Factorization for jet radius and algorithm effects in jet mass distributions at the LHC

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based on work with
Daniel Kolodrubetz, Iain Stewart, Frank Tackmann, and Wouter Waalewijn

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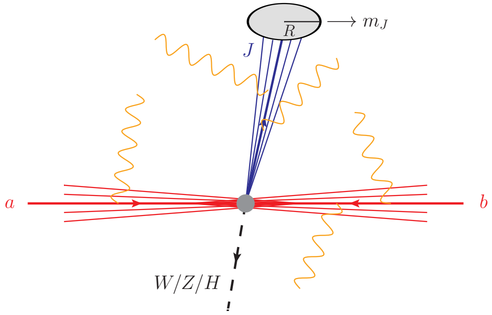
Scope and Goals

predict jet mass spectra at the LHC, specifically:

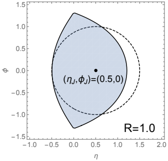
- exclusive jet spectra: veto on additional jets
- focus on $pp \to W/Z/H + 1$ jet (dijets $\to$ Yiannis' talk)
- here: without grooming (for soft drop $\to$ Kai Yan's & Christopher's talks)

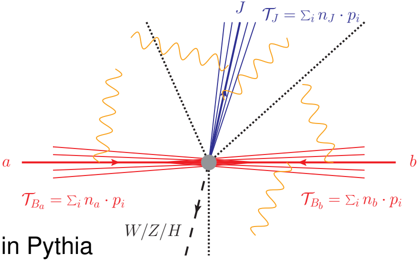


NNLL analysis performed for $pp \to H + 1$ jet

[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

- large R jets with $m_J \ll p_T^J R \sim p_T^J$
- 1-jettiness contributions as jet veto
- jet boundary via 1-jettiness minimization with jet area πR^2





$\Rightarrow$ their results for *normalized* spectra:

- dependence on jet veto mainly cancels
- rather weak dependence on jet algorithm in Pythia

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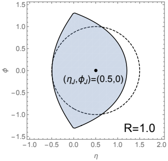

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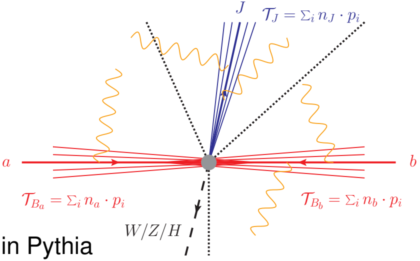

$\Rightarrow$ their results for *normalized* spectra:

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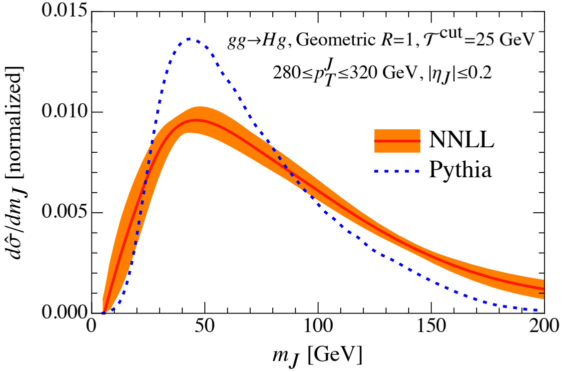
our aim: direct comparison with experiment

- other jet algorithms (anti-kT, XCone)
- common (MPI insensitive) jet vetoes (e.g. p_T^{jet})
- small jet radii ($R \sim 0.5$)
- jet boundary effects for $m_J \sim p_T^J R$

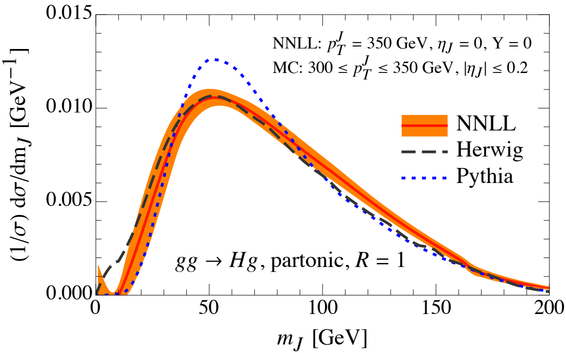
Comparison with Pythia for $pp \to H + 1$ jet



[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

$\Rightarrow$ Need to add nonsingular corrections in the far tail
(large cancellation for $m_J \sim p_T^J R/2$!)

Comparison with Pythia for $pp \to H + 1$ jet



[Stewart, Tackmann, Waalewijn (2014)]

$\Rightarrow$ Add nonsingular corrections in the far tail $\surd$

Goal: Do this systematically for small R with $p_T^J R/2 \ll p_T^J \sim Q$

Outline

1. Factorization of jet radius effects
   - Description of hierarchies $m_J \leftrightarrow p_T^J R \leftrightarrow p_T^J$
   - Relations between the hierarchies
2. Soft functions for jet algorithms at hadron colliders
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   - Results
3. Summary

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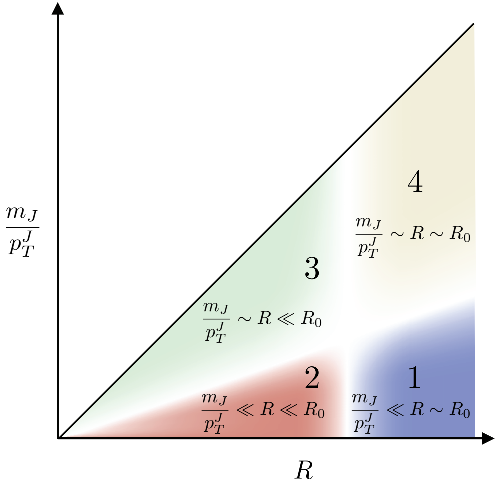
Different regimes according to hierarchies

