# Cosmic ray physics with the KASCADE-Grande observatory

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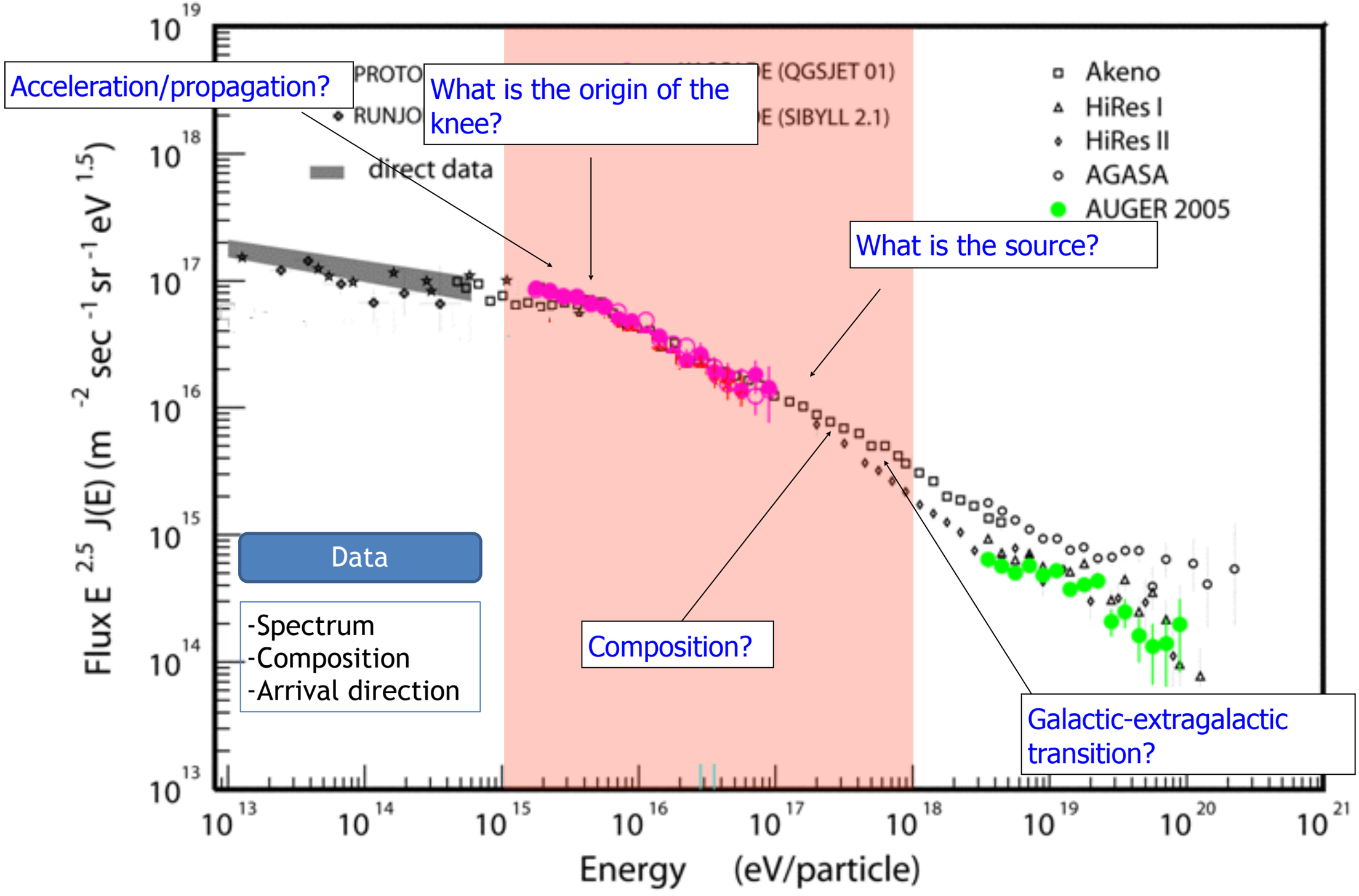
*Universidad Michoacana, México*

Overview

1) Introduction
2) The KASCADE experiment
3) The KASCADE-Grande detector
4) Recent results
5) Summary

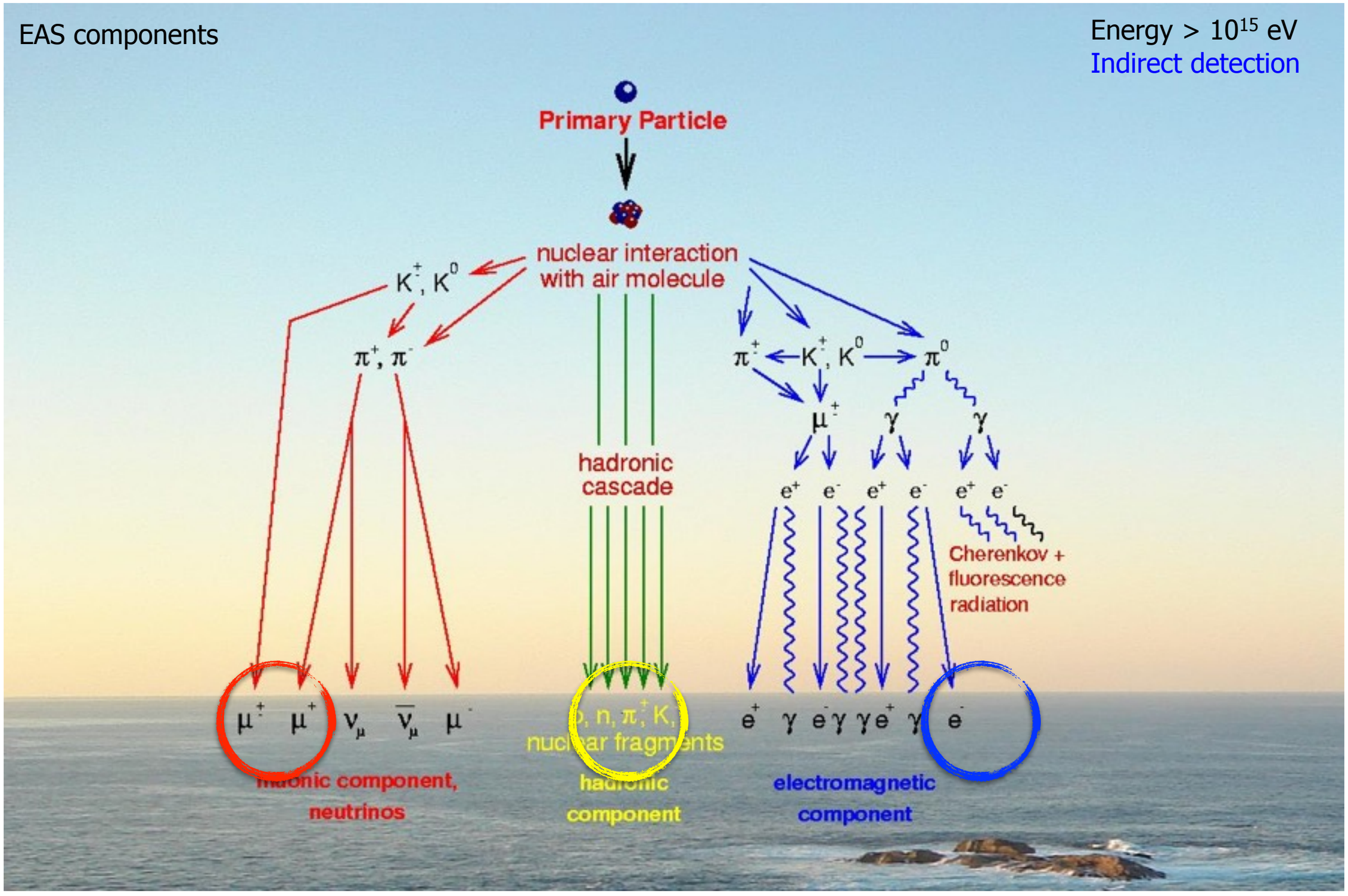
# Introduction



# Introduction

EAS components

Energy > $10^{15}$ eV
Indirect detection



# The KASCADE-Grande experiment

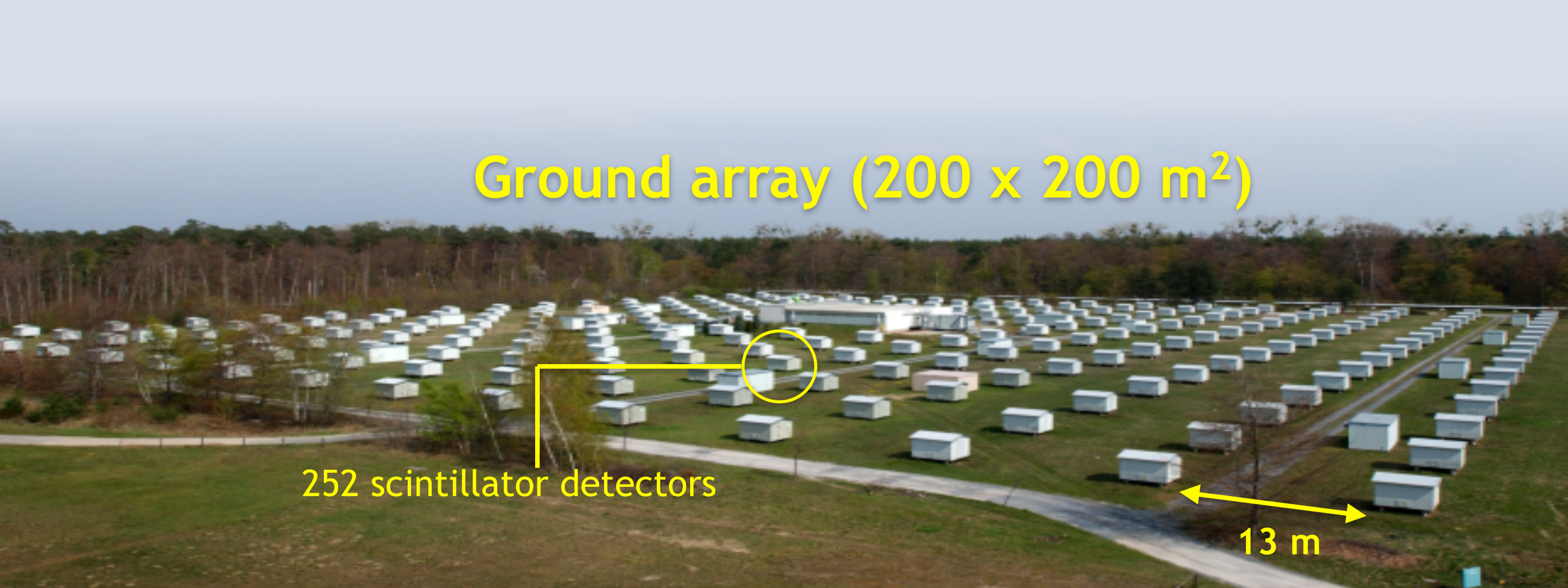
December 2003 - November 2012

1. Location: KIT-Campus North, Karlsruhe, Germany

# The KASCADE experiment

E= 100 TeV - 80 PeV

Karlsruhe Shower Core and Array Detector



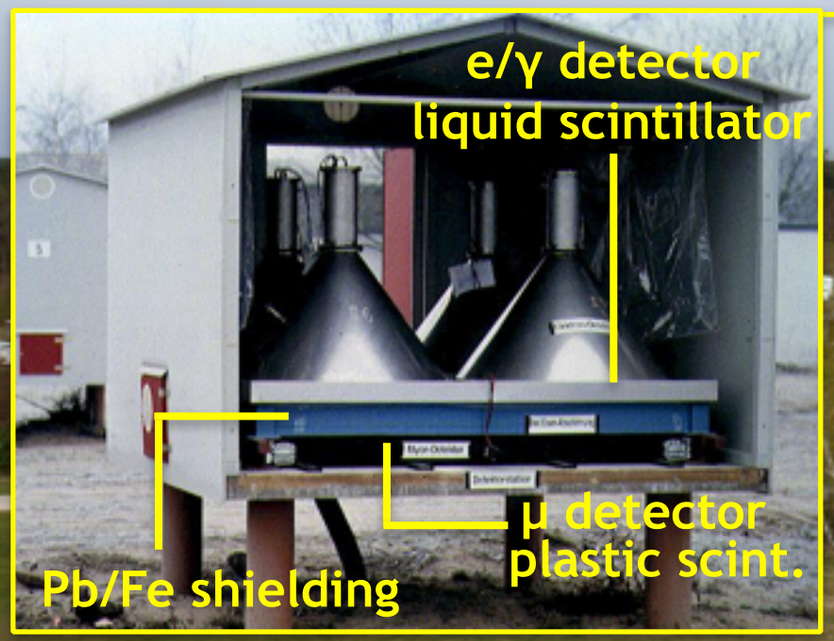
# The KASCADE experiment

Karlsruhe Shower Core and Array Detector

E= 100 TeV - 80 PeV

Ground array

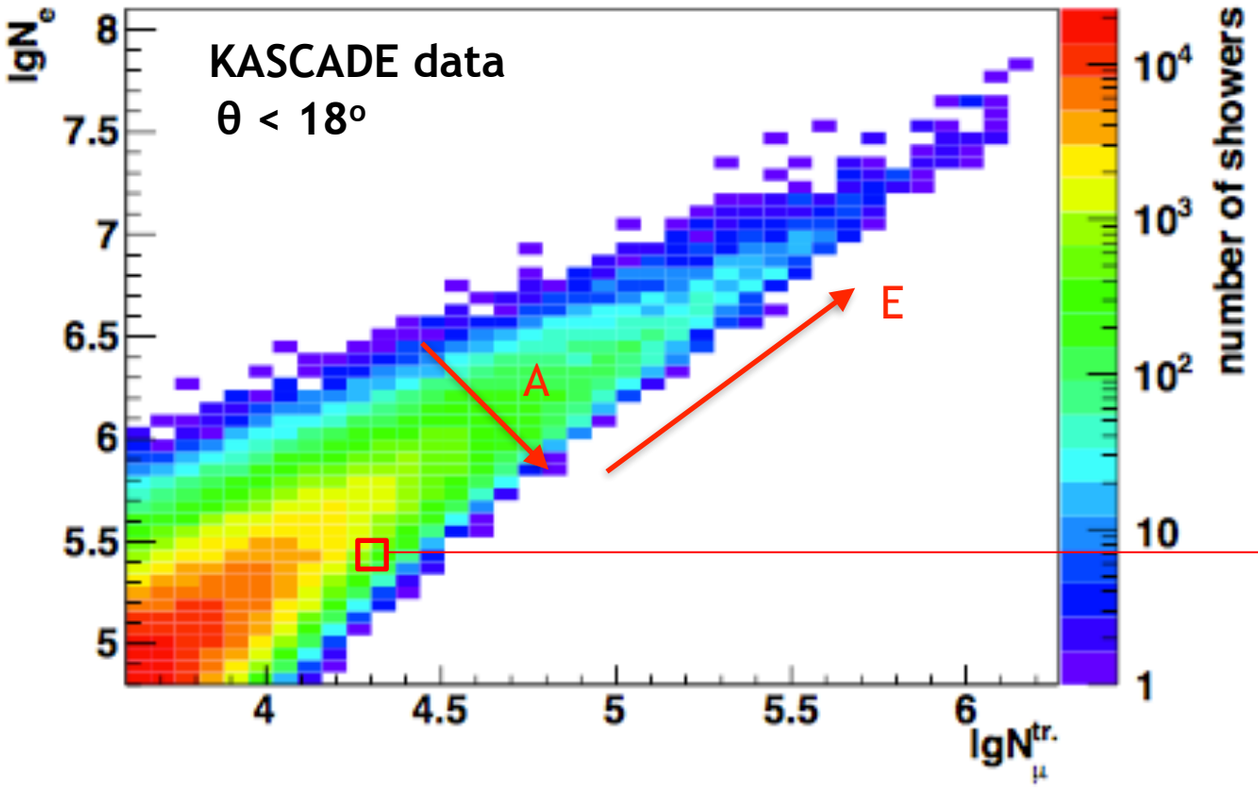
Scintillator detectors




- Ne (> 5 MeV) and
  $N^{tr}\mu$ (> 230 MeV, r = 40 - 200 m)

*T. Antoni, et al., NIMA 513 (2003) 490*

# KASCADE: Unfolding elemental spectra



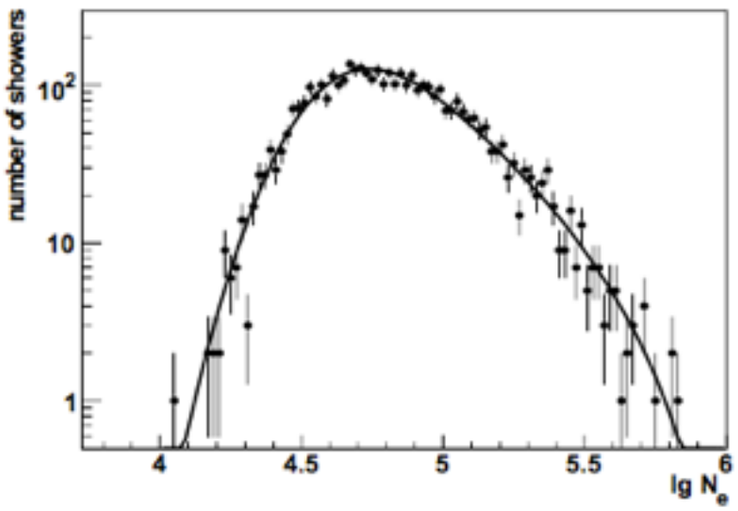

**Problem:** To find E and A for primary CR's from $N_e$ and $N^{tr}_{\mu}$.

$$n(lgN_e, lgN^{tr}_{\mu}) = \Sigma_A \int P_A(lgN_e, lgN^{tr}_{\mu} \mid E)\, f_A(E) dE$$

