Higgs Production at NNLL′ + NNLO using Rapidity-Dependent Jet Vetoes.

World SCET 2020

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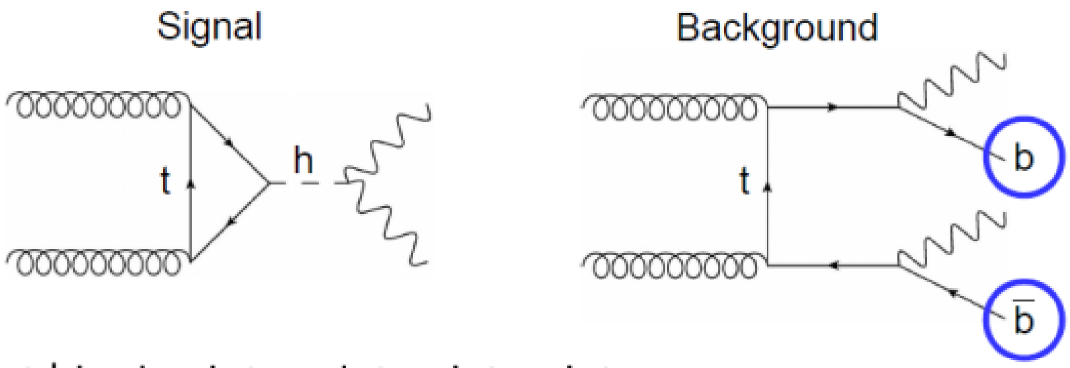
Based on: SG, J. Gaunt, F. Tackmann , E. Vryondiou : JHEP 2005 054.

Introduction

- Jet vetoes are important at the LHC for separating signal from background.



eg: $H \to WW$: Jet binning into 0-jet, 1-jet, 2-jet.

0-jet bin: Hard jets with $p_T^{jet} > p_T^{cut} \sim 20 - 30$ GeV are vetoed.

Jet selection cuts and vetoes on additional emissions induce Sudakov double logarithms.

Eg: gg $\to H + 0$ jet: $\sigma_0(p_T^{cut}) \propto \sigma_B(1 - 2\frac{\alpha_s C_A}{\pi} \log^2 \frac{p_T^{cut}}{m_H} + ...)$

- For tighter jet vetoes ($p_T^{cut} \ll m_H$), these logs become large and dominate the perturbative series $\longrightarrow$ increased theoretical uncertainties.
- These logs must be systematically resumed to obtain reliable theory predictions.

Rapidity- dependent Jet Vetoes

Using the p_T of the jet as a veto: In harsh pile up, low p_T jets hard to identify in forward region of detector $|\eta| > 2.5$.

- Can try to get around this by a hard rapidity cut: vetoing only jets with $|\eta| < 2.5$.
- Or raise p_T^{cut} everywhere : Lose the utility of a tight central jet veto.
- Use a different jet veto that depends smoothly on the rapidity of jets.

$$\mathcal{T}_{fj} = |\vec{p}_{Tj}| f(y_j)$$

Tackmann, Walsh, Zuberi ‘12 , SG, Stahlhofen, Tackmann ’14.

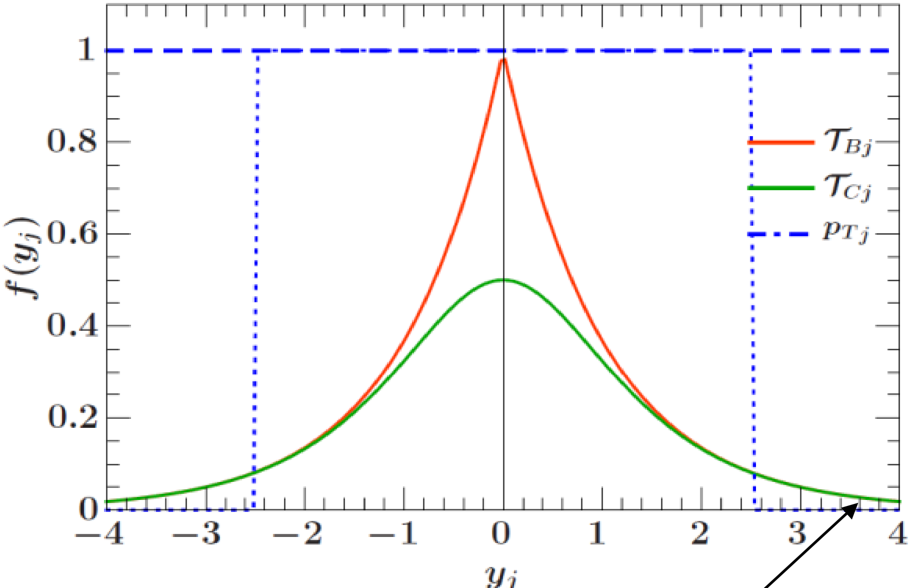
$f(y_j)$: decreasing function of $|y_j|$. Tight veto at small rapidity and loose at large rapidity.

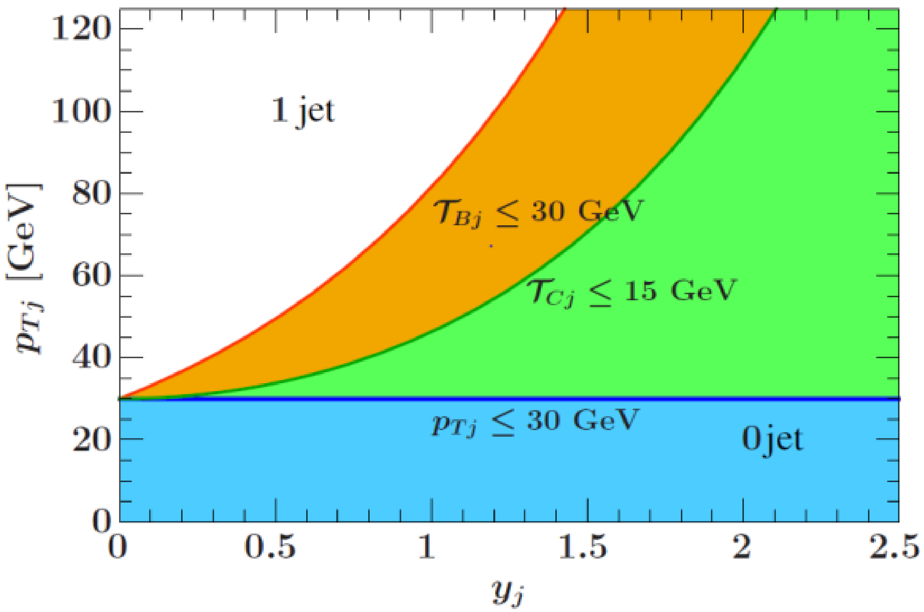
$$p_{Tj} < \frac{\mathcal{T}^{\rm cut}}{f(y_j)} \ , \ \mathcal{T}_f^{\rm jet} = \max_{j \in R} \mathcal{T}_{fj}$$

Rapidity-dependent Jet Vetoes

Two observables: $\mathcal{T}_B^{\mathrm{j}} : f(y_j) = e^{-|y_j - Y|}$, $\mathcal{T}_{B\mathrm{cm}}^{\mathrm{j}} : f(y_j) = e^{-|y_j|}$

$$\mathcal{T}_C^{\mathrm{j}} : f(y_j) = \frac{1}{2\cosh(y_j - Y)} \quad , \quad \mathcal{T}_{C\mathrm{cm}}^{\mathrm{j}} : f(y_j) = \frac{1}{2\cosh(y_j)}$$





Two observables become equal at forward rapidites.

