Remarks on the PDF systematics in the measurement of M_W

Mieczyslaw Witold Krasny, CNRS, LPNHE
University Paris VI et VII

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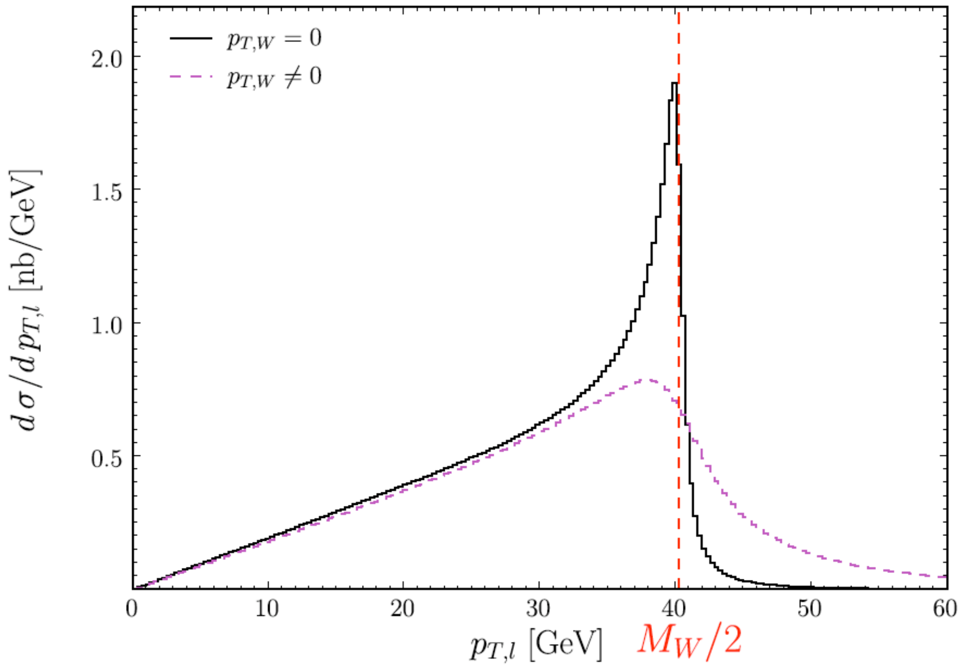
The method based on **m_T** will not be considered in this presentation.

This observable cannot be controlled at the LHC to the precision < 10 MeV because of several reasons. The most important one: **at the LHC a large fraction of W bosons produced by the second family quarks**

Excess of left-over strange (charm) particles associated with W production -- with respect to Z (calibration candle) -- requires an unrealistically precise simulation of the transport of strangeness (up to the strange-hadron decay point) in the hadronic calorimeter

note: $K \longrightarrow \mu\nu$ and $M_K = 493$ MeV >> 10 MeV

What influences the Jacobian peak position?



M_W is determined from $p_{t,l}$ distribution:

For $\Delta(M_W)$ =10 MeV, need to control the peak position with 0.01% (~4 MeV) precision - use the Z-boson spectra as the standard candle

The peak position is determined by the M_W value…

…. but also by:

- The measurement biases
- The transverse momentum distribution of the produced W-bosons, $P_{T,W}$
- The polarisation-density-matrix-dependent angular distributions of charged lepton in W decays

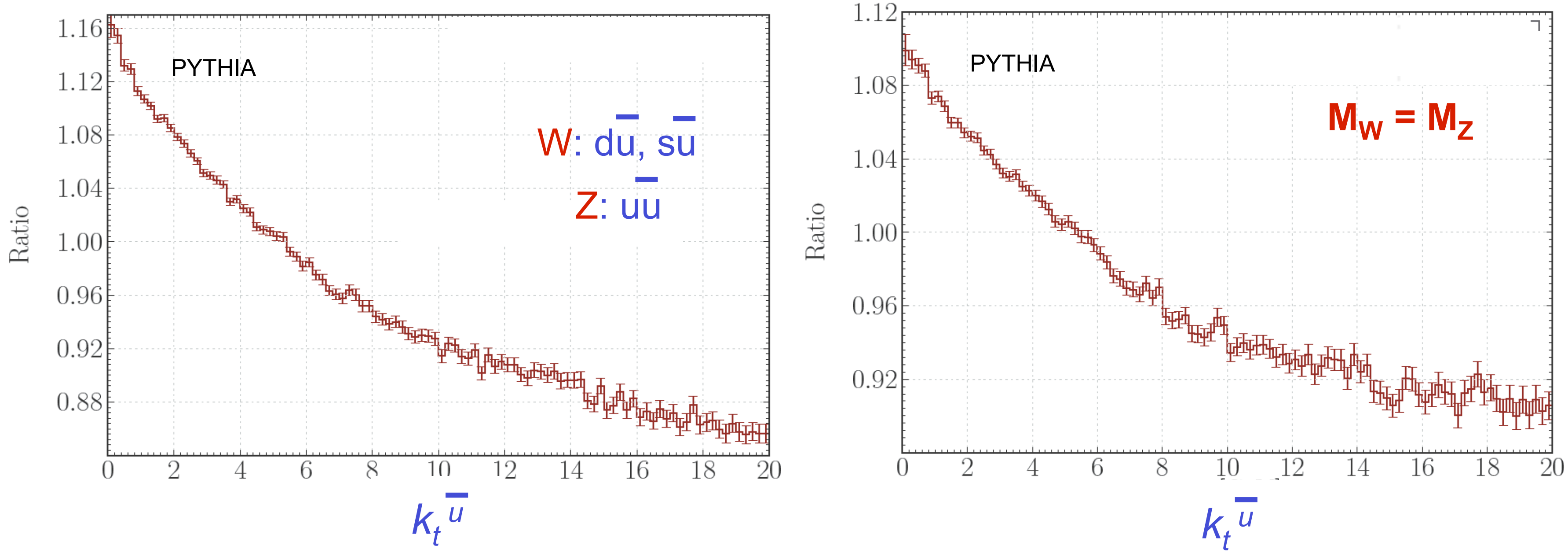
…. How do the PDFs enter here???

