$D^*\mu$ correlations and D production in ep scattering at HERA

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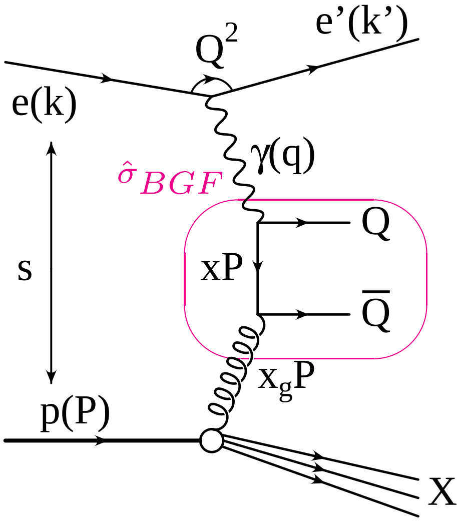
- Heavy quark production at HERA
- $D^*\mu$ correlations:
  - Separation of charm and beauty
  - Total charm and beauty cross sections
  - Differential cross sections
- D production
  - Measurement of D^+, D_s^+, D^0 and D^* cross sections
  - Determination of $f(c \to D)$
  - Differential D production cross sections

Heavy quark production

LO: Boson gluon fusion (BGF)



$m_b \approx 3 \cdot m_c$ and $|Q_b| = \frac{1}{2} \cdot |Q_c|$

$$\Rightarrow \sigma_b \approx \frac{1}{200} \cdot \sigma_c$$

momentum fraction of gluon: $x_g = x \cdot \left(\frac{M(Q\bar{Q})}{Q^2} + 1 \right)$

$$\sigma(ep \to Q\bar{Q}X) \sim g(x_g) \cdot \hat{\sigma}_{BGF}(\gamma g \to Q\bar{Q})$$

m_Q serves as pQCD scale

Heavy quarks are a direct probe of the gluon

Tagging of HQ:

Q : D mesons (e.g. D^*) , e or μ
$Q\bar{Q}$: $D^{*+}D^{*-}$, l^+l^- for $l = e, \mu$
$D^{*\pm}l^{\mp}$ for $l = e, \mu$

$D^*\mu$ analysis

Detection of **both heavy quarks** of the BGF by their decay and fragmentation products:

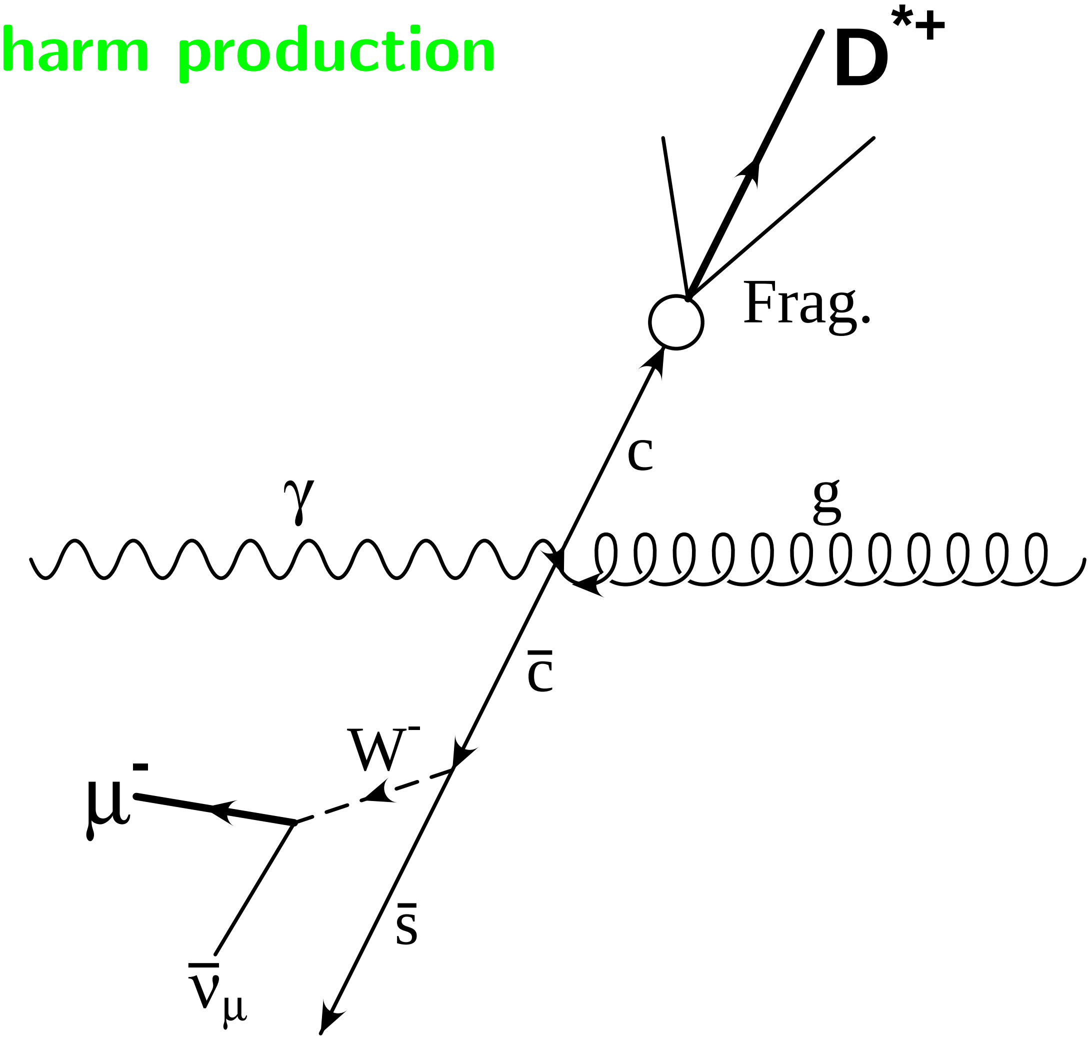
$$Q \longrightarrow D^* \to D^0\pi_s \to K\pi\pi_s$$