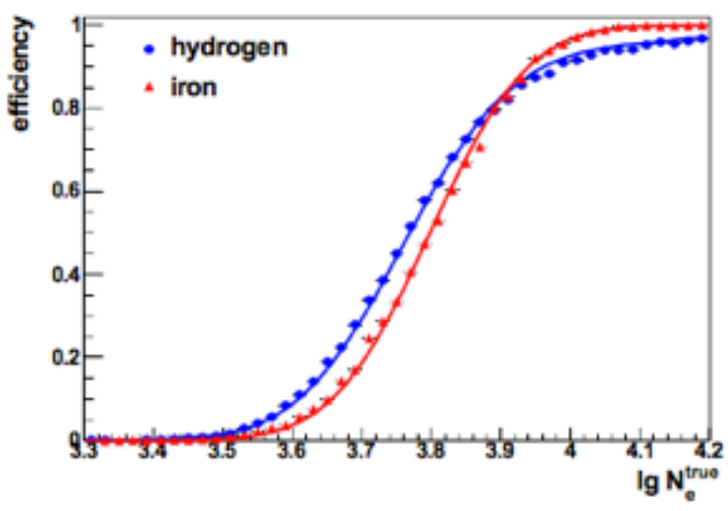
*Flux*

*CORSIKA*

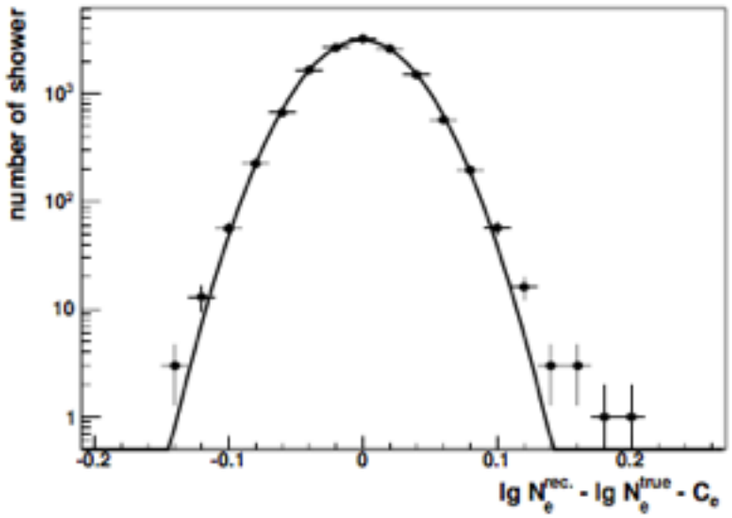
*EAS fluctuations*




*Efficiency*



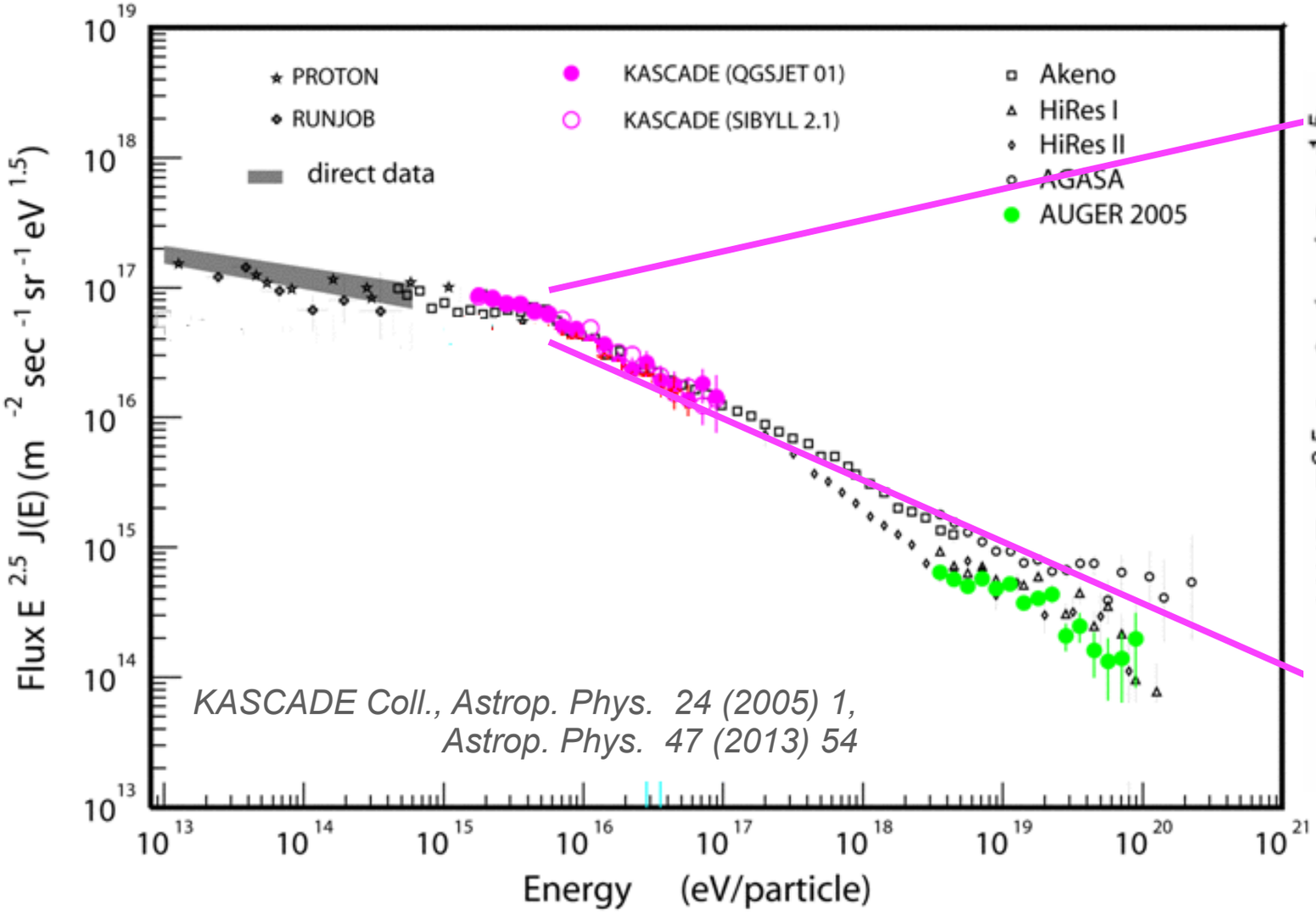

*Reconstruction uncertainties*

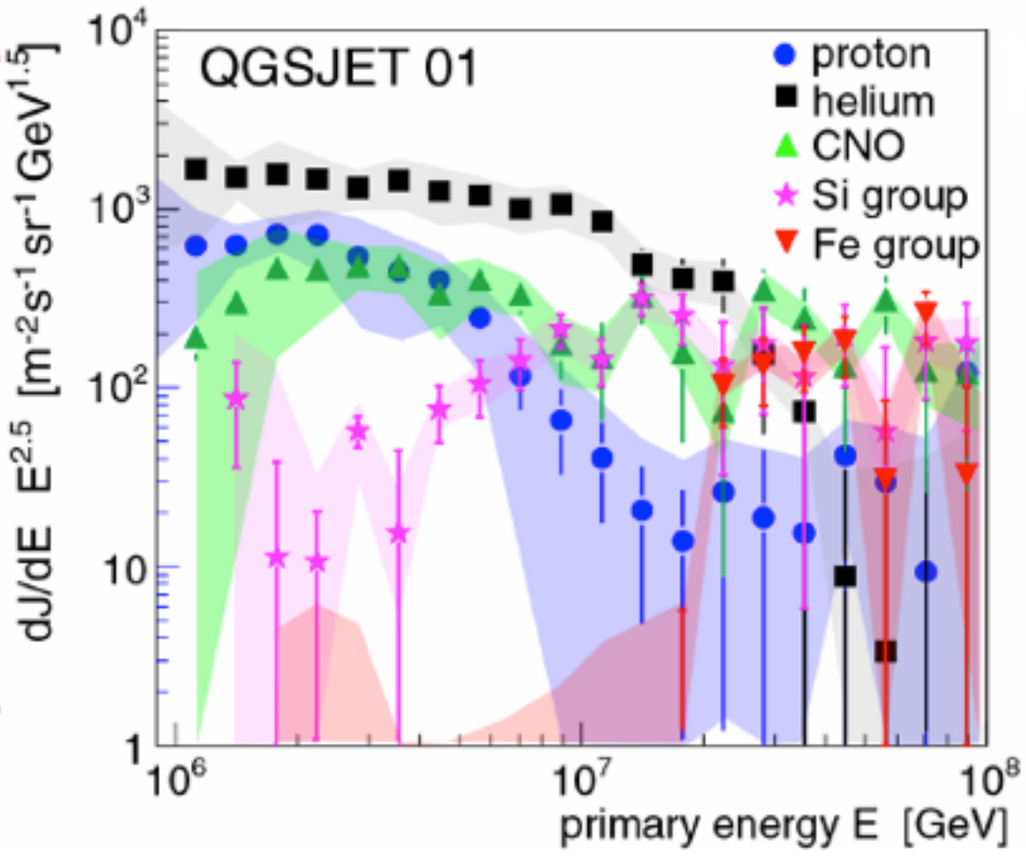



M. Finger PhD Thesis, KIT, (2011)

# KASCADE: Unfolding elemental spectra

– Unfolding methods capable of reconstructing all-particle and elemental spectra

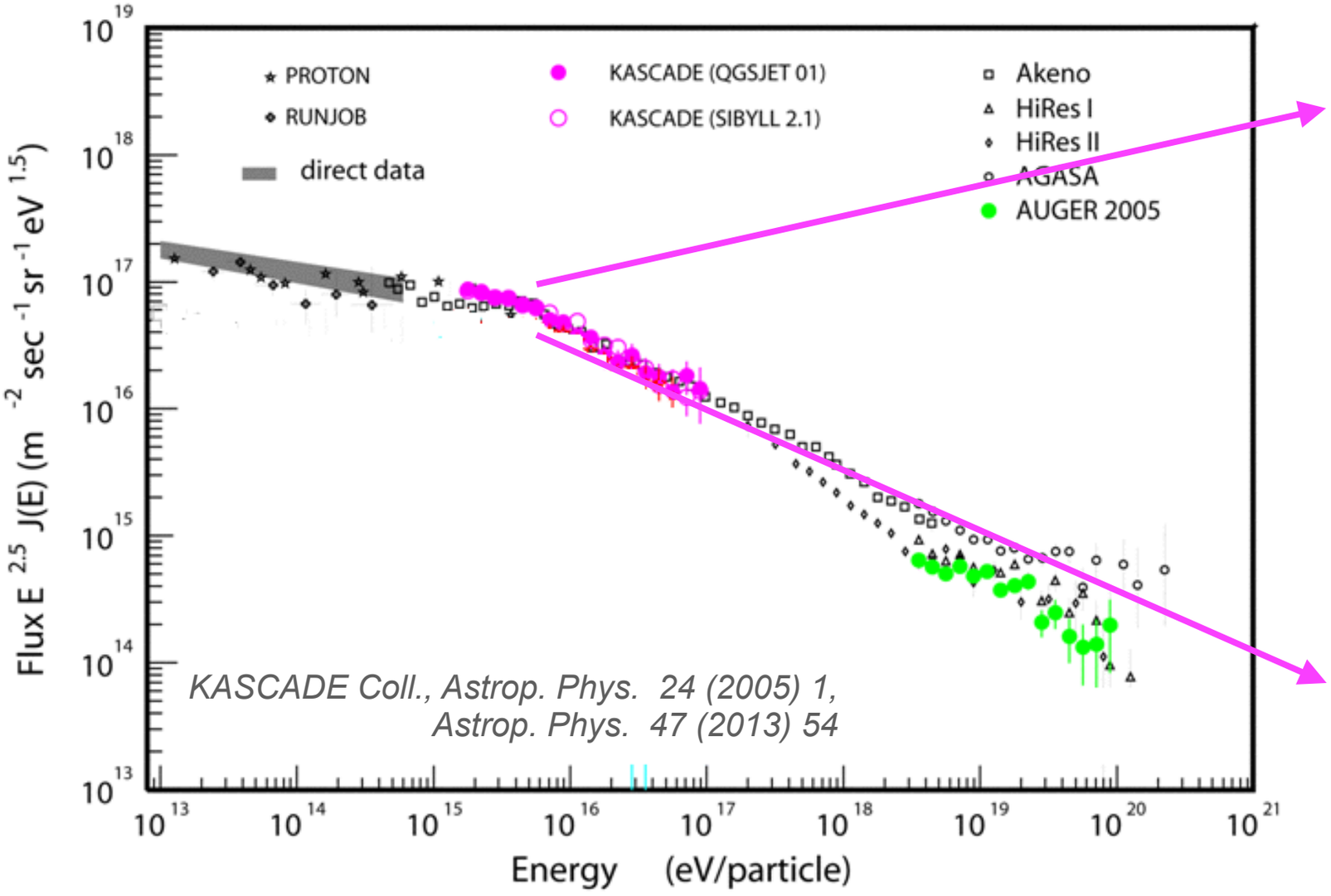


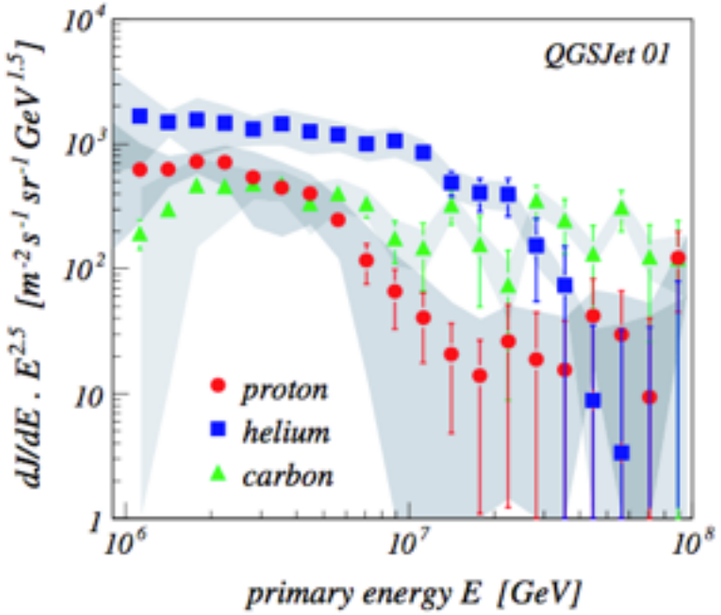



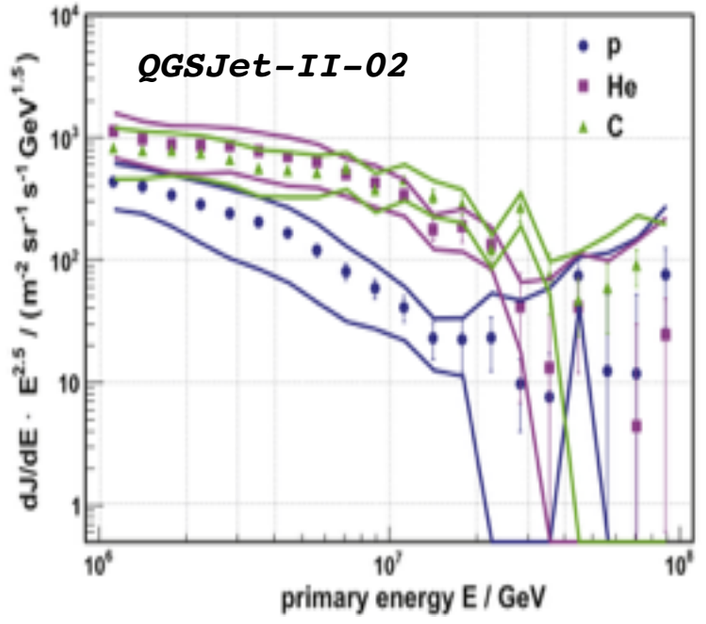

– Confirmation of the **Knee** feature at around **4-5 PeV**

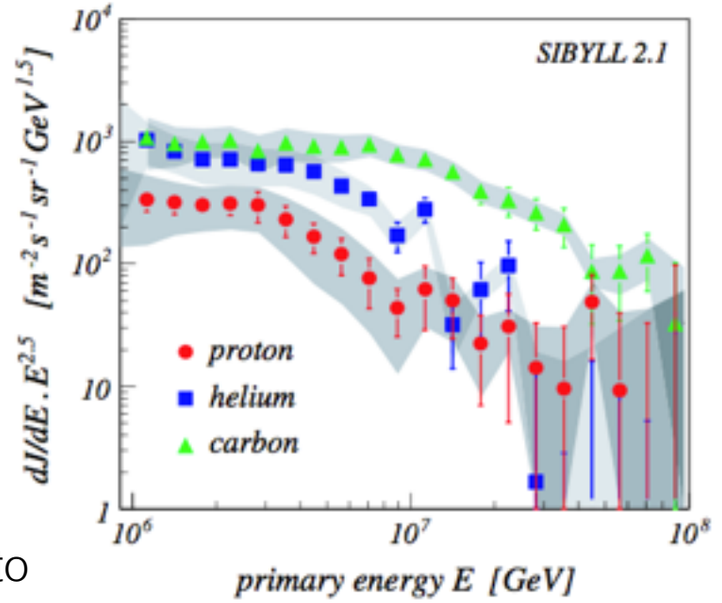
# KASCADE: Unfolding elemental spectra

- **Knee** due to a break in the spectrum of light components



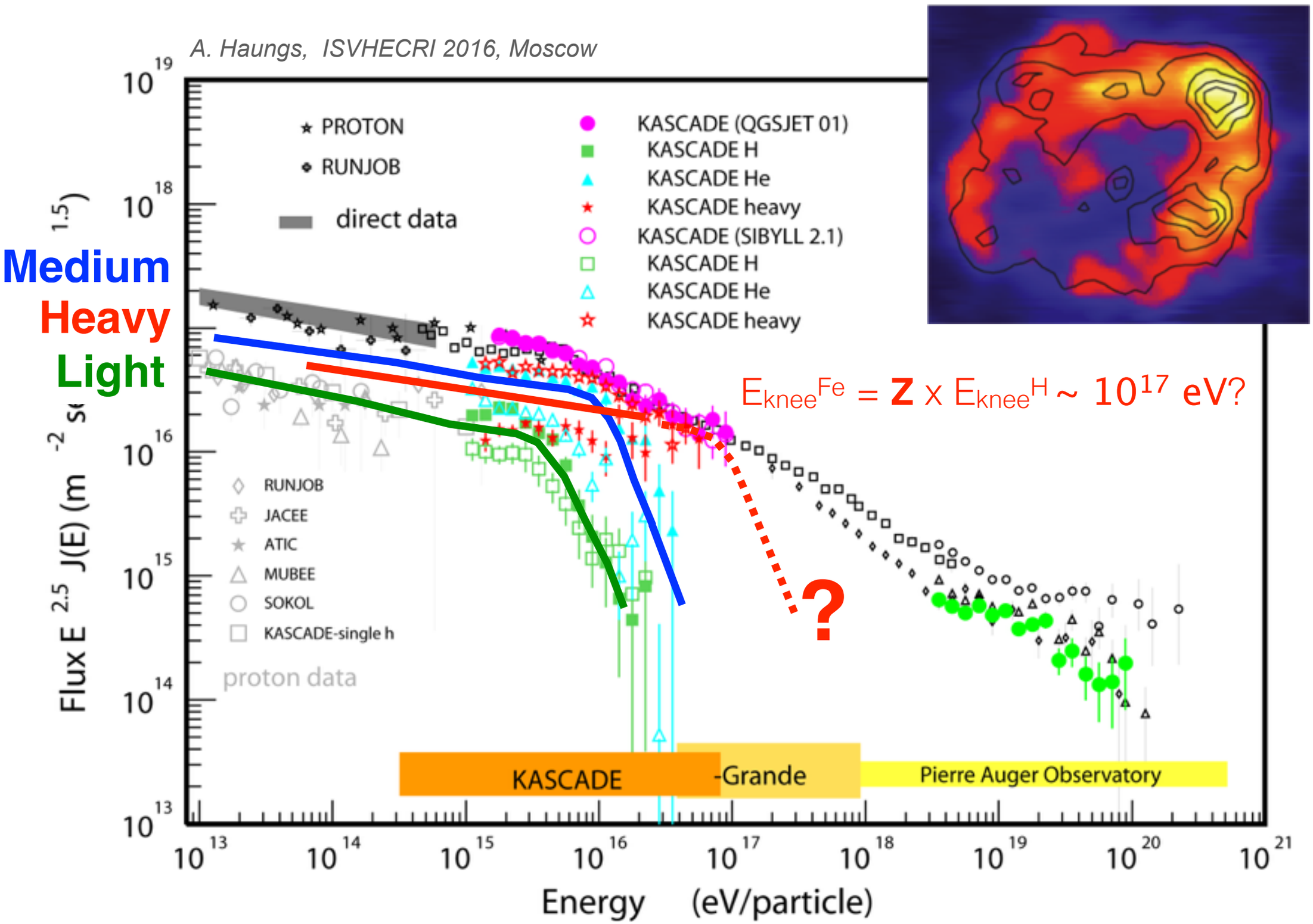




- Result is independent of the high-energy hadronic interaction model
- Relative abundances are model dependent

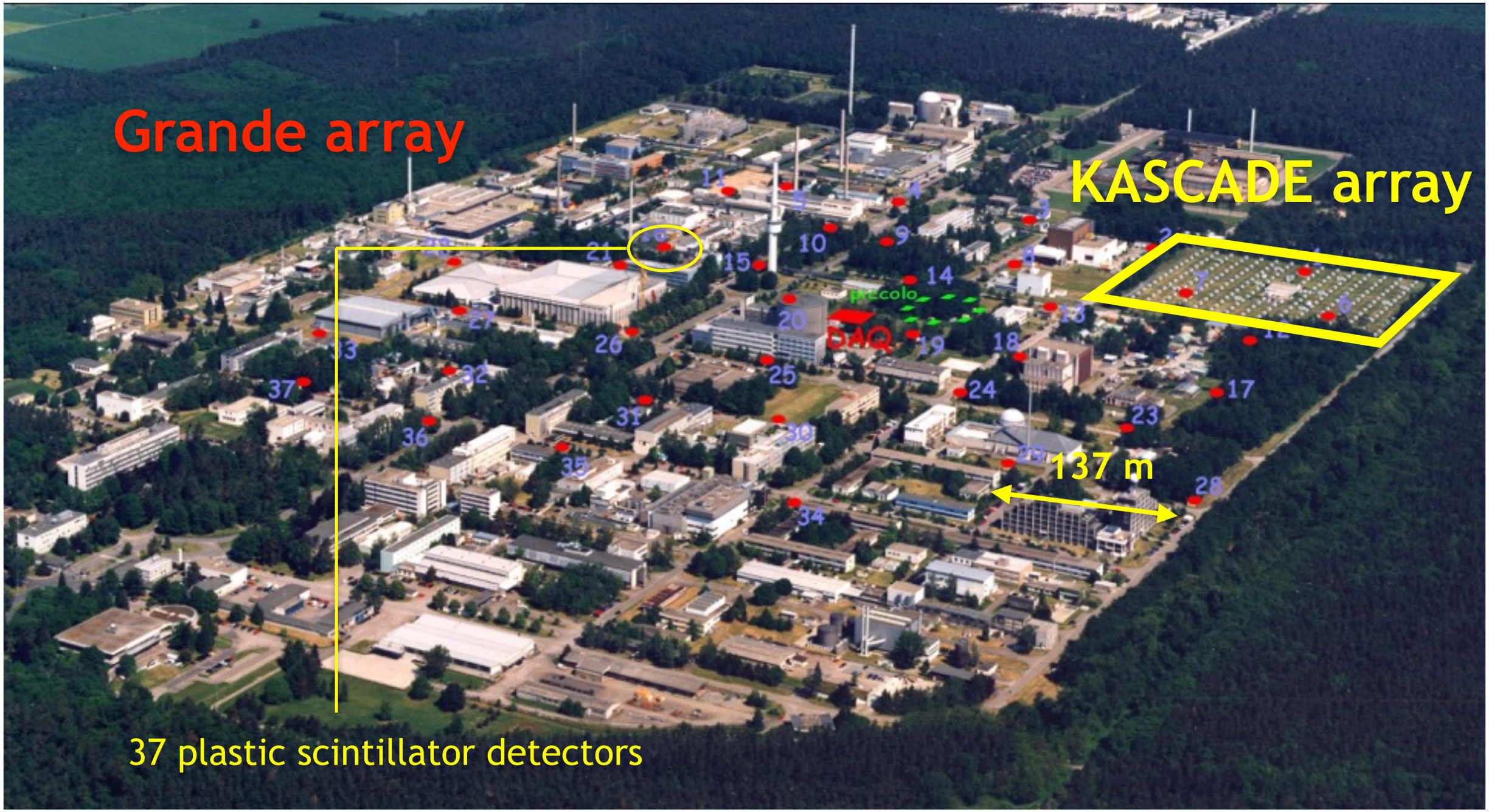
# KASCADE: rigidity dependence of individual knees?



# The KASCADE-Grande detector

E= 1 PeV - $10^{18}$ eV

A = 0.5 km$^2$




*W.D. Apel et al., NIMA 620 (2010) 490*

# The KASCADE-Grande detector

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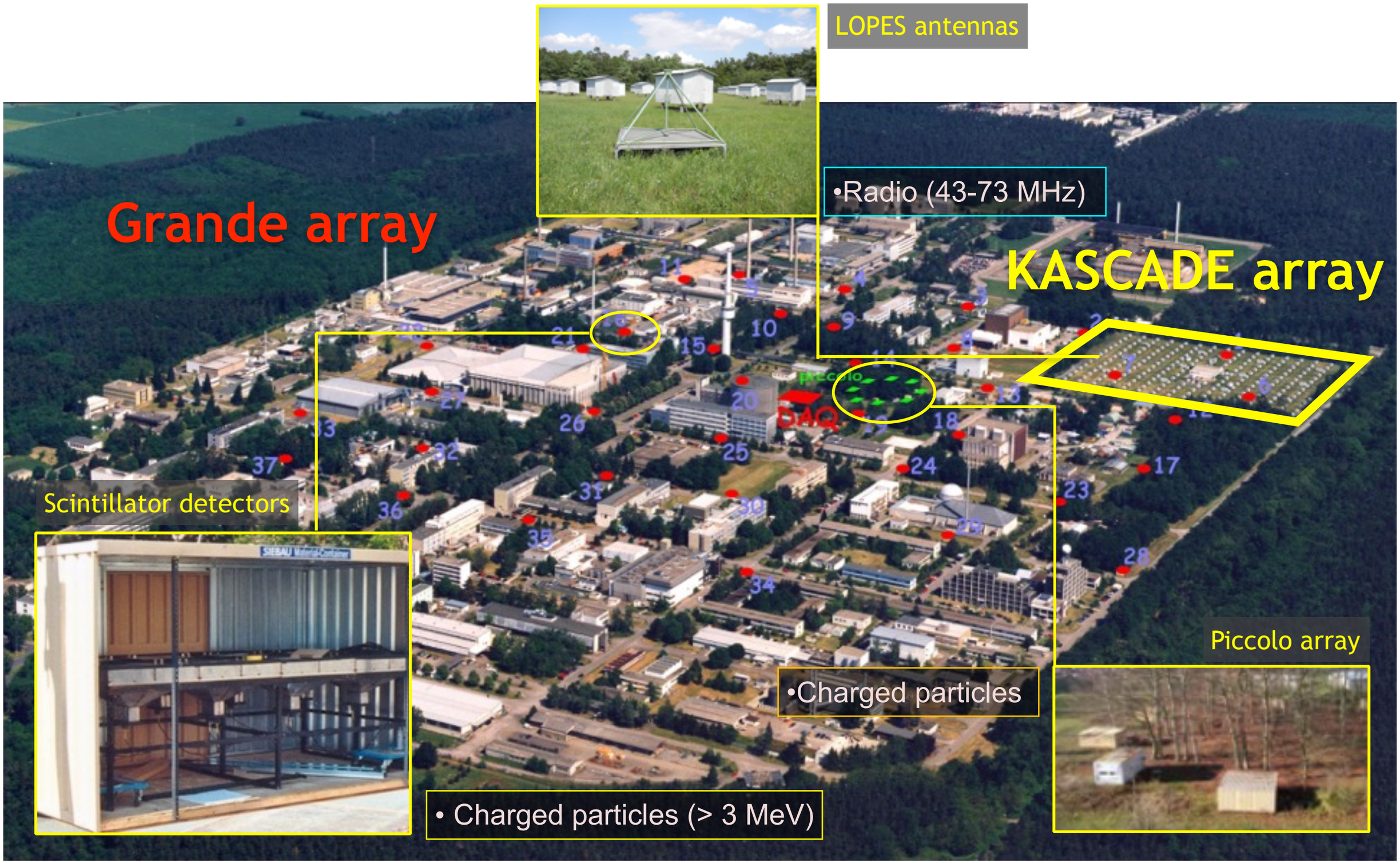


