

Measurements of the EWSM parameters: LHC pp versus Tevatron ppbar

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Paris, 15-18 December 2010

Summary

The measurement of EWSM parameters at the LHC is much more difficult than at the Tevatron

A dedicated measurement strategy for the precision determination of EWSM parameters is needed

Feasible

A better precision is needed than presently available on
(i) valence versus sea PDFs, and (ii) on heavy-quark
PDFs --- both in x and k_T

Not clear how to achieve

$M_W / \text{Jacobian peak} \approx 1/4000$

Z must serve as reference

@LHC: $W^+ \neq W^- \neq Z$

a) theory:

different PDFs

different x, k_T, Q^2

different polarization

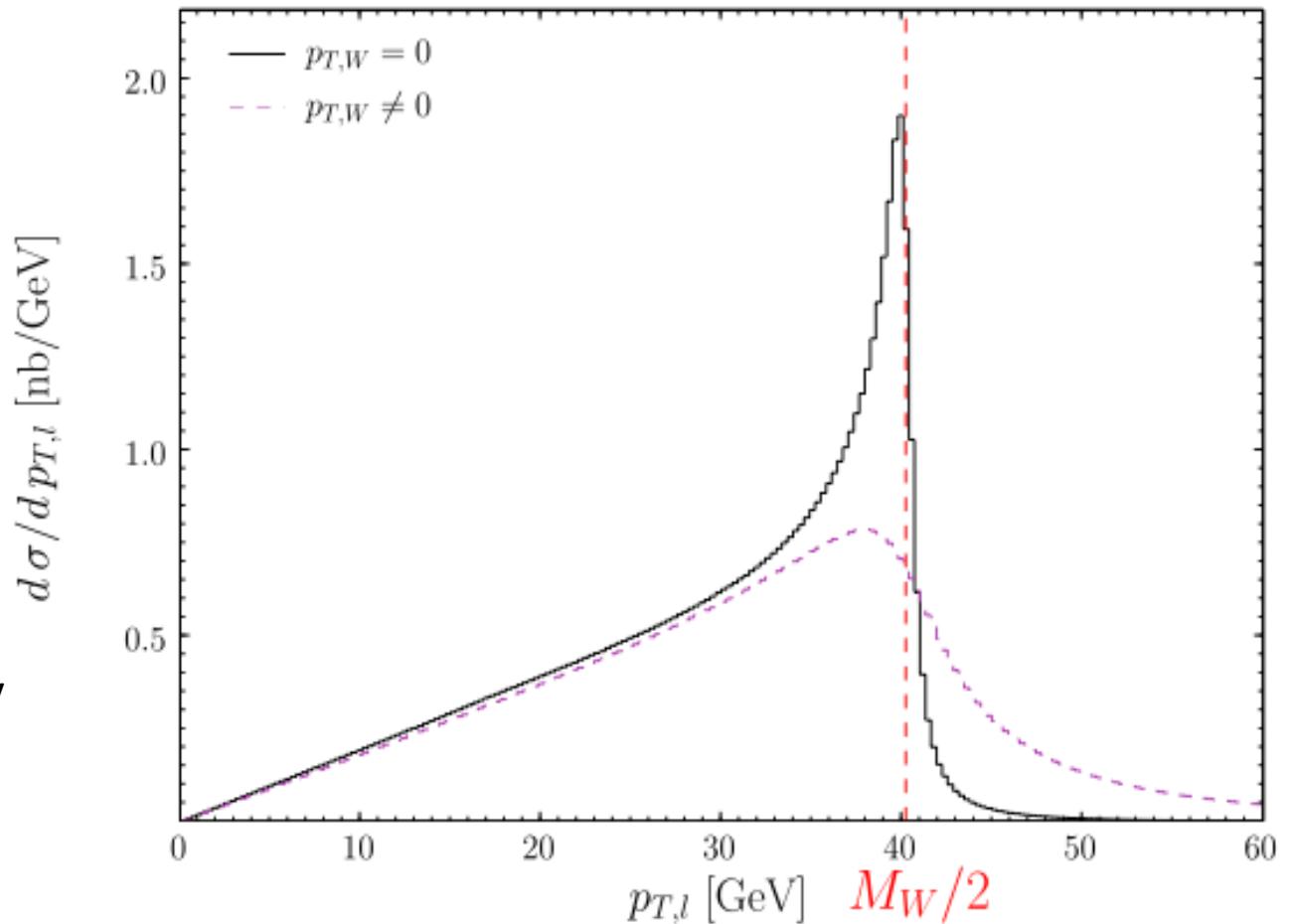
b) experiment:

