Precision electroweak physics at the LHC

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Annecy, 11th of December, 2009

The energy and the precision frontier at the LHC

Present constraints on new (BSM) contact interactions

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{SM}} + \mathcal{O}/\Lambda^2$$

	operator $\mathcal{O}$	affects	present constraint on Λ
	$\frac{1}{2}(\bar{L}\gamma_\mu \tau^a L)^2$	μ-decay	10 TeV
	$\frac{1}{2}(\bar{L}\gamma_\mu L)^2$	LEP 2	5 TeV
T→	$\lvert H^\dagger D_\mu H \rvert^2$	θ_{W} in M_W/M_Z	5 TeV
S→	$(H^\dagger \tau^a H) W^a_{\mu\nu} B_{\mu\nu}$	θ_{W} in Z couplings	8 TeV
	$i(H^\dagger D_\mu \tau^a H)(\bar{L}\gamma_\mu \tau^a L)$	Z couplings	10 TeV
	$i(H^\dagger D_\mu H)(\bar{L}\gamma_\mu L)$	Z couplings	8 TeV
⇒	$H^\dagger(\bar{D}\lambda_D \lambda_U \lambda_U^\dagger \gamma_{\mu\nu} Q) F^{\mu\nu}$	$b \to s\gamma$	5 TeV
⇒	$1/2(\bar{Q}\lambda_U \lambda_U^\dagger \gamma_\mu Q)^2$	B mixing	6 TeV
⇒	$1/2(\bar{Q}\lambda_U \lambda_U^\dagger \gamma_\mu Q)^2$	*K mixing*	6 TeV

<u>The BSM discovery programme at the 10 (14?) TeV collider must be a precision measurements programme…</u>

…. as much as the Standard Model “unitarity-cure” programme:

$$\mathcal{L}_{SM} = -\frac{1}{4}F^{a}_{\mu\nu}F^{a\mu\nu} + i\psi D\psi$$

The gauge sector

$$+\psi_i\lambda_{ij}\psi_j h + h.c.$$

The flavor sector

$$\boxed{+|D_\mu h|^2 - V(h)}$$

The EWSB sector

Challenges:

1. Understanding of the production,propagation, interactions, and decays of polarized electroweak bosons (not discussed in this talk) .

2. Precision measurements of the Standard Model parameters

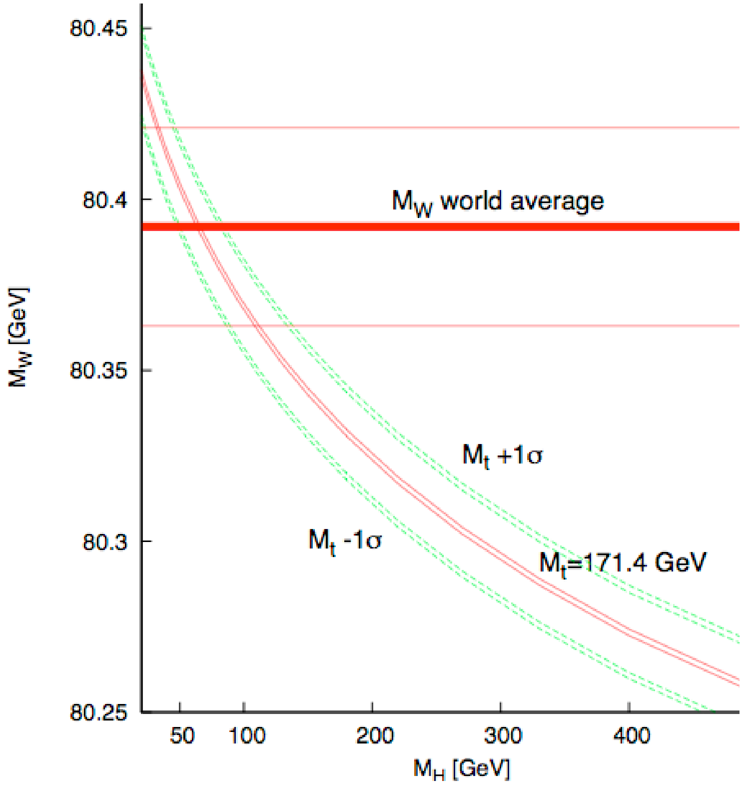
Electroweak Standard Model

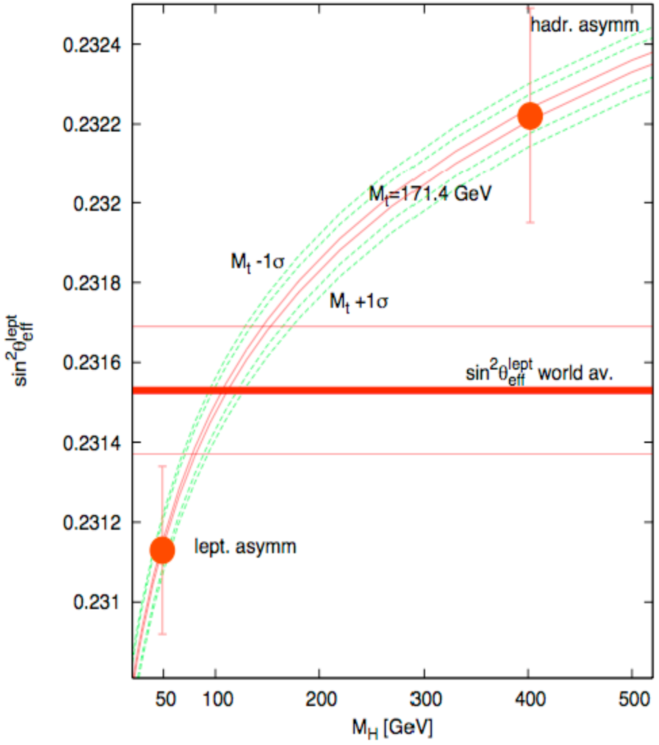
$$\alpha,\ M_Z,\ G_F$$

↓ higgs?, supersymmetry?,…any field theory

$$M_{W,}\ \sin^2(\theta_W),\ \Gamma_{W,}\ldots$$

Precision goals





precision target ~ 10 MeV

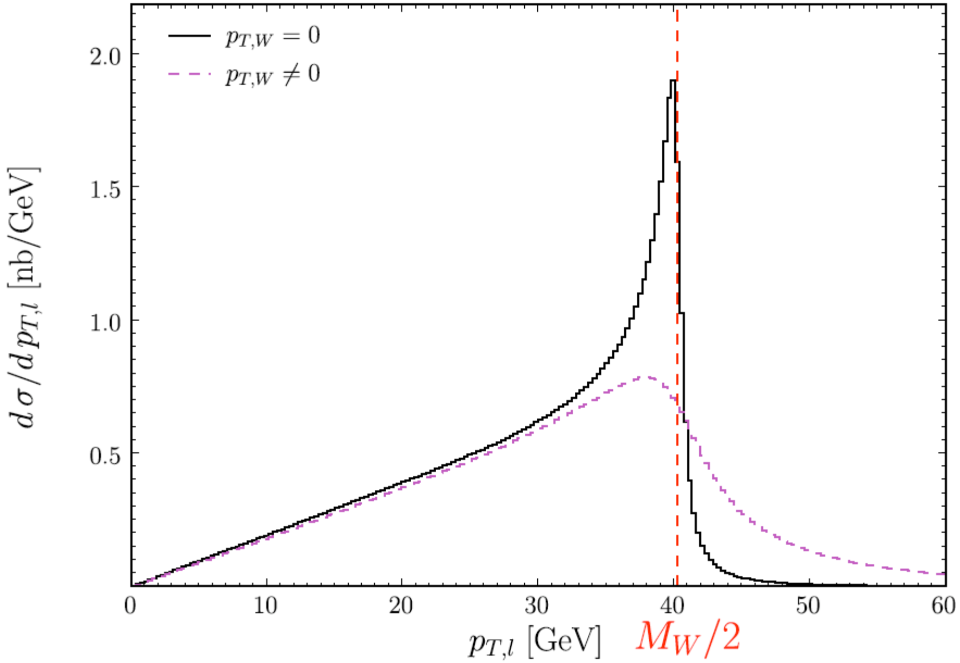
precision target ~ 0.0001

…can we improve the measurement precision of the Standard Model parameters at the LHC?

Official reply of CMS and ATLAS:

YES

M_W and Γ_W and are determined from $p_{t,l}$ distribution…

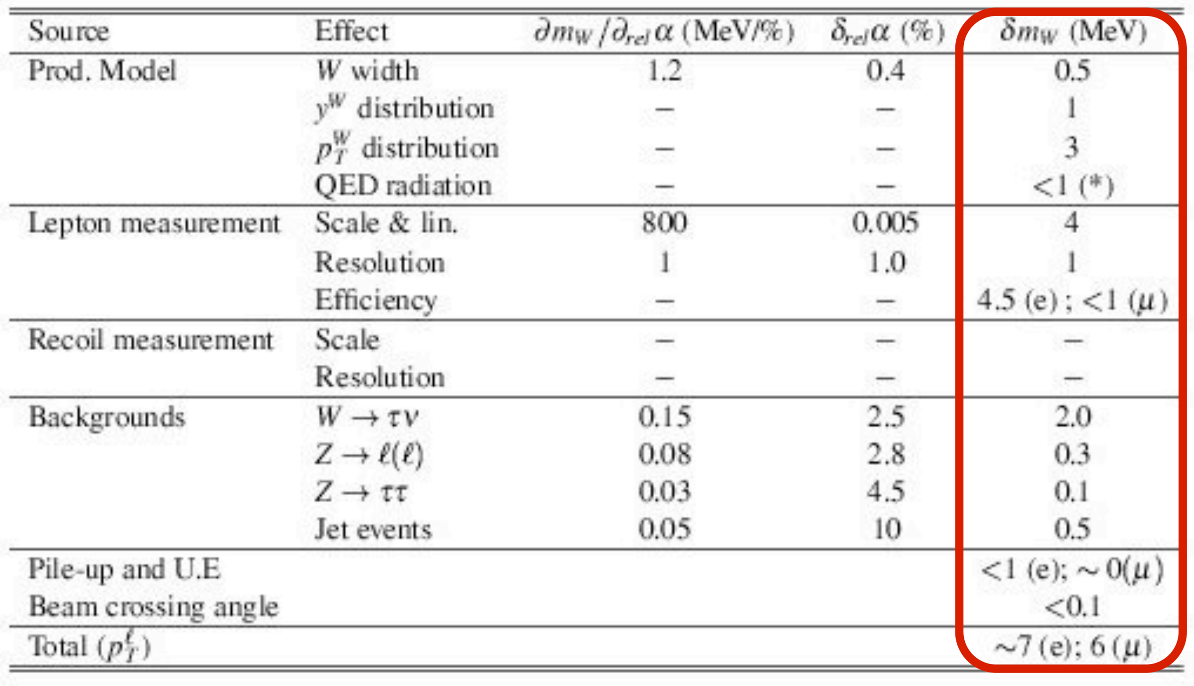


- factor 4000 between 40 GeV and $\Delta(M_W)$ =10 MeV
- utmost care needed to anything that affects $p_{t,l}$

(…those which affect W^+, W^- and Z boson in a different way…)

EXAMPLE:

