MILAN CHRISTMAS MEETING 2024

STUDY OF NON-PERTURBATIVE POWER CORRECTIONS TO EVENT SHAPES USING PanScales SHOWERS

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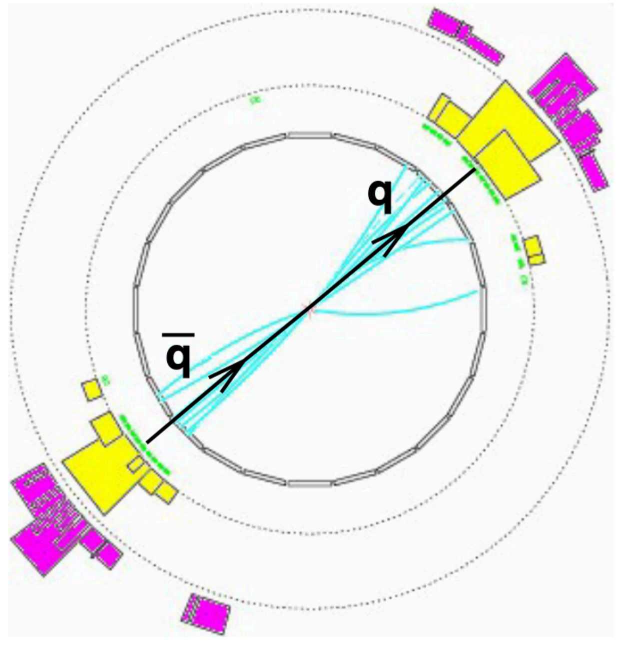
University of Oxford

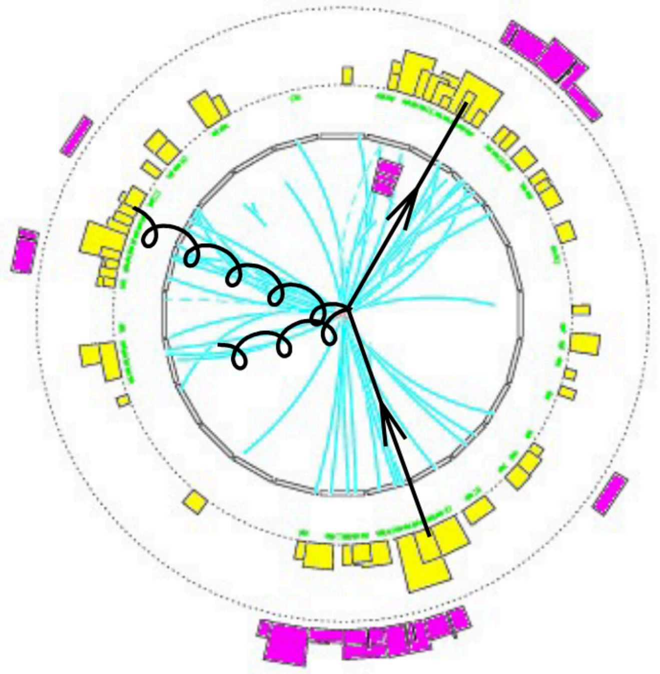
UNIVERSITY OF OXFORD

Ongoing work with F. Caola, C. Farren-Colloty, J. Helliwell, R. Patel, G.P. Salam

EVENT SHAPES

Used mostly in the context of e^+e^- collisions , they provide information on the geometry of an event.





pencil-like → spherical

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- Very clean environment for experimental measurements.
- IR safe, so they can be computed in perturbative QCD.
- Known at high orders in QCD (including resummation).

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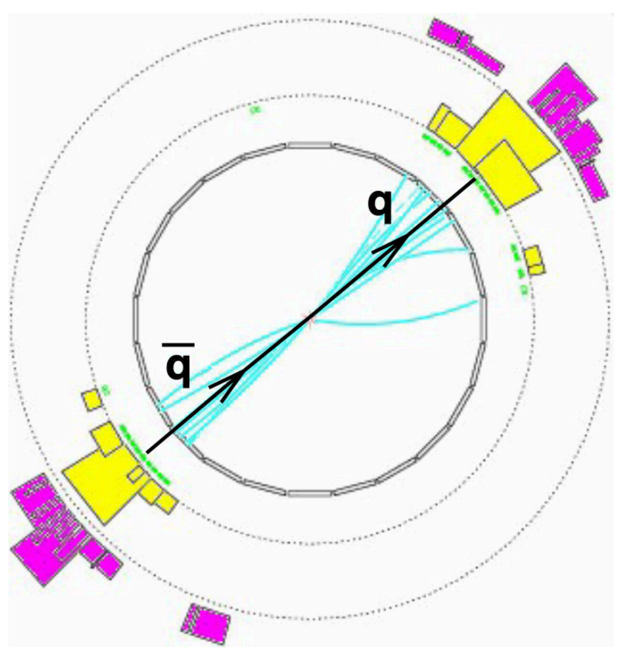

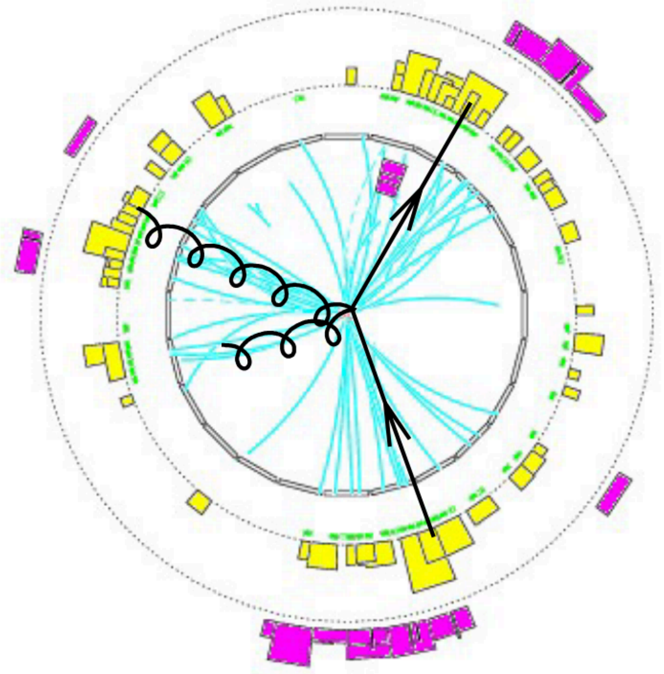

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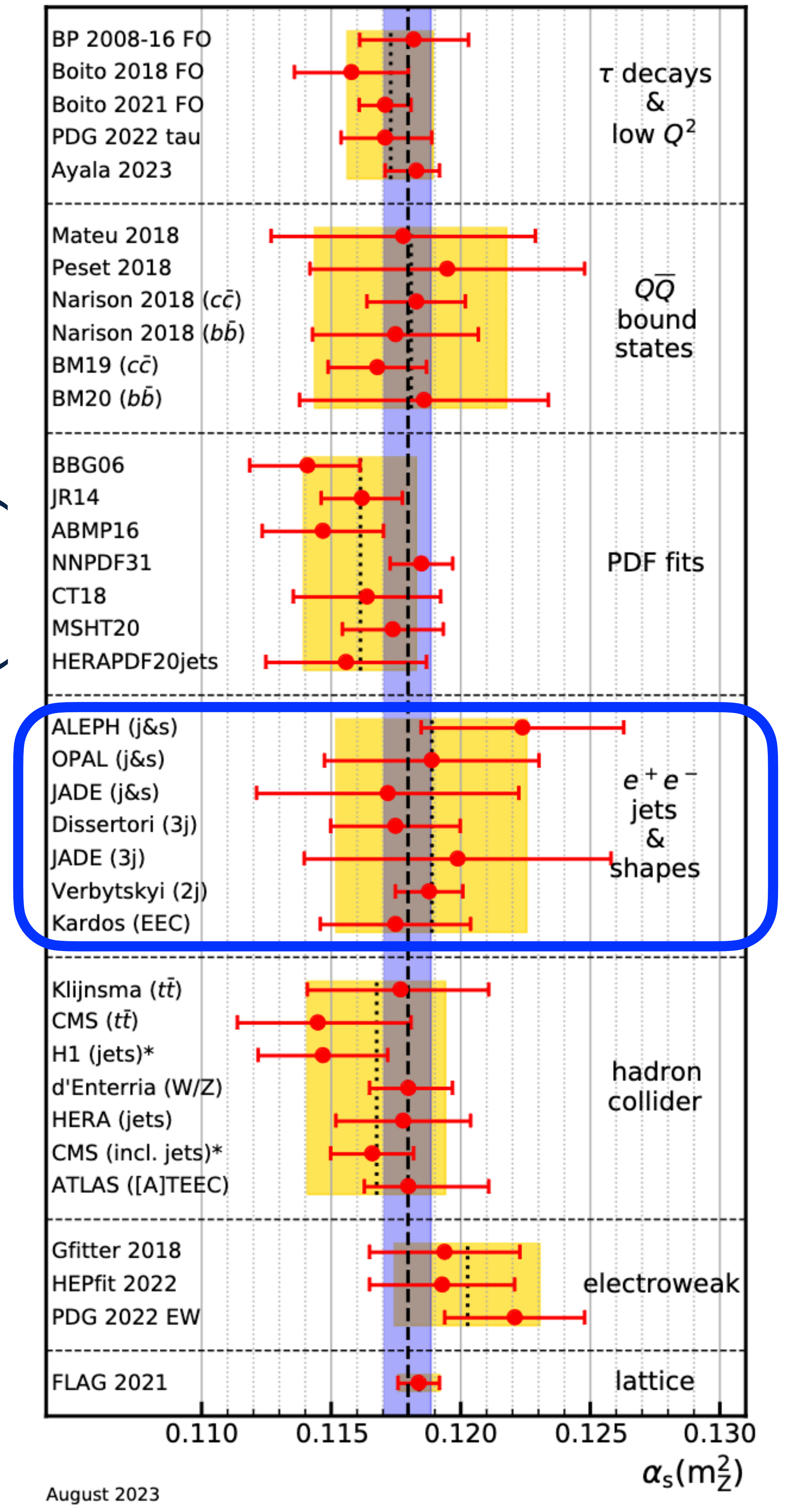
AFFECTED BY SIGNIFICANT NON-PERTURBATIVE CORRECTIONS (Λ/Q)

DETERMINATION OF α_S

Hadronic final state of e^+e^- collisions:

LATEST PDG (2023)



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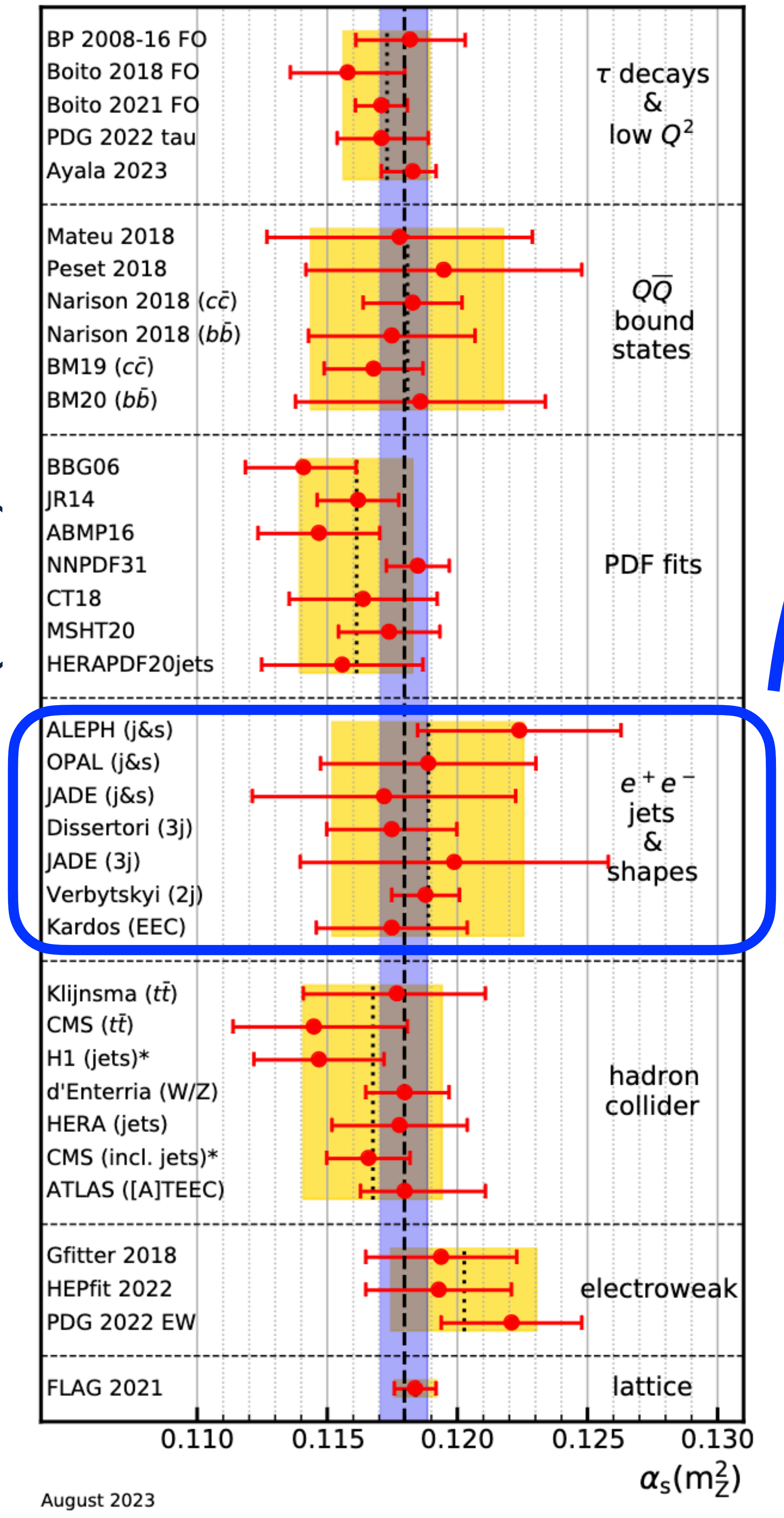

NON-PERTURBATIVE (=HADRONIZATION) CORRECTIONS CAN BE OBTAINED IN TWO DIFFERENT WAYS:

1 - FROM A MC GENERATOR

✔ Very practical: construct a migration matrix describing the parton to hadron transition, and apply it in the data/theory comparison.