detection efficiency

reconstruction efficiency

pseudorapidity cut

p_T bias



W^+	$u\bar{d} + u\bar{s} + u\bar{b} + c\bar{d} + c\bar{s} + \dots$
W^-	$d\bar{u} + d\bar{c} + s\bar{u} + s\bar{c} + \dots$
Z	$u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} + b\bar{b} + \dots$

p_T of π, K production is 0.3-0.5 GeV/c

p_T of W, Z production is 6 GeV/c

k_T different for different quark flavours

k_T correlated with x

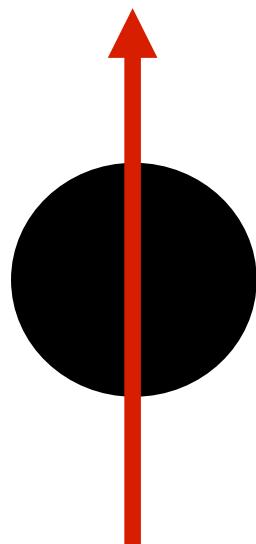
Hence change of paradigm appropriate:

Traditional k_T -integrated PDF($x; Q^2$)

→ 2-dimensional PDF($x, k_T; Q^2$) [k_T -nonintegrated PDF]

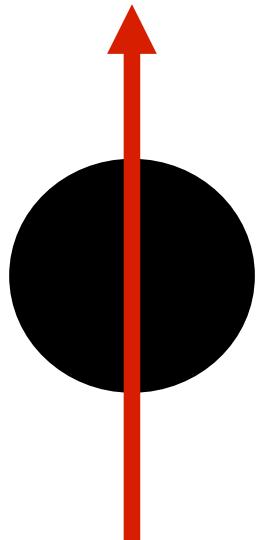
Weak Interaction coupling constants of W and Z

W	$g_L = 1$ $g_R = 0$	\oplus CKM
Z	$g_L^u = 1 - 2q \sin^2 \theta_w$	0.69
	$g_R^u = -2q \sin^2 \theta_w$	0.31
	$g_L^\nu = 1 - 2q \sin^2 \theta_w$	1
	$g_R^\nu = -2q \sin^2 \theta_w$	0
	$g_L^d = -1 - 2q \sin^2 \theta_w$	-0.85
	$g_R^d = -2q \sin^2 \theta_w$	0.15
	$g_L^e = -1 - 2q \sin^2 \theta_w$	-0.54
	$g_R^e = -2q \sin^2 \theta_w$	0.46



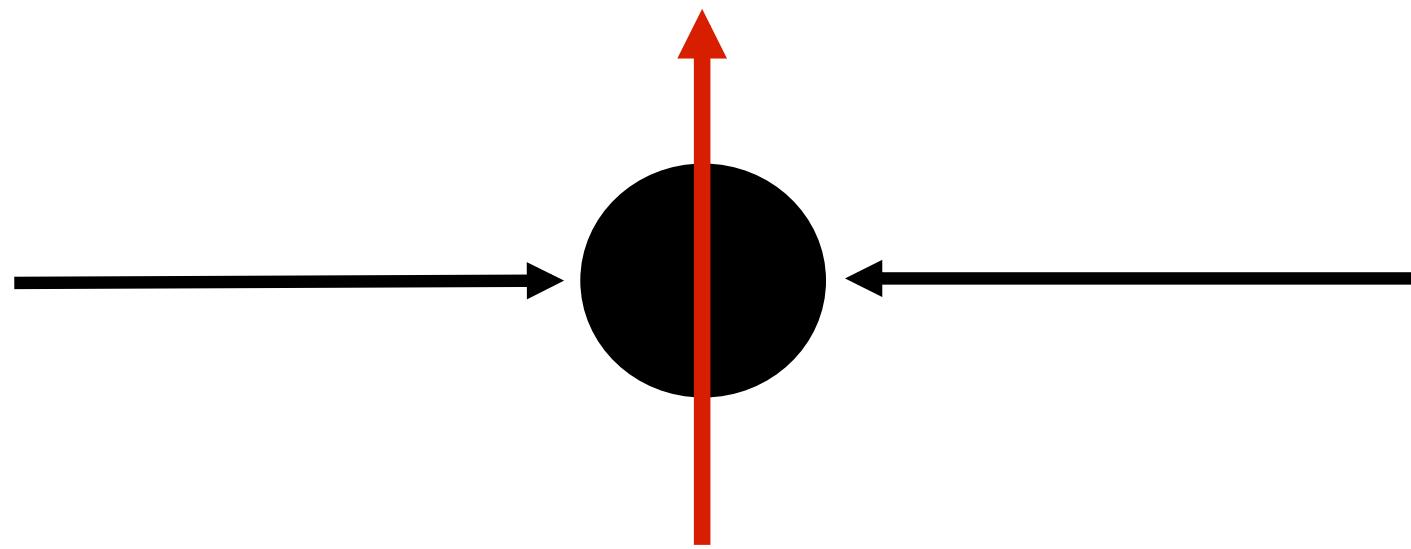
- $\theta =$ c.m. lepton emission angle w.r.t. spin vector
- $w(\theta) = 1 \pm \cos\theta$
- reflects V-A coupling

