Summer Student Report
"Charged Particle Transverse Momentum Spectra in DIS"

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Motivation:

The electron-proton collider HERA allows to get deep inelastic scattering (DIS) of the electron off the proton down to a very small x [1] of about 10^{-5}. At such small x parton dynamics beyond DGLAP are expected to become important and the gluons dominate among the proton partons. It is believed that semi-inclusive DIS measurements with the hadrons in the final state may offer more sensitive means to discriminate DGLAP or BFKL. Ten years ago charged particle transverse momentum spectra in DIS were measured by H1 collaboration and were compared with spectra obtained by use of the various MC generators: ARIADNE, LEPTO, HERWING (*Nucl. Phys, B485(1997)3*). After the lumi upgrade re-measurements can be carried out with much more statistics, allowing to decrease substantially the errors and thus to return to the discussion of different parton dynamics scenarios.

Results (were reported at HaQ meeting, September 3, 2008):

- 2006 positron data (with $E_p = 920$ GeV) are analysed and compared to the previous analysis of 1994 data (with $E_p = 820$ GeV). The generators RAPGAP and CASCADE have been compared for two proton beam energies, 820 and 920 GeV. In Fig. 1 the ratios of p_T-distributions (MC with $E_p = 920$ GeV / MC with $E_p = 820$ GeV) obtained with RAPGAP in the central pseudo-rapidity interval $1.5 < \eta^* < 2.5$ are shown [2]. The

[1] $x = \frac{Q^2}{2qk_p}$, where q and k_p are four-momenta of the exchanged photon and a proton respectively.

[2] p_T and η^* refer to CM system. $\eta^* = -ln(tan(\theta^*/2))$, where θ^* is the angle with respect to the virtual photon direction.

same ratios obtained by using CASCADE are demonstrated in Fig. 2. Ratios are shown for nine various kinematical regions (bins) in x and Q^2 as well as for the combined sample (bin 0). CASCADE gives consistent results for both beam energies in contrast to RAPGAP, which predicts substantial deficit of charged particles produced at $E_p = 920$ compared to $E_p = 820$ GeV for bins 0 and 6.

- Measured p_T spectra and MC predictions of charged particles in the central region of the pseudo-rapidity, $1.5 < \eta^* < 2.5$, for the hadronic center of mass system (HCM) are presented in Fig. 3. Green and blue points correspond to the 1994 and 2006 data taking periods respectively. Data are compared to CASCADE 2.0.1 simulations for 820 GeV (black dashed line) and RAPGAP 3.1 simulations for 920 GeV (red solid line). Data are shown for nine kinematic bins and combined sample (bin 0). It can be seen that 2006 data are consistent with published data. CASCADE results and 1994 data points have been obtained by use of HZTOOL package (HZ96215). All distributions are normalized to the number of events N, surviving the event selection. In current analysis only statistical errors are included and data are not corrected to the hadron level. The discrepancy between RAPGAP 3.1 and 2006 data at small x may be due to insufficient description of the gluon radiation. This discrepancy disappear when increasing x and Q^2, where gluons cease to dominate among other partons. Data are well described by the CASCADE in which parton radiation is not ordered in k_T.

- CASCADE generator have been studied. It is based on CCFM evolution equation for the initial state cascade of gluons which gives angular ordering of the emitting gluons. Unintegrated gluon density $A(x, k_T, \bar{q})$ (where k_T is a transverse momentum of the gluon participating in hard scattering) is also a function of the evolution scale $\bar{q}$ determined by the rapidity of $q\bar{q}$ pair (maximal angle). In order to see the effects of gluon densities on p_T spectra, various gluon densities available in CASCADE were tested: J2003(sets 1-3), set A ($F_2(x, Q^2)$ fit with different cut-offs) and set C ($F_2(x, Q^2)$ fit + jets). Also two new PDFs were used, one which has been fitted to HERA di-jet data and another one witch has been determined by fit to $F_2(x, Q^2)$ by using time-like parton shower scenario. The p_T spectra for these different scenarios and for different kinematical regions are shown in Fig. 4. It can be seen that there is no dependence of p_T spectra on various gluon densities. Different parton emission models with different scenario of ordering is much more important.

