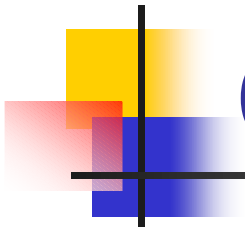
HERA Heavy Flavour Physics

David Bailey

University of Bristol

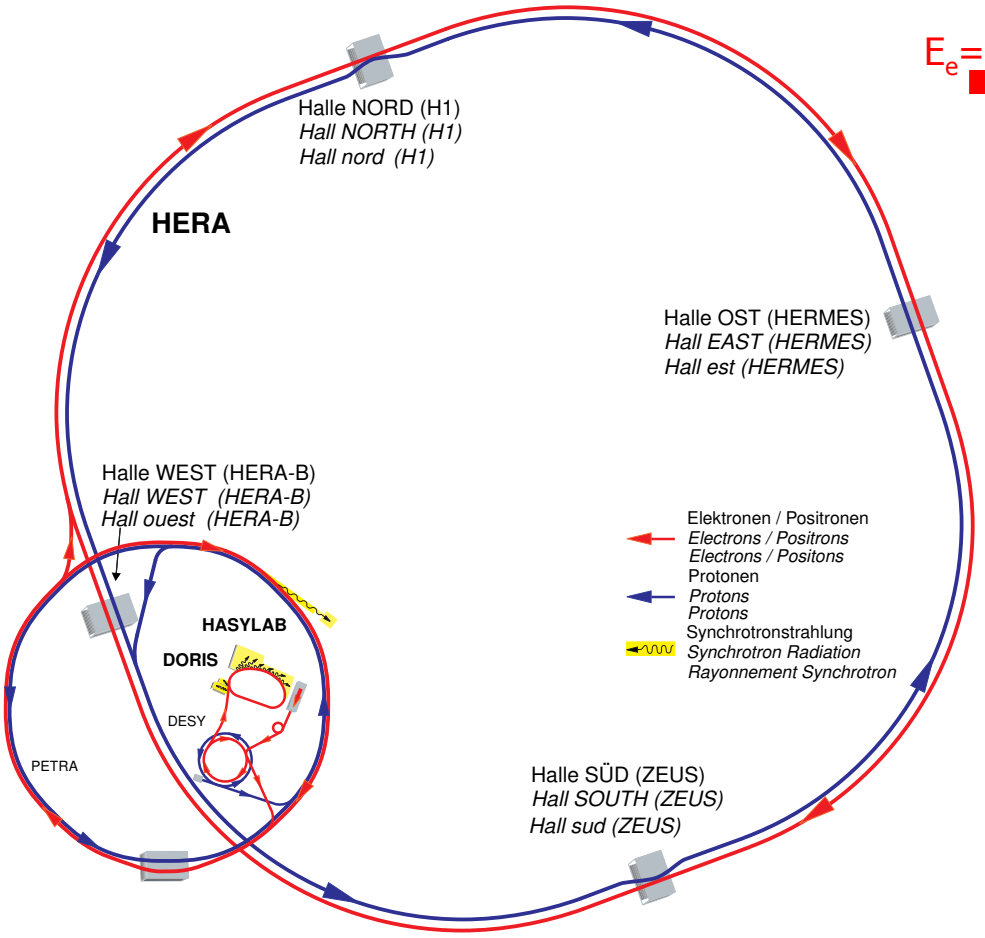
on behalf of the ZEUS and H1 collaborations

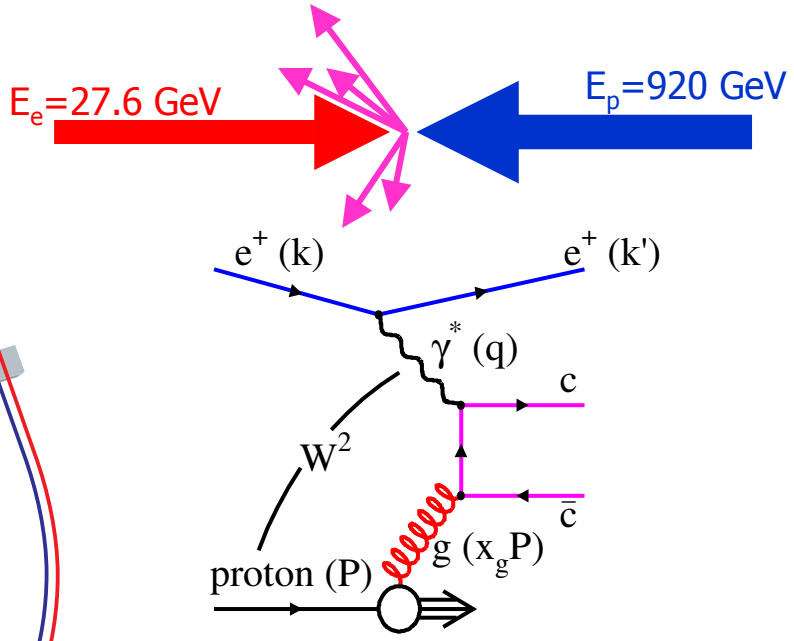


Outline

- This is a conference on "New Trends in HEP"
  - Summarise the current HERA results with emphasis on areas that still need to be understood
  - Look forward to the HERA upgrade and its physics potential for heavy flavour

