Summing logarithms with a parton shower

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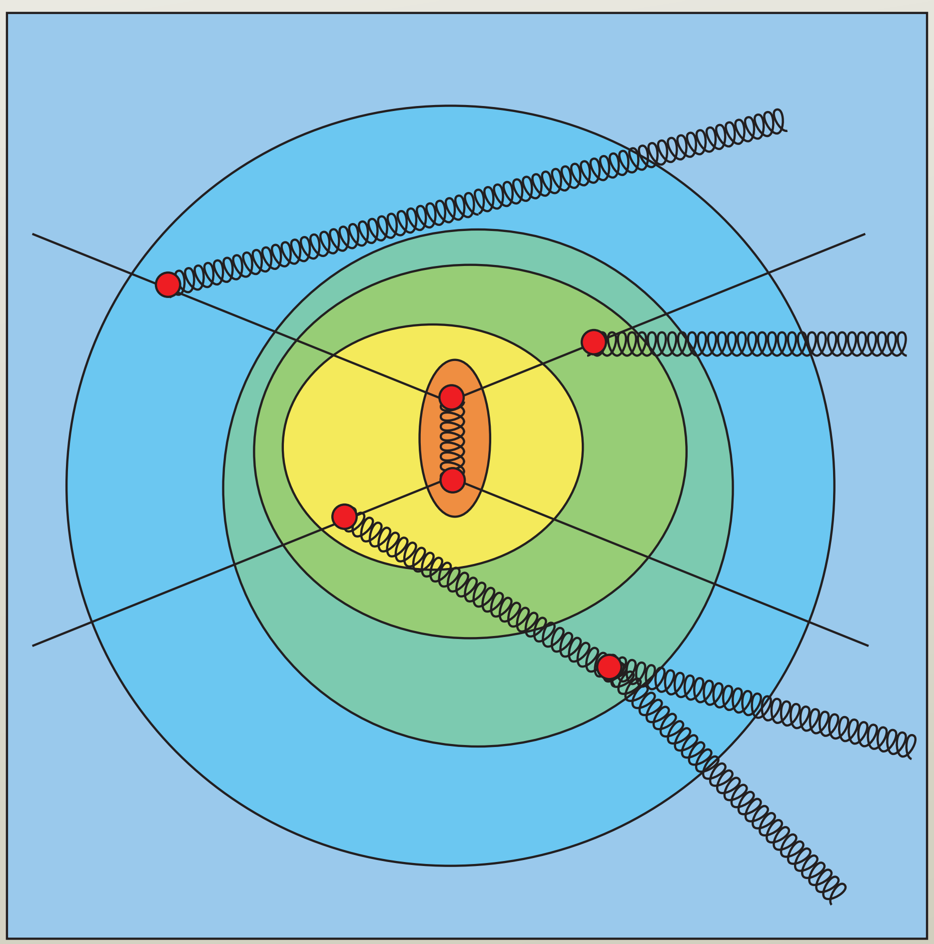
The prequel

- Parton shower event generators are an important tool for physics.
- Dave Soper (UofO) and I have a parton shower generator, DEDUCTOR.

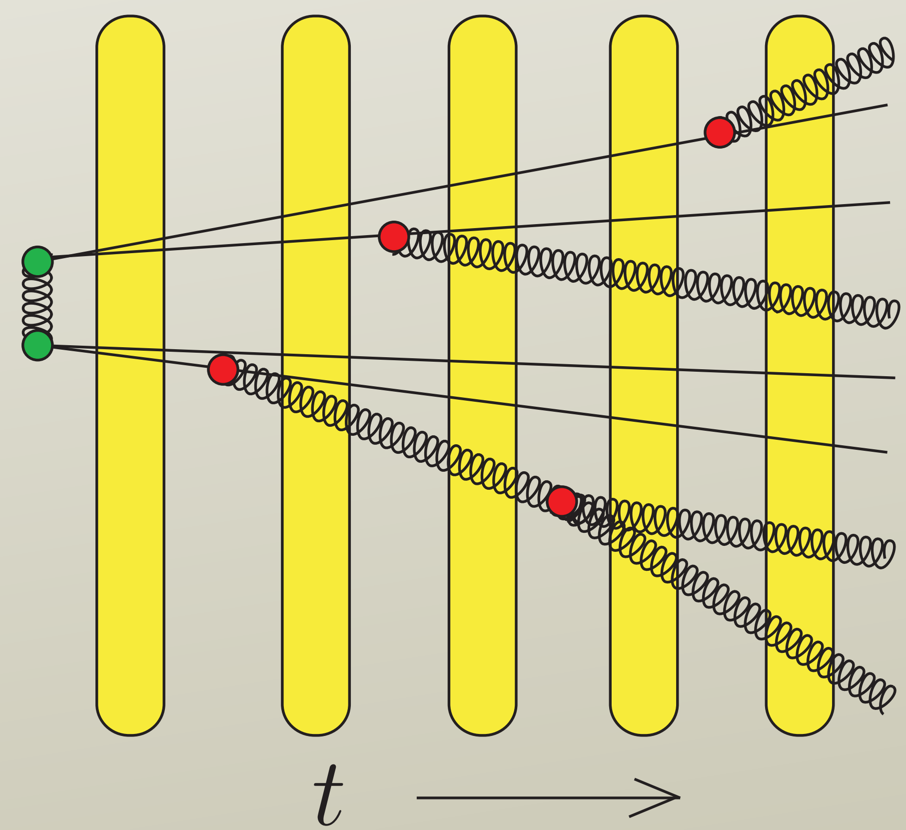
- What evolution equation should describe a shower?
  - ✳ We suggest a formulation that includes spin and color correlations.
- How can this equation be approximated in a computer program?
  - ✳ Start with spin averaged.
  - ✳ For color, we use an “LC+” approximation, somewhat better than the leading color approximation.
- Can this sum logarithms?
  - ✳ This talk.

Shower evolution

- Showers develop in “shower time.”
- Hardest interactions first.



Real time picture



Shower time picture

Shower ordering variable

- Originally, PYTHIA used virtuality to order splittings.
- Now, PYTHIA and SHERPA use "$k_{\rm T}$."
- DEDUCTOR uses Λ,

$$\Lambda_i^2 = \frac{p_i^2 - m_i^2}{2\,p_i \cdot Q_0}\,Q_0^2 \qquad \text{(final state)}$$

$$\Lambda_i^2 = \frac{|p_i^2 - m_i^2|}{2\eta_i\,p_{\rm A} \cdot Q_0}\,Q_0^2 \qquad \text{(initial state)}$$

where

Q_0 is a fixed timelike vector;

