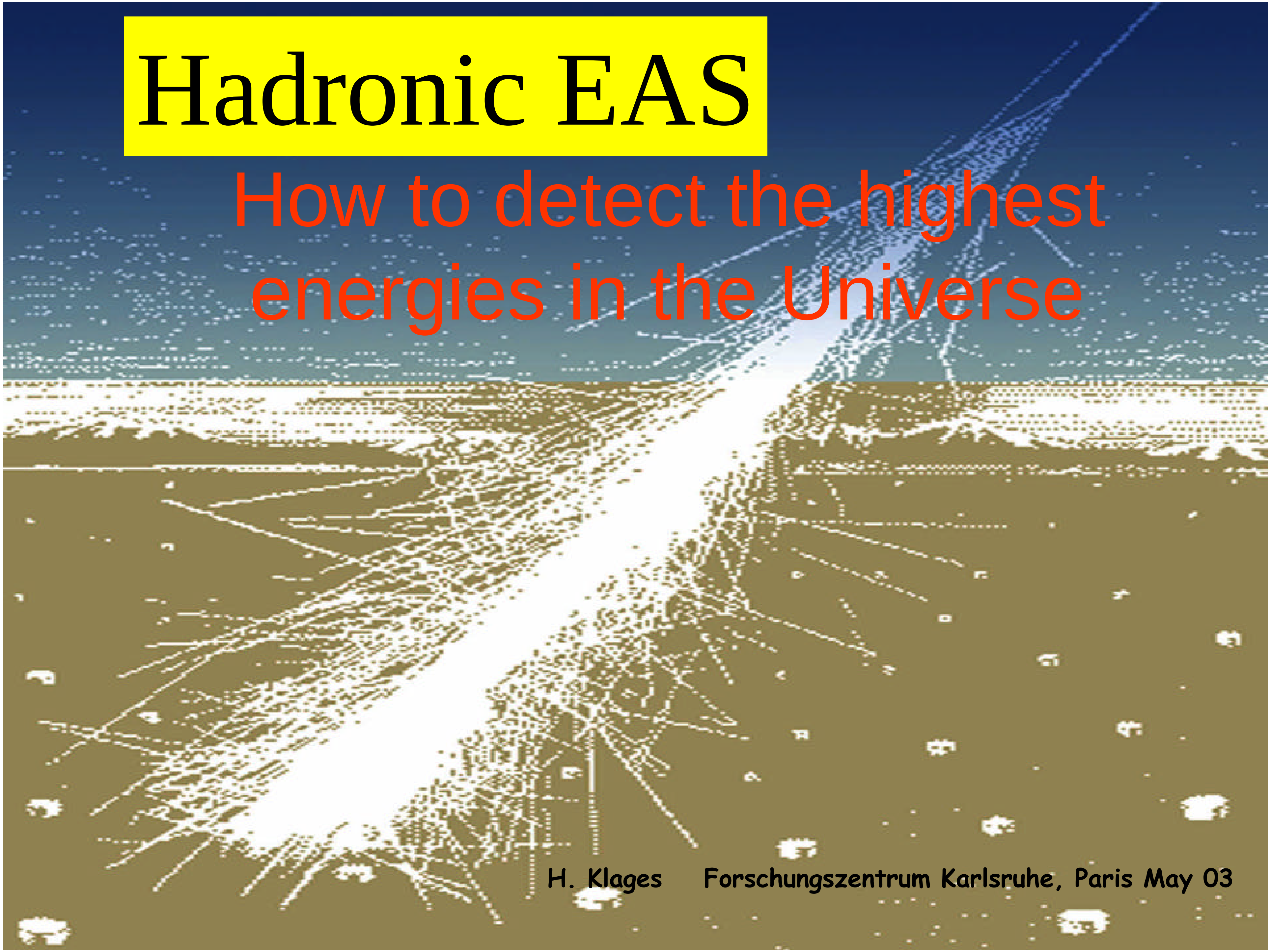
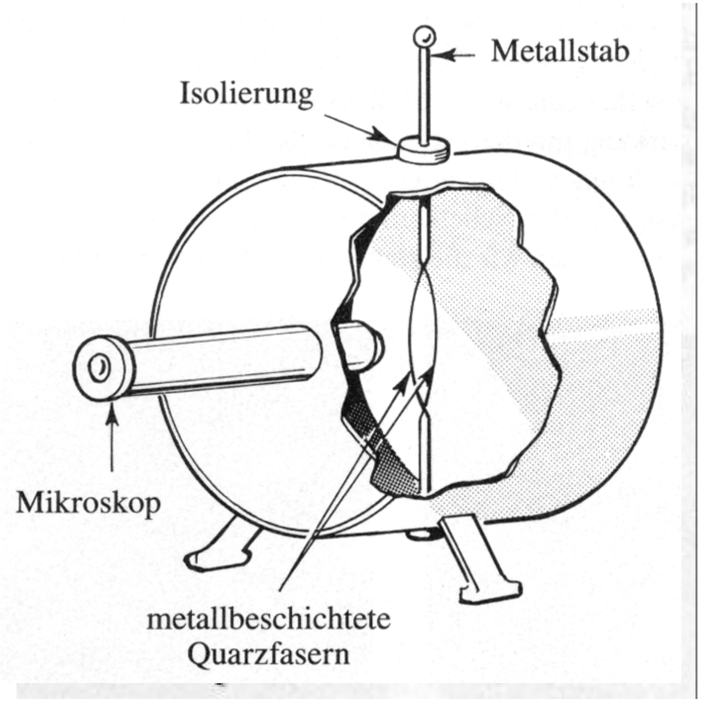
Hadronic EAS

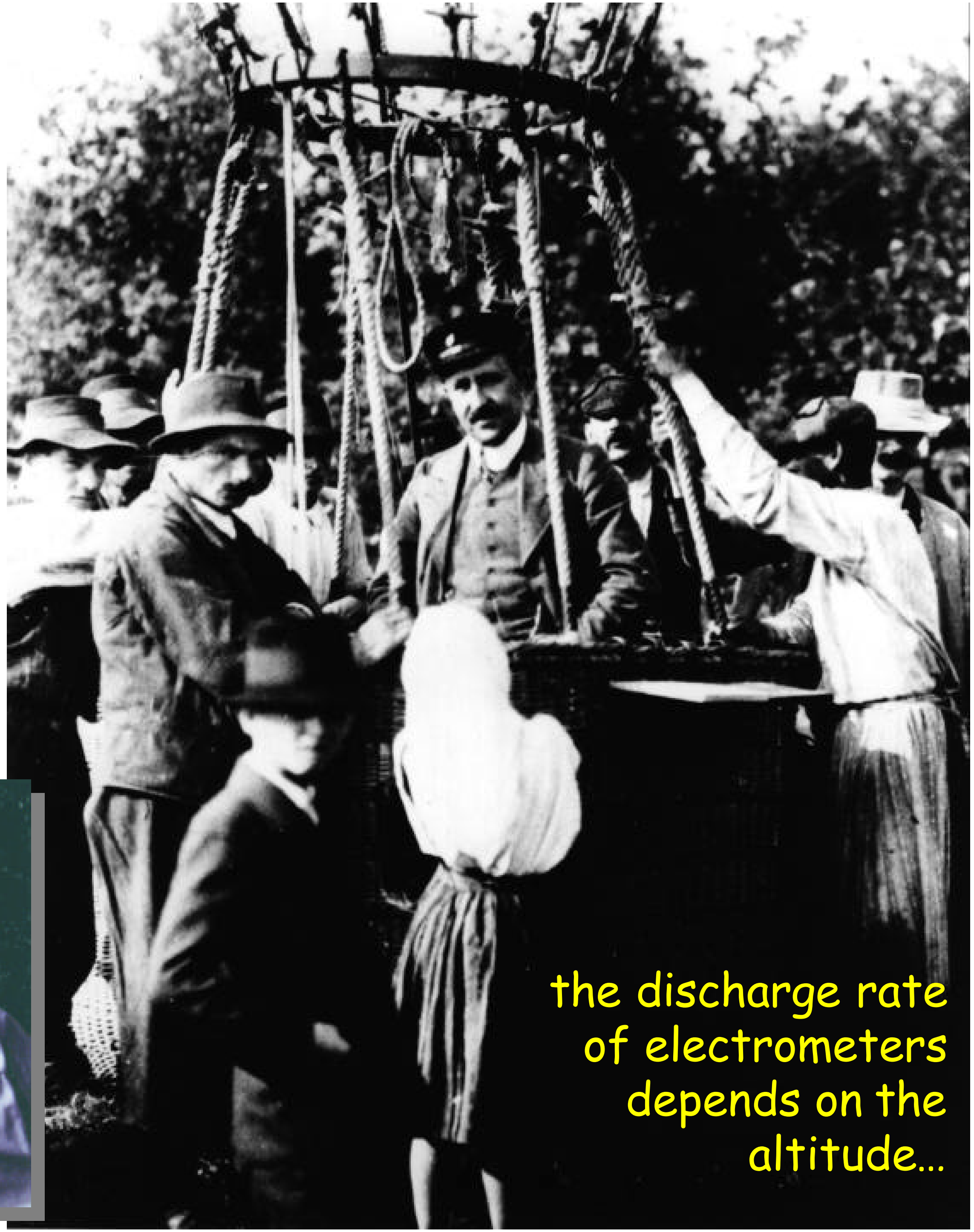
How to detect the highest energies in the Universe



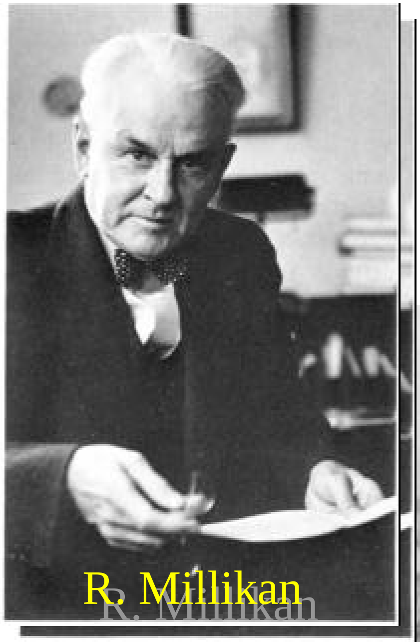
H. Klages Forschungszentrum Karlsruhe, Paris May 03

Victor Hess (1912)





„Cosmic Rays“



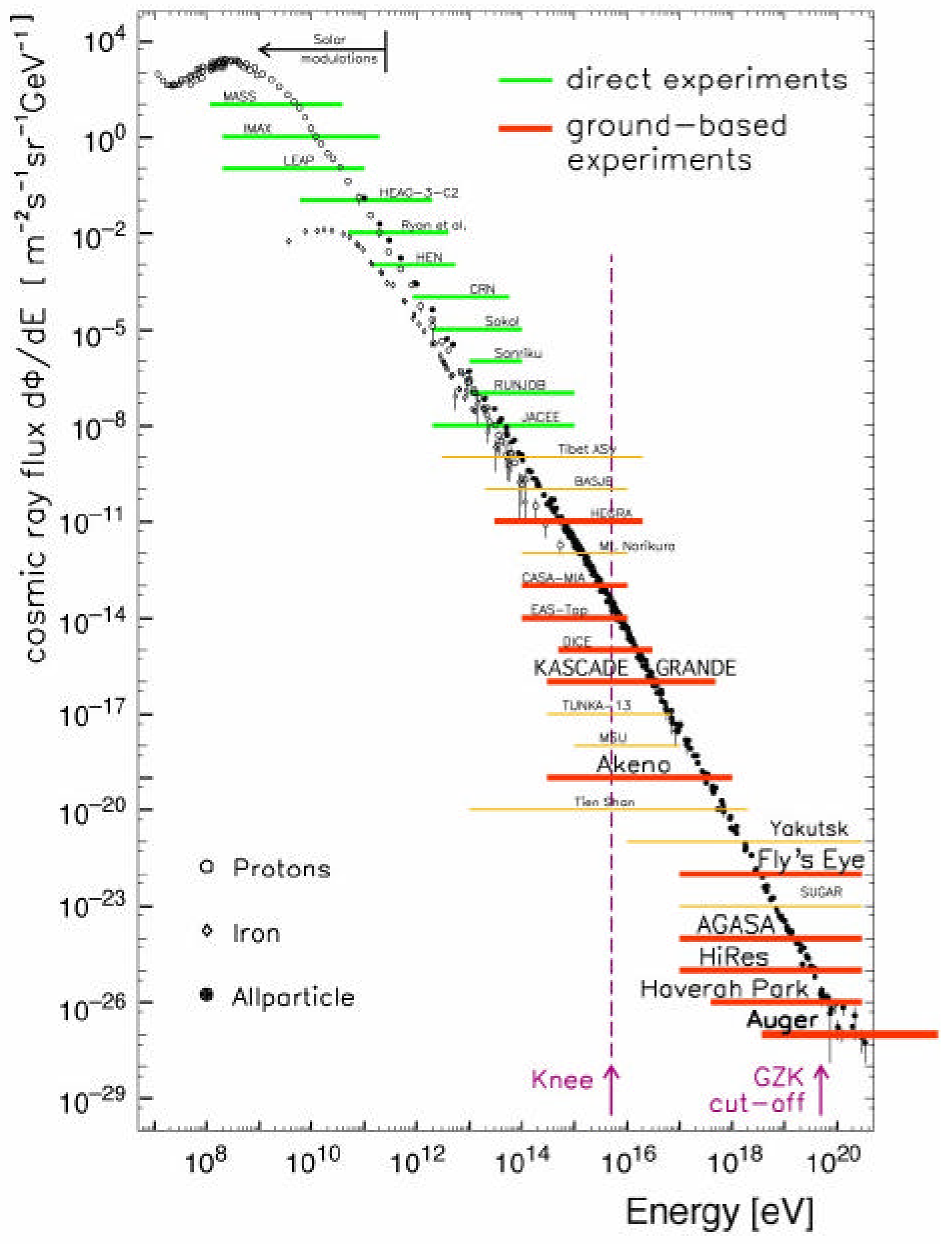
direct detection:

satellites or balloons

limited to ~ $E_0 < 10^{14}$ eV

$I(E>E_0) \propto E_0^{-2}$

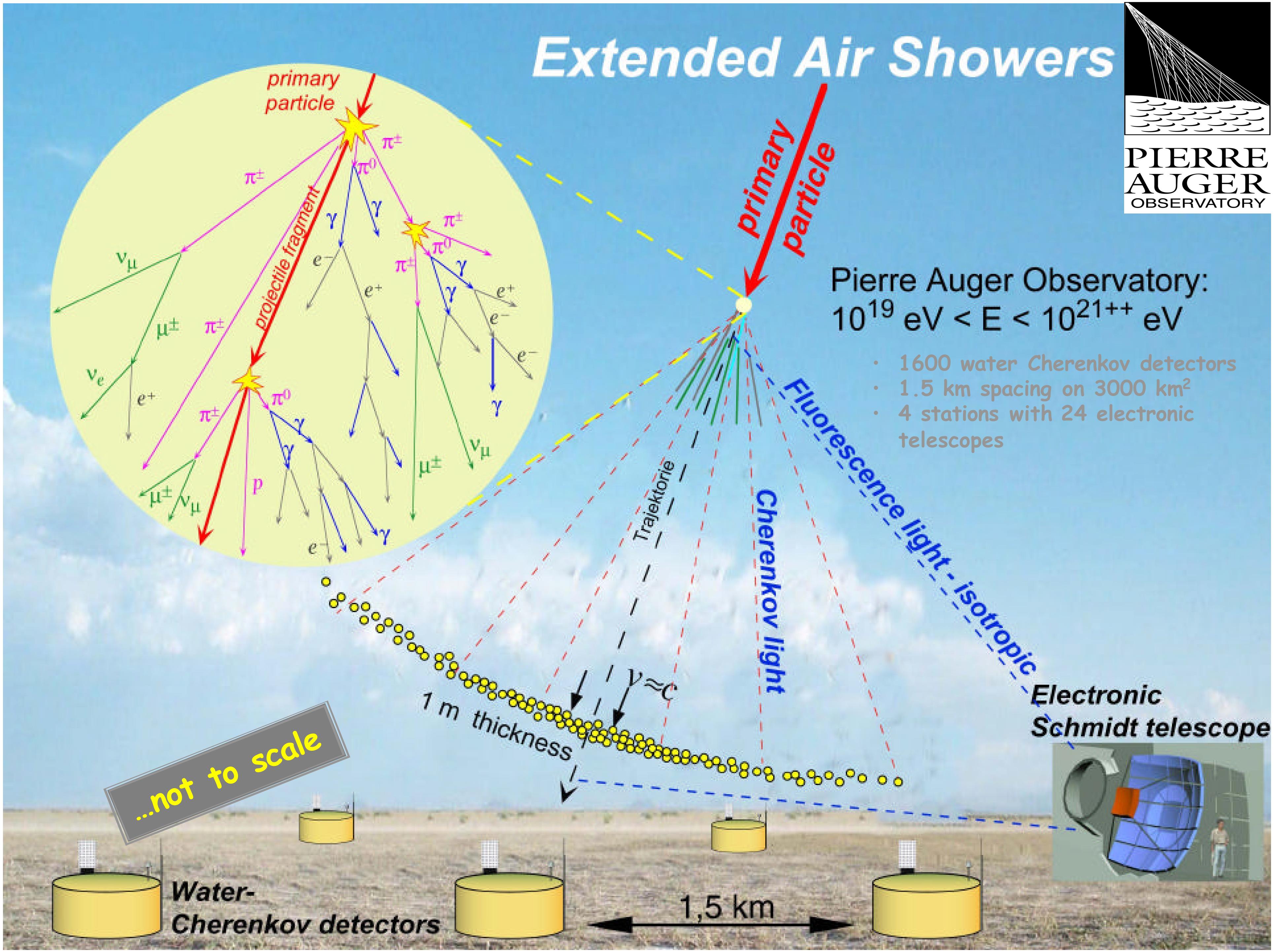
The differential energy spectrum of cosmic rays: > 30 decades in flux



Pierre Auger (1938)
Extensive air showers

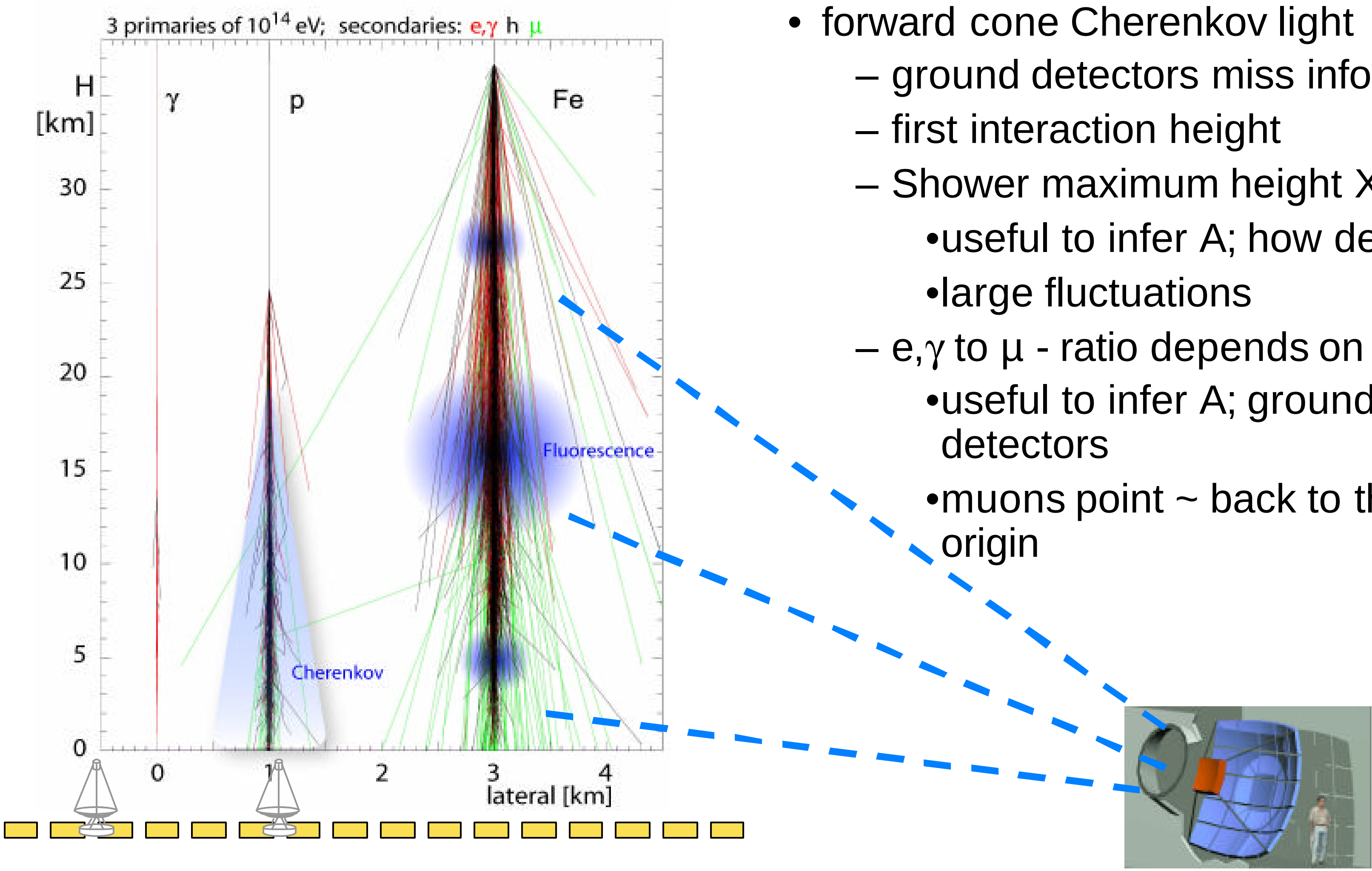
- Coincidence experiment on the Jungfraujoch
  - counting rate decreased only slowly as detectors were $\rightarrow$ 300m apart
- Primary particles of very high energy create large cascades of secondaries which hit the ground
  - estimate: 10^{15} eV !

"… it is impossible to imagine a single process which could give such energies to a particle. It seems much more probable that … they get their energies in electric fields of large dimensions."



Extended Air Showers
PIERRE AUGER OBSERVATORY
primary particle
Pierre Auger Observatory:
10^19 eV < E < 10^21++ eV
1600 water Cherenkov detectors
1.5 km spacing on 3000 km²
4 stations with 24 electronic telescopes
primary particle
projectile fragment
π±
π0
γ
e−
e+
νμ
μ±
νe
p
Trajektorie
v≈c
Cherenkov light
Fluorescence light - isotropic
1 m thickness
...not to scale
Electronic Schmidt telescope
Water-Cherenkov detectors
1,5 km

Extended Air Showers

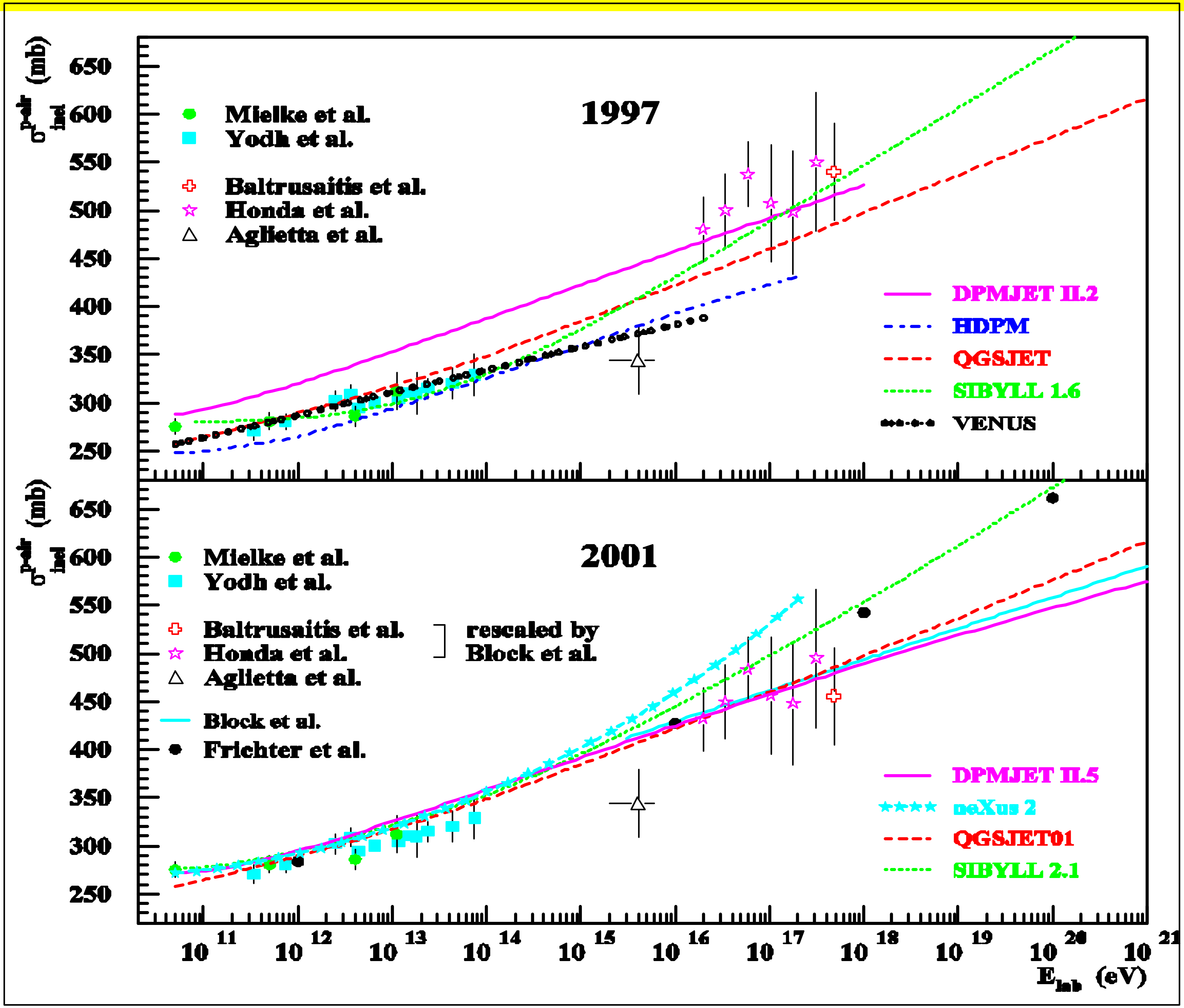


- energy > 10^{14} eV:
- particle detectors at ground
- isotropic air fluorescence light
- forward cone Cherenkov light
  - ground detectors miss information
  - first interaction height
  - Shower maximum height X_{max}
    - useful to infer A; how detect ?
    - large fluctuations
  - e,γ to μ - ratio depends on A
    - useful to infer A; ground detectors
    - muons point ~ back to their origin

