Inclusive Properties of Hadronic Final States at HERA

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H1

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ZEUS

Presented Results

Measurement of Azimuthal Asymmetries in NC DIS.
hep-ex 0608053 (Zeus Collab.,S. Chekanov et al., Eur. Phys. J. C51 (2007) 289-299)

Measurement of Event Shape Variables in DIS.
hep-ex 0512014 (H1 Collab., A. Aktas et al., Eur. Phys. J. C46 (2006) 343-356)

Charged Particle production in High Q2 DIS.
hep-ex 0706.2456

similar analyses

Scaled Momentum Spectra in the Current Region of the Breit Frame. (ZEUS Preliminary)

Phase Space

Similar phase space for all analyses

Azimuthal Asymmetries

$100 < Q^2 < 8{,}000$ GeV^2

$0.2 < y < 0.8$

$0.01 < x < 0.1$

Energy Flow Objects

$P_t > 0.15$ GeV, $\theta > 8°$.

calo + tracks

Event Shapes

$196 < Q^2 < 40{,}000$ GeV^2

$0.1 < y < 0.7$

Energy Flow

$4° < \theta < 177°$

Scaled Momentum (H1)

$100 < Q^2 < 20{,}000$ GeV^2

$0.05 < y < 0.6$

Charged Particles

$P_t > 0.12$ GeV, $20° < \theta < 165°$

Scaled Momentum (ZEUS)

$160 < Q^2 < 40{,}960$ GeV^2

$0.0024 < x < 0.75$

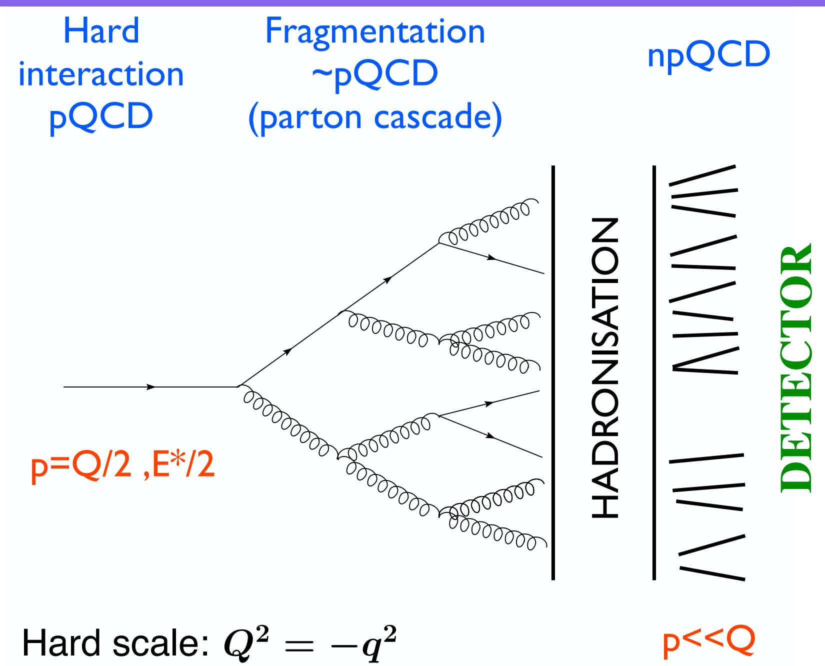
Charged Particles

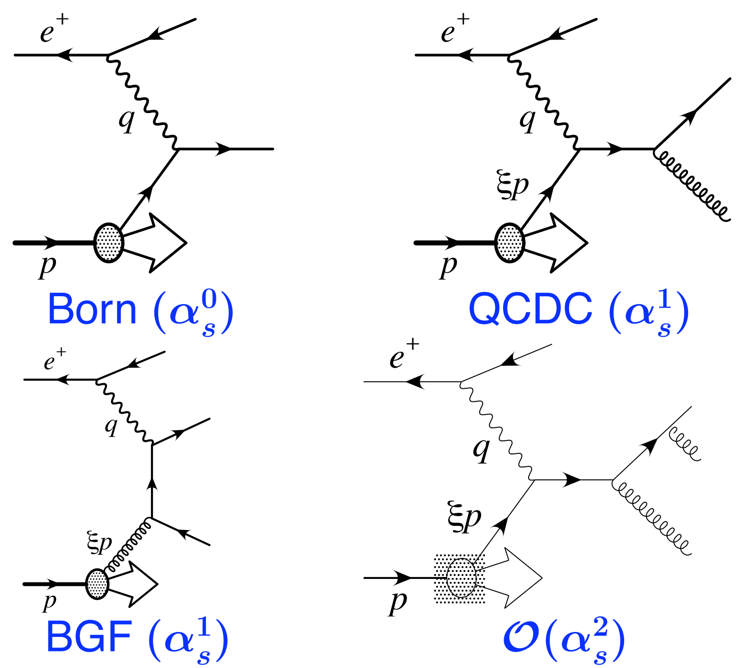
$P_t > 0.15$ GeV, $20° < \theta < 164°$

High Q^2 (>100 GeV^2), reasonably large x

→ single large scale "Q", good place to test pQCD

Phenomenology





Monte-Carlo (LO ME)

LEPTO (Parton Showers + String)

ARIADNE (Colour Dipole Model + String)

NLO pQCD

Azimuthal Asymmetries NLO - DISENT

phenomenological had corr (MC)

Event shapes NLO - DISASTER + DISPATCH

NLL resummation - DISRESUM

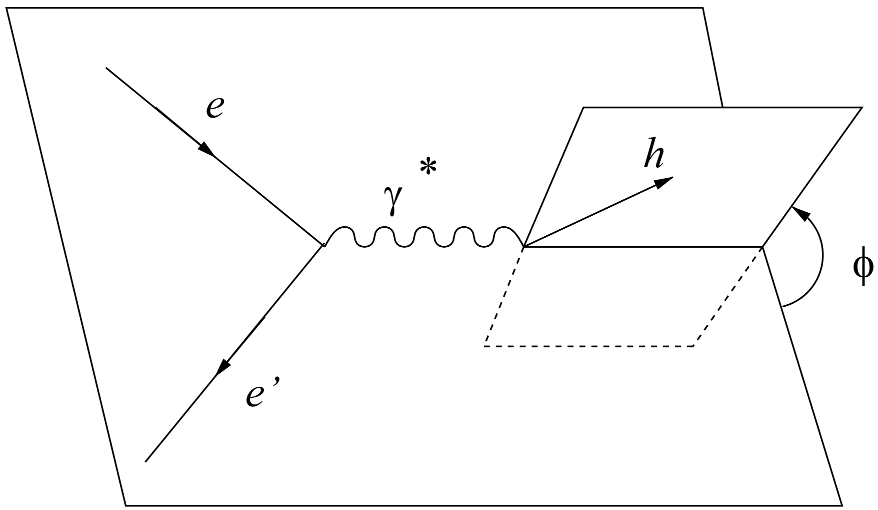
analytical Power Corrections

Scaled Momentum NLO - CYCLOPS

Fragmentation Functions - e^+e^- fits

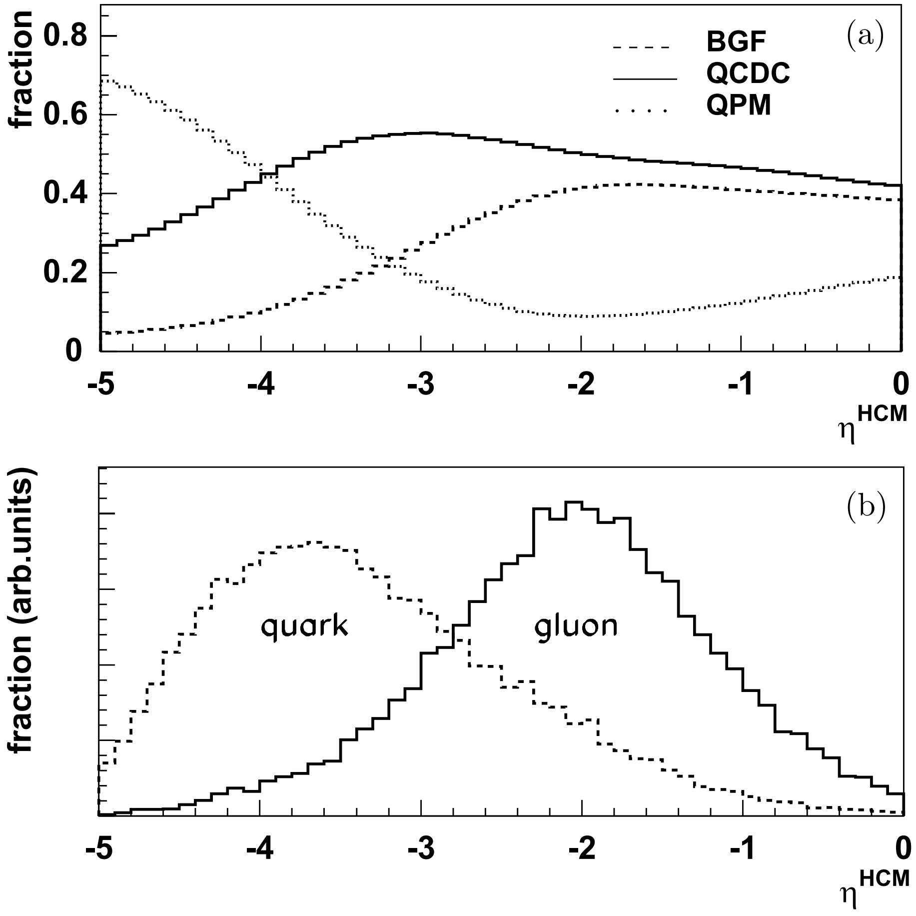
Azimuthal Asymmetries

$$\frac{d\sigma^{ep\rightarrow ehX}}{d\phi} = \mathcal{A} + \mathcal{B}\cos\phi + \mathcal{C}\cos 2\phi + \mathcal{D}\sin\phi + \mathcal{E}\sin 2\phi$$

