Black Body Limit in Cosmic Ray Air Showers

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with Adrian Dumitru, Mark Strikman

- scattering on dense targets
- Black body limit
- suppression of forward scattering
- Monte Carlo implementation
- application to air showers

Hadronic models in Air Shower

- Air shower simulations
  - Needed to reconstruct primary properties
  - Study physics with natural acelerators
- GZK energy much higher than LHC
  - Hadronic physics biggest uncertainty in airshowers
- Extrapolation of physics to high E in air shower event generators:
  - Implement energy dependent pt-cutoff — Engel, ICRC99
  - Enhanced Pomeron diagrams — Ostapchenko, ICRC2001

Black Body Limit

Calculate qA scattering within color glass condensate approach

→ See talk by Dumitru

$$\sigma^{\mathrm{el}} = \int \mathrm{d}^2 b \left[1 - e^{-Q_s^2/4\pi\Lambda^2}\right]^2$$

$$\sigma^{\mathrm{tot}} = 2\int \mathrm{d}^2 b \left[1 - e^{-Q_s^2/4\pi\Lambda^2}\right]$$

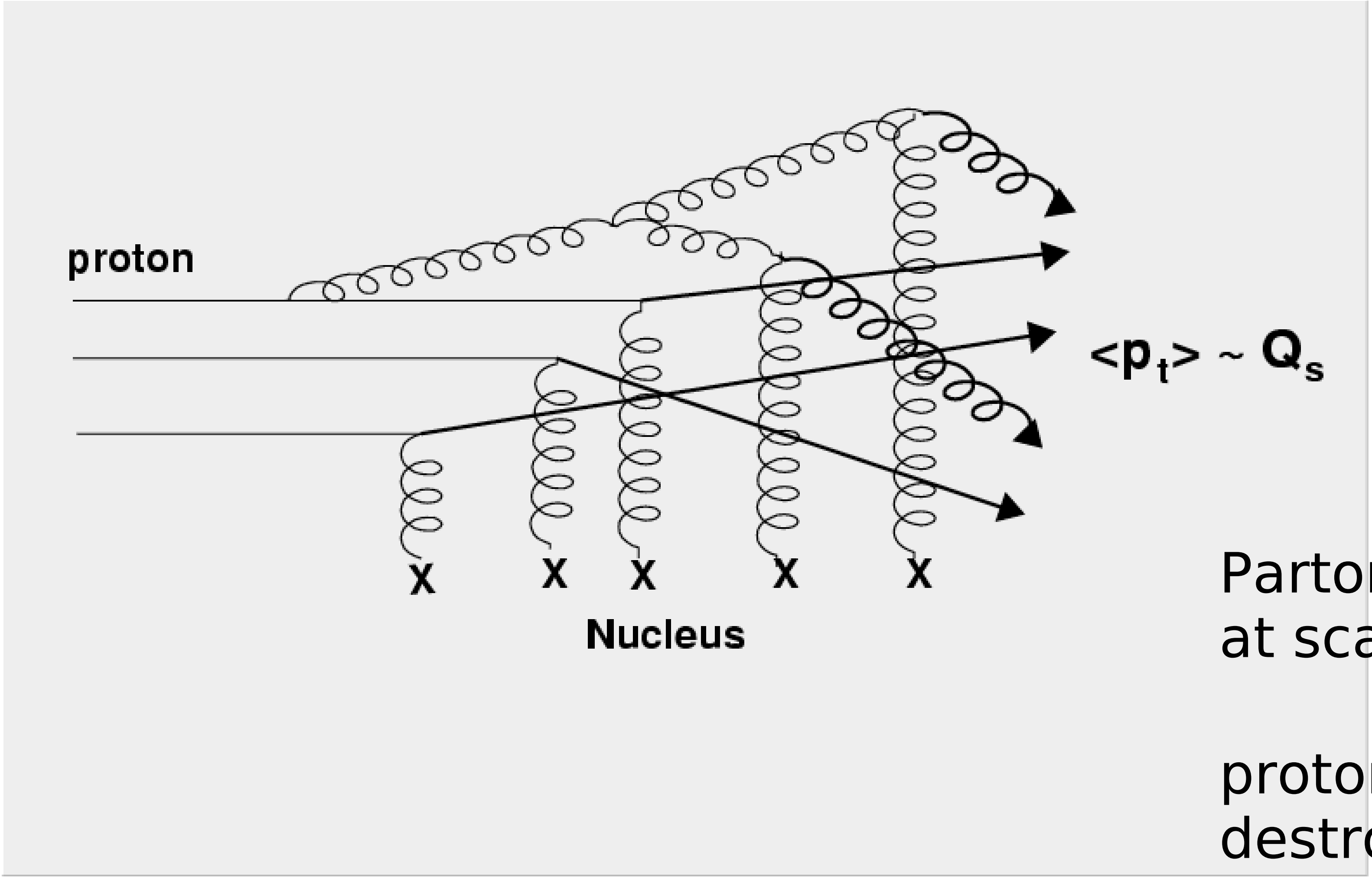
Dumitru, Jalilian-Marian
PRL 89 (2002)

→ Suppression of soft physics

→ Suppression of forward scattering
(no leading particle)

Gerland, Dumitru, Strikman
PRL 90 (2003)

BBL code



Partons are resolved at scale $Q_S(x)$

proton coherence destroyed

BBL code

Valence quarks, gluon distribution:

$$P_i(x) = f_i(Q_s^2(x), x)$$

$$< p_t > \approx Q_S(x)$$

valence quarks: GRV94 PDF (xf(x) dominant at high x)

gluons: $$x\,g(x, q_t^2) \propto \frac{1}{\alpha_s} \min(q_t^2, Q_s^2(x))(1-x)^4$$

(Kharzeev, Levin, Nardi, NPA 2004)

