Drell-Yan processes at LHC

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HERA & LHC

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work in collaboration with

G. Balossini, C.M. Carloni Calame, G. Montagna, M. Moretti, O. Nicrosini, M. Treccani and A. Vicini

and also with

the Les Houches 07 Dilepton Group (S. Ferrag et al.) and ATLAS Pavia

Outline

- Relevance of DY processes in precision studies at hadron colliders
- Current theoretical status
  1. QCD radiative corrections
  2. electroweak radiative corrections
- Combination EW$\oplus$QCD
- Conclusions

emphasys will be given to the high Q^2 region

Drell-Yan processes at hadron colliders

- easy detection: high $p_\perp$ leptons pair or lepton+missing $p_\perp$ (tipically look for $p_\perp > 25$ GeV in the central detector region)
- large cross sections. At LHC:
  - $\sigma(W) = 30\ nb$, i.e. 3×10^8 events with $\mathcal{L} = 10\ fb^{-1}$
  - $\sigma(Z) = 3.5\ nb$, i.e. 3.5×10^7 events with $\mathcal{L} = 10\ fb^{-1}$
  - no statistics limitations for precision physics
- main physics motivations (DY processes are considered "standard candles")
  - ⋆ detectors calibration
  - ⋆ PDF validation and constraint
  - ⋆ W mass and Γ measurement
  - ⋆ collider luminosity monitoring (as done at LEP with Bhabha)
  - ⋆ background to New Physics searches
- Precise theoretical prediction are strongly required

Linking theory and experiment

$$\sigma^{\text{exp}} \equiv \frac{1}{\int \mathcal{L} dt} \frac{N^{obs} - N^{bkg}}{A\ \epsilon} =$$

$$\sigma^{\text{theory}} \equiv \sum_{a,b} \int_0^1 dx_1 dx_2 f_{a,H_1}(x_1, \mu_F^2, \mu_R^2) f_{b,H_2}(x_2, \mu_F^2, \mu_R^2) \times$$
$$\times \int_\Phi d\sigma_{a,b}^h(x_1, x_2, Q^2/\mu_F^2, Q^2/\mu_R^2)$$

With DY processes, we can

- ⋆ monitor the collider luminosity, the parton luminosities, measure the PDFs
  - relevant observables: total cross section, W and Z rapidity distribution, lepton(s) rapidity distribution
  - an accuracy of $\mathcal{O}(1\%)$ is required/achievable

Frixione & Mangano '04 and refs. therein

- ⋆ measure the W mass and width from M_T^W distribution
- ⋆ discover deviations from SM physics in the distribution tails

Status of QCD calculations (& tools)

- NLO/NNLO corrections to W/Z total production rate

  G. Altarelli, R.K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. **B246** (1984) 12

  R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. **B359** (1991) 343

  W.L. van Neerven and E.B. Zijlstra, Nucl. Phys. **B382** (1992) 11

- fully exclusive NLO corrections to W/Z production (**FEWZ**, **MCFM**)

  J. M. Campbell and R.K. Ellis, Phys. Rev. **D65** 113007

- fully exclusive NNLO corrections to W/Z production (**FEWZ**)

  C. Anastasiou et al., Phys. Rev. **D69** (2004) 094008

  K. Melnikov and F. Petriello, Phys. Rev. Lett. **96** (2006) 231803

- resummation of LL/NLL p_T^V/M_V logs (**RESBOS**)

  C. Balazs and C.P. Yuan, Phys. Rev. **D56** (1997) 5558

- NLO merged with **HERWIG** Parton Shower [PS] (**MC@NLO**)

  S. Frixione and B.R. Webber, JHEP **0206** (2002) 029

- NLO merged with any PS (**POWHEG**)

  Frixione Nason Ridolfi Oleari

- ME MC (**ALPGEN**, **SHERPA**, **MADEVENT**,...) matched with PS

  M.L. Mangano et al., JHEP **0307**, 001 (2003)

