Next-to-soft-virtual resummed prediction for pseudoscalar Higgs boson production at NNLO+$\overline{\text{NNLL}}$

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Phys.Rev.D 105 (2022) 11, 116015

November 9, 2022

Outline of Talk

Introduction

- A. H. Ajjath, P. Mukherjee, and V. Ravindran (2020)

Partonic Coefficient Function near threshold, $z = \frac{\tau}{y} \to 1$:

$$\Delta^X_{ab}\left(z, q^2, \mu_R^2, \mu_F^2\right) = \underbrace{\Delta^{X,SV+NSV}_{ab}(z, q^2, \mu_i^2)} + \underbrace{\Delta^{X,hard}_{ab}(z, q^2, \mu_i^2)}$$

$\delta(\mathbf{1-z}), \; \mathcal{D}_\mathbf{i} = [\frac{\ln^\mathbf{i}(\mathbf{1-z})}{(\mathbf{1-z})}]_+; \; \log^i(1-z)$

Regular terms in z like $(1-z)^i$

$$\Delta^{X,SV+NSV}_c\left(z, q^2, \mu_R^2, \mu_F^2\right) = \mathcal{C} \exp\left\{\Psi^X_c\left(z, q^2, \mu_R^2, \mu_F^2, \varepsilon\right)\right\}|_{\varepsilon=0}$$

For diagonal channels, $\Psi^\mathbf{X}_\mathbf{c}\left(\mathbf{z}, \mathbf{q}^2, \mu_\mathbf{R}^2, \mu_\mathbf{F}^2, \varepsilon\right) \xRightarrow[\text{dependent on}]{\text{derived to be}}$

$Z^A_g \to$ overall operator UV renormalization constant, $\mathcal{F}^A_g \to$ form factors, $\Gamma_{gg} \to$ mass factorization kernels, $\Phi_g \to$ **soft collinear distribution.**

$\Phi_\mathbf{g}$: Has pole structure in ε similar to the residual divergences

- $\Phi_\mathbf{g} = \Phi^\mathbf{SV}_\mathbf{g} + \Phi^\mathbf{NSV}_\mathbf{g}$ where $\Phi^{NSV}_g\left(\hat{a}_s, q^2, \mu^2, z, \varepsilon\right) \to$ unknown.

☞ $\varphi^{\mathbf{NSV},(\mathbf{i})}_\mathbf{g}(\mathbf{z}, \varepsilon) = \varphi^{\mathbf{NSV},(\mathbf{i})}_{\mathbf{s,g}}(\mathbf{z}, \varepsilon) + \varphi^{\mathbf{NSV},(\mathbf{i})}_{\mathbf{f,g}}(\mathbf{z}, \varepsilon)$.

$\varphi^{\mathbf{NSV},(\mathbf{i})}_{\mathbf{s,g}}$'s acquire a known universal structure.

$\varphi^{\mathbf{NSV},(\mathbf{i})}_{\mathbf{f,g}}$'s $\xrightarrow[\text{in terms of}]{\text{are expressed}}$ $\phi^{NSV,(i)}_{f,g}$ (Finite coefficients).

Determining the expansion coefficients

By exploiting the similarity between pseudoscalar and scalar Higgs!

- T. Ahmed, M. Bonvini, M. C. Kumar, P. Mathews, N. Rana, V. Ravindran, L. Rottoli (2016)

$$\mathbf{\Delta^{A}_{gg}}\left(\mathbf{z},\mathbf{q}^2,\mu_\mathbf{R}^2,\mu_\mathbf{F}^2\right)=\frac{\mathbf{g_0}\left(\mathbf{a_s}\right)}{\mathbf{g_0^H}\left(\mathbf{a_s}\right)}\left[\mathbf{\Delta^{H}_{gg}}\left(\mathbf{z},\mathbf{q}^2,\mu_\mathbf{R}^2,\mu_\mathbf{F}^2\right)+\delta\mathbf{\Delta^{A}_{gg}}\left(\mathbf{z},\mathbf{q}^2,\mu_\mathbf{R}^2,\mu_\mathbf{F}^2\right)\right]$$

.