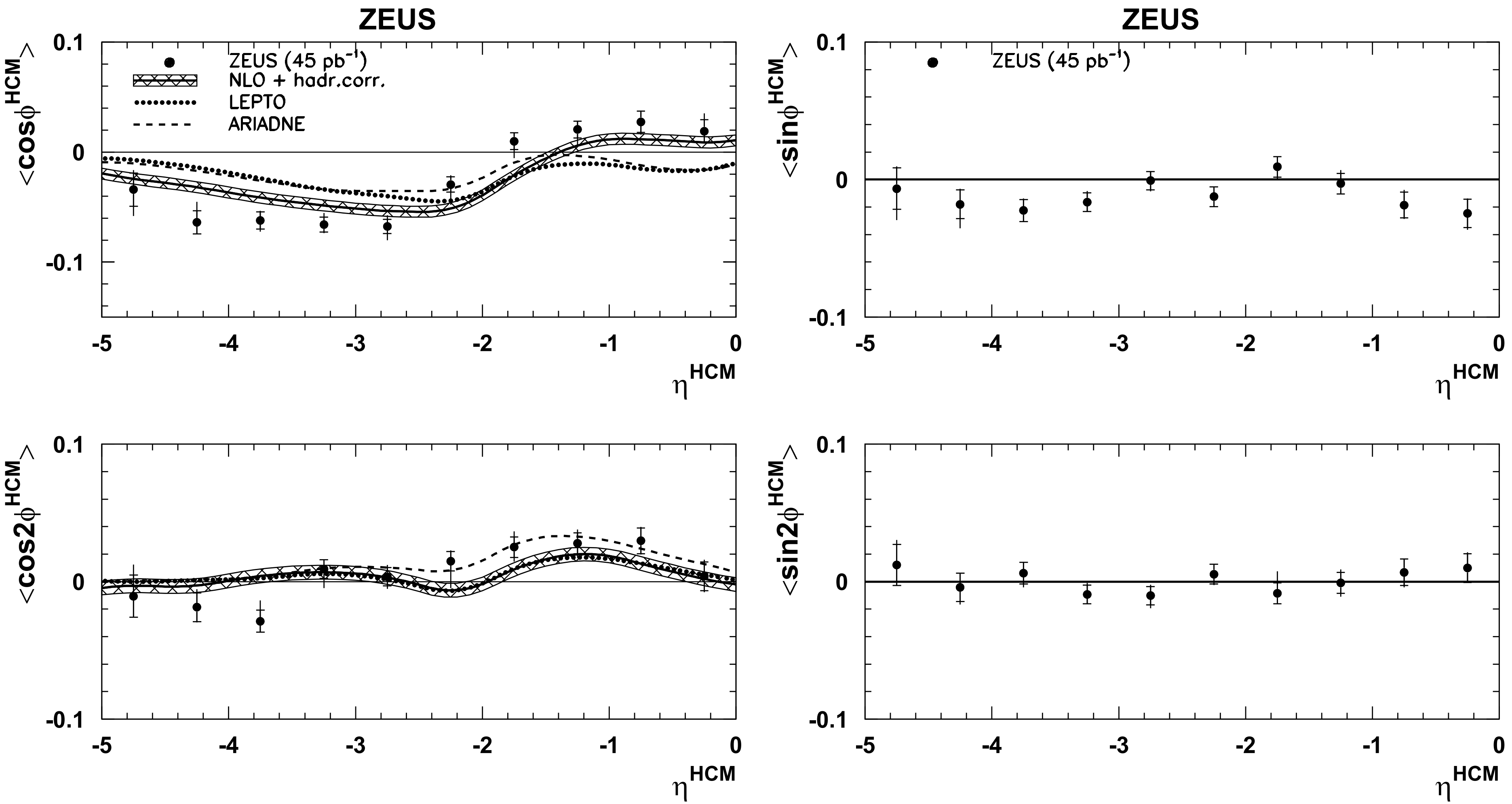


$$< \cos\phi >= \frac{\mathcal{B}}{2\mathcal{A}} \qquad < \sin\phi >= \frac{\mathcal{D}}{2\mathcal{A}}$$

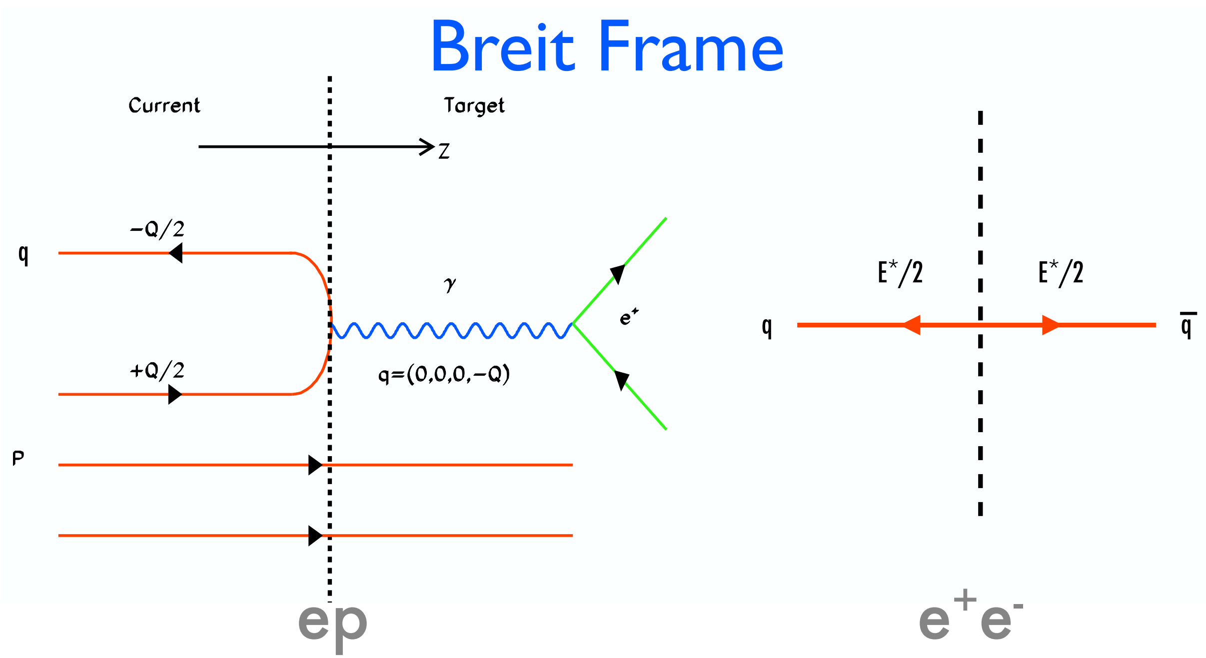
$$< \cos 2\phi >= \frac{\mathcal{C}}{2\mathcal{A}} \qquad < \sin 2\phi >= \frac{\mathcal{E}}{2\mathcal{A}}$$



Azimuthal Asymmetries



Event Shapes



$\tau = 1 - T_\gamma$ with $T_\gamma = \frac{\sum_h |\vec{p}_{z,h}|}{\sum_h |\vec{p}_h|}$

$\tau_C = 1 - T_C$ - thrust along the axis maximising T (like in e^+e^-)

$B = \frac{\sum_h |\vec{p}_{t,h}|}{2\sum_h |\vec{p}_h|}$ – Jet Broadening

$\rho = \frac{(\sum_h E_h)^2 - (\sum_h \vec{p}_h)^2}{(2\sum_h |\vec{p}_h|)^2}$ – Jet inv. mass

$C = \frac{3}{2} \frac{\sum_{h,h'} |\vec{p}_h||\vec{p}_{h'}| \sin^2\theta_{h,h'}}{(\sum_h |\vec{p}_h|)^2}$