EW calculations for W & tools

- $\mathcal{O}(\alpha)$ electroweak corrections to W production
  - ⋆ Pole approximation ($\sqrt{\hat{s}} = M_W$)
    - ⟶ D. Wackeroth and W. Hollik, PRD **55** (1997) 6788
    - ⟶ U. Baur et al., PRD **59** (1999) 013002
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - ⟶ V.A. Zykunov et al., EPJC **3** 9 (2001)
    - ⟶ S. Dittmaier and M. Krämer, PRD **65** (2002) 073007
    - ⟶ U. Baur and D. Wackeroth, PRD **70** (2004) 073015
    - ⟶ A. Arbuzov, et al., EPJC **46**, 407 (2006)
    - ⟶ C.M. Carloni Calame. et al., JHEP 0612:016 (2006)
    - ⟶ S. Brensing et al., arXiv:0710.2209[hep-ph]

DK
WGRAD2
SANC
HORACE

- Multi-photon radiation
  - ⟶ C.M. Carloni Calame et al., PRD **69**, 037301 (2004);
    JHEP 0612:016 (2006)
  - ⟶ S. Jadach, W. Płaczek, EPJC **29** 325 (2003)

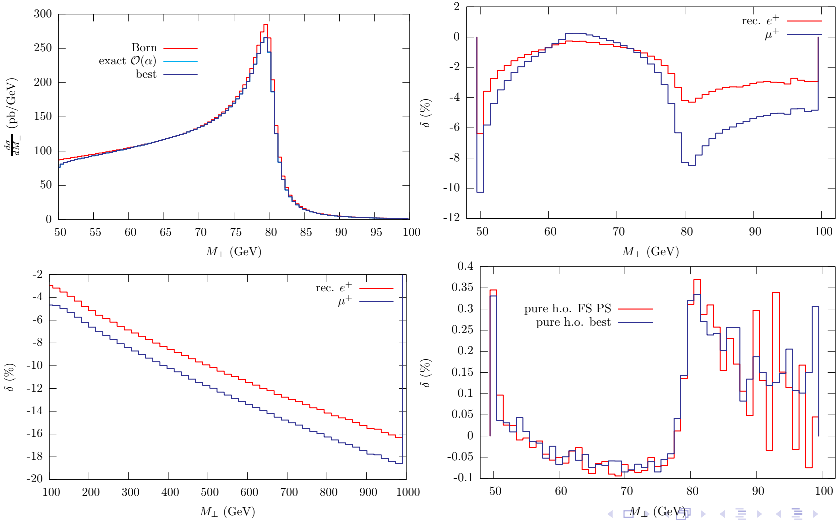
HORACE
WINHAC

EW calculations for Z

- $\mathcal{O}(\alpha)$ electroweak corrections to Z production
  - ⋆ QED corrections
    - → U. Baur, *et al.*, Phys. Rev. **D57** (1998) 199 (**ZGRAD**)
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - → U. Baur, *et al.*, Phys. Rev. **D65** (2002) 033007 (**ZGRAD2**)
    - → C.M. Carloni Calame et al, JHEP 0710:109 (2007) (**HORACE**)
    - → Bardin et al., **arXiv:0711.0625 [hep-ph]** (**SANC**)
- Multi-photon radiation
  - → C.M. Carloni Calame et al., JHEP 0505:019 (2005); JHEP 0710:109 (2007) (**HORACE**)
  - → W. Płaczek et al., in preparation (**ZINHAC**)
  - → K. Hamilton and P. Richardson, JHEP **0607** (2006) 010 (SOPHTY → HERWIG++)
  - → P. Golonka and Z. Was, Eur. Phys. J. **C45** (2006) 97 (PHOTOS)

