Progress in NLO-EW MonteCarlo's

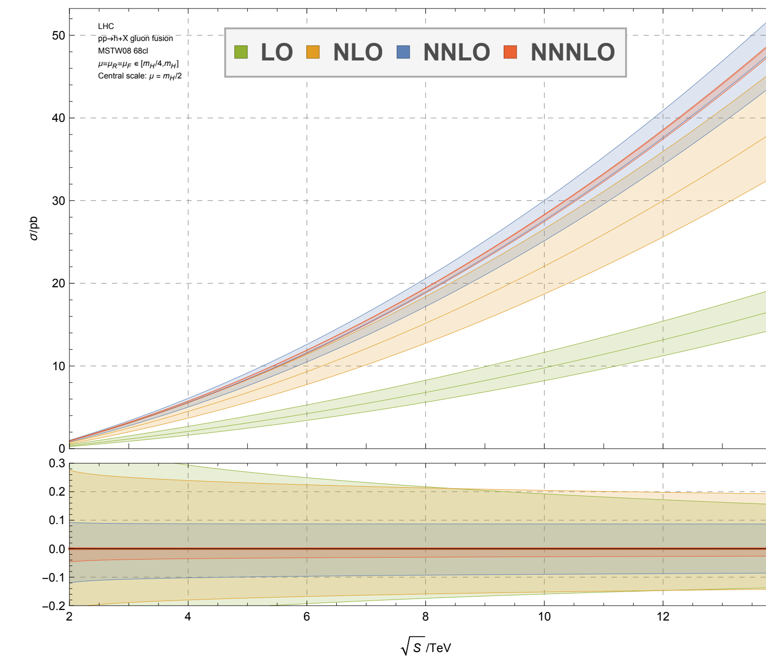
Marco Zaro — SM@LHC 2021

Istituto Nazionale di Fisica Nucleare
Sezione di Milano

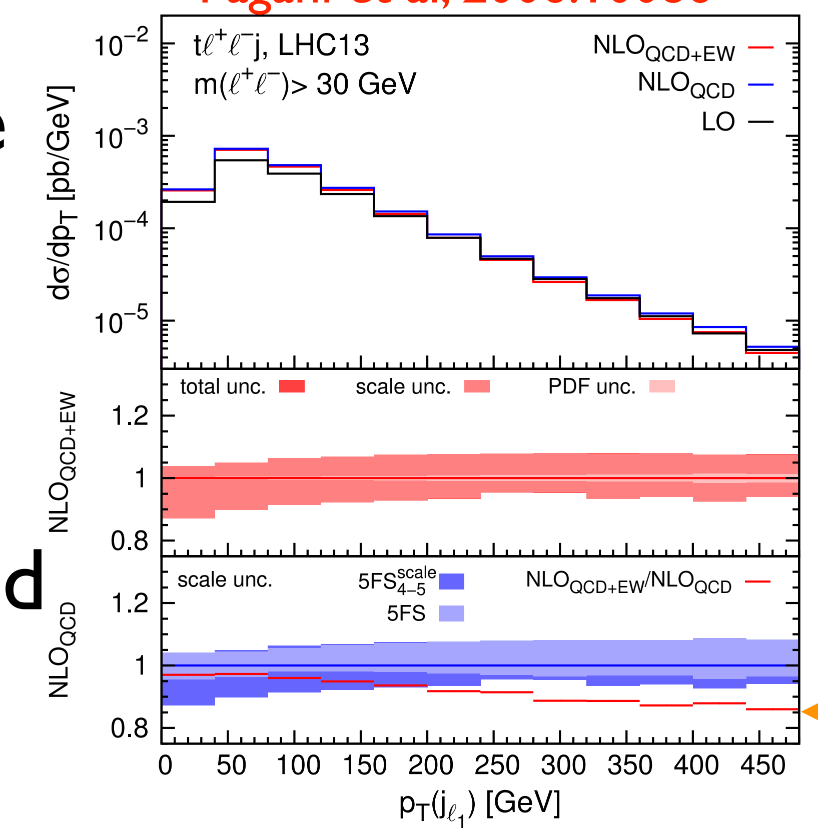
EW corrections

- QCD corrections generally improve precision of computations (shrink theoretical errors)
- EW corrections necessary to improve accuracy of predictions, specially in the tails of distributions (Sudakov enhancement)
- EW and complete-NLO corrections automated! Sherpa+Openloops: 1412.5157; Sherpa+Recola: 1704.05783 MG5_aMC: 1804.10017
  - In some cases, EW corrections do not behave as expected: can give effects as large as QCD!
  - First results beyond fixed-order, including matching with PS
  - Since recently, EW corrections can be included in PDF fits

