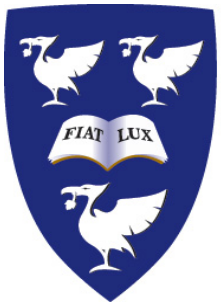
Benchmarking W,Z theory calculations used by LHC experiments



Uta Klein

University of Liverpool

LPCC EW WG meeting, 3.10.2012

NNLO QCD and HO EW corrections

NNLO QCD : FEWZ 2.X and DYNNLO 1.0 → used so far in the publications

World-new : FEWZ 3.1 (pre-releases used since several months) :

Combining QCD and electroweak corrections to dilepton production in FEWZ, Ye Li, Frank Petriello, arXiv:1208.5967 (August 2012)

Aim:

Combine HO QCD and HO EW corrections for precision analysis of NC and CC DY production.

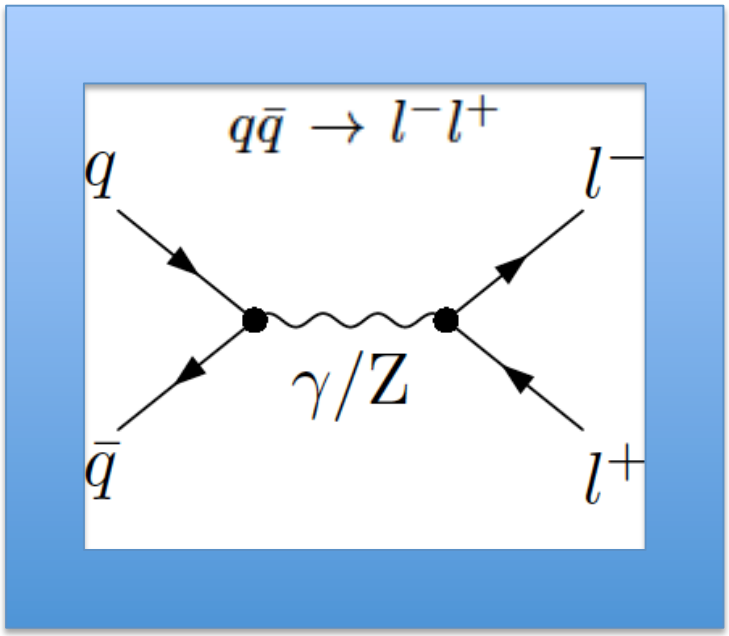
Focus by Atlas : Currently ongoing high and low mass Drell-Yan analysis → crucial to evaluate impact for NNLO QCD fits

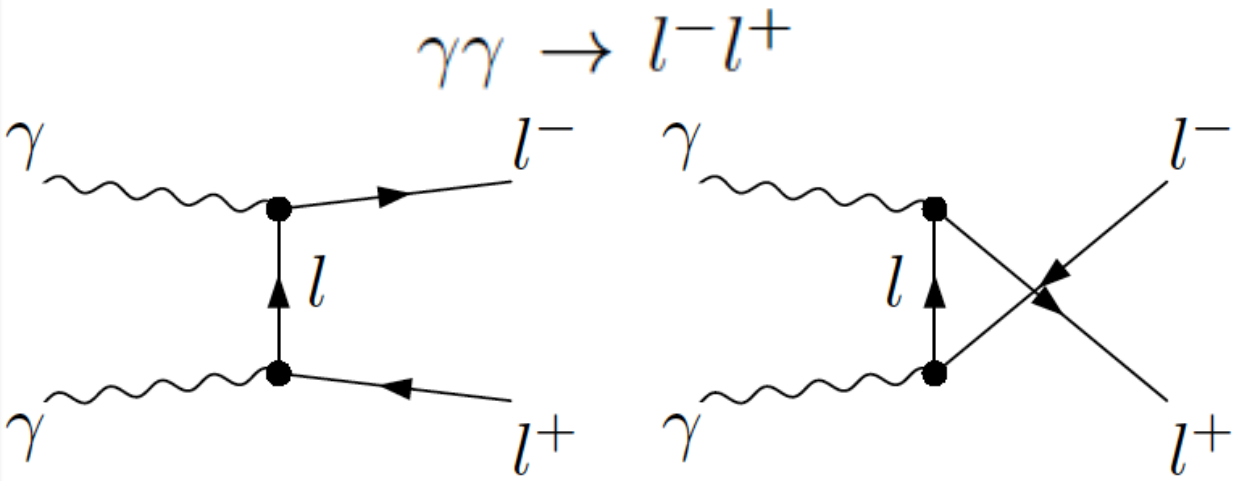
Issues discussed here : benchmarking of results between the experiments