At the Tevatron and at the LHC the relationship between the $p_{T,W}$ and $p_{T,Z}$ distributions is governed predominantly by the difference the QCD scales: M_W and M_Z.

However, **at the LHC**, the largest uncertainty in this relationship comes from differences in the flavour- and x-dependence of the “effective” fluxes of annihilating quarks(anitiquarks) into W and Z bosons

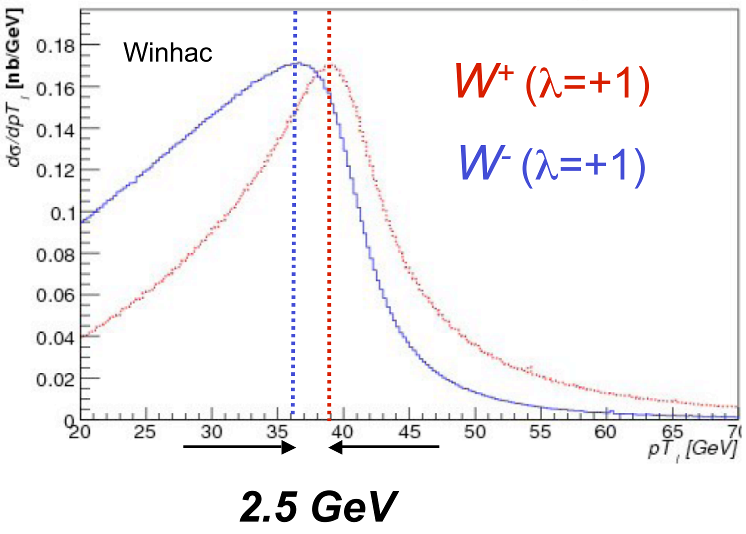
At the LHC, this is a dominant mechanism by which the collinear (k_T-integrated) PDFs influence the relationship between the transverse momentum distributions of W and Z bosons.

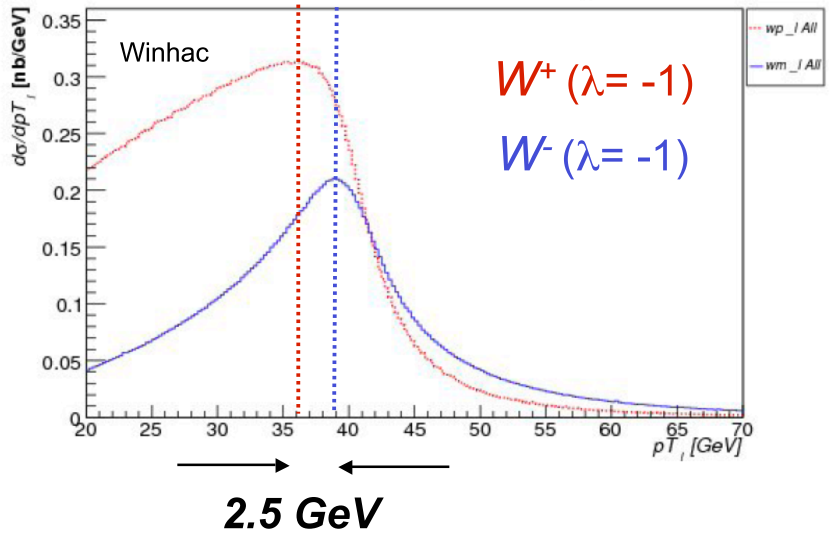
***Illustrative example**: the "Ratio" of transverse momentum distributions of ubar quarks producing W and Z bosons - in the acceptance region of the ATLAS detector*



- The longitudinal momentum distribution of the "matching parton" (the one needed to create W- and Z-bosons) determines the relative transverse momentum distribution of the W and Z bosons!!! **Must know Up(x) versus Down(x) with a high precision** for each of the quark families… and need a precise MC to control $k_{T,b}(x)$ vs $k_{T,c}(x)$ vs $k_{T,u,d,s}(x)$ … **or a procedure to determine these distributions using the LHC data.**

