Next-to-next-to-leading logarithmic resummation for transverse thrust

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Based on T. Becher and XGT, JHEP **1506** (2015) 071; T. Becher, XGT and J. Piclum, arXiv:1512.00022 [hep-ph].

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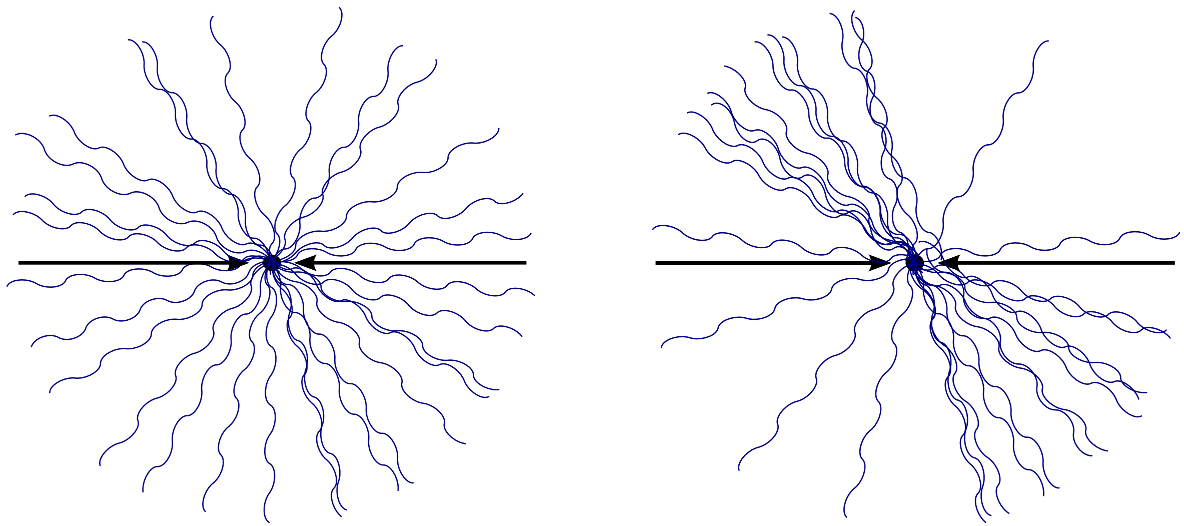
Event shapes e

Event shapes: measure energy flow in collisions. Important tool to characterize QCD effects at colliders



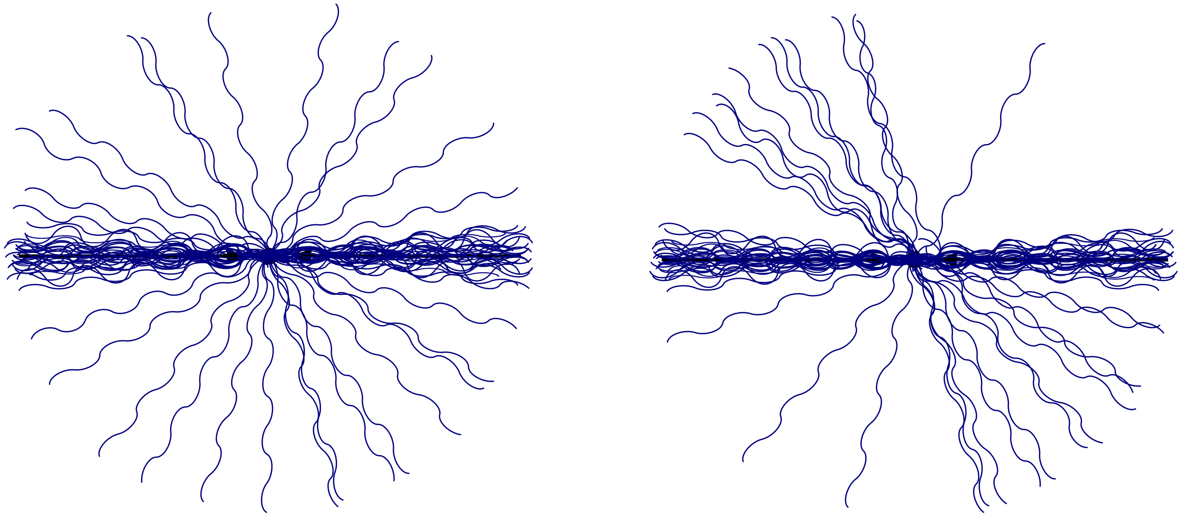
Inclusive nature: computed perturbatively, mild sensitivity to hadronisation

