Angularity in Higgs decay at NNLL′ accuracy

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Abstract

We present improved theoretical predictions for angularity distribution in Higgs decays into hadrons. Digluon channel is one of main decay channels of Higgs boson decay, and predictions on angularity distribution have large theoretical uncertainty associated with large logarithms. In the framework of SCET, we independently determine the 2-loop constant term in the gluon-jet function of angularity from a fit to NLO QCD results via an asymptotic form with recoil corrections in SCET-II limit and make predictions for resummed angularity distribution at NNLL′ in logarithmic accuracy and $\mathcal{O}(\alpha_s^2)$ in fixed-order accuracy.

1. Motivation

Event shapes are observables designed to characterize the geometric shape of hadron distribution, widely used in study of Higgs hardonic decay and in determination of fundamental parameters in SM. A specific event shape called angularity is defined by:

$$\tau_a = \frac{1}{Q}\sum_i |\mathbf{p}_\perp^i| e^{-|\eta_i|(1-a)} \tag{1}$$

Advantage:

1, Can be used for precision determination of fundamental parameter, e.g. strong coupling constant, Yukawa coupling constant.

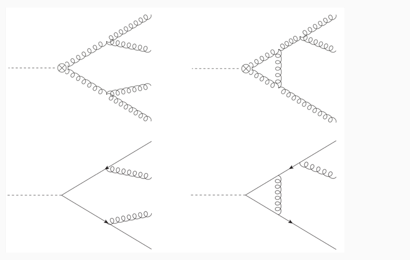
2, $a<2$, reshape the distribution to highlight the physics process we interested.

2. SCET factorization

Soft-collinear effect theory is a theoretical framework for studying the interactions of energetic partons with multiple momentum scales:

$$p_H^\mu \sim Q, \quad p_c^\mu \sim Q\left(\lambda^2,1,\lambda\right) \quad \text{and} \quad p_s^\mu \sim Q\lambda^{2-a} \tag{2}$$

In Laplace space, Higgs digluon and diquark decay channel can be factorized into:



$$\tilde\Gamma^i(\nu_a) = \Gamma_B^i(\mu)\, t(m_t^2,\mu)\, H(m_H^2,\mu) \tilde J_n^i(\nu_a,\mu)\ \tilde J_{\bar n}^i(\nu_a,\mu)\ \tilde S^i(\nu_a,\mu) \tag{3}$$

$H(m_H^2,\mu)$: hard function, matching from QCD to SCET.

$\tilde J_n^i(\nu_a,\mu)$: jet function from collinear radiation.

$\tilde S^i(\nu_a,\mu)$: soft function from soft radiation.

Structure of each function at 2-loop:

$$G^i(L_G,\mu_G) = \sum_{n=0}^{\infty}\left(\frac{\alpha_s(\mu_G)}{4\pi}\right)^n G^{i(n)}(L_G)$$

$$\begin{aligned} G^{i(2)}(L_G) = &\left[\frac{1}{2}\left(\Gamma_G^0\right)^2 L_G^4 - \Gamma_G^0\left(\gamma_G^0+\frac{2}{3}\beta_0\right)L_G^3\right. \\ &\left. + \left(\Gamma_G^1+\frac{1}{2}\left(\gamma_G^0\right)^2+\gamma_G^0\beta_0+c^1\Gamma_G^0\right)L_G^2 - \left(\gamma_G^1+c^1\gamma_G^0+2c^1\beta_0\right)L_G + \mathbf{c^2}\right] \end{aligned} \tag{4}$$

All functions are known up to 2-loop except for the 2-loop constant in gluon-jet function, $\mathbf{c_g^2}$.

3. Determination strategy

Full QCD gives:

$$\frac{1}{\Gamma_0}\frac{d\Gamma}{d\tau_a} = A\delta(\tau_a) + [B(\tau_a)]_+ + r(\tau_a) \tag{5}$$

SCET gives:

$$\frac{1}{\Gamma_0}\frac{d\Gamma_s}{d\tau_a} = A\delta(\tau_a) + [B(\tau_a)]_+ \tag{6}$$

Total decay rate gives:

$$\frac{\Gamma_t}{\Gamma_0} = \int_0^1 d\tau_a' \frac{1}{\Gamma_0}\frac{d\Gamma}{d\tau_a'} = A + r_c \tag{7}$$

where $\mathbf{c^2}$ in each function contributes to A, while A in Eq. (5) from MC is not captured, in Eq. (6) lacks $\mathbf{c_g^2}$ in gluon-jet function, and in Eq. (7) cannot picked up.

Strategy:

Step 1, Obtain $r(\tau_a)$ by subtracting SCET singular distribution Eq. (6) from MC full QCD distribution Eq. (5), and integrate out τ_a from $\tau_a^{\min}$ to $\tau_a^{\max}$ to get remainder function.

Step 2, Fit remainder function to get asymptotic result r_c in $\tau_a \to 0$.

Step 3, Subtract r_c in total decay rate Eq. (7), and obtain unknown $\mathbf{c_g^2}$ in gluon-jet function in A.

Challenge:

1, Due to finite machine precision, $r(\tau_a)$ from MC has large uncertainty.

