Electroweak radiative corrections to Drell-Yan processes in SANC

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Outline

- Motivation for Drell-Yan studies
- The SANC project
- Theoretical description of DY
- Electroweak corrections
- Description of FSR
- Results for Φ^* distribution
- Conclusions

Motivation

- LHC is *not only a discovery* machine
- SM single W and Z production at LHC have *large cross sections* and *clear signatures*
- The best LHC experimental precision below 1%
- CC and NC Drell-Yan processes are used for
  - luminosity monitoring;
  - W mass and width measurement;
  - extraction of parton density functions;
  - detector calibration;
  - background to many other processes;
  - new physics searches
- Are we ready to provide an adequately accurate theoretical description of Drell-Yan?

SANC Project

SANC: a project to Support of Analytic and Numeric calculations for experiments at Colliders

- SANC web-sites: http://sanc.jinr.ru, http://pcphsanc.cern.ch
- A. Andonov et al., *"SANCscope - v.1.00,"* Comput. Phys. Commun. **174** (2006) 481
- A. Andonov et al., *"Standard SANC Modules,"* Comput. Phys. Comm. **181** (2010) 305
- D. Bardin et al., *"Implementation of SANC EW corrections in WINHAC Monte Carlo generator,"* Acta Phys. Pol. B **40** (2009) 75
- SANC: Integrate Development Environment (IDE) for calculations of one-loop radiative corrections
- SANC2 project: to make SANC more flexible and scalable

Description of Drell-Yan like processes

Aiming at high precision of DY description we need:

- QCD in LO, NLO and NNLO
- Parton shower and hadronisation effects
- EW radiative corrections in one-loop at least
- Most important higher order effects (resummed where possible)
- Interplay of QCD and EW effects
- Input: coupling constants, hadronic vacuum polarization, and PDFs for the appropriate energy scales and x-values
- All relevant effects to be implemented in a Monte Carlo event generator(s)

Drell-Yan in SANC

Automatized analytic calculations in `SANC` provide `FORM` and `FORTRAN` modules, which can be downloaded and used in a stand-alone mode (see Comput. Phys. Comm.'09 and the SANC web-site)

For the CC and NC Drell-Yan in SANC we have:

– Complete one-loop EW RC [A.A. et al., EPJC'06 (CC DY); EPJC'08 (NC DY)]

– Photon induced DY processes [A.A. & R.S., JETP'08]

– Complete one-loop (NLO) QCD [A.Andonov et al., Yad. Fiz.'10; Phys.Part.Nucl.Lett.'07]

– Interface to parton showers in PYTHIA and HERWIG [P.Richardson, R.Sadykov, A.Sapronov, M.Seymour, P.Skands, *"QCD parton showers and NLO EW corr. to DY,"* JHEP'12]

– Higher order photonic and pair FSR in LLA

– MC integrator and MC event generator

Some features of calculations

- The total one-loop EW cross-section consists of the following terms:

$$\sigma^{1-loop} = \sigma^{Born} + \sigma^{virt}(\lambda) + \sigma^{soft}(\bar{\omega}, \lambda) + \sigma^{hard}(\bar{\omega}).$$

  The auxiliary parameters $\bar{\omega}$ and λ cancel out after summation.

- The calculation of the complete set of Feynman diagrams is realized within `SANC` environment.
- The Passarino–Veltman reduction is applied.
- For virtual corrections we use `SANC` and `LoopTools` libraries.
- *On-shell* singularities are regularized by the W-width: $\log(s^{'} - M_W^2 + i\epsilon) \to \log(s^{'} - M_W^2 + iM_W\Gamma_W)$.

Quark mass singularities

One-loop QED RC to the partonic DY processes contain terms proportional to logarithms of quark masses $\log \frac{s}{m_q^2}$. But this terms are also effectively taken into account in QED evolution of PDF's. To avoid double-counting we should subtract them either from the cross-section or from PDF's.

- Subtraction from the cross-section:

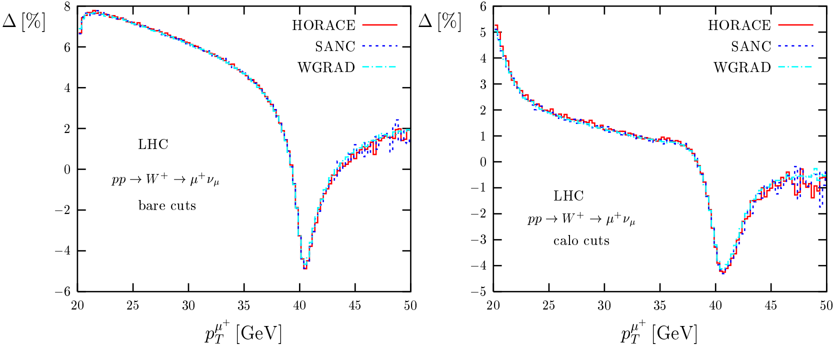
$$\sigma \to \sigma - \sum_{i=1,2} \int_0^1 \mathrm{d}x \; \sigma_0(x) \frac{\alpha}{2\pi} Q_i^2 \left[\frac{1+x^2}{1-x} \left(\log \frac{M^2}{m_i^2} - 1 - 2\log(1-x) \right) \right]_+ .$$