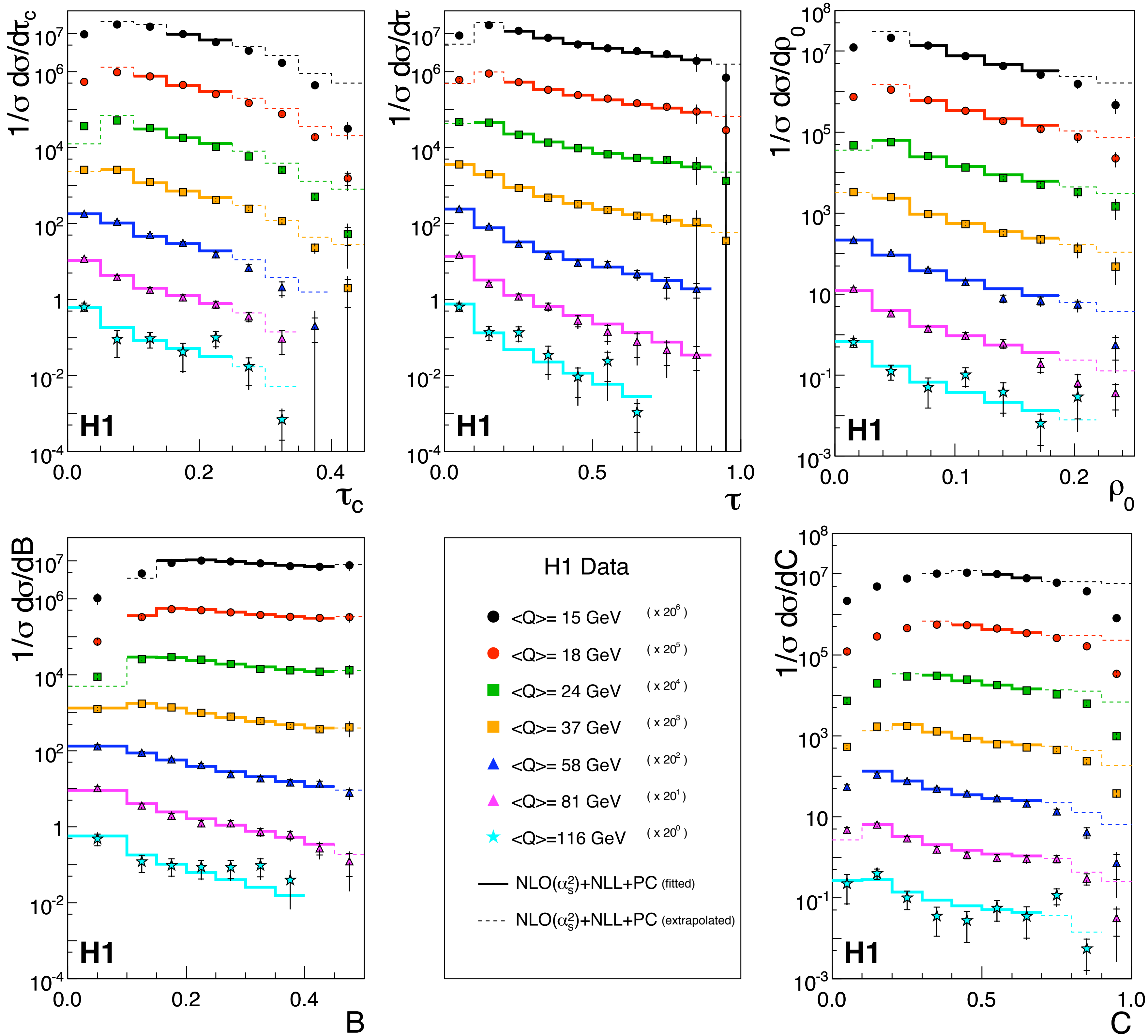
Born Level (α_s^0), current quark has no E_T
Jets in the Breit frame are $O(\alpha_s)$

Provides clearest separation between particles from hard scattering and proton remnant. Allows for easy comparison with e+e− data

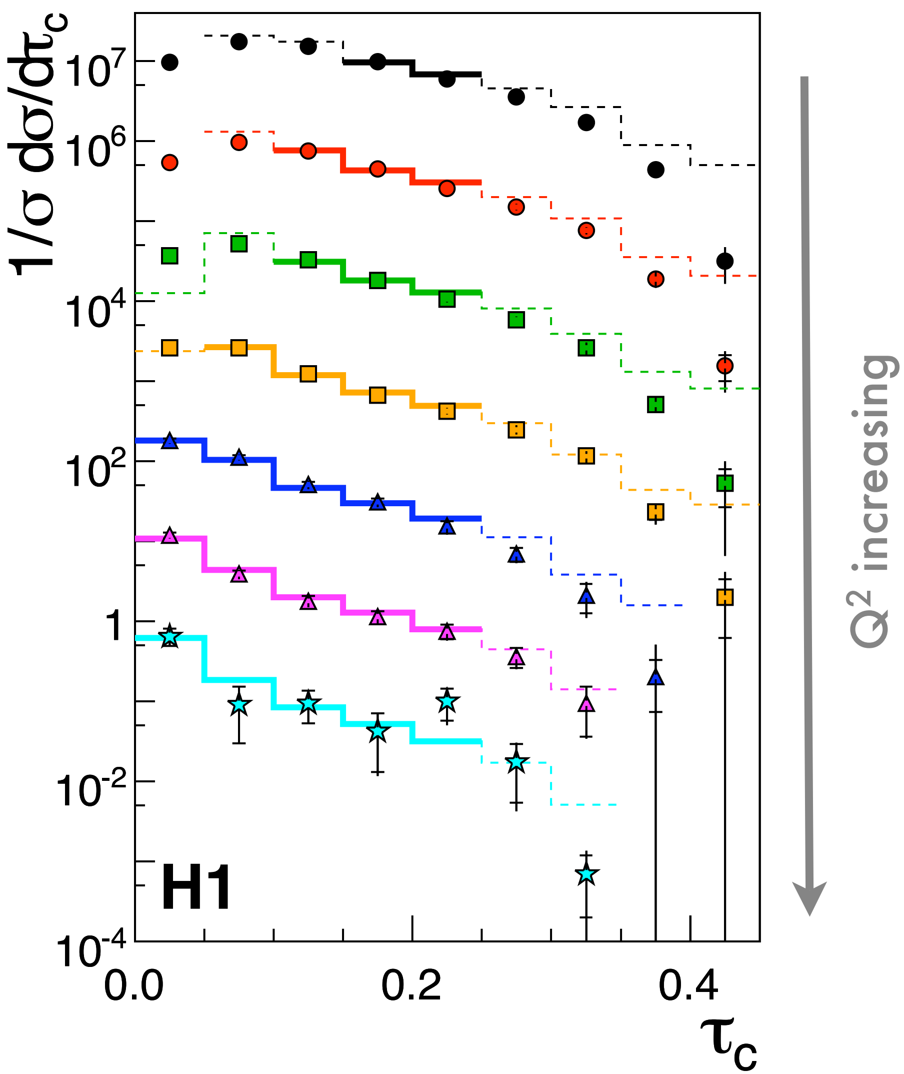
current region energy scale is Q

sums extend over all particles (energy flow) in current hemisphere of the Breit frame

→ 0 for Born Level
> 0 for higher orders


H1 Data
<Q>= 15 GeV (x 20^6)
<Q>= 18 GeV (x 20^5)
<Q>= 24 GeV (x 20^4)
<Q>= 37 GeV (x 20^3)
<Q>= 58 GeV (x 20^2)
<Q>= 81 GeV (x 20^1)
<Q>=116 GeV (x 20^0)
NLO(α_s^2)+NLL+PC (fitted)
NLO(α_s^2)+NLL+PC (extrapolated)
H1
$1/\sigma\, d\sigma/d\tau_c$
τ_c
$1/\sigma\, d\sigma/d\tau$
τ
$1/\sigma\, d\sigma/d\rho_0$
ρ_0
$1/\sigma\, d\sigma/dB$
B
$1/\sigma\, d\sigma/dC$
C

Event Shapes



Fit of NLO+NLL+PC to data

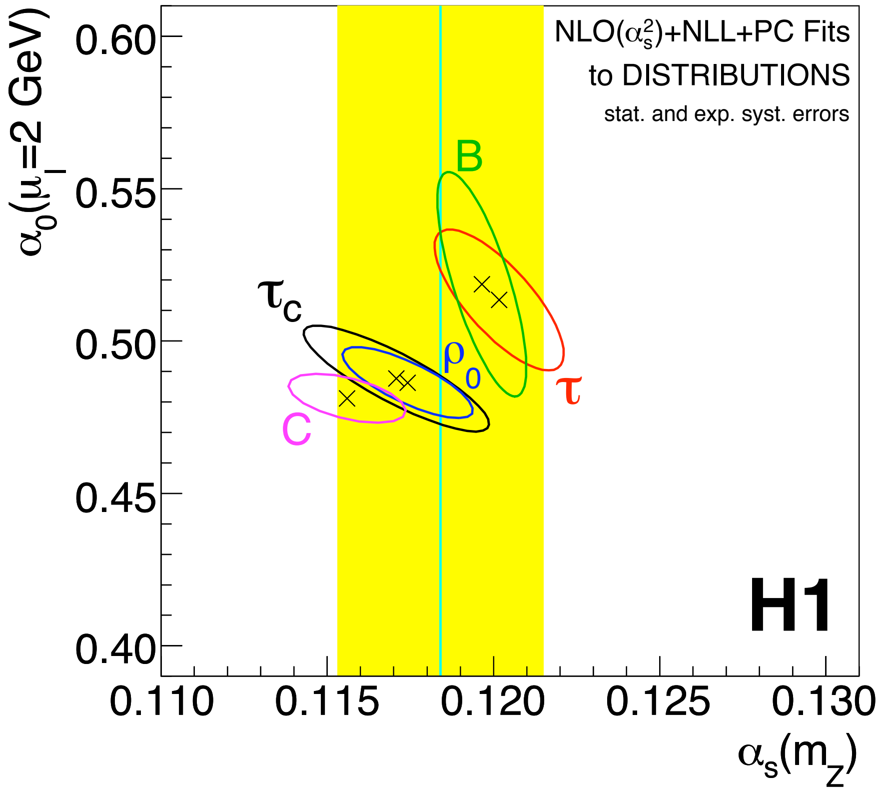
Theory has limited range of applicability

