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Multiple Scattering & Collective Effects in pp Scattering at the LHC

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Multiple scattering and collective effects in pp scattering at the LHC

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Contents

1 Airshower simulation with EPOS

Missing muons

Situation in 2006:

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

in particular:

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

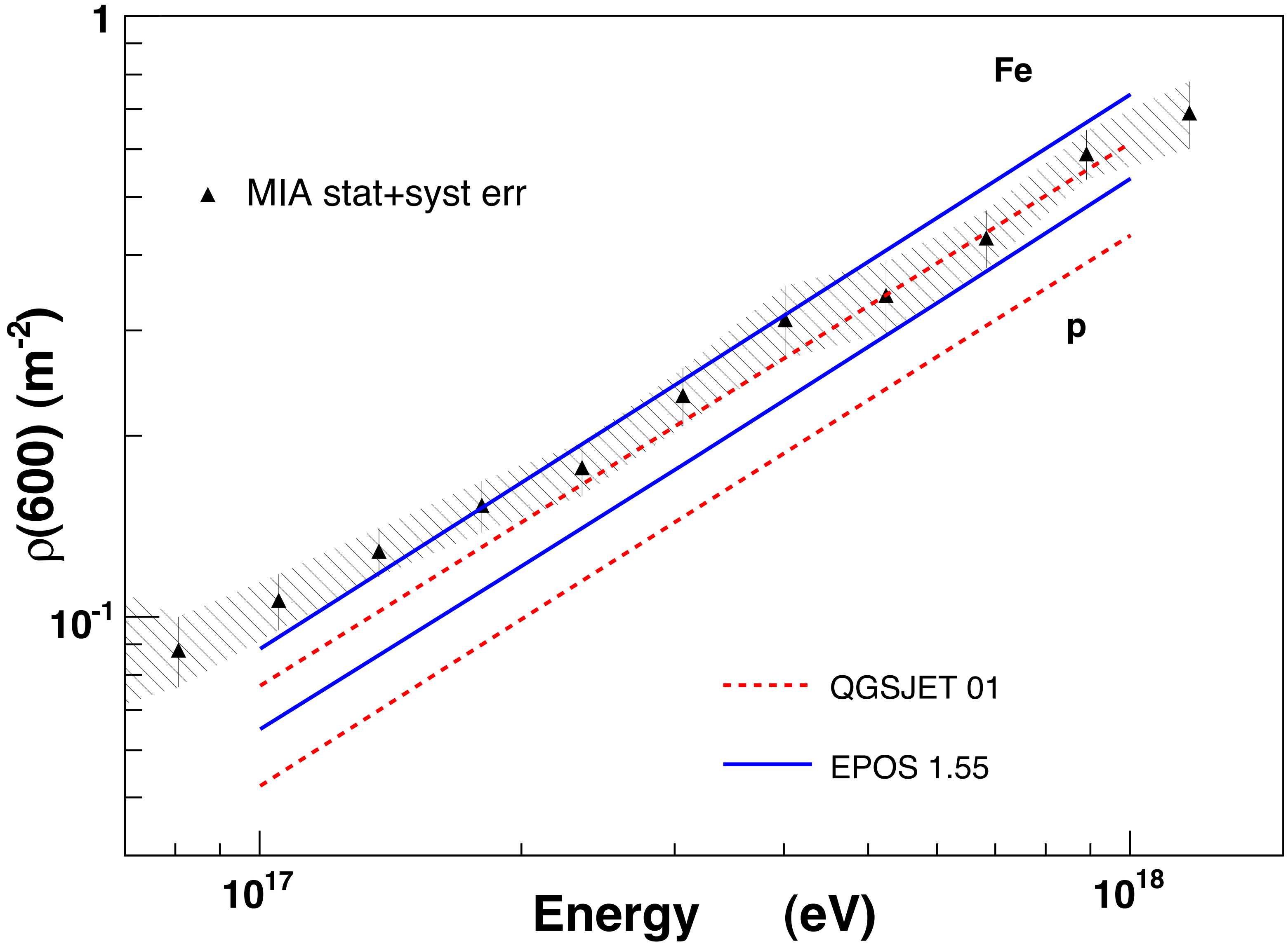
Not obvious how to fix this problem without creating others

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

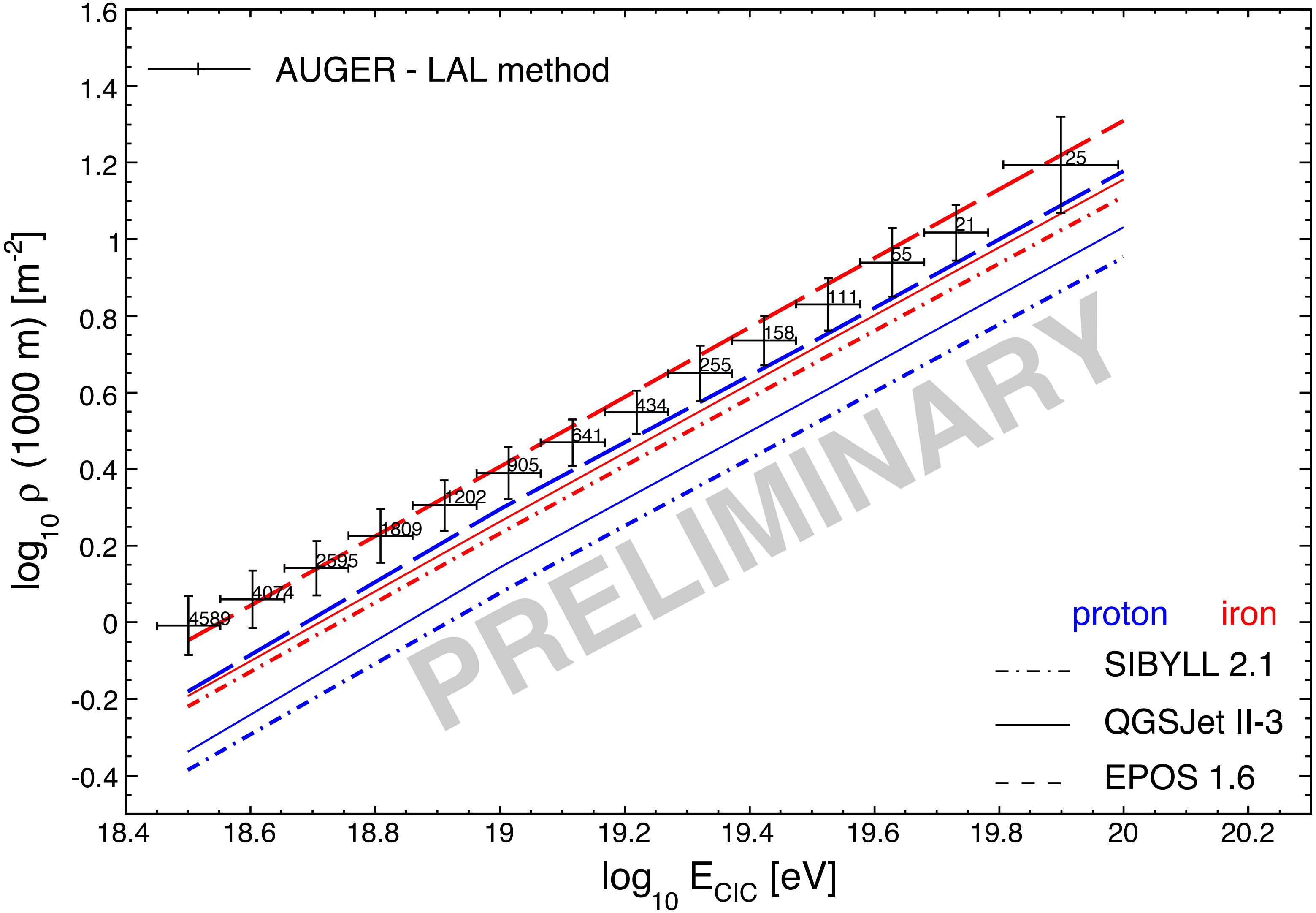
- □ one gets significantly more muons,
- □ without changing observables like $X_{\max}$ too much

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

Muon density MIA

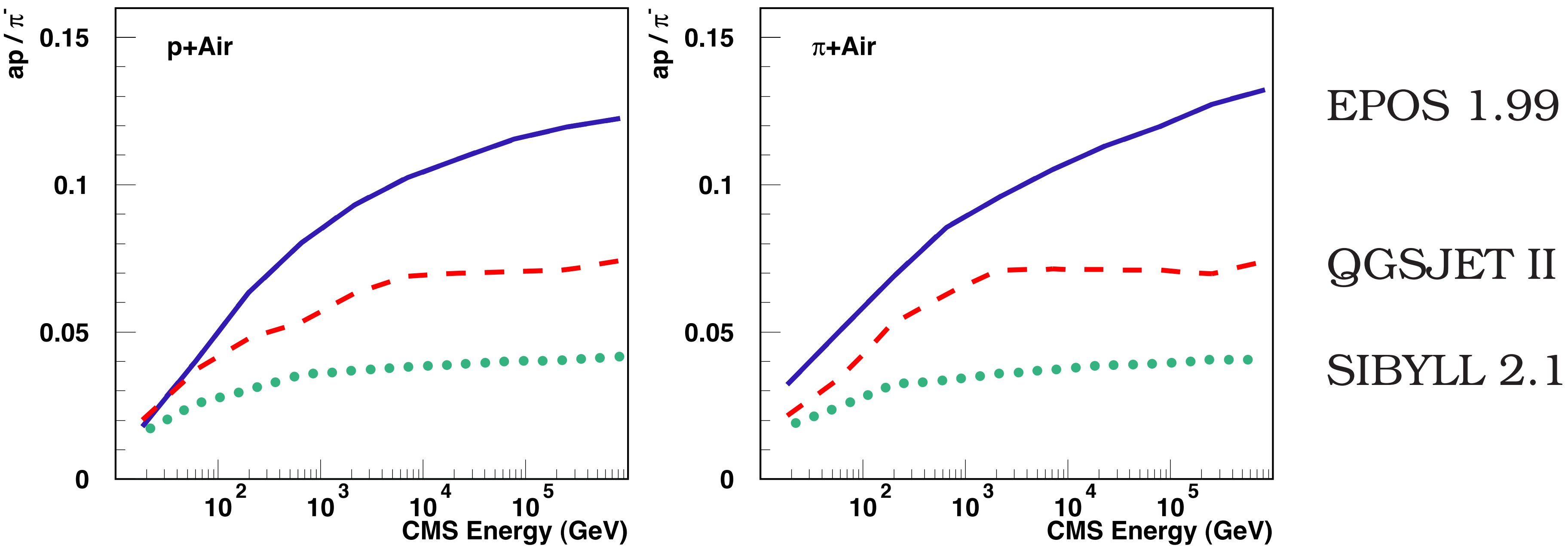


Muon density AUGER



Why more muons in EPOS ?

