Measurement of Charm and Beauty Photoproduction at HERA using $D^*\mu$ correlations

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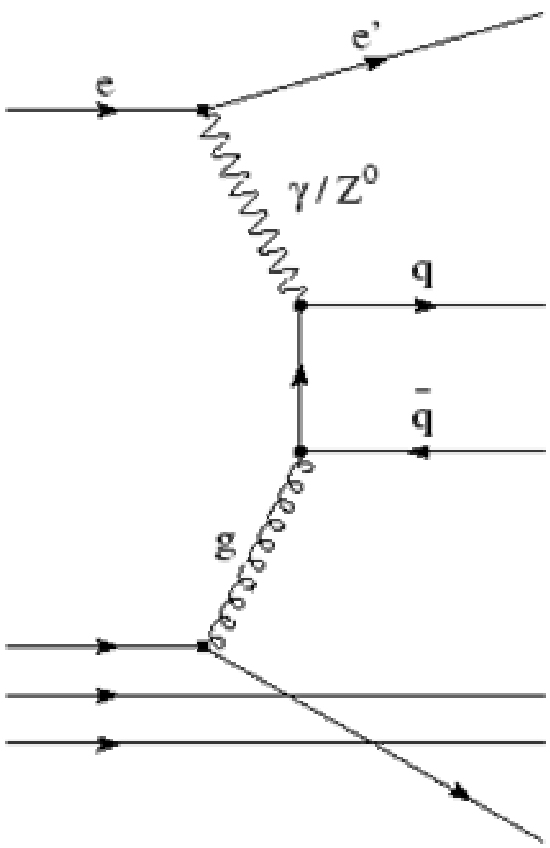
XIII International Workshop on Deep Inelastic Scattering

Madison, Wisconsin, U.S.A. – 29th April 2005

Heavy quarks from Boson Gluon Fusion



- **At HERA heavy quarks mainly produced via photon-gluon fusion: $\gamma g \rightarrow c\bar{c}$ or $b\bar{b}$ in photoproduction ($Q^2 < 1$ GeV^2).**

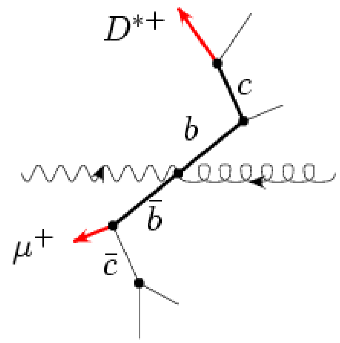
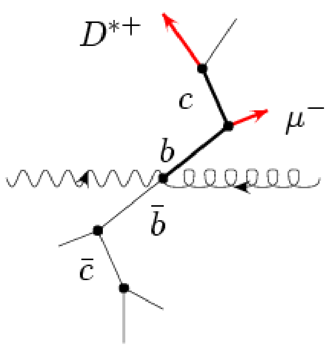
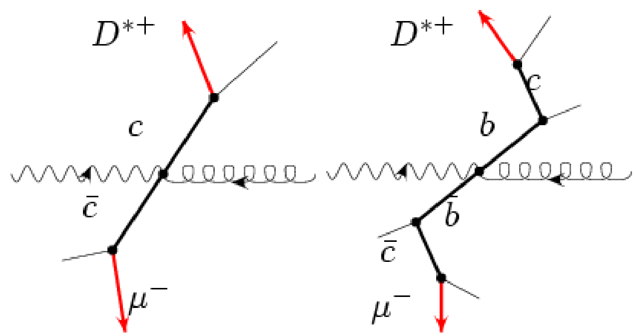
- ***c* & *b* are produced rarely w.r.t. *u*, *d* & *s***
  Also $c \approx 200 * b$.

- **'Classic' heavy quark analysis tags one heavy quark: from reconstructed D mesons (charm) or semi-leptonic decays / lifetime signatures (beauty).**

- **Do *both* here: select muon and reconstruct D* from:**

$$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow K^-\pi^+\pi_s^+ \text{ (BR 2.59\%)}$$

D*-μ charge-azimuthal angle correlations

	$\Delta\Phi < 90°$	$\Delta\Phi > 90°$
$Q(D^*) = Q(\mu)$	I	II 
	charm (%) 0.1 beauty (%) 3.8	0.1 20.4
$Q(D^*) \neq Q(\mu)$	III 	IV 
	charm (%) 6.0 beauty (%) 50.0	93.8 25.9

- Define 4 'correlation regions'

- Without $P_T(g)$ or $P_T(\gamma)$ heavy quarks are 'back-to-back'