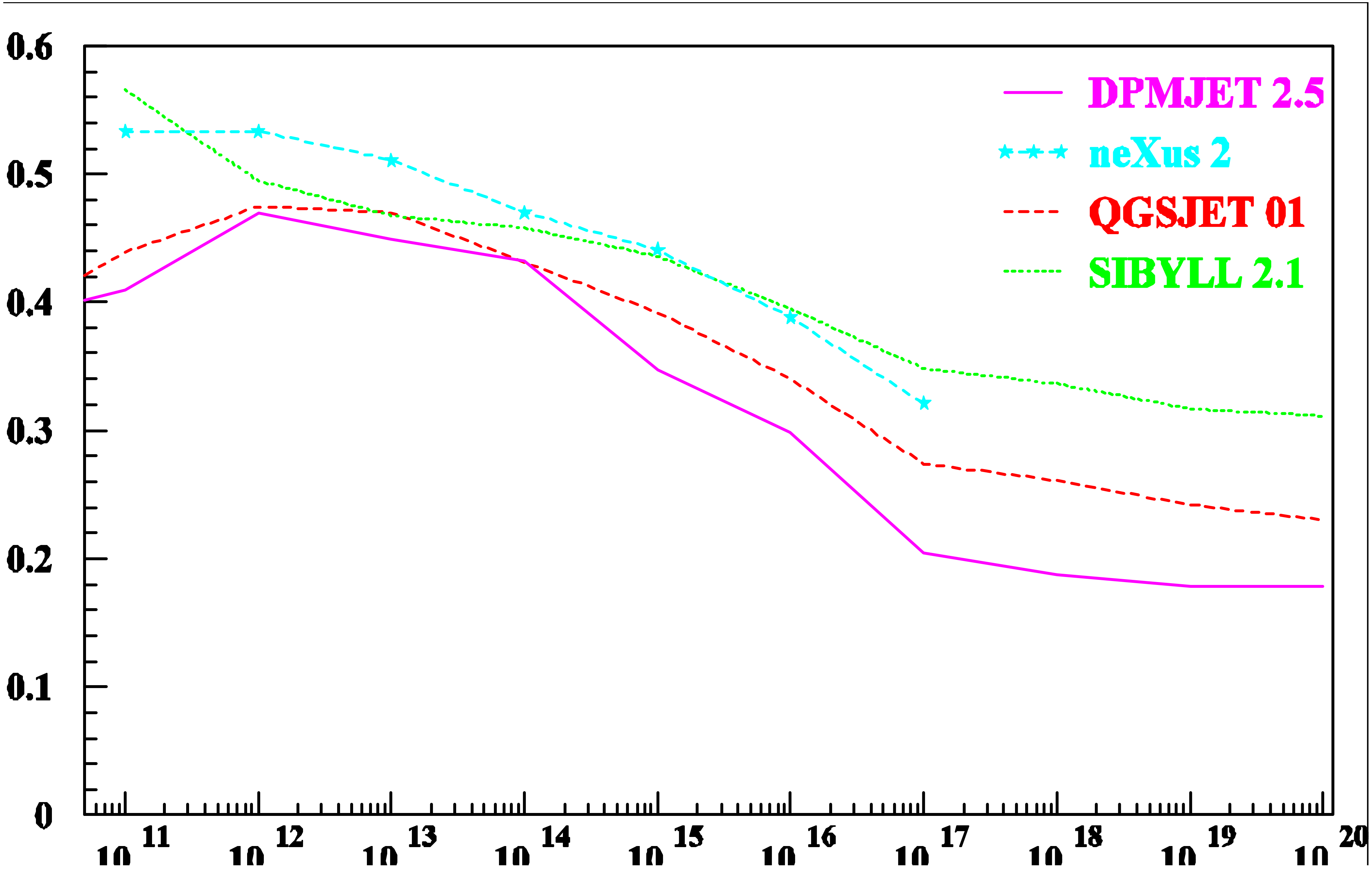
nucleon-nucleon and nucleon – air interaction details

- energy dependence of cross sections
- (in-)elasticity
- secondary particles
- particle multiplicities
- angular distributions
- energy distributions
- development of interaction models with time

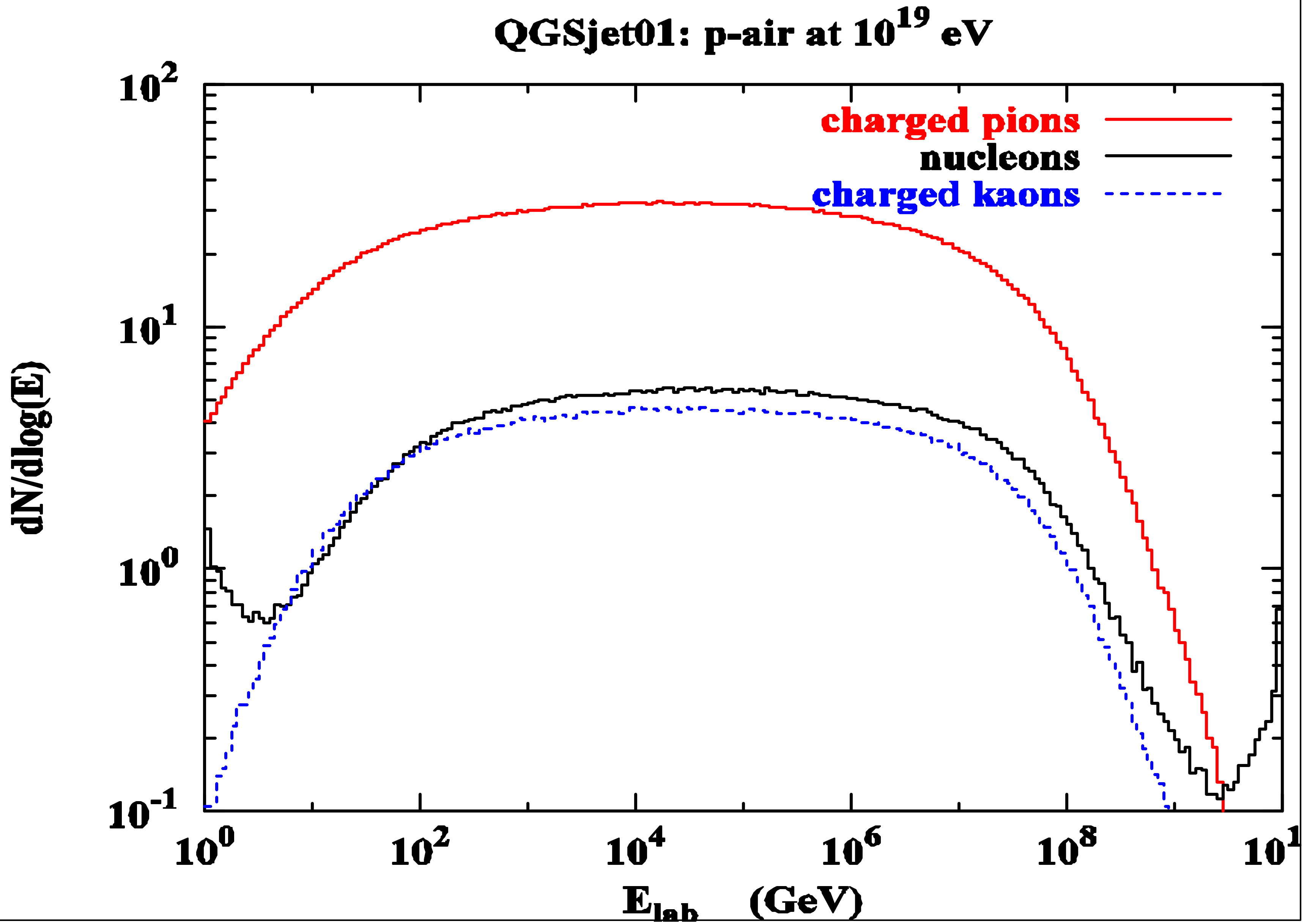
p – air cross sections



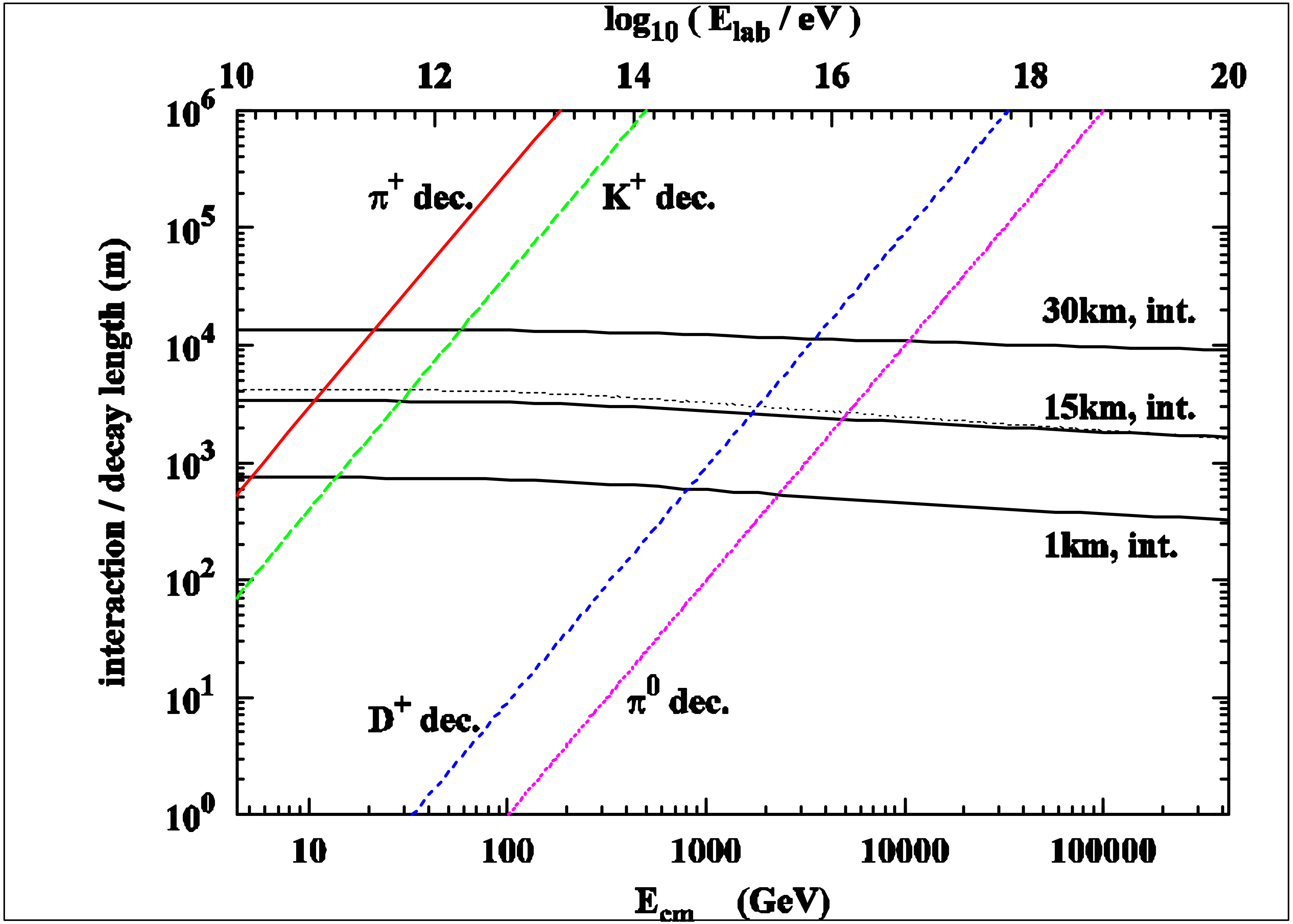
p – air elasticity (x_F of leading hadron)