2, Convergent of r_c becomes slow in lage a due to recoil correction.

Our Solution: Asymptotic approach with recoil correction under Tikhonov regularization.

Asymptotic behaviour of $r(\tau_a)$ in $a \le 0$:

$$\sum_{i=0}^{3}\alpha_i \ln^i\tau_a \quad \text{at NLO} \tag{8}$$

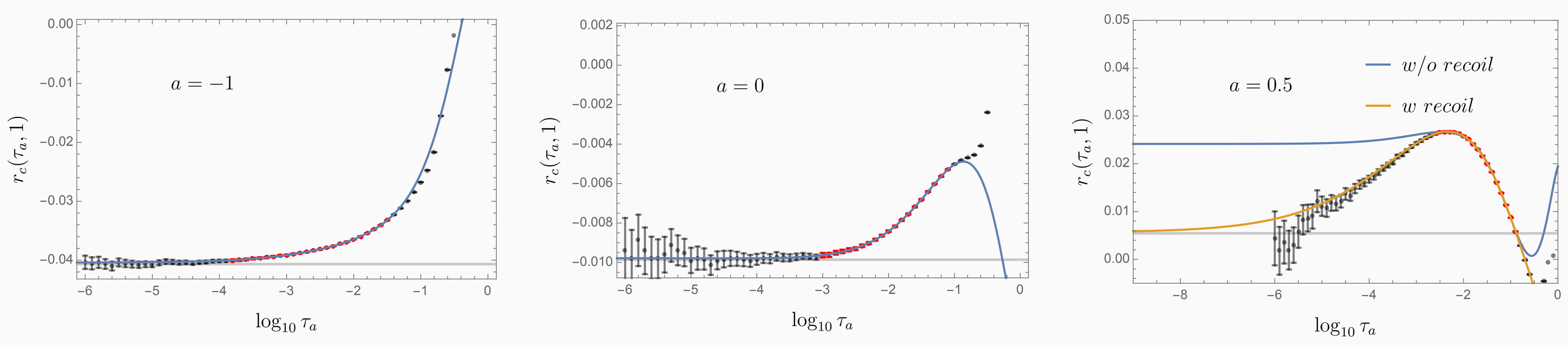
Recoil correction at $0<a<1$ is from $p_n^\perp \sim p_s^\perp$:

$$\sum_{n=1}^{\lceil 1/(1-a)\rceil -1}\frac{e_{n,2}\ln^2\tau_a + e_{n,1}\ln\tau_a + e_{n,0}}{\tau_a^{1-n(1-a)}} \quad \text{at NLO (assumption)} \tag{9}$$

which based on convolution of 1-loop recoil correction in soft function and 1-loop jet function.

4. Examination and determination

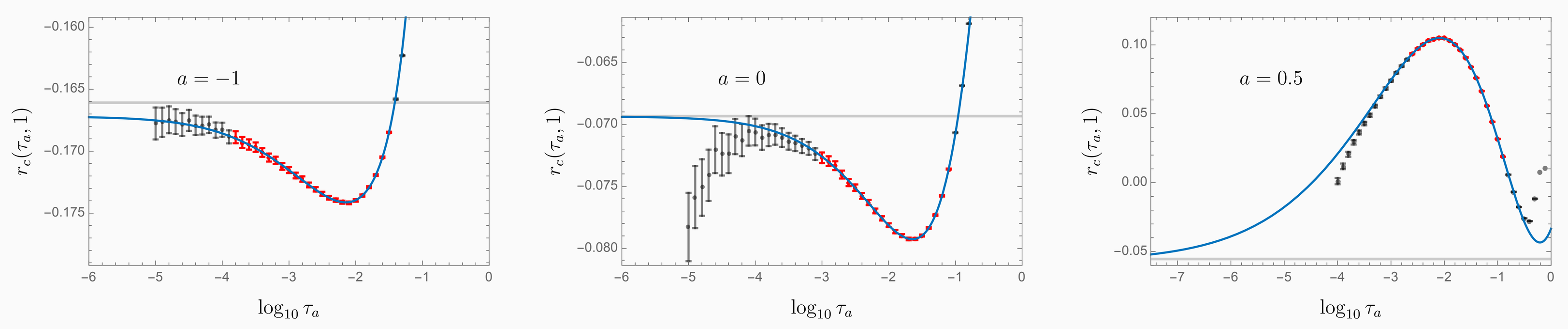
Examination: Known c_q^2 in quark-jet function in Higgs diquark decay channel:



Red (Black) error bar: the data in (out of) fitting region.

Gray line: known result.

Determination: $\mathbf{c_g^2}$ in gluon-jet function in Higgs digluon decay channel:



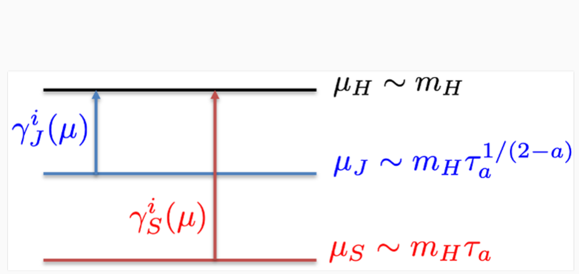
Gray line: known result (unpublished thesis, number read from plot).