$$\bar{Q} \longrightarrow \mu$$

- separation of charm and beauty possible due to charge and angle correlations of the D^* and the muon
- almost complete reconstruction of the $Q\bar{Q}$ final state
  - ◇ measurement of the gluon density
  - ◇ sensitivity to higher orders

Correlations in the γg-CMS (I)

Charm production

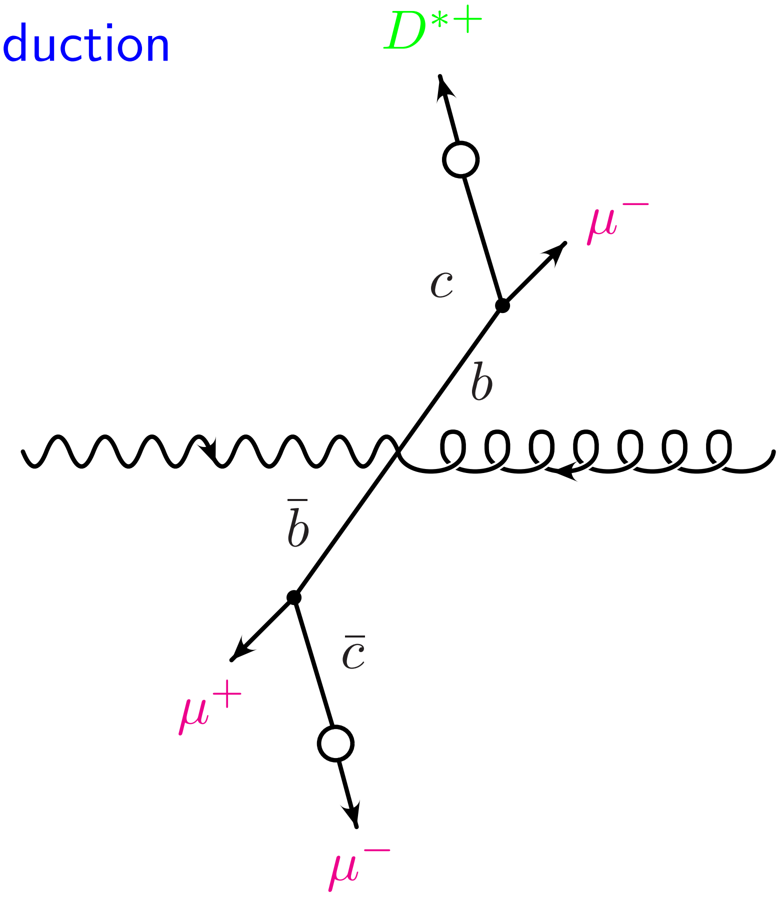


$$\mathbf{\Delta\Phi \approx 180^\circ}$$

$$\mathbf{Q(D^*) \neq Q(\mu)}$$

Correlations in the γg-CMS (II)

