Forward Scattering in Cosmic Ray Air Showers

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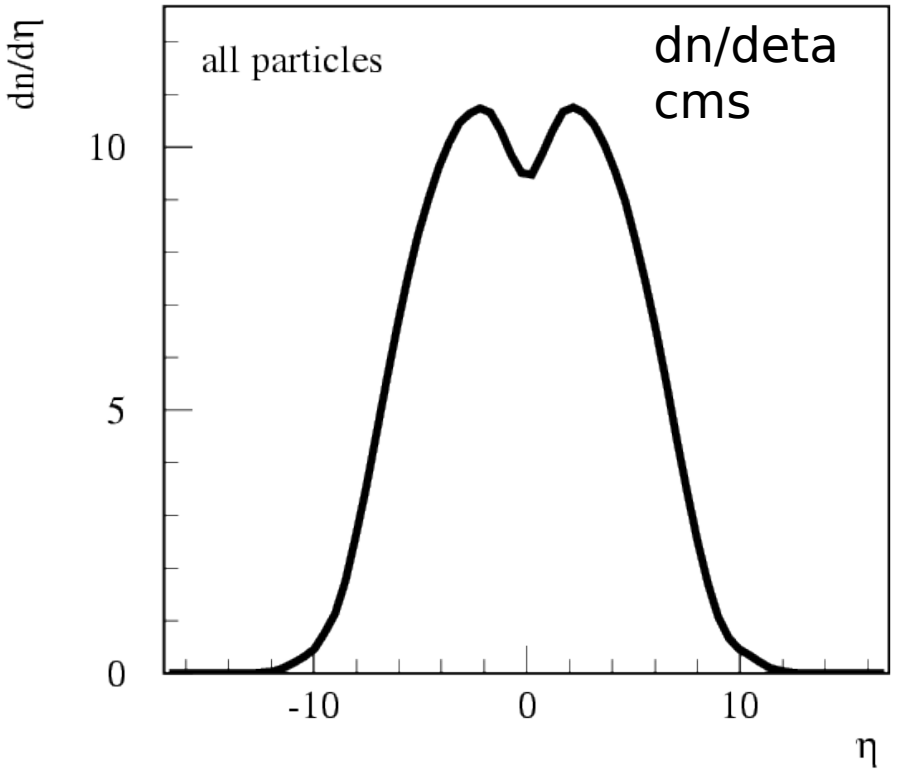
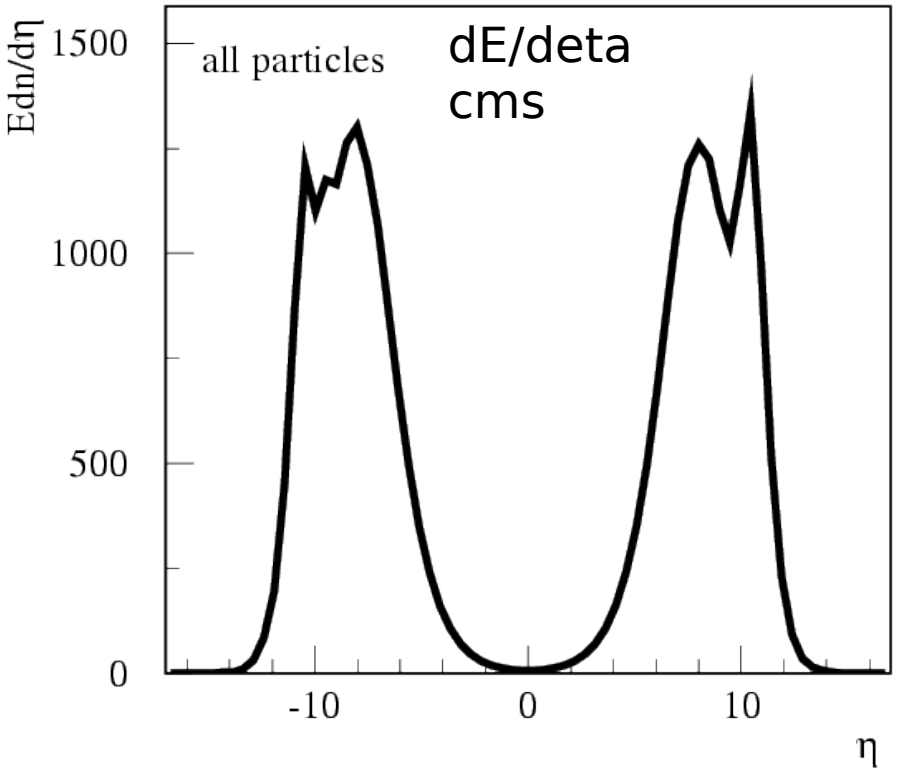
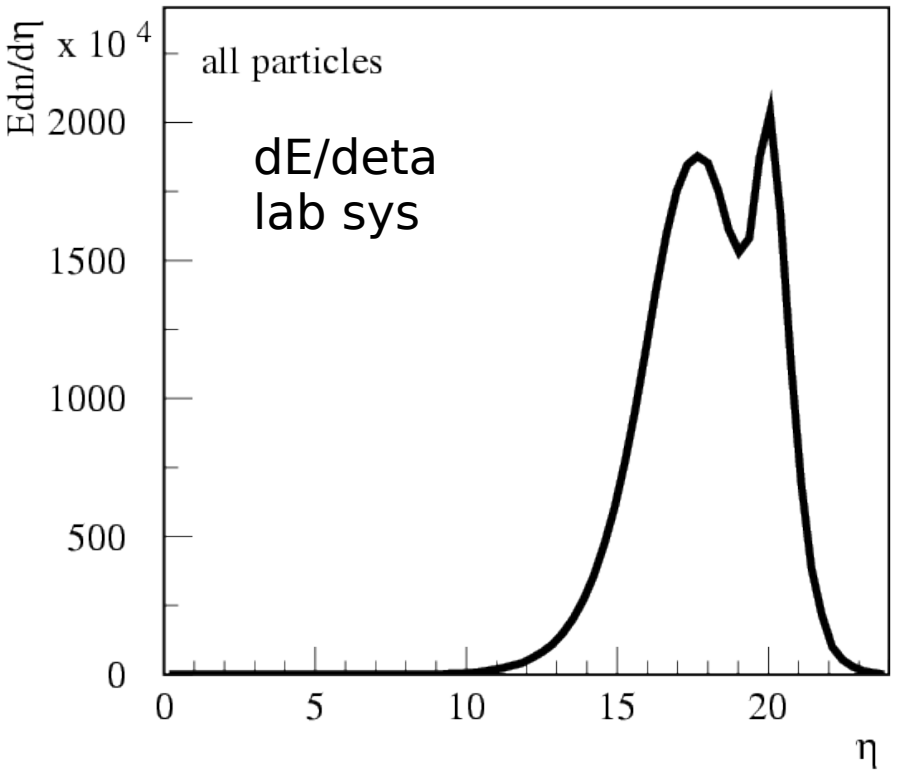
- Forward hadron production important in air showers
- Leading particles in Monte Carlo models diquark versus excited remnant treatment
- Predictions for LHCf
- Influence on air showers

