On the inclusive N3LO Higgs cross section in ggF

Achilleas Lazopoulos
18% on behalf of the ggf task force

from summer ‘15 meeting (within Les Houches)

- Discussions on residual uncertainties (beyond N3LO EFT)
- EW corrections: suggested to vary NLO EW WC by a factor of 3.
- Parametric uncertainties: small (with internal report on SM parameters that followed, ‘small’ can be more precise)
- Quark mass effects beyond NLO

DISCLAIMER

- The following is a summary of the results by the N3LO collaboration, **not yet processed** by the ggf task force.
- No attempt is made to compare uncertainties with uncertainty estimates published in the past (this will be done within the WG soon).

DISCLAIMER

Results on behalf of the N3LO collaboration

C. Anastasiou, C. Duhr, F. Dulat, E. Furlan, T. Gehrmann, F. Herzog, A.L., B. Mistlberger

Presented also at: 11 dec @ CERN by F. Dulat and 6 jan@ZPW by C. Duhr

CONTRIBUTIONS TO TOTAL XS

$$\hat{\sigma}_{ij} \simeq R_{LO}\,\left(\hat{\sigma}_{ij,EFT} + \delta_t \hat{\sigma}^{NNLO}_{ij,EFT} + \hat{\sigma}_{ij,EW}\right) + \delta\hat{\sigma}^{LO}_{ij,ex;t,b,c} + \delta\hat{\sigma}^{NLO}_{ij,ex;t,b,c}$$

$$R_{LO} \equiv \frac{\sigma^{LO}_{ex;t}}{\sigma^{LO}_{EFT}}$$

INPUT PARAMETERS

SETUP I

$\sqrt{S}$	13 TeV
m_h	125 GeV
PDF	`PDF4LHC15_nnlo_100`
$a_s(m_Z)$	0.118
$m_t(m_t)$	162.7 GeV ($\overline{\rm MS}$)
$m_b(m_b)$	4.18 GeV ($\overline{\rm MS}$)
$m_c(3GeV)$	0.986 GeV ($\overline{\rm MS}$)
$\mu = \mu_R = \mu_F$	62.5 GeV ($= m_H/2$)

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```
R_LO                    = 1.06274

R_LO * eftlo            = 16.00
R_LO * eftnlo           = 36.84
R_LO * eftnnlo          = 46.40

R*eftn3lo                       = 47.89

@mh/2

ew rescaled                     = 2.40

delta mt exp total              = 0.34

exactlo  (t+b+c)        = 14.83
exactnlo (t+b+c)        = 34.78
delta QCD                       = -2.06
```

Higgs XS = 48.57pb

DISCLAIMER

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delta mt exp total      = 0.34

exactlo                 = 14.83
exactnlo                = 34.78
delta QCD               = -2.06
```

+3.2%

@mh/2

Higgs XS = 48.57pb

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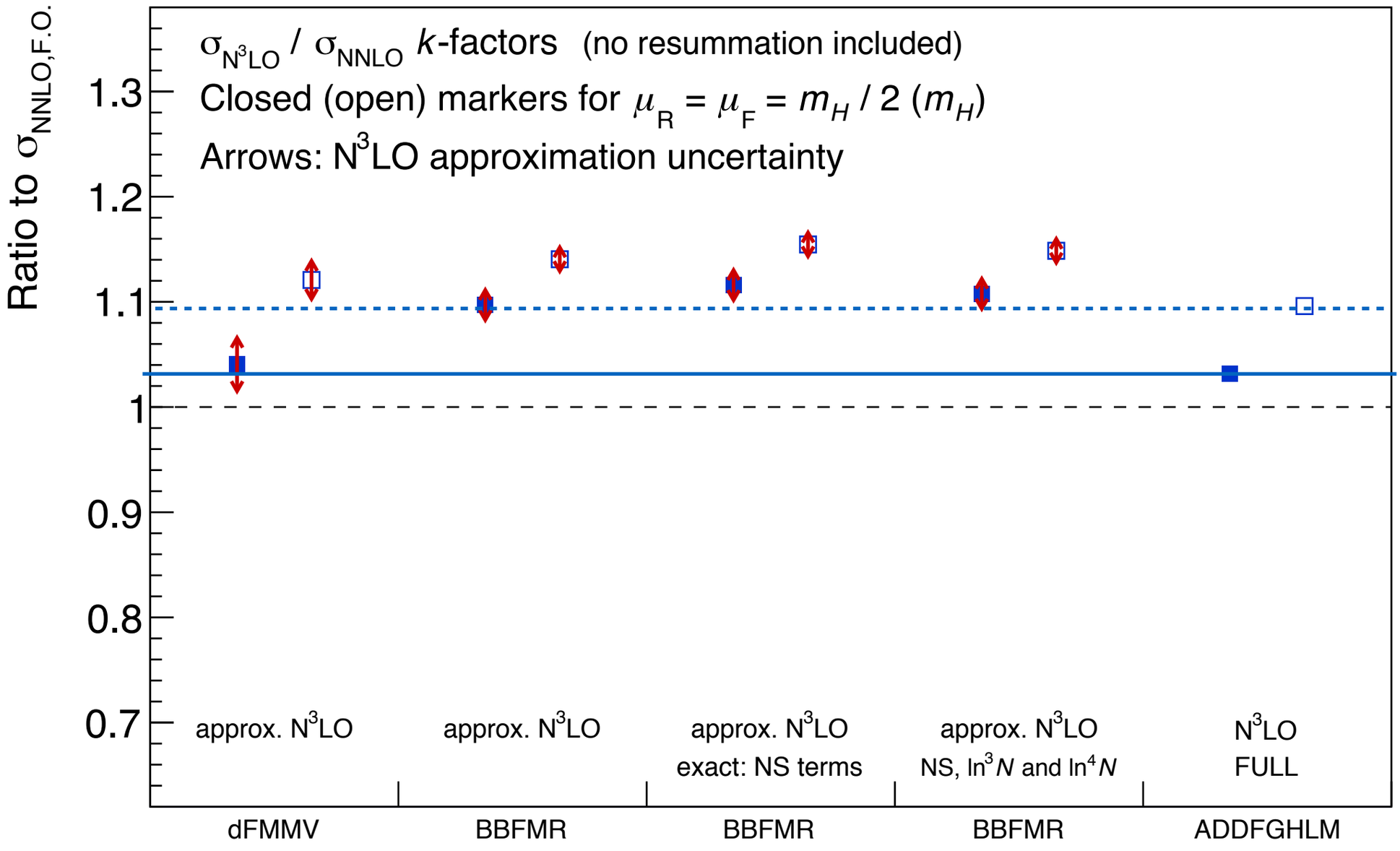

