Università degli Studi di Milano

Istituto Nazionale di Fisica Nucleare

Higher-order corrections for precision measurements an update of the WG1 activities

Alessandro Vicini
University of Milano, INFN Milano

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Motivations

precision tests of the SM, with focus on MW and $\sin^2\theta_{eff}$ determination

- ptW and ptZ are fundamental auxiliary observables to determine ptlep and MT → MW
- $A_{FB}(M_{ll})$ is the observable under scrutiny to extract $\sin^2\theta_{eff}$

we need to include in a systematic way leading and subleading corrections to these observables

the residual uncertainties propagate as systematic errors to MW and $\sin^2\theta_{eff}$

Developments in the study of ptZ, ptW and ptW/ptZ distributions

Fast progress in the understanding of these distributions

- jump in the theoretical precision with new results available with N3LL+NNLO QCD accuracy
  → RadISH
- possibility to perform fast simulations of ptV with NLO QCD accuracy on the spectrum
  → DYTurbo
- update to N3LL of the ResBos implementation of CSS resummation
  → ResBos2
- new studies on the correlations between W and Z uncertainties
  → Geneva

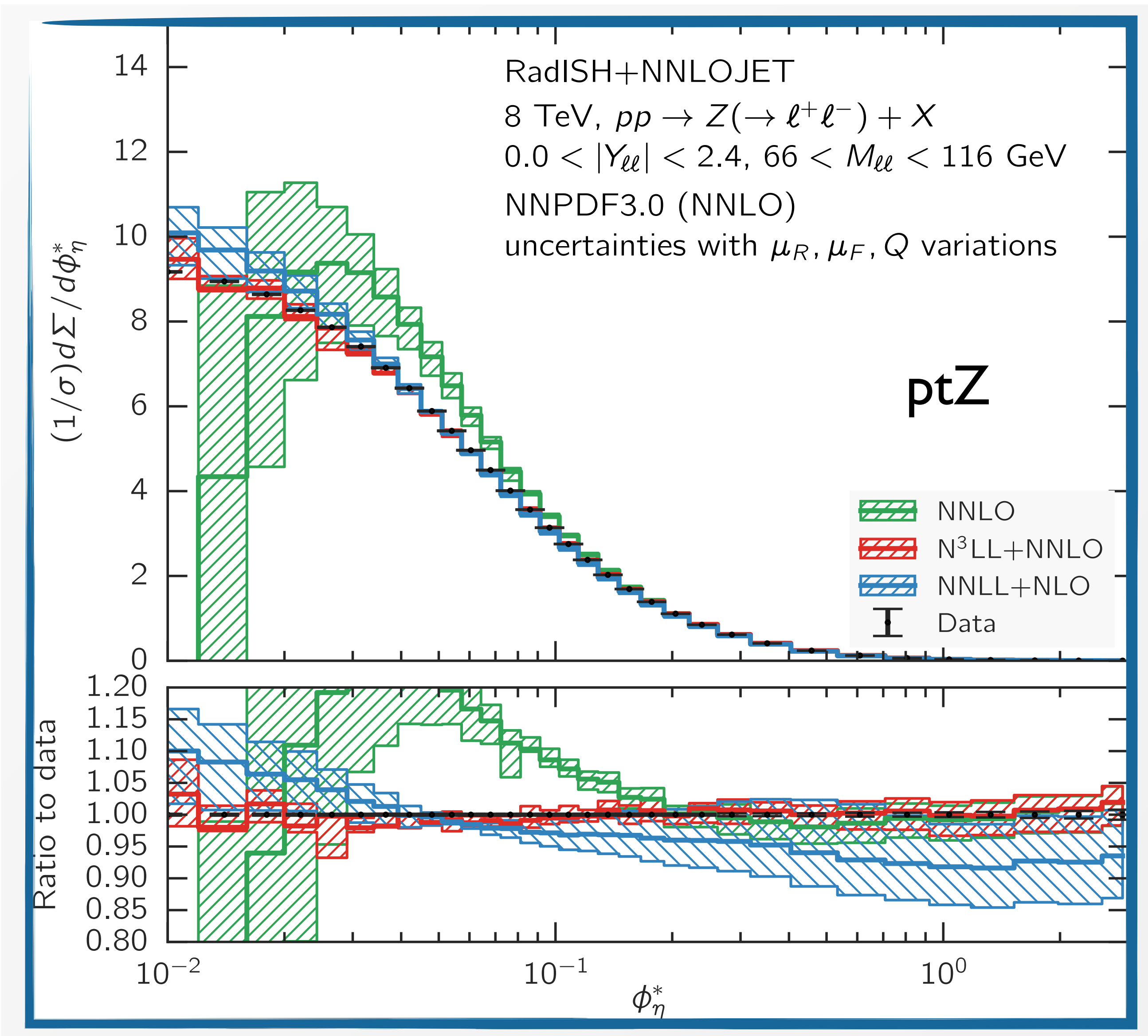
The QCD codes under study can handle some, but not all, classes of subleading effects
"subleading" effects ≡ effects with an impact at the 1% level on the shape of ptV distribution

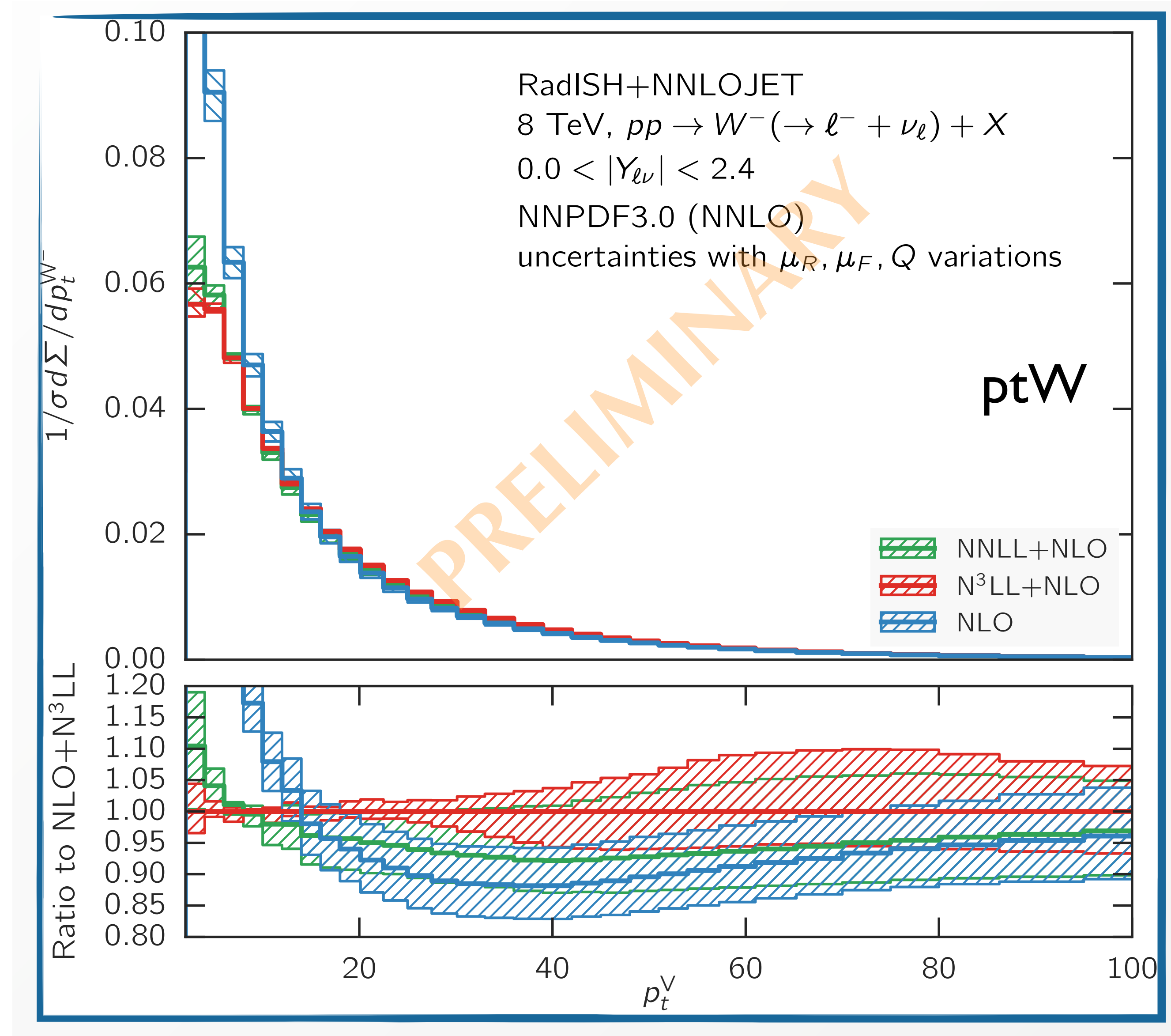
→ quark mass corrections (matrix elements, kinematics)
→ QED corrections,
→ flavour dependent initial state non-perturbative corrections

these effects distinguish W from Z

Developments in the study of ptZ, ptW and ptW/ptZ distributions

[data from ATLAS 1512.02192]
[Bizon, Chen et al. 1805.05916]