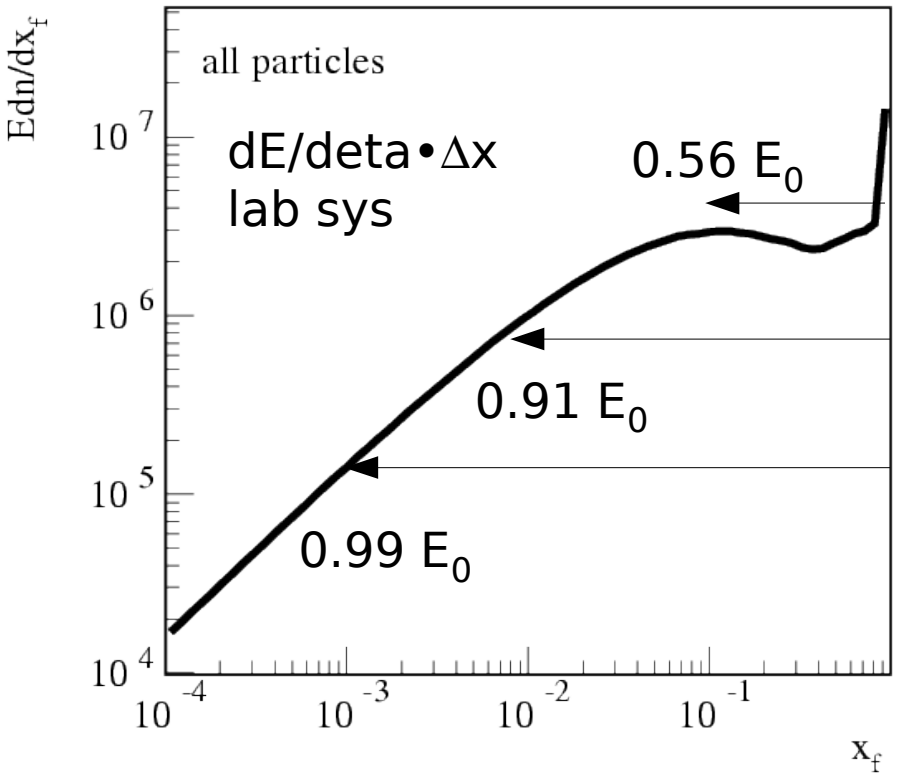
Forward scattering

for p-p
14000 GeV
cms







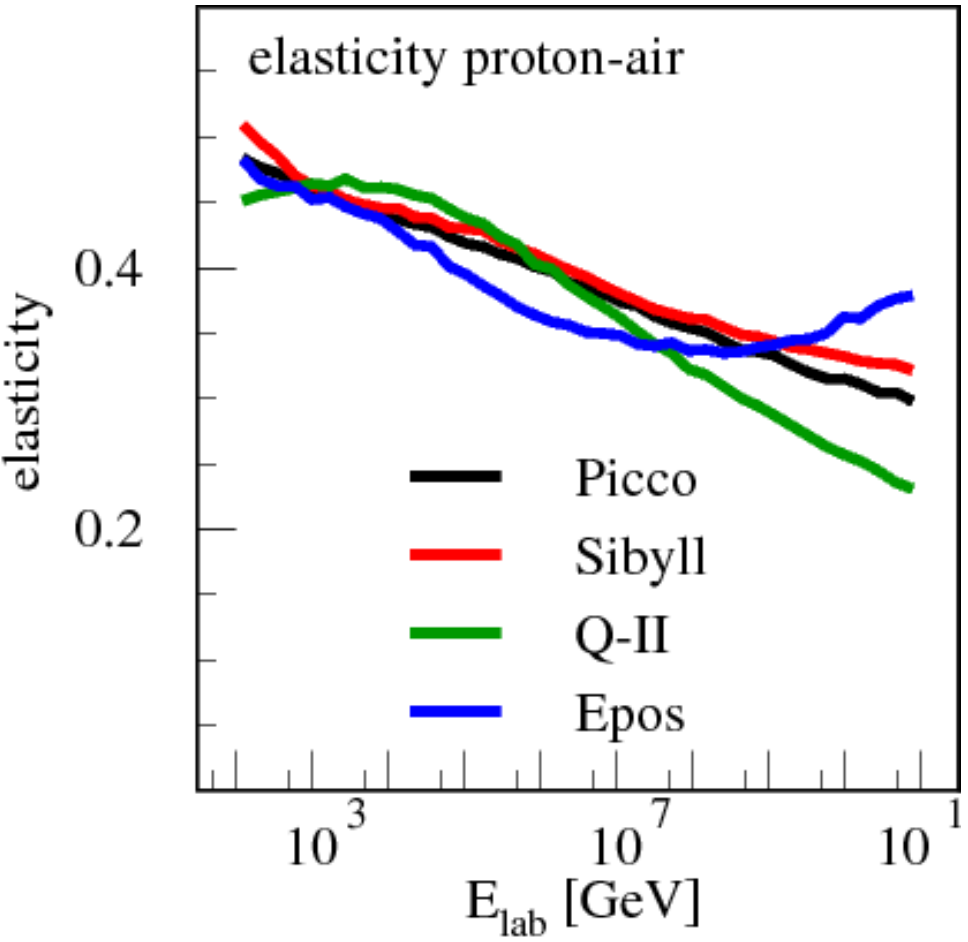


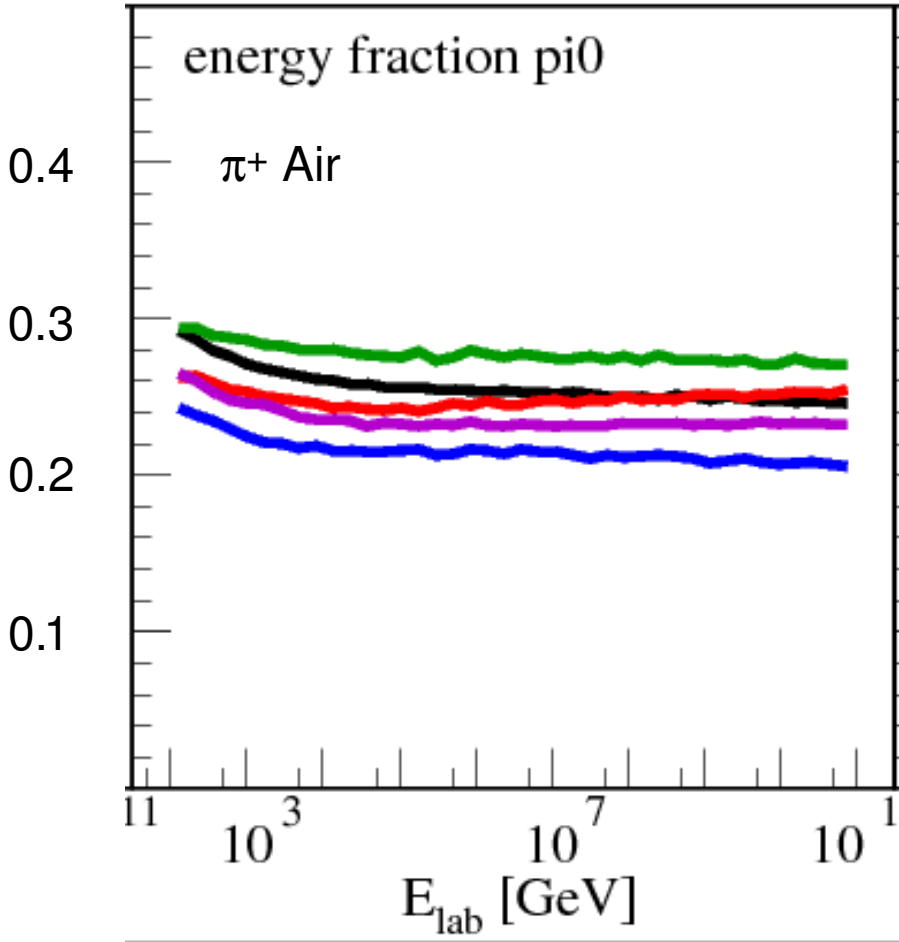
Forward scattering in air showers

Sibyll: R.Engel et al.
QGSjet:S. Ostapchenko
Epos: K.Werner,T.Pierog
Picco: H.Drescher

energy goes into high xF region:
important for penetration depth of air showers

but also for muons: how much energy goes into pi0
how much into hadronic channel





A new flexible and modular event generator as a tool to study influence of hadronic models on air showers:

