Measurement of Charm and Beauty Jets in Deep Inelastic Scattering at HERA

Paul Thompson (Birmingham)

for the H1 Collaboration

- Recently published H1 paper Eur.Phys.J. C71 (2011) 1509
- Motivation
- Analysis method (vertex tagging)
- Results (comparison with other methods and with QCD)

DIS 2011, Newport News, VA, April 11th-15th, 2011

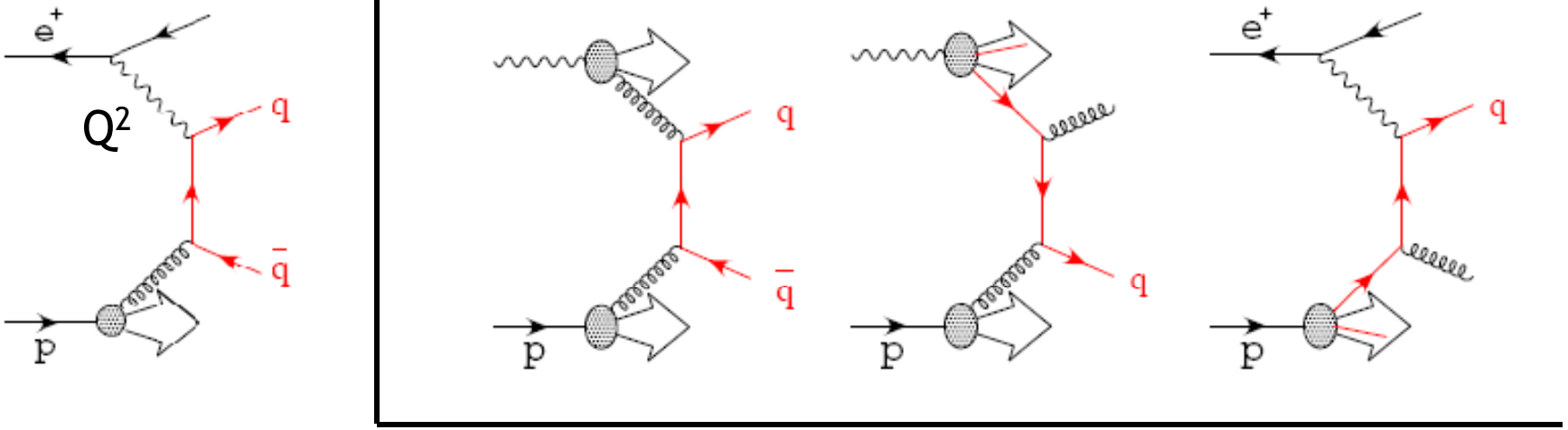
Production of Heavy Quarks

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 (DIS)

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) (HVQDIS – parton level)

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 (RAPGAP)

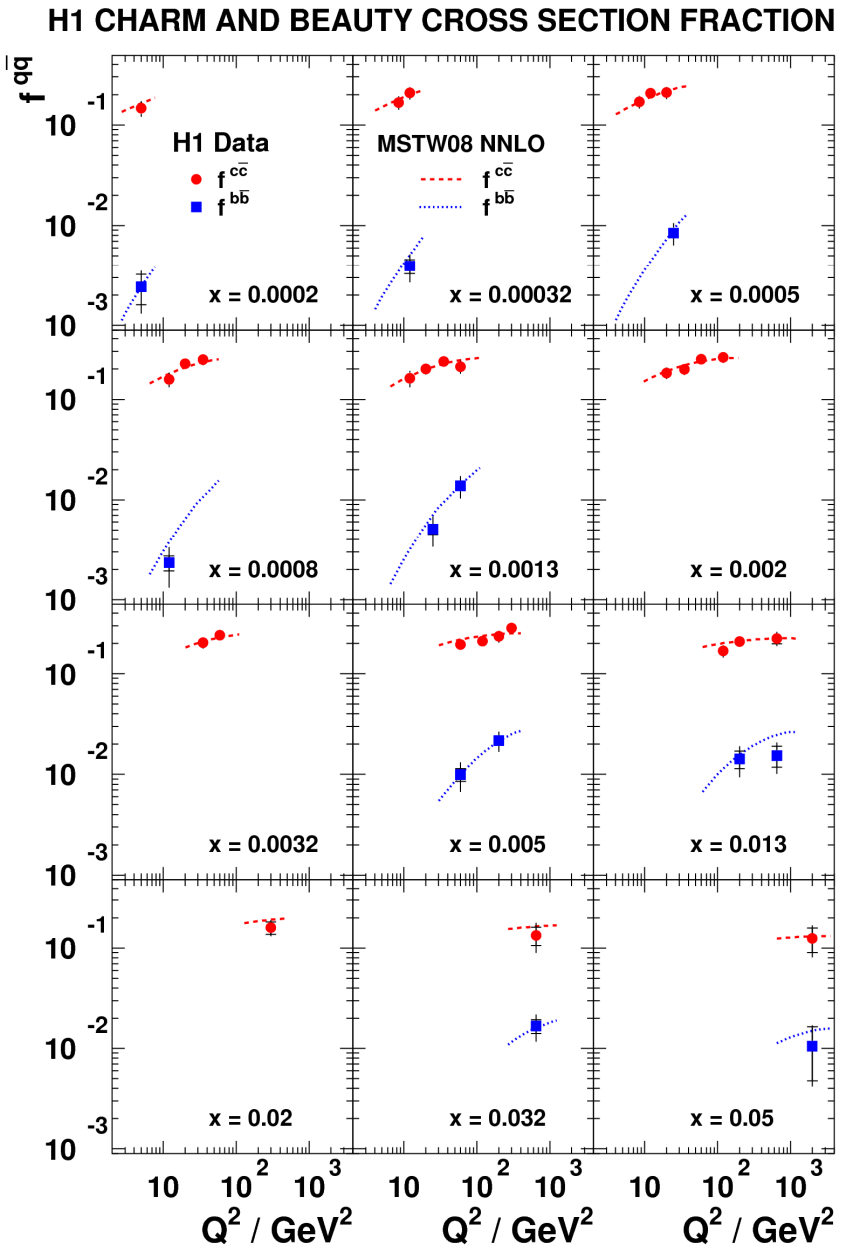
K_T factorisation, CCFM (CASCADE)

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
- described by NNLO QCD

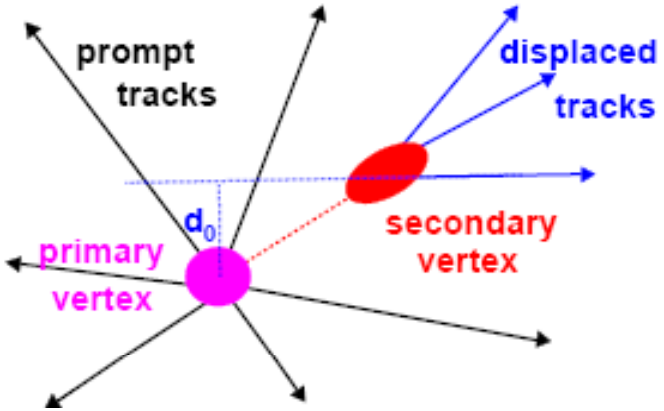
But what about sub-sample with additional hard jet?



