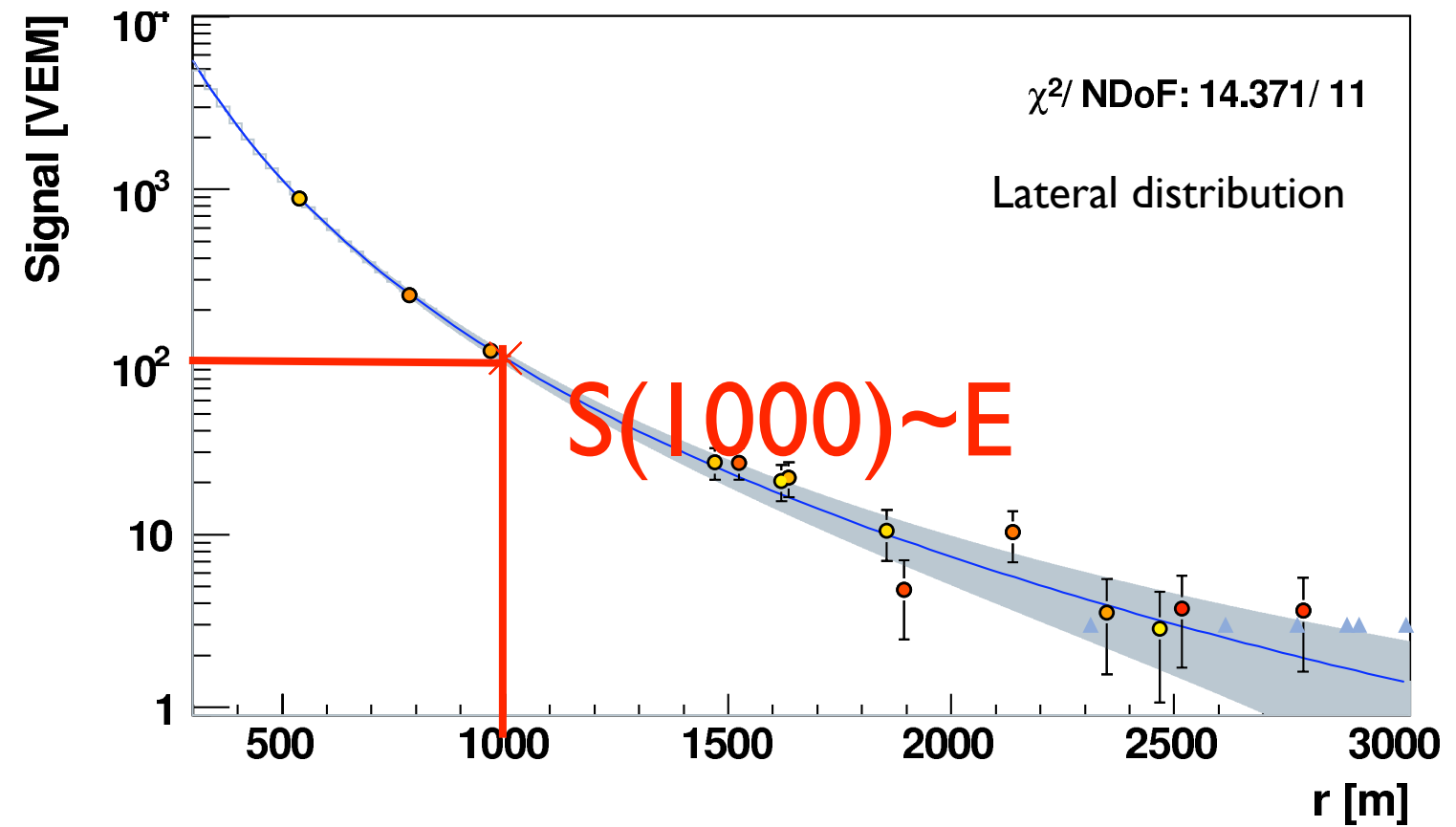
