HERA-LHC Workshop
WG3: Charm and Bottom

CERN
11-13 October 2004

MC, Massimo Corradi, Andrea Dainese, Andreas Meyer,
Maria Smizanska, Ulrich Uwer, Christian Weiser + all people who gave talks

HQ production

E. Laenen
B. Kniehl
F. Maltoni
A. Tonazzo

Small x

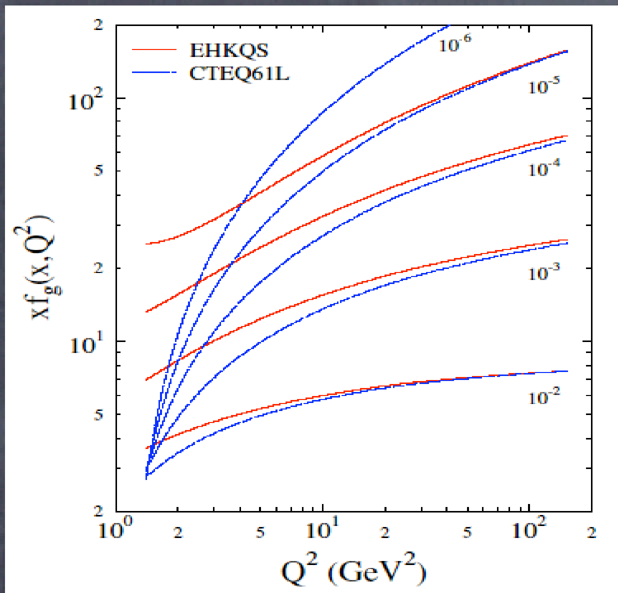
S. Baranov
A. Dainese
H. Jung
V. Kolhinen
K. Kutak
N. Zotov

Fragmentation, correlations, MonteCarlo's

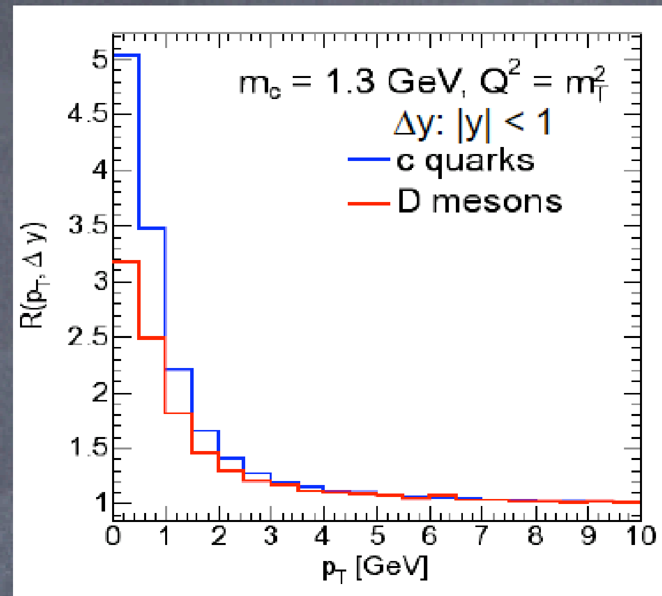
See M. Corradi's summary

Small-x issues

Huge amount of work done. Many predictions for HQ production at HERA/LHC. Examples:



V. Kolhinen



A. Dainese

gluon enhancement due to non-linear effects in DGLAP evolution. Caveat: evolution only LO!

enhancement in charm production at LHC over standard DGLAP prediction

2.Extended Balitzkij-Kovchegov(BK) equation

Nonlinear evolution equation for unintegrated gluon distribution.

$$f(x,k^2) = \tilde{f}^{(0)}(x,k^2) + K^1 \otimes f - K^2 \otimes f^2 \quad (1)$$

