The measurement of the W mass at the LHC: shortcuts revisited

F. Dydak and M.W. Krasny

Workshop on

"New Opportunities in the Physics Landscape at CERN"

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M_W measurement

Example: ATLAS contribution to the Philadelphia ICHEP 2008 conference

Source	Effect	$\partial m_W / \partial_{rel} \alpha$ (MeV/%)	$\delta_{rel} \alpha$ (%)	δm_W (MeV)
Prod. Model	W width	1.2	0.4	0.5
	y^W distribution	–	–	1
	p_T^W distribution	–	–	3
	QED radiation	–	–	<1 (*)
Lepton measurement	Scale & lin.	800	0.005	4
	Resolution	1	1.0	1
	Efficiency	–	–	4.5 (e) ; <1 (μ)
Recoil measurement	Scale	–	–	–
	Resolution	–	–	–
Backgrounds	$W \to \tau\nu$	0.15	2.5	2.0
	$Z \to \ell(\ell)$	0.08	2.8	0.3
	$Z \to \tau\tau$	0.03	4.5	0.1
	Jet events	0.05	10	0.5
Pile-up and U.E				<1 (e); $\sim 0(\mu)$
Beam crossing angle				<0.1
Total (p_T^ℓ)				~7 (e); 6 (μ)

At the LHC we collide pp

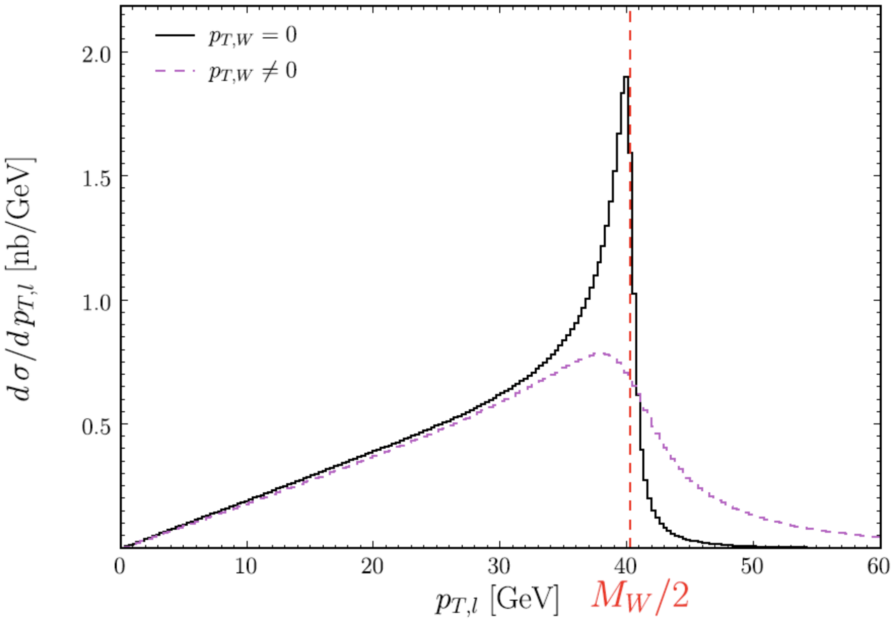
not $\bar{p}p$ like at the Tevatron

At the LHC:

Symmetry relations not at work

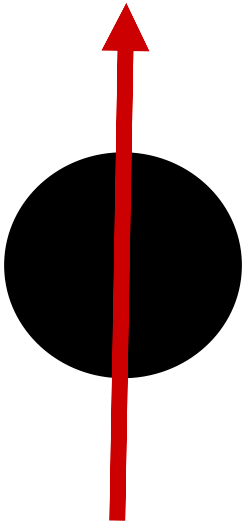
Stronger dependence on the proton's parton distribution functions (pdf's)

M_W is determined from $p_{T,l}$



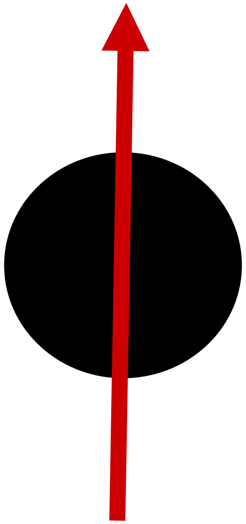
- factor 4000 between 40 GeV and $\Delta(M_W)$ =10 MeV
- utmost care needed to anything that affects $p_{T,l}$

