

Potential improvements to the fitting of the α_s through means of soft drop

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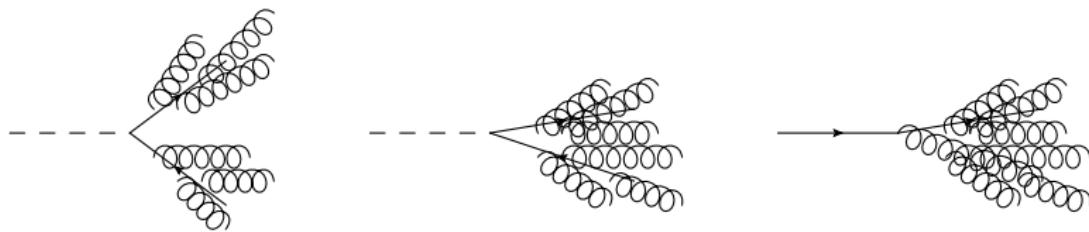
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Boosted particles

- LHC energy much larger than heavy particle masses
- Massive particles predominately produced boosted ($p_T \gg m$)
- Harder to distinguish from QCD jets



Non-perturbative contributions

Many effects cannot be described by perturbation theory:

- Hadronization effects
- Multi-parton interactions
- Pile-up

Jet substructure

- Many jet substructure techniques developed; **Grooming** and Tagging
- Created with the purpose of distinguishing signal from background
- Removes soft wide-angle radiation
- Can also help reduce non-perturbative corrections

mMDT & Soft drop

Main technique we will deal with is soft drop:

[Larkoski, Marzani, Soyez, Thaler; '14]

$$\frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_c \left(\frac{\Delta R_{12}}{R} \right)^\beta$$

or at e^+e^- colliders:

$$\frac{\min [E_i, E_j]}{E_i + E_j} > z_{\text{cut}} (1 - \cos \theta_{ij})^{\beta/2}$$

Makes use of Cambridge/Aachen clustering.

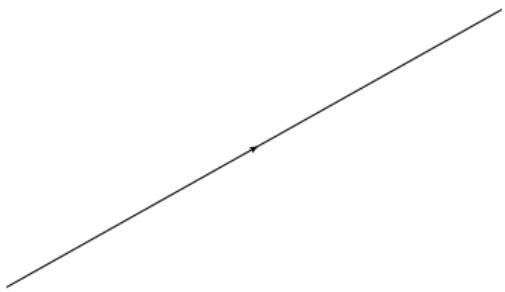
[Dokshitzer, Leder, Moretti, Webber; '97] [Wobisch, Wengler; '99]

Reduces to modified Mass Drop Tagger (mMDT) for $\beta = 0$

[Dasgupta, Fregoso, Marzani, Salam; '13]

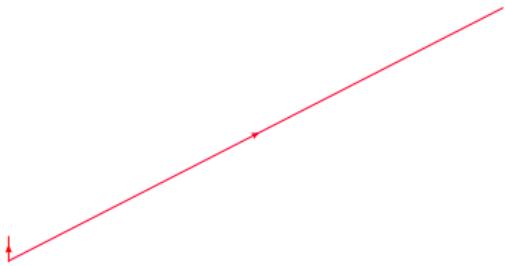
Full Soft drop

- 1) Decluster the last step
- 2) Check the soft drop condition for this splitting
- 3) If it fails drop the softest and repeat
- 4) If it passes finish the grooming



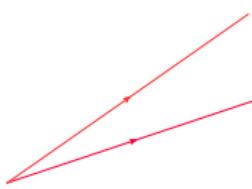
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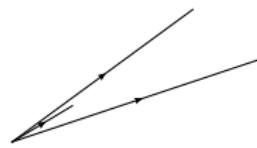
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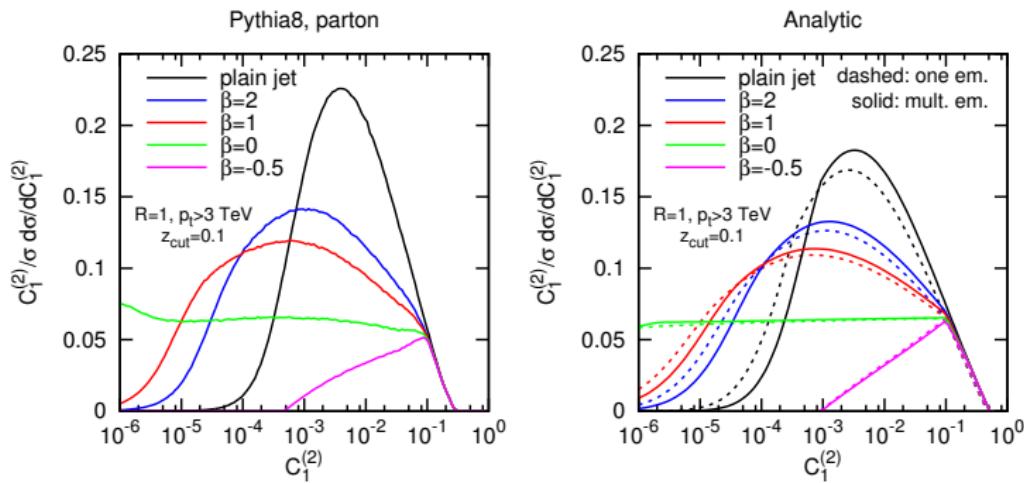
Need for resummation