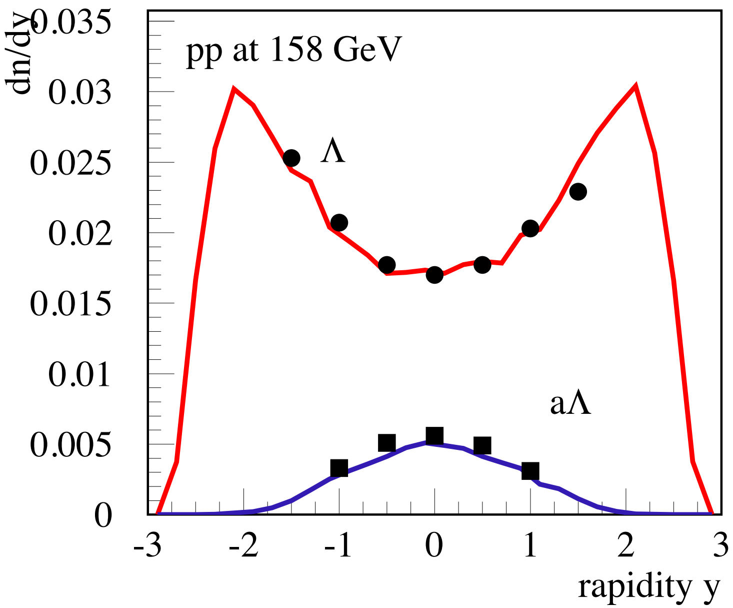
... because EPOS produces more baryons

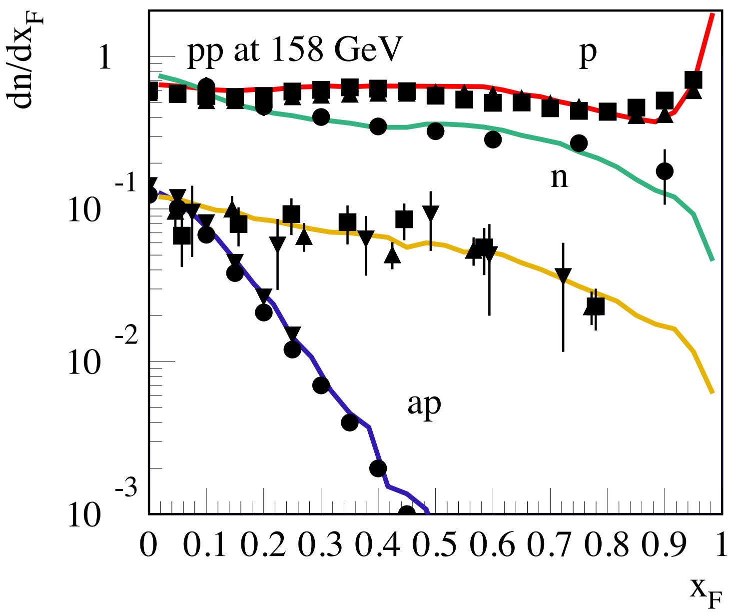


Baryon = no π^0 $\rightarrow$ no EM cascade

$\rightarrow$ chance to make muons

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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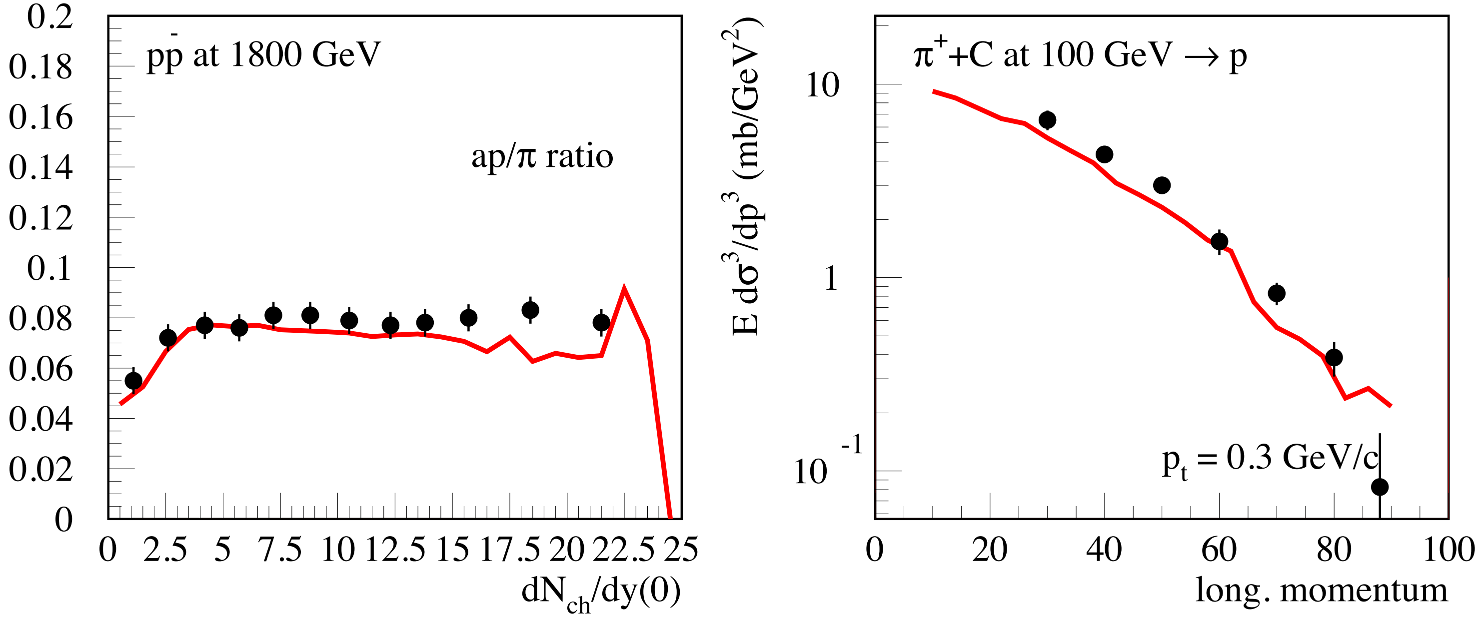
* without thinking about CR applications

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

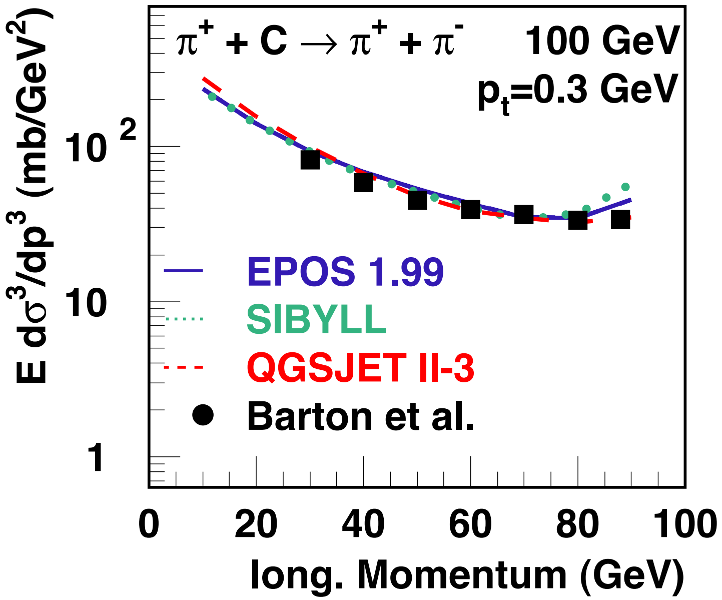
also πp, pA and πA

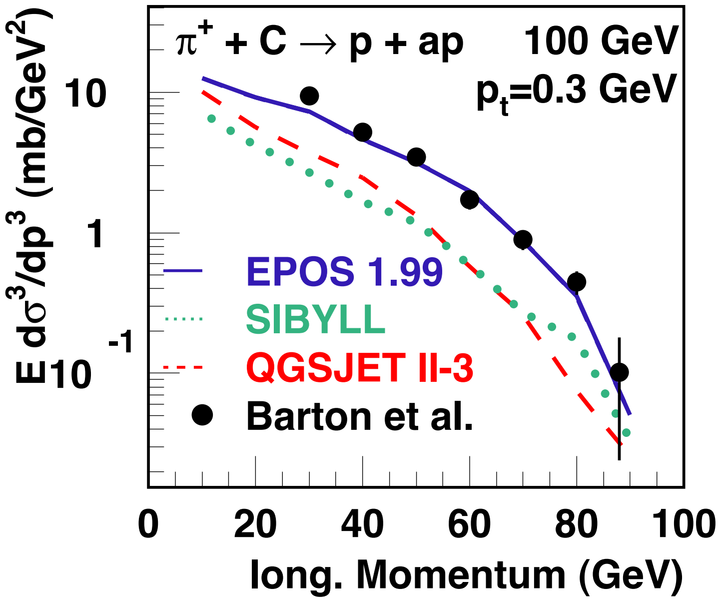


EPOS 1.99

EPOS compared to other models:

