# Resummed vector $Q_T$ distribution in DIS as a probe of small $x$ broadening effects

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# Motivation



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Do conventional resummed predictions and $x$-independent NP corrections hold at small $x$? (BFKL?)

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However, semi-inclusive DIS $q_T$ (transverse energy) distribution appears to be broadened in impact parameter space, $b$, by a gaussian:

$$e^{-b^2\rho(x)}, \quad \rho(x) \sim \frac{1}{x} \text{ at small } x.$$

e.g. S. Berge, P. M. Nadolsky, F. I. Olness, C.-P. Yuan, 2005
arXiv: hep-ph/0508215

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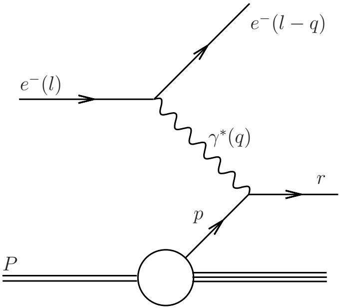
DIS at Born level:



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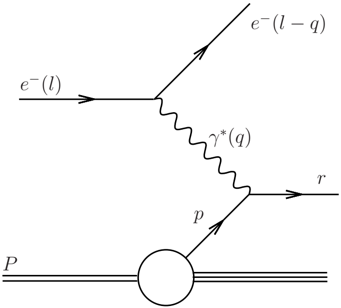


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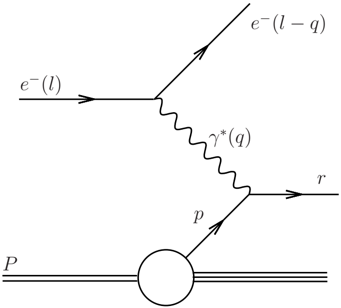


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$x$: momentum fraction of struck quark relative to proton.

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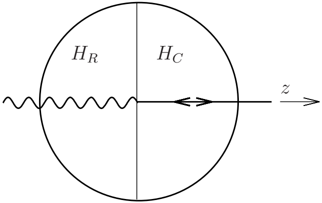

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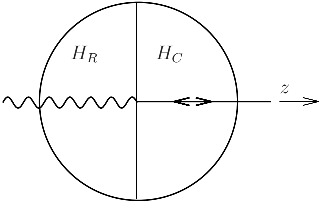

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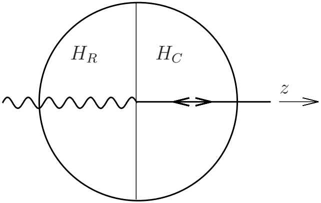


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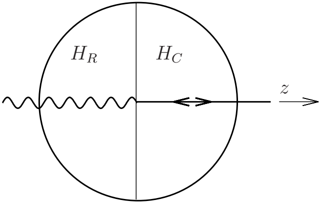


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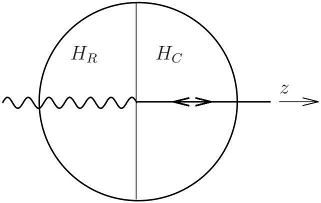


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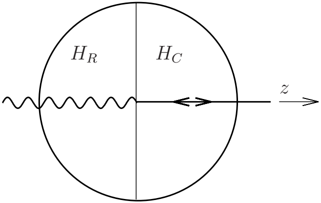


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- Analogous to one hemisphere in $e^+e^-$.

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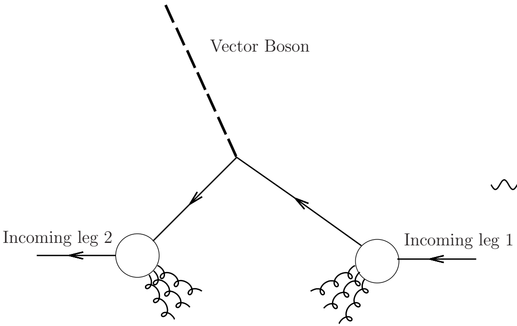
## Comparison between DIS Breit frame and Hadron-Hadron collisions



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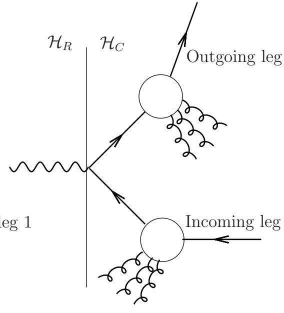


DIS Breit frame

# Leading Order $Q_T$ distribution



Number of events with $\left|\sum_{i\in\mathcal{H}_C} \vec{k}_{Ti}\right| < Q_T$, for small $Q_T$, is:

$$\frac{\sigma}{\sigma_0} = \frac{\alpha_S}{2\pi}\Bigg( -\frac{1}{2}C_F \ln^2\frac{Q_T^2}{Q^2} - \frac{3}{2}C_F \ln\frac{Q_T^2}{Q^2} + \frac{P_{qq}^{(0)}\otimes q(x,Q^2)}{q(x,Q^2)}\ln\frac{Q_T^2}{Q^2} + \frac{\mathbf{C}_1\otimes\mathbf{q}(x,Q^2)}{q(x,Q^2)}\Bigg),$$