For boosted jets, great separation of scales $p_T \gg m$ leads to large logarithms:

$$\log \left(\frac{m_J^2}{p_T^2 R^2} \right)$$

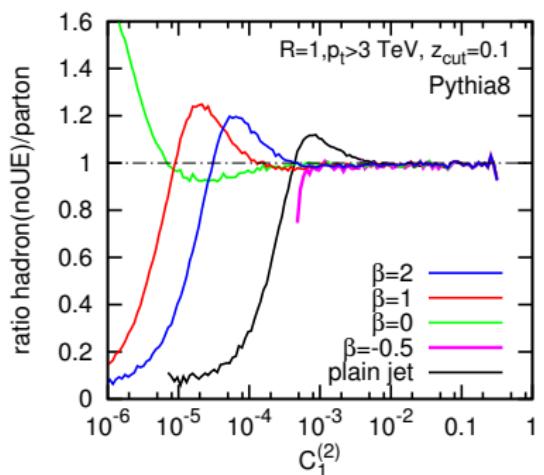
Large logarithms need to be resummed.

Analytic computations



[Larkoski, Marzani, Soyez, Thaler; '14]

Reduction in NP corrections



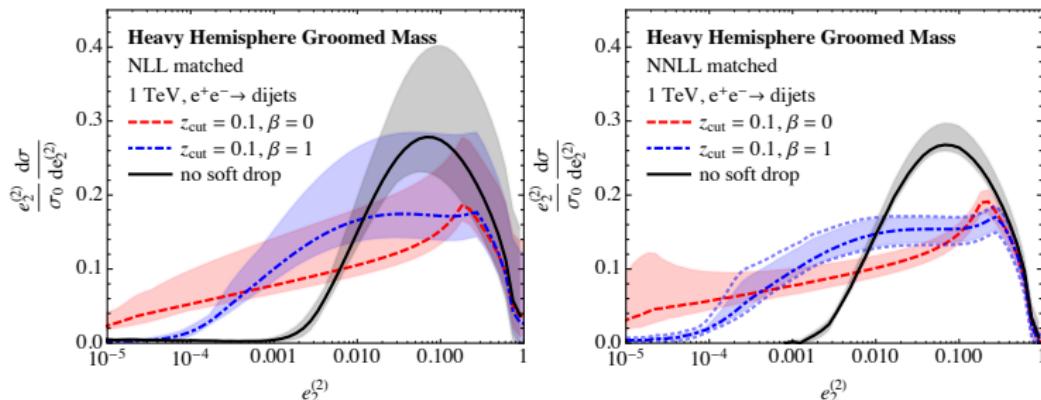
[Larkoski, Marzani, Soyez, Thaler; '14]

Further computations

- Computation of soft drop using SCET at NNLL accuracy approximated for $e_2^{(2)} \ll z_{cut}$ [Frye, Larkoski, Schwartz, Yan; '16]
- Calculation in dQCD including finite z_{cut} effects [Marzani, Schunk, Soyez; '17]
- Including jet radius resummation in SCET [Kang, Lee, Liu, Ringer; '18]
- Good agreement to experiments [CMS; '17] [ATLAS; '17]
- Application to top quark mass measurements [Hoang, Mantry, Pathak, Stewart; '17]
- And α_s measurements at LHC [Les Houches; '18] and e^+e^- [Baron, Marzani, VT; '18] ← **This talk**

Computation at NNLL accuracy

- Computation of soft drop using SCET at NNLL accuracy
 $[Frye, Larkoski, Schwartz, Yan; '16]$
- Approximated for $e_2^{(2)} \ll z_{cut}$

