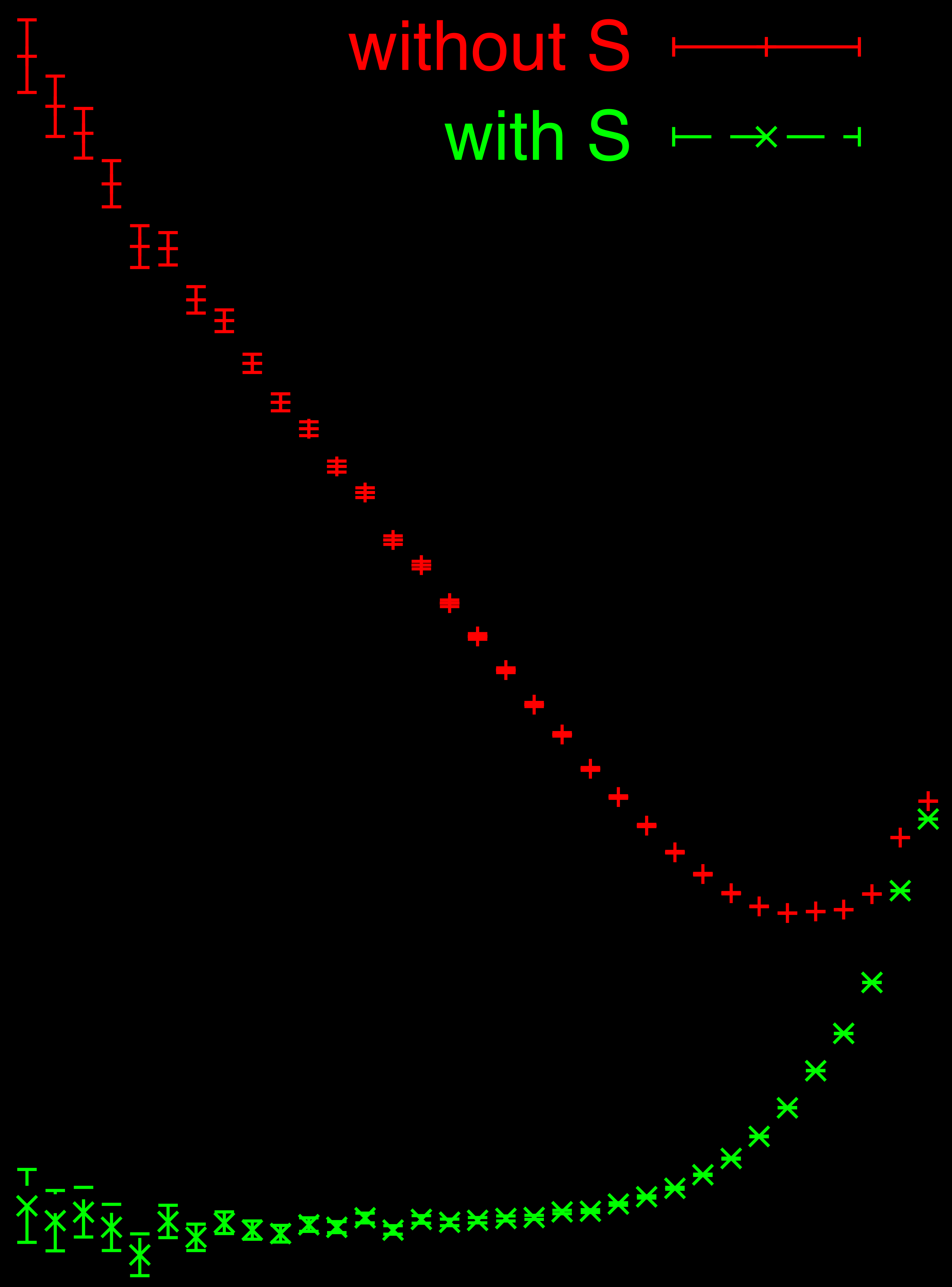
The discovery of non-global logarithms in QCD

Parton Showers and Resummation
9 July 2026
Manchester



Gavin Salam
Rudolf Peierls Centre for Theoretical Physics
& All Souls College, Oxford

UNIVERSITY OF OXFORD

Science and Technology Facilities Council

THE ROYAL SOCIETY

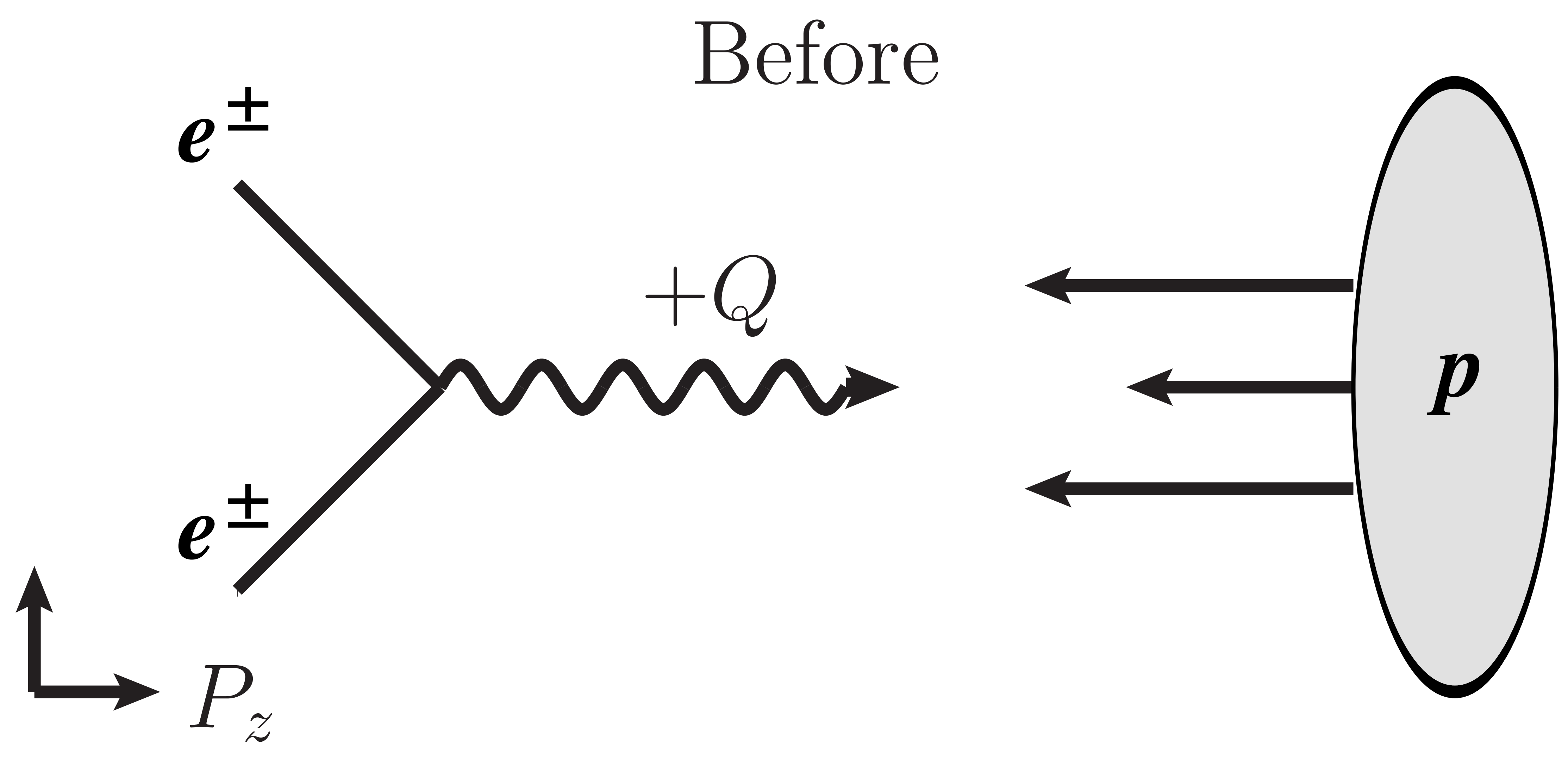
Mrinal Dasgupta and I overlapped as postdocs in Milan (c. 1998-1999)

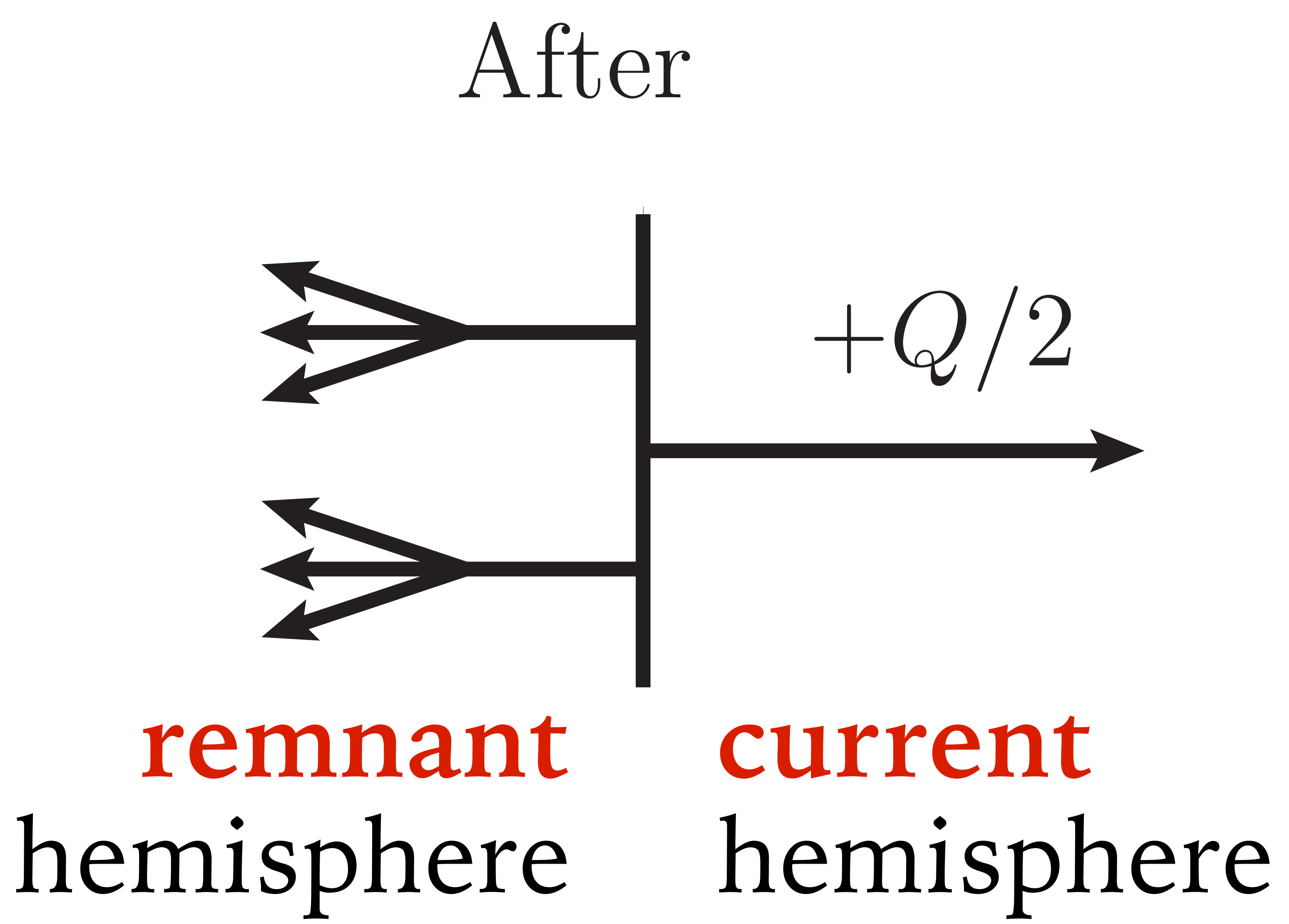
Our senior mentors (Yuri Dokshitzer, Pino Marchesini, Bryan Webber) had suggested we look at resummations of event shapes in DIS

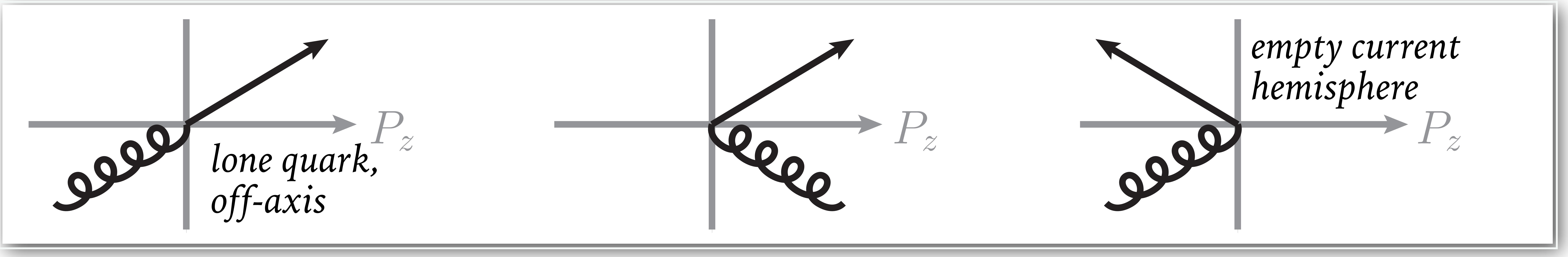
- DIS@HERA had a good lever-arm in Q, so interesting for studying Λ/Q corrections
- e^+e^- event shapes had been done, DIS should be **straightforward** — good project for factorising out to postdocs!

watch out for “straightforward” plans...