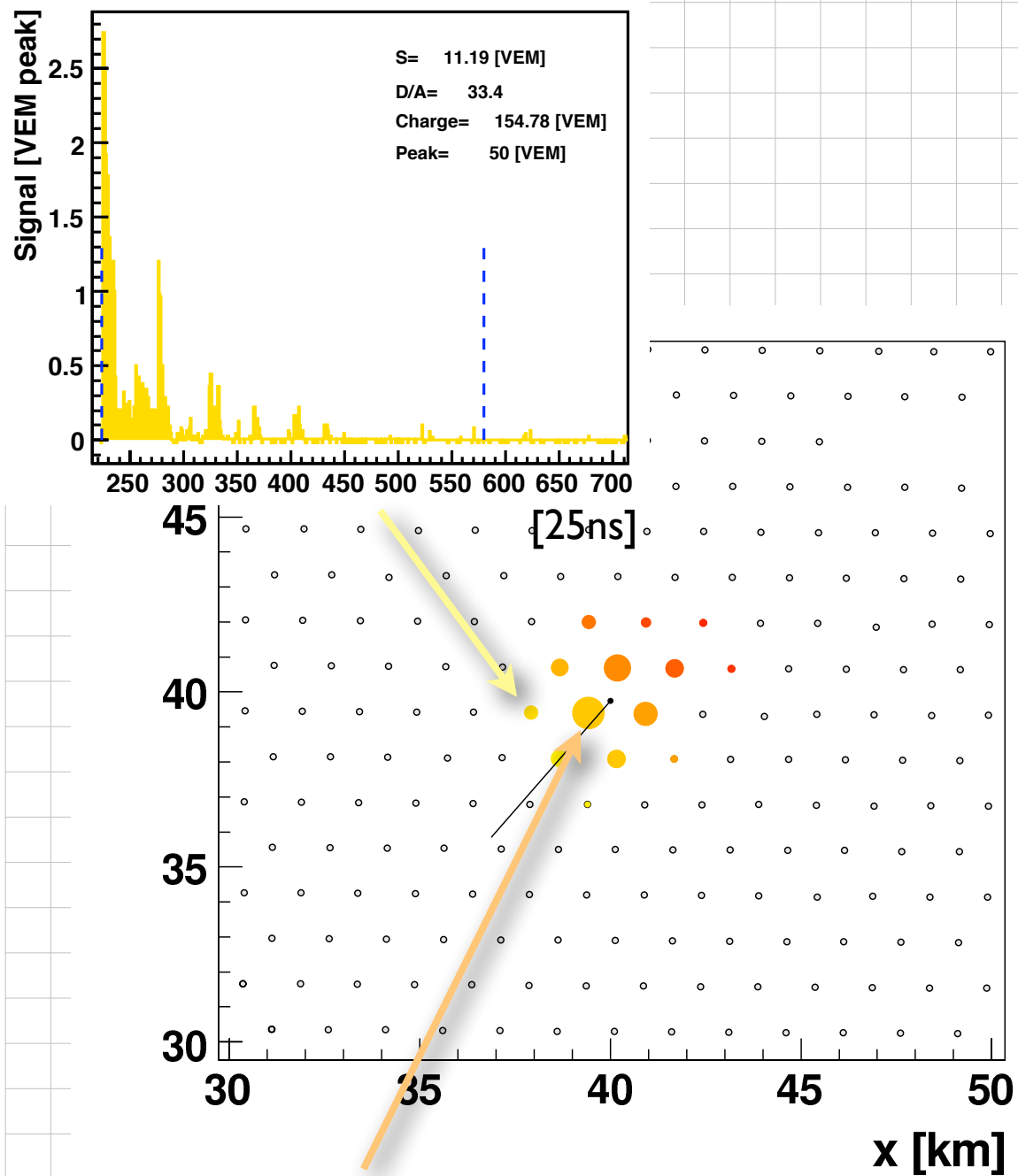