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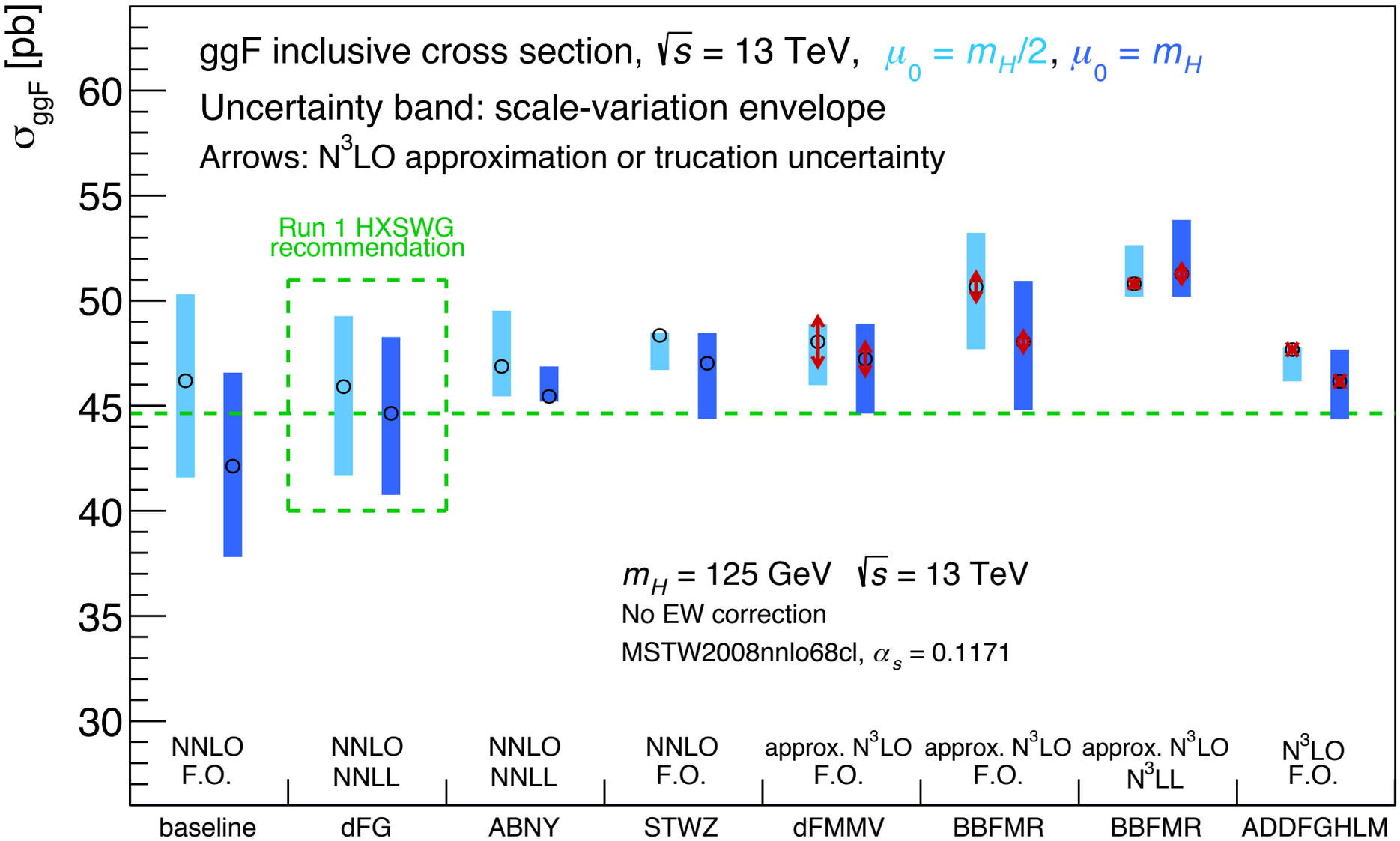

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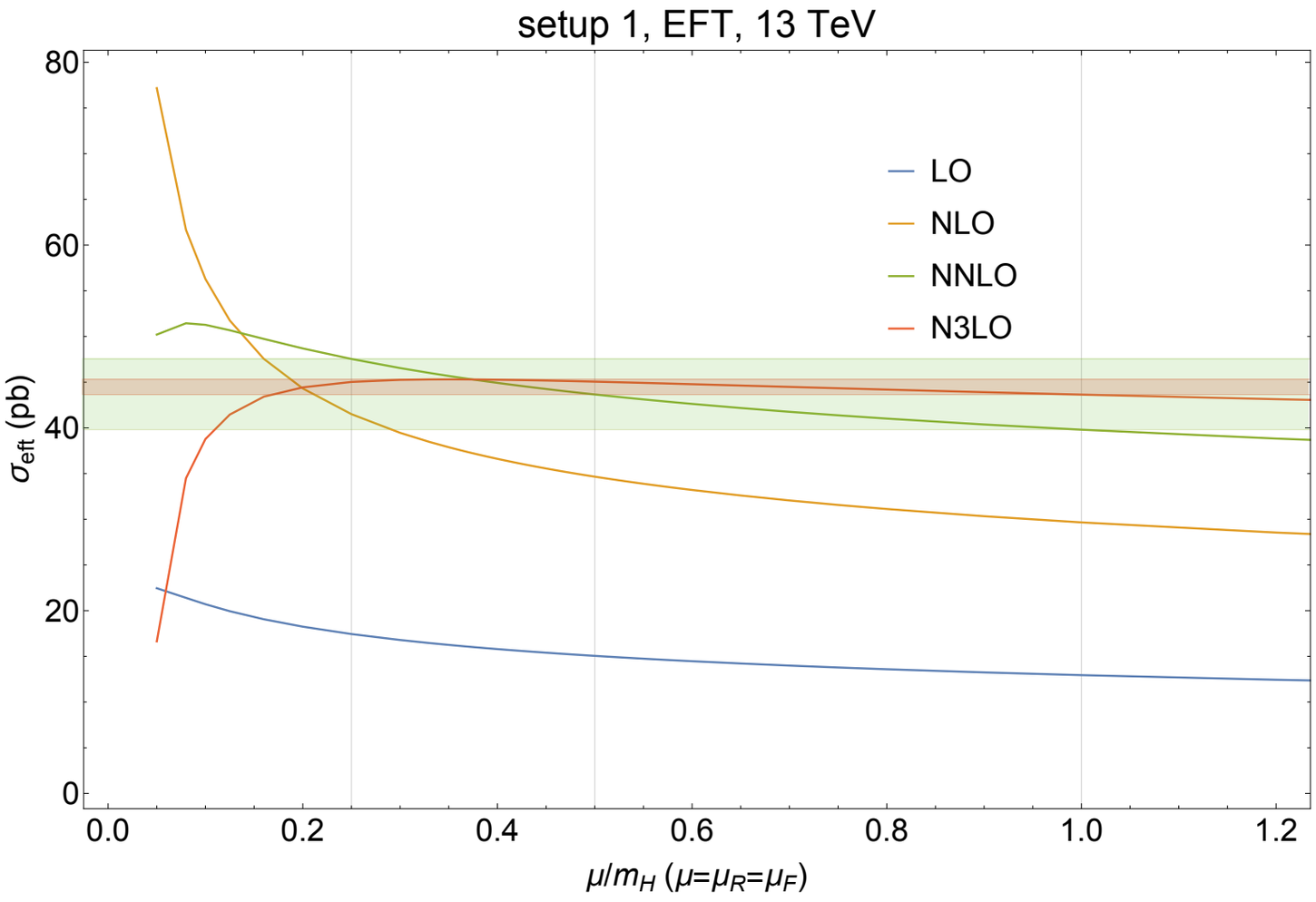
UNCERTAINTIES: EFT (from scale uncertainty)



