CRs from the Knee to the transition region: Synthesis of KASCADE-Grande

Karl-Heinz Kampert
(University of Wuppertal, Department of Physics, kampert@uni-wuppertal.de)

- **Science Case and Birth of KASCADE-Grande**
- **Move with Obstacles**
- **Structures in the E-Spec: a 2nd Knee?**
- **Composition from KA-Grande**
- **What advances can we expect in the next years from EAS Expt's ?**

Gianni giving his last talk at KASCADE-Grande closure 30.3.2009

1997: first discussions

First visit to EAS-TOP with Gianni
to discuss open Cherenkov-measurements and
merger of EAS-TOP & KASCADE

1999: LoI & Proposal to INFN & FZK

Proposal to Study Cosmic Ray Primaries and their Interactions at $E_0 \simeq 10^{16}$ - $5 \cdot 10^{17}$ eV (EXTASE)

M. Aglietta, A. Castellina, W. Fulgione, P.L. Ghia, C. Morello, G. Trinchero, C. Vigorito

Istituto di Cosmo-Geofisica del CNR, Torino, Italy
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Istituto Nazionale di Fisica Nucleare, sezione di Torino
and Dipartimento di Fisica Generale dell'Universita' di Torino

W.D. Apel, K. Bekk, H. Blümer, K. Daumiller, P. Doll, H.J. Gils, R. Glasstetter, A. Haungs, D. Heck, J. Hörandel, K.-H. Kampert, H. Keim, H.O. Klages, J. Engler, H.J. Mathes, J. Oehlschläger, H. Rebel, M. Roth, T. Thouw, J. Weber, J. Wochele

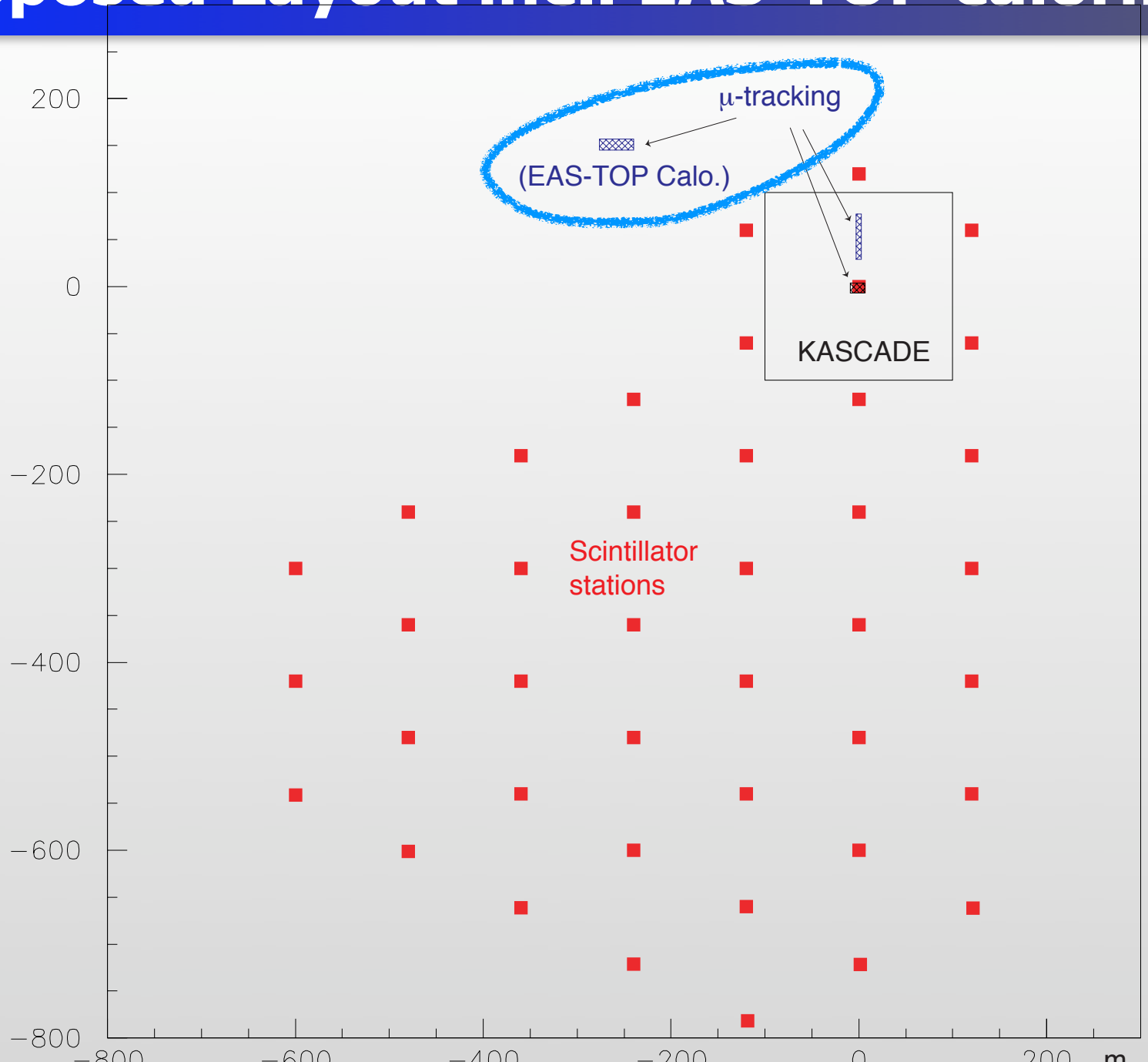
Institut für Kernphysik, Forschungszentrum Karlsruhe, and
Institut für Experimentelle Kernphysik, Universität Karlsruhe

1999: LoI & Proposal to INFN & FZK

Abstract

We present a proposal of an Extensive Air Shower array with the aims of studying the cosmic ray primary composition and the hadronic interactions in the energy range $E_0 = 10^{16} - 5 \cdot 10^{17}$ eV. The array with the required characteristics is realized by reassembling the EAS-TOP detectors at Forschungszentrum Karlsruhe next to the KASCADE site. This allows a calibration of the extended array and experimental techniques at $5 \cdot 10^{15} \lesssim E_0 \lesssim 10^{16}$ eV. Furthermore, the integration makes optimal use of existing investments by exploiting already existing instrumentation. The measurements will establish an important bridge towards the highest energy experiments, also from the point of view of the time schedule, i.e. by finishing its operation in five years from the beginning of the installation procedures.

Proposed Layout incl. EAS-TOP calorimeter



Supporting Letters from Germany to INFN

Institut für Kernphysik
Prof.Dr.H.Blümer

Forschungszentrum Karlsruhe GmbH, Postfach 3640, D-76021 Karlsruhe

Prof. Carlo Bemporad

Cairman of INFN Comm. 2

Istituto Nazionale di Fisica Nucleare

Via Livornese, 1291

I – 56010 S. Piero a Grado (PI)

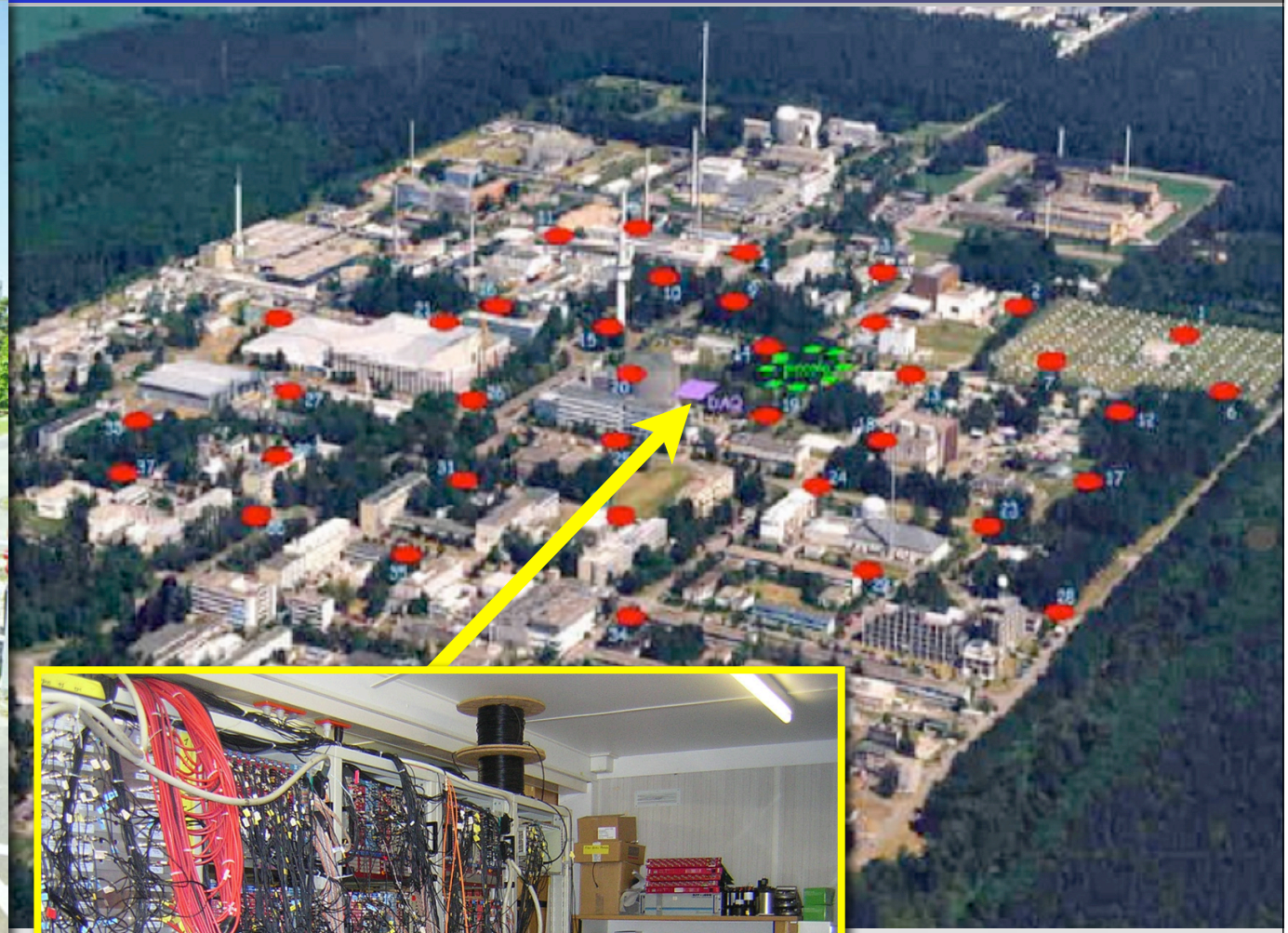
Datum: 6.12.1999
Bearbeiter/-in:
Telefon 07247/82- 3545
Telefax 07247/82- 3548
E-mail:hans.bluemer@ik1.fzk.de
Ihre Mitteilung:

Copies to:
Prof. E. Iarocci, President of INFN
Prof. G. Matthiae, Spokesperson AUGER Italy
Prof. G. Navarra, Spokesperson EAS-TOP
Prof. K.-H. Kampert, Spokesperson KASCADE

Dear Professor Bemporad,

please allow me to address some aspects of the cooperation between Istituto Nazionale di Fisica Nucleare and Forschungszentrum Karlsruhe and Universität Karlsruhe (TH). The imagination and skillful work of Prof. Navarra of Torino, Prof. Kampert of Karlsruhe and a few others gave birth to the idea of integrating the EAS-TOP and KASCADE equipment for a new measurement, EXTASE. A proposal has been submitted to the INFN detailing the project. Today I would like to provide some additional

Early 2000: Construction started



EXTASE becomes KASCADE-Grande

Von: Karl-Heinz Kampert <kampert@ik1.fzk.de>
Betreff: **Seeking a name for the baby...**
Datum: 11. Juli 2000 16:42:21 MESZ

Dear Collaborators,

with this first mail to a hopefully growing mailing list
I would like to inform everybody that all the EAS-TOP detectors including their electronics meanwhile have arrived at FZK and are stored in three different halls.
We also have received the first hut which is presently being mounted to see whether it fits our needs.
Two EAS-TOP scintillators have been assembled and cable tests will be done these days to measure the attenuation in 1 km (worst case) long cables of different kind.
Also more elaborate EAS simulations have been performed to get an idea of performance, cross triggering, etc.
It turned out that it would be very useful to have one additional cluster of detectors primarily aimed at delivering a fast trigger to KASCADE & EAS-TOP.
More on this in a separate mail later on.

In all the discussions we always stumble by the fact that there is

!! NO NAME OF THE EXPERIMENT, YET !!

