Power corrections in event-shape distributions

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- Resummation at N^3LL (SCET) [JHEP 07 (2008) 034]
- Dijet power corrections [PRD 75 (2007) 014022]
- Soft renormalon subtraction [PLB 660 (2008) 483-493]

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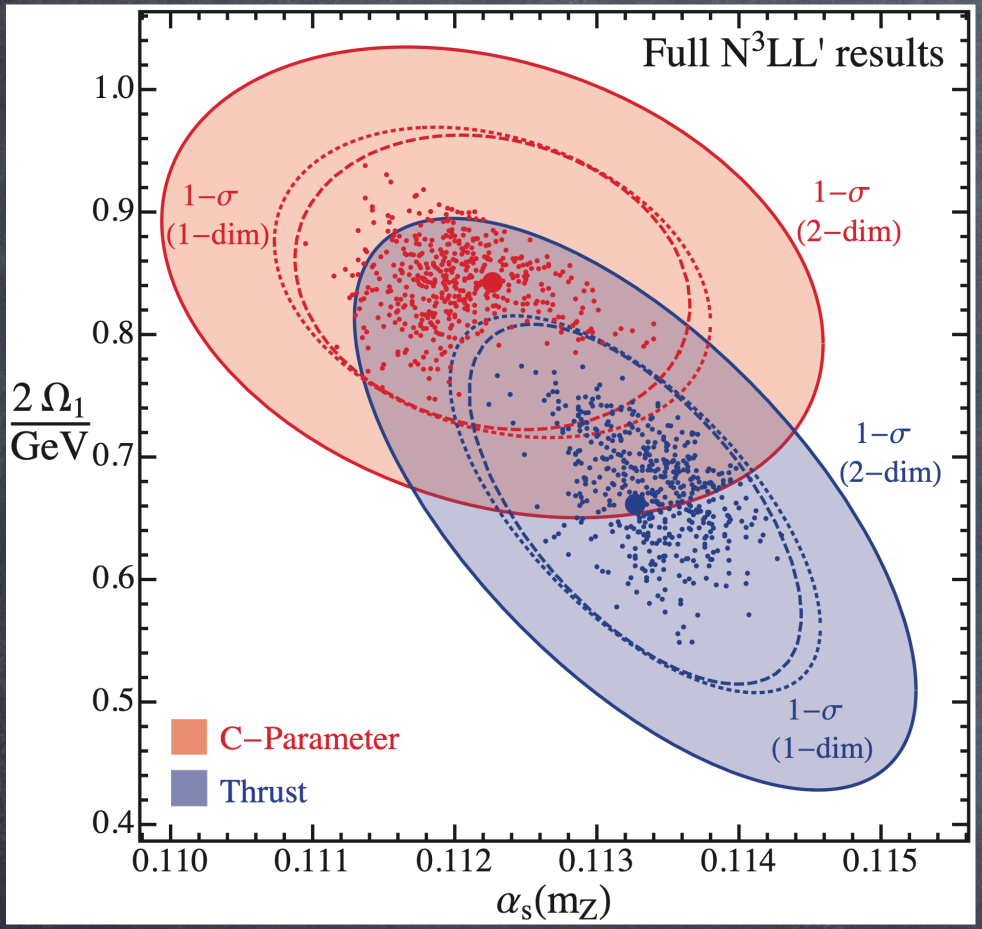
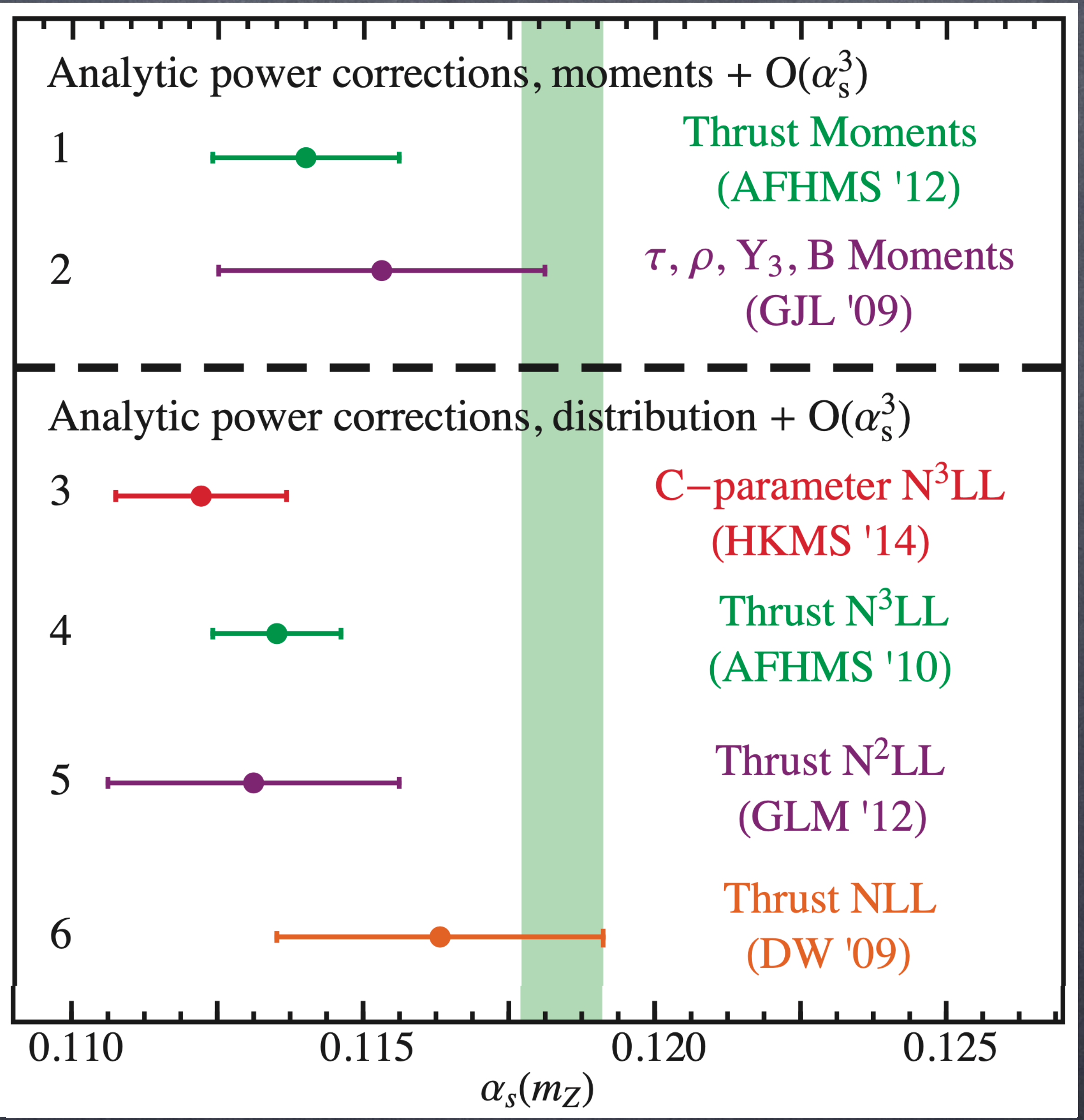
Experimental data on event shapes also very precise

Motivated fits to data to obtain strong coupling

- Thrust [PRD 83 (2011) 074021, EPJC 73 (2013) 1, 2265]
- Thrust moments [PRD 86 (2012) 094002]
- C-parameter [PRD 91 (2015) 9, 094017-18]
- Moments to many event-shapes [EPJC 67 (2010) 57-72]

Introduction





Although α_s was obtained with high accuracy, the central value is uncomfortably small (compared to world average)

