EW processes at LHC

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- CERN -

LHCP 2013

Barcelona - May, 17 2013

Outline

- Drell-Yan processes
  - motivations
  - theoretical tools
    - QCD & EW Radiative corrections
    - Mixed QCD & EW effects

- Dibosons
  - motivations
  - theoretical tools

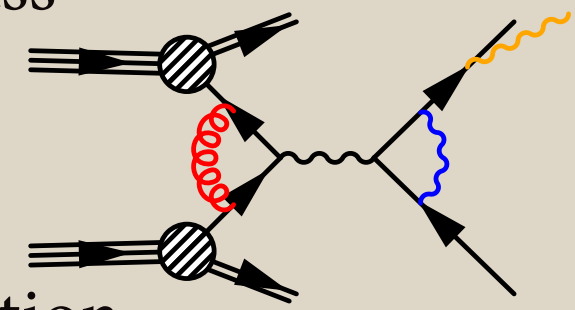
Drell-Yan Processes (Z/γ^*, $W^\pm$ production)

(see talk by Mutuberria)

- clear experimental signature;
- integrated luminosity at the end of 2012 → $\mathcal{L} \sim 20\ \mathrm{fb}^{-1}$
  - $\sigma_W \sim 10$ nb ⇒ $\sim 2 \cdot 10^8\ W$
  - $\sigma_Z \sim 1$ nb ⇒ $\sim 2 \cdot 10^7\ Z$

  } ⇒ No statistical limitation

- W mass & width ⇒ { • W transverse mass • lepton $p_\perp$ }
  (see talk by Kotwal)
- $\sin^2 \vartheta_W \Rightarrow A_{FB}$



- PDF fit *(see talk by Rojo)*
- collider luminosity

⇒ { • Total cross section • $W/Z/l$ (pseudo)rapidity • ratios W / Z }

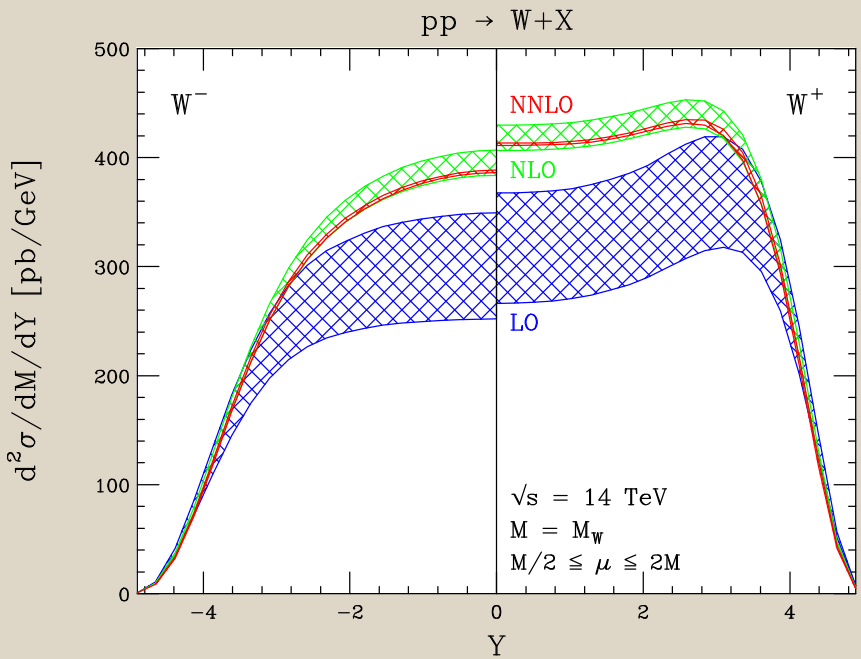
- detector calibration ⇒ Z invariant mass
- background for NP ⇒ high energy tails

