The PanScales parton showers for hadron collisions

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2205.02237

European Research Council

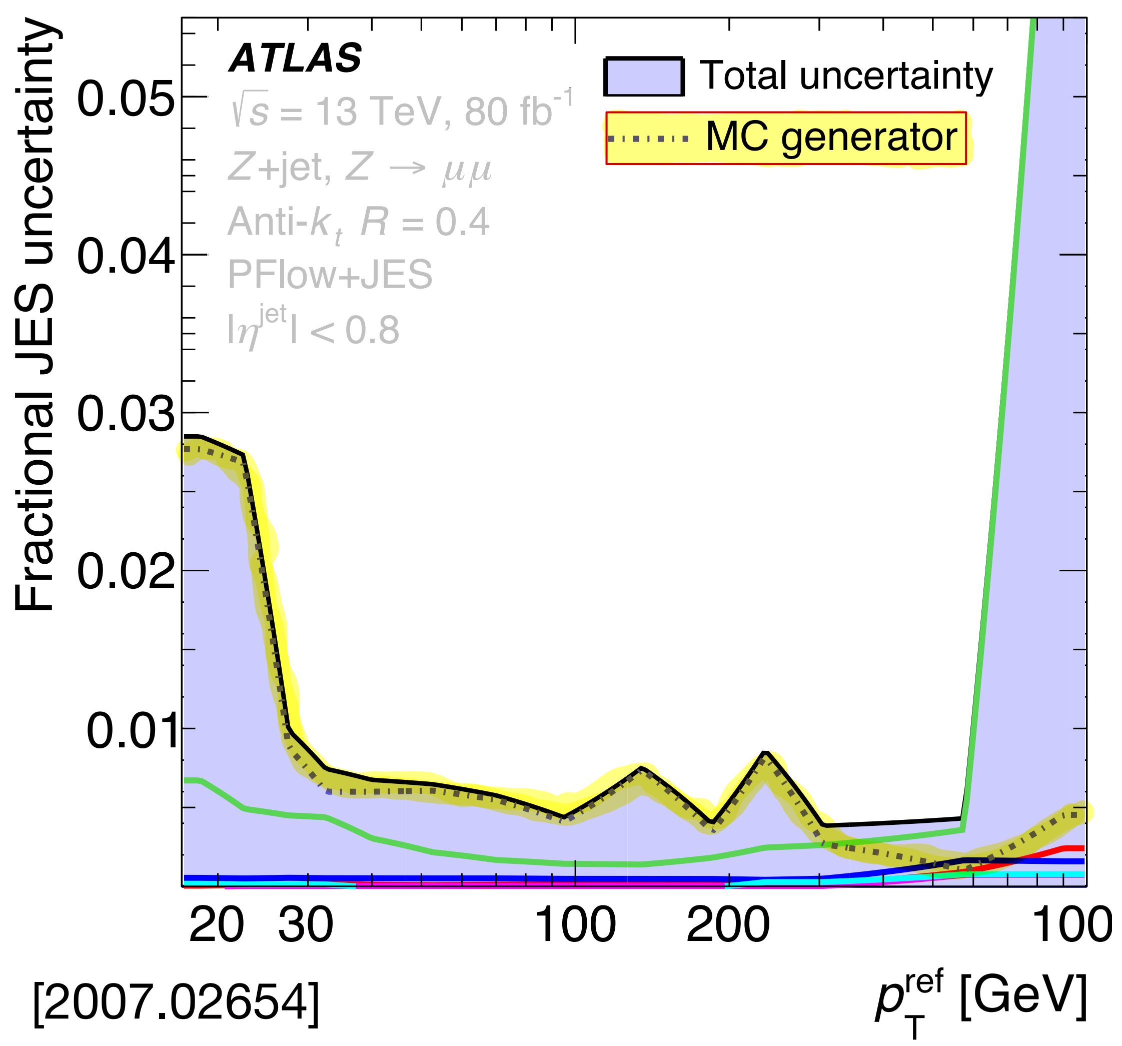
Established by the European Commission

Parton Showers

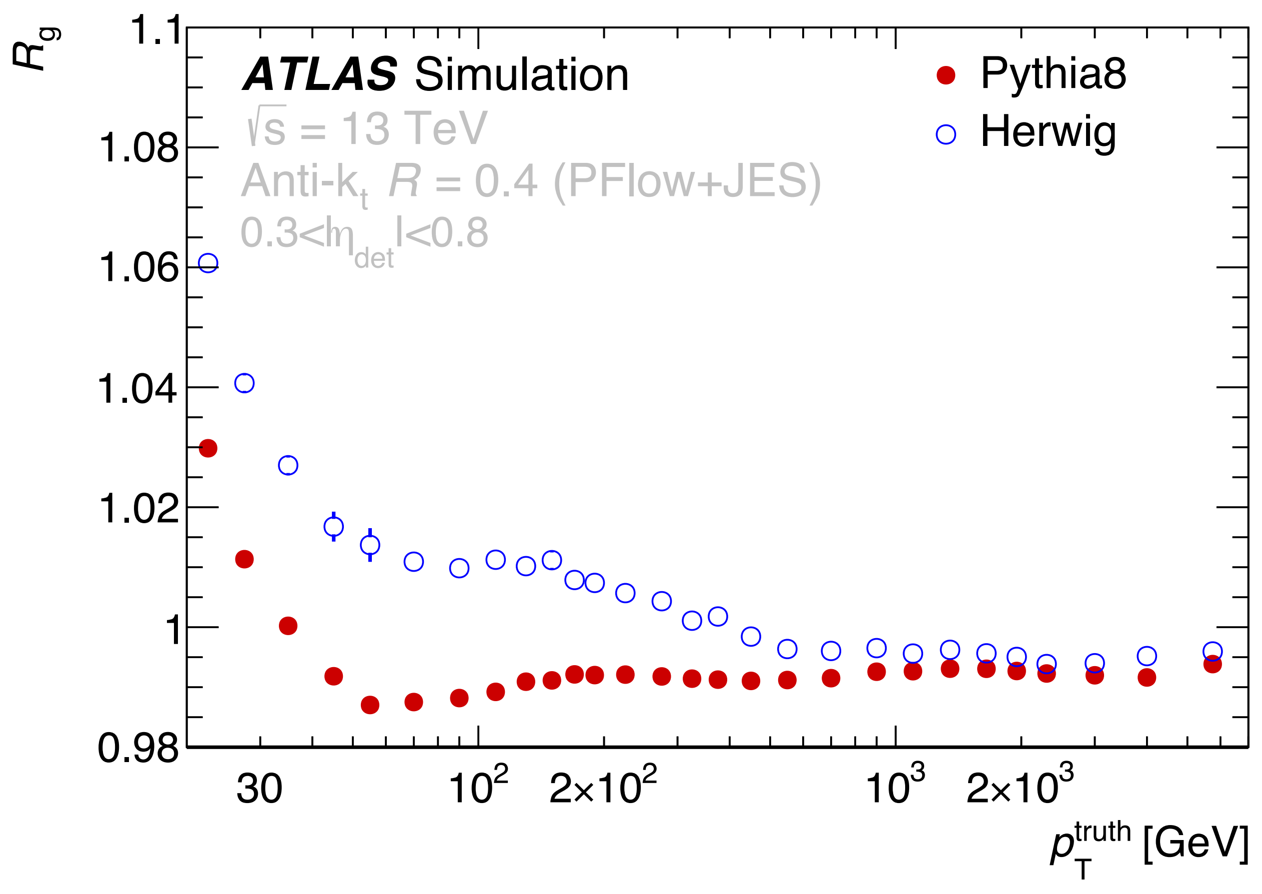