Certainly, EXTASE cannot be used anymore because of its history at INFN. There have been some proposals, including

KASCADE-GRANDE
KASCAGRANDE
GRAN-KASCADE
KASCADE-II

Today, 10 years ago:
Sept. 20, 2000: Gianni's vote

Von: Gianni Navarra <navarra@to01xd.to.infn.it>
Betreff: **Re: Name of Experiment**
Datum: 20. September 2000 14:32:34 MESZ
An: Karl-Heinz Kampert <kampert@ik1.fzk.de>

KASCADE GRANDE

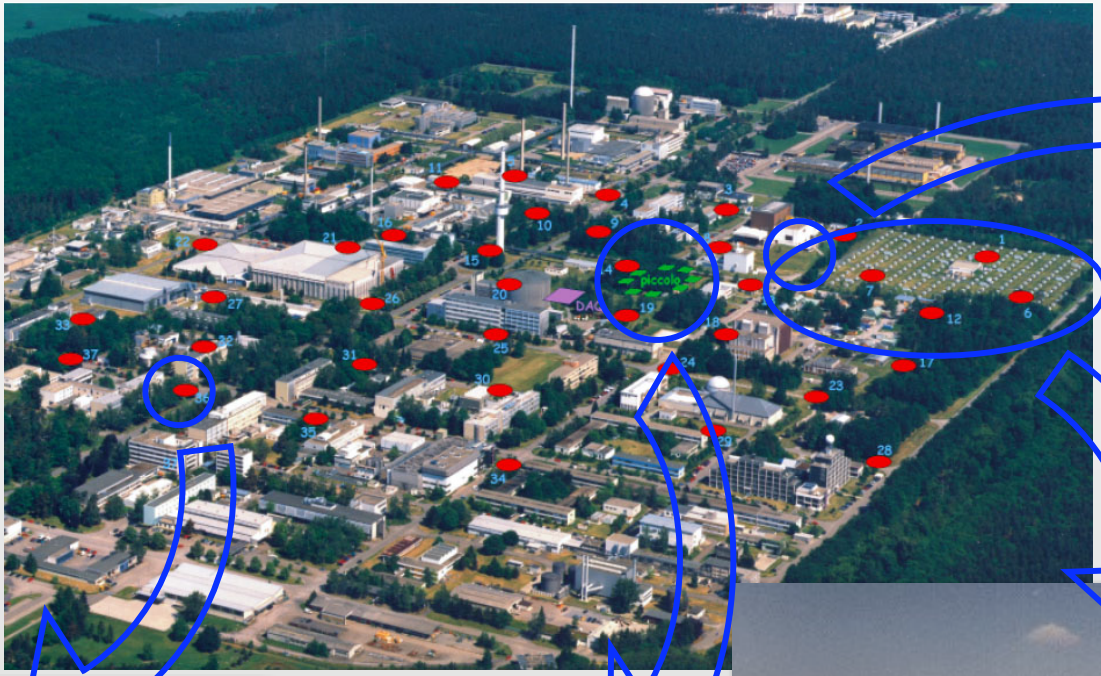
Gianni

On Tue, 19 Sep 2000, Karl-Heinz Kampert wrote:

> Dear Colleagues,
>
> at the last meeting we have discussed each of the different proposals. Three of them were preferred by most of the people:
>
> KASCADE II
> KASCADE GRANDE
> KASCADE TOP
>
> In order to arrive at a final decision, everybody is asked for a single vote. Please send it to me as soon as possible, possibly even by tomorrow morning (9:00). After about two weeks from now I will distribute the result.
>
> Best regards, Karl-Heinz Kampert
>
> _____
> PS: Not everybody has an e-mail account and possibly I have forgotten some names. Please feel to forward this call for

KASCADE-Grande
= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

Measurements of EAS in the energy range E_0 = 100 TeV - 1 EeV



KASCADE-Grande Collaboration

Institut für Kernphysik & Institut für Experimentelle Kernphysik
KIT - Karlsruhe Institute of Technology

W.D.Apel, K.Bekk, J.Blümer, H.Bozdog, F.Cossavella, K.Daumiller, P.Doll, R.Engel, J.Engler, M.Finger, H.J.Gils, A.Haungs, D.Heck, T.Huege, P.G.Isar, D.Kang, H.O.Klages, K.Link, M.Ludwig, H.-J.Mathes, H.J.Mayer, M.Melissas, J.Milke, S.Nehls, J.Oehlschläger, N.Palmieri, T.Pierog, H.Rebel, M.Roth, H.Schieler, F.Schröder, H.Ulrich, A.Weindl, J.Wochele, M.Wommer

Universität Siegen
Experimentelle Teilchenphysik
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D.Kickelbick, S.Over

Universität Wuppertal
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Soltan Institute for
Nuclear Studies, Lodz
P. Luczak, J. Zabierowski

Institute of Physics and Nuclear
Engeneering and University
Bucharest
I.M. Brancus, B. Mitrica,
M. Petcu, O. Sima, G. Toma

Universidade Sao Paulo, Brasil
V. de Souza

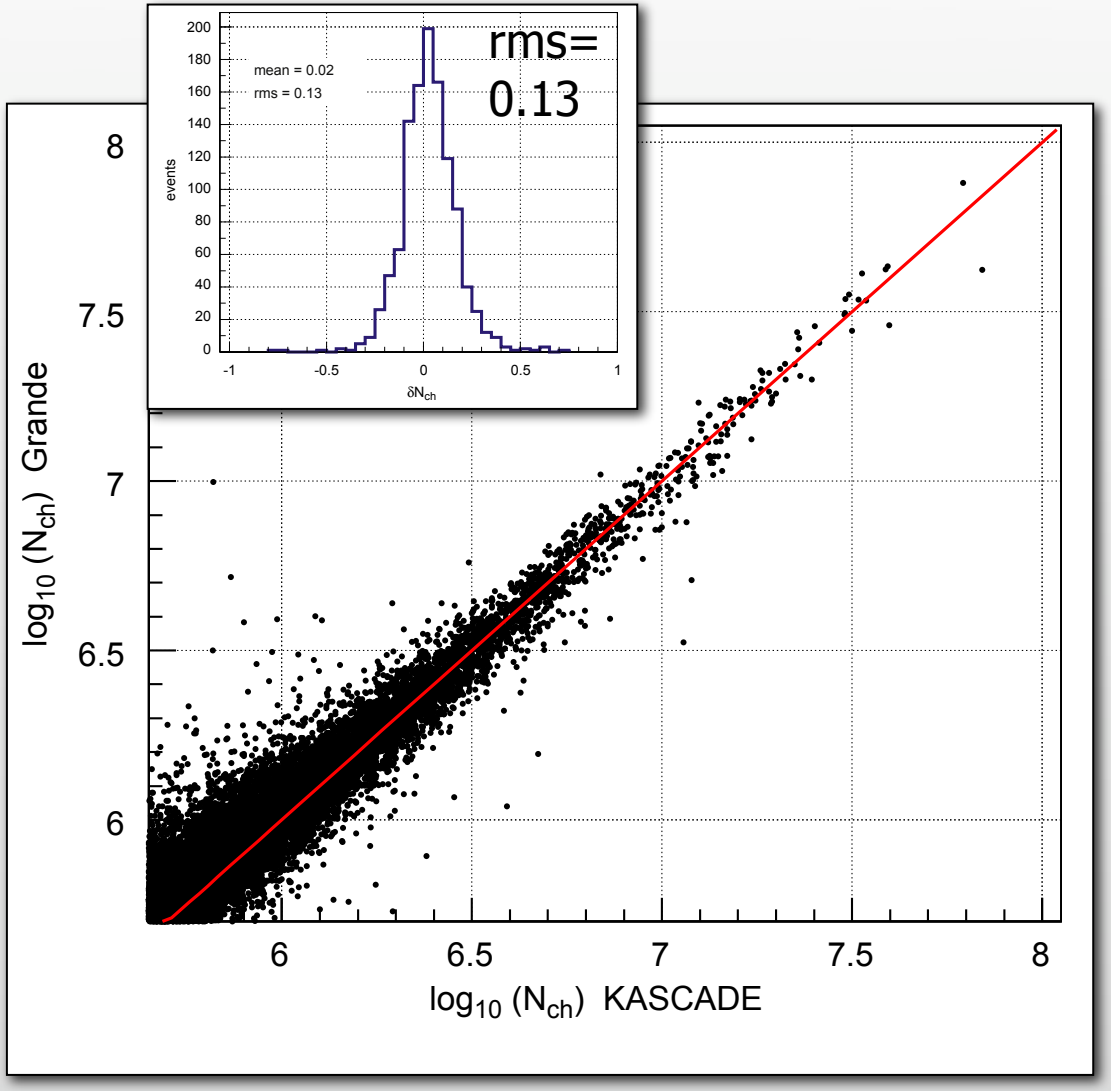
http://www-ik.fzk.de/KASCADE-Grande/

*deceased

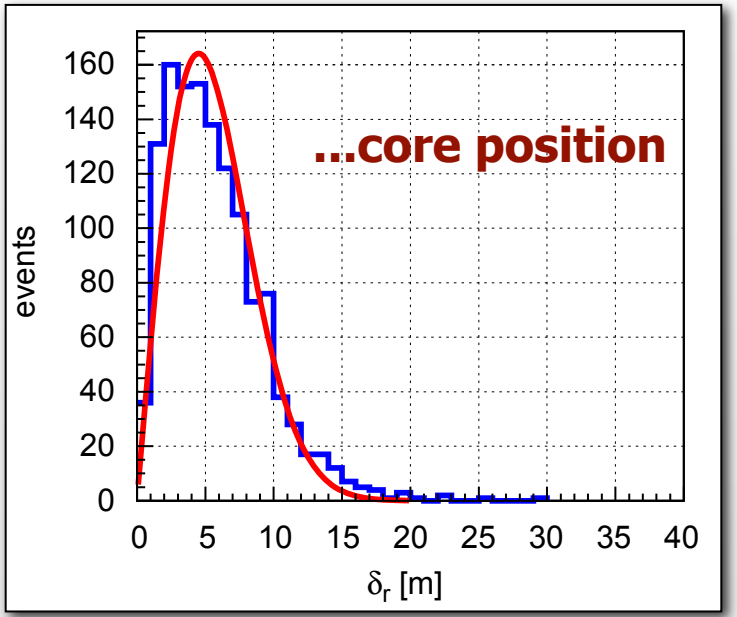
Check of Performance, few examples

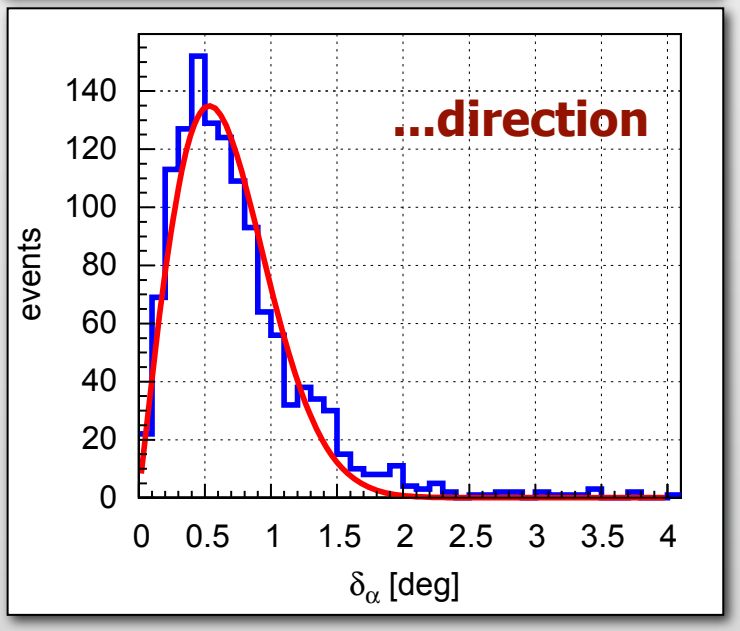
Nucl. Instr. Meth. A620 (2010) 202

comparison of reconstr. shower sizes...