- Charm pairs populate region IV

- Region (II/III/IV) for beauty pairs depends on the origin of the μ

- NB %'s are at parton level

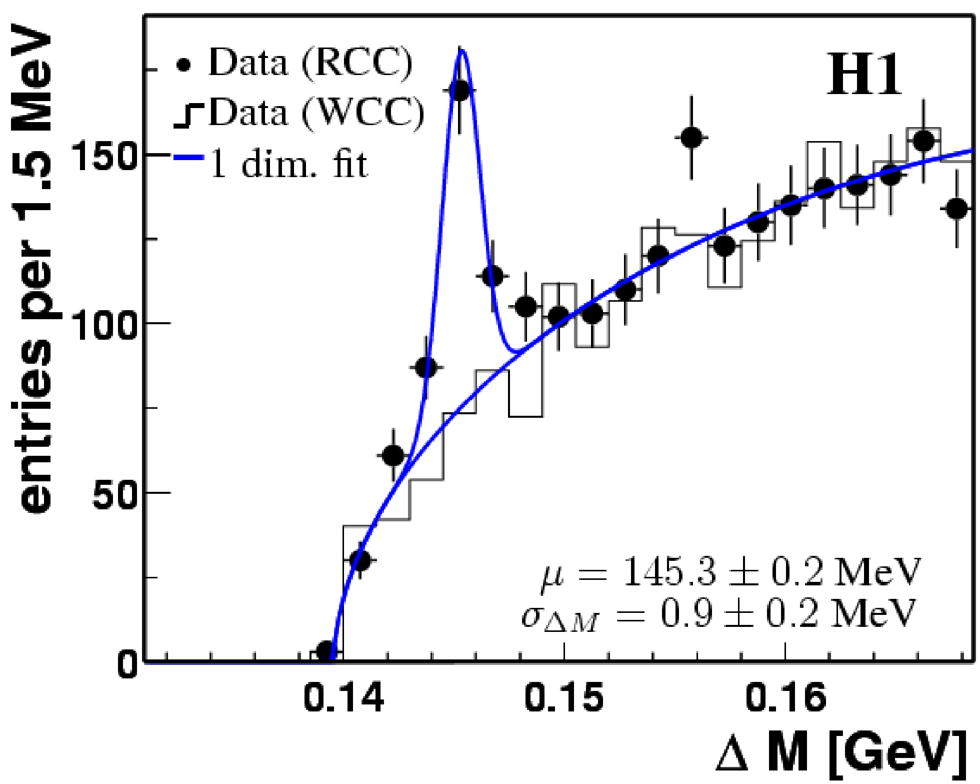
Modelling heavy quark production

- **2 Monte Carlos PYTHIA and CASCADE**
  - **- LO Matrix Elements + parton showers**
  - **- Parton evolution via DGLAP (PYTHIA) and CCFM (CASCADE) – Should give similar results in this kinematic region**

- **(N)LO pQCD "massive scheme" calculations with FMNR**
  - **- expected to be reliable in kinematic region: $P_T(q) \approx m_q$**
  - **- error calculated from simultaneously varying μ_r and μ_f (by 0.5 and 2)**

D* yield from mass difference technique (total sample)

Right Charge Combinations / Wrong Charge Combinations



L = 89 pb^{-1} mostly at CM $\sqrt{s}$= 320 GeV

D* yield measured from the *ΔM technique* :

$$\Delta M = m_{K\pi\pi_S} - M_{K\pi}$$

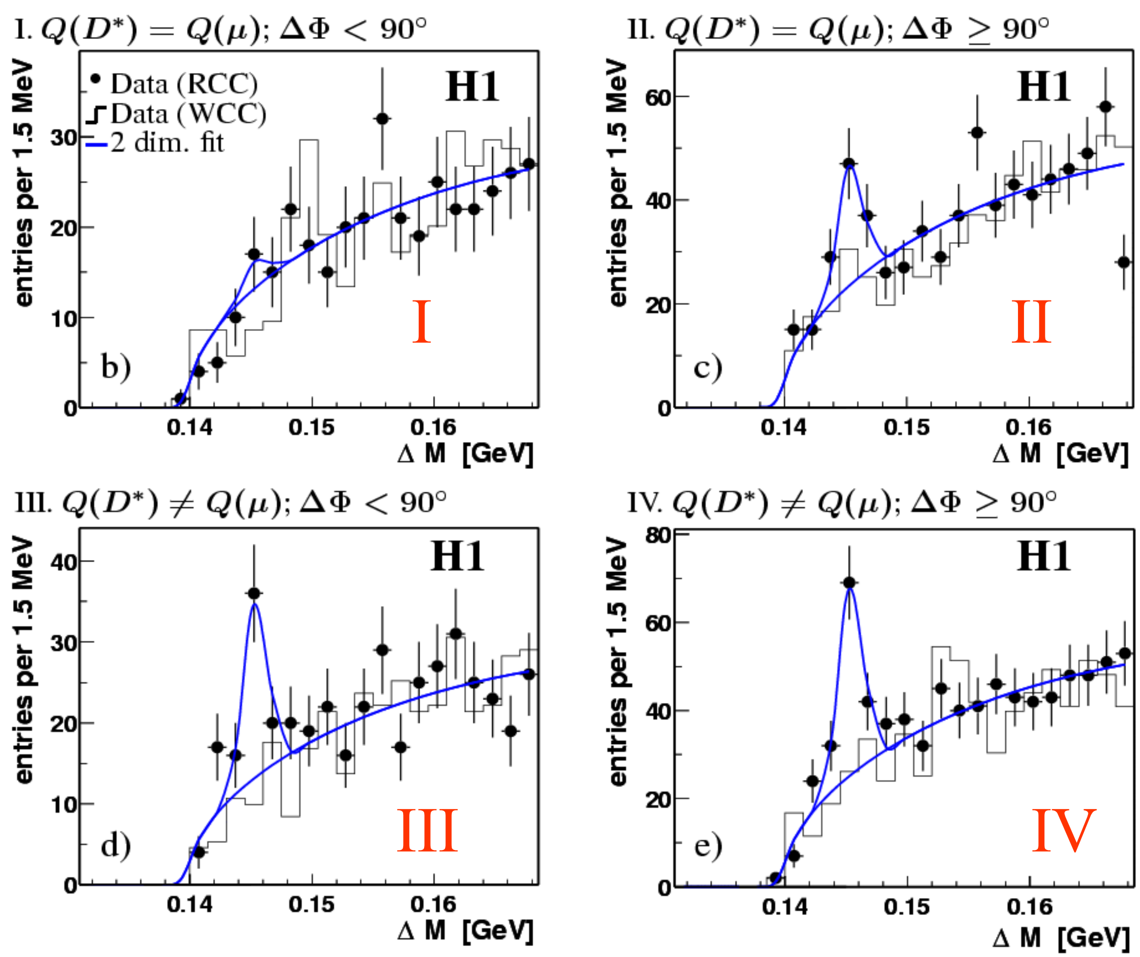
WCC normalised to RCC in non-resonant range above peak

