Heavy Flavour Group Summary
Part 2: Experiment

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Outline

- **Fragmentation in hadronic enviroment**
- **Heavy quark PDFs at HERA and LHC**
- $Q\bar{Q}$ **correlations**
- **Tuning MC for b production with JetWeb**

Fragmentation of c and b, the experimental side

Fragmentation is a key ingredient to calculate HQ production at HERA and LHC (see M. Cacciari's talk)

How can we understand it better and reduce uncertainties ?

- **Input from e^+e^-: use this data to get the best knowledge (fits)**
- **Evaluate accurately uncertainties deriving from fragmentation**
- **Check portability of HQ fragmentation to an hadronic enviroment by measuring it at HERA (and LHC ?)**
- **what to do with regions where non perturbative effects are large (e.g. low p_T) ?**

Charm fragmentation (M. Wing)

Existing charm fragmentation measurements:

Experiment	$\sqrt{s}$ (GeV)	corrected?
ARGUS	10.6	YES
CLEO	10.55	YES
OPAL	91	NO
ALEPH	91	NO
TPC	29	YES
DELCO*	29	(YES)
TASSO	$28 \rightarrow 46.8$	YES
HRS	29	YES
JADE	$29.9 \rightarrow 38.7$	YES
ZEUS	> 18 (~ 30)	YES

Program: Use the large e^+e^- data set to

- **Check consistency of data sets within Pythia, fit best parameters in Pythia**
- **use NLL theory**
- **compare to measurements from HERA (see next page)**

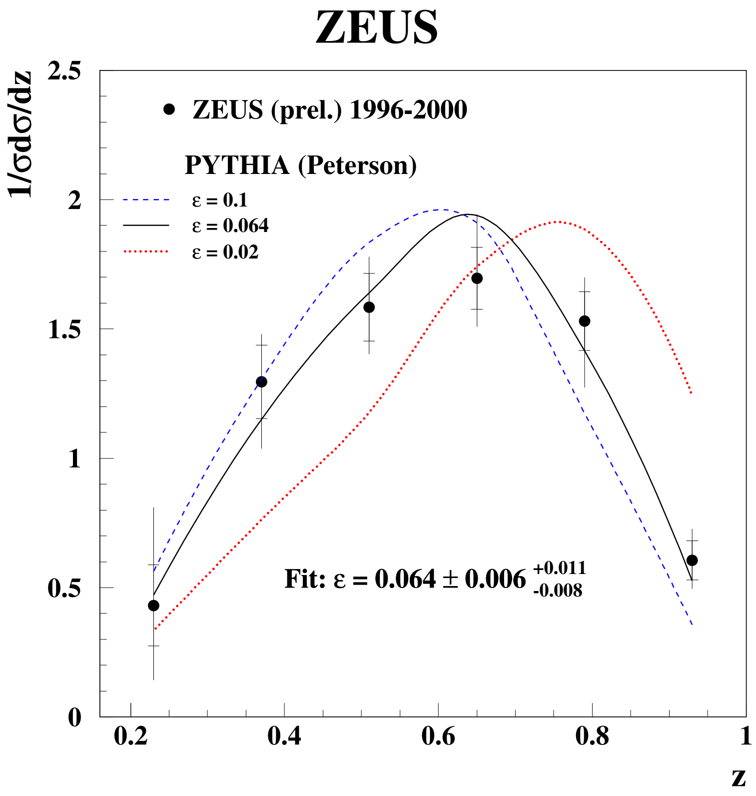
Charm fragmentation at HERA (M. Wing)

ZEUS (prel.) measurement:
D^*+jet photoproduction

Difference from e^+e^-:
need to normalize to jet energy:
$z = \frac{(E+P_{\mathrm{par}})_D}{(E+P)_{\mathrm{jet}}}$

Compared to MC with different fragmentation models and parameter

To Do: compare also with NLO ?
needs Jet hadronization correction



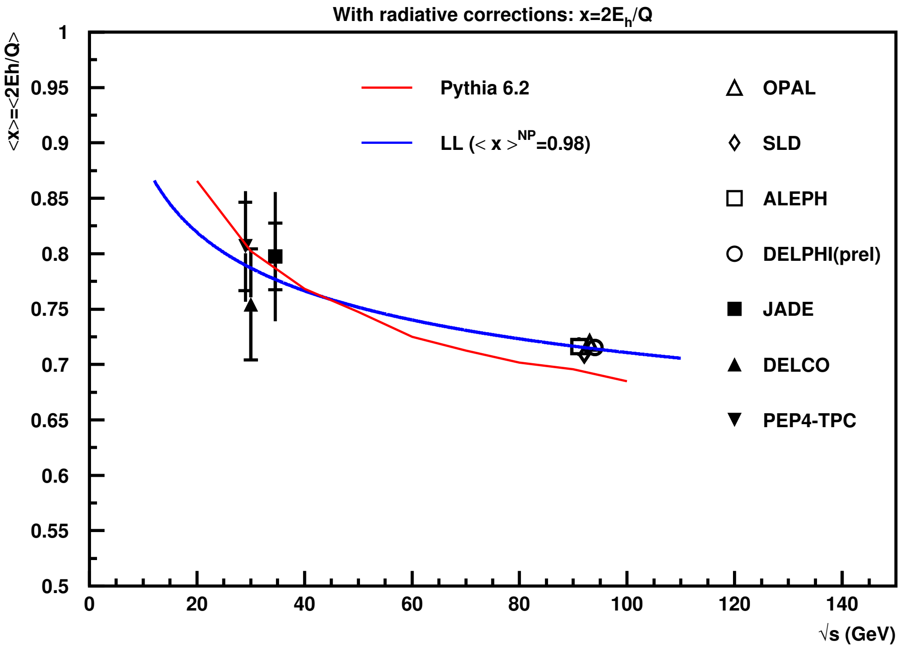
Jets introduce typical jet uncertainties: hadronization, energy scale etc.