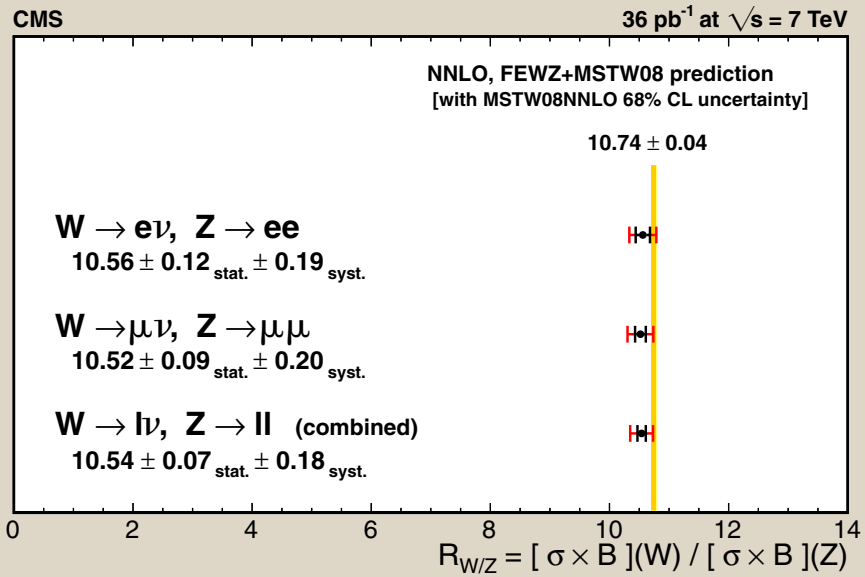
DY Processes - QCD tools - fixed order

$$\sigma = \sigma_0 + \sigma_{\alpha_s} + \sigma_{\alpha_s^2} + \ldots$$

Fully differential NLO QCD corrections → MCFM - *Campbell & Ellis, PRD 65:113007, ...*

Fully differential NNLO QCD corrections → DYNNLO - *Catani & al., PRL 103 (2009) 082001, ...*
→ FEWZ - *Melnikov & al., PRD 74 (2006) 114017, ...*





- perturbative expansion well converging
- good description of inclusive results

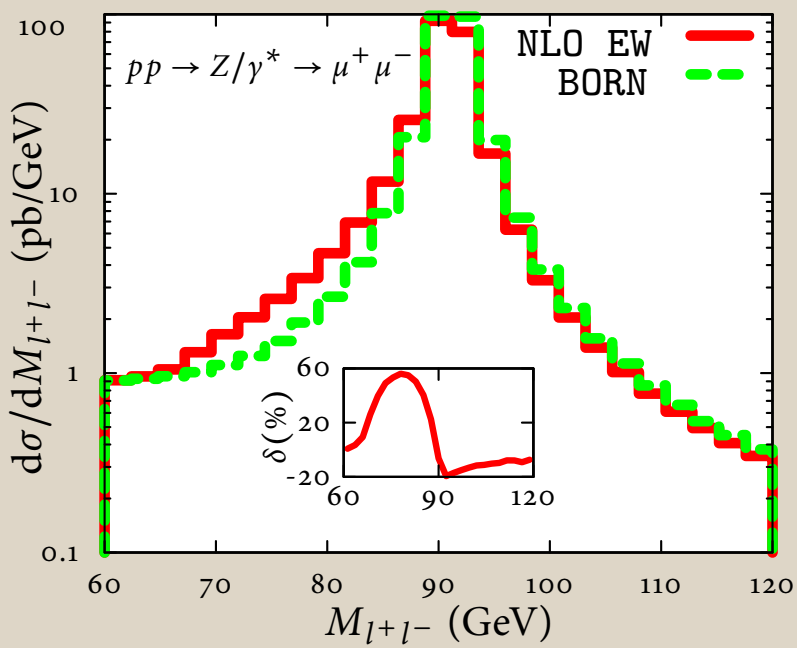
(experimental accuracy ~ 1%)