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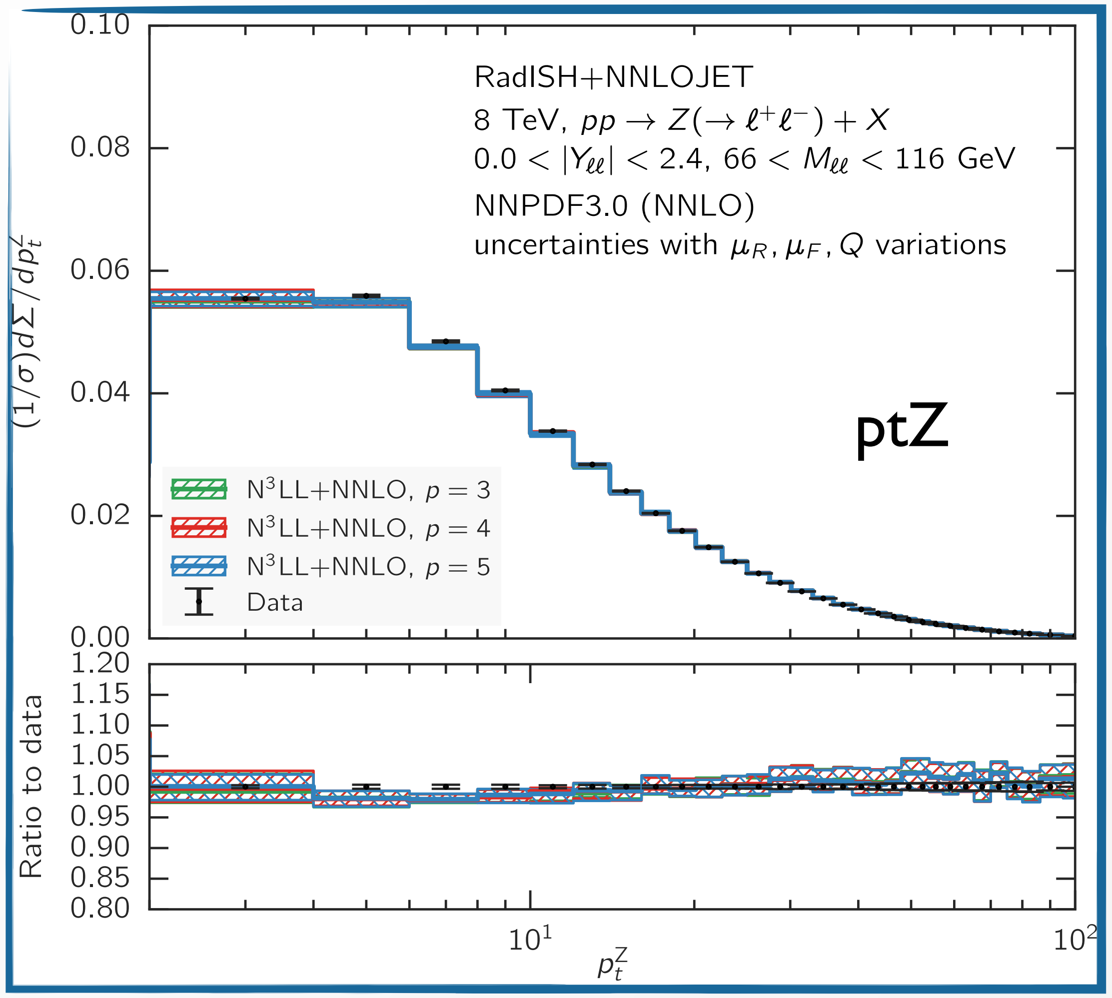
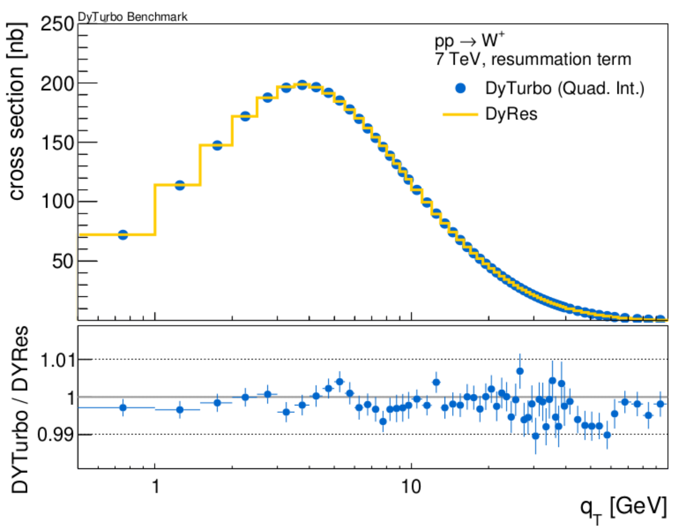
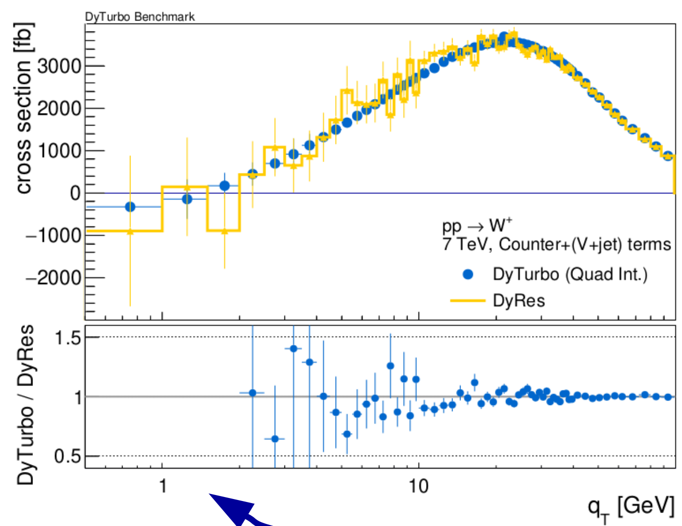


The comparison of different matching schemes provides information complementary to QCD scale variations and a more conservative uncertainty estimate in the transition region 10 < ptV < 40 GeV

Developments in the study of ptZ, ptW and ptW/ptZ distributions

Benchmark results





- DYTurbo predictions are benchmarked with DYRes at NNLL, and with other programs at NNLO

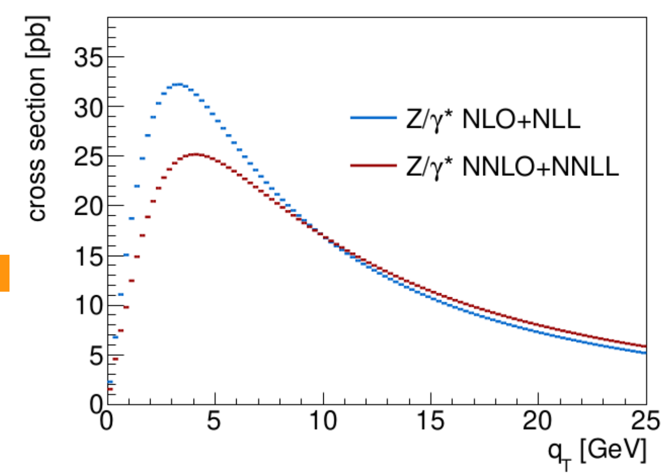
	SHERPA	DYNNLO	FEWZ	DYTurbo (Quad.)
$\sigma(pp \to W^+ \to l^+\nu)$ [pb]	3204 ± 4	3191 ± 7	3207 ± 2	3196 ± 7
$\sigma(pp \to W^- \to l^-\nu)$ [pb]	2252 ± 3	2243 ± 6	2238 ± 1	2248 ± 4
$\sigma(pp \to Z/\gamma \to l^+l^-)$ [pb]	502.0 ± 0.6	502.4 ± 0.4	504.6 ± 0.1	502.8 ± 1.0

Small differences between FEWZ and the other predictions are expected due to phase space with p_T^l symmetric cuts, and different subtraction scheme

Stefano Camarda

Renewed implementation of DYRes
with substantial performance improvement
→
it allows to perform fits and precision studies
(CPU demanding)

Example calculation



- Example calculation for Z p_T spectrum at 13 TeV
  - No cuts on the leptons
  - Full rapidity range
  - 100 p_T bins
  - 20 parallel threads

Time required	RES	CT	V+jet
NLO+NLL	6 s	0.2 s	4 min
NNLO+NNLL	10 s	0.7 s	3.4 h

- The most demanding calculation is V+jet

→ can use APPLgrid/FASTnlo for this term

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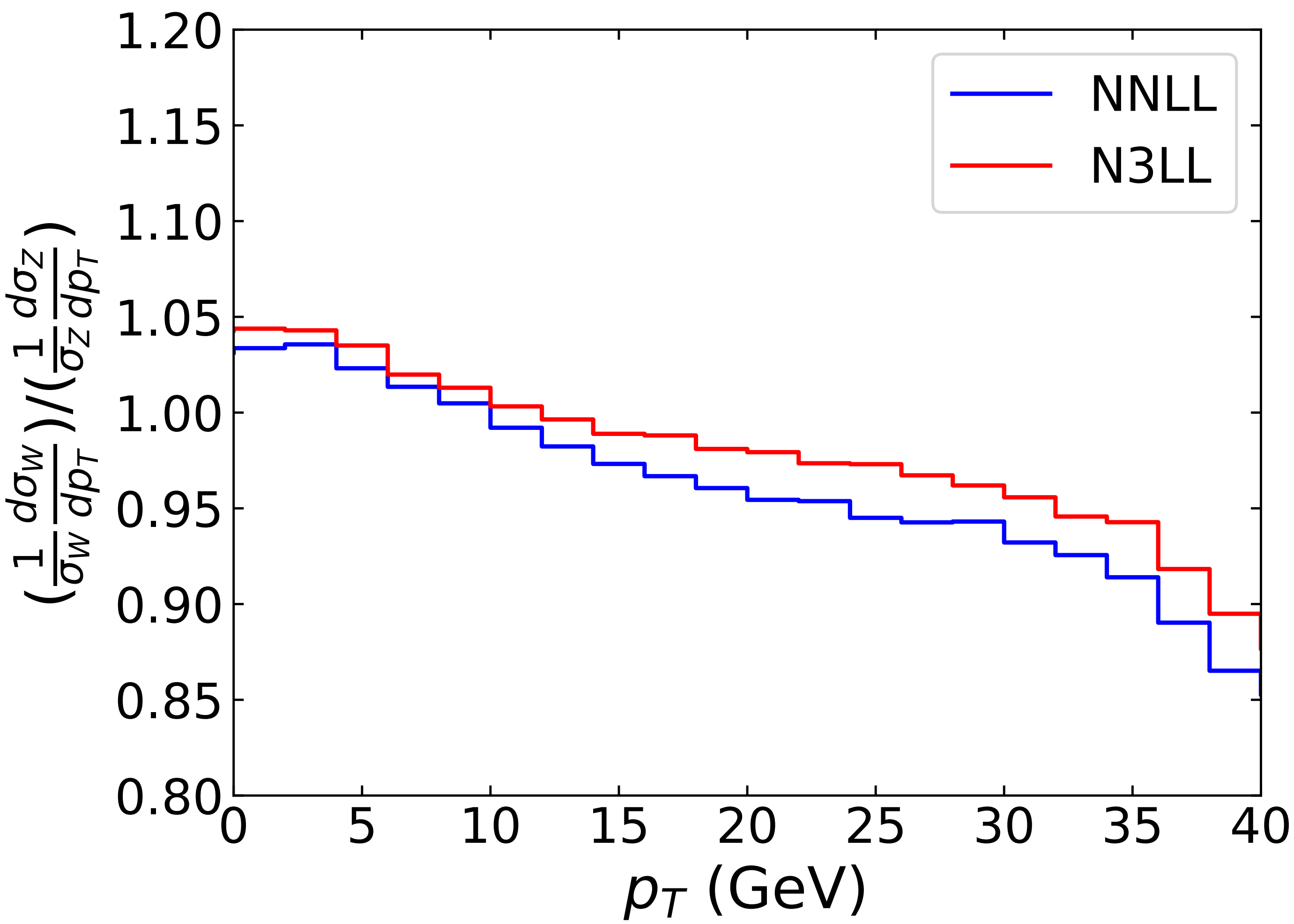
Developments in the study of ptZ, ptW and ptW/ptZ distributions