Polarisation/charge dependent positions of Jacobian peaks





No longer the Tevatron miracle. We must precisely control both the charge and the polarisation asymmetries of the W boson

Must know precisely not only u/d but also u_v/u and d_v/d (two extra degrees of freedom)

Roots of the LHC specific problems

…at the LHC we collide pp not $p\bar{p}$ like at the Tevatron, in addition much higher E_{CM}

→ Symmetry relations not at work:

at the LHC, contrary to the Tevatron: " $W^+ \neq W^-$ ", $\uparrow_W \neq \uparrow_Z$ (polarization)

- need of separate analyses of W^+ and W^-, and similarly Z^+ and Z^-, no charge-blind analysis possible (like in $p\bar{p}$ collisions at the Tevatron)
- need to control the relative calibration of the l^+/ l^- momentum scales, Z-peak of little use

→ Collisions at much higher energy!

at the LHC ~30% of W and Z bosons are produced by s,c and b quarks

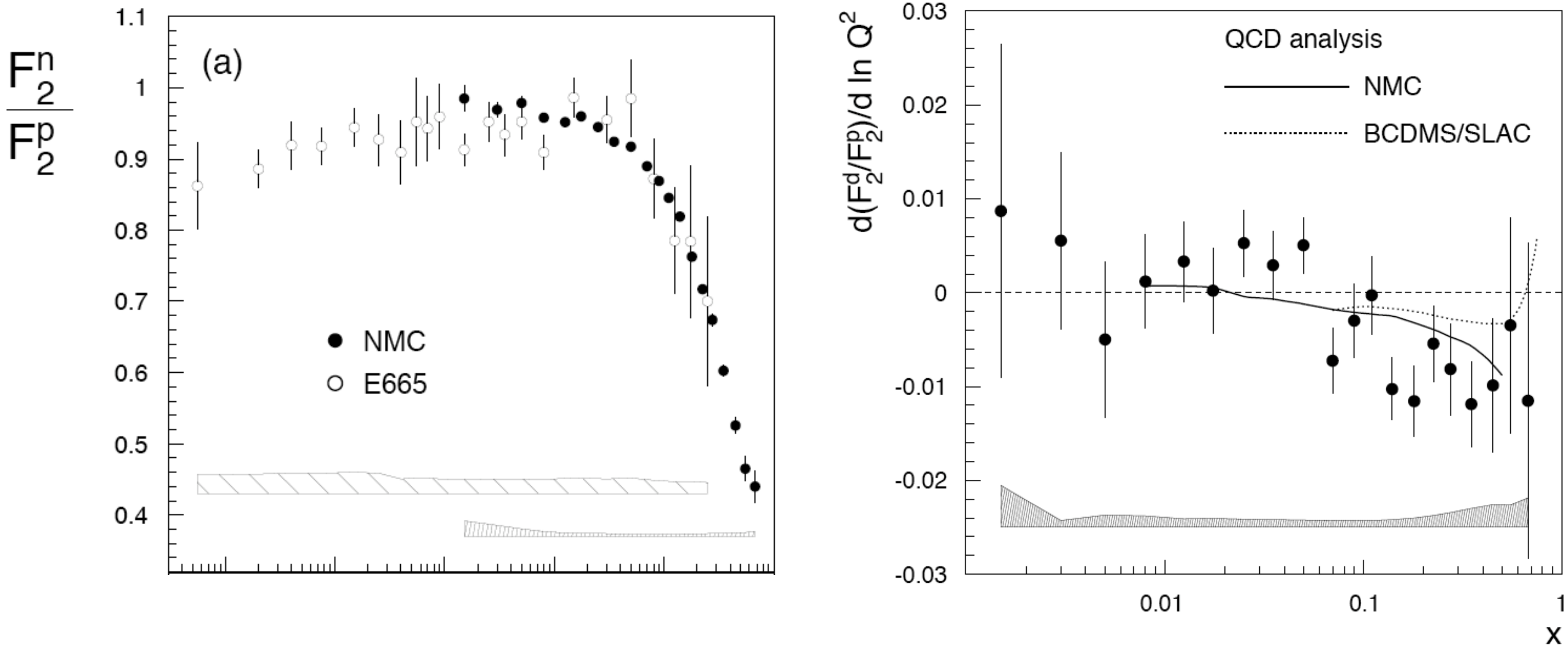
- need to understand heavy flavours with much better precision

Recap:

For the LHC precision EW programme we must know the proton valence/sea and flavour structure with much higher precision than that required at the Tevatron…

The flavour structure of protons drives the relationship between the P_T spectra and W and Z (template) bosons and their polarisation asymmetries The valence sea/structure drives the their polarisation asymmetries, thus, the distributions of the W and Z boson decay products.

