HERA SYMPOSIUM 2010

Recent results from H1

Karin Daum -Wuppertal/DESY
on behalf of the H1 collaboration

and on behalf of the H1 and ZEUS collaborations

H1 Harvest 2009/10

Structure Functions & PDFs

- x-section at medium Q^2 & H1PDF2009
- x-section at low Q^2
- **Polarised CC x-section high Q^2**
- **Polarised NC x-section high Q^2**
- **Combined EW+QCD Fit**
- FL at low, medium and high Q^2
- **x-section HERA I & HERAPDF1.0**
- HERA combined x-section @ high Q^2 *
- HERA combined F_L *
- **HERA PDFs including F_2^c**
- HERA PDFs including LER/MER *

Diffraction

- **Longitudinal structure function F_L^D**
- Leading neutron production in DIS: F_2^{LN}
- **F_2^D with LRG**
- **F_2^D with protons in FPS**
- F_2^D with protons in VFPS
- **Jet production in DIS protons in FPS**
- **Di-jet photo-production with LRG**
- Di-jet production in DIS using VFPS
- DVCS and charge asymmetry
- Diffractive ρ and φ in DIS
- Photons with large p_T in diffraction
- Forward photons in FNC

Physics beyond the SM

- Single top quark production
- Exited quarks
- Generic search for new phenomena
- **L-violating Leptoquarks**
- **R-parity violating Squarks**
- Isolated leptons and W production
- Contact interactions
- HERA combined analysis of multileptons *
- HERA combined analysis of isolated leptons *

Hadronic Final State

- **Jet production and α_s @ medium Q^2**
- Jet production and α_s @ high Q^2
- Prompt photons in γp
- **Forward jet correlations @ medium Q^2**
- Charged particle production
- Charge Asymmetry @ high Q^2
- Photo-production of ρ^0,K^{*0} and φ mesons
- Strangeness production @ medium Q^2
- K^0 production @ high Q^2

Heavy Flavour

- Inelastic J/ψ in γp and DIS
- Charm fragmentation into D* in DIS
- Photo-production of D* + di-jets
- D* and F_2^c @ high Q^2
- D* @ medium Q^2
- F_2^b and F_2^c with vertex detector
- **HERA combined F_2^c**
- **Charm and beauty jets in DIS**

* See Jola's talk

Structure Functions

NC: $e^{\pm}p \rightarrow e^{\pm}X$

$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha_{em}}{xQ^4}\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right] \equiv \frac{2\pi\alpha_{em}}{xQ^4}\tilde{\sigma}^{\pm}_{NC}$$

with $Y_{\pm} = 1 \pm (1-y^2)$

$$\tilde{F}_2 = \{F_2, F_2^{\gamma Z}, F_2^{Z}\} = x\Sigma_q \{e_q^2, 2e_q v_q, v_q + a_q\}(q+\bar{q})$$
$$x\tilde{F}_3 = \{xF_3^{\gamma Z}, xF_3^{Z}\} = 2x\Sigma_q \{e_q a_q, v_q a_q\}(q-\bar{q})$$
$$\tilde{F}_L \sim \alpha_s xg(x,Q^2)$$

dominates in LO QCD
parity violating terms ($Q^2 \approx m_Z^2$) important at high y

CC: $e^{\pm}p \rightarrow \upsilon X$

$$\frac{d^2\sigma_{CC}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{m_W^2}{Q^2+m_W^2}\right]^2 \left[Y_+W_2 \mp Y_- xW_3 - y^2W_L\right]$$

$W_2^- = x(u + c + \bar{d} + \bar{s})$ sensitive to u_v @ high x
$W_2^+ = x(\bar{u} + \bar{c} + d + s)$ sensitive to d_v @ high x

Combined incl. ep x-section

Combination of all HERA I inclusive cross sections by minimising

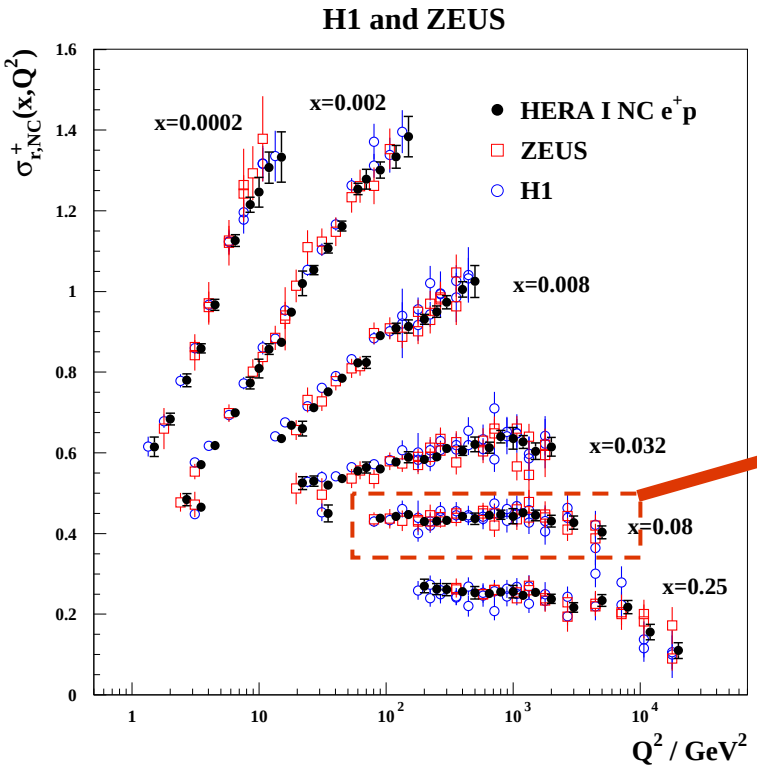
correlated systematic errors

$$\chi^2(\vec{m},\vec{b}) = \sum_i \frac{\left(m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right)^2}{(\delta_{i,stat}\,\mu^i)^2 + (\delta_{i,unc}\,m^i)^2} + \sum_j b_j^2$$

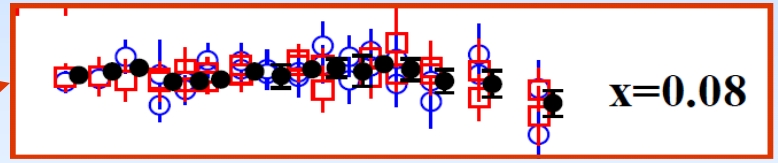
statistical errors

uncorrelated systematic errors

JHEP1001(2010)109



12 different data sets
1402 H1 and ZEUS measurements
→ 741 data point $\sigma_r(x,Q^2)$
110 sources of systematic uncertainties



Significantly improved precision due to cross-calibration 1-2% for NC

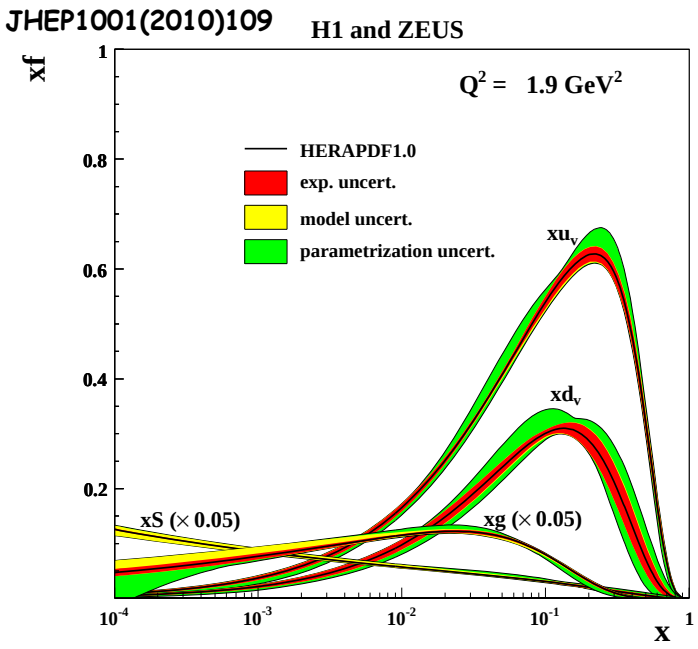
HERAPDF1.0

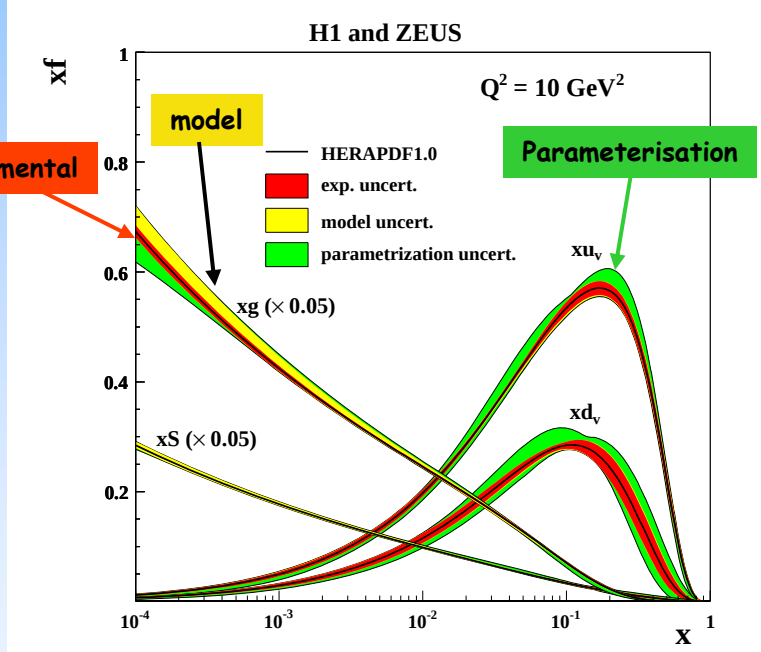
Functional form of PDF at starting scale Q_0: $xf(x)=Ax^B(1-x)^C(1+Ex^2)$

$Q_0=1.9\ GeV^2$, $f_s=0.31$, $m_c=1.4\ GeV$, $m=4.75\ GeV$, $a_s(M_Z)=.1176$

Heavy quark treatment: GMVFNS RT2008

Sum rules $\Rightarrow$ 10 free parameters ($E\neq 0$ only for u_v)





'valence like' gluon at starting scale

Precise gluon @ small x

u_v, d_v not too well constrained @ large x (parameterisation uncertainties)

HERAPDF1.0

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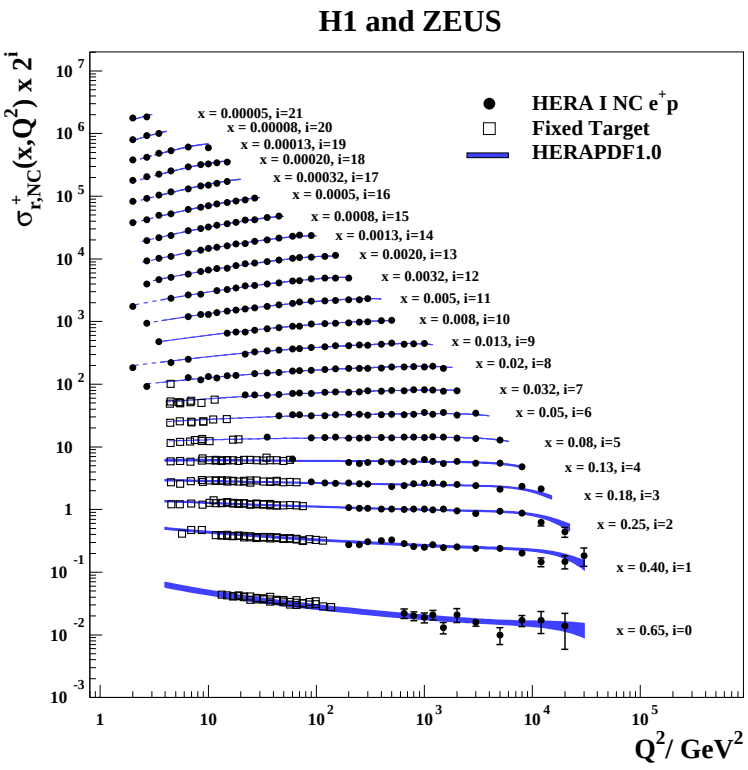
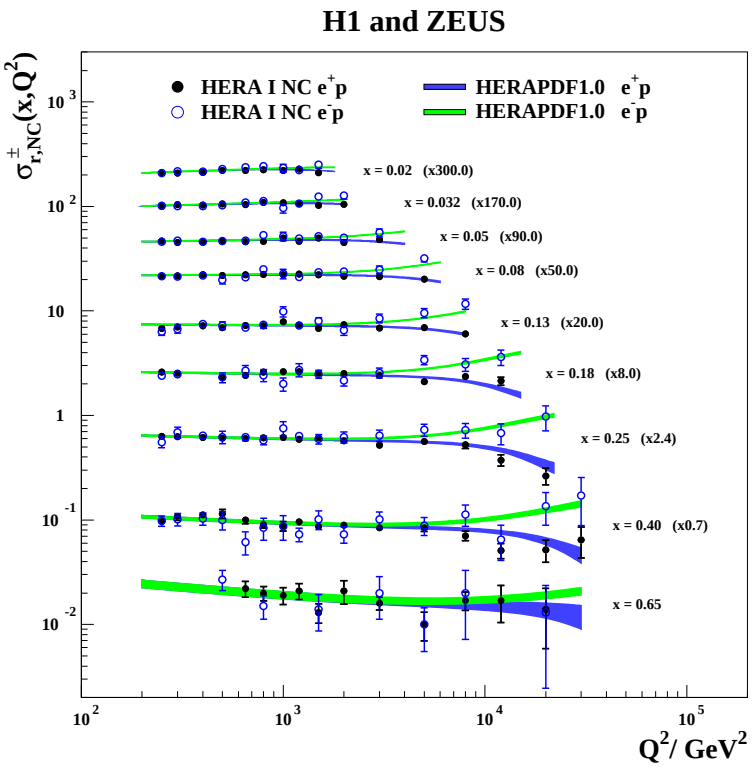
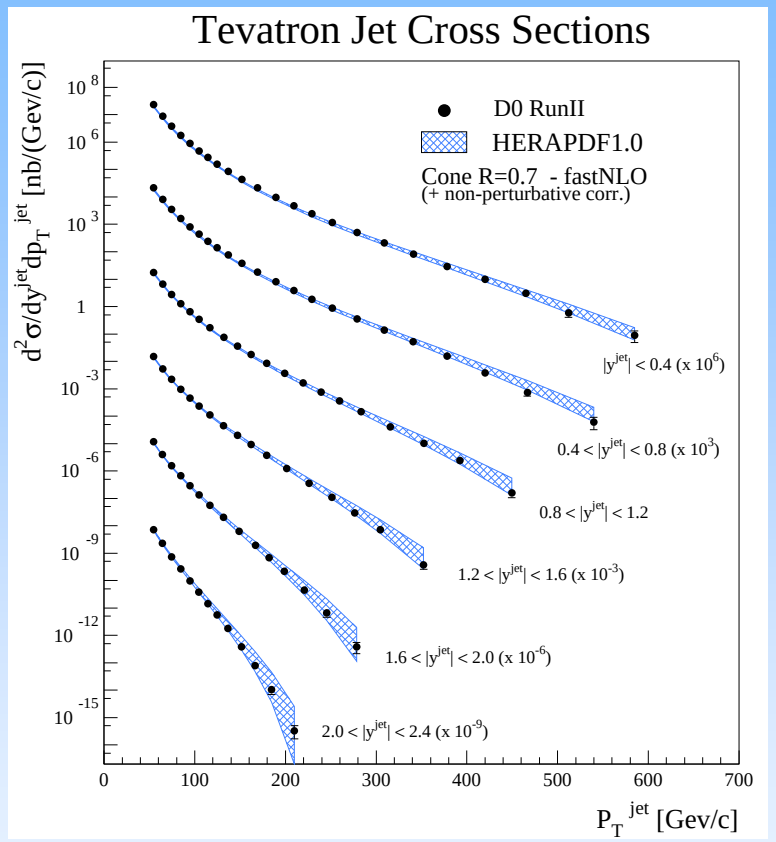
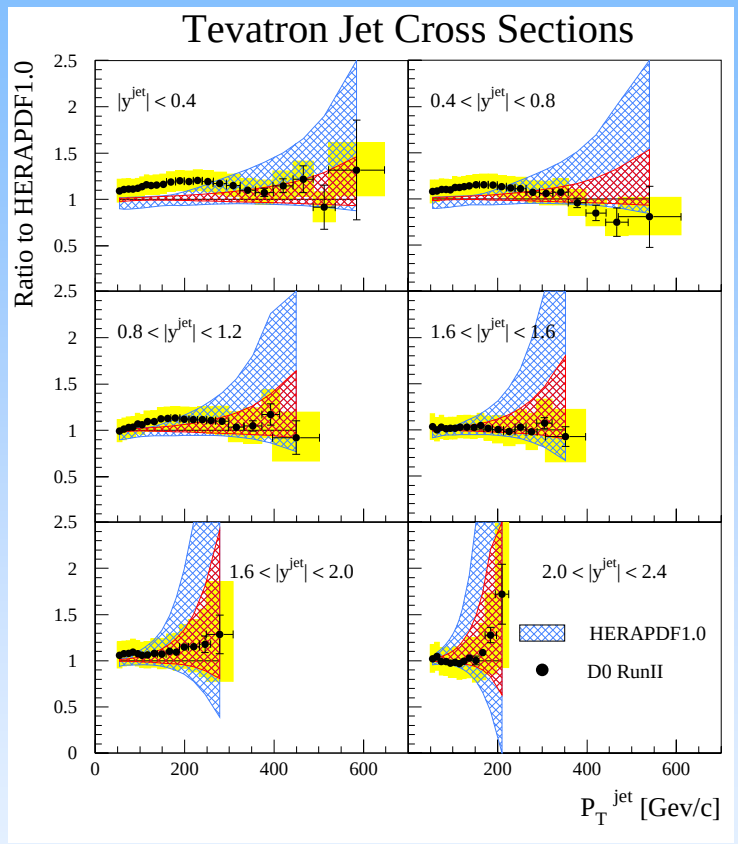




