Particle Production at HERA

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On behalf of the H1 collaboration

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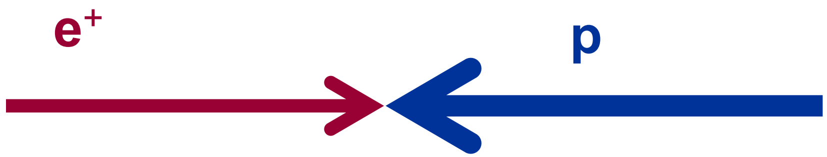
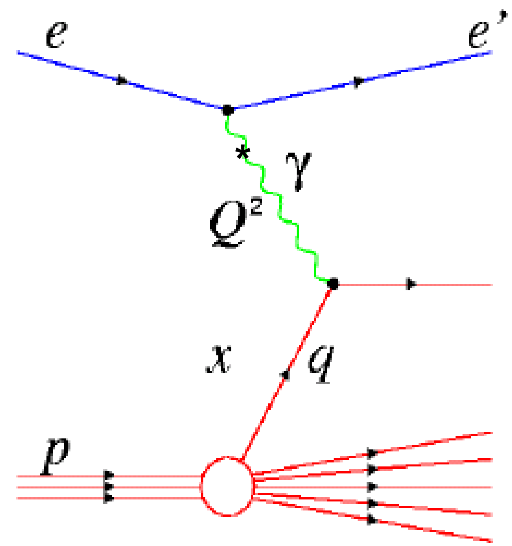
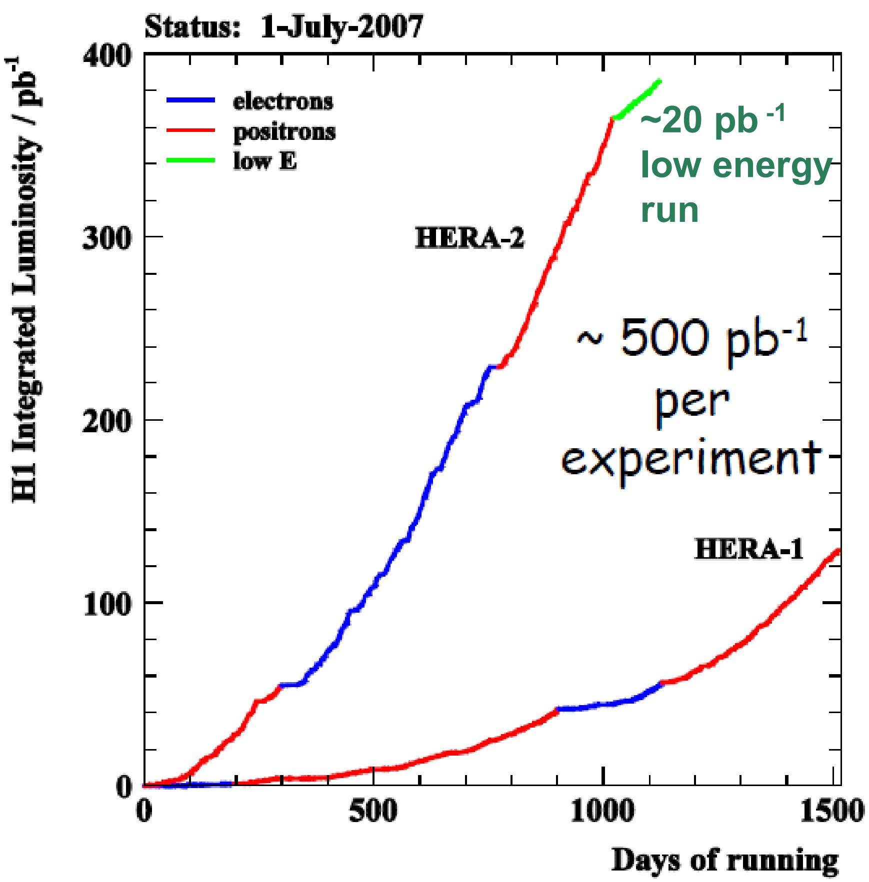
HERA experiments



E_e = 27.6 GeV E_p = 920-460 GeV





Q^2 photon virtuality

x Bjorken scaling variable

y inelasticity in proton rest frame

Charged Particle Production at HERA

A large body of the experimental data on charged particle production spectra has been accumulated during last forty years.

However the underlying dynamics of hadron production in high energy particle interaction is still not fully understood.

New investigation of H1 on charged particle spectra are presented:

- With proton energy E_p =920 GeV and $\sqrt{s}$ = 319 GeV (EPJ C73 (2013) 2406)
- With proton energy E_p=460 GeV and $\sqrt{s}$ = 225 GeV (H1prelim-13-032)

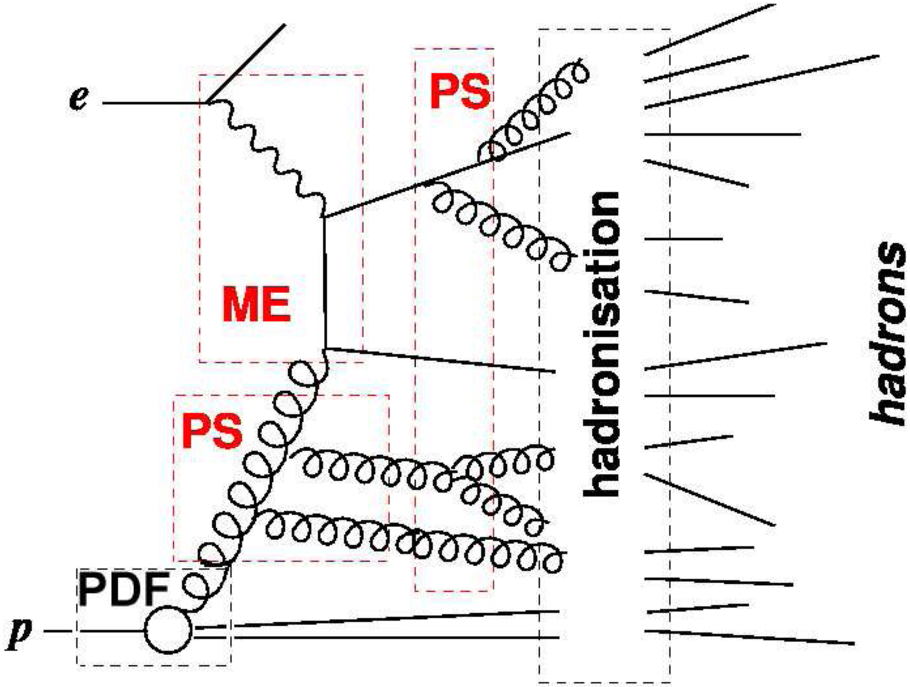
Hadronisation and Parton Shower

Low p_T region

- Mainly hadronisation effects are expected
- Low sensitive to different parton dynamic models

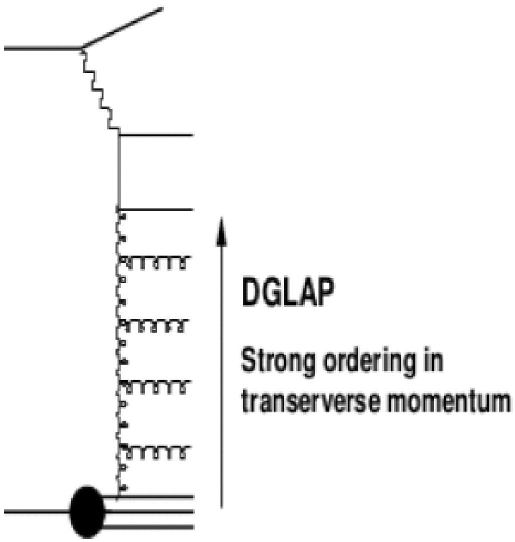
High p_T region

- Parton dynamics effects are expected
- High sensitivity to different parton dynamic models

