EW theoretical uncertainties on the W mass measurement

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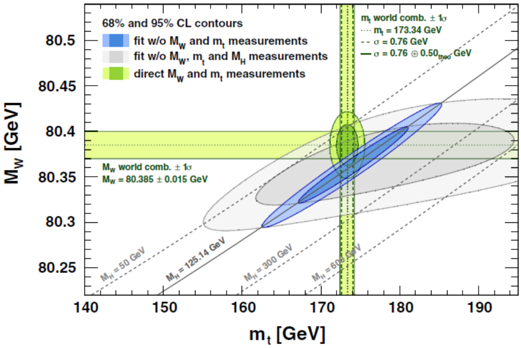
Outline

- Introduction and motivation.
- Methodology.
- Preliminary results.
- Conclusions and work in progress.

Motivation

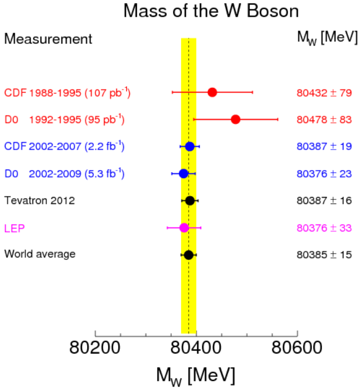
Global EW fit update (July 2014, Eur. Phys. J. C (2014) 74:3046 (Gfitter group):



- An improved measurement of m_W represents a powerful test of the SM predictions, and allows to constrain and shed light on new physics scenarios.

State of the art

Phys.Rev. D88 (2013) 052018 (Tevatron update)



- The current precision is of 15 MeV (world average).
- Tevatron updates together with the ongoing LHC measurements aim to improve this precision.

W mass measurement in hadron colliders

At hadron colliders, the W boson mass is measured using template fits to data. The templates are obtained from Monte Carlo (MC), so the uncertainty on the theoretical model is a source of systematic uncertainty on the measurement. The theoretical uncertainties can be divided in 3 main components:

- Parton distribution functions (PDFs).
- Modeling of W boson transverse momentum (perturbative and non perturbative QCD effects).
- **Electroweak and mixed EW-QCD corrections**.

Example: D0 2012 measurement, 11 MeV (PDF), 2 MeV (boson pT), 7 MeV (corrections), out of a total uncertainty of 26 MeV (Phys. Rev. Lett. 108 (2012) 151804).

Electroweak corrections: state of the art

Electroweak corrections in Drell-Yan processes (W production) are known up to NLO level (exact). Leading effects at each order are implemented up to LL accuracy. The corrections are available from different tools:

- NLO corrections are currently available from a number of independent calculations e.g. POWHEG (Nason et al.), HORACE (Carloni Calame et al.), WZGRAD (Baur U. et al), SANC (JINR).
- The QED leading logs (LL) are included using resummation or parton showers e.g. WINHAC (Placzek et al.), PHOTOS (Was et al.), PYTHIA (Sjstrand et al.), HERWIG (Gieseke et al.).
- Recent work on mixed $\alpha\alpha_s$ contributions by Dittmaier et al.: Nucl.Phys. B885 (2014) 318-372 (pole approximation in the W resonance region).

Electroweak uncertainties

The EW uncertainties starts at NNLO:

- LL corrections (e.g. pair production) and NLL QED corrections.
- Missing exact higher order corrections.

We perform a comparison of the available tools, in order to:

- Classify and quantify the effects that are under control.
- Provide estimations of the uncertainty, taking into account the methods and benchmark generators used by the experimental communities.

Methodology

Mimic the experimental procedure (template fits), in order to estimate the impact of different corrections.

- Generate 2 different MC samples, using the same value of m_W as input (m_W^{nom}). The samples have different level of EW accuracy.
- Generate templates distribution, using a reweighting procedure of sample 1. (using the Breit-Wigner dependence of the cross section). This way we obtain distributions as if produced with different input values of m_W. This is called the "template sample".
- Compare the templates with the distribution in the other sample ("pseudodata"). Each comparison gives a χ^2 value. We then find the minimum of the χ^2 vs. m_W plot (using a parabolic fit), and obtain m_W^{meas}.
- The shift $m_W^{meas} - m_W^{nom}$ is a measure of the impact on the measurement of m_W, of the different EW accuracy used in sample 2 with respect to that of sample 1.

