Combination of Electroweak and QCD Effects to Charged Current Drell Yan

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in collaboration with Doreen Wackeroth

Importance of Precise M_W Measurement

Charged Current (CC) & Neutral Current (NC) Drell-Yan - valuable physics

- single W, Z production large σ and clear signatures $W \rightarrow \ell + \not{E}_T$ or $Z \rightarrow \ell^+\ell^-$

  $\Rightarrow M_W$, PDFS, luminosity monitoring

  $\Rightarrow$improved SM Higgs mass constraint

- uncertainty from radiative corrections:

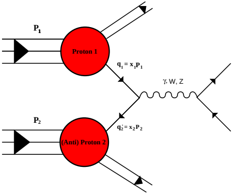
  Tevatron EW Working Group 2012

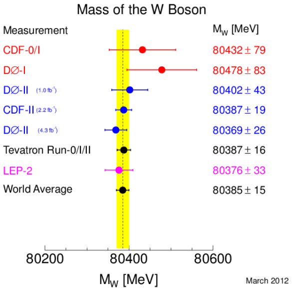
  $\Rightarrow$CDF-II: 4 of 19 MeV

  $\Rightarrow$DØ-II: 7 of 26 MeV

- anticipated LHC measurement of ΔM_W to within 15 MeV Haywood *et al* 2000

  $\Rightarrow$ precise theoretical handling of higher-order QCD and EW corrections





WGRAD2

WGRAD2[1,2] is a MC code for charged-current (CC) Drell-Yan with full NLO EW corrections

$$d\sigma = \sum_{\text{flavors}} dx_1\, dx_2\, f_1(x_1)\, f_2(x_2) \left[d\hat{\sigma}_{\mathrm{B}} + \underbrace{d\hat{\sigma}_{\mathrm{v+s}}}_{\sim \delta_s} + \int_{1,2} \frac{dz}{z} \underbrace{d\hat{\sigma}_{\mathrm{HC}}(z)}_{\sim \delta_c} + \int_{\delta_s,\delta_c} d\Phi_{\mathrm{rad}} d\hat{\sigma}_{\mathrm{H\bar{C}}} \right]$$

- soft, collinear divergences treated with 2-cutoff phase space slicing[3] technique

  $\Rightarrow$ dependence on δ_s and δ_c must cancel in physical result

- **options/switches:** gauge invariant FS, IS, interference subsets of photon radiation for separate study

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

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

[3] 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[4,5,6]

- contains NLO QCD corrections matched to Parton Shower (PYTHIA and HERWIG) for several processes (POWHEG-BOX)
- POWHEG method:
  1. generate events with the hardest radiation at NLO
  2. 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

[4] P.Nason, *JHEP* **0411** (2004) 040, hep-ph/0409146

[5] S.Frixione,P.Nason and C. Oleari, *JHEP* **0711** (2007) 070, arXiv:0709.2092

[6] S.Alioli,P.Nason,C. Oleari and E.Re, *JHEP* **1006** (2010) 043, arXiv:1002.2581

[7] S.Alioli,P.Nason,C. Oleari and E.Re, *JHEP* **0807** (2008) 060, arXiv:0805.4802

WGRAD2 + POWHEG-W⇒POWHEG-W_ew-BW

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

$$\bar{\mathrm{B}}(\Phi_2) = \mathrm{B}(\Phi_2) + V_{\mathrm{QCD}}(\Phi_2) + V_{\mathrm{EW}}(\Phi_2) + \int_{\oplus} \frac{dz}{z} \left[\mathrm{G}_{\oplus,\mathrm{QCD}}(\Phi_{2,\oplus}) + \mathrm{G}_{\oplus,\mathrm{EW}}(\Phi_{2,\oplus})\right]$$

$$+ \int_{\ominus} \frac{dz}{z} \left[\mathrm{G}_{\ominus,\mathrm{QCD}}(\Phi_{2,\ominus}) + \mathrm{G}_{\ominus,\mathrm{EW}}(\Phi_{2,\ominus})\right] + \sum_{\alpha_r \in \mathrm{IS}} \int d\Phi_{\mathrm{rad},IS} \left[\hat{\mathrm{R}}(\Phi_3) + \mathrm{R}_{\mathrm{EW}}(\Phi_3)\right]$$

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

Resulting public code available within POWHEG-BOX as subprocess W_ew-BW

CB, Doreen Wackeroth arXiv:1201.4804

Crosschecks and Validation

First, can we get WGRAD2 results from POWHEG-W_BW by turning off NLO QCD? Yes.