Can be used to test QCD, and to discriminate new physics against SM
e.g.: precision determinations of α_s

Traditionally mostly studied and used in leptonic collisions

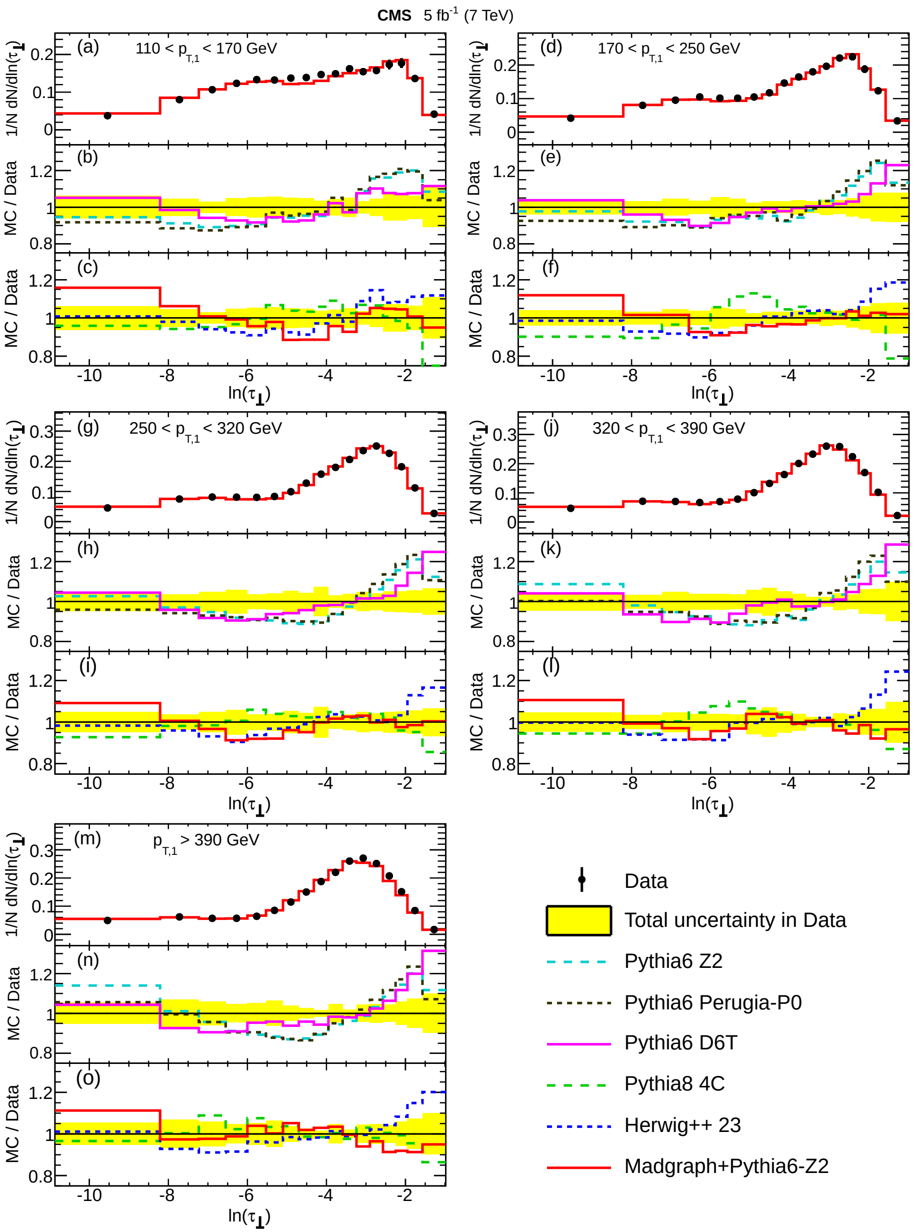
Hadronic event shapes $e_\perp$

Also of great interest in hadronic collisions. e.g.: study jet substructure, improve knowledge of underlying-event effects, ...