pure EFT symmetric

LO: $\pm$14.8%

NLO: $\pm$16.6%

NNLO: $\pm$ 8.8%

N3LO: $\pm$ 1.8%

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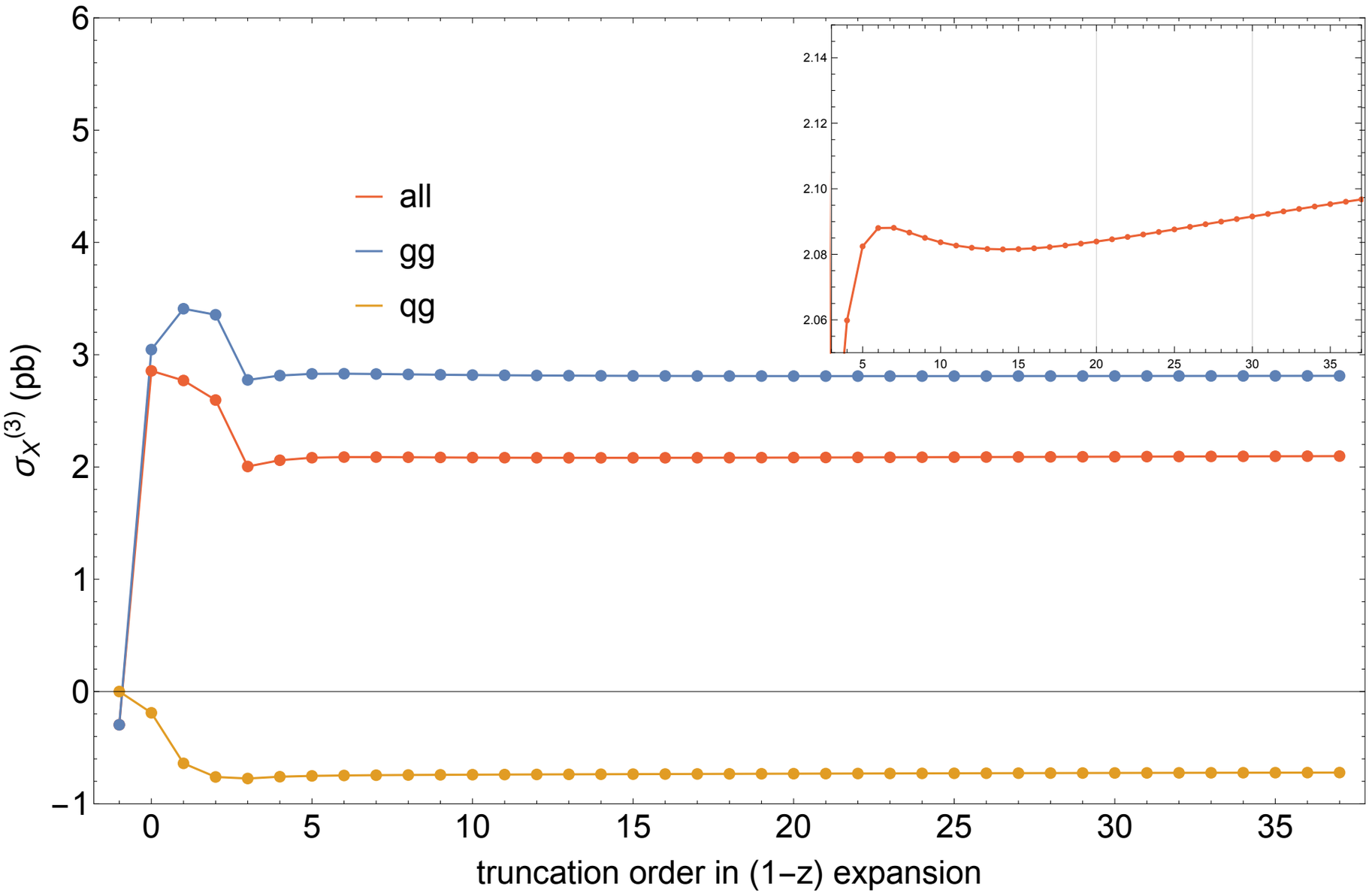
UNCERTAINTIES: truncation of threshold expansion



$$\sigma^{(3)}_{EFT}\Big|_{\text{expansion}} - \sigma^{(3)}_{EFT}\Big|_{\text{full logs}} = 0.006\,\text{pb}$$

TRUNCATION UNCERTAINTY

$$5 \times \frac{\sigma^{(3)}_{EFT}(30) - \sigma^{(3)}_{EFT}(20)}{\sigma^{\text{N}^3\text{LO}}_{EFT}} = 0.25\%$$

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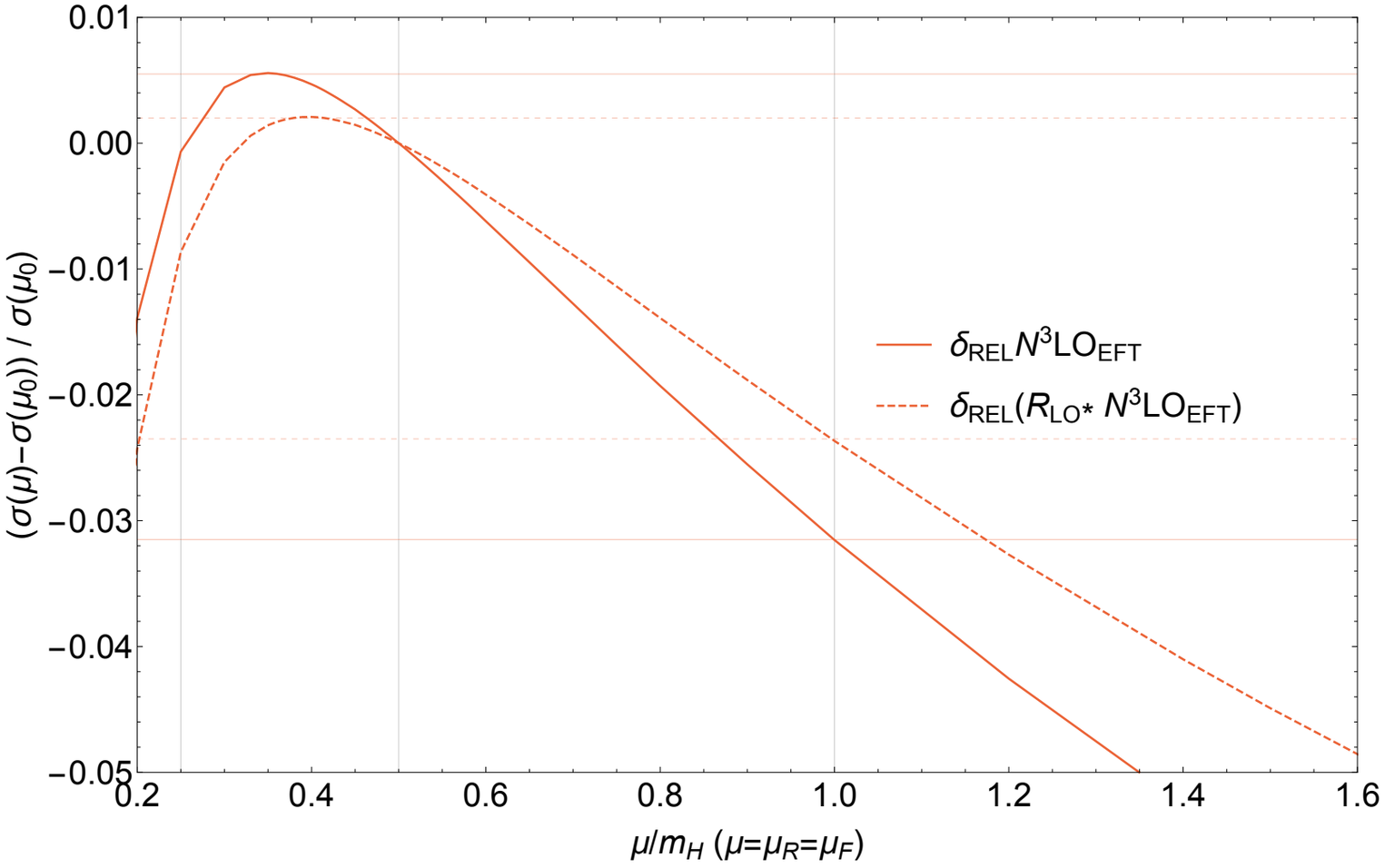
UNCERTAINTIES: EFT RESCALED



