(SOME) FEATURES OF PP INTERACTIONS AT LHC IN QGSM

E. Zabrodin (UiO & SINP MSU)

in collaboration with

J. Bleibel, L. Bravina, M.S. Nilsson

QGSM version

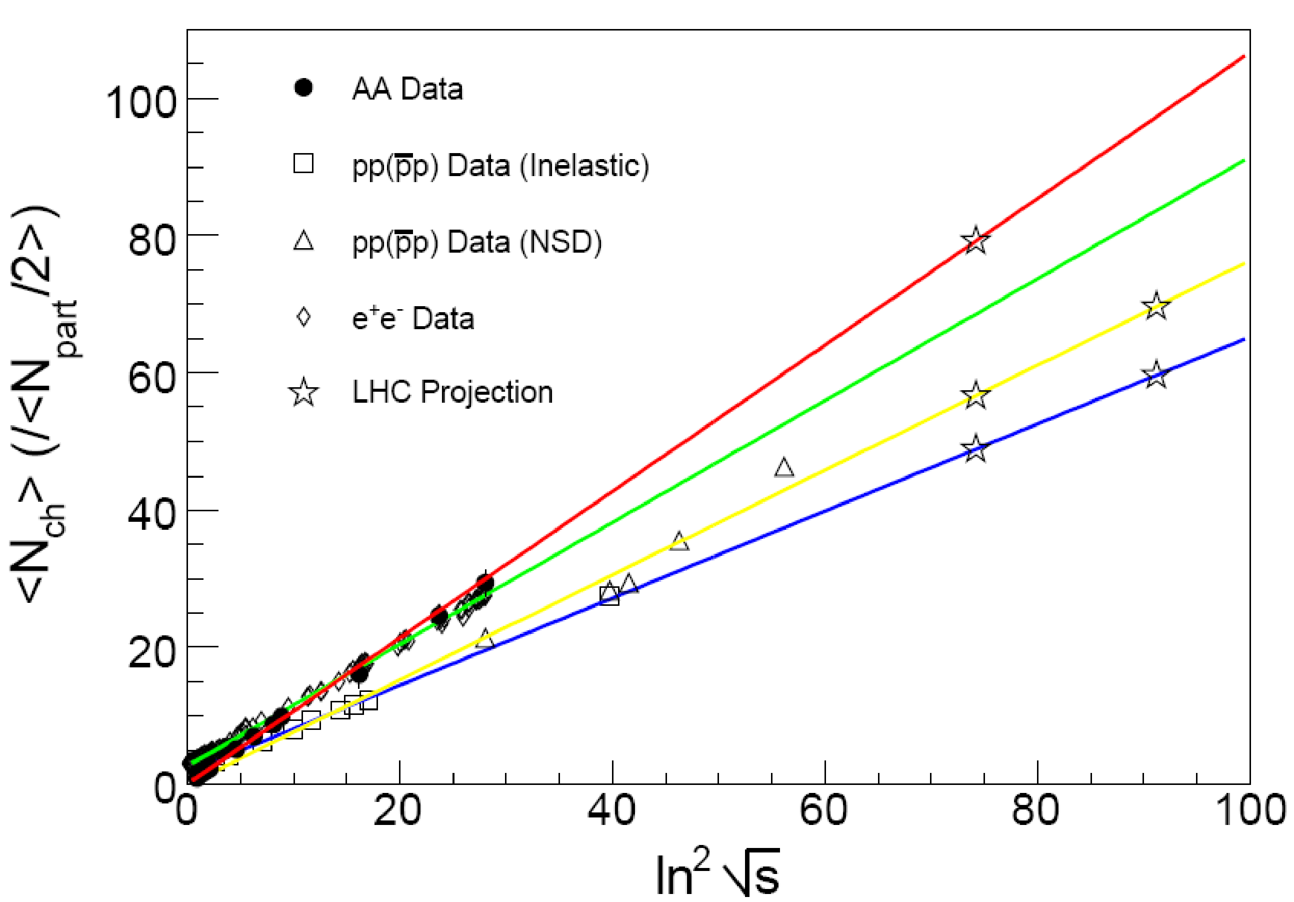
theory: A.B. Kaidalov MC realisation: **N.S. Amelin**

Int. Moscow Workshop on Phenomenology of Particle Physics (Moscow, 21-25.07.2013)

Devoted to the memory of A.B.Kaidalov

MOTIVATION: SCALING BEHAVIOR

W. Busza, JPG 35 (2008) 044040



Predictions for LHC

inelastic pp :

N_{ch}=60 ±10 (14TeV)

N_{ch}=49 ± 8 (5.5TeV)

NSD pp :

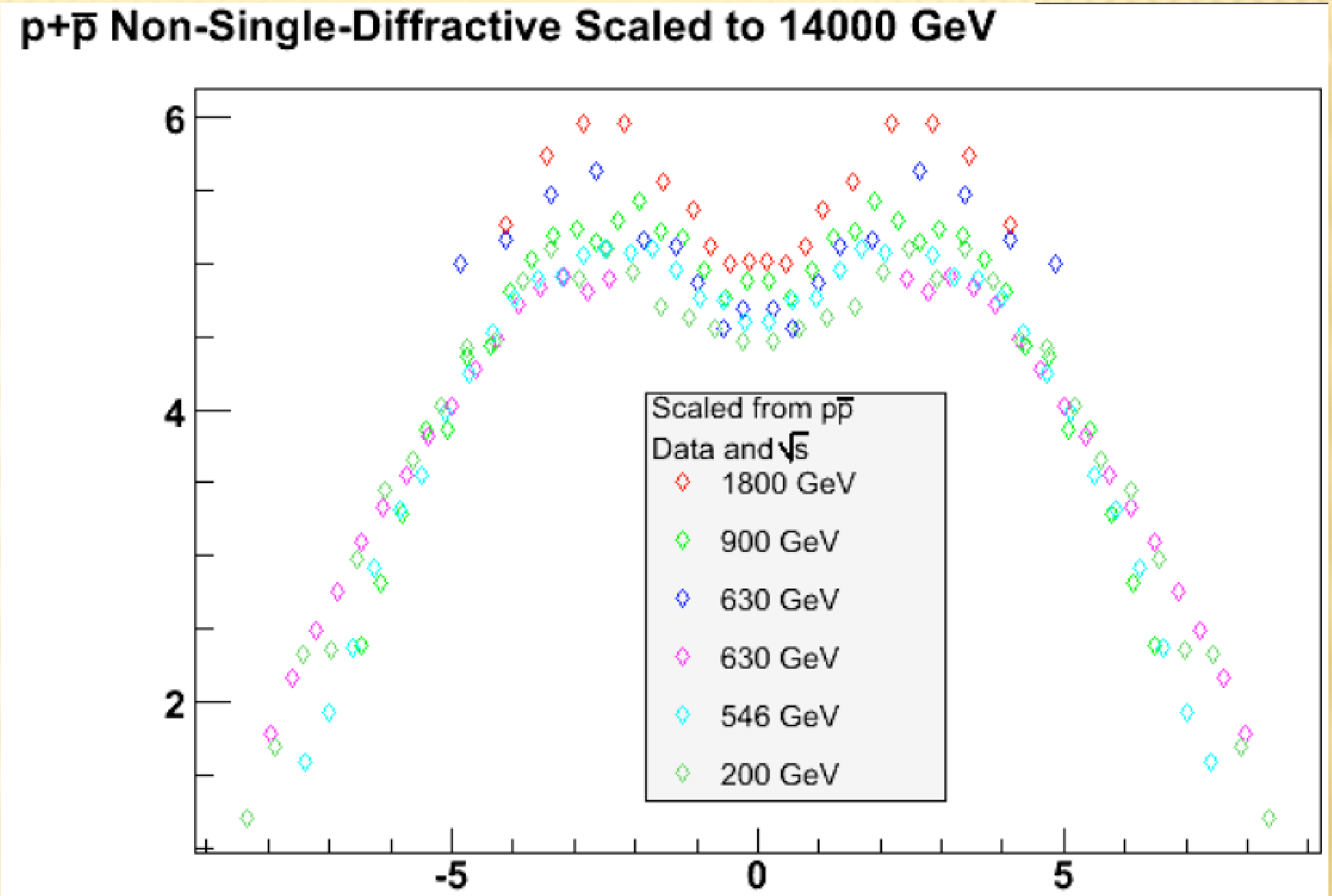
N_{ch}=70 ± 8 (14 TeV)

N_{ch}=57 ± 7 (5.5TeV)

Energy dependence of particle multiplicities

MOTIVATION: EXPERIMENTAL RESULTS

W. Busza, JPG 35 (2008) 044040

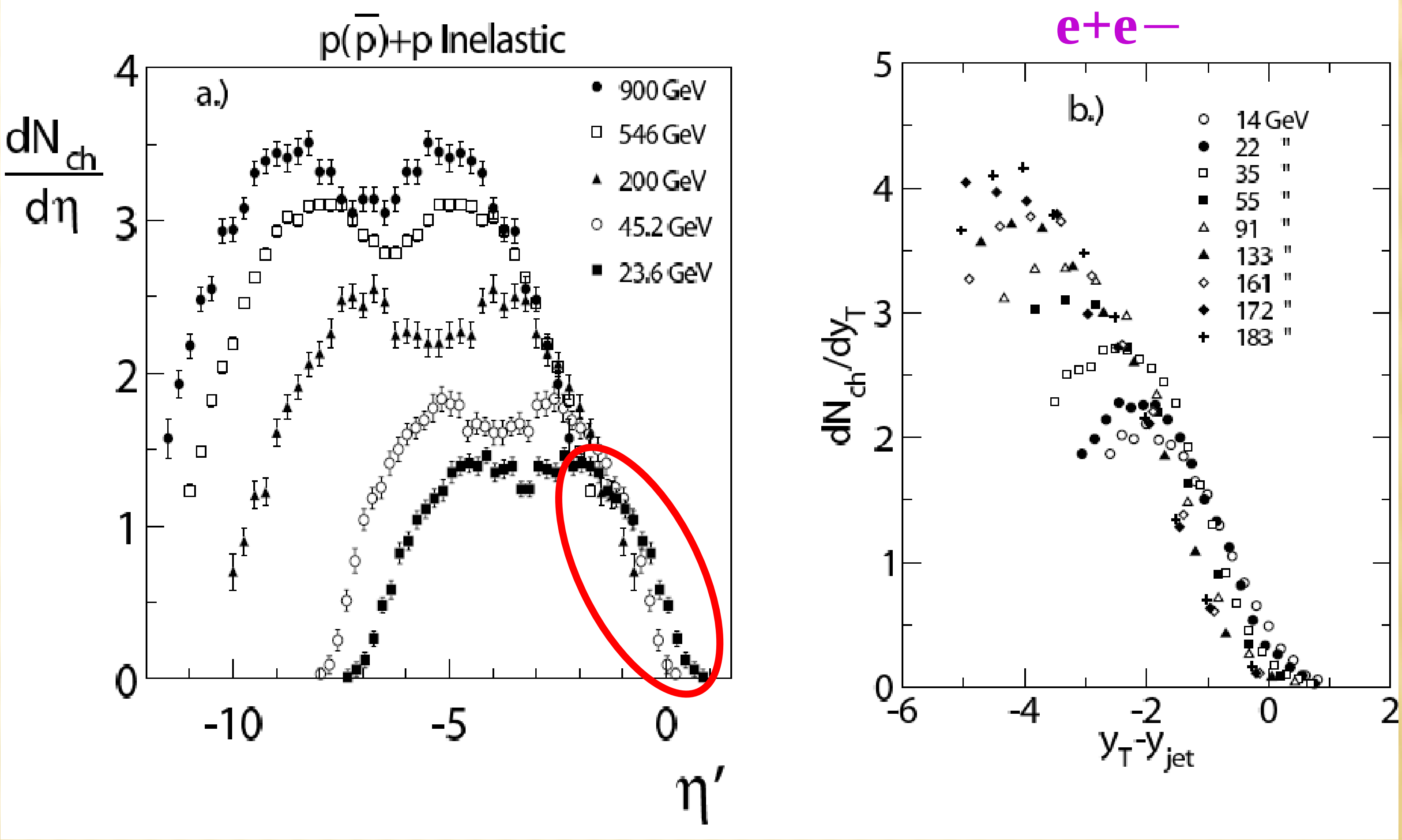


Extrapolation of NSD pp data to LHC using ln√s scaling of the width and height of the distribution

MOTIVATION: EXPERIMENTAL RESULTS

Extended longitudinal scaling

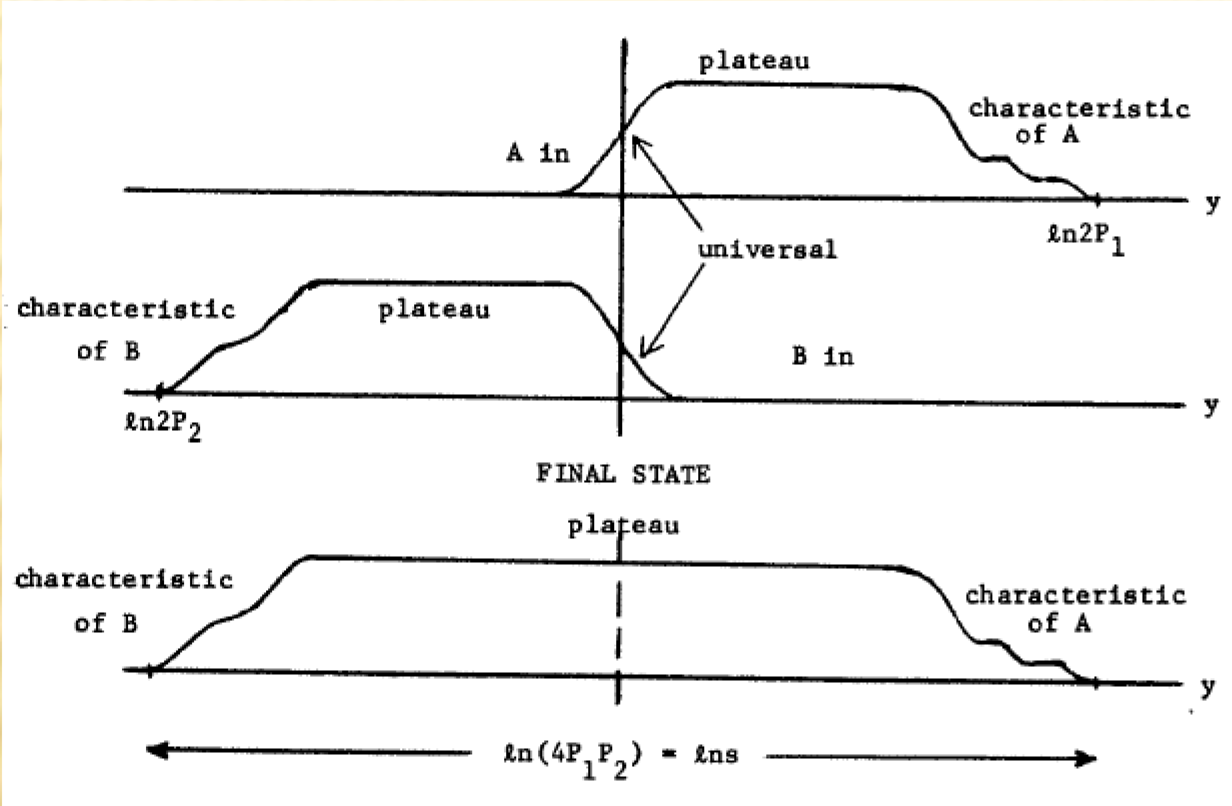
W. Busza, JPG 35 (2008) 044040



Example of extended longitudinal scaling in different reactions

HYPOTHESIS OF FEYNMAN SCALING

R. Feynman, PRL 23 (1969) 1415; also in ”Photon-hadron interactions”



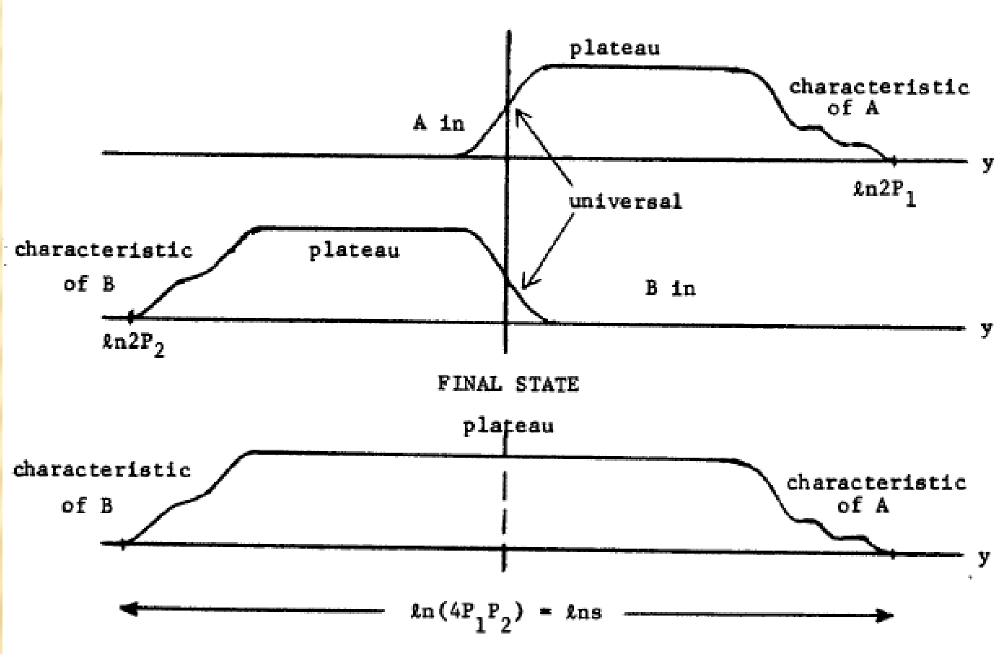
In terms of rapidity

$$-\ln[x_0\sqrt{s}/m_T] \le y^* \le \ln[x_0\sqrt{s}/m_T]$$

Basic assumption: scaling of inclusive spectra within the whole kinematically allowed region of x_F (or c.m. y)

In addition: existence of central area $-x_0 \le x_F \le x_0$, where $x_0 \approx (0.1-0.2)$ is assumed.

