Determining α_s from Thrust with Power Corrections

Miguel Benitez-Rathgeb

VNiVERSiDAD Đ SALAMANCA

IUFFyM
Instituto Universitario
de Física Fundamental y Matemáticas

MBR, A. Hoang, V. Mateu, I. Stewart, G. Vita - 2404.XXXXX

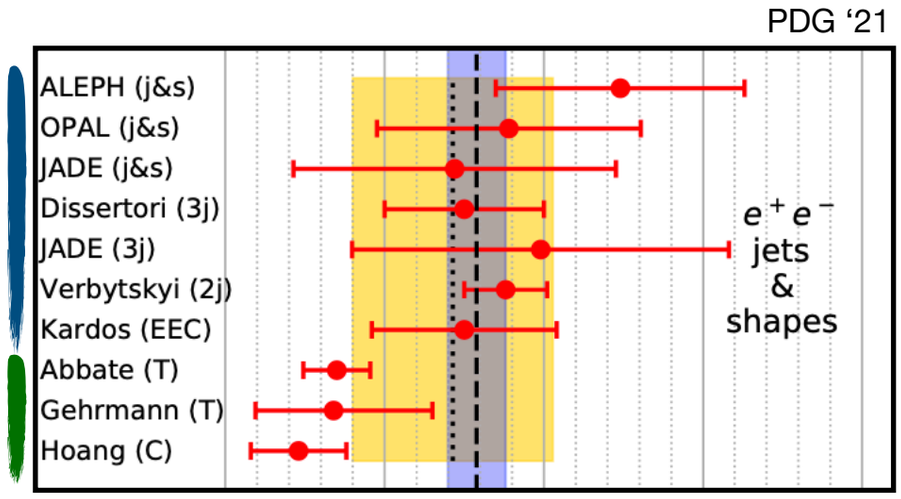
Overview

Discrepancy between α_s determinations using non-perturbative corrections based on **Monte Carlos**, and those based on **analytic approaches**

Discrepancy between α_s determinations from e^+e^- event shape observables based on analytic treatment of power corrections and world average

Triggered new analyses on treatment of power corrections in 3-jet region

Luisoni, Monni, Salam ‘20 Caola et al ‘21 Caola et al ‘22



New α_s analysis (used new model for treatment of PCs based on 3-jet kinematics, no resummation, …)

Nason, Zanderighi ‘23

Analysis suggests that uncertainties on α_s should increase

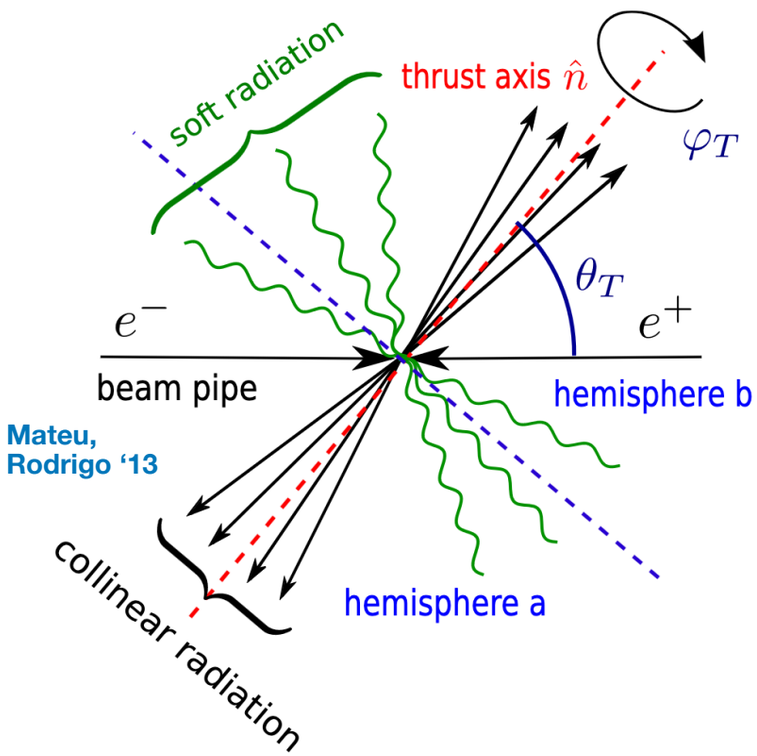
<u>Topics addressed in this talk:</u>

Improvements compared to the analysis carried out in 2010

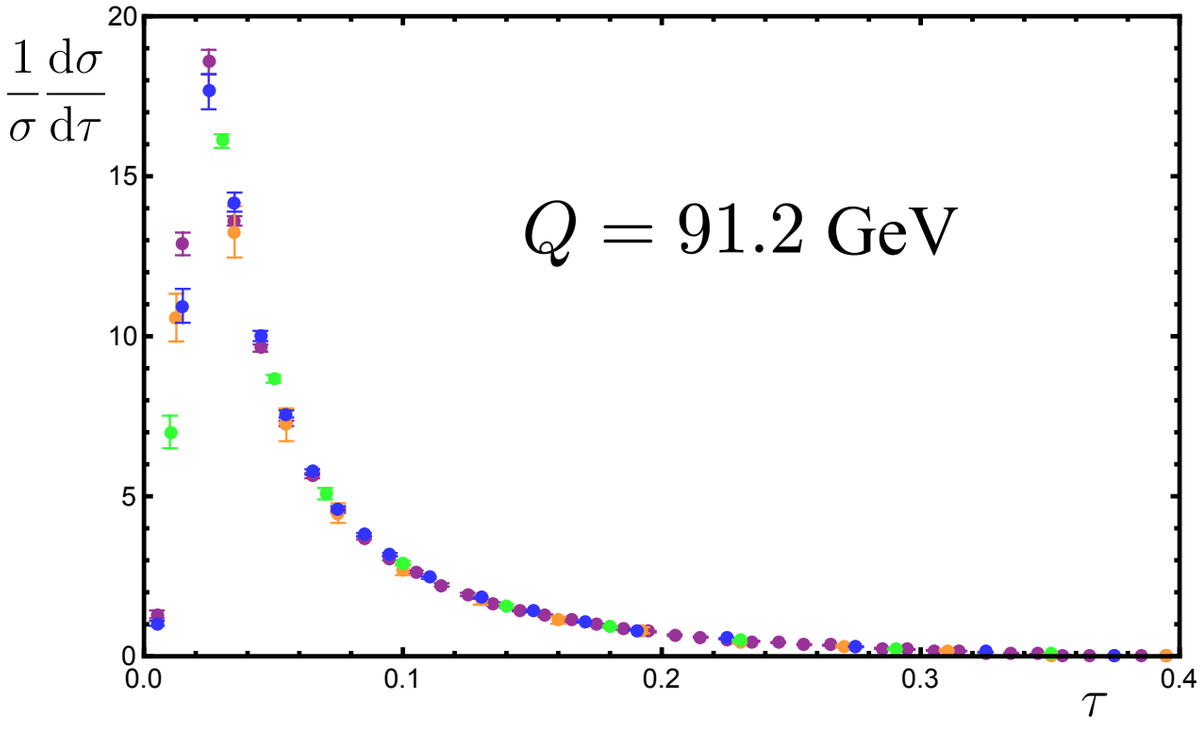
Address questions raised in the recent literature/criticism directed towards the 2010 analysis

How to carry out a determination of the strong coupling from thrust in 2024

Experimental data



	Experiment	Values of the center of mass energy Q
LEP	ALEPH	$\{91.2, 133.0, 161.0, 172.0, 183.0, 189.0, 200.0, 206.0\}$
	DELPHI	$\{45.0, 66.0, 76.0, 89.5, 91.2, 93.0, 133.0, 161.0, 172.0, 183.0, 189.0, 192.0, 196.0, 200.0, 202.0, 205.0, 207.0\}$
	OPAL	$\{91.0, 133.0, 177.0, 197.0\}$
	L3	$\{41.4, 55.3, 65.4, 75.7, 82.3, 85.1, 91.2, 130.1, 136.1, 161.3, 172.3, 182.8, 188.6, 194.4, 200.0, 206.2\}$
SLAC	SLD	$\{91.2\}$
DESY	TASSO	$\{14.0, 22.0, 35.0, 44.0\}$
	JADE	$\{35.0, 44.0\}$
KEK	AMY	$\{55.2\}$



Standard dataset: $35\ \text{GeV} \leq Q$

$$\frac{6\ \text{GeV}}{Q} \leq \tau \leq 0.33$$

487 bins

Correlations treated in minimal overlap model

Theory: Dijet Factorization Formula for e^+e^- Thrust distribution

Perform tail region fits of Thrust Distribution in dijet region

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

Based on factorization formula from SCET Fleming, Hoang, Mantry, Stewart '07 Bauer, Lee, Fleming, Sterman '08 Abbate, Fickinger, Hoang, Mateu, Stewart '10

