Strong coupling determination with grooming

Vincent Theeuwes

Georg-August-University Göttingen

In Collaboration with:

Jeremy Baron and Simone Marzani [arXiv:1803.04719] and

Simone Marzani, Daniel Reichelt, Steffen Schumann, Gregory Soyez [in Progress]

HARPS Genoa, 31-10-2018

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

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]

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

or at e^+e^- colliders:

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

Makes use of Cambridge/Aachen clustering.

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

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

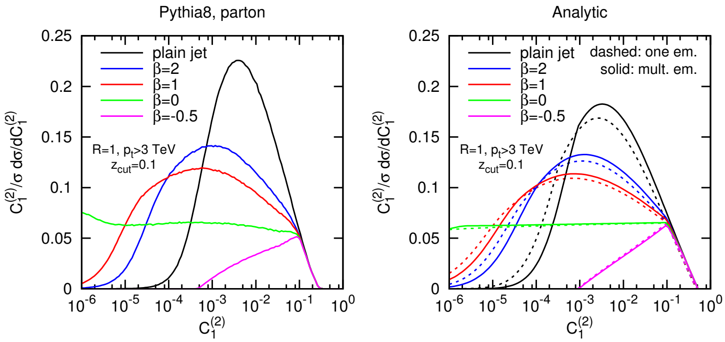
[Dasgupta, Fregoso, Marzani, Salam; '13]

Need for resummation

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

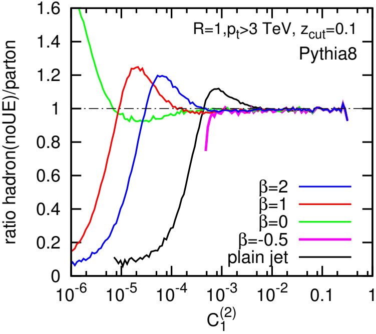
$$\log\left(\frac{m_J^2}{p_T^2 R^2}\right)$$

Large logarithms need to be resummed.



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

Reduction in NP corrections



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

Further work

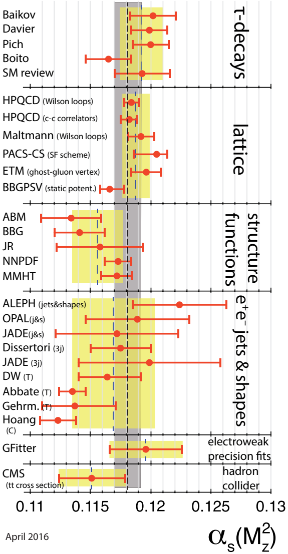
- Computation of soft drop using SCET at NNLL accuracy approximated for $e_2^{(2)} \ll z_{cut}$ *[Frye, Larkoski, Schwartz, Yan; '16]*
- Calculation in dQCD including finite z_{cut} effects *[Marzani, Schunk, Soyez; '17]*
- Including jet radius resummation in SCET *[Kang, Lee, Liu, Ringer; '18]*
- Good 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]*

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

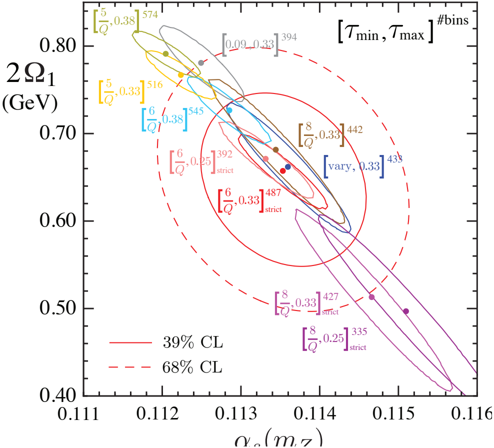
An accurate measurement of α_s is necessary for precession LHC measurements

α_s Measurement



[Particle Data Group; 16]

NP contributions



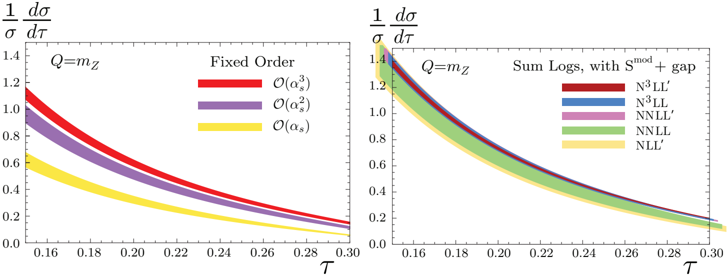
[Abbate, Fickinger, Hoang, Mateu, Stewart; '10]