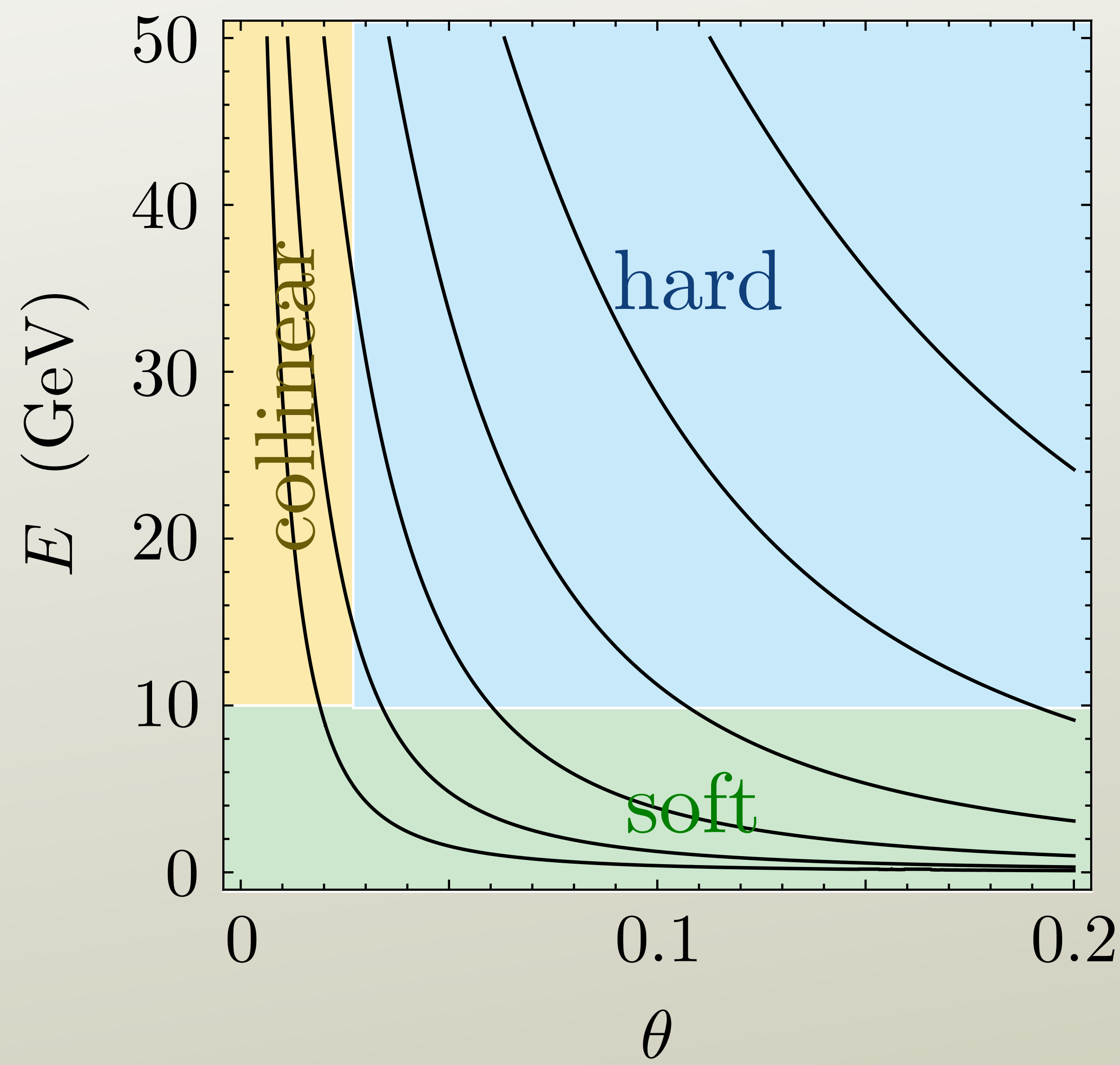
$p_{\rm A}$ is the incoming hadron momentum;

η_i is the parton momentum fraction.

Contrast with SCET

- SCET divides gluon emissions into hard, collinear to hadron A, collinear to hadron B, and soft.
- Each region gets its own special treatment.
- Since the boundaries between regions should not matter, we get differential equations to solve.

- In a parton shower, we have just two regions: hard and everything else.
- We solve a differential equation in the hardness variable that sets the boundary between hard and everything else.
- We count on having a good approximation to sort out collinear regions from the soft region.



Evolution equation

The shower state evolves in shower time.

$$\big|\rho(t')\big) = \mathcal{U}(t,t')\big|\rho(t')\big)$$

$$\frac{d}{dt}\mathcal{U}(t,t') = [\mathcal{H}_{\rm I}(t) - \mathcal{V}(t)]\mathcal{U}(t,t')$$

$$\mathcal{H}_{\rm I}(t) = \text{splitting operator}$$

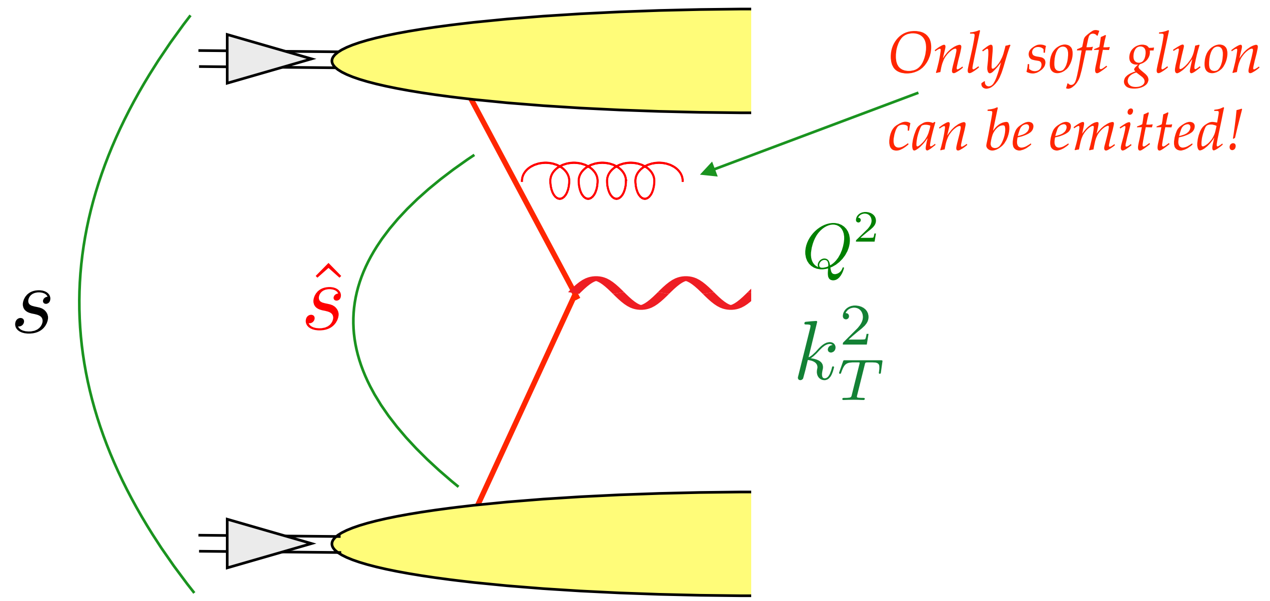
$$\mathcal{V}(t) = \text{virtual splitting operator}$$

An obvious question

- Is this going to sum large logarithms?

Visible Logs

"Visible logs", something like the transverse momentum of the Drell-Yan pair. This is also called to "recoil logs".



$$L = \log \frac{Q^2}{k_T^2}$$

Logarithms of $p_\perp$

- Consider $A + B \to Z + X$
- Measure the $p_\perp$ of the Z-boson for $p_\perp^2 \ll M_Z^2$,

$$\frac{d\sigma}{dp_\perp dY}$$

- There are large logarithms $\log(M_Z^2/p_\perp^2)$.

- We know how to sum these in QCD.