Large class of event shapes involving only momentum components transverse to the beam $e_\perp$ Banfi, Salam, Zanderighi '04'10. Archetypal example is transverse thrust $T_\perp$

$$T_\perp = \max_{\vec{n}_\perp} \frac{\sum_i |\vec{p}_{i\perp} \cdot \vec{n}_\perp|}{\sum_i |\vec{p}_{i\perp}|} \quad ; \quad \tau_\perp = 1 - T_\perp$$


CMS 5 fb-1 (7 TeV)
(a) 110 < pT,1 < 170 GeV
(d) 170 < pT,1 < 250 GeV
(g) 250 < pT,1 < 320 GeV
(j) 320 < pT,1 < 390 GeV
(m) pT,1 > 390 GeV
1/N dN/dln(τ⊥)
MC / Data
ln(τ⊥)
Data
Total uncertainty in Data
Pythia6 Z2
Pythia6 Perugia-P0
Pythia6 D6T
Pythia8 4C
Herwig++ 23
Madgraph+Pythia6-Z2

In the dijet limit $\tau_\perp \to 0$, enhanced effects need to be resummed to obtain reliable perturbative predictions

$$\sigma(\tau_\perp) \sim 1 + \alpha_s \left(\ln^2 \tau_\perp + \ln \tau_\perp + \cdots\right) + \alpha_s^2 \cdots$$

Resummation was performed at NLL accuracy, using the automated framework provided by CAESAR, and combined with matching to fixed order

Banfi, Salam, Zanderighi '10

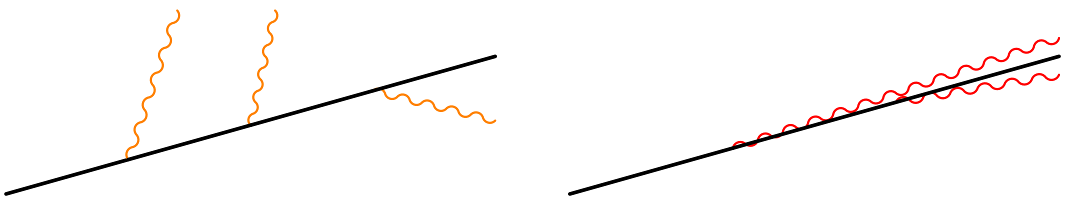
$\tau_\perp$ can be seen as ratio of disparate energy scales

$$\tau_\perp \sim \frac{\text{jet mass}}{\text{hard-collision energy}}$$

Effective Field theory techniques exploit hierarchy of energy scales to simplify the problem. Systematically factorize effects from different scales, resum enhanced terms

Soft Collinear Effective Theory

Collider processes receive enhancements from soft (low energy) and collinear (small angle) emission of radiation