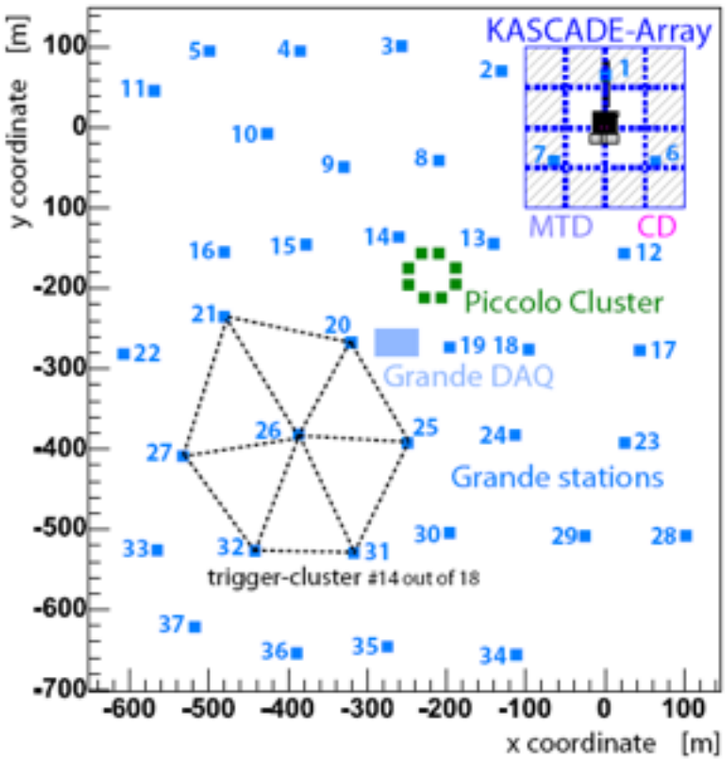

*H. Falcke et al., Nature 435 (2005) 313*

*W.D. Apel et al., NIMA 620 (2010) 490*

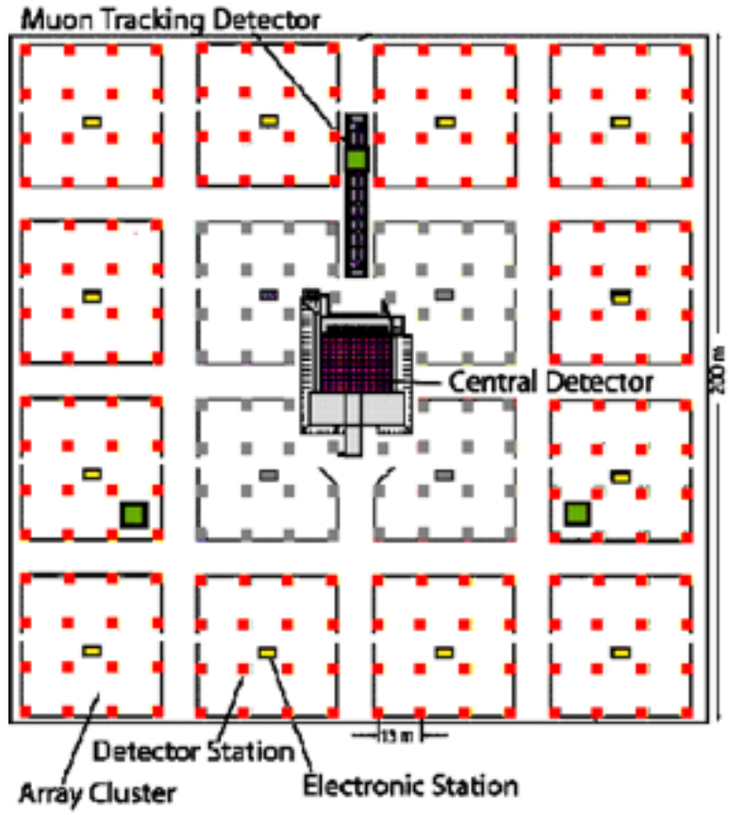
# The KASCADE-Grande detector

# E= 1 PeV - $10^{18}$ eV

1. Grande provides
   **$N_{ch}$**: Number of charged particles




2. KASCADE provides
   **$N_{\mu}$** : Number of muons



# The KASCADE-Grande detector

# E= 1 PeV - $10^{18}$ eV

1. Grande provides
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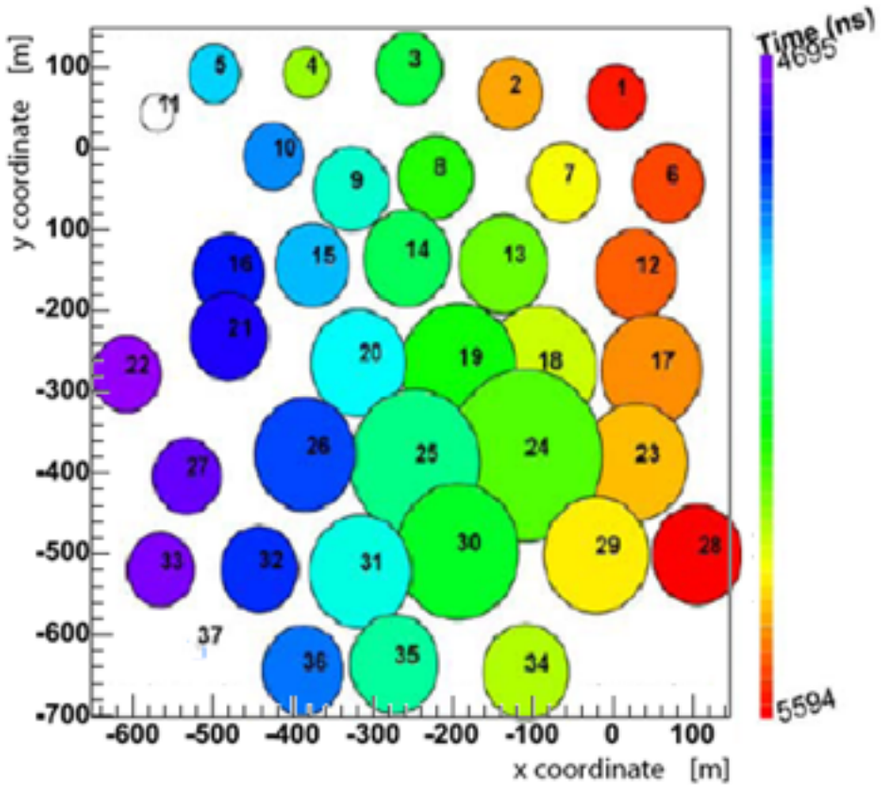


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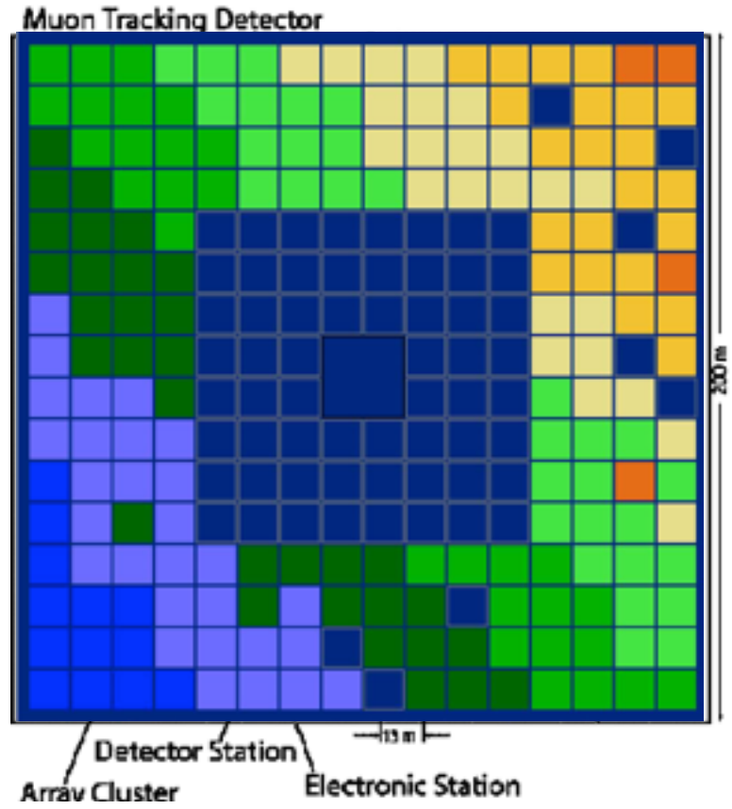
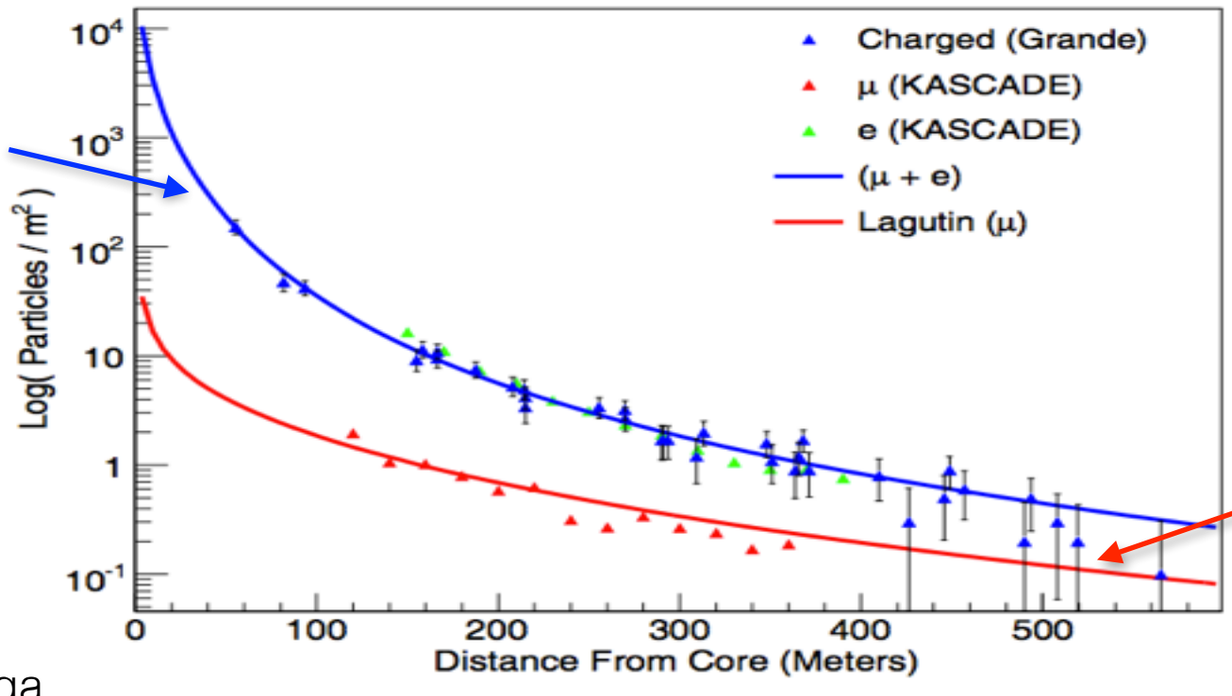
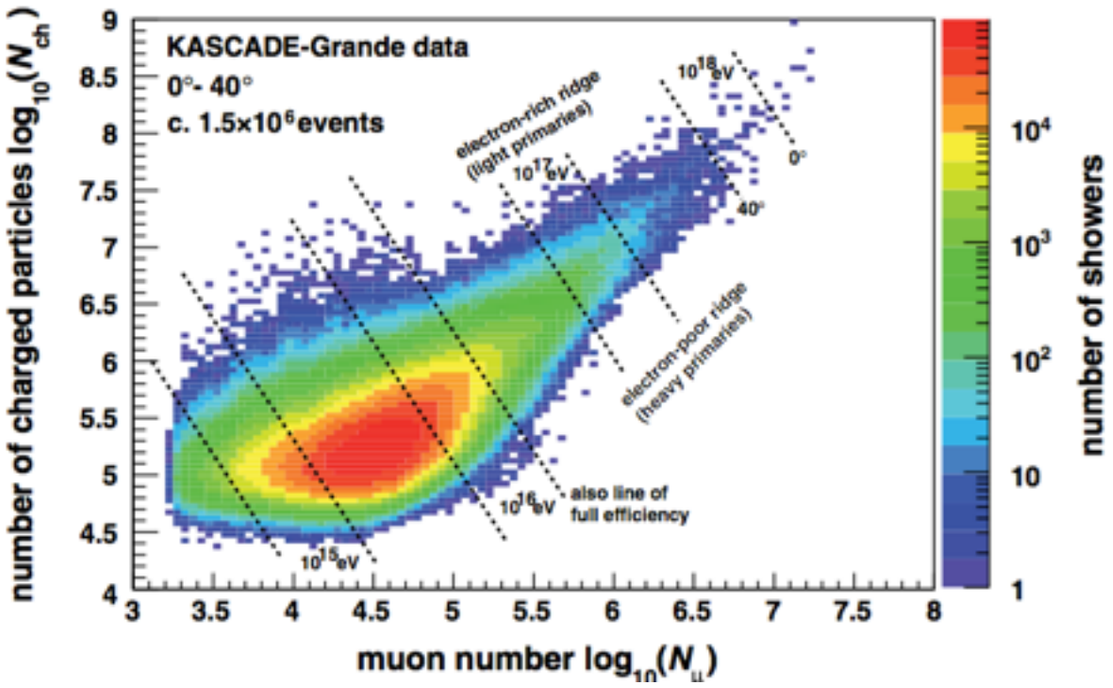



Fit to data:
$\rho_{ch}(r) = N_{ch} \cdot f_{ch}^{NKG}(s, r)$




Fit to data:
$\rho_{\mu}(r) = N_{\mu} \cdot f_{\mu}^{Lagutin}(r)$

# KASCADE-Grande: all-particle spectrum



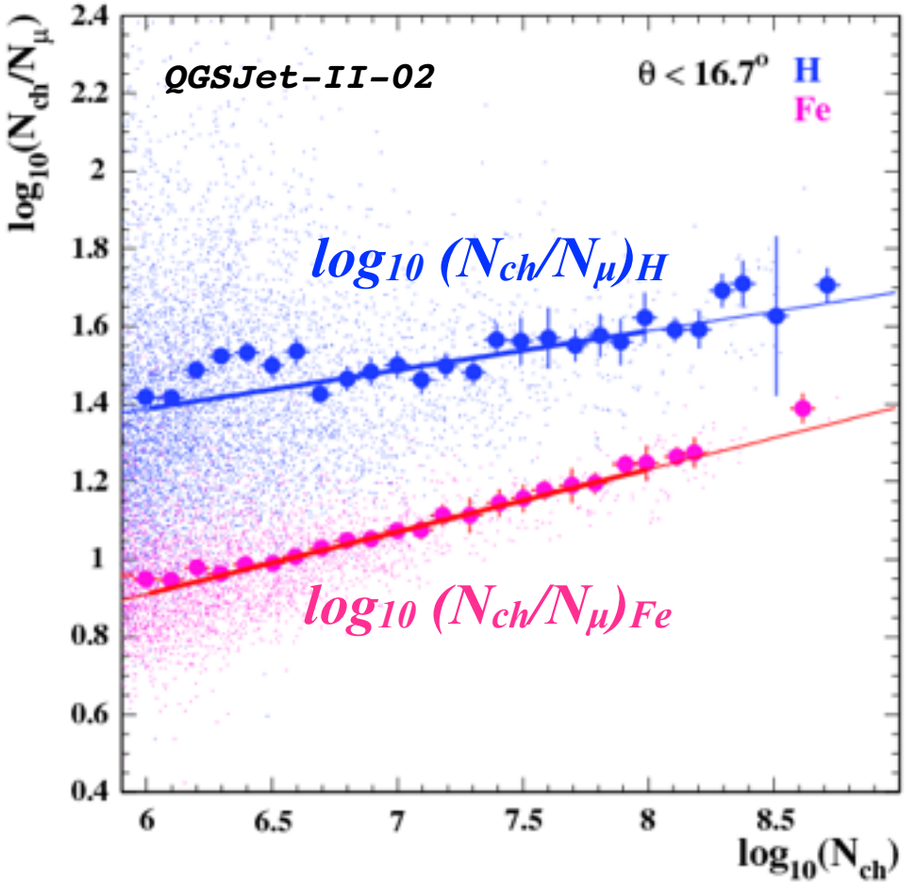

Energy calibration with MC simulations

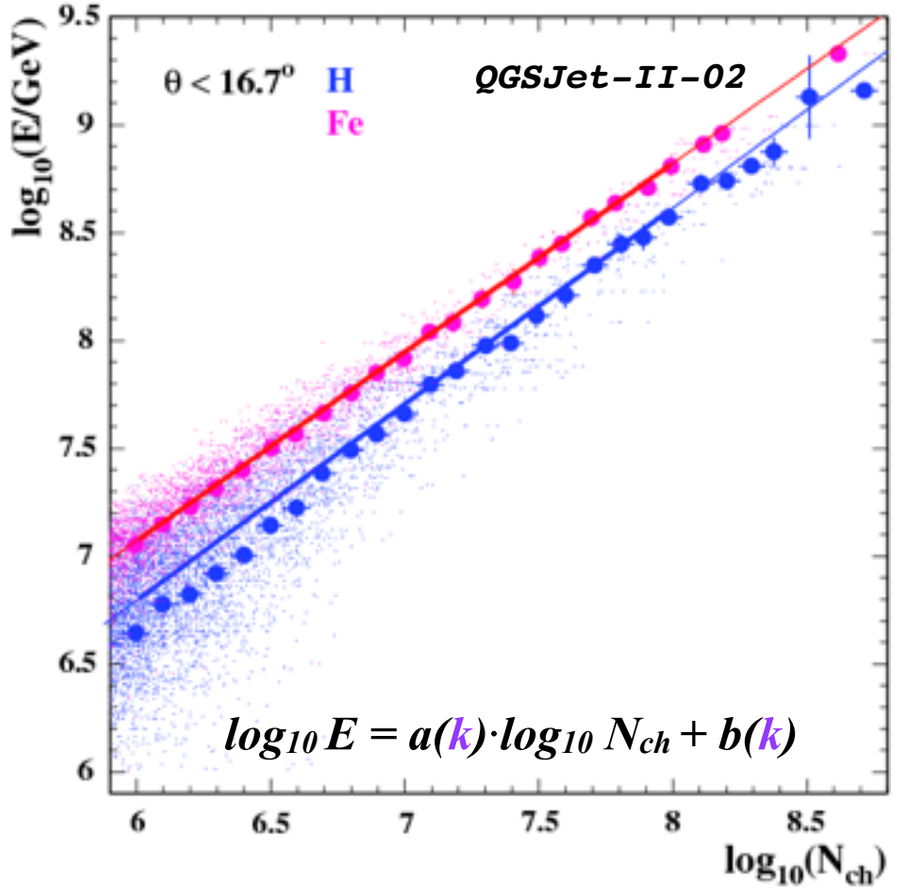
$$\log_{10} E = a(k)\cdot \log_{10} N_{ch} + b(k)$$

where:

$$k(N_{ch}, N_\mu) = \frac{\log_{10}(N_{ch}/N_\mu) - \log_{10}(N_{ch}/N_\mu)_H}{\log_{10}(N_{ch}/N_\mu)_{Fe} - \log_{10}(N_{ch}/N_\mu)_H}$$

with: $k = 0$ (H) $k = 1$ (Fe)

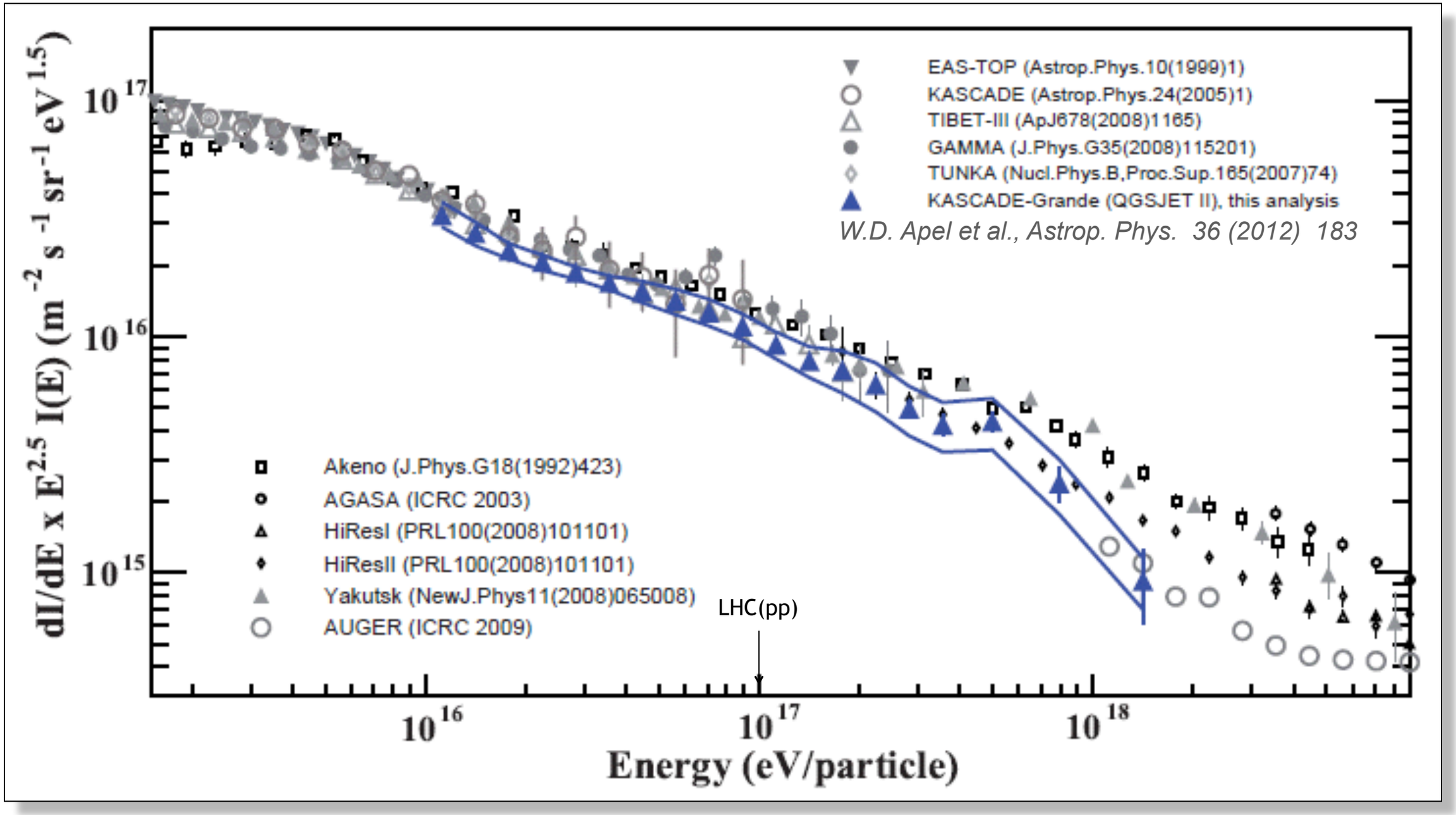



*W.D. Apel et al., Astrop. Phys. 36 (2012) 183*

# KASCADE-Grande: all-particle spectrum

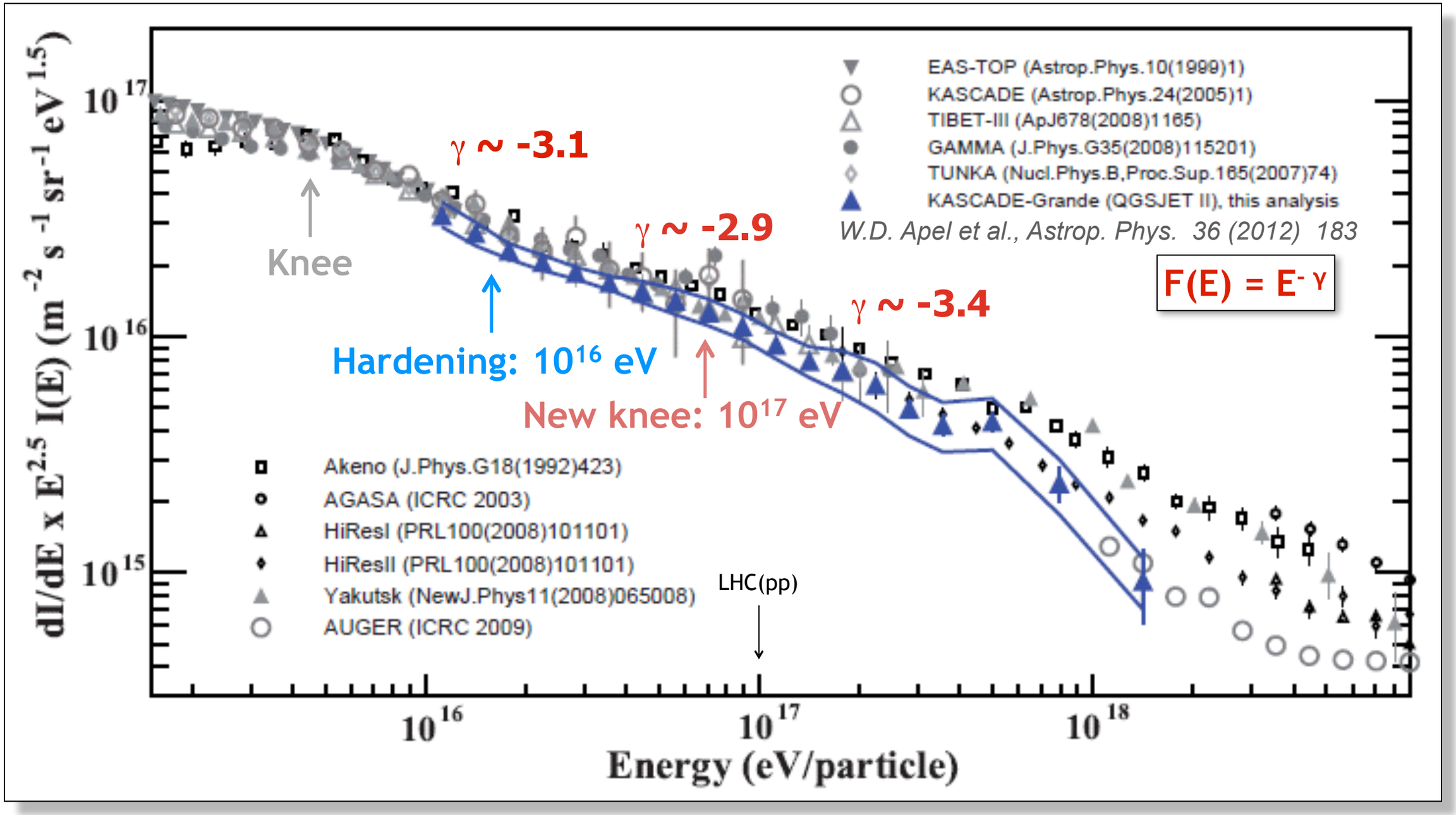
– Spectrum does **not** follow a **simple power-law**