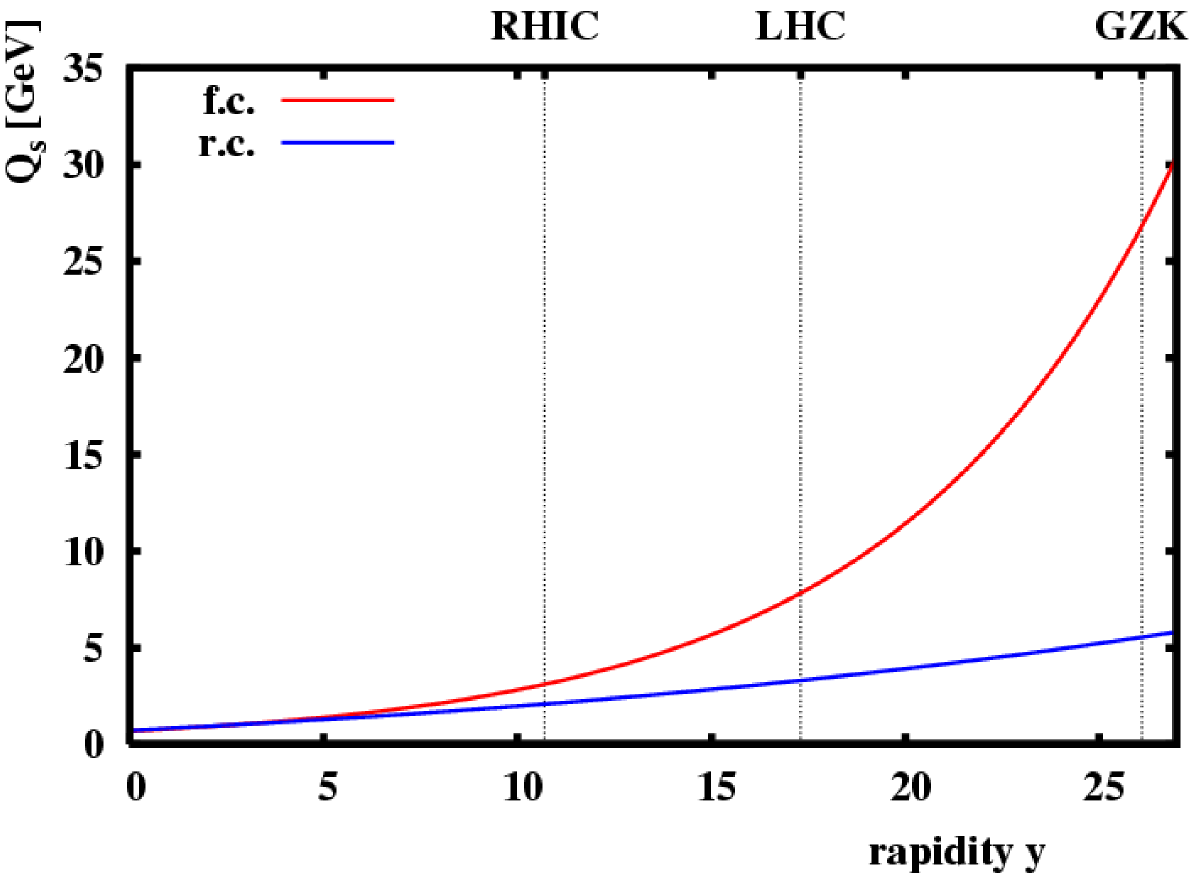
Q_s evolution scenarios

Fixed coupling: $Q_s^2(x, A)=Q_0^2(A)(\frac{x_0}{x})^{\lambda}$ λ=0.28

$$Q_0^2(A)\sim A^{(1/3)}\log(1+A)\sim N_{\text{part}}(b)$$

Running coupling: $\alpha_s(Q^2)=b_0/\log(Q^2/\Lambda^2)$

$$Q_s^2=\Lambda^2\exp(\log(Q_0^2/\Lambda^2)\sqrt{1+2c\alpha_s y})$$



Qs for central p-N events

Monte Carlo implementation

- Choose model as function of density, energy

  $$Q_s(b, x_F = 0.001) > 1\,\mathrm{GeV}$$

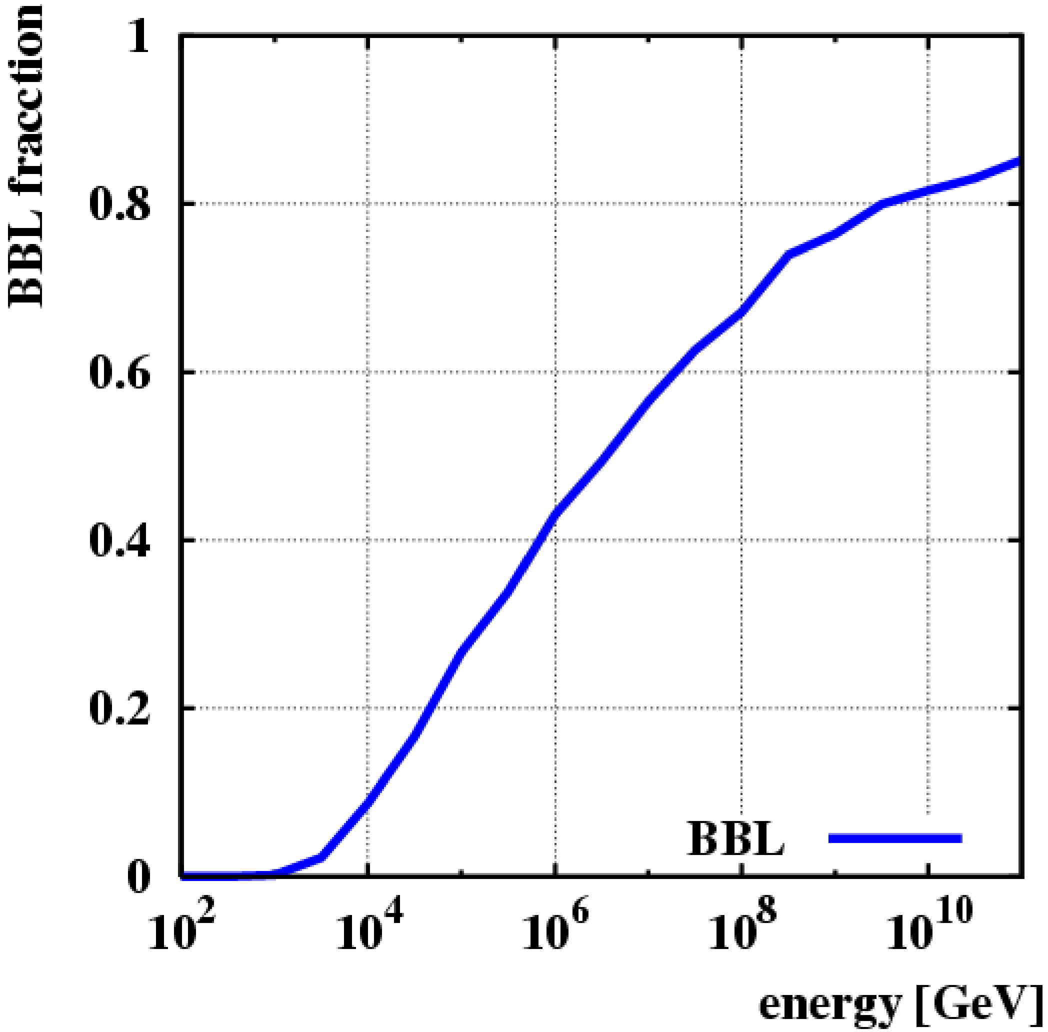
  → BBL
  else
  → Sibyll (standard pQCD EG, $p_t(s)$ cut-off)

