QCD-EW corrections interplay in Drell-Yan like single W and Z production at LHC

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on behalf of SANC group

Epiphany Conference, Cracow, January 4-6, 2007

SANC v1.00

Server $\leftrightarrow$ client realization, SANC IDE.

`SANC` version `v1.00` is accessible from two servers:

at Dubna http://sanc.jinr.ru/ (159.93.75.10)

and CERN http://pcphsanc.cern.ch/ (137.138.180.42)

Client may be downloaded from these two sites,

see User Guide in:

Ref.: SANCscope — v.1.00
A. Andonov, A. Arbuzov, D. Bardin, S. Bondarenko, P. Christova,
L. Kalinovskaya, G. Nanava and W. von Schlippe,
Comput. Phys. Comm. 174 (2006) 481; hep-ph/0411186
See also D. Bardin report on the ATLAS Monte-Carlo Meeting
(February 20, 2006):
http://indico.cern.ch/conferenceDisplay.py?confId=a06589.

Outline

- **ONE-LOOP EW CORRECTIONS**
  - CHARGED CURRENT
  - NEUTRAL CURRENT
  - Present status, v.1.00
  - Comparisons:
    – 4th Les Houches Workshop Physics at TeV Colliders: DY, EW CC
    – TEV4LHC: DY, EW CC, NC
- **ONE-LOOP QCD CORRECTIONS**
- **QCD-EW INTERPLAY**
- **CONCLUSIONS**

Introduction

We will consider QCD and EW one-loop corrections to the next processes:

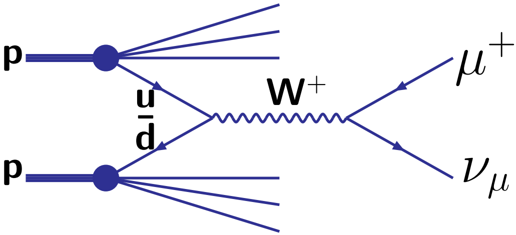
- **Neutral current Drell-Yan production:**

$$p[q] + p[\bar{q}] \to \gamma, \mathbf{Z} \to X + \ell^+ + \ell^-(+\gamma)$$
$$p[\gamma] + p[q] \to \gamma, \mathbf{Z} \to X + \ell^+ + \ell^-(+\gamma)$$
$$(\ell = e, \mu)$$

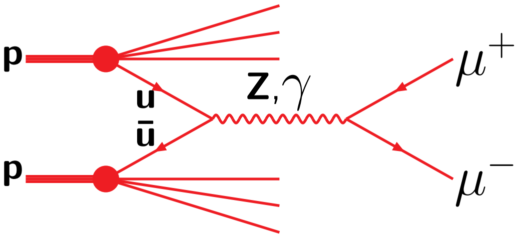
- **Charged current Drell-Yan production:**

$$p[q] + p[\bar{q}'] \to \mathbf{W}^\pm \to X + \ell^\pm + \nu_\ell(+\gamma)$$
$$p[\gamma] + p[q] \to \mathbf{W}^\pm \to X + \ell^\pm + \nu_\ell(+\gamma)$$
$$(\ell = e, \mu)$$

Born level diagrams for Drell-Yan like W and Z boson production



Charged current subprocess



Neutral current subprocess

SANC, DY, EW, CHARGE CURRENT

$$\begin{pmatrix} q\bar{q}' \\ \gamma q \end{pmatrix}$$

γ — parton!

<u>inverse bremsstrahlung</u>

SANC, DY, EW, CHARGE CURRENT

$$\begin{pmatrix} q\bar{q}' \\ \gamma q \end{pmatrix} \otimes \begin{pmatrix} p_T^{\ell} \\ M_T^{\ell\nu} \end{pmatrix}$$

$$M_T^{\ell\nu} = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos\varphi_{\ell\nu})}$$

SANC, DY, EW, CHARGE CURRENT

$$\begin{pmatrix} q\bar{q}' \\ \gamma q \end{pmatrix} \otimes \begin{pmatrix} \mathrm{p}_T^{\ell} \\ M_T^{\ell\nu} \end{pmatrix} \otimes \begin{pmatrix} e \\ \mu \end{pmatrix}$$

e — γ recombination

μ — bare

We participated in tuned comparison within
2005 Les Houches Workshop.

List of participants:

- DK — S. Dittmaier and M. Krämer (MPI)
- HORACE — C.M. Carloni Calame, G. Montagna, O. Nicrosini, A. Vicini (PAVIA)
- SANC — SANC group (JINR)
- W(Z)GRAD2 — U. Baur, D. Wackeroth (FNAL)
- **Ref.: C. Buttar et al,** *Les Houches Physics at TEV colliders 2005, Standard Model, QCD, EW and Higgs working group: Summary report, 61-67*, *hep-ph/0604120.*

Input parameters and scheme definition

The relevant input parameters are

$$G_\mu = 1.16637 \times 10^{-5}\mathrm{GeV}^{-2}, \quad \alpha(0) = 1/137.03599911,$$
$$M_W = 80.425\mathrm{GeV}, \quad \Gamma_W = 2.124\mathrm{GeV}, \quad \alpha_s = 0.1187,$$
$$M_Z = 91.1876\mathrm{GeV}, \quad \Gamma_Z = 2.4952\mathrm{GeV}, \quad M_H = 115\mathrm{GeV},$$
$$m_e = 0.51099892\mathrm{MeV}, \quad m_\mu = 105.658369\mathrm{GeV}, \quad m_\tau = 1.77699\mathrm{GeV},$$
$$m_u = 0.066\mathrm{GeV}, \quad m_c = 1.2\mathrm{GeV}, \quad m_t = 178\mathrm{GeV},$$
$$m_d = 0.066\mathrm{GeV}, \quad m_s = 150\mathrm{MeV}, \quad m_b = 4.3\mathrm{GeV}.$$
$$|V_{ud}| = 0.975, \quad |V_{us}| = 0.222,$$
$$|V_{cd}| = 0.222, \quad |V_{cs}| = 0.975,$$

The lowest order cross-section is parametrized in "G_μ scheme" ($\alpha_{G_\mu} = \sqrt{2}G_\mu M_W^2(1 - M_W^2/M_Z^2)/\pi$).
In the relative radiative corrections, however, $\alpha(0)$ is used.

We use the set of PDF's "MRST2004QED".

Phase-space cuts and events selection

The set of lepton identification cuts is

$$\mathrm{P}_{\mathrm{T}}^{\ell} > 25\mathrm{GeV}, \qquad \mathrm{P}_{\mathrm{T}}^{\mathrm{missing}} > 25\mathrm{GeV}, \qquad |\eta_{\ell}| < 1.2.$$

For electrons the following photon recombination procedure is considered:

- **Photons with a rapidity $|\eta_{\gamma}| > 2.5$ are treated as invisible.**
- **If the photon survived the first step, and if the resolution $\mathrm{R}_{\ell\gamma} = \sqrt{(\eta_{\ell} - \eta_{\gamma})^2 + \phi_{\ell\gamma}^2}$ is smaller than 0.1 then photon is recombined with the charged lepton.**

For muons bare setup is used.