Corrected for migration effects

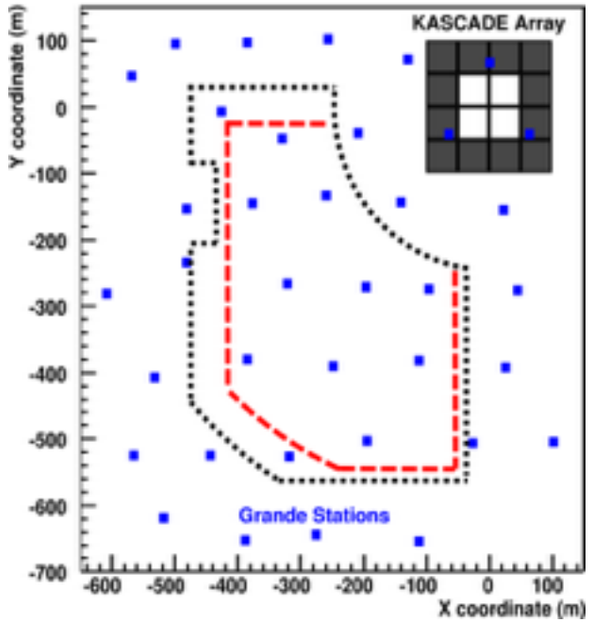
# KASCADE-Grande: all-particle spectrum

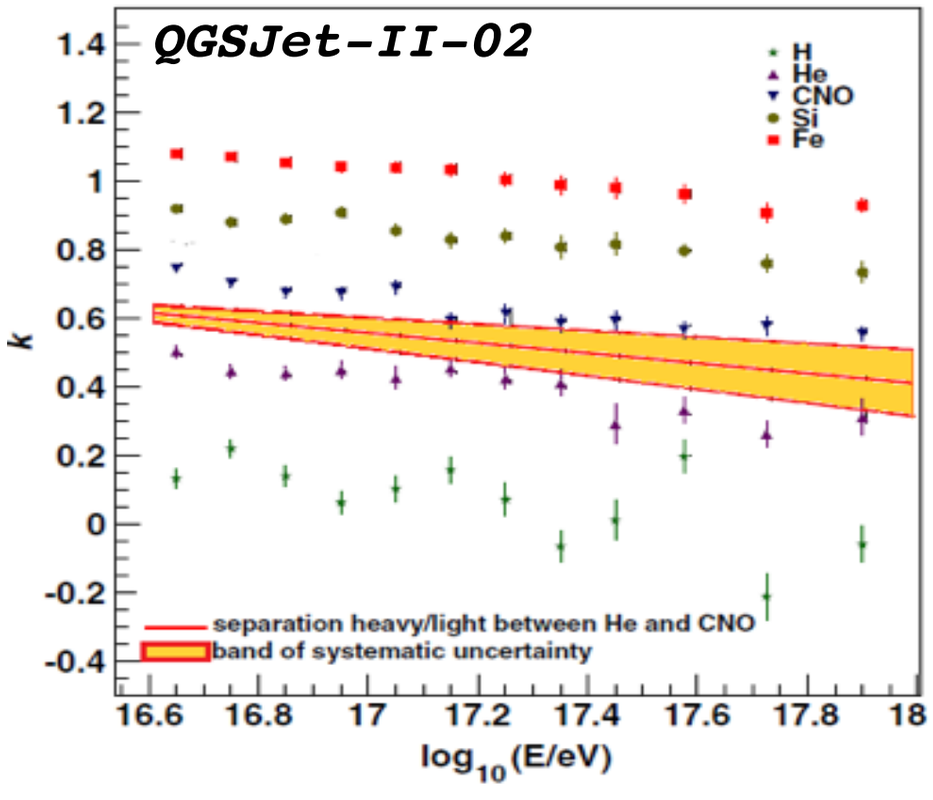
– Observation of two **new structures**



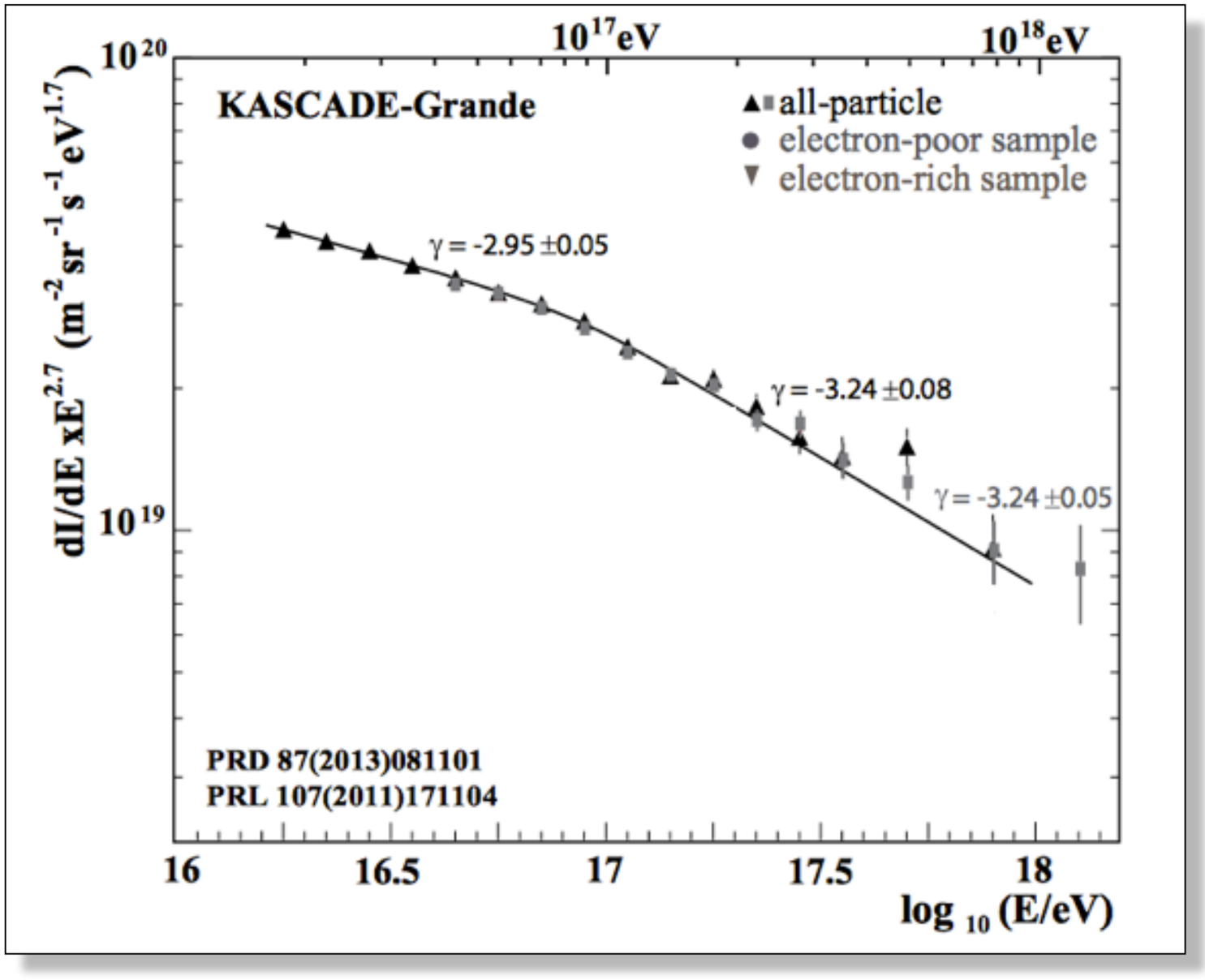

Corrected for migration effects

# KASCADE-Grande: light/heavy mass groups



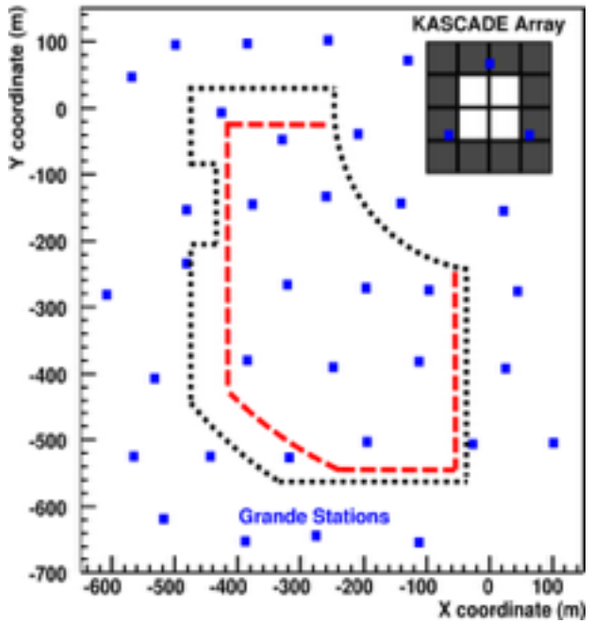




– Separation into a light and a heavy components



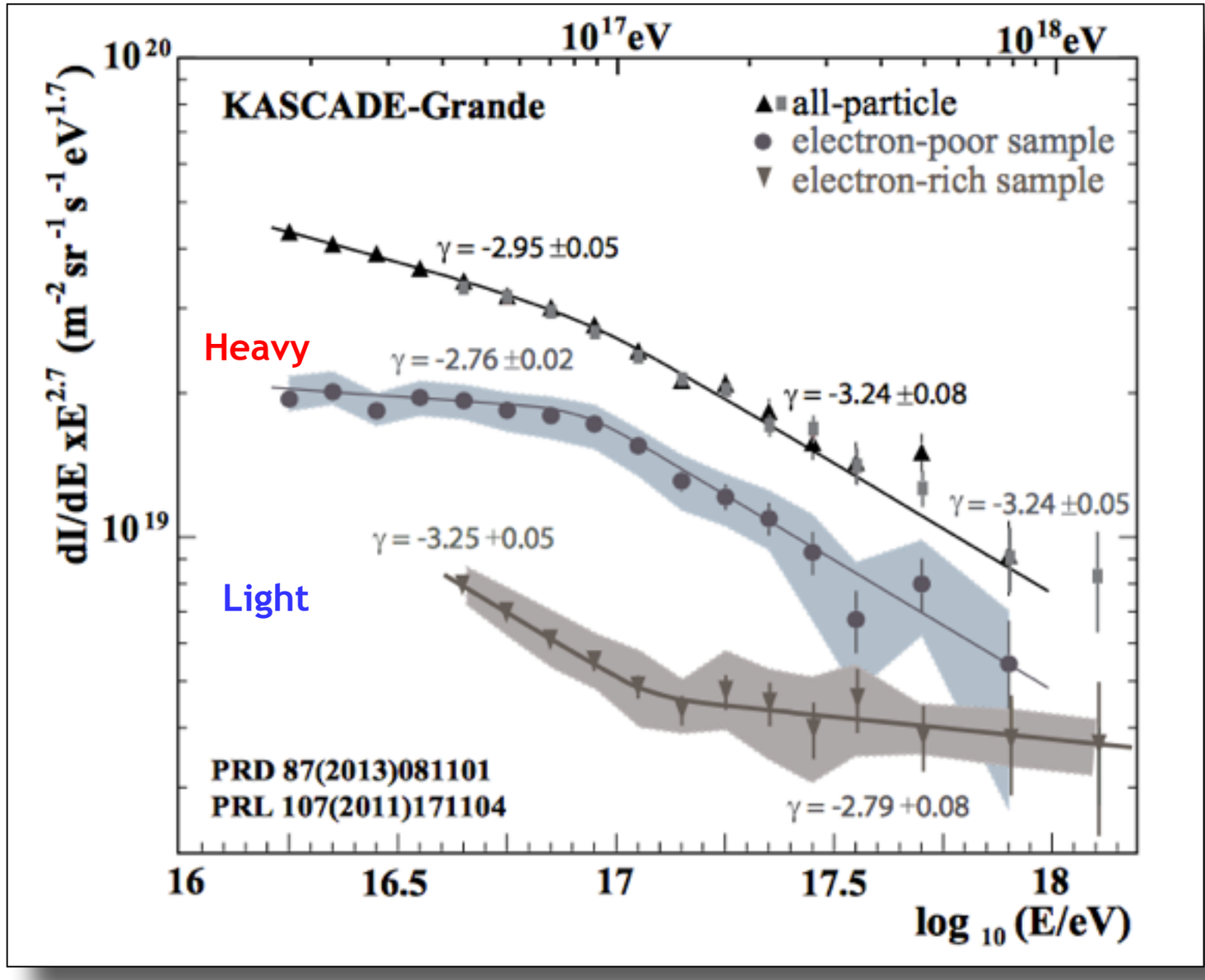

No correction for migration effects

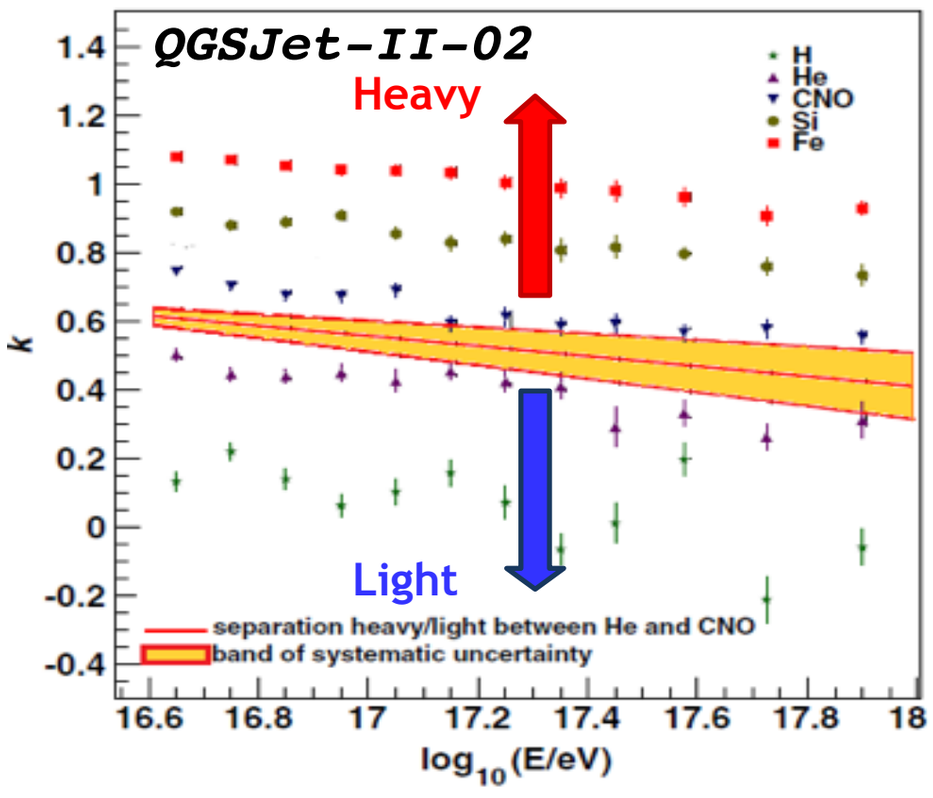
# KASCADE-Grande: light/heavy mass groups




Heavy Knee: 8 x $10^{16}$ eV

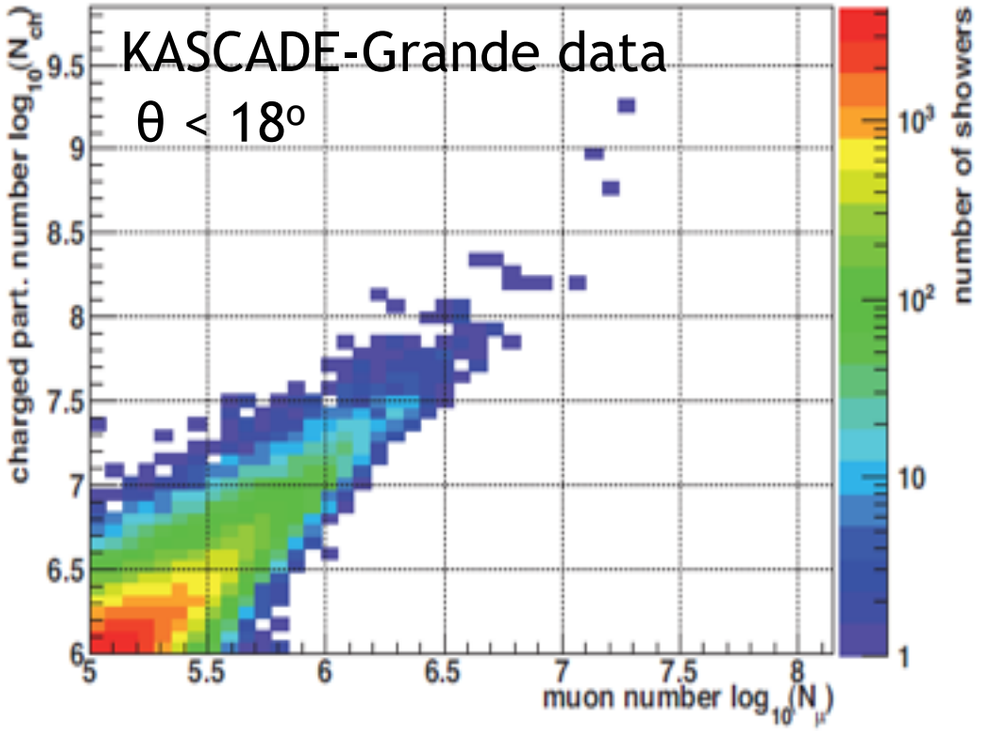
Light Ankle: $10^{17}$ eV




No correction for migration effects

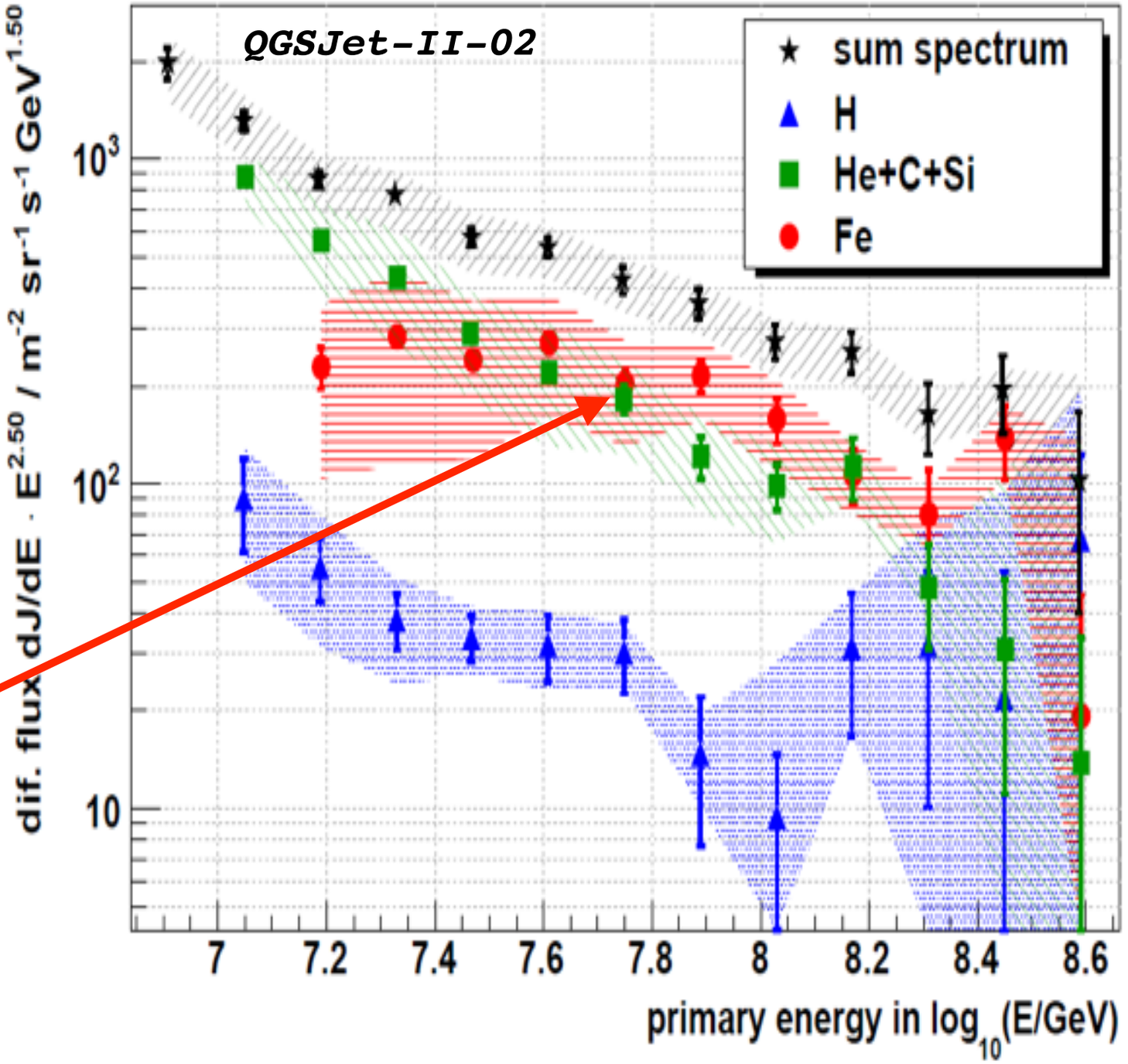
# KASCADE-Grande: Unfolding elemental spectra




- **Separation** into **three** different mass groups.

- Iron Knee ~ 80 PeV

**In agreement with a Z dependence of the knees.**

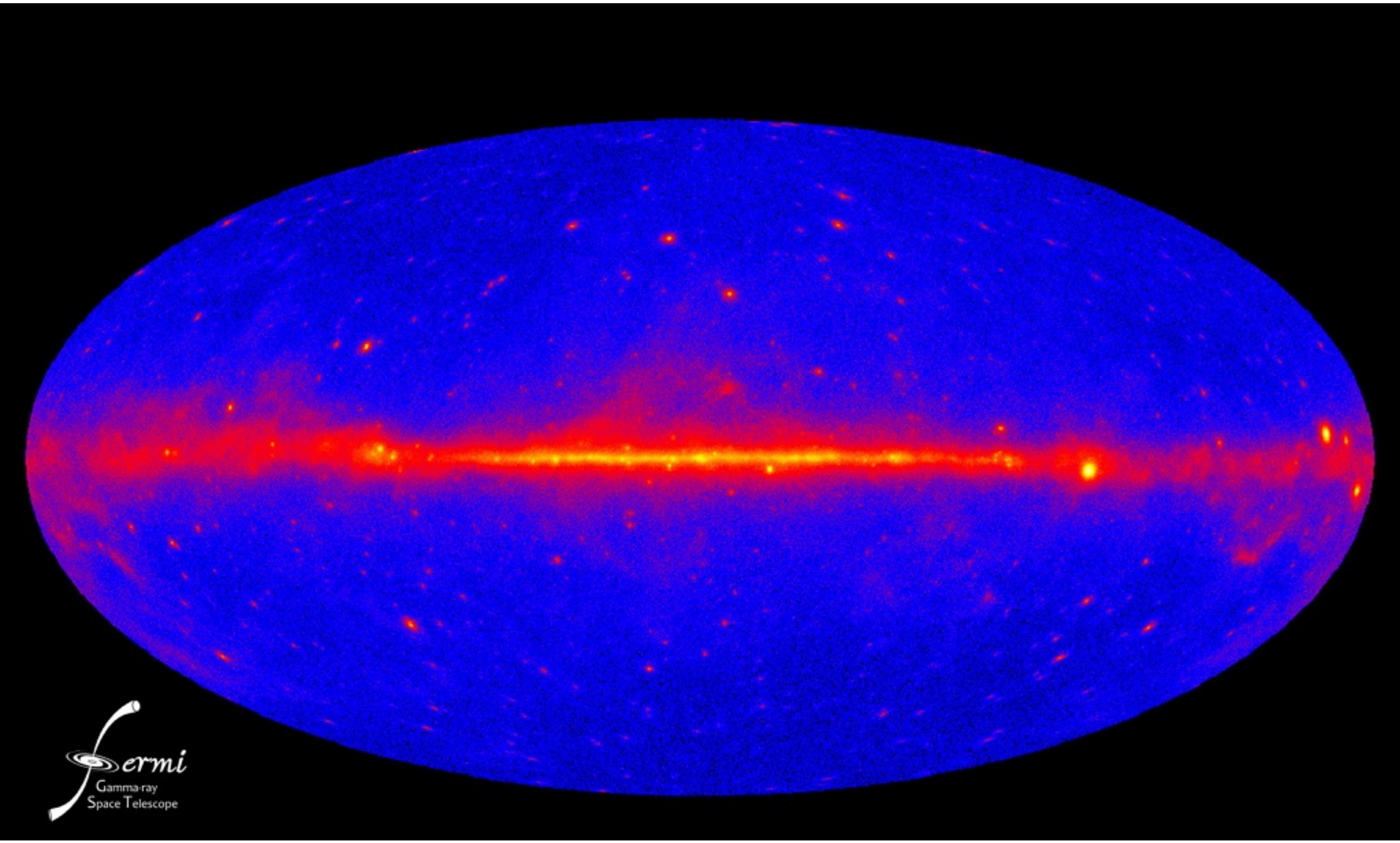



D. Fuhrmann et al., Astrop. Phys. 47 (2013) 54

# KASCADE-Grande: Mission Accomplished !!

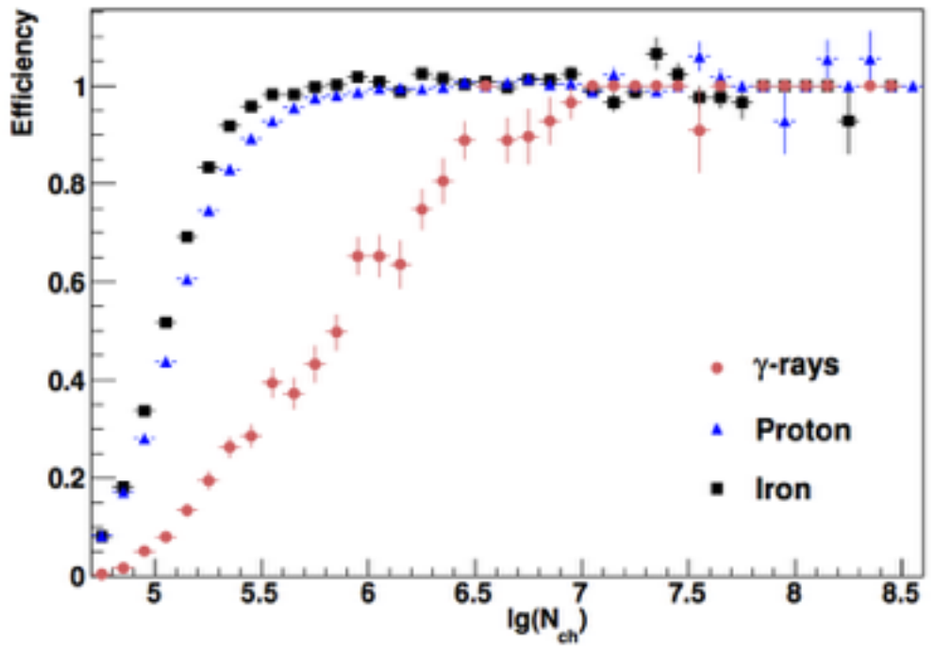
- **KASCADE-Grande** has **terminated data acquisiton**
- Collaboration still continues detailed data analysis

