# WGRAD2, and other workshop activities

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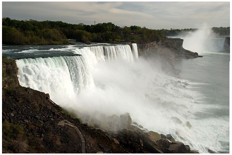
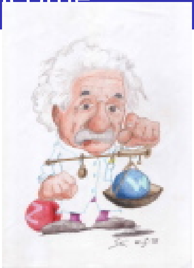


University at Buffalo
The State University of New York

*W mass workshop, University of Milano*

March 17, 2009

# Welcome



Organizers: Alessandro Vicini, D.W.

http://wwwteor.mi.infn.it/∼vicini/wmass.html

sponsored by the University of Milano and INFN

The aim of this meeting is to have extensive discussion sessions where

- the authors of the NLO MC programs (HORACE, RESBOS, SANC, WGRAD, MC@NLO, MCFM ...) can discuss theoretical uncertainties, limitations of their codes, possible improvements, plans/recipes for combining with or interfacing to different codes;
- the experimentalists involved in the $W$-mass and $W$-width measurements can present and discuss the challenges in the analysis with emphasis on the theory input, and communicate the necessary improvements in the available codes.

The results of the workshop will be made available in form of a workshop report.

# Welcome

$W$ and $Z$ production processes are one of the theoretically best understood, most precise probes of the Standard Model at hadron colliders.
Impressive progress has been made in providing precise predictions at NLO EW and QCD, NNLO QCD and higher (leading and subleading logarithms).
Are predictions for $W/Z$ observables, especially the ones relevant for $W$ mass measurements, really sufficiently under control ?
This involves a careful study of the residual theoretical uncertainties.

# A brief description of WGRAD2

- WGRAD2 is a parton level MC program that computes cross sections to $W$ production via the Drell-Yan mechanism.
- The calculation is based on the full matrix elements for massless fermions ( mass only used as regulator), including the complete EW $\mathcal{O}(\alpha)$ corrections (real+virtual photons and weak 1-loop corrections).
- The matching of soft and collinear singularities between virtual and real corrections is done using phase space slicing :

$$E_\gamma < \delta_s \sqrt{\hat{s}}/2 \;\; ; \;\; (1 - \cos\theta_{i\gamma}) < \delta_c$$

- Quark mass singularities are absorbed by universal collinear counterterms to the PDFs (mass factorization done in complete analogy to QCD and introduces dependence on QED factorization scale).
- Some options: EW input schemes, h.o. corrections ($\Delta\rho$) , $W$ width calculated or input, running or constant width, only resonant $W$ production

WGRAD2 generates weighted events: one weight for events with $2 \longrightarrow 2$ kinematics and one for $2 \longrightarrow 3$ kinematics (hard photon). Both weights depend on $\delta_s, \delta_c$, but this dependence cancels in the sum:

$$|\mathcal{M}|^2 = |\mathcal{M}^{(0)}|^2 \, [1 + 2\mathcal{R}e(\tilde{F}^{initial}_{weak} + \tilde{F}^{final}_{weak})(M_W^2)] + |\mathcal{M}_{non-res.}|^2(\hat{s}, \hat{t})$$

$$+ \sum_{\substack{a=initial\,,final\,,\\ interf\,.}} |\mathcal{M}^{(0)}|^2 \, F^a_{QED}(\hat{s}, \hat{t}, \delta_{s,c}) + \sum_{\substack{a=initial\,,final\,,\\ interf\,.}} |\mathcal{M}_{2\to 3}|^2_a(\delta_{s,c})$$

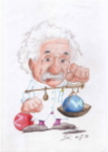
Work in progress:

- Inclusion of multiple final-state photon radiation and EW Sudakov-like logarithms (see Les Houches 2007 workshop report).
- Combination of WGRAD2 and ZGRAD2 in one code.
- Root ntuples, interface provided by Pavel Nadolsky (see CTEQ4LHC working group).

# Examples of studies of theoretical uncertainties

Theoretical uncertainty due to *missing* higher-order corrections:

- Tevatron: D0 Note 5893-CONF (Winter 2009)
  $\delta M_W^{theory} \approx 7(7)$ MeV ($M_T(p_T^l)$) due to missing higher-order photon radiation
- LHC: N.Adam *et al.*, arXiv:0808.0758 [hep-ph]
  $\delta\sigma_W/\sigma_W = 4.00 \pm 0.61\%$ due to missing O($\alpha$) EW corrections
  $\delta\sigma_W/\sigma_W = 1.66 \pm 0.69\%$ due to missing NNLO QCD corrections



Theoretical uncertainty due to *unknown* higher-order corrections:

A MC program providing the *best* prediction by including all known higher-order corrections (EW and QCD) is not available (yet).

