Charged particle production in deep inelastic scattering at HERA

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On behalf of H1 Collaboration

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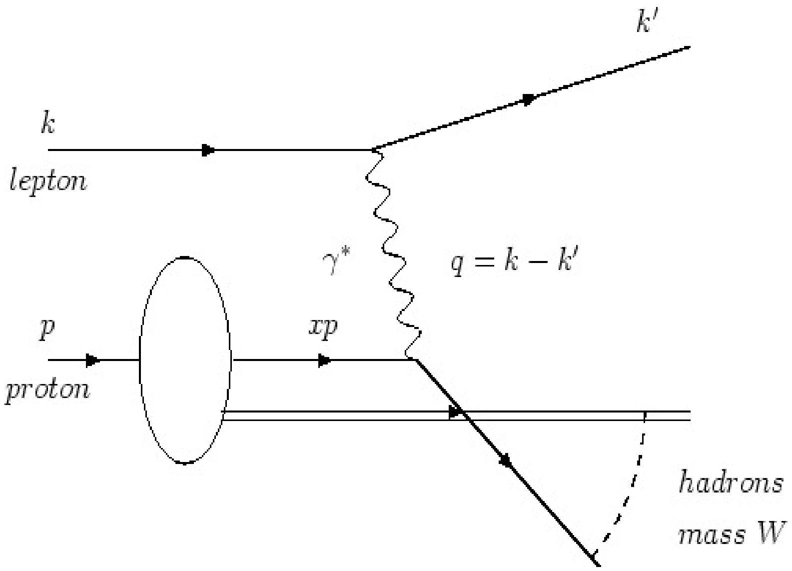
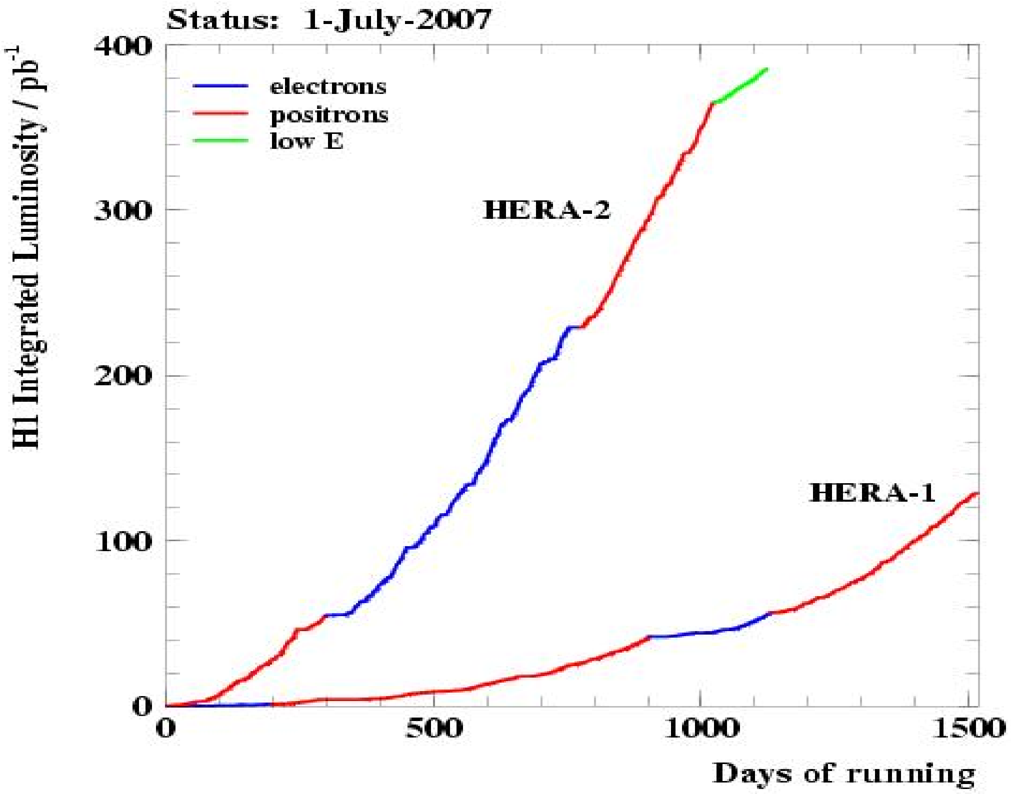
Outline

- Introduction
- Recent experimental results
  - Recent H1 publication (DESY-13-012)
    - Parton evolution + hadronisation
  - Recent H1 preliminary (H1prelim-13-032)
    - Phenomenological models

DIS at HERA





Two measurement of charged particle spectra in DIS:

1. Nominal proton beam energy (Ep = 920 GeV)

√s = 319 GeV $\quad Data\,2006\,e^{+}: \quad \mathscr{L} = 88.6\,\mathrm{pb}^{-1}$

2. Reduced proton beam energy (Ep = 460 GeV)

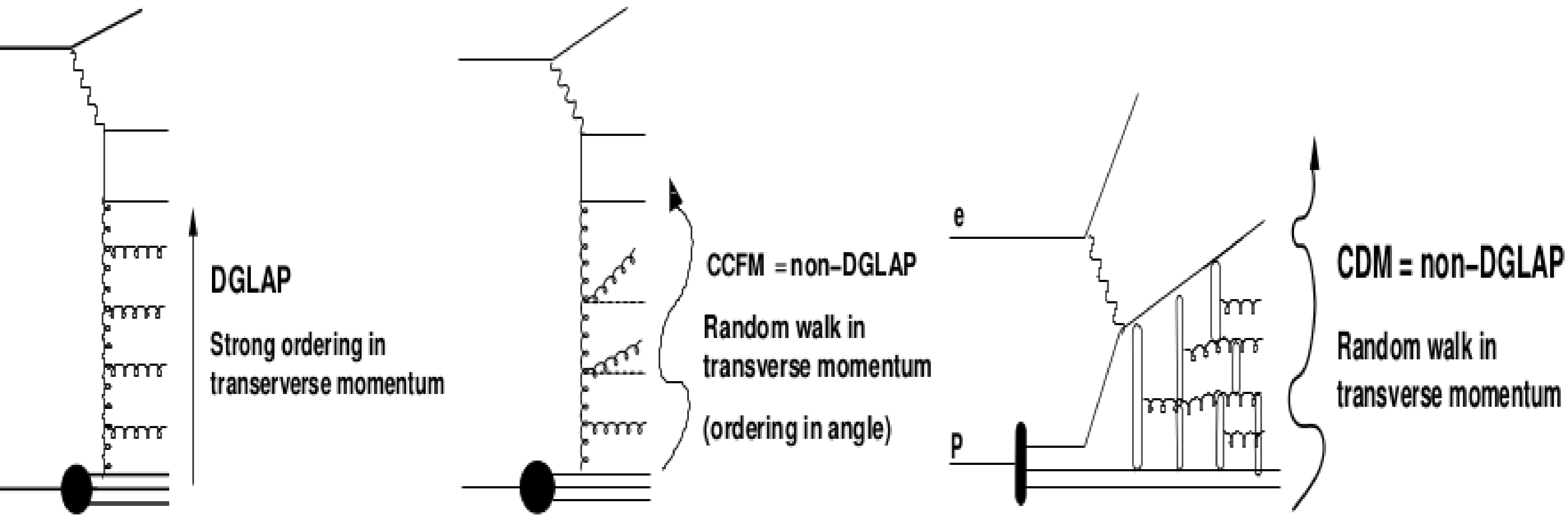
√s = 225 GeV $\quad Data\,2007\,e^{+}: \quad \mathscr{L} = 12.45\,\mathrm{pb}^{-1}$

Parton evolution models

RAPGAP — DGLAP

CASCADE — CCFM

DJANGOH — CDM (Colour Dipole Model)



DGLAP Model (Matrix Element + Parton Shower)

Works when Q^2 is large, but x is not too small

Beyond-DGLAP Models

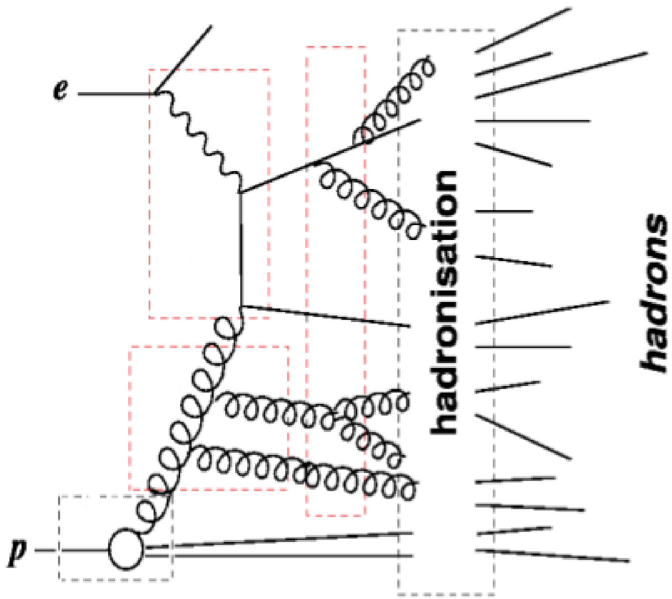
CCFM

Valid for both, small and large x

CDM (BFKL-like parton evolution)

Works for small x and Q^2 is not large

HFS as an access to the dynamics of the cascade



Hadrons at low P_T [$0 < P_T < 1$ GeV]:
Dominated by hadronisation
Small sensitivity to different parton dynamic models

Hadrons at high P_T [$1 < P_T < 10$ GeV]:
Dominated by parton dynamics
Small sensitivity to hadronisation

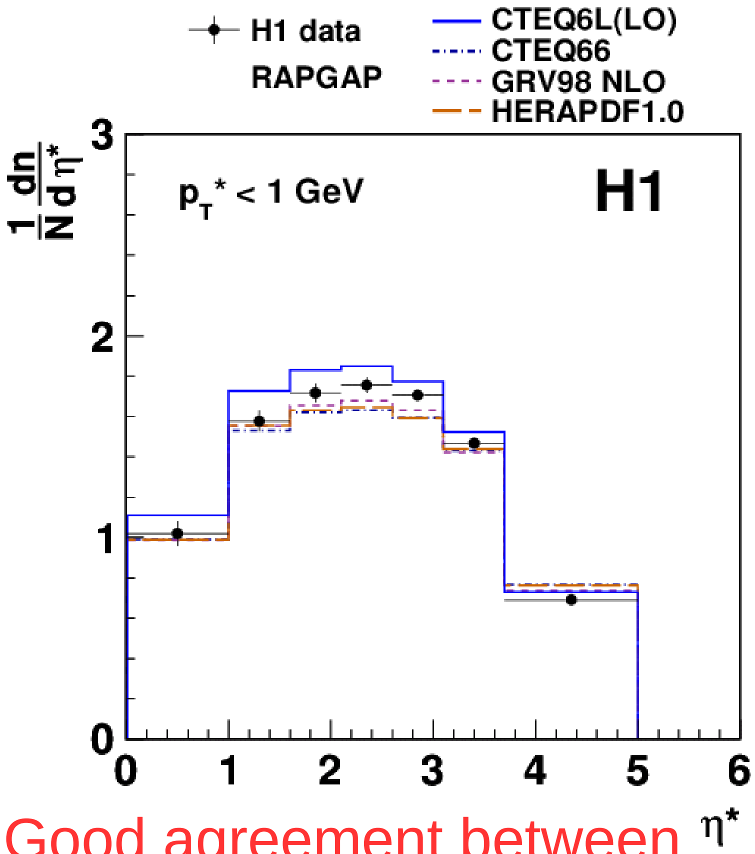
H1 recent results (DESY-13-012):
$5 < Q^2 < 100$ GeV^2, $10^{-4} < x < 10^{-2}$
Measurements are performed in hadronic centre-of-mass system (P_T^*,η^*)