K. Kutak

reduction of cross section compared to linear BFKL

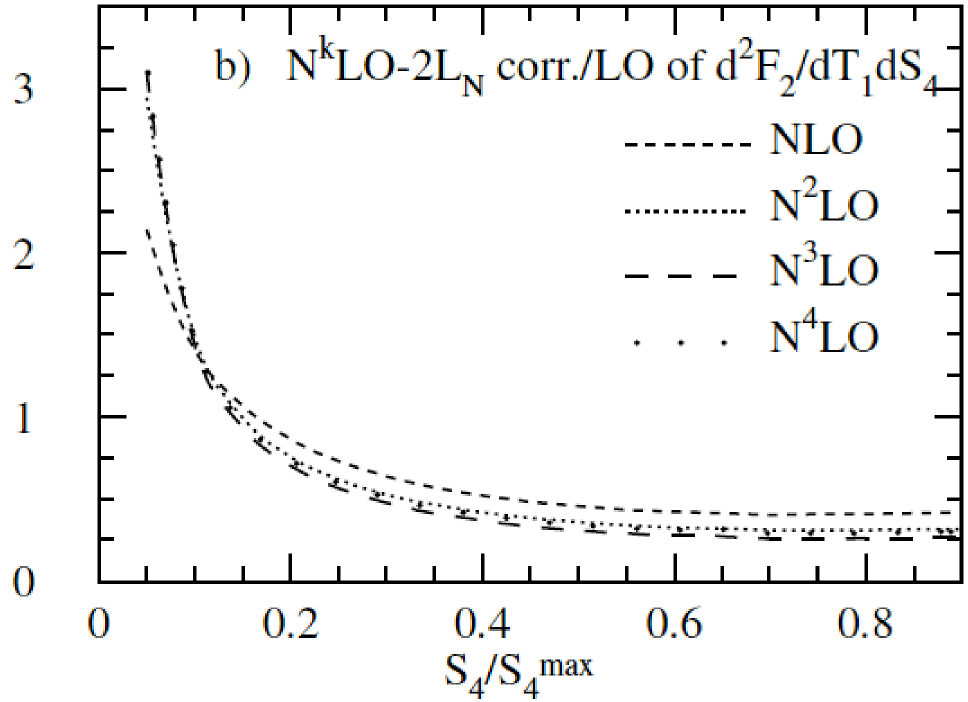
For LHC we estimate:

- $\frac{\sigma_{tot}(R{=}3.1GeV^{-1})}{\sigma_{tot}(linear)} = .97$
- $\frac{\sigma_{tot}(R{=}1.5GeV^{-1})}{\sigma_{tot}(linear)} = .8$

Main goal for future (personal opinion):
improve theoretical accuracy, estimate theoretical uncertainties

Threshold-resummed differential F_2^c

Rather rapid convergence to final answer.



Eynck, EL, Vogt

E. Laenen

Will allow more accurate comparisons of experimental data and theory in visible phase space regions

Joint resummation for HQ hadroproduction also in progress. Useful for ttbar, or bbar at HERA

Bottom quark PDF

The bottom quark can enter, in the form of a PDF, a number of interesting processes:

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

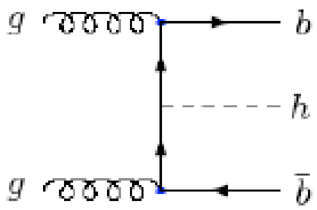
Standard processes

Searches (discoveries?)

F. Maltoni

Single out Higgs production with bottom quarks

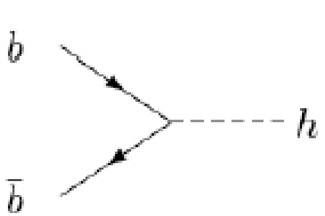
One way:



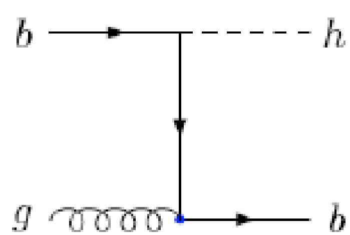
Keep the b massive and use the gg process for all three studies. The b mass acts as an infrared cutoff and there are no divergences. This is the 4 Flavour Scheme (4FS)

or the other:

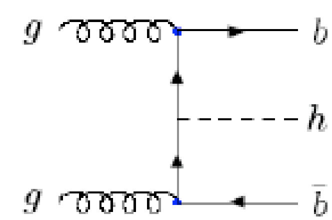
The "leading-order process" depends on how INCLUSIVE is the measurement to be performed:



FULLY INCLUSIVE



1 b at high p_T

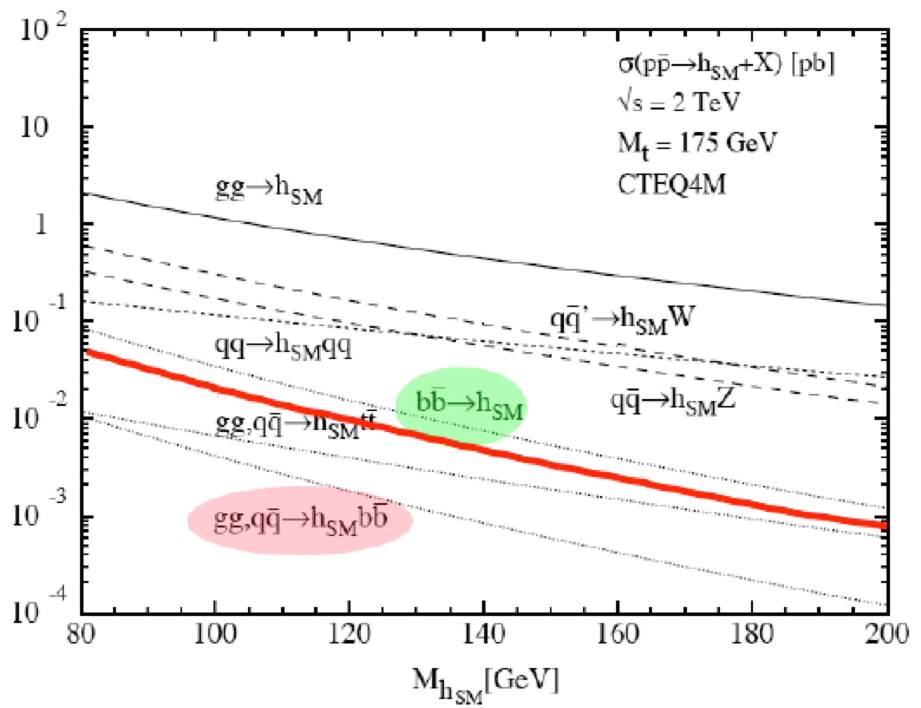


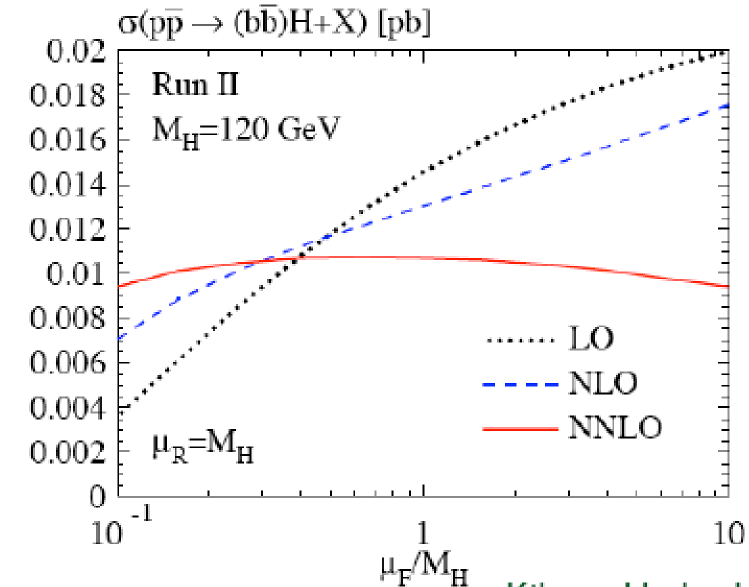
2 b's at high p_T

In so doing the large logs $\alpha_S \ln\left(\frac{m_h^2}{m_b^2}\right)$ are resummed into the b distribution function $b(x, m_h^2)$
This is the 5 flavour scheme.