DIS Breit frame — event shapes measured in current hemisphere [pictures from 2403.08982 by H1, annotated]

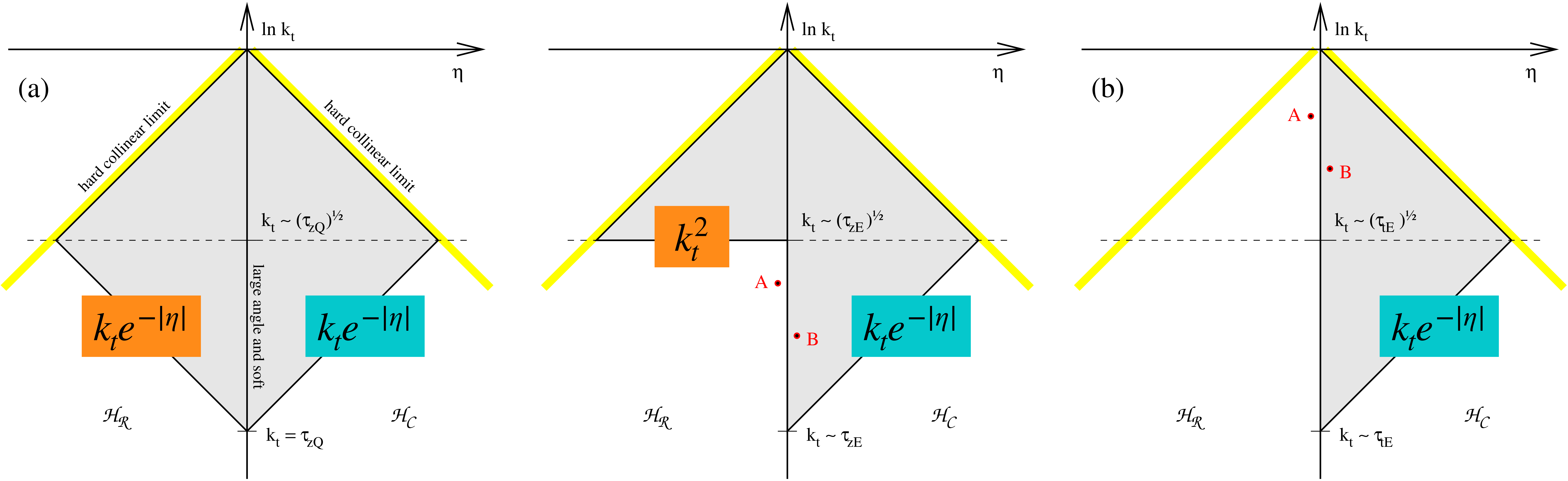






Thrust: three variants

Defined on current hemisphere particles; recoil sensitivity to remnant hemisphere



$$T_Q = \frac{2}{Q} \sum_{a \in \mathcal{H}_C} p_{za}$$

$$T_{zE} = \frac{\sum_{a \in \mathcal{H}_\mathcal{C}} p_{za}}{\sum_{a \in \mathcal{H}_\mathcal{C}} |\vec{p}_a|}$$

$$T_{tE} = \max_{\vec{n}} \frac{\sum_{a \in \mathcal{H}_\mathcal{C}} |\vec{n} \cdot \vec{p}_{za}|}{\sum_{a \in \mathcal{H}_\mathcal{C}} |\vec{p}_a|}$$

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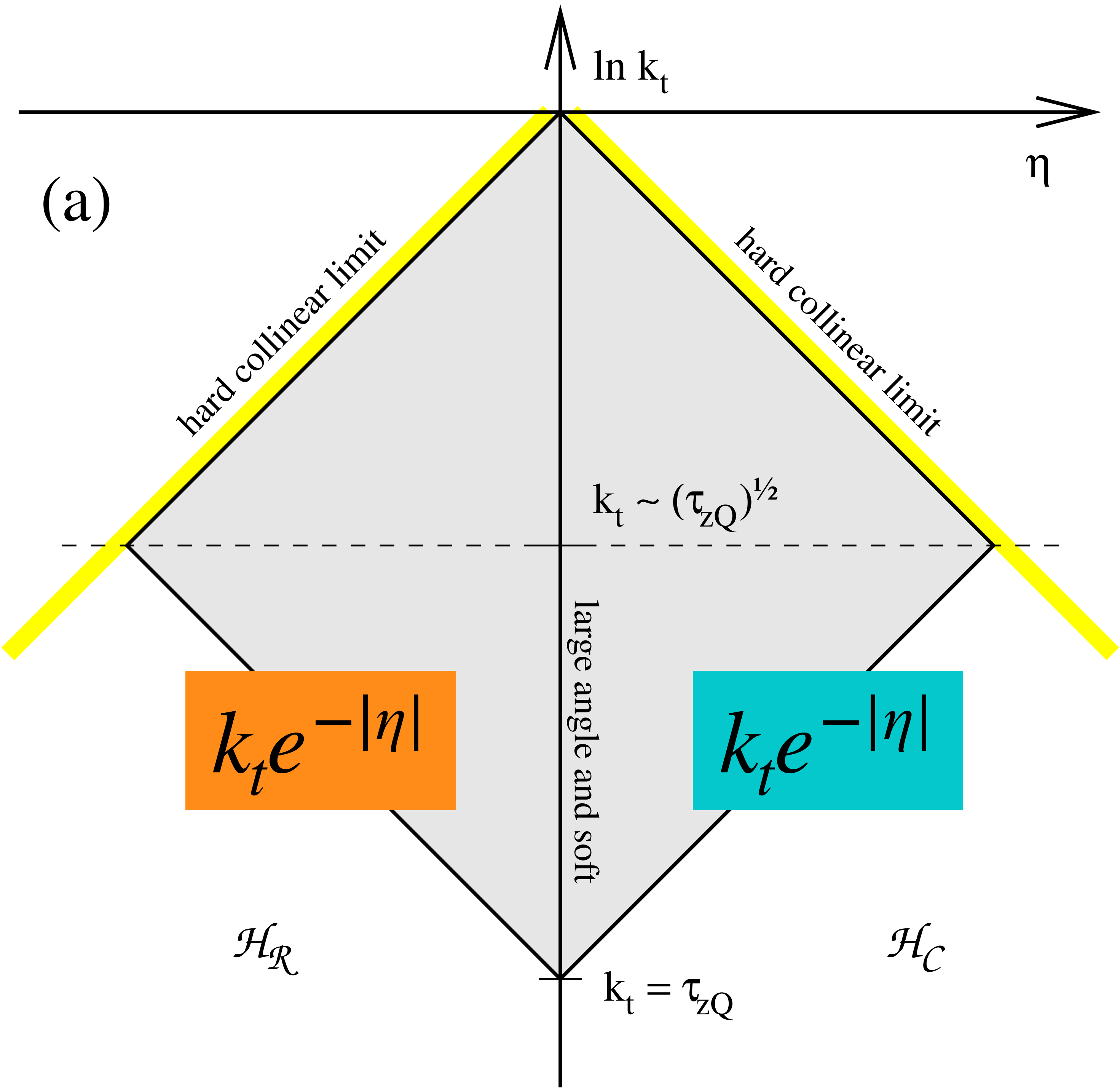

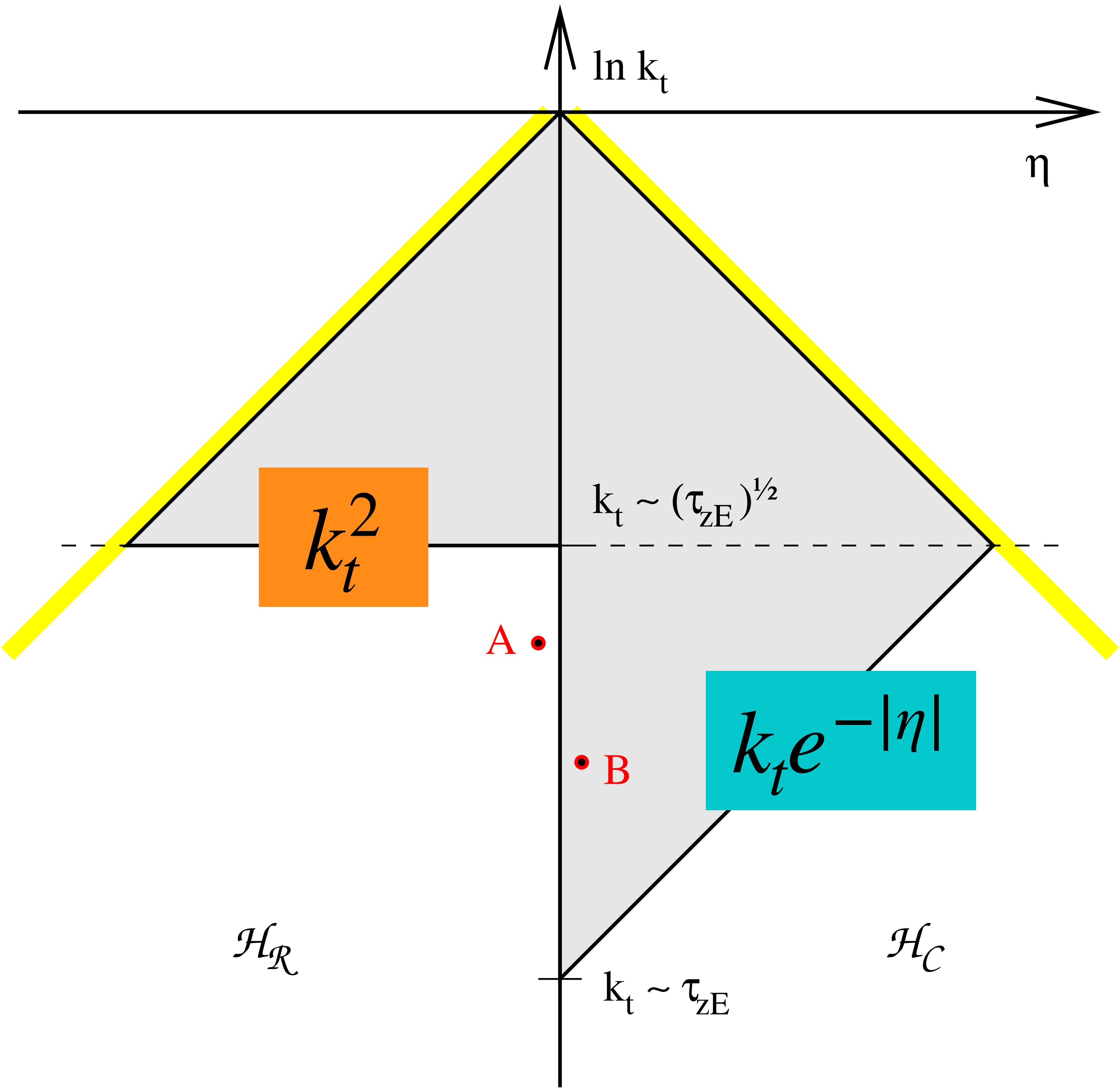

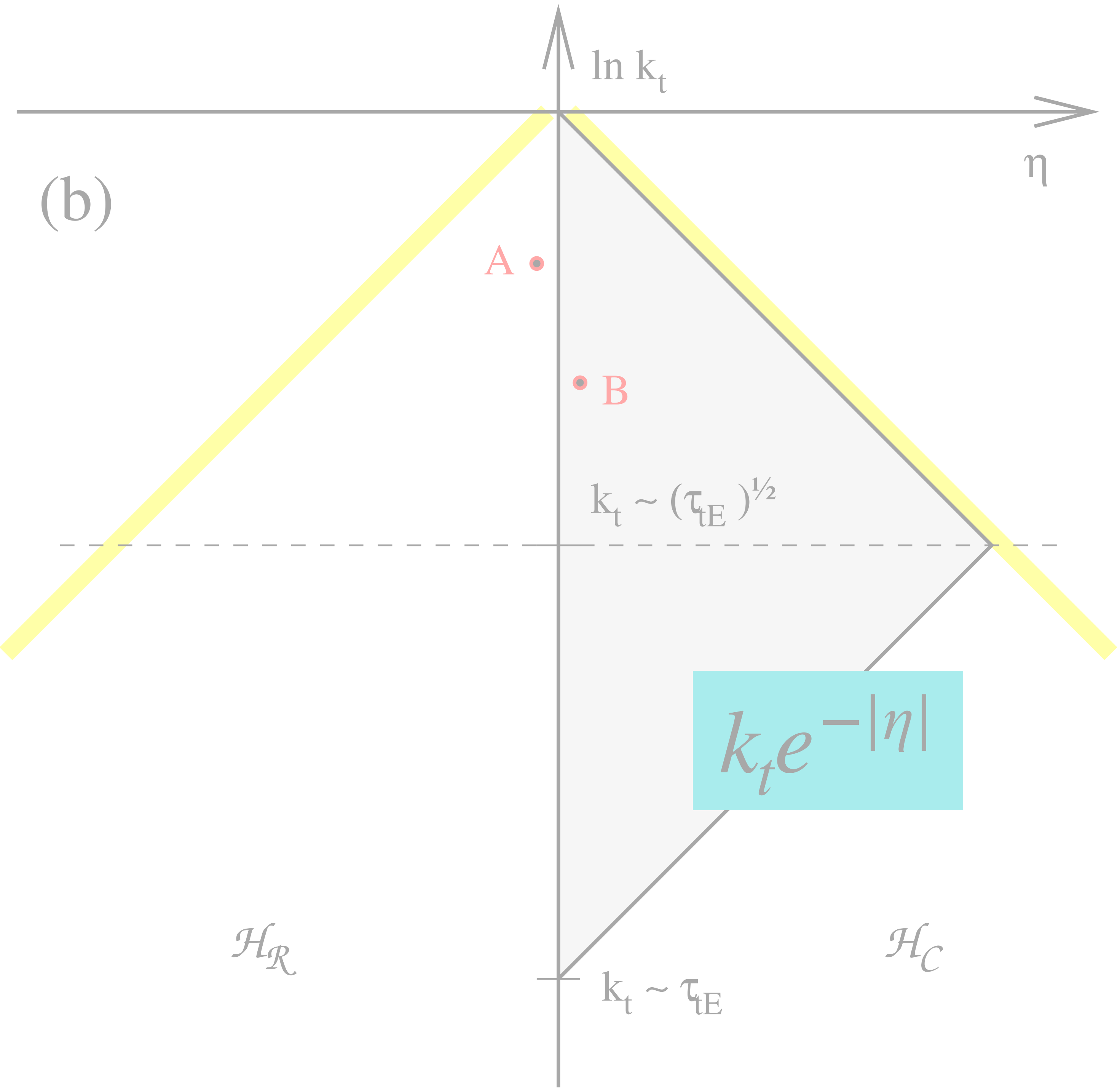

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Resummation of large logarithms in e^+e^- event shape distributions *

