Measurement of F_2^{cc} and F_2^{bb} using the H1 Vertex Detector and combination of F_2^{cc} with D* method

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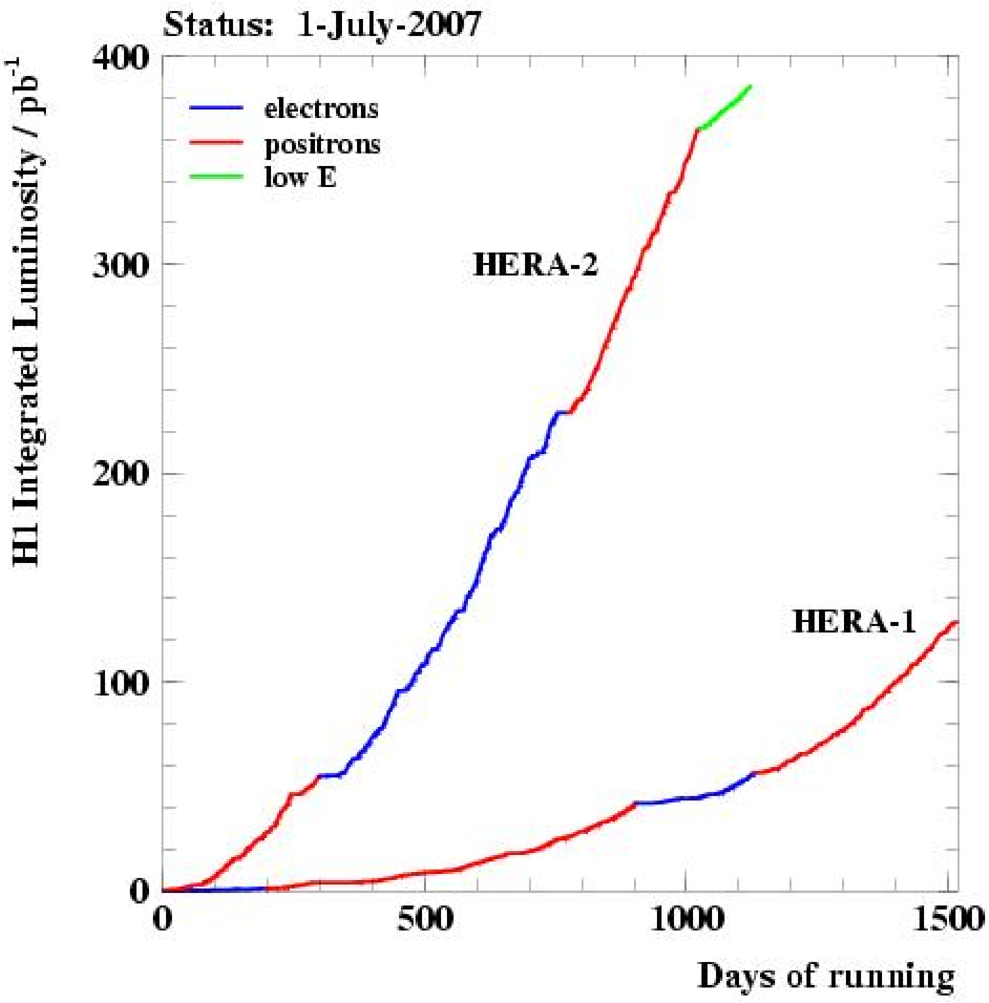
Katerina Lipka (DESY)

for the H1 Collaboration

- Motivation
- Experimental Techniques
- charm and beauty inclusive cross sections in DIS
- Combination of D* and vertex detector methods

DIS 2009, Madrid 26th-30th April, 2009

Available Data

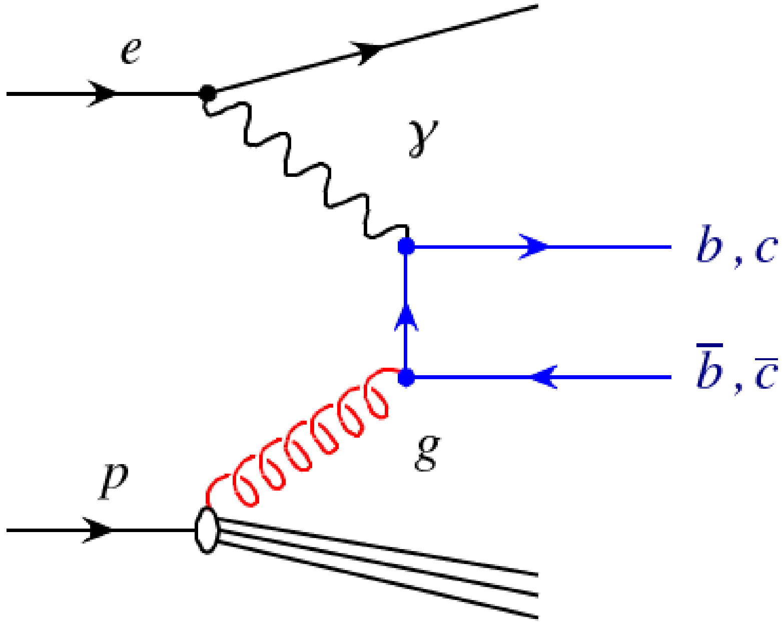


- In total ~500pb^{-1} of high energy data collected
- luminosity upgrade in 2001
- detectors adjusted

Preliminary analyses on full HERA II data

Working on final publication and combination of results

Production of Heavy Quarks



Predominantly via *boson gluon fusion* (BGF)

Test of perturbative QCD:

multi-scale problem (Q^2, M^2, p_T^2)

Directly sensitive to gluon density in the proton (PDFs)

Heavy quark contribution to structure function

F_2^{bb} measurements at high Q^2 important for LHC e.g. *bb->H*

$$\frac{d^2\sigma^{b\bar{b}}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x} Y_+ \left[F_2^{b\bar{b}}(x, Q^2) - \frac{y^2}{Y_+} F_L^{b\bar{b}}(x, Q^2) \right]$$

$$\text{for low } Q^2 \text{ with } Y_+ = (1 + (1-y)^2)$$

Heavy Quark Production

Number of theoretical approaches for treatment of quark mass:

"massive" (Fixed Flavour) $Q^2 \sim M^2$, neglects $\alpha_s ln Q^2/M^2$
"Massless" (Zero Mass) $Q^2 >> M^2$, resums $\alpha_s ln Q^2/M^2$
Combination of massive/massless – *general mass* (GM) and *intermediate mass* (IM) flavour *number schemes* (NS).

QCD Calculations:
-FFNS NLO Fixed Order BGF(α_s^2) (final state - HVQDIS)
-GM-VFNS used in latest global PDF fits:
-MSTW08 NLO (BGF α_s^2), *MSTW08 NNLO* (BGF α_s^3)
-CTEQ 6.6 NLO (BGF α_s)

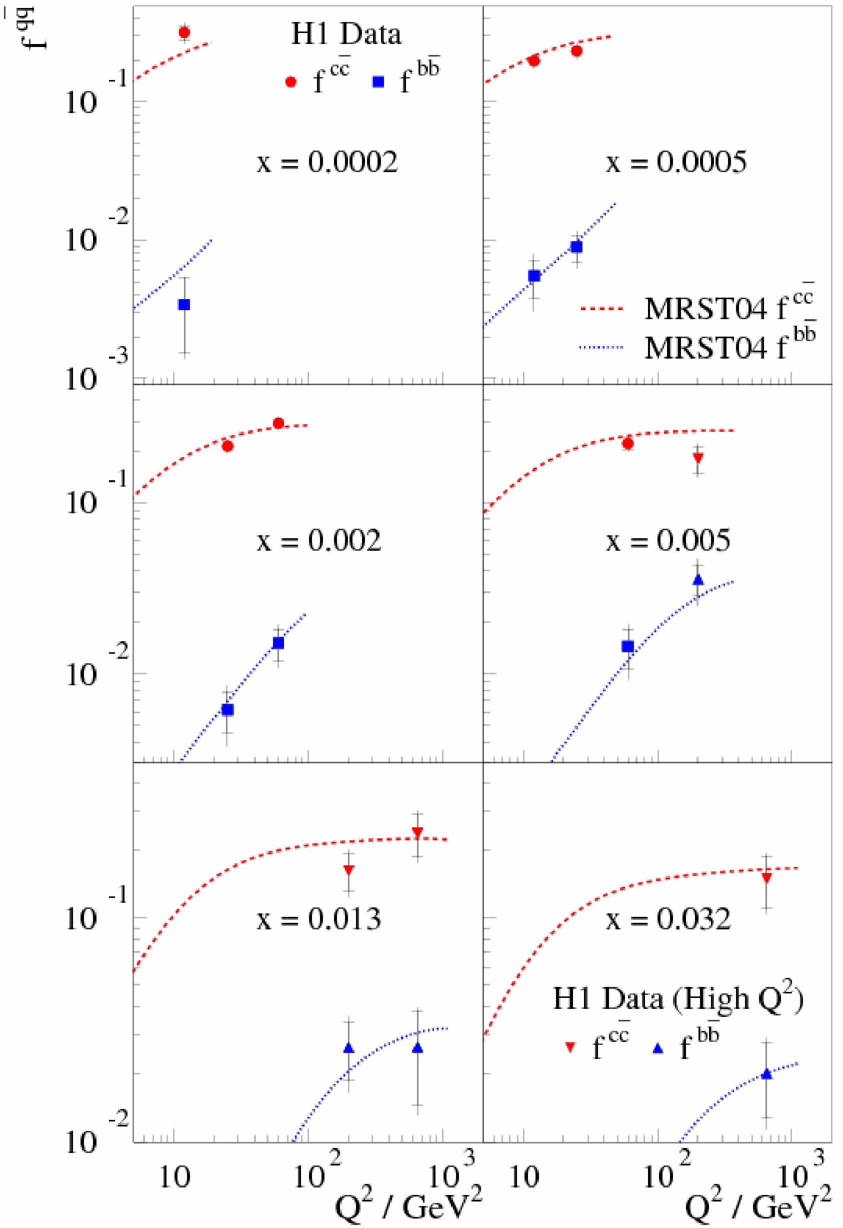
Monte-Carlo: LO (α_s) + Parton shower:

-K_T factorisation, CCFM (CASCADE)
-Collinear factorisation, DGLAP (RAPGAP)

Contribution to Cross Section

HERA I result:

- fraction of total DIS cross section from charm and beauty
- large charm fraction (~30%)
- small beauty fraction ~% (lower at low Q^2)
- mass thresholds visible
- reasonable description by QCD



Tagging Heavy Quarks (c)