- Generate partons according to PDF
- Valence quarks and gluons form strings with kinks:

  - Collinear g absorbed (low q_t)

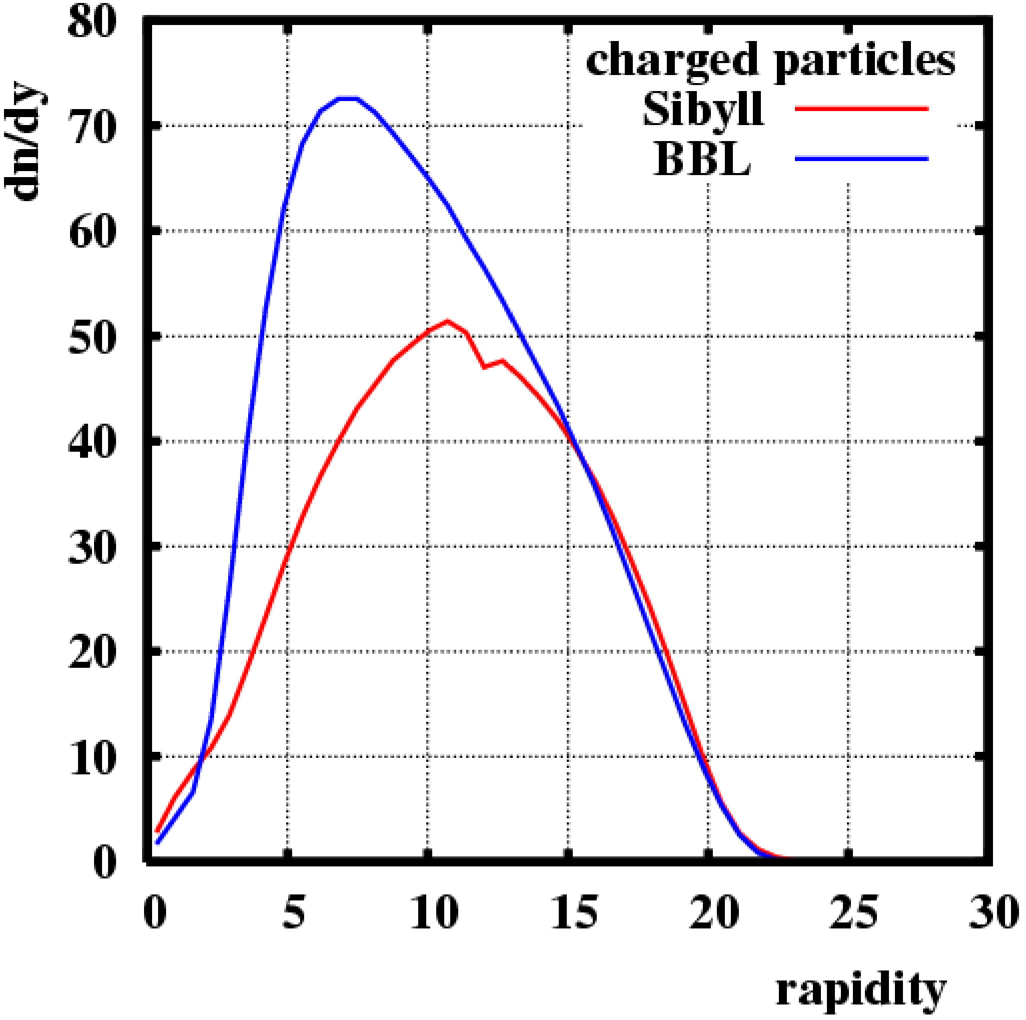
  - Low invariant mass of quarks forms diquark
    recovers leading particle effect for low Qs

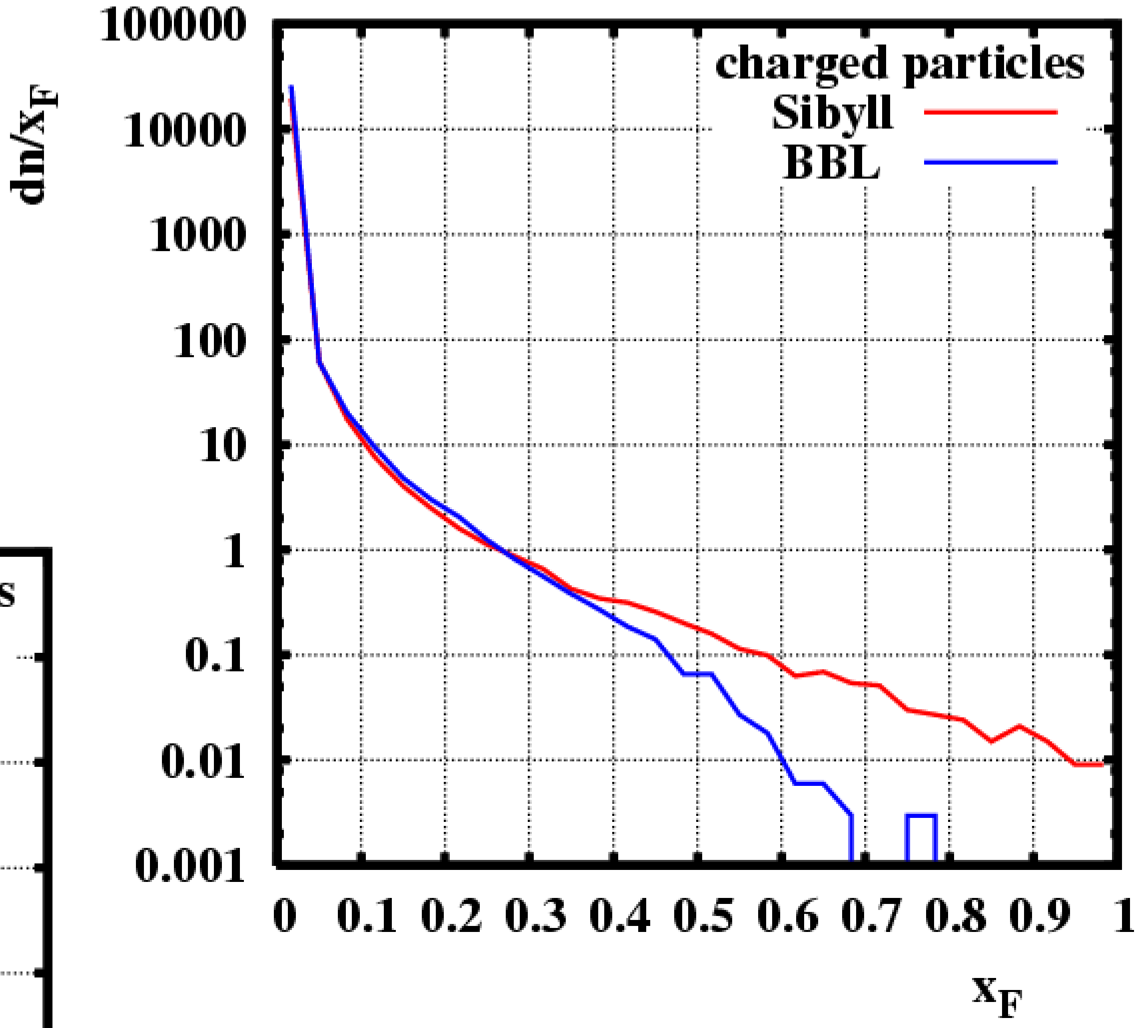
Fraction of BBL events versus Sibyll events for min bias p-Air