The EW physics at the LHC requires a precise understanding of the non-perturbative, flavour non-singlet aspects of the PDFs, … **which are constrained predominantly by the available data rather than by the QCD-fit technology.** →



Note, stability with respect to the scale-dependent QCD evolution

Unconstrained PDF degrees of freedom at the LHC

Assume: $s(x)=\bar{s}(x)$, $c(x)=\bar{c}(x)$, $b(x)=\bar{b}(x)$ then:

- 5 sea-quark flavours (u,d,s,c,b) + 2 valence quark flavours ($u^{(v)}$, $d^{(v)}$) 7 unknown PDFs:
- 4 constraints coming from the ($p_{T,l}$, η_l) spectra for W^+, W^-, "Z^+" and "Z^-" decays
- 7-4=3 degrees of freedom in the flavour-dependent pdf's remain unconstrained at the LHC

Important note:

At the Tevatron only the first quark family is relevant. In addition p collides with $\bar{p}$.

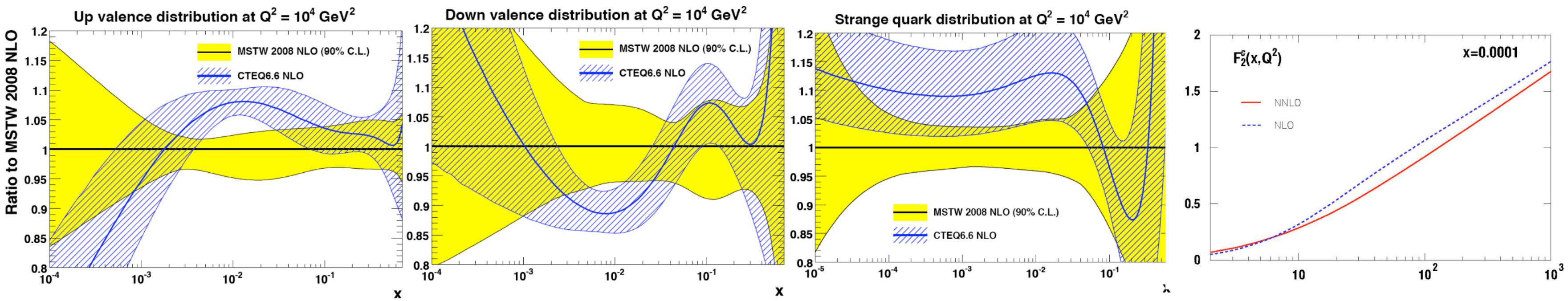
This leaves only 2 (out of 7) flavour dependent pdf's. They are over-constrained by the the η_l dependence of the Z and W cross-sections

Present precision of: “missing” PDF and its impact on the M_W measurement error

	ΔM_{W}
$u_{\mathrm{v}}^{\mathrm{bias}} = 1.05\, u_{\mathrm{v}}$ $d_{\mathrm{v}}^{\mathrm{bias}} = d_{\mathrm{v}} - 0.05\, u_{\mathrm{v}}$	$+79\ \mathrm{MeV}/c^2$
$u_{\mathrm{v}}^{\mathrm{bias}} = 0.95\, u_{\mathrm{v}}$ $d_{\mathrm{v}}^{\mathrm{bias}} = d_{\mathrm{v}} + 0.05\, u_{\mathrm{v}}$	$-64\ \mathrm{MeV}/c^2$

	ΔM_{W}
$c^{\mathrm{bias}} = 0.9\, c$ $s^{\mathrm{bias}} = s + 0.1\, c$	$+148\ \mathrm{MeV}/c^2$
$c^{\mathrm{bias}} = 1.1\, c$ $s^{\mathrm{bias}} = s - 0.1\, c$	$-111\ \mathrm{MeV}/c^2$

	ΔM_{W}
$b^{\mathrm{bias}} = 1.2\, b$	$+42\ \mathrm{MeV}/c^2$
$b^{\mathrm{bias}} = 0.8\, b$	$-39\ \mathrm{MeV}/c^2$



The uncertainty in the non-singlet distributions are driven by the precision of the experimental data and their phenomenological interpretation rather than by the precision of the QCD fits!!!

Example: u_v-d_v driven by the NMC “p/d” data (2%), E866 “D-Y” data (4%), nucl. corr (2%)

A comment to Forte’s contradicting conclusion at the LPNHE-Paris workshop

SUMMARY

- ACCURATE DETERIMINATION OF THE LIGHT FLAVOUR STRUCTURE POSSIBLE USING HERA+LHC DATA ONLY

  → NO LOW ENERGY DATA!

- LHC CAN LEAD TO ACCURATE DETERMINATION OF THE HEAVY FLAVOUR COMPONENTS

  → NO LOW ENERGY DATA!