Good description of HERA I data χ^2/NDF=637/656

HERAPDF1.0 and Tevatron



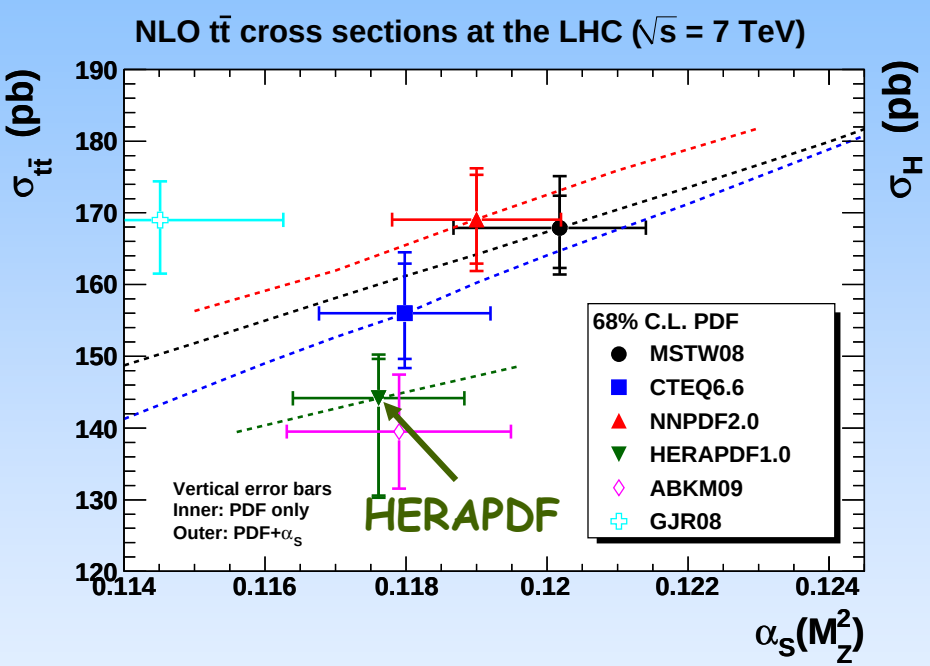


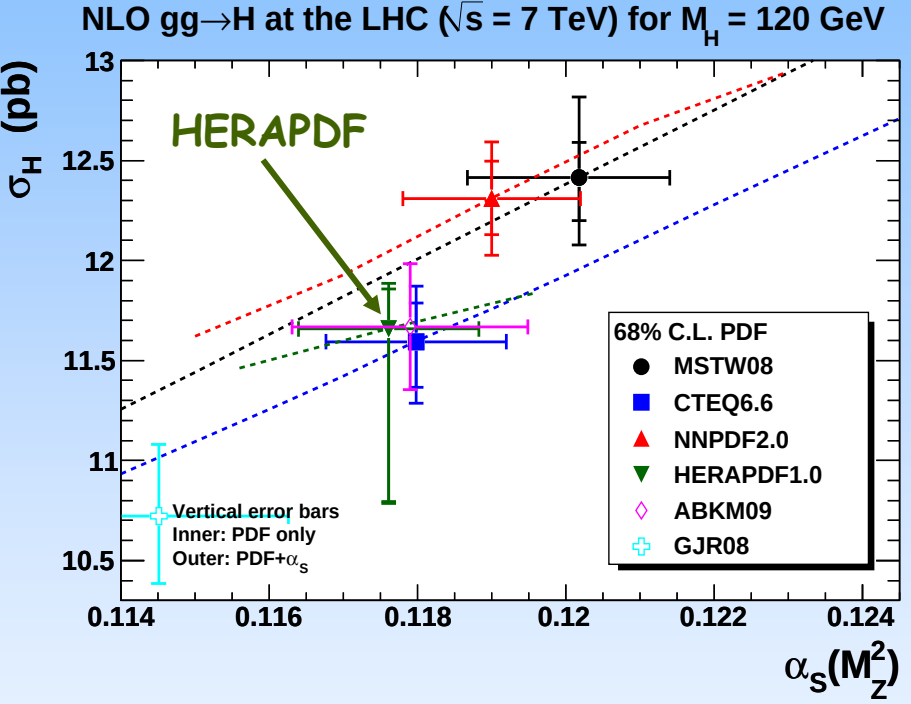
(only PDF uncertainties shown)

HERAPDF1.0 based on HERA I data provides a good description of Tevatron high E_T jet cross sections

HERAPDF1.0 for the LHC

Cross section predictions





HERAPDF prediction of comparable precision

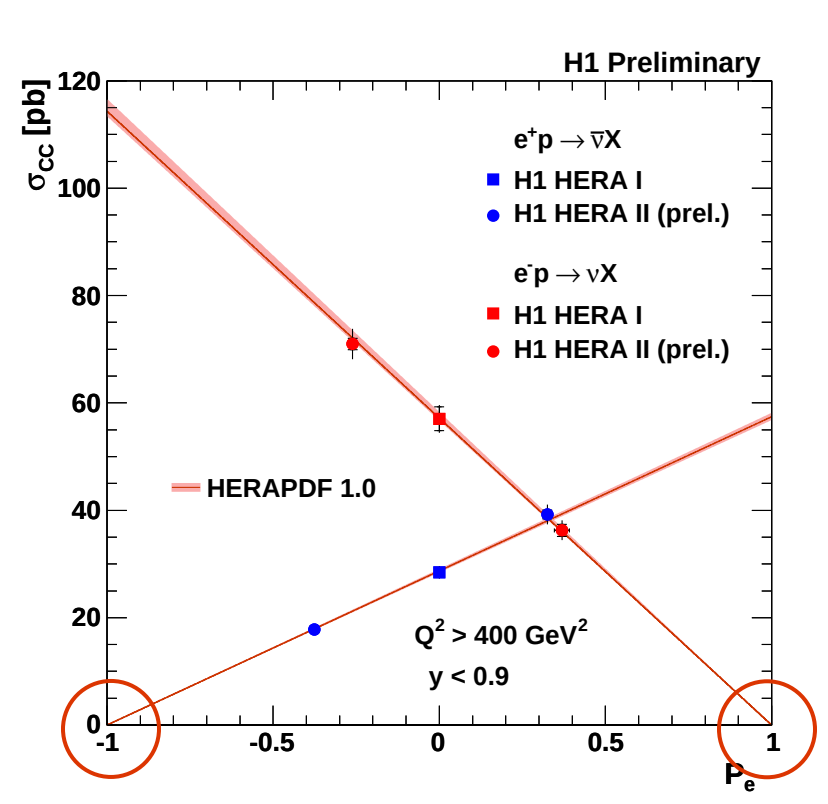
(HERAPDF includes more complete treatment of uncertainties)

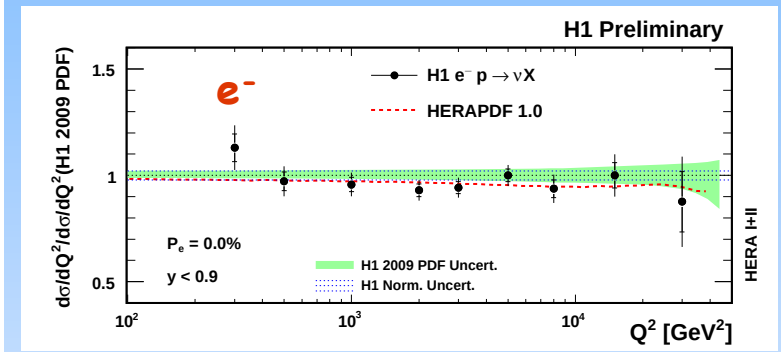
Significant spread in cross section predictions

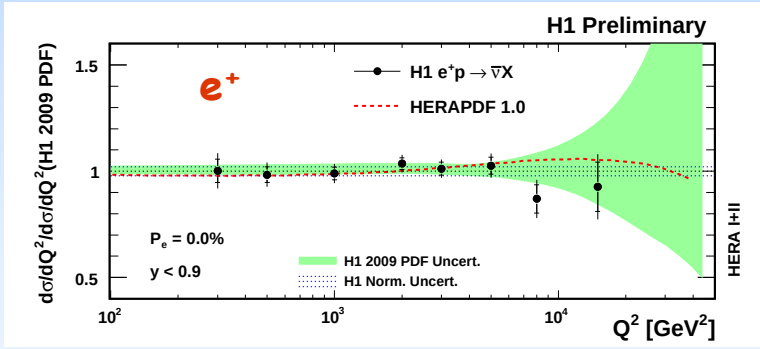
CC at high Q^2 (HERA II)

H1prelim-09-043

Cross section: $\sigma_r^{\pm} \propto (1 \pm P_e) W_2^{\pm}$



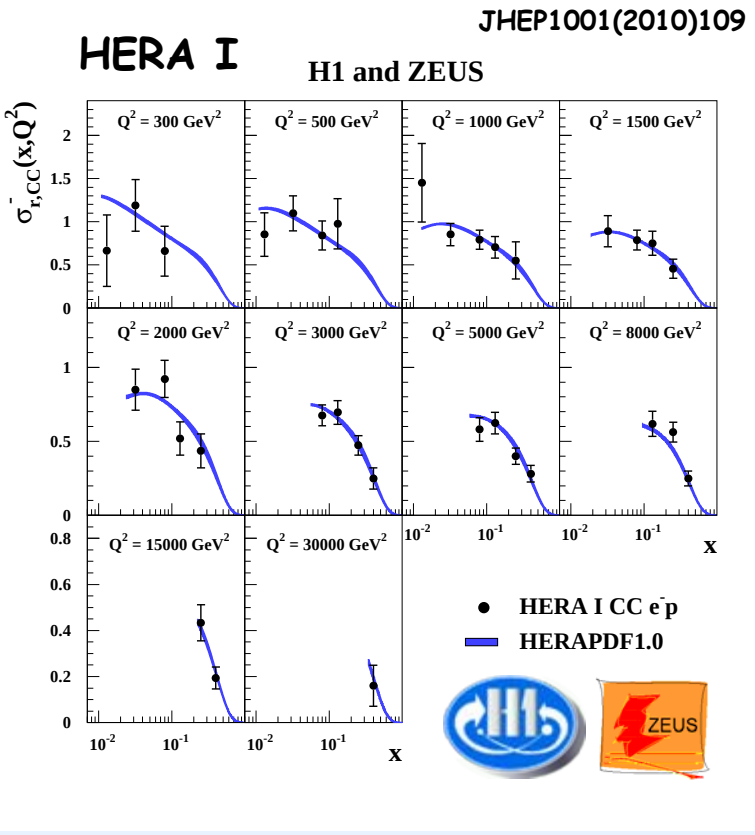


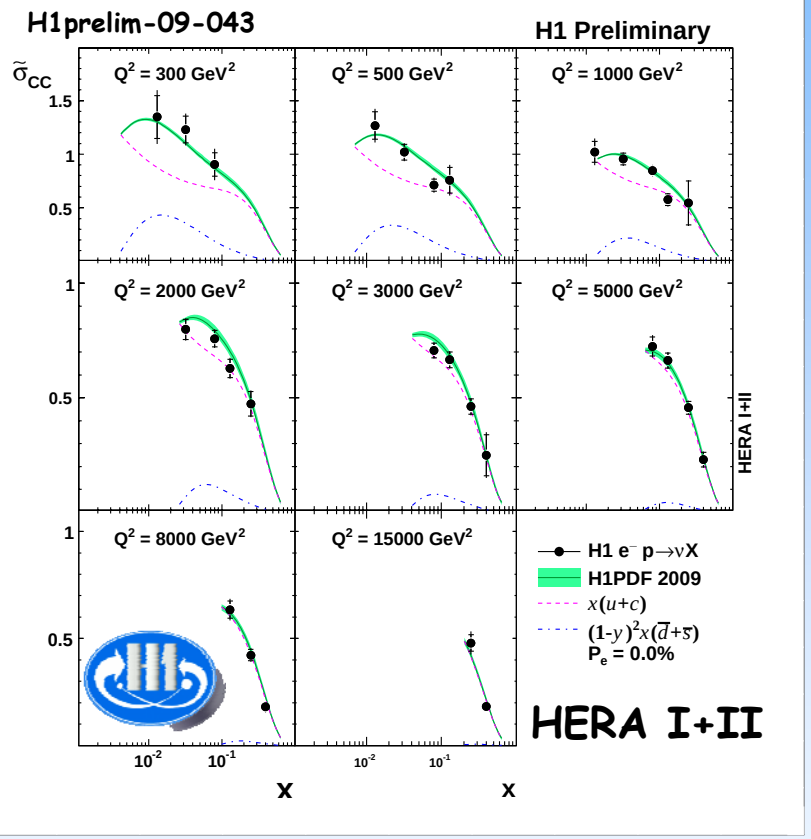


Agrees with SM expectation ⇒ No sign of right-handed CC

HERAPDF1.0 (HERA I) describes CC data (HERA I+II) well

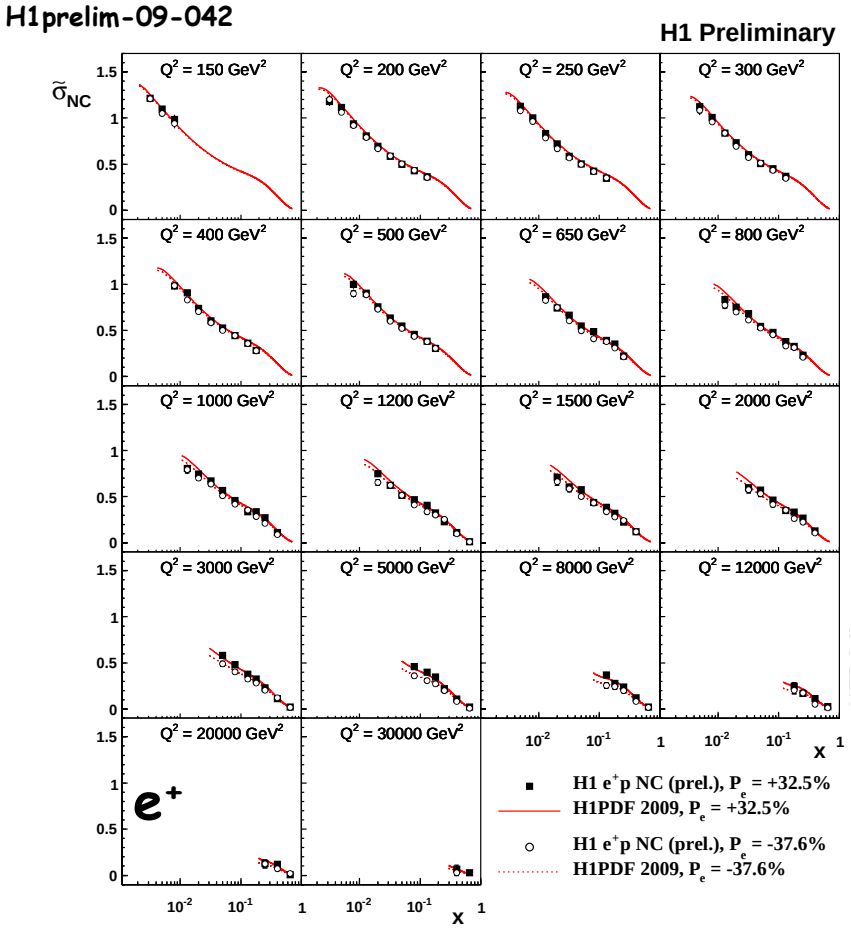
CC at high Q^2 (HERA II)





