Introduction and news

- **Welcome to our last meeting in 2021!**

- **<u>News item 1</u>: a few changes in our WG organisation, some very recent (Simone), some less so.**
  Conveners (and affiliation!) as of now are:
  Fulvio (theory), Aleko and Simone (CMS), Mika (LHCb), Aram and Daniel (ATLAS)

- **<u>News item 2</u>: we are now about to enter year 5 of our benchmarking work started in April 2018. Priority in 2022 has to be to document and publish even if we have to descope some aspects.**

- **News item 3: we are indeed reaching the end-game of ongoing calculations and this is a great achievement, thanks to all contributors!**
  Example of QED status overview in next slides

Summary of status of QED corrections

- **Overview of what was shown at last (especially) and previous meetings**

Definition of $A_{\mathrm{FB}}^{\mathrm{IFI}}$

- We define it as

$$A_{\mathrm{FB}}^{\mathrm{IFI}} = \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\left(\sigma_F + \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F + \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F + \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F + \sigma_B\right)^{\mathrm{LO}}}$$

- Linearised definition

$$A_{\mathrm{FB}}^{\mathrm{IFI,\,linear.}} = \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\left(\sigma_F + \sigma_B\right)^{\mathrm{LO}}}$$

- Naive definition

$$A_{\mathrm{FB}}^{\mathrm{IFI,\,naive}} = A_{\mathrm{FB}}^{\mathrm{NLO}} - A_{\mathrm{FB}}^{\mathrm{ISR}} - A_{\mathrm{FB}}^{\mathrm{FSR}} + 2A_{\mathrm{FB}}^{\mathrm{LO}}$$

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Summary of status of QED corrections

- **Issue discussed by Powheg-EW gang: definition of A_{FB}^{IFI}**

The linearised definition of $A_{\mathrm{FB}}^{\mathrm{IFI}}$

- Starting from our definition

$$A_{\mathrm{FB}}^{\mathrm{IFI}} = \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\sigma^{\mathrm{NLO}} - \sigma^{\mathrm{ISR}} - \sigma^{\mathrm{FSR}} + 2\sigma^{\mathrm{LO}}}$$

difference of $\mathcal{O}(\alpha^3)$ numerically equivalent

$$= \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\sigma^{\mathrm{LO}}\left[1 + \delta^{\mathrm{NLO}} - \delta^{\mathrm{ISR}} - \delta^{\mathrm{FSR}}\right]}$$

$$\simeq \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\sigma^{\mathrm{LO}}} \left[1 - \delta^{\mathrm{NLO}} + \delta^{\mathrm{ISR}} + \delta^{\mathrm{FSR}}\right]$$

- Linearised definition

$$A_{\mathrm{FB}}^{\mathrm{IFI,\,linear.}} = \frac{\left(\sigma_F - \sigma_B\right)^{\mathrm{NLO}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{ISR}} - \left(\sigma_F - \sigma_B\right)^{\mathrm{FSR}} + 2\left(\sigma_F - \sigma_B\right)^{\mathrm{LO}}}{\sigma^{\mathrm{LO}}}$$

