DIS at HERA and new phenomenological model for hadroproduction

Alexander Bylinkin
Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
Moscow Institute of Physics and Technology (MIPT), Moscow, Russia

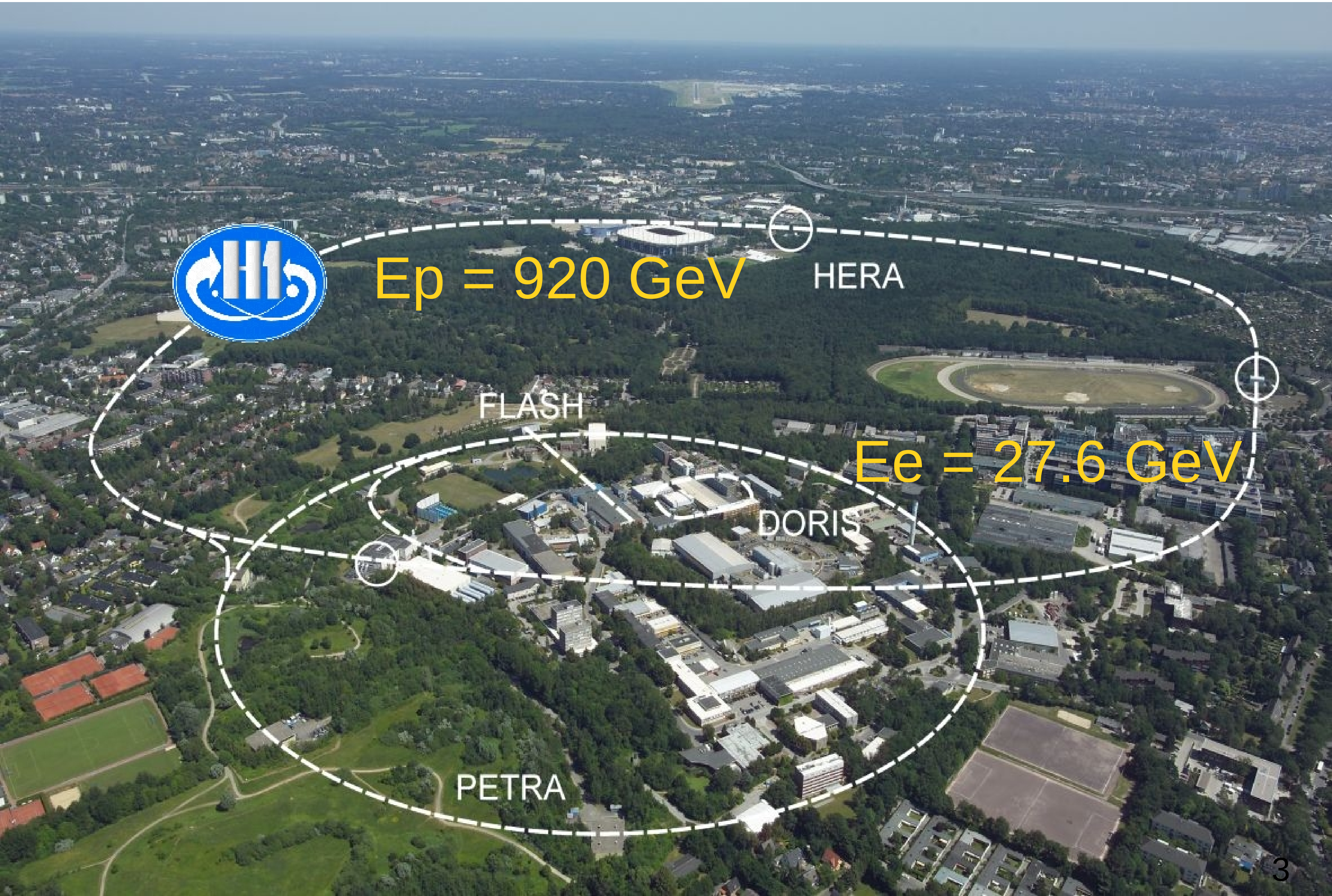
On behalf of H1 Collaboration

XXIX International Workshop on High Energy Physics
27 June, 2013, IHEP, Protvino, Russia

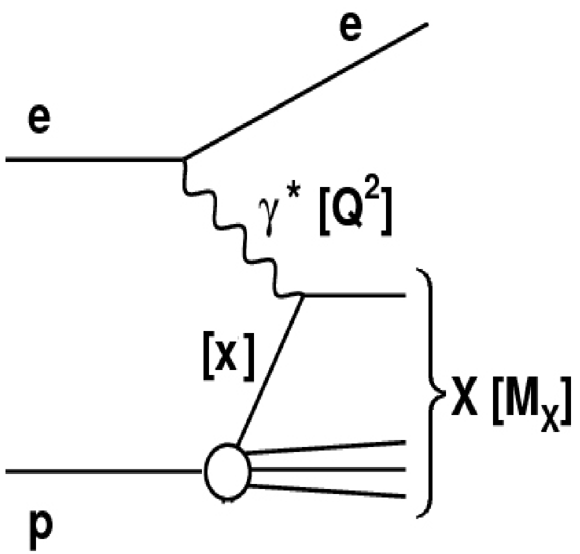
Outline

- Introduction
- Recent experimental results on charged particle production in DIS (H1prelim-13-032)
  - Test of Monte Carlo Models
    - Parton evolution dynamics
  - Test of the new phenomenological model
- Other predictions of the model

DIS at HERA



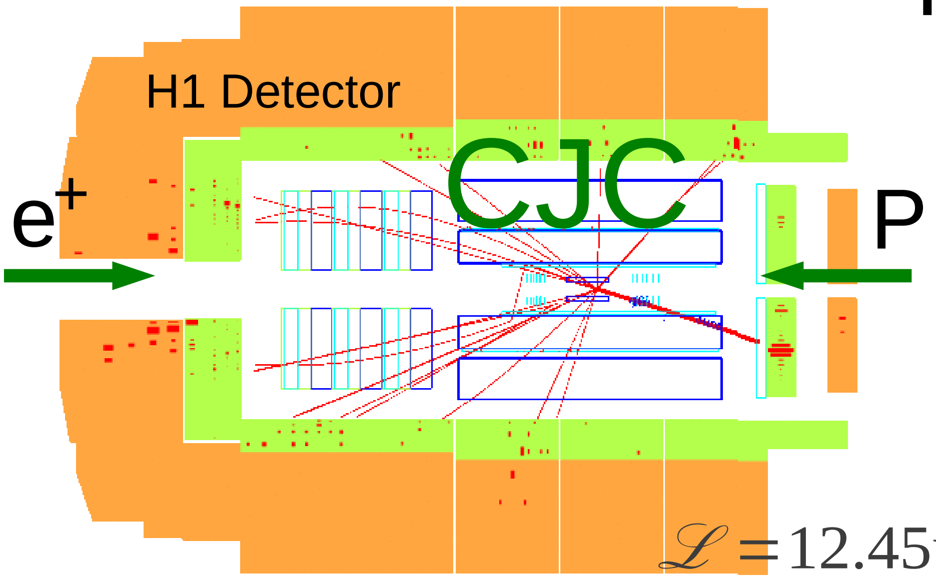
DIS at HERA

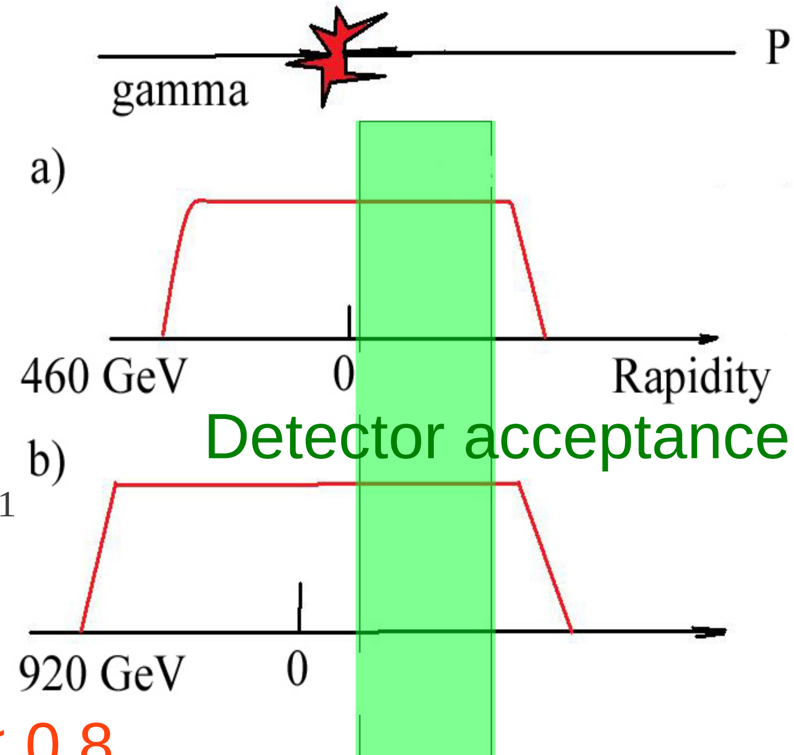


Event kinematics is defined by

√s — ep centre-of-mass energy
Q^2 — photon virtuality
x — Bjorken variable
y — inelasticity
W — photon-proton system mass [Mx]

H1 Detector and experimental setup





$\mathscr{L} = 12.45 \text{pb}^{-1}$

1. Reduced proton beam energy
   Ep = 460 GeV $\sqrt{s}$ = 225 GeV
2. High values of inelasticity $0.35 < y < 0.8$
3. Low photon virtuality $5 < Q^2 < 10$ GeV²

Measurements are performed in γp centre-of-mass system (P_T^*, η^*)