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = \int \mathrm{d}k \left(\frac{\mathrm{d}\hat{\sigma}_{\mathrm{s}}}{\mathrm{d}\tau} + \frac{\mathrm{d}\hat{\sigma}_{\mathrm{ns}}}{\mathrm{d}\tau} \right) \left(\tau - \frac{k}{Q} \right) F_\tau(k)$$

Includes Resummation

$$\frac{\mathrm{d}\hat{\sigma}_s^{\mathrm{QCD}}}{\mathrm{d}\tau} = Q \sum_I \sigma_o^I H_Q^I(Q, \mu_H) U_H(Q, \mu_H, \mu)$$
$$\times \int \mathrm{d}s \mathrm{d}s' \; J_\tau(s', \mu_J) U_J^\tau(s - s', \mu, \mu_J)$$
$$\times \int \mathrm{d}k' U_S^\tau(k', \mu, \mu_s) e^{\frac{-2\delta(R,\mu_S)}{Q} \frac{\partial}{\partial \tau}} S_\tau^{\mathrm{part}} \left(Q\tau - \frac{s}{Q} - k', \mu_s \right)$$
$$\approx \sum_n \alpha_s^n \delta(\tau) + \sum_{n,l} \alpha_s^n \left[\frac{\ln^l(\tau)}{\tau} \right]_+ + \text{subtractions}$$

Singular partonic for massless quarks

QCD final states

$$\frac{\mathrm{d}\hat{\sigma}_{ns}}{\mathrm{d}\tau} = \sum_n \alpha_s^n f_n(\tau) + \text{subtractions}$$

$$f_n(\tau) = \sum_{i,j=0}^{\infty} a_{ij}^n \tau^i \ln^j(\tau)$$

$\mathcal{O}(\alpha_s)$ contribution known analytically

$\mathcal{O}(\alpha_s^2)$ from EVENT2 (incl. more statistics)

$\mathcal{O}(\alpha_s^3)$ from Colorful (formerly EERAD3)

Nonsingular partonic

$F_\tau(k) \rightarrow$ shape function: parametrizes dominant source of soft NP had. effects

In tail of distribution $F_\tau(k)$ expanded in OPE

Leading NP matrix-element reads

$$\bar{\Omega}_1 = \frac{1}{2N_c} \langle 0 | \mathrm{tr} \; \overline{Y}_{\bar{n}}^T(0) Y_n(0) i(Q\hat{\tau}) Y_n^\dagger(0) \overline{Y}_{\bar{n}}^*(0) | 0 \rangle$$

Nonperturbative soft function

Updated Profile functions

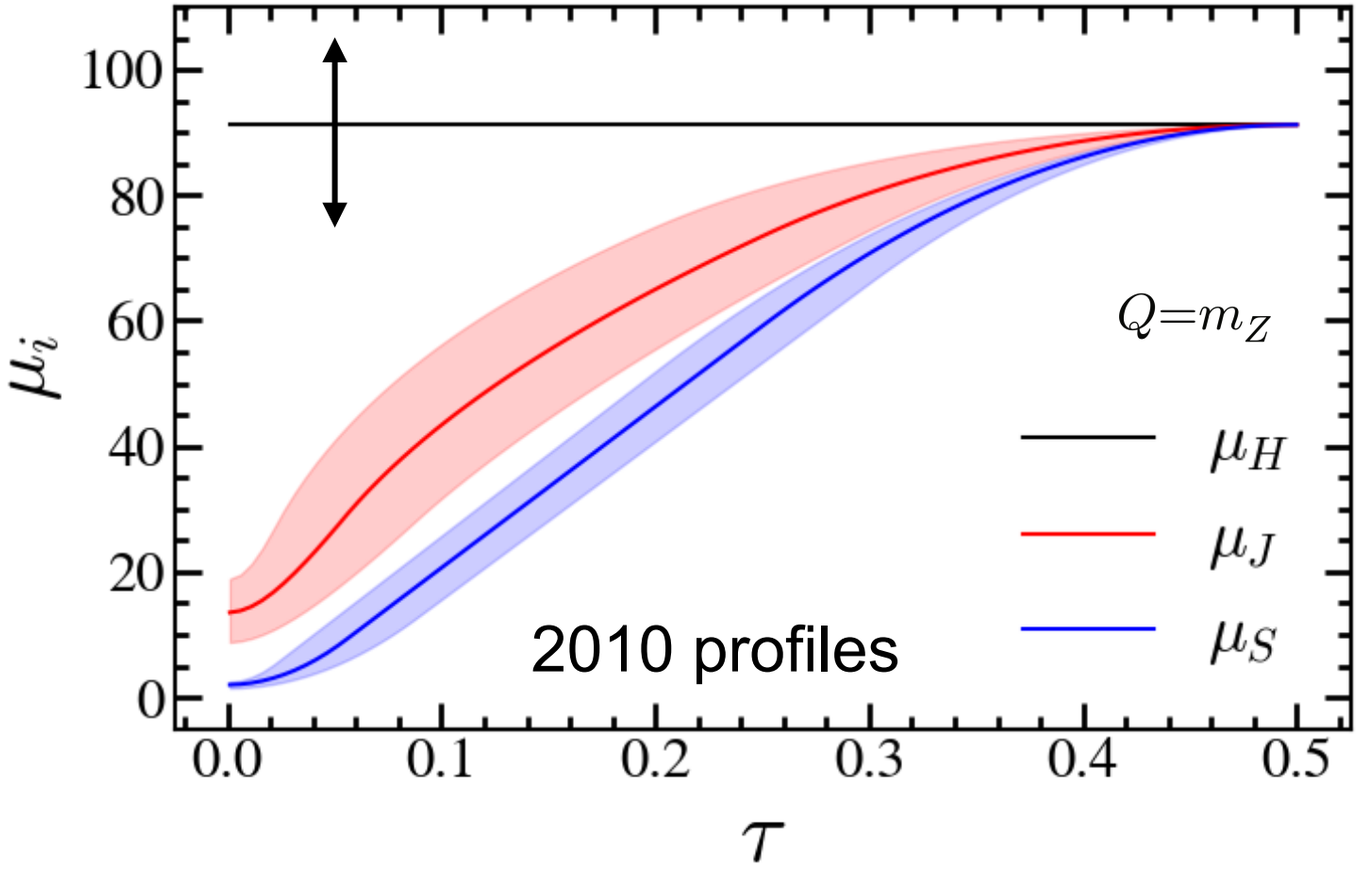
Factorization formula for the singular partonic thrust distribution governed by three renormalization scales

Hard scale: μ_H Jet scale: μ_J Soft scale: μ_S

To avoid large logs while not spoiling singular vs non-singular cancellation in the far tail, the above scales must satisfy

Abbate, Fickinger, Hoang, Mateu, Stewart '10

$$\begin{aligned}
&\text{peak:} && \mu_H \sim Q\,, \quad \mu_J \sim \sqrt{\Lambda_{\rm QCD} Q}\,, && \mu_S \gtrsim \Lambda_{\rm QCD} \\
&\text{tail:} && \mu_H \sim Q\,, \quad \mu_J \sim Q\sqrt{\tau}\,, && \mu_S \sim Q\tau \\
&\text{far-tail:} && \mu_H = \mu_J = \mu_S \sim Q
\end{aligned}$$



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Hoang, Kolodrubetz, Mateu, Stewart '15