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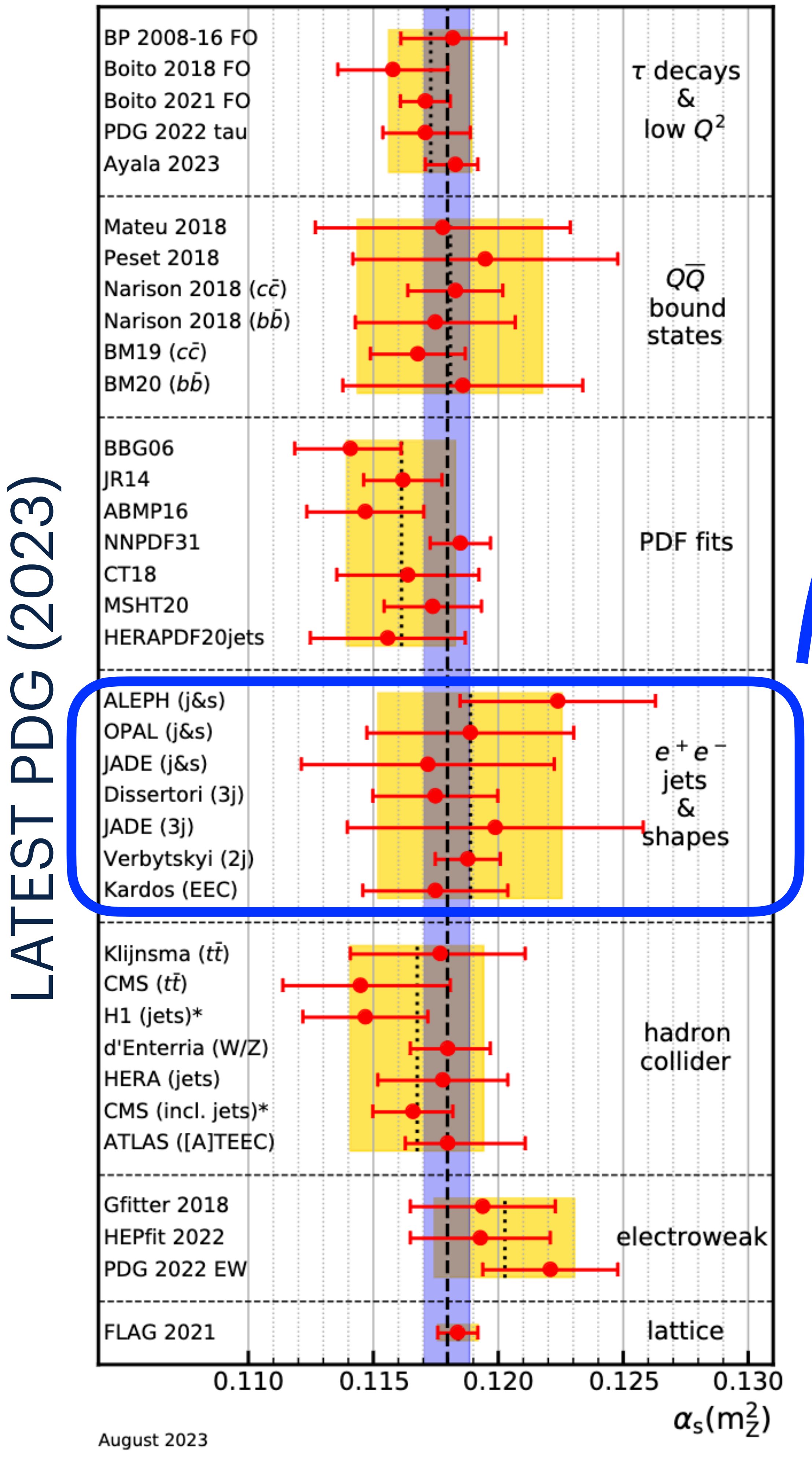

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2 - FROM ANALYTIC MODELS

Fit of thrust data: $\alpha_s(m_Z^2) = 0.1135 \pm 0.0011$ [1]

$\alpha_s(m_Z^2) = 0.1134^{+0.0031}_{-0.0025}$ [2]

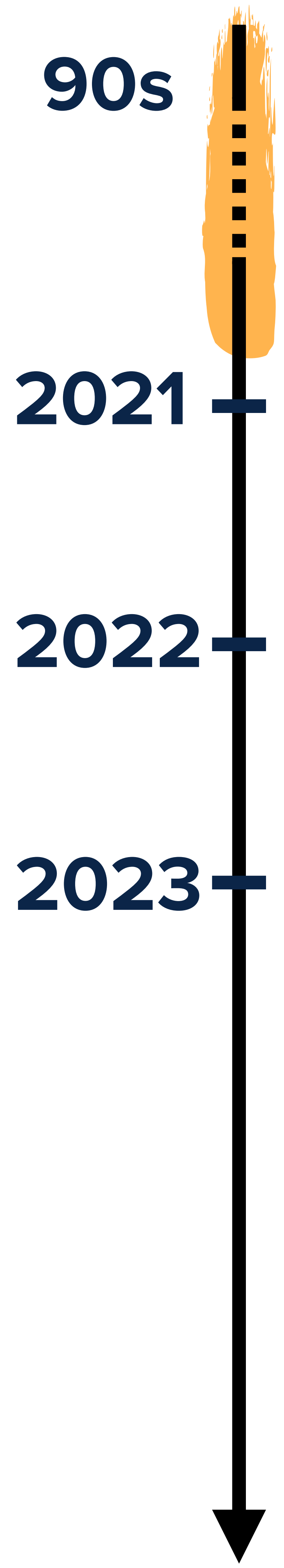
Fit of C parameter data: $\alpha_s(m_Z^2) = 0.1123 \pm 0.0015$ [3]

World average: $\alpha_s(m_Z^2) = 0.1180 \pm 0.0008$

?

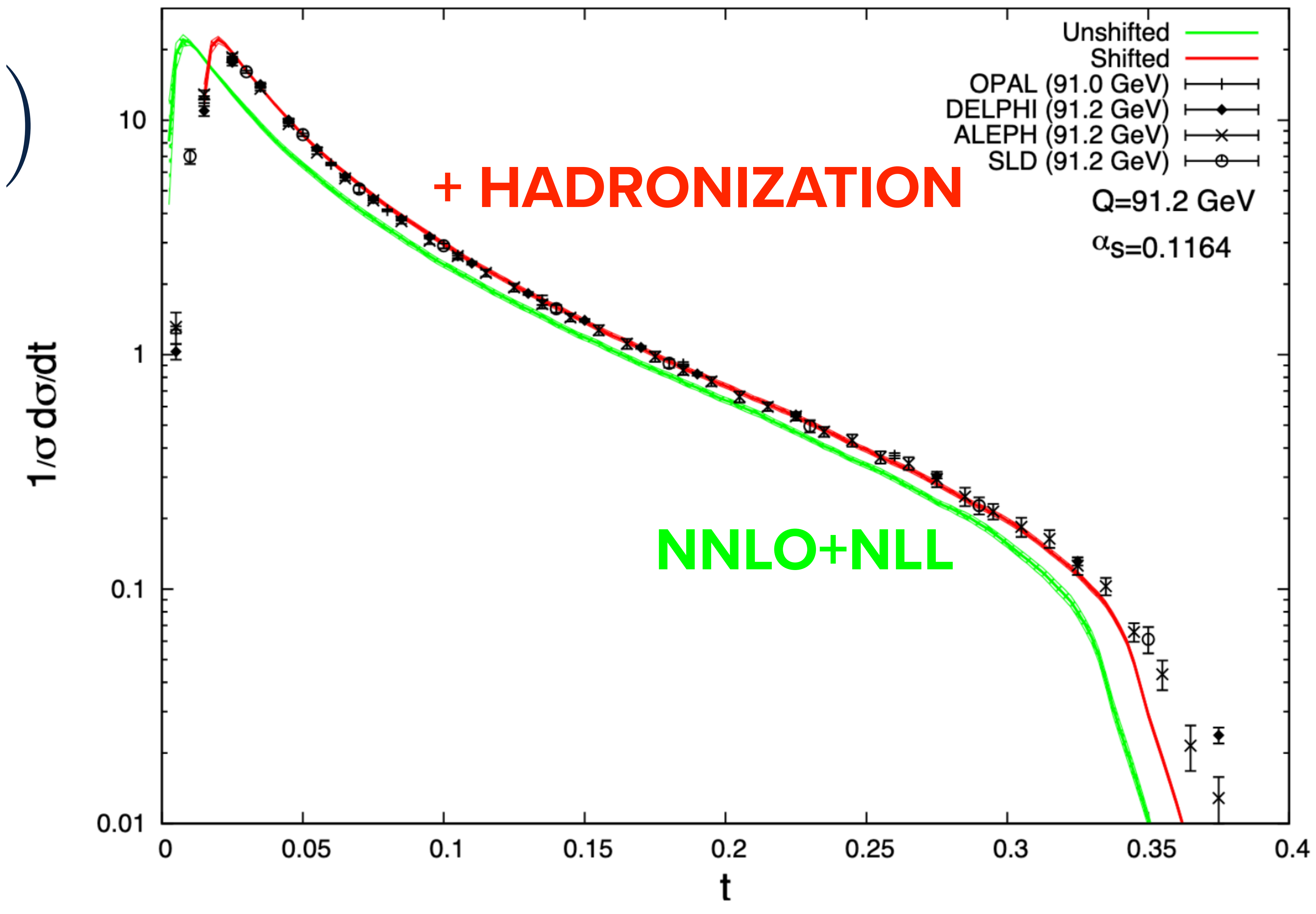
[1: Abbate et al. 1006.3080] [2: Gehrmann, Luisoni, Monni 1210.6945][3: Hoang et al. 1501.04111]

TIMELINE OF ANALYTIC MODELS



Analytic models are based on a 2-jet limit analysis, **assuming that non perturbative effects are constant in the entire kinematic spectrum.** This leads to α_s **much smaller than the world average.**

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



$$\left.\frac{1}{\sigma}\frac{d\sigma}{dt}\right|_t = \left.\left(\frac{1}{\sigma}\frac{d\sigma}{dt}\right)^{\text{pert}}\right|_{t+\delta t}$$

δt = constant 1/Q shift

[Davison, Webber 0809.3326]

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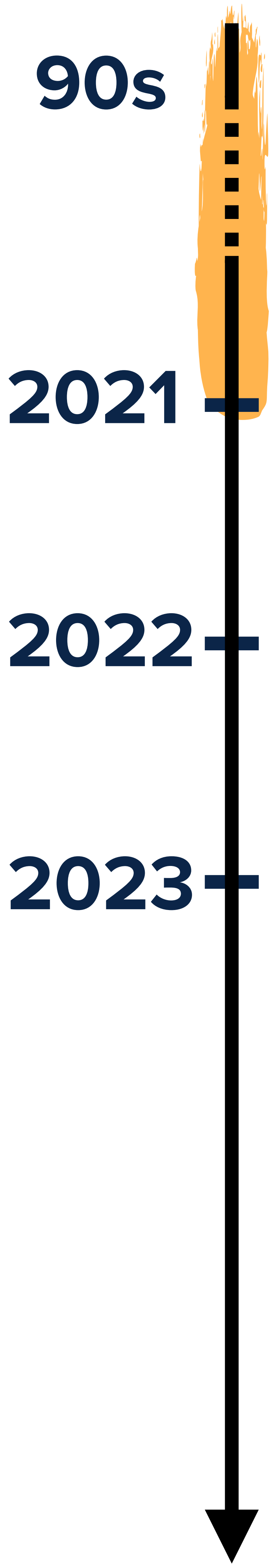

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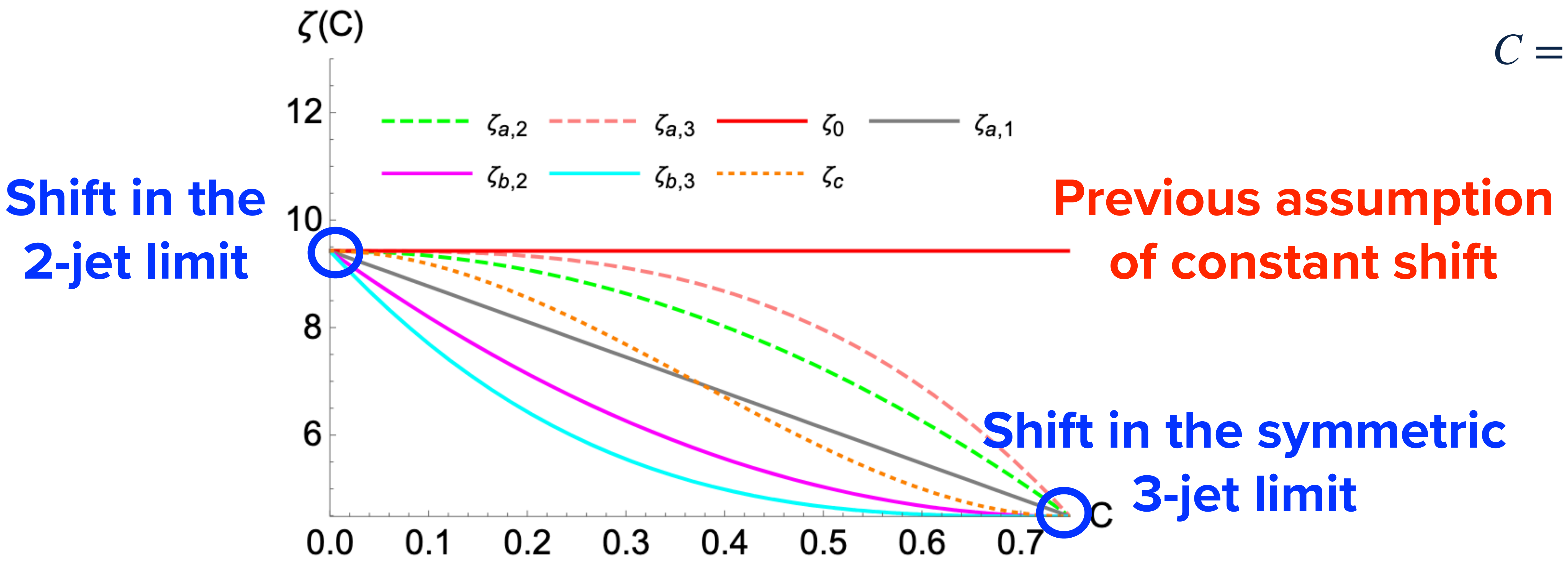
The previous assumption is proven to be wrong calculating the leading non-perturbative correction to the C parameter in C=0 and C=3/4.

$$\Theta^{\alpha\beta}\frac{1}{\sum_i |p_i|}\sum_i \frac{p_i^\alpha p_i^\beta}{|\vec{p}_i|},$$

$$C = 3\cdot(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3)$$



[Luisoni, Monni, Salam 2012.00622]