F. Maltoni

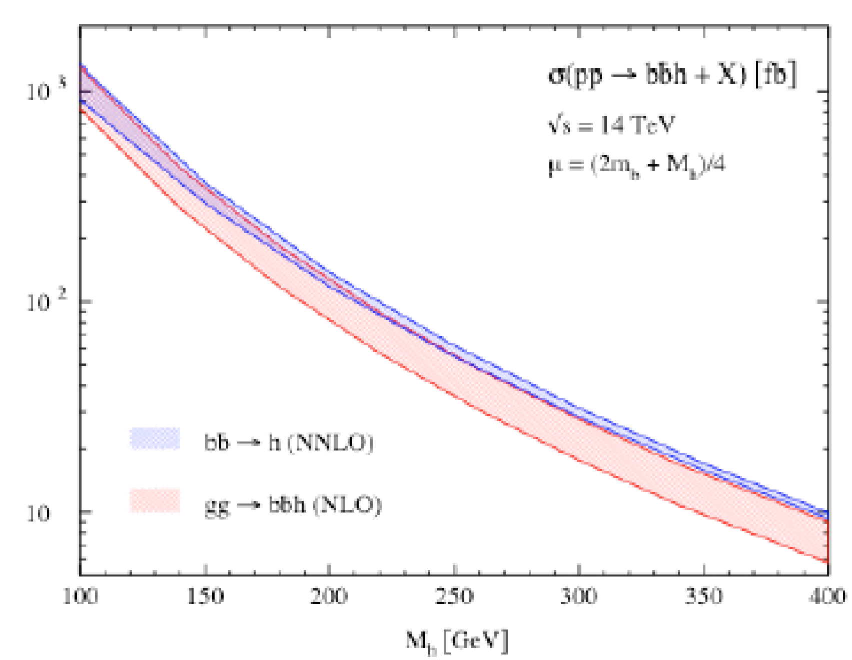
No further phenomenological input in b-quark PDF, but rather resummation of logs and therefore improvement of theoretical prediction





Kilgore Harlander, 2003

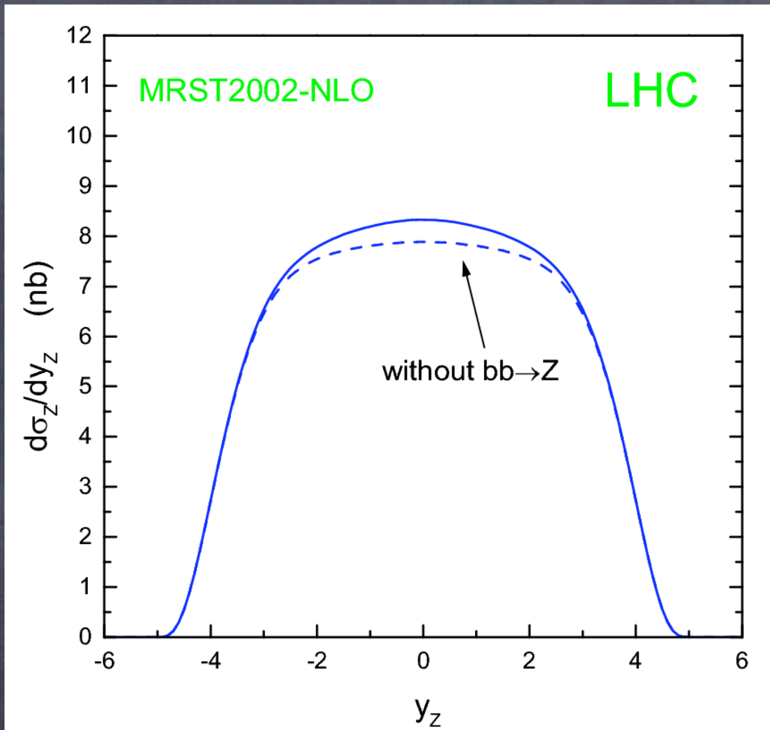
NNLO calculation confirms preferred scale choice for NLO calculation ≈ mh/4 (F.M., Sullivan, Willenbrock, 2003).



