H1 Measurements of F_2, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

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F_2 Measurements at low Q^2

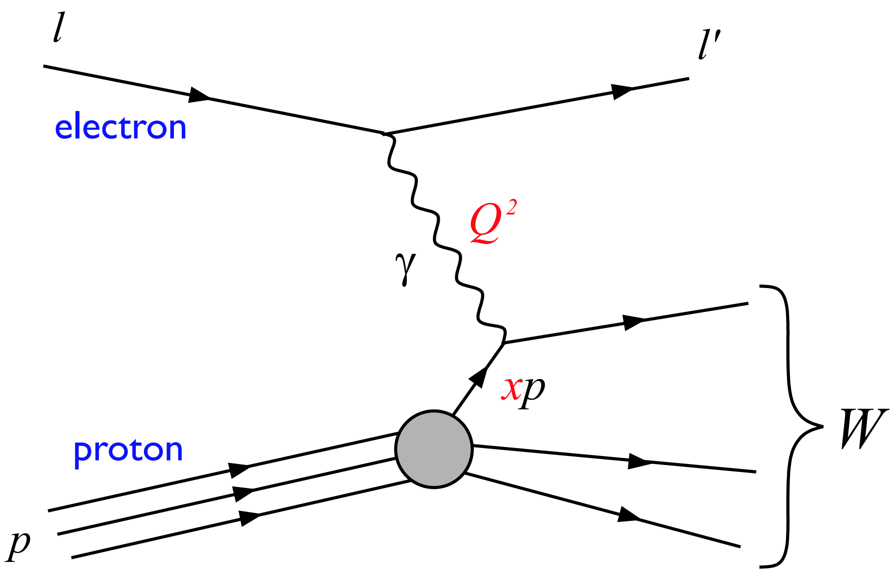
Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

Experimental method

Results at medium and high Q^2

Deep Inelastic Scattering

Neutral Current



cms energy $\sqrt{s} = \sqrt{(l+p)^2}$

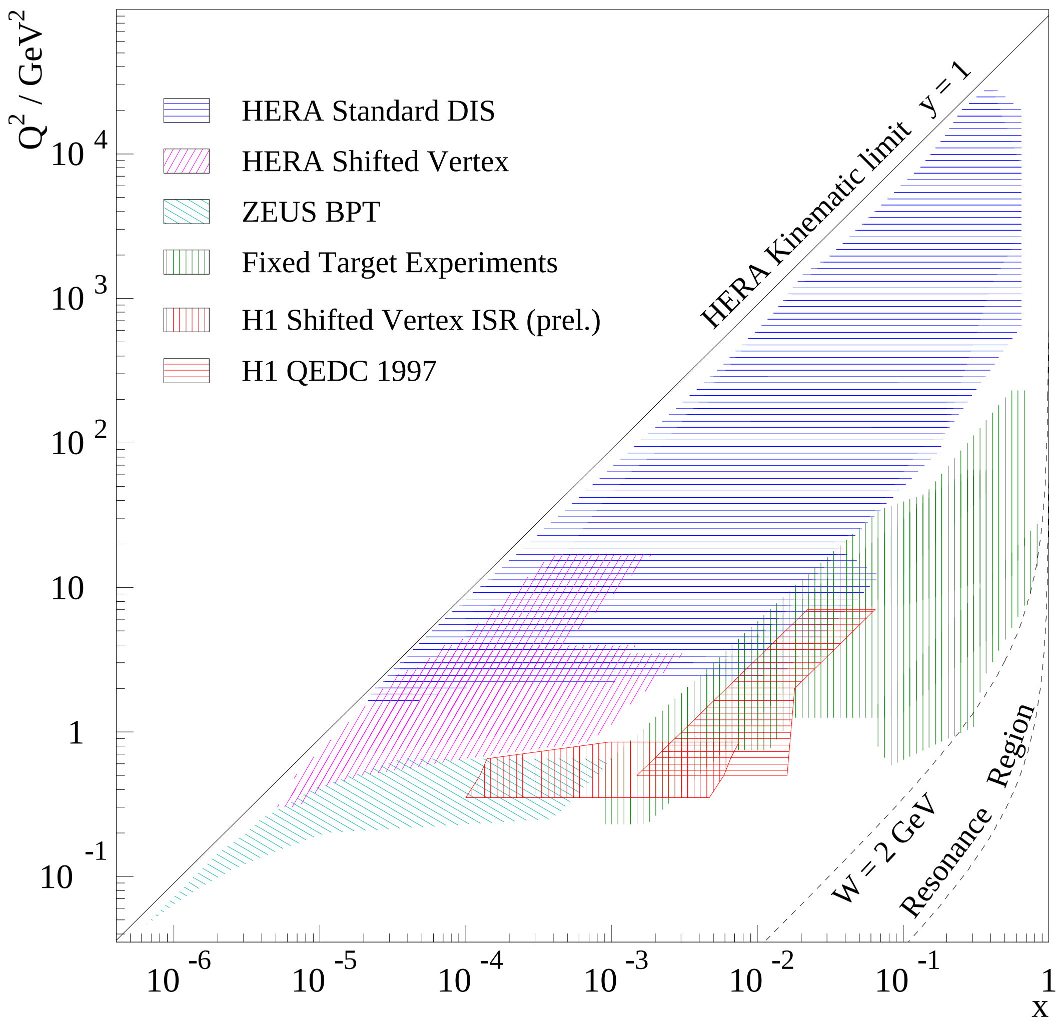
γ virtuality $Q^2 = -(l-l')^2$

Bjorken variable $x = \frac{Q^2}{2p\cdot(l-l')}$

inelasticity $y \approx \frac{Q^2}{xs}$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{x\,Q^4}[(1+(1-y)^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)]$$