Factorization for H+0- jet

$$\frac{d\sigma_0}{dY}(\mathcal{T}_f^{\rm jet} < \mathcal{T}^{\rm cut}) = \frac{d\sigma_0^{\rm resum}}{dY}(\mathcal{T}_f^{\rm jet} < \mathcal{T}^{\rm cut}) + \frac{d\sigma_0^{\rm nons}}{dY}(\mathcal{T}_f^{\rm jet} < \mathcal{T}^{\rm cut})$$

$$\frac{d\sigma_0^{\rm resum}}{dY}(\mathcal{T}_{B,C}^{\rm jet} < \mathcal{T}^{\rm cut}) = \sigma_B H_{gg}(m_t, m_H^2, \mu_H)\, B_g(m_H \mathcal{T}^{\rm cut}, x_a, R, \mu_B) B_g(m_H \mathcal{T}^{\rm cut}, x_b, R, \mu_B)$$

$$S_{gg}^{B,C}(\mathcal{T}^{\rm cut}, R, \mu_S) + O(R^2)$$

(Tackmann, Walsh, Zuberi '12)
(Stewart, Tackmann, Waalewijn '09)

$$d\sigma \sim |C_{ggH}|^2 \langle p_a p_b | \, O_{ggH}^\dagger \hat{\mathcal{M}} \, O_{ggH} \, | p_a p_b \rangle$$

$$\sim O_a O_s O_b$$

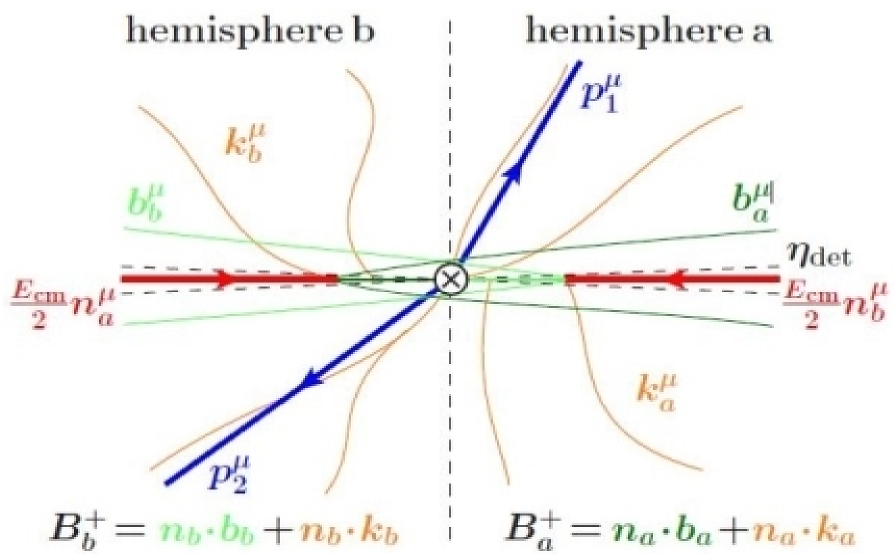
Measurement Function

$$O_{ggH} = H \mathcal{B}^\mu_{n_a \perp} T[\mathcal{Y}^\dagger_{n_a} \mathcal{Y}_{n_b}] \mathcal{B}^\mu_{n_b \perp}$$

$$\mathcal{M}^{\rm jet} \sim \mathcal{M}_a \times \mathcal{M}_b \times \mathcal{M}_s + \delta \mathcal{M}^{\rm jet}_{SC}$$

$$B_a(\mu) = \langle p_a | \, O_a^\dagger \hat{\mathcal{M}}_a O_a \, | p_a \rangle$$

$$S(\mu) = \langle 0 | \, O_s^\dagger \hat{\mathcal{M}}_s \mathcal{O}_b \, | 0 \rangle$$



Factorization in SCET

$$B_g(t^{\rm cut}, x, \mu) = \langle p_n(P^-)|\, \mathcal{B}_{n\perp\mu}(0)\mathcal{M}^{\rm jet}[\delta(\omega - \bar{\mathcal{P}}_n)\mathcal{B}_{n\perp\mu}(0)]\,|p_n(P^-)\rangle$$

$x \to \omega/P^-$

$\mathcal{B}_{n\perp\mu}$: Collinear Gluon field

Stewart, Tackmann, Waalewijn '10

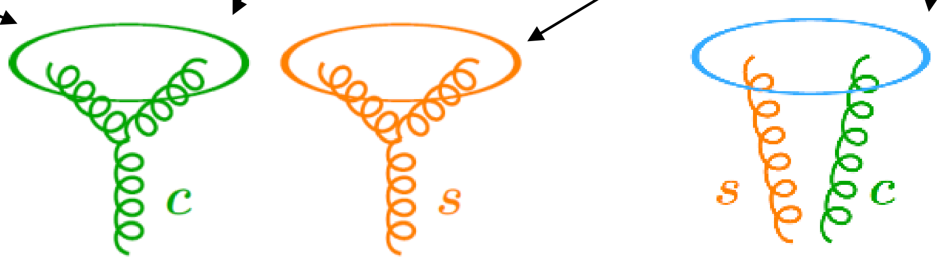
Measurement function: $\mathcal{M}_B^{\rm jet}(\mathcal{T}^{\rm cut}) = \theta(\mathcal{T}_B^{\rm jet} < \mathcal{T}^{\rm cut}) = \prod_{j \in J(R)} \theta(k_j^+ < \mathcal{T}^{\rm cut})$

For $m_H \mathcal{T}^{\rm cut} \gg \Lambda_{QCD}^2$: $B_g(t^{\rm cut}, x, \mu) \sim \sum_j \int_x^1 \frac{dz}{z} \mathcal{I}_{gj}\Big(t^{\rm cut}, z, \mu, R\Big) f_j\Big(\frac{x}{z}, \mu\Big)$

Soft Collinear factorization implies: (Tackmann, Walsh, Zuberi '12)

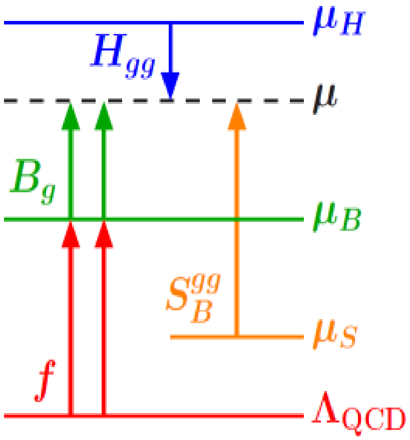
$$\mathcal{M}^{\rm jet} = (\mathcal{M}_a + \Delta\mathcal{M}_a^{\rm jet}) \times (\mathcal{M}_b + \Delta\mathcal{M}_b^{\rm jet}) \times (\mathcal{M}_s + \Delta\mathcal{M}_s^{\rm jet}) + \delta\mathcal{M}_{SC}^{\rm jet}$$

clustering within each collinear and soft sector.



Clustering of soft and collinear components into the same jet. ~O(R^2)

Resummation in SCET



Natural Scale choice: $\mu_H \simeq m_H$, $\mu_B \simeq \sqrt{\mathcal{T}^{\rm cut} m_H}$, $\mu_S \simeq \mathcal{T}^{\rm cut}$

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

Beam Function RGE: $\mu \frac{d}{d\mu} \ln\left[B_g(t^{\rm cut}, x, R, \mu)\right] = \gamma_B^g(t^{\rm cut}, R, \mu)$

$$\begin{aligned} \sigma_0(\mathcal{T}^{cut}) = & \, H_{ggH}(m_H, \mu_H)\, U_H(m_H, \mu_H, \mu) \\ & \times B_g(m_H \mathcal{T}^{cut}, x_a, R, \mu_B) B_g(m_H \mathcal{T}^{cut}, x_b, R, \mu_B)\, U_B(m_H \mathcal{T}^{cut}, \mu_B, \mu)^2 \\ & \times S_{gg}^{B,C}(\mathcal{T}^{cut}, R, \mu_S)\, U_S(\mu_S, \mu) \end{aligned}$$

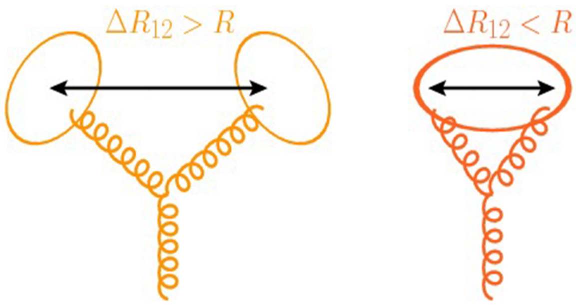
Log counting:	Fixed-order corrections matching	nonsingular	Resummation input $\gamma^\mu_{H,B,S}$	$\Gamma_{\rm cusp}$	β
NLL	1	-	1-loop	2-loop	2-loop
NLL′	NLO	-	1-loop	2-loop	2-loop
NLL′+ NLO	NLO	NLO	1-loop	2-loop	2-loop
NNLL′+NNLO	NNLO	NNLO	2-loop	3-loop	3-loop

Jet Clustering Corrections

We need finite parts of 2-loop beam and soft functions.

