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Remnant Treatment and Hadron Production in Air Showers

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Outline

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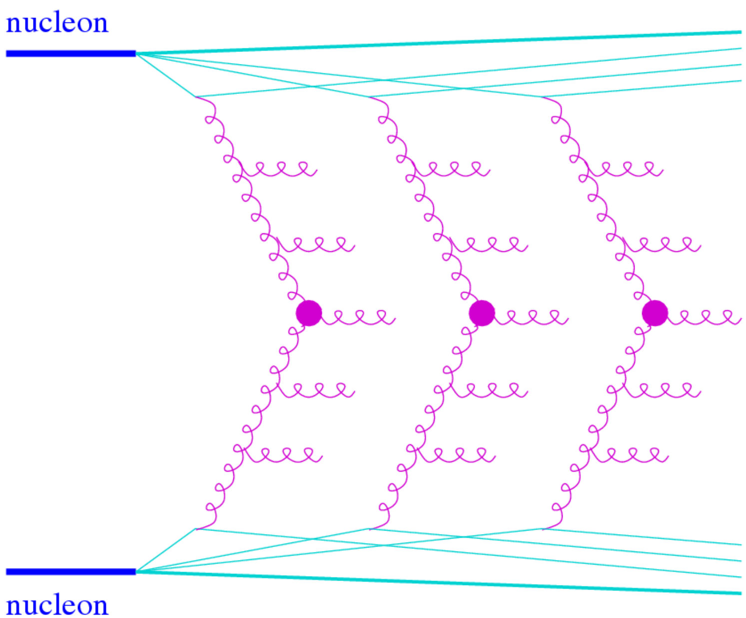
- Model : EPOS
- Parton-Based Gribov-Regge Theory
- Remnants
- HERA data
- Air Showers
- Summary and Outlook

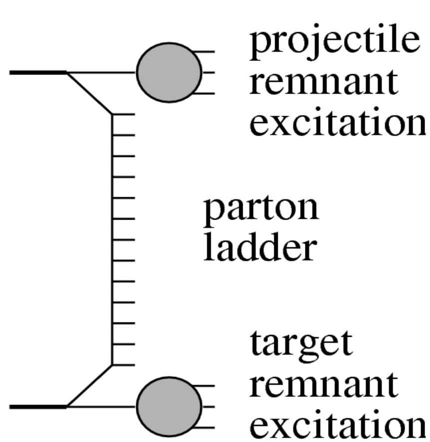
Model : EPOS

Evolution of models by K. Werner et al. :

- VENUS : soft physic
- NEXUS 2 : first realization of Parton-Based Gribov Regge Theory (PBGRT) with soft, semi-hard and hard Pomerons
  - No screening
- NEXUS 3.97 : enhanced diagrams in PBGRT and new remnant treatment.
  - No Cronin effect and problems at high energy
- EPOS : Enery sharing
  Parton based theory with
  Off-shell remnants and ladder
  Splitting.
  - PBGRT + remnants + Effective treatment of higher order effect and high density effect + ...

Parton-Based Gribov Regge Theory

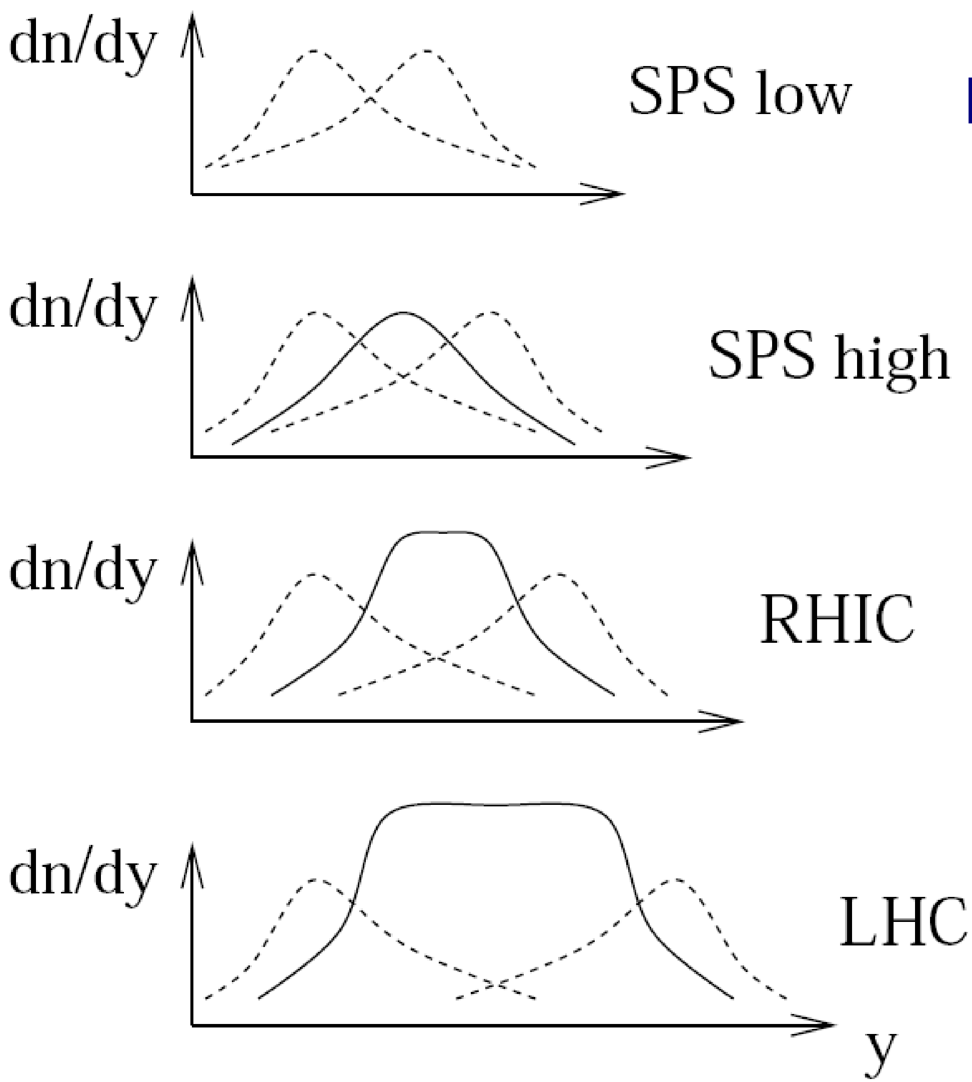




EPOS is a parton model, with many binary parton-parton interactions, each one creating a parton ladder.

- Energy-sharing :
  - for cross section calculation AND particle production
- Multiple scattering (interference term)
- All ladder similar
  - valence quark in remnants
- Screening and shadowing via unitarization and splitting
- Ladder = soft + hard = field = string

Remnants



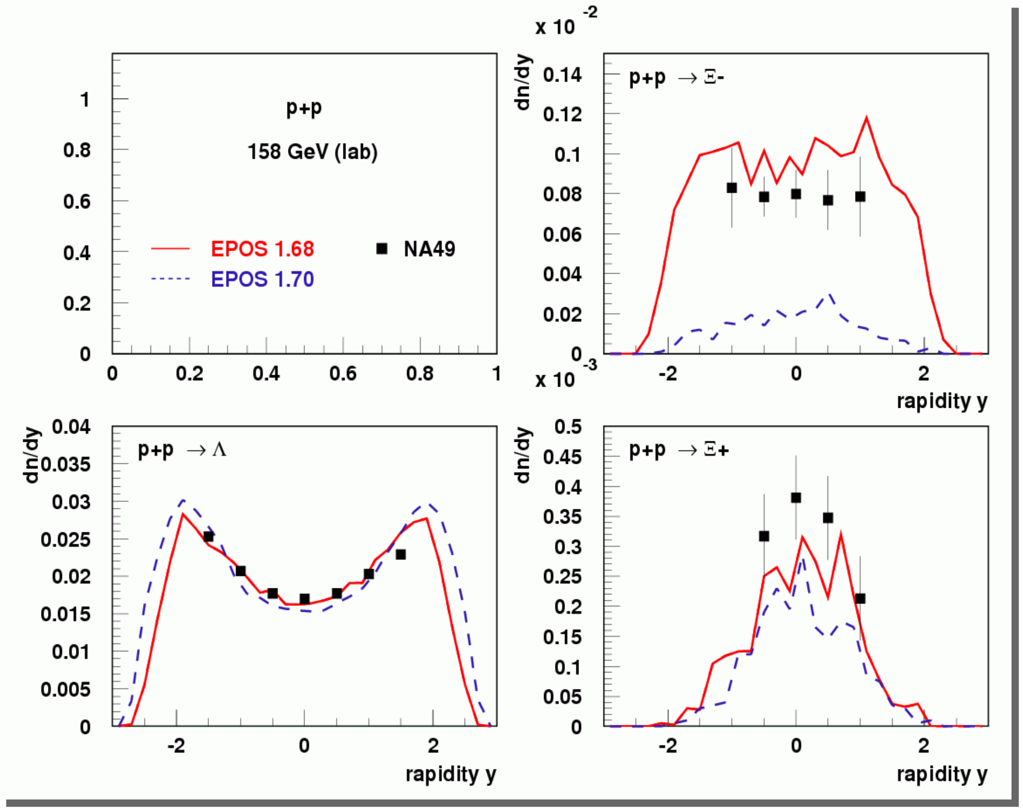
High mass remnants in EPOS:

- very large contribution at low energy
- forward region at high energy
- depending on quark content and mass (excitation):
  - resonance
  - string
  - droplet (if #q>3)
  - string+droplet

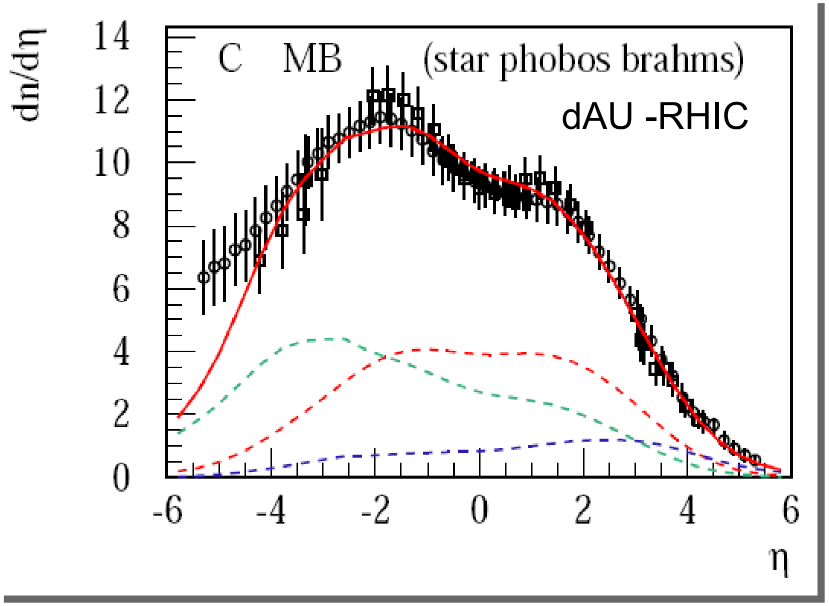
Remants (2)

Valence quark not necessarily connected to parton ladder :

- necessary to have aΩ/Ω < 1 (cf Hajo's talk)
- very broad remnant distribution
- very important for Cosmic Ray



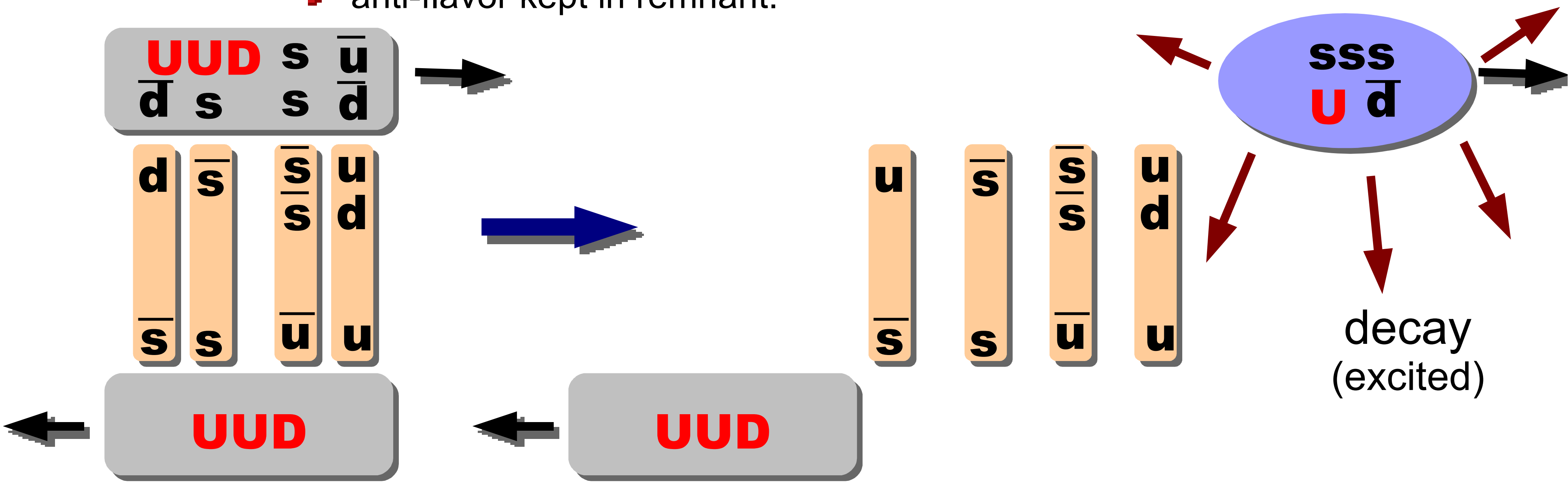
EPOS 1.68 : multiquark remnant
EPOS 1.70 : remnant=proton



Remants (3)

Results presented with two different remnant treatments :

- EPOS 1.68 (NEXUS like remnant) : each string end quark has different flavor
  - anti-flavor kept in remnant.