$\eta^* = -\ln \tan(\theta^*/2)$

θ^* - with respect to virtual photon direction

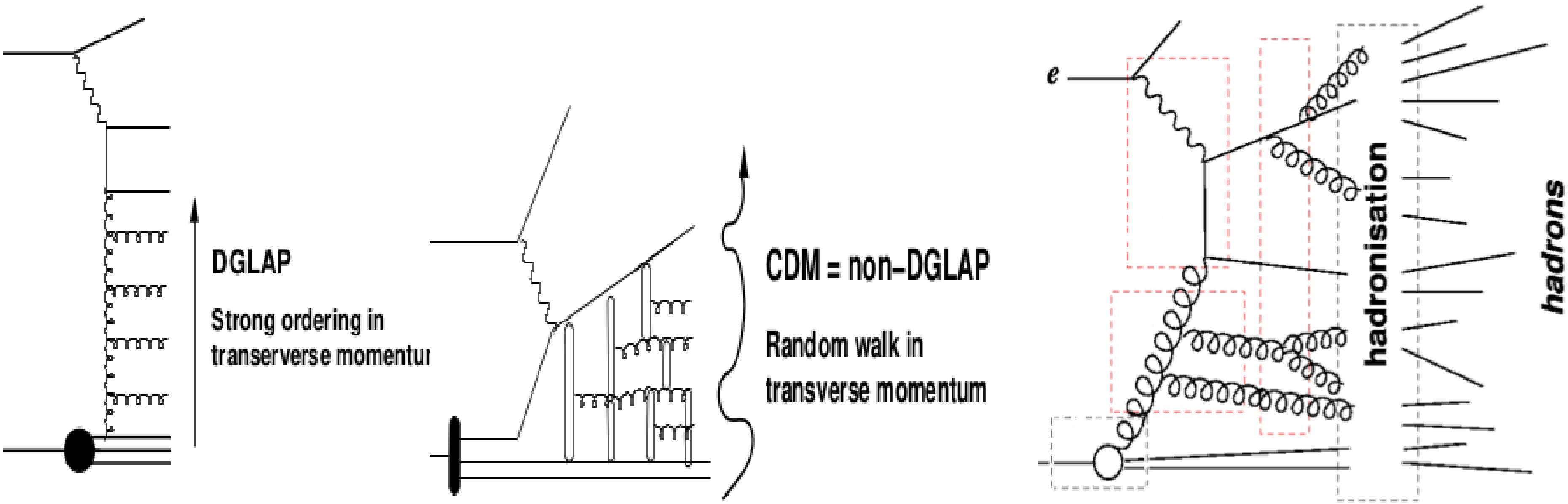
$\eta^* < 0$ — proton direction

7 η^* bins $0 < \eta^* < 3.5$

Parton evolution models and HFS

RAPGAP
DGLAP

DJANGOH
CDM (Colour Dipole Model)



Parton Distribution Functions (CTEQ6 (LO))

+

DGLAP Model (Matrix Element + Parton Shower)

Colour Dipole Model (BFKL-like parton evolution)

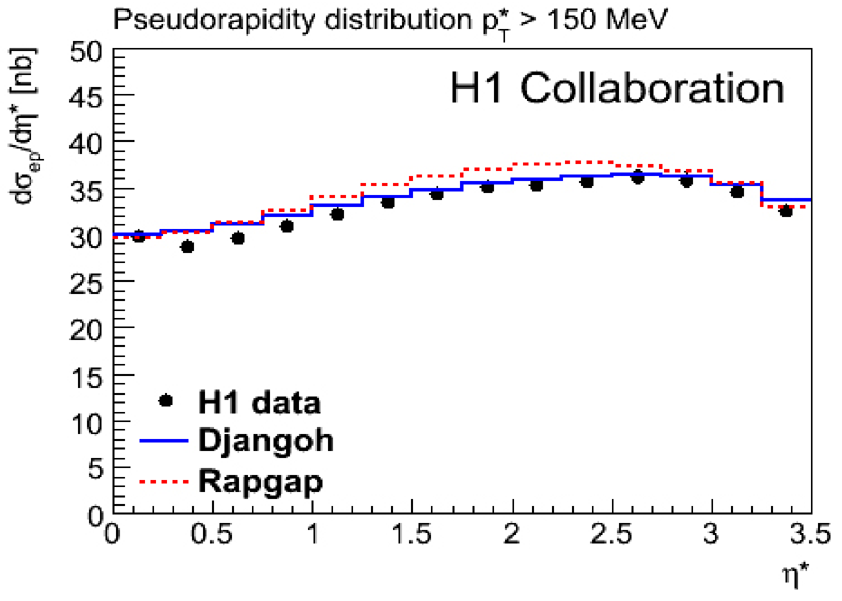
+

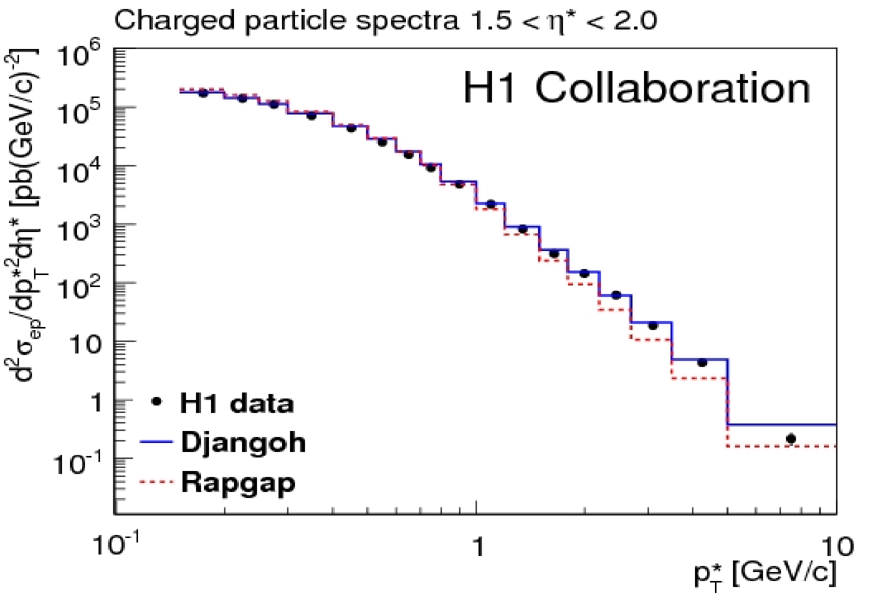
Lund string fragmentation model for hadronisation

=

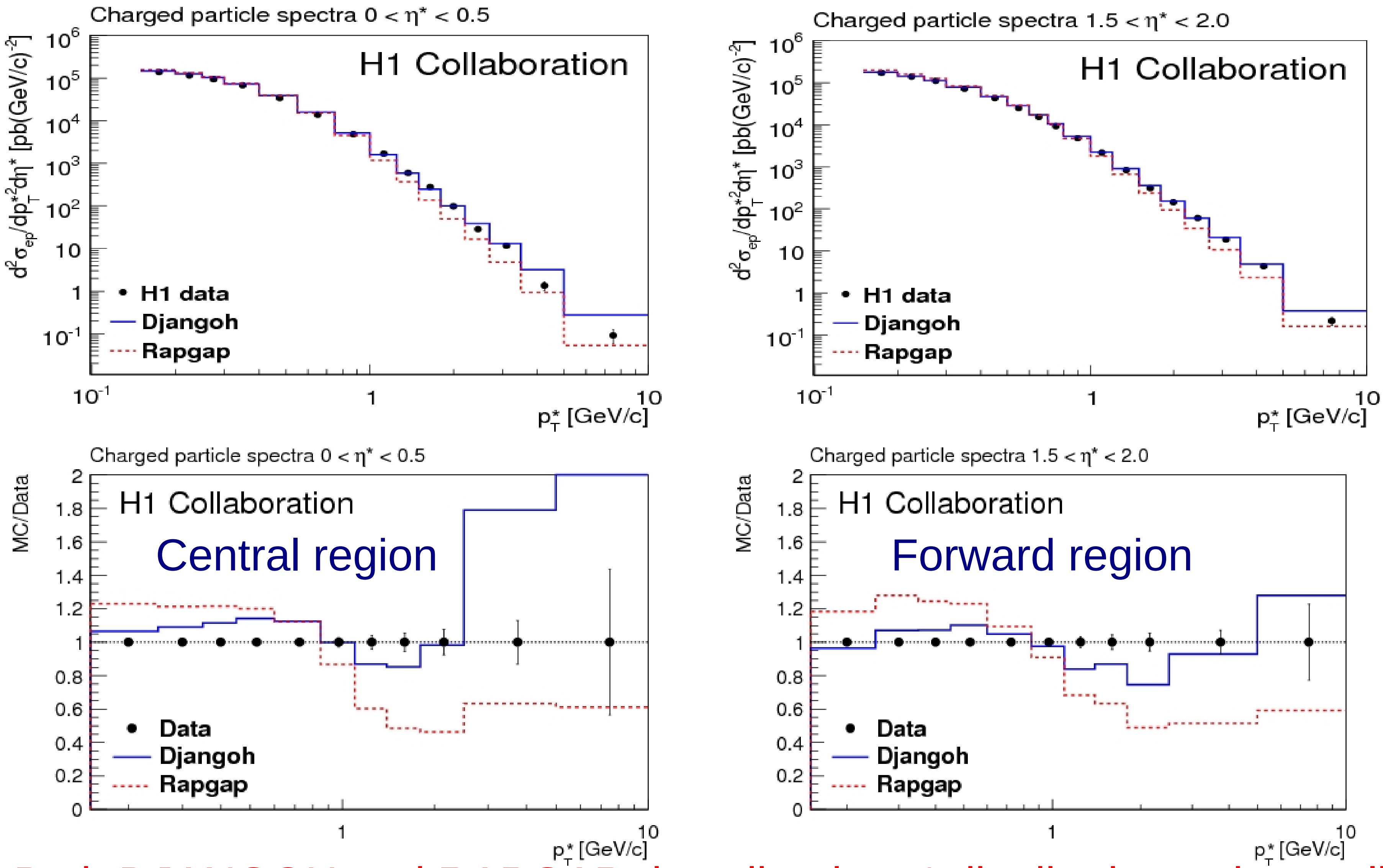
Hadronic Final State

Results: Comparison with MC





Results: Comparison with MC



Both DJANGOH and RAPGAP describe the η* distribution rather well, but NOT the spape of the P_T* spectra in the central region

