Parton showers and resummations for non-global QCD observables

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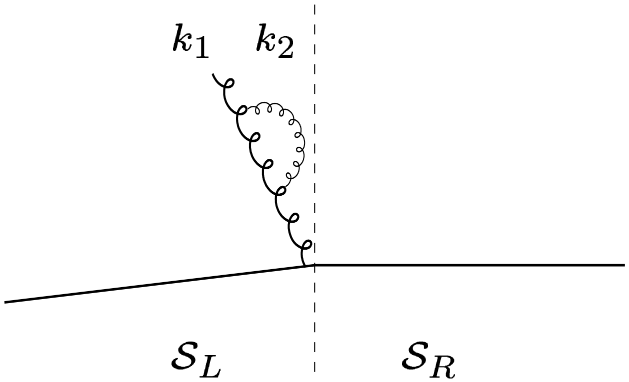
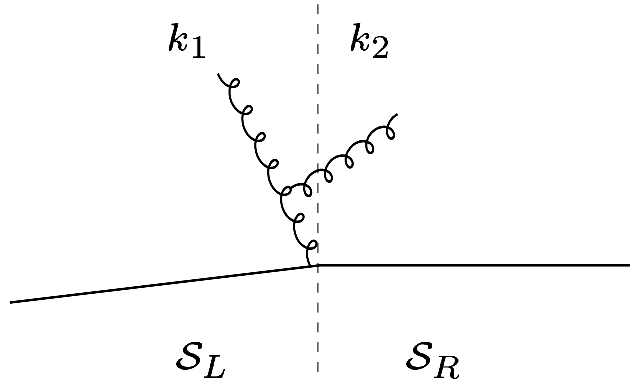
1. Non-global QCD observables: LO and resummed calculations
2. Angular-ordering approximation for non-global observables
3. Parton shower algorithms
4. Comparison of HERWIG, PYTHIA and resummed calculations
5. Conclusions

A. Banfi, G.C. and M. Dasgupta, hep-ph/0612282 (JHEP)

Non-global observables are sensitive to radiation in a limited region of the phase space

M. Dasgupta and G. Salam, PLB (2001) 323; JHEP 0203 (2002) 017; M. Dasgupta, Pramana 62 (2004) 675





Example: Jet invariant mass $(\sum_i k_i)^2$ in the right hemisphere $\mathcal{S}_R$

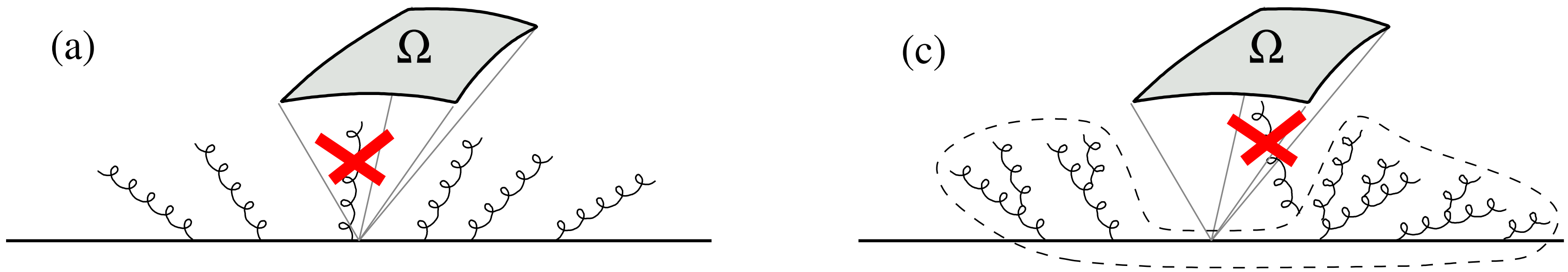
Two soft gluons $\quad |k_2| \ll |k_1| \ll Q = \sqrt{s}$

Incomplete cancellation of real and virtual diagrams in $\mathcal{S}_R$

Contributions $\alpha_S^2 L^2$: non-global logarithm due to soft and large-angle radiation in the right hemisphere

$\Sigma(L) = \exp[L g_1(\alpha_S L) + g_2(\alpha_S L) + \ldots]$ $\quad$ $L g_1$: $\alpha_S^n L^{n+1}$ (LL); g_2: $\alpha_S^n L^n$ (NLL) $\quad$ if $g_1 \neq 0$

