Charm and Beauty Production from Secondary Vertexing at HERA

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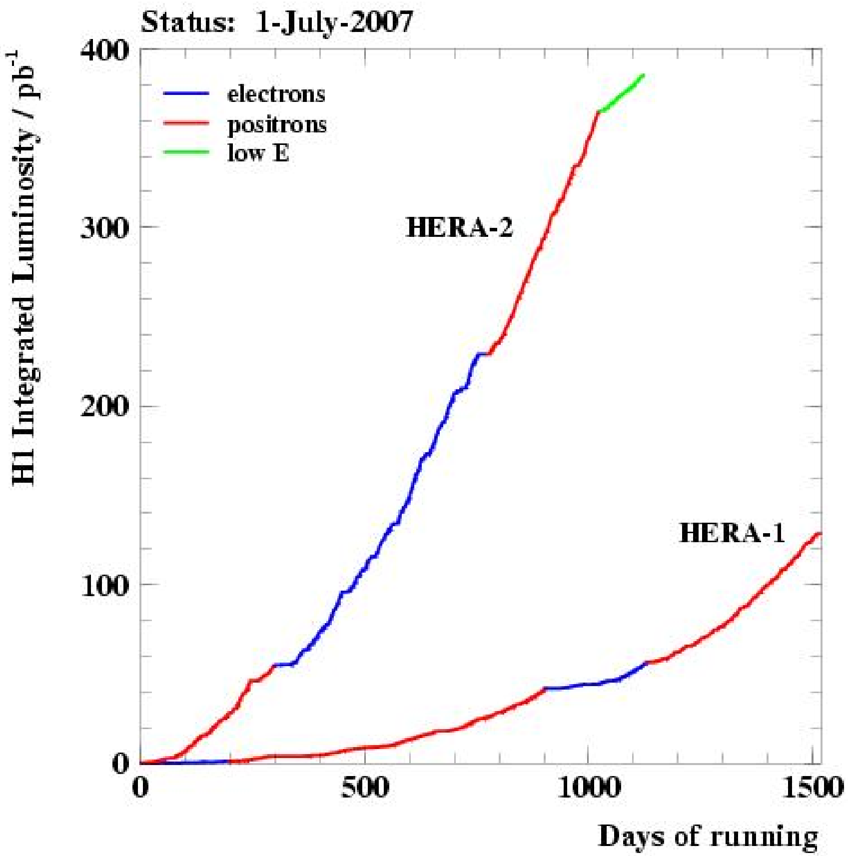
for the H1 and ZEUS Collaborations

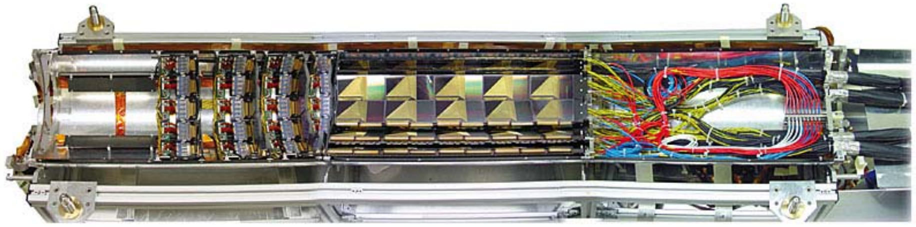
- Motivation and analysis method
- Heavy Flavour jets in photoproduction
- Heavy Flavour jets in Deep Inelastic Scattering
- Contribution of Heavy Flavours to proton structure

ICHEP 2010, Paris 22nd-28th July, 2010

Heavy Flavour Analyses



- In total ~500pb^{-1} of high energy data collected per experiment
- luminosity upgrade in 2001
- detectors adjusted
- ZEUS: silicon micro vertex detector

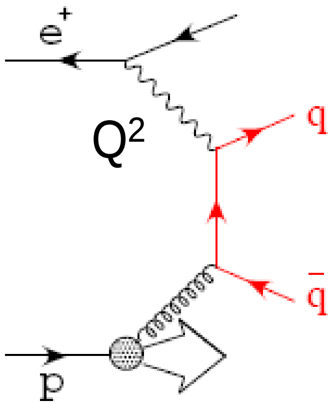


Many heavy flavour final analyses on full HERA I+II data. Working on publication of remaining preliminaries and combination of results

Production of Heavy Quarks

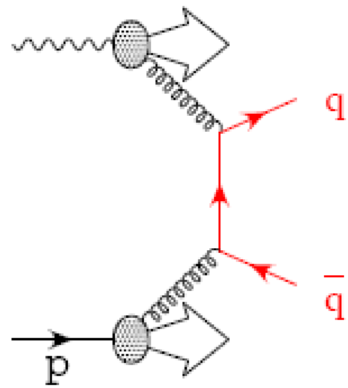
Contribution of quasi-real photons at low Q^2

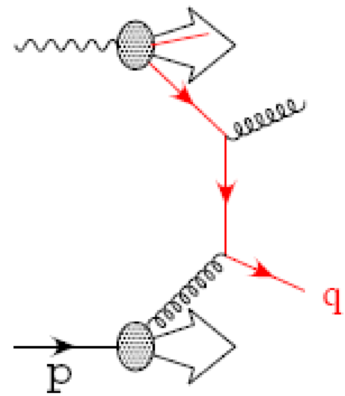
Direct γ

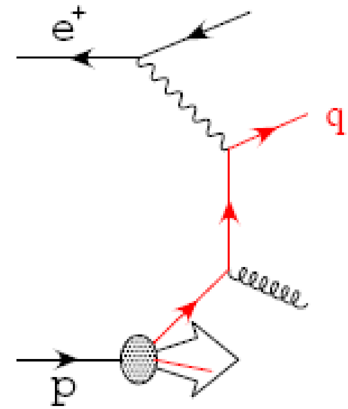


Resolved γ

(flavour excitation)







$Q^2 < 1$ GeV ^{2} Photoproduction, $Q^2 > 1$ GeV ^{2} DIS

Predominantly via boson gluon fusion

Test of perturbative QCD:

multi-scale problem (M, Q, p_T)

Directly sensitive to gluon density in the proton (PDFs)

Heavy Quark Production

Number of theoretical approaches:

Massless (Zero Mass), massive (Fixed Flavour) and general mass (GM) flavour number schemes (combination of massless/massive should provide best theoretical model).

QCD Calculations:

Fixed order - massive FFNS NLO(α_s^2) (FMNR, HVQDIS)
GM-VFNS PDFs – used in latest PDF fits
MSTW08 to NLO (α_s^2) and NNLO (α_s^3)
CTEQ 6.6 to NLO (α_s)