Accessible Phase Space



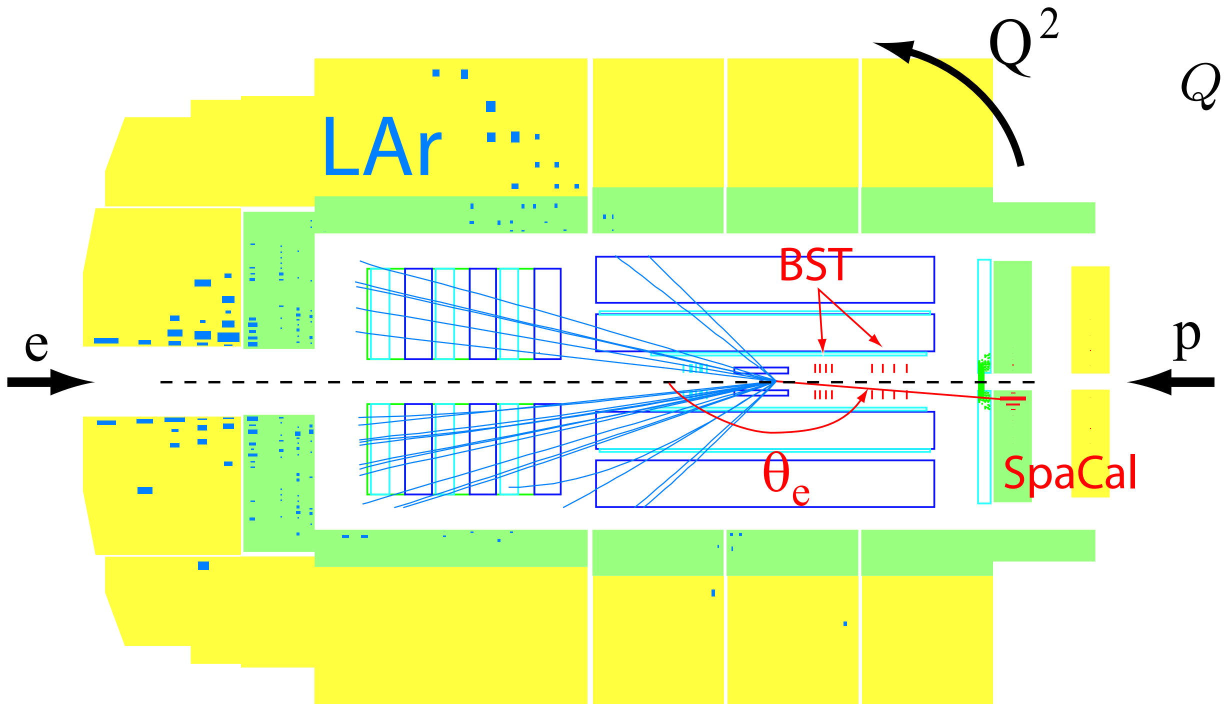
medium-high Q^2

- asymptotic freedom
- perturbative QCD

low Q^2

- transition to soft hadronic physics
- $\alpha_s(Q^2)$ becomes large
- phenomenological models

The H1 Detector



$$Q^2 = 2E_e E'_e(1 + \cos\theta_e)$$

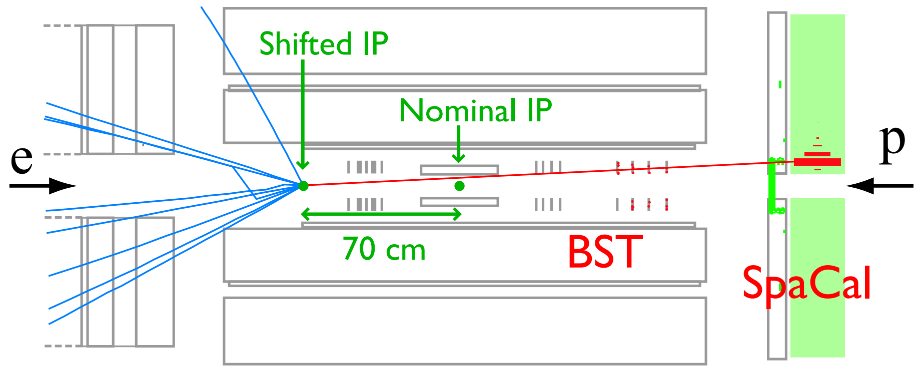
standard DIS in
LAr Calorimeter:
$Q^2 \gtrsim 100\ \text{GeV}^2$

SpaCal
$2 \lesssim Q^2 \lesssim 100\ \text{GeV}^2$

possibilities to reach lower Q^2:

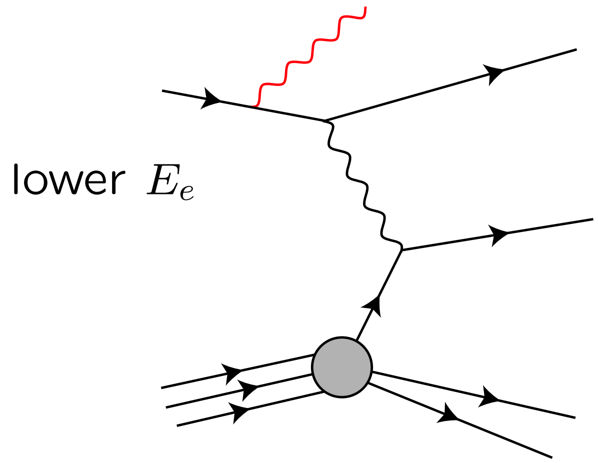
- extend to larger polar angles θ_e
- use events with lower initial electron energy E_e

F_2 at low Q^2: Experimental Techniques

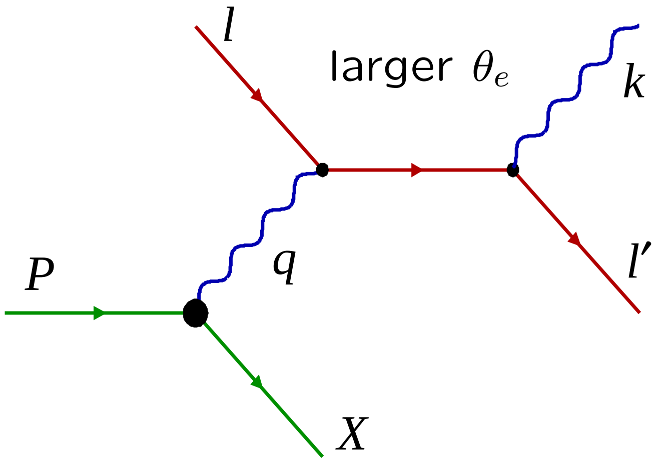


Shifted Vertex Runs

larger θ_e

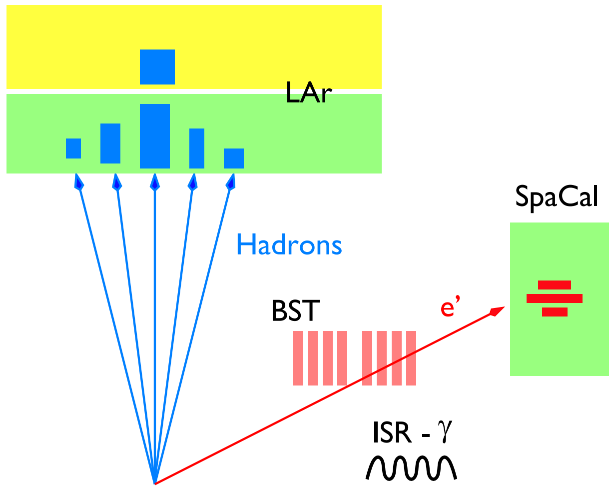


Initial State Radiation (ISR)



QED Compton (QEDC)