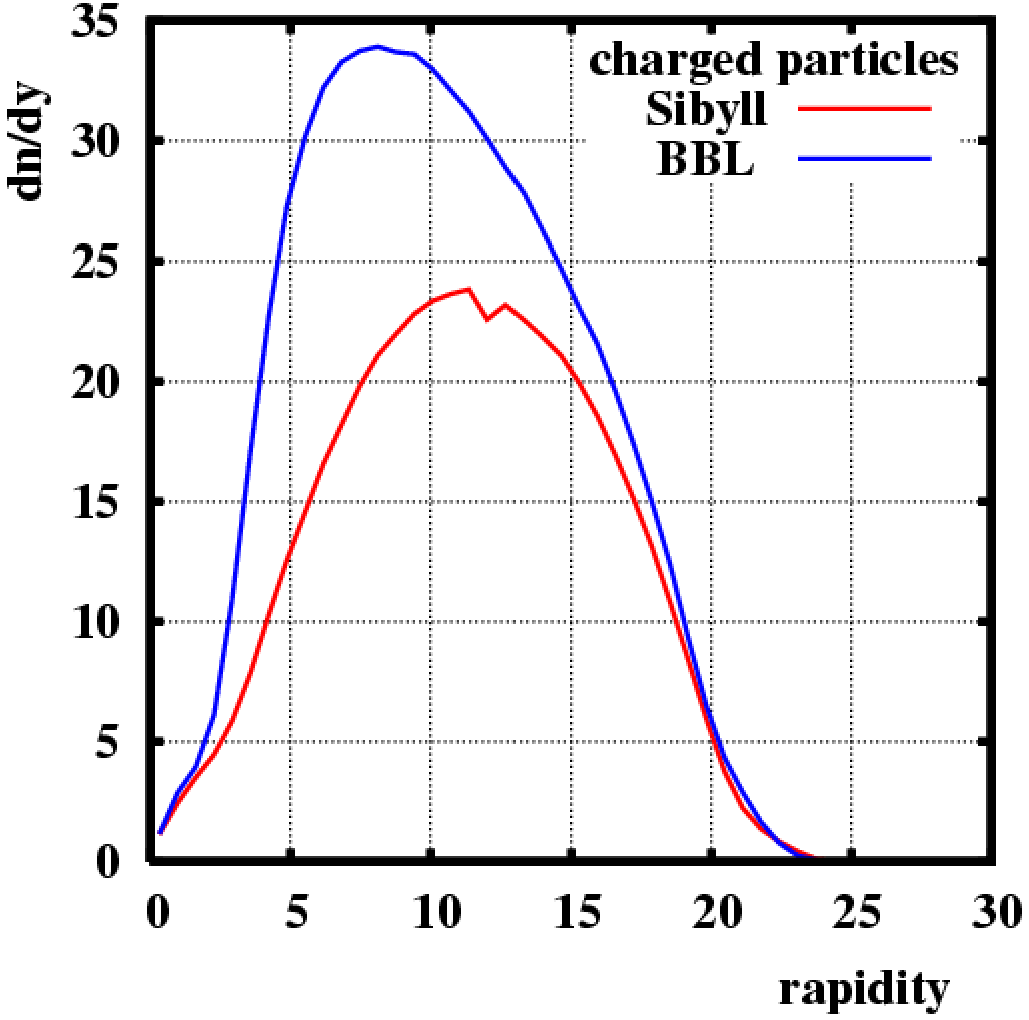
Central p-Air events

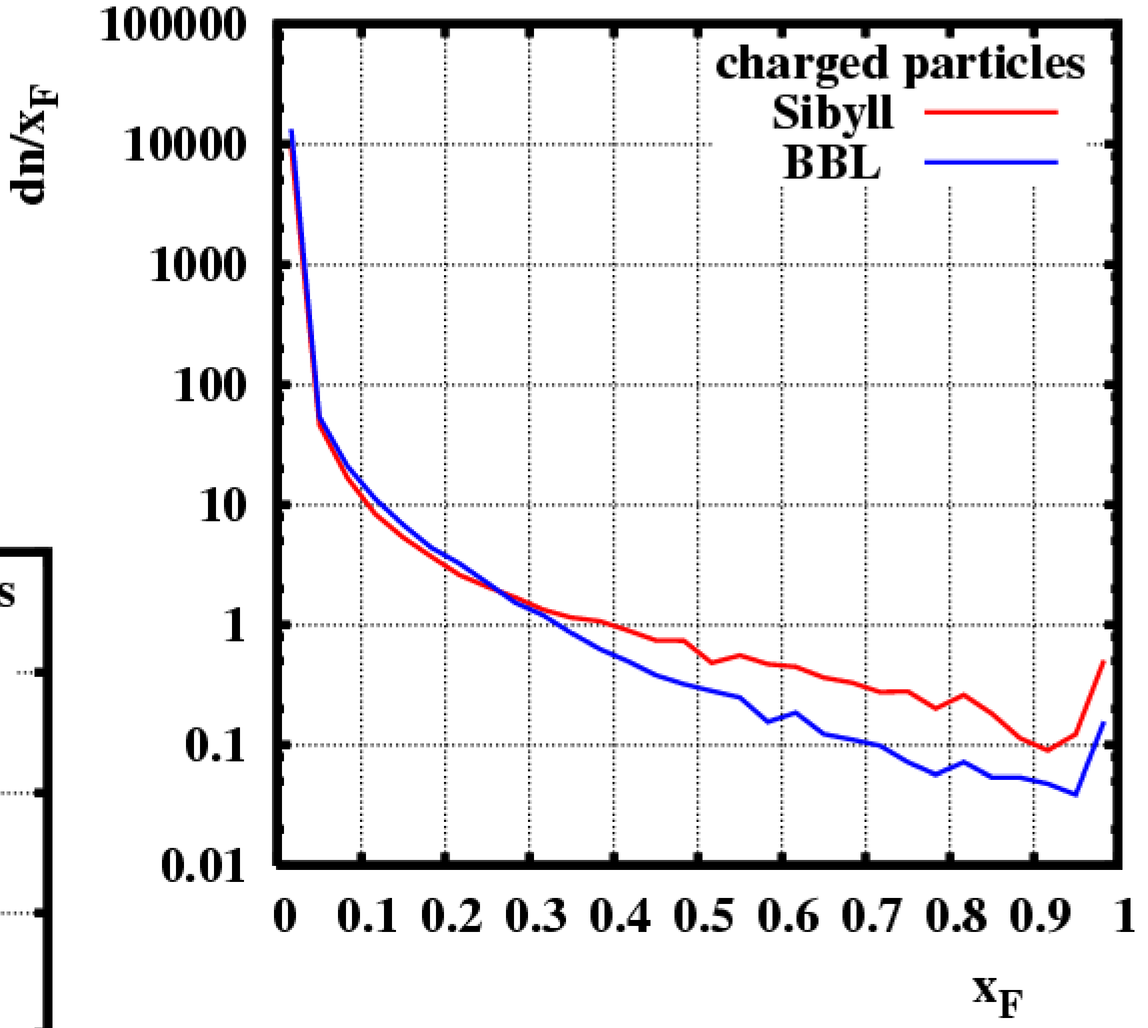
E=10^{10} GeV





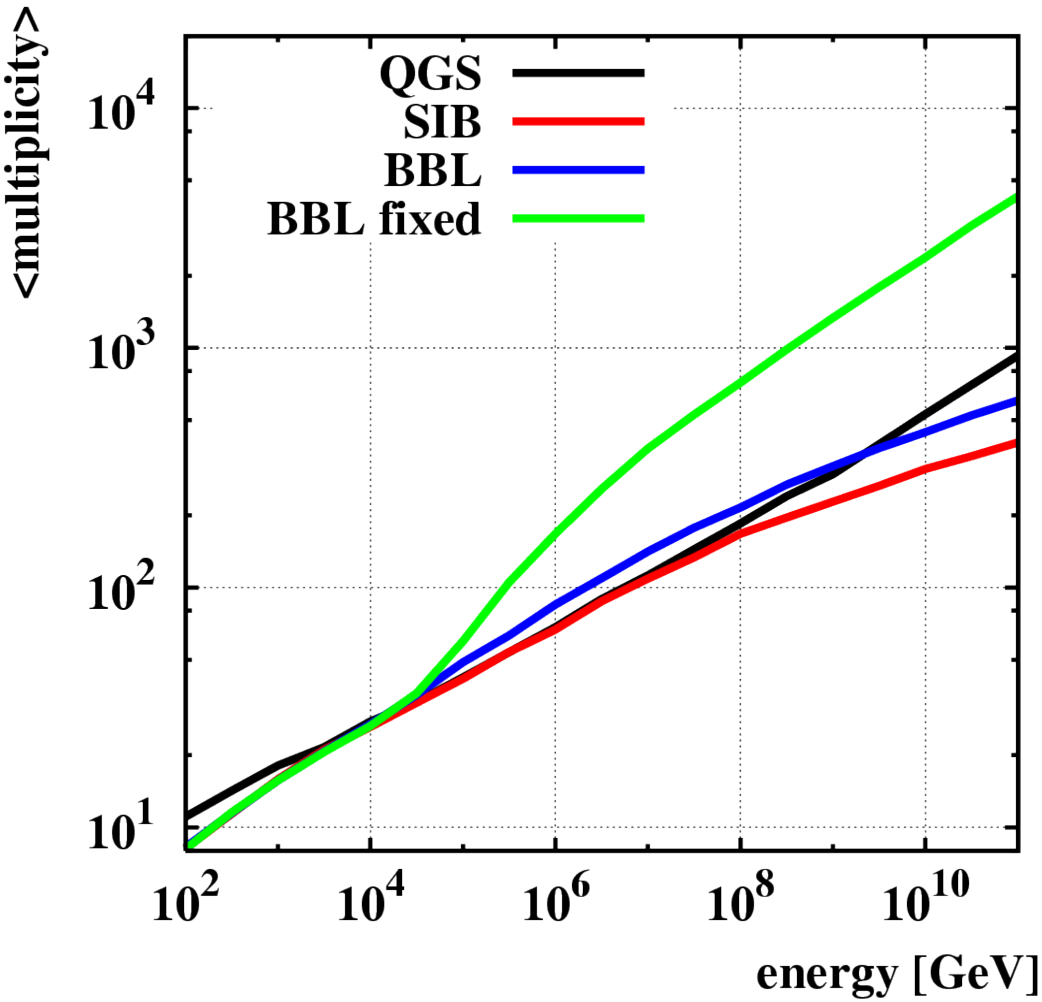