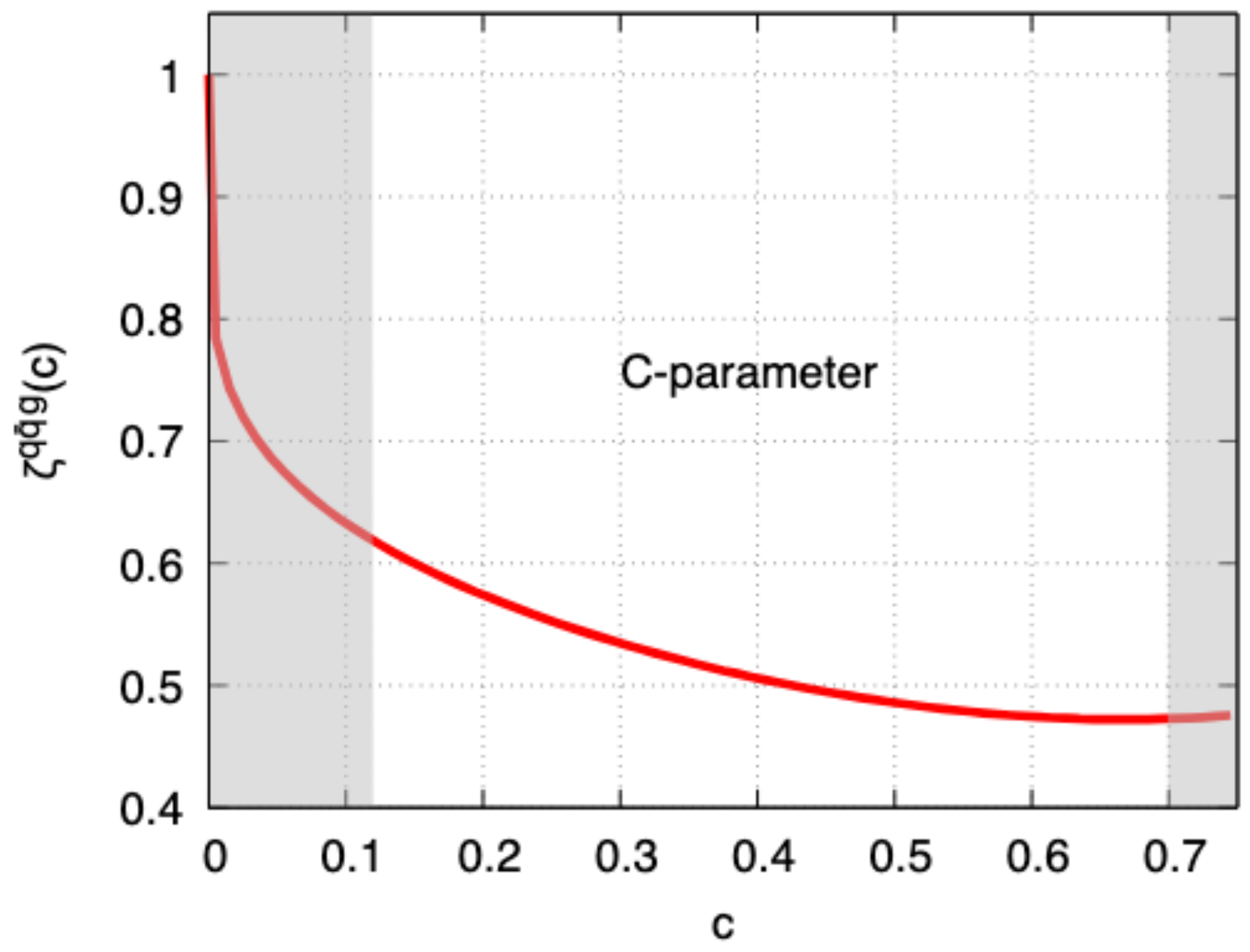
TIMELINE OF ANALYTIC MODELS

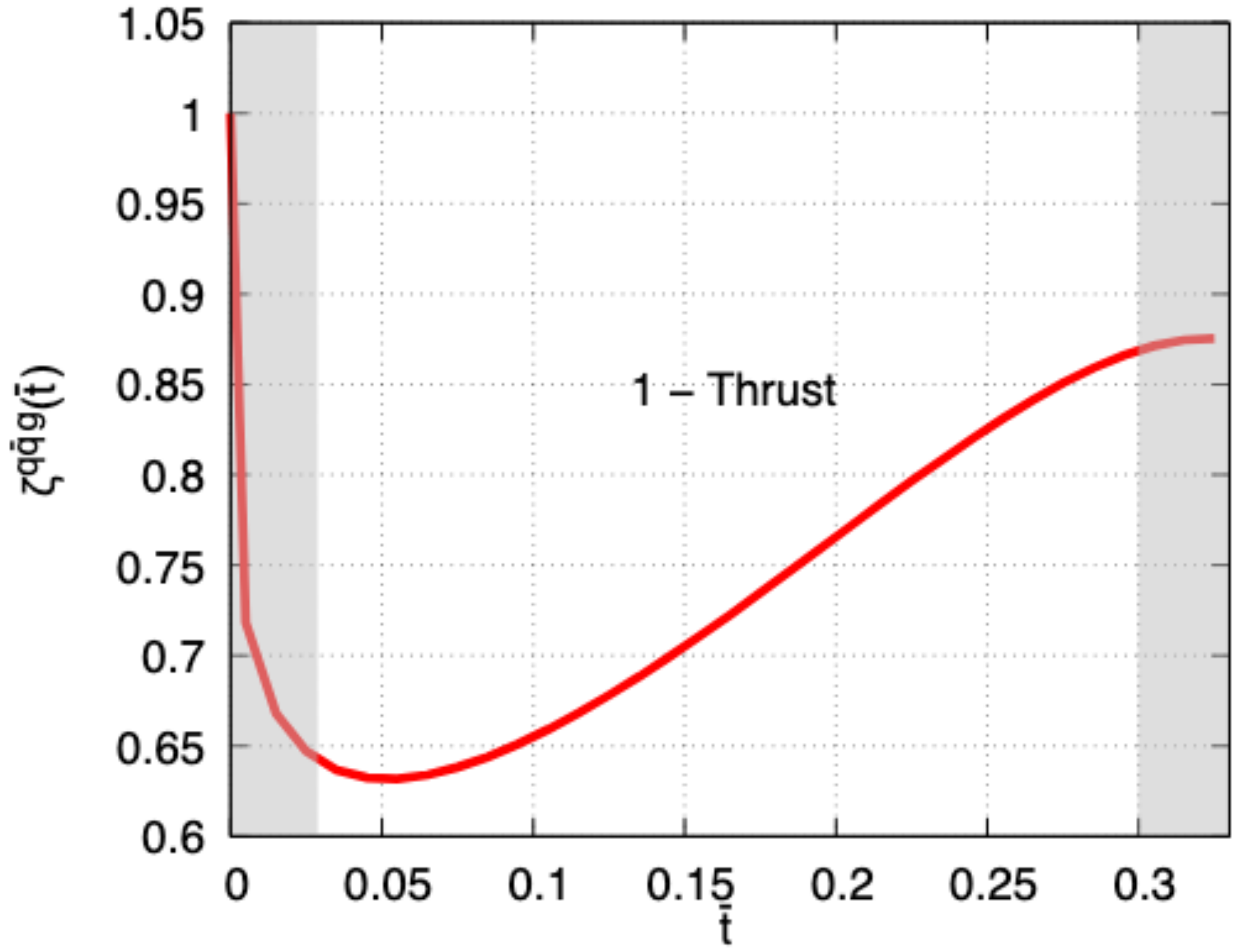
90s — Analytic models are based on a 2-jet limit analysis, **assuming that non perturbative effects are constant in the entire kinematic spectrum.** This leads to α_s **much smaller than the world average.**

2021 — **The previous assumption is proven to be wrong** calculating the leading non-perturbative correction to the C parameter in C=0 and C=3/4.

2022 — **Full calculation in the 3-jet limit** for the thrust and the C parameter.

2023





NON TRIVIAL SHAPE!

[Caola, Ferrario Ravasio, Limatola, Melnikov, Nason 2108.08897; +Ozcelik 2204.02247]

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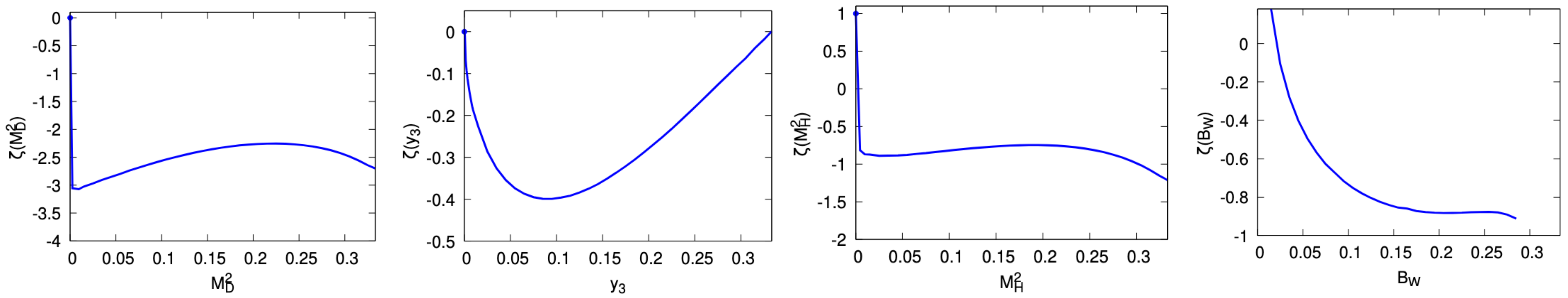
2023 — **Extension of the calculation to other event shapes, confirming the previous results.**



[Nason, Zanderighi 2301.03607]

THE DOKSHITZER-WEBBER MODEL

[Dokshitzer, Webber hep-ph/9504219]

HADRONIZATION ≡ emission of soft $k_T \sim \Lambda$ non-perturbative gluon (= "*gluer*")

The divergent behaviour of the running coupling at low scales is cured by an effective coupling that is finite:

Intrinsic ambiguity of pQCD
"renormalons picture"

$$\int_0^Q \mathrm{d}k\, \alpha_s(k) = \int_0^{\mu_I} \mathrm{d}k\, \alpha_s(k) + \int_{\mu_I}^Q \mathrm{d}k\, \alpha_s(k) \longrightarrow \mu_I\, \bar{\alpha}_0(\mu_I) + \int_{\mu_I}^Q \mathrm{d}k\, \alpha_s(k)$$

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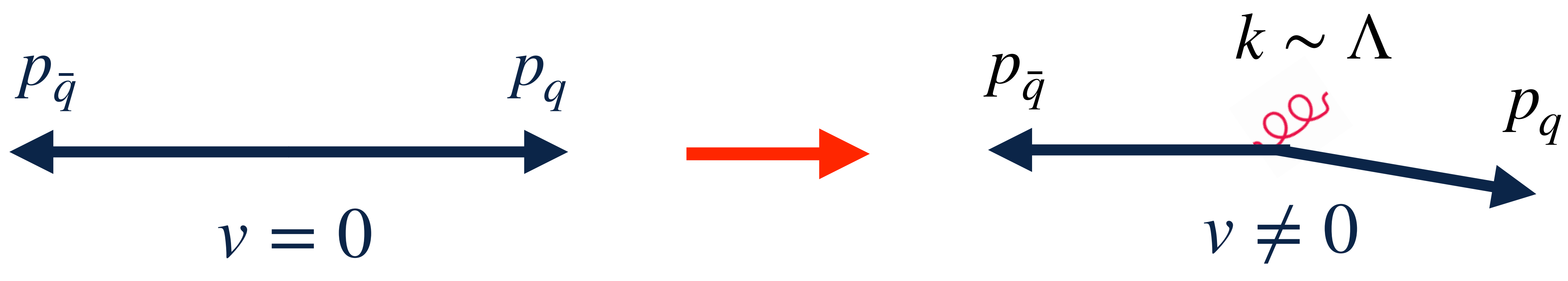

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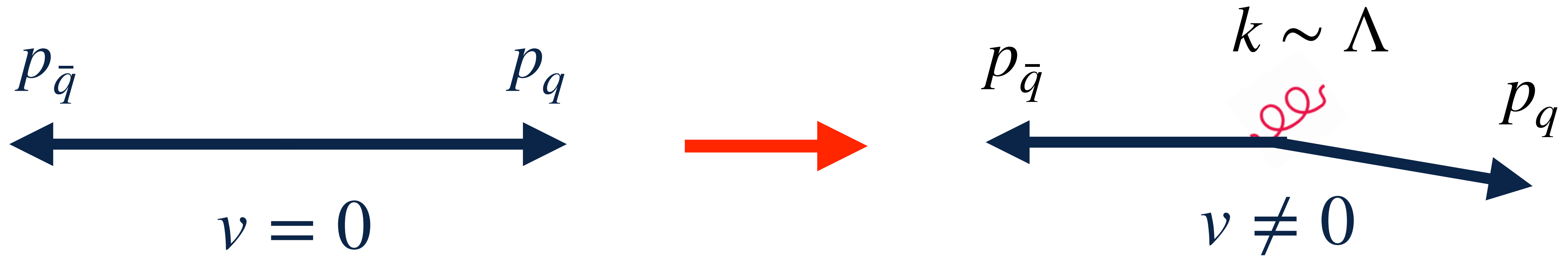

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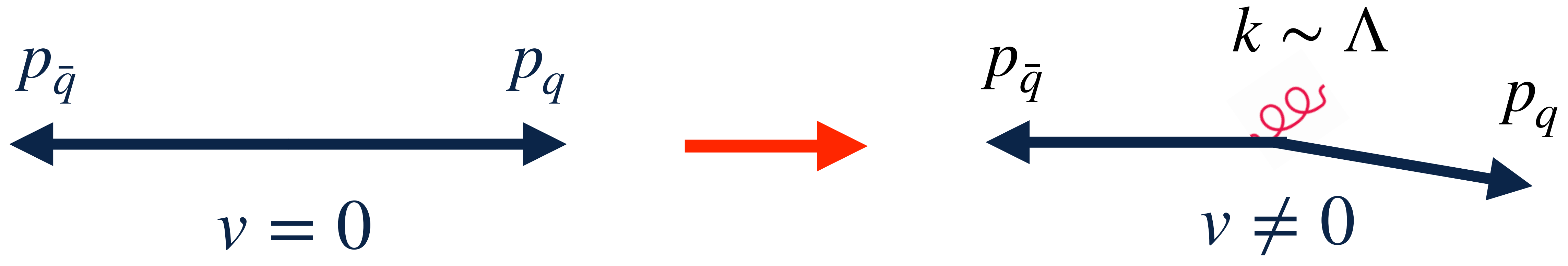

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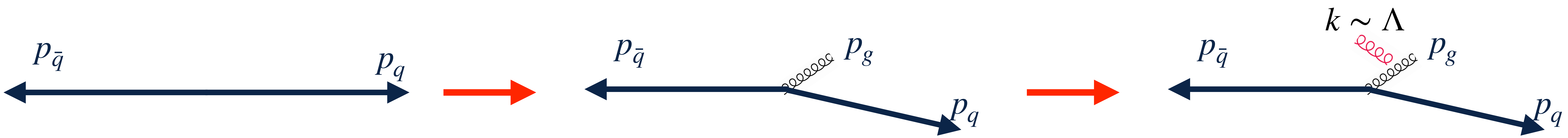
3 Average this shift over the gluer emission probability: $\langle \delta v \rangle^{NP} = \dfrac{1}{\sigma}\displaystyle\int d\Gamma \mathcal{M}^2 \delta v$

PERTURBATIVE EVOLUTION IN Q

[Dasgupta, Hounat 2411.16867]

We start with a $q\bar{q}$ system dressed with a soft perturbative gluon, and then we proceed as in the previous slide.



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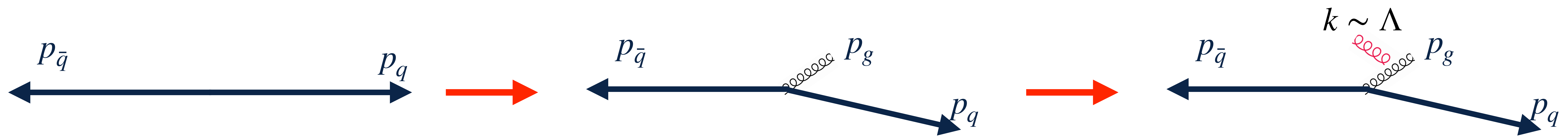

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- **Soft-enhanced gluon**
- **Strongly-ordered emissions**

Interplay between the soft emission and the gluer leading to **large logarithmic corrections:**

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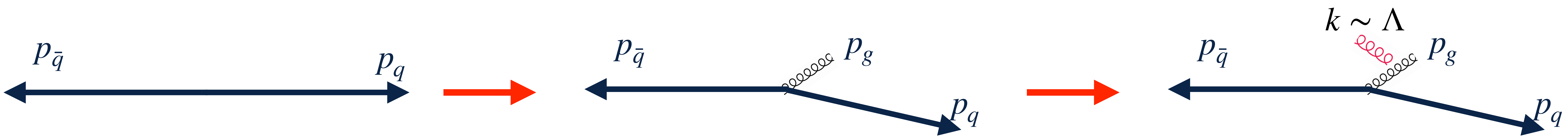

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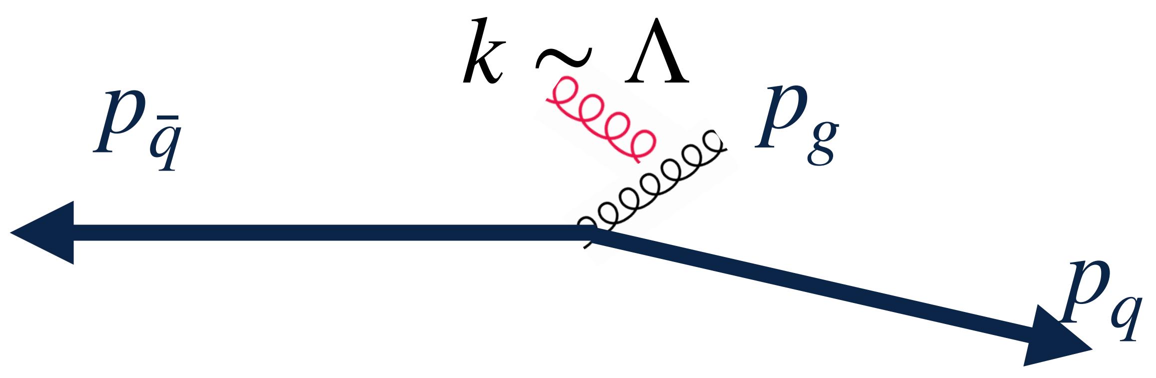
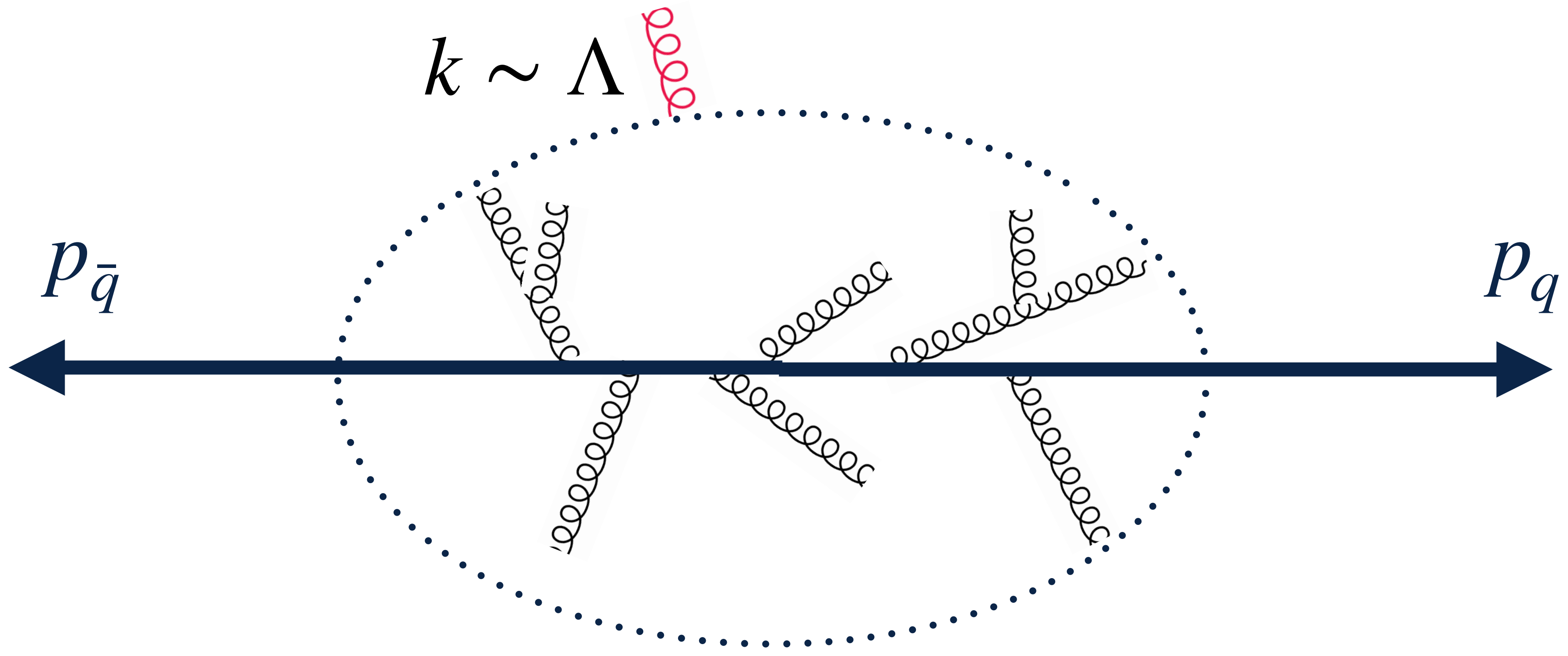
WHAT IF WE ADD MORE EMISSIONS?