Tagging Heavy Quarks

Heavy quarks rarely produced, use properties of beauty hadrons:

- lifetime and mass
  - reconstruction of a secondary vertex
  - decay length and number of tracks from secondary vertex
  - impact parameter

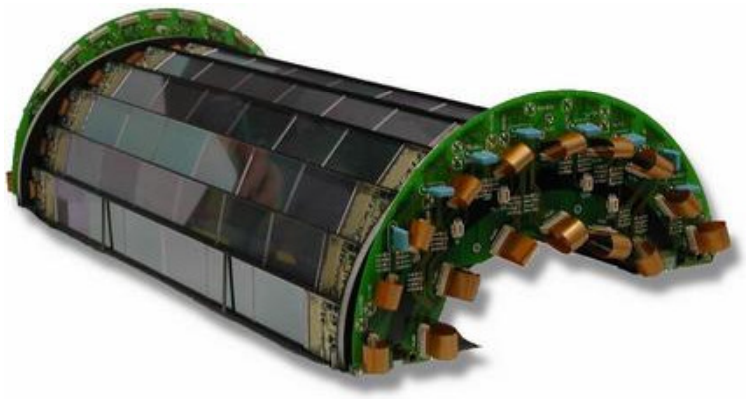


Vertex method allows measurement of all tracks to low p_T – increase statistics and reduce extrapolations to full phase space. Can compare with other methods semi-leptonic, reconstruction of charmed meson decays

H1 Vertex Detector (CST)

Central Silicon Tracker

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



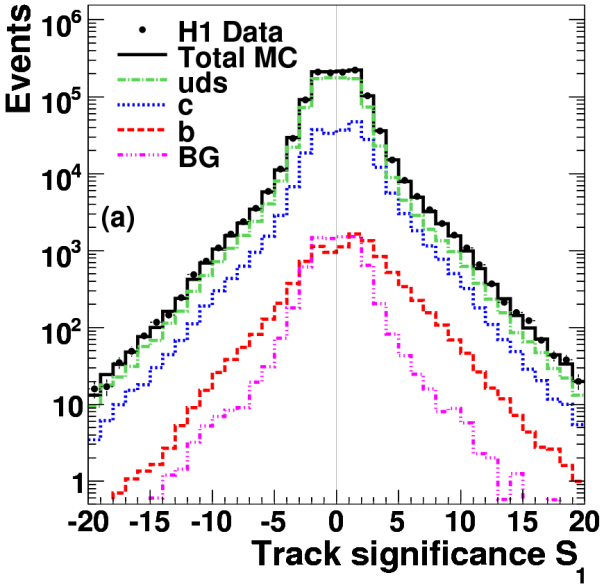
- Rebuilt to take into account HERA II beam-line
- Double layer double sided strips
- Precise determination of impact parameter in transverse plane
- Resolution of $|\delta|$ for hits in both layers:

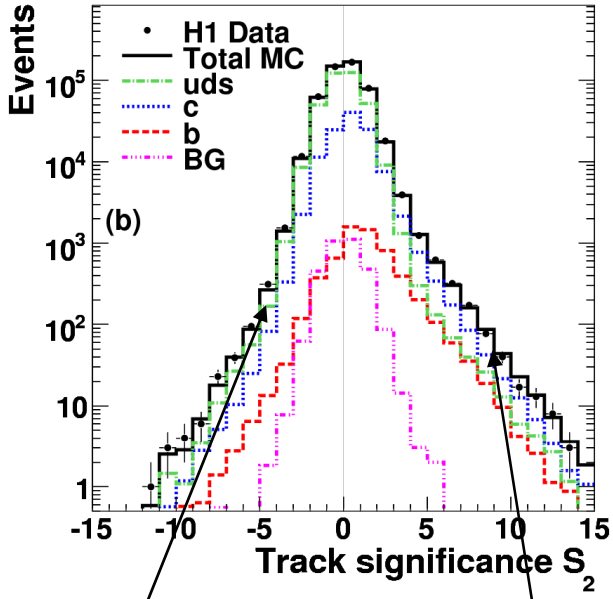
$$33\mu m \oplus \frac{90\mu m}{P_T}[GeV]$$

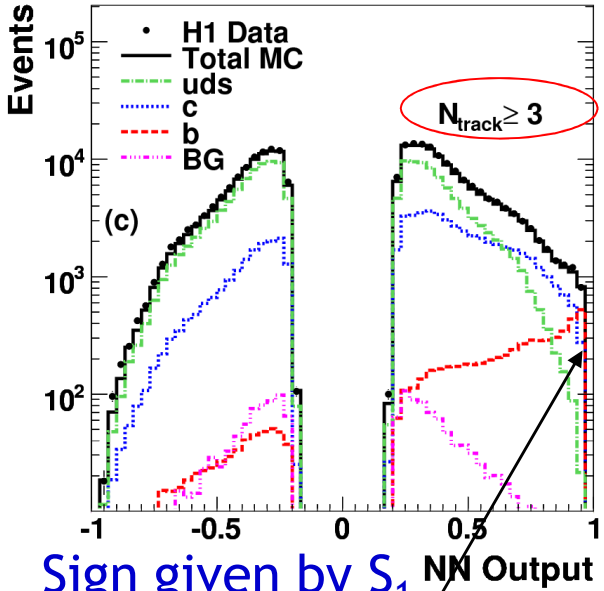
Flavour Separation

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

For >2 tracks use NN







S_1 highest |S|

S_2 2nd highest |S|

resolution

lifetime

Sign given by S_1

c/b separation

Charm and beauty asymm. due to lifetime

Light flavours mostly symmetric

Photoproduction background small

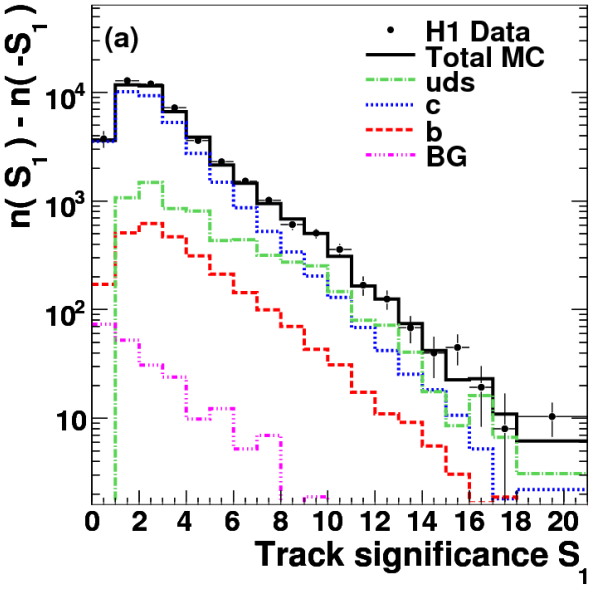
Neural Network inputs include S_1, S_2, S_3, S_L and number of silicon tracks