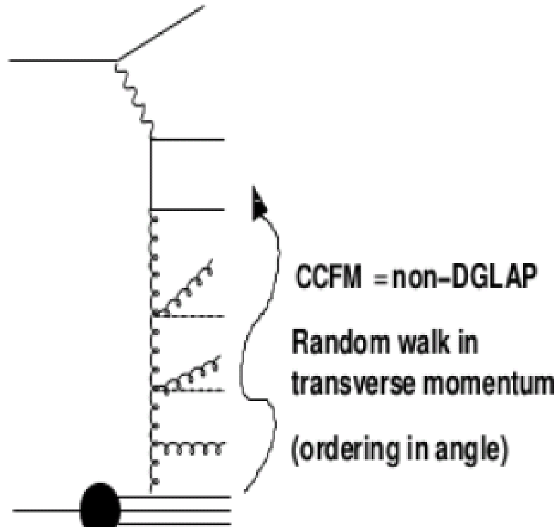


Parton Evolution Models

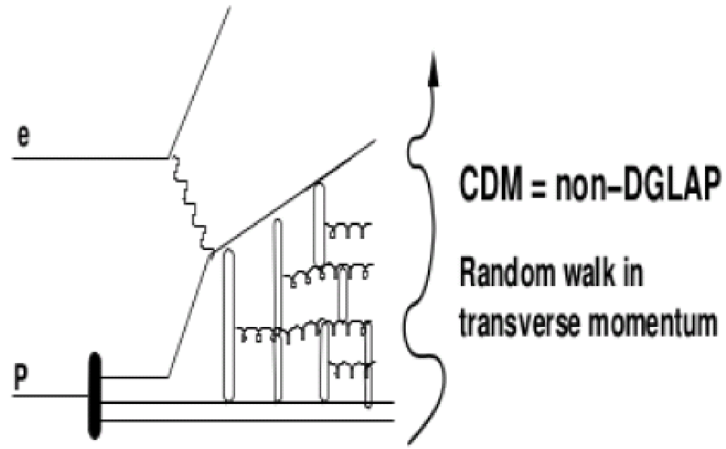
RAPGAP/HERWIG++ DGLAP



CASCADE CCFM



DJANGOH CDM



DGLAP: strong k_T ordering $k^2_{T0} << \ldots << k^2_{Ti} << \ldots << Q^2$

- RAPGAP (LO ME + DGLAP parton showers)
- HERWIG++ (POWHEG + DGLAP parton showers :

Beyond DGLAP (random walk in k_T)

- CASCADE (off shell ME + CCFM parton showers)
- DJANGOH (LO ME + CDM parton showers)

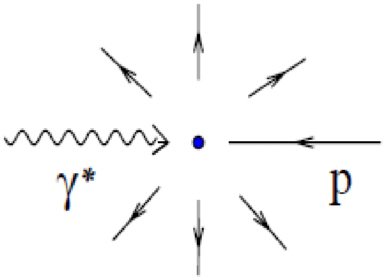
Fragmentation parameters tuned to e^+e^- data (ALEPH tune)

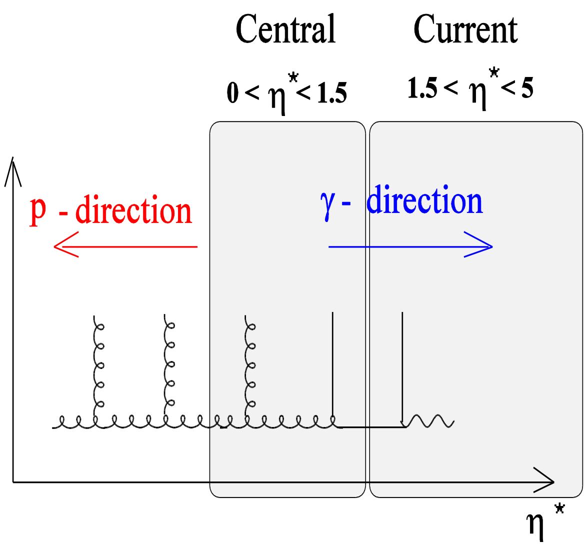
HFS and parton cascade dynamics

As $F_2(x,Q^2)$ has little sensitivity to cascade dynamics (DGLAP and beyond-DGLAP) investigations of cascade dynamics in semi-inclusive reactions ep -> e'hX has been conducted at H1 detector at DESY:.

HERA bins energies: **E_e = 27.6 GeV, E_p =920 GeV,**
Kinematical region: **low photon vituality ($5 < Q^2 < 100$ GeV^2);**
small Bjorken x ($10^{-4} < x < 10^{-2}$)

Charged particles spectra are measured as function of pseudorapidity (η^*) and transverse momentum (p^*_T) in hadronic centre-of-mass system (Θ^* with respect to virtual photon)





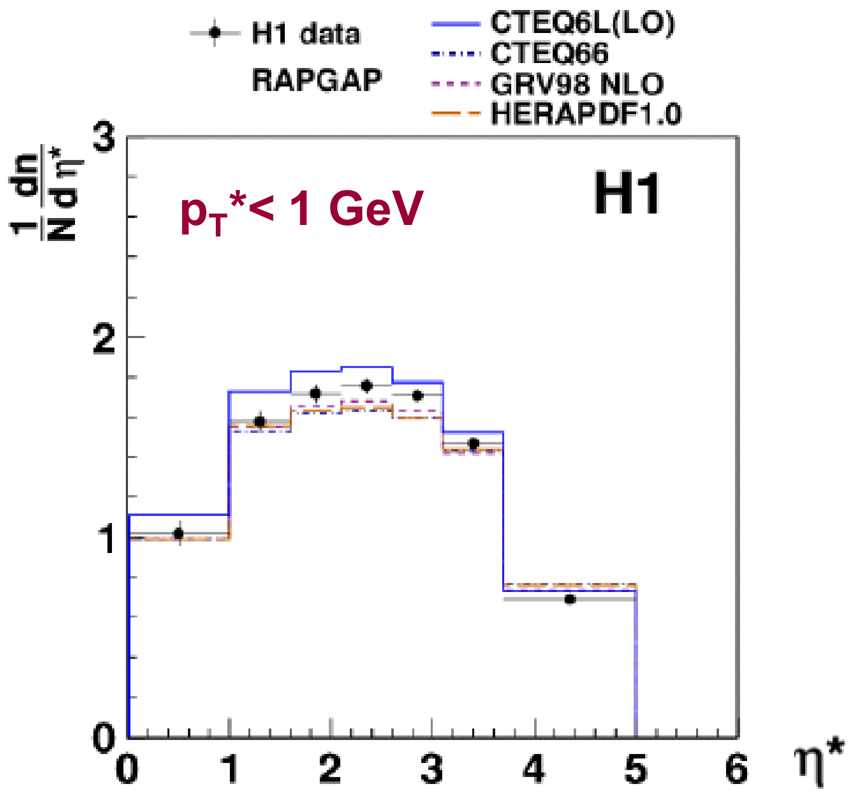
To distinguish hadronisation effects from effects due to parton evolution signature the measurements are divided into two regions:

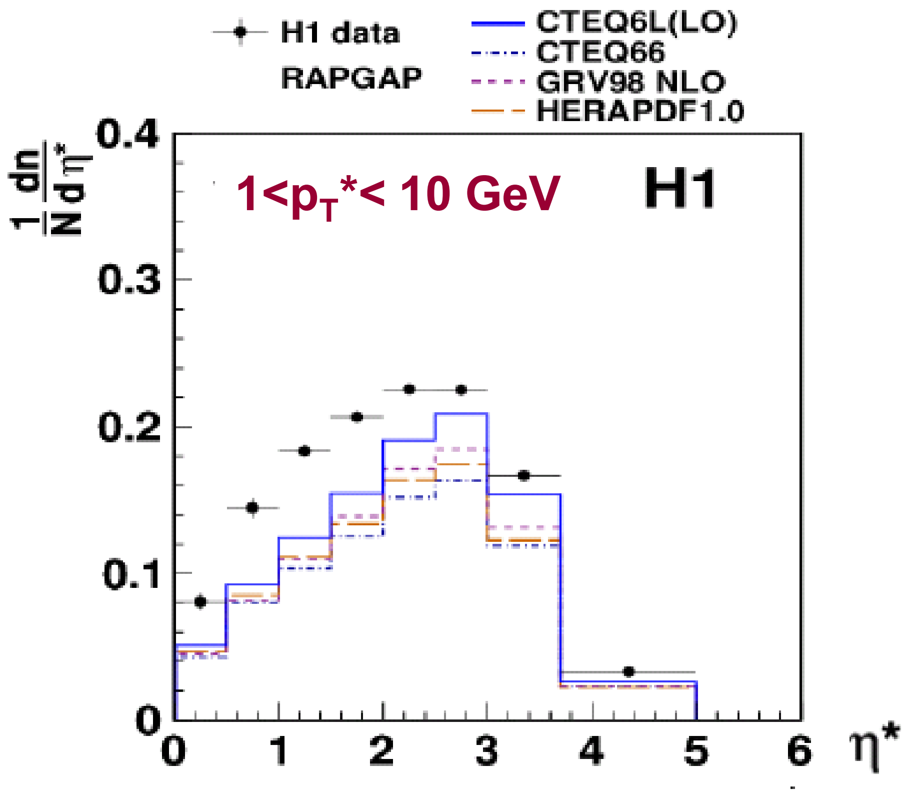
- at low p^*_T ($0<p^*_T<1$ GeV) predominantly sensitive to hadronisation
- at high p^*_T ($1<p^*_T<10$ GeV) predominantly sensitive to parton dynamics.

The p^*_T dependence is studied in the pseudorapity intervals:

$0< \eta^*<1.5$ (central region)
$1.5< \eta^*<5$ (current region)

Pseudorapidity distribution (DGLAP model)

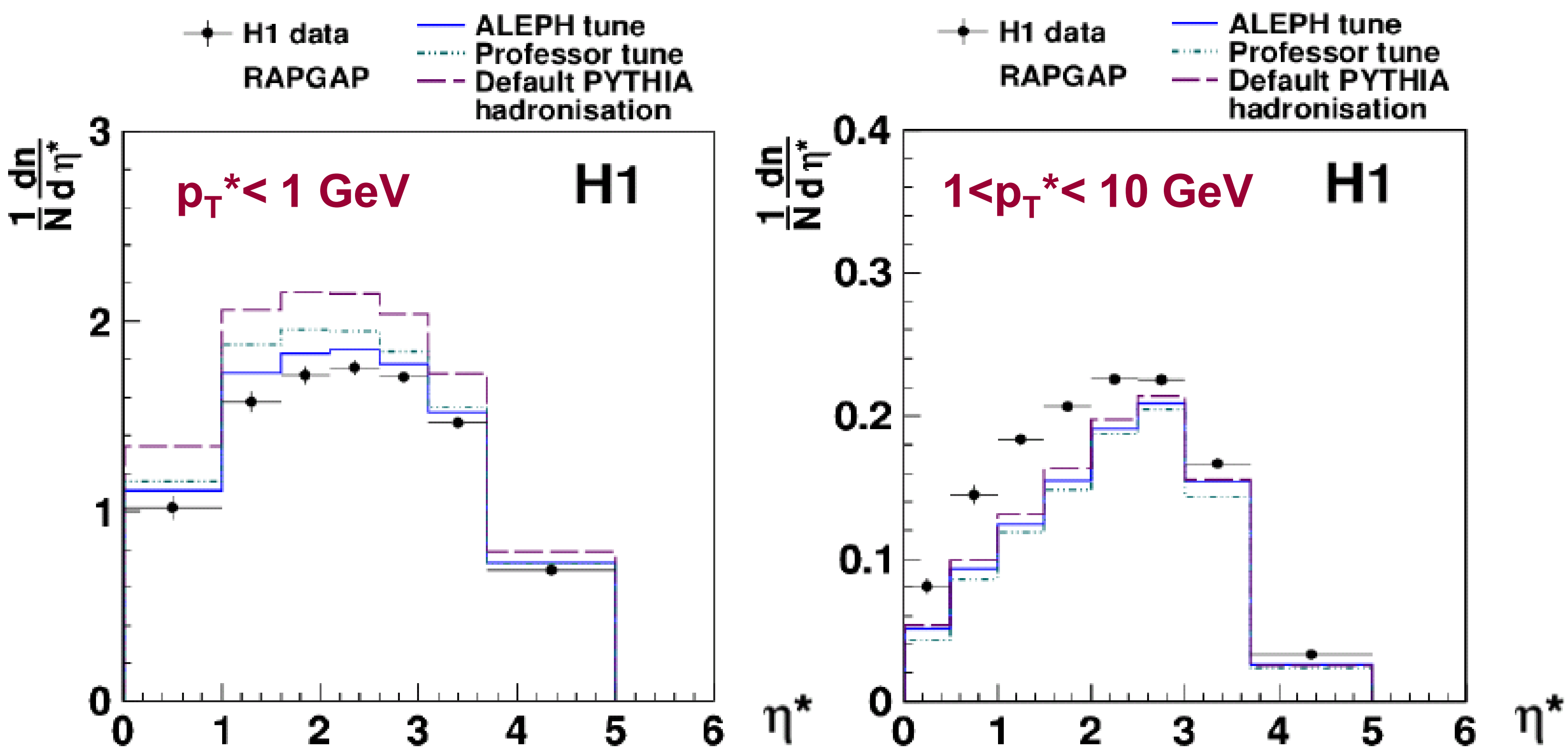




- All predictions are close to data
- LO + parton shower predictions using different p-PDFs at NLO are close to each other

- None of the predictions using different PDFs describe the data
- Differences between predictions for various PDFs are smaller than differences to the data

