

Novel logarithmic structures in transverse energy flow

Non-global logs promoted to LL, and coherence violation to NNDL

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Outline

OUTLINE

- 1 The observable and its relevance
- 2 Non-global logarithms enhanced to LL, and resummation challenges
- 3 Coherence-violating logarithms enhanced to NNDL
- 4 Summary



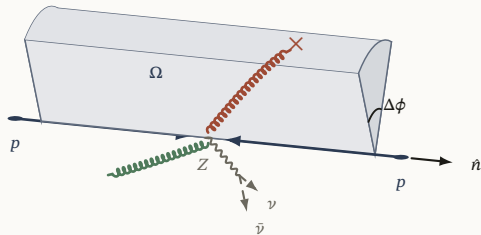
1 · The observable and its relevance

The observable

§1 · E_T FLOW INTO AZIMUTHAL SLICES

- We consider a colour-singlet system of invariant mass Q in pp collisions, and veto QCD radiation in an azimuthal gap Ω of width $\Delta\phi$ w.r.t. the beam axis.
- Σ is the fraction of events that survive a veto E_T on the transverse-energy flow $E_{T,\Omega}$ inside Ω .
- No dedicated rapidity boundary to the veto region – equivalently, $\eta_{\text{cut}} > L$.

$$E_{T,\Omega} = \sum_{k_i \in \Omega} k_{t,i}, \quad f \equiv \frac{\Delta\phi}{2\pi}, \quad L \equiv \ln \frac{Q}{E_T}$$



Dasgupta, Fraley, Monni, Nabeebaccus, PRL 137 (2026) 111906 [2511.14681]; Dasgupta, Salam, JHEP 03 (2002) 017 [hep-ph/0203009]

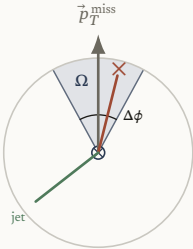
Where it is already used

§1 · ISOLATION CRITERIA

- In missing- E_T searches, radiation within an azimuthal distance $\Delta\phi$ of $\vec{p}_T^{\text{miss}}$ is vetoed as an isolation criterion.
- The azimuthal veto comes with a veto η_{cut} on the rapidity of jets. Where $\eta_{\text{cut}} \geq L$, the same infrared structures appear:

	$p_T^{\text{miss}} >$	jets vetoed	$\Delta\phi/2$	η_{cut}	L
ATLAS mono-jet	200 GeV	up to 4, $p_T > 30$ GeV	0.4–0.6	2.8	1.9
CMS mono- γ	200 GeV	leading 4, $p_T > 30$ GeV	0.5	5	1.9

$$L = \ln \frac{p_T^{\text{miss}}}{p_T^{\text{jet}}}$$



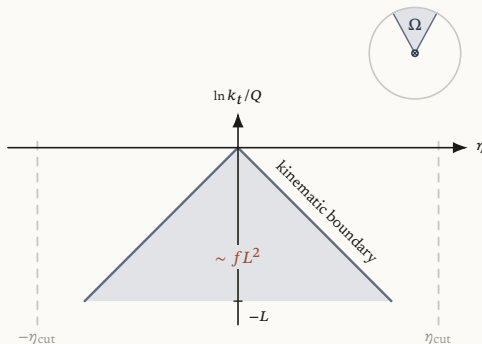
CMS, JHEP 11 (2021) 153 [2107.13021]; ATLAS, PRD 103 (2021) 112006 [2102.10874]; ATLAS, JHEP 08 (2024) 223 [2403.02793]; CMS, PRD 113 (2026) 072020 [2511.17310]