- In order to estimate the hardness of the p_T spectrum over the entire range in pseudo-rapidity accessible to this analysis, the average multiplicity of charged particles with $p_T > 1$ GeV have been measured. The results for both 94 and 06 data periods for combined sample (bin 0) are compared in Fig.5. For 1994 data the forward tracks and the CJC were used, while for current analysis only central tracks were collected. This is why 2006 data points are lower than 1994 ones.

Monte Carlo exercises

Several MC exercises on HERA kinematics, histogramming, four-vector operations and relativistic kinematics preceded the main tasks. All results were obtained with CASCADE. To access the MC information (kinematics, mother particle, decay products, etc.) from event list the HZTool package was used. In Fig. 6 some of the results are shown. On the top and bottom right plots the Q^2-distributions calculated in laboratory frame, Breit-frame, proton rest frame and hadronic center-of-mass frame are presented. The aim was to demonstrate the frame invariance of the quantities like Q^2 and y. The middle plots present the ratio of Q^2- distributions calculated in the laboratory and in the proton rest frames, and the same for y calculated in the laboratory and in the Breit frames. And finally on the right plots $\frac{d\sigma}{dy}$ and $\frac{d\sigma}{dQ^2}$ are shown.

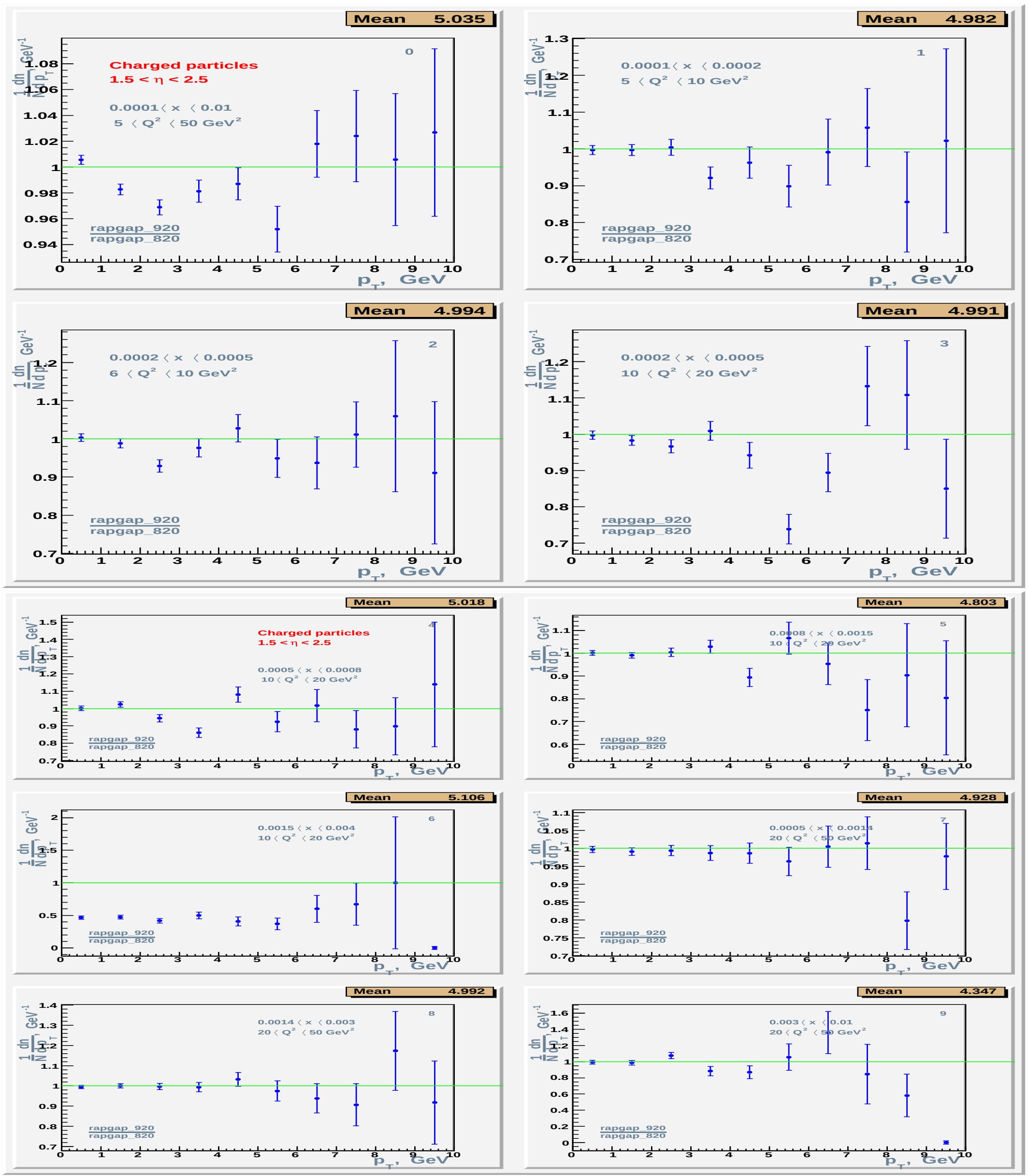

Figure 1: *The ratios of p_T-distributions (MC with E_p = 920 GeV / MC with E_p = 820 GeV) obtained with RAPGAP in the central pseudo-rapidity interval $1.5 < \eta^* < 2.5$ for nine various kinematical regions (bins) in x and Q^2 as well as for the combined sample (bin 0).*