Wasser-Cherenkovdetektor



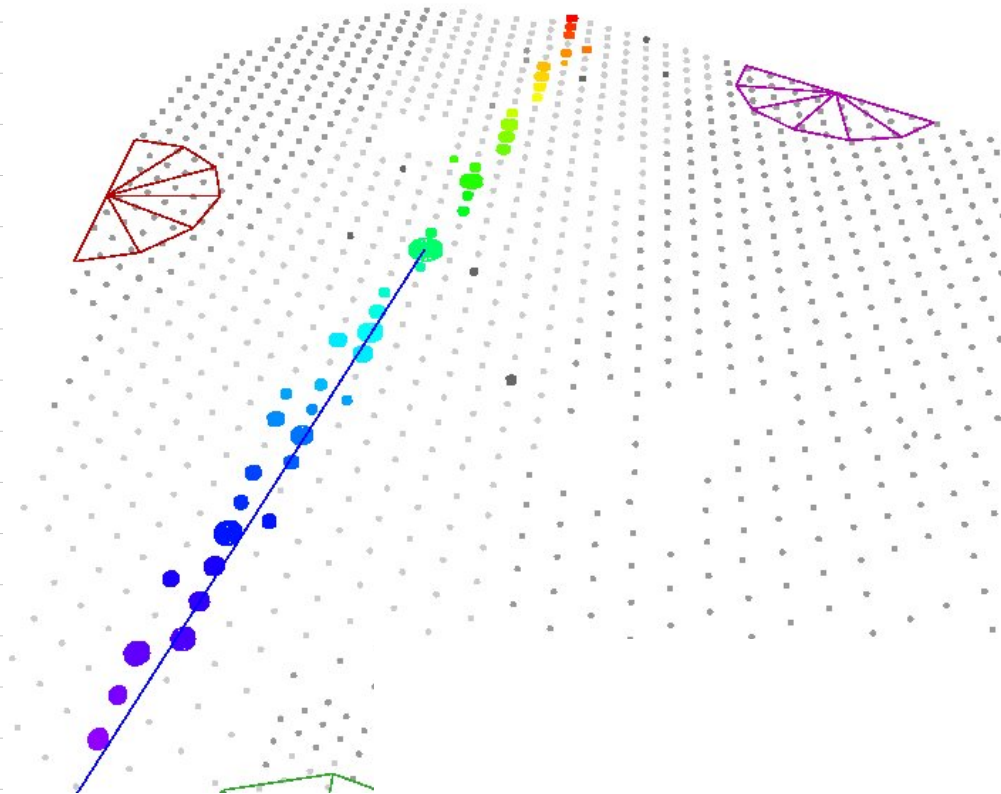


SD reconstruction

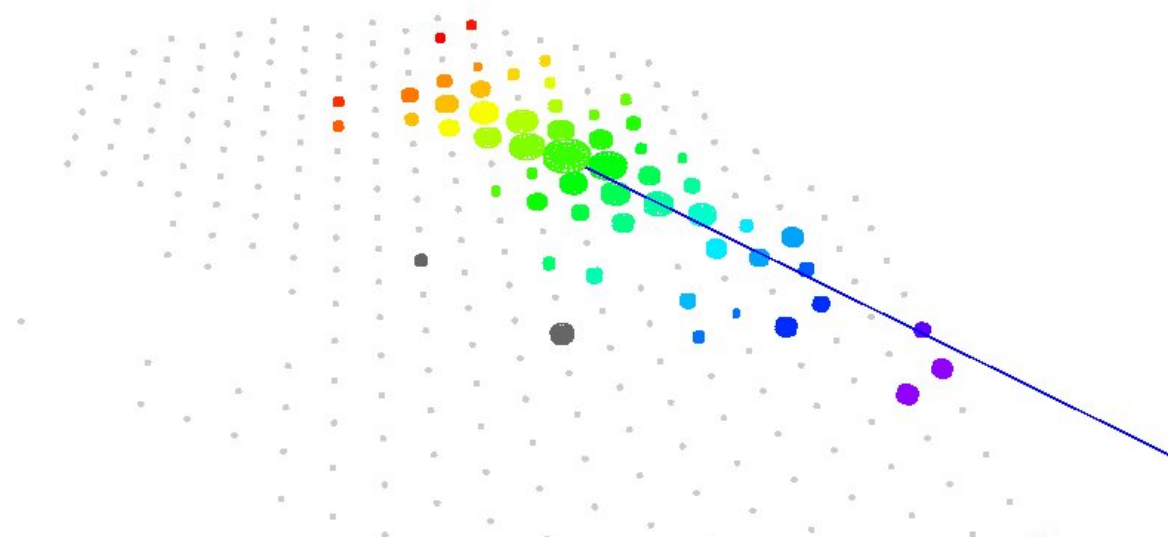