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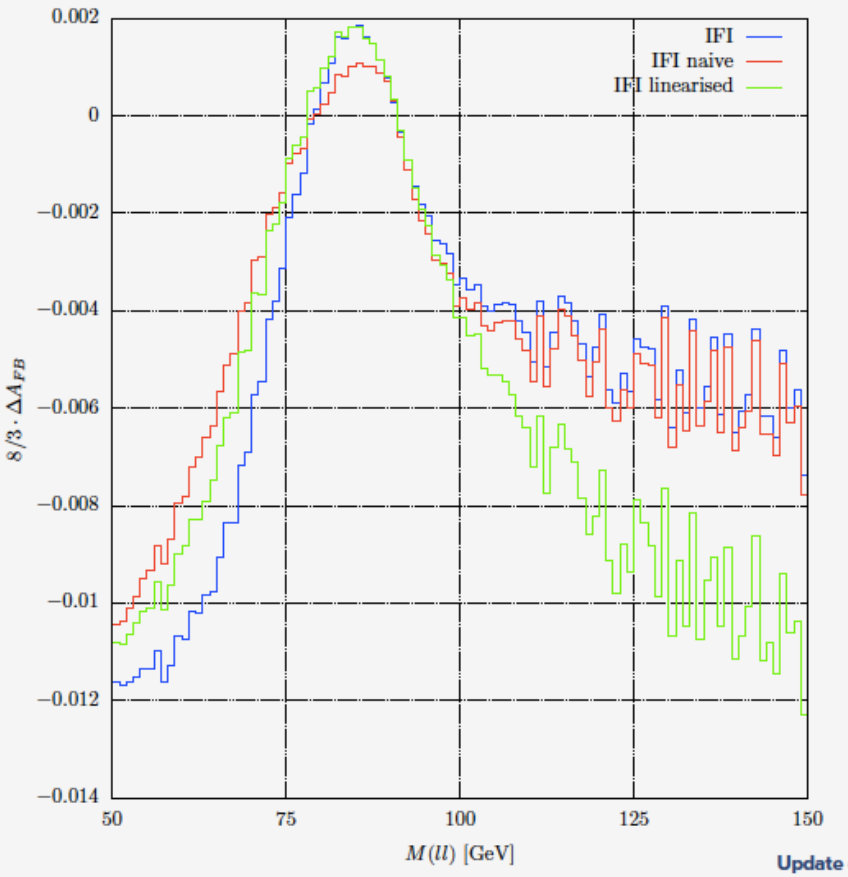
Summary of status of QED corrections

PRELIMINARY

Comparison of IFI definitions

$\bar{A}_4 = 8/3 \cdot A_{FB}$



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Summary of status of QED corrections

- **The exact definition has a significant impact outside Z pole region**

PRELIMINARY

Comparison of QED corrections

$\bar{A}_4 = 8/3 \cdot A_{FB}$

Code:		$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
$[A_{FB}\,(\text{NLO QED ISR}) - A_{FB}\,(\text{LO})]/10^{-4}$					
MCSANC		0.2(3)	−5(2)	0.2(3)	5(2)
WZGRAD2		0.2(5)	−5(3)	0.3(5)	6(4)
KKMC-hh		−1.0(6)	0.2(1.1)	−0.5(5)	−8(2)
RADY (CMS)		0.16(4)	−4.05(3)	0.12(3)	4.90(3)
A. Huss		0.17(1)	−4.07(1)	0.11(1)	4.94(4)
POWHEG_{ew}		0.1(1)	−4.0(4)	0.1(1)	4.5(7)
$[A_{FB}\,(\text{NLO QED IFI}) - A_{FB}\,(\text{LO})]/10^{-4}$					
MCSANC		−2.8(5)	−34(2)	−4.0(4)	−60(3)
WZGRAD2		−1.1(5)	−37(3)	−2.3(5)	−51(4)
KKMC-hh		2.0(3)	3.4(9)	3.1(2)	−62(1)
RADY (CMS)		−1.5(1)	−33.6(4)	−2.49(7)	−59.5(1)
A. Huss		−1.42(6)	−33.9(6)	−2.57(7)	−58.7(3)
POWHEG_{ew}	IFI	−1.2(3)	−62(1)	−2.5(4)	−59(2)
	naive IFI	−1.6(6)	−35(3)	−2.8(5)	−64(3)
	linear. IFI	−0.7(3)	−43(1)	−2.2(4)	−87(2)

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Summary of status of QED corrections