Jet Dependent Measurement Function:

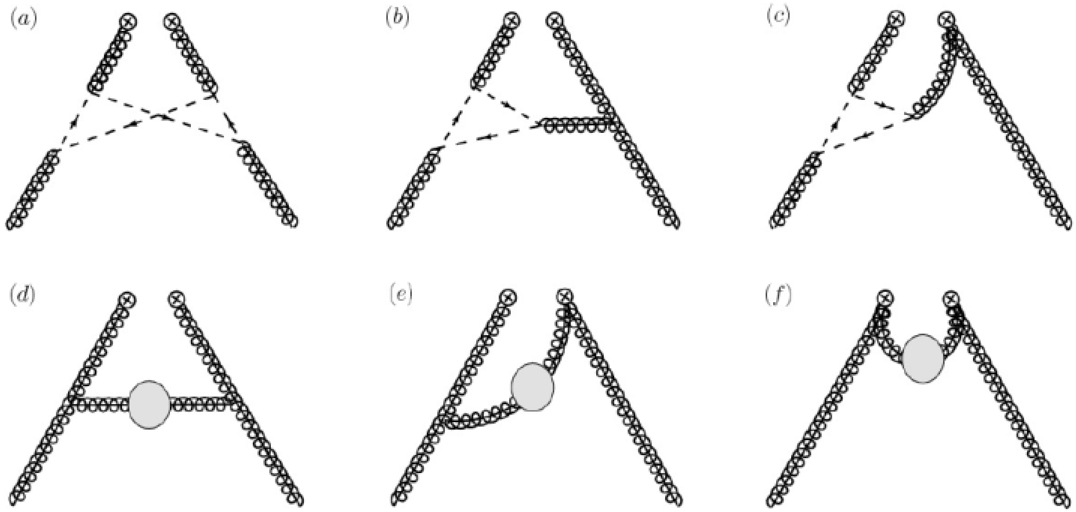
$$\mathcal{M}_i^{\rm jet}(\mathcal{T}^{\rm cut}, R) = \theta(\Delta R > R)\theta(\mathcal{T}_{B1} < \mathcal{T}^{\rm cut})\theta(\mathcal{T}_{B2} < \mathcal{T}^{\rm cut}) + \theta(\Delta R < R)\theta(\mathcal{T}_B^{\rm jet} < \mathcal{T}^{\rm cut})$$



- Inclusive 2 loop Beam and soft function calculation available.
- Compute difference to these inclusive (jet-algorithm independent global) Beam and Soft functions.
- Global reference measurement we use coincide with jet-dependent at 1 loop → We only need to consider double real emission amplitudes.
- All IR Divergences disappear in the difference.

$$\begin{aligned}\Delta\mathcal{M}_i^{\rm jet}(\mathcal{T}^{\rm cut}) &= \theta(\Delta R > R)\theta(\mathcal{T}_{B1} < \mathcal{T}^{\rm cut})\theta(\mathcal{T}_{B2} < \mathcal{T}^{\rm cut}) + \theta(\Delta R < R)\theta(\mathcal{T}_B^{\rm jet} < \mathcal{T}^{\rm cut}) \\ &\quad - \theta(\mathcal{T}_{B1} + \mathcal{T}_{B2} < \mathcal{T}^{\rm cut}) \\ &= \theta(\Delta R > R)\Big[\theta(k_1^+ < \mathcal{T}^{\rm cut})\theta(k_2^+ < \mathcal{T}^{\rm cut}) - \theta(k_1^+ + k_2^+ < \mathcal{T}^{\rm cut})\Big]\,.\end{aligned}$$

2-loop Beam Function



J. Gaunt, M.Stahlhofen, F.Tackmann ‘14

$$B_{ij}(t^{\rm cut}, x, \mu, R) = B_{G,ij}(t^{\rm cut}, x, \mu) + \Delta B_{ij}(t^{\rm cut}, x, \mu, R)$$

- Consider double real amplitudes: $\mathcal{A}(k_1, k_2, x) = \mathcal{A}_A(k_1, k_2, x) + \mathcal{A}_B(k_1, k_2, x)$

Obtained by taking soft limit of one of the partons $\mathcal{A}_A = \mathcal{A}_i^{S(1)}\ \mathcal{A}_{ij}^{B(1)}$
“Uncorrelated emission”

“Correlated emission”
$\log(R)$, $\log^2(R)$

Use the additional measurement constraint : $\delta(k_1^- + k_2^- - (1-x)p^-)$

$$k_1^+ = z\mathcal{T}_T\ ,\ k_2^+ = (1-z)\mathcal{T}_T\ ,\ \cos\Delta\phi = \frac{k_1^\perp \cdot k_2^\perp}{|k_1^\perp||k_2^\perp|}\ ,\ y_t = y_1 + y_1\ ,\ \Delta y = y_1 - y_2$$

2-loop Beam Function

Integration of $\mathcal{A}_A$ with $(1-\theta(\Delta R < R))$: Done analytically. Result as divergent as $1/\varepsilon^2$ and R^2/ε.

J. Gaunt, SG, M.Stahlhofen et al '17

Integration of $\mathcal{A}_B$: Expand in small ΔR limit to extract log R terms analytically. Three 1D functions determined numerically by fitting : f(R), g(R) and h(x) in correlated. All # : determined analytically.

Correlated Contribution

$$\Delta B_{ij}(t^{\rm cut}, x, R) = \left(\frac{\alpha_s}{\pi}\right)^2 \left(\frac{\mu^2}{t^{\rm cut}}\right)^\epsilon \Bigg[\delta(1-x)\Big\{\frac{1}{\epsilon}\Big[\#\log R + f(R)\Big] + \Big[\#\log[R]^2 + \#\log R + g(R)\Big]\Big\} + \mathcal{L}_0(1-x)\{\#(x)\log R + h(x) + \#(x)R^2 + \#(x)R^4 + \ldots\} \Big\{\frac{1}{\epsilon^2}\#(x) + \frac{1}{\epsilon}(\#(x) + \#(x)R^2) + \#(x)R^2 + \#(x)R^2\log R + \ldots\Big\}\Bigg]$$

Expansion of $(1-x)^{-1-2\varepsilon}$

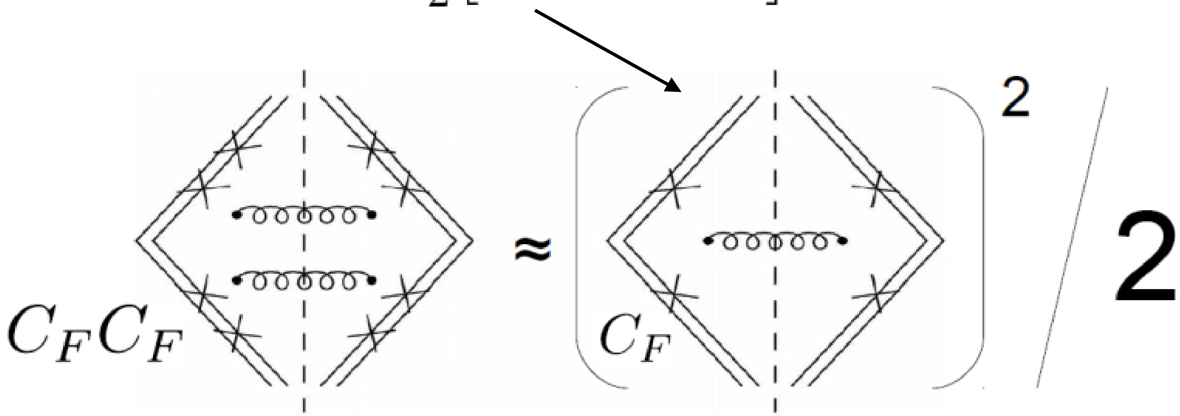
Uncorrelated Contribution

$$\mathcal{I}^{(2)}_{gj}(t^{\rm cut}, x, \mu, R) = \mathcal{I}^{(2)}_{G,gj}(t^{\rm cut}, x, \mu) + \Delta\mathcal{I}^{(2)}_{gj}(t^{\rm cut}, x, \mu, R) + \Delta\mathbb{I}^{(2)}_{gj}(t^{\rm cut}, x, \mu, R)$$

2-loop Soft Function

Treat Abelian ($C_F C_F$) uncorrelated piece in different way to Non- Abelian ($C_F C_A$, $C_F T_F$) .

$$S_f^{\mathrm{bare}(2,C_F^2)}(\mathcal{T}^{\mathrm{cut}},R) = \frac{1}{2}\left[S^{\mathrm{bare}(1)}(\mathcal{T}^{\mathrm{cut}})\right]^2 + \Delta S_{f,\mathrm{indep}}^{\mathrm{bare}(2)}(\mathcal{T}^{\mathrm{cut}},R)$$



SG, Gaunt, Stahlhofen, Tackmann '17

$$\mathcal{M}_i^{\mathrm{jet}}(\mathcal{T}^{\mathrm{cut}},R) = \theta(\Delta R > R)\theta(\mathcal{T}_{B1} < \mathcal{T}^{\mathrm{cut}})\theta(\mathcal{T}_{B2} < \mathcal{T}^{\mathrm{cut}}) + \theta(\Delta R < R)\theta(\mathcal{T}_B^{\mathrm{jet}} < \mathcal{T}^{\mathrm{cut}})$$

$$\begin{aligned}\Delta\mathcal{M}_f^{\mathrm{indep}}(\mathcal{T}^{\mathrm{cut}},R) &= \mathcal{M}_i^{\mathrm{jet}}(\mathcal{T}^{\mathrm{cut}},R) - \theta(\mathcal{T}_{f1} < \mathcal{T}^{\mathrm{cut}})\theta(\mathcal{T}_{f2} < \mathcal{T}^{\mathrm{cut}}) \\ &= \theta(\Delta R < R)\left[\theta(\mathcal{T}_{fj} < \mathcal{T}^{\mathrm{cut}}) - \theta(\mathcal{T}_{f1} < \mathcal{T}^{\mathrm{cut}})\theta(\mathcal{T}_{f2} < \mathcal{T}^{\mathrm{cut}})\right]\end{aligned}$$

Results proportional to R^2/ε and O(R^4).