Core component of MC event generators

Need for improvement in theoretical accuracy

Jet Calibration

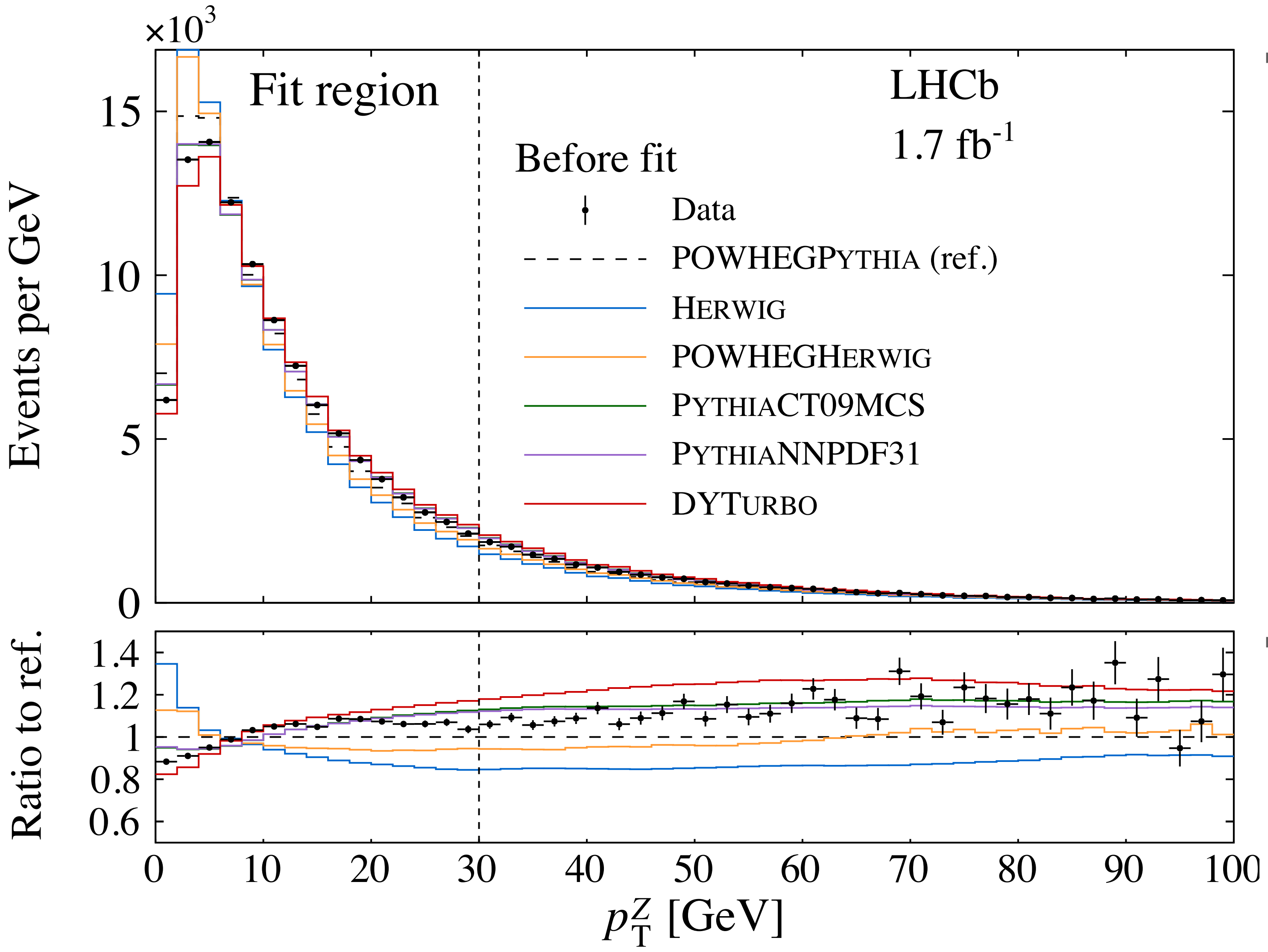


[2007.02654]



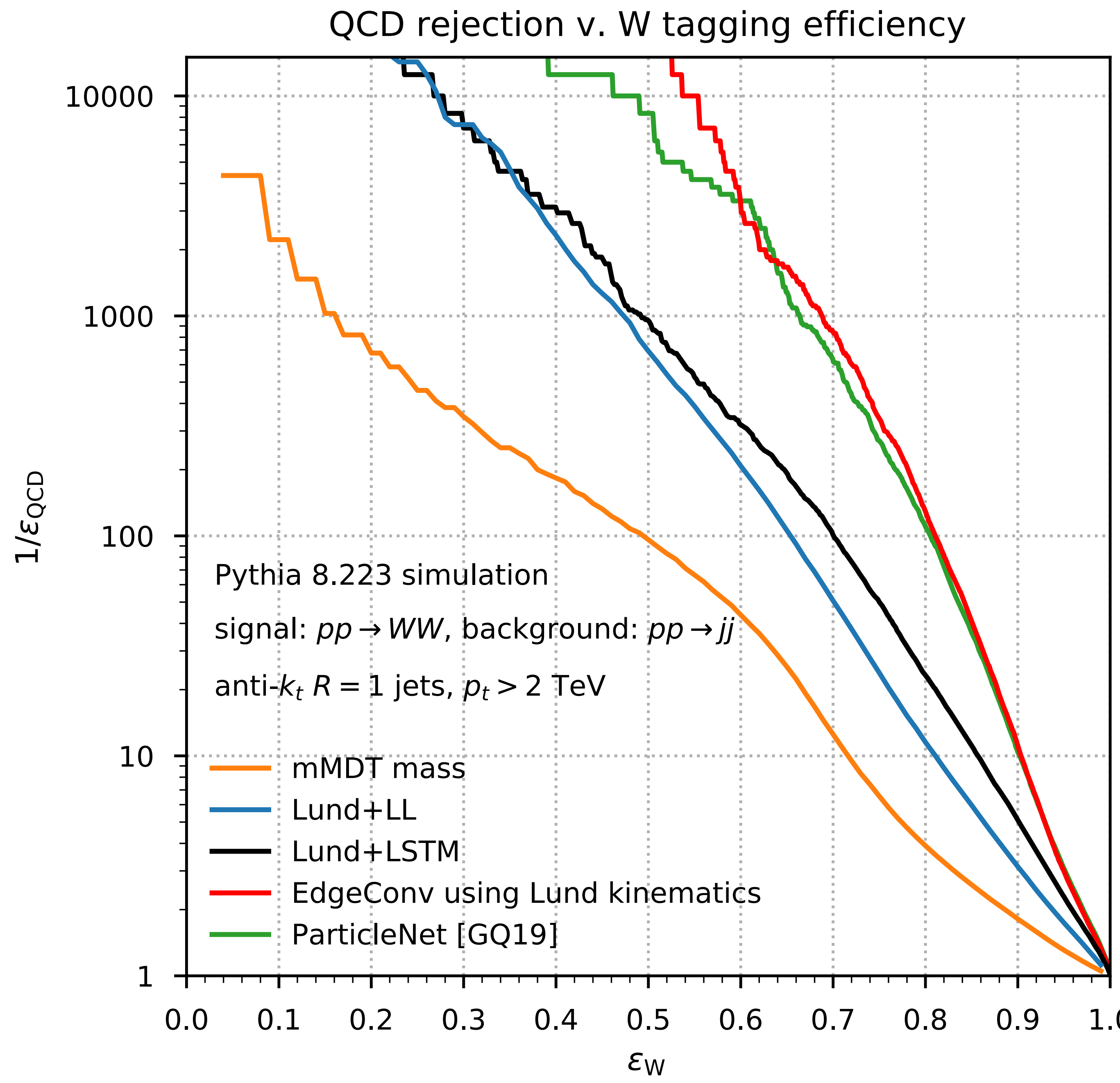
[ATLAS Eur.Phys.J.C 81 (2021) 8, 689]

EW precision measurements



[Chen et al. 2203.01565]