Phenomenological model

Two contributions to hadron production

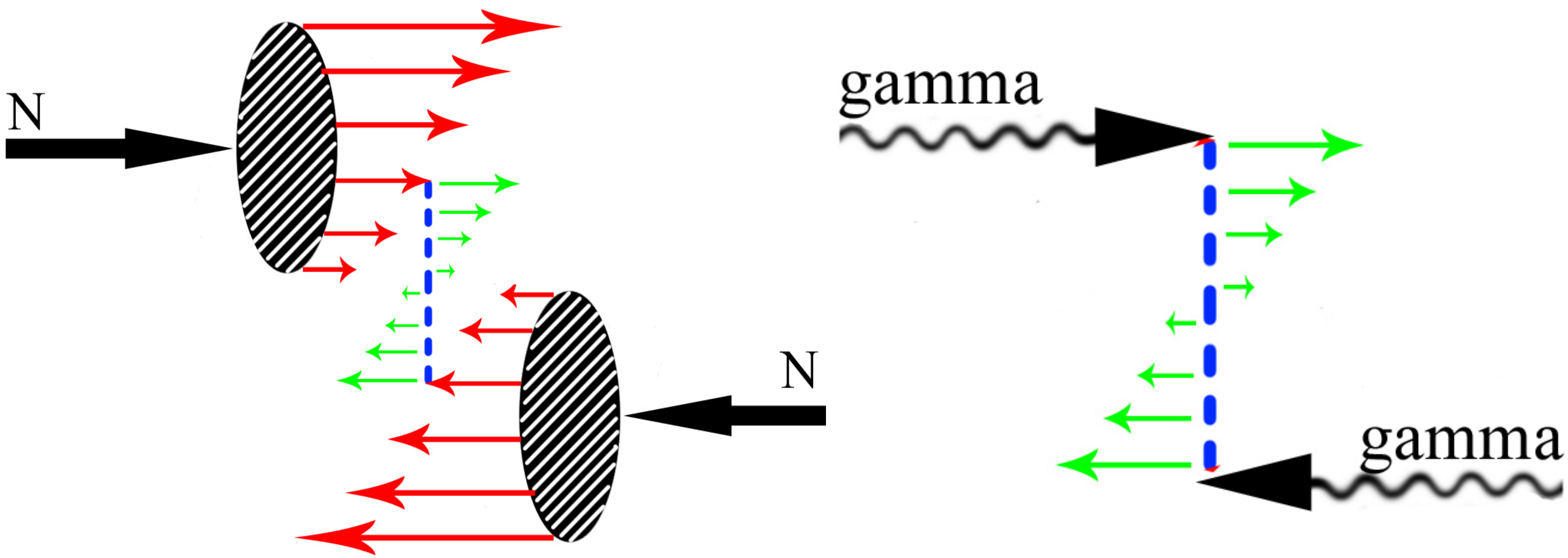
1. Radiation of hadrons by valence quarks

Theses partons exist long before the interaction and considered as a thermalized statistical state

⇨ Boltzmann-like exponential distribution

2. Virtual partons exchanged between colliding partonic systems

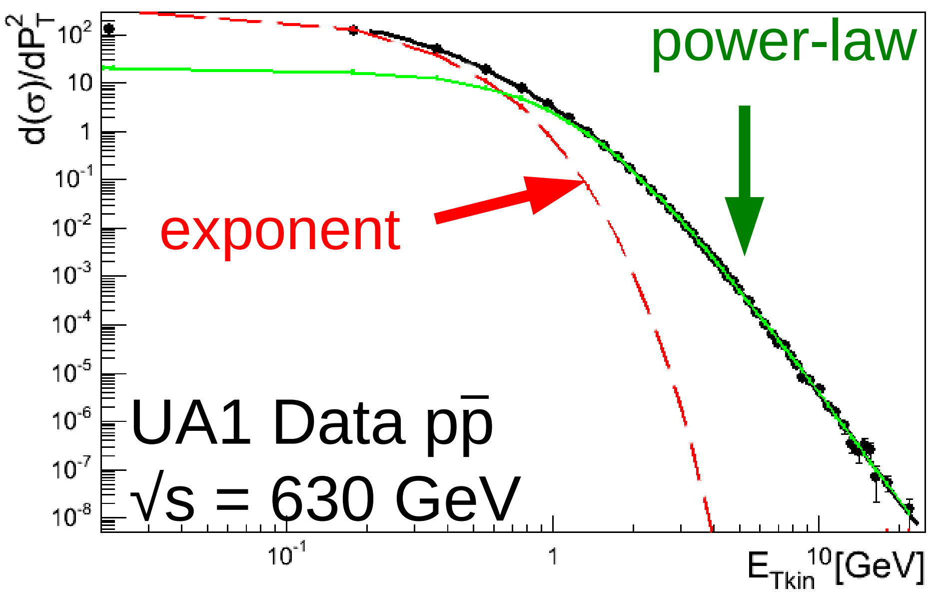
⇨ power-law spectrum (typical for pQCD)

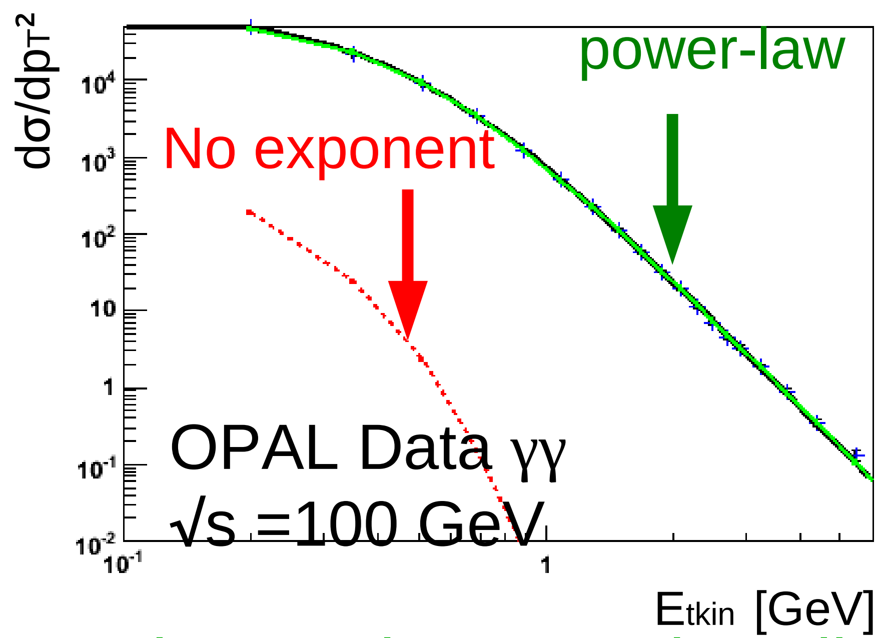


A.A. Bylinkin and A.A. Rostovtsev arXiv: 1209.0958 [hep-ph]

Comparison of pp and γγ Spectra

$$\frac{d^2\sigma}{\pi dy(dp_t^2)} = A_1 exp(-E_{Tkin}/T_e) + \frac{A_2}{(1+\frac{P_T^2}{T^2 N})^N}$$





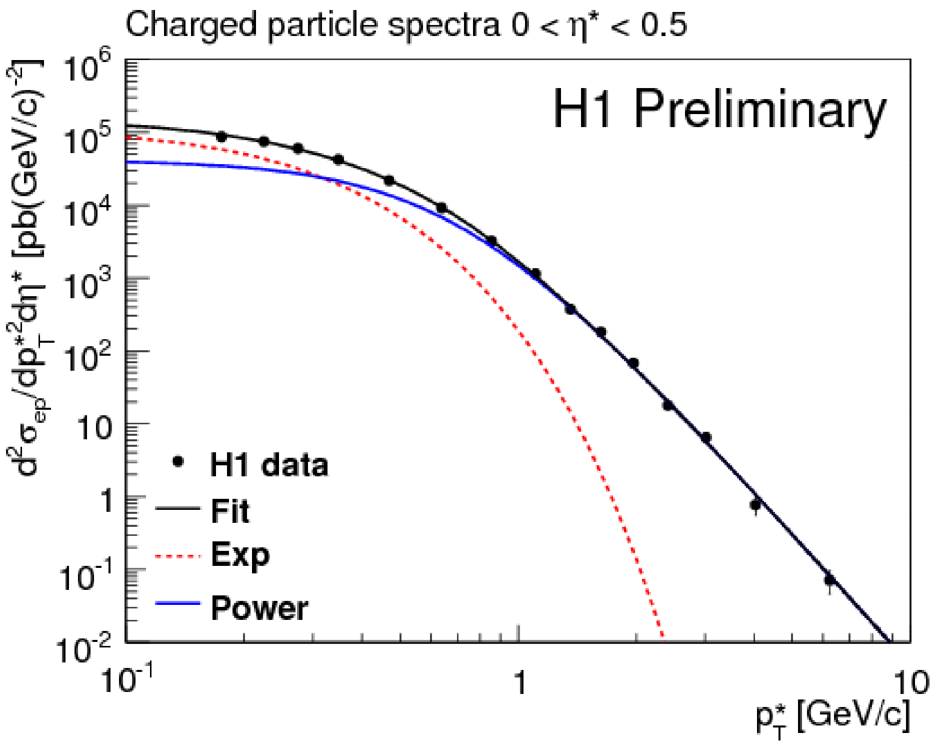
pp-collisions have large Exponential term contribution

γγ-interactions are described by the power-law only

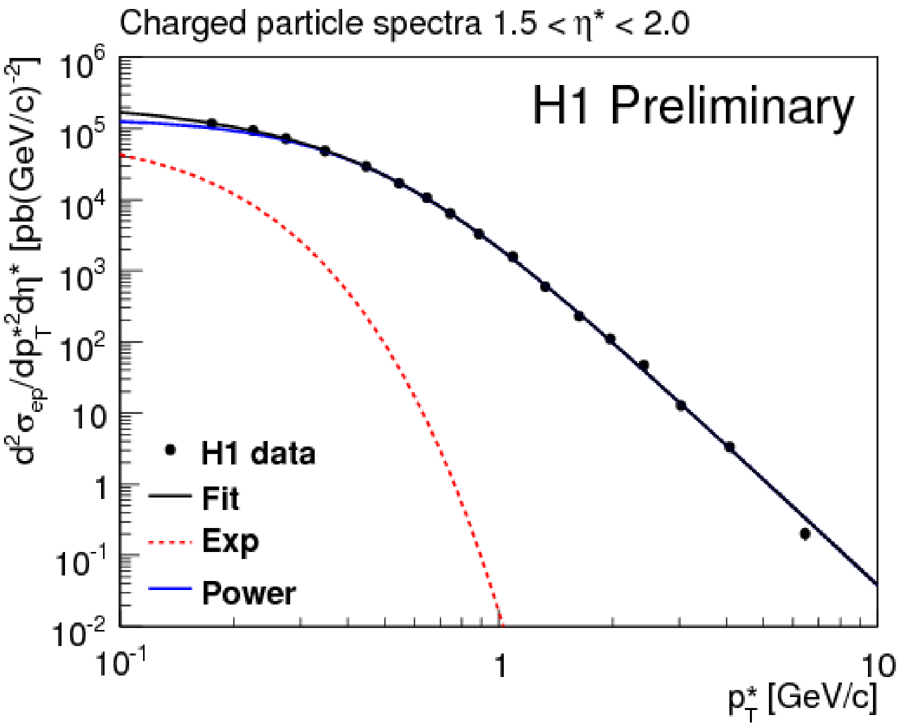
DIS at HERA (γp) is the unique possibility to study the transition in hadroproduction dynamics

What is in ep-collision?