RESUMMATION OF THE ANOMALOUS DIMENSION



$$\frac{\Lambda}{Q} \cdot \alpha_s \ln \frac{Q}{\Lambda}$$

$Q \gg k_{T,1} \gg k_{T,2} \gg \ldots \gg \Lambda$



$$\frac{\Lambda}{Q} \cdot \left(\alpha_s \ln \frac{Q}{\Lambda}\right)^n$$

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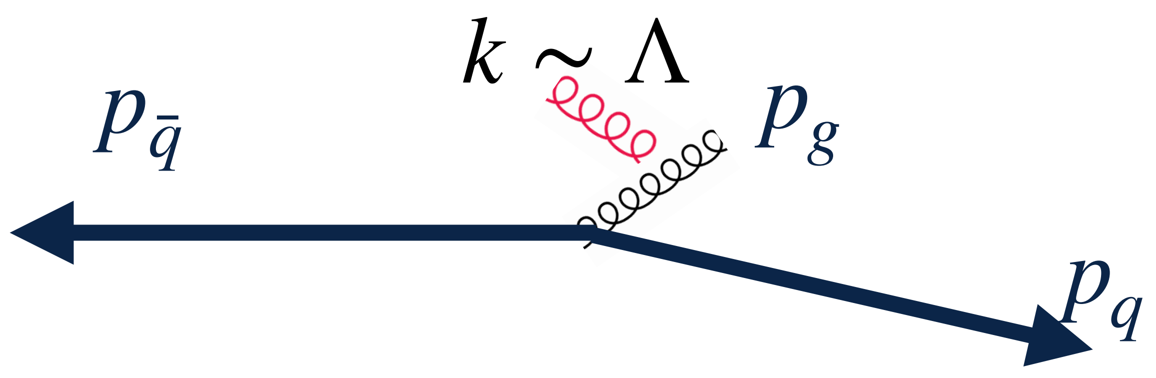

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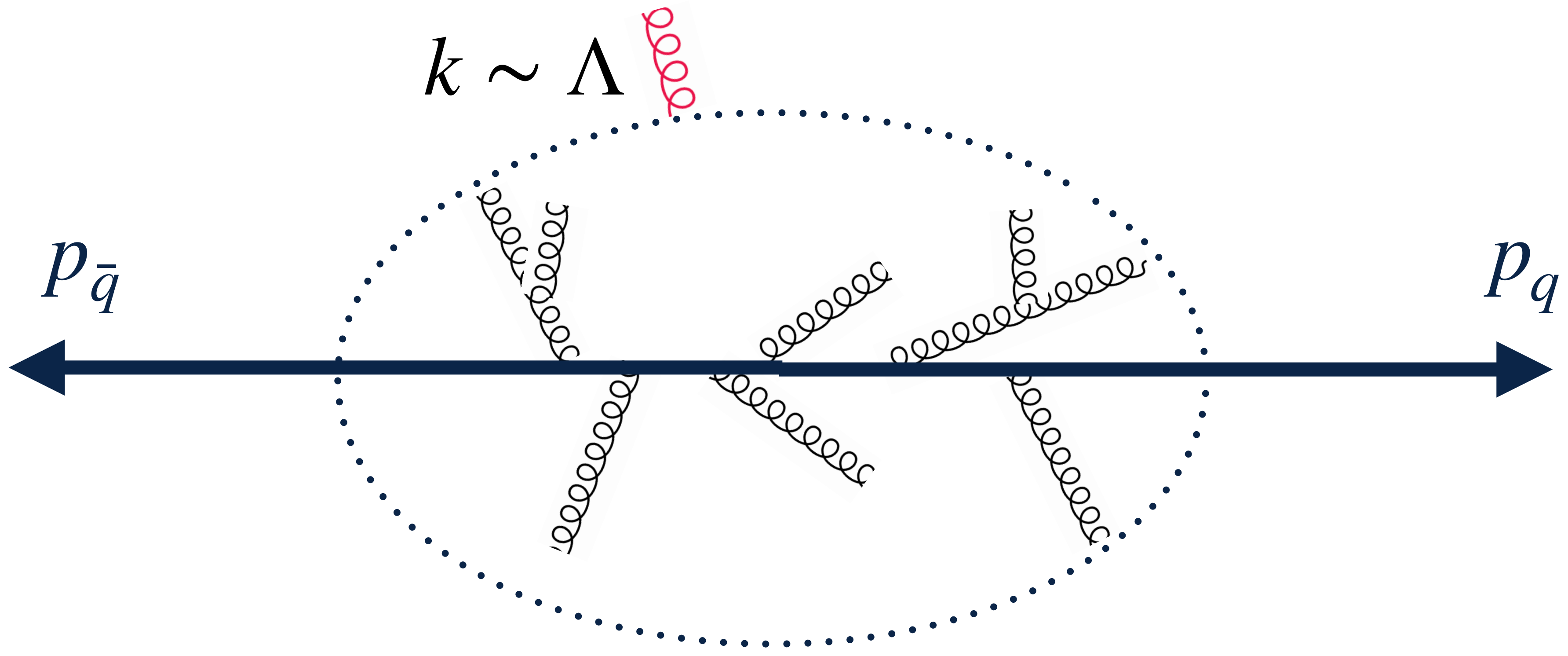

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NON-GLOBAL RESUMMATION

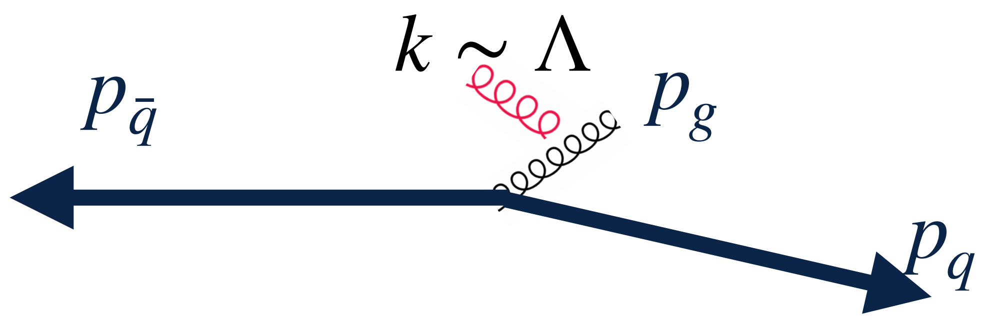
OUR PLAN: resum this contribution to all orders using PanScales showers.

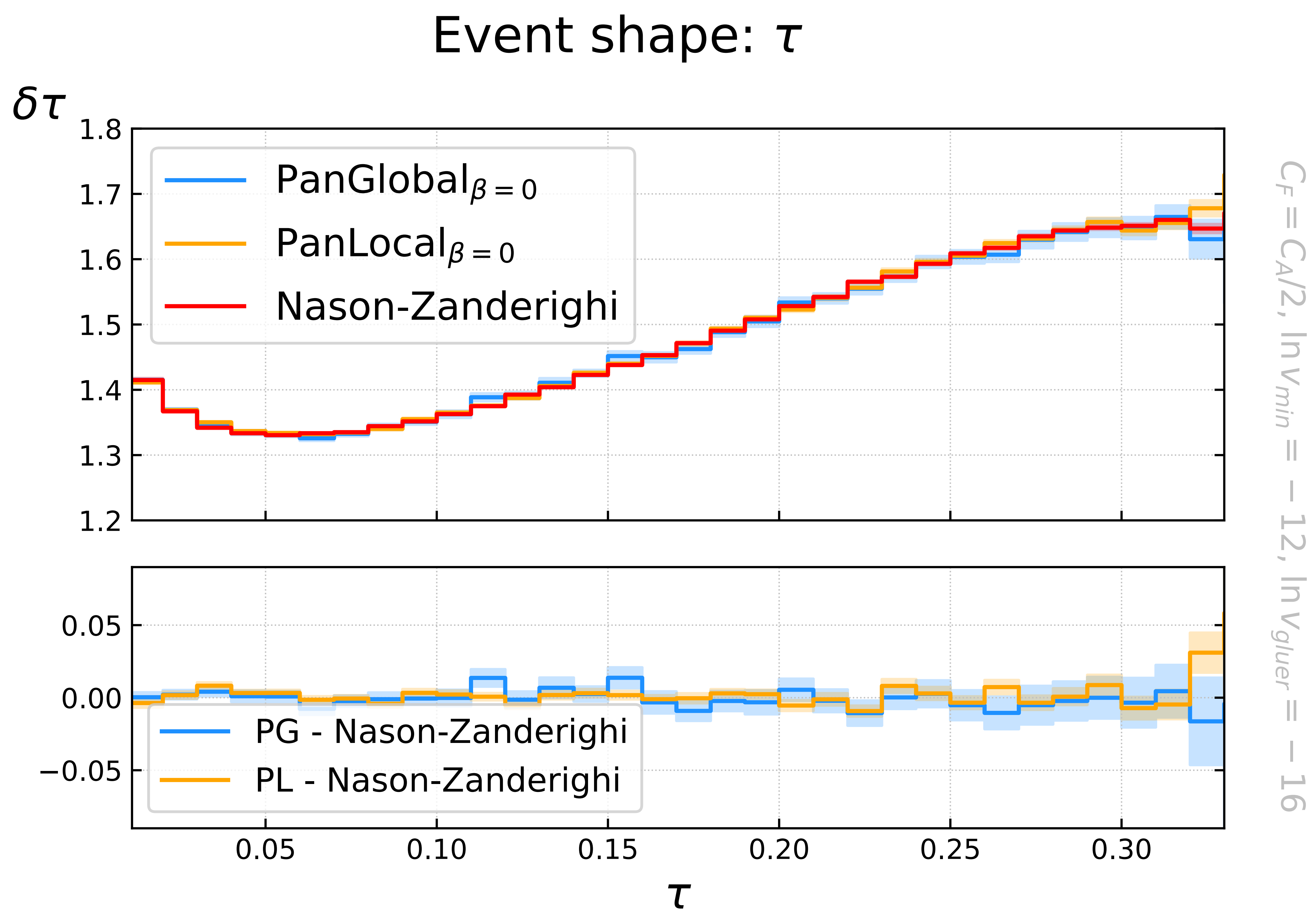
Note: PanScales mappings are consistent with the smoothness criteria pointed out in [2108.08897; 2204.02247]

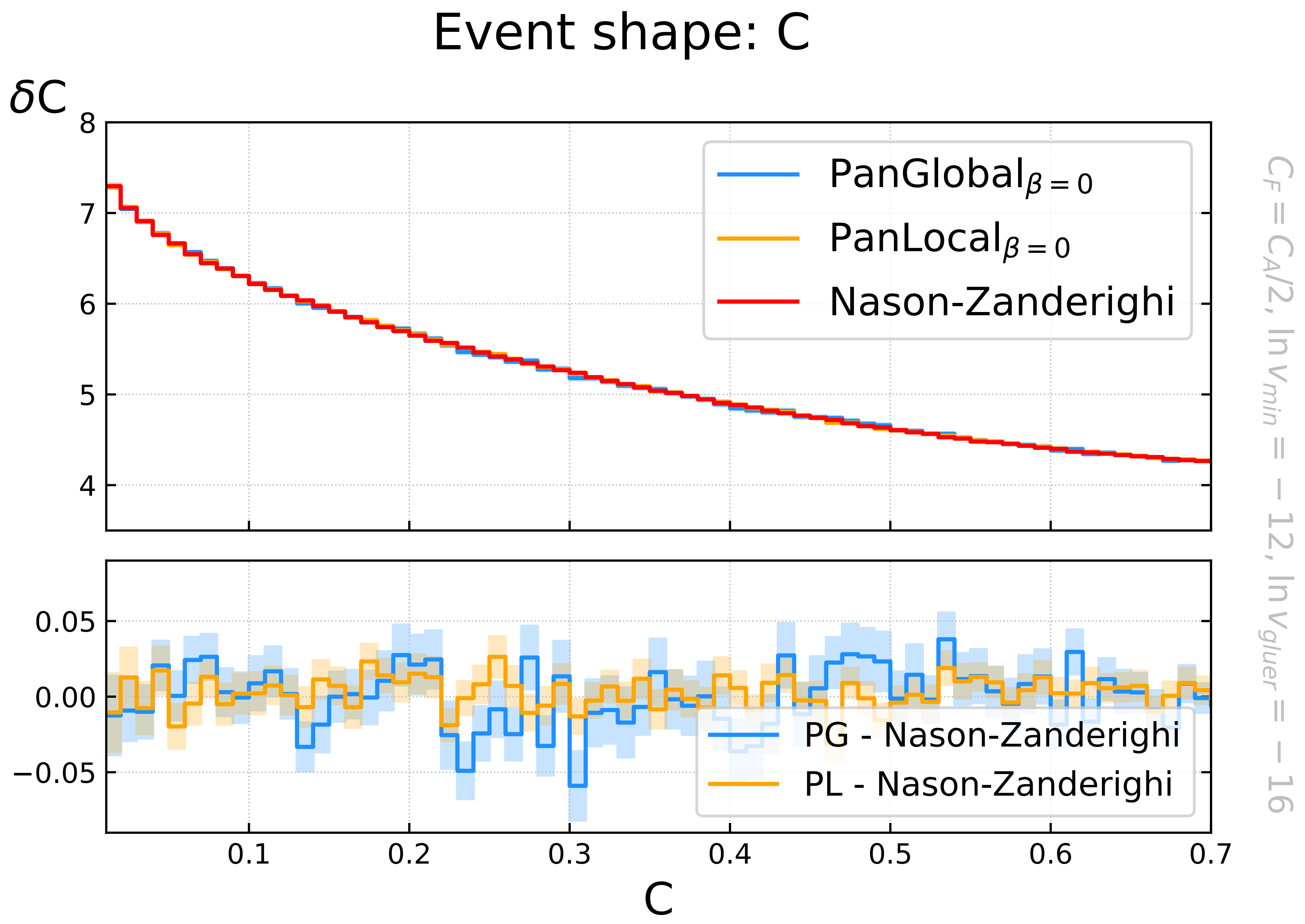
VALIDATION OF OUR METHOD (1)

COMPARISON TO NASON-ZANDERIGHI, 3-jet

We reproduce the non-perturbative shift in event shapes generating a 3-jet configuration and adding subsequently a gluer.