➔ Quantify level of agreement between data and theory for the various experiments, e.g. CMS normalised cross sections while LHcb and Atlas compare to absolute cross sections → mandatory to understand the theory calculations performed by the experiments

arXiv:0911.2329v2

Lowest order partonic cross section





Neutral Current Drell Yan processes

- qqbar induced processes : sensitive to structure of the **proton**

Irreducible background

- γγ induced processes : QED process, and sensitive to structure of the ***photon***

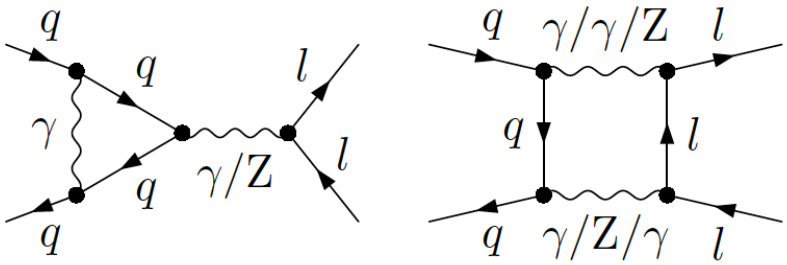
➔ *non-resonant; suppressed due to the smallness of the photon PDF*

➔ MRST 2004 qed fit (NLO QCD):" Parton distributions incorporating QED contributions", A.Martin, R.Thorne, hep-ph/0411040