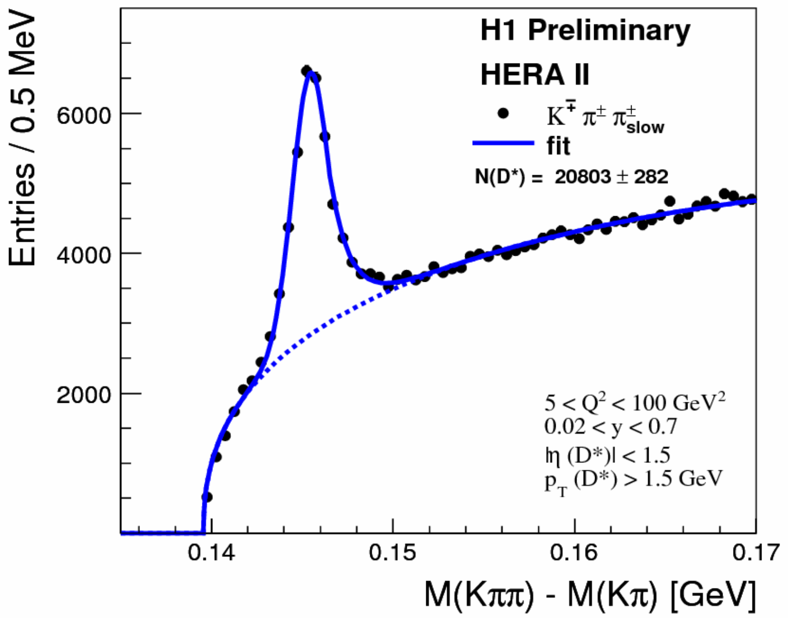
D* method for combination later   Use $D^* \to D^0\pi_s \to K\pi\pi_s$

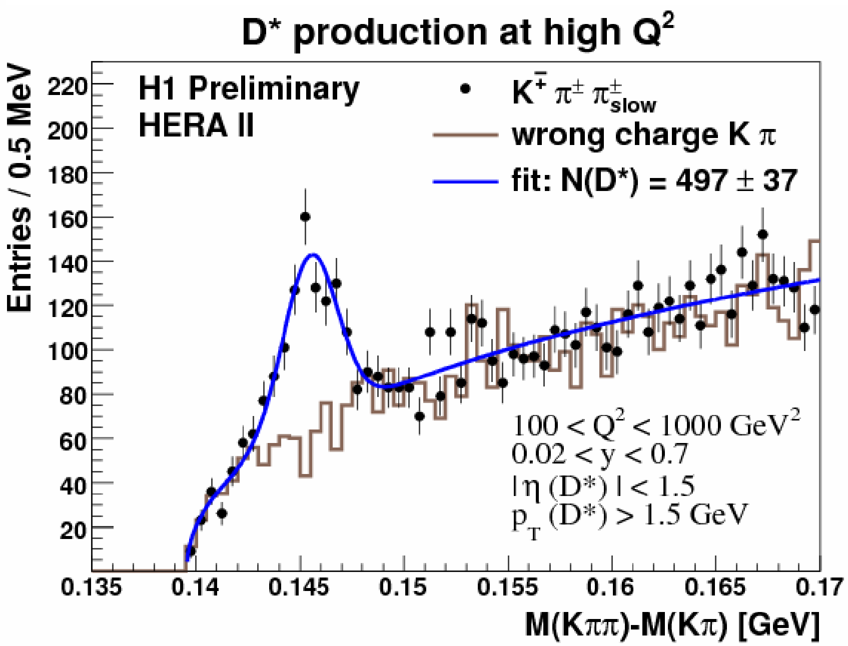
Tracks reconstructed in H1 Central Tracking Detector

Full HERA II statistics (~350pb^{-1})

$5 < Q^2 < 100$ GeV^2 $100 < Q^2 < 1000$ GeV^2

H1prelim-08-072   H1prelim-08-074





See talk from M. Brinkmann

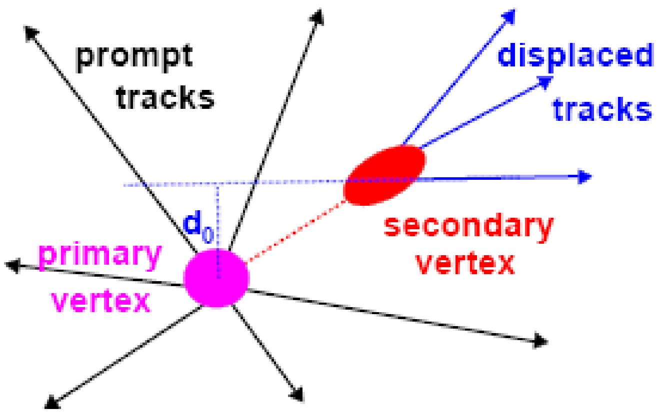
Tagging Heavy Quarks (*b*)

Beauty quarks rarely produced, use properties of beauty hadrons:

- multiplicity
- lifetime (vertex detectors)

 - reconstruction of a secondary vertex

 - impact parameter δ



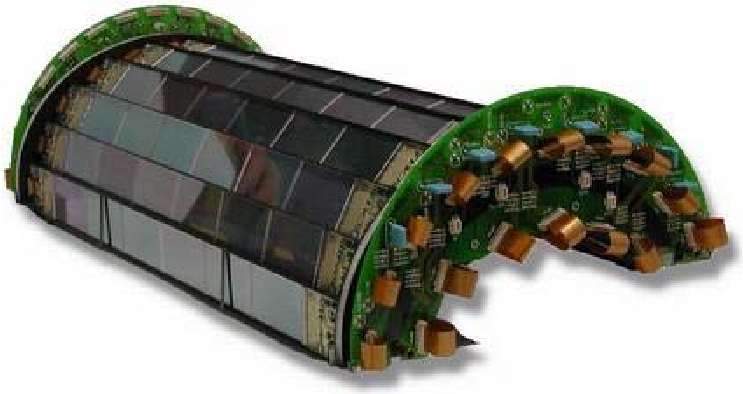
4.5 < Q^2 < 1600 GeV^2 H1prelim-08-173

Measurement of charm as well. Higher efficiency and acceptance (inclusive measurement) but larger background compared with D* method

H1 Vertex Detector (CST)

Central Silicon Tracker

($30^o < \theta < 150^o$)



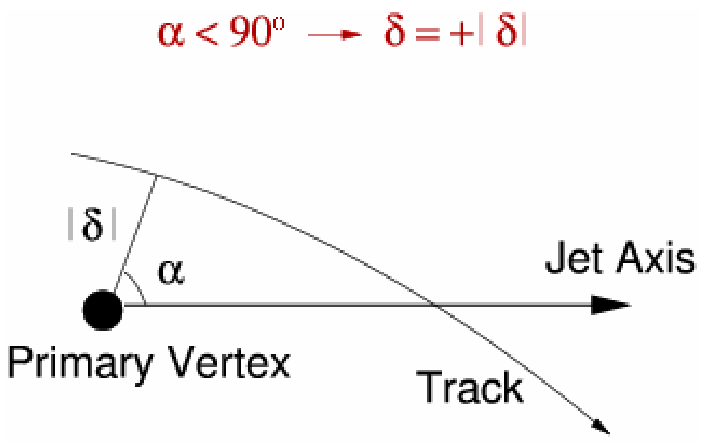
- Rebuilt to take into account HERA II beam-line
- Double layer double sided strips
- Precise determination of impact parameter in transverse plane
- Resolution of |δ| for hits in both layers:

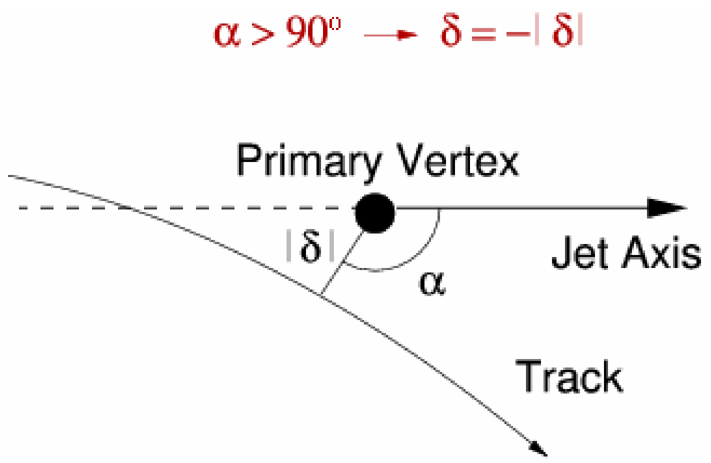
$$33\mu m \oplus \frac{90\mu m}{P_T}[GeV]$$

Impact Parameter

- Inclusive analysis: use all tracks with hits in silicon detector ($p_t > 0.3$ *GeV*)
- Single track events can contribute to impact parameter
- Sign of impact parameter given wrt highest p_T jet axis