The QCD answer,

$$\frac{d\sigma}{d\boldsymbol{p}_\perp dY} \approx \int \frac{d^2\boldsymbol{b}}{(2\pi)^2}\, e^{i\boldsymbol{b}\cdot\boldsymbol{p}_\perp}$$

$$\times \sum_{a,b} \int_{x_\mathrm{a}}^1 \frac{d\eta_\mathrm{a}}{\eta_\mathrm{a}} \int_{x_\mathrm{b}}^1 \frac{d\eta_\mathrm{b}}{\eta_\mathrm{b}}\, f_{a/A}(\eta_\mathrm{a}, C^2/\boldsymbol{b}^2)\; f_{b/B}(\eta_\mathrm{b}, C^2/\boldsymbol{b}^2)$$

$$\times \exp\left(- \int_{C^2/\boldsymbol{b}^2}^{M^2} \frac{d\boldsymbol{k}_\perp^2}{\boldsymbol{k}_\perp^2} \left[A(\alpha_\mathrm{s}(\boldsymbol{k}_\perp^2)) \log\left(\frac{M^2}{\boldsymbol{k}_\perp^2}\right) + B(\alpha_\mathrm{s}(\boldsymbol{k}_\perp^2)) \right] \right)$$

$$\times \sum_{a',b'} H^{(0)}_{a'b'}\; C_{a'a}\left(\frac{x_\mathrm{a}}{\eta_\mathrm{a}}, \alpha_\mathrm{s}\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) C_{b'b}\left(\frac{x_\mathrm{b}}{\eta_\mathrm{b}}, \alpha_\mathrm{s}\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) \;.$$

$$A(\alpha_\mathrm{s}) = 2\, C_\mathrm{F}\, \frac{\alpha_\mathrm{s}}{2\pi} + 2\, C_\mathrm{F}\, \left\{ C_\mathrm{A} \left[\frac{67}{18} - \frac{\pi^2}{6}\right] - \frac{5\, n_\mathrm{f}}{9} \right\} \left(\frac{\alpha_\mathrm{s}}{2\pi}\right)^2 + \cdots \quad ,$$

$$B(\alpha_\mathrm{s}) = -4\, \frac{\alpha_\mathrm{s}}{2\pi} + \left[-\frac{197}{3} + \frac{34 n_\mathrm{f}}{9} + \frac{20\pi^2}{3} - \frac{8 n_\mathrm{f}\pi^2}{27} + \frac{8\zeta(3)}{3} \right] \left(\frac{\alpha_\mathrm{s}}{2\pi}\right)^2 + \cdots \quad ,$$

$$C_{a'a}(z, \alpha_\mathrm{s}) = \delta_{a'a}\delta(1-z) + \frac{\alpha_\mathrm{s}}{2\pi}\left[\delta_{a'a} \left\{ \frac{4}{3}\,(1-z) + \frac{2}{3}\,\delta(1-z)\,\left(\pi^2 - 8\right) \right\} + \delta_{ag}\, z(1-z) \right]$$

$$x_\mathrm{A} = \sqrt{\frac{M^2}{s}} e^{Y} \qquad x_\mathrm{B} = \sqrt{\frac{M^2}{s}} e^{-Y} \qquad C = 2 e^{-\gamma_E}$$

What we might hope for,

$$\frac{d\sigma}{d\boldsymbol{p}_\perp dY} \approx \int \frac{d^2\boldsymbol{b}}{(2\pi)^2}\, e^{i\boldsymbol{b}\cdot\boldsymbol{p}_\perp}$$

$$\times \sum_{a,b} \int_{x_\mathrm{a}}^1 \frac{d\eta_\mathrm{a}}{\eta_\mathrm{a}} \int_{x_\mathrm{b}}^1 \frac{d\eta_\mathrm{b}}{\eta_\mathrm{b}}\; f_{a/A}(\eta_\mathrm{a}, C^2/\boldsymbol{b}^2)\; f_{b/B}(\eta_\mathrm{b}, C^2/\boldsymbol{b}^2)$$

$$\times \exp\left(- \int_{C^2/\boldsymbol{b}^2}^{M^2} \frac{d\boldsymbol{k}_\perp^2}{\boldsymbol{k}_\perp^2} \left[A(\alpha_\mathrm{s}(\boldsymbol{k}_\perp^2)) \log\left(\frac{M^2}{\boldsymbol{k}_\perp^2}\right) + B(\alpha_\mathrm{s}(\boldsymbol{k}_\perp^2)) \right] \right)$$

$$\times \sum_{a',b'} H^{(0)}_{a'b'}\; C_{a'a}\left(\frac{x_\mathrm{a}}{\eta_\mathrm{a}}, \alpha_\mathrm{s}\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) C_{b'b}\left(\frac{x_\mathrm{b}}{\eta_\mathrm{b}}, \alpha_\mathrm{s}\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) \;.$$

$$A(\alpha_\mathrm{s}) = 2\,C_\mathrm{F}\,\frac{\alpha_\mathrm{s}}{2\pi} + 2\,C_\mathrm{F}\left\{ C_\mathrm{A}\left[\frac{67}{18} - \frac{\pi^2}{6}\right] - \frac{5\,n_\mathrm{f}}{9} \right\} \left(\frac{\alpha_\mathrm{s}}{2\pi}\right)^2 + \cdots \;,$$

$$B(\alpha_\mathrm{s}) = -4\,\frac{\alpha_\mathrm{s}}{2\pi} + \left[-\frac{197}{3} + \frac{34 n_\mathrm{f}}{9} + \frac{20\pi^2}{3} - \frac{8 n_\mathrm{f}\pi^2}{27} + \frac{8\zeta(3)}{3} \right] \left(\frac{\alpha_\mathrm{s}}{2\pi}\right)^2 + \cdots \;,$$

$$C_{a'a}(z, \alpha_\mathrm{s}) = \delta_{a'a}\delta(1-z) + \frac{\alpha_\mathrm{s}}{2\pi}\left[\delta_{a'a}\left\{ \frac{4}{3}(1-z) + \frac{2}{3}\delta(1-z)(\pi^2 - 8) \right\} + \delta_{ag}\, z(1-z) \right]$$

$$x_\mathrm{A} = \sqrt{\frac{M^2}{s}}\, e^{Y} \qquad x_\mathrm{B} = \sqrt{\frac{M^2}{s}}\, e^{-Y} \qquad C = 2e^{-\gamma_E}$$

Why this should work

- The splitting probabilities have the right soft and collinear singularities.
- Parton splitting is iterated.
- So how could it fail?

Why this should not work

- It has been known since the 1980s that exponentiation of double logs comes from emissions ordered in angles.
- The angle ordering comes from quantum coherence.
- So you need a shower ordered in angles, not a hardness variable.
- Or else we need SCET.
- The hardness ordered shower is doomed.

Analytical approach

- Start with the Fourier transform of the cross section.

$$\big(\boldsymbol{b}, Y \big| \rho(t)\big) = \int \frac{d\boldsymbol{p}_\perp}{(2\pi)^2}\, e^{i\boldsymbol{p}_\perp\cdot\boldsymbol{b}} \big(\boldsymbol{p}_\perp, Y \big| \rho(t)\big)$$

- Use the shower evolution equation.

$$\frac{d}{dt}\big(\boldsymbol{b}, Y \big| \rho(t)\big) = \big(\boldsymbol{b}, Y \big| \mathcal{H}_{\mathrm{I}}(t) - \mathcal{V}(t) \big| \rho(t)\big)$$

- Use what we know about the operators involved.