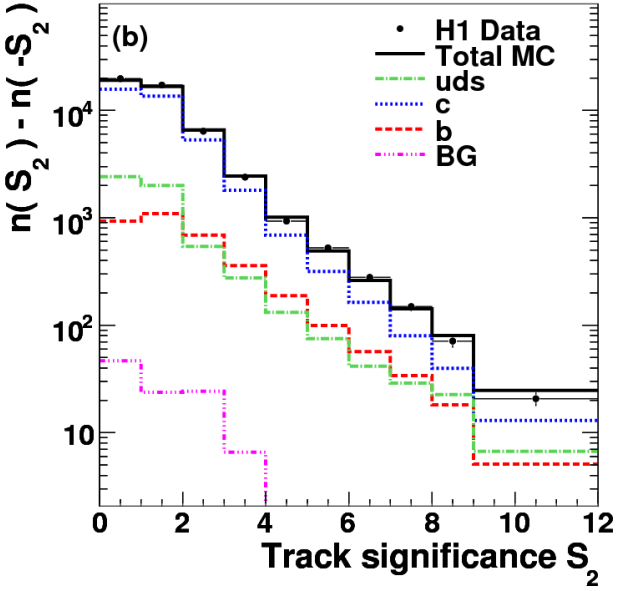
Fitting Flavour Fractions

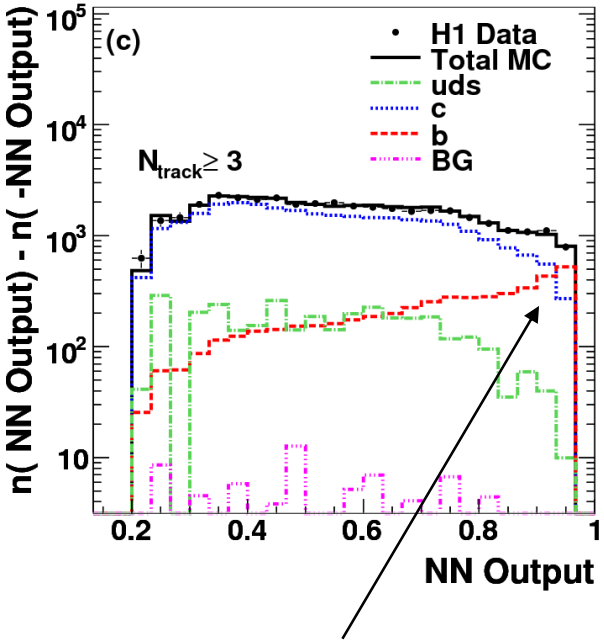
Subtract –'ve from +'ve to reduce systematic errors

These distributions are fitted for ρ_c, ρ_b in each bin (e.g. E_T^{jet}) with ρ_{uds} constrained by total number of DIS jet events.

Shown here for integrated jet sample







Good description of data by MC

b dominates

Kinematic Range of Jet Measurements

Use K_T algorithm and jet with highest E_T in the range

$E_T > 6$ GeV, $-1 < \eta < 1.5$

Analysis also in Breit Frame: $E_T^* > 6$ GeV, $-1 < \eta < 1.5$

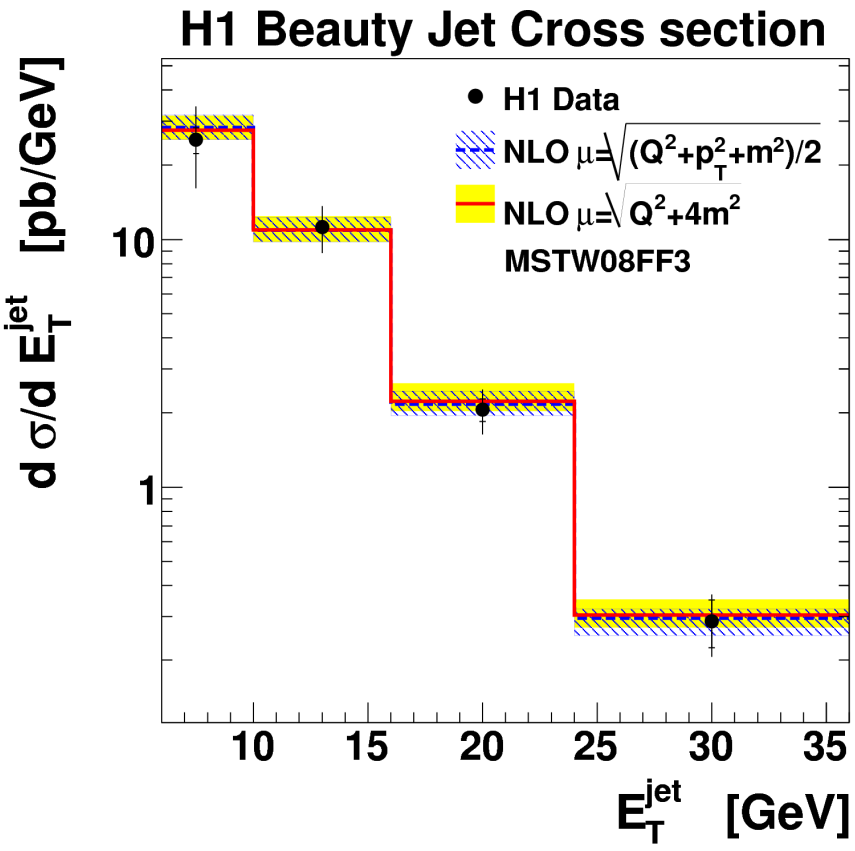
Hadron Level: Determine if b (else c) hadron within $\Delta R < 1$ of jet axis. Work in region where parton to hadron corrections are small (<15%)