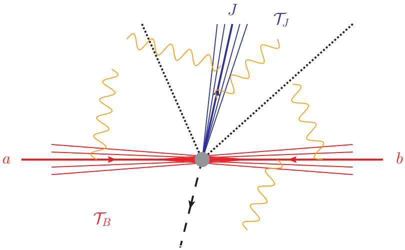


in the following: concentrate on hierarchies 1, 2 and 3

Factorization for regime 1: $m_J \ll p_T^J R \sim p_T^J$

consider here:

- hard, central jet: $p_T^J \sim Q$
- $\mathrm{SCET_I}$-type global veto:
  $\mathcal{T}_B = \sum_{i \notin \text{jet}} p_{Ti} f(\eta_i)$ with $f(\eta) \xrightarrow{\eta \to \pm\infty} e^{-|\eta|}$
  (e.g. C-parameter: $f_C(\eta) = \frac{1}{2\cosh\eta}$)
- $\mathcal{T}_J = \sum_{i \in \text{jet}} n_J \cdot p_i$
  ($\Leftrightarrow m_J$ for hierarchies 1 – 3)
- jet algorithm with jet area $\approx \pi R^2$ in η-ϕ-plane



mode	$p^\mu = (+, -, \perp)$	$\sqrt{p^2}$
$n_{a,b}$ – collinear	$\left(\mathcal{T}_B, p_T^J, \sqrt{p_T^J \mathcal{T}_B}\right)_B$	$\sqrt{p_T^J \mathcal{T}_B}$
n_J – collinear	$\left(\mathcal{T}_J, p_T^J, \sqrt{p_T^J \mathcal{T}_J}\right)_J$	$\sqrt{p_T^J \mathcal{T}_J}$
usoft	$(\mathcal{T}_B, \mathcal{T}_B, \mathcal{T}_B)$	$\mathcal{T}_B$
	$(\mathcal{T}_J, \mathcal{T}_J, \mathcal{T}_J)$	$\mathcal{T}_J$

correlated emissions

Factorization for regime 1: $m_J \ll p_T^J R \sim p_T^J$

Factorization formula: [Stewart, Tackmann, Waalewijn (2009); + Jouttenus (2013)]

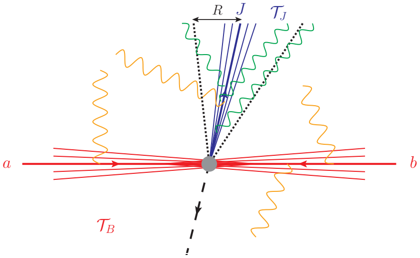
$$\frac{d\sigma_1}{d\Phi \, d\mathcal{T}_B \, d\mathcal{T}_J} = \sum_\kappa H_\kappa(\Phi,\mu) \, B_a(Q_a\mathcal{T}_B, x_a, \mu) \otimes B_b(Q_b\mathcal{T}_B, x_b, \mu) \, J_{\kappa_J}(Q_J\mathcal{T}_J, \mu)$$
$$\otimes S_\kappa(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu) \left[1 + \mathcal{O}\left(\frac{\mathcal{T}_J}{p_T^J}, \frac{\mathcal{T}_B}{p_T^J}\right)\right]$$

- channel dependent hard function $H_\kappa(\Phi,\mu)$ (partonic kinematics)
- standard inclusive beam and jet functions $B_i(t,x,\mu)$ and $J_{\kappa_J}(s,\mu)$
- soft function $S_\kappa(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu)$: jet algorithm and radius dependence
  $\rightarrow$ one-loop computation in second part of my talk
  $\rightarrow$ no large NGLs for $\mathcal{T}_J \sim \mathcal{T}_B$
  $\rightarrow$ "refactorization": (to avoid fake Sudakov logs $\alpha_s \ln^2(\mathcal{T}_J/\mathcal{T}_B)$)

$$S_\kappa(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu) = S_\kappa^{\mathrm{jet}}(\mathcal{T}_J, \eta_J, R, \mu) S_\kappa^{\mathrm{beam}}(\mathcal{T}_B, \eta_J, R, \mu) + S_\kappa^{\mathrm{NG}}(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu)$$

Factorization for regime 2: $m_J \ll p_T^J R \ll p_T^J$

- small R: jet algorithms give circular jets
- n_J-coll. modes do not resolve jet boundary
- wide-angle soft modes do not resolve jet
- additional "boundary" modes:
  csoft/soft-coll. (coft) modes $\to \mathrm{SCET}_{+(+)}$
  [Larkoski, Moult, Neill (2015)]
  [Becher, Neubert, Rothen, Shao (2015)]
  [Chien, Hornig, Lee (2015)]
  $\to$ see Ding Yu's and Andrew's talks



mode	$p^\mu = (+,-,\perp)$	$\sqrt{p^2}$
$n_{a,b}$ – collinear	$(\mathcal{T}_B, p_T^J, \sqrt{p_T^J \mathcal{T}_B})_B$	$\sqrt{p_T^J \mathcal{T}_B}$
n_J – collinear	$(\mathcal{T}_J, p_T^J, \sqrt{p_T^J \mathcal{T}_J})_J$	$\sqrt{p_T^J \mathcal{T}_J}$
usoft	$(\mathcal{T}_B, \mathcal{T}_B, \mathcal{T}_B)$	$\mathcal{T}_B$
csoft	$\mathcal{T}_J/R^2 (R^2, 1, R)_J$	$\mathcal{T}_J/R$
(soft-collinear)	$\mathcal{T}_B (R^2, 1, R)_J$	$\mathcal{T}_B R$