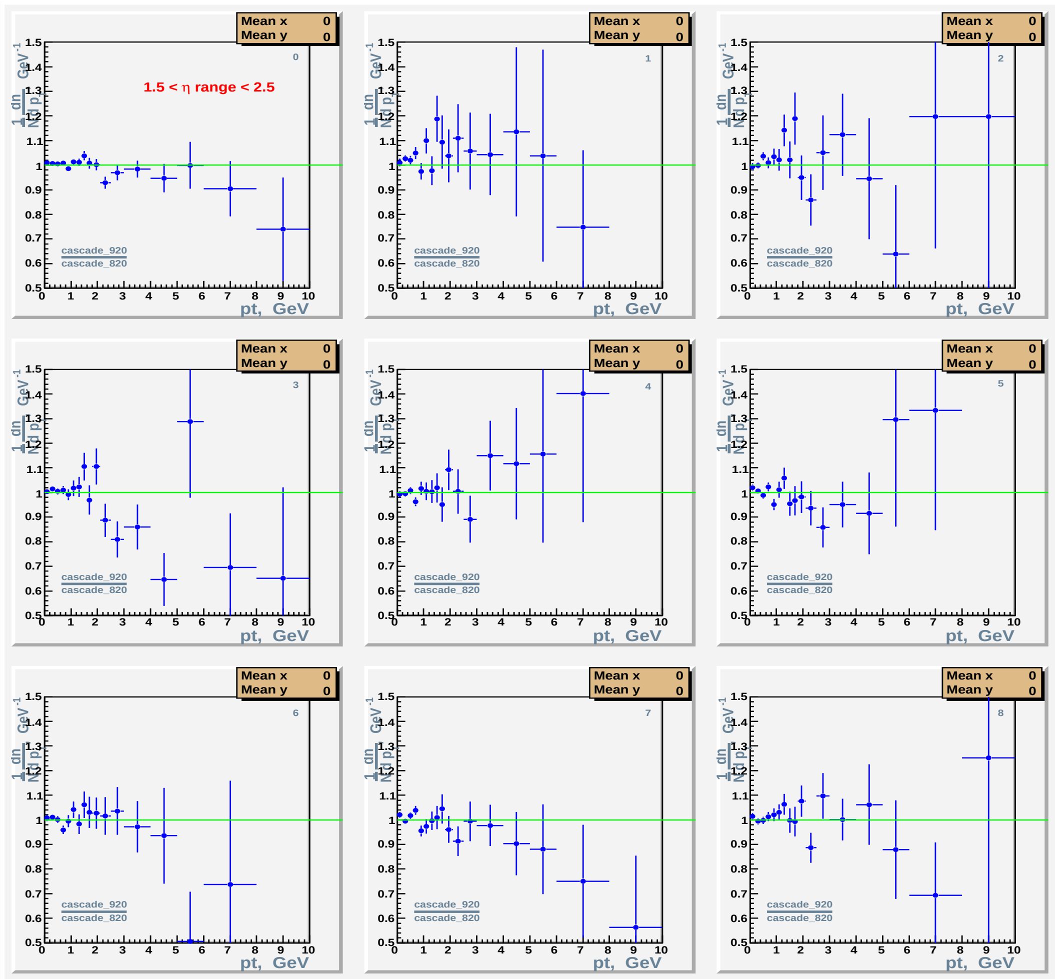

Figure 2: *The ratios of p_T-distributions (MC with $E_p = 920$ GeV / MC with $E_p = 820$ GeV) obtained with CASCADE in the central pseudo-rapidity interval $1.5 < \eta^* < 2.5$ for eight various kinematical regions (bins) in x and Q^2 as well as for the combined sample (bin 0).*

