SCET 2026

UNIVERSITÄT BERN

Resumming transverse observables for NNLO+PS matching in GENEVA

Alessandro Gavardi, **Rebecca von Kuk,** Matthew Lim, 2505.14773

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Resumming transverse observables for NNLO+PS matching in GENEVA for the $b\bar{b}H$ channel

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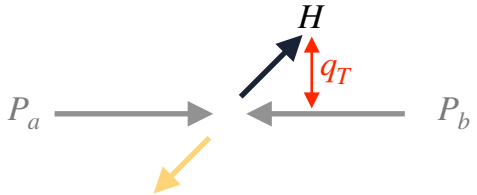
Outline



1. **Motivation**
2. **Resolution variables q_T and $\mathcal{T}_1^{p_T}$**
3. **Resummation of relevant observables**
   - q_T resummation in SCET
   - Resummation of generalized one-jettiness $\mathcal{T}_1^{p_T}$
4. **Results for $b\bar{b}H$**
5. **Outlook and Summary**

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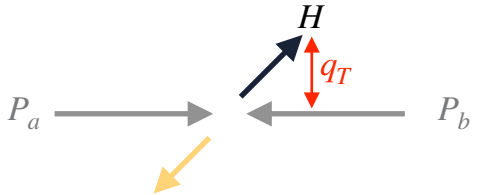
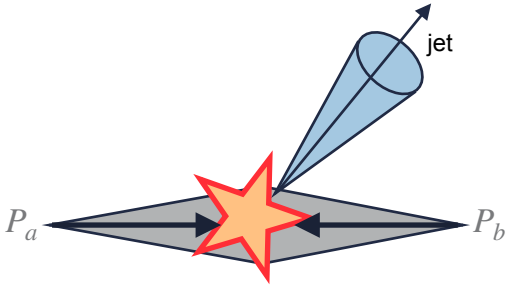




$\mathcal{T}_1 \sim 0$

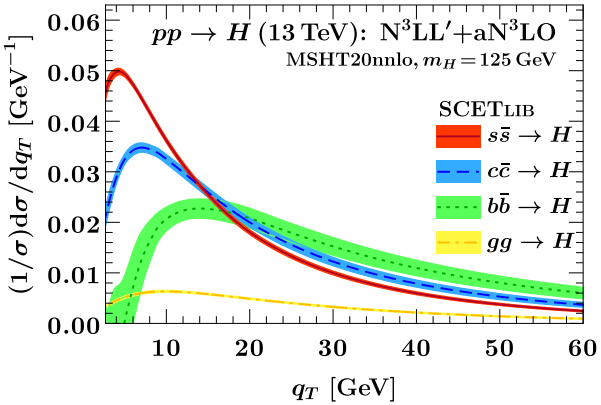
Introduction

Motivation

- LHC precision demands theoretical tools at highest accuracy
- Event generators provide important bridge between theory and experiment
  - Simulate process from hard interaction to final states that can be detected at colliders
- State-of-art for predictions matched to parton showers: NNLO+PS
  - **GENEVA** [Alioli et al., ’13, ’15]
  - MiNNLO$_{\text{PS}}$ [Monni, Nason, Re, Wiesemann, Zanderighi, ’20]
- Study different choices for jet resolution variables

Quark initiated Higgs production

- Higgs q_T spectrum allows to access Yukawa coupling from Higgs production
- Allows initial state discrimination [Ebert et al. '16, Bishara et al. '16]
  - q_T spectra of ggH and qqH have different shapes
- High precision prediction available [Cal, RvK, Lim, Tackmann '23]
- NNLO+PS prediction in MiNNLO$_{\text{PS}}$
  [Biello, Sankar, Wiesemann, Zanderighi '24]
- **Now:** implementation in GENEVA with transverse observables



Resolution variables

Calculations beyond leading order

- IR divergences cancel between matrix elements with different numbers of final states

$$\sigma^{\mathrm{NLO}} = \int \mathrm{d}\Phi_N [B_N(\Phi_N) + V_N(\Phi_N)] + \int \mathrm{d}\Phi_{N+1} [B_{N+1}(\Phi_{N+1})]$$

$$\frac{A}{\epsilon^2} + \frac{B}{\epsilon} + C \qquad -\frac{A}{\epsilon^2} - \frac{B}{\epsilon} + D$$

- MC: cancellation achieved numerically by defining appropriate subtraction terms
- In GENEVA: convert IR-divergent final state with $N+1$ partons into IR-finite final state with N partons

Resolution variables

- Resolution variables r: divide phase space into bins: $r < r^{\text{cut}}$
  - Examples: N-jettiness ($\mathcal{T}_N$) [Stewart, Tackmann, Waalewijn '10], q_T, …
  - Need to be resummed to high orders
- Predictions for exclusive observables depend on choice of resolution variable
  - Compare prediction with different resolution variables to gauge uncertainties
- Higher-accuracy parton showers are becoming available [Dasgupta, Dreyer, Hamilton, Monni, Salam, Sodes '20, Herren, Höche, Krauss, Reichelt, Schoenherr '23, van Beekveld et al. '24, Höche, Krauss, Reichelt '24]
  - Explore novel variable choices that preserve shower accuracy

Resolution variables

Original resolution variables in GENEVA:

$\mathcal{T}_0$ and $\mathcal{T}_1$

- Simple factorization structure

  \+ Facilitates resummation

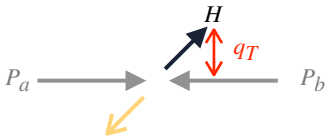
- Usually uses invariant mass-like measure

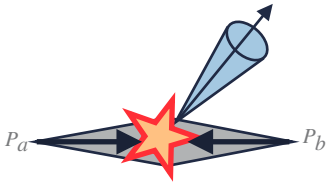
  − complicates matching to PS

Here: transverse observables to separate bins

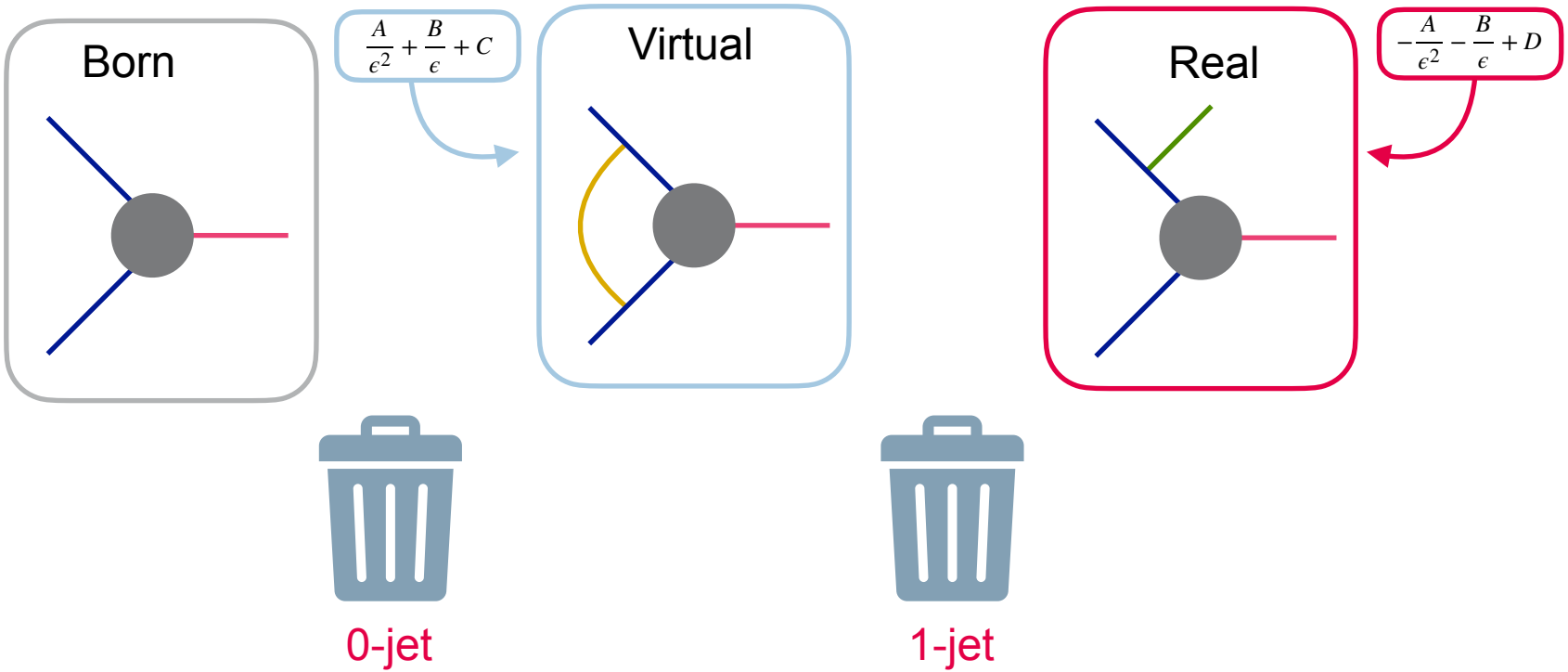
- Transverse momentum q_T to separate 0/1-jet bin
- $\mathcal{T}_1$ with transverse momentum-like measure