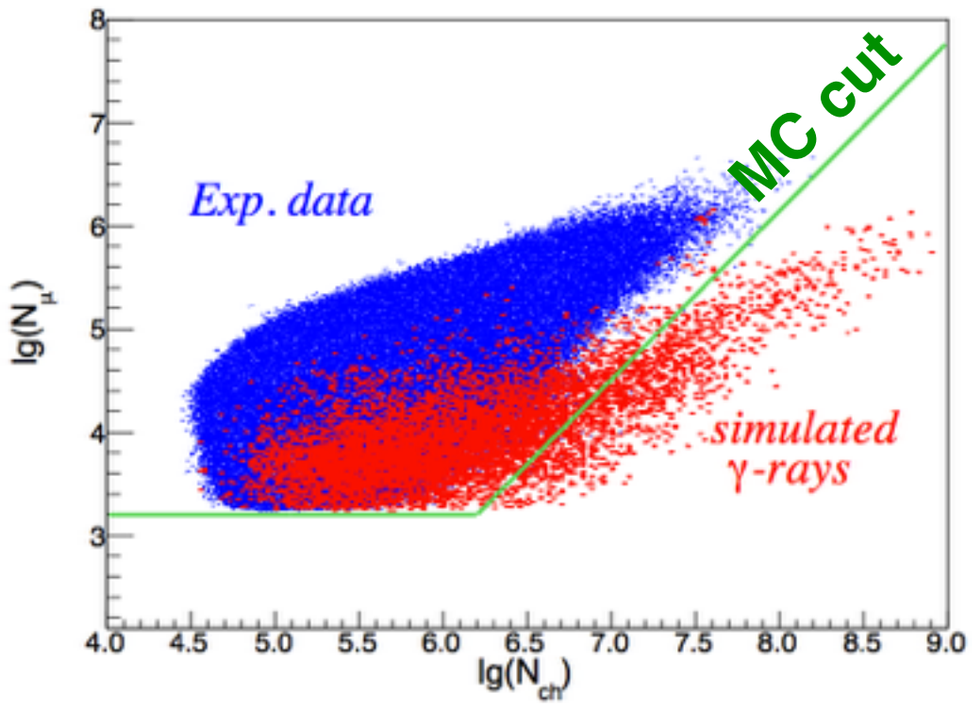
# KASCADE-Grande: Gamma ray searches

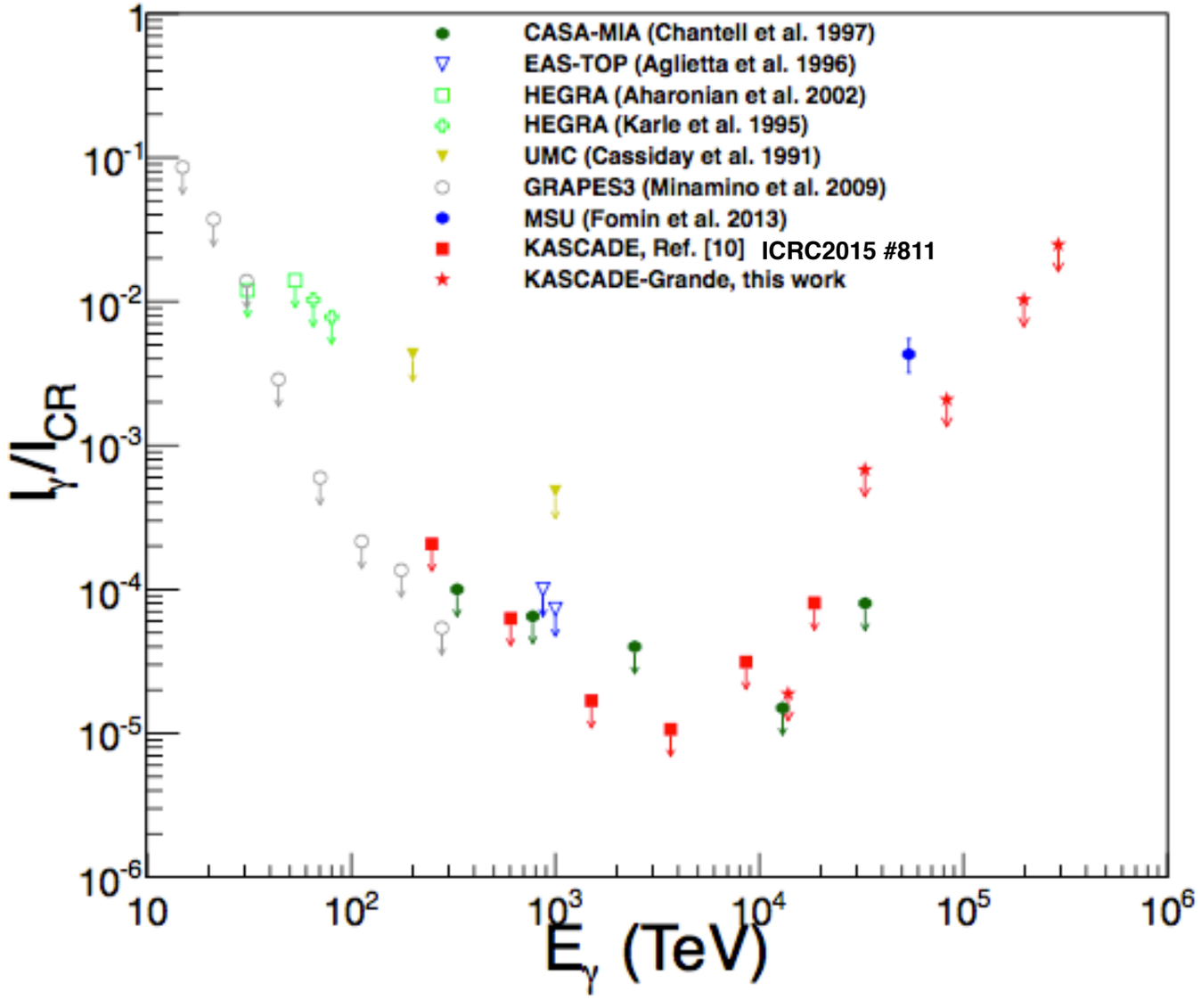


# KASCADE-Grande: Gamma ray searches

– Limits on the ratio of diffuse gamma-ray flux to cosmic ray flux



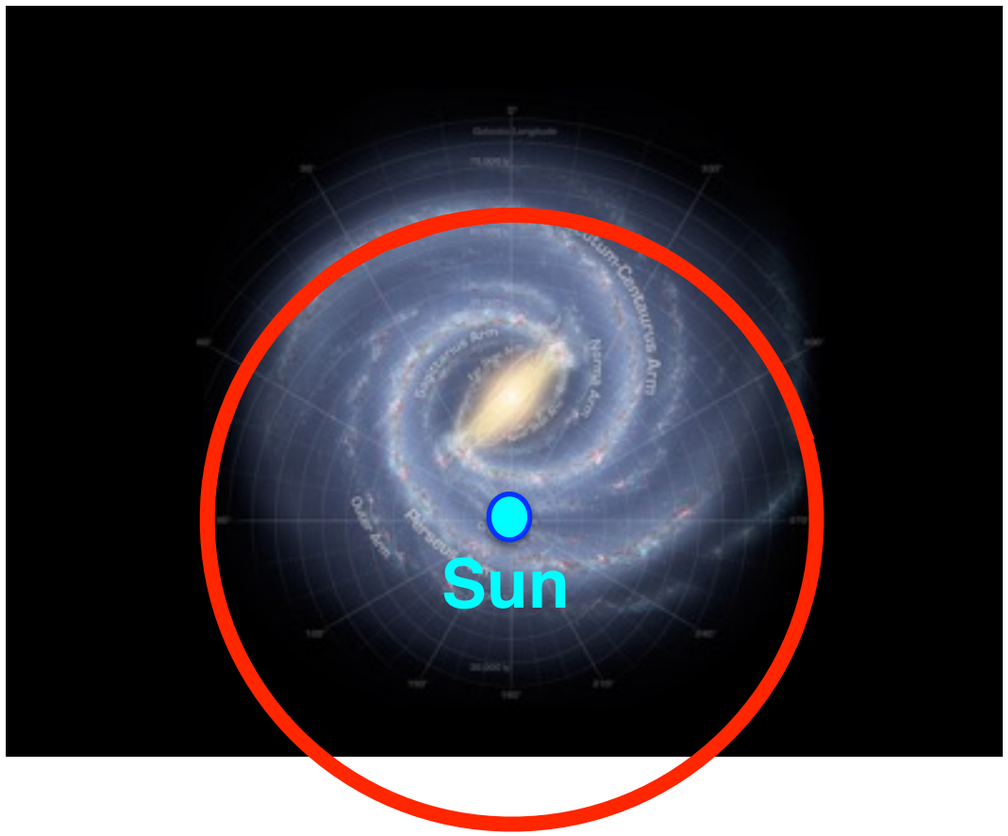



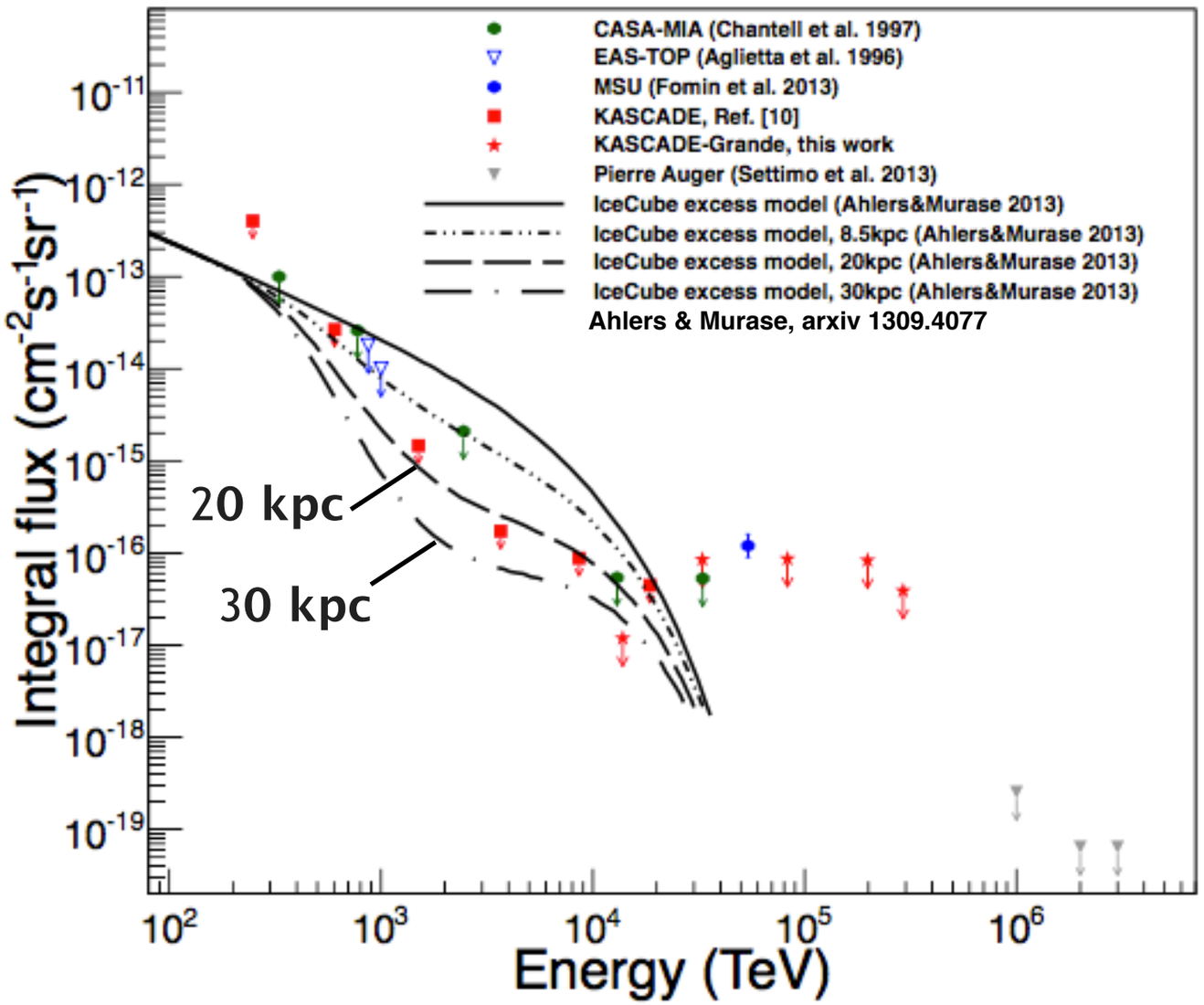

*D. Kang et al., PoS(ICRC2015) 810; Paper in progess*

# KASCADE-Grande: Gamma ray searches

– Limits on the diffuse gamma-ray flux

- Constrain origin of **ICECUBE neutrinos.**
- **Reject** model of **ICECUBE excess** coming **from < 20 kpc** in the galaxy.

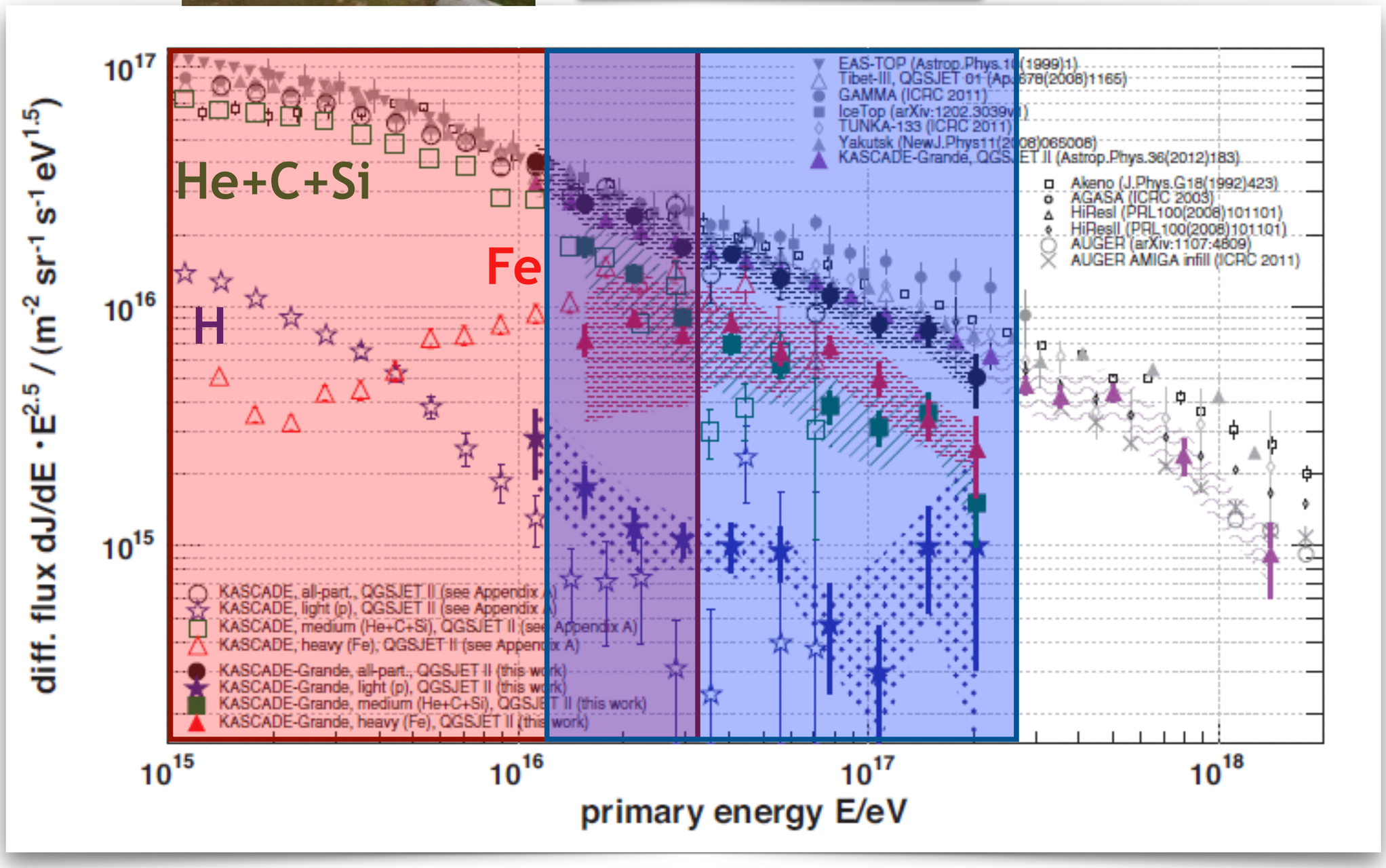


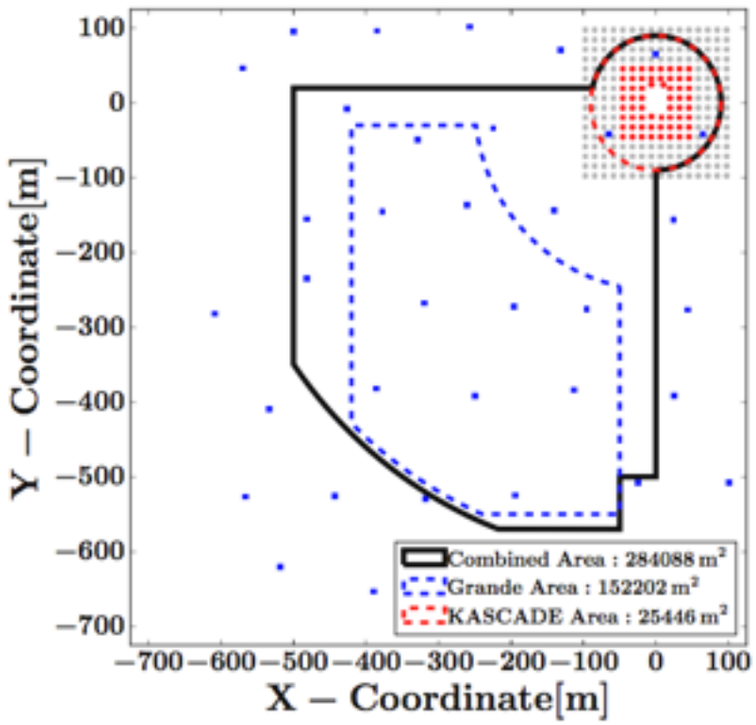

*D. Kang et al., PoS(ICRC2015) 810; Paper in progess*

# KASCADE and KASCADE-Grande mass group spectra

– Based on different **EAS reconstruction procedures**



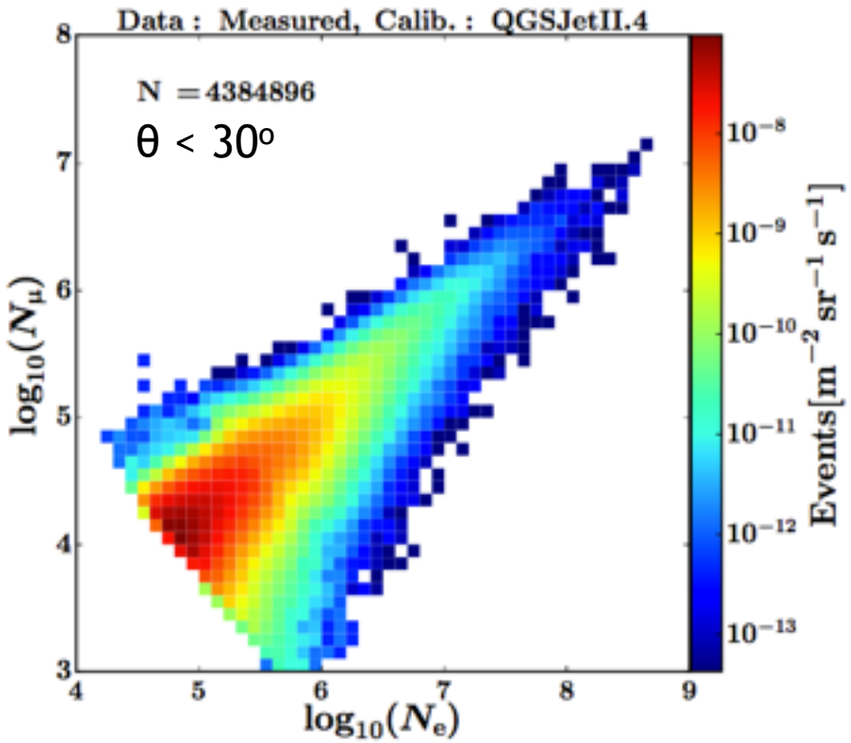
# Combined KASCADE--Grande analysis




– Use data from both arrays in the **same EAS reconstruction procedure.**

– Advantages:

- Eliminates systematic differences due to distinct reconstruction procedures.

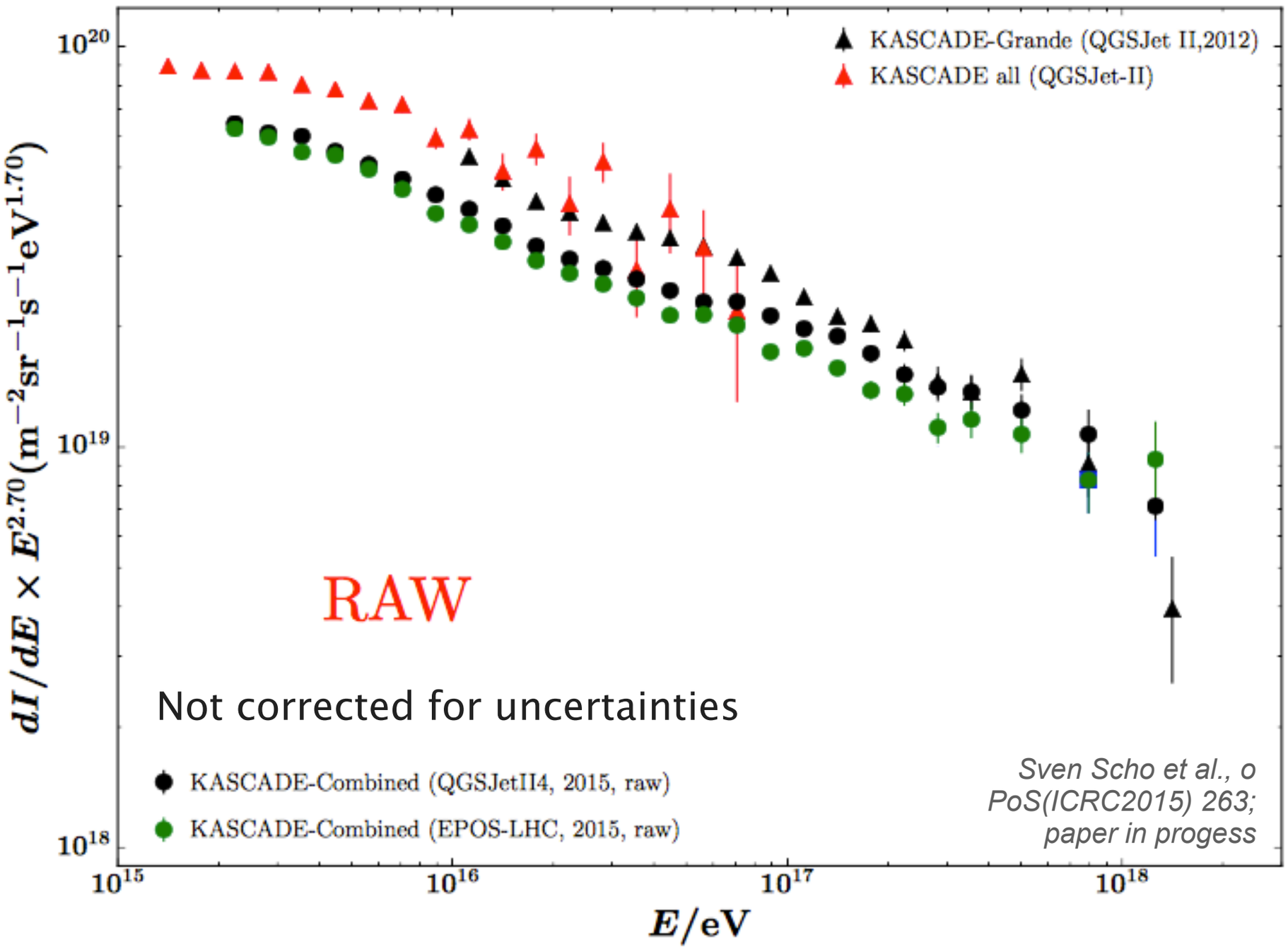



- Increases effective area
- Improves accuracy.
- Provides spectra and composition over the combined energy range.