Extract N(D*μ) from fit to Gaussian peak + background

N(D*μ) = 151 ± 22

(NB: This still includes 'fake muon' contribution – hadrons /light meson decay)

Fits to ΔM mass differences (Four correlation regions)



'2d fit' – simultaneous likelihood fit to *ΔM* in 4 correlation regions to extract *c* and *b* contributions

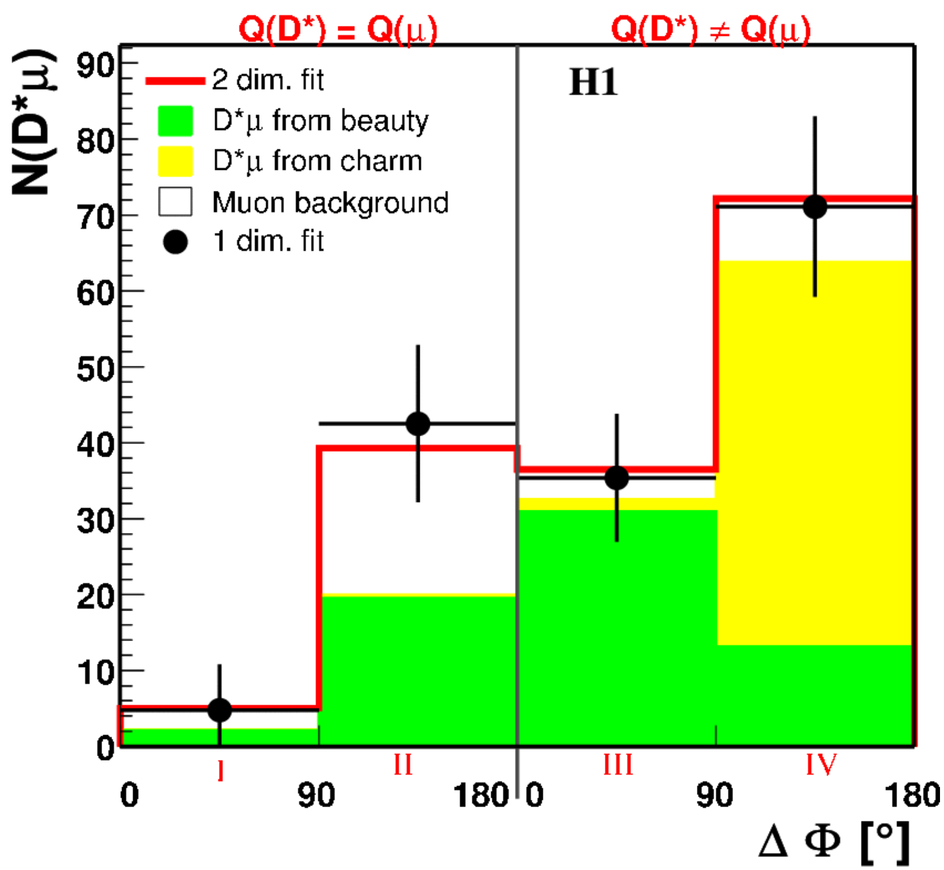
D* peak and background shape from 1D fit

Normalisation of combinatorial background using RCC/WCC done separately

6 free parameters: N_c, N_b and four background regions

$\chi^2 = 145.5 / 154$ d.o.f

Populations of the 4 correlation regions



V. good agreement between 2D fit and individual 1D fits

$N_c = 53 \pm 12$

$N_b = 66 \pm 17$

Use these to calculate visible cross sections for :