Picco (**p**QCS **I**nteraction **C**ode for **Co**smics)

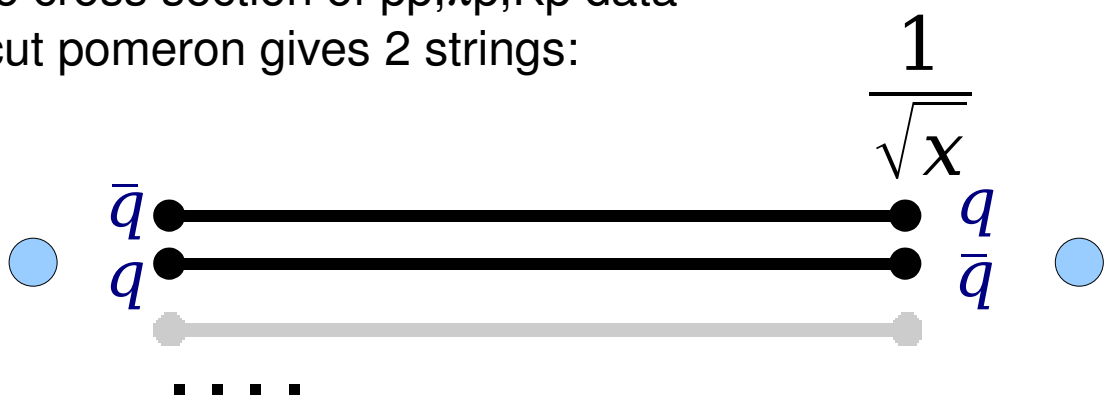
(hadron-Nucleus)

$$\chi(s,b)=\gamma\frac{s^{\alpha(0)-1}}{\lambda(s)}\exp\left(\frac{-b^2}{4\lambda(s,b)}\right) \qquad \lambda(s)=R_0^2+\alpha'(0)\ln s$$

$$\sigma_{inel}(s)=\int d^2b\left[1-e^{-2\chi(s,b)}\right] \longrightarrow$$ Number of Pomerons for given s,b

Two Pomerons (eikonals): soft and semi-hard, parameters fitted to cross section of pp,πp,Kp data

each cut pomeron gives 2 strings:



Hard scattering (hard partons) and string fragmentation via Pythia/Lund model

Remnant energy fraction:

