LHC jet masses and resummation

Mrinal Dasgupta

University of Manchester

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- Introduction
- Towards all-orders predictions for jet masses
- Non-global logs
- The role of the jet definition
- Still open questions

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- Jet masses significant variables in studies of boosted objects and jet substructure. Important role in LHC phenomenology.
- One important feature is potentially large logarithms $\alpha_s \ln^2 \frac{P_t^2}{M^2}$. LHC opens up large phase space.
- Have seen measurements of inclusive jet distributions and comparisons solely to event generators.
- What about analytical resummation of the large logarithms involved? Analytical handles on jet substructure?

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Some work has been carried out.

- Leading order estimate by Almeida et.al

$$\frac{1}{\sigma}\frac{d\sigma}{dp_T dm_J} \sim \alpha_s(p_T)\frac{4C_J}{\pi m_J}\log\left(\frac{Rp_T}{m_J}\right)+\cdots$$

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Already compared to Tevatron data! Above result is straightforward to improve. If the logarithm dominates we need to resum, if not use NLOJET++.

- Work involving resummation within the context of SCET for e^+e^- annihilation but aiming at extension to hadron colliders. Jet angularities with a jet veto e.g.

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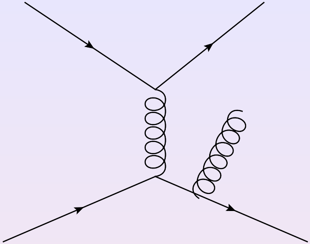

Consider $q(p_1) + q'(p_2) = q(p_3) + q'(p_4)$ with $p_3 = p_J$.

$$
\begin{aligned}
p_1 &= \frac{\sqrt{s}}{2} x_1 (1, 0, 0, 1) \\
p_2 &= \frac{\sqrt{s}}{2} x_2 (1, 0, 0, -1) \\
p_3 &= p_t (\cosh y_1, 1, 0, \sinh y_1) \\
p_4 &= p_t (\cosh y_2, -1, 0, \sinh y_2) \\
k &= k_t (\cosh \eta, \cos \phi, \sin \phi, \sinh \eta)
\end{aligned}
$$

$$\Sigma(\rho, p_t) = -\frac{\alpha_s}{2\pi} \sum_{(ij)} C_{ij} \int \frac{dk_t}{k_t} d\eta \frac{d\phi}{2\pi} \times$$

$$\times \frac{(p_i.p_j)}{(p_i.k)(p_j.k)} \Theta\left(\frac{M_j^2}{p_t^2} - \rho\right) \Theta_{\mathrm{in}}(k)$$

Results for dipole involving triggered jet will contain leading double logarithms:

$$W_{23} = W_{13} = \frac{1}{2}\ln^2\frac{R^2}{\rho} + \ln\frac{1}{\rho}\left(\frac{R^2}{4} + \frac{R^4}{288} + \mathcal{O}(R^6)\right)$$

$$W_{34} = \frac{1}{2}\ln^2\frac{R^2}{\rho} + \ln\frac{1}{\rho}\left(\frac{R^4}{16} + \mathcal{O}(R^6)\right)$$

Other dipoles will produce single logarithms and terms regular in R wide-angle soft contributions:

$$W_{12} = \ln\frac{1}{\rho}\,(R^2)$$

$$W_{24} = W_{14} = \ln\frac{1}{\rho}\left(\frac{R^2}{4} + \frac{R^4}{32}\right)$$

Overall one gets

$$\Sigma(\rho) \sim 1 - C_F \frac{\alpha_s}{2\pi} \left[\ln^2 \frac{R^2}{\rho} + 2 \ln \frac{1}{\rho} \left(\frac{R^2}{2} + \frac{5R^4}{144} + \cdots \right) \right] - \frac{\alpha_s}{\pi} \frac{1}{N} \ln \frac{1}{\rho} \left[R^2 - \frac{R^4}{24} + \cdots \right]$$

Note series in R will converge rapidly for smaller R values such as $R = 0.4$ and $R = 0.6$. May proceed in a small R approximation. Above result is ok in any algorithm. The leading double-log term is the one used by Almeida et.al.

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The leading log behaviour we have computed straightforwardly exponentiates. The finite R terms also exponentiate but with matrix valued coefficients – ignore for simplicity.