	Tevatron, W^+	LHC, W^+	LHC, W^-
WGRAD2	362.55(2) pb	1059.6(1) pb	759.26(3) pb
POWHEG-W_BW	362.4(2) pb	1059.0(5) pb	758.7(8) pb

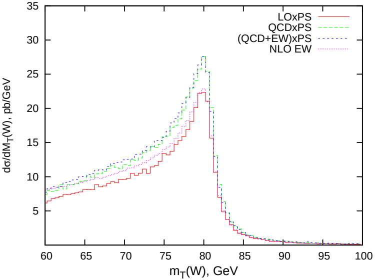
Second, are they stable wrt unphysical δ_s and δ_c? Yes.

(δ_s,δ_c)	Tevatron, W^+	LHC, W^+	LHC, W^-
0.01, 0.005	362.4(2) pb	1059.0(5) pb	758.7(8) pb
0.01, 0.001	362.4(2) pb	1059.1(7) pb	759.2(5) pb
0.001, 0.0005	362.3(2) pb	1059.4(9) pb	759.4(5) pb
0.001, 0.0001	362.3(2) pb	1059.2(8) pb	759.3(5) pb

Process: $W^\pm \to \mu^\pm \nu_\mu$ **Bare Cuts:** $p_T(\mu^\pm)$, $p_T(\nu_\mu) > 25\text{GeV}$, $|\eta_\mu| < 1$

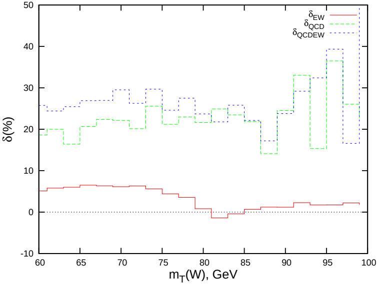
$M_T(W)$ Distributions - Tevatron

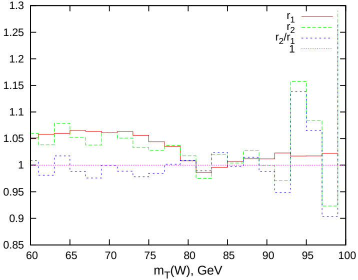
$p\bar{p} \to W^+ \to \mu^+\nu_\mu$, $\sqrt{S} = 1.96$ TeV, Pythia showering



$$M_T(W) = \sqrt{2p_T(\ell)p_T(\nu)(1-\cos(\Delta(\phi_{\ell\nu})))}$$

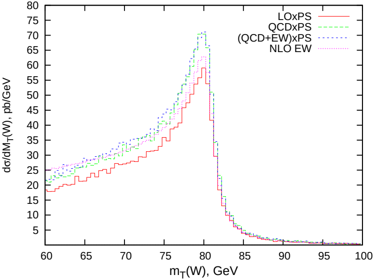
- fits of $d\sigma/dM_T(W)$ used to measure M_W
  - $\Rightarrow$ lineshape sensitive to FS QED effects around Jacobian peak due to collinear logs $\sim \alpha\, log(m_l^2/\hat{s})$
- $\delta_a = \left[\left(\frac{d\sigma_a}{d\mathcal{O}} - \frac{d\sigma_{LO}}{d\mathcal{O}} \right) / \frac{d\sigma_{LO}}{d\mathcal{O}} \right] \times 100$
- $r_1 = \frac{d\sigma_{EW}}{d\mathcal{O}} / \frac{d\sigma_{LO}}{d\mathcal{O}}$, $r_2 = \frac{d\sigma_{(QCD+EW)xPS}}{d\mathcal{O}} / \frac{d\sigma_{QCDxPS}}{d\mathcal{O}}$