CONSEQUENCES OF FEYNMAN SCALING



(1) Logarithmic rise of the central rapidity region with energy

$$(\Delta y^*) \approx 2\ln(x_0\sqrt{s}/m_T)$$

(2) Fragmentation regions are fixed

$$(\Delta y^*) \approx \ln(1/x_0)$$

(3) Main contribution to mean multiplicity comes from the central area

$$\langle n\rangle \sim \ln(x_0\sqrt{s}/m_T)$$

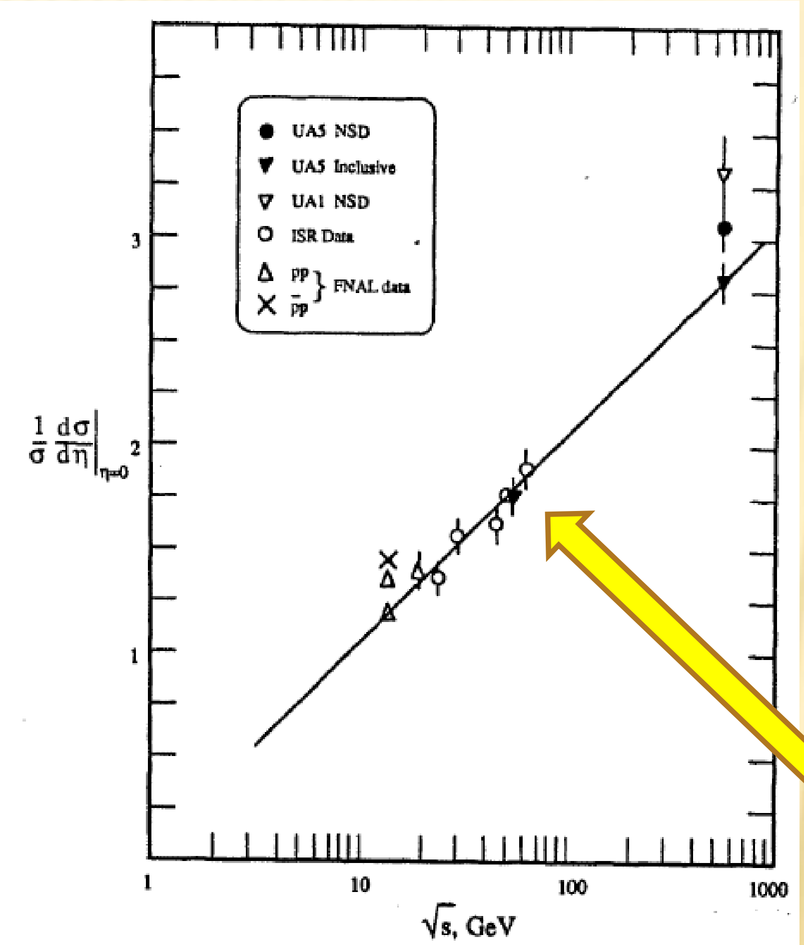
(4) In the central area particle density does not depend on energy and rapidity

$$\rho(y^*, p_T; \sqrt{s}) = \rho(p_T)$$

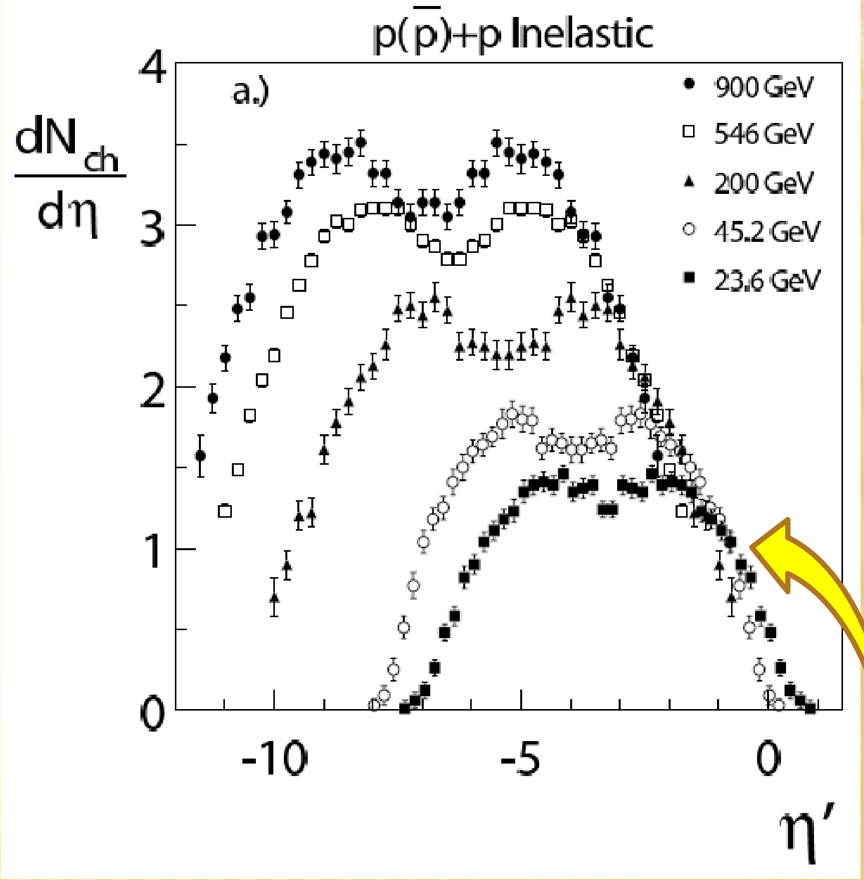
(5) Contribution from the fragmentation regions is energy independent

VIOLATION OF FEYNMAN SCALING

UA5 Collab., Phys. Rep. 154 (1987) 247



W. Busza, JPG 35 (2008) 044040

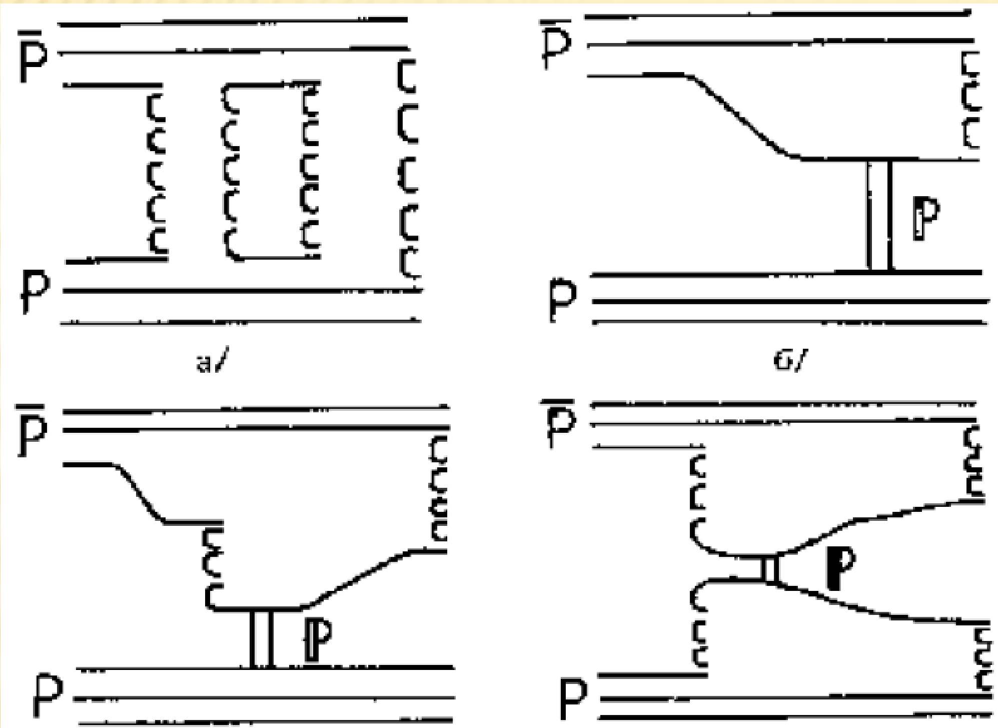


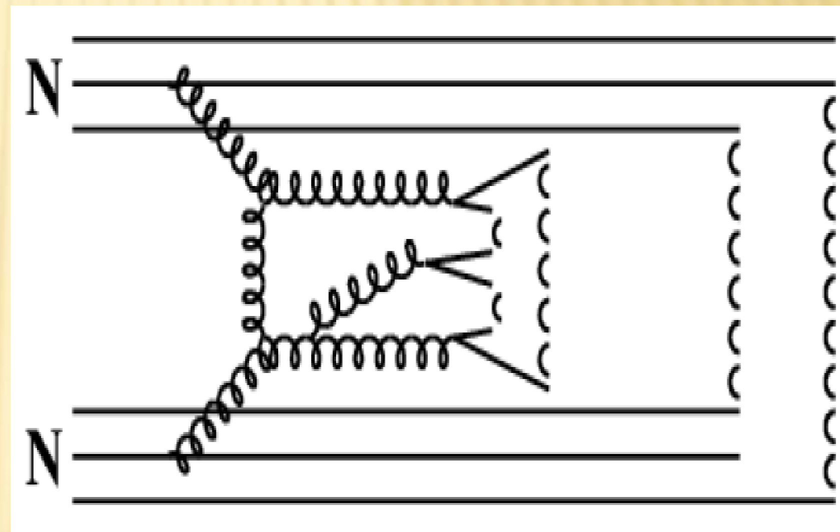
Charged particle pseudorapidity density at $\eta = 0$ as a function of $\sqrt{s}$

Violation of Feynman scaling, but ext. long. scaling holds?!

QUARK-GLUON STRING MODEL

A.B. Kaidalov, K.A.Ter-Martirosyan, PLB 117 (1982)
N.S.Amelin, L.V.Bravina, Sov.J.Nucl.Phys. 51 (1990) 133
N.S.Amelin, E.F.Staubo, L.P.Csernai, PRD 46 (1992) 4873





At ultra-relativistic energies: multi-Pomeron scattering, single and double diffraction, and jets (hard Pomeron exchange)

Gribov’s Reggeon Calculus + string phenomenology

QUARK-GLUON STRING MODEL

$$\sigma_{ND}(s) = \sum_{n=1}^{\infty} \sigma_n(s) + \sigma_{DD}(s) \ .$$

$$\sigma_{tot}(s) = \sum_{n=0}^{\infty} \sigma_n(s) = \sigma_P \, f\left(\frac{z}{2}\right) \ ,$$

$$\sigma_n(s) = \frac{\sigma_P}{nz}\left(1 - \exp(-z)\sum_{k=0}^{n-1}\frac{z^k}{k!}\right) \ , \ k \geq 1$$

$$\sigma_0 = \sigma_P \left(f\left(\frac{z}{2}\right) - f(z)\right) \ ,$$

$$f(z) = \sum_{\nu=1}^{\infty} \frac{(-z)^{\nu-1}}{\nu \nu!} \ ,$$

$$\sigma_P = 8\pi\gamma_P \exp(\Delta\xi) \ ,$$

$$z = \frac{2C\gamma_P}{(R_P^2 + \alpha'_P\xi)} \exp(\Delta\xi) \ .$$

$$u(s,b) = u_{soft}(s,b) + u_{hard}(s,b)$$

$$\sigma_{inel}(s) = 2\pi \int_0^{\infty} \left\{1 - \exp\left[-2u^R(s,b)\right]\right\} bdb \ .$$

$$u^R_{soft/hard}(s,b) = z_{soft/hard}(s) \exp\left[-\frac{\beta^2}{4\,\lambda_{soft/hard}(s)}\right]$$

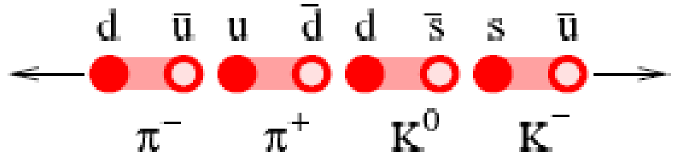
$$z_{soft/hard}(s) = \frac{\gamma_P}{\lambda_{soft/hard}(s)} \left(\frac{s}{s_0}\right)^{\alpha_P(0)-1}$$

$$\lambda_{soft/hard}(s) = R_P^2 + \alpha'_P \ln\left(\frac{s}{s_0}\right) \ .$$

QUARK-GLUON STRING MODEL

Decay of strings - production of mesons and baryons:

- the colorfield between a quark and a antiquark gets "streched"
- a meson (baryon) with some transverse momentum is formed and gets a fraction *z* of the primordial momentum of the string
- *z* is generated from the fragmentation function
- the rest of the string either decays further of forms a cluster



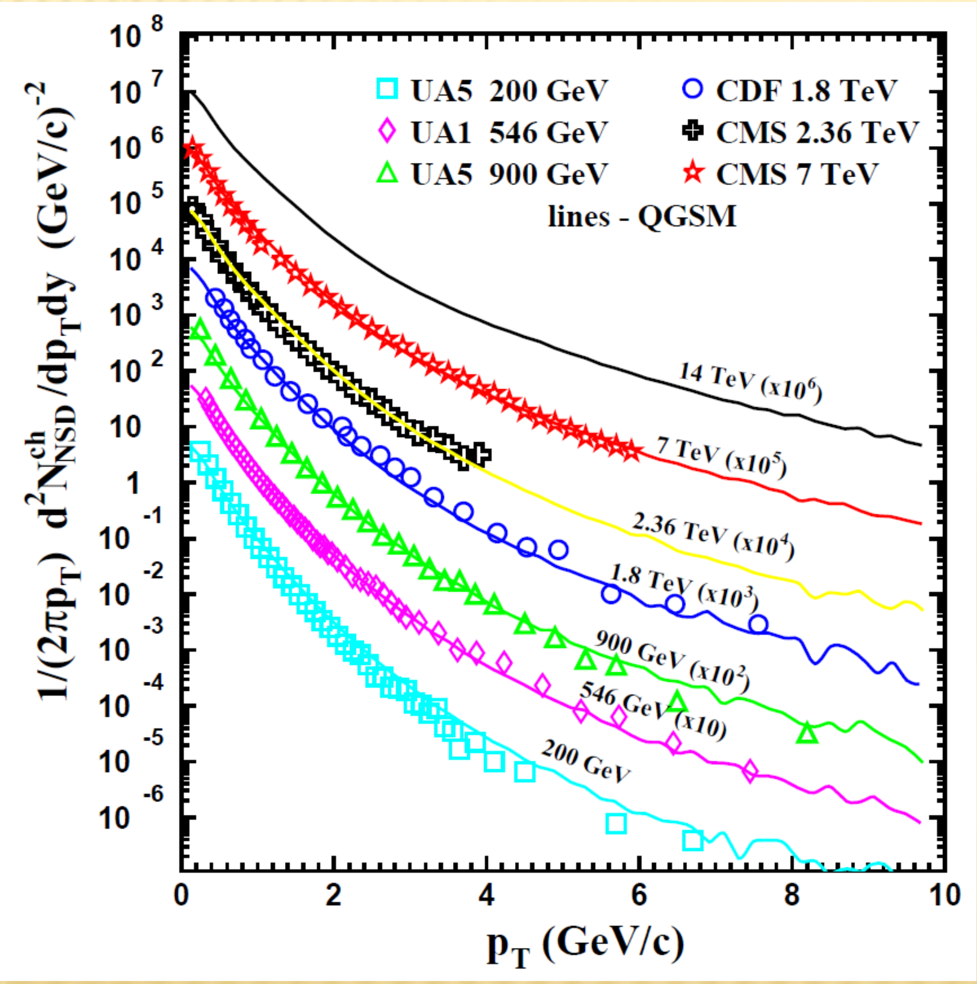
production of mesons

production of baryons

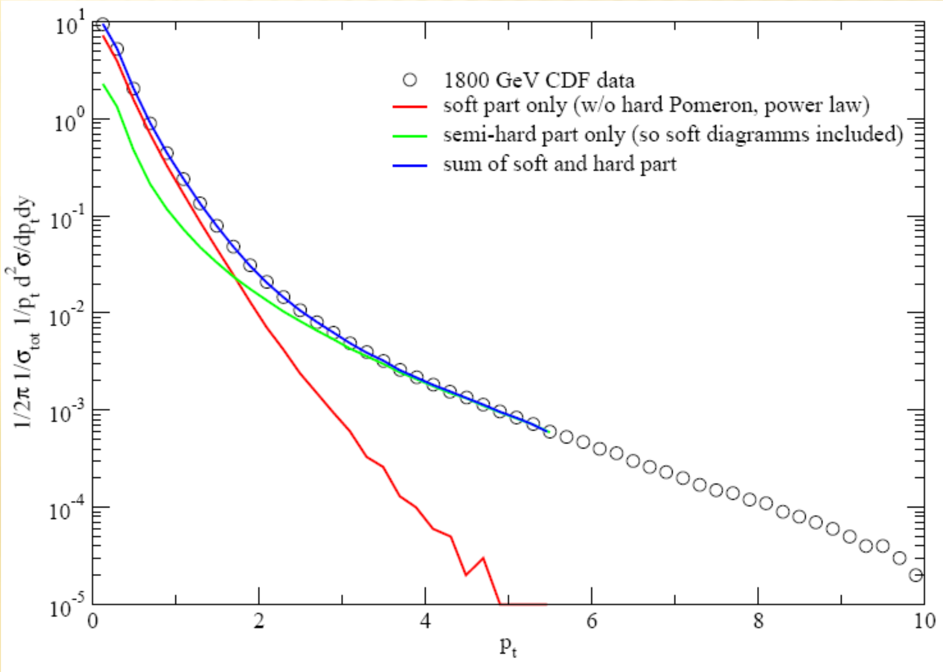
Decay of strings and particle production