…Indeed, but provided that we could use W and Z rather than charged lepton observables for precision electroweak physics at the LHC

(… and still under the assumption that the relative charm and bottom mass threshold effects in the relative k_T distributions at the M_W scale can be precisely controlled by the perturbative QCD)

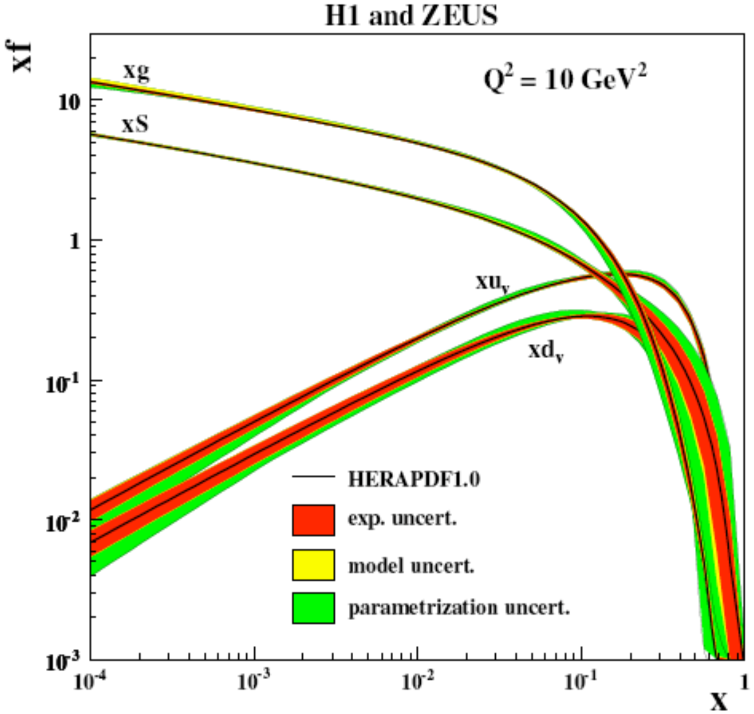
… this is clearly not the case for the precision we want to achieve!

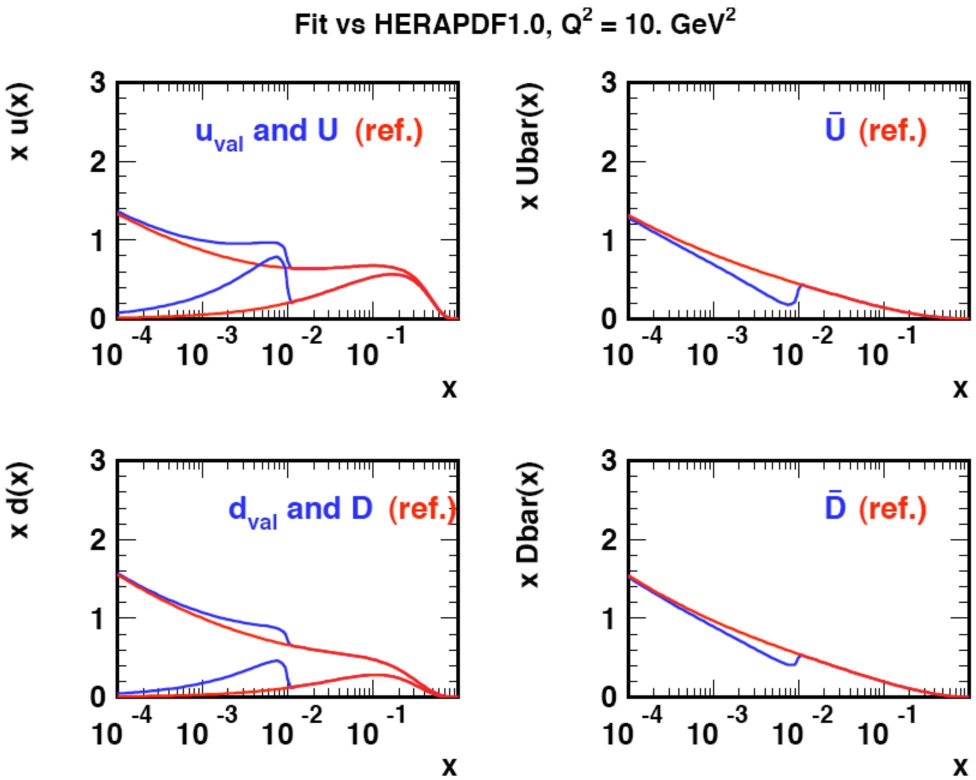
A question? Which set of the $u(x,Q_0^2)$ and $d(x,Q_0^2)$ distributions give better χ^2 (the HERA DIS data)?