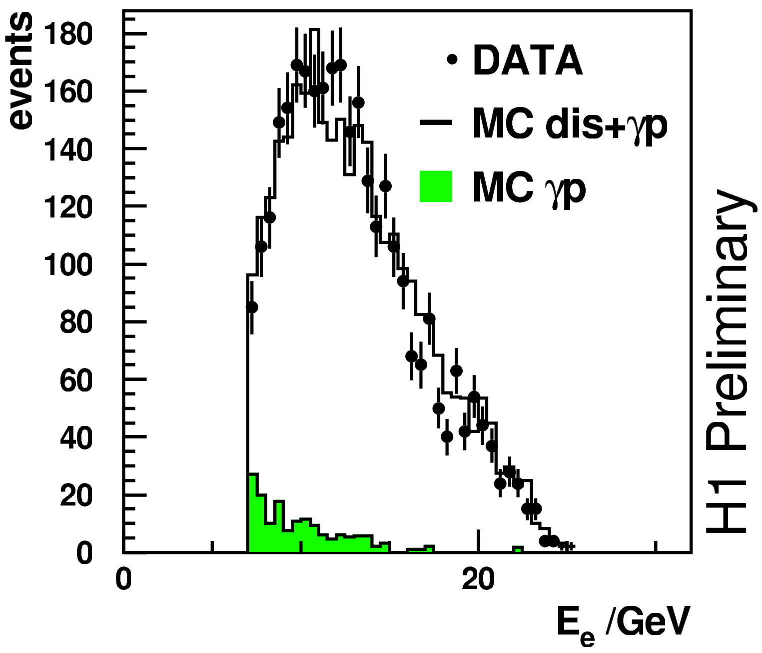
Untagged ISR in Shifted Vertex Runs



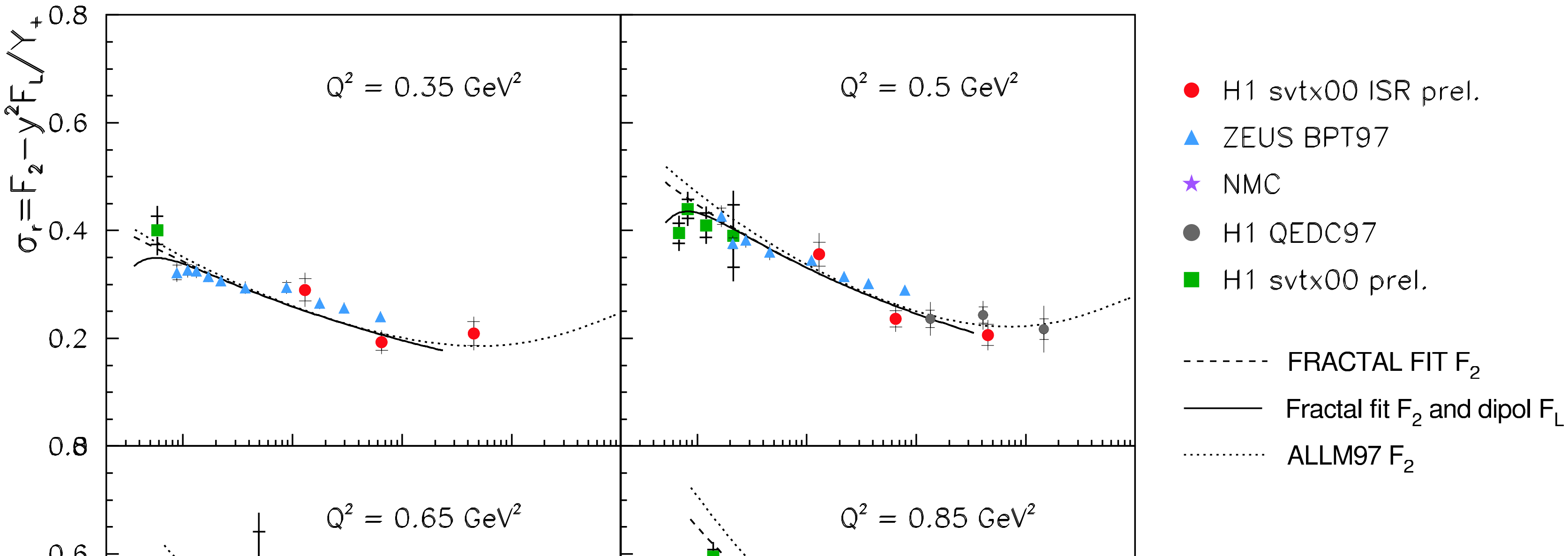
- γ is undetected
- photoproduction background rejected by BST

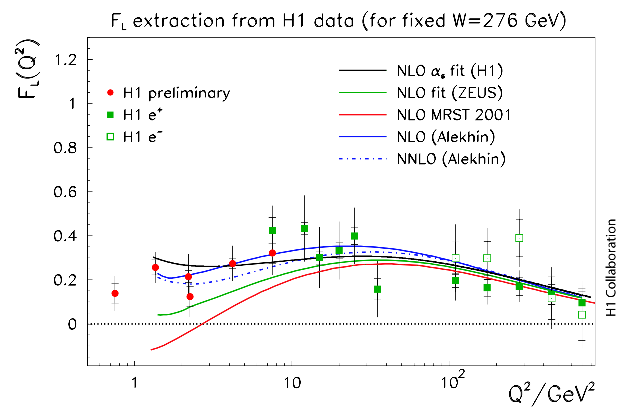
- reconstruction of initial electron energy by $E - p_z$:

  $2E_e = (E - p_z)_{e'} + (E - p_z)_{\text{had}}$



Untagged ISR in Shifted Vertex Runs: F_2



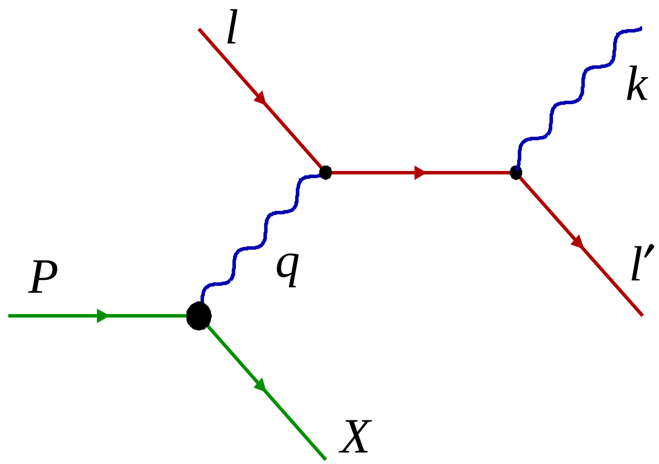


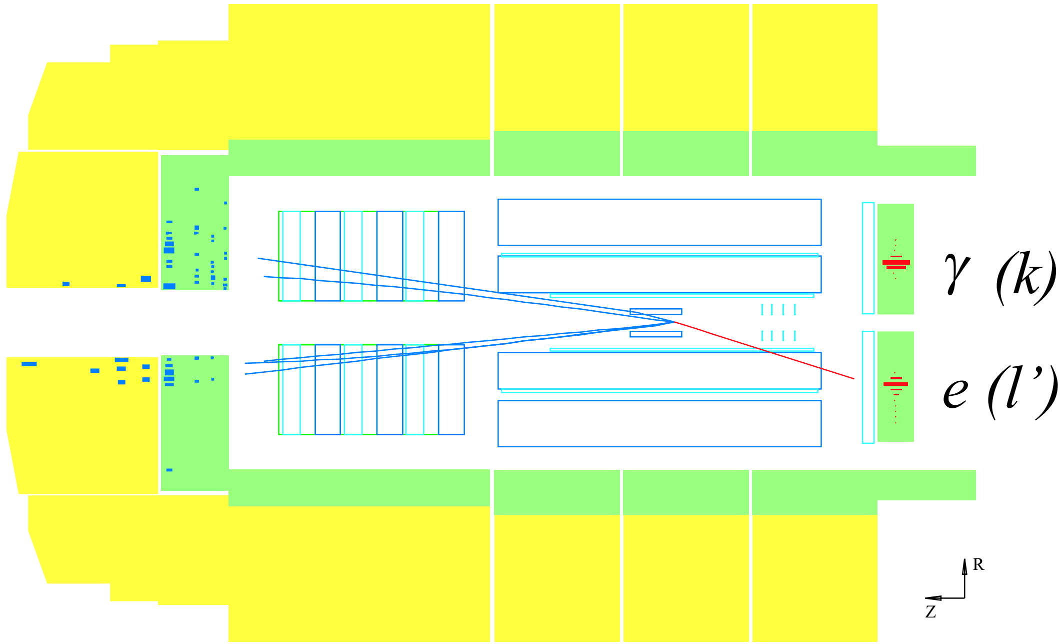
$\Rightarrow$ ISR extends shifted vertex measurement at low Q^2 to higher x

difference between reduced cross section and F_2 at low x allows F_L measurement

Inelastic QED Compton Events

$$e + p \rightarrow e + \gamma + X$$

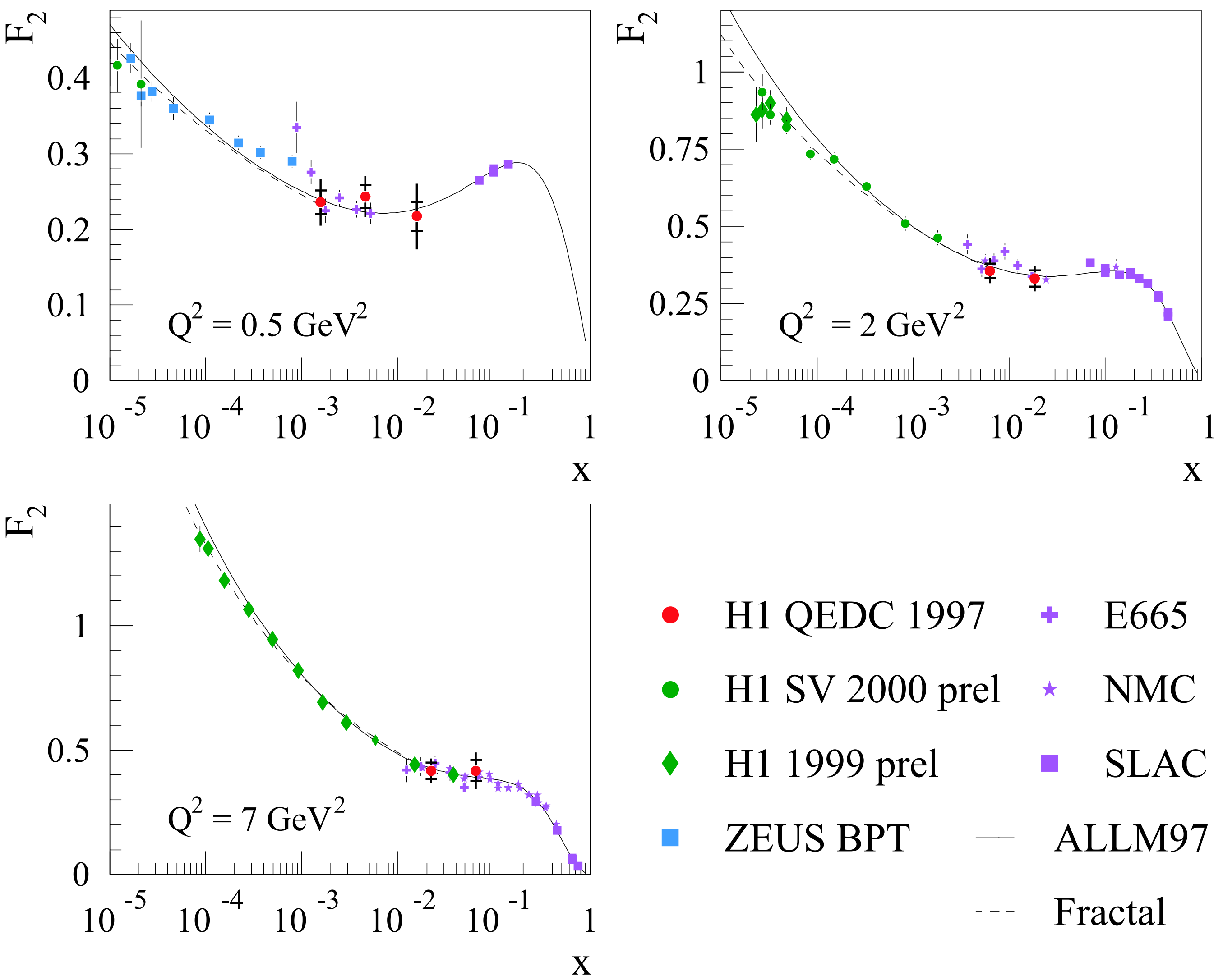




- smaller θ of the final state electron and photon
- larger θ of the intermediate electron $\Rightarrow$ access to low Q^2

- DIS background: – π^0 fakes QEDC photon
  – dominates at low x

Inelastic QED Compton Events: F_2



⇒ high x: overlap with fixed target experiments, good agreement

$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ Measurement

Goal: measure structure function for heavy quarks
as inclusively as possible

$\Rightarrow$ use impact parameter of as many tracks as possible

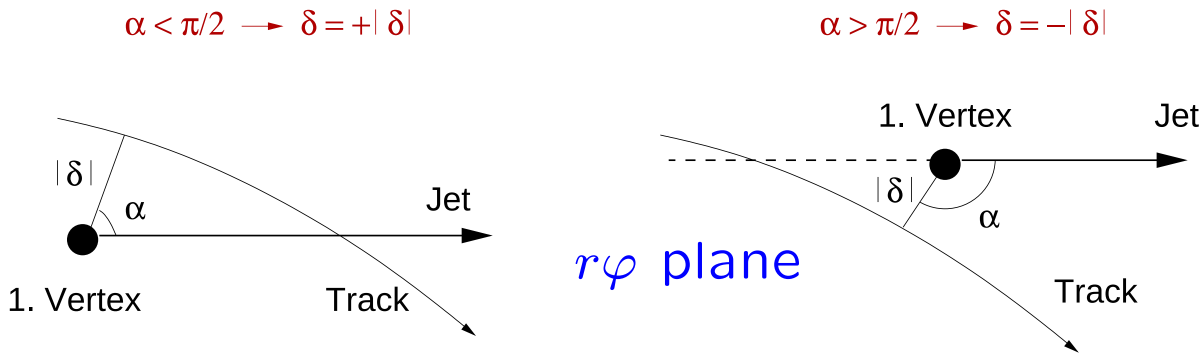
two Q^2 regions:

- high Q^2: scattered electron in LAr: $Q^2 > 150\,\text{GeV}^2$
  (Eur. Phys. J. C**40** (2005) 349, hep-ex/0411046)
  - high beauty fraction ($\sim 3\%$)
  - high p_t of hadronic final state
- medium Q^2: scattered electron in Spacal: $3.75 < Q^2 < 60\,\text{GeV}^2$
  experimentally much more difficult!