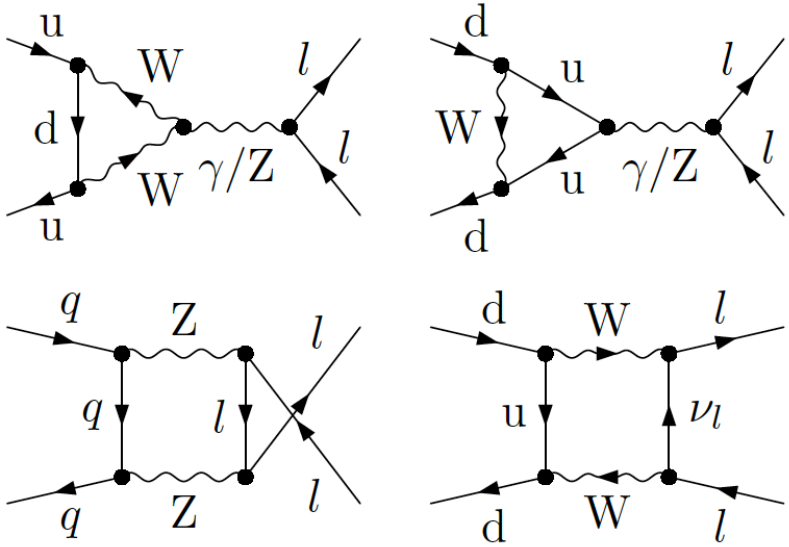
arXiv:0911.2329v2

HO EW processes : Vertex and Box diagrams

- Photonic correction examples



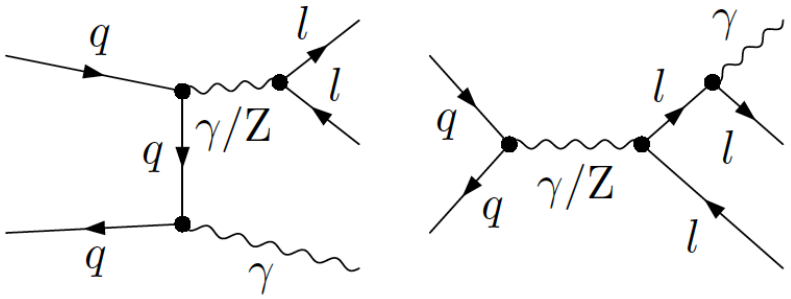
- Weak correction examples



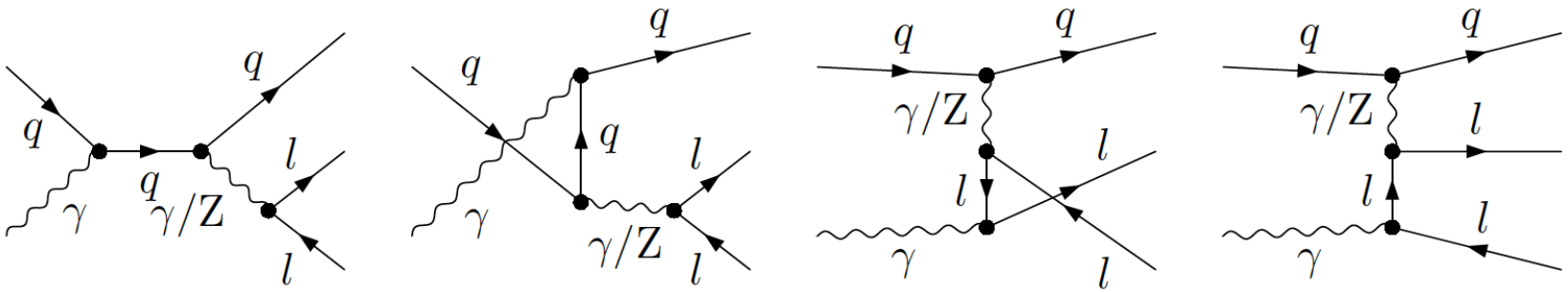
arXiv:0911.2329v2

HO EW processes : Photonic corrections

- Real (single) photon emission examples



- Photon induced processes with incoming quarks



arXiv:0911.2329v2

EW parameter schema

- $\alpha(0)$-*scheme:* The fine-structure constant $\alpha(0)$ and all particle masses define the complete input. In this scheme, the relative corrections to the $q\bar{q} \to \gamma/\mathrm{Z} \to l^- l^+$ cross sections sensitively depend on the light-quark masses via $\alpha \ln m_q$ terms that enter the charge renormalization. ➔ has to be used for photon induced processes