Anastasiou et al, 1503.06056

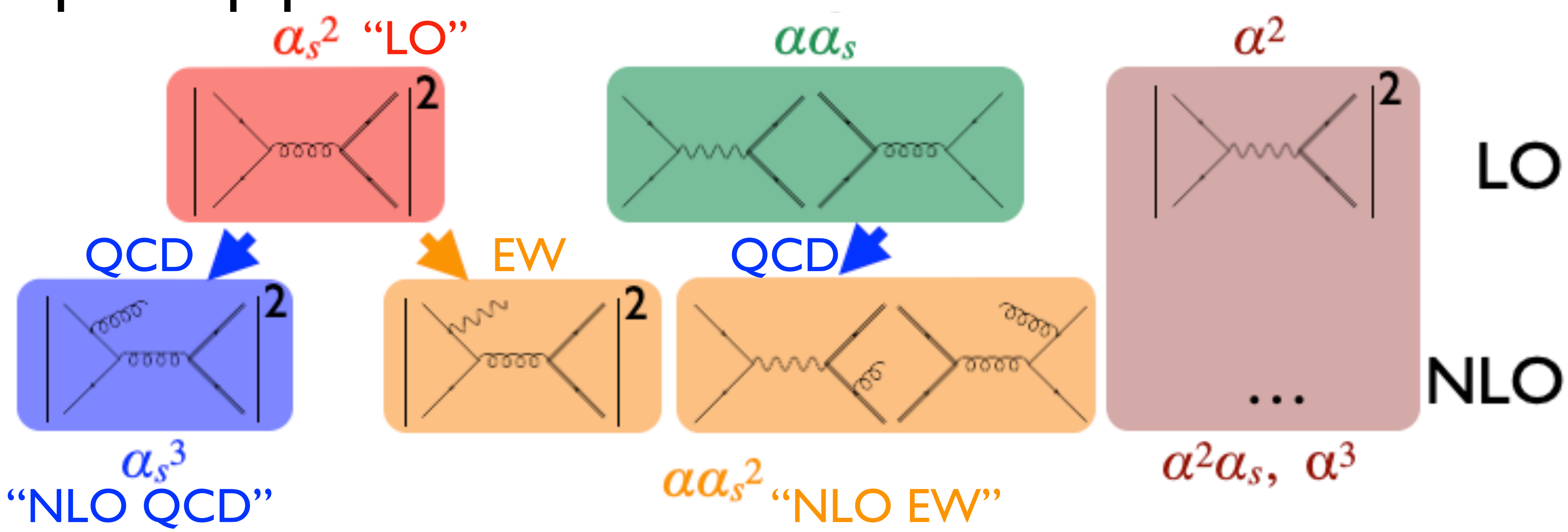


Pagani et al, 2006.10086



EW corrections vs EW effects

- A general process has more contributions at LO, NLO, …
- Example: top pair

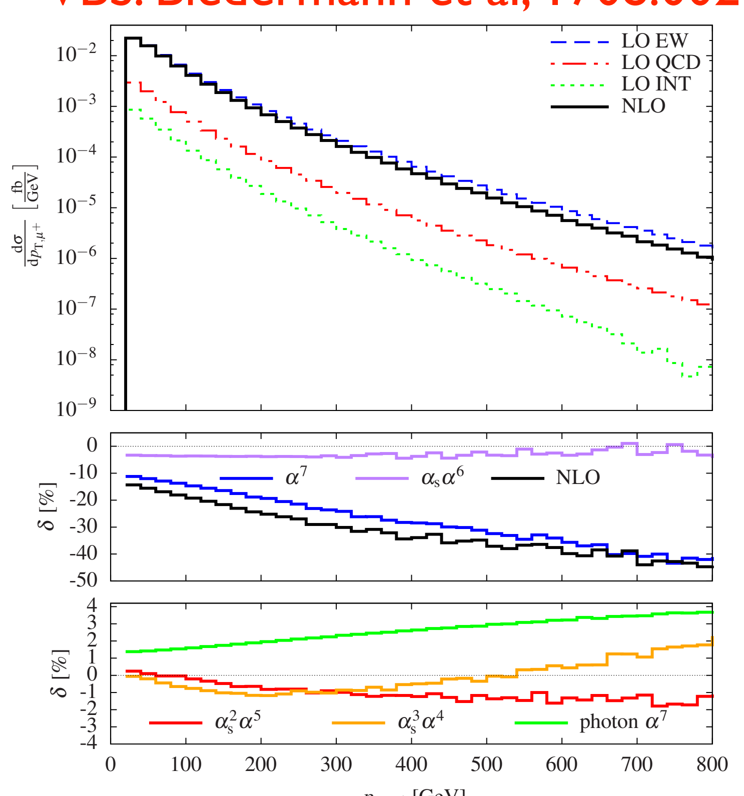


- The LO is often identified with the contribution with most α_s
- At NLO the first two contributions are identified with the NLO QCD and NLO EW corrections
- This structures induces mixed QCD-EW effects at NLO: $\mathrm{NLO}_i = \mathrm{LO}_{i-1} \otimes \mathrm{EW} + \mathrm{LO}_i \otimes \mathrm{QCD}$