Central region



Forward region

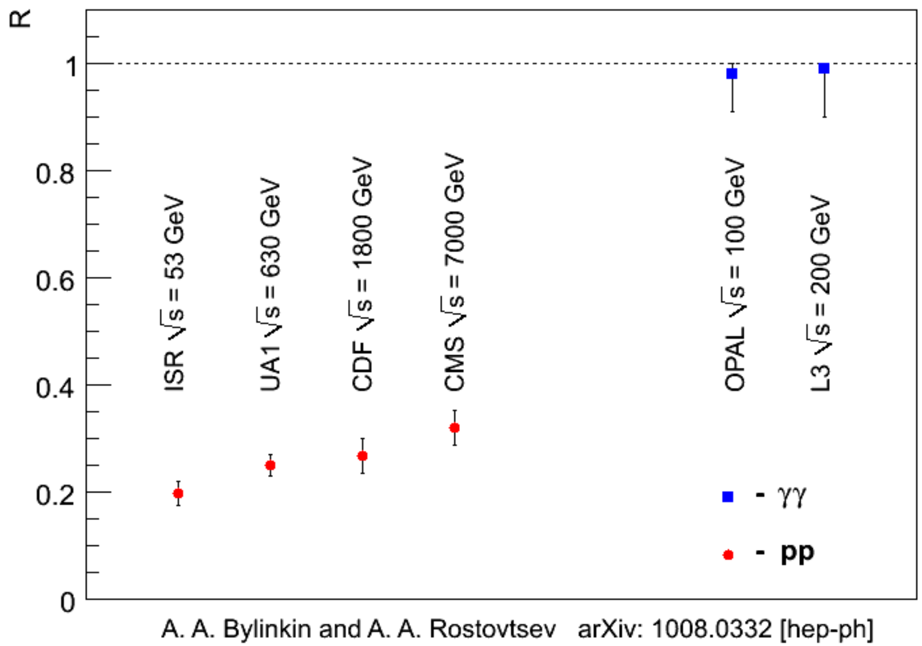


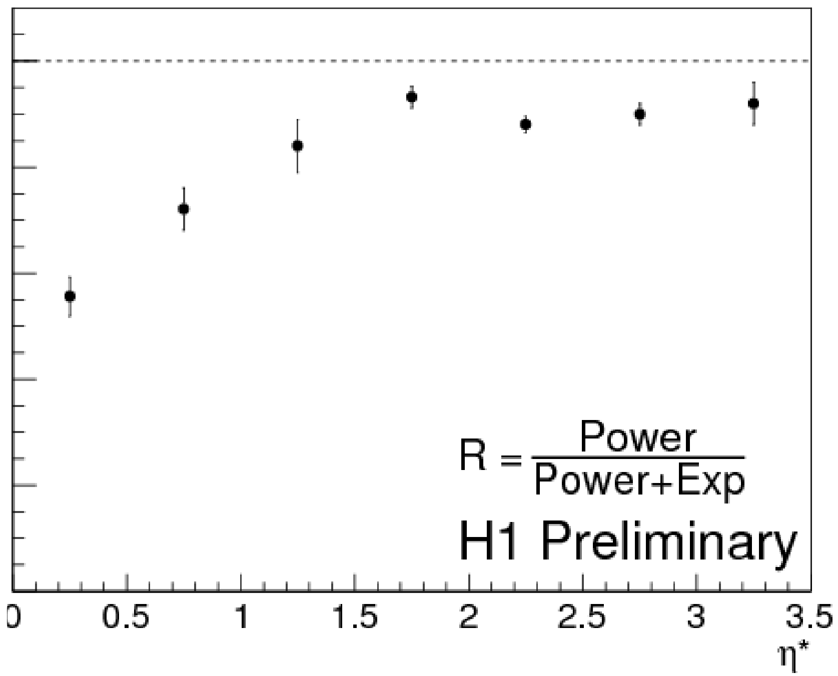
Large exponential contribution

Small exponential contribution

Power-law term contribution

$$R = \frac{\text{Power-law}}{\text{Exp} + \text{Power-law}}$$





Transition between two hadroproduction contributions is observed with approaching the proton fragmentation region

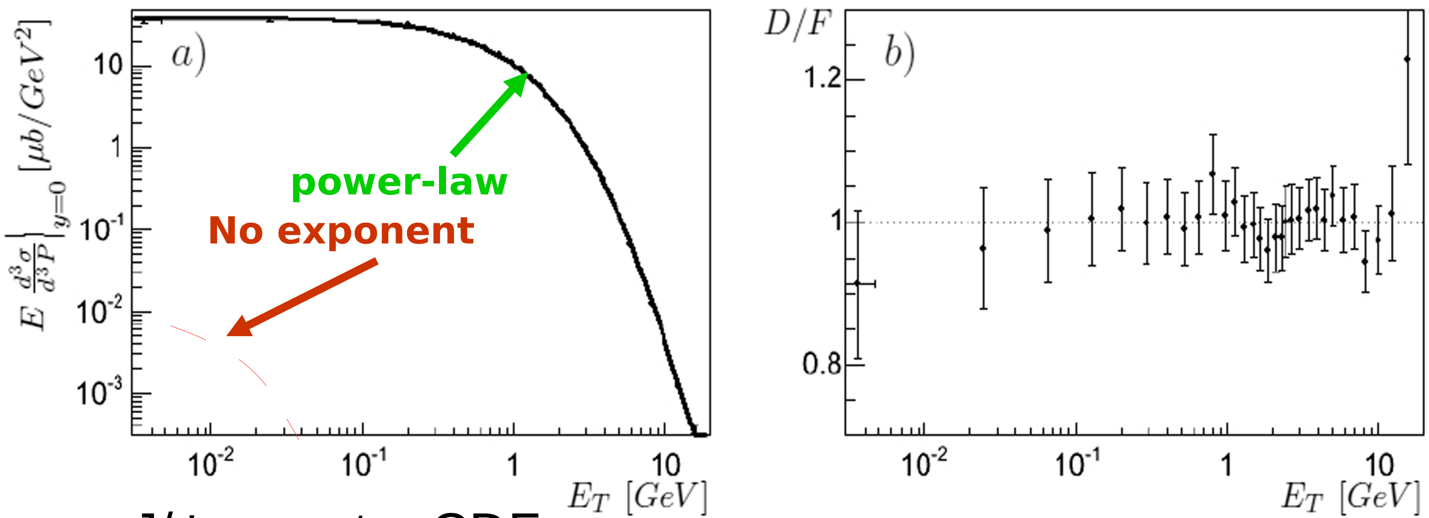
As it is qualitatively predicted by the model

Type of produced particle

QCD-fluctuations are democratic to quark flavour while valence quark radiation can't produce heavy flavours

Prediction: Kaon (and J/ψ) spectra should have less exponential contribution then pion

$$R = \frac{\text{Power-law}}{\text{Exp + Power-law}}$$



J/ψ spectra CDF

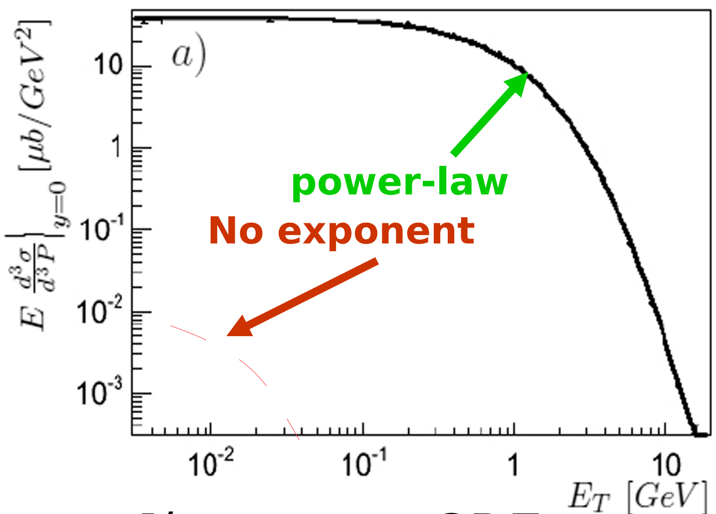
$\sqrt{s}$ = 1.96 TeV

Type of produced particle

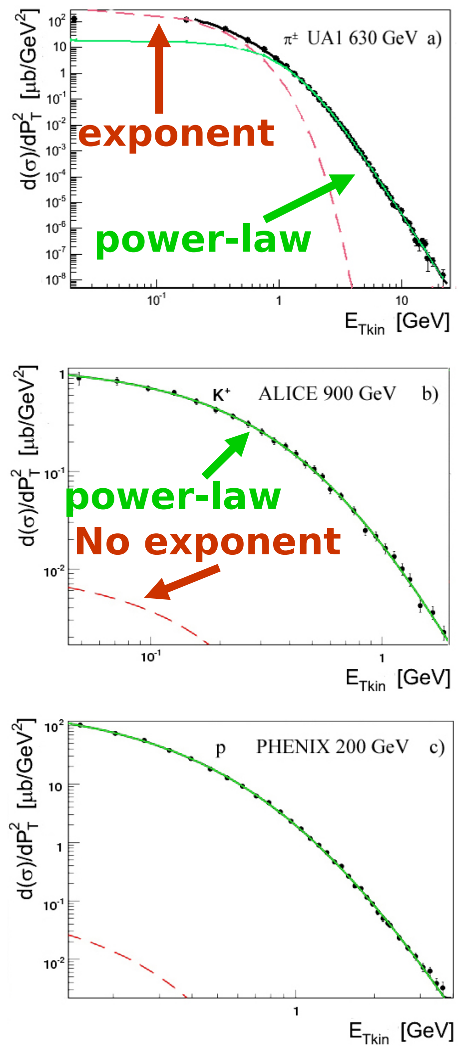
QCD-fluctuations are democratic to quark flavour while valence quark radiation can't produce heavy flavours