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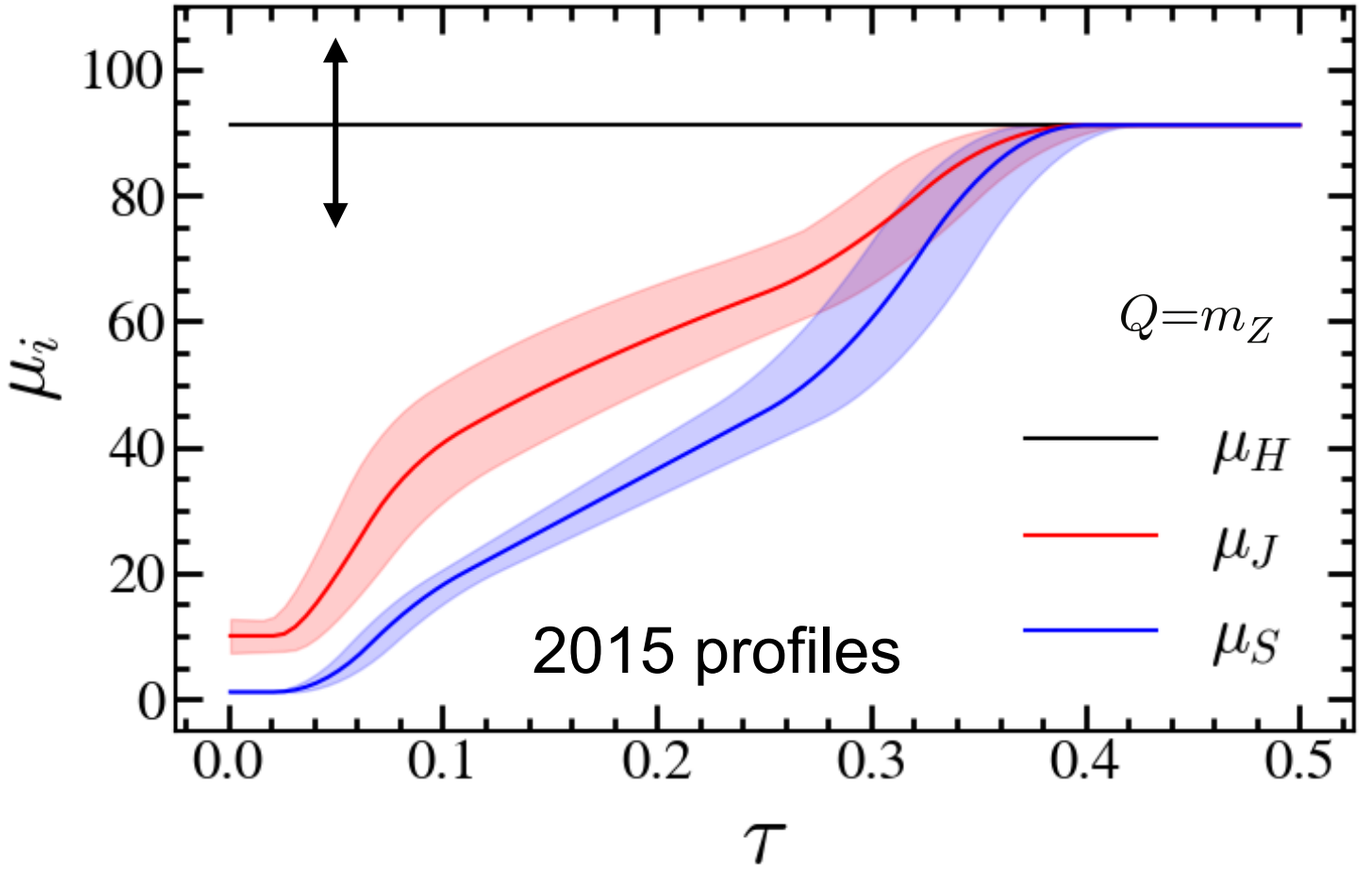