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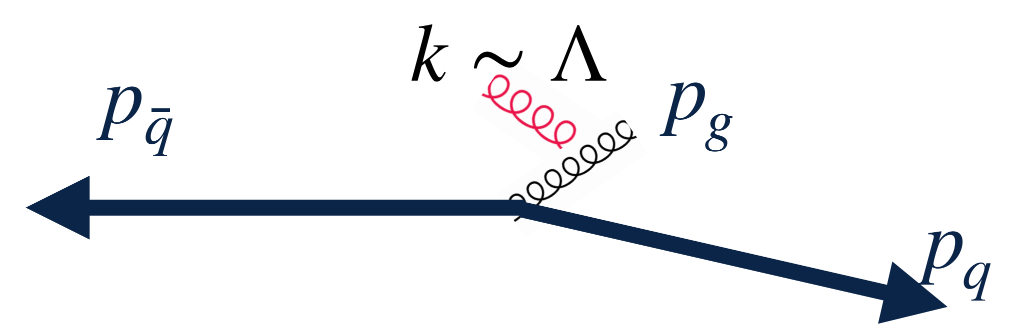

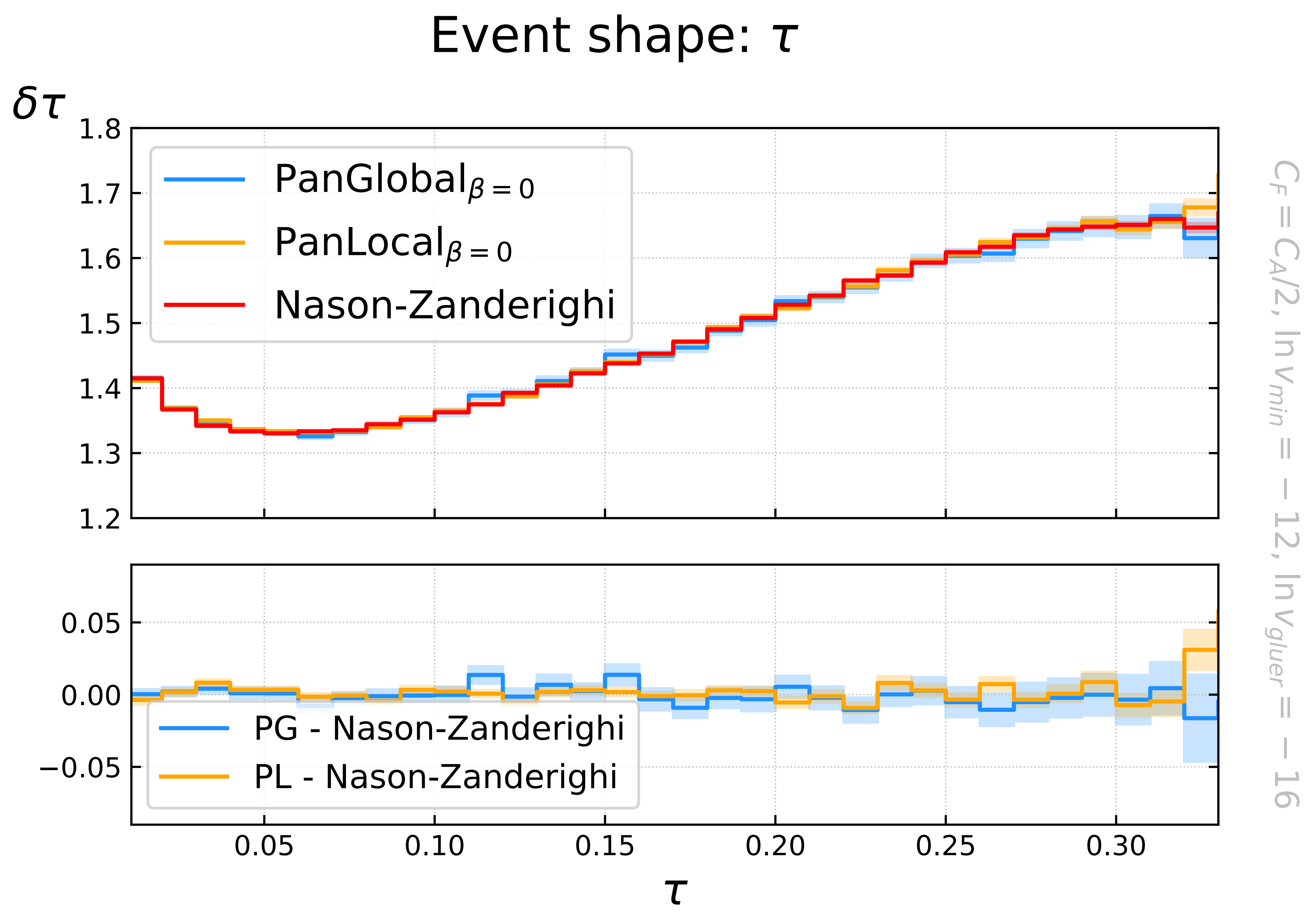

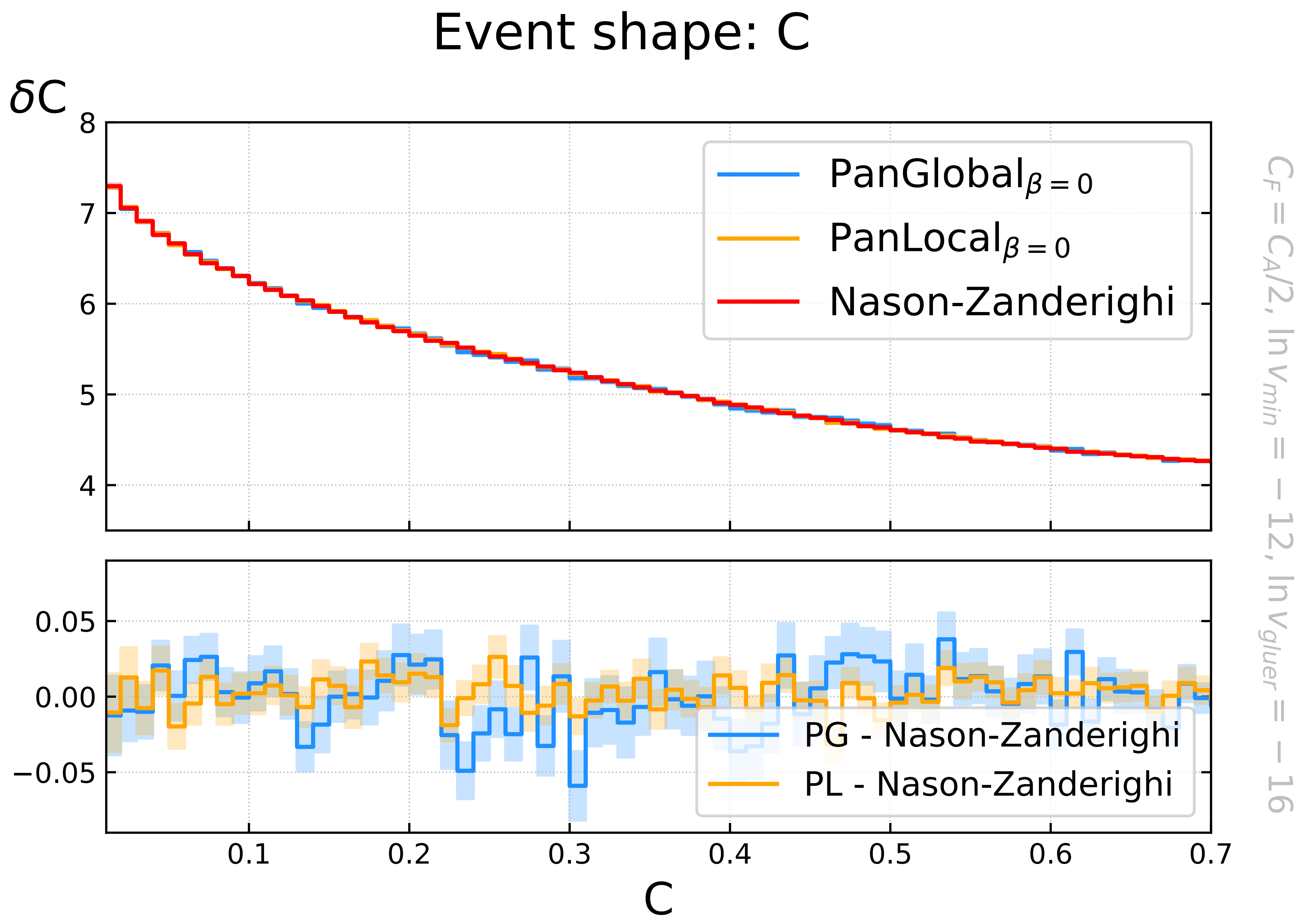

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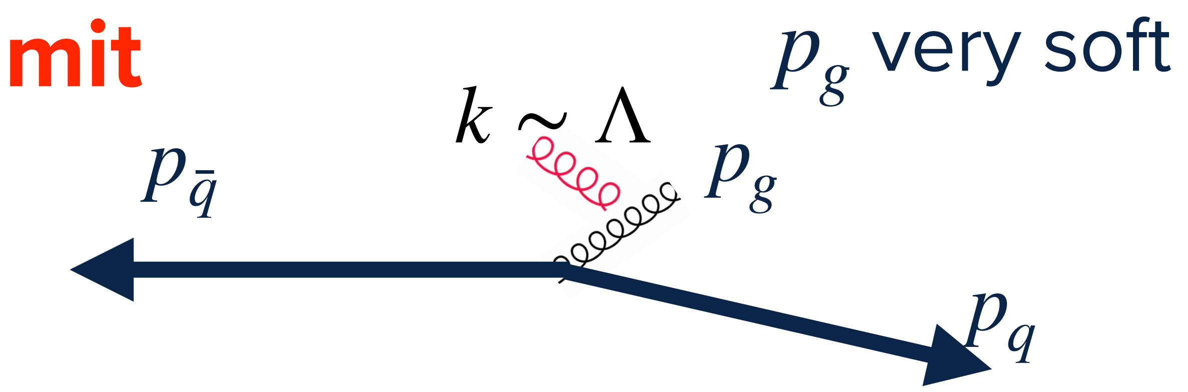
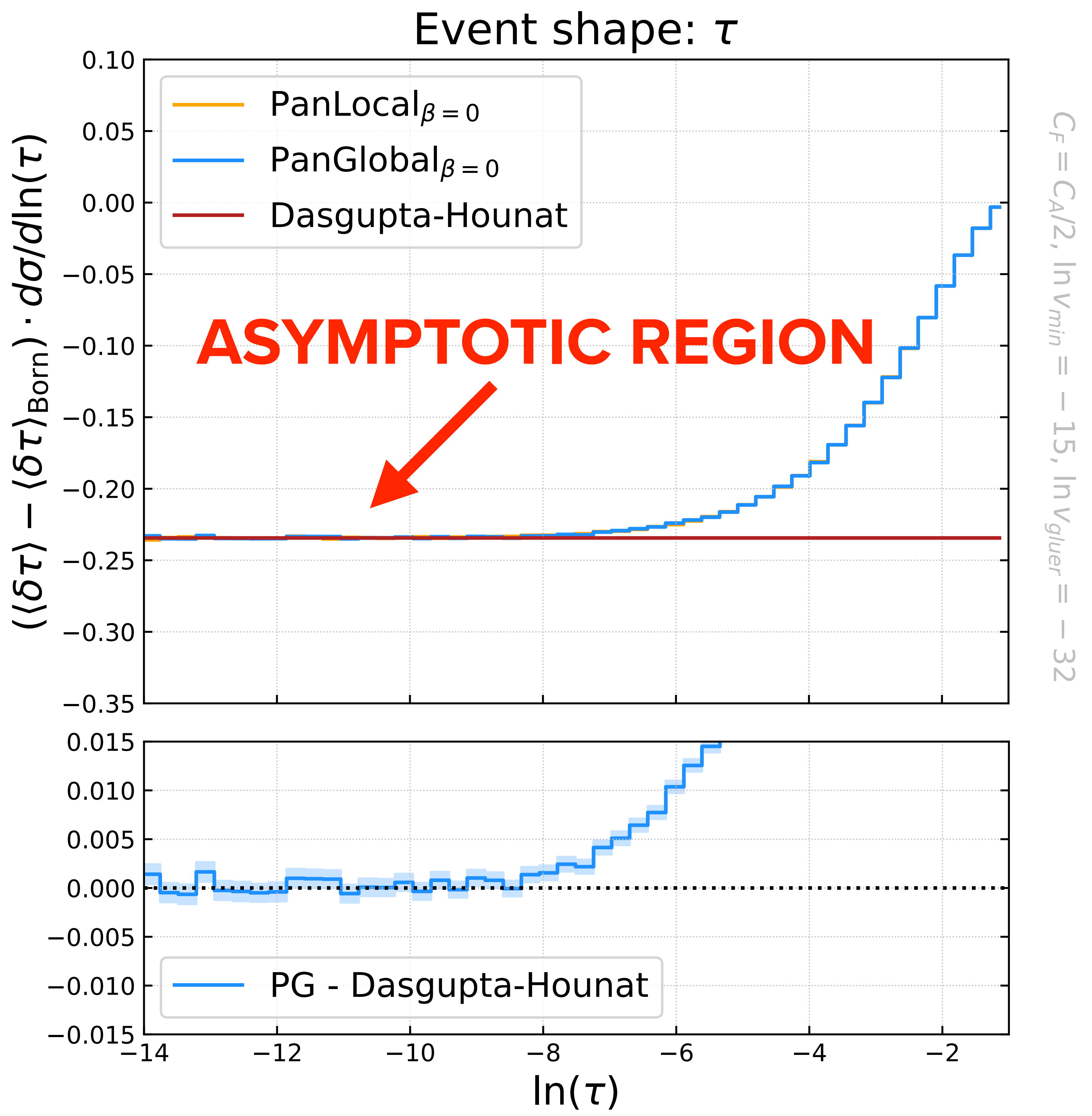
✔ Good agreement - same conclusions hold for y23, broadening and heavy-jet mass.

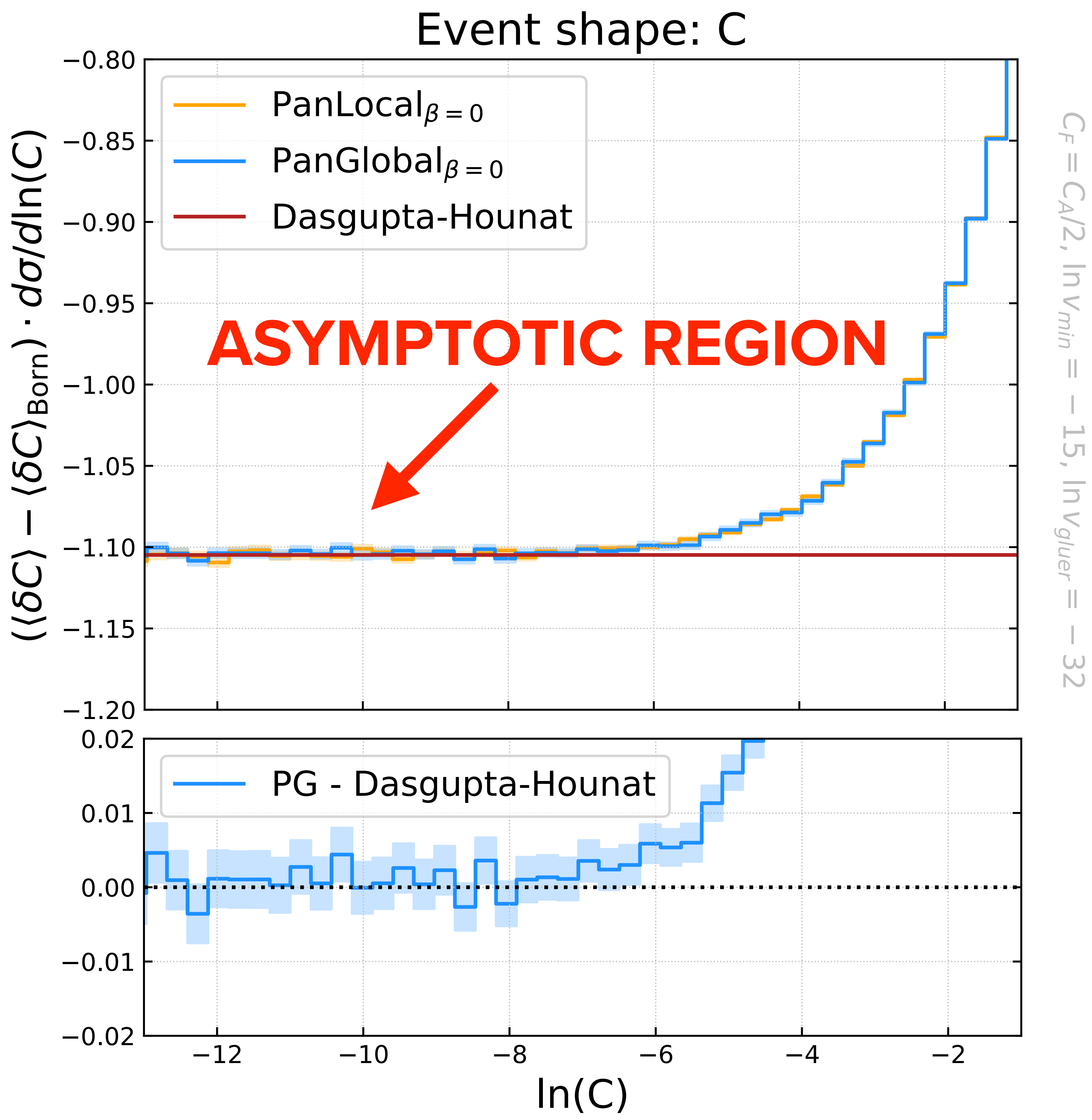
VALIDATION OF OUR METHOD (2)

COMPARISON TO DASGUPTA-HOUNAT, 3-jet in asymptotic limit



We obtain the coefficient of the first $\alpha_s \ln(Q/\Lambda)$ correction generating a 3-jet configuration in the asymptotic limit, adding subsequently a gluer.