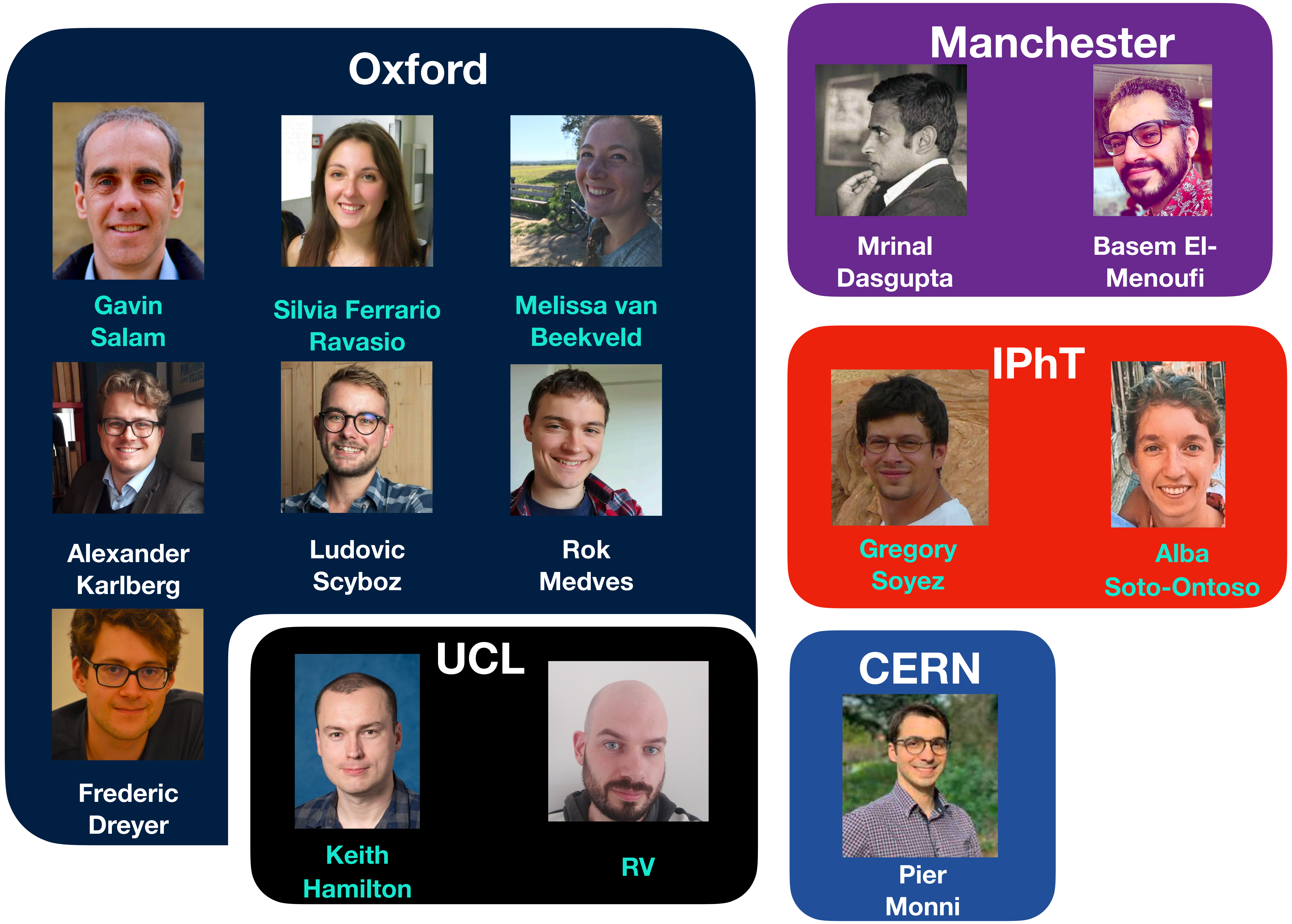
Machine Learning



Adapted from Dreyer, Qu, *JHEP* 03 (2021) 052

PanScales

Goal: Improving theoretical accuracy of parton showers



Work so far

NLL-accurate e^+e^- showers

1805.09327, 2002.11114

Full colour at NLL for global event shapes

2011.10054

Spin correlations at NLL accuracy

2103.16526, 2111.01161

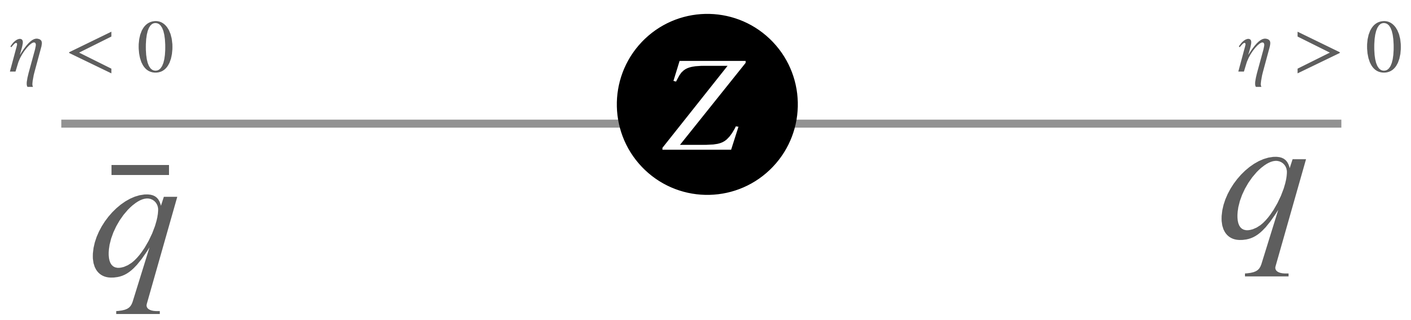
First steps toward NNLL

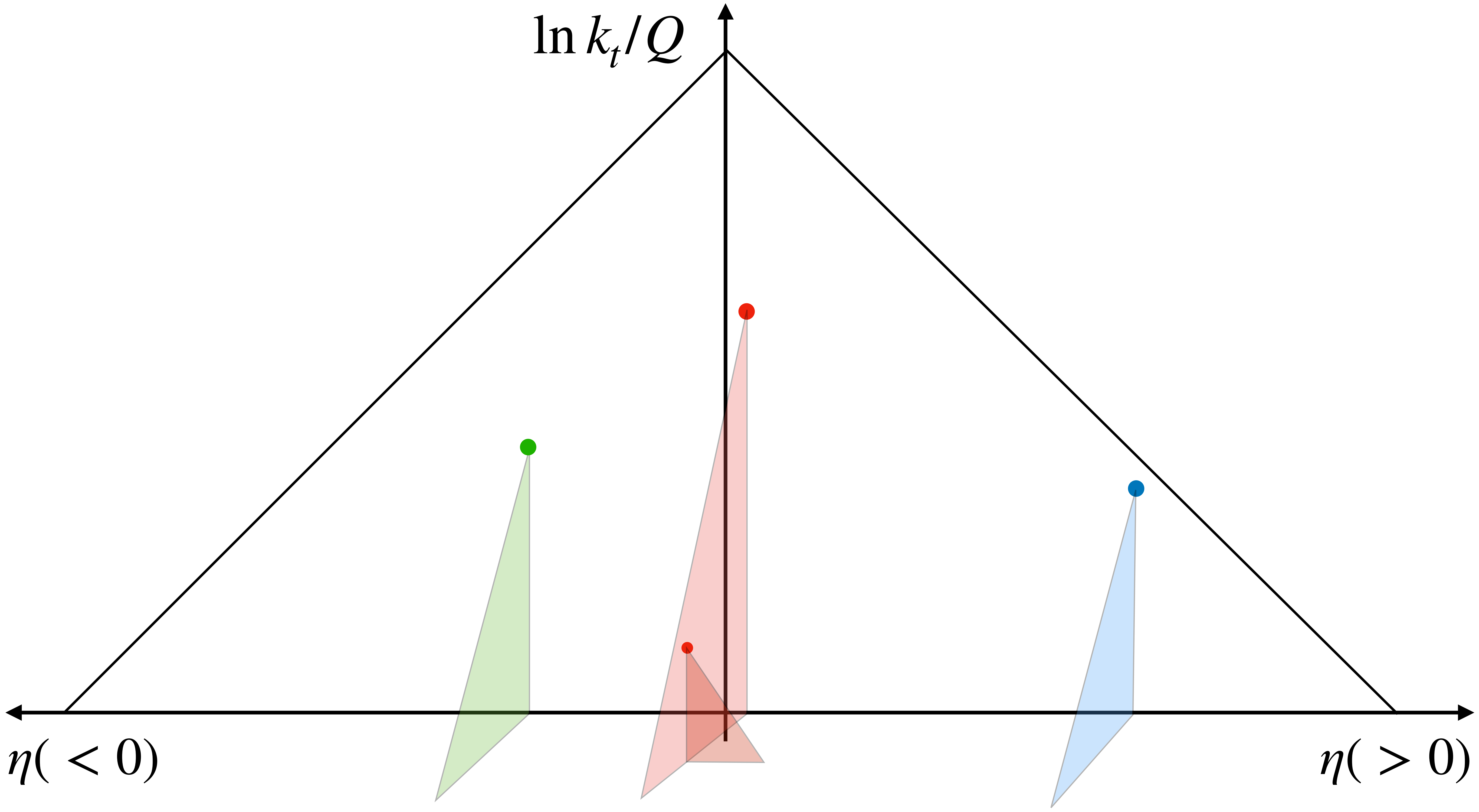
2007.10355, 2109.07496

NLL-accurate showers in hadronic colour-singlet production

2205.02237, 22XX.XXXXX

The Lund plane

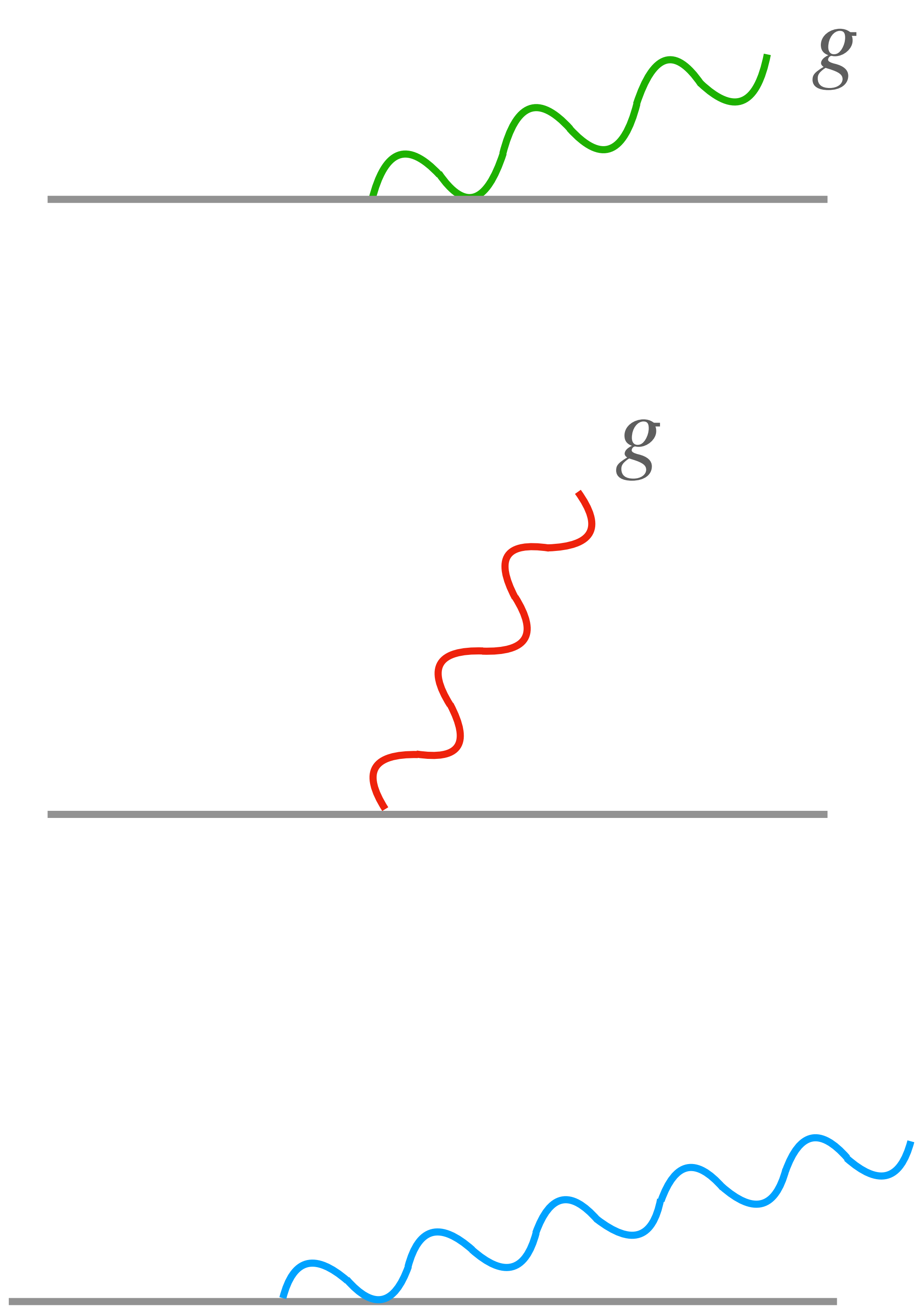




Soft-collinear

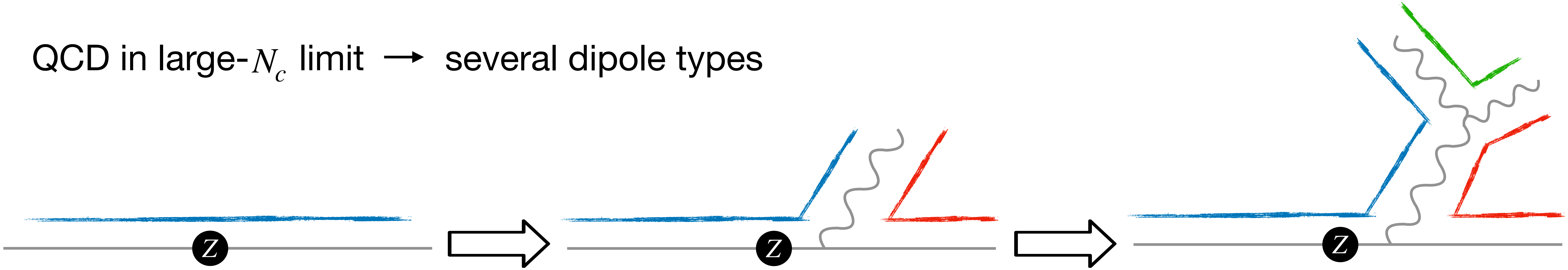
Soft wide-angle

Hard-collinear



Dipole showers in hadron collisions

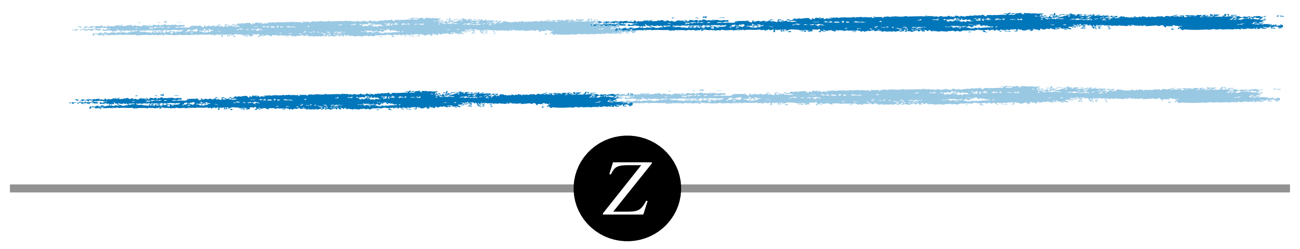
QCD in large-N_c limit ⟶ several dipole types



2x Initial-Initial (II)