$x^{\frac{3}{2}}$ baryon

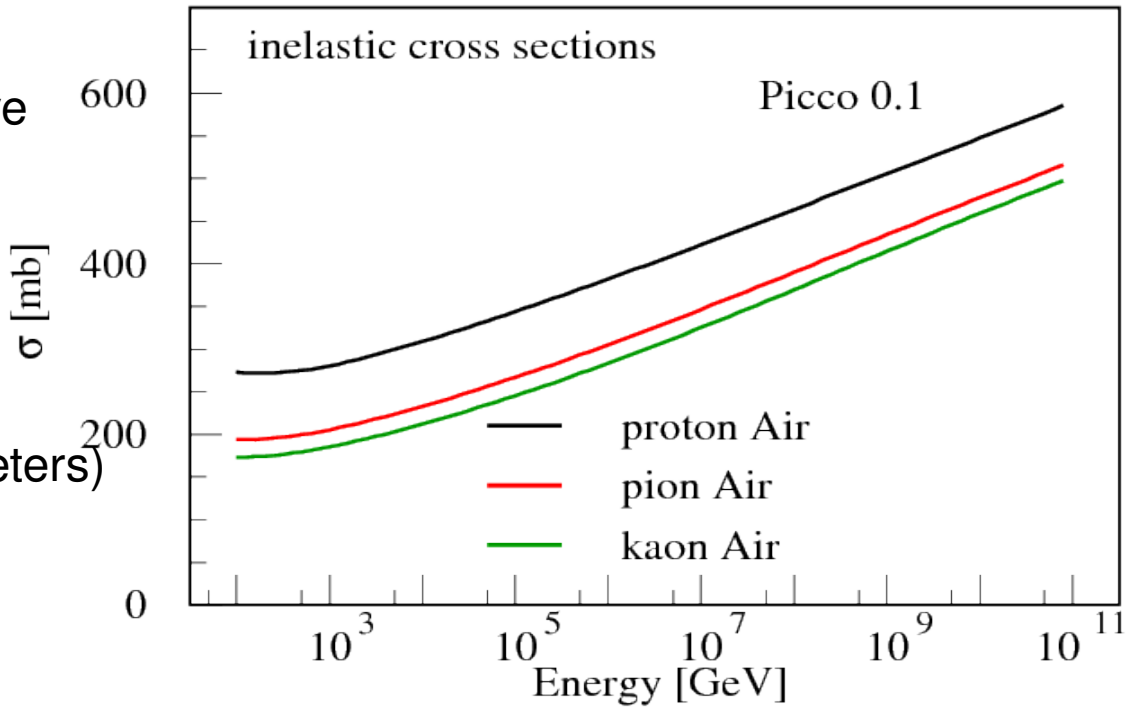
$\frac{1}{\sqrt{x}}$ meson

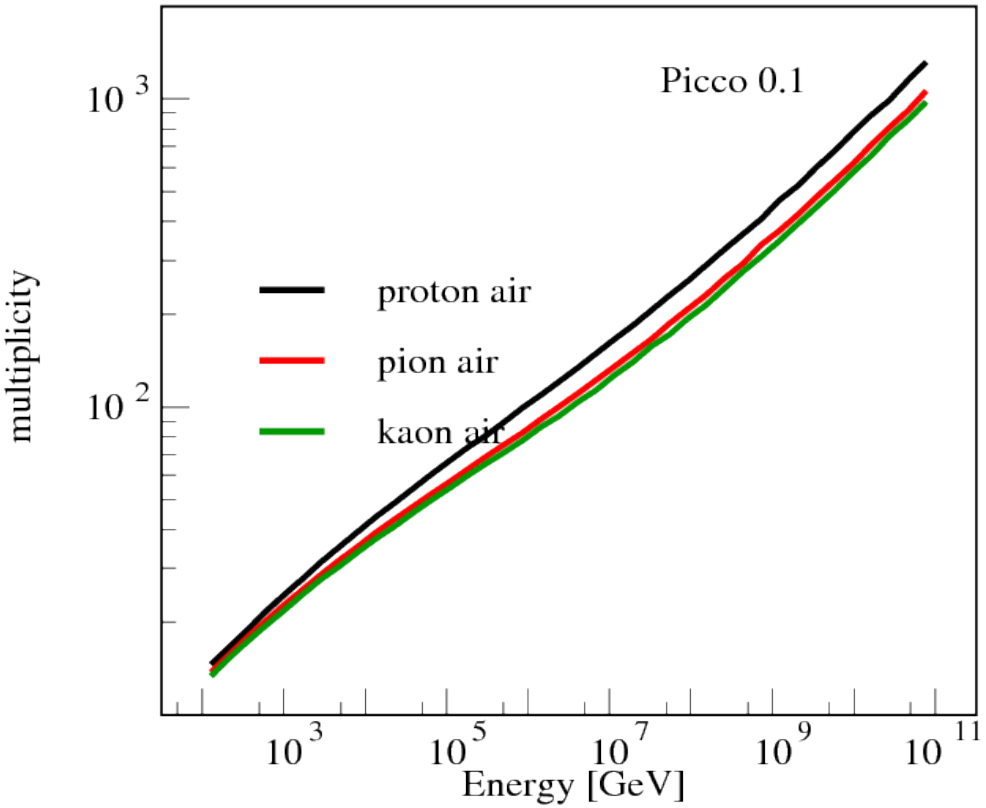
More remnant →

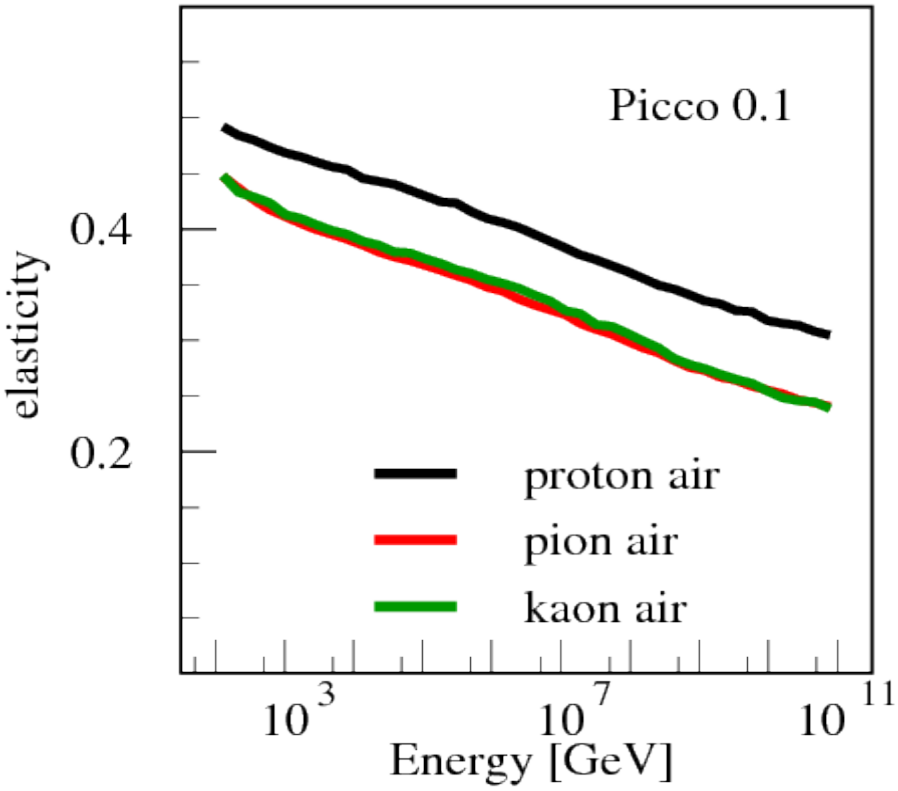
Picco represents a log-linear conservative extrapolation to high energies

so far no screening/high density effects

simple construction permits parameter studies of models (incl. all Pythia parameters)

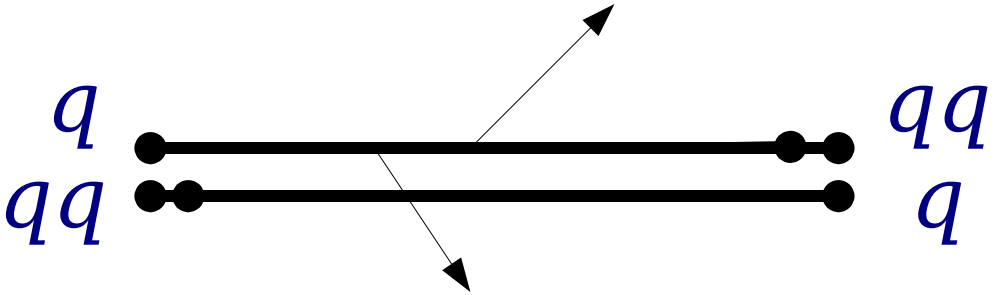






Remnant treatment in air shower models

Usual approach:
diquark string end
(Pythia)



diquark gives leading baryon:
•treats first interaction different from the others

Other Problem:
•diquark string predicts
anti-Ω/Ω > 1

Bleicher et al.,
Phys.Rev.Lett.88:202501,2002.