P_T SPECTRA: MODEL VS. DATA

Transverse momentum spectra



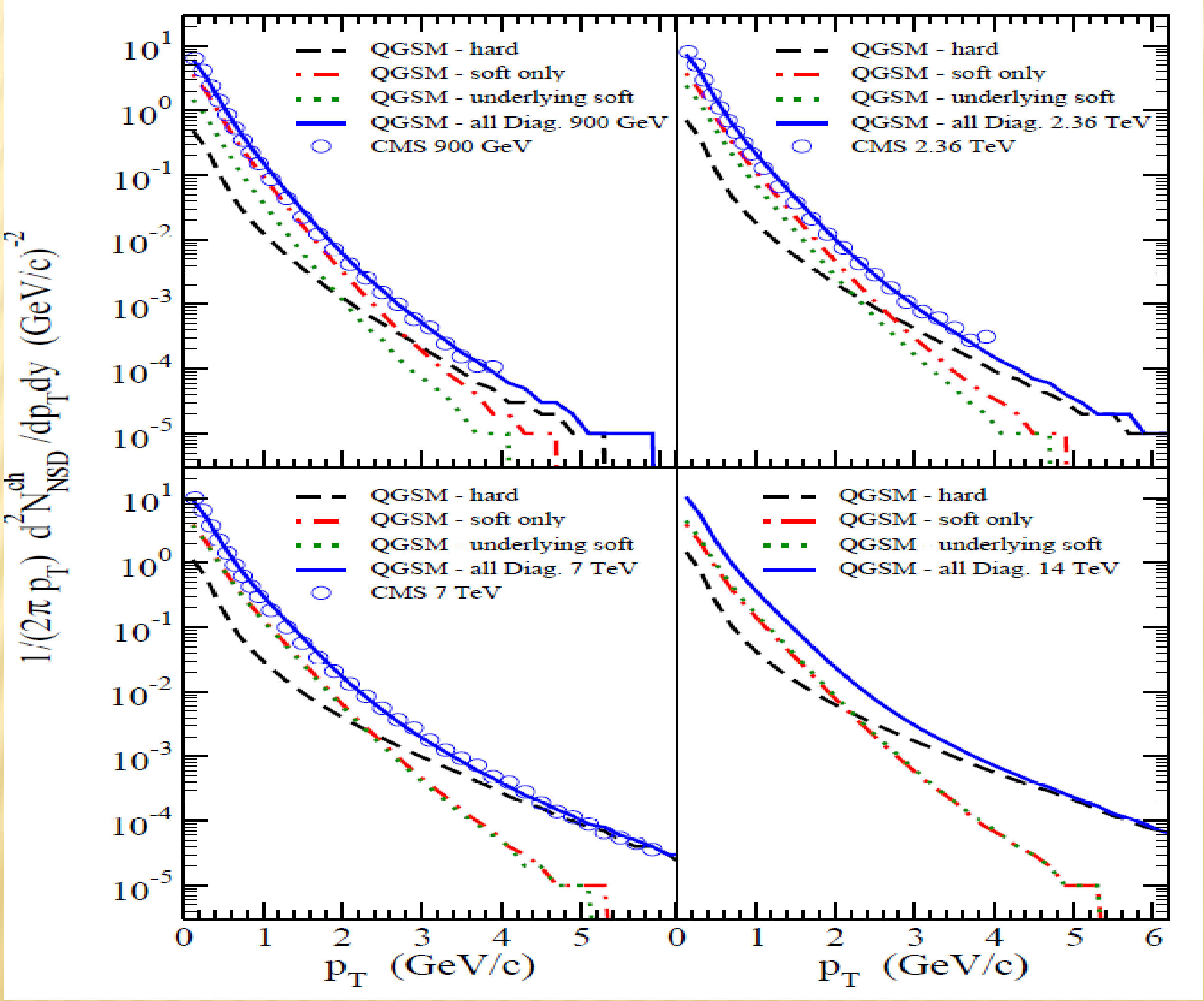
Hard and soft components



Description of P_t spectra seems to be good

P_T SPECTRA: MODEL VS. DATA

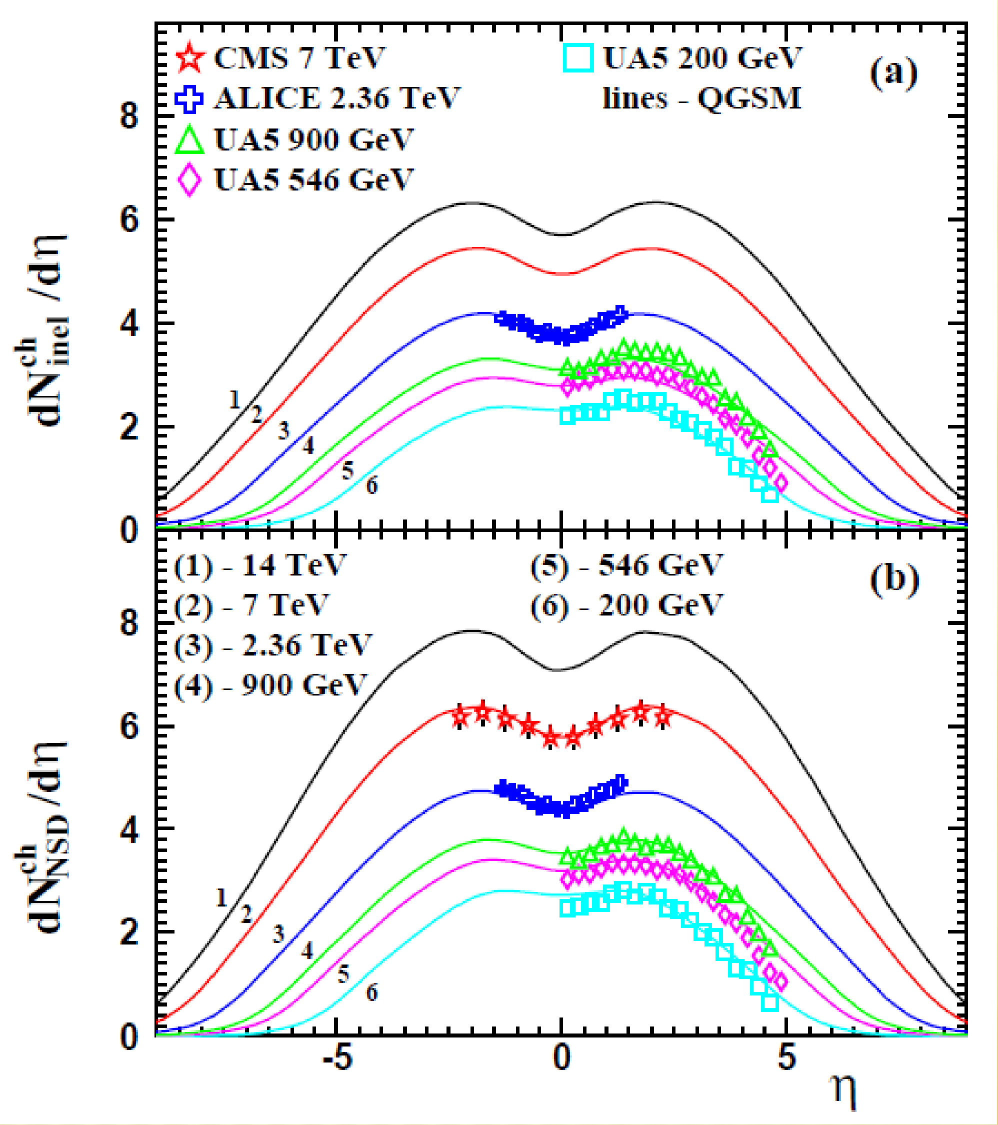
Hard and soft components from $\sqrt{s}$ = 900 GeV to 14 TeV



RAPIDITY SPECTRA: MODEL VS. DATA

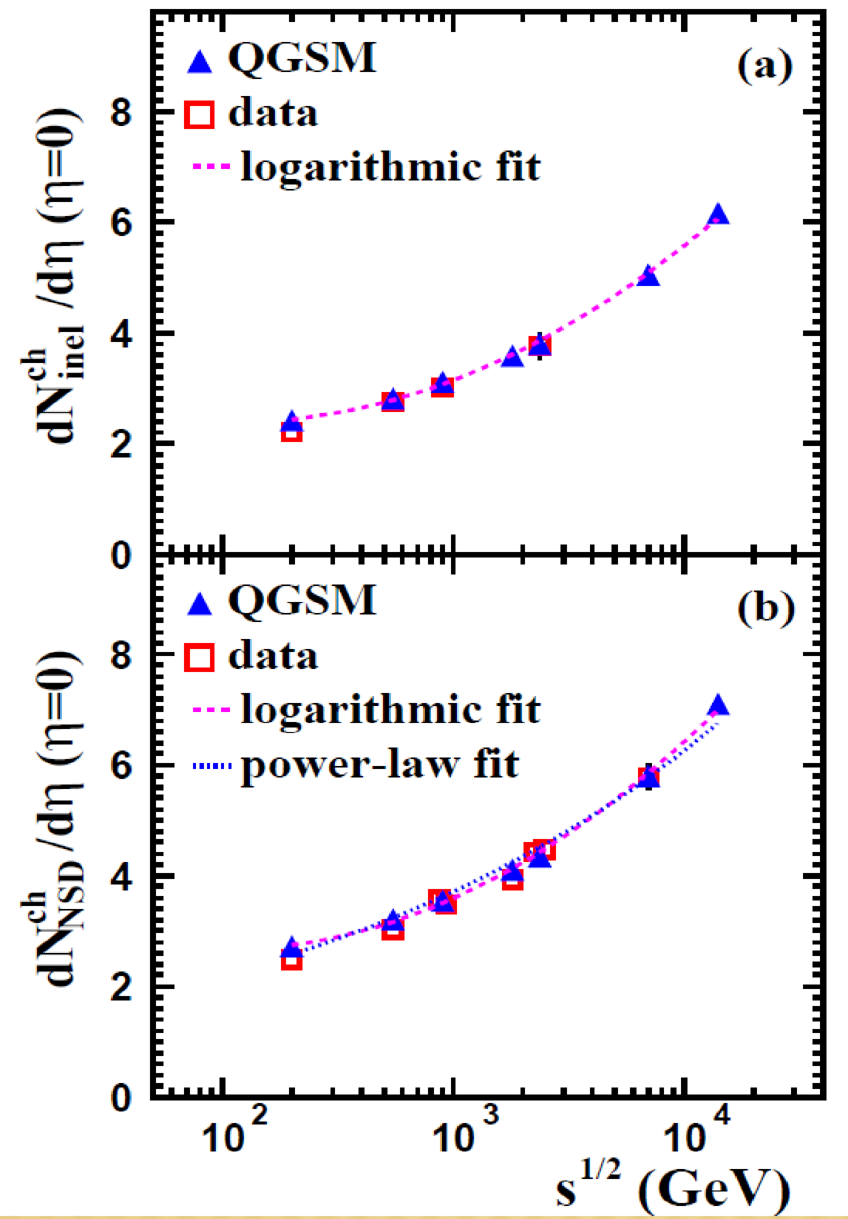
Inelastic collisions

NSD collisions



Description of pseudorapidity spectra also seems to be good

FIT TO DATA: LOGARITHMIC OR POWER-LAW ?



CMS Collaboration (K. Khachatryan *et al.*), Phys. Rev. Lett. **105**, 022002 (2010) (arXiv:1005.3299 [hep-ex]).

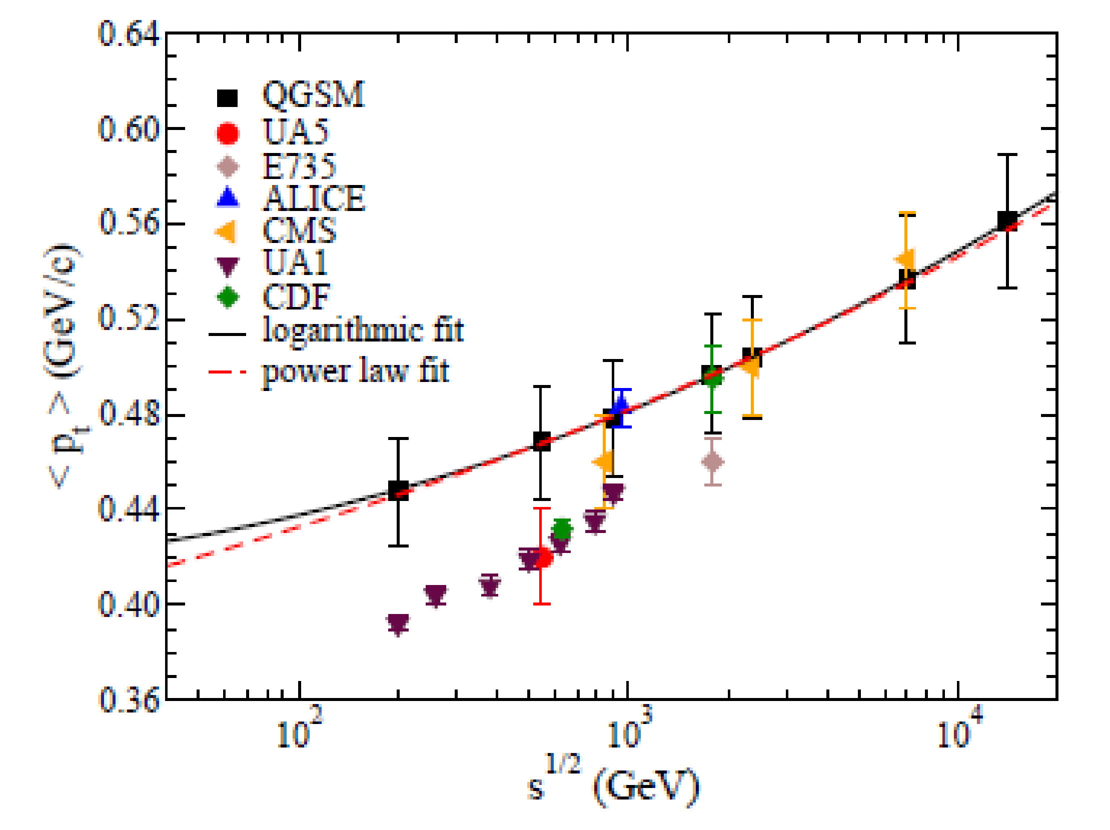
$$\frac{dN_{inel}}{d\eta}\Big|_{\eta=0}(s) = 5.87 - 0.74\ \ln s + 0.39\ \ln^2 s\ \ ,$$

$$\frac{dN_{NSD}}{d\eta}\Big|_{\eta=0}(s) = 6.58 - 0.84\ \ln s + 0.45\ \ln^2 s\ \ ,$$

$$\frac{dN_{NSD}}{d\eta}\Big|_{\eta=0}(s) = 0.77\, E^{0.23}\ \ .$$

L. McLerran and M. Praszalowicz, Acta Phys. Polon. B 41, 1917 (2010).

FIT TO DATA: LOGARITHMIC OR POWER-LAW ?