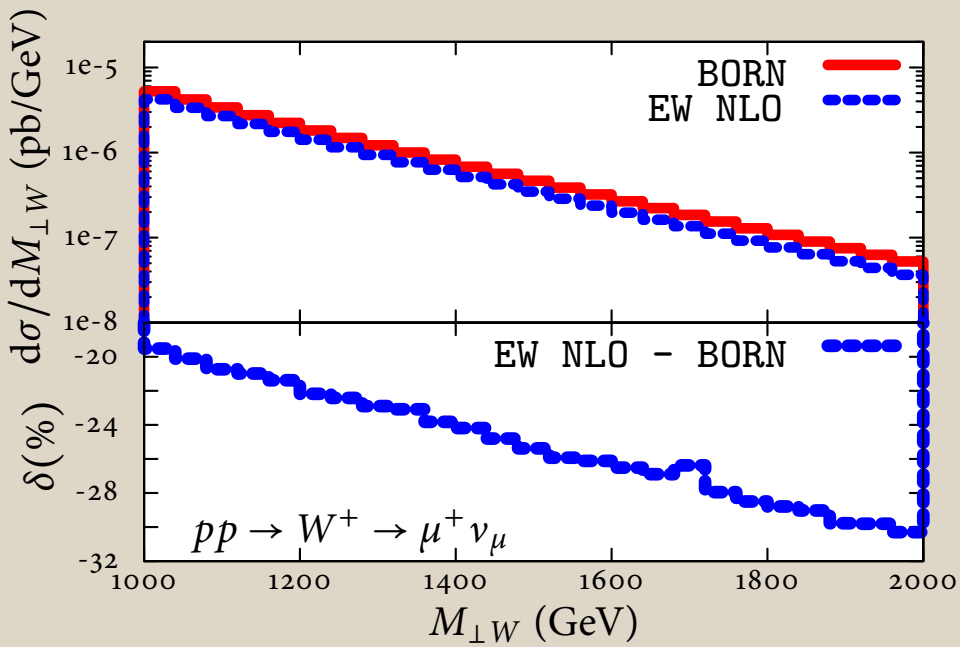
DY - EW tools - fixed order

$$\sigma = \sigma_0 + \sigma_{\alpha_s} + \sigma_{\alpha_s^2} + \sigma_{\alpha} + \ldots$$

Fully differential NLO EW corrections

- SANC - *Arbuzov & al., EPJC 46 (2006) 407, ...*
- W/ZGRAD - *Baur & al., PRD 70 (2004) 073015, ...*
- HORACE - *Carloni & al., JHEP 0612:016 (2006), ...*
- *Dittmaier & al., PRD 65 (2002) 073007, ...*





- EW NLO ~ QCD NNLO on inclusive quantities
- important kinematic effects ($\Delta M_W \sim 100$ MeV)
- EW Sudakov logs ($\log(M_V/\hat{s})$) in high energy limit

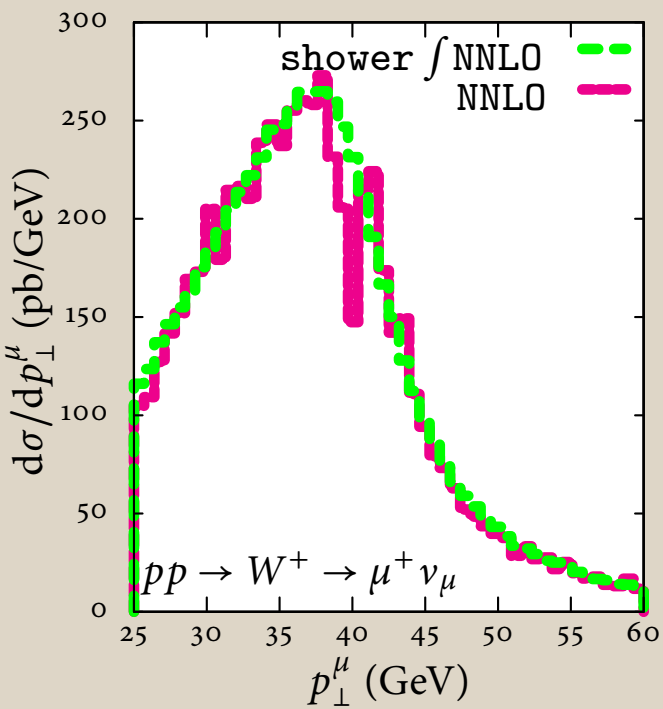
DY - QCD & EW tools - Resummation effects