2-loop Soft Function

$C_F C_A$, $C_f T_f n_f$ channel: Correction computed via difference from inclusive soft.

$$\Delta\mathcal{M}_f = \theta(\Delta R > R)\theta(\mathcal{T}_{f1} < \mathcal{T}^{\rm cut})\theta(\mathcal{T}_{f2} < \mathcal{T}^{\rm cut}) + \theta(\Delta R < R)\theta(\mathcal{T}_f^{\rm jet} < \mathcal{T}^{\rm cut}) - \theta(\mathcal{T}_{f1} + \mathcal{T}_{f2} < \mathcal{T}^{\rm cut})$$

$$\Delta S^{(2)}_{B/C}(\mathcal{T}^{\rm cut}, R) = \Delta S^{(2)}_{\rm base}(\mathcal{T}^{\rm cut}, R) + \Delta S^{(2)}_{\rm rest}(\mathcal{T}^{\rm cut}, R)$$

$\Delta S^{(2)}_{\rm base}$: Captures remaining $1/\varepsilon$ divergence.

$\Delta S^{(2)}_{\rm rest}$: Finite, numerically integrate.

$\Delta S_{\rm base}$: $\log R$, $\log^2 R$ terms analytically

$\Delta S_{\rm rest} = \Delta S_f - \Delta S_{\rm base}$: Computed by integrating numerically

$$S_f^{(2)}(\mathcal{T}^{\rm cut}, R, \mu) = S_{G,f}(\mathcal{T}^{\rm cut}, \mu) + \frac{1}{2}[S_f^{(1)}(\mathcal{T}^{\rm cut}, \mu)]^2 + \Delta S_f^{(2)}(\mathcal{T}^{\rm cut}, R, \mu) + \Delta \mathbb{S}_f^{(2)}(\mathcal{T}^{\rm cut}, R, \mu)$$

Anom. Dimension: $\gamma_{(S,B)}(\mathcal{T}^{\rm cut}, \mu, R) = \gamma_{G,(S,B)}(\mathcal{T}^{\rm cut}, \mu) + \Delta\gamma_{(S,B)}(\mathcal{T}^{\rm cut}, \mu, R)$

J. Gaunt, SG, M.Stahlhofen, F.Tackmann '17

Non Singular at NNLO

$$\sigma_0^{\rm nons,NNLO}(\mathcal{T}_{fj} < \mathcal{T}^{\rm cut}, \mu_{\rm FO}) = \sigma_0^{\rm FO,NNLO}(\mathcal{T}_{fj} < \mathcal{T}^{\rm cut}) - \sigma_0^{\rm resum,NNLL'}(\mathcal{T}_{fj} < \mathcal{T}^{\rm cut}, \mu_B = \mu_S = \mu_H = \mu_{\rm FO})$$

$$\sigma_0^{\rm FO,NNLO}(\mathcal{T}_{fj} < \mathcal{T}^{\rm cut}) = \sigma_{\geq 0}^{\rm FO,NNLO} - \sigma_{\geq 1}^{\rm FO,NLO}(\mathcal{T}_{fj} > \mathcal{T}^{\rm cut})$$

Full NNLO inclusive
Catani, Grazzini: HNNLO

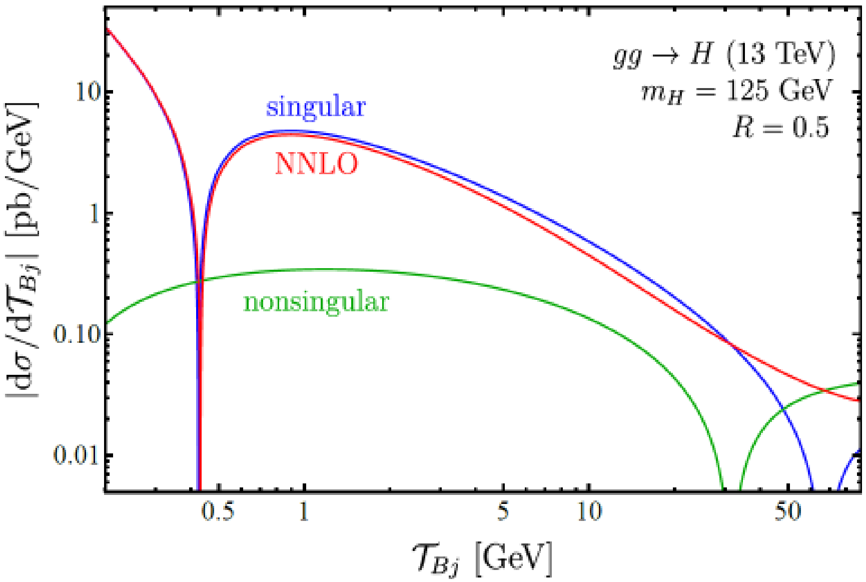
NLO H + 1 jet

Resummation region: Logs are large and resummed:

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

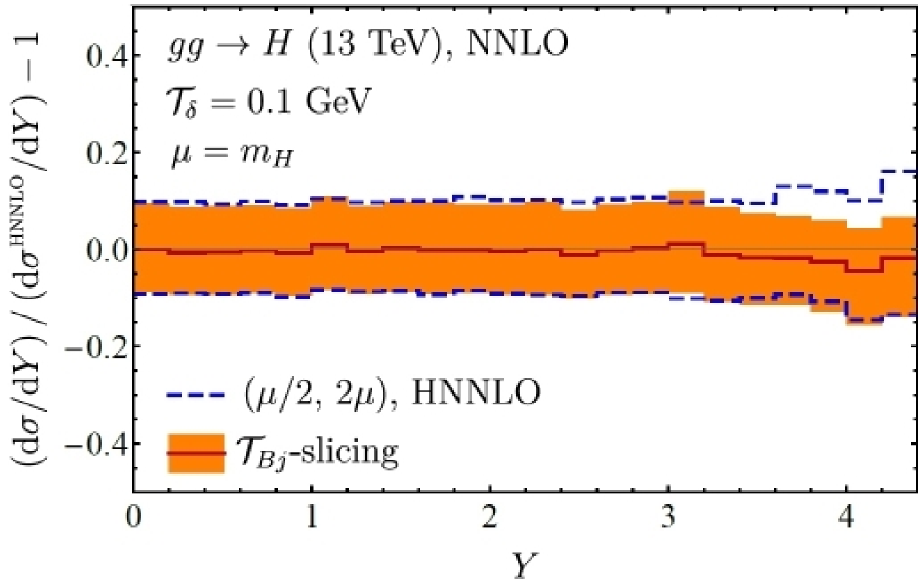
Fixed Order region: Resummation is turned off:

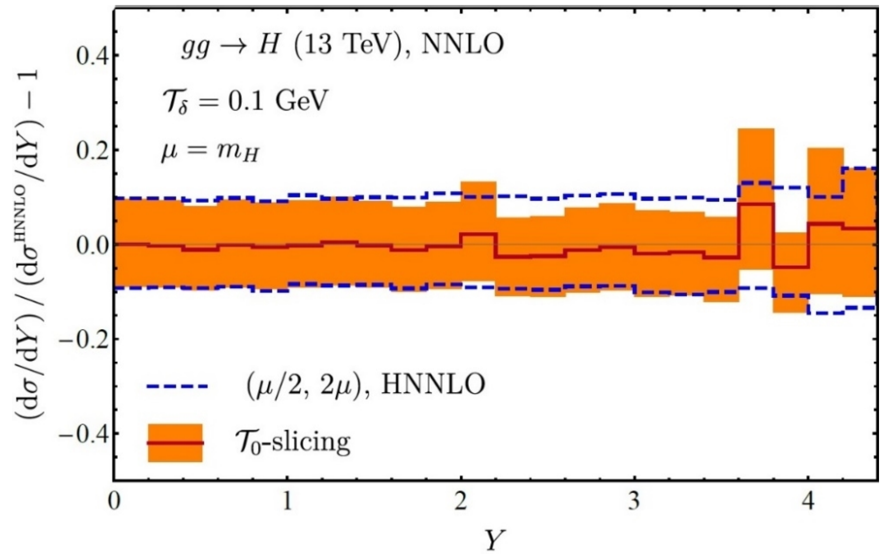
$$\mu_B, \mu_S \to \mu_{\rm FO} \sim m_H$$



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

NNLO Slicing Cross-check





$$(\mathrm{FO,\ NNLO}) = \mathrm{NNLL}'(\mathcal{T} < \mathcal{T}^{\mathrm{cut}}) + \mathrm{nonsing}(\mathcal{T} < \mathcal{T}^{\mathrm{cut}}) + \mathrm{NLO\ 1\text{-}jet}(\mathcal{T} > \mathcal{T}^{\mathrm{cut}})$$

SCET Resummed results

~0 for cut = 0.1 GeV

Madgraph H+1-jet

- Reproduce right FO HNNLO cross section for both B and C observables.
- Good cross check for 2-loop B and S including constant terms in the resumed prediction.

J. Gaunt, M. Stahlhofen, F. Tackmann et al ‘15

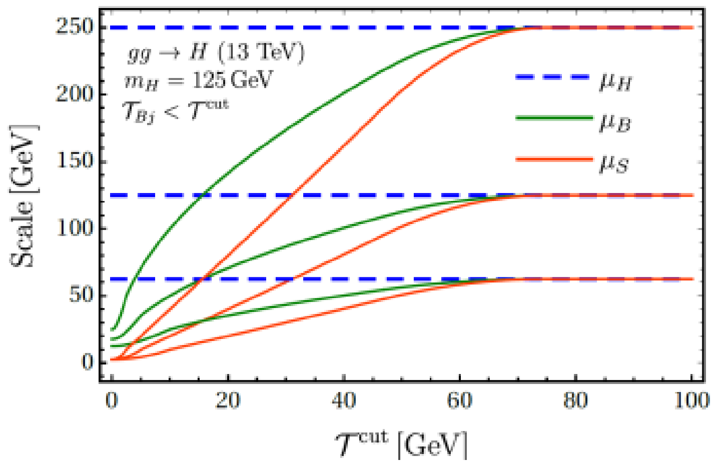
Uncertainties using Profile Scale Variations

Central Profile Scales: $\mu_H = -i\mu_{FO}\,,\quad \mu_S(\mathcal{T}^{\rm cut}) = \mu_{FO} f_{\rm run}(\mathcal{T}^{\rm cut}/m_H)\,,$

$$\mu_B(\mathcal{T}^{\rm cut}) = \mu_{FO}\sqrt{f_{\rm run}(\mathcal{T}^{\rm cut}/m_H)}$$

Stewart, Tackmann, Walsh et al '13

Resummation Region: $f_{\rm run}(x) = r_s x$

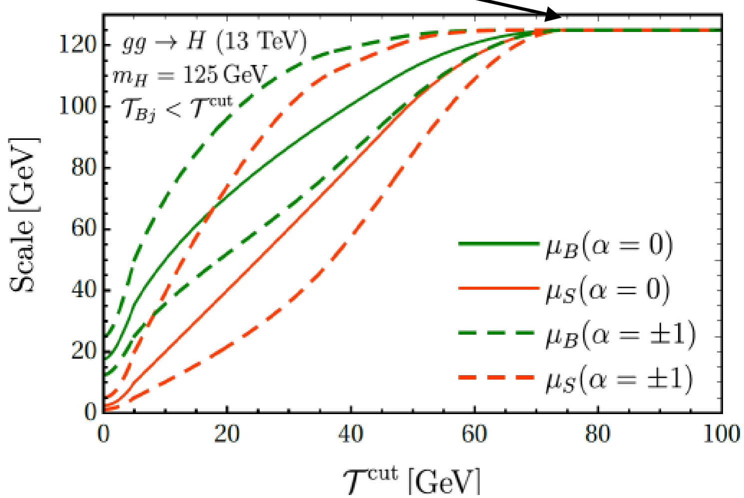


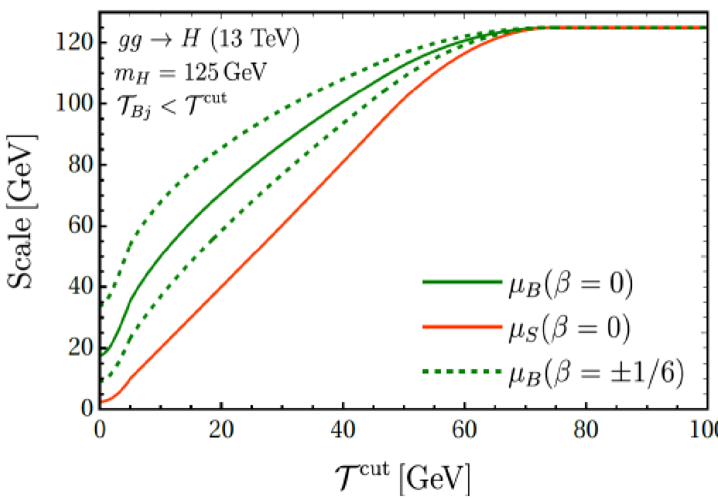
Total Uncertainty :

$$\Delta_0^2 = [\Delta^{\rm FO}(\mathcal{T}^{\rm cut})]^2 + [\Delta^{\rm resum}(\mathcal{T}^{\rm cut})]^2.$$

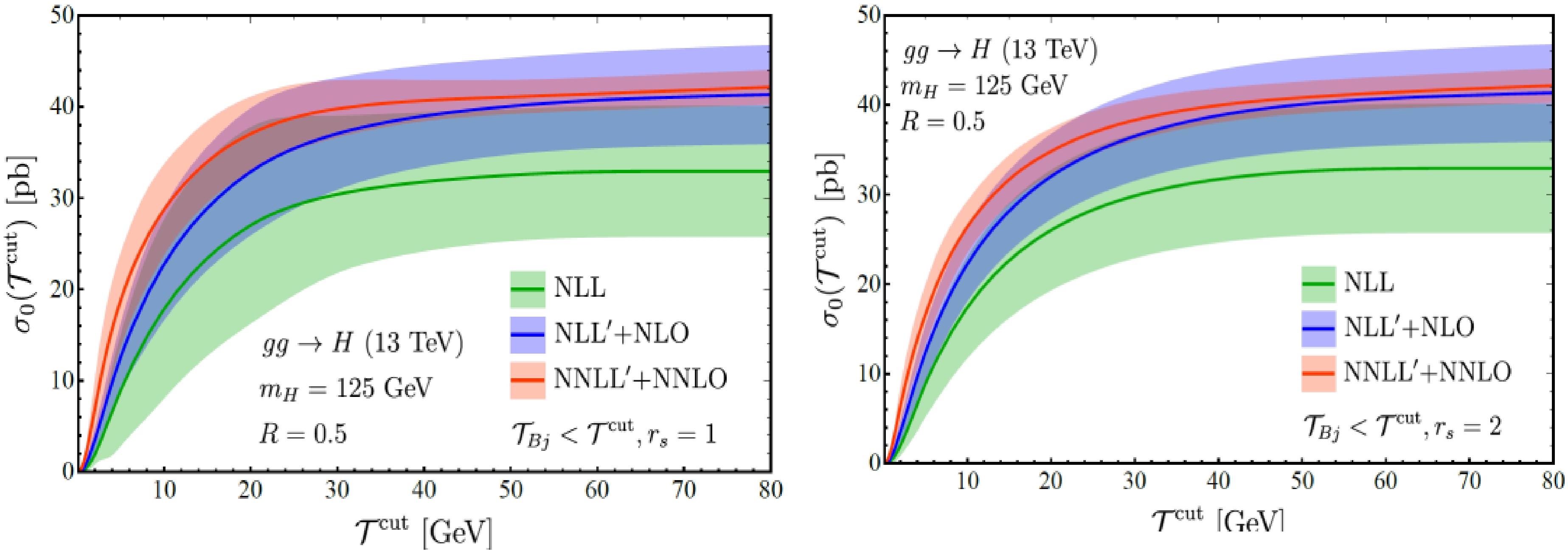
Fixed Order: $(\mathcal{T}^{\rm cut} \sim Q)$: $\Delta_0^y = \Delta^{\rm FO}$