$Z \rightarrow l^+ l^-$



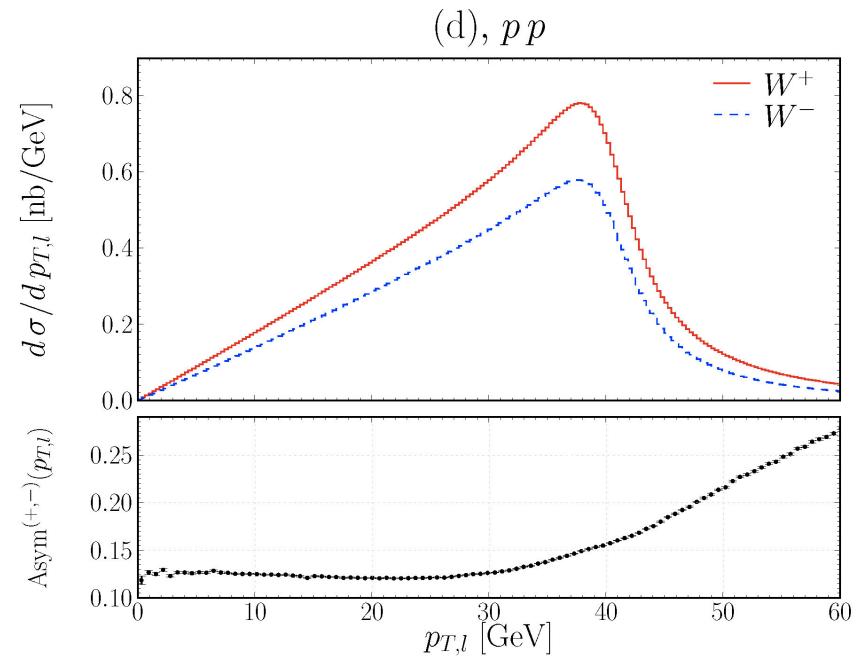
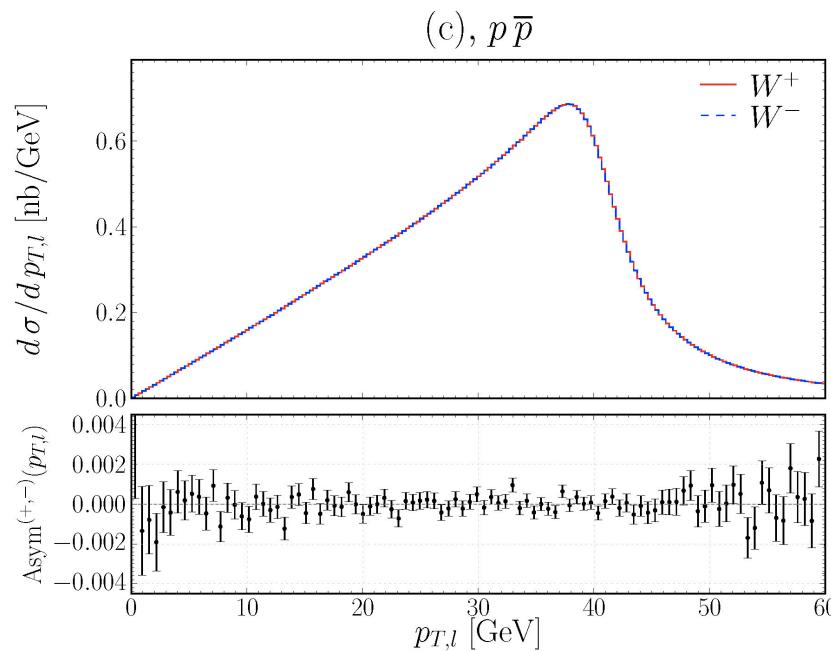
- $w(\theta) = 1 + \gamma \cos\theta$
with $0 < \gamma \ll 1$
- reflects mixture of V-A and
V+A coupling