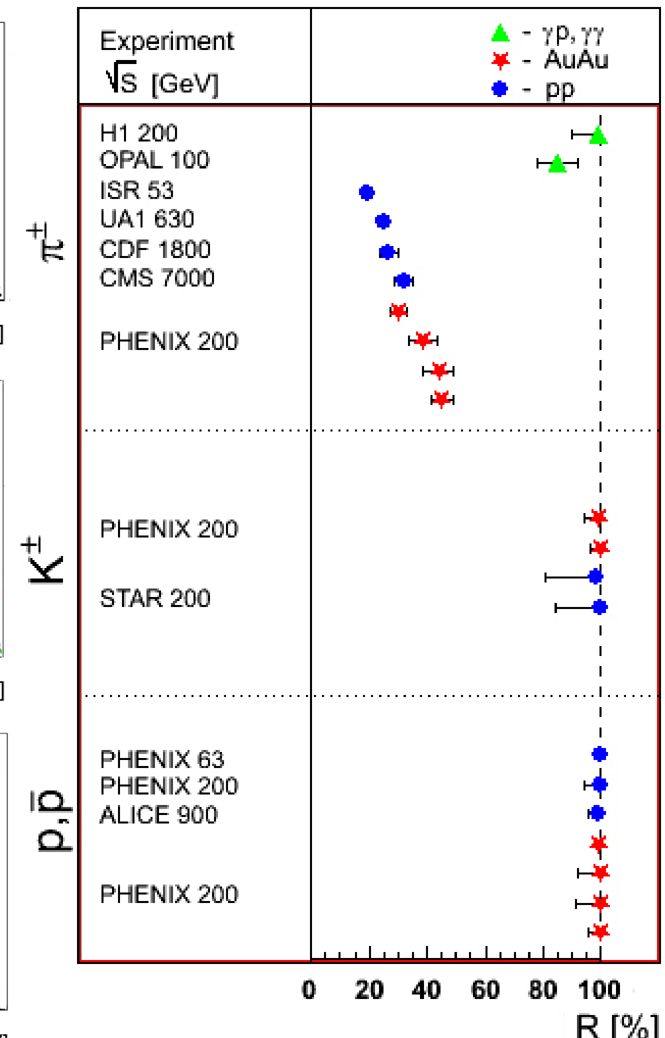
Prediction: Kaon (and J/ψ) spectra should have less exponential contribution then pion

$$R = \frac{\text{Power-law}}{\text{Exp + Power-law}}$$



J/ψ spectra CDF
√s = 1.96 TeV





Dependence of the spectra shape on multiplicity

Charge multiplicity is proportional to the number of Pomerons involved

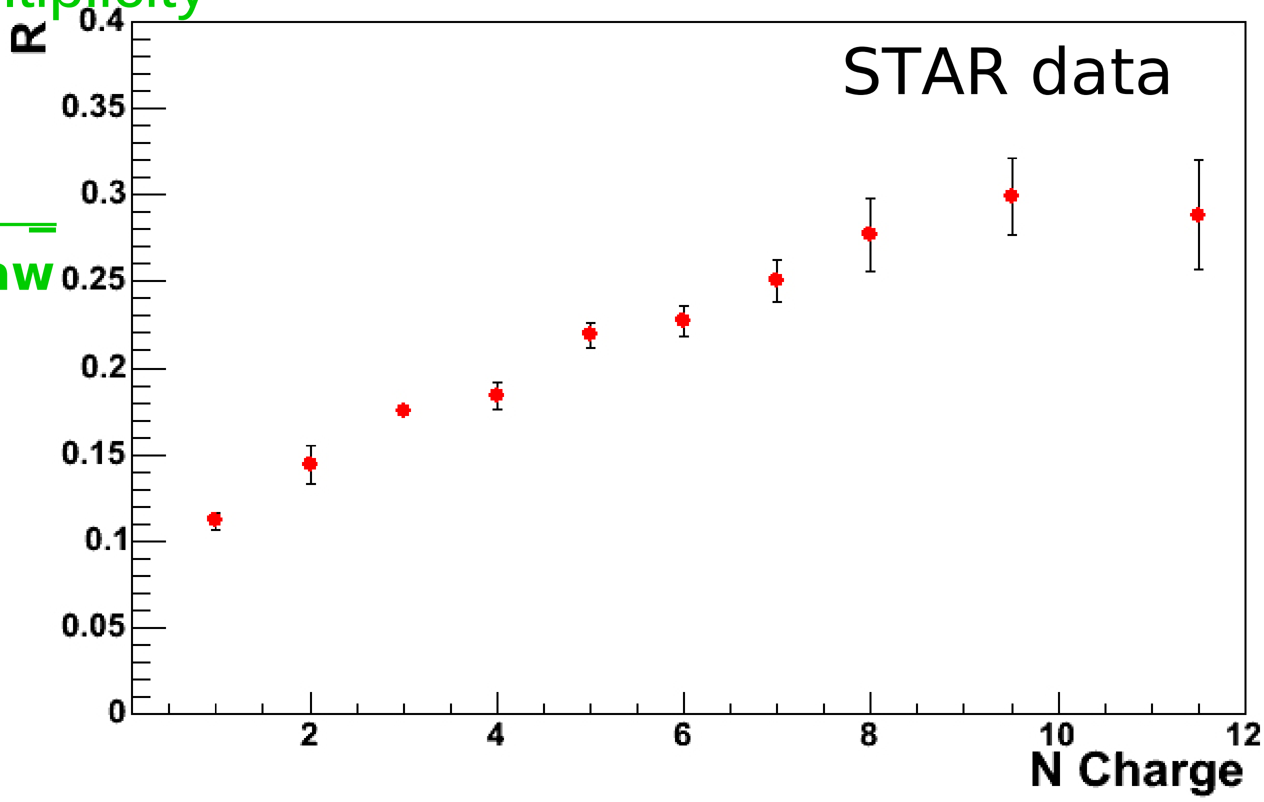
Prediction: Power-law contribution will increase with the increase of multiplicity

Dependence of the spectra shape on multiplicity

Charge multiplicity is proportional to the number of Pomerons involved

Prediction: Power-law contribution will increase with the increase of multiplicity

$$R = \frac{\text{Power-law}}{\text{Exp + Power-law}}$$



Energy of Collision

The number of pomerons involved is increasing with the growth of the collision energy

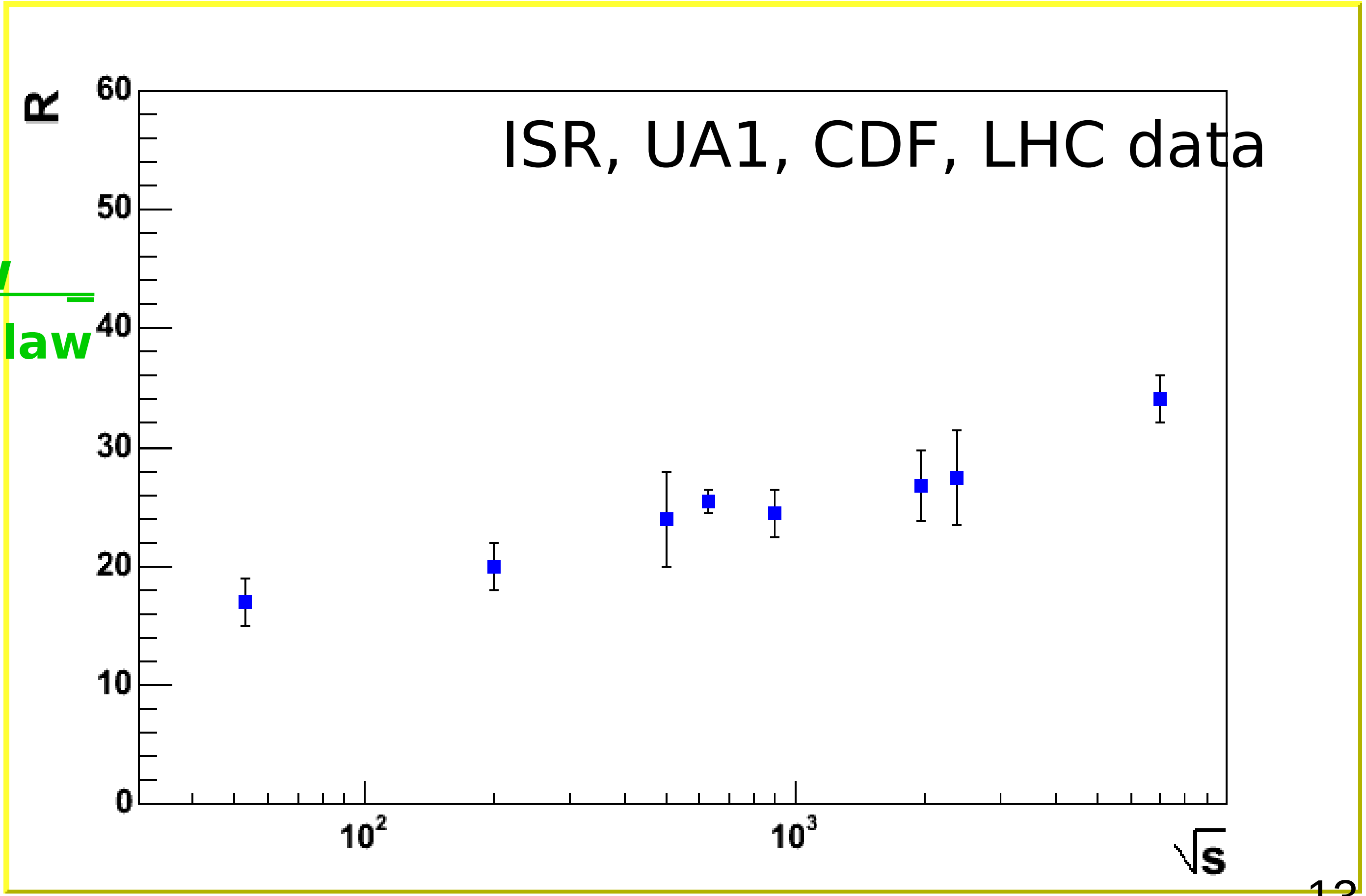
Prediction: Power-law contribution will increase with the increase of $\sqrt{s}$