Campbell et al. (Les Houches Higgs Group), 2004

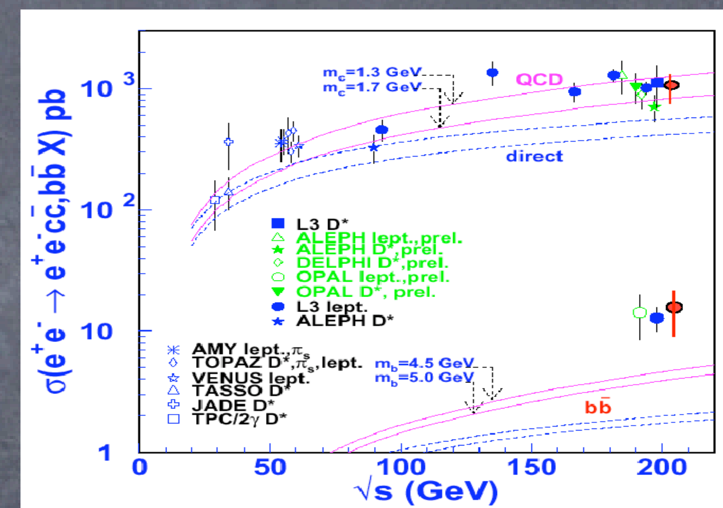
2004: good agreement between NLO for 4-flavours and NNLO for 5-flavour

pp -> Z

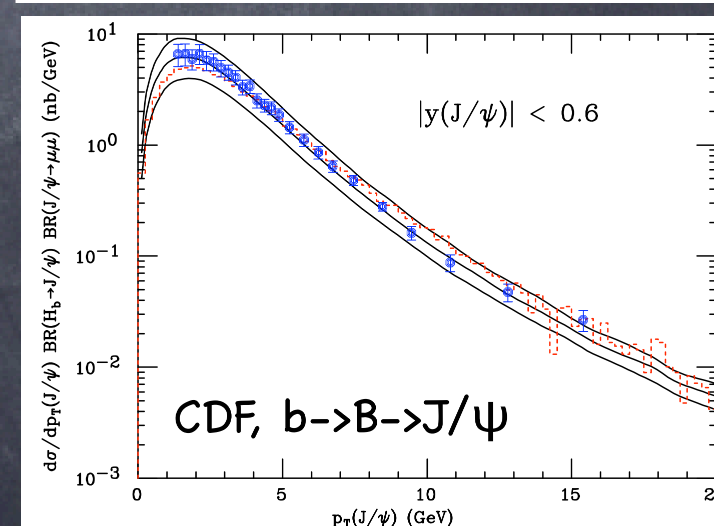


J. Stirling

Besides entering NNLO calculations for Higgs production, b-quark PDF also make up 5% of the total Z production at LHC. If we aim at a 1% accurate hadronic physics, we must make sure we control the b PDF at the 20% level



Recalling that the b PDF is nothing but a "chunk" of the NLO calculations in b productions, and given some recent scares (though the situation now looks better) we might wonder if we are really confident we control the b PDF