S. Catani [1]
Theory Division, CERN, CH-1211 Geneva 23, Switzerland

G. Turnock
Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge CB3 0HE, UK

L. Trentadue
Dipartimento di Fisica, Università di Roma II, Tor Vergata, I-00173 Rome, Italy

B.R. Webber [2]
Theory Division, CERN, CH-1211 Geneva 23, Switzerland

Nuclear Physics B407 (1993) 3–42

$1 + O(\bar{k}^2/Q^2)$ and $\bar{x} = 1 + O(k^2/Q^2)$. In the small-τ limit this correlation is of relative order τ and can be neglected, leading to the factorized expression

$$\underbrace{R_T(\tau)}_{\text{full event}} = \int_0^\infty \mathrm{d}k^2\, \mathrm{d}\bar{k}^2\, \underbrace{J^q(Q^2,k^2)}_{\text{hemisphere}}\, \underbrace{J^{\bar{q}}(Q^2,\bar{k}^2)}_{\text{hemisphere}}\, \Theta(\tau Q^2 - k^2 - \bar{k}^2)\,. \quad (51)$$

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Nuclear P

All we needed to do was to add PDFs…

$1 + O(\bar{k}^2/Q^2$ … mall-τ limit this correlation is

of r … leading to the factorized expression

$$\ldots \underbrace{dk^2 J^q(Q^2,k^2)}_{\text{hemisphere}}\ \underbrace{J^{\bar{q}}(Q^2,\bar{k}^2)}_{\text{hemisphere}}\ \Theta(\tau Q^2 - k^2 - \bar{k}^2)\ . \qquad (51)$$

…ull event

How do you test your resummation? An example from e+e− Broadening

- Expand your all-order resummation to order α_s^2
- Run a NLO calculation (EVENT2) for the differential distribution
- Take the difference. If you're really NLL, $\alpha_s^2 L^3$, $\alpha_s^2 L^2$, $\alpha_s^2 L$ should coincide with NLO
- All that's left is a constant term α_s^2, i.e. a flat curve

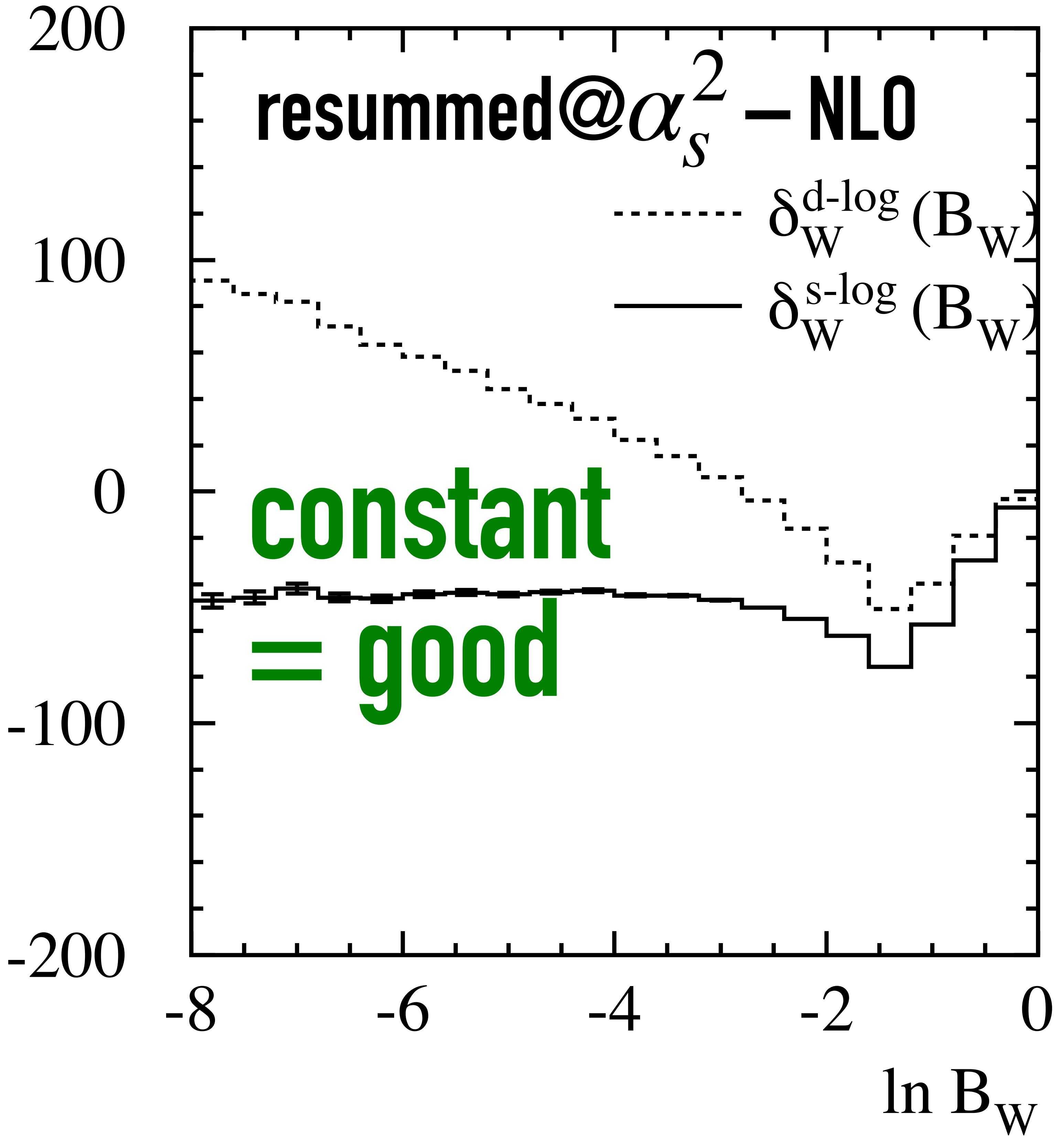


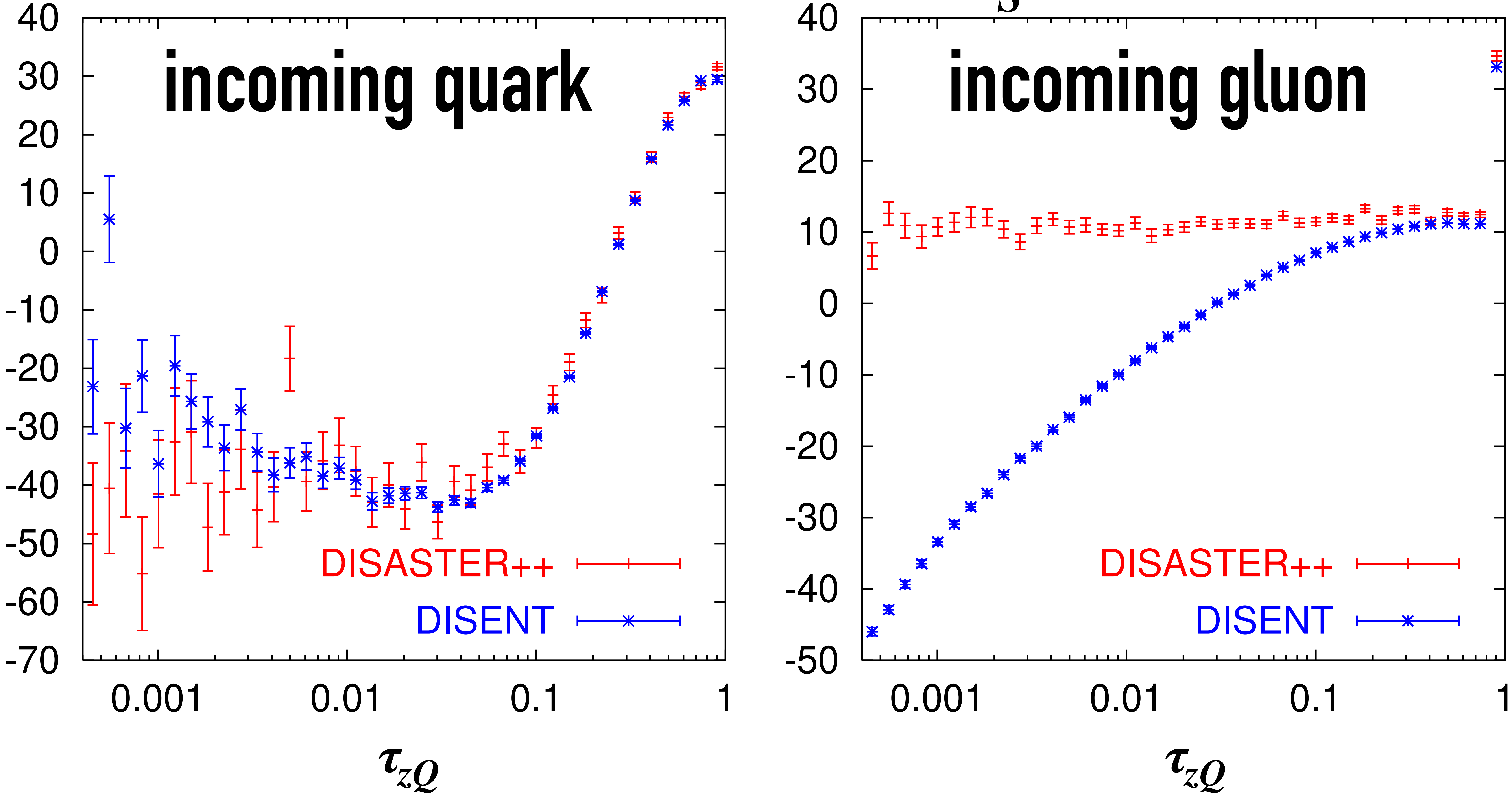
Figure 1: The coefficient of the $(\alpha_s C_F/2\pi)^2$ component of the difference, $\delta_i(B_i)$, between the numerical two-loop calculation of the B-distribution, performed with EVENT2, and the expansion to single and double logarithmic accuracies of the resummed result. Shown for the total and wide broadenings.

Our first DIS attempt: two variants of DIS thrust

hep-ph/9912488

- PDFs made things more complicated
- different terms according to incoming channel
- two different codes, didn't agree
- within stat. fluctuations, DISASTER++ looked "flat enough"

NLO – Resum@α_s^2



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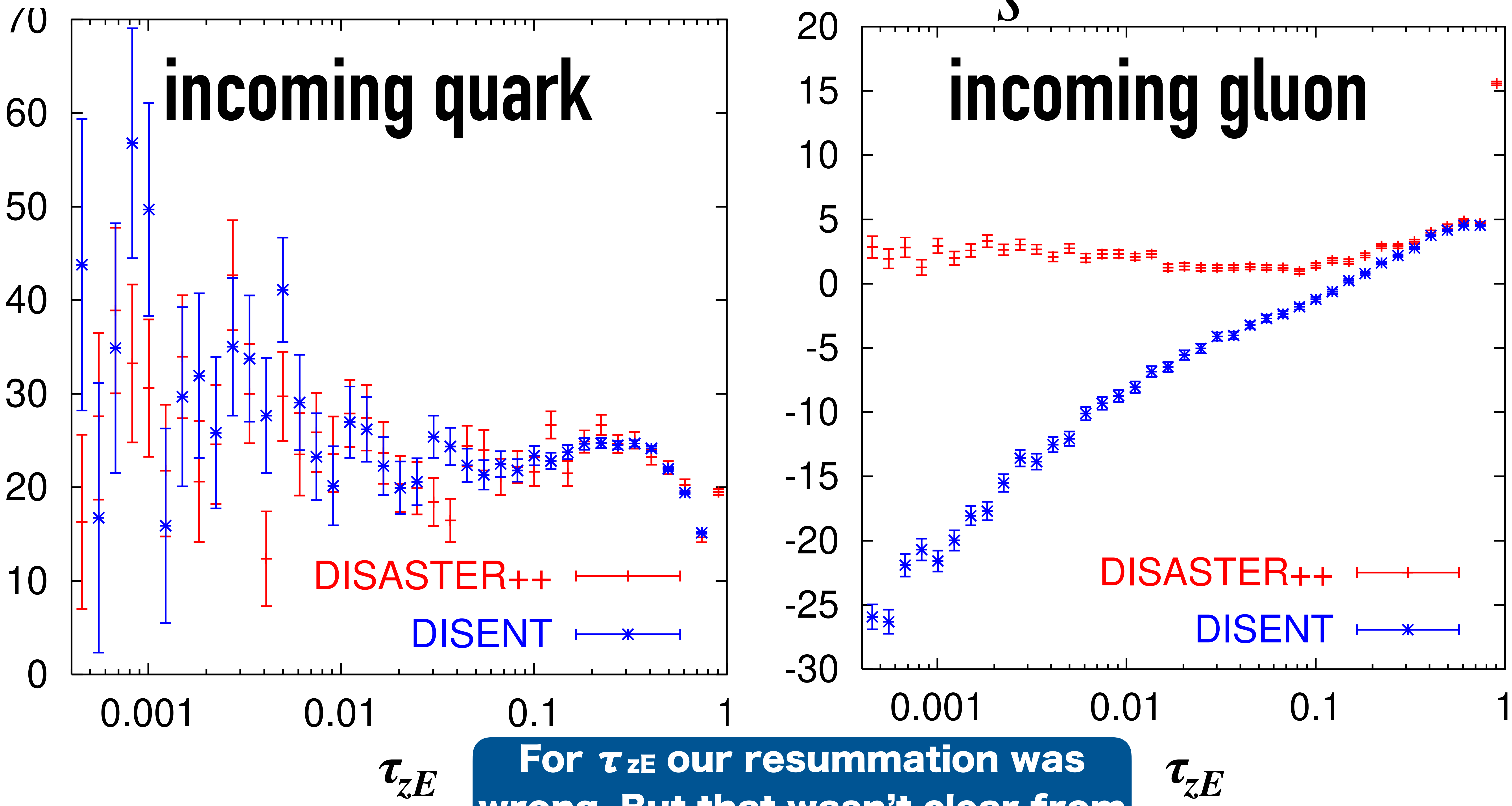

For τ_{zE} our resummation was wrong. But that wasn't clear from NLO checks

More observables, further progress was not smooth...