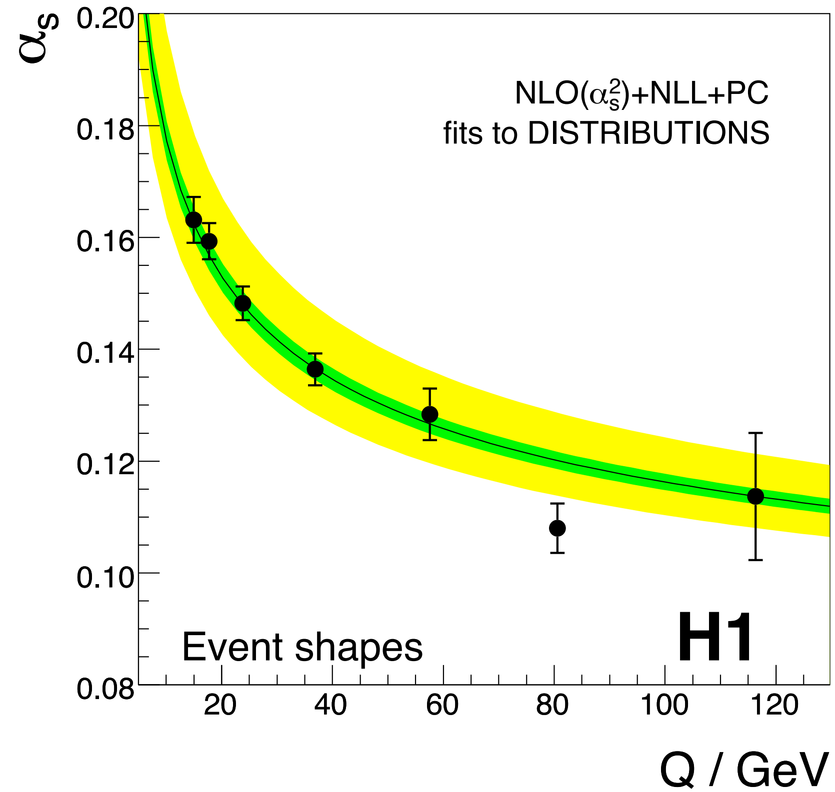
Extrapolation of fit to "unsafe" regions seems to work

Except for highest Q bin exprimental errors really small.

τc = 1-Tc :Thrust along the axis Maximising T

Event Shapes





α_0: effective non-perturbative coupling from power corrections. Theory expects ≅ 0.5

$\alpha_0 = 0.476 \pm 0.008(\text{exp}) {}^{+0.018}_{-0.059}(\text{theo})$,

α_0 universal to about ±10%

$\alpha_s(m_Z) = 0.1198 \pm 0.0013(\text{exp}) {}^{+0.0056}_{-0.0043}(\text{theo})$,

Scaled Momentum

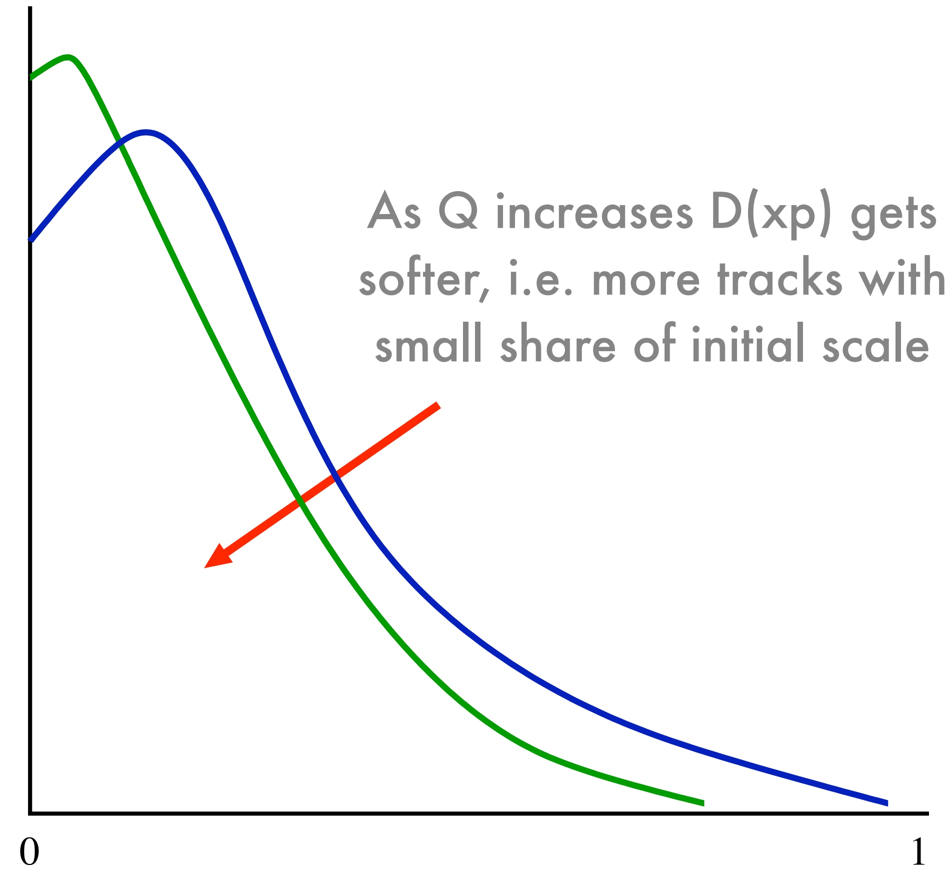
$$x_p = \frac{(2P_h)}{Q}$$

$$D(x_p) = \frac{1}{N_{event}} dn/dx_p$$

x_p = scaled momentum variable

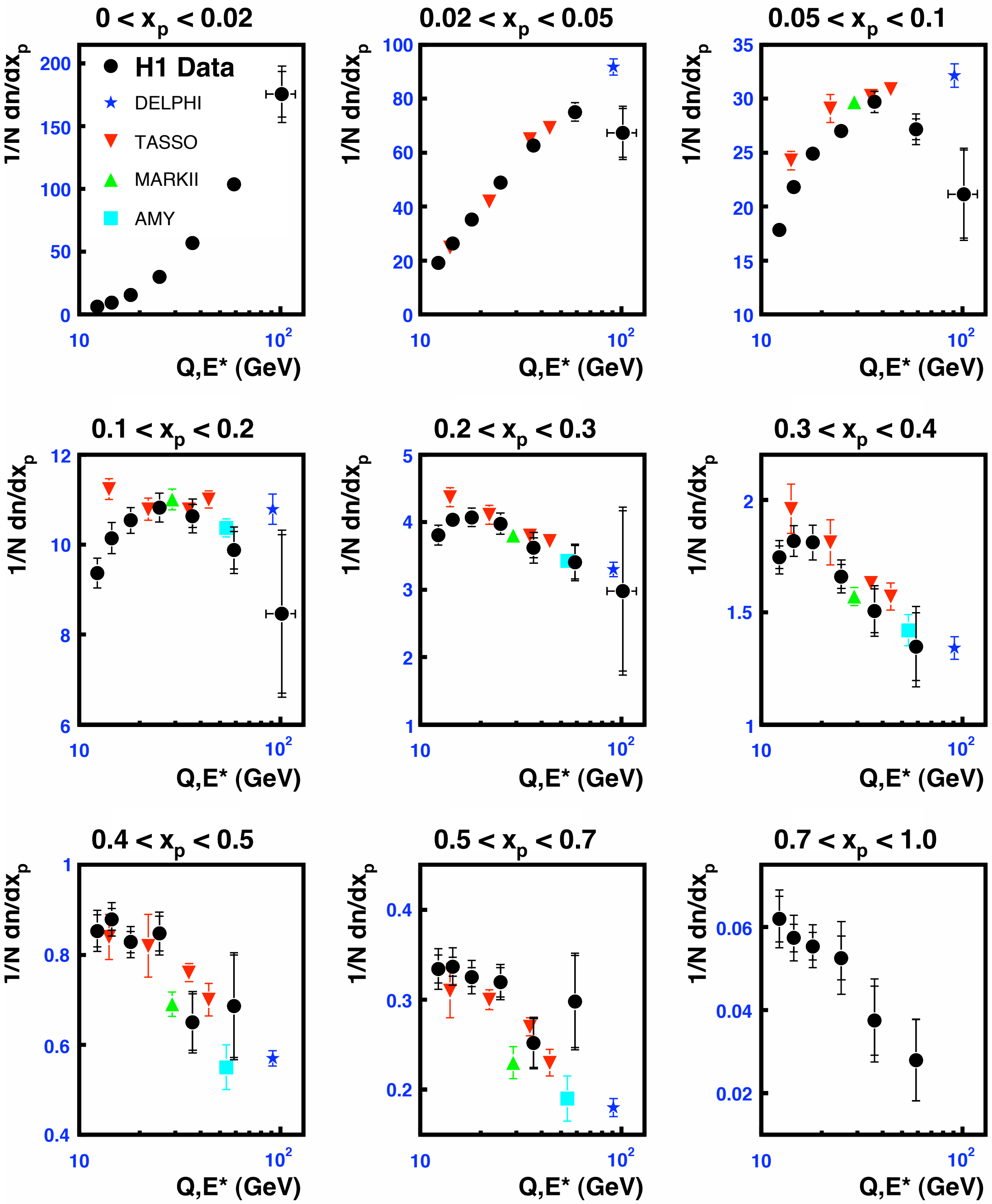
$Q/2$ = Scale in current region of Breit Frame