Result

✓ Exponentiation

$$\frac{d\sigma}{d\boldsymbol{p}_\perp dY} \approx \int \frac{d^2\boldsymbol{b}}{(2\pi)^2}\, e^{i\boldsymbol{b}\cdot\boldsymbol{p}_\perp}$$

$$\times \sum_{a,b} \int_{x_a}^1 \frac{d\eta_a}{\eta_a} \int_{x_b}^1 \frac{d\eta_b}{\eta_b}\; f_{a/A}(\eta_a, C^2/\boldsymbol{b}^2)\; f_{b/B}(\eta_b, C^2/\boldsymbol{b}^2)$$

$$\times \exp\left(- \int_{C^2/\boldsymbol{b}^2}^{M^2} \frac{d\boldsymbol{k}_\perp^2}{\boldsymbol{k}_\perp^2} \left[A(\alpha_s(\boldsymbol{k}_\perp^2)) \log\left(\frac{M^2}{\boldsymbol{k}_\perp^2}\right) + B(\alpha_s(\boldsymbol{k}_\perp^2)) \right] \right)$$

$$\times \sum_{a',b'} H^{(0)}_{a'b'}\; C_{a'a}\left(\frac{x_a}{\eta_a}, \alpha_s\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) C_{b'b}\left(\frac{x_b}{\eta_b}, \alpha_s\left(\frac{C^2}{\boldsymbol{b}^2}\right)\right) \quad .$$

✓ ✓

$$A(\alpha_s) = 2\, C_F\, \frac{\alpha_s}{2\pi} + 2\, C_F \left\{ C_A \left[\frac{67}{18} - \frac{\pi^2}{6}\right] - \frac{5\, n_f}{9} \right\} \left(\frac{\alpha_s}{2\pi}\right)^2 + \cdots \quad ,$$

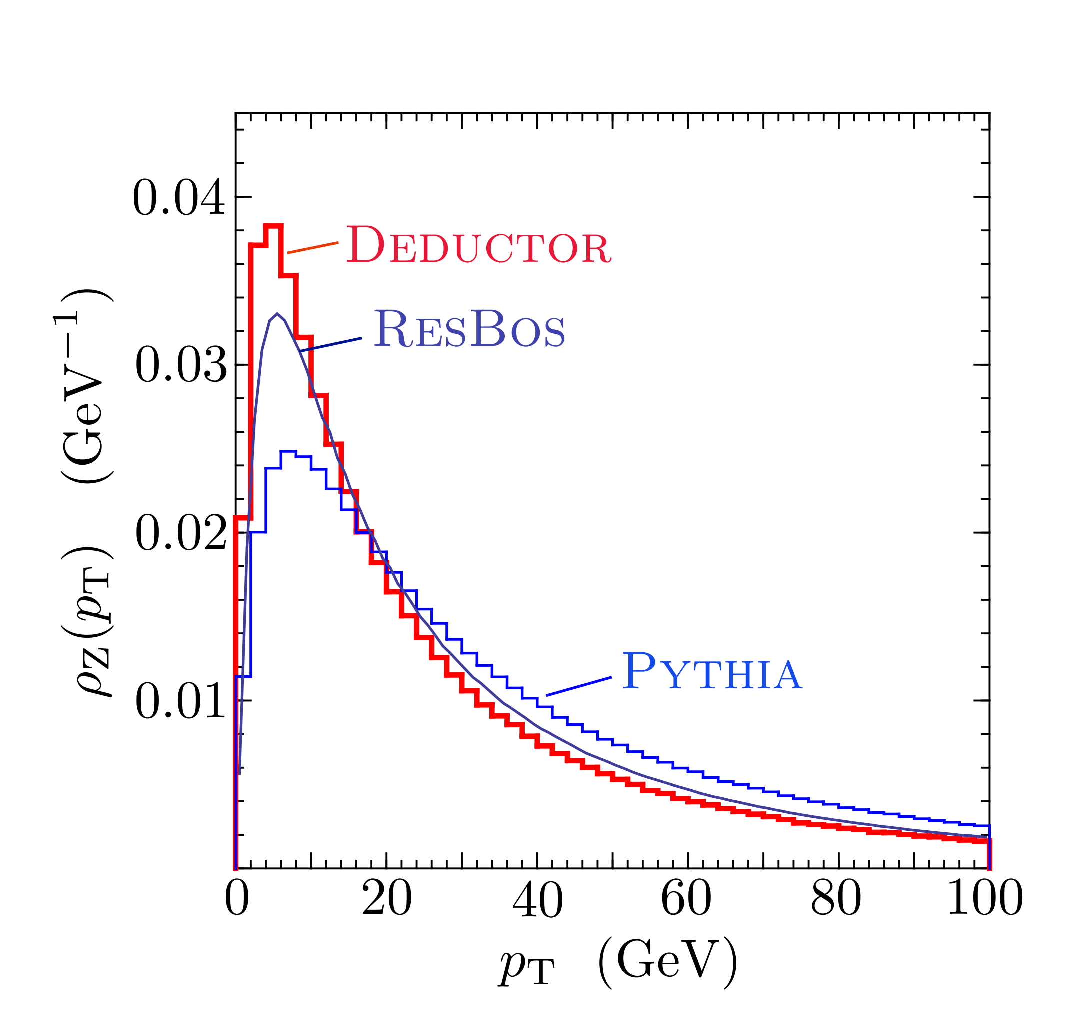
✓

$$B(\alpha_s) = -4\, \frac{\alpha_s}{2\pi} + \left[-\frac{197}{3} + \frac{34 n_f}{9} + \frac{20\pi^2}{3} - \frac{8 n_f \pi^2}{27} + \frac{8\zeta(3)}{3} \right] \left(\frac{\alpha_s}{2\pi}\right)^2 + \cdots \quad ,$$

$$C_{a'a}(z, \alpha_s) = \delta_{a'a}\delta(1-z) + \frac{\alpha_s}{2\pi} \left[\delta_{a'a} \left\{ \frac{4}{3}(1-z) + \frac{2}{3}\delta(1-z)(\pi^2 - 8) \right\} + \delta_{ag}\, z(1-z) \right]$$

Numerical approach with Deductor

- Look at distribution of P_{T} of e^+e^- pairs with $M > 400$ GeV.
- $\int_0^{100\ \mathrm{GeV}} dp_{\mathrm{T}}\,\rho(p_{\mathrm{T}}) = 1.$
- A parton shower should get this right except for soft effects at $P_{\mathrm{T}} < 10$ GeV.

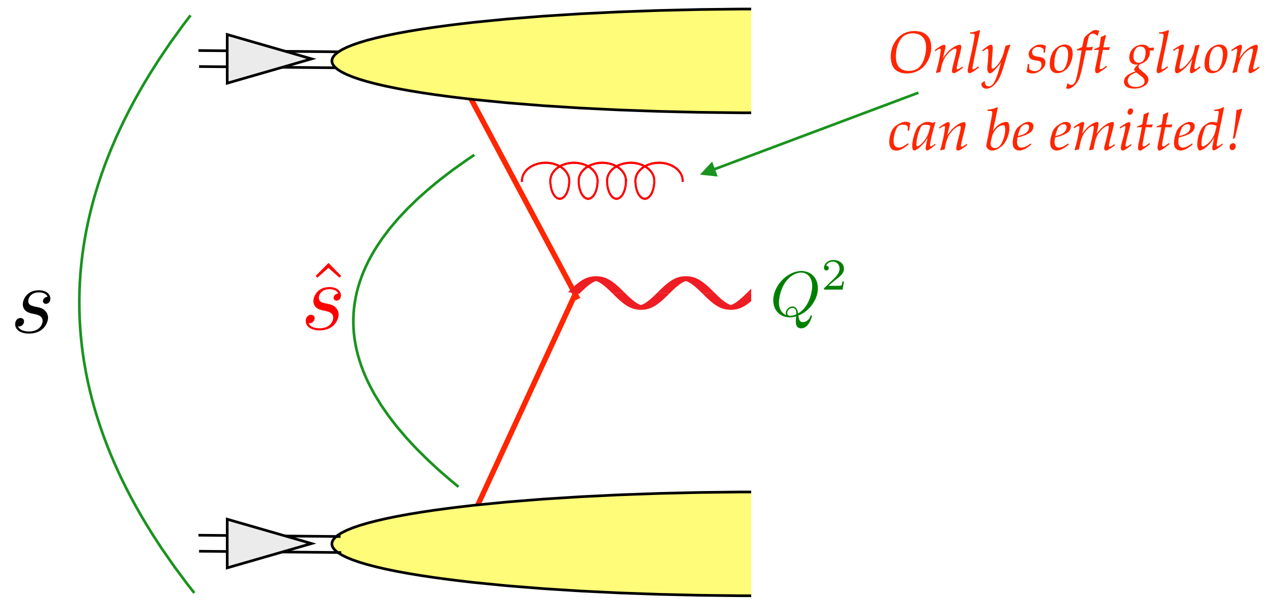


- We compare DEDUCTOR, PYTHIA, and the analytic log summation in RESBOS.
- DEDUCTOR appears to do well.