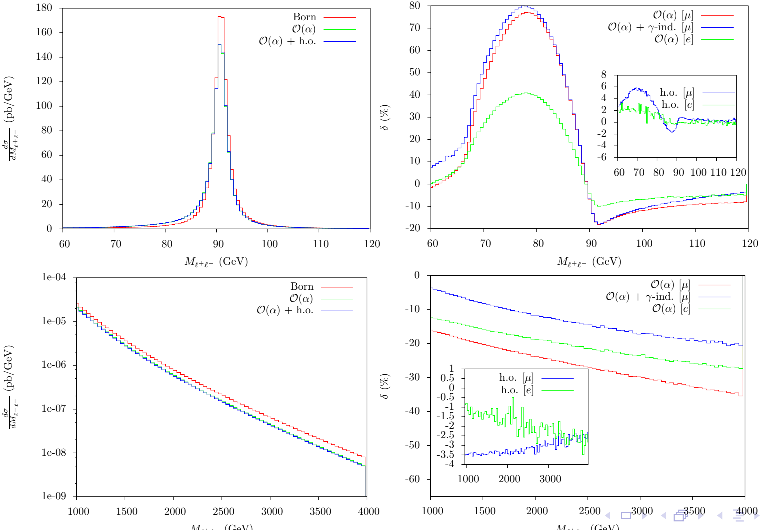
EW effects for W

- M_T^W distribution, $\mathcal{O}(\alpha)$ effect at peak and in the tail, h.o. QED effects at peak



EW effects for Z

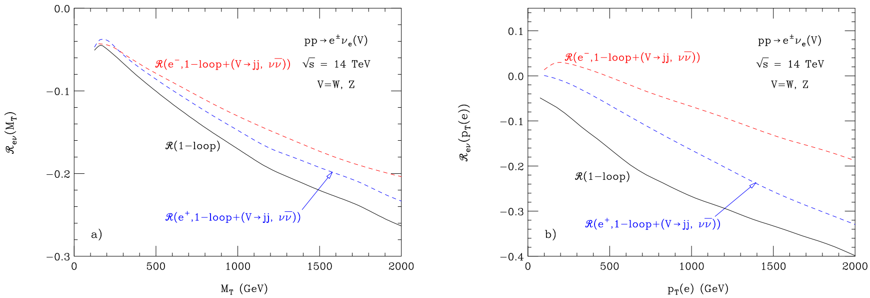
- $M_{\ell^+\ell^-}$ distribution, $\mathcal{O}(\alpha)$ effect at peak and in the tail, h.o. QED effects at peak



Emission of real weak bosons

U. Baur, Phys. Rev. **D** 75:013005, 2007

- ⋆ virtual weak corrections induce large negative effects due to Sudakov (logs)^2 in the high Q^2 region
- real radiation of (undetected) real vector bosons (partially) cancels the Sudakov effect
- e.g., $pp \to e^+\nu_e V + X \quad V \equiv W, Z \quad V \to jj, \nu\bar{\nu}, \ldots$



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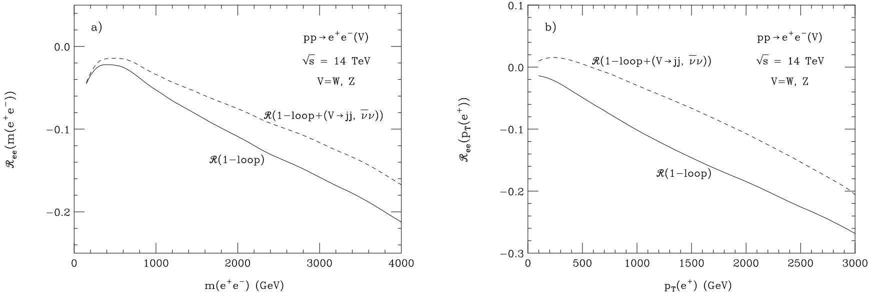


- partial cancellation of Sudakov (logs)^2 by real vector boson radiation

Combining EW and QCD corrections I

- First attempt: combination of soft-gluon resummation with NLO final-state QED corrections (RESBOS-A)

Cao and Yuan PRL 93 042001 (2004) and `hep-ph/0401171`

- QCD and QED corrections can be combined in a YFS resummation framework, taking into account shower/matrix element matching

B.F.L. Ward and S.A. Yost, Acta Phys. Polon. **B38** (2007) 2395

- New parton shower MC for W/Z production at LHC, combining Constrained MC's for the evolution of single hadron beam into a single MC for IS QCD radiation under development (QCD@NLO, EW and FSR ME, ...)

