EPOS 2

Klaus Werner <werner@subatech.in2p3.fr>

in collaboration with

B. Guiot, Iu. Karpenko, T. Pierog

EPOS 3

Klaus Werner <werner@subatech.in2p3.fr>

in collaboration with

B. Guiot, Iu. Karpenko, T. Pierog

Key elements:

E nergy conserving multiple scattering

P arton ladders (multiple)

O ff-shell (excited) remnants

S aturation (NEW)

3 dim viscous EbyE hydro (NEW)
+ hadronic afterburner

E nergy conserving multiple scattering

S aturation

E nergy conserving multiple scattering

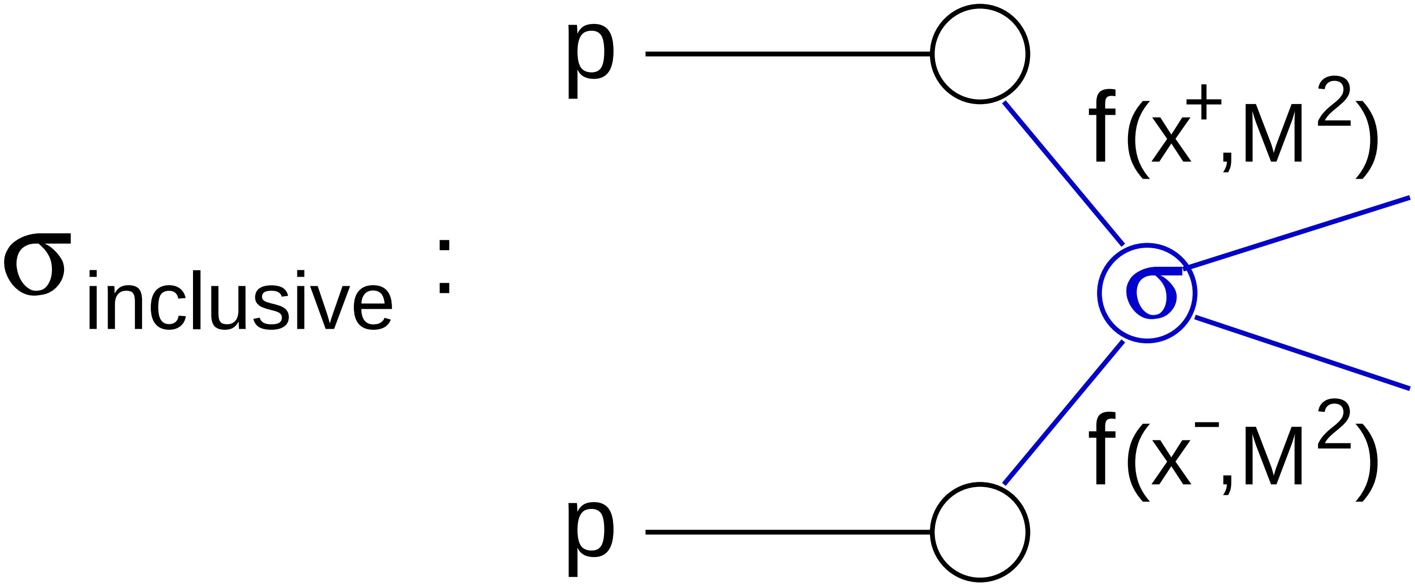
S aturation

are very closely related

both necessary for a consistent MS scheme

Two fundamentally different approaches

(1) Starting from the factorization formula,



one "reconstructs" multiple scattering such that factorization is reproduced;

PDFs f are input

(2) Starting from a Gribov-Regge multiple scattering Ansatz, one ends up (if things are done properly) with

factorization for $\sigma_{\text{inclusive}}$ (pp,AA)

binary scaling (AA, also pp)

PDFs are outcome

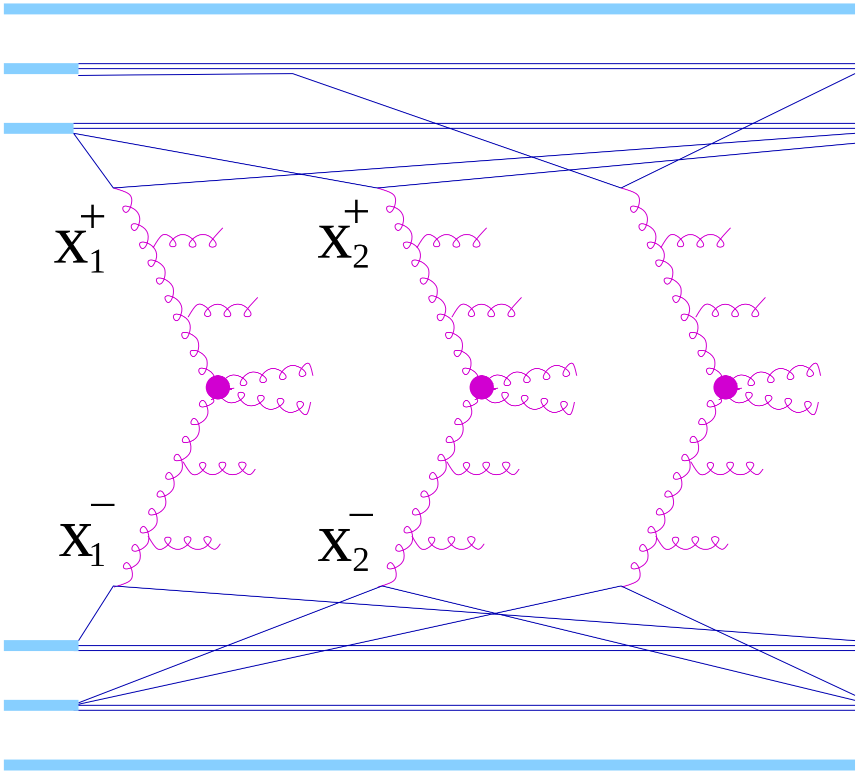
Some history of GRT:

☐ 1960-1970: Gribov-Regge Theory
of multiple scattering.
pp = multiple exchange of “Pomerons”
(parameterized amplitudes)

☐ 1980-1990: pQCD processes
added into GRT scheme (Capella)

☐ 1990: M.Braun, V.A.Abramovskii, G.G.Leptoukh:
problem with energy conservation
(not done consistently)

☐ 2001: H.J.Drescher, M.Hladik, S.Ostapchenko, T. Pierog, and K. Werner, Phys. Rept. 350, p93: Marriage pQCD + GRT, with energy sharing



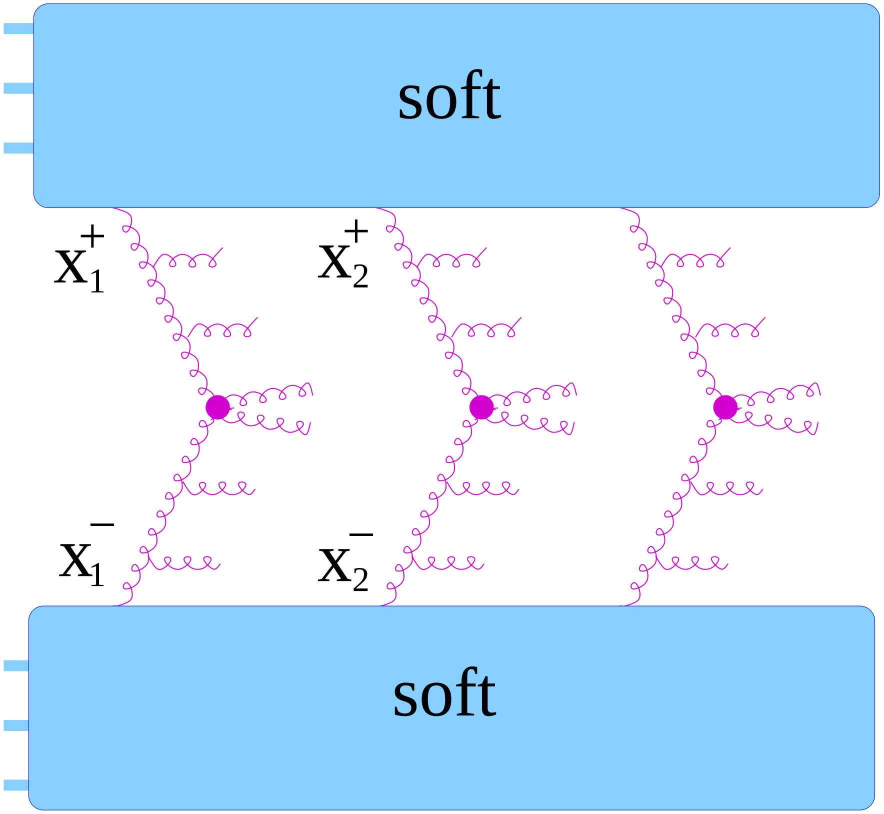
$$\boxed{\sum x_i^{\pm} + x_{\rm remn}^{\pm} = 1}$$