$\eta^* = -\ln\tan(\theta^*/2)$
θ^* - with respect to virtual photon direction
$\eta^* < 0$ — proton direction

Charged particle densities as function of pseudorapidity

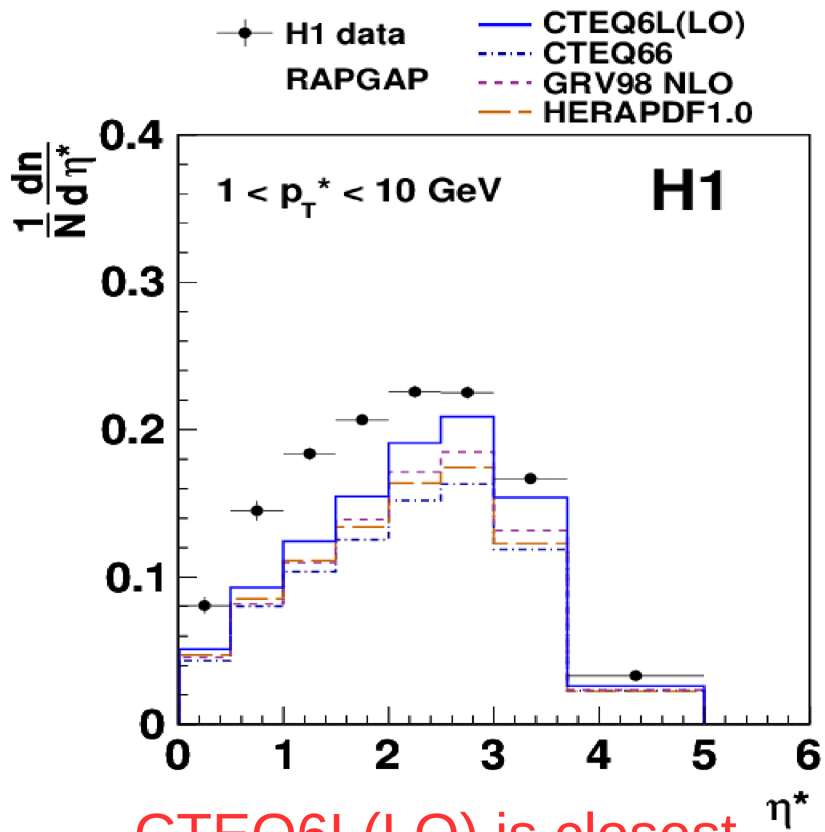
DGLAP (RAPGAP) prediction for different PDFs