Threshold logarithms

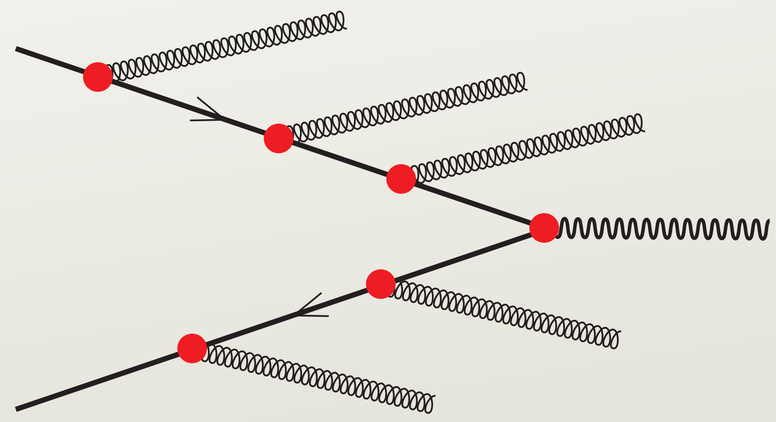
Invisible Logs

"Invisible logs", live under the integral. They are the so called threshold logs.



$$s \approx Q^2 \quad \Longrightarrow \quad \frac{Q^2}{\hat{s}} \approx 1 \quad \Longrightarrow \quad L = \log\left(1 - \frac{Q^2}{\hat{s}}\right)$$

- Consider the Drell-Yan process with dimoun rapidity Y and mass M.



- There are logarithms of $(1 - z)$ where

$$z = \frac{M}{\eta_\mathrm{a}\sqrt{s}}e^{Y} \qquad \text{or} \qquad z = \frac{M}{\eta_\mathrm{b}\sqrt{s}}e^{-Y}$$

- These "threshold logs" are important when the parton distribution functions are steeply falling.

- They affect the cross section

$$\frac{d\sigma}{dM^2\,dY}$$

- A typical parton shower fixes the cross section at the Born cross section.

- Therefore the threshold logarithms are not included.

Including threshold logs

- A parton shower can sum logarithms if you let it.
- We propose to do that, at a leading log level.
- This is work in progress, not yet implemented in DEDUCTOR.
- I can show you the main idea.

What not to do

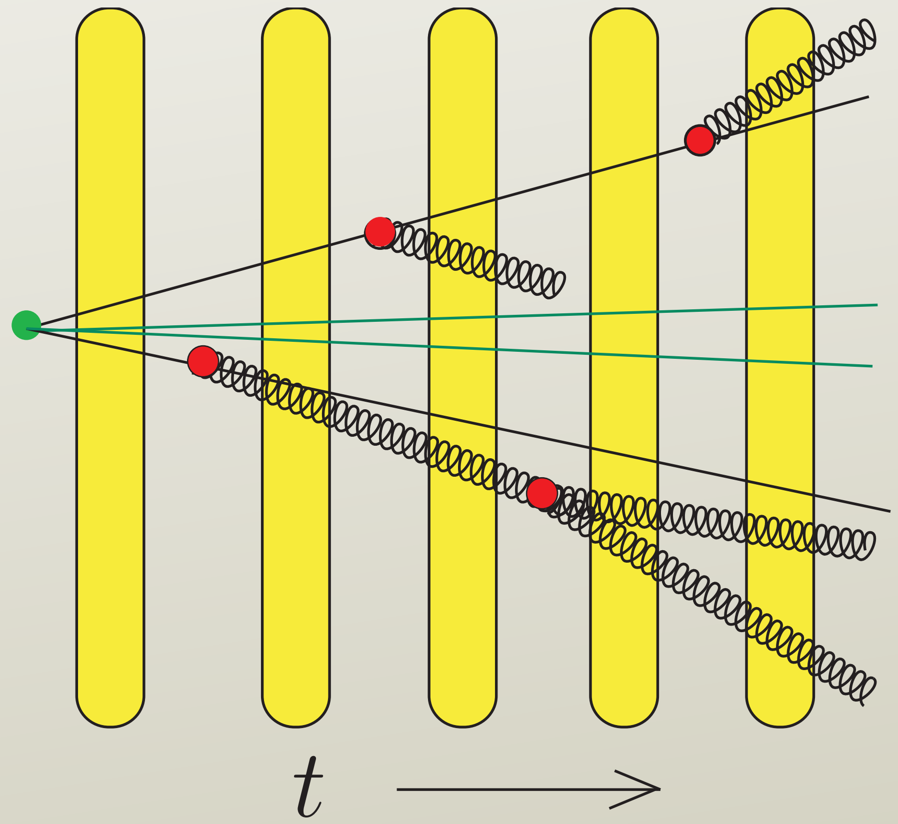
- The shower state evolves in shower time.

$$\big|\rho(t')\big) = \mathcal{U}_{\mathcal{V}}(t,t')\big|\rho(t')\big)$$

$$\frac{d}{dt}\mathcal{U}_{\mathcal{V}}(t,t') = [\mathcal{H}_{\rm I}(t) - \mathcal{V}(t)]\mathcal{U}(t,t')$$

$$\mathcal{H}_{\rm I}(t) = \text{splitting operator}$$

$$\mathcal{V}(t) = \text{no-splitting operator}$$



- We calculate $\mathcal{V}(t)$ from $\mathcal{H}_I(t)$ so that the inclusive cross section does not change during the shower.

What to do

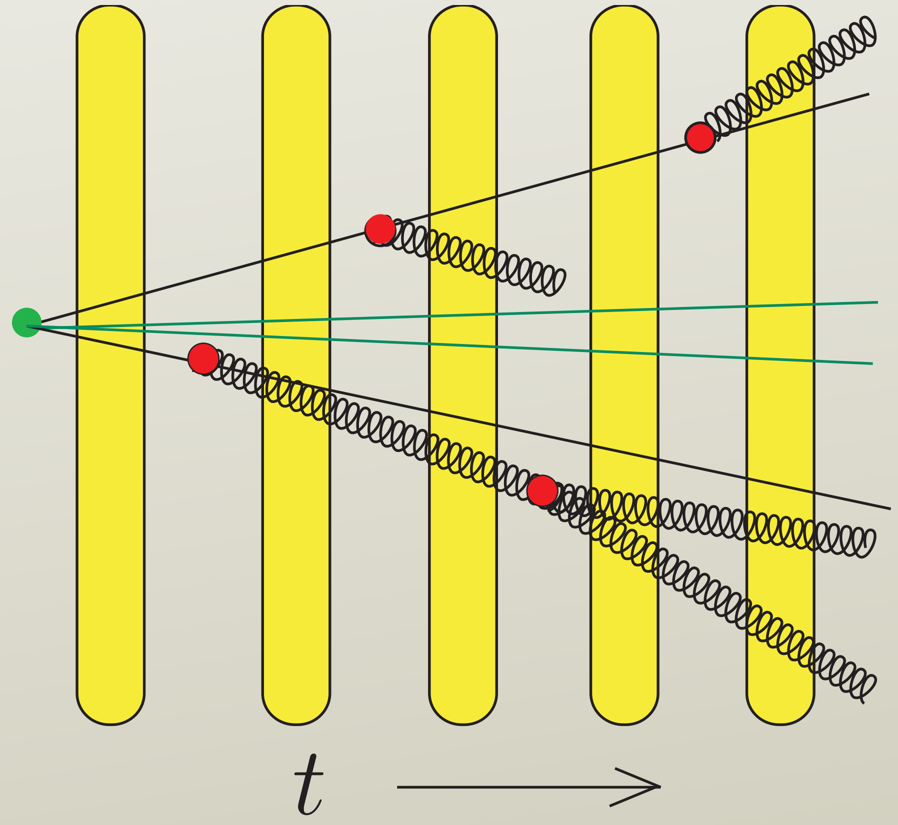
- The shower state evolves in shower time.