Beispiele sehr schräger Schauer

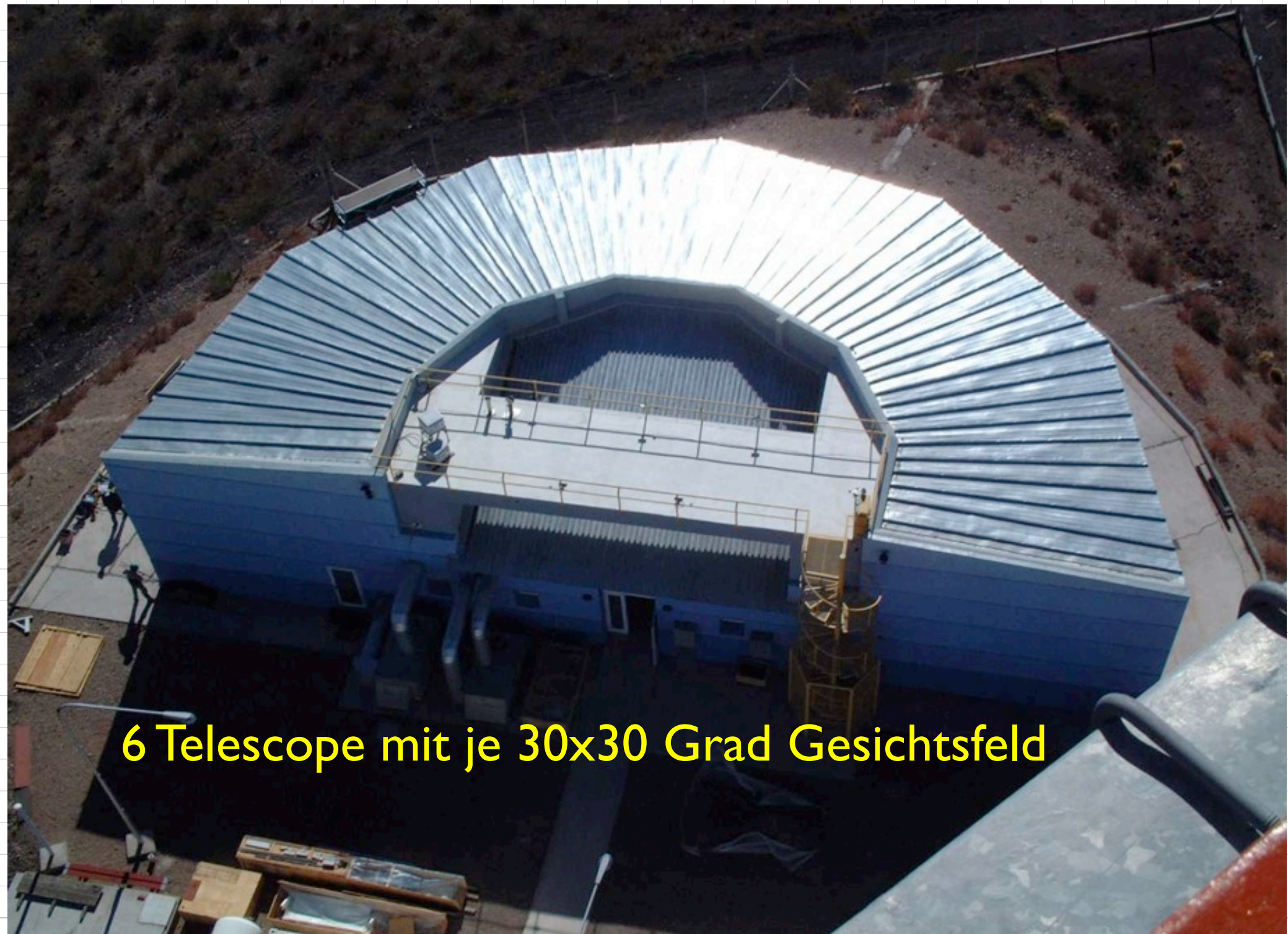
- 14.07.2008
- longest event: 65 km, 45 stations
- zenith: 87 degrees