  \+ Facilitates matching to PS which tend to be ordered in transverse momentum





Defining IR safe events



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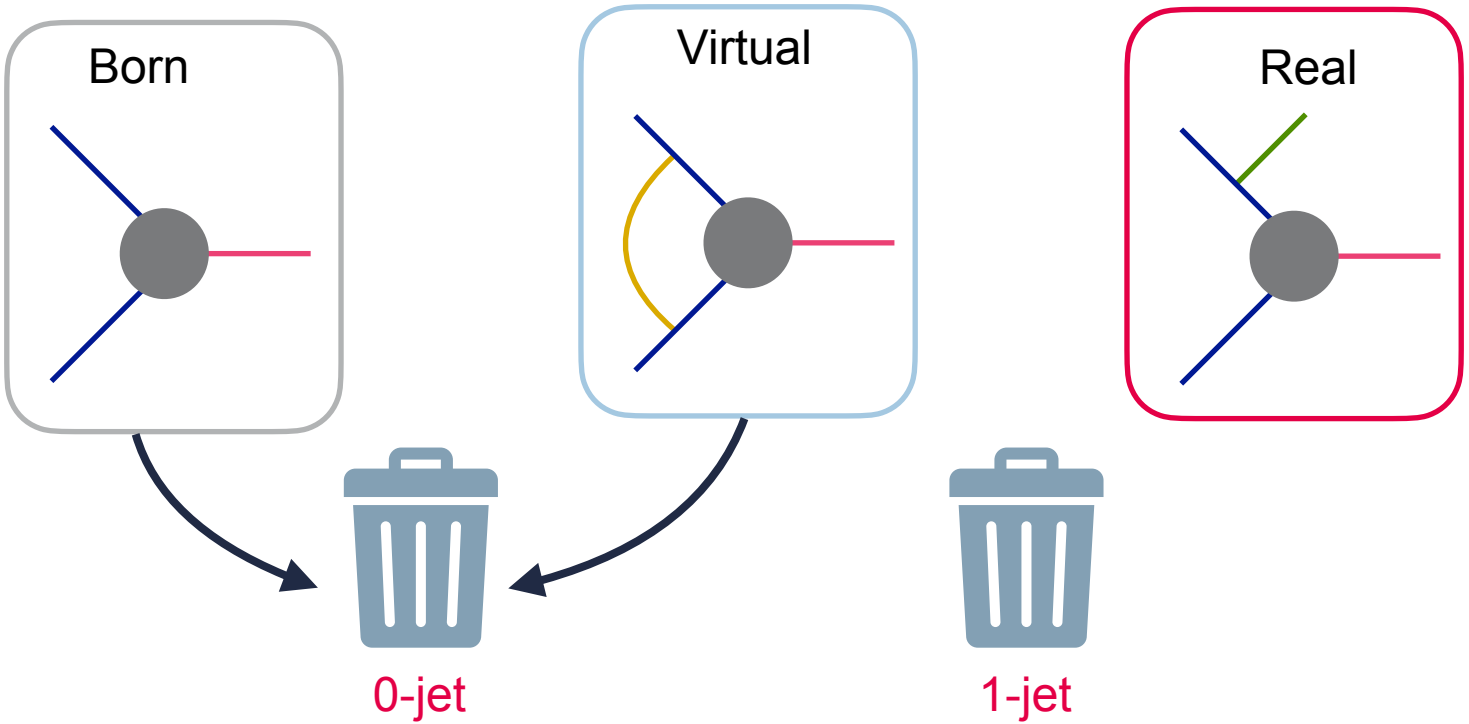

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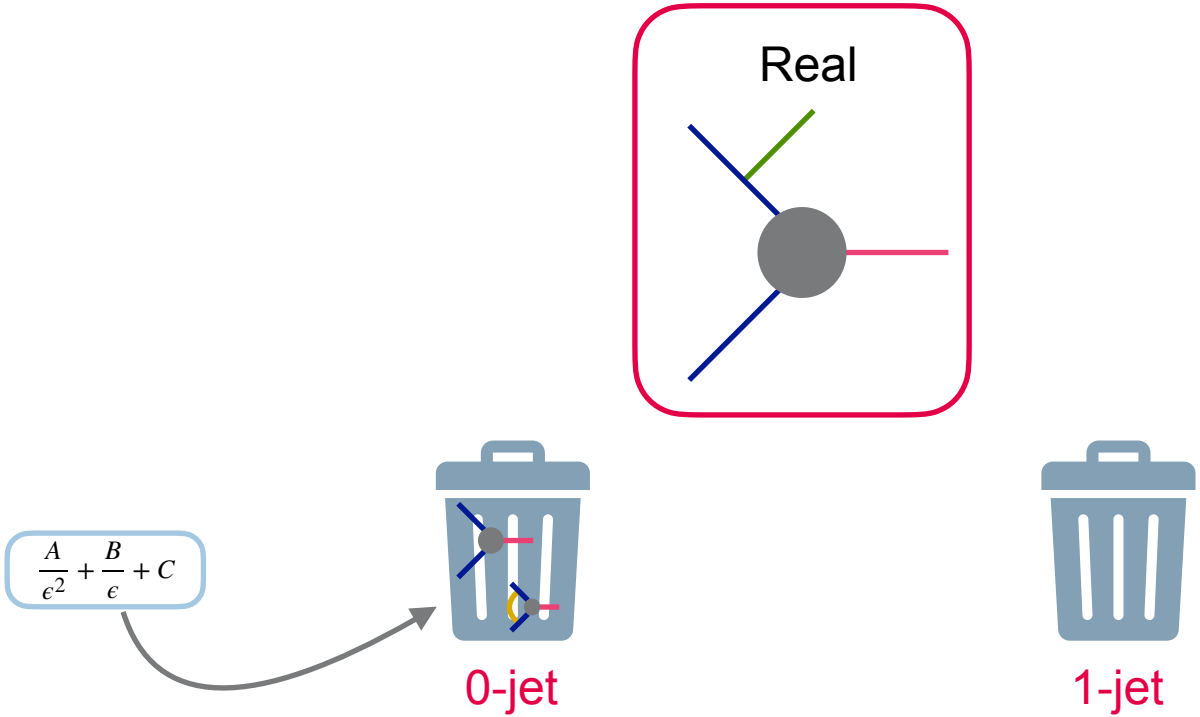

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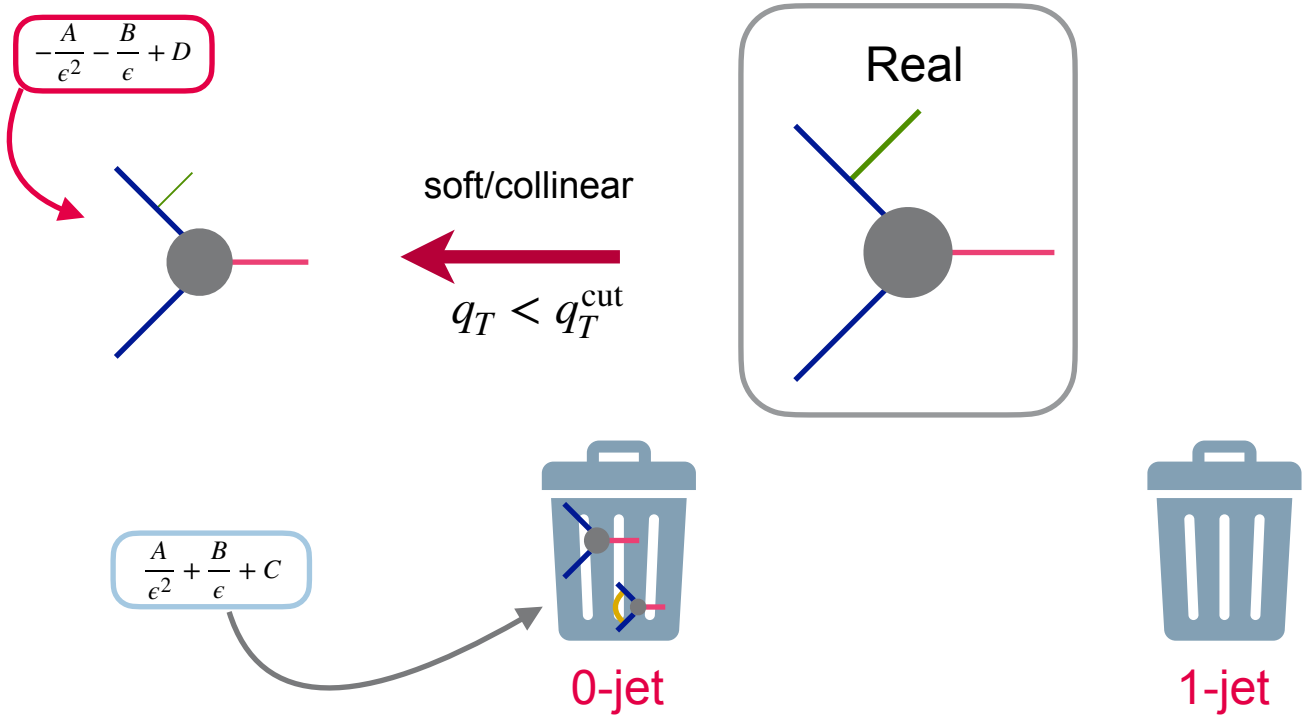