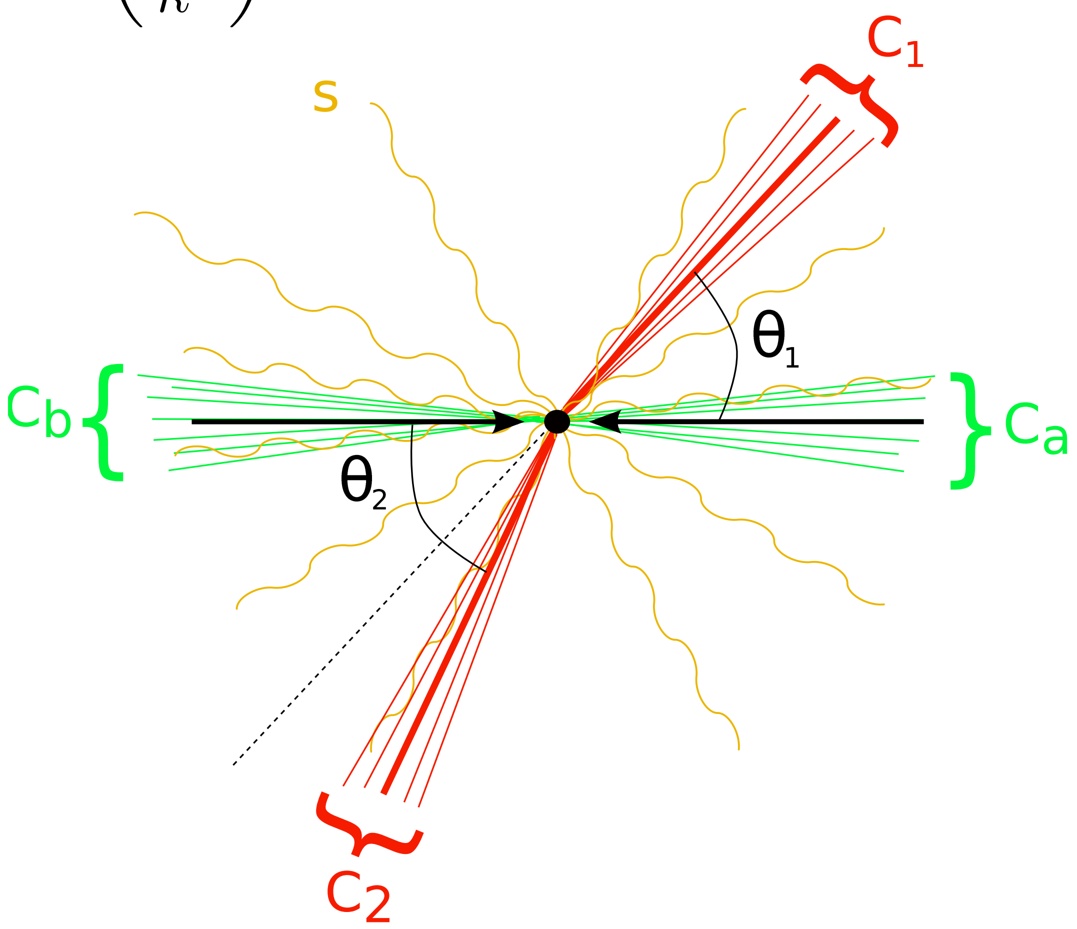


We study the transverse-thrust distribution within the effective theory framework of SCET.
Factorization formula for a generic event shape $e_\perp$ $(ab \to ij)$

$$\frac{d\sigma}{de_\perp} = \sum_{a,b,i,j} P_{IJ}^{ab\to ij} \otimes S_{JI}^{ab\to ij} \otimes J_i \otimes J_j \otimes B_a \otimes B_b$$

$$\widetilde{t}(\kappa) \sim H_{IJ}^{ab\to ij} \left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab\to ij}(\kappa)} \widetilde{S}_{JI}^{ab\to ij}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa)$$

$$\widetilde{t}(\kappa) \sim H_{IJ}^{ab\to ij}\left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab\to ij}(\kappa)} \widetilde{S}_{JI}^{ab\to ij}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa)$$



$$\widetilde{t}(\kappa) \sim H_{IJ}^{ab\to ij} \left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab\to ij}(\kappa)} \widetilde{S}_{JI}^{ab\to ij}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa)$$

Target is N^{2}LL accuracy; need **2-loop γ_f**, **2-loop anomaly exponent**, 1-loop functions (and 1-loop H, 3-loop $\gamma_{\rm cusp}$)

$$\frac{d}{d\ln\mu}\widetilde{f}(L,\mu) = \left[-C_f\,\gamma_{\rm cusp}L + \gamma_f\right]\widetilde{f}(L,\mu)$$

$$\widetilde{t}(\kappa) \sim H_{IJ}^{ab\to ij}\left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab\to ij}(\kappa)} \widetilde{S}_{JI}^{ab\to ij}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa)$$