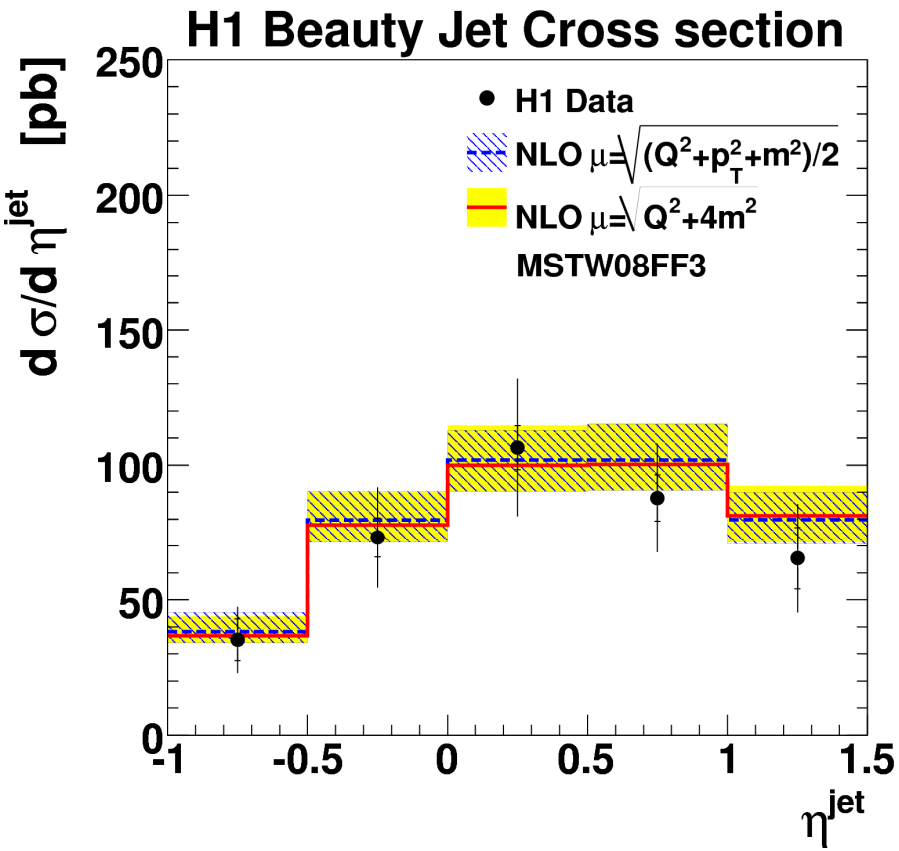
Flavour separation always in the laboratory. Require **reconstructed** CST tracks to be matched to jet $\Delta R < 1$

Measure cross section directly (no "ratio method")

$6 < Q^2 < 1000$ GeV^2 , $0.07 < y < 0.625$

Beauty Jets In DIS



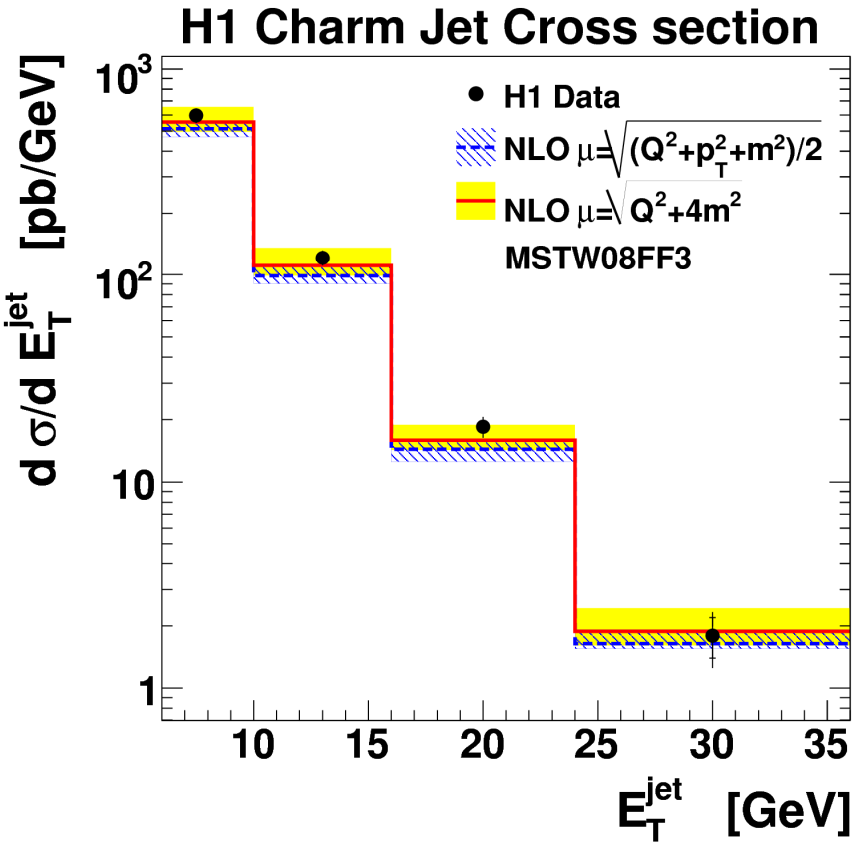


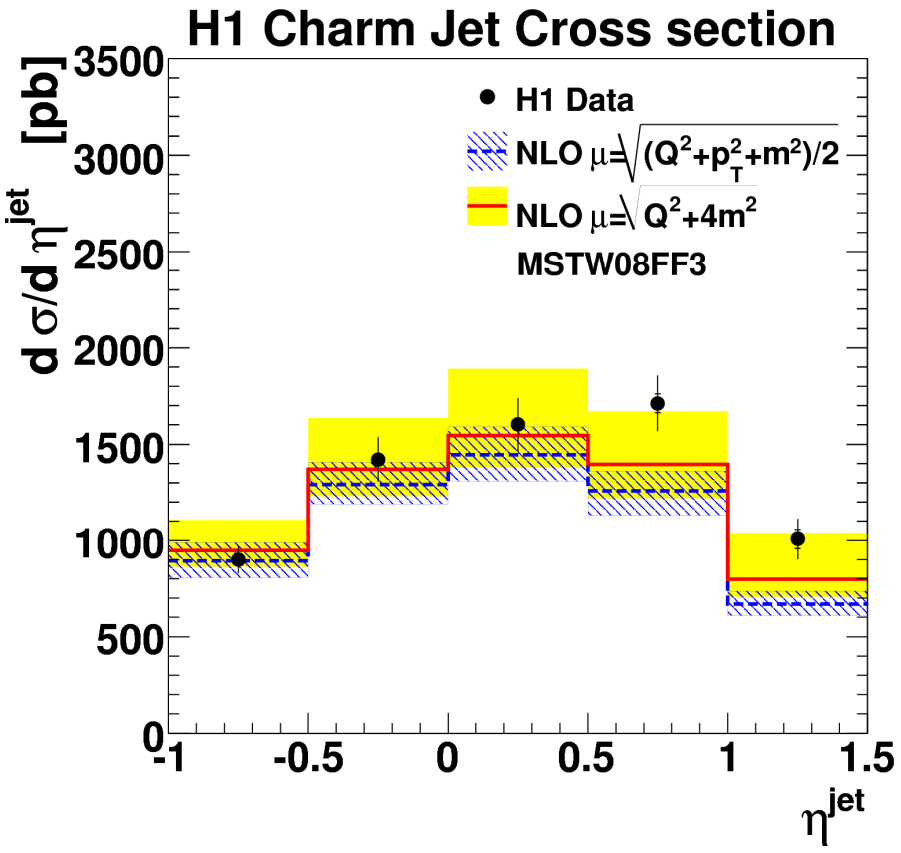
Beauty jet cross sections vs E_T^{jet} and η^{jet}