A) standard, **red one**

B) modified, **red + blue(small x)**

S. Glazow, M.W. Krasny, V. Radescu





Note,the quark distributions are modified in the x-domain of interest for centrally produced W/Z bosons

… and the answer is:

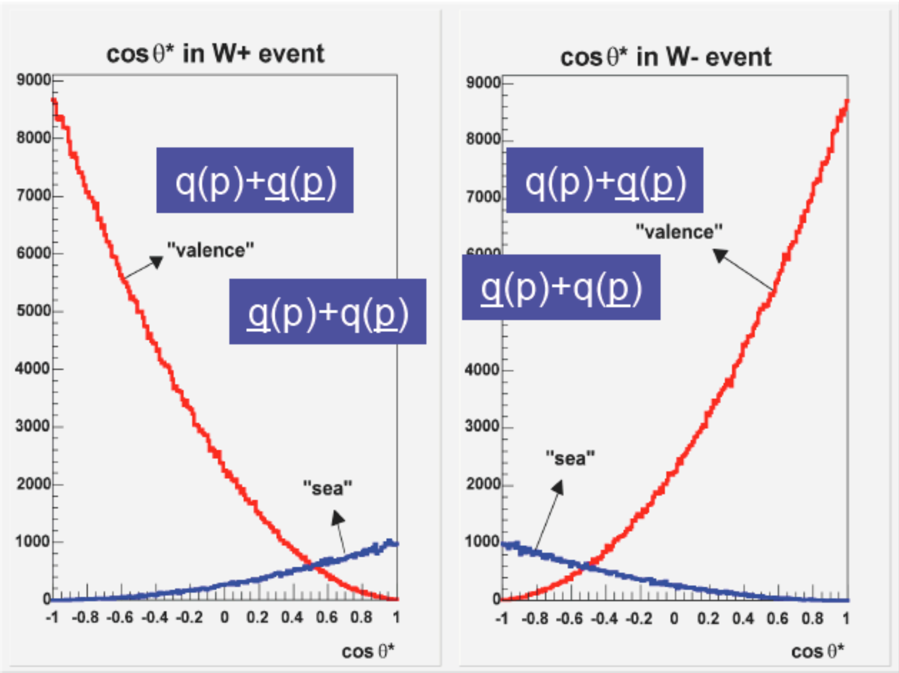
red + blue (χ^2/ndf improved by 1.5)

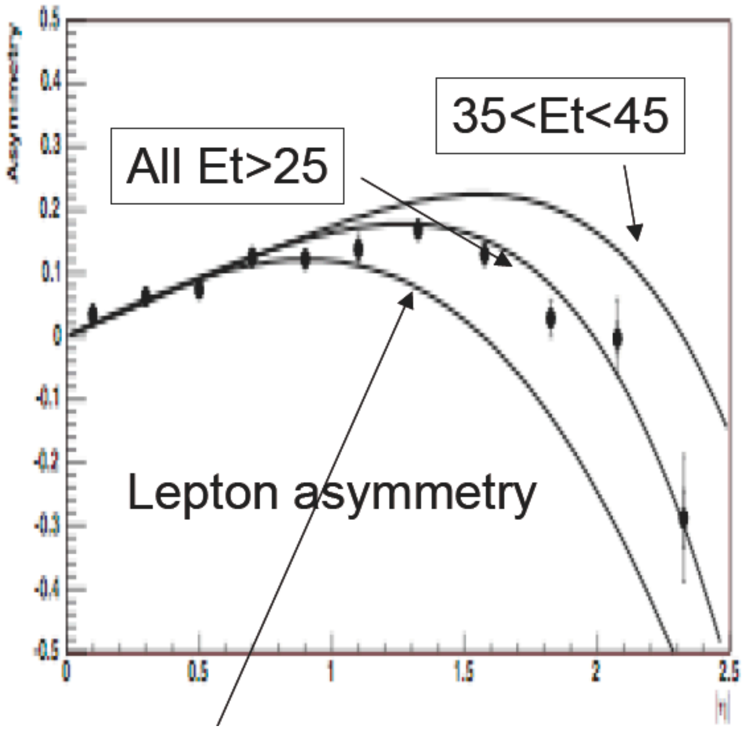
Nota bene:

A measurement programme was proposed for HERA back in 1996 capable to resolve the **u/d**, **valence/sea, and LT/HT(small x)** ambiguities with the requisite precision for the LHC precision EW programme (at “negligible cost” for DESY ~25 M DM)…

A side remark: The valence/sea ambiguity has an important consequence for the PDF constraints derived from the analysis of the W+/W- asymmetries measured at the Tevatron