Date: Mon, **28 Aug 2000** 19:22:44 +0200 (CEST)
Subject: yuck
From/To: ❋

I was just looking at some disaster results with the new fixed order coeffs. [...]

On rho and tau_tE things look OK in the gluon sector. But **the quark sector is a bit disastrous**: are we sure of our formulas? The only other possibility is that things are very non-asymptotic... There is some evidence of this in the gluon sector (the region where things flatten out is precisely where stats go to hell in the q sector, at least for rho -- less so for tau_tE).

❋: *if From/To are missing, it's an email between Mrinal and myself, not specifying who sent/received*

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On r … **sector is a bit**
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least … so for tau_tE).

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Date: Sat, **10 Feb 2001** 00:45:24
From/To: ✻

[…] I will write up the letter. I will couch the missing pieces of the resummation in such a way that no one will eve[r] know **how hopelessly stuck we are.**

✻: *if From/To are missing, it's an email between Mrinal and myself, not specifying who sent/received*

Looking elsewhere [one of us as a referee] gave us a clue

Resumming the Light Hemisphere Mass and Narrow Jet Broadening distributions in e^+e^- annihilation*

hep-ph/0101226

S. J. Burby[a] and E. W. N. Glover[b]

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hep-ph/0101226

S. J. Burby[a] and E. W. N. Glover[b]

Date: Fri, **9 Mar 2001** 23:31:28 +0100 (CET)
From/To: *

[in Event2] in e+e- for the single-hemisphere mass there is also a problem in the CF.CA piece (other pieces seem to work reasonably well). It looks very much of the same order as the DIS problem. [...]

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[in Event2] in e+e- for the single-hemisphere mass there is also a problem in the CF.CA piece (other pieces seem to work reasonably well). It looks very much of the same order as the DIS problem. [...]

If Burby & Glover follow the suggestion of studying event2 they will soon see that they have one HELLUVA problem in the CF.CA piece [...] they may realise where it's coming from and resum it before us...

arXiv > hep-ph > arXiv:hep-ph/0104277

Search...

Help | A

High Energy Physics – Phenomenology

[Submitted on 26 Apr 2001]

Resummation of non-global QCD observables

M. Dasgupta, G.P. Salam

We discuss issues related to the resummation of non-global observables in QCD, those that are sensitive to radiation in only a part of phase space. Examples of such observables are certain single-hemisphere event shapes in e+e- and DIS. Compared to global observables (those sensitive to all emissions, e.g. the e+e- thrust) a new class of single-logarithmic terms arises. These have been neglected in recent calculations in the literature. For a whole set of single hemisphere e+e- and DIS event shapes, we analytically evaluate the first such term, at order alpha_s^2, and give numerical results for the resummation of these terms in the large-Nc limit.

Comments: 10 pages

The core result at fixed order

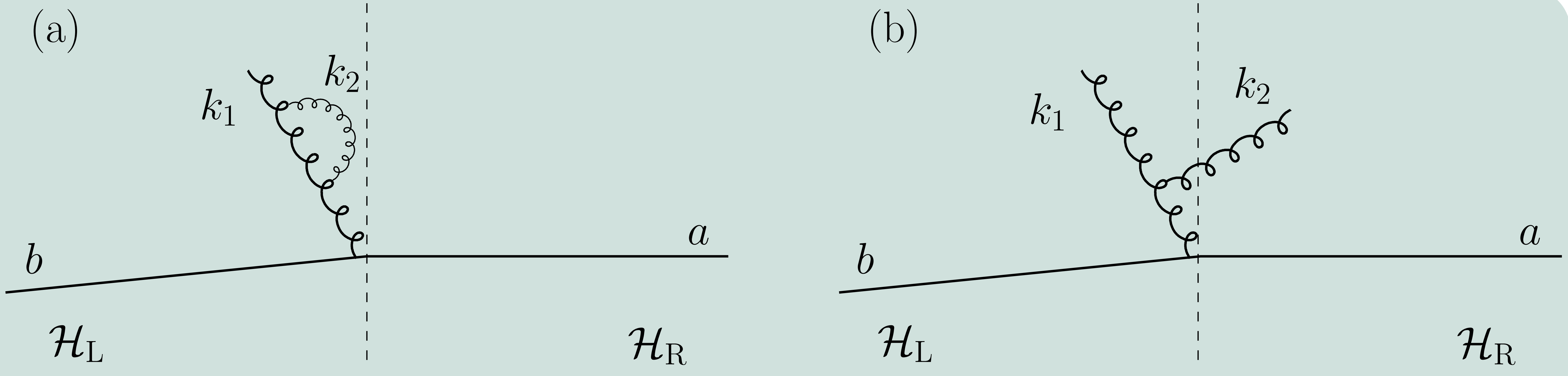
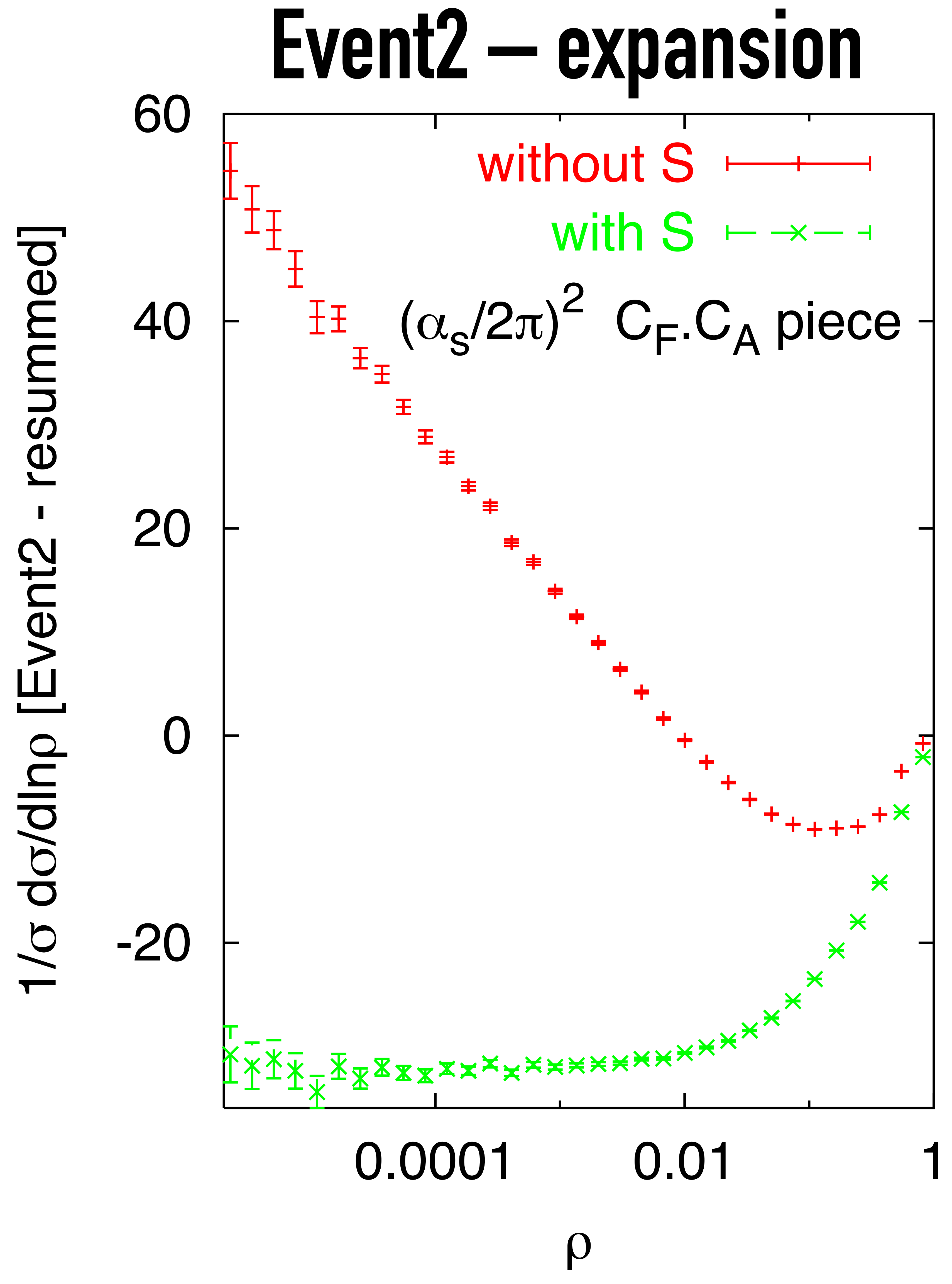


Figure 1: Kinematic configurations of interest

$$S_2 = -2C_F C_A \int_0^1 d\cos\theta_2 \int_{-1}^0 d\cos\theta_1\, \Omega_2(\cos\theta_1, \cos\theta_2)$$
$$= -C_F C_A \frac{\pi^2}{3}\,.$$



The core result at all orders

The exact details of the Monte Carlo algorithm are given in the appendix. Here we restrict ourselves to giving a parameterisation for $\mathcal{S}$ obtained by fitting to the Monte Carlo results:

$$\mathcal{S}(\alpha_{\mathrm{s}} L) \simeq \exp\left(-C_F C_A \frac{\pi^2}{3}\left(\frac{1+(at)^2}{1+(bt)^c}\right) t^2\right), \tag{18}$$

with

$$t(\alpha_{\mathrm{s}} L) = \frac{1}{2\pi}\int_{e^{-L}}^{1} \frac{dx}{x}\alpha_{\mathrm{s}}(xQ) = \frac{1}{4\pi\beta_0}\ln\frac{1}{1-2\beta_0\alpha_{\mathrm{s}} L}, \tag{19}$$

where $\beta_0 = (11C_A - 2n_f)/(12\pi)$ and

$$a = 0.85 C_A\,, \qquad b = 0.86 C_A\,, \qquad c = 1.33\,. \tag{20}$$

The parameterisation should be accurate to the order of a few percent (better in most of the region) for $t < 0.7$, corresponding to $1 - 2\alpha_{\mathrm{s}}\beta_0 L \gtrsim 0.005$.[4]

That enabled us to move on with DIS [hep-ph/0208073]