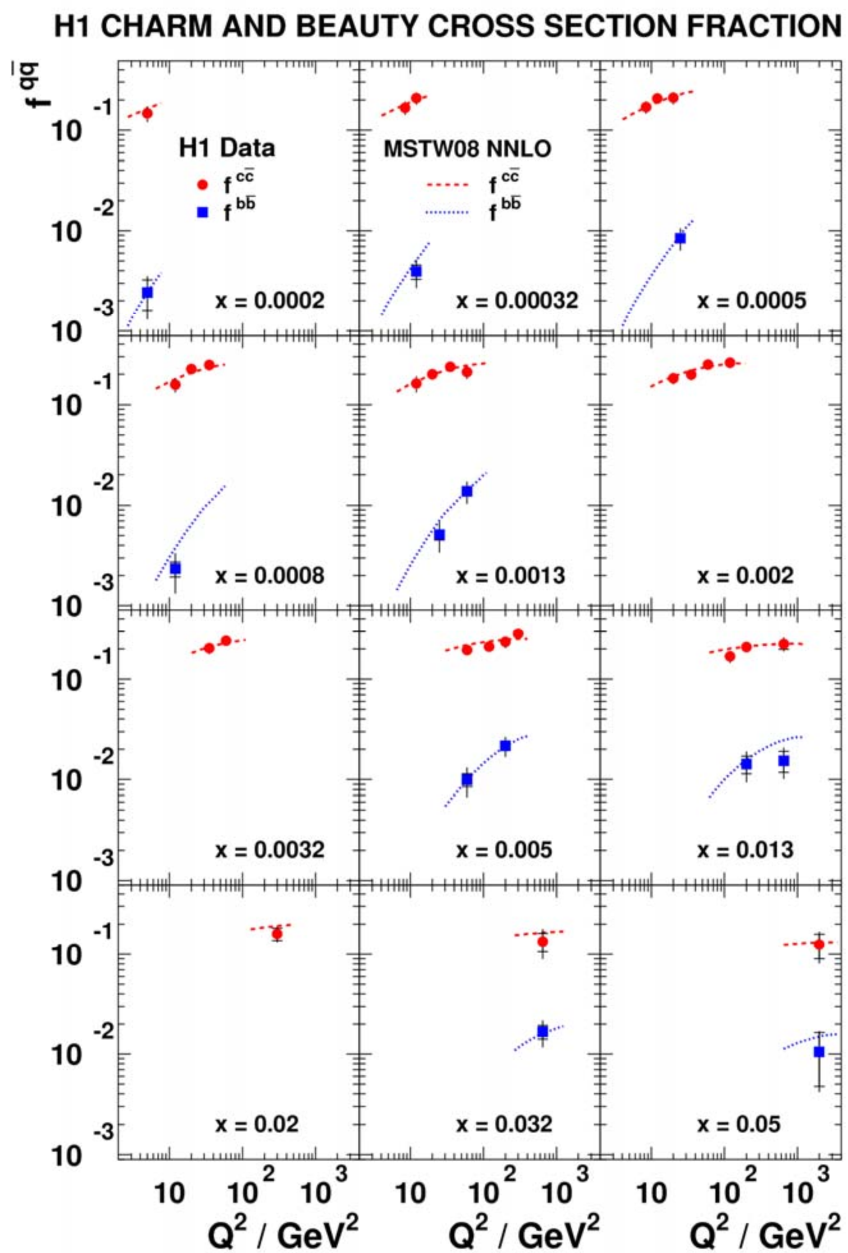
Monte-Carlo: LO (α_s) + Parton shower:

Collinear factorisation, DGLAP (PYTHIA, RAPGAP)

Contribution to Cross Section (DIS)

HERA I+II result:

- fraction of total DIS cross section from charm and beauty
- large charm fraction (~30%). Has influence on PDFs!
- small beauty fraction ~% (lower at low Q^2)
- mass thresholds visible
- good description by NNLO QCD



Tagging Heavy Quarks

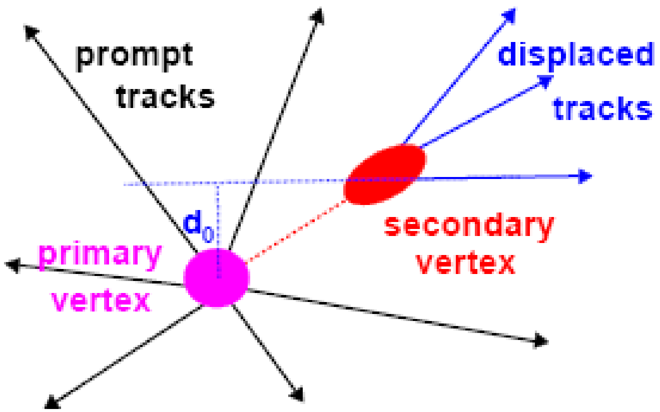
Heavy quarks rarely produced, use properties of beauty hadrons:

- lifetime and mass

  - reconstruction of a secondary vertex

  - decay length and mass of tracks from secondary vertex

  - impact parameter



Vertex method allows measurement of all tracks to low p_T – increase statistics and reduce extrapolations to full phase space. Can compare with other methods semi-leptonic (1163 Juengst), reconstruction of charmed meson decays (1160 Jung, 1162 Roloff)

H1 and ZEUS vertex measurements

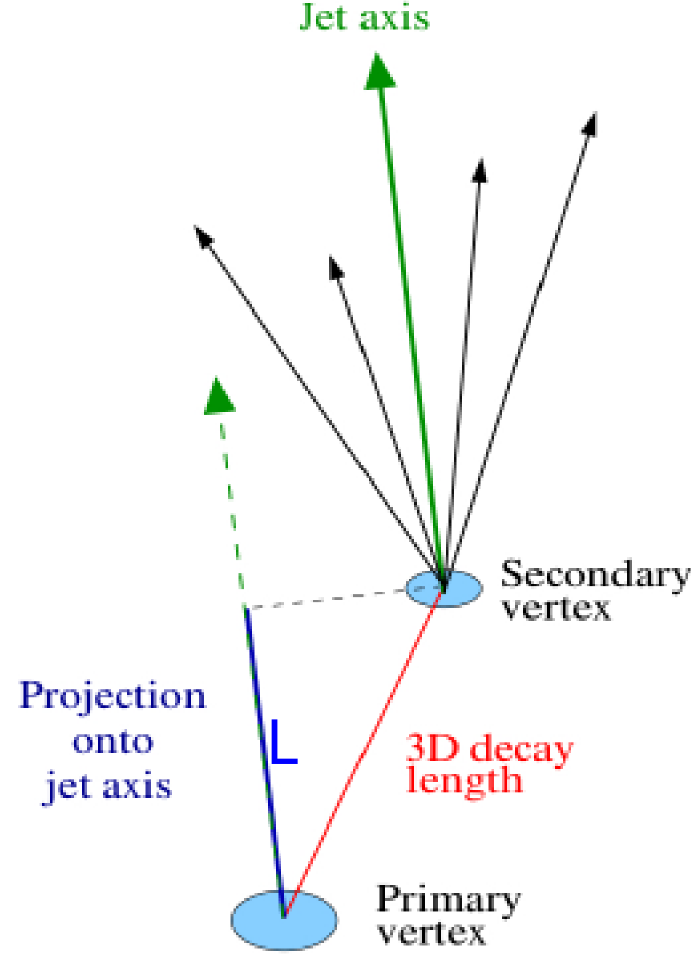
H1	ZEUS
• Inclusive charm and beauty in DIS Eur.Phys.J. C65 (2010) 89 arXiv:0907.2643 • Charm and beauty jets in DIS DESY 10-083	• Beauty dijets in Photoproduction ZEUS-prel-09-005 • Beauty jets in DIS and F_2^{bb} ZEUS-prel-10-004

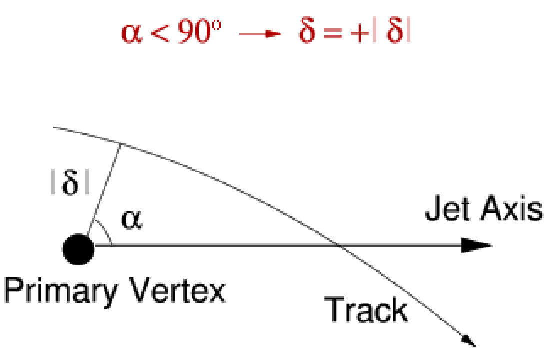
Methods to discriminate heavy flavours from light quarks and to disentangle c from b are very similar for H1 and ZEUS

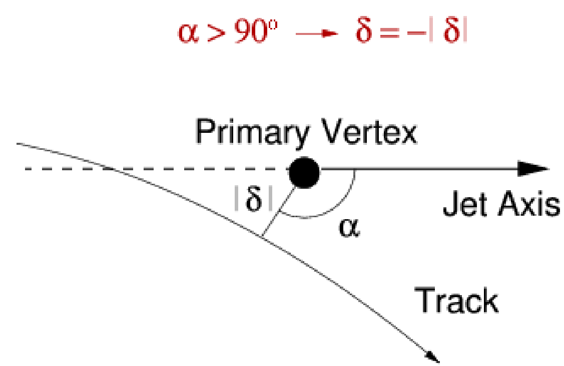
Highlight the important features here...