Multiple scattering in pp, pA, or AA

Single scattering

= hard elementary scattering including IS + FS radiation

☐ 2001: H.J.Drescher, M.Hladik, S.Ostapchenko, T. Pierog, and K. Werner, Phys. Rept. 350, p93: Marriage pQCD + GRT, with energy sharing



$$\boxed{\sum x_i^{\pm} + x_{\text{remn}}^{\pm} = 1}$$

Multiple scattering in pp, pA, or AA

Single scattering

= hard elementary scattering including IS + FS radiation

A (unique) feature of our scheme:

All scatterings are equal !

There is nothing like a first and second collision.

No need for anything like color reconnection

since we start from multiple scatterings,
all being equal, also the string structures.

BUT (Clear from the beginning) picture is not complete:

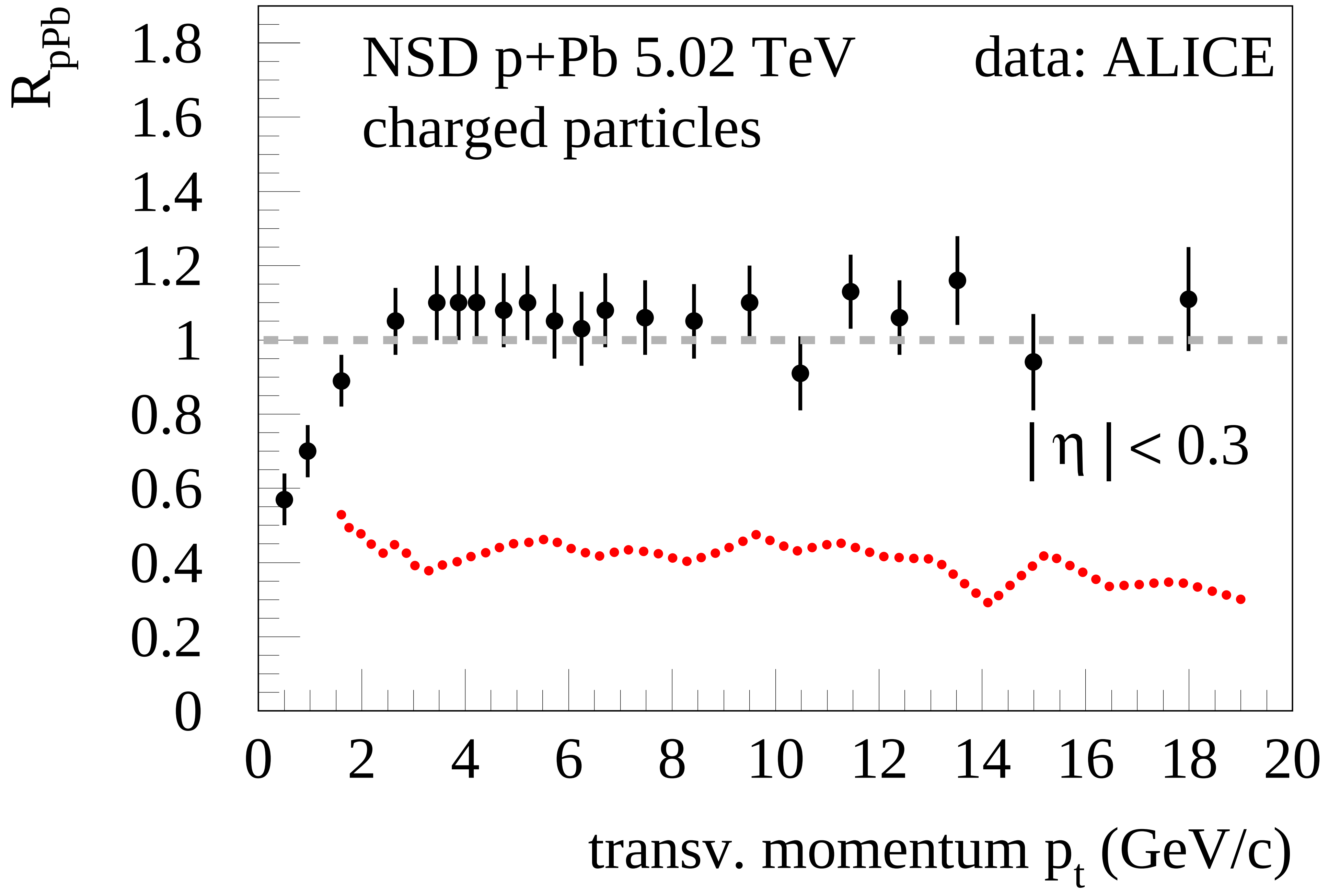
☐ introducing energy conservation (which is a must)

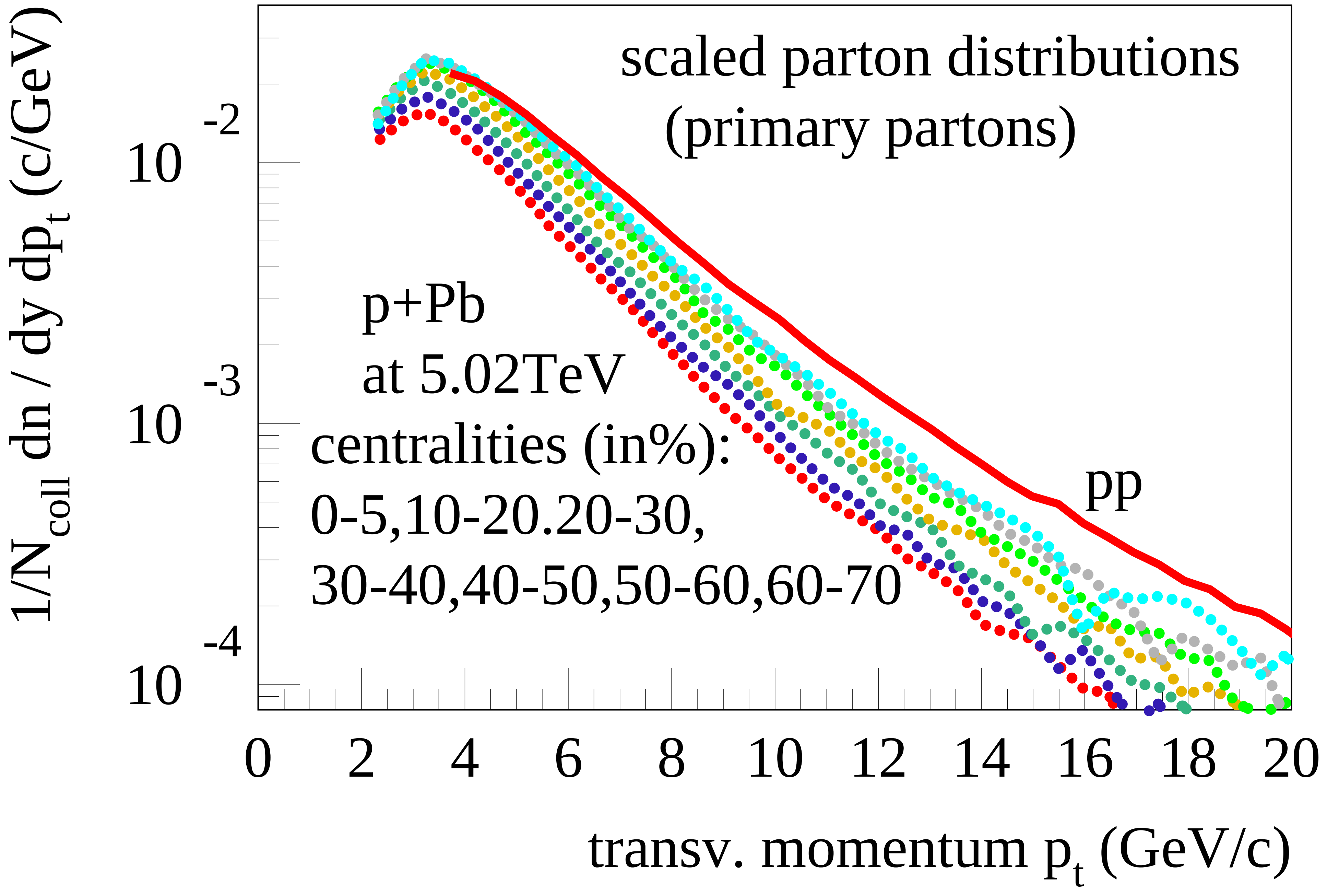
☐ one generates a violation of the observed “binary scaling”,