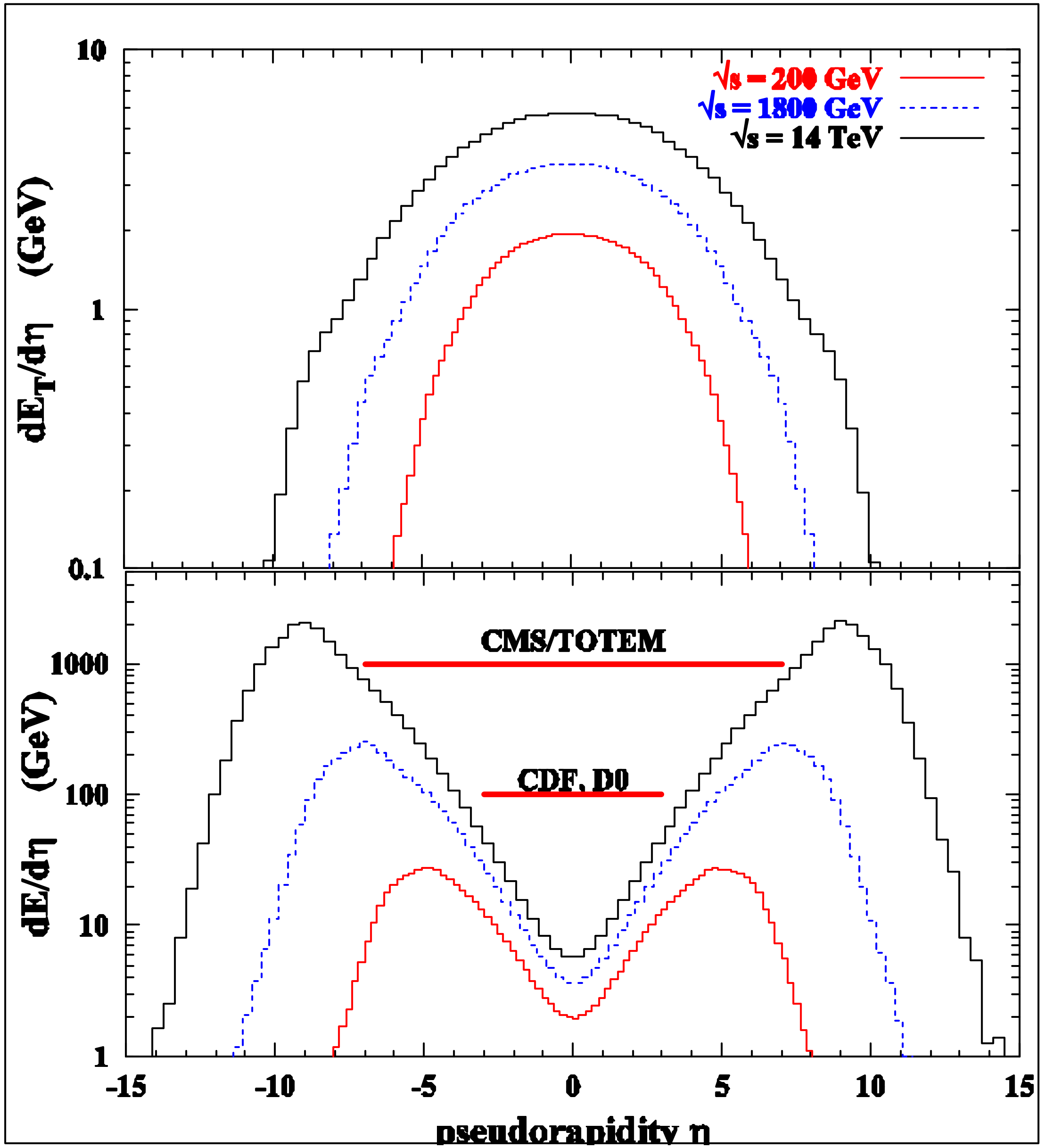
energy distribution of secondary particles



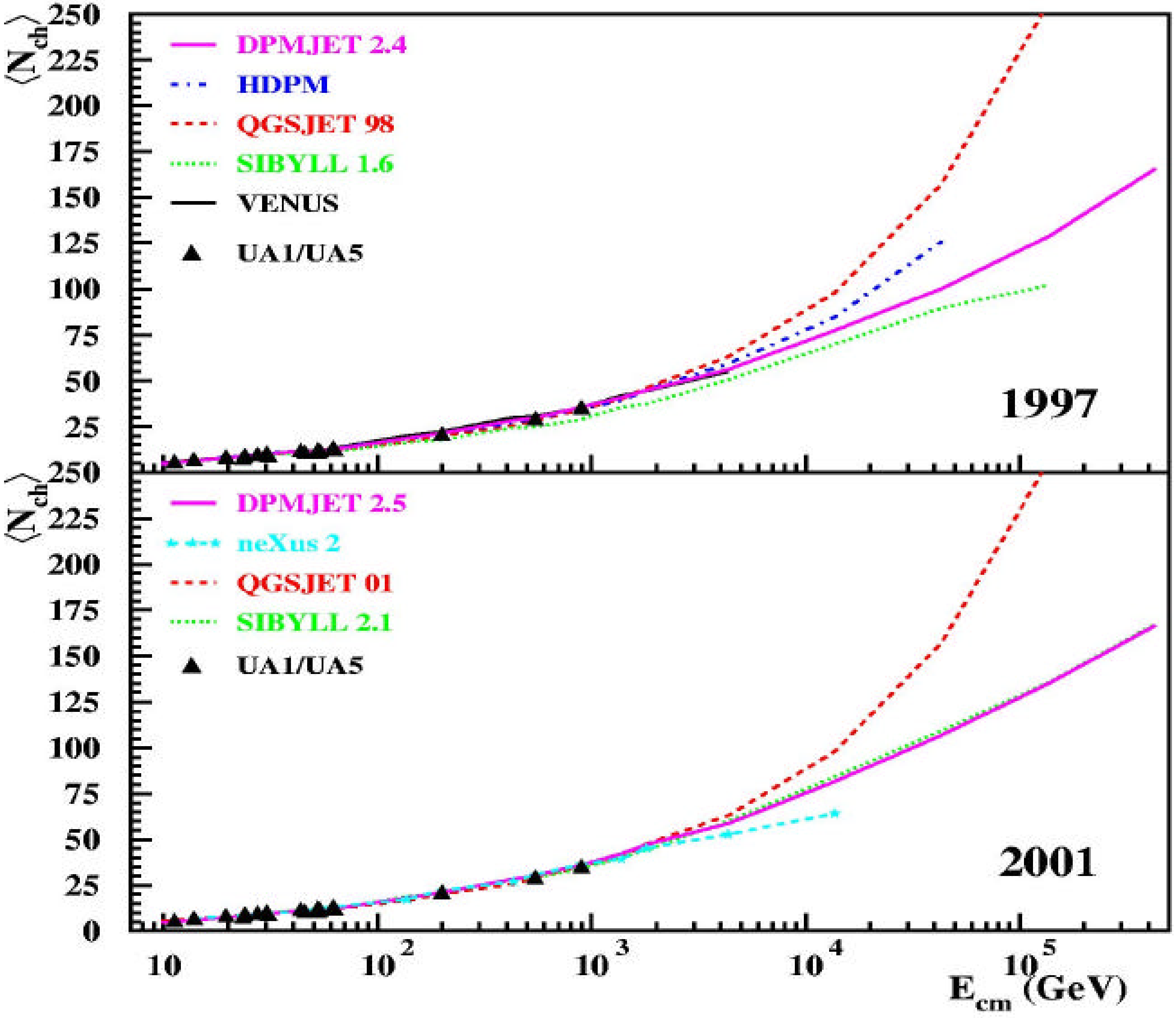
do particles decay ... or ... interact ??



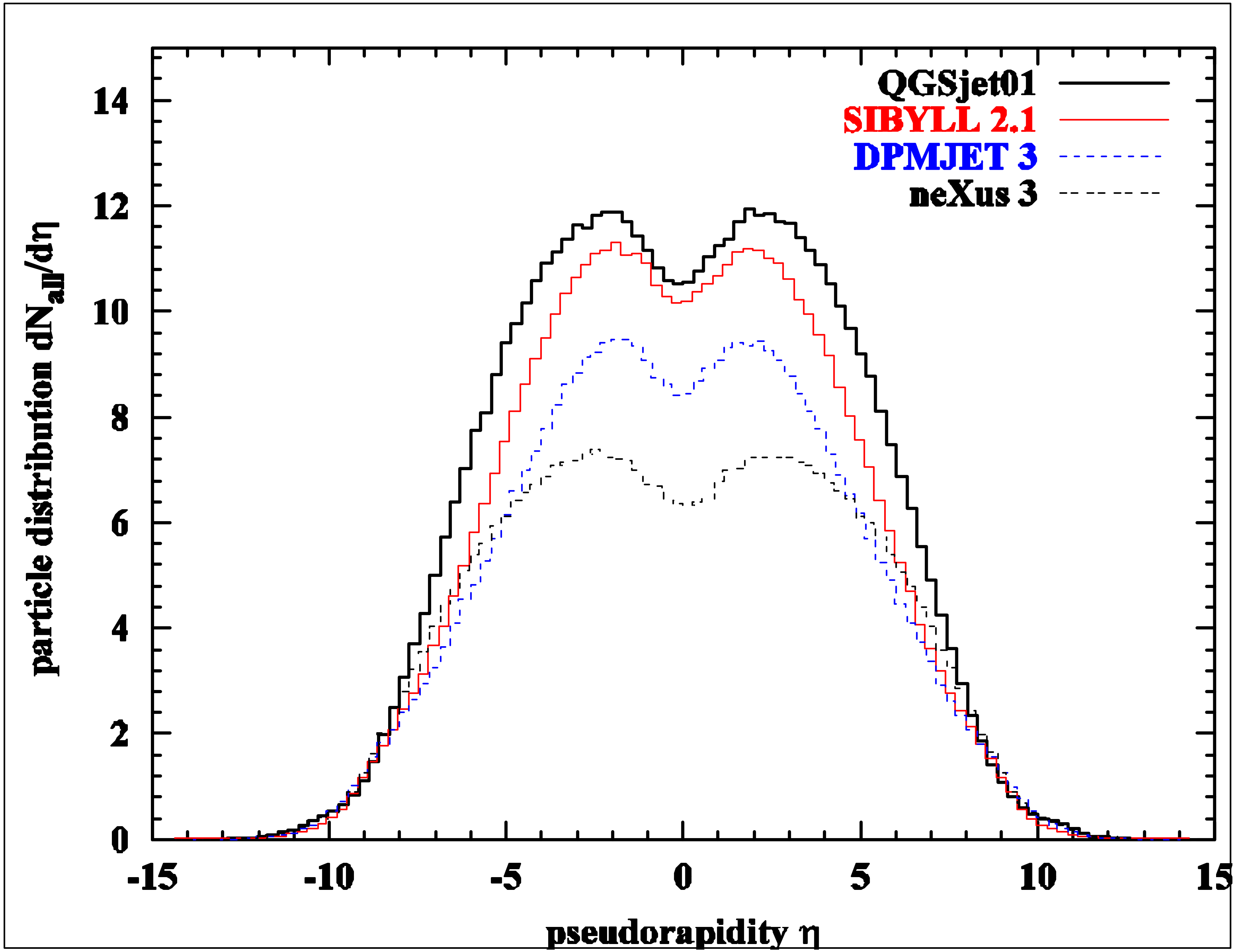
„angular acceptance“ of collider experiments