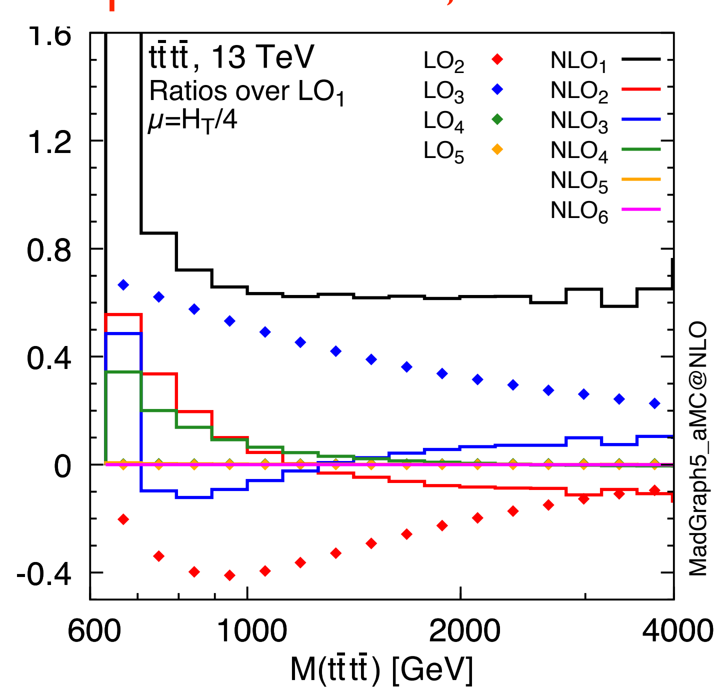
Large EW corrections

- Despite the naive estimate $\alpha \sim \alpha_s^2$, there are cases when EW corrections comparable to NLO QCD or larger. It happens when:
  - Large scales are probed (VBS) feature of all VBS channels, see also Denner et al, 1904.00882, 2009.00411
  - Power counting is altered (4 top: y_t vs α)
  - New production mechanisms, different than those at the "dominant" LO, enter (ttW, bbH)