Importance of fragmentation.
See M. Corradi's summary

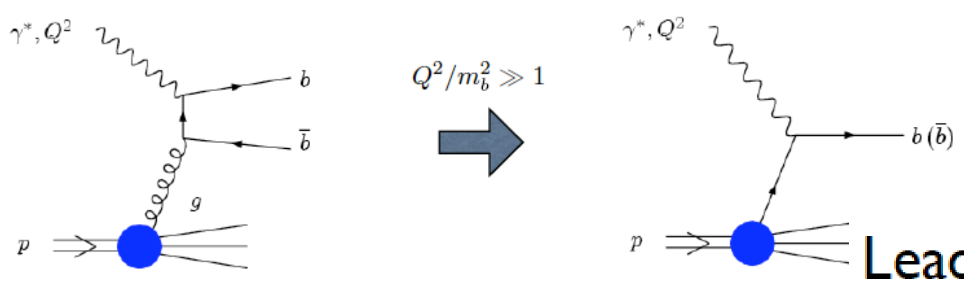
Can we measure the b-pdf directly?

Proposals:

1. Use HERA "inclusive" b measurements

2. Use Tevatron and/or LHC data for Z+b (and gamma+b?)

HERA Bottom production in DIS

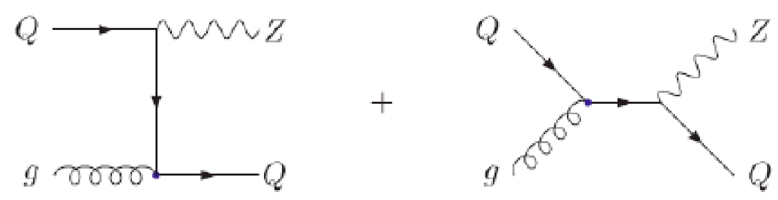


Plenty of HQ measurements at HERA. Goal: accuracy of results, no extrapolations to total cross sections

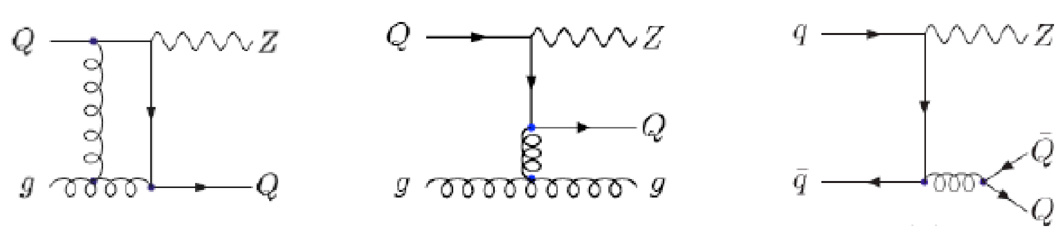
pp -> Z + HQ

Tevatron LHC

Leading order:



Next-to-leading order (Campbell, Ellis, F.M., Willenbrock, 2003):



D0 measurement

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

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

LHC

Cross sections (pb)	ZQ	$Z(Q\overline{Q})$	ZQj	$ZQ\overline{Q}$	ZQ inclusive
$gb \to Zb$	(826) 649	11.3	304	78.1	$1040^{+70}_{-60}{}^{+70}_{-100}{}^{+30}_{-50}$
$q\bar{q} \to Zb\bar{b}$	24.3	13.5	–	11.4	49.2
$gc \to Zc$	(989) 921	8.8	396	61.5	$1390 \pm 100^{+60}_{-70}{}^{+40}_{-80}$
$q\bar{q} \to Zc\bar{c}$	36.7	41.7	–	11.3	89.7
	Zj		Zjj		Zj inclusive
$q\bar{q} \to Zg, gq \to Zq$	(13500) 11600		4270		$15870^{+900}_{-600}{}^{+60}_{-300}{}^{+300}_{-500}$

