$\mathcal{T}_{jet}$ resummation in Higgs production at NLL$'$ + NLO

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Outline

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2. Soft-Collinear Factorization and Resummation
3. Perturbative Uncertainties
4. Resummation results for Higgs + 0 jet at NLL$'$ + NLO
5. Summary

Introduction

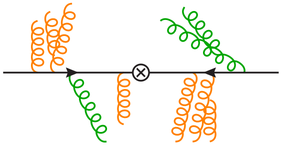
- Precision measurement of the Higgs boson properties at the LHC : Accurate theoretical prediction of cross section is required.
- Experimental analyses separate the data into jet bins. Eg: In H $\rightarrow$ W W* : any hard jets with $p_T^{jet} > p_T^{\mathrm{cut}} \sim 20 - 30\,\mathrm{GeV}$ are vetoed.
- Jet vetoes induce large Sudakov (double) logs: $\alpha_s^n \log^m [p_T^{\mathrm{cut}}/m_H]$ that need to be resummed.
- Eg: gg $\rightarrow H + 0$ jet

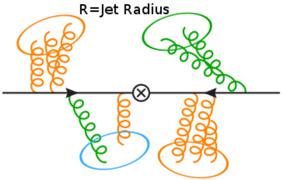
$$\sigma_0(p_T^{\mathrm{cut}}) \propto \sigma_B(1 - 2\frac{\alpha_s C_A}{\pi} \log^2 \frac{p_T^{\mathrm{cut}}}{m_H} + ...)$$

- Perturbative corrections get large at small $p_T^{\mathrm{cut}} \ll m_H$.
- Resummation of logs give improved prediction and uncertainty estimates.

Introduction

Alternative jet veto Observables:





Global Veto

restricts $\sum$ of all emissions

"beam broadening"

$$E_T = \sum_i |\vec{p_{Ti}}|$$

"beam thrust"

Local Veto

restrict (local chunks of) individual emissions

"jet p_T"

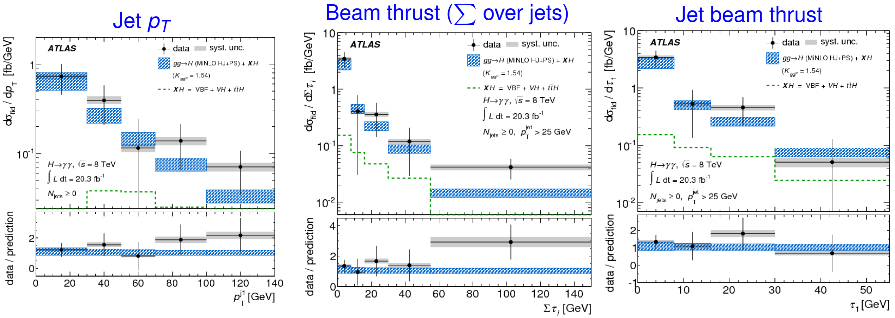
$$\vec{p}_T^{jet} = \max_{i \in \text{jets}} |\vec{p}_{Ti}|$$

"jet beam thrust"

$$\mathcal{T} = \sum_i |\vec{p_T}_i| e^{-|y_i - Y|} \qquad \mathcal{T}_{\text{jet}} = \max_{i \in \text{jets}} |\vec{p_T}_i| e^{-|y_i - Y|} \; ; \quad \mathcal{T}_C = \max_{i \in \text{jets}} \frac{|\vec{p_T}_i|}{2\cosh(y_i - Y)}$$

(y_i and Y are the jet and Higgs rapidity respectively.)

Introduction



- Resummation of various jet veto observables known:
  1. Beam Thrust resummation: [Berger, Marcantonini, Stewart, Tackmann, Waalewijn]
  2. Jet p_T resummation: [Banfi, Monni, Salam, Zanderighi ; Becher, Neubert, Rothen; Stewart,Tackmann, Walsh, Zuberi.]
- Different Observables have sensitivity to virtuality or p_T of emission: different resummation structures.
- $\mathcal{T}_{jet}$ resummation important: to provide complementary information in the exclusive 0-jet region and testing the resummation framework.