- 17.08.2008
- highest multiplicity: 54 stations
- zenith: 82 degrees







6 Telescope mit je 30x30 Grad Gesichtsfeld

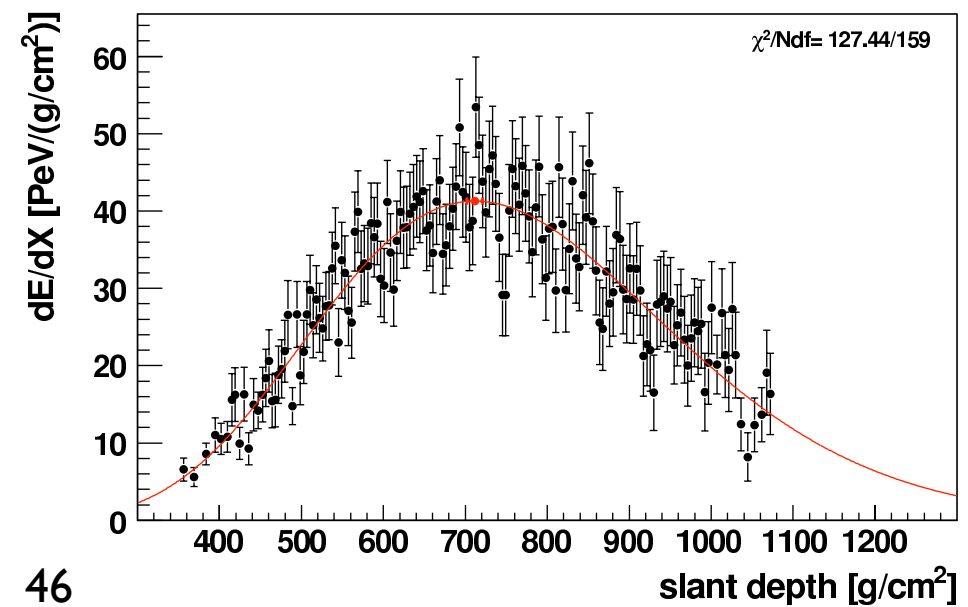