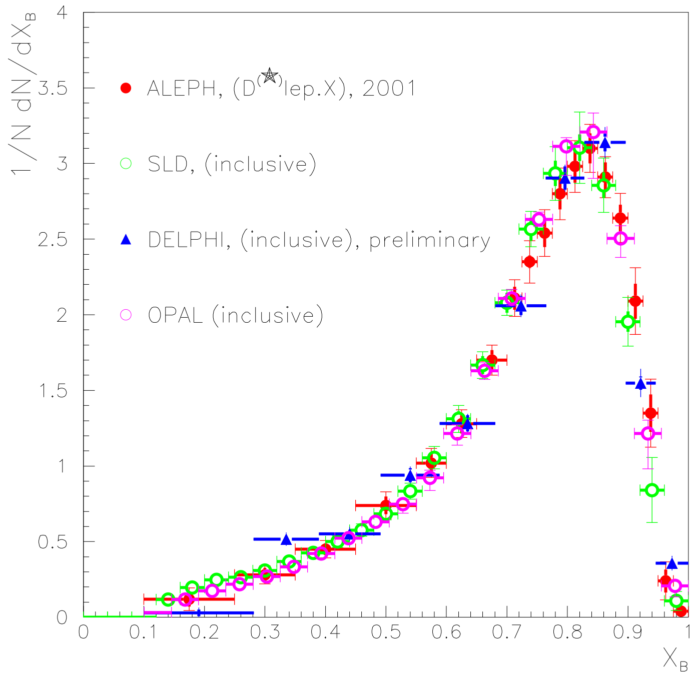
Alternative (for DIS): $z^D = \frac{p_D \cdot P}{q \cdot P} = \frac{(E-P_z)_D}{2yE_e}$

in quark-parton-model: $z^D = E_D/E_c$ **in the proton rest frame**
equivalent to $x_E = E_D/E_{\mathrm{beam}}$ **in** e^+e^- **at** $\mathcal{O}(\alpha_S^0)$**, no jet involved**
Directly comparable to NLO (FONLL ?) calculations.

Beauty fragmentation (M. Corradi)

Beauty data from e^+e^-: $\langle x_E \rangle$ from low energy, $f(x_E)$ from LEP/SLD





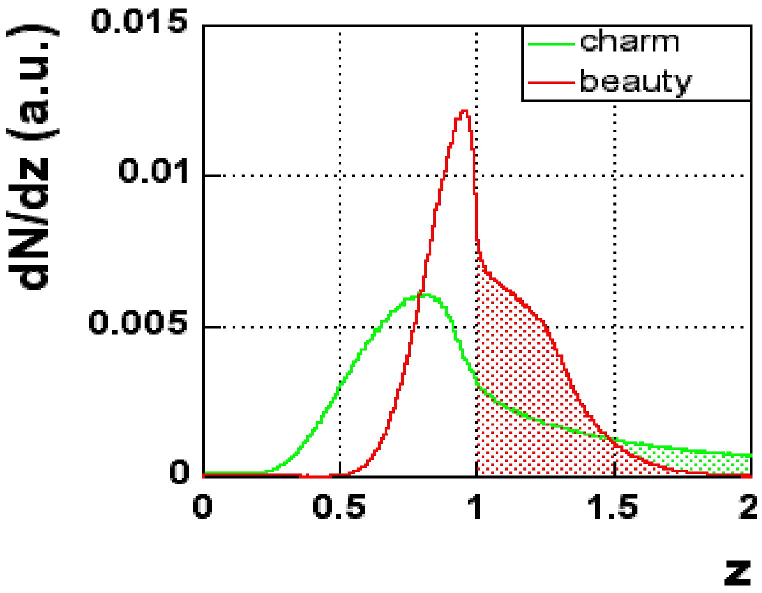
what can be done:

- **Global Fit of all the e^+e^- data with Pythia and NLL theory**
- **Can it be measured at HERA-II ?, may be . . .**
- **Study the dependence of HERA/LHC observables from fragmentation (typically effects up to 30% at large p_T at HERA)**

Beauty fragmentation at Alice (G. Guernane)

- **Alice forward muon spectrometer covers** $2.5 < y < 4$ **and low** p_T **(**$p_T^l > 2GeV$**)**
  Region very sensitive to non-perturbative effects!

Fragmentation in Pythia $z > 1$ **due to beam-drag effect:**



Can this effect be measured experimentally ?
For example low p_T **charm at HERA in forward direction ?**

Even more exotic effects expected in HQ fragmentation with Heavy Ions

Heavy Quark PDFs at LHC

Some examples of b-initiated processes

Table from F. Maltoni (just shown by M. Cacciari):

Important procesess at LHC calculable from b PDF with high accuracy

b PDF calculable from $g(x)$ but a direct measurement would be desirable

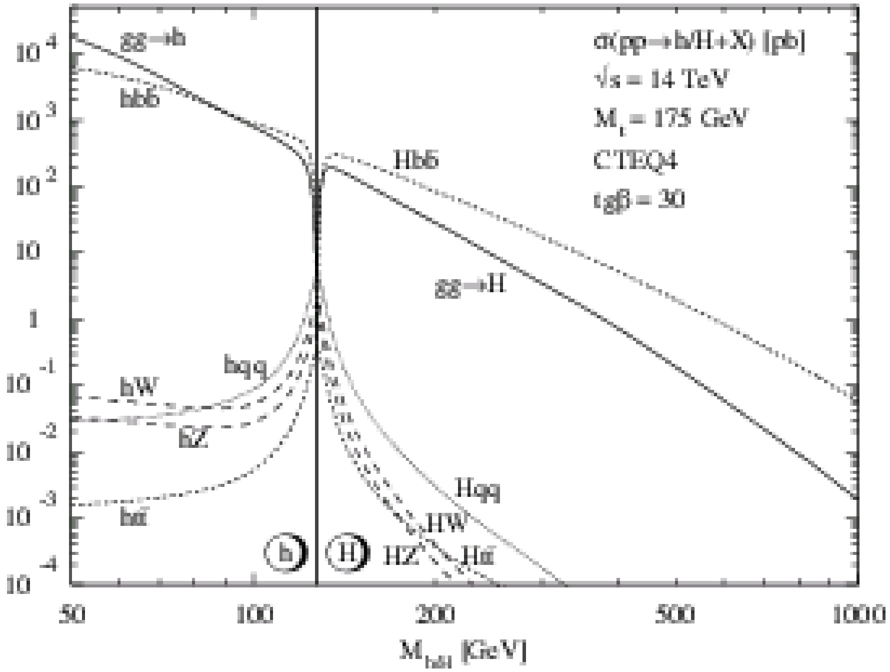
How well these processes can be measured ?