Beauty production



For beauty production three correlations are possible:

- $\mathbf{\Delta\Phi} \approx \mathbf{180^\circ}$ and $\mathbf{Q}(\mathbf{D}^*) \neq \mathbf{Q}(\mu)$
- $\mathbf{\Delta\Phi} \approx \mathbf{180^\circ}$ and $\mathbf{Q}(\mathbf{D}^*) = \mathbf{Q}(\mu)$
- $\mathbf{\Delta\Phi} \approx \mathbf{0^\circ}$ and $\mathbf{Q}(\mathbf{D}^*) \neq \mathbf{Q}(\mu)$

$D^*\mu$-events

H1 data: 97-00 $\mathcal{L} = 91.2$ pb^{-1}

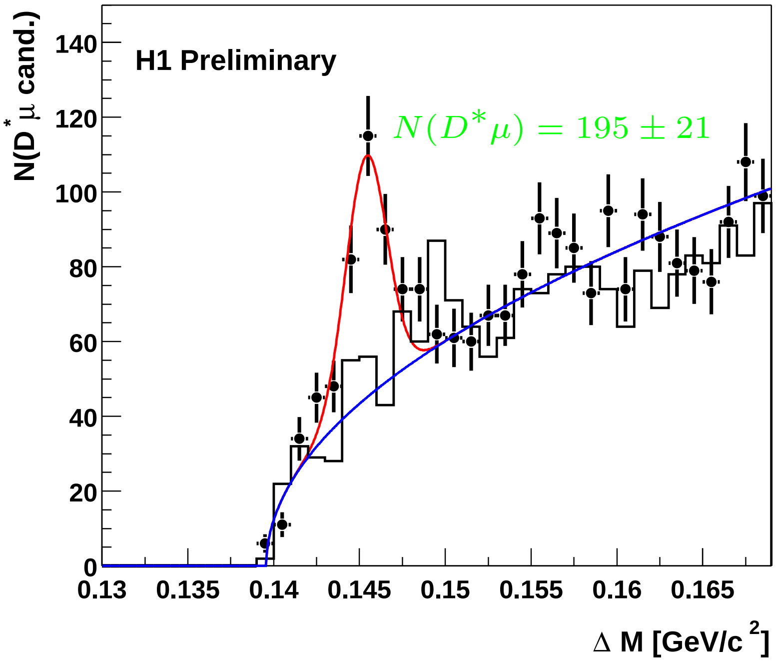
visible range:

- $p_T(D^*) > 1.5$ GeV/c ; $|\eta_{D^*}| < 1.5$
- $p_T(\mu) > 1.0$ GeV/c ; $20° \leq \theta_\mu \leq 160°$
- $0.05 < y < 0.75$; no cut on Q^2

⇒ resolved photon contribution suppressed

Reconstruction of D^{*+}: $D^{*+} \rightarrow D^0\pi_s^+ \rightarrow K^-\pi^+\pi_s^+$

simultaneous fit of right $(K^-\pi^+\pi_s^+)$ and wrong $(K^+\pi^+\pi_s^-)$ charge combinations



Correlation in the lab frame

DIS $\Longrightarrow$ transform into γp system ($\Delta\Phi \rightarrow \Delta\Phi^*$)

Smearing by:

$\star$ perturbative effects (**gluon radiation**)
$\star$ non perturbative effects (**fragmentation**)

$\Longrightarrow$ angle between the D^* and the muon $\Delta\Phi^*$ can differ substantially from 180° or 0° respectively

$\longrightarrow$ distinction only between $\Delta\Phi^* \geq 90^\circ$ and $\Delta\Phi^* \leq 90^\circ$

