Current concepts in theory and modelling of high energy hadronic interactions

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in collaboration with

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Outline

- Key observations, large differences in the predictions from the different models
- The physics of
  - SIBYLL 2
  - QGSJET II
  - EPOS 1.99

Key observations

large differences in the predictions from the different models

Missing muons

Situation in 2006:

- □ non of the existent models (QGSJET, SIBYLL, NEXUS) can consistently describe all cosmic ray airshower data,

in particular:

- □ data show considerably more muon production compared to simulations.

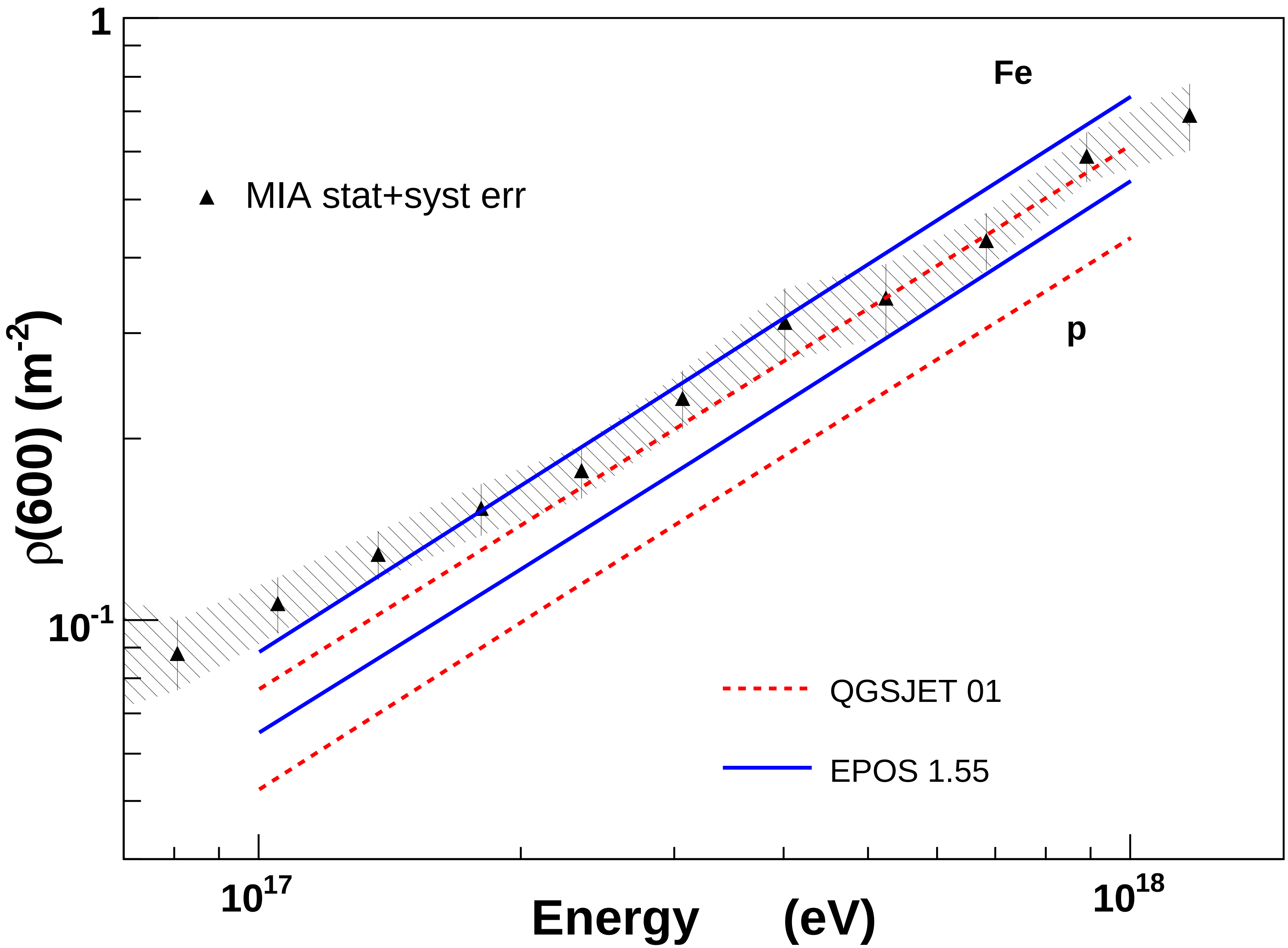
Not obvious how to fix this problem without creating others

Starting to use EPOS as interaction model, is was found :