This has raised controversy in recent years

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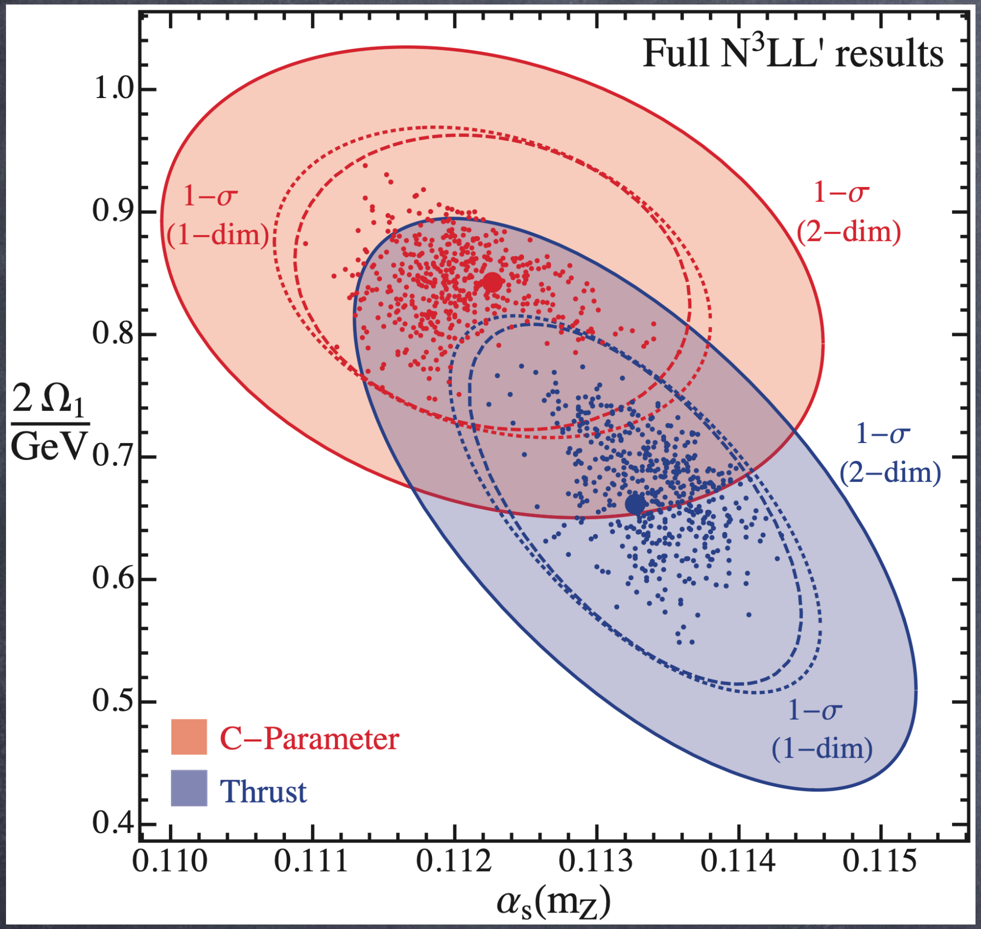

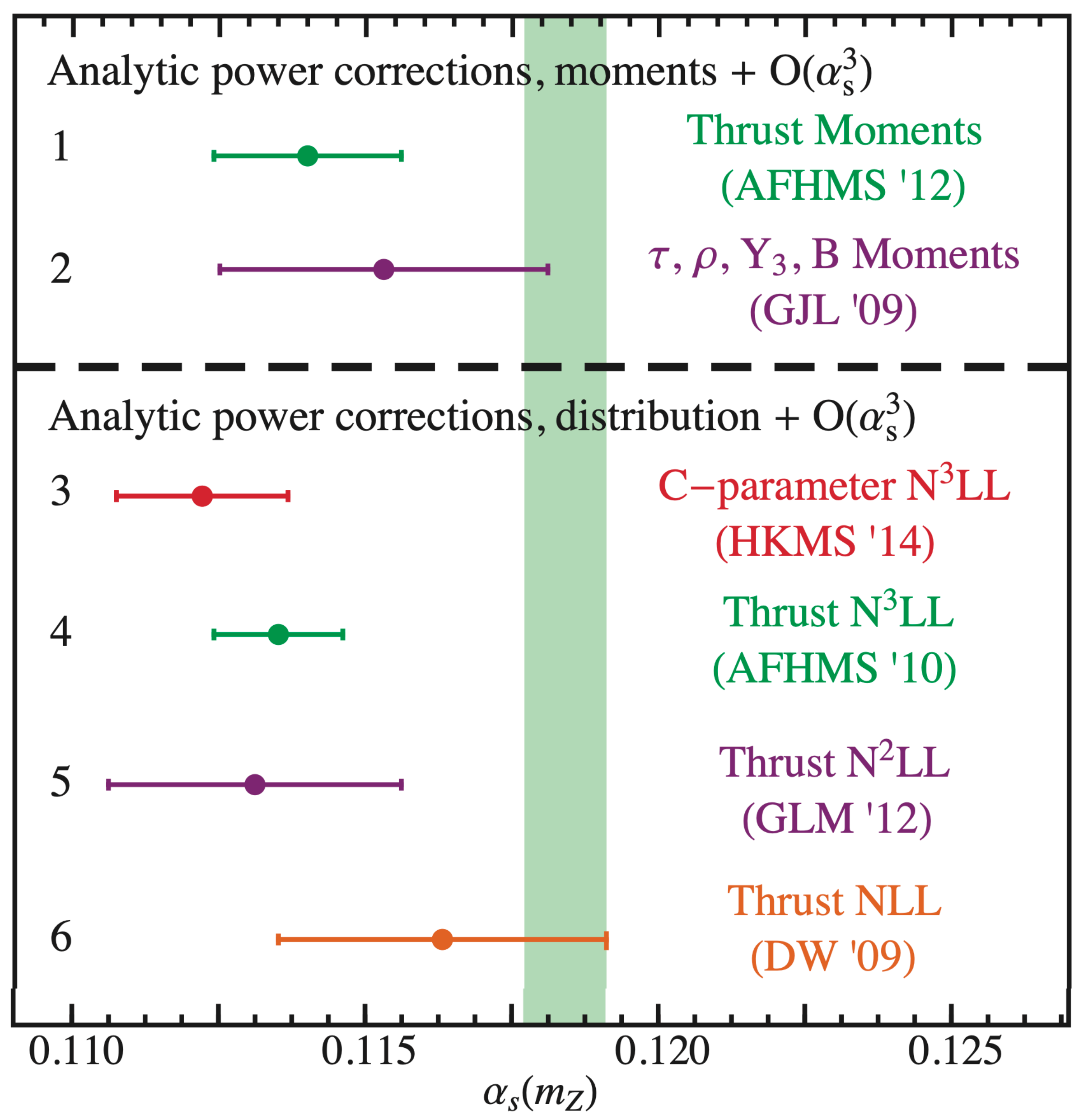

Low values confirmed by recent analysis

[Bell, Lee, Makris, Talbert, Yan, 2311.03990]

Review on strong coupling fits from event-shape distributions

Theoretical overview

Partonic cross section

Partonic cross section $$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\tau} = \frac{\mathrm{d}\hat{\sigma}_s}{\mathrm{d}\tau} + \frac{\mathrm{d}\hat{\sigma}_{ns}}{\mathrm{d}\tau}$$

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Singular dominates in peak and tail

large Sudakov logs, need resummation

factorisation achieved in SCET, resummation through RG evolution

$$\frac{1}{\sigma_0}\frac{d\hat{\sigma}_s}{d\tau} = H(Q,\mu_H)U_H(Q,\mu_H,\mu_J)\int ds\, J_\tau(s,\mu_J)\int dk\, U_s^\tau(k',\mu_J,\mu_S)\hat{S}_\tau\Big(Q\tau - \frac{s}{Q},\mu_S\Big)$$

[Schwartz PRD 77 (2008) 014026]

[Becher & Schwartz JHEP 07 (2008) 034]

[Fleming, Hoang, Mantry, Stewart PRD 77 (2008) 074010]

[Bauer, Fleming, Lee, Sterman PRD 78 (2008) 034027]

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$\mu_H \sim Q$

$\mu_J \sim Q\sqrt{\tau}$

$\mu_S \sim Q\tau$

"canonical" scale setting

if $\mu_H = \mu_H = \mu_S$ resummation is switched off

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Non-singular is a power correction in peak and tail

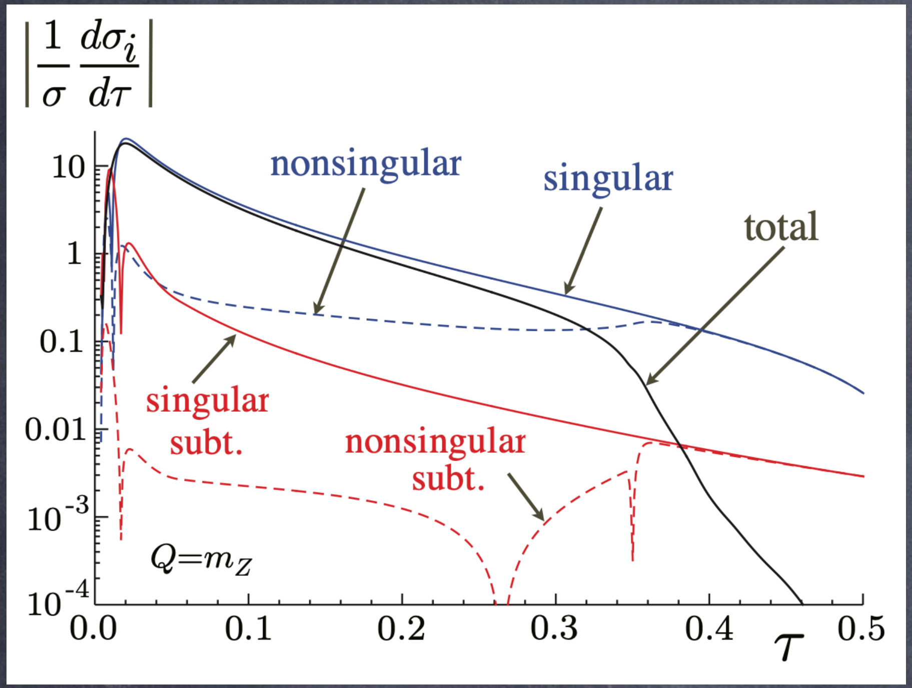
resummation in non-singular is work in progress (known @ LL)