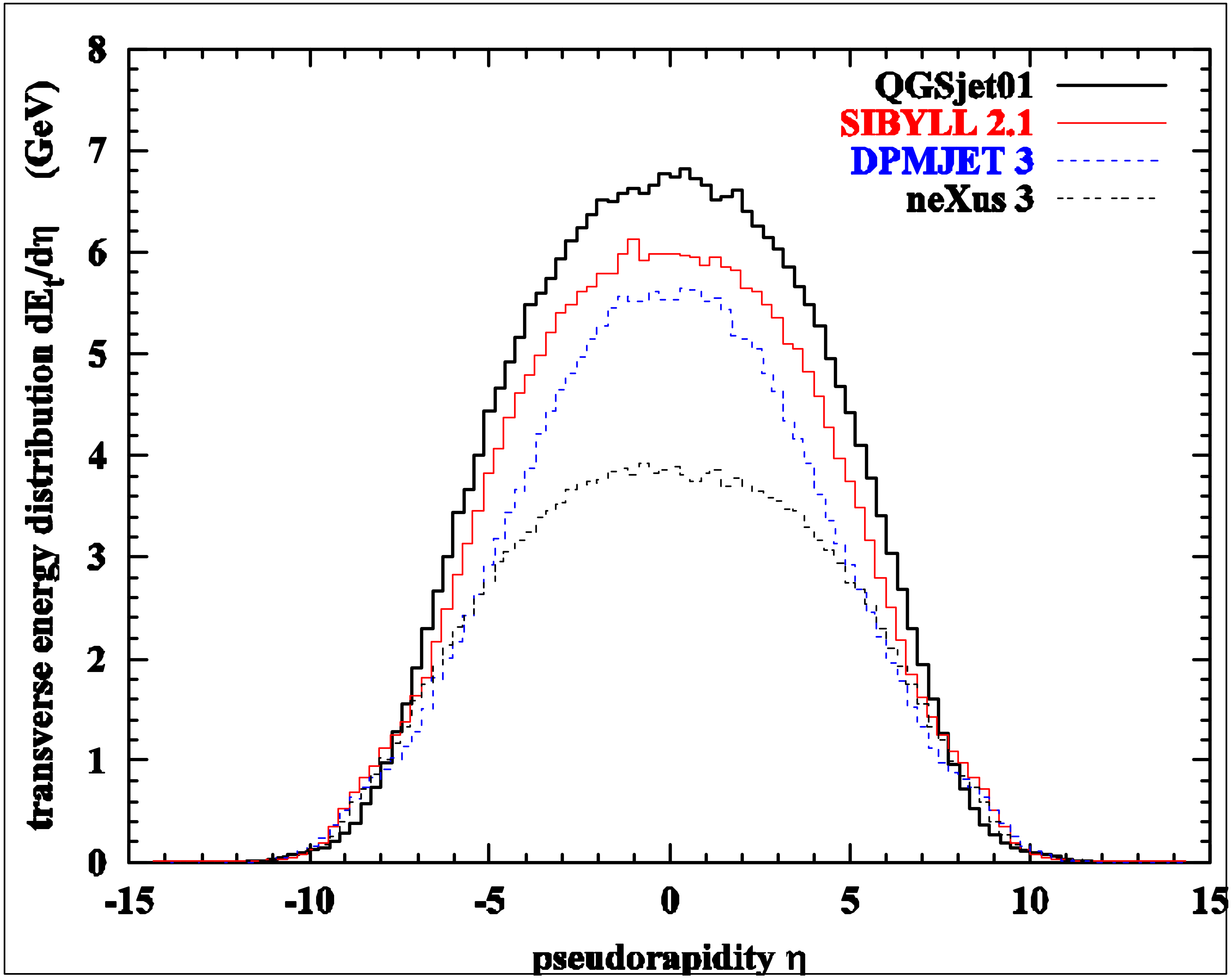
model predictions for p-p : charged particle multiplicities



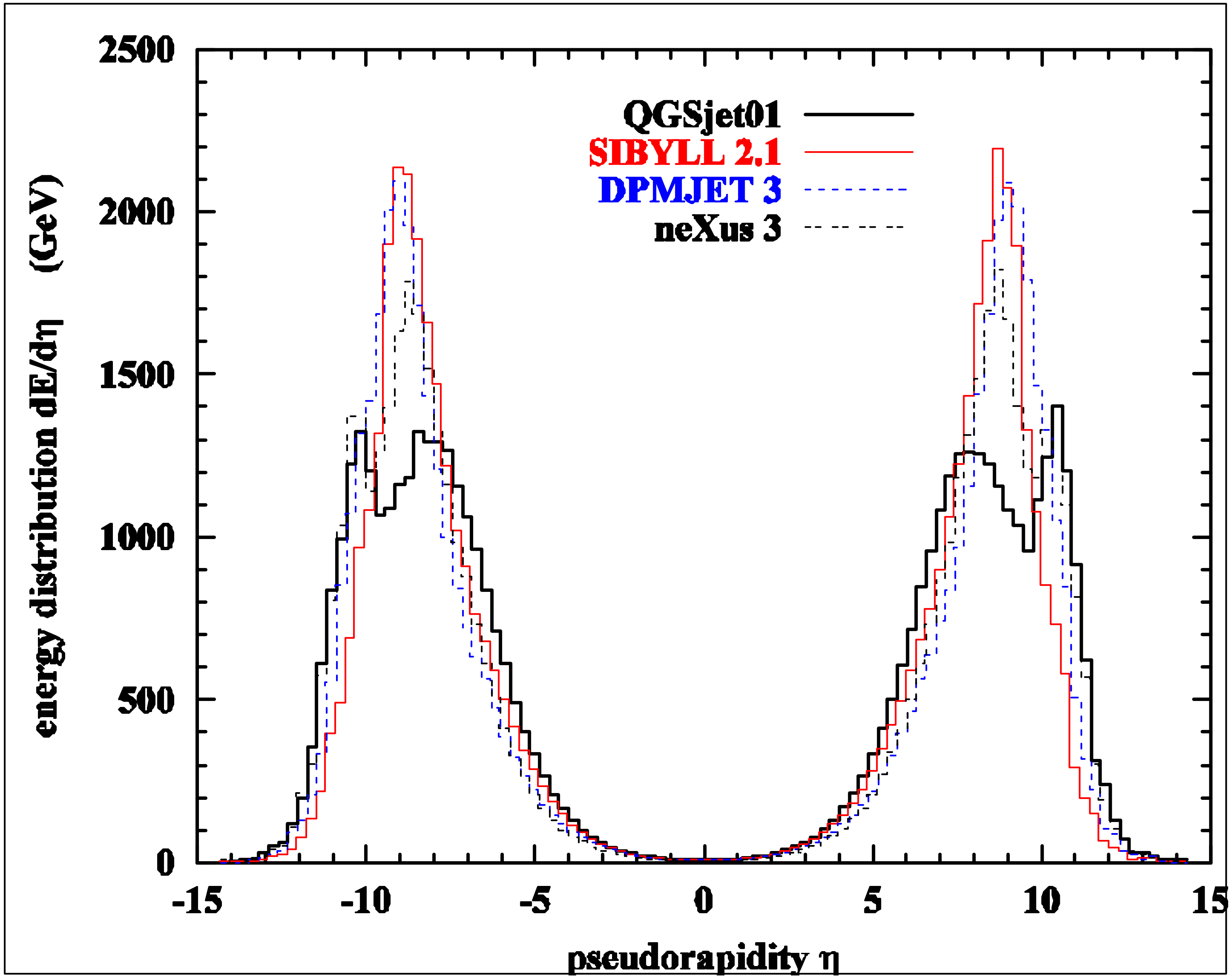
predicted „angular distributions“ of secondary particles at LHC energies