R * EFT (symmetric)

N3LO: $\pm$1.3%

asymmetric

+0.2% -2.4%

We use this scale uncertainty as an estimate of missing higher orders beyond N3LO

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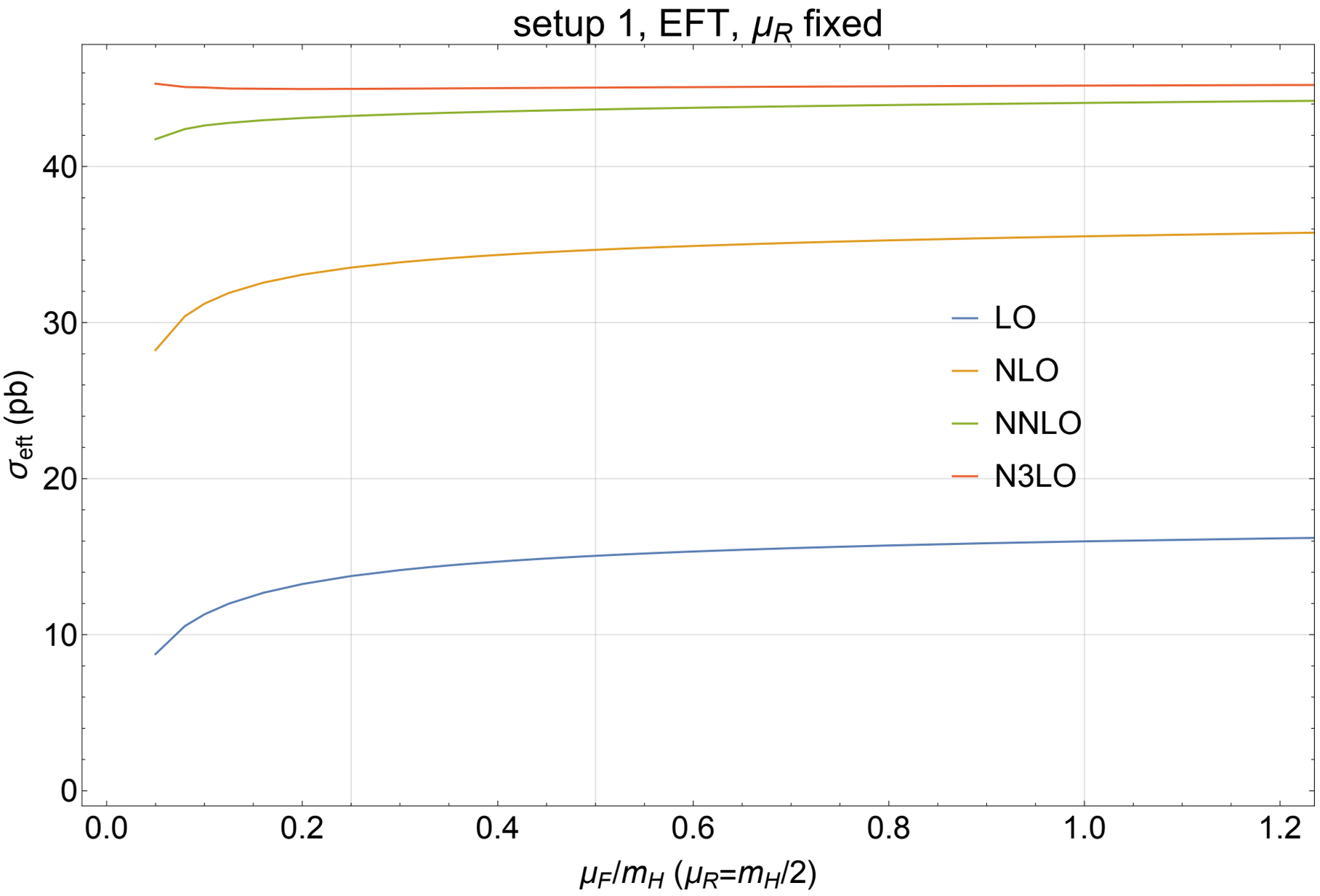
UNCERTAINTIES: factorisation scale dependence



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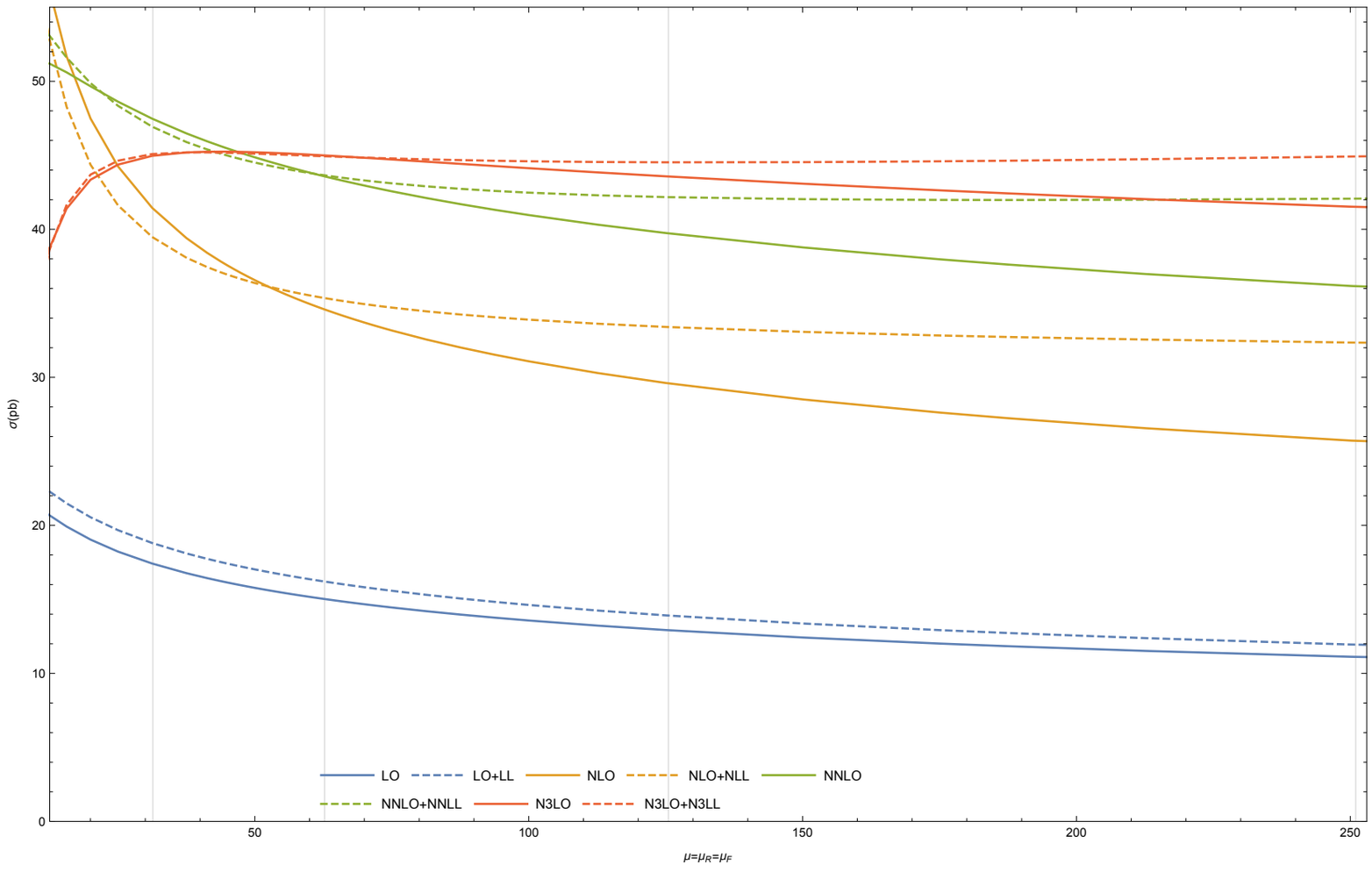
beyond N3LO: threshold resummation



Negligible contribution at central scale.