The M_W measurement at the LHC - perspectives



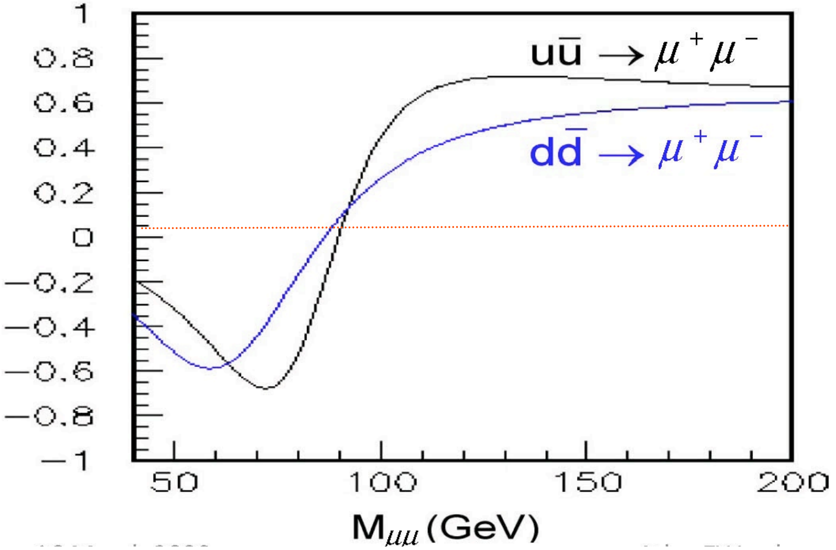
Source	Effect	$\partial m_W/\partial_{rel}\alpha$ (MeV/%)	$\delta_{rel}\alpha$ (%)	δm_W (MeV)
Prod. Model	W width	1.2	0.4	0.5
	y^W distribution	–	–	1
	p_T^W distribution	–	–	3
	QED radiation	–	–	<1 (*)
Lepton measurement	Scale & lin.	800	0.005	4
	Resolution	1	1.0	1
	Efficiency	–	–	4.5 (e) ; <1 (μ)
Recoil 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)

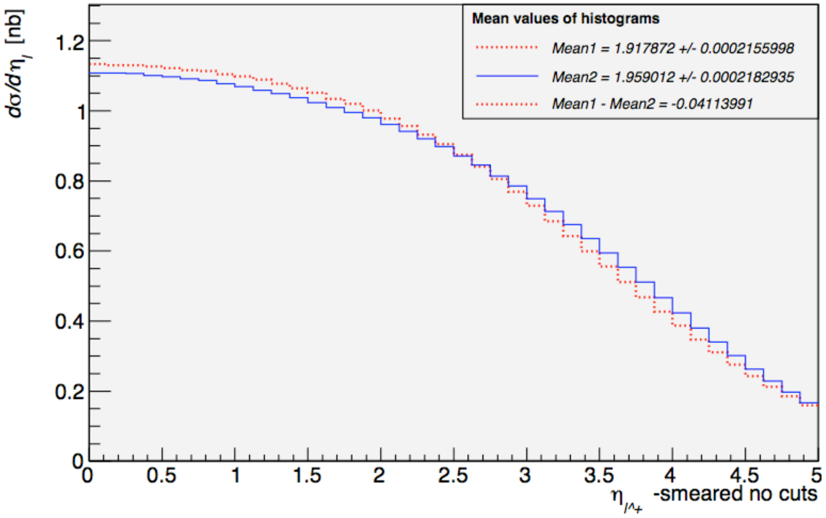
contribution to the Philadelphia ICHEP 2008 and EPS 2009 conference

$\sin^2(\theta_W)$ is determined from forward-backward asymmetry of positive and negative leptons…

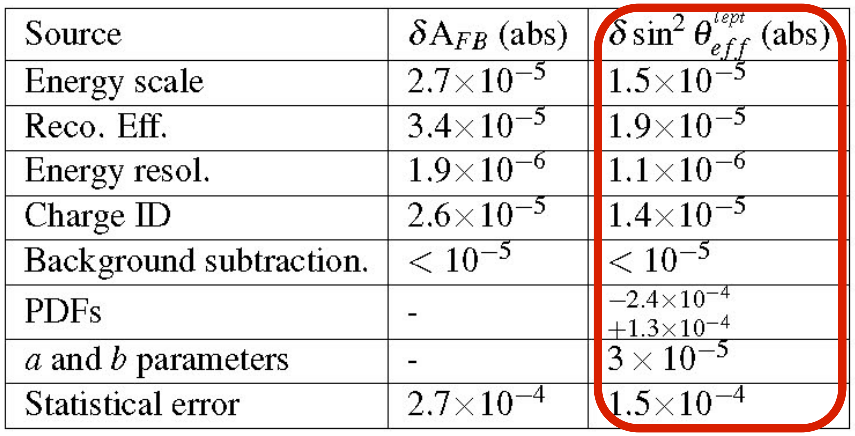
$$A_{\mathrm{FB}} = \frac{3}{4}\frac{-2q_{\mathrm{q}}a_{\mathrm{q}}a_{\ell}\,\mathrm{Re}(\chi) + 2v_{\mathrm{q}}a_{\mathrm{q}}\,2v_{\ell}a_{\ell}\,|\chi|^2}{q_{\mathrm{q}}^2 - 2q_{\mathrm{q}}v_{\mathrm{q}}v_{\ell}\,\mathrm{Re}(\chi) + \left(v_{\mathrm{q}}^2 + a_{\mathrm{q}}^2\right)\left(v_{\ell}^2 + a_{\ell}^2\right)|\chi|^2}; \qquad \chi(\hat{s}) = \frac{\sqrt{2}G_{\mathrm{F}}}{16\pi\alpha}\frac{\hat{s}M_{\mathrm{Z}}^2}{\hat{s} - M_{\mathrm{Z}}^2 + i\hat{s}\Gamma_{\mathrm{Z}}/M_{\mathrm{Z}}}$$

$$a_{\mathrm{f}} = 2I_3^{\mathrm{f}}; \qquad v_{\mathrm{f}} = 2I_3^{\mathrm{f}} - 4q_{\mathrm{f}}\sin^2\theta_W; \qquad \mathrm{f} = \mathrm{q}, \ell$$





The $\sin^2(\theta_W)$ measurement at the LHC - perspectives



Source	δA_{FB} (abs)	$\delta \sin^2 \theta_{eff}^{lept}$ (abs)
Energy scale	2.7×10^{-5}	1.5×10^{-5}
Reco. Eff.	3.4×10^{-5}	1.9×10^{-5}
Energy resol.	1.9×10^{-6}	1.1×10^{-6}
Charge ID	2.6×10^{-5}	1.4×10^{-5}
Background subtraction.	$< 10^{-5}$	$< 10^{-5}$
PDFs	-	-2.4×10^{-4} $+1.3\times10^{-4}$
a and b parameters	-	3×10^{-5}
Statistical error	2.7×10^{-4}	1.5×10^{-4}

Table 4: Summary of the systematic and statistical uncertainties on A_{FB} and $\sin^2 \theta_{eff}^{lept}$ for events with at least one electron in the central region (C-F). The uncertainty on $\sin^2 \theta_{eff}^{lept}$ is determined using Eqs. 11 and a and b parameters from figure 21.

CERN-OPEN-2008-020 December 2008

BUT…

…at the LHC we collide pp

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

Symmetry relations not at work!

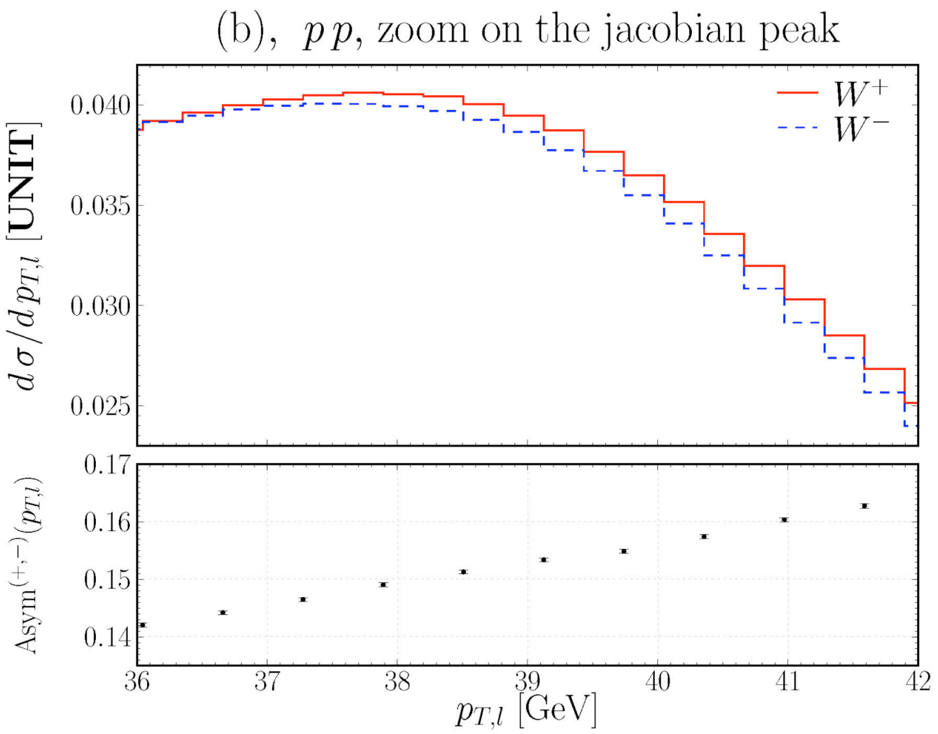
(need to understand the charge and polarization asymmetries in W and Z production)

…also:

Collisions at much higher energy!

(need to understand heavy flavours with much better precision)

Charge asymmetries


(b), $p\,p$, zoom on the jacobian peak

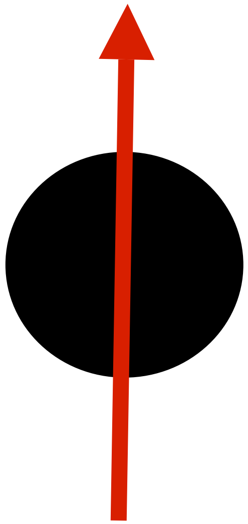
relative shifts of peak position estimated using a parabola fit in the range:

$37\ \mathrm{GeV} < p_{T,l} < 40\ \mathrm{GeV}$

phase space domain	$\varpi_+ - \varpi_-$ [MeV]
Inclusive	170
$\lvert y_W \rvert < 0.3$	-100
$\lvert \eta_l \rvert < 0.3$	-240
$3.5 < \lvert y_W \rvert < 4.5$	300
$3.5 < \lvert \eta_l \rvert < 4.5$	2000

($M_{W+} - M_{W-}$ biases at the level of ~(200 - 4000) MeV …at the Tevatron 0 MeV)