$\Rightarrow$ details and plots in the following for medium Q^2 analysis

$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$: Experimental Method

Study the signed impact parameter in the $r\varphi$ plane for all tracks with precise masurement from Central Silicon Tracker (CST)

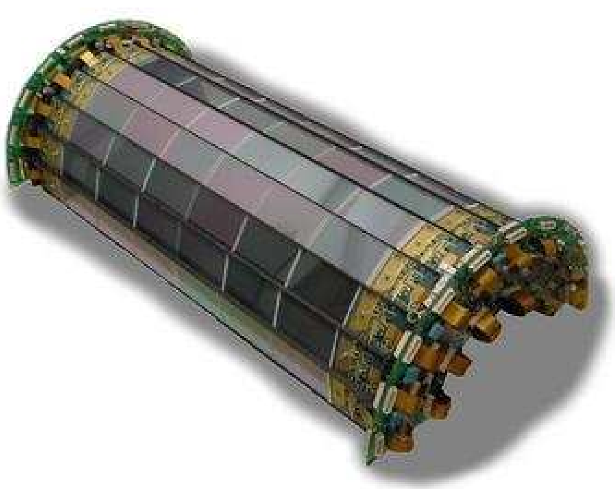


- sign determination needs a reference axis approximating the original quark direction

events with decays of long-lived heavy flavour particles will have large positive impact parameters w.r.t. the primary vertex

light flavour primary decays will have small negative and positive impact parameters due to resolution effects

The H1 Central Silicon Tracker



- 2 cylindrical layers of double-sided silicon strip detectors surrounding the beam pipe
- radii 5.7 cm and 9.7 cm
- angular coverage: $30^\circ < \theta < 150^\circ$
- hit resolution: $12\,\mu$m in $r\varphi$,
  $25\,\mu$m in z
- impact parameter resolution (for central tracks with CST hits in both layers):
  $$33\,\mu\text{m} \oplus \frac{90\,\mu\text{m}}{p_T}[\text{GeV}]$$
- hit efficieny: 97% for $r\varphi$ hits

Determination of Reference Axis: Jets vs. HFS

two possible methods to determine the reference axis:

- jet axis of the highest p_T jet
- four-vector of the Hadronic Final State:
  $\varphi_{\text{ref.axis}}$ approximated by opposite φ to electron

jet measurement much more precise than HFS

$\Rightarrow$ jet cuts as low as possible to have high jet fraction

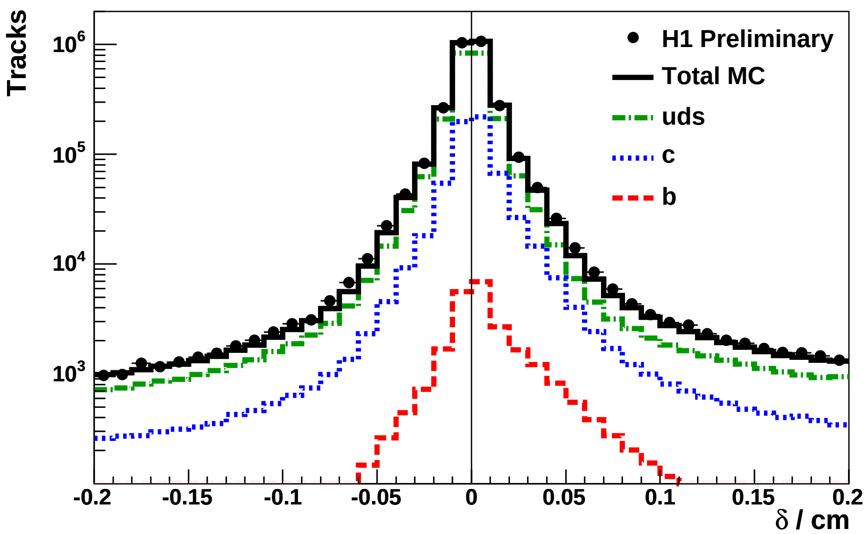
- inclusive k_T algorithm in the lab frame
- $p_T > 4\,\text{GeV}$
- $15^\circ < \theta < 155^\circ$

low jet fraction at low Q^2 due to small p_T of hadrons

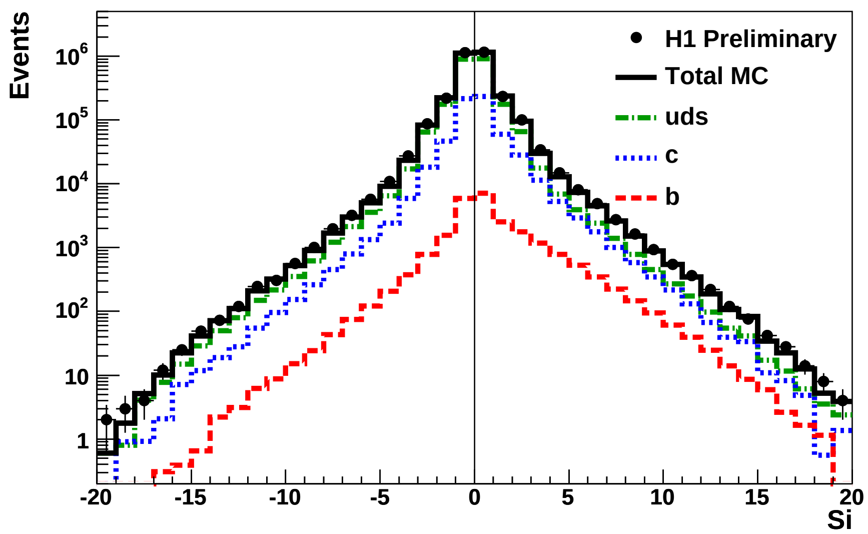
Impact Parameter and Significance

- tracks matched to reference axis within $\Delta\varphi_{\mathrm{ref.axis}} < \pi/2$
- for matched tracks, plot impact parameter δ in $r\varphi$ plane
  cut $|\delta| < 0.1\,\mathrm{cm}$ to remove e.g. K^0s
- significance of each track given by $S_i = \delta/\sigma_\delta$