- $\delta\Delta^{A,NSV}_{gg}\left(z,q^2,\mu_R^2,\mu_F^2\right)\rightarrow$ Corrections to the scalar Higgs CFs,
- $g_0\left(a_s\right)$ and $g_0^H\left(a_s\right)\rightarrow$ Known constant functions.
- $\mathbf{\Delta^{A,NSV}_{gg}}\left(\mathbf{z},\mathbf{q}^2,\mu_\mathbf{R}^2,\mu_\mathbf{F}^2\right)=\frac{\mathbf{g_0}\left(\mathbf{a_s}\right)}{\mathbf{g_0^H}\left(\mathbf{a_s}\right)}\left[\mathbf{\Delta^{H,NSV}_{gg}}\left(\mathbf{z},\mathbf{q}^2,\mu_\mathbf{R}^2,\mu_\mathbf{F}^2\right)\right].$

To evaluate the $\phi^{NSV,(i)}_{f,g}$'s for pseudoscalar Higgs production *via* gluon fusion:

1. Using the analytical formalism, - A. H. Ajjath, P. Mukherjee, and V. Ravindran (2020)
2. Using the above relation. - T. Ahmed, M. Bonvini, M. C. Kumar, et. al. (2016)

$\Longrightarrow$ **❶ yields the corresponding pseudoscalar Higgs SV+NSV CFs in terms of the $\varphi^{(k)}_{g,i}$'s which are evaluated by comparison with the result from ❷ .**

Analytical Observations

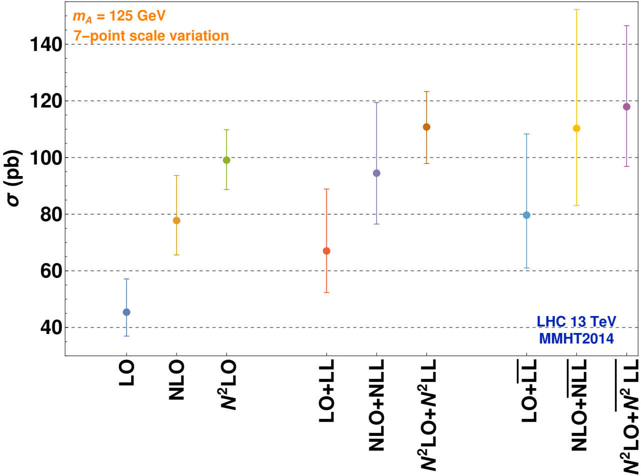
Our Observation: The $\varphi_{g,i}^{(k)}$'s, for the scalar and the pseudoscalar Higgs boson productions *via* gluon fusion, are identical to each other till two-loop.

Earlier Observations: - **A. H. Ajjath, P. Mukherjee, and V. Ravindran (2020)**

- Same was noticed for the DY process and scalar Higgs production *via* bottom quark annihilation up to two-loop level.
- This failed for the quark annihilation process at third order for $k = 0, 1$.

Hence, this behaviour at third order for the pseudoscalar Higgs boson production can be checked only when the corresponding explicit N^3LO results are available.

7-point scale uncertainty plot for $m_A = 125$ GeV

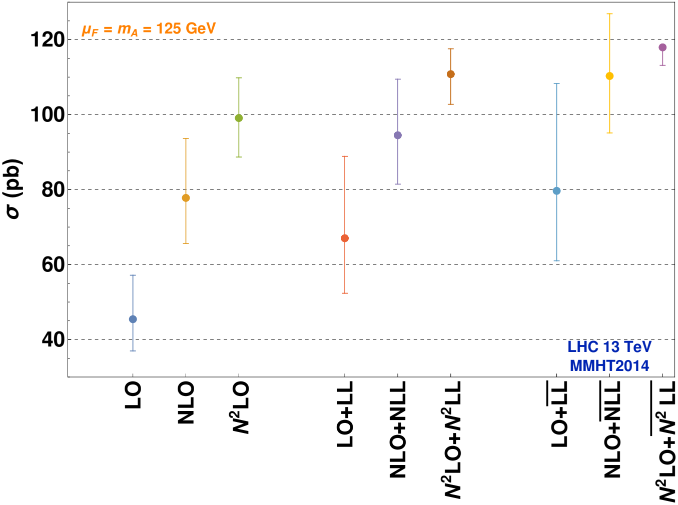


Observation ⇒ The uncertainties reduce from NLO to NNLO, NLO+NLL to NNLO+NNLL, and NLO+$\overline{\text{NLL}}$ to NNLO+$\overline{\text{NNLL}}$ $\xRightarrow{\text{Problem}}$

NSV resummation exhibits higher uncertainties than SV.