Well described by (massive) NLO QCD

Similar conclusion as for H1 γp jet analysis hep-ex/0605016

Charm Jets In DIS

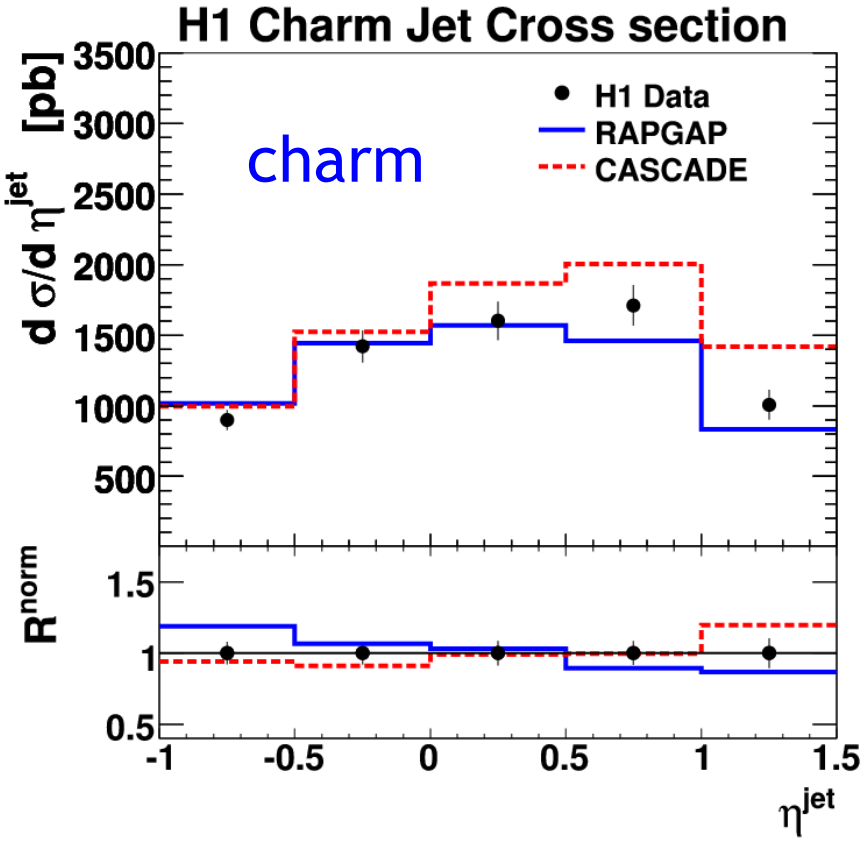


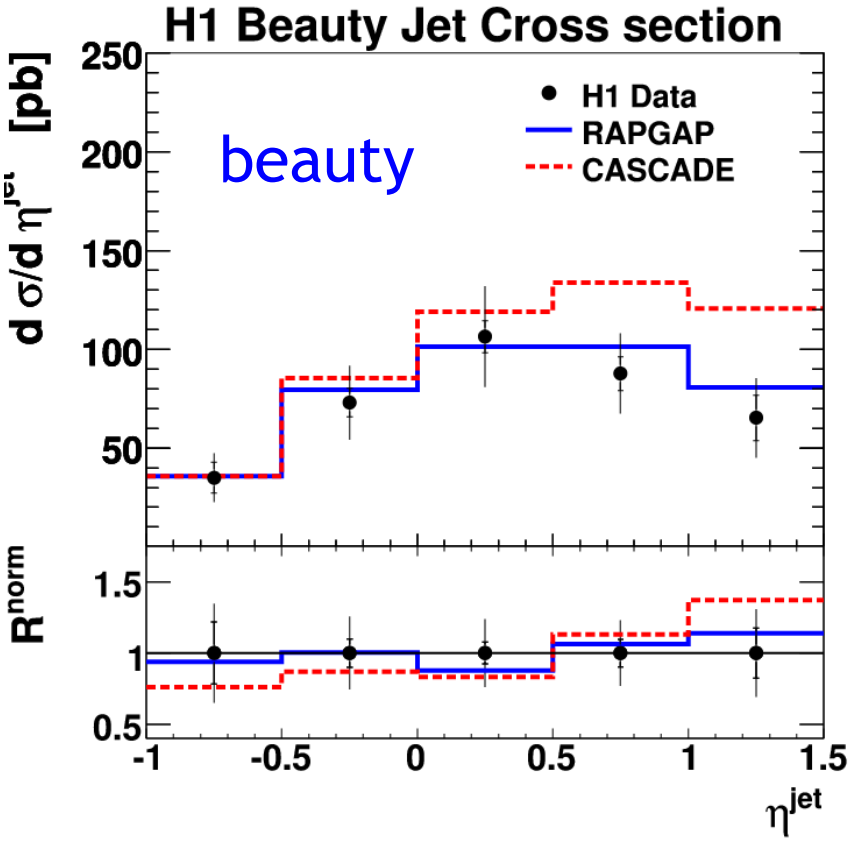


Charm jet cross sections vs E_T^{jet} and η^{jet}

Sensitivity to scale choice. Reasonable description within uncertainties for certain scale

