

Issues on jets in kt-factorisation

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How to obtain TMDs ?

- take derivative of integrated PDF:

$$f(x, k_{\perp}^2) = \frac{dg(x, k_{\perp}^2)}{dk_{\perp}^2} = \left[\frac{\alpha_s}{2\pi} \int_x^{1-\delta} P(z) g\left(\frac{x}{z}, k_{\perp}^2\right) dz \right]$$

- KMR approach:

$$f(x, k_{\perp}^2, \mu^2) = \frac{dg(x, \mu^2)}{d\mu^2} \exp \left(- \int_{k_{\perp}^2}^{\mu^2} \frac{\alpha_s}{2\pi} d \log k_{\perp}^2 \sum_i \int_0^1 P(z') dz' \right)$$

- generated from integrated PDF, only last emission generates transverse momentum via sudakov form factor.
- this is essentially what is done in standard MC event generators:
 - use of collinear ME
 - add parton shower which produces k_t kick for ME parton
 - no double counting, since p_t of ME partons larger than k_t of shower partons $p_t \geq k_t$

How to obtain TMDs ? CCFM approach

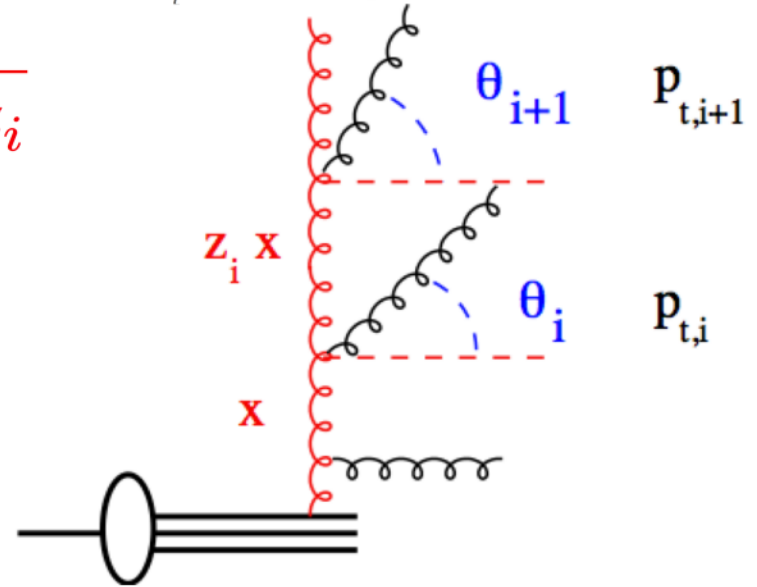
- Color coherence requires angular ordering instead of p_t ordering ...

$$q_i > z_{i-1} q_{i-1} \quad \text{with} \quad q_i = \frac{p_{ti}}{1 - z_i}$$

→ recover DGLAP with q ordering
at medium and large x

→ at small x , no restriction on q
 p_{ti} can perform a random walk

→ splitting fct:



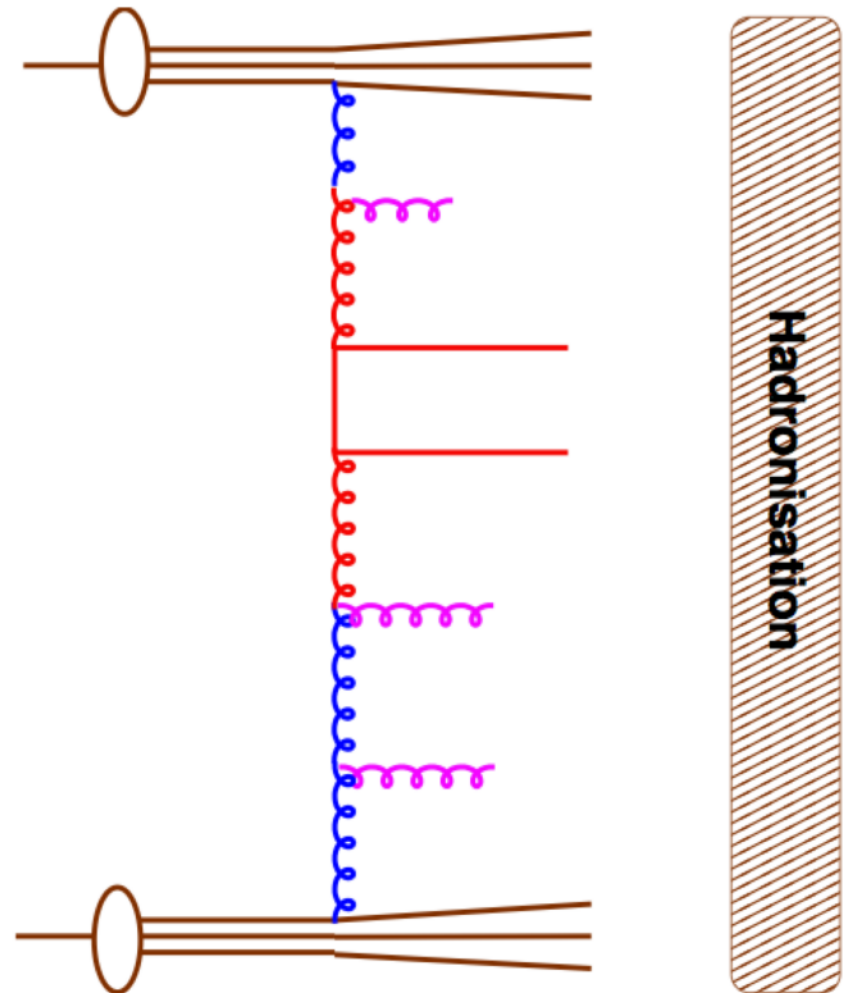
$$\tilde{P}_g(z, q, k_t) = \bar{\alpha}_s \left[\frac{1}{1-z} - 1 + \frac{z(1-z)}{2} + \left(\frac{1}{z} - 1 + \frac{z(1-z)}{2} \right) \Delta_{ns} \right]$$