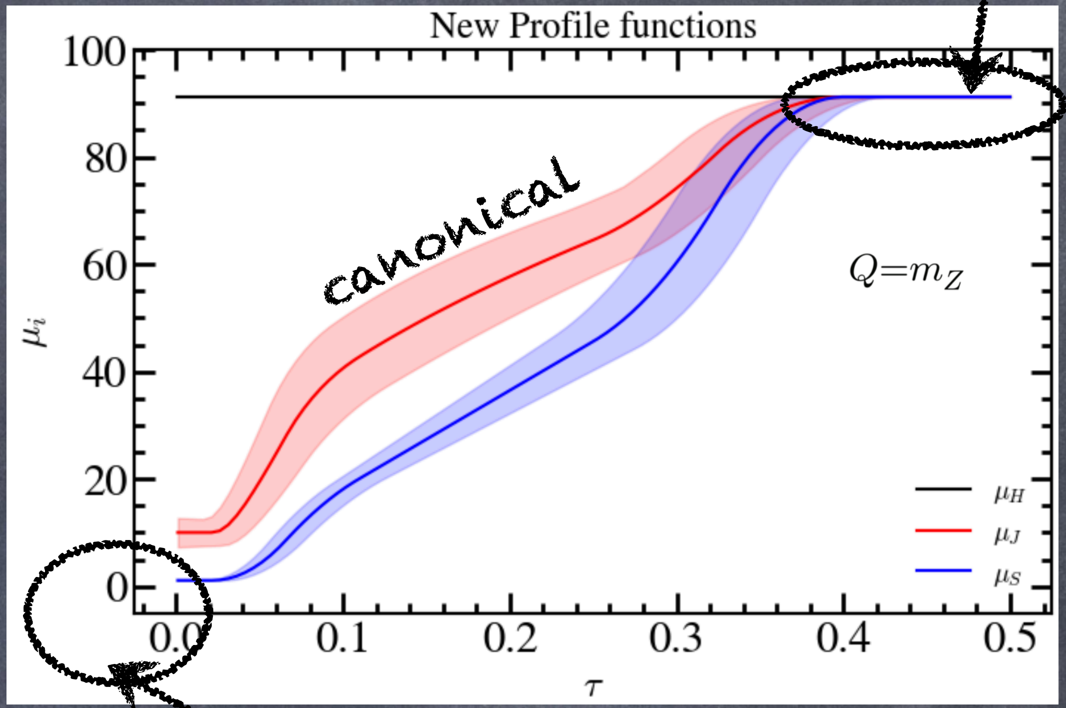
as important as singular in far-tail region

Partonic cross section

no resummation

[PRD 91 (2015) 9, 094017]





cross section totally dominated by dijet for $\tau < 0.11$

non-perturbative

The soft function has an $u = 1/2$ renormalon that must be removed [PLB 660 (2008) 483-493]

Use soft gap subtractions [see talk by M. Benitez]

Other subtractions & profile for subtraction scale: [see talk by C. Lee]

Hadronization corrections

Dominant source of non-perturbative corrections → modes with lowest virtuality confined to soft function

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shape function

OPE: valid in the tail $Q\tau \gg \Lambda_{\mathrm{QCD}}$

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Operator definition: [Lee, Sterman] [VM, Thaler, Stewart]

$$\Omega_1^e = \langle 0 | \bar{Y}_{\bar{n}}^\dagger Y_n^\dagger (Q\hat{e}) Y_n \bar{Y}_{\bar{n}} | 0 \rangle$$

involves 4 Wilson lines in fixed directions

because 2-jet configuration is "unique"

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Implications for the cross section

$$\frac{\mathrm{d}\sigma_s}{\mathrm{d}\tau} = \frac{\mathrm{d}\hat{\sigma}_s}{\mathrm{d}\tau}\left(\tau - \frac{\Omega_1^\tau}{Q}\right) + \mathcal{O}\left(\frac{\Lambda_{\mathrm{QCD}}^2}{Q^2\tau^2}\right) \longrightarrow \frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\tau}\left(\tau - \frac{\Omega_1^\tau}{Q}\right) + \mathcal{O}\left(\frac{\Lambda_{\mathrm{QCD}}^2}{Q^2\tau^2}\right)$$

is this justified?

Fit results

Results

Fit to thrust data at many c.o.m. energies $\tau \in \left[\frac{6}{Q}, 0.33\right]$

Use minimal overlap model for experimental correlations

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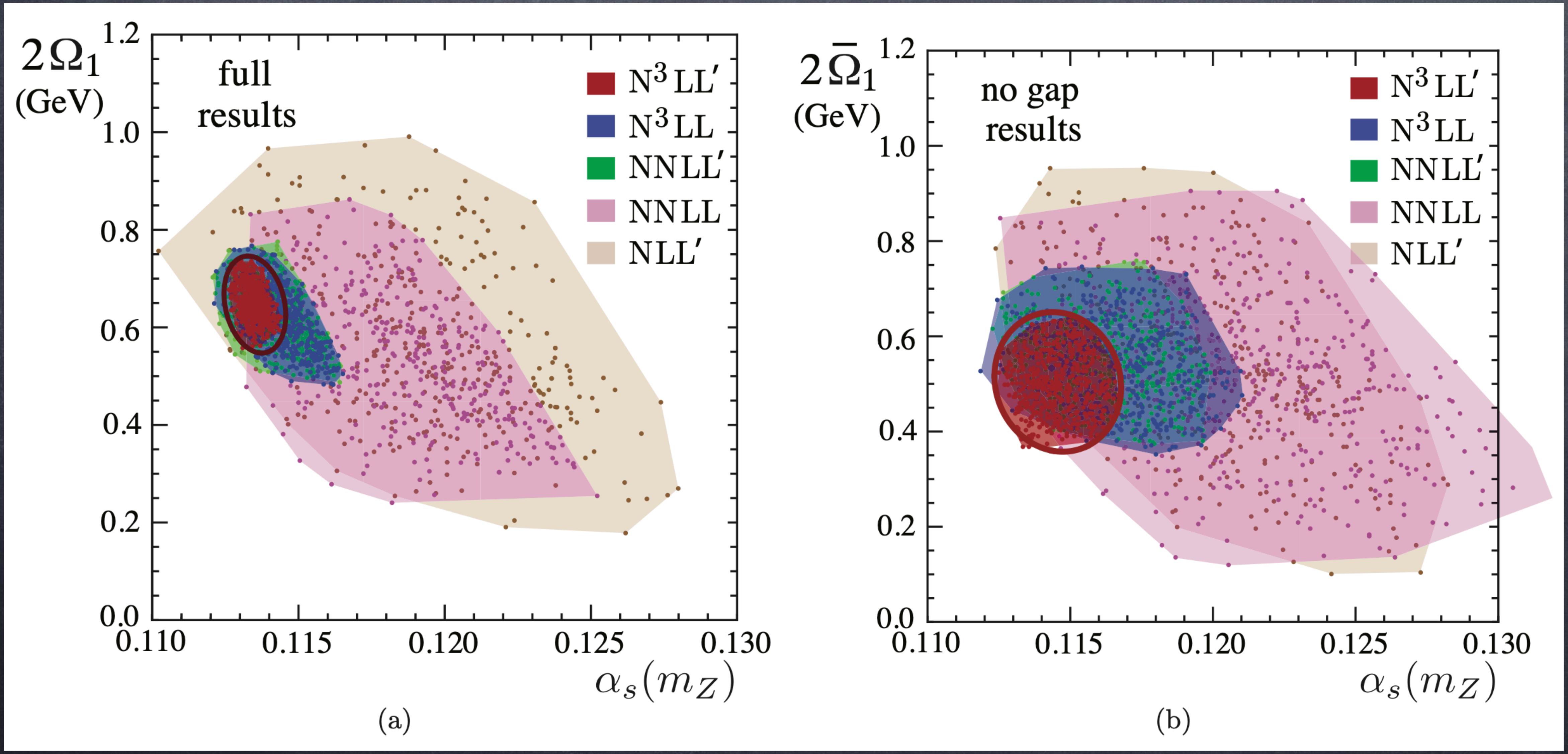
Perform random scan on perturbative parameters to account for theory correlations



Updated results in [talk by M. Benitez]

Caveats on fit results

Main point of concern: dataset in fits includes 3-jet region assuming the 2-jet power correction is valid there