S. Jadach, W. Placzek, M. Skrzypek, P. Stephens and Z. Was, Acta Phys. Polon. **B38** (2007) 2305 and refs. therein

Combining EW and QCD corrections II

work in progress: Balossini, Carloni Calame, Montagna, M. Moretti, Nicrosini, F.P., Treccani, Vicini

- our exercise (preliminary results) is based on the following formula

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{QCD}\oplus\text{EW}} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{best QCD}} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{best EW}} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{Born}}\right\}_{\texttt{HERWIG}\text{ PS}}$$

- best QCD ⇒ **MC@NLO**, **ALPGEN** (with PS matching according to MLM prescription, `0+1 jet`, `0+1+2 jets`)
- EW part (**HORACE**) is interfaced to **HERWIG** PS (EW $\oplus$ QCD LL)
    - ⋆ NLO EW is convoluted with QCD LL parton shower ⇒ $\mathcal{O}(\alpha\alpha_s)$ corrections not reliable where hard non log QCD corrections are important (e.g. high $p_\perp$ lepton distribution without cut on the W transverse mass). In this case a two-loop calculation needed for a sound estimate of $\mathcal{O}(\alpha\alpha_s)$ effects

⋆ not suited for true event generation...

Monte Carlo tuning: Tevatron and LHC

Monte Carlo	ALPGEN	FEWZ	HORACE	ResBos-A
$\sigma_{\rm LO}$ (pb)	906.3(3)	906.20(16)	905.64(4)	905.26(24)

Table: MC tuning at the Tevatron for the LO cross section with cuts of the process $p\bar{p} \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, using CTEQ6M with $\mu_R = \mu_F = \sqrt{x_1 x_2 s}$

Monte Carlo	ALPGEN	FEWZ	HORACE
$\sigma_{\rm LO}$ (pb)	8310(2)	8304(2)	8307.9(2)

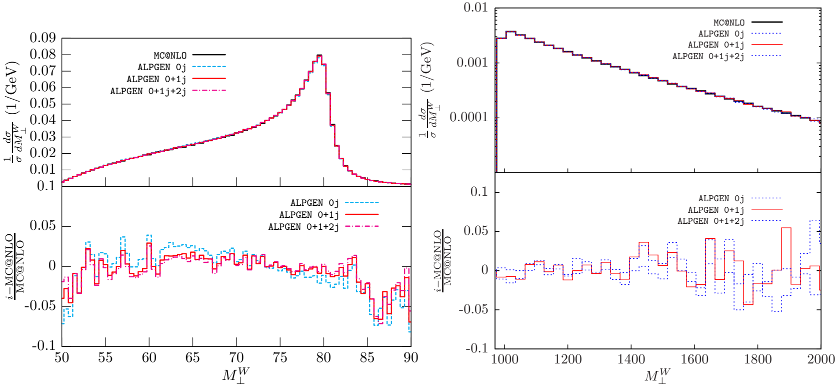
Table: MC tuning at the LHC for the LO cross section with cuts of the process $pp \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, using MRST2004QED with $\mu_R = \mu_F = \sqrt{p_{\perp,W}^2 + M_W^2}$

Monte Carlo	$\sigma_{\rm NLO}^{\rm Tevatron}(\rm pb)$	$\sigma_{\rm NLO}^{\rm LHC}(\rm pb)$
MC@NLO	2638.8(4)	20939(19)
FEWZ	2643.0(8)	21001(14)

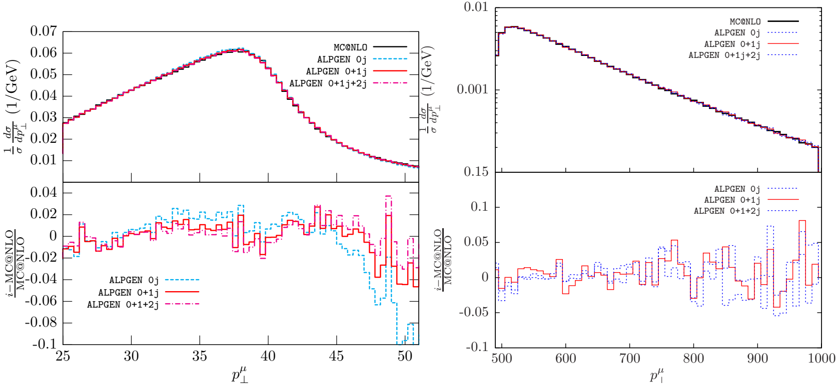
Table: MC tuning for MC@NLO and FEWZ NLO inclusive cross sections of the process $\overset{(-)}{p}p \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, with CTEQ6M (Tevatron) and MRST2004QED (LHC)