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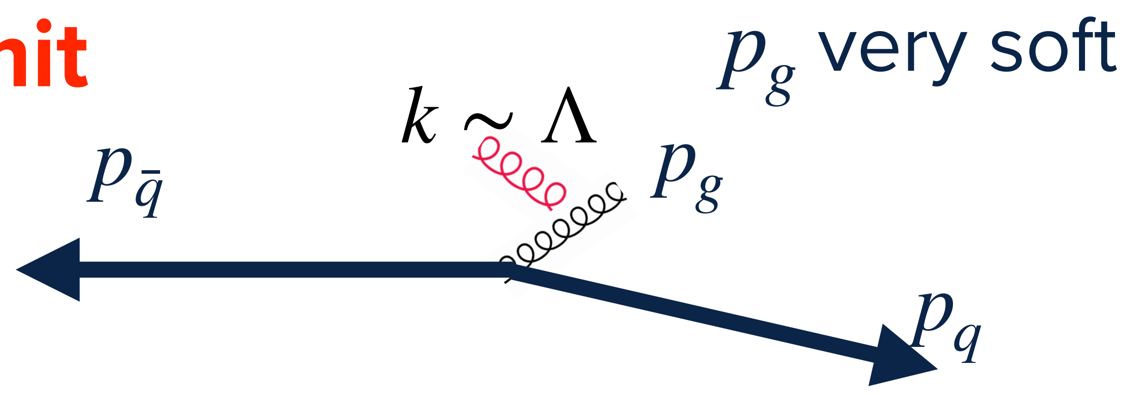

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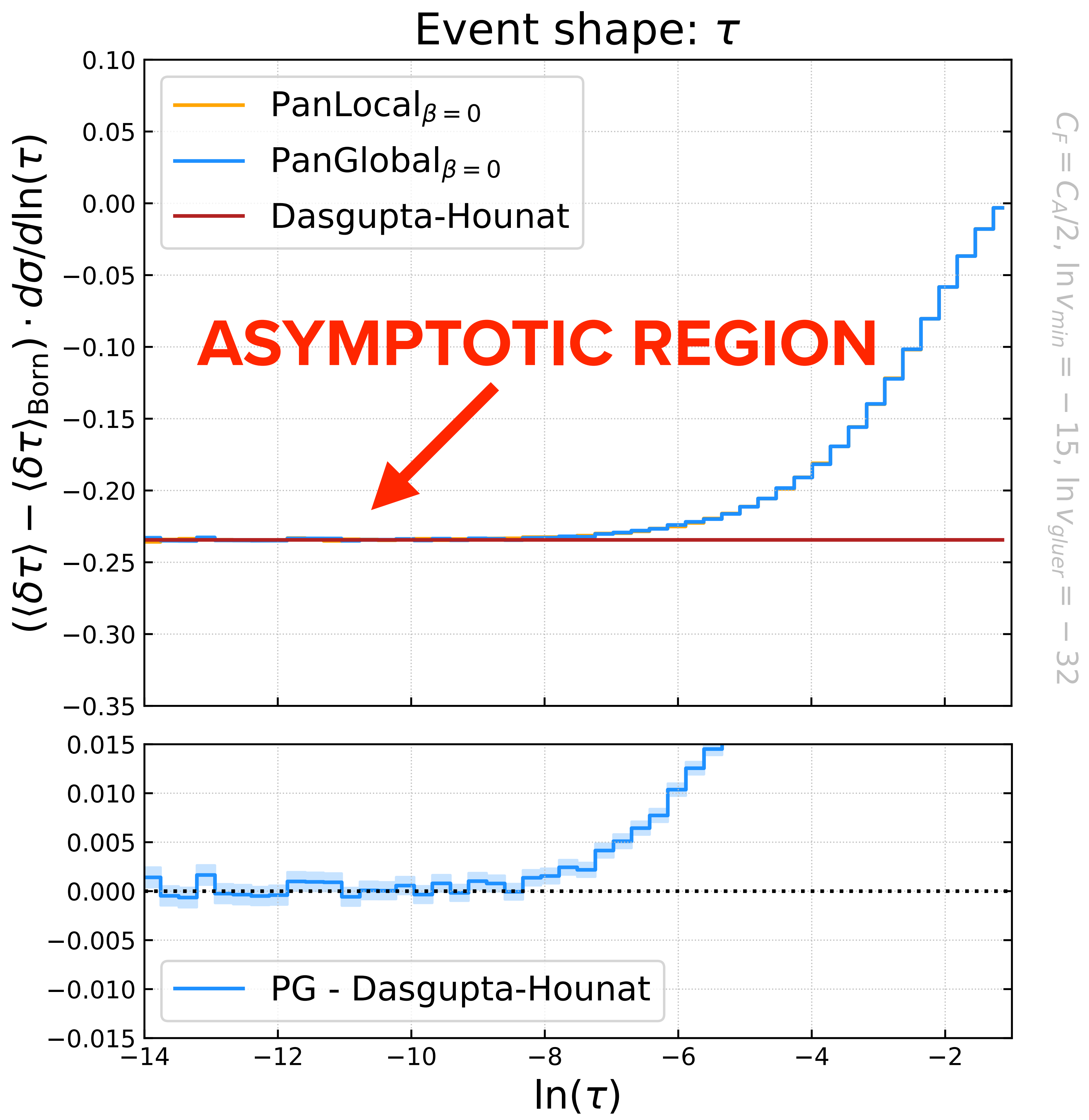
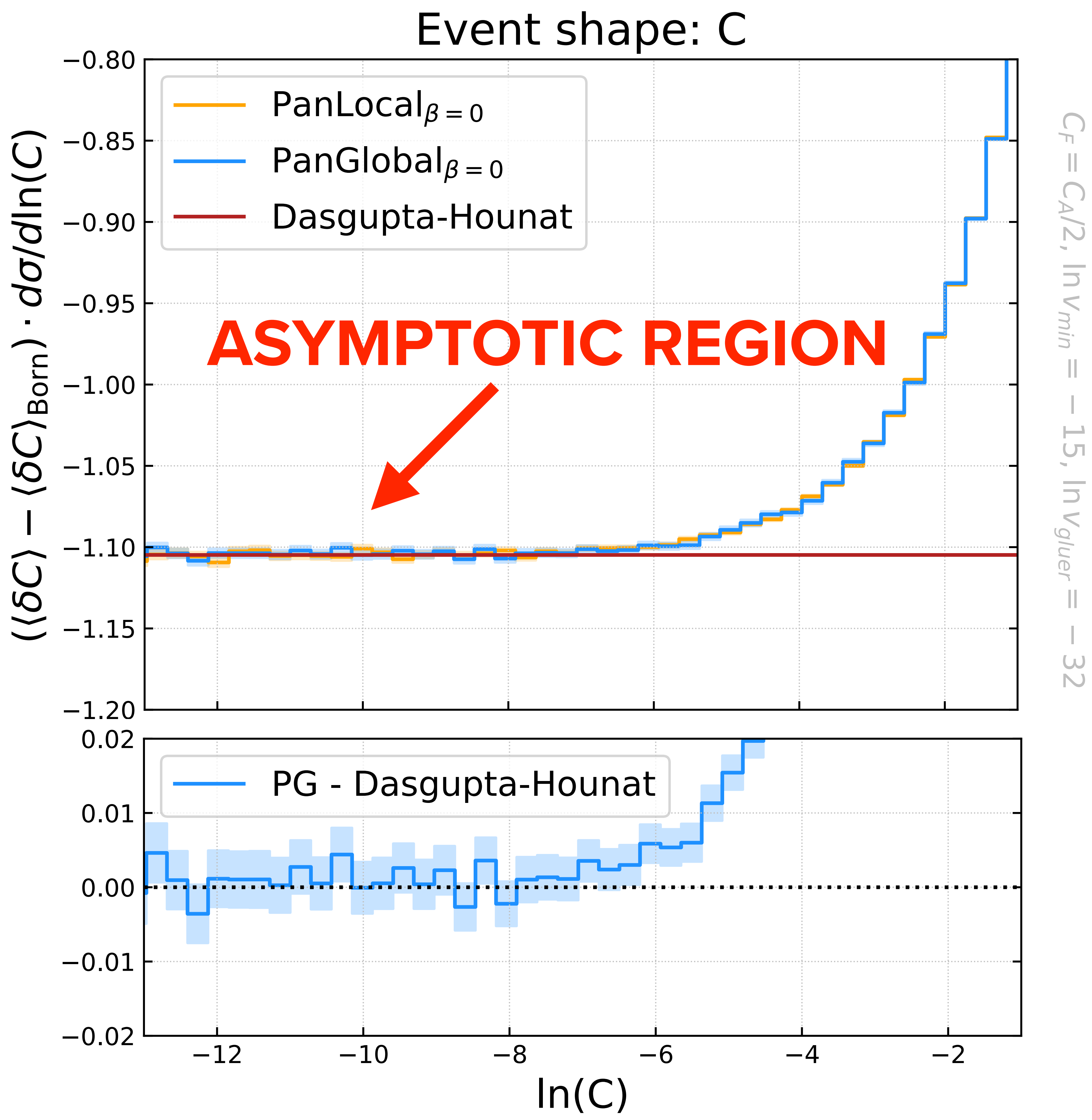
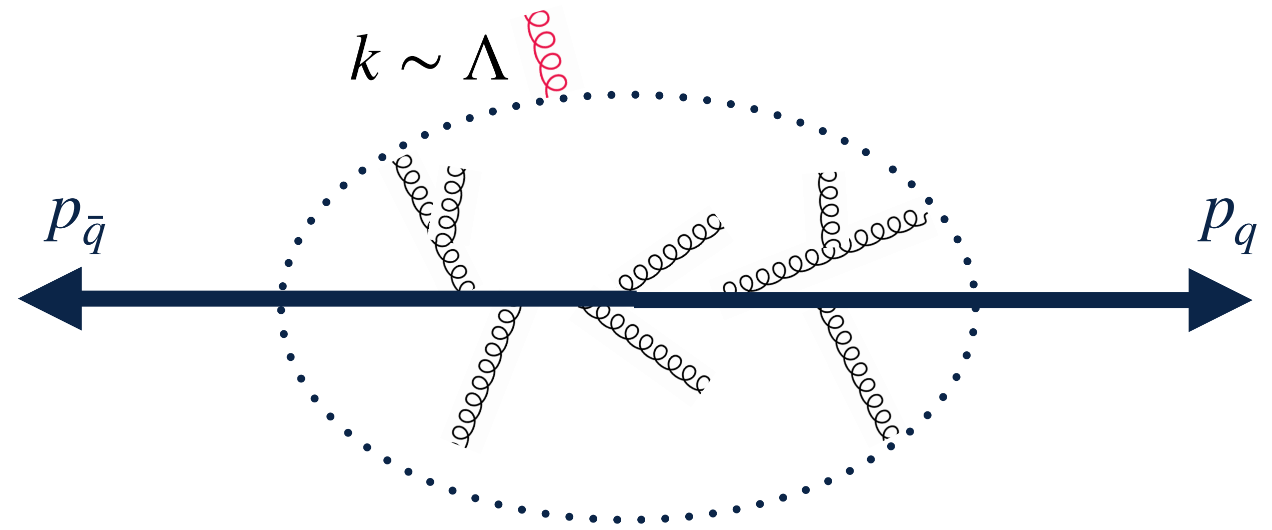


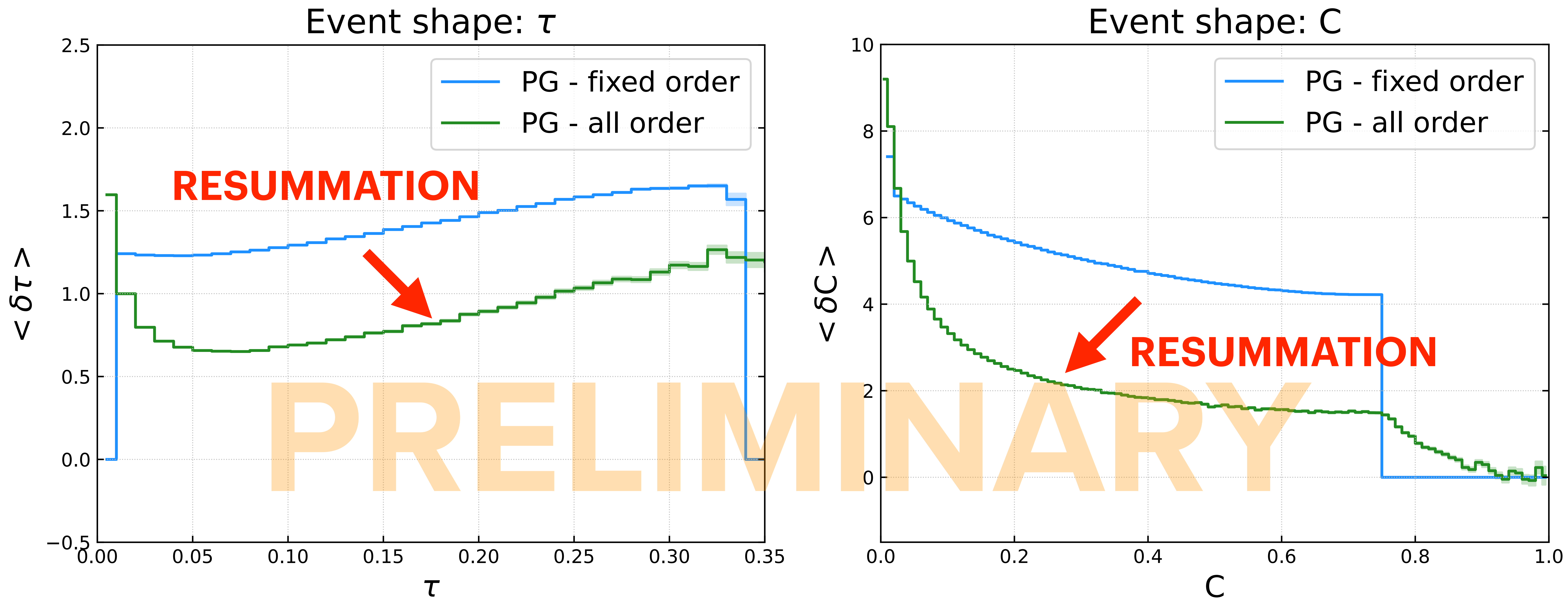


✔ Good agreement. Possibility to predict the same correction for other event shapes.

RESUMMATION OF THE ANOMALOUS DIMENSION

We resum the anomalous dimension to all orders generating an ensemble of p_{T}-ordered emissions, adding subsequently a gluer.