$M_T(W)$ Distributions - LHC

$pp \to W^+ \to \mu^+\nu_\mu$, $\sqrt{S} = 7$ TeV, Pythia showering



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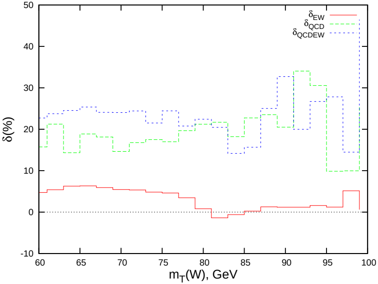

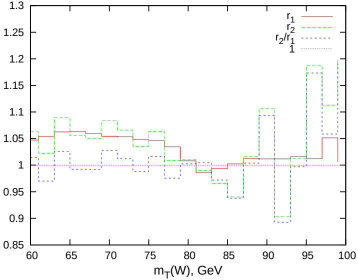

$p_T(l)$ Distributions - Tevatron

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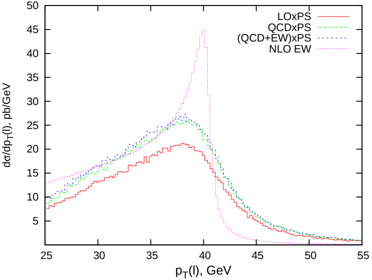

- fits of $d\sigma/dp_T(\mu)$ used to measure M_W
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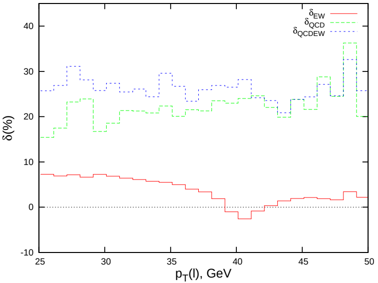

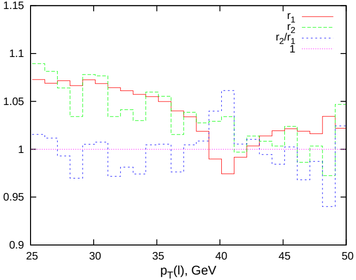

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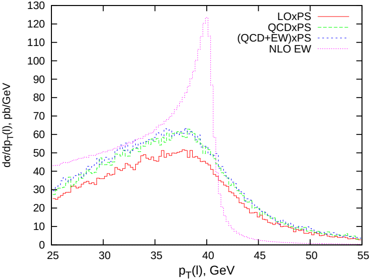

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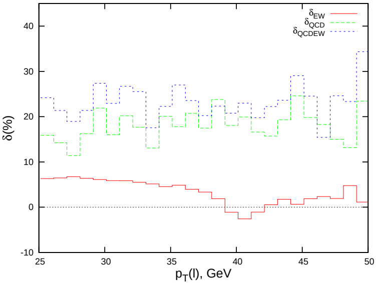

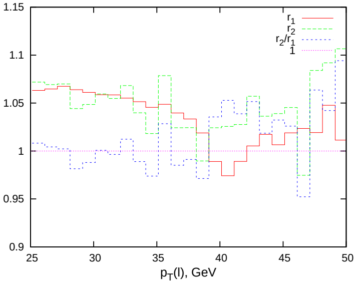

Summary: QCD + EW Effects on Distributions

What can we conclude about effects of *combined* EW and QCD corrections on $\frac{d\sigma}{dM_T(W)}$ and $\frac{d\sigma}{dp_T(l)}$?

$$\underbrace{r_2 = \frac{d\sigma_{(QCD+EW)xPS}}{d\mathcal{O}} / \frac{d\sigma_{QCDxPS}}{d\mathcal{O}}}_{\text{effect of EW corrections on } \frac{d\sigma}{dp_T(\mu)} \text{ in presence of QCD}} \quad \textit{not the same as} \quad \underbrace{r_1 = \frac{d\sigma_{EW}}{d\mathcal{O}} / \frac{d\sigma_{LO}}{d\mathcal{O}}}_{\text{effect of EW corrections only}}$$

if it was, $\frac{r_2}{r_1} \simeq 1$

- $\mathcal{R} = \frac{r_2}{r_1}$ deviation from unity implies non-additive (interference) EW, QCD effects $\Rightarrow p_T(l)$
- understanding of interplay of QCD and EW corrections to Drell-Yan useful to reduce QED uncertainty in M_W measurement.

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Thank You!

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