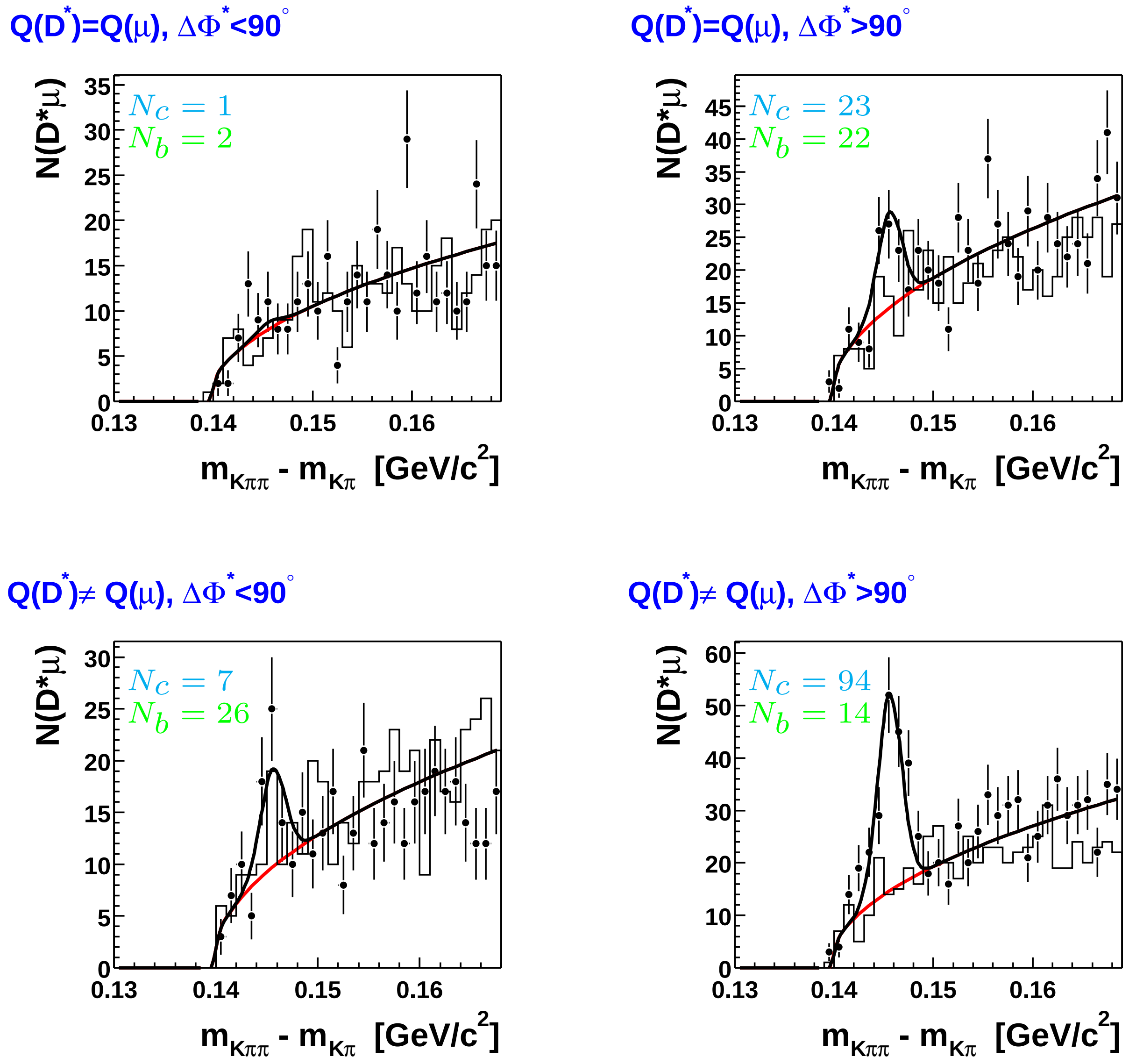
	$\boldsymbol{\Delta\Phi^* \leq 90^\circ}$	$\boldsymbol{\Delta\Phi^* \geq 90^\circ}$
$Q(\mu) = Q(D^*)$	1 **no charm** **few beauty**	2 **no charm** **beauty**
$Q(\mu) \neq Q(D^*)$	3 **few charm** **beauty**	4 **charm** **beauty**