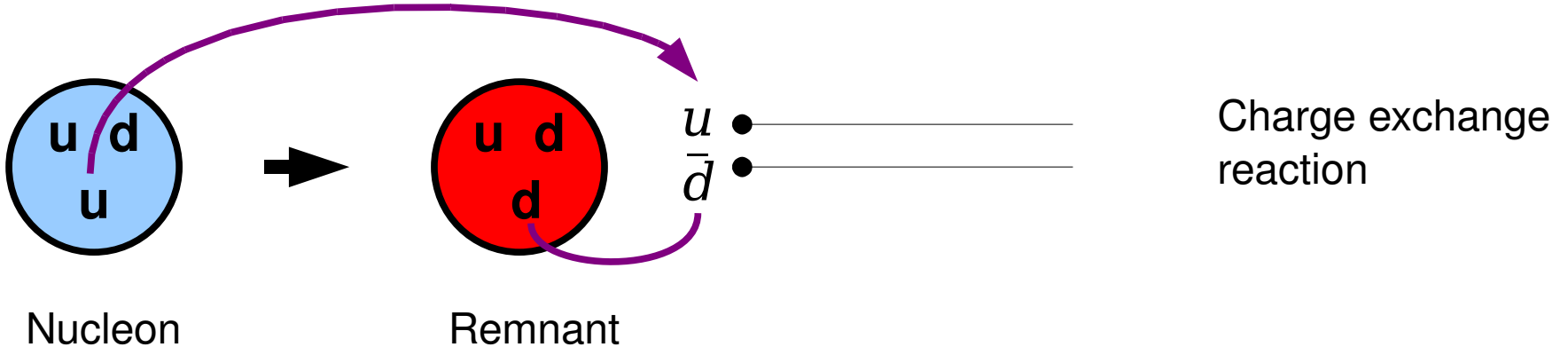
$u---\bar{s} \quad s---ss \quad s\bar{s}---\bar{d} \quad d---ud$

$u----ss \quad s\bar{s}---\bar{s} \quad s---ud$

Consistent remnant treatment

each elementary interaction (soft or hard) pulls a quark-antiquark pair from the nucleon

(QGSjet,Nexus,Epos,Picco)



Epos: pick up any sea quark/antiquark ---> remnant as quark bags
Picco: picks up valence quark/anti sea quark ---> remnant always 3 quarks
QGSjet-II: one charge exchange reaction only ---> remnant always 3 quarks

After dealing with flavor content of remnant: excitation

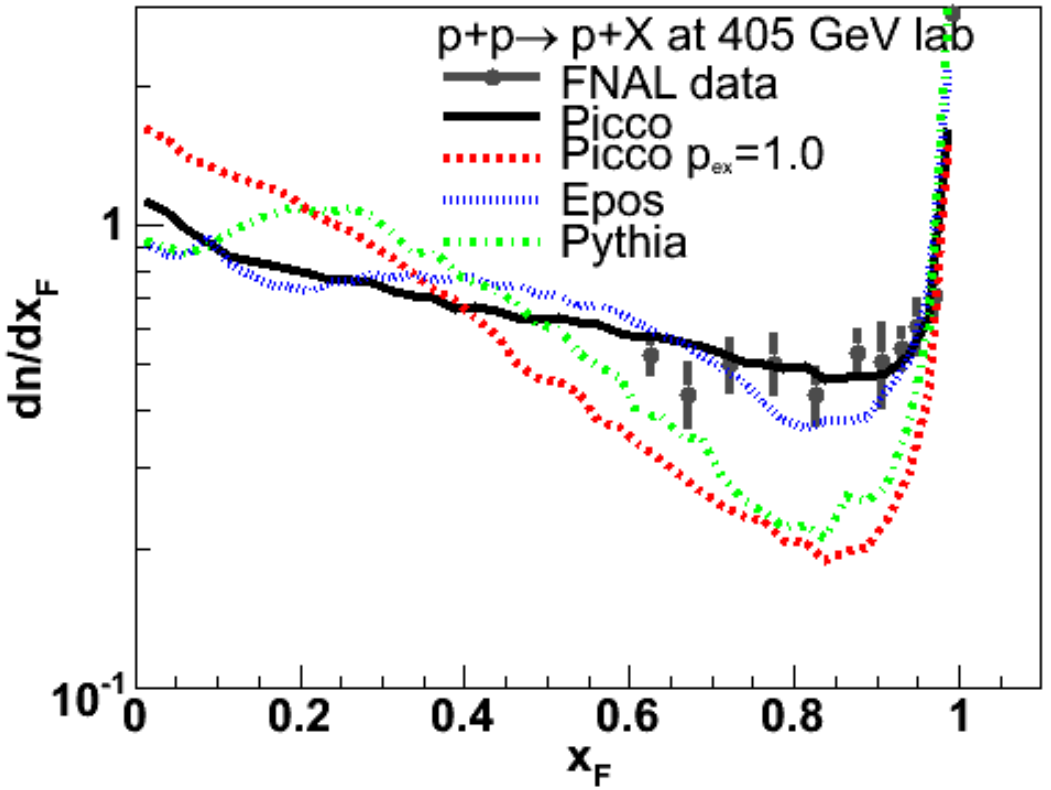
$f(M) \sim M^{\alpha}$ with excitation probability P_{ex} with M_{min} and M_{max}

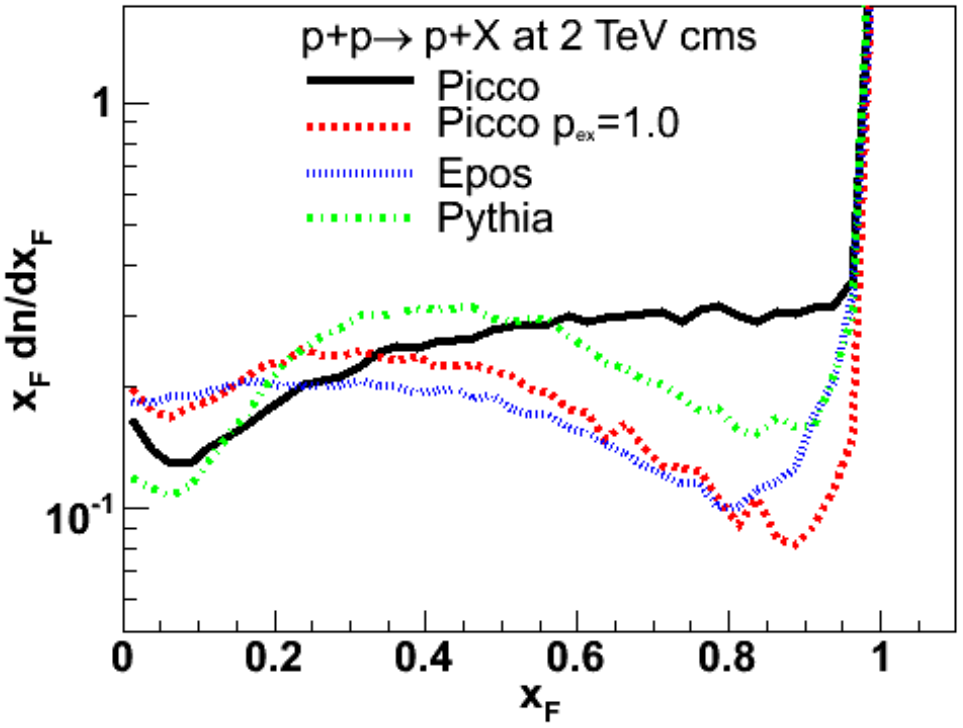
remnant then forms diquark-quark string or proton/neutron/Lambda