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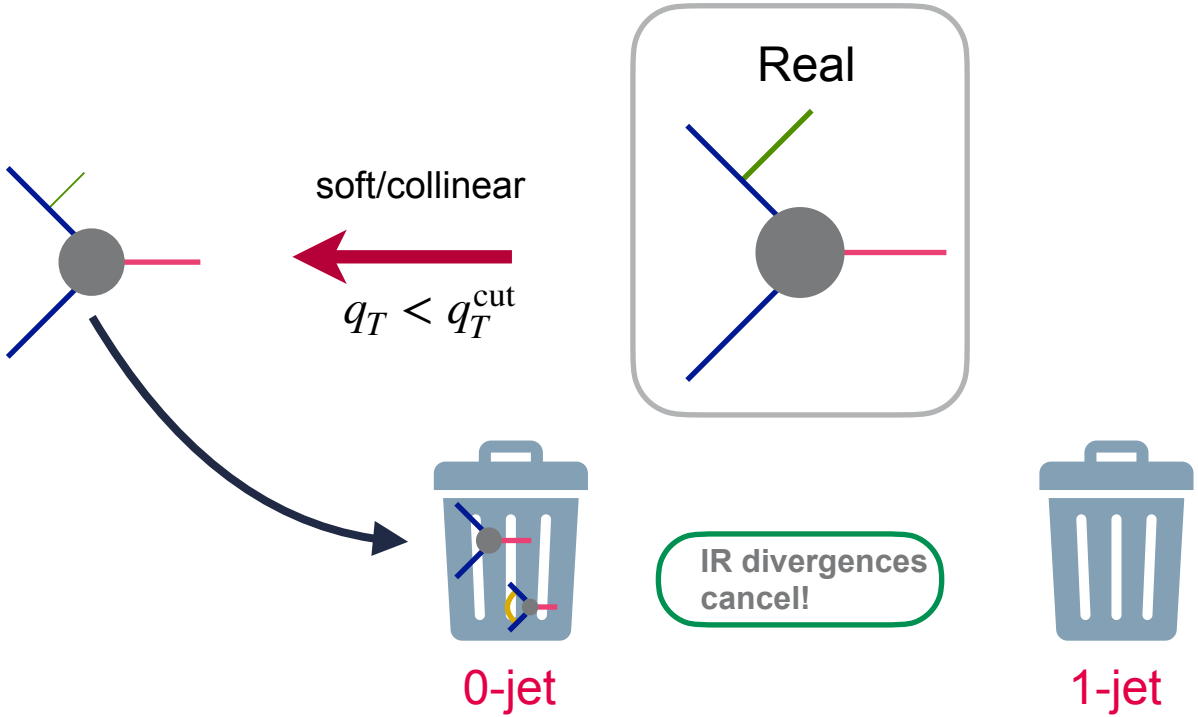

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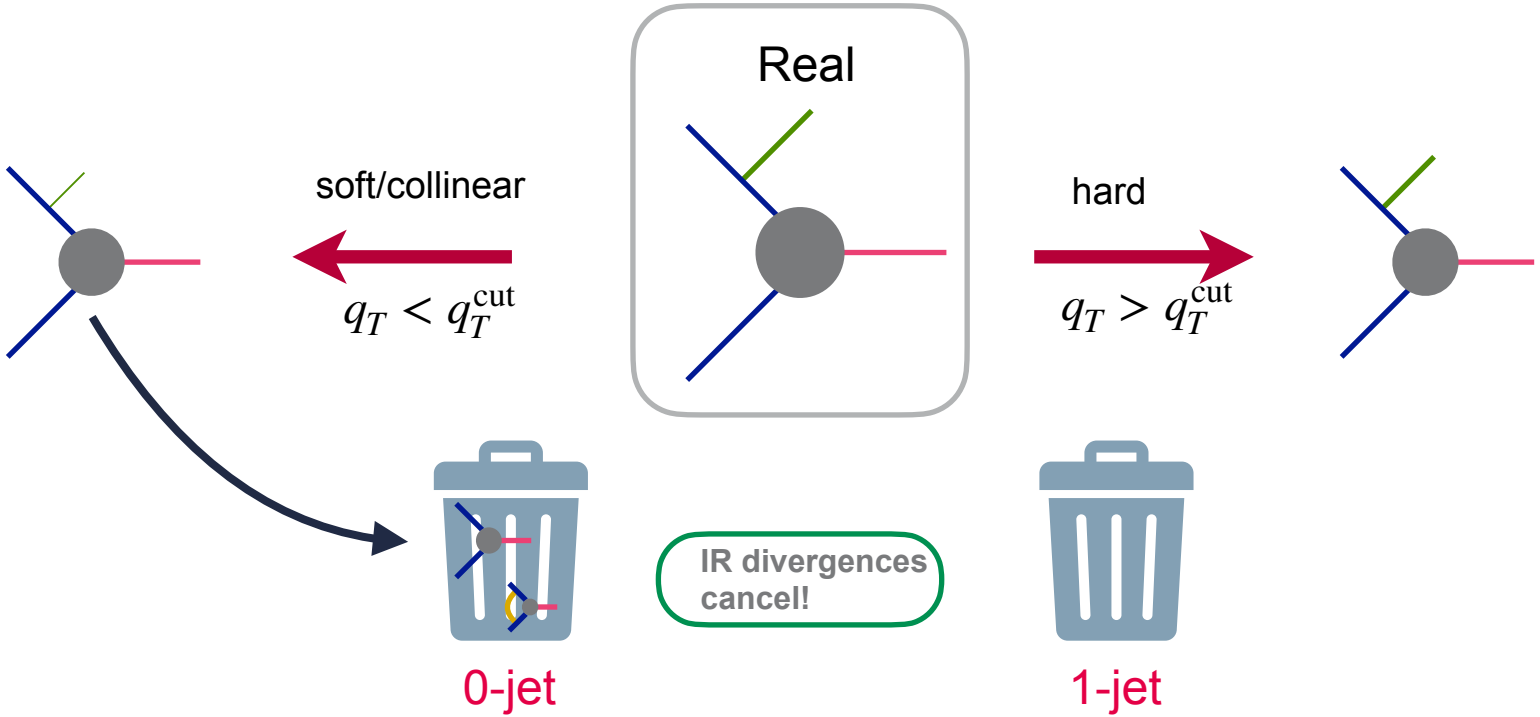