Soft-collinear Factorization and Resummation

The cross section in SCET for $gg \to H$:

$$d\sigma_0 = |C_{ggH}|^2 \langle p_a p_b | O^\dagger_{ggH} M^{veto} O_{ggH} | p_a p_b \rangle$$

$$O_{ggH} \sim H O_a O_s O_b \sim H B^\mu_{n_a} T[Y^\dagger_{n_a} Y_{n_b}] B_{n_b \, \mu}$$

Measurement function M^{veto}

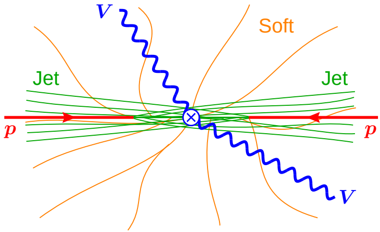
- Implements phase space constraints due to jet veto.
- Soft-collinear factorization implies

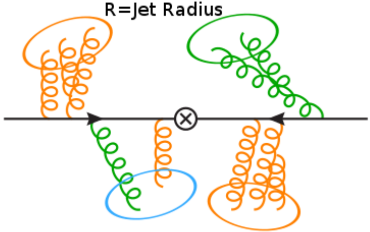
$$M^{veto} = M^{veto}_a \times M^{veto}_b \times M^{veto}_s + \mathrm{O}(R^2)$$

- Matrix elements factorize into independent soft and collinear matrix elements

$$B_{a,b}(\mu) = \langle p_a | O^\dagger_{a,b} M_{a,b} O_{a,b} | p_b \rangle$$
$$S_{a,b}(\mu) = \langle 0 | O^\dagger_s M_s O_s | 0 \rangle$$

Soft collinear Factorization and Resummation





Jet Beam Thrust Factorized cross section for $gg \to H$ with $\mathcal{T}_{\text{jet}} < \mathcal{T}^{cut}$ derived in SCET: [Tackmann, Walsh, Zuberi]

$$\sigma_0(\mathcal{T}^{cut}) = H(m_H, \mu) B^j(R, m_H \mathcal{T}^{cut}, x_a, \mu) B^j(R, m_H \mathcal{T}^{cut}, x_b, \mu) S^j(R, \mathcal{T}^{cut}, \mu) + \sigma^{ns}(\mathcal{T}^{cut}, \mu)$$

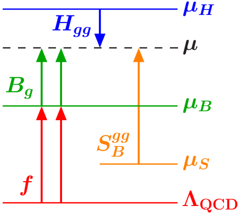
- Gluon beam function can be computed in an OPE:

$$B_g^j(R, m_H \mathcal{T}^{cut}, x, \mu_B) = \sum_j \int_x^1 I_{gj}(R, m_H \mathcal{T}^{cut}, z, \mu_B) f_j\left(\frac{x}{z}, \mu_B\right) \left[1 + O\left(\frac{\Lambda_{QCD}^2}{m_H \mathcal{T}^{\text{cut}}}\right)\right]$$

Soft collinear Factorization and Resummation

- Hard, beam and soft functions live at different scales:

  $\mu_H \simeq m_H$, $\mu_B \simeq \sqrt{\mathcal{T}^{\rm cut} m_H}$, $\mu_S \simeq \mathcal{T}^{\rm cut}$
- Hard Function contains: $\ln^2\left[-m_H^2/\mu_H^2\right]$
- Beam functions: $\ln^2\left[m_H \mathcal{T}^{cut}/\mu_B^2\right]$
- Soft function: $\ln^2\left[\mathcal{T}^{cut}/\mu_S\right]$
- Logarithms are split apart and resummed using RGE



$$\ln^2\frac{\mathcal{T}^{cut}}{m_H} = 2\ln^2\frac{m_H}{\mu} - \ln^2\frac{\mathcal{T}^{cut} m_H}{\mu^2} + 2\ln^2\frac{\mathcal{T}^{cut}}{\mu}$$

Resummation Structure:

$$\ln\sigma_0(\mathcal{T}^{\rm cut}) \sim \sum_n \alpha_s^n \ln\left[\frac{\mathcal{T}^{\rm cut}}{m_H}\right]^{n+1}(1+\alpha_s+\alpha_s^2+\cdots) \sim \text{LL} + \text{NLL} + \text{NNLL} + \cdots$$

- The RGE for beam function:

$$\mu \frac{d}{d\mu} B_g(\mathcal{T}^{cut}, x, \mu) = \gamma_B^g(\mathcal{T}^{cut}, \mu) B_g(\mathcal{T}^{cut}, x, \mu)$$

$$\gamma_B^g(\mathcal{T}^{cut}, \mu_B) = -2\Gamma_{\text{cusp}} \ln\left[\frac{m_H \mathcal{T}^{cut}}{\mu_B^2}\right] + \gamma_B^g[\alpha_s]$$