Multiple radiation from a $q\bar{q}$ dipole in a region Ω



Transverse-energy flow in a given angular region Ω: contributions from primary (independent) and secondary (coherent) radiation

$$E_t = \sum_{i\in\Omega} E_{ti} \qquad \Sigma(Q, Q_\Omega) = \frac{1}{\sigma}\int_0^{Q_\Omega} \frac{d\sigma}{dE_t} dE_t = \exp(-4C_F A_\Omega t) S(t)$$

$$A_\Omega = \int d\eta \frac{d\phi}{2\pi} \quad ; \quad t = \frac{1}{2\pi}\int_{Q_\Omega}^{Q/2} \frac{dk}{k}\alpha_S(k) = \frac{1}{4\pi\beta_0}\ln\frac{\alpha_S(Q/2)}{\alpha_S(Q_\Omega)} \quad ; \quad Q_\Omega \ll Q$$

$\exp(-4C_F A_\Omega t)$: **exponentiation of primary radiation (angular ordering)**

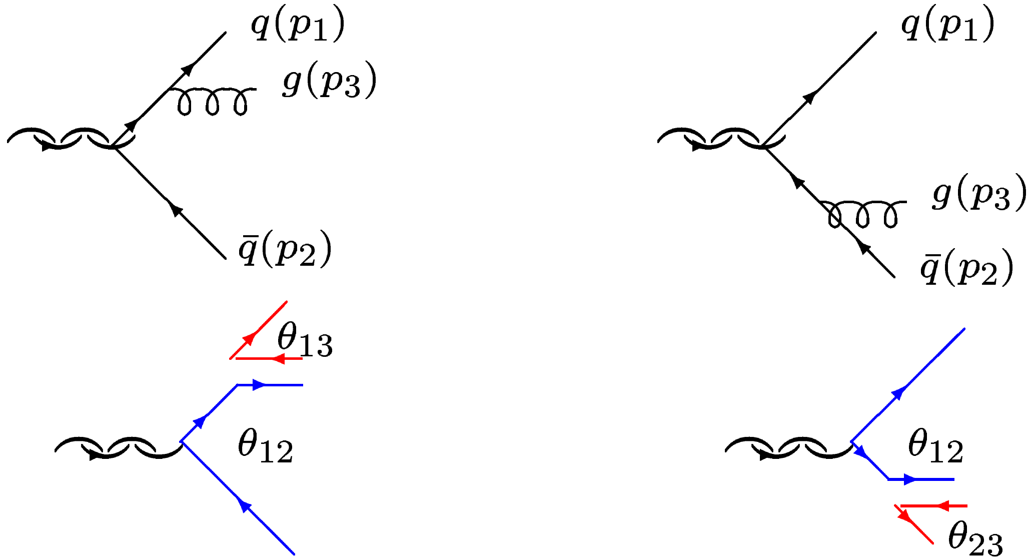
$S(t) = \sum_{n=2} S_n t^n$: **non-global logarithms, due to correlated gluon emissions**

Leading order $\sim \alpha_S^2 S_2 \ln^2(Q/Q_\Omega)$ **computed analytically** $\qquad S_2 \sim C_F C_A$

Resummation carried out numerically in the large-N_c limit:

$g_1 = 0 \Rightarrow \alpha_S^n L^n$ **are the LLs in $\Sigma(L)$**

Angular ordering



$$|\mathcal{M}|^2 \sim W = \frac{\omega^2}{2}\left(\frac{p_1}{p_1 \cdot p_3} - \frac{p_2}{p_2 \cdot p_3}\right)^2 = \frac{1-\cos\theta_{12}}{(1-\cos\theta_{13})(1-\cos\theta_{23})} \quad \textbf{(soft limit)}$$