*Sven Schoo et al., paper in progess*

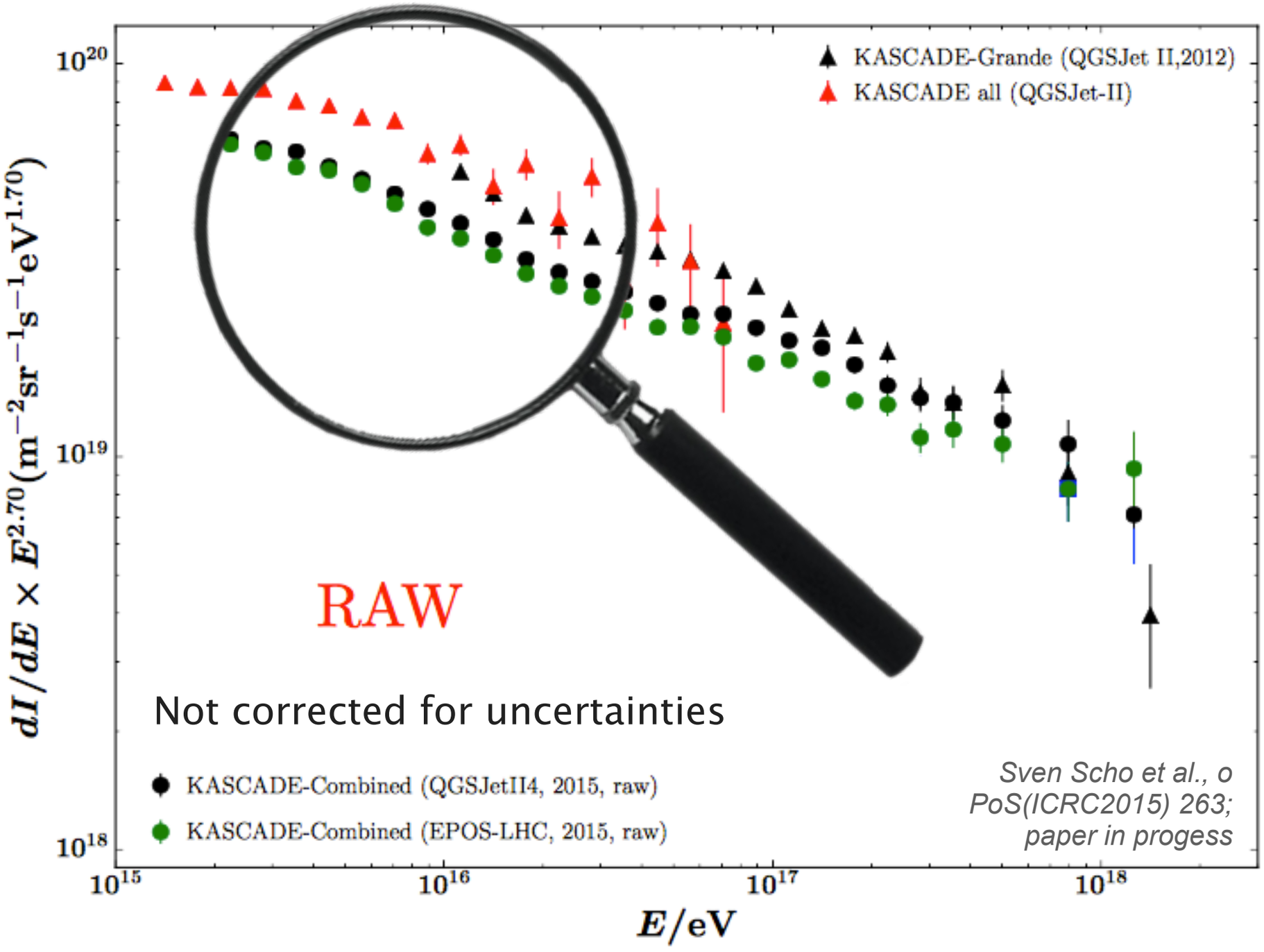
# Combined KASCADE-Grande analysis: all-particle spectrum

- Result extended over three energy decades
- **Shape** is retained



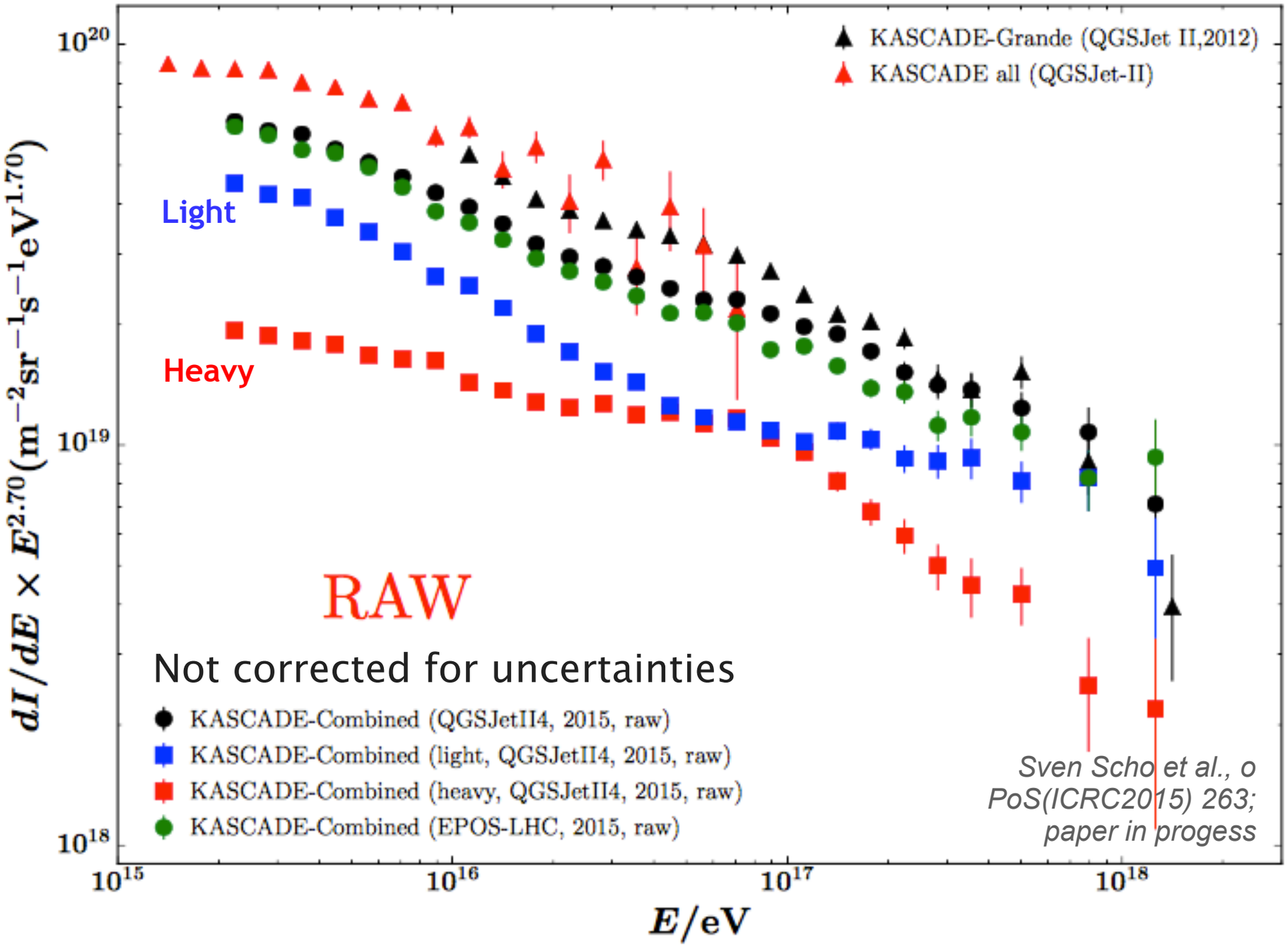
# Combined KASCADE-Grande analysis: all-particle spectrum

- Result extended over three energy decades
- **Shape** is retained
- **Post-LHC models**: Lower flux at LE's



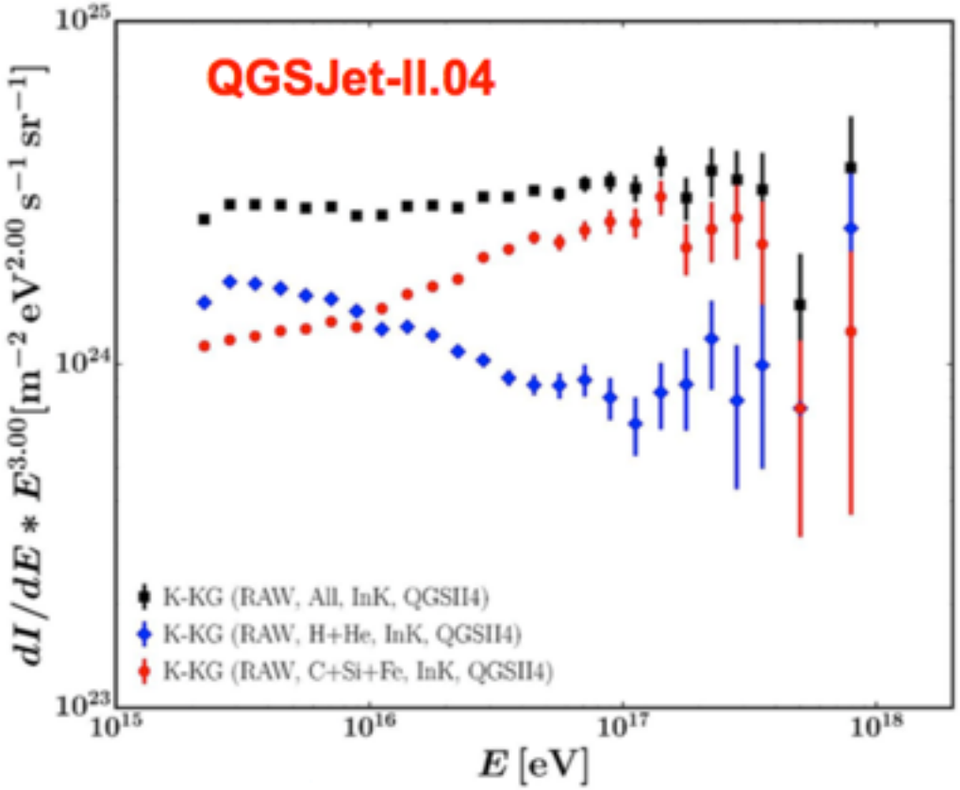
# Combined KASCADE-Grande analysis: mass group spectra

- Result extended over three energy decades
- Main **structures** are still observed

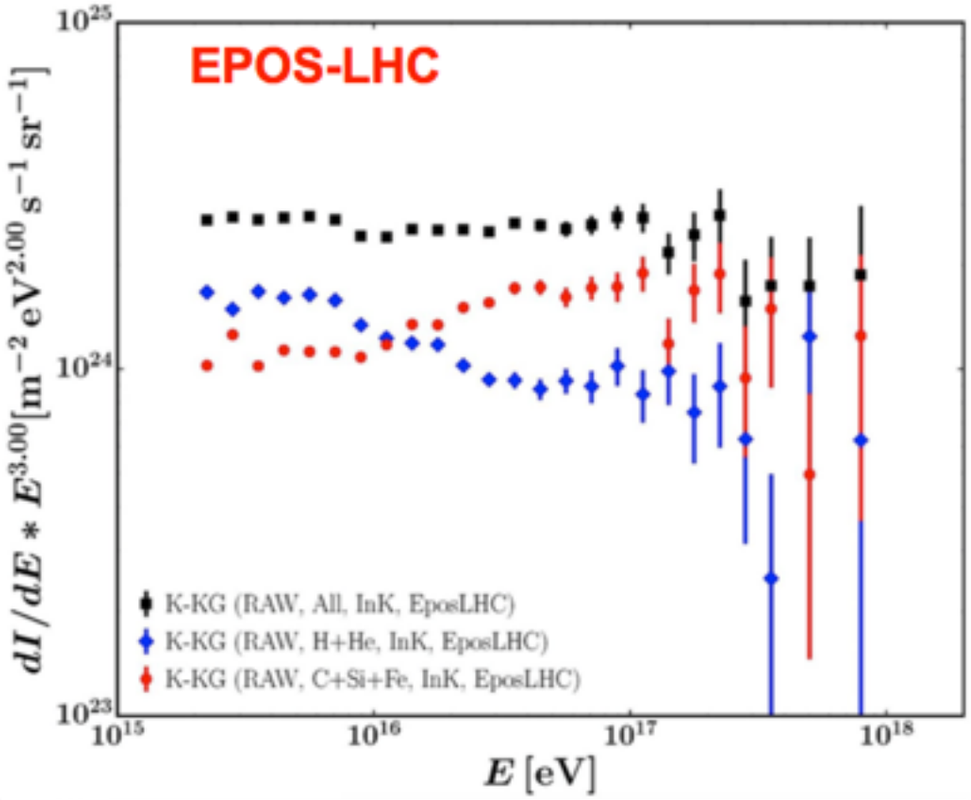


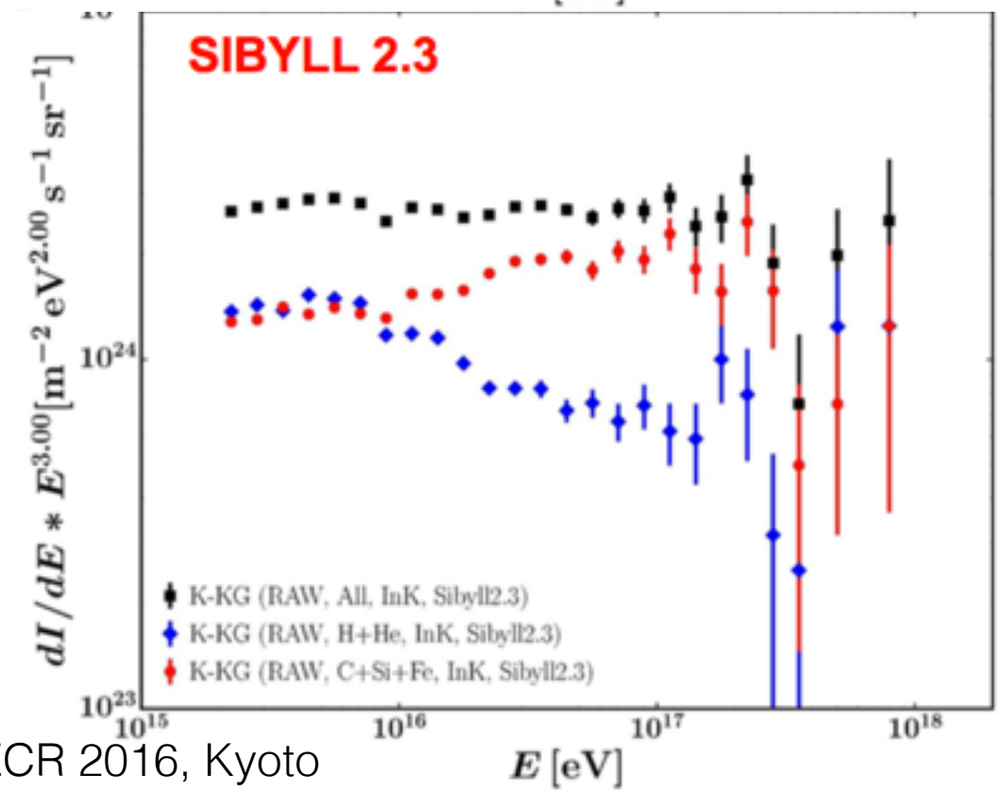
# Combined KASCADE-Grande analysis: mass group spectra