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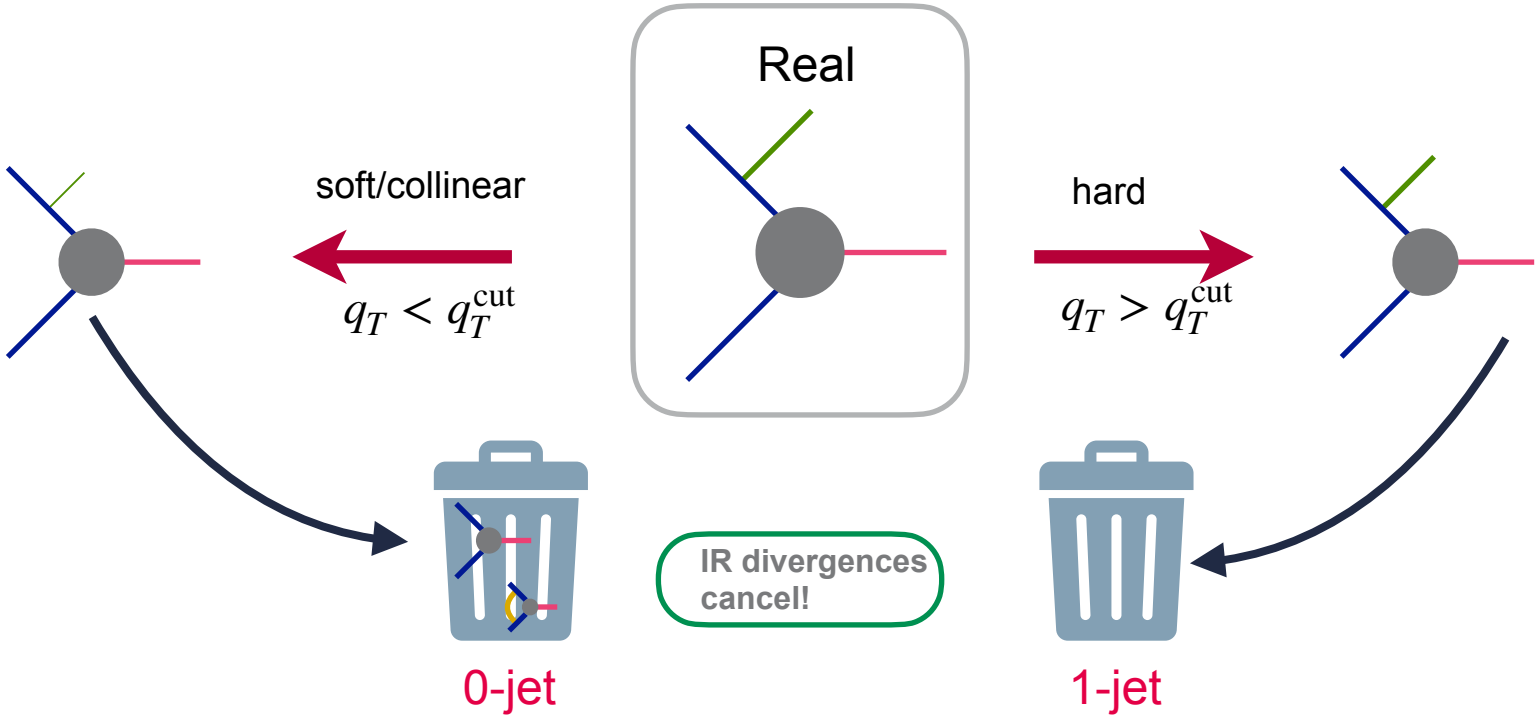

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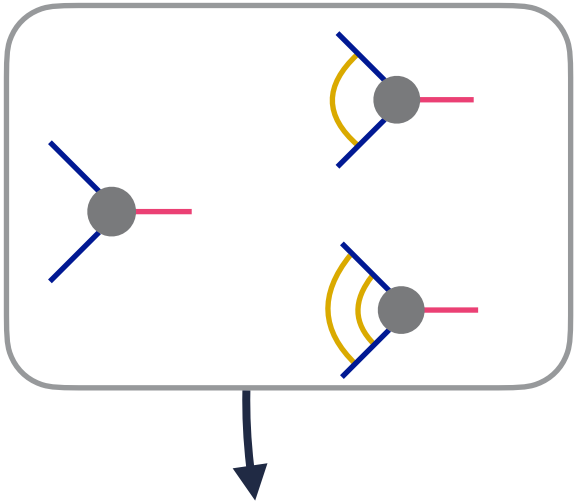
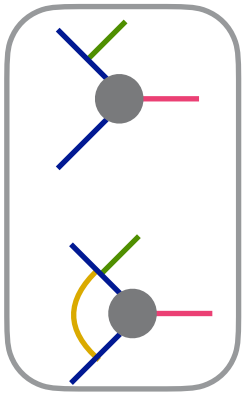
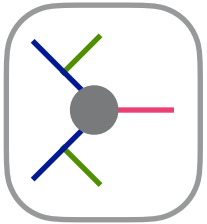