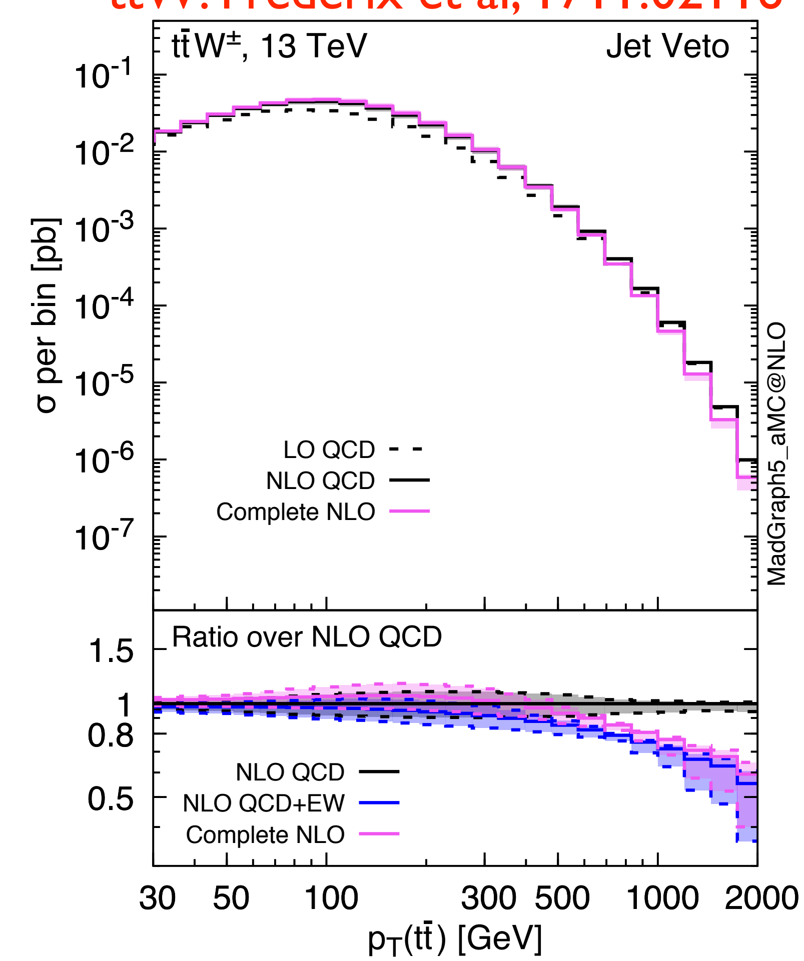
VBS: Biedermann et al, 1708.00268



4 top: Frederix et al, 1711.02116

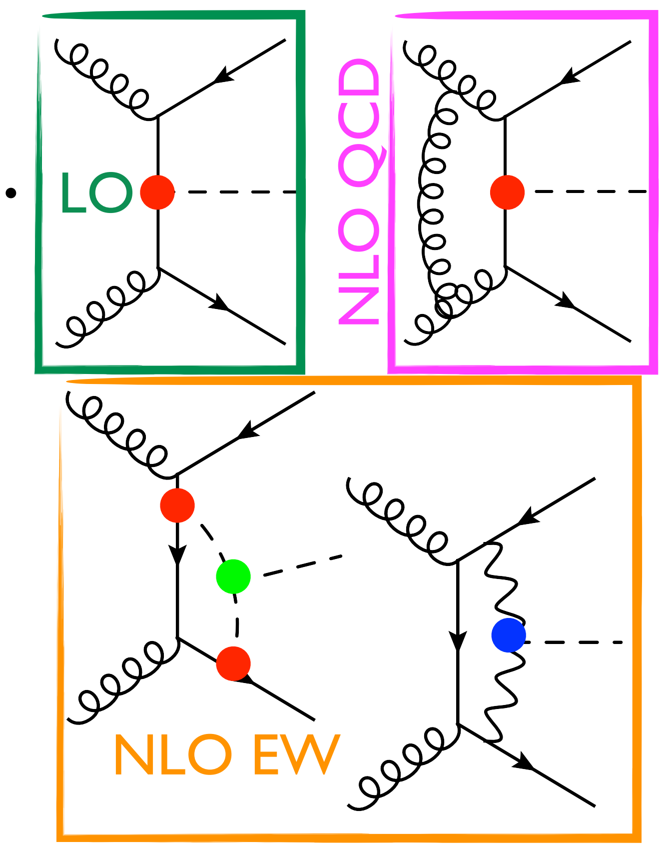


ttW: Frederix et al, 1711.02116

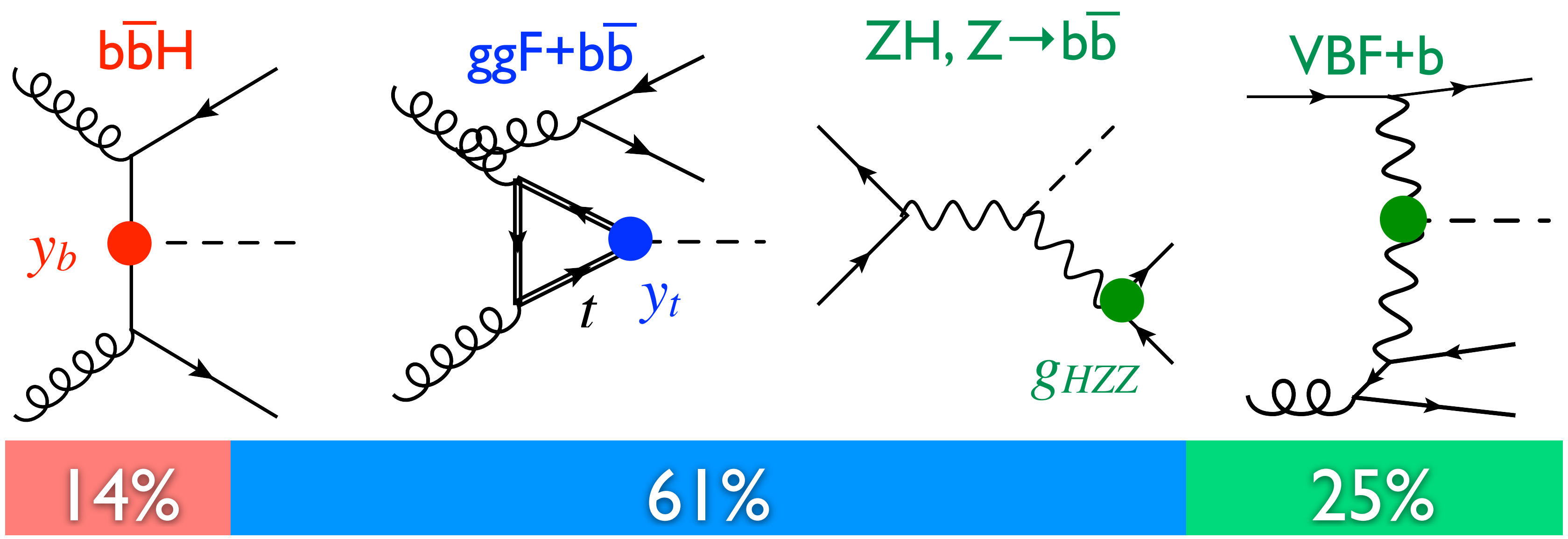


EW corrections and Higgs couplings

- QCD effects mostly preserve the relation "one process, one coupling": ggF↔k_g, VBF↔k_V, ttH↔k_t, …
- EW and complete-NLO corrections mix coupling dependence
- Mandatory to assess their effect if aim is ~few %'s on coupling extraction
- Effects small (2%) for ttH, but enormous for bbH



ttH: Frixione et al, 1504.03446; **bbH**: Deutschmann et al, 1808.01660, Pagani et al, 2005.10277