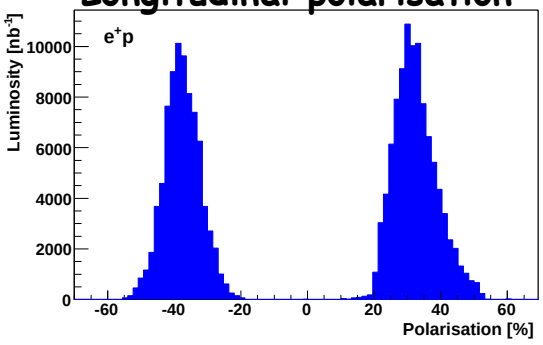
CC data (HERA I+II) will improve precision especially of u_v

NC at high Q^2 (HERA II)



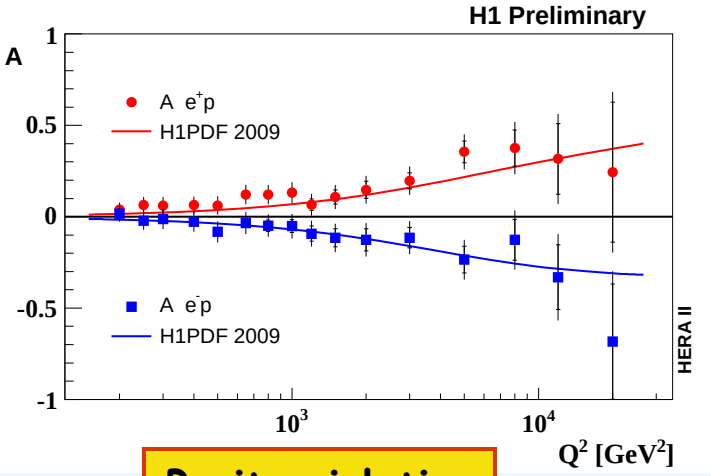
NC data (HERA I+II) well described by H1PDF2009 (HERA I)

Longitudinal polarisation



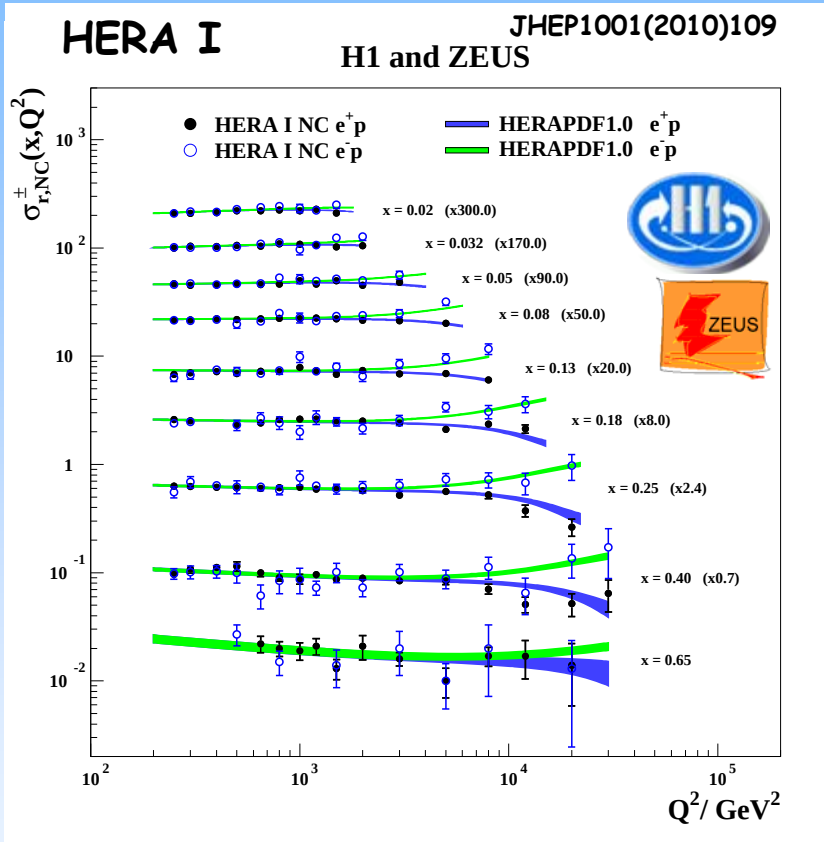
Asymmetry:

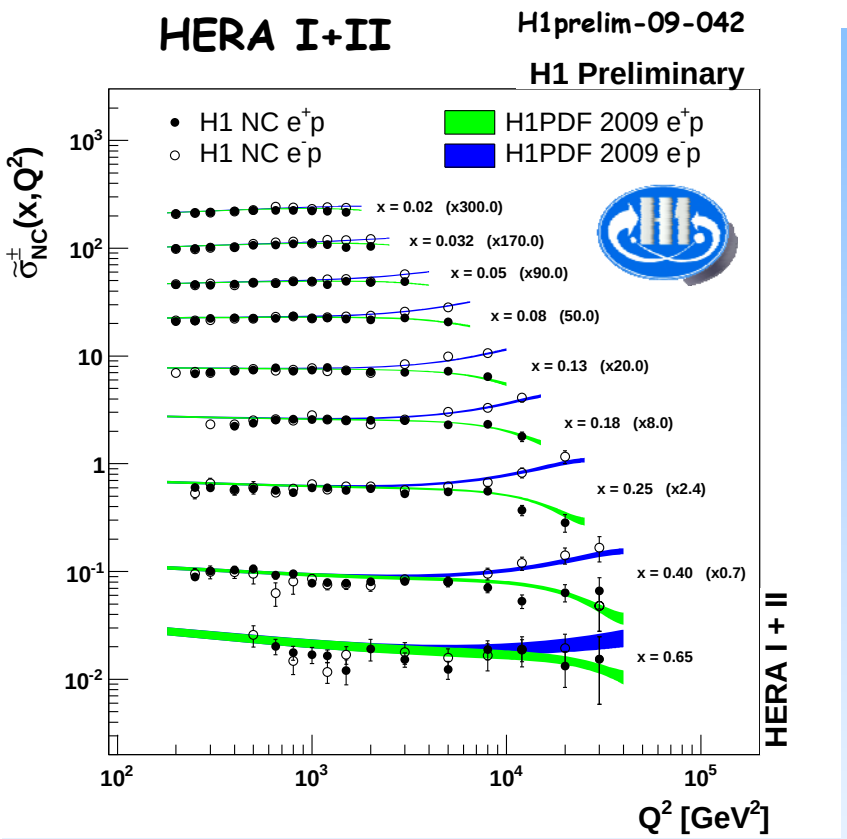
$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$



Parity violation

NC at high Q^2 (HERA II)





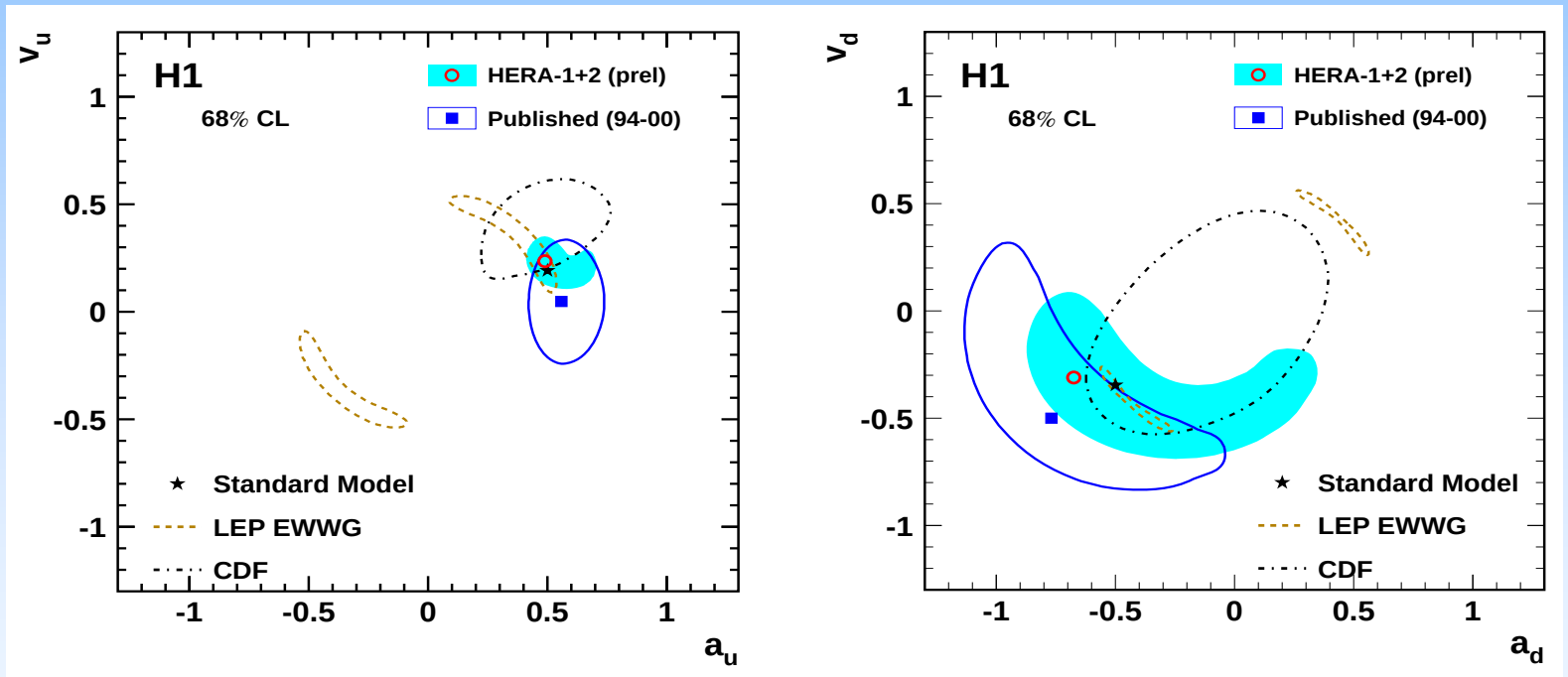
NC data (HERA I+II): improvements for d_v/u_v @ large x in HERAPDF expected

EW+QCD Fit to NC+CC Data

Simultaneous EW+QCD fit to HERA I+II data including data with polarised electron beams ⇒ u and d quarks couplings to Z^0

$$v_q = I_3 - 2e_q \sin^2\theta_w \qquad a_q = I_3$$

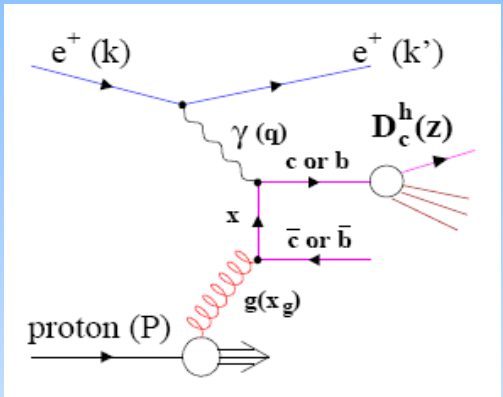
H1prelim-10-042



- Improved results on v_u due to polarisation of HERA II data
- Resolve ambiguity on LEP solutions for down quark coupling

Charm Contribution F_2^c to the Proton

Dominant production mechanism:
Boson-gluon-fusion



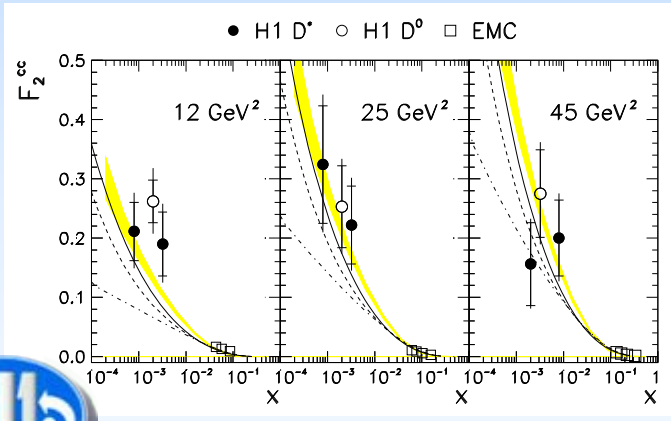
- Large contribution to F_2
  naïve limit: $e_c^2/\Sigma e_q^2 = 4/11$
- Sensitive to gluon density
- Multiple scale problem (m_Q, p_T, Q^2)
- Different NLO schemes:
  - FFNS: charm massive, 3 active flavours
  - ZMVFNS: $m_c = 0$
  - GMVFNS: $m_c \neq 0$ @ $\mu \approx 0$, $m_c = 0$ @ $\mu >> 0$
    (RT, ACOT)

Charm structure function:

$$\frac{d^2\sigma_{c\bar{c}}}{dQ^2 dx} = \frac{2\pi\alpha}{xQ^4}\left[\left(1+(1-y)^2\right)F_2^{c\bar{c}} - y^2 F_L^{c\bar{c}}\right]$$

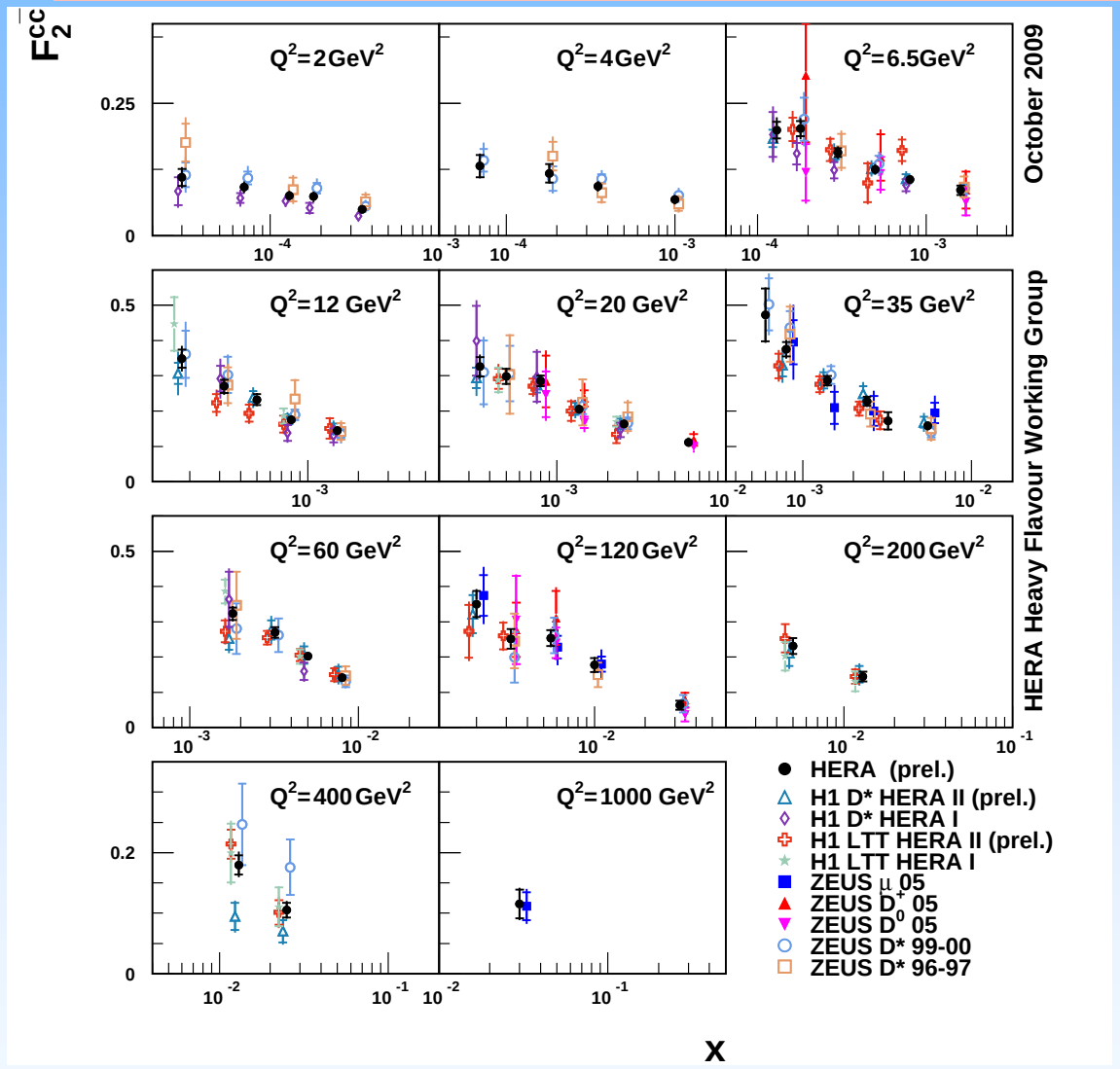
tagging via
-D mesons,
-semileponic decays
-displaced tracks