correlated emissions

Factorization for regime 2: $m_J \ll p_T^J R \ll p_T^J$

Factorization formula:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} = \sum_\kappa H_\kappa(\Phi,\mu)\, B_a(Q_a\mathcal{T}_B, x_a, \mu) \otimes B_b(Q_b\mathcal{T}_B, x_b, \mu)\, J_{\kappa_J}(Q_J\mathcal{T}_J, \mu)$$
$$\otimes\, \mathcal{S}_{\kappa_J}\Big(\frac{2\cosh\eta_J \mathcal{T}_J}{R}, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\Big) \otimes S_\kappa^B(\mathcal{T}_B, \eta_J, \mu)$$
$$\times \Big[1 + \mathcal{O}\Big(\frac{\mathcal{T}_B}{p_T^J}, \frac{\mathcal{T}_J}{p_T^J R^2}, R^2\Big)\Big]$$

- $S_\kappa^B(\mathcal{T}_B, \eta_J, \mu)$: contributes only to $\mathcal{T}_B$ measurement, no R dependence
  $\rightarrow$ analytic one-loop result for beam thrust, C-parameter & p_T-type vetoes
- $\mathcal{S}_{\kappa_J}(k_J, k_B, \mu)$: csoft function $\equiv$ double hemisphere soft function
  $\rightarrow$ jet radius dependence only through its arguments
  $\rightarrow$ dependence on jet algorithm is power suppressed by $\mathcal{O}(R^2)$
  $\rightarrow$ no large NGLs for $k_B \sim k_J \longleftrightarrow \mathcal{T}_J \sim \mathcal{T}_B R^2$
  $\rightarrow$ "refactorization":

$$\mathcal{S}_{\kappa_J}(k_J, k_B, \mu) = S_{\kappa_J}^{\mathrm{hemi}}(k_J, \mu)\, S_{\kappa_J}^{\mathrm{hemi}}(k_B, \mu) + S_{\kappa_J}^{\mathrm{NG}}(k_J, k_B, \mu)$$

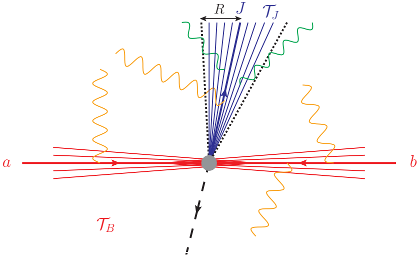
Factorization for regime 3: $m_J \sim p_T^J R \ll p_T^J$

- wide-angle soft modes do not resolve jet
- n_J-collinear modes resolve jet boundary, merge with csoft modes

  $$\left(\mathcal{T}_J, p_T^J, \sqrt{p_T^J \mathcal{T}_J}\right) \sim \mathcal{T}_J/R^2\left(R^2, 1, R\right) \sim p_T^J\left(R^2, 1, R\right)$$

  [Chien, Hornig, Lee (2015)]
- soft-collinear modes resolve individual n_J-collinear emissions

  [Becher, Neubert, Rothen, Shao (2015)]



mode	$p^\mu = (+, -, \perp)$	$\sqrt{p^2}$
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n_J – collinear	$p_T^J\left(R^2, 1, R\right)_J$	$p_T^J R$
usoft	$\left(\mathcal{T}_B, \mathcal{T}_B, \mathcal{T}_B\right)$	$\mathcal{T}_B$
soft-collinear	$\mathcal{T}_B\left(R^2, 1, R\right)_J$	$\mathcal{T}_B R$

correlated emissions

Factorization for regime 3: $m_J \sim p_T^J R \ll p_T^J$

"Factorization" formula:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} = \sum_\kappa H_\kappa(\Phi,\mu)\, B_a(Q_a\mathcal{T}_B, x_a, \mu) \otimes B_b(Q_b\mathcal{T}_B, x_b, \mu) \otimes \mathcal{J}_{\kappa_J}\Big(Q_J\mathcal{T}_J, p_T^J R, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\Big) \otimes S_\kappa^B(\mathcal{T}_B, \eta_J, \mu)\left[1 + \mathcal{O}\left(\frac{\mathcal{T}_B}{p_T^J}, R^2\right)\right]$$

new ingredient: jet function $\mathcal{J}_{\kappa_J}$

- contains jet algorithm and radius dependence
- corrections to jet and beam measurements from hard-coll. and soft-coll. modes
- "refactorization":

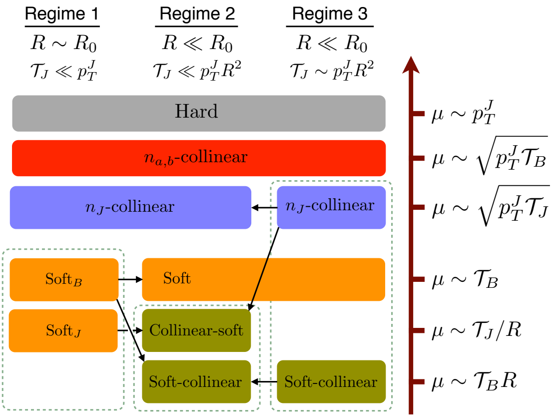
$$\mathcal{J}_{\kappa_J}(s_J, p_T^J R, k_B, \mu) = J_{\kappa_J}^R(s_J, p_T^J R, \mu)\, S_{\kappa_J}^{\rm hemi}(k_B, \mu) + \mathcal{J}_{\kappa_J}^{\rm NG}(s_J, p_T^J R, k_B, \mu)$$