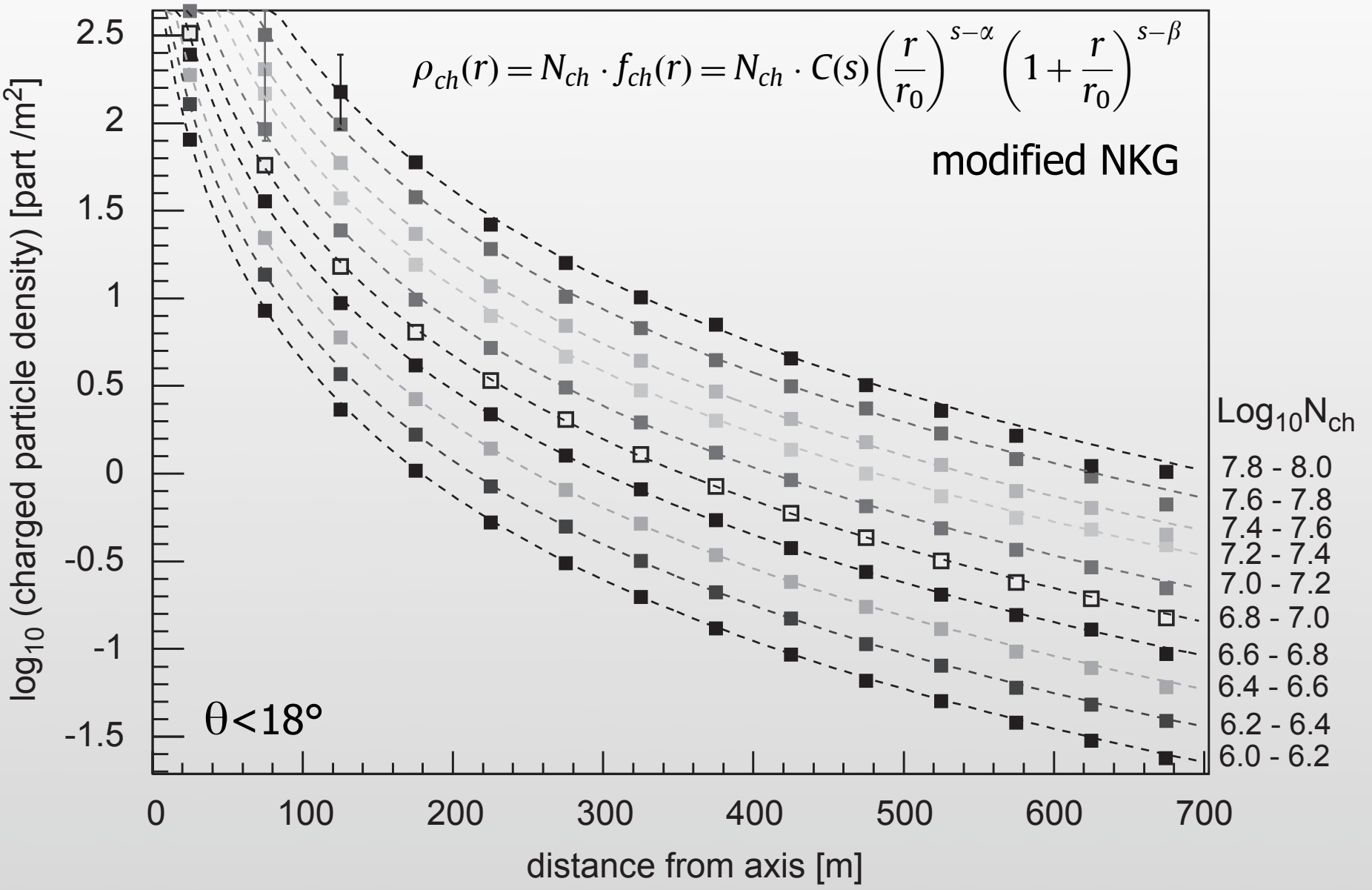


for showers landing in KASCADE



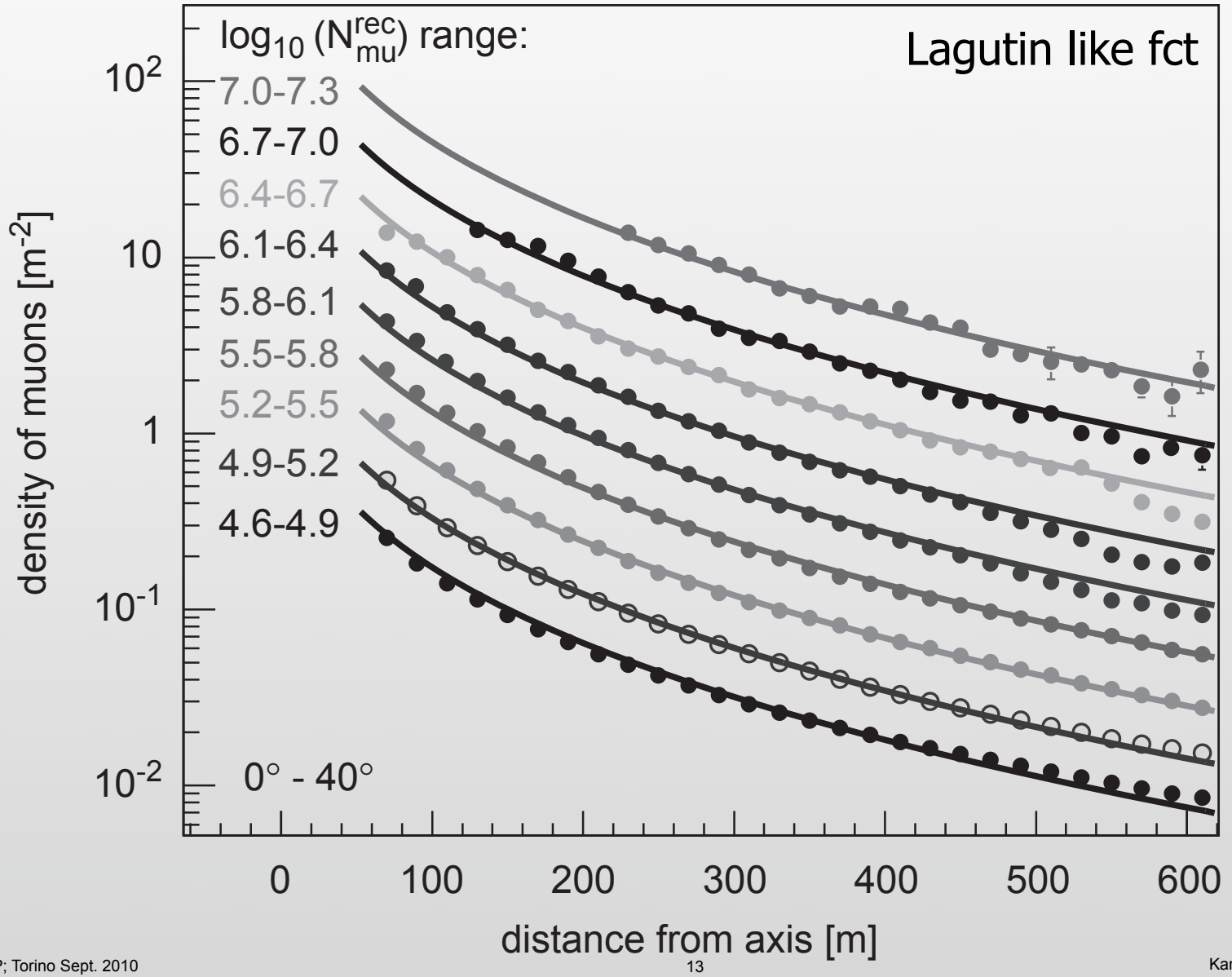


Charged Particle LDF by Grande

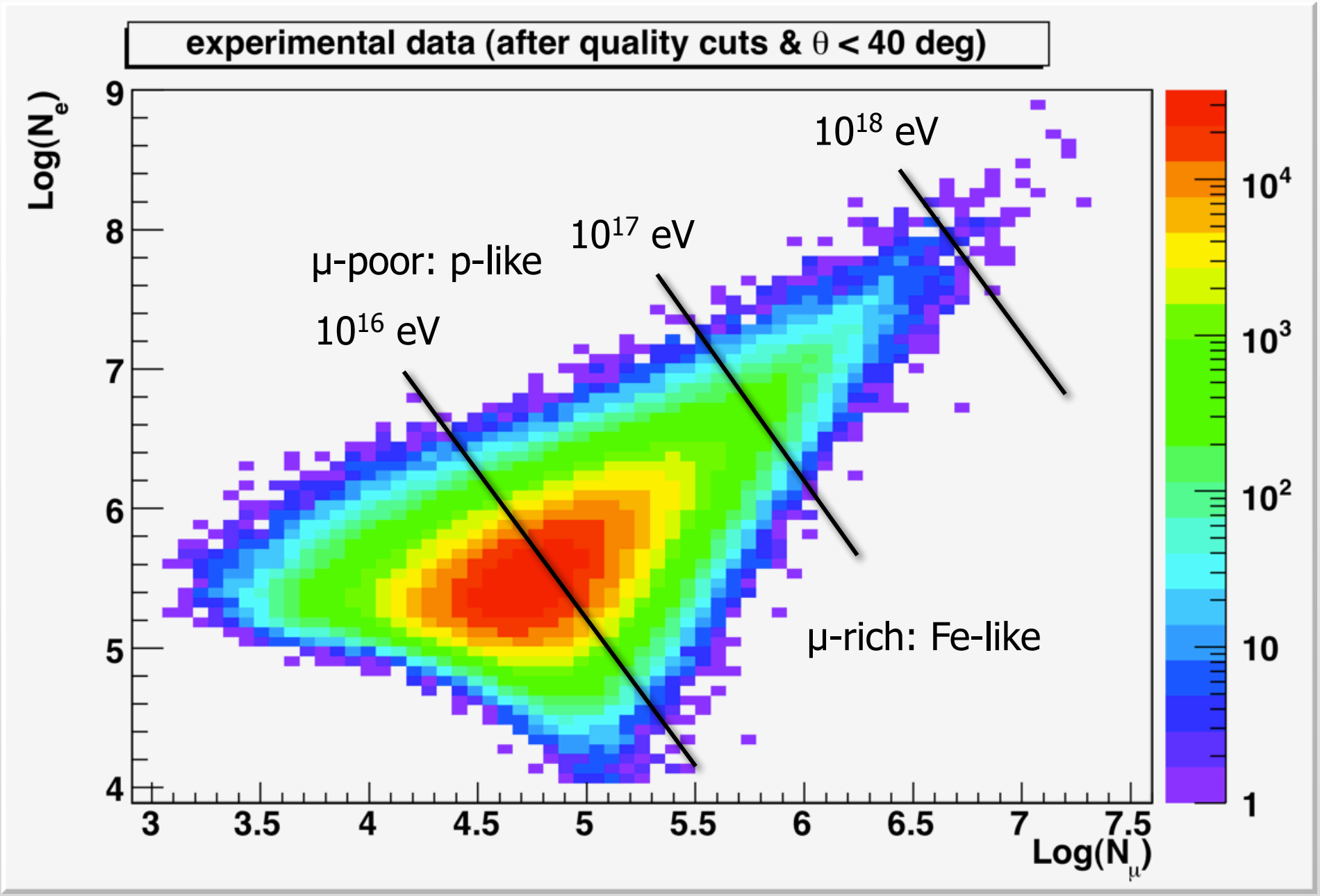


Muon LDF from KASCADE

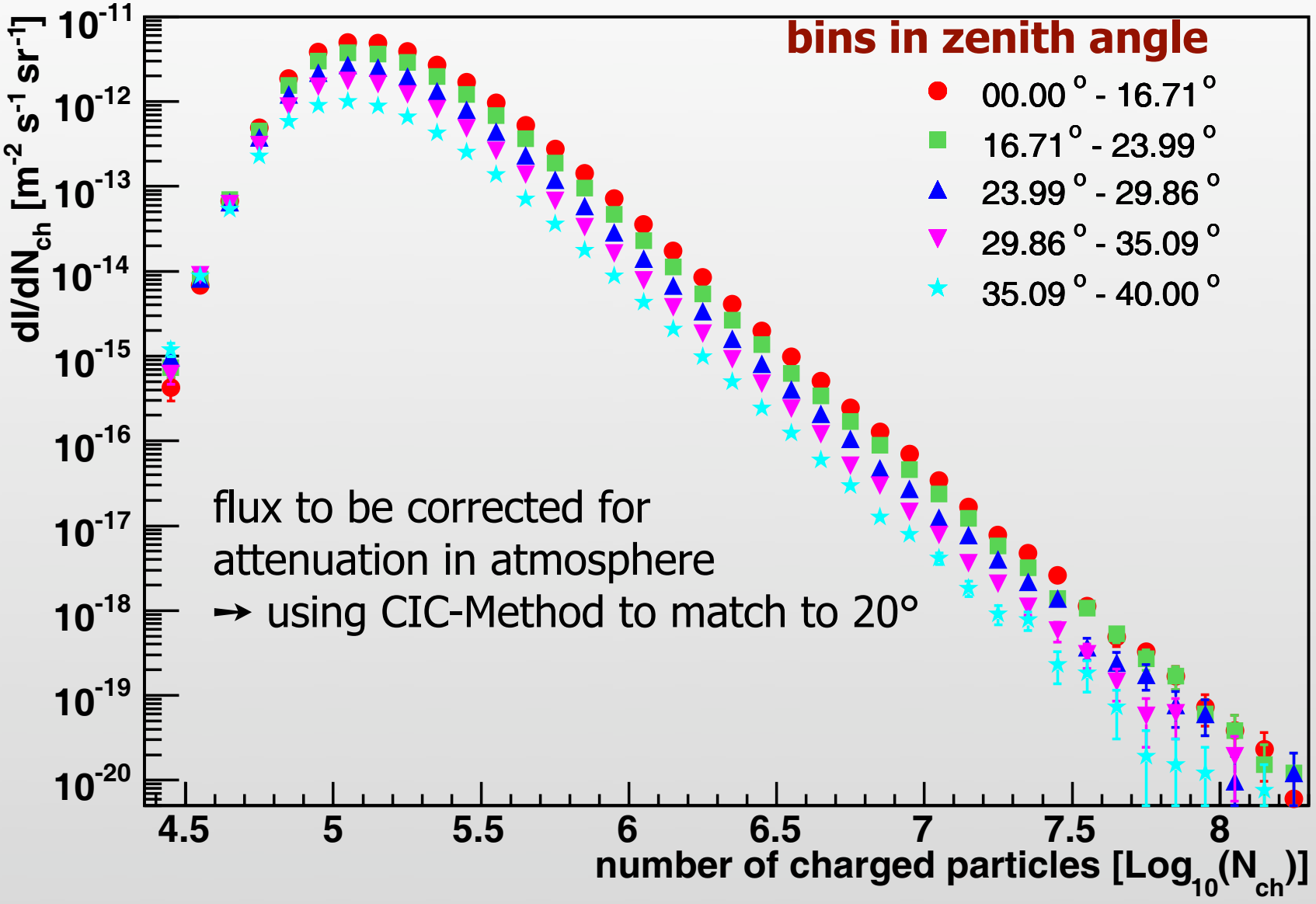
$$\rho_\mu(r) = N_\mu \cdot f_\mu(r) = N_\mu \cdot \frac{0.28}{r_0^2}\left(\frac{r}{r_0}\right)^{p_1}\left(1+\frac{r}{r_0}\right)^{p_2}\left(1+\left(\frac{r}{10\cdot r_0}\right)^2\right)^{p_3}.$$