Energy of Collision

The number of pomerons involved is increasing with the growth of the collision energy

Prediction: Power-law contribution will increase with the increase of √s

R = $\frac{\textbf{Power-law}}{\textbf{Exp + Power-law}}$

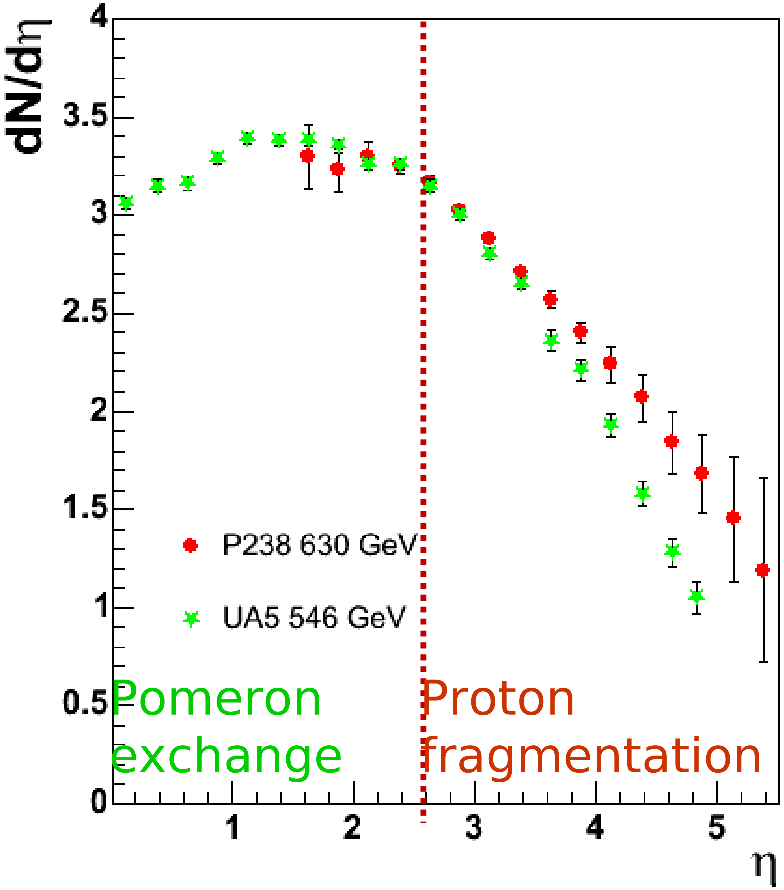


Dependence of the spectra shape on pseudorapidity

In proton fragmentation region the role of valence quarks is more important

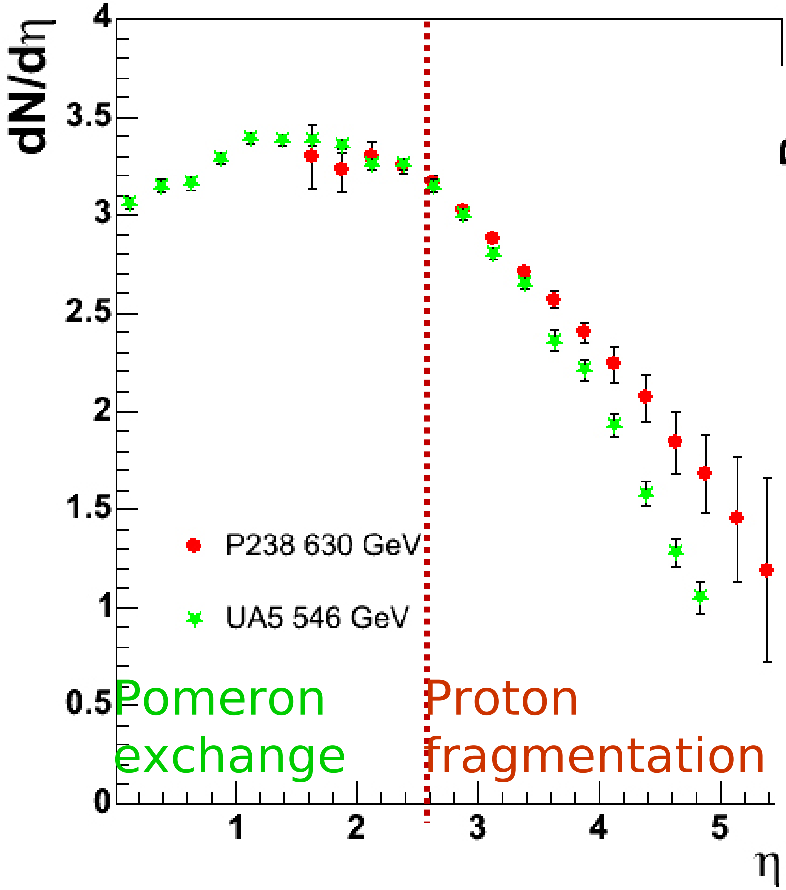
Prediction: Dominance of exponential term in the high rapidity region

Charge particle pseudorapidity distribution at √s ~ 630 Gev



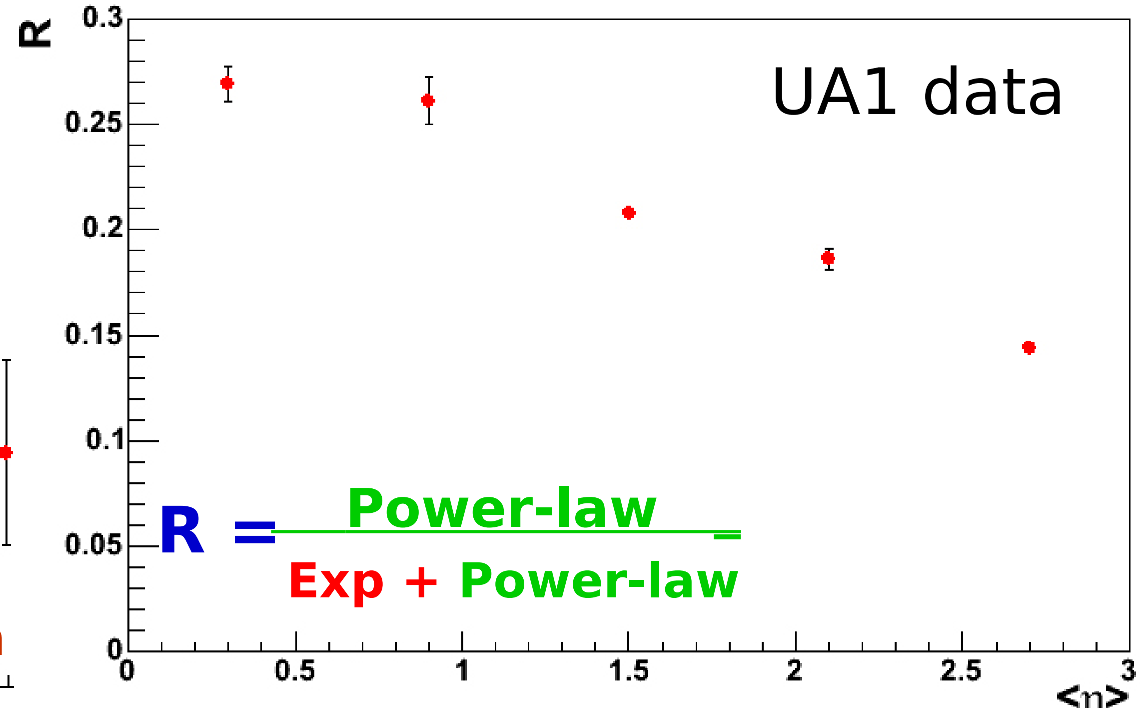
Dependence of the spectra shape on pseudorapidity

Charge particle pseudorapidity distribution at √s ~ 630 Gev



In proton fragmentation region the role of valence quarks is more important

Prediction: Dominance of exponential term in the high rapidity region



Summary

- Transverse momenta and rapidity spectra were measured with H1 detector at HERA at $\sqrt{s}$ = 225 GeV.
- Different parton dynamics models were studied:
  - DJANGOH(CDM) provides the best description of the data
  - However it fails to describe the spectra in central region
- Phenomenological model for hadroproduction was introduced
- Good agreement between the qualitative prediction of the model and the experimental data was found.
- Other predictions of the model have been tested

Thank you for your attention!

Other predictions of the introduced model have been already tested

1. Exponential term is due to valence quarks

→ Spectra in γγ-collisions should have power-law term only

[1] Systematic studies of hadron production spectra in collider experiments
A.Bylinkin and A.Rostovtsev, **arXiv:1008.0332 [hep-ph].**

2. QCD-fluctuations are democratic to quark flavour

→ Kaon spectra should have less exponential distribution then pion

[2] Anomalous behavior of pion production in high energy particle collisions
A.Bylinkin and A.Rostovtsev, **Eur.Phys.J.C 72(2012)1961,**

[3] Comparative Analysis of Pion, Kaon and Proton Spectra Produced at PHENIX
A.Bylinkin and A.Rostovtsev, **arXiv:1203.2840 [hep-ph].**

3. Charge multiplicity is proportional to the number of Pomerons involved

→ Exponential contribution will decrease with the increase of multiplicity

[4] An analysis of charged particles spectra in events with different charged multiplicity. *A.Bylinkin and A.Rostovtsev*, **arXiv:1205.4432 [hep-ph].**

4. In proton fragmentation region the role of valence quarks is more important

→ Dominance of exponential term in the high rapidity region

[5] A variation of the charged particle spectrum shape as function of rapidity in high energy pp collisions. *A.Bylinkin and A.Rostovtsev*, **arXiv:1205.6382.**

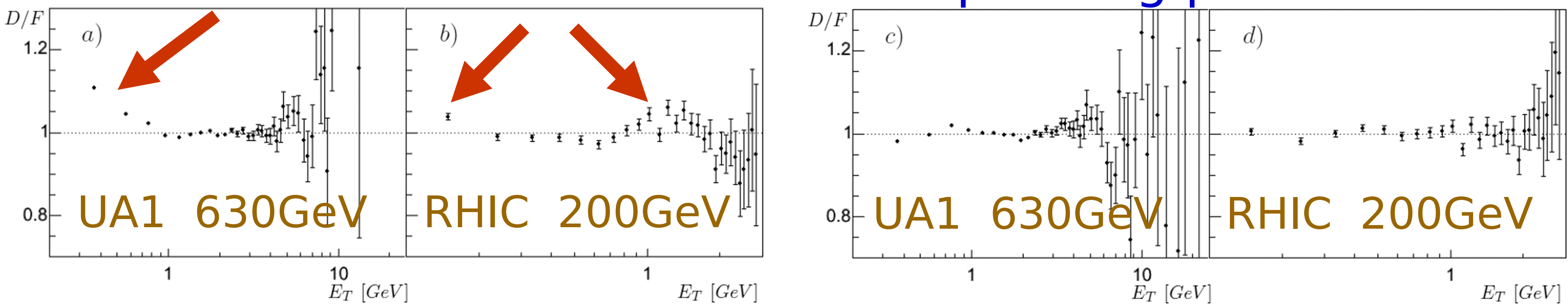
5. The number of pomerons involved is increasing with the growth of the collision energy

→ Power-law contribution will increase with the increase of $\sqrt{s}$

Why our approach is better?