  $\rightarrow$ J^R: jet function with boundary effects [Ellis et al. (2010); Chay, Kim, Kim (2015)]

  $\rightarrow$ $S^{\rm hemi}$: soft-coll. function (= single hemisphere soft function)

- large NGLs unavoidable in above formula for $\mathcal{T}_B \ll p_T^J$
  $\rightarrow$ systematic incorporation of the dominant effects with recent progress possible
  [Larkoski, Moult, Neill (2015); Caron-Huot (2015); Becher, Neubert, Rothen, Shao (2015)]

Relations between the hierarchies



Relations between matrix elements:

$$S_\kappa(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu) = S_\kappa^B(\mathcal{T}_B, \eta_J, \mu) \otimes \mathcal{S}_{\kappa_J}\left(\frac{2\cosh\eta_J \mathcal{T}_J}{R}, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\right)\left[1 + \mathcal{O}(R^2)\right]$$

$$\mathcal{J}_{\kappa_J}\left(Q_J \mathcal{T}_J, p_T^J R, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\right) = J_{\kappa_J}(Q_J \mathcal{T}_J, \mu) \otimes \mathcal{S}_{\kappa_J}\left(\frac{Q_J \mathcal{T}_J}{p_T^J R}, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\right)\left[1 + \mathcal{O}\left(\frac{m_J^2}{(p_T^J R)^2}\right)\right]$$

Combining cross sections by nonsingular matching

- in regime 2 ($\mathcal{T}_J \ll p_T^J R^2 \ll p_T^J$): resummation of $\ln R$, $\ln(\mathcal{T}_J/(p_T^J R^2))$
- add power corrections of $\mathcal{O}(R^2)$ from region 1 and of $\mathcal{O}(\mathcal{T}_J/(p_T^J R^2))$ from region 3

$$\frac{\mathrm{d}\sigma_{1+2+3}}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} = \frac{\mathrm{d}\sigma_2}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} + \left(\frac{\mathrm{d}\sigma_1}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} - \frac{\mathrm{d}\sigma_2}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J}\bigg|_{\mu_{\mathcal{S}}=\mu_{\mathcal{S}}^B=\mu_S}\right)$$
$$+ \left(\frac{\mathrm{d}\sigma_3}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J} - \frac{\mathrm{d}\sigma_2}{\mathrm{d}\Phi\,\mathrm{d}\mathcal{T}_B\,\mathrm{d}\mathcal{T}_J}\bigg|_{\mu_{\mathcal{S}}=\mu_J=\mu_J^R}\right)$$

- remaining power corrections: $\mathcal{O}(\mathcal{T}_B/p_T^J)$, $\mathcal{O}(R^2 \times \mathcal{T}_J/(p_T^J R^2)) = \mathcal{O}(\mathcal{T}_J/p_T^J)$
  $\rightarrow$ full QCD corrections

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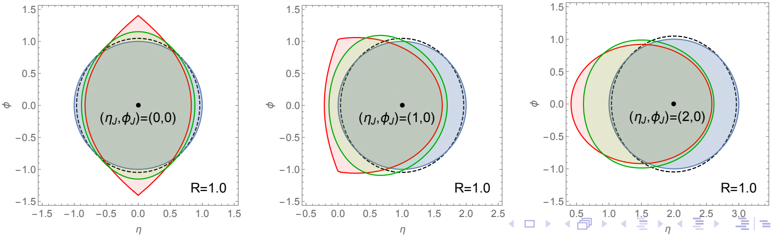
Jet algorithms

- clustering of soft radiation (for coll. core) according to distance measures d_B, d_J $\rightarrow d_J(\eta,\phi) < d_B(\eta,\phi)$ ($d_B < d_J$): soft particle in the jet (beam) region
- examples for algorithms: (see also [Stewart, Tackmann, Thaler, Vermilion, Wilkason (2015)])

jet algorithm	d_B	d_J
A: anti-kT	R^2	$(\Delta\eta)^2 + (\Delta\phi)^2$
B: Geometric R	$p_T e^{-\vert\eta\vert}$	$\frac{1}{\rho(R,\eta_J)}\, n_J \cdot p$
C: Mod. Geometric R	$p_T/(2\cosh\eta)$	$\frac{1}{\rho(R,\eta_J)}\, n_J \cdot p$
D: XCone ($\beta = 2$)	$p_T/(2\cosh\eta)$	$\frac{\cosh\eta_J}{R^2\cosh\eta}\, n_J \cdot p$
	$R^2/2$	$\cosh(\Delta\eta) - \cos(\Delta\phi)$

- shapes of jet areas for $R = 1$ for different η_J:



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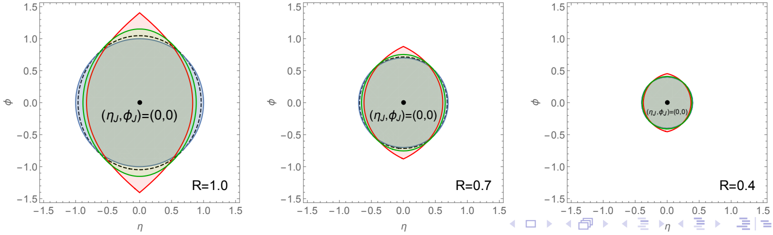
D: XCone ($\beta = 2$)	$p_T/(2\cosh\eta)$	$\frac{\cosh\eta_J}{R^2\cosh\eta}\, n_J \cdot p$
	$R^2/2$	$\cosh(\Delta\eta) - \cos(\Delta\phi)$