Within the scale uncertainty range in the entire interval.

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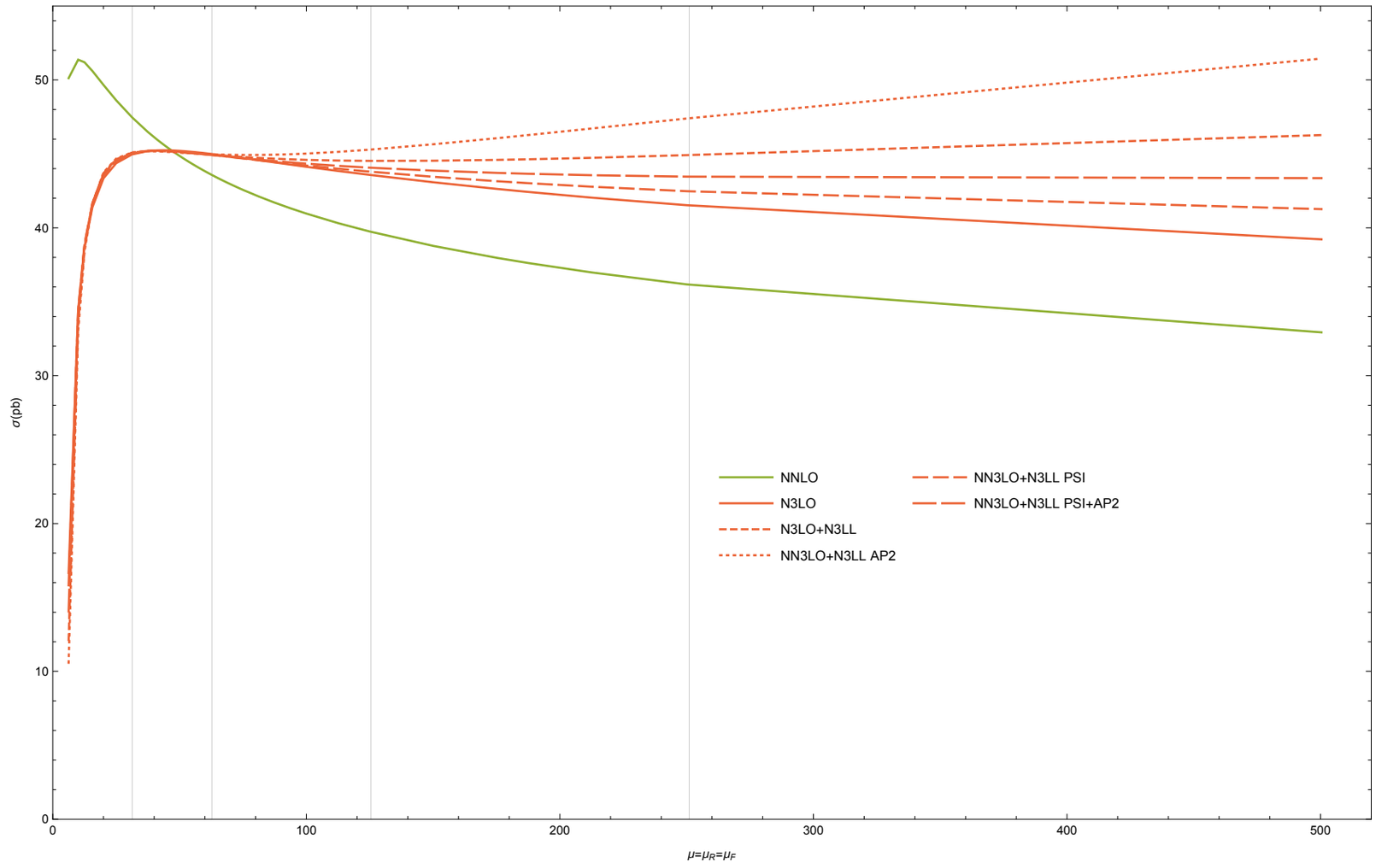
beyond N3LO: threshold resummation variants



Negligible contribution at central scale.

Within the scale uncertainty range in the entire interval.

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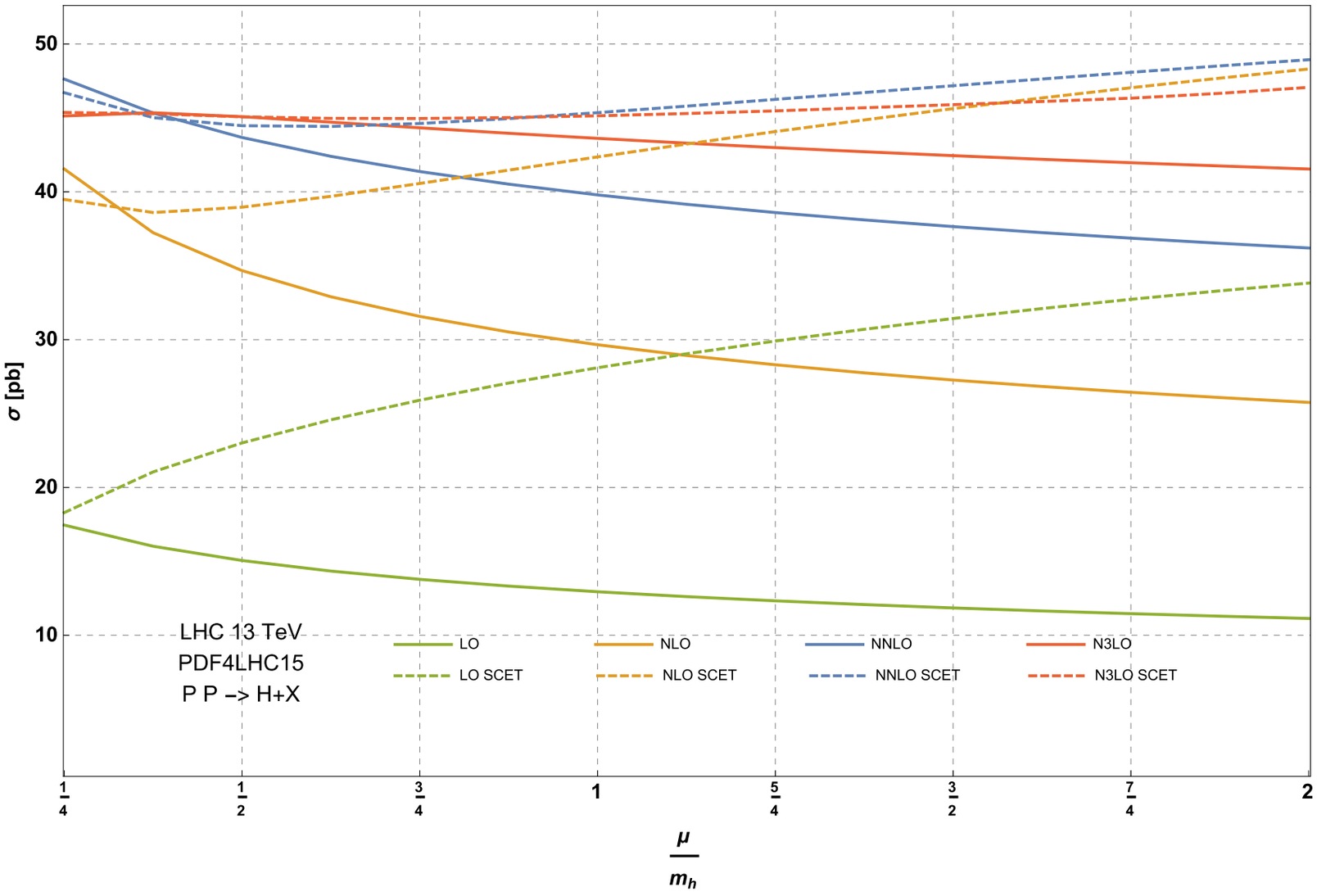
beyond N3LO: SCET resummation



Negligible contribution at central scale.