Tev4LHC ( arXiv:0705.3251 [hep-ph]) and Les Houches (arXiv:0803.0678 [hep-ph]) workshop reports

Assessment of QCD uncertainties:

- QCD factorization/renormalization scale dependence
- Treatment of non-perturbative QCD effects for $q_T \lesssim 20$ GeV) in soft-gluon resummation

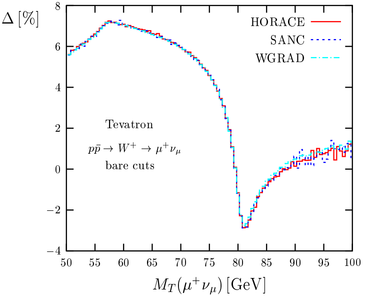
Assessment of EW uncertainties:

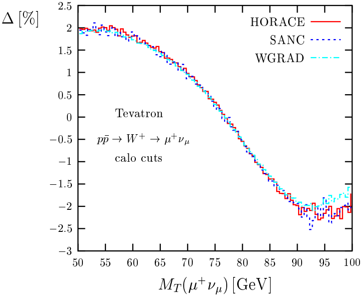
- Tuned comparisons of EW $\mathcal{O}(\alpha)$ calculations
- EW input scheme dependence and different implementations of higher-order corrections
- QED scale dependence of PDFs

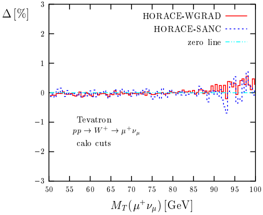
PDF uncertainty: $\delta M_W^{PDF} = 9(11)$ MeV and $\delta\sigma_W/\sigma_W(PDF) = 4\%$

D0 Note 5893-CONF (Winter 2009), and N.Adam *et al.*, arXiv:0808.0758 [hep-ph]

# Results of a tuned comparison




C.Gerber *et al*, TEV4LHC TopEW WG report, arXiv:0705.3251 [hep-ph]

Estimate of uncertainty due to unknown h.o. EW corrections (with WGRAD2):

- 'NLO at $\mathcal{O}(\alpha^3)$ incl. h.o.': EW input of tuned comparison with

$$\delta M_Z^2 = \mathcal{R}e\left(\Sigma^Z(M_Z^2) - \frac{(\hat{\Sigma}^{\gamma Z}(M_Z^2))^2}{M_Z^2 + \hat{\Sigma}^{\gamma}(M_Z^2)}\right)$$

  higher-order (irreducible) corrections connected to the $\rho$ parameter, $\Delta\rho^{HO}$

$$\frac{\delta M_Z^2}{M_Z^2} - \frac{\delta M_W^2}{M_W^2} \to \frac{\delta M_Z^2}{M_Z^2} - \frac{\delta M_W^2}{M_W^2} - \Delta\rho^{HO}$$

- 'NLO at $\mathcal{O}(\alpha G_\mu^2)$ incl. h.o.': In addition, change the EW input parameter scheme ($\alpha(0)$ scheme $\to$ $G_\mu$ scheme)

$$\alpha(0) \to \alpha(G_\mu) = \frac{\sqrt{2} G_\mu M_W^2}{\pi}\left(1 - \frac{M_W^2}{M_Z^2}\right)(1 - \Delta r),$$

| | Tevatron, $\sigma_W$ [pb] | LHC, $\sigma_W$ [pb] |
|---|---|---|
| | $p\bar{p} \to W^+ \to \mu^+\nu_\mu$ | $pp \to W^+ \to \mu^+\nu_\mu$ |
| NLO at $\mathcal{O}(\alpha^3)$ | 738.00(1) | 4943.0(1) |
| NLO at $\mathcal{O}(\alpha^3)$ incl. h.o. | 745.80(1) | 4995.5(1) |
| NLO at $\mathcal{O}(\alpha G_\mu^2)$ incl. h.o. | 747.62(1) | 5006.5(1) |

This was just the beginning.
There are many open issues and more work is needed to get a handle on the theoretical uncertainty at the required level of precision.
More details in the discussion session this afternoon ...
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pwd: wmass2009