$W^+ \rightarrow l^+ \nu$

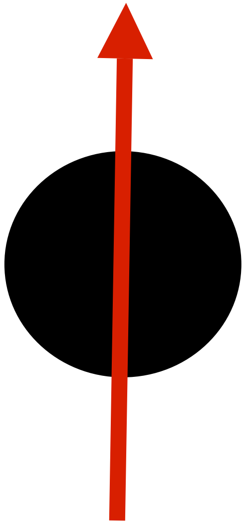


- θ = lepton emission angle w.r.t. spin vector

- $W(\theta) = 1 + \cos(\theta)$

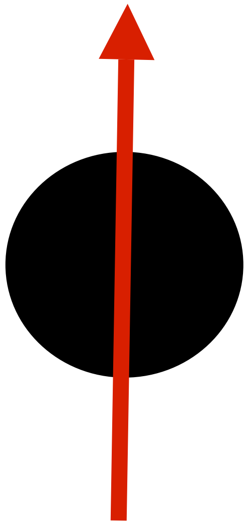
- reflects V-A coupling

$W^- \longrightarrow l^- \nu$



- $W(\theta) = 1 - \cos(\theta)$

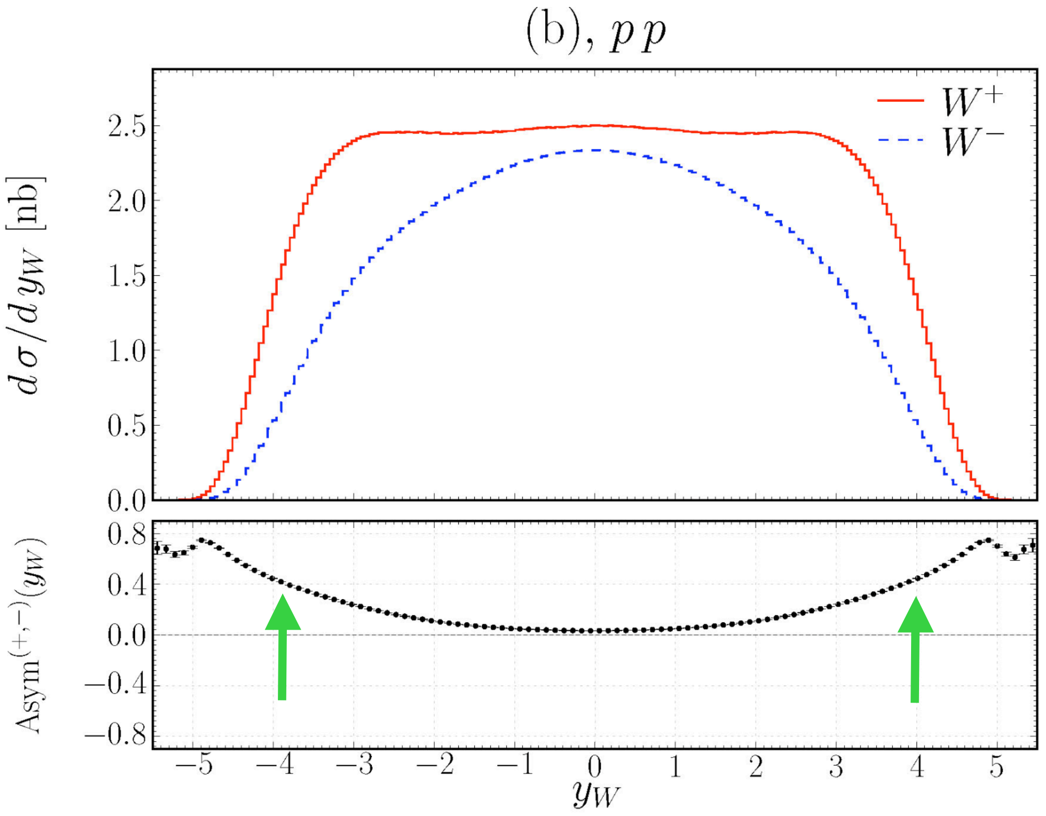
$Z \rightarrow l^+l^-$



- $W(\theta) = \alpha + \beta \cos(\theta)$
- reflects mixture of V-A and V+A coupling

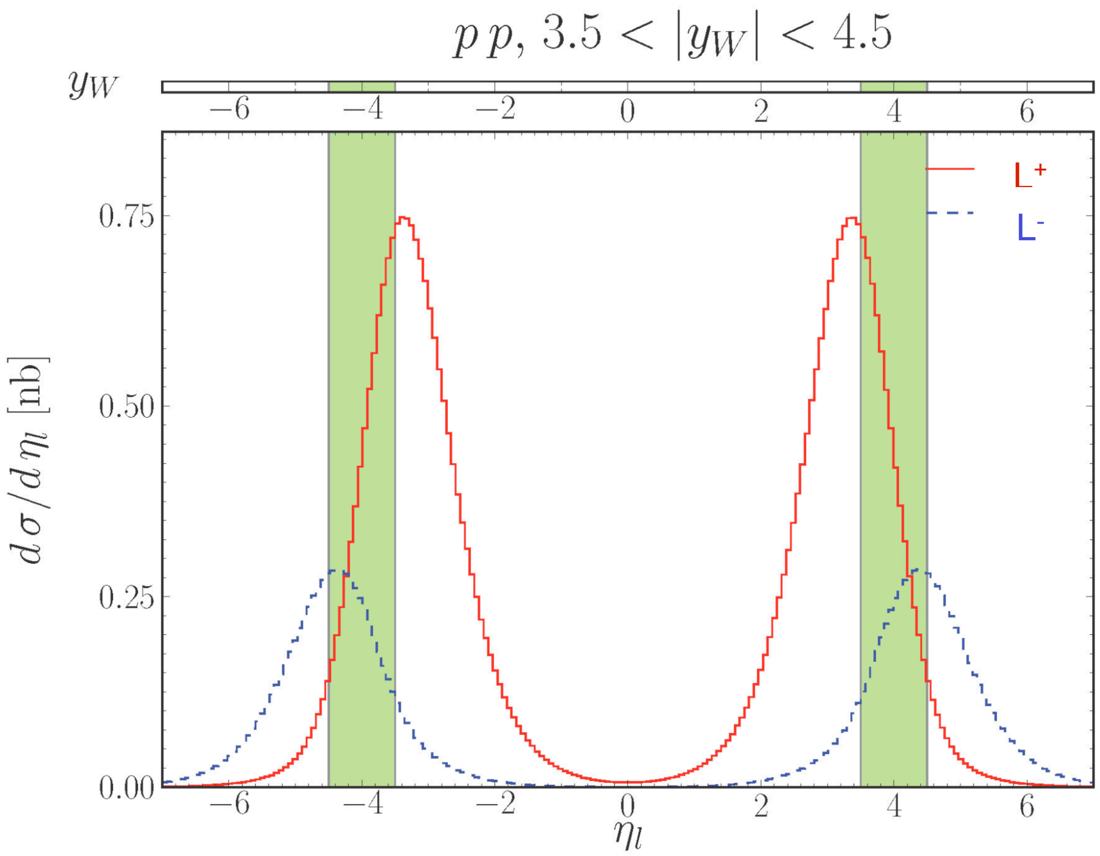
At the Tevatron symmetry relations at work: $N_{W+} = N_{W-}$ and lepton angular distribution for Z *almost the same as for* $W^+ + W^-$

W production and decay
pp collisions



Note: $N_{W+} > N_{W-}$

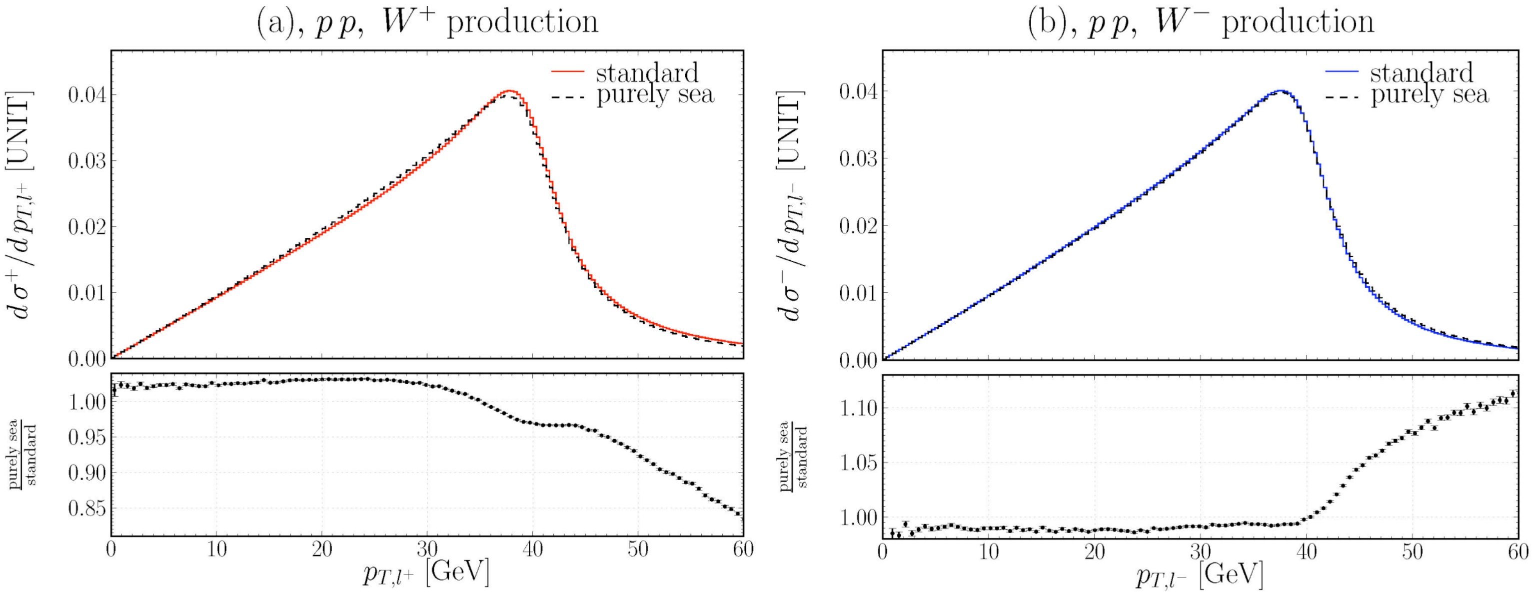
W production and decay
pp collisions



Note: opposite migration direction for l^+ and l^-

The asymmetry between W^+ and W^- in pp collisions is driven by the asymmetry between quarks and antiquarks in the proton, generated by the valence quarks.

Example: Valence quark effects in W mass measurement

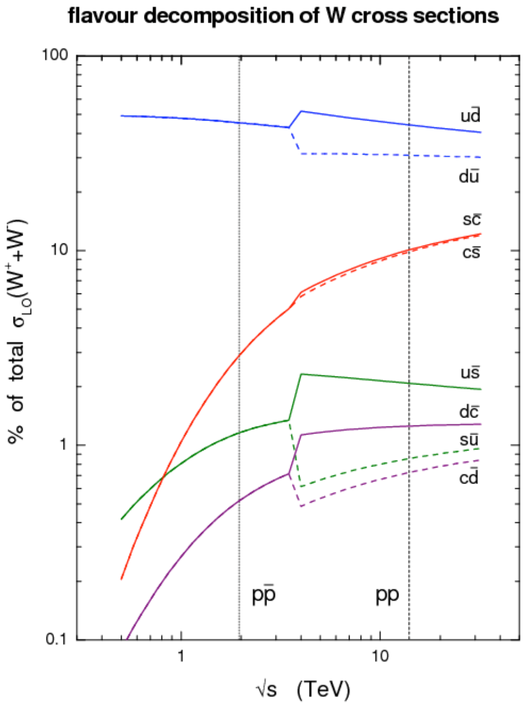


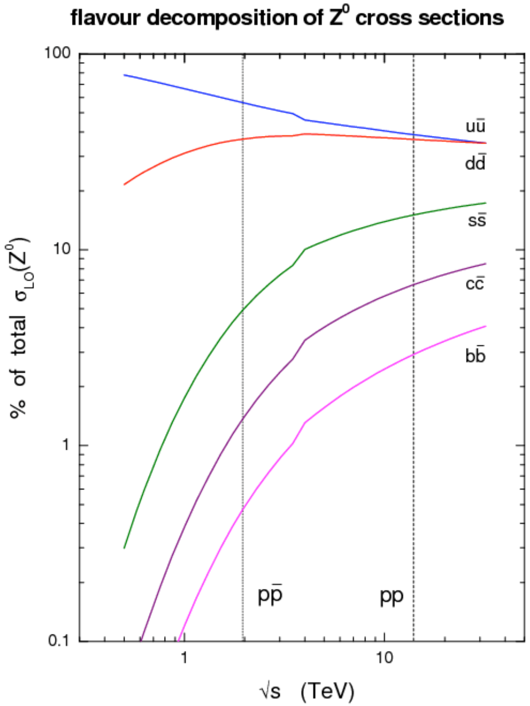
estimated shifts of the peak position due to polarisation effects