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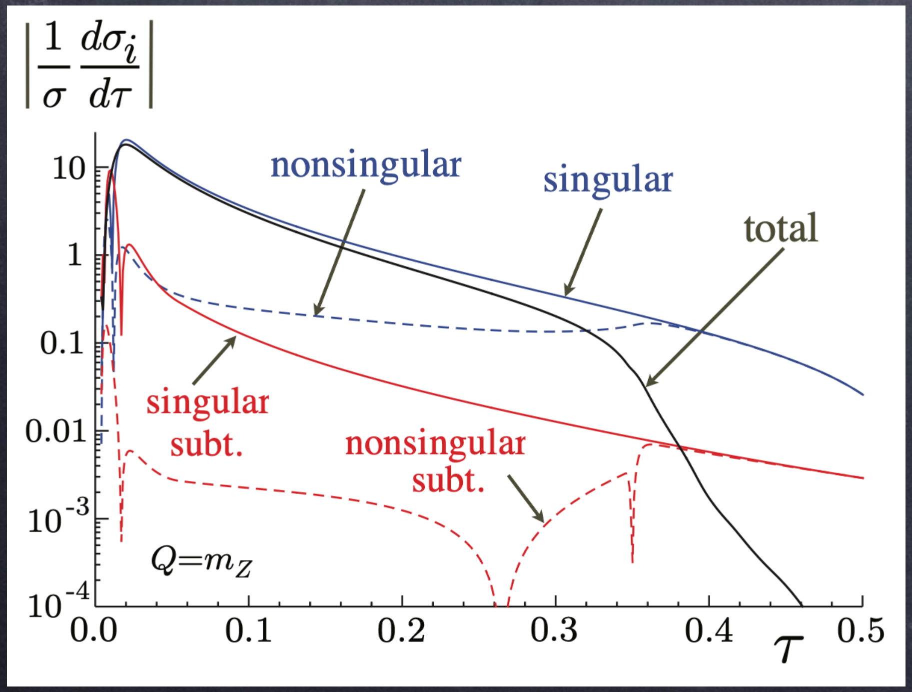
Motivations for such assumption:

- Ensures singular-vs non-singular cancellation

if singular and ns shifted differently, cancellation ruined



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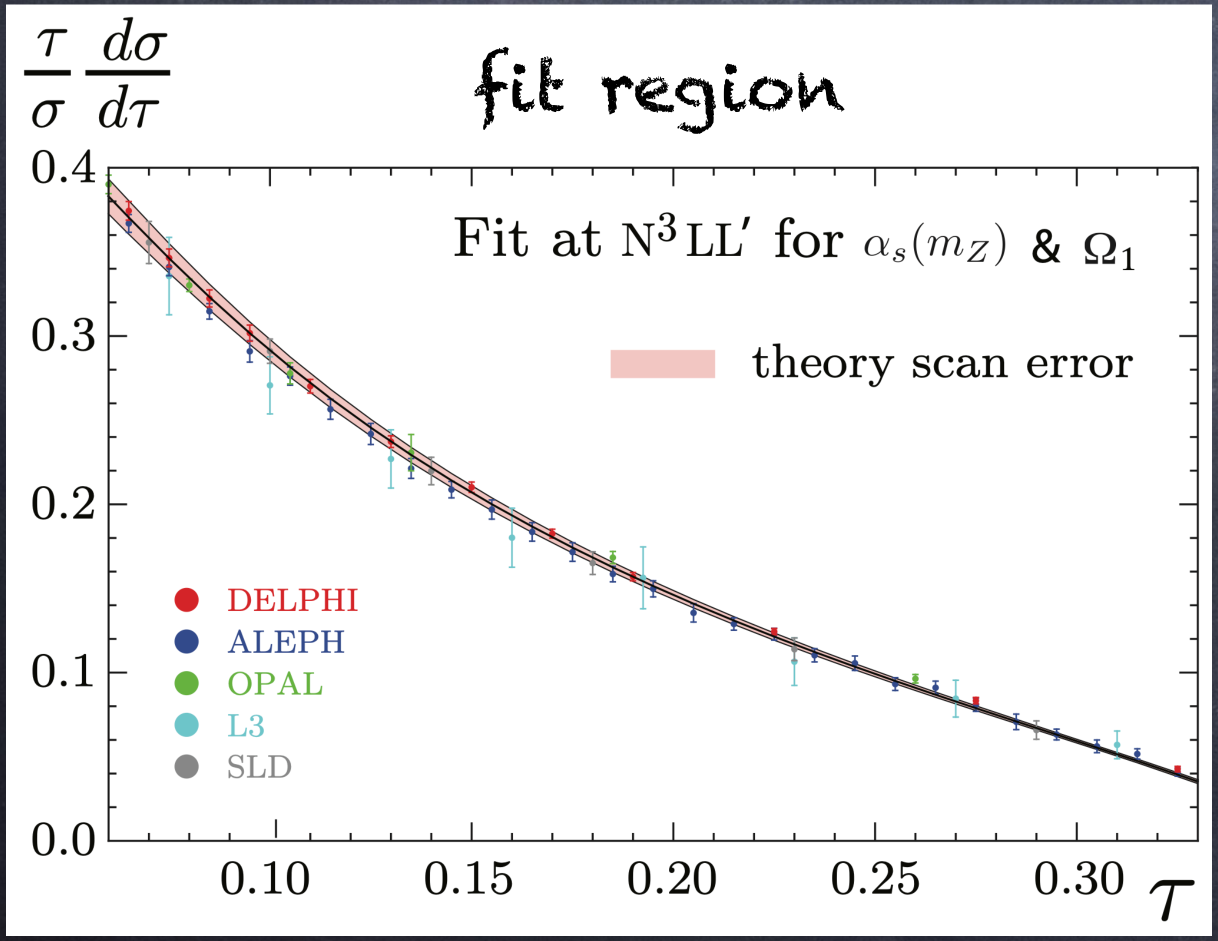