0-jet

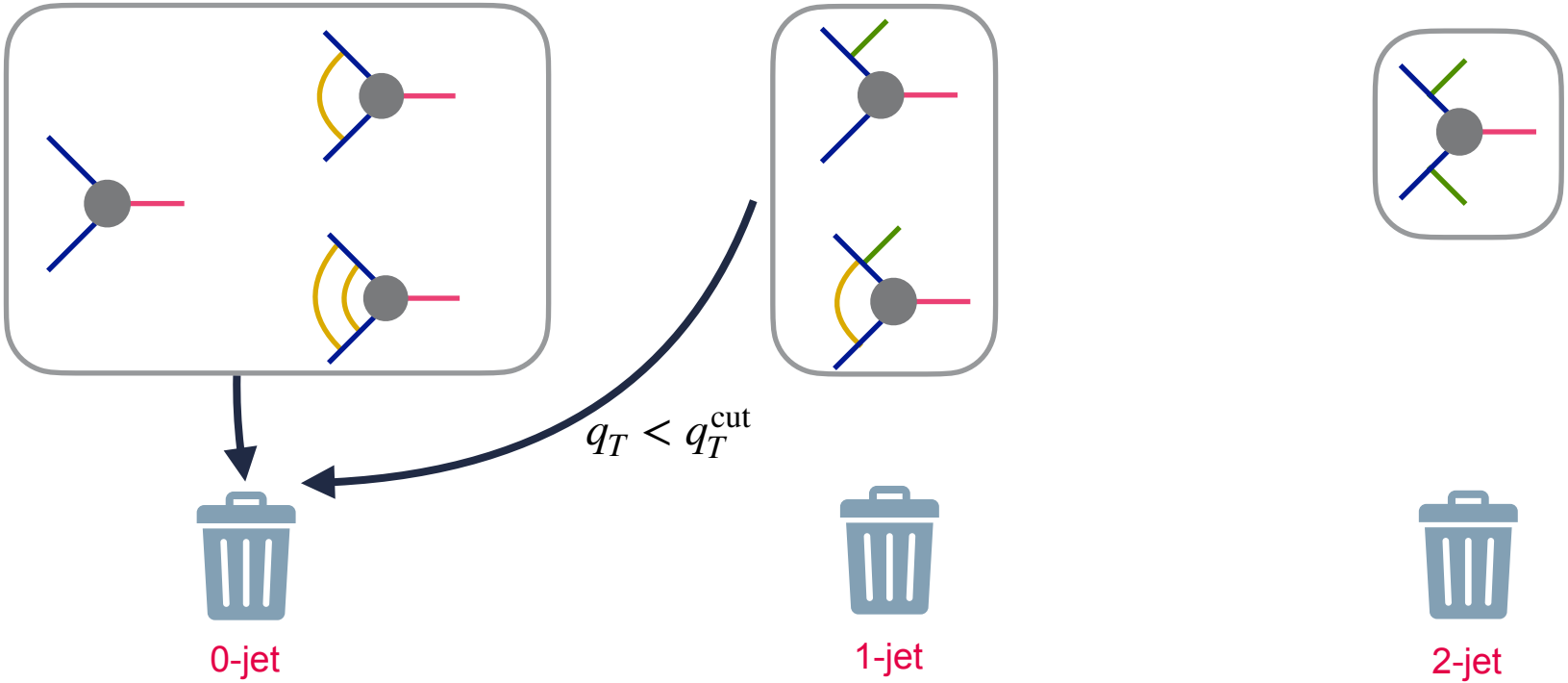


1-jet



2-jet

Defining IR safe events



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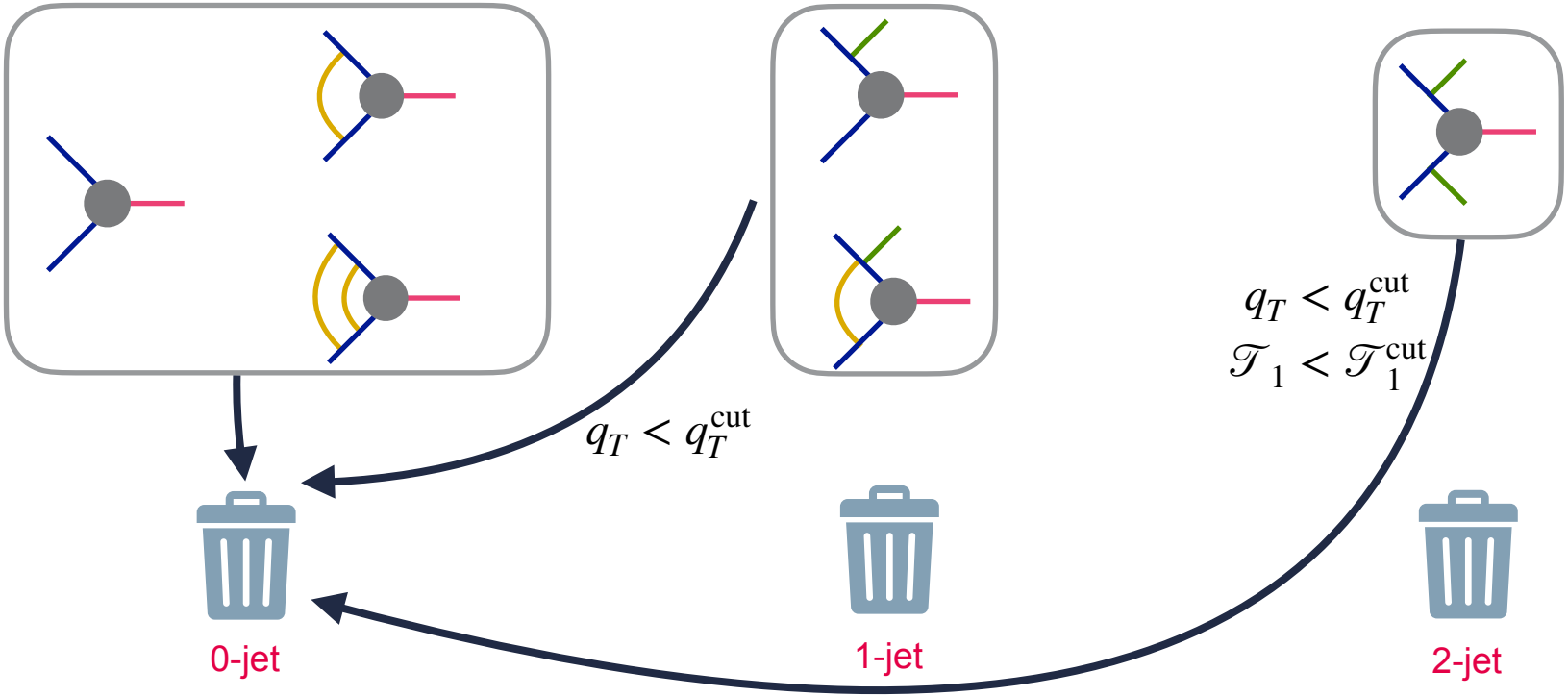

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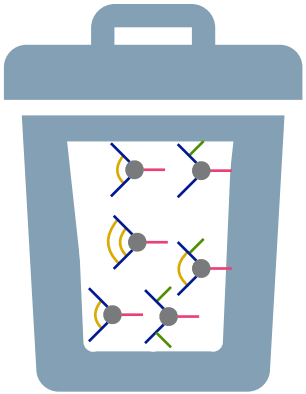

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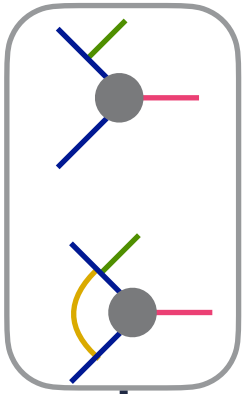
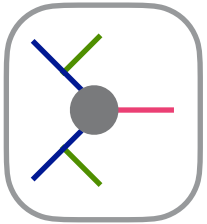


$q_T > q_T^{\text{cut}}$

1-jet



2-jet

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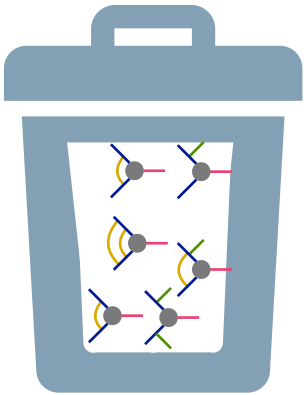
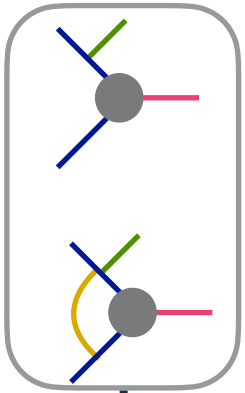


0-jet



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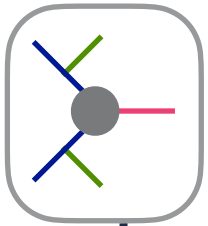
$q_T > q_T^{\text{cut}}$

$\mathcal{T}_1 < \mathcal{T}_1^{\text{cut}}$



2-jet

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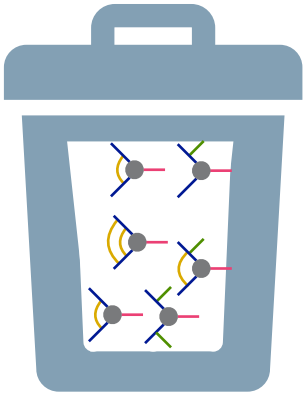

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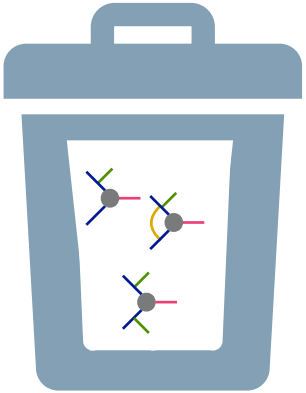
$q_T > q_T^{\text{cut}}, \mathcal{T}_1 < \mathcal{T}_1^{\text{cut}}$



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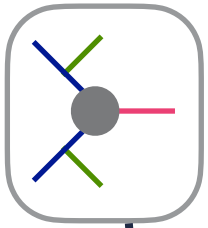

$q_T > q_T^{\text{cut}}$

$\mathcal{T}_1 > \mathcal{T}_1^{\text{cut}}$

2-jet

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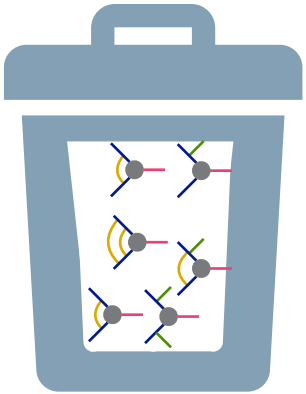

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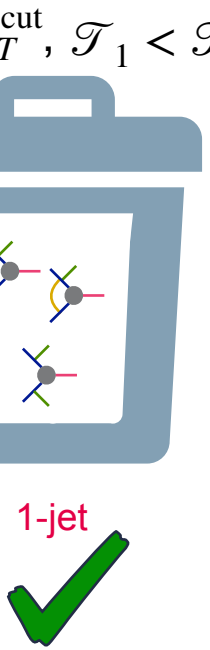

$q_T > q_T^{\text{cut}}, \mathcal{T}_1 < \mathcal{T}_1^{\text{cut}}$

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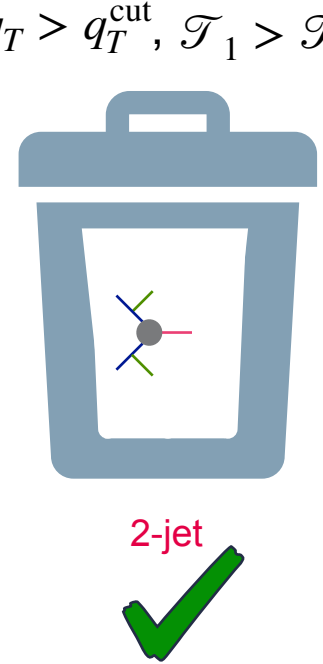
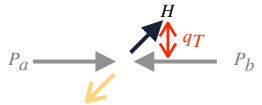


$q_T > q_T^{\text{cut}}, \mathcal{T}_1 > \mathcal{T}_1^{\text{cut}}$

2-jet

Resumming q_T and $\mathcal{T}_1$

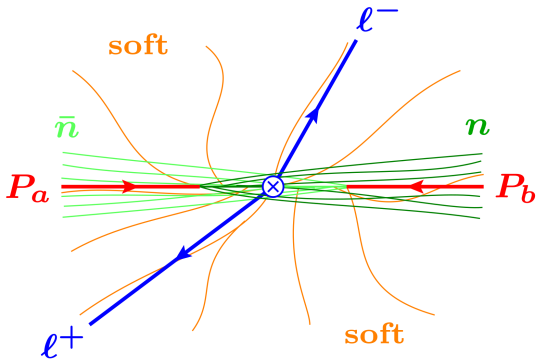
q_T factorization



- Factorization in soft-collinear effective theory (SCET):