p_h = momentum of charged particle in current region of Breit frame



D(xp) = event normalised, charged particle, scaled momentum distribution

Scaled Momentum



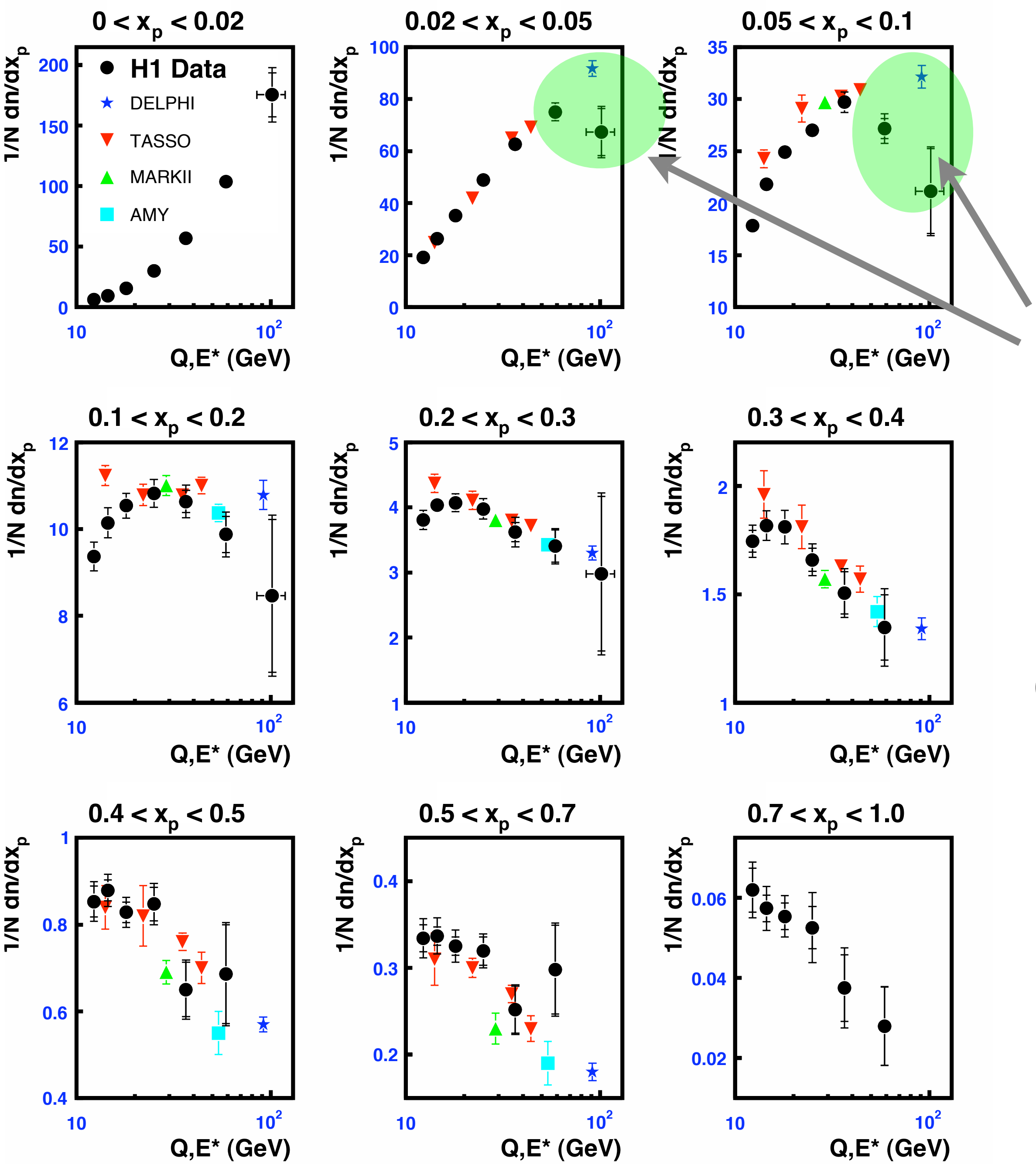
Pretty good agreement between ep and e^+e^- !

high Q^2 and small x_p reason unclear

low Q^2, mid x_p. expected to be due to BGF kinematics producing empty current region

NB: suppressed zeros

Scaled Momentum



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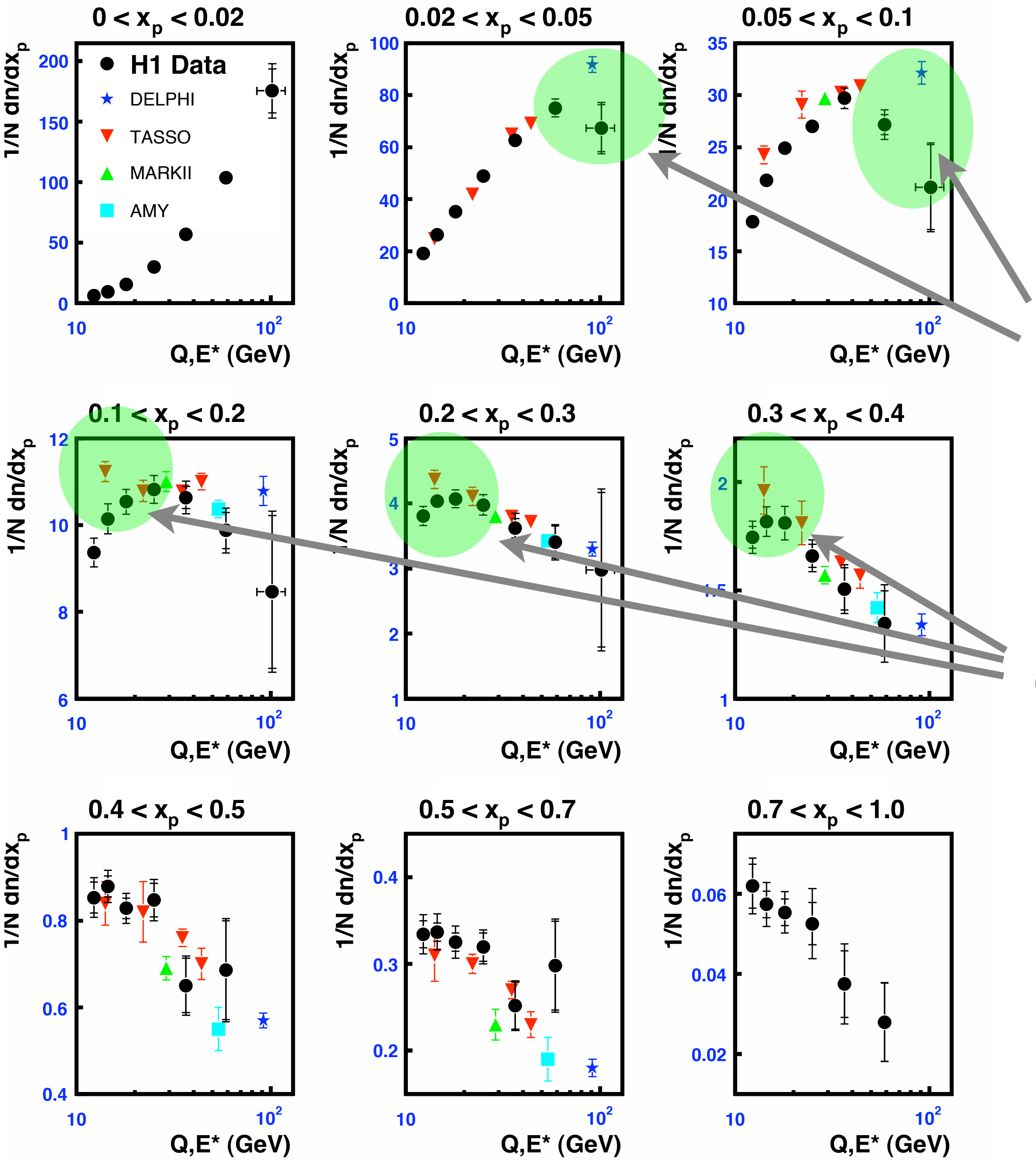