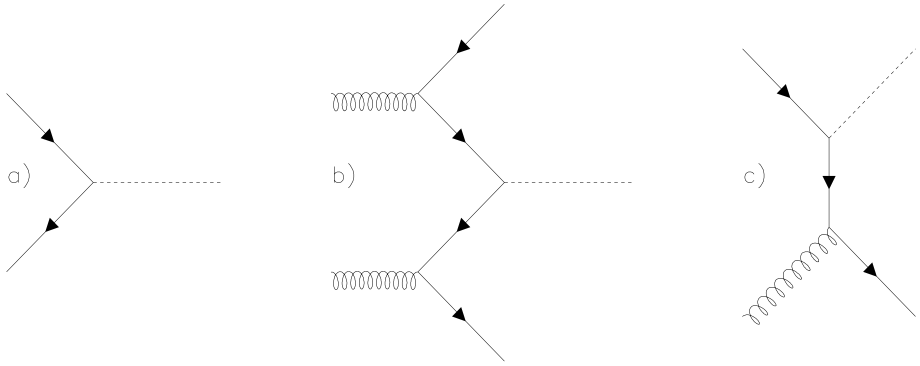
Process	Interest	Accuracy
single-top t-channel	SM, top EW couplings and polarization, V_{tb}. Anomalous couplings.	NLO
single-top + W		NLO
Wbj	SM, bkg to single top	(NLO)
gamma+b	SM, SUSY bkg, b-pdf	NLO
Z+b		NLO
inclusive h,A	SUSY discovery/ measurements at large tan(beta)	NNLO
h,A+b		NLO
H^+ + t	SUSY discovery, couplings	NLO

Wide interests and best attainable accuracy

$H \to \tau^+\tau^-$ from $Hb\bar{b}$ (Z. Was)

MSSM:
for large $\tan\beta$ **Higgs produced mainly via** $gg \to Hb\bar{b}$
and decays into $H \to \tau^+\tau^-$





Total cross section calculable to very high accuracy

Consistent results from 4-flavour $(gg \to b\bar{b}h)$ **and 5-flavour** $(b\bar{b} \to h)$ **schemes**

BUT acceptance depends strongly on the simulation of the final state . . .

Study based on PYTHIA+TAUOLA+AcerDET (Z.Was)

Selection	$b\bar{b} \to H$	$gb \to bH$	$gg \to b\bar{b}H$	$gg \to H$	$--$
1 iso ℓ, $p_T^{\ell} > 20$ GeV 1 τ-jet, $p_T^{\tau-jet} > 30$ GeV	$19.5 \cdot 10^{-2}$	$19.3 \cdot 10^{-2}$	$19.7 \cdot 10^{-2}$	$19.5 \cdot 10^{-2}$	
PARTICLE level					
resolved neutrinos	$16.6 \cdot 10^{-2}$	$16.6 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	A
$\vert sin(\Delta\phi_{\ell\ \tau-jet})\vert > 0.2$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$8.9 \cdot 10^{-2}$	$9.7 \cdot 10^{-2}$	$8.9 \cdot 10^{-2}$	$9.8 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$1.3 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$8.5 \cdot 10^{-3}$	$2.2 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	$3.1 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$6.1 \cdot 10^{-3}$	$1.9 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	B
DETECTOR level					
resolved neutrinos	$11.0 \cdot 10^{-2}$	$11.6 \cdot 10^{-2}$	$11.1 \cdot 10^{-2}$	$12.5 \cdot 10^{-2}$	C
$\vert sin(\Delta\phi_{\ell\ \tau-jet})\vert > 0.2$	$5.9 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$	$6.5 \cdot 10^{-2}$	$8.2 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$5.5 \cdot 10^{-2}$	$6.6 \cdot 10^{-2}$	$6.2 \cdot 10^{-2}$	$7.6 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$9.1 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$6.5 \cdot 10^{-3}$	$1.8 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	$2.7 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$4.9 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$9.3 \cdot 10^{-3}$	$2.3 \cdot 10^{-2}$	D

Different processes simulated at LO+PS (Pythia)

$H \to \tau^+\tau^-$ **well reconstructed only at large** p_T

Acceptance depends strongly on the process:

$b\bar{b} \to H$: **low** p_T **acceptance** $\sim 0.5\%$

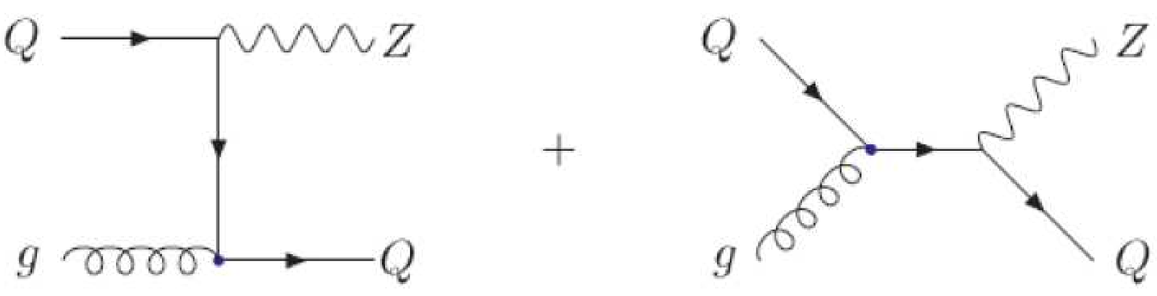
$gb \to Hb$: **high** p_T **acceptance** $\sim 1.5\%$

$gg \to Hb\bar{b}$: **acceptance** $\sim 1\%$

How to control the p_T spectrum ?, need NLO differential distributions ?
Can we learn from HQ production in DIS ?

$Z + b$ production at ATLAS (A. Tonazzo)

$Z + b$ **at high** p_T



Sensitive to b **pdf,** **background to** hb **NLO predictions available**

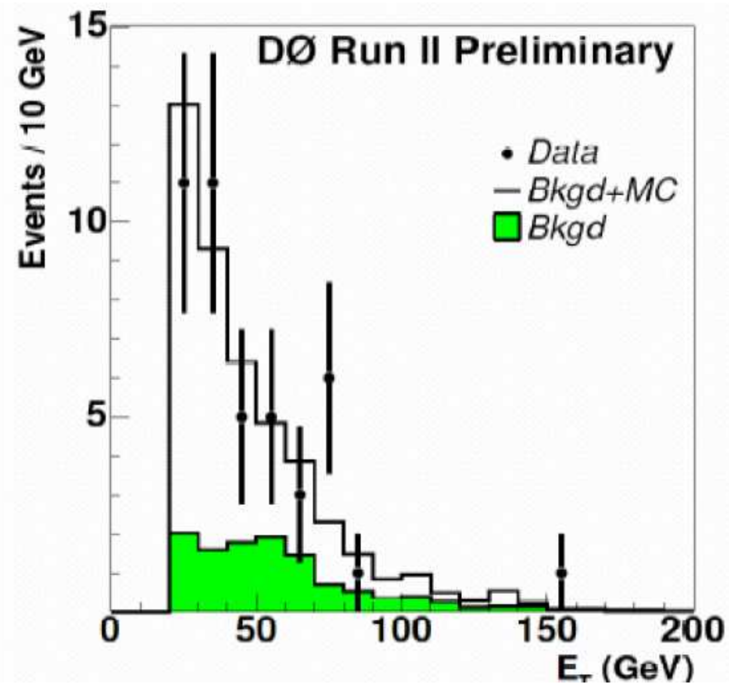
D0 Measurement

Tevatron:
for $p_T > 15$**GeV,** $|\eta| < 2.5$
$\sigma(Zb) \sim 20$**pb** (63% **from** gb)
$\sigma(Zj) \sim 1000$**pb**

$$\frac{\sigma(Z+b)}{\sigma(Z+j)} = 0.024 \pm 0.005(stat) {}^{+0.005}_{-0.004}(syst)$$

