EW theoretical uncertainties on the W mass measurement

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October 2014
W mass meeting - GGI Florence

Outline

- Introduction and motivation.
- Methodology.
- Preliminary results.
- Conclusions and remarks.
- Work in progress.

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).
- Modelling of W boson transverse momentum (perturbative and non perturbative QCD effects).
- **Electroweak and mixed EW-QCD corrections**.

Electroweak corrections: state of the art

Electroweak corrections in Drell-Yan processes 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, HORACE, WZGRAD, SANC...).
- The QED leading logs (LL) are included using resummation or parton showers (e.g. WINHAC, PHOTOS, PYTHIA, HERWIG...).

Electroweak uncertainties

The EW uncertainties starts at NNLO:

- LL corrections (e.g. pair production) and NLL QED corrections.
- Choice of EW input parameters scheme.

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.

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.

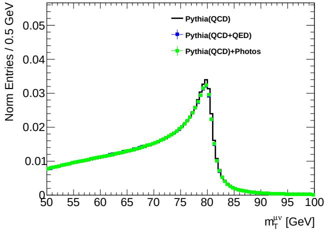
Methodology

Some technical details about the analysis:

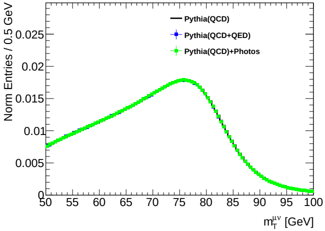
- The events are generated with $\sqrt{s} = 14$ TeV. The samples contain 100 M events (or 10 M for some tests).
- All the samples were generated with $m_W^{nom} = 80.398$ GeV and $\Gamma_W = 2.141$ GeV. The reweighting is done for m_W values spanning 1.2 GeV around m_W^{nom} and separated 1 MeV from 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

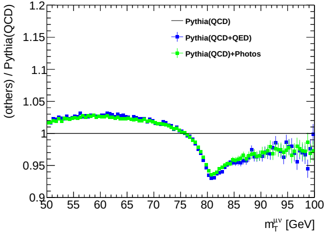
Example of distributions used

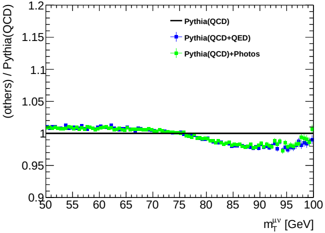
Particle level



Detector level

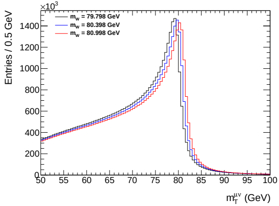




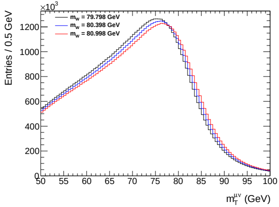


- Events generated with POWHEG(QCD)+PYTHIA(QCD)+(QED).
- This shows the impact in $m_T(W)$ of the QED corrections.
- We are interested in quantifying the tiny difference between the two color curves (different implementations).

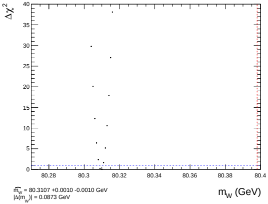
Example of templates
Particle level



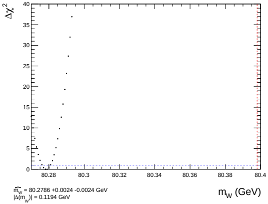
Detector level



Example of fit
Particle 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	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.
- Before interpreting this shift as a systematic, we need to perform a more detailed check of the internal settings of each code.

Preliminary results

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- The test number (4) (impact of exact NLO EW corrections) is to be completed soon.
- From the HORACE test, we see that the impact of the introduction of lepton pair production is small, of the order of few MeV.

Conclusions and comments

- 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.
- So far, the tests seem to give consistent results.

Work in progress

- Complete the test involving exact 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.
- So far we have worked with muons (bare), but we plan to do the same tests with electrons.

Thanks!

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