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Consider different processes:

$$ab\to ij: \qquad H_{IJ}^{ab\to ij}\left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab\to ij}(\kappa)} \widetilde{S}_{JI}^{ab\to ij}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa)$$

$$e^+e^-\to ij: \qquad H^{ij}\left(\frac{Q^2}{\kappa^2}\right)^{-F^{ij}(\kappa)} \widetilde{S}^{ij}(\kappa)\widetilde{J}_i(\kappa)\widetilde{J}_j(\kappa),$$

$$ab\to e^+e^-: \qquad H^{ab}\left(\frac{Q^2}{\kappa^2}\right)^{-F^{ab}(\kappa)} \widetilde{S}^{ab}(\kappa)\widetilde{B}_a(\kappa)\widetilde{B}_b(\kappa),$$

Renormalization group and factorization constraints require

$$\begin{aligned}
\gamma_{H^{ab\to ij}} + \gamma_{S^{ab\to ij}} + \gamma_{B_a} + \gamma_{B_b} + \gamma_{J_i} + \gamma_{J_j} &= 0 \\
\gamma_{H^{ij}} + \gamma_{S^{ij}} + \gamma_{J_i} + \gamma_{J_j} &= 0 \\
\gamma_{H^{ab}} + \gamma_{S^{ab}} + \gamma_{B_a} + \gamma_{B_b} &= 0
\end{aligned}$$

$$F^{ab\to ij} = F^{ab} + F^{ij} = \frac{C_a + C_b}{2} F_\perp + \frac{C_i + C_j}{2} F'_\perp$$

Renormalization group and factorization constraints require

$$\begin{aligned} \gamma_{H^{ab\to ij}} + \gamma_{S^{ab\to ij}} + \gamma_{B_a} + \gamma_{B_b} + \gamma_{J_i} + \gamma_{J_j} &= 0 \\ \gamma_{H^{ij}} + \gamma_{S^{ij}} + \gamma_{J_i} + \gamma_{J_j} &= 0 \\ \gamma_{H^{ab}} + \gamma_{S^{ab}} + \gamma_{B_a} + \gamma_{B_b} &= 0 \end{aligned}$$

$$F^{ab\to ij} = F^{ab} + F^{ij} = \frac{C_a + C_b}{2} F_\perp + \frac{C_i + C_j}{2} F'_\perp$$

From $pp \to e^+e^-/\gamma\gamma$ get γ_B at two loops

From $e^+e^- \to q\bar{q}$ and using fixed-order code get γ_{J_q} and $\gamma_{S^{qq}}$

$\gamma_{S^{qq}}$ and $\gamma_{S^{gg}}$ at two loops are related by Casimir scaling, from $e^+e^- \to gg$ get γ_{J_g}

γ_S in any other channel is fixed by RG invariance

To get $F_\perp$ ($d_2^\perp$): define new observable, with known d_2, that starts differing from $e_\perp$ when there are at least two emissions. Compute difference of observables
$\tau_\perp$ in $pp \to e^+e^-$:

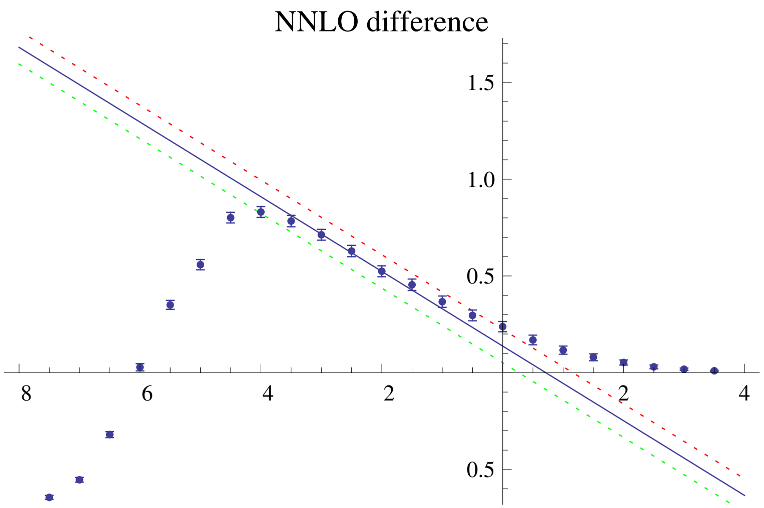
$$\mathcal{S}_\perp := |\vec{q}_\perp| - |\vec{q}_\perp \cdot \vec{n}_\perp| = |\sum_m \vec{p}_{m\perp}| - |\sum_m \vec{p}_{m\perp} \cdot \vec{n}_\perp|$$