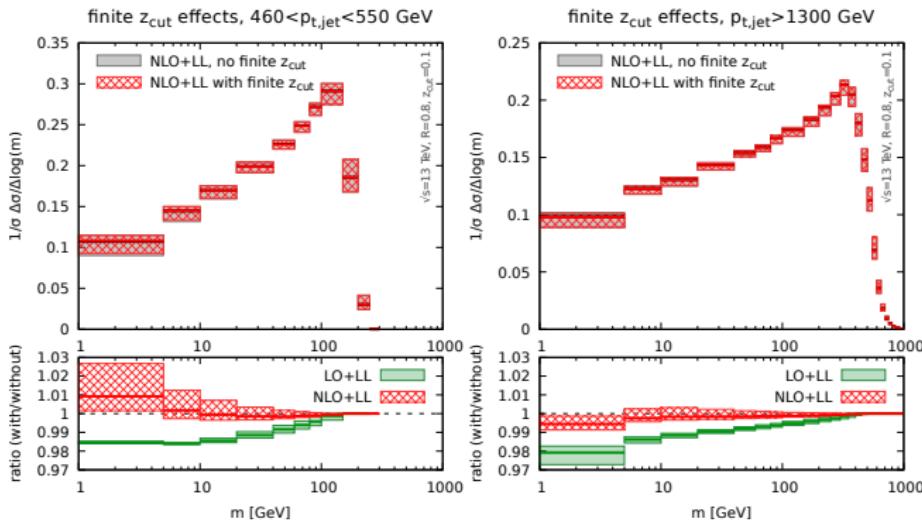


- Significant reduction in uncertainty
- Values remain comparable

Finite z_{cut} effects

Continued calculation in dQCD including finite z_{cut} effects

[Marzani, Schunk, Soyez; '17]:



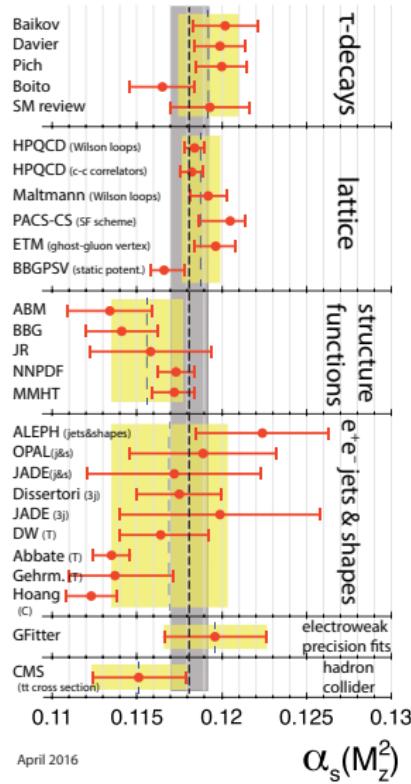
Percent level corrections for $z_{\text{cut}} = 0.1$, but can be larger for other values

The importance of α_s

- Jet physics of great importance to the LHC
- Higher order perturbative corrections shown to be important scale with higher powers of α_s
- Higgs boson production scales as α_s^2

An accurate measurement of α_s is necessary for precision LHC measurements

α_s Measurement

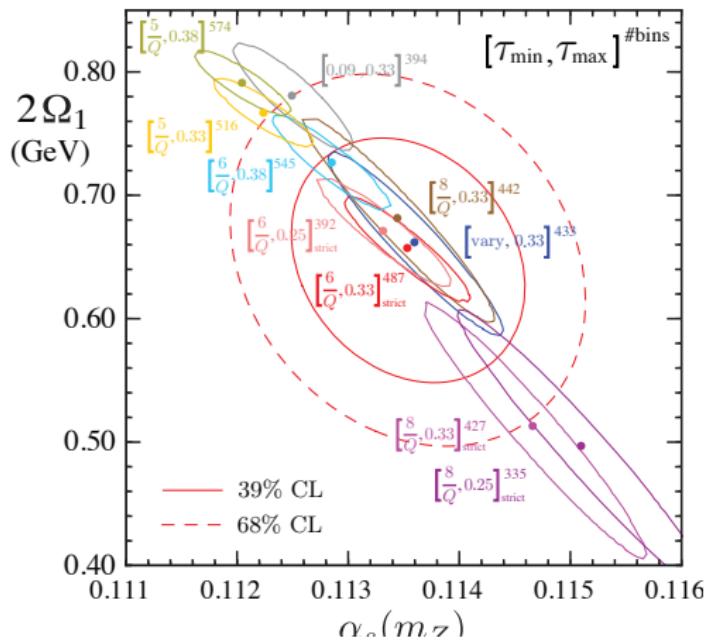


April 2016

$$\alpha_s(M_z^2)$$

[Particle Data Group; 16]

NP contributions



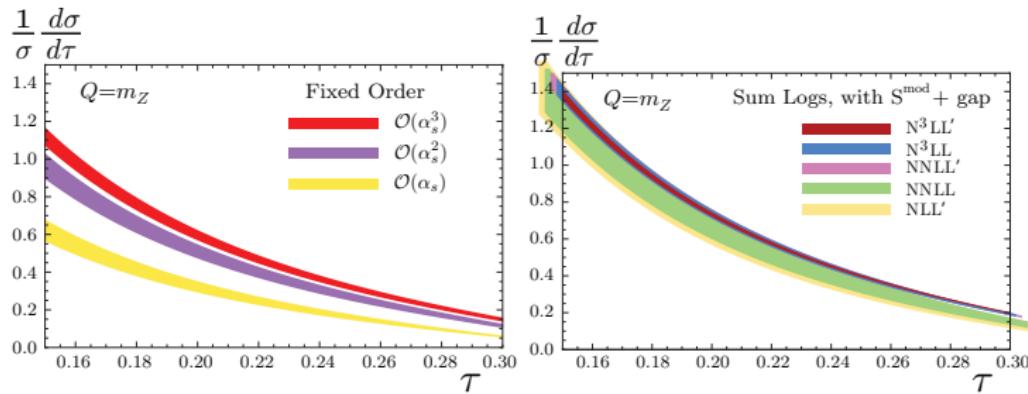
[Abbate, Fickinger, Hoang, Mateu, Stewart; 10]