2 dim. Log-Likelihood-Fit

using a 2dim.Log-Likelihood-Fit to separate c and b

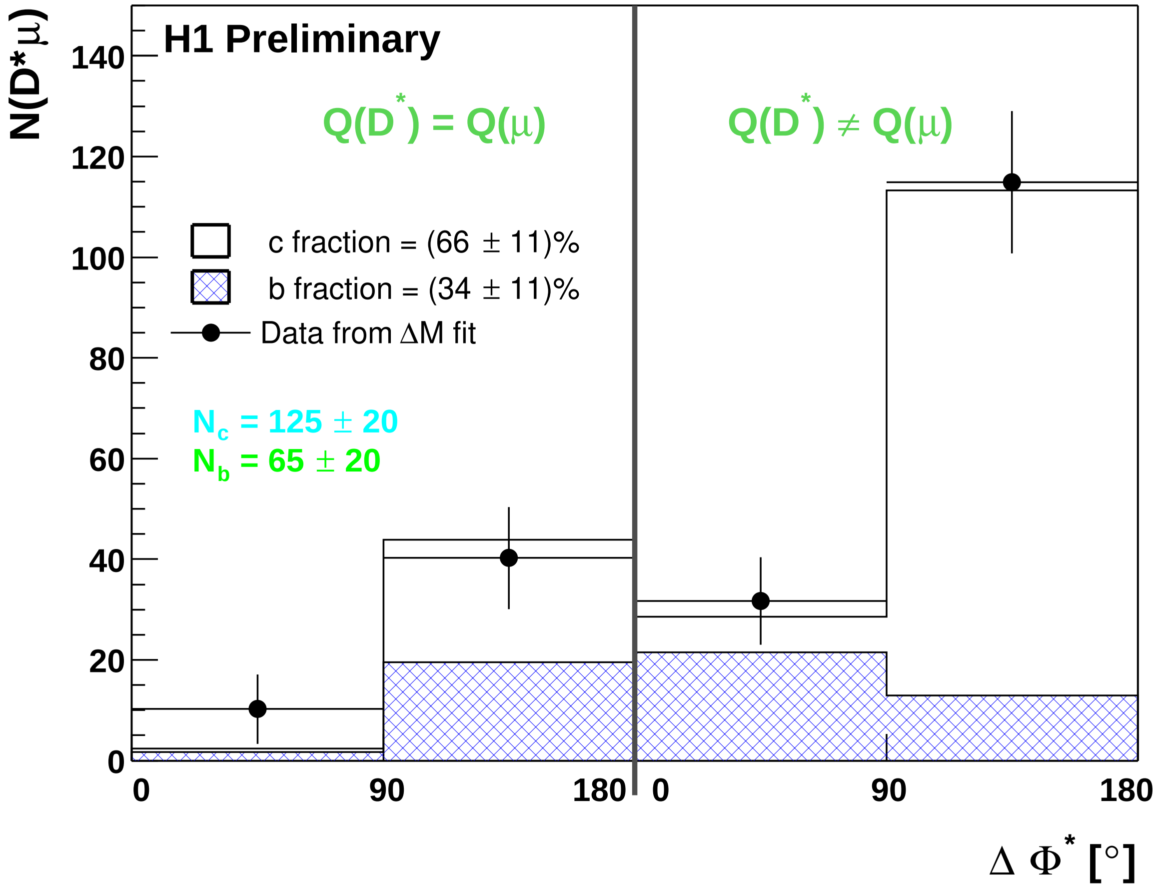
- ⋆ Quantities: correlation region, ΔM
- ⋆ simultaneous fit of right and wrong charge combinations

H1 Preliminary



2 dim. Log-Likelihood-Fit

(correlation regions)



Subtract background due to wrongly identified muons (c: $\approx 30\%$, b: $\approx 5\%$):

$N_c = 88 \pm 14 \Longrightarrow$ c contribution: 59%

$N_b = 62 \pm 19 \Longrightarrow$ b contribution: 41%

Total c and b cross sections

Visible range:

$p_T(D^*) > 1.5$ GeV/c ; $|\eta(D^*)| < 1.5$

$p_T(\mu) > 1.0$ GeV/c ; $20^\circ < \theta_\mu < 160^\circ$

$0.05 < y < 0.75$

$$\boldsymbol{\sigma^c_{vis}(ep \rightarrow e'D^*\mu X) \;=\; (720 \pm 115 \pm 245)}\ \text{pb}$$
$$\boldsymbol{\sigma^b_{vis}(ep \rightarrow e'D^*\mu X) \;=\; (380 \pm 120 \pm 130)}\ \text{pb}$$