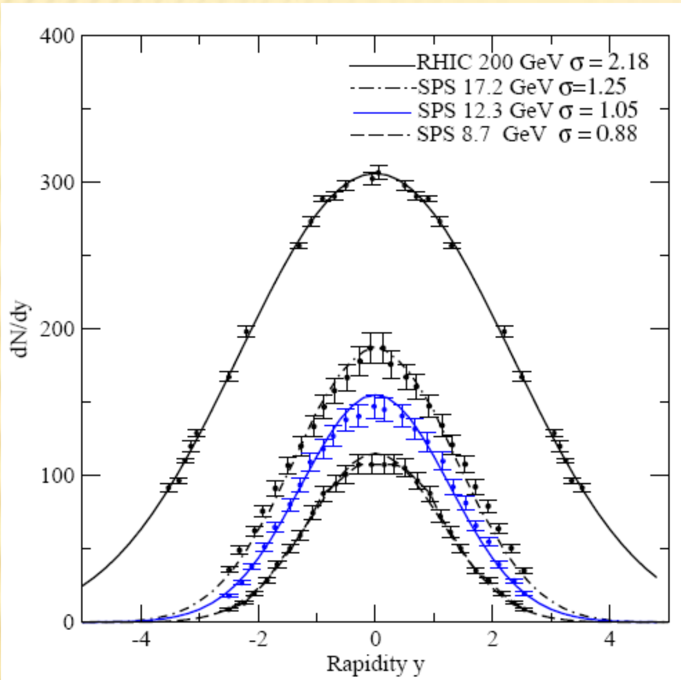


$$\langle p_T \rangle = 0.42 - 0.006 \ln s + 0.0022 \ln^2 s ,$$
$$\langle p_T \rangle = 0.27 + 0.212 E^{0.115} .$$

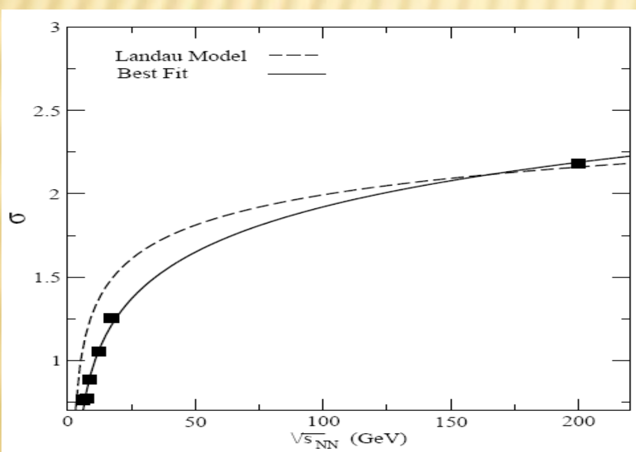
It is impossible to distinguish between these two fits even at 14 TeV

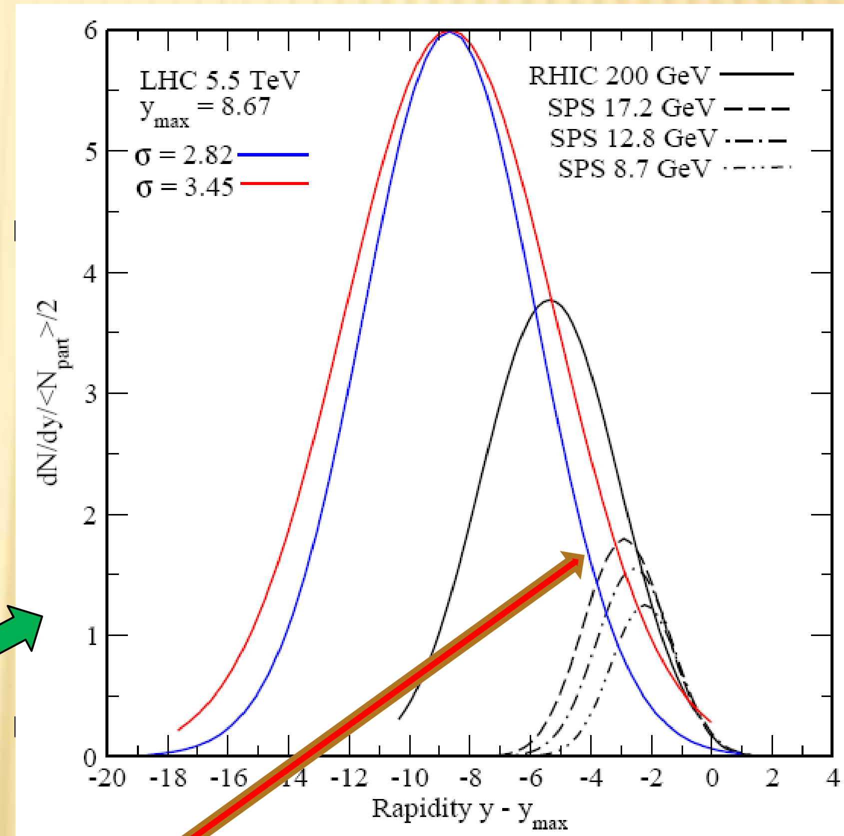
VIOLATION OF ELS IN A+A AT LHC?

J. Cleymans, J.Struempfer, L.Turko, PRC 78 (2008) 017901



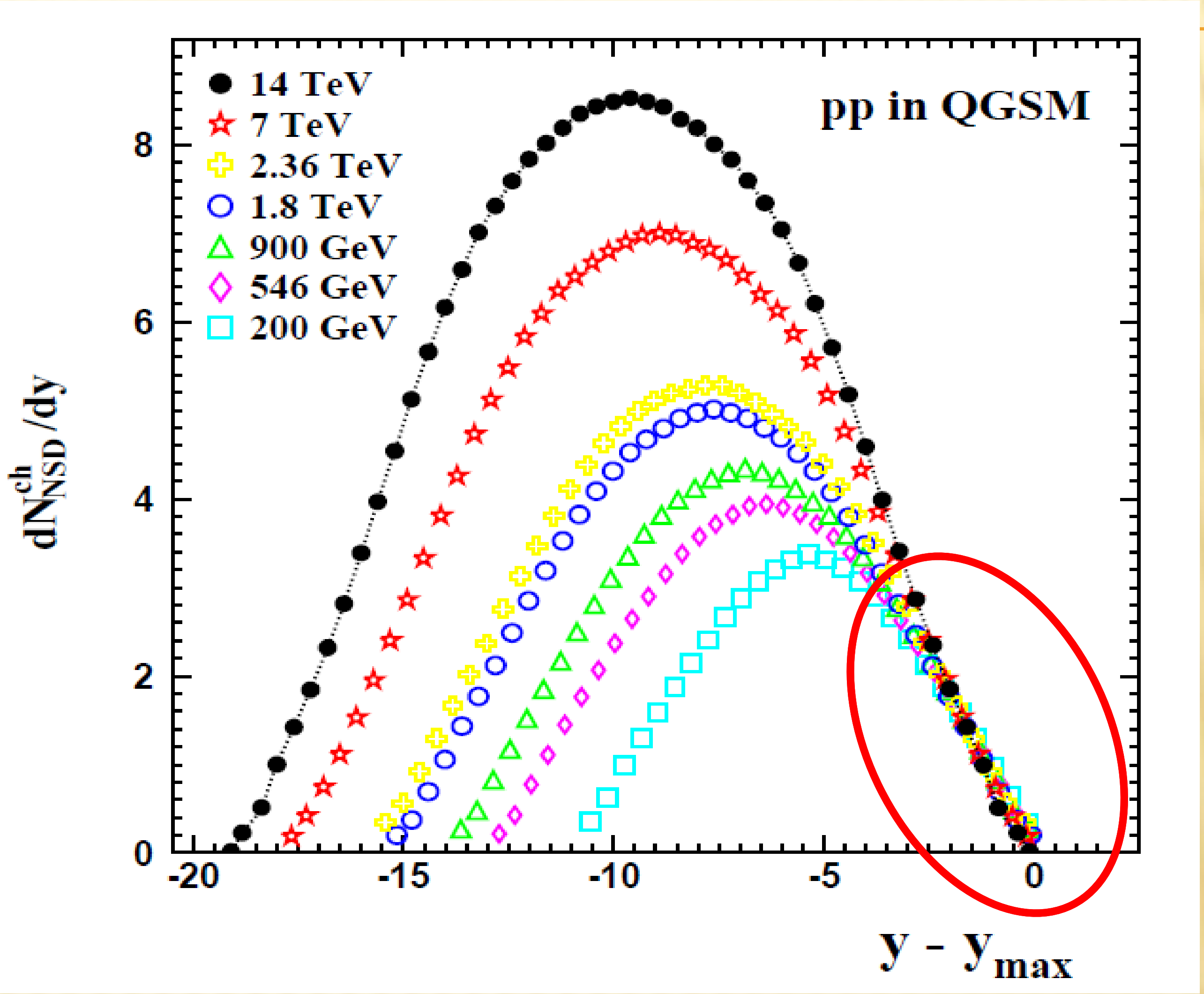
σ





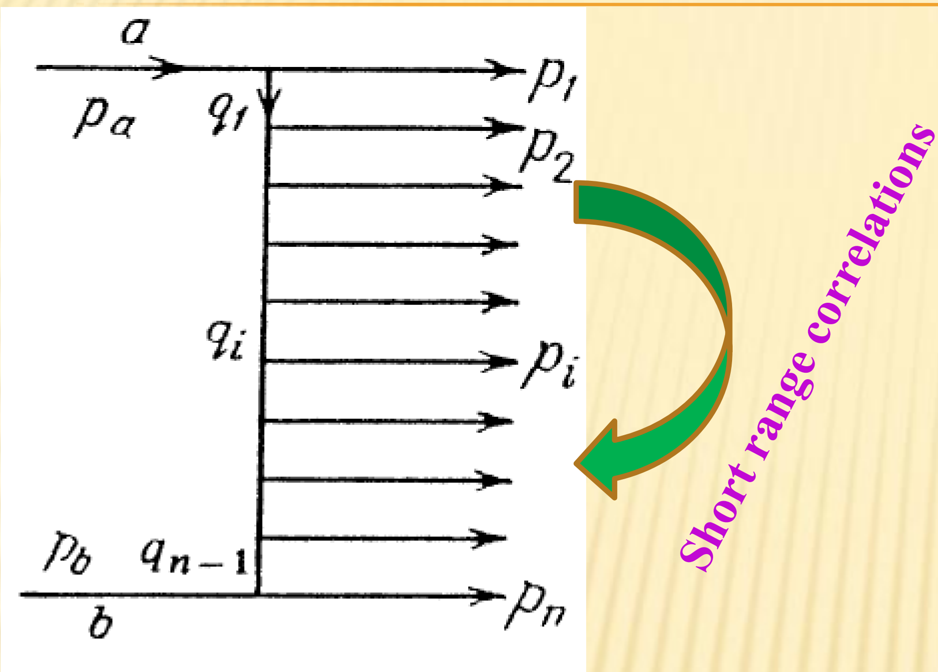
Statistical thermal model: ELS will be violated in A+A @ LHC. What about pp ?

EXTENDED LONGITUDINAL SCALING @ LHC



QGSM: extended longitudinal scaling in pp collisions holds

WHY SCALING HOLDS IN THE MODEL



Correlation function

$$C(y_i, y_j) \propto \exp\{-\lambda(y_i - y_j)\}$$

Particles are uncorrelated if

$$y_i - y_j \equiv \Delta y \gg 1$$

Consider now inclusive process

$$1 + 2 \to i + X$$

Particle inclusive cross section

$$f_i = \frac{d^2\sigma(y_1 - y_i, y_i - y_2, p_{iT}^2)}{dy_i d^2 p_{iT}}$$

In the fragmentation region of particle 1

$$y_1 - y_i \approx 1,\ y_i - y_2 \approx y_1 - y_2 \gg 1$$

$$x_F^{(i)} \equiv \frac{p_{i\|}}{p_\|^{\max}} \approx \exp\{-(y_1 - y_i)\}$$

therefore

$$n_i = \psi(x_F^{(i)}, p_{iT}^2)$$

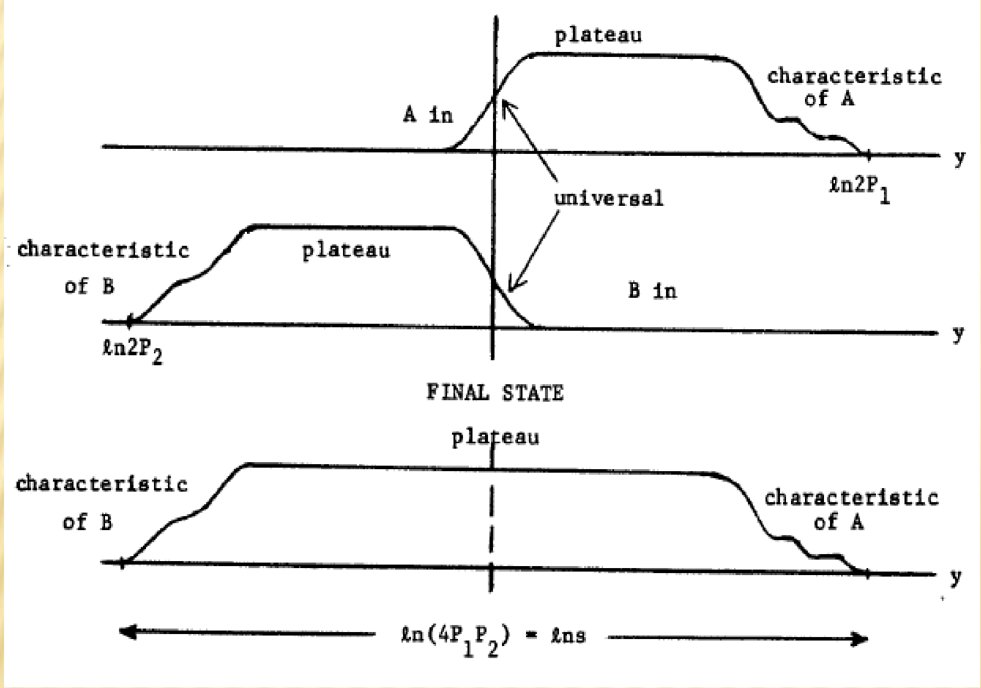
Inclusive density

$$\mathrm{n}_i = f_i / \sigma_{inel} = \phi(y_1 - y_i, p_{iT}^2)$$

In string models both FS and ELS holds in the fragmentation regions

KOBA-NIELSEN-OLESEN (KNO) SCALING

Z.Koba, H.B.Nielsen, P.Olesen, NPB 40 (1972) 317



They claim that if Feynman scaling holds, then the multiplicity distribution is independent of energy except through the variable