- similar concerning pions
- big differences concerning baryons

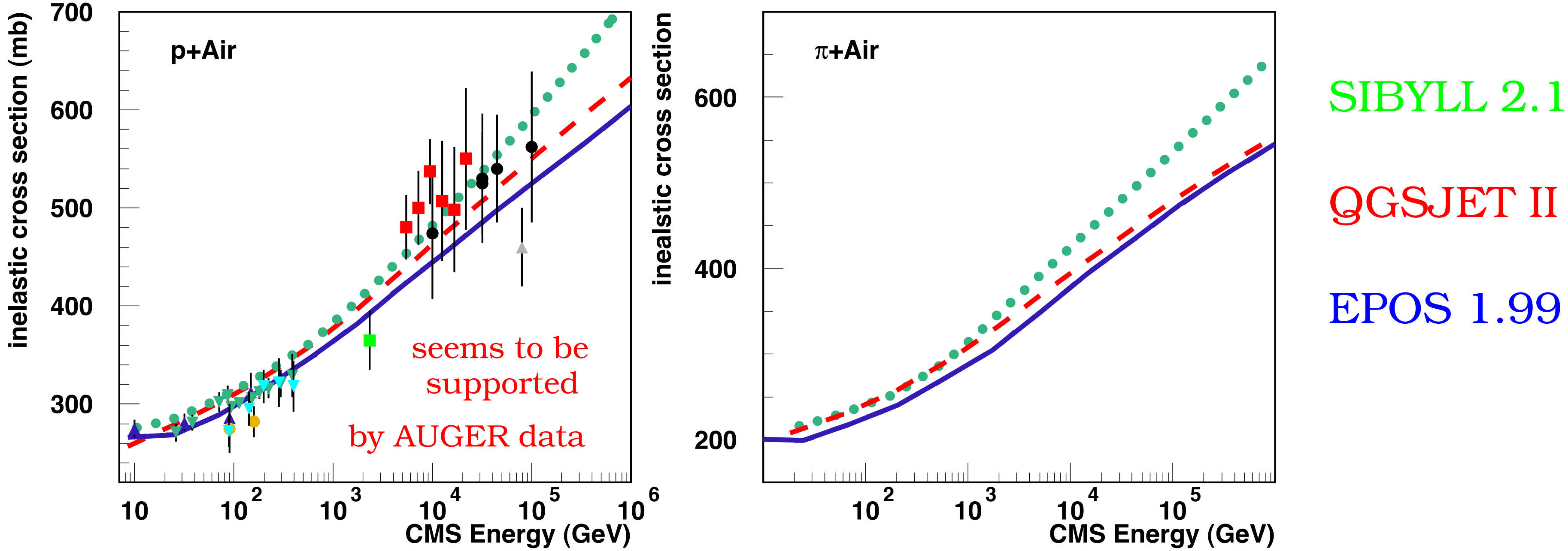




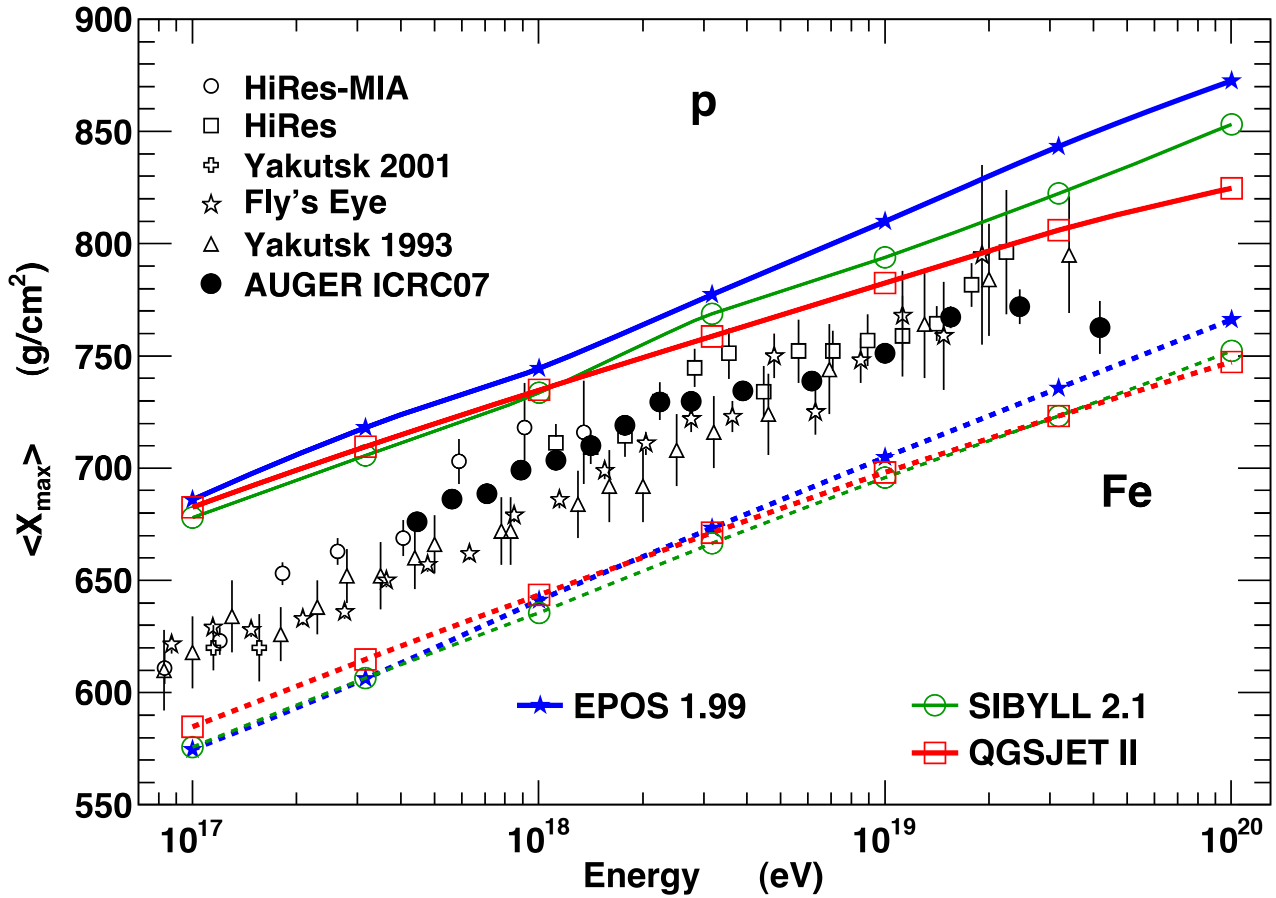
More muons require more electrons

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

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



Consequences for Xmax



2 Multiple Scattering in p-p collisions

At high energies one has certainly multiple scattering even in pp ($\sigma_{\rm jet} > \sigma_{\rm tot}$).

Inclusive cross sections:

- quantum interference (“AGK cancellations”) may help to provide simple formulas referred to as “factorization” (multiple scattering is “hidden”)

LHC: very interesting observables beyond inclusive (multiplicity dependencies...):

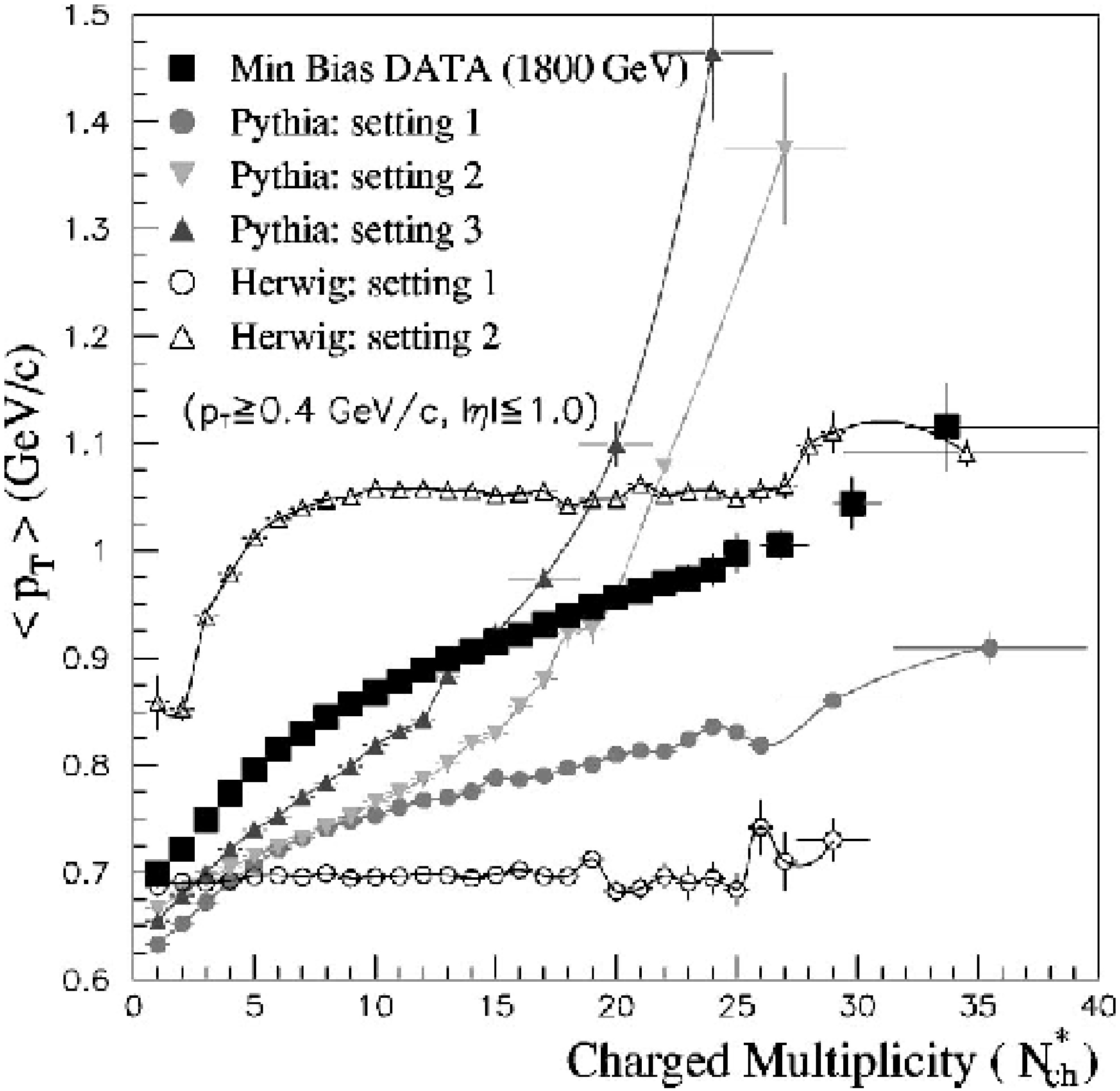
- one has to go beyond factorization and formulate a consistent multiple scattering theory

Interesting observations already at Tevatron ...

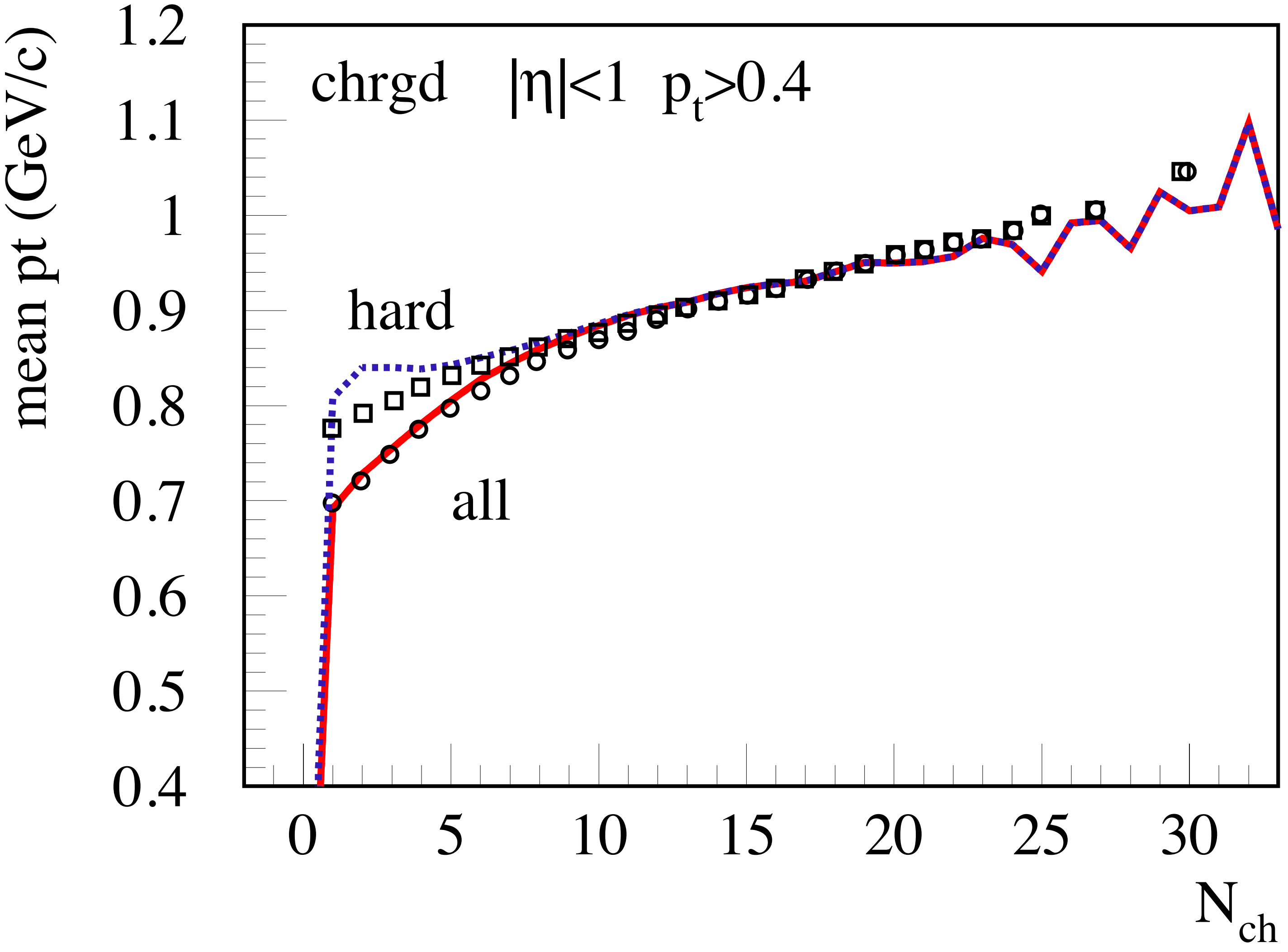
pp@1800GeV
data: CDF

Phys. Rev. D
Vol 65,
072005 (2002)