implements correctly canonical scale setting in tail region

variable slope

parameters for different regions more independent

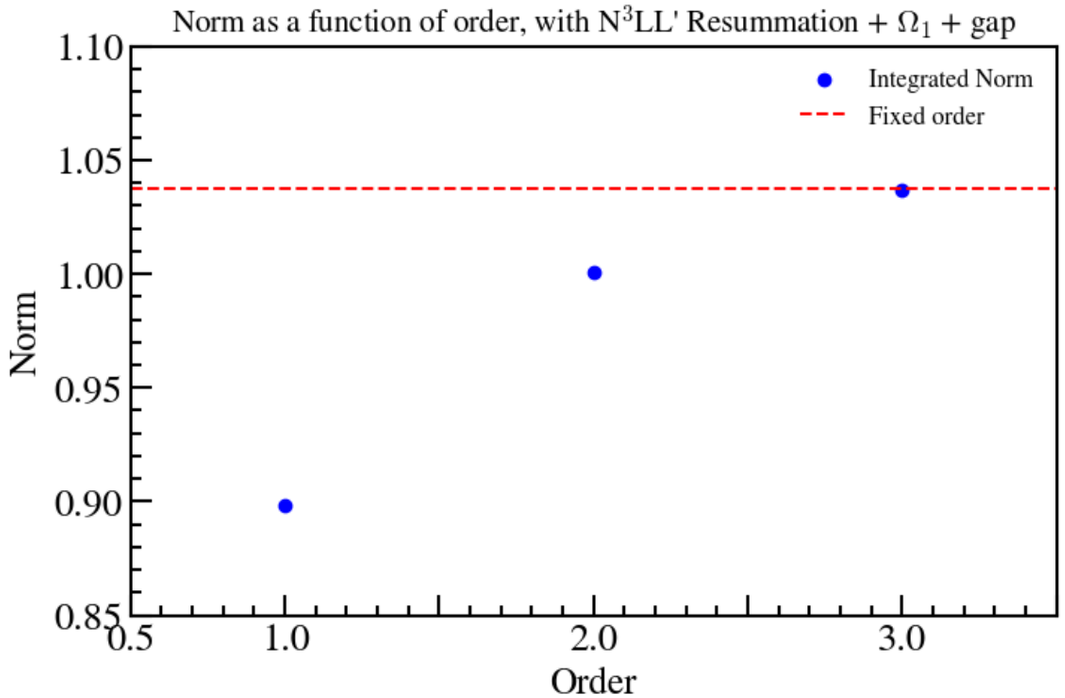
scales merge earlier

→ fit stability

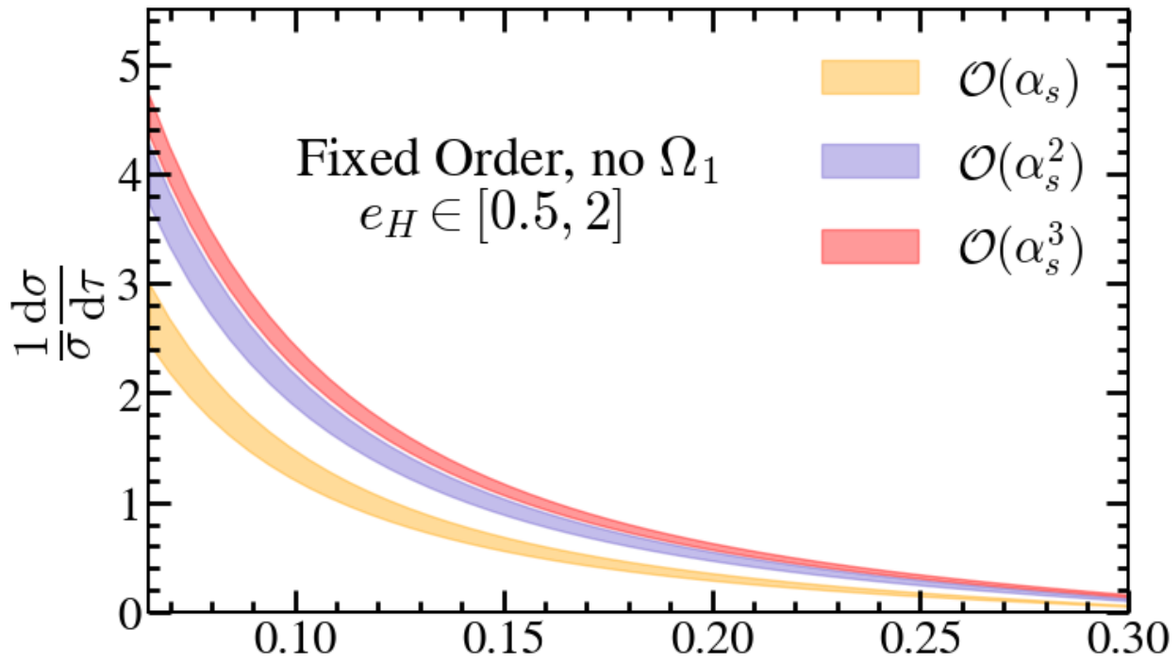
Theory: Final comments

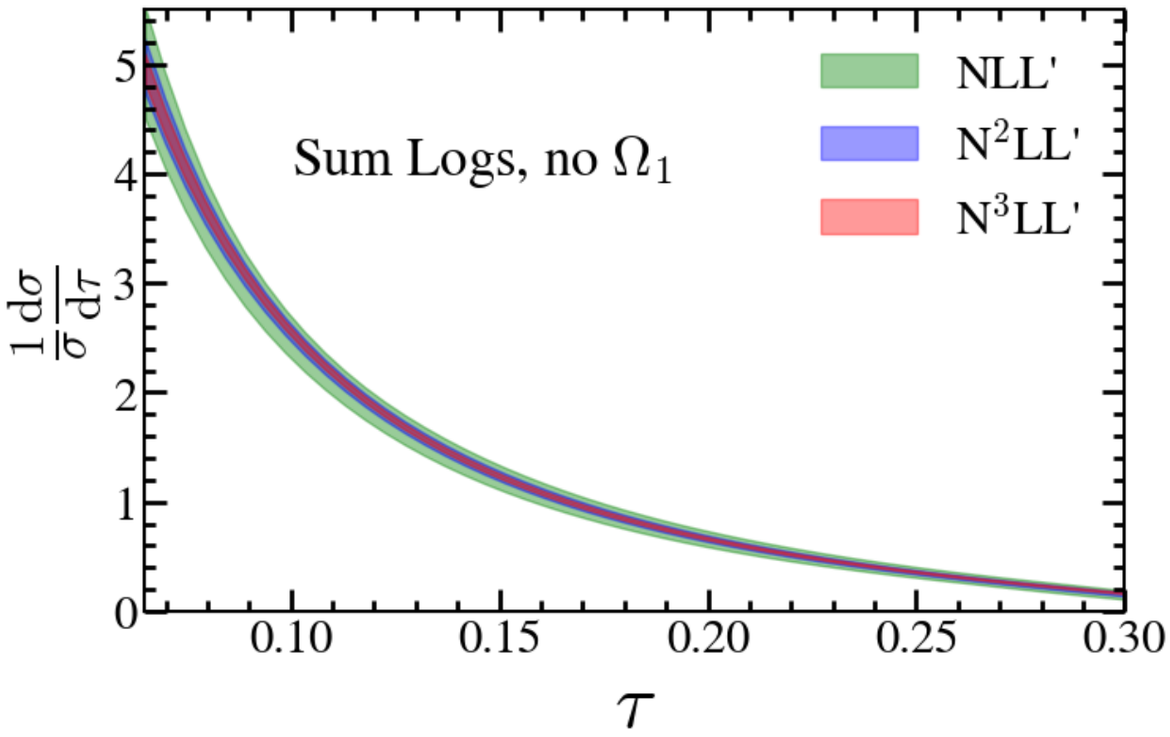
Self normalization of Cross Section:

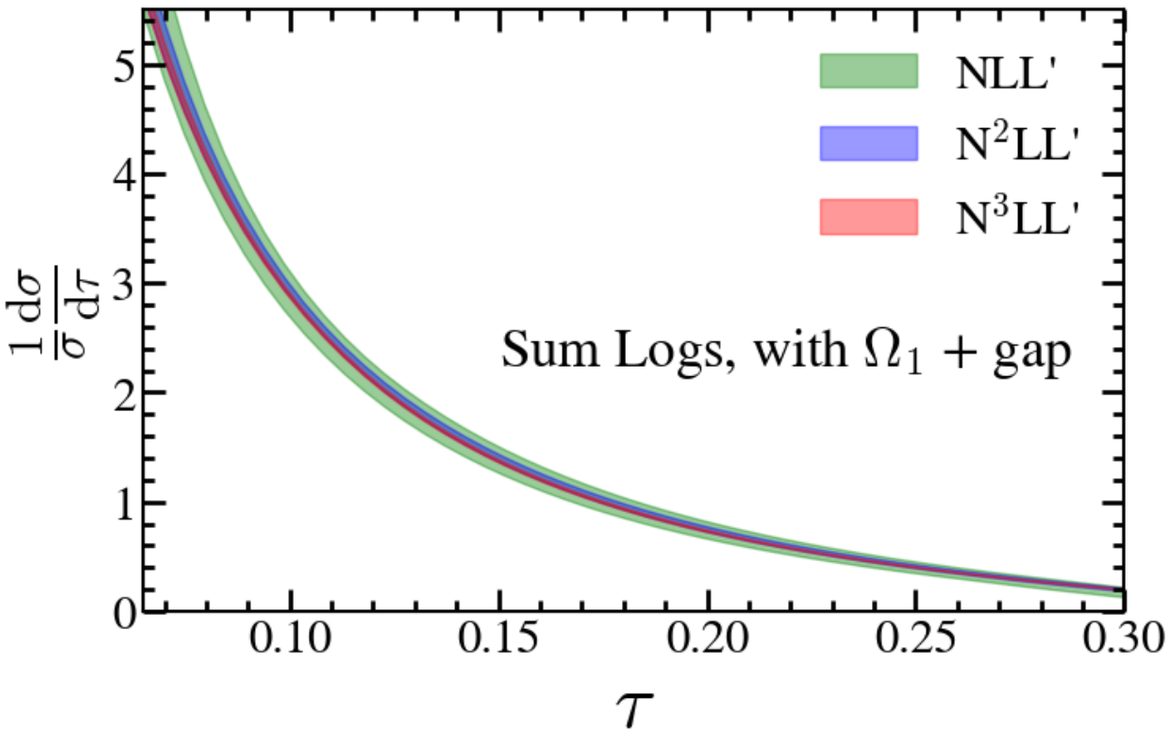
- Experimental data normalized to total number of events
- Need to normalize distribution to the total Cross section
- Can use available fixed-order result for total hadronic Cross Section or integral of $\mathrm{d}\sigma/\mathrm{d}\tau$ distribution
- For gap scheme, integrated norm and fixed-order norm give compatible results