Fix excitation probability in forward pp scattering

Fitting data yields P_{ex} ~ 0.5 for Picco

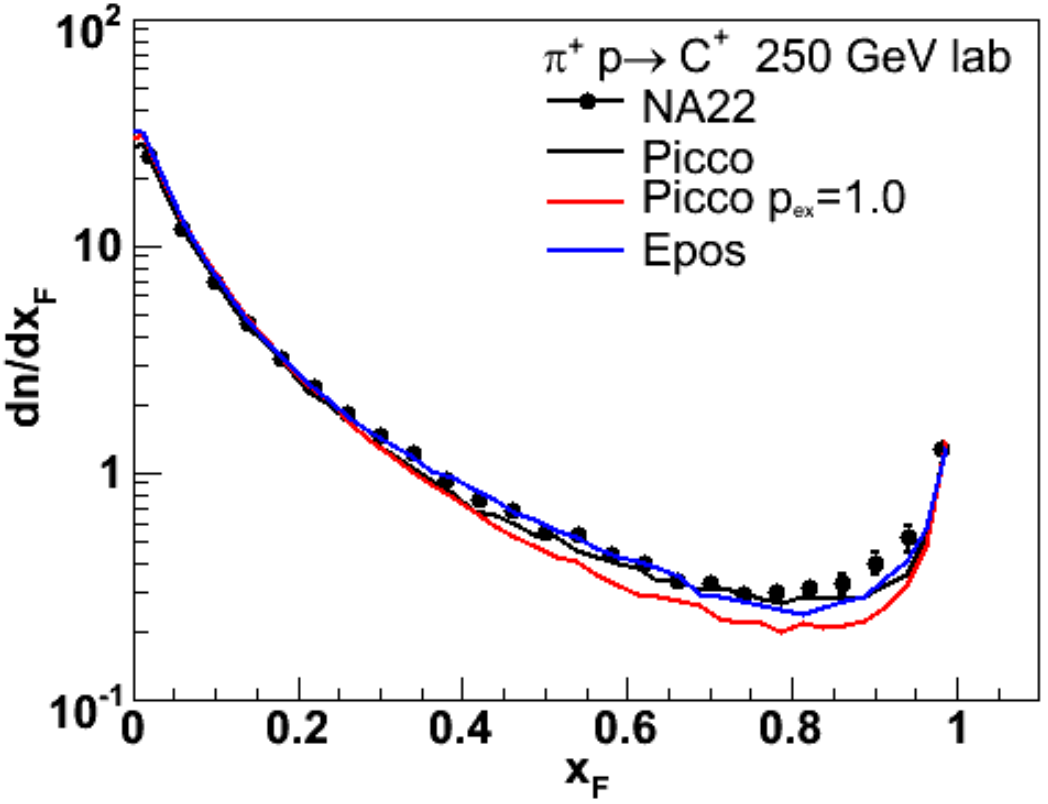
P_{ex} determines dip or flat forward spectrum