$W^{\pm} \longrightarrow l^{\pm}\ \nu$



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

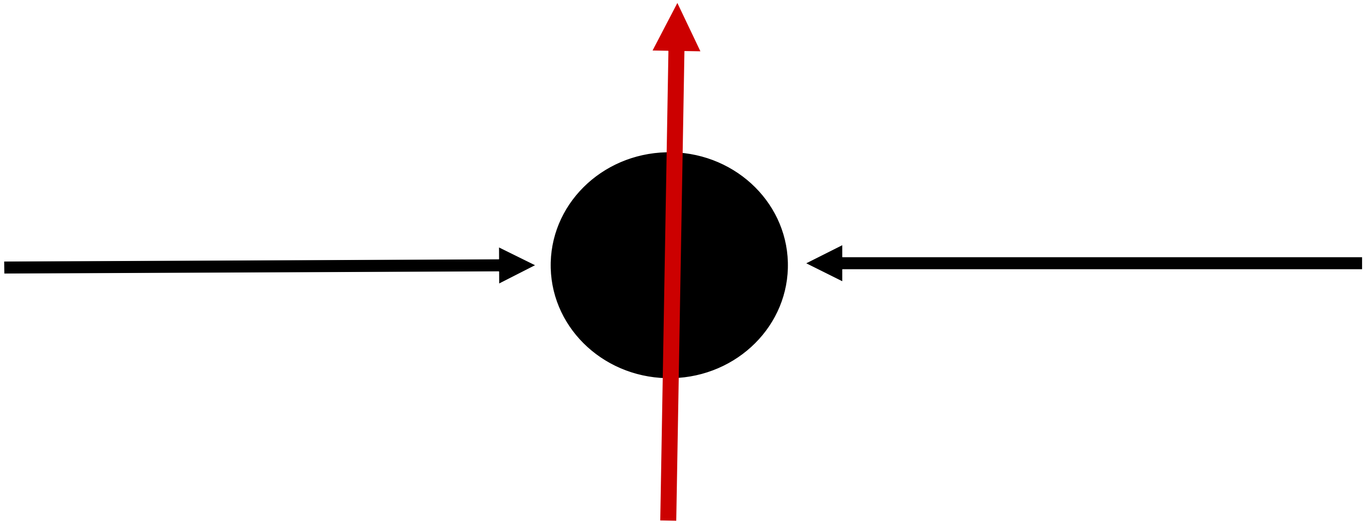
$Z \longrightarrow l^+l^-$



- $W(\theta) = \alpha + \beta \cos(\theta)$

- reflects mixture of V-A and V+A coupling

Note the asymmetries in the polarization of W+, W- and Z bosons in the direction perpendicular to the beam axis…



(“longitudinal" polarization)

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

different quark pdf's

different quark couplings

different quark k_T's

=> different W^+, W^- and Z polarization

=> different $p_{T,l}$ spectra

Effect of polarization on $p_{T,l}$ spectra in all LHC studies ignored so far

=> 0(10) MeV is unrealistic

How unrealistic?

Simulation of the W mass measurement

- Apparatus: The ATLAS detector
- Luminosity: 10 fb^{-1}
- Trigger and Acceptance cuts: $p_{T,l} > 20$ GeV/c, $|\eta_l| < 2.5$
- Event Generators: WINHAC/ZINHAC (spin amplitudes) and Pythia
- Simulation: parameterized response of the ATLAS detector
- Study based on $O(10^{11})$ simulated events
- The team: F. Fayette, M.W. Krasny, W. Placzek, K. Rejzner, A. Siodmok

Because the W+ and the W- bosons exhibit different characteristics at the LHC, they must be analyzed separately.