Methodology

We use the following tools:

- POWHEG to generate the Drell-Yan W events ($pp \to W^+ + X \to \mu^+ + \nu_\mu + X$). We use two versions:
  - Version with QCD NLO corrections: $\sigma \sim \sigma_{LO}(1 + \mathcal{O}(\alpha_s))_{PS}$.
  - Version with both QCD and EW NLO corrections: $\sigma \sim \sigma_{LO}(1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\alpha))_{PS}$.
- QCD showers are performed with PYTHIA or HERWIG.
- QED corrections are incorporated with 3 different implementations, all accurate up to LL:
  - PYTHIA (p_T ordered shower).
  - HERWIG++ (YFS exponentiation).
  - PHOTOS (soft and collinear photon radiation, with matrix element correction for DY).

Methodology

- We use also the HORACE generator (which includes EW NLO corrections matched to a QED parton shower), in order to test the effect of splitting $\gamma \to l^+ l^-$ in the QED shower.
- We perform the tests at particle level and also at detector level. A generic detector is simulated using the DELPHES fast simulation package.
- The fits of the χ^2 distributions are done using the MINUIT package as implemented in ROOT.

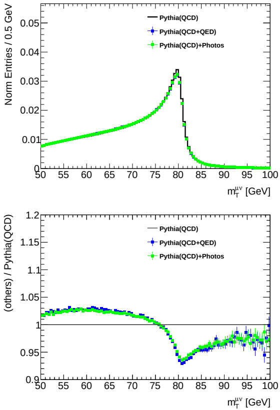
Methodology

Some technical details about the analysis:

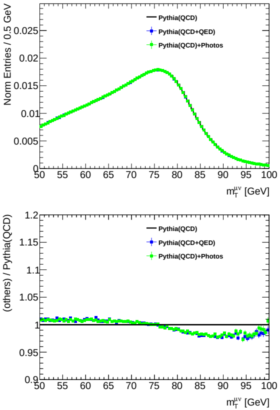
- The events are generated with $\sqrt{s} = 14$ TeV. The samples contain 100 M events (or 10 M for some tests).
- All the samples were generated with $m_W^{nom} = 80.398$ GeV and $\Gamma_W = 2.141$ GeV. The reweighting is done for m_W values spanning 1.2 GeV around m_W^{nom} and separated 1 MeV from each other.
- We perform the fits using the lepton pair transverse mass distribution $m_T^W = \sqrt{2|p_T^{\mu}||p_T^{\nu_\mu}|(1 - \cos\Delta\phi)}$
- We use the selection:
  - $p_T^{\mu} > 20$ GeV
  - $p_T^{\nu_\mu}$, $E_T^{miss} > 20$ GeV
  - $|\eta^{\mu}| < 2.5$
  - 50 GeV $< m_T(W) <$ 100 GeV

Example of distributions used

Particle level



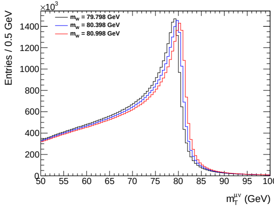
Detector level



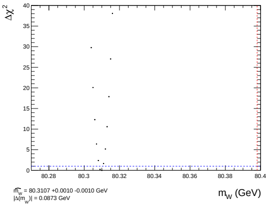
- Events generated with POWHEG(QCD)+PYTHIA(QCD)+(QED).
- This shows the impact in $m_T(W)$ of the QED corrections.
- We are interested, for example, in quantifying the tiny difference between the two color curves (different implementations).

Example of fits

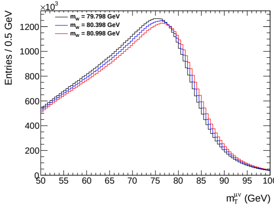
Example of templates
Particle level



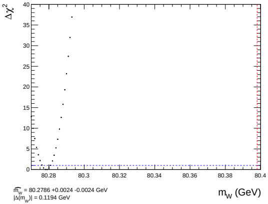
Example of fit
Particle level



Detector level



Detector level



- The "measured" m_W value is obtained from the x coordinate of the parabola minimum.
- The error on the fit is extracted using $\Delta\chi^2 = 1$.

Preliminary results

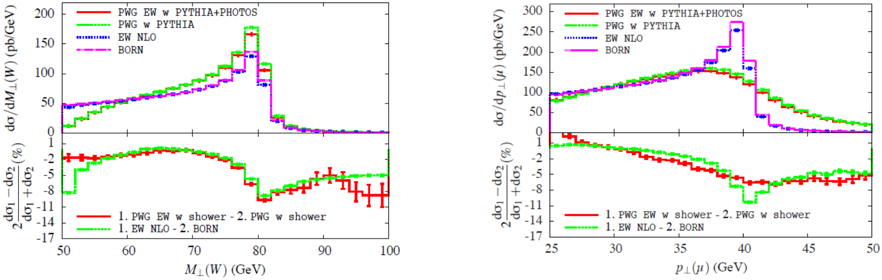
Mass shifts obtained using the transverse mass distribution (preliminary!)