longitudinal W polarization



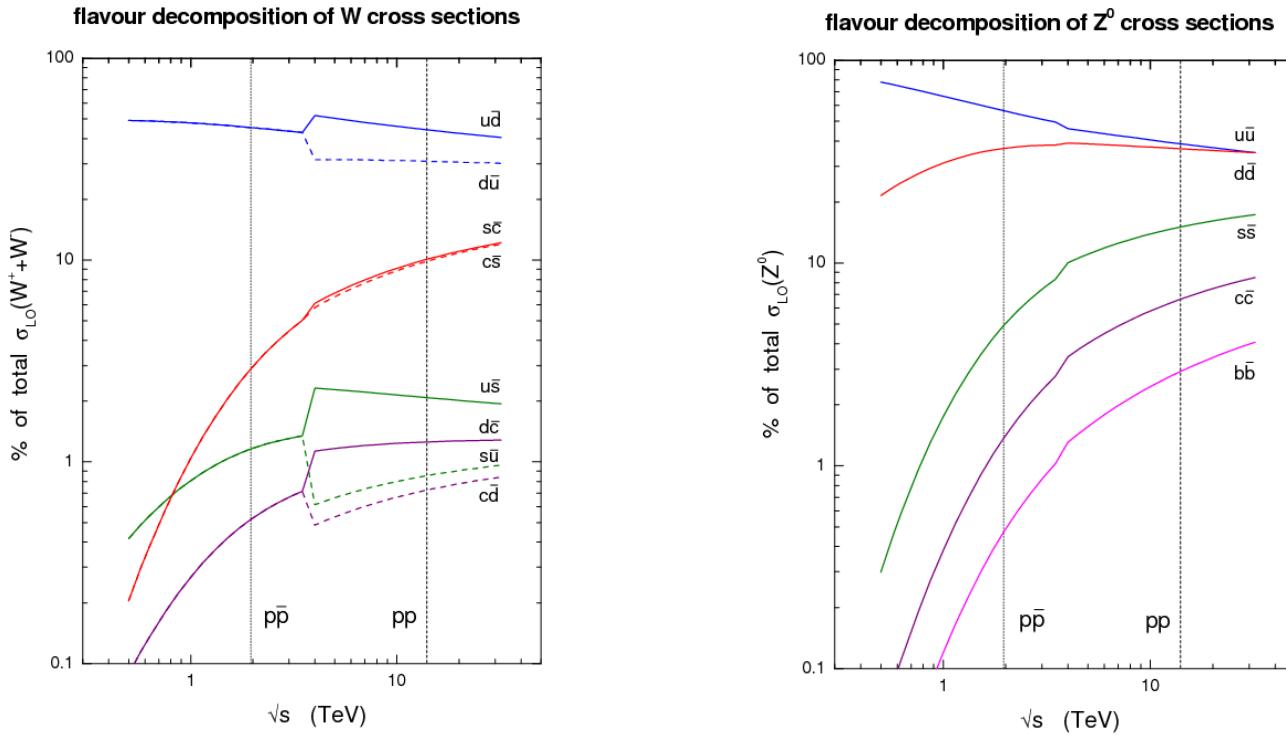
Tevatron: $W^+ + W^- \approx Z$

Lepton p_T



Transverse momentum of charged leptons from the leptonic decay of W^\pm
A charge-blind analysis is OK at the Tevatron but not OK at the LHC

Flavours of participating quarks



BERGE, NADOLSKY, AND OLNESS

PHYSICAL REVIEW D **73**, 013002 (2006)

TABLE I. Partial contributions $\sigma_{q\bar{q}}/\sigma_{\text{tot}}$ of quark-antiquark annihilation subprocesses to the total Born cross sections in W^+ and Z^0 boson production at the Tevatron and LHC (in percent).

Subprocesses	W^+					W^-					Z^0				
	$u\bar{d}$	$u\bar{s}$	$c\bar{d}$	$c\bar{s}$	$c\bar{b}$	$d\bar{u}$	$s\bar{u}$	$d\bar{c}$	$s\bar{c}$	$b\bar{c}$	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$
Tevatron Run-2	90	2	1	7	0	90	2	1	7	0	57	35	5	2	1
LHC	74	4	1	21	0	67	2	3	28	0	36	34	15	9	6