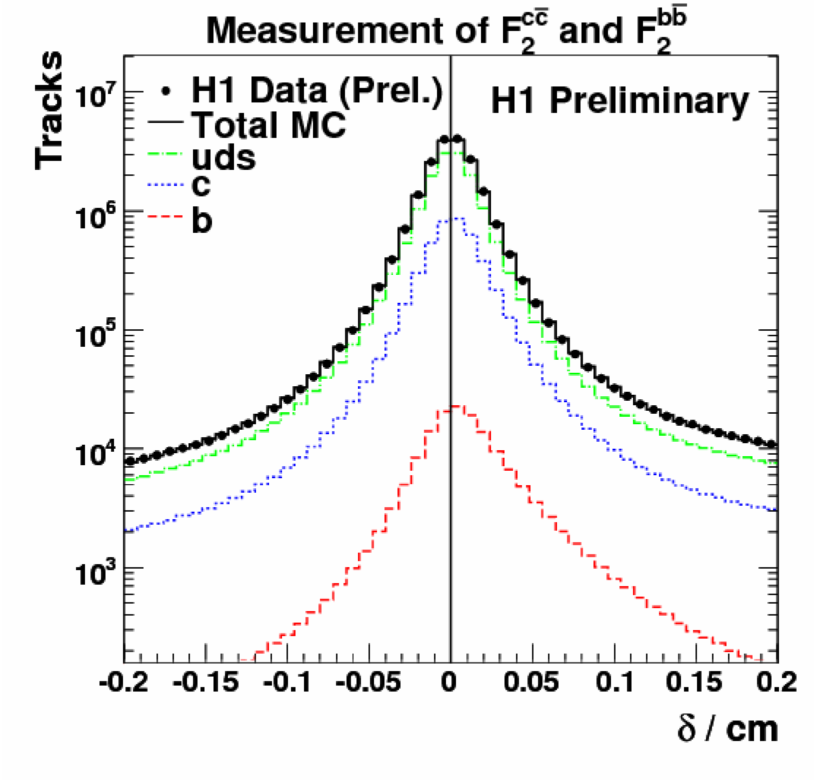
Signed impact parameter δ





Impact Parameter Significance

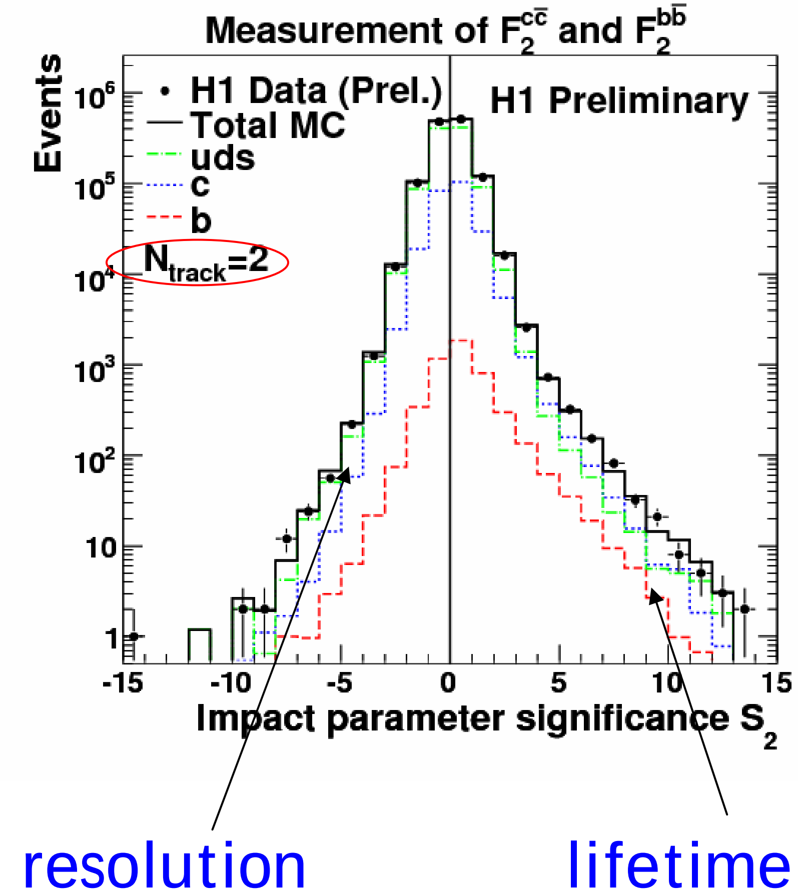
Signed Impact parameter δ



Charm and beauty asymmetric due to lifetime

Light flavours mostly symmetric

Significance $S = \delta/\sigma(\delta)$

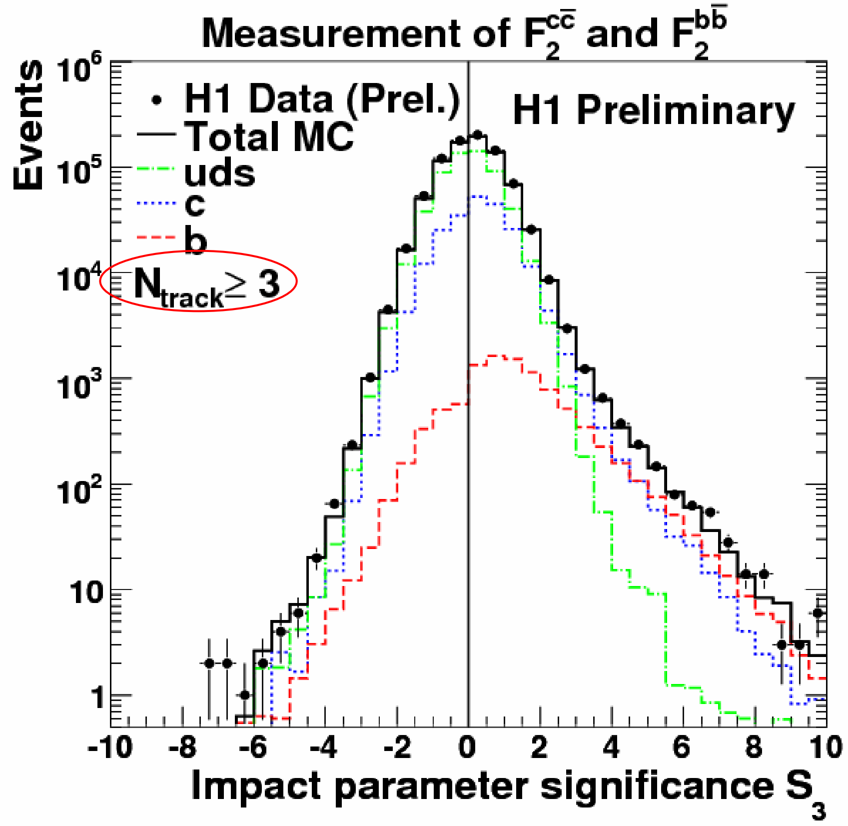


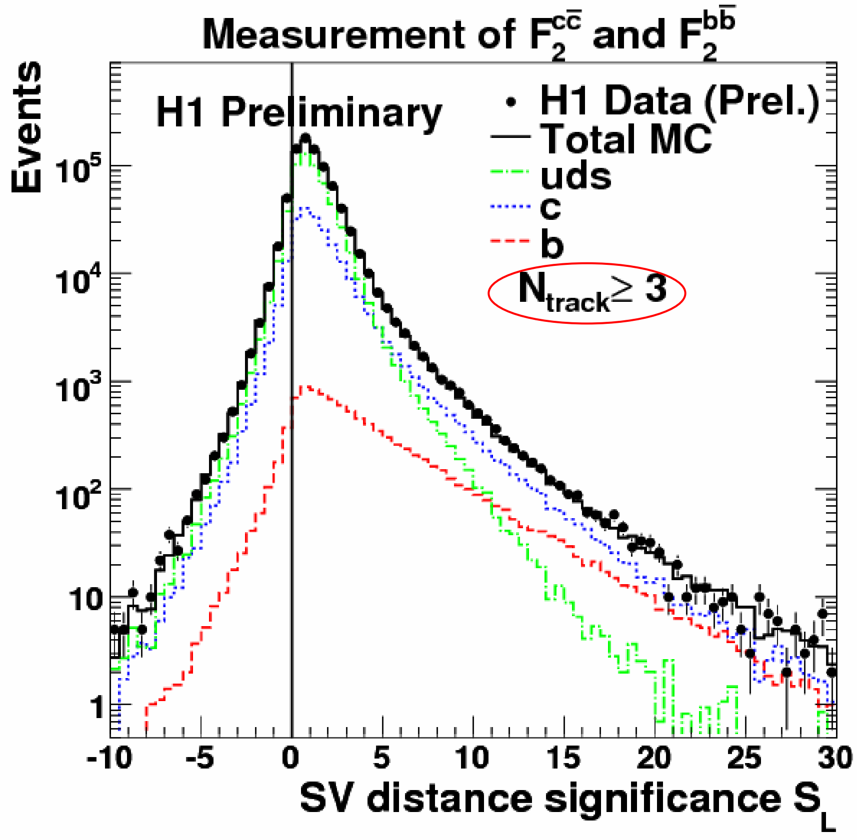
S_1 highest |S| for $N_{track}=1$

S_2 2nd highest |S| for $N_{track}=2$

Neural Network

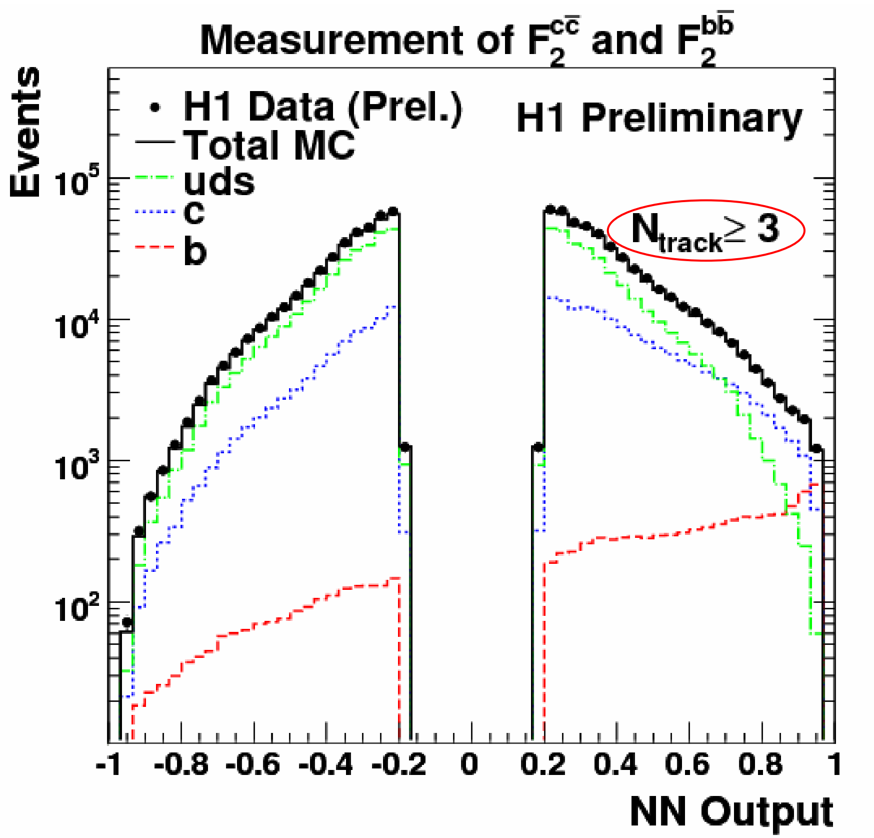
- Improve *c,b* separation: use neural network for >= 3 tracks
- Inputs: S_1, S_2, S_3, sec. vertex decay length significance S_L, $1^{st}(2^{nd})$ highest track p_T, number of CST (sec. vertex) tracks

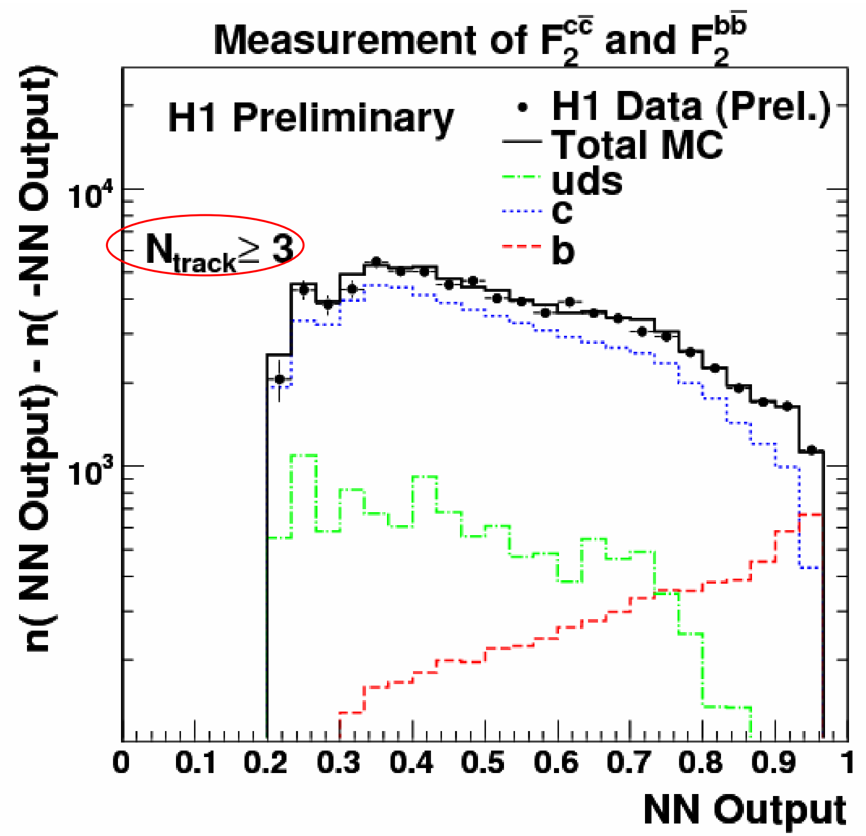




Neural Network Output

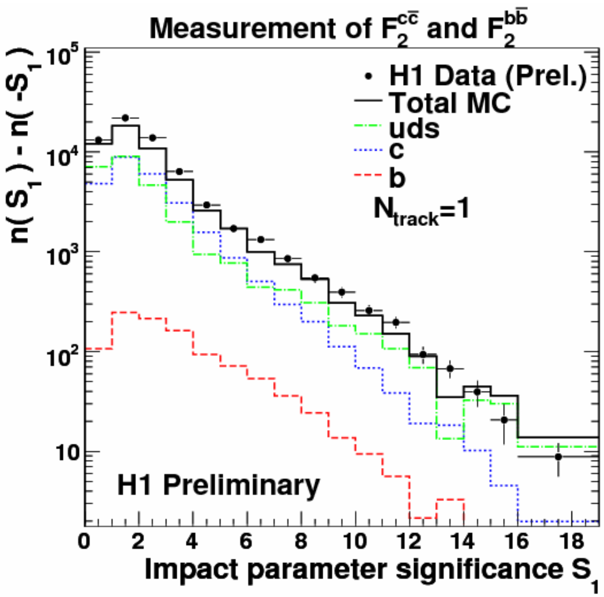
- NN output gives clear separation of charm and beauty
- Sign given by S_1. Subtract –'ve from +'ve to reduce syst. error
- Fit subtracted S_1, S_2 and NN output to obtain c,b fractions

