

# Combined EW and QCD Corrections to Drell-Yan Processes with POWHEG

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The goal of this work is to incorporate the NLO-EW corrections of WGRAD2 into the POWHEG-w NLO-QCD+Parton Showered process of the POWHEG-BOX in order to study the effects of combined EW and QCD NLO corrections to single-vector boson production at the Tevatron and LHC.

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- 3 POWHEG-w
- 4 WGRAD2  $\Rightarrow$  POWHEG-w
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## Charged Current (CC) & Neutral Current (NC) Drell-Yan - valuable physics

- recently provided most precise measurement of  $M_W$ 
  - DØ+CDF combined  $M_W = 80.420 \pm 0.031$  GeV Tevatron EW Working Group 2009  
⇒ 9.3 MeV of uncertainty from radiative corrections
  - anticipated LHC measurement of  $\Delta M_W$  to within 15 MeV Haywood et al 2000  
⇒ precise theoretical handling of higher-order QCD and EW corrections
- single W, Z production large  $\sigma$  and clear signatures  $W \rightarrow \ell + \cancel{E}_T$  or  $Z \rightarrow \ell^+ \ell^-$
- better measurements of parton distribution functions (PDF's)
  - a calculation is only as good as the errors in the pdf's
  - LHC is proton-proton machine - yields best glimpse of antiquark distributions
- calibration of detectors - remeasure Standard Model benchmark parameters at LHC
- collider luminosity monitoring

**WGRAD2**<sup>1,2</sup> is a MC code for charged-current (CC) Drell-Yan with full NLO EW corrections

$$d\sigma = \sum_{\text{flavors}} dx_1 dx_2 f_1(x_1) f_2(x_2) \left[ d\hat{\sigma}_B + \underbrace{d\hat{\sigma}_{V+S}}_{\sim \delta_s} + \int_{1,2} \frac{dz}{z} \underbrace{d\hat{\sigma}_{\text{HC}}(z)}_{\sim \delta_c} + \int_{\delta_s, \delta_c} d\Phi_{\text{rad}} d\hat{\sigma}_{\text{HC}} \right]$$

- soft, collinear divergences treated with 2-cutoff phase space slicing<sup>3</sup> technique
  - ⇒ dependence on  $\delta_s$  and  $\delta_c$  must cancel in physical result
- **options/switches:** gauge invariant FS, IS, interference subsets of photon radiation for separate study

<sup>1</sup>U.Baur and D.Wackeroth, Phys. Rev. **D70**, 073015 (2004), hep-ph/0405191

<sup>2</sup>U.Baur,S.Keller and D.Wackeroth, Phys. Rev. **D59**, 013002 (1999), hep-ph/9807417

<sup>3</sup>B.W. Harris,J.F. Owens, Phys. Rev. **D65**, 094032 (2002), hep-ph/0102128

# POWHEG-BOX

## POsitive W eight H ardest E vent G enerator<sup>4,5,6</sup>

- contains NLO QCD corrections matched to Parton Shower (PYTHIA and HERWIG) for several processes (POWHEG-BOX)
  - ⇒ of interest are **POWHEG-w**<sup>7</sup> and **POWHEG-z**<sup>7</sup> (more on this later..)
- POWHEG method:
  - generate events with the hardest radiation at NLO
  - feed events into PYTHIA/HERWIG, all showering is softer than the first, hardest event
- POWHEG master formula:

$$d\sigma = \sum_{\text{flavors}} \bar{B}(\Phi_n) d\Phi_n \left\{ \Delta(\Phi_n, p_T^{\min}) + \sum_{\alpha_r} \frac{\left[ d\Phi_{\text{rad}} \Delta(\Phi_n, k_T > p_T^{\min}) R(\Phi_{n+1}) \right]}{B(\Phi_n)} \right\}$$

- $\bar{B} \Rightarrow$  exact NLO differential cross-section  $\Rightarrow$  FKS subtraction
- $\Delta(\Phi_n, k_T) \Rightarrow$  Sudakov form-factor  $\Rightarrow$  ensures hardest event

<sup>4</sup>P.Nason, *JHEP* **0411** (2004) 040, hep-ph/0409146

<sup>5</sup>S.Frixione, P.Nason and C. Oleari, *JHEP* **0711** (2007) 070, arXiv:0709.2092

<sup>6</sup>S.Alioli, P.Nason, C. Oleari and E.Re, *JHEP* **1006** (2010) 043, arXiv:1002.2581

<sup>7</sup>S.Alioli, P.Nason, C. Oleari and E.Re, *JHEP* **0807** (2008) 060, arXiv:0805.4802

We incorporate the EW corrections into  $\bar{B}$ :

$$\begin{aligned} \bar{B}(\Phi_2) = & B(\Phi_2) + V_{\text{QCD}}(\Phi_2) + V_{\text{EW}}(\Phi_2) + \int_{\oplus} \frac{dz}{z} [G_{\oplus, \text{QCD}}(\Phi_{2, \oplus}) + G_{\oplus, \text{EW}}(\Phi_{2, \oplus})] \\ & + \int_{\ominus} \frac{dz}{z} [G_{\ominus, \text{QCD}}(\Phi_{2, \ominus}) + G_{\ominus, \text{EW}}(\Phi_{2, \ominus})] + \sum_{\alpha_r \in \text{IS}} \int d\Phi_{\text{rad}, \text{IS}} [\hat{R}(\Phi_3) + R_{\text{EW}}(\Phi_3)] \end{aligned}$$