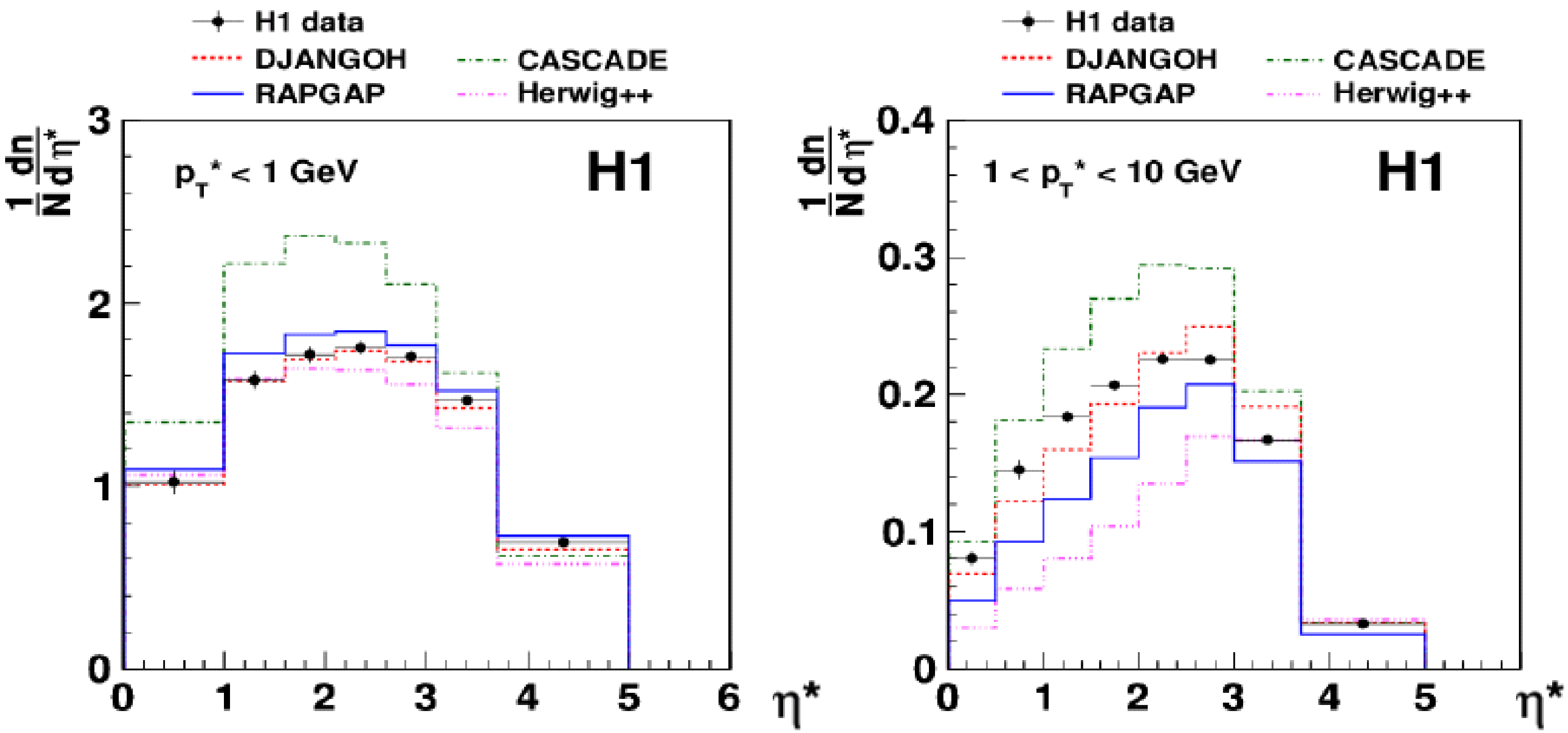
Effect of Hadronisation in the DGLAP Model



- Sensitive to tuning of hadronisation parameters
- ALEPH tuning (e^+e^-) describes the data best

- Small sensitivity to hadronisation are expected
- Parton dynamics of the RAPGAP model fails to describe the data

Parton Evolution Models

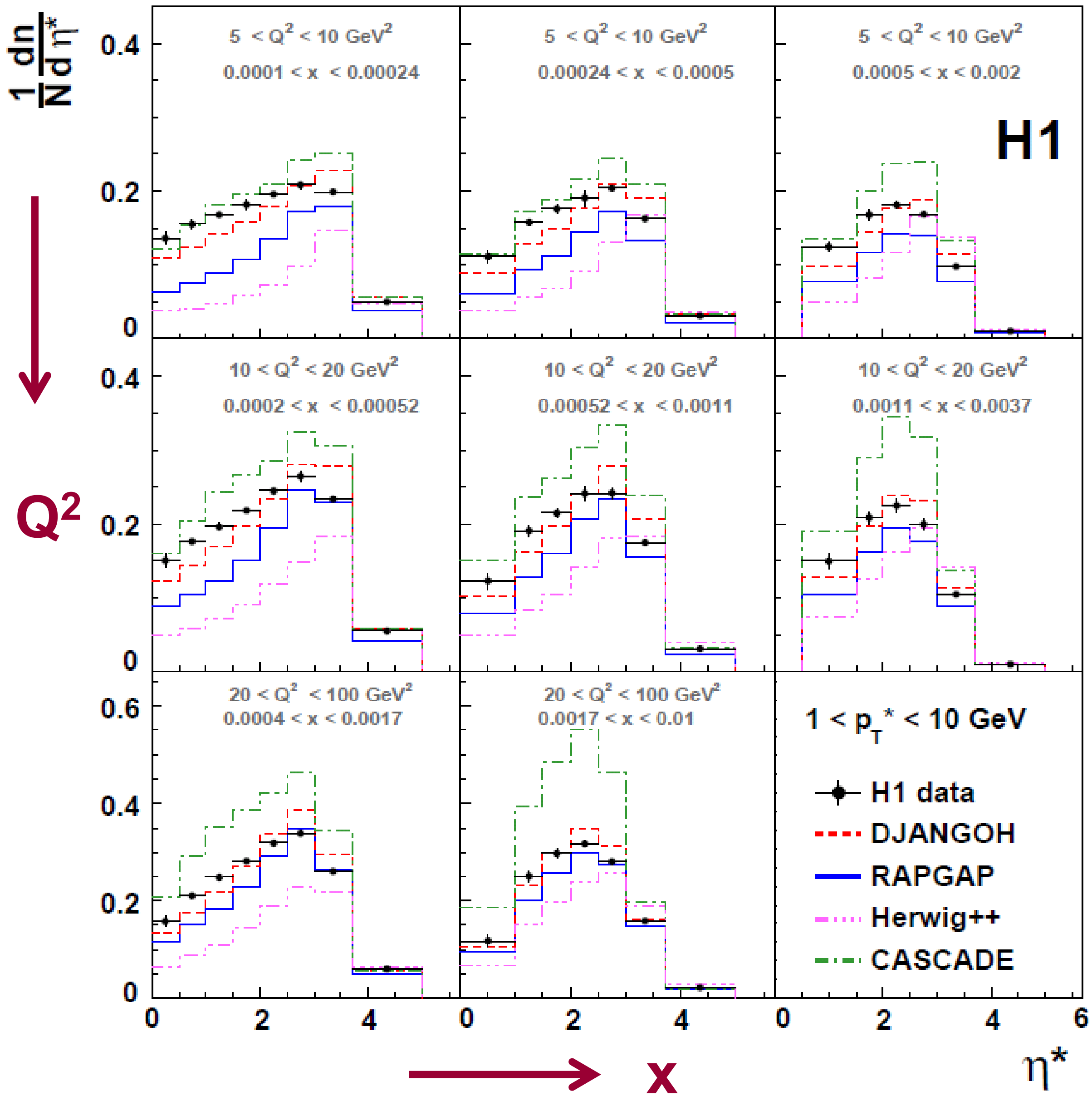


All models, except CASCADE, describe the data within PDF uncertainties

- Large differences between the various models
- RAPGAP and HERWIG++ (DGLAP models) undershoot the data for $\eta^* < 3$