We consider

$$M_W = (M_{W+} + M_{W-})/2$$

and

$$M_{W+} - M_{W-}$$

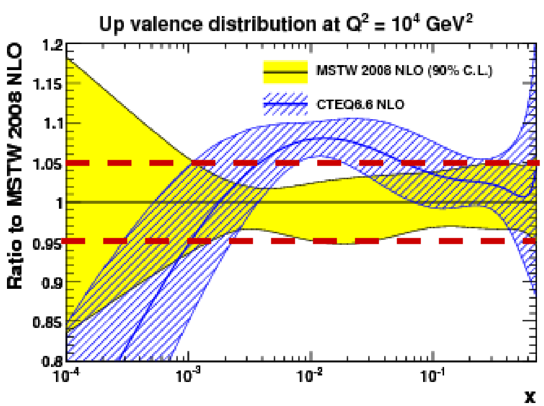
Effect of 1st quark family

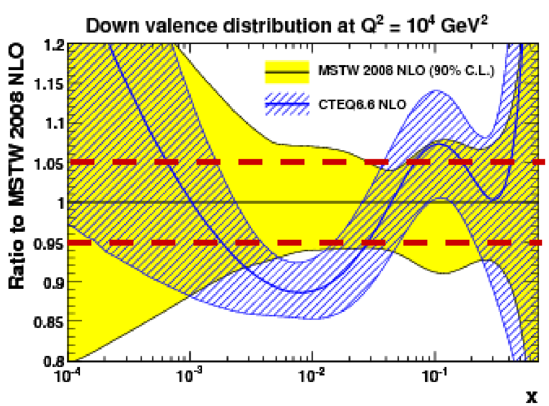
Expected biases in the measured values of M_{W+}-M_{W-}

$u^{(v)},\ d^{(v)(*)}$	$u^{(v)}_{max} = 1.05\,u^{(v)}$ $d^{(v)}_{min} = d^{(v)} - .05\,u^{(v)}$	114.5
	$u^{(v)}_{min} = 0.95\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .05\,u^{(v)}$	-138.5
	$u^{(v)}_{max} = 1.02\,u^{(v)}$ $d^{(v)}_{min} = 0.92\,d^{(v)}$	85.2
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = 1.08\,d^{(v)}$	-85.9

Expected biases in the measured values of M_W

$u^{(v)},\ d^{(v)}$	$u^{(v)}_{max} = 1.05\,u^{(v)}$ $d^{(v)}_{min} = d^{(v)} - .05\,u^{(v)}$	79
	$u^{(v)}_{min} = 0.95\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .05\,u^{(v)}$	-64
	$u^{(v)}_{min} = 1.02\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} - .02\,u^{(v)}$	32
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .02\,u^{(v)}$	-18
	$u^{(v)}_{max} = 1.02\,u^{(v)}$ $d^{(v)}_{min} = 0.92\,d^{(v)}$	48
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = 1.08\,d^{(v)}$	-32





Note: Only mutually compensating shifts leave the Z-boson rapidity distributions invariant

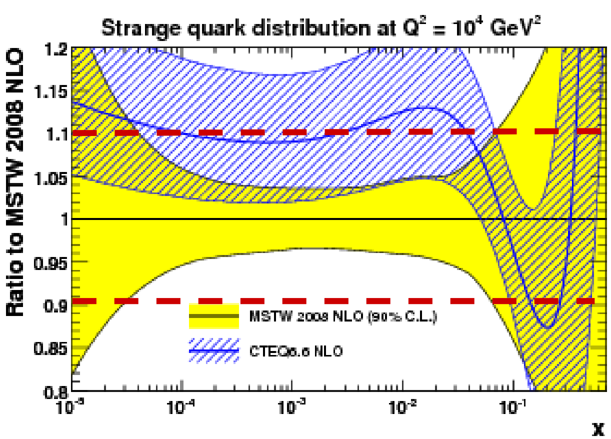
Effect of 2nd quark family

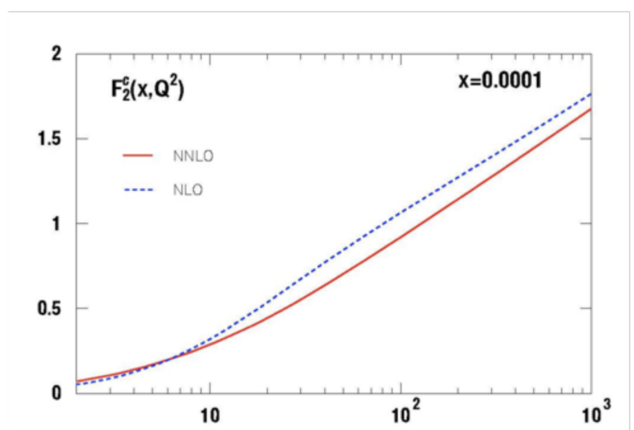
Expected biases in the measured values of M_{W+}-M_{W-}

$s,\ c^{(*)}$	$c_{min} = 0.9\,c,\ s_{max} = s + 0.1\,c$	17.1
	$c_{max} = 1.1\,c,\ s_{min} = s - 0.1\,c$	-10.8
	$c_{min} = 0.8\,c,\ s_{max} = s + 0.2\,c$	38.8
	$c_{max} = 1.2\,c,\ s_{min} = s - 0.2\,c$	-29.0