Impact Parameter



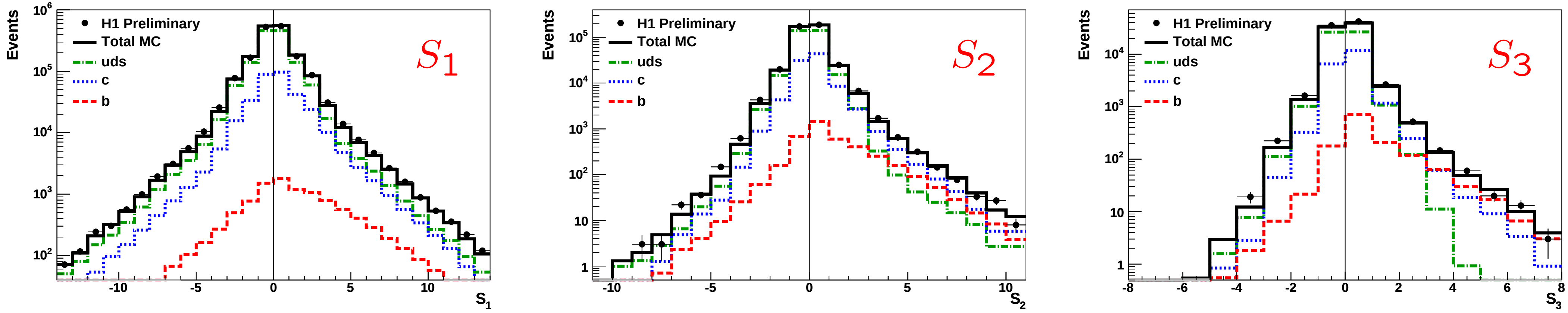
Significance



Significance Distributions

at medium Q^2 beauty fraction is smaller than at high Q^2

$\Rightarrow$ need 3 distributions to separate b, c, and uds (2 at high Q^2)

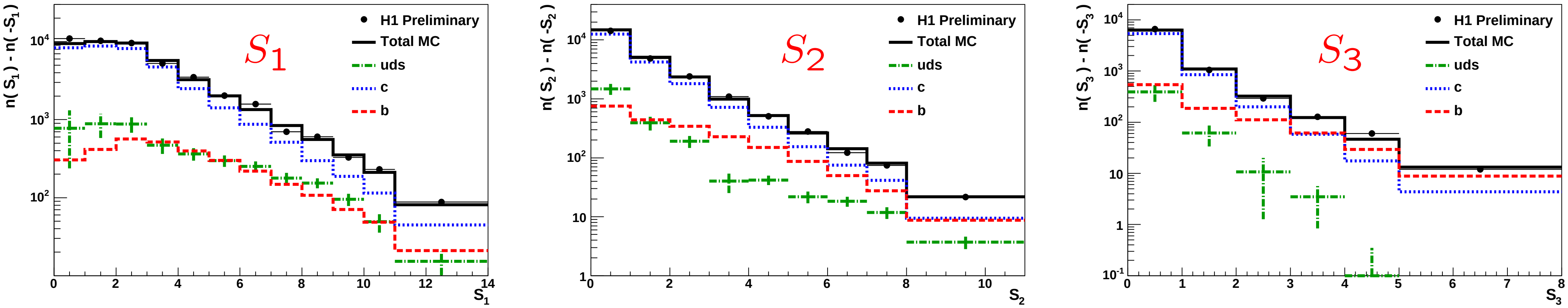


- S_1 signif. of highest significance track
- S_2 signif. of 2nd highest significance track with same sign as S_1
- S_3 signif. of 3rd highest significance track with same sign as S_1 and S_2

'Negatively Subtracted' Significance Distributions

subtract bins at negative S_i from the corresponding positive bin

$\Rightarrow$ reduce sensitivity to resolution effects



for each $x - Q^2$ bin fit simultanously the subtracted S_i distributions and the total number of inclusive events before the CST track selection with 3 parameters:

- P_c scale factor for charm MC (RAPGAP) $\quad P_c = 1.34 \pm 0.06$
- P_b scale factor for beauty MC (RAPGAP) $\quad P_b = 1.43 \pm 0.17$
- P_l scale factor for light quark MC (DJANGO) $\quad P_l = 1.16 \pm 0.01$

Extraction of Cross Section Fractions, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

- reduced charm cross section $\tilde{\sigma}^{c\bar{c}}$:

  $\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \tilde{\sigma}(x,Q^2)\,\frac{P_c N_c^{\mathrm{MCgen}}}{P_c N_c^{\mathrm{MCgen}} + P_b N_b^{\mathrm{MCgen}} + P_l N_l^{\mathrm{MCgen}}}$

  $\tilde{\sigma}(x,Q^2)$ taken from the inclusive H1 measurement

- charm cross section fraction:

  $f^{c\bar{c}} = \tilde{\sigma}^{c\bar{c}}/\tilde{\sigma}$

- charm structure function $F_2^{c\bar{c}}$:

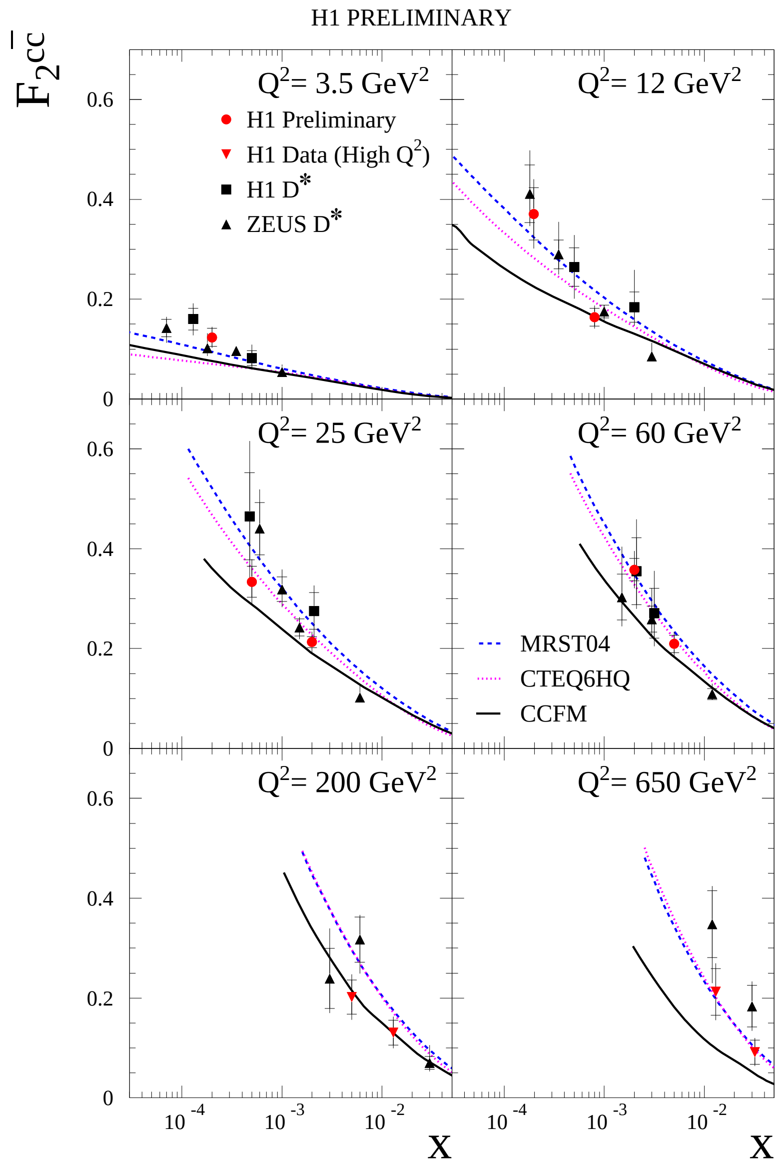
  $\tilde{\sigma}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{1+(1-y)^2} F_L^{c\bar{c}}$