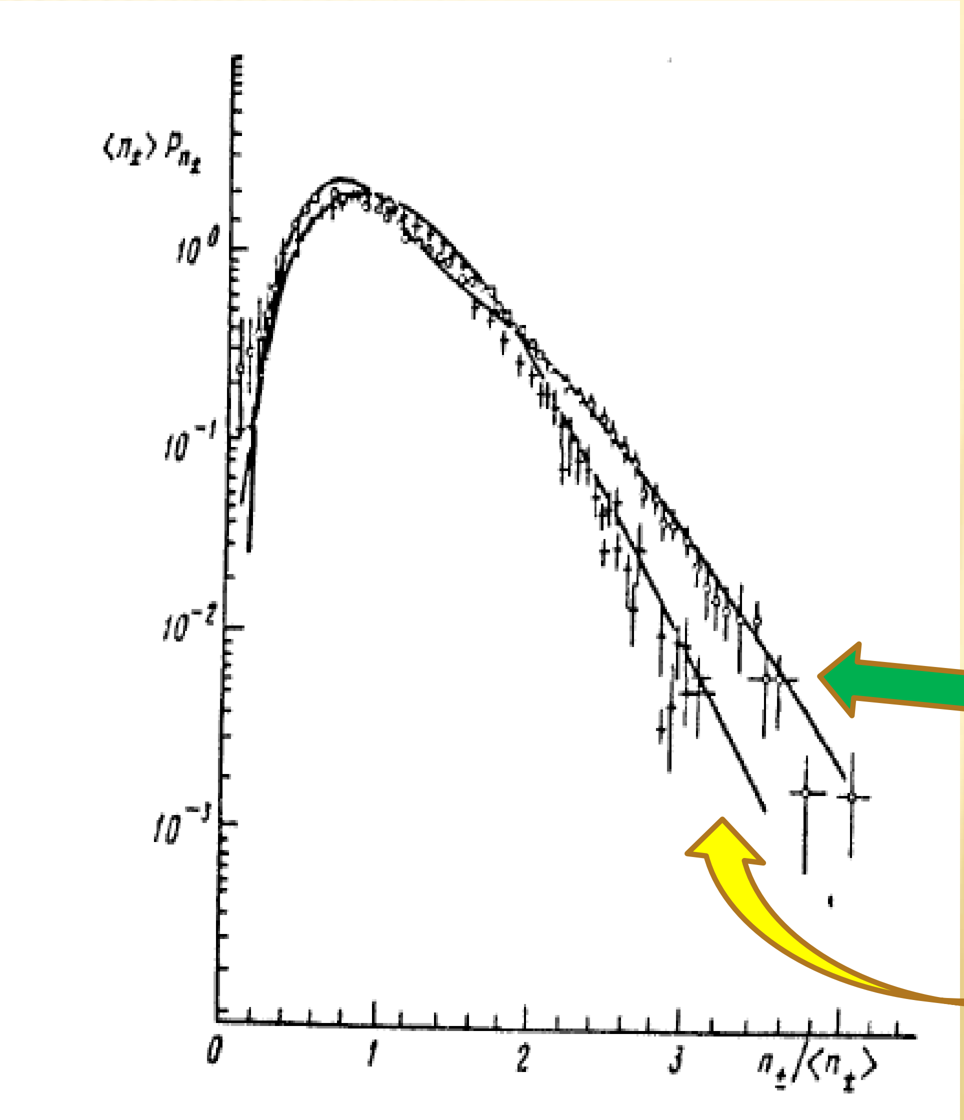
$$z = n / \langle n \rangle$$

$$P_n(s) = \frac{\sigma_n(s)}{\sigma_{tot}(s)} = \frac{1}{\langle n \rangle} \Psi\left(\frac{n}{\langle n \rangle} \right)$$

Experimental data: KNO scaling holds in *hh* collisions up to √s = 53 GeV (ISR)

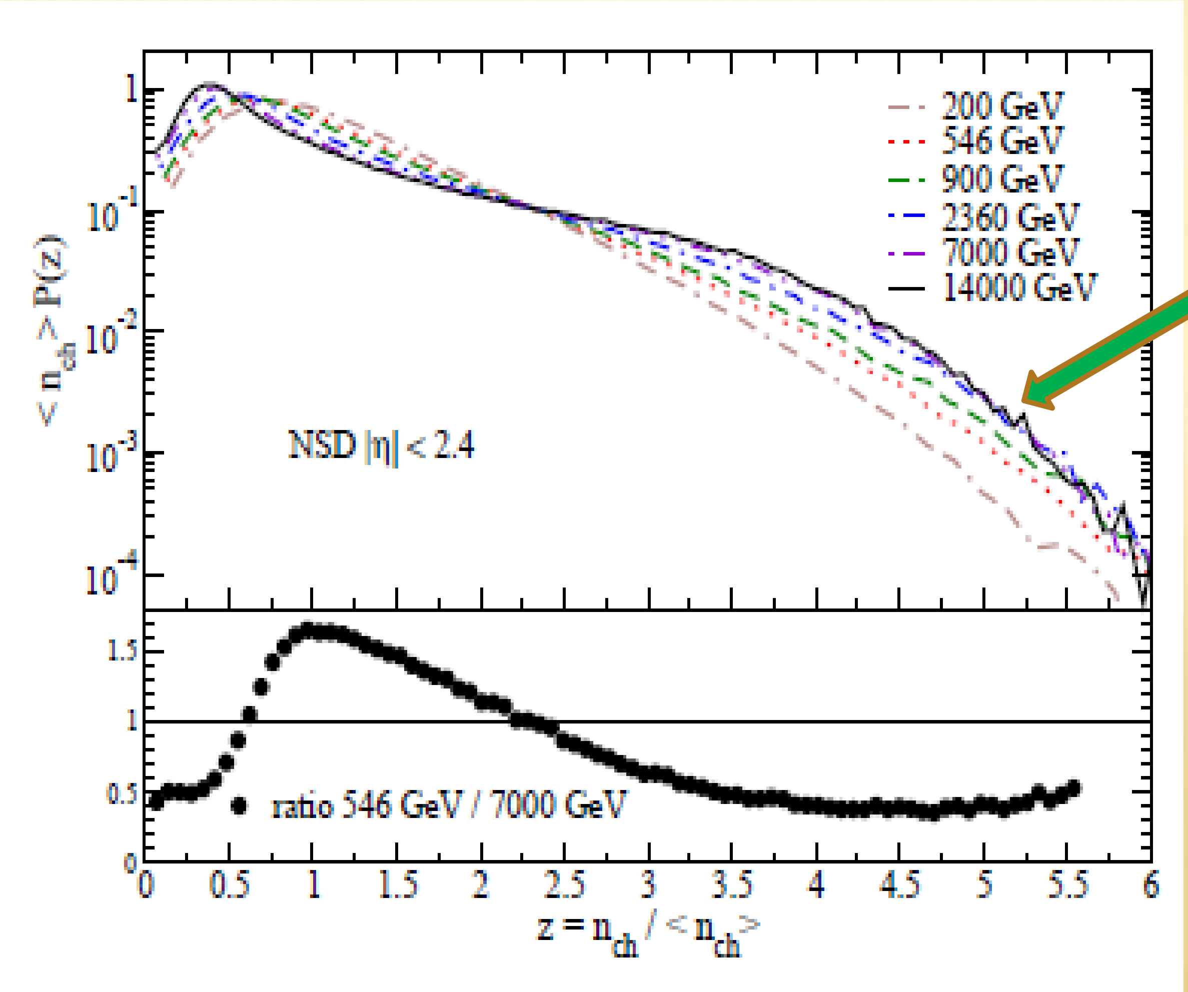
VIOLATION OF KNO SCALING

A.B.Kaidalov, K.A.Ter-Martirosyan, PLB 117 (1982) 247
UA5 Collaboration, Phys. Rep. 154 (1987) 247
N.S.Amelin, L.V.Bravina, Sov.J.Nucl.Phys. 51 (1990) 133



Charged-particle multiplicity distributions in the KNO variables in nondiffractive antiproton-proton collisions at $\sqrt{s}$ = 546 GeV and 53 GeV

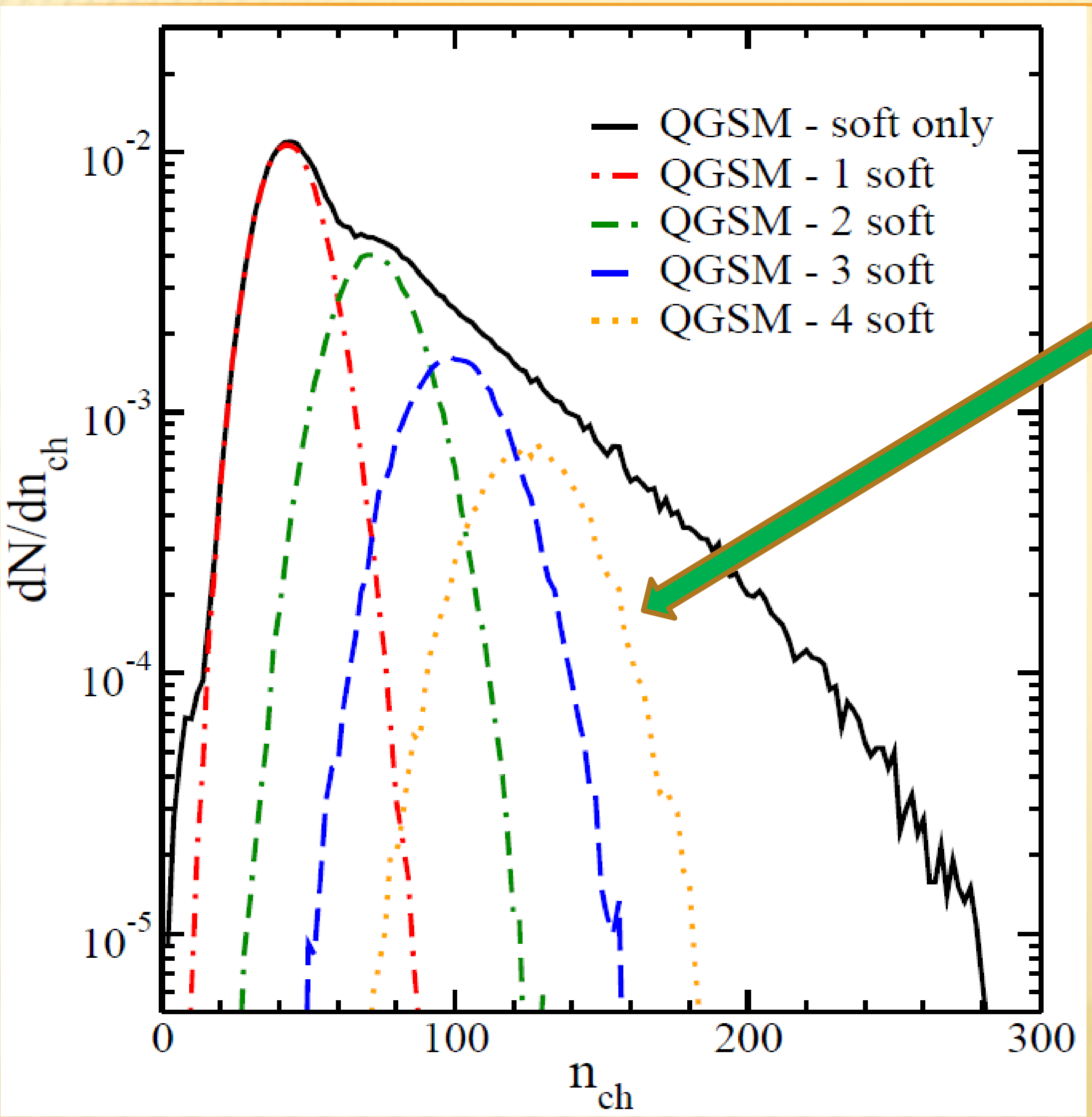
VIOLATION OF KNO SCALING AT LHC



High-multiplicity tail is pushed up, whereas maximum of the distribution is shifted towards small values of z

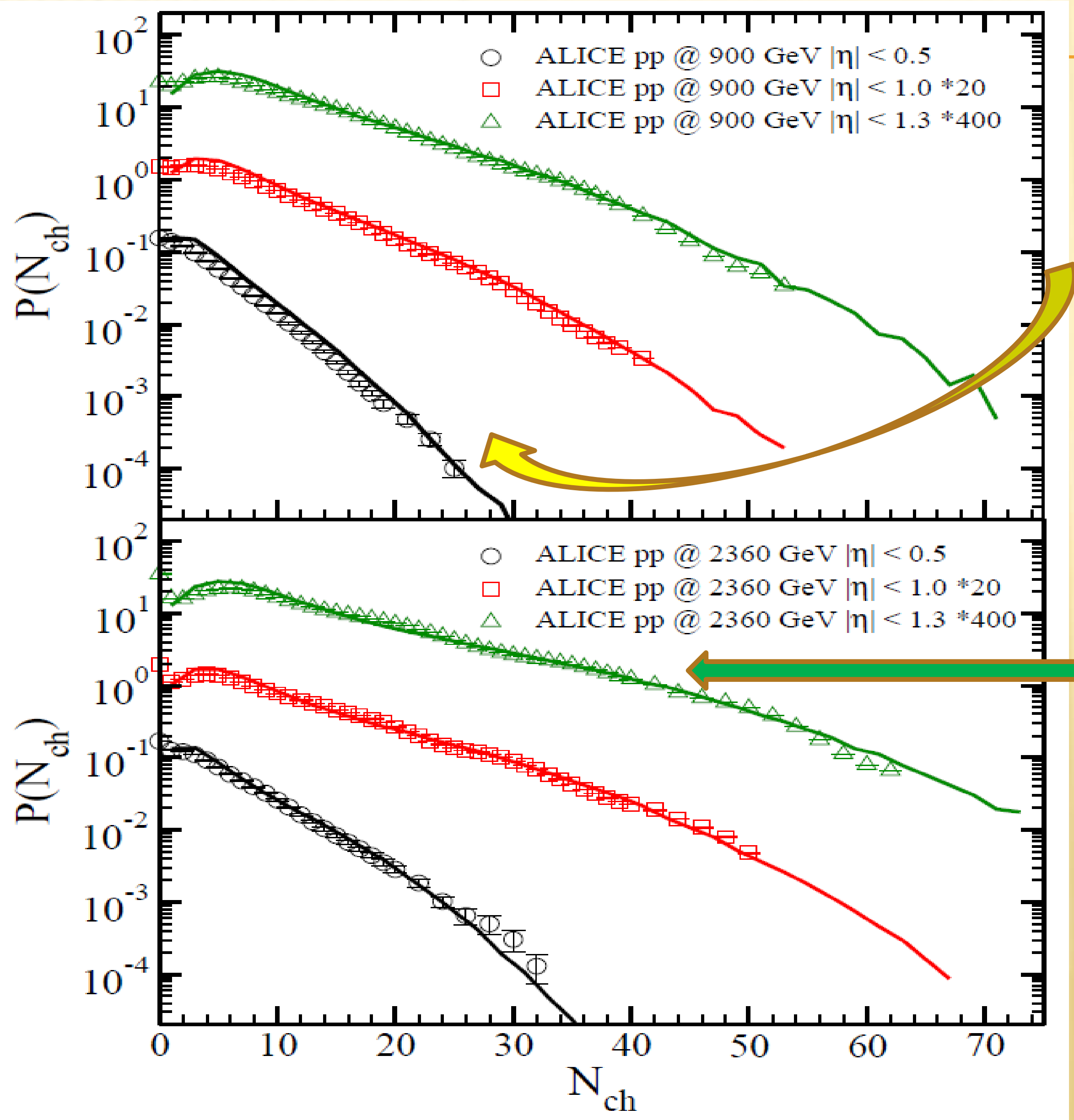
Enhancement of high multiplicities

VIOLATION OF KNO SCALING AT LHC



At energies below 100 GeV different contributions overlap strongly, whereas at higher energies – more multi-string processes

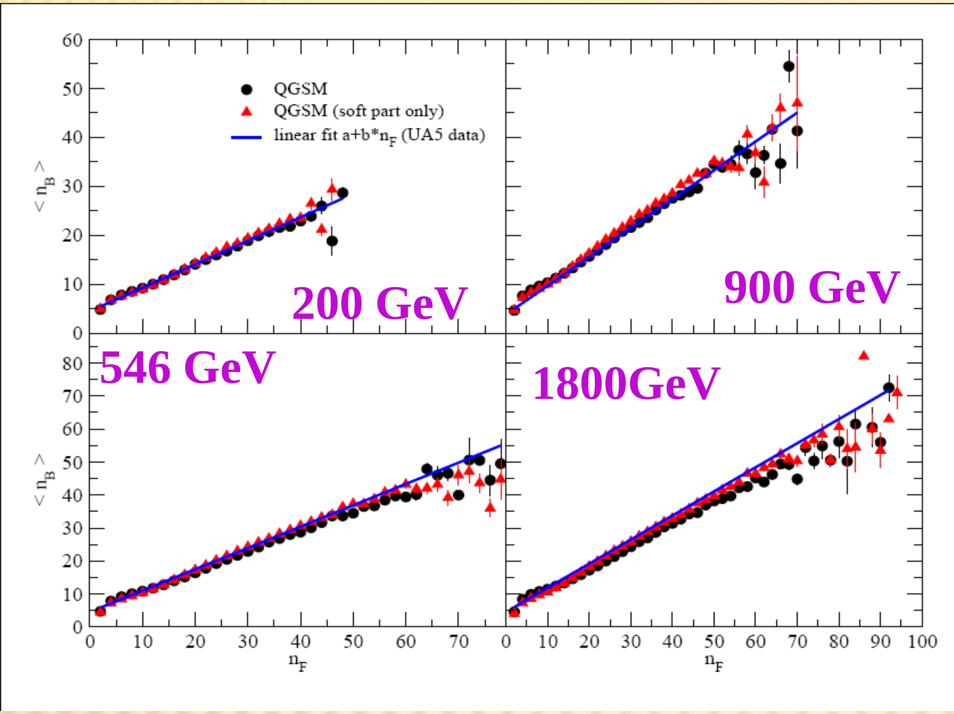
COMPARISON WITH EXPERIMENTAL DATA

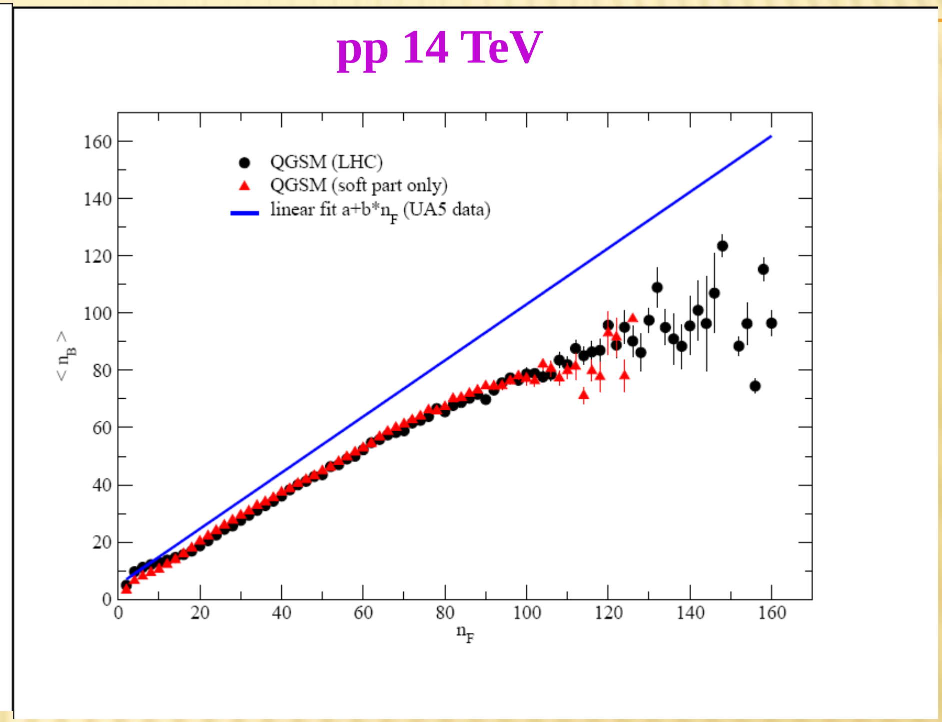


At midrapidity KNO scaling holds.