DJANGOH (CDM) describes the data better than other models for both p^*_T regions

Charged Particles η* Spectra in Q^2 and x bins

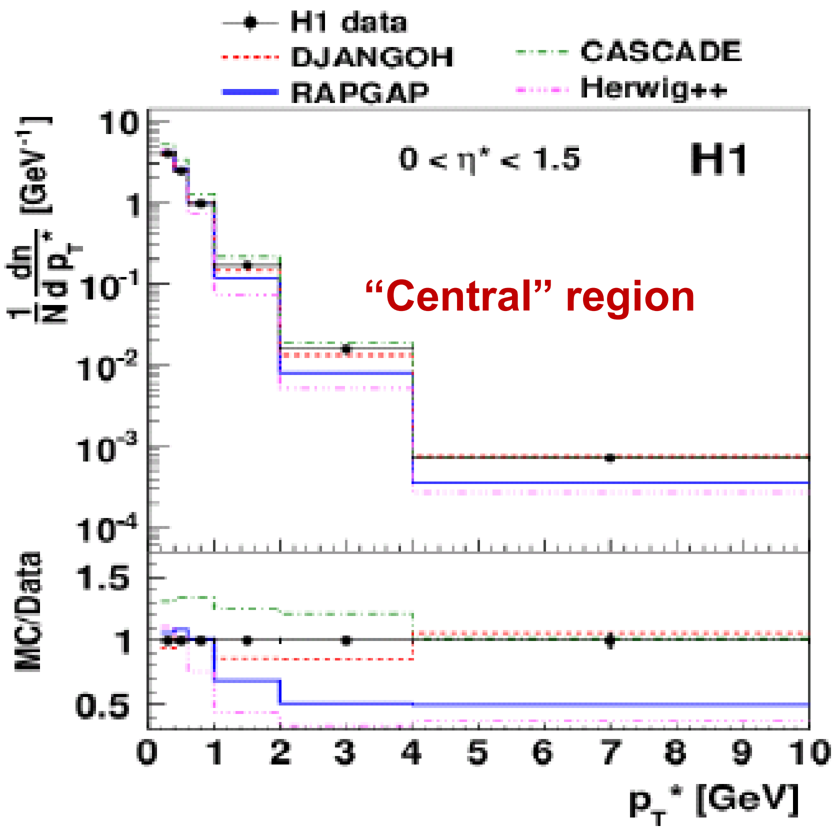


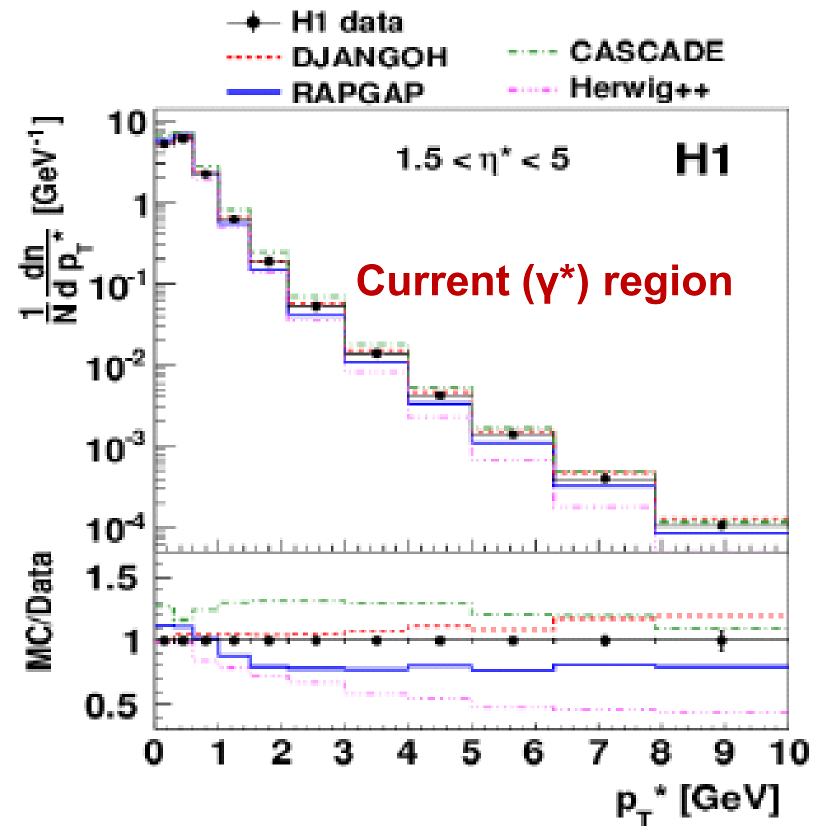
DJANGOH (CDM) provides the best description of experimental data but still deviate from the data

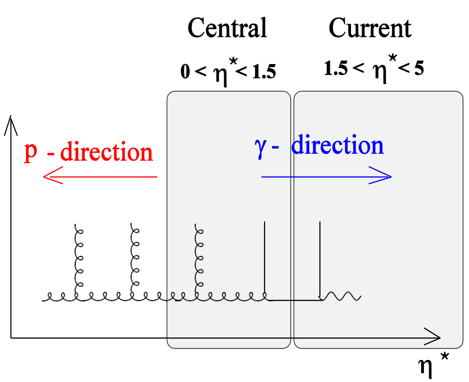
RAPGAP (DGLAP) fails at low x (low Q^2) HERWIG++ even worse