Soft P_T



Good agreement between the data and predictions

Hard P_T

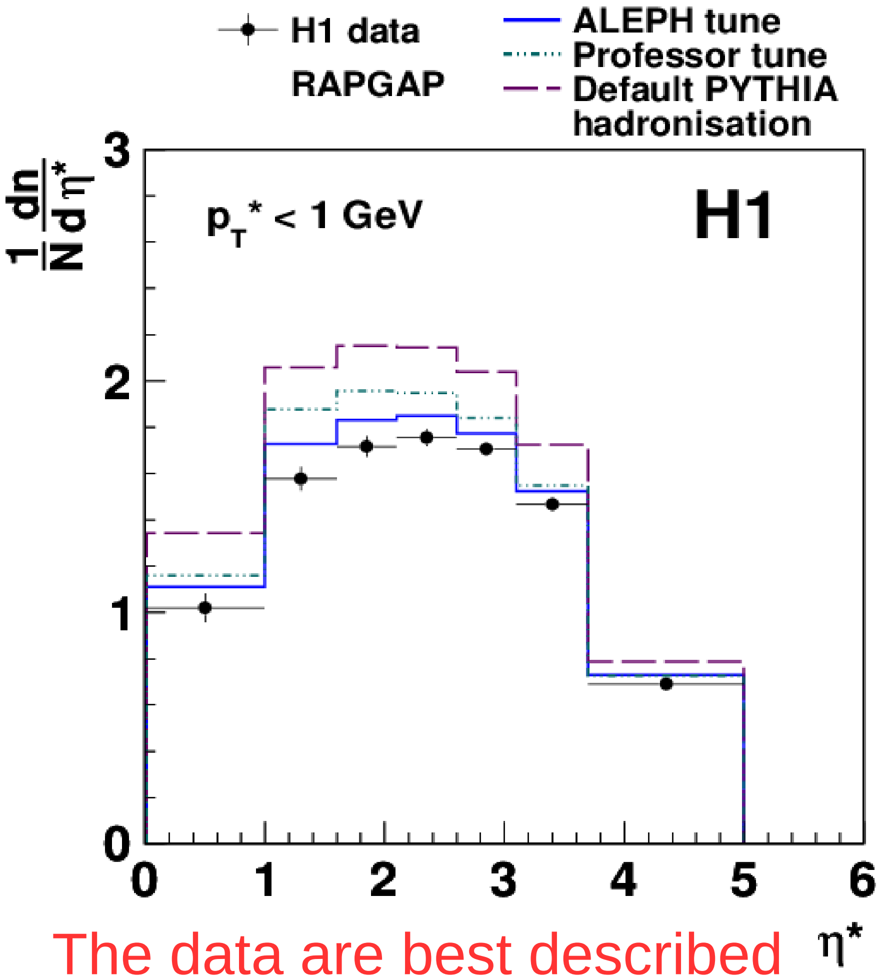


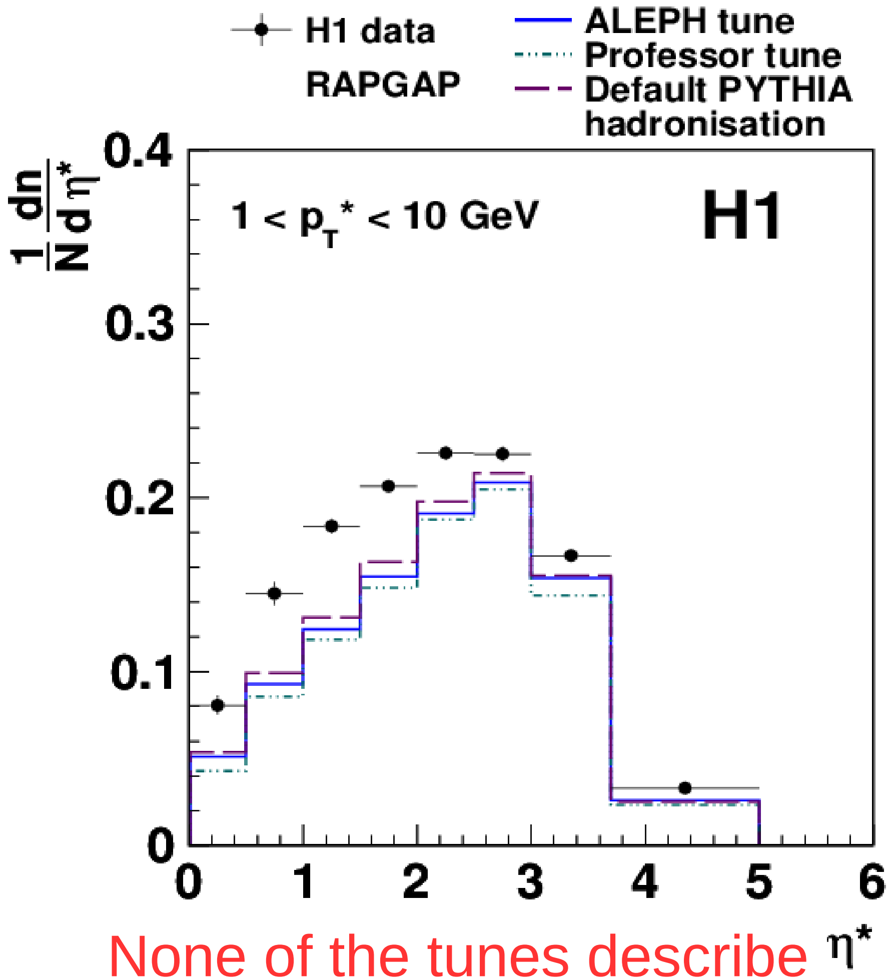
CTEQ6L(LO) is closest to the data

Some sensitivity to PDF variation at hard P_T^*

Charged particle densities as function of pseudorapidity

DGLAP (RAPGAP) prediction for different fragmentation tunes





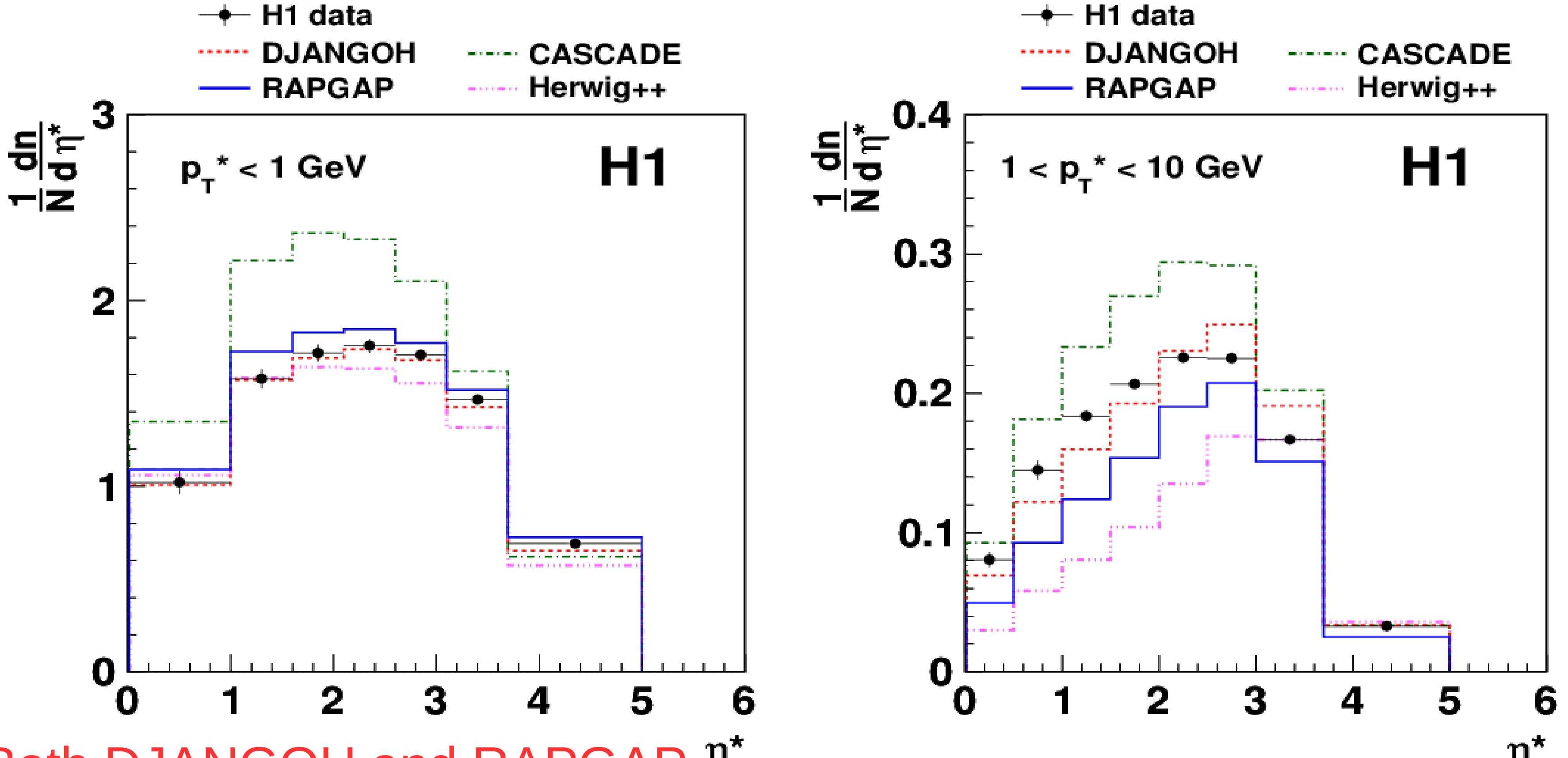
The data are best described by the ALEPH tune

None of the tunes describe the data

Sensitivity to hadronization parameters is strong at low-P_T^* only

Charged particle densities as function of pseudorapidity

Different models for parton evolution



Both DJANGOH and RAPGAP provide a good description of the experimental data

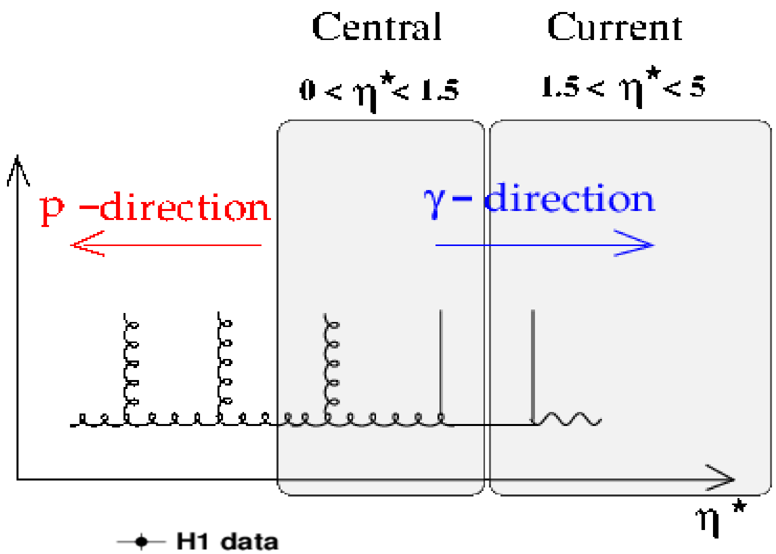
DJANGOH(CDM) provides the best description

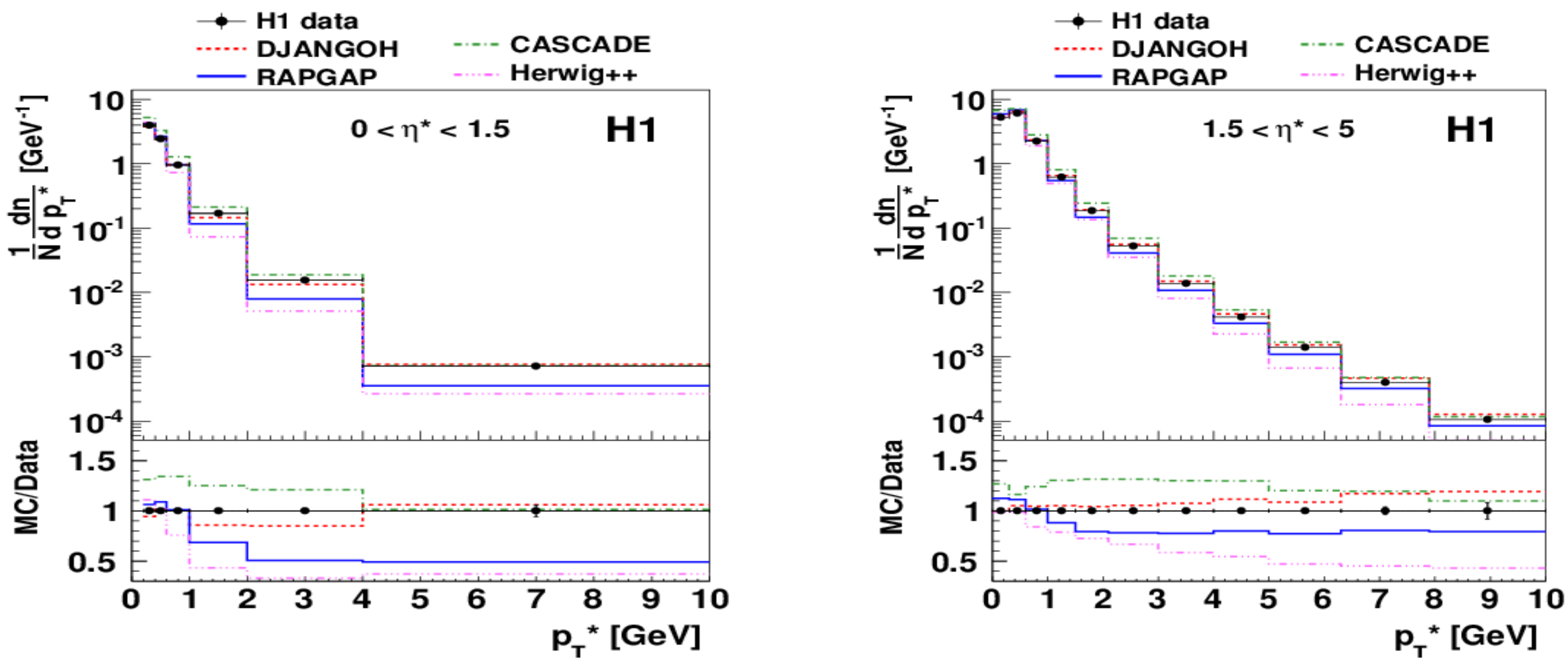
Strong sensitivity to different parton dynamics at high-P_T*

Charged particle densities as function of transverse momentum

Different models for parton evolution

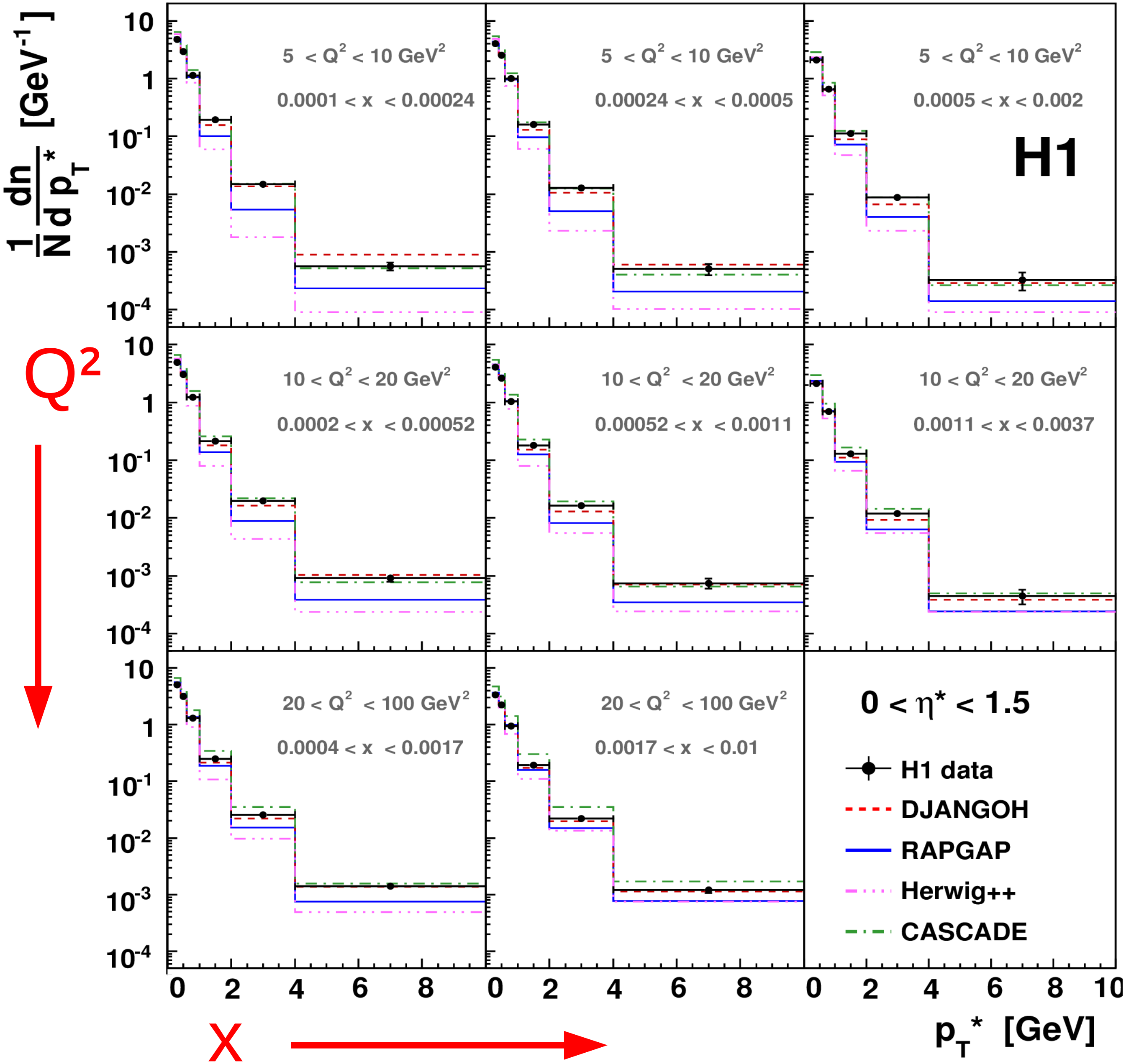
Two pseudorapidity intervals
$0 < \eta^* < 1.5$ and $1.5 < \eta^* < 5$