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 $\vec{n}$

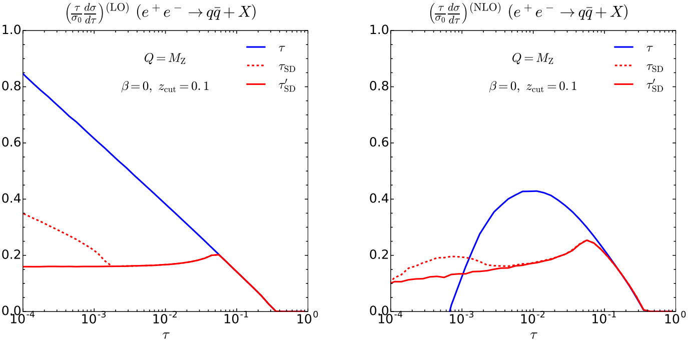
[Abbate, Fickinger, Hoang, Mateu, Stewart; '10]



SD Distribution

Hemisphere jets at an e^+e^- collider $\rightarrow$ Different soft drop condition:

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



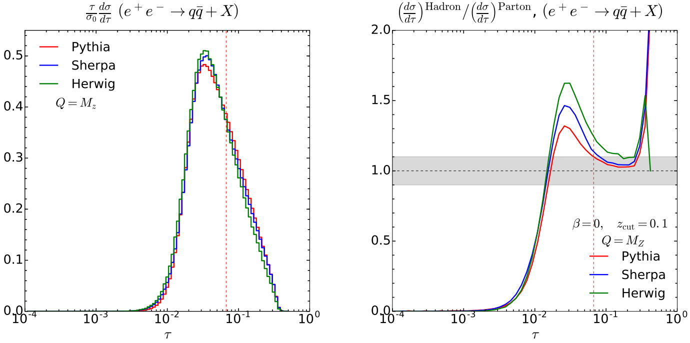
Alternative definition

- 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

$$T'_{\mathsf{SD}} = \frac{\sum_{i\in\mathcal{H}^L_{\mathbf{SD}}} |\vec{n_L}\cdot\vec{p}_i|}{\sum_{i\in\mathcal{E}_{\mathbf{SD}}} |\vec{p}_i|} + \frac{\sum_{i\in\mathcal{H}^R_{\mathbf{SD}}} |\vec{n_R}\cdot\vec{p}_i|}{\sum_{i\in\mathcal{E}_{\mathbf{SD}}} |\vec{p}_i|}$$

MC studies

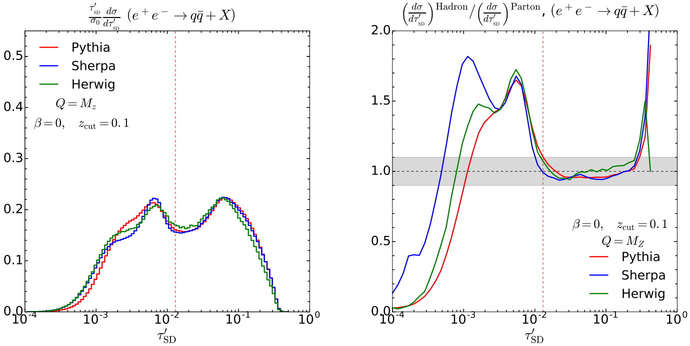
[Baron, Marzani, VT; '18]



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

MC studies with soft drop

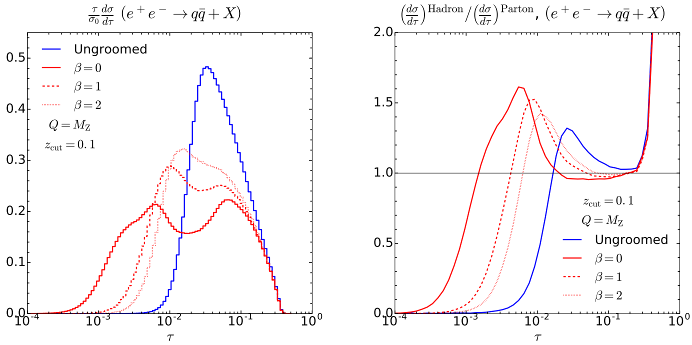
[Baron, Marzani, VT; '18]