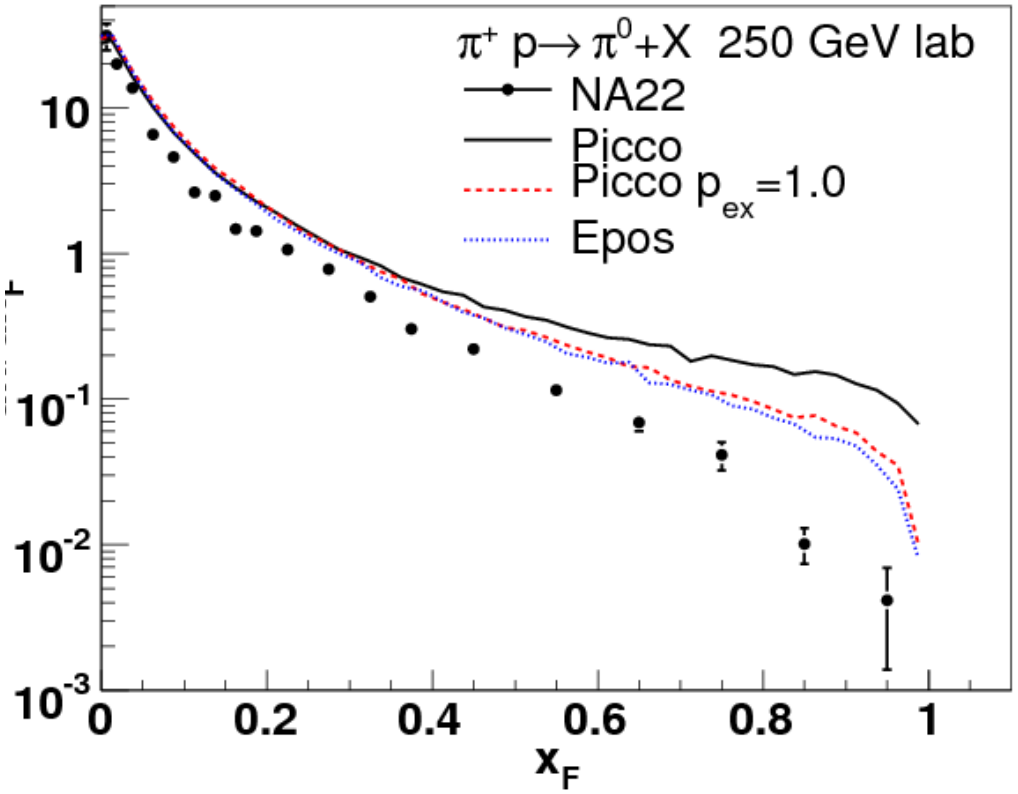


Forward pion-proton scattering

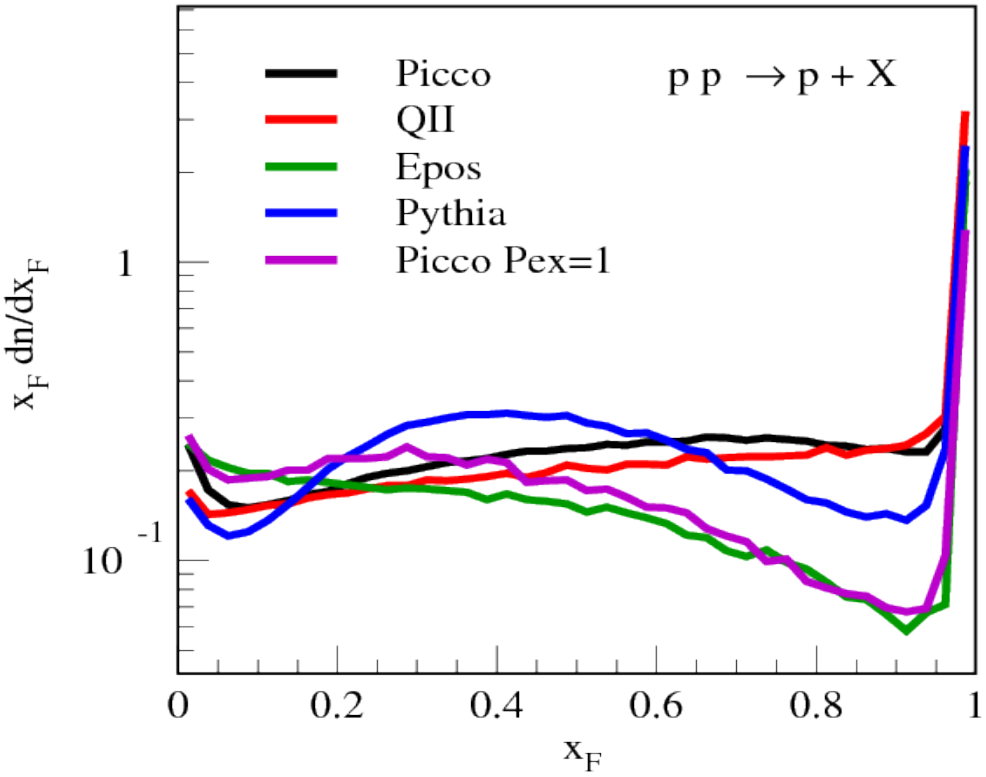
Data from NA22/EHS (1992)
Situation less clear:
Are all models wrong or has the data some problems?

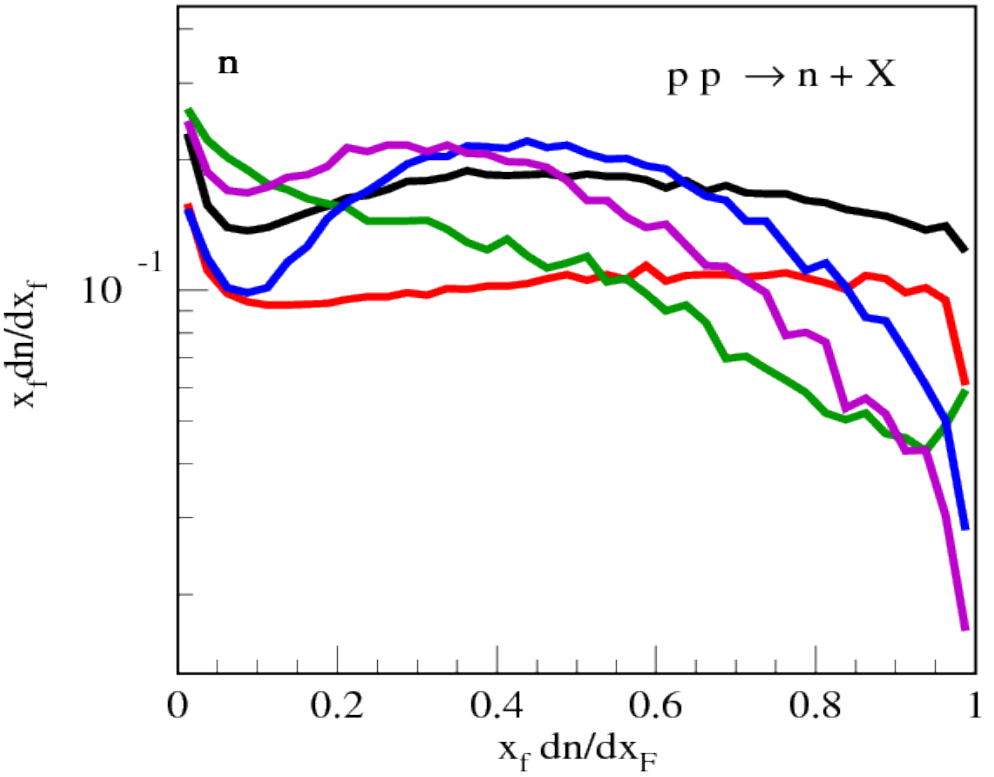


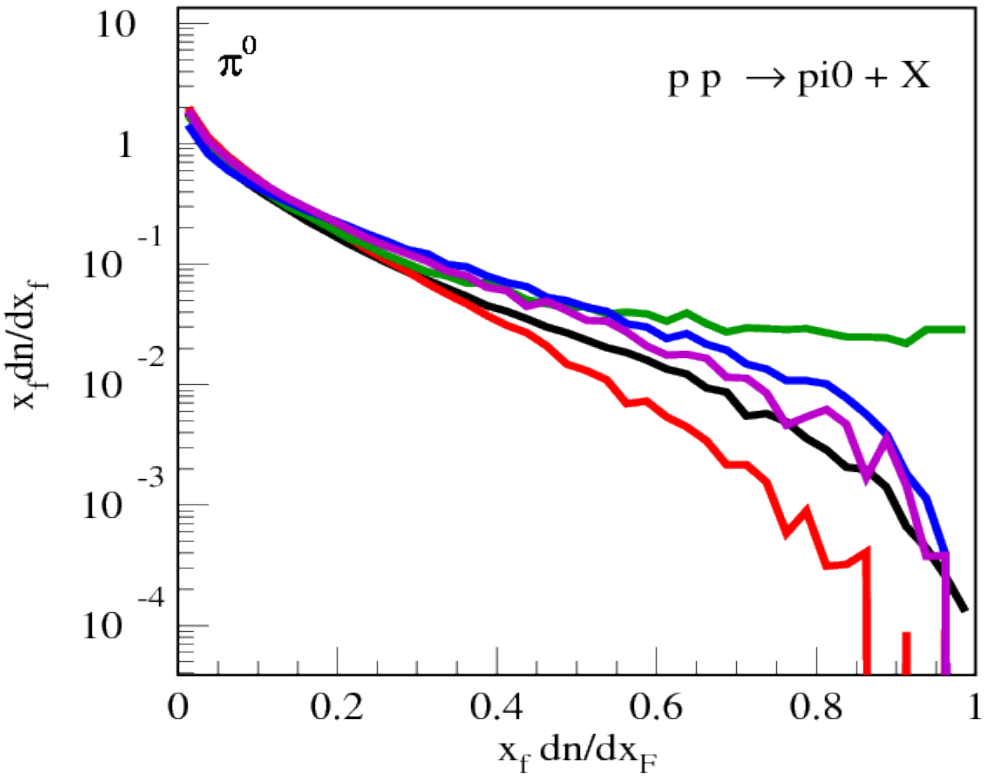
Forward charged



Forward pi0







Predictions for LHCf

measures pi0 and neutrons in forward region

enhanced break-up at high energy??
how much charge exchange ??
how much forward pi0 ??