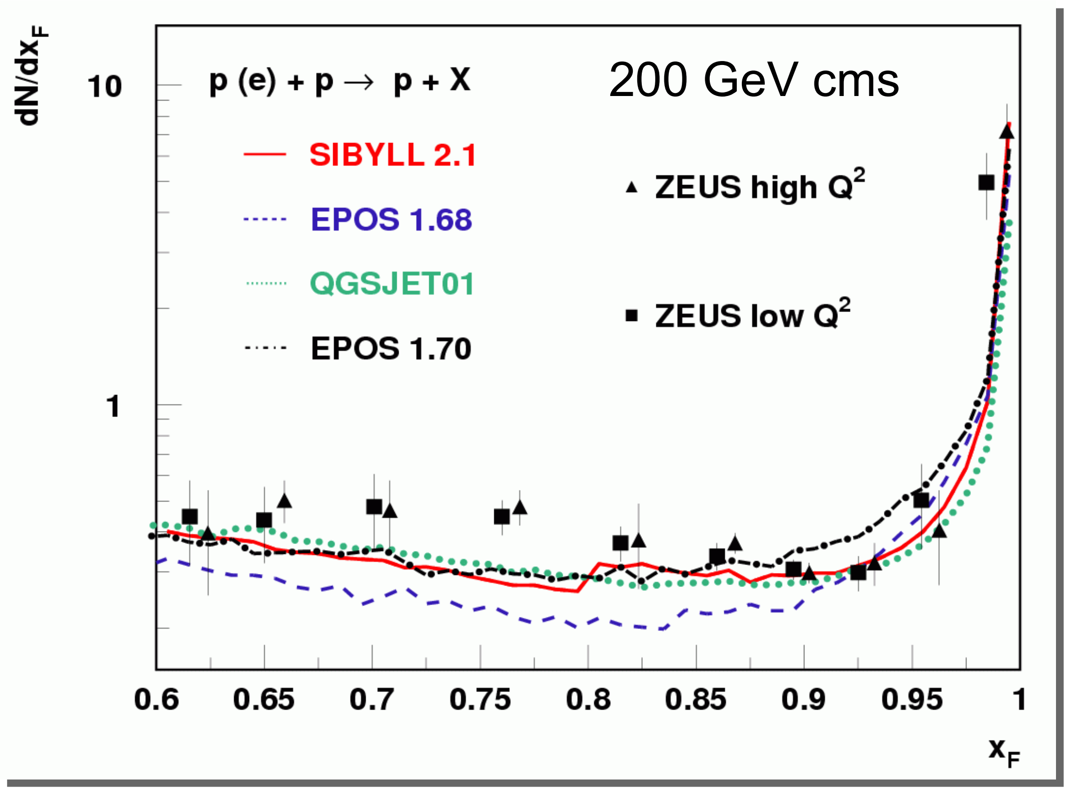


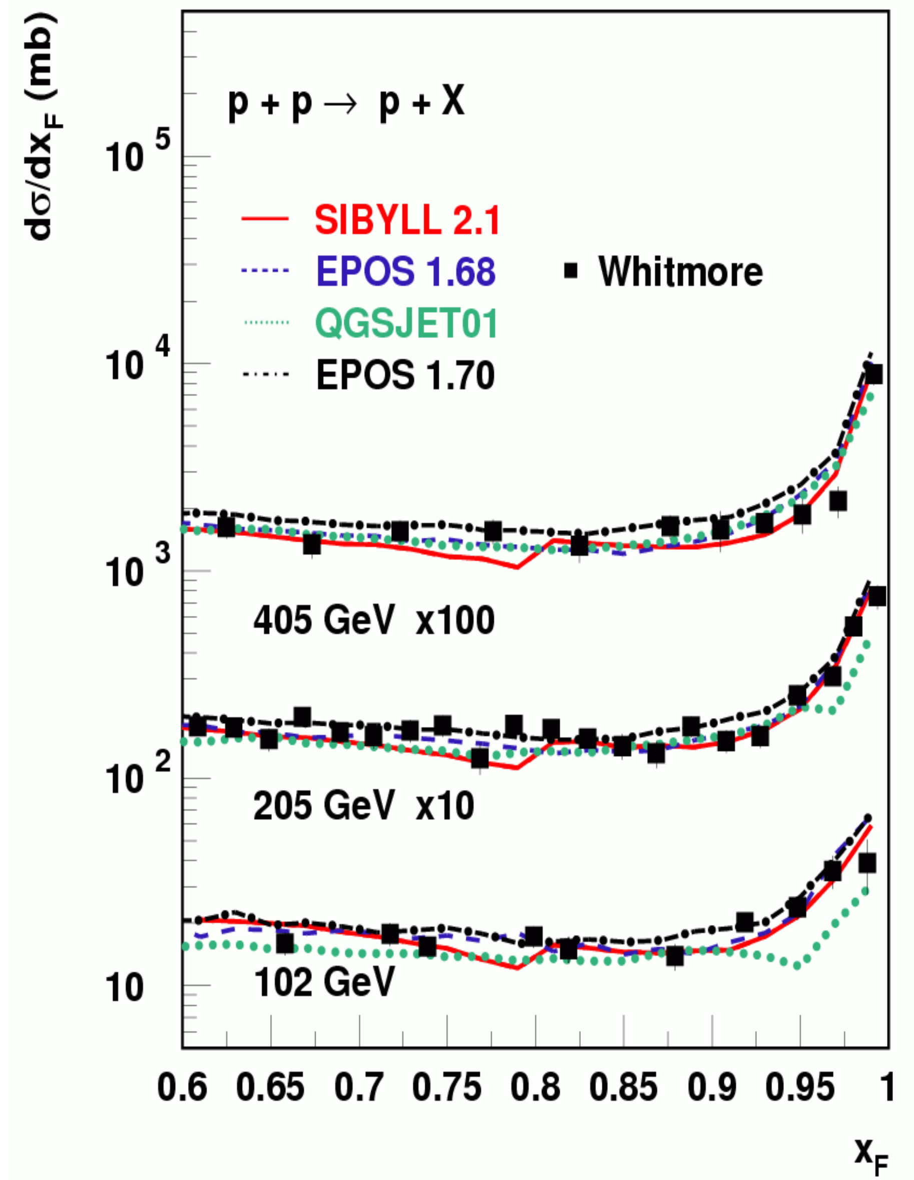
- EPOS 1.70 (simplified test) : neutral flavor for all Pomeron connection
  - remnant = projectile always.

HERA Data

Remnant excitation change projectile forward distribution → elasticity !

- More excitation in EPOS
- compatible with data at low energy
- not compatible at high energy (HERA)





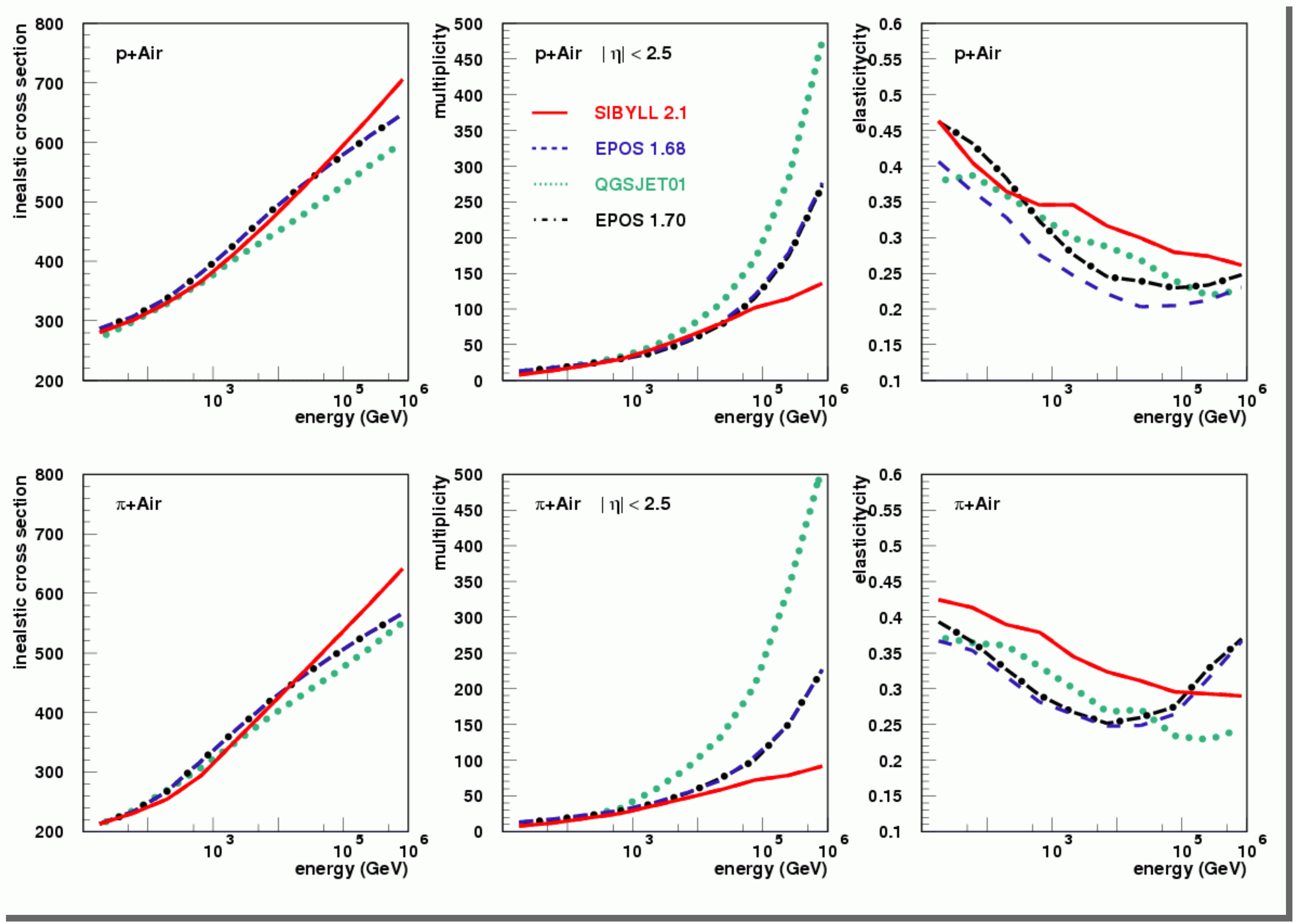
Compared Results

2 versions of EPOS:

- EPOS 1.68 high remnant excitation
- EPOS 1.70 remnant excitation fixed (80%)