Systematic defects in the data description using traditional approach

Experimental data divided over the values of the fit function in corresponding points



χ^2/ndf = 288/44 χ^2/ndf = 87/25 χ^2/ndf = 54/42 χ^2/ndf = 22/23

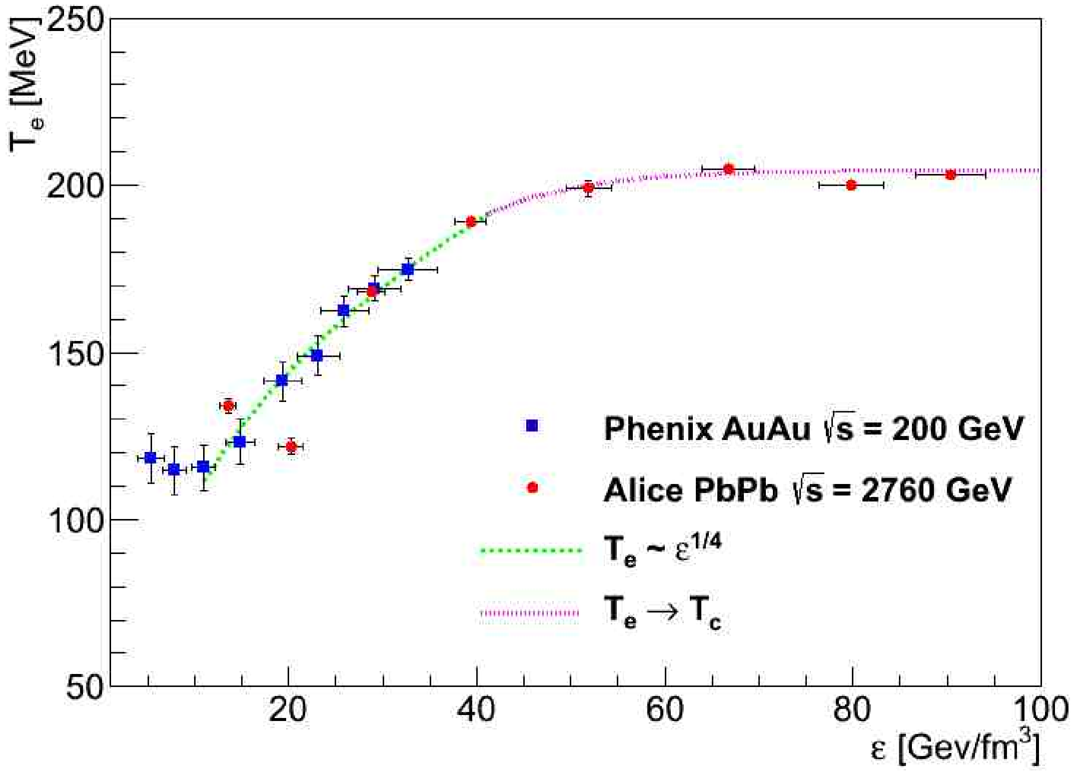
$$\frac{d^2\sigma}{\pi dyd(p_T{}^2)} = \frac{A}{(1+\frac{E_{Tkin}}{T*N})^N}$$

$$\frac{d^2\sigma}{\pi dy(dp_t^2)} = A_1 exp(-E_{Tkin}/T_e) + \frac{A_2}{(1+\frac{P_T^2}{T^2 N})^N}$$

The new parameterization shows much better approximation of the experimental data.

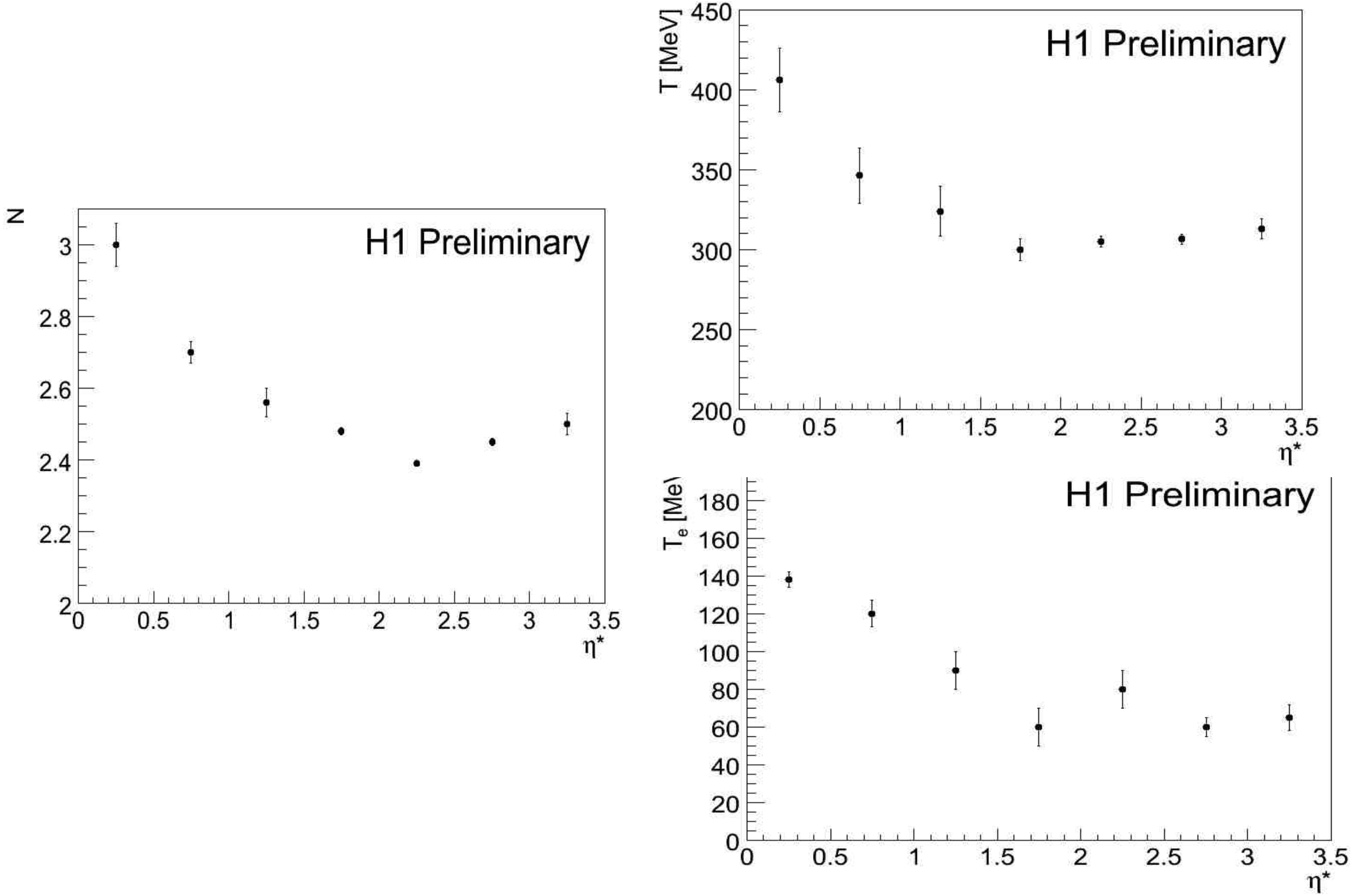
Temperature in heavy-ion collisions

T as function of energy density



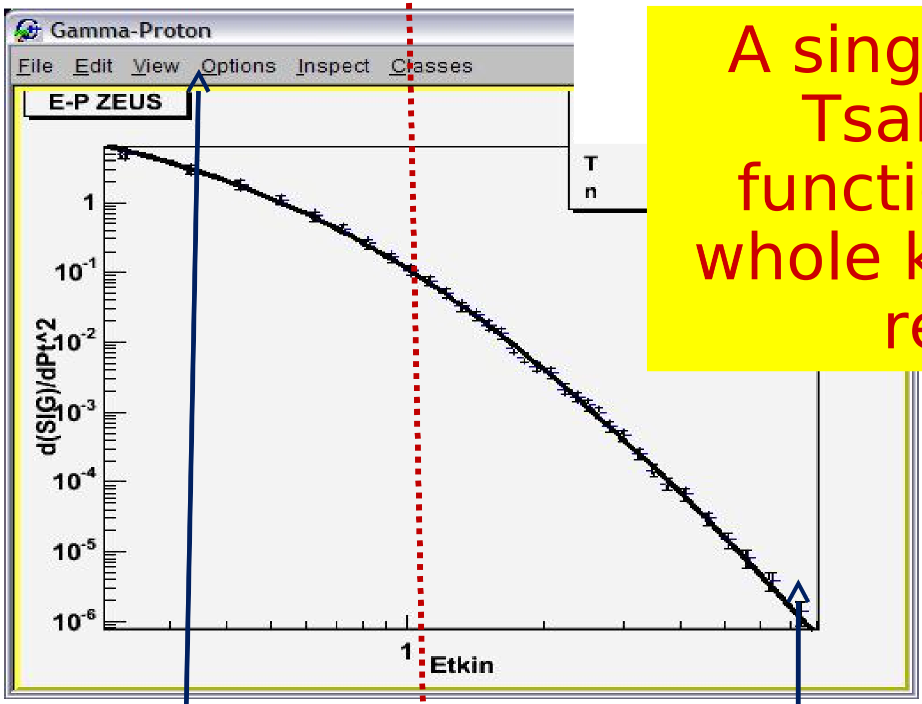
Backup slides

Parameters of the Fit



Transverse Momentum Spectra of Charged Particles

(Differential Invariant Cross-Section)