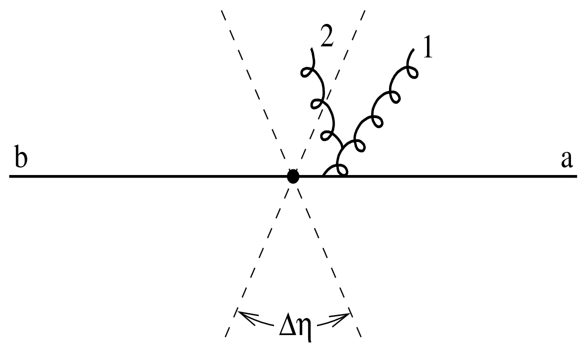
After azimuthal average:

$$W \quad \longrightarrow \quad \frac{1}{1-\cos\theta_{13}}\Theta(\theta_{12}-\theta_{13}) + \frac{1}{1-\cos\theta_{23}}\Theta(\theta_{12}-\theta_{23})$$

Angular-ordering and independent-emission approximation allow resummation of primary radiation: investigation for non-global observables

Non-global logarithms and angular ordering

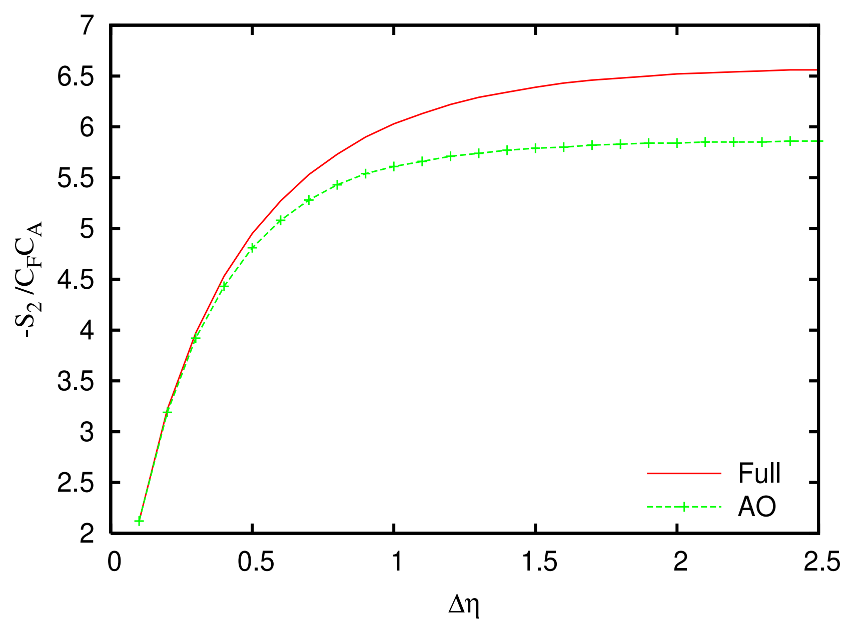
Rapidity slice $\Delta\eta$:



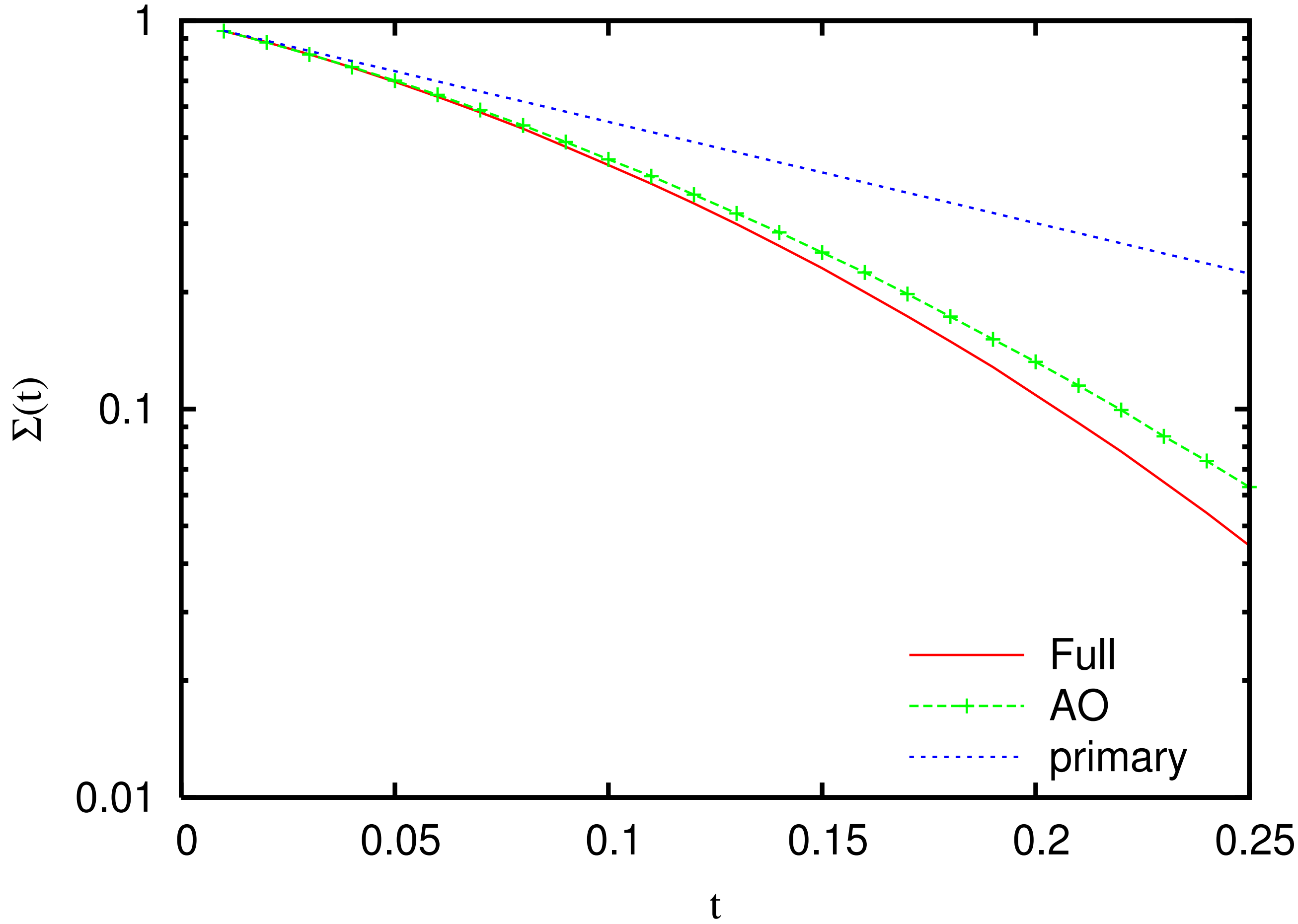
$E_t = \sum_{i\in\Delta\eta} E_{ti}$ $\quad\Sigma(Q, Q_\Omega) = \frac{1}{\sigma}\int_0^{Q_\Omega} \frac{d\sigma}{dE_t} dE_t = \exp(-4C_F A_\Omega t) S(t)$

Azimuthal average and angular-ordering approximation: $\theta_{12} < \theta_{1a}$

Full and angular-ordered result for $S(t)$ at LO $\sim \alpha_S^2 S_2 \ln^2(Q/Q_\Omega)$ for $\Delta\eta = 1$:



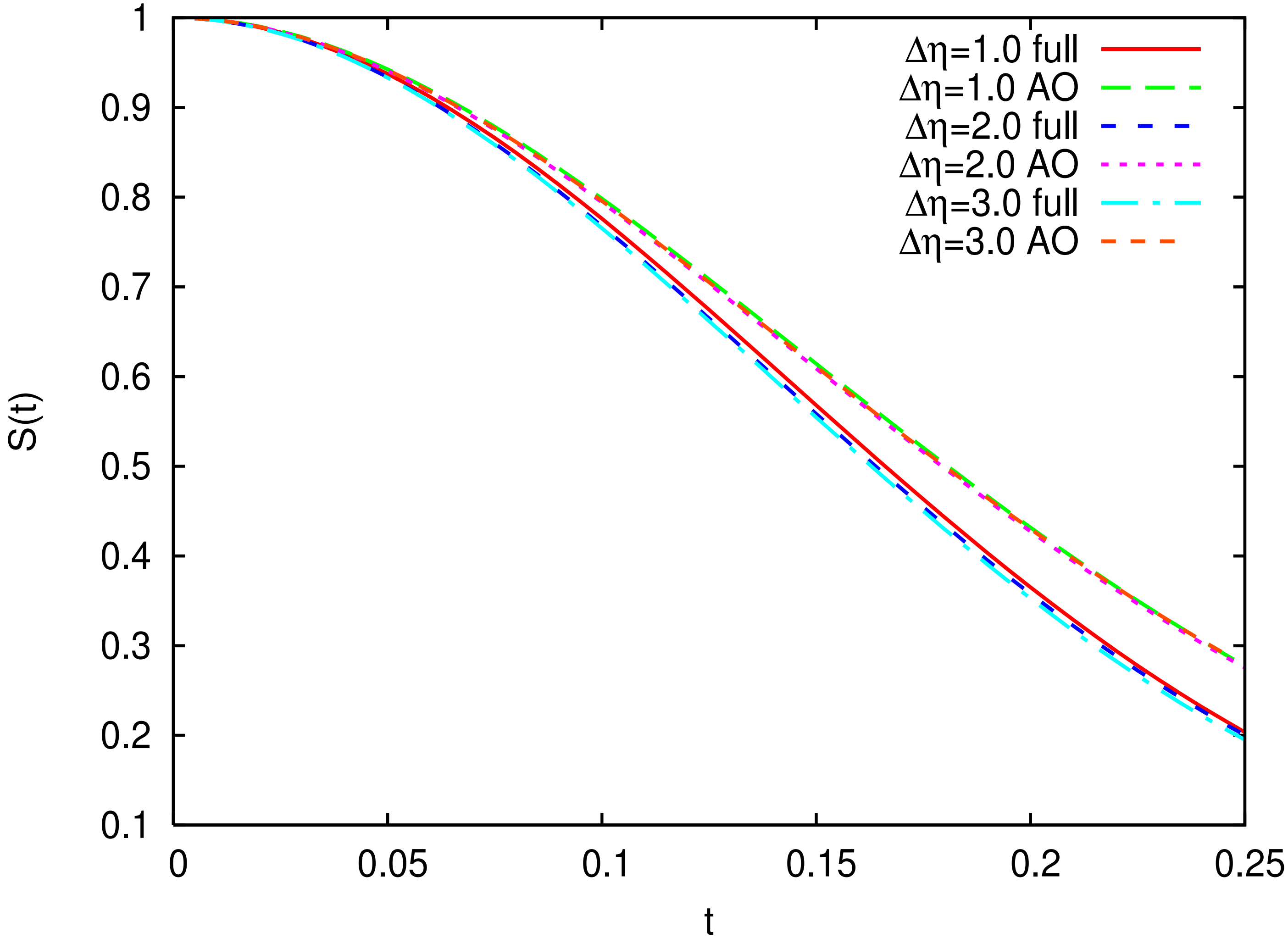
All-order resummation and angular ordering



$\Delta\eta = 1$, $t = 0.15$ ($Q = 100$ GeV; $Q_\Omega = 1$ GeV) :

AO is 10% higher than full result; primary is 75% above

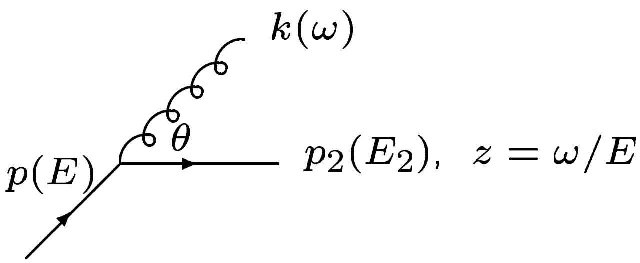
Non-global contribution for different rapidity slices:



Results are roughly independent of the value of the rapidity-slice width

Monte Carlo event generators are often tuned to non-global observables

Parton showers in the soft or collinear approximation



$$dP = \frac{\alpha_S}{2\pi} \, P(z) dz \, \frac{dQ^2}{Q^2} \, \Delta_S(Q^2_{\max}, Q^2)$$

Q^2: **ordering variable**

$\Delta_S(Q^2_{\max}, Q^2)$ **Sudakov form factor: no radiation in** $[Q^2, Q^2_{\max}]$

$$\Delta_S(Q^2_{\max}, Q^2) = \exp\left[-\frac{\alpha_S}{2\pi} \int_{Q^2}^{Q^2_{\max}} \frac{dQ'^2}{Q'^2} \int_{z_{\min}}^{z_{\max}} dz P(z) \right]$$

HERWIG : $Q^2 = E^2(1 - \cos\theta) \simeq E^2\theta^2/2$ **Soft limit: angular ordering**