4. Non-global logarithms and discontinuously global observables

4.1 Non-global logs

4.2 Discontinuously global observables

4.3 Dynamically discontinuously global observables

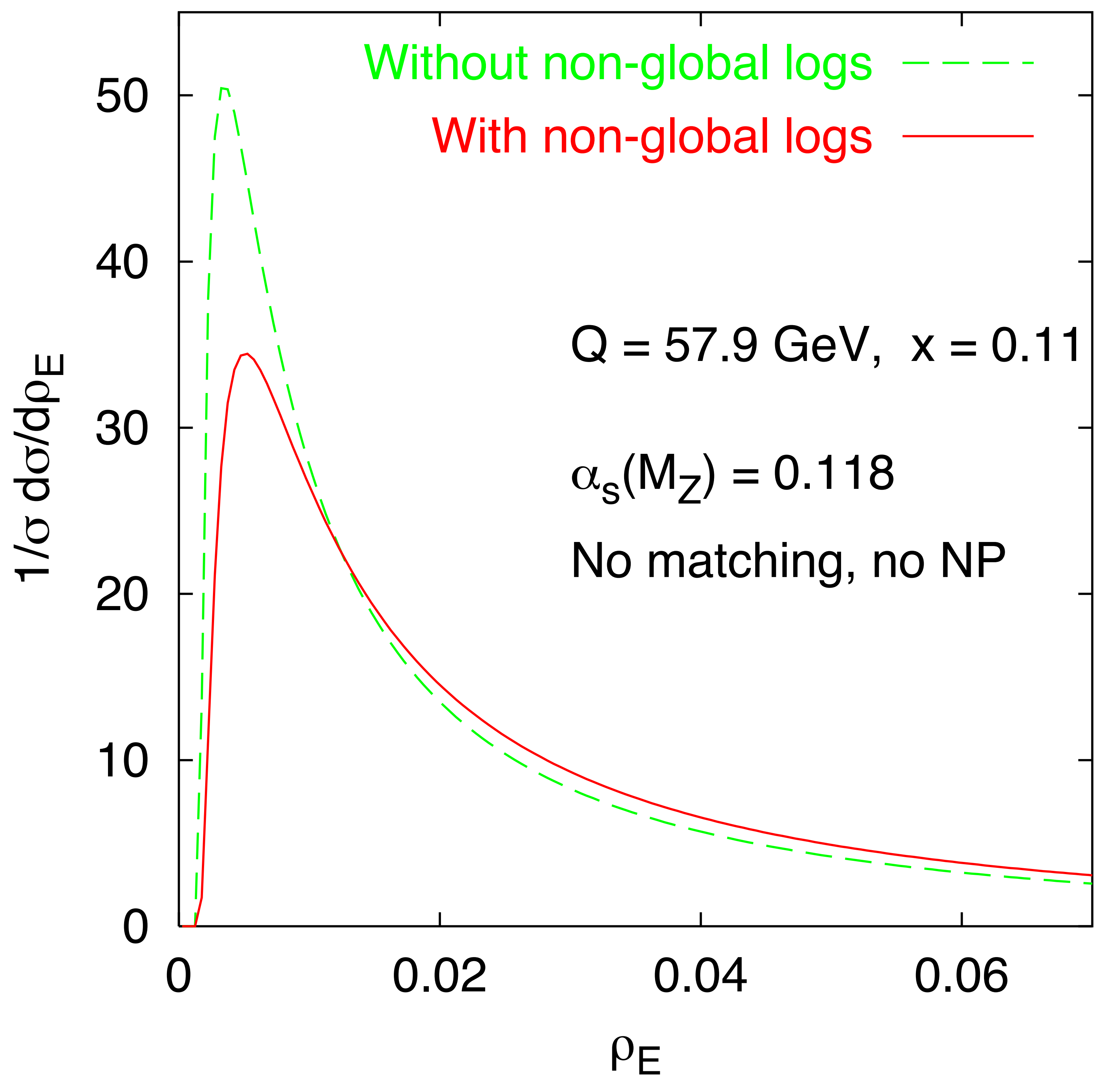


Figure 3: Resummation with and without non-global logs (shown without matching to fixed order).

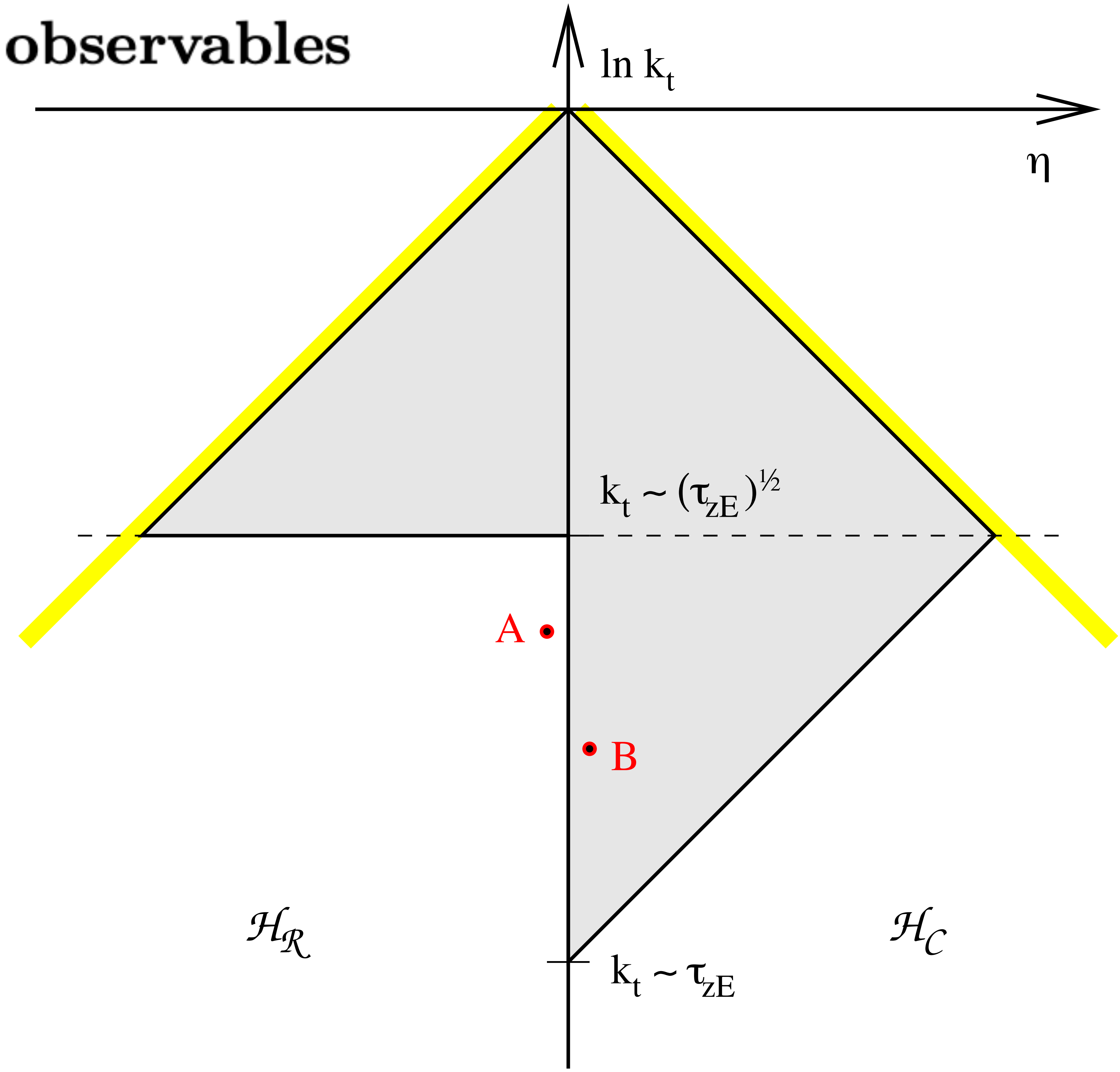


Figure 2: Analogue of fig. 1, shown for a discontinuously global observable, the photon-axis thrust, normalised to the energy in $\mathcal{H}_C$, τ_{zE}.

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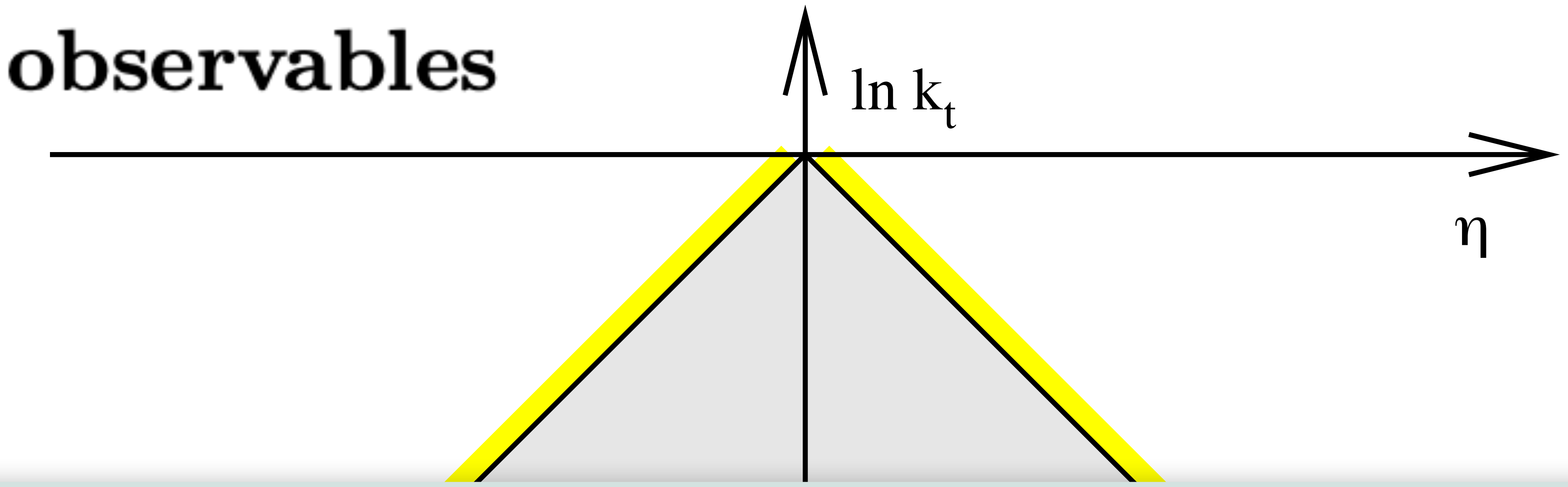

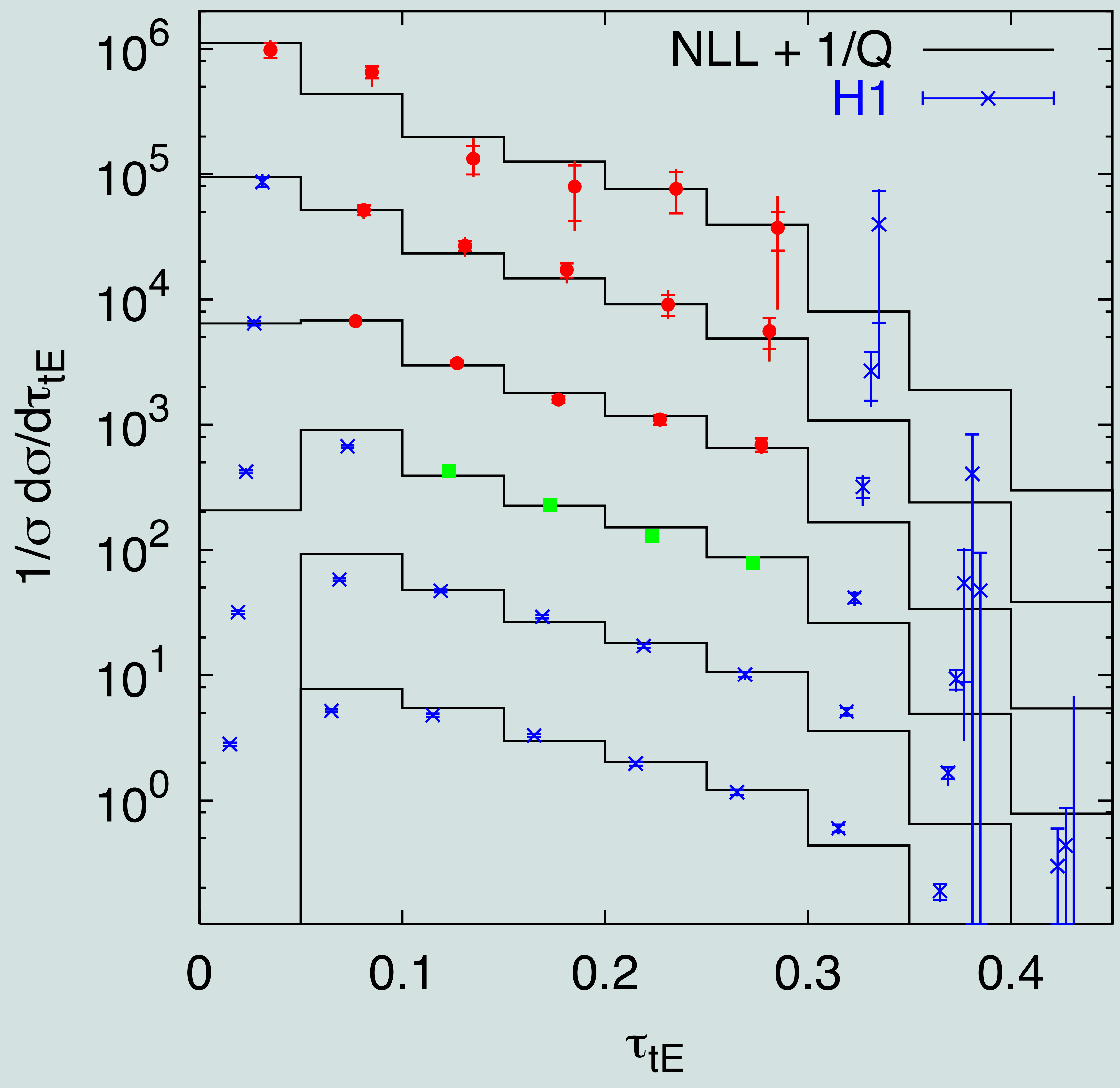

$\mathcal{V}$	α_s	α_0	χ^2/d.o.f.
ρ	0.1199 ± 0.0027	0.452 ± 0.030	90.4/40
C_E	0.1205 ± 0.0029	0.435 ± 0.021	25.7/17
τ_{tE}	0.1165 ± 0.0039	0.479 ± 0.032	11.9/14
τ_{zE}	0.1236 ± 0.0067	0.462 ± 0.121	11.0/23
B_{zE}	0.1257 ± 0.0048	0.469 ± 0.073	6.7/21

Table 3: Fit results and χ^2 values using data with $Q > 30$ GeV.

just because it's on arXiv doesn't mean it's been communicated arXiv > hep-ph > arXiv:hep-ph/0110004v1

Search...