Comparison with LO direct prediction (AROMA):

	$\sigma^{dir.}_{LO}(ep \rightarrow e'D^*\mu X)$ [pb]
charm	≈ 400
beauty	≈ 100

Double tagging with $D^*\mu$ correlations

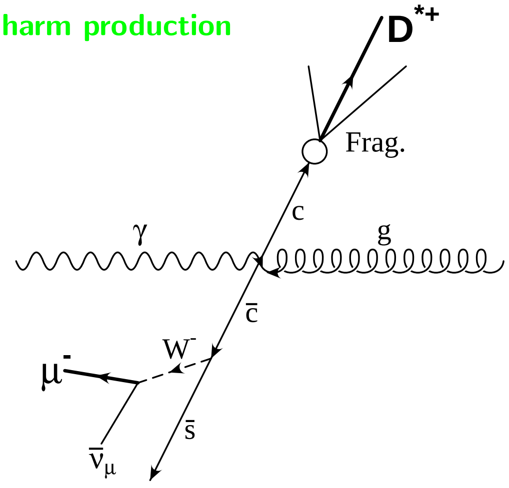
- ◇ $D^*\mu$ quantities are taken as an approximation of $Q\bar{Q}$ quantities
- ◇ Characteristic quantities:

  $p_T(D^*\mu)$: transverse momentum of $D^*\mu$ pair
  $M(D^*\mu)$: invariant mass of $D^*\mu$ pair
  $\hat{y}(D^*\mu)$: rapidity of $D^*\mu$ pair
  $\Delta\Phi$: azimuthal angle difference of the D^* and the μ

Leading order (LO):