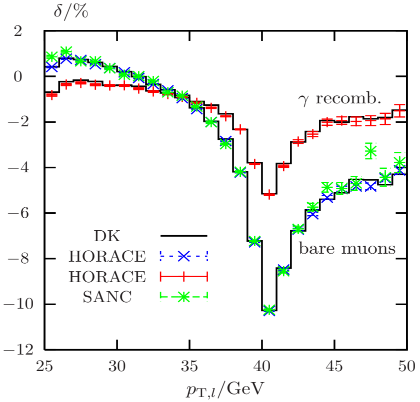
δ definition

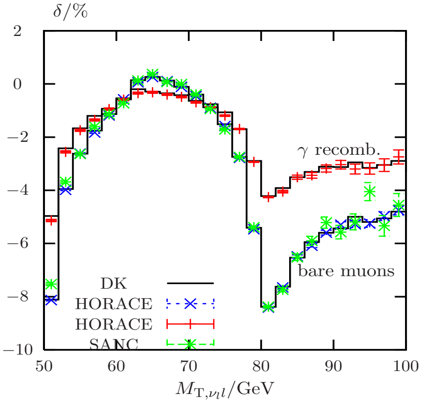
We produced the distributions for cross-section σ and correction δ, where the last is defined by $\delta = \sigma^{1-loop}/\sigma^{Born} - 1$ for NLO EW corrections

and by

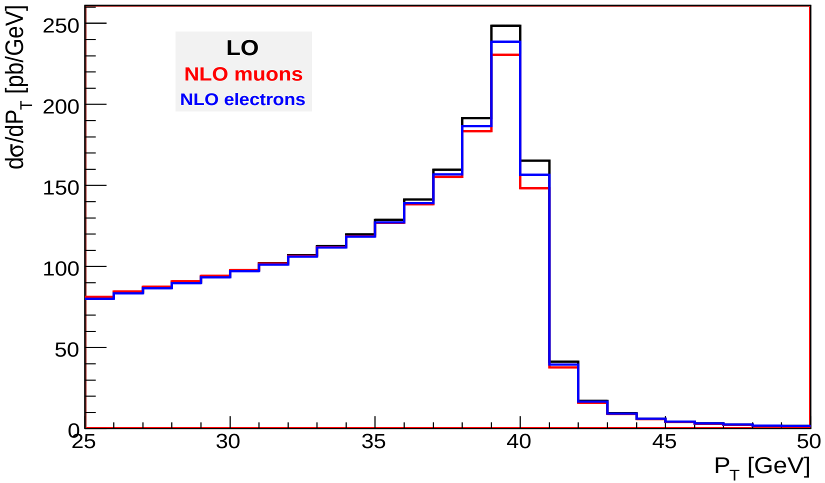
$\delta = \sigma^{\gamma q}/\sigma^{Born}$ for corrections originating from the photon induced process.

Les Houches Workshop, EW, CC, δ [%]

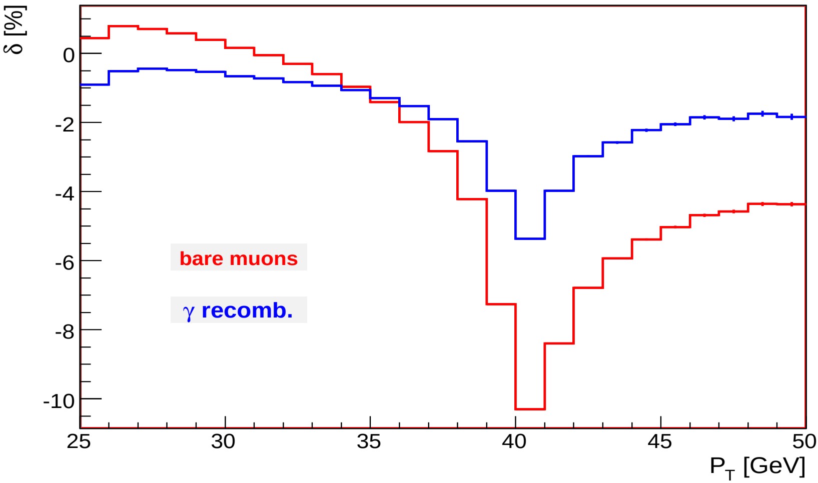




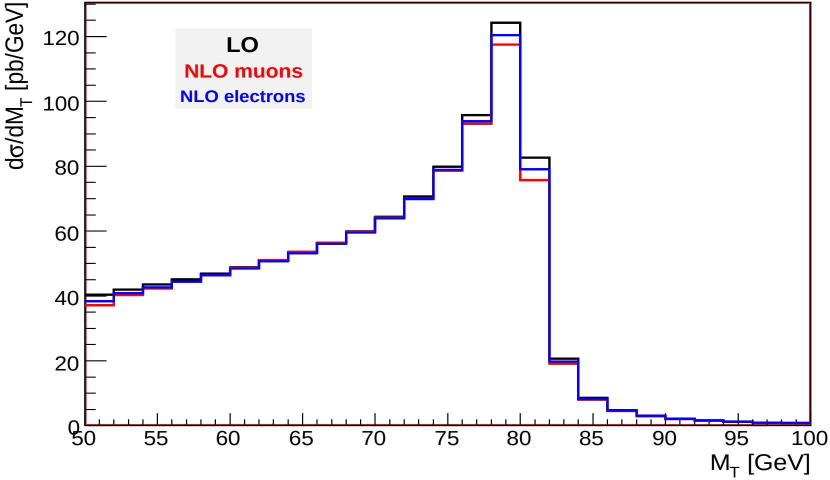
CC DY: σ, P_T^ℓ distribution



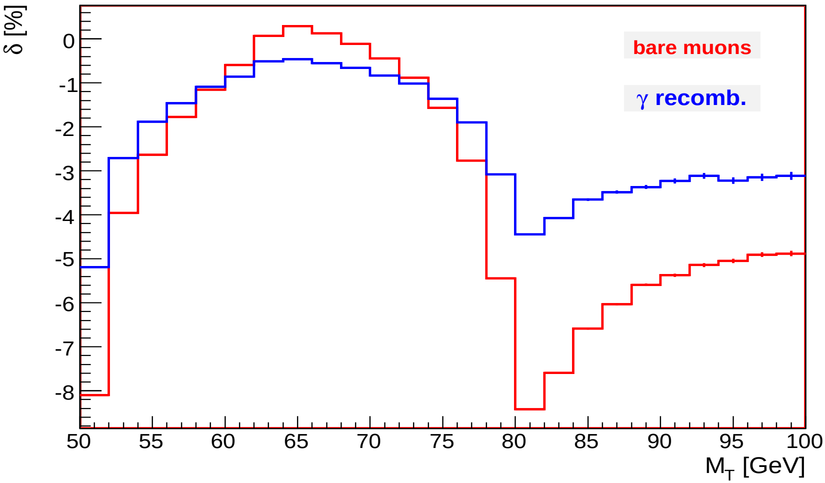
CC DY: δ, P_T^ℓ distribution



CC DY: σ, $M_T^{\ell\nu}$ distribution



CC DY: δ, $M_T^{\ell\nu}$ distribution



CC inverse bremsstrahlung: comparison between SANC and DK

$P_{T,\ell}$/GeV	$25-\infty$	$50-\infty$	$100-\infty$
σ_0/pb			
DK	+2112.2(1)	+13.152(2)	+0.9452(1)
SANC	+2112.22(2)	+13.1507(2)	+0.94506(1)
$\sigma_{\gamma q}$/pb			
DK	+1.50(2)	+0.689(1)	+0.1238(1)
SANC	+1.566(1)	+0.6890(4)	+0.12374(6)
$\delta_{\gamma q}$/%			
DK	**+0.071(1)**	**+5.24(1)**	**+13.10(1)**
SANC	**+0.07414(5)**	**+5.239(3)**	**+13.091(6)**