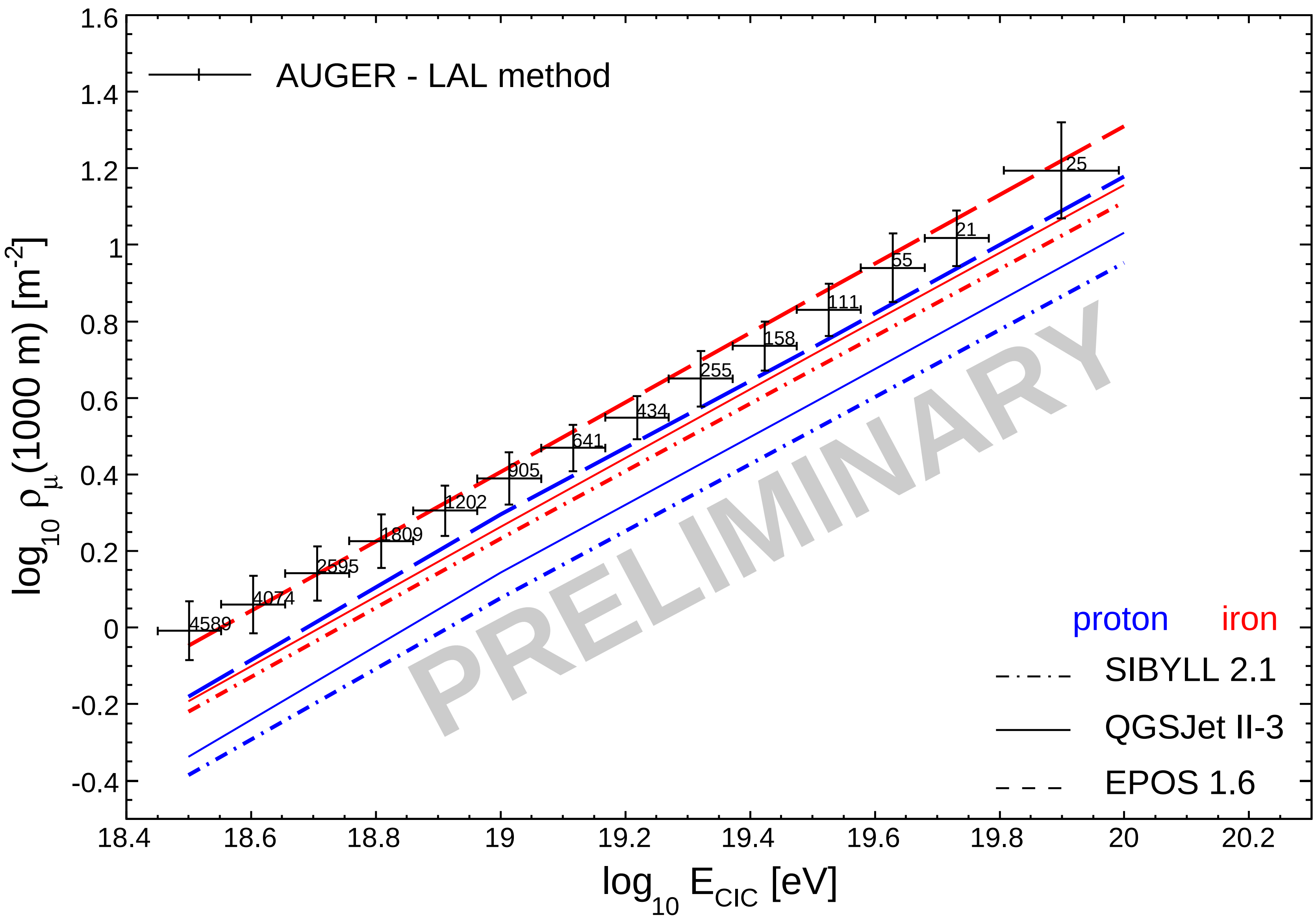
- □ one gets significantly more muons,
- □ without changing observables like X_{max} too much

MUON PRODUCTION IN EXTENDED AIR SHOWER SIMULATIONS. Tanguy Pierog, Klaus Werner. Phys. Rev. Lett. 101, 171101 (2008).

Muon density MIA

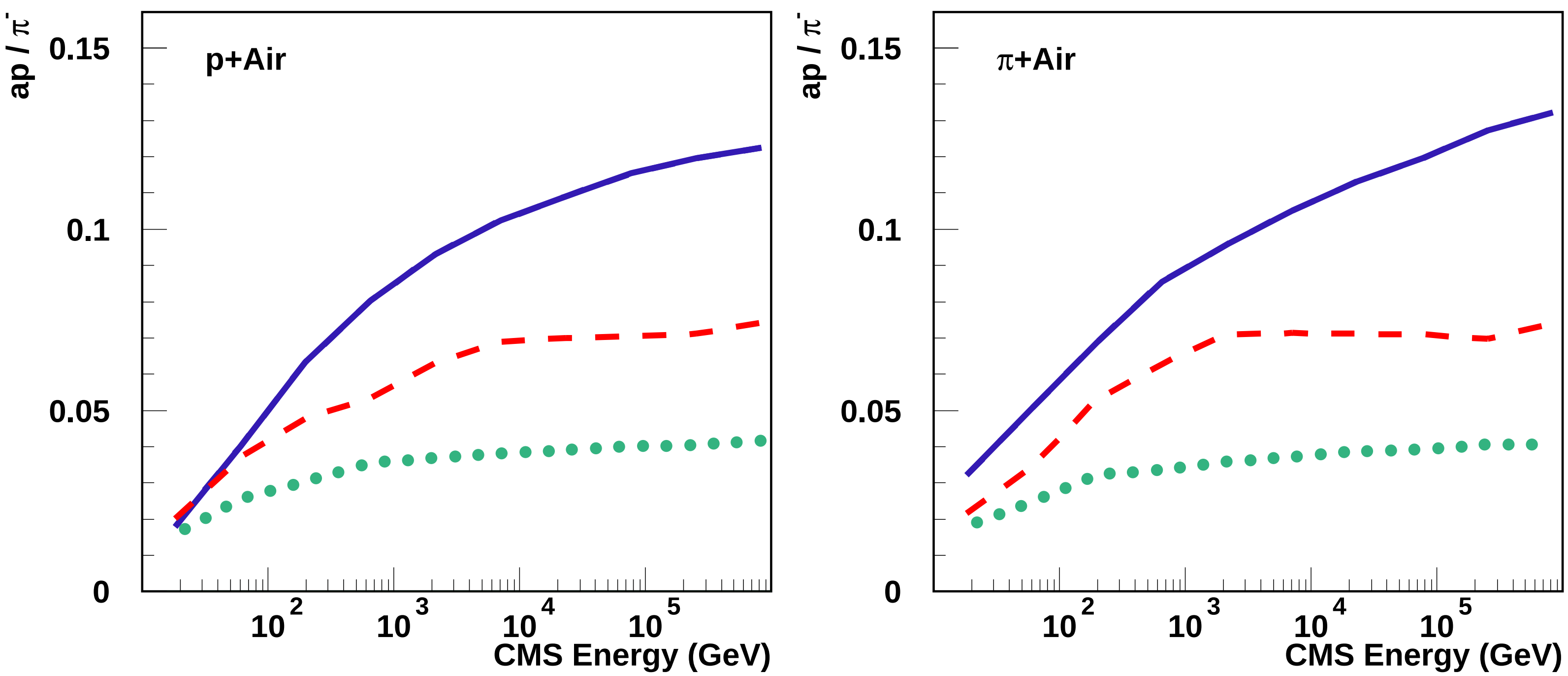


Muon density AUGER



Why more muons in EPOS ?