Within the scale uncertainty range in the entire interval.

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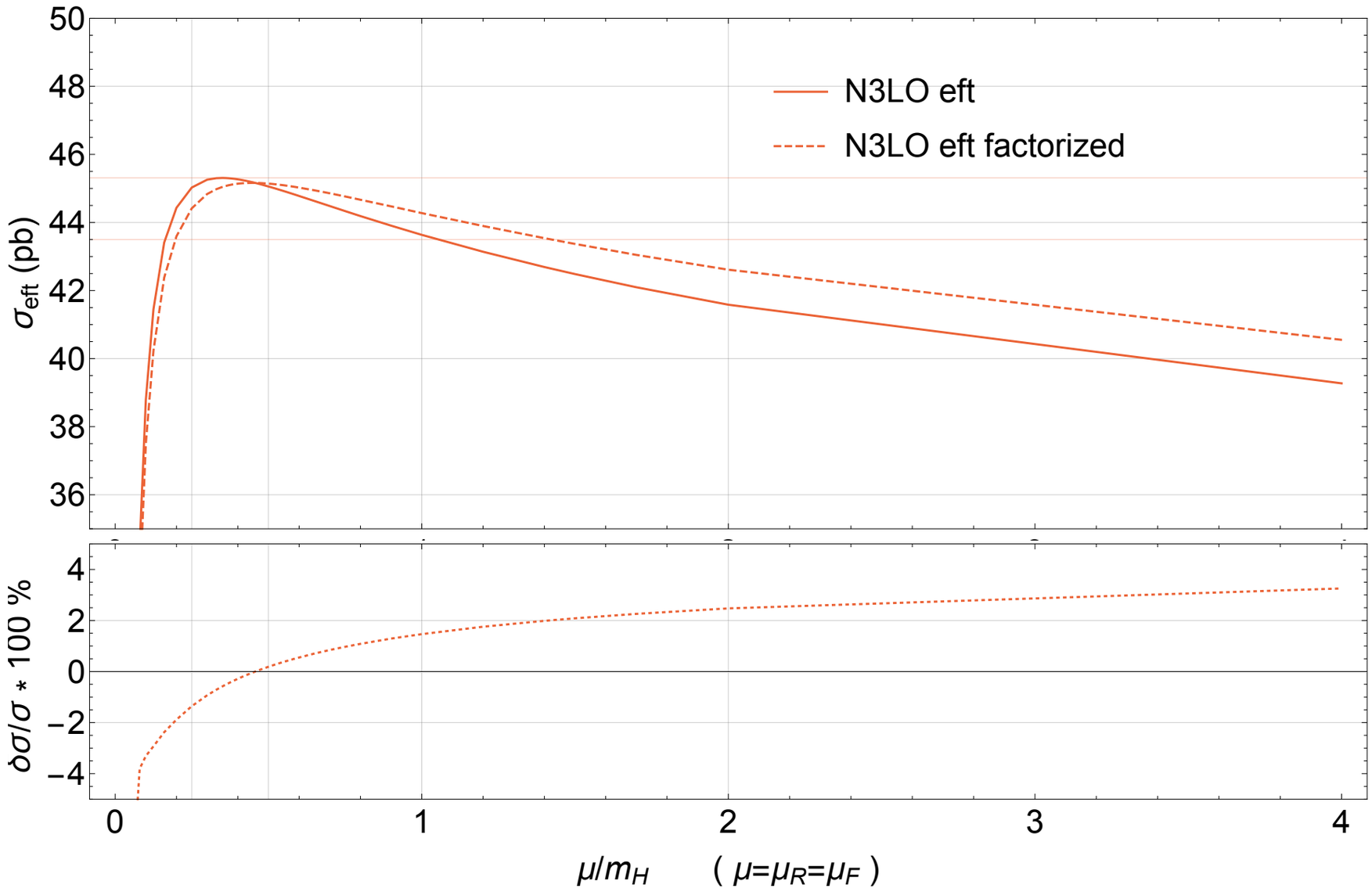
beyond N3LO: factorized Wilson coefficient



Negligible contribution at central scale.

Within the scale uncertainty range in the entire interval.

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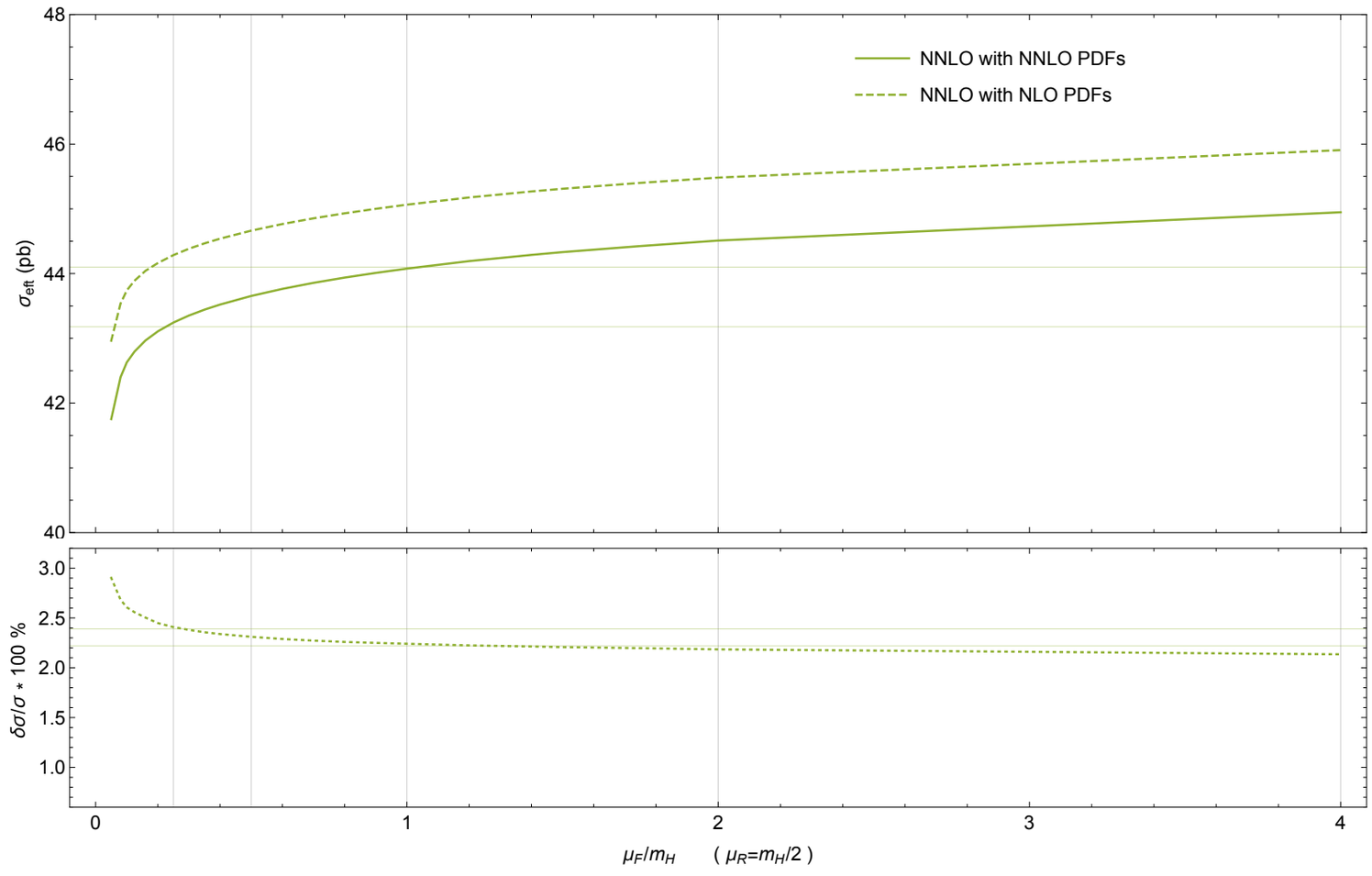
Uncertainties: Missing N3LO PDFs