Transverse Momentum Ratio



Increase to N3LL of the logarithmic accuracy in ResBos in the CSS approach

ptZ and ptW/ptZ benchmarking and comparisons

Motivation:

provide best predictions for these two distributions
assess the overall residual theoretical uncertainty

Available QCD predictions can be divided in two groups:

all orders analytical resummation of log(ptV/MV) enhanced terms
RadISH { N3LL (small ptV) + NNLO (large ptV) QCD }
DyRes/DYTurbo, ResBos2, Geneva { NNLL + NLO QCD }

MC simulation of QCD radiation effects, matching exact matrix elements and Parton Shower
POWHEG, Sherpa, (aMC@NLO ?) { NLL + LO QCD }
DYNNLOPS?, Sherpa-UN2LOPS { NLL + NLO QCD }

First phase of comparison (current):
codes implementing analytical resummation of log(ptV/MV) enhanced term

Second phase of comparison (future):
discuss how the predictions of analytical codes can "guide" the implementation of MC event generators

Prepare the ground to include in a systematic way leading and subleading corrections

Channel-dependent effects

Impact on MW of non-pert. flavour dependent effects

- Take the “Z-equivalent” *flavour-dependent* parameter sets and compute *low-statistics* (135M) m_T, p_{Tl}, p_{Tn} distributions

  ➡ **pseudodata**

- Take the *flavour-independent* parameter set and compute *high-statistics* (750M) m_T, p_{Tl}, p_{Tn} distributions for 30 different values of M_W

  ➡ **templates**

- **perform the template fit procedure and compute the shifts induced by flavour effects**

- transverse mass: zero or few MeV shifts, generally favouring lower values for W^- (preferred by EW fit)

	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	0	-1	-2	-2	3	-3
2	0	-6	0	-2	0	-5
3	-1	9	0	-2	4	-10
4	0	0	-2	-2	-4	-10
5	0	4	1	-1	-3	-6
6	1	0	2	-1	4	-4
7	2	-1	2	-1	0	-8
8	0	2	8	1	7	8
9	0	4	-3	-1	0	7

TABLE I: ATLAS 7 TeV

	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	-1	-5	8	-1	-2	7
2	-1	-15	5	-1	5	10
3	-1	1	11	-1	-6	5
4	-1	-15	4	-1	-4	4
5	-1	-5	8	-1	-7	4

TABLE II: LHCb 13 TeV

Preliminary

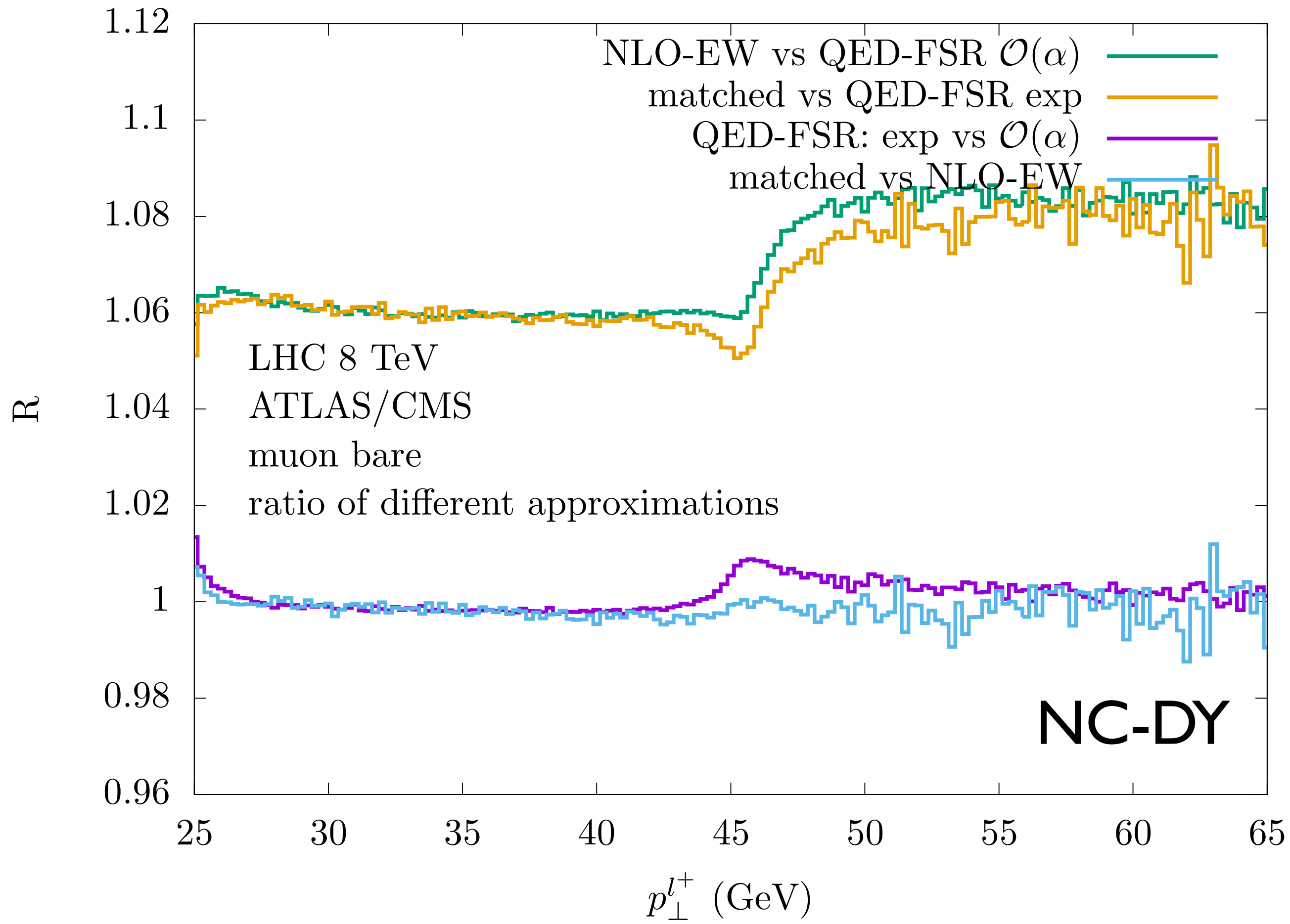
Set	u_v	d_v	u_s	d_s	s
1	0.34	0.26	0.46	0.59	0.32
2	0.34	0.46	0.56	0.32	0.51
3	0.55	0.34	0.33	0.55	0.30
4	0.53	0.49	0.37	0.22	0.52
5	0.42	0.38	0.29	0.57	0.27
6	0.40	0.52	0.46	0.54	0.21
7	0.22	0.21	0.40	0.46	0.49
8	0.53	0.31	0.59	0.54	0.33
9	0.46	0.46	0.58	0.40	0.28

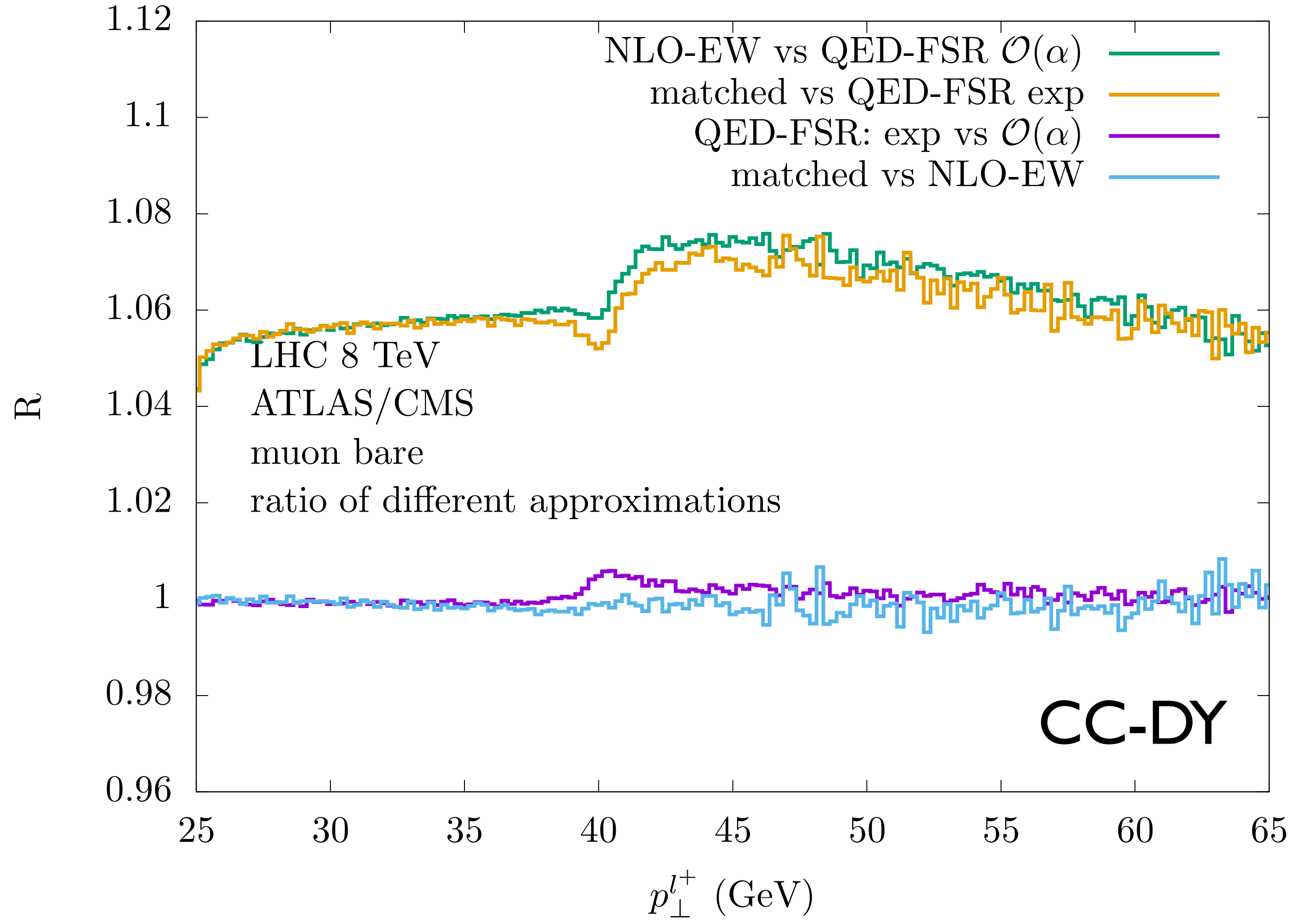
NLL+LO QCD analysis obtained through a modified version of the **DYRes** code [Catani, deFlorian, Ferrera, Grazzini (2015)]

