NLO QCD in POWHEG-BOX-ew

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EWWG 27-11-2024

From previous meeting of 8 September 2024

Work to be done since last meeting:

- Tables with higher statistics

- Tables with factorised QCD+QED combination

- Scale variations with higher statistics

* the best with our computation power

Code inputs and definitions

- EW scheme: (α, M_Z, M_W)
- CMS scheme
- $\sqrt{s} = 8$ TeV
- PDF: MSTW2008nlo68cl (LHA 21100)
- factorisation scheme: $\overline{MS}$

  $\mu_F = \mu_R = M_{\ell\bar{\ell}}$

Parameter	Value
α	$7.297353 \cdot 10^{-3}$
G_μ	$1.166389 \cdot 10^{-5}$
M_Z*	91.1876
Γ_Z*	2.4952
M_W*	80.385
Γ_W*	2.085
M_H	125
m_e	$0.51099907 \cdot 10^{-3}$
m_μ	0.1056583
m_τ	1.77705
m_b	4.7
m_t	173

Parameter	Value
m_u	0.06983
m_d	0.06984
m_s	0.15
m_c	1.2

* Automatically translated to pole values

NLO QED and QCD corrections - how to combine them?

1: additive method

$$\sigma_{\text{QED+QCD}} = \sigma_{\text{NLOQCD}} + \sigma_{\text{NLOQED}} - \sigma_{\text{LO}} = \sigma_{\text{LO}}\,(1 + \delta_{\text{QCD}} + \delta_{\text{QED}})$$

$$A_{\text{FB}}^{\text{QED+QCD}} = \frac{\left(\sigma_F - \sigma_B\right)^{\text{NLOQED}} + \left(\sigma_F - \sigma_B\right)^{\text{NLOQCD}} - \left(\sigma_F - \sigma_B\right)^{\text{LO}}}{\left(\sigma_F + \sigma_B\right)^{\text{NLOQED}} + \left(\sigma_F + \sigma_B\right)^{\text{NLOQCD}} - \left(\sigma_F + \sigma_B\right)^{\text{LO}}}$$

Equivalent at NLO
difference due to $\mathcal{O}(\alpha\alpha_S)$ terms

2: factorized method

$$\sigma_{\text{QED+QCD}} = \sigma_{\text{LO}}\,(1 + \delta_{\text{QCD}})\,(1 + \delta_{\text{QED}})$$

$A_{\text{FB}}^{\text{QED+QCD}}$ to be computed bin-by-bin from $d\sigma/d\cos\theta$ - has more complicated expression

starting point: $\dfrac{d\sigma_{\text{QED+QCD}}}{d\cos\theta} = \dfrac{d\sigma_{\text{NLOQCD}}}{d\cos\theta}\left(\dfrac{d\sigma_{\text{NLOQED}}}{d\cos\theta} \Big/ \dfrac{d\sigma_{\text{LO}}}{d\cos\theta}\right)$

QED and QCD corrections - additive combination

$A_4 = 8/3 \cdot A_{FB}$

$89 - 93$ GeV	$60 - 81$ GeV	$81 - 101$ GeV	$101 - 150$ GeV
$8/3 \cdot A_{FB}(\mathrm{LO})$			
0.12414(1)	−0.54106(2)	0.119513(8)	0.60285(2)
$8/3 \cdot [A_{FB}(\mathrm{NLOQCD}) - A_{FB}(\mathrm{LO})]/10^{-2}$			
−0.39(2)	2.074(2)	−0.37(1)	−1.811(2)
$8/3 \cdot [A_{FB}(\mathrm{NLOQCD+QED}) - A_{FB}(\mathrm{LO})]/10^{-2}$			
−0.078(5)	27.220(5)	−0.162(3)	−1.73(1)

$\mathrm{QED} : [A_{FB}(\mathrm{NLO\ QED}) - A_{FB}(\mathrm{LO})]/10^{-2}$

$\mathrm{NLOQCD + QED} : [A_{FB}(\mathrm{NLO\ QCD + QED}) - A_{FB}(\mathrm{NLO\ QCD})]/10^{-2}$