Minimum bias
p-Air events





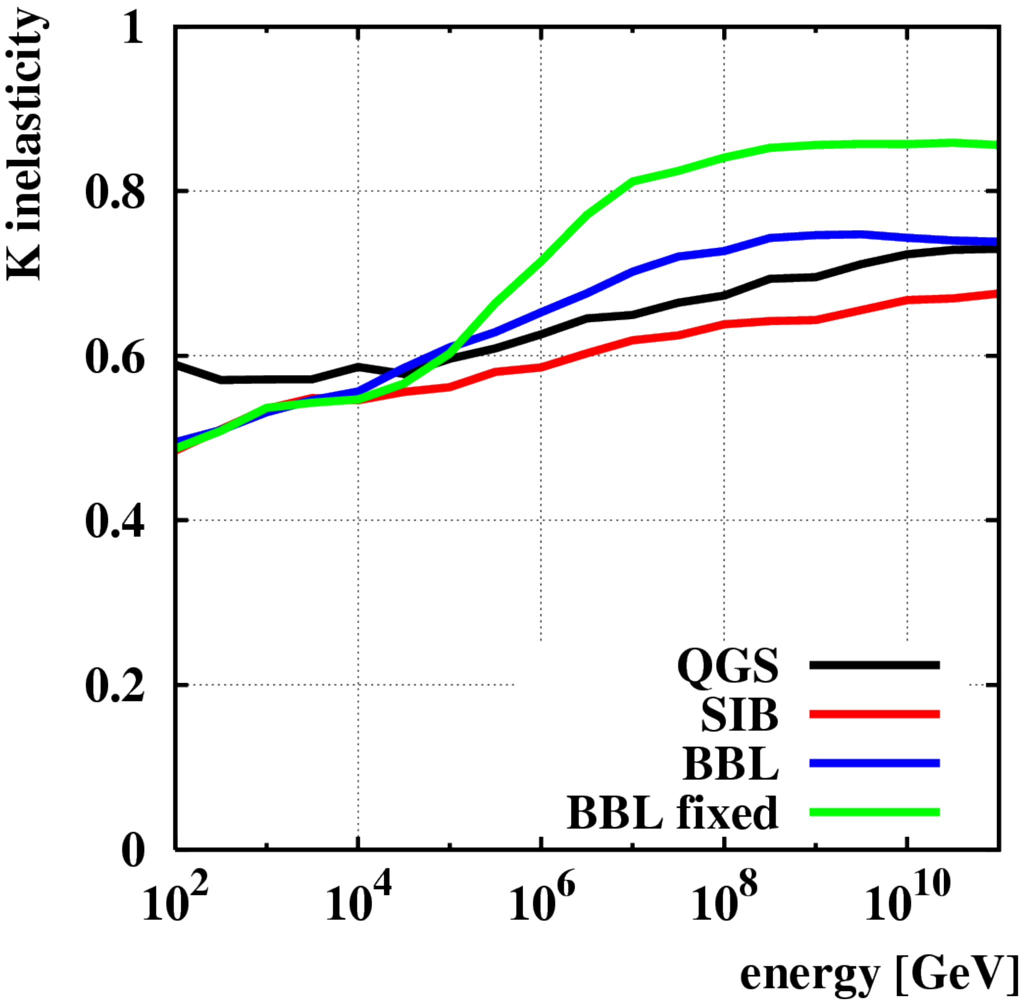
Event shape

Multiplicity



Inelasticity

K=1-<x_F of fastest particle>



H.D., Glennys Farrar