Help

High Energy Physics – Phenomenology

[Submitted on 28 Sep 2001 (this version),

Energy Flow in Interjet Radiation

Carola F. Berger, Tibor Kucs, George Sterman (Stony Brook)

We calculate the distribution of transverse energy, Q_Omega, radiated into an arbitrary interjet angular region Omega, in high p_T two-jet events. We find a distribution that can be extrapolated smoothly to Q_Omega = Lambda_QCD, where it vanishes. This method provides a class of predictions on transverse energy radiated between jets, as a function of jet energy and rapidity, and of the choice of the region Omega in which the energy is measured.

$$\Gamma_S^{(q\bar{q}\to q\bar{q})} = \begin{pmatrix} C_F \beta^{(q\bar{q}\to q\bar{q})} & \frac{C_F}{2N_c}\left(\alpha^{(q\bar{q}\to q\bar{q})} + \gamma^{(q\bar{q}\to q\bar{q})}\right) \\ \alpha^{(q\bar{q}\to q\bar{q})} + \gamma^{(q\bar{q}\to q\bar{q})} & C_F \alpha^{(q\bar{q}\to q\bar{q})} - \frac{1}{2N_c}\left(\alpha^{(q\bar{q}\to q\bar{q})} + \beta^{(q\bar{q}\to q\bar{q})} + 2\gamma^{(q\bar{q}\to q\bar{q})}\right) \end{pmatrix}$$

To: George Sterman <sterman@insti.physics.sunysb.edu>
Date: **10 Oct 2021**

Dear George,

A few months ago Mrinal Dasgupta and I came across some single logs that arise in the resummations of observables which measure energy flows in restricted angular regions ("non-global" observables) -- they come from secondary emissions off primary emissions outside the observed region. They'd been neglected a couple of times before, and are quite subtle, because they only start at O(as^2 L^2). In the large-NC limit we managed to resum them numerically, hep-ph/0104277, but that's about as far as we got.

We were wondering if you have any thoughts about this kind of contribution...

One context in which they could well arise is the sort of observable that you propose in hep-ph/0110004, because of the cuts at large angles.

Best regards,
Gavin & Mrinal

Date: Fri, **25 Jan 2002** 12:28:07 +0100 (MET)
From/To: *

I think we should market the non-global stuff a lot because I had to convince Pino [Marchesini] over 3 days that what one had done was useful. In the end he was very interested...

Date: Fri, **25 Jan 2002** 12:28:07 +0100 (MET)
From/To: ❋

I think we should market the non-global stuff a lot because I had to convince Pino [Marchesini] over 3 days that what one had done was useful. In the end he was very interested...

Date: Fri, **25 Jan 2002** 12:40:01 +0100 (CET)
From/To: ❋

That Pino is interested (at last!) is good news -- though I'd sort of assumed he already knew about it since we talked about it a couple of times (I thought) in Milan. I was sort of surprised that Bryan also was unaware of it when I saw him briefly at CERN a couple of months ago

Date: Wed, **20 Feb 2002** 09:06:14 +0000 (GMT)
From: Bryan Webber <webber@hep.phy.cam.ac.uk>
To: Mrinal Dasgupta <dasgupta@mail.desy.de>,
Gavin Salam <salam@lpthe.jussieu.fr>
Subject: Re: Advice

Hello Mrinal & Gavin,

[...]

Stefano Catani and I were aware that the J function doesn't describe the jet mass distribution according to any (simple) operational definition of a jet, but only when part of a suitably global observable. I'm not sure we could define "suitably global" but just checked on a case-by-case basis. But that's why we never published the NLL resummation of the Durham (or any other) 2-jet fraction.

I think you should go ahead and write a short note on this a.s.a.p. [...]

High Energy Physics – Phenomenology

[Submitted on 1 Mar 2002]

Accounting for coherence in interjet E_t flow: a case study

Mrinal Dasgupta, Gavin P. Salam

Recently, interest has developed in the distribution of interjet energy flows, with for example the leading-log calculation of the highly non-trivial colour structure of primary emissions in 4-jet systems. Here we point out however that at leading-log level it is insufficient to consider only multiple primary emission from the underlying hard antenna -- additionally, one must take into account the coherent structure of emission from arbitrarily complicated ensembles of large-angle soft gluons. Similar considerations apply to certain definitions of rapidity gaps based on energy flow. We examine this new class of terms in the simpler context of 2-jet events, and discover features that point at novel aspects of the QCD dynamics.

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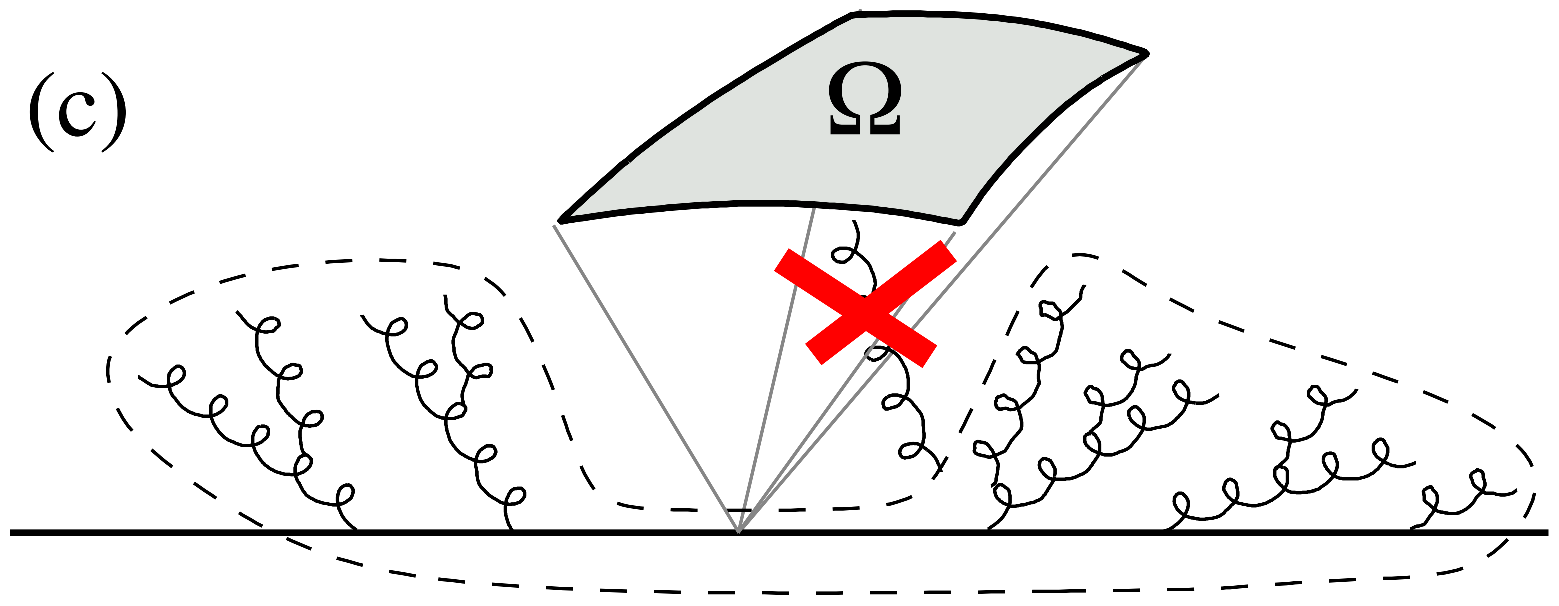


$$\mathcal{S}(t) \sim e^{-4C_F t^2 \left\langle \frac{\delta\eta}{\delta t} \right\rangle}$$

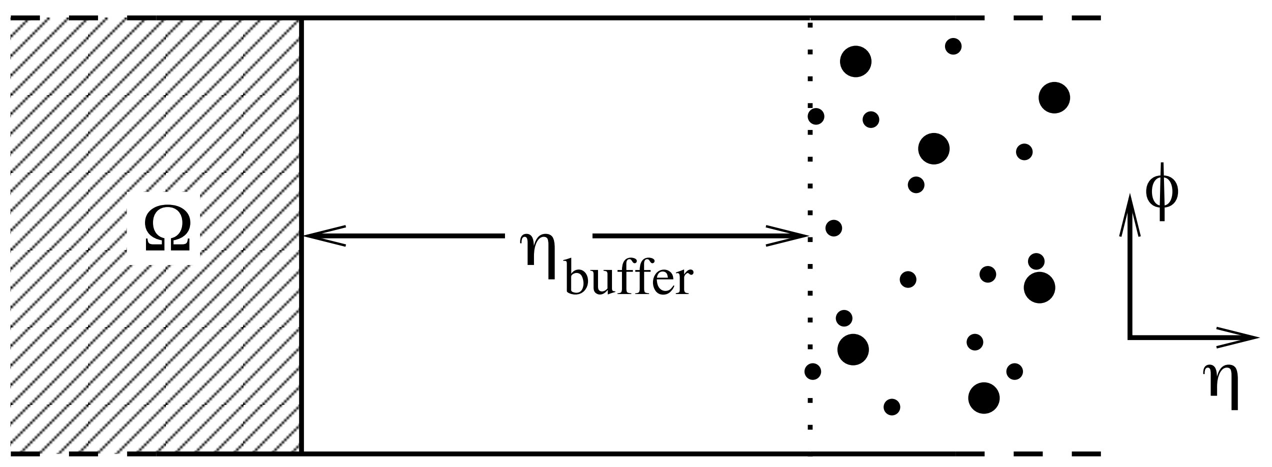
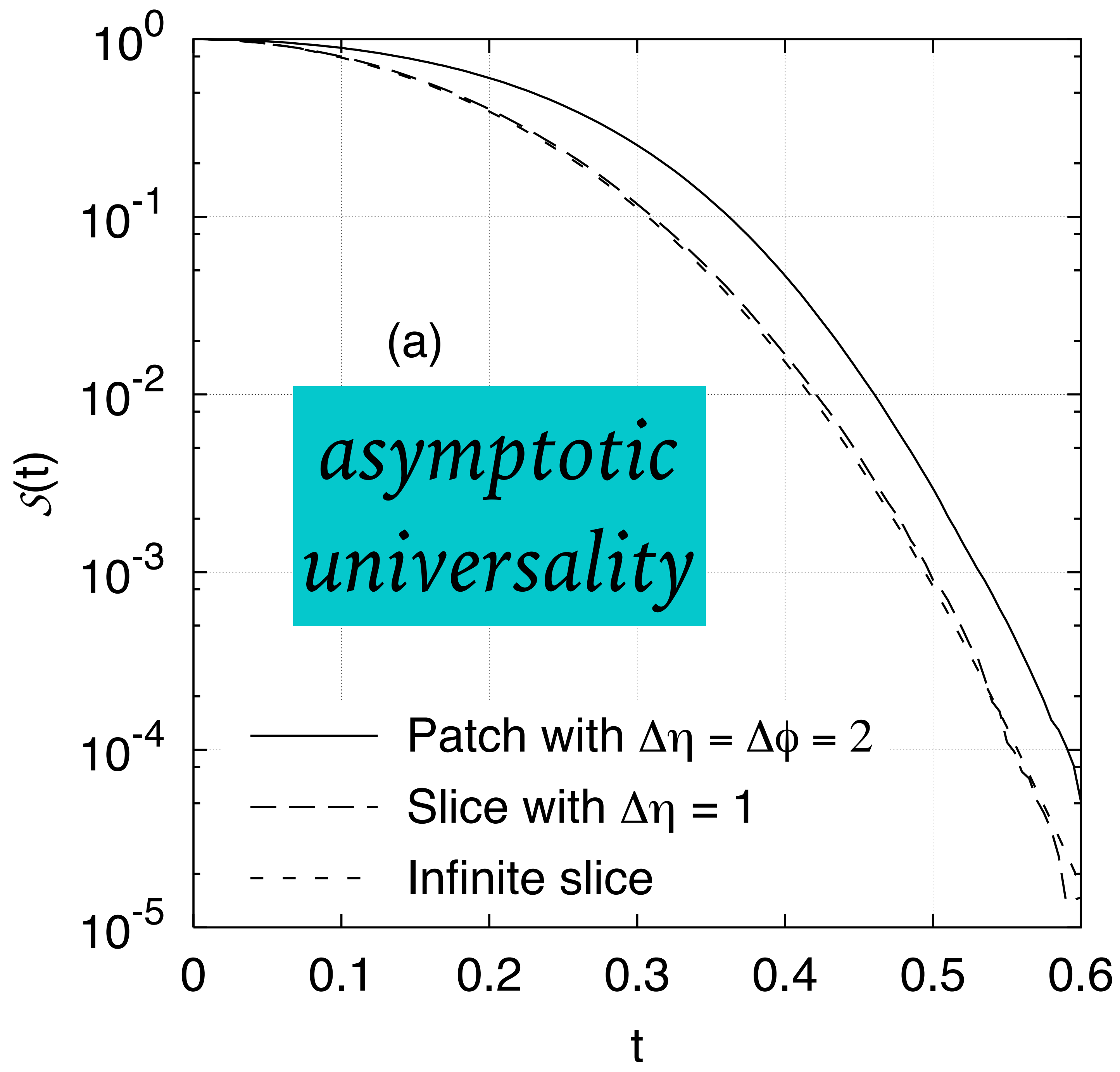


Figure 4: A possible structure for emissions harder than some intermediate resolution scale t' for an event in which Ω stays empty down to some scale $t > t'$. In this scenario, at scale t' an empty buffer region exists between Ω and the emission closest to Ω.



don't just write an MC algorithm

Away-from-jet energy flow*

Bicocca–FT–02/10
hep-ph/0206076
June 2002

A. Banfi, G. Marchesini, G. Smye

$$\partial_\Delta G_{ab}(\Delta) = -r_{ab}\, G_{ab}(\Delta) + \int_{\mathcal{C}_{\rm in}} \frac{d^2\Omega_k}{4\pi}\, w_{ab}(k)\left[\, G_{ak}(\Delta)\cdot G_{kb}(\Delta) - G_{ab}(\Delta)\,\right],$$

above. Proceeding as in subsection 6.2 we find the following asymptotic behaviour for the distribution with ab in opposite jet regions

$$G_{ab}(\Delta) \simeq e^{-\frac{c}{2}\Delta^2}\left(\frac{\theta_{\rm in}^2\,\hat\lambda(\vec a)\,\hat\lambda(\vec b)\,e^{-c'}}{2}\right)^{\Delta}\,\hat f(\vec a)\hat f(\vec b)\,, \qquad (6.27)$$

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$$\partial_\Delta G_{ab}(\Delta) = -r_{ab}\, G_{ab}(\Delta) + \int_{\mathcal{C}_{\rm in}} \frac{d^2\Omega_k}{4\pi}\, w_{ab}(k) \left[G_{ak}(\Delta) \cdot G_{kb}(\Delta) - G_{ab}(\Delta) \right],$$

BFKL Dynamics in Jet Evolution

hep-ph/0308284

G. Marchesini [a] and A.H. Mueller [b,1]

The surprise is that the dominant part of the BMS equation is identical to the Kovchegov equation [7]

Non-global jet evolution at finite N_c

hep-ph/0312050

Heribert Weigert

The [BMS] equation itself is nonlinear in the part describing contributions arising inside the jet regions and linear outside. The contributions inside, quite surprisingly, have a striking analogy with the Balitsky-Kovchegov (BK) equation [4–6], which resums small x corrections in the nonlinear domain.