	$89 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 150$
QED	0.423(2)	28.296(3)	0.262(2)	0.27(1)
NLO QCD + QED	0.315(6)	25.146(5)	0.209(5)	0.08(1)
QED FSR	0.439(2)	28.604(7)	0.289(1)	0.87(1)
NLO QCD + QED FSR	0.326(6)	25.4261(7)	0.231(4)	0.59(1)
QED ISR	0.001(1)	−0.040(4)	0.001(1)	0.045(6)
NLO QCD + QED ISR	0.002(4)	−0.043(4)	0.002(4)	0.052(5)
QED IFI	−0.013(6)	−0.34(2)	−0.026(7)	−0.59(3)
NLO QCD + QED IFI	−0.011(7)	−0.30(2)	−0.022(7)	−0.52(3)

QED and QCD corrections - additive combination

$$A_4 = 8/3 \cdot A_{FB}$$

$89 - 93$ GeV	$60 - 81$ GeV	$81 - 101$ GeV	$101 - 150$ GeV
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0.12414(1)	−0.54106(2)	0.119513(8)	0.60285(2)
$8/3 \cdot [A_{FB}(\mathrm{NLOQCD}) - A_{FB}(\mathrm{LO})]/10^{-2}$			
−0.39(2)	2.074(2)	−0.37(1)	−1.811(2)
$8/3 \cdot [A_{FB}(\mathrm{NLOQCD+QED}) - A_{FB}(\mathrm{LO})]/10^{-2}$			
−0.078(5)	27.220(5)	−0.162(3)	−1.73(1)

$\mathrm{QED} : [A_{FB}(\mathrm{NLO\ QED}) - A_{FB}(\mathrm{LO})]/10^{-2}$

$\mathrm{NLOQCD+QED} : [A_{FB}(\mathrm{NLO\ QCD+QED}) - A_{FB}(\mathrm{NLO\ QCD})]/10^{-2}$

	$89 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\mathrm{GeV}] < 150$
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NLO QCD + QED FSR	0.326(6)	25.4261(7)	0.231(4)	0.59(1)
QED ISR	0.001(1)	−0.040(4)	0.001(1)	0.045(6)
NLO QCD + QED ISR	0.002(4)	−0.043(4)	0.002(4)	0.052(5)
QED IFI	−0.013(6)	−0.34(2)	−0.026(7)	−0.59(3)
NLO QCD + QED IFI	−0.011(7)	−0.30(2)	−0.022(7)	−0.52(3)

* the best with our computation power

QED and QCD corrections - additive combination

$A_4 = 4 < \cos\theta >$

$89 - 93$ GeV	$60 - 81$ GeV	$81 - 101$ GeV	$101 - 150$ GeV
$A_4 = 4 < \cos\theta >$ (LO)			
0.031034(1)	−0.135266(3)	0.029878(1)	0.150727(2)
$[A_4(\text{NLOQCD}) - A_4(\text{LO})]/10^{-2}$			
−0.384(4)	2.11(1)	−0.363(3)	−1.89(1)
$[A_4(\text{NLOQCD} + \text{QED}) - A_4(\text{LO})]/10^{-2}$			
−0.085(6)	27.128(4)	−0.172(4)	−1.87(1)

QED : $[A_4\,(\text{NLO QED}) - A_4\,(\text{LO})]/10^{-2}$

NLOQCD + QED : $[A_4\,(\text{NLO QCD + QED}) - A_4\,(\text{NLO QCD})]/10^{-2}$

	$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
QED	0.420(2)	28.196(3)	0.256(1)	0.131(8)
NLO QCD + QED	0.312(8)	25.057(4)	0.203(5)	−0.04(1)
QED FSR	0.438(1)	28.553(6)	0.288(1)	0.862(9)
NLO QCD + QED FSR	0.325(7)	25.382(6)	0.229(5)	0.58(1)
QED ISR	0.0007(9)	−0.040(3)	0.0010(7)	0.048(4)
NLO QCD + QED ISR	0.002(5)	−0.042(3)	0.002(3)	0.048(7)
QED IFI	−0.015(5)	−0.43(1)	−0.030(4)	−0.72(3)
NLO QCD + QED IFI	−0.013(8)	−0.37(1)	−0.026(6)	−0.62(3)

QED and QCD corrections - factorised combination

$A_4 = 8/3 \cdot A_{FB}$

	$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
QED	0.423(2)	28.296(3)	0.262(2)	0.27(1)
NLO QCD + QED	0.315(6)	25.146(5)	0.209(5)	0.08(1)

additive

	$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
NLO QCD + QED	0.42(1)	28.110(9)	0.30(1)	0.30(2)

factorised

$A_4 = 4 < \cos\theta >$

	$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
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additive