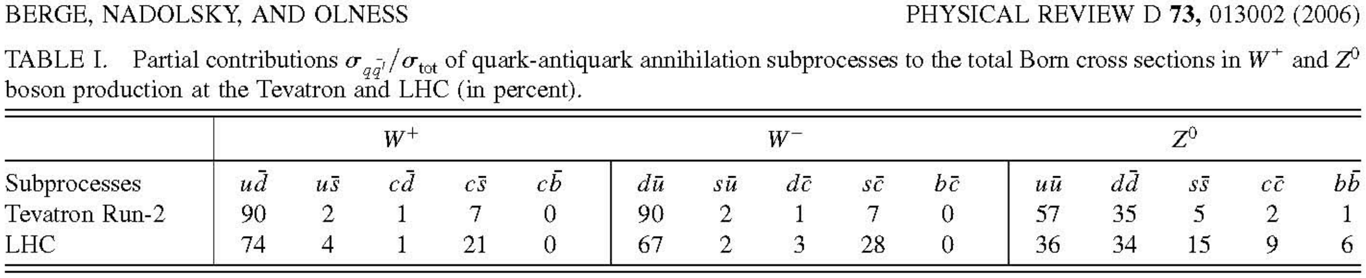
Fit range	Channel	$\varpi_{\text{standard}} - \varpi_{\text{sea}}$ [MeV]
$37\,\text{GeV} < p_{T,l} < 52\,\text{GeV}$	W^+	178.0
	W^-	−23.8

(M_W biases at the level of ~400 MeV …at the Tevatron 0 MeV)

Flavour asymmetries







BERGE, NADOLSKY, AND OLNESS PHYSICAL REVIEW D **73,** 013002 (2006)

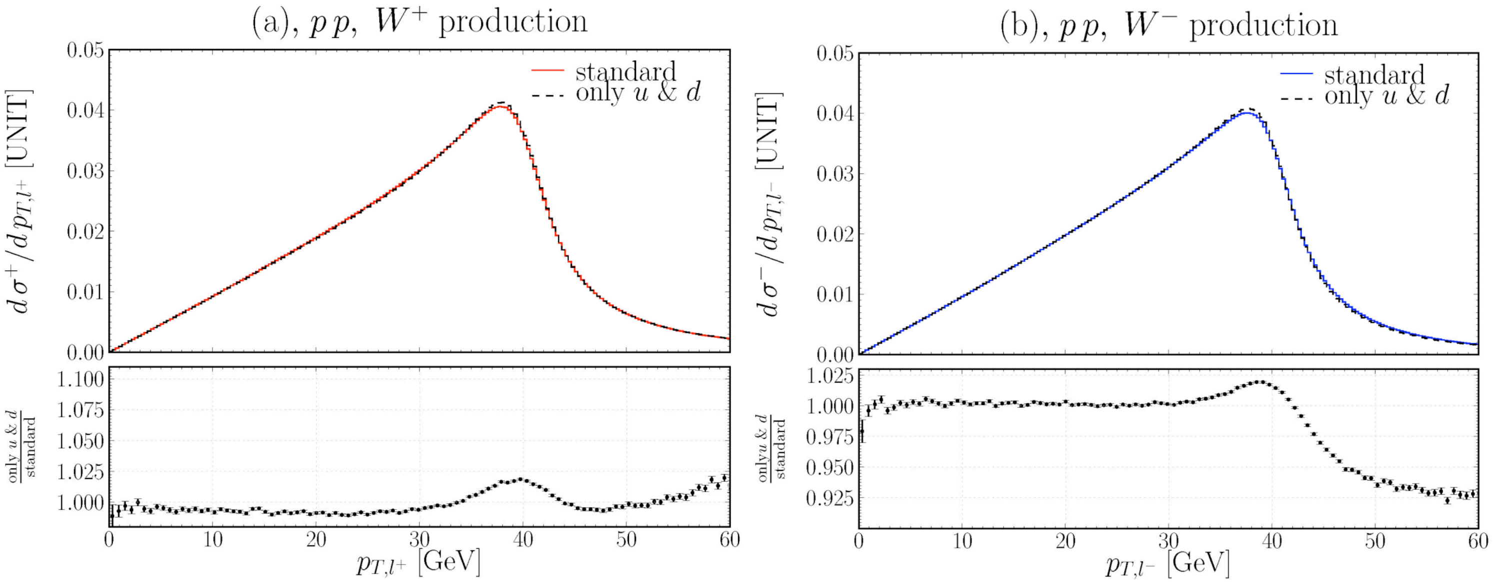
TABLE I. Partial contributions $\sigma_{q\bar{q}'}/\sigma_{\text{tot}}$ of quark-antiquark annihilation subprocesses to the total Born cross sections in W^+ and Z^0 boson production at the Tevatron and LHC (in percent).

	W^+					W^-					Z^0				
Subprocesses	$u\bar{d}$	$u\bar{s}$	$c\bar{d}$	$c\bar{s}$	$c\bar{b}$	$d\bar{u}$	$s\bar{u}$	$d\bar{c}$	$s\bar{c}$	$b\bar{c}$	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$
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

Heavy flavour effects are driven by the asymmetries in the momentum distribution of heavy and light quarks - reflecting asymmetries in quark masses

(at the LHC the heavy quark effects are no longer small and must be experimentally controlled)

Example: Heavy flavour effects in W mass measurement



estimated shifts of the peak position due to the presence of heavy quarks in the Wide Band Partonic Beam (WBPB)

Fit range	Channel	$\varpi_{\text{standard}} - \varpi_{\text{only } u,d}$ [MeV]
$37\,\text{GeV} < p_{T,l} < 52\,\text{GeV}$	W^+	-69.9
	W^-	-59.2

(M_W biases at the level of ~150 MeV …at the Tevatron <30 MeV)

- 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 pdf’s
different couplings
different k_T’s
different masses

As a consequence, at the LHC:

- different $p_{T,W+}$, $p_{T,W-}$, and $p_{T,Z,}$ spectra
- different polarizations
- different $p_{T,l}$ spectra

Common root of the problems at the LHC:

Interplay of the charge, polarization and flavour effects

- In all LHC studies ignored so far
- Improving the precision of the SM parameters at the LHC is not realistic unless…

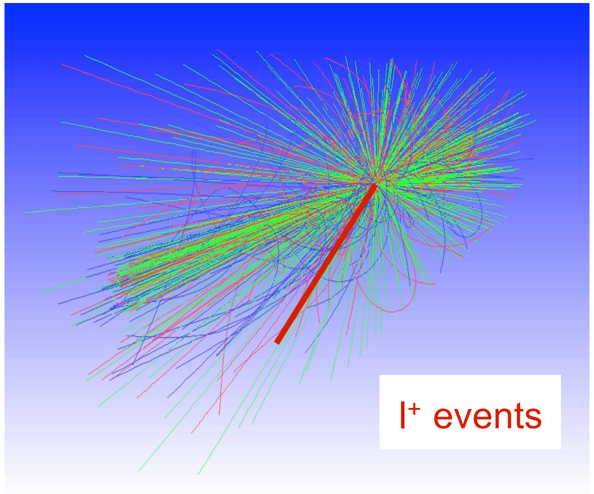
… dedicated LHC-specific measurement methods are developed…

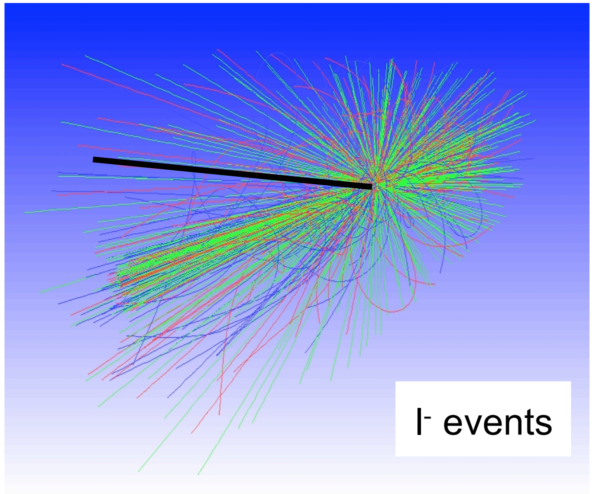
the rest of my talk will be devoted to the presentation of a global, LHC-dedicated strategy to measure the standard model parameters…

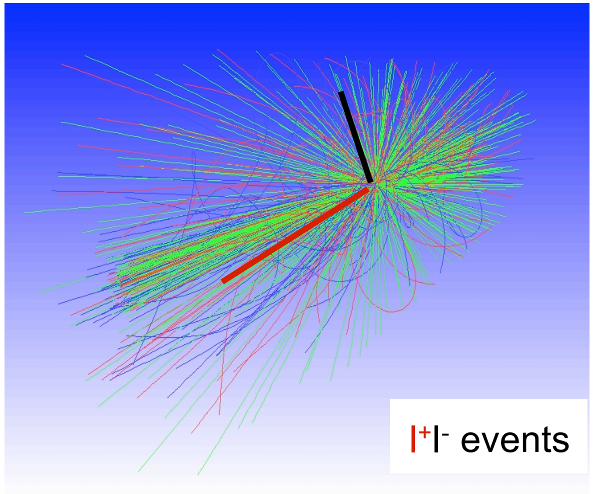
The measurement and the tools for its simulation

- Apparatus: The ATLAS detector
- Luminosity: 10 fb $^{-1}$
- Trigger and Acceptance cuts: $p_{T,l} > 20$ GeV/c, $|\eta_l| < 2.5$
- Dedicated event generators: WINHAC/ZINHAC (spin amplitudes)
- Simulation: parameterized response of the ATLAS detector
- Challenge: study based on O(10^{10}) simulated events
- The team: F. Fayette (PhD- 2009) now in Univ. Goetingen, W. Placzek, K. Rejzner (master-2009) now in Univ. Hamburg, A. Siodmok (PhD-2009) now in Univ. Karlsruhe, M.W. Krasny
  - IN2P3-COPIN cooperation program 05-116