RESUMMATION OF THE ANOMALOUS DIMENSION

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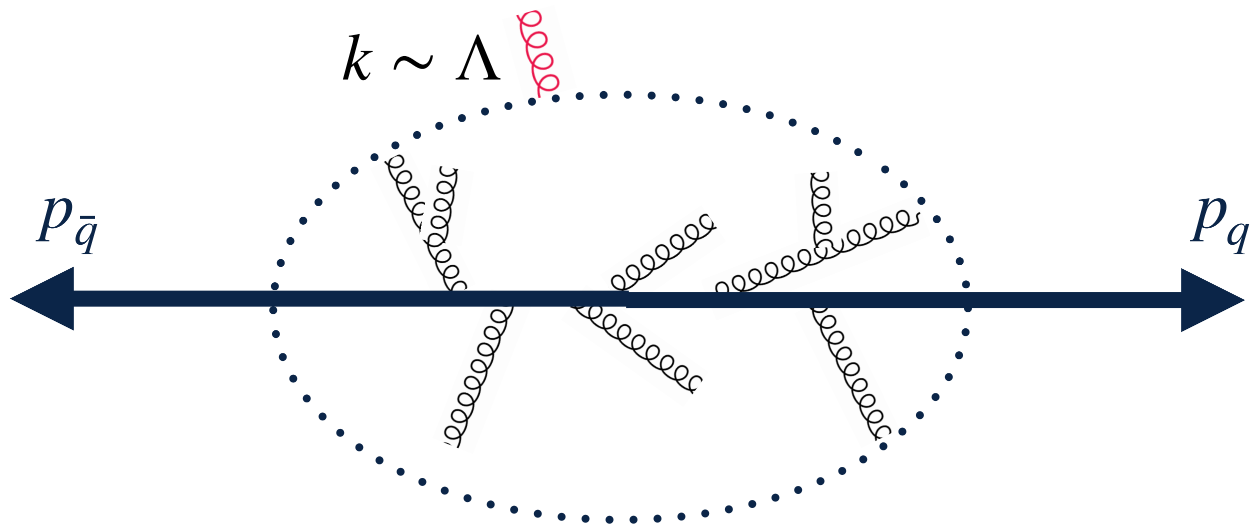
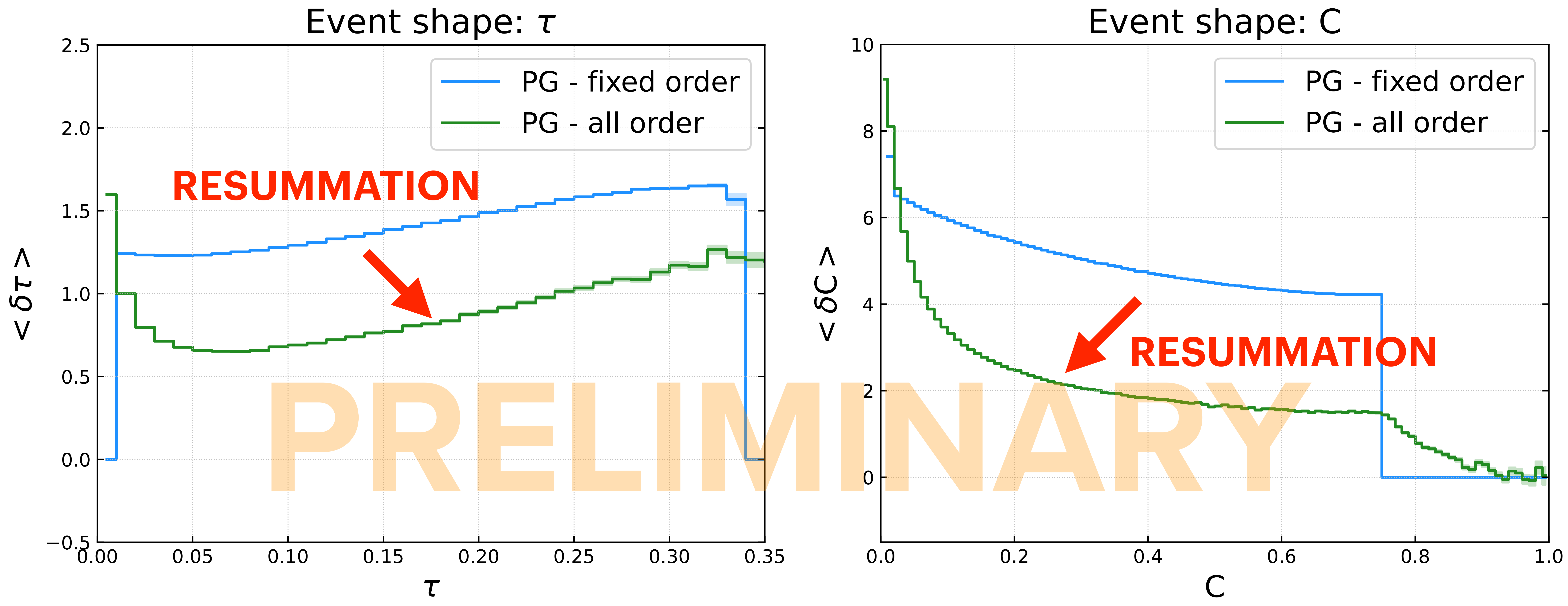




Very large effect that needs to be taken into account for e.g. α_S extrapolation.

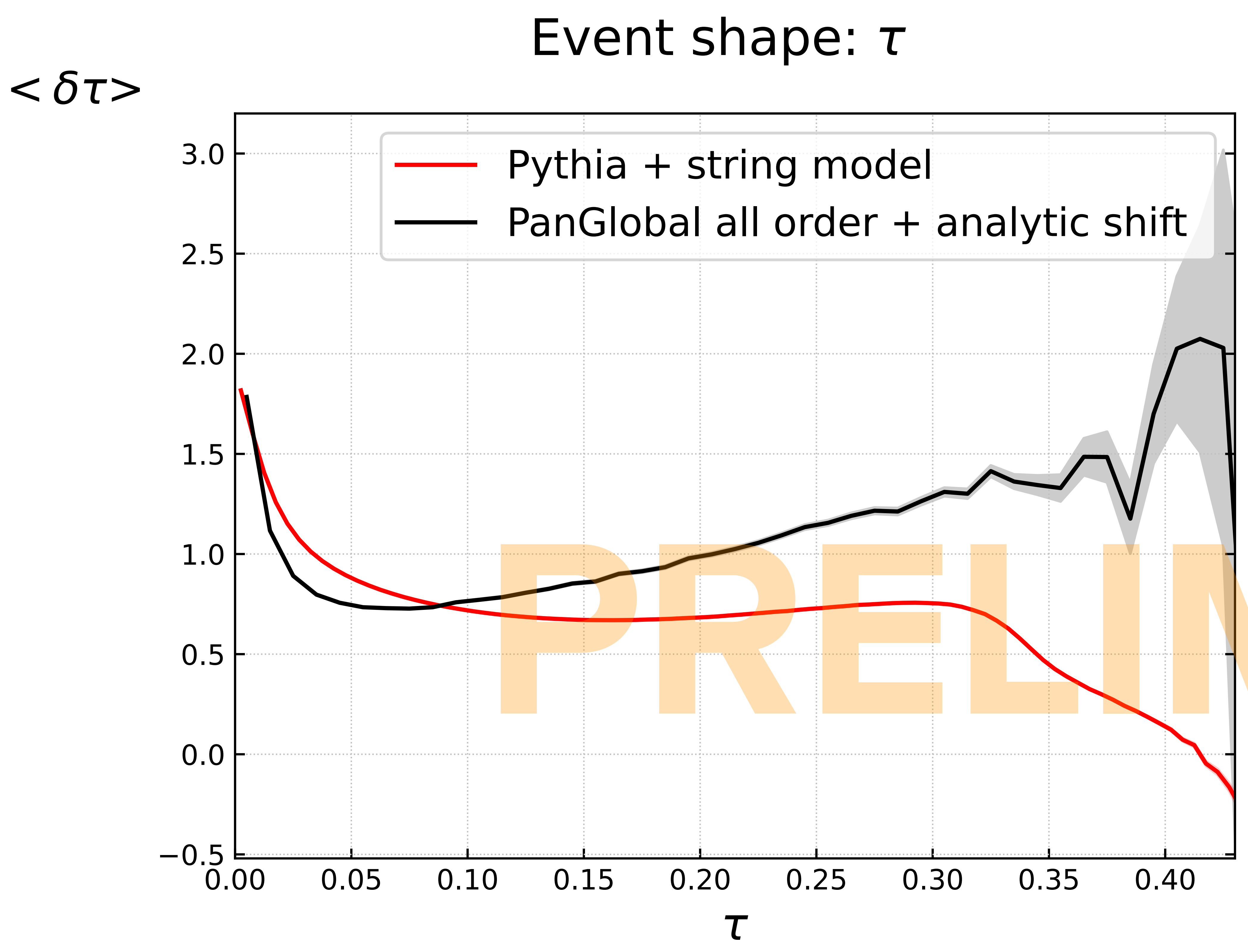
CAN WE LEARN SOMETHING ON HADRONIZATION?

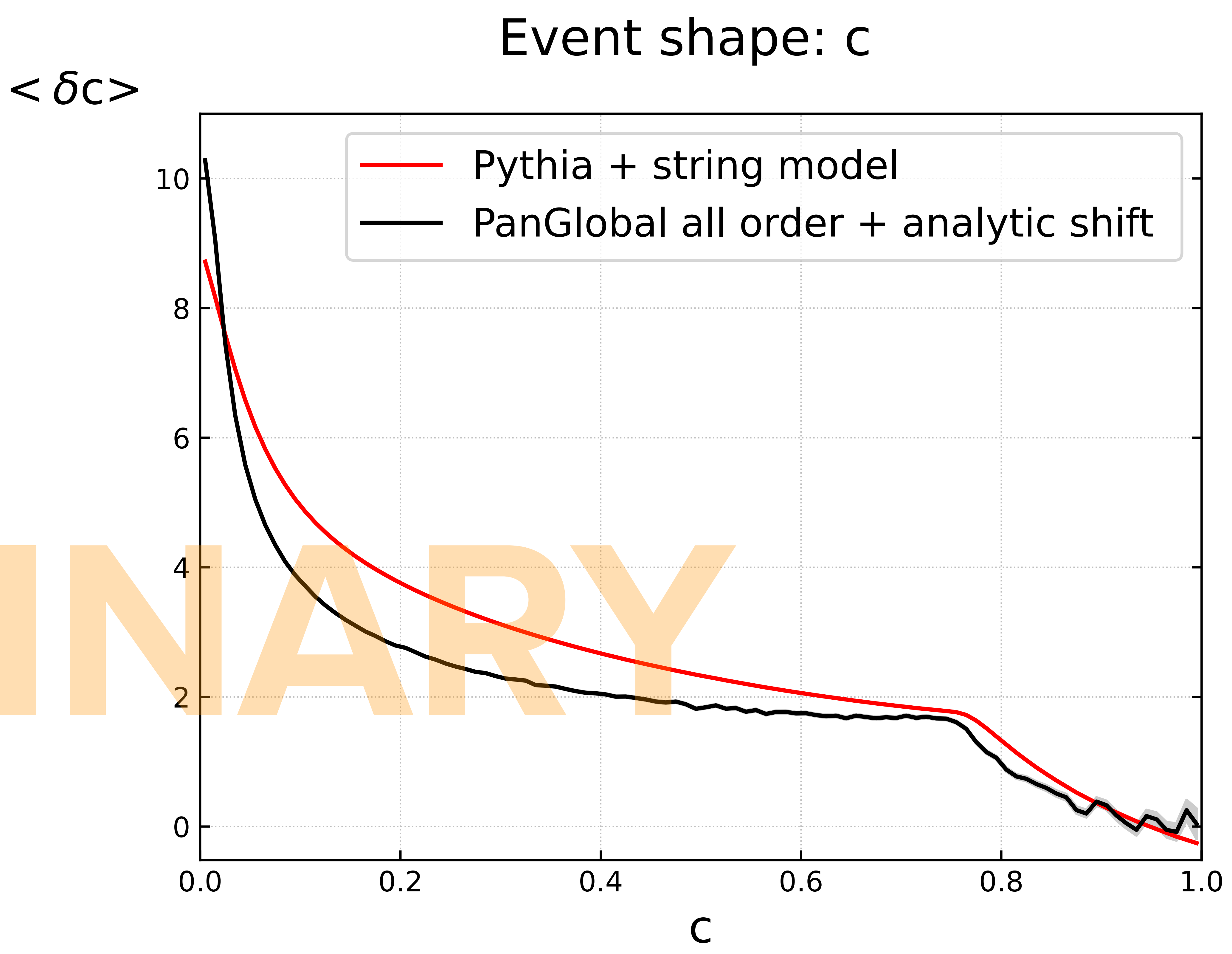
Q: Do usual hadronization models (e.g. string model in PYTHIA) capture this all order effect?

Pythia $\longrightarrow \quad \delta v = v^{\text{hadron}} - v^{\text{parton}}$

PanGlobal $\longrightarrow \quad \delta v = v^{\text{shower+gluer}} - v^{\text{shower}}$

- **Curves normalized to the avegare shift in the thrust.**
- Ambiguities in the treatment of masses (see backup)





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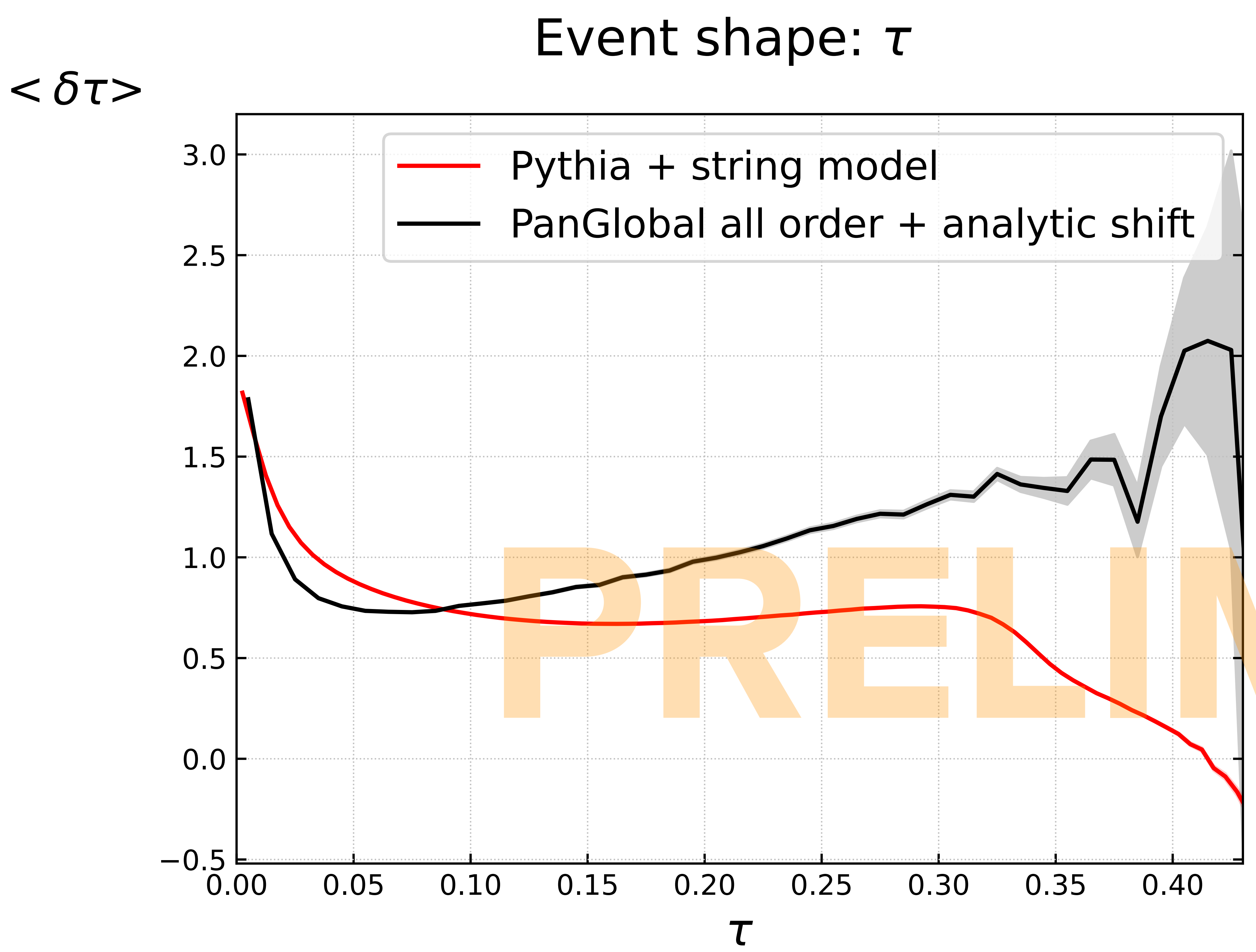