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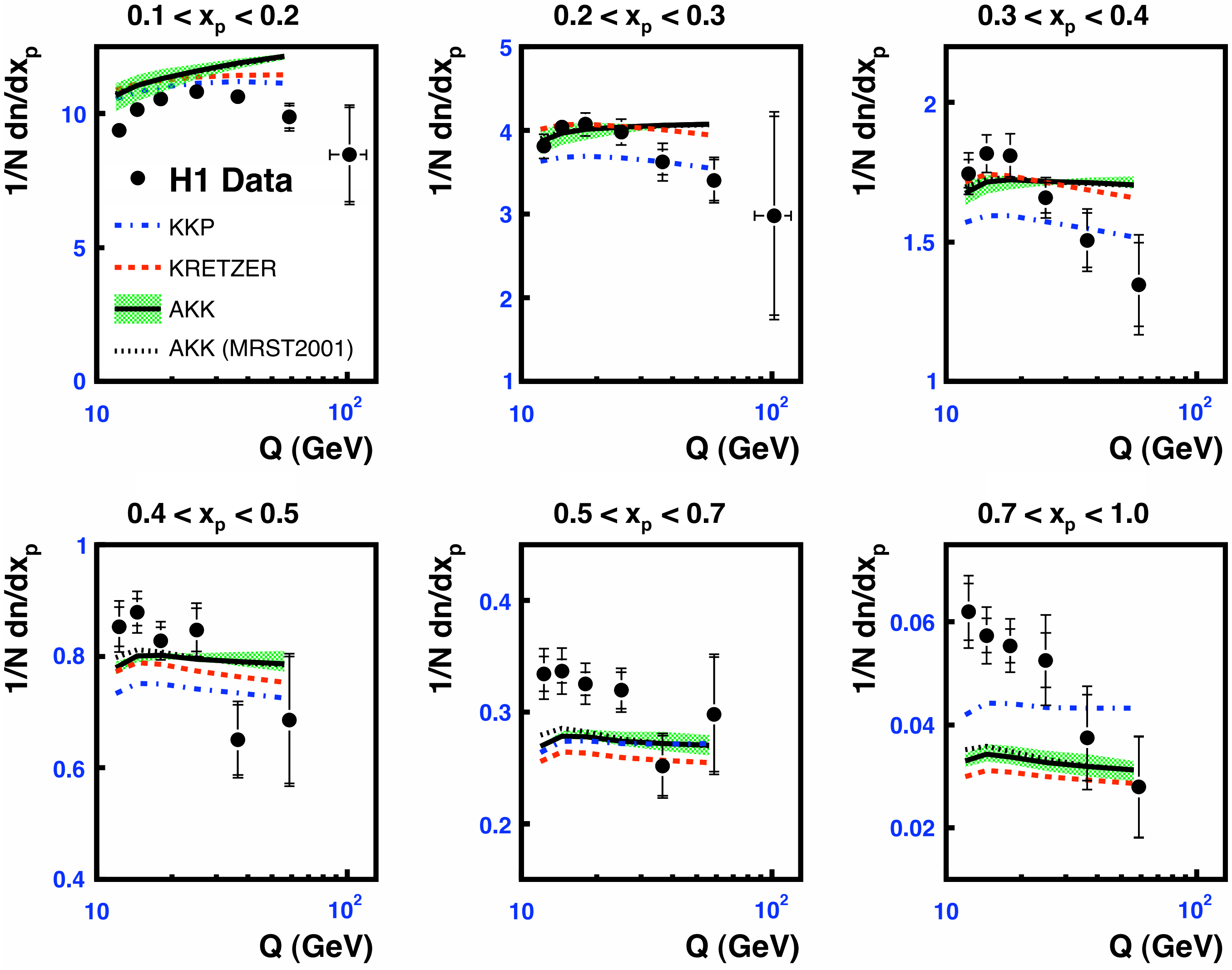


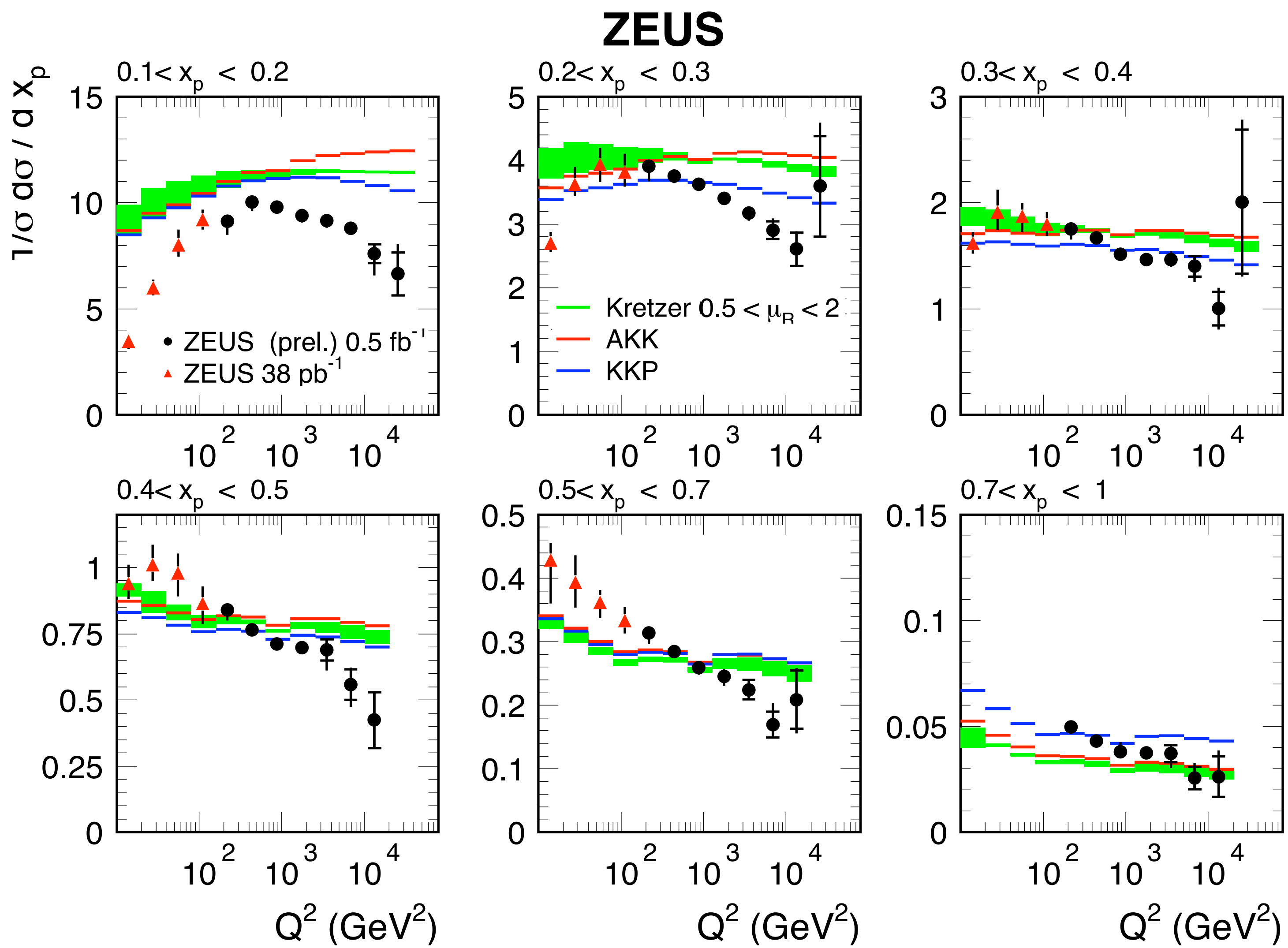
Fragmentation functions (KKP, KRETZER, AKK) taken from fits to e^+e^- data