Leading-order structure

§1 · DOUBLE LOGS AND NAIVE RESUMMATION

- At $\mathcal{O}(\alpha_s)$ the veto restricts only the emission's azimuth; its rapidity runs to the kinematic bound $|\eta| \leq \ln Q/k_t$.
- The double logarithm comes from vetoing soft-collinear radiation in the gap, with $\bar{\alpha} \equiv \alpha_s/2\pi$:

$$\Sigma_{\text{DL}}^{(1)} = -R_{\text{DL}}(L) = -4C_F f \bar{\alpha} L^2$$



Leading-order structure

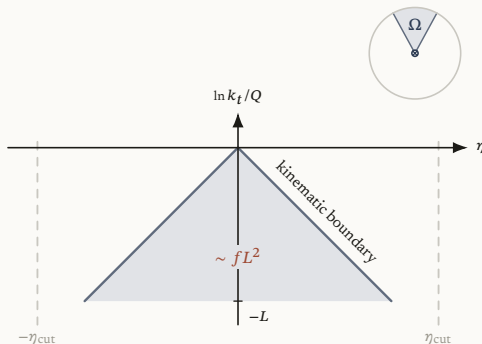
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- Naively, LL resummation is achieved by exponentiating this radiator, evaluated with a running coupling:

$$\Sigma \simeq e^{-R(L)}, \quad R(L) = \frac{4C_F f}{\pi} \int_0^L d\ell \alpha_s(Qe^{-\ell}) \ell$$



Here $e^{-R(L)}$ does not reproduce Σ at LL: non-global corrections enter already at this order.

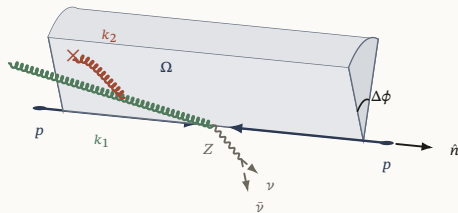


2 · Non-global logarithms enhanced to LL, and resummation challenges

Non-global logarithms

§2 · THE ENHANCEMENT AT FIXED ORDER

- The leading non-global correction, at $\mathcal{O}(\alpha_s^2)$: a soft parent k_1 outside Ω emits a softer daughter k_2 into Ω .



Dasgupta, Salam, PLB 512 (2001) 323 [hep-ph/0104277]; Banfi, Marchesini, Smye, JHEP 08 (2002) 006 [hep-ph/0206076]

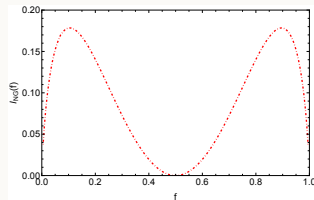
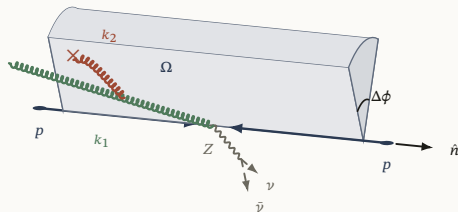
Non-global logarithms

§2 · THE ENHANCEMENT AT FIXED ORDER

- The leading non-global correction, at $\mathcal{O}(\alpha_s^2)$: a soft parent k_1 outside Ω emits a softer daughter k_2 into Ω .
- As for any non-global observable, the vetoed k_2 brings a single log. But the out-of-gap k_1 can reach the soft-collinear region, giving an extra log – $\bar{\alpha}^2 L^3$ rather than $\bar{\alpha}^2 L^2$:

$$\Sigma_{\text{NG}}^{(2)} = -\frac{8}{3} C_F C_A I_{\text{NG}}(f) \bar{\alpha}^2 L^3$$

$$I_{\text{NG}}(f) = \int_{k_1 \notin \Omega} \frac{d\phi_1}{2\pi} \int_{k_2 \in \Omega} \frac{d\phi_2}{2\pi} \int_{-\infty}^{\infty} d\eta_{12} \frac{\cos \phi_{12}}{\cosh \eta_{12} - \cos \phi_{12}}$$