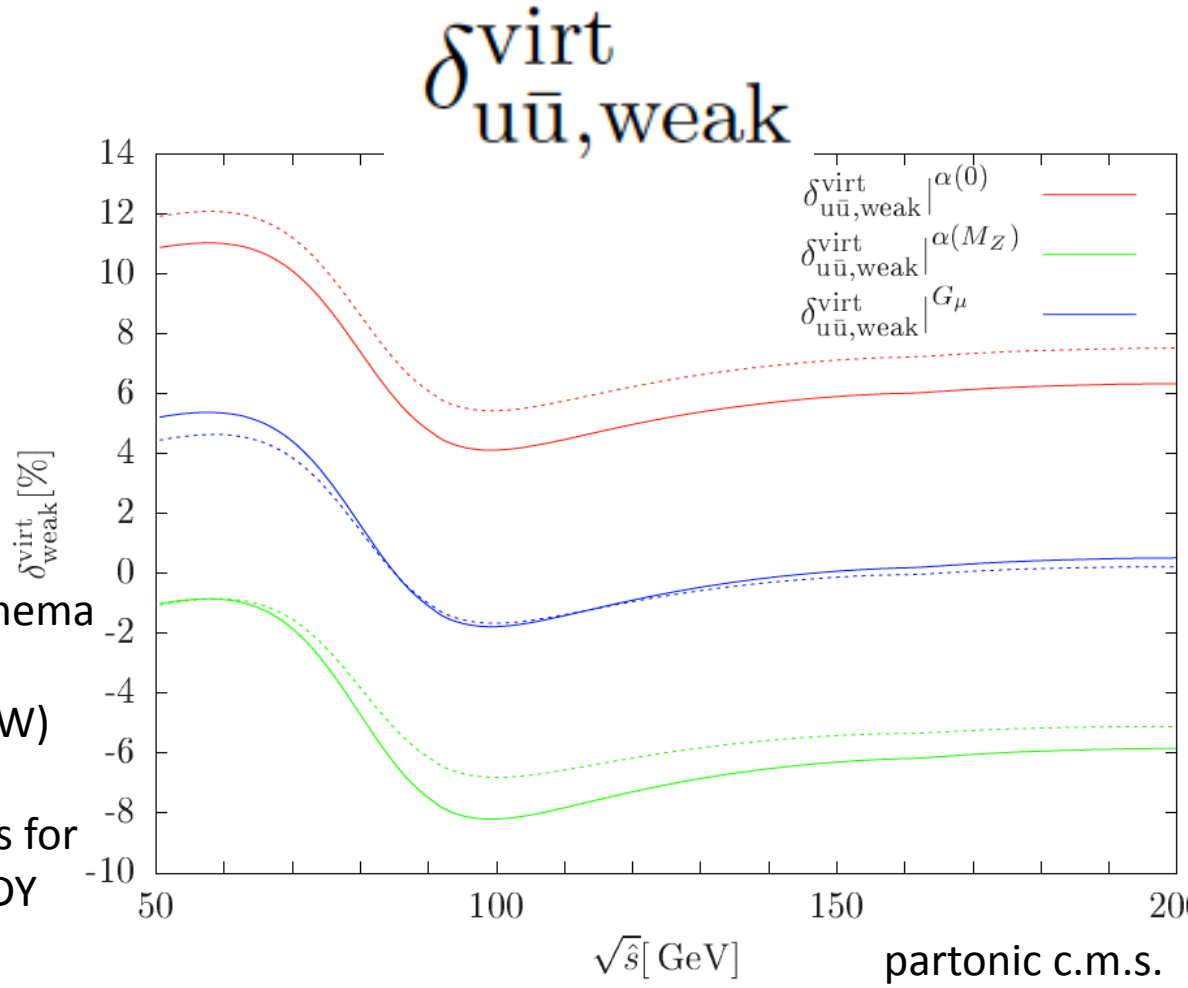
- $\alpha(M_\mathrm{Z})$-*scheme:* The effective electromagnetic coupling $\alpha(M_\mathrm{Z})$ and all particle masses define the basic input. Tree-level couplings are derived from $\alpha(M_\mathrm{Z})$, and the relative corrections receive contributions from the quantity $\Delta\alpha(M_\mathrm{Z})$, which accounts for the running of the electromagnetic coupling from scale $Q = 0$ to $Q = M_\mathrm{Z}$ (induced by light fermions) and cancels the corresponding $\alpha \ln m_q$ terms that appear in the corrections to the $q\bar{q}$ channels in the $\alpha(0)$-scheme. ➔ default schema in FEWZ 2.0, 2.1, e.g. used by CMS for PAS EWK-11-007
  ➔ **we use it as a cross check**