Assessment: Impact of Resummation







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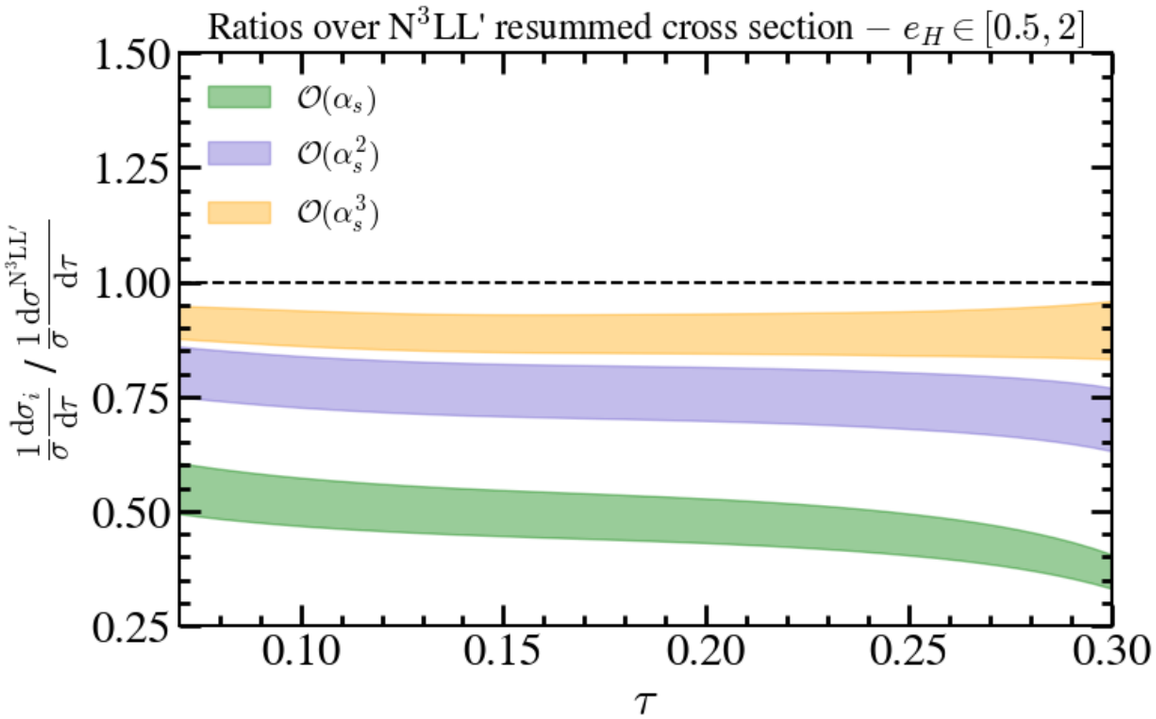
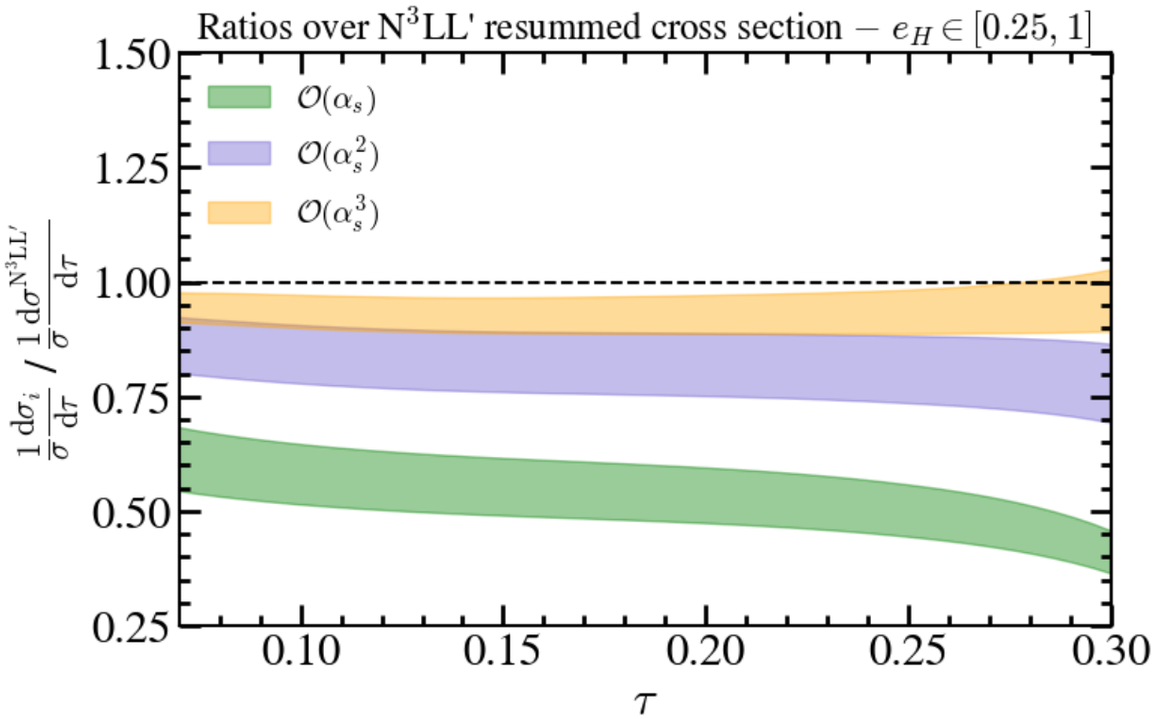
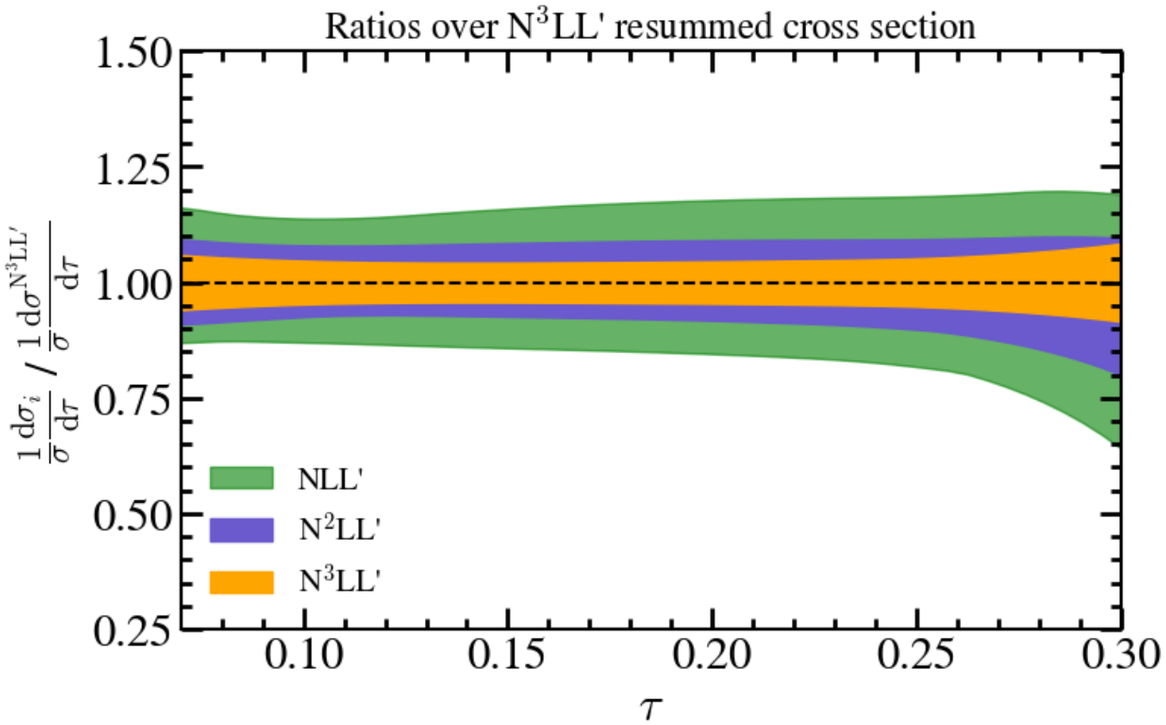
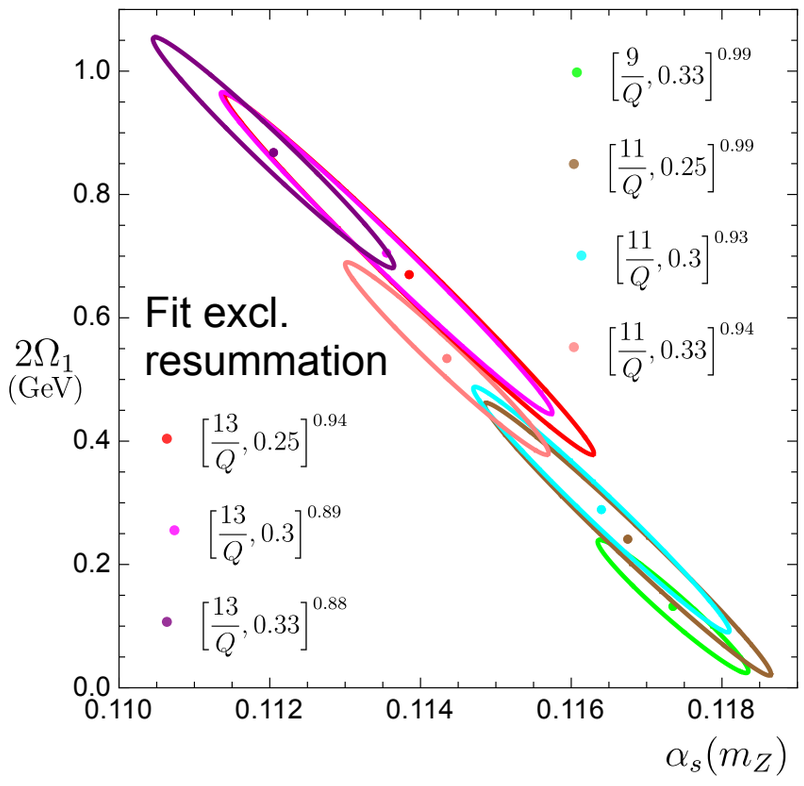