Flavour Tagging - secondary vertex

- Use all tracks ("inclusive") with hits in silicon detectors $p_T > 0.3(0.5)$ *GeV* H1(ZEUS)
- 2D(3D) hits H1(ZEUS). Calculate 2D secondary vertex decay length and decay length significance $S_L = L/\sigma(L)$
- Sign of vertex given w.r.t jet axis
- Use also signed impact parameter δ of individual tracks

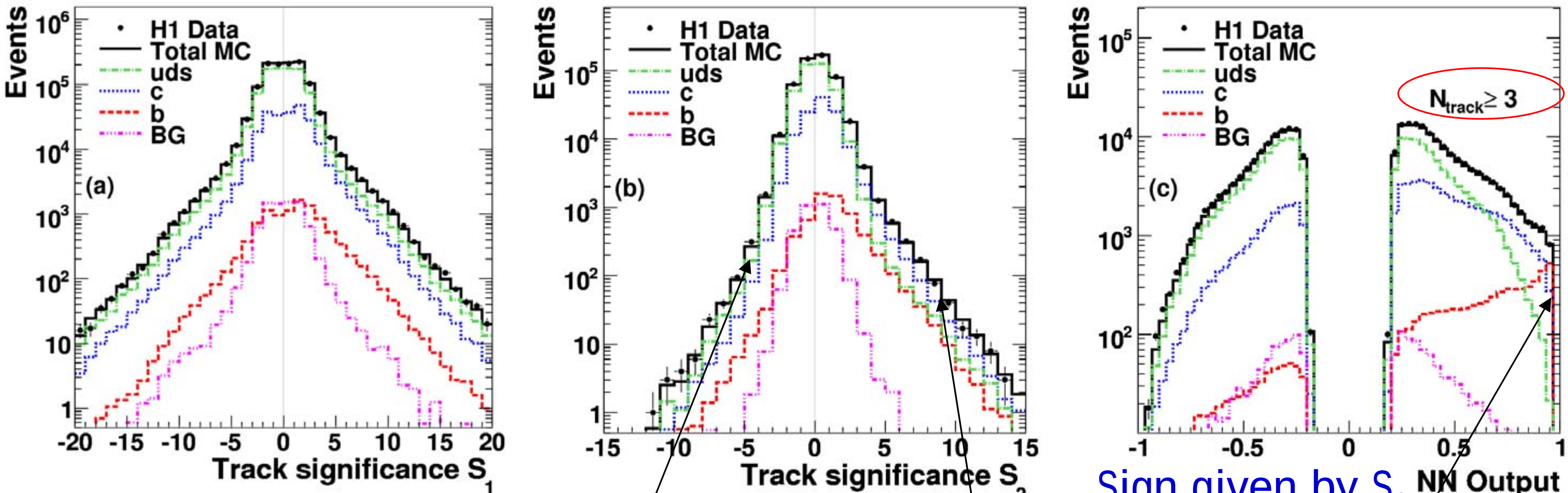






Flavour Separation

Significance $S = \delta/\sigma(\delta)$ DESY 10-083 For >2 tracks use NN



Sign given by S_1

resolution

lifetime

c/b separation

S_1 highest |S|

S_2 2nd highest |S|

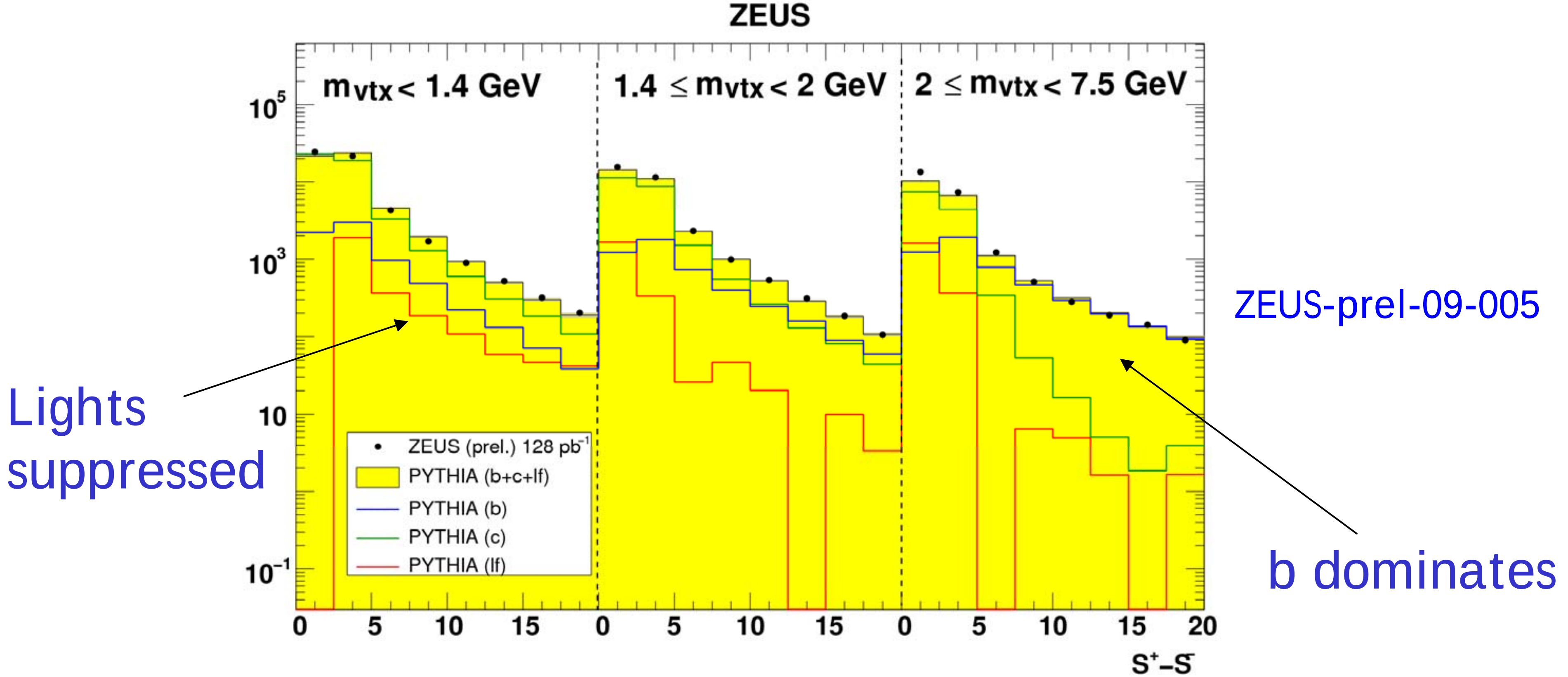
Charm and beauty asymm. due to lifetime

Light flavours mostly symmetric

Photoproduction background small

Neural Network inputs include S_1, S_2, S_3, S_L and number of silicon tracks