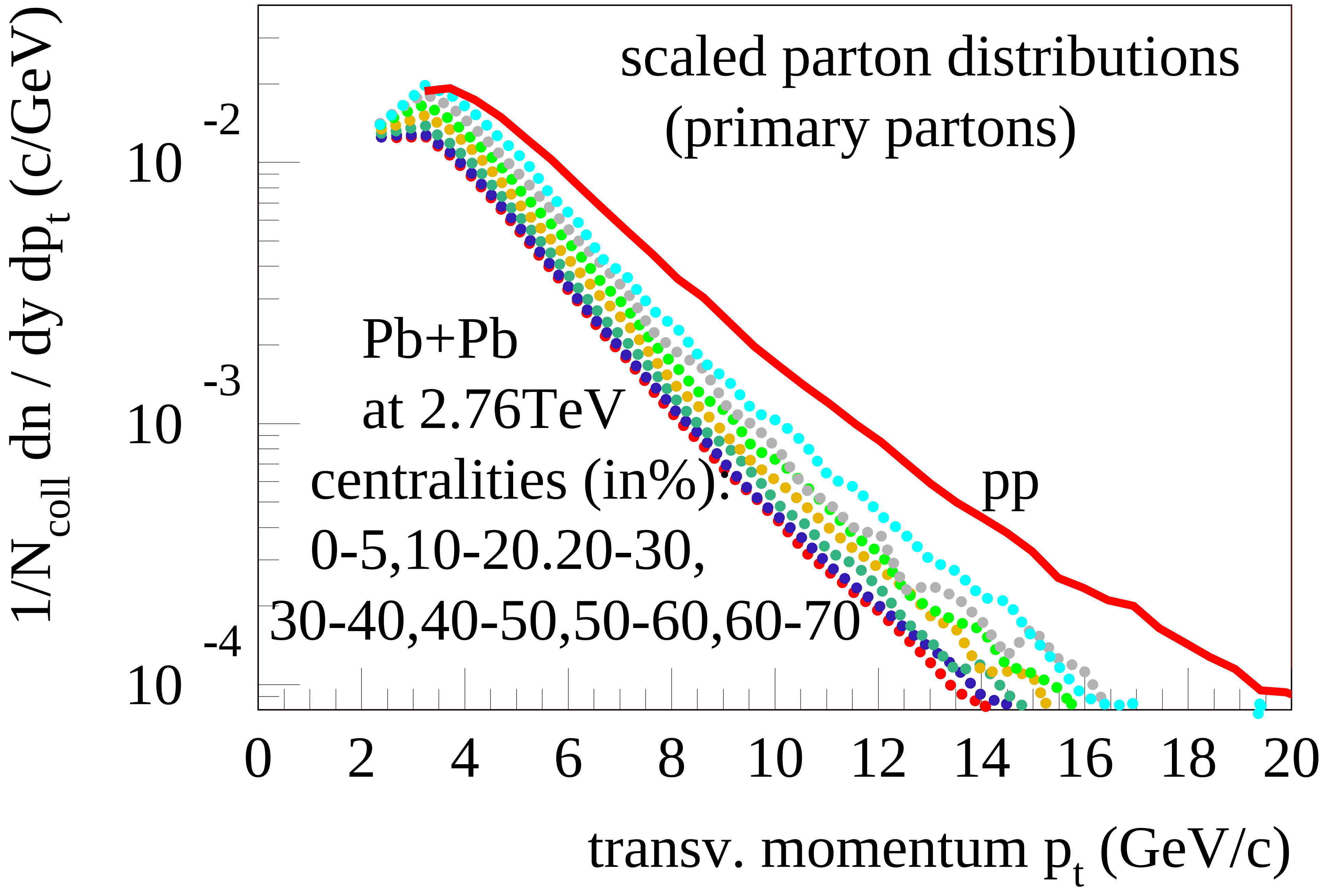
$$R_{AA} = \left.\frac{dn}{dp_t}\right|_{AA} \Big/ \left(N_{\mathrm{coll}} \left.\frac{dn}{dp_t}\right|_{pp} \right) = 1$$

in pA, (AA for photons, W)

(very useful to consider pp, pA, and AA)


R_{pPb}
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
transv. momentum p_t (GeV/c)
NSD p+Pb 5.02 TeV
charged particles
data: ALICE
$|\eta| < 0.3$


scaled parton distributions
(primary partons)
p+Pb
at 5.02TeV
centralities (in%):
0-5,10-20.20-30,
30-40,40-50,50-60,60-70
pp
1/N_coll dn / dy dp_t (c/GeV)
10^-2
10^-3
10^-4
0
2
4
6
8
10
12
14
16
18
20
transv. momentum p_t (GeV/c)

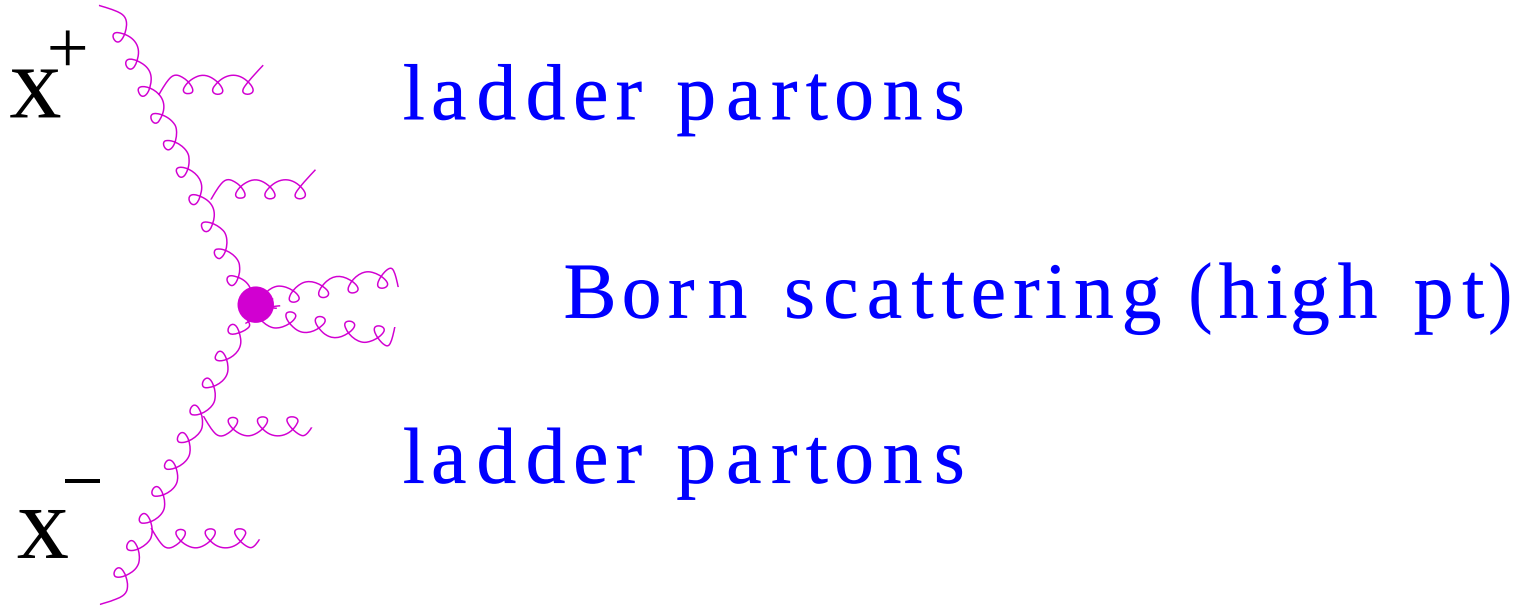

scaled parton distributions
(primary partons)
Pb+Pb
at 2.76TeV
centralities (in%):
0-5,10-20.20-30,
30-40,40-50,50-60,60-70
pp
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$1/N_{coll}$ dn / dy dp_t (c/GeV)
transv. momentum p_t (GeV/c)