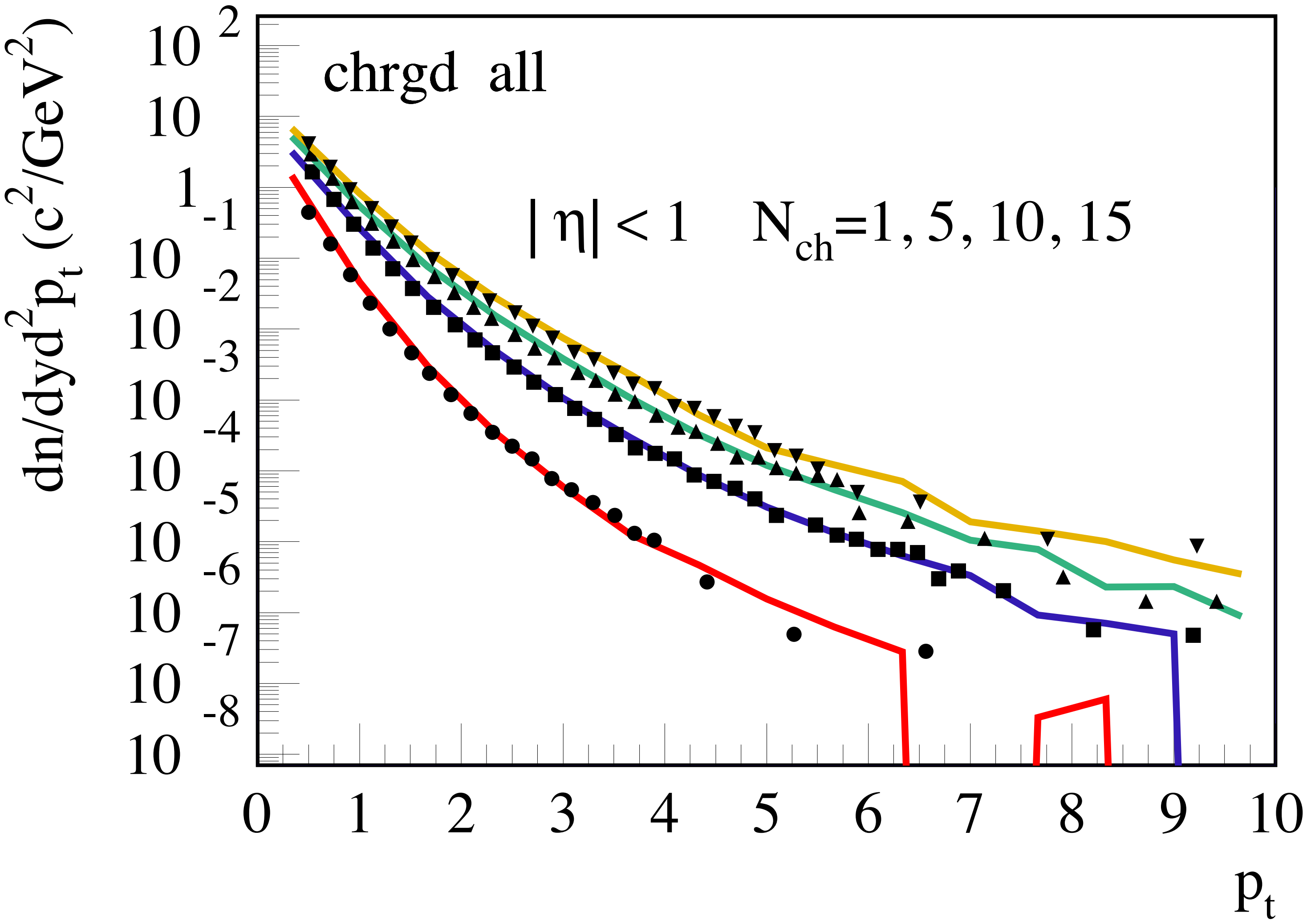
recent activities in Pythia community → MPI@LHC workshop



pp@1800GeV **points: CDF** **curves EPOS**



pp@1800GeV **points: CDF** **curves EPOS**



In EPOS:

- high multiplicity is clearly related to multiple scattering

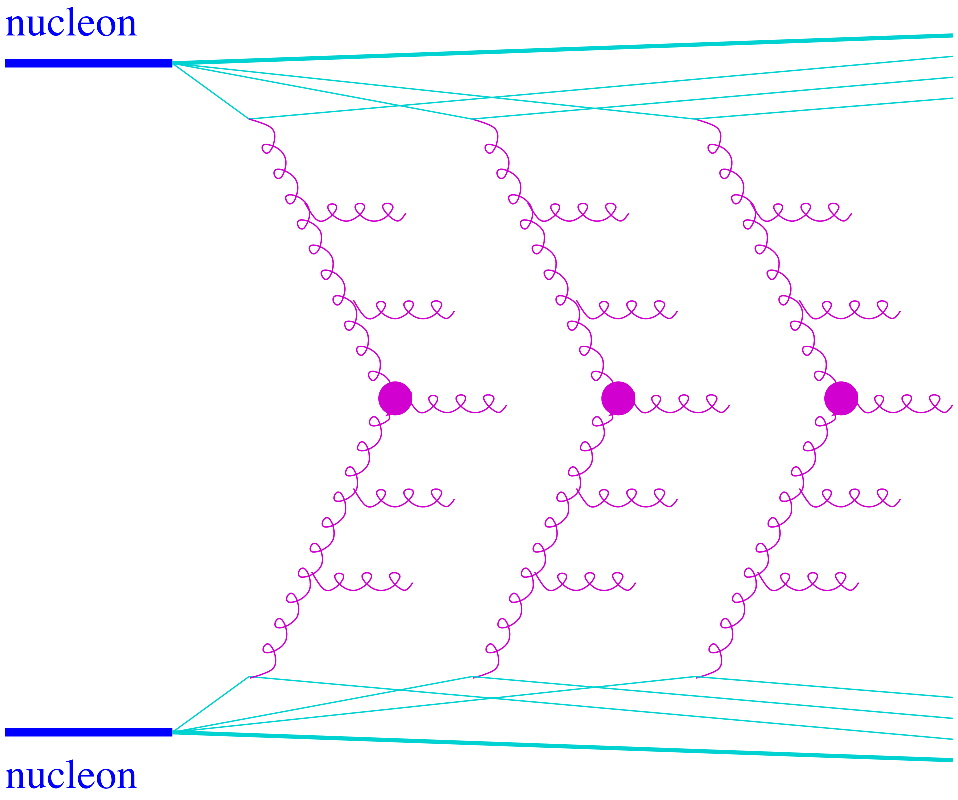
- However, multiple scattering also favours hard scatterings (just higher probability)

Multiple scattering approach

Possible solution:
Gribov's Pomeron calculus,

- several "Pomerons" are exchanged in parallel
- provides logarithmic increase of cross sections with energy

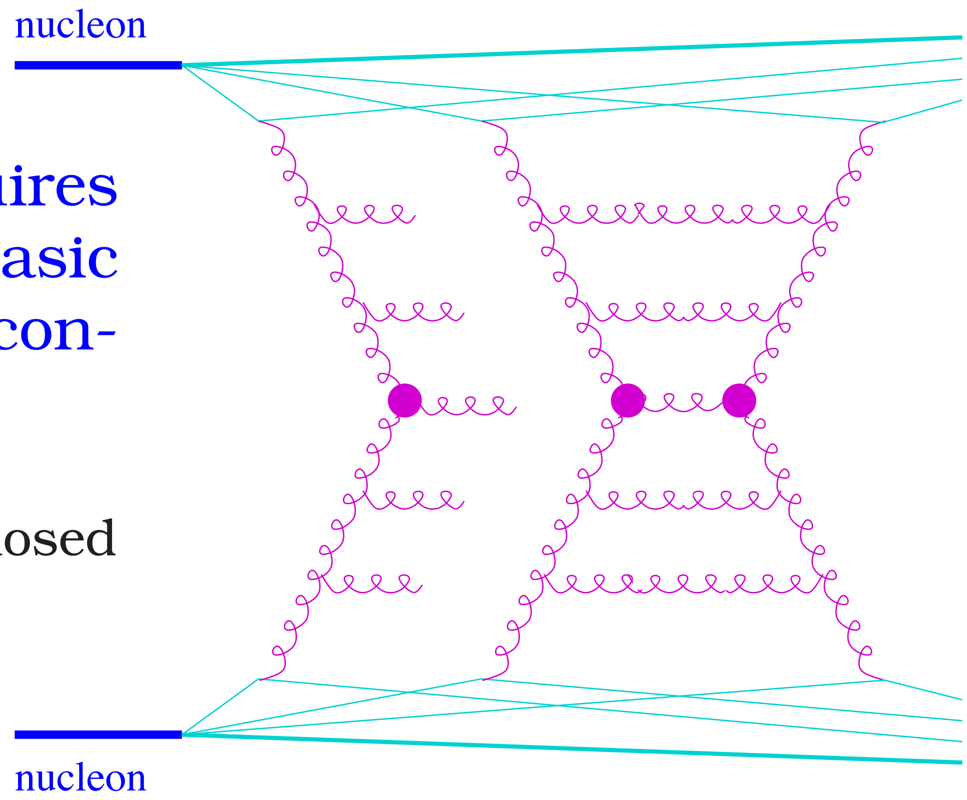
EPOS: Pomeron = parton ladder



important: multiple exchange of parton ladders, with energy sharing

Consistency requires inelastic and elasic processes to be considered

(here: open and closed ladders)



Squaring such graphs leads to “cut diagrams”
$\rightarrow$ handled by employing “cutting rule techniques”

Energy sharing requires Markov chain techniques

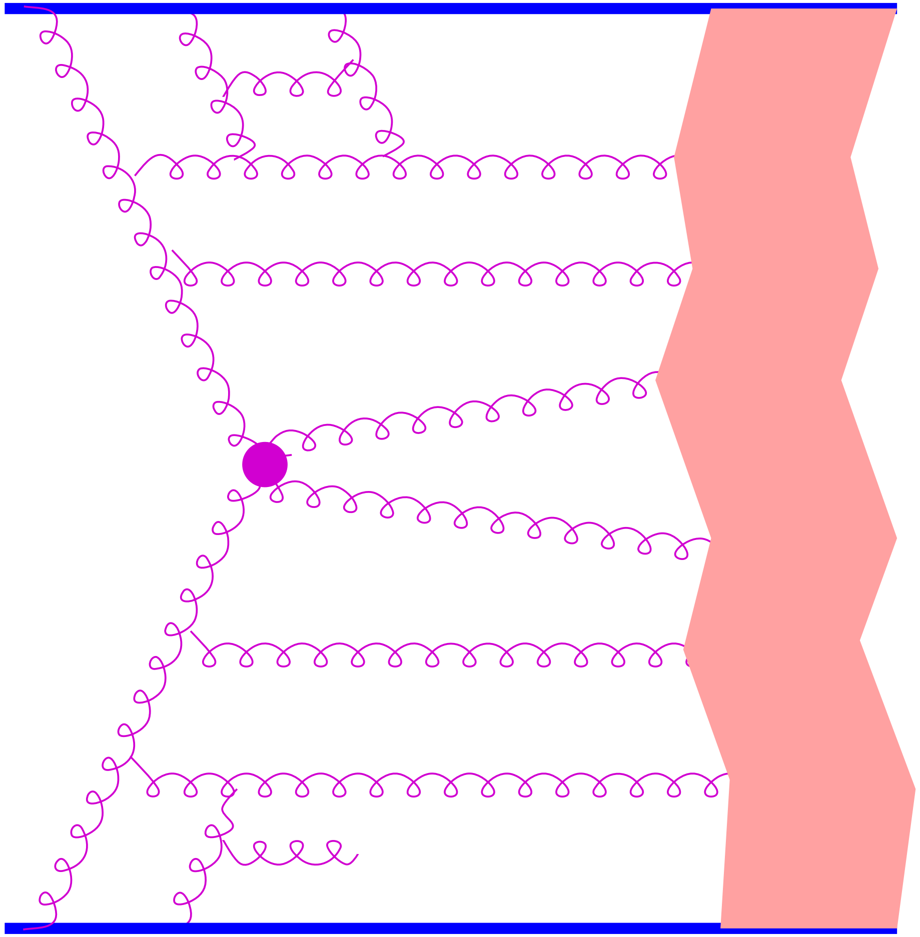
More details:

Parton-based Gribov-Regge Theory, H. J. Drescher, M. Hladik, S. Ostapchenko, T.Pierog, and K. Werner, Phys. Rept. 350 (2001) 93-289

Parton ladder splitting and the rapidity dependence of transverse momentum spectra in deuteron-gold collisions at RHIC, K. Werner, F.M. Liu, T. Pierog, hep-ph/0506232, Phys. Rev. C 74, 044902 (2006)

3 Space-time considerations

EPOS parton ladder



quasi longitudinal
color field
“flux tube”

gluons =
transverse
kinks

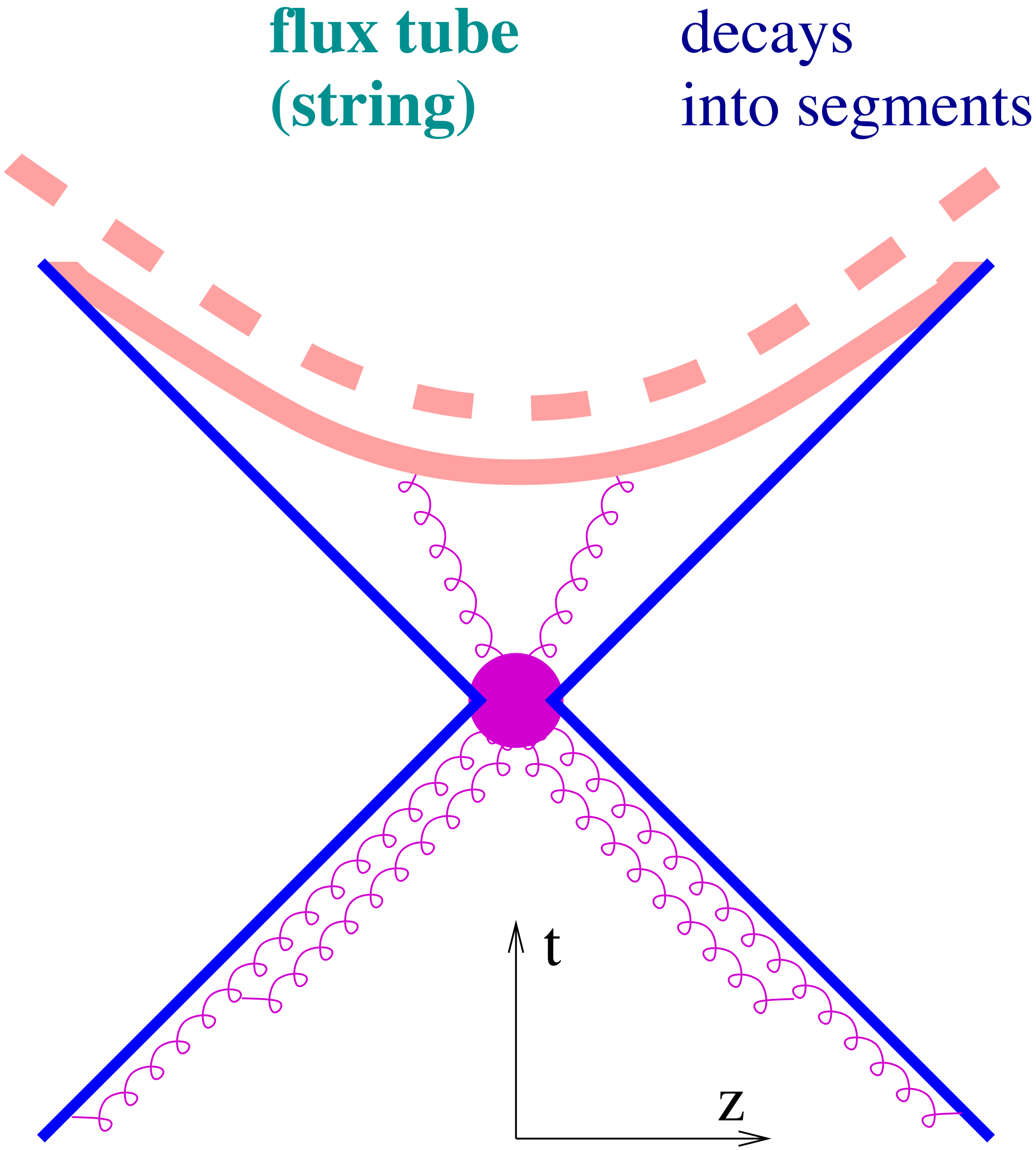
decay
via pair
production

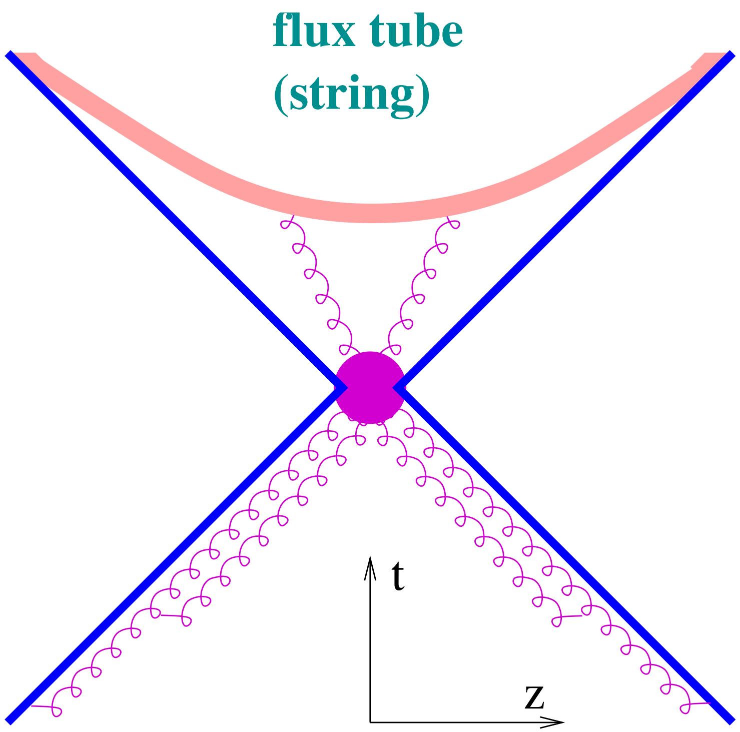
Flux tube stretches over wide range in rapdity

decays via pair production

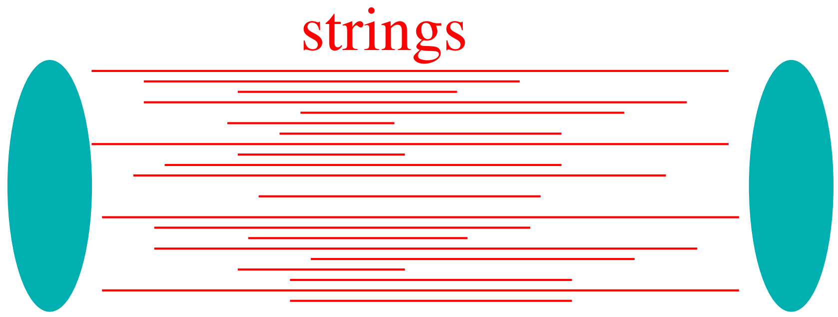
Hadrons are NOT associated to individual partons!

unless one considers hard processes





in AA or central pp: many overlapping flux tubes



cannot decay independently

color fields / strings represent initial condition for hydro-evolution

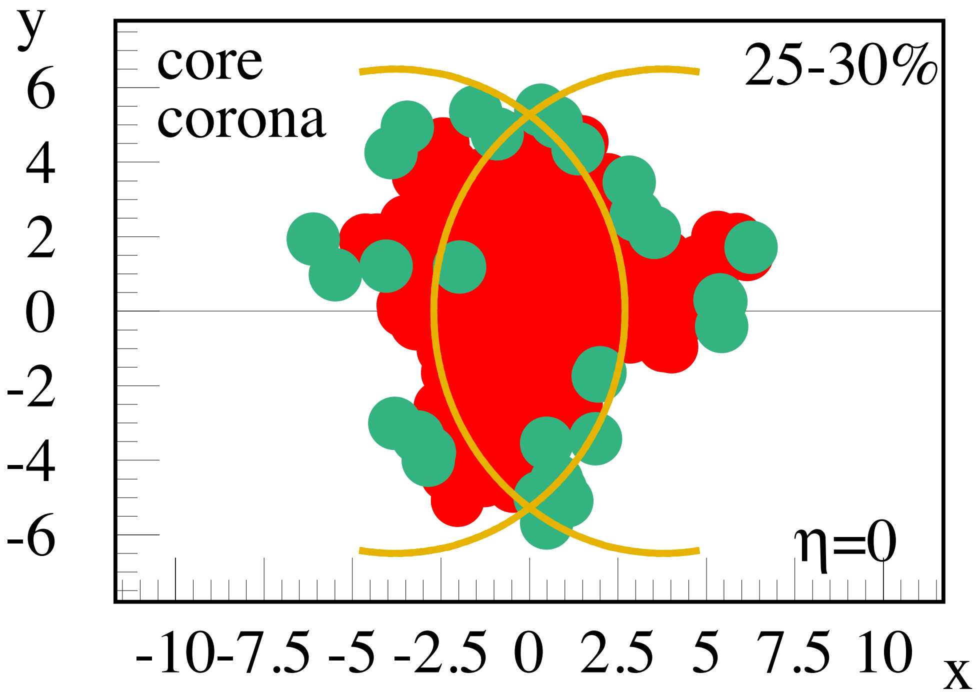
Core-corona separation (in AA)

Consider strings at some $\tau = \tau_0$

separate high density volume areas (which constitute the **core**)

from low density areas (**corona**)

high pt string pieces count as corona



core: we include inwards moving corona segments

Only core used to compute initial conditions for hydrodynamical evolution

at τ_0 : from space and momentum four-vectors of string segments, we get

- energy density $\varepsilon(\vec{x})$,
- flow velocity $\vec{v}(\vec{x})$
- net flavor densities $f(\vec{x})$

$$T^{\mu\nu} = \frac{1}{\Delta V} \sum_{i \in \Delta V} \frac{p_i^\mu p_i^\nu}{p_i^0}$$

$$N_q^\mu = \frac{1}{\Delta V} \sum_{i \in \Delta V} \frac{p_i^\mu}{p_i^0} q_i$$

with

$$p = \int_A^B \left\{ \frac{\partial X(r,t)}{\partial t} dr + \frac{\partial X(r,t)}{\partial r} dt \right\}$$

$$X(r,t) = X_0 + \frac{1}{2} \left[\int_{r-t}^{r+t} g\left(\xi\right) d\xi \right]$$