- Subtraction from PDF:

$$q_i(x, M^2) \to q_i(x, M^2) - \int_x^1 \frac{\mathrm{d}z}{z} \; q_i(\frac{x}{z}, M^2) \frac{\alpha}{2\pi} Q_i^2 \left[\frac{1+z^2}{1-z} \left(\log \frac{M^2}{m_i^2} - 1 - 2\log(1-z) \right) \right]_+ .$$

Tuned comparison of EW RC

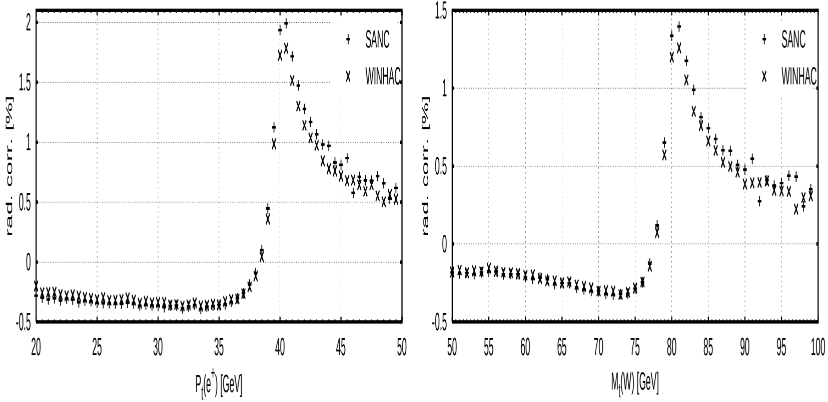
Tuned comparison with results of HORACE and Z(W)GRADE for EW RC to CC and NC DY were performed within *Les Houches* '05, '07 and *TEV4LHC* '06 workshops



- Set-up: $P_T(l,\nu) > 20$ GeV, $|\eta(l)| < 2.5$; $\alpha(0)$ EW scheme; MRST2004QED; NLO QED DIS subtraction scheme

Higher order photonic FSR

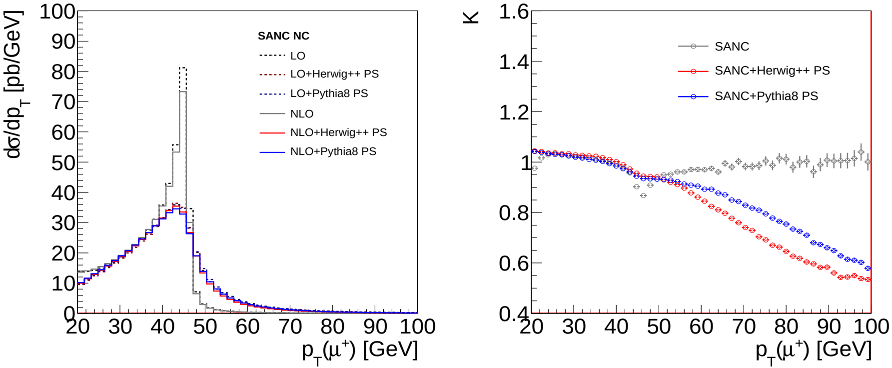
Multiple FSR photon radiation in LLA
Comparison with `WINHAC` (BARE e^+)



Interfacing SANC with PYTHIA and HERWIG

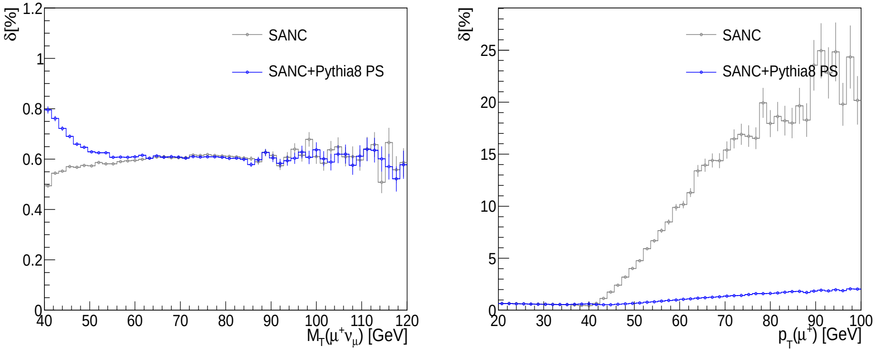
- SANC Monte-Carlo generators for neutral and charged current Drell-Yan processes produce unweighted events with help of FOAM algorithm
- The transfer of information between SANC Monte Carlo generator and the general purpose event generators PYTHIA and HERWIG is organized via data files containing the event information in the standard Les Houches Accord format
- Matching for the Born-level and $\mathcal{O}(\alpha)$ EW contributions with parton showers is *almost* trivial
- Matching of $\mathcal{O}(\alpha_s)$ QCD contributions is scheme dependent