Statistical uncertainty: 2.5 MeV

Bacchetta, Bozzi, Radici, Ritzmann, Signori (arXiv:1807.02101, accepted by PLB)

Channel-dependent effects





ISR+IFI QED radiation distorts in different ways the ptlep distribution in NC and CC DY

EW corrections relevant for the determination of $\sin^2\theta_{eff}$

A_{FB}: basic definitions

invariant mass Forward-Backward asymmetry
in neutral-current DY

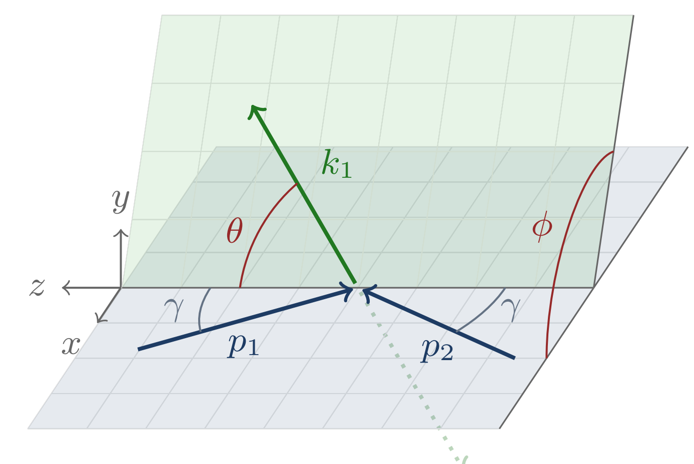
$$A_{FB}(M_{l^+l^-}) = \frac{F(M_{l^+l^-}) - B(M_{l^+l^-})}{F(M_{l^+l^-}) + B(M_{l^+l^-})}$$

$$F(M_{l^+l^-}) = \int_0^1 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^* \qquad B(M_{l^+l^-}) = \int_{-1}^0 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$$

scattering angle defined in the Collins-Soper frame → "Forward" ("Backward")

$$\cos\theta^* = f \frac{2}{M(l^+l^-)\sqrt{M^2(l^+l^-) + p_t^2(l^+l^-)}} [p^+(l^-)p^-(l+) - p^-(l^-)p^+(l^+)]$$

$$p^\pm = \frac{1}{\sqrt{2}}(E \pm p_z) \qquad f = \frac{|p_z(l^+l^-)|}{p_z(l^+l^-)}$$



the asymmetry is possible at $Y_Z \neq 0$ and grows with $|Y_Z|$
where the unbalance between valence and sea quarks defines a forward direction

the asymmetry is due to parity-violating terms:

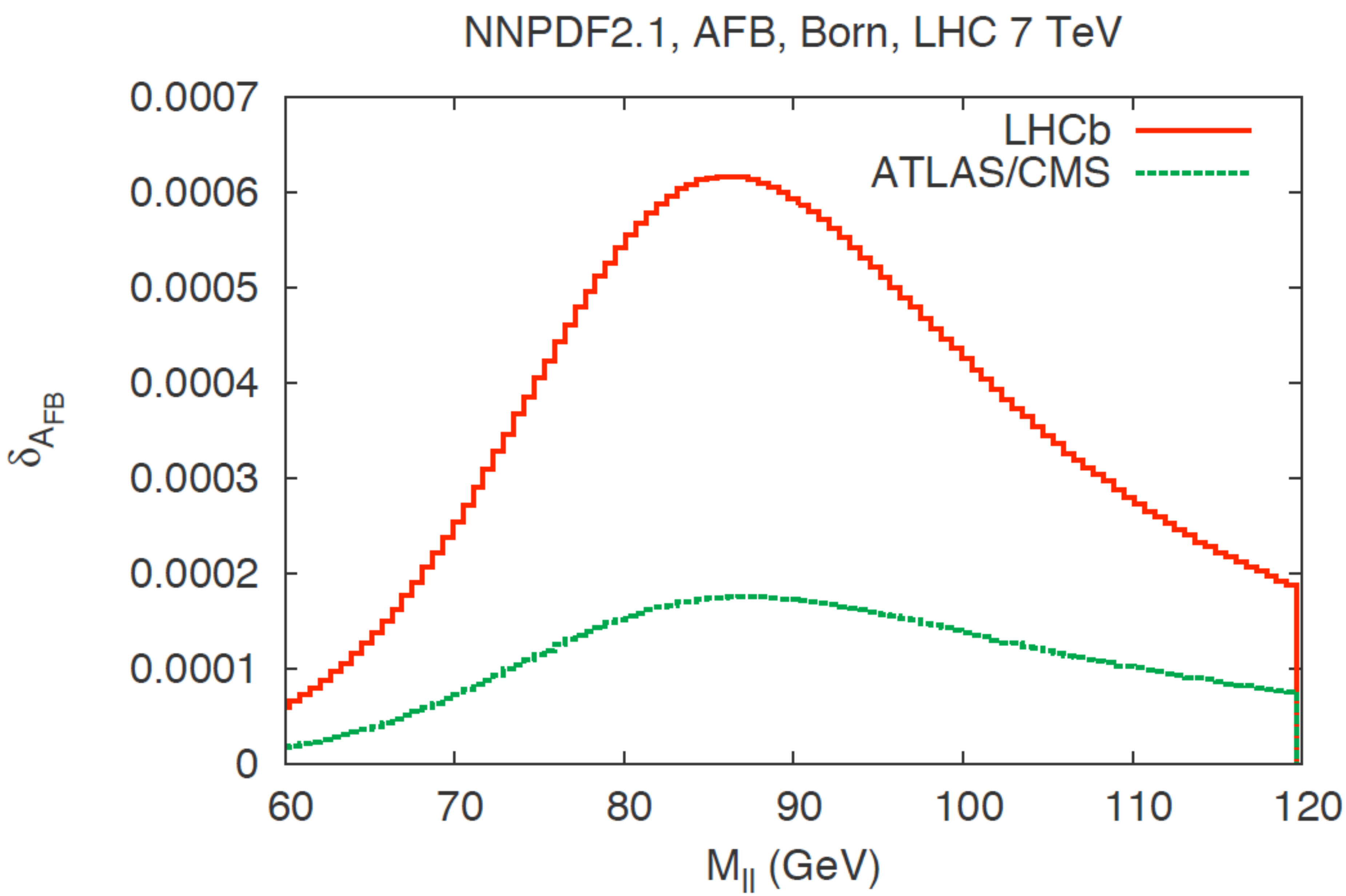
$|M_Z|^2$ → sensitivity to $\sin^2\theta_{eff}$

2 Re($M_\gamma M_Z^\dagger$) → large asymmetry due to axial-vector couplings (but no sensitivity to $\sin^2\theta_{eff}$)

Sensitivity to $\sin^2\theta_W$

$$\delta A_{FB} = A_{FB}(\sin^2\theta_W + \delta\sin^2\theta_W) - A_{FB}(\sin^2\theta_W - \delta\sin^2\theta_W)$$

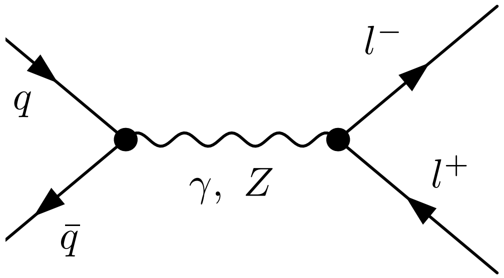
$$\delta\sin^2\theta_W = 0.0001$$



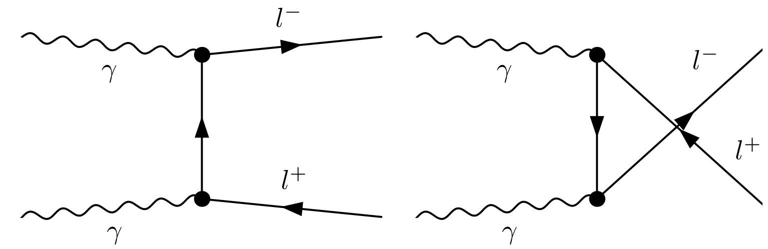
the maximal sensitivity to $\sin^2\theta_{eff}$ is observed in the Z resonance region

we need to predict A_{FB} having under control all the effects yielding $\delta A_{FB} \sim 10^{-4}$