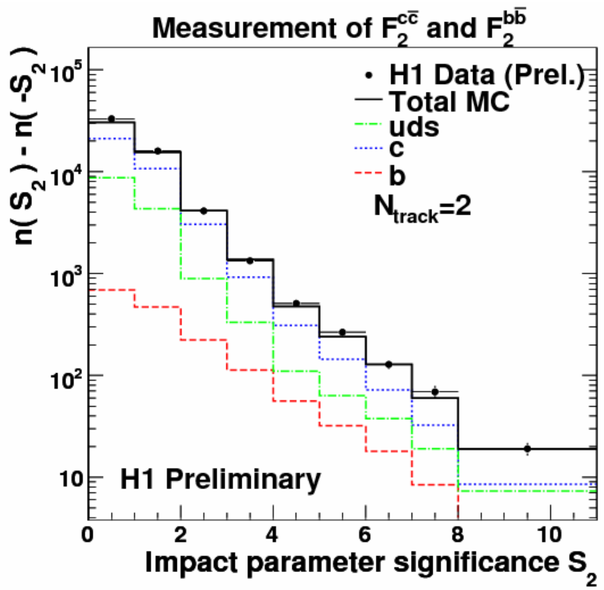


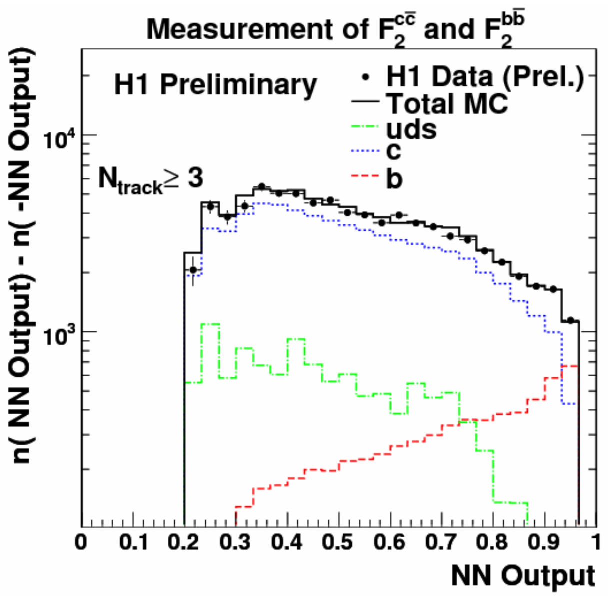


Fitting Flavour Fractions

These distributions are fitted for ρ_c, ρ_b in each x,Q^2 bin with ρ_{uds} constrained by total number of DIS events



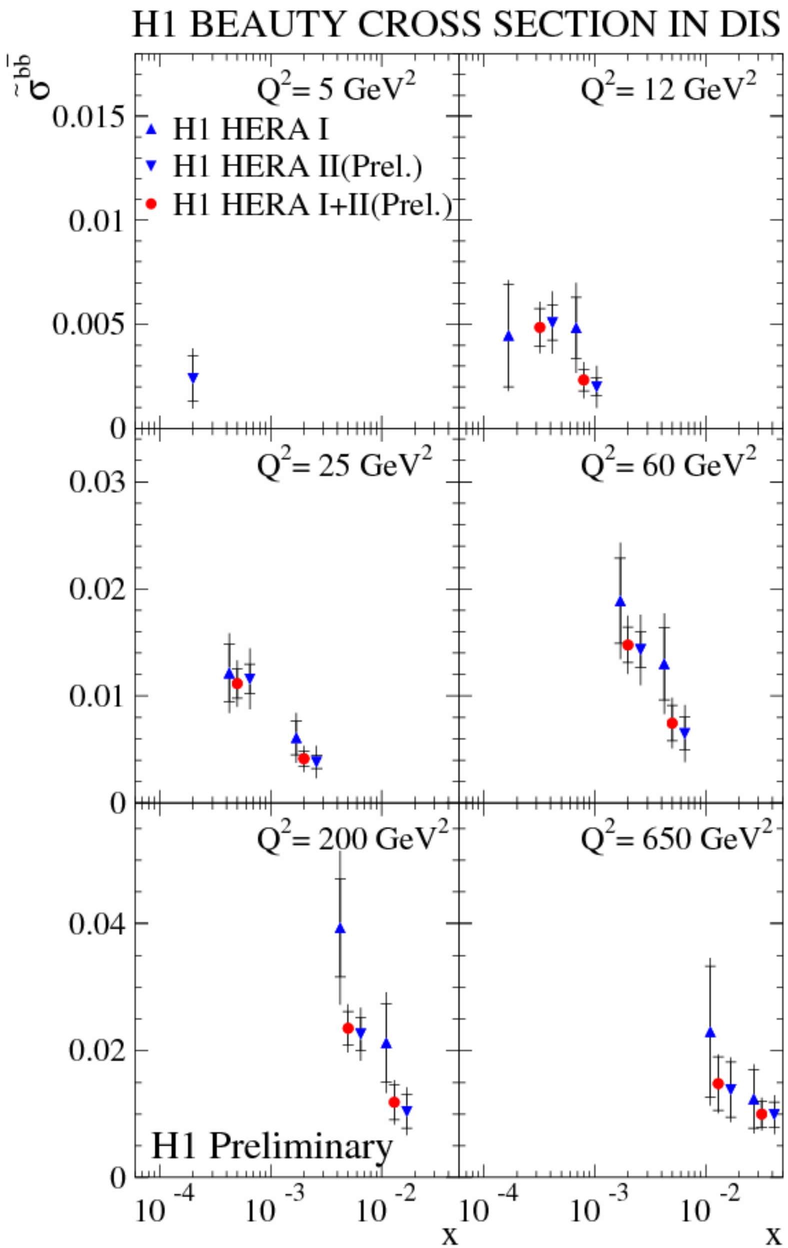




$$\sigma^{cc}(x,Q^2) = \frac{\rho_c . N_c^{gen}}{\rho_c . N_c^{gen} + \rho_b N_b^{gen} + \rho_{uds} . N_{uds}^{gen}} \sigma(x,Q^2)\ \delta_{BCC}$$

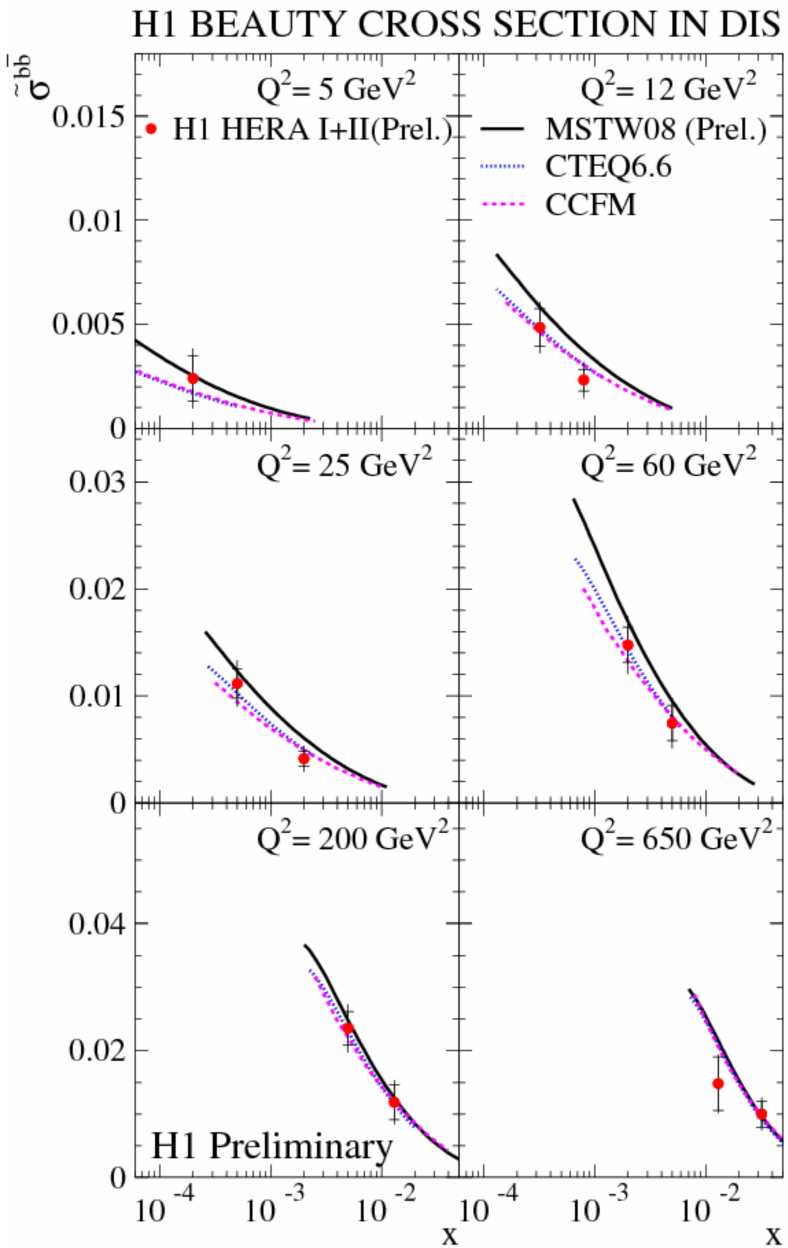
Normalisation from inclusive cross section $\sigma(x,Q^2)$