$\sigma_c^{vis}(ep \rightarrow e\, D^*\, \mu\, X)$

$\sigma_b^{vis}(ep \rightarrow e\, D^*\, \mu\, X)$

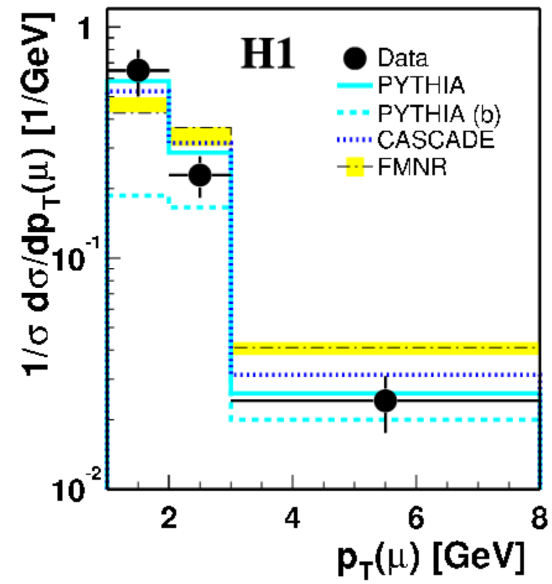
Cross section determinations

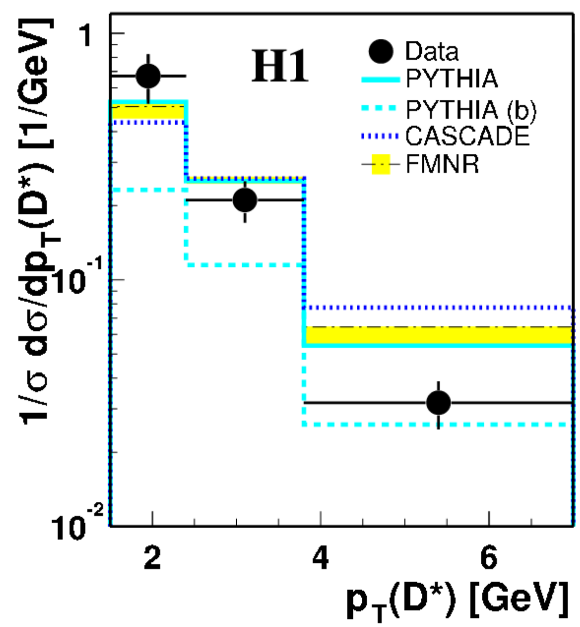
Charm	Cross section (pb)	Data / Theory
Data	$250 \pm 57 \pm 40$	
PYTHIA (direct)	242 (142)	1.0
CASCADE	253	1.0
FMNR	286^{+159}_{-59}	0.9
Beauty		
Data	$206 \pm 53 \pm 35$	
PYTHIA	57 (44)	3.6
CASCADE	56	3.7
FMNR	52^{+14}_{-9}	4.0

Visible kinematic region : $p_T(D^*) > 1.5$ GeV; $|\eta(D^*)| < 1.5$; $p(\mu) > 2$ GeV; $|\eta(\mu)| < 1.735$; $0.05 < y < 0.75$; $Q^2 <$ GeV^2.

- Similar cross sections due to visible kinematic region def'n –high p_T μ requirement suppresses central charm production
- Good agreement for charm production
- Beauty production exceeds prediction
- NB: Analysis extends down to *b*-pair production threshold cf. jet measurements ≈ 5 GeV higher

Normalised differential cross sections (w.r.t. p_T)





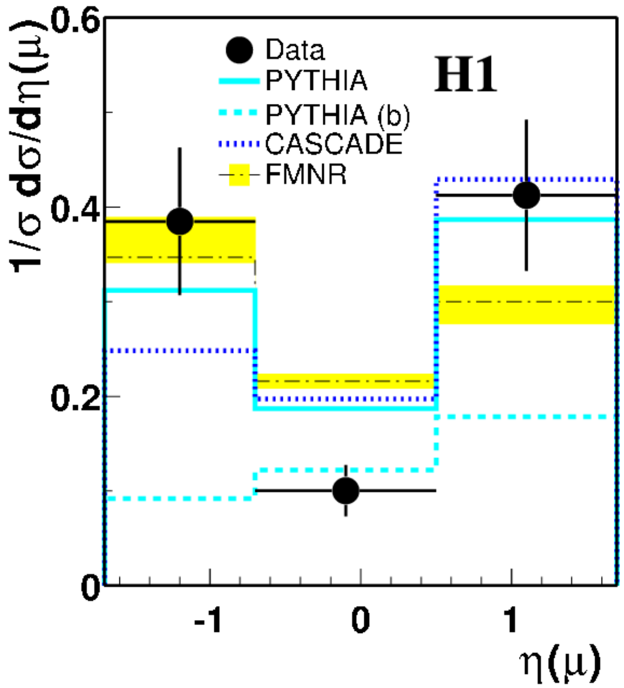
- **Bin-by-bin fit for all differential variables to the *ΔM* distribution**

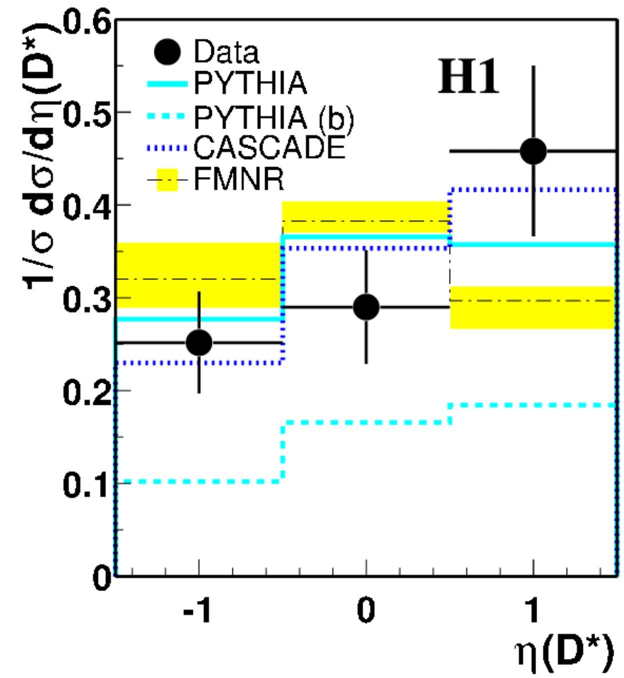
- **No separation of charm and beauty – correction for 'fake muons' from MC**