This analogy is used to generalize the former beyond the leading N_c approximation. The result shows striking analogy with the JIMWLK equation describing the small x evolution of the color glass condensate.

Resummation of non-global logarithms at finite N_c

Yoshitaka Hatta[a] and Takahiro Ueda[b]

1304.6930
also 2011.04154

In the context of inter-jet energy flow, we present the first quantitative result of the resummation of non-global logarithms at finite N_c. This is achieved by refining Weigert's approach in which the problem is reduced to the simulation of associated Langevin dynamics in the space of Wilson lines. We find that in e^+e^- annihilation, the exact result is rather close to the result previously obtained in the large–N_c mean field approximation. However, we observe enormous event–by–event fluctuations in the Langevin process which may have significant consequences in hadron collisions.

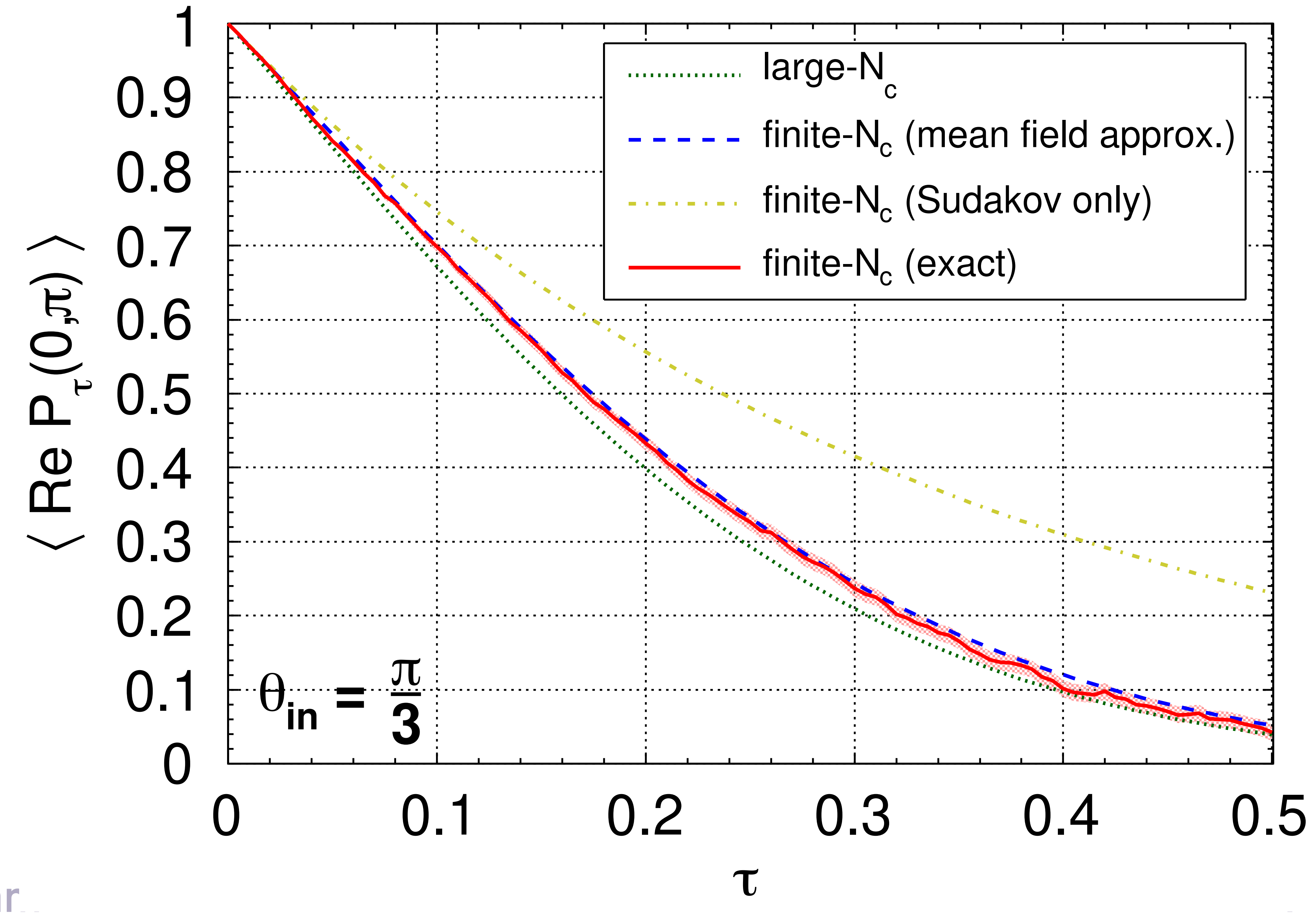
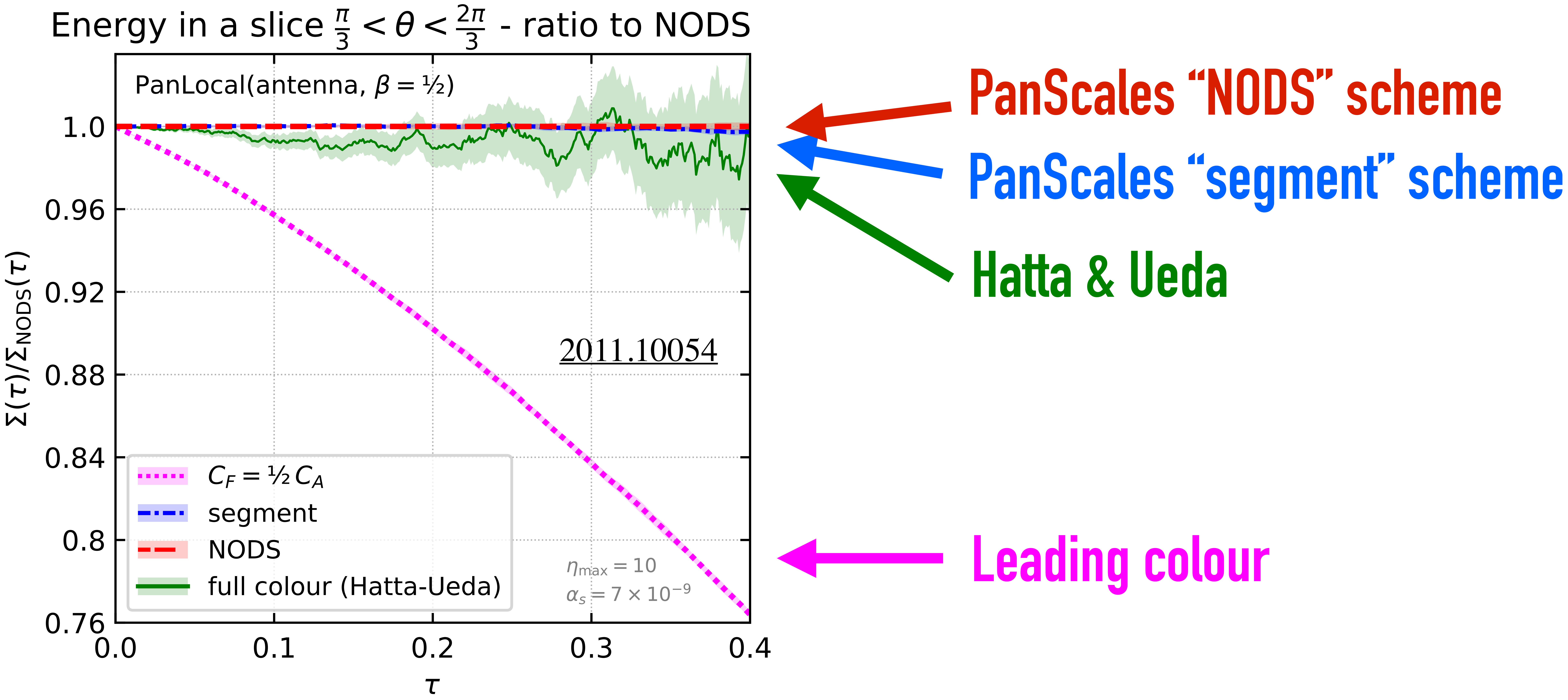


Fig. 2. Solid line (red): exact $N_c = 3$ solution to (21). The band indicates the standard error. Dashed line (blue): $N_c = 3$, mean–field solution to (58). Dotted line (green): solution to the BMS equation (16) from [22]. Dash–dotted line (yellow): result with only the Sudakov term.

Hatta & Ueda result remains a key reference for validation parton shower colour schemes



where does it matter?

gaps between jets are fun, but not LHC mainstay

any time you apply photon/lepton isolation cuts
(e.g. to predicting isolation efficiency)

arXiv > hep-ph > arXiv:1803.07045

High Energy Physics – Phenomenology

[Submitted on 19 Mar 2018 (v1), last revised 15 Aug 2018 (this version, v2)]

Non-global logarithms in jet and isolation cone cross sections

Marcel Balsiger, Thomas Becher, Ding Yu Shao

[we compute] isolation cone cross sections relevant for photon production. We compare our results with fixed-order computations and LHC measurements. We find that naive exponentiation is often not adequate, especially when the vetoed region is small, since non-global contributions are enhanced due to their dependence on the veto-region size.

arXiv > hep-ph > arXiv:2208.01554

High Energy Physics – Phenomenology

[Submitted on 2 Aug 2022 (v1), last revised 14 Feb 2023 (this version, v2)]

QCD anatomy of photon isolation

Thomas Becher, Samuel Favrod, Xiaofeng Xu

[…] Based on this factorization we also resum the non-global logarithms of the ratio of the photon energy and the isolation energy, so that we control all logarithmically enhanced terms in the cross section.

arXiv > hep-ph > arXiv:hep-ph/0211426

High Energy Physics – Phenomenology

[Submitted on 27 Nov 2002]

Non-global logarithms in inter-jet energy flow with kt clustering requirement

R.B. Appleby, M.H. Seymour

impact of the non-global logarithms is reduced, but not removed, when clustering is demanded,

arXiv > hep-ph > arXiv:2309.17355

High Energy Physics – Phenomenology

[Submitted on 29 Sep 2023]

Factorization and Resummation for Sequential Recombination Jet Cross Sections

Thomas Becher, Jürg Haag

any time you reconstruct EW-scale resonances with decays to jets (mass shift & resolution)

arXiv > hep-ph > arXiv:1307.0007

High Energy Physics – Phenomenology

[Submitted on 28 Jun 2013 (v1), last revised 5 Sep 2013 (this version, v2)]

Towards an understanding of jet substructure

Mrinal Dasgupta, Alessandro Fregoso, Simone Marzani, Gavin P. Salam

The modified mass-drop tagger is special in that it involves only single logarithms, and is **free from a complex class of terms known as non-global logarithms**

arXiv > hep-ph > arXiv:1402.2657

High Energy Physics – Phenomenology

[Submitted on 11 Feb 2014 (v1), last revised 13 May 2014 (this version, v2)]

Soft Drop

Andrew J. Larkoski, Simone Marzani, Gregory Soyez, Jesse Thaler

we also include a discussion of […] (the absence of) non-global logarithms arXiv > hep-ph > arXiv:2006.00014

High Energy Physics – Phenomenology

[Submitted on 29 May 2020]