Inclusive b Cross Section



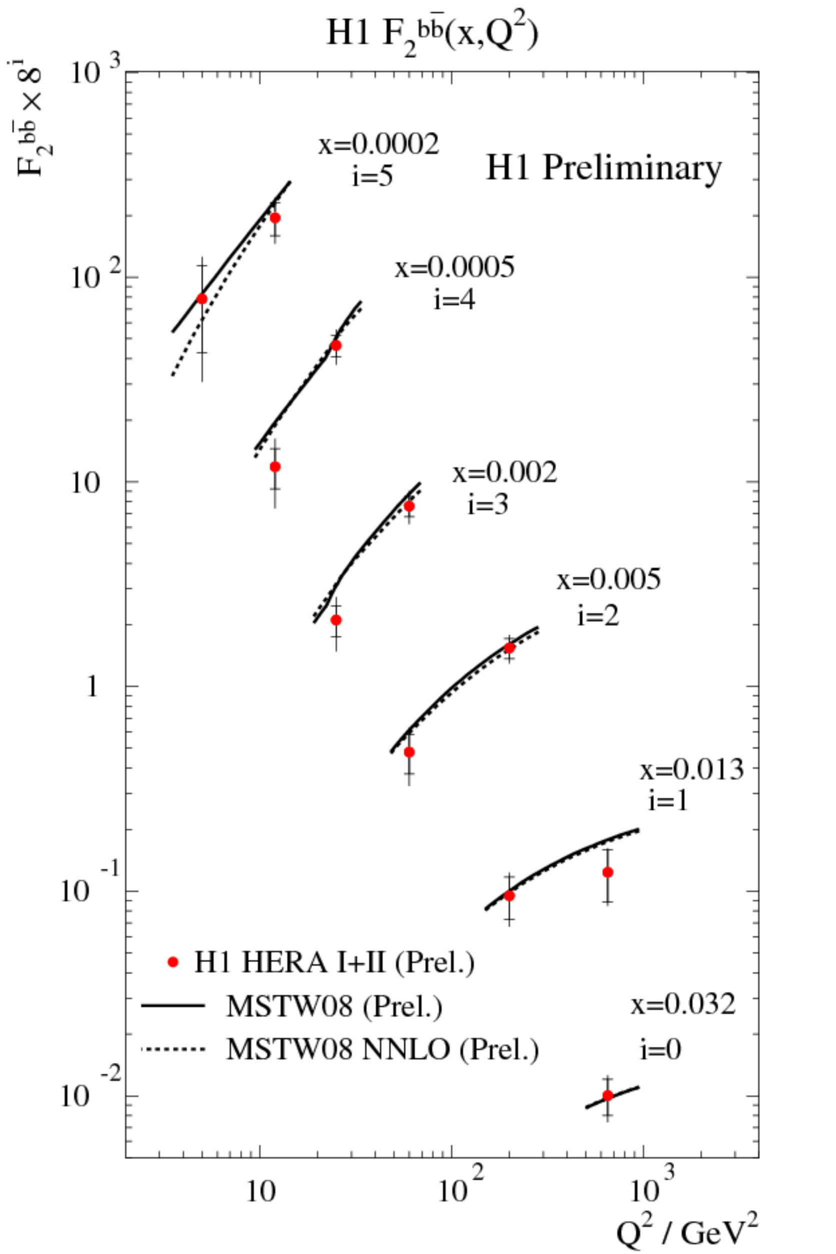
- Inclusive *b* cross section as function of *x* for fixed Q^2
- Agreement with HERA I and improvement in precision
- Binning similar between HERA I and HERA II allows combination using the H1 “averaging” procedure (see later)
- Extension to lower Q^2 for HERA II (improved method)

Comparison of σ^{bb} with theory



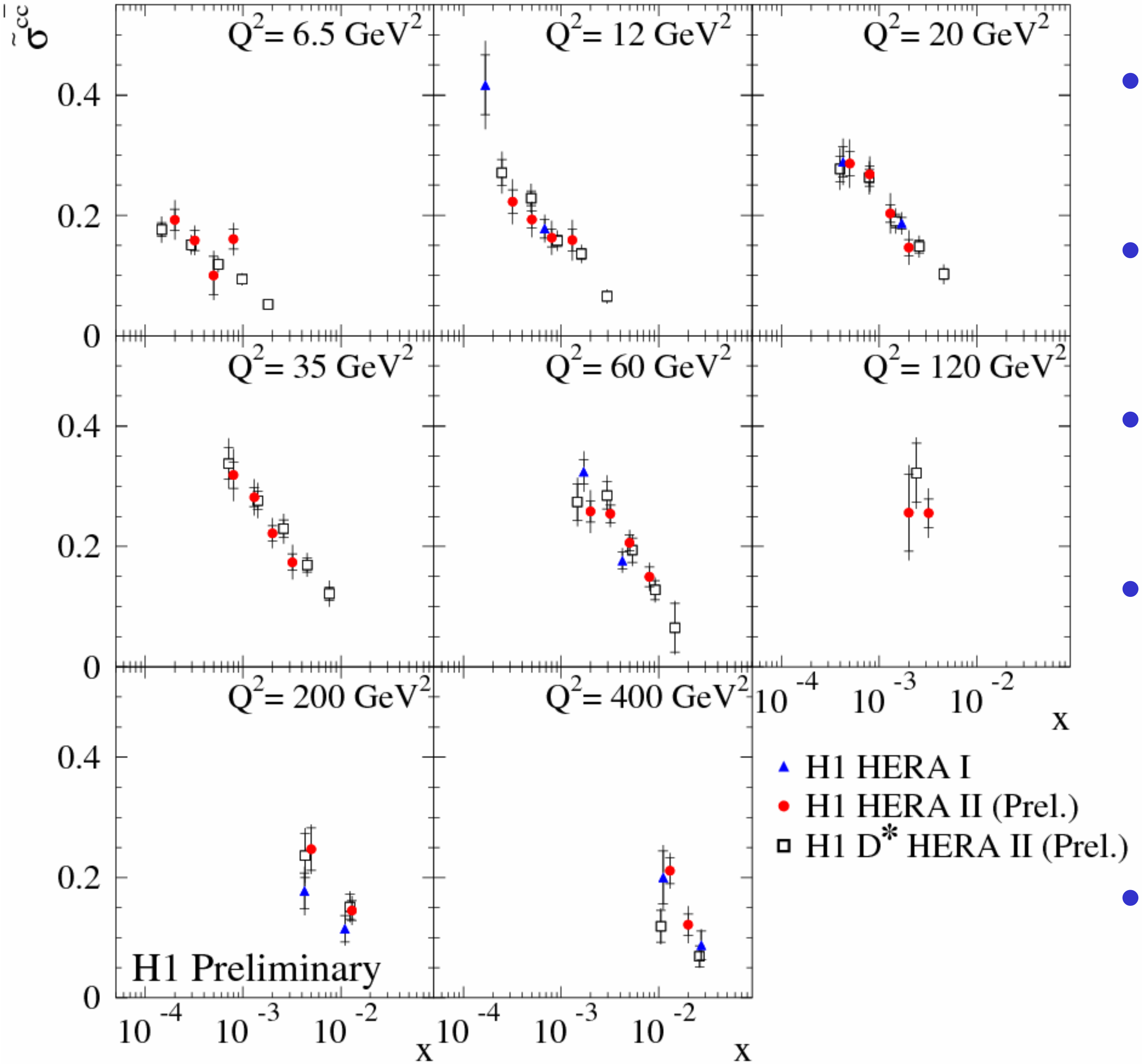
- Compare HERA I+II combined b cross section as function of *x* for fixed Q^2 with theory
- Note rapid increase in magnitude from low Q^2 to high Q^2
- Described by NLO QCD and CCFM
- Differences in theory, generally within scale uncertainties

Measurement of F_2^{bb}



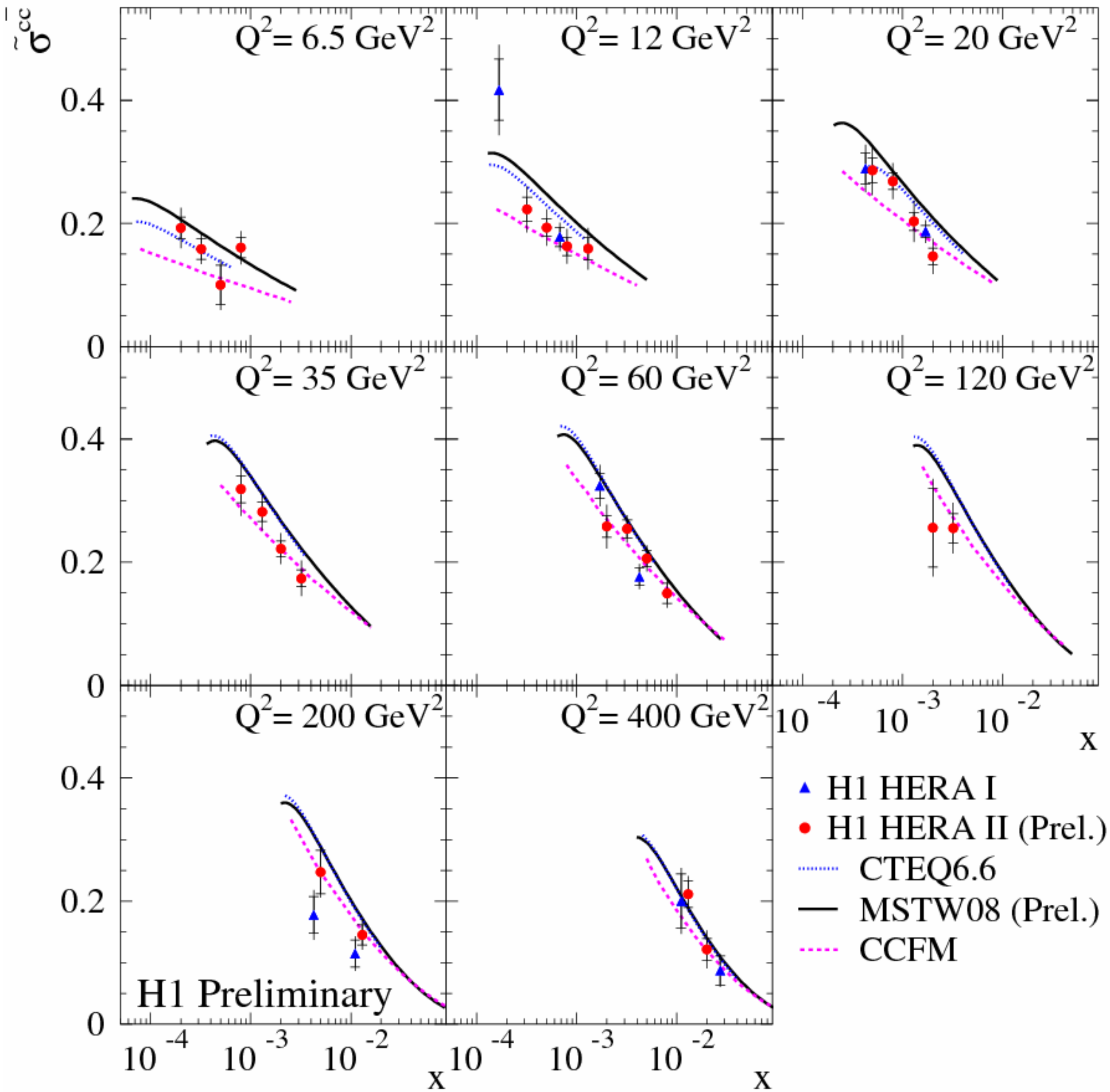
- Beauty structure function versus Q^2 for fixed x
- NNLO predictions available
- Differences between NLO and NNLO small except for $Q^2<(m_b)^2$
- Data well described