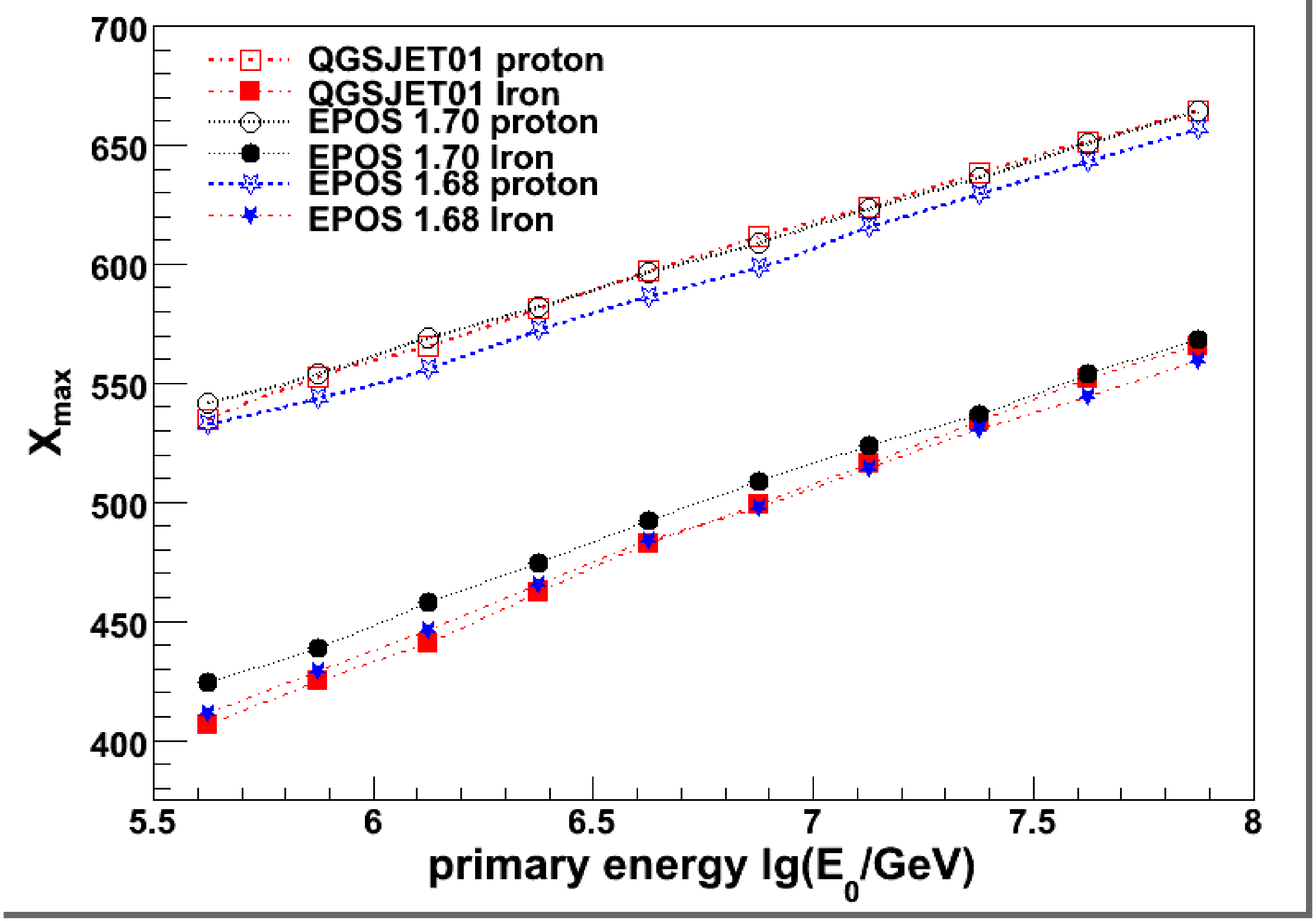
Difference :

- only elasticity
- multiplicity unchanged because of slightly different parameters (data constraint)



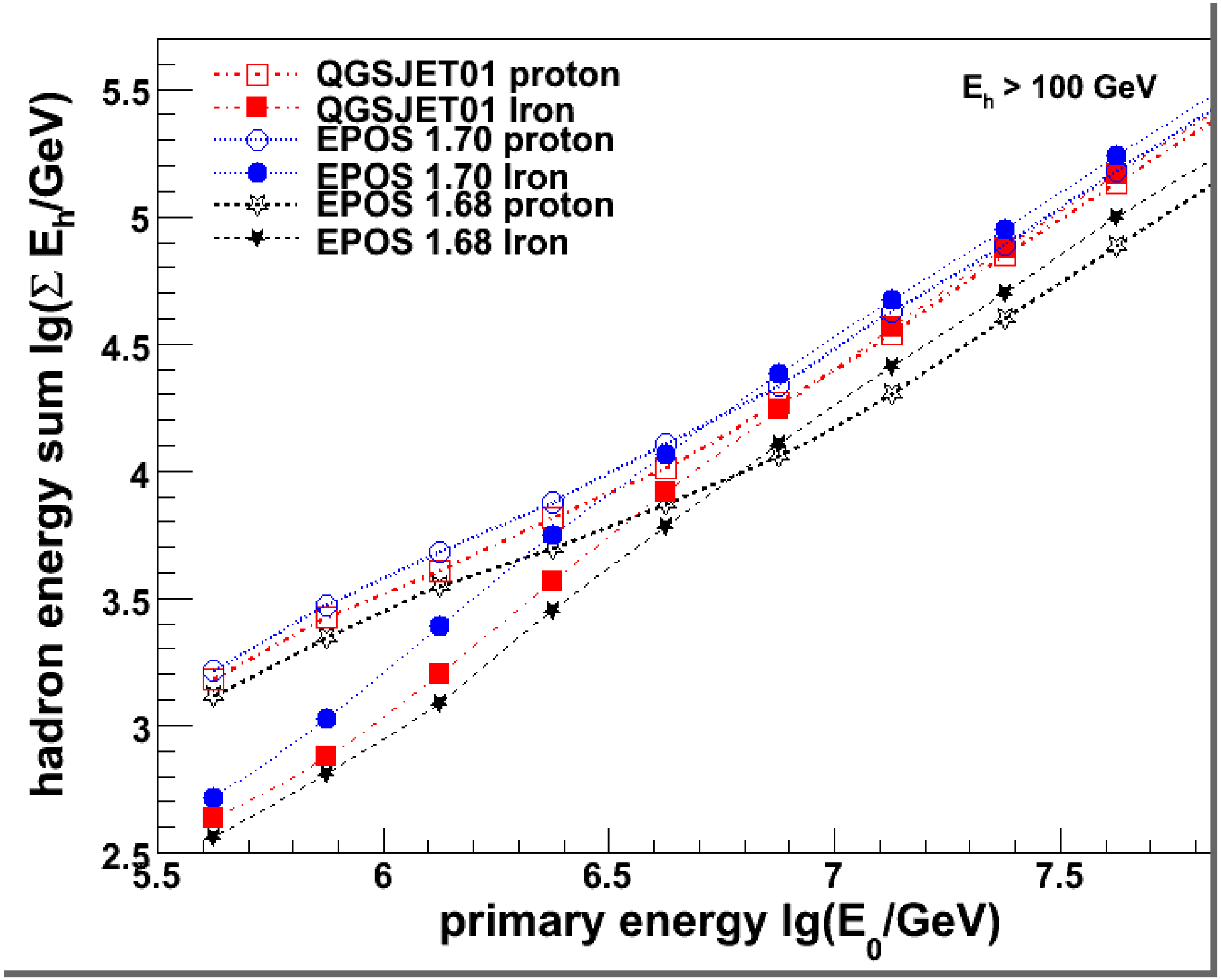
Results for EAS : <X_{max}>

Large (but realistic) difference in elongation if less excitation.



Results for EAS : Hadrons

Hadron energy very much dependent on collision elasticity ...

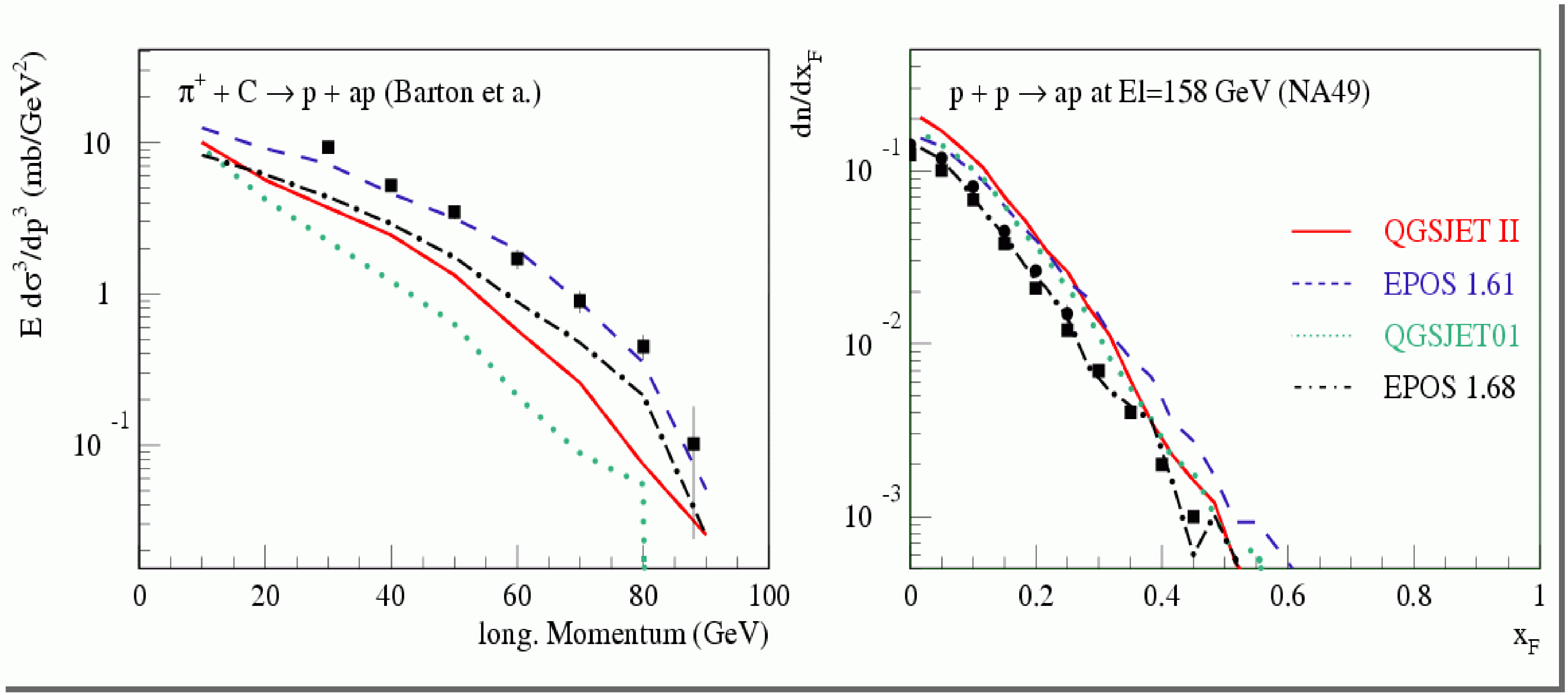


Clear difference due to remnant excitation (+60%)

Forward production of antiprotons

Crucial point for muon production:

- parse data of antibaryon/baryon production in forward direction
- large uncertainty for muon production in air showers
- can (or do) HERA measure antiprotons at large x_F ?