Thrust

$$\tau = 1 - T = \min_{\vec{n}} \left(1 - \frac{\sum_i |\vec{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|} \right)$$

Minimize for thrust axis \vec{n}

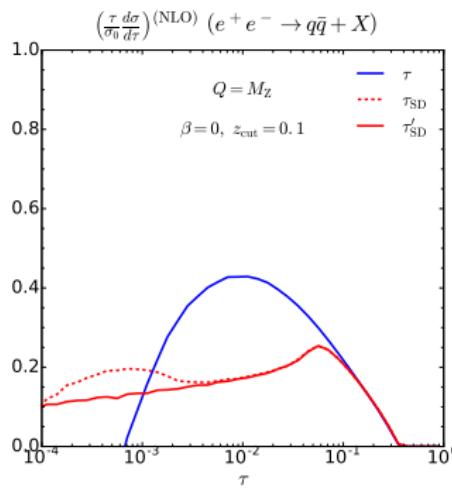
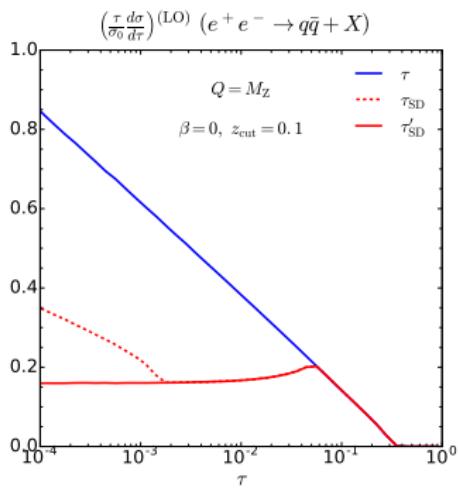
[Abbate, Fickinger, Hoang, Mateu, Stewart; 10]



SD Distribution

Hemisphere jets at an e^+e^- collider → Different soft drop condition:

$$\frac{\min [E_i, E_j]}{E_i + E_j} > z_{\text{cut}} (1 - \cos \theta_{ij})^{\beta/2}$$



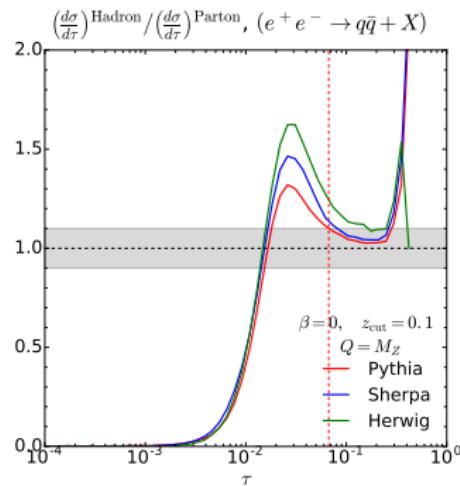
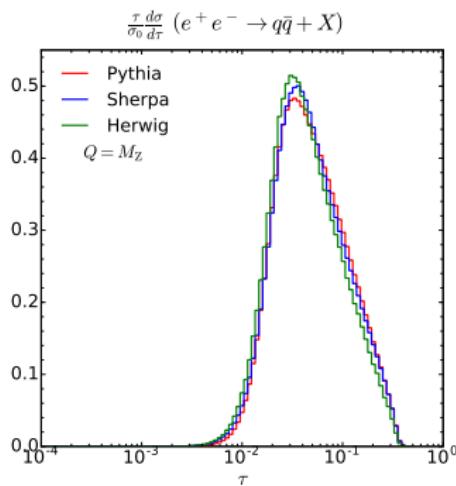
Alternative definition

- Separation into two jets at the hand of thrust axis pre-softdrop
- After softdrop each hemisphere will have its own axis
- Each thrust axis is the jet axis

$$T'_{\text{SD}} = \frac{\sum_{i \in \mathcal{H}_{\text{SD}}^L} |\vec{n}_L \cdot \vec{p}_i|}{\sum_{i \in \mathcal{E}_{\text{SD}}} |\vec{p}_i|} + \frac{\sum_{i \in \mathcal{H}_{\text{SD}}^R} |\vec{n}_R \cdot \vec{p}_i|}{\sum_{i \in \mathcal{E}_{\text{SD}}} |\vec{p}_i|}$$