PYTHIA (up to 6.2 version): $Q^2 = p^2$

It includes angular ordering via an additional veto

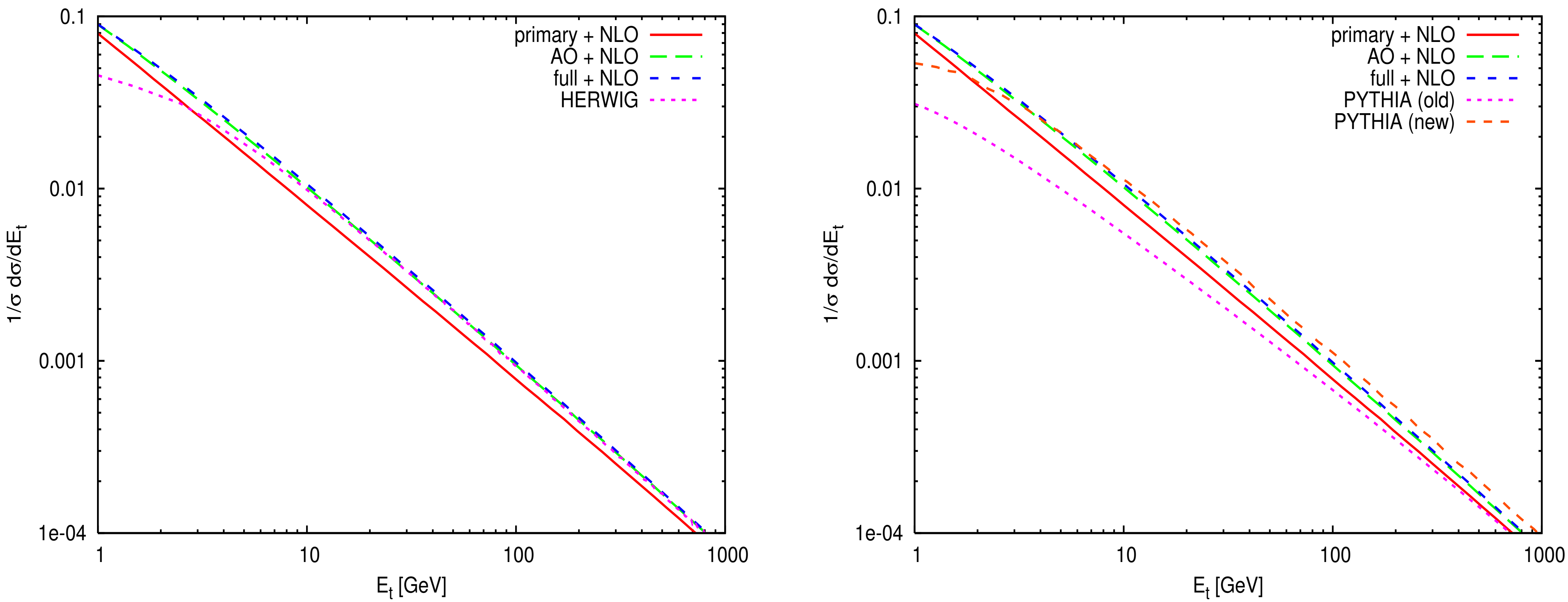
PYTHIA 6.3: $Q^2 = k_T^2$ **(better treatment of angular ordering)**

Parton showers are equivalent to LL (g_1) **resummation including some NLLs** (g_2)