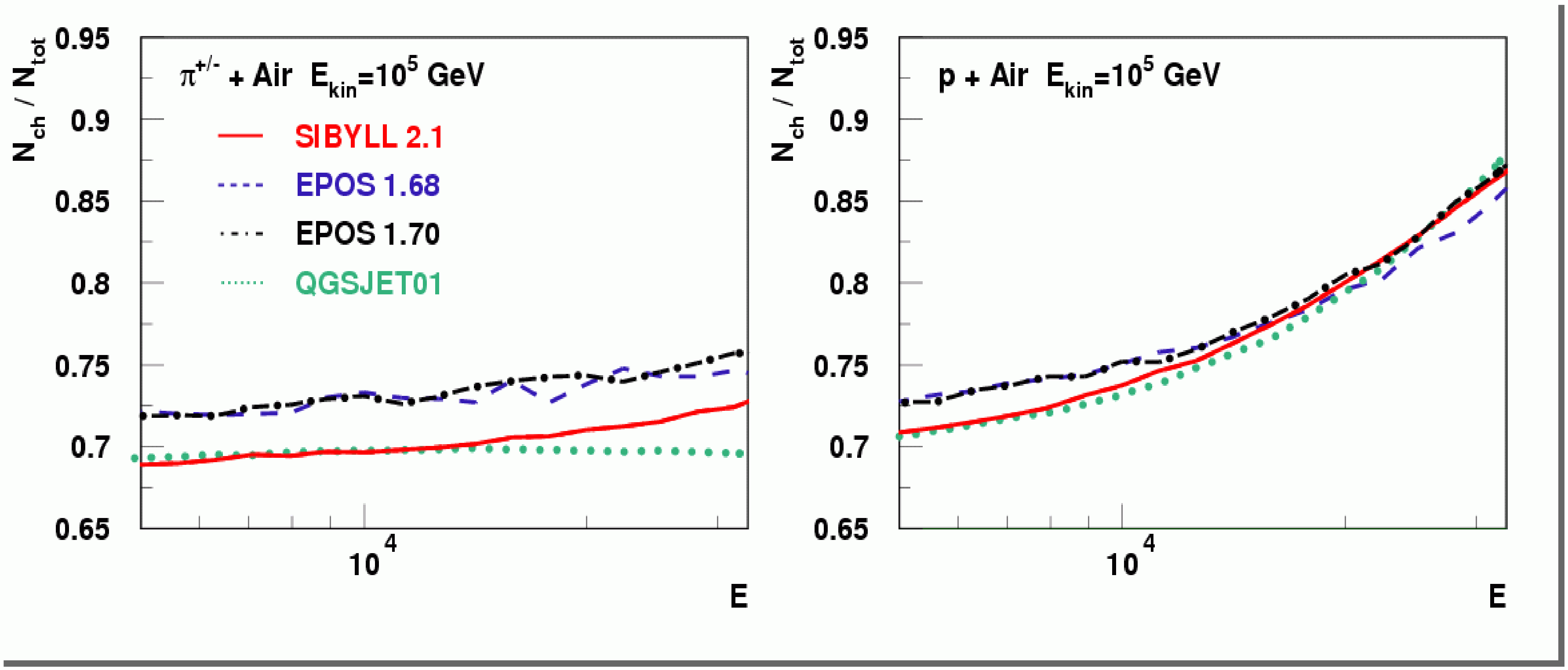


Number of muons

Ratio $R=N_{charged}/N_{tot}$ related to number of muons in air shower:

- EPOS 1.68
- EPOS 1.70

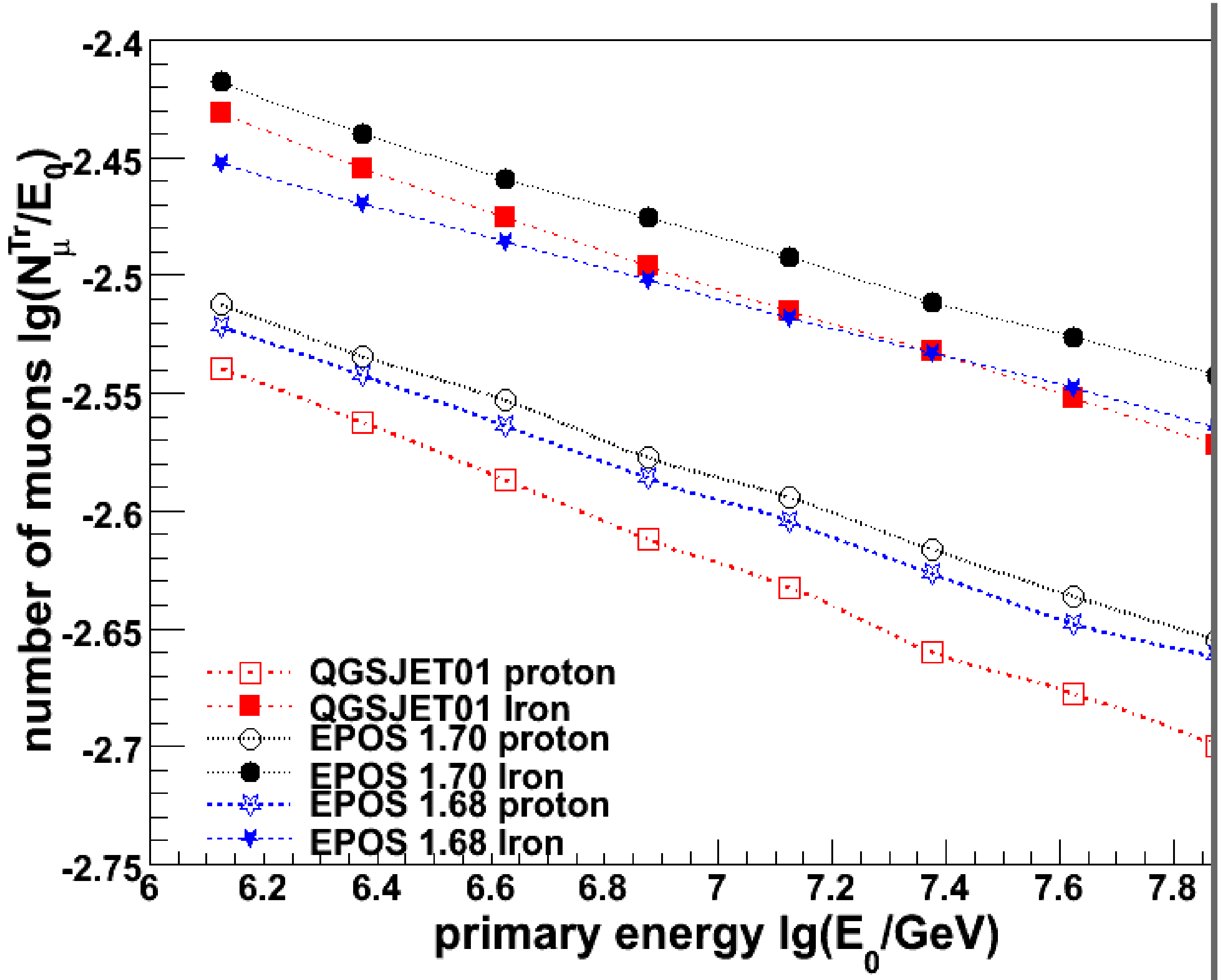
no big difference due to remnant excitation



Results for EAS : N_μ

small difference EPOS 1.68 / 1.70 (larger for Fe)

(compensated effect pi/p ? (Hajo's talk)



Different slope for muon production between QGSJET and EPOS → antibaryon production rate.