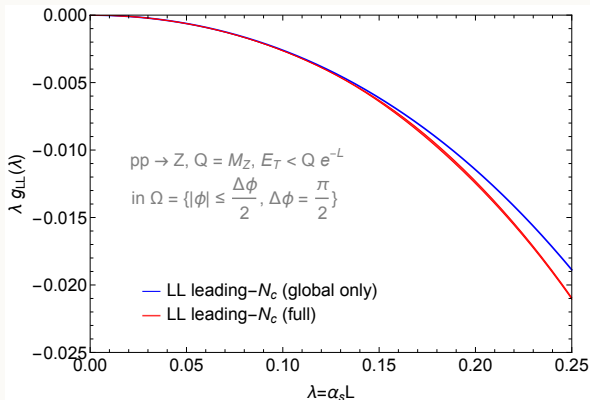
Dasgupta, Salam, PLB 512 (2001) 323 [hep-ph/0104277]; Banfi, Marchesini, Smye, JHEP 08 (2002) 006 [hep-ph/0206076]

LL resummation

§ 2 · RESUMMATION

$$\ln \Sigma = L g_{\text{LL}}(\alpha_s L) + g_{\text{NLL}}(\alpha_s L) + \dots$$

- LL resummation in the Veneziano limit, $N_c \sim n_f \gg 1$: the full non-global tower of soft emissions at commensurate angles and strongly ordered energies, in GnoLe.
- Emission rapidities are bounded by $|\eta_i| \leq \ln Q/k_{t,i}$, which captures the additional collinear enhancement.
- The deviation from the global result, $g_{\text{LL}}^{\text{global}} = -R/L$, shows non-global logarithms are present at LL.



$\lambda = \alpha_s L$, $f = \frac{1}{4}$; $\lambda \simeq 0.25$ is $E_T = 30$ GeV at $Q = 500$ GeV.

Banfi, Dreyer, Monni, JHEP 10 (2021) 006 [2104.06416]; JHEP 03 (2022) 135 [2111.02413]

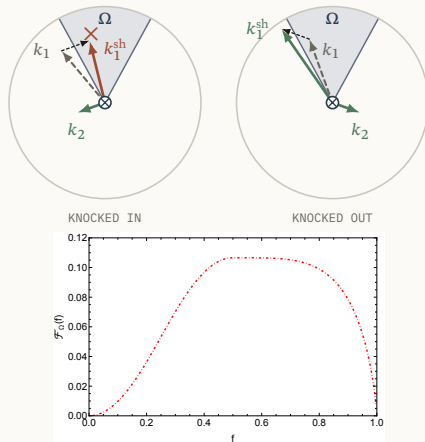
Parton showers

§2 · ISSUES WITH DIPOLE-LOCAL RECOIL

- In k_t -ordered dipole showers with dipole-local recoil, two soft emissions with commensurate k_t and disparate rapidity get their transverse recoil wrongly attributed.
- That modifies $k_{t,1}$ by an $\mathcal{O}(1)$ factor, usually contributing an NLL effect.
- Here the recoil can move k_1 into or out of Ω , causing an enhanced LL error that kicks in at $\mathcal{O}(\alpha_s^2)$:

$$\delta\Sigma = \left(\frac{2C_F\alpha_s}{\pi}\right)^2 \frac{2}{3} L^3 \mathcal{F}_\Omega$$

- This highlights the need for higher-logarithmic-accuracy parton showers.



Dasgupta, Dreyer, Hamilton, Monni, Salam, JHEP 09 (2018) 033 [1805.09327]

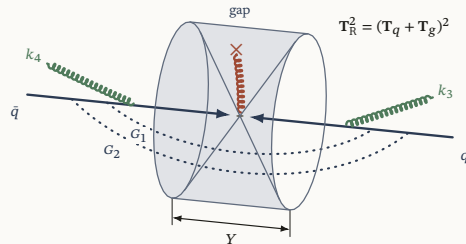
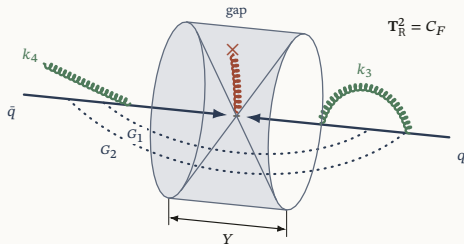