A, B: two neighboring points on X

$g(r) = v_k \quad$ for $r_{k-1} \le r \le r_k, \; 1 \le k \le n$

$v_k = p_k / p_k^0$, $r_k = p_k^0 / \kappa$

$p_k =$ parton four-momentum

H.J. Drescher, S. Ostapchenko, T. Pierog, and K.Werner, hep-ph/0011219, Phys.Rev.C65:054902,2002

...back to pp

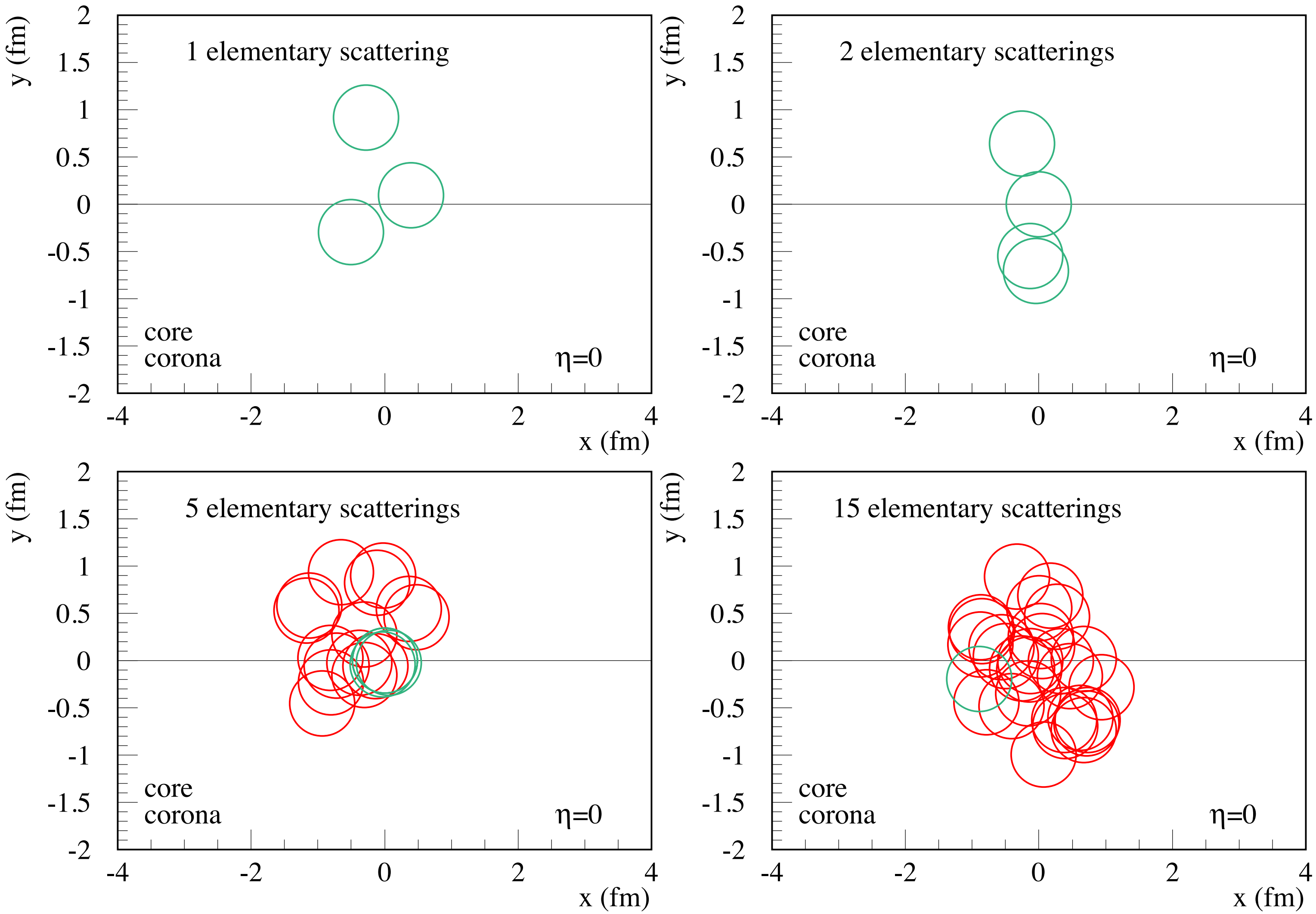
Be $\nu_{\rm inel}$ the number of inelastic elementary scatterings.

The total charged multiplicity $n_{\rm ch}$ is certainly a monotonic (linear?) function of $\nu_{\rm inel}$.

Instead of centrality dependence as in AA ,

here we study the $\nu_{\rm inel}$ or $n_{\rm ch}$ dependence of observables.

Core-corona approach in pp



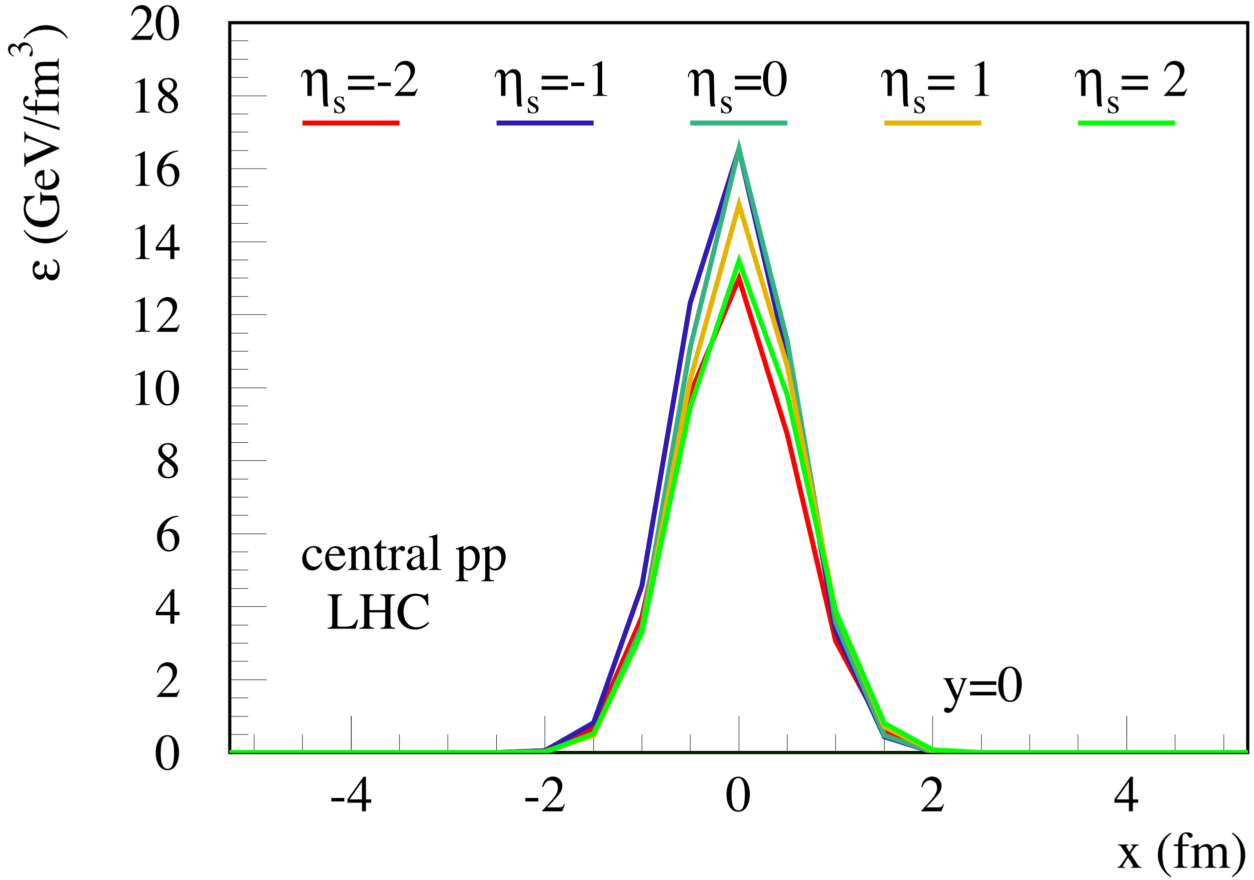
Core-corona in AA:

- separation of volume into (central) core and (peripheral) corona part

Completely different in pp:

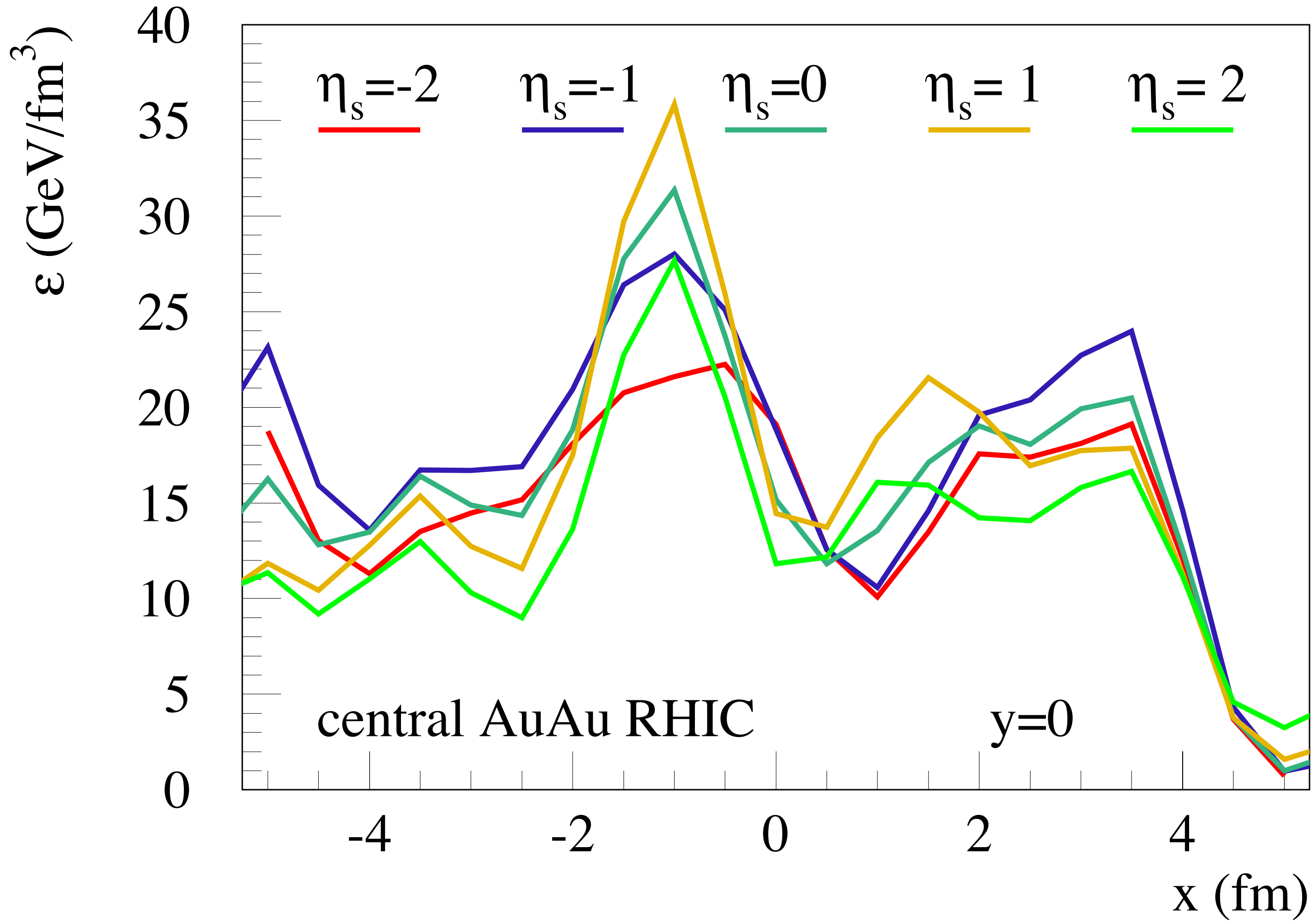
- separation of events into two classes: core and corona events