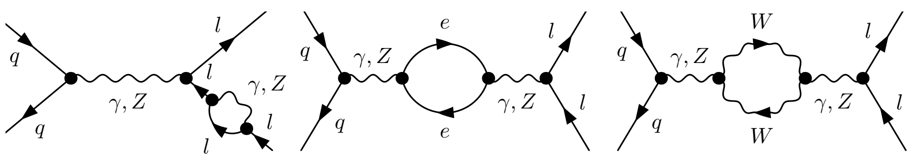
Partonic subprocesses contributing at O(α)



Born

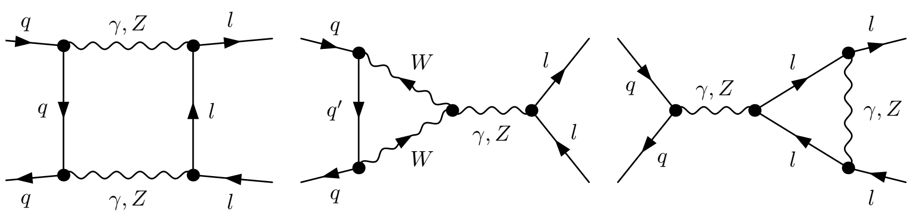


(b) (c)

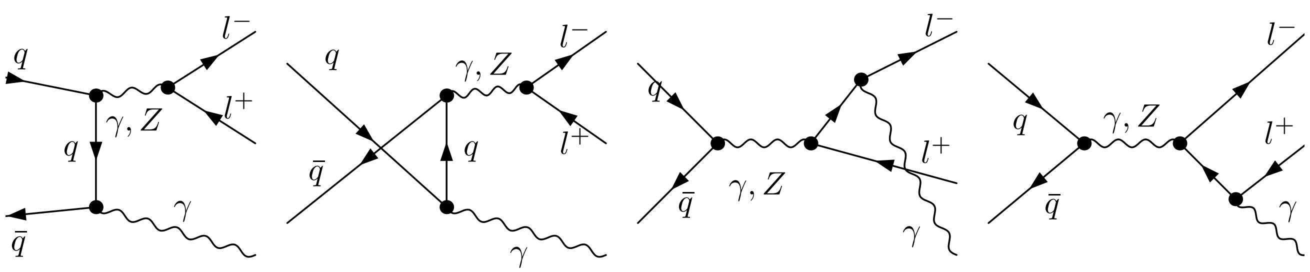


(a) (b) (c)

O(α) virtual: photonic and purely weak

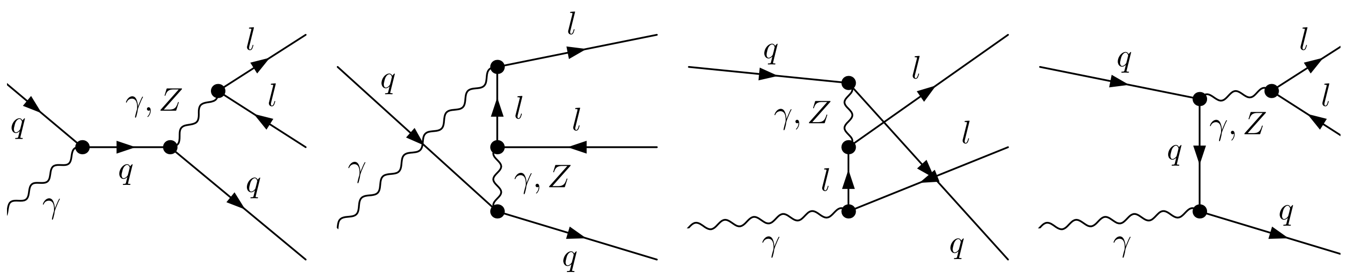


(d) (e) (f)



(a) (b) (c) (d)

O(α) real bremsstrahlung:
FSR, ISR, IFI



(a) (b) (c) (d)

O(α) photon induced

Plan of the comparisons of simulation codes

observables: M_{ll} and A_{FB} distributions

approximations: LO, NLO, NLO+h.o.

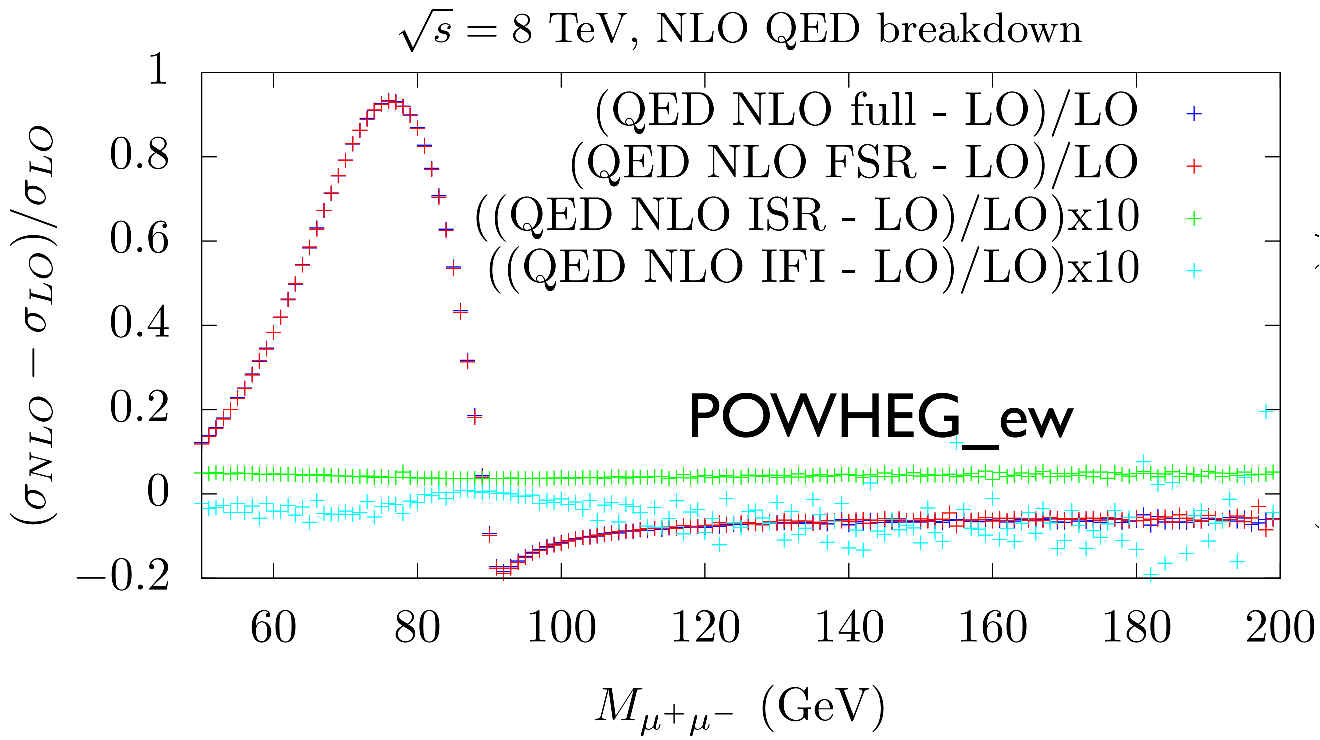
codes involved: POWHEG_ew, MCSANC, HORACE, WZGRAD
predictions based on the DIZET library (see talk by E. Richter-Was)
comparison with KKMC

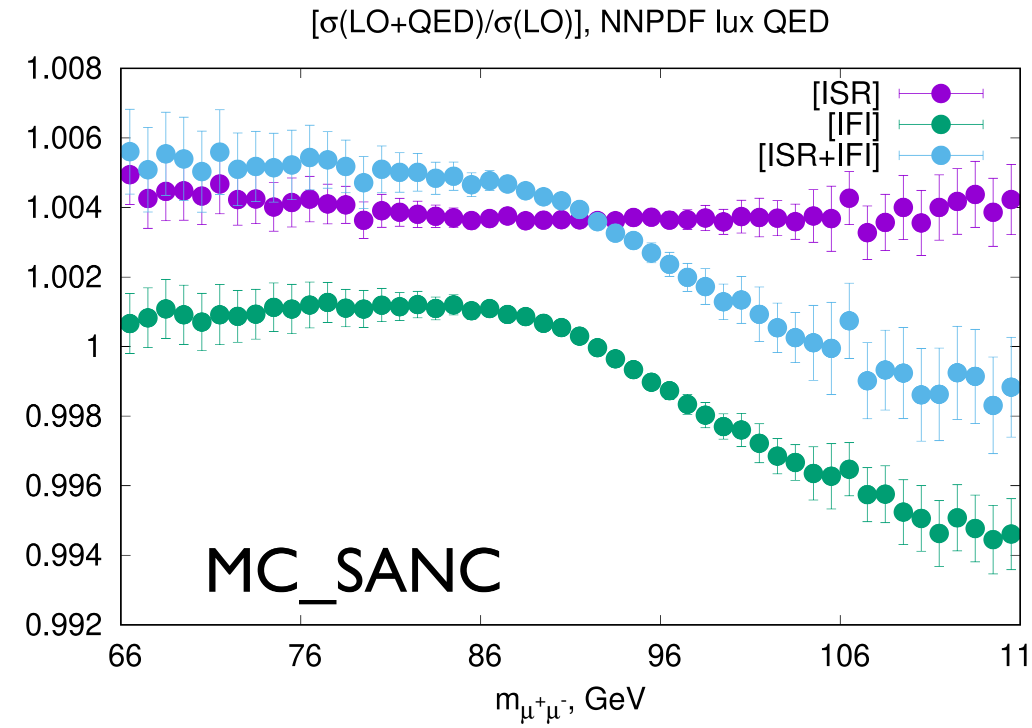
overlap with 1606.02330 at NLO for the M_{ll} distribution (now breakdown of $O(\alpha)$ corrections)