Only DJANGOH(CDM) provides a reasonable description of the data

Charged particle densities as function of transverse momentum



DJANGOH(CDM) describes the data for whole P_T* spectra

Strong deviation from RAPGAP(DGLAP) at low x and Q^2

CASCADE(CCFM) describes the data at high P_T* only

Phenomenological model

Two contributions to hadron production

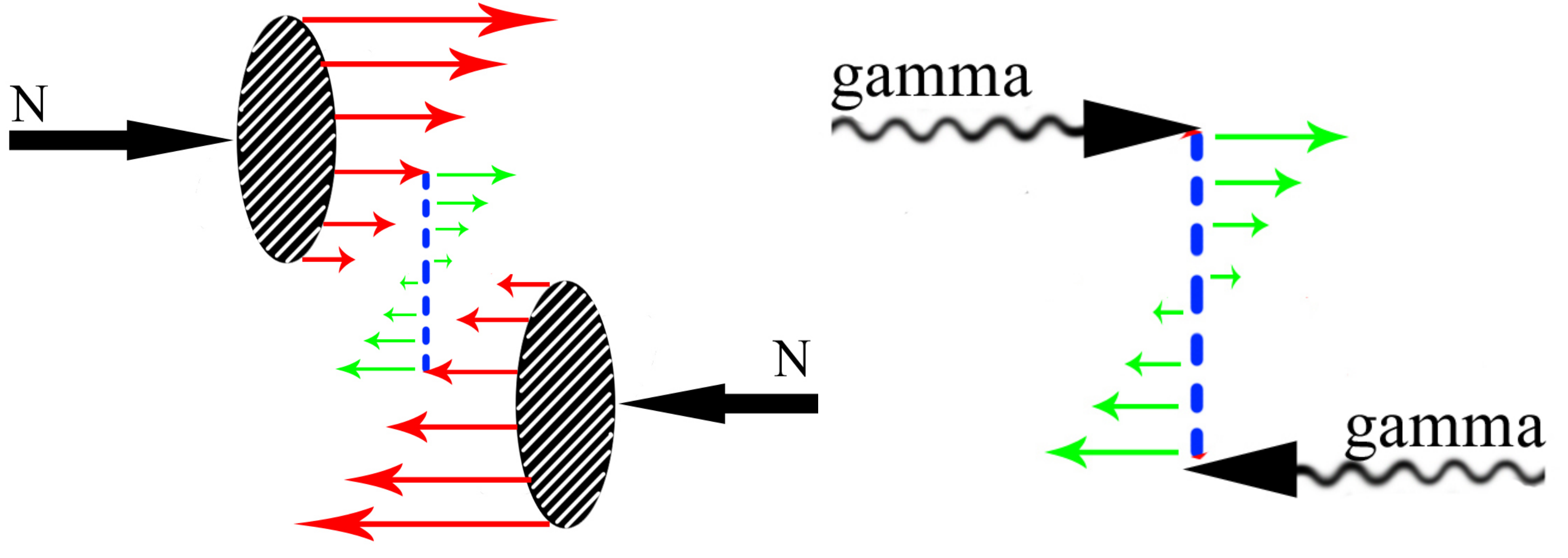
1. Radiation of hadrons by valence quarks

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

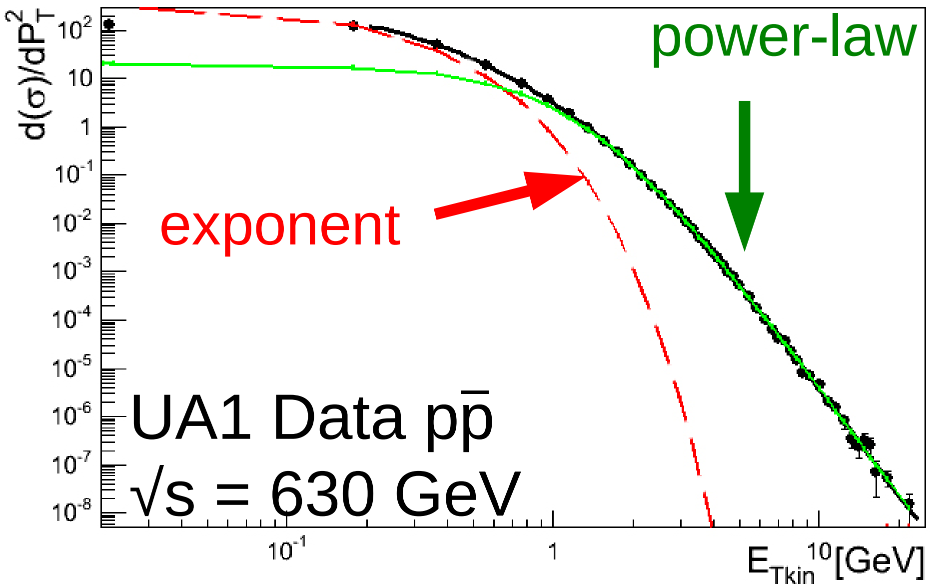
⇨ power-law spectrum (typical for pQCD)

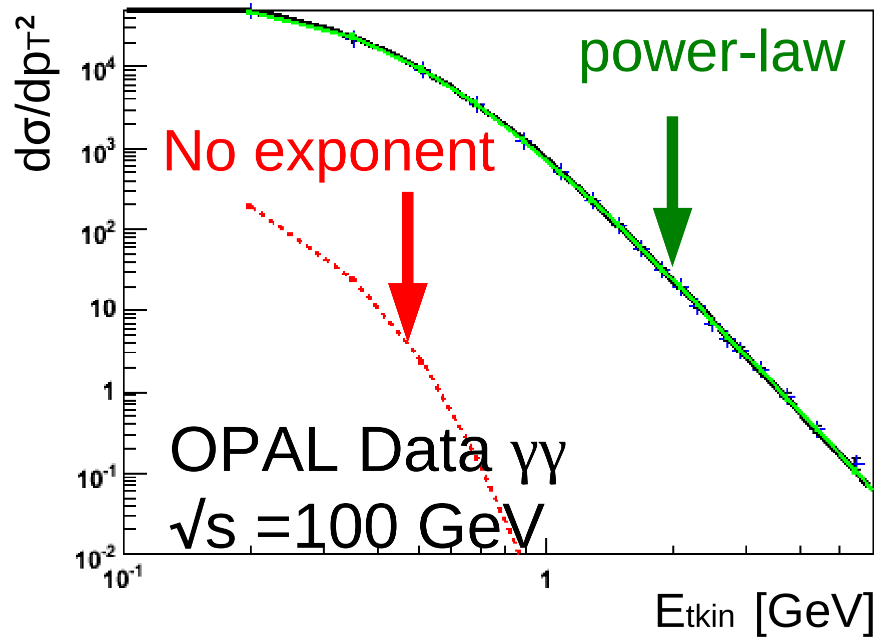


A.A. Bylinkin and A.A. Rostovtsev arXiv: 1209.0958 [hep-ph]