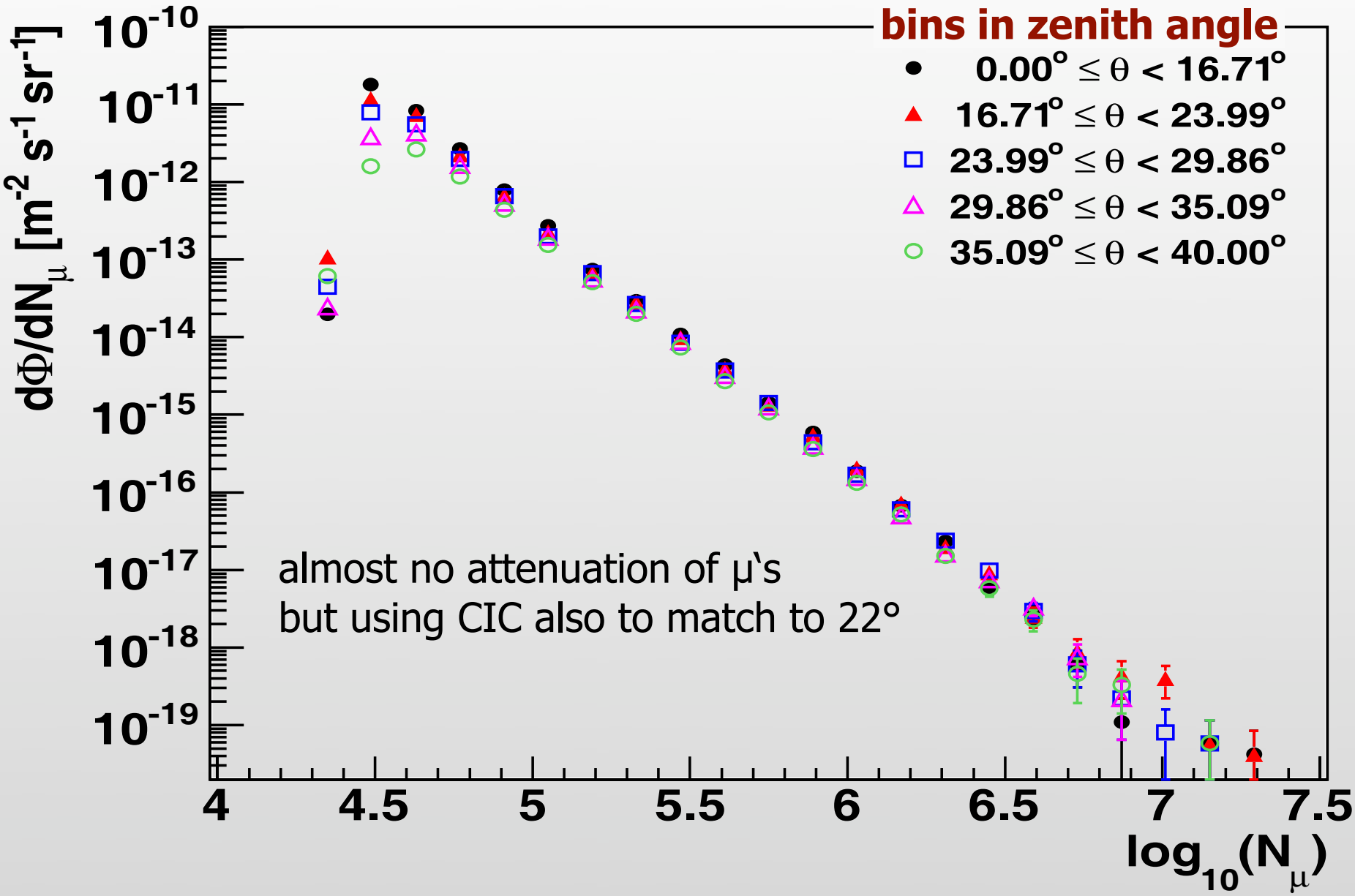
N_{ch} vs N_μ


experimental data (after quality cuts & θ < 40 deg)
Log(N_e)
9
8
7
6
5
4
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
Log(N_μ)
10^18 eV
10^17 eV
10^16 eV
μ-poor: p-like
μ-rich: Fe-like
10^4
10^3
10^2
10
1

$N_{charged}$ shower size distr.



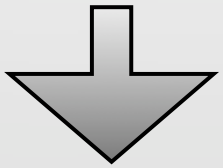
N_μ distribution



Reconstruction of E-Spectrum

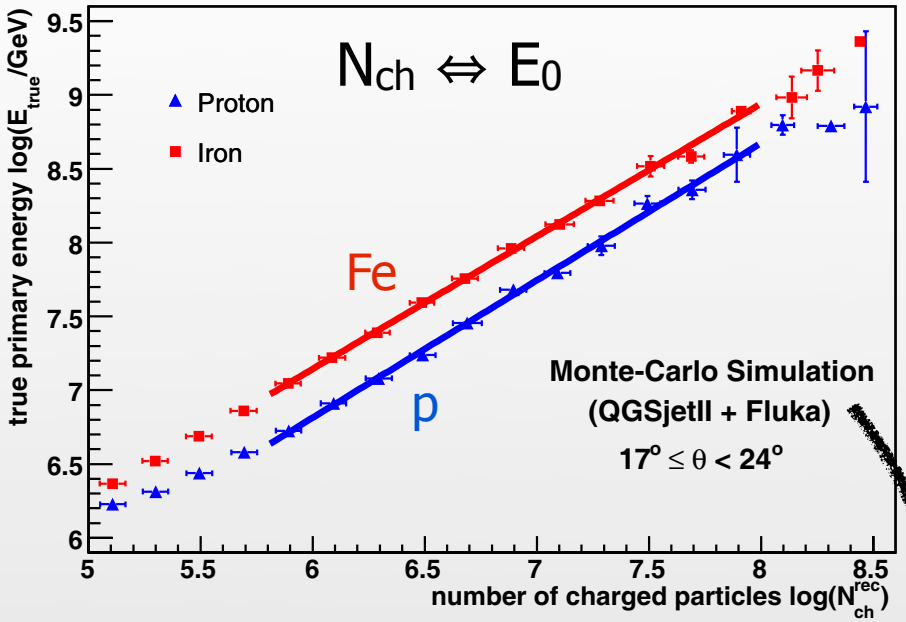
3 basic methods (at present):

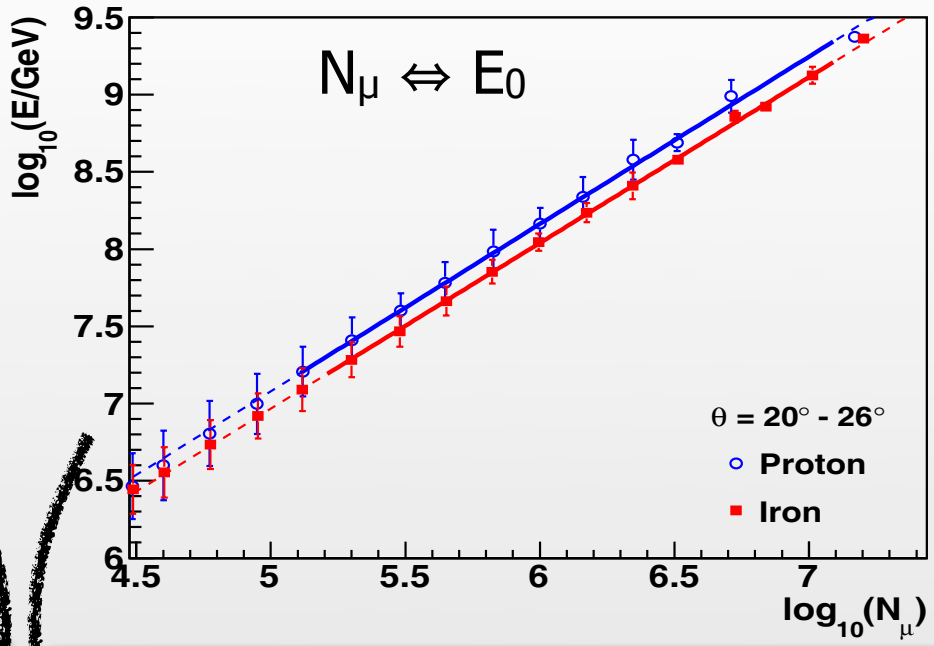
- N_{ch} as observable
  - ➠ $E_0 \propto N_{ch}^{\alpha}$ using CORSIKA and assuming primary mass
- N_{μ} as observable
  - ➠ $E_0 \propto N_{\mu}^{\beta}$ using CORSIKA and assuming primary mass
- N_{ch} vs N_{μ} combined as observable
  - ➠ minmizes composition dependence

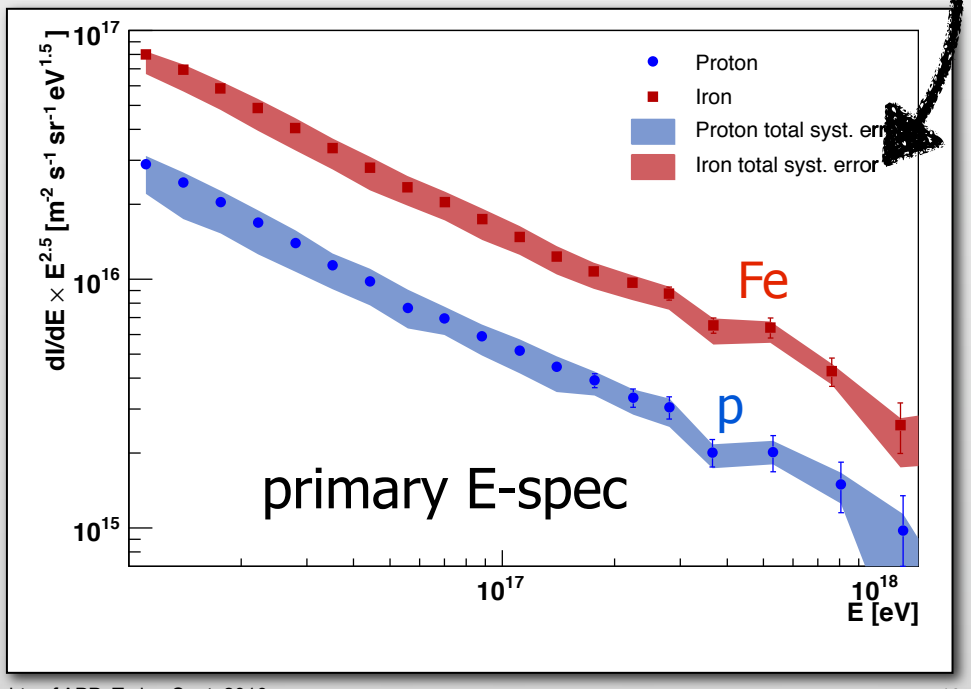


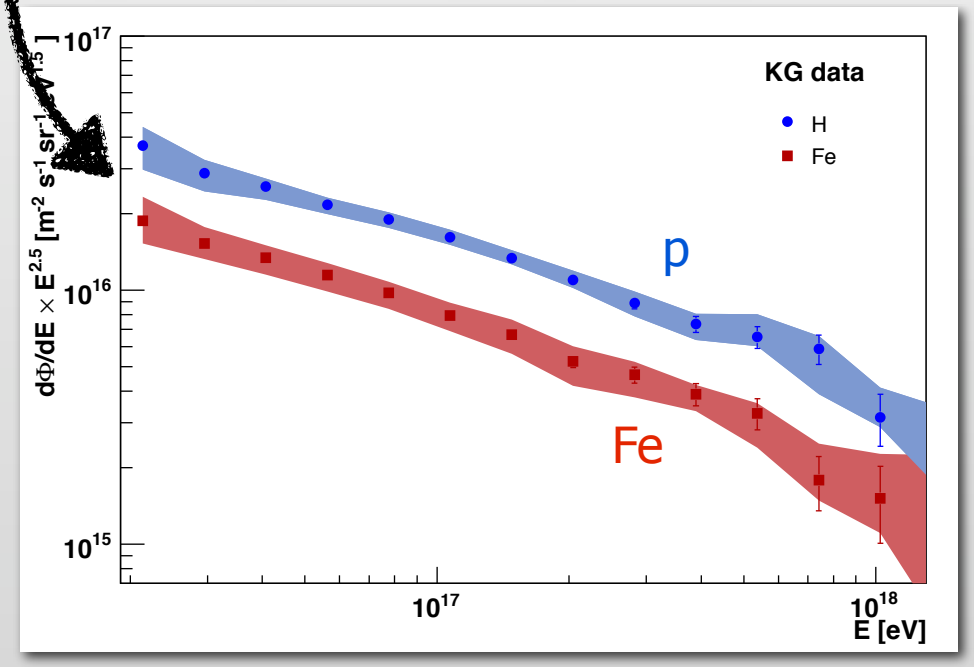
- Cross check of reconstruction procedures
- Cross check of systematic uncertainties
- Test sensitivity to composition
- Cross check of validity of hadronic interaction models