Plots from Arie Bodek's presentation

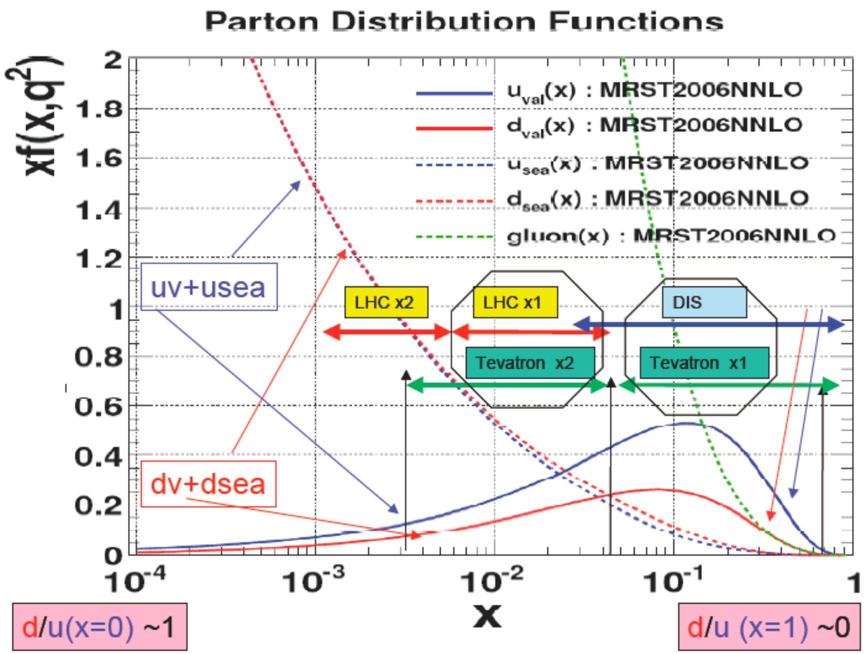


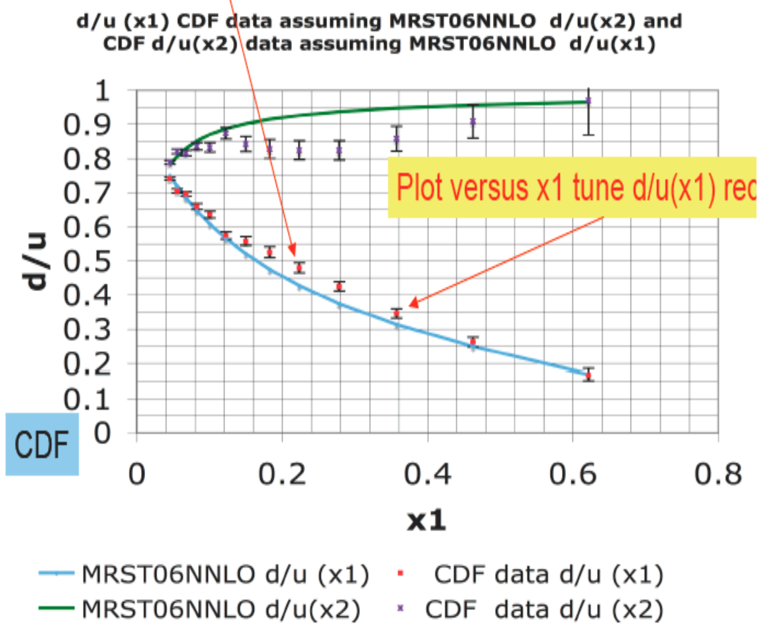


The sensitivity of the Et reflect strong effects related to the W polarization - the lepton asymmetry is driven not only by d/u but also by u_v/u and d_v/d and cannot be unambiguously interpreted in terms of d/u

…in addition, consider d/u(x1) versus d/u(x2) ambiguity:

Plots from Arie Bodek's presentation





…The precision of M_W cannot be improved at the LHC…

(…the same conclusion for $\sin^2(\theta_W)$, Γ_W, M_{W+}- M_{W-} ,Γ_{W+}- Γ_{W+},

…e.g. $\Delta\sin^2(\theta_W) \sim 0.001$, $\Delta\Gamma_W \sim$ 50 MeV, !… note feedback on M_W)

…unless a dedicated measurement strategy is undertaken…

Several strategies could be considered…

1. Based on single LHC experiment data

Atlas(CMS) Z/W data + experimental control of W polarisation + modelling of the quark mass threshold effects - not even feasible using the present MC tools)

Atlas(CMS) Z/W and low mass DY data - highly unlikely to achieve a requisite precision - 2(1) PDFs remain unconstrained

LHCb Z/W and low mass DY data - feasible in the extreme lepton pseudurapidity region (very large x_1, very small x_2, where W/Z production is confined to the first quark family) but large statistical errors

1. Based on combined LHC experiment data

Combined analysis of the ATLAS (CMS) and LHCb W/Z data - not feasible - different x_1 and x_2 domains probed

Combined analysis of the LHCb and the Tevatron W/Z data - statistically limited, in addition must rely on the extrapolation of the HERA data to the LHCb x_2 domain

Combined analysis of the ATLAS(CMS) and the Tevatron W/Z data (need an external constraint from a dedicated DIS experiment)

The proposed way forward

- LHC-specific measurement and analysis programme
  (**dedicated observables**, trigger, data selection and running and measurement procedures, dedicated methods of cross normalisation of the pertinent data sets, new analysis tools)

and

- An extension of the canonical LHC proton collision programme:

  deuteron-deuteron collisions at the LHC

  or

  DIS experiment with deuterium and hydrogen target

  LOI for such an experiment submitted to SPSC and LHCC

  (no support (yet?) from the PDF4LHC, ATLAS and CMS communities for such an initiative - proposal ignored)

supplementary slides

Reported work

- **Goal:** Evaluate the achievable precision of the EW SM parameter measurement at the LHC. Develop a coherent, LHC-dedicated strategy to measure: $M_{W,}$, $\sin^2(\theta_W)$, Γ_W, M_{W+}- M_{W-} ,Γ_{W+}- Γ_{W+}