- Including the RGE running the resummed cross section for $\mathcal{T}^{jet}$

$$\sigma_0(\mathcal{T}^{cut}) = H_{gg}(m_H, \mu_H)\, U_H(m_H \mu_H, \mu) \times \left[B_g^{jet}(R, \mathcal{T}^{cut}, \mu_B)\, U_B(m_H, \mu_B, \mu)\right]^2 \times S_{gg}(R, \mathcal{T}^{cut}, \mu_S)\, U_S(\mu_S, \mu) \times [1 + O(R^2)] + \sigma^{ns}(\mathcal{T}^{cut}, \mu)$$

Log counting:	Fixed-order corrections matching	Fixed-order corrections nonsingular	Resummation input $\gamma^{\mu}_{H,B,S}$	Resummation input Γ_{cusp}	Resummation input β
NLL	1	-	1-loop	2-loop	2-loop
NLL′+ NLO	NLO	NLO	1-loop	2-loop	2-loop
NNLL′+NNLO	NNLO	NNLO	2-loop	3-loop	3-loop

Non-singular Contribution

- In the large $\mathcal{T}$ limit, the resummed results should reproduce the correct FO cross section.

$$\frac{d\sigma^{FO}}{d\mathcal{T}dY} = \sigma_0 \alpha_s^2(\mu^2) \int \frac{d\xi_a}{\xi_a}\frac{d\xi_b}{\xi_b} \sum_{ij} C_{ij}(x_a/\xi_a, x_b/\xi_b, \mathcal{T}, Y) f_i(\xi_a, \mu) f_j(\xi_b, \mu)$$

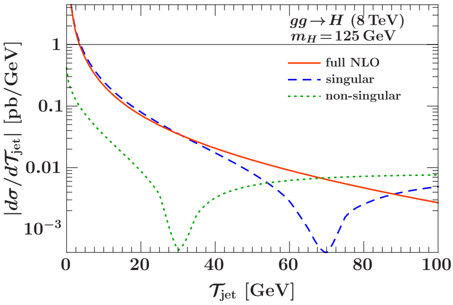
- The coefficients C_{ij} for the FO cross section can be thought of as:

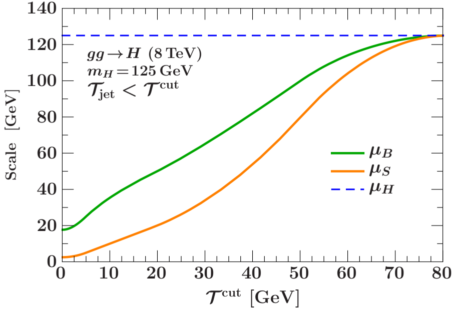
$$C_{ij}^{\mathrm{FO}} = |M_{ij}|^2 \times (\text{phase space factor}) \times M^{\mathrm{veto}}$$

- M^{veto} depends on the jet-veto observable.
- The FO cross section is a sum of the singular and the non-singular parts.

$$\frac{d\sigma^{ns,FO}}{d\mathcal{T}} = \frac{d\sigma^{FO}}{d\mathcal{T}} - \frac{d\sigma^{s,FO}}{d\mathcal{T}}$$

Resummation scales and Perturbative Uncertainties





- Resummation region: Logs are resummed using canonical scaling

$$|\mu_H| \sim m_H \qquad \mu_S \sim \mathcal{T}^{\rm cut} \qquad \mu_B \sim \sqrt{m_H \mathcal{T}^{\rm cut}}$$

- FO region: Resummation is turned off to get the right FO cross section at large $\mathcal{T}^{\rm cut}$

$$\mu_B, \mu_S \to \mu \sim m_H$$

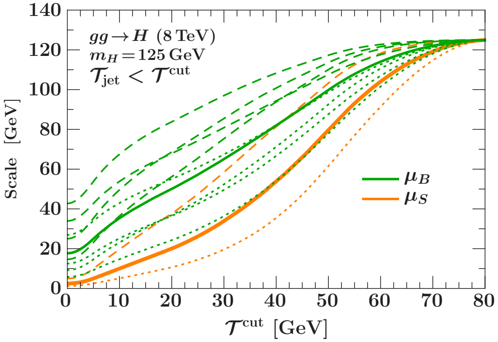
- Transition region: Profiles for μ_B, μ_S provide smooth transition from resummation to fixed-order region.

Resummation scales and Perturbative Uncertainties

Resummation uncertainty Δ_{resum}: [Setup analogous to p_T^{jet} in (STWZ'12)]

- Varying the argument of logs estimates their size and missing higher log terms.
- Variation of beam and soft scales performed with a multiplicative factor $f_{\text{vary}}(\mathcal{T}^{\text{cut}})$:

$$\mu_S(\mathcal{T}^{\text{cut}}) = f_{\text{vary}}^{\alpha}(\mathcal{T}^{\text{cut}})\mu_S^{central}, \quad \mu_B = \mu^{1/2+\beta}(\mu_S(\mathcal{T}^{\text{cut}}))^{1/2-\beta}$$



- These variations are smoothly turned off at large $\mathcal{T}^{cut}$ where the resummation turns off.