Observables

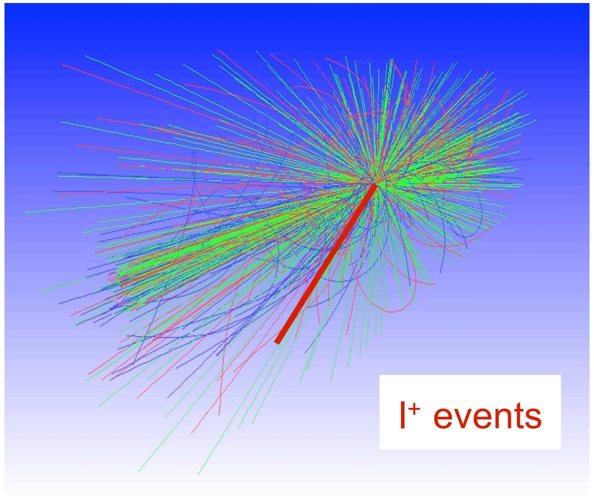




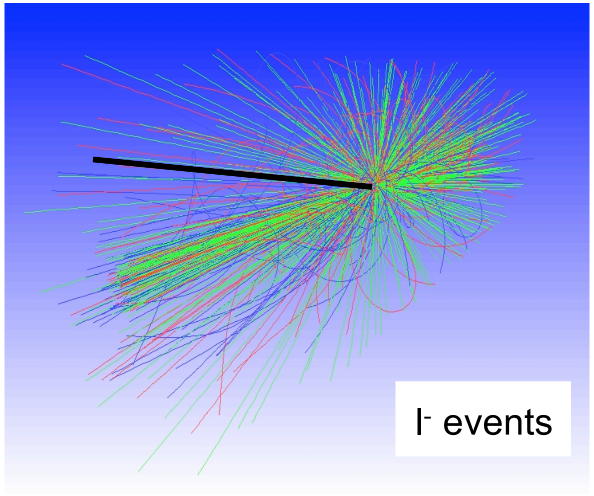


- $O_{W^+}(p_{T,l}, \eta_l) = \frac{d^2\sigma}{dp_{T,l^+} d\eta_{l^+}}(\text{“}l^+ \text{ events”}),$
- $O_{W^-}(p_{T,l}, \eta_l) = \frac{d^2\sigma}{dp_{T,l^-} d\eta_{l^-}}(\text{“}l^- \text{ events”}),$
- $O_{Z/\gamma}(M_{ll}, p_{T,ll}, y_{ll}) = \frac{d^3\sigma}{dM_{ll} dp_{T,ll} dy_{ll}}(\text{“}l^+l^- \text{ events”}),$
- $O_{(Z/\gamma)^+}(M_{ll}, p_{T,ll}, y_{ll}, p_{T,l}, \eta_l) = \frac{d^5\sigma}{dM_{ll} dp_{T,ll} dy_{ll} dp_{T,l^+} d\eta_{l^+}}(\text{“}l^+l^- \text{ events”}),$
- $O_{(Z/\gamma)^-}(M_{ll}, p_{T,ll}, y_{ll}, p_{T,l}, \eta_l) = \frac{d^5\sigma}{dM_{ll} dp_{T,ll} dy_{ll} dp_{T,l^-} d\eta_{l^-}}(\text{“}l^+l^- \text{ events”}).$

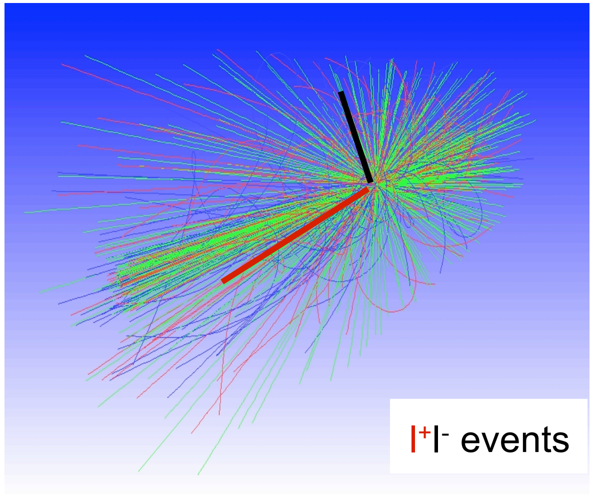
…and their interpretation



l^+ events



l^- events



l^+l^- events

- $O_{W^+} = T_{W^+}(\epsilon_{l^+}, u, d, s, c, \bar{u}, \bar{d}, \bar{s}, \bar{c}, M_{W^+}, \Gamma_{W^+}),$
- $O_{W^-} = T_{W^-}(\epsilon_{l^-}, u, d, s, c, \bar{u}, \bar{d}, \bar{s}, \bar{c}, M_{W^-}, \Gamma_{W^-}),$
- $O_{Z/\gamma} = T_{Z/\gamma}(\epsilon_{l^-}, \epsilon_{l^+}, u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}, M_Z, \Gamma_Z, sin^2(\theta_W), \alpha_{EM}),$
- $O_{(Z/\gamma)^+} = T_{(Z/\gamma)^+}(\epsilon_{l^+}, u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}, M_Z, \Gamma_Z, sin^2(\theta_W), \alpha_{EM}),$
- $O_{(Z/\gamma)^-} = T_{(Z/\gamma)^-}(\epsilon_{l^+}, u, d, s, c, b, \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}, M_Z, \Gamma_Z, sin^2(\theta_W), \alpha_{EM}).$

ε -calibration scale of lepton momentum, **k_t** -unintegrated partonic distributions: $q(x,k_t,M_{scale})$, parameters of the Standard Model

Precision observables

1.
$$\mathrm{Asym}_W^{(+,-)}(p_{T,l},\eta_l)=\frac{O_{W^+}(p_{T,l},\eta_l)-O_{W^-}(p_{T,l},\eta_l)}{O_{W^+}(p_{T,l},\eta_l)+O_{W^-}(p_{T,l},\eta_l)},$$

→ sensitive to M_{W+}- M_{W-} and Γ_{W+} - Γ_{W-}

2.
$$\mathrm{Asym}_Z^{(+,-)}(y_{ll},p_{T,ll},p_{T,l},\eta_l)=\frac{O_{Z^+}(y_{ll},p_{T,ll},p_{T,l},\eta_l)-O_{Z^-}(y_{ll},p_{T,ll},p_{T,l},\eta_l)}{O_{Z^+}(y_{ll},p_{T,ll},p_{T,l},\eta_l)+O_{Z^-}(y_{ll},p_{T,ll},p_{T,l},\eta_l)},$$

→ sensitive to $\sin^2(\theta_W)$

3.
$$\boxed{\mathrm{R}_{WZ}(p_{T,l},\eta_l)=\frac{O_{W^+}(p_{T,l},\eta_l)+O_{W^-}(p_{T,l},\eta_l)}{O_{Z^+}(p_{T,l},\eta_l)+O_{Z^-}(p_{T,l},\eta_l)},}$$

→ sensitive to α_s, M_{W+}+ M_{W-}, and Γ_{W+} + Γ_{W-}

4.
$$\mathrm{R}_Z^{norm}(p_{T,ll},y_{ll})=\frac{O_Z(p_{T,ll},y_{ll})}{O_{l^+l^-}^{norm}},$$

$$O_Z(p_{T,ll},y_{ll})=\int^{M_Z+3\Gamma_Z}O_{(Z/\gamma)}(M_{ll},p_{T,ll},y_{ll})dM_{ll},$$

$$O_{Z^{+(-)}}(y_{ll},p_{T,ll},p_{T,l},\eta_l)\;=\;\int_{M_Z-3\Gamma_Z}^{M_Z+3\Gamma_Z}\left[O_{(Z/\gamma)^{+(-)}}(M_{ll},y_{ll},p_{T,ll},p_{T,l},\eta_l)\right]dM_{ll}\,,$$

→ only Z-peak masses

$$O_{l^+l^-}^{norm}=\int\int\int O_{Z/\gamma}(M_{ll},y_{ll},p_{T,ll})dM_{ll}dy_{ll}dp_{T,ll}.$$

→ coplanar pairs - dedicated method of absolute normalization developed in parallel M.W. Krasny et al. NIM papers

Making Z-boson (QCD)-identical to W-boson

1. Collect data at the two CM-energies: $\sqrt{s_1}$ and $\sqrt{s_2} = (M_Z/M_W) \times \sqrt{s_1}$. These two settings allow to keep the momentum fractions of the partons producing the Z and W-bosons equal if the W-boson sample is collected at the CM-energy $\sqrt{s_1}$ and the Z-boson sample at the CM-energy $\sqrt{s_2}$.
2. Rescale the solenoid current while running at the two CM-energies $\sqrt{s_1}$ and $\sqrt{s_2}$ by a factor $i_2/i_1 = M_Z/M_W$ to equalize the distribution of the curvature radius ρ_l for charged leptons originating from the decays of the Z and W-bosons.
3. Redefine the RWZ observable as follows:

$$\mathrm{R}^c_{WZ}(\rho_l, \eta_l) = \frac{O_{W^+}(\rho_l, \eta_l; s_1, i(s_1)) + O_{W^-}(\rho_l, \eta_l; s_1, i(s_1))}{O_{Z^+}(\rho_l, \eta_l; s_2, i(s_2)) + O_{Z^-}(\rho_l, \eta_l; s_2, i(s_2))}, \qquad (9)$$

The remaining scale dependence of this observable is eliminated by modifying further the above observable :

$$\mathrm{R}^c_{WZ}(\rho_l, \eta_l) = \mathrm{R}^c_{WZ}(\rho_l, \eta_l) * \mathrm{C}_{\mathrm{QCD}}$$

Making Z boson “QCD-identical” to W boson

1. *Select events with opposite charge, same flavour lepton pairs*
2. *Determine the invariant mass of lepton par* M^{l+l-}
3. *Measure the QCD correction factor* C_{QCD} *defined as:*

$$C_{QCD} = \frac{\int_{M_Z-3\Gamma_Z}^{M_Z+3\Gamma_Z} N^{l+l-}(s_2, i(s_2), M^{l+l-})\, dM^{l+l-}}{\int_{M_W-3\Gamma_W}^{M_W+3\Gamma_W} \boxed{f_{BW}(M_W, \Gamma_W)} \times \boxed{w_{EW}} \times N^{l+l-}(s_1, i(s_1), M^{l+l-})\, dM^{l+l-}}$$

Breit-Wigner weight

Electroweak weight correcting for asymmetries of angular distribution of leptons in the continuum and Z-peak region

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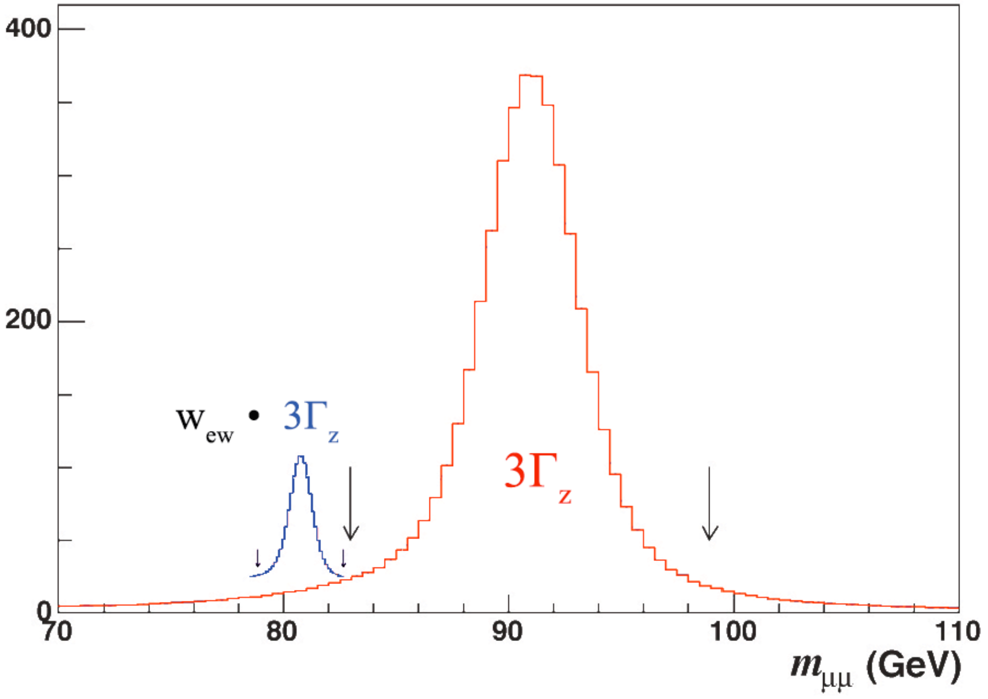
The scale dependence in the partonic distributions is eliminated - up to all orders of perturbative expansion !!! QCD- “eliminated” from the unfolding !!!