2x Initial-Final (IF)
2x Final-Initial (FI)

2x Initial-Final (IF)
2x Final-Initial (FI)
2x Final-Final (FF)



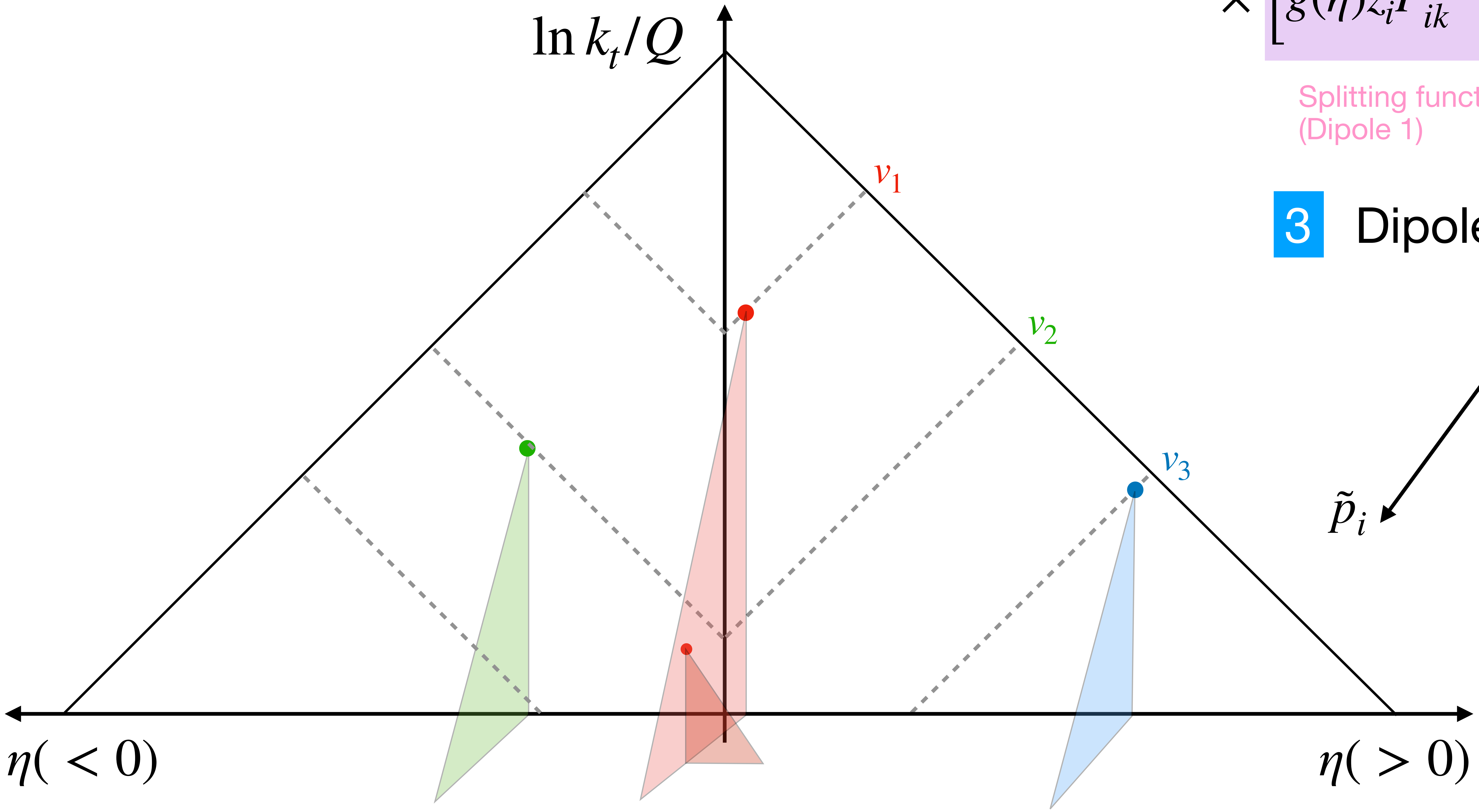
- One dipole per collinear limit
- Sum up to soft limit

Initial-state radiation ⟶ backward evolution

T. Sjöstrand, Phys. Lett. 157B (1985) 321–325.

Dipole shower

1 Ordering scale $v = k_t \exp(-\beta_{\rm ps}|\eta|)$



2 Differential splitting probability

Phase space

PDF factor

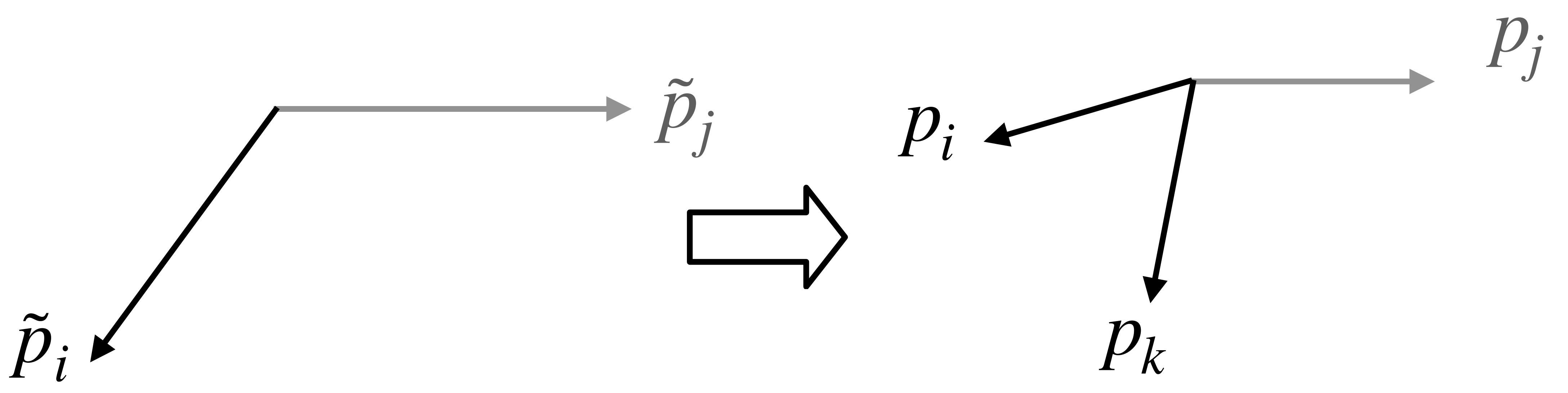
$$\mathrm{d}\mathscr{P}_{\tilde{i}\tilde{j}\to ijk} = \frac{\alpha_s(\mu_R^2)}{2\pi}\frac{\mathrm{d}v^2}{v^2}\mathrm{d}\bar{\eta}\frac{\mathrm{d}\varphi}{2\pi}\frac{x_i f_i(x_i,\mu_F^2)}{\tilde{x}_i f_{\tilde{i}}(\tilde{x}_i,\mu_F^2)}\frac{x_j f_j(x_j,\mu_F^2)}{\tilde{x}_j f_{\tilde{j}}(\tilde{x}_j,\mu_F^2)}$$

$$\times\left[g(\eta)z_i P_{ik}^{\rm IS/FS}(z_i) + g(-\eta)z_j P_{jk}^{\rm IS/FS}(z_j)\right]$$