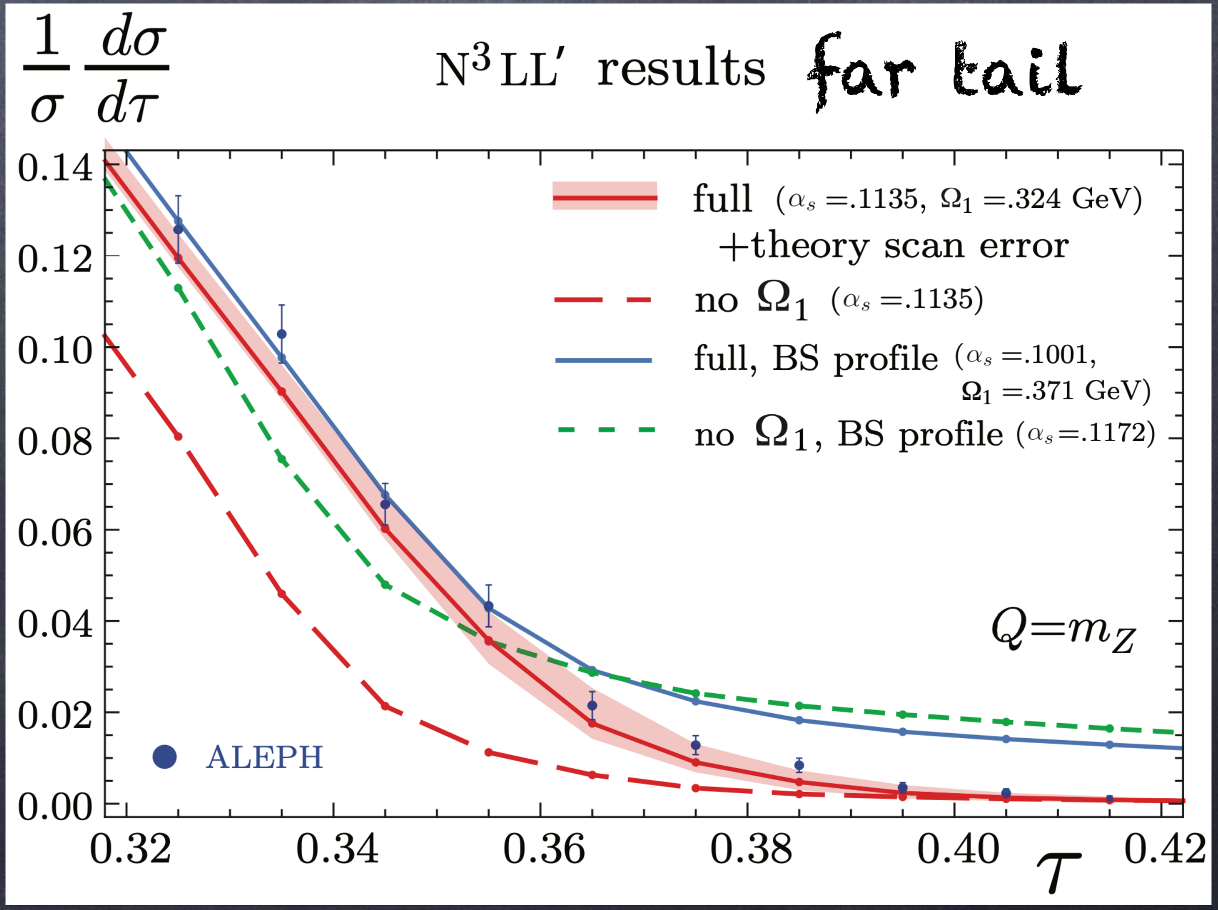

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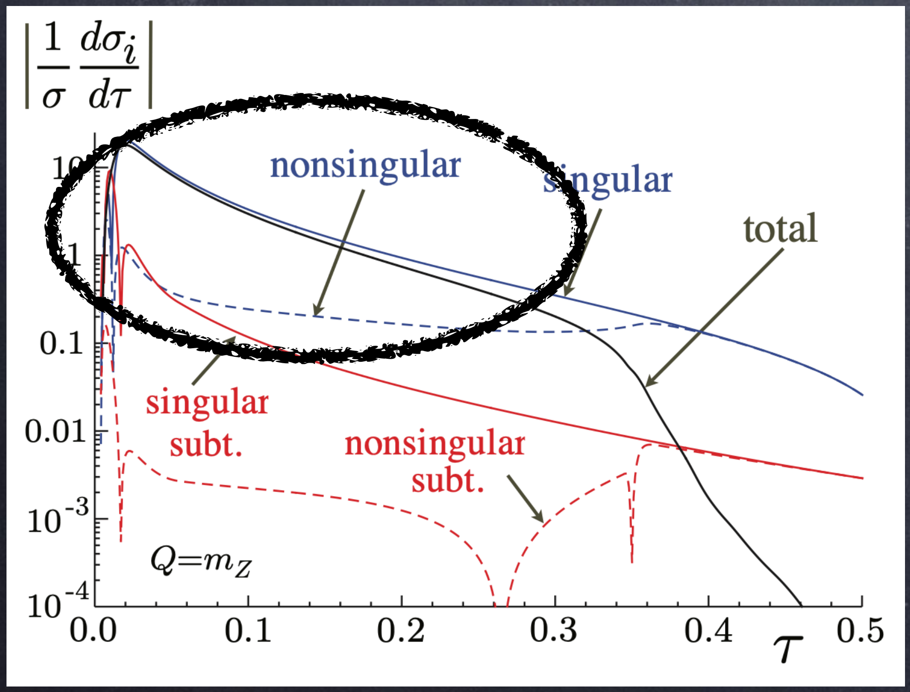
Motivations for such assumption:

- Ensures singular-vs non-singular cancellation
- Data suggests such behaviour
- If singular terms dominate, this is justified



in most of the fit region, singular clearly dominates

dijet region obviously exists!!!

more conservative analysis:
restrict fit region [see talk by M. Benitez]

Recent Progress in power corrections

Recent studies of power corrections

Luisoni, Monni, Salam [EPJC 81 (2021) 2, 158]

Use dispersive model to "compute" power correction at C = 3/4

Find that, within that model $\Omega_1^{2-\mathrm{jet}} \simeq 2\,\Omega_1^{3-\mathrm{jet}}$

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Real-life computation: needs an operator definition

2-jet: in terms of 4 Wilson lines
3-jet: in terms of 6 Wilson lines
} can't be related

Non-perturbative vacuum matrix element of different operators

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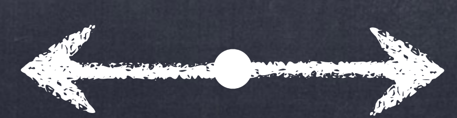
In certain limits, direction of WLs are fixed

2-jet



shoulder

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Power correction given by term linear in m_g

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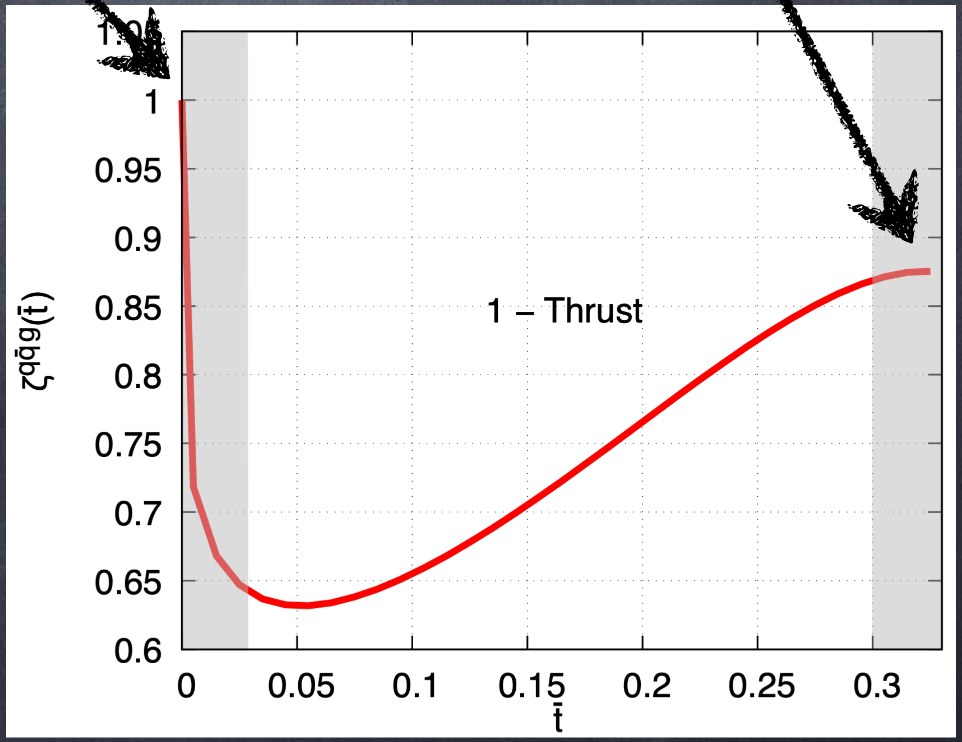
Power correction is a shift, but the shift is τ dependent

2-jet p.c.

3-jet p.c.



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Caveats

Assume gluon mass is the smallest scale in the problem

Assume 3 jets can be resolved in di-jet regions

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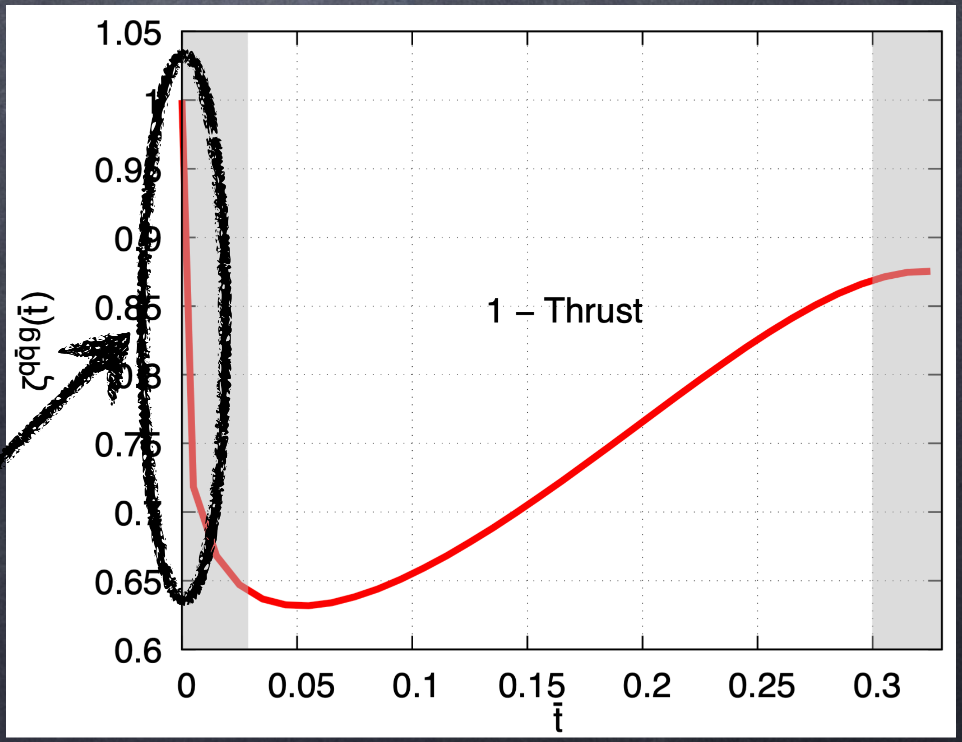

very steep falloff

implies dijet does not exist!