Resummation of non-global logarithms in cross sections with massive particles

Marcel Balsiger, Thomas Becher, Andrea Ferroglia

A factorization formalism for jet processes involving **massive colored particles such as the top quark is developed,**

arXiv > hep-ph > arXiv:2605.13953

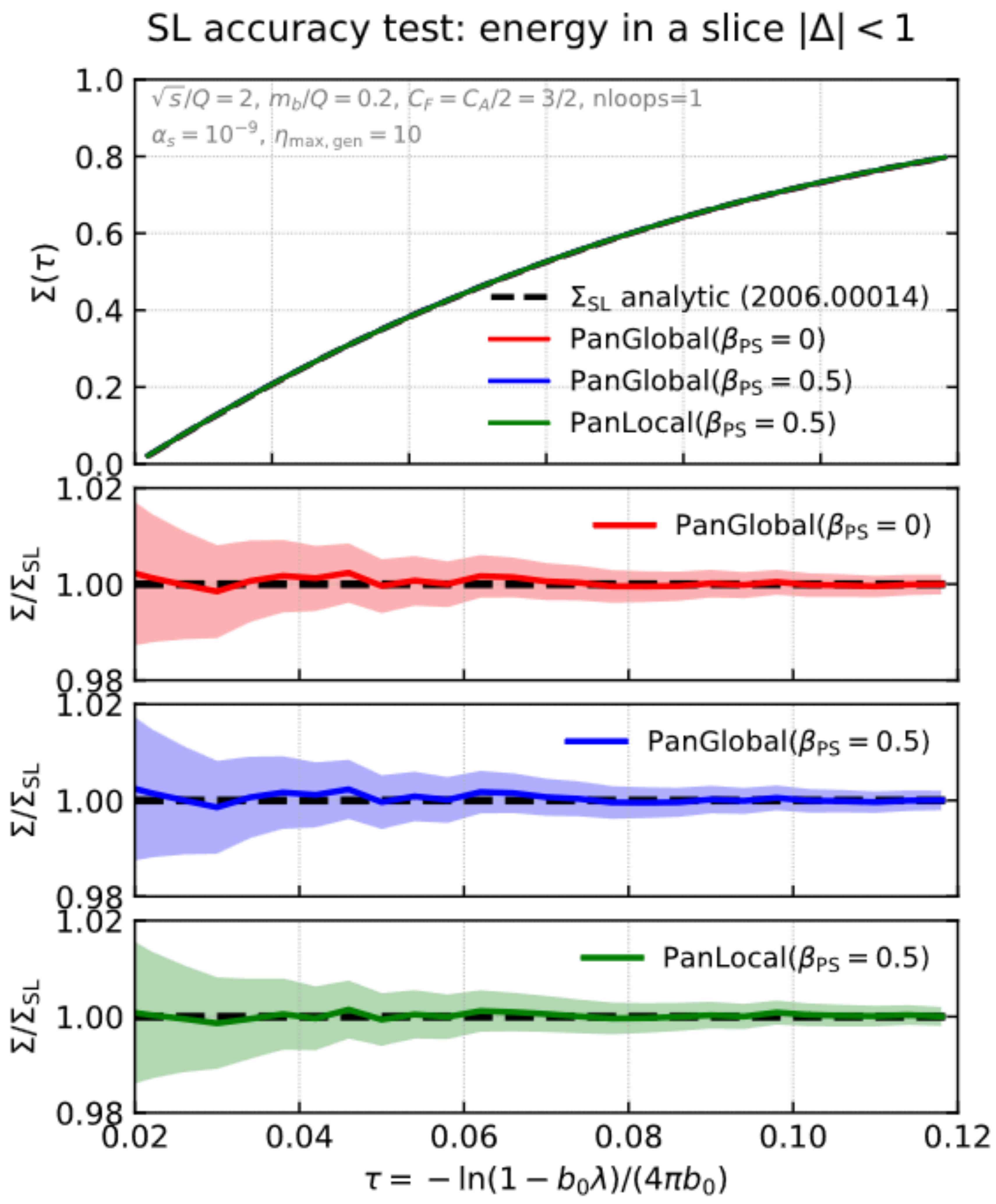
High Energy Physics – Phenomenology

[Submitted on 13 May 2026]

Logarithmically-accurate showers with massive quarks

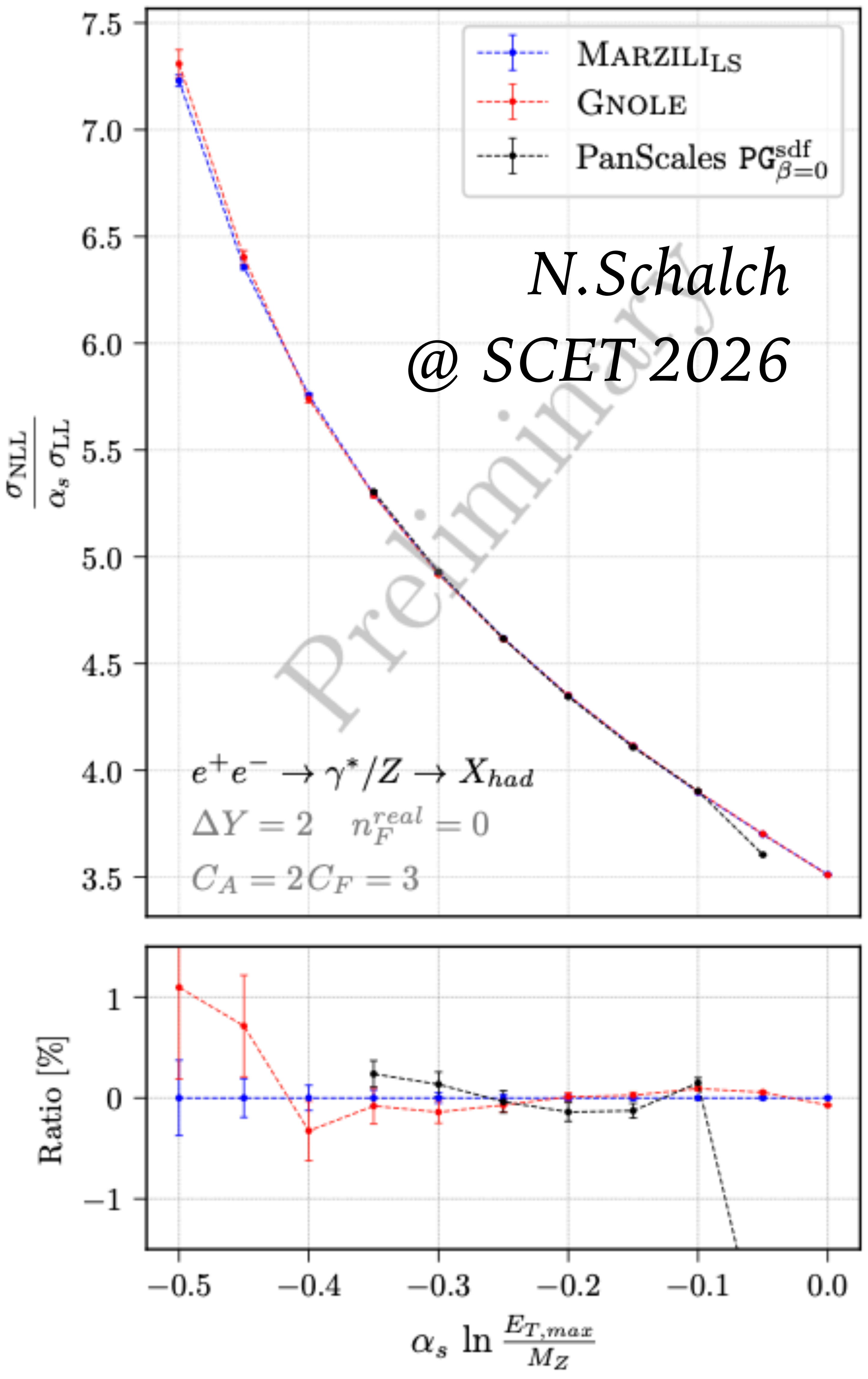
Melissa van Beekveld, Silvia Ferrario Ravasio, Alba Soto-Ontoso, Gregory Soyez, Rob Verheyen

We validate the accuracy of the shower algorithms by performing fixed-order tests up to second order in the strong coupling constant, and all-order comparisons to (semi-)analytic resummed calculations for a series of observables, including Lund-tree shapes, **non-global energy flows** and Lund sub-jet multiplicities.



critical for top mass?
(how much radiation from top is in W and b jets)

Comparison at NLL



Agreement between frameworks

- MARZILI [2307.02283 + upcoming]
- GNOLE [2111.02413]
- PanScales [2307.11142]

the varied phenomenological impact is motivation for past few years' development of resummations and parton showers with higher NGL accuracy

→ more in Thomas's talk!

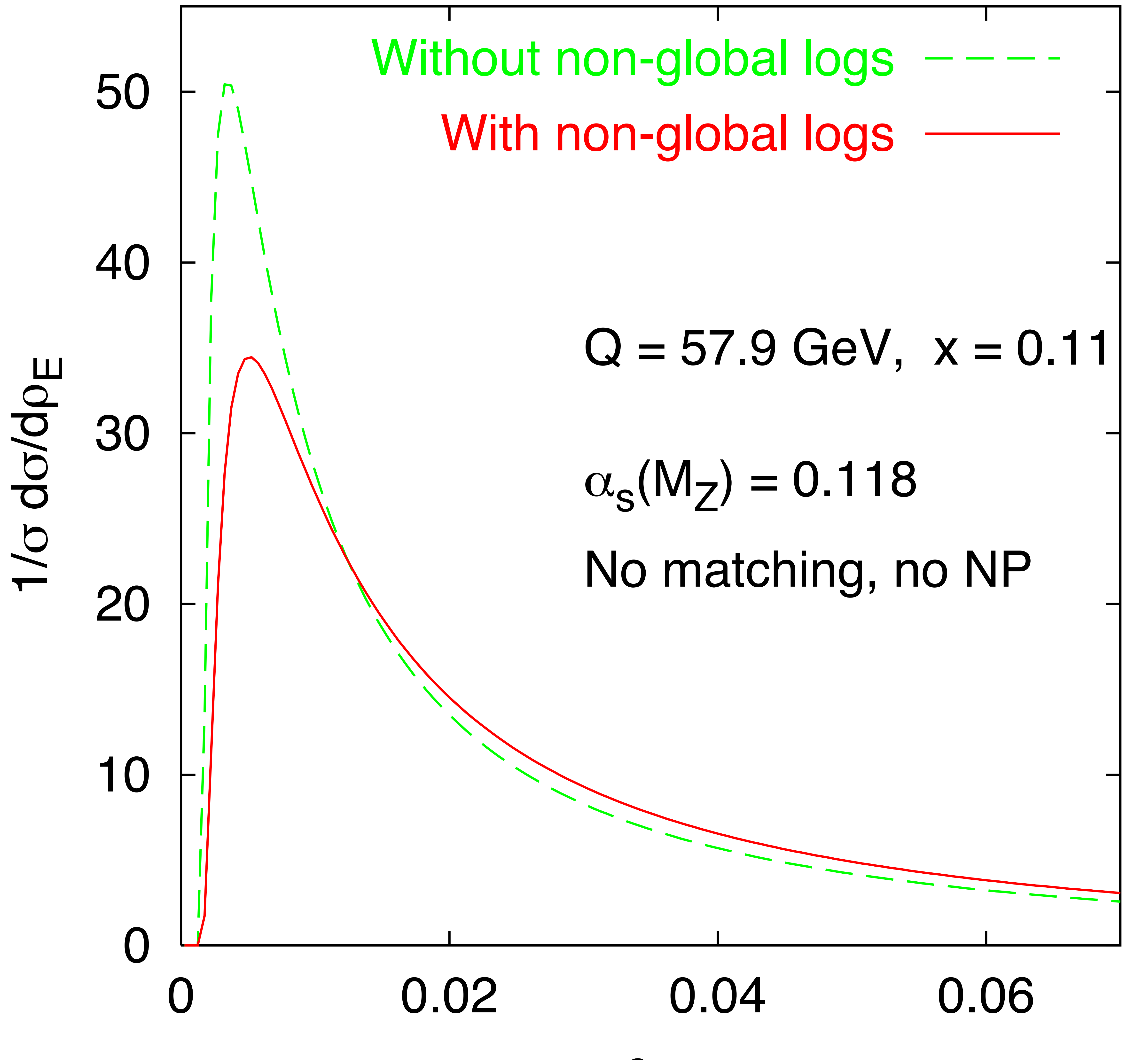
What do I wish we'd done differently?

- published a plot and numbers for the NG $S(t)$ function, showing what accuracy it had compared to the parametrisation
- published the code for calculating $S(t)$
- in the DIS papers, published the comparison to fixed order
- kept the plots with intermediate results (but once we understood things, it was fast moving and keeping "mistakes" wasn't a priority)

backup

4.4 Phenomenological impact of non-global logs

In figure 3 we illustrate the effect of non-global logarithms in the resummation of ρ_E (other non-global observables are similar). The figure compares (unmatched) resummations with and without account of non-global logs. One sees that neglecting them leads to an overestimate of the peak-height by almost 50%, though elsewhere in the distribution, the effect is smaller. In practice, matching to fixed-order calculations reduces the impact of neglecting the non-global logarithms, but the effects are still of the order of 20 to 30%.



This non-global contribution was erroneously omitted in the original resummation for τ_{zE} [20]. This ought, in principle, to have been revealed by the comparison with fixed-order calculations, however in practice the numerical accuracy of the fixed-order calculations is such that it is not possible to distinguish between comparisons with and without the non-global logs (this is specific to τ_{zE} — other observables such as τ_{tE} have effects which are four times larger and which therefore can be more straightforwardly distinguished in comparisons to fixed-order calculations).

arXiv > hep-ph > arXiv:hep-ph/0110004

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High Energy Physics – Phenomenology

[Submitted on 28 Sep 2001 (v1), last revised 5 Mar 2002 (this version, v2)]

Energy Flow in Interjet Radiation

Carola F. Berger, Tibor Kucs, George Sterman (Stony Brook)

We study the distribution of transverse energy, Q_Omega, radiated into an arbitrary interjet angular region, Omega, in high-p_T two-jet events. Using an approximation that emphasizes radiation directly from the partons that undergo the hard scattering, we find a distribution that can be extrapolated smoothly to Q_Omega=Lambda_QCD, where it vanishes. This method, which we apply numerically in a valence quark approximation, provides a class of predictions on transverse energy radiated between jets, as a function of jet energy and rapidity, and of the choice of the region Omega in which the energy is measured. We discuss the relation of our approximation to the radiation from unobserved partons of intermediate energy, whose importance was identified by Dasgupta and Salam.