Scale and PDF errors small

Sensitivity to different FF

NLO theory does not describe the scaling violations seen in data

Scaled Momentum

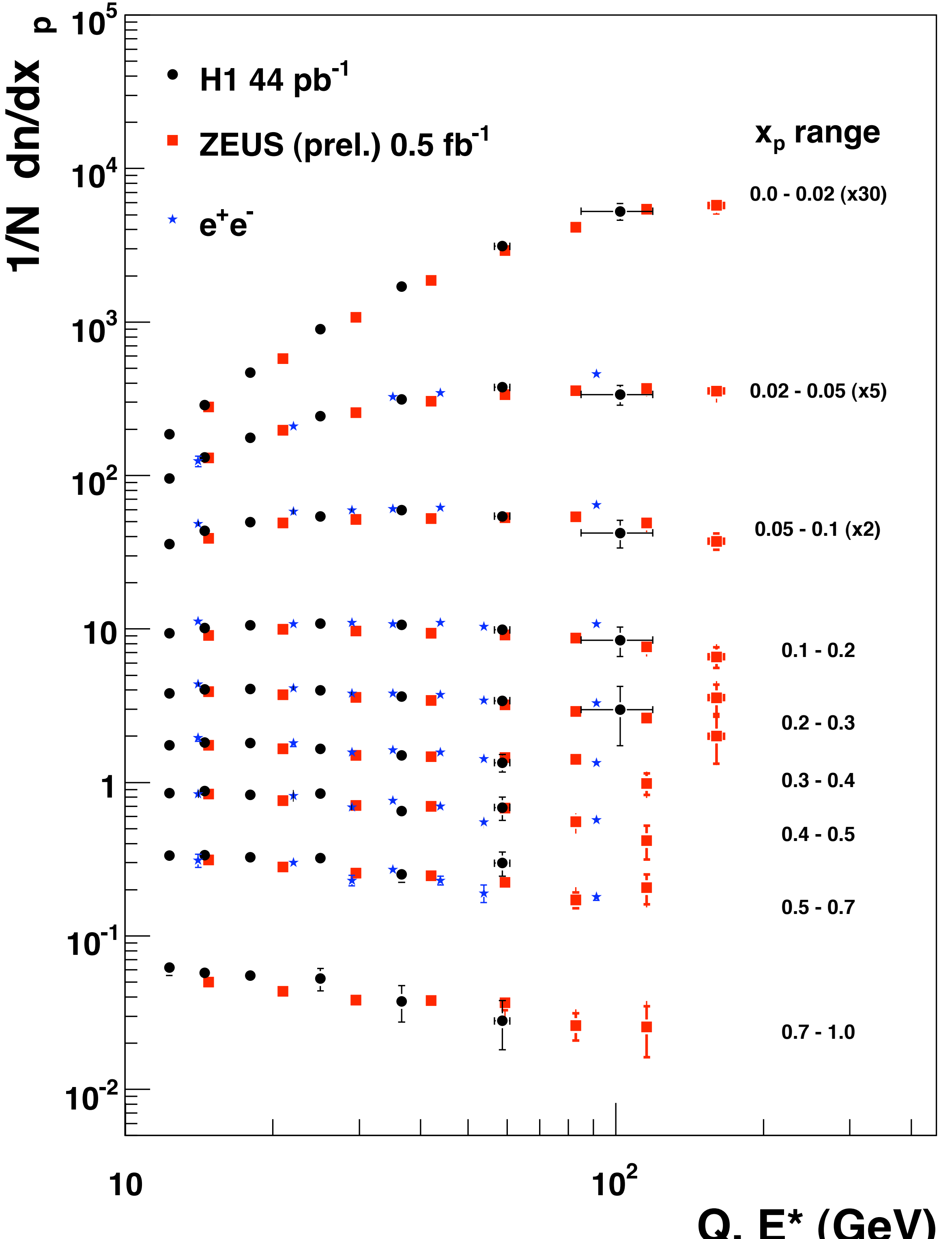


black points new High Q^2 analysis full HERA I+II stats ~0.5 fb^{-1}!

red points old low Q^2 analysis

Similar picture as seen by H1

Scaled Momentum



summary:

Published H1 results

Preliminary ZEUS data

Selected e^+e^- results

Summary

- HERA provides a rich source of data for studies of the hadronic final state.
- Azimuthal Asymmetries : NLO better that MC at describing data but still fails to describe the magnitude of the asymmetries.
- Event shapes: NLO + NLL + PC describe the data well. Power corrections give universal α_0. Competitive value of α_s extracted, running of α_s also shown.
- Scaled Momentum: Broadly supports quark fragmentation universality between e^+e^- and ep. NLO fails to describe the scaling violations seen in the data.

Backup

Event shapes in Breit Frame

- Event shapes F are defined such that F→0 for pencil-like hadron configurations aligned with z-axis.
- Born level quark in Breit Frame has p_T=0 so its fragments produce F≈0
- Multijet configurations produce F > 0 in extreme F≈1

$$\tau = 1 - \frac{\sum_h |\vec{p}_{z,h}|}{\sum_h |\vec{p}_h|}$$ thrust

$$B = \frac{\sum_h |\vec{p}_{t,h}|}{2\sum_h |\vec{p}_h|}$$ Jet broadning

Z-axis parallel to exchanged boson

Reference to axis external to HFS – sensitive to quark recoil effect due to QCD radiation

τ_C : thrust a la e^+e^- ; z || axis maximizing thrust

ρ: Jet invariant mass

C-parameter, hadron-hadron correlation

$$C = \frac{3}{2}\frac{\sum_{h,h'} |\vec{p}_h||\vec{p}_{h'}| \sin^2\theta_{h,h'}}{(\sum_h |\vec{p}_h|)^2}$$

No reference to external axis

All event shapes are normalized to total momentum – less sensitive to uncertainty of hadronic calorimeter scale !

Power correction approach

★ Introduce effective non-pert. coupling $\alpha_0 = \frac{1}{\mu_I}\int_0^{\mu_I}\alpha_{eff}(k)dk$ ($\alpha_0 = \alpha_s$ at $\mu_I = 2$GeV)
(theory predicts universal $\alpha_0 \simeq 0.5$)

★ PC (Dokshitzer at al.): non-pert. corrections (suppressed by powers of $1/Q$) obtained from first principles

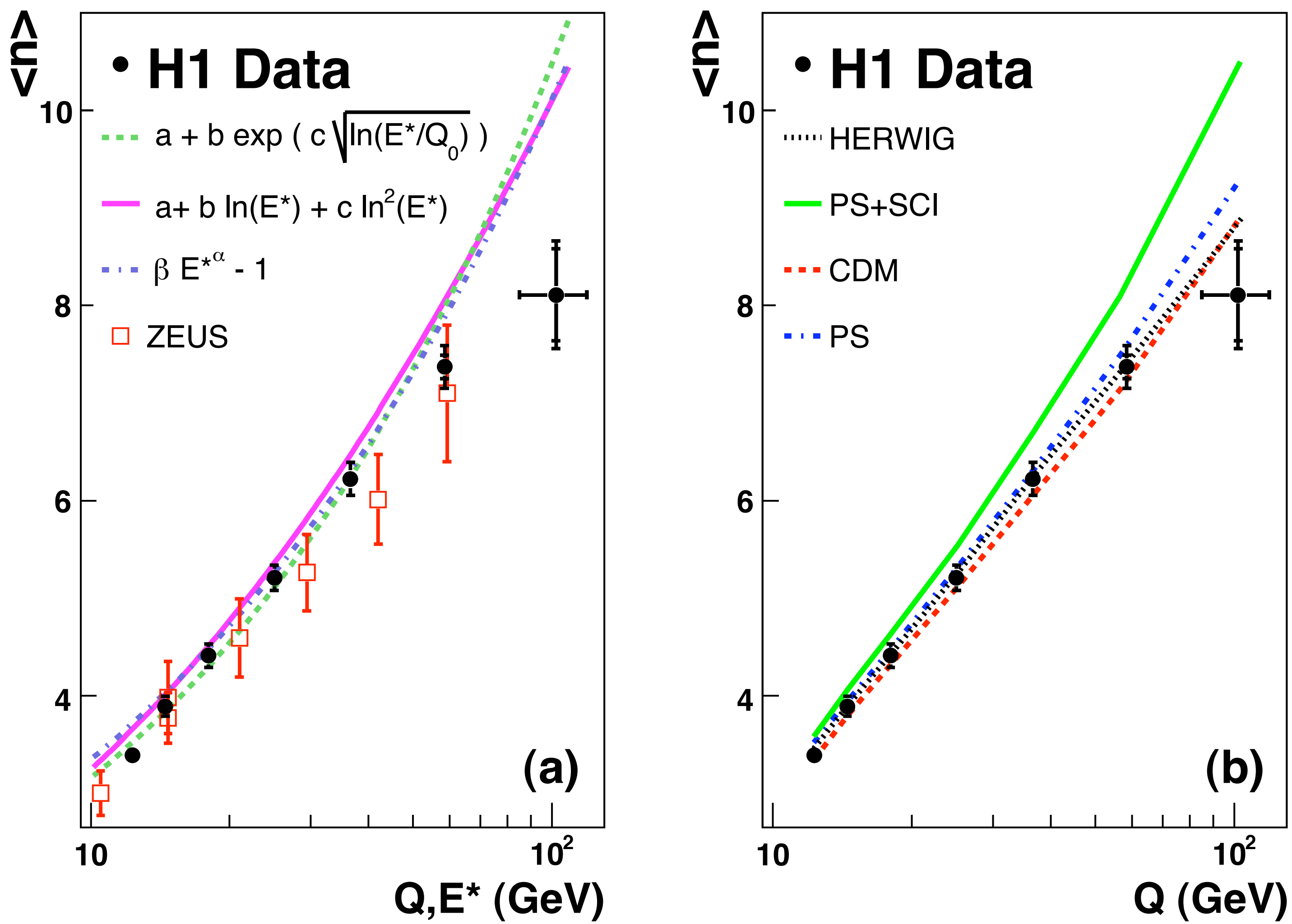
- for distributions $\frac{1}{\sigma}\frac{d\sigma(F)}{dF} = \frac{1}{\sigma}\frac{d\sigma^{\mathrm{pQCD}}(F - a_F\mathcal{P})}{dF}$ New
- for mean values $\langle F\rangle = \langle F\rangle^{\mathrm{pQCD}} + a_F\mathcal{P}$ (with universal PC term $\mathcal{P}$)

★ Complete description for F: NLO+NLL+PC
Recent progress in theory (as compared to previous round of event shape analyses in DIS) – resummation of large log terms and matching it to fixed order NLO (DISRESUM package by Dasgupta and Salam, 2002)

★ Limitations: very low F ($F \le a_F\mathcal{P} \sim \mu_I/Q$) and very high F (substantial HO corr.)