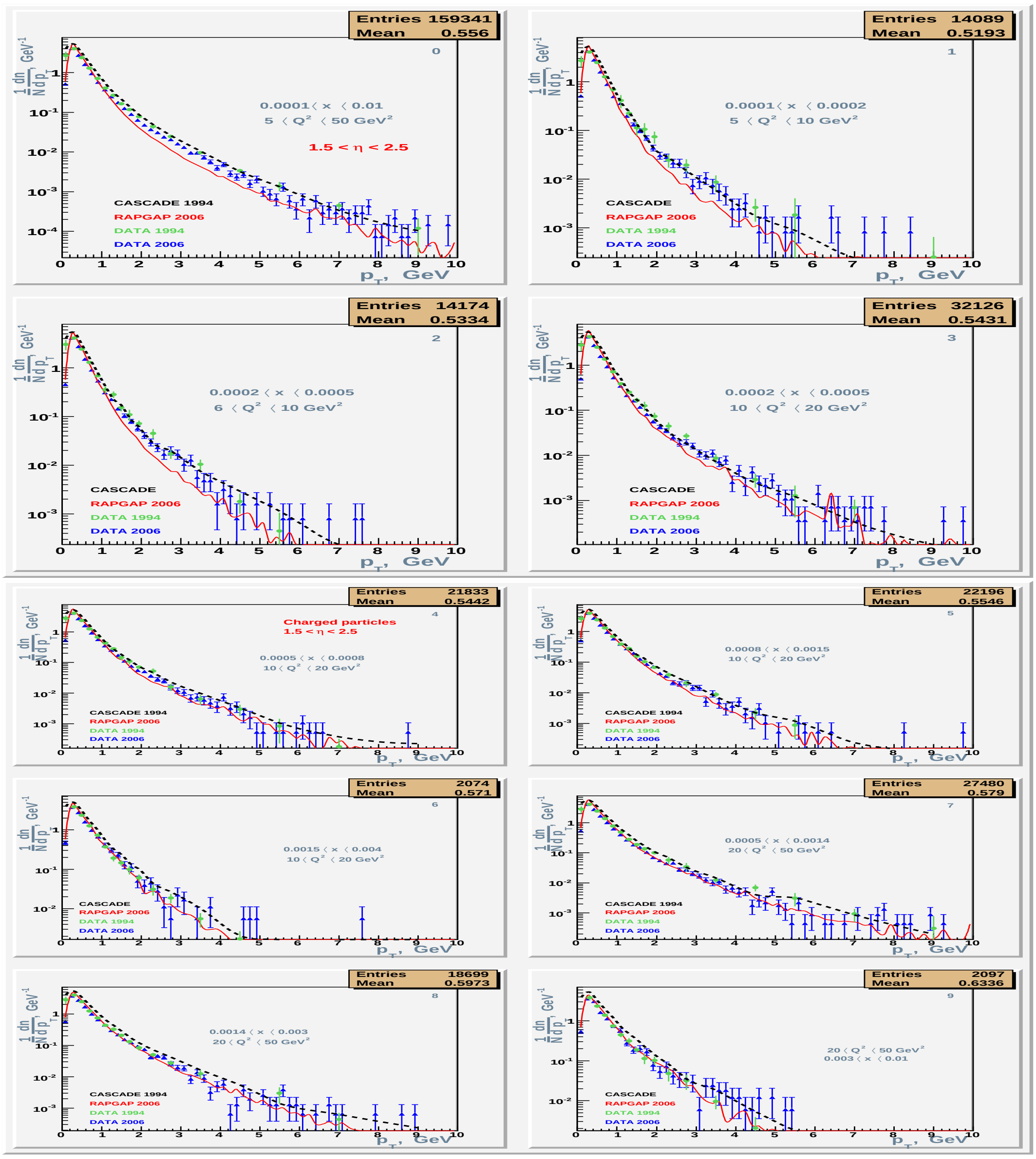

Figure 3: *Measured p_T spectra and MC predictions of charged particles in the central region of the pseudo-rapidity, $1.5 < \eta^* < 2.5$, for the hadronic center of mass system (HCM). Green and blue points correspond to the 1994 and 2006 data taking periods respectively. Data are compared to CASCADE 2.0.1 simulations for 820 GeV (black dashed line) and RAPGAP 3.1 simulations for 920 GeV (red solid line). Data are shown for nine kinematic bins and combined sample (bin 0).*