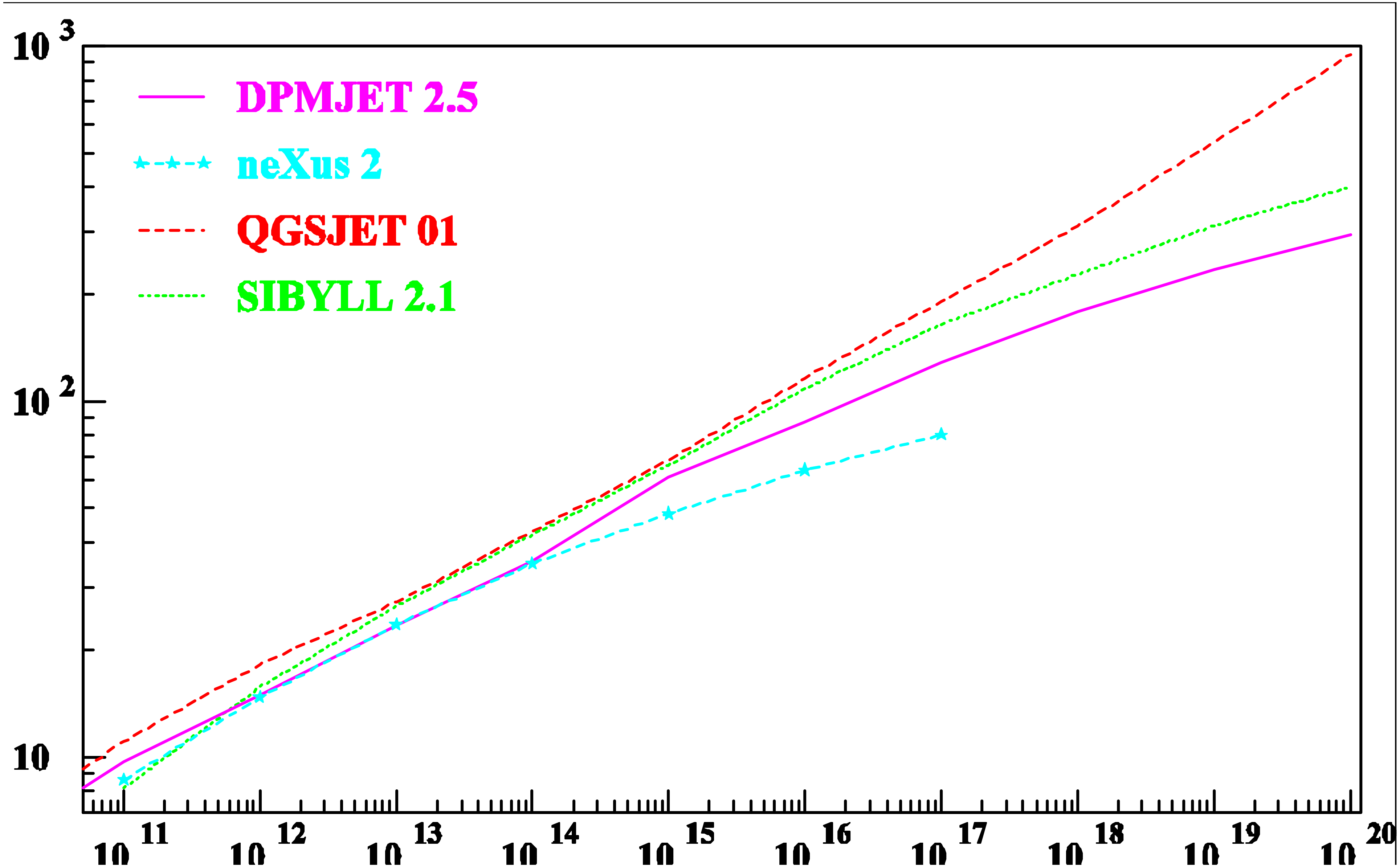
the domain of all collider experiments



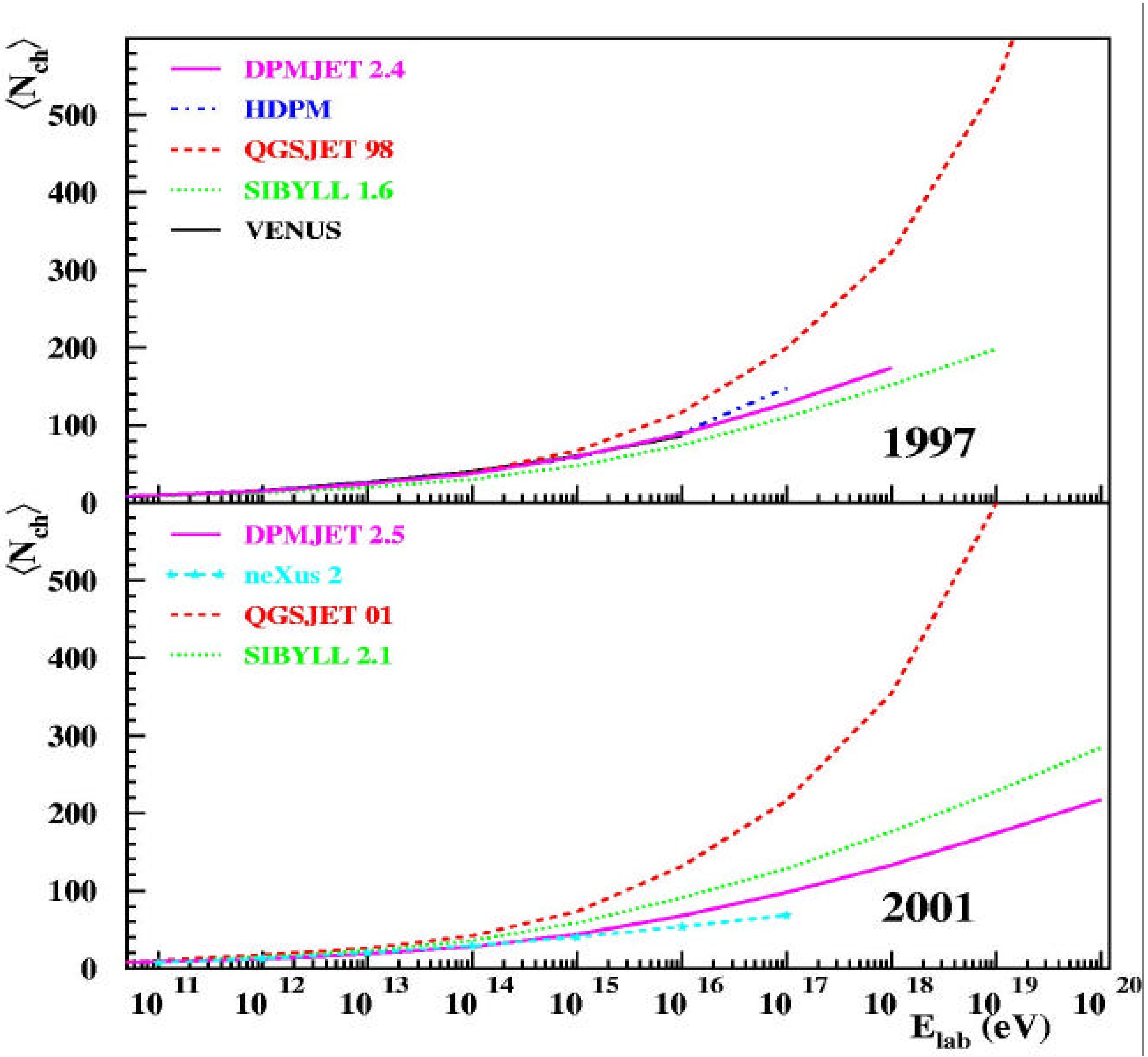
the energy goes „forward“ at $E_{c.m.}$ = 14 TeV



p – air charged particle multiplicity



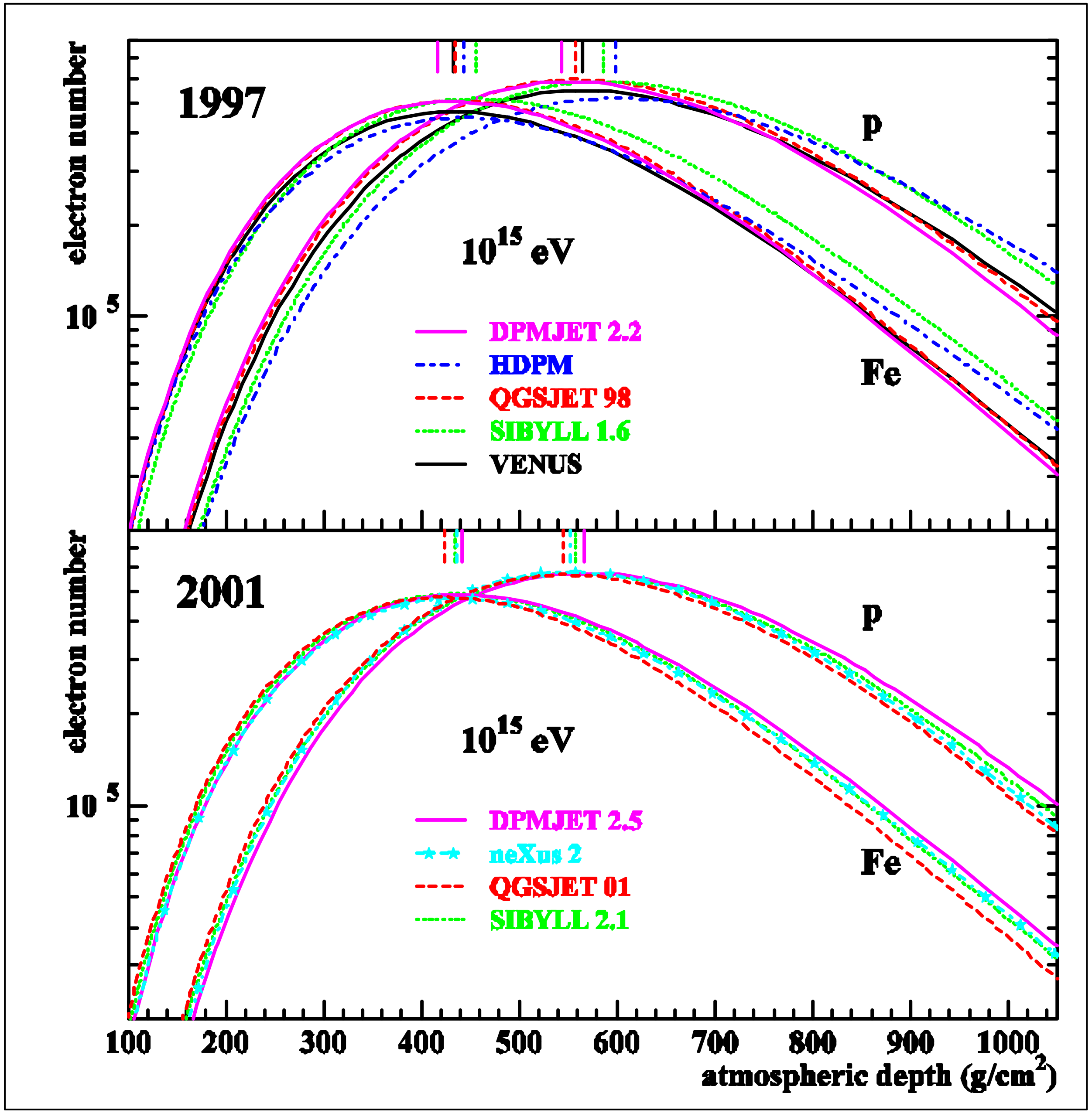
model predictions for p – air : charged particle multiplicities



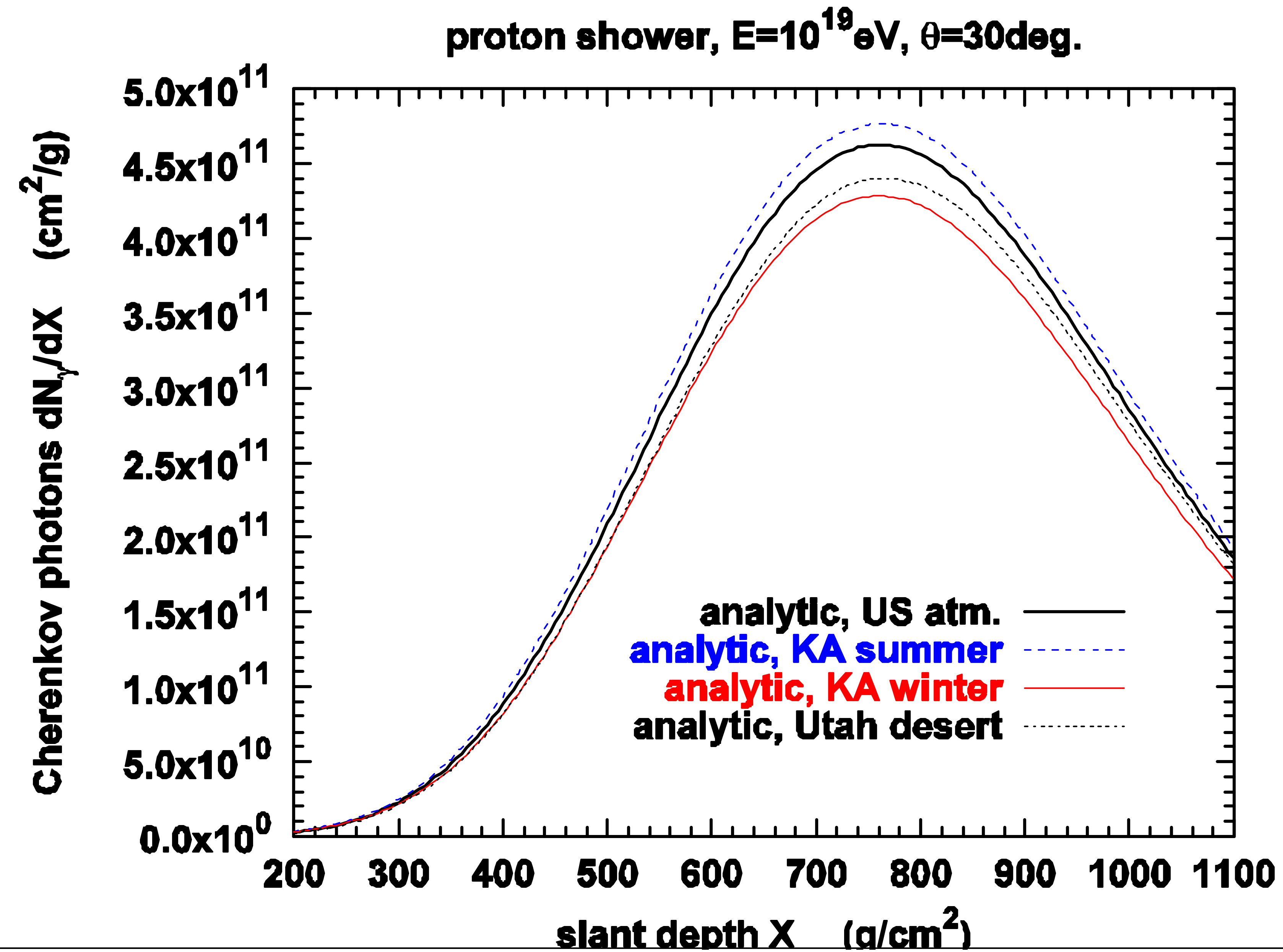
longitudinal shower development

- particle numbers : Cherenkov ?
- X_{max} ~ ~ mass ; atmospheric profiles ?
- energy loss processes
- local energy deposit : fluorescence ?
- lateral shower „size“

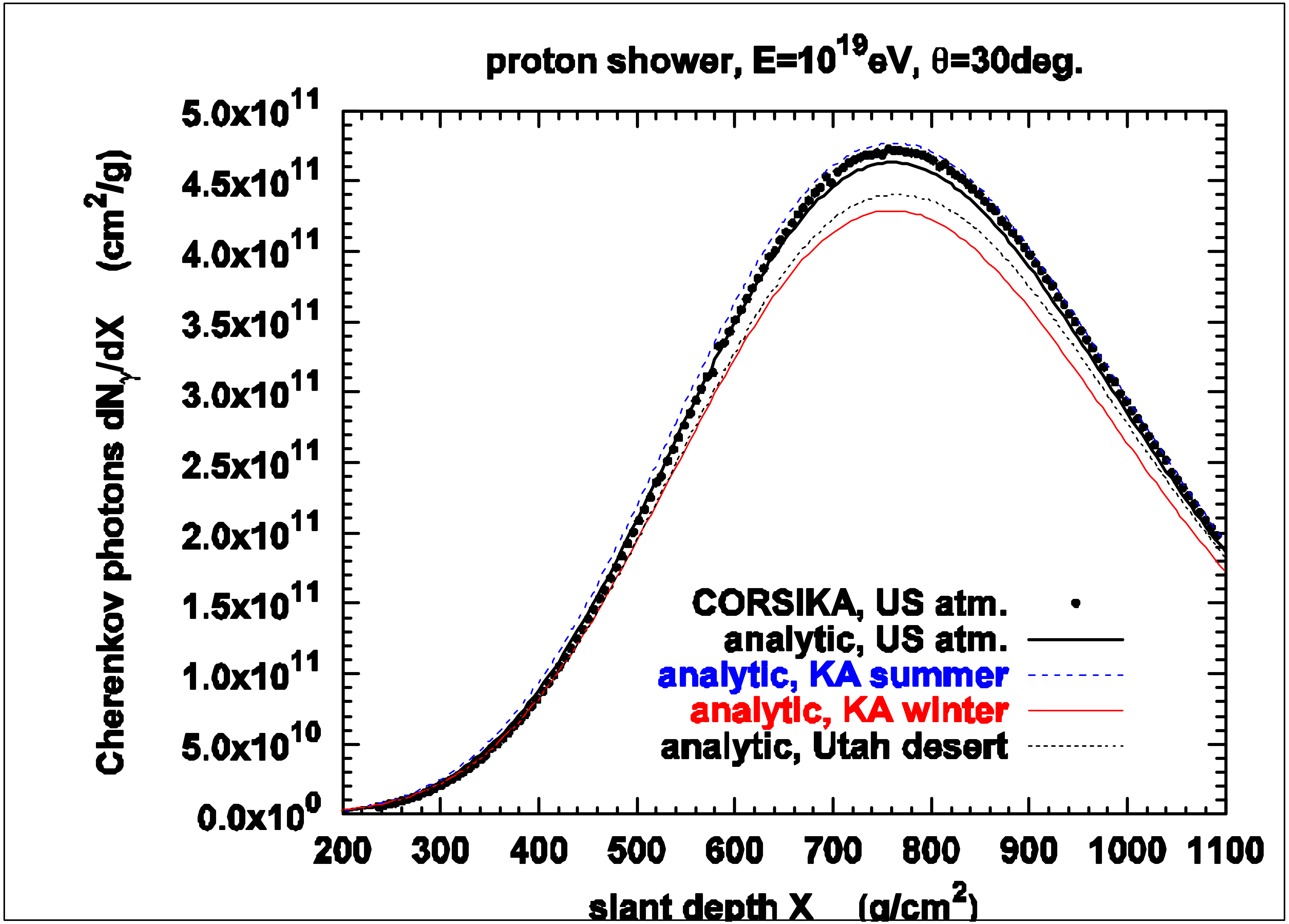
longitudinal shower development at the knee