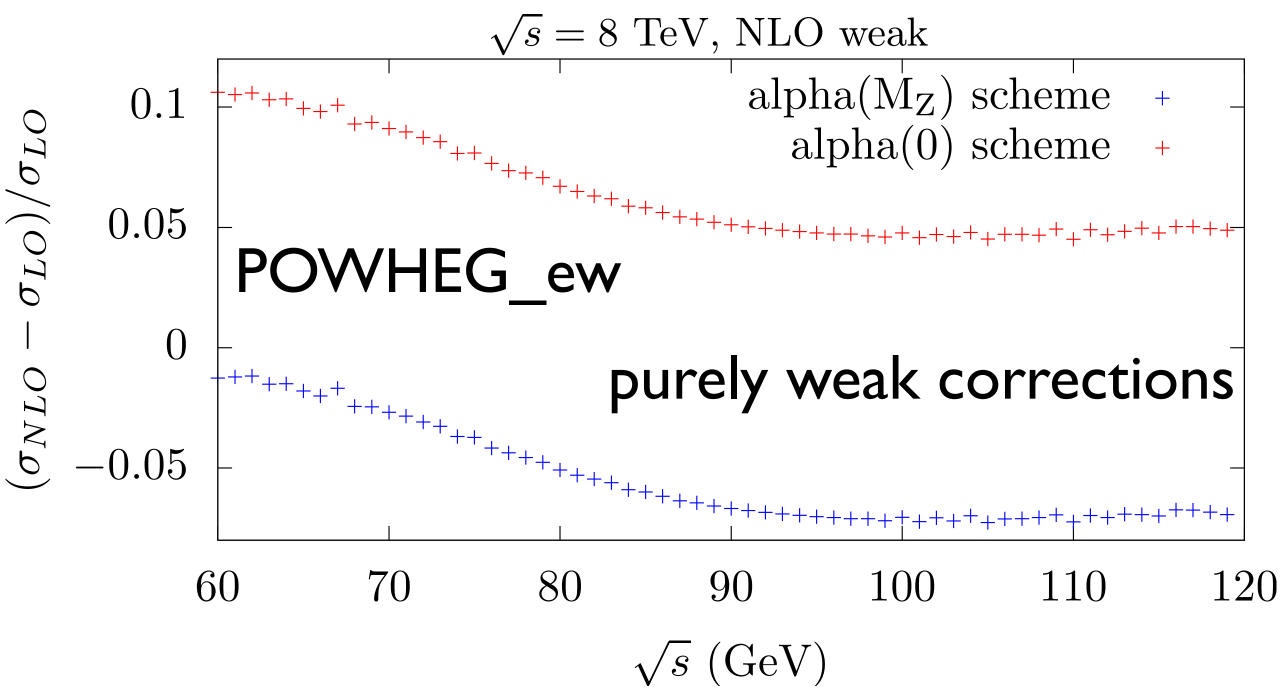
1606.02330 includes a systematic analysis of $O(\alpha^2)$ contributions, only for the M_{ll} distribution

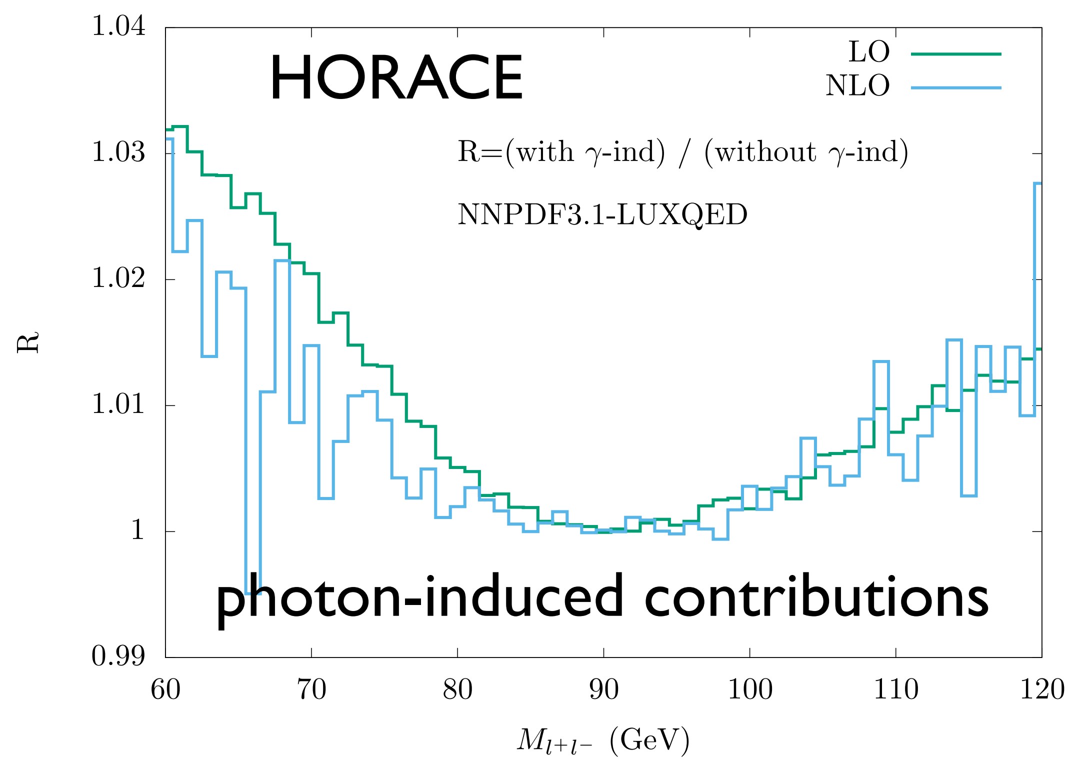
now focus on A_{FB} and on the $\sin^2\theta_{eff}$ determination

Lepton-pair invariant mass distribution: breakdown of O(α) corrections







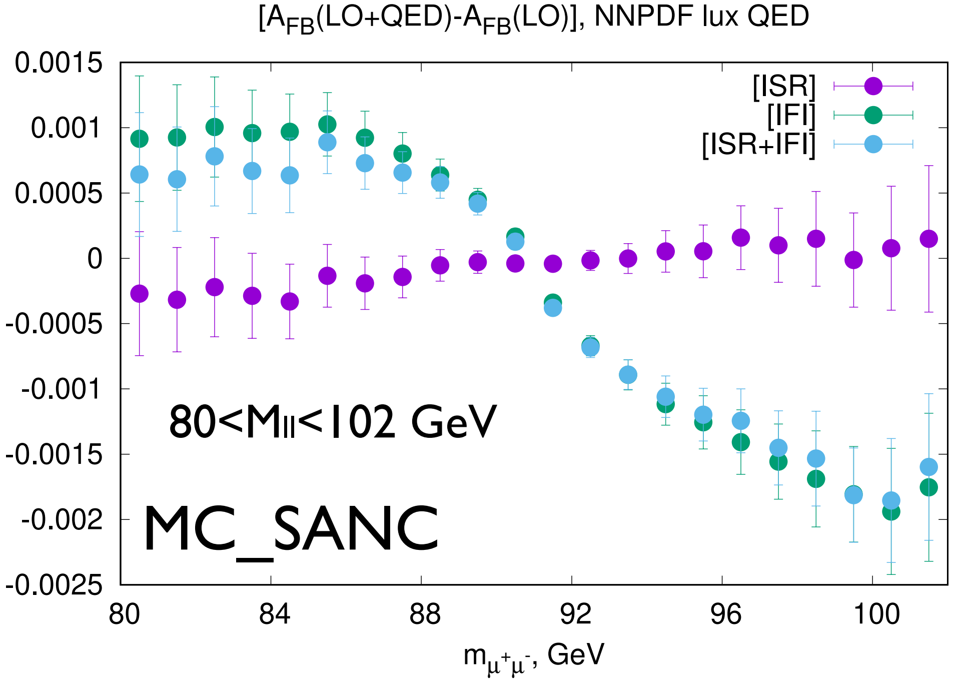


for each subset of corrections, a detailed comparison between the participant codes is ongoing

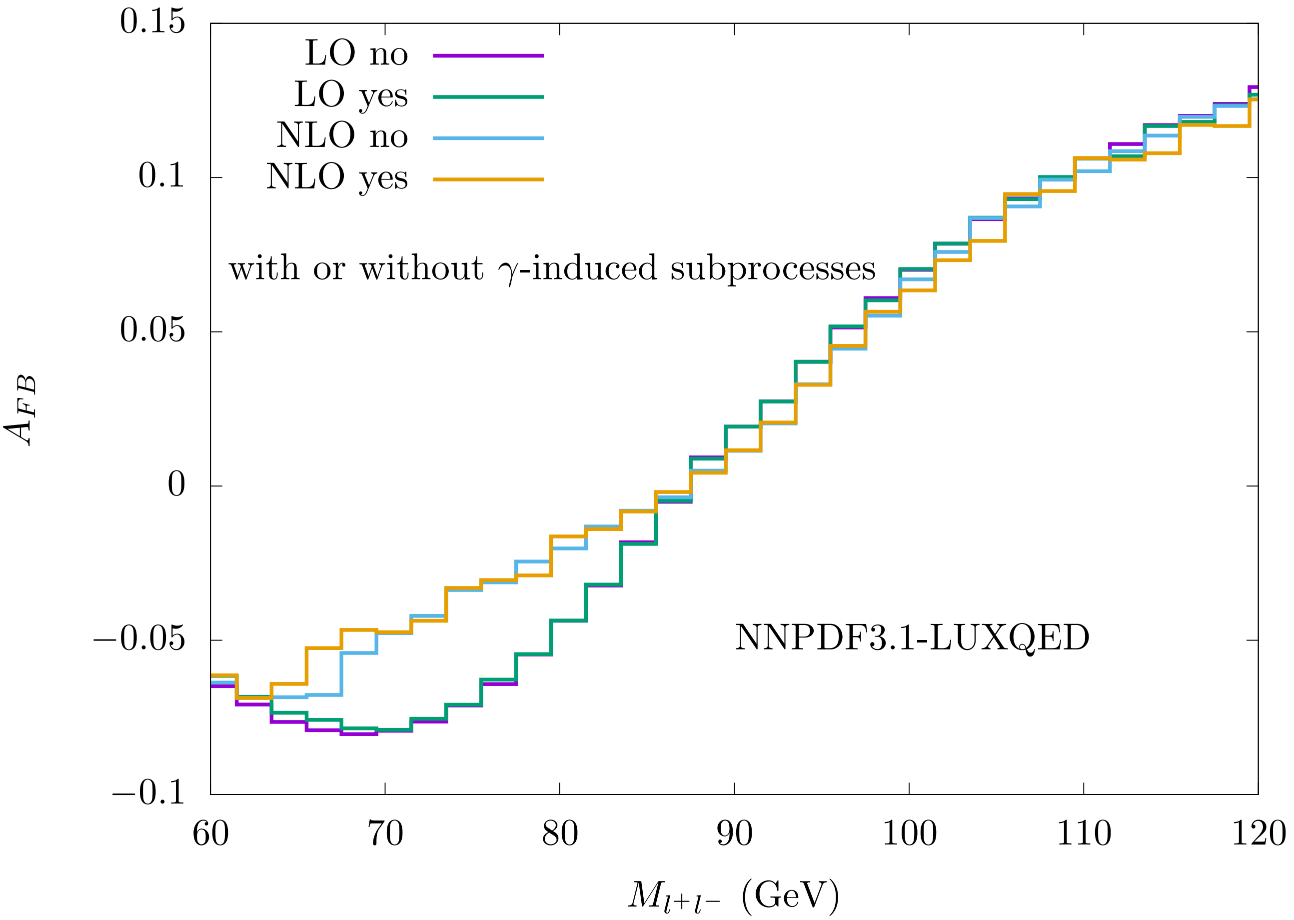
A_{FB} distribution: breakdown of O(α) corrections