Comparison of pp and γγ Spectra

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



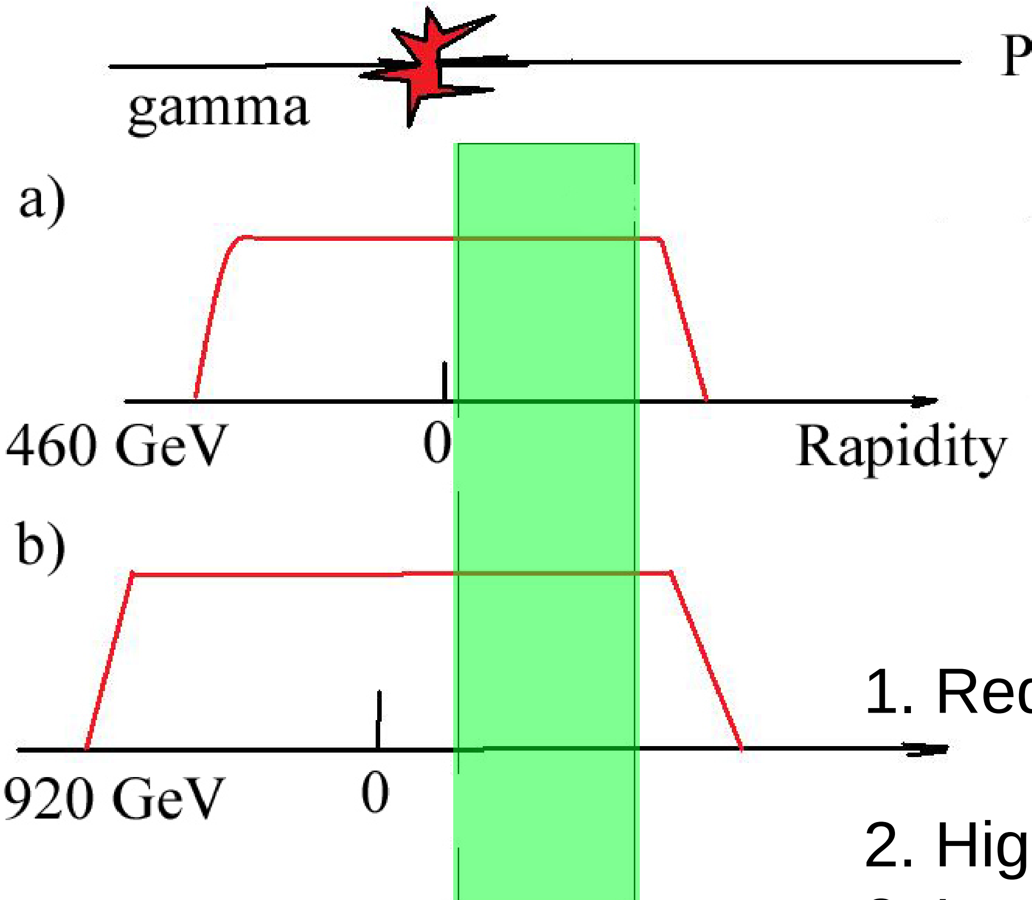


pp-collisions have large exponential term contribution

γγ-interactions are described by the power-law only

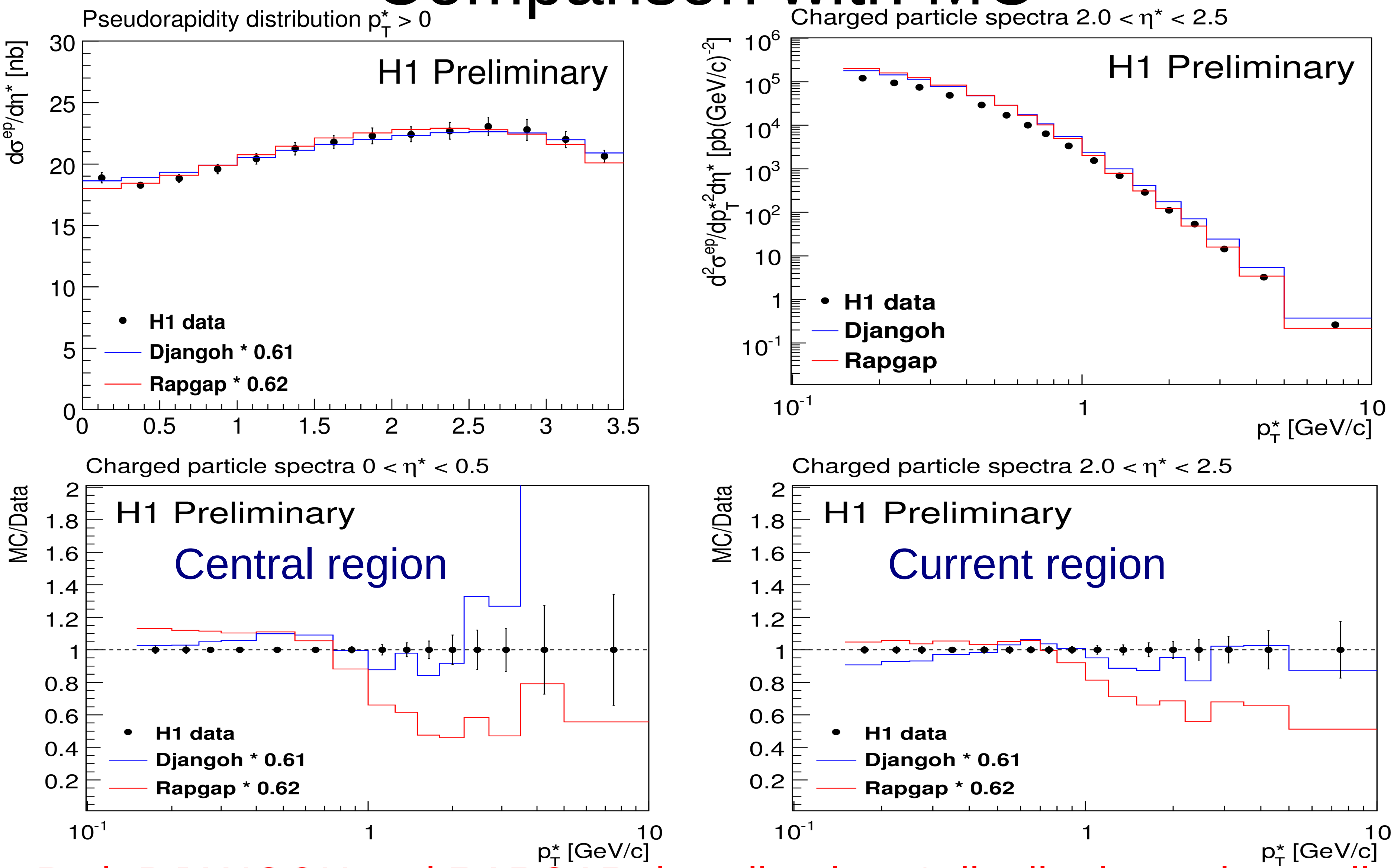
What is in ep collisions?

DIS at HERA is the unique possibility to study such change in hadroproduction dynamics



1. Reduced proton beam energy
   Ep = 460 GeV
2. High Y-values $0.35 < y < 0.8$
3. Low Q^2 $5 < Q^2 < 10$ GeV^2
4. 7 η^* bins $0 < \eta^* < 3.5$

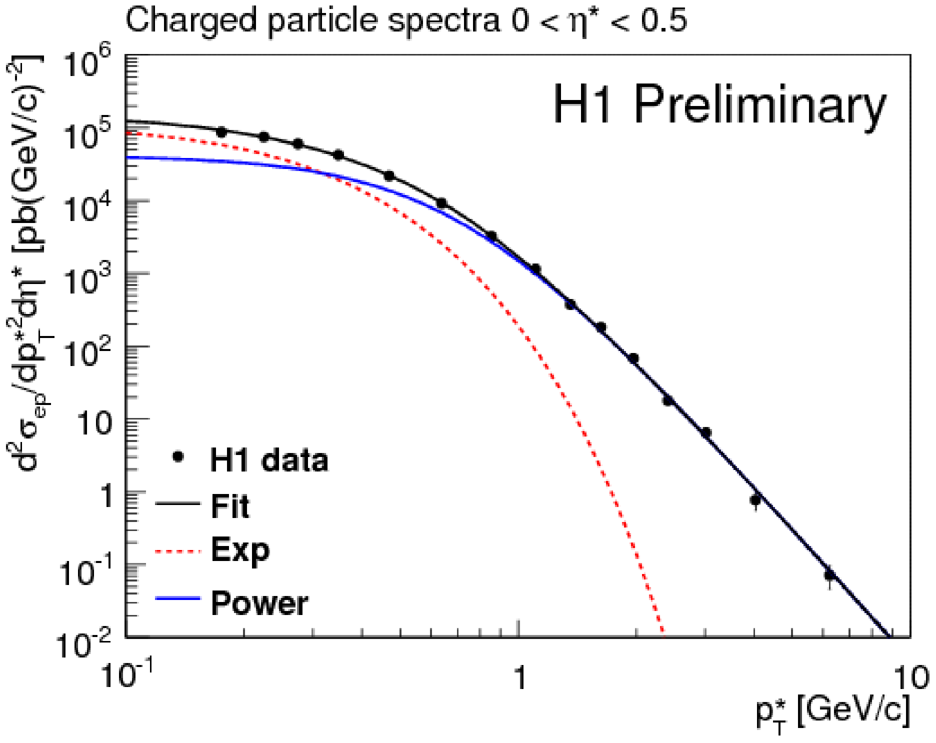
Comparison with MC



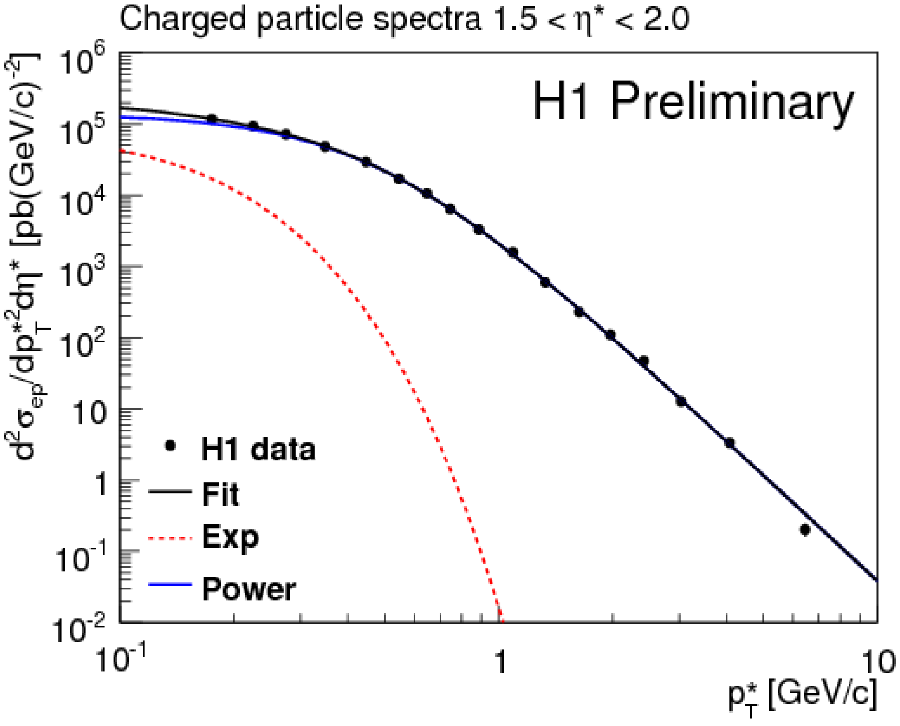
Both DJANGOH and RAPGAP describe the η* distribution rather well, but NOT the spape of the P_T* spectra in the central region