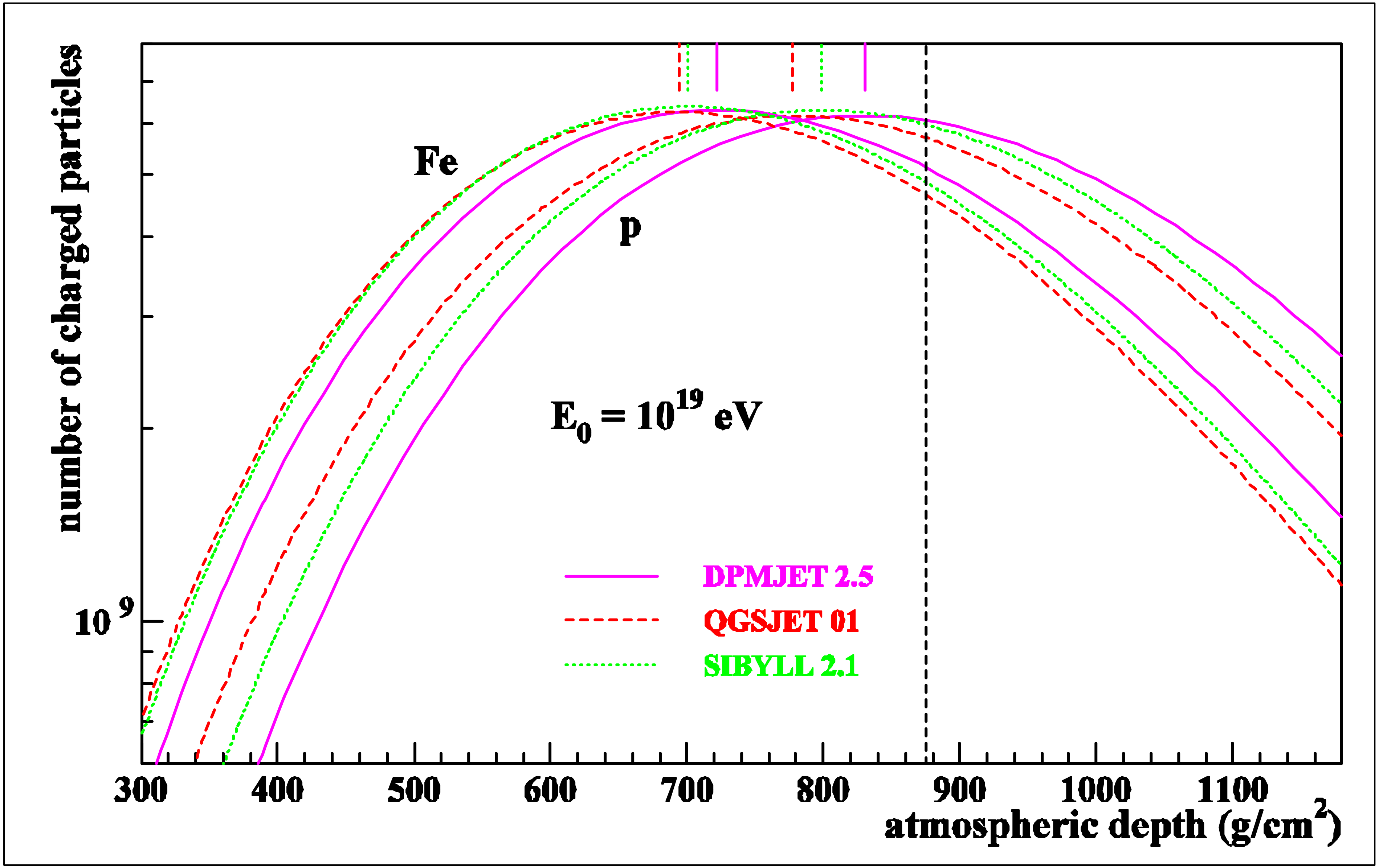
Cherenkov light production in different atmospheres



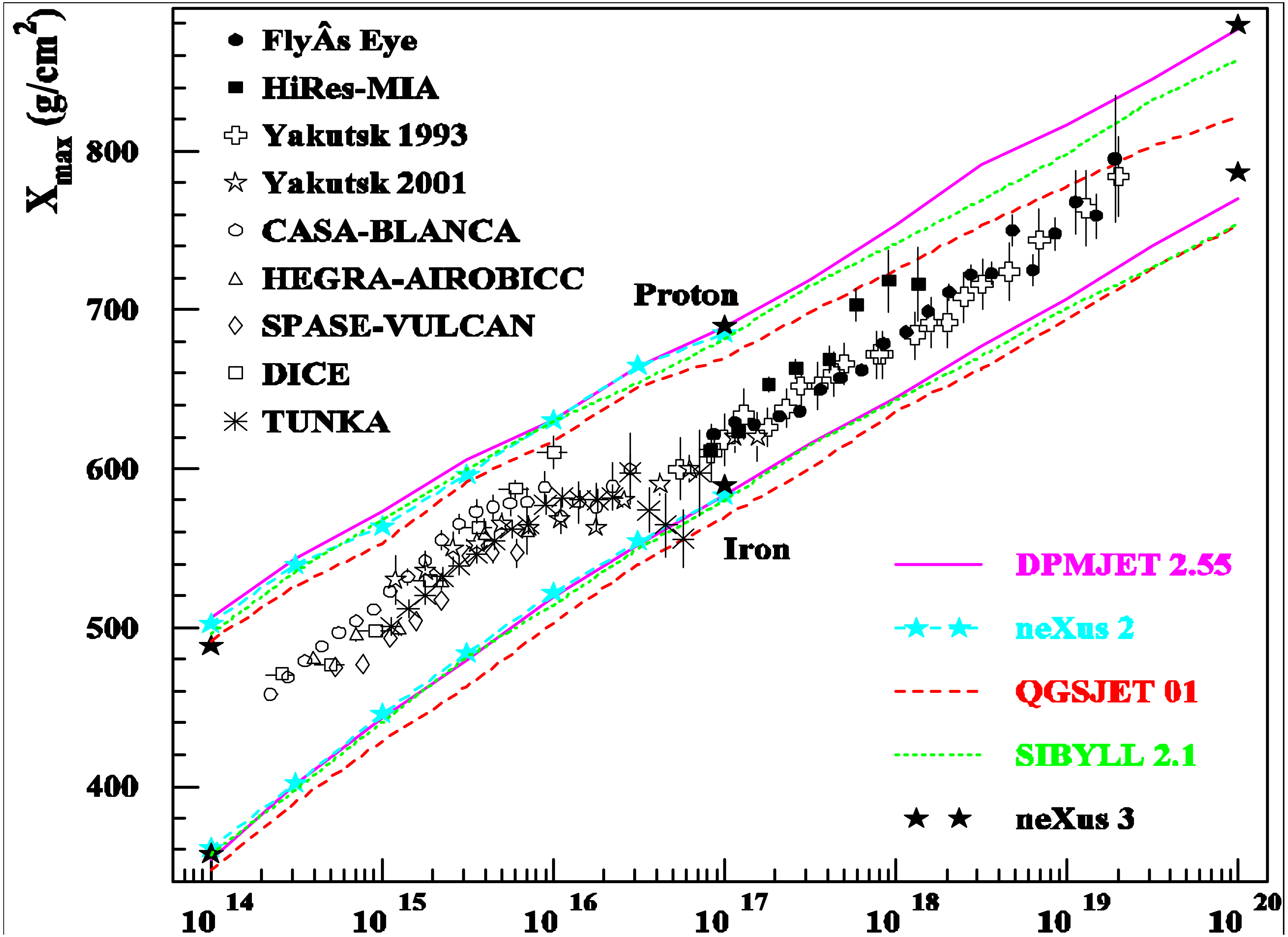
Cherenkov light production : MC and analytic