The effect of parton showers



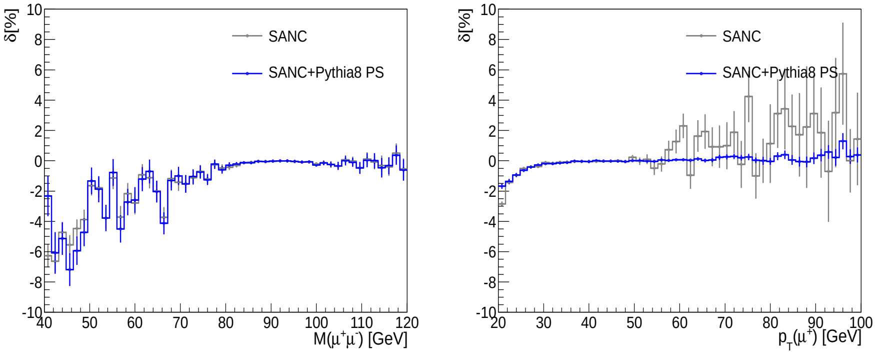
Distributions of muon transverse momentum in cross section (left) and EW NLO K-factor (right) in NC Drell–Yan process [JHEP'12]

Inverse bremsstrahlung (CC)



Distributions of the inverse bremsstrahlung contribution correction for muon-neutrino pair transverse mass (left) and muon transverse momentum (right) in the charged current Drell–Yan process [JHEP'12]

Inverse bremsstrahlung (NC)



Distributions of the inverse bremsstrahlung contribution correction for $\mu^+\mu^-$ pair invariant mass (left) and muon transverse momentum (right) in the neutral current Drell–Yan process [JHEP'12]

Notation

Beware on different notation in EW and/or QCD studies

Born vs improved Born

LO vs Born

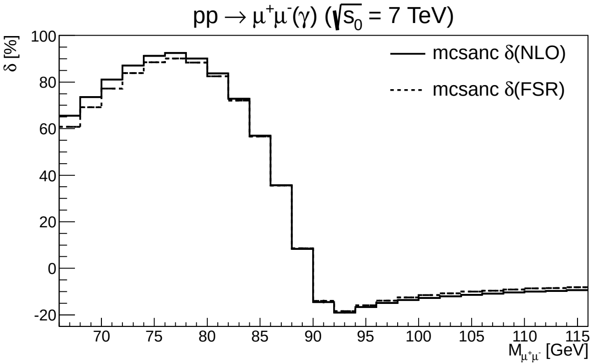
Leading log approximation vs LO

NLO vs one-loop

One-loop vs virtual corrections

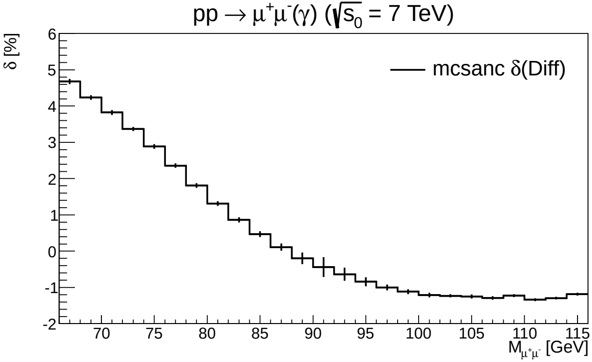
NNLO vs two-loop

NLO EW vs FSR (I)



δ in % with complete NLO EW (solid histogram) and FSR (dashed histogram) corrections

NLO EW vs FSR (II)



Difference correction δ^{Diff} in % for the distribution over $M_{\mu^+\mu^-}$

RC to inclusive DY

DY	NC	CC W^+	CC W^-
LO	3338(1)	10696(1)	7981(1)
LO MCFM	3338(1)	10696(1)	7981(1)
NLO QCD	3388(2)	12263(4)	9045(4)
NLO MCFM	3382(1)	12260(1)	9041(5)
δ_{QCD}	1.49(3)	14.66(1)	13.35(3)
NLO EW	3345(1)	10564(1)	7861(1)
δ_{EW}	0.22(1)	-1.23(1)	-1.49(1)

Cross sections in pb and corrections in %.

Theoretical uncertainty

- Uncertainties in PDF, but after a new fit from LHC data ...
- Treatment of heavy quarks (c and b) ...
- QCD (and QED) factorization scheme and scale dependence
- pure QCD higher order terms $\Leftarrow$ recent NNLO results (`FEWZ`, `DY@NNLO`)
- pure EW higher order terms:
  - EW scheme dependence: $\alpha(0)$ *vs.* G_F *vs.* $\alpha(M_Z)$
  - resummation of higher order EW Sudakov logs
  - other unknown EW higher order terms (should be small?)
  - hadronic vacuum polarization
  - top and Higgs mass dependence
- Interplay of EW and QCD effects: multiplicative *vs.* additive treatment
- All this to be quantified for every observable

Outlook

- SANC provides an advanced description of CC and NC Drell-Yan processes
- Monte Carlo event generators are created, their development is continued
- Packages with MC and partonic level modules are available for download
- SANC modules with EW RC to CC Drell-Yan were implemented in `WINHAC` event generator
- Tuned comparison with other groups continues
- Further theoretical studies are still required for better understanding of DY at LHC