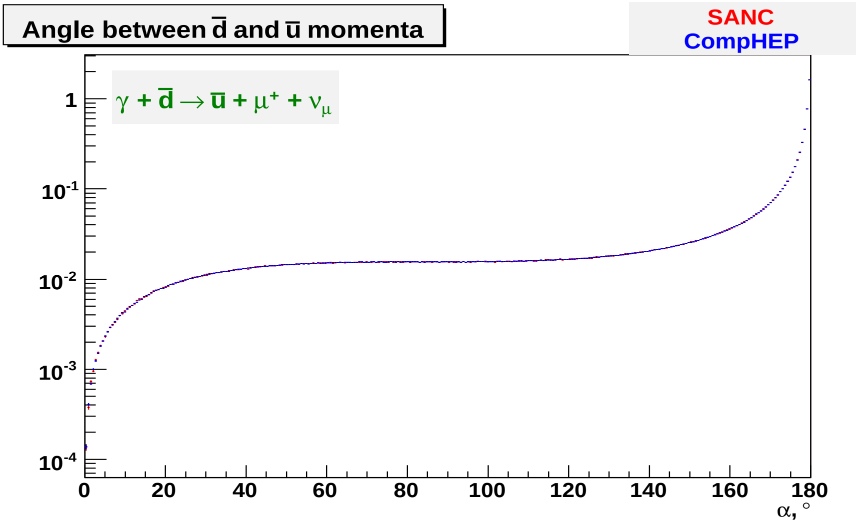
$P_{T,\ell}$/GeV	$200-\infty$	$500-\infty$	$1000-\infty$
σ_0/pb			
DK	+0.11511(2)	+0.0054816(3)	+0.00026212(1)
SANC	+0.115106(1)	+0.00548132(6)	+0.000262108(3)
$\sigma_{\gamma q}$/pb			
DK	+0.01892(2)	+0.0007839(5)	+0.00003117(3)
SANC	+0.01891(1)	+0.0007838(2)	+0.00003118(1)
$\delta_{\gamma q}$/%			
DK	**+16.44(2)**	**+14.30(1)**	**+11.89(1)**
SANC	**+16.43(1)**	**+14.300(4)**	**+11.895(4)**

CC inverse bremsstrahlung: comparison between SANC and DK

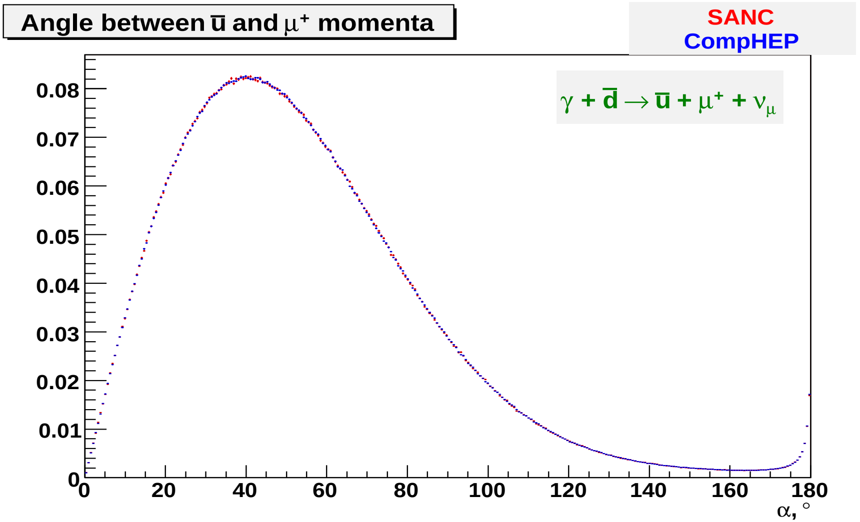
$M_{T,\nu_\ell \ell}$/GeV	$50-\infty$	$100-\infty$	$200-\infty$
σ_0/pb			
DK	+2112.2(1)	+13.152(2)	+0.9452(1)
$\sigma_{\gamma q}$/pb			
DK	+1.198(6)	+0.01772(1)	+0.002406(1)
SANC	+1.264(1)	+0.017749(3)	+0.0023976(2)
$\delta_{\gamma q}$/%			
DK	+**0.0567(3)**	+**0.1347(1)**	+**0.2546(1)**
SANC	+**0.05321(5)**	+**0.13495(2)**	+**0.25366(5)**

$M_{T,\nu_\ell \ell}$/GeV	$500-\infty$	$1000-\infty$	$2000-\infty$
σ_0/pb			
DK	+0.057730(5)	+0.0054816(3)	+0.00026212(1)
$\sigma_{\gamma q}$/pb			
DK	+0.00019241(6)	+0.000017908(5)	+0.0000008194(3)
SANC	+0.00019134(1)	+0.000017788(1)	+0.00000081102(4)
$\delta_{\gamma q}$/%			
DK	+**0.3333(1)**	+**0.3267(1)**	+**0.3126(1)**
SANC	+**0.33144(2)**	+**0.32450(2)**	+**0.30941(2)**

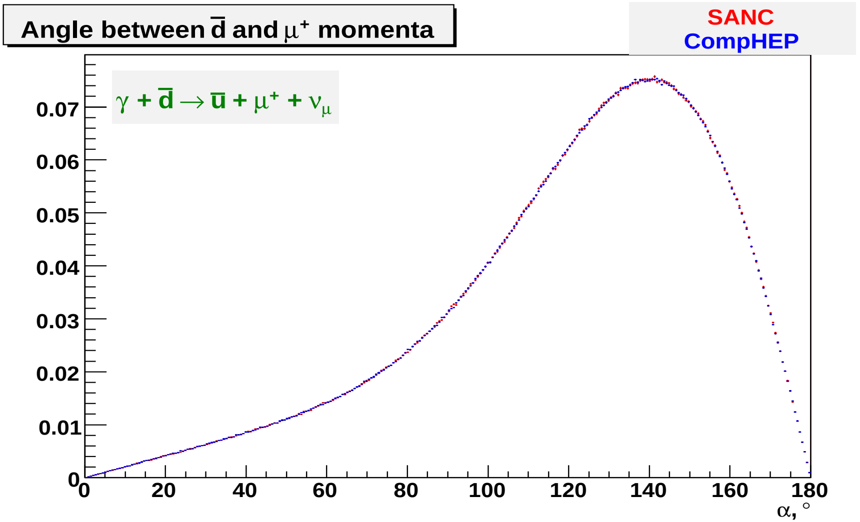
CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



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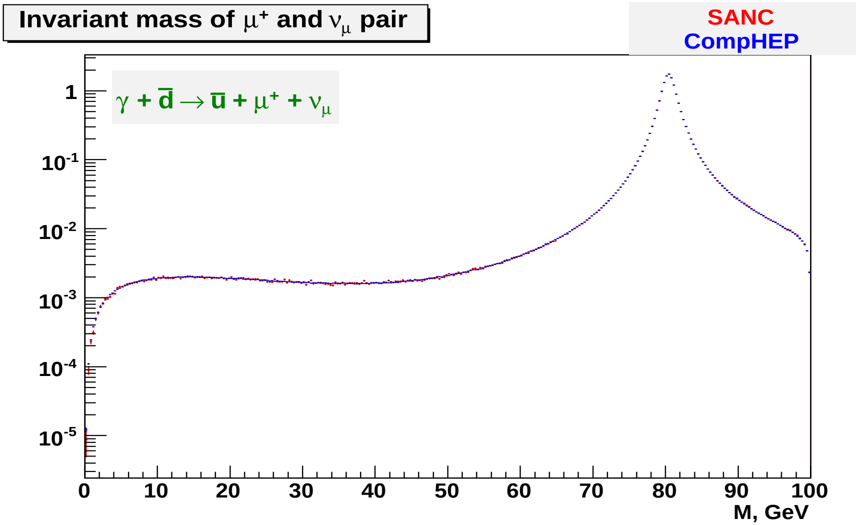