With the rise of the rapidity interval the characteristic wavy-structure appears.

FORWARD-BACKWARD MULTIPLICITY CORRELATIONS





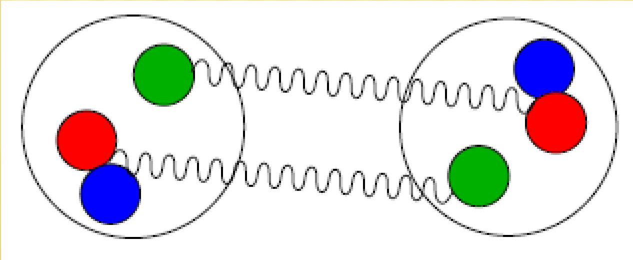
$\langle n_B(n_F)\rangle = a + b n_F$ is linear with

increasing of the slope b with energy

due to

1) Multi-chain diagrams

2) Color exchange type of string excitation



FREEZE-OUT OF PARTICLES AT LHC

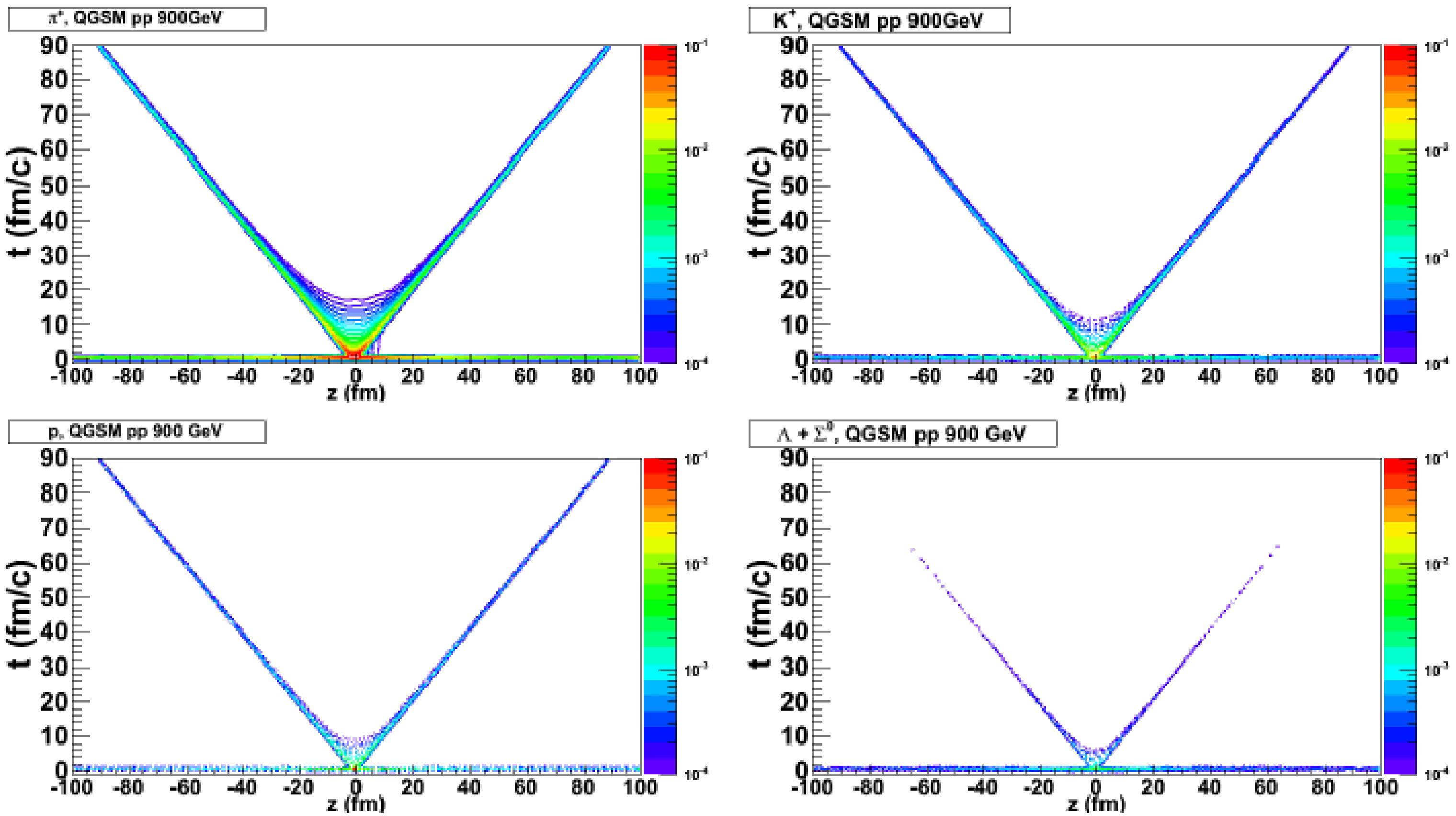


Figure 5.1: $\frac{d^2N}{dzdt}$ distributions from pp 900 GeV in QGSM

Mass hierarchy: heavier hadrons are frozen earlier

FREEZE-OUT OF PARTICLES AT LHC

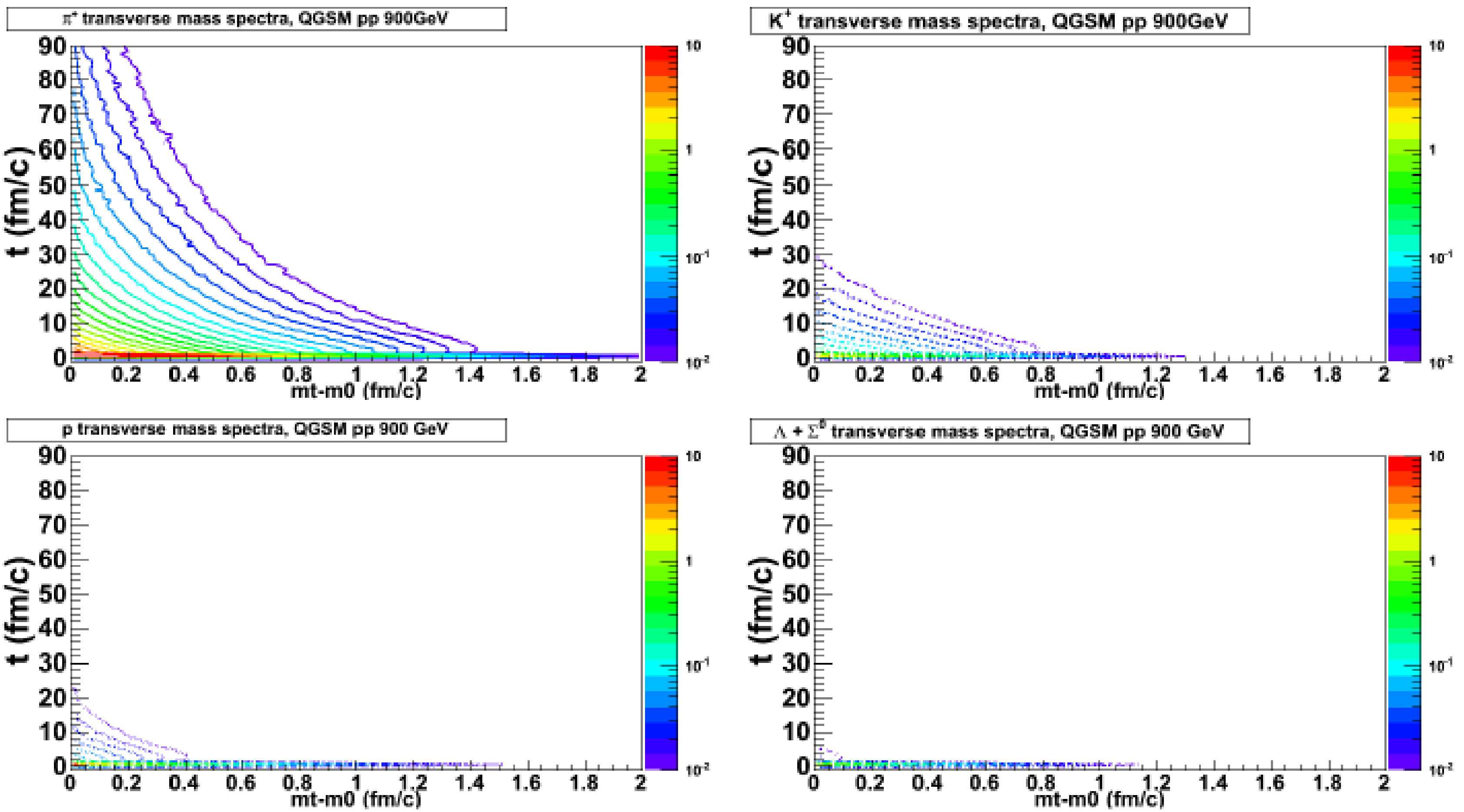


Figure 5.2: $\frac{d^2N}{m_T dm_t dt}$ distributions from pp 900 GeV in QGSM

Early freeze-out of heavy particles

FREEZE-OUT OF PARTICLES AT LHC

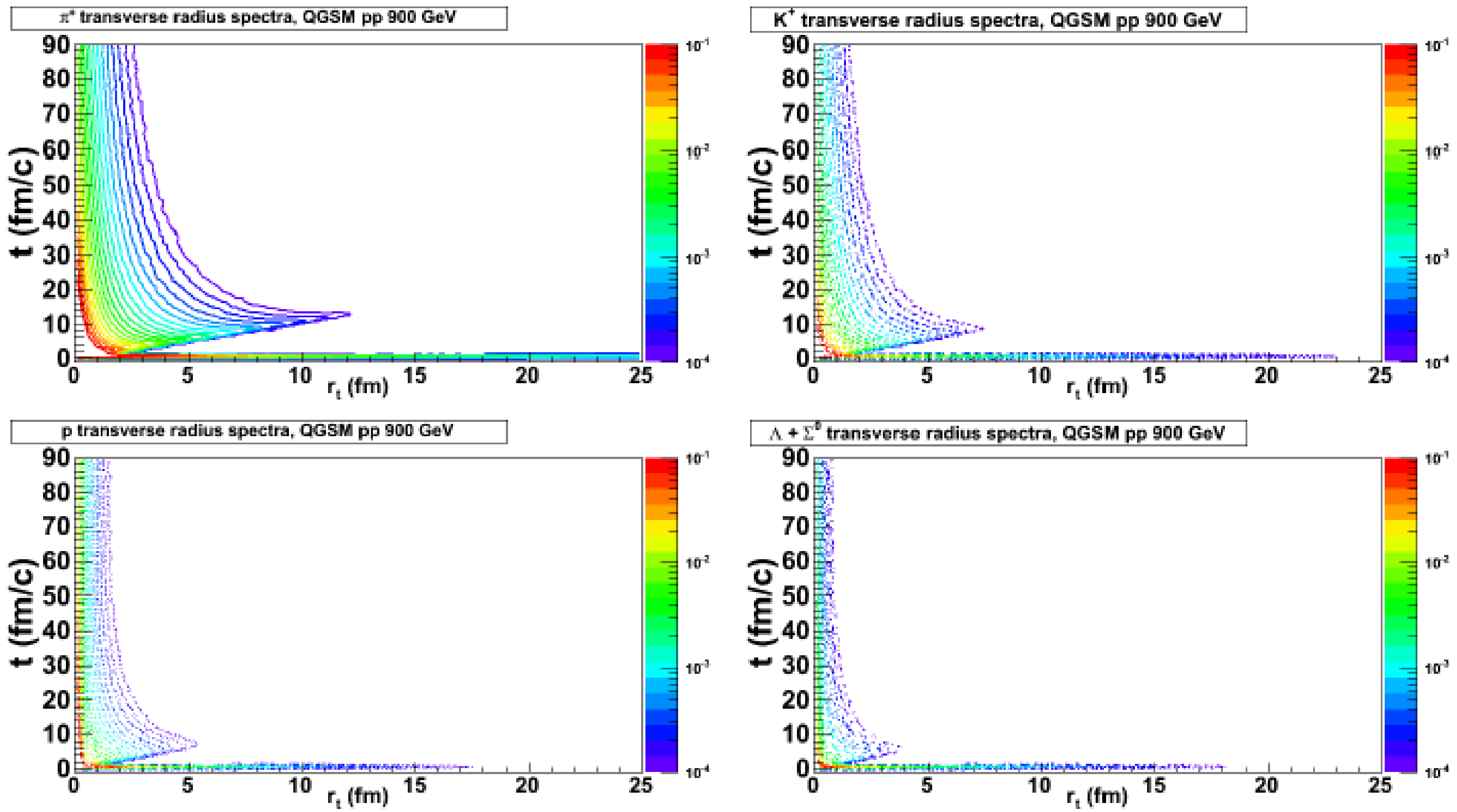


Figure 5.3: $\frac{d^2N}{r_t dr_t dt}$ distributions from pp 900 GeV in QGSM

Second peak – because of short-lived resonances

SPACE-MOMENTUM CORRELATIONS

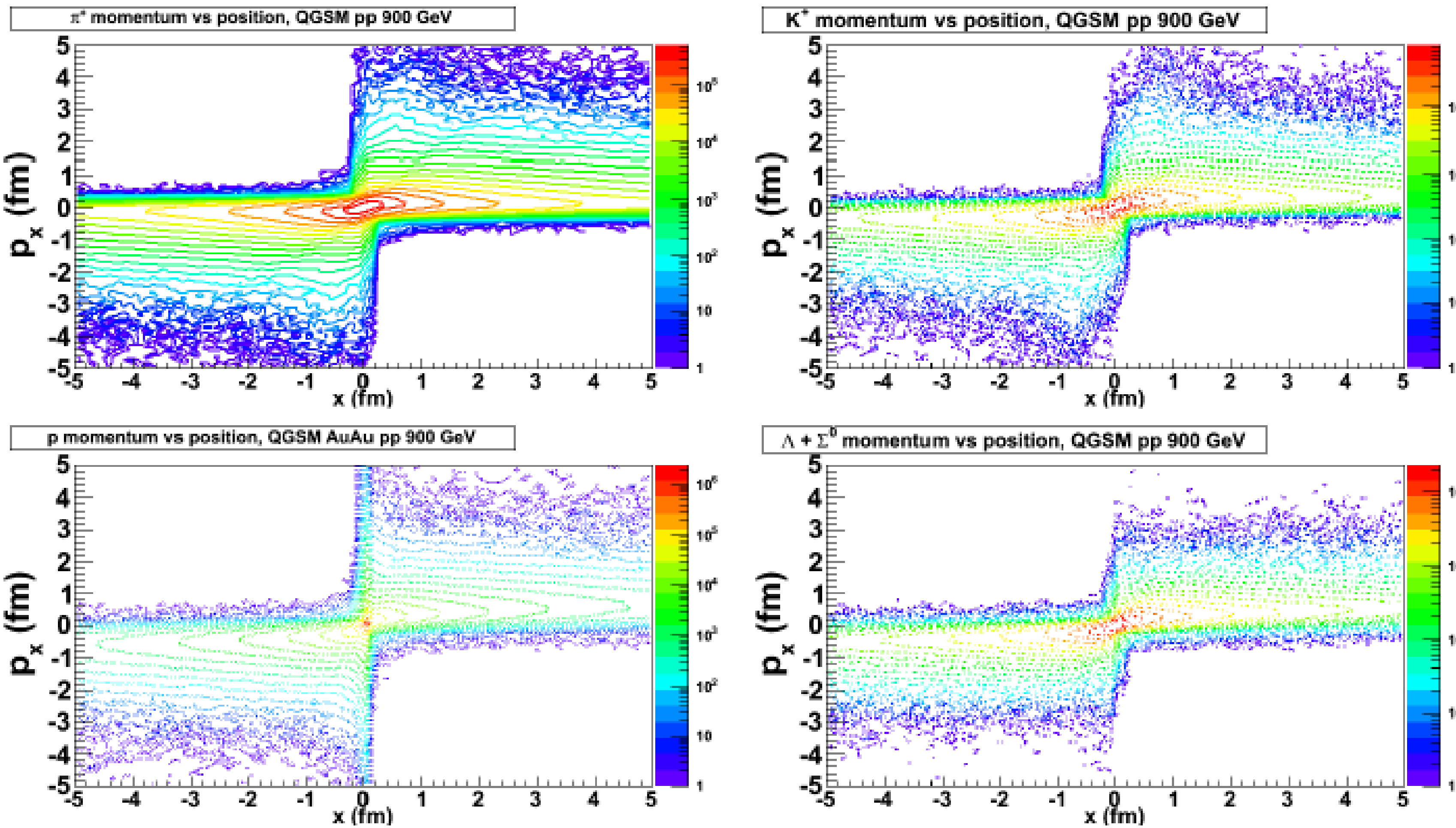
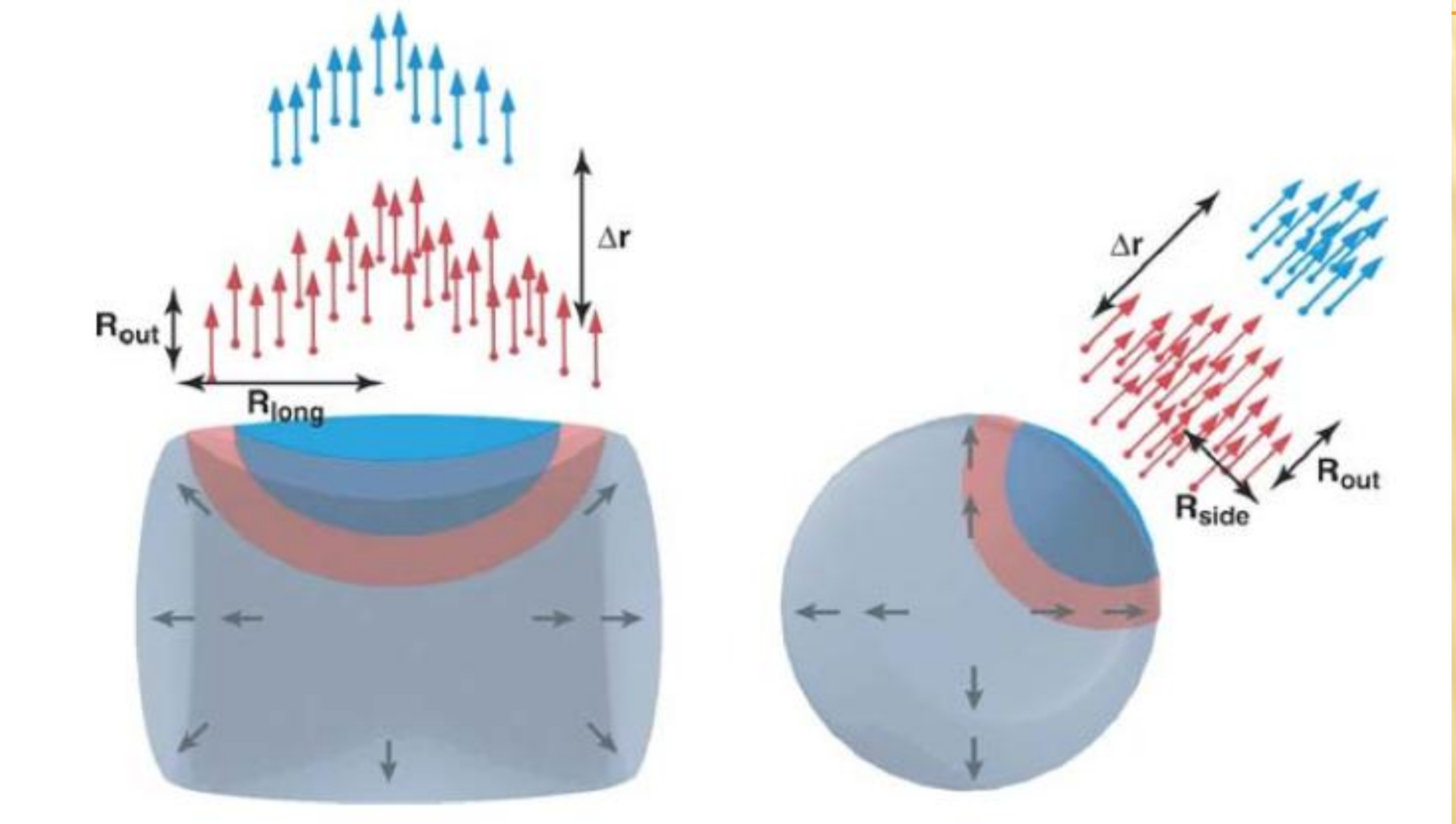


Figure 5.4: $p_x - x$ distributions from pp 900 GeV in QGSM

In hydrodynamics such correlations arise due to collective flow, in string models – due to dynamics of string fragmentation

FEMTOSCOPY CORRELATIONS