CASCADE (CCFM) works only at low x

Transverse momentum distribution

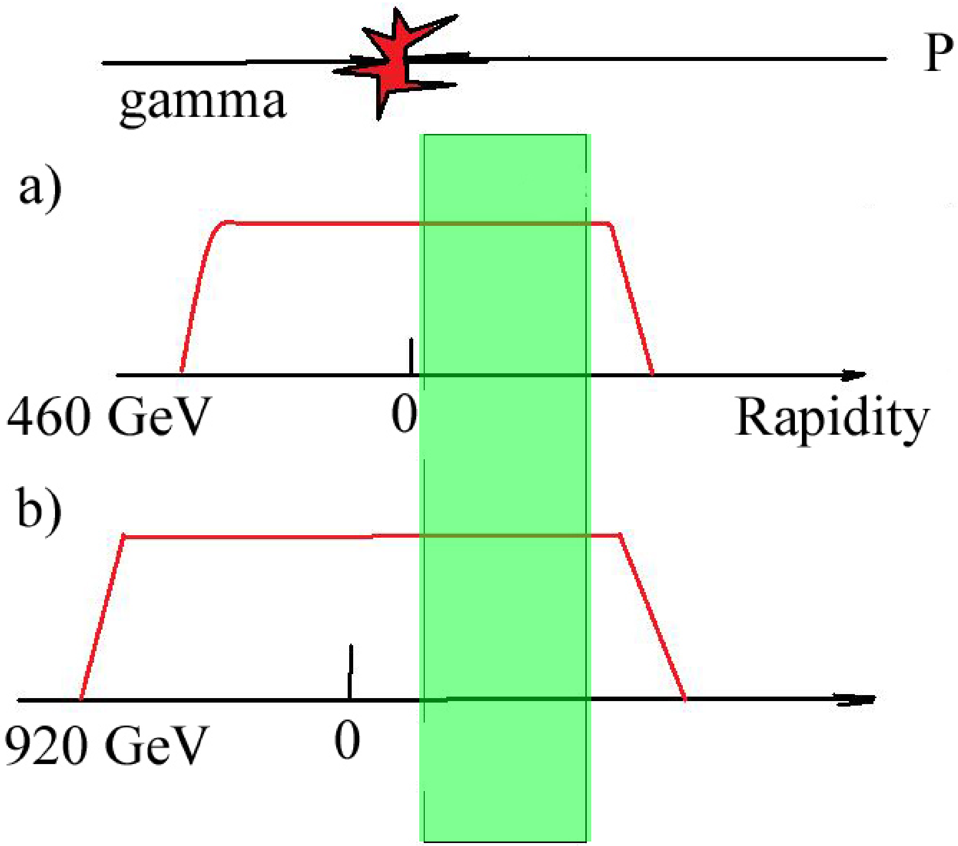






- Predictions are sensitive to different parton shower dynamics at high p^*_T.
- RAPGAP and HERWIG++ (DGLAP) strongly undershoots the data in the central but also in the current region
- DJANGOH (CDM) provides the best description of experimental data in both p^*_T and η^* regions but still not good

Charged Particles Spectra at Low $\sqrt{s}$

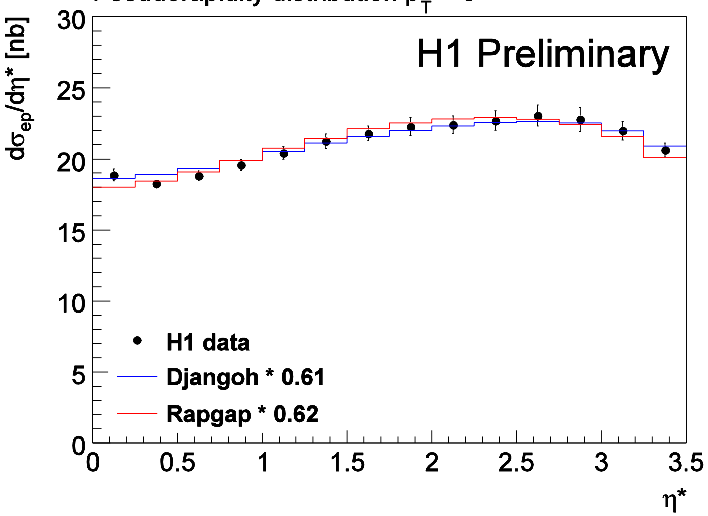


- Use data with reduced proton beam energy E_p = 460 GeV to have acceptance in η* closer to the central region
- High y: 0.35 < y < 0.8
- Low Q^2: 5 < Q^2< 10 GeV^2
- η* in central and current region (0, 3.5)

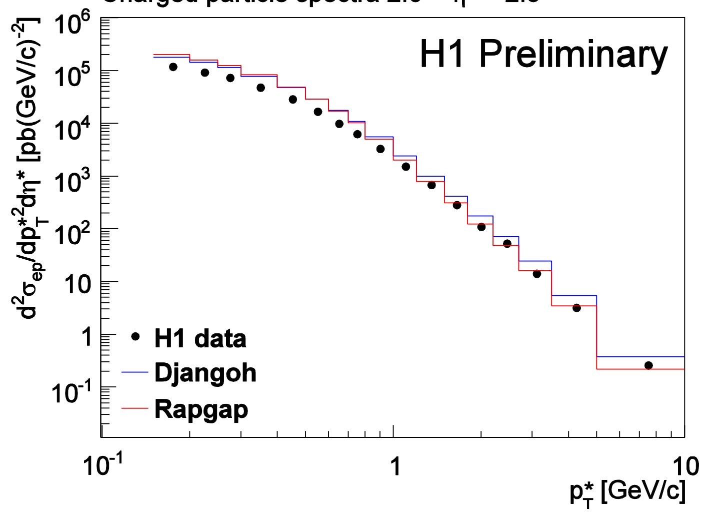
Unfortunately, the proton hemisphere in γ*p collisions at HERA is not reachable for accurate track measurements both in H1 and ZEUS detectors, due to the boost of the proton

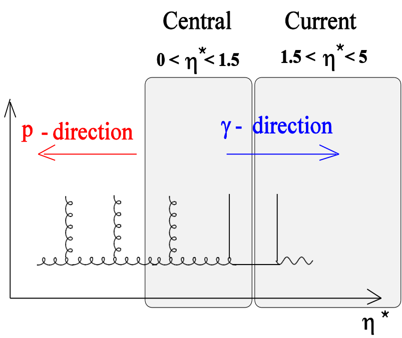
Data and MC Comparison

Pseudorapidity distribution $p^*_T > 0$

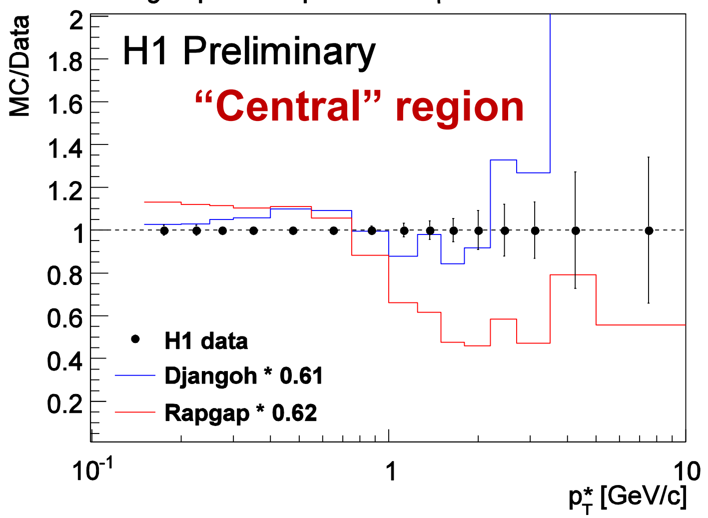


Charged particle spectra $2.0 < \eta^* < 2.5$

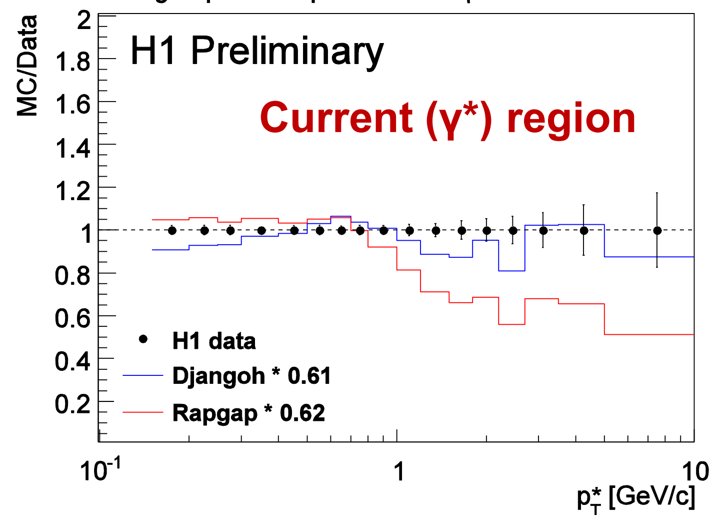




Charged particle spectra $0 < \eta^* < 0.5$



Charged particle spectra $2.0 < \eta^* < 2.5$



DJANGOH and RAPGAP describe the shape of η^* distribution well, but none describes the shape of p^*_T spectra