$$\big|\rho(t')\big) = \mathcal{U}_{\mathcal{A}}(t,t')\big|\rho(t')\big)$$

$$\frac{d}{dt}\mathcal{U}_{\mathcal{A}}(t,t') = [\mathcal{H}_{\rm I}(t) - \mathcal{A}(t)]\mathcal{U}(t,t')$$

$$\mathcal{H}_{\rm I}(t) = \text{splitting operator}$$

$$\mathcal{A}(t) = \text{virtual splitting operator}$$



- We simply calculate $\mathcal{A}(t)$ from one loop virtual graphs.

What happens

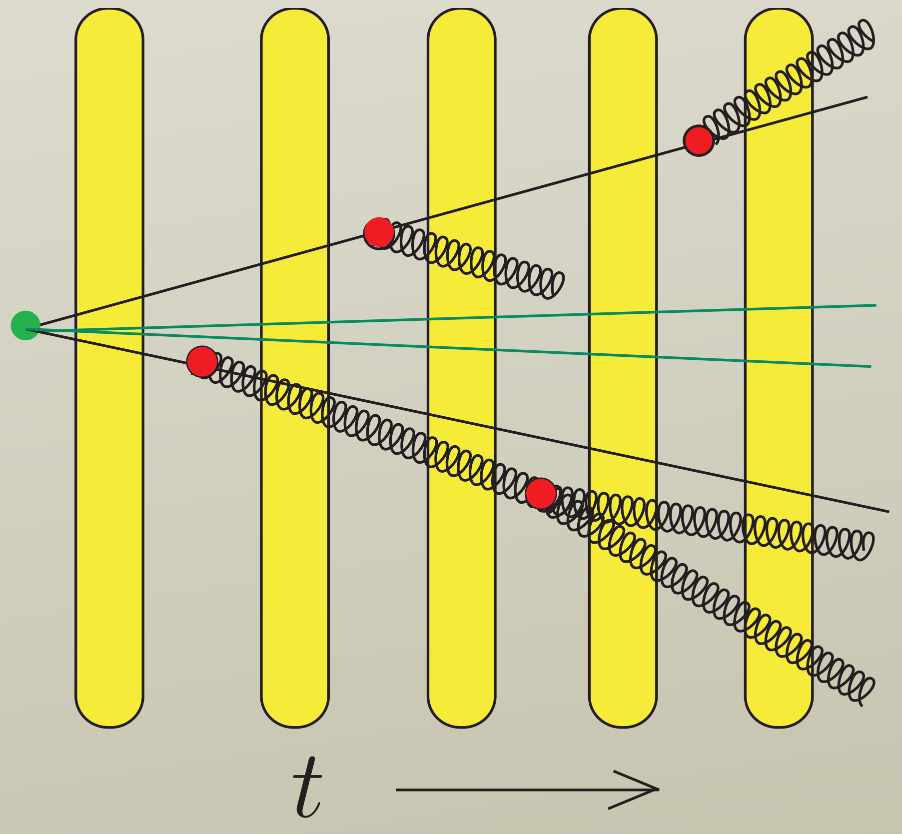
$$\mathcal{U}_{\mathcal{A}}(t,t_0) = \mathcal{N}_{\mathcal{A}}(t,t_0) + \int_{t_0}^{t} d\tau\, \mathcal{U}_{\mathcal{A}}(t,\tau)\mathcal{H}_I(\tau)\mathcal{N}_{\mathcal{A}}(\tau,t_0)$$

$$\mathcal{N}_{\mathcal{A}}(t_2,t_1) = \mathbb{T}\exp\left[\int_{t_1}^{t_2} d\tau\ [-\mathcal{V}(\tau) + (\mathcal{V}(\tau) - \mathcal{A}(\tau))]\right]$$

- Within the LC+ approximation, the operators commute.
- There is an extra factor

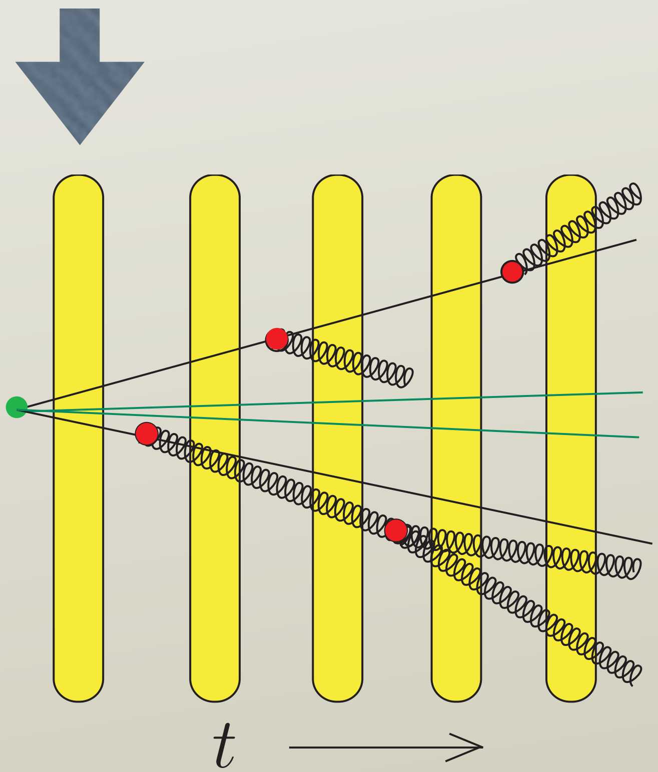
$$\exp\left[\int_{t_1}^{t_2} d\tau\ (\mathcal{V}(\tau) - \mathcal{A}(\tau))\right]$$

that changes the cross section.



The most important term

- Look at the Drell-Yan process.
- Look at the factor for line "a" just after the hard interaction.
- Assume that no real gluons have been emitted yet.



- Use y = dimensionless virtuality variable (with $y \ll 1$) and z = momentum fraction.

$$
\begin{aligned}
&[\mathcal{V}_{\rm a}(t) - \mathcal{A}_{\rm a}(t)]\big|\{p,f,s',c',s,c\}_m\big) = \\
&\Bigg\{\frac{\alpha_s}{2\pi}\int_0^{1-y}\frac{dz}{z}\sum_{\hat a}\ \left(\frac{f_{\hat a/A}(\eta_{\rm a}/z, Q^2 y/z)}{f_{a/A}(\eta_{\rm a}, Q^2 y)} P_{a\hat a}(z) - \delta_{a\hat a}\frac{2C_a z}{1-z}\right)[1\otimes 1] \\
&\ -\frac{\alpha_s}{2\pi}\int_0^{1}\frac{dz}{z}\sum_{\hat a}\left(\frac{f_{\hat a/A}(\eta_{\rm a}/z, Q^2 y/z)}{f_{a/A}(\eta_{\rm a}, Q^2 y)} P_{a\hat a}(z) - \delta_{a\hat a}\frac{2C_a z}{1-z}\right)[1\otimes 1] \\
&\ + \cdots\Bigg\}\big|\{p,f,s',c',s,c\}_m\big)
\end{aligned}
$$

- Almost everything has cancelled.
- Two terms do not quite cancel.
- $(1-z) > y$ comes from splitting kinematics.
- $(1-z) > 0$ comes parton evolution.