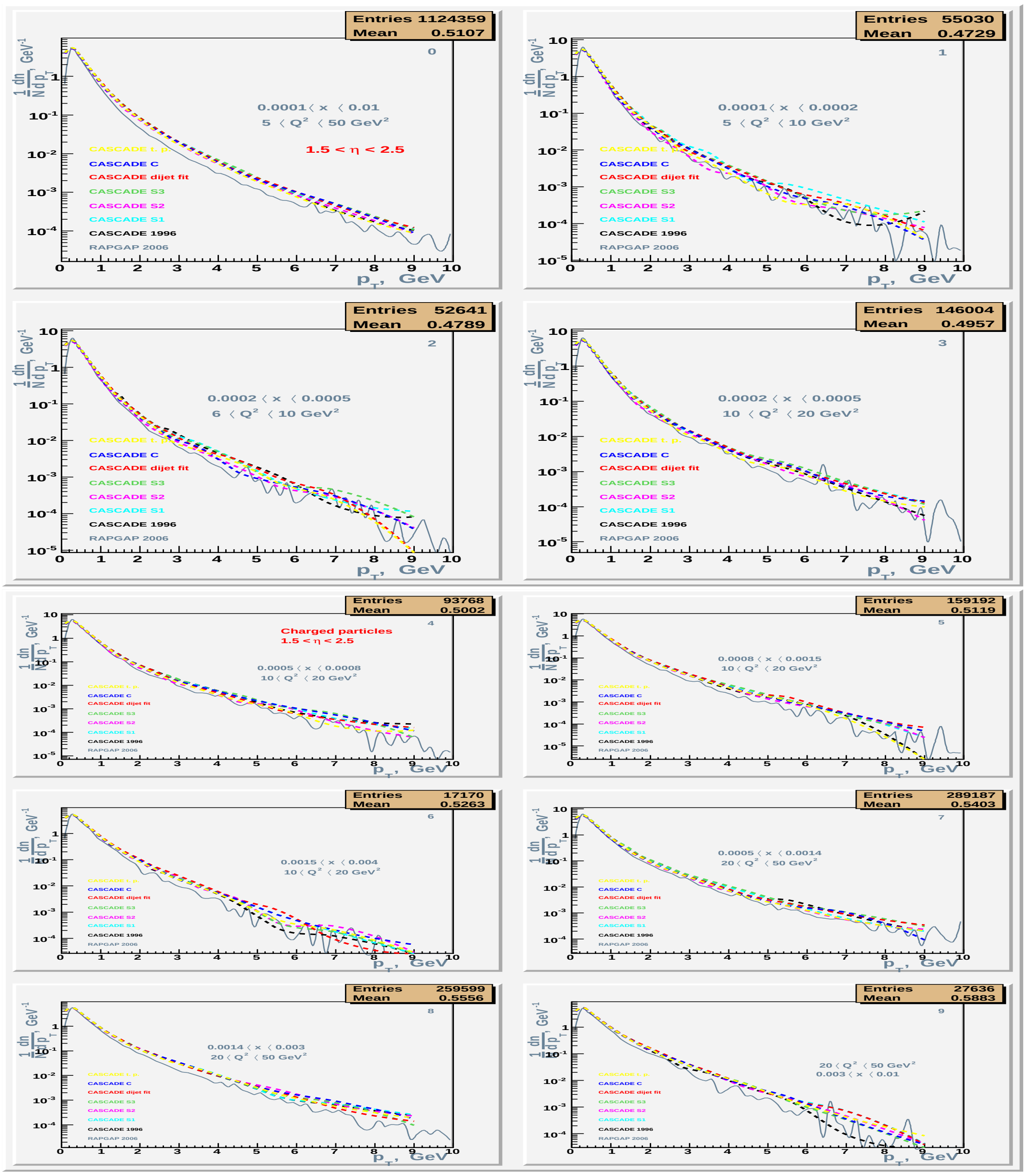

Figure 4: *RAPGAP and CASCADE simulations for p_T spectra of charged particles in the central region of the pseudo-rapidity, $1.5 < \eta^* < 2.5$, for the hadronic center of mass system (HCM) and for nine kinematic bins and combined sample (bin 0). Various gluon densities