Theory NLO (F.Maltoni et al.): 0.018 +/- 0.004

Low statistics



Preliminary $Z + b$ study with ATLAS (A. Tonazzo)

Situation much more favourable at LHC
larger cross section and lower (relative) backgrounds

for $p_T > 15$**GeV,** $|\eta| < 2.5$

- $\sigma(Zb) \sim 1000$**pb (95% from** $gb \to bZ$**)**
- $\sigma(Zj) \sim 16000$ **pb**

Analysis:
start with $Z \to \mu\mu$ **+ jet (**70% **efficiency)**

Two $b - jet$ **tagging strategies considered:**

- **3**$^{\mathrm{rd}}$ **soft muon (6% efficiency, 50% purity)**
- **inclusive b jet tag (21% efficiency, 35% purity)**

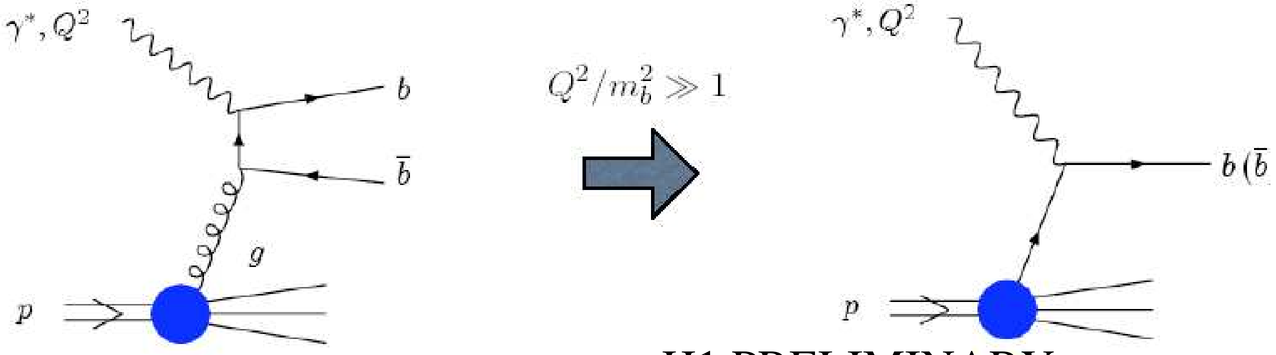
Large statistics (~ 100**k** $Z + b$ **events in 10** fb^{-1}**),**
differential cross sections

Promising study, will be continued ...

main issue (in my view): how to control/subtract the background

HQ PDFs from HERA

At large Q^2 calculations based on the PDF approach expected to have high accuracy
A precise direct measurement at HERA of c, b at large Q^2 is desirable

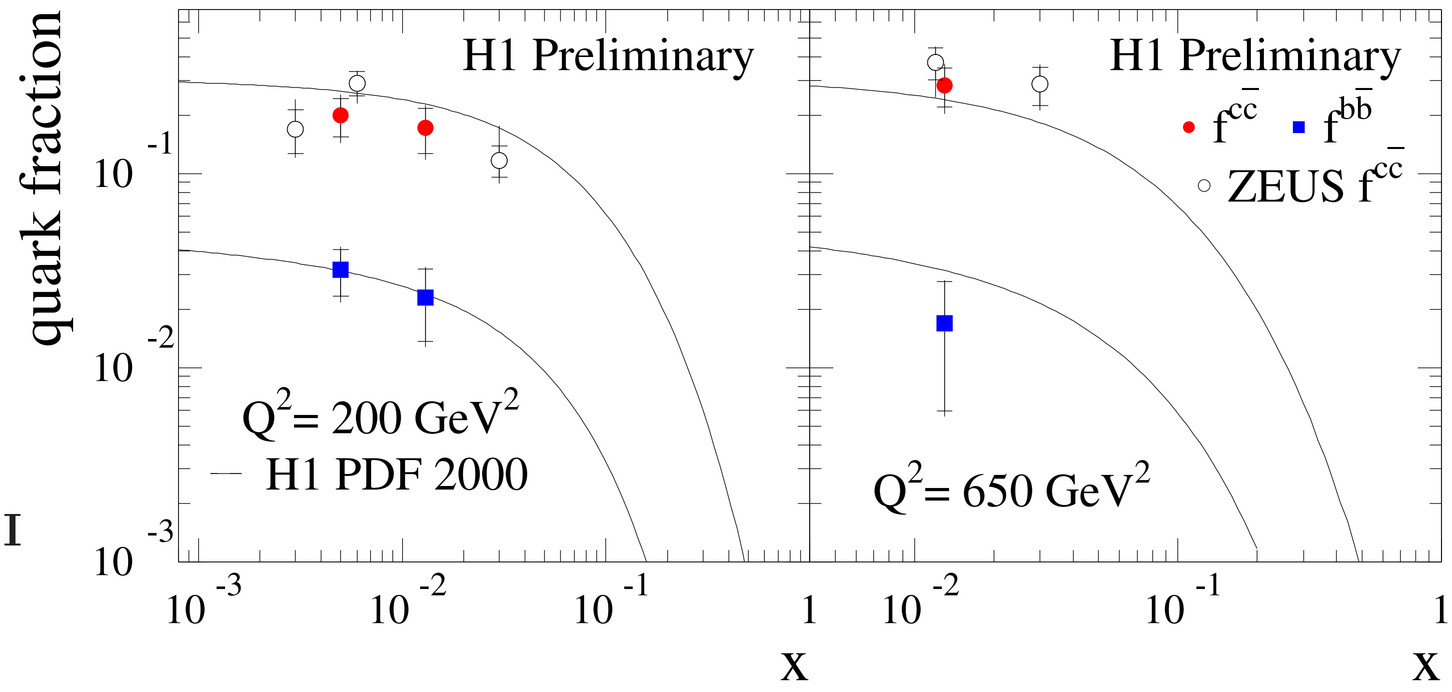


H1 PRELIMINARY

High-Q^2 $F_2^{c,b}/F_2$ from HERA

Compared to H1 PDFs

More precise results expected from HERA-II



Heavy Quark Correlations

$Q\bar{Q}$ correlation may give more information than just inclusive measurements

- **directly sensitive to higher orders in α_S**
- **access particular phase space regions where interesting effects are lurking, e.g.:**

  bb pairs with large rapidity interval sensitive to BFKL effects (see F. Maltoni)

  $b\bar{b}$ pairs at low $p_T^{b\bar{b}}$ sensitive to non-linear $g(x)$ evolutions (see K. Kutak)

- **multi-b events at LHC: background to exotic signals**
- **help to tune the fraction of different subprocesses in MC:**
  (flavour creation, flavour excitation, gluon splitting)

But much lower statistics respect to inclusive measurements

What experimental precision can be obtained at HERA and LHC ?