$$CF(q) = 1 + \lambda \exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2)$$

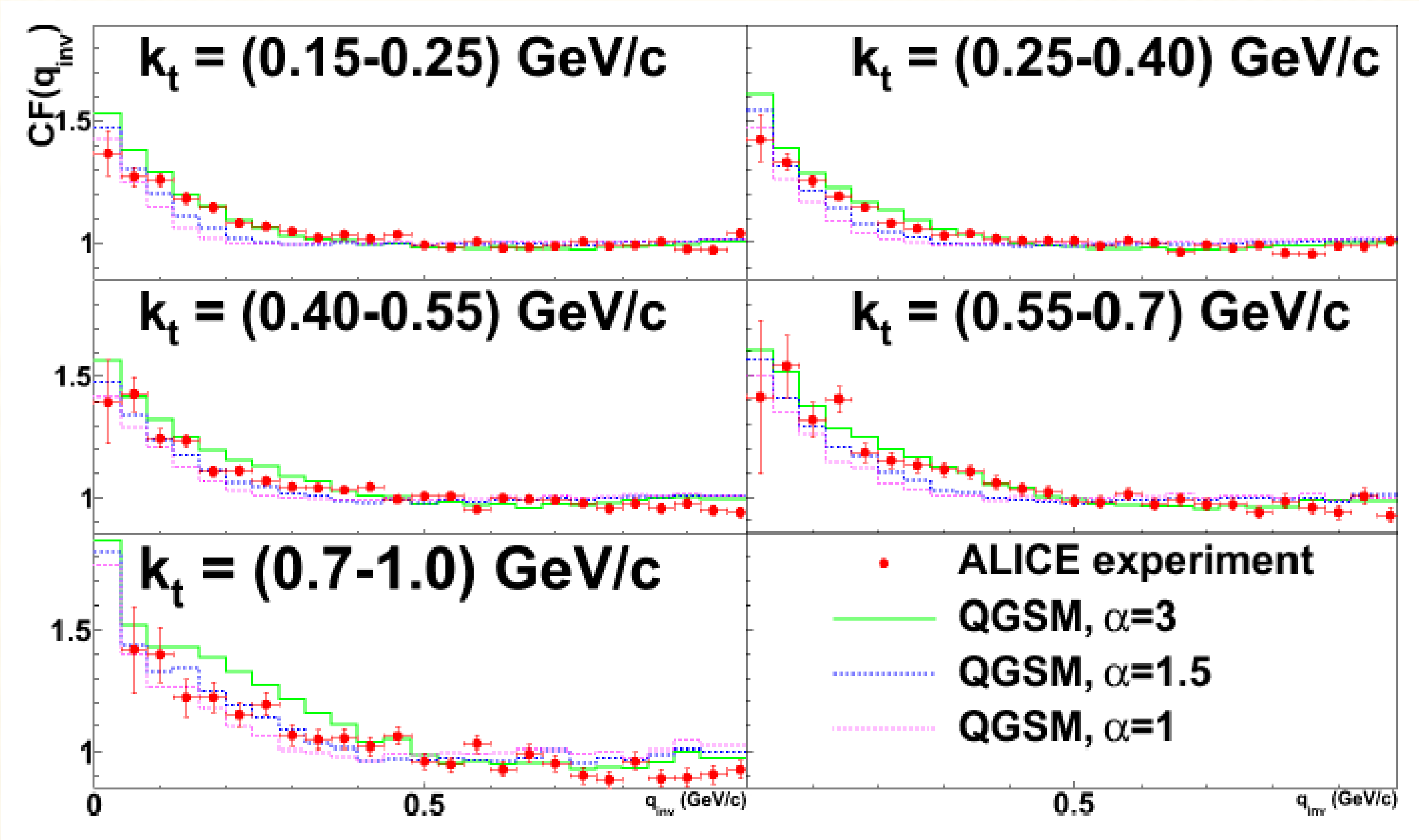
$$P_1(p_i) = E_i \frac{dN_i}{d^3 p_i}$$

$$P_2(p_1, p_2) = E_1 E_2 \frac{dN_{12}}{d^3 p_1 d^3 p_2}$$

$$CF(q_{inv}) = 1 + \lambda \exp(-R_{inv}^2 q_{inv}^2)$$

$$CF(p_1, p_2) = \frac{dN_{12}/(d^3 p_1 d^3 p_2)}{(dN_1/d^3 p_1)(dN_2/d^3 p_2)}$$

FEMTOSCOPY CORRELATIONS



FEMTOSCOPY CORRELATIONS

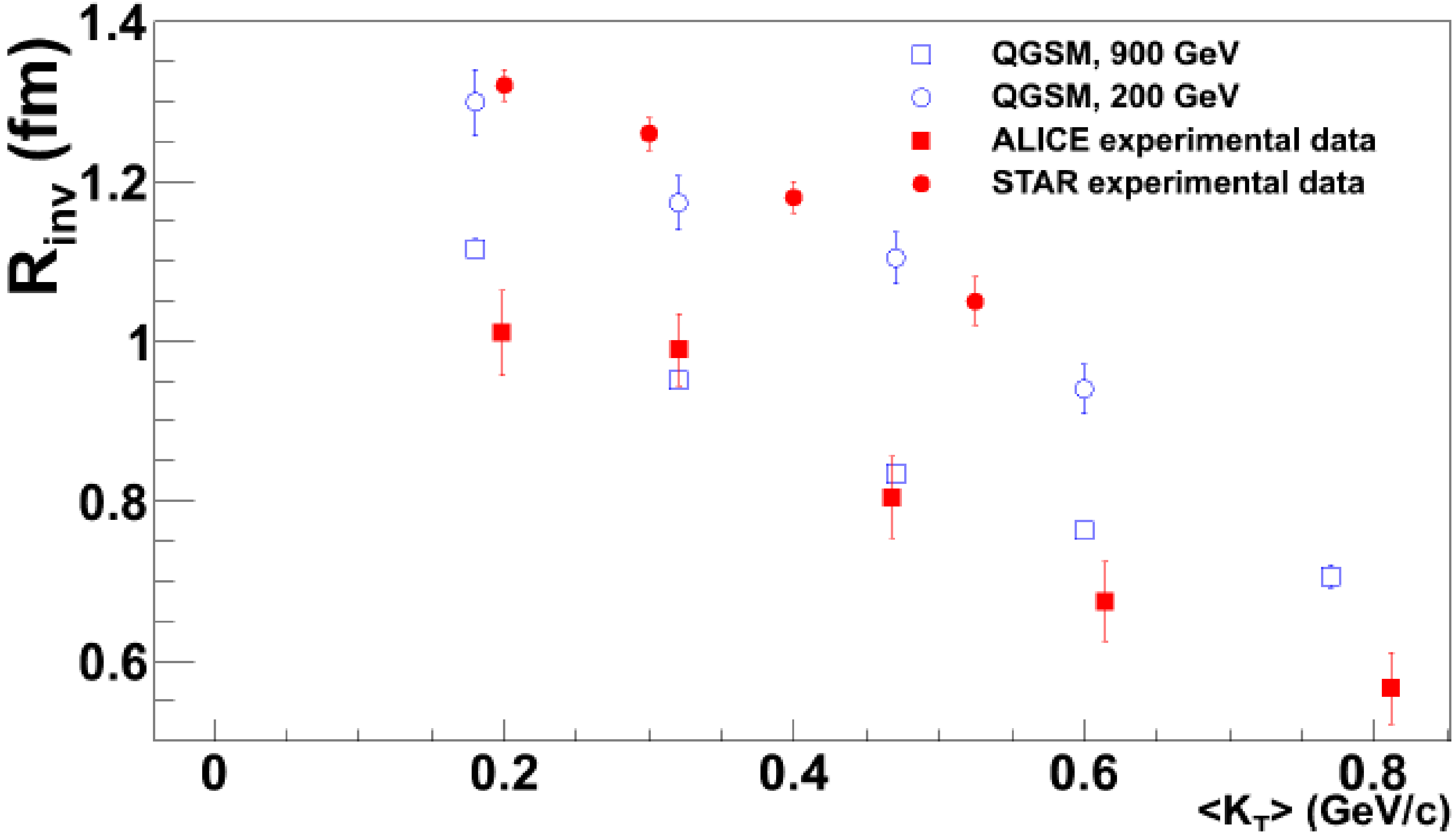


Figure 5.10: One-dimensional $\pi^+\pi^+$ correlation radii as functions of K_T in pp-collisions at $\sqrt{s} = 200\ GeV$ and $\sqrt{s} = 900\ GeV$, compared with STAR [67] and ALICE [71] experimental data. Both model results and experimental data are obtained from a fit using a flat baseline.

A.B.Kaidalov Predictions for LHC.

1.	$\sigma^{(tot)}$	103 mb	$(\sigma^{(tot)}(s) \sim \ln^2 \frac{s}{s_0})$
2.	$\sigma^{(el)}$	26 mb	$(\sigma^{(el)}(s) \sim \ln^2 \frac{s}{s_0})$
3.	$B(0)$	21.5 GeV^{-2}	$(B(0) \sim \ln^2 \frac{s}{s_0})$
4.	$\rho = \frac{Re\,T(0)}{Im\,T(0)}$	0.11	
5.	σ_{SD}	$12 \div 13$ mb	$(\sigma_{SD} \sim \sigma_{DD} \sim \ln \frac{s}{s_0})$
6	σ_{DD}	$11 \div 13$ mb	

$$\sigma^{(el)} + \sigma_{SD} + \sigma_{DD} = 51\,mb \approx \frac{1}{2}\sigma^{(tot)}$$

A.B.Kaidalov Predictions for LHC.