Resummation : $(\mathcal{T}^{\rm cut} \ll Q)$: $\Delta^{\rm cut} = \Delta^{\rm resum}$



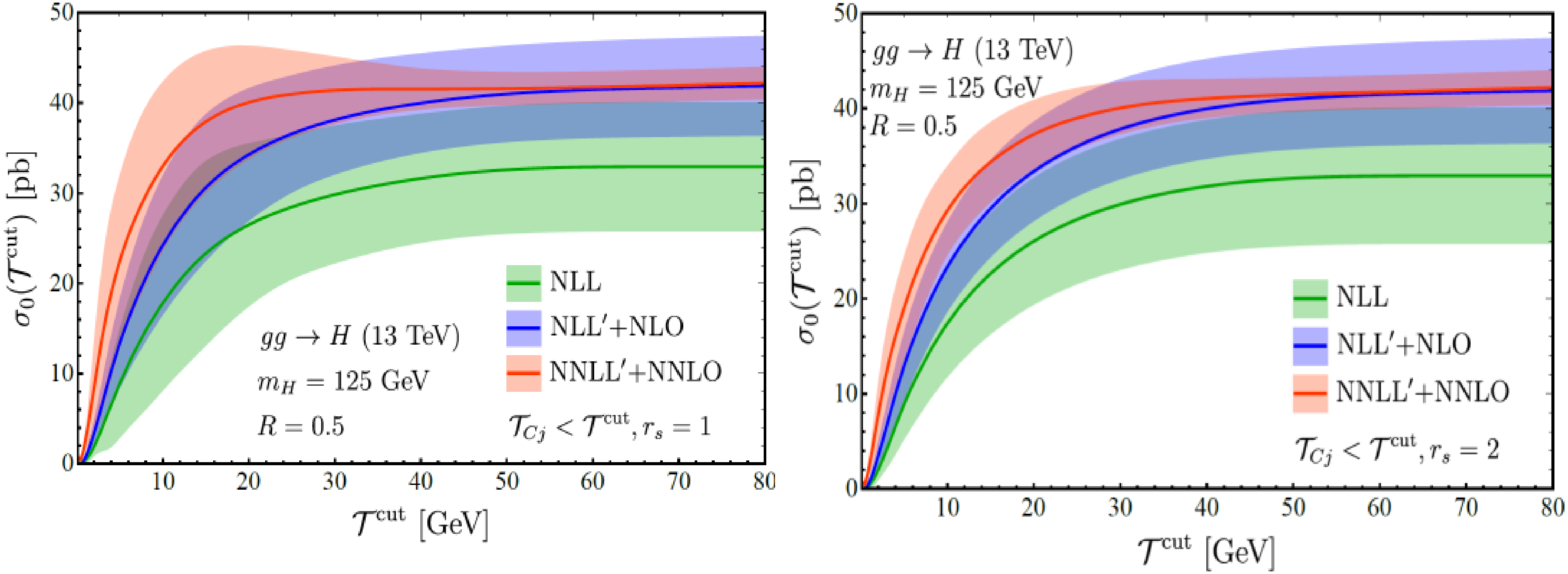


H+0-jet cross section at NNLL′ + NNLO



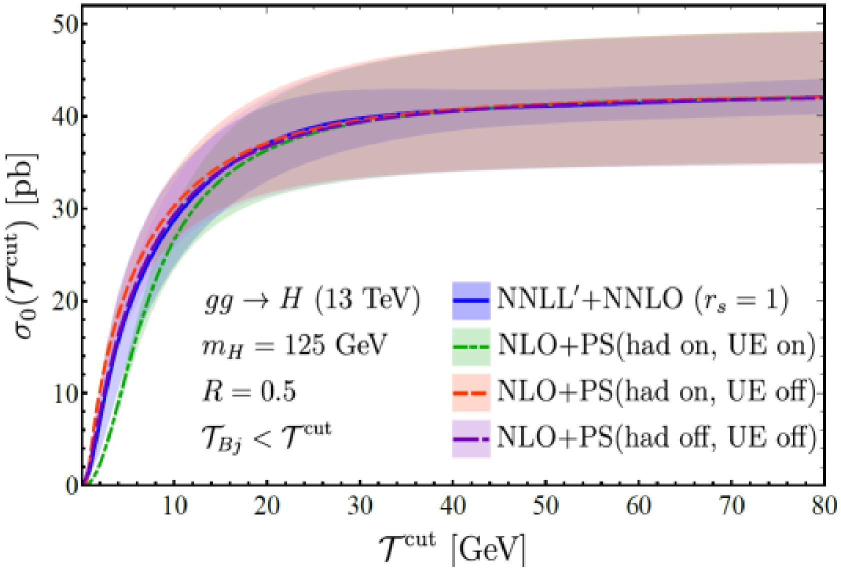
	$\sigma_0(\mathcal{T}^{\rm cut})$[pb] ($r_s = 1$)	$\sigma_0(\mathcal{T}^{\rm cut})$[pb] ($r_s = 2$)
NLL′+NLO		
$\mathcal{T}_{Bj} < \mathcal{T}^{\rm cut} = 20$ GeV	$32.88 \pm 6.95\,(21.2\%)$	$32.02 \pm 4.75\,(14.8\%)$
$\mathcal{T}_{Bj} < \mathcal{T}^{\rm cut} = 30$ GeV	$37.05 \pm 6.12\,(16.5\%)$	$36.50 \pm 4.96\,(13.6\%)$
NNLL′+NNLO		
$\mathcal{T}_{Bj} < \mathcal{T}^{\rm cut} = 20$ GeV	$37.03 \pm 4.06\,(10.9\%)$	$34.81 \pm 2.57\,(7.39\%)$
$\mathcal{T}_{Bj} < \mathcal{T}^{\rm cut} = 30$ GeV	$39.77 \pm 3.11\,(7.82\%)$	$38.30 \pm 2.23(5.82\%)$