Making Z boson “QCD-identical” to W boson



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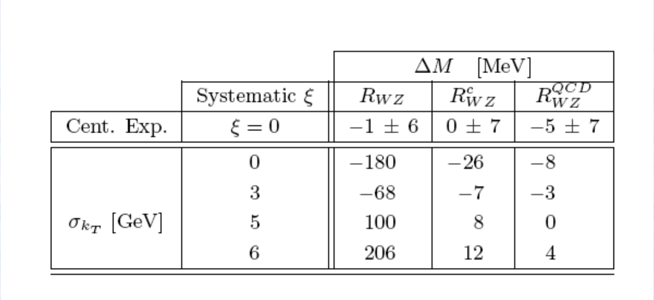


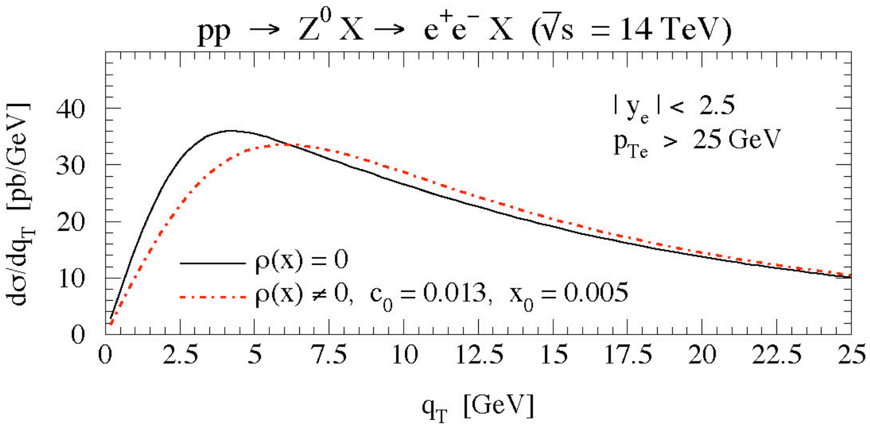
		ΔM [MeV]		
	Systematic ξ	R_{WZ}	R^c_{WZ}	R^{QCD}_{WZ}
Cent. Exp.	$\xi = 0$	-1 ± 6	0 ± 7	-5 ± 7
σ_{k_T} [GeV]	0	−180	−26	−8
	3	−68	−7	−3
	5	100	8	0
	6	206	12	4

QCD world of quark and gluons

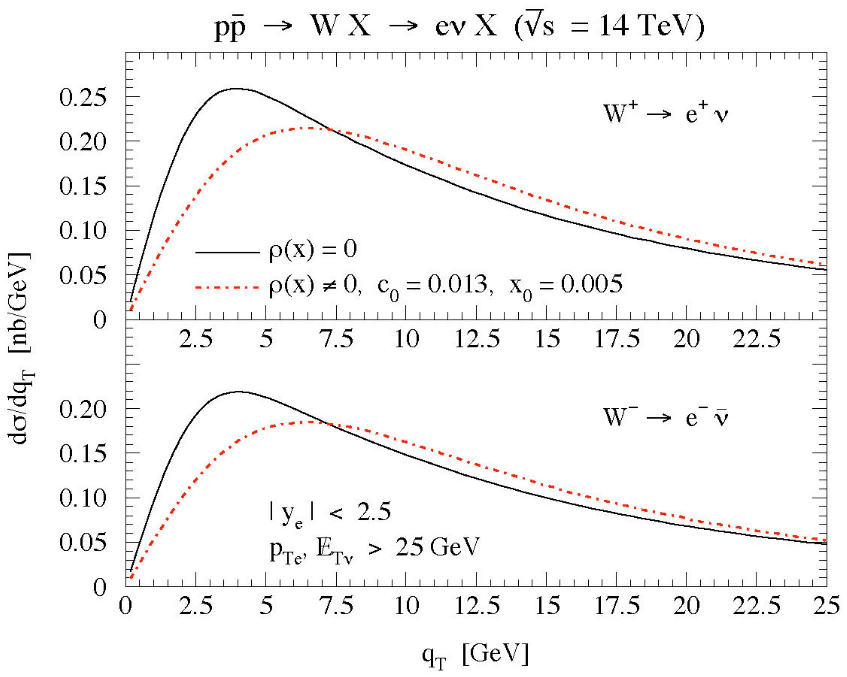
Observed with $1/M_Z$ resolution

Observed with $1/M_W$ resolution

Making Z boson “QCD-identical” to W boson



S. Berge, et al., hep-ph/0410375.



- The relationship between the transverse momentum distributions of the Z-bosons and the W-bosons cannot be predicted and must be modelled. It involves a choice of: (1) the evolution scheme (DGLAP, BFKL, CCFM,…), (2) the parameters of the nonperturabative Sudakov form factors, (3) primordial k_T modelling
- The discussed above trick allows to get rid of all the flavour singlet aspects of modelling these distributions

… counting unknown partonic distributions

$q_i(x,k_t,M_{scale})$

5 flavours x 2 (q and $\bar{q}$) x 2 (scale) = 20

The QCD scale degrees of freedom circumvented …

$$q_i(x,k_t,M_{scale}) \longrightarrow q_i(x,k_t)$$

… unfolding confined to the polarization and flavour sectors: 10 unknown partonic distributions

Unfolding k_t-depndence of $q_i(x,k_t)$

Anzatz:

1. $k_t^{quark}(x) = k_t^{antiquark}(x)$

(transverse momentum generated by gluon radiation (high energy limit))

2. $k_t^{u}(x) = k_t^{d}(x) = k_t^{s}(x)$

(m_u, m_d, m_s >> Λ_{QCD})

Remaining unknowns:

$$k_t^{u,d,s}(x),\ \ k_t^{c}(x),\ \ k_t^{b}(x)$$

They can be unfolded using observables 1(or 2), 3 and 4 provided that the x dependence of the quark distributions is known (the PDFs: q_i(x, M_W)= $q_i(x)$)

Unconstrained PDF degrees of freedom at the LHC

Assume for a while: $s(x)=\bar{s}(x)$, $c(x)=\bar{c}(x)$, $b(x)=\bar{b}(x)$ 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 observables (1-4)

A choice of 3 unconstrained degrees of freedom:

1. $u^{(v)}$ - $d^{(v)}$ - a missing constraint for the 1st family
2. s - c - a missing constraint for the 2nd family
3. b - a missing constraint for the 3rd family

Note:

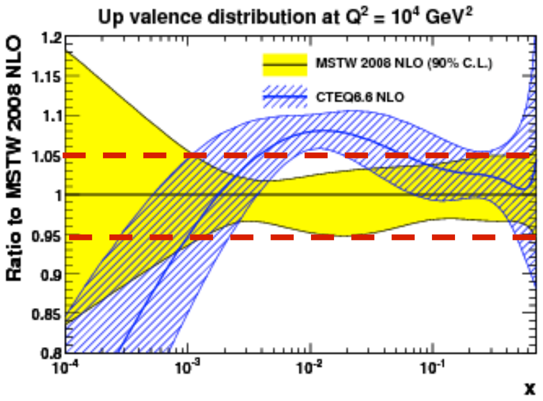
- $u^{(v)}$ can move up and $d^{(v)}$ move down such that the rapidity distribution of Z-boson remain unchanged, the same for s and c
- The non-singlet partonic distributions have only small scale dependence (they are robust with respect to the choice: (1) of QCD evolution scheme and (2) of order of perturbative expansion

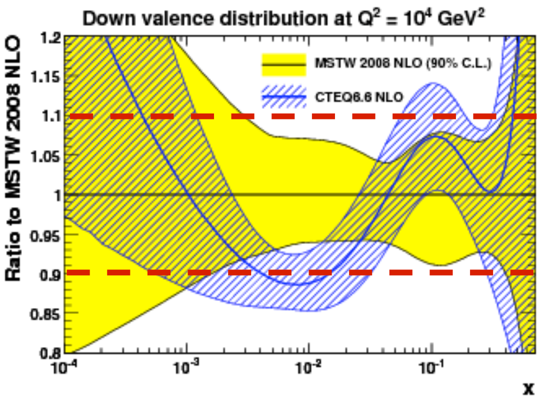
Can we constrain the PDFs using W and Z boson data collected at the LHC?

…No, we cannot. External constraints are needed. Is the precision of existing constraints sufficient?

Present precision of: “$u^{(v)}$ - $d^{(v)}$” PDF and its impact on the M_W measurement error

	$\Delta[(M_{W^+} + M_{W^-})/2]$	$\Delta[(M_{W^+} - M_{W^-})]$
$u_v^{bias} = 1.05\ u_v$ $d_v^{bias} = d_v - 0.05\ u_v$	79 MeV	115 MeV
$u_v^{bias} = 0.95\ u_v$ $d_v^{bias} = d_v + 0.05\ u_v$	−64 MeV	−139 MeV

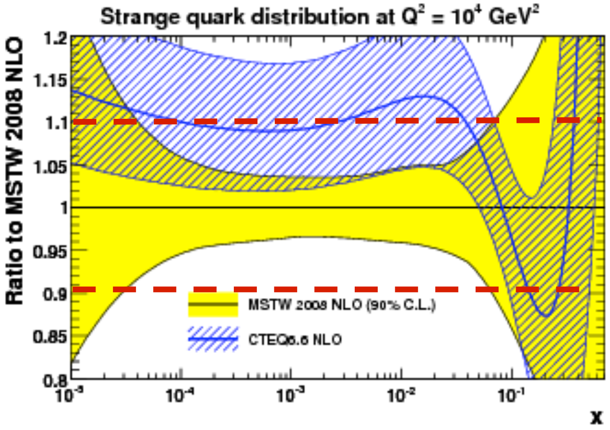


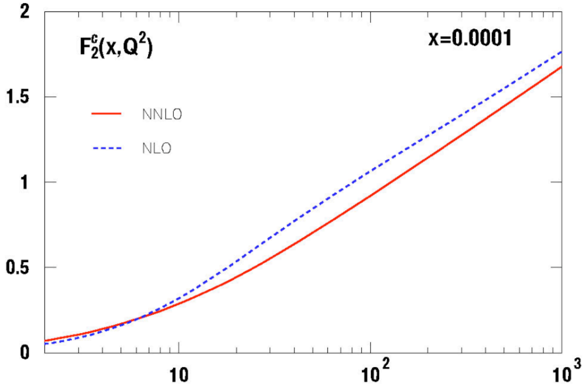


Note: Only mutually compensating shifts leave the Z-boson rapidity distributions invariant