Phys.Rev.D67:116001,2003

Air shower calculation with the Seneca model

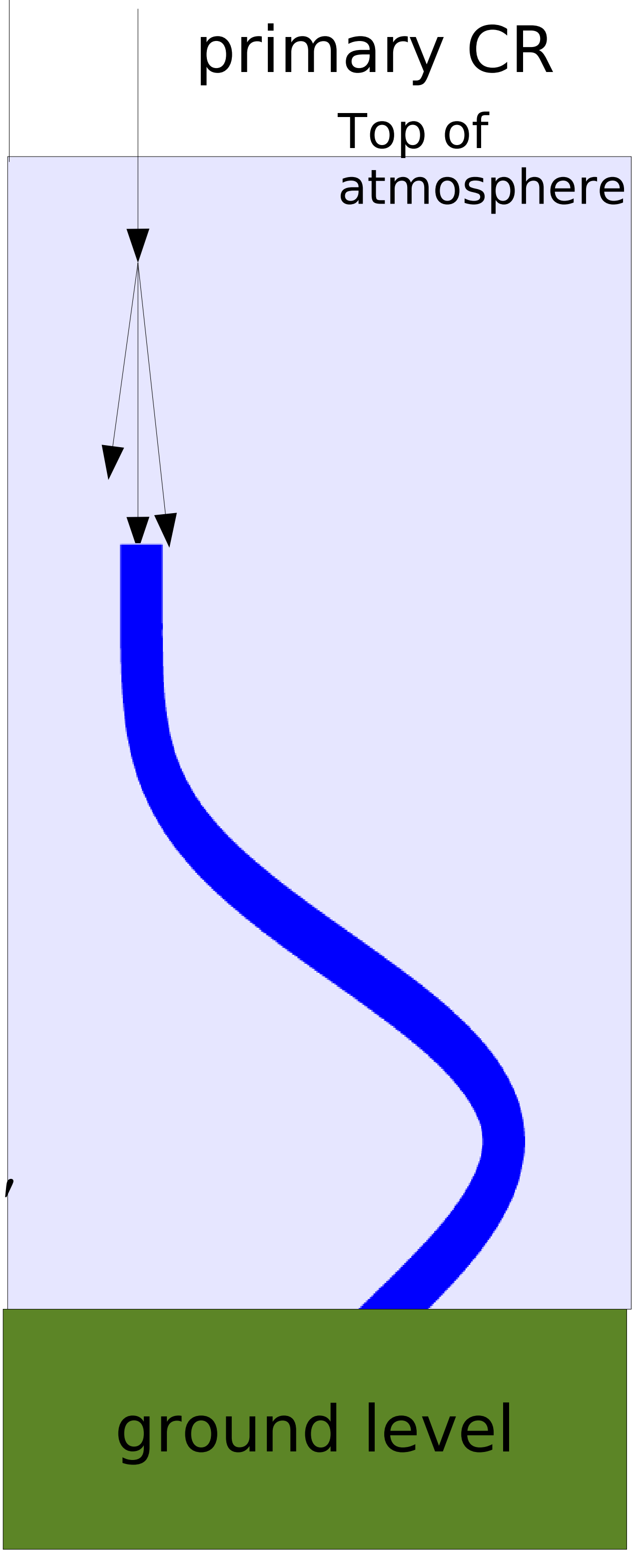
one dimensional transport equation (CE)