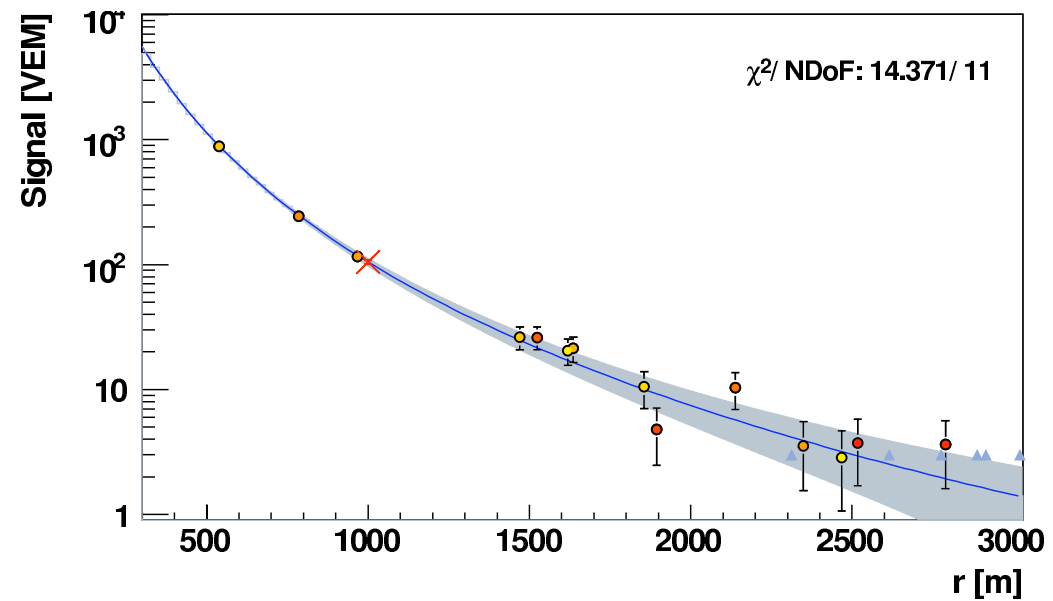
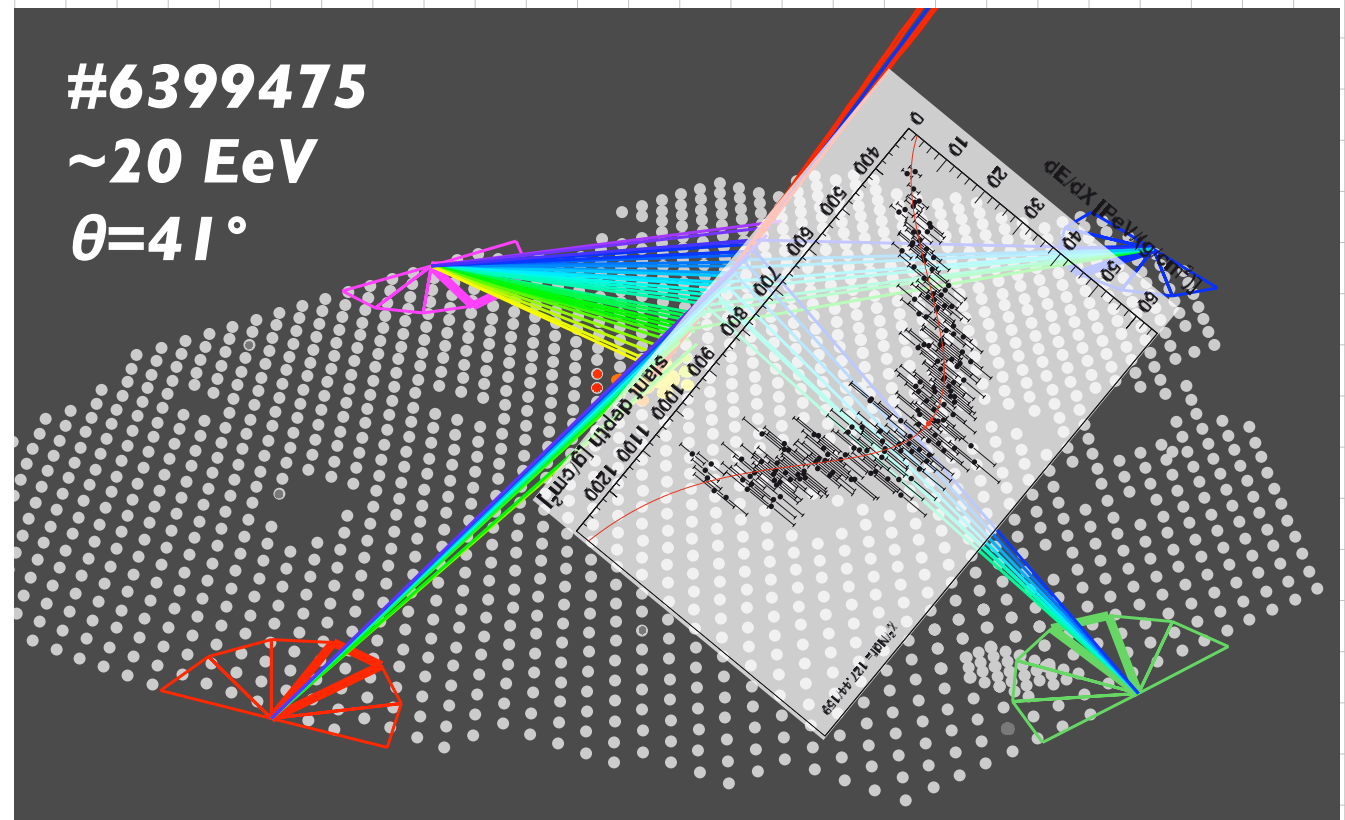
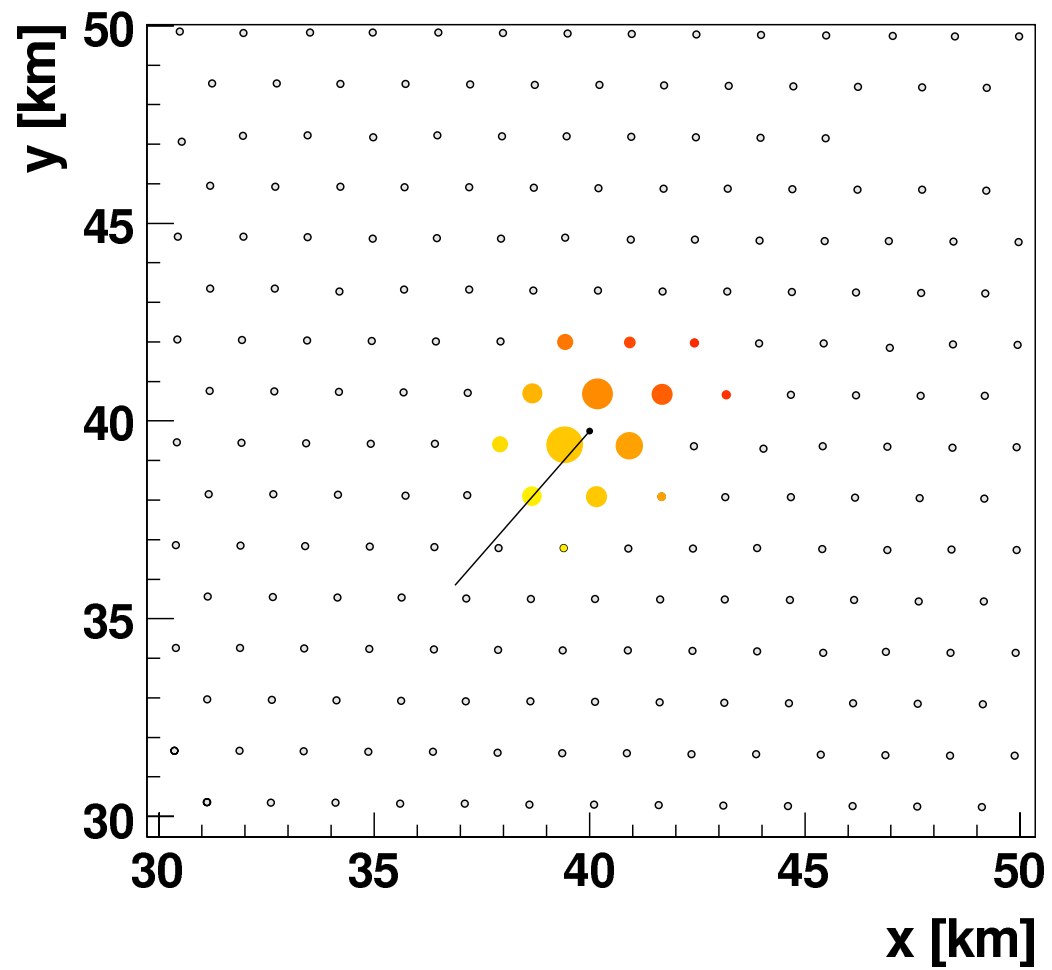
Einzelnes Fluoreszenzteleskop