$b\bar{b}H$

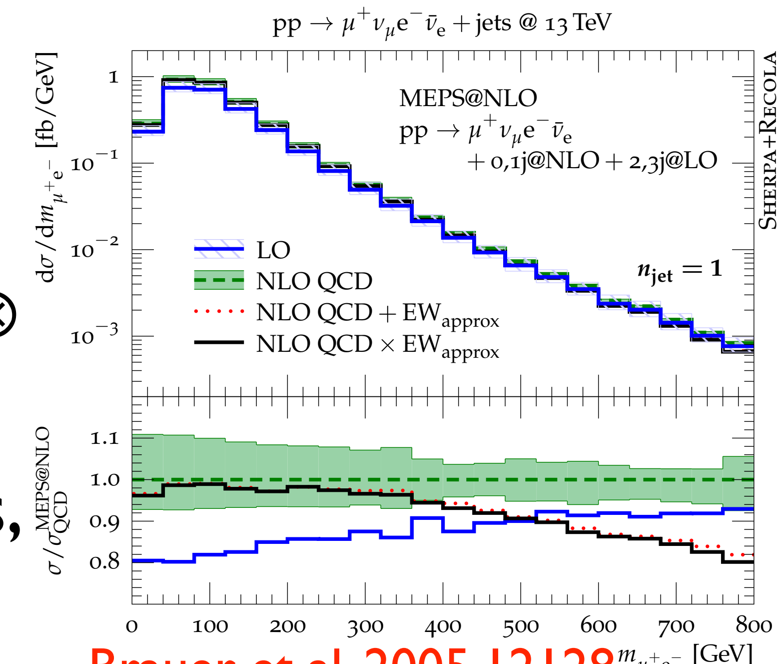
LO ① ② ③

NLO ① ② ③ ④

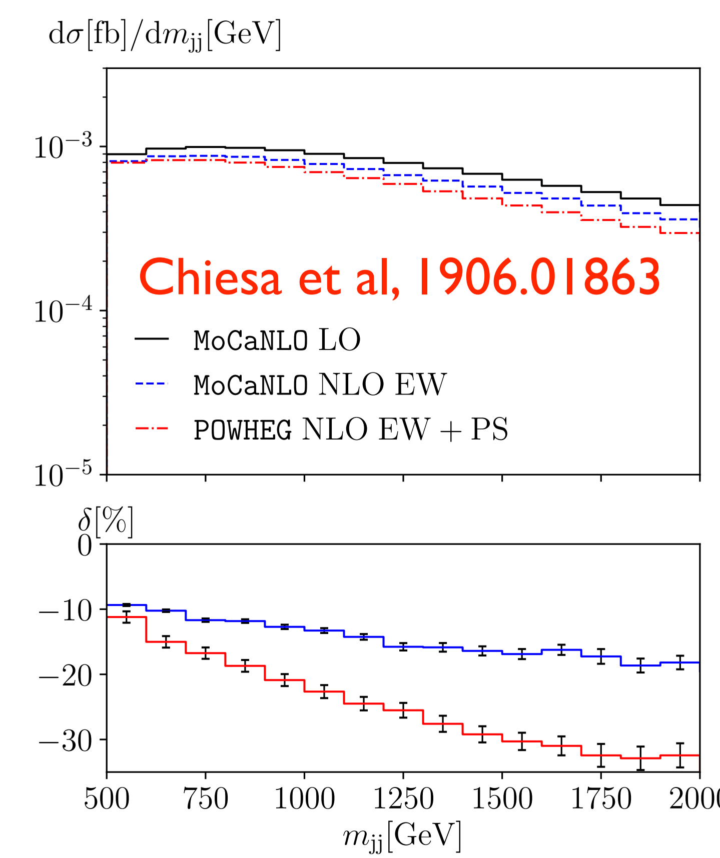
NNLO ① …

EW corrections @NLO+PS

- Matching with QED parton shower available for few processes
  - Most important contribution [NLO QCD+QED] ⊗ QCD PS
    Can be achieved with approximate EW corrections, only including n-body contribution ("EWvirt" or Sudakov approx.) Not valid for hard photon radiation
    VV(J): Brauer et al, 2005.12128; **top**: Gutschov et al, 1803.00950;
    V+jets: Kallweit et al, 1511.08692
  - Besides DY, few cases of consistent matching of n-body and n+1 body for EW corrections (in the Powheg scheme)
    DY: Barzè et al,1302.4606; **HV(J)**: Granata et al, 1706.03522;
    VBS: Chiesa et al, 1906.01863
    All these processes have only 1 contribution at LO (2 for HVJ, but not stemming from interferences)



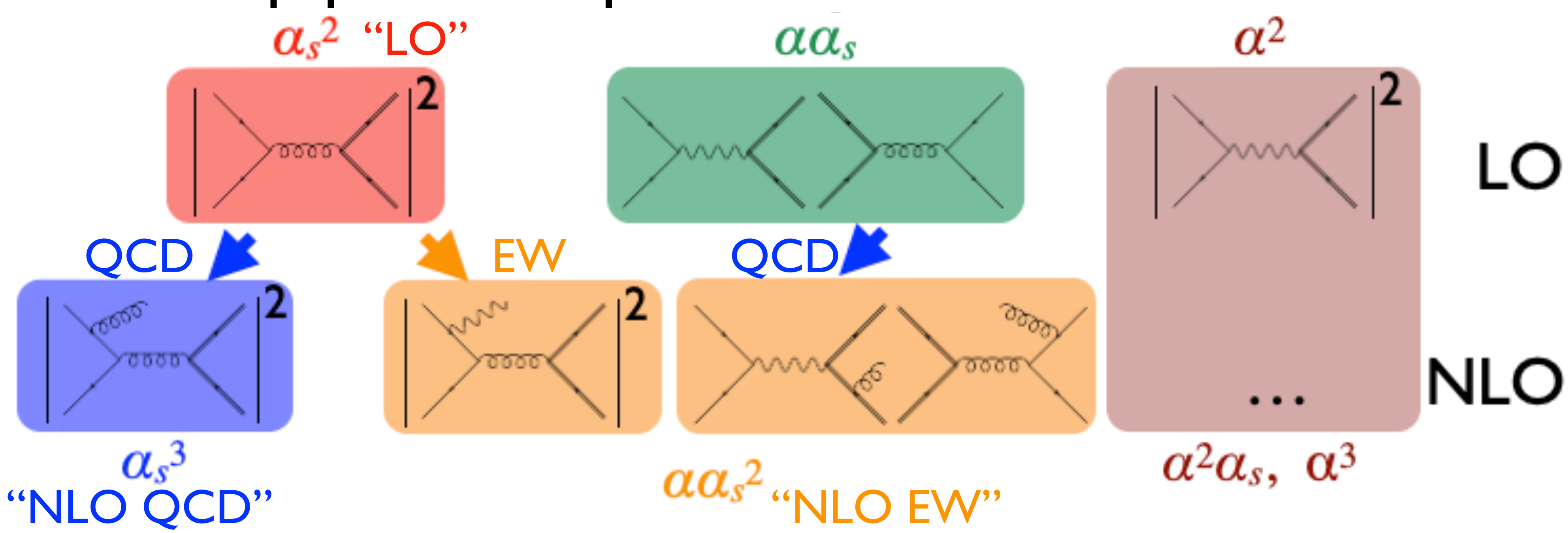
Brauer et al, 2005.12128



Chiesa et al, 1906.01863

Complete NLO + PS?