Inclusive Charm Cross Section



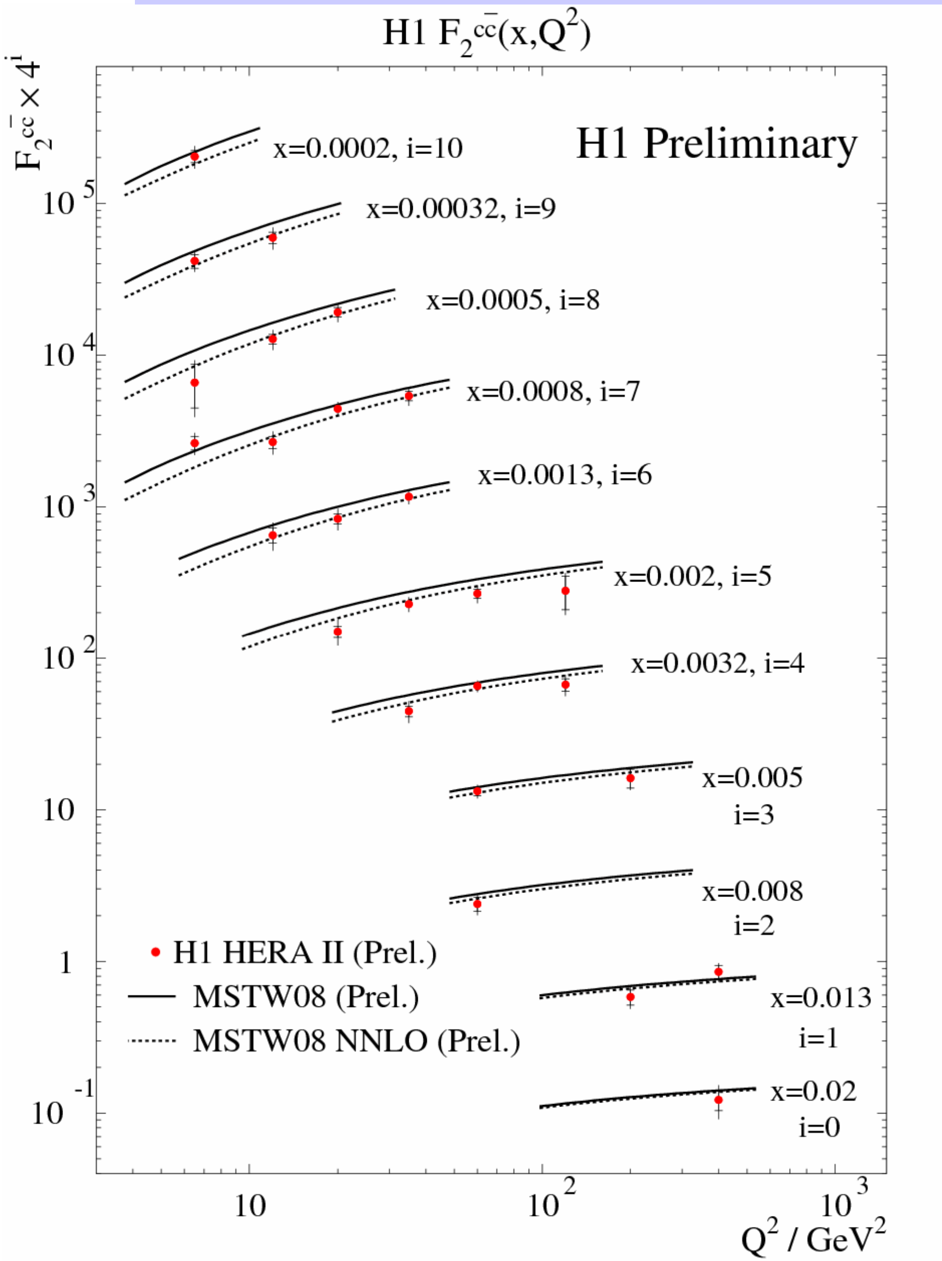
- HERA I and HERA II measurements agree
- Finer binning means no combination
- Method agrees well with results from D*
- D* measurements from DGLAP extrap.. No uncertainty shown (see details later)
- D*/lifetime give best precision at low/high Q^2

Inclusive Charm Cross Section



- Data described by QCD predictions
- CTEQ and MSTW NLO predictions very similar. Small difference at low Q^2
- CCFM lower predictions especially at low Q^2 but still reasonable

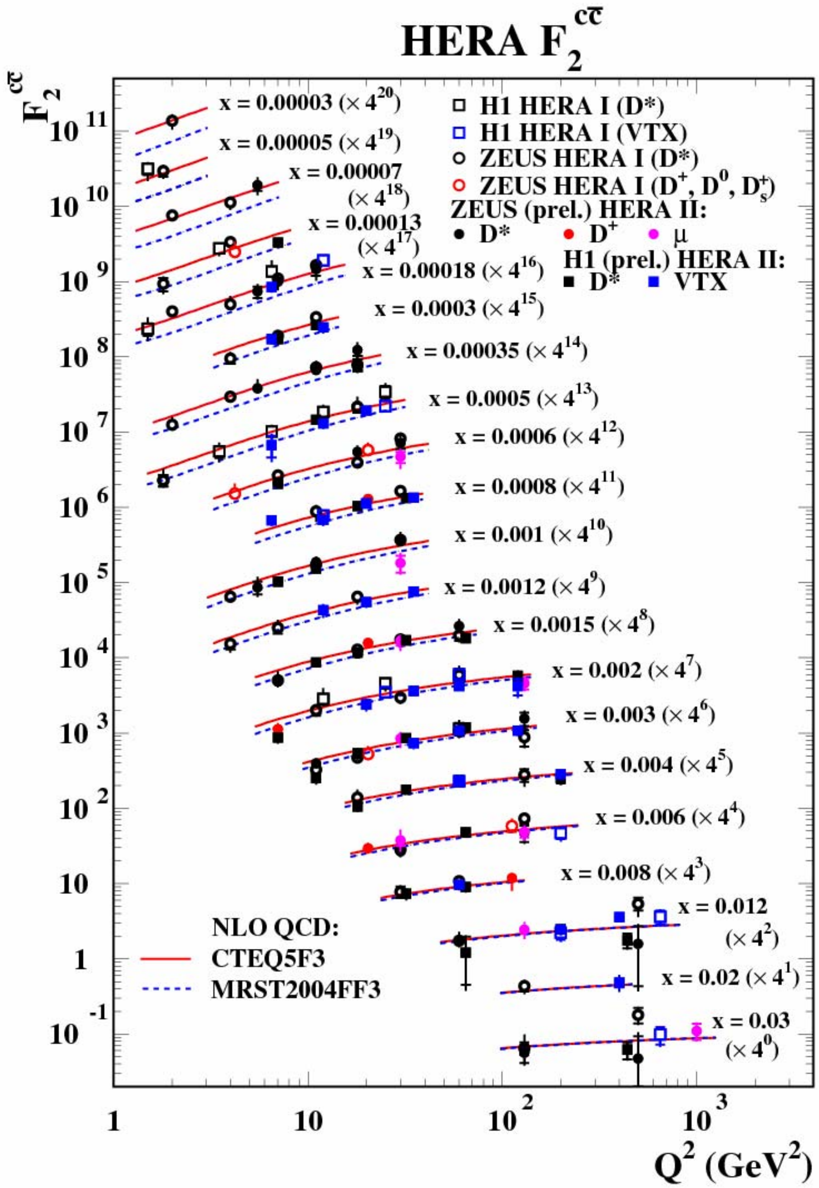
Measurement of F_2^{cc}



- Look at H1 lifetime data vs Q^2 for fixed x
- Difference between MSTW NNLO and NLO larger for charm then beauty
- MSTW NNLO somewhat better description than NLO

What does all the HERA data look like…?

Measurements of F_2^{cc}

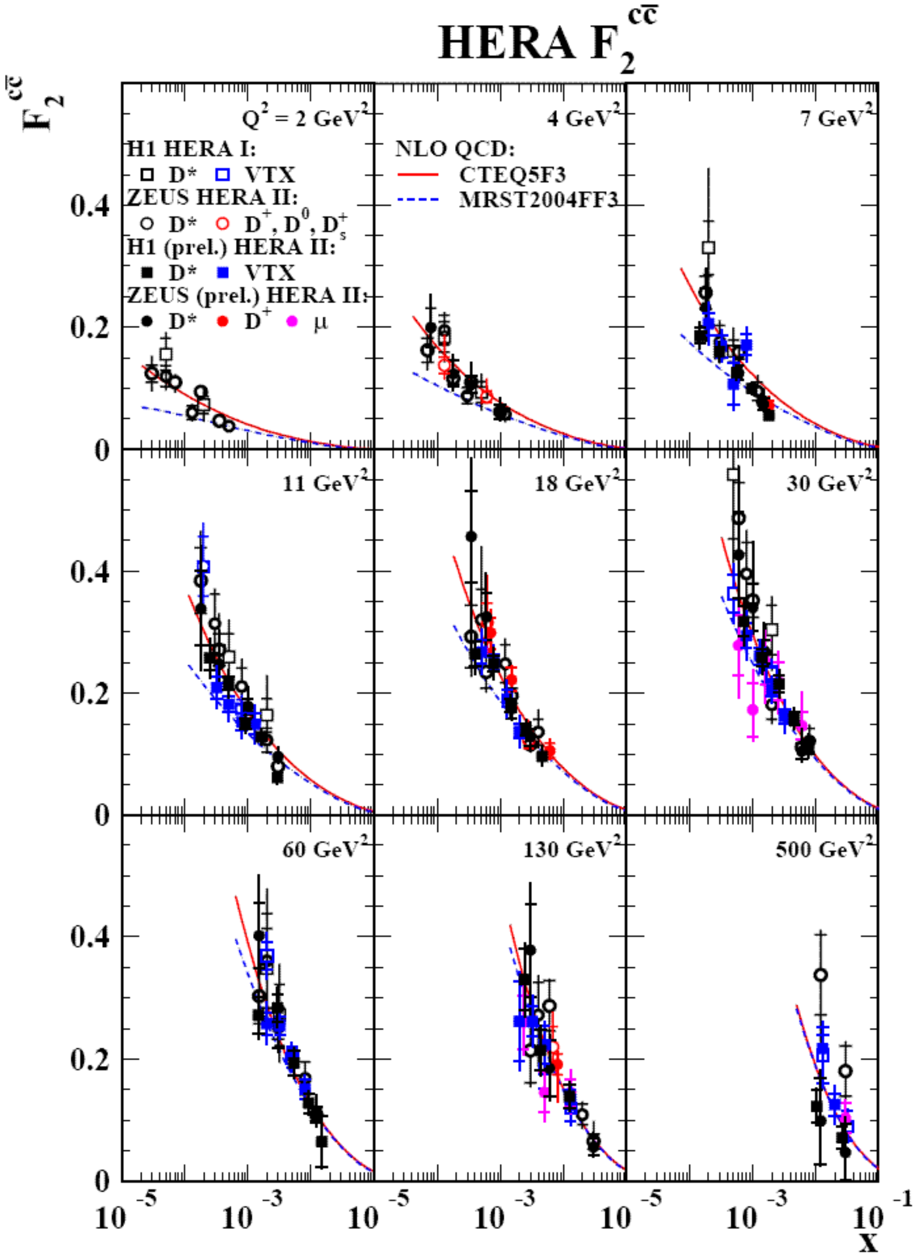


Plenty(!) of measurements:

- different precision
- different systematics
- (partially) different phase space

Can make use of different measurements by *combination of data*

Motivation: gain in precision



Gain in precision to make the message more conclusive:

- combine different tag methods
- combine H1 and ZEUS

Get more discrimination between models?