3 . Coherence-violating logarithms enhanced to NNDL

Gaps between jets

§3 · LEADING CVL IN DRELL--YAN

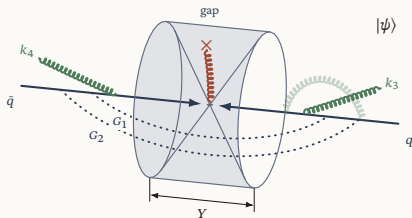
- Coherence-violating logarithms (CVLs) arise from a lack of real-virtual cancellation for soft-collinear emissions out of the gap.
- A soft gluon vetoed in the gap is emitted coherently by everything on one side of it: its colour factor is the squared colour charge on that side, T_R^2 .
- Coherence violation arises because, with k_3 real, a Coulomb gluon can change the total colour charge on the right, T_R^2 . With k_3 virtual, $T_R^2 = C_F$ and it cannot.



Forshaw, Kyrieleis, Seymour, JHEP 08 (2006) 059 [hep-ph/0604094]; Forshaw, Kyrieleis, Seymour, JHEP 09 (2008) 128 [0808.1269]; Becher, Neubert, Shao, PRL 127 (2021) 212002 [2107.01212]

The colour structure

§3 · LEADING CVL IN DRELL--YAN



- $|\psi\rangle$ is the state of the Born $q\bar{q}$ plus k_3 and k_4 , with k_3 either real or virtual. Each side of the gap is a pure triplet: $\mathbf{T}_R^2|\psi\rangle = C_F|\psi\rangle$.
- $\mathbf{T}_{12}$, a Glauber exchange, moves colour across the gap.
- $\mathbf{P}_\rho$ projects the hemisphere colour charge onto the irrep ρ , with Casimir $\mathbf{T}_R^2 = \lambda_\rho$.

The coherence-violating contribution is proportional to

$$\langle\psi|[\mathbf{T}_{12}, [\mathbf{T}_{12}, \mathbf{\Gamma}^R]]|\psi\rangle = -2 \sum_{\rho} (\lambda_{\rho} - C_F) \langle\psi| \mathbf{T}_{12} \mathbf{P}_{\rho} \mathbf{T}_{12} |\psi\rangle \quad \leftarrow \text{For } \rho \neq 3: \text{ zero unless both hemispheres contain a real gluon.}$$

Any emission into the gap sees this change in colour charge, so the contribution comes with a factor Y .

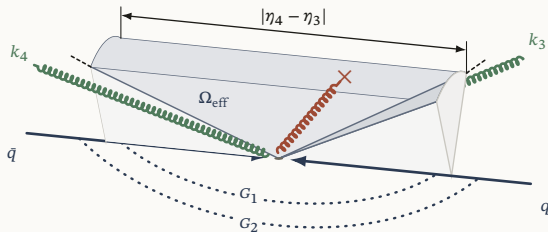
- After the Glauber exchange the hemisphere colour charge lies in $\mathbf{3} \otimes \mathbf{8} = \mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$, with $\lambda_{\rho} = \frac{4}{3}, \frac{10}{3}, \frac{16}{3}$.
- The triplet has $\lambda_3 = C_F$ and drops out, so only $\bar{\mathbf{6}}$ and $\mathbf{15}$ contribute.

Forshaw, Kyrieleis, Seymour, JHEP 09 (2008) 128 [0808.1269]; Becher, Neubert, Shao, Stillger, JHEP 12 (2023) 116 [2307.06359]

CVLs in azimuthal vetoes

§3 · THE EFFECTIVE GAP

- Everything is as before except the geometry of the gap: k_3 and k_4 split Ω into three rapidity regions.
- Between η_3 and η_4 lies an **effective gap**: emissions into it see exactly the same coherence violation as before.
- In the two regions collinear to the beam, the colour factor for radiating into them is still C_F : the Glauber has no effect.