... because EPOS produces more baryons



EPOS 1.99

QGSJET II

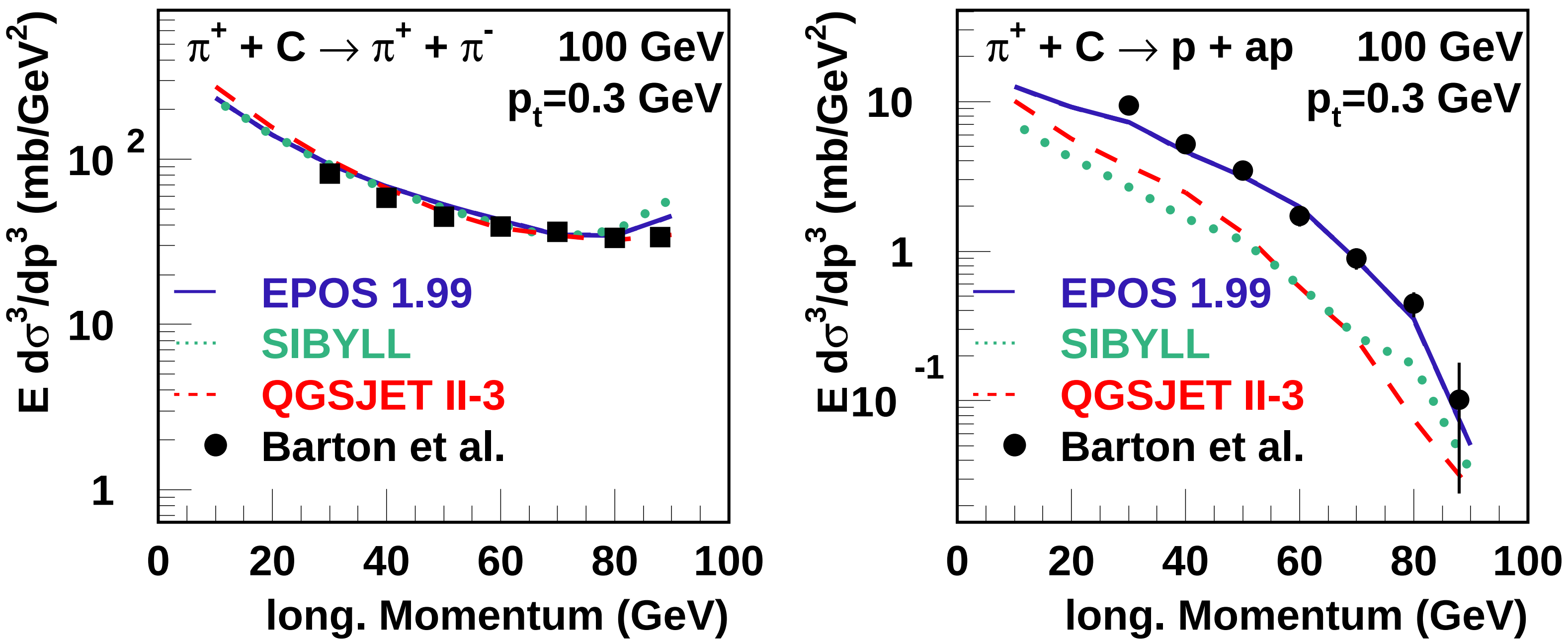
SIBYLL 2.1

Baryon $=$ no π^0 $\rightarrow$ no EM cascade

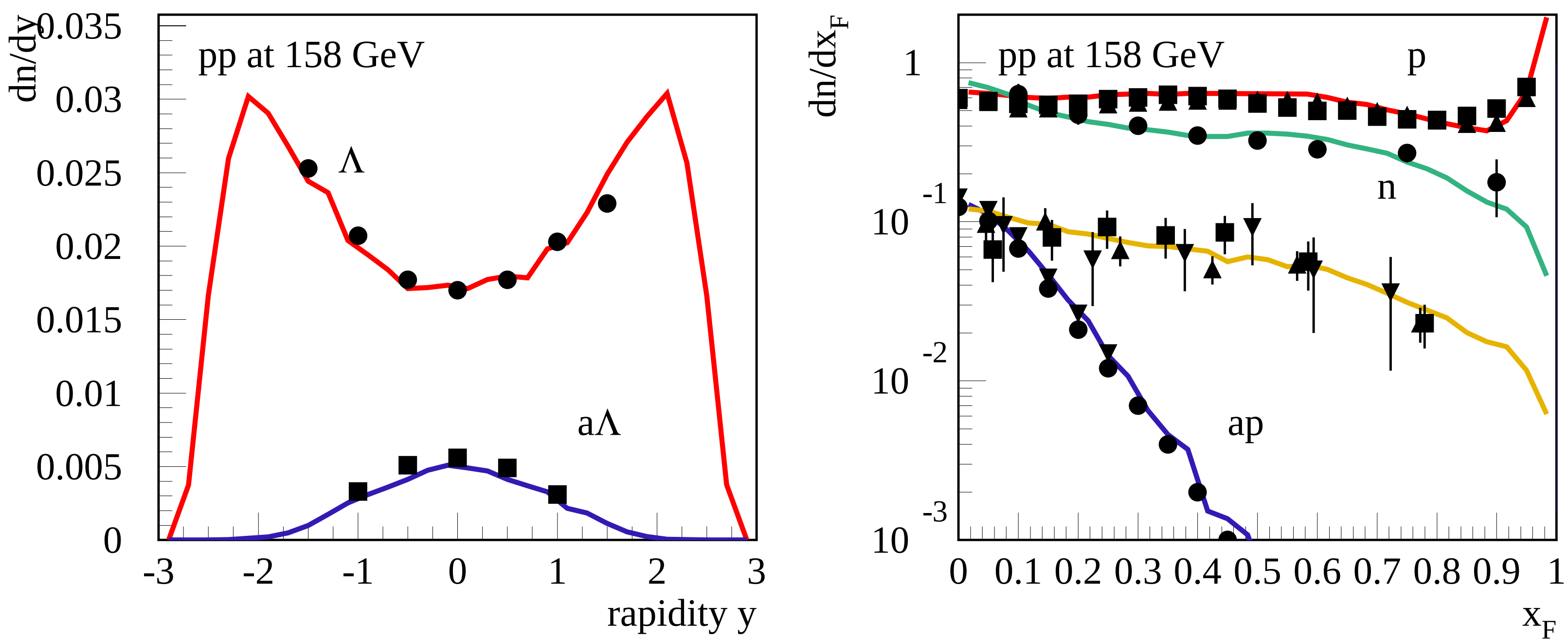
$\rightarrow$ chance to make muons

The different models compared to accelerator data:

- similar concerning pions
- big differences concerning baryons



EPOS has been designed (and optimized)
to understand ALL types of hadrons
→ careful studies of baryon production *



EPOS 1.99

SPS data

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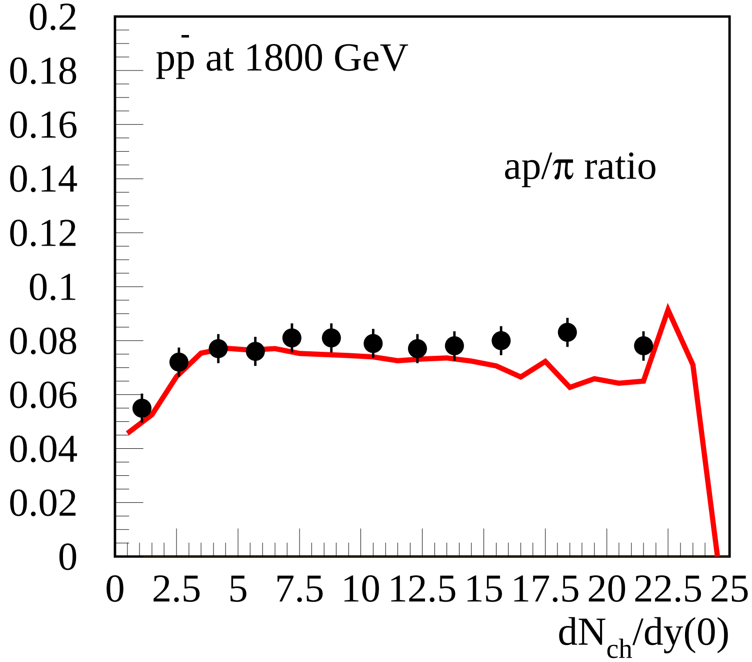
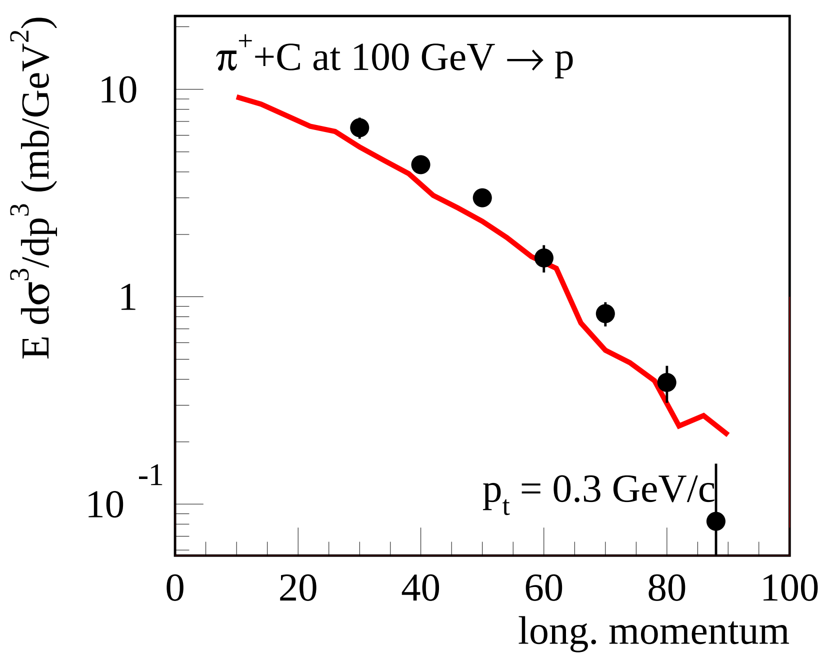
* without thinking about CR applications