1st measurement of F_2^c @ HERA (96)



1994 data 3pb^{-1}

HERA combined F_2^c



H1prelim-09-171
ZEUS-prel-09-015

Input:
9 different data sets

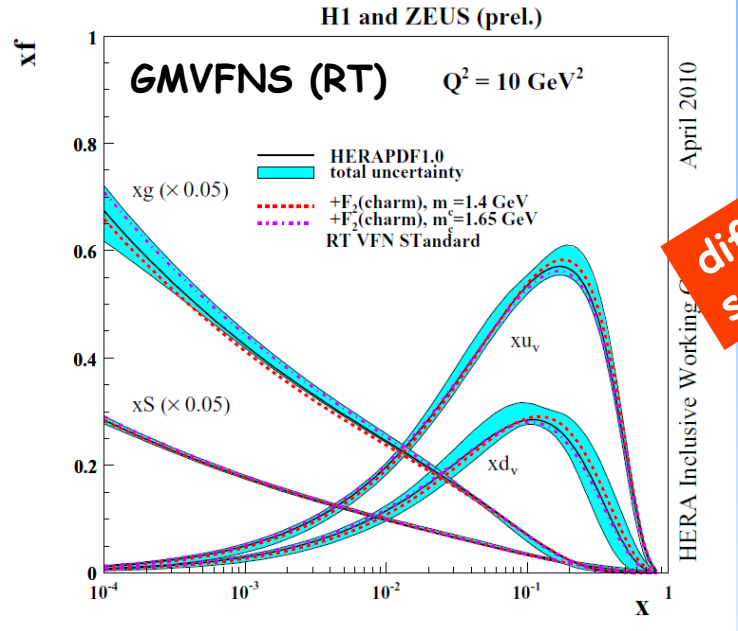
54 sources of systematic uncertainties considered

Precision of combined result:

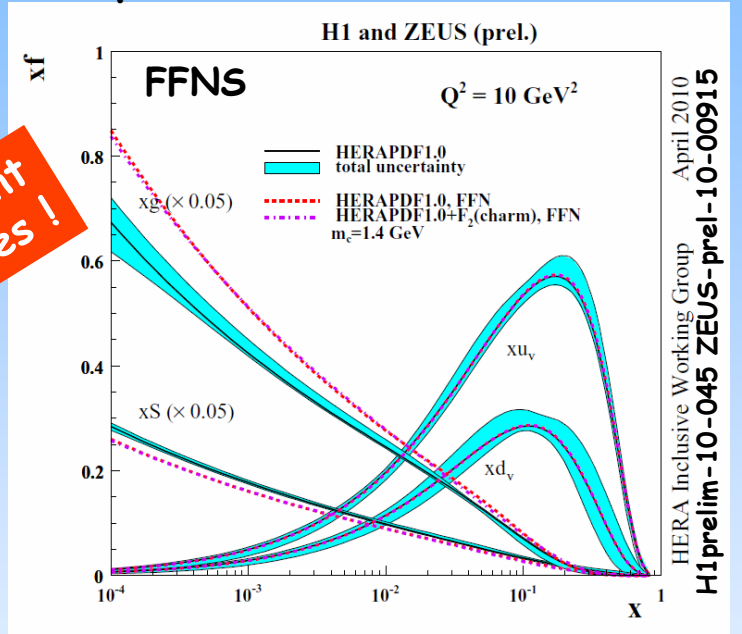
5-10%

HERAPDF1.0 with F_2^c

Problems of including F_2^c: different schemes of heavy quark treatment
choice of charm quark mass



different schemes !

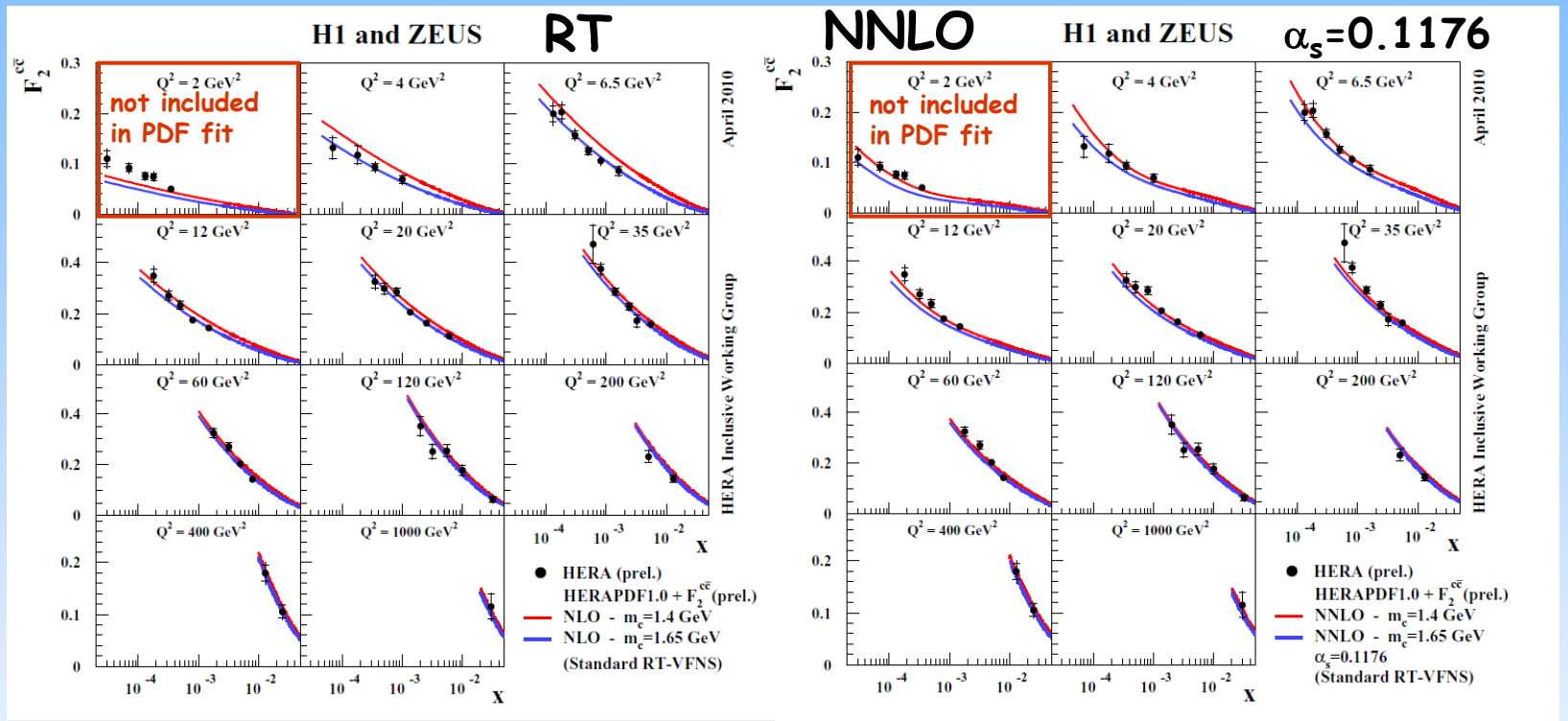


scheme m_c	RT Std 1.4	RT Std 1.65	ACOT 1.4	ACOT 1.65	points	FFNS 1.4	FFNS 1.65	points
χ^2	730.7	627.5	653.9	605.7	633	567.0	852.0	565
F_2^c χ^2	134.5	43.5	89.5	41.4	41	51.7	248.9	41

GMVFNS favours m_c=1.65 GeV – FFNS favours m_c=1.4 GeV

HERAPDF1.0 with F_2^c

H1prelim-10-045 ZEUS-prel-10-00915

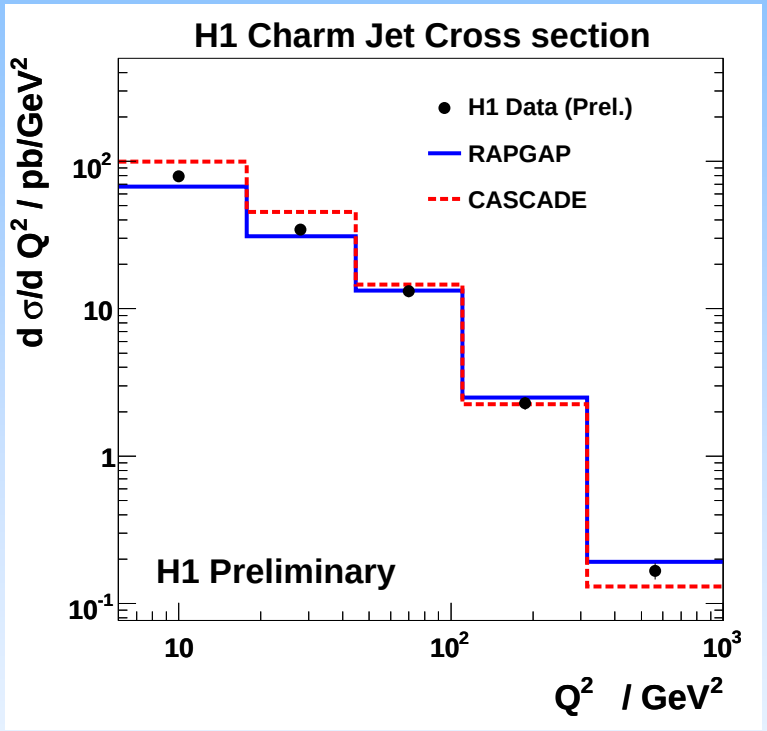


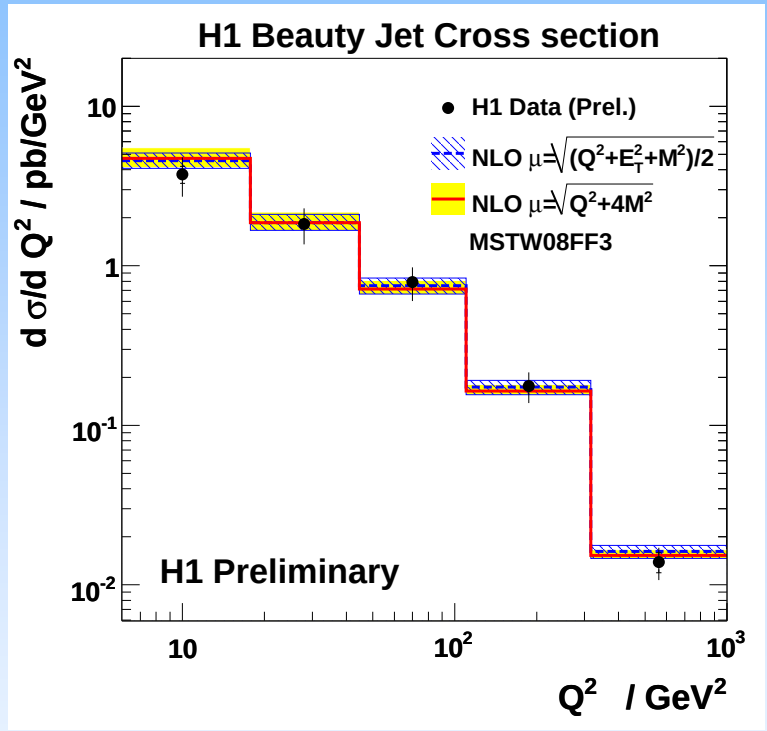
NNLO gives best description of data also in the region excluded from fit

Charm and Beauty Jets

H1prelim-10-073

Tagging of charm/beauty via lifetime - Inclusive k_t-jets E_T^{jet}>6 GeV





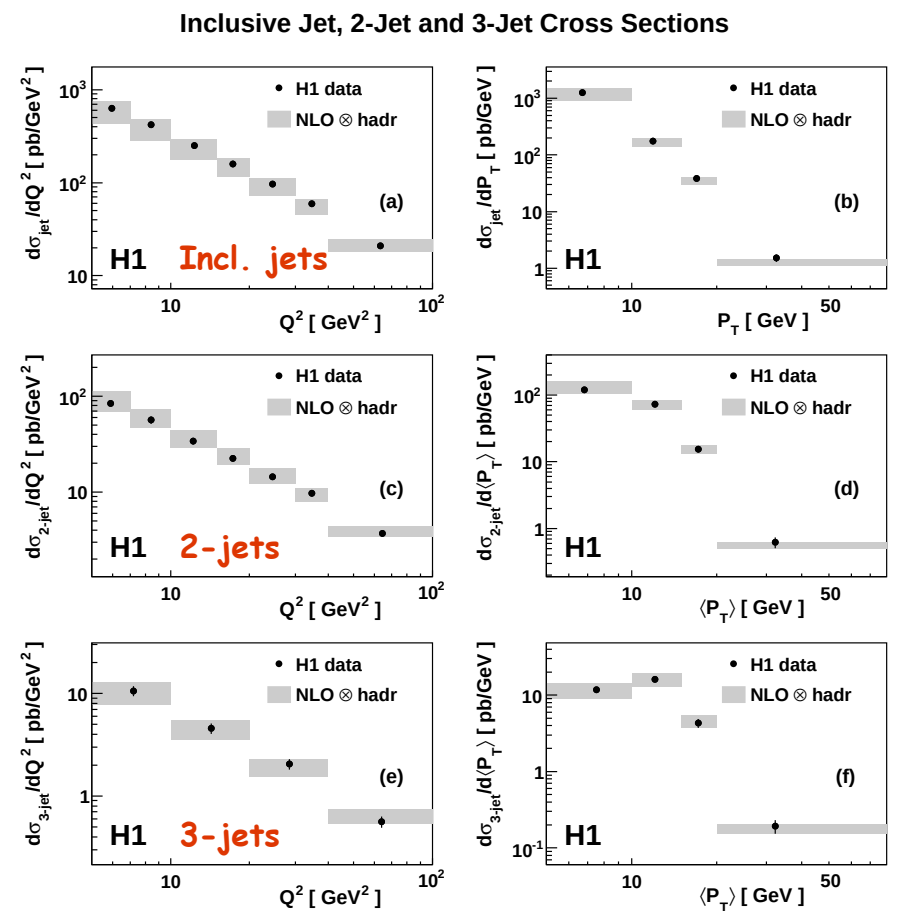
Charm jet cross section well described by RAPGAP
CASCADE too large @ low Q^2