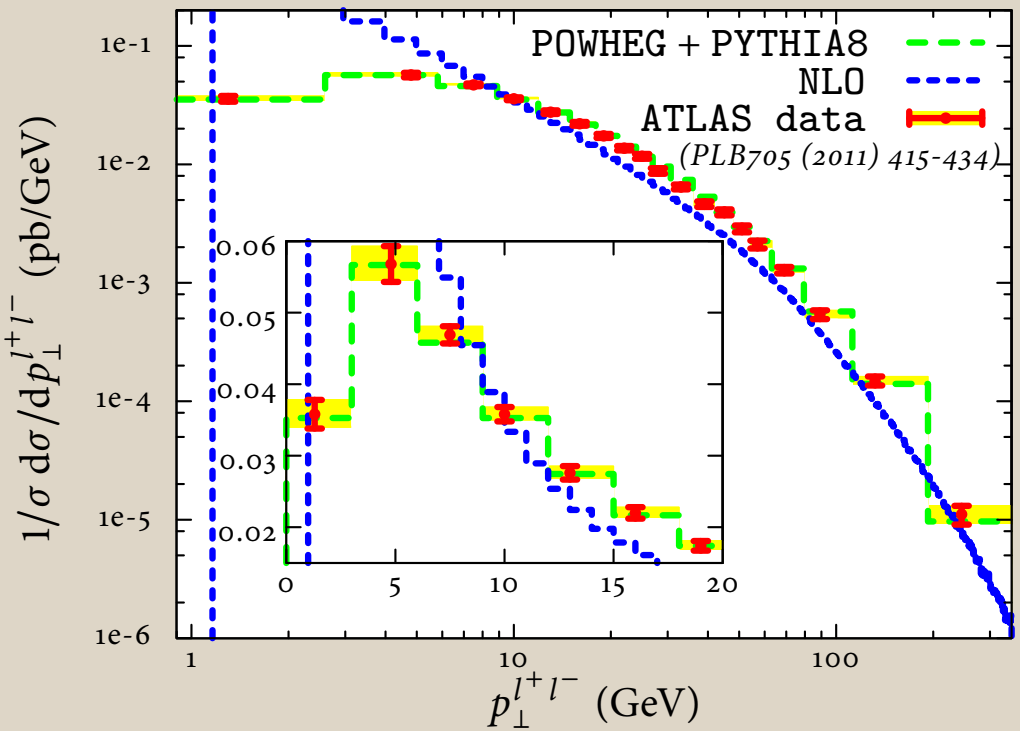
$$\sigma = \sigma_0 + \overset{\sigma_{\alpha_s}}{\sum_{n\geq 2} a_n \alpha_s^n L^{2n}} + \ldots + \overset{\sigma_{\alpha}}{\sum_{n\geq 2} b_n \alpha^n L^{2n}} + \ldots$$

NLO QCD ⊗ QCD shower → POWHEG - *Nason & al, JHEP 1006 (2010) 043, ...*
→ (a)MC@NLO - *Frixione & Webber, JHEP 0206 (2002) 029, ...*
→ SHERPA - *Höche & al., JHEP 04 (2011) 24, ...*

NNLL matched with NLO calculation → DYqT - *Catani & al., NPB596 (2001) 299-312, ...*

NLO EW ⊗ QED shower → WINHAC - *Jadach & Placzek, EPJC 29 (2003) 325, ...*
→ HORACE - *Carloni Calame & al., JHEP 0612:016 (2006), ...*