E-Spectra from N_{ch} & N_μ for p , Fe-assumption



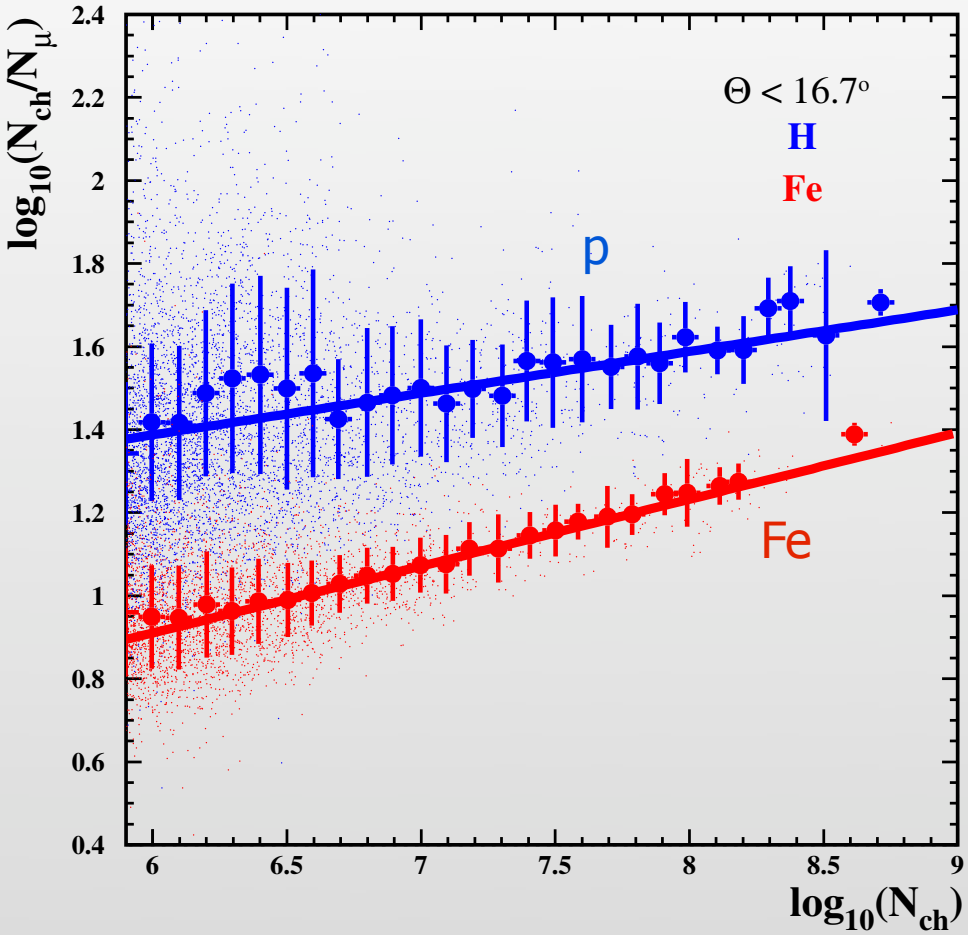


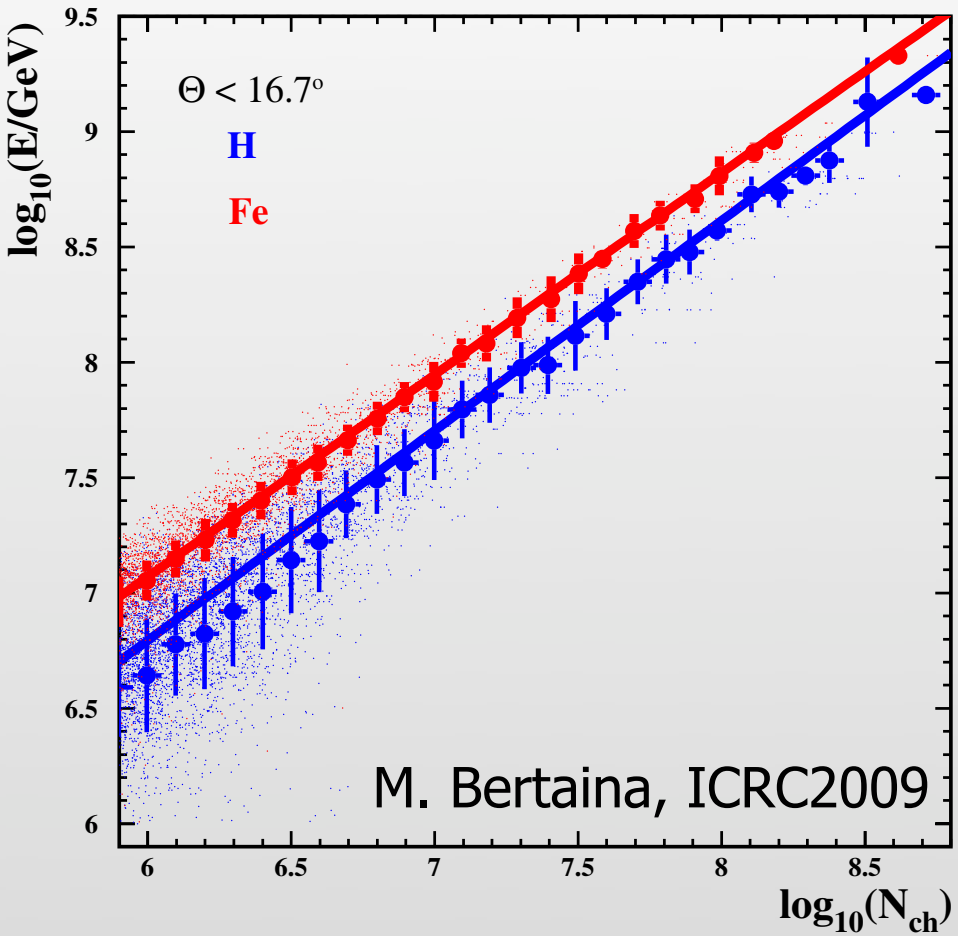




E-Spec from (N_{ch} & N_μ) combined

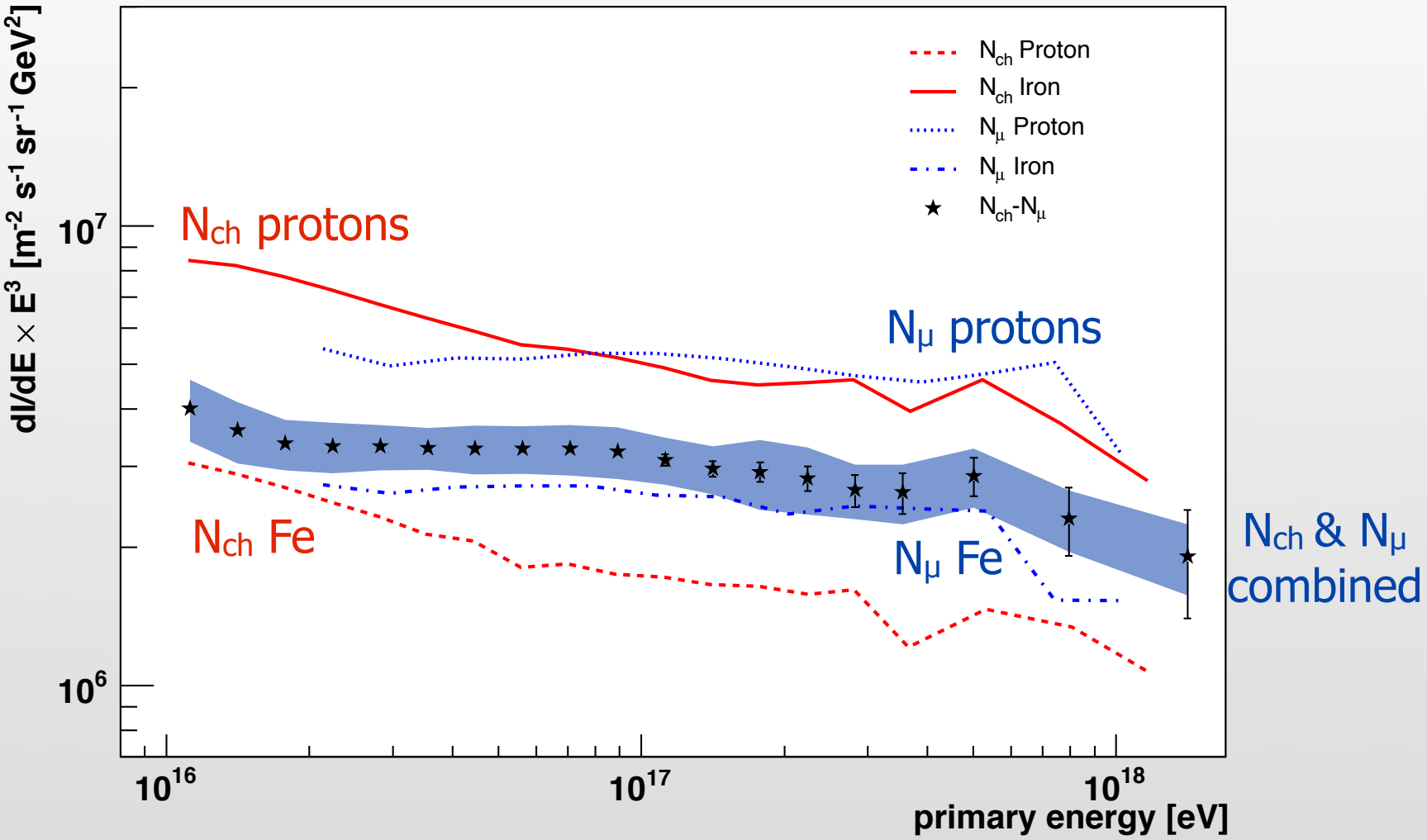
$$E = f(N_{ch}, k) \qquad k = \frac{log_{10}(N_{ch}/N_\mu) - log_{10}(N_{ch}/N_\mu)_p}{log_{10}(N_{ch}/N_\mu)_{Fe} - log_{10}(N_{ch}/N_\mu)_p}$$