MC studies

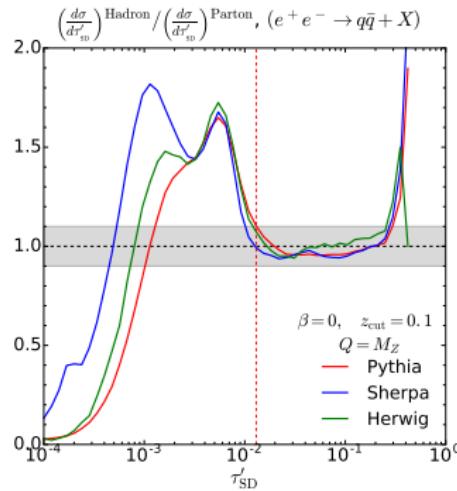
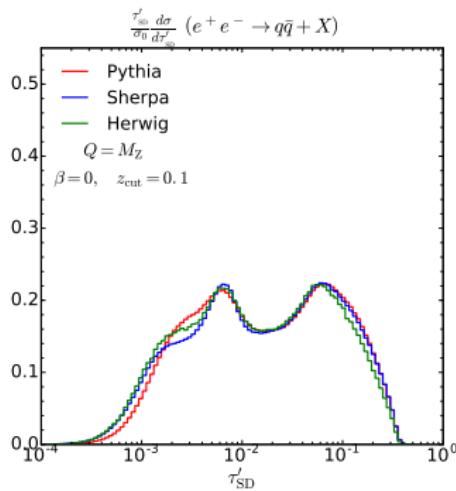
[Baron, Marzani, VT; '18]



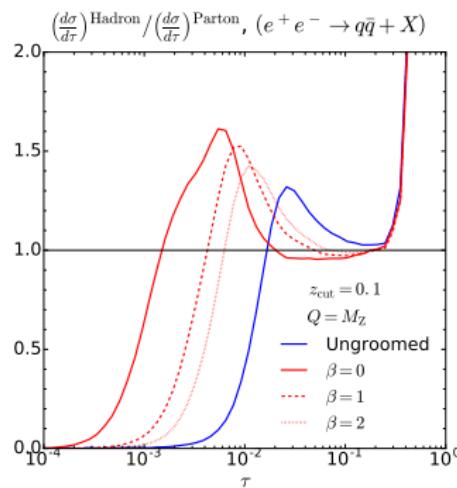
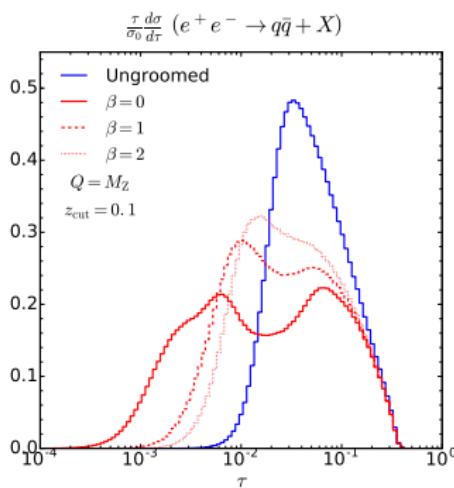
Non-perturbative corrections above 10% around $\tau \simeq 0.07$

MC studies with soft drop

[Baron, Marzani, VT; '18]



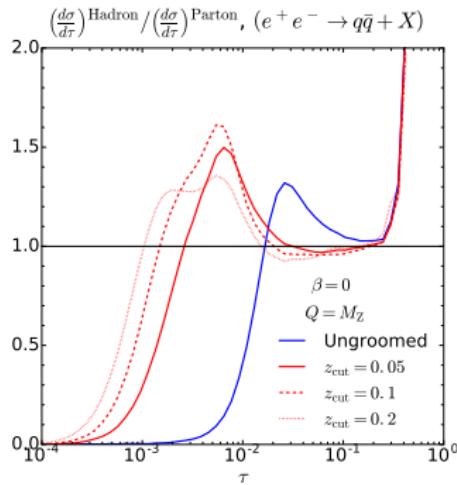
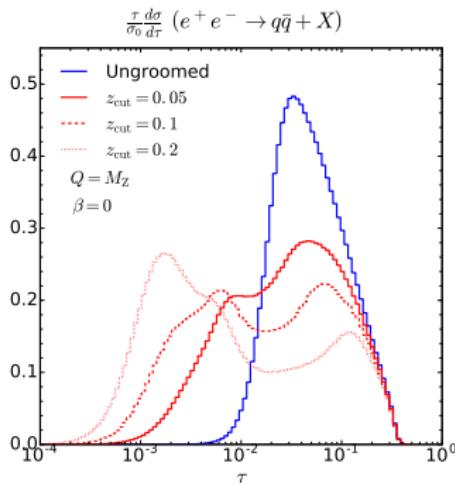
Non-perturbative corrections above 10% around $\tau \simeq 0.001$
Reduction in non perturbative corrections.

z_{cut} & β values*[Baron, Marzani, VT; '18]*

Different values of β do not offer improvement

z_{cut} & β values

[Baron, Marzani, VT; '18]



Smaller values of z_{cut} offer more data in the relevant region with only a slight increase in non-perturbative corrections.