Dasgupta, Fraley, Monni, Nabeebaccus, PRL 137 (2026) 111906 [2511.14681]

The leading CVL

§ 3 · NNDL

The leading $\mathcal{O}(\alpha_s^5)$ contribution, with $k_{t,3} \gg k_{t,4} \gg k_t \gg E_T$ and $|\eta_i| < \ln Q/k_{t,i}$:

$$\hat{\sigma}_{\text{CVL}} = \left(-\frac{2\alpha_s}{\pi} \right)^5 (1-f)^2 \int_{E_T}^Q \frac{dk_{t,3}}{k_{t,3}} \int_{-\eta_3^{\max}}^{\eta_3^{\max}} d\eta_3 \int_{E_T}^{k_{t,3}} \frac{dk_{t,4}}{k_{t,4}} \int_{-\eta_4^{\max}}^{\eta_4^{\max}} d\eta_4 \int_{E_T}^{k_{t,4}} \frac{dk_t}{k_t} \frac{1}{3} \ln^2 \frac{k_{t,4}}{E_T} \\ \times \langle \psi | [\Gamma^{\text{I}}, [\Gamma^{\text{I}}, \Gamma^{\text{R}}]] | \psi \rangle$$

The only change from the rapidity gap is the angular factor, $Y \rightarrow f |\eta_4 - \eta_3|$; the colour algebra is the same:

$$\langle \psi | \cdots | \psi \rangle = \pi^2 C_F \frac{N_c^2}{8} f |m_0|^2 |\eta_4 - \eta_3|$$

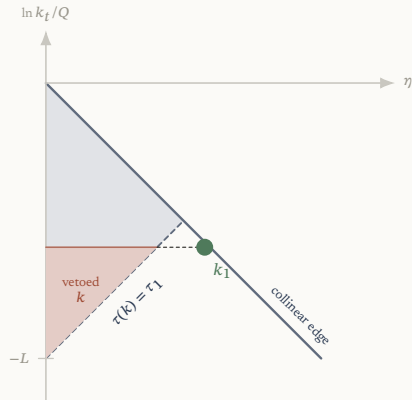
$$\Sigma_{\text{CVL}}^{(5)} = -\pi^2 C_F N_c^2 f (1-f)^2 \frac{8}{45} \bar{\alpha}^5 L^8$$

Dasgupta, Fraley, Monni, Nabeebaccus, PRL 137 (2026) 111906 [2511.14681]; Forshaw, Kyrieleis, Seymour, JHEP 09 (2008) 128 [0808.1269]

Other log-enhanced CVLs

§3 · ONE-JETINESS, AND RESUMMATION

- One-jettiness in colour-singlet + jet production: CVLs start at $\alpha_s^4 L^6$ (NNDL), one log beyond gaps between jets.
- Same mechanism, with the jet already there: one soft-collinear k_1 suffices, and a vetoed k at wider angle still fills a **double-log** phase space.
- Resummation: in gaps between jets the vetoed gluon is single-log, so one soft insertion suffices. Here any number of vetoed emissions must be resummed.



Banfi, Forshaw, Holguin, 2511.11799; Becher, Neubert, Shao, PRL 127 (2021) 212002 [2107.01212]; Becher, Neubert, Shao, Stillger, JHEP 12 (2023) 116 [2307.06359]



4 · Summary

Summary & outlook

§ 4 · SUMMARY

- With an azimuthal veto, $\eta_{\text{cut}} > L$, the observable is double-logarithmic.
- Resummed at LL with Gno1e, including the non-global logarithms, which enter already at LL.
- k_t -ordered dipole showers with dipole-local recoil fail at LL.
- CVLs enter at NNDL, $\bar{\alpha}^5 L^8$.

Outlook

- Evaluate higher-logarithmic-accuracy showers on this observable.
- Attempt a resummation of the CVLs.
- Study the regime $\eta_{\text{cut}} \sim L$, completing the coverage of E_T vetoes in non-global regions.