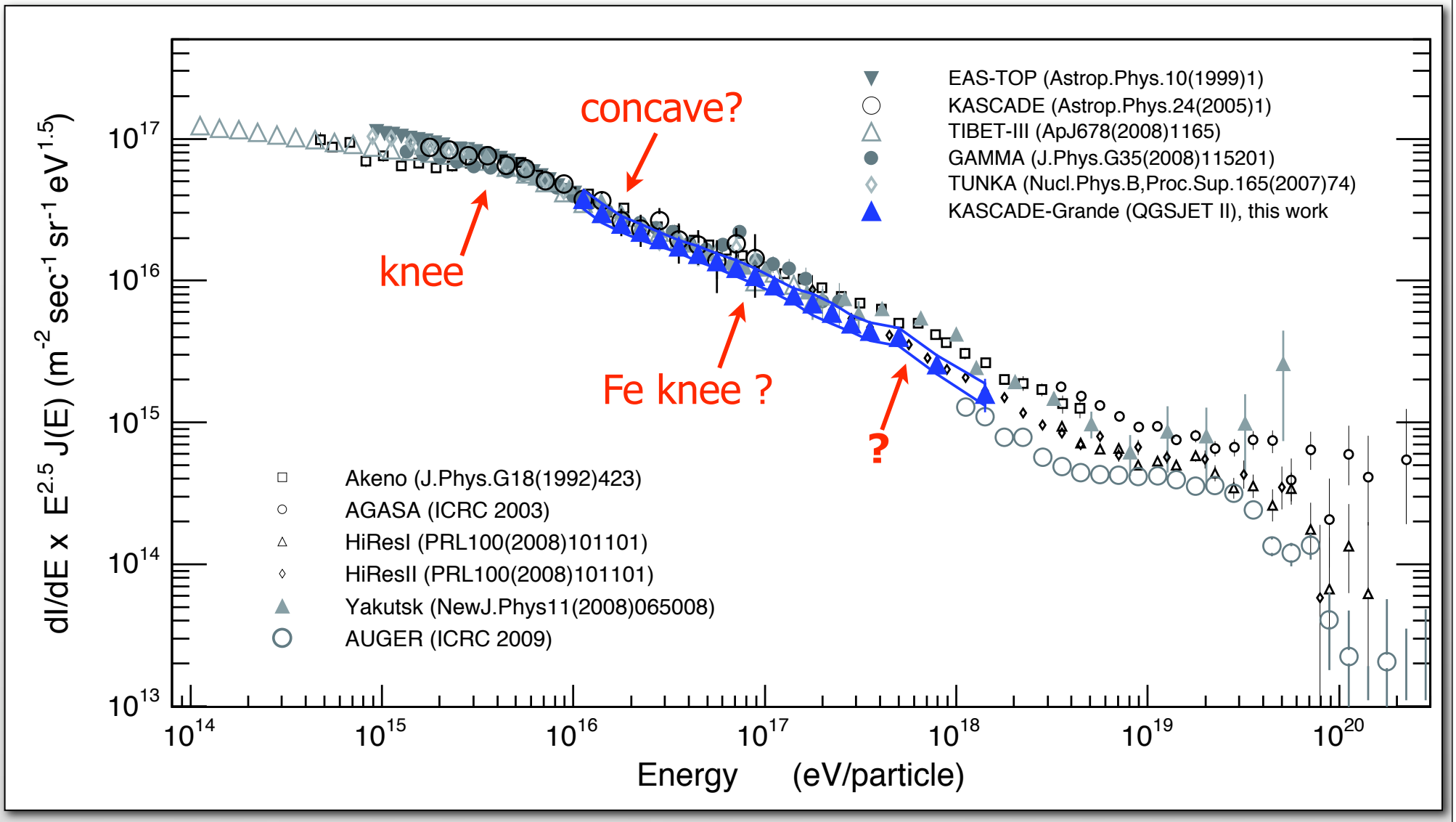


Method is independent from composition
but to be applied separately for each angular bin

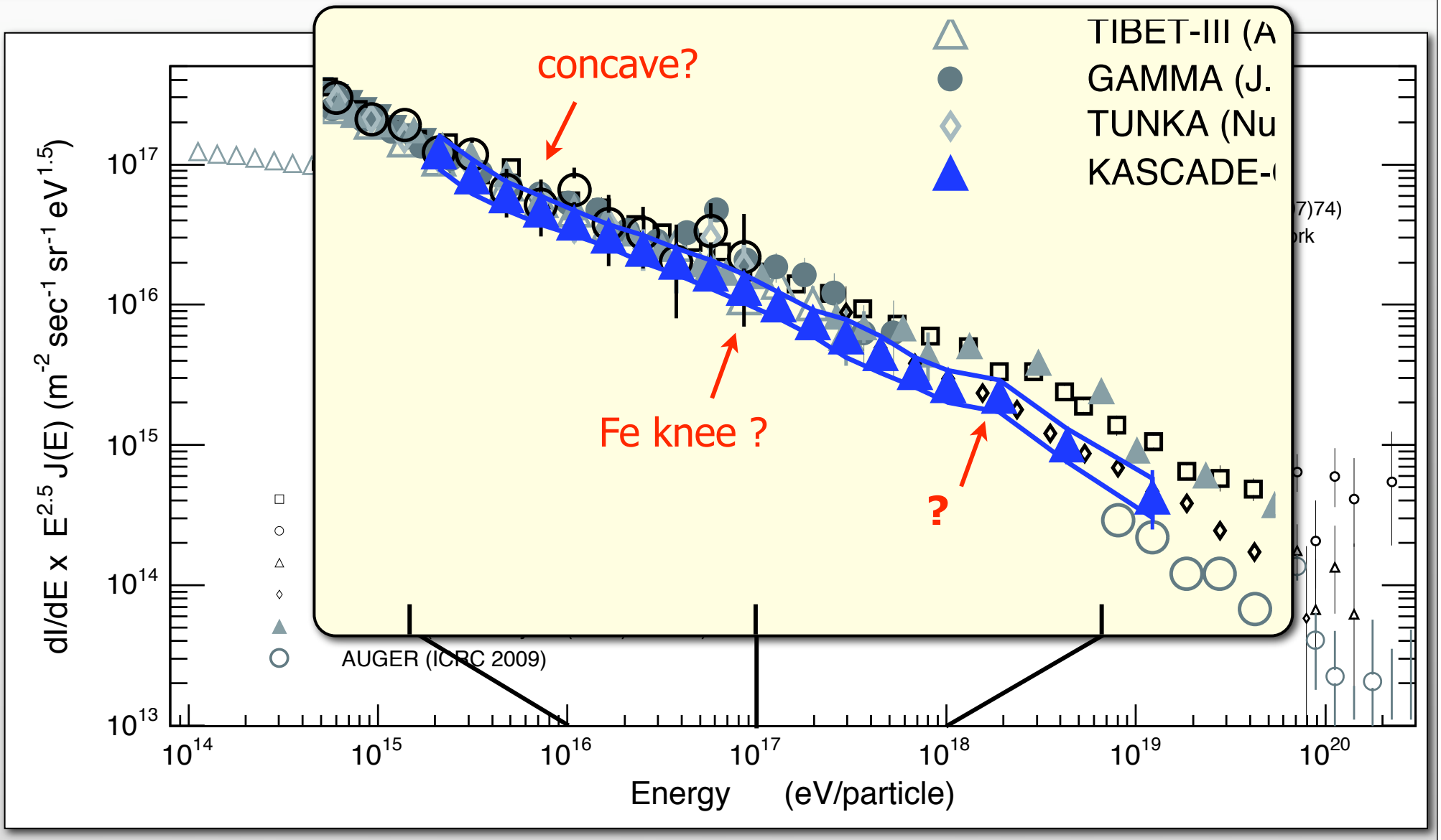
E-Spec: Comparison of Methods



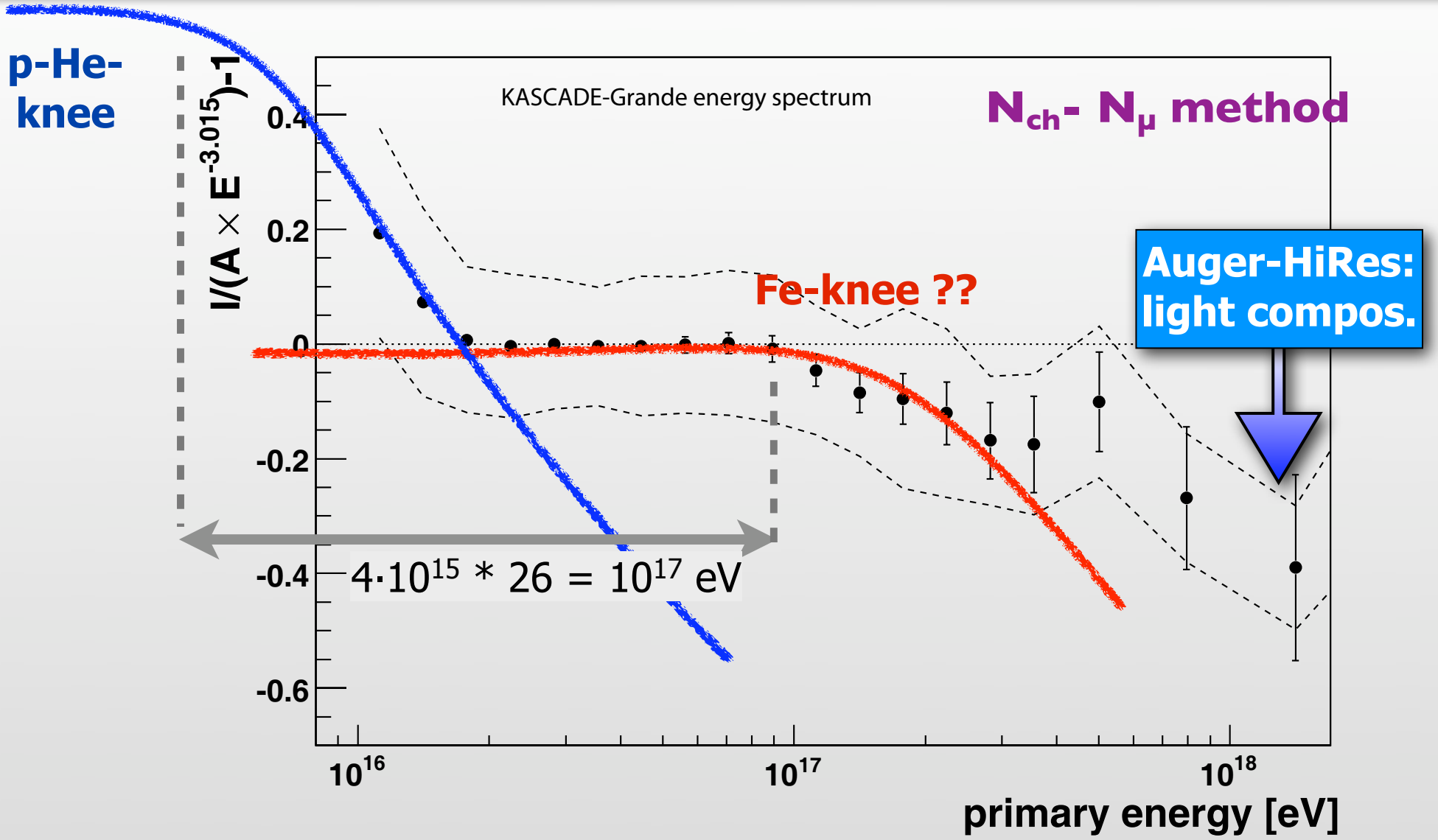
Comparison to other Expt's



Comparison to other Expt's



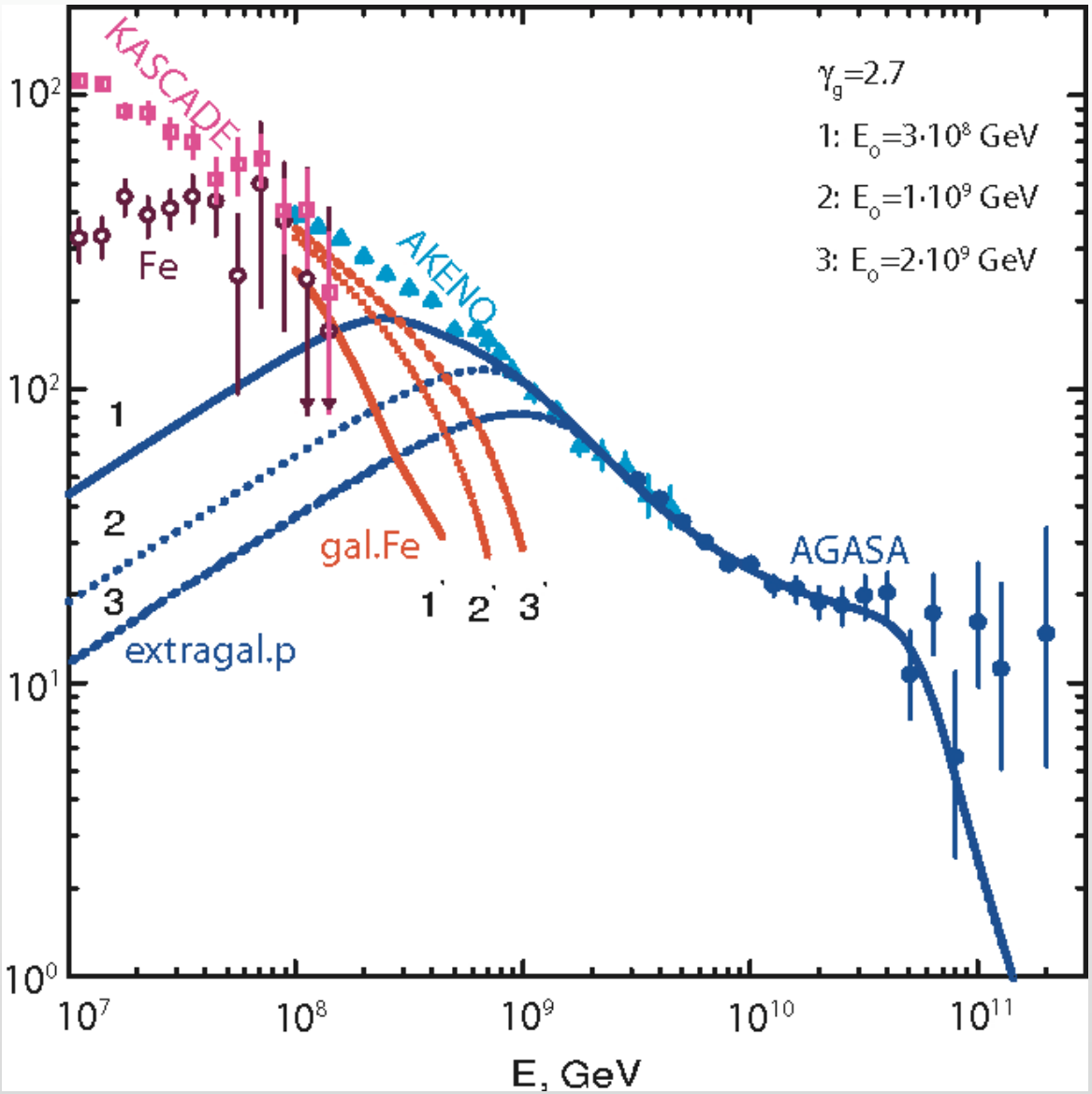
Residual Plot



~10% systematic uncertainty in flux (energy independent)