Double differential cross-section

Central region



Current region

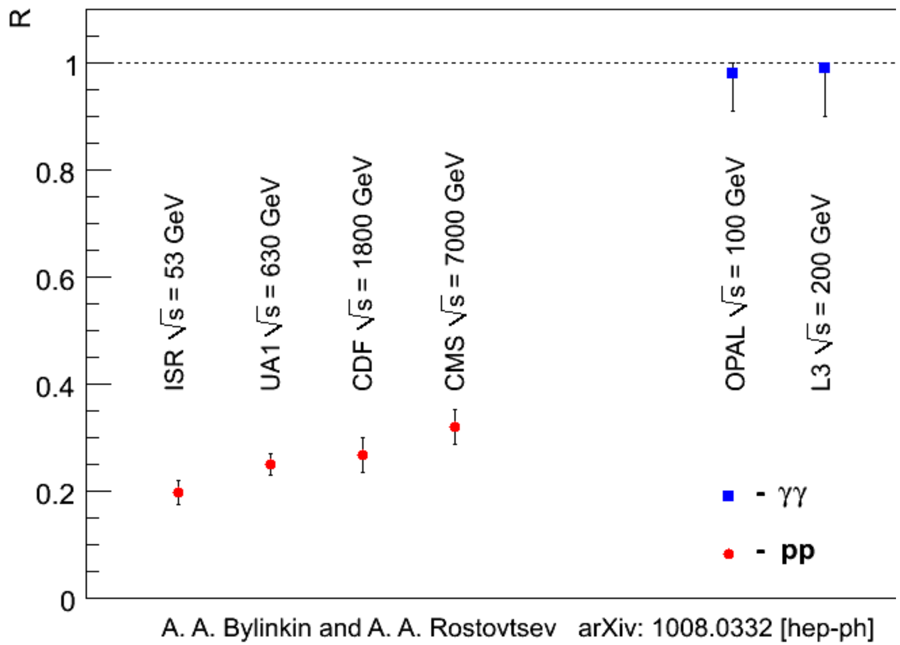


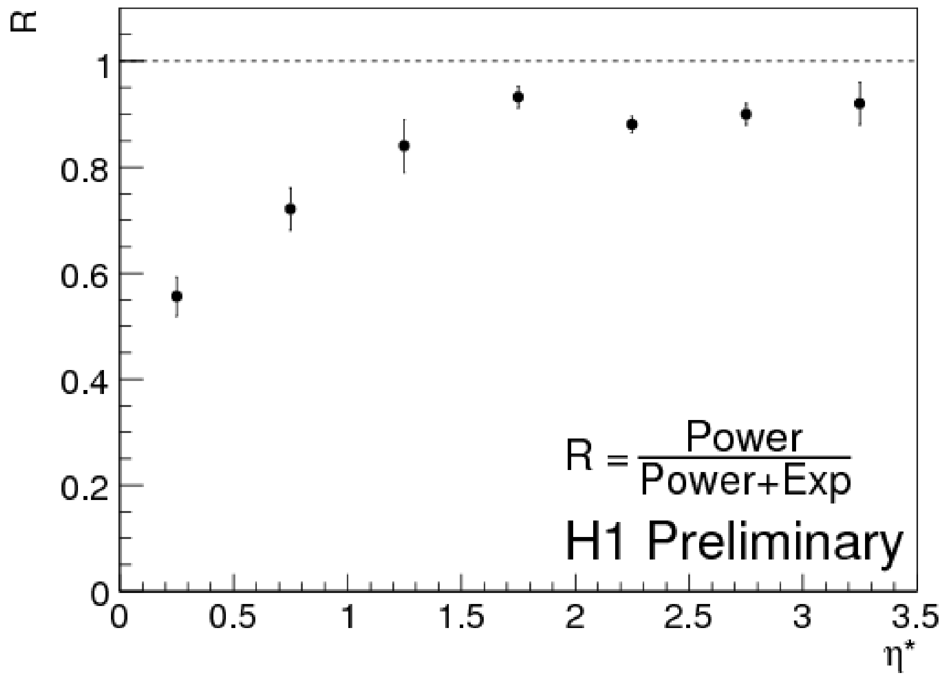
Large exponential contribution

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

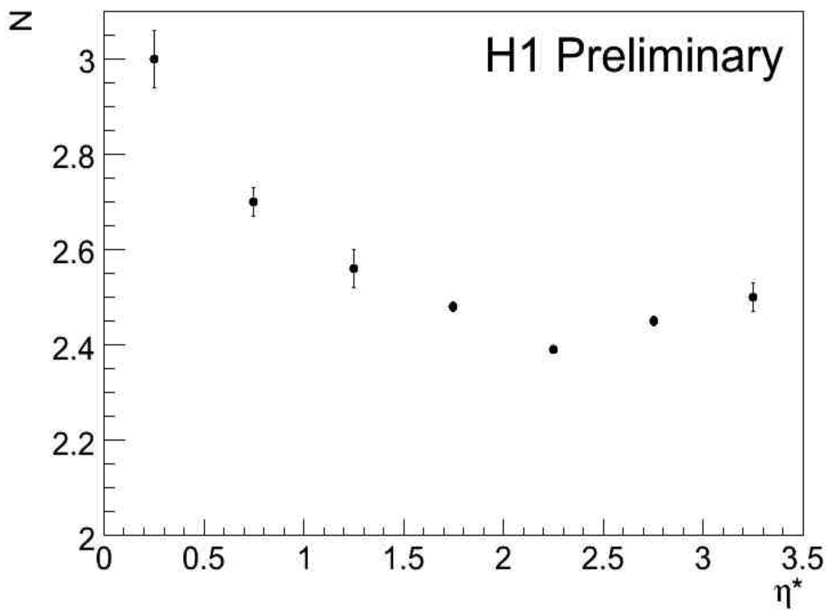
Summary

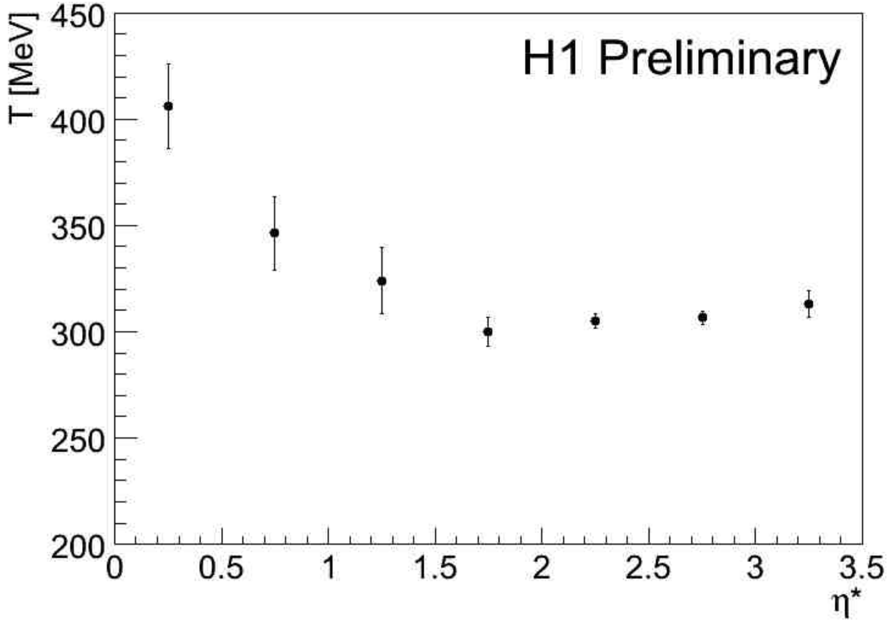
- Transverse momenta and rapidity spectra were measured with H1 detector at HERA at $\sqrt{s}$ = 319 GeV and $\sqrt{s}$ = 225 GeV.
- Different parton dynamics models were studied:
  - DJANGOH(CDM) provides the best description of the data
- Phenomenological model for hadroproduction was introduced
- Good agreement between the qualitative prediction of the model and the experimental data was found.

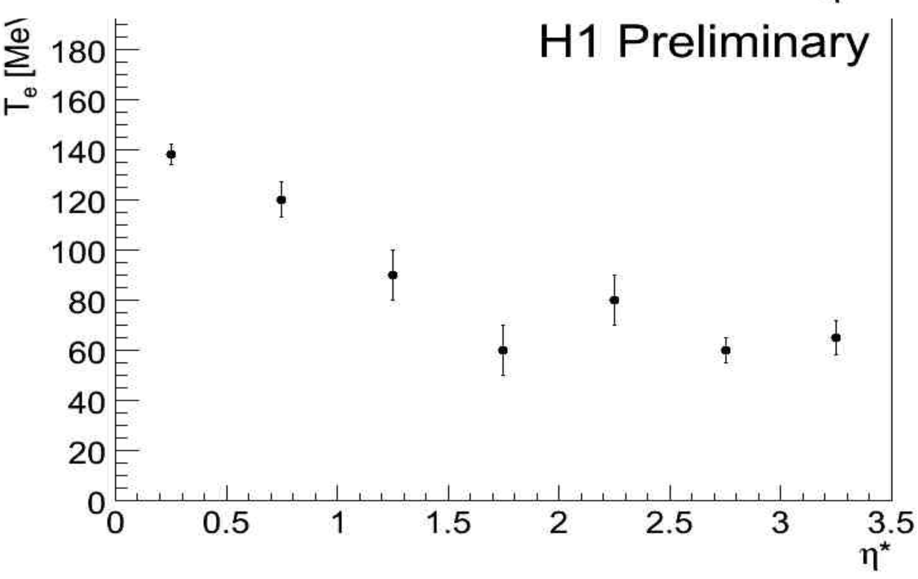
Thank you for your attention!

Backup slides

Parameters of the Fit







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 $\sqrt{s}$

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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

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

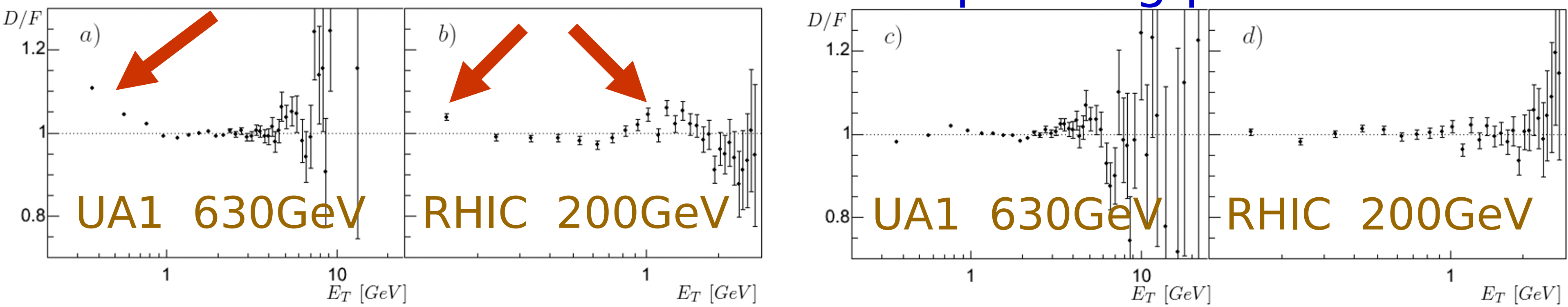
$$A_e \int_0^\infty exp(-E_{Tkin}/T_e) dP_t^2 = A_e(2mT_e + 2T_e^2)$$

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

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



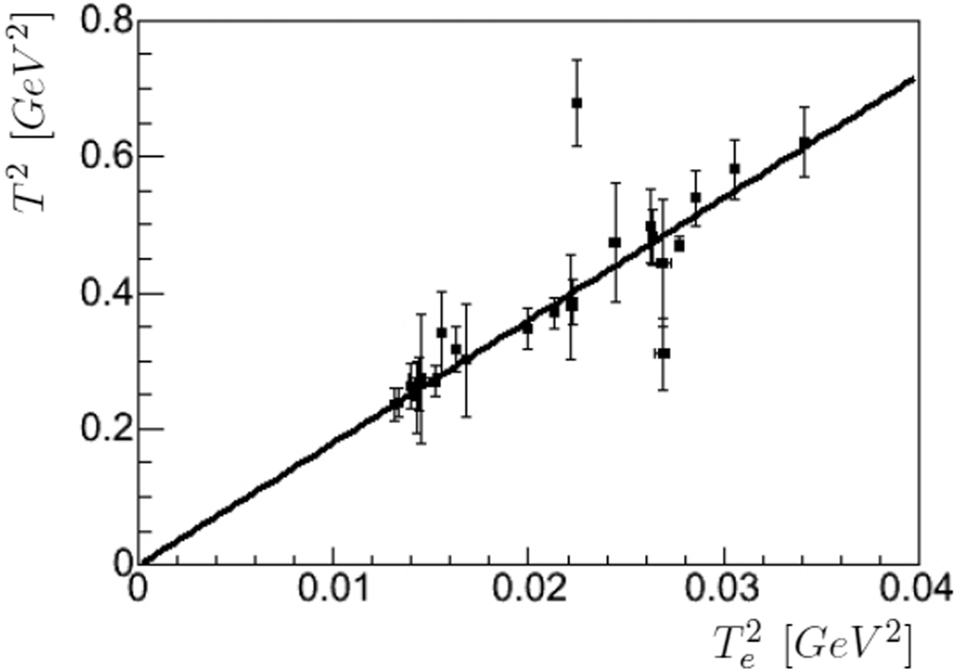
χ^2/ndf = 288/44 χ^2/ndf = 87/25 χ^2/ndf = 54/42 χ^2/ndf = 22/23