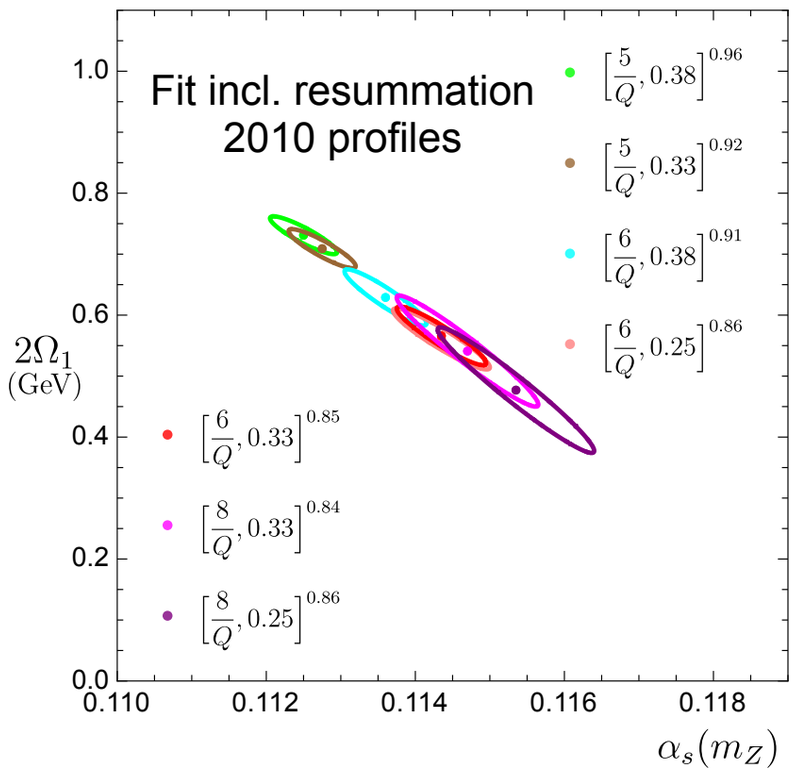


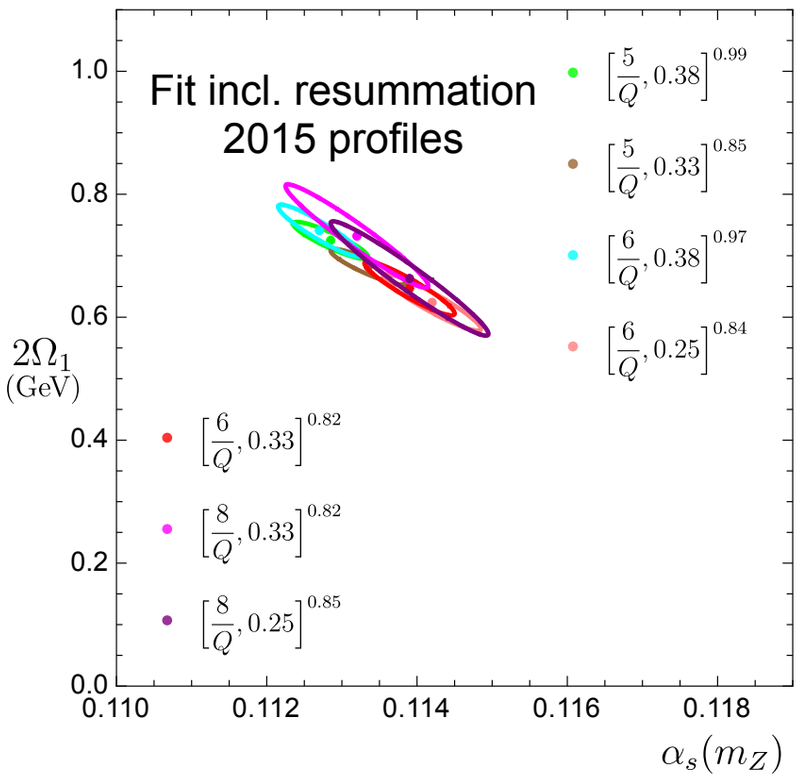


Assessment: Impact of Resummation

$[\tau_{\min}, \tau_{\max}]^{\chi^2/\mathrm{dof}}$







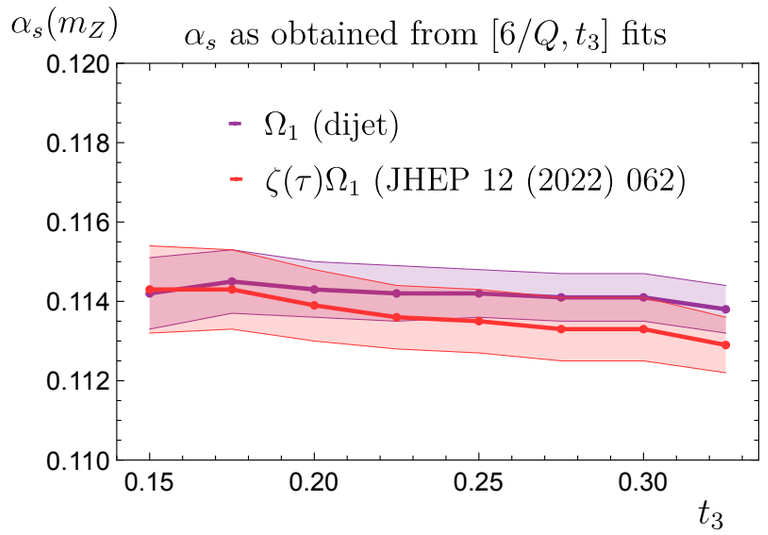
Using a fixed-order description leads to equivalent predictions as the resummed description in regions where resummation effects become small, but is accompanied by severe problems:

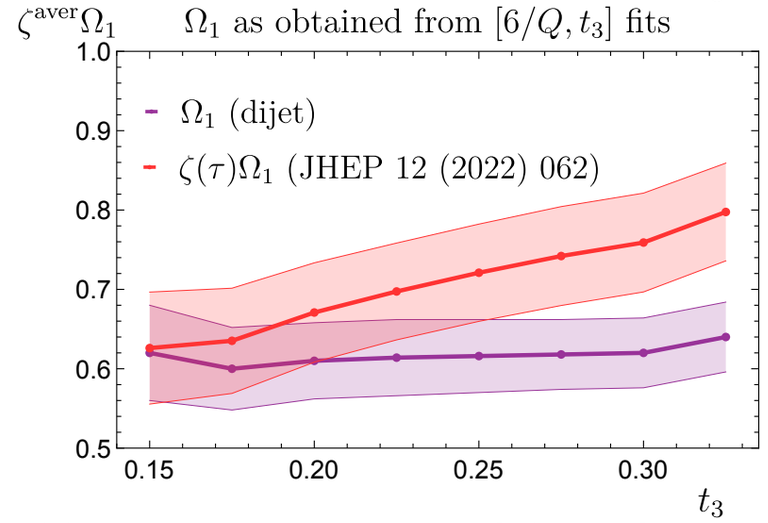
- Order-by-order convergence of cross section spoiled
- Instability
- Less data available
- Larger χ^2

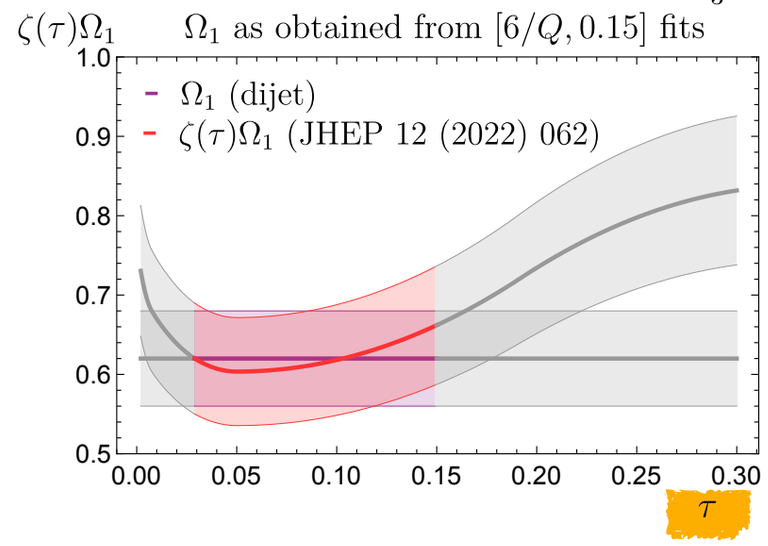
Assessment: Treatment of Power Corrections

We compare fit results for α_s and Ω_1 for two different treatments of PC

- Our previous treatment of PC, i.e. flat behavior across thrust spectrum **Abbate, Fickinger, Hoang, Mateu, Stewart '10**
- Model predictions for 3-jet region **Caola et al '21** **Caola et al '22**





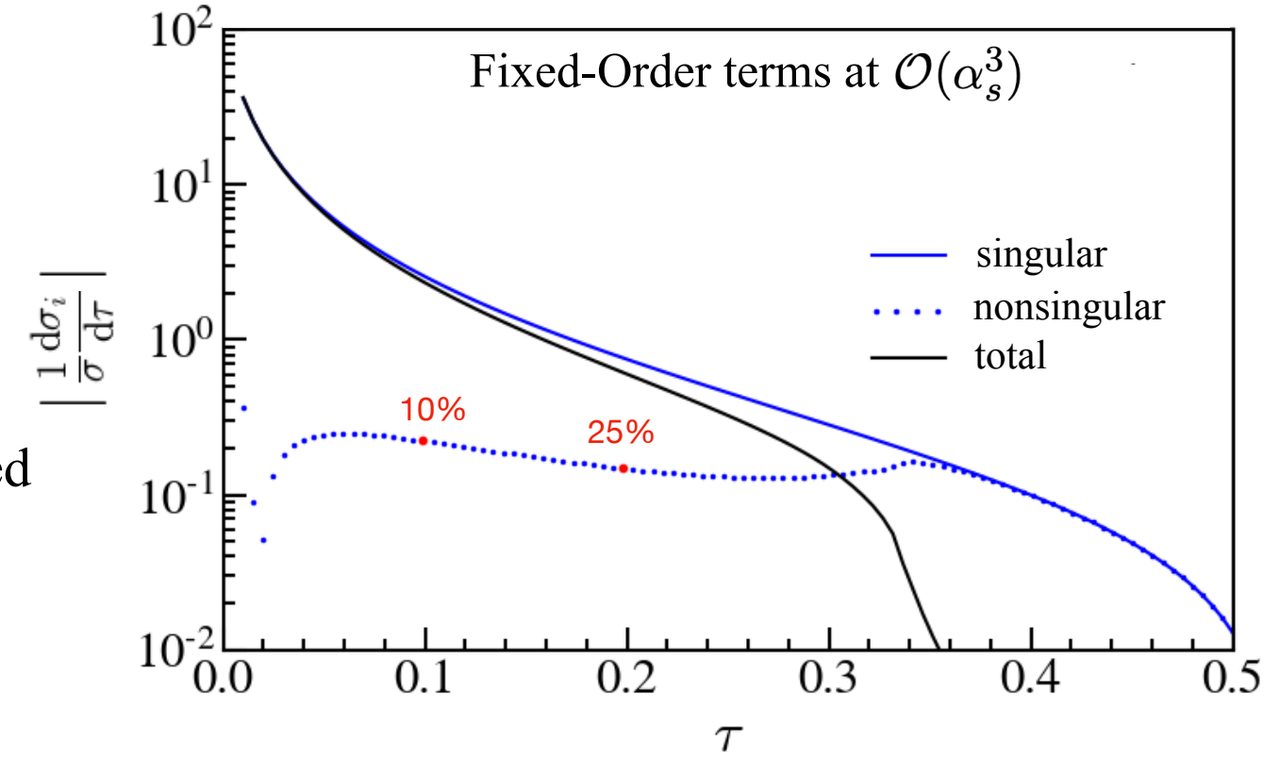


<u>What we observe:</u> (Error bands contain only experimental errors)