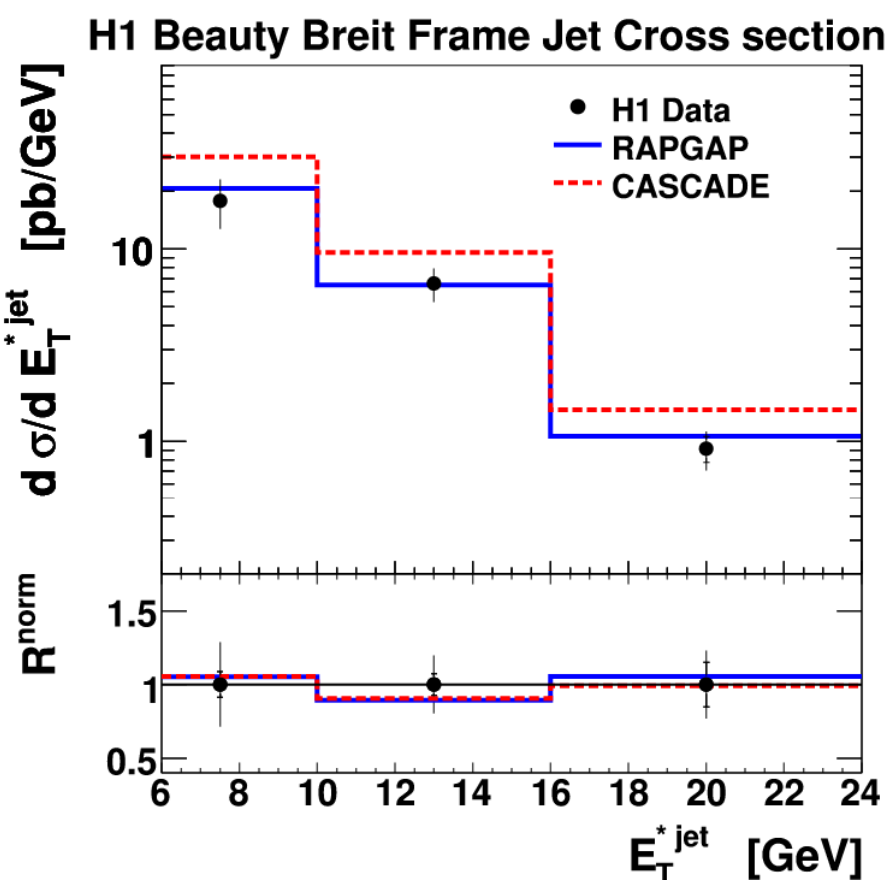
Comparison with MC

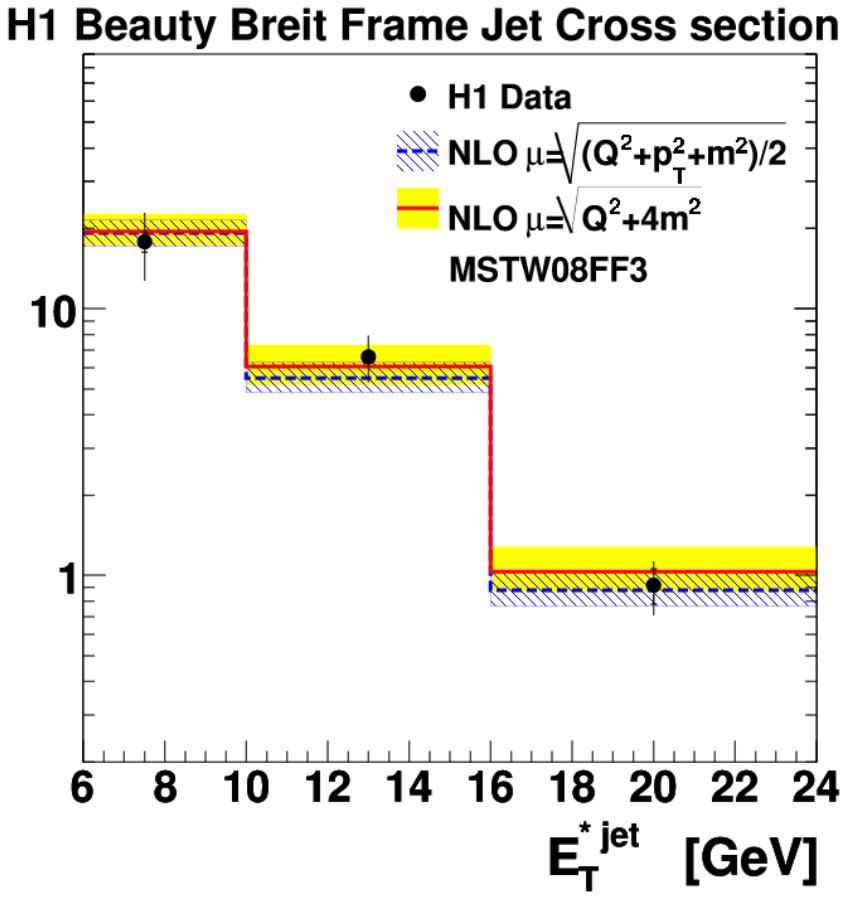




Distributions sensitive to underlying dynamics. Neither RAPGAP nor CASCADE perfect. Reasonable description of shapes.