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

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

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

Correlation Between Parameters



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

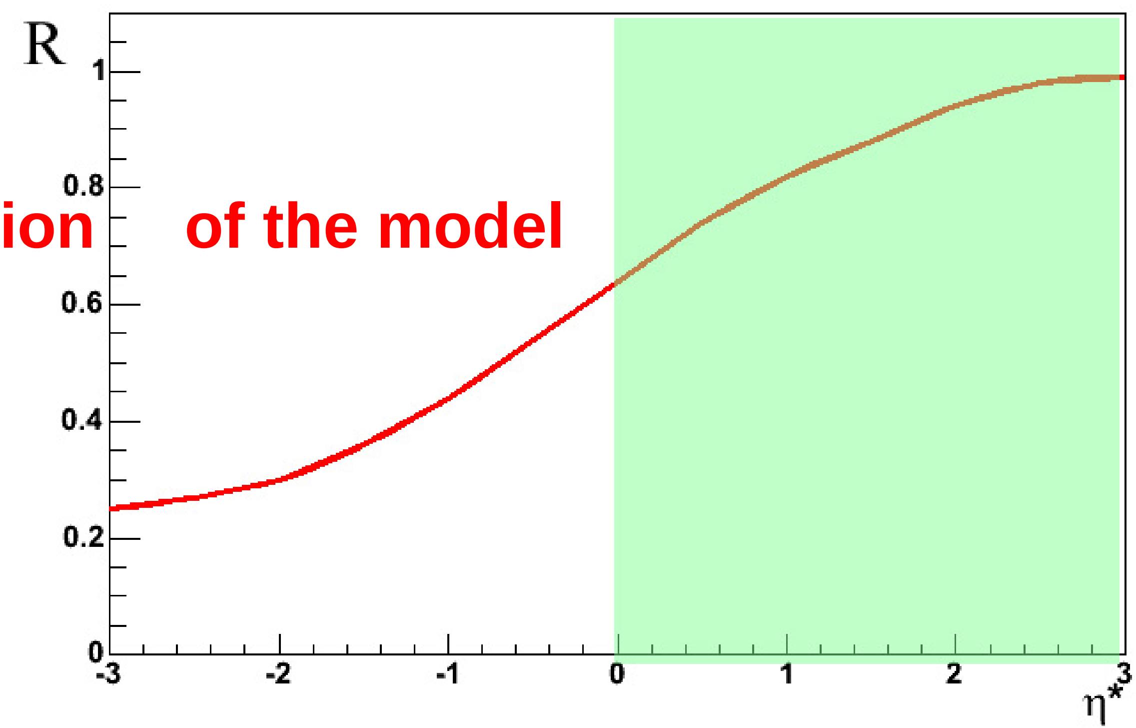
$$\frac{d^2\sigma}{\pi dy(dp_t^2)} = A_1 exp(-E_{Tkin}/T_e) + \frac{A_2}{(1+\frac{P_T^2}{T^2 N})^N}$$

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

Expected Results for DIS

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

Qualitative prediction of the model

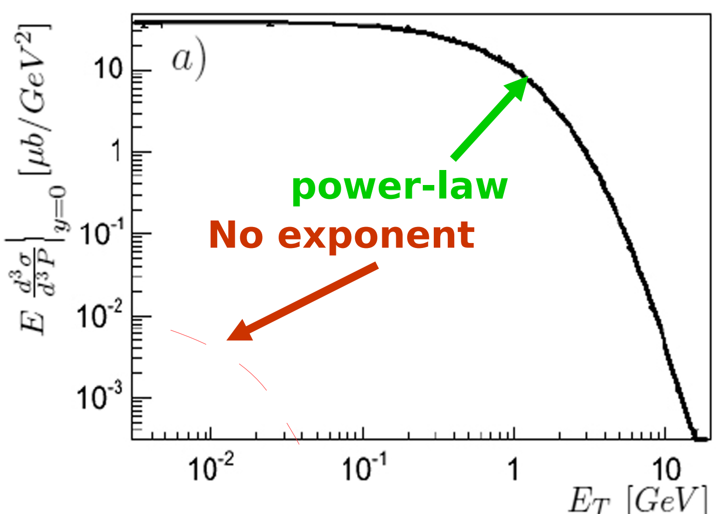


Type of produced particle

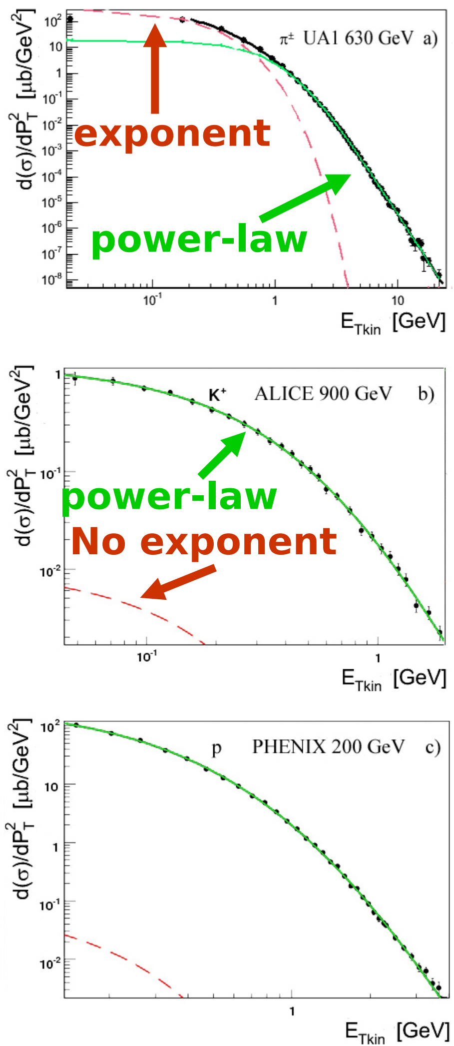
QCD-fluctuations are democratic to quark flavour while valence quark radiation can't produce heavy flavours

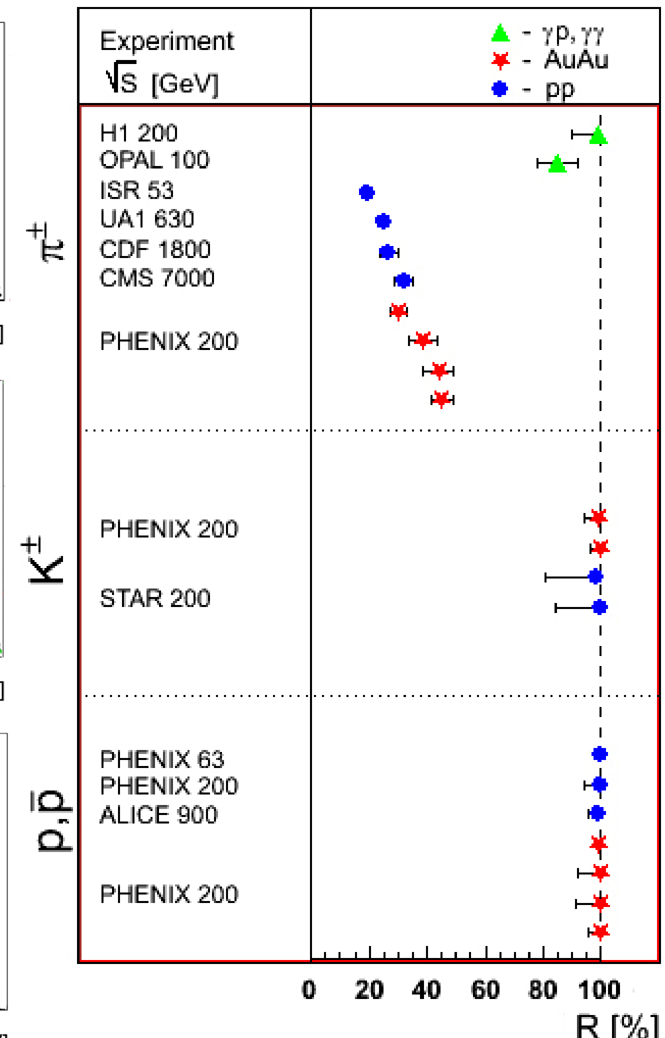
Prediction: Kaon (and J/ψ) spectra should have less exponential contribution then pion