HERA and its Kinematics



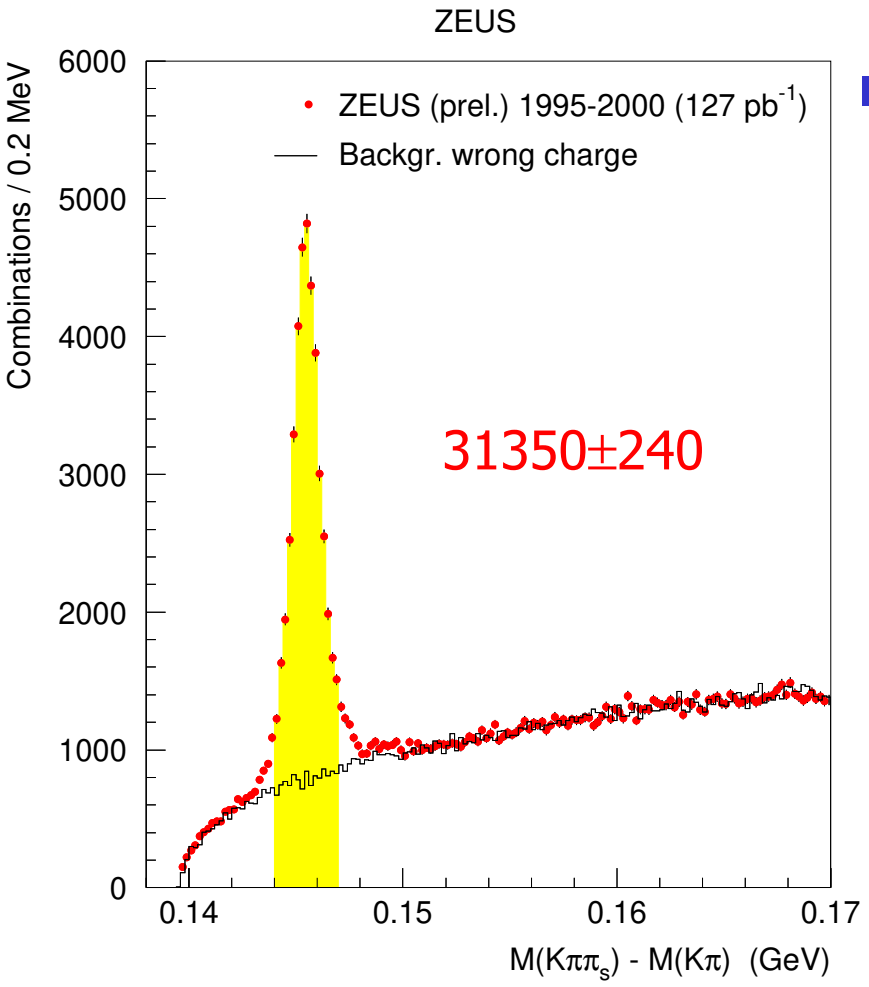


$$s = (P + k)^2$$

$$Q^2 = -q^2 = -(k - k')^2$$

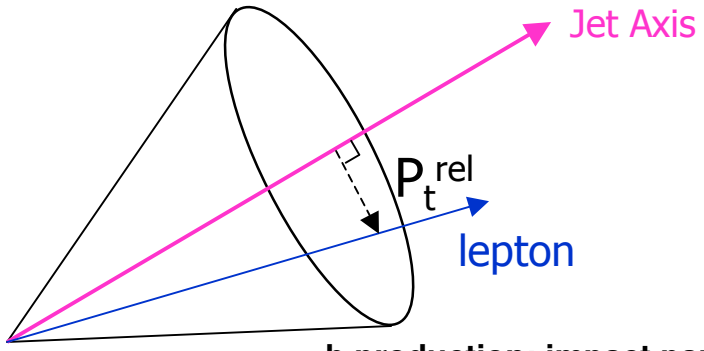
$$y = \frac{q \cdot P}{k \cdot P}$$

Heavy Flavour Tagging

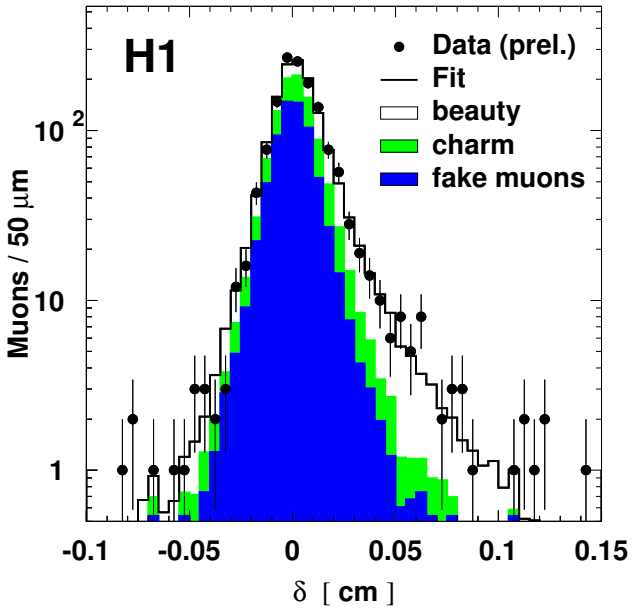


- Charm tagging
  - Primarily uses D^* mesons in decay to $D^0\pi$ with subsequent decay $D^0 \rightarrow K\pi$
  - Other decays and mesons are used
    - $D^* \rightarrow D^0\pi$, $D^0 \rightarrow K\pi\pi\pi$
    - $D_s \rightarrow \phi\pi$
    - Semi-Leptonic electrons
    - J/ψ

Heavy Flavour Tagging



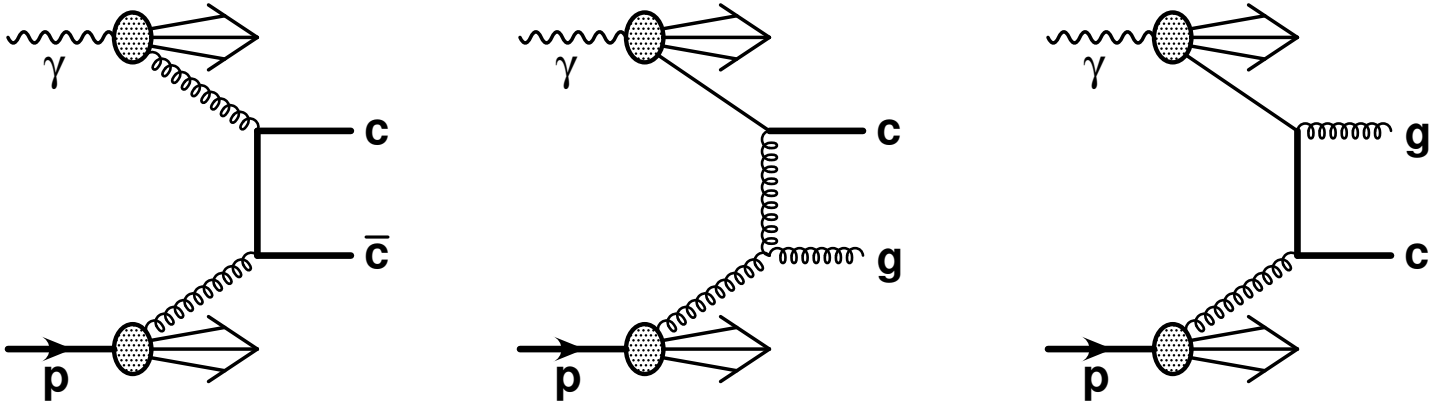
b production: impact parameter



- Beauty Tagging
  - Both experiments use semi-leptonic decays with a P_t^{rel} method
  - H1 also have first results using impact parameter data from silicon vertex detector

Charm in Photoproduction

Resolved Photon Processes



gg fusion | Quark excitation

- This is a LO picture. At all orders we can define:

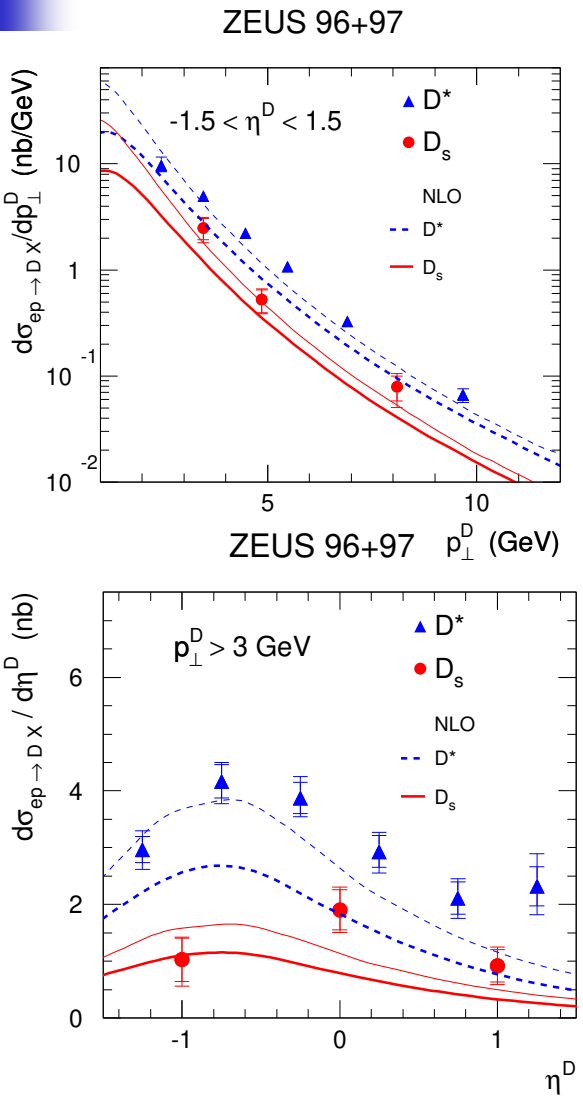
$$x_\gamma^{OBS} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e}$$