- ◇ $p_T(Q\bar{Q}) \approx 0$
- ◇ $\Delta\Phi \approx 180°$

Charm production



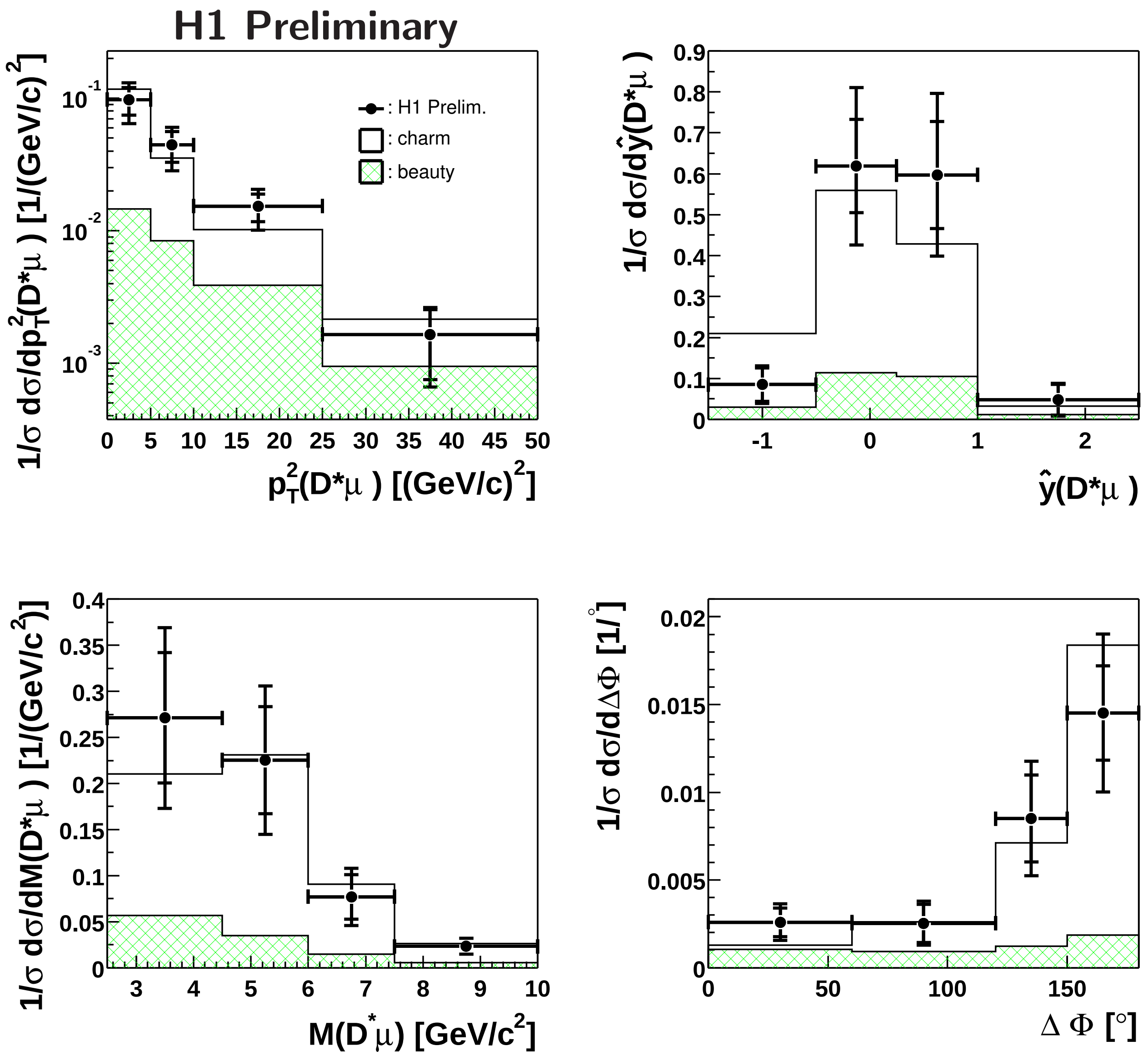
LO modified: Smearing

- ◇ parton shower (PS)
- ◇ fragmentation
- ◇ non-zero k_T of initial partons

$p_T(Q\bar{Q})$,$\Delta\Phi$ and $\hat{y}(Q\bar{Q})$ used to study non pert. effects.

$M(Q\bar{Q})$ and $\hat{y}(Q\bar{Q})$: needed to determine the gluon density

Normalized differential cross sections



⇒ LO + PS prediction describes the shape of the data.

Intermediate conclusions

- ◇ First **double tagging** measurement at HERA:

$$\begin{aligned} \boldsymbol{Q} &\longrightarrow \boldsymbol{D^*} \to D^0\pi_s \to K\pi\pi_s \\ \boldsymbol{\bar{Q}} &\longrightarrow \boldsymbol{\mu} \end{aligned}$$

- ◇ **separation** of charm and beauty with the aid of charge and angle correlations

- ◇ charm and beauty **cross sections** are compatible with previous results

- ◇ LO+PS model describes the **shape** of the $D^*\mu$ variables

D meson production in DIS

First part of talk:

Fragmentation leads to smearing of the $D^*\mu$ variables

⇒ Consider **fragmentation** in second part of the talk:

◇ Compare fragmentation (ep) with fragmentation in e^+e^-

◇ Universality of fragmentation in the charm sector: $e^+e^- = ep = p\bar{p}$

But does it hold?

⇒ Measurement of the production of different D mesons in DIS

(using for all D mesons the **same method**)

D mesons

	D^+	D^0	D_s^+	D^{*+}
valence quarks	$c\bar{d}$	$c\bar{u}$	$c\bar{s}$	$c\bar{d}$
Spin J^P	0^-	0^-	0^-	1^-
$c\tau$ $[\mu m]$	315	124	149	-

Reconstruction:

$D^{*+} \longrightarrow D^0\pi_s \longrightarrow (K^-\pi^+)\pi_s^+$

$D^+ \longrightarrow K^-\pi^+\pi^+$ (3 tracks → much comb. background)

$D^0 \longrightarrow K^-\pi^+$

$D_s^+ \longrightarrow \Phi\pi^+ \longrightarrow (K^+K^-)\pi^+$

H1 data (99+00)e^+p $\mathcal{L} = 47.8$ pb^{-1}

visible range:

2 GeV^2 $< Q^2 <$ 100 GeV^2 ; $0.05 < y < 0.7$
$p_T(D) >$ 2.5 GeV/c ; $|\eta(D)| < 1.5$

◇ Identify all four D mesons with a common method (systematic uncertainties cancel)

◇ Central silicon vertex detector (CST) is essential

Central Silicon Tracker (CST)