Kamera mit 440 Pixeln, aber 10
Millionen Bilder/Sekunde

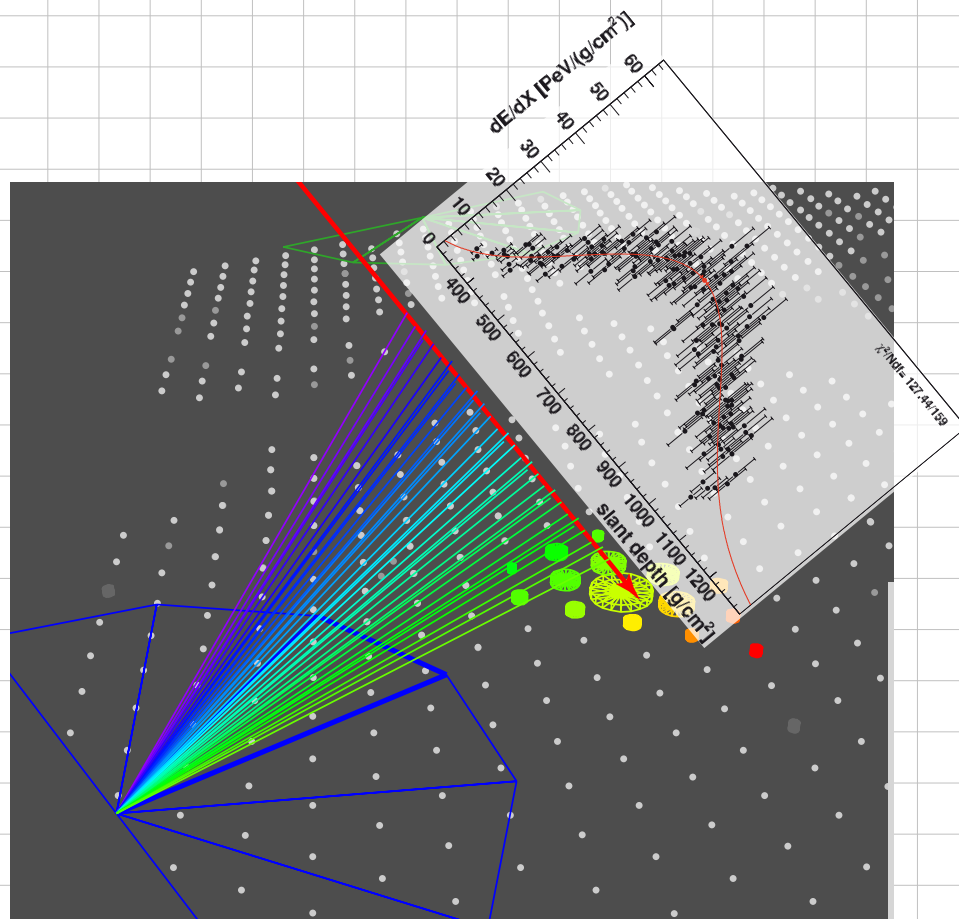
Apertur, UV-
durchlässiger
Filter und
Korrekturlinse