- Outcome for strong coupling gives compatible results for the fit range $\tau \in [6/Q, t_3]$
- Nonperturbative matrix element is comparable between the different treatments as well
- Expected, since model predictions are flat in the region where we perform the fit → this only acts as a shift in the distribution but will not influence α_s

α_s from Thrust in 2024: Treatment of Power Corrections

- Range of dijet region in thrust spectrum currently under debate
- Numerically, singular terms dominate beyond the peak region, irrespective of com-energy
- For $\tau = 0.1$, the kinematically power suppressed nonsingular contributions only amount to 10% of the pure fixed-order cross section at $\mathcal{O}(\alpha_s^3)$



→ consider dijet power corrections to dominate for $\tau < 0.11$

(scaling arguments would lead to an analogous conclusion)

α_s from Thrust in 2024: Treatment of Power Corrections

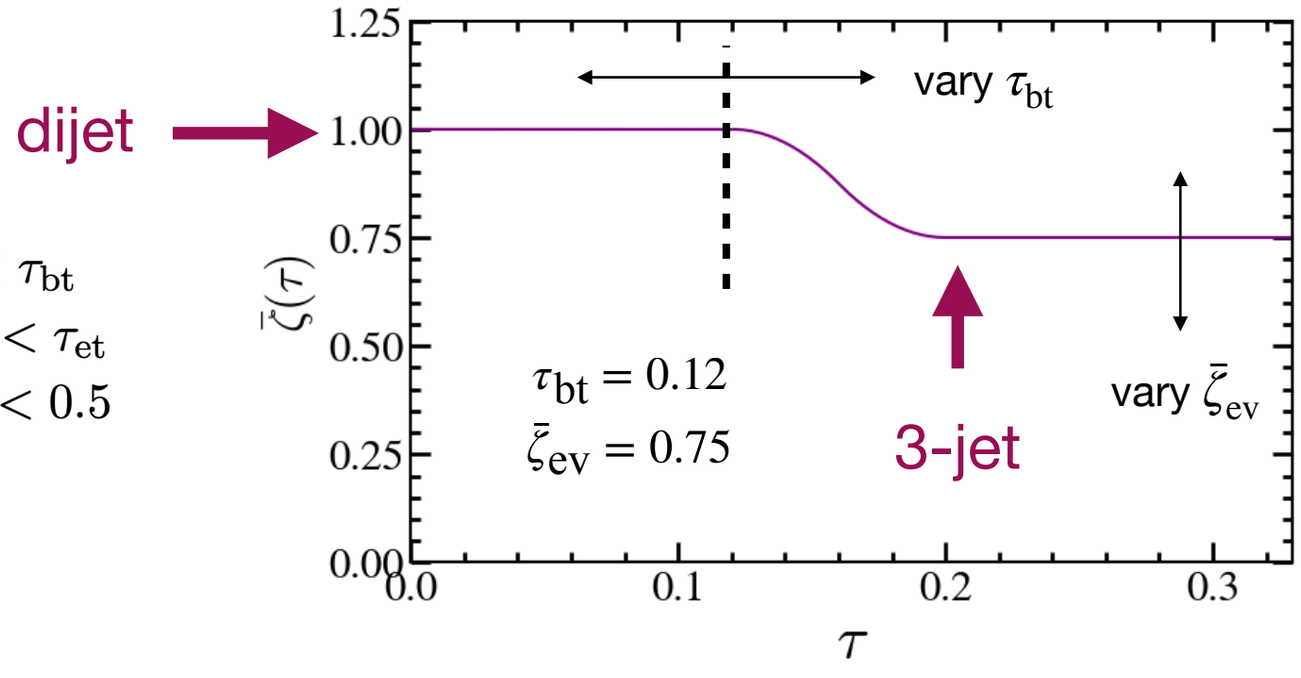
From now on: restrict fit range to [6/Q,0.15] → possible due to new profiles which provide stability of fit

Question: How to obtain an error estimate for deviations from the dijet treatment of the power correction for $\tau > 0.11$?

Proceed as follows:

- Use model function for PC

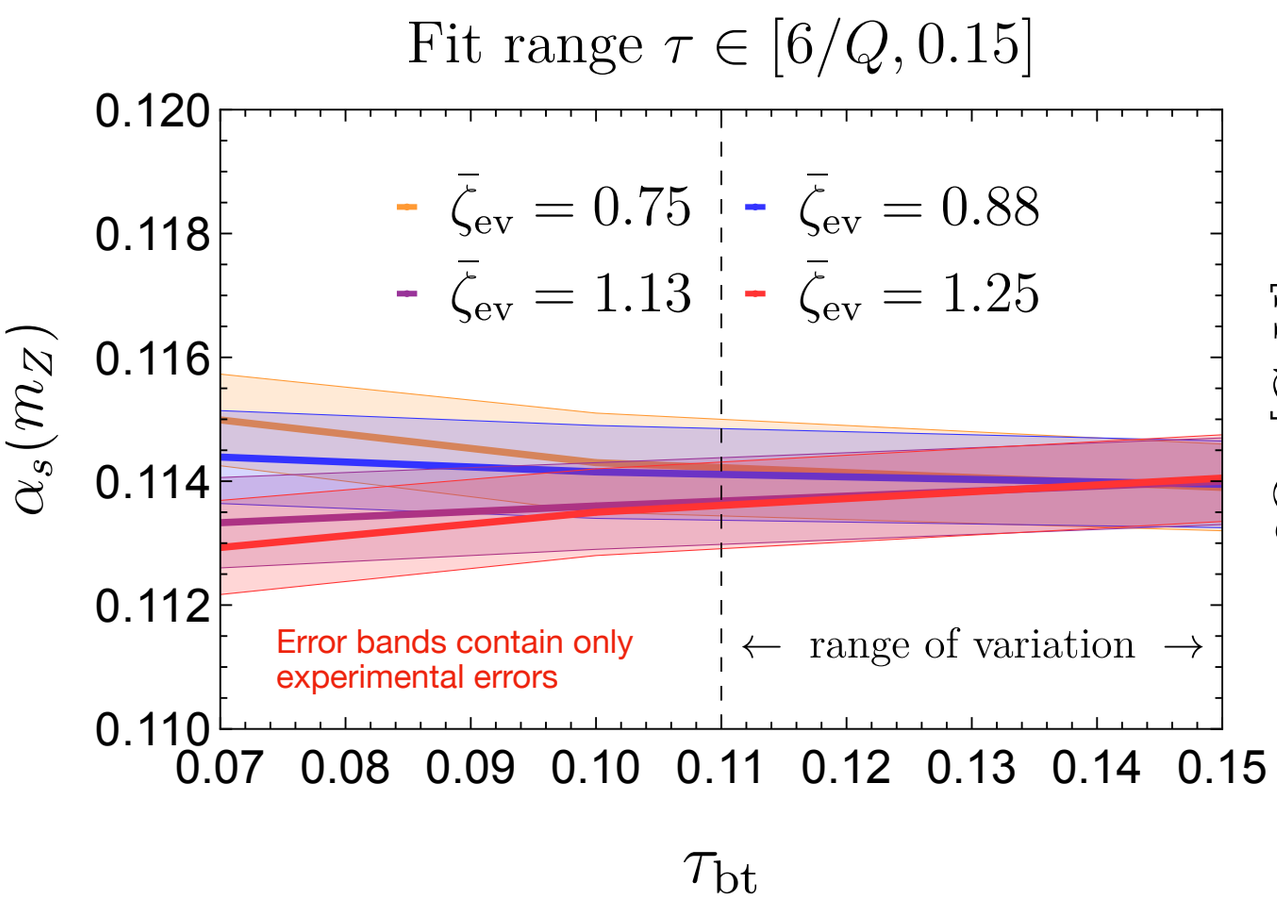
$$\bar{\zeta}(\tau) = \begin{cases} \bar{\zeta}_{\rm iv} & 0 \le \tau < \tau_{\rm bt} \\ \zeta_C(\tau_{\rm iv}, 0, 0, \tau_{\rm ev}, \tau_{\rm bt}, \tau_{\rm et}, \tau) & \tau_{\rm bt} \le \tau < \tau_{\rm et} \\ \bar{\zeta}_{\rm ev} & \tau_{\rm et} \le \tau < 0.5 \end{cases}$$