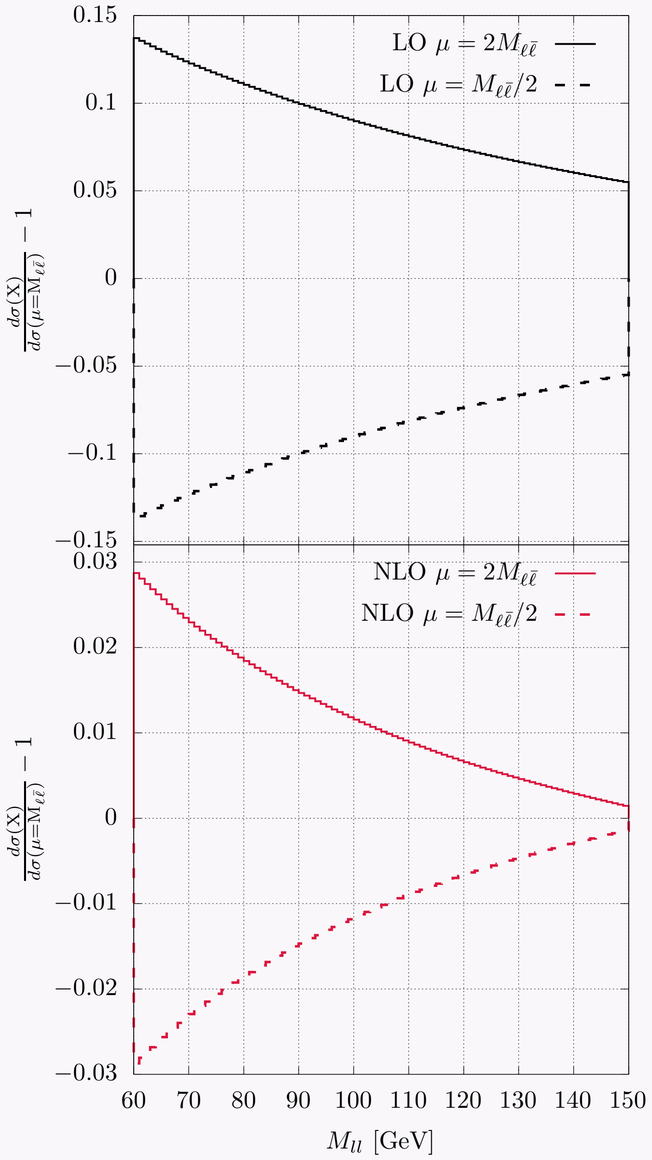
	$89 < M_{\ell\bar{\ell}}[\text{GeV}] < 93$	$60 < M_{\ell\bar{\ell}}[\text{GeV}] < 81$	$81 < M_{\ell\bar{\ell}}[\text{GeV}] < 101$	$101 < M_{\ell\bar{\ell}}[\text{GeV}] < 150$
NLO QCD + QED	0.40(2)	27.147(4)	0.246(8)	0.17(1)

factorised

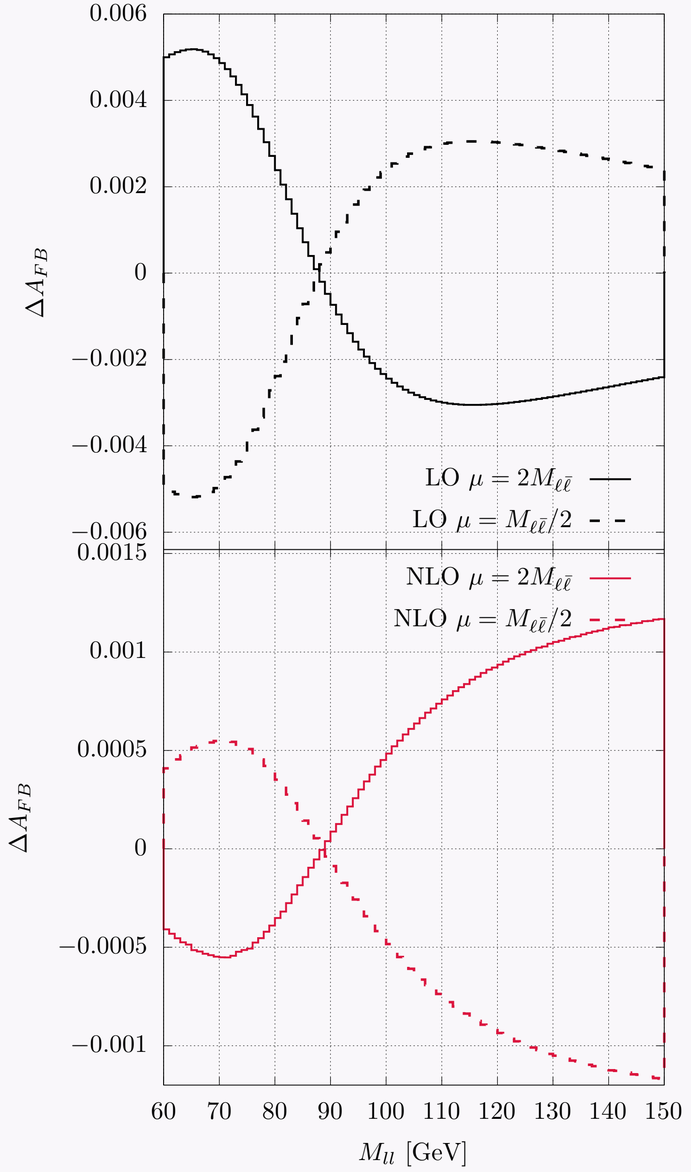
$\text{NLOQCD + QED} : [\text{A}_{\text{FB}}\,(\text{NLO QCD + QED}) - \text{A}_{\text{FB}}\,(\text{NLO QCD})]/10^{-2}$