enormous amount of pp ($p\bar{p}$) data considered, at SPS, ISR, RHIC, TEVATRON

also πp, pA and πA



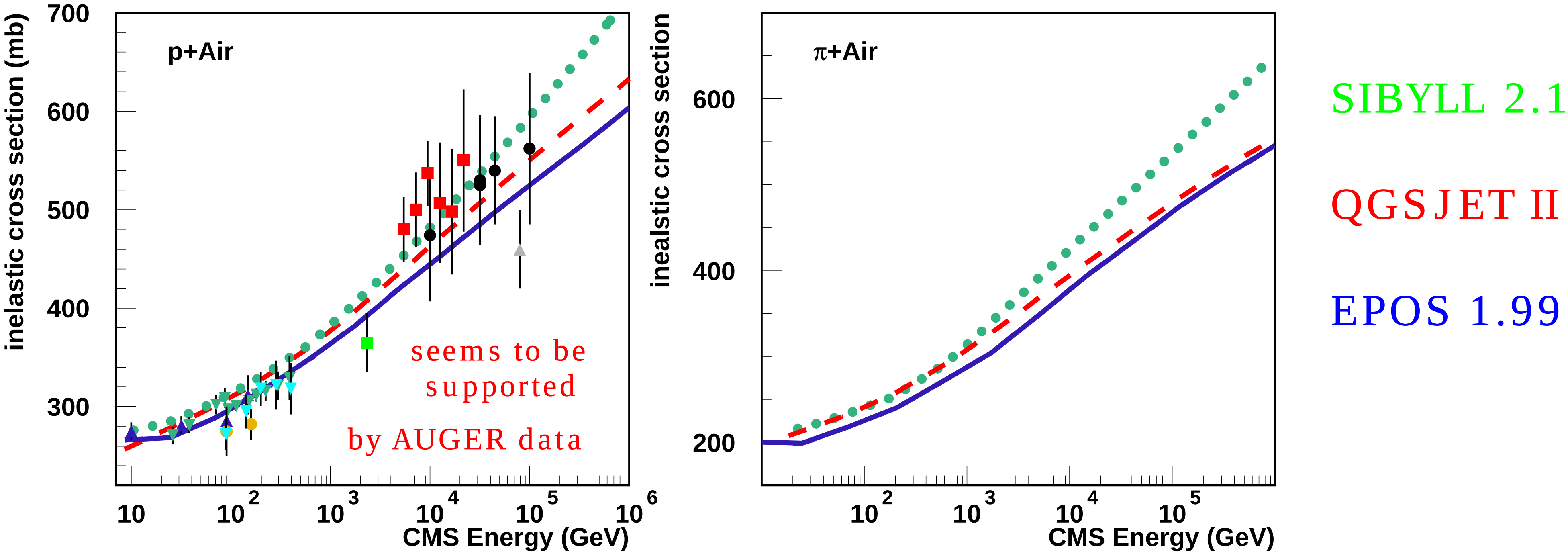


EPOS 1.99

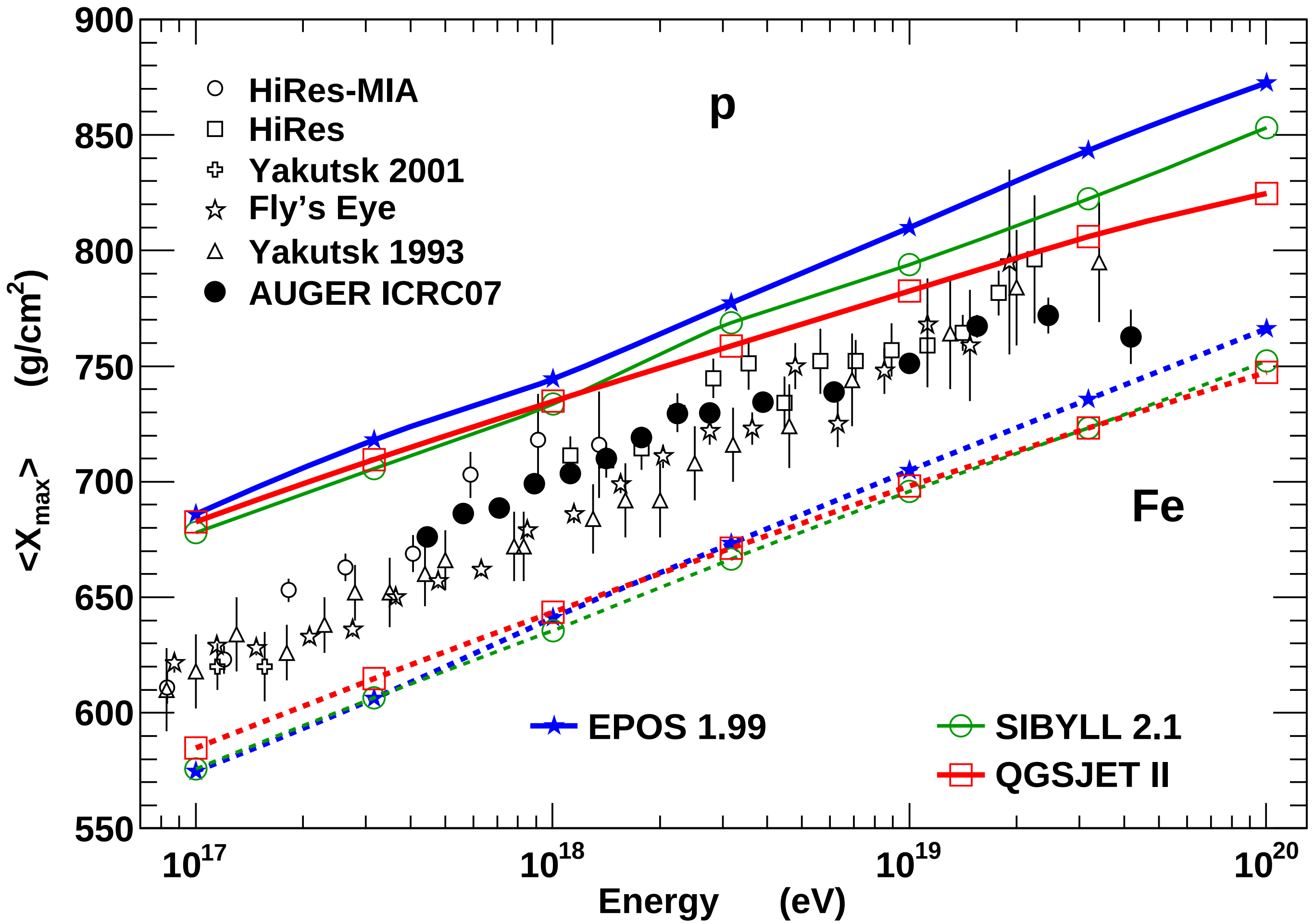
More muons require more electrons

Increase muon number (without changing the electrons)
$\rightarrow$ contradiction with KASCADE (N_{muons}- N_{electron} correlation)