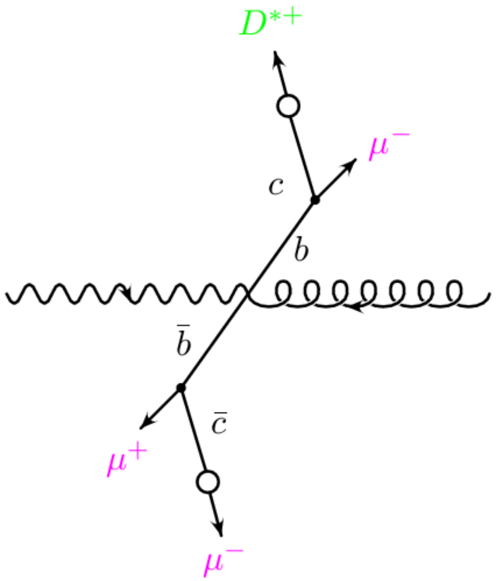
$D^*\mu$ Correlation in H1 (O. Behnke)

Preliminary results from H1 and ZEUS based on $D^*\mu$ correlations

Opposite charge $D^{*\pm}\mu^{\mp}$ pairs:

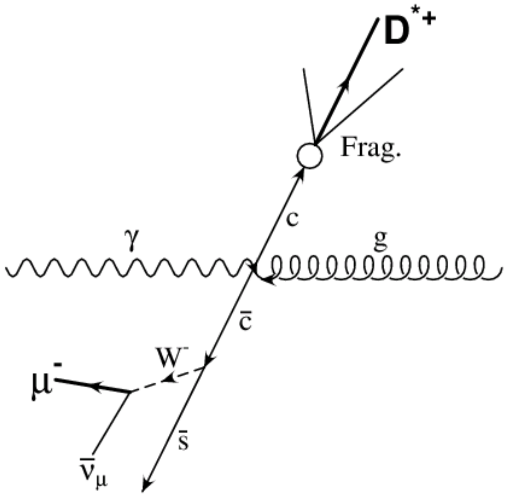
Bottom:
Low $\Delta\Phi$
(same B)

Large $\Delta\Phi$
(different B)



Charm:

Large $\Delta\Phi$
only



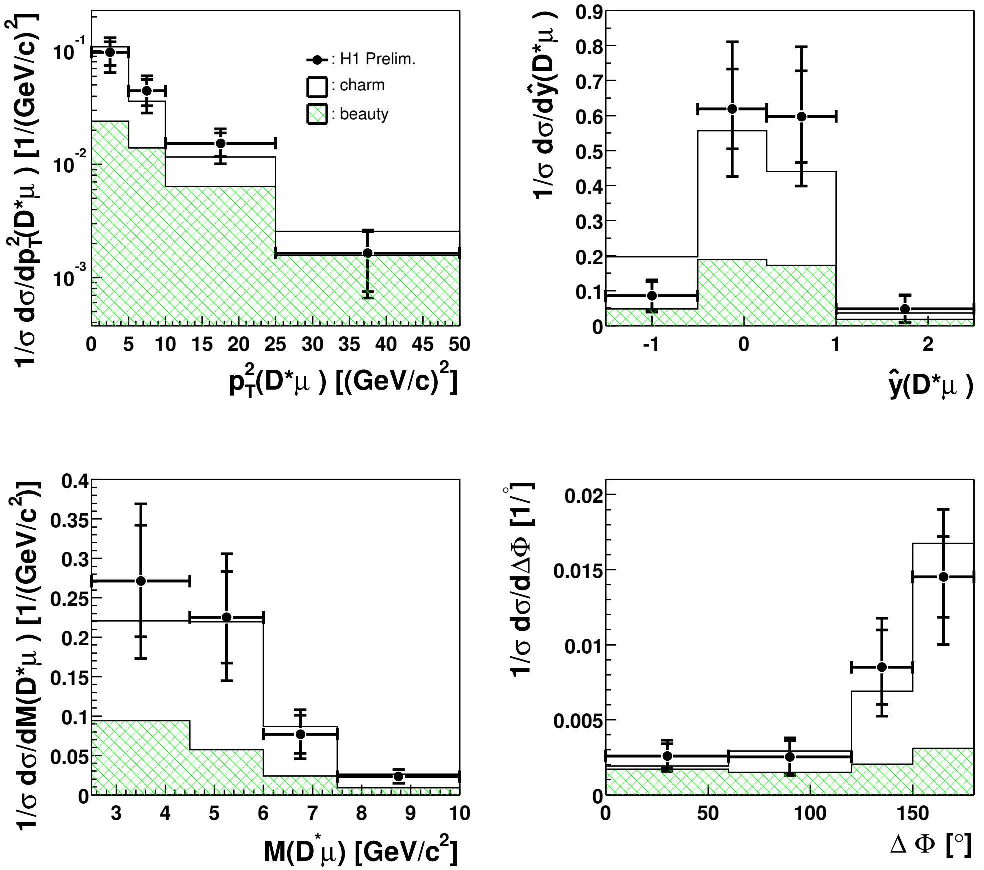
Double tag allows soft cuts
$p_T(D^*) > 1.5$ **GeV**
$p_T(\mu) > 1$ **GeV**