Beauty jet cross section well described by NLO QCD
only little scale dependence

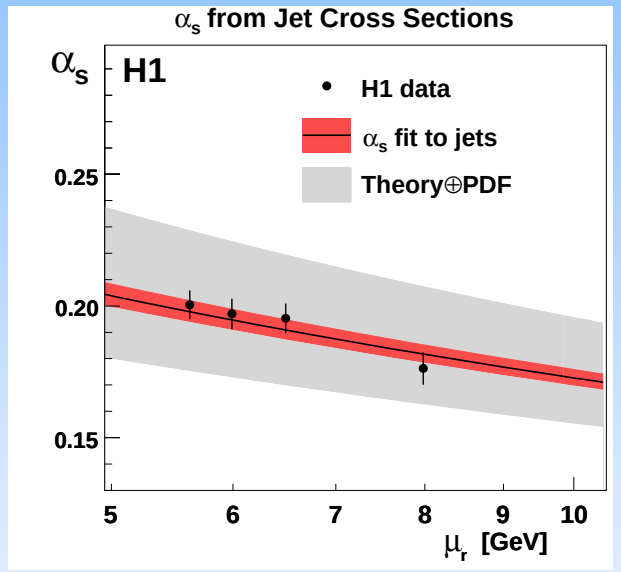
Jet Production at low Q^2

Inclusive k_t-jets in Breit frame $E^*_T > 5$ GeV

EPJ C67(2010)1



α_s from fit with NLOJET++

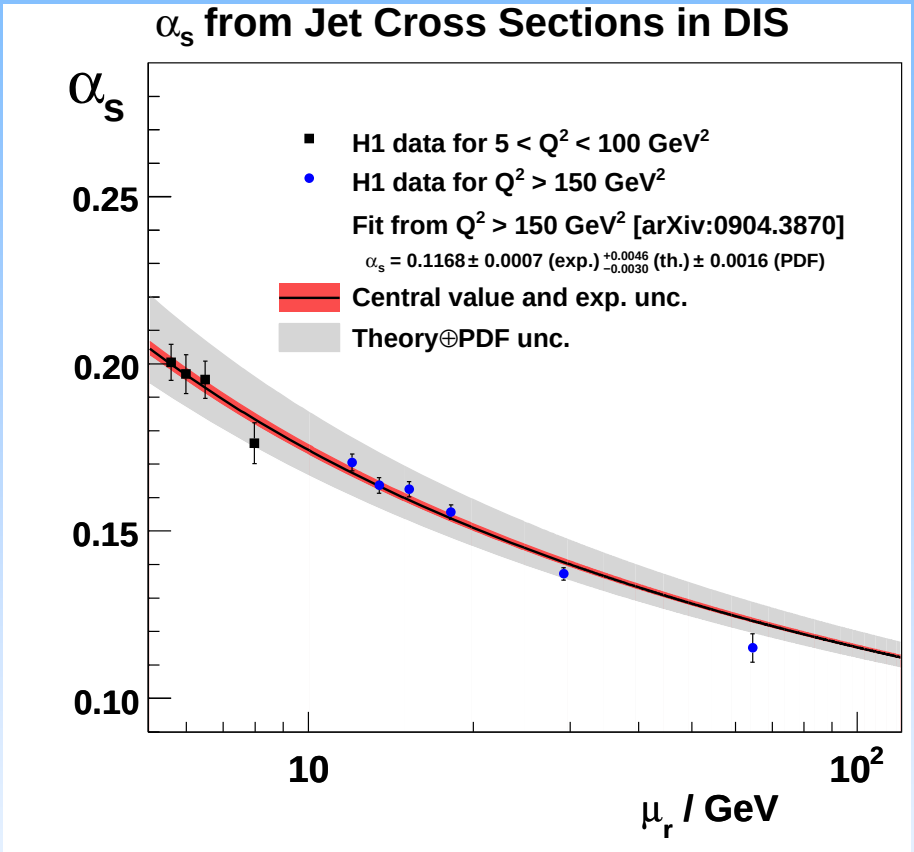


Dominant uncertainty from renormalisation scale uncertainty

$$\alpha_s(M_Z) = 0.1160 \pm 0.0014(\text{exp.}) \; {}^{+0.0093}_{-0.0077} \; (\text{th.}) \pm 0.0016(\text{PDF})$$

α_s from Jets in DIS

EPJ C67(2010)1



remarkable agreement

despite scale uncertainties

Low Q^2: $\alpha_s(M_Z)=0.1160 \pm 0.0014(\text{exp.}) \; ^{+0.0093}_{-0.0077} \; (\text{th.}) \pm 0.0016(\text{PDF})$

High Q^2: $\alpha_s(M_Z)=0.1168 \pm 0.0007(\text{exp.}) \; ^{+0.0046}_{-0.0030} \; (\text{th.}) \pm 0.0016(\text{PDF})$

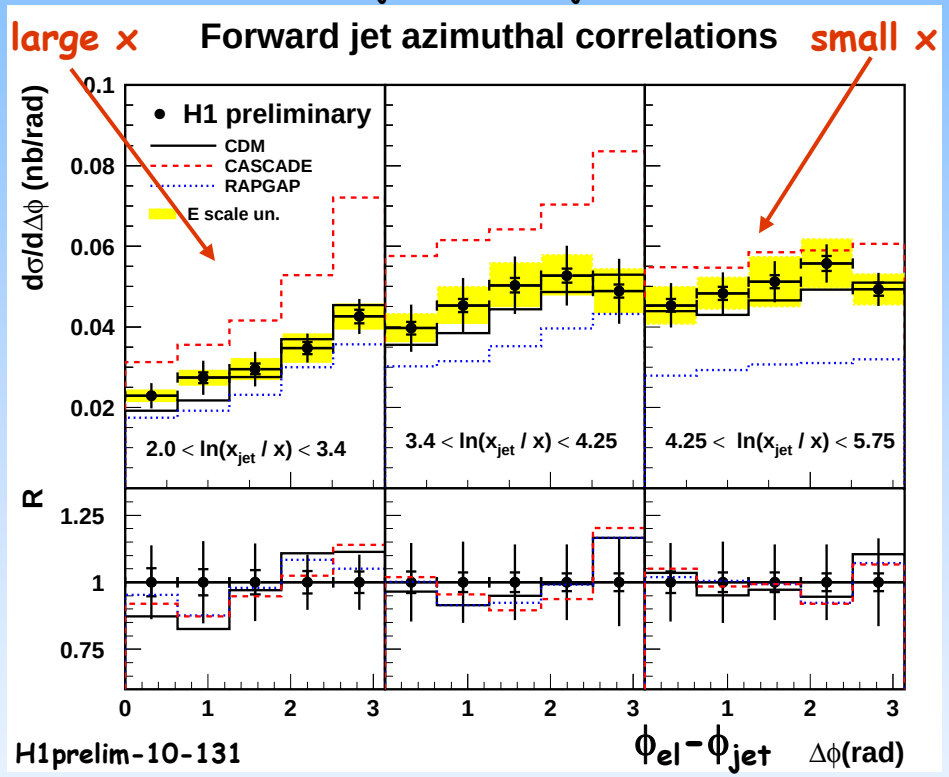
Forward Jet Correlations

k_t-jets in Breit frame - analysis in lab frame
$E_T > 6$ GeV, $7° < \Theta_{jet} < 20°$, $x_{jet} > 0.035$

Test of QCD dynamics @ low x:

- DGLAP: strong k_T ordering
- BFKL: only weakly ordered in k_T
  $\Rightarrow$ more high p_T fwd jets
- CCFM: random walk in k_T
  $\Rightarrow$even more high p_T fwd jets

Expected de-correlation effects from $O(\alpha_s^n)$



- Cross section described best by BFKL-type model (CDM)
- $\Delta\varphi$ shape: initial differences washed out by parton showers

Diffraction

At HERA: 10% diffraction @ low x in DIS

Additional kinematic variables:

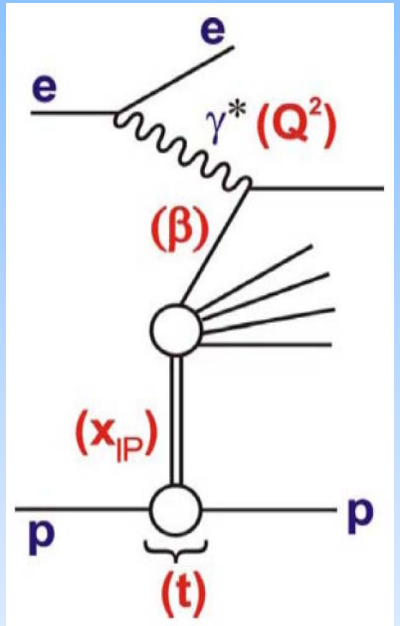
- x_{IP} momentum fraction of the proton carried by the colourless exchange
- β momentum fraction of the colourless exchange carried by the struck quark
- t momentum transfer at the proton vertex

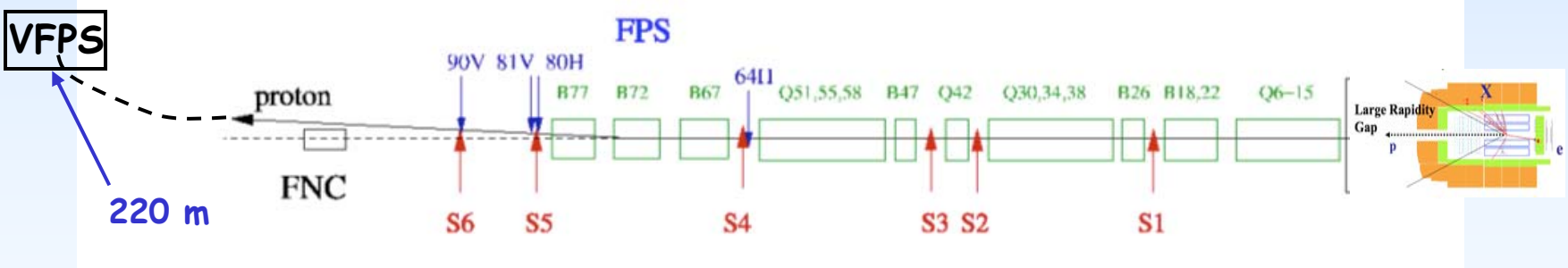
Experimental methods:

- Large rapidity gap selection (LRG)
- Leading proton (neutron) measurement

Structure of colourless exchange?

Validity of factorisation ansatz?





$F_2^{D(3)}$ with LRG

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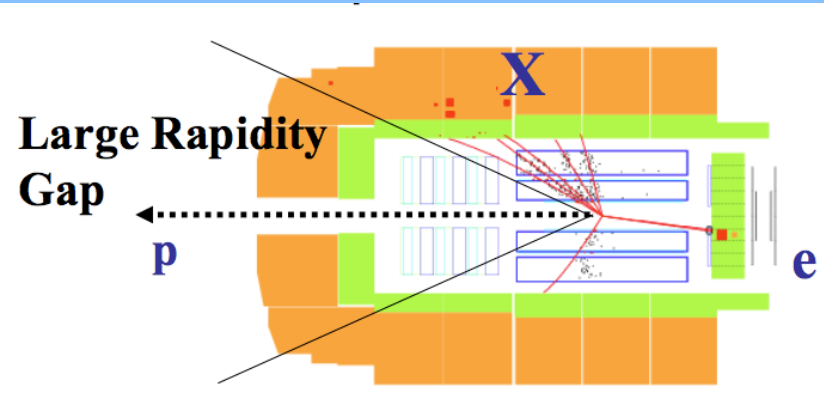
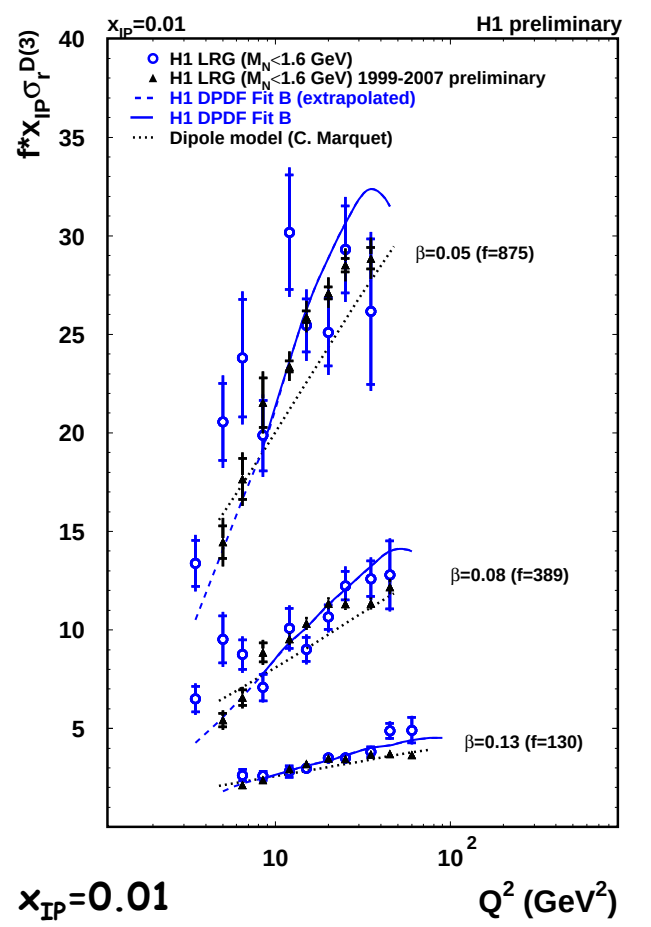


Full HERA statistics

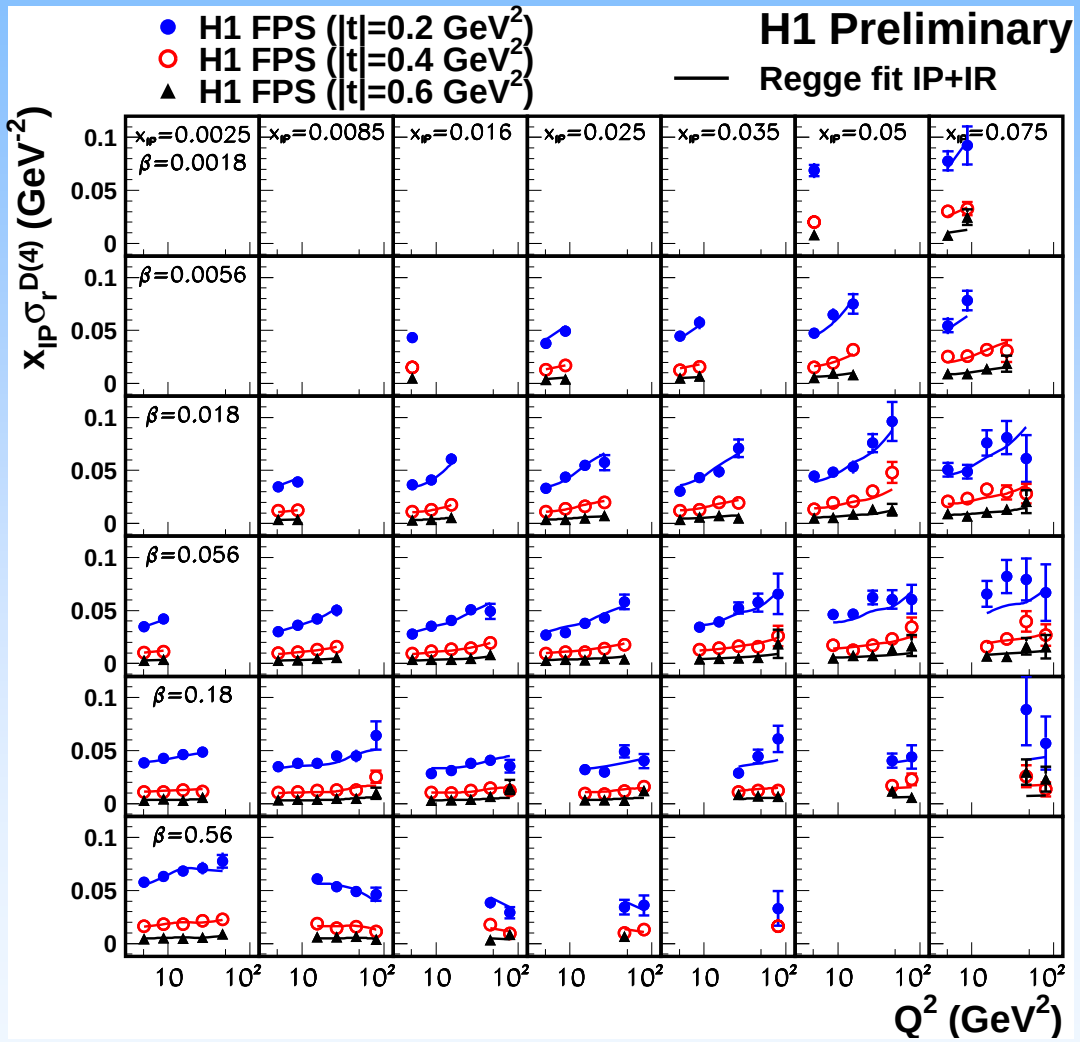
Reduced cross sections as a function of Q^2, β and x_{IP}