the fraction of the photon's momentum participating in dijet production

Heavy Flavour Calculations

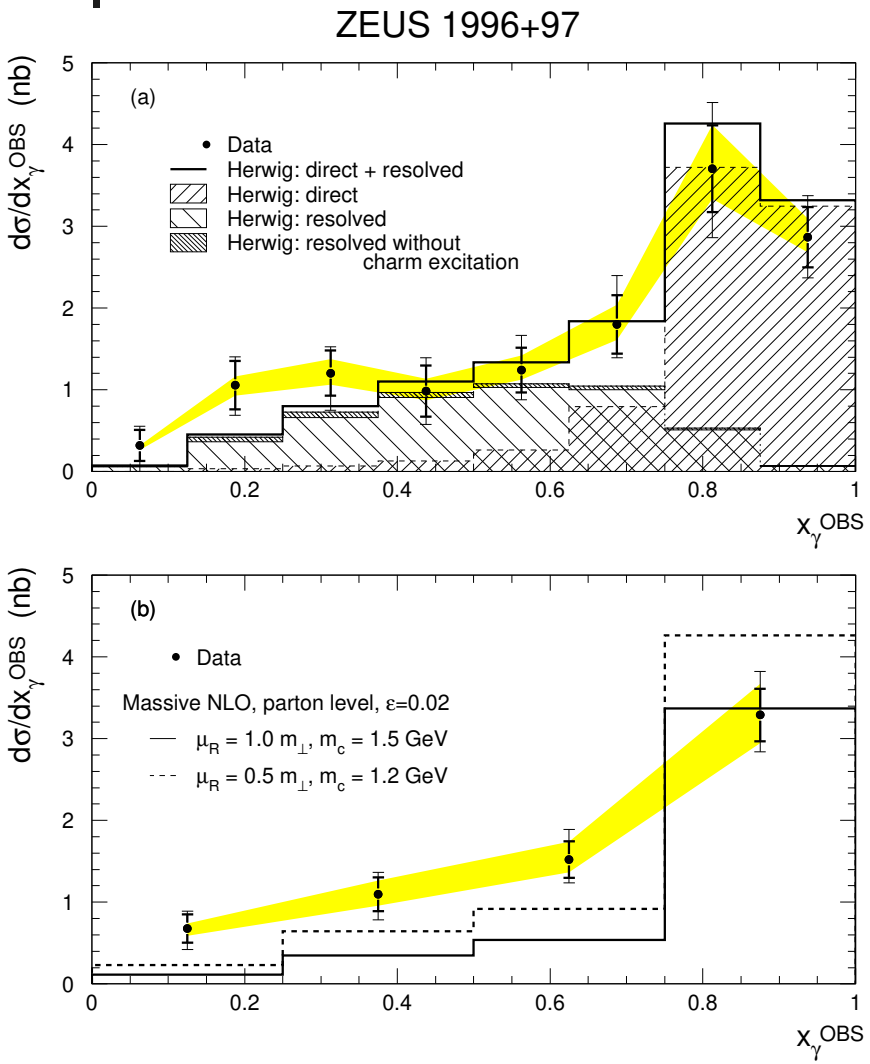
- FMNR NLO Fixed Order ("Massive") scheme for photoproduction
  - Resummed "Massless" calculations also available, but more applicable for $p_t >> m_{c/b}$
- NLO Fixed Order implemented in HVQDIS for DIS
- LO Monte Carlos
  - HERWIG
  - PYTHIA
  - AROMA
  - RAPGAP
  - CASCADE – implements CCFM unintegrated gluon with photon-gluon fusion

Charm in Photoproduction



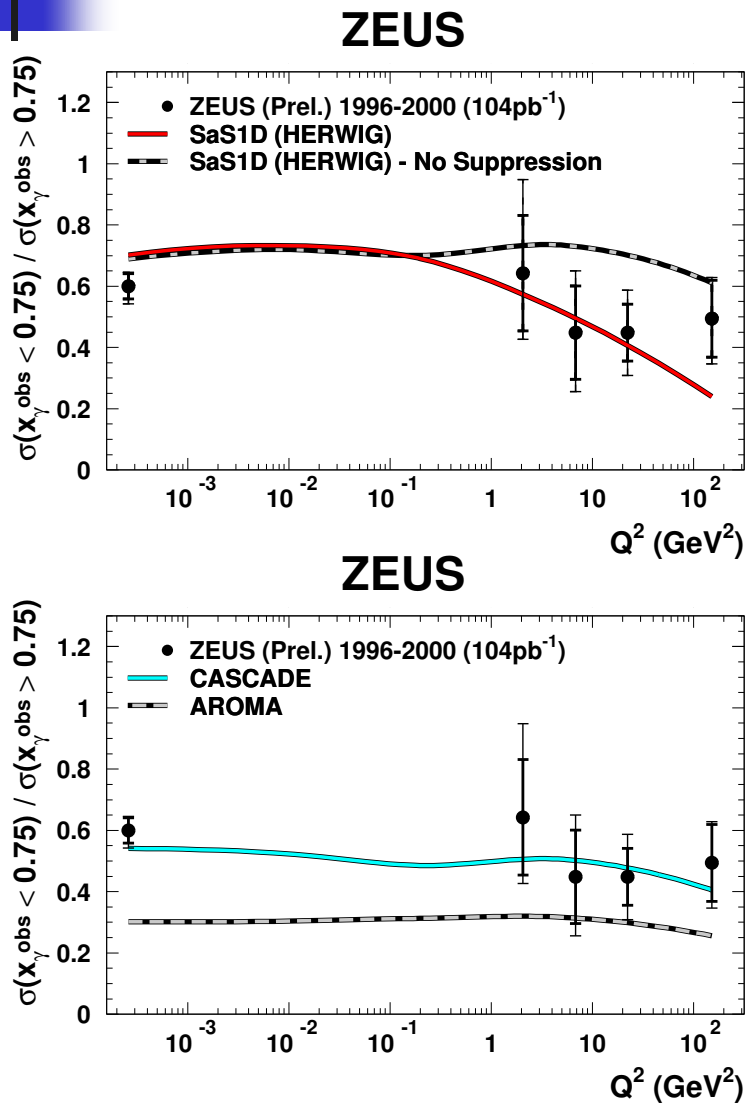
- $Q^2<1$ GeV^2, $130 < W < 280$ GeV
- NLO
  - FMNR with MRSG and GRV-G HO
  - Thick lines $m_c=1.5$ GeV
  - Underestimate measured cross sections by a factor of almost 2
  - Is shape wrong at low P_t?
  - Clear underestimation of the measured cross sections at high η (the proton beam direction). Sign of interaction with the beam remnant?