- initial fluctuation via MC
- low energy particles via MC or table

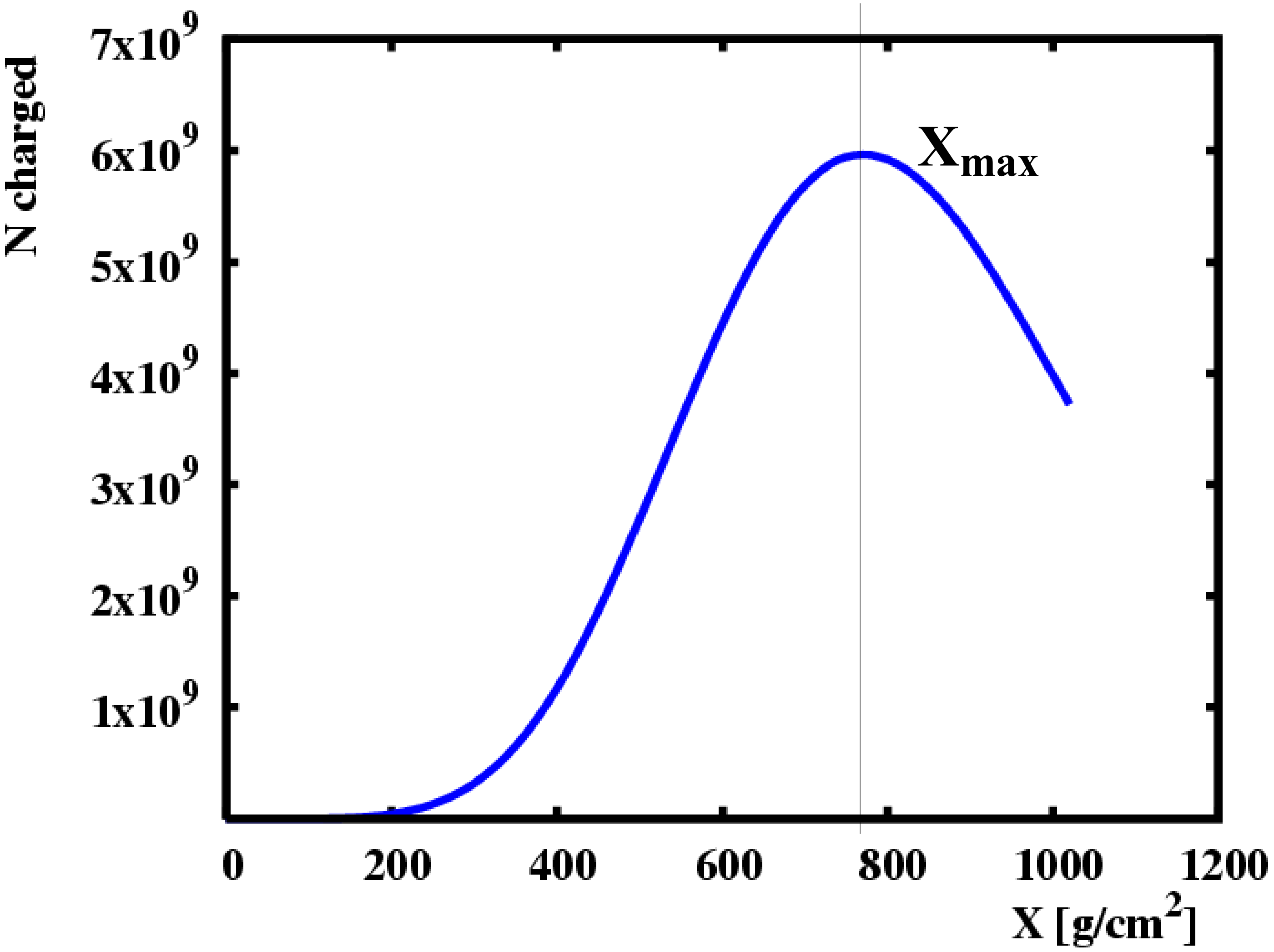
- Hadronic model is discretized in dN_i/dE
- Electromagnetic part: EGS4

$$\frac{\partial h_n(E,X)}{\partial X} = -h_n(E,X)\left(\frac{1}{\lambda_n(E)} + \frac{B_n}{E\,X}\right)$$
$$+\sum_m \int_{E_{min}}^{E_{max}} h_m(E',X)\left(\frac{W_{mn}(E',E)}{\lambda_m(E')} + \frac{B_m D_{mn}(E',E)}{E'\,X}\right) dE'$$