## Post-LHC models




Events located in **KASCADE**



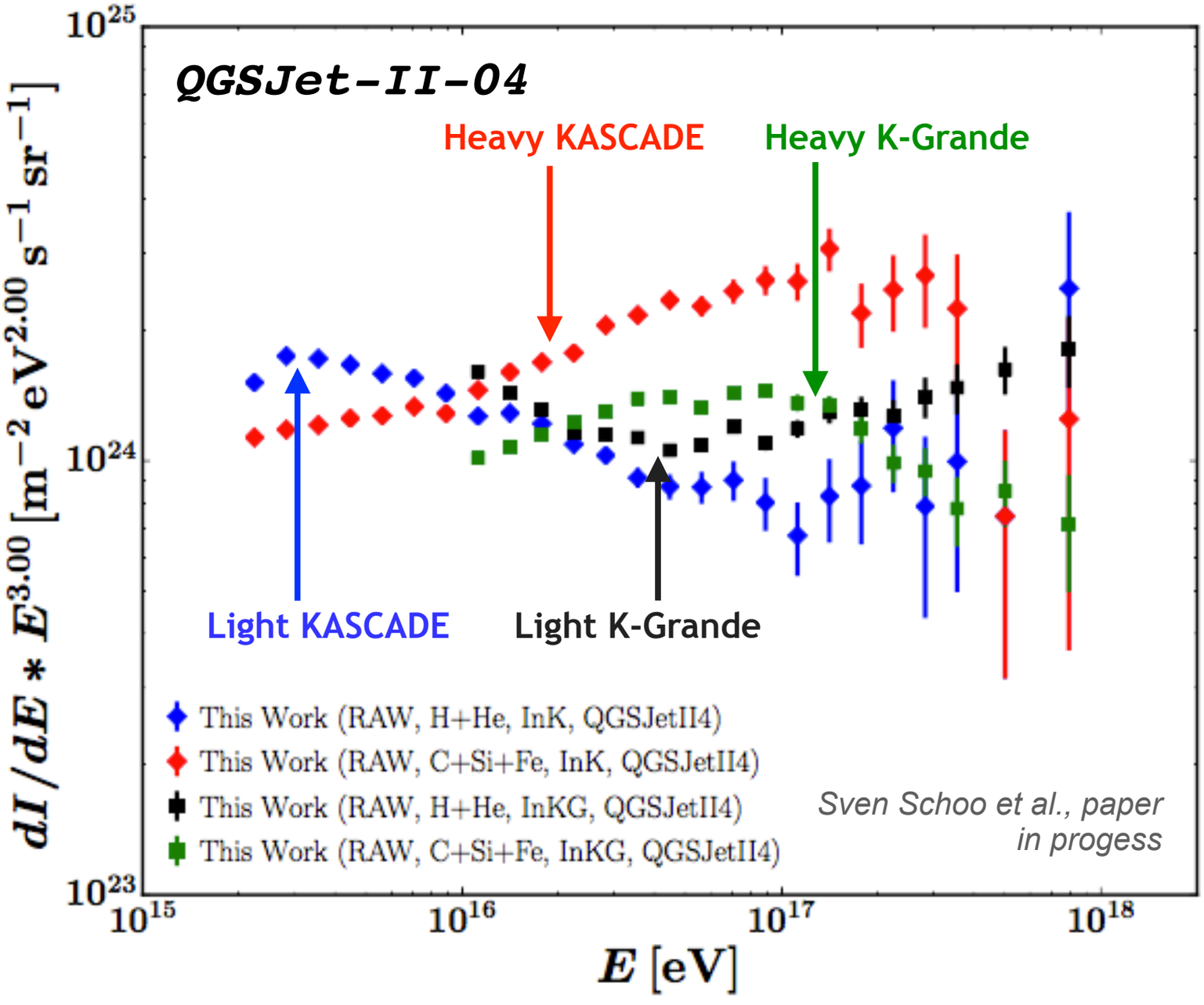



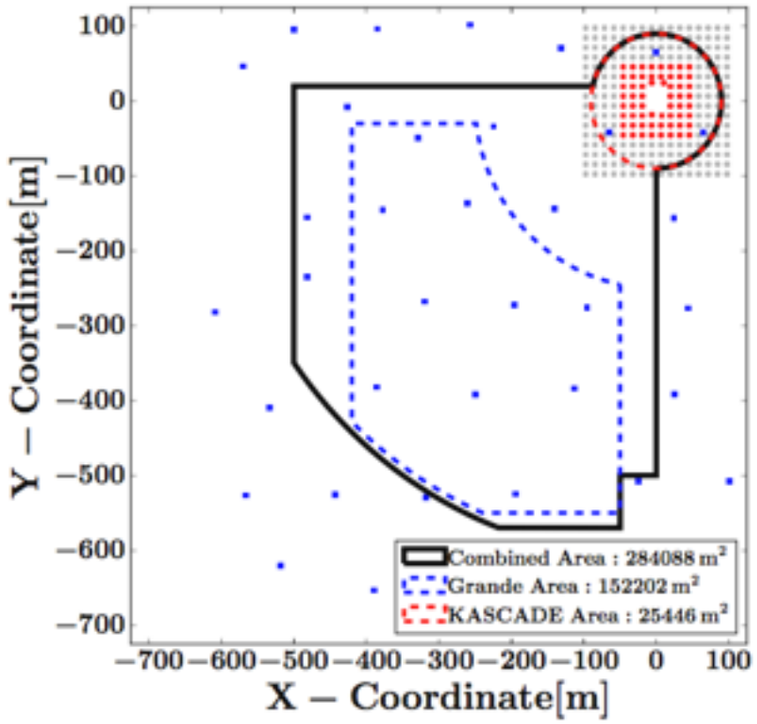

- Main structures confirmed
- Relative abundances are model dependent

*Sven Schoo et al., paper in progess*

# Test of models: radial dependence

Events located in **KASCADE vs** events in **Grande**

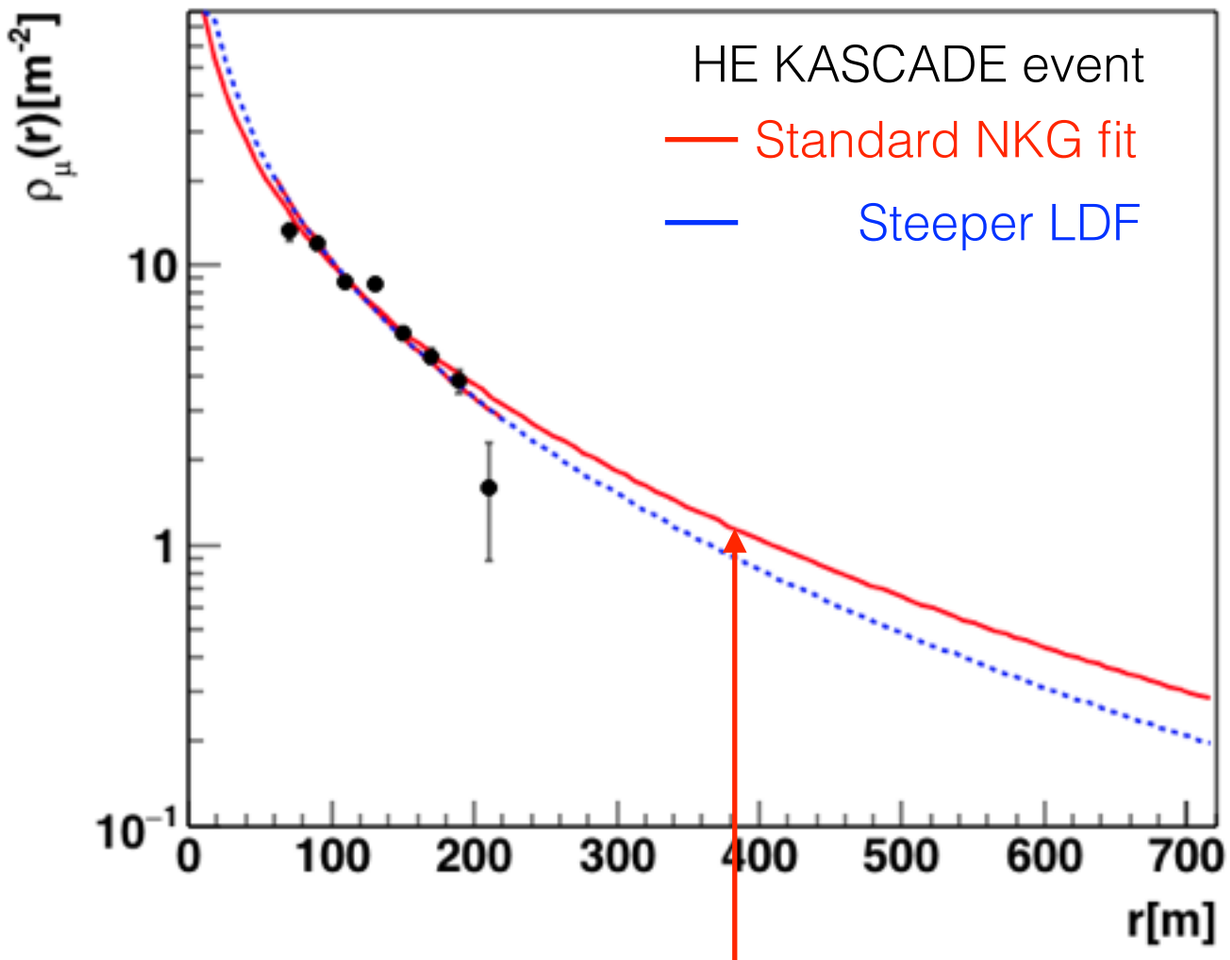


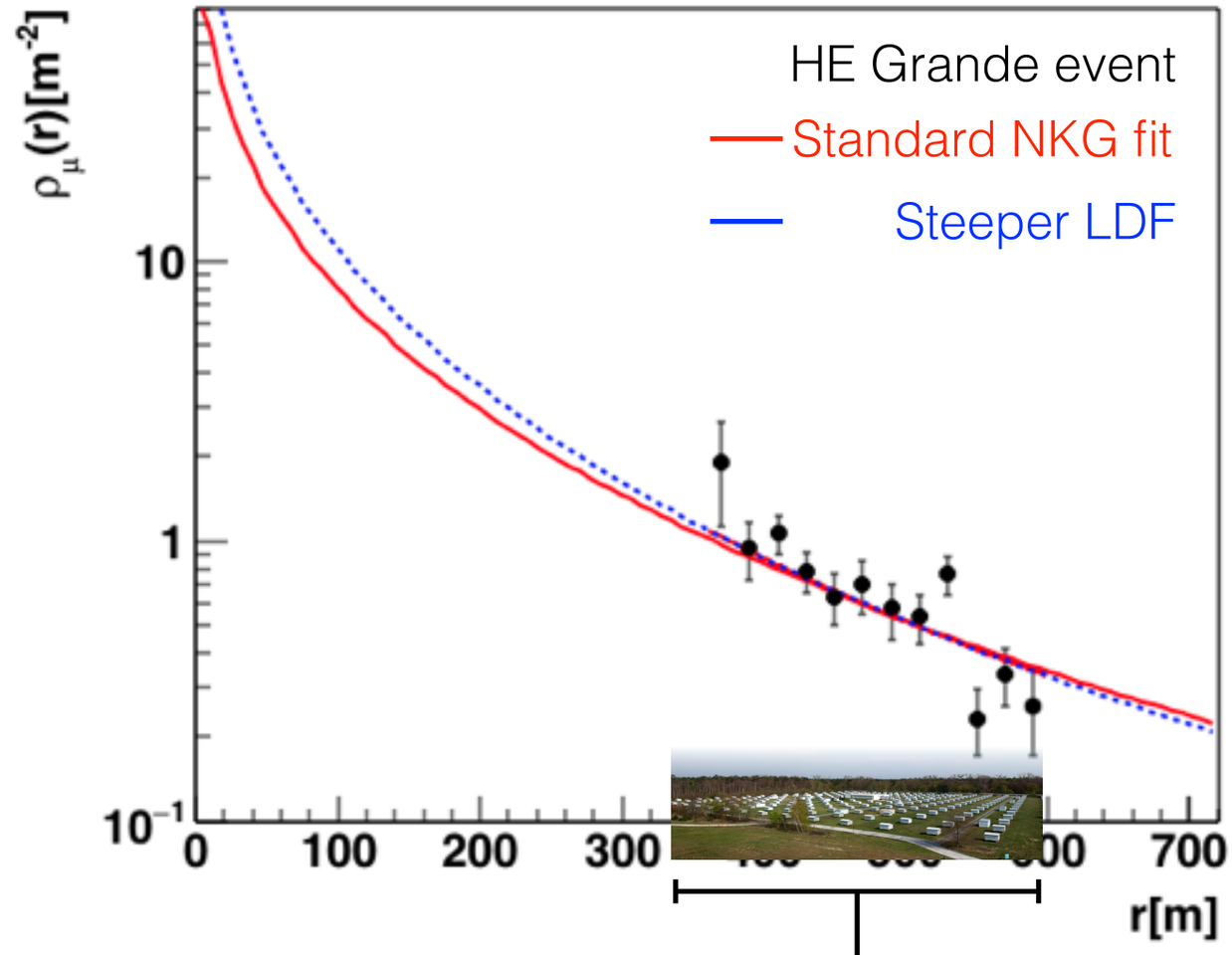

– Respective spectra show **strong differences**

# Test of models: radial dependence

Events located in **KASCADE vs** events in **Grande**



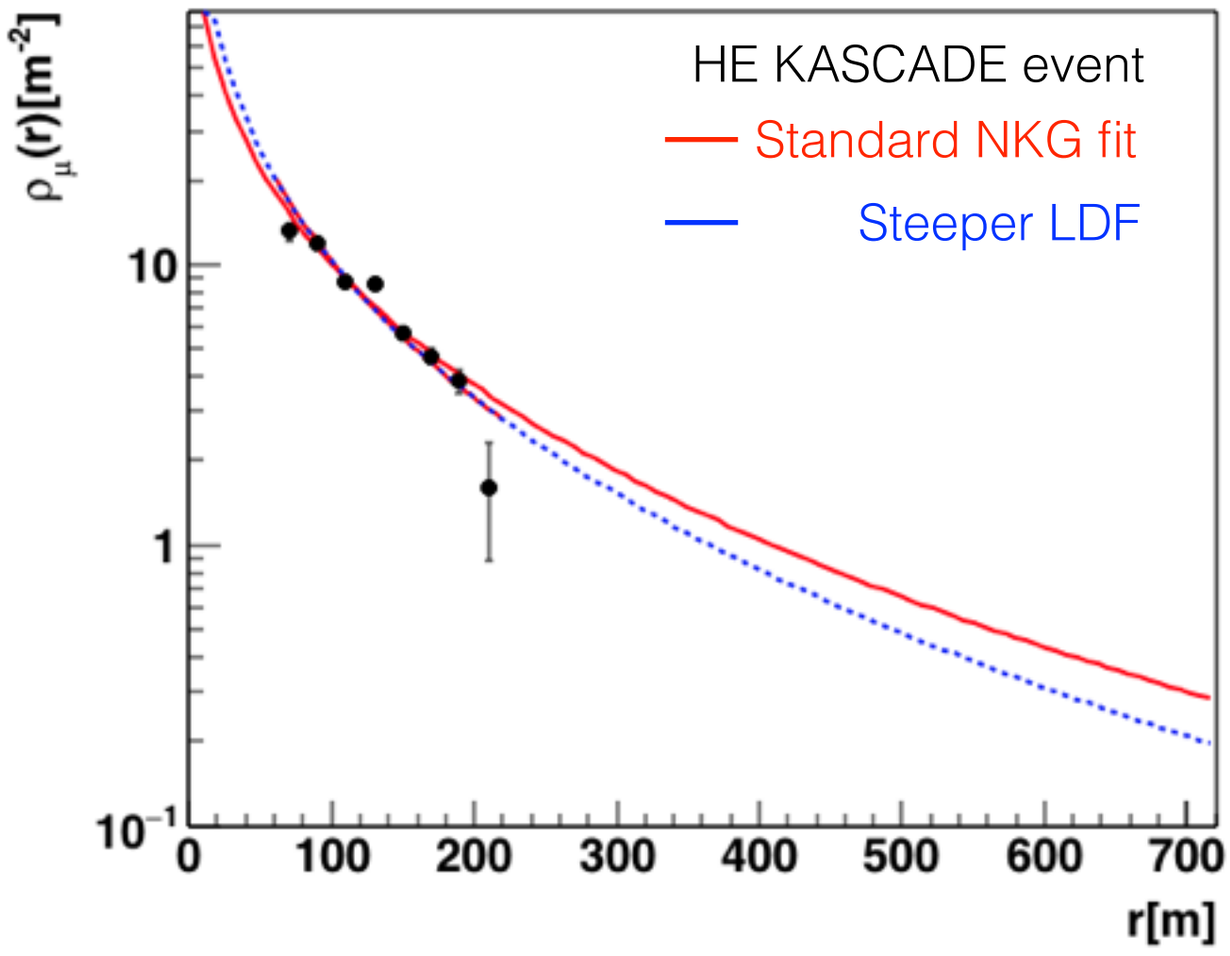

Slope of muon LDF used in standard EAS fit is fixed and too flat.

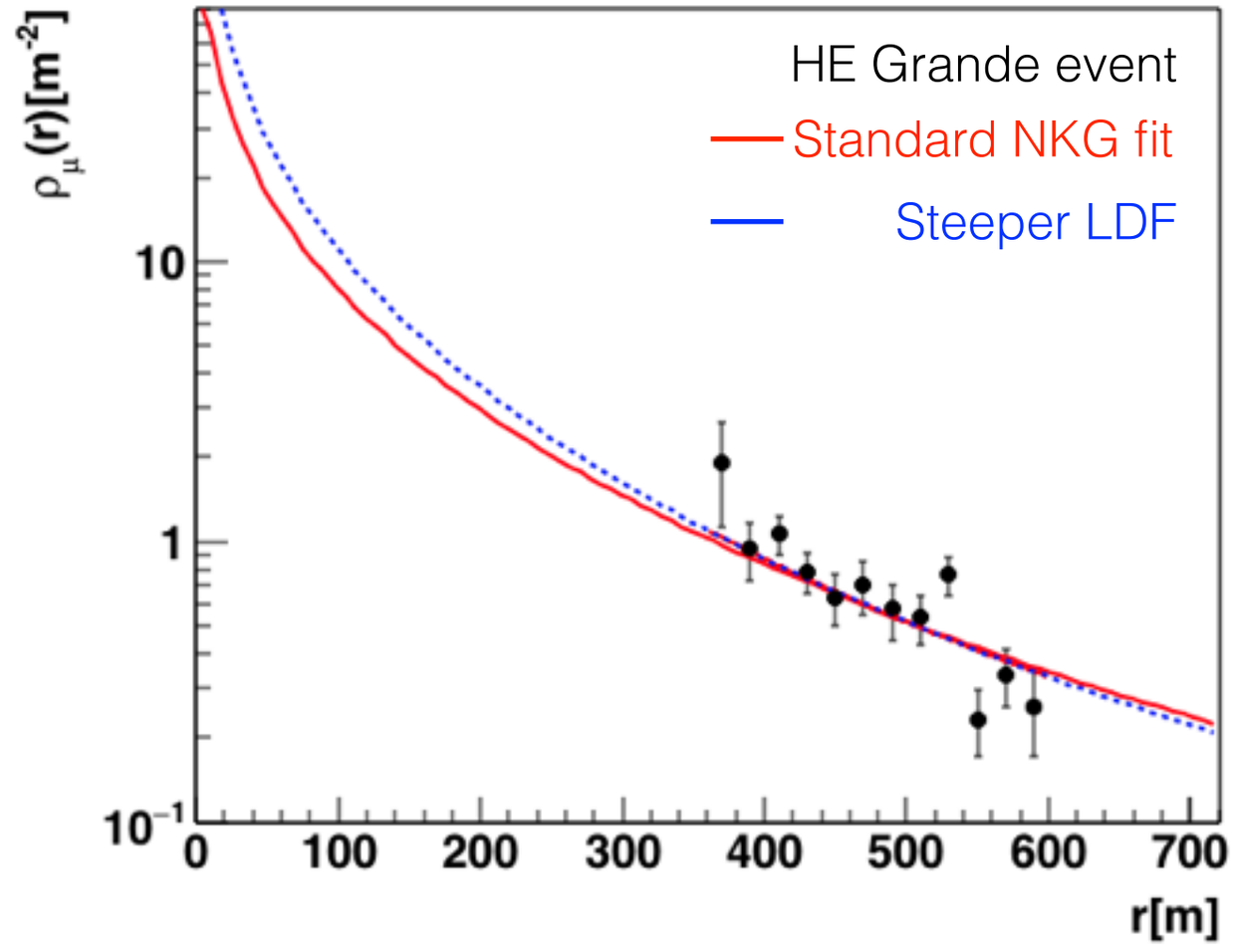



**Muon detectors** cover a **limited portion of EAS front.**

# Test of models: radial dependence

Events located in **KASCADE vs** events in **Grande**



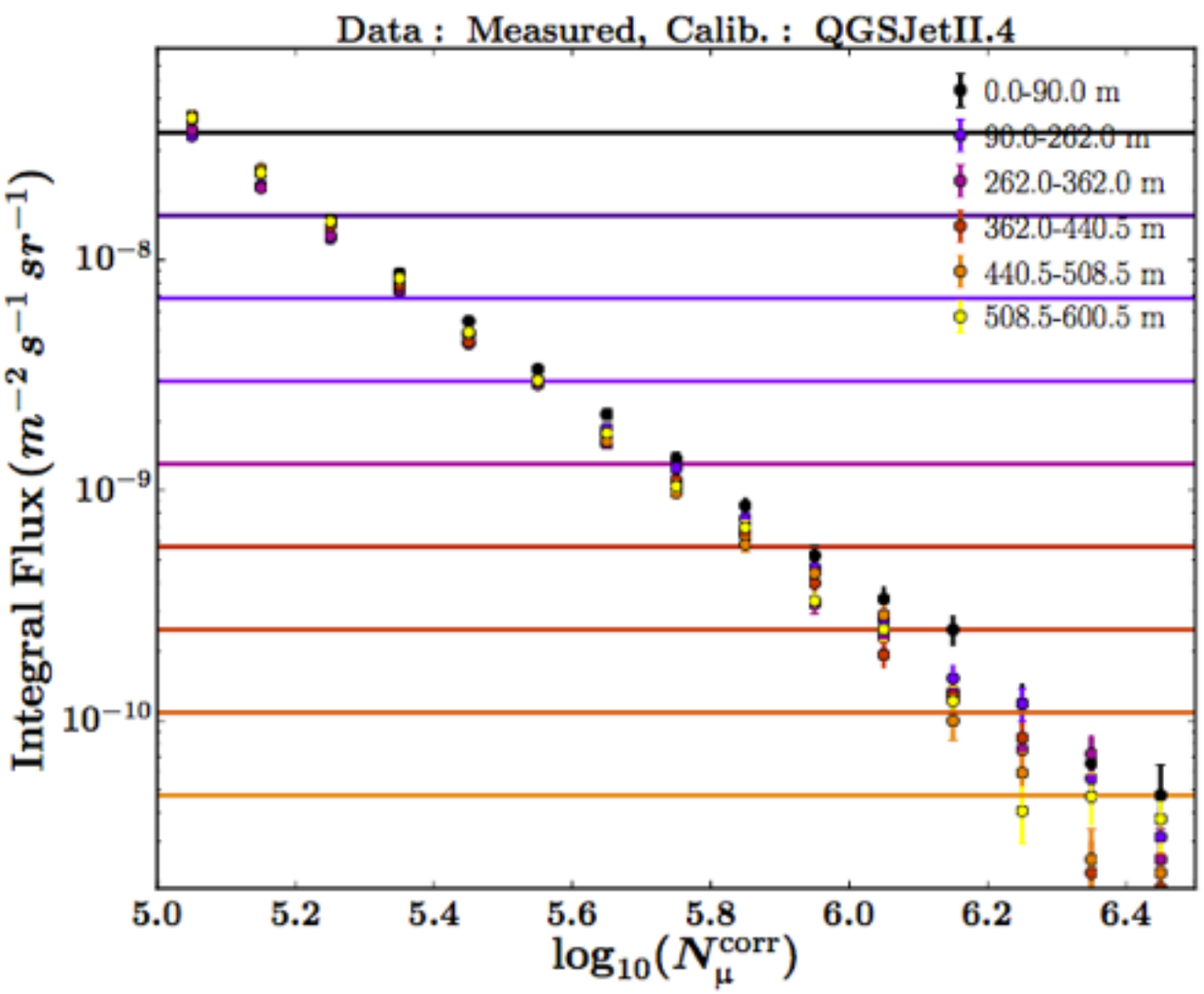



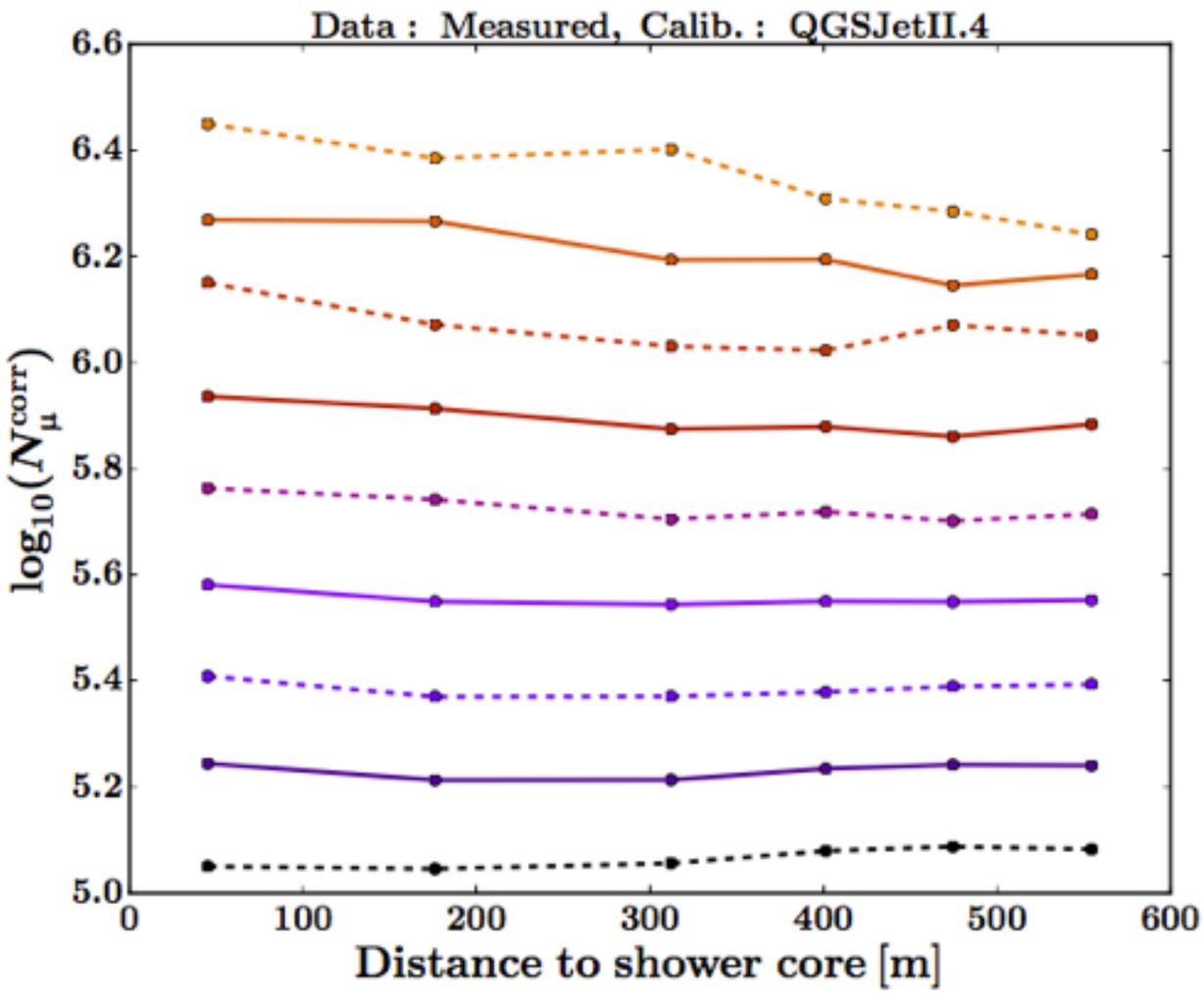

If core within **KASCADE** → too many muons

If core within **Grande** → too few muons

# Test of models: radial dependence

*Sven Schoo et al., paper in progess*



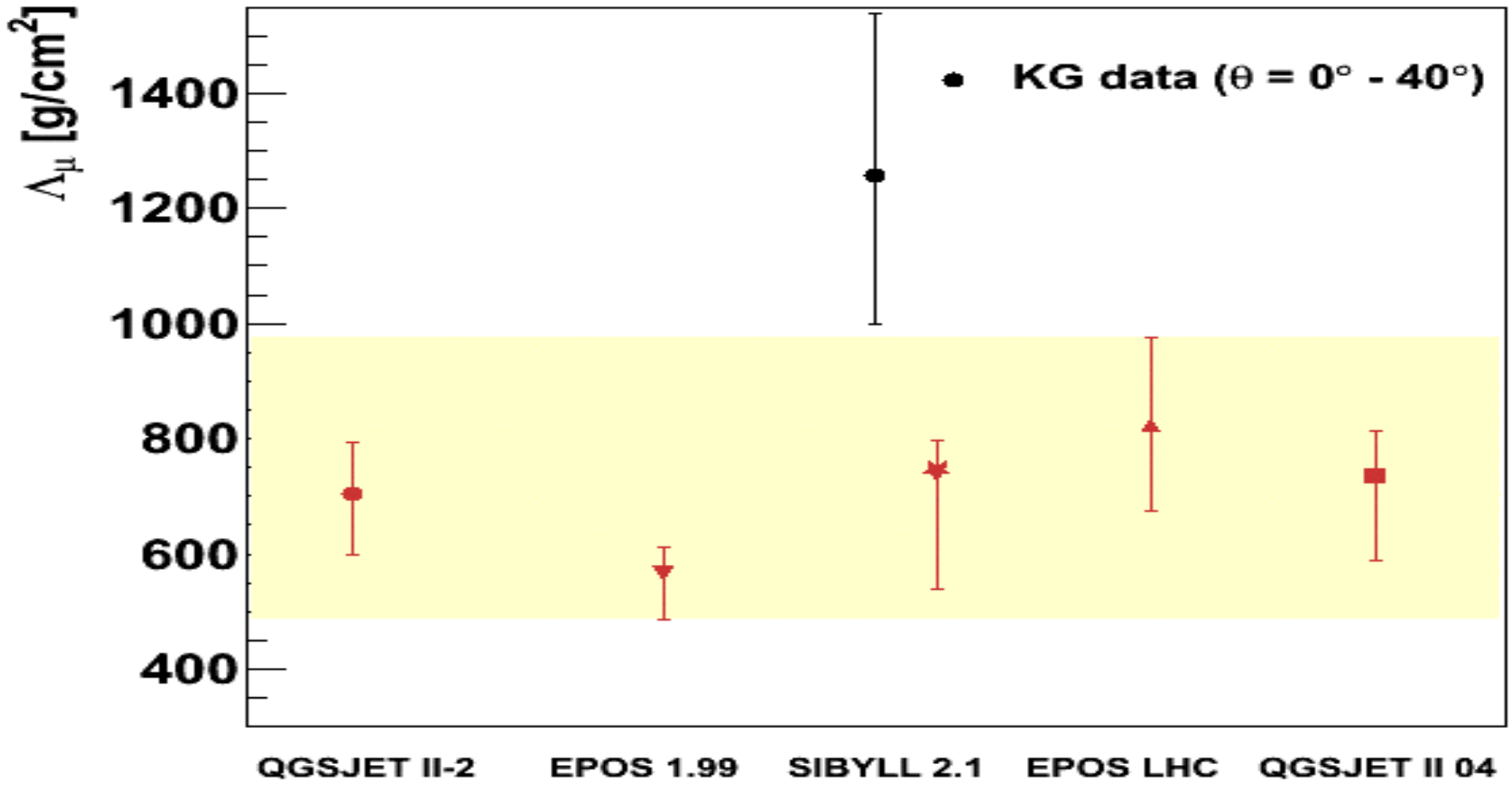

Cross checks using **Constant Intensity Cuts**

At high energies $N_\mu$ corresponding to the same intensity **drops with radial distance**.

# Test of models: zenith angle dependence

$N_\mu$ attenuation length: $N_\mu = N_{\mu,o}\, exp[-X_o\, sec(\theta)/\Lambda_\mu\ ]$

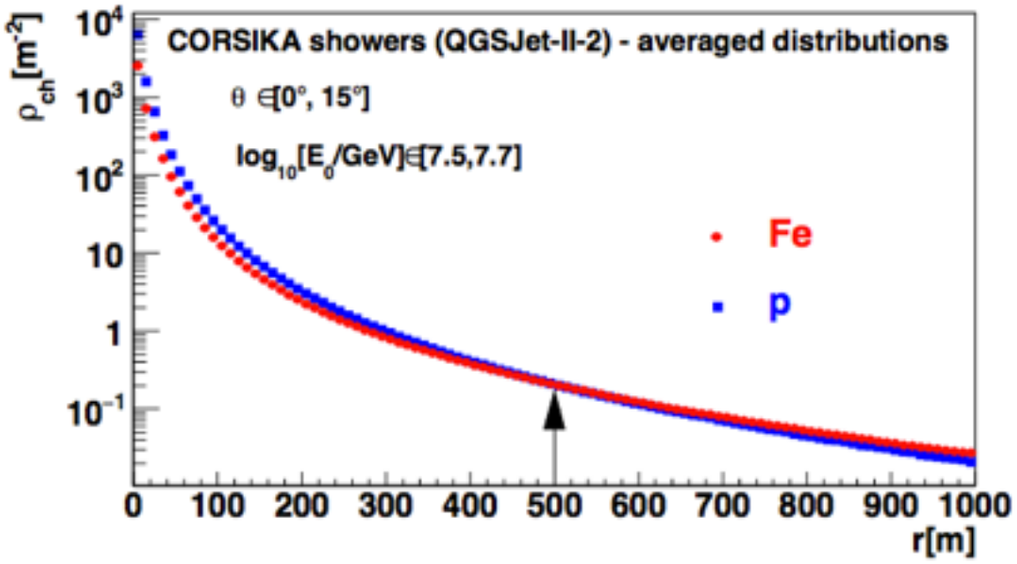
*J.C. Arteaga-Velázquez et al., paper in progess*



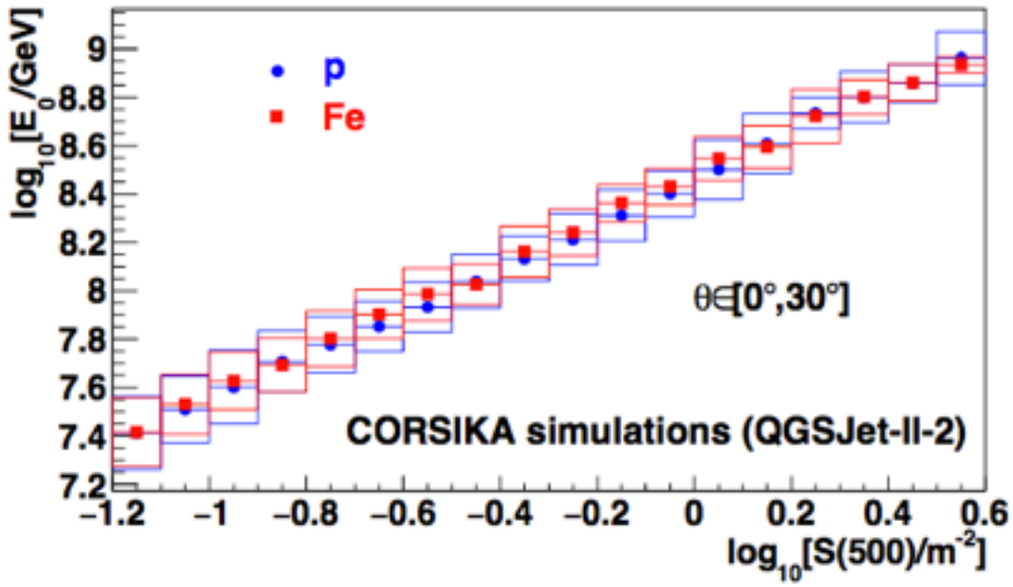

**Less attenuation** in experimental **data** than in **MC**

– Problems with predicted Energy spectra of muons?