DY - QCD ⊗ EW tools

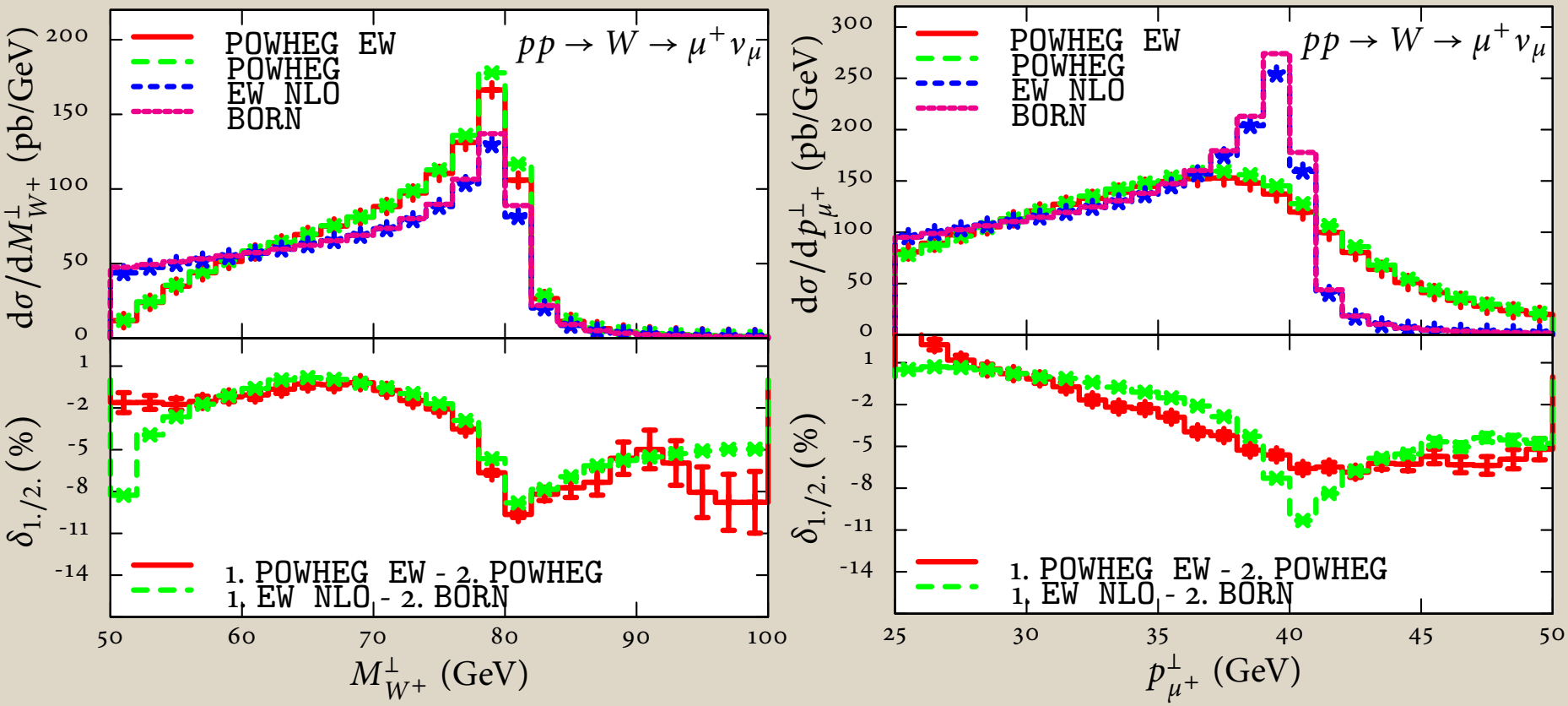
$$\sigma \quad = \quad \textit{(previous slide)} \quad + \quad \sum_{n\geq 1, m\geq 1} a_{nm} \alpha_s^n L^{2n} \alpha^m L^{2m} \quad + \quad \ldots$$

PHOTOS interfaced to RESBOS — *Balazs & al. PRD56, 558; Was & al., CPC 79, 291*

SANC interfaced to HERWIG++ and PYTHIA8 — *Richardson & al., arXiv:1011.5444*

Mixed EW & QCD (HORACE⊗/⊕MC@NLO) — *Balossini & al., JHEP 1001:013, 2010*

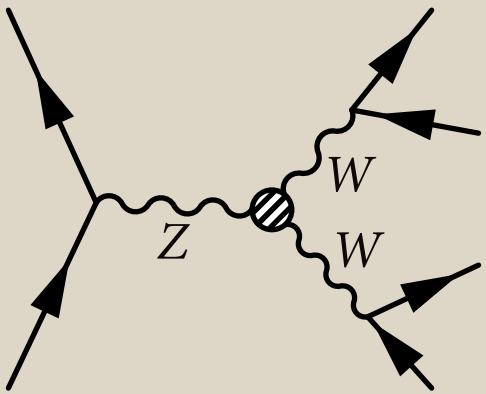
POWHEG w EW NLO — *L.B. & al., JHEP 1204 (2012) 037*