  $F_L^{c\bar{c}}$ estimated from the NLO QCD expectation

Charm Structure Function $F_2^{c\bar{c}}$

- results consistent with H1 and ZEUS D^* measurements
- consistent with pQCD predictions
- highest Q^2 $F_2^{c\bar{c}}$ measurement for H1

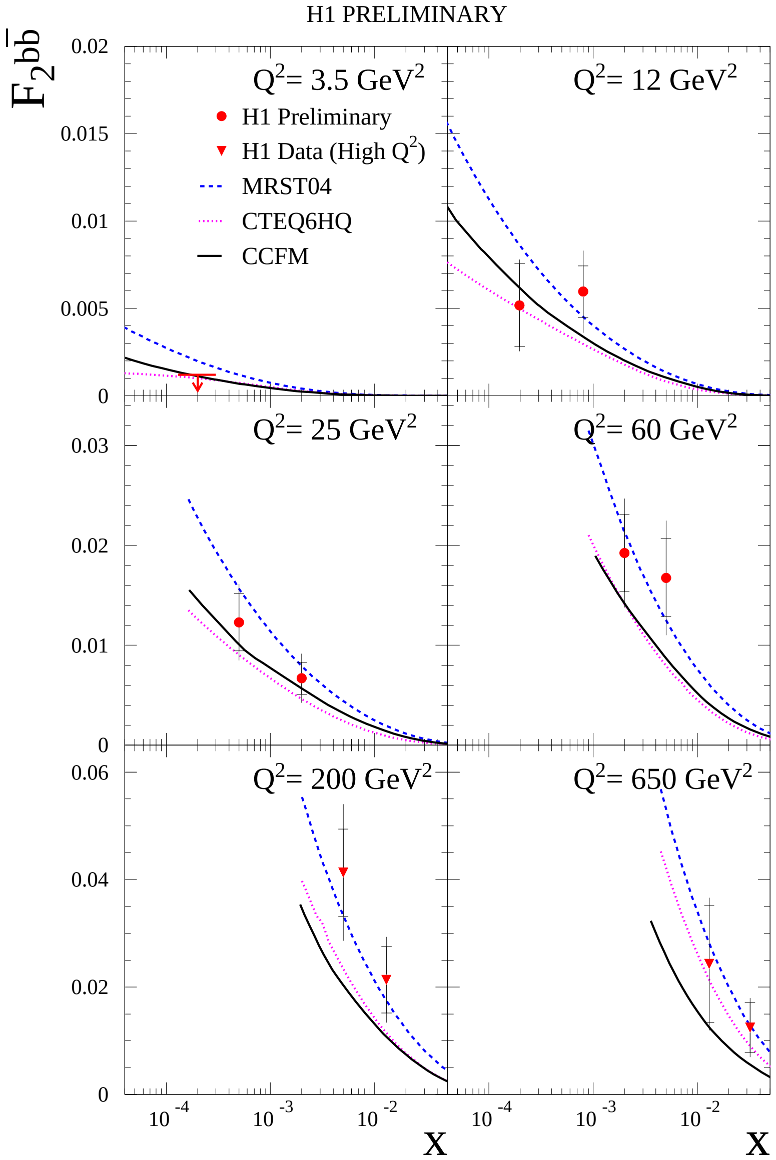
theory curves:
MRST04 - Variable FNS
CTEQ6HQ - Variable FNS
CCFM - Massive BGF



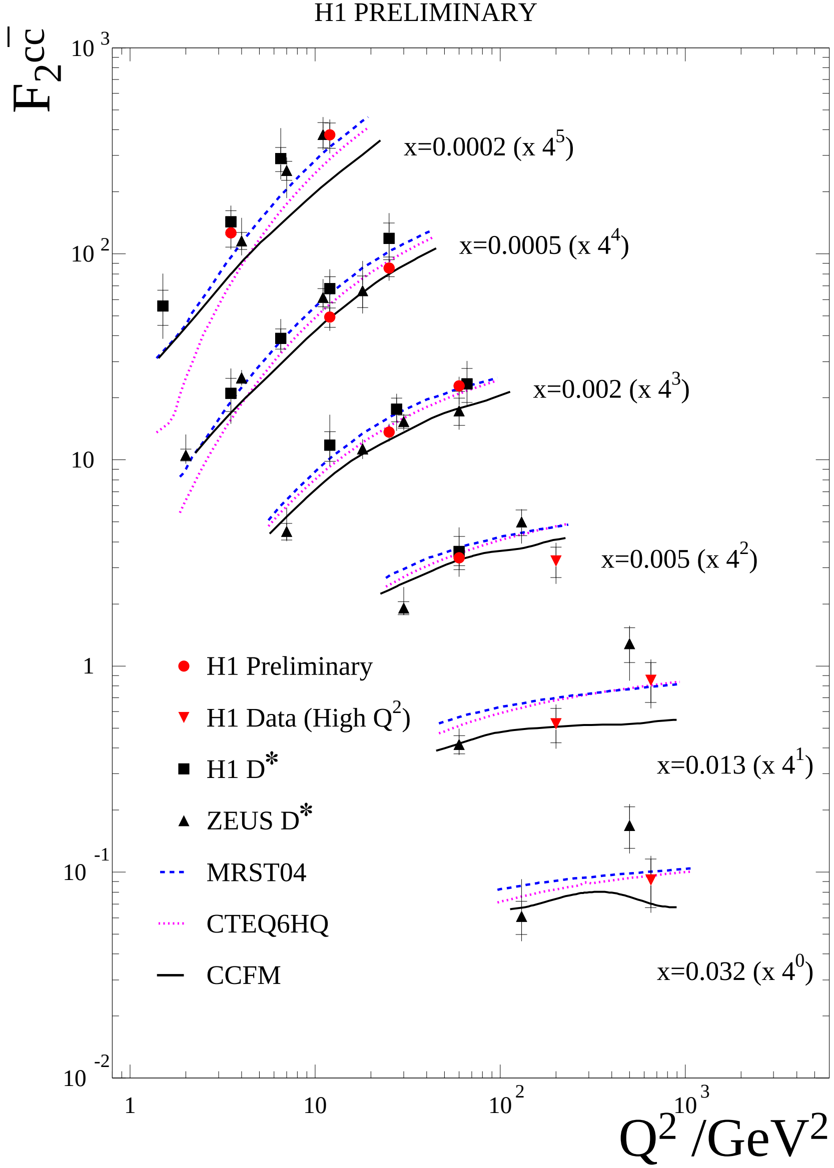
Beauty Structure Function $F_2^{b\bar{b}}$