- **Models use *c* and *b* contributions combined according to total visible cross sections and are *normalised to their sum* for shape comparisons**

- **QCD models describe the shape quite well, although data tend to be softer than the calculations**

Normalised differential cross sections (w.r.t. pseudorapidity)

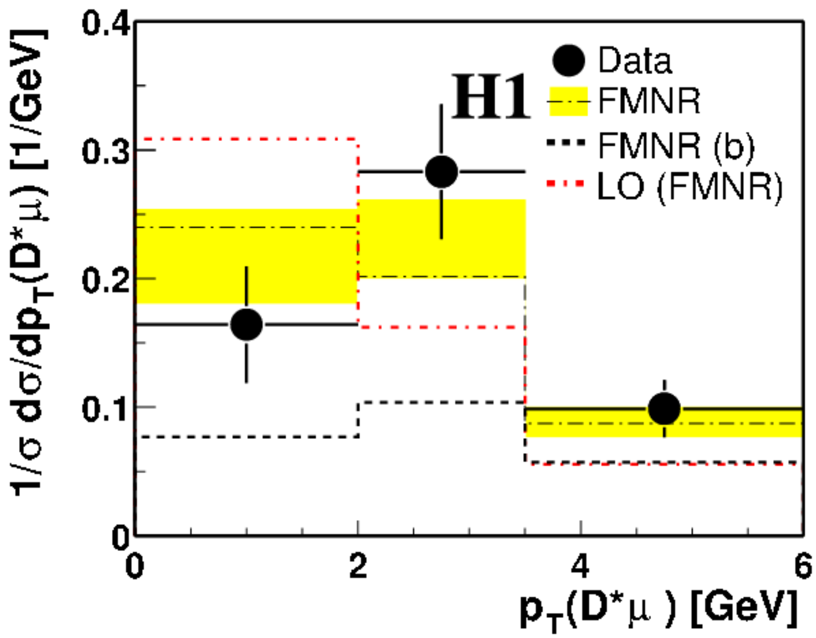


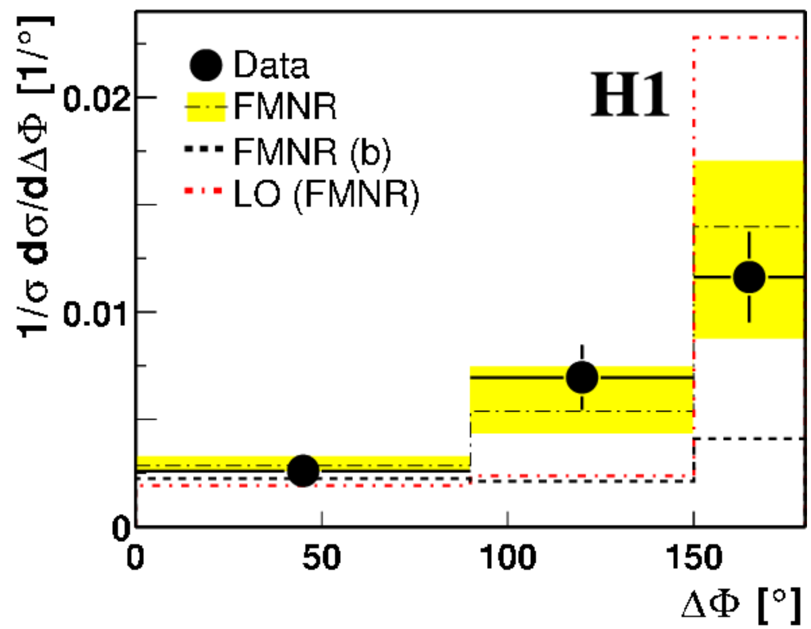


- **Similar agreement in shape, except for the muon pseudorapidity which shows a central dip due to the large p_T muon requirement**

