Fitting the strong coupling constant for soft-drop thrust

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In Collaboration with:

Jeremy Baron and Simone Marzani [arXiv:1803.04719]

Simone Marzani, Daniel Reichelt, Steffen Schumann, Gregory Soyez [arXiv:1906.10504]

BOOST, 07-25-2019

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

DAAD

Federal Ministry of Education and Research

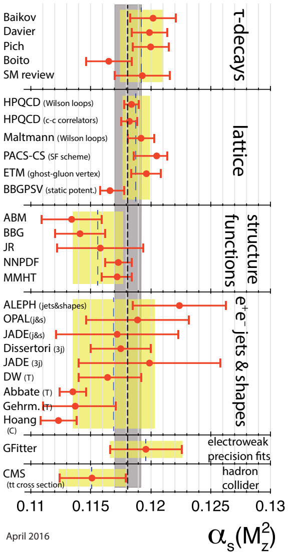
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605728

The importance of α_s

- No new physics at LHC → requires higher theoretical precision
- Jet physics of 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

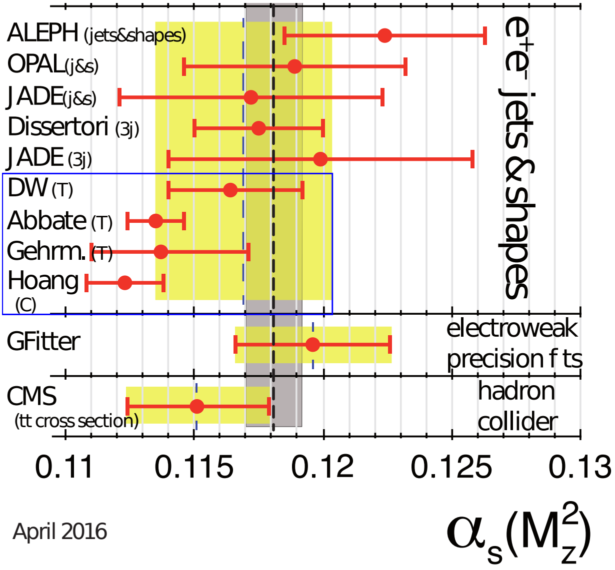
An accurate measurement of α_s is necessary for LHC precision measurements

α_s Measurement



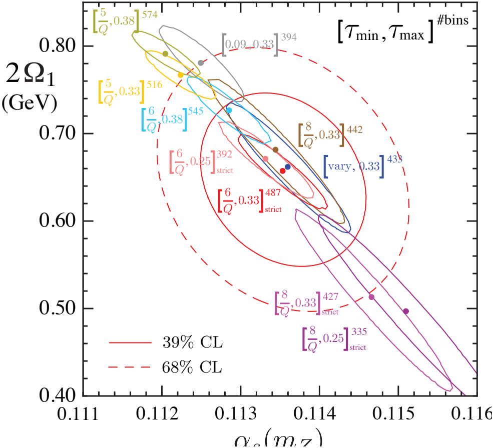
[Particle Data Group; '16]

α_s Measurement



[Particle Data Group; '16]

NP contributions



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

mMDT & Soft drop

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:

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

Makes use of Cambridge/Aachen clustering.

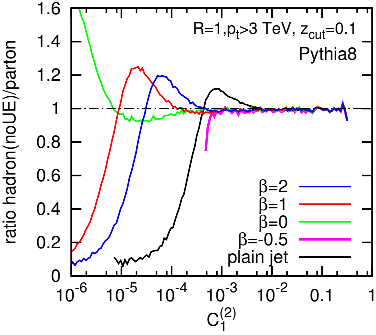
[Dokshitzer, Leder, Moretti, Webber; '97][Wobisch, Wengler; '99]

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

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

Reduction in NP corrections

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



Reduces non-perturbative effects, such as hadronization

Further work

- 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 $z_{\rm cut}$ 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] [Andreassen, Schwartz;'17]*
- And α_s measurements at LHC *[Les Houches;'18]* and e^+e^- *[Baron, Marzani, VT; '18][Marzani, Reichelt, Schumann, Soyez, VT; 19]*