Charm in Photoproduction



- D^* with at least 2 jets
- Large LO charm excitation in photon (about 40%)
- Fixed order NLO is below the data at low x_γ

Charm in Photoproduction



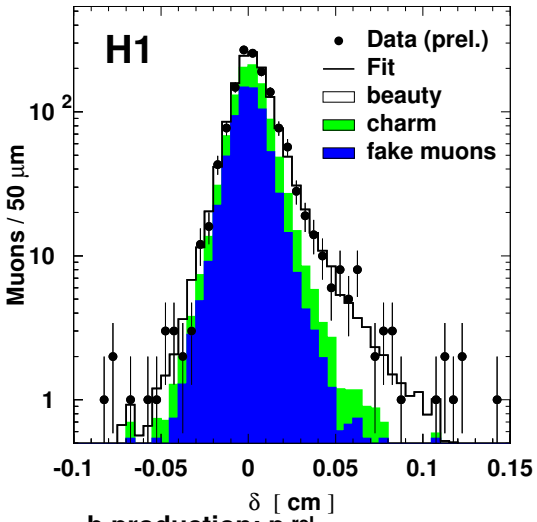
- Transition to DIS
  - Naïvely expect resolved fraction to drop with Q^2 as photon virtuality increases
  - D^* with at least 2 jets
  - Plot ratio

$$\frac{\sigma\left(x_\gamma^{OBS} < 0.75\right)}{\sigma\left(x_\gamma^{OBS} > 0.75\right)}$$

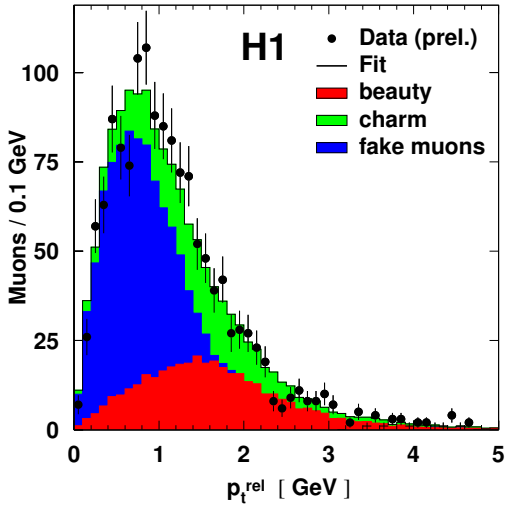
- Is there any suppression with Q^2?
- Cascade prediction agrees with data
  - No explicit resolved component
  - Aroma (direct only) too low

Beauty in Photoproduction

b production: impact parameter



b production: p_t^{rel}

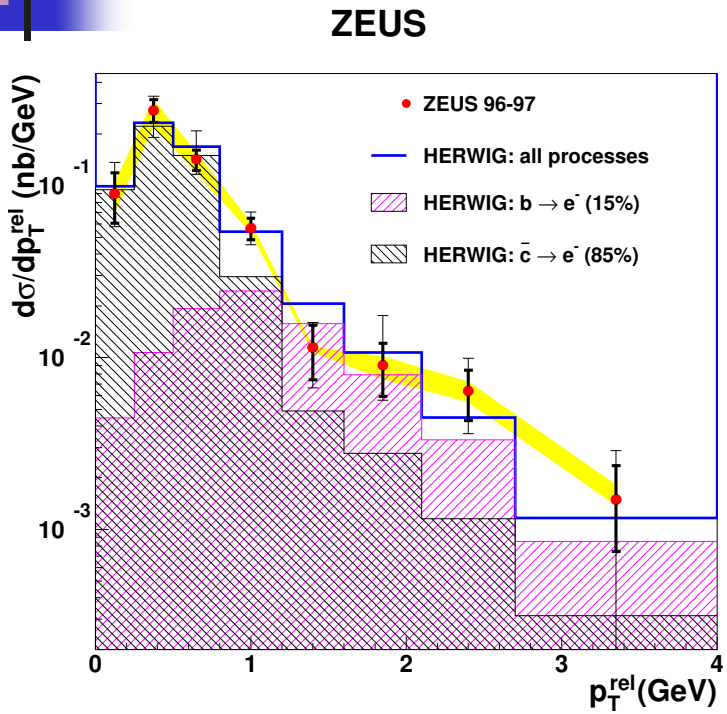


- H1 Muon analysis
- b fraction 27±3%

$$\sigma_{Vis}\left(ep \to b\bar{b}X \to \mu^{\pm}X\right) = 170 \pm 25\,\text{pb}$$

- Compare to predictions:
  - NLO (FMNR) 54±9 pb
  - Aroma (LO, no resolved) 38 pb
  - Cascade 67 pb
- All significantly below data