S. Catani, G. Marchesini and B.R. Webber, NPB 349 (1991) 635

Comparing resummation and parton showers

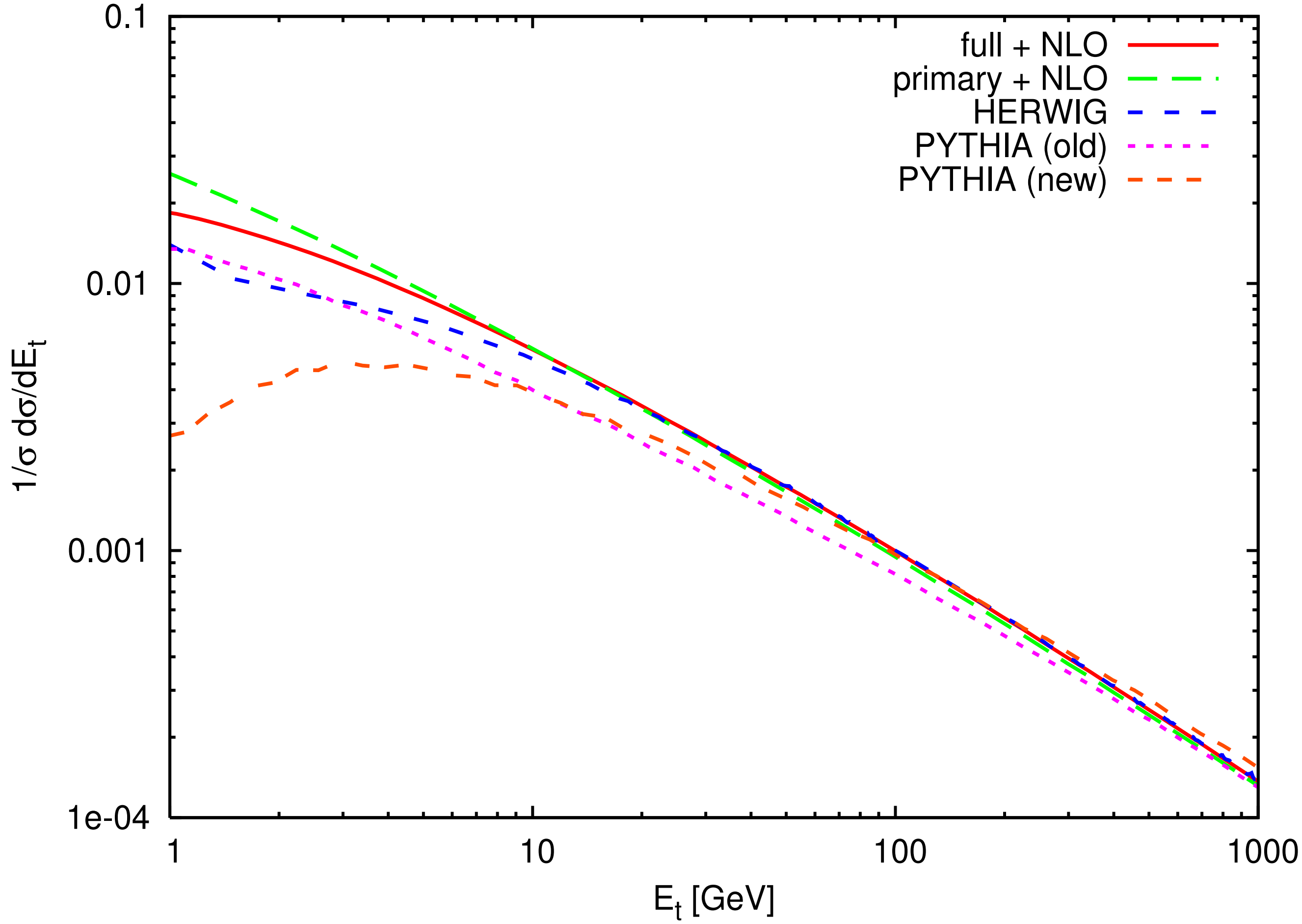
$Q = 10^5$ GeV to neglect subleading effects $\mathcal{O}(\alpha_S(Q))$ and quark masses



Difference with respect to the full resummed result for $E_t = 10$ GeV:

– 10% (HERWIG); + 7.5% (PYTHIA new); – 50% (PYTHIA old)

Comparison for $\Delta\eta = 3$



Remarkable discrepancy between the new PYTHIA model and the resummation for $E_t < 100$ GeV and large rapidity slices: further investigation is needed

Conclusions

Implementation of angular ordering in LO and resummed calculations for non-global QCD observables

Angular ordering catches a relevant part of non-global logarithms

Comparison of HERWIG, PYTHIA and resummations for transverse-energy flow in a rapidity slice

Overall reasonable agreement of HERWIG with the resummation

Discrepancies with the old PYTHIA model and with the new model for large rapidity slices

Care must be taken when fitting event generators to non-global-observable data

In progress:

Comparison with ARIADNE

Understanding the PYTHIA behaviour at large rapidity gaps

Extension to hadron collisions