A_{FB}	LO	NLO QED	NLO QED FSR	NLO QED ISR
		66 GeV $< m_{ll} < 116$ GeV		
QED PDF	0.03986(2)	0.04056(4)	0.04060(5)	0.03985(3)
$\Delta_{x-\mathrm{LO}}$		0.00070(6)	0.00074(7)	-0.00001(3)
NO-QED PDF	0.03964(3)	0.04033(4)	0.04038(5)	0.03963(3)
$\Delta_{x-\mathrm{LO}}$		0.00069(7)	0.00074(8)	-0.00001(3)
		66 GeV $< m_{ll} < 116$ GeV, $m_{ll} > 50$ GeV, $p_\perp^\ell > 25$ GeV, $\lvert\eta_\ell\rvert < 2.5$		
QED PDF	0.01815(3)	0.01836(6)	0.01835(6)	0.01815(3)
$\Delta_{x-\mathrm{LO}}$		0.00021(9)	0.00020(9)	0.0
NO-QED PDF	0.01793(4)	0.01815(6)	0.01814(8)	0.01794(3)
$\Delta_{x-\mathrm{LO}}$		0.00022(10)	0.00021(12)	0.00001(7)
		80 GeV $< m_{ll} < 102$ GeV		
QED PDF	0.04481(2)	0.04593(4)	0.04588(5)	0.04481(3)
$\Delta_{x-\mathrm{LO}}$		0.00112(6)	0.00107(7)	0.0
NO-QED PDF	0.04457(3)	0.04567(4)	0.04562s(5)	0.04457(3)
$\Delta_{x-\mathrm{LO}}$		0.00100(7)	0.00104(8)	0.0
		66 GeV $< m_{ll} < 116$ GeV, $m_{ll} > 50$ GeV, $p_\perp^\ell > 25$ GeV, $\lvert\eta_\ell\rvert < 2.5$		
QED PDF	0.01895(3)	0.01937(6)	0.01935(7)	0.01815(3)
$\Delta_{x-\mathrm{LO}}$		0.00042(9)	0.00040(10)	-0.00080(6)
NO-QED PDF	0.01873(4)	0.01916(6)	0.01913(8)	0.01873(3)
$\Delta_{x-\mathrm{LO}}$		0.00043(10)	0.00040(12)	0.0