Main aim of the analysis: check the validity of PC concept and universality of α_0
By product: yet another method/observables to extract $\alpha_s(M_Z)$

Scaled Momentum



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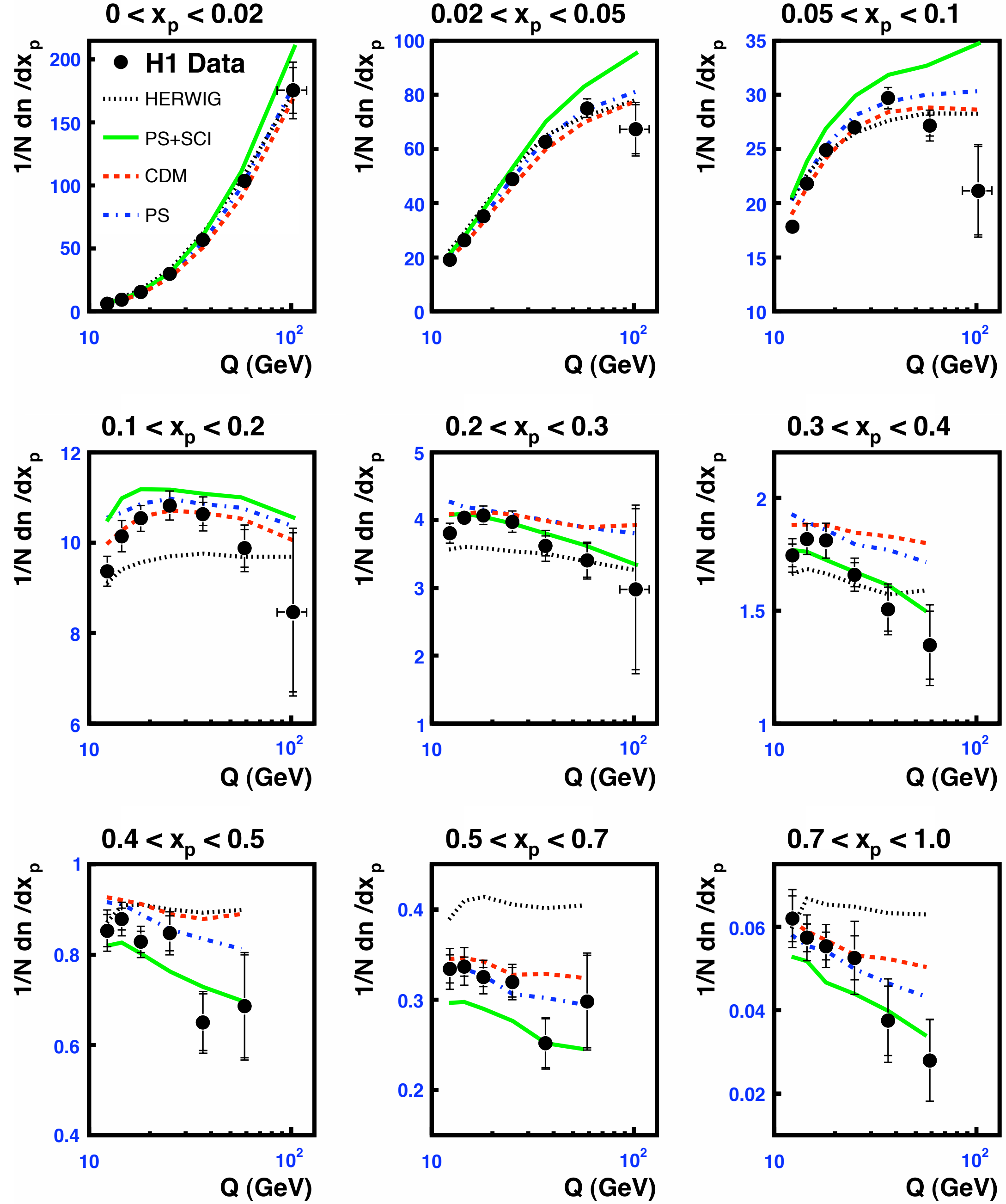

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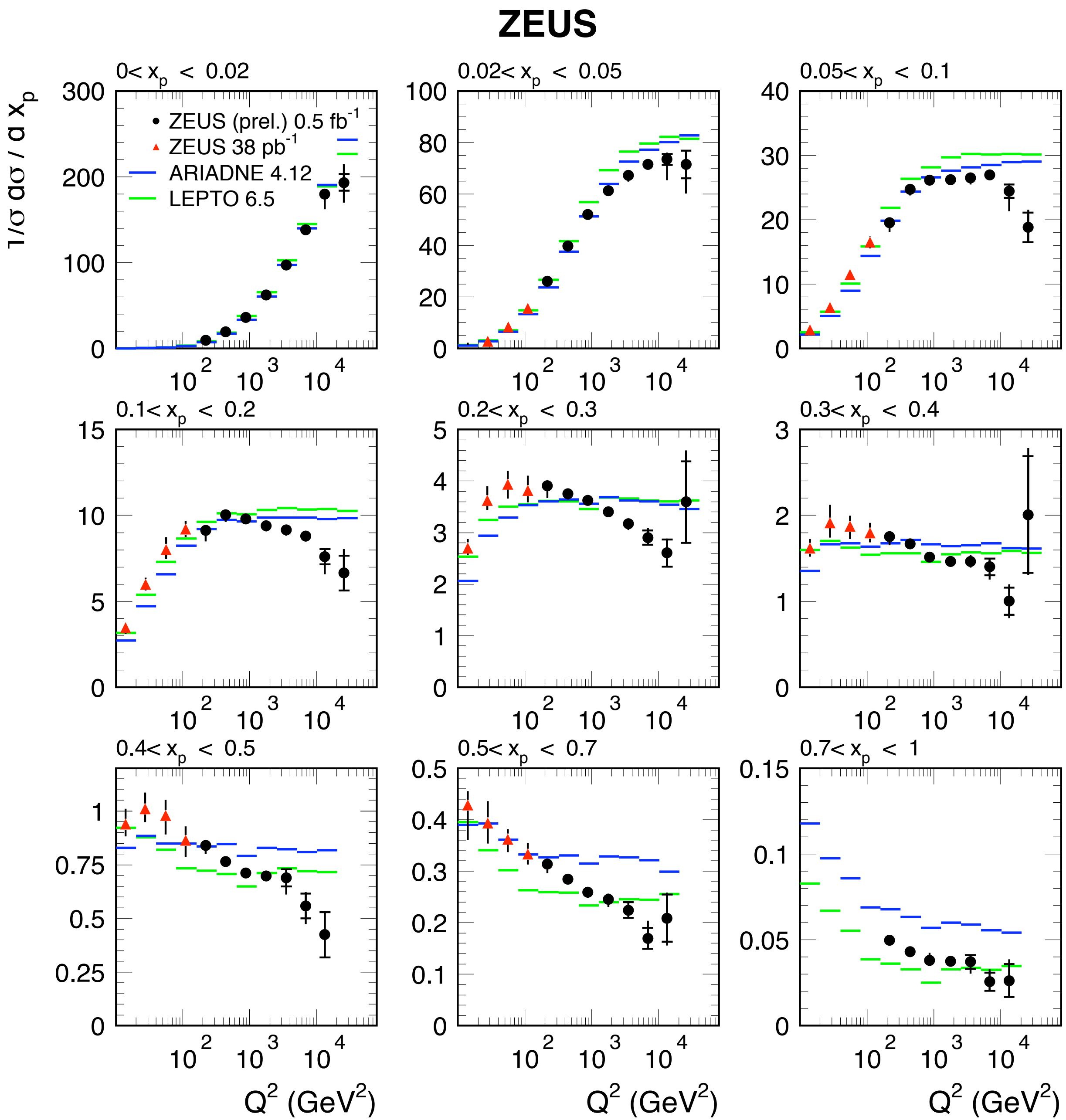

Scaled Momentum