Scale variations at NLO QCD

Cross section



Asymmetry

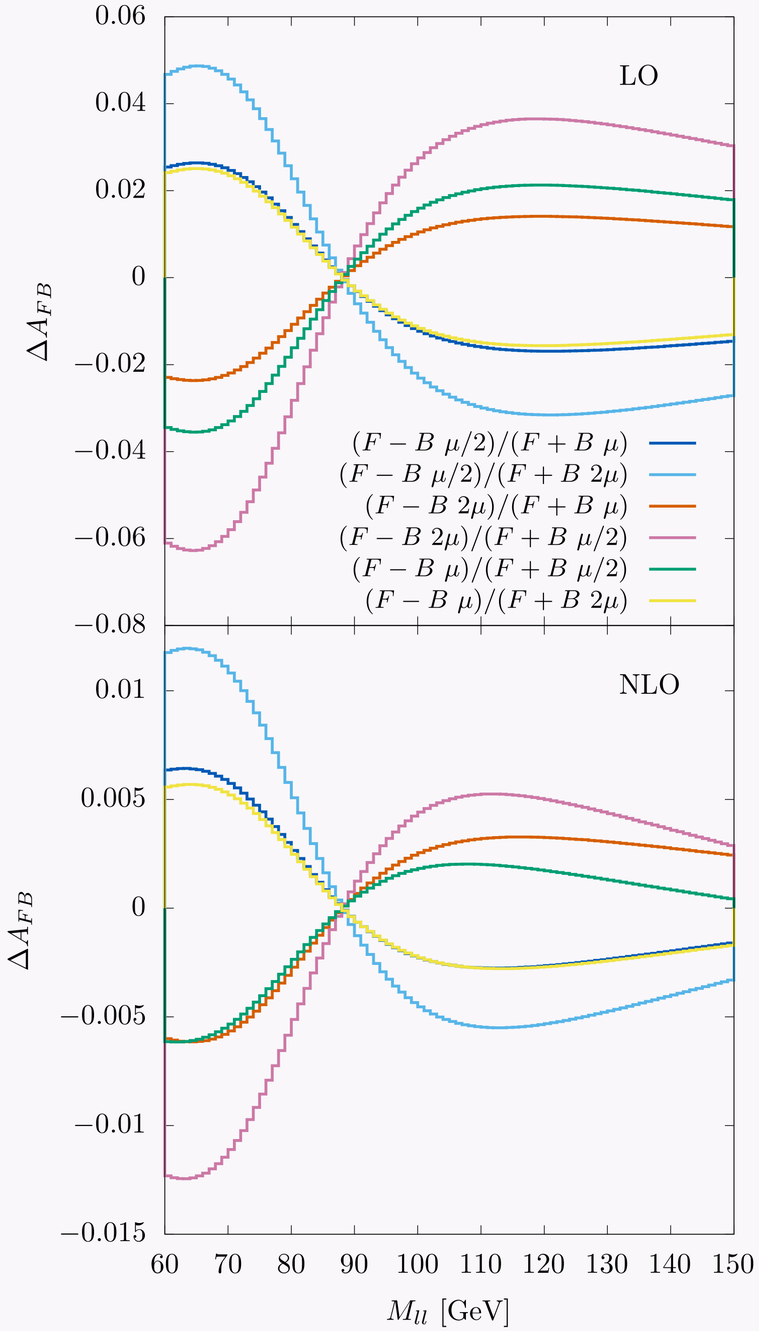


“Envelope” of scale variations

NLO QCD

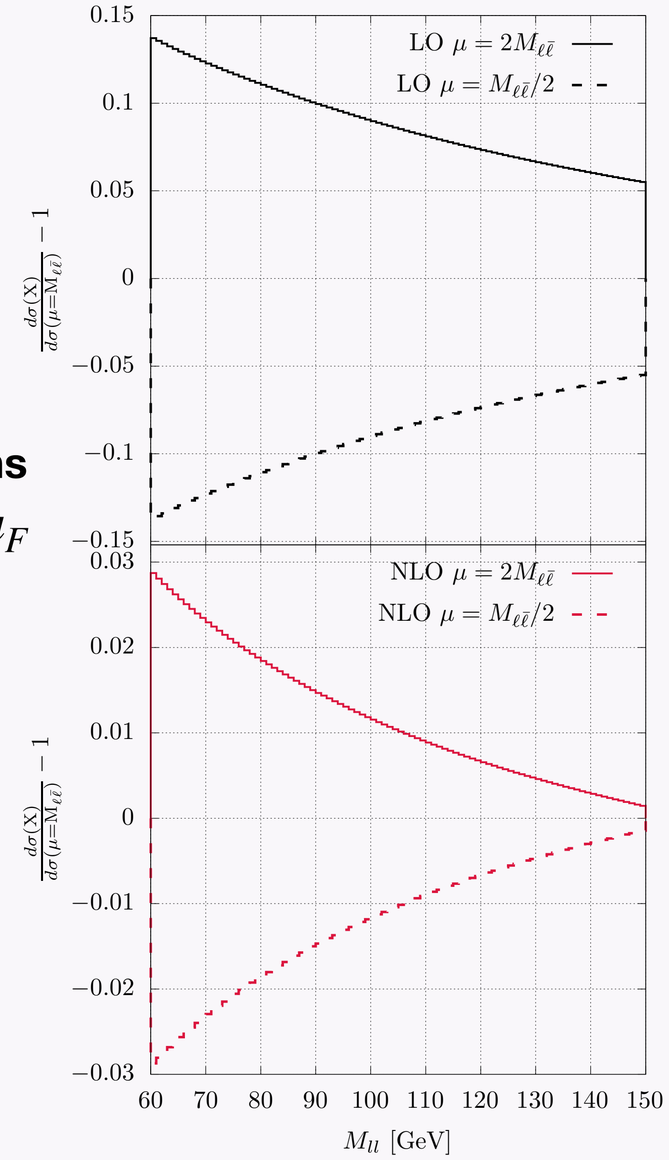
$$\Delta A_{FB} = \frac{\sigma_F^X - \sigma_B^X}{\sigma_F^Y + \sigma_B^Y} - A_{FB}^{LO}$$

X, Y different scales: $\mu = M_{\ell\bar{\ell}}, 2M_{\ell\bar{\ell}}, M_{\ell\bar{\ell}}/2$