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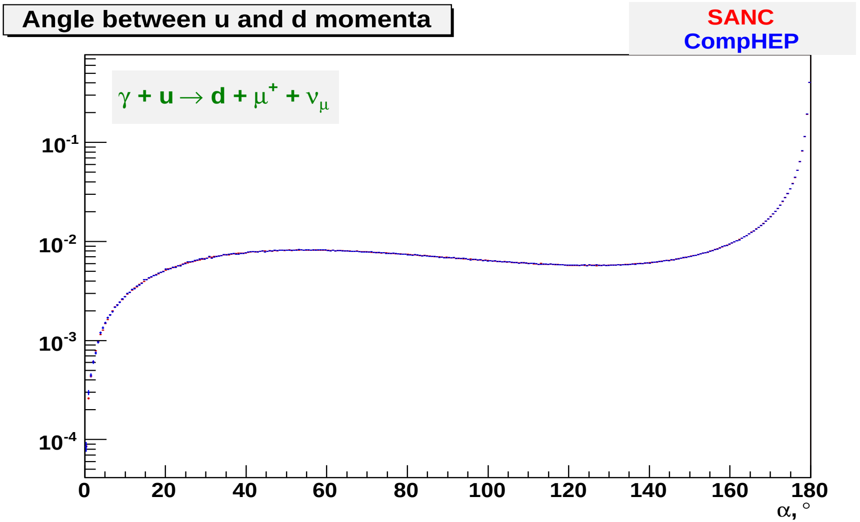
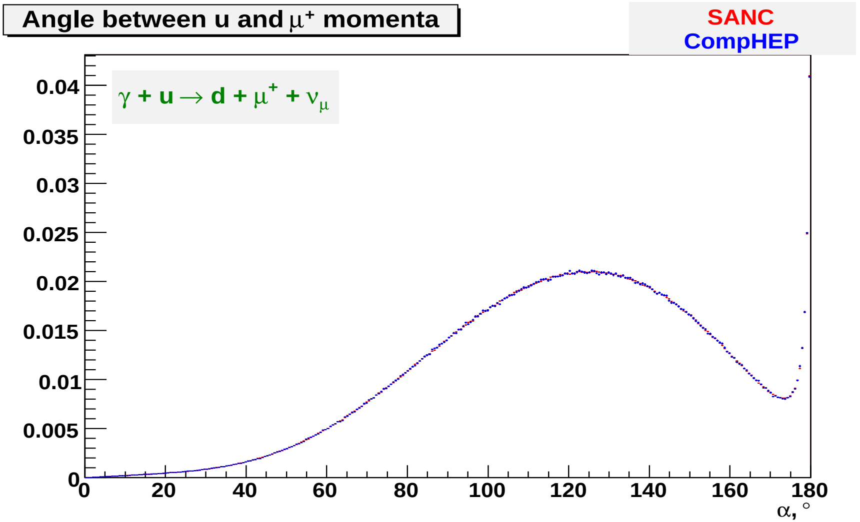
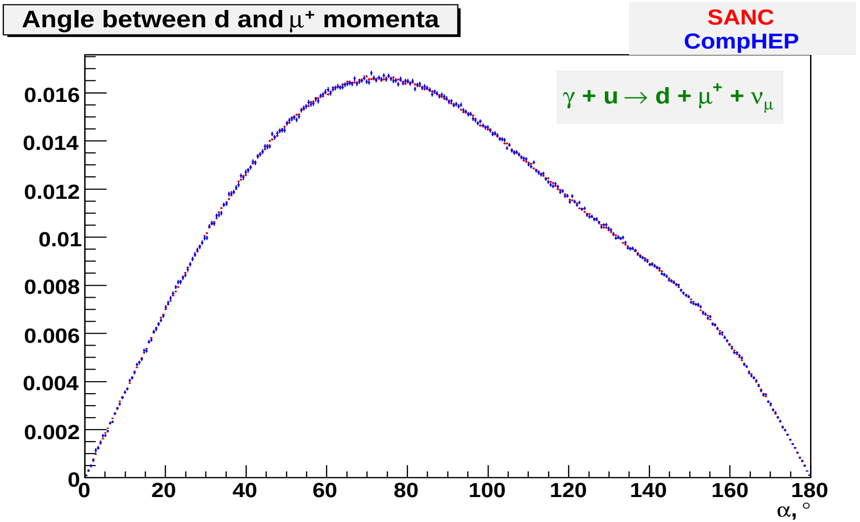


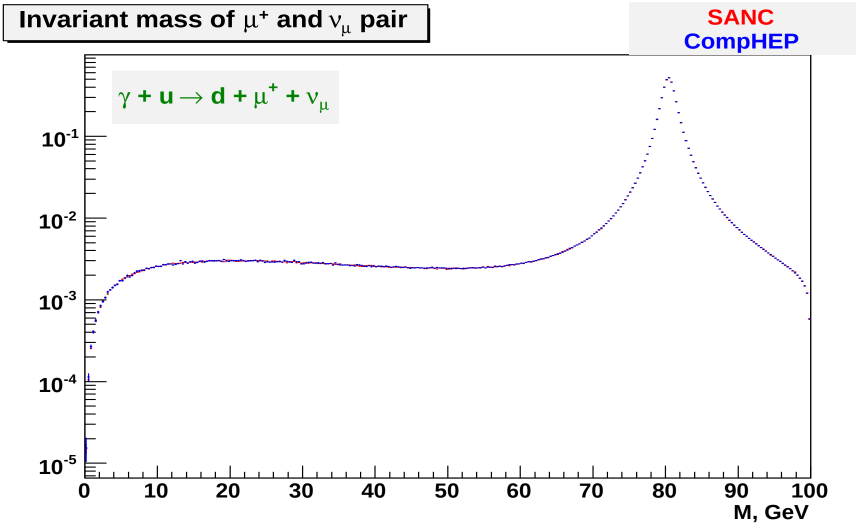
CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



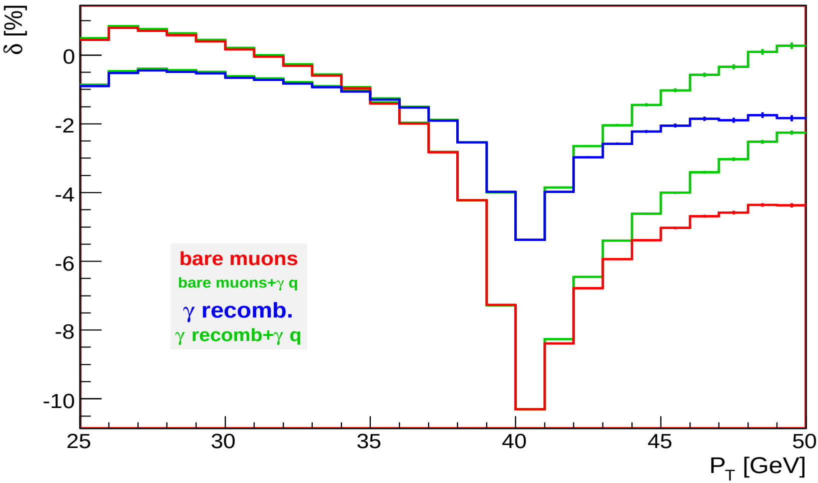
CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