- Back to the top-pair example



- Which color-flow, mother-daughter history, … shall we assign to the $\alpha\alpha_s$ LO contribution?
- Interferences cannot be treated at LC (à la Odagiri)

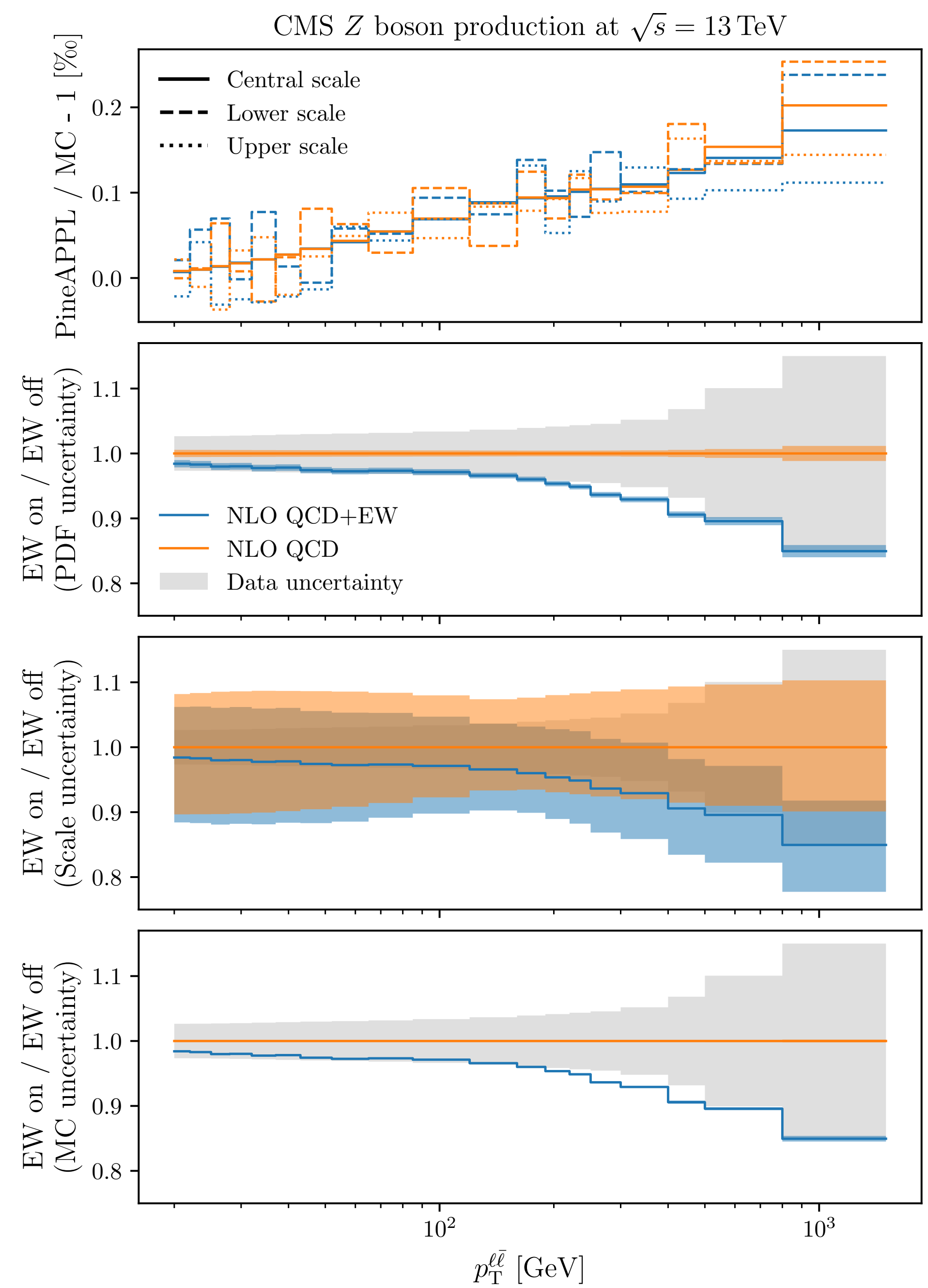
Including EW effects in PDF fits

- So far, only QED effects were included in PDFs via the photon density and the DGLAP evolution
- Other effects (e.g. Sudakov suppression at high p_T) not included, though relevant. Possibly treated as systematic error
- It would be desirable to include EW effects in the short-distance cross-section which enters PDF fits
- Now we can do it!

PineAPPL

Carrazza, Nocera, Schwan, MZ, 2008.12789

- PineAPPL stores PDF-independent theoretical predictions in interpolation grids
- Convolution with PDFs can be obtained very quickly, with excellent agreement with MC results
- Same idea as APPLGrid, FastNLO, etc…
- Compliant with mixed-order expansion (not restricted to NLO), makes it possible to include EW corrections in the fit
- Interface with MG5_aMC available in v3.1 (replaces aMCFast), with other MCs WIP