- $\Rightarrow V_{\text{EW}}(\Phi_2)$  virtual + soft finite EW corrections
  - $\Rightarrow$  switch for resonant/non-resonant (box diagrams) effects
- $\Rightarrow G_{\text{EW}}(\Phi_2, z)$  IS and FS collinear EW pieces
- $\Rightarrow R_{\text{EW}}(\Phi_3)$  finite real piece - IS and FS together
  - $\Rightarrow$  switch for IS, FS, interference QED radiation

# Preliminary Results - total cross-sections

First, can we get WGRAD2 results from POWHEG-w by turning off NLO QCD and, is it stable wrt unphysical  $\delta_s$  and  $\delta_c$ ?

$(\delta_s, \delta_c)$	POWHEG-w + EW - QCD	WGRAD2
0.01, 0.005	1040.6(2) pb	1040.2(1) pb
0.01, 0.0005	1040.4(5) pb	1040.5(2) pb
0.001, 0.0005	1040.8(6) pb	1040.4(8) pb

Second, when we leave on NLO-QCD (no showering yet)?

$(\delta_s, \delta_c)$	POWHEG-w + EW
0.01, 0.005	1249.1(3) pb
0.01, 0.0005	1249.0(5) pb
0.001, 0.0005	1248.5(4) pb

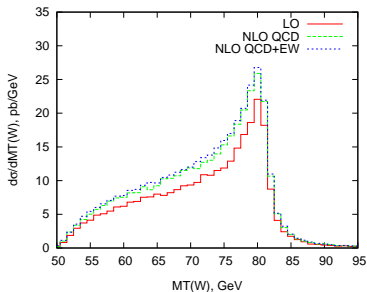
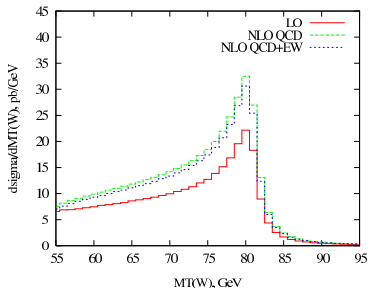
Process:  $p\bar{p} \rightarrow W^+ \rightarrow \mu^+ \nu_\mu$

$\sqrt{S} = 1.96$  TeV

**no kinematic cuts**

# Preliminary Results - distributions

no parton shower,  $p\bar{p} \rightarrow W^+ \rightarrow \mu^+\nu_\mu$ ,  $\sqrt{S} = 1.96$  TeV



**left plot:** exact NLO (no gluon resummation, no parton shower)

⇒ EW corrections reduce cross-section at NLO

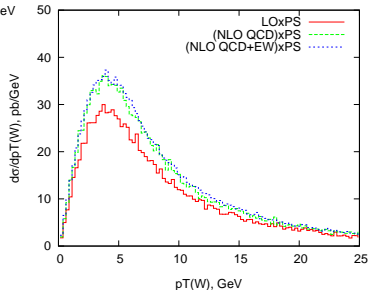
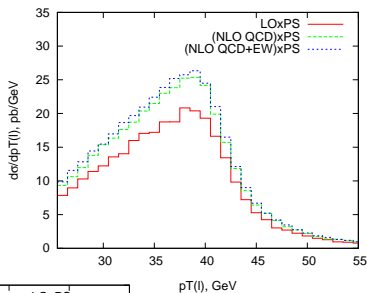
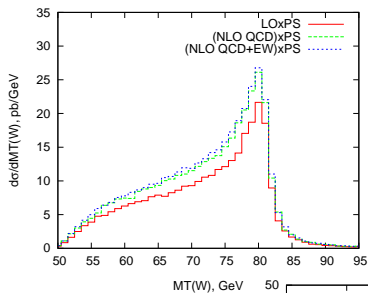
**right plot:** exact NLO + gluon resummation, (no parton shower)

**acceptance kinematics cuts:**  $p_T(l) > 25$  GeV,  $p_T(\nu) > 25$  GeV,  $|\eta_l| < 1$



# Preliminary Results - distributions

with parton shower(Pythia),  $p\bar{p} \rightarrow W^+ \rightarrow \mu^+\nu_\mu$ ,  $\sqrt{S} = 1.96$  TeV



## For the immediate future:

- comparison with previous work on QCD+EW combinations by HORACE+MC@NLO<sup>8</sup>
- Next, NLO-EW corrections to NC Drell-Yan (ZGRAD2<sup>9</sup>) into POWHEG-z
- Include multiple soft FS photon radiation (QED structure functions) to both processes

## For the next-to-immediate future:

- Match QED parton shower in PYTHIA to EW corrections of both Drell-Yan processes.

<sup>8</sup>G. Balossini et.al., JHEP 1001:013 (2010), arXiv:0907.0276

<sup>9</sup>U.Baur et.al., Phys. Rev. **D65**, 033007 (2002), hep-ph/0108274