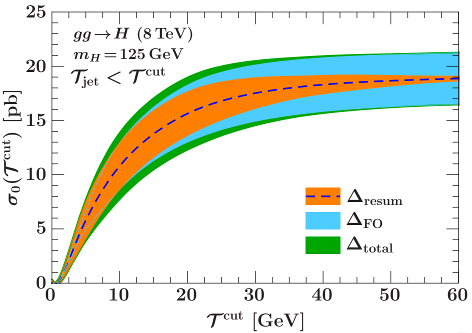
Resummation scales and Perturbative Uncertainties

Fixed Order Uncertainty:

- Maximum of collective variation of all scales by a factor of 2 keeping scale ratios fixed.
- Reproduces the inclusive cross section uncertainty for large $\mathcal{T}^{\rm cut}$.

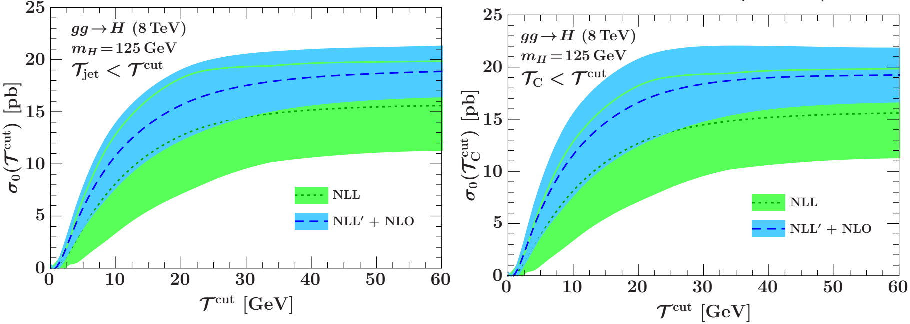
Total Uncertainty:

$$\Delta_{tot} = \sqrt{\Delta^2_{\rm resum} + \Delta^2_{FO}}$$



Results for H +0 jet at NLL′+ NLO

$$\mathcal{T}_{jet} = \max_{i \in \text{jets}} |\vec{p}_{T\,i}| e^{-|y_i - Y|} \qquad \mathcal{T}_C = \max_{i \in \text{jets}} \frac{|\vec{p}_{T\,i}|}{2\cosh(y_i - Y)}$$



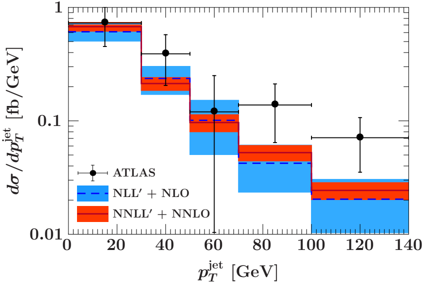
- Complex hard scale $(\mu_H = -im_H)$: To minimize the double logs of $-m_H^2/\mu_H^2$ in the hard function.
- Significantly improves perturbative convergence.

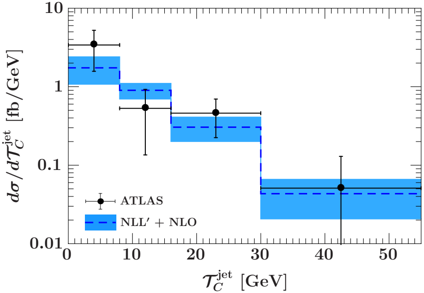
Summary

- Exclusive jet cross section measurements are key to precision Higgs physics at the LHC.
- Resummation of jet veto logs: important for accurate cross section predictions.
- Resummation of different jet veto observables provides complementary information: In this talk $\mathcal{T}_{\rm jet}$
- $gg \to H$ cross section with a $\mathcal{T}_{jet}$ and $\mathcal{T}_{C}$ veto to $\mathrm{NLL}' + \mathrm{NLO}$.
- Perturbative uncertainties in the resummed predictions using profile variations.

Outlook

- Preliminary comparison to the ATLAS data (arxiv:1407.4222) for $p_T^{\rm jet}$ (STWZ '12) and $\mathcal{T}_C^{jet}$





- $\mathcal{T}_{\rm jet}$ resummation to NNLL′+ NNLO (W.I.P)