Energy density of central ($\nu_{\rm inel} \geq 14$) pp at LHC



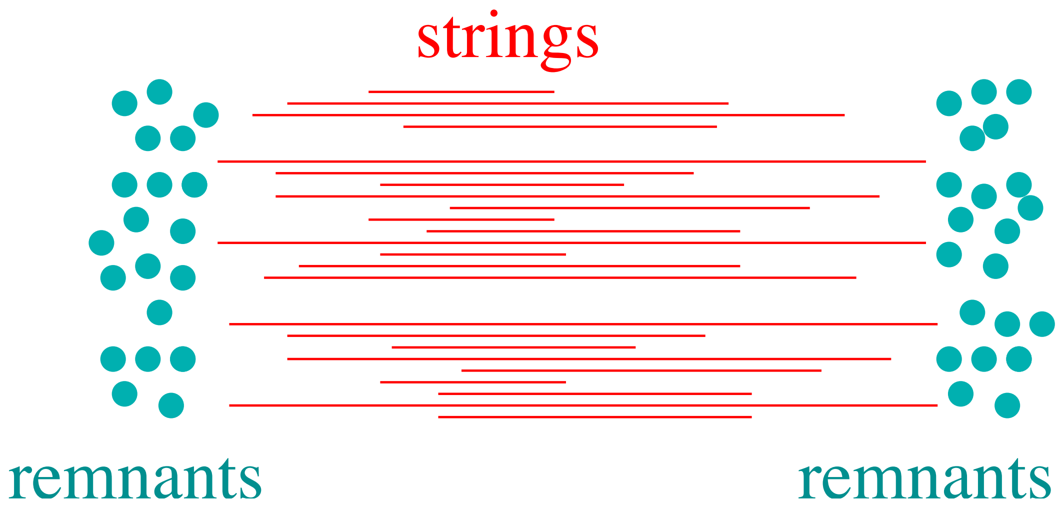
AuAu@RHIC

ridge structure in $\eta_s - \phi$ (coordinates)



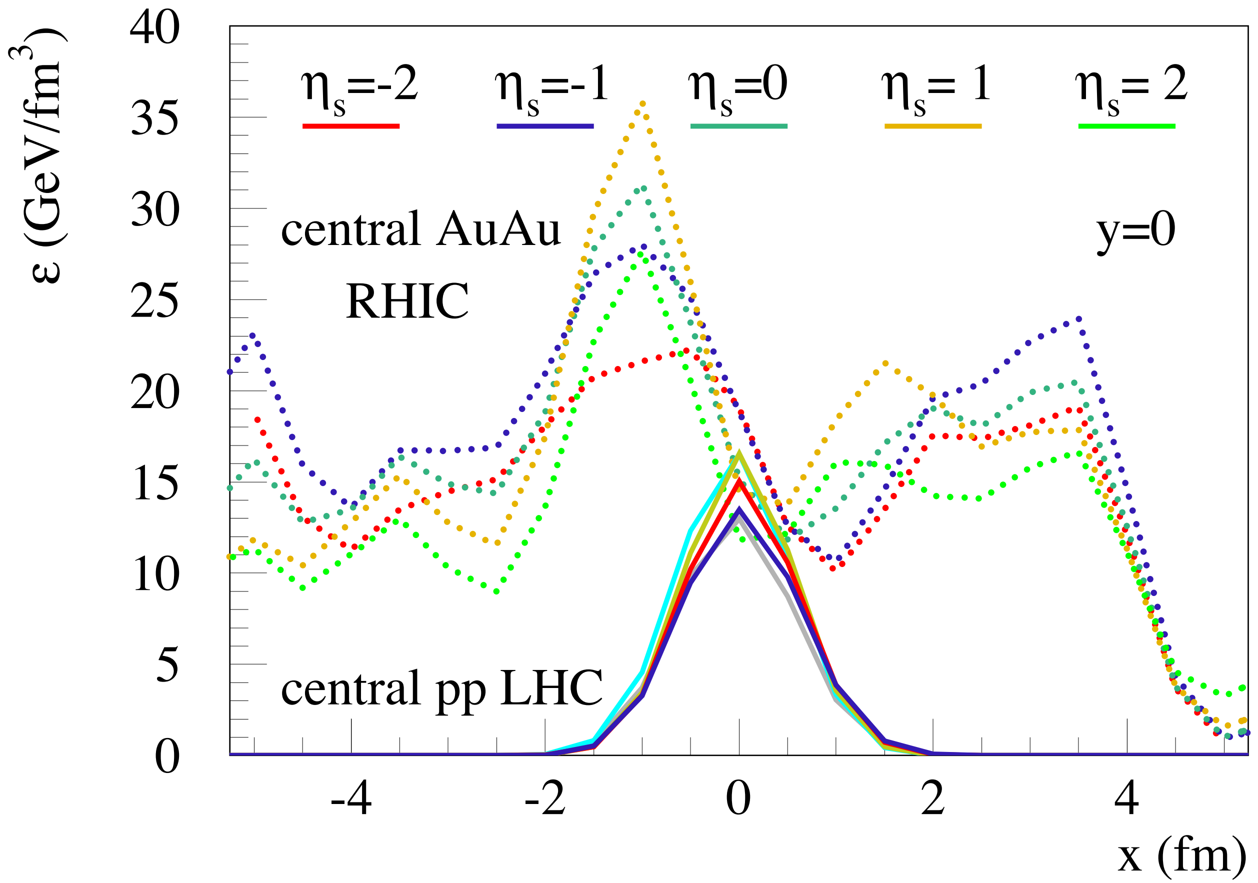
A single EPOS event is composed of several high density flux tubes (covering many η_s units)

The fluxtubes are due to random "clusterings" of nucleons in nuclei



One flux tube is the result of merging many individual strings

Epos: initial energy density obtained from strings, not partons



The widths of the sub-flux in AuAu tubes are of the order of 2fm ... like the flux tubes for "central" pp scatterings!

- Energy density comparable to AuAu@RHIC

- So maybe as well hydrodynamical expansion + statistical decay

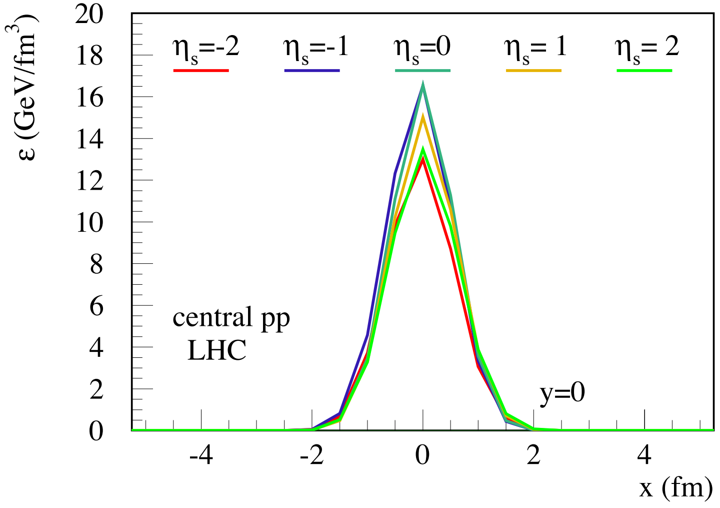
- We will do the corresponding simulation

How to verify ?

- study "centrality dependence" of particle yields, spectra, ...

- multiple scattering events should exhibit long range y correlations

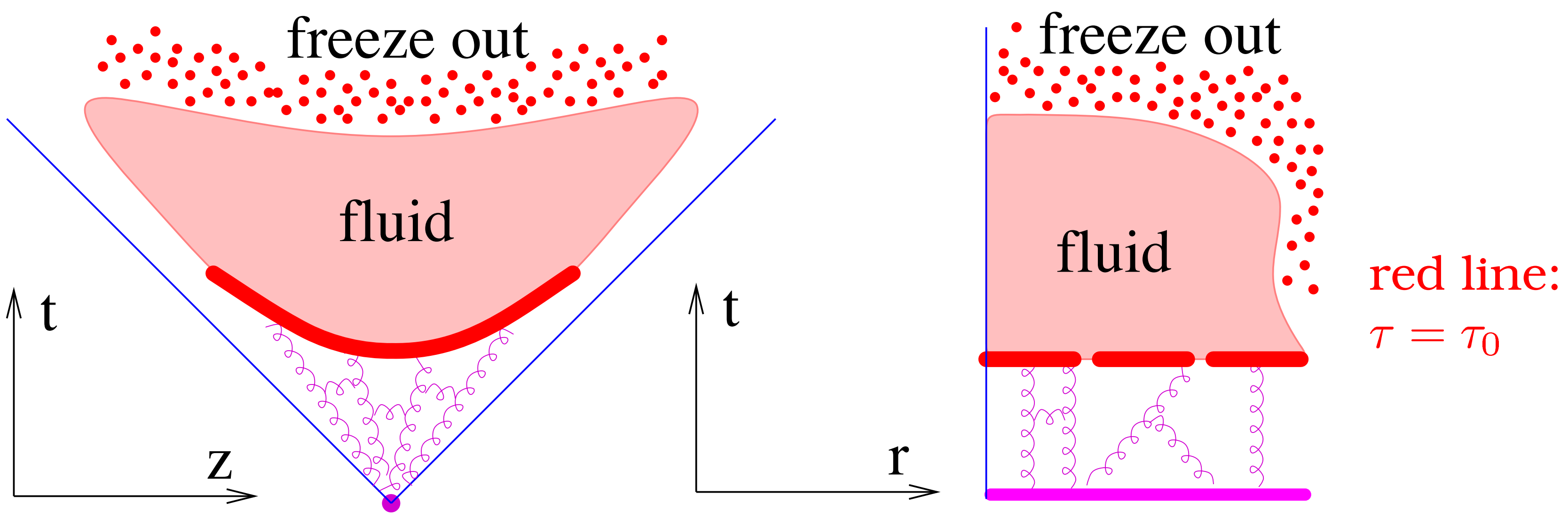
  coming from the η_s correlation of the initial flux tubes



- study particle yields, spectra, ... at forward rapidity as a function of the backward multiplicity