$$\mathcal{T}_\perp := Q_\perp \tau_\perp = \sum_m \left(|\vec{p}_{m\perp}| - |\vec{p}_{m\perp} \cdot \vec{n}_\perp|\right)$$

Two-loop result for $\mathcal{S}_\perp$ from known Drell-Yan results. Difference involves $d_2^{DY} - d_2^\perp$; this term is determined by rapidity divergences of soft function. Numerically evaluate coefficient of rapidity divergence in tree-level two-emission soft amplitude squared

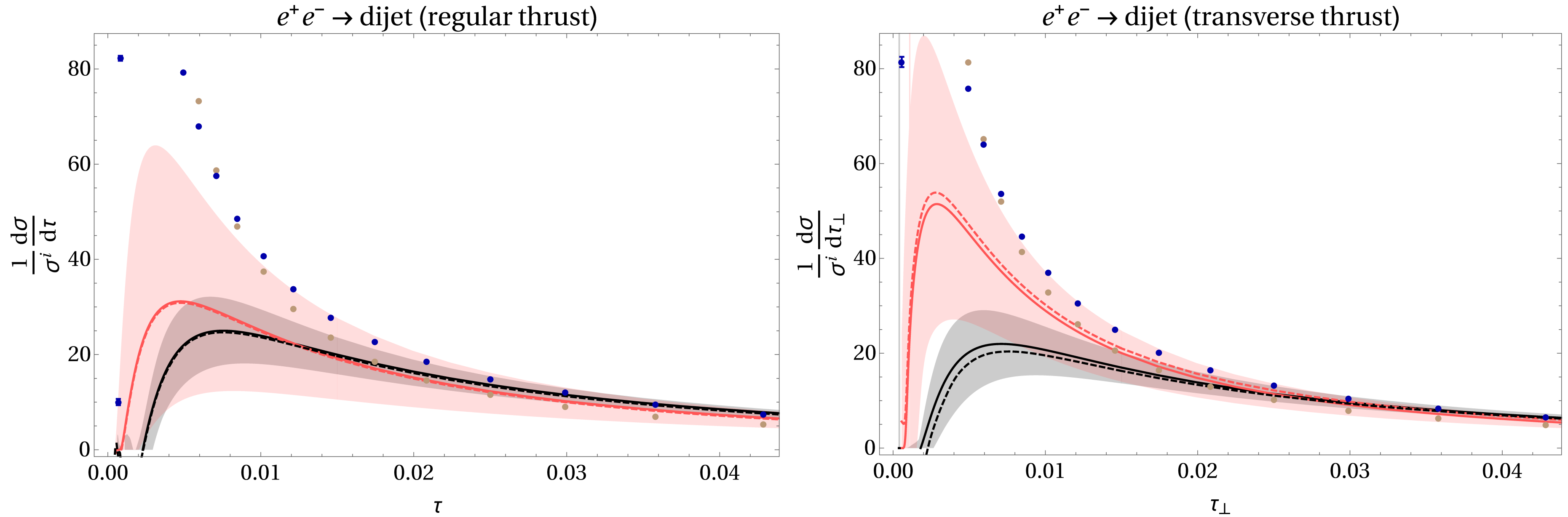
$$d_2^{\perp} = (182.3 \pm 0.1)\, C_A + (-51.881 \pm 0.006)\, T_F n_f$$