- shapes of the jet areas for $\eta_J = 0$ for different R:



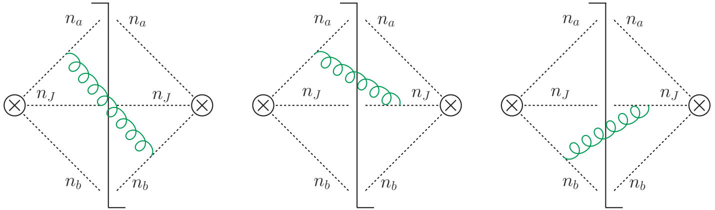
Soft function diagrams

- aim: compute associated one-loop soft functions

$$S(\ell_J,\ell_B) \sim \mathrm{tr}\Big[\big\langle 0\big|\bar{T}[Y^\dagger_{n_a} Y_{n_b} Y_{n_J}]\big|X_s\big\rangle\big\langle X_s\big|T[Y^\dagger_{n_J} Y^\dagger_{n_b} Y_{n_a}]\big|0\big\rangle\Big] F(\ell_J,\ell_B,\{p_i^{X_s}\})$$

$$F(\ell_B,\ell_J,\{p_i\}) = \delta\Big(\ell_J - \sum_{i\in J} n_J\cdot p_i\Big)\delta(\ell_B) + \delta\Big(\ell_B - \sum_{i\in B} p_{Ti}\, f(\eta_i)\Big)\delta(\ell_J)$$

- real radiation diagrams



$$S^{(1)} \equiv S_{ab} + S_{aJ} + S_{bJ}$$

- integral expression:

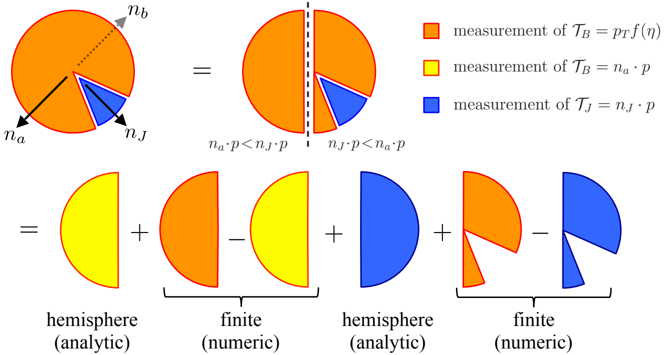
$$S_{ij} = -2\mathbf{T}_i\cdot\mathbf{T}_j\left(\frac{e^{\gamma_E}\mu^2}{4\pi}\right)^{\epsilon} g^2 \int \frac{\mathrm{d}^d p}{(2\pi)^{d-1}}\,\frac{n_i\cdot n_j}{(n_i\cdot p)(n_j\cdot p)}\,\delta(p^2)\,\theta(p^0)\,F(\ell_J,\ell_B,p)$$

General hemisphere decomposition

- Strategy:
  $\rightarrow$ compute analytic result for a measurement with the same divergent behavior
  $\rightarrow$ compute the remaining mismatch numerically in 4d
- hemisphere decomposition [Jouttenus, Stewart, Tackmann, Waalewijn (2011)]
  (related method used also in [Bauer, Dunn, Hornig (2011)])
  $\rightarrow$ soft function for N-jettiness jets with N-jettiness measurement
  $\rightarrow$ generalization to other observables and jet boundaries possible
  (see also Tomas' talk [Kasemets, Waalewijn, Zeune (2015)])

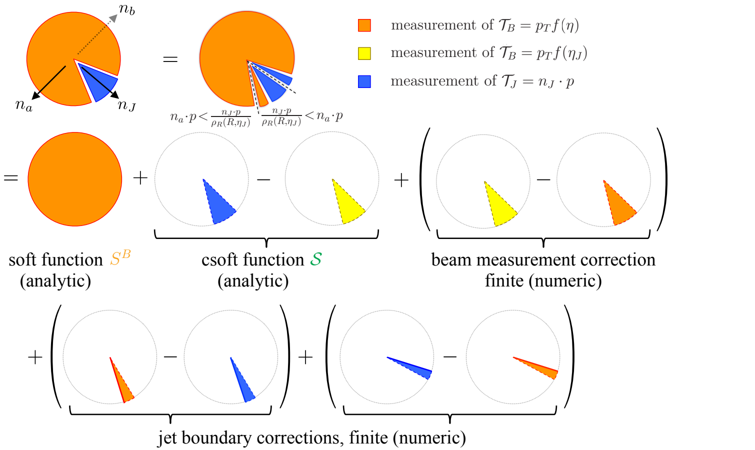
General hemisphere decomposition

- Strategy:
  $\rightarrow$ compute analytic result for a measurement with the same divergent behavior
  $\rightarrow$ compute the remaining mismatch numerically in 4d
- hemisphere decomposition [Jouttenus, Stewart, Tackmann, Waalewijn (2011)]
- example: correction from aJ-dipole for $\mathrm{SCET_I}$ measurements



- more efficient: use analytic results and compute numeric $\mathcal{O}(R^2)$ corrections

$$S_\kappa(\mathcal{T}_J, \mathcal{T}_B, \eta_J, R, \mu) = S_\kappa^B(\mathcal{T}_B, \eta_J, \mu) \otimes \mathcal{S}_{\kappa_J}\Big(\frac{2\cosh\eta_J \mathcal{T}_J}{R}, \frac{\mathcal{T}_B R}{f(\eta_J)}, \mu\Big)\,[1 + \mathcal{O}(R^2)]$$