Analytic computation

Additional calculation for contributions where $\tau \sim z_{\text{cut}}$ at NLL' accuracy:

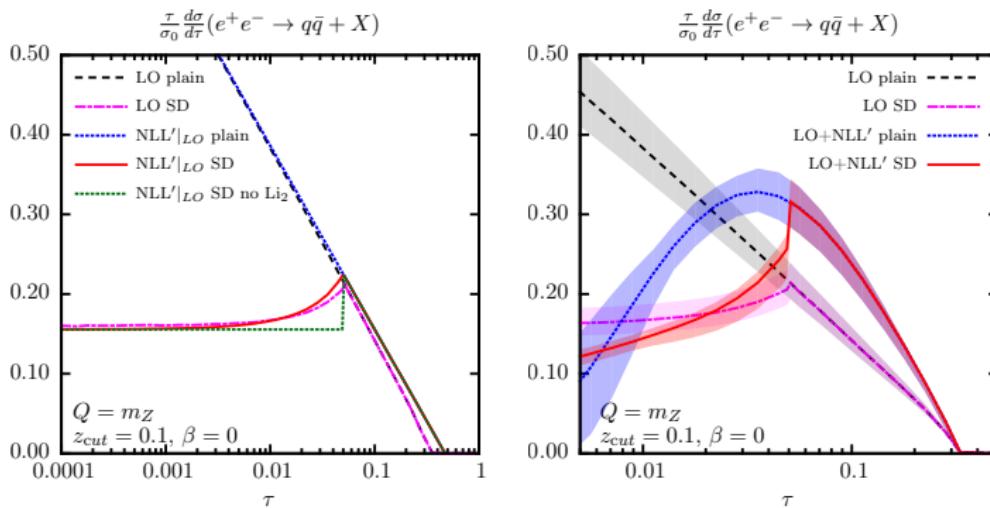
$$\frac{\alpha_s}{\pi} C_F (\beta + 2) \operatorname{Li}_2 \left[\frac{1}{2} \left(\frac{2\tau}{z_{\text{cut}}} \right)^{\frac{2}{\beta+2}} \right]$$

Can be neglected for $\tau \ll z_{\text{cut}}$, but offers a constant contribution near the transition point $\tau = z_{\text{cut}}/2$.

Additional corrections for the end-point of the resummation and expansion.

Resummation results

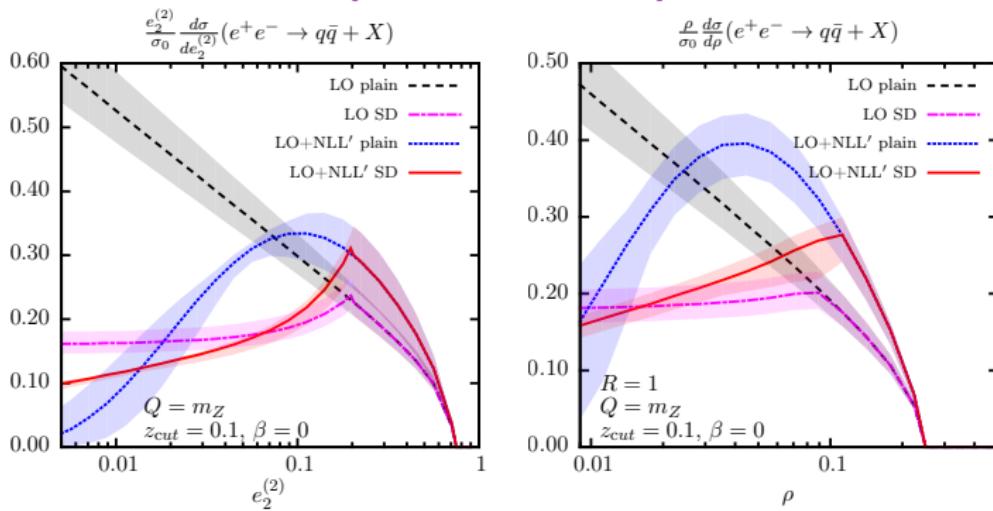
[Baron, Marzani, VT; '18]



- Expansion offers a good approximation for fixed order
- Transition corrections are important for thrust

Alternative observables

[Baron, Marzani, VT; '18]



Other observables allow for a reduction in transition point effects.