Beauty Jets in the Breit Frame

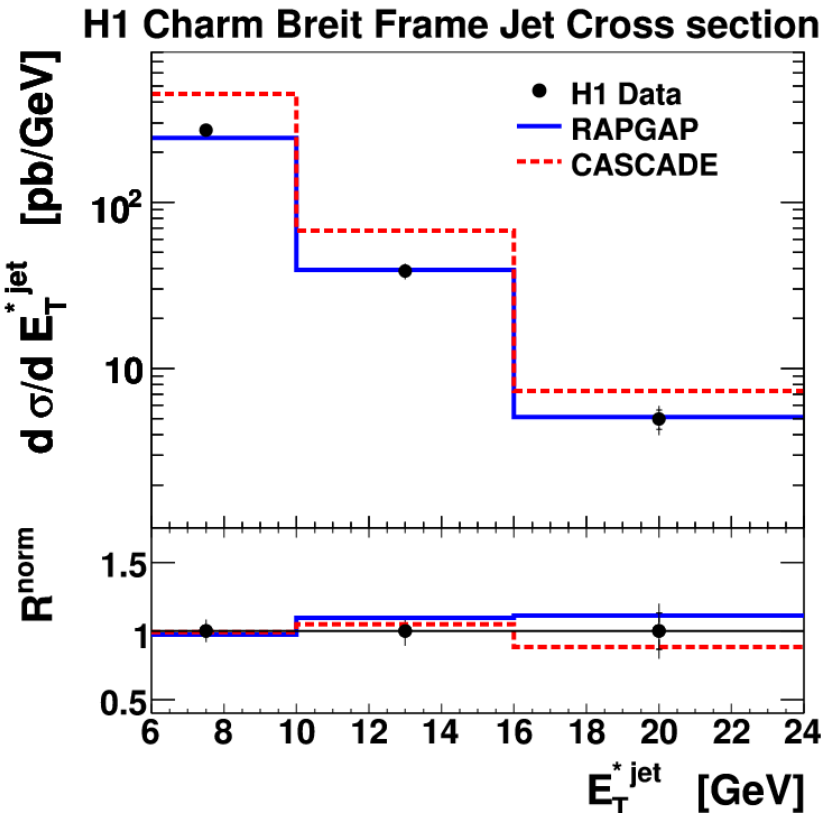


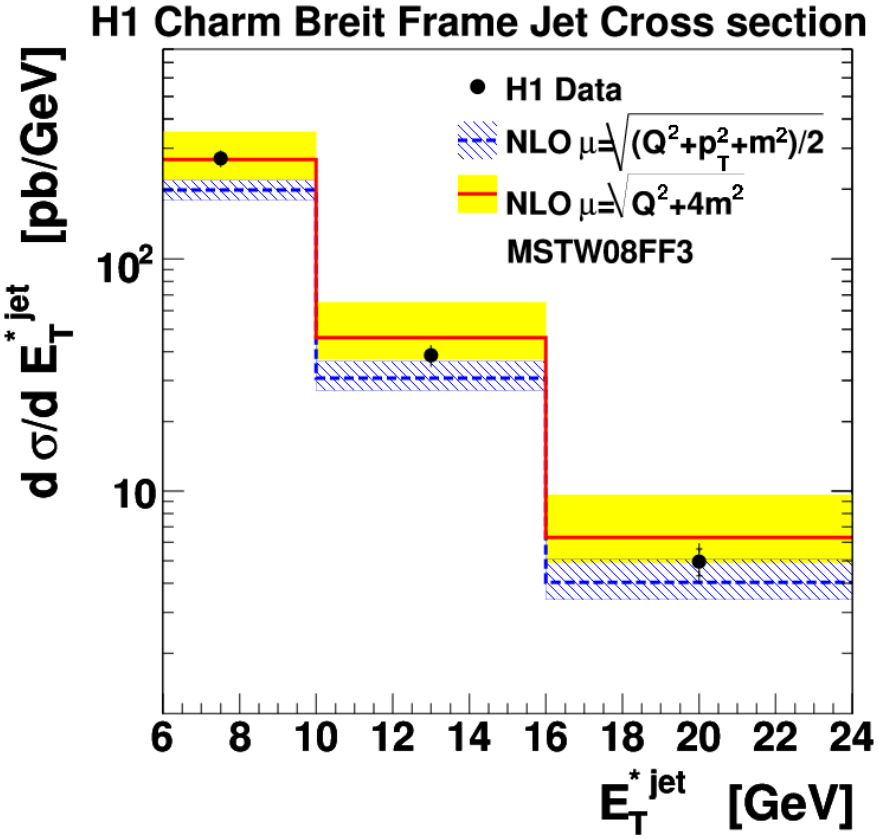


CASCADE overestimates Breit frame rate (due to k_T)

Similar description of beauty cross sections for Breit Frame Jet sample as with laboratory frame

Charm Jets in the Breit Frame

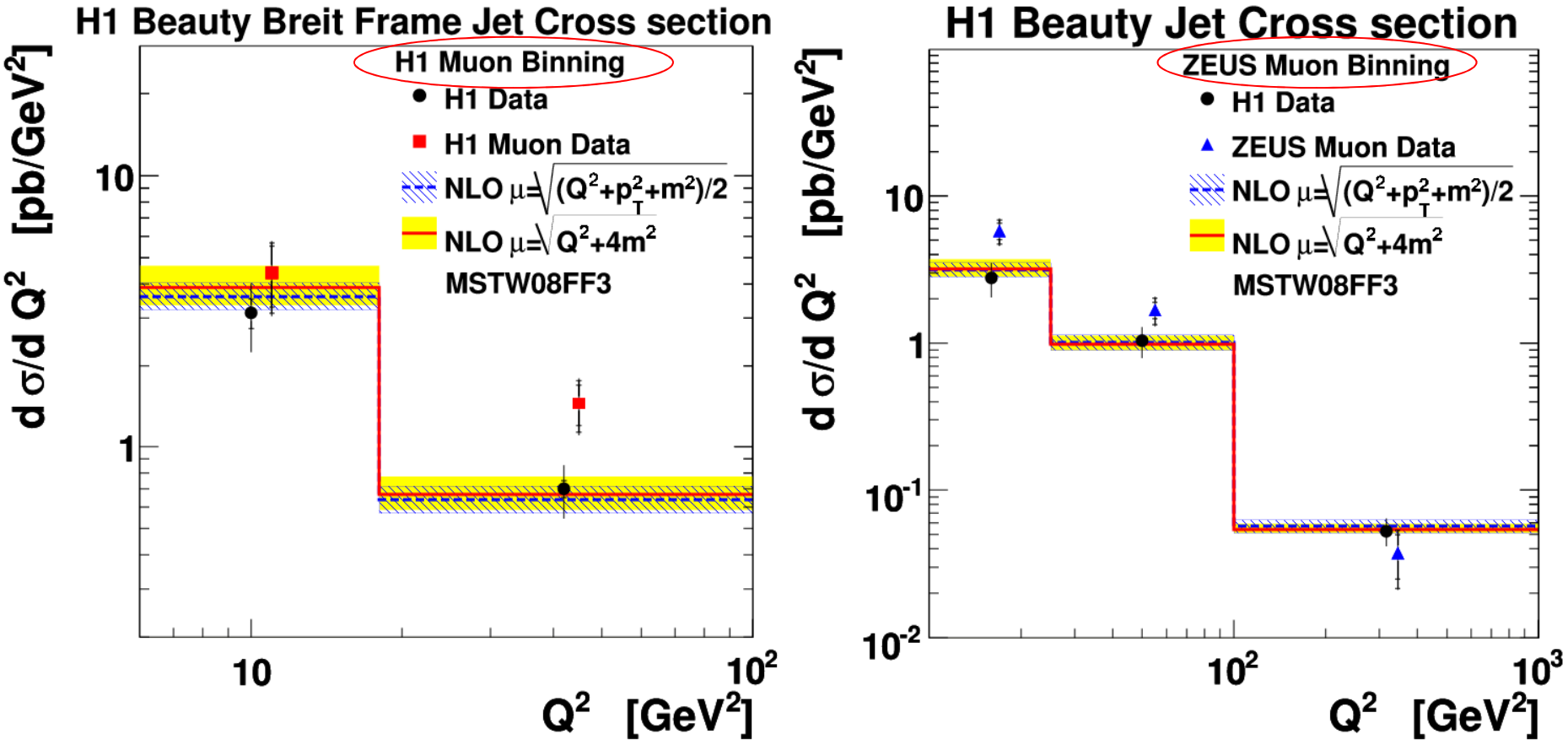




CASCADE too high, although shapes reasonably described

For NLO sensitivity to scale with Breit Frame Jet. Agreement within uncertainties

Comparison with Muon Tagged b Data



- Extrapolate muon data to full phase space (~10% uncertainty)
- H1 and ZEUS data from muon tagging differ from vertex data at either high or low Q^2, although agreement within errors