★ After appropriate “tuning”, and with same input parameters, cuts and PDFs, Monte Carlos agree at $\sim 0.1\%$ level (or better) ★

QCD @ LHC: M_T^W



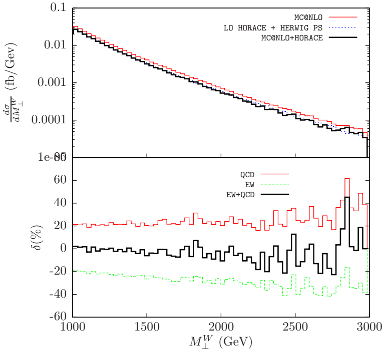
- each distribution normalized to its cross section (shape differences)

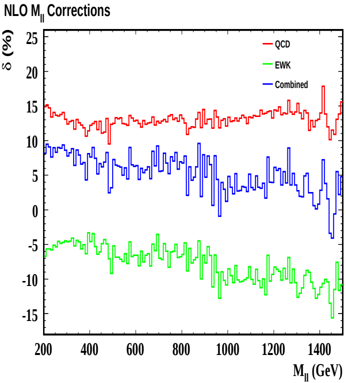


- each distribution normalized to its cross section

⋆ $p_\perp$ distribution obtained requiring $M_T^W > 1$ TeV

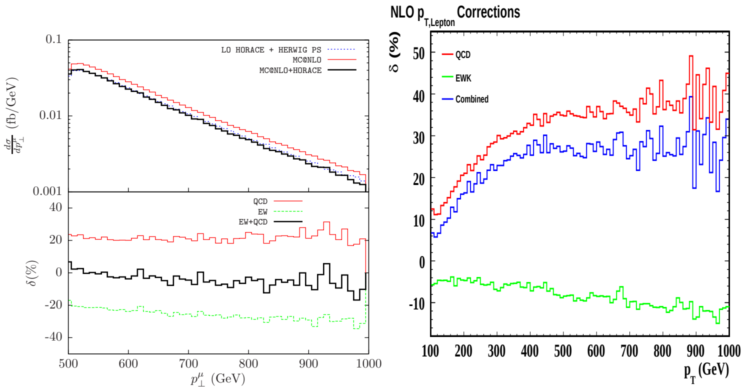
QCD $\oplus$ EW @ LHC: M_T^W and M_{l+l-}





- absolute distributions
- strong cancellation between QCD and EW corrections

QCD $\oplus$ EW @ LHC: $p_\perp^\mu$ for W and Z



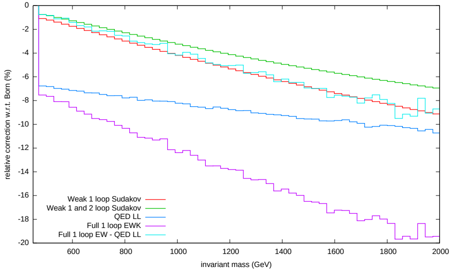
- absolute distributions

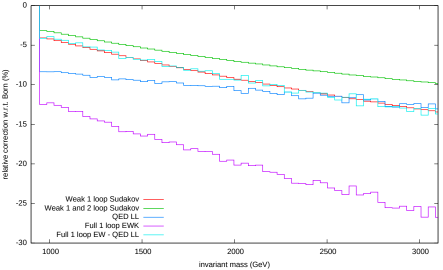
⋆ $p_\perp$ distribution obtained requiring $M_T^W > 1$ TeV