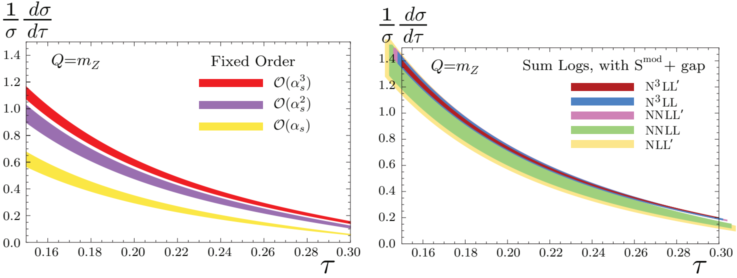
- Calculation of non-perturbative effects *[Hoang, Mantry, Pathak, Stewart, '19]* Talk by Aditya Pathak

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 $\vec{n}$

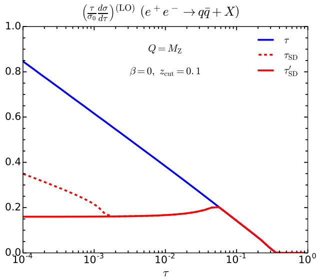
[Abbate, Fickinger, Hoang, Mateu, Stewart; '10]

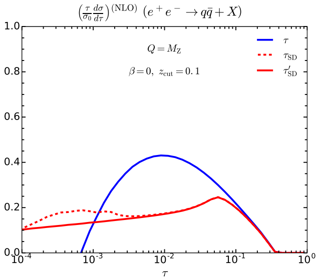


SD Distribution

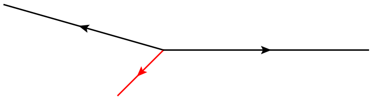
Hemisphere jets at an e^+e^- collider → Different soft drop condition:

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





Alternative definition

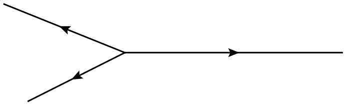


- Separation into two jets at the hand of thrust axis pre-softdrop
- After softdrop each hemisphere will have its own axis
- Each thrust axis is the jet axis

$$\tau_{SD} = \frac{\sum_{i\in\mathcal{E}_{SD}} |\vec{p}_i|}{\sum_{i\in\mathcal{E}} |\vec{p}_i|} \left[1 - \frac{\sum_{i\in\mathcal{H}^L_{SD}} |\vec{n}_L \cdot \vec{p}_i| + \sum_{i\in\mathcal{H}^R_{SD}} |\vec{n}_R \cdot \vec{p}_i|}{\sum_{i\in\mathcal{E}_{SD}} |\vec{p}_i|}\right]$$

Factor for collinear safety

Collinear safety



Failure of cancellation between virtual and real:
Virtual corrections at

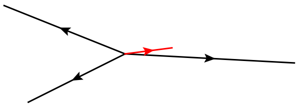
$$\tau = 1 - \frac{2E_R}{Q} = \frac{Q - 2E_R}{Q}$$

While a collinear emission that is groomed results in:

$$\tau_{SD}^{unsc.} = 1 - \frac{E_R}{Q - zE_R} - \frac{E_R(1-z)}{Q - zE_R} = \frac{Q - 2E_R}{Q - zE_R}$$

Rescaled soft-drop thrust fixes this. The issue is unique to a single particle in one hemisphere

Collinear safety



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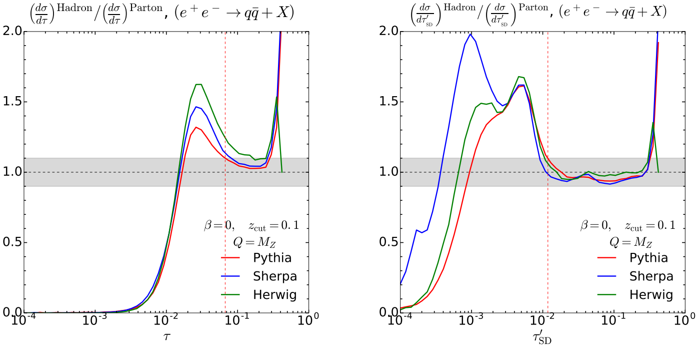
Reduction of hadronization with soft drop

[Baron, Marzani, VT; '18]



Non-perturbative corrections above 10% from $\tau \simeq 0.07$ to $\tau \simeq 0.001$
Reduction in hadronization corrections.