- This should clearly exhibit the flux tube structure

4 Hydro evolution / freeze out



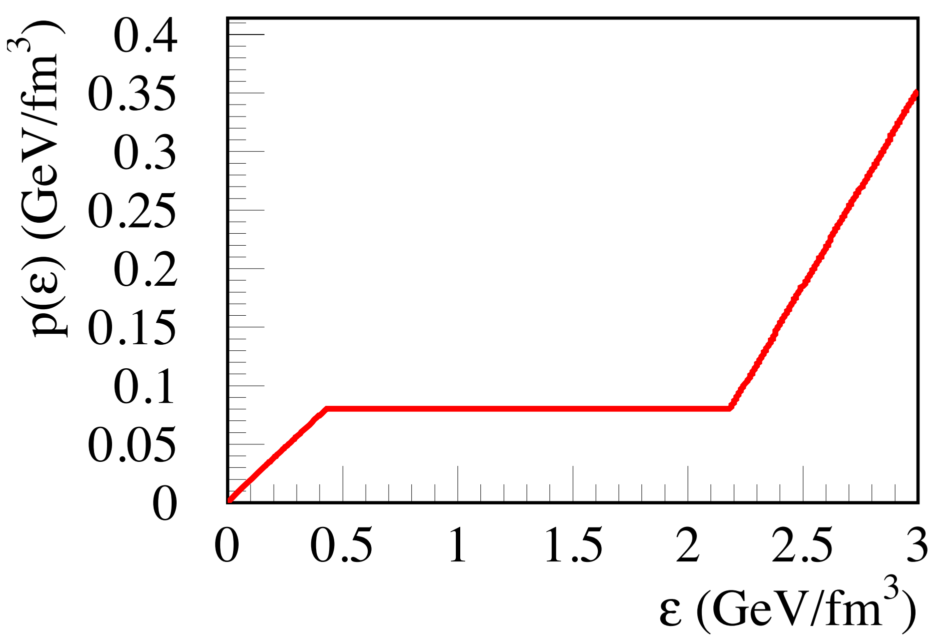
- For $\tau > \tau_0$: 3D hydrodynamic evolution
- determine freeze out hypersurface and collective velocities
- particle production via Cooper-Frye formula
- hadronic cascade

Hydro code (1) - T. Hirano

□ T. Hirano, U. Heinz, D. Kharzeev, R. Lacey, Y. Nara, Phys.Rev.C77: 044909,2008, and T. Hirano, U.W.Heinz, D. Kharzeev, R. Lacey and Y. Nara, Phys. Lett. B 636 (2006) 299

□ EoS: Massless quarks and gluons, $p = \frac{1}{3}(\varepsilon - 4B)$, $B^{1/4} = 247.19$MeV, $\mu_B = 0$

hadron resonance gas, PCE (chemical FO at $T = T_c = 170$ MeV)



Hydro code (2) - Yuri Karpenko (unpublished)

- C++ code, coupled directly to EPOS
- Code based on Godunov method
  - introducing finite cells and computing fluxes between cells using the (approximate) Riemann problem solution for each cell boundary.
- Use relativistic HLLE solver to solve Riemann problems
- To achieve more accuracy in time : the predictor-corrector scheme is used for the second order of accuracy in time, i.e. the numerical error is $O(dt^3)$, instead of $O(dt^2)$
- To achieve more accuracy in space : to achieve the second order scheme, the linear distributions of quantities (conservative variables) inside cells are used. The conservative quantities are $(e + p * v^2)/(1 - v^2)$, $(e + p) * v/(1 - v^2)$.
- The code is written in hyperbolic coordinates

Hydro code (3) - SPHERIO 4, Wei-Liang Qian

- Wei-Liang Qian, Rone Andrade, Frederique Grassi, Otavio Socolowski Jr., Takeshi Kodama, Yogiro Hama, Int.J.Mod.Phys.E16:1877-1882,2007
  coupled directly to EPOS
  EbE possible

- SPH (Smoothed Particle Hydrodynamics) technique.
  Physical quantities are written as
  $$f(\vec{x},t) = \sum_{i=1}^{N} f_i \, W\big(\vec{r} - \vec{r}_i(t)\big)$$
  $\partial_\mu T^{\mu\nu} = 0$ & conservations laws lead to eqs. for $\vec{r}_i$.

- EoS: Ideal gas of quarks and gluons,
  $m_u = m_d = 0$, $m_s = 120\text{MeV}$; $B^{1/4} = 232\text{MeV}$,
  $\mu_u = \frac{1}{3}\mu_B + \frac{1}{2}\mu_{I3}$, $\mu_d = \frac{1}{3}\mu_B - \frac{1}{2}\mu_{I3}$, $\mu_s = \frac{1}{3}\mu_B - \mu_S$;

  hadron resonance gas,
  $\mu_h = B\mu_B + S\mu_S + I_3\mu_{I3}$

Final state hadronic rescatterings

- UrQMD, M. Bleicher et al., J. Phys. G25 (1999) 1859, H. Petersen, J. Steinheimer, G. Burau, M. Bleicher and H. Stocker, Phys. Rev. C78 (2008) 044901,

- EPOS coupling in collaboration with S.Haussler, M.Bleicher, S. Porteboeuf

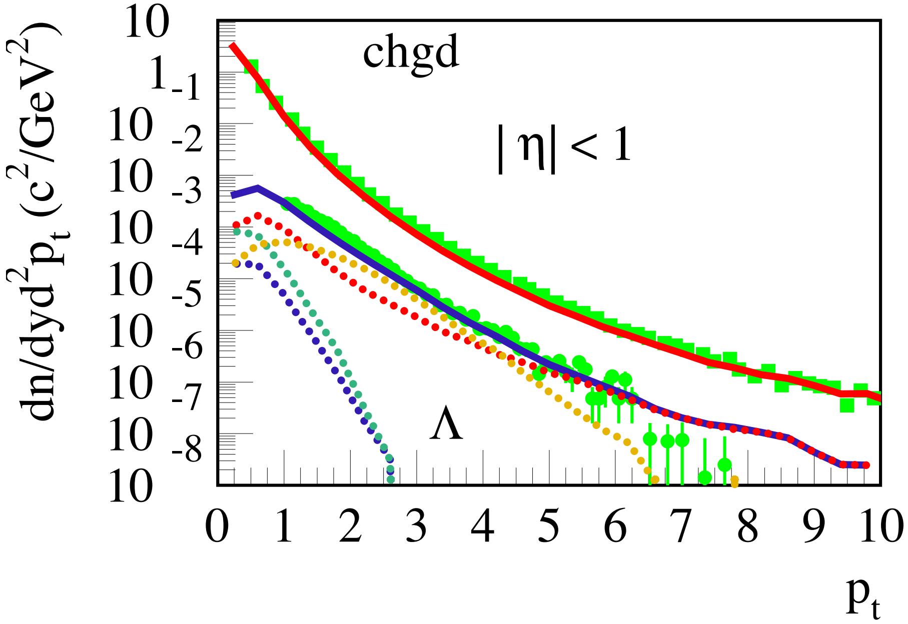
- FO at some temperature (in the hadronic phase), FO hadrons & corona hadrons
  = initial condition for hadronic cascade

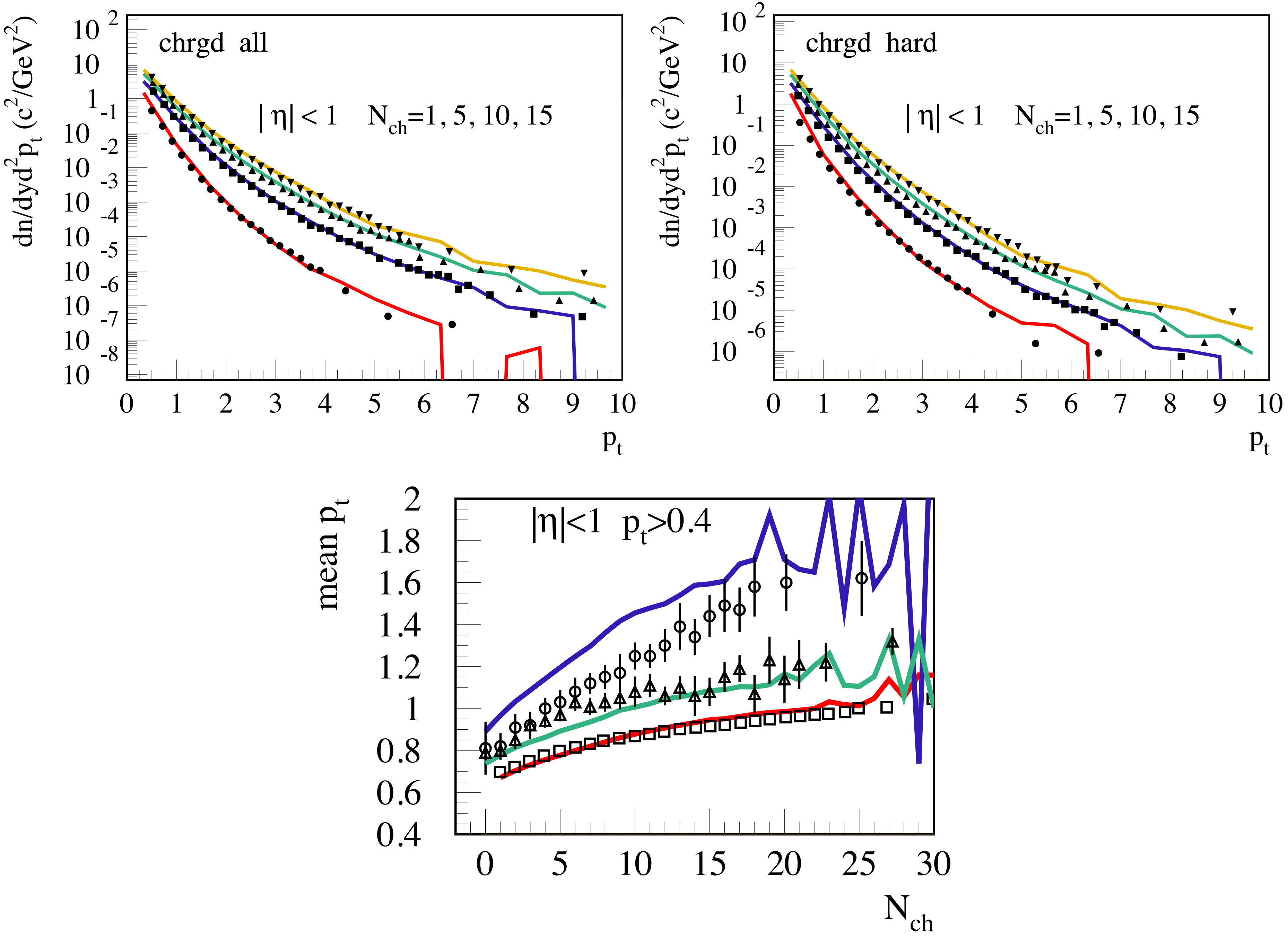
5 Results for pp

- Real hydro calculation: work in progress...

- So far only "hydro-inspired" (parameterization of FO-flow)

Charged particle and lambda pt spectra: different shapes (as in AA)




chrgd all
$|\eta| < 1$ N_{ch}=1, 5, 10, 15
dn/dyd^2p_t (c^2/GeV^2)
p_t
chrgd hard
$|\eta| < 1$ N_{ch}=1, 5, 10, 15
dn/dyd^2p_t (c^2/GeV^2)
p_t
mean p_t
$|\eta|<1$ $p_t>0.4$
N_{ch}

to summarize

- Air shower simulations with EPOS: more muons, due to more baryon production, compared to conventional models. Smaller pA cross section (also necessary to be consistent with Kascade). Consequence: larger Xmax
- EPOS proton-proton collisions at LHC: Multiple scattering important $\rightarrow$ high energy density flux tubes
- Flux tubes in pp@LHC very similar to in size and density to sub-flux tubes in AuAu@RHIC $\rightarrow$ same collective behavior expected
- Flux tube picture also supported by "Ridge" phenomenon, and by v2 η dependence