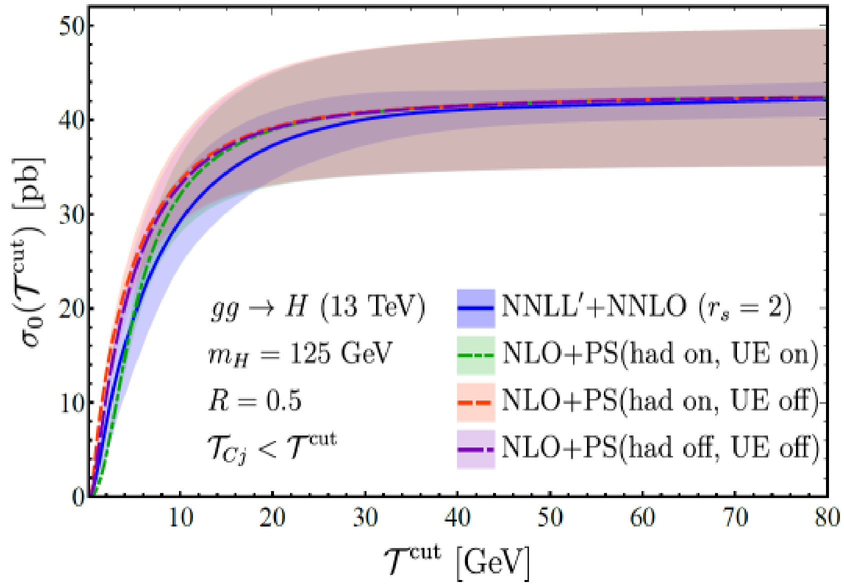
H+0-jet cross section at NNLL′ + NNLO

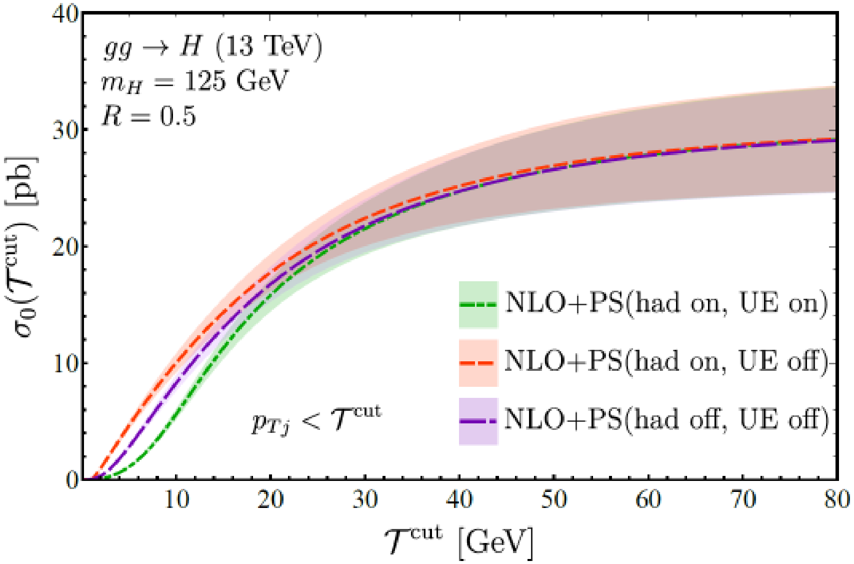


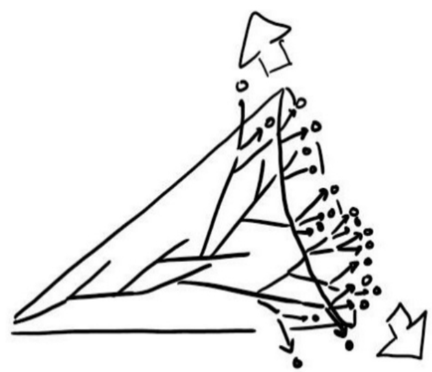
NLL′+NLO		
$\mathcal{T}_{Cj} < \mathcal{T}^{\rm cut} = 20\,\text{GeV}$	$34.28 \pm 7.37\,(21.5\%)$	$33.40 \pm 5.24\,(15.7\%)$
$\mathcal{T}_{Cj} < \mathcal{T}^{\rm cut} = 30\,\text{GeV}$	$38.10 \pm 6.05\,(15.8\%)$	$37.82 \pm 5.27\,(13.9\%)$
NNLL′+NNLO		
$\mathcal{T}_{Cj} < \mathcal{T}^{\rm cut} = 20\,\text{GeV}$	$40.05 \pm 6.28\,(15.69\%)$	$37.27 \pm 3.64\,(9.77\%)$
$\mathcal{T}_{Cj} < \mathcal{T}^{\rm cut} = 30\,\text{GeV}$	$41.39 \pm 3.75\,(9.07\%)$	$40.05 \pm 2.75\,(6.88\%)$

Effects of Underlying Event and Hadronisation

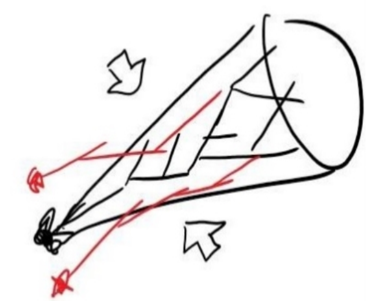






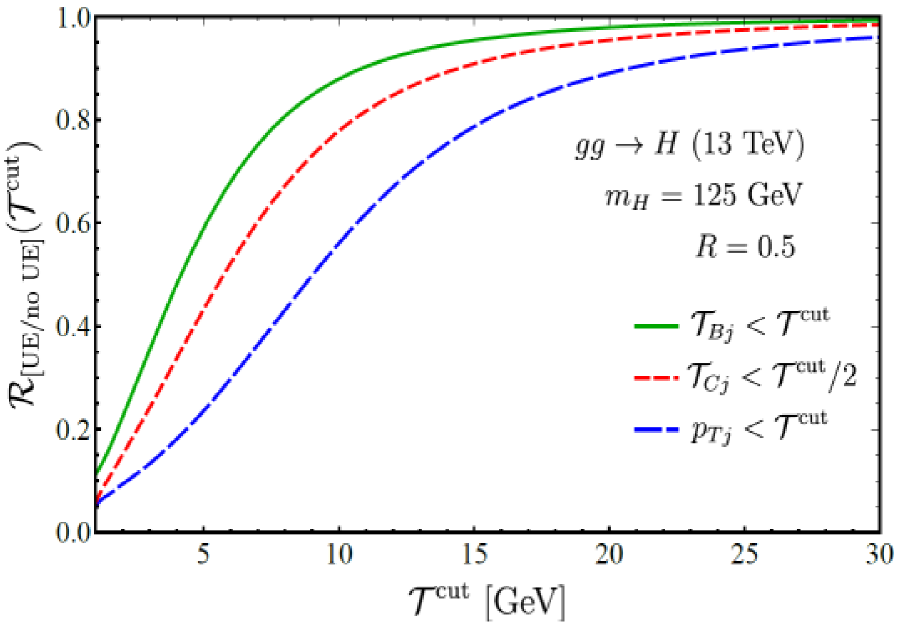


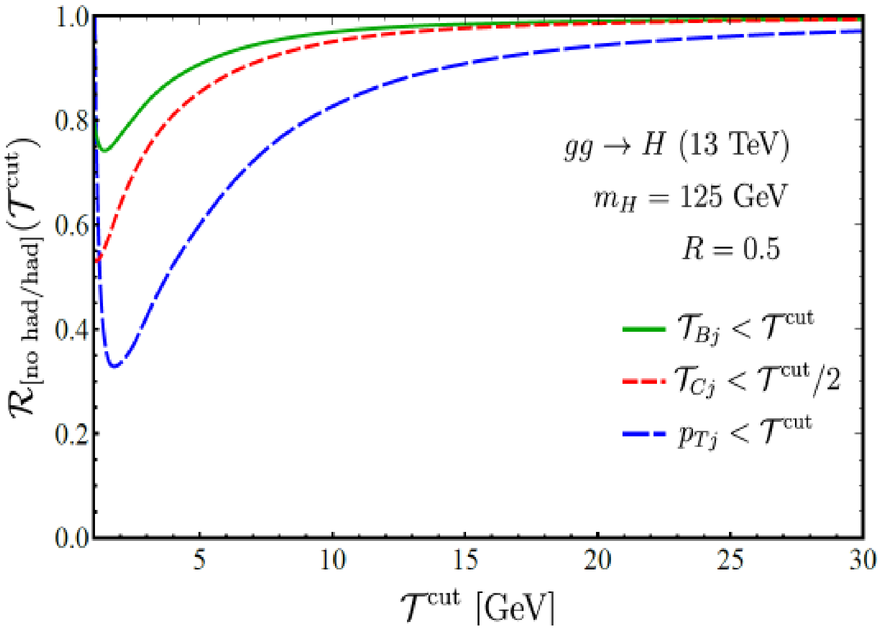
Hadronisation



Underlying Event

Effects of Underlying Event and Hadronisation





$$\mathcal{R}_{(\text{UE/no UE})}(\mathcal{T}^{\text{cut}}) = \frac{\sigma_0\left(\mathcal{T}^{\text{cut}}\right)\big|_{\text{had on, UE on}}}{\sigma_0\left(\mathcal{T}^{\text{cut}}\right)\big|_{\text{had on, UE off}}}$$

$$\mathcal{R}_{(\text{no had/had})}(\mathcal{T}^{\text{cut}}) = \frac{\sigma_0\left(\mathcal{T}^{\text{cut}}\right)\big|_{\text{had off, UE off}}}{\sigma_0\left(\mathcal{T}^{\text{cut}}\right)\big|_{\text{had on, UE off}}}$$

Summary.

- Rapidity-dependent Jet vetoes : Efficient to veto central jets.
  Can avoid experimental and theoretical limitations p_{Tj} veto.
  Can provide complementary ways to perform jet binning.

- Computed 2-loop beam and soft functions for the rapidity-dependent jet vetoes, including all parton and color channels.

- Computed H+ 0-jet cross section at NNLL’ + NNLO for Rapidity - dependent jet vetoes. Precision of resummation to same level as p_{Tj} .

- The cross sections with Rapidity dependent jet vetoes have a reduced sensitivity to underlying event and hadronisation effects compared to that with a p_{Tj} veto .