6%

Better ratio at LHC

Tevatron

Cross sections (pb)	ZQ	$Z(Q\overline{Q})$	ZQj	$ZQ\overline{Q}$	ZQ inclusive
$gb \to Zb$	(8.23) 10.4	0.169	2.19	0.631	$13.4 \pm 0.9 \pm 0.8 \pm 0.8$
$q\bar{q} \to Zb\bar{b}$	3.32	1.92	–	1.59	6.83
$gc \to Zc$	(11.3) 16.5	0.130	3.22	0.49	$20.3^{+1.8}_{-1.5} \pm 0.1^{+1.3}_{-1.2}$
$q\bar{q} \to Zc\bar{c}$	5.66	6.45	–	1.70	13.8
	Zj		Zjj		Zj inclusive
$q\bar{q} \to Zg, gq \to Zq$	(876) 870		137		$1010^{+44}_{-40}{}^{+9}_{-2}{}^{+7}_{-12}$

1.3%

Preliminary study in ATLAS (A. Tonazzo).
See M. Corradi's summary

Calculating benchmark cross sections

Different theoretical approaches for for heavy flavour cross-sections
each approach typically available both for HERA and LHC
An incomplete set of those with full differential prediction reported here:

Model	HERA γp	HERA DIS	LHC
LO(massless)+PS	Pythia	Pythia, Lepto	Pythia
LO+PS+MI	Pythia/JIMMY		Pythia/JIMMY
LO(massive)+PS	Pythia	Rapgap, Aroma	Pythia
CCFM MC (Cascade)	X	X	X
NLO	FMNR	HVQDIS	HVQMNR
FONLL	X		X
NLO(massive)+PS	(MCaNLO ?)		MCaNLO
Massless (KK)	X		X
K_T factorization			X
Enhancment at low-x		?	X
Saturation at Low-x Kutak			X

Preliminary shopping list

LHC

1.1) p_T central rapidity $|y| < 2.5$ (ATLAS/CMS)
1.2) p_T large rapidity $2.5 < |y| < 4.5$ (LHC-B)
1.3) y for $p_T > 2$ GeV ? (LHC-B/Alice)

need special Alice range ?
different cuts for charm and b ?

Correlations:

observables sensitive to intrinsic k_T and g splitting:
1.4) $p_T(Q + \bar{Q})$
1.5) $\Delta\phi(Q - \bar{Q})$

observables sensitive to 4b prod
1.6) $\Delta y(QQ)$

HERA

Here it's more complex: many variables (x, Q^2 and y, p_t, ϕ of the HQ)
I see two possible choices:
a) plot y,p_T for ranges in x, Q^2 ?
b) fix a range in y, p_T and plot x, for different Q^2 ?

Option b) is probably better:

1.1-4) x for $Q^2 = 1, 10, 100, 1000$ GeV^2, $p_T > 1.5$, $|y| < 1.5$
similar to "visible" F_2^c

with or without EW corrections ? (without)

Basic cross sections:
2.1) p_T for $|y| < 1.5$, $130 < W < 300$GeV, $Q^2 < 1$GeV^2 (range of existing D^* mesureme
2.2) y for $p_T > 2$ GeV, $130 < W < 280$GeV, $Q^2 < 1$GeV^2

More complex vars:
x_γ is interesting but beyond a very simple implementation of Heavy Hadron cross sections

Correlations:
2.3) $p_T(Q + \bar{Q})$ and/or
2.4) $\Delta\phi(Q - \bar{Q})$

Still being discussed.
Purpose: upgrade previous benchmarks (better PDF's, etc) and provide a common ground for different theoretical approaches

Summary's summary

Only part of the work summarized here. Apologies to the other speakers. Slides available on the web.

Plenty of work to do before following meetings. From now on we'll probably mainly concentrate on developing these topics rather than adding new ones.

Bottom PDF's probably one of the most important issues, but let's not forget resummations and small-x.

Last but not least, improvement of predictions and measurements within visible regions of phase space probably key ingredients for 'high precision' hadronic physics