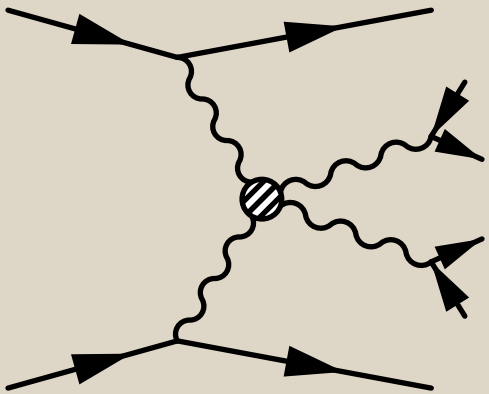


Vector-Boson Pair Production

(see talk by Ward)

- SM background for BSM searches
- Background to Higgs studies *(many, many talks)*
- Access to triple and quartic (anomalous?) EW couplings





Vector Boson Fusion

- NLO QCD corrections moderate and under control for many processes
- Hjj, Zjj, Wjj, $WWjj$, $ZZjj$, ...at NLO — `VBFNLO` - *Arnold & al., CPC 180:1661-1670, 2009,...*
- Hjj, Zjj, Wjj, $WWjj$ at NLO+shower — *Schissler & al., arXiv:1302.2884,...*
- For Hjj EW NLO ~ QCD NLO — *Ciccolini & al., PRD77 (2008) 013002*

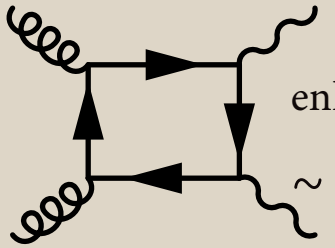
Vector-Boson Pair Production - NLO Effects

- W / Z / γ pair at NLO QCD — `VBFNLO/MCFM` - *Campbell & al. JHEP 1107 (2011) 018,...*
- W / Z pairs with `POWHEG`, `MC@NLO` — *Melia & al. 2011, JHEP 1111 (2011) 078, ...*
- Full NLO EW for WW — *Bierweiler & al., JHEP 1211 (2012) 093*
- NLO EW for $W\gamma$, $Z\gamma$ — *Accomando & al., EPJ C47 (2006) 125-146*
- NNLL EW for WW — *Kuhn & al., JHEP 1106 (2011) 143*
- Full NNLO QCD for $\gamma\gamma$ — *Catani & al., PRL 108 (2012) 072001*
- Virtual NNLO QCD for $W\gamma$, $Z\gamma$ — *Gehrmann & al., JHEP 1202 (2012) 004*

N(N)LO effects usually important

- New channels
- high energy limit → NP

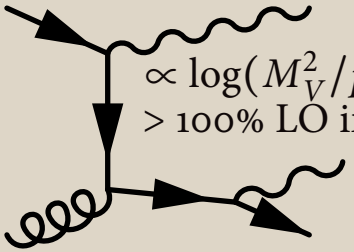
NNLO QCD



enhanced by g PDF

$\sim O(\mathrm{LO})$

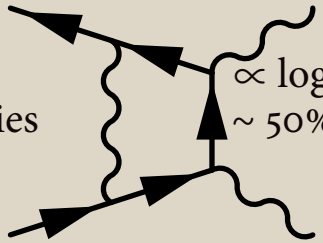
NLO QCD



$\propto \log(M_V^2/p_\perp^2)$

> 100% LO in high energies

NLO EW



$\propto \log(M_V^2/\hat{s})$

$\sim$ 50% LO in high energies

Conclusions

- LHC will integrate a huge statistics
  $\rightarrow$ high precision EW measurements will be possible;
- single and dibosons production will be fundamental tools to probe the SM with high level of precision
  - NLO QCD important and under control
    - interfaced to shower (`POWHEG`, `MC@NLO`)
    - fully automatized (`aMC@NLO`, ...)
  - NNLO QCD important for precision studies
  - EW NLO important on phenomenology
  - for DY mixed QED $\otimes$ QCD not negligible

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THANK YOU!