Hadronic thrust UE $\rightarrow$ poster by Jeremy Baron

Factorization

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

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

Computed in Laplace space and inverted leading to:

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

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

Multiple emission correction

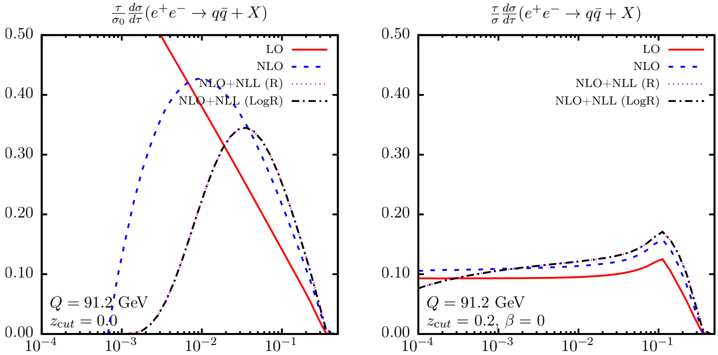
Additional transition point effect from multiple emissions.

$$\Sigma_{\mathrm{res}}|_{\tau>\mathrm{tr}} = C\frac{e^{R(\tau)}}{\Gamma\left(1-R'(\tau)\right)}\exp\left[R'(\tau)\frac{\mathrm{tr}}{\tau}{}_3F_2\left(1,1,1+R'(\tau);2,2;\frac{\mathrm{tr}}{\tau}\right)\right]$$
$$\times\exp\left[\log\left(\frac{\tau}{\mathrm{tr}}\right)\left\{R''(\tau)-R''(\tau=\mathrm{tr},z_{\mathrm{cut}})\right\}\right]$$

Originates from extrapolation of derivative in the inversion across the transition point.

Resummation results

[Marzani, Reichelt, Schumann, Soyez, VT; '19]



- Significant corrections from both fixed order and resummation
- Agreement between matching schemes
- In order to take into account $\tau \sim z_{\text{cut}}$ shift transition point to $\text{tr} = z_{\text{cut}} 2^{\beta/2}$, which holds at NLL

Fitting setup

- Compared to ALEPH data for thrust *[ALEPH;'04]*
- Fit to MEPS@NLO 2-5j Sherpa result for soft drop
  [Schumann, Krauss;'07] [Gehrmann, Hoche, Krauss, Schonherr, Siegert;'12]
- Assume ALEPH uncertainty with $\sqrt{\sigma}$ scaling for statistical uncertainty
- Same systematic uncertainty with minimal correlation

- Minimization of chi-squared
- Using range $\tau \in [0.06, 0.25]$

Setup is similar to a combination of methods from
[Abbate, Fickinger, Hoang, Mateu, Stewart;'10] and *[Gehrmann, Luisoni , Monni;'12]*

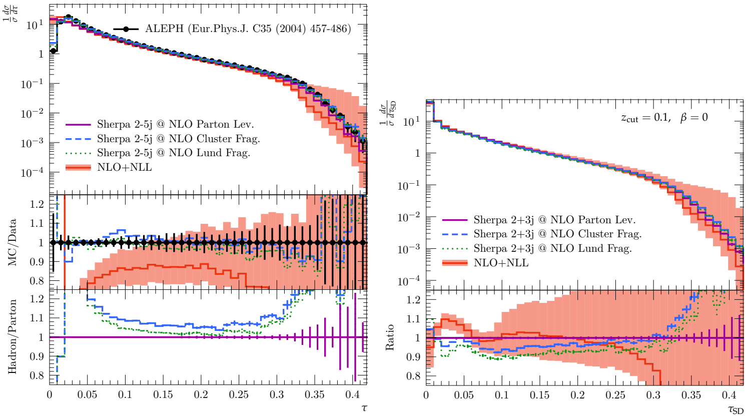
Non-perturbative corrections Analytical

For the non-perturbative model use a shift in τ and z_{cut} from
[Dasgupta, Fregoso, Marzani, Salam;'13] [Marzani, Schunk, Soyez;'17]

- Shift in τ from non-perturbative emission within a cone defined by thrust
- Shift in z_{cut} from non-perturbative emission that reduces energy leading to it being groomed
- Both are computed in a $2 \to 2 + \mathrm{NP}$ with small τ limit configuration
- More detailed calculation can be performed as a better approximation