- This leaves

$$[\mathcal{V}_{\rm a}(t) - \mathcal{A}_{\rm a}(t)]\big|\{p,f,s',c',s,c\}_m\big) =$$
$$\Bigg\{\frac{\alpha_s}{2\pi}\int_{1-y}^{1}\frac{dz}{z}\sum_{\hat a}\ \left(\frac{f_{\hat a/A}(\eta_{\rm a}/z,Q^2y/z)}{f_{a/A}(\eta_{\rm a},Q^2y)}P_{a\hat a}(z) - \delta_{a\hat a}\frac{2C_a z}{1-z}\right)[1\otimes 1]$$
$$+\cdots\Bigg\}\big|\{p,f,s',c',s,c\}_m\big)$$

- for $(1-z) < y \ll 1$ use

$$P_{a\hat a}(z) \sim \delta_{a\hat a}\frac{2C_a z}{1-z}$$

- This gives

$$
\big[\mathcal{V}_{\rm a}(t) - \mathcal{A}_{\rm a}(t)\big]\big|\{p,f,s',c',s,c\}_m\big) =
$$

$$
\Bigg\{\frac{\alpha_s}{2\pi}\int_{1-y}^{1}\frac{dz}{z}\sum_{\hat a}\left(\frac{f_{\hat a/A}(\eta_{\rm a}/z, Q^2 y/z)}{f_{a/A}(\eta_{\rm a}, Q^2 y)} - 1\right)\delta_{a\hat a}\,\frac{2C_a z}{1-z}[1\otimes 1]
$$

$$
+\cdots\Bigg\}\big|\{p,f,s',c',s,c\}_m\big)
$$

- The $1/(1-z)$ factor creates the “threshold log.”

- But the parton factor contains a factor $(1-z)$ so there is no actual log.

- For $y \ll 1$, this contribution is suppressed by a factor of y.

- But, the parton factor can be large, so we keep this.

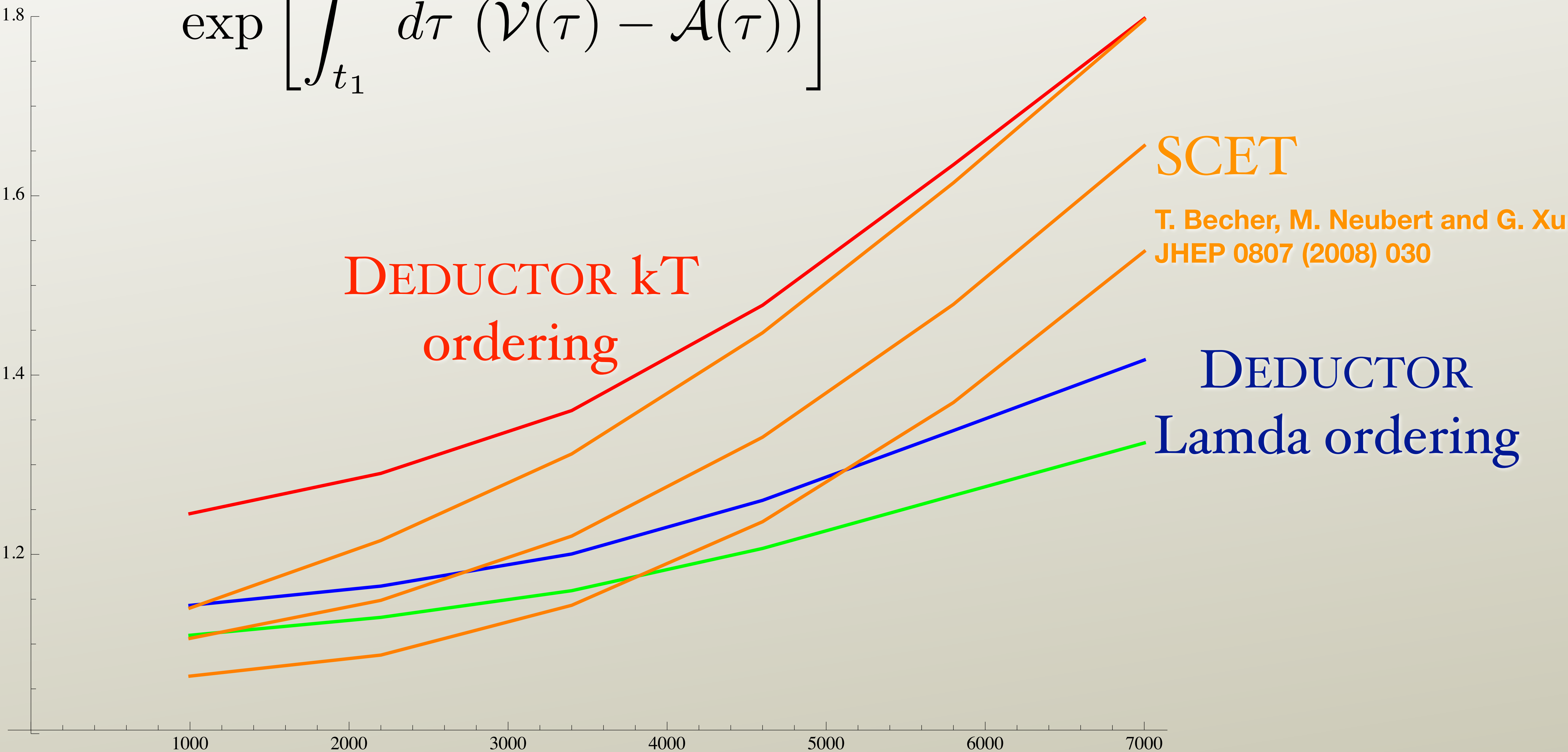
The full contribution to the threshold logs is

$$
\begin{aligned}
&[\mathcal{V}_{\rm a}(t) - \mathcal{A}_{\rm a}(t)]\big|\{p,f,s',c',s,c\}_m\big) \\
&\quad = \Bigg\{ -\frac{\alpha_{\rm s}}{2\pi}\int_{1/(1+y)}^{1}\frac{dz}{z}\left[\frac{f_{a/A}(\eta_{\rm a}/z,\mu_{\rm a}^2(t))}{f_{a/A}(\eta_{\rm a},\mu_{\rm a}^2(t))} - 1\right]\frac{2C_a z}{1-z}\,[1\otimes 1] \\
&\qquad - \frac{\alpha_{\rm s}}{2\pi}\,y\sum_{\hat{a}\neq a}\frac{f_{\hat{a}/A}(\eta_{\rm a},\mu_{\rm a}^2(t))}{f_{a/A}(\eta_{\rm a},\mu_{\rm a}^2(t))}\,P_{a\hat{a}}(1)\,[1\otimes 1] \\
&\qquad - \frac{\alpha_{\rm s}}{2\pi}\int_{0}^{1/(1+y)}\frac{dz}{z}\left[\frac{f_{a/A}(\eta_{\rm a}/z,\mu_{\rm a}^2(t))}{f_{a/A}(\eta_{\rm a},\mu_{\rm a}^2(t))} - 1\right] \\
&\qquad\quad \times\left[\sum_{k\neq {\rm a,b}} w_{ak}(z,y)\,\frac{1}{2}\,[(\boldsymbol{T}_{\rm a}\cdot\boldsymbol{T}_k)\otimes 1 + 1\otimes(\boldsymbol{T}_{\rm a}\cdot\boldsymbol{T}_k)]\right] \\
&\qquad + \frac{\alpha_{\rm s}}{2\pi}\Big[-{\rm i}\pi[(\boldsymbol{T}_{\rm a}\cdot\boldsymbol{T}_{\rm b})\otimes 1] + {\rm i}\pi[1\otimes(\boldsymbol{T}_{\rm a}\cdot\boldsymbol{T}_{\rm b})]\Big]\Bigg\} \\
&\qquad \times\big|\{p,f,s',c',s,c\}_m\big)
\end{aligned}
$$

Let us compare this to SCET!