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

$z_{\rm cut}$ & β values

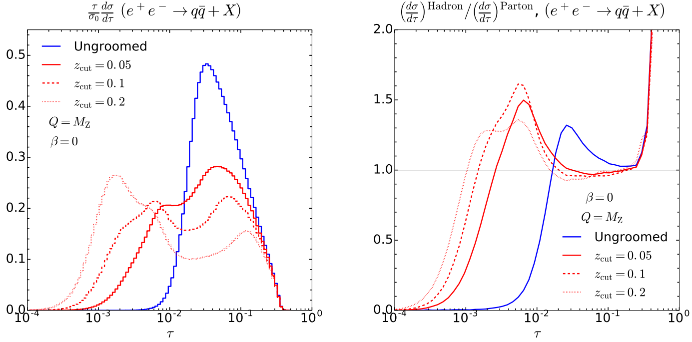
[Baron, Marzani, VT; '18]



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.
For more observables *[talk Jeremy Baron]*

Factorization

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

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

Computed in Laplace space and inverted leading to:

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

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

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

Analytic computation

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

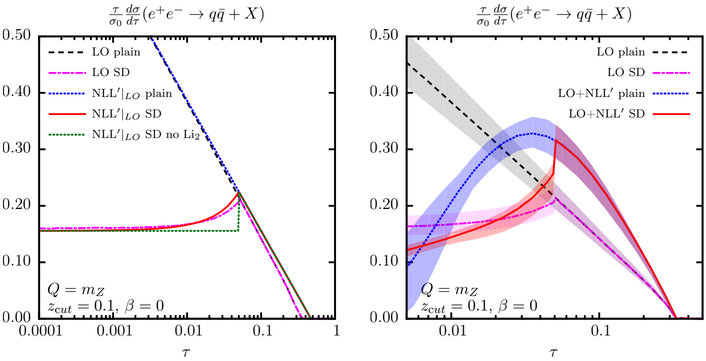
$$\frac{\alpha_s}{\pi} C_F (\beta + 2) \,\text{Li}_2 \left[\frac{1}{2} \left(\frac{2\tau}{z_{\text{cut}}} \right)^{\frac{2}{\beta+2}} \right]$$

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

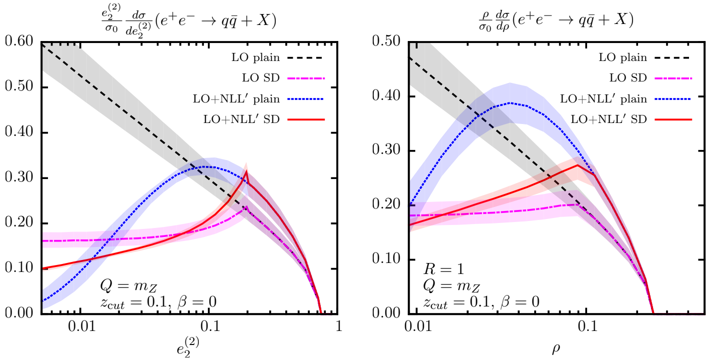
[Baron, Marzani, VT; '18]



- 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.

Higher accuracy for fit

Some changes in the setup:

- Matching to NLO
- End point corrections from plain thrust applied over full range
- Additional transition point effect from multiple emissions

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

$$\times \exp\left[\log\left(\frac{2\tau}{z_{\text{cut}}}\right)\left\{R''(\tau) - R''(\tau = z_{\text{cut}}/2, z_{\text{cut}})\right\}\right]$$

End point corrections

[Catani, Trentadue, Turnock, Webber;'93] [Jones, Ford, Salam, Stenzel, Wicke;'03]

Modification of the logarithm:

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

And Resummation:

$$\Sigma = C\exp\left[\tilde{R}(\tau) - \frac{\tau}{\tau_{\max}}\tilde{R}'(\tau \to \tau_{\max})\log\bar{\tau}\right]$$