Beauty in Photoproduction

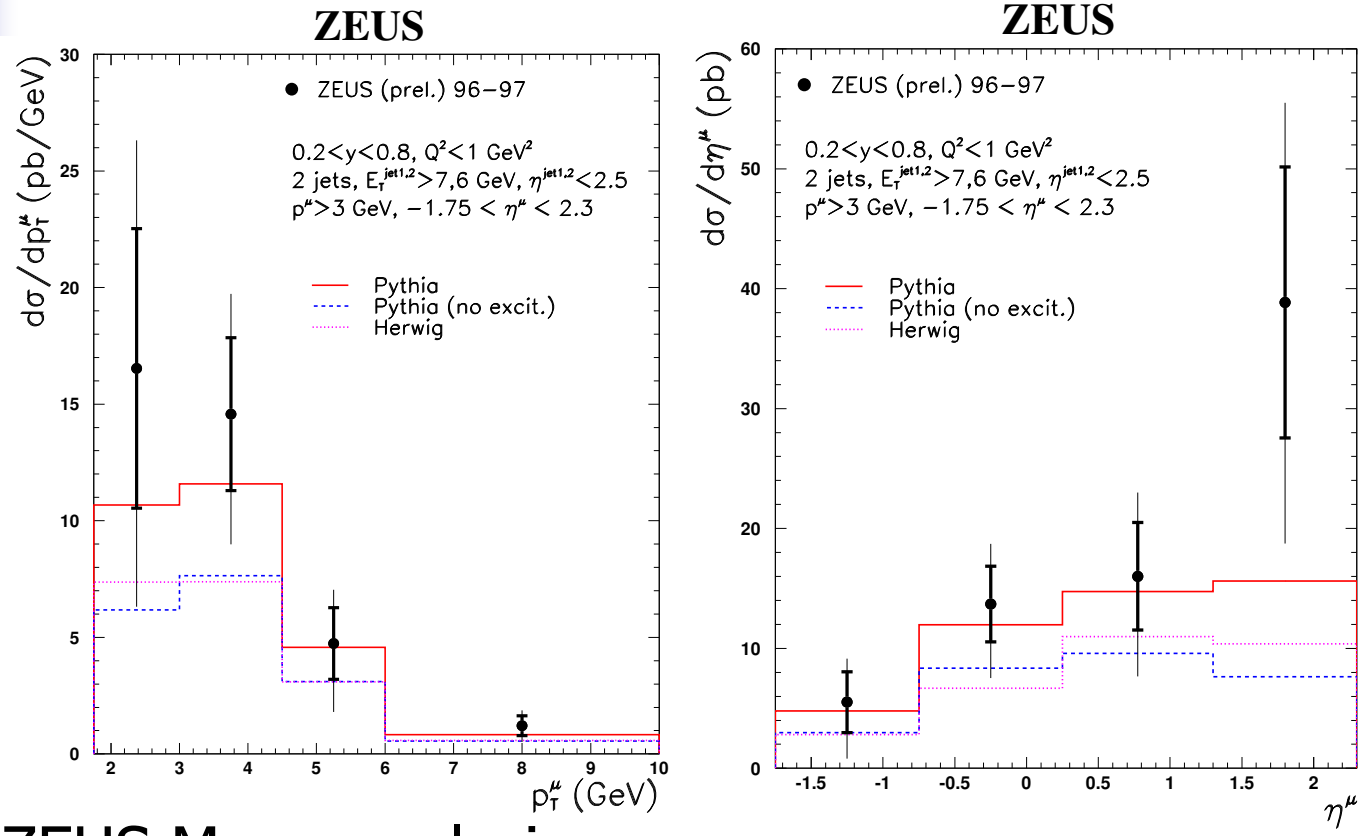


- ZEUS Electron analysis
  - Use calorimeter and dE/dx from tracks to identify electrons

$$\sigma^{b\to e^-}_{e^+p\to e^+ + \text{dijet} + e^- + X} = 24.9 \pm 6.4(\text{stat})^{+4.2}_{-7.3}(\text{sys})\ \text{pb}$$

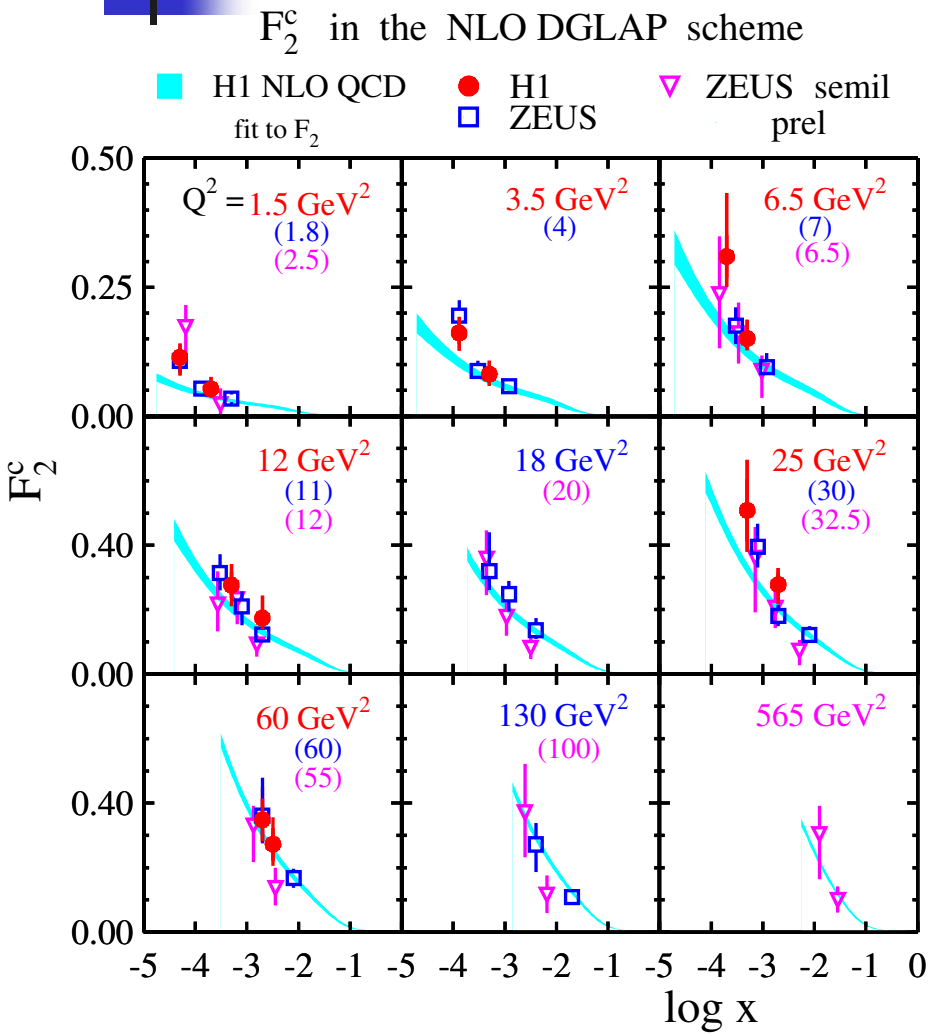
- Again, calculations are on the low side:
  - Herwig 8pb, Pythia 18pb, Cascade 18pb