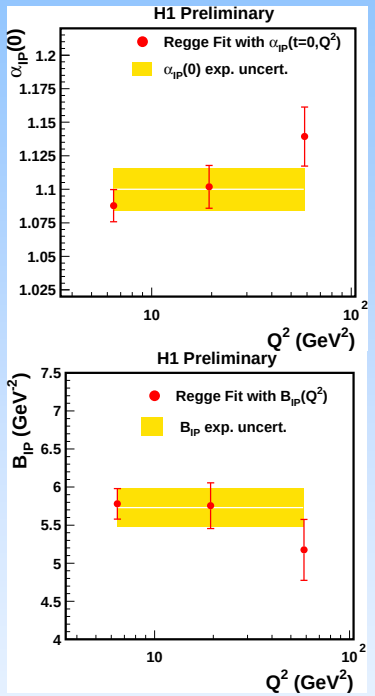
- Significantly improved statistics
- Good agreement with HERA I
- Good agreement with DPDF fit

$F_2^{D(4)}$ with protons in FPS

H1prelim-10-012



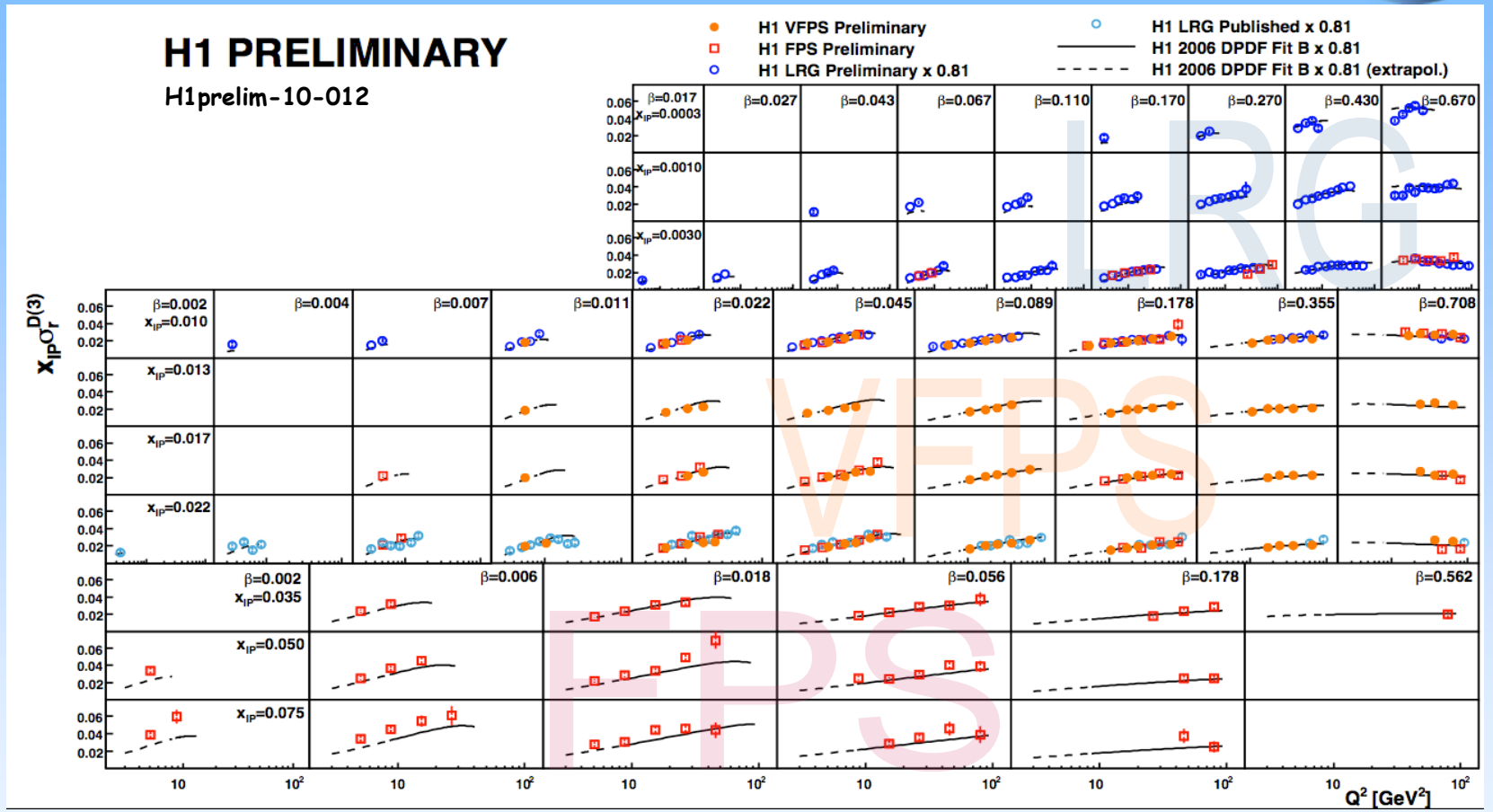
t-dependence measured
Regge fit to data:



α_{IP}, α'_{IP} and B_{IP} consistent with being independent of Q^2

⇒Supports proton vertex factorisation

$F_2^{D(3)}$ Summary

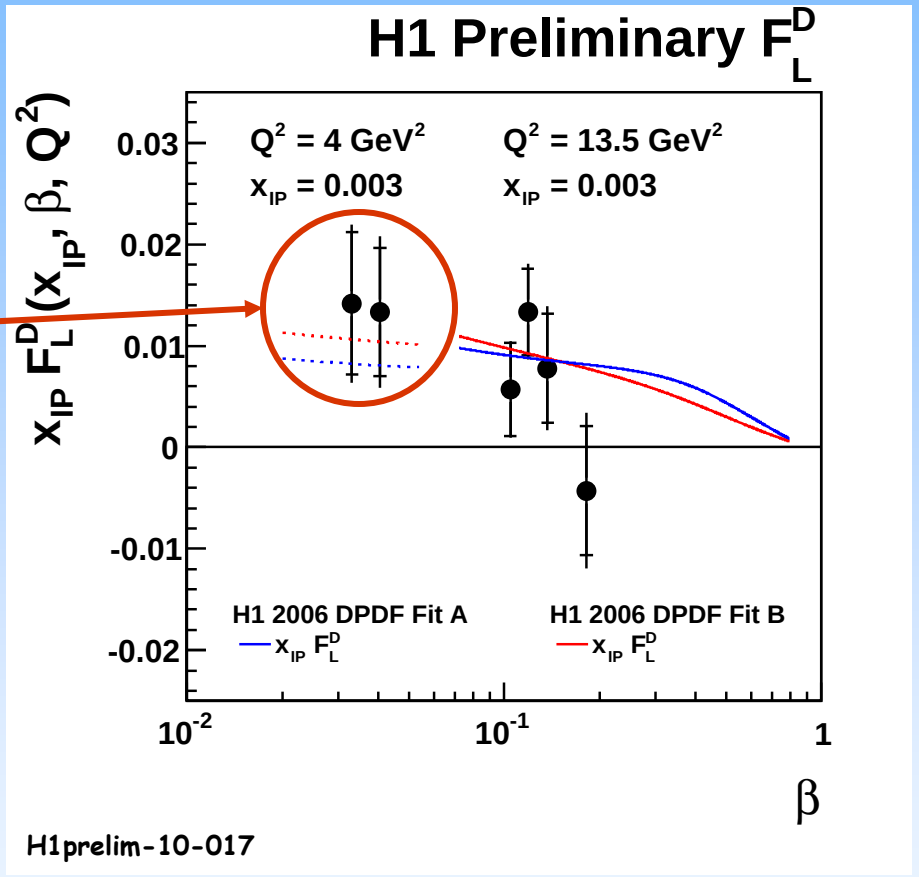


- Excellent coverage of kinematic plane
- Results agree well in regions of overlap
- DPDF Predictions from LRG agree nicely with FPS and VFPS data

F_L^D in extended Q^2 range

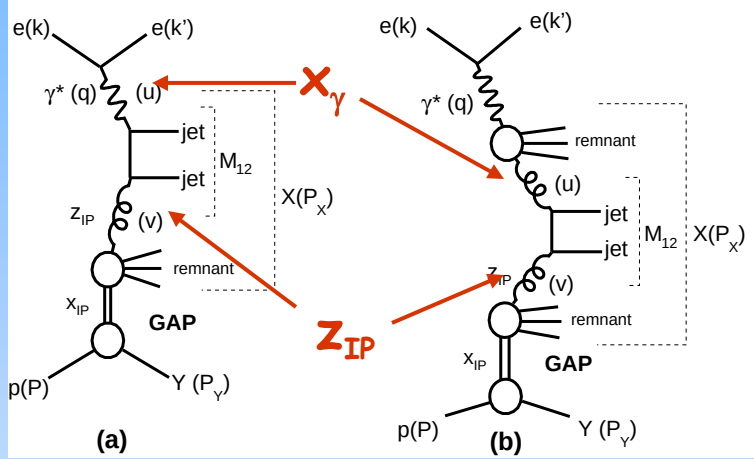
$$\sigma_r^D \propto F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$$

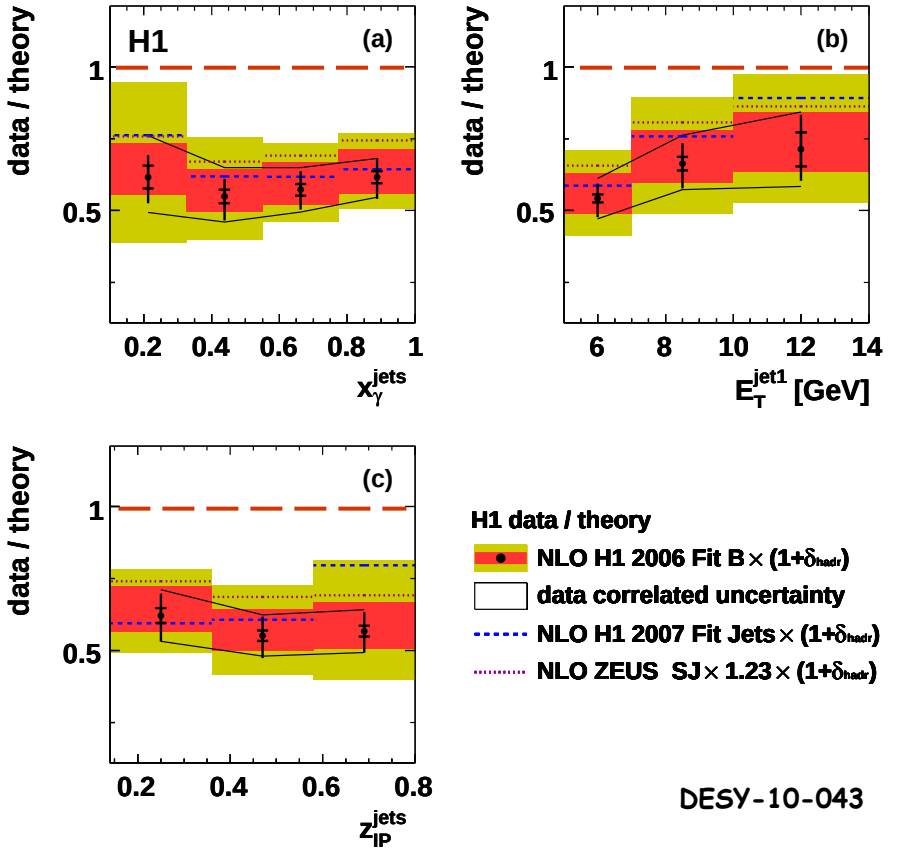
Extension to low Q^2
(based on low E_p HERA II data and published HERA I data with E_p=820 GeV)



- Clearly non-zero F_L^D
- NLO predictions based on DPDF (extrapolated) agree with data well

Di-Jets with LRG in γp



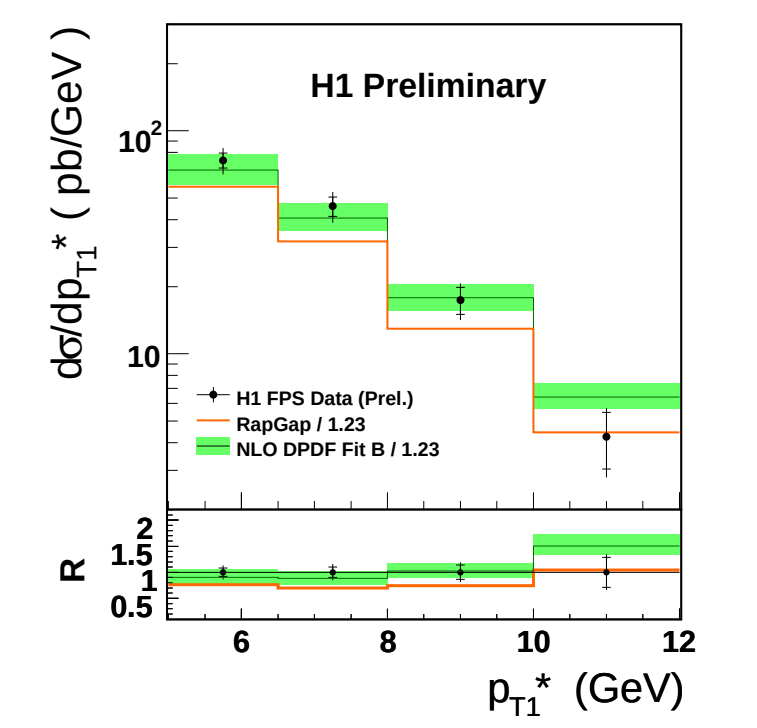


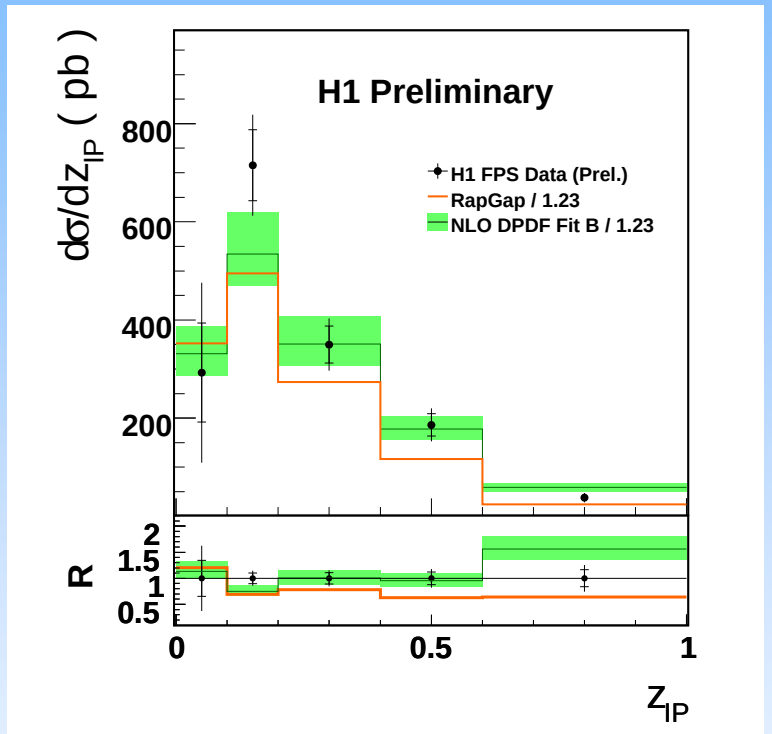
$$\frac{\sigma^{tot}_{data}}{\sigma^{tot}_{NLO}} = 0.58 \pm 0.21$$

- Diffractive Di-jet photo-production suppressed w.r.t. NLO
- Proposed modifications to NLO fails in differential cross sections
- Hint of a rise in $\sigma_{data}/\sigma_{NLO}$ with increasing E_T^{jet}

Di-Jets with FPS in DIS

H1prelim-10-013





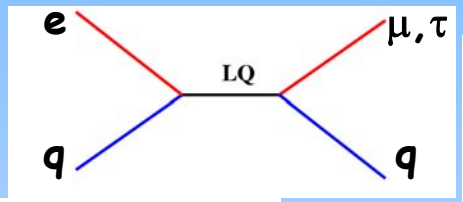
NLO reproduces diffractive di-jet data well in DIS
Vertex factorisation only in the presence of a hard scale ?