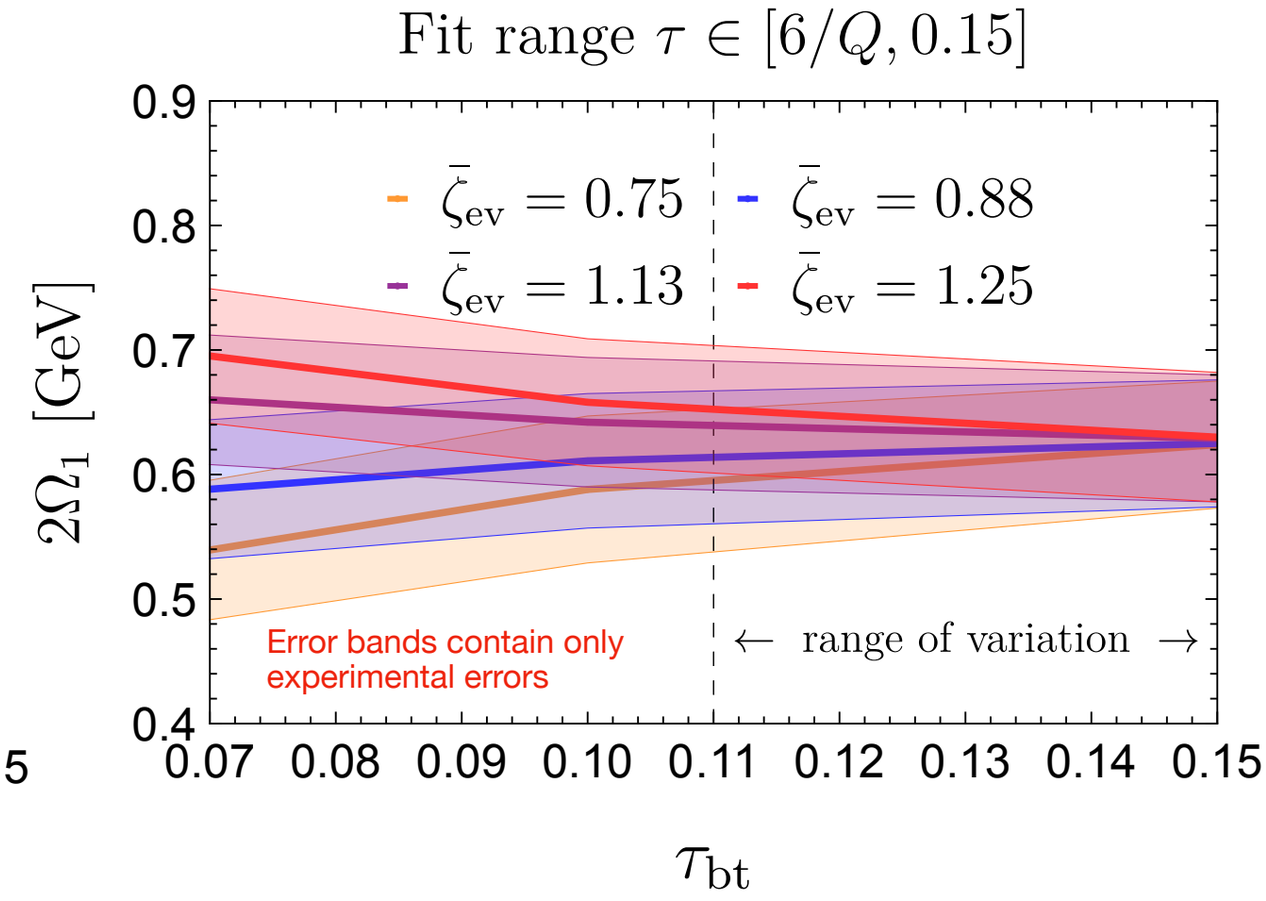


- Vary parameter responsible for deviation away from dijet treatment of PC's, as well as parameter defining the value the model function attains at $\tau = 0.5$

- Look at impact on α_s and Ω_1

α_s from Thrust in 2024: Treatment of Power Corrections

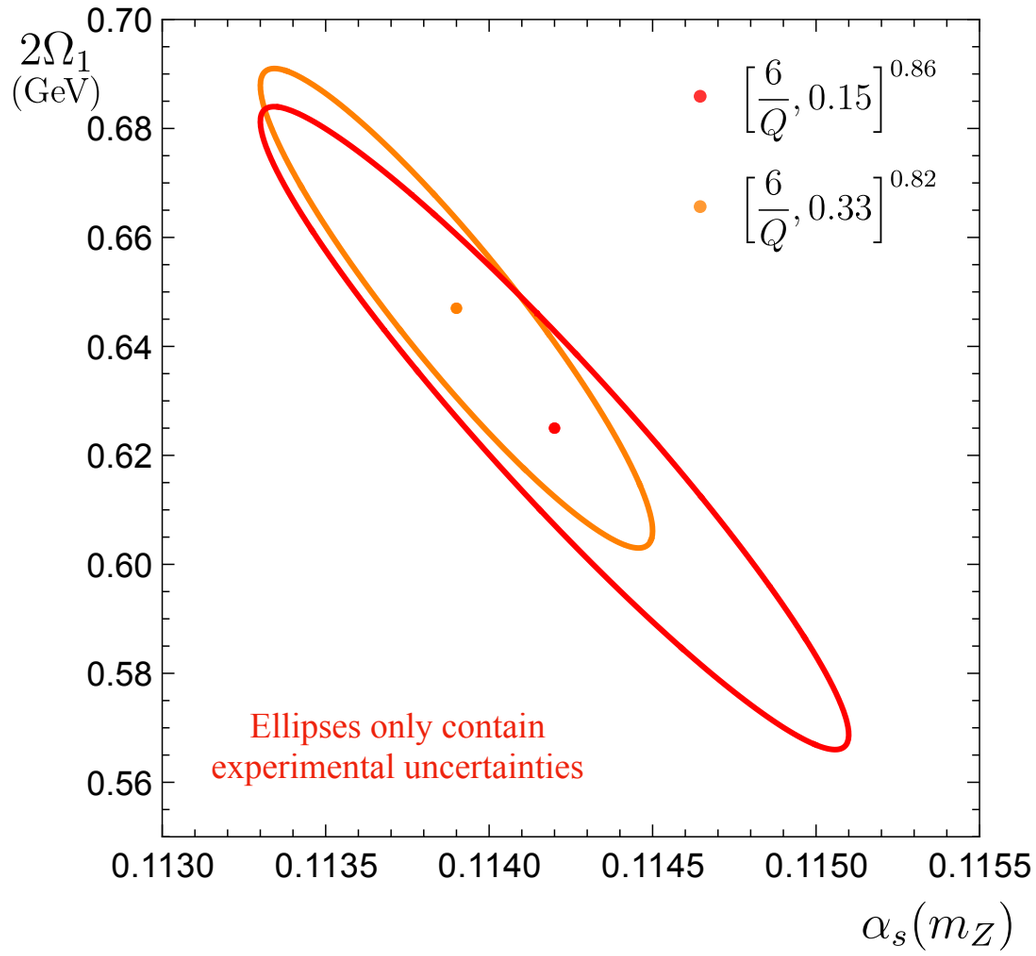




Consider upper part of $\tau_{\rm bt}$ range to make the error estimate

Uncertainty estimate: Half of the difference between the maximum and minimum best fit value of α_s obtained when varying $\bar{\zeta}_{\rm ev}$ in the range [0.75, 1.25] for constant $\tau_{\rm bt} = 0.11$

α_s from Thrust in 2024: Updated default setup



- Increased experimental uncertainty due to smaller fit region [6/Q,0.15]:

$$\alpha_s = 0.1142 \pm 0.0006_{\rm pert} \pm 0.0009_{\rm exp+\Omega_1} \pm 0.0004_{\rm 3jet} = 0.1142 \pm 0.0012_{\rm tot} \qquad \langle\chi^2\rangle/{\rm dof} = 0.86$$

- Compare to 2010 thrust fit ([6/Q,0.33], without QED corrections): Abbate, Fickinger, Hoang, Mateu, Stewart '10

$$\alpha_s = 0.1140 \pm 0.0008_{\rm pert} \pm 0.0005_{\rm exp+\Omega_1} \pm 0.0001_{\rm had} = 0.1140 \pm 0.0010_{\rm tot}$$

Historical Outline & Conclusions

- 2010 analysis used profile functions, which gave rise to unstable behavior of fits and furthermore used a wider default fit range, i.e. $\tau \in [6/Q,0.33]$

- Use of 2015 profiles improves stability of fit

- 2024 assessment shows that resummation is important when carrying out fits in this context. It further demonstrates, that 3-jet model of Caola et al. only has small effect on outcome of strong coupling

- Due to improved stability of the the fit → able to restrict fit region to [6/Q, 0.15], which is mostly dijet

- Even in new improved default setup, which is mostly dijet and contains error estimate of deviations from dijet treatment of power correction, strong coupling is still small compared to the world average → this is in agreement with 2311.03990