Beauty in Photoproduction



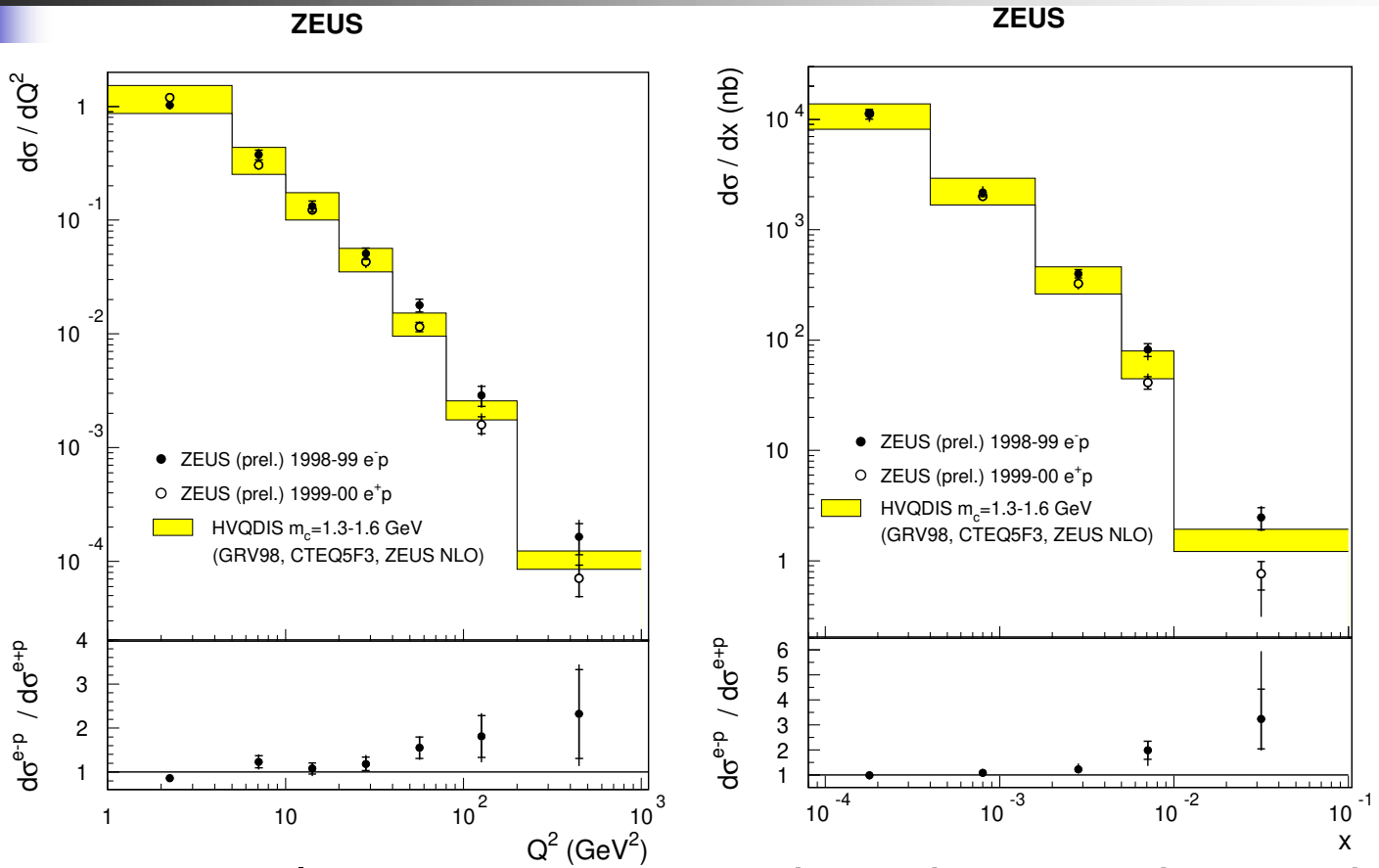
- ZEUS Muon analysis.
  - Pythia with b excitation describes data reasonably well, but data lie above predictions in the forward direction.
  - Waiting for NLO.

Charm in Deep Inelastic Scattering



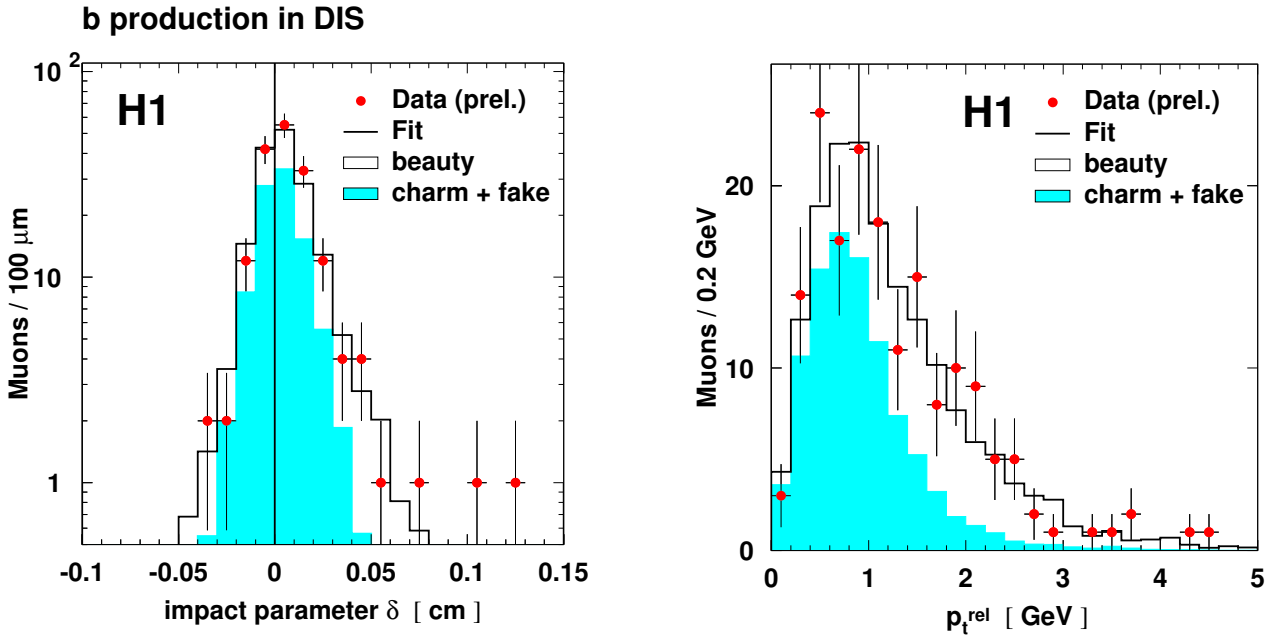
- Both experiments have measured F_2^{charm}
  - Problem in theoretical definition and model dependence through extrapolations.
- Both ZEUS and H1 agree, and ZEUS results consistent between different decay modes.

Charm in Deep Inelastic Scattering



- Do new results comparing e^+p and e^-p charm production show a discrepancy? e^+ and e^- data are barely consistent, but both are still consistent with NLO predictions due to large uncertainty from charm mass.

Beauty in DIS

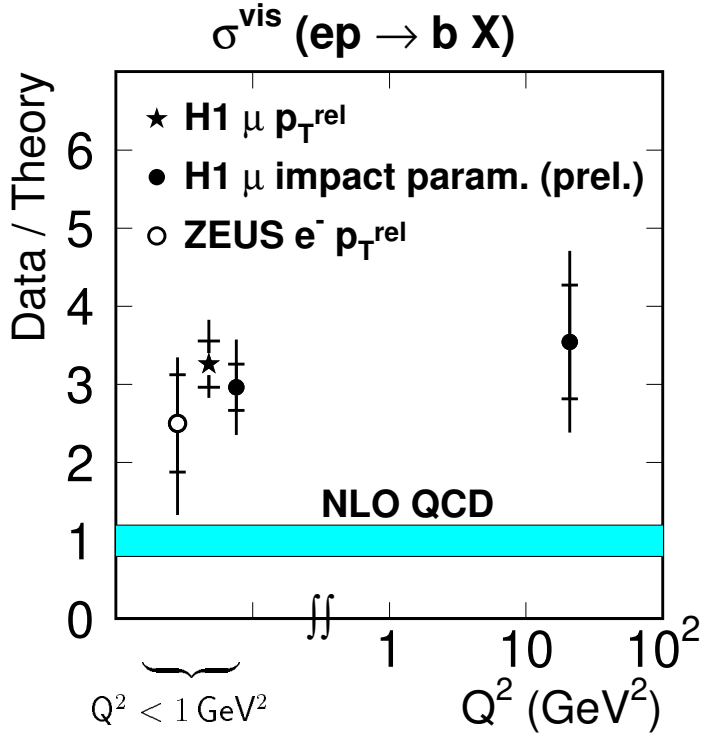


- H1 have new results on beauty production in DIS
  - Same technique as the photoproduction analysis
  - μ with P_t^{rel} and lifetime tagging using silicon vertex detector information
  - Fit gives b fraction = 43±8%