First attempt
to solve the problem:

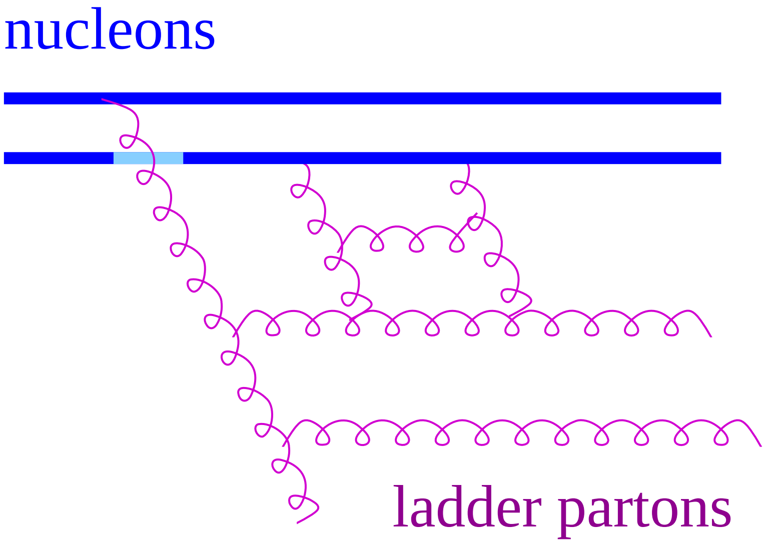
(in EPOS1 and EPOS2)

Reminder for the following discussion:

elementary object = parton ladder



$x^{\pm}$: light cone momenta of “outer” partons "high parton density" effects : ladder partons may interact with proj / target



Considered
in a phenomenological way:

- ☐ fit parton-ladder [1] as $\alpha\,(x^{+})^{\beta}(x^{-})^{\beta}$
- ☐ modify as $\alpha\,(x^{+})^{\beta}(x^{-})^{\beta+\varepsilon}$,

---

[1] imaginary part of the corresponding amplitude in $b-$space

The exponent ε depends on

- energy
- impact parameter
- the environment (nucleons around in AA)

Easy to implement, but at the end ...

despite introducing quite a few parameters, the "binary scaling problem not solved" (clearly visible in pPb)

New solution

based on the saturation scale Q_s

1983 - 1994: L.V. Gribov, E.M. Levin, M.G. Ryskin, J.-P. Blaizot, A.H. Mueller, J. Qiu, L. McLerran, R. Venugopalan

> 1995: Yu. Kovchegov, J. Jalilian-Marian, A. Kovner, A. Leonidov, H. Weigert,E. Iancu, D. Kharzeev, E. Levin, M. Nardi, ...

Nucleus-nucleus (A+B) collisions:

Take a parton ladder connected to projectile nucleon i and target nucleon j. Count “participants”:

$N^{A}_{\mathrm{part}}(j)$: # of proj nucleons “interacting” with j

$N^{B}_{\mathrm{part}}(i)$: # of target nucleons “interacting” with i

$$N_{\mathrm{part}}(i,j) = \max\left\{\, N^{B}_{\mathrm{part}}(i)\ ,\ N^{A}_{\mathrm{part}}(j)\,\right\}$$

For a given Monte Carlo configuration.

Hypothesis: The usual “soft” scale

$$Q_0^2 = 4\mathrm{GeV}^2$$

is replaced by

$$\boxed{Q_s^2 = Q_0^2 \left(1 + B_{\mathrm{satur}} N_{\mathrm{part}}(i,j)\right)}$$

So each parton ladder has “its own” saturation scale, depending on the number of connected participants

Proton-proton:

In our approach similar to AB: small or large number of scatterings depending on impact parameter.

But rather than counting, we estimate the number of "participating partons" $z_{\mathrm{part}}(b)$. With

$$\boxed{Q_s^2 = Q_0^2\left(1 + B_{\mathrm{satur}}\, z_{\mathrm{part}}(b)\right)}$$

we have also a centrality dependent saturation scale in pp!

To have a unique procedure for pp and AB:

We still count for each ladder the participants in AB, but each participant gets a “weight” $z_{\mathrm{part}}(b)$.

The result is referred to as $Z_{\mathrm{part}}(i,j)$
instead of $N_{\mathrm{part}}(i,j)$.

We use

$$z_{\mathrm{part}}(b) = f(A_{\mathrm{satur}} e^{-b^2/4\pi\lambda}),$$

where $e^{-b^2/4\pi\lambda}$ is our “usual” transverse momentum factor, and with

$$f(x) = \frac{x}{1 - \exp(-x)}.$$

We use

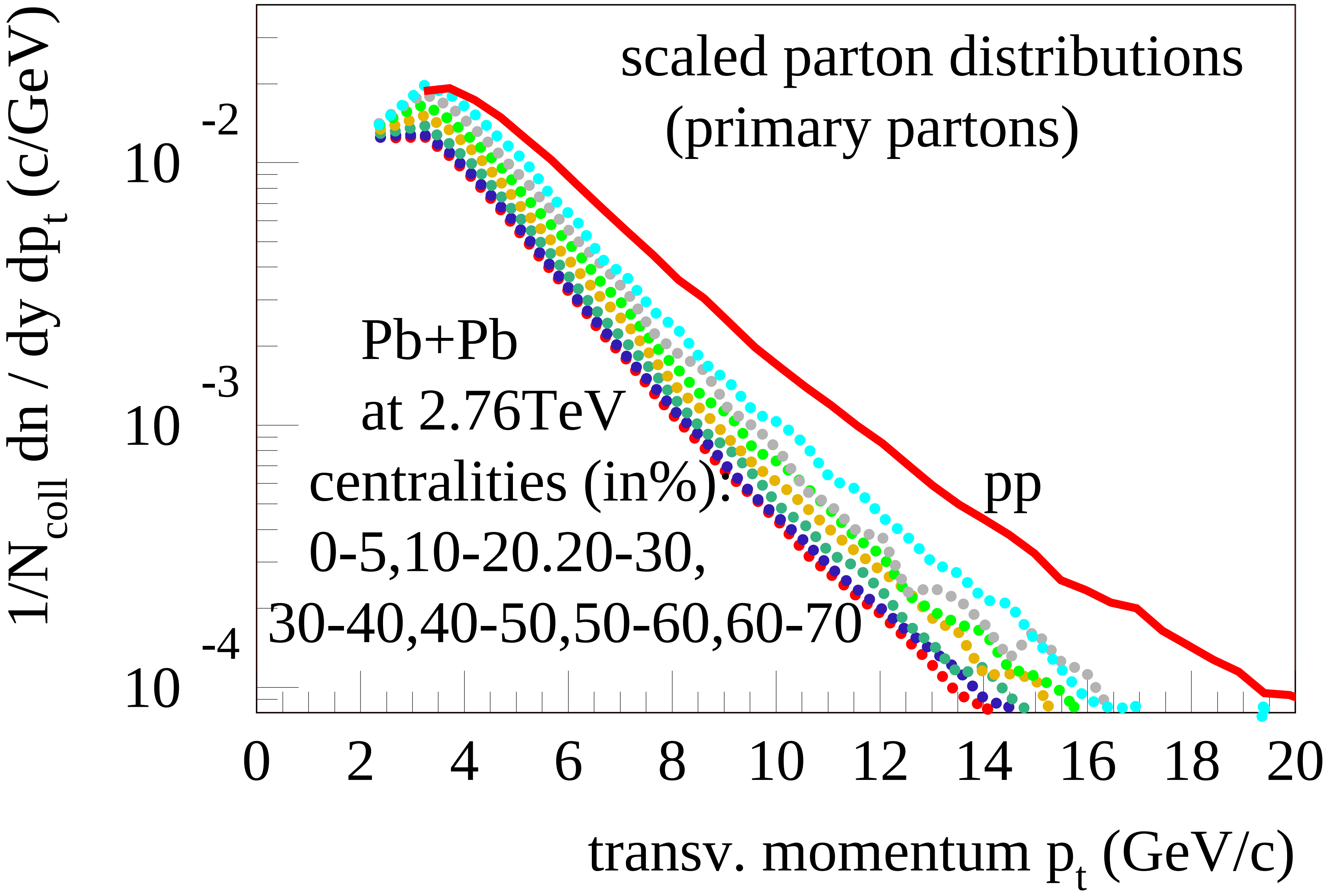
$$Q_s^2 = Q_0^2 \left(1 + B_{\mathrm{satur}} Z_{\mathrm{part}}(i,j)\right)$$