D*μ variables – (N)LO FMNR comparisons

$$p_T(D^*\mu) = \left|\vec{p}_T(D^*) + \vec{p}_T(\mu)\right|$$

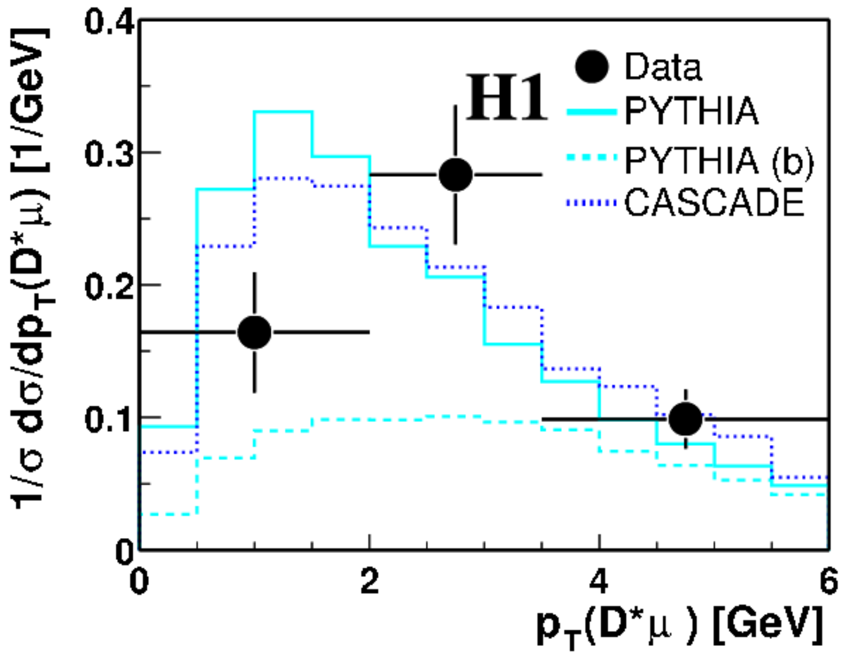


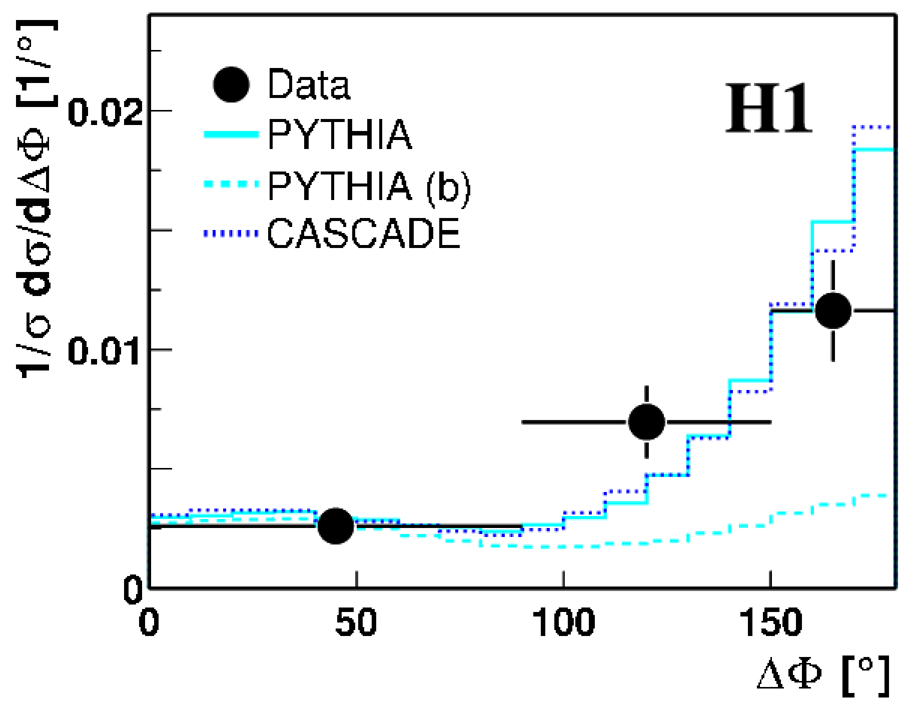


- **Expected deviations from LO due to higher order effects – flatter p_T distribution and broader ΔΦ peak.**