Ensures that $\frac{d\sigma}{d\tau}(\tau_{\max}) = 0$ for resummation and expansion

Fitting setup

- Fit 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

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

- Experimental uncertainty at the hand of $\Delta\chi^2 = 1$
- Theoretical uncertainty based on 500 random 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: Multiplicative, additive and Multiplicative expanded out

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

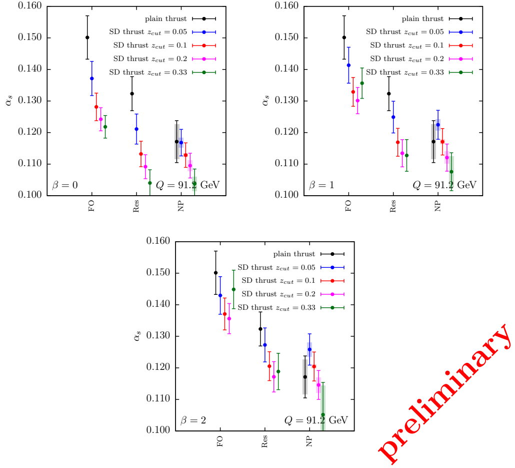
Non-perturbative corrections

For the non-perturbative model use a shift in τ and $z_{\rm cut}$ 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 $z_{\rm cut}$ 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

Variation of z_{cut} and β

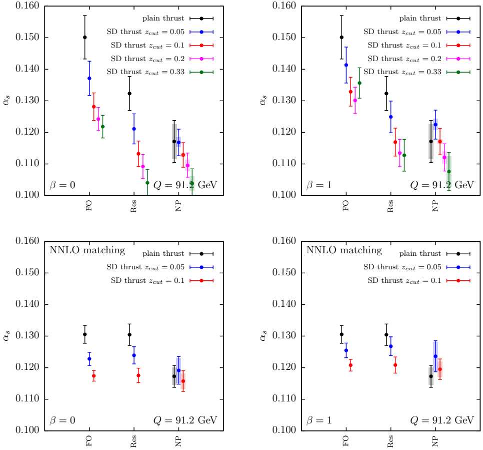
[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]



Significant reduction in hadronization uncertainty and shift

NNLO corrections

[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]

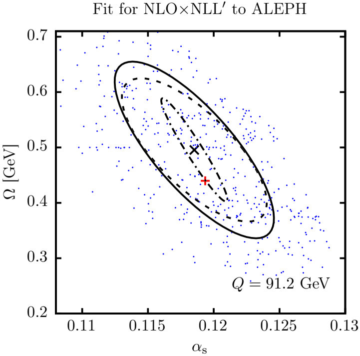


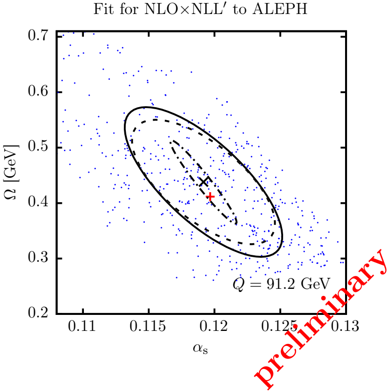
preliminary

Using NNLO corrections *[Kardos, Somogyi, Trócsányi;'18]*
Reduction of uncertainty and stabilization for NLL corrections

Effect of smearing NP corrections

[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]

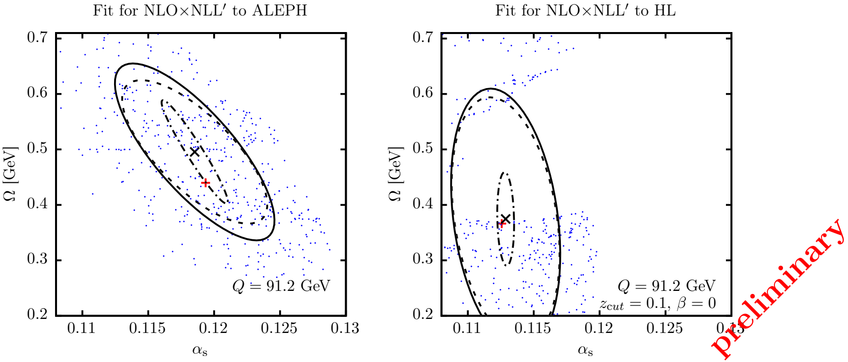




Smearing does not impact fit significantly at this accuracy, helps reduce uncertainty