with

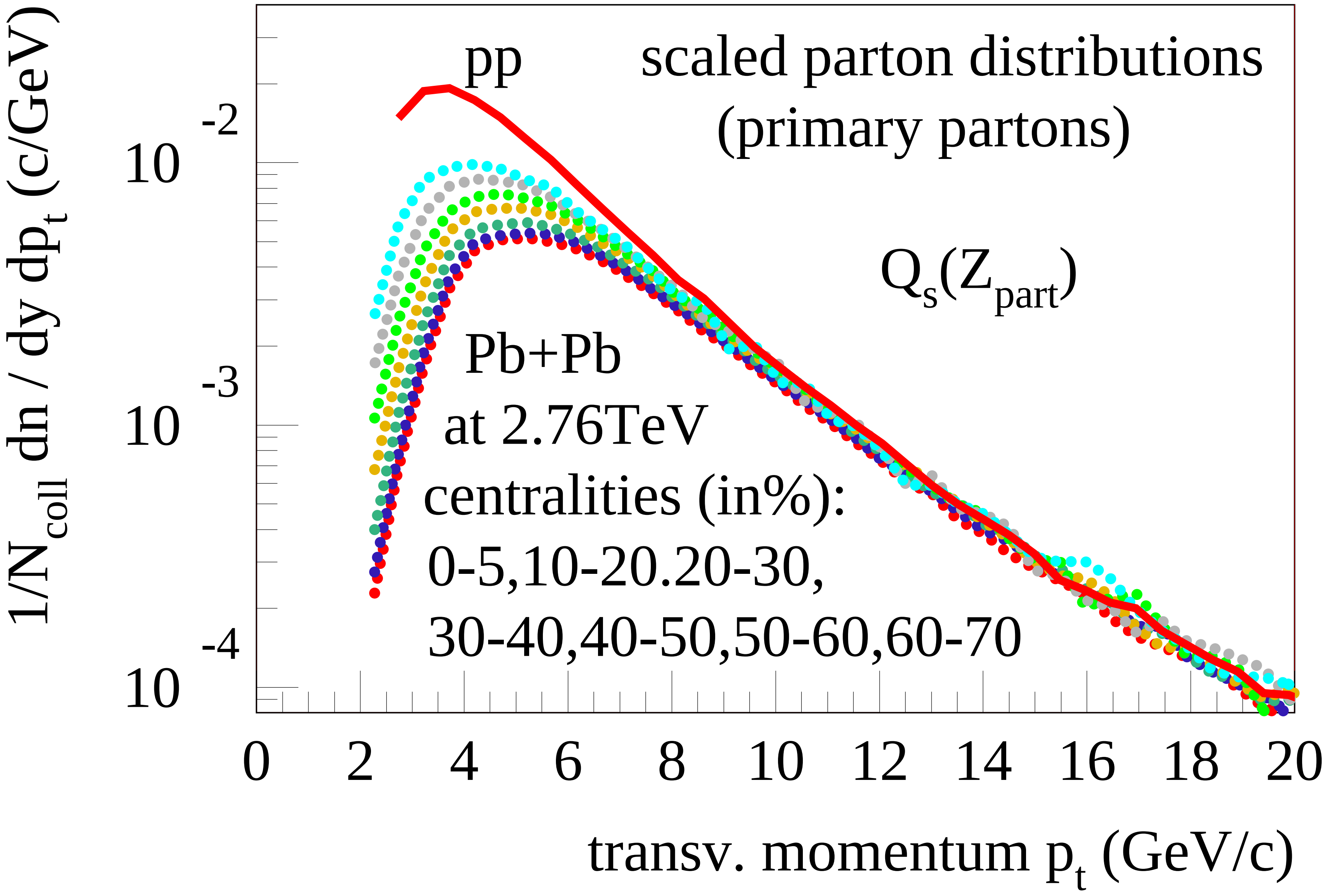
$$B_{\mathrm{satur}} = 0.6$$

for the following results.