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



J/ψ spectra CDF
√s = 1.96 TeV



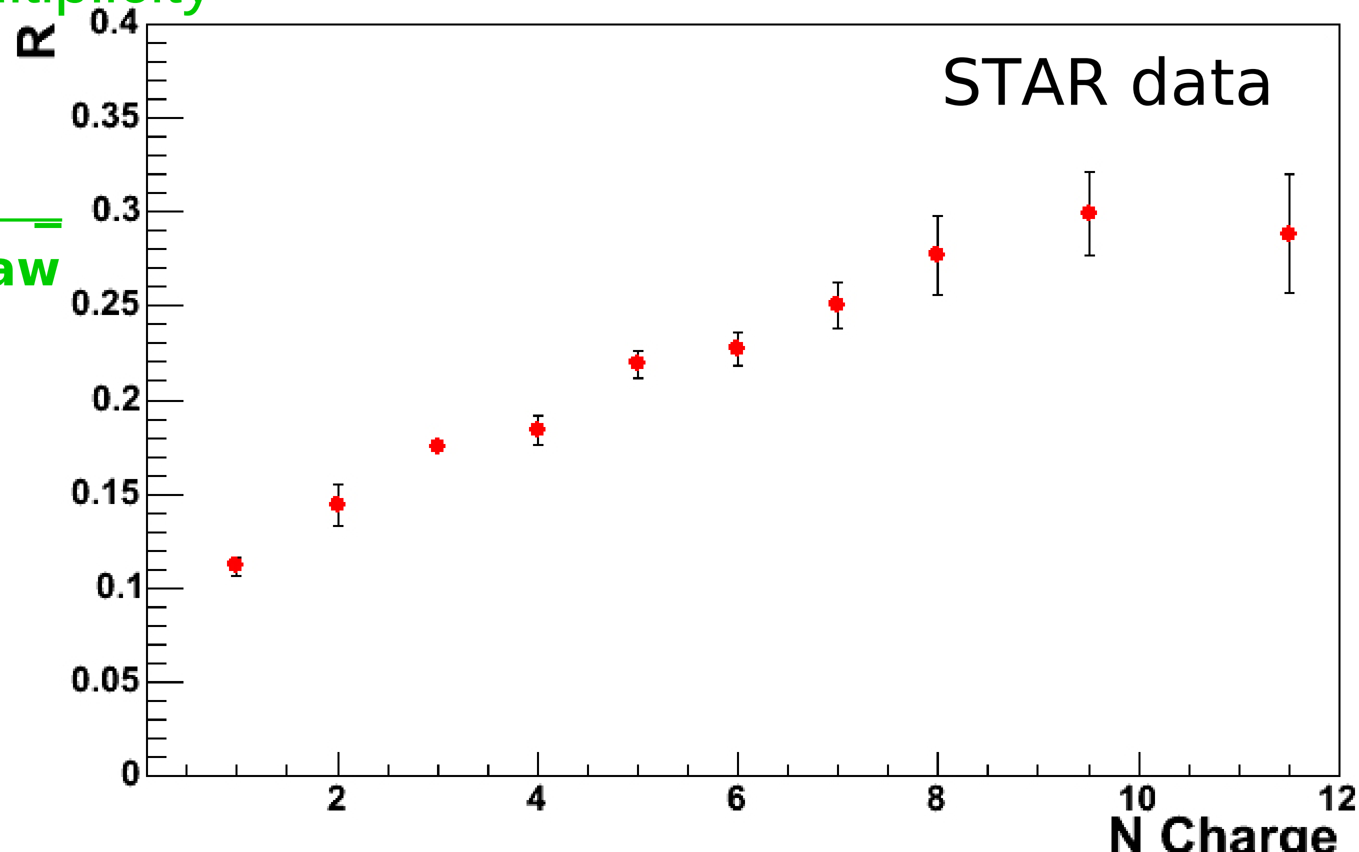


Dependence of the spectra shape on multiplicity

Charge multiplicity is proportional to the number of Pomerons involved

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

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

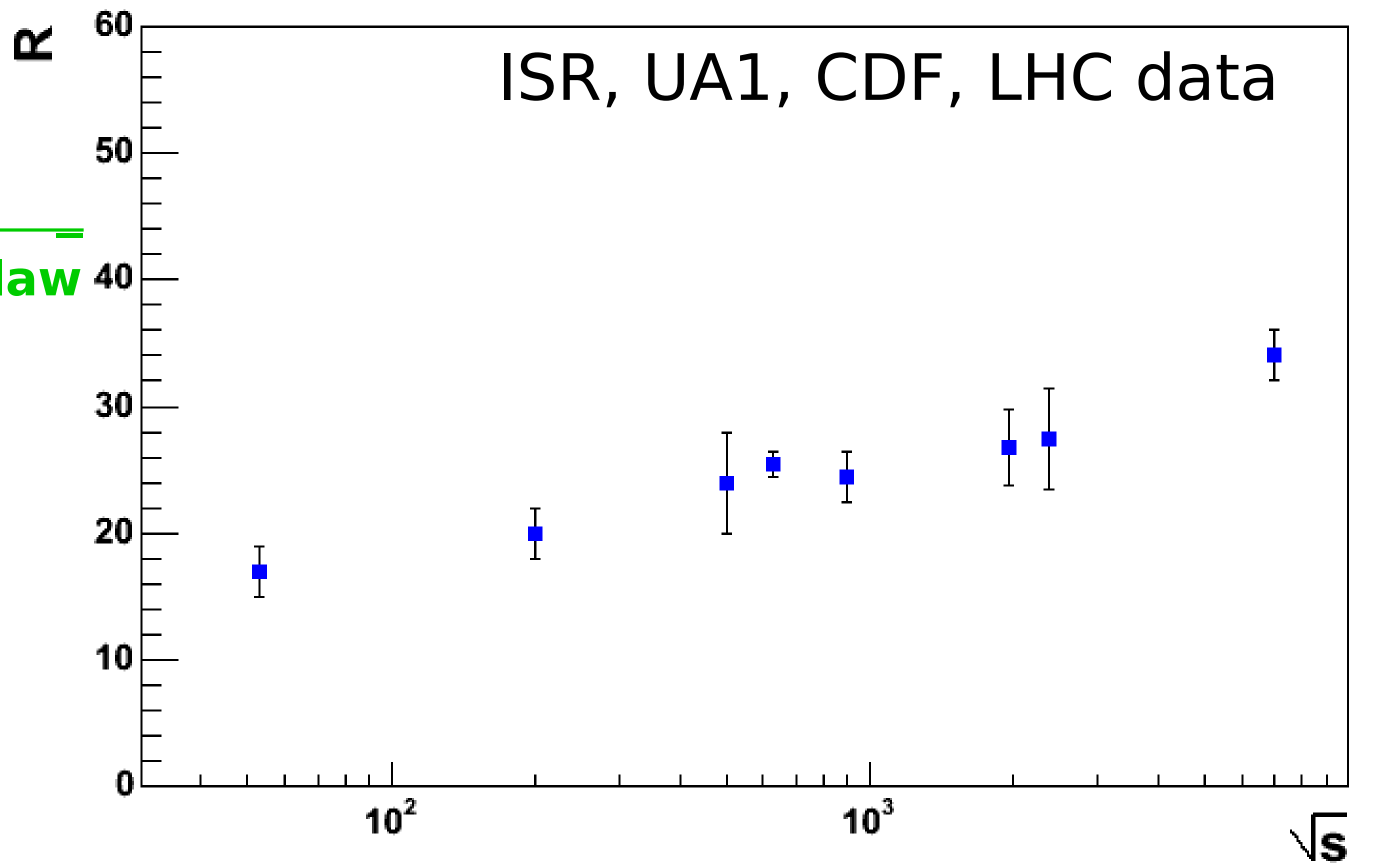


Energy of Collision

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

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

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

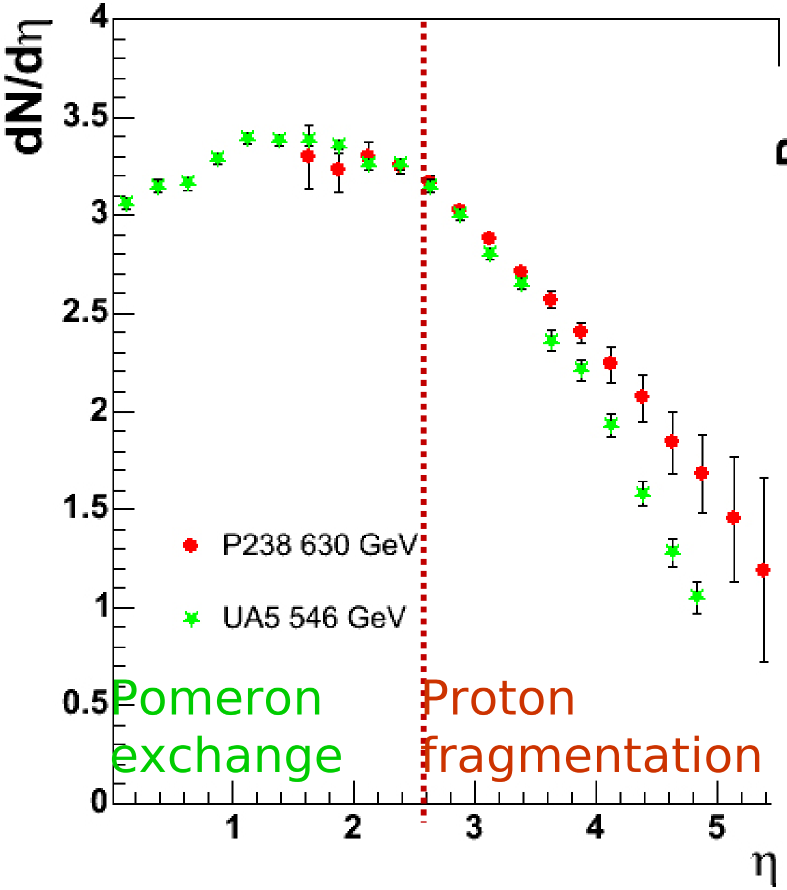


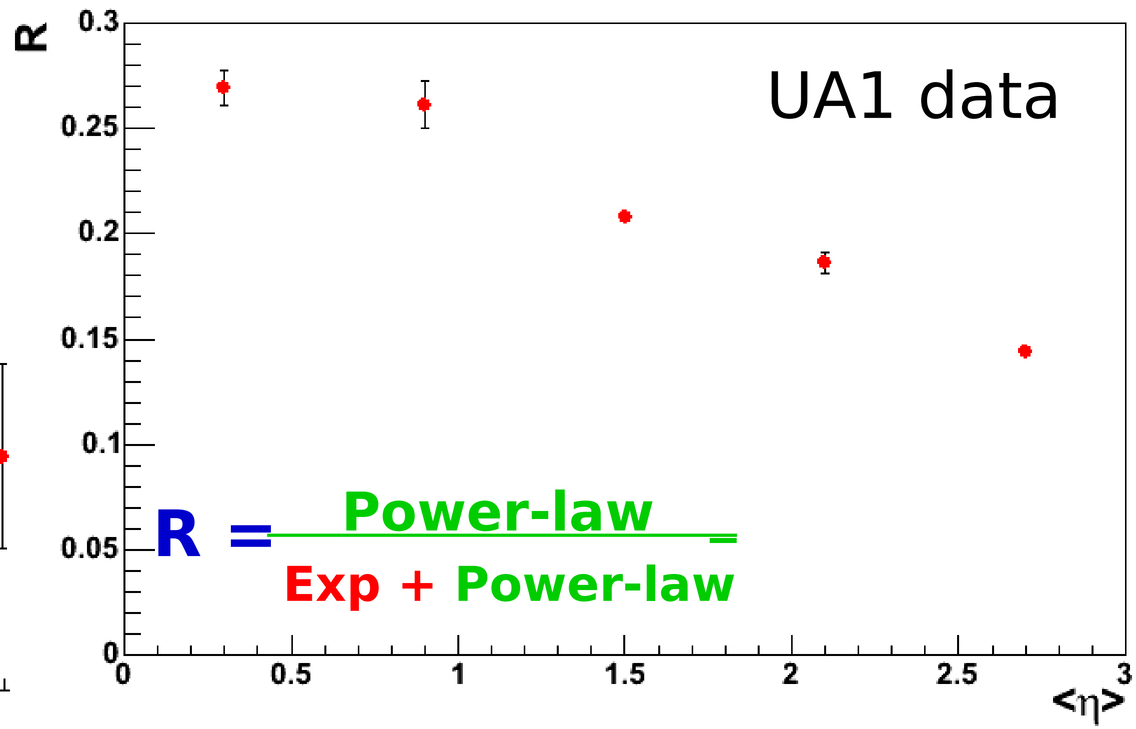
Dependence of the spectra shape on pseudorapidity

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





Temperature in heavy-ion collisions

T as function of energy density