Splitting function (Dipole 1)

Splitting function (Dipole 2)

3 Dipole recoil scheme

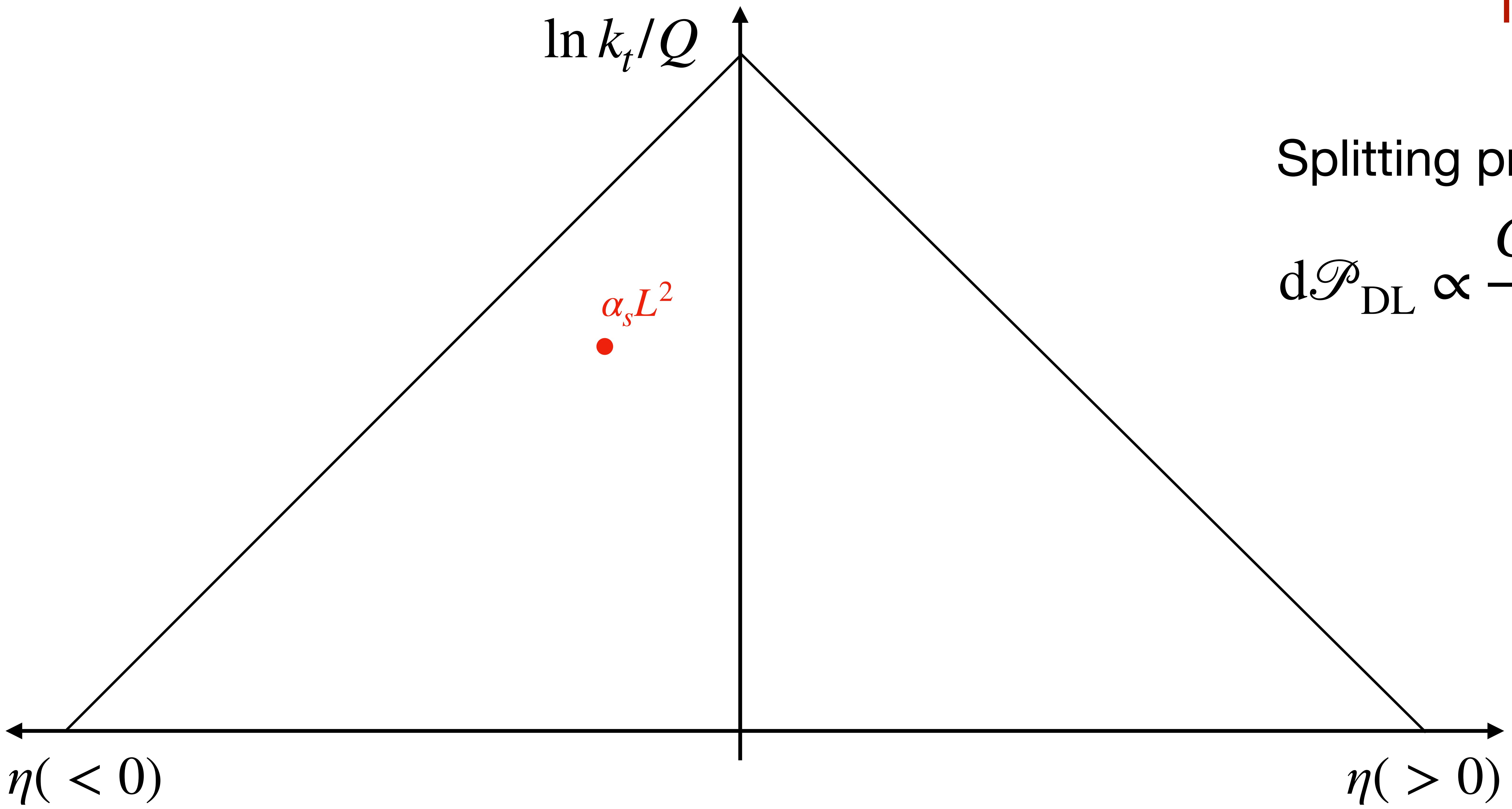


Resummation & the Lund plane

LL $\sim \mathcal{O}(1/\alpha_s)$ NNLL $\sim \mathcal{O}(\alpha_s)$

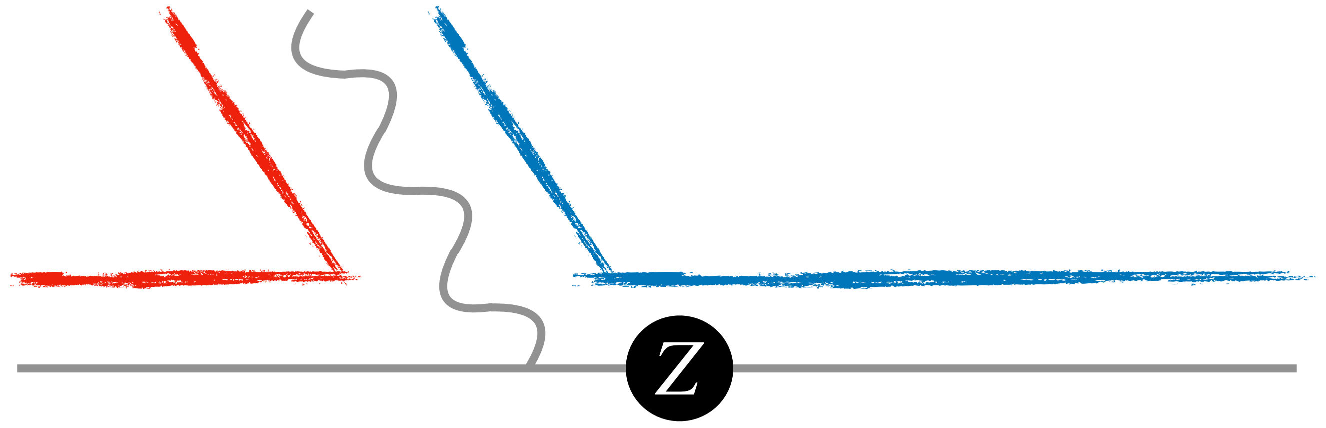
$$\Sigma(\bar{O} < e^{-L}) = \exp\left[Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \mathcal{O}(\alpha_s^n L^{n-1})\right]$$