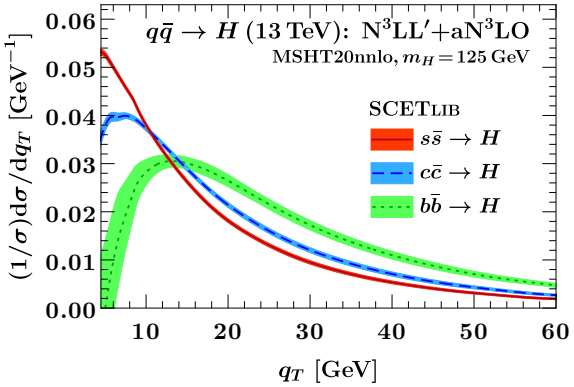
$$\frac{\mathrm{d}\sigma}{\mathrm{d}q_T} = H(Q,\mu) \times B(q_T,\mu) \otimes B(q_T,\mu) \otimes S(q_T,\mu) \left[1 + \mathcal{O}\left(\frac{q_T^2}{Q^2}\right)\right]$$

- Hard function: hard interaction at high scale Q
- Beam function: collinear radiation
- Soft function: soft, isotropic radiation



q_T resummation

- Solve RGEs for $H(Q,\mu)$, $B(q_T,\mu)$ and $S(q_T,\mu)$ to resum large logs of q_T/Q
- In practice: use SCETlib [Ebert, Michel, Tackmann '18] to perform resummation
- **New:** directly interface SCETlib to GENEVA
- Resummation for $q\bar{q}H$ available up to N^{3}LL`
  - $H(Q,\mu)$ [Gehrmann, Kara '14; Ebert, Michel, Tackmann '17]
  - $B(q_T,\mu)$ [Luo, Yang, Zhu, Zhu '19; Ebert, Mistlberger, Vita '20]
  - $S(q_T,\mu)$ [Li, Zhu, Neill '16; Li, Zhu, '16]
  - 4-loop cusp and 3-loop non-cusp
    [Henn, Korchemsky, Mistlberger '20; v. Manteuffel, Panzer, Schabinger '20]
    [Li, Zhu, '16; Vladimirov '16]

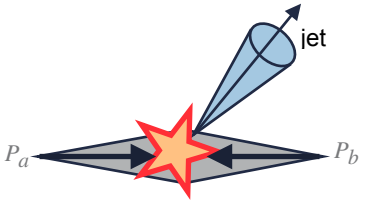


[Cal, RvK, Lim, Tackmann '23]

Generalized $\mathcal{T}_1$

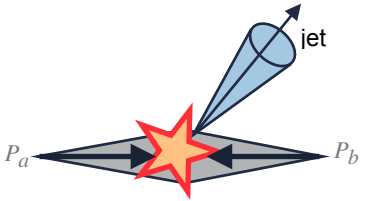
- Standard definition of jettiness [Stewart, Tackmann, Waalewijn, '10]

$$\mathcal{T}_1 = \sum_i \min\{d_1(p_i), d_a(p_i), d_b(p_i)\}$$



colored final states p_i , $m \in \{1,\ldots,N+2\} = \{1,2,3\}$, distance measure to region m $d_m(p_i)$

Generalized $\mathcal{T}_1$



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$$\mathcal{T}_1 = \sum_i \min\{d_1(p_i), d_a(p_i), d_b(p_i)\}$$

colored final states p_i , $m \in \{1,...,N+2\} = \{1,2,3\}$, distance measure to region m $d_m(p_i)$

- Generalized definition: measure $d_m(p_i)$ doesn't need to be identical to observable f_m

[Stewart, Tackmann, Waalewijn, '10]

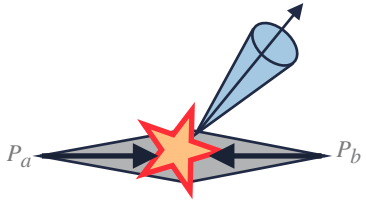
$$\mathcal{T}_1 = \sum_m \sum_{i \in m} f_m(\eta_i, \phi_i) p_{T,i}$$

observable f_m, pseudo rapidity η_i, azimuth ϕ_i and transverse momentum $p_{T,i}$

Generalized $\mathcal{T}_1$: p_T -like measure

- Define generalized $\mathcal{T}_1$ with transverse momentum-like measure where $\mathcal{T}_1 \sim p_{T,i} \sim Q\lambda$

$$\mathcal{T}_1^{p_T} = \sum_i \begin{cases} p_{T,i}, & \text{for } d_B(p_i) < d_J(p_i), \\ p_{T,i}\, f_J(\eta_i, \phi_i), & \text{for } d_J(p_i) < d_B(p_i), \end{cases}$$



- Beam region: p_T is sufficient as observable definition
- Jet region: emission collinear to jet axis scale ➔ need angular projection

➔ Use boost-invariant generalization of broadening $f_J(\eta_i, \phi_i) = \sqrt{2\cosh(\Delta\eta_{iJ}) - 2\cos(\Delta\phi_{iJ})}$

[Banfi, Salam , Zanderighi '04, Bertolini, Kolodrubtez, Neill, Pietrulewicz, Stewart, Tackmann, Waalewijn '17]

$$\Delta\eta_{iJ} = \eta_{iJ} - \eta_J$$
$$\Delta\phi_{iJ} = \phi_{iJ} - \phi_J$$

$\mathcal{T}_1$ factorization

- Choice of observables correspond to SCET$_{\text{II}}$ setup
- Factorization theorem [Bertolini, Kolodrubtez, Neill, Pietrulewicz, Stewart, Tackmann, Waalewijn '17]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\mathcal{T}_1^{p_T}} = H(Q,\mu) \otimes S\left(\mathcal{T}_1^{p_T},\mu\right) \otimes B\left(\mathcal{T}_1^{p_T}\mu,\right) \otimes B\left(\mathcal{T}_1^{p_T},\mu\right) \otimes J\left(\mathcal{T}_1^{p_T},\mu\right)$$

- Hard, beam and soft functions similar as for q_T factorization
- Additional jet function describes collinear radiation from the jet

$\mathcal{T}_1^{p_T}$ resummation

- Solve RGEs for $H(Q,\mu)$, $B(\mathcal{T}_1^{p_T},\mu)$, $S(\mathcal{T}_1^{p_T},\mu)$ and $J(\mathcal{T}_1^{p_T},\mu)$ to resum large logs
  - 1-loop soft function [Bertolini, Kolodrubtez, Neill, Pietrulewicz, Stewart, Tackmann, Waalewijn '17]
  - 1-loop beam functions [Becher, Neubert '12; Becher, Neubert, Rothen '13; Stewart, Tackmann, Walsh, Zuberi '14]
  - 1-loop recoil-free jet function [Larkoski, Neill, Thaler '14]
- Evolution equations solved in Laplace space
  - At NLL$'$: evolution equations can be solved analytically
  - Non-trivial dependence of rapidity anom. dim. on transverse momenta complicates inverse Laplace transform at higher orders

Results for $b\bar{b}H$

Fixed-order Validation

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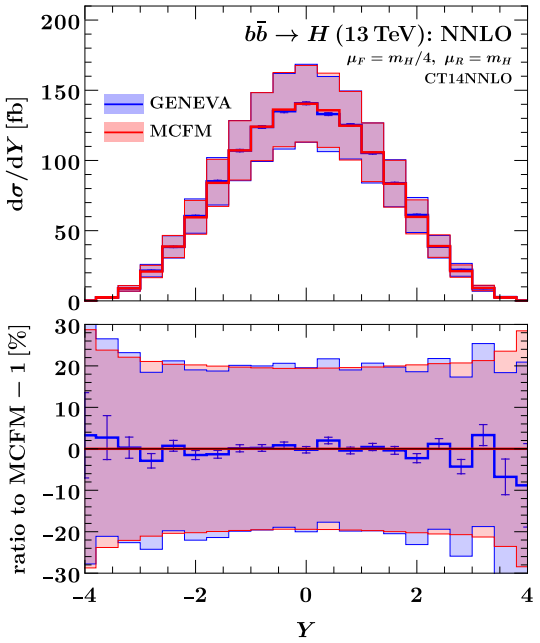
NNLO Higgs boson rapidity spectrum