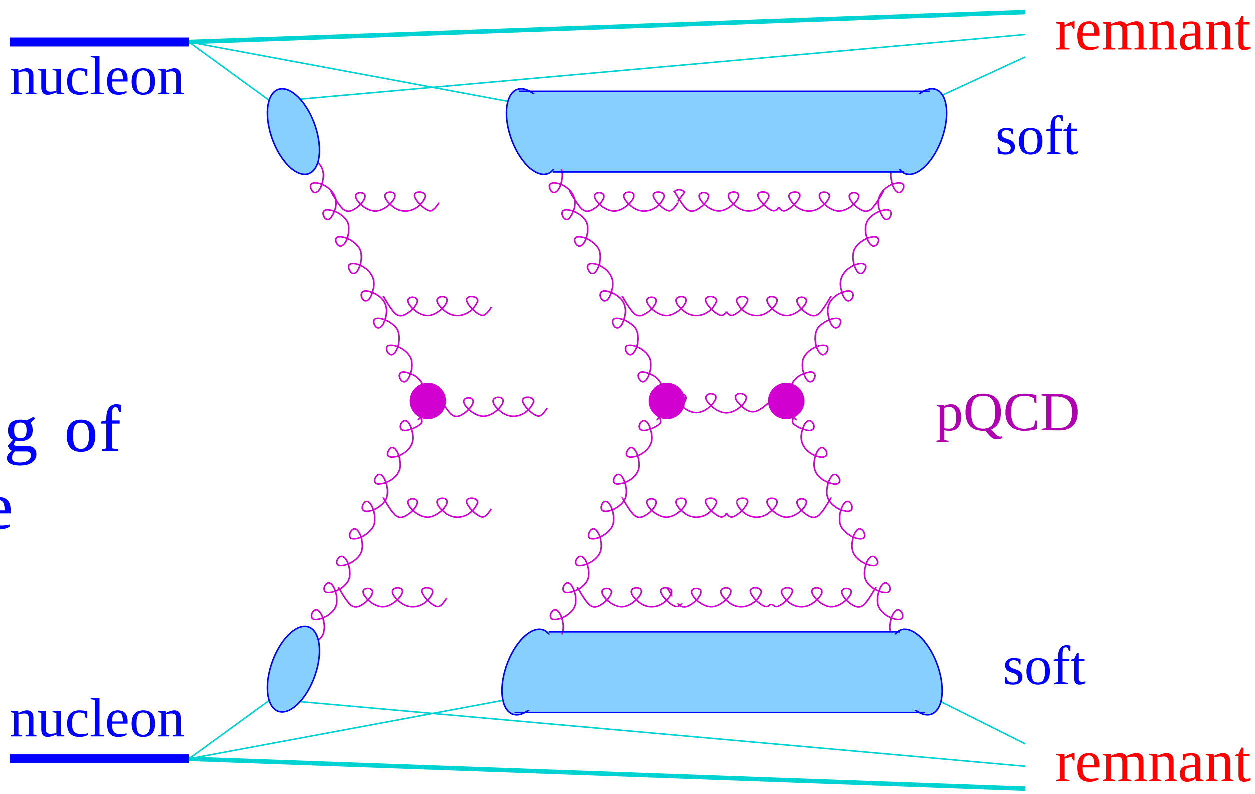
Solution: non-linear effects (considered for particle production) also for cross section calculations



Consequences for Xmax



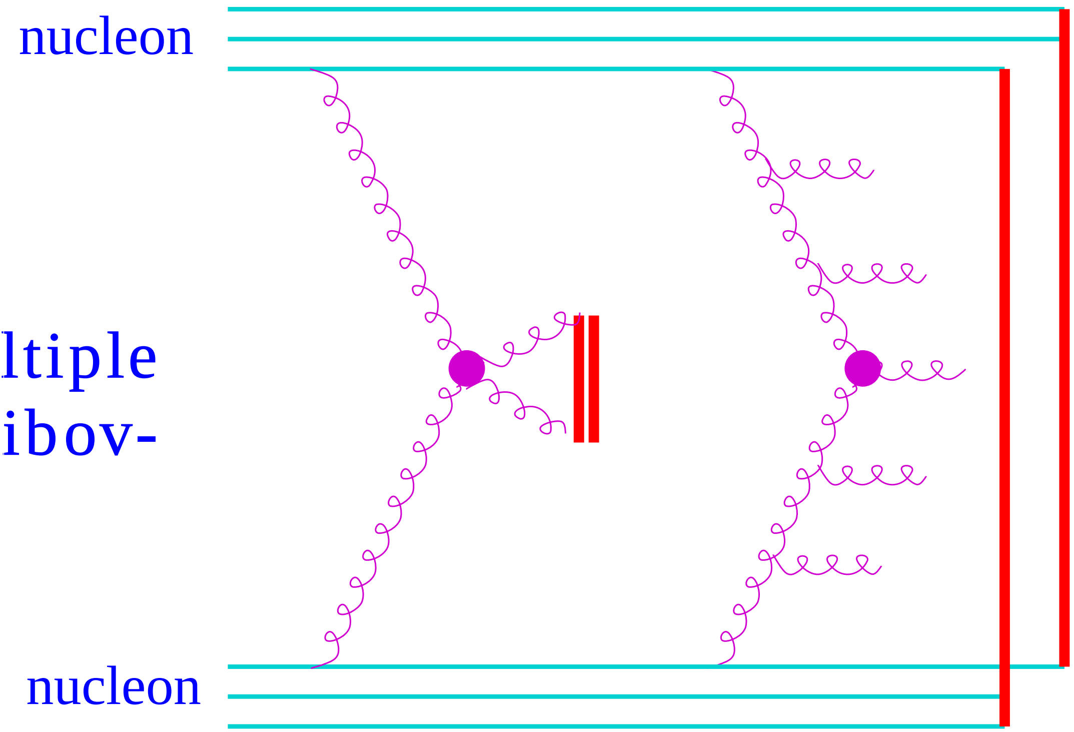
The physics of the models



EPOS, QGSJET

Multiple scattering of
Gribov-Regge type

- ☐ Semihard “Pomerons” : soft - pQCD - soft
- ☐ Remnants
- ☐ Partonic final state => strings



SIBYLL

as well multiple scattering of Gribov-Regge type

☐ no Remnants

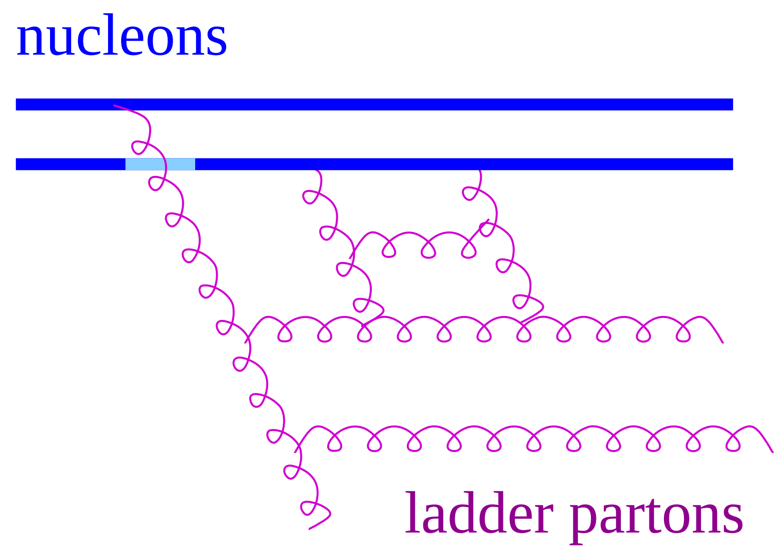
☐ “main” scattering => qq-q strings

☐ further scatterings => strings between gluon pairs

Nonlinear effects in EPOS

To include rescatterings of partons,
fit parton-ladder[1] as $\alpha\,(x^{+})^{\beta}(x^{-})^{\beta}$ [2], modify as

$$\alpha\,(x^{+})^{\beta}(x^{-})^{\beta+\varepsilon},$$



Effect can be summarized by a simple positive exponent ε

(dep on $\log s$ and N_{particip}, incorporating saturation)