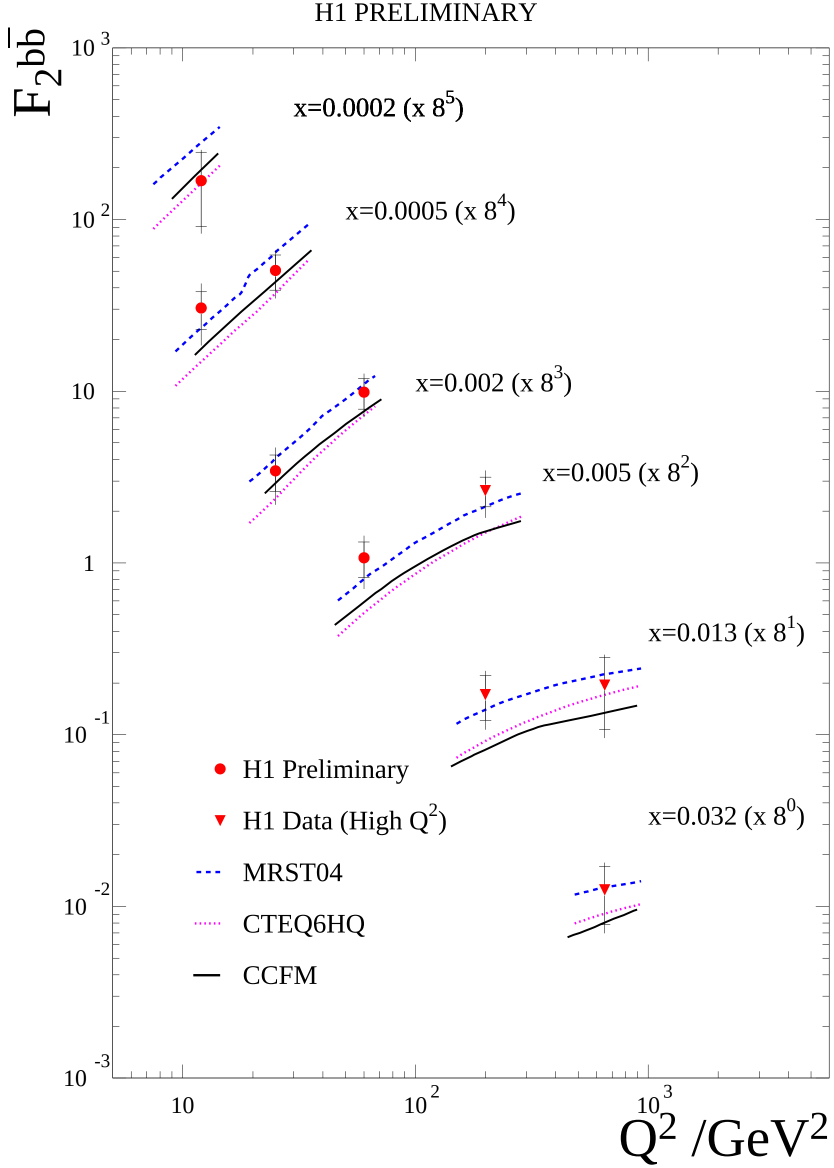
- first $F_2^{b\bar{b}}$ measurement
- lowest Q^2 point consistent with zero
- consistent with pQCD predictions
- MRST04 preferred by data

theory curves:
MRST04 - Variable FNS
CTEQ6HQ - Variable FNS
CCFM - Massive BGF



$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ vs. Q^2

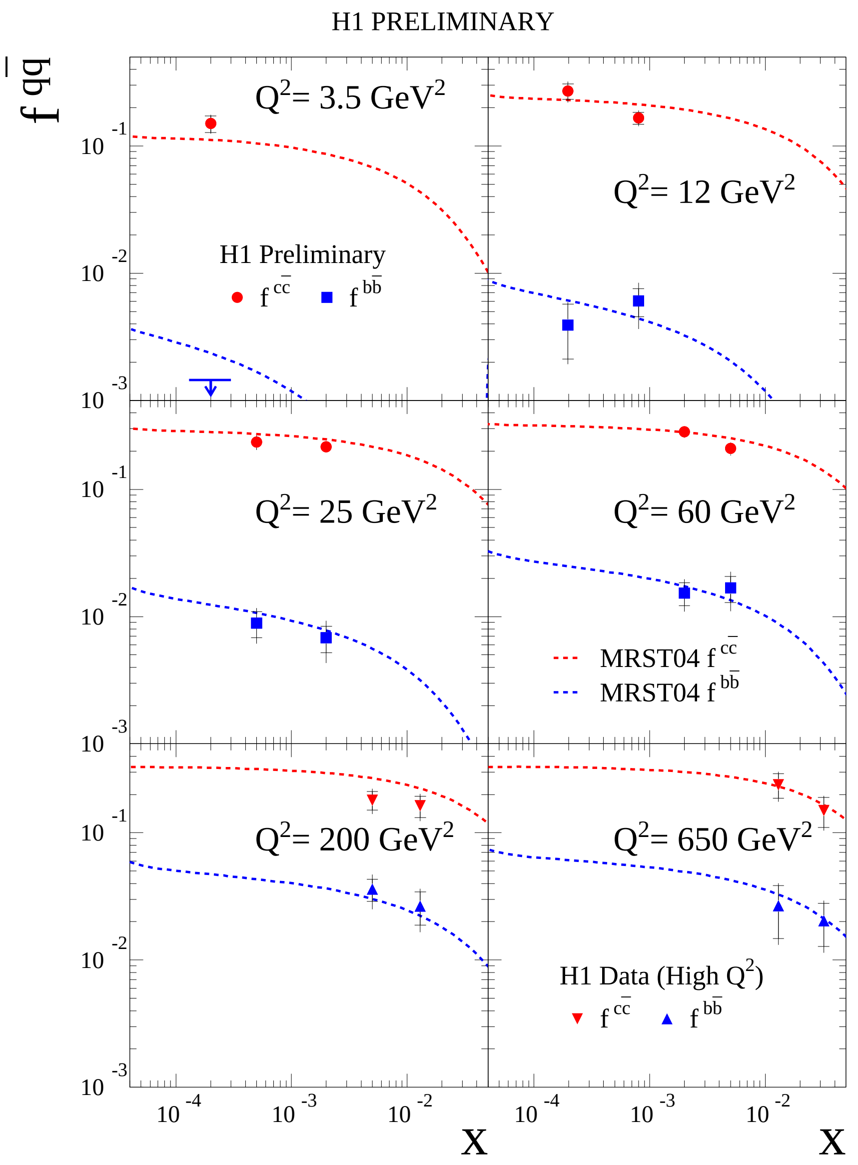




Cross Section Fractions $f^{c\bar{c}}$ and $f^{b\bar{b}}$

- $f^{q\bar{q}} = \tilde{\sigma}^{q\bar{q}}/\tilde{\sigma}$
- c and b fractions increase with Q^2
- c fraction up to $\sim 30\%$
  b fraction up to $\sim\ 3\%$

theory curves:
MRST04 - Variable FNS



Summary

- phase space for F_2 measurements at low Q^2 extended by special techniques like untagged ISR in shifted vertex runs and inelastic QEDC scattering

- inclusive measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at medium and high Q^2 using impact parameter method
  - first measurement of $F_2^{b\bar{b}}$
  - measurements well described by pQCD