- Comparing to NNLO MCFM result
  [Boughezal, Campbell, Ellis, Focke, Giele, Liu, Petriello, Williams ’17]
  [Mondini, Williams ’21]

- Good agreement with central value and 7-point scale variations

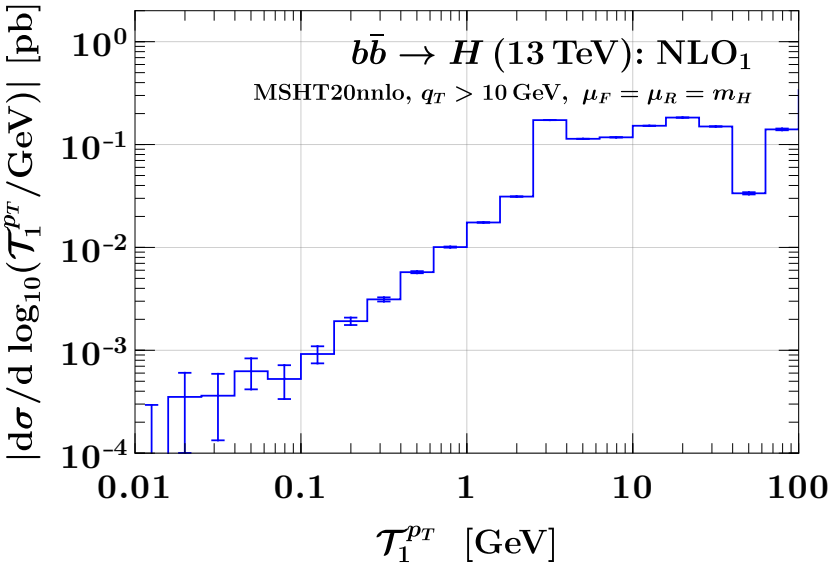


1/2-jet bin separation

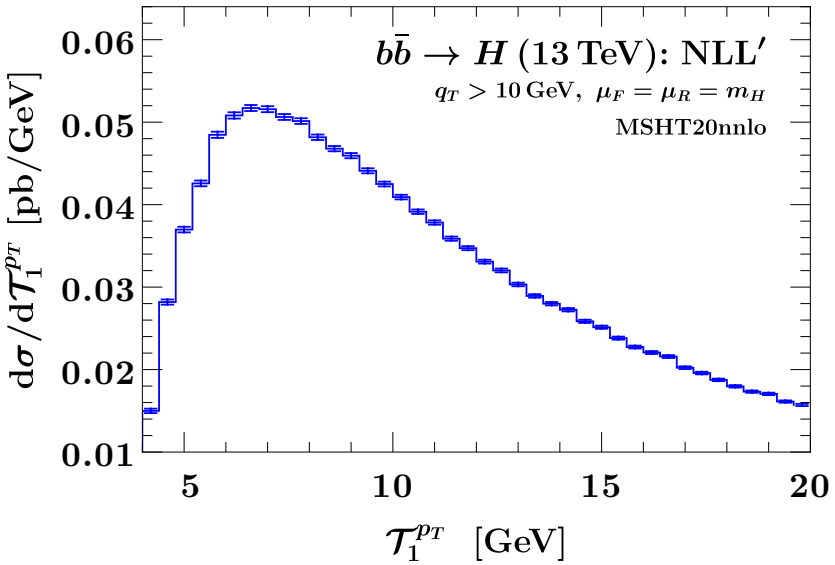
$\mathcal{T}_1^{p_T}$ spectrum

[Gavardi, RvK, Lim '25]

Non-singular



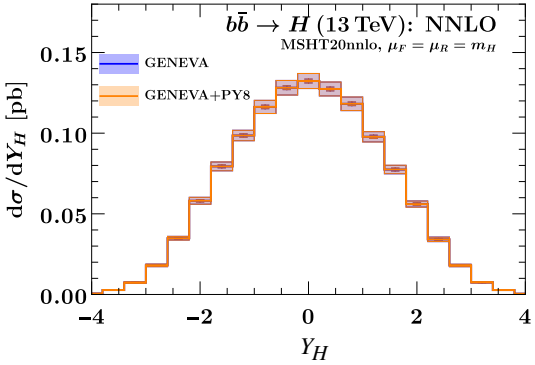
Resummed



Effect of the showering

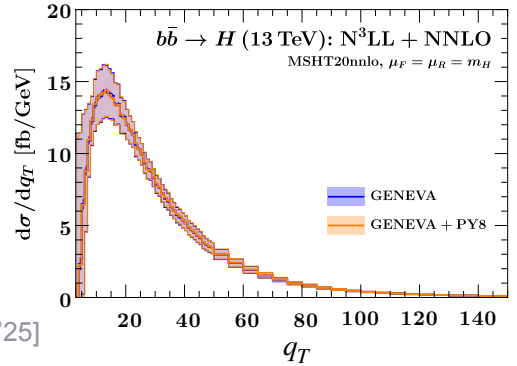
Higgs rapidity spectrum

- PS does not affect distribution
- Expected as Y_H is an inclusive quantity



Higgs transverse momentum spectrum

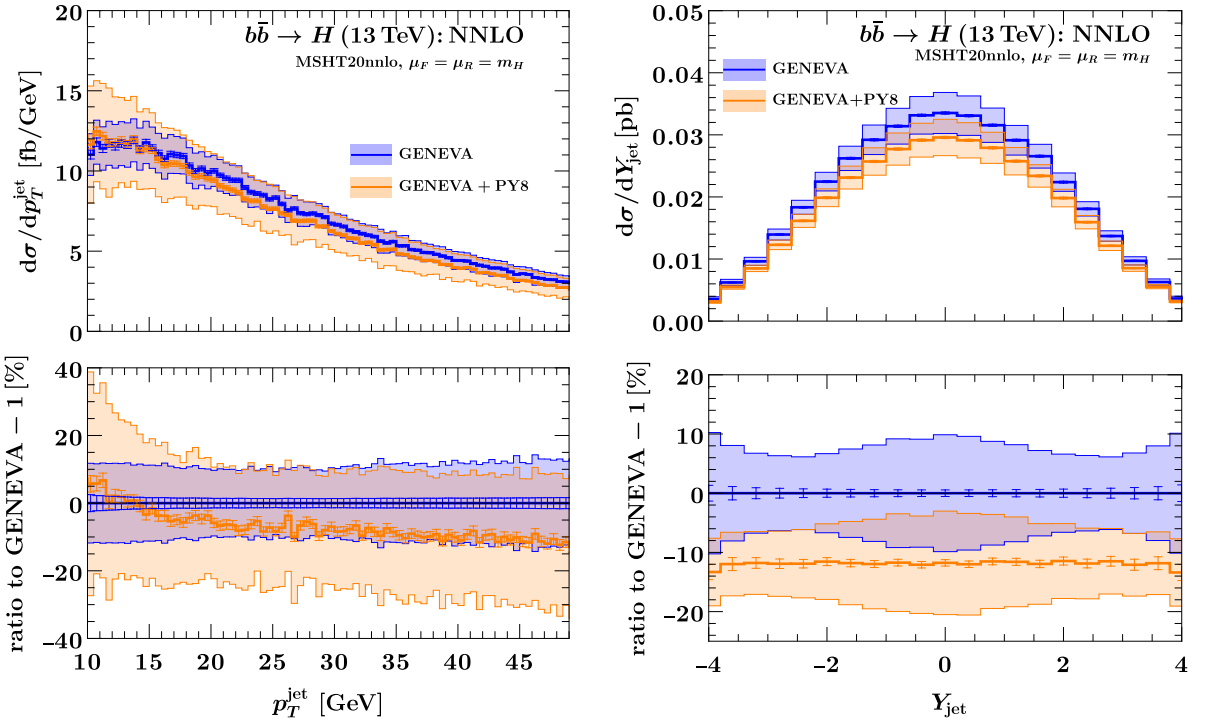
- Very good agreement between parton-level and showered results
- Can't formally claim N^{3}LL+NNLO accuracy for showered results but distributions are indistinguishable



[Gavardi, RvK, Lim '25]

Effect of the showering

- More exclusive observables
  - p_T^{jet}: p_T of hardest jet
  - Y_{jet}: rapidity of hardest jet
- Shower effects expected



[Gavardi, RvK, Lim '25]