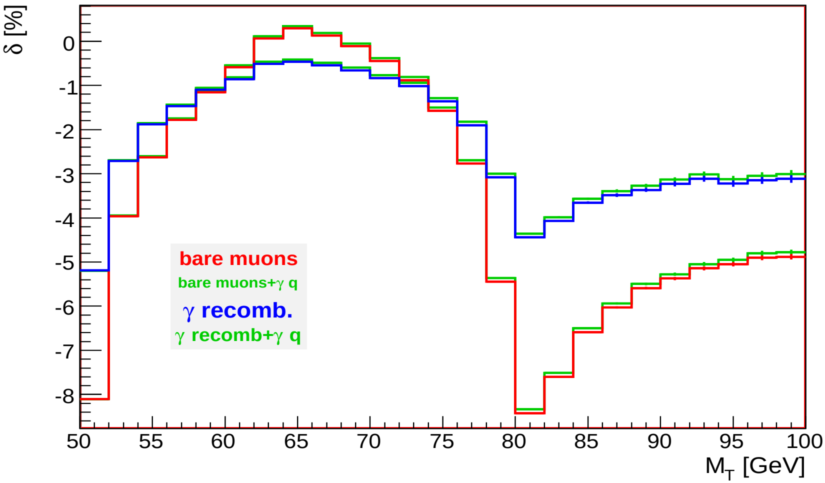
CC inverse bremsstrahlung at partonic level: comparison between SANC and CompHEP



CC DY: δ, P_T^ℓ distribution



CC DY: δ, $M_T^{\ell\nu}$ distribution



SANC, DY, EW, NEUTRAL CURRENT

$$\begin{pmatrix} q\bar{q} \\ \gamma q \end{pmatrix}$$

γ — parton!

inverse bremsstrahlung

SANC, DY, EW, NEUTRAL CURRENT

$$\begin{pmatrix} q\bar{q} \\ \gamma q \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_{\ell^+\ell^-} \end{pmatrix}$$

SANC, DY, EW, NEUTRAL CURRENT

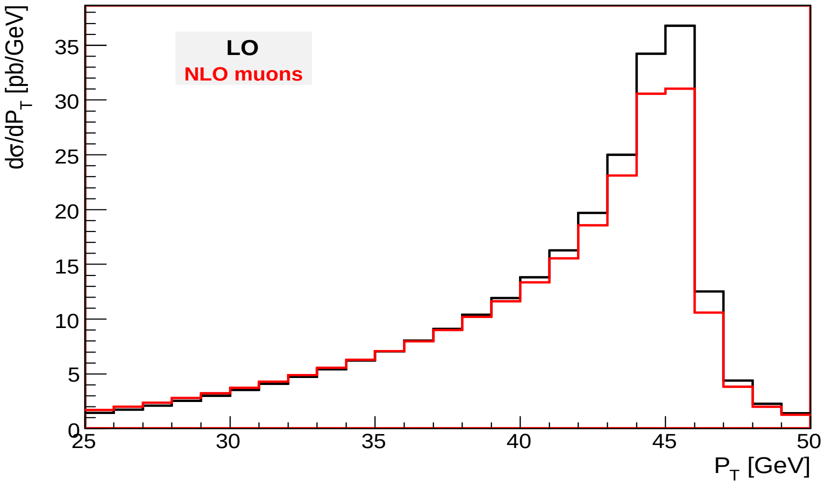
$$\begin{pmatrix} q\bar{q} \\ \gamma q \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_{\ell^+\ell^-} \end{pmatrix} \otimes \begin{pmatrix} e \\ \mu \end{pmatrix}$$

e — γ **recombination**

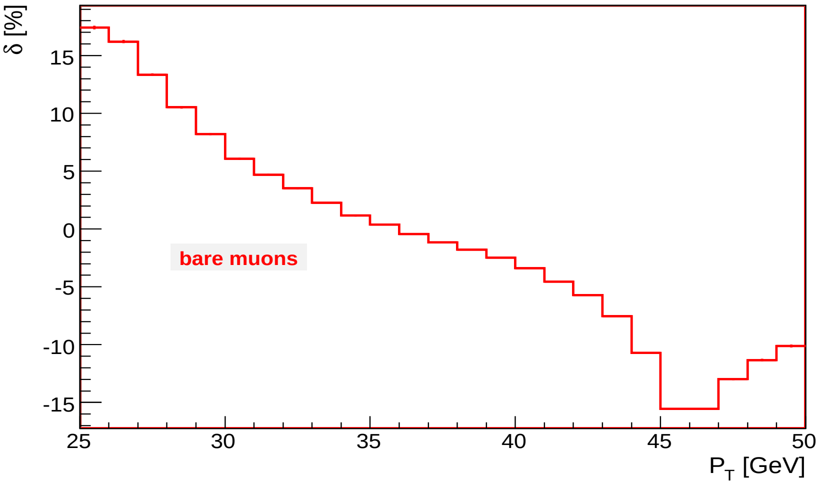
μ — **bare**

γq, e — **in progress**

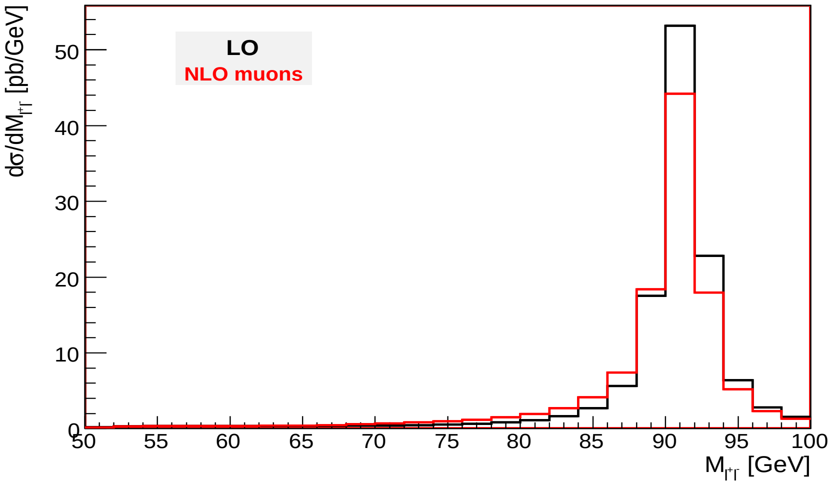
NC DY: σ, P_T^ℓ distribution



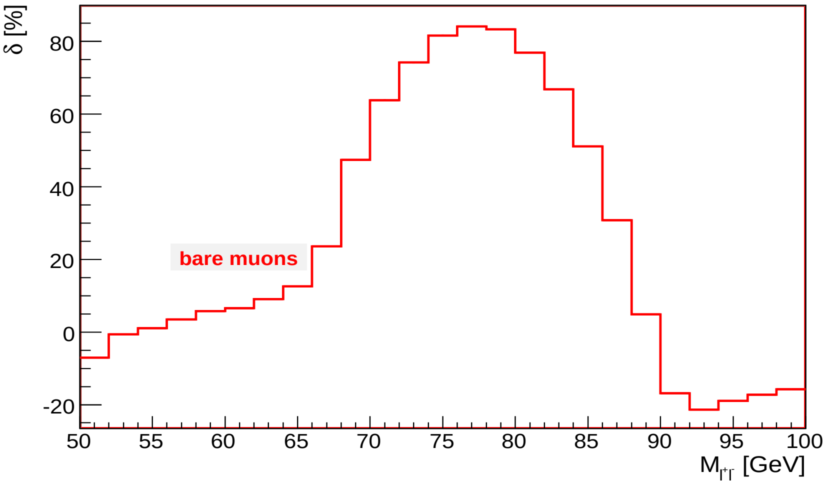
NC DY: δ, P_T^ℓ distribution



NC DY: σ, $M_{\ell^+\ell^-}$ distribution



NC DY: δ, $M_{\ell^+\ell^-}$ distribution



NC EW corrections

The corrections for NC DY invariant mass $M_{\ell^+\ell^-}$ distribution are huge around Z-resonance. This effect is well known from the world literature. See, for example