- **Good agreement with NLO calculation**

D*μ variables – PYTHIA & CASCADE MC comparisons

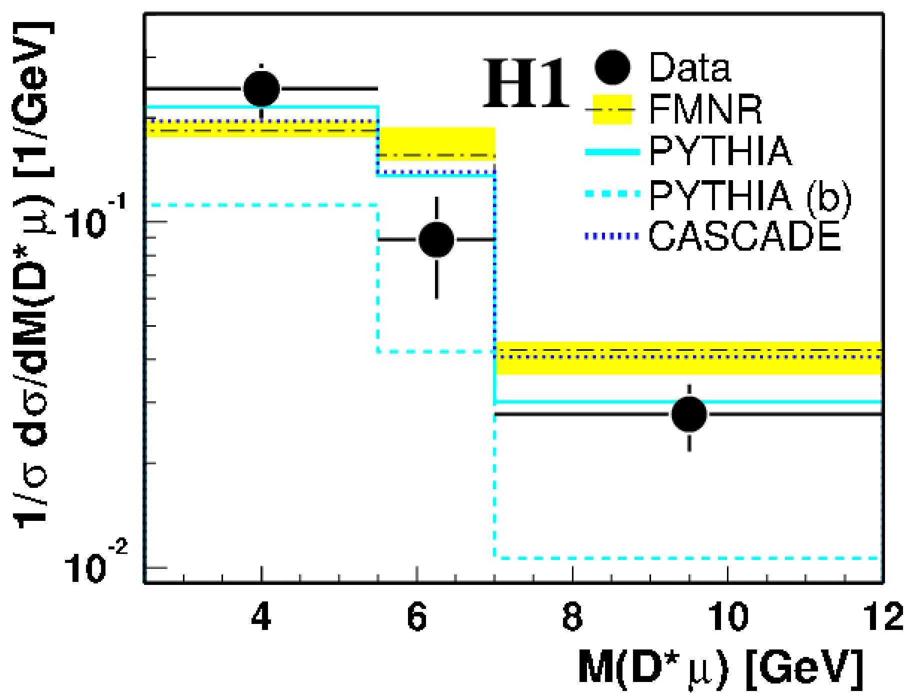


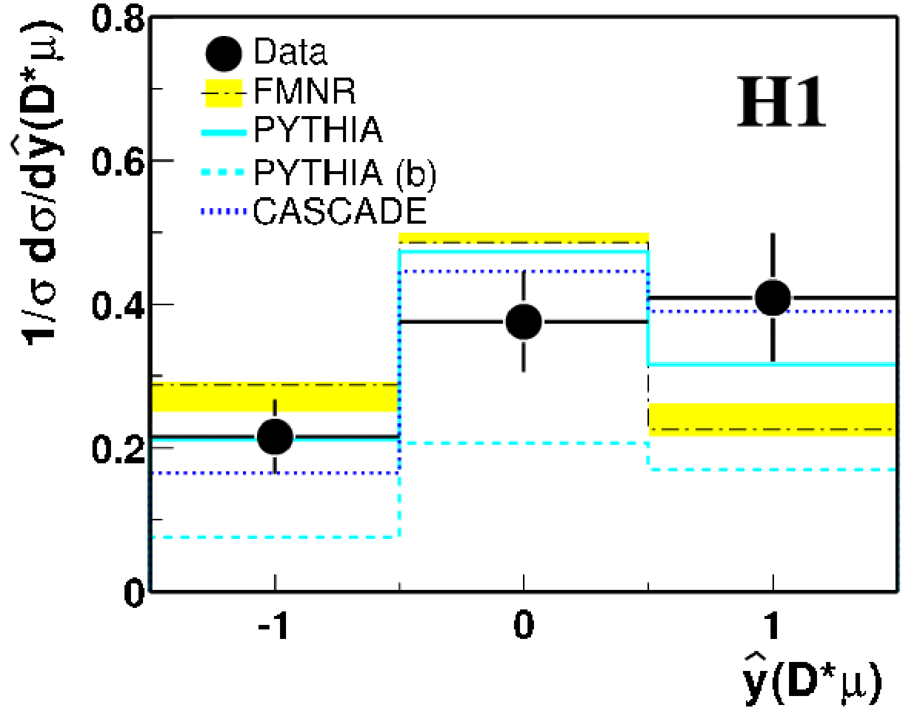


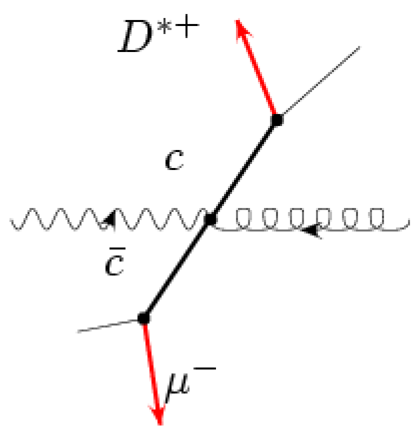
- **Both MCs give a good description of the data**

- **NB: Although different approaches to parton evolution are taken, the differences are smaller than the experimental errors**

D*μ variables – Invariant mass and rapidity







M(D*μ) **reflects the CM energy of the quark pair and $\hat{y}$ is related to the ratio of the energies of the interacting partons from the proton and the photon**

Adequate description by all models

$$\hat{y} = \frac{1}{2}\ln\left|\frac{E+p_z}{E-p_z}\right|$$

Quark antiquark tag

Previous cross sections include events (region III) where D* and μ originate from the same *b* quark – dilution of correlations

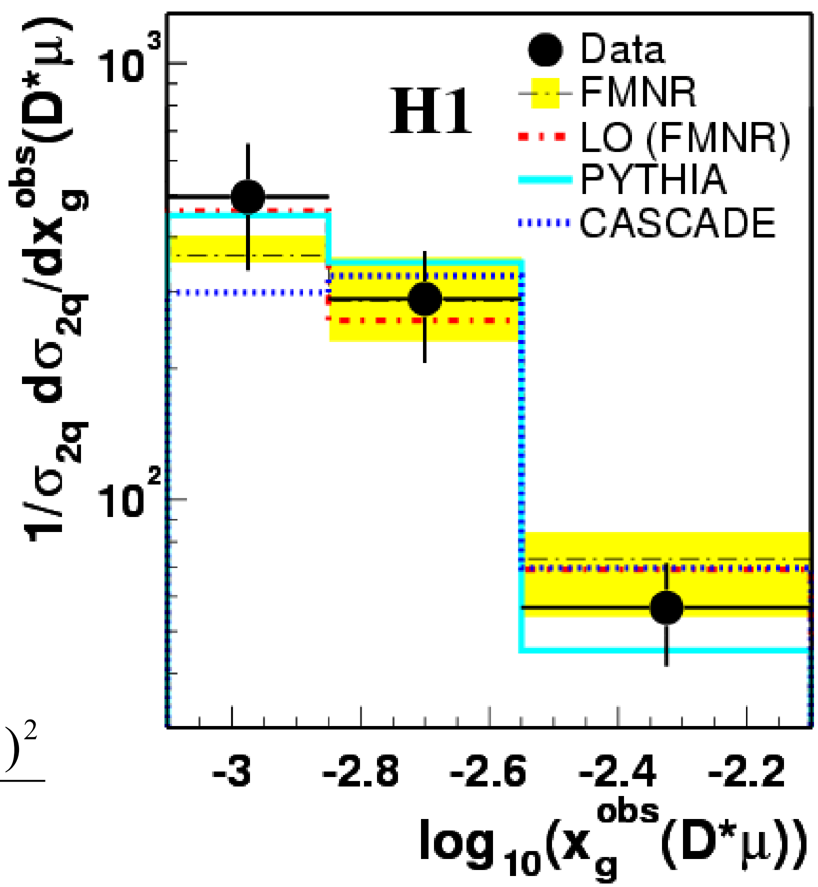
Tag both quarks by either a D* or a muon (region IV – mainly $c\bar{c}$)

$b\bar{b}$ contribution 18% from 2D fit.