NLL $\sim \mathcal{O}(1)$



Splitting probability

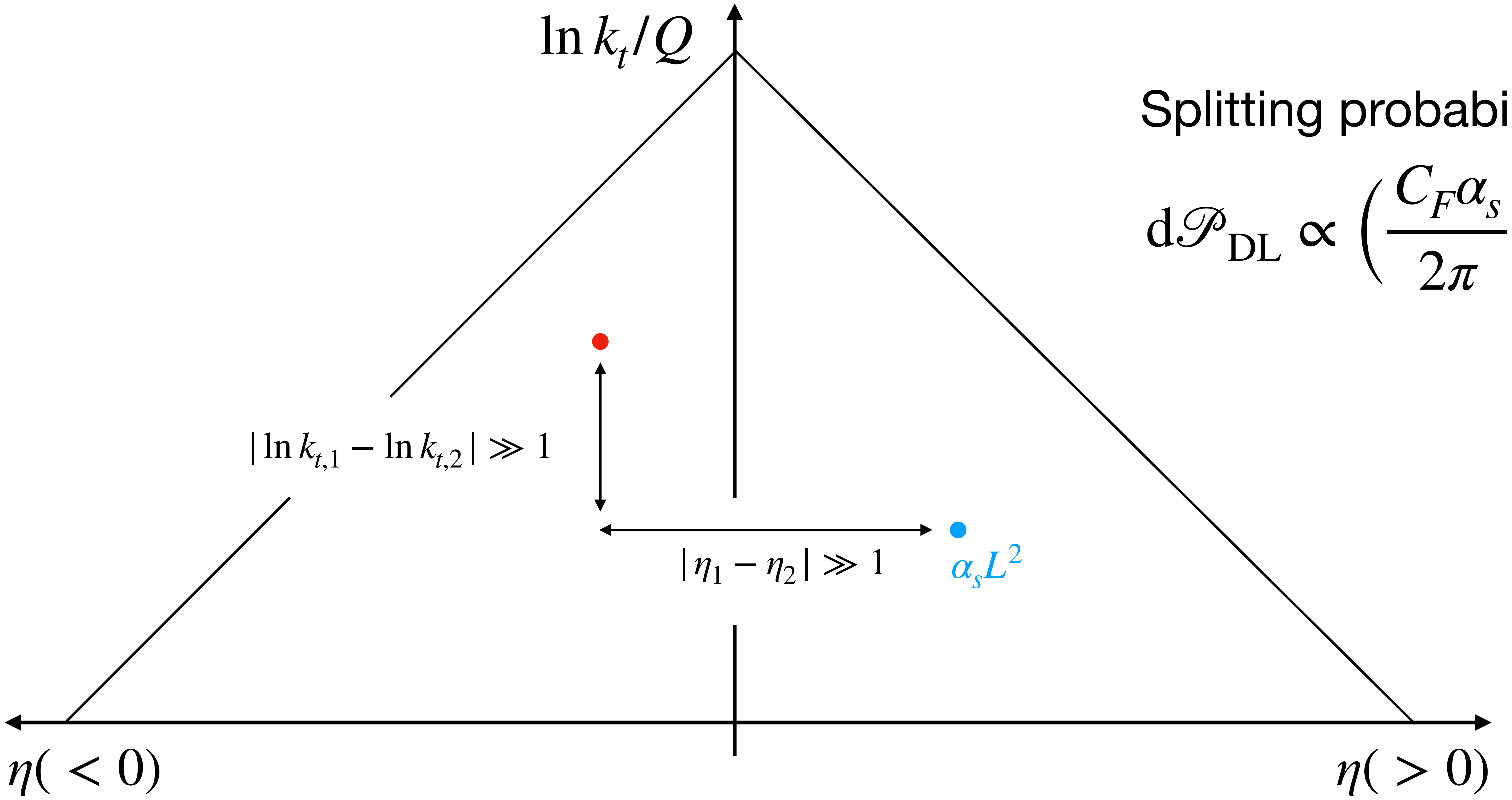
$$d\mathcal{P}_{\mathrm{DL}} \propto \frac{C_F \alpha_s}{2\pi} d\eta \frac{dk_t}{k_t}$$



Resummation & the Lund plane

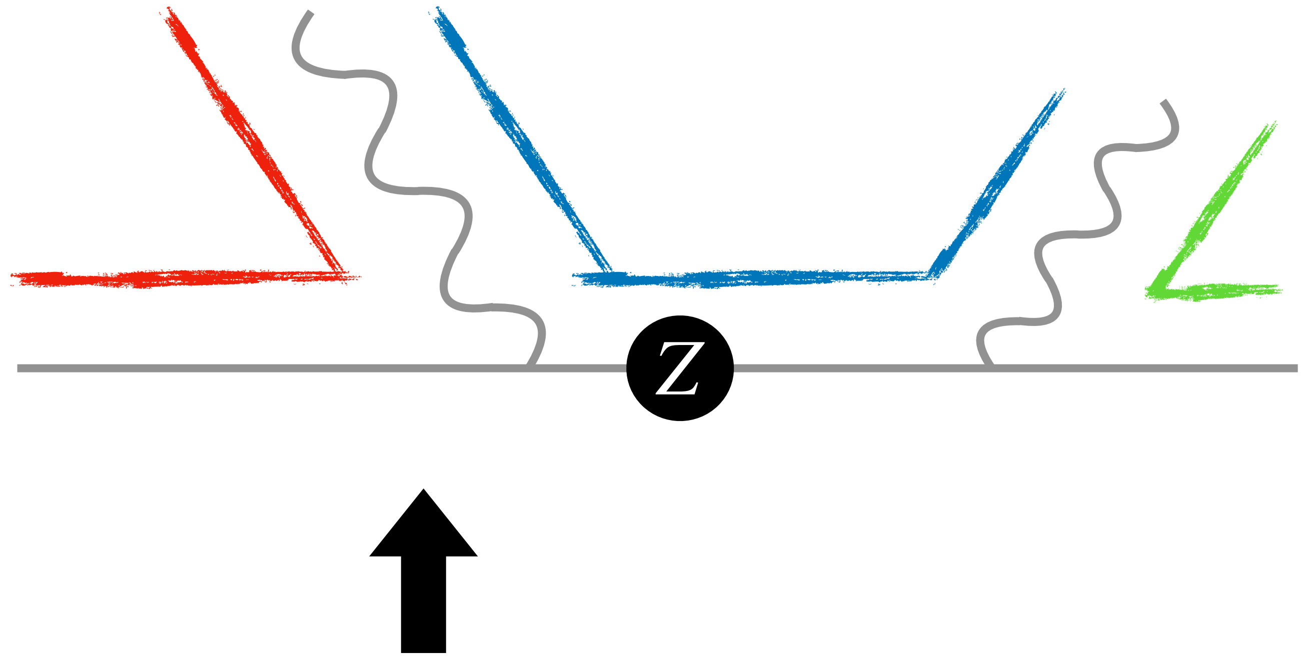
LL$\sim \mathcal{O}(1/\alpha_s)$

$$\Sigma(\bar{O} < e^{-L}) = \exp\left[Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \mathcal{O}(\alpha_s^n L^{n-1})\right]$$



Splitting probability

$$\mathrm{d}\mathcal{P}_{\mathrm{DL}} \propto \left(\frac{C_F\alpha_s}{2\pi}\right)^2 \mathrm{d}\eta_1 \frac{\mathrm{d}k_{t,1}}{k_{t,1}} \times \mathrm{d}\eta_2 \frac{\mathrm{d}k_{t,2}}{k_{t,2}}$$