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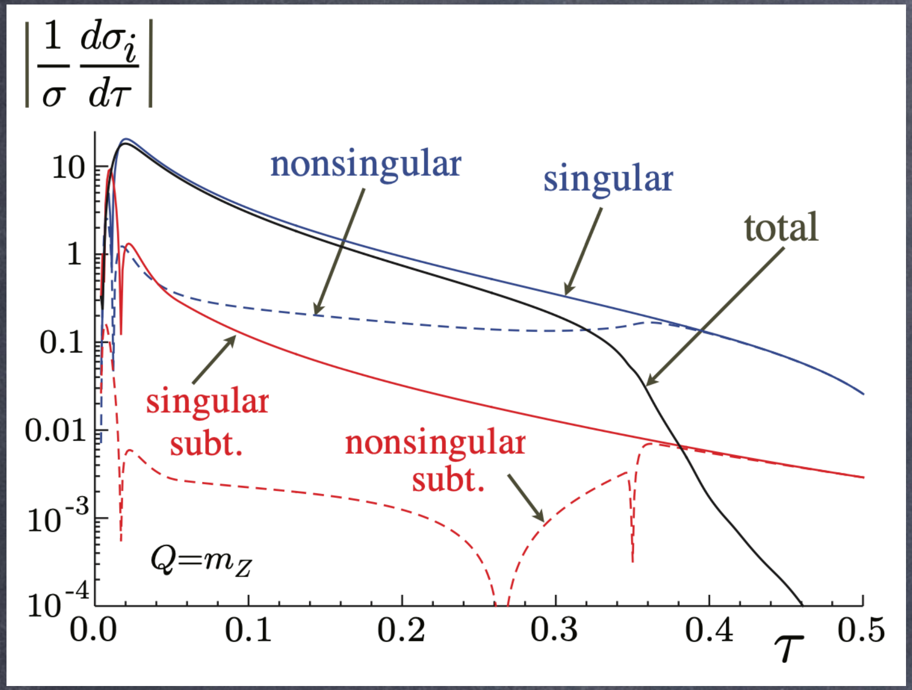
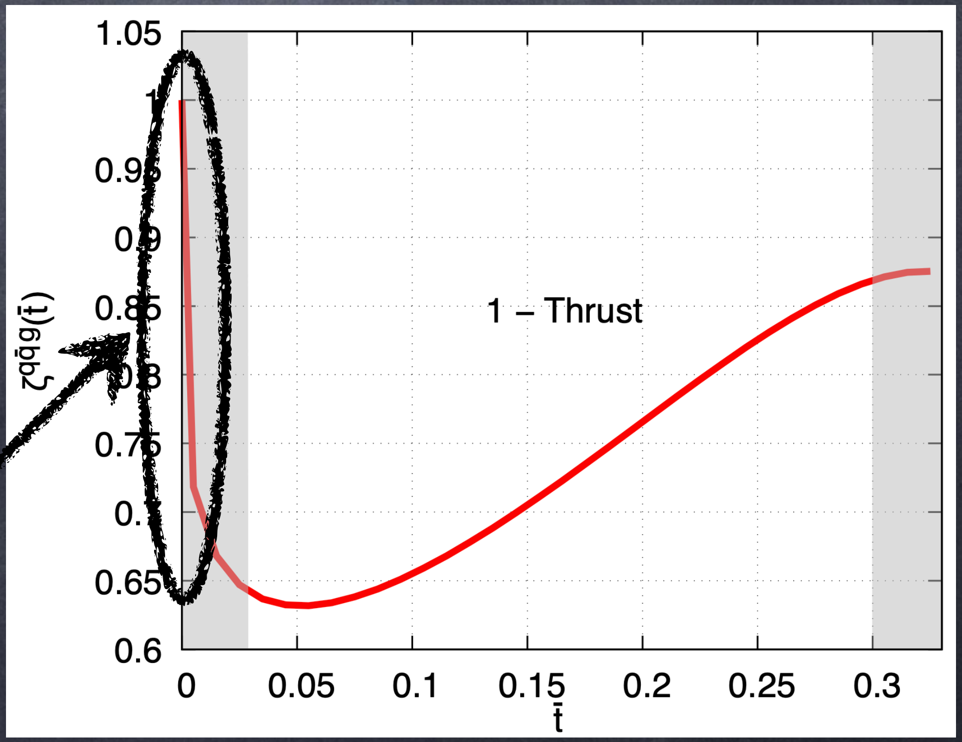


but it does... and overly dominates!



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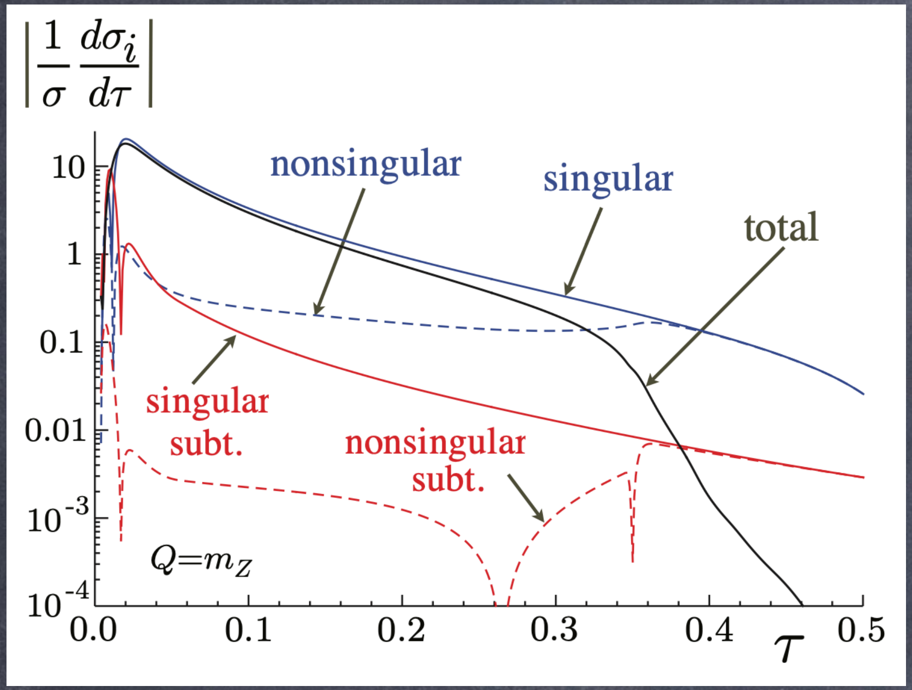

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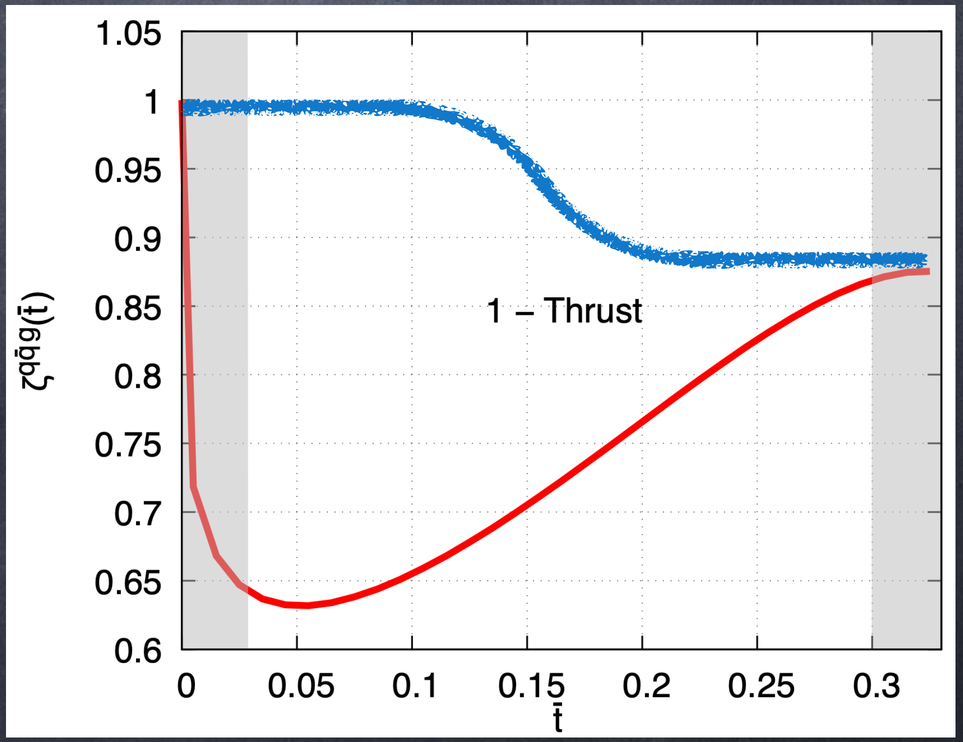
seems more natural



di-jet dominates for a while and then smoothly becomes the 3-jet power correction

exact form not known: one must investigate the effect of varying its functional form on uncertainty