longitudinal shower development at 10^{19} eV

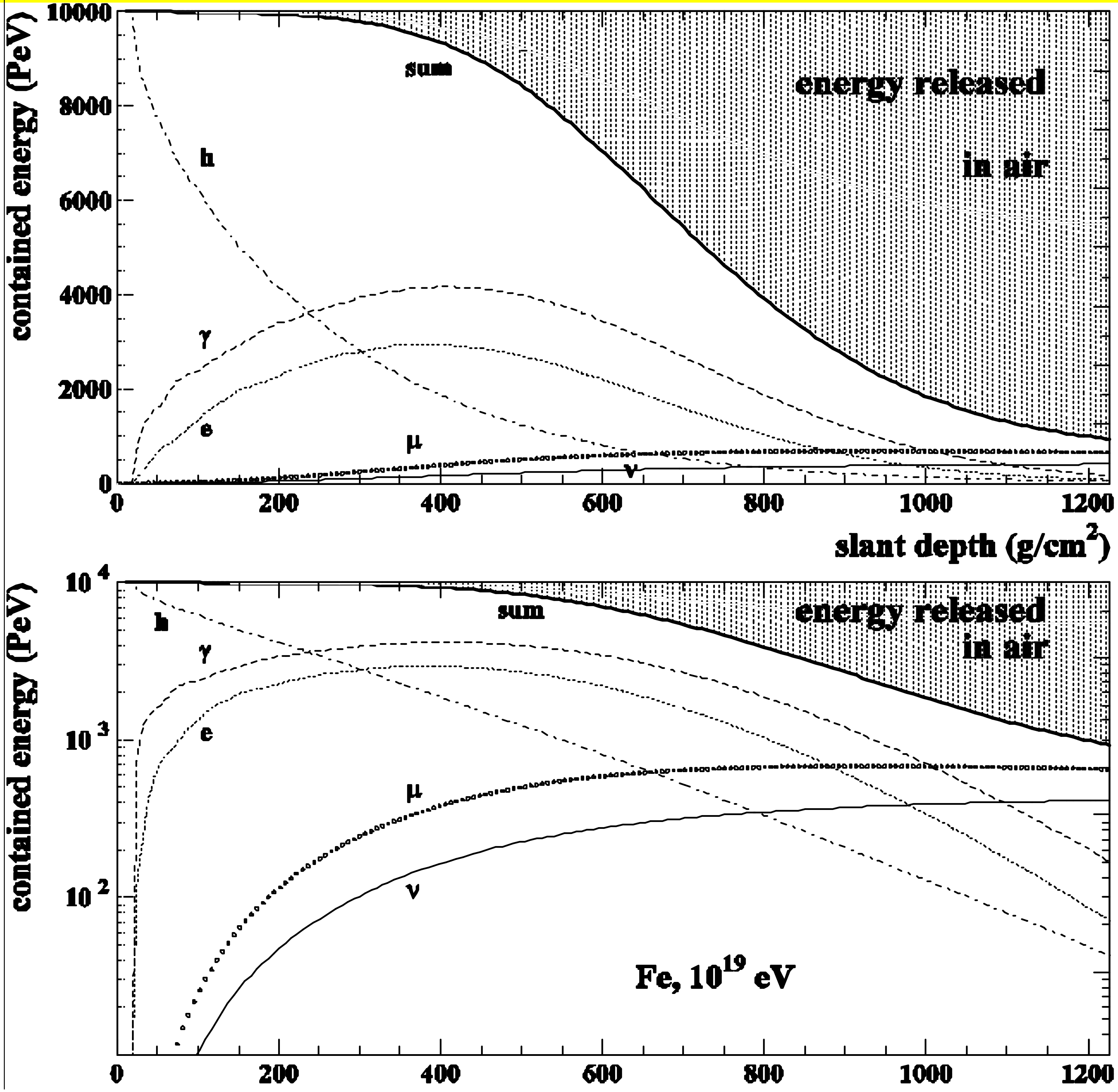


X_{max} - experiments and models



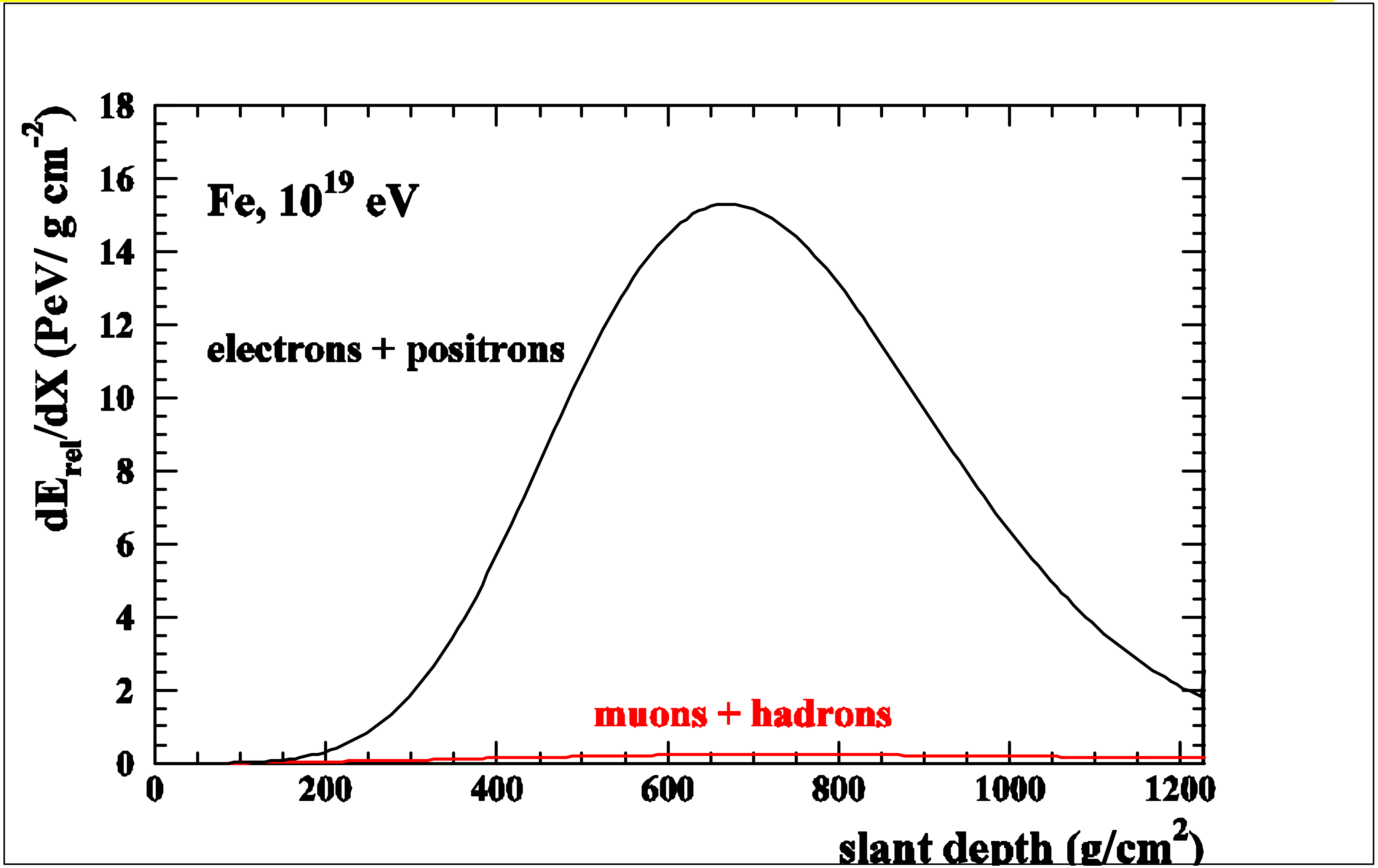
energy content of the different shower components

(M. Risse and D. Heck, in print)



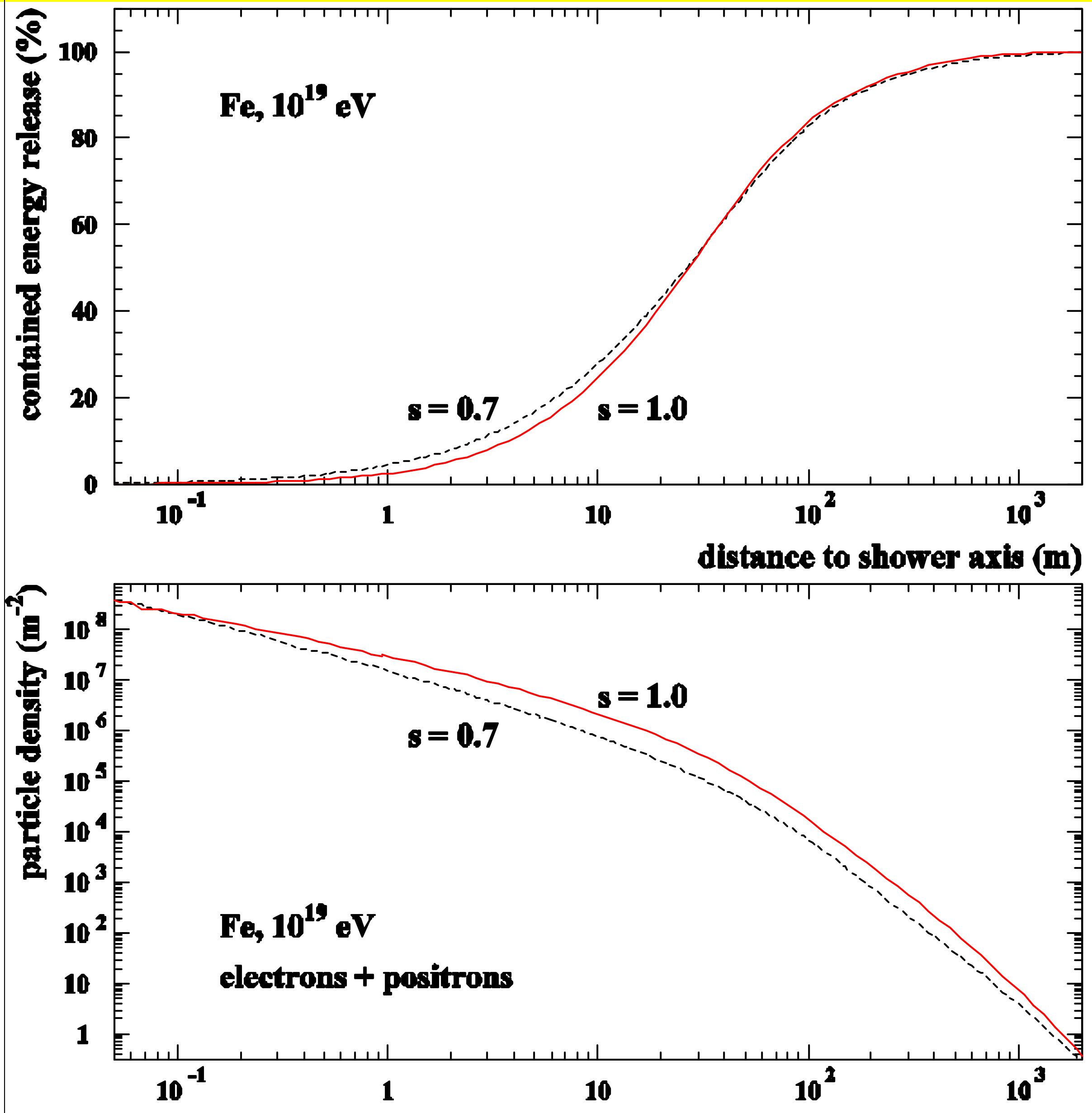
longitudinal development of energy deposit

(M. Risse and D. Heck, in print)



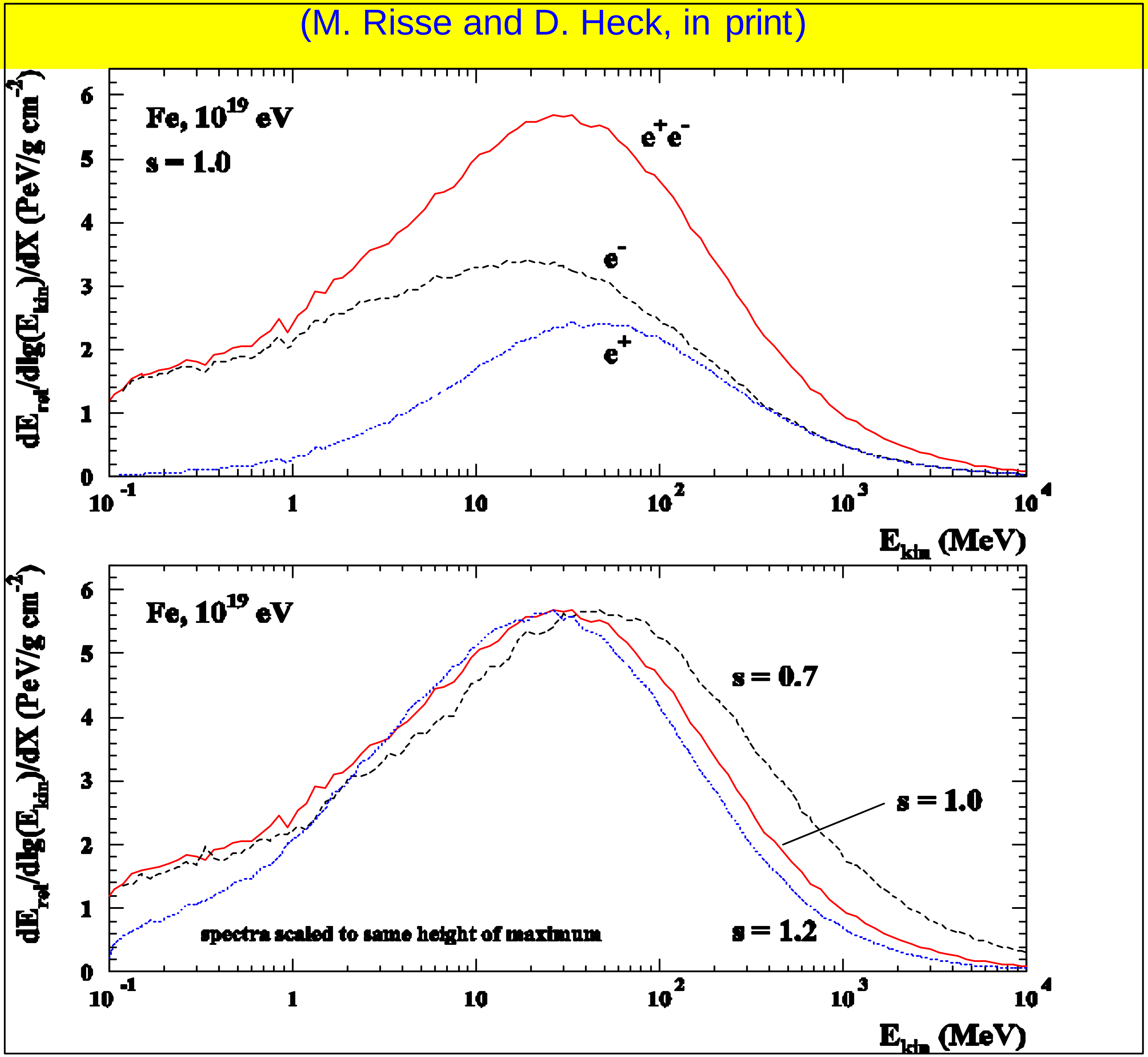
effective shower size

(M.Risse and D. Heck, in print)



energy distribution of parent particles

(M. Risse and D. Heck, in print)



10%	12%	23%	35%	17%	3%

Conclusions

- interaction models and different MC codes „converge“
- longitudinal development not ~ ~ atmospheric profiles
- Cherenkov yield changes (refraction index)
- fluorescence yield ~ energy deposit (?) , P and T
- energy deposit by particles of < 0.1MeV up to > GeV

Outlook

- faster MC codes at ultrahigh energies
- better tests of interaction models
- use realistic atmospheric profiles
-
- better Cherenkov simulations
- good understanding of energy deposit
- new data on fluorescence ~~ E, P, T
- the future is bright !