- G_μ-*scheme:* The Fermi constant G_μ and all particle masses define the basic input. Tree-level couplings are derived from the effective coupling $\alpha_{G_\mu} = \sqrt{2} G_\mu M_\mathrm{W}^2 (1 - M_\mathrm{W}^2/M_\mathrm{Z}^2)/\pi$, and the relative corrections receive contributions from the quantity Δr [40], which describes the radiative corrections to muon decay. Since $\Delta\alpha(M_\mathrm{Z})$ is contained in Δr, there is no large effect on the $q\bar{q}$ channels induced by the running of the electromagnetic coupling in the G_μ-scheme either. ➔ we used it in our W,Z publication
  ➔ **our nominal EW parameter schema**

arXiv:0911.2329v2

Scheme dependence of weak corrections

- **Full lines** : includes **leading** two-loop terms
- Dashed lines : include leading higher order corrections



Default schema FEWZ 2.0 (w/o HO EW) → smaller corrections for low mass DY

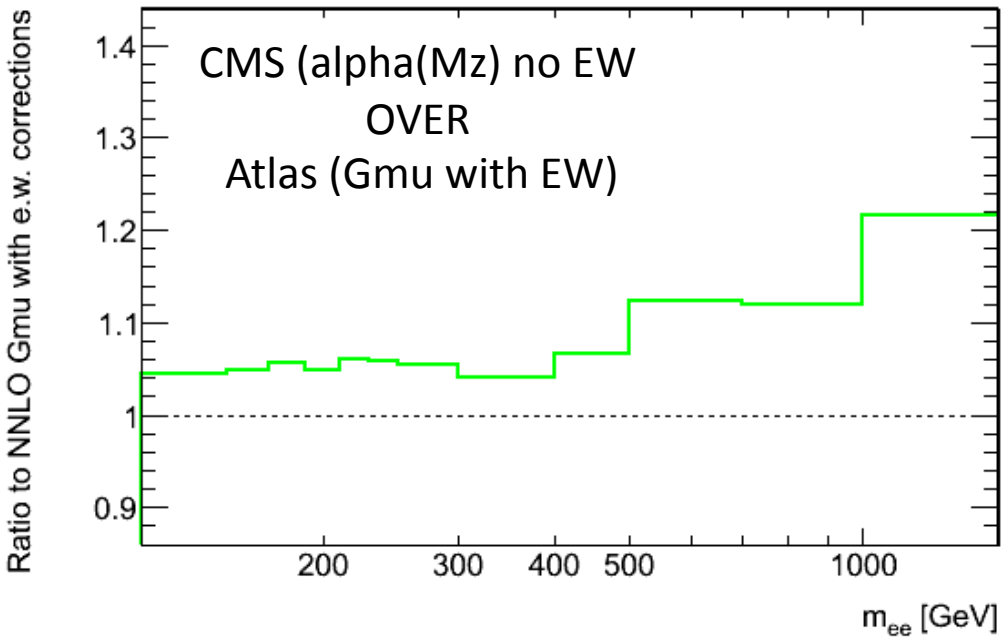
partonic c.m.s.

Gμ : smallest corrections for Z exchange

"offset" = ($\alpha_G/\alpha(m_Z)$)^2 -1
SANC : 5.74 %
FEWZ 3.1.a3 : 5.44%
FEWZ 2.0 : 6.9%
→ choice of $\alpha(m_Z)$

Comparison Atlas – LHcb – CMS (CMS-PAS EWK-11-007)

Values obtained from Dimitri and Alexey (CMS) over Atlas Gmu schema+EW corrections
Dedicated comparison for one bin 1000-1500 GeV
CMS (FEWZ 2.0 default alpha(Mz)) : 0.00122601 pb
Atlas (FEWZ 2.1 or FEWZ 3.1.a3 alpha(Mz) schema) : 0.00121 pb (expect to be 1.3% → alpha (Mz) choice) ➔ Katharina (LHcb) cross check performed at NLO and perfect agreement found with Atlas
Atlas (FEWZ 2.1 or FEWZ 3.1.a3 Gmu) : 0.00114 pb ➔ Katharina (LHcb) cross check performed at NLO and perfect agreement found
➔ BUT EW corrections to be added ➔ OVERALL effects illustrated in plot below



LO predictions

$M_{ll} > 50\,\text{GeV}, \quad p_{\text{T},l^\pm} > 25\,\text{GeV}, \quad |y_{l^\pm}| < 2.5,$ arXiv:0911.2329v2

$\text{pp} \to l^+l^- + X$ at $\sqrt{s} = 14\,\text{TeV}$ Table 1

MRST2004QED

G_μ ; scales=M_Z (!)