Cross-check with fixed order code (DYNNLO Grazzini)



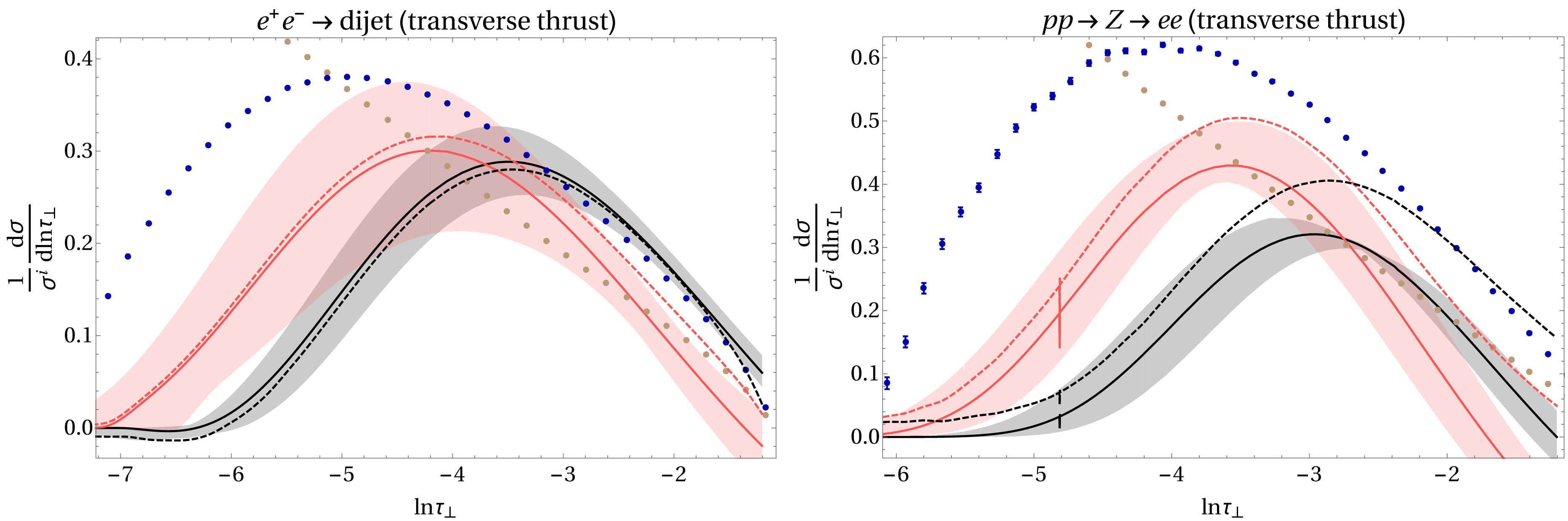
We find in general much larger coefficients than in lepton-collider event shapes

Results



NLL   N^{2}LL $\mathcal{O}(\alpha_s)$ fixed-order results $\mathcal{O}(\alpha_s^2)$ fixed-order results

Results



NLL N^{2}LL $\mathcal{O}(\alpha_s)$ fixed-order results $\mathcal{O}(\alpha_s^2)$ fixed-order results

Conclusions and outlook

Obtained unprecedented N^{2}LL accuracy for hadronic $e_\perp$ event shapes, by exploiting separation of scales from EFT

Procedure valid for generic $e_\perp$

Outlook:

Perform comprehensive phenomenological study of relevant processes: $pp \to \mathrm{dijet}$, $pp \to Z + \mathrm{jet}$, $pp \to ZZ$

- Need to combine with fixed order results, available or in progress from Zurich group

All ingredients are being implemented in a numerical code, to be made publicly available

Combined with numerical evaluation of one-loop jet, soft, and beam functions, obtain automated EFT-based framework for N^{2}LL resummation

Study Glauber-gluon effects issues/Relation to UE effects

Novel α_s extraction at much higher energies than with leptonic event shapes