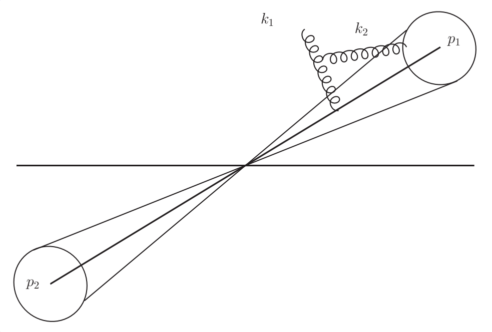
Include collinear emission and running coupling

$$\Sigma^{ind}\left(\frac{R^2}{\rho}, p_t\right) = \frac{\exp\left[-\mathcal{R}_\rho - \gamma_E \mathcal{R}'_\rho\right]}{\Gamma\left(1+\mathcal{R}'_\rho\right)}.$$

$$\mathcal{R}_\rho = \frac{C_F}{\pi}\int \frac{dk_t^2}{k_t^2}\alpha_s(k_t)\mathcal{F}(k_t^2)\,,$$

$$\mathcal{F}(k_t^2) = \ln\left(\frac{p_t R e^{-\frac{3}{2}}}{2k_t}\right)\Theta\left(\frac{Rp_t}{2} - k_t\right)\Theta\left(\frac{k_t^2}{p_t^2} - \frac{\rho}{4}\right) + \ln\left(\frac{2Rk_t}{\rho p_t}\right)\Theta\left(\frac{\rho}{4} - \frac{k_t^2}{p_t^2}\right)\Theta\left(\frac{k_t^2}{p_t^2} - \frac{\rho^2}{4R^2}\right),$$

Soft wide-angle emissions beyond one-loop



The fun starts at two-loop level. Looking in the interior of jet corresponds to non-globalness. Can do explicit calculation with 2 soft energy ordered gluons $\omega_1 \gg \omega_2$.

Configuration would *cancel* to our accuracy in global observables.

MD and Salam, 2001, 2002

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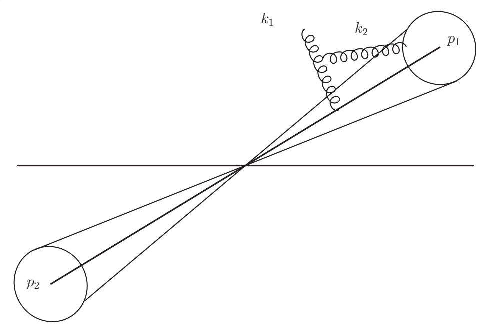

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Non-global logs

One can ask what happens in the limit of a small jet $R \to 0$.

$$\begin{aligned} p_1 &= E\,(1,0,0,1) \\ p_2 &= E\,(1,0,0,-1) \\ k_1 &= \omega_1\,(1,\sin\theta_1,0,\cos\theta_1) \\ k_2 &= \omega_2\,(1,\sin\theta_2\cos\phi,\sin\theta_2\sin\phi,\cos\theta_2) \end{aligned} \tag{1}$$

$$\Omega = \frac{2}{(\cos\theta_2 - \cos\theta_1)(1-\cos\theta_1)(1+\cos\theta_2)}.$$

Energy ordering $\to$ logarithmic enhancement $\alpha_s^2 \ln^2 \frac{1}{\rho}$

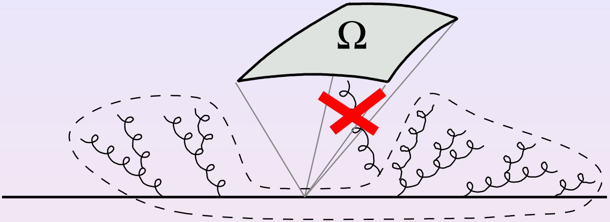
$$S_2 = -2C_F C_A \left(\frac{\alpha_s}{2\pi}\right)^2 \int_{1-R^2/2}^{1} d\cos\theta_2 \int_{-1+R^2/2}^{1-R^2/2} d\cos\theta_1$$
$$\ln^2 \frac{\rho E}{4E_0(1-\cos\theta_2)} \Theta\left(1 - \frac{\rho E}{4E_0(1-\cos\theta_2)}\right)\Omega\,.$$

Integrating over angles

$$S_2 = -C_F C_A \left(\frac{\alpha_s}{2\pi}\right)^2 \frac{\pi^2}{3} \ln^2 \frac{2E_0 R^2}{\rho E}.$$

Relevant single-log term. Same coefficient as for hemisphere masses upto corrections $\mathcal{O}(R^2)$. Effect comes from edge of jet. E_0 is a veto scale.