Phenomenolodycal Descriprion of Hadronic Spectra in $p\bar{p}$ and γγ

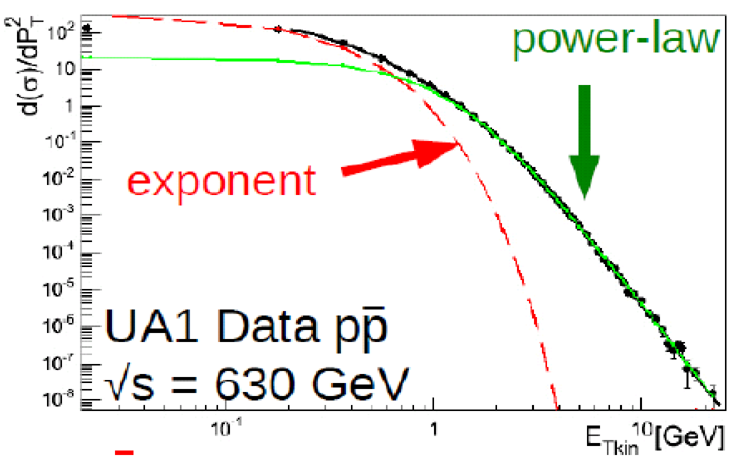
It was shown *(A.Bylinkin and A.Rostovtsev, Phys.Atom.Nucl. 75 (2012) 999)* that the shapes in $p\bar{p}$ and γγ can be simultaneously described with unique formulae

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

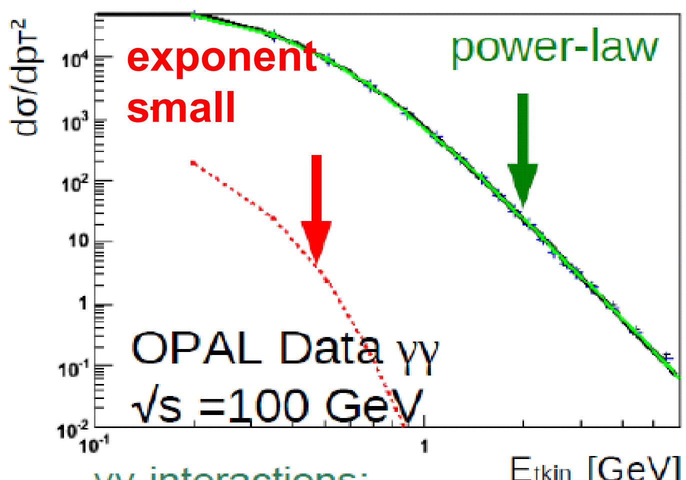
Radiation of parton (-> hadrons) by valence quark

These partons are considered to be in a thermalized statistical state and have a Boltzmann-like exponential distribution

Virtual partons exchanged between colliding partonic system and have power-law spectrum as expected in pQCD



$p\bar{p}$ -collisions: exponential term dominates

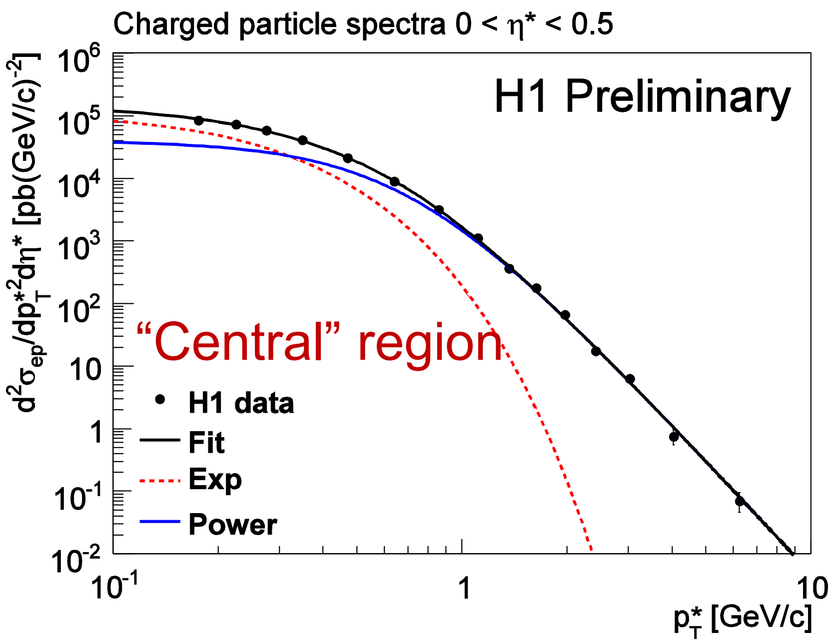


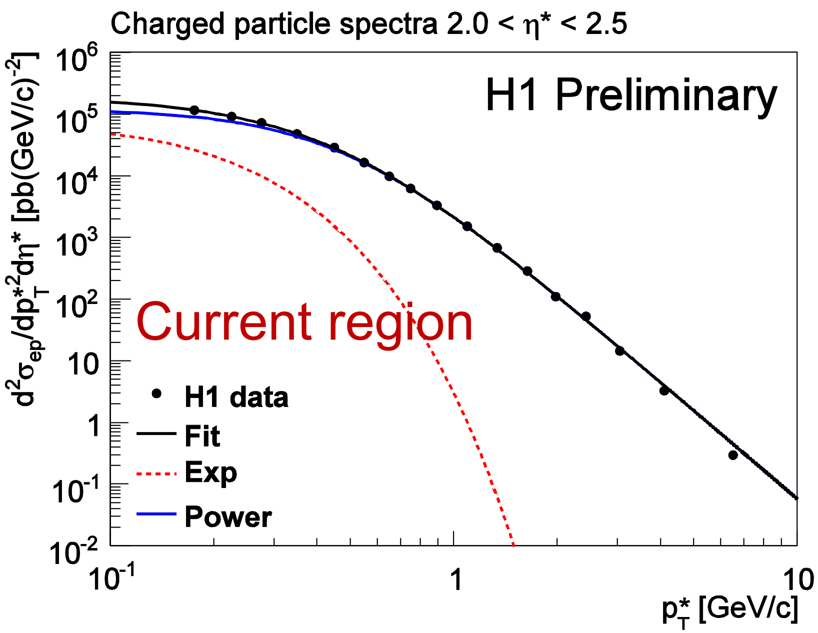
γγ-interactions: described by power-law only

Could the model describes the shapes in ep scattering as well?