$$\delta(\mathrm{PDF}-\mathrm{TH}) = \frac{1}{2}\,2.5\% = \mathbf{1.25\%}$$

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Uncertainties: 1/mt efects

We've used the expressions provided by R. Harlander et al., and also their prescription for small-z matching. Due to the unknown sub-leading coefficient of the small-z limit we assign an uncertainty of ~1% (which is also the size of the net effect) following their recommendation.

Uncertainty for 1/mt NNLO contribution = 1%

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Uncertainties: Light Quark effects

Table 6: QCD effects for the parameters of Setup 1.

σ^{LO}_{EFT}	15.05 pb	σ^{NLO}_{EFT}	34.66 pb
$R_{LO}\,\sigma^{LO}_{EFT}$	16.00 pb	$R_{LO}\,\sigma^{NLO}_{EFT}$	36.84 pb
$\sigma^{LO}_{ex.;t}$	16.00 pb	$\sigma^{NLO}_{ex;t}$	36.60 pb
$\sigma^{LO}_{ex.;t+b}$	14.94 pb	$\sigma^{NLO}_{ex;t+b}$	34.96 pb
$\sigma^{LO}_{ex.;t+b+c}$	14.83 pb	$\sigma^{NLO}_{ex;t+b+c}$	34.77 pb

$$\pm \left| \frac{\delta\sigma^{NLO}_{ex,t} - \delta\sigma^{NLO}_{ex,t+b+c}}{\delta\sigma^{NLO}_{ex,t}} \right| (R_{LO}\delta\sigma^{NNLO}_{EFT} + \delta_t\hat{\sigma}^{NNLO}_{gg+qg,EFT}) \simeq \pm 0.32\,\text{pb}$$

0.7% on total XS

$$\delta\sigma^{NLO}_X \equiv \sigma^{NLO}_X - \sigma^{LO}_X \quad , \quad \delta\sigma^{NNLO}_X \equiv \sigma^{NNLO}_X - \sigma^{NLO}_X$$

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Quark mass scheme dependence

	$\overline{\text{MS}}$	OS	$\delta\sigma^{sc}$
$\sigma^{LO}_{ex;t+b+c}$	14.83 pb	13.81 pb	-6.9%
$\sigma^{NLO}_{ex;t}$	36.60 pb	36.63 pb	0.08%
$\sigma^{NLO}_{ex;t+b}$	34.96 pb	34.49 pb	-1.3%
$\sigma^{NLO}_{ex;t+b+c}$	34.77 pb	34.04 pb	-2.1%
σ^{NNLO}_{eft}	43.65 pb	43.66 pb	0.02%
$R_{LO}\,\sigma^{NNLO}_{eft}$	46.39 pb	46.53 pb	0.3%
σ^{N3LO}_{eft}	45.06 pb	45.06 pb	0%
$R_{LO}\,\sigma^{N3LO}_{eft}$	47.88 pb	48.03 pb	0.3%

We expect the scheme dependence to decrease to below 1% at NNLO, and be accounted by the uncertainty due to light quark masses. We do not assign an extra uncertainty due to scheme choice.

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Uncertainties: Parametric uncertainties

Table 8: Parametric uncertainties on quark masses.

Top quark			Bottom quark			Charm quark		
$\delta m_t = 1$ GeV	$\sigma^{NLO}_{ex;t+b+c}$	34.77	$\delta m_b = 0.03$ GeV	$\sigma^{NLO}_{ex;t+b+c}$	34.77	$\delta m_c = 0.026$ GeV	$\sigma^{NLO}_{ex;t+b+c}$	34.77
$m_t + \delta m_t$	$\sigma^{NLO}_{ex;t+b+c}$	34.74	$m_b + \delta m_b$	$\sigma^{NLO}_{ex;t+b+c}$	34.76	$m_c + \delta m_c$	$\sigma^{NLO}_{ex;t+b+c}$	34.76
$m_t - \delta m_t$	$\sigma^{NLO}_{ex;t+b+c}$	34.80	$m_b - \delta m_b$	$\sigma^{NLO}_{ex;t+b+c}$	34.79	$m_c - \delta m_c$	$\sigma^{NLO}_{ex;t+b+c}$	34.78

Entirely negligible

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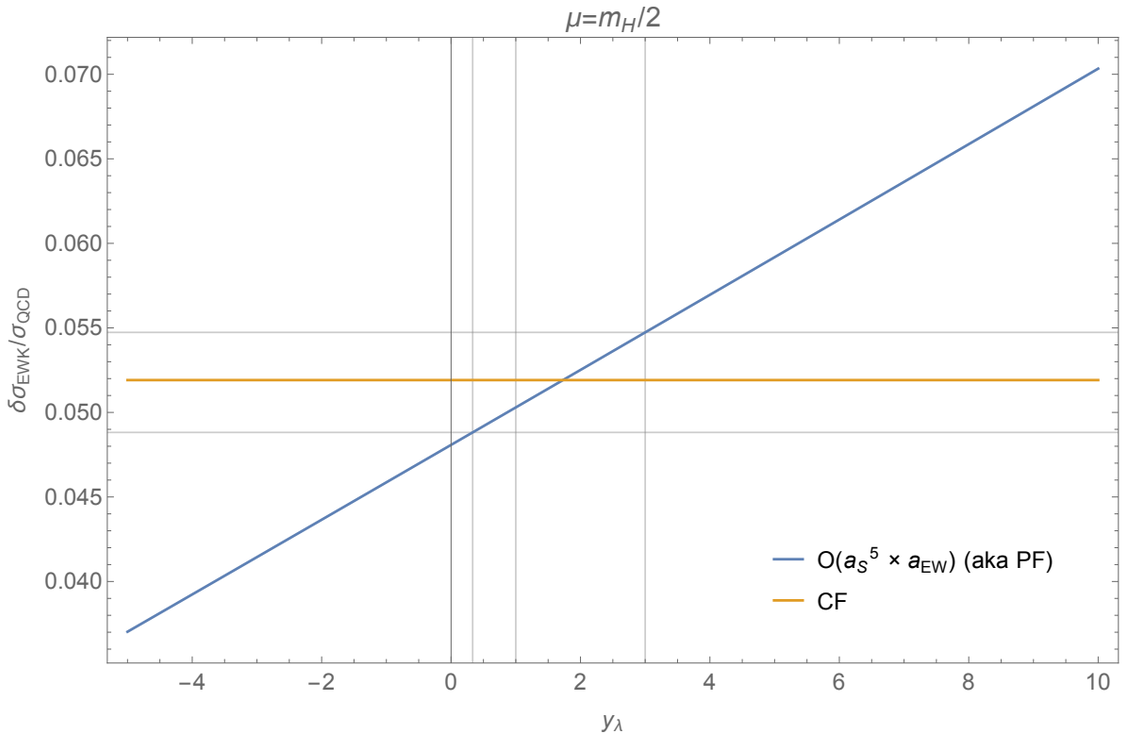
Uncertainties: EW corrections at NLO