available in CASCADE were tested, which correspond to different lines on the plots.*

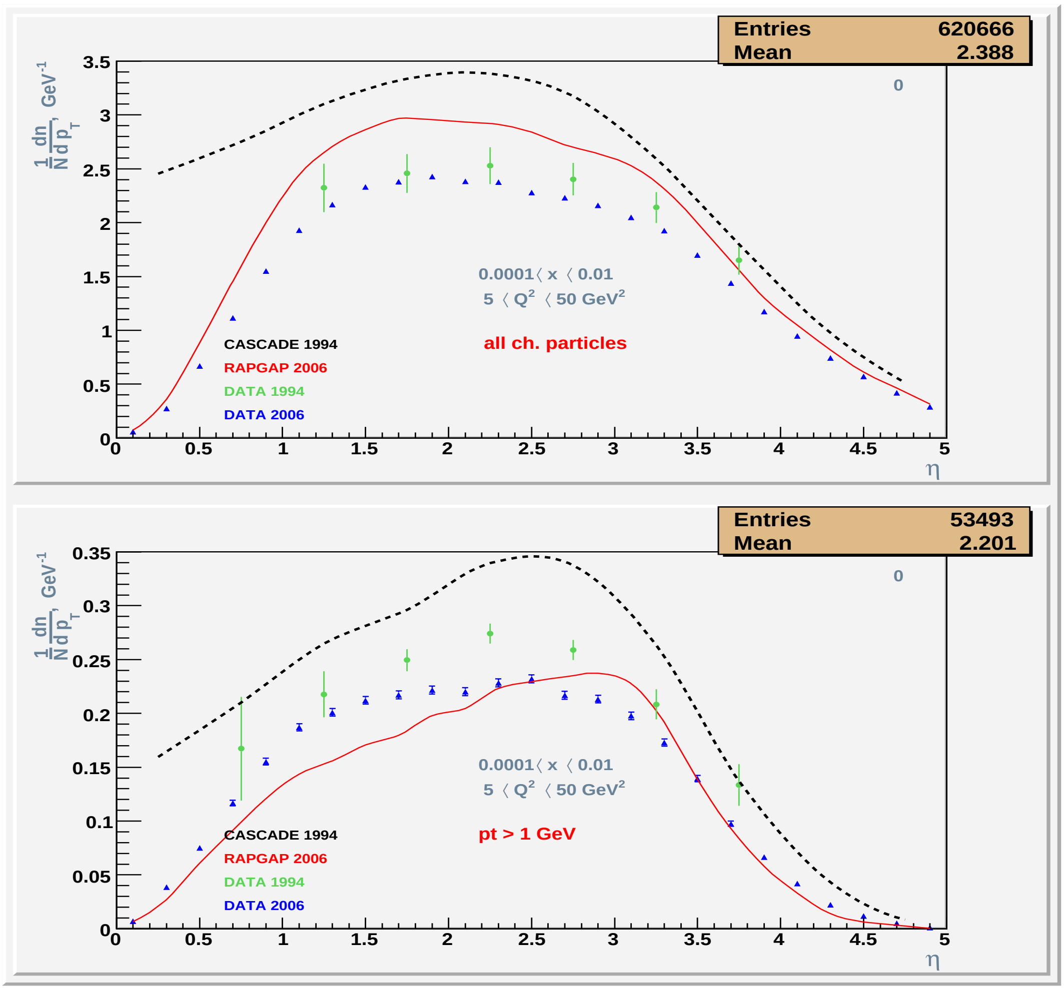

Figure 5: *The HCM pseudo-rapidity spectra for all charged particles (top plot) and for charged particles with $p_T > 1$ GeV (bottom plot). Data are shown for combined sample (bin 0).*