Dasgupta, Fraley, Monni, Nabeebaccus, PRL 137 (2026) 111906 [2511.14681]

Backup

Two log countings

BACKUP

Count in Σ , at fixed $\alpha_s L^2 \sim 1$:

$$\Sigma = 1 + g_{\text{DL}}(\alpha_s L^2) + \frac{1}{L} g_{\text{NDL}}(\alpha_s L^2) + \dots$$

or, where Σ exponentiates, in $\ln \Sigma$ at fixed $\alpha_s L \sim 1$:

$$\ln \Sigma = L g_{\text{LL}}(\alpha_s L) + g_{\text{NLL}}(\alpha_s L) + \dots$$

- With $|\eta| < \eta_{\text{cut}} \sim \mathcal{O}(1)$ the series is single-logarithmic: $g_{\text{DL}} = g_{\text{LL}} = 0$. CVLs start at $N^3\text{DL}$ in Σ ; in $\ln \Sigma$ they are super-leading, so that counting holds only at large N_c .
- Here non-global logarithms appear already in g_{NDL} and g_{LL} .

Dasgupta, Salam, PLB 512 (2001) 323 [hep-ph/0104277]; Forshaw, Kyrieleis, Seymour, JHEP 08 (2006) 059 [hep-ph/0604094]

The Gno1e algorithm

BACKUP

- Start from the Born $q\bar{q}$ dipole, with a collinear cutoff η_M in its rest frame.
- Pick dipole ℓ with probability $\Delta\eta_\ell/\Delta\eta_{\text{tot}}$; step the evolution time by $e^{-\Delta\eta_{\text{tot}}\Delta t} = r$.
- Generate $k_{t,i}$ from t_i ; ϕ_i and η_i uniform in the dipole frame, with $|\eta_i| \leq \ln Q/k_{t,i}$.
- Split the dipole in two. If $k_i \in \Omega$, histogram t_i and start a new event.

Evolution time:

$$t = \int_{k_t/Q}^1 \frac{dx}{x} \frac{N_c \alpha_s(xQ)}{\pi} = -\frac{N_c}{2\pi\beta_0} \ln(1 - 2\beta_0\lambda)$$

- Normalised momenta and no momentum conservation: no subleading-power terms.
- The bound generates small subleading logs; they are removed by $\lambda g_{\text{LL}} = \lim_{\alpha_s \rightarrow 0} \alpha_s \ln \Sigma$.

Dasgupta, Salam, PLB 512 (2001) 323 [hep-ph/0104277]; Banfi, Dreyer, Monni, JHEP 10 (2021) 006 [2104.06416]; JHEP 03 (2022) 135 [2111.02413]; Dasgupta *et al.*, PRL 125 (2020) 052002 [2002.11114]

The colour algebra

BACKUP

Real and imaginary parts of the anomalous dimension:

$$\Gamma^R = -\frac{1}{2} \sum_{i < j} \mathbf{T}_i \cdot \mathbf{T}_j \int_{k \in \Omega} \frac{d\eta d\phi}{2\pi} \omega_{ij}, \quad \Gamma^I = i\pi \mathbf{T}_1 \cdot \mathbf{T}_2 + \frac{i\pi}{4} (\mathbf{T}_1^2 + \mathbf{T}_2^2 - \sum_{i \geq 3} \mathbf{T}_i^2)$$

With strongly ordered rapidities, $\omega_{ij} \approx \Theta(\eta_i - \eta) \Theta(\eta - \eta_j) + (i \leftrightarrow j)$, and

$$\Gamma^R = f \left[C_F \ln \frac{Q}{k_t} + \Theta(\eta_3 - \eta_4)(\eta_3 - \eta_4) \left(\frac{C_A}{2} + \mathbf{T}_1 \cdot \mathbf{T}_3 \right) + (3 \leftrightarrow 4) \right]$$

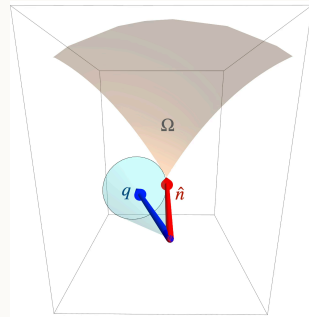
- The Casimir terms cancel in $[\Gamma^I, [\Gamma^I, \Gamma^R]]$ – including $C_F \ln Q/k_t$: the soft gluon's collinear singularity does not contribute to CVLs.
- What survives carries $|\eta_4 - \eta_3|$.