$q(x,Q^2) = \sum_i^{n_f} e_{qi}^2\left[q_i(x,Q^2)+\bar{q}_i(x,Q^2)\right]$, (PDFs).
$P_{qq}^{(0)}$: $q \to q$ LO splitting function.
$\mathbf{q}$: column of PDFs (including gluon density).
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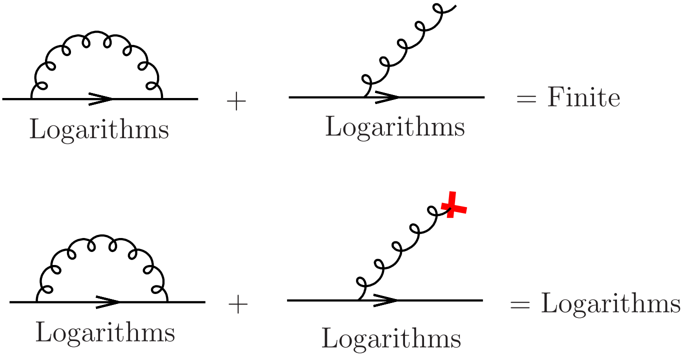
Regular terms in $Q_T$ that tend to zero when $Q_T \to 0$ can be obtained from a DIS event generator, e.g. DISPATCH:

M. Dasgupta and G. P. Salam, 2001

# Leading Order $Q_T$ distribution
## Origin of Logarithms



Restricting real emissions spoils the complete cancelation of infrared and/or collinear singularities between real and virtual contributions to Feynman diagrams.



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## Origin of Logarithms



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These logs must be resummed to all orders.

# Resummed $Q_T$ distribution

## Result



$$\frac{1}{\sigma_0}\frac{d\sigma}{dQ_T} = \frac{1}{q(x,Q^2)}\frac{d}{dQ_T}\left[\left\{q(x,Q_T^2) + \frac{\alpha_S}{2\pi}\mathbf{C}_1 \otimes \mathbf{q}(x,Q^2)\right\}\right.$$
$$\left.\times\, e^{\gamma_E h} e^{-\{Lg_1(\alpha_S L)+g_2(\alpha_S L)+\alpha_S g_3(\alpha_S L)+\cdots\}}\frac{\Gamma(1+h/2)}{\Gamma(1-h/2)}\right],$$

$L = \ln\frac{Q_T^2}{Q^2}$, $\gamma_E$: Euler constant, $\Gamma$: Euler Gamma function. $h$ and $g_i$ are functions of $\alpha_S L$.

The expansion of the above equation to $\mathcal{O}(\alpha_S)$ gives exactly the leading order result.

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Hence we add the resummed result and Monte Carlo result, and remove double counted terms (the Logs and constant $\mathbf{C}_1$).

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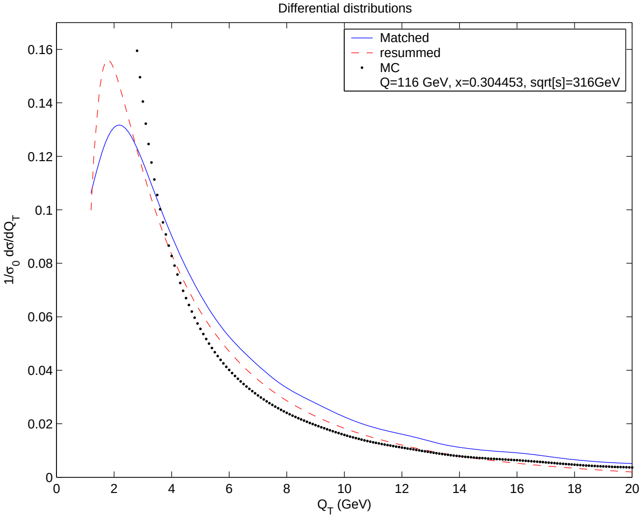

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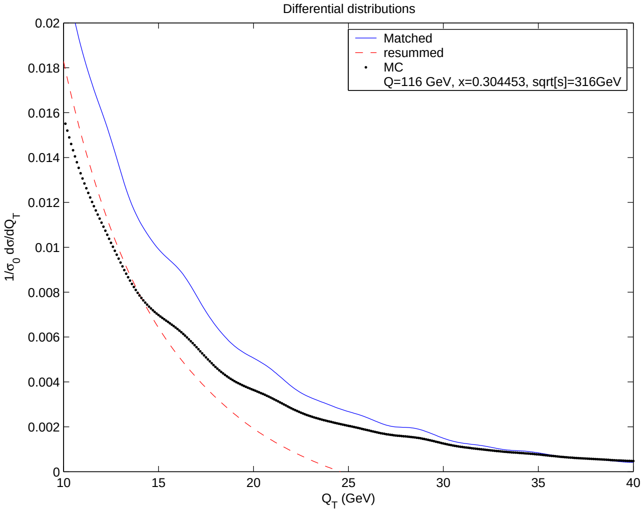

# Conclusions and outlook

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By comparing to small $x$ data, our plots should reveal any dependence of $k$ on $x$.

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Results will be important for LHC Physics: If broadening effects are observed, then this will have an impact on measurements of the mass and width of $W^{\pm}$, $Z$ and Higgs.

This observable is an excellent example of using HERA data for the LHC.