Expected biases in the measured values of M_W

$s,\ c$	$c_{min} = 0.8\,c,\ s_{max} = s + 0.2\,c$	257
	$c_{max} = 1.2\,c,\ s_{min} = s - 0.2\,c$	-237
	$c_{min} = 0.9\,c,\ s_{max} = s + 0.1\,c$	148
	$c_{max} = 1.1\,c,\ s_{min} = s - 0.1\,c$	-111
	$c_{min} = 0.95\,c,\ s_{max} = s + 0.05\,c$	78
	$c_{max} = 1.05\,c,\ s_{min} = s - 0.05\,c$	-58



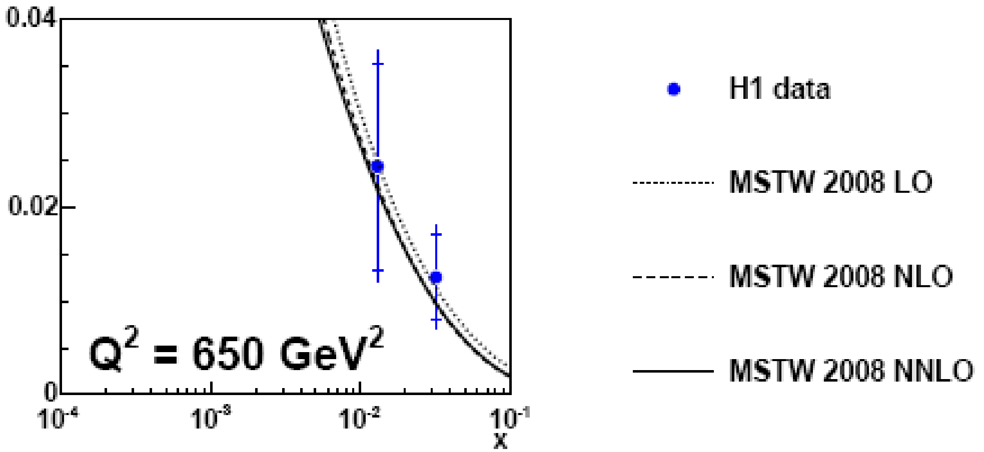


Note: Only mutually compensating shifts leave the Z-boson rapidity distributions invariant

Effect of 3rd quark family

Expected biases in the measured values of M_W

b	$b_{max} = 1.4\,b$	77
	$b_{min} = 0.6\,b$	−56
	$b_{max} = 1.2\,b$	42
	$b_{min} = 0.8\,b$	−39
	$b_{max} = 1.1\,b$	13
	$b_{min} = 0.9\,b$	−12



Note: b-quarks influence the biases when relating the spectra for W bosons to the corresponding ones for Z-bosons

The present precision of M_W cannot be improved by the standard LHC programme

unless…

…"support" programmes are initiated

- Programme 1: the LHC is run with deuteron (He_4) beams (feasible, elegant … but not realistic)

or

- Programme 2: a dedicated high-precision DIS experiment using the CERN-SPS muon beam

Programme 2: DIS experiment

- will submit LoI to the SPSC
- experiment could be done in parallel to collecting the first 10 fb^{-1} of pp collision data at the LHC

Programme 2: DIS experiment

Salient features:

CERN-SPS μ+ beam (e.g., 80 and 160 GeV/c)

2.10^8 μ+ per spill

One year running (2011)

Hydrogen/deuterium target (10 m long)

COMPASS detector

$0.01 < x < 0.8$, $1 < Q^2 < 100$ $(GeV/c)^2$

Measure F_2^n/F_2^p to 0.1%

Programme 2: DIS experiment

Expected biases* in the measured values of M_W

Systematic ξ	Expected precision [%]	ΔM [MeV]
"$\epsilon^+ - \epsilon^-$"	0.2	8
"u_v / d_v"	1 **	12
"$s - c$"	1	10
"b"	20	7 ***

* …at this level of precision other systematic effects, not discussed in this presentation, may become dominant

** …a 1% precision is achievable for this measurement

*** …biases reflecting the uncertainties in the b-quark distributions reduced in a dedicated measurement in the restricted $2.0 < |\eta_{l}| < 2.5$ region

Conclusion

With a **dedicated muon scattering programme**

we can improve at the LHC the present precision of

the W mass, and achieve

$$\Delta\,(M_W) \sim 10\ \text{MeV}$$