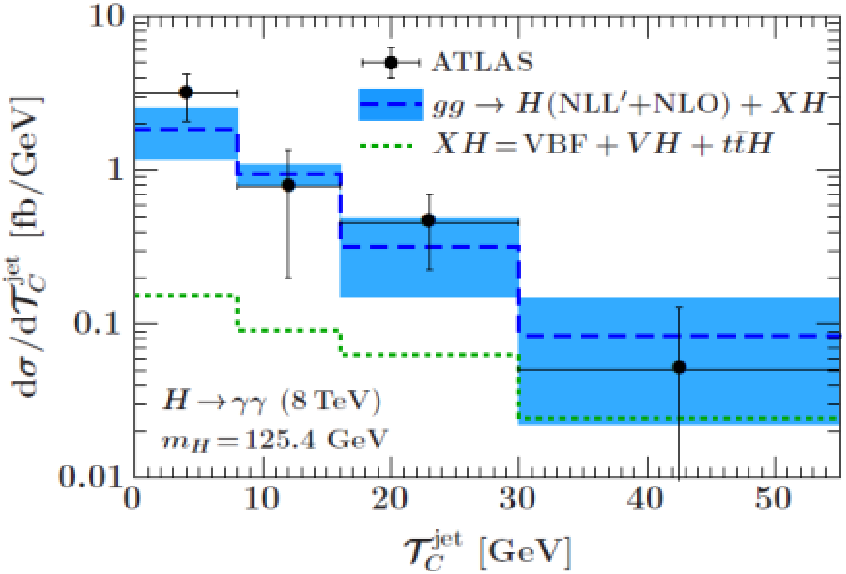
- Future Directions: Drell Yan cross section at NNLL’ + NNLO.

H+0-jet at NLL' + NLO

Comparison of our NLL'+ NLO predictions in bins of $\mathcal{T}_C^{\rm jet}$

with the ATLAS measurements in the $H \to \gamma\gamma$ analysis.

SG, Tackmann, Stahlhofen '14



Ingredients at NNLL':

$$H_{gg} = |C^{(0)}_{ggH}|^2 + \alpha_s \mathrm{Re}\left[C^{(1)}_{ggH} C^{(0)*}_{ggH}\right] + \alpha_s^2 \left(2\mathrm{Re}\left[C^{(2)}_{ggH} C^{(0)*}_{ggH}\right] + |C^{(1)}_{ggH}|^2\right)$$

Harlander, Kant, '05
Berger, Marcantonini, Stewart et al '11

$$\sigma_0^{\rm Rsub} = \frac{\alpha_s^2(\mu_{\rm avg})}{(4\pi)^2} H^{(0)}_{gg}\, U_{\rm total}(\mathcal{T}^{\rm cut}, \mu_H, \mu_B, \mu_S, \mu_{\rm FO}) \times \Big[\Big\{ f_g\,(x_a, \mu_B)\, f_j\,(x_b, \mu_B)$$
$$\otimes \Big(\Delta\mathbb{I}^{(2)}_{gj}(x_b, \mu_{\rm avg}, R) + SC^{(2)}_{gj}(x_b, \mu_{\rm avg}, R)\Big) + (x_a \leftrightarrow x_b)\Big\}$$
$$+ f_g\,(x_a, \mu_B)\, f_g\,(x_b, \mu_B)\, \Delta\mathbb{S}^{(2)}_f\,(\mathcal{T}^{\rm cut}, \mu_{\rm avg}, R)\Big]$$

Stewart, Tackmann, et al '13
Banfi, Monni, Salam et al '12

$$f_{\rm run}(x) = \begin{cases} x_0\big[1+(2r_s-1)(x/x_0)^2/4\big] & x \le 2x_0\,, \\ r_s x & 2x_0 \le x \le x_1\,, \\ r_s x + \frac{(2-r_s x_2 - r_s x_3)(x-x_1)^2}{2(x_2-x_1)(x_3-x_1)} & x_1 \le x \le x_2\,, \\ 1 - \frac{(2-r_s x_1 - r_s x_2)(x-x_3)^2}{2(x_3-x_1)(x_3-x_2)} & x_2 \le x \le x_3\,, \\ 1 & x_3 \le x\,. \end{cases}$$

$$\mu_S^{\rm vary}(x,\alpha) = \mu_{FO}\, f_{\rm vary}^{\alpha}(x)\, f_{\rm run}(x)\,,$$

$$\mu_B^{\rm vary}(x,\alpha,\beta) = \mu_S^{vary}(x,\alpha)^{1/2-\beta}\mu_{FO}^{1/2+\beta} = \mu_{FO}\big[f_{\rm vary}^{\alpha}(x)\, f_{\rm run}(x)\big]^{1/2-\beta}$$

$$C = \frac{3}{2}\frac{1}{(\sum_i \vec{p_i})^2}\sum_{ij}[\vec{p_i}\vec{p_j}]\sin^2\theta_{ij} \qquad\qquad C = \frac{3}{Q}\sum_{j\in c,s}\frac{p_j^{\perp}}{\cosh\eta_j}$$

$$\Delta\mathcal{M}_{\rm base} = 2\theta(y_t>0)\theta(\Delta R > R)[\theta(k_1^+ < \mathcal{T}^{\rm cut})\theta(k_2^+ < \mathcal{T}^{\rm cut}) - \theta(k_1^+ + k_2^+ < \mathcal{T}^{\rm cut})$$

$$\Delta S_f(\mathcal{T}^{\rm cut}, R, \mu) = \Delta\gamma_{S1}^i(R)\log\frac{\mu}{\mathcal{T}^{\rm cut}} + \Delta s_{2f}^i(R)$$

$$\Delta\mathcal{I}_{ij}(t^{\rm cut}, x, R, \mu) = \delta_{ij}\frac{\Delta\gamma_{S1}^i(R)}{4}\Big[\delta(1-x)\log\frac{\mathcal{T}^{\rm cut}}{\mu^2} + \mathcal{L}_0(1-x)\Big] + \Delta\mathcal{I}_{ij,run}(t^{\rm cut}, x, \mu)$$
$$+\,\Delta I_{ij}(x,R)$$

Uncorrelated and Soft-Collinear Mixing

$$A_{A,ij} = \frac{1}{2} A_{ij}^{B(1)}(k_2, x) A_i^{S(1)}(k_1)$$

$$A_{ij}^{B(1)}(k_2, x) = \frac{2g^2 P_{ij}^{(0)}(1-x)p^-}{k_2^+ k_2^-} \; , \quad A_i^{S(1)}(k_1) = \frac{4g^2 C_i}{k_1^+ k_1^-}$$

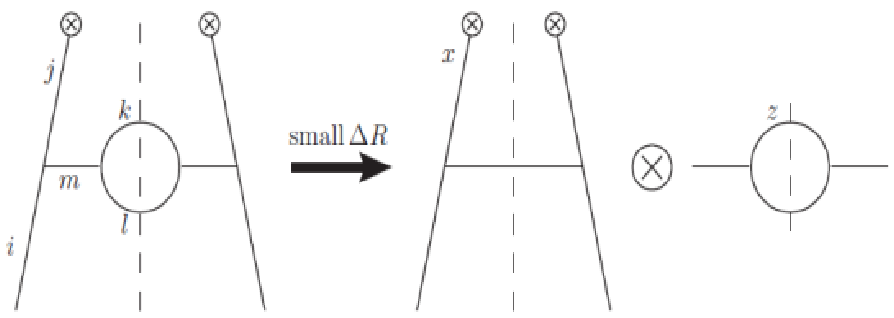
$$\Delta\sigma_{CC} \sim \int d\Delta y \, d\Delta\phi \, dz \, \theta(\Delta R < R)\theta\Big[\mathcal{T}^{cut} < \mathcal{T}_T < \frac{\mathcal{T}^{cut}}{max[z,(1-z)]}\Big]\delta(k_1^- + k_2^- = (1-x)p^-)P_{ij}^{(0)}(1-x)p^-$$

$$\Delta\sigma_{CC}^{indep} = -\sigma_0 \frac{1}{\epsilon}\Big(\frac{\alpha_s C_A}{\pi}\Big)^2 \Big(\frac{\mu^2}{m_H \mathcal{T}^{cut}}\Big)^{2\epsilon} \frac{\pi^2}{12} R^2 \longrightarrow$$ Uncorrelated CC - Zero bin

$$\Delta M_{as} = \theta(\Delta R < R)[\theta(\mathcal{T}_c + \mathcal{T}_s < \mathcal{T}^{cut}) - \theta(\mathcal{T}_c < \mathcal{T}^{cut})\theta(\mathcal{T}_s < \mathcal{T}^{cut})]$$

$$\Delta\sigma_{SC} = \sigma_0 \frac{1}{\epsilon}\Big(\frac{\alpha_s C_A}{\pi}\Big)^2 \Big(\frac{\mu^2}{m_H \mathcal{T}^{cut}}\Big)^{2\epsilon} \frac{\pi^2}{6} R^2$$

Log(R) Terms: Only Bubble Insertion Graphs



$$A_R = \hat{P}_{ij\to q}(x,\epsilon)\hat{P}_{q\to kl}(z,\epsilon)\frac{2g^4}{\Delta R^2 (p^- \mathcal{T}_T)^2 (1-x)(z(1-z)}$$