U. Baur, S. Keller, W.K. Sakumoto, *QED radiative corrections to Z boson production and the forward backward asymmetry at hadron colliders.*, Phys.Rev.D57:199-215,1998, hep-ph/9707301

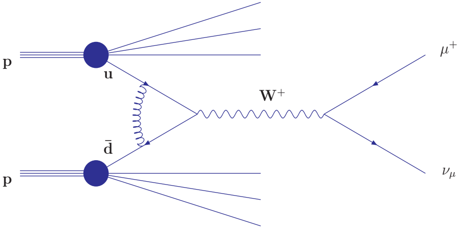
U. Baur, O. Brein, W. Hollik, C. Schappacher, D. Wackeroth, *Electroweak radiative corrections to neutral current Drell-Yan processes at hadron colliders.*, Phys.Rev.D65:033007,2002, hep-ph/0108274

We continue tuned comparison within TEV4LHC Workshop.

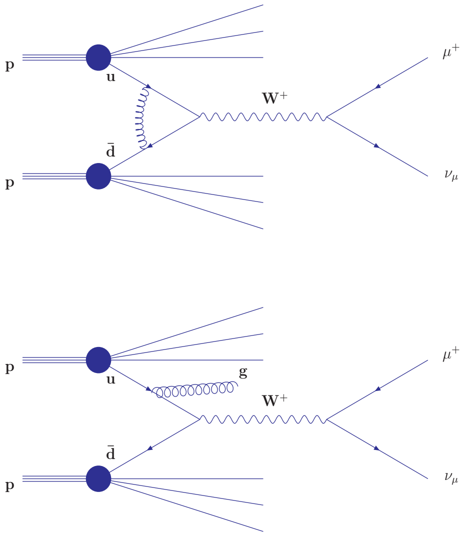
List of participants:

- HORACE — C.M. Carloni Calame, G. Montagna, O. Nicrosini, A. Vicini (PAVIA)
- SANC — SANC group (JINR)
- W(Z)GRAD2 — U. Baur, D. Wackeroth (FNAL)

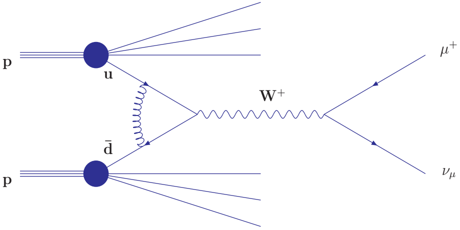
QCD NLO diagrams for DY CC

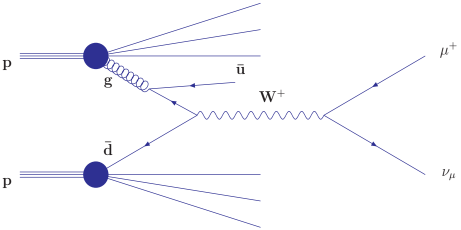


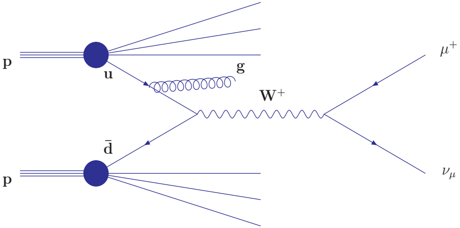
QCD NLO diagrams for DY CC



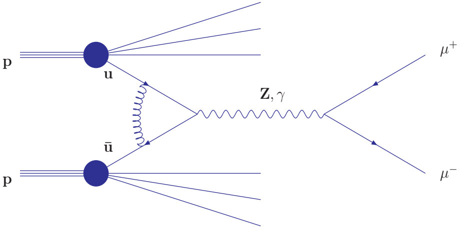
QCD NLO diagrams for DY CC

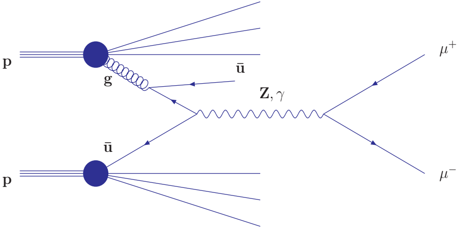


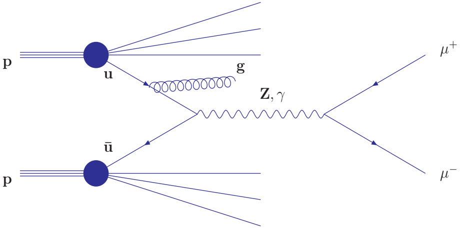




QCD NLO diagrams for DY NC







MC integrator

Using SANC system we performed analytical calculations for these processes and got FORTRAN modules at parton level. Than we created a MC integrator based on VEGAS[1] algorithm to obtain a hadron level distributions convoluting parton level cross-sections with PDF (we used MRST2004QED). Also the substraction scheme (see, for instance[2]) was applied to avoid double counting of quark mass logarithms. Presented data are obtained with Les Houches workshop input parameters and setup.

[1] G.P. Lepage, J.Comput.Phys. **27** (1978) 192.
[2] A. Arbuzov et al. Eur.Phys.J. **C 46** (2006) 407 hep-ph/0506110.

Drell-Yan process distributions

CC:

$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix}$$

Drell-Yan process distributions

CC:

$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_T \end{pmatrix}$$

Drell-Yan process distributions

CC:

$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_T \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

Drell-Yan process distributions

CC:

$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_T \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

NC:

$$\begin{pmatrix} q\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_{\ell^+\ell^-} \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

Drell-Yan process distributions

CC:

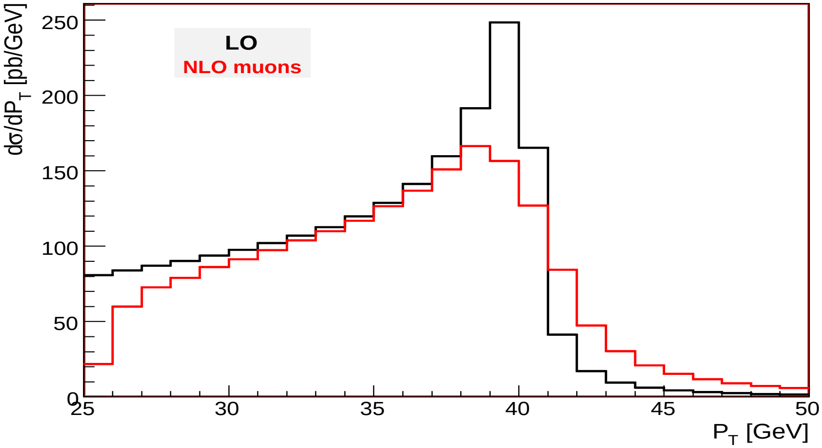
$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_T \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

NC:

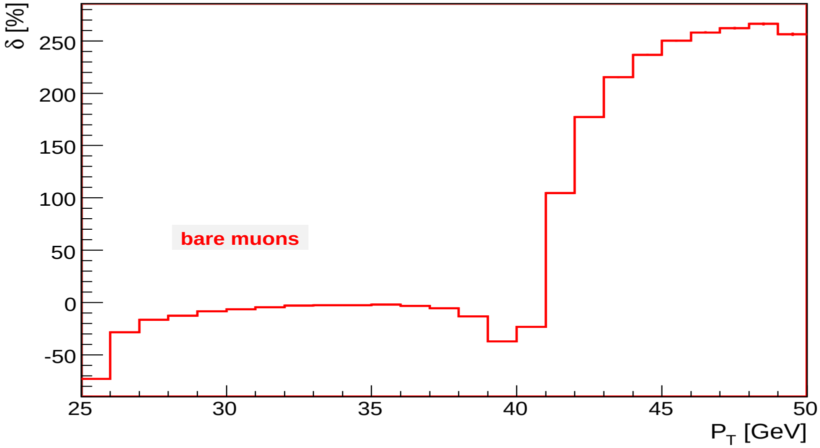
$$\begin{pmatrix} q\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_{\ell^+\ell^-} \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

almost done.

CC: σ, LO & NLO, P_T distribution

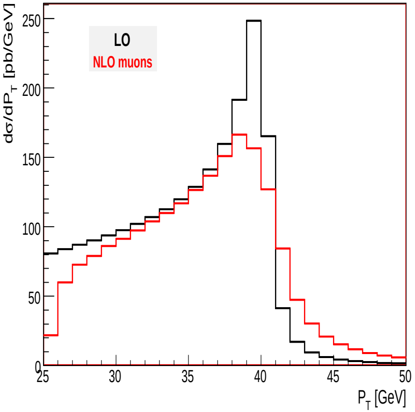


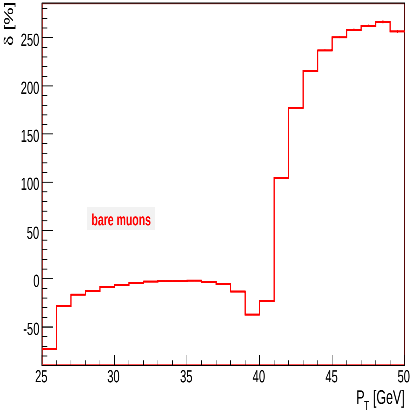
CC: δ, P_T distribution



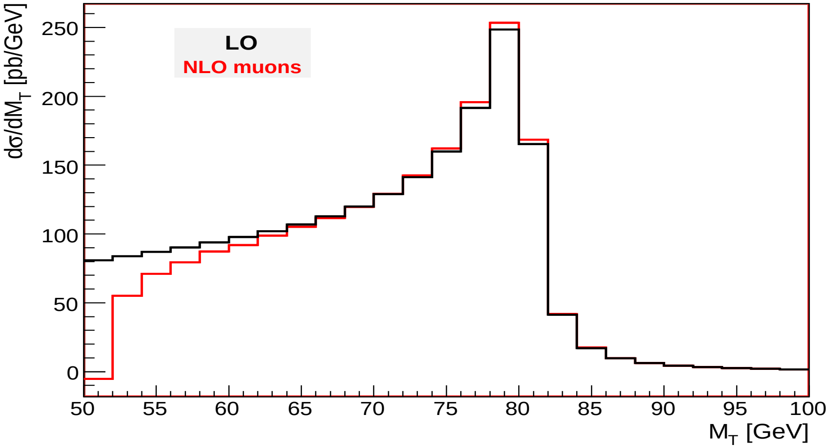
CC: σ and δ, P_T distribution

σ δ

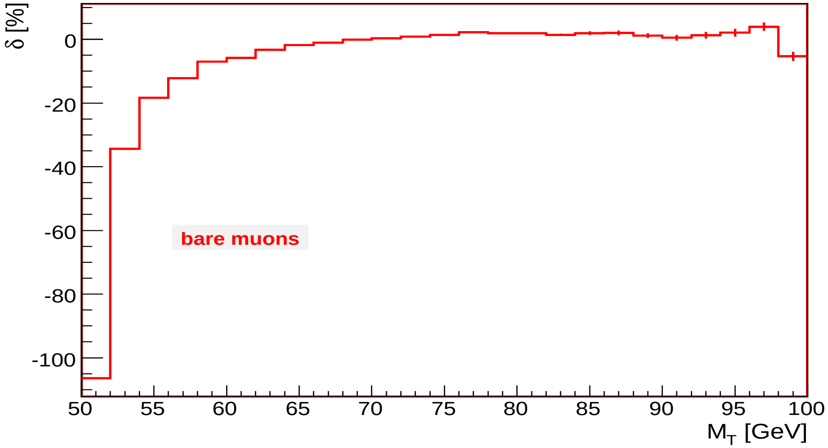




CC: σ, LO & NLO, M_T distribution



CC: δ, M_T distribution



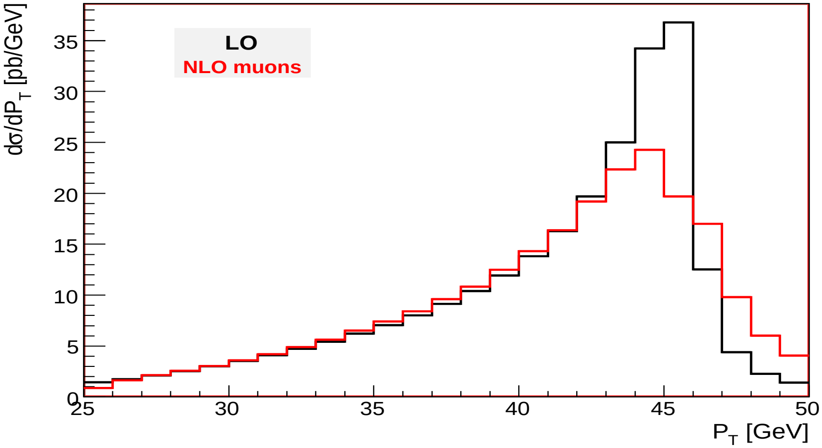
DY NC: LO & NLO distributions

NC:

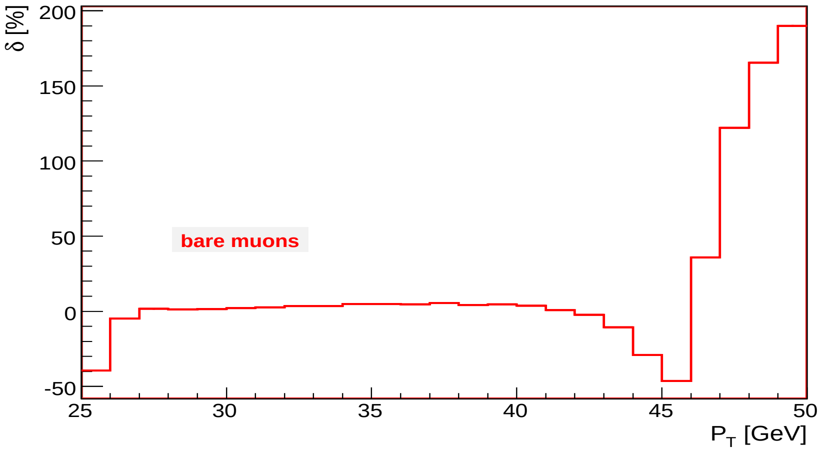
$$\begin{pmatrix} q'\bar{q} \\ gq \end{pmatrix} \otimes \begin{pmatrix} p_T \\ M_{\ell^+\ell^-} \end{pmatrix} \otimes \begin{pmatrix} \mu \\ e \end{pmatrix}$$

almost done.