$$C \equiv C_{QCD} + \lambda_{EW}\,(1 + C_{1w}\,a_s + C_{2w}\,a_s^2 + \ldots) \qquad \lambda_{EW}\,(1 + C_{1w}\,a_s + \ldots) \to \lambda_{EW}\,(1 + y_\lambda\,C_{1w}\,a_s + \ldots)$$




```
ew rescaled as^2     = 0.84
ew rescaled as^3     = 1.04
ew rescaled as^4     = 0.45
ew rescaled as^5     = 0.07
ew rescaled          = 2.39
```

EW beyond LO: 3.2% of total

→ +0.4% -0.2%

Assume: EW factorization misses entirely the HARD contribution at NLO (~40% of NLO contribution to NLO XS)

→ 40% * 3.2% = **1.3%**

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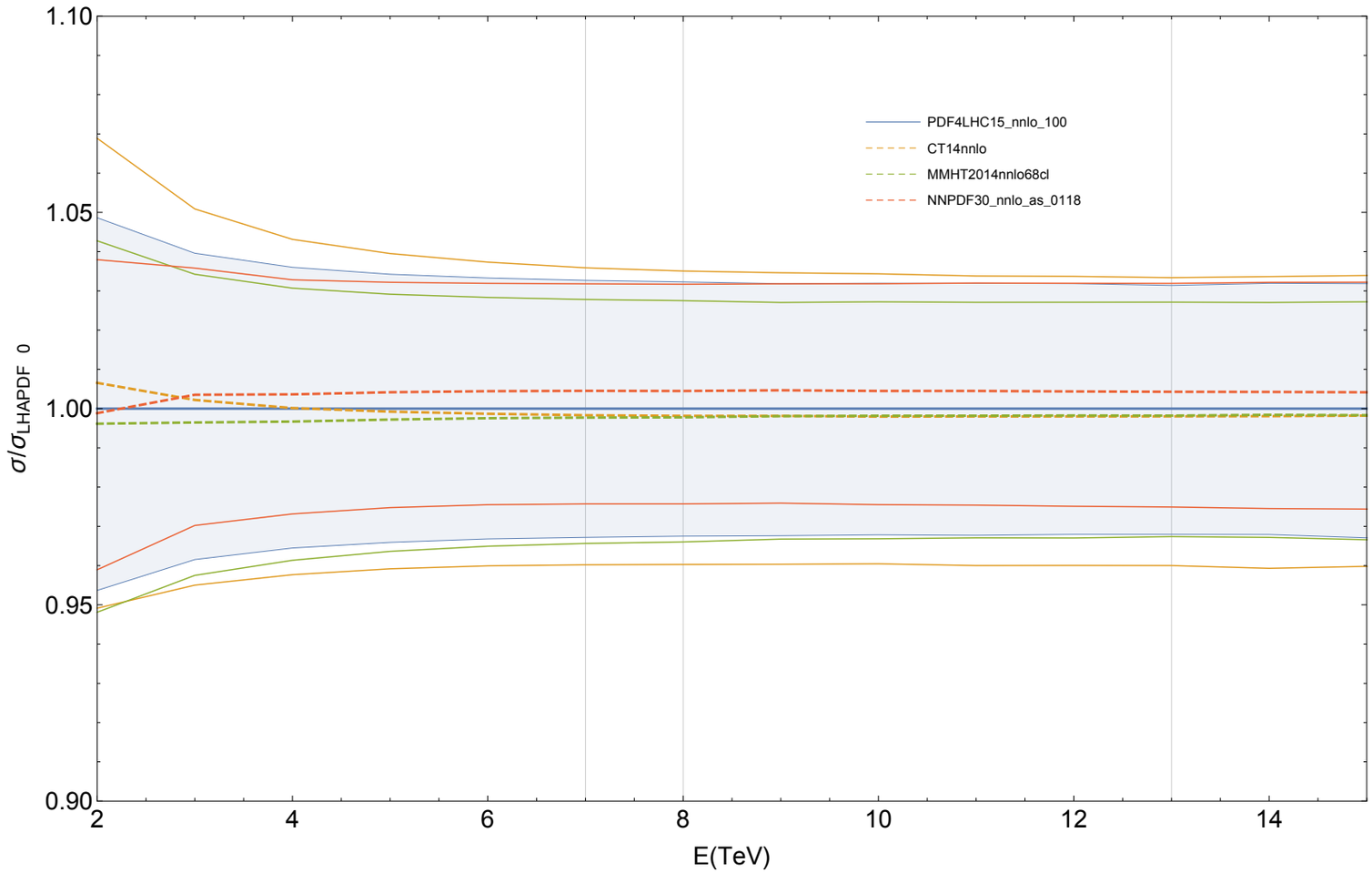
Uncertainties: PDFs & a_s

$$\delta(\mathrm{PDF}+\alpha_s)=\sqrt{\delta(\mathrm{PDF})^2+\delta(\alpha_s)^2} \qquad \alpha_s(m_Z^2)=0.118$$



3.15%

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adding up the theory uncertainties linearly

Higgs XS = 48.57pb

δ(scale) (pb)	δ(trunc) (pb)	δ(PDF-TH) (pb)	δ(EW) (pb)	$\delta(t,b,c)$ (pb)	$\delta(1/m_t)$ (pb)
$^{+0.10}_{-1.15}$	± 0.12	± 0.56	± 0.49	± 0.34	± 0.49
$^{+0.20\%}_{-2.37\%}$	$\pm 0.25\%$	$\pm 1.16\%$	$\pm 1\%$	$\pm 0.7\%$	$\pm 1\%$

+4.31%
-6.47%
theory

+3.15%
PDF+as

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Higgs XS = 48.57pb

$^{+4.31\%}_{-6.47\%}$ theory +3.15% PDF+as

Note, however that using ABM12
(and their best fit value for as)

$$\sigma_{\mathrm{ABM12}} = 45.07\,\mathrm{pb}$$

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Higgs XS = 48.57pb

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$^{+0.10}_{-1.15}$	± 0.12	± 0.56	± 0.49	± 0.34	± 0.49
$^{+0.20\%}_{-2.37\%}$	$\pm 0.25\%$	$\pm 1.16\%$	$\pm 1\%$	$\pm 0.7\%$	$\pm 1\%$

+4.31% -6.47% theory

+3.15% PDF+as

current HXSWG recommendation = 44.14pb

by M. Grazzini

differences due to HXSWG vs N3LO

1. NNLO+NNLL vs N3LO
2. central scale at mh vs mh/2
3. b,c at OS scheme vs MSBAR
4. no 1/mt vs included 1/mt
5. EW treatment

} to be clarified soon within the ggf task force

Roadmap to recommendation

- we discuss about organising a meeting soon on the various sources of theory uncertainties and their combination.
- As soon as the N3LO paper is published the ggf task force will process it and proceed to form a recommendation.
- This should be in time for the YR3 deadline of 29 Feb.