Beauty in DIS

- Cross section

$$\sigma_{Vis}^{ep\to b\bar{b}X\to\mu X} = 39 \pm 8(\text{stat}) \pm 10(\text{sys})\ \text{pb}$$



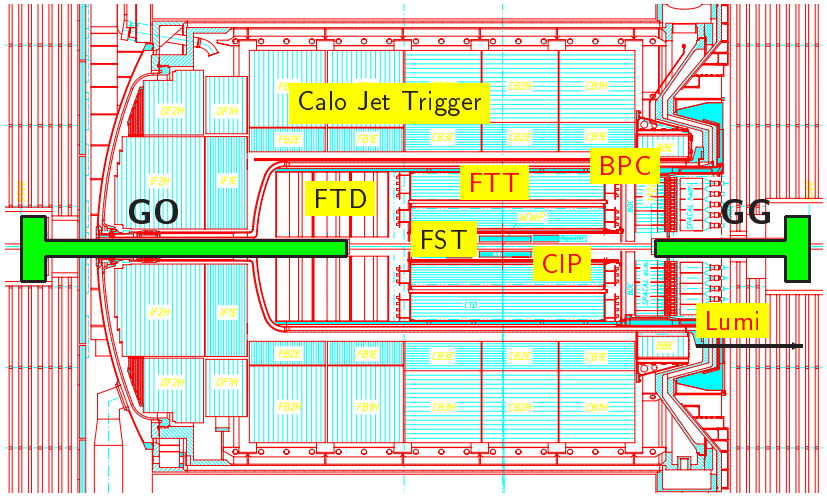
- Compare with calculations:
  - NLO 11±2 pb
  - LO Aroma 9 pb
  - LO Cascade 15 pb
- Summary of beauty data shows a consistent excess of measured cross sections over theoretical predictions

The HERA Upgrade

- Major upgrades to both the machine and detectors

	HERA I	**HERA II**
Inst. Lumi	1.5×10^{31}	7×10^{31}
Beam Spot	$150 \times 30\ \mu m^2$	$80 \times 20\ \mu m^2$
Integrated Lumi	$0.1\ fb^{-1}$	$1\ fb^{-1}$
Lepton Polarization	N/A	60%

Detector Upgrades



modifications

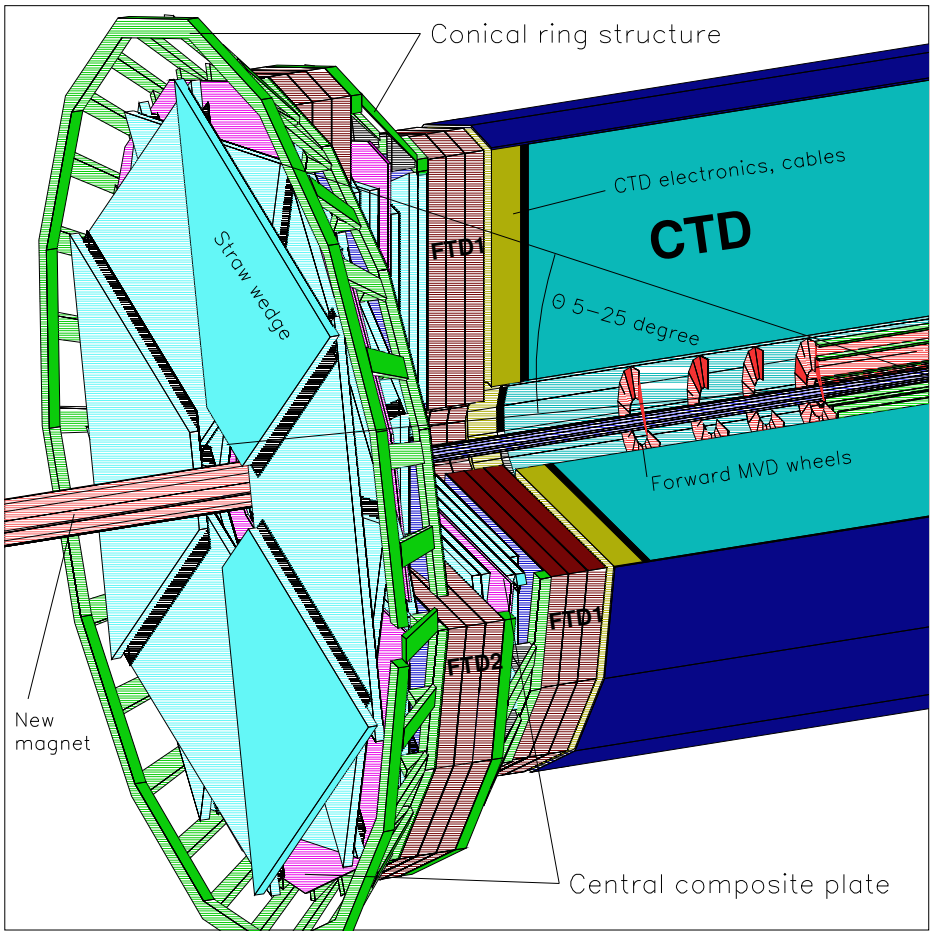
- backward ToF
- SpaCal
- beam pipe
- backward Si Tracker
- central Si Tracker
- LAr G0 Support
- Plug
- forward ToF
- FPS/FNC
- Polarimeter

upgrades

- Fast Track Trigger (FTT)
- Lumi Monitors
- Inner Prop. Chamber (CIP)
- Backward Prop. Chamber (BPC)
- Forward Tracker (FTD)
- Calo Jet Trigger
- Forward Si Tracker (FST)