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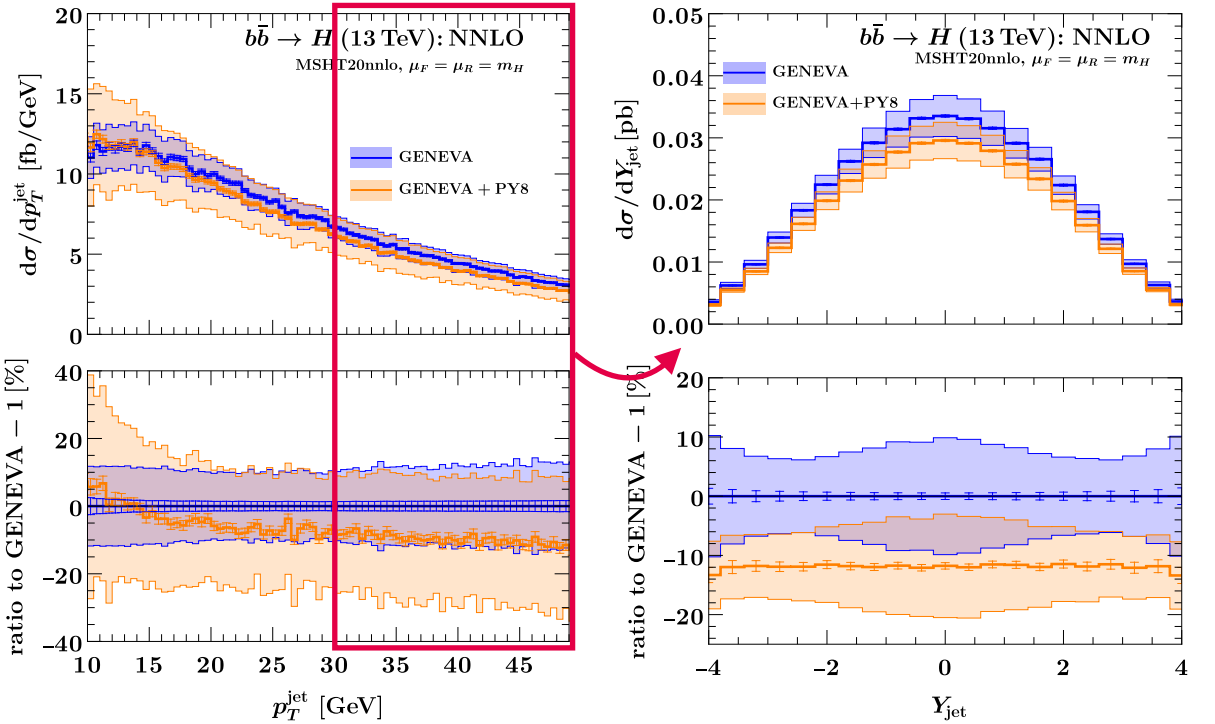

[Gavardi, RvK, Lim '25]

Outlook and Summary

Outlook and Summary

Outlook

- Extension to other color-singlet processes
- Achieve NNLL` resummation accuracy for $\mathscr{T}_1^{p_T}$

Summary

- New set of resolution variables in GENEVA for NNLO+PS matching
  - Facilitates matching to parton showers
- Good agreement with independent fixed-order prediction
- Resummation accuracy not affected by the shower

Outlook and Summary

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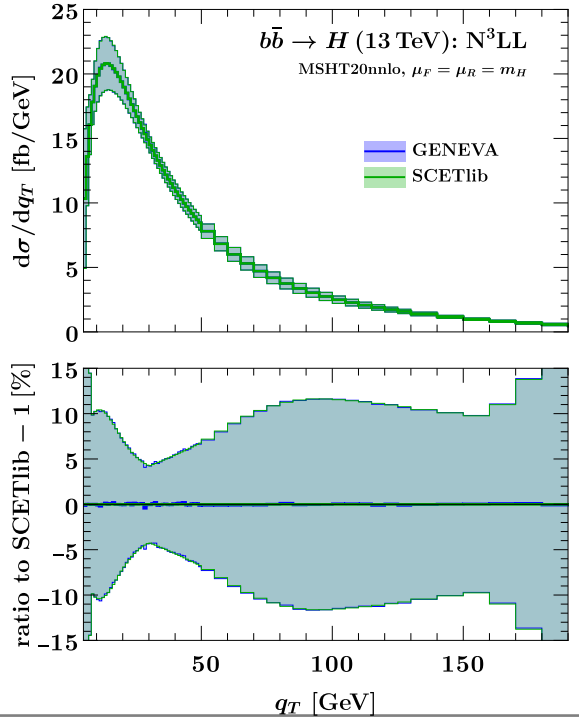
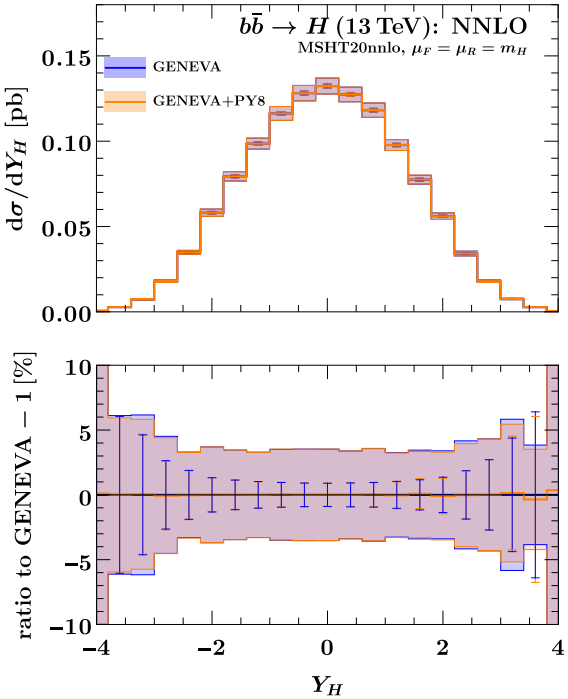
Thank you!

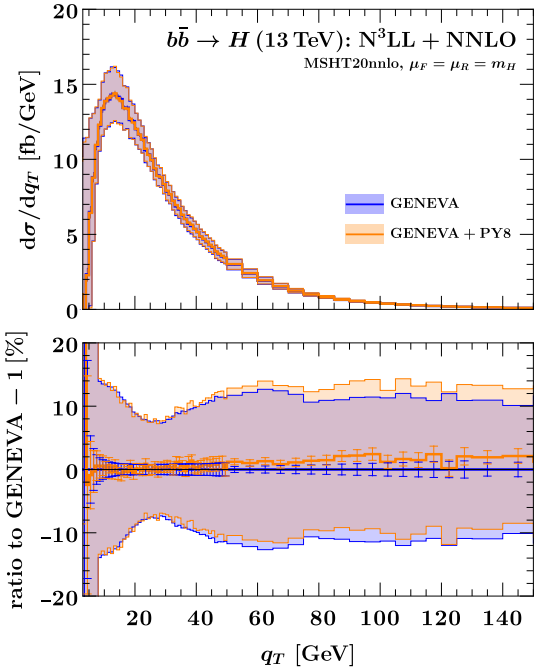
Back up

Resumed Validation

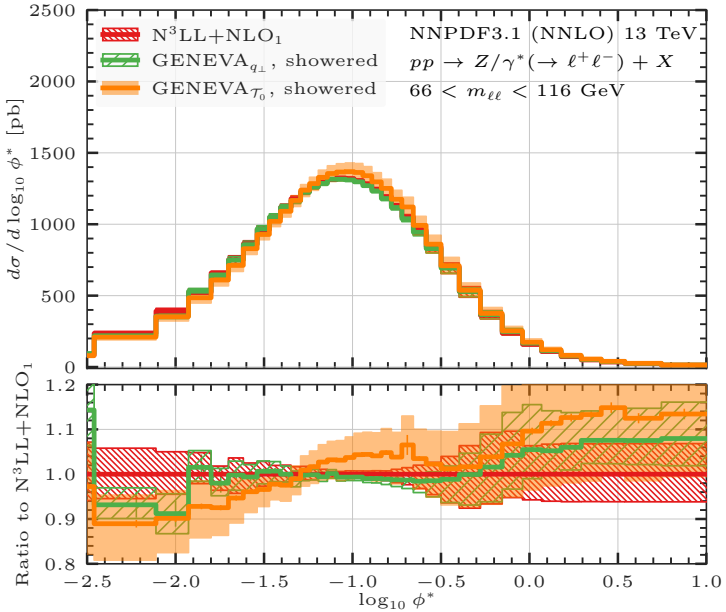


Effect of the showering





Comparison of resolution variables



[Alioli et al. '21]