$$\log \Delta_{ns} = -\bar{\alpha}_s \int_0^1 \frac{dz'}{z'} \int \frac{dq^2}{q^2} \Theta(k_t - q) \Theta(q - z' p_t)$$

→ Catani-Ciafaloni-Fiorani-Marchesini evolution forms a bridge between DGLAP and BFKL evolution

TMDs and the general pp case

- basic elements are:
 - Matrix Elements:
 - on shell/off shell
 - PDFs
 - unintegrated PDFs
 - Parton Shower
 - angular ordering (CCFM)
- Proton remnant and hadronization handled by standard hadronization program, e.g. PYTHIA

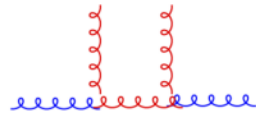


$$\sigma(pp \rightarrow q\bar{q} + X) = \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2 k_{t1} d^2 k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q}) \times x_{g1} \mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2} \mathcal{A}(x_{g2}, k_{t2}, \bar{q})$$

Factorisation issues

$g g \rightarrow g g$

collinear factorisation

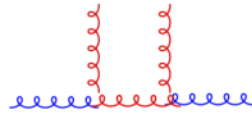


- Collinear factorization
no k_t of initial state

Factorisation issues

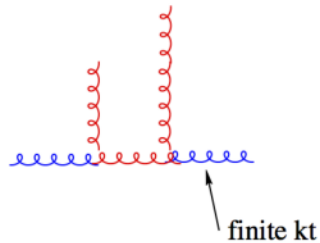
$g g \rightarrow g g$

collinear factorisation



$g g \rightarrow g g$

k_t factorisation

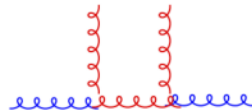


- Collinear factorization
no k_t of initial state
- k_t factorization
initial state partons have k_t

Factorisation issues

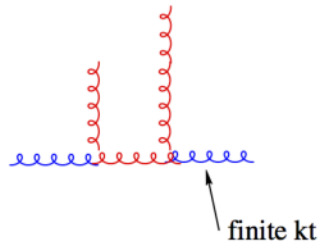
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collinear factorisation



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k_t factorisation

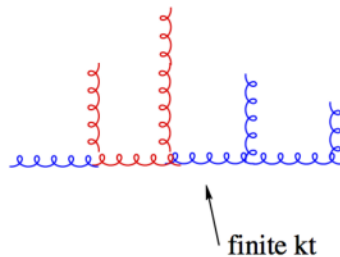


$g g \rightarrow g g$

k_t factorisation

implies parton radiation

double counting

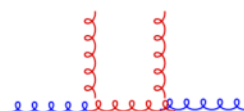


- Collinear factorization
no k_t of initial state
- k_t factorization
initial state partons have k_t
- k_t factorization
finite k_t implies parton radiation
 k_t of shower parton can be as large as p_t of ME parton
→ no ordering in k_t
→ double counting