M_{ll}/GeV	50–∞	100–∞	200–∞	500–∞	1000–∞	2000–∞
σ_0/pb	738.733(6)	32.7236(3)	1.48479(1)	0.0809420(6)	0.00679953(3)	0.000303744(1)
$\sigma_0\vert_{\text{FS/PS}}$/pb	738.773(6)	32.7268(3)	1.48492(1)	0.0809489(6)	0.00680008(3)	0.000303767(1)
$\delta_{\gamma\gamma,0}$/%	0.17	1.15	4.30	4.92	5.21	6.17
$\delta^{\text{rec}}_{q\bar{q},\text{phot}}$/%	−1.81	−4.71	−2.92	−3.36	−4.24	−5.66
$\delta^{\mu^+\mu^-}_{q\bar{q},\text{phot}}$/%	−3.34	−8.85	−5.72	−7.05	−9.02	−12.08
$\delta^{\mu^+\mu^-}_{\text{multi}-\gamma}$/%	$0.073^{+0.027}_{-0.024}$	$0.49^{+0.18}_{-0.15}$	$0.17^{+0.06}_{-0.05}$	$0.23^{+0.07}_{-0.06}$	$0.33^{+0.09}_{-0.08}$	$0.54^{+0.13}_{-0.12}$
$\delta_{q\bar{q},\text{weak}}$/%	−0.71	−1.02	−0.14	−2.38	−5.87	−11.12
$\delta_{\text{h.o.weak}}$/%	0.030	0.012	−0.23	−0.29	−0.31	−0.32
$\delta^{(2)}_{\text{Sudakov}}$/%	−0.00046	−0.0067	−0.035	0.23	1.14	3.38
$\delta_{q/\bar{q}\gamma,\text{phot}}$/%	−0.11	−0.21	0.38	1.53	1.91	2.34
$\delta^{\text{rec}}_{\gamma\gamma,\text{phot}}$/%	−0.0060	−0.032	−0.11	−0.14	−0.16	−0.23
$\delta^{\mu^+\mu^-}_{\gamma\gamma,\text{phot}}$/%	−0.011	−0.058	−0.22	−0.30	−0.39	−0.59
$\delta_{\gamma\gamma,\text{weak}}$/%	0.000045	0.00056	−0.025	−0.14	−0.31	−0.64
δ_{QCD}/%	4.0(1)	13.90(6)	26.10(3)	21.29(2)	8.65(1)	−11.93(1)

photon induced

weak

to be added : NLO photon induced (photon-quark contribution, not in FEWZ 3.1.)

'Benchmark' FEWZ 3.1.b2
→ I could reproduce exactly those numbers within 0.2% for photon-induced and weak contributions (c.f. also FEWZ 3.1. paper).
→ Perform calculations for Atlas cuts and bins !
→ISSUE : how to ADD?

Working list for experiments

Benchmark exercise

- ✧ Agree on tools : FEWZ 3.1.X including EW corrections (special : treatment of single photon QED FSR)
- ✧ Agree on nominal schema : Gmu
- ✧ Agree on nominal PDF
- ✧ Agree on selected bins and cuts
- ✧ Agree on precision
- ✧ Perform alternative cross checks : change of EW schema

ToDo :

- agree on documentation of theory calculations per publication : where to put it?
- option : agree on a proposal for the forthcoming publications (and have our document as the baseline for the EW etc details)

To be discussed : final combination of photon induced effects and estimate theory uncertainties