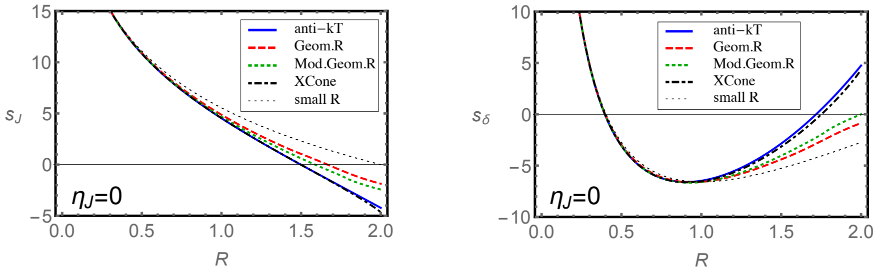


- jet boundary corrections only in regions without collinear divergences
  $\rightarrow$ applicable to all combinations of $\mathrm{SCET_I}/\mathrm{SCET_{II}}$ jet and beam measurements

Corrections from beam-jet dipole for C-parameter ($\mathrm{SCET_I}$)

$$S_{aJ}^{(1)}(\ell_J,\ell_B,\eta_J,R,\mu) = \frac{\alpha_s(\mu)}{4\pi}\,\mathbf{T}_a\cdot\mathbf{T}_J\bigg\{\frac{8}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) + \frac{8}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_J}{\mu}\Big)\,\delta(\ell_B)$$
$$+ s_B(R,\eta_J)\,\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) + s_J(R,\eta_J)\,\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_J}{\mu}\Big)\,\delta(\ell_B)$$
$$+ s_\delta(R,\eta_J)\,\delta(\ell_J)\,\delta(\ell_B)\bigg\}$$

Results for $\eta_J = 0$ in terms of R for C-parameter veto: $f_C = \frac{1}{2\cosh\eta}$

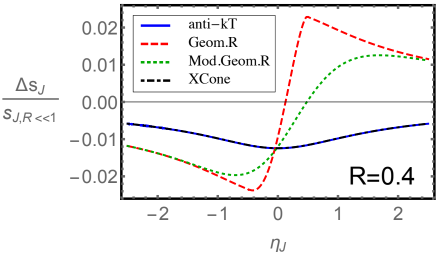


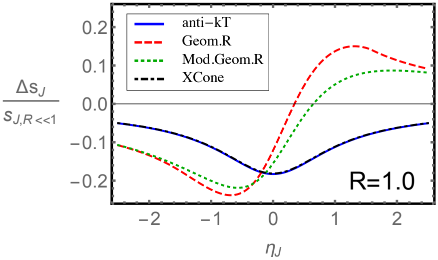
$\rightarrow$ small deviations for $R \lesssim 1$ (for central jets)

Corrections from beam-jet dipole for C-parameter ($\mathrm{SCET_I}$)

$$S^{(1)}_{aJ}(\ell_J,\ell_B,\eta_J,R,\mu) = \frac{\alpha_s(\mu)}{4\pi}\,\mathbf{T}_a\cdot\mathbf{T}_J\Big\{\frac{8}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) + \frac{8}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_J}{\mu}\Big)\,\delta(\ell_B)$$
$$+\, s_B(R,\eta_J)\,\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) + s_J(R,\eta_J)\,\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_J}{\mu}\Big)\,\delta(\ell_B)$$
$$+\, s_\delta(R,\eta_J)\,\delta(\ell_J)\,\delta(\ell_B)\Big\}$$

Relative deviations from small R limit for $R = 0.4$ and $R = 1.0$ in terms of η_J:





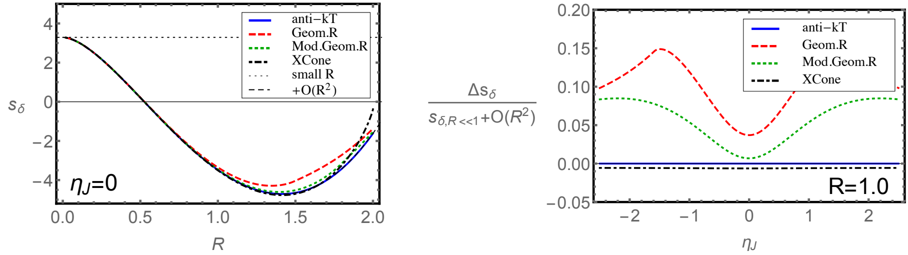
$\rightarrow$ deviations between algorithms can be sizable for large rapidities (different shape)

$\rightarrow$ small R limit reasonable approximation even for $R = 1$

Corrections from beam-beam dipole for p_T^{jet} (SCET_{II})

$$S_{ab}^{(1)}(\ell_J, p_T^{\text{cut}}, \eta_J, R, \mu, \nu) = \frac{\alpha_s(\mu)}{4\pi}\,\mathbf{T}_a \cdot \mathbf{T}_b \Big\{ \Big[8\ln^2\Big(\frac{p_T^{\text{cut}}}{\mu}\Big) - 16\ln\Big(\frac{p_T^{\text{cut}}}{\mu}\Big)\ln\Big(\frac{\nu}{\mu}\Big) \Big] \delta(\ell_J) + s_B(R,\eta_J)\Big[\ln\Big(\frac{p_T^{\text{cut}}}{\mu}\Big)\delta(\ell_J) - \mathcal{L}_0\Big(\frac{\ell_J}{\mu}\Big)\Big] + s_\delta(R,\eta_J)\,\delta(\ell_J) \Big\}$$

Result for $\eta_J = 0$ and relative deviation for $R = 1$:



→ large, common corrections to small R limit

→ with analytic $\mathcal{O}(R^2)$ corrections: identical to anti-kT

Outline

1. Factorization of jet radius effects
   - Description of hierarchies $m_J \leftrightarrow p_T^J R \leftrightarrow p_T^J$
   - Relations between the hierarchies
2. Soft functions for jet algorithms at hadron colliders
   - Calculation of jet algorithm effects
   - Results
3. Summary

Summary & Outlook

Summary:

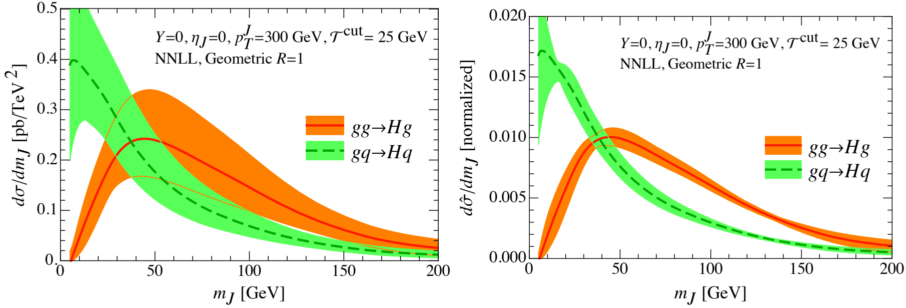
- proper treatment of jet boundary effects important for substructure analyses
  $\rightarrow$ clustering of soft radiation
  $\rightarrow$ small R effects
- for jet mass measurements: several hierarchies for $m_J \leftrightarrow p_T^J R$, $R \leftrightarrow R_0$
  $\rightarrow$ resummation of $\ln R$ in SCET_+
  $\rightarrow$ systematic combination with nonsingular corrections
  $\rightarrow$ computation of soft functions for typical jet algorithms
  $\rightarrow$ results based on small R expansion give a good approximation for $R \lesssim 1$

Coming up:

- phenomenological study for $pp \rightarrow H/W/Z + 1$ jet extending current NNLL analysis
  [Jouttenus, Stewart, Tackmann, Waalewijn (2013)]
- soft functions for overlapping jets: different clustering for anti-kT and XCone

Outline

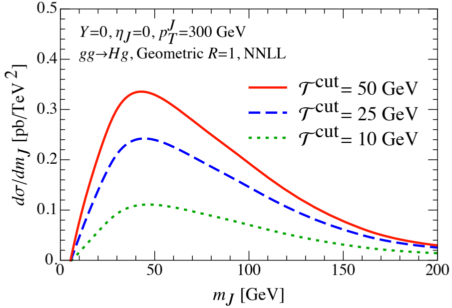
Perturbative uncertainties at NNLL

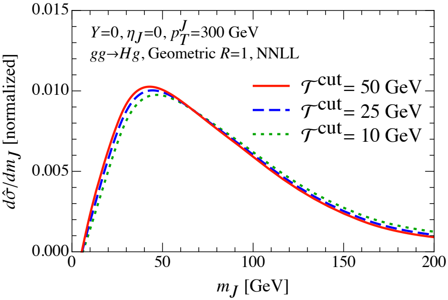


[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

⇒ reduction of perturbative uncertainties for normalized spectrum

Jet veto dependence at NNLL

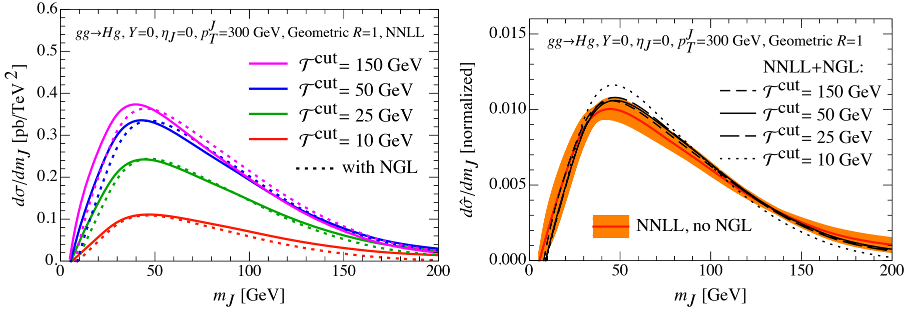




[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

$\Rightarrow$ jet veto dependence cancels mainly in normalized spectrum

Effect of NGLs

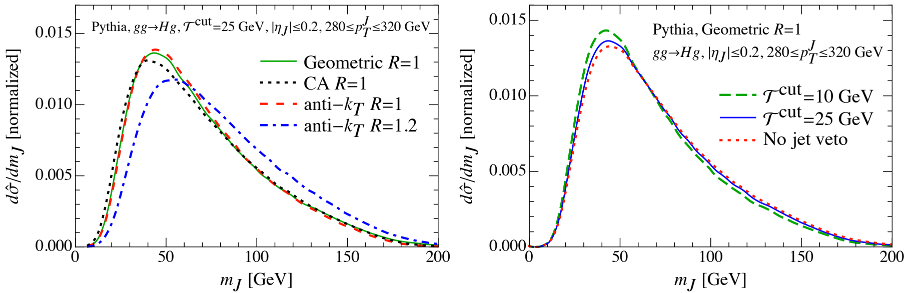


[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

$\Rightarrow$ tight veto minimizes NGLs for unnormalized spectrum around the peak region

$\Rightarrow$ mild impact of NGLs on the normalize spectrum for a wide range of jet vetoes