Reduction of NP uncertainty

[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]



Significant reduction in correlation between α_s and Ω

Fit using MC for hadronziation effects

If Parton level agrees well with resummation *[talk Daniel Reichelt]*, can make use of hadronization model of Monte Carlo:

- Sherpa MEPS@NLO 2-3j results
  [Schumann, Krauss;'07] [Gehrmann, Hoche, Krauss, Schonherr, Siegert;'12]
- Sherpa's Cluster model *[Winter, Krauss, Soff;'03]*
- Pythia's Lund string model in Sherpa *[Sjostrand, Mrenna, Skands;'06]*
- Uncertainty given by difference and value is average

For soft drop thrust with $z_{\mathrm{cut}} = 0.1$ and $\beta = 0$:

$\alpha_s = 0.1163 \pm 0.0008(exp)\pm 0.0030(had)\pm 0.0042$(th)

preliminary

Compared to:
$\alpha_s = 0.1128 \pm 0.0007(exp)\pm 0.0006(had)\pm 0.0038$(th)

Other observables

This approach can also be applied to heavy hemisphere mass.
There is tension for thrust and heavy hemisphere mass without grooming *[Chien, Schwartz;'10]*

For soft drop heavy hemisphere mass (for $\rho_+ \in [0.08, 0.18]$):

$\alpha_s = 0.1159 \pm 0.0060(\text{exp}) \pm 0.0011(\text{had}) \pm 0.0036(\text{th})$

Compared to thrust:
$\alpha_s = 0.1163 \pm 0.0008(\text{exp}) \pm 0.0030(\text{had}) \pm 0.0042(\text{th})$

Leading to a combined fit:
$\alpha_s = 0.1160 \pm 0.0005(\text{exp}) \pm 0.0019(\text{had}) \pm 0.0039(\text{th})$

preliminary

No tension in the two fits

Summary

Conclusions

- Soft drop can help reduce dependence on non-perturbative corrections for thrust
- Can help break degeneracy between non-perturbative contributions and α_s in fit leading to significant reduction in hadronization uncertainty
- Can help reduce tension between different observables
- Higher order corrections can help further reduce uncertainty and increase stability

Future work

- Heavy hemisphere mass with non-perturbative shift
- More precise calculation of shift
- Potential use of ΔPS for other values of z_{cut} and β

Summary

Further future work

- Explore an increased fitting range
- Move to NNLL accuracy including transition point effects
- Analyze different types of observables
- Potential to simultaneously study two or more independent observables
- Hopefully one day a full measurement

Summary

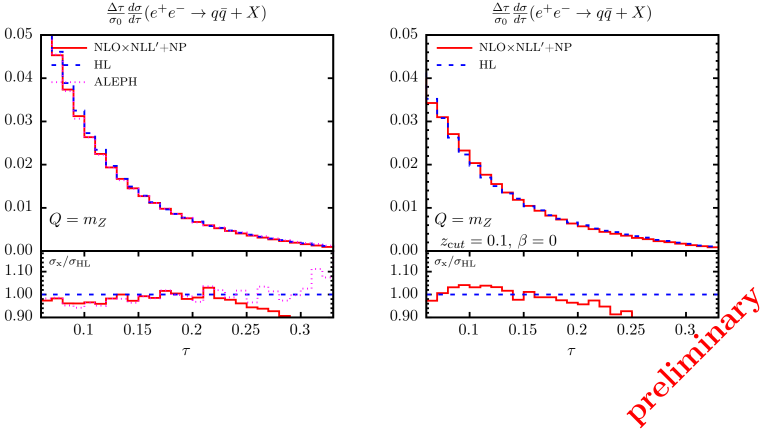
Further future work

- Explore an increased fitting range
- Move to NNLL accuracy including transition point effects
- Analyze different types of observables
- Potential to simultaneously study two or more independent observables
- Hopefully one day a full measurement

Thank you for your attention

Comparison HL to fit

[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]



Comparison HL/PL to fit

[Marzani, Reichelt, Schumann, Soyez, VT; In Preparation]