Recent studies of power corrections

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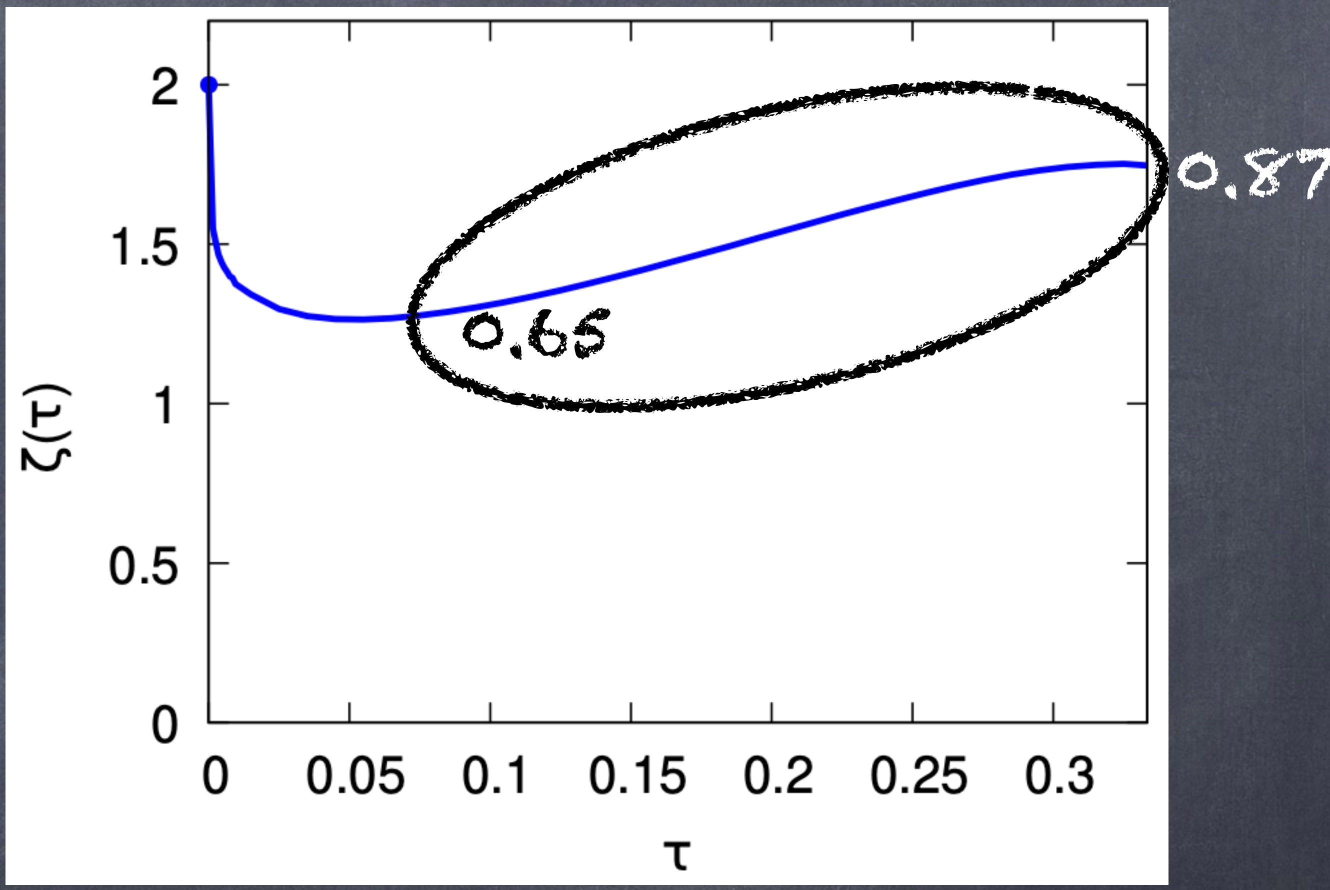
variation quite mild in fit region (30%)

expect mild effect on α_s fits



since power correction grows in the fit region, one expects α_s will come out smaller when fitting

Concerns on Caola et al.

Same problems as Luisoni et al.

- Gluon mass "universal" non-perturbative parameter
- No operator definition was given
- One would expect operator with 6 WLs with variable directions
  - a single thrust value requires varying the WLs direction

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Conceptual issue: 3 jets cannot be resolved for small tau values

scaling of jet momentum:

$$p^\mu = (p^+, p^-, \vec{p}_\perp)$$

$$\left.\begin{array}{l} p^- \sim Q \\ p^+ \sim \Delta \end{array}\right\} \longrightarrow |\vec{p}_\perp| \sim \sqrt{\Delta Q}$$

Δ can be estimated from peak position or size of Ω_1

$$\Delta \in (1.3, 2.3)\,\mathrm{GeV}$$

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opening angle of jet $\theta_J \sim 4\sqrt{\dfrac{2\Delta}{Q}}$

to resolve 3-jets: angle between jets larger than opening angle

jet energy larger than $p_\perp$ of sub-jet

Resolving 3 jets

To be definite, $a \gg b$ means $a > 3b$

2 subjets collinear, back to back with the hardest jet

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1 subjet soft, other subjet collinear to the hardest jet

$$E_1 = E_2 = \frac{Q}{2}(1-\tau)$$

$$E_3 = Q\tau \ll E_{1,2}$$

$$|\vec{p}_2^{\perp}| \sim \sqrt{Q\Delta(1-\tau)} \simeq \sqrt{Q\Delta}$$

Resolving 3 jets

To be definite, $a \gg b$ means $a > 3b$ or $a > \sqrt{2}\, b$ more conservative

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$$|\vec{p}_2^{\perp}| \sim \sqrt{Q\Delta(1-\tau)} \simeq \sqrt{Q\Delta}$$

from the condition $E_3 \gg |\vec{p}_2^{\perp}|$ one gets $\tau > 0.2$ at $Q = m_Z$

No 3-jet consideration is of any relevance for $\tau < 0.2$ at $Q = m_Z$

Recent analysis using new developments

Analysis of Nason-Zanderighi

New results on power corrections have triggered a new analysis

[JHEP 06 (2023) 058]

- Uses data only at the Z pole (exclude low Q data)
- Combines various variables: thrust, C-param, y_3
- Includes event-shape dependent power correction
- Neglects resummation in the entire spectrum
- Ignores theory correlation among observables and bins

Analysis of Nason-Zanderighi

New results on power corrections have triggered a new analysis

[JHEP 06 (2023) 058]

- Uses only ALEPH data at the Z pole (exclude low Q data)
- Combines various variables: thrust, C-param, y_3
- Includes event-shape dependent power correction
- Neglects resummation in the entire spectrum
- Ignores theory correlation among observables and bins

No info on outcome {
- including resummation
- including low energy data
- including theory correlations
- of fits at lower orders (convergence?)

Reduced χ^2 is astonishingly small (below 0.2)

Concerns on Nason-Zanderighi

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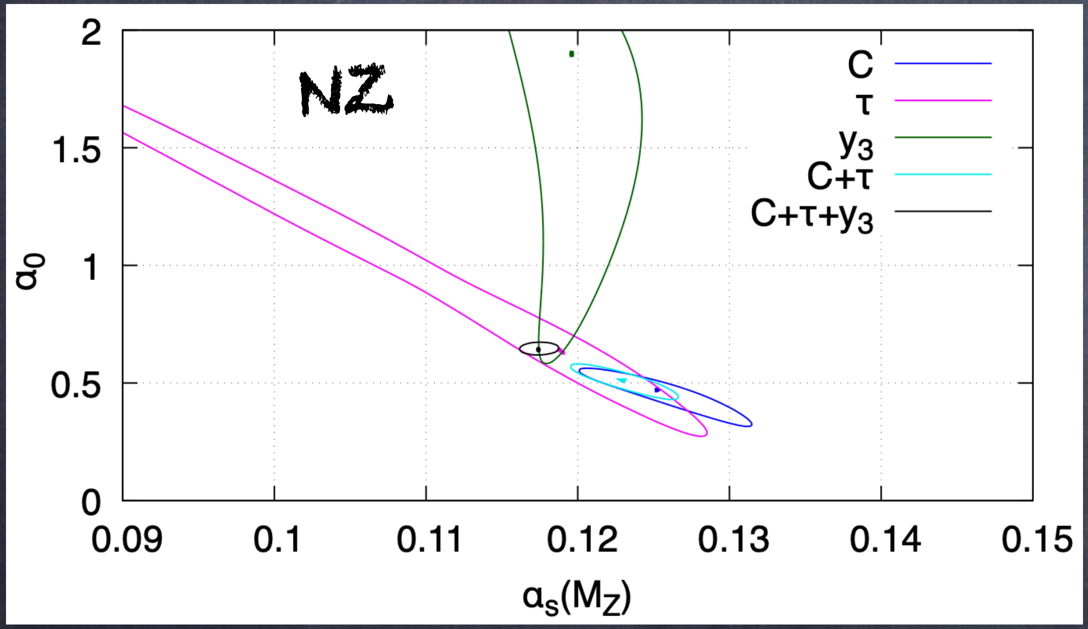

in particular since it is crucial to break degeneracy between strong coupling and power correction