Comparison to SCET

$$\exp\left[\int_{t_1}^{t_2} d\tau\ (\mathcal{V}(\tau) - \mathcal{A}(\tau))\right]$$



- We use parton distribution functions $f_{a/A}(\eta, \mu^2)$. The definition ought to be determined by the choice of shower time that we use, even with massless quarks. The difference between definitions is of order α_s, at least if make good choices.
- I would appear that the standard MSbar PDF corresponds to kT ordering. How does PDF depend on the choice of the ordering variable?

$$\mu^2(\lambda) = \frac{\mu_\perp^2}{(1-z)^\lambda}$$

$$\begin{aligned} \lambda = 0 &\implies \text{kT ordering} \\ \lambda = 1 &\implies \text{virtualty ordering} \\ \lambda = 2 &\implies \text{angular ordering} \end{aligned}$$

The PDF depends on lambda and using DGLAP we can obtain this dependence in a rather simple form:

$$f_{q/A}(\eta, \mu^2, 0) = Z_{\rm a}(\eta, \mu^2)\, f_{q/A}(\eta, \mu^2, 1)$$

Where

$$Z_q(\eta,\mu^2) = \exp\left(\int_0^1 dz\ \log\left(\frac{1}{1-z}\right)\frac{\alpha_s((1-z)\mu^2)}{2\pi}\frac{2C_F}{1-z}\left[1-\frac{f_{q/A}(\eta/z,\mu^2)}{f_{q/A}(\eta,\mu^2)}\right]\right)$$

The starting point of the shower is the Born cross section and we should use MSbar PDF.

$$\sigma_B = f_{q/A}(\eta_a,\mu^2,0)\, f_{\bar{q}/B}(\eta_b,\mu^2,0)\,\hat{\sigma}_B$$

That is

We have to consider these threshold factors at the beginning of the shower evolution.

$$\sigma_B = \overbrace{Z_q(\eta_a,\mu^2)Z_{\bar{q}}(\eta_b,\mu^2)}\ \underbrace{f_{q/A}(\eta_a,\mu^2,1)\, f_{\bar{q}/B}(\eta_b,\mu^2,1)\,\hat{\sigma}_B}$$

This is implemented in DEDUCTOR.

Summary

- DEDUCTOR is designed to do a better job with color, spin and resummation of large logarithms compared to other shower generators.
  - Lambda ordering with and without initial state massive quarks
  - LC+ color treatment. It allows us to do color evolution at amplitude level
  - Spin correlations are not yet computed
- Next version is available soon...
  - The shower equation is implemented at very abstract level. It allows us to use other ordering variables like kT or angle (massless or massive initial state partons).
  - Initial state threshold log resummation.
- It is available at

```
http://www.desy.de/~znagy/deductor
http://pages.uoregon.edu/soper/deductor
```

Summary

```cpp
/*   Defining the ordering dependent functions for the INITIAL state splittings  */
template<bool _Is_msbar>
struct __ordering_traits<ini, ordering::lambda, _Is_msbar>
{
  /*  calculates the limits on the variable v    */
  static void vlimits(double&, double&, const __hard_params<ini> *);

  /*  calculates the z limits  */
  static void zlimits(double&, double&, const __hard_params<ini> *, int, int, double);

  /*  pdf scale  */
  static double pdf_scale(const __hard_params<ini> *pars, double x, double y) {...}

  /*  kT2/(v*Q2) \approx (1-z)^alpha   */
  static constexpr unsigned int kT_alpha = 1u;

  /*  mapping the indipendent splitting variables v and z to the normalized virtuality, y   */
  static double mapping_to_y(const __hard_params<ini> *, int, int, double v, double) {...}

  /*  mapping the indipendent splitting variables v and z to the normalized virtuality, y
   *  It also returns the jacobian of  v --> y mapping.
   */
  static void mapping_to_y(double& y, double& yjac, const __hard_params<ini> *, int, int, double v, double) {...}

  /*  helps to define the shower time: exp(-t) = v/vnull   */
  static double vnull(double Q2, const lorentzvector<double>& qnull, const lorentzvector<double>& pa) {...}


  /*   Ordering dependent properties for the threshold resummation    */
  struct threshold
  {...};
};
```

http://pages.uoregon.edu/soper/deductor

Summary

- DEDUCTOR is designed to do a better job with color, spin and resummation of large logarithms compared to other shower generators.
  - Lambda ordering with and without initial state massive quarks
  - LC+ color treatment. It allows us to do color evolution at amplitude level
  - Spin correlations are not yet computed

- Next version is available soon...
  - The shower equation is implemented at very abstract level. It allows us to use other ordering variables like kT or angle (massless or massive initial state partons).
  - Initial state threshold log resummation.

- It is available at

```
http://www.desy.de/~znagy/deductor
http://pages.uoregon.edu/soper/deductor
```

Conclusion, Outlook

This is *just a design of the parton shower* and it make sense at LO level. As far as I know there is no formal definition even at leading order level.

$$\sigma[F_J] = \sum_{m=2}^{\infty} \big(\rho_m \big| \mathcal{F}_J \big| 1\big) = \sum_m \big[d\{p,f\}_m\big] \mathrm{Tr}\{\rho(\{p,f\}_m) F_J(\{p,f\}_m)\}$$

We need a formal proof that the perturbative sum of the cross section can be rearranged as a product.

$$\sigma[F_J] = \big(1\big|\mathcal{F}_J\Big[\mathcal{W}^{LO}(\mu_\mathrm{f}^2) + \mathcal{W}^{NLO}(\mu_\mathrm{f}^2) + \cdots\Big]$$

Finite corrections

$$\mathbb{T}\exp\left\{\int_{\mu_\mathrm{f}^2}^{\mu_0^2} \frac{d\mu^2}{\mu^2}\Big[\mathcal{H}^{LO}(\mu^2) + \mathcal{H}^{NLO}(\mu^2) + \cdots\Big]\right\}$$

Parton shower

$$\Big[\big|\rho^{LO}(\mu_0^2)\big) + \big|\rho^{NLO}(\mu_0^2)\big) + \big|\rho^{NNLO}(\mu_0^2)\big) + \cdots\Big]$$

Hard state

Parton Showers, Event Generators & Resummation

26-28 May 2015

Cracow

Topics:

- Parton-shower development
- Resummation techniques
- Connection between analytical resummation and parton showers
- Automated frameworks
- Matching to fixed-order results

Organizing committee:
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Local organizing committee:
Oleksandr Gituliar, Andreas van Hameren, Staszek Jadach, Krzysztof Kutak, Andrzej Siodmok, Maciej Skrzypek

For more details and registration go to:

http://PSR15.ifj.edu.pl

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