Summary

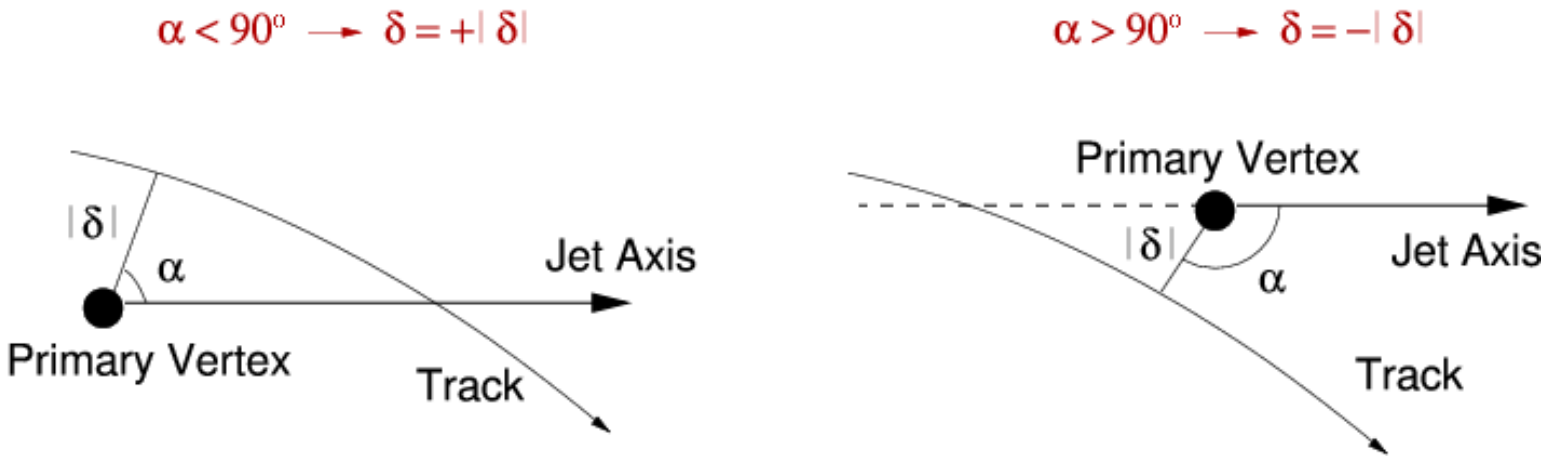
- Heavy Flavour jet production at HERA is an important testing ground for perturbative QCD
- In general, a reasonable description of the data is provided by Monte Carlo programs with sensitivity to modelling of QCD
- Comparison of the vertex tagged results with those from muon tagging reveal differences in the central values but agreement within errors
- The good description of the data provided by NLO QCD for the inclusive case continues in the presence of an additional hard scale provided by a jet

Extra Slides

Impact Parameter

- Inclusive and jet 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 E_T jet axis

Signed impact parameter δ



Jets NLO QCD

HVQDIS: massive FFNS NLO QCD (BGF α_s^2) parton level

PDF: MSTW08FF3 – FFNS partons from MSTW08 GM VFNS fit

CTEQ6.6 – GMVFNS partons (small incompatibility in α_s def)

CTEQ5F3 – Older FFNS partons.

MSTW08/CTEQ6.6 similar results. CTEQ5F3 10% lower.

Scale: $\mu^2=(Q^2+E_T^2+M^{2)}/2$ – recent H1 inclusive jet analysis

$\mu^2=Q^2+M^2$ – used often for HF analyses.

Variation 2μ, $\mu/2$

Parton-to-hadron:

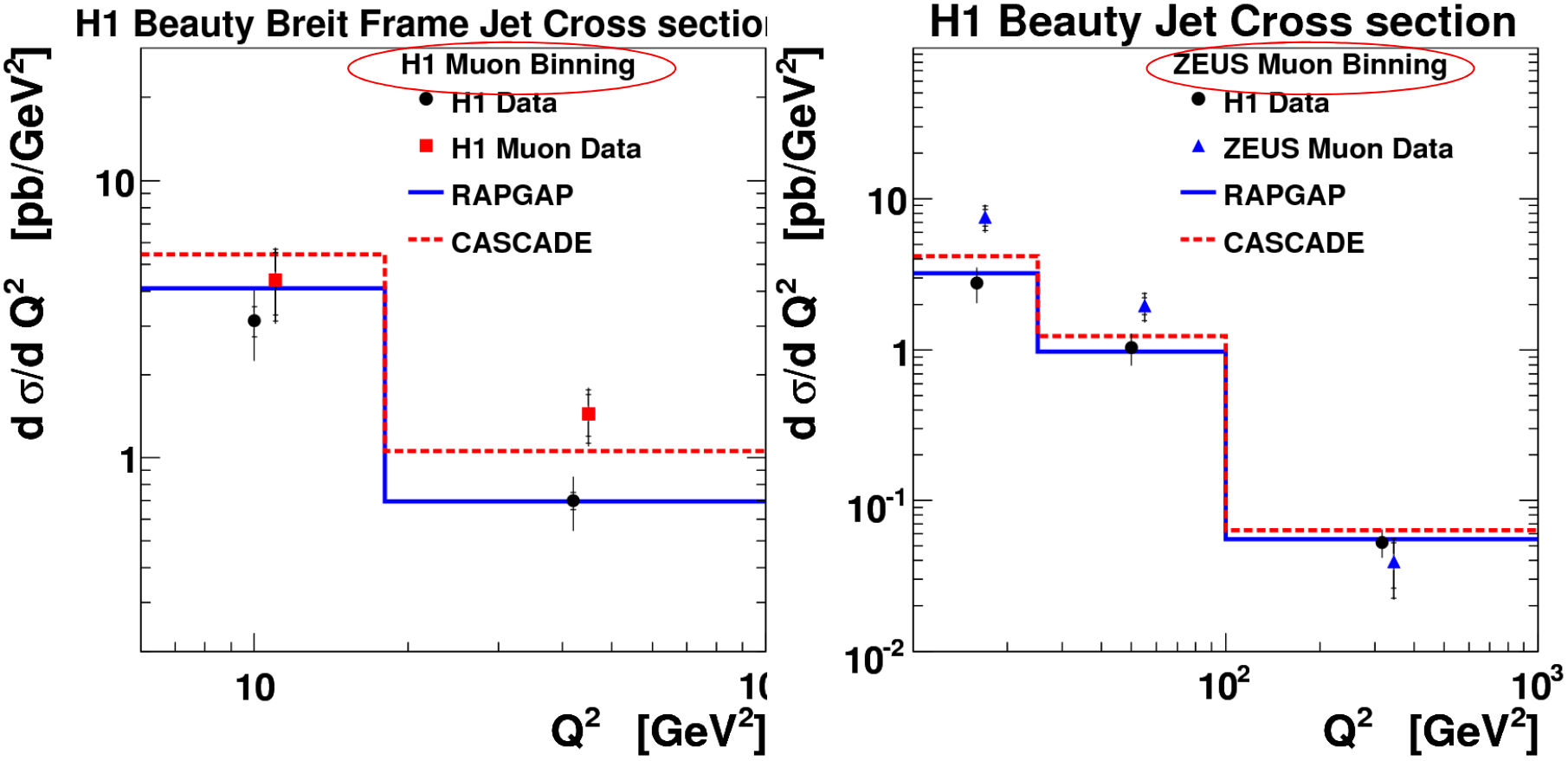
Calculated using RAPGAP with Lund-Bowler. Small except at low η for *b*. Uncertainty evaluated using Lund Symmetric.

Quark Masses: m_c=1.5 +/- 0.2 GeV, m_b=4.75 +/- 0.25 GeV

Breit Frame Jet Analysis

- Analysis extended to Breit frame. Theoretically more favourable and used in previous HF jet analyses (allows comparison with other measurements).
- Jet flavour evaluated in the *laboratory* frame for highest E_T jet satisfying $E_T>1.5$ GeV, $-1 < \eta < 1.5$.
- Look separately for high E_T jet in the Breit Frame $E_T^*>6$ GeV, $-1 < \eta < 1.5$ (any flavour).
- Cross sections as function of E_T^*, Q^2

Comparison with Muon Tag (MC)



- 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