LHC pp versus Tevatron ppbar

LHC pp

Pro: θ and $\pi-\theta$ identical
for l^+ and, separately, for l^-

Permits exp. cross-check
forward versus backward

Con: W^+ and W^- rates
different, charge-blind
analysis not possible

Tevatron ppbar

Pro: l^+ at θ identical to l^- at
 $\pi-\theta$

Permits exp. cross-check on
 p_T bias between l^+ and l^-

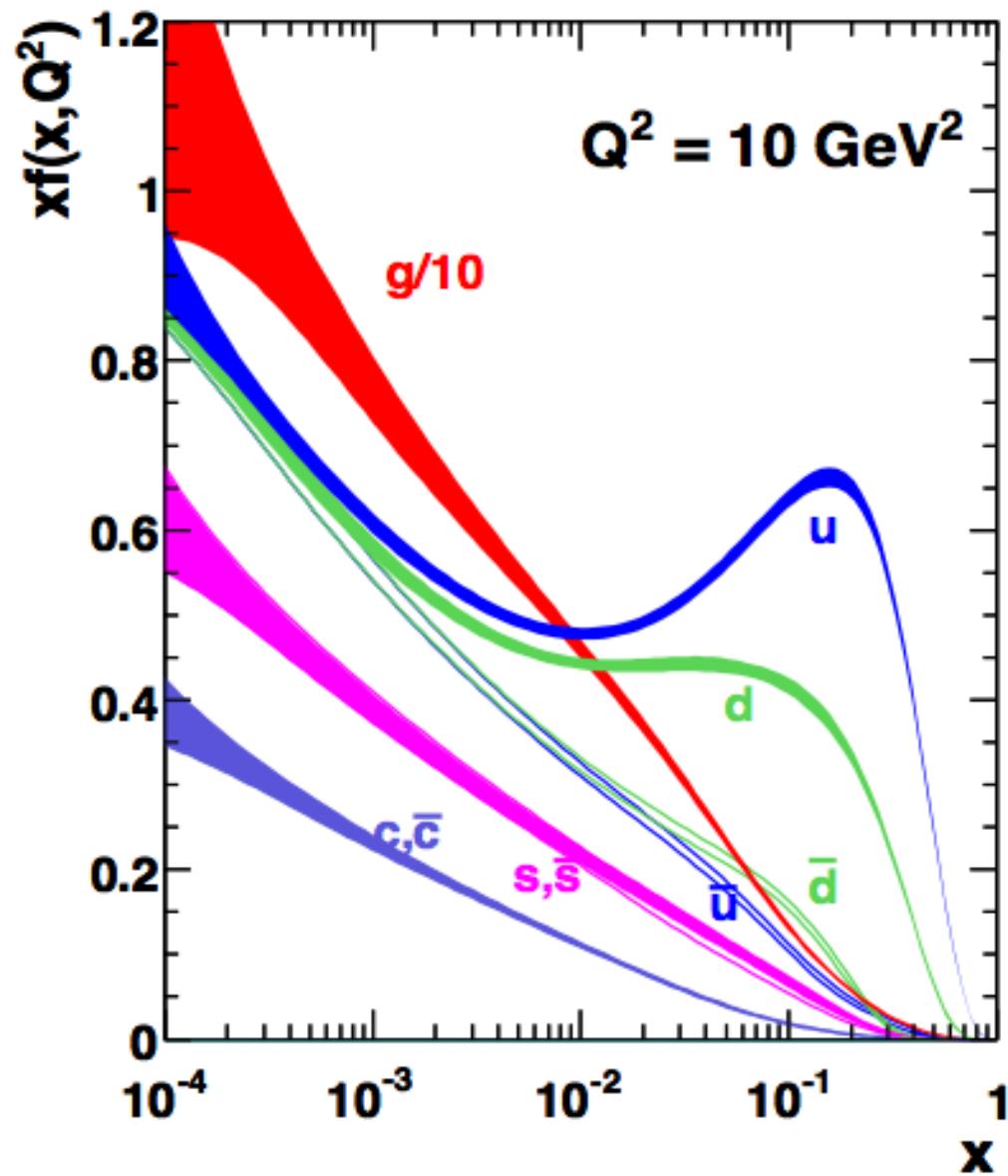
Charge-blind analysis possible

Simulation

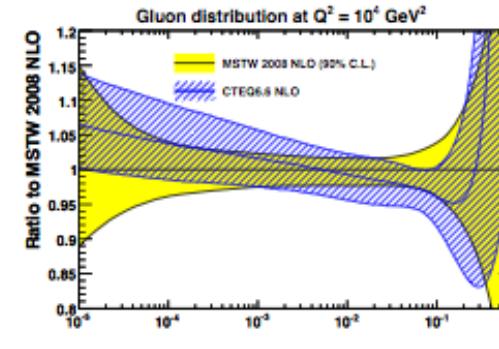
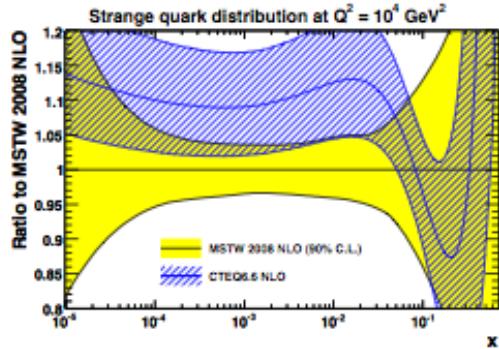