EW⊕QCD for Z production

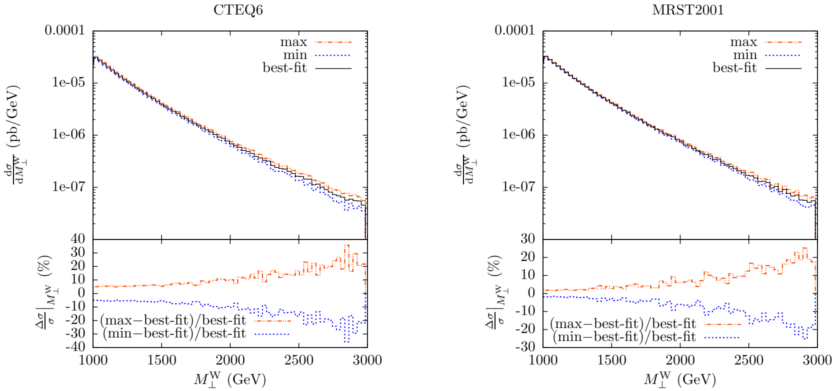
- ⋆ considering also 2-loop weak Sudakov effects

B. Jantzen, S. Pozzorini



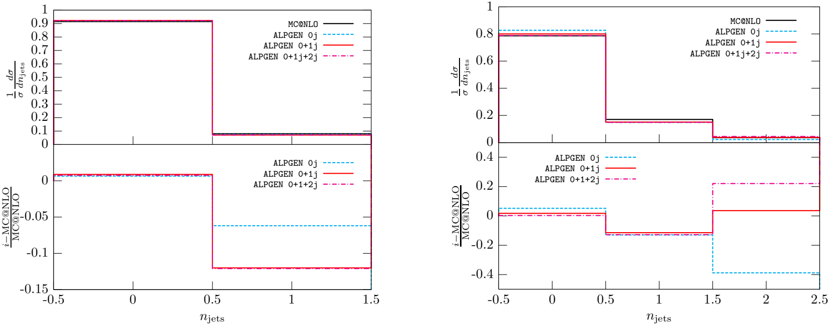


PDF uncertainties at large Q^2



- large uncertainty from the sea at large x

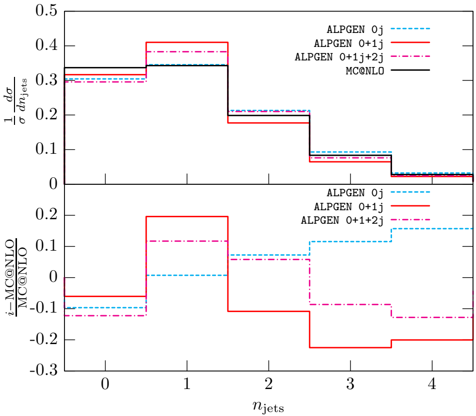
★ How many jets are present with W production events for standard selection cuts? ★



- Tevatron: $\sim 91\%$ W events without extra jets; $\sim 8\%$ with one extra jet
- LHC: $\sim 79\%$ W events without extra jets; $\sim 17\%$ with one extra jet; $\sim 3\%$ with two extra jets

Jet multiplicity @ the LHC ($M_\perp^W > 1$ TeV)

★ How many are the jets present in association with W production events in the region of interest for new physics searches? ★



- In the high transverse mass region at the LHC: $\sim 30\%$ W events without extra jets; $\sim 40\%$ with one extra jet; $\sim 20\%$ with two extra jets; $\sim 8\%$ with three extra jets; $\sim 2\%$ with four extra jets

Conclusions

- Drell-Yan processes will be “standard candles” processes at LHC
- they’ll help to understand machine & detectors
- and will be used as calibration tools (in particular Z)
- important precision physics can be carried out
  - ⋆ very precise M_W direct measurement
  - ⋆ constraints on PDFs
  - ⋆ precise evaluation of collider luminosity
- they play a key role in the direct and indirect search for BSM physics
- theoretical predictions need to match the required accuracy. All the relevant SM effects and RC have to be well under control
  - ⋆ QCD corrections
  - ⋆ Electro-Weak corrections
  - ⋆ PDF knowledge at large x (for large Q^2 region)