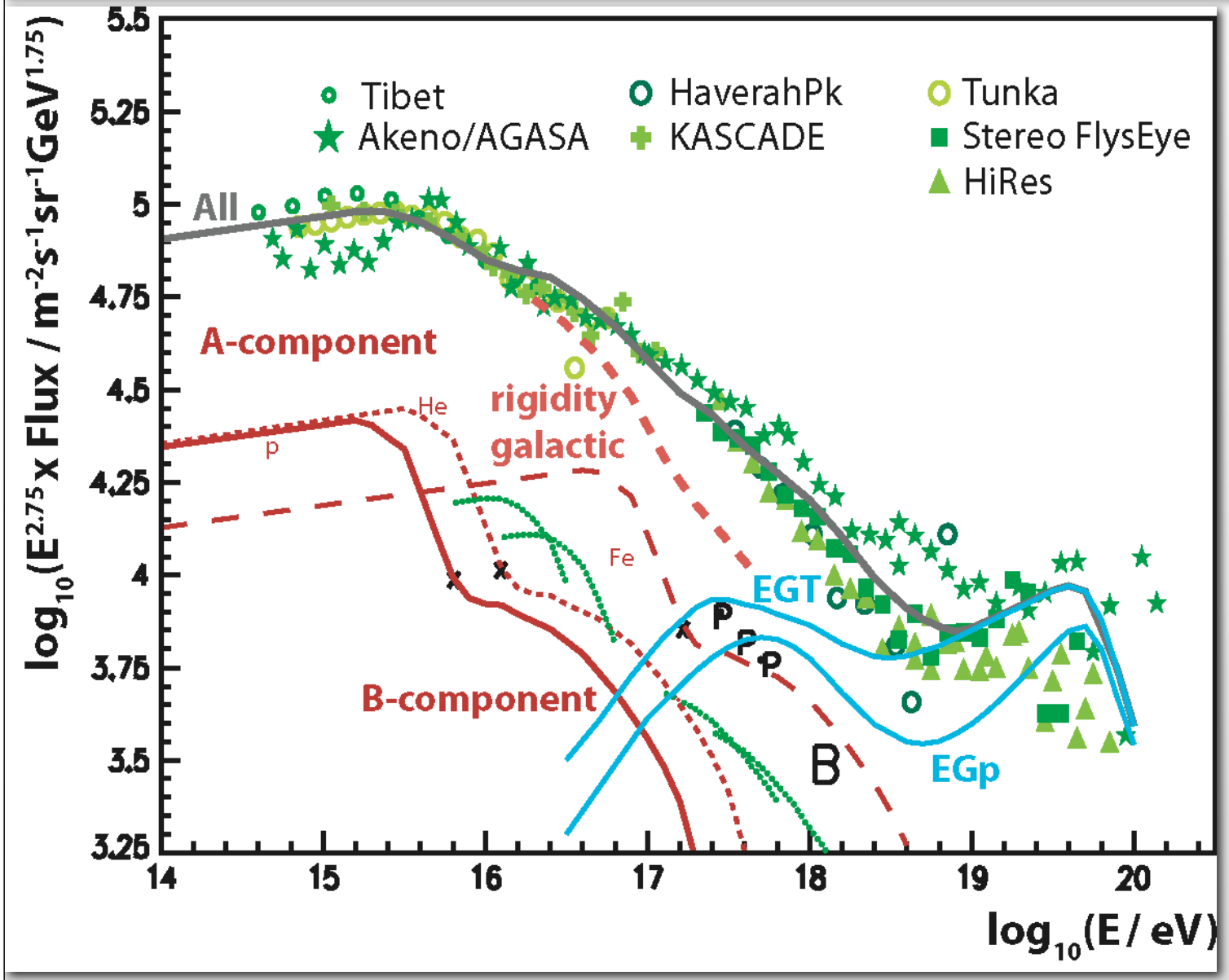
QGSJET II hadronic interaction model

Interpretation of CR-spectrum



Berezinsky
e+e- dip model
simple transition from galactic to extra-galactic

Interpretation of CR-spectrum

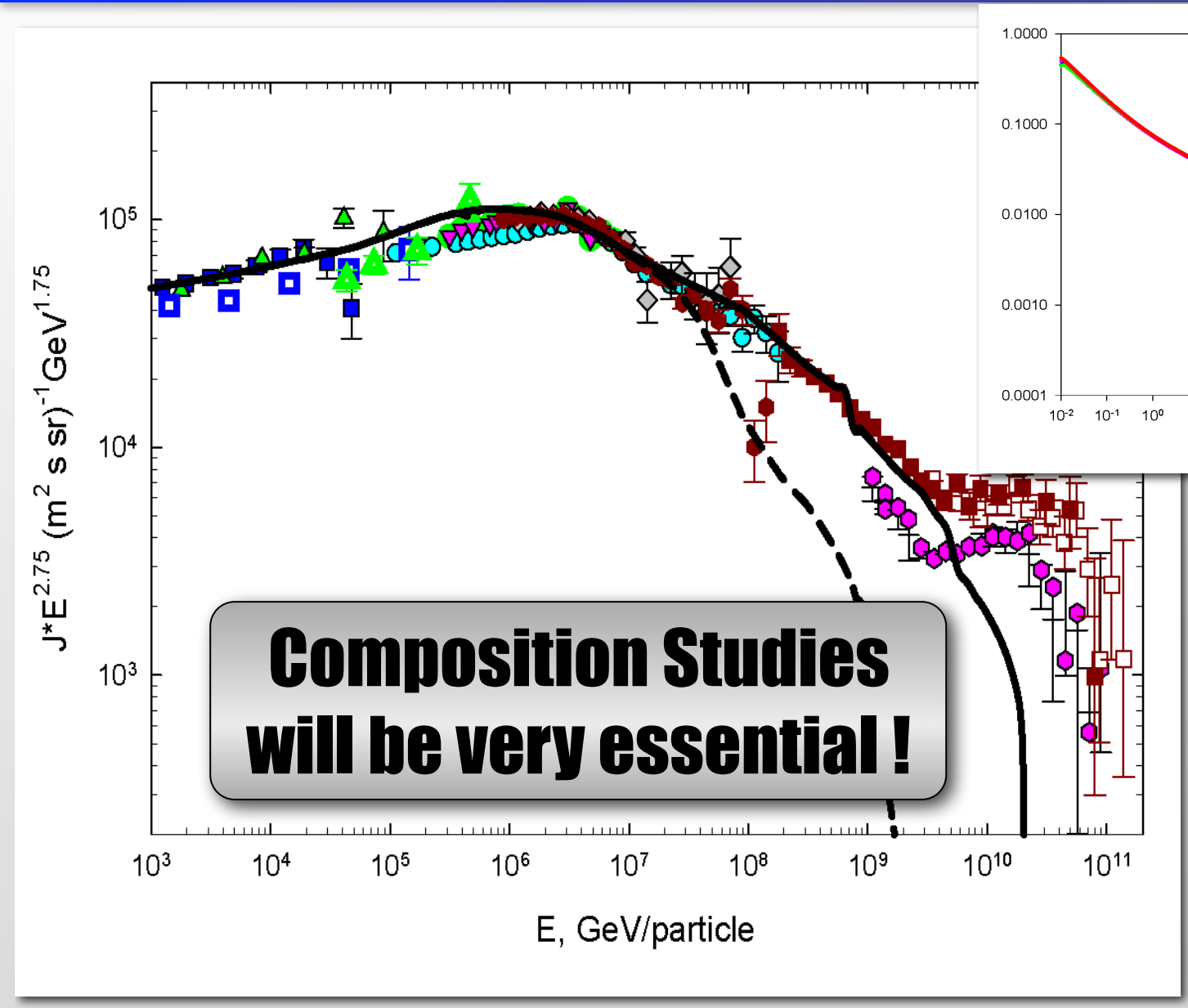


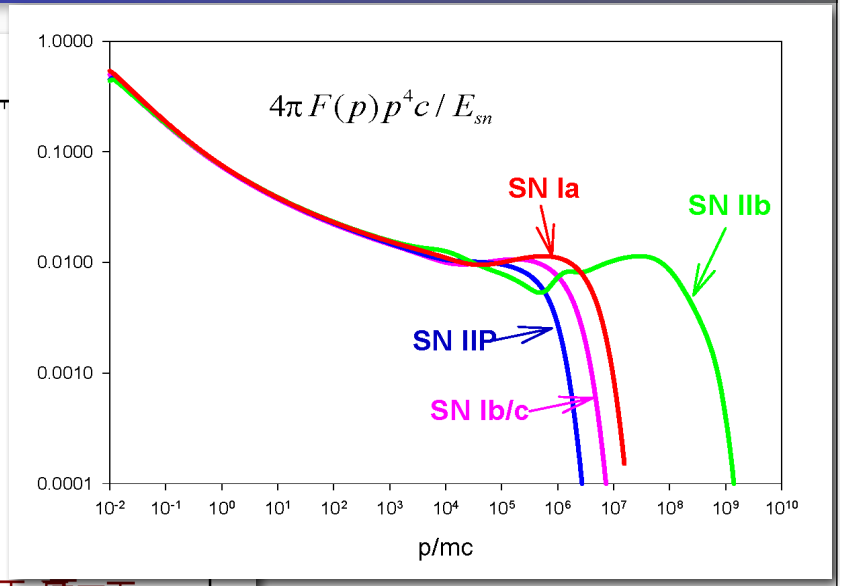
M. Hillas
JPG 31 (2005) R95

similar structures as seen in data originate from galactic comp. B (e.g. by different type of SNe)

single source model of E&W also give rise to structures...