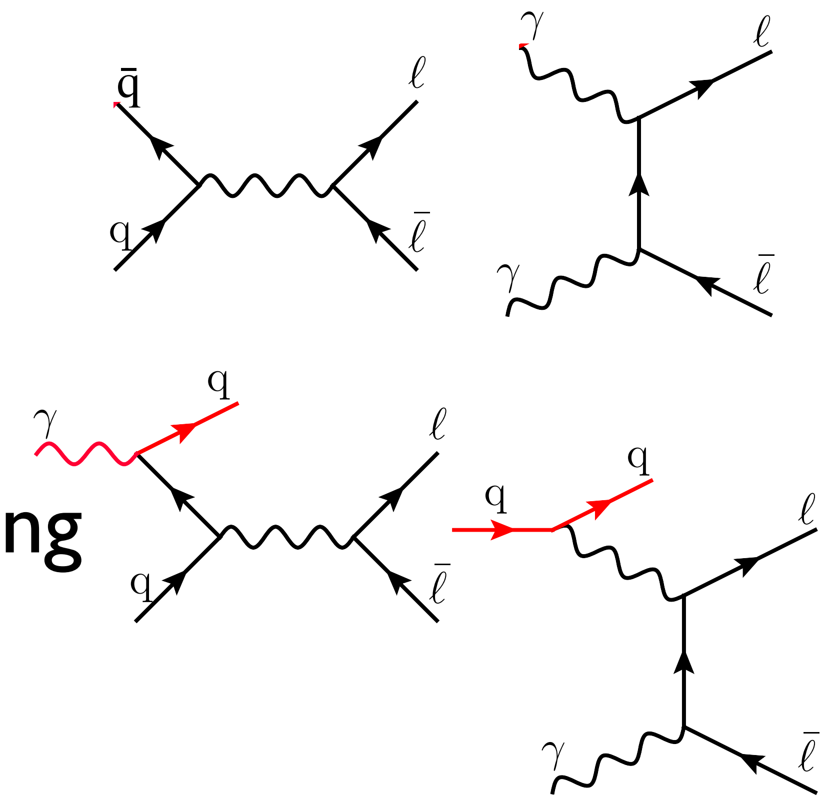


What is missing for a QCD+EW PDF fit?

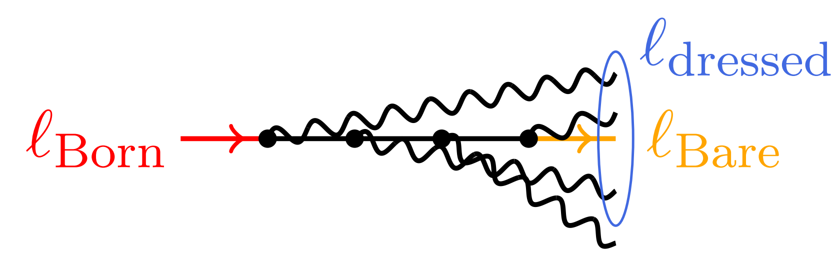
- There are (at least) two points to be addressed:
  - Consistency between data and NLO EW predictions
  - Consistency between EW renormalisation scheme in DGLAP and in matrix elements

Consistency between data and NLO EW predictions

- Not all datasets can be part of a fit with NLO EW corrections
- In particular, compensating for EW (QED) effects (FSR, subtraction of photon-induced contributions, …) lead to some double-counting when data and NLO-EW predictions are compared



- Note: compensating for FSR is sensible and necessary when only QCD corrections are considered



- We encourage experimental collaboration to publish also data defined in terms of QED IR-safe observables (dressed leptons)

Consistency between EW ren. scheme in DGLAP and in ME's

- Most common EW schemes for EW corrections are $\alpha(m_Z)$ or G_μ. EW coupling is scale-independent
- DGLAP uses MSbar renormalisation, with $\alpha^{\overline{\rm MS}} = \alpha^{\overline{\rm MS}}(\mu_R)$
- If LO~α^b, the mismatch at NLO is $\alpha^b b \dfrac{\Delta\alpha}{\alpha}$
- However, running effects are mild: $\dfrac{\alpha^{\overline{\rm MS}}(m_Z) - \alpha^{\overline{\rm MS}}(m_e)}{\alpha^{\overline{\rm MS}}(m_Z)} \simeq 4\%$
- If the PDF initial scale is set μ_0~1 GeV, then $\mu_0 > (m_e m_Z)^{1/2}$
- Effects may be discarded if precision is above few %s. However, better to have some handle on it

Conclusions and Outlook

- Inclusion of EW corrections mandatory for accurate predictions
- EW corrections automated by several collaborations
- Depending on the process, EW corrections can be (very) large. Coupling-based estimate violated!
- First results @NLO+PS! Event generators @NLO QCD+EW available. What is the best strategy for automation?
- EW corrections can now be included in PDF fits. Need consistency between data and theory, and of α throughout the whole computation