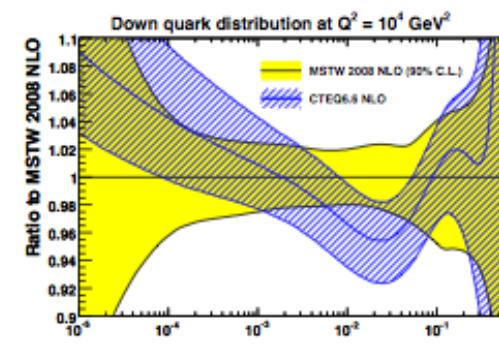
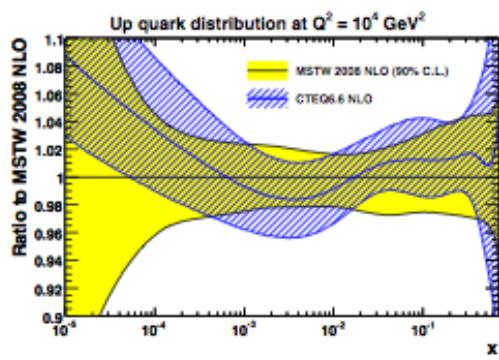
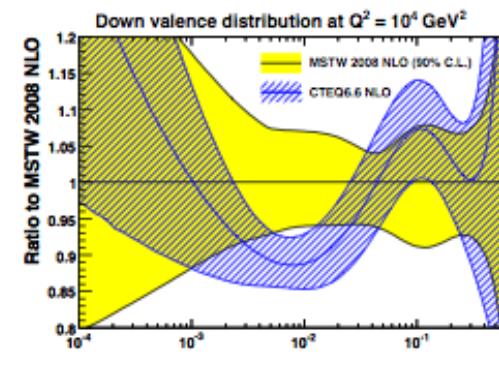
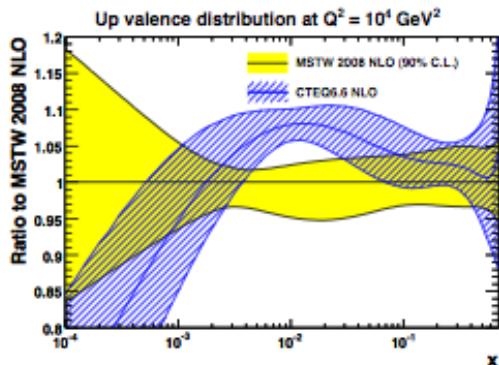
- Apparatus: ATLAS detector
- Luminosity: 10 fb^{-1}
- Trigger and Acceptance cuts: $p_{T,\parallel} > 20 \text{ GeV}/c$, $|\eta_\parallel| < 2.5$
- Event Generators: WINHAC/ZINHAC (spin amplitudes) and Pythia
- Parameterized response of the ATLAS detector
- Study based on $O(10^{10})$ simulated events

For details, see M.W. Krasny *et al.*, Eur. Phys. J. C69 (2010) 379

MSTW2008 (NLO)