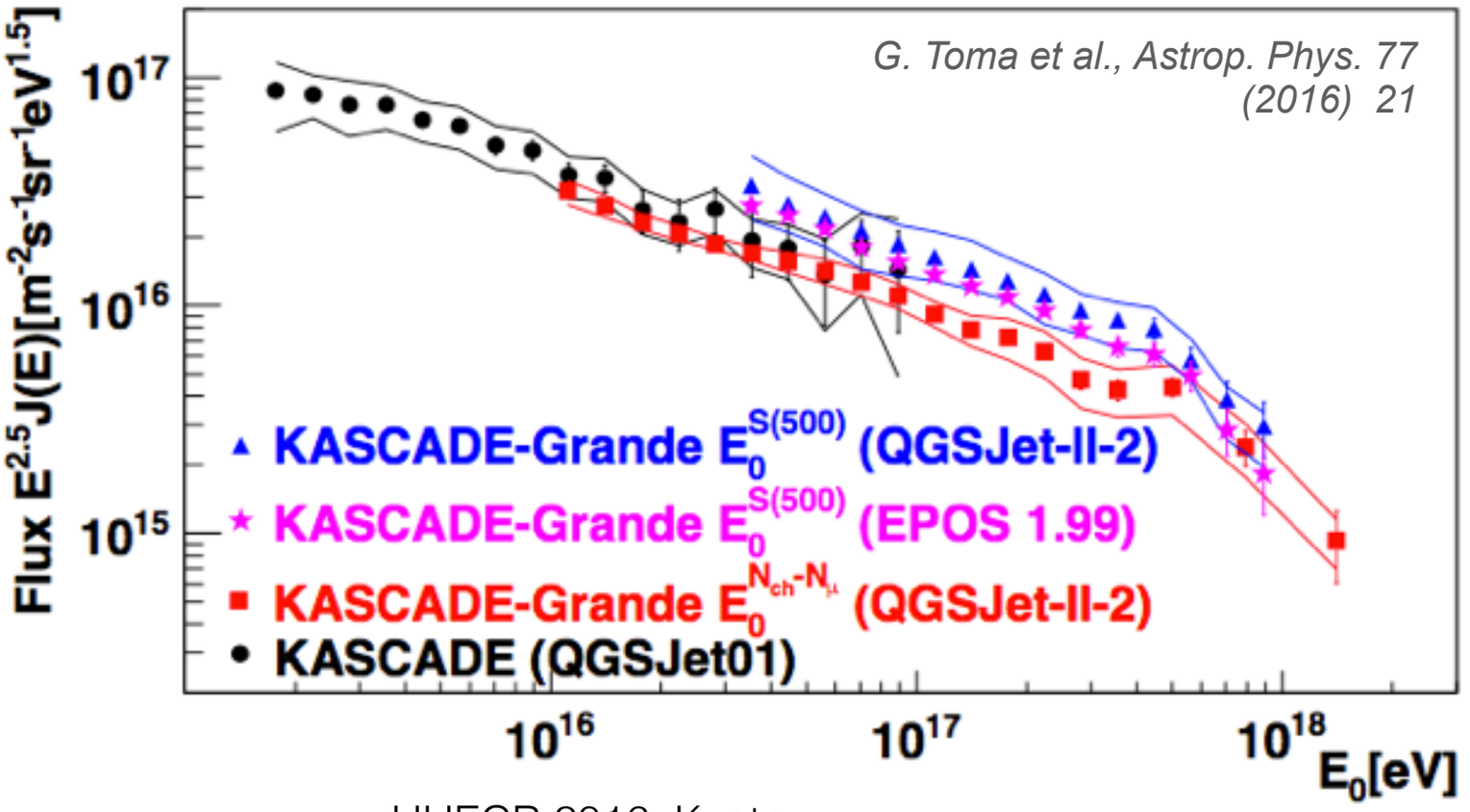
# All-particle energy spectrum from S(500)



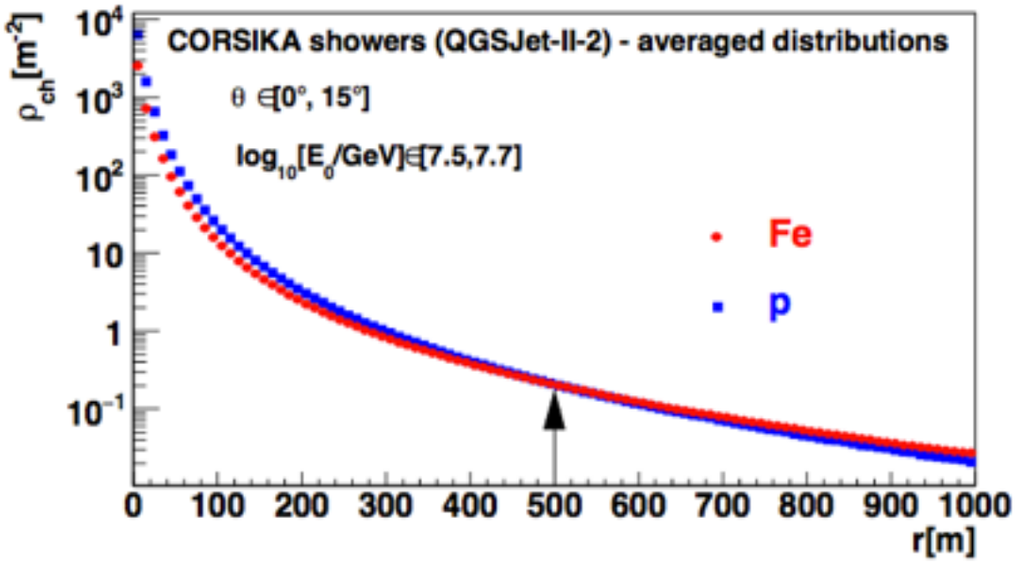

S(500) = $\rho_{ch}$(r = 500 m) is **independent of mass** of primary particle



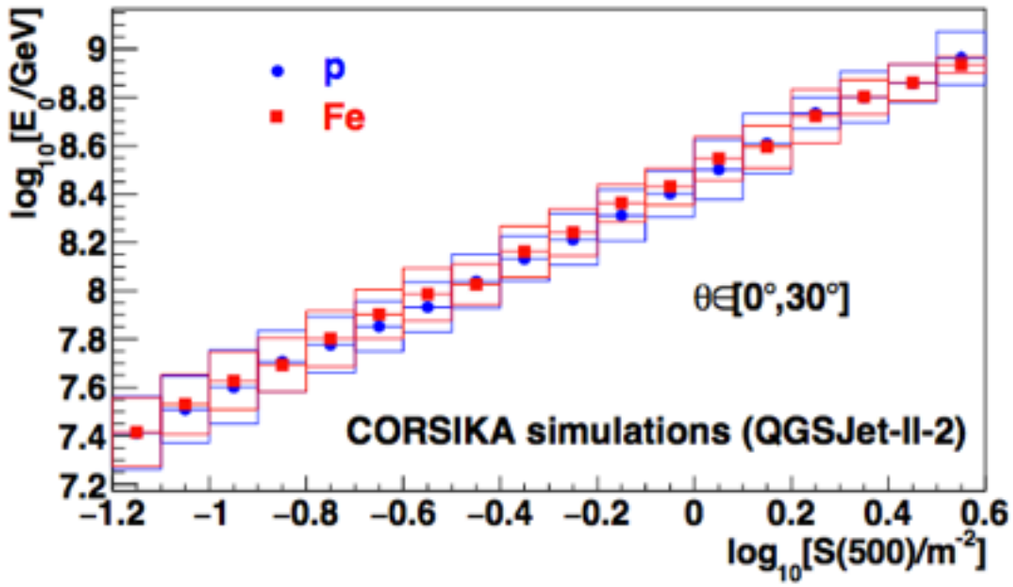

**Sensitive** to primary **energy**



# All-particle energy spectrum from S(500)

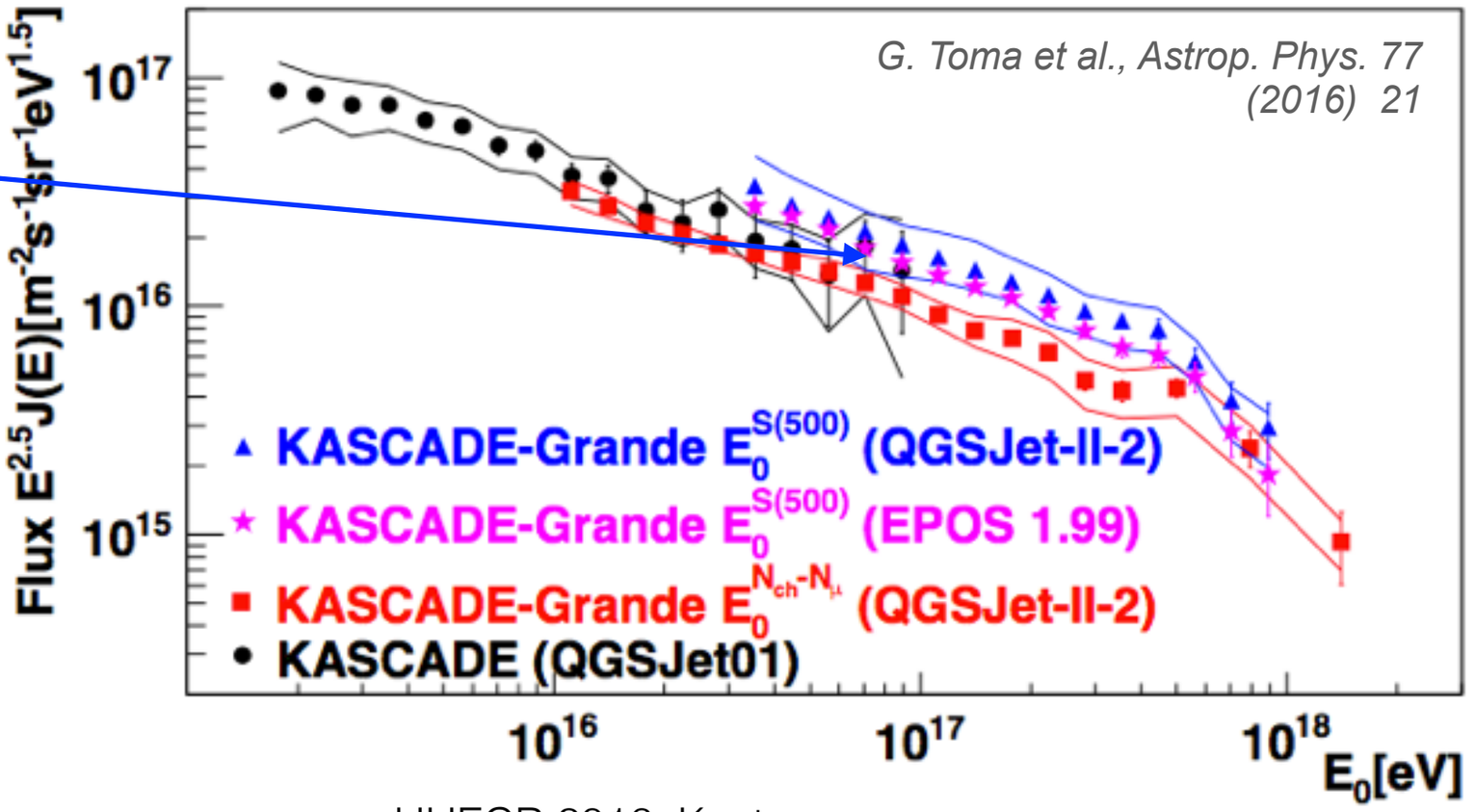



S(500) = $\rho_{ch}$(r = 500 m) is **independent of mass** of primary particle




**Sensitive** to primary **energy**

**Shift** in energy




- Bad description of LDF in simulations

# KASCADE Cosmic Ray Data Center

*A. Haungs et al., J. of Phys. Conf. S. 632 (2015) 012011*

open access to research data
https://kcdc.ikp.kit.edu

KIT | IKP | HOME | Impressum | login

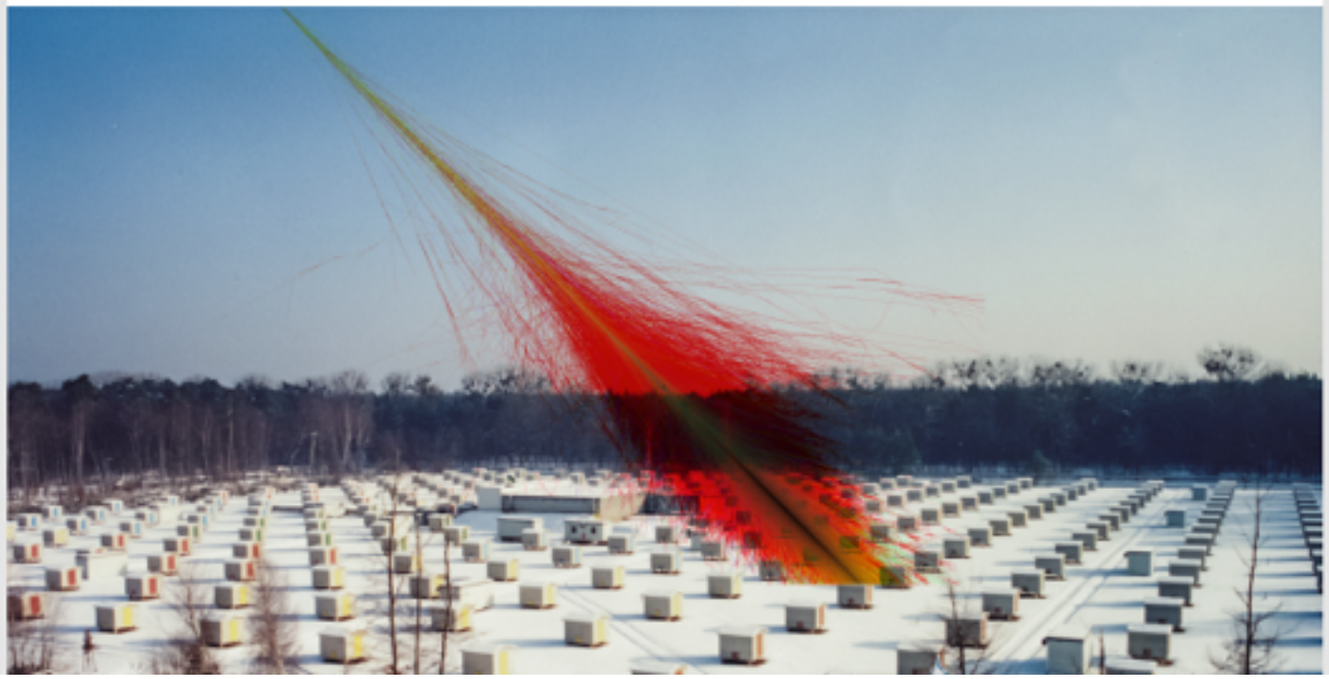
Karlsruhe Institute of Technology

KASCADE Cosmic Ray Data Centre (KCDC) / *Open β*

- KCDC Homepage
- KCDC Motivation
- KCDC Regulations
- Information
- Announcements
- FAQs
- User Account
- Data Shop
- Publications
- Education/Lehre
- Report a Bug

## Welcome to KCDC

The aim of the project **KCDC** (**K**ASCADE **C**osmic Ray **D**ata **C**entre) is the installation and establishment of a public data centre for high-energy astroparticle physics based on the data of the KASCADE experiment. KASCADE was a very successful large detector array which recorded data during more than 20 years on site of the KIT-Campus North, Karlsruhe, Germany (formerly Forschungszentrum, Karlsruhe) at 49,1°N, 8,4°E; 110m a.s.l. KASCADE collected within its lifetime more than 1.7 billion events of which some 425.000.000 survived all quality cuts. Initially about 147 million events are available here for public usage.

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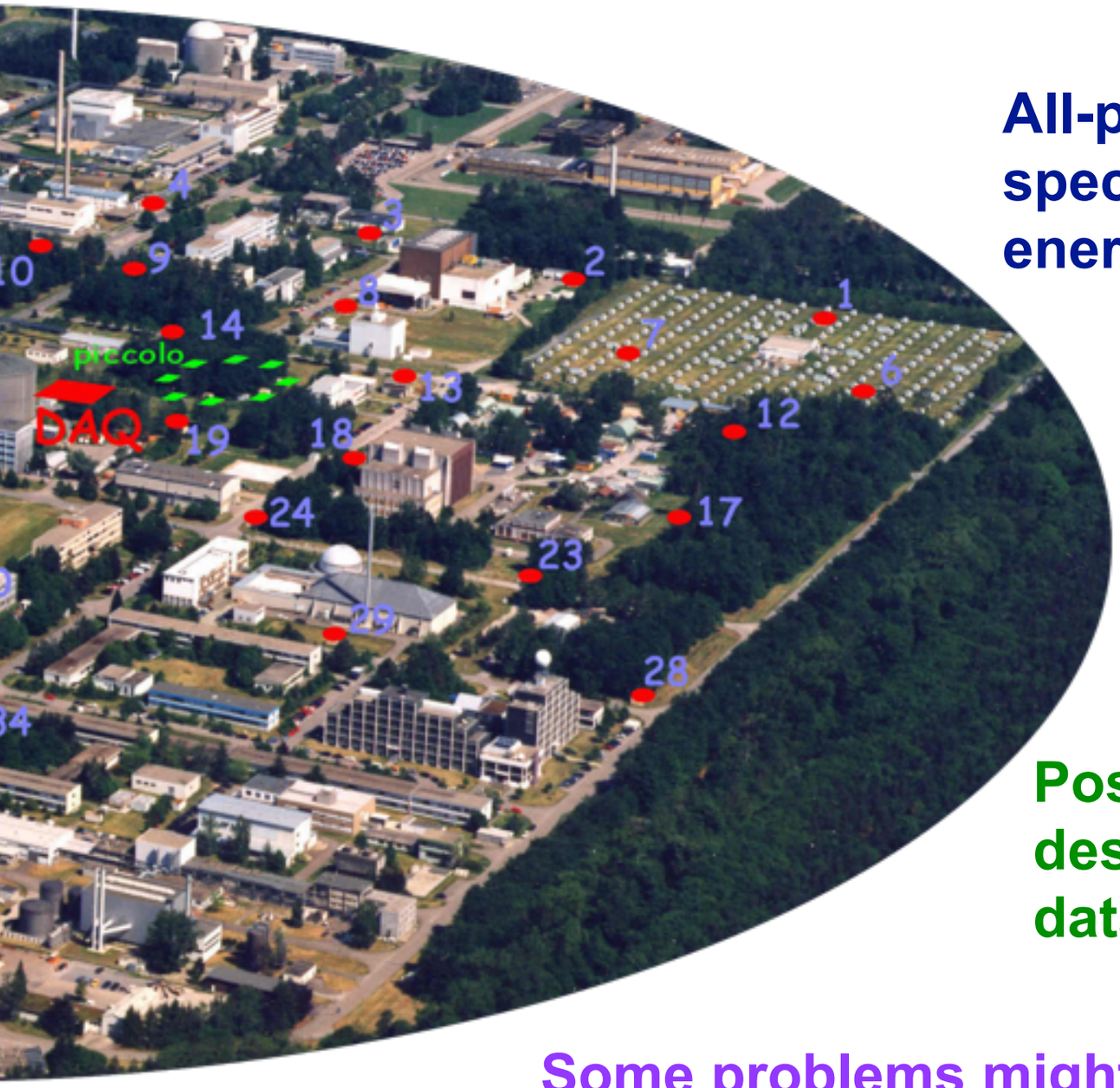
**Downloads**
KCDC Manual (english)

# Summary

**Limits on the diffuse flux of VHE γ rays have been established.**




**All-particle, light and heavy spectra were obtained for 3 energy decades.**

**Combined analysis confirms structures of spectra.**

**Post-LHC models do not describe the measured data.**

**Some problems might be due to predicted muons.**

# Thank you!

## KASCADE-Grande Collaboration

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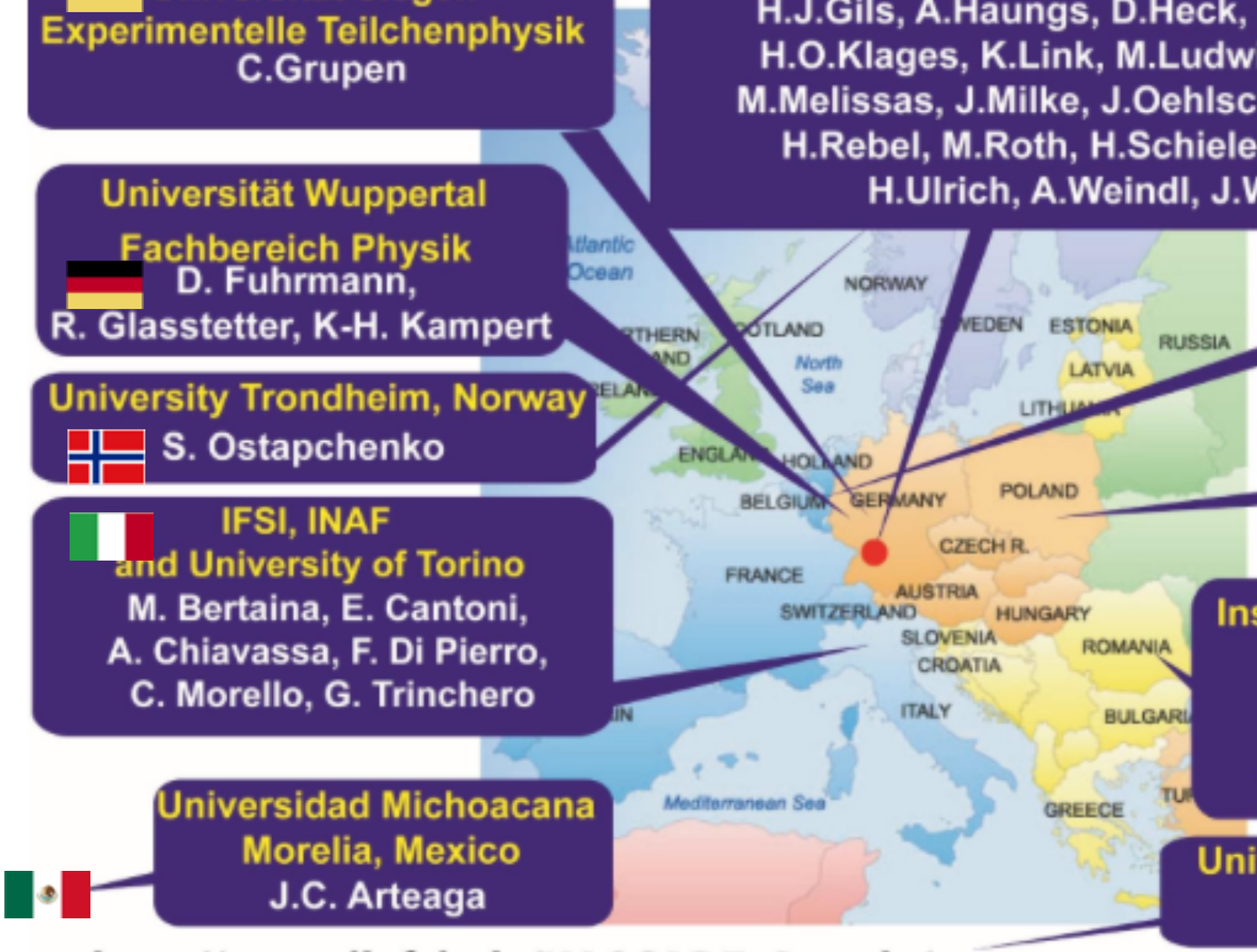


http://www-ik.fzk.de/KASCADE-Grande/

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