Summary

EPOS = hadronic interaction model constructed to understand accelerator data AND used for CR

- Wide range of accelerator data used to constrain parameters and properties of the model (strange baryons ...)
  - influence on cosmic ray physic

    (more muons → lighter primary)
- Air shower data can constrain the model too
  - influence on hadronic physic

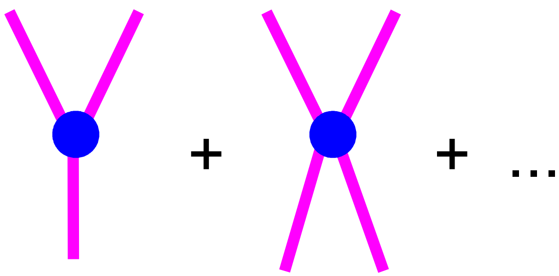
    (hadron energy → forward hadron production)

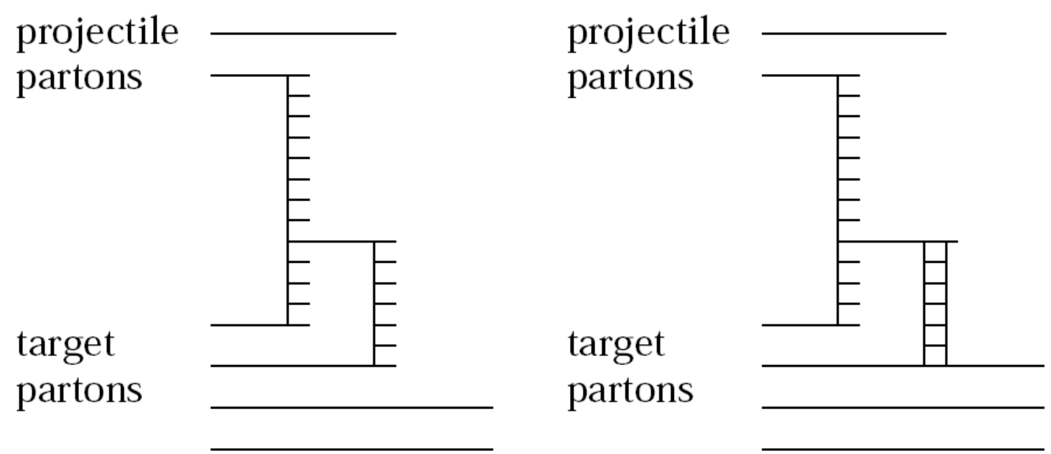
Good link between the 2 communities !

Splitting

A ladder parton may interact with a second target parton (splitting)

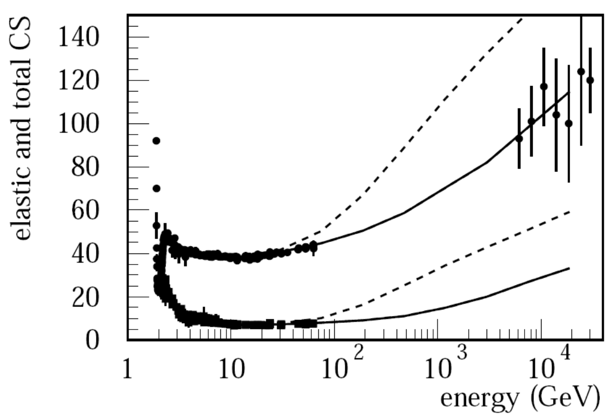
➔ enhanced diagrams





collective hadronization (like string fusion)

Screening (reduces small x partons)



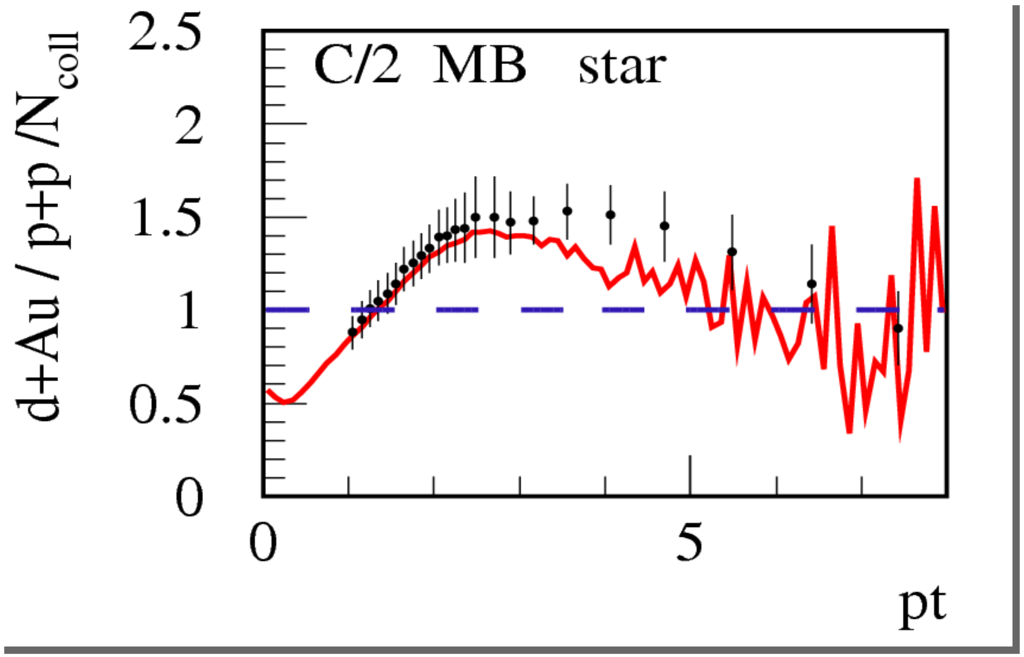
Effect effectively treated : modified parameters in terms of the number of partons available for making additional legs.

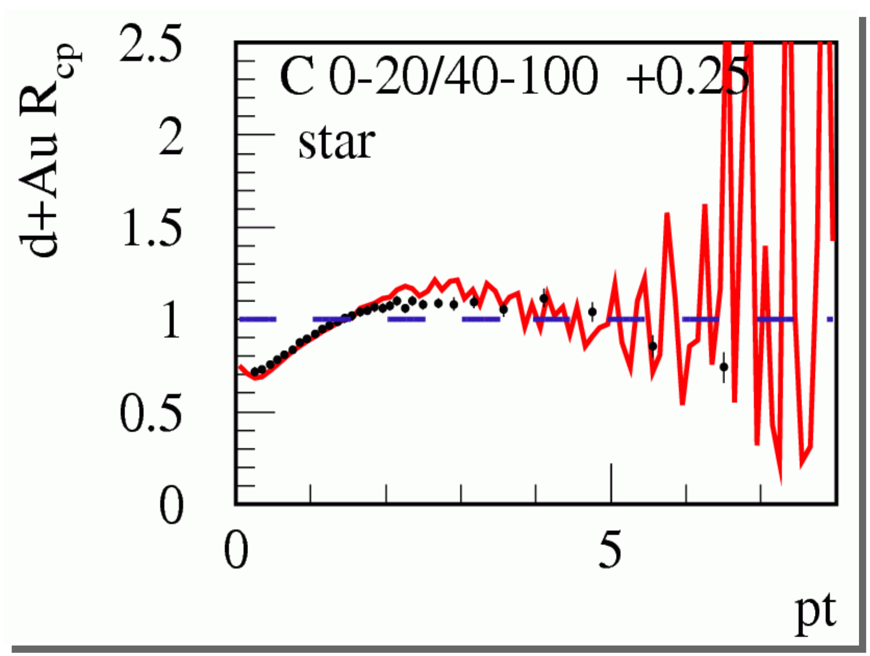
Safe extrapolation : high mass = high energy

Splitting (2)

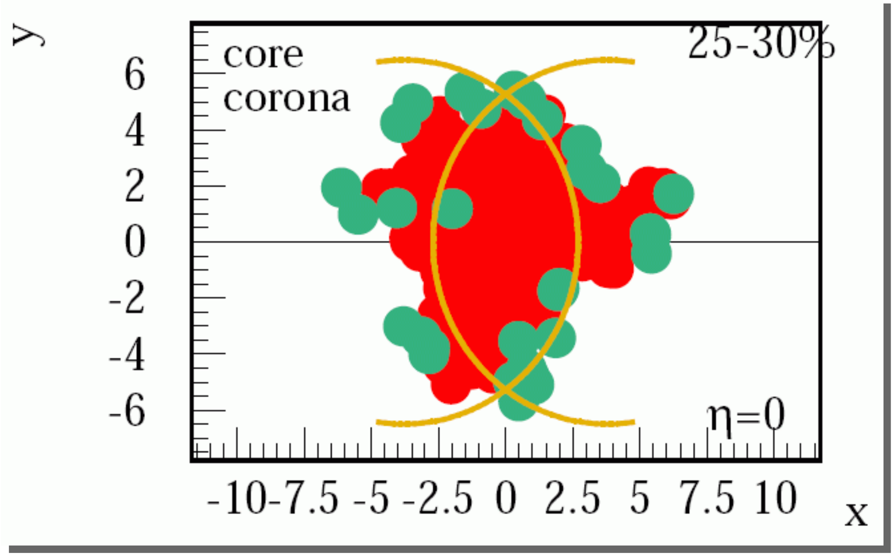
Main effects of splitting :