Correct for D*μ from same quark (migrations from region III)

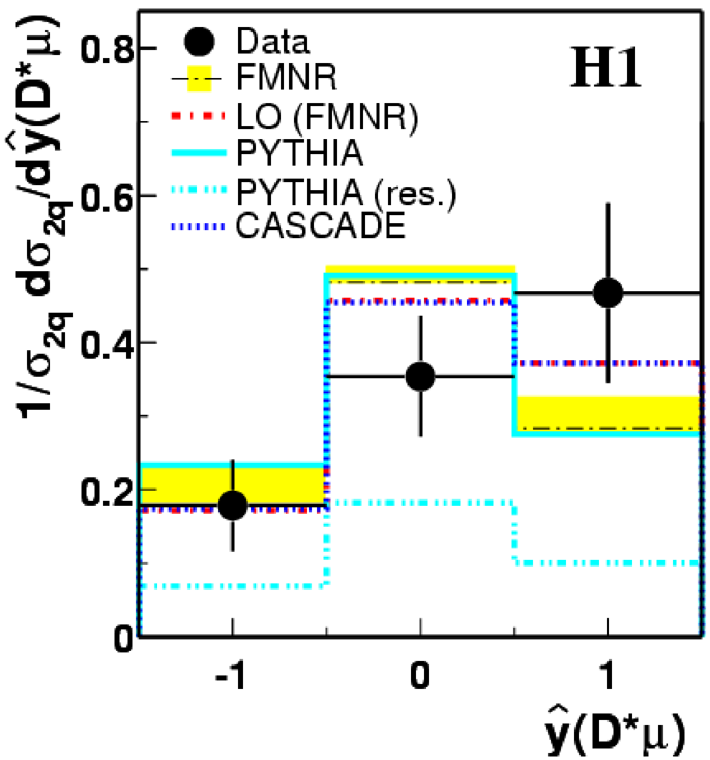
Here correlation of kinematic quantities reconstructed for D* & μ to those of the quark pairs is good for x_g and *y*, while weaker for p_T(D*μ)

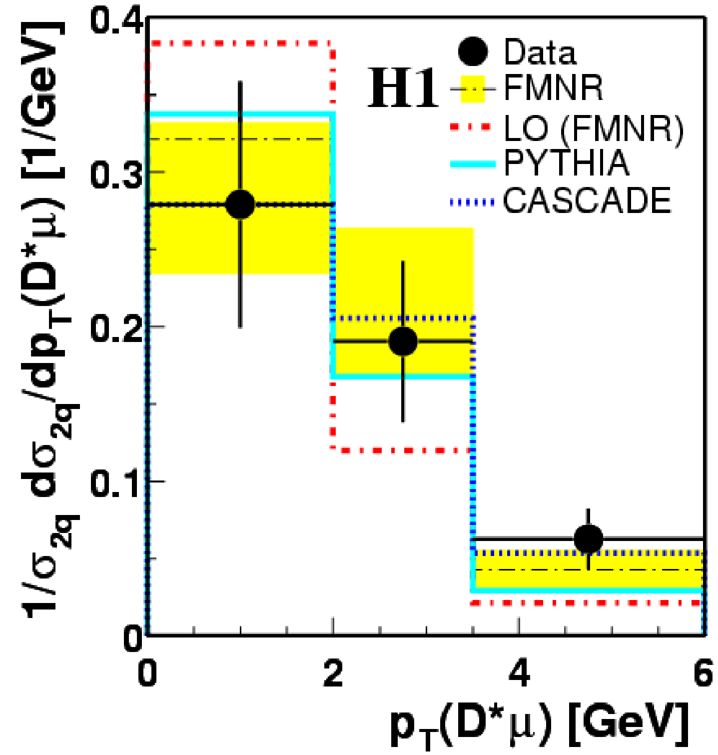
All QCD calculations give a reasonable description of x_g



$$x_g^{obs} = \frac{M(D^*\mu)^2}{ys}$$

Quark antiquark tag





- LO FMNR prediction for $p_T(D^*\mu)$ is again too soft, as for the total sample, whilst NLO FMNR fits the data well

- PYTHIA (collinear factorisation) and CASCADE (k_t factorisation) very similar in the region studied

Summary

- **Measurement of $c\bar{c}$ and $b\bar{b}$ photoproduction cross sections at HERA**
- **Tagged D* meson and muon as signature**
- **Separate charm and beauty contributions due to differing correlations between charge/angle for D* and muon**
- **Measured cross section for charm agrees with NLO QCD, beauty is higher (at lower $b\bar{b}$ c.o.m than most previous analyses)**
- **QCD calculations predict shapes and H.O. effects reasonably well.**

b cross section comparisons