Non-perturbative corrections Monte Carlo

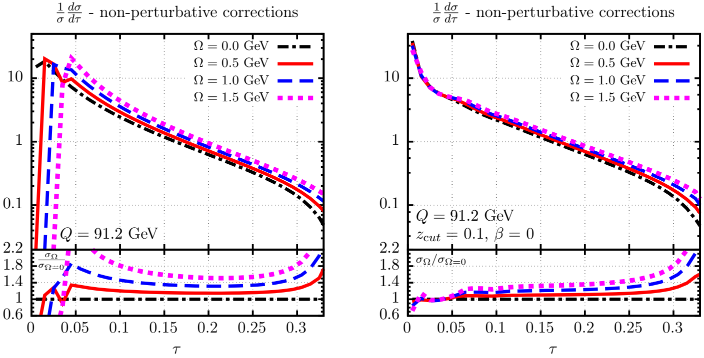
[Marzani, Reichelt, Schumann, Soyez, VT; '19]



- Based on MEPS@NLO Sherpa 2+3j to have comparable accuracy
- Significant differences between hadronization models
- Better agreement analytical model to PL

Comparison hadronization models

[Marzani, Reichelt, Schumann, Soyez, VT; '19]



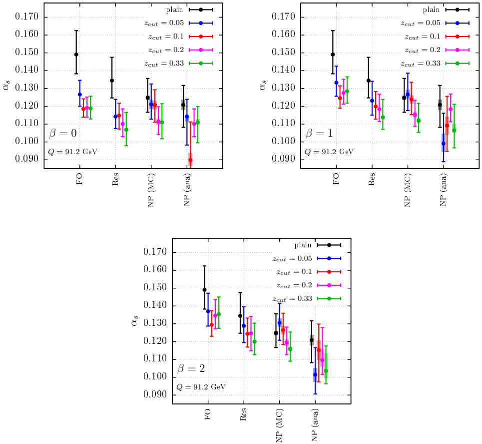
- Plain thrust replicates shape
- Increase instead of decrease above transition point

Uncertainties

- Experimental uncertainty at the hand of $\Delta\chi^2 = 1$ for fixed hadronization
- Theoretical uncertainty based all extreme variations:
  - Variation of μ_R and x_L with $1/2 < \mu_R x_L/Q < 2$
  - Variation of end-point p variable 1 or 2
  - Switch between matching scheme: R or LogR matching
- Hadronization uncertainty:
  - Analytical model: $\Delta\chi^2 = 1$ for varying Ω
  - Monte Carlo model: Switch between Clustering *[Winter, Krauss, Soff, '03]* and Lund String *[Sjöstrand, '82]*

Variation of z_{cut} and β

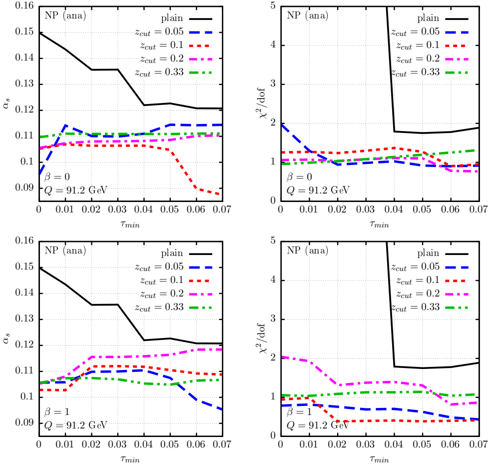
[Marzani, Reichelt, Schumann, Soyez, VT; '19]



Significant reduction in shift from hadronization corrections

Variation of minimum of fit range

[Marzani, Reichelt, Schumann, Soyez, VT; '19]



Stabilization of the fit over a longer range of $\tau_{\rm min}$

Summary

Conclusions

- Better agreement between analytical results and PL MC
- Soft drop helps reduce non-perturbative effects for α_s with thrust
- Fits are more stable with respect to an increase in fitting range
- Conclusions do not depend on hadronization model

Future work

- Study other observables and definitions of soft drop
- More precise calculation of analytical hadronization model
  Possibly through means of *[Hoang, Mantry, Pathak, Stewart, '19]*
- Higher accuracy fixed order and resummation
- Actual experimental measurement
- Extension to LHC

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Thank you for your attention