As a *start* take most recent measurements of H1

Averaging procedure

- Data in combination:

  - H1 Preliminary "lifetime" HERA-II

  - H1 Preliminary D* HERA-II. Inclusive cross section obtained from differential cross section(Q^2,y) using NLO FFNS (see next slide)

- Measurements at different x and Q^2:

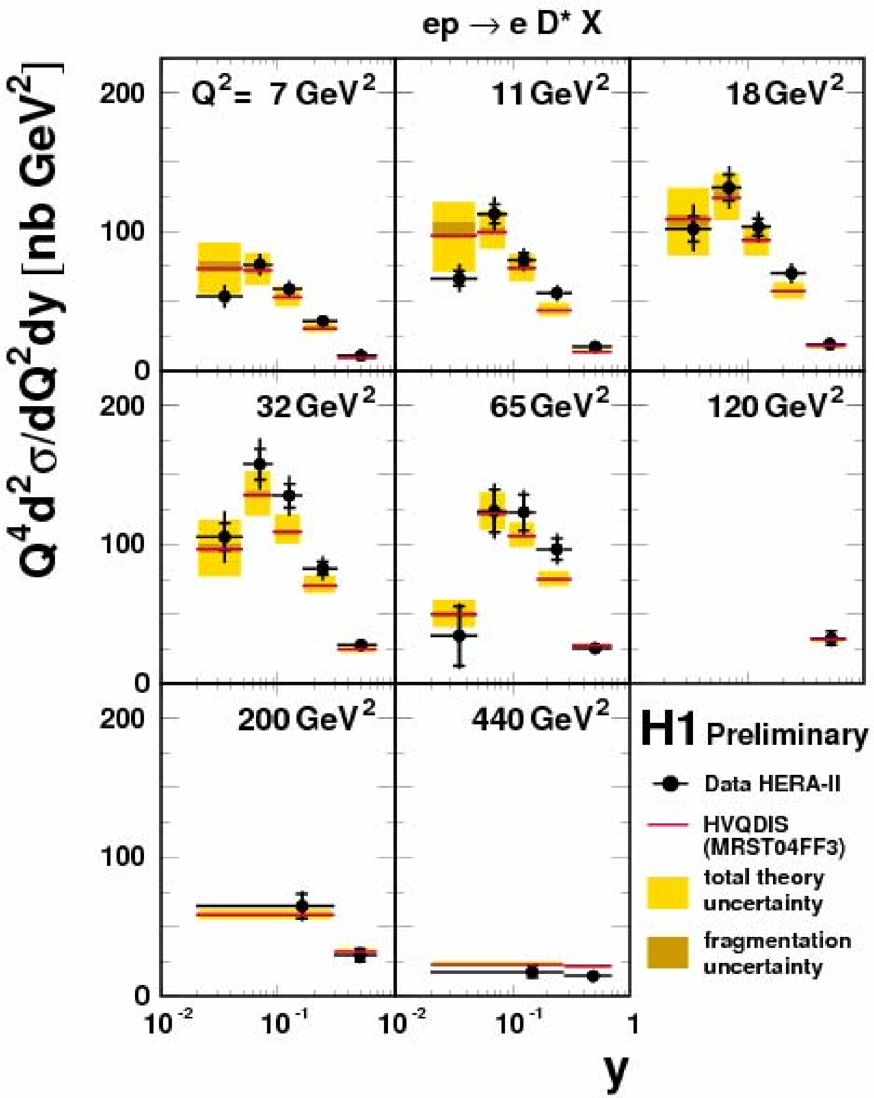
  - point swimming to the common grid using FFNS NLO DGLAP (Riemersma), PDF MRST04FF, m_c=1.43 GeV

- Correlation of experimental uncertainties taken into account

  - 20 sources of point-to-point systematic correlations

  - 3 correlated sources between the methods

Note on D* extrapolation



Extrapolation factors calculated from ratio of $\sigma_{vis}(Q^2,y)$ to σ_{tot}

Use either NLO FFNS (HVQDIS) or CCFM (CASCADE)

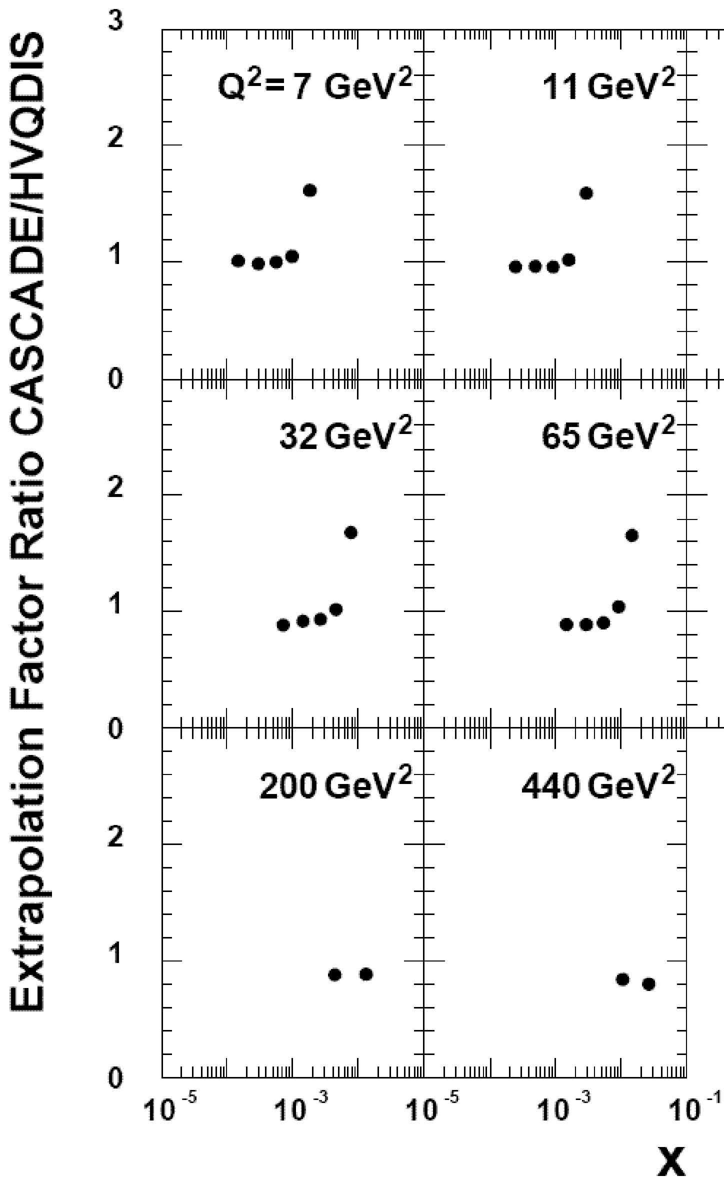
Extrapolation values in the range:

1.5 – 5

high Q^2 - *low* Q^2*(low y/high x)*

See talk from A. Jung

D* extrapolation



Differences in extrapolation factors HVQDIS vs CASCADE:

Generally <10% (low x) but up to 100%(high x). Due to:

- LO+PS vs NLO
- Different evolution
- Different hadronization

Highest *x* points not included in the combination procedure

Difference accounted for as an additional model uncertainty

Averaging procedure: definition

$$\chi^2(M^{i,true},\Delta\alpha_j)=\sum\frac{\left[M^{i,true}-\left(M^i+\sum_j\frac{\partial M^i}{\partial\alpha_j}\frac{M^{i,true}}{M_i}\Delta\alpha_j\right)\right]^2}{\left(\sigma_i\frac{M^{i,true}}{M_i}\right)^2}+\sum_j\frac{\left(\Delta\alpha_j\right)^2}{\sigma^2_{\alpha_j}}$$

Detailed in H1 paper arXiv:0904.0929

M^i measured central values

σ_i statistical + uncorrelated systematic error

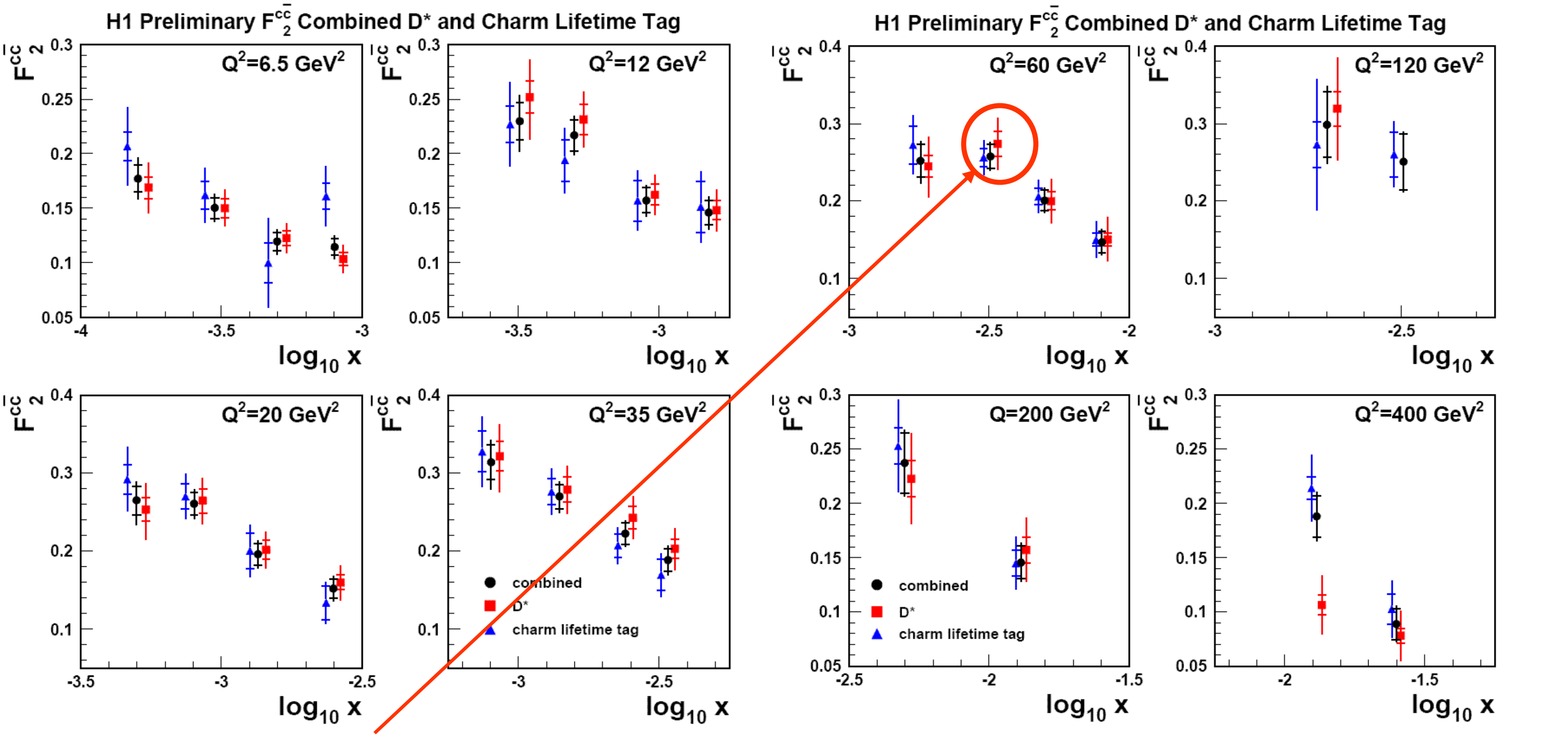
$\sigma_{\alpha j}$ – correlated systematic error