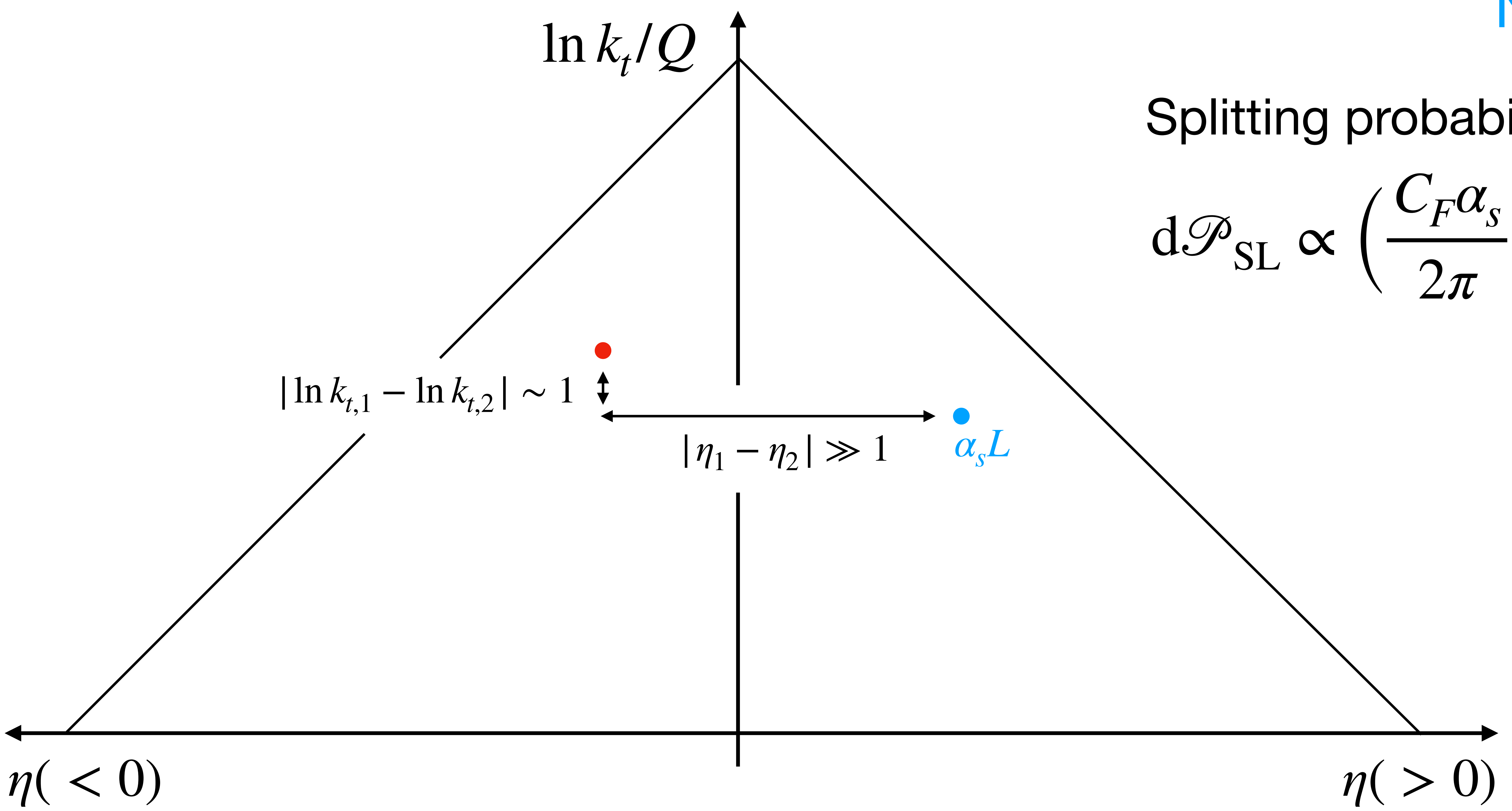


No recoil on the first emission

Resummation & the Lund plane

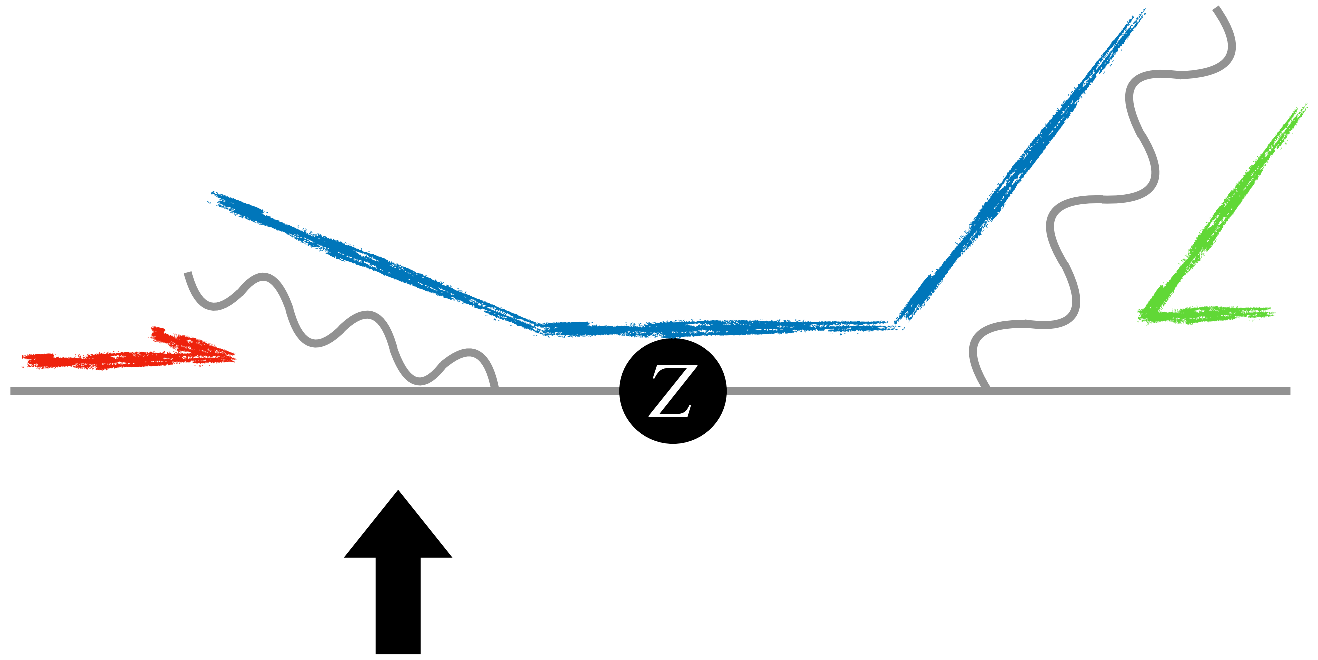
$$\Sigma(\bar{O} < e^{-L}) = \exp\left[Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \mathcal{O}(\alpha_s^n L^{n-1})\right]$$

NLL $\sim \mathcal{O}(1)$



Splitting probability

$$d\mathcal{P}_{SL} \propto \left(\frac{C_F \alpha_s}{2\pi}\right)^2 d\eta_1 \frac{dk_{t,1}}{k_{t,1}} \times d\eta_2 \frac{dk_{t,2}}{k_{t,2}}$$