Factorisation issues

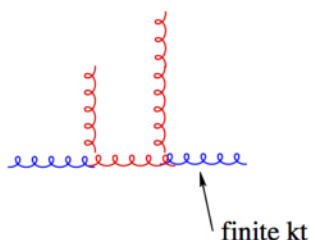
$g g \rightarrow g g$

collinear factorisation



$g g \rightarrow g g$

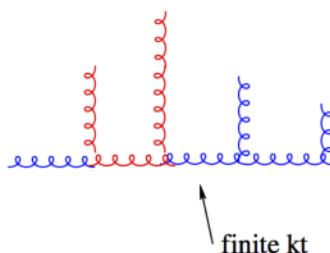
k_t factorisation



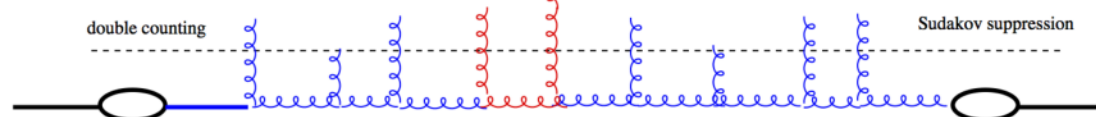
$g g \rightarrow g g$

k_t factorisation
implies parton radiation

double counting



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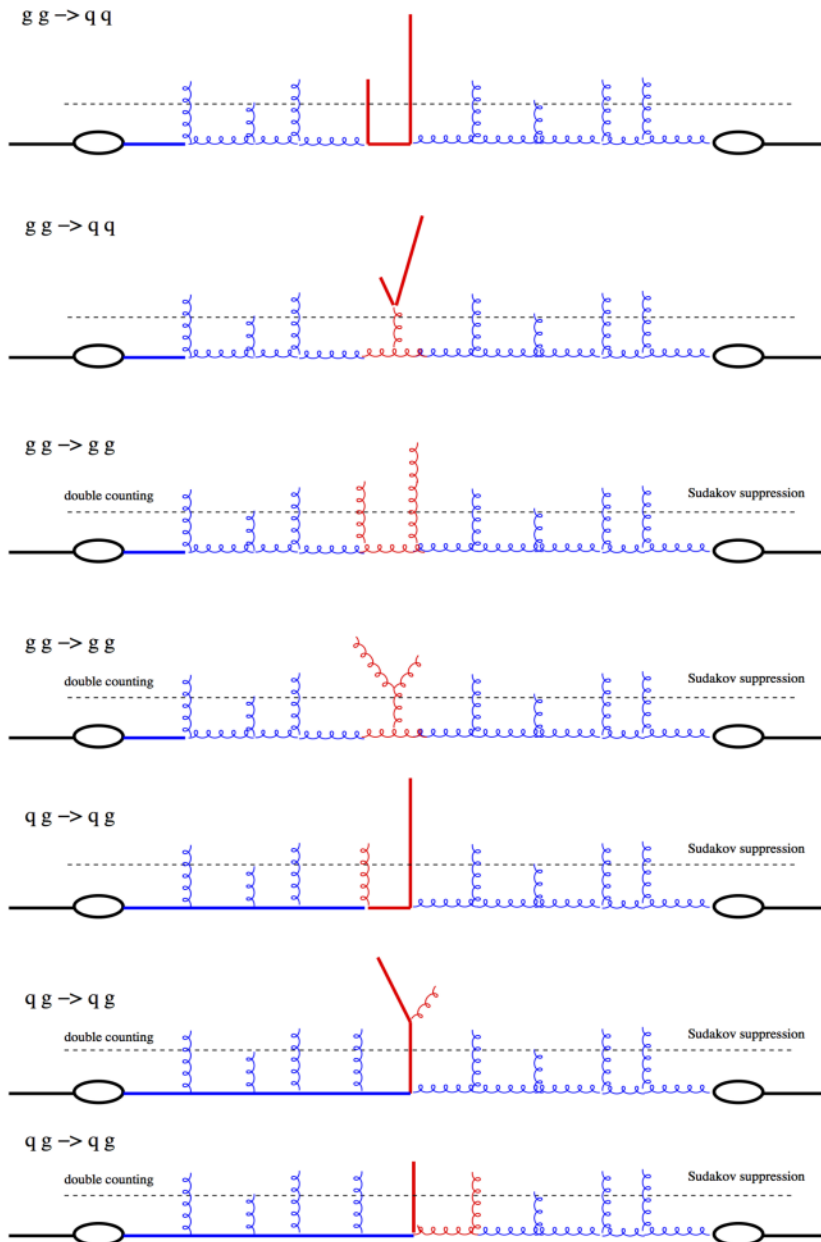


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TMDs and pp: factorization issues



- k_t of initial partons a priori not restricted, extends to large k_t
- with k_t of initial partons, identification of hard scattering **no longer trivial for light partons**
- double counting issues (factorization) within and crossed process chains: $gg \rightarrow gg$ partially included in $gg \rightarrow qq$

Factorization issues for TMDs in pp

- High energy factorization proven for
 - DIS at small x
 - heavy quark production in pp
 - Boson (Z,W,H) production in pp
- TMD factorization proven for
 - (semi)-inclusive DIS
 - Boson production in pp
- Factorization breaking in
 - back-to-back di-hadron (di-jet) production in pp
 - how large ?
 - problems also in non back-to-back region ?

Backup Slides

Initial state parton showers using uPDFs

- Backward evolution from hard scattering towards proton
- No change in kinematics of hard scattering, since k_t of initial state partons treated by uPDF
- In all branchings kinematics are constraint by uPDF
- using the same frame for uPDF evolution and parton shower, no free or additional parameters are left for shower