Remnant break-up influences muon production in air showers

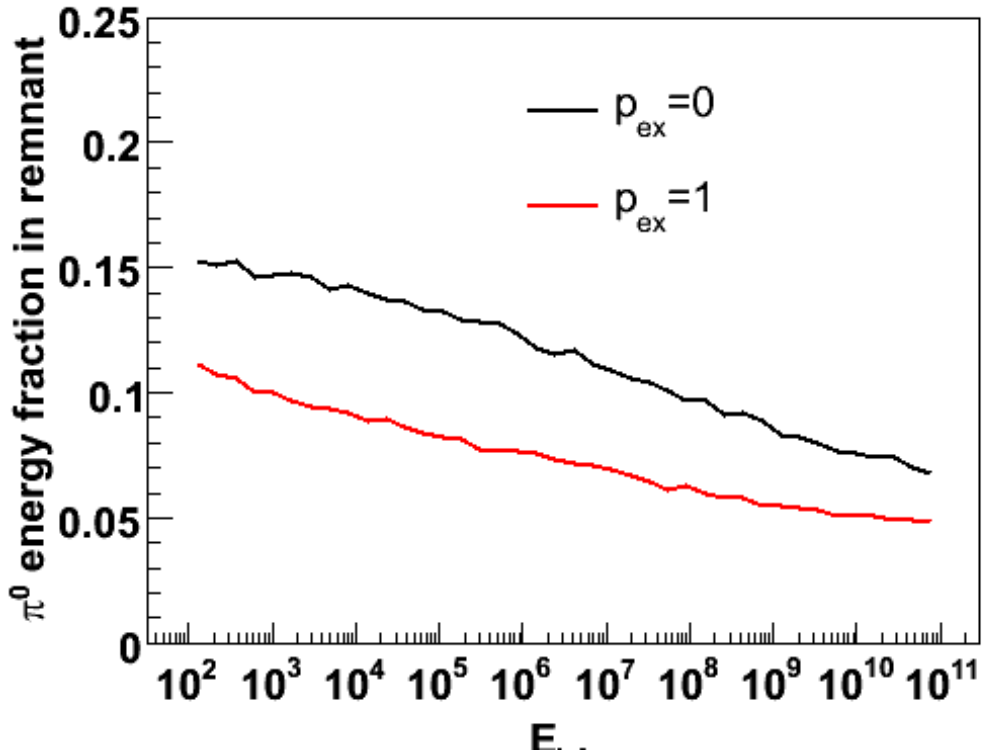
Baryon remnant break-up increases pi0 fraction and decreases muons

p ⟶ p + f pi0

Pion remnant break-up decreases pi0 and increases muons

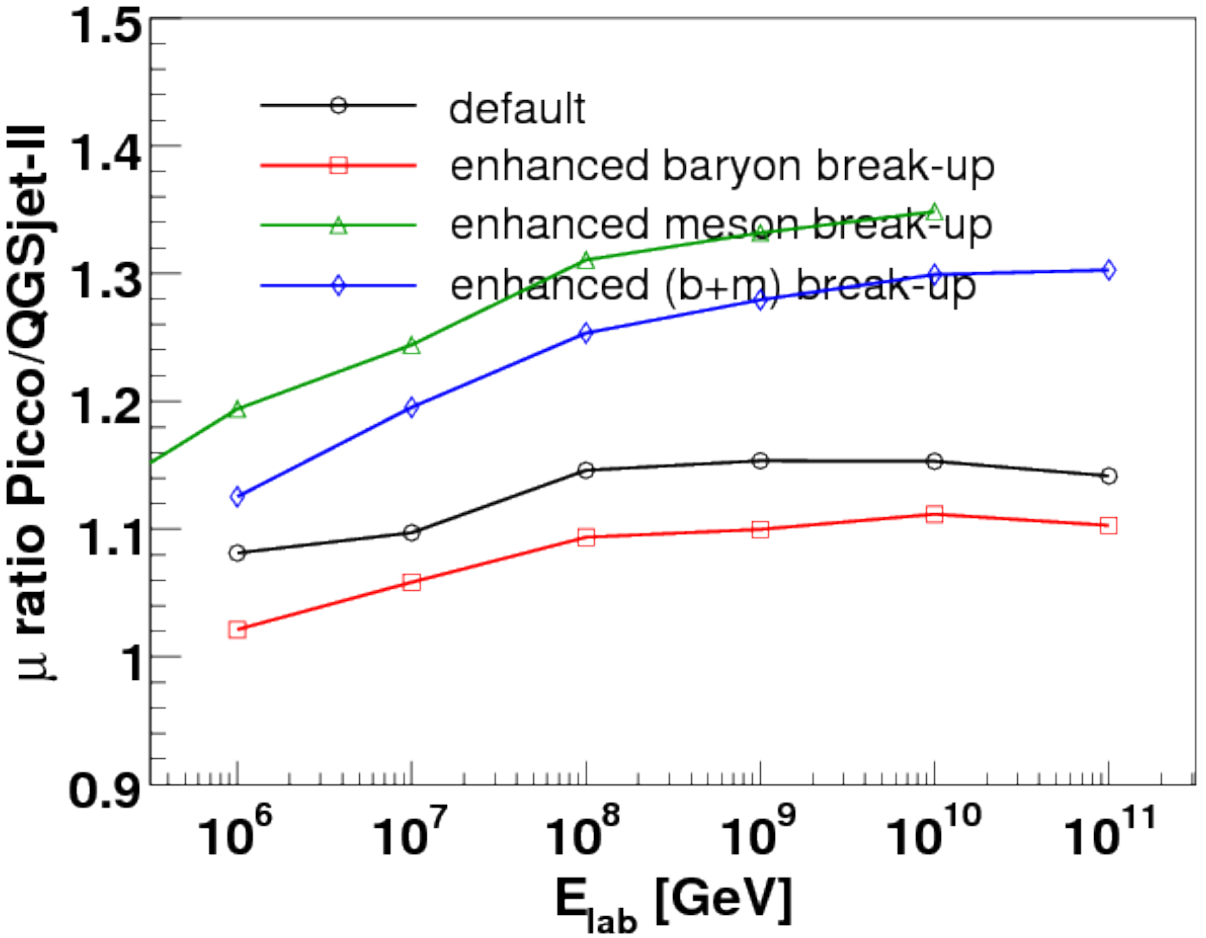
pi+ ⟶ 1/3 pi0 + 2/3 pi+-

pi0 ⟶ 1/3 pi0 + 2/3 pi+-



Influence on muon production

proton induced 14000m altitude (Auger)



Total muon numbers on the ground are plotted normalized to QGSjet-II

Conclusions

- Forward hadron production quite unclear in models
- Flat dn/dx_F spectrum at low energies for baryons
- LHCf to measure forward neutrons/pi0
- Big influence on muon production in air showers