$dM^i/d\alpha_j$ – sensitivity of data *i* to systematic uncertainty *j*

$M^{i,true}$ - fitted combined data D* + lifetime

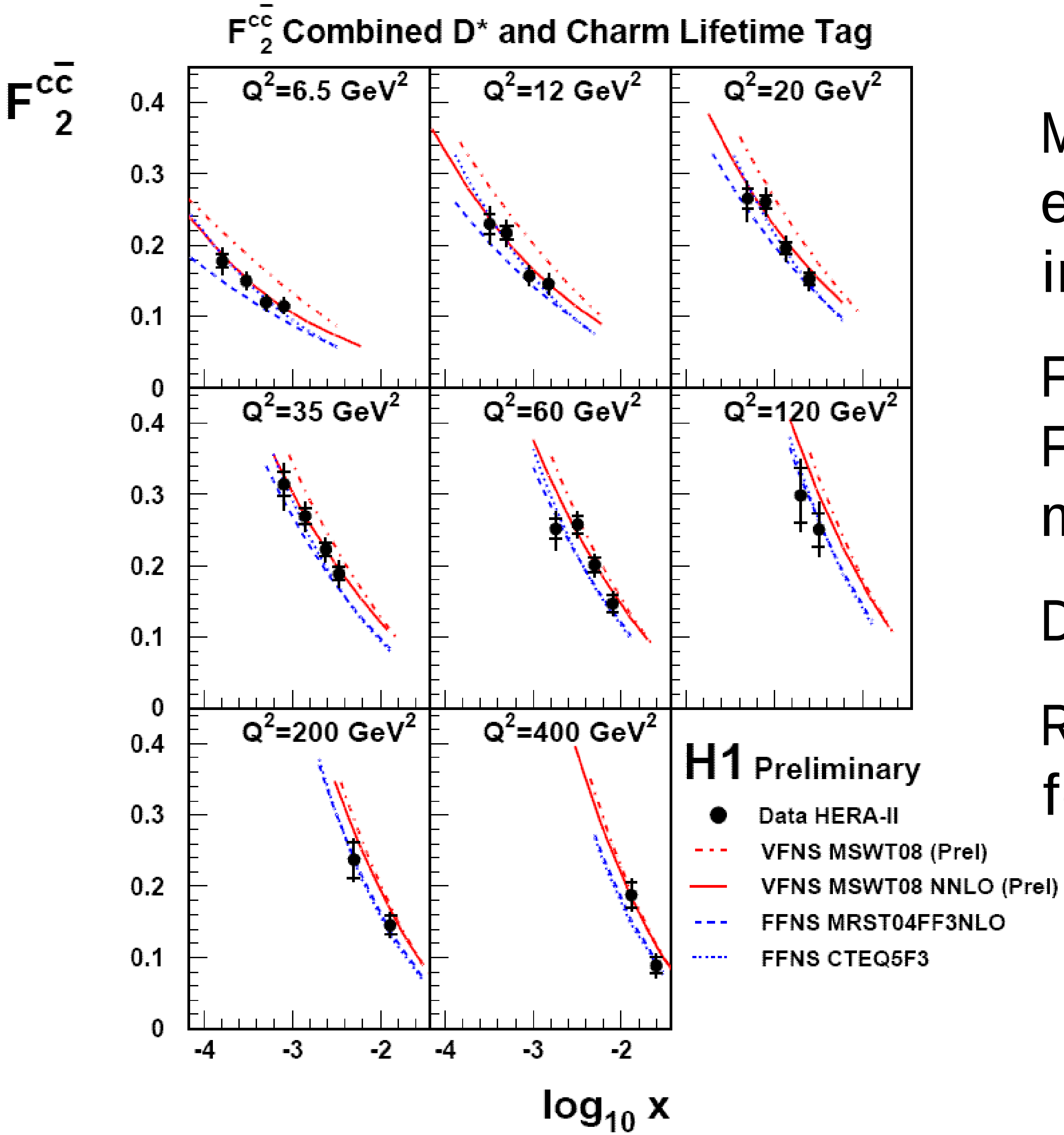
$\Delta\alpha_j$ – fitted shifts of correlated uncertainties

Results: precision improvement



- Most gain (50%) where D* and lifetime similar precision
- Overall improvement in precision (10-50%)
- Results stable wrt variation of systematic treatment, χ^2 =26/25

Results



Model dependence in extrapolation factors included in systematics

F_2^{cc} can be compared with FFNS and GM VFNS models

Description reasonable

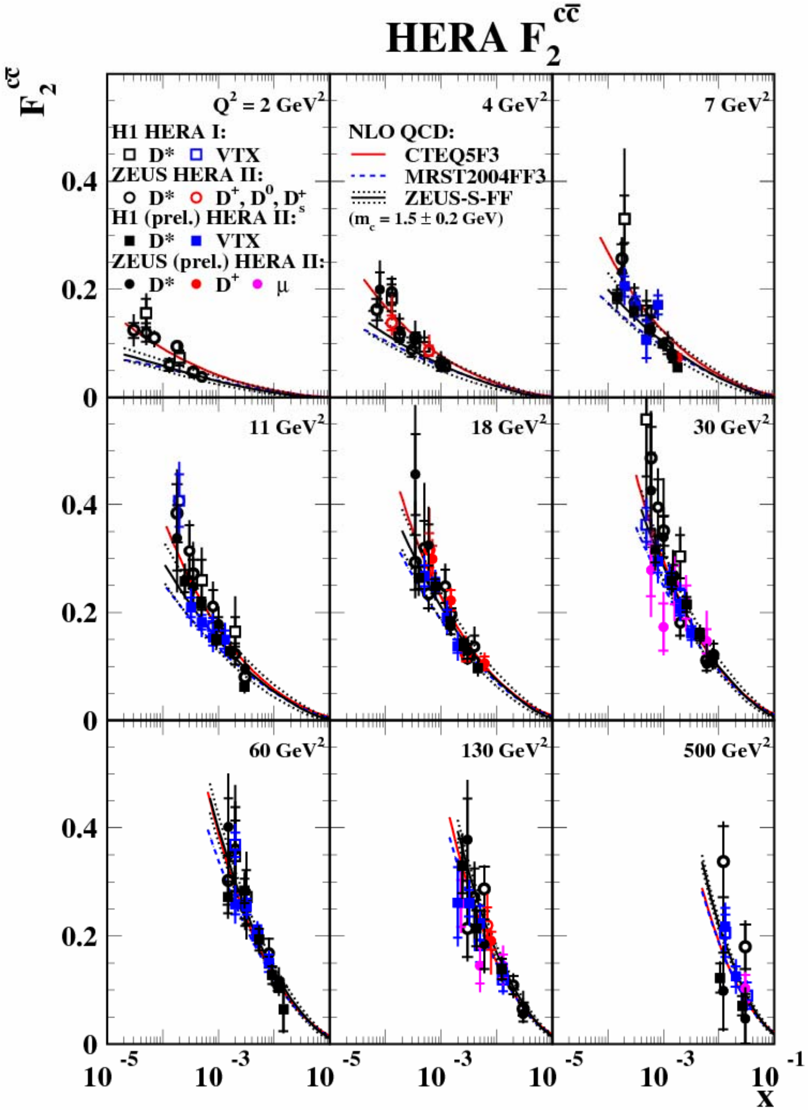
Room for improvement for some models

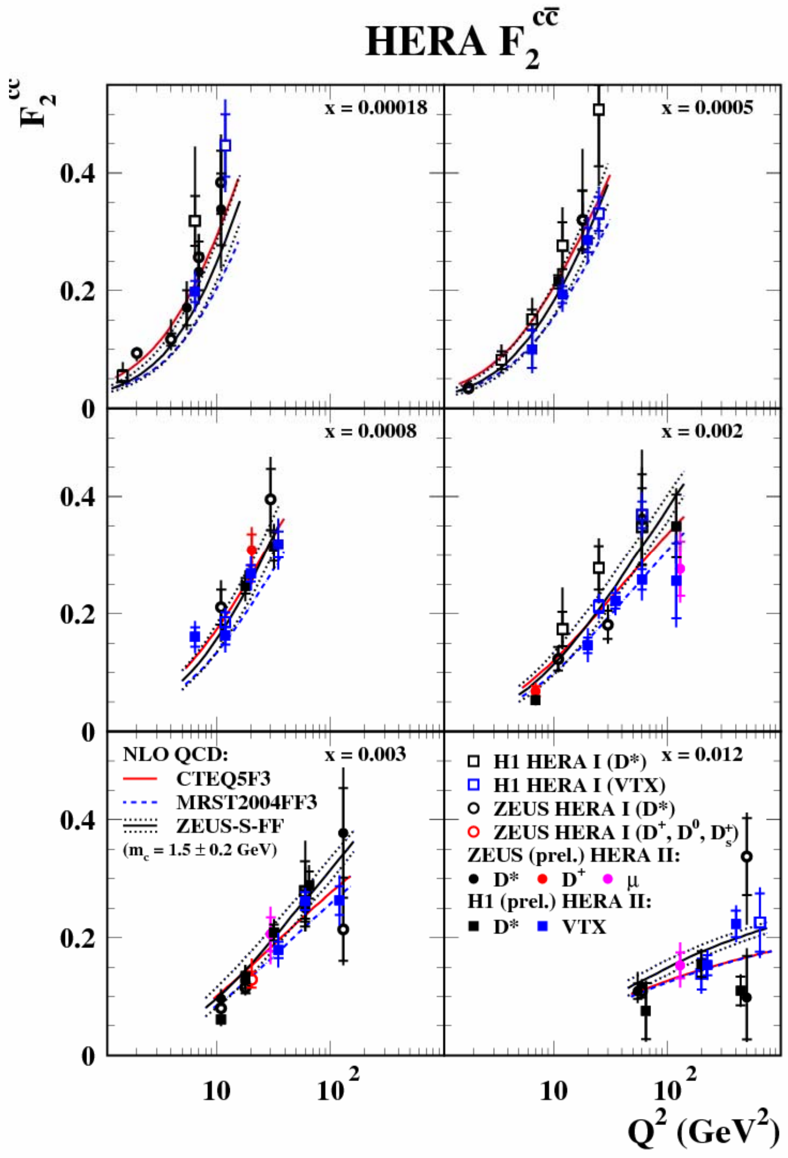
Conclusions

- Presented H1 measurements of the heavy flavour content of the proton from HERA II and HERA I data
- Extraction of structure functions F_2^{cc} allows comparison of different measurement techniques
- Extra precision can be gained from combination (improvement 10-50%)
- Combination H1 + ZEUS is worked on
- Data are described by (N)NLO pQCD calculations
- Final data with improved precision (expected soon) will help to constrain theory mass treatments and PDFs for LHC era

Back Up

Scale Uncertainty (c)





Scale Uncertainty (b)