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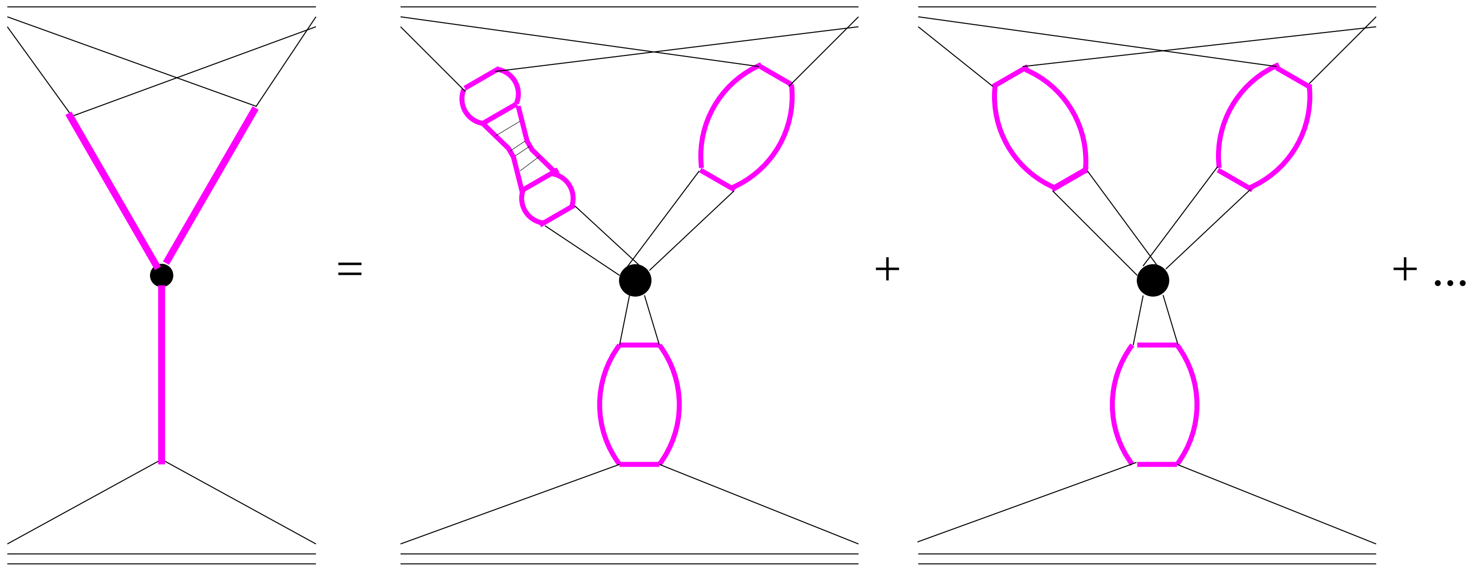
[1] imaginary part of the corresponding amplitude in $b-$space
[2] x^{+}, x^{-}: light cone momentum fractions of the first ladder partons

Nonlinear effects in QGSJET

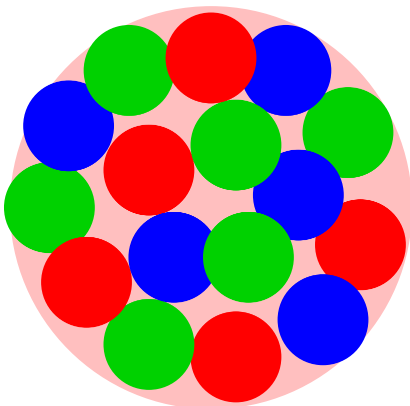
Pomeron-Pomeron coupling



- ☐ Summing all orders
- ☐ No energy conservation
- ☐ (in EPOS full energy conservation, but effective treatment of nonlinear effects)