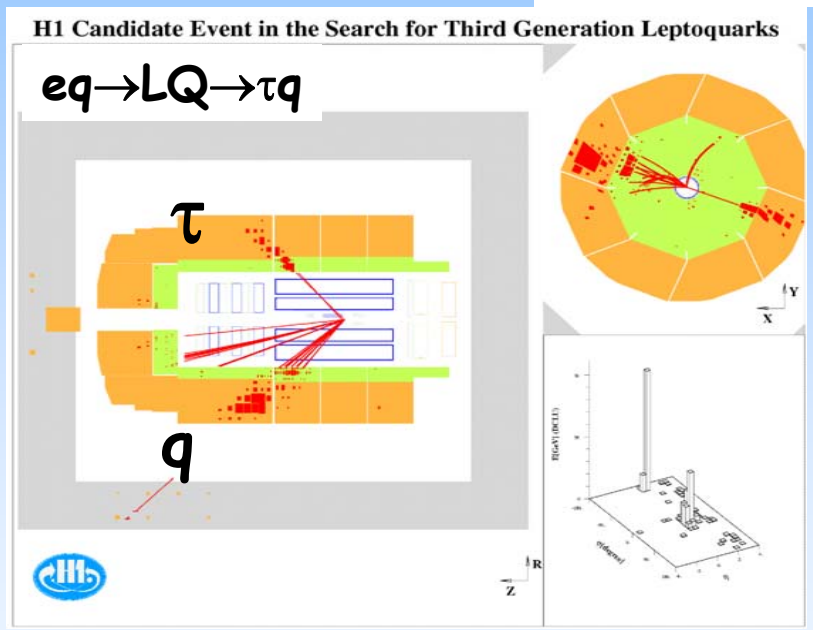
Lepton Flavour Violation

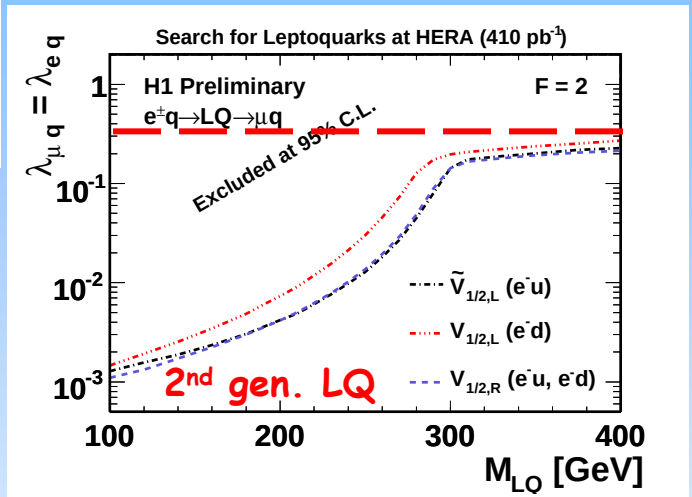
H1prelim-10-061

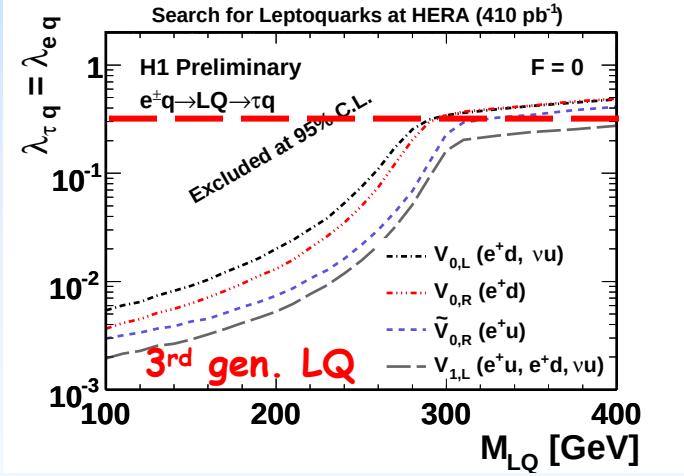
Interaction of lepton flavour violating leptoquarks:

$eq \rightarrow LQ \rightarrow \mu(\tau)q$





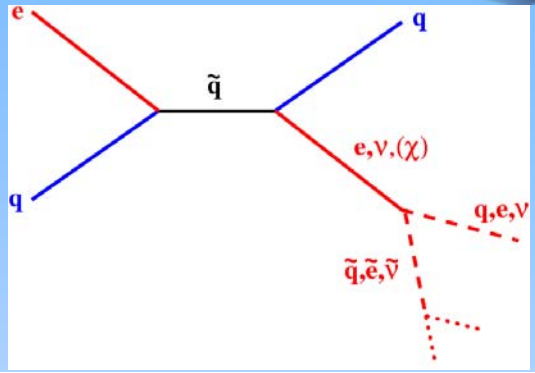


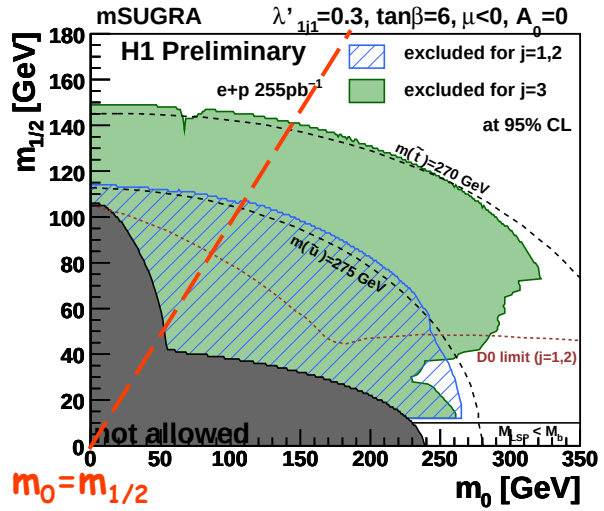


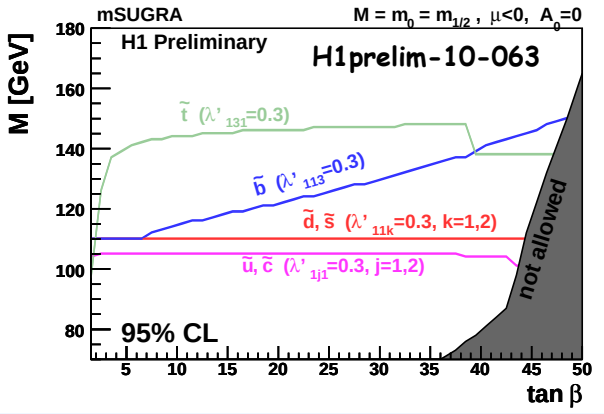
Mass limits (λ=0.3) ranges up to
>530 GeV (2nd generation LQ)
>440 GeV (3rd generation LQ)

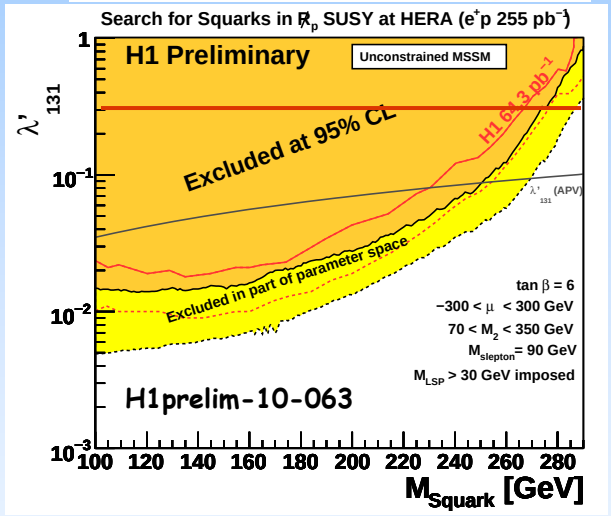
R-Parity violation SUSY

- Complete HEAR I+II data
- Limit on all 3 generations in unconstrained MSSM and mSUGRA









Squarks up to m=290 GeV excluded

Summary

- 3 years after HERA shutdown H1 analyses/publications continue at full speed

  Since last HERA symposium: 14 publications, ≥20 preliminaries

- Data and detector - understood to very high precision

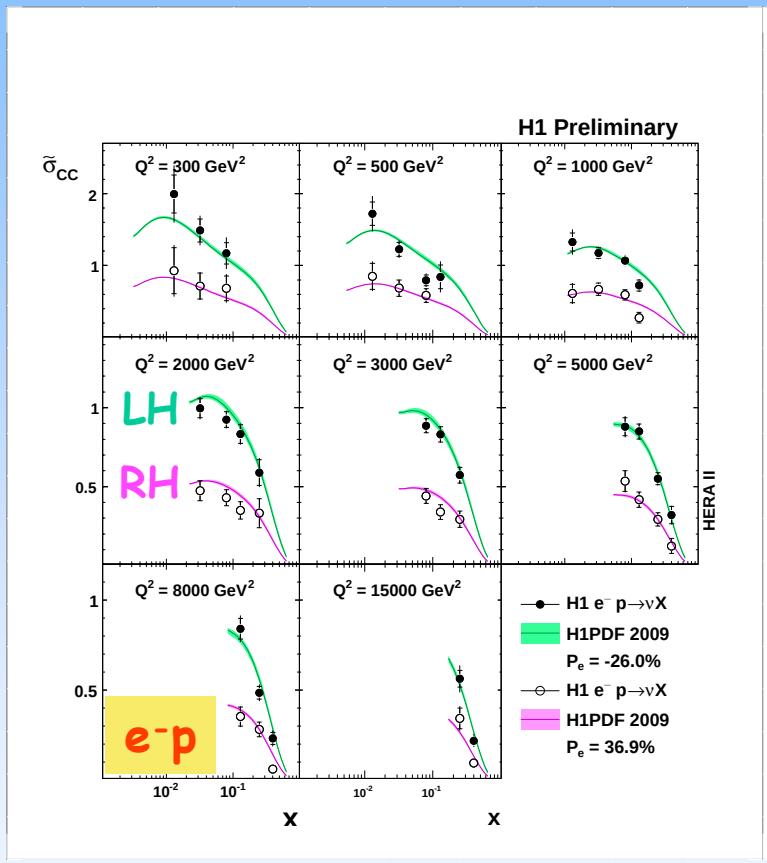
  Many uncertainties understood to the per mille level

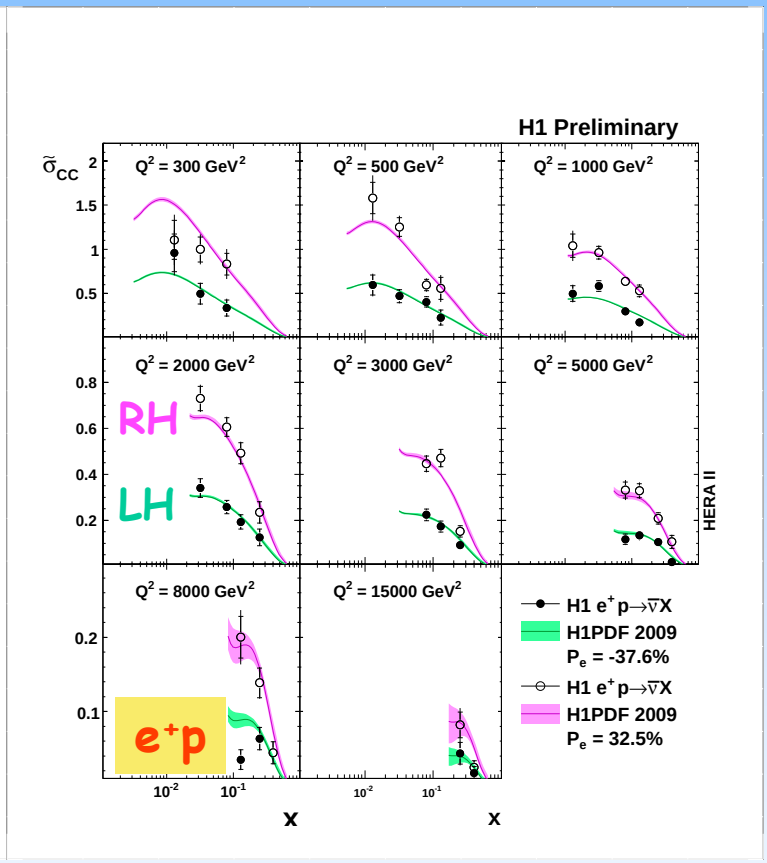
- Activities in the HERA combination working groups is of utmost importance to reach the ultimate precision

➡ HERA was a QCD precision machine - as LEP was for electroweak physics

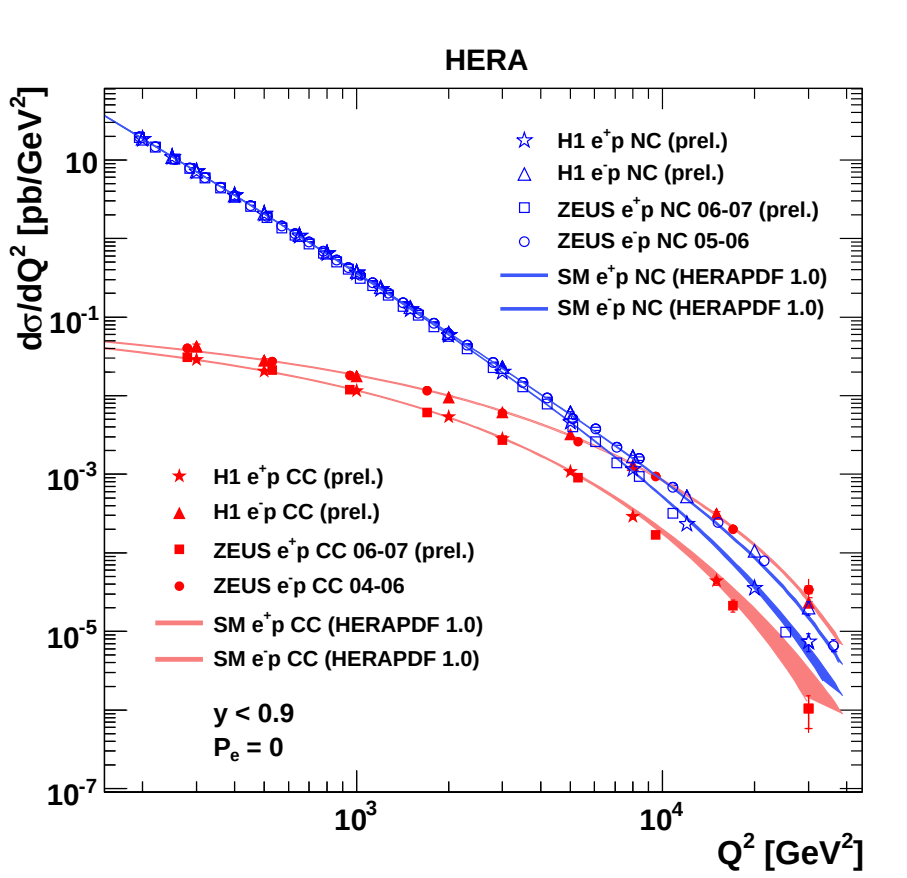
We are building the H1 and HERA legacy now and in the coming years

CC at high Q^2 (HERA II)