$$W \equiv \frac{dN}{dE} \qquad D \equiv \text{decays}$$



Air showers measurements



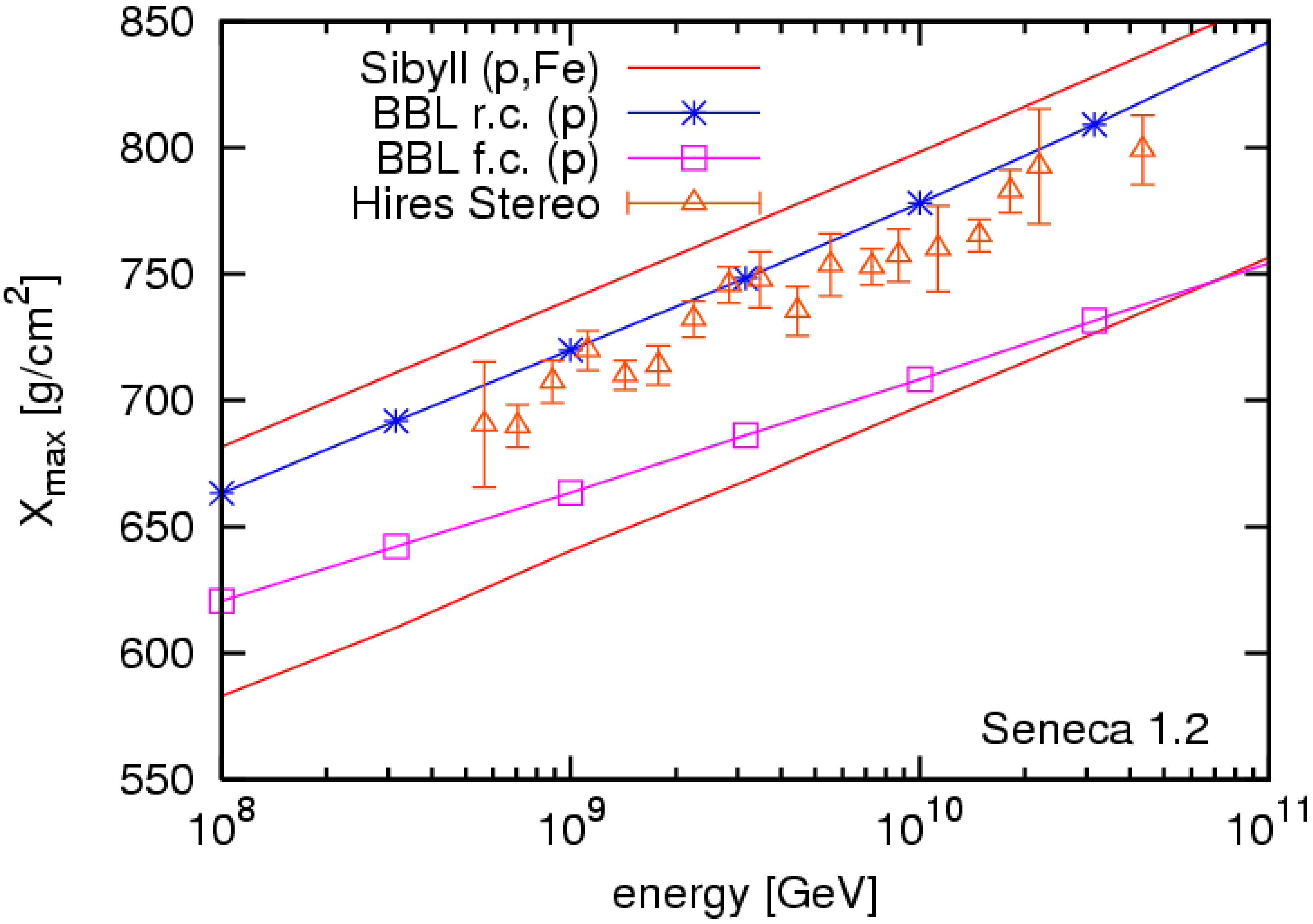
Fluorescence experiments measure $N_{charged}$ as function of depth in atmosphere

$$X = \mathrm{d}\, s\, \rho(s)$$

$X_{max} \sim \ln(E)$

$E = A * E_{nucleon}$

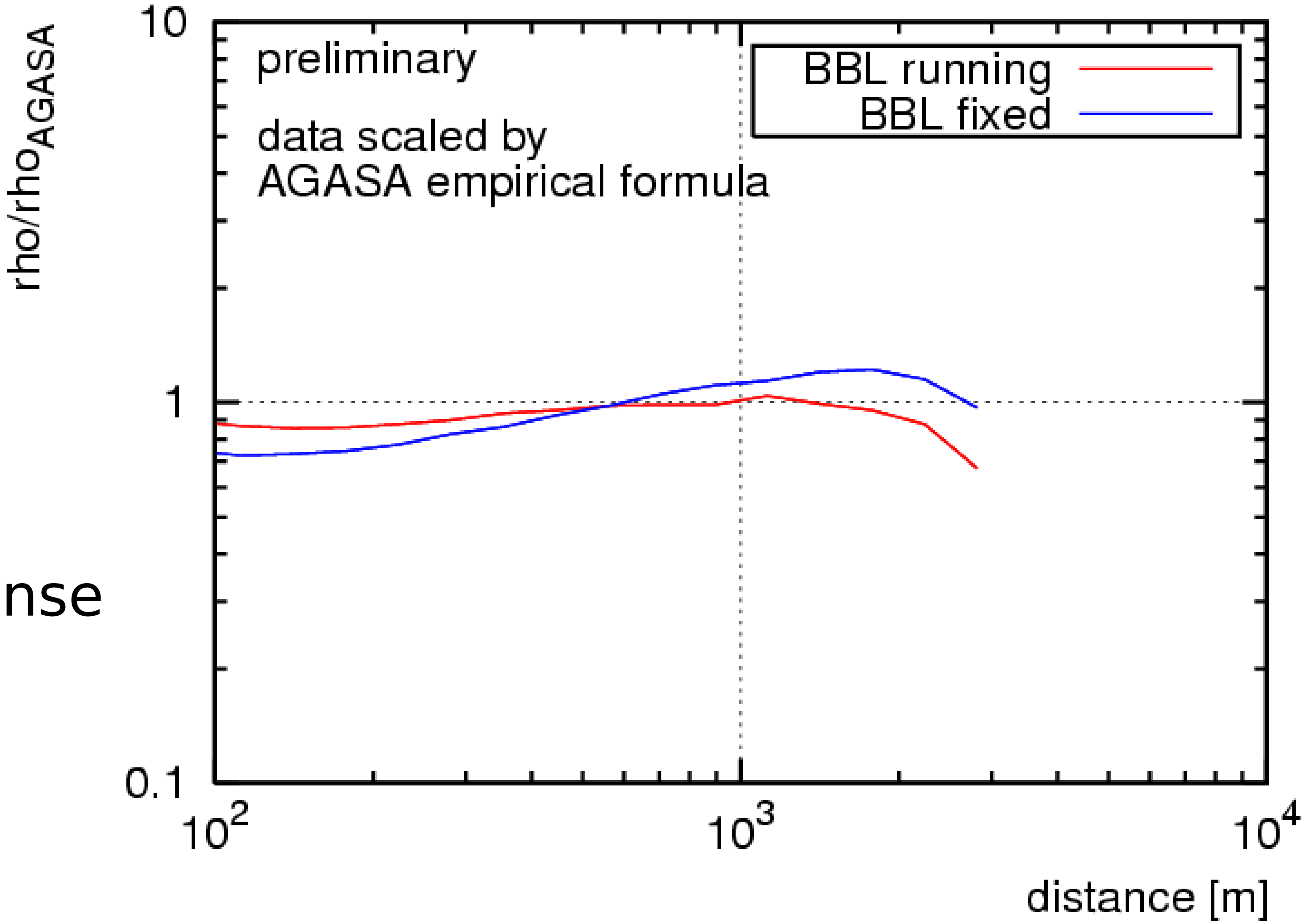
X_{max} plot for fixed and running coupling



- Xmax sensitive to evolution scenario

H.D, Dumitru, Strikman
hep-ph/0408073

Lateral Distribution function compared to AGASA parameterization



Full featured
simulation
with
detector response

fixed coupling
is flatter