Nonlinear effects in SIBYLL

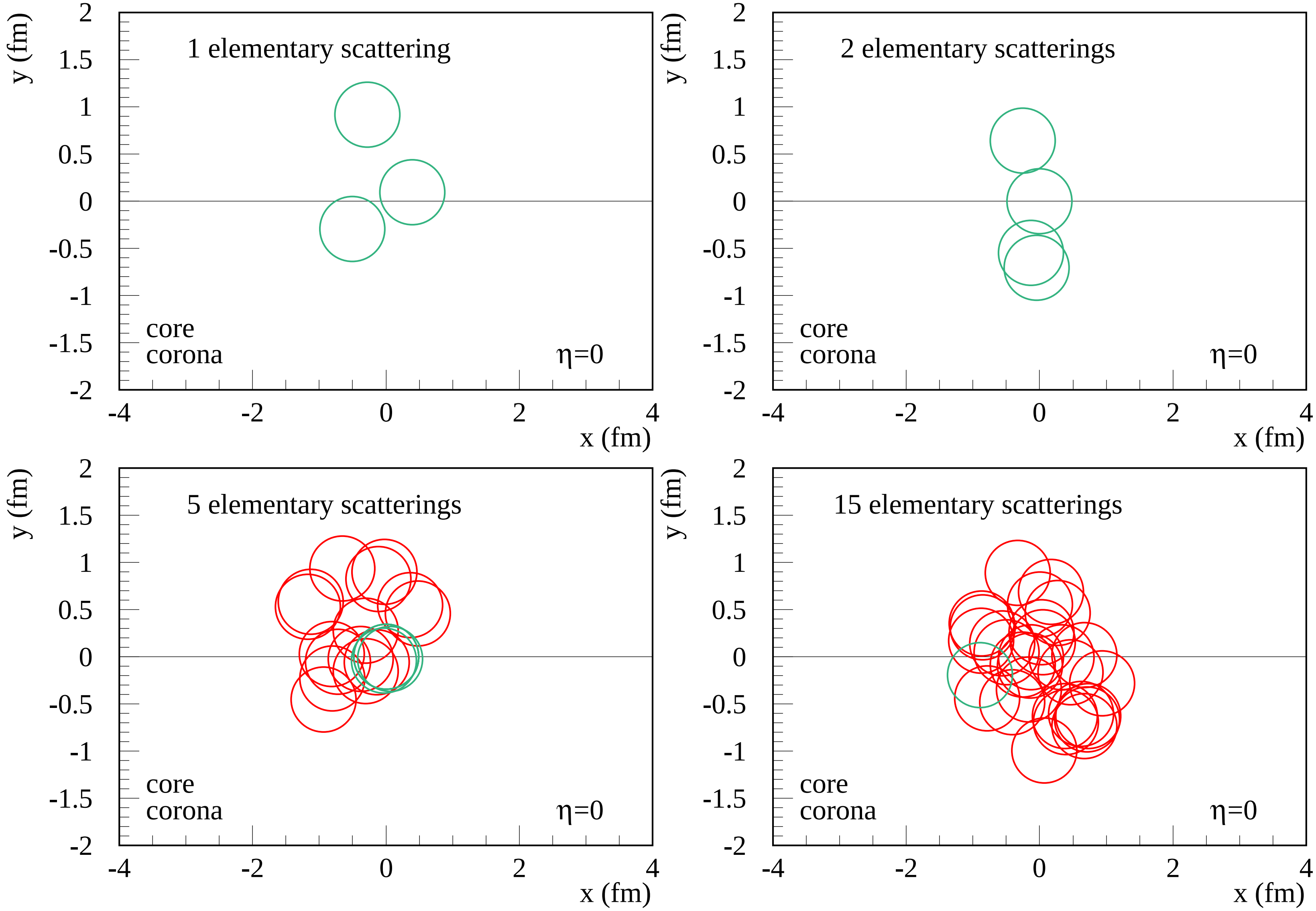
Saturation scale obtained from



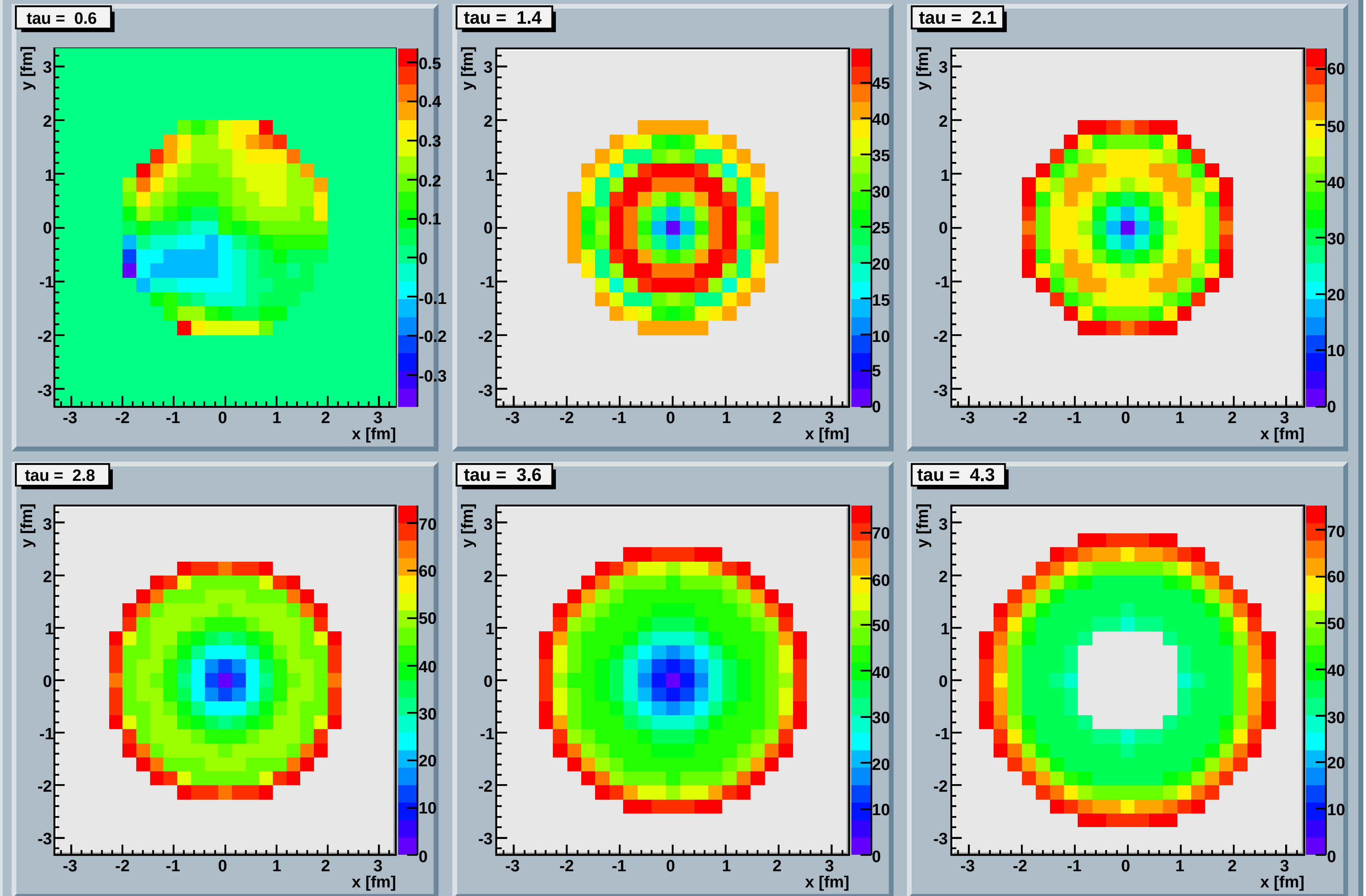
$$\frac{\alpha_s N_c}{Q^2} \times \frac{1}{N_c^2 - 1} \frac{xG}{\pi R^2} = 1$$

□ Used as cutoff

Collective effects in EPOS in pp: high string densities possible => hydro



rad velocity [% of c] (eta_s=0) b=0fm 15coll



Summary

- Interaction models:
  - SIBYLL 2
  - QGSJET II
  - EPOS 1.99
- Theoretical concepts similar (multiple scattering of Gribov-Regge type, strings), but the practical implementation quite different
- Large differences in the predictions from the different models (=> muons)