3.4 Meter
segmentierter
Spiegel

Hybrid-Messung

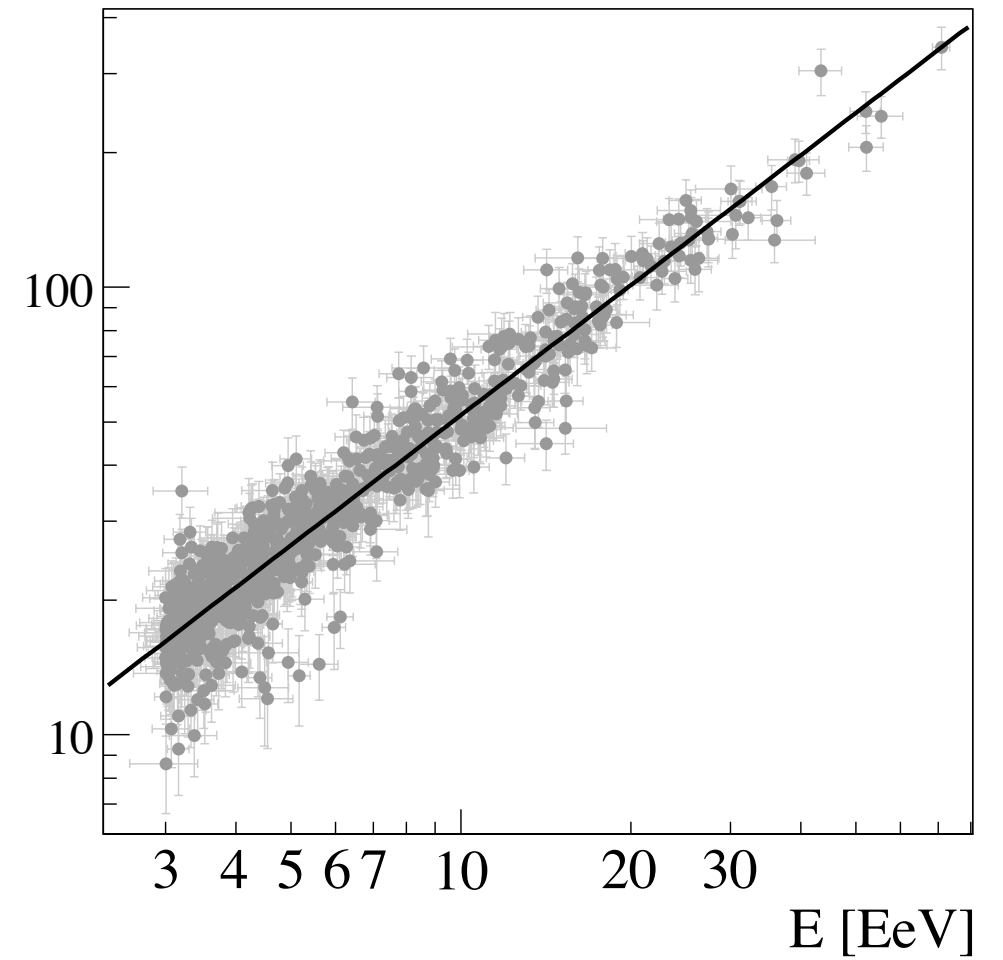


Energiekalibration des Oberflächendetektors



Oberflächensignal bei 1000m, $\theta=38^\circ$

S_{38} [VEM]



Energie gemessen mit
Fluoreszenzdetektor