Fitting Flavour Fractions

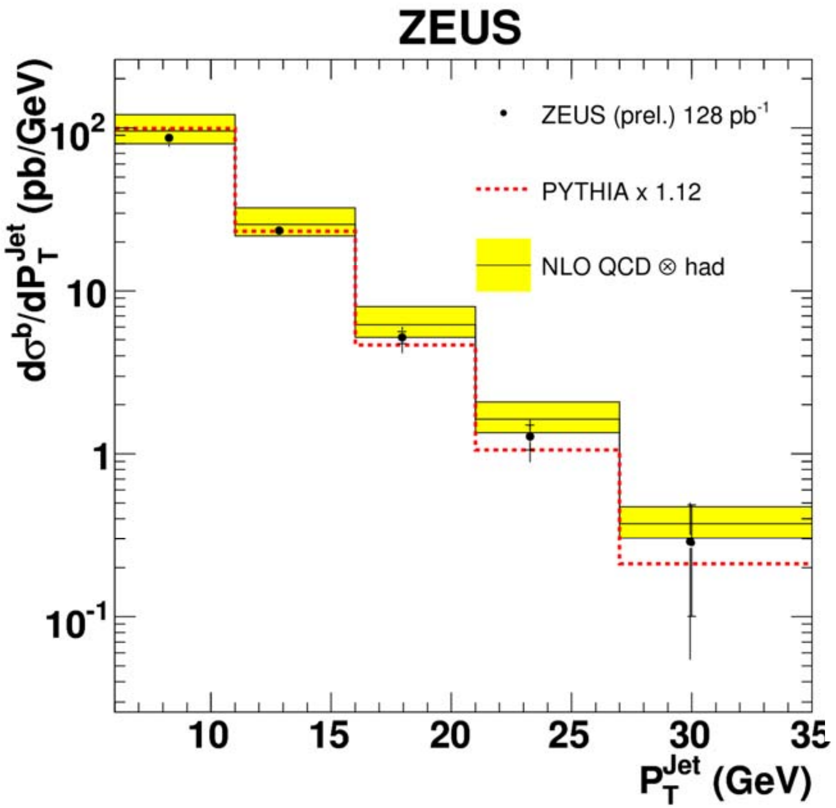


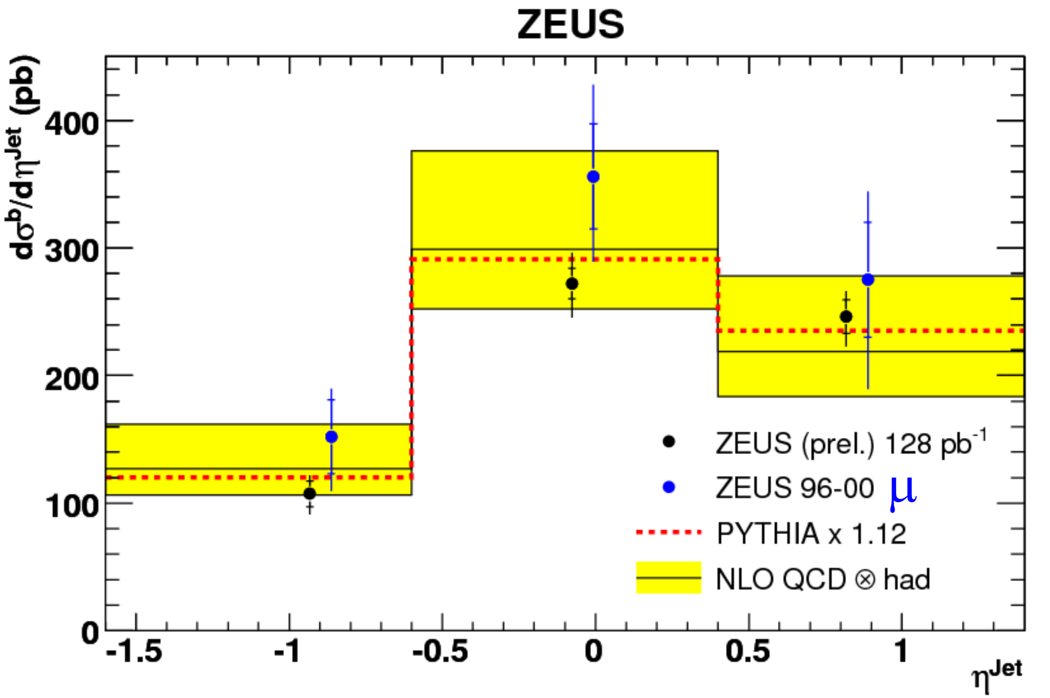
Reduce contribution of lights by using "mirror image" i.e. subtract negative bins from positive.

ZEUS fit S_L in bins of M_{VTX}, H1 fit S_1, S_2 and NN output

Perform *l,c,b* fits in bins of e.g. p_T^{jet} or x, Q^2 to extract F_2^{bb}

Photoproduction *b* Dijets (ZEUS)





$Q^2 < 1$ GeV^2, $P_T^{Jet} > 7(6)$ GeV, $-1.6 < \eta^{Jet} < 1.3$

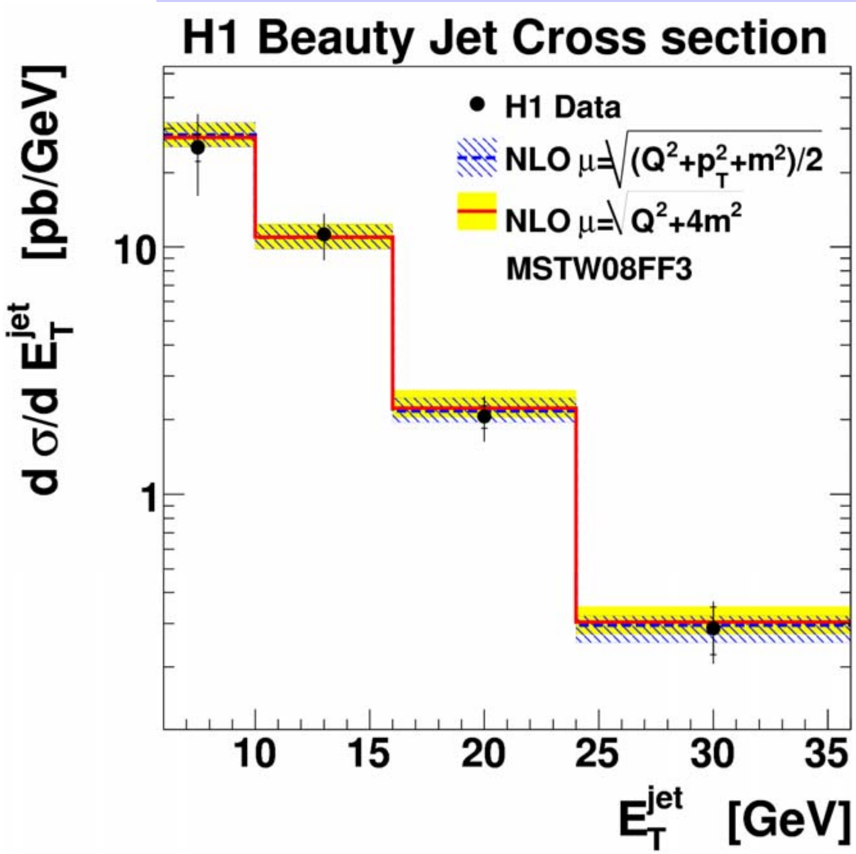
ZEUS-prel-09-005

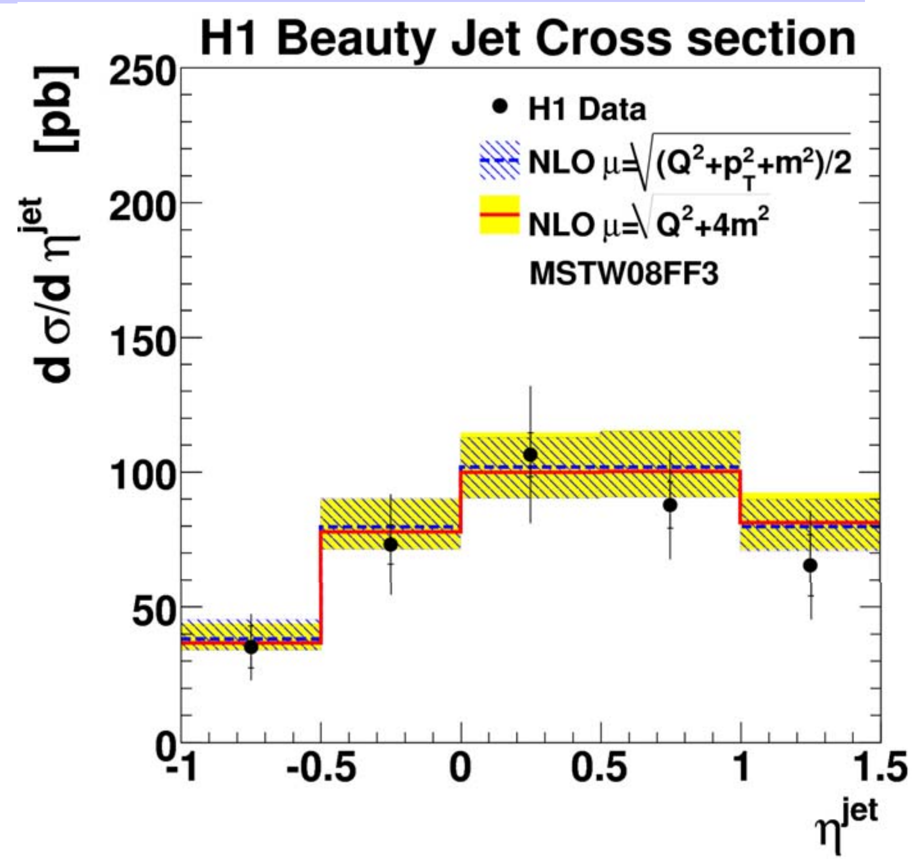
Beauty jet cross section vs p_T^{Jet}, η^{Jet}

Well described by (massive) NLO QCD

Agreement found with measurements from muon tagging (864 Geiser)

Beauty Jets In DIS (H1)