7. $\langle n_{ch} \rangle$ $80 \div 100$

8. $\left.\frac{dn_{ch}}{dy}\right|_{y=0}$ $5.5 \div 6.0$

9. Structures in σ_n

10. Strong long-range (in y) correlations

11. Large amount of minijets.

Summary and perspectives

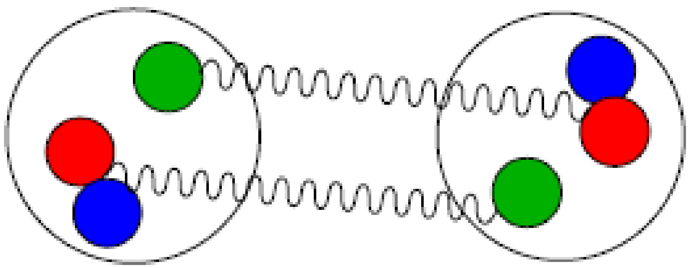
- *Feynman scaling is not observed yet*
- *Extended longitudinal scaling holds*
- *It would be interesting to check the ELS for pp collisions within the statistical thermal model*
- *KNO scaling is strongly violated at LHC.*
  The origin of the violation is traced to multi-string processes
- *Long-range forward-backward correlations are expected*
- *Femtoscopy correlations – basic features are reproduced*

BACK-UP SLIDES

QUARK-GLUON STRING MODEL

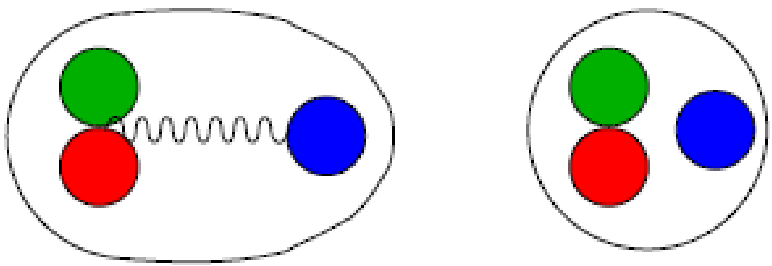
two different mechanisms:

- excitation due to exchange of pomerons (color exchange)
- transverse strings



- n cut pomerons give $2n$ strings

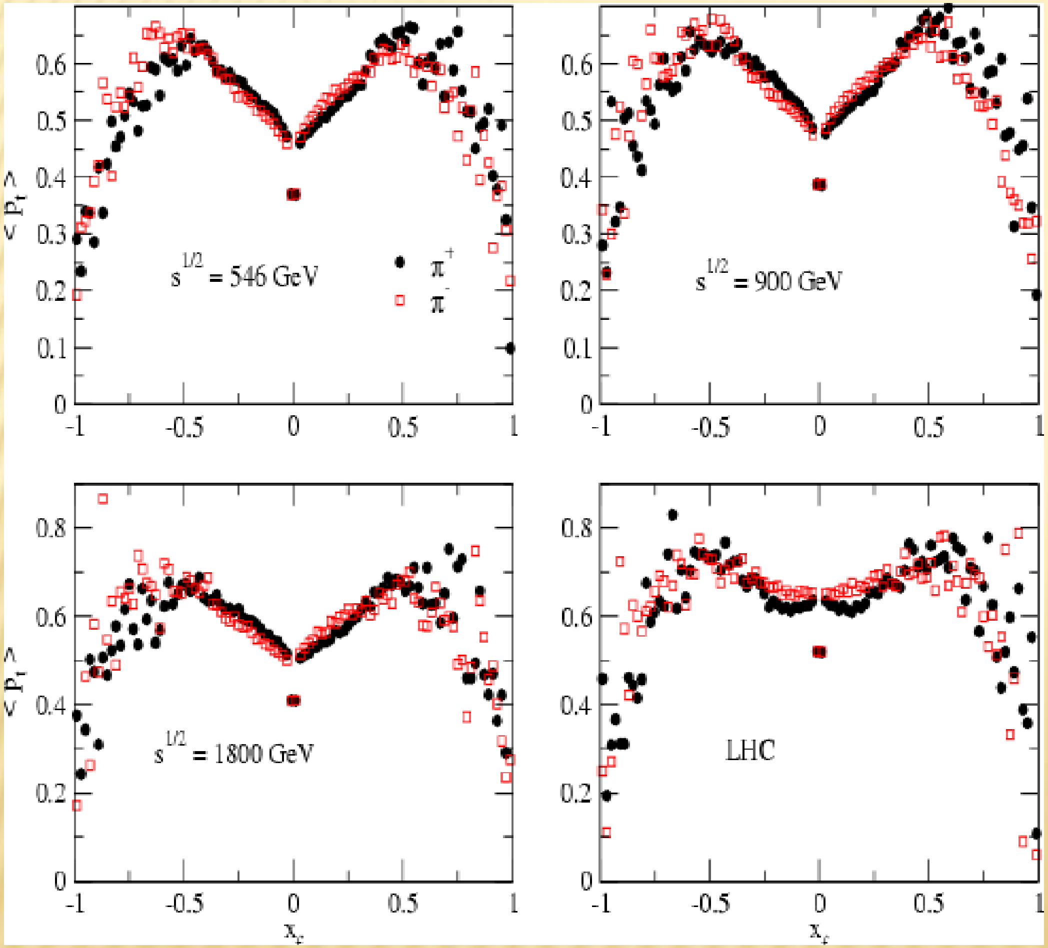
- excitation due to tranfer of momentum to a single parton
- longitudinal string

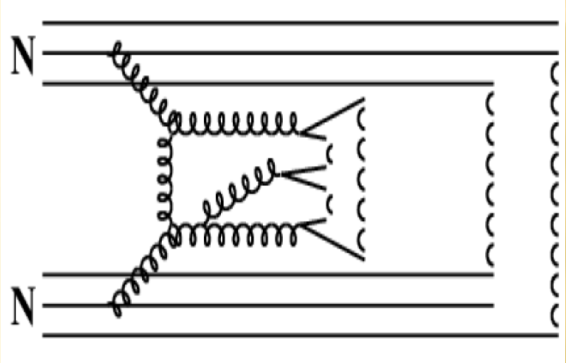


- purely phenomenological process

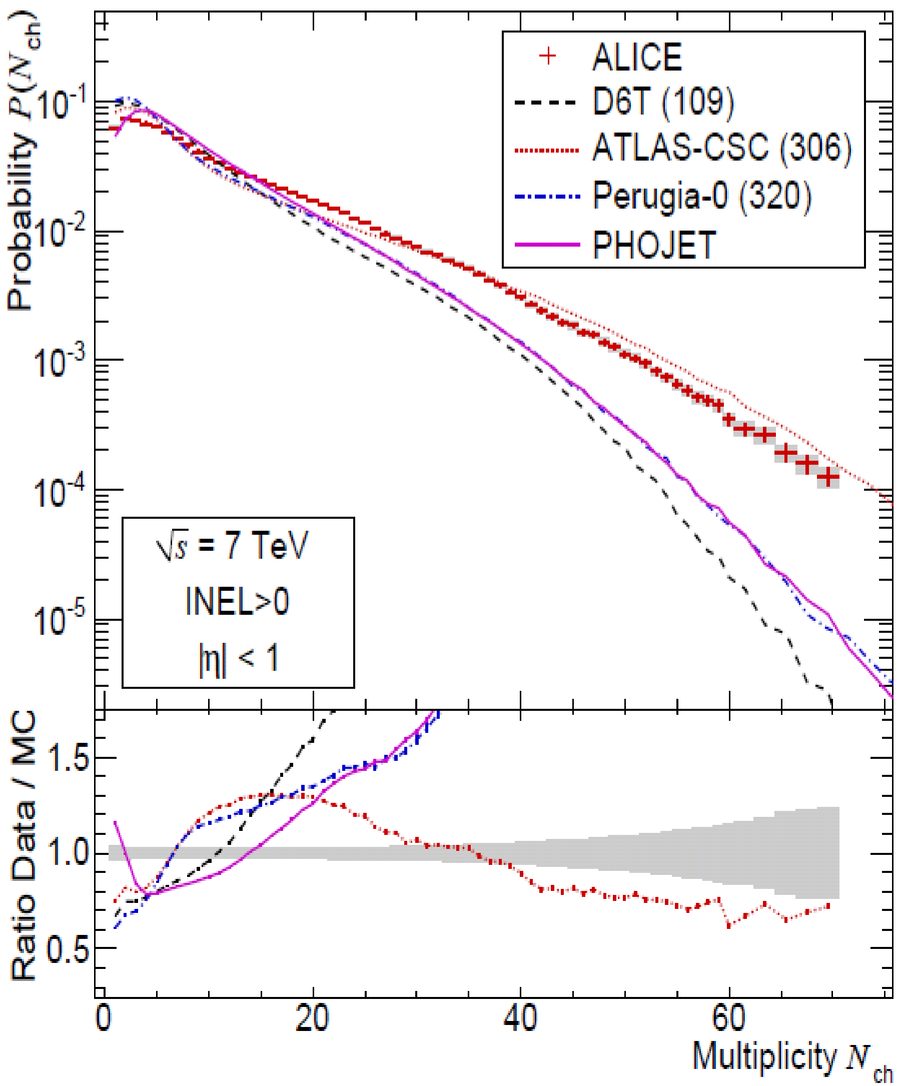
Excitation of color neutral strings

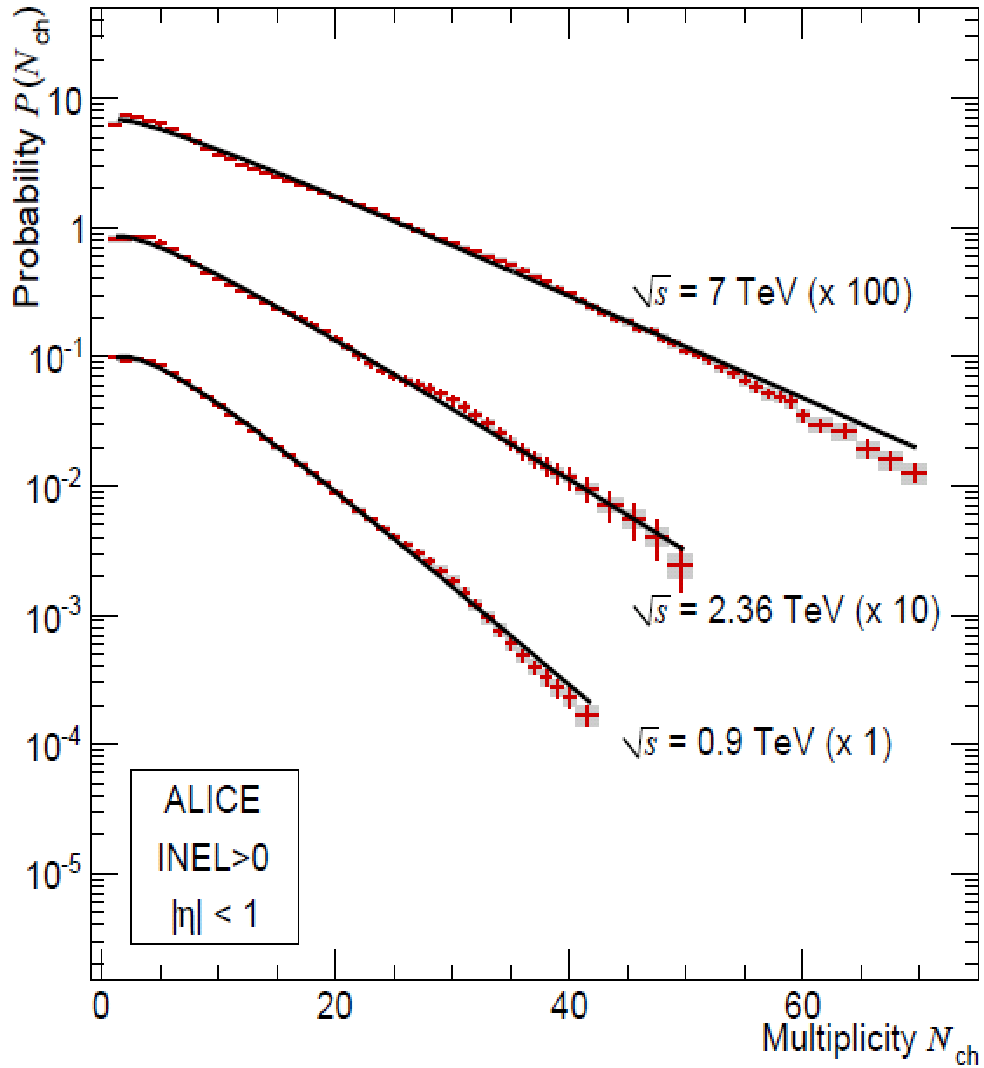
STRONG SEA-GULL EFFECT <PT(XF)>

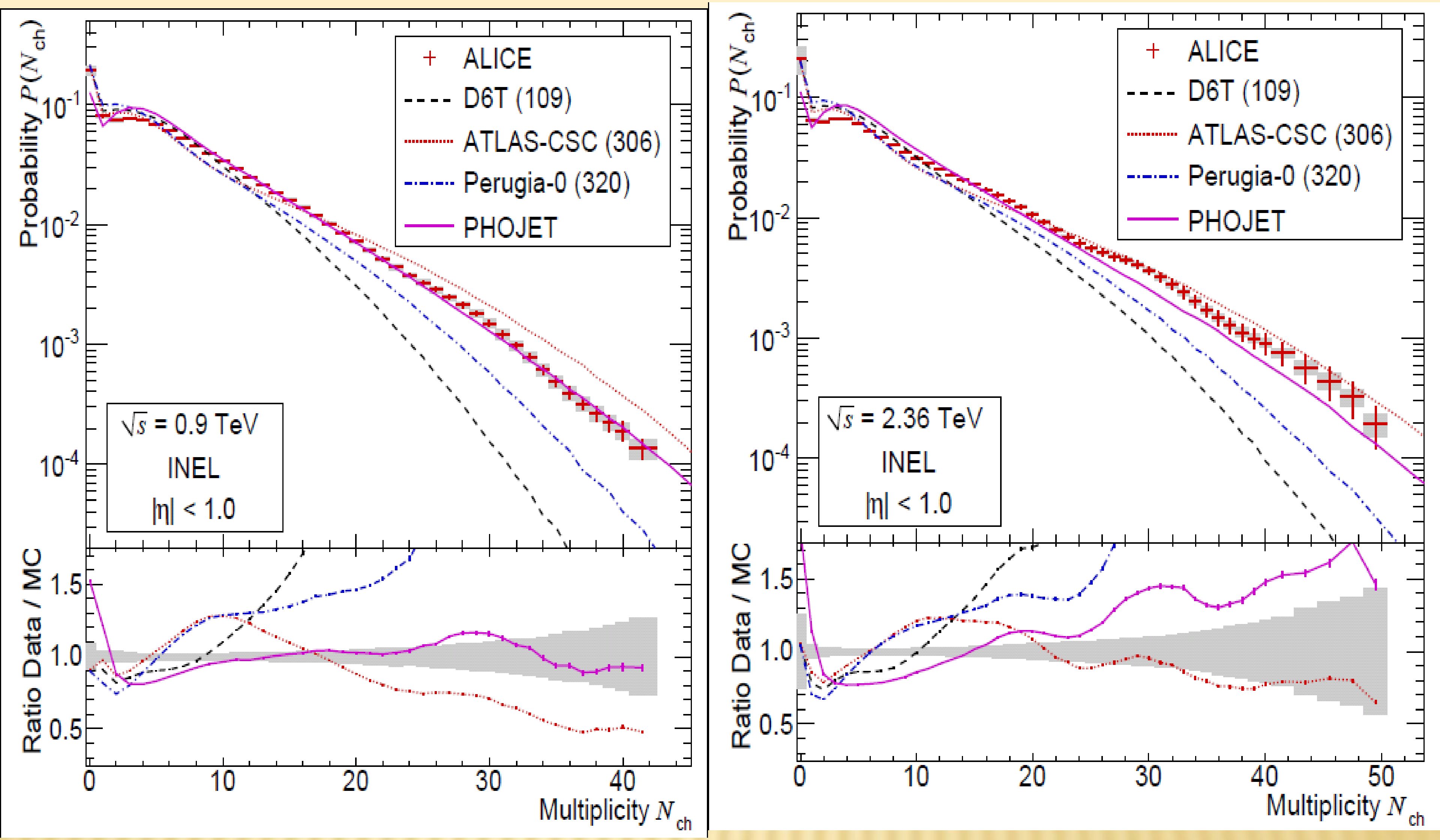




Sea-gull effect becomes more pronounced with energy


ALICE
D6T (109)
ATLAS-CSC (306)
Perugia-0 (320)
PHOJET
√s = 7 TeV
INEL>0
|η| < 1
Probability P(N_ch)
Ratio Data / MC
Multiplicity N_ch


√s = 7 TeV (x 100)
√s = 2.36 TeV (x 10)
√s = 0.9 TeV (x 1)
ALICE
INEL>0
|η| < 1
Probability P(N_ch)
Multiplicity N_ch



ALICE
D6T (109)
ATLAS-CSC (306)
Perugia-0 (320)
PHOJET
$\sqrt{s}$ = 0.9 TeV
INEL
|η| < 1.0
$\sqrt{s}$ = 2.36 TeV
INEL
|η| < 1.0
Probability $P(N_{ch})$
Ratio Data / MC
Multiplicity N_{ch}