Present precision of: "s - c" PDF and its impact on the M_W measurement error

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

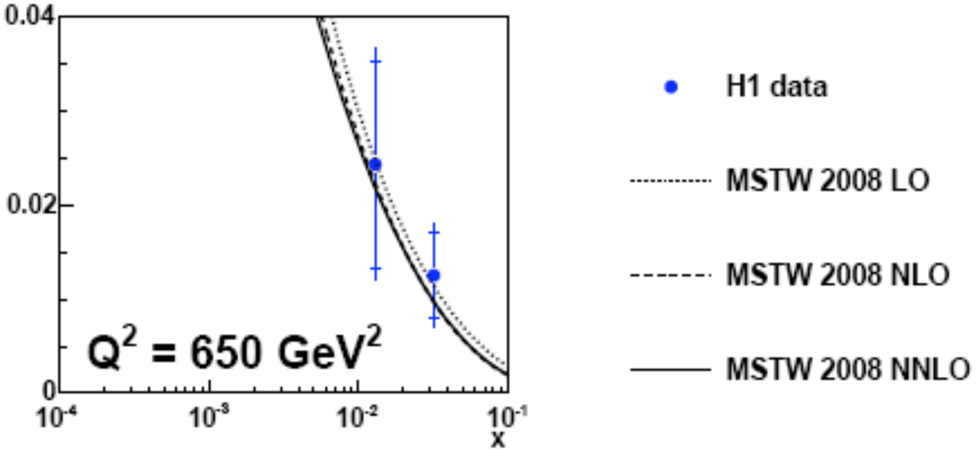




<u>Note:</u> Only mutually compensating shifts leave the Z-boson rapidity distributions invariant

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

	$\Delta[(M_{W+} + M_{W-})/2]$
$b^{bias} = 1.2\ b$	42 MeV
$b^{bias} = 0.8\ b$	−39 MeV



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

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

(…similar conclusion for $\sin^2(\theta_W)$ and Γ_W)

…neither now nor at the completion phase of the standard LHC programme…

The way forward

- A dedicated “precision-support” programme auxiliary to the standard LHC

- Note that neither the TJNAF programme (too low energy) nor the HERA programme (lack of deuteron data, too low statistics for CC processes, small statistics and large acceptance corrections for heavy quark sector) will improve the present experimental information

Programme 1: Isoscalar beams at the LHC

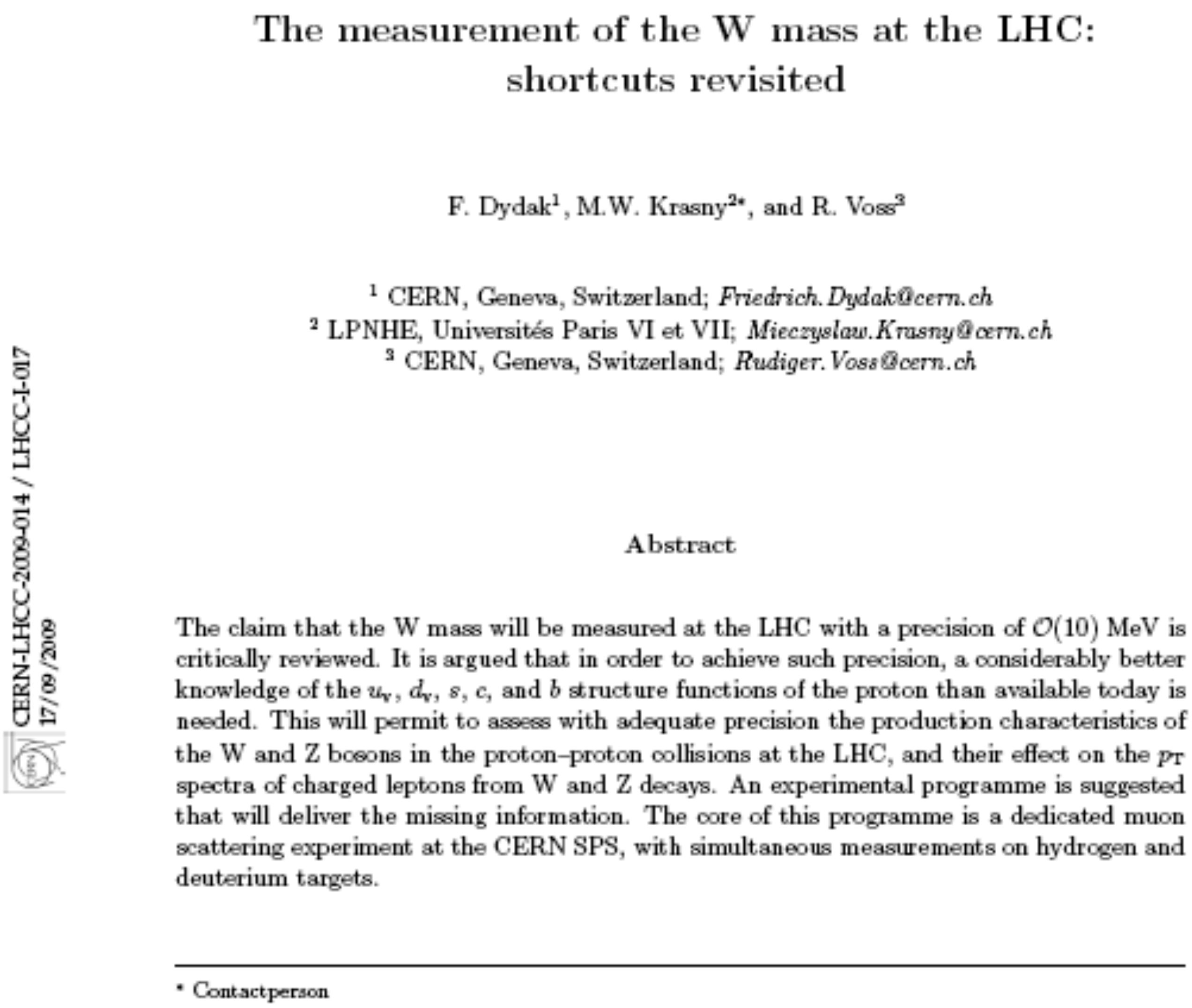
- Isoscalar beams $u^{(v)} = d^{(v)}$ cancel the majority of W^+, W^- and Z production differences
- The measurement of the W-boson charge asymmetry constrain directly the s-c distribution
- Analysis restricted to forward lepton pseudorapidities reduces errors due to b distribution uncertainty
- In addition, no need to assume $s(x)=\bar{s}(x)$, $c(x)=\bar{c}(x)$, $b(x)=\bar{b}(x)$

elegant .. but unrealistic in the initial phase of the LHC operation

Programme 2: An "LHC-precision-support" DIS experiment with:

COMPASS

The Letter of Intent for such an experiment has been submitted a month ago to the SPSC and LHCC…



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

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CERN-LHCC-2009-014 / LHCC-I-017
17/09/2009

Abstract

The claim that the W mass will be measured at the LHC with a precision of $\mathcal{O}(10)$ MeV is critically reviewed. It is argued that in order to achieve such precision, a considerably better knowledge of the u_v, d_v, s, c, and b structure functions of the proton than available today is needed. This will permit to assess with adequate precision the production characteristics of the W and Z bosons in the proton–proton collisions at the LHC, and their effect on the p_T spectra of charged leptons from W and Z decays. An experimental programme is suggested that will deliver the missing information. The core of this programme is a dedicated muon scattering experiment at the CERN SPS, with simultaneous measurements on hydrogen and deuterium targets.

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[*] Contactperson

Reminder: Unconstrained PDF degrees of freedom

- 5 sea-quark flavours (u,d,s,c,b) and 2 valence quark flavours ($u^{(v)}$, $d^{(v)}$)
- 4 constraints coming from the ($p_{T,l}$, η_l) spectra for W^{+}, W^{-}, “Z^{+}” and “Z^{-}” decays
- 3 degrees of freedom in the flavour-dependent pdf’s remain unconstrained at the LHC (external input needed)

How to obtain the missing input?

1. b-quark distribution uncertainties can be assesses at the LHC by splitting the measurement domain $0 < |\eta_l| < 2.5$ and $2.0 < |\eta_l| < 2.5$

2. an assumption: $s = s\,(u^{(s)}, d^{(s)}\,|\,\kappa_s\,)$ and $\bar{s} = \bar{s}\,(\bar{u}^{(s)}, \bar{d}^{(s)}\,|\,\kappa_s\,)$

   Note: $m_s \sim m_u, m_d < \Lambda_{QCD} << m_c, m_b$

Result: 7 unknown distributions constrained by 4 observables, 1 "large luminosity" observable and 1 "natural" assumption

→ only 1 high precision experimental constraint needed

…preferentially in the light quark sector, and of flavour non-singlet type

An optimal (in terms of its complementarities to the LHC measurements) constraint can be provided by a COMPASS high precision measurement of:

$$\mathrm{Asym}_{DIS}{}^{(p,n)}(Q^2,x) = (d\sigma^p/dQ^2dx - d\sigma^n/dQ^2dx)/(d\sigma^p/dQ^2dx + d\sigma^n/dQ^2dx)$$

…where $d\sigma^n/dQ^2dx = d\sigma^d/dQ^2dx - d\sigma^p/dQ^2dx$

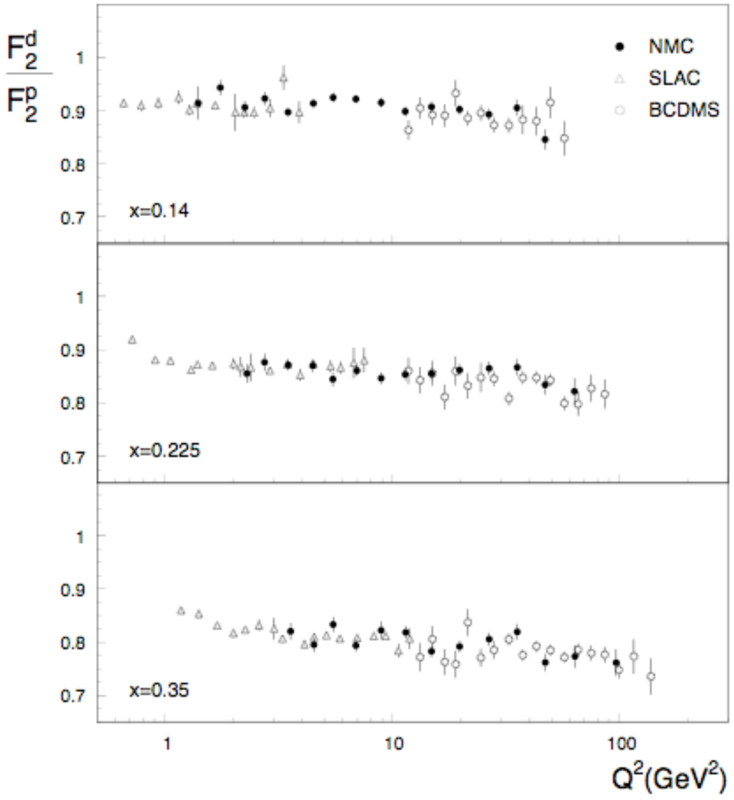
Complementarities:

$$\mathrm{Asym}_{DIS}{}^{(p,n)} \sim 1/3\,(u^{(v)} - d^{(v)}) + 2/3\,(u^{(s)} - d^{(s)})$$

$$\mathrm{Asym}_{W}{}^{(+,-)} \sim u^{(v)}d^{(s)} - u^{(s)}d^{(v)}$$

… asymmetry $\mathrm{Asym}_{DIS}{}^{(p,n)}$ provides a precious constraint for the valence/sea decomposition

Experimental precision



Achieved:
statistical precision: 1-3 %
systematic precision: 0.1- 0.3 %

Required:
Increase of statistical precision by a factor of 5-10

… and, what is of extreme importance, reduced uncertainty, O(1%), of the extrapolation of the measured asymmetry to the Q^2 domain of the LHC

Steps from the measured asymmetries to their use at the LHC

1. Radiative corrections (small, better knowledge of quasi-elastic tails)

2. Corrections for nuclear effects: (1)Fermi motion in the deuterium nucleus, (2) off-shellness effect, (3) shadowing (better understanding of (1) and (2) (TJNAF), (3) HERA, …in addition try to measure the proton spectator as a cross check)

3. p/n asymmetries of higher twists(significant progress in understanding both from theory side, S. Alekhin et al., and from exp. side (TJNAF), use two or three beam energies for a cross check)

4. p/n asymmetries of $R = \sigma_L / \sigma_T$ (new NNLO QCD calculations)

5. QCD evolution of the asymmetry from the measured Q^2 to M_W^2 (better knowledge of α_s, new dedicated NLO QCD tools linking time-like and space-like parton showers being prepared (S. Jadach et al.))