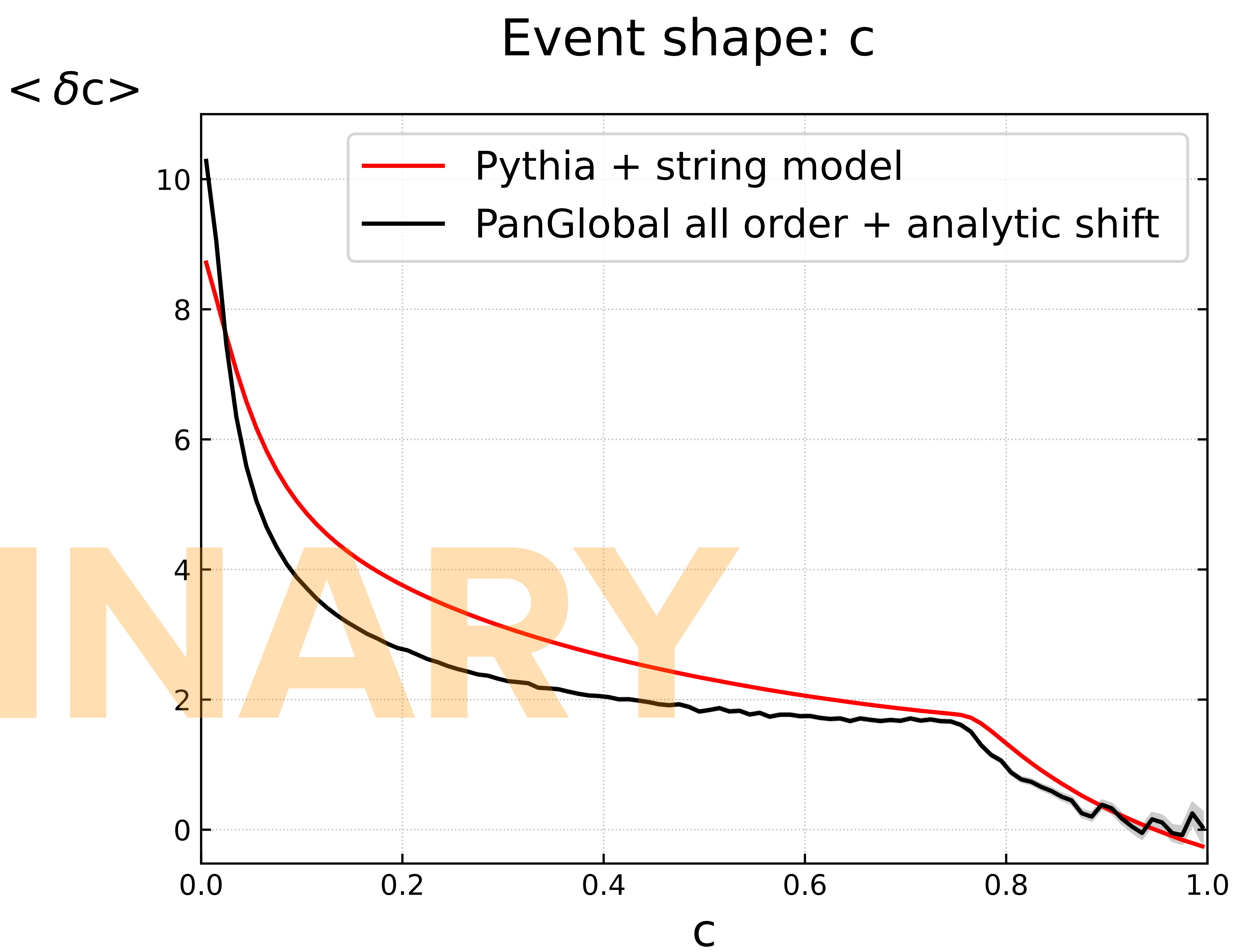

The shape looks consistent for C-parameter, not so clear for the thrust.

CONCLUSIONS

Our understanding of analytic models for the description of hadronization effects has evolved significantly in the past few years, but there is still room for improvements.

- **Analytic models are strongly affected by higher-orders effects.** We are currently working on the inclusion of all order effects from the **resummation of the anomalous dimension** in the DW model.
- We are exploring how we could gain **new directions of insight into the possible behaviour of hadronization.** *
- We plan to analyze the Q dependence of the analytic model presented before, compared to e.g. Pythia.

* Hadronization is fundamental also for the precision physics programme of the LHC: gaining insight into this beyond Herwig/Pythia/Sherpa differences is crucial.

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We ultimately plan to explore the impact of our findings on the fit of α_S.

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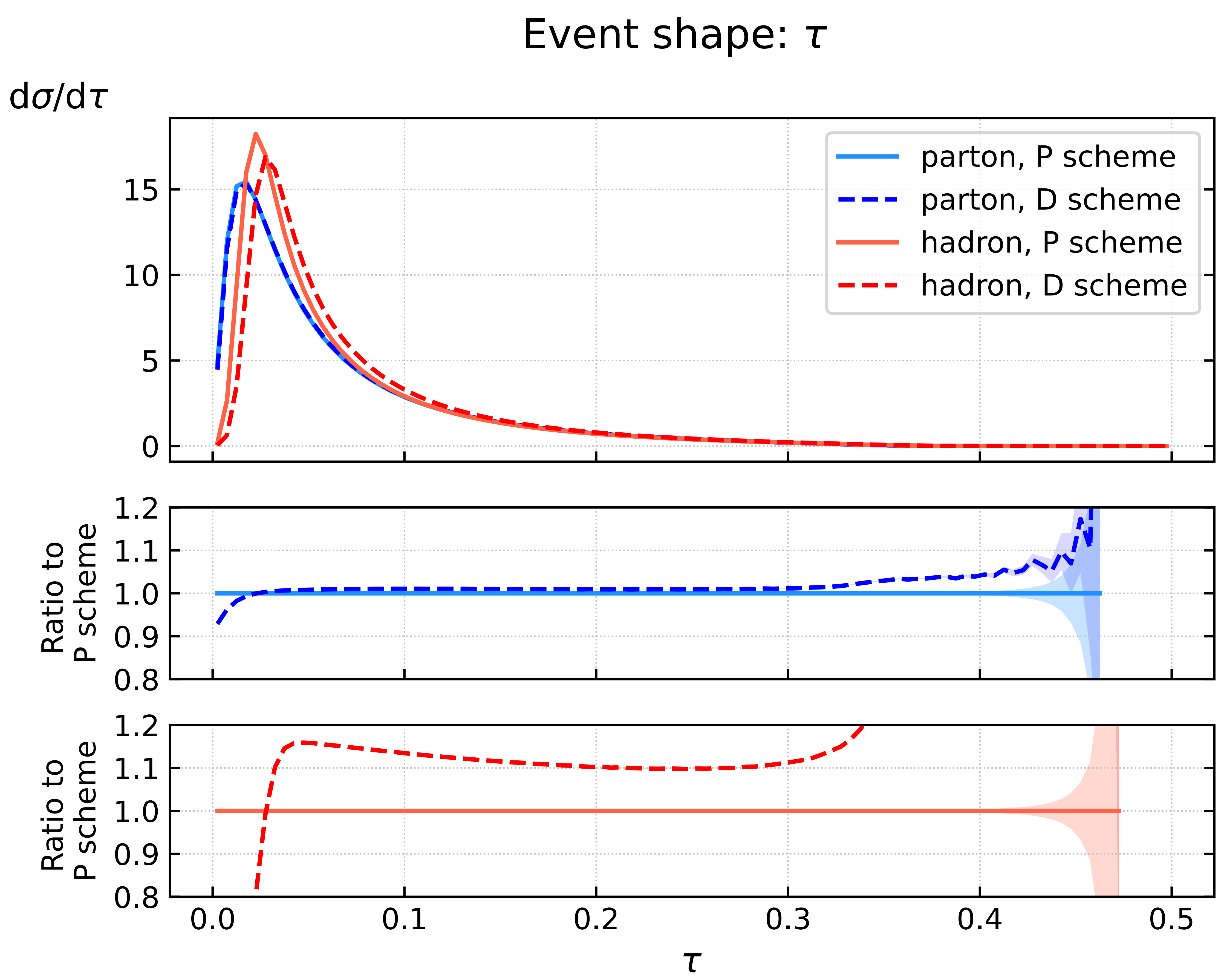
BACKUP

TREATMENT OF MASSES

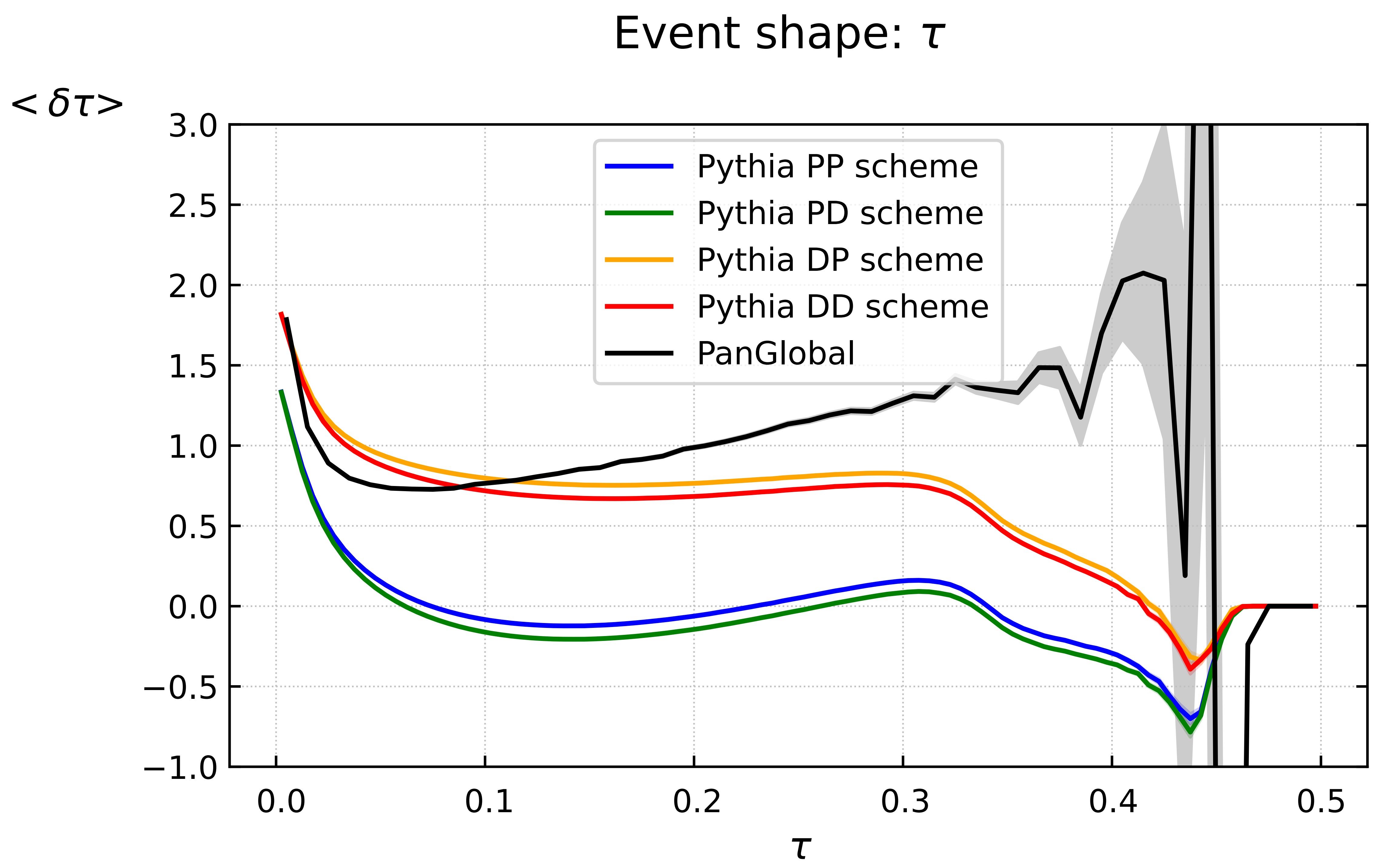
Perturbative calculations assume massless partons, while experimental measurements deal with massive hadrons. In general, the definition of an event shape is different in the two cases.



[Salam, Wicke hep-ph/0102343]

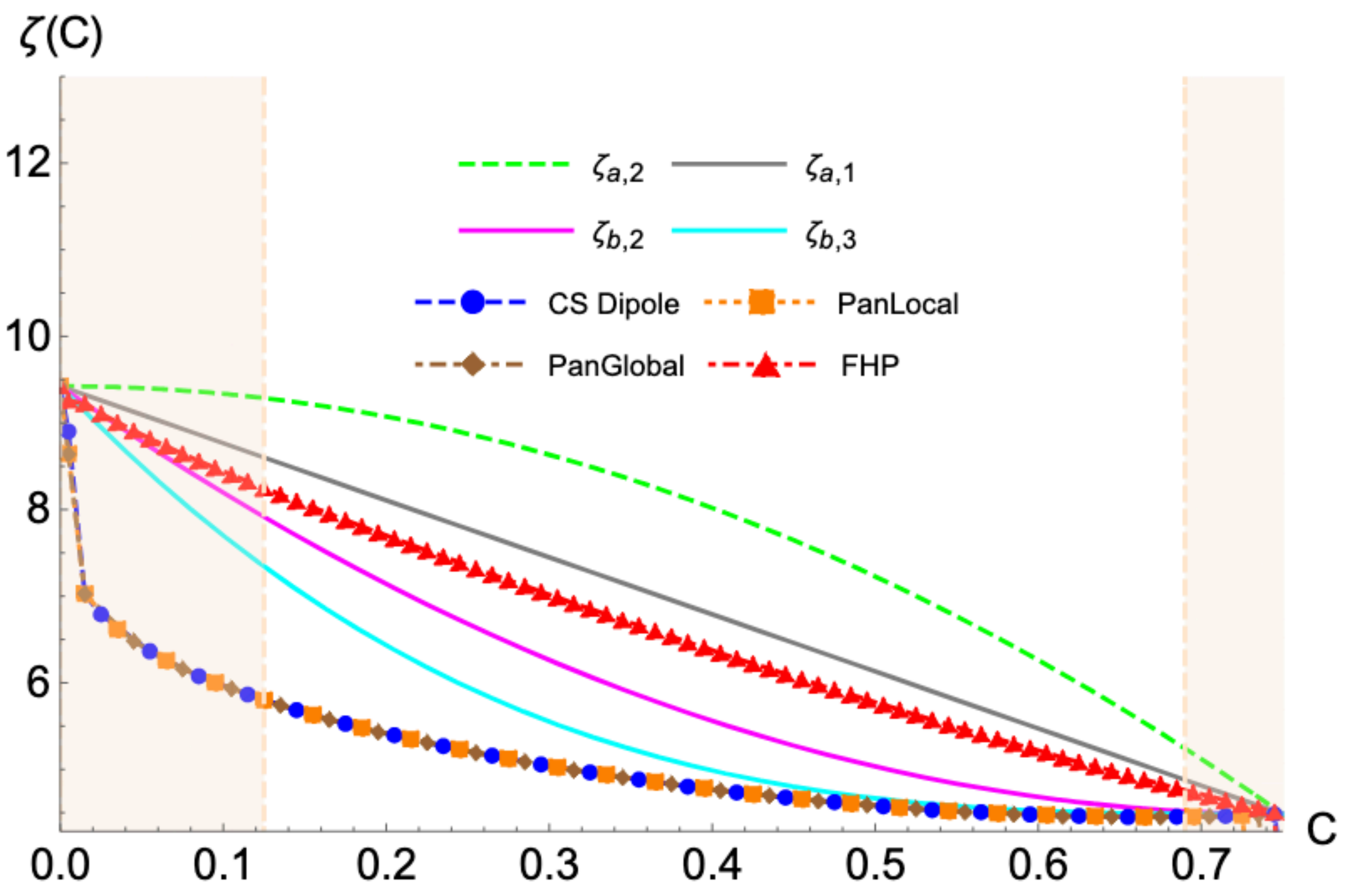
P scheme: $\vec{p}_i \to \vec{p}_i\,, \qquad E_i \to |\vec{p}_i|$

D scheme: massive particles are decayed isotropically into 2 massless partons



IMPACT OF MAPPINGS

The calculation of the non perturbative shift associated to a gluer emission requires a recoil scheme to enforce energy-momentum conservation. What is the impact of this choice on our result?



[Luisoni, Monni, Salam 2012.00622]

Same results for mappings in which the longitudinal recoil is kept local within the dipole

The mappings adopted in this work (PG and PL) satisfy the smoothness requirement in the soft limit that is needed in order for the recoil effects not to contribute to linear power corrections.

[Caola, Ferrario Ravasio, Limatola, Melnikov, Nason 2108.08897; +Ozcelik 2204.02247]