Double Differential Cross Sections

Using the phenomenological model to describe ep scattering. Exponential contribution improves the description of the shape of the p^*_T spectrum



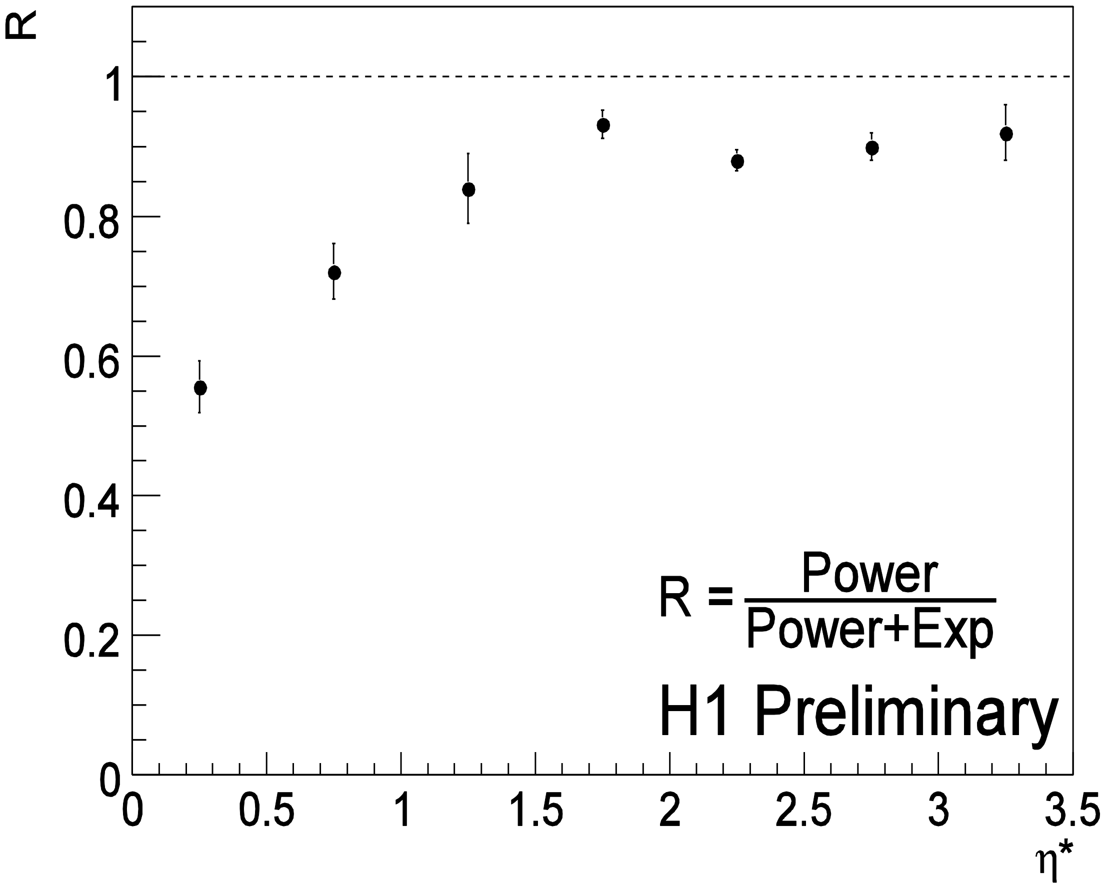


Large exponential contribution + power-law

Small exponential contribution, predominantly power-law

Contribution from Power-law vs. η*

R = (Power-law)/(Exp + Power-law)



Observe transition between two different contributions for hadroproduction in ep:

from power-law distribution in the current region (large η*) to significant exponential contribution when approaching the proton fragmentation region (the power law contribution is always dominating: >90% at large η* to 55% at η* = 0)

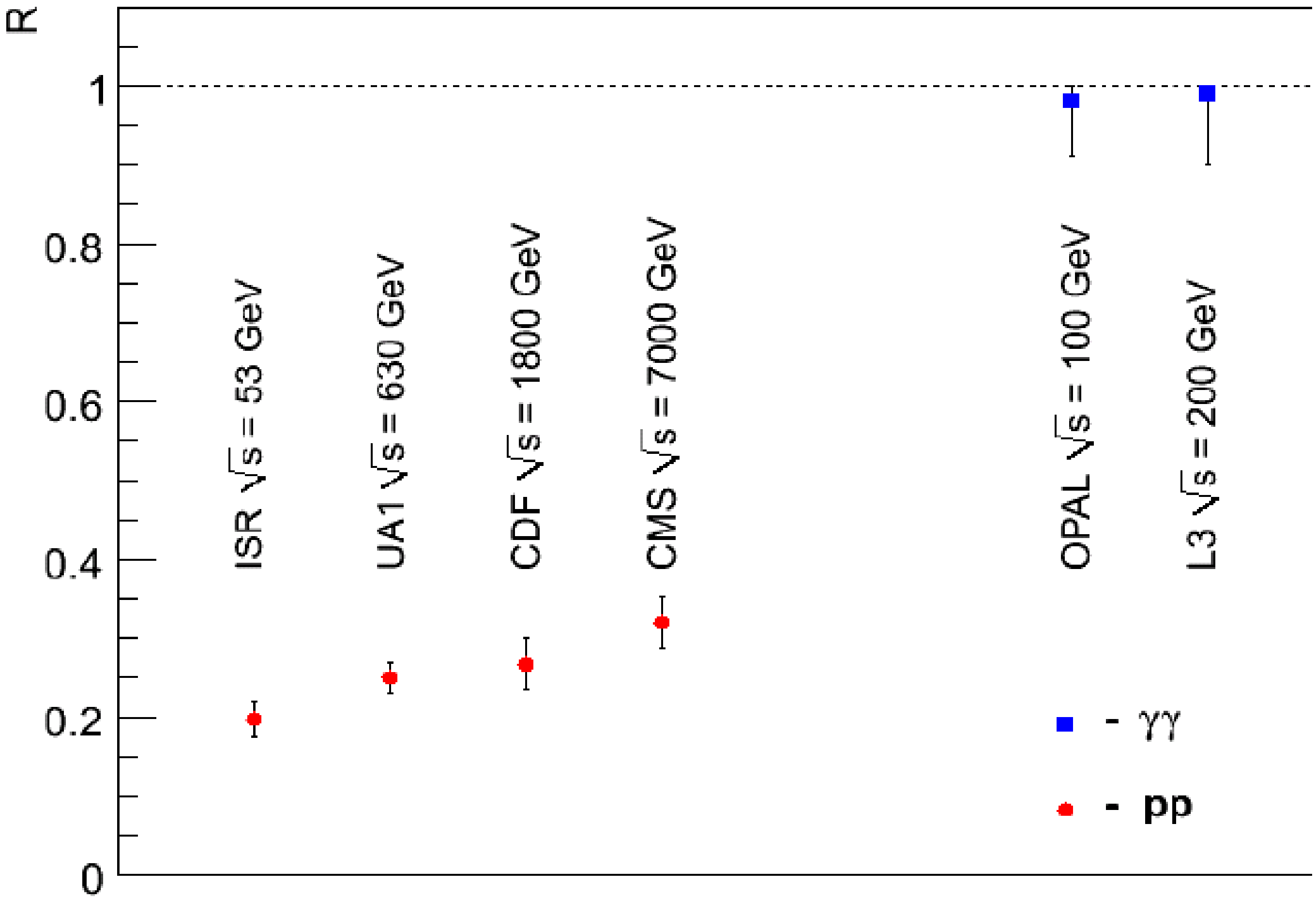
Summary

- Transverse momenta and pseudorapidity spectra were measured with H1 detector at HERA at $\sqrt{s}$ = 319 GeV and $\sqrt{s}$ = *225 GeV*
- Different tunes of hadronisation parameters were studied in the low p_T^* region
- Models with different implementations of parton dynamics (CDM, DGLAP, CCFM) were studied in the high p_T^* region
- DGLAP like models are significantly below the data for low x and large p_T^* of charged particles
- DJANGOH (CDM) gives the best description of charged particle spectra

- Phenomenological model for hadron production with an exponential and a power-low contributions has been tested on ep data
- The model yields a good fit to the data
- A significant exponential contribution is needed in the central region, but not in the current region

BACKUP

Contribution from Power-law vs. √s



A. A. Bylinkin and A. A. Rostovtsev arXiv: 1008.0332 [hep-ph]