- Luminosity: 10 fb $^{-1}$
- Event generators: WINHAC/ZINHAC
- Simulation: parameterized response of the ATLAS detector
- Study based on $O(10^{10})$ simulated events, $O(10^2)$ event samples
- The team: F. Fayette, W. Placzek, K. Rejzner, A. Siodmok, M.W. Krasny, in collaboration with F. Dydak (IN2P3-COPIN cooperation program 05-116)

- **This presentation:** M_W measurement

  Eur.Phys.J **C69** 379, 2010

  Eur.Phys.J **C63,** 33, 2009

  Eur.Phys.J **C51** 607, 2007

LHC specific strategy (elements)

1.Precision observables:

LHC + Tevatron	$$\mathcal{A}_{\mathrm{W}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) = \frac{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) - \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})}{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})},$$	sensitive to M_{W+}- M_{W-} and Γ_{W+} - Γ_{W-}
	$$\mathcal{A}_{\mathrm{Z}}(y_{\mathrm{ll}},p_{\mathrm{T,ll}},p_{\mathrm{T,l}},\eta_{\mathrm{l}}) = \frac{\Sigma_{\mathrm{Z+}}(y_{\mathrm{ll}},p_{\mathrm{T,ll}},p_{\mathrm{T,l}},\eta_{\mathrm{l}}) - \Sigma_{\mathrm{Z-}}(y_{\mathrm{ll}},p_{\mathrm{T,ll}},p_{\mathrm{T,l}},\eta_{\mathrm{l}})}{\Sigma_{\mathrm{Z+}}(y_{\mathrm{ll}},p_{\mathrm{T,ll}},p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{Z-}}(y_{\mathrm{ll}},p_{\mathrm{T,ll}},p_{\mathrm{T,l}},\eta_{\mathrm{l}})},$$	sensitive to $\sin^2(\theta_W)$
	$$\mathcal{R}_{\mathrm{WZ}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) = \frac{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})}{\Sigma_{\mathrm{Z+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{Z-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})}, \text{ and}$$	sensitive to α_s, M_{W+}+ M_{W-}, and Γ_{W+} + Γ_{W-}
	$$\mathcal{R}_{\mathrm{Z}}^{\mathrm{norm}}(p_{\mathrm{T,ll}},y_{\mathrm{ll}}) = \frac{\Sigma_{\mathrm{Z}}(p_{\mathrm{T,ll}},y_{\mathrm{ll}})}{\Sigma_{\mathrm{l+l-}}^{\mathrm{norm}}},$$	dedicated method of absolute normalization
DIS	$$\mathrm{Asym}_{\mathrm{DIS}}^{(p,n)}(x,Q^2) = \frac{\frac{d^2\sigma^p}{dxdQ^2}(x,Q^2) - \frac{d^2\sigma^n}{dxdQ^2}(x,Q^2)}{\frac{d^2\sigma^p}{dxdQ^2}(x,Q^2) + \frac{d^2\sigma^n}{dxdQ^2}(x,Q^2)}$$	missing constraint for d_v, $\bar{d}$, u_v, $\bar{u}$

2. Two dimensional PDFs (k_T,x)

3. Experimental procedures to control of all the relative QCD effects for W and Z bosons (Z as a candle for EW effects)

Technicalities (M$_W$ study)

- Likelihood analysis of the LHC observables for the pseudo-data (PD) and mass-templates (MT) event samples
- Each of the PD samples represents a specific measurement or modeling bias, implemented respectively in the event-simulation or event-generation process
- Observables relevant for the M_W study:

$$\mathcal{A}_{\mathrm{W}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) = \frac{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) - \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})}{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})} \quad \mathcal{R}_{\mathrm{WZ}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) = \frac{\Sigma_{\mathrm{W+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{W-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})}{\Sigma_{\mathrm{Z+}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}}) + \Sigma_{\mathrm{Z-}}(p_{\mathrm{T,l}},\eta_{\mathrm{l}})} \quad \mathcal{R}^{\mathrm{mod}}_{\mathrm{WZ}}(\rho_{\mathrm{l}},\eta_{\mathrm{l}}) \quad \mathcal{R}^{\mathrm{QCD}}_{\mathrm{WZ}}(\rho_{\mathrm{l}},\eta_{\mathrm{l}})$$

- Mass templates on the (M_{W+}, M_{W-}) grid, for the above observables an equivalent grid in (M_{W+} + M_{W-}) and (M_{W+} - M_{W-}) (M_W defined as (M_{W+} + M_{W-})/2)
- Study sensitivity: O(5 MeV)
- … more details in the PhD theses of Florent Fayette and Andrzej Siodmok