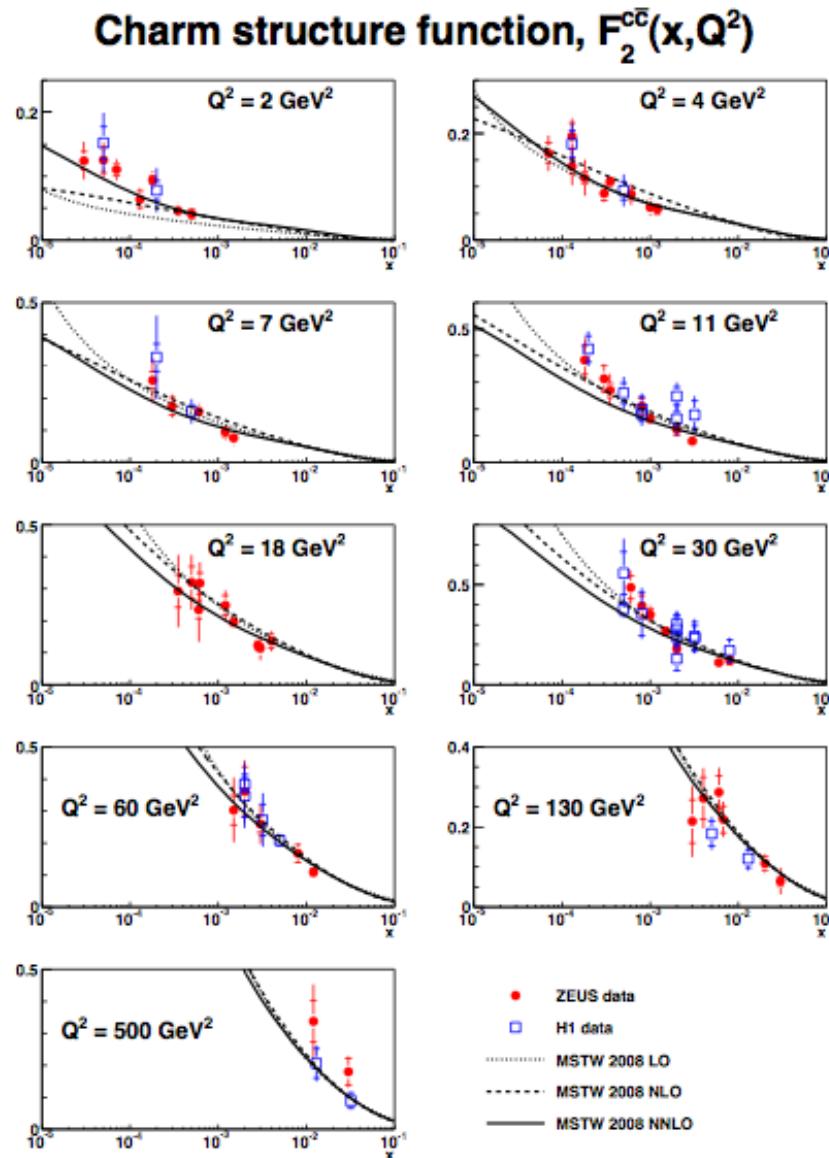
CTEQ6.6 vs MSTW2008 (NLO)



Biases from uncertainties in the 1st quark family

	ΔM_W	$\Delta[(M_{W^+} - M_{W^-})]$
$u_v^{\text{bias}} = 1.05 u_v$ $d_v^{\text{bias}} = d_v - 0.05 u_v$	+79 MeV	+115 MeV
$u_v^{\text{bias}} = 0.95 u_v$ $d_v^{\text{bias}} = d_v + 0.05 u_v$	-64 MeV	-139 MeV