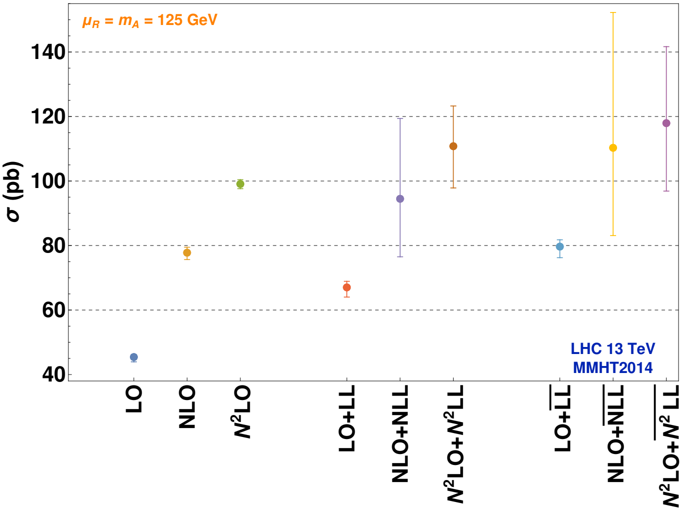
Uncertainty plot for μ_F scale fixed at $m_A = 125$ GeV

To comprehend this unexpected behaviour $\xrightarrow{\text{we study}}$ scale variations due to μ_R and μ_F separately by varying one and keeping the other fixed at m_A.



At NNLO, uncertainties reduce from FO to resummed results & NSV more stable than SV.

Uncertainty plot for μ_R scale fixed at $m_A = 125$ GeV



Observations: Results are in contrast to the μ_R variation ones, *i.e.*

- NLO+$\overline{\text{NLL}}$ $>$ NLO+NLL $>$ NLO,
- NNLO+$\overline{\text{NNLL}}$ $>$ NNLO+NNLL $>$ NNLO.

Possibility of scalar-pseudoscalar Higgs boson mixed state

Parameter: Mixing angle α. - **M. Jaquier, R. Röntsch (2019)**

Consider a Higgs boson production, while neglecting its decay,

$$\xrightarrow[\text{the results up to NNLO}]{\text{for any arbitrary value of } \alpha,} \sigma = \cos^2\alpha \cdot \sigma_{\mathbf{H}} + \sin^2\alpha \cdot \sigma_{\mathbf{A}}.$$

K-Factor	$\alpha = 0$	$\alpha = \pi/2$	$\alpha = \pi/4$	$\alpha = \pi/6$
$K_{(1)}$	1.6990	1.7124	1.7083	1.7048
$K_{(2)}$	2.1571	2.1814	2.1741	2.1677
$K_{(1)}^{resum}$	2.0033	2.0803	2.0570	2.0368
$K_{(2)}^{resum}$	2.2785	2.4392	2.3907	2.3485
$\overline{K}_{(1)}^{resum}$	2.3425	2.4284	2.4025	2.3799
$\overline{K}_{(2)}^{resum}$	2.4737	2.5966	2.5595	2.5272

Observation: Changing α modifies the corresponding QCD corrections only by a few percent.

Consequence: Availibility of the pseudoscalar Higgs boson production cross-section to a precision comparable to that of the scalar Higgs $\xRightarrow{\text{will prove helpful}}$

In extracting the mixing angle, α, to a better accuracy.

Summary

Aim: NSV resummation for pseudoscalar Higgs boson production *via* gluon fusion to $\overline{\text{NNLL}}$ accuracy.

1. Compute the NSV corrections up to second order, and compare them with the corresponding FO corrections.
   - **Conclude** These corrections significantly impact the pseudoscalar production cross-section compared to the conventional SV logarithms.
2. Estimate theory uncertainties.
   - The 7-point scale uncertainties.
   - μ_F & the μ_R scale variations.

   $\Downarrow$

   Conclude $\rightarrow$ The need of NSV contributions from other parton channels, & beyond NSV contributions in the gluon fusion channel.
3. Evaluate the production cross-sections for mixed scalar-pseudoscalar state for different values of the mixing angle, α which changes by a few percent.

Thank you...