Catani, Seymour, NPB 485 (1997) 291 [hep-ph/9605323]; Forshaw, Kyrieleis, Seymour, JHEP 09 (2008) 128 [0808.1269]

Lepton colliders

BACKUP

- $e^+e^- \rightarrow q\bar{q}$ at centre-of-mass energy Q : the logarithmic structure depends on the choice of reference axis $\hat{n}$.
- A soft-collinear emission at angle θ to its emitter can enter Ω only if θ exceeds the emitter-axis misalignment $\theta_{\hat{n},\text{em}}$: **tilt**.
- Thrust axis: recoil of the hardest soft-collinear emission sets $\theta_{\hat{n},q} \approx k_{t,1}/Q$ – tilt at DL. WTA axis: misalignment needs a hard-collinear branching – NDL.
- There are no CVLs: no incoming coloured partons.



Brandt *et al.*, PL 12 (1964) 57; Farhi, PRL 39 (1977) 1587; Larkoski, Neill, Thaler, JHEP 04 (2014) 017 [1401.2158]

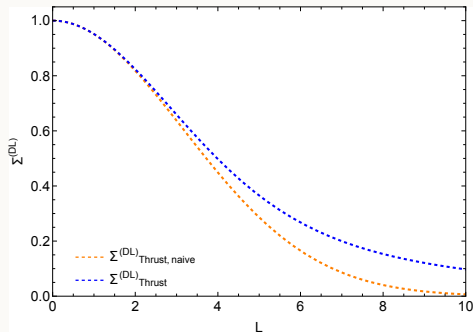
Thrust axis

BACKUP

The naive factorised veto fails even at DL. The hardest emission k_1 recoils the quark; the others are not vetoed from the recoil region Ω_c , nor beyond $\eta_{nq} \simeq \ell_1$. Closed form at DL, $f < \frac{1}{2}$:

$$\Sigma_{\text{Thrust}}^{(\text{DL})} = \frac{1}{(1-2f)^2} \left(1 - 2f + e^{\kappa f^2 L^2} \sqrt{\kappa} (1-2f) f L \sqrt{\pi} \right. \\ \left. \times [\text{erf}(-\sqrt{\kappa}(1-f)L) + \text{erf}(\sqrt{\kappa}fL)] \right)^2$$

$\kappa \equiv 2\bar{\alpha}C_F/(1-2f)$; fixed coupling.



$f = 1/4, \bar{\alpha} = 0.118/2\pi$.

WTA axis

BACKUP

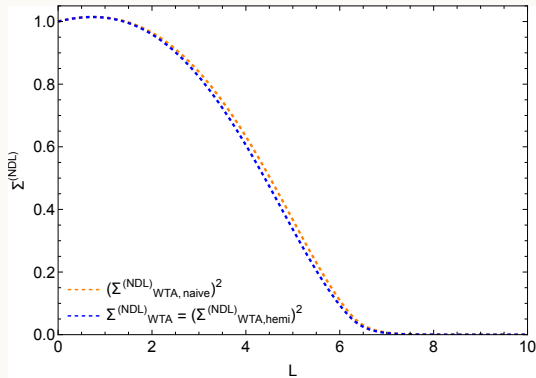
The WTA axis aligns with the quark: no recoil, and the DL result is simple exponentiation,

$$\Sigma_{\text{WTA}}^{(\text{DL})} = e^{-4C_F f \bar{\alpha} L^2}$$

- At NDL the axis can swap onto a hard-collinear gluon ($z > \frac{1}{2}$) and the veto no longer factorises. With the running coupling and non-global logarithms:

$$\Sigma_{\text{WTA}}^{(\text{NDL})} = e^{-\hat{R}(L)} \left(1 - \frac{8}{3} C_F C_A I_{\text{NG}}(f) \bar{\alpha}^2 L^3 \right) + \frac{1}{2} C_F \bar{\alpha} e^{-\hat{R}(L)} (1-f)(16 \ln 2 - 5) \left(\sqrt{\pi} \frac{\text{erf}(\xi L)}{2\xi} - L \right)$$

$\xi \equiv \sqrt{2\bar{\alpha}f(C_A - C_F)}$; $\hat{R}$ the NDL radiator of the pp case.