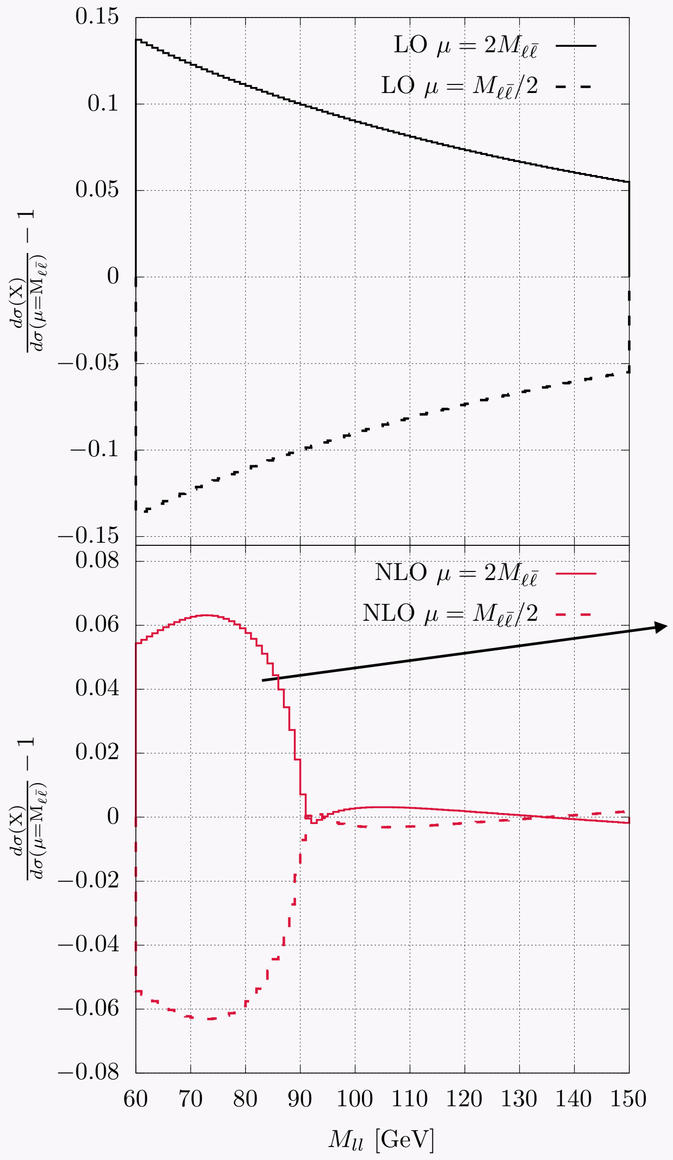
Scale variations at NLO QCD+QED

Cross section factorised method



Hp. QED corrections do not depend on μ_F

Cross section additive method

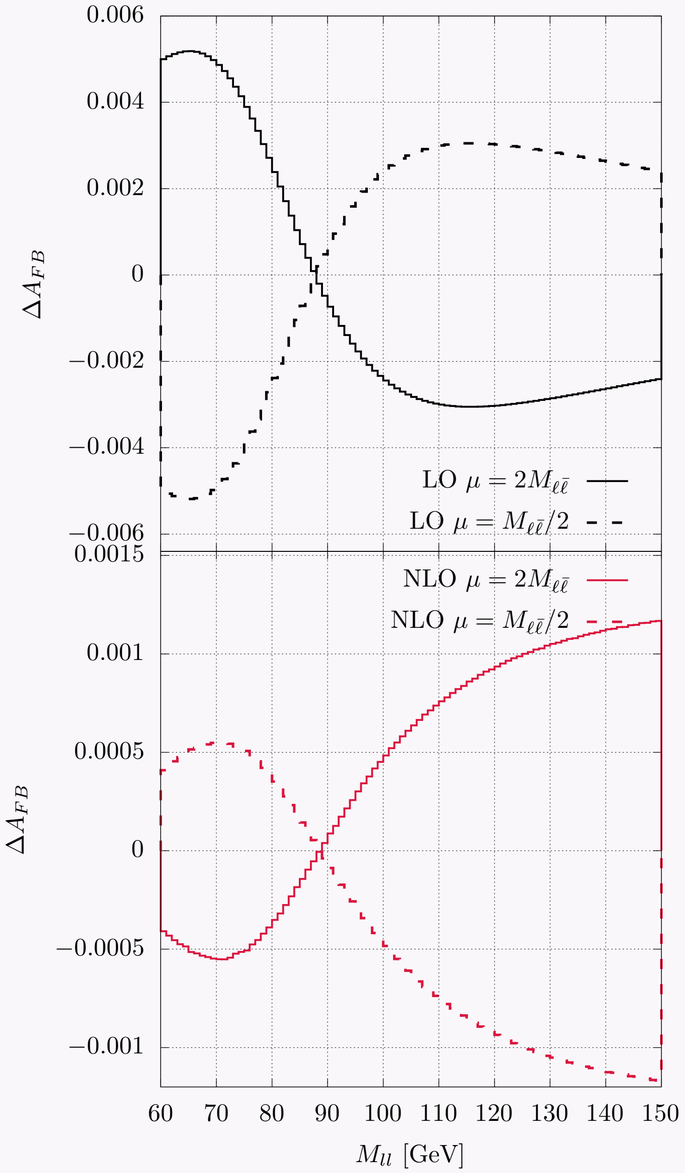


Bulk due to QED

Scale variations at NLO QCD+QED

Asymmetry factorised method

Hp. QED corrections do not depend on μ_F



Asymmetry additive method