- **The exact definition has a significant impact outside Z pole region**

PRELIMINARY

Comparison of QED corrections

$\bar{A}_4 = 4\langle \cos\theta \rangle$

Code:		$89 < M_{\ell\bar{\ell}}$[GeV] < 93	$60 < M_{\ell\bar{\ell}}$[GeV] < 81	$81 < M_{\ell\bar{\ell}}$[GeV] < 101	$101 < M_{\ell\bar{\ell}}$[GeV] < 150
$[A_{FB}\,(\text{NLO QED ISR}) - A_{FB}\,(\text{LO})]/10^{-4}$					
RADY (CMS)		0.15(3)	−4.05(3)	0.10(2)	4.89(2)
A. Huss		0.16(1)	−4.07(1)	0.11(1)	4.87(2)
POWHEG$_{ew}$		0.07(9)	−4.0(3)	0.10(7)	4.8(4)
$[A_{FB}\,(\text{NLO QED IFI}) - A_{FB}\,(\text{LO})]/10^{-4}$					
RADY (CMS)		−1.7(1)	−42.3(4)	−2.97(6)	−71.6(2)
A. Huss		−1.68(6)	−42.4(6)	−3.05(8)	−71.2(3)
POWHEG$_{ew}$	IFI	−1.5(5)	−70(1)	−3.0(4)	−71(3)
	naive IFI	−1.9(4)	−39(9)	−3.3(3)	−77(2)
	linear. IFI	−1.0(5)	−52(1)	−2.7(3)	−99(3)

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Summary of status of QED corrections

- **Overall summary including update from KKMC-hh by Scott last month**

IFI Contribution to "A_4" $\equiv \frac{8}{3} A_{FB}$: Updated

The table shows the difference in $A_4 \times 10^4$ with IFI on minus IFI off. The numbers are from Stefan Dittmaier's May presentation with new KKMChh results for 38 billion events. KKhhFoam is a soft photon approximation to KKMChh. It agrees when hard photon corrections are not important.

version	$89 < M_{ll} < 93$	$60 < M_{ll} < 81$	$81 < M_{ll} < 101$	$101 < M_{ll} < 150$
KKMChh	−2.2(2)	−16.7(6)	−2.4(2)	−59(1)
KKhhFoam	−3.8(6)	−17 (1)	−4.1(5)	−46(3)
KKMChh (NISR)	−3.1(6)	−17(1)	−3.2(5)	−60(3)
KKhhFoam (NISR)	−3.6(7)	−17(2)	−3.8(5)	−48(3)
MCSANC	−2.8(5)	−34(2)	−4.0(4)	−60(3)
WZGRAD2	−1.1(5)	−37(3)	−2.3(5)	−51(4)
POWHEG_ew	**-1.2(3)**	**-62(1)**	**-2.5(4)**	**-59(2)**
RADY (CMS)	−1.5(1)	−33.6(4)	−2.49(7)	−59.5(1)
A. Huss	−1.42(6)	−33.9(6)	−2.57(7)	−58.7(3)

S.A. Yost KKMC-hh Update LHC EW Working Group Meeting, November 17, 2021

Next steps, outstanding issues for QED calculations

- **Resolve issue of definition of ISR and IFI contributions:**
  - formulae as discussed above by Powheg-EW
  - differences outside pole region : do these really correspond to somehow theoretical uncertainties related to these calculations or should we dig deeper?
  Clearly, the most important numbers are those in the pole region which are in excellent agreement …
  - question of usage or not of QED PDFs raised initially by Alessandro and emphasised more recently by work reported by Scott
  Here we need a definite decision on how to proceed but bearing in mind that QED PDFs are not used at all yet in any large-scale MC production of the experiments.
- **Get missing updates (certainly from WZGRAD2 in the new year and possibly also from MC-SANC?)**
- **Associate an uncertainty to the QED calculations (Stefan?)**

- **Document these results starting with a nice pedagogical introduction linking the work presented based on pure γ^*/Z DY with the more correct and general framework of calculations including photon-induced processes (Alessandro)!**
  Please also remember to start writing appendices for each calculation ☺