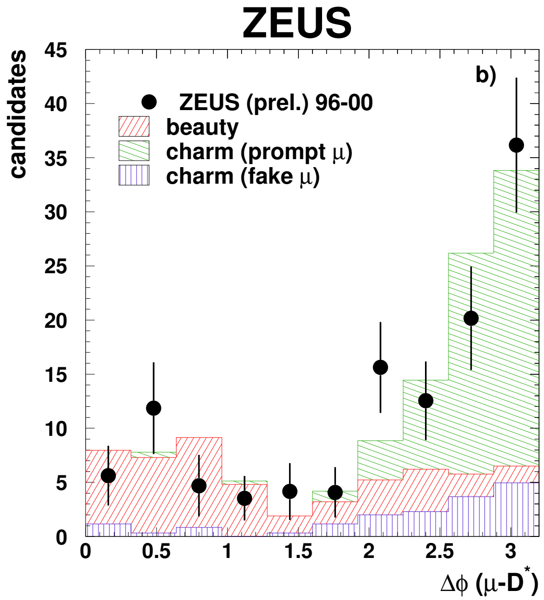
Different correlations for b and c

Fix b and c components to fit the correlation

Measurement of b production near threshold

$D^*\mu$ Correlation in H1 (O. Behnke)





similar result from ZEUS

Once the b/c fraction is fixed, LO+PS MC describes the data well

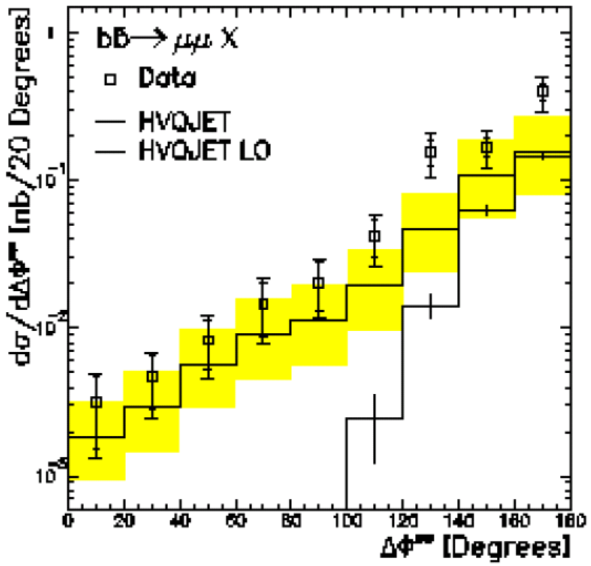
Sensitive to initial g K_T, PS details

Present HERA-I $D^*\mu$ results suffer from low stat.

More sensitivity expected from $\mu\mu$ correlations and lifetime tagging, compare to NLO

$b\bar{b}$ correlations with ATLAS (T. Lagouri)

Dimuon correlations measured at UA1, Tevatron



Much more precise measurements possible at ATLAS:

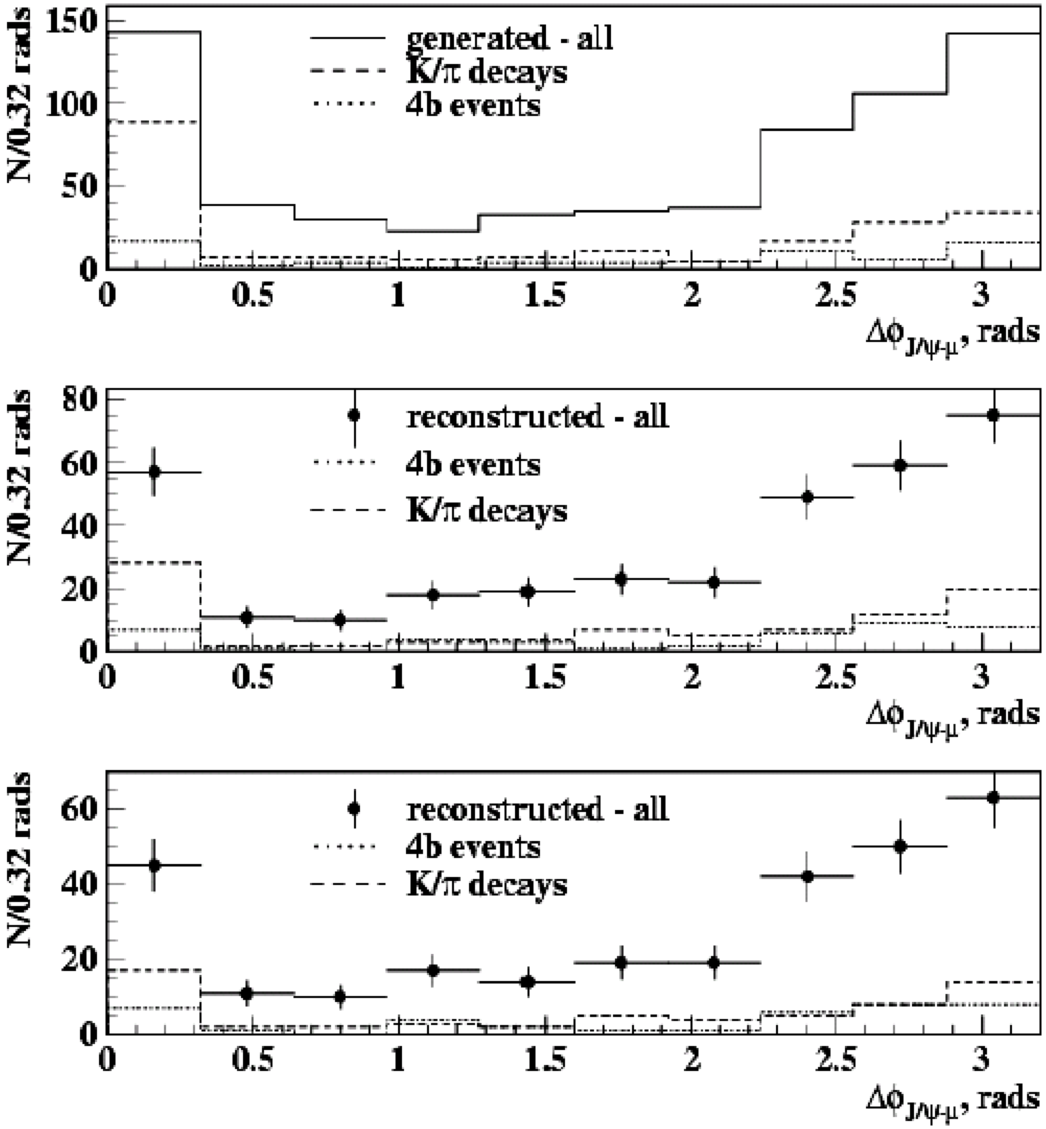
Use $(B \to J/\Psi \to \mu\mu) - (b \to \mu)$ **correlations**

Huge statistics expected, even for exclusive channels after 3 years:
$(B \to J/\Psi \to \mu\mu) + (b \to \mu) \sim 3 \times 10^6$ **events,**
of which $\sim 2 \times 10^5$ **have B meson completely reconstructed**

Exploit high muon efficiency and very good resolution: low backgrounds

$b\bar{b}$ correlations with ATLAS (T. Lagouri)

Exclusive channels considered in preliminary analysis:
$B^0 \rightarrow J/\Psi K_s^0 + \mu$
$B_s \rightarrow J/\Psi \Phi + \mu \Longrightarrow$



Low background

low $\Delta\Phi$ accessible

more channels will be studied

try also 3 or 4 b tagging ?

study same charge correlations ?