Summary

Conclusions

- Soft drop can help reduce dependence on non-perturbative corrections for thrust
- Could help break degeneracy between non-perturbative contributions and α_s in fit
- Significant transition point effects that will need to be taken into account at NNLL accuracy
- Other observables could reduce the transition point effects

Summary

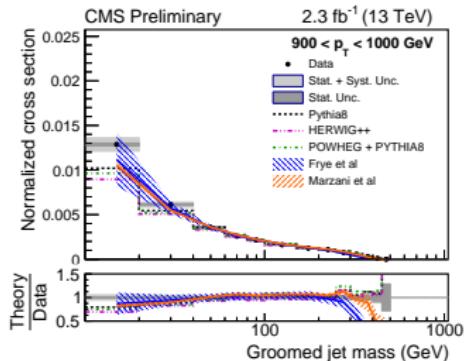
Conclusions

- Soft drop can help reduce dependence on non-perturbative corrections for thrust
- Could help break degeneracy between non-perturbative contributions and α_s in fit
- Significant transition point effects that will need to be taken into account at NNLL accuracy
- Other observables could reduce the transition point effects

Thank you for your attention

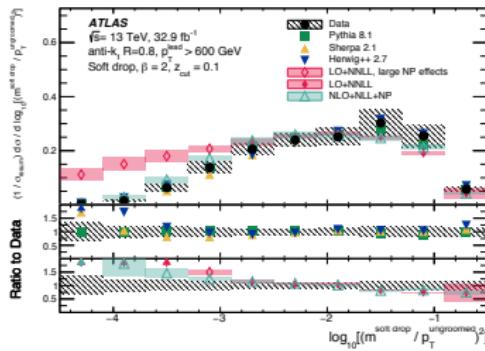
Measurements

Recent comparison to LHC data:



[CMS; '17]

Good agreement with Data



[ATLAS; '17]

Factorization

Factorization for $\tau \ll z_{\text{cut}} \ll 1$ [Frye, Larkoski, Schwartz, Yan; '16]:

$$\frac{d\sigma}{d\tau} = H(Q) S_G(z_{\text{cut}}, \beta) [S_C(\tau, z_{\text{cut}}, \beta) \otimes J(\tau)]^2$$

Computed in Laplace space and inverted leading to:

$$\Sigma(\tau) = \left[1 + \left(\frac{\alpha_s}{\pi} \right) C^{(1)} + \dots \right] \exp \left[\frac{1}{\alpha_s} g_1(-\lambda_\tau, \lambda_{z_{\text{cut}}}) + g_2(-\lambda_\tau, \lambda_{z_{\text{cut}}}) + \dots \right]$$

for $\lambda_x = \alpha_s b_0 \log x$ and confirmed using dQCD.

With matching:

$$\tau \frac{d\sigma^{\text{LO+NLL}'} }{d\tau} = \tau \frac{d\sigma^{\text{LO}}}{d\tau} + \left[\tau \frac{d\sigma^{\text{NLL}'} }{d\tau} - \tau \frac{d\sigma^{\text{NLL}'|_{\text{LO}}}}{d\tau} \right]$$

End point corrections

Modification of the logarithm:

$$\log(x_L \tau) \rightarrow -\log\left(\frac{1}{x_L \tau} - \frac{1}{x_L \tau_{\max}} + 1\right)$$

Additional contribution:

$$\tau \frac{d\sigma_{\text{exp}}}{d\tau} = \frac{\alpha_s}{\pi} \left[\frac{1}{2} G_{12} \log \bar{\tau} + G_{11} \left(1 - \frac{\tau}{\tau_{\max}} \right) \right]$$

Leads to resummation:

$$\tau \frac{d\sigma_{\text{res}}}{d\tau} = \left(F'(\log \bar{\tau}) - \frac{\tau}{\tau_{\max}} \frac{\alpha_s}{\pi} G_{11} \right) C \exp \left[F(\log \bar{\tau}) - \frac{\tau}{\tau_{\max}} \frac{\alpha_s}{\pi} G_{11} \log \bar{\tau} \right]$$