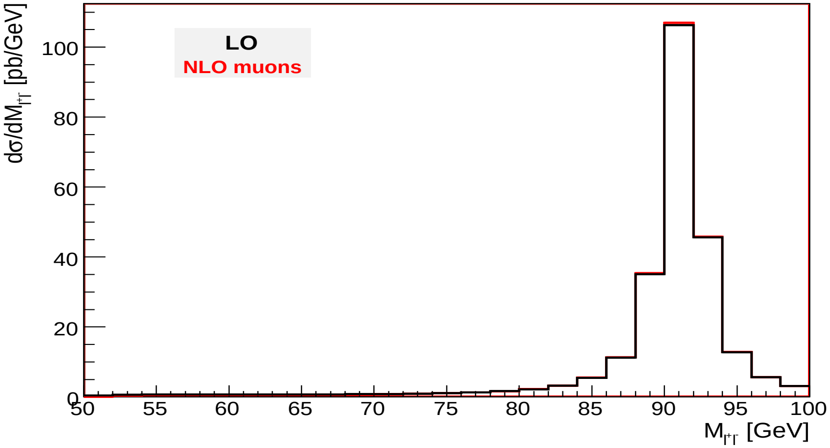
NC: σ, LO & NLO, P_T distribution



NC: δ, P_T distribution



NC: σ, LO & NLO, $M_{\ell^+\ell^-}$ distribution



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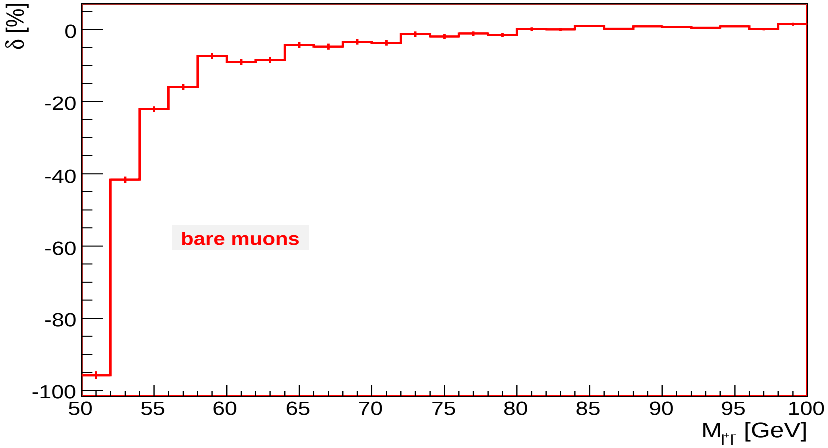
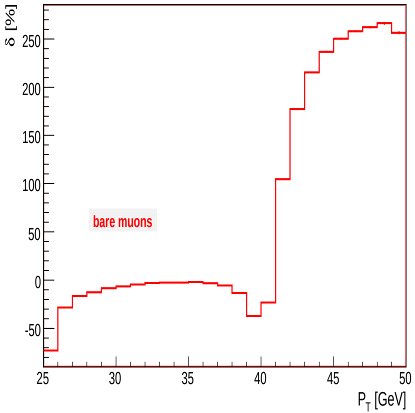
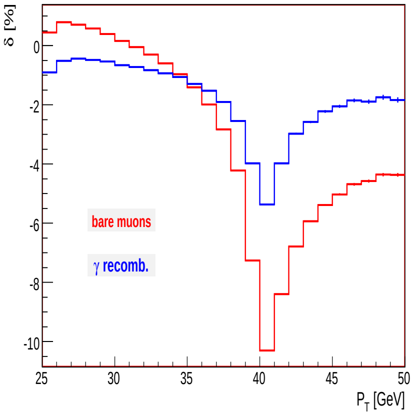


QCD-EW interplay.
CC: δ, P_T distribution

QCD



EW



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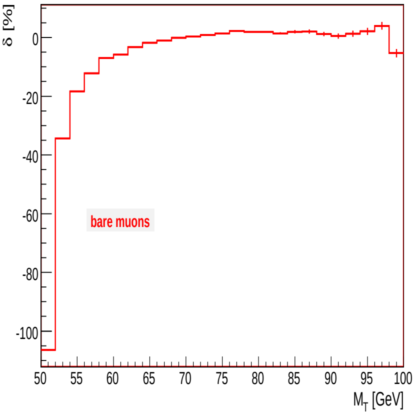
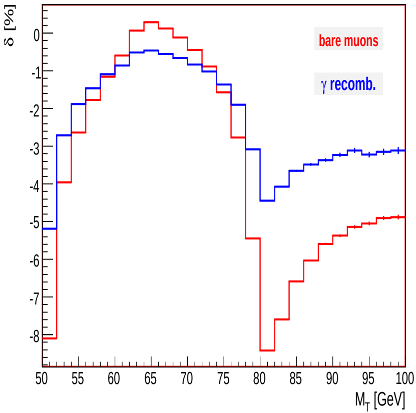


EW



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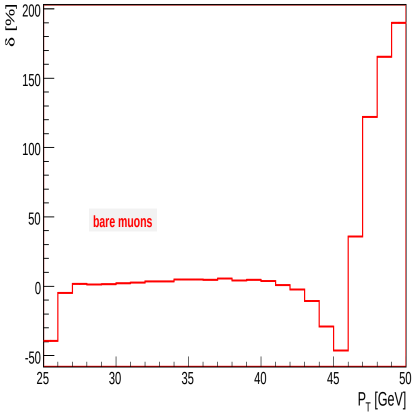

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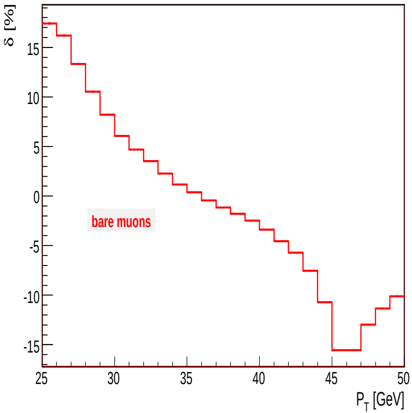

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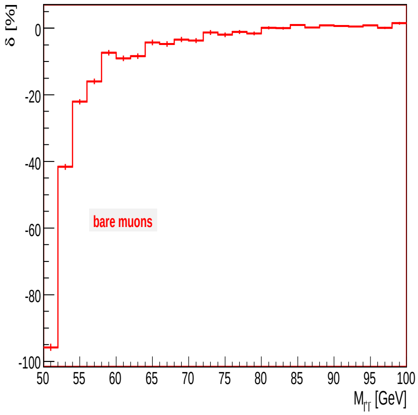
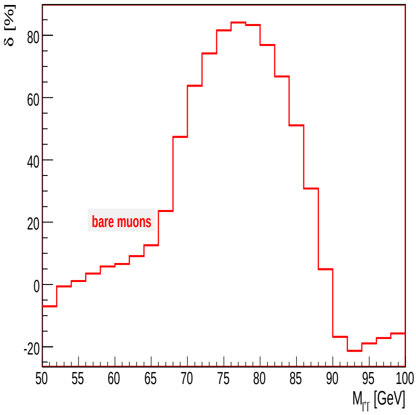


EW



Conclusions

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- to create "the best you can" (BYC) on this basement