Q2>6 GeV^2, P_T^{Jet}>6 GeV, -1 < η^{Jet}< 1.5

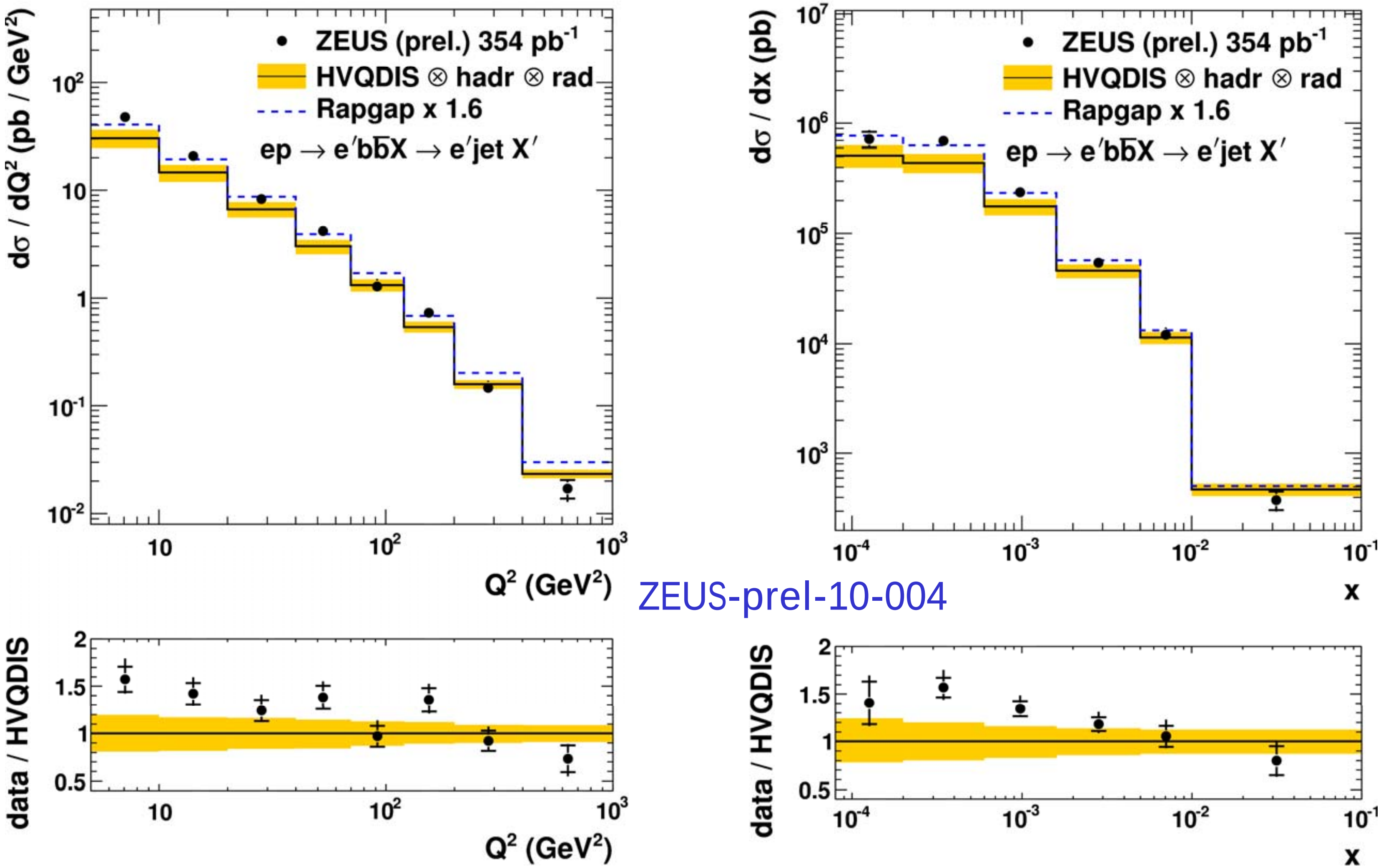
Beauty jet cross sections vs E_T^{jet} and η^{jet}

DESY 10-083

Well described by (massive) NLO QCD

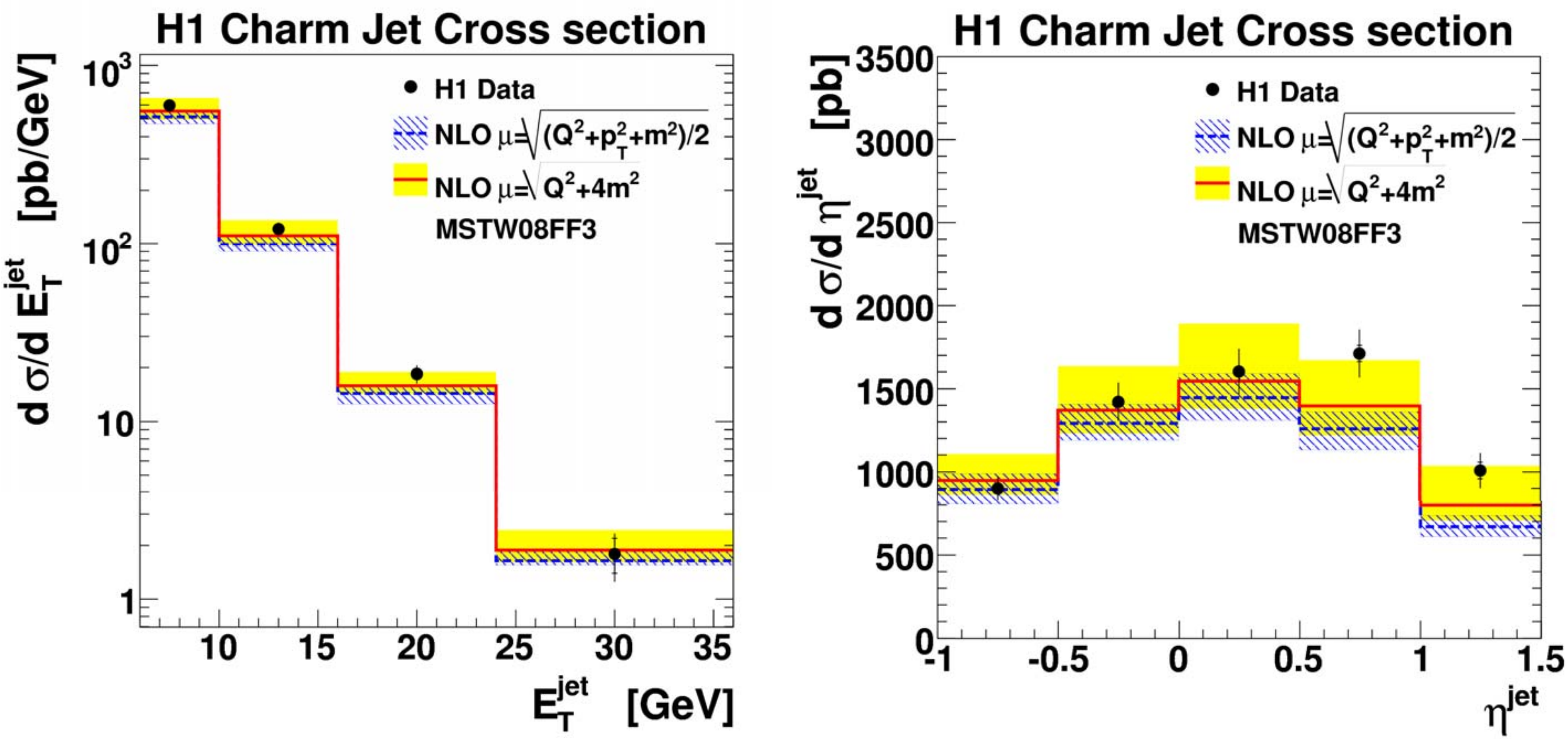
Good description (as for H1 γp analysis hep-ex/0605016)

Beauty Jets In DIS (ZEUS)



Beauty jet cross sections vs Q^2 and x. Agreement with NLO QCD, although QCD lower at low Q^2 and low x

Charm Jets In DIS (H1)