End point corrections soft drop

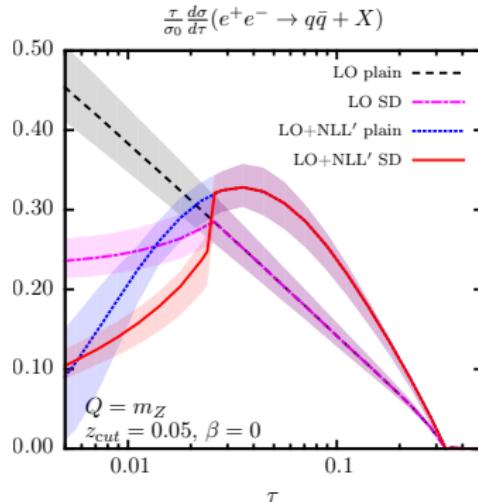
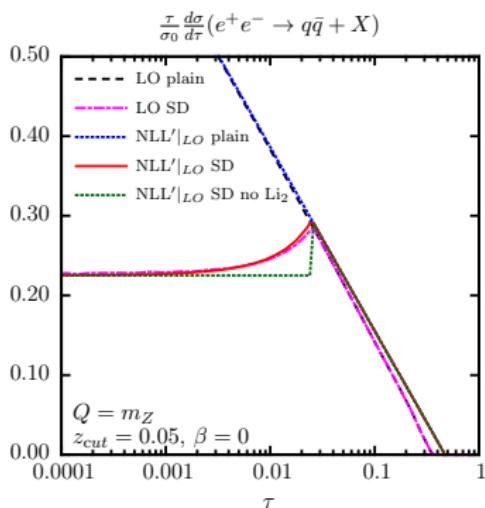
$$\tau \frac{d\sigma_{\text{res}}}{d\tau} = \left(F'(\log \bar{\tau}) - \frac{\tau}{\tau_{\max}} \frac{\alpha_s}{\pi} G_{11} \right) C \exp \left[F(\log \bar{\tau}) - \frac{\tau}{\tau_{\max}} \frac{\alpha_s}{\pi} G_{11} \log \bar{\tau} \right]$$

In order to treat both sides of the transition point the same:

$$\begin{aligned} \tau \frac{d\sigma_{\text{res}}}{d\tau} &= \left(F'(\log \bar{\tau}, \log z_{\text{cut}}) - \frac{\tau}{\tau_{\max}} \left(G_{11}^{(\text{SD})} + S'_0 \right) \right) \\ &\quad C^{(\text{SD})} \left(\frac{2\tau}{z_{\text{cut}}} \right) \exp [F(\log \bar{\tau}, \log z_{\text{cut}})] \\ &\quad \times \prod_K \exp \left[\frac{\tau}{\tau_{\max}} \frac{G_{11}^{(K)}}{p_K^{(\bar{N})}} \left(-p_K^{(\bar{N})} \log \bar{\tau} + p_K^{(z_{\text{cut}})} \log \left(x_L \frac{z_{\text{cut}}}{2} \right) \right) \right] \end{aligned}$$

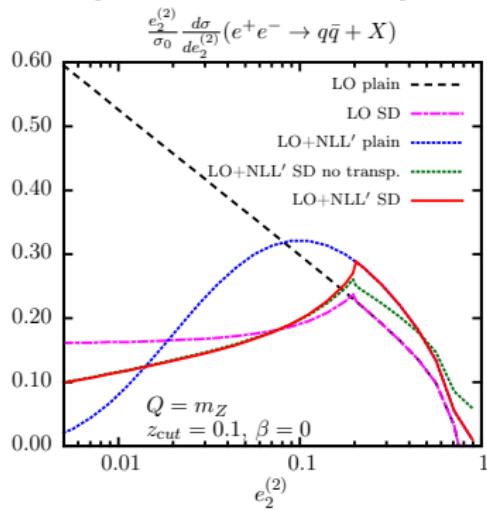
Resummation results

[Baron, Marzani, VT; '18]



Transition point methods

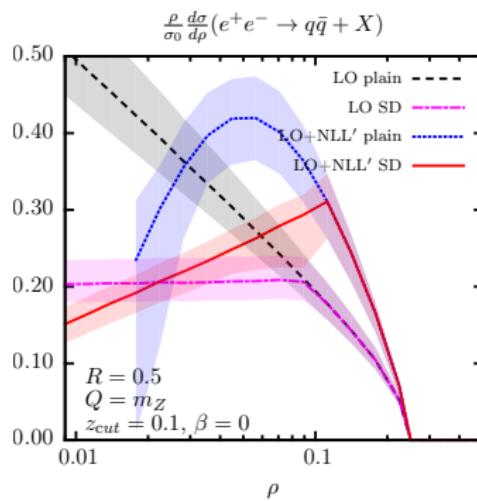
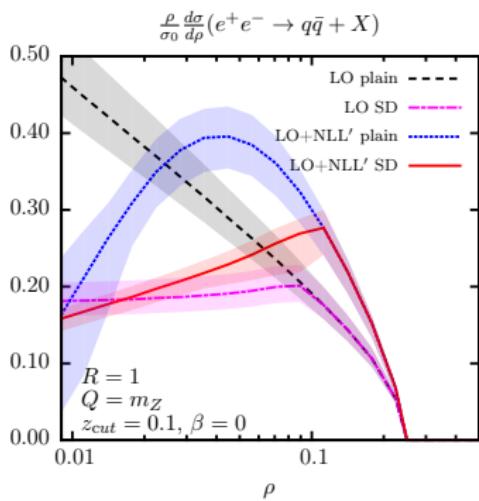
[Baron, Marzani, VT; '18]



For this observable matching can take into account bulk of the effect.

R dependence

[Baron, Marzani, VT; '18]



Other observables allow for a reduction in transition point effects.