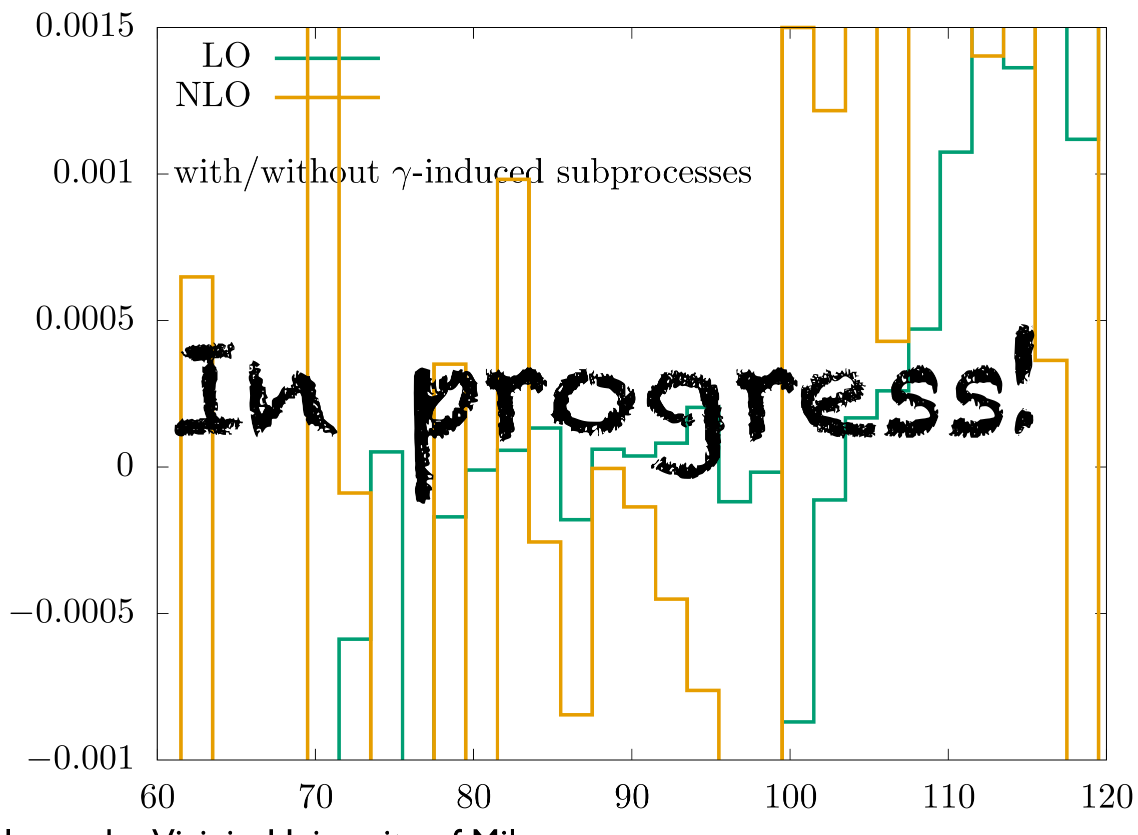
POWHEG_ew

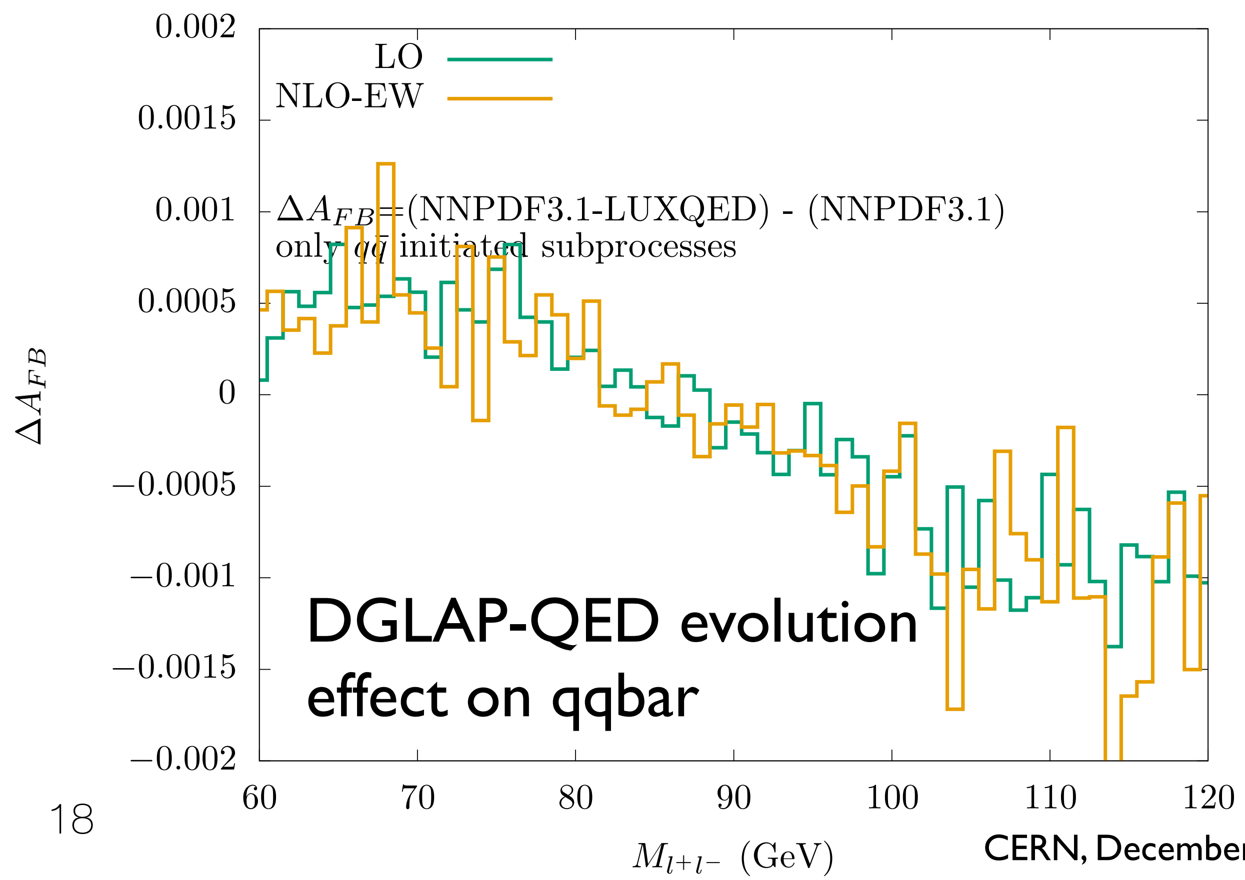


A_{FB} distribution: photon-induced contributions



comparison between POWHEG_ew, MCSANC, HORACE in progress

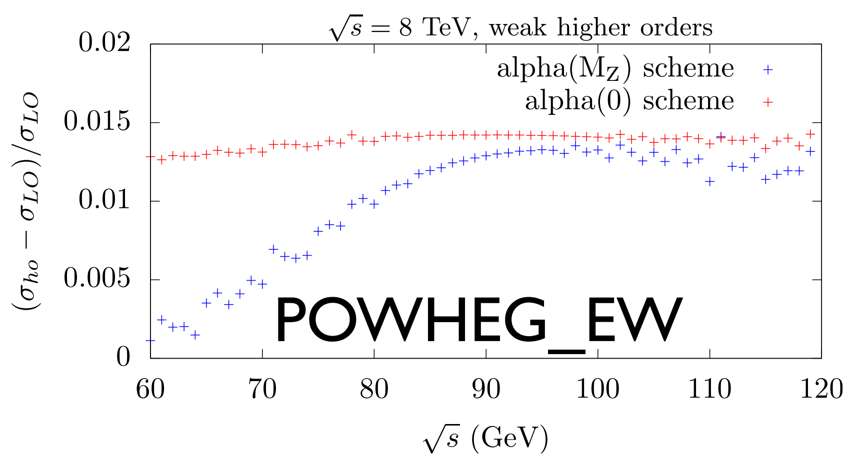


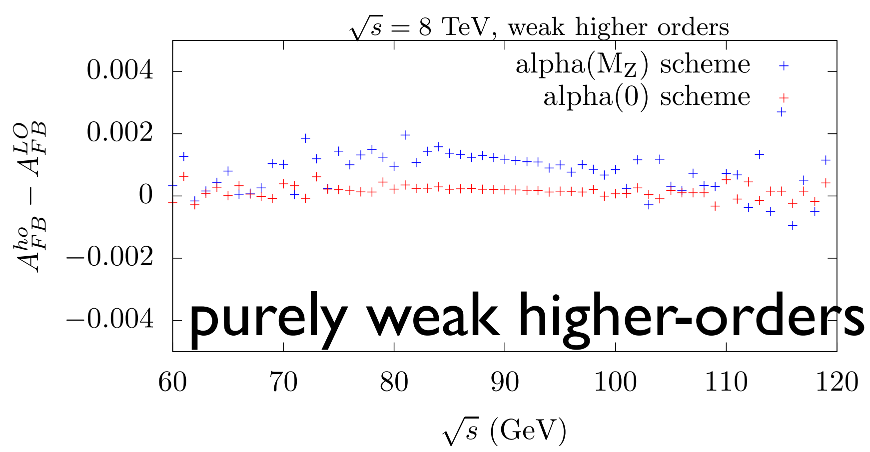


A_{FB} distribution: future steps

Beyond NLO, several classes of higher-order corrections are available (cfr. 1606.02330)

- multiple photon emissions (broken into FSR, ISR and IFI components)
- universal corrections to LO couplings
- additional light pair emission
- interplay of factorizable real-virtual contributions





comparison between POWHEG_EW and DIZET lib in progress

A_{FB} distribution: future steps

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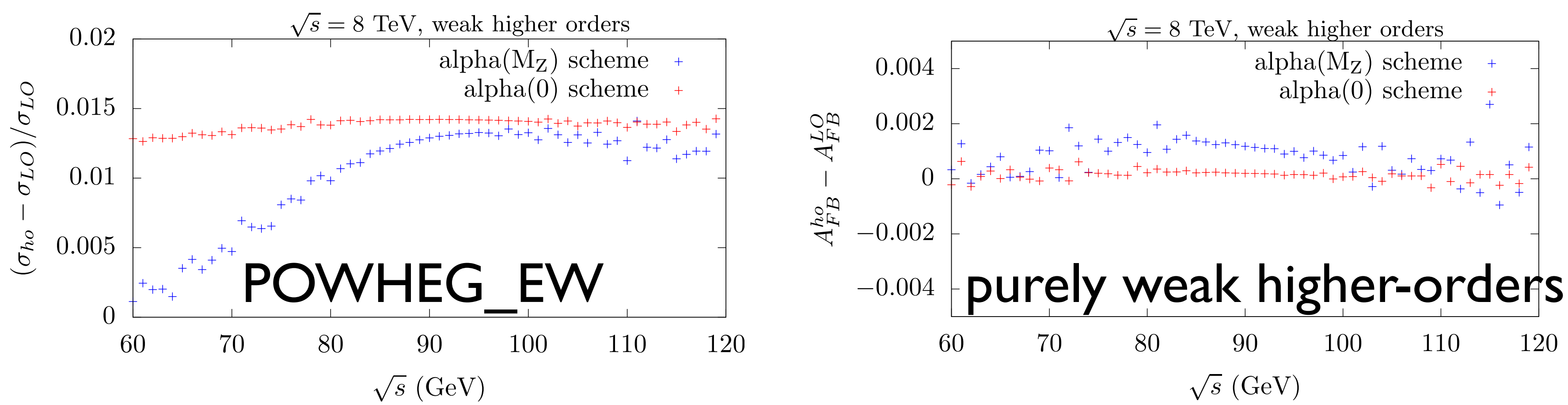


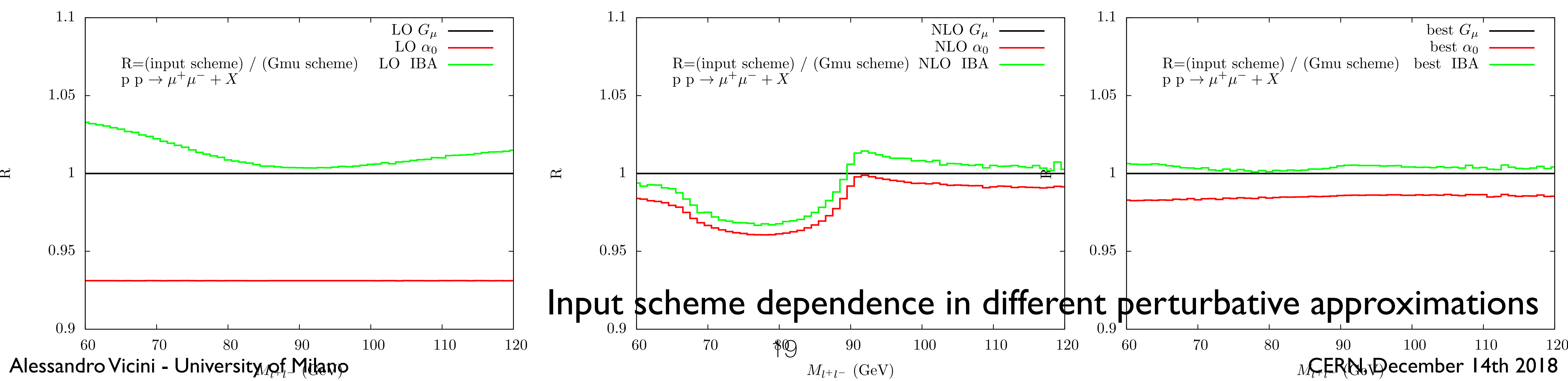
comparison between POWHEG_EW and DIZET lib in progress

The matching between fixed-order matrix elements and all-order emissions requires a prescription

→ arbitrariness of $O(\alpha^2)$

→ impact on kinematical distributions, different effect of virtual and real-virtual corrections

possible comparison between HORACE and POWHEG matching schemes



Input scheme dependence in different perturbative approximations

Determination of $\sin^2\theta_{eff}$

We wish that the procedure followed to determine the effective weak mixing angle
allows the measurement of a quantity
that can be consistently combined with previous results from LEP/SLD and Tevatron

Two distinct approaches are necessary
- model independent fit
- measurement in the SM (closure test)

The LEP/SLD measurements relied on
- a specific special kinematical point (Z resonance)
- τ polarisation and LR polarization measurements
- the possibility to assume, with tested good accuracy, the factorisation of the A_{FB} expression

$$A_{FB}^f = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

Outside the peak the factorisation degrades and eventually breaks

A detailed study is desirable
→ to understand the properties and limitations of the hadron collider setup.
→ the details of the experimental procedures (e.g. dilution corrections) and their equivalence
in terms of scope

Reporting problems about precision codes

a benchmarking activity is ongoing for several years and documented with a repository of public codes
https://twiki.cern.ch/twiki/bin/view/Main/DrellYanComparison
available for usage and guaranteed by the respective authors to reproduce benchmark numbers

arXiv:1606.02330 has been published by the authors of several popular codes
showing agreement for many observables at the few per mil level

the feedback of all the users
testing the codes in different setups and for different observables
is crucial to improve the quality of the codes

WG1 on precision measurements is the natural place where these problems should be addressed
(e.g. discrepancies between DYNNLO and FEWZ with specific acceptance cuts)

Conclusions

Concrete steps to prepare the tools that will be used in high-precision analyses

Benchmarking activities between different groups/codes started

Several “subleading” effects potentially relevant for the LHC precision goal identified and under scrutiny

settings for benchmarking of EW codes

- PDF set
  - `NNPDF31_nlo_as_0118_luxqed`, `LHAPDF ID = 324900`
  - `NNPDF31_nlo_as_0118`, `LHAPDF ID = 303400`
- $\mu_F = \hat{s}$
- complex pole M_Z and M_W mass values
- G_μ scheme
- kinematic acceptances
  - a) $m_{\ell\ell} > 50$ GeV without additional cuts
  - b) 66 GeV $< m_{\ell\ell} < 116$ GeV
  - c) 80 GeV $< m_{\ell\ell} < 102$ GeV
  - d) $m_{\ell\ell} > 50$ GeV, $p_\perp^\ell > 25$ GeV, $\eta_\ell < 2.5$
- observables: $m_{\ell\ell}$ and A_{FB}