#	Templates	Pseudodata	Mass shift (MeV) Particle level	Mass shift (MeV) Detector level
1	Powheg(QCD)+Pythia(QCD)	Powheg(QCD)+Pythia(QCD,QED)	-96.0 $\pm$ 1.0	-128.6 $\pm$ 2.4
2	Powheg(QCD)+Pythia(QCD)	Powheg(QCD)+Pythia(QCD)+Photos	-87.3 $\pm$ 1.0	-119.4 $\pm$ 2.4
3	Powheg(QCD)+Herwig(QCD)	Powheg(QCD)+Herwig(QCD,QED)	-86.5 $\pm$ 3.3	-118.0 $\pm$ 9.1
4	Powheg(QCD)+Pythia(QCD)	Powheg(QCD+EW)+Pythia(QCD)+Photos	-	-
5	Horace	Horace + lepton pairs	-3.0 $\pm$ 1.4	-

- We observe a shift of the order of ~ 100 MeV, due to the inclusion of QED effects (starting at order α and containing approximate $\alpha_s\alpha$).
- Comparing the QED implementations: PYTHIA vs PHOTOS, we observe a difference of the order of ~ 10 MeV (detailed check of internal settings of each code is needed before interpreting this shift as a systematic).
- From the HORACE test, we see that the impact of the introduction of lepton pair production is small, of the order of few MeV.

Impact of exact EW and mixed QCD-EW corrections

Comparison of the two implementations of POWHEG (JHEP 1204 (2012) 037)



- The green curve in the bottom panel, gives the effect of pure EW effects. This effect is included through the QED parton shower.
- The red curve in the bottom panel gives the effect of EW and mixed QCD+EW corrections POWHEG(QCD+EW) with PS.
- This gives an idea of the impact of the corrections. **We are currently working on the accurate propagation of this effect to the W mass fits.**

Conclusions

- We have started an analysis aiming to test the compatibility of available tools, quantify the EW effects that are known, and provide and estimate of the uncertainties that affect the m_W measurement.
- So far, the tests seem to give consistent results.
- We plan to provide realistic estimates of uncertainties, to be used as reference by the experimental collaborations, but also provide the tools/recipes needed for their estimation.
- We are open to suggestions, use of new tools, etc.

Work in progress

- Complete the test involving exact EW and QCD+EW corrections.
- Improve the accuracy of the QED comparisons (check the internal setting of each code).
- Perform the analysis using different distributions: lepton transverse momentum p_T^{μ} and neutrino transverse momentum $p_T^{\nu_\mu}$ (or E_T^{miss} at detector level). Here, some work need to be done in order to understand the impact of QCD in p_T modeling.
- After discussion with experimentalists, we plan to revisit the kinematic cuts used in the analysis.
- So far we have worked with muons (bare), but we plan to repeat the tests with electrons.

Thanks to LHCPhenoNet!

Backup

Reweighting

For every event "i", compute weights given by $wt_i = BW(s_i, m^W_{temp})/BW(s_i, m^W_{nom})$, where:

- $BW(s,m) = \frac{s}{(s-m^2)^2 + m^2\Gamma^2}$
- s_i: Invariant mass squared of the lepton pair $(\mu + \nu_\mu)$ of the event "i".
- m^W_{temp}: W mass of the template.
- m^W_{nom}: Fixed W mass of the generation (80.398 GeV).
- Γ: W decay width of the generation (2.141 GeV).

With these weights, filling distributions for every value of m^W_{temp}.

EW input scheme

Preliminary results done with HORACE, with different configurations and different input schemes.

			m_T		p_T^l		$\not{E}_T$	
line	approx. 1	approx. 2	e	μ	e	μ	e	μ
1	$\mathcal{O}(\alpha)$ α_0	$\mathcal{O}(\alpha)$ $G_\mu - I$	- 9.0	-11.6	-10.8	-11.8	- 2.8	- 7.4
2	$\mathcal{O}(\alpha)$ α_0	$\mathcal{O}(\alpha)$ $G_\mu - II$	1.2	-0.3	-0.2	0.2	1.7	-0.7
3	$\mathcal{O}(\alpha)$ $G_\mu - I$	$\mathcal{O}(\alpha)$ $G_\mu - II$	10.1	11.2	10.6	12.0	4.4	6.6
4	matched α_0	matched $G_\mu - I$	-0.1	-0.1	0.0	-1.1	2.0	1.8
5	matched α_0	matched $G_\mu - II$	1.7	1.1	1.3	-0.3	4.0	2.6
6	matched $G_\mu - I$	matched $G_\mu - II$	1.8	1.2	1.0	0.8	2.0	0.9