- more hard collisions
- Cronin effect (larger pt at fragmentation)
- more aBaryon/Baryon pair (larger diquark probability)



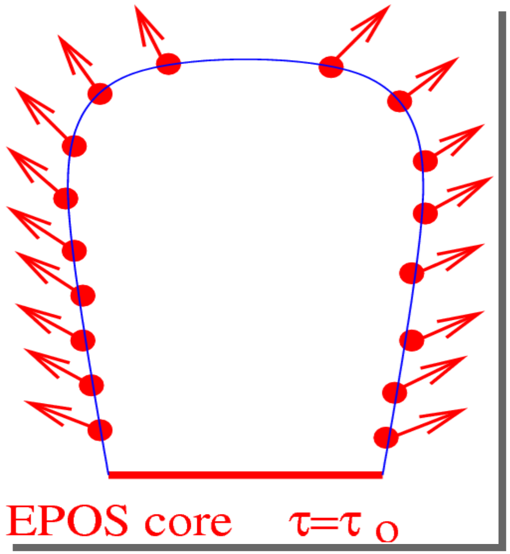


Fusion



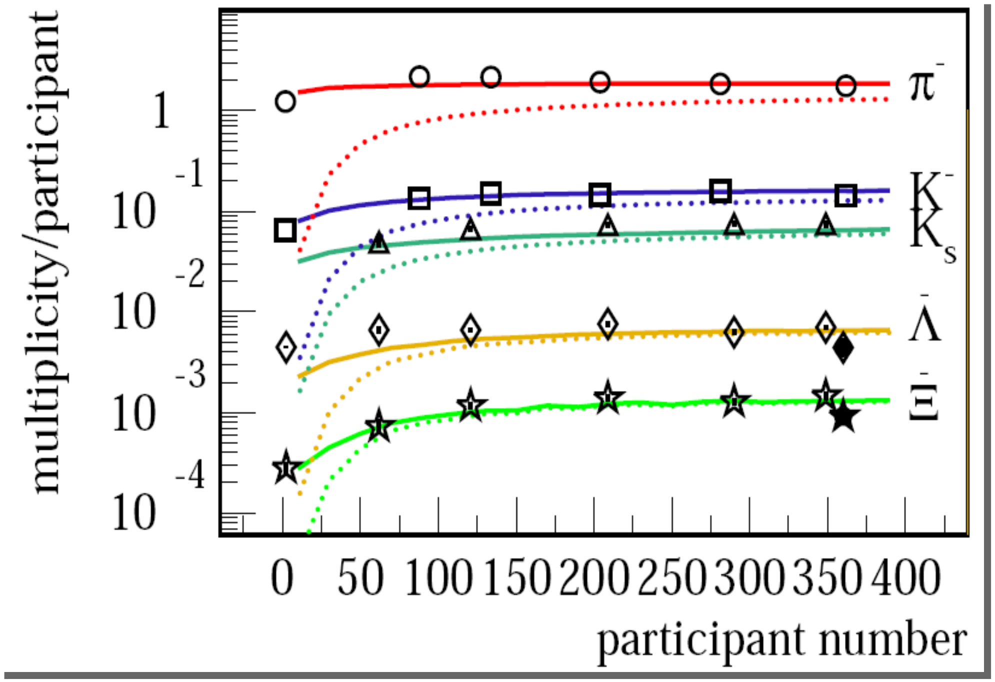
- EPOS as usual
- parton ladder
- string segments
- separation core/corona at a given $\tau = \tau_0$

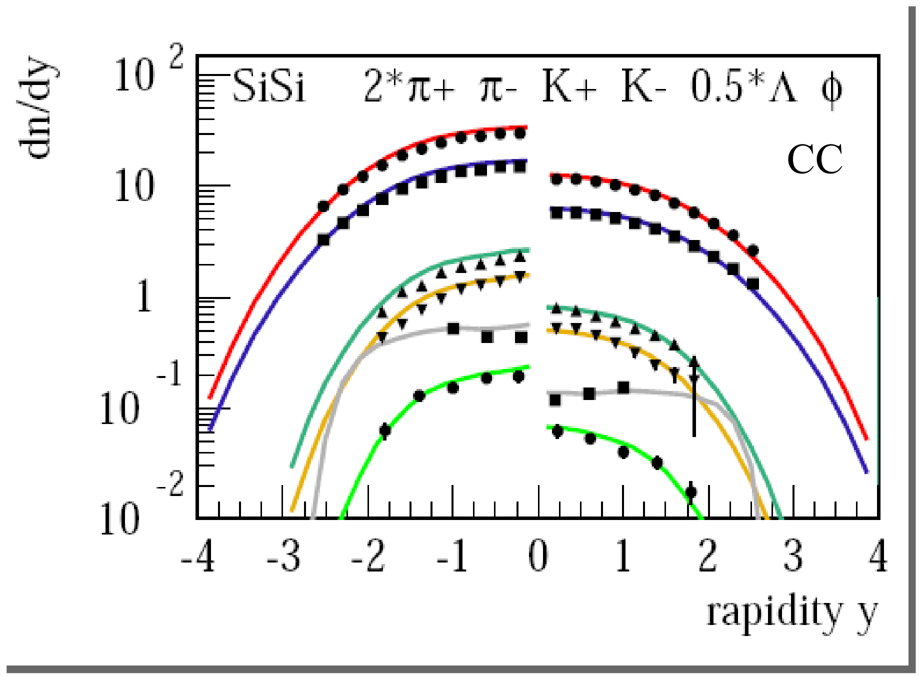
Concerning the high-density core:
We need to link the EPOS core at $\tau = \tau_0$ to the freeze-out hypersurface (having in mind a collective hydro-like expansion)



Decay of Clusters

- Effective invariant mass M decays according to covariant microcanonical phase space.
- The particles adopt the flow according to the corresponding position on the FO hypersurface. (now parametrized, soon real hydro. calculation)

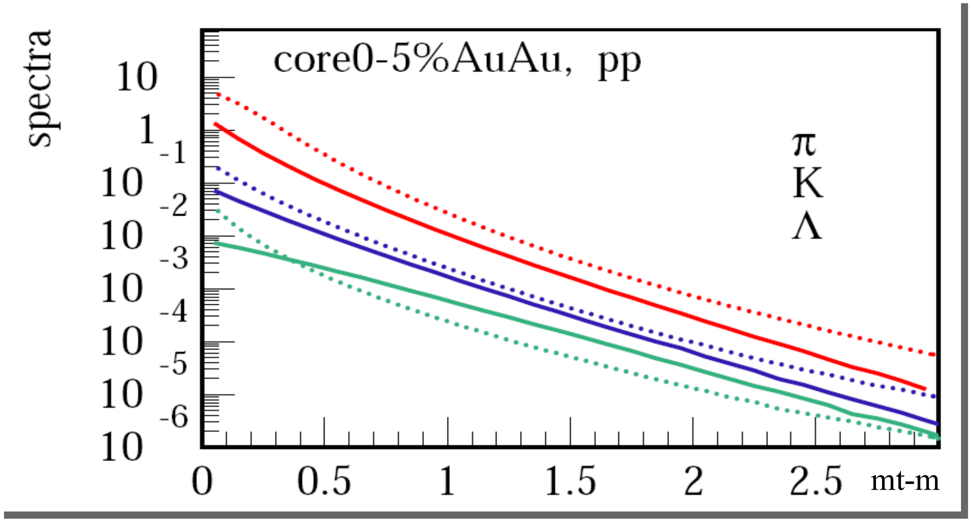


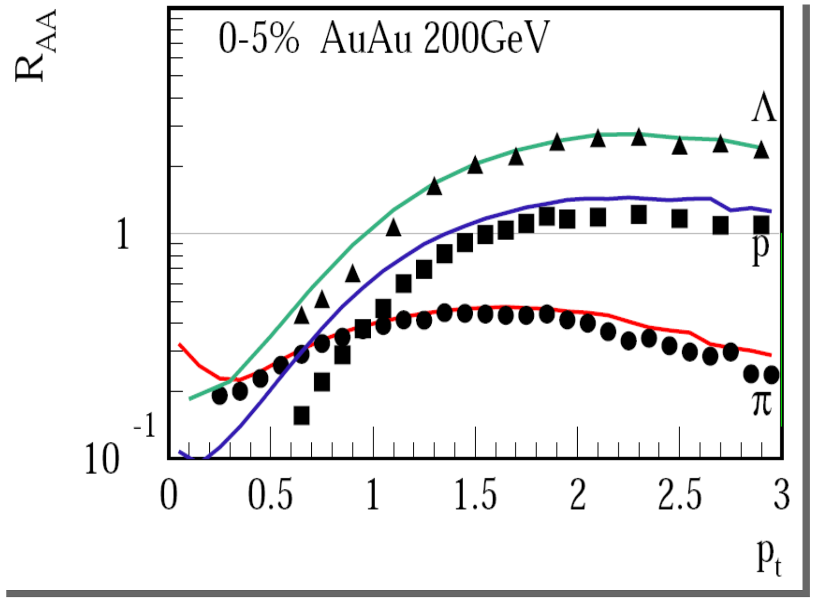


Fusion effect on Pt

R_AA easy to understand: compare core and pp:

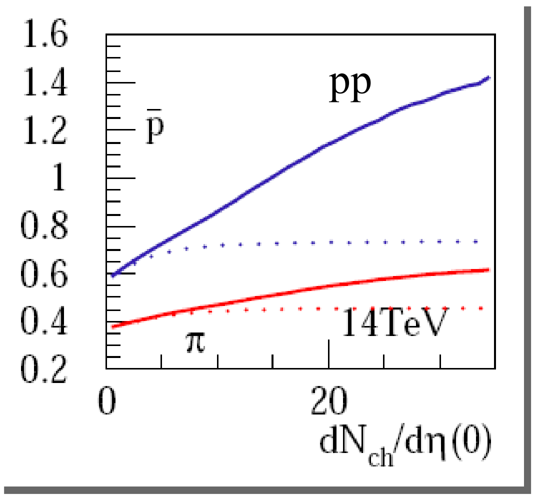
- flow affects shape of heavy particles





High densities reached in pp:

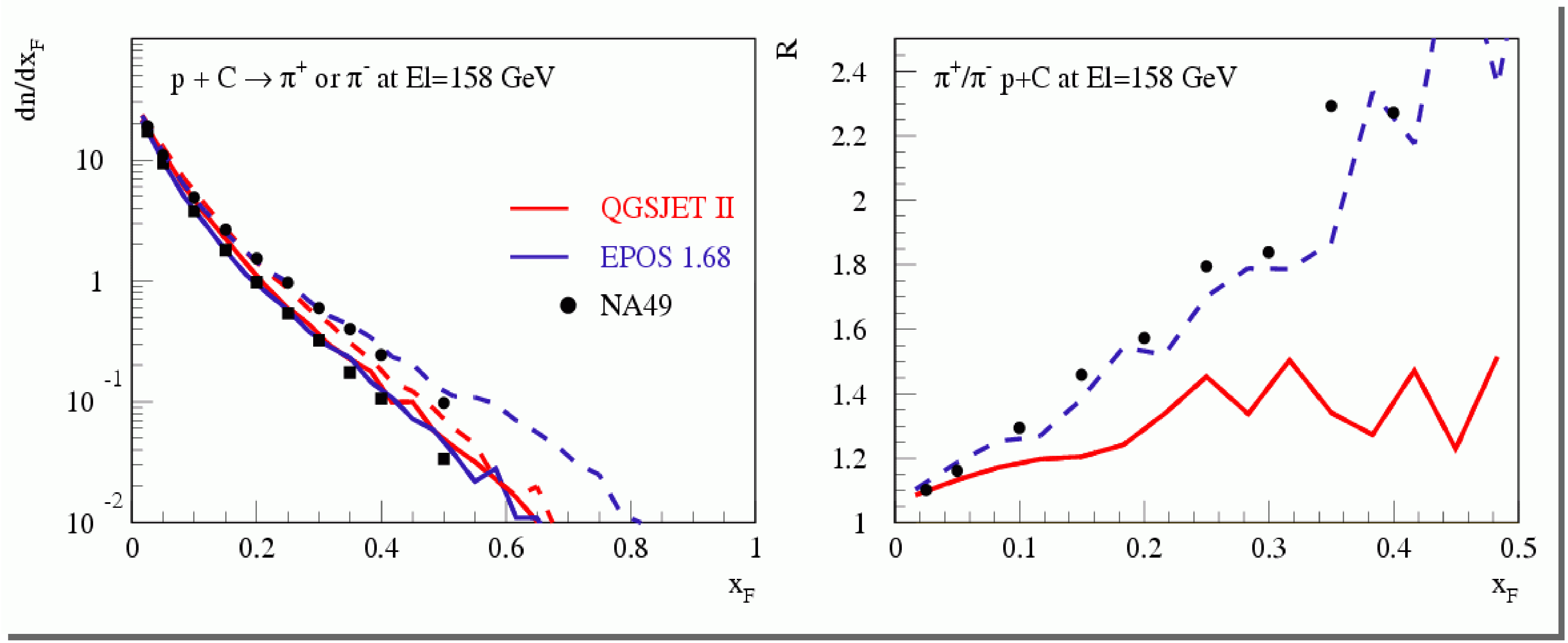
- reduced multiplicity
- increased Pt
  - But only at mid-rapidity



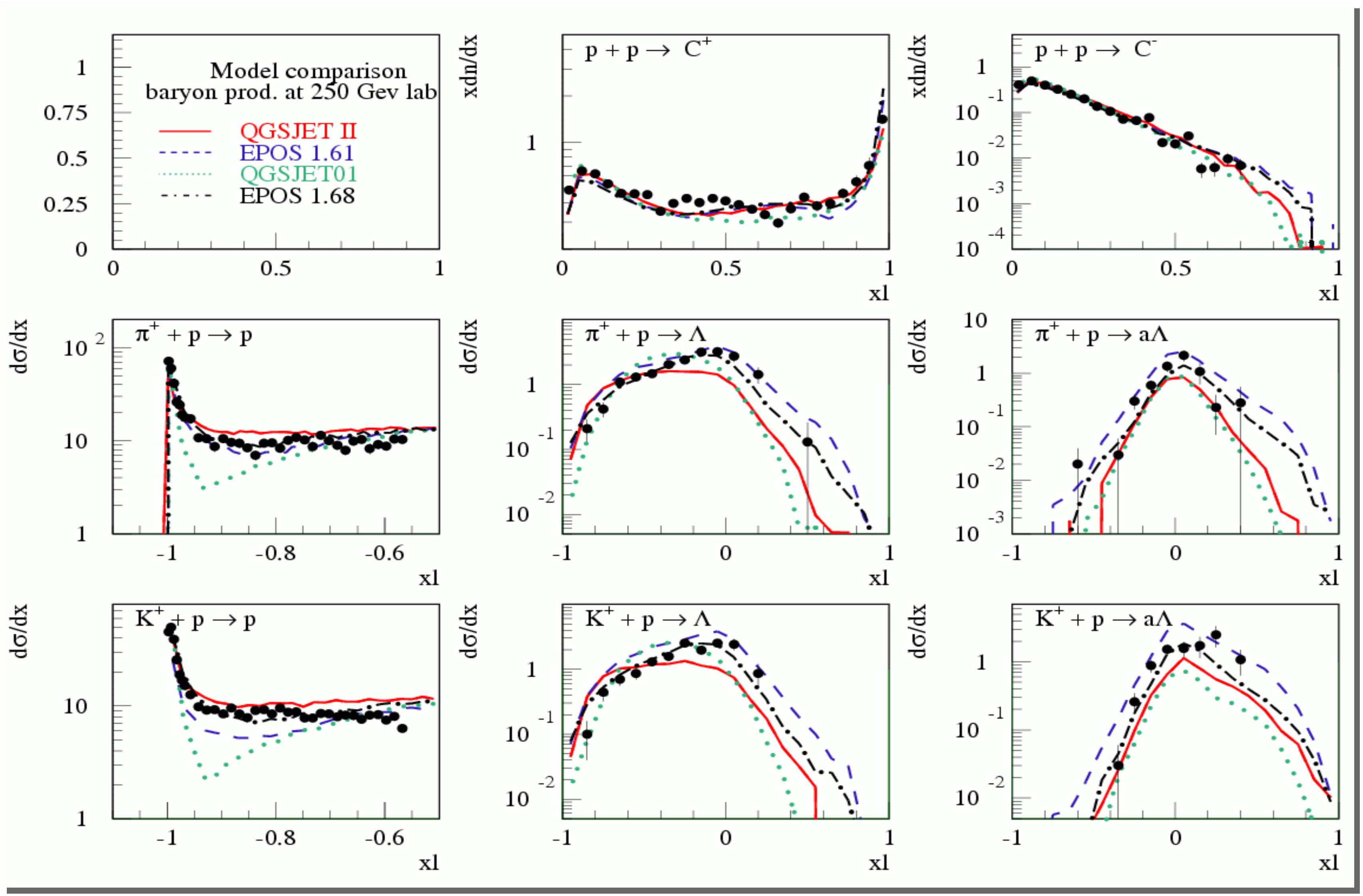
Pop-Corn Effect

Positive pions have harder xF distribution than negative pions and baryons are softer than expected (stronger for Kaons, stronger in pA than pp).

- inversion of the leading baryon with the following mesons
- confirmed by muon charged ratio in CR.



Compared Results (2)



Compared Results (3)