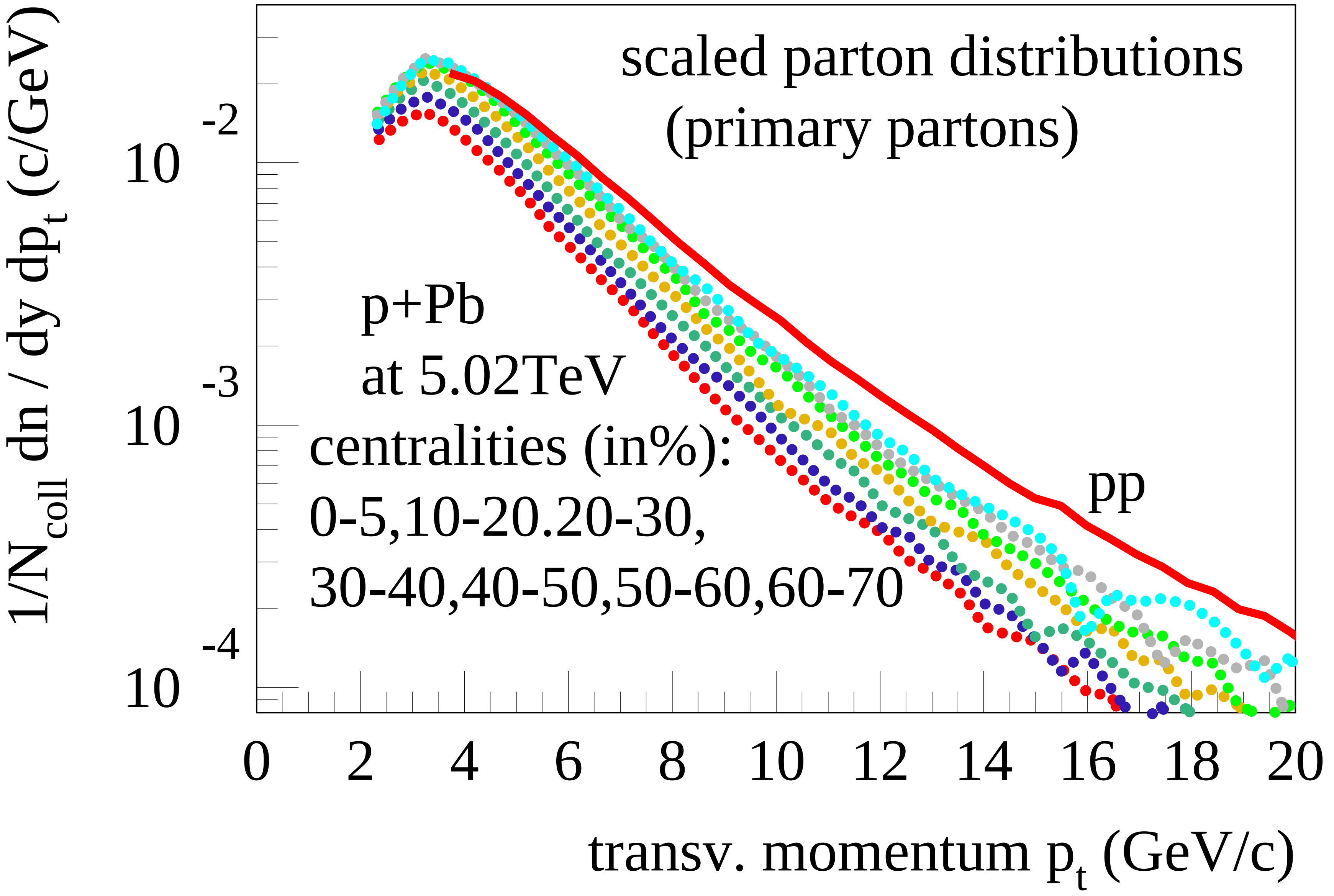
Reminder: PbPb with constant scale Q_0



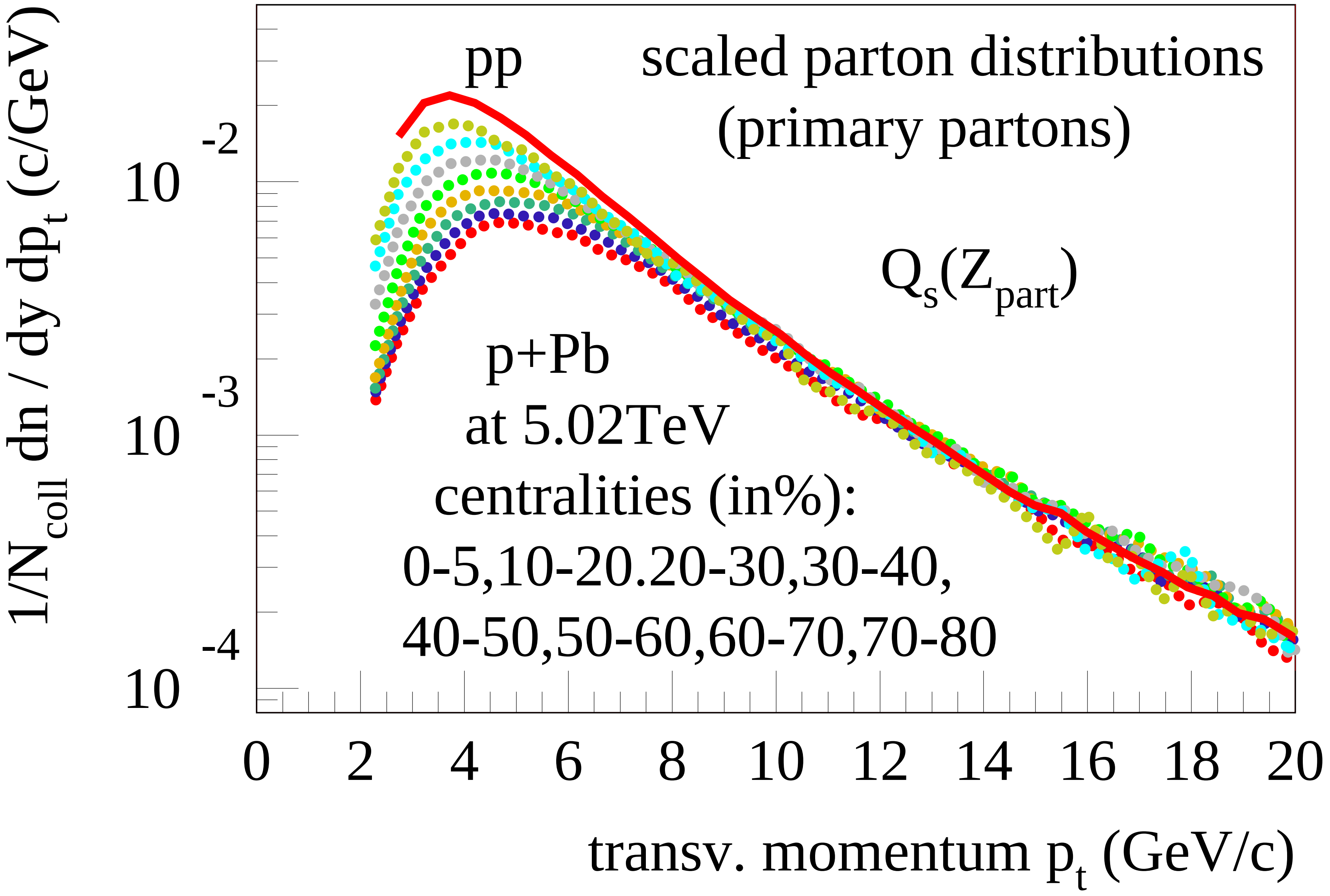
... with saturation scale



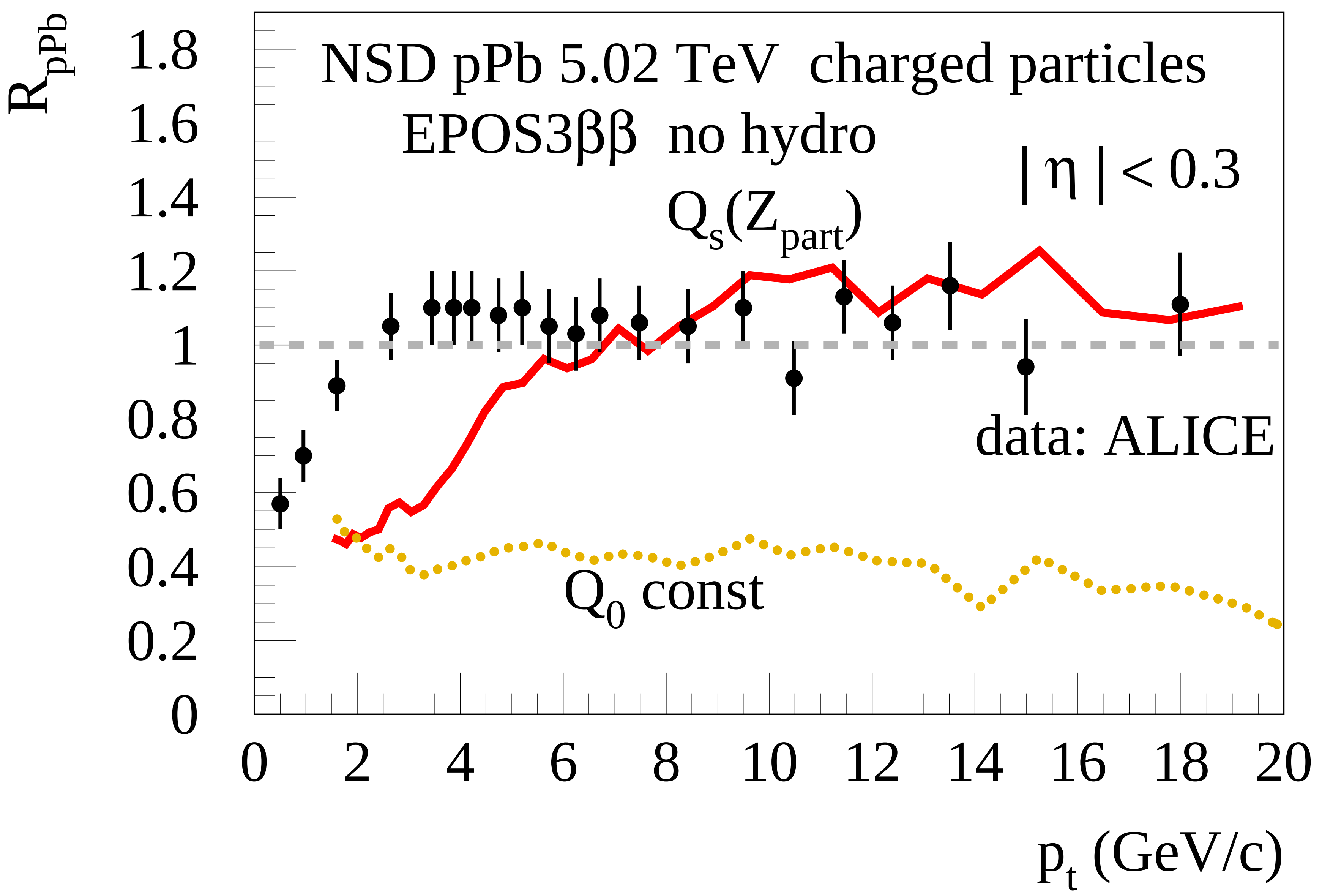
Reminder: pPb with constant scale Q_0



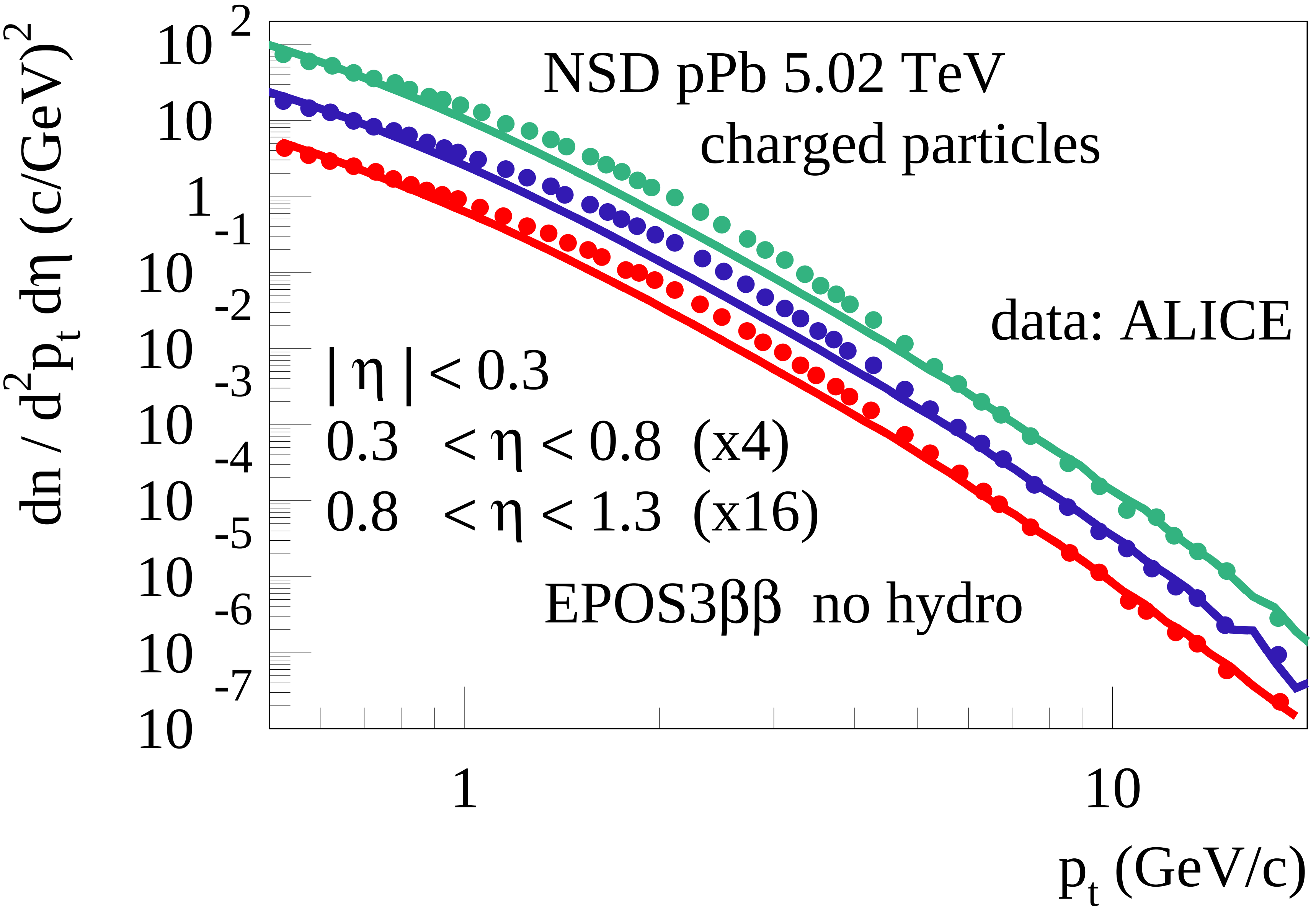
... with saturation scale



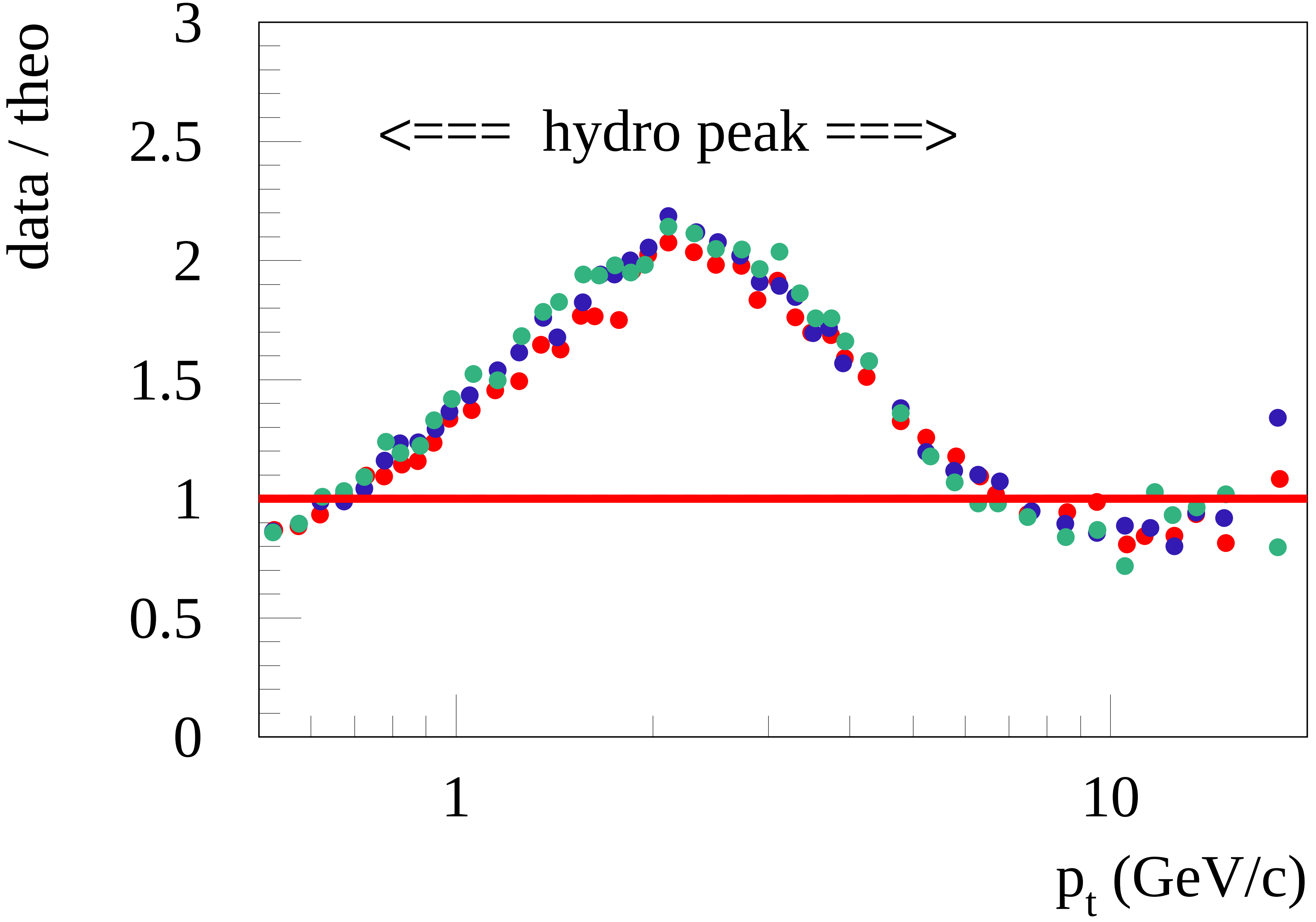
Charged particle production in pPb



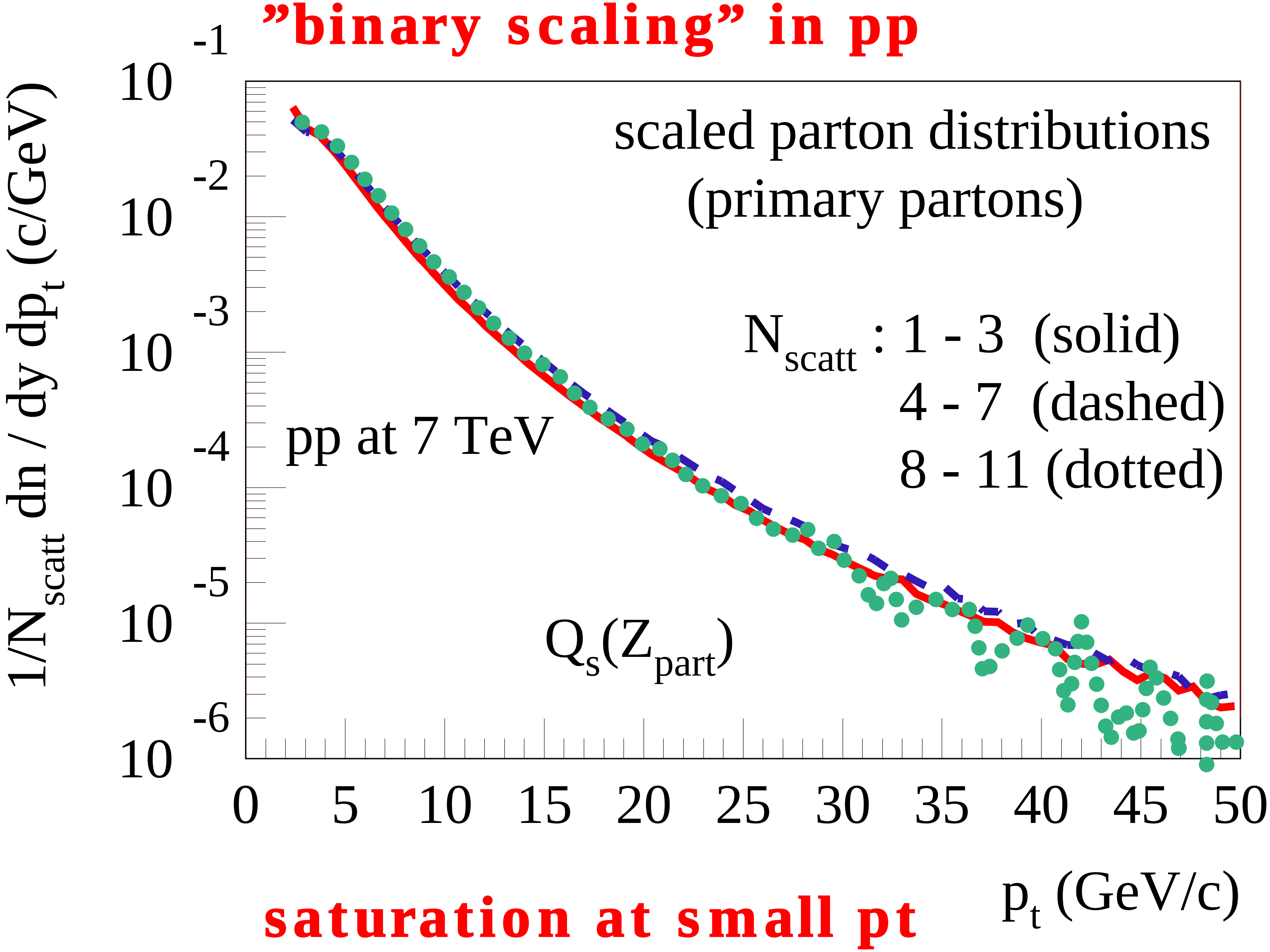
η dependence of pt spectra in pPb



data / theory in pPb



"binary scaling" in pp