Interpretation of CR-spectrum



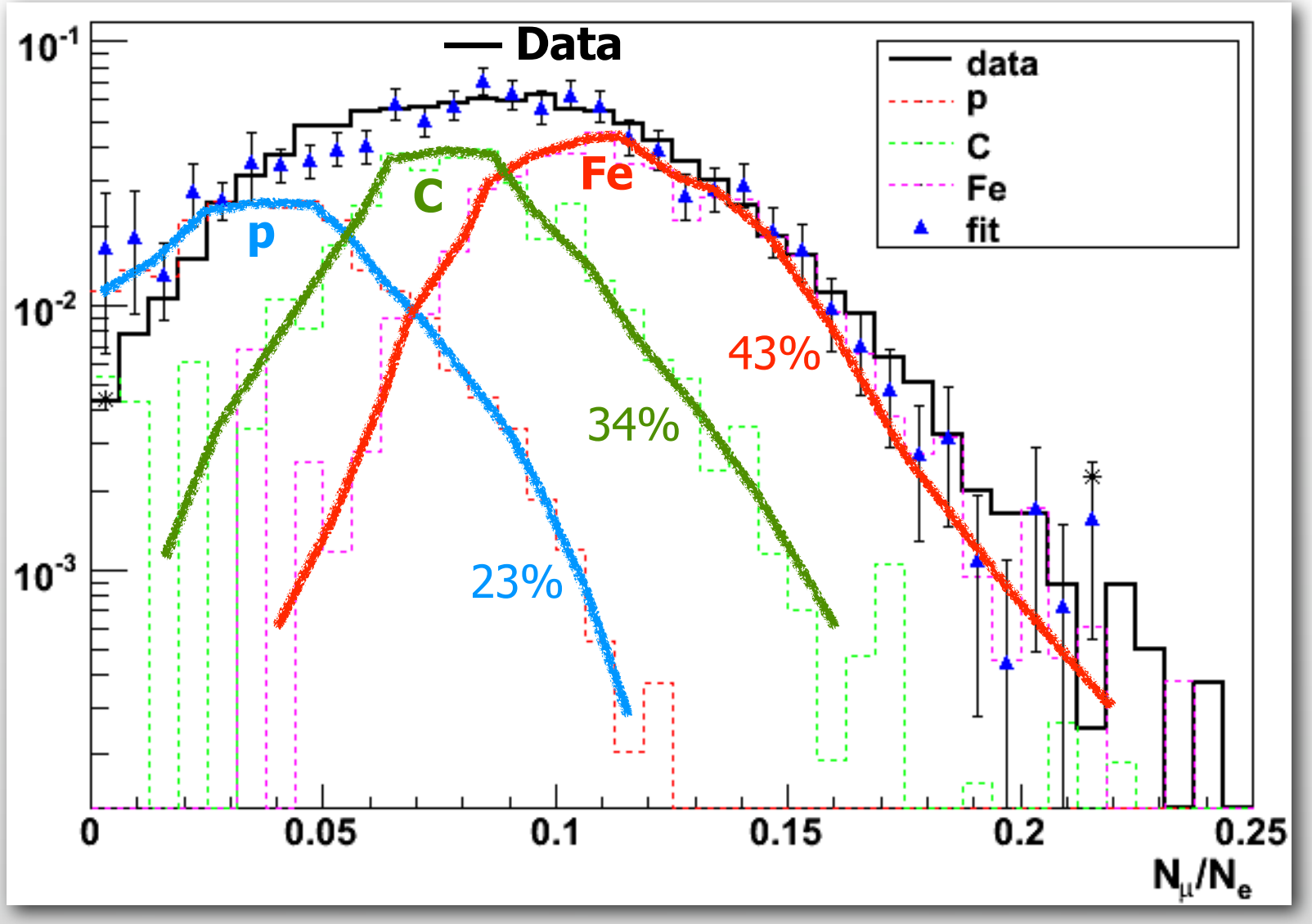


V. Ptuskin et al., Astrophysical Journal 718 (2010) 31.

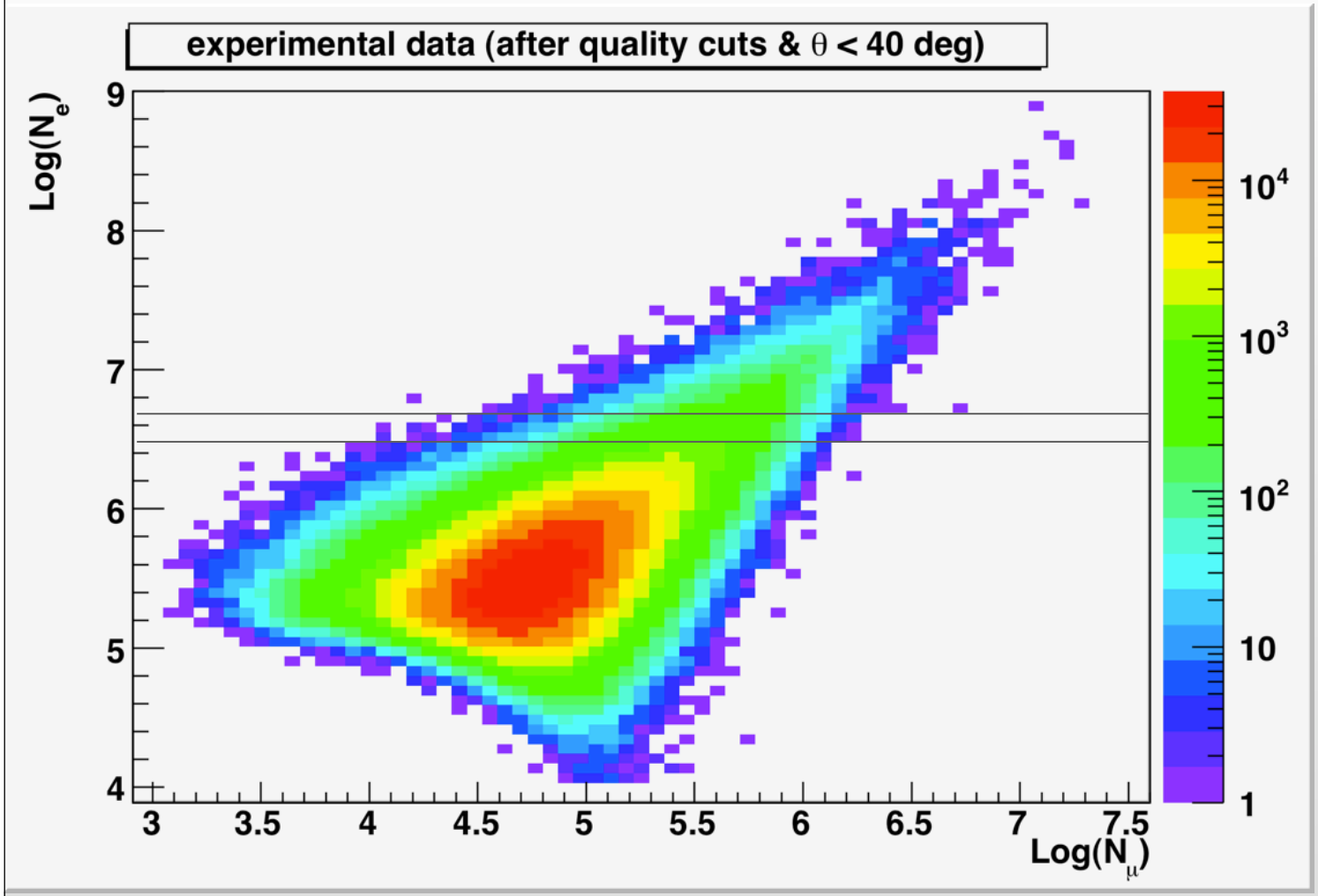
Simple Approach: Composition from N_μ/N_e ratio

$6.49 \leq \lg(Ne) \leq 6.74$

Cantoni et al. ICRC 2009



2D-regularized unfolding



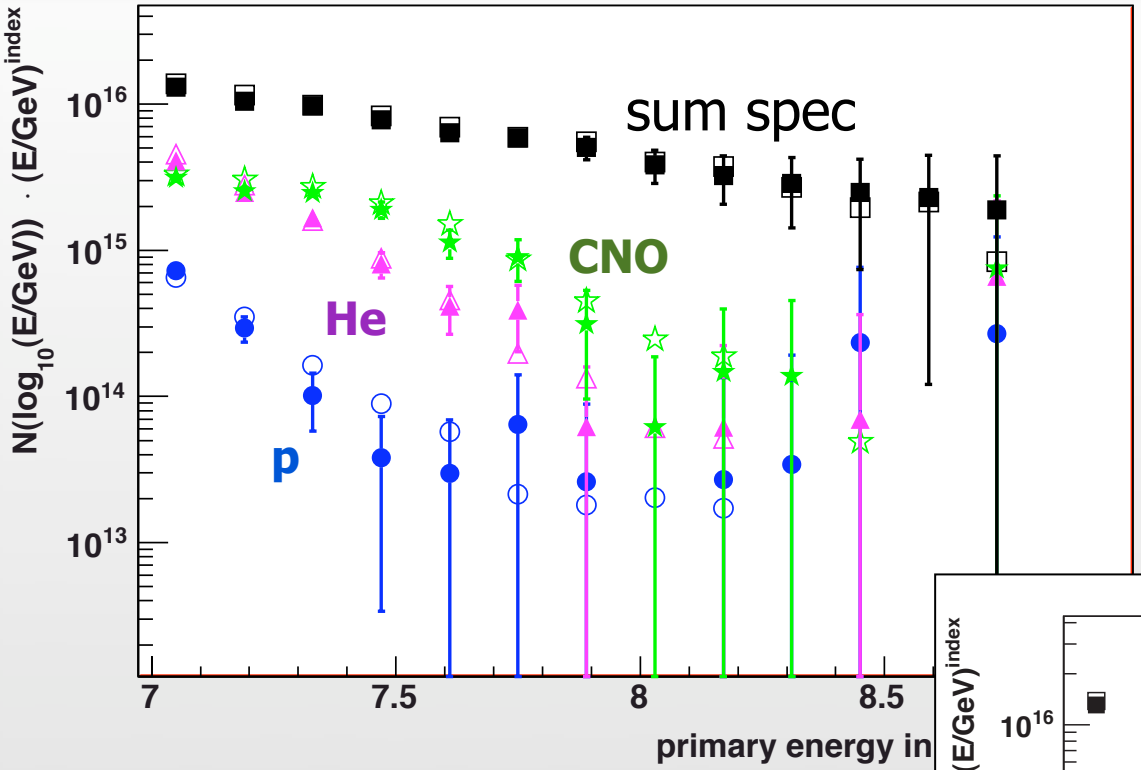
KASCADE-Grande data

- 1173 days of effective DAQ time.
- Performance of reconstruction and detector is stable.
- θ < 40°
- Exposure: $2 \cdot 10^{17}$ cm^2 s sr

see: Antoni et al. APP 24 (2005) 1

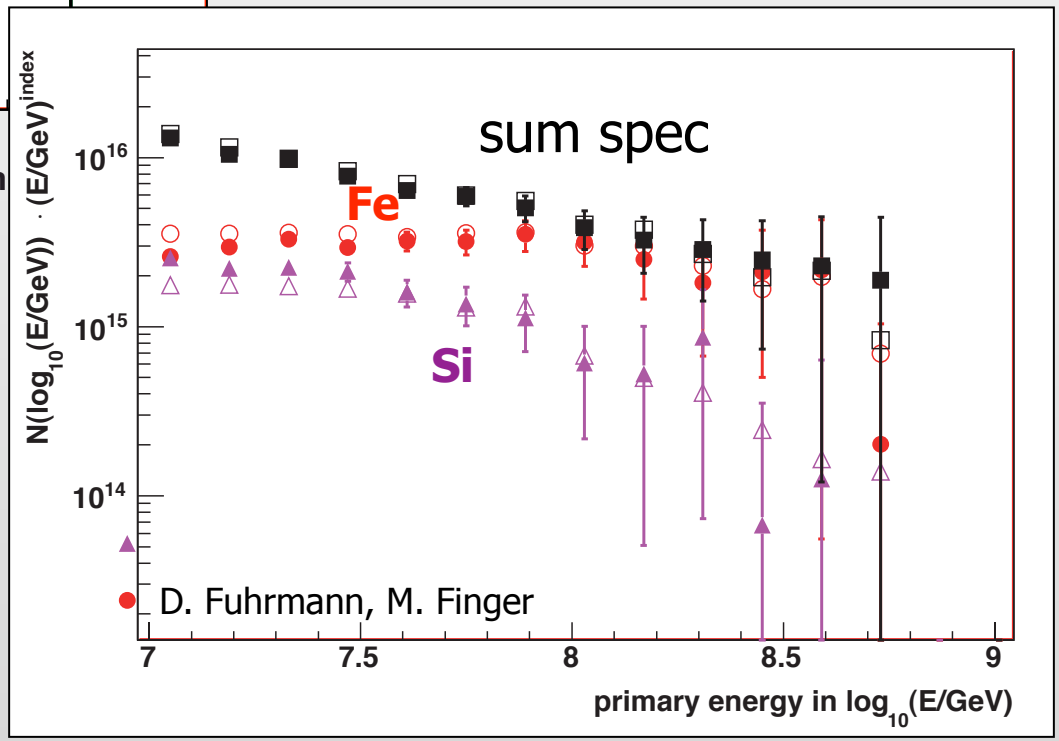
$$\frac{dJ}{d\lg(N_{ch}^{\mathrm{rec}})\, d\lg(N_\mu)} = \sum_A \int_{-\infty}^{-\infty} \frac{dJ_A}{d\lg(E)} p_A(\lg(N_{ch}^{\mathrm{rec}}, \lg(N_\mu^{\mathrm{rec}})|\lg(E)) d\lg(E)$$

Test of Unfolding (5 mass groups)



open symbols:
synthetic spectra + stat. fluctuations based on KASCADE used as input here

full symbols:
reconstructed spectra with full detector MC



stable unfolding
next step:
application to real data

Conclusion

- KASCADE-Grande had quite a difficult start

  but Giannis passion & stubbornness made it become true
- co-location to KASCADE enables many tests of data quality
- all particle spectra consistent with EAS-TOP & KASCADE
- 10^{16} – 10^{18} eV region very important to verify Fe-knee and transition galactic - extra-galactic
- No single power law; structures seen in spectra
- Unfolding of spectra in progress - stay tuned!
- data from Auger AMIGA/HEAT, IceTop, etc. will be very interesting to compare with

patient...

hard working...

... with humor

1999 in Lapland (KHK)