Jet algorithm and jet veto dependence in Pythia



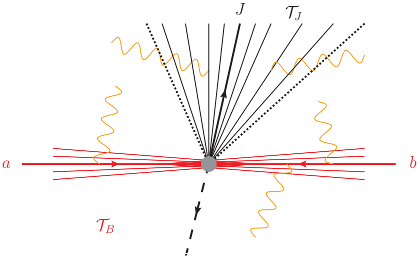
[Jouttenus, Stewart, Tackmann, Waalewijn (2013)]

⇒ 1-jettiness jets (Geometric R) give almost equivalent result to anti-kT jets in Pythia

⇒ Jet veto dependence in Pythia is small, inclusive and exclusive case not far apart

regime 4: $m_J \sim p_T^J R \sim p_T^J$

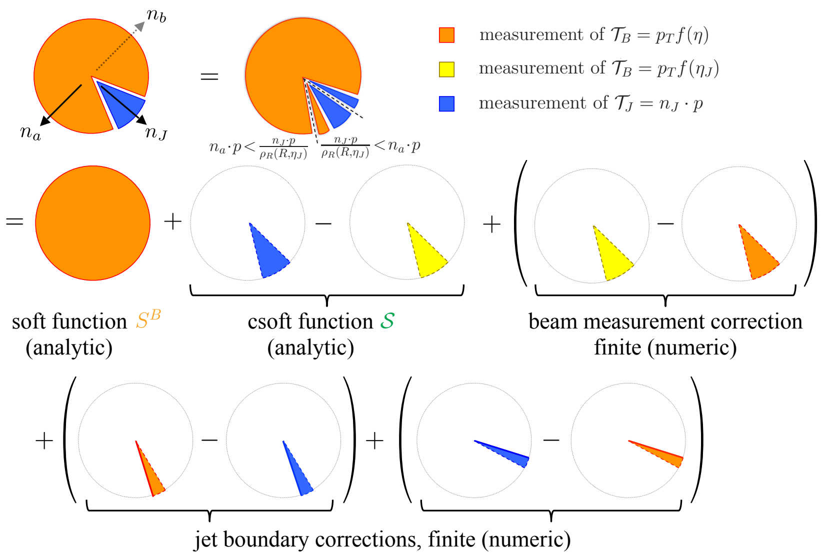
- only hard wide-angle radiation inside the “jet", no n_J-collinear modes
- soft modes resolve individual hard emissions



mode	$p^\mu = (+, -, \perp)$	$\sqrt{p^2}$
hard	(p_T^J, p_T^J, p_T^J)	p_T^J
$n_{a,b}$ – collinear	$\left(\mathcal{T}_B, p_T^J, \sqrt{p_T^J \mathcal{T}_B}\right)_B$	$\sqrt{p_T^J \mathcal{T}_B}$
usoft	$(\mathcal{T}_B, \mathcal{T}_B, \mathcal{T}_B)$	$\mathcal{T}_B$

correlated emissions

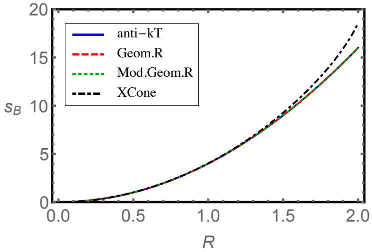
Hemisphere decomposition for small R

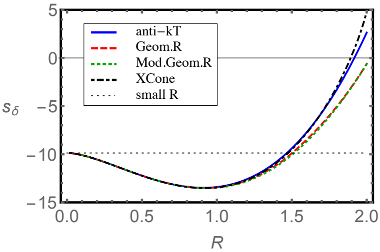


Corrections from beam-beam dipole ($\mathrm{SCET_I}$) (C-parameter)

$$S_{ab}^{(1)}(\ell_J, \ell_B, \eta_J, R, \mu) = \frac{\alpha_s(\mu)}{4\pi}\,\mathbf{T}_a \cdot \mathbf{T}_b \Big\{ \frac{16}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) + s_B(R,\eta_J)\Big[\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_B}{\mu}\Big)\,\delta(\ell_J) - \frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_J}{\mu}\Big)\,\delta(\ell_B)\Big] + s_\delta(R,\eta_J)\,\delta(\ell_J)\,\delta(\ell_B)\Big\}$$

Results for $\eta_J = 0$ for C-parameter veto: ($s_B(R,\eta_J) = 4/\pi\times$ jet area $\approx 4R^2$)





Corrections from beam-jet dipole $(\mathrm{SCET_{II}})$

$$S_{aJ}^{(1)}(\ell_J, p_T^{\mathrm{cut}}, \eta_J, R, \mu, \nu) = \frac{\alpha_s(\mu)}{4\pi}\,\mathbf{T}_a \cdot \mathbf{T}_J \Bigg\{ \Bigg[4\ln^2\Big(\frac{p_T^{\mathrm{cut}}}{\mu}\Big) - 8\ln\Big(\frac{p_T^{\mathrm{cut}}}{\mu}\Big)\ln\Big(\frac{\nu e^{-\eta_J}}{\mu}\Big)\Bigg]\delta(\ell_J)$$
$$+ \frac{8}{\mu}\,\mathcal{L}_1\Big(\frac{\ell_J}{\mu}\Big) + s_B(R,\eta_J)\ln\Big(\frac{p_T^{\mathrm{cut}}}{\mu}\Big)\delta(\ell_J)$$
$$+ s_J(R,\eta_J)\,\frac{1}{\mu}\,\mathcal{L}_0\Big(\frac{\ell_J}{\mu}\Big) + s_\delta(R,\eta_J)\,\delta(\ell_J)\Bigg\}$$

Result for $\eta_J = 0$ and for $R = 1.0$ (for p_T^{cut}):