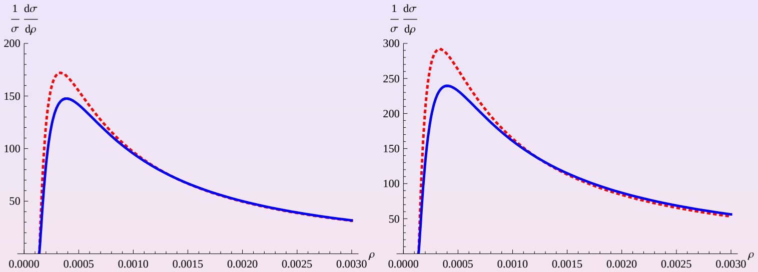
Resummation



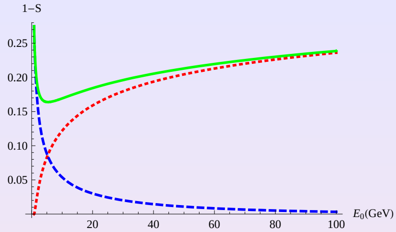
Only in leading N_c limit. Can use the hemisphere result computed numerically via dipole evolution.

$$S(t) = \exp\left(-C_F C_A \frac{\pi^2}{3}\left(\frac{1+(at)^2}{1+(bt)^c}\right)t^2\right),$$

where $a = 0.85 C_A$, $b = 0.86 C_A$, $c = 1.33$ and $t \sim \alpha_s L$.



Plots are for $p_t = 250$ GeV and $E_0 = 15$ GeV and $E_0 = 60$ GeV Banfi, MD ,Khelifa Kerfa, Marzani, 2010



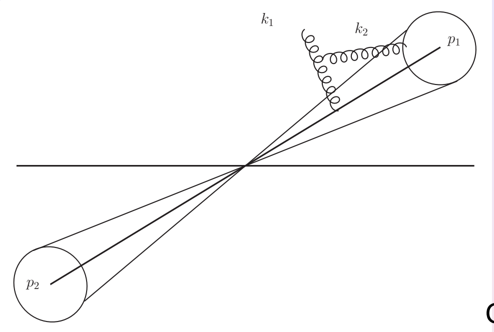
Also non-global factors from edges of recoiling (unrestricted) jets.

$$t_{\text{measured}} = -\frac{1}{4\pi\beta_0}\ln\left(1-\beta_0\alpha_s\left(E_0\right)\ln\frac{2E_0R^2}{E\rho}\right),$$
$$t_{\text{unmeasured}} = -\frac{1}{4\pi\beta_0}\ln\left(1-\beta_0\alpha_s\left(E/2\right)\ln\frac{E}{2E_0}\right).$$

Playing with veto scale doesnt help. Need to restrict emissions everywhere like for global event shape variables. 20 to 30 percent effect of NG logs on peak height.

Banfi, Salam, Zanderighi, 2004, 2010.

Jets in other algorithms



Consider jet masses in algorithms like C-A where self clustering of soft gluons is important. Non-global logs will be affected by clustering. Using a large R value may eliminate them.

Appleby and Seymour 2002

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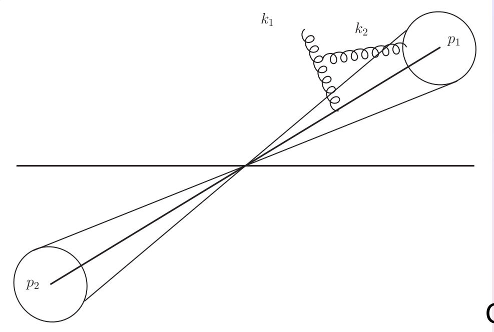

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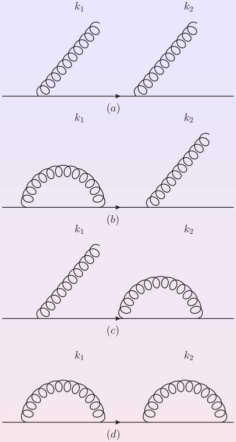
Further complications



Clustering spoils the naive gluon exponentiation ! Impacts real virtual cancellations. Generates additional terms.

Uncancelled contributions appear. E.g configuration (b) contributes a new term to distribution when k_1 is out and k_2 in.

Clustering Logs

$$\frac{\mathrm{d}}{\mathrm{d}\rho}\Sigma_2^{\text{cluster}} = -4C_F^2\left(\frac{\alpha_s}{2\pi}\right)^2 \frac{1}{\rho}\ln\frac{1}{\rho}\int\frac{d\phi}{\pi}\ln^2(2\cos\phi)\,\Theta\left(\cos\phi-\frac{1}{2}\right) = -0.728C_F^2\left(\frac{\alpha_s}{2\pi}\right)^2\frac{1}{\rho}\ln\frac{1}{\rho}.$$

These terms are independent of R at small R and need to be retained. They exponentiate but computing the exponent is tough!

Delenda,Appleby,Banfi, MD2006

Outlook

- There is a lot of scope for resummation in the context of substructure variables.
- Unfortunately many of the most interesting variables are non-global.
- In long term NG logs need to be better understood.
- In the short term one can focus on those ingredients that are important for a phenomenolgical description. Need for systematic approximations.