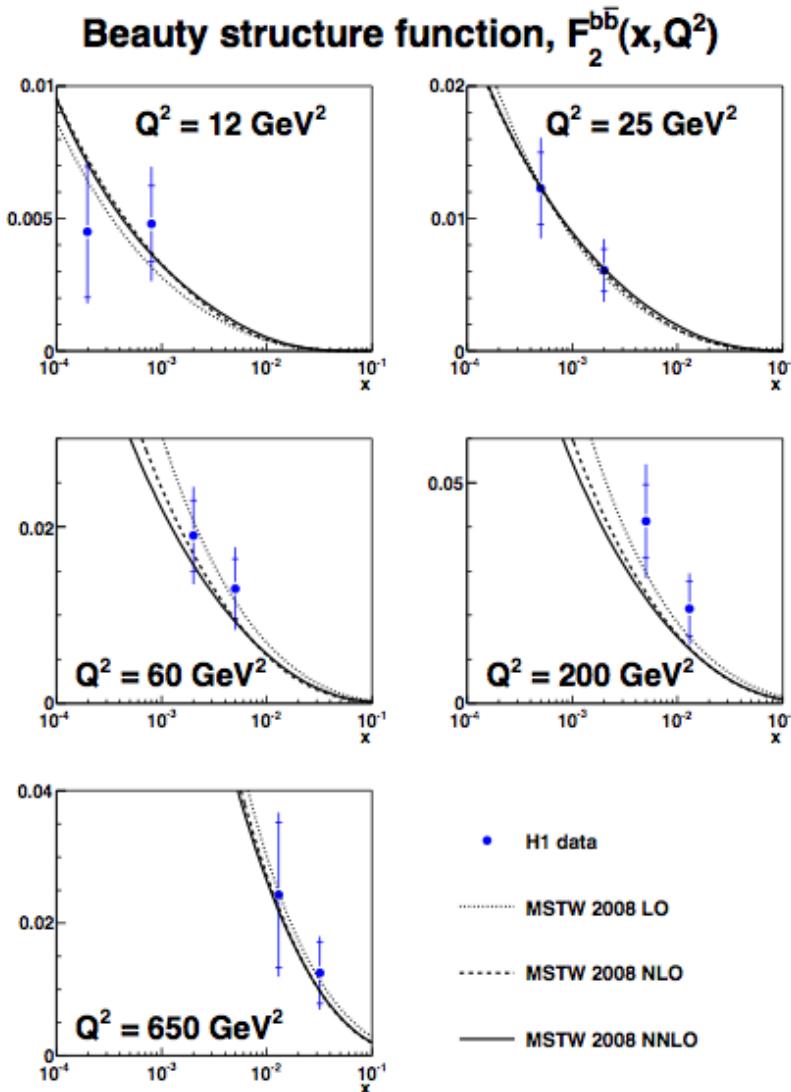
PDF of the charm quark



Biases from uncertainties in the 2nd quark family

	ΔM_W	$\Delta[(M_{W^+} - M_{W^-})]$
$c^{\text{bias}} = 0.9 c$	+148 MeV/c ²	+17 MeV/c ²
$s^{\text{bias}} = s + 0.1 c$		
$c^{\text{bias}} = 1.1 c$	-111 MeV/c ²	-11 MeV/c ²
$s^{\text{bias}} = s - 0.1 c$		

PDF of the bottom quark



Biases from uncertainties in the 3rd quark family

	ΔM_W
$b^{\text{bias}} = 1.2 b$	+42 MeV/c ²
$b^{\text{bias}} = 0.8 b$	-39 MeV/c ²

The dilemma

4+4 observables (p_T, η):

$\Sigma_w^+(p_T, \eta), \Sigma_w^-(p_T, \eta), \Sigma_z^+(p_T, \eta), \Sigma_z^-(p_T, \eta)$

versus

10+10 two-dimensional PDFs (x, k_T):

$u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}$

$u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}$ 10 + 10



$k_T(q) = k_T(\bar{q})$ 10 + 5



$k_T(u) = k_T(d)$ 10 + 4



$s(x) = \bar{s}(x), c(x) = \bar{c}(x), b(x) = \bar{b}(x)$ 7



$u_v(x) - d_v(x), s(x) - c(x), b(x)$ still missing

LHC-specific strategy

- ★ k_T -integrated PDFs → two-dimensional PDFs (x, k_T)
- ★ Ratios as observables

$$\mathcal{A}_W(p_{T,l}, \eta_l) = \frac{\Sigma_{W^+}(p_{T,l}, \eta_l) - \Sigma_{W^-}(p_{T,l}, \eta_l)}{\Sigma_{W^+}(p_{T,l}, \eta_l) + \Sigma_{W^-}(p_{T,l}, \eta_l)},$$

$$\mathcal{A}_Z(y_{ll}, p_{T,ll}, p_{T,l}, \eta_l) = \frac{\Sigma_{Z^+}(y_{ll}, p_{T,ll}, p_{T,l}, \eta_l) - \Sigma_{Z^-}(y_{ll}, p_{T,ll}, p_{T,l}, \eta_l)}{\Sigma_{Z^+}(y_{ll}, p_{T,ll}, p_{T,l}, \eta_l) + \Sigma_{Z^-}(y_{ll}, p_{T,ll}, p_{T,l}, \eta_l)},$$

$$\mathcal{R}_{WZ}(p_{T,l}, \eta_l) = \frac{\Sigma_{W^+}(p_{T,l}, \eta_l) + \Sigma_{W^-}(p_{T,l}, \eta_l)}{\Sigma_{Z^+}(p_{T,l}, \eta_l) + \Sigma_{Z^-}(p_{T,l}, \eta_l)}, \text{ and}$$

$$\mathcal{R}_Z^{\text{norm}}(p_{T,ll}, y_{ll}) = \frac{\Sigma_Z(p_{T,ll}, y_{ll})}{\Sigma_{l+l-}^{\text{norm}}},$$

- ★ Two LHC energies: E and $(m_Z/m_W) \bullet E$
- ★ Two respective magnet currents: I and $(m_Z/m_W) \bullet I$

Why previous analyses were too optimistic:

1. The PDFs are less precise than claimed, for the assumption of imperfect functional forms
2. k_T is theoretically not under control and needs to be measured
3. The correlation between x and k_T needs due consideration
4. The importance of polarization has been underestimated
5. Compensating changes of PDFs within the same family that leave the Z rapidity distribution invariant, have been ignored
6. The precision of relevant PDFs will not improve with the statistics of Z events, for missing information
7. Charge-dependent biases of the lepton p_T measurement have been ignored

Other than at the Tevatron, a charge-blind analysis is not possible at the LHC. W^+ and W^- must be treated separately