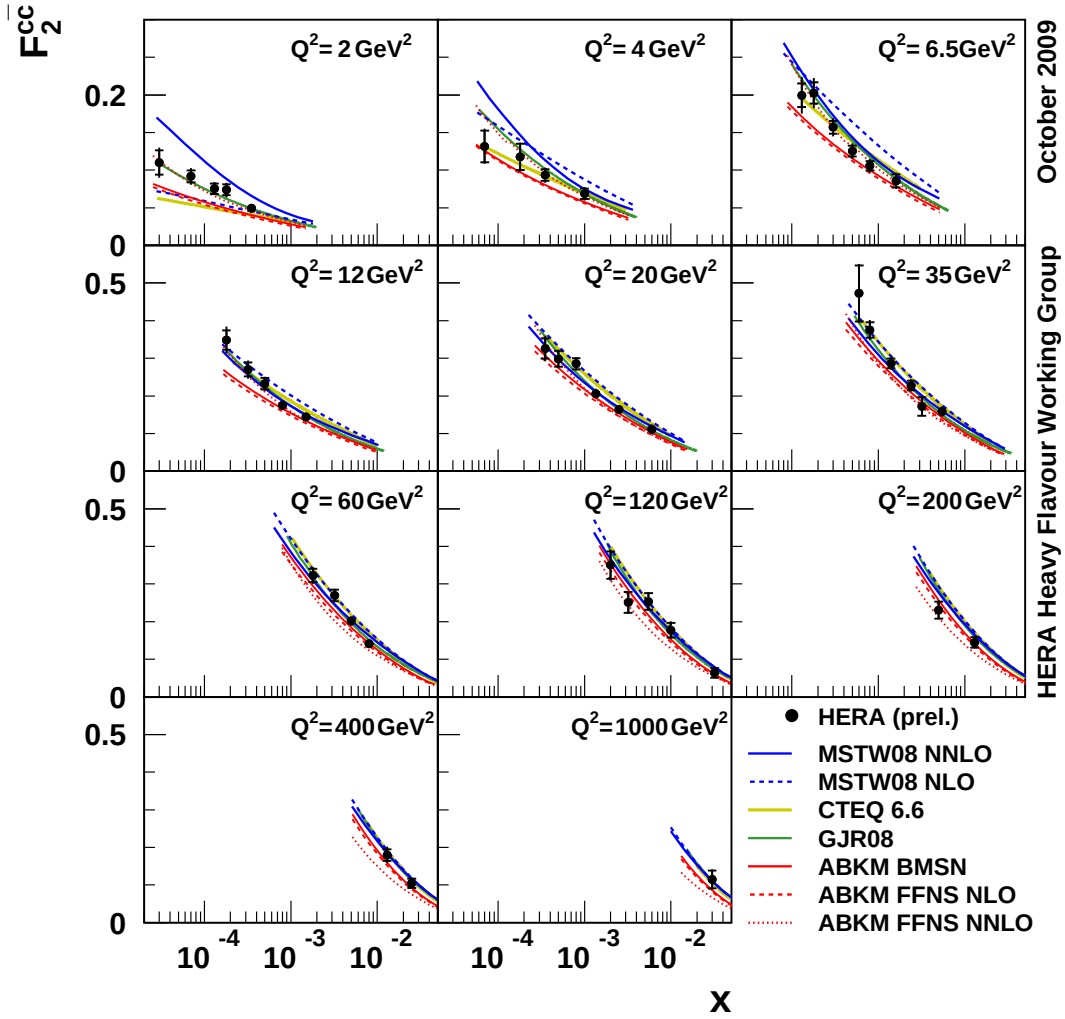




CC+NC at high Q^2 (HERA II)



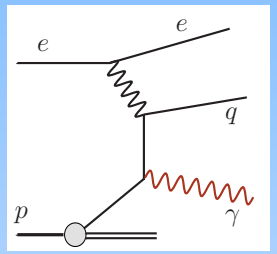
HERA combined F_2^c



Precision of HERA F_2^c similar to differences in calculations
⇒ potential to discriminate

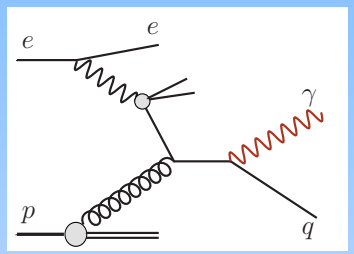
Prompt photons in γp

direct γp



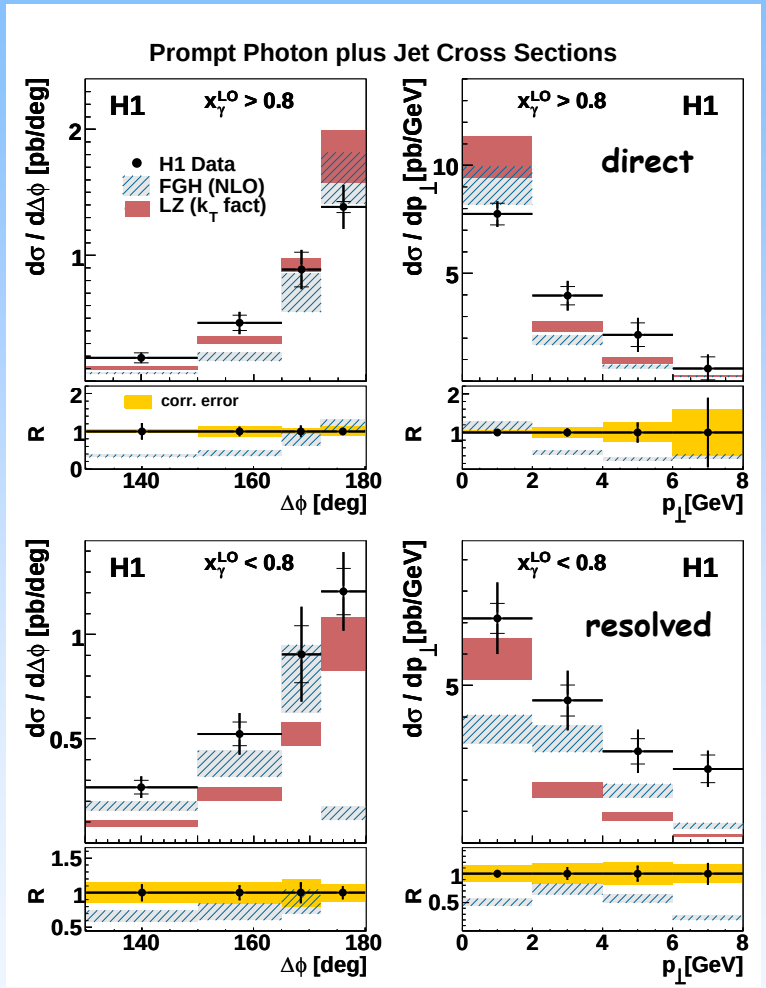
Sensitive to proton PDF (q)

resolved γp



Sensitive to proton & photon PDF

Predictions in
-colinear factorisation (FGH)
-kt factorisation approach (LZ)

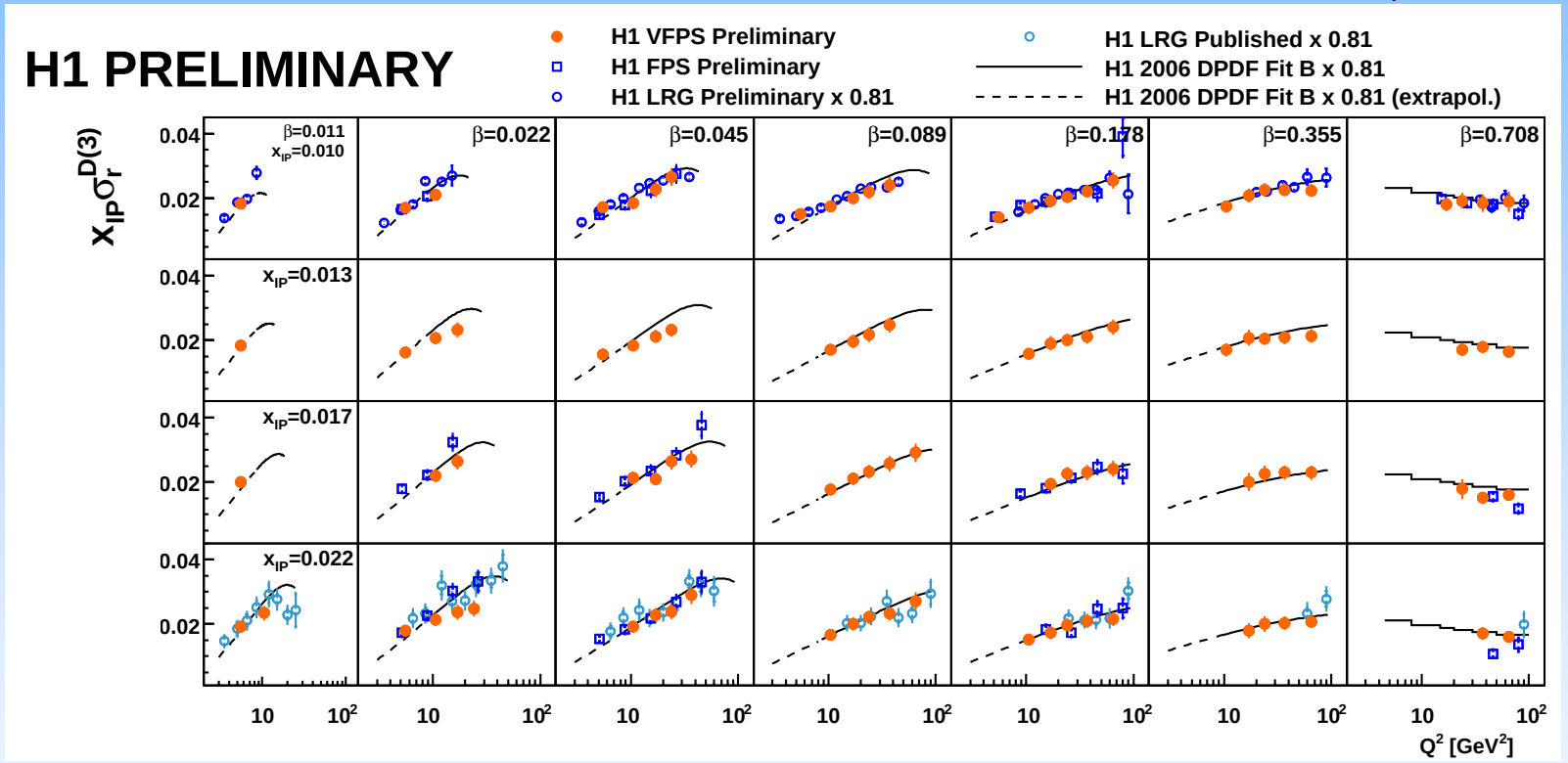


- Large deviations from 180° in γ-jet correlations observed
- Models fail to describe data

$F_2^{D(3)}$ with protons in VFPS

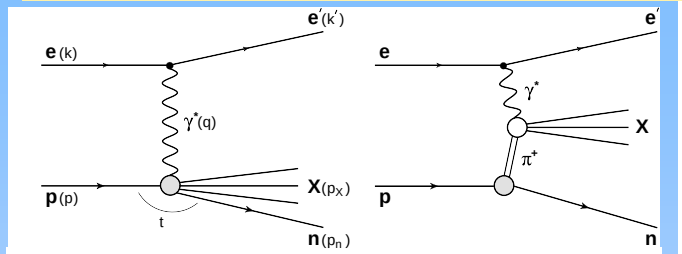
VFPS: good acceptance for $|t|<0.25$ GeV^2 and $0.009<x_{IP}<0.026$
precise reconstruction of β and x_{IP}

H1prelim-10-014

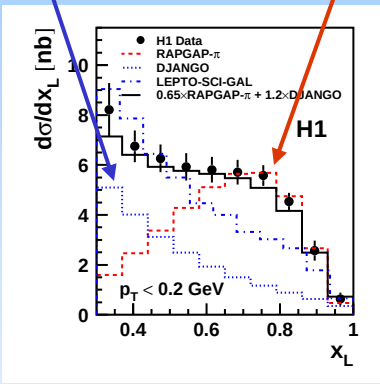


VFPS data agree well with LRG and FPS measurements

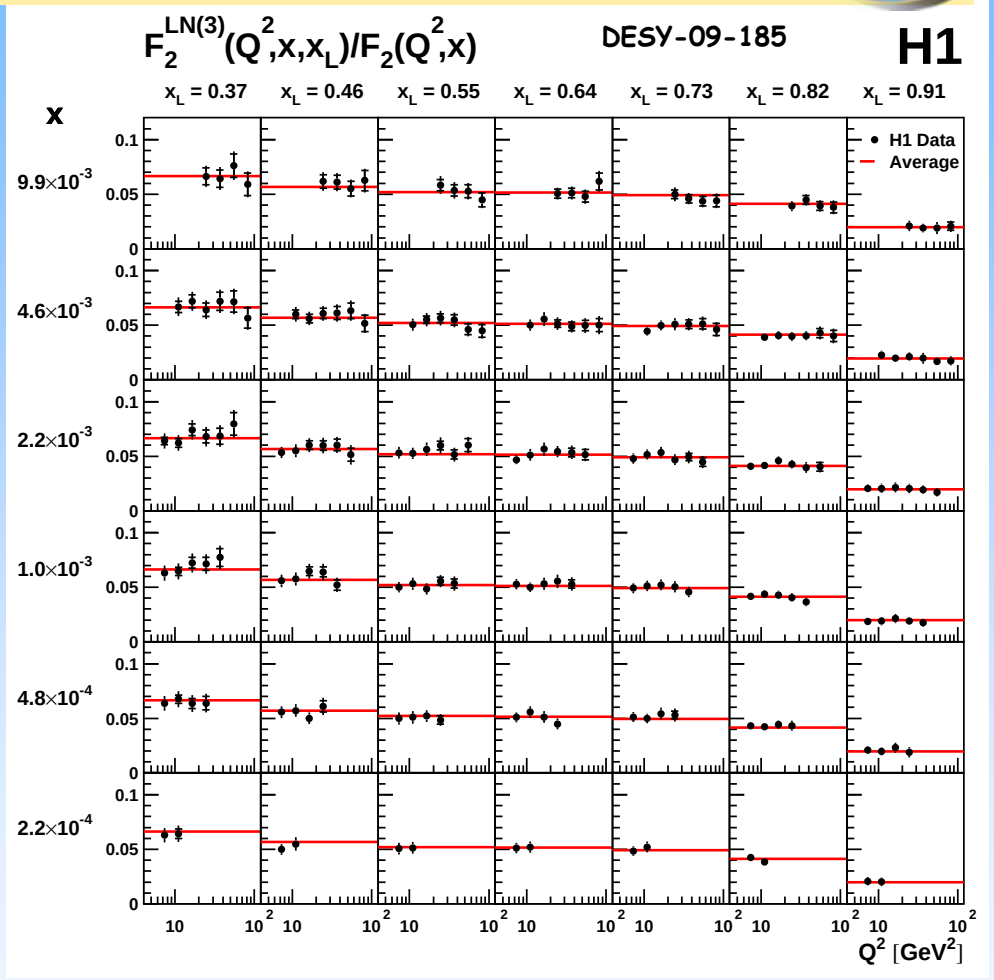
$F_2^{LN(3)}$ with neutrons in FNC



p-fragmentation π-exchange



Data allows the estimate of the pion structure function up to uncertainties of π-flux and absoption



$F_2^{LN(3)}/F_2$ independent of x, Q^2
Consistent with 'limiting fragmentation'

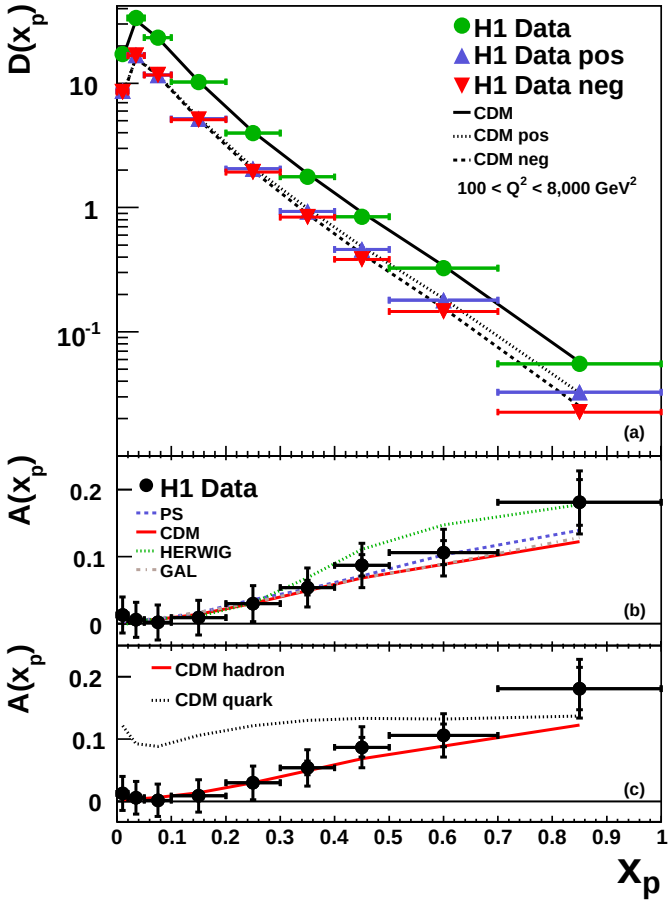
Charge Asymmetry @ high Q^2

PL B681(2009)125

Expectation in ep scattering:

more positive particles
in current jet due to
charge & abundance of u-quark

Breit frame (current hemisphere)



- Significant asymmetry of positive to negative charged particles @ large x_p (current region)
- No asymmetry @ small xp (fragmentation region)
- Data well described by models