Recoil on the first emission

Dipole-k_t: A standard dipole shower

1 Ordering scale

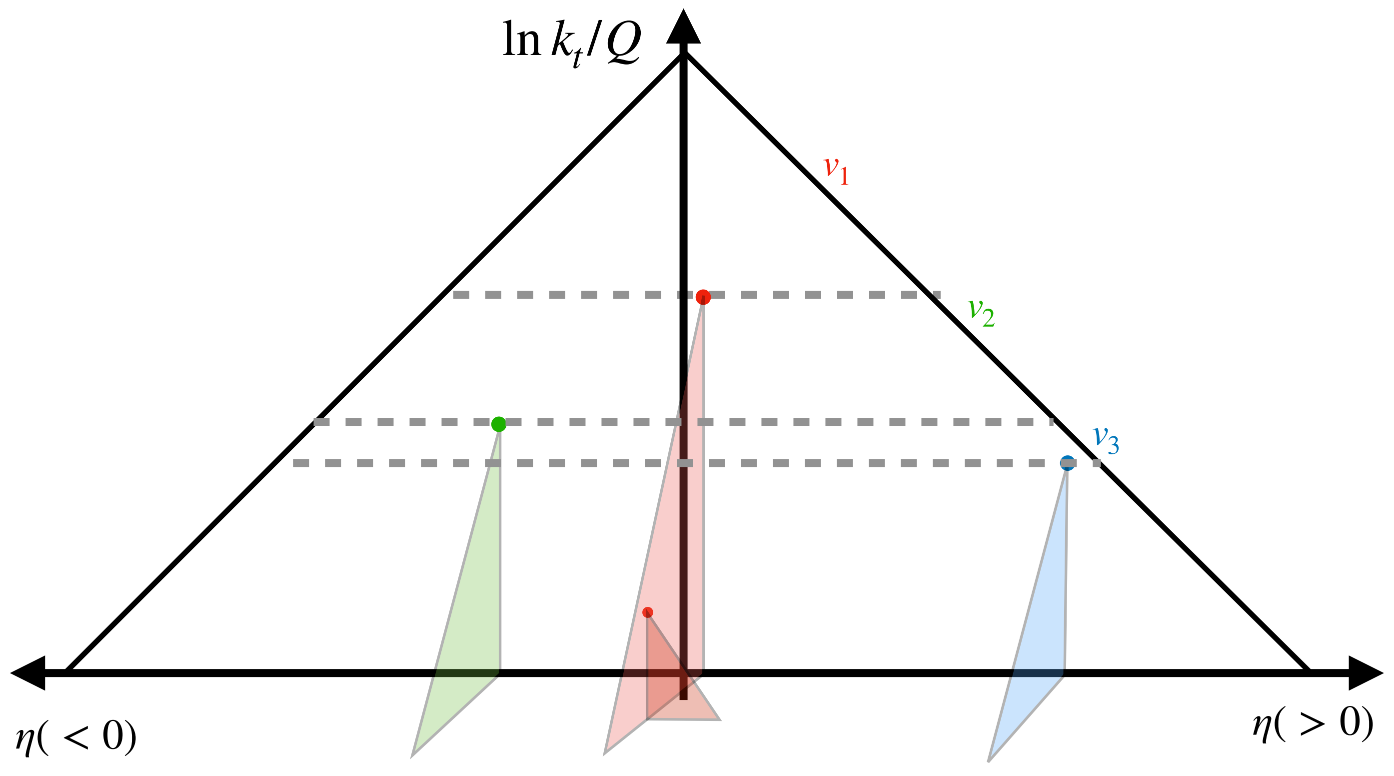
$v = k_t$

2 Recoil scheme

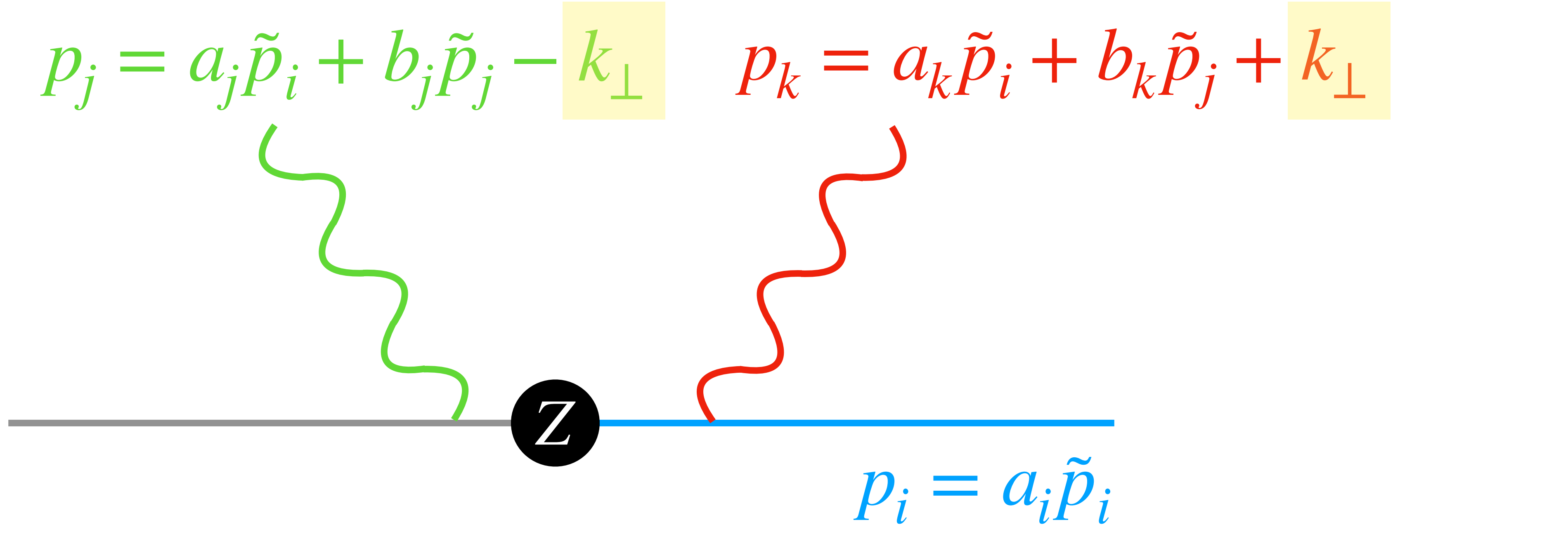
a II: Global recoil

b FI, FF: Local recoil

c IF: Local/global recoil



IF Local ⇒



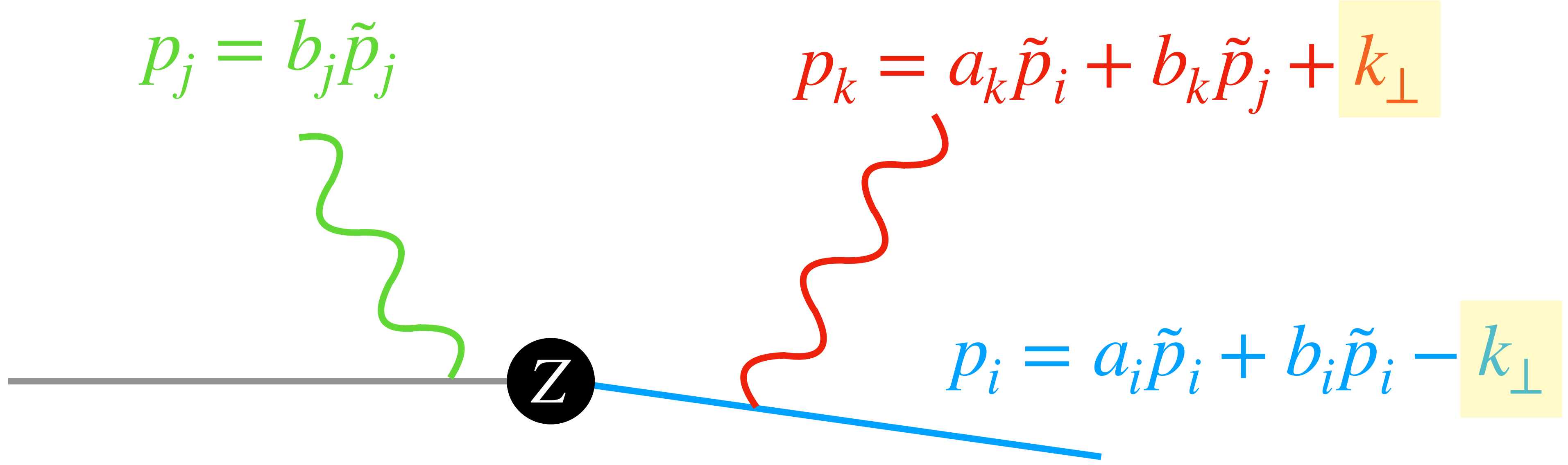
⇒ **Wrong p_t^Z at NLL**

[Platzer, Gieseke JHEP 01 (2011) 024]

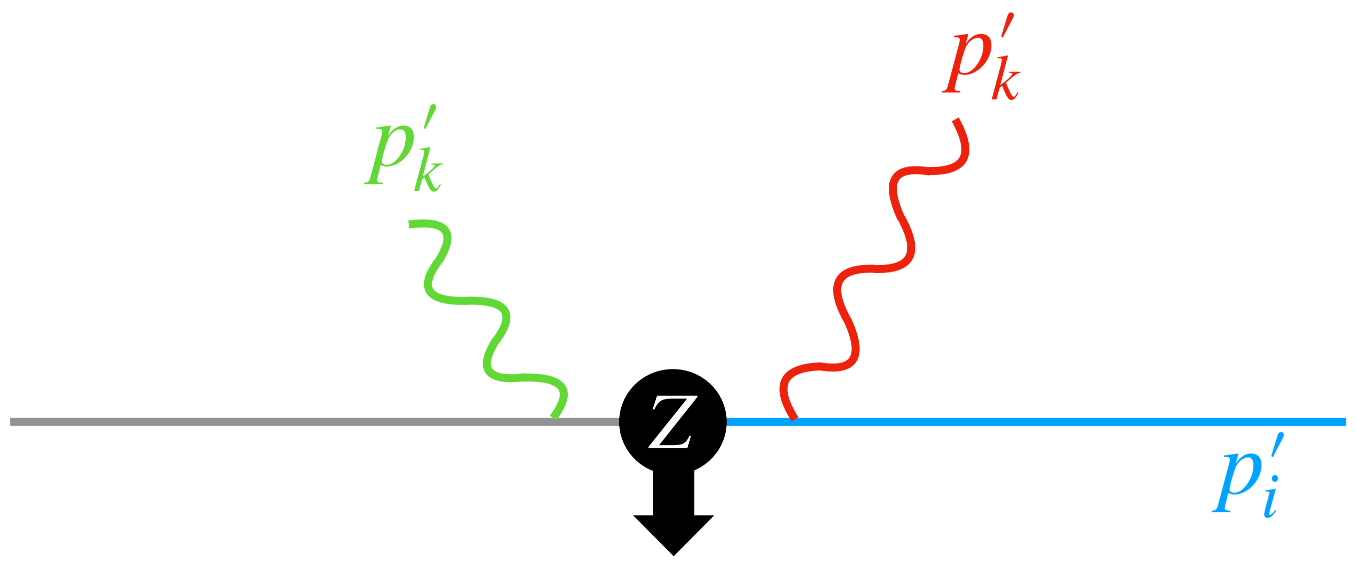
[Nagy, Soper JHEP 03 (2010) 097]

[Parisi, Petronzio, NPB 154 (1979) 427-440]

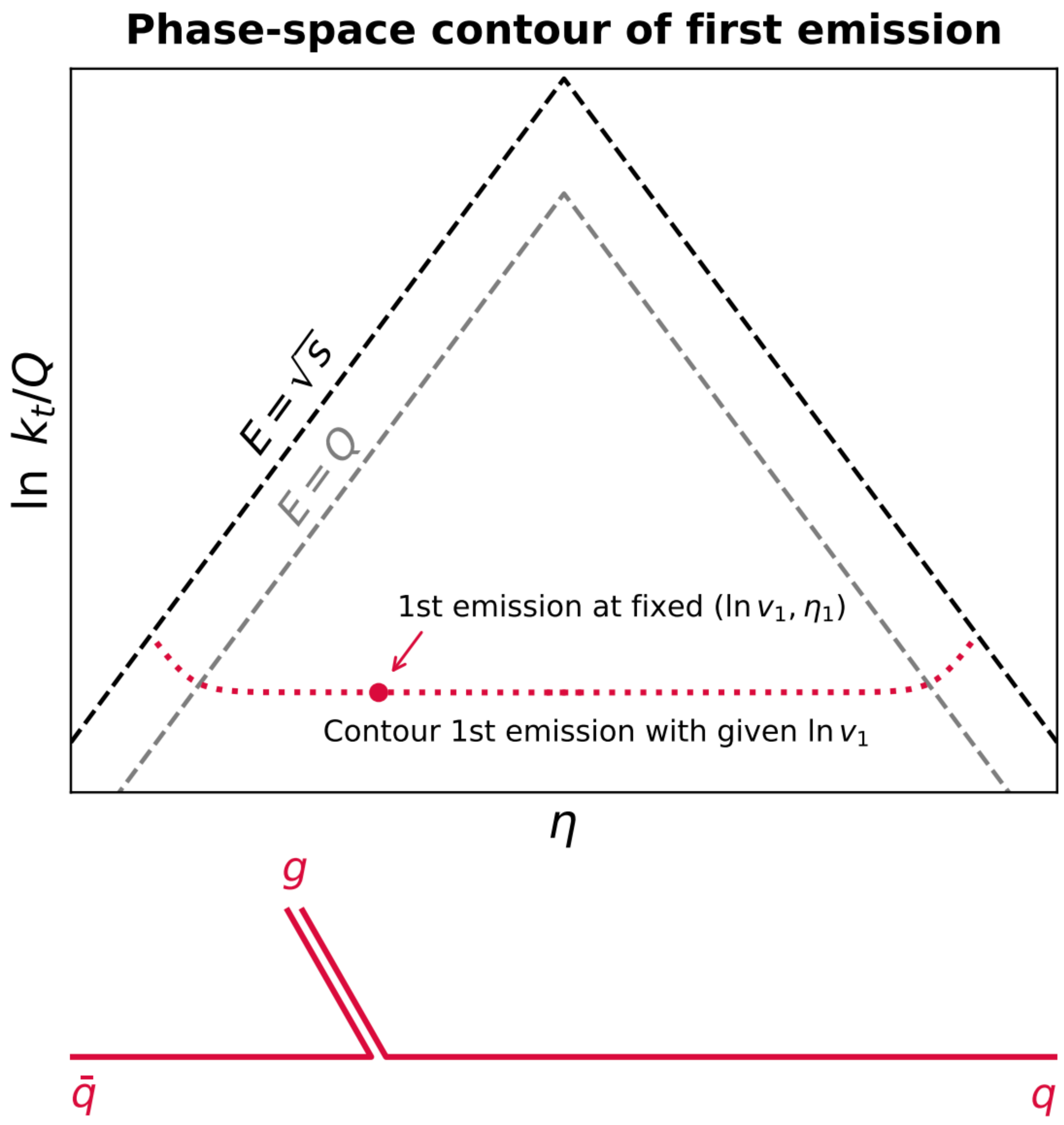
IF Global ⇒