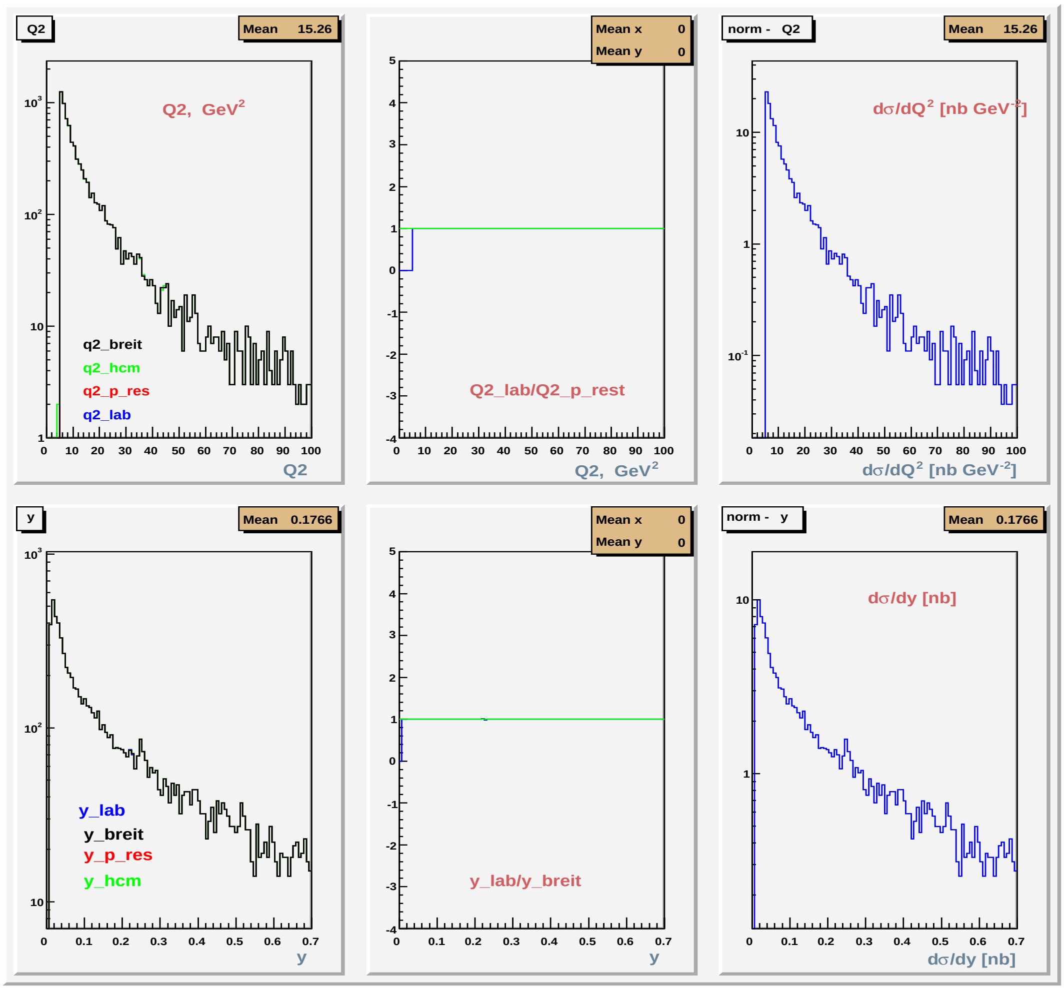

Figure 6: *Top and bottom left plots show CASCADE simulations for Q^2 and y-distributions calculated in laboratory frame, Breit-frame, proton rest frame and hadronic center-of-mass frame. Middle plots show the ratio of Q^2-distributions calculated in the laboratory and in the proton rest frames, and the same for y calculated in the laboratory and in the Breit frames. $\frac{d\sigma}{dy}$ and $\frac{d\sigma}{dQ^2}$ distridutions are presented on the right plots.*