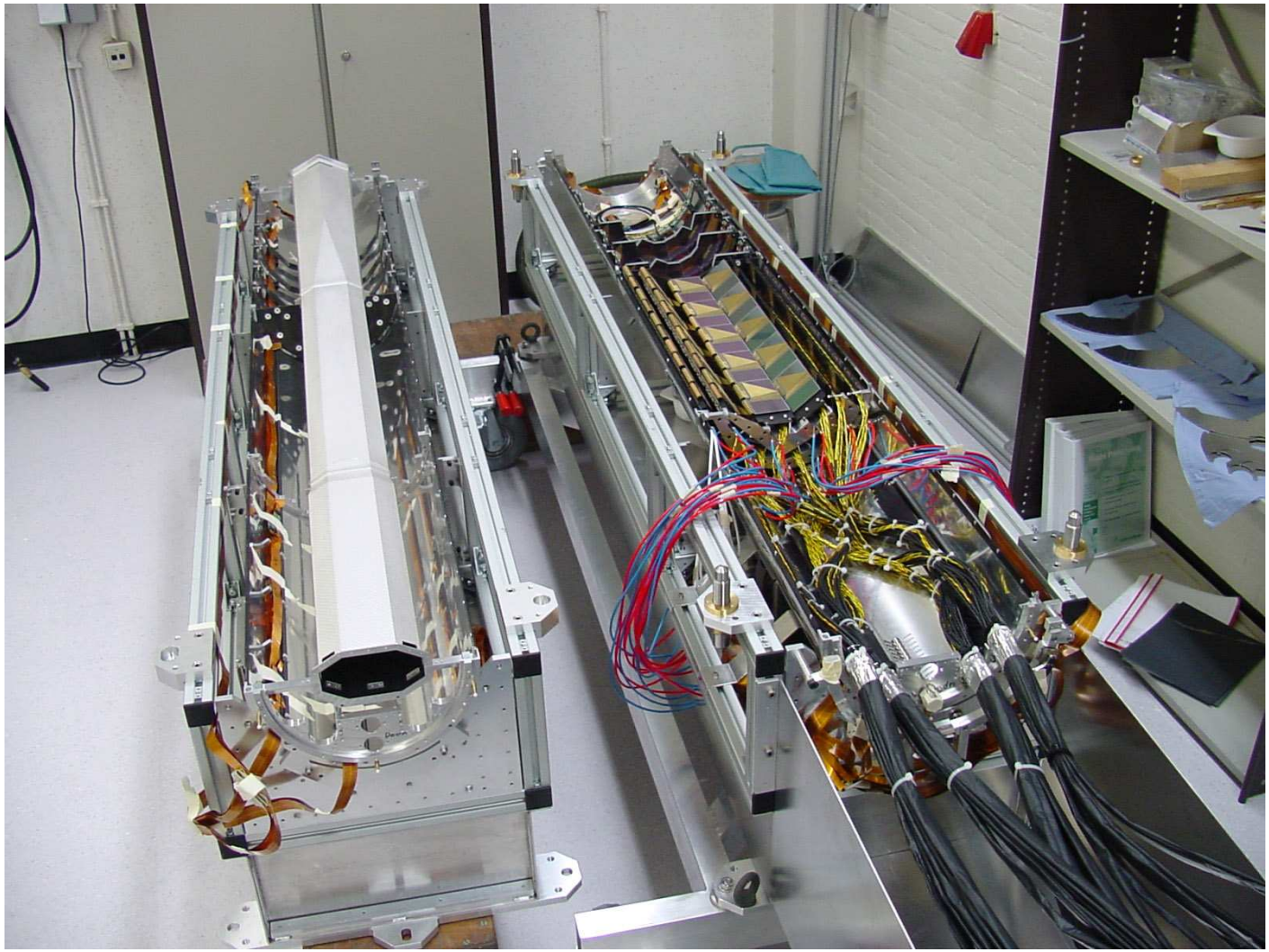
- H1 major upgrades with a direct impact on heavy flavour
  - Fast Tracking Trigger
  - Forward Silicon Detectors and upgrades to central silicon

Detector Upgrades

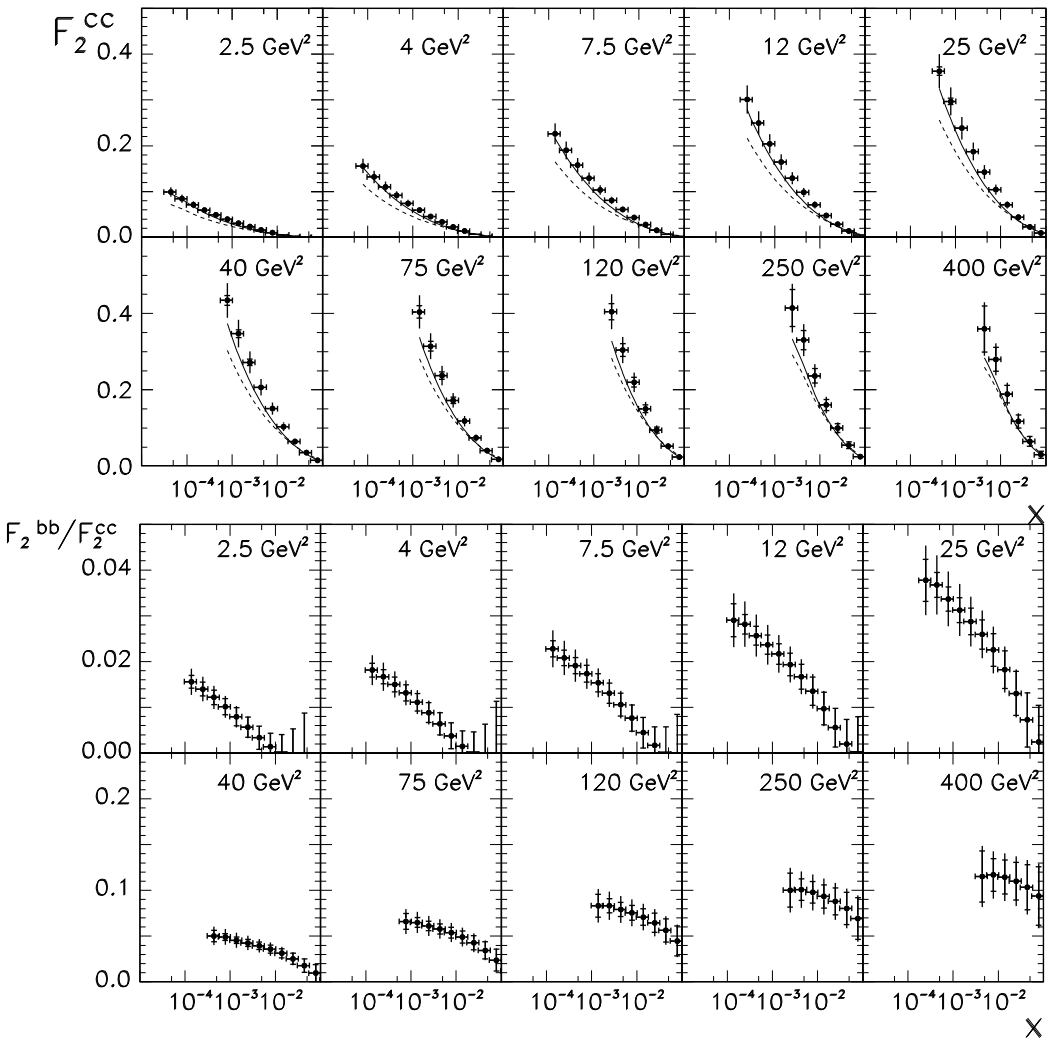


- ZEUS have a similar upgrade program
  - Brand new silicon vertex detector
  - Forward tracking upgrade using straw tubes
  - Upgraded tracking triggers

The ZEUS Microvertex Detector



Physics with HERA II and beyond



- Potential measurements of F_2^{charm} with 0.5 fb^{-1}
- High precision measurements of F_2^{b}

Physics with HERA II and beyond

- A great opportunity for heavy flavour physics
  - Precise differential cross sections
  - Extend to new areas
    - Charm in charged current DIS
    - Measurements of the gluon
- But we also need theoretical upgrades!
  - NLO Monte Carlo?
  - Improved calculations, both in photoproduction and DIS
    - NNLO
    - Matched calculations (combine fixed order and resummed calculations)

Summary

- HERA I has produced a wealth of information on heavy quarks
  - Charm
    - Photoproduction cross sections lie above predictions
    - x_γ^{obs} measurements show a large (DGLAP) LO resolved component. Fixed order NLO underestimates this contribution
    - DIS measurements show consistency in F_2^{charm} between experiments, but are we beginning to see differences between e^+ and e^-?
  - Beauty
    - First results now emerging show production cross sections higher than predicted. Clearly we await more data to improve the measurements and address this issue