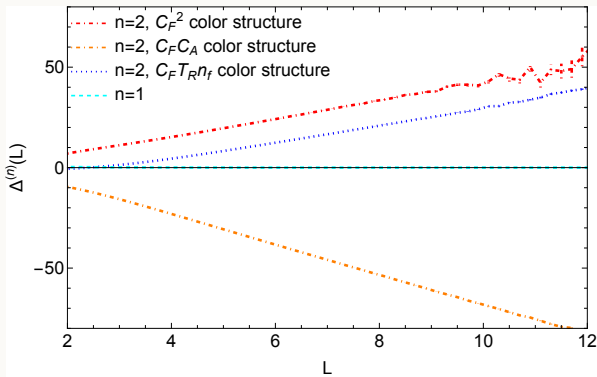


$f = 1/4, Q = M_Z.$

Checked against Event2

BACKUP

- Expand to $\mathcal{O}(\alpha_s^2)$ and compare $d\Sigma/dL$ with Event2 at $f = \frac{1}{4}$: $\Delta^{(n)}(L)$ is the difference at order n .
- At NDL one expects $\Delta^{(1)}(L) \rightarrow 0$ and $\Delta^{(2)}(L) \propto L$ as $L \rightarrow \infty$: confirmed numerically.
- This checks the NDL terms, at fixed order.



Catani, Seymour, NPB 485 (1997) 291 [hep-ph/9605323]

- At NDL: the radiator gains its hard-collinear piece, I_{NG} keeps full N_c , and a real initial-state hard-collinear emission appears:

$$\begin{aligned}\Sigma_{\text{NDL}} = & e^{-R(L)} \left(1 - \frac{8}{3} C_F C_A I_{\text{NG}}(f) \bar{\alpha}^2 L^3 \right) \\ & - 2\bar{\alpha} C_F f e^{-R(L)} L \left(\frac{(\hat{P}^{(0)} \otimes h)_q(x_1, Q)}{h_q(x_1, Q)} + \{1 \leftrightarrow 2\} \right)\end{aligned}$$

- In a typical NDL resummation the second line is reabsorbed into the evolution of the parton densities; the factor $f \neq 1$ makes that impossible.
- Beyond NDL the azimuthal cut interplays with hard-collinear dynamics (at higher orders, with spin correlations), and so with PDF evolution.

Dasgupta, Fraley, Monni, Nabeebaccus, PRL 137 (2026) 111906 [2511.14681]

The recoil coefficient

BACKUP

- $\mathcal{F}_\Omega = \mathcal{F}_\Omega^{\text{in}} + \mathcal{F}_\Omega^{\text{out}}$: k_1 recoiled into Ω from outside, and out of it from inside, with $k_2 \notin \Omega$ throughout;
 $x = k_{t,2}/k_{t,1}$.

$$\mathcal{F}_\Omega^{\text{in}} = \int \frac{dx}{x} \frac{d\phi_1}{2\pi} \frac{d\phi_2}{2\pi} \Theta_{k_1^{\text{sh}} \in \Omega} \Theta_{k_1 \notin \Omega} \Theta_{k_2 \notin \Omega}, \quad \mathcal{F}_\Omega^{\text{out}} = - \int \frac{dx}{x} \frac{d\phi_1}{2\pi} \frac{d\phi_2}{2\pi} \Theta_{k_1^{\text{sh}} \notin \Omega} \Theta_{k_1 \in \Omega} \Theta_{k_2 \notin \Omega}$$

- k_1^{sh} has $\tan \phi_1^{\text{sh}} = (\sin \phi_1 - x \sin \phi_2)/(\cos \phi_1 - x \cos \phi_2)$; the integrals are evaluated numerically.

Dasgupta, Dreyer, Hamilton, Monni, Salam, JHEP 09 (2018) 033 [1805.09327]