A single smooth Tsallis-type function for the whole kinematical region

E^{kin}_T [GeV]

Traditional approximation:

$$E\frac{d^3\sigma}{d^3p}(y\approx 0)=\frac{A}{(1+\frac{E_T^{kin}}{T\cdot N})^N}$$

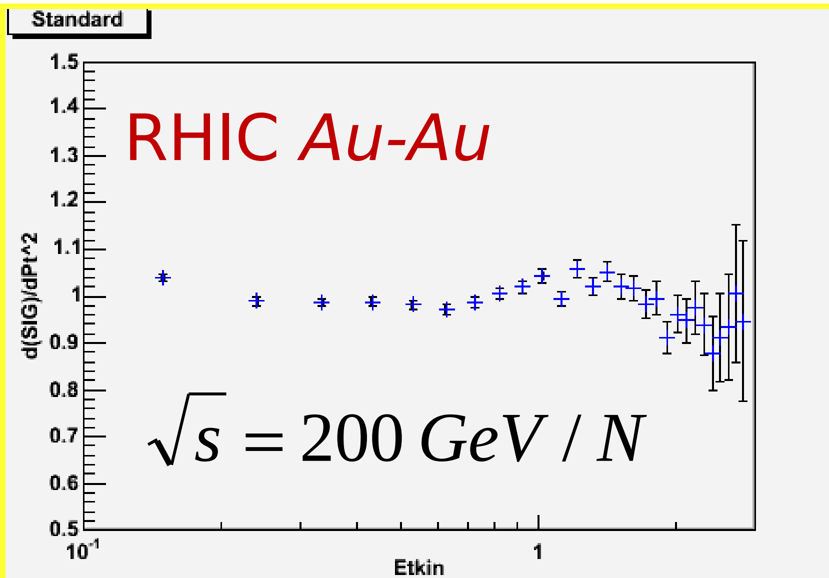
$$E_T^{kin}=\sqrt{p_T^2+m_\pi^2}-m_\pi$$

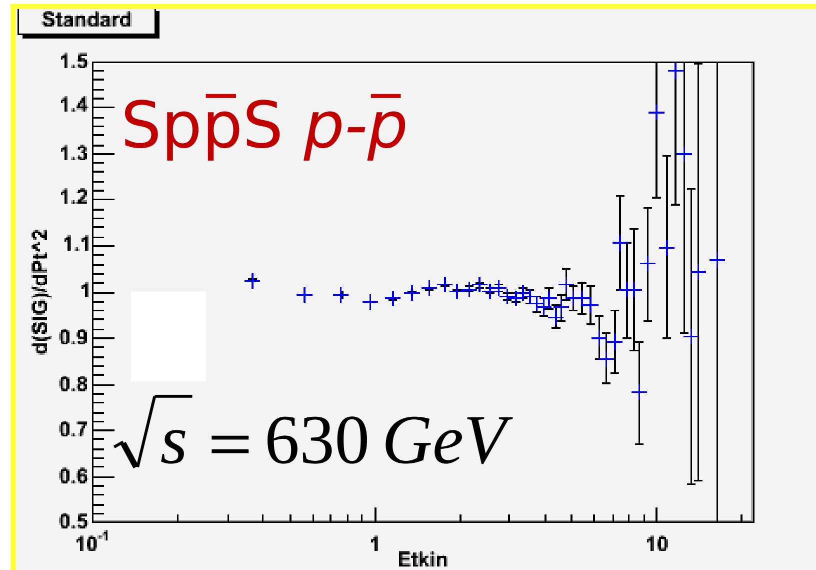
Nonperturbative thermodynamics

pQCD

Does Tsallis-type power law distribution really describe the hadron production spectra?

To answer this question let's plot a ratio = data / fit function





On both plots one observes a shallow dip at E_T values below 1 GeV followed by a broad bump above 1 GeV.

These defects are hidden on usual logarithmic plots!

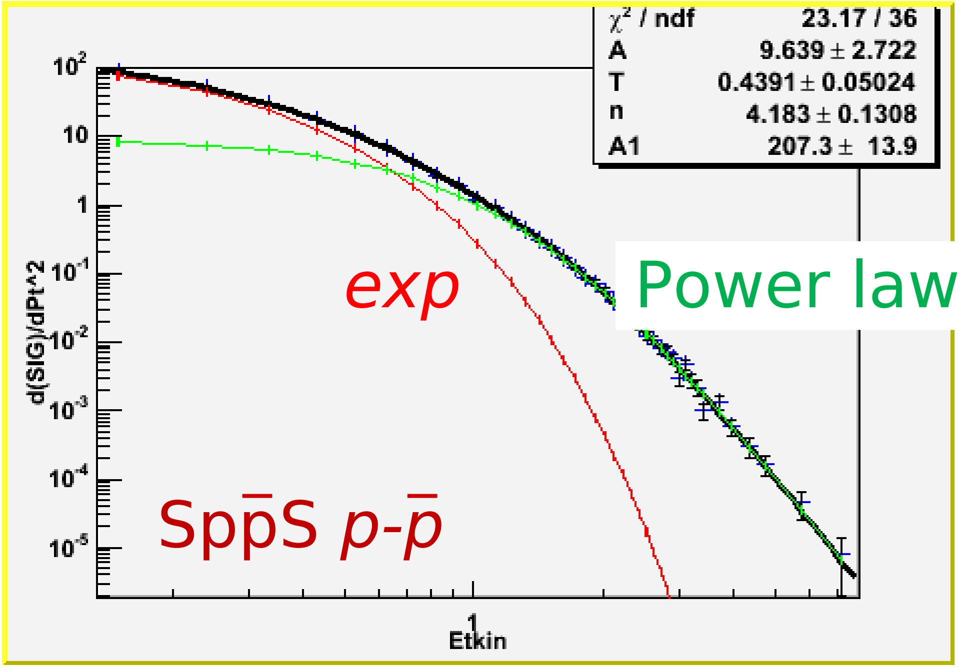
served systematic defects require to modify the approximati

A modification of the Tsallis function

Take two contributions: Exponential + Power law functions

Generalized forms: $\exp(-F(P_T)/T_e)$ $\quad 1/(1+F'(P_T)/N)^N$

With true scalars $F, F' = P_T^2$ *or* E_T^{kin} $\quad$ (*not* P_T *or* P_T^3)



The best fits are given by $A_e \cdot \exp(-E_T^{kin}/T_e) + A/(1+P_T^2/T^2N)^N$

R Value

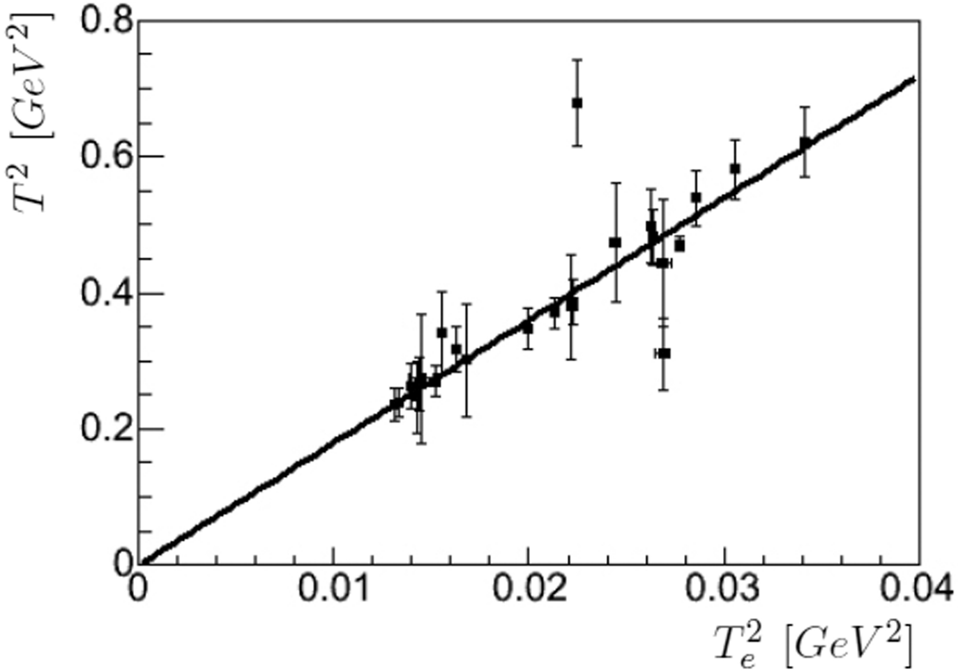
The relative contribution of exponential and power-law terms can be calculated by integrating each term by transverse momentum from 0 to the upper bound of the kinematical region

$$\int_0^\infty \frac{A}{(1+\frac{P_T^2}{TN})^N} dP_t^2 = \frac{ANT}{N-1}$$

$$A_e \int_0^\infty exp(-E_{Tkin}/T_e) dP_t^2 = A_e(2mT_e + 2T_e^2)$$

$$R = \frac{ANT}{ANT + A_e(2mT_e + 2T_e^2)(N-1)}$$

Correlation Between Parameters



T and Te parameters in the power-law and exponential terms of the fit function are strongly correlated with each other

$$\frac{d^2\sigma}{\pi dy(dp_t^2)} = A_1 exp(-E_{Tkin}/T_e) + \frac{A_2}{(1+\frac{P_T^2}{T^2N})^N}$$

Better approximation is not just a result of exceeding the number of parameters of the fit function

Expected Results for DIS

$$\frac{d^2\sigma}{\pi dy(dp_t^2)} = A_1 exp(-E_{Tkin}/T_e) + \frac{A_2}{(1+\frac{P_T^2}{T^2N})^N}$$

Qualitative prediction of the model