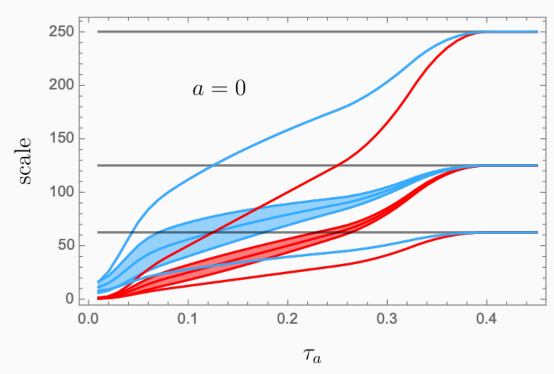
5. Resummation

Hard, jet and soft function are RG evolved from its nature scale μ_G to a target scale μ, shown in below equation and left plot. Profile function $\mu^i(\tau_a)$ and uncertainty estimation are shown in below right plot, where profile is designed to connect resummation region and fixed-order region, and uncertainty estimation is band method.

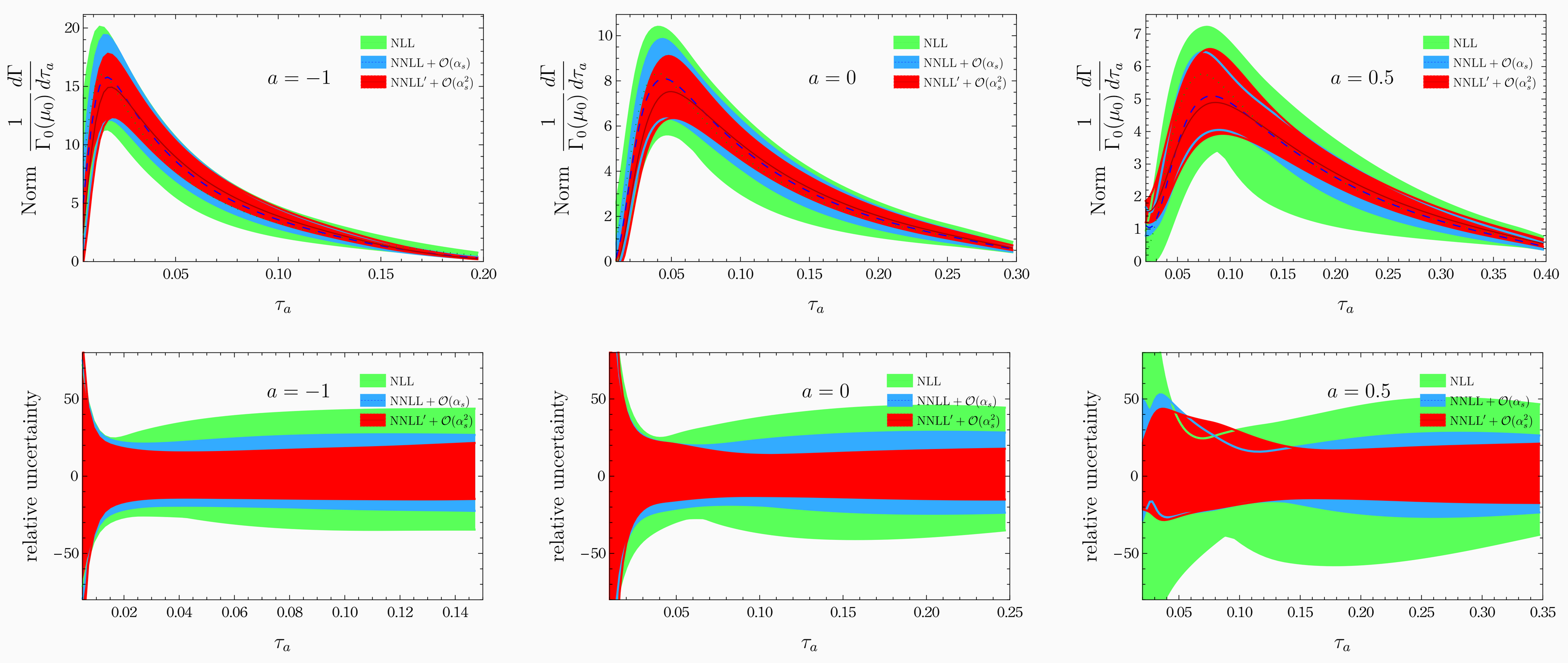
$$G(\nu,\mu) = G(\nu,\mu_G)e^{K_G(\mu_G,\mu)+j_G\eta_G(\mu_G,\mu)L_G} \tag{10}$$

$$\text{where } e^{K_G(\mu_G,\mu)+j_G\eta_G(\mu_G,\mu)L_G} = \underbrace{\sum(\alpha_s L)^n L}_{\text{LL}} + \underbrace{\sum(\alpha_s L)^n}_{\text{NLL}} + \cdots$$





Prediction of resummed angularity distribution of Higgs digluon decay channel:



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