Requirements

1) Highest possible flux: ~ 2×10^8 μ /spill

2) Three months of data taking with 70% efficiency - 8×10^{13} μ^+/target

3) The target length - 12 m, 5 cm radius segmented 4m H_2, 2 m D_2, 4m H_2, 2 m D_2 (compression of the most downstream part of the beam-line? … or compromise with the running time?)

4) Recoil proton detector?

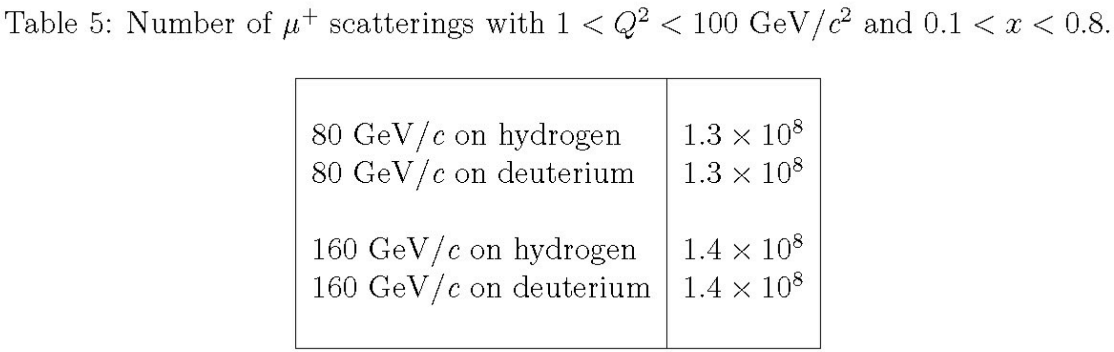


Table 5: Number of μ^+ scatterings with $1 < Q^2 < 100$ GeV/c^2 and $0.1 < x < 0.8$.

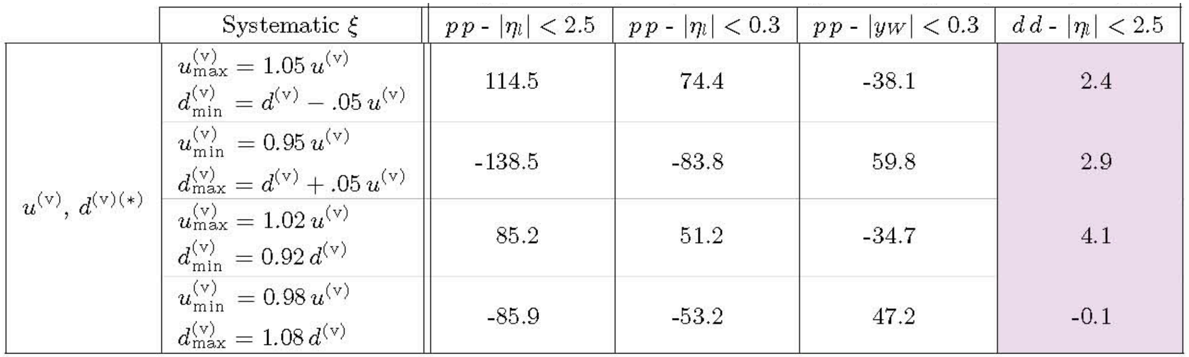
80 GeV/c on hydrogen	1.3×10^8
80 GeV/c on deuterium	1.3×10^8
160 GeV/c on hydrogen	1.4×10^8
160 GeV/c on deuterium	1.4×10^8

Programme 1: Isoscalar beams

example: expected precision of $M_{W+} - M_{W-}$

- Isoscalar beams $u^{(v)} = d^{(v)}$ up to a small ~0.2 % QED corrections

Expected biases in the measured values of $M_{W+} - M_{W-}$ [MeV]



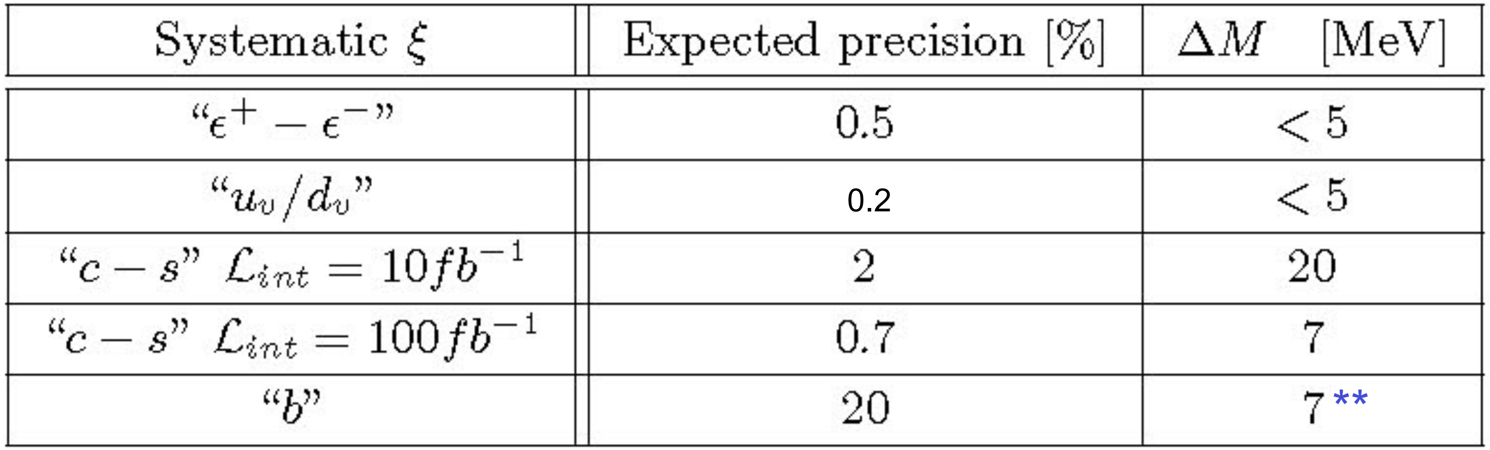
	Systematic ξ	pp - $\lvert\eta_l\rvert < 2.5$	pp - $\lvert\eta_l\rvert < 0.3$	pp - $\lvert y_W\rvert < 0.3$	dd - $\lvert\eta_l\rvert < 2.5$
$u^{(v)}, d^{(v)(*)}$	$u^{(v)}_{max} = 1.05\,u^{(v)}$ $d^{(v)}_{min} = d^{(v)} - .05\,u^{(v)}$	114.5	74.4	-38.1	2.4
	$u^{(v)}_{min} = 0.95\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .05\,u^{(v)}$	-138.5	-83.8	59.8	2.9
	$u^{(v)}_{max} = 1.02\,u^{(v)}$ $d^{(v)}_{min} = 0.92\,d^{(v)}$	85.2	51.2	-34.7	4.1
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = 1.08\,d^{(v)}$	-85.9	-53.2	47.2	-0.1

In addition the measurement of the W-bosons charge asymmetry constrain directly the s-c distribution…

Programme 1: Isoscalar beams

example: expected precision of $M_W = (M_{W+} + M_{W-})/2$

Expected biases* in the measured values of M_W



Systematic ξ	Expected precision [%]	ΔM [MeV]
"$\epsilon^+ - \epsilon^-$"	0.5	< 5
"u_v/d_v"	0.2	< 5
"$c - s$" $\mathcal{L}_{int} = 10 fb^{-1}$	2	20
"$c - s$" $\mathcal{L}_{int} = 100 fb^{-1}$	0.7	7
"b"	20	7**

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

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

Programme 2: DIS experiment

example: expected precision of M_{W+} - M_{W-}

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

Systematic ξ	Expected precision [%]	M_{W+} - M_{W-} [MeV]
“$\epsilon^{+} - \epsilon^{-}$”	0.01	~10 **
“s - c”	2	< 5
“u_v/d_v” $\mathcal{L}_{int} = 10 fb^{-1}$	1	~25
“u_v/d_v” $\mathcal{L}_{int} = 100 fb^{-1}$	1	~10 ***

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

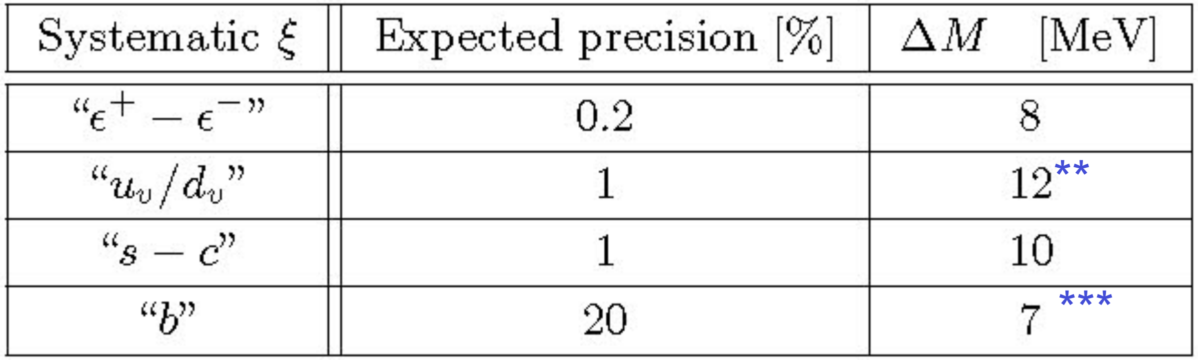
** change of polarisation of the solenoid current … or use of unfolded $u^{(v)}/d^{(v)}$ in the $\varepsilon+ - \varepsilon-$ calibration

*** …biases reduced in a dedicated measurement in the restricted $0.3< |\eta_l| <0.3$ region

Programme 2: DIS experiment

example: expected precision of $M_W = (M_{W+} + M_{W-})/2$

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…

** the precision of unfolding the valence quark asymmetry is driven mainly by the precision of the measurement of $\mathrm{Asym}_{DIS}^{(p,n)}$ (Q^2, x) and by the uncertainty of its extrapolation to the M^2_W scale

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

Conclusions

- The electroweak precision measurements at the LHC require a dedicated measurement programme in order to improve the LEP and the Tevatron ones.
- Measurement of the proton/neutron μ–DIS cross section asymmetry appears to be the simplest way of complementing the LHC electroweak precision measurement program (a complementary program involves running light isoscalar ions in the LHC machine)
- The proposed experiment could do this measurement with minor hardware modification of the COMPASS detector
- This experiment, to be performed, requires a recognition within the LHC community that the auxiliary, LHC-support programme is indispensable for a competitive EW-precision programme at the LHC