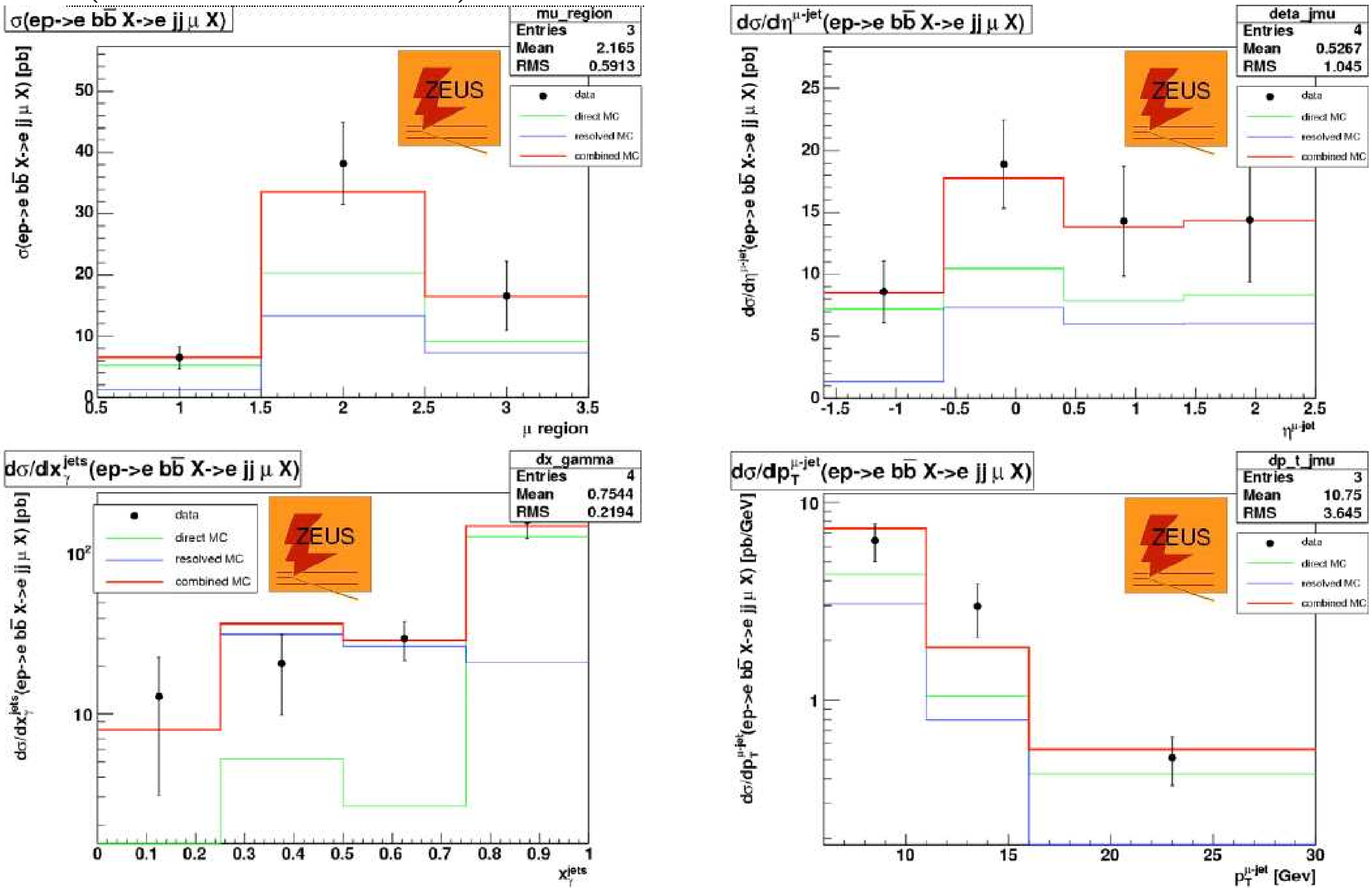
b production with JetWeb (O. Gutsche)

- **JetWeb is a tool to tune MC models to available data based on HZTOOL routines and a powerful web interface, see** `http://jetweb.ucl.ac.uk/`
- **Allows to compare the same MC model to different measurements from different experiments**
- **e.g. tune MC to reproduce b data from HERA, $Sp\bar{p}S$, Tevatron**
- **we may expect more resonable MC parameters than from a single measurement. More reliable extrapolation to LHC energies ?**

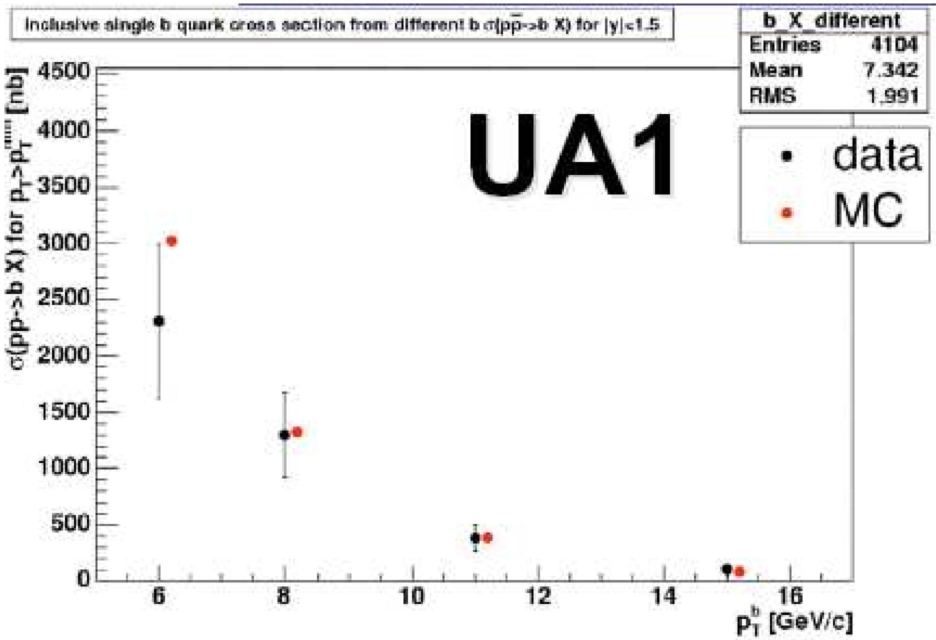
b production in Jetweb:

- **b production measurements from**
  ZEUS, UA1, D0
  implemented in HZTOOL routines
- **Compared to Herwig and Pythia**
- **MC normalization fixed from High E_T jets at HERA (1.45/1.7 for Pythia/Herwig)**

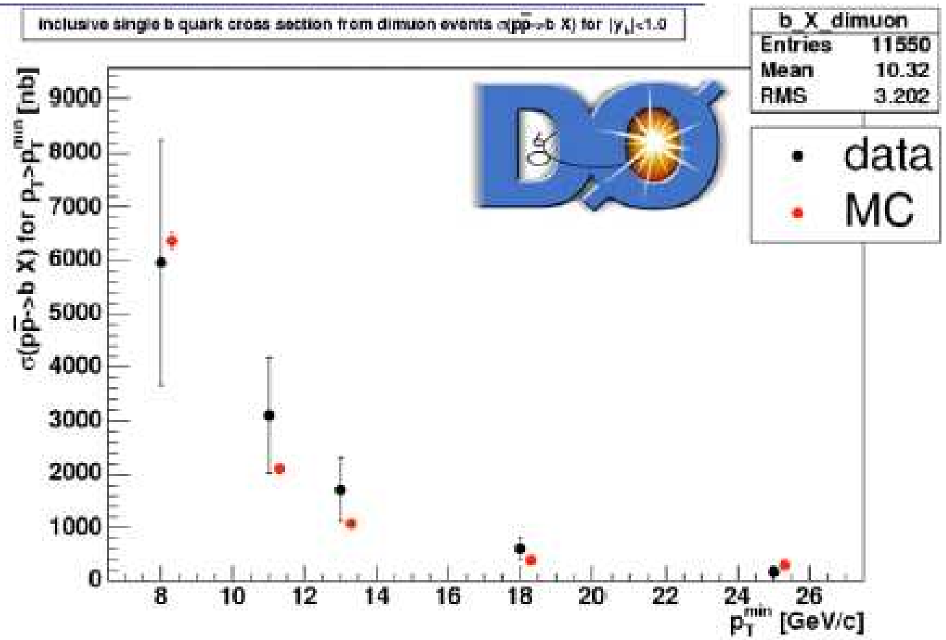
Pythia (with massless ME) describes ZEUS data well

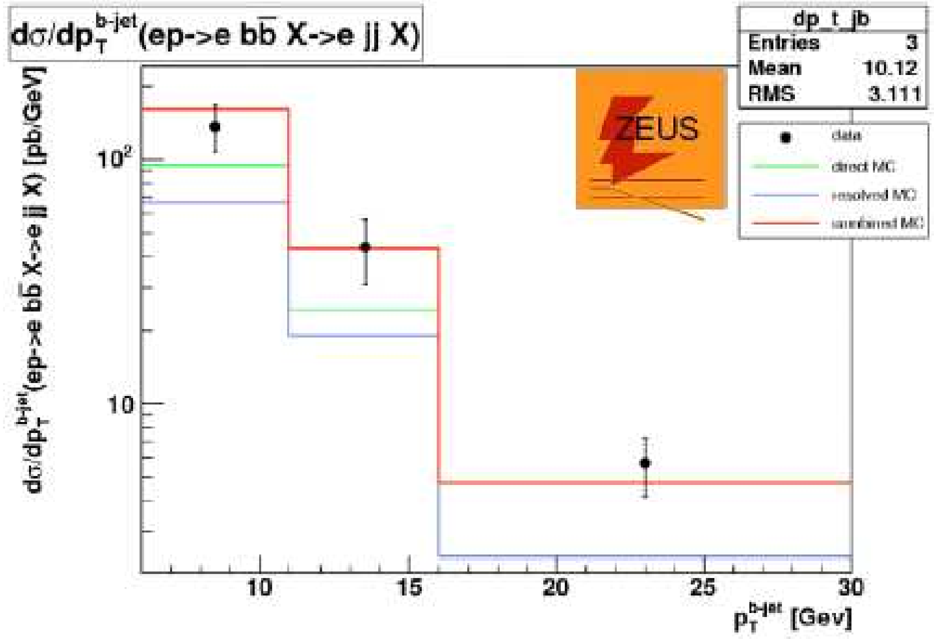


UA1, D0, ZEUS data described by a Pythia with the same parameters

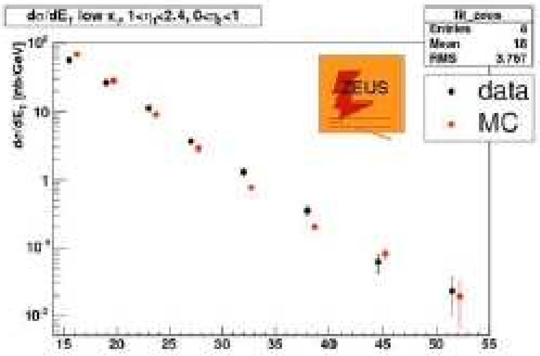


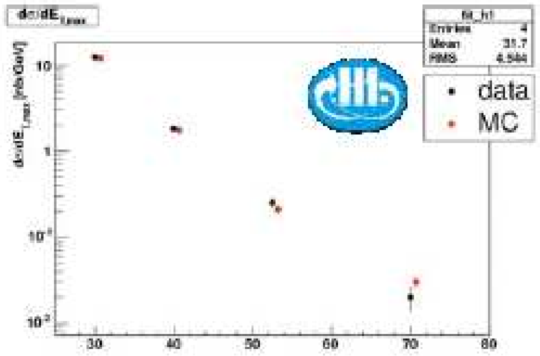
PYTHIA





- good simultaneous description of UA1 and D0 results and HERA-jet cross sections





Possible extensions for this Workshop

JetWeb:

- **Add other b measurements (H1, CDF, . . .)**
- **Interface to NLO theoretical predictions (MCatNLO?, use NLOLIB) ?**

The same Pythia tuning gives a good description of b production at HERA/$Sp\bar{p}S$/Tevatron

- **what are the predictions for LHC ?**
- **how this tuning compares with Pythia tunes used by LHC collaborations ?**

Tentative conclusion from the intermediate WG3 meeting

- **HERA HQ measurements are important for LHC to test common theoretical and phenomenological tools**
  - MC tuning
- **Precison measurements of**
  - HQ-PDFs,
  - Fragmentation,
  - $Q\bar{Q}$ Correlations
  at HERA may be of great value for LHC
- **various idea are present**
  some work started
  more is expected for the next meetings !