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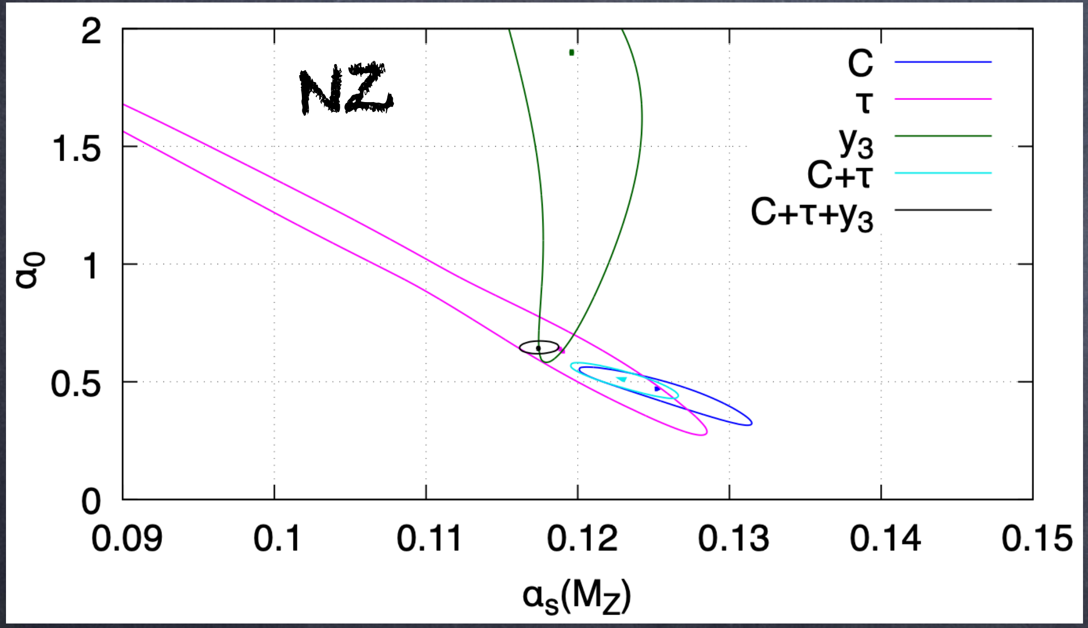

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Using low-energy data could help clarify these issues

Since we do not understand some points, we did a reanalysis [see talk by M. Benitez]

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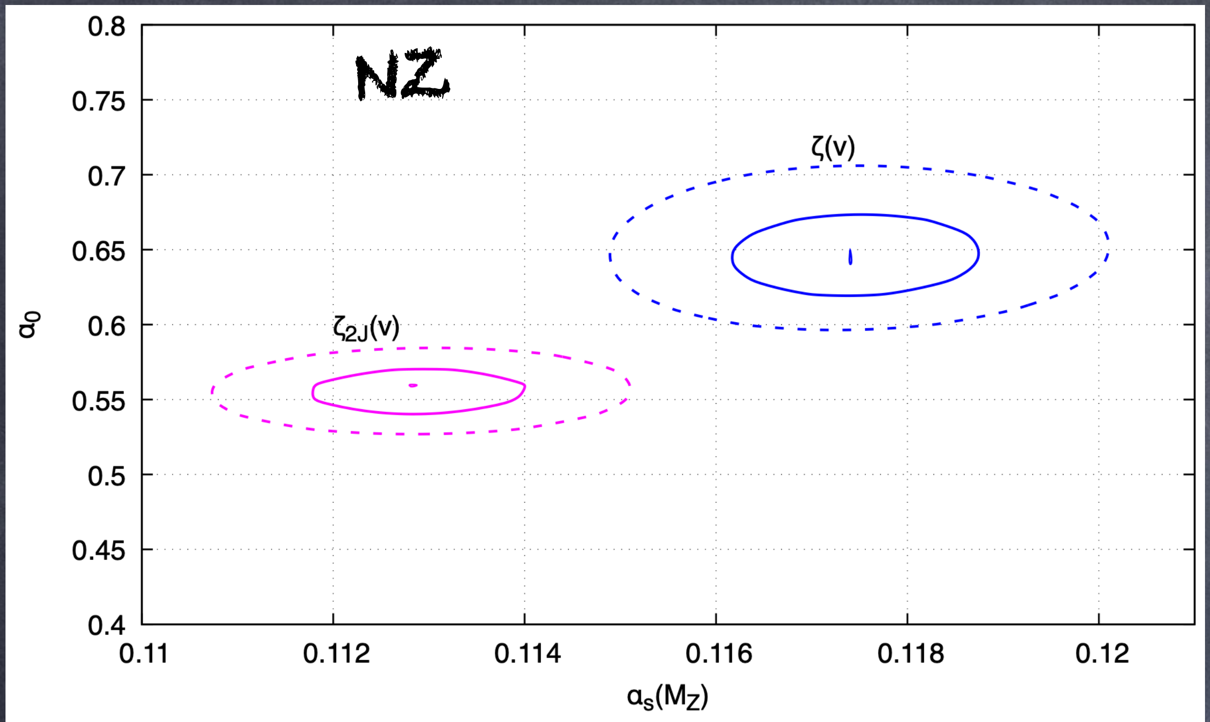
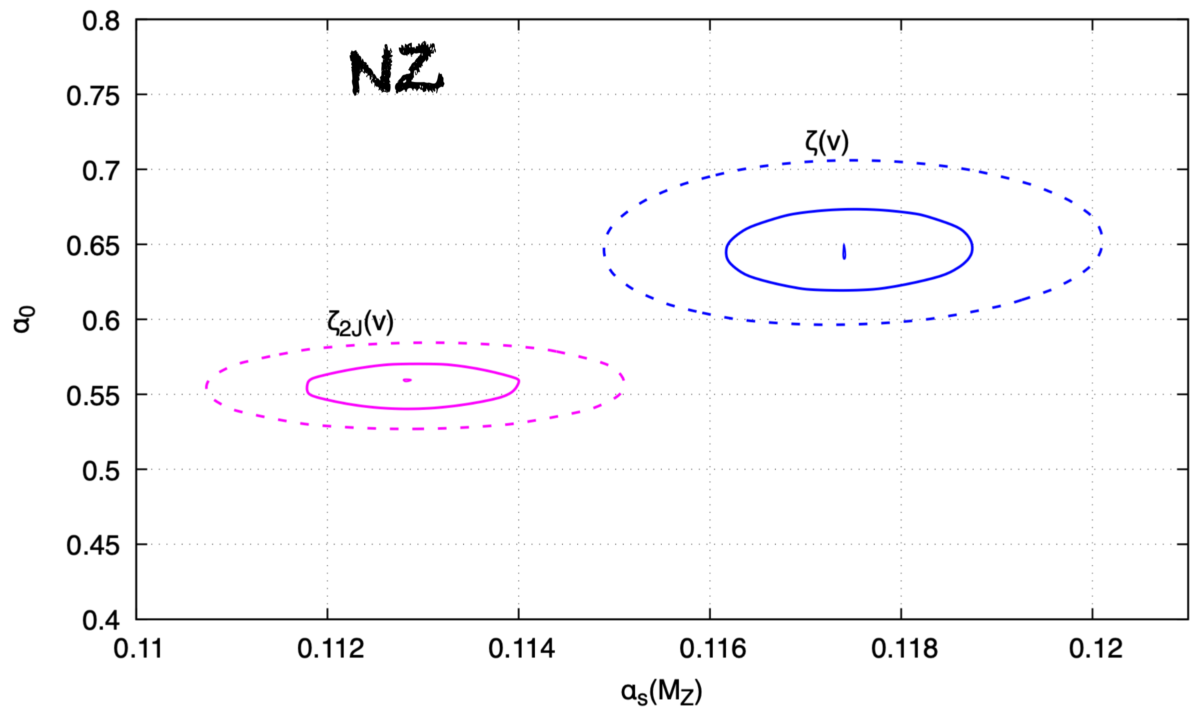


surprising outcome given the mild dependence of power correction in fit region

Our reanalysis looks quite different! [see talk by M. Benitez]

Could this mean NZ's fits are not robust?

Concerns on Nason-Zanderighi



surprising outcome given the mild dependence of power correction in fit region

Our reanalysis looks quite different! [see talk by M. Benitez]

Could this mean NZ's fits are not robust?

Looking at thrust by itself, indeed mild change, but pushes α_s down

	Variation	$\alpha_s(M_Z)$	α_0	χ^2	$\chi^2/N_{\rm deg}$	
NZ	τ	0.1188	0.64	0.7	0.03	τ-dependent power correction
NZ	τ	0.1194	0.51	1.0	0.05	constant power correction

Large values of α_s possibly caused by excluding resummation

Conclusions

Very relevant point raised by recent publications:

Can one trust 2-jet power corrections in the 3-jet region?

Most likely: no

This has triggered new computations and a new analysis

But these are based on some questionable assumptions

- Outcome of models not necessarily correct
- 3-jets cannot be resolved for small event-shape values
- Dijet region exists!
- Resummation is important
- Low energy data is important
- Correlations are important

Motivated to make a reanalysis

More details in next talk [by M. Benitez-Rathgeb]