saturation at small pt

Multiple scattering test in pp:

Correlate multiplicities of hard (D, J / Psi,...) and soft production (low pt pions, charged):

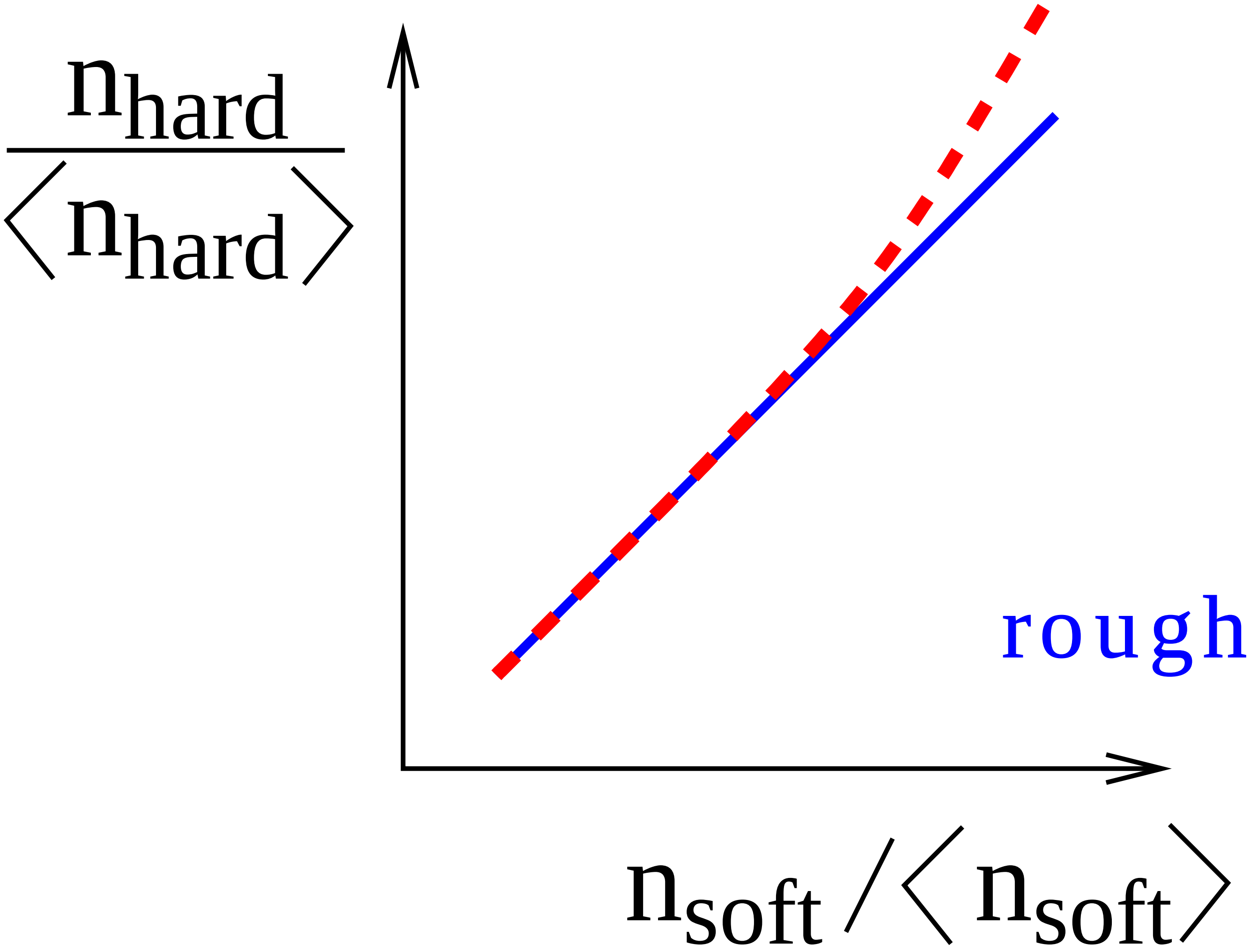
Binary scaling =>

$$n_{\mathrm{hard}} \propto N_{\mathrm{scatt}}$$

Saturation =>

$$n_{\mathrm{soft}} \lesssim N_{\mathrm{scatt}}$$

(but small effect)



Excess at
high mult
(saturation!!)

roughly linear

see E.G.Ferreiro, C.Pajares, arXiv:1203.5936

Summary: We present a multiple scattering scheme with the following principles:

☐ **All scatterings are equal**, implying

☐ democratic **energy sharing**

☐ **Binary scaling is perfectly restored**
when introducing
individual saturation scales $Q_s(N_{part})$

☐ **Binary scaling also in pp!**

Summary: We present a multiple scattering scheme with the following principles:

☐ **All scatterings are equal**, implying

☐ democratic **energy sharing**

☐ **Binary scaling is perfectly restored**
when introducing
individual saturation scales $Q_s(N_{part})$

☐ **Binary scaling also in pp!**

Thank you