Q2>6 GeV^2, P_T^{Jet}>6 GeV, -1 < η^{Jet}< 1.5

DESY 10-083

Charm jet cross sections vs E_T^{jet} and η^{jet}

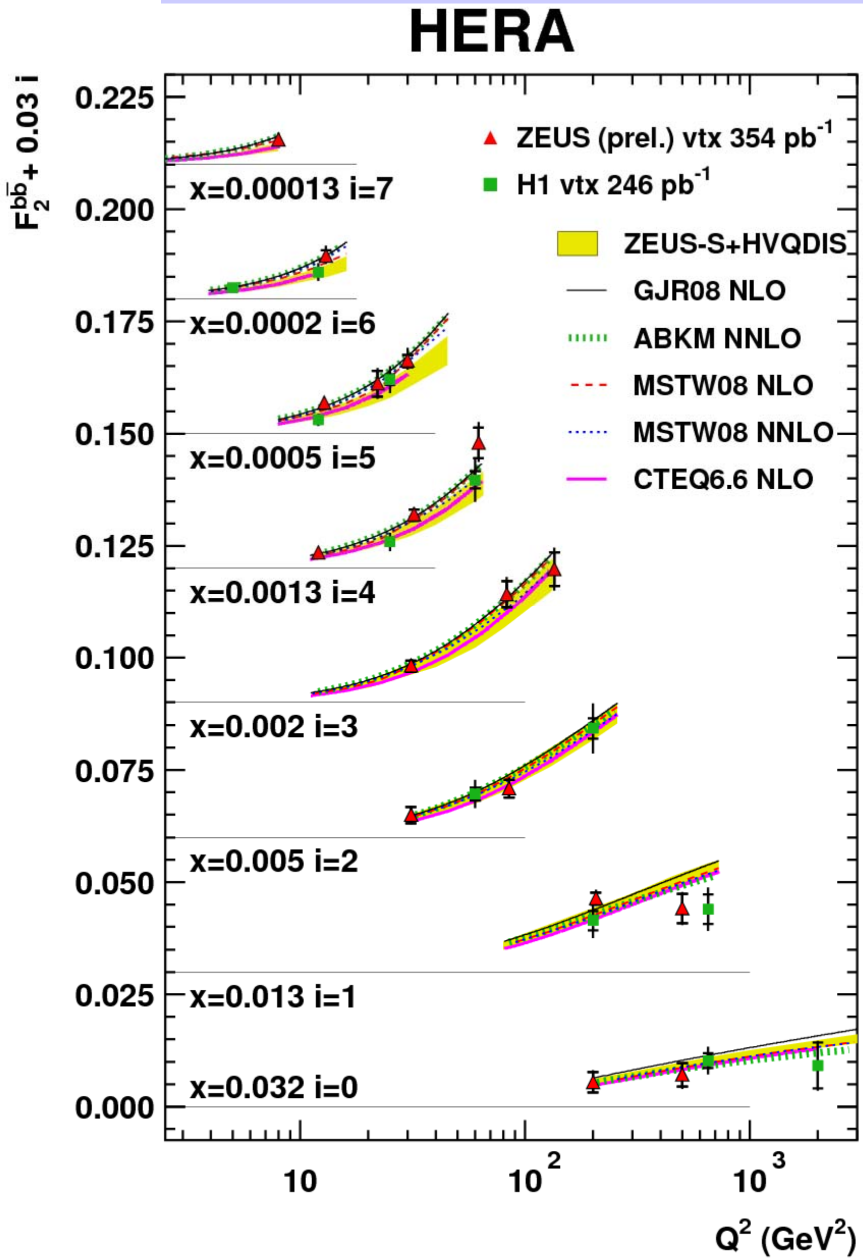
Sensitivity to scale choice. Reasonable description with scale choice.

Measurement of F_2^{cc} and F_2^{bb}

$$F^{b}_{2,meas}(x_i, Q_i^2) = \frac{\sigma_{meas,i}}{\sigma_{theo,i}} \times F^{b}_{2,theo}(x_i, Q_i^2)$$

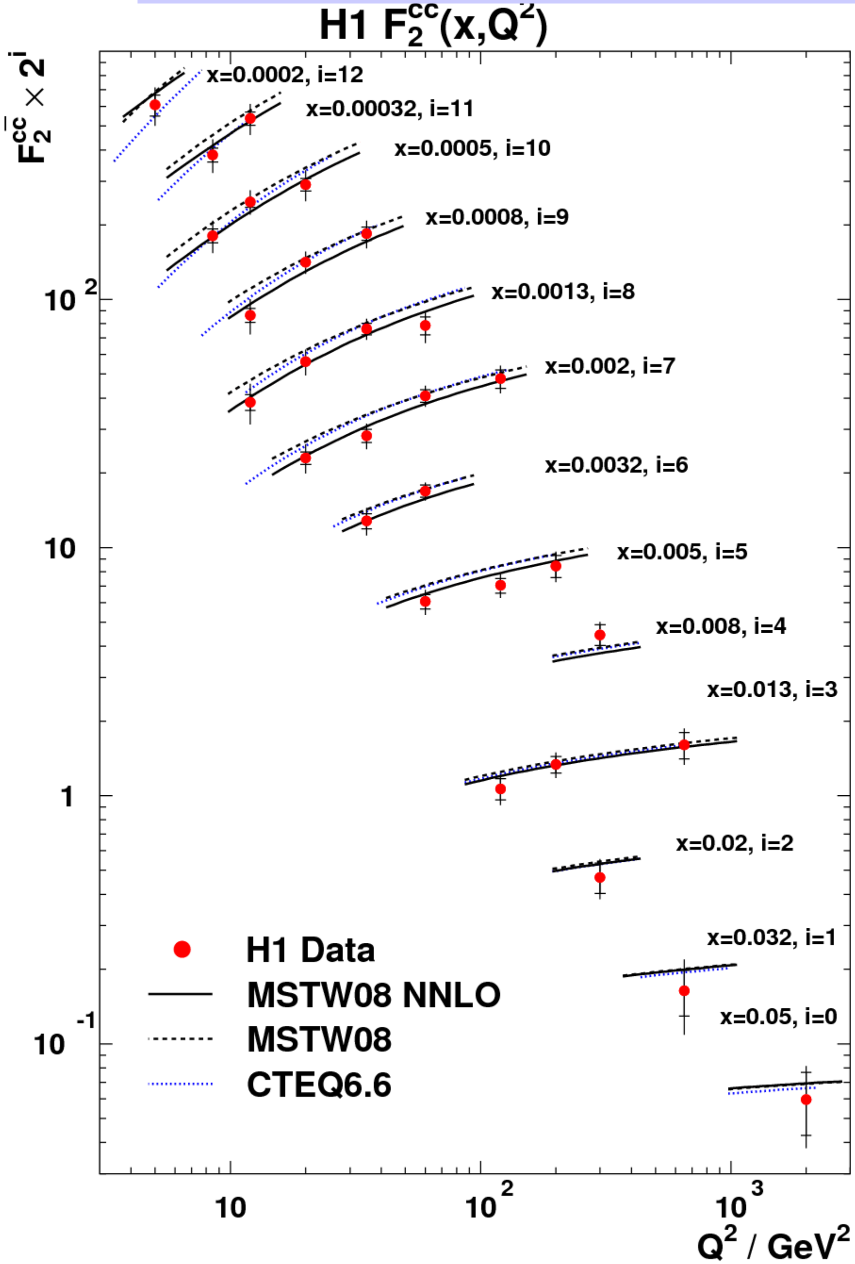
- Extraction of inclusive structure functions (F_L is small)
- Double differential cross section
- Use HVQDIS to calculate theoretical predictions
- Extrapolation to full phase space small for beauty
- Larger for charm, but reduced compared to exclusive methods because of low p_T track acceptance

Measurement of F_2^{bb}



- Beauty structure function versus Q^2 for fixed x
- Vertex methods between H1 and ZEUS agree
- Agreement also found with semi-leptonic analyses
- NNLO predictions available
- Some differences between theories
- Data well described

Measurement of F_2^{cc}



- Charm structure function vs Q^2 for fixed x
- Higher precision tests theory
- Differences between MSTW NNLO and NLO predictions for charm. NNLO somewhat better description than NLO
- CTEQ NLO describes data
- Data being used to complement D meson and semi-leptonic measurements in combination of HERA data (1159 Corradi)

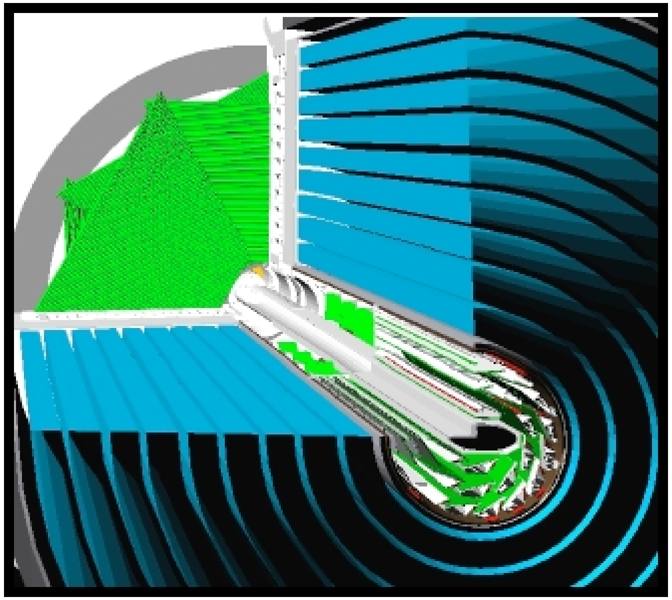
Summary

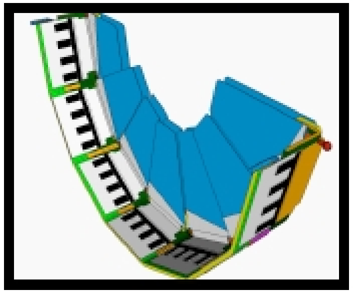
- Heavy Flavour production at HERA is a vital testing ground for perturbative QCD
- Vertex detectors are a powerful tool to extract heavy flavour cross sections
- In general a good description is provided by pQCD
- The vertexing method allows to make measurements of the contribution of heavy flavours to the proton structure function. Charm data precision provides constraint for theory. Beauty well described.
- Better discrimination to come from combination of results.

Extra Slides

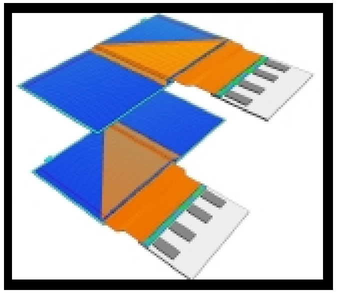
Flavour Tagging - Vertex Detectors

ZEUS tracking **(MicroVertexDetector)**



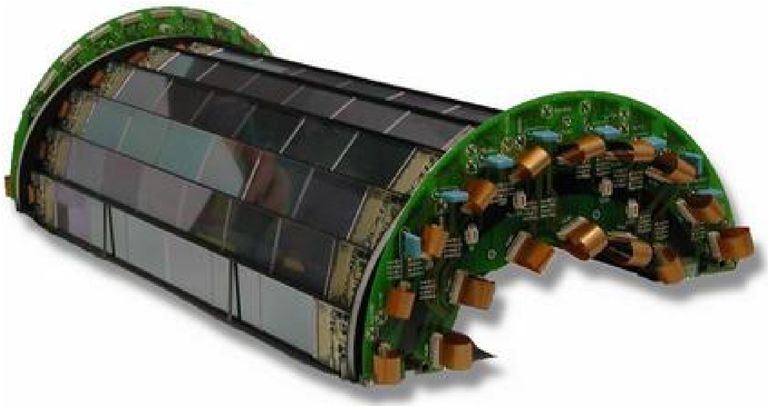


Half Wheel



Barrel module

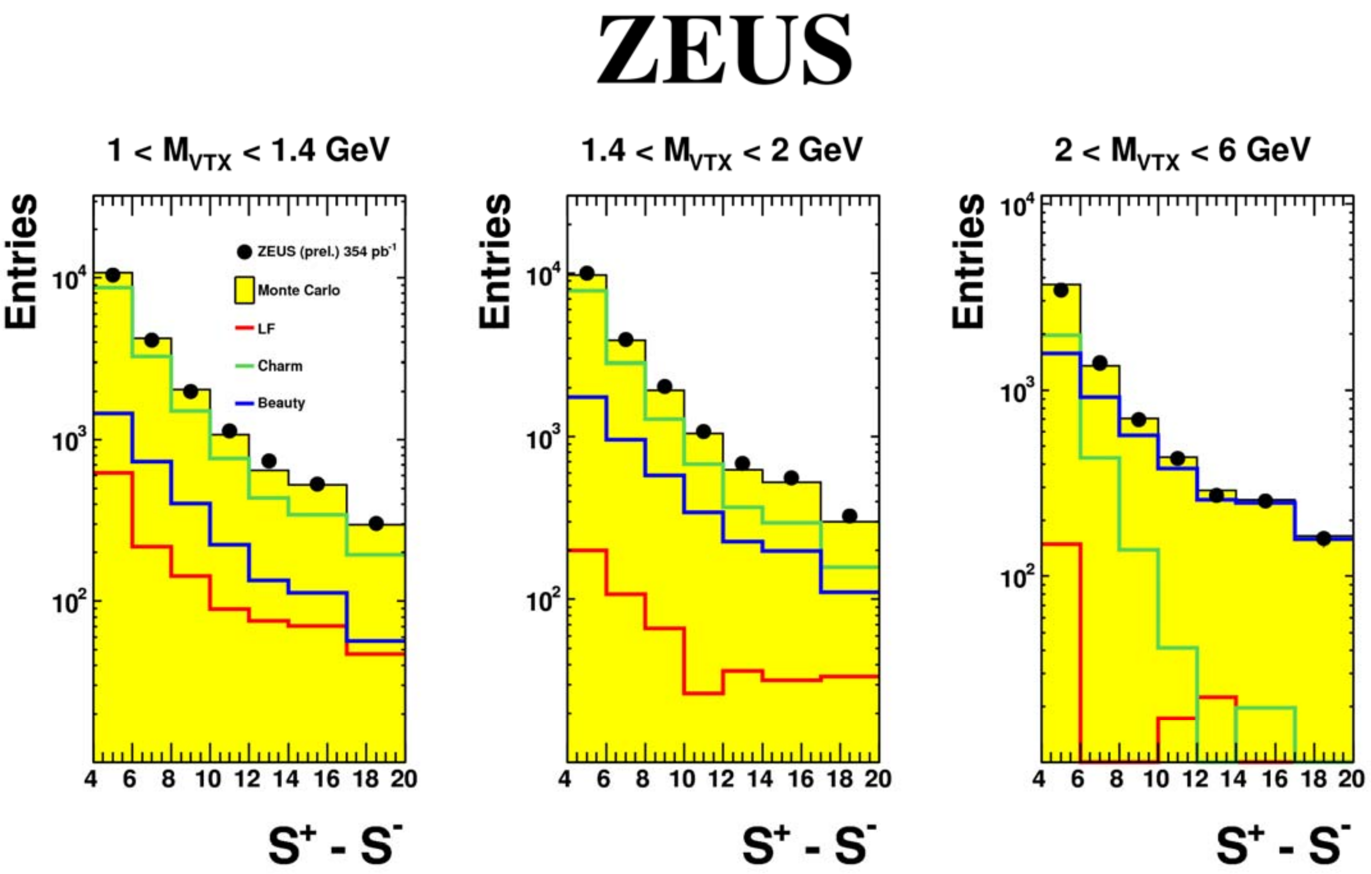
H1 CentralSiliconTracker



H1 and ZEUS vertex detectors:

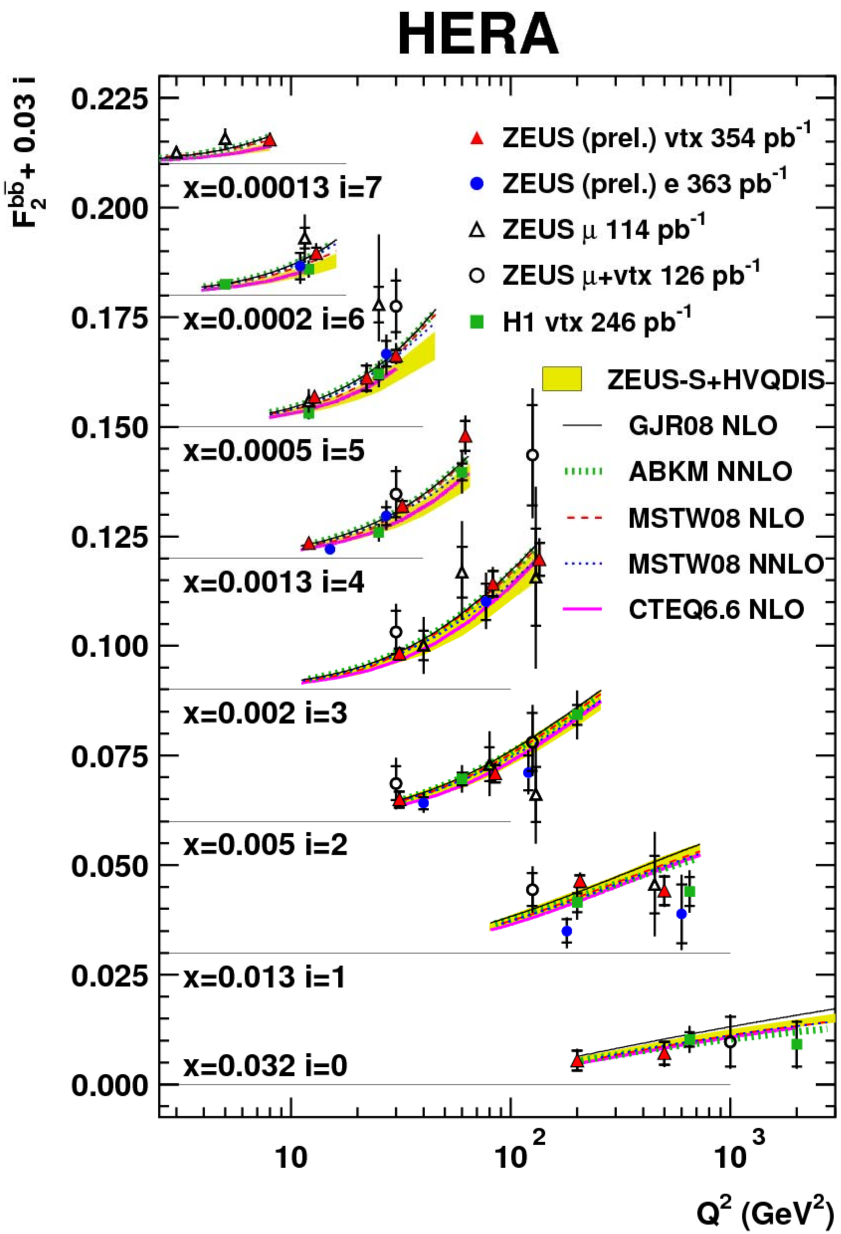
- Multi-layered single and double sided silicon microstrip detectors
- Combine precise spatial information from vertex detectors with tracks from central drift chambers
- Resolution of impact parameter in transverse plane < 100 μm

Fitting Flavour Fractions



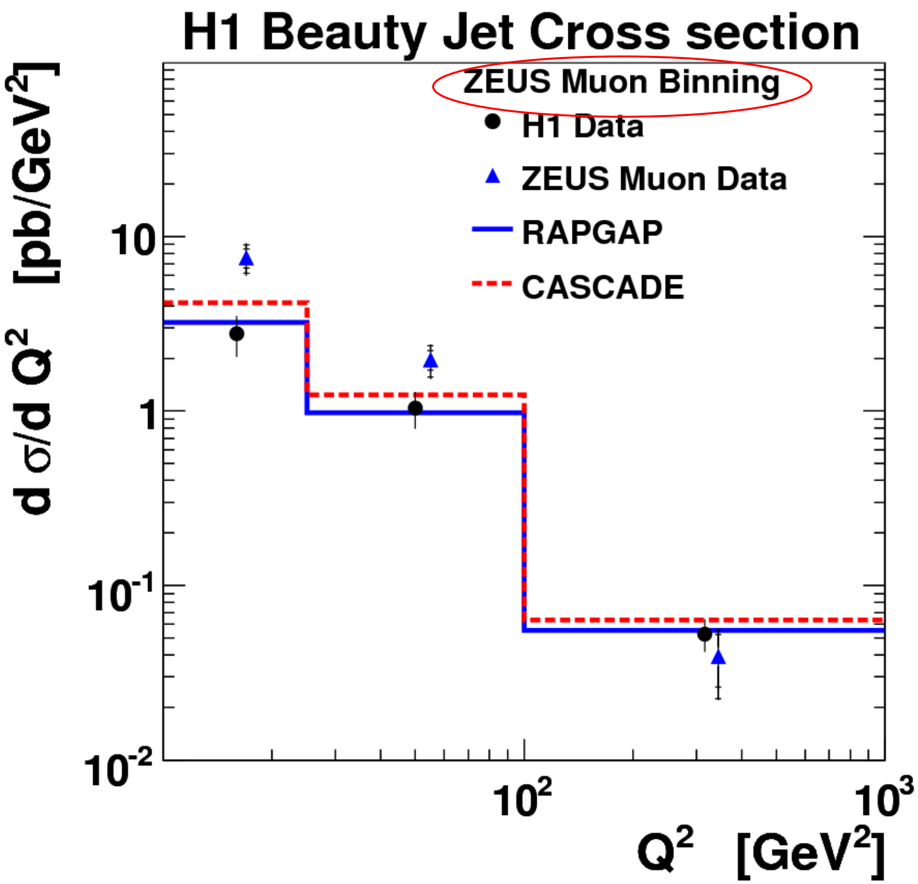
Example of ZEUS 2D M_{VTX} and S_L fitting for DIS

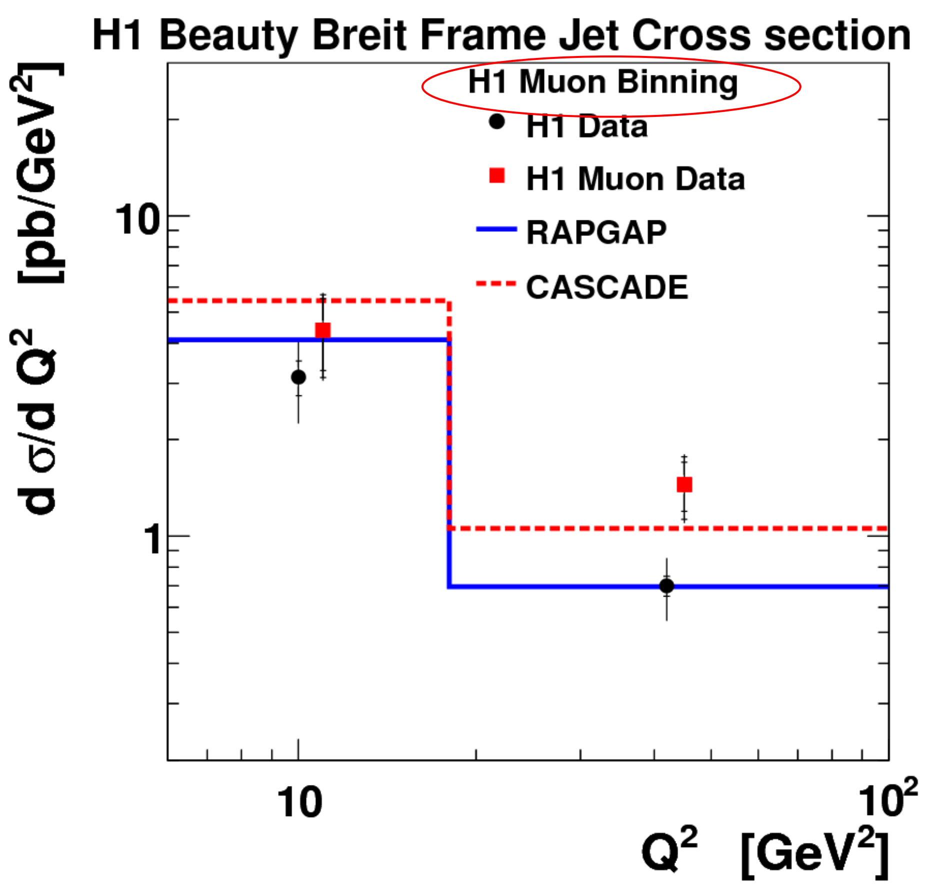
Measurement of F_2^{bb}



Comparison of vertexing results with semi-leptonic

Comparison with Muon Tagged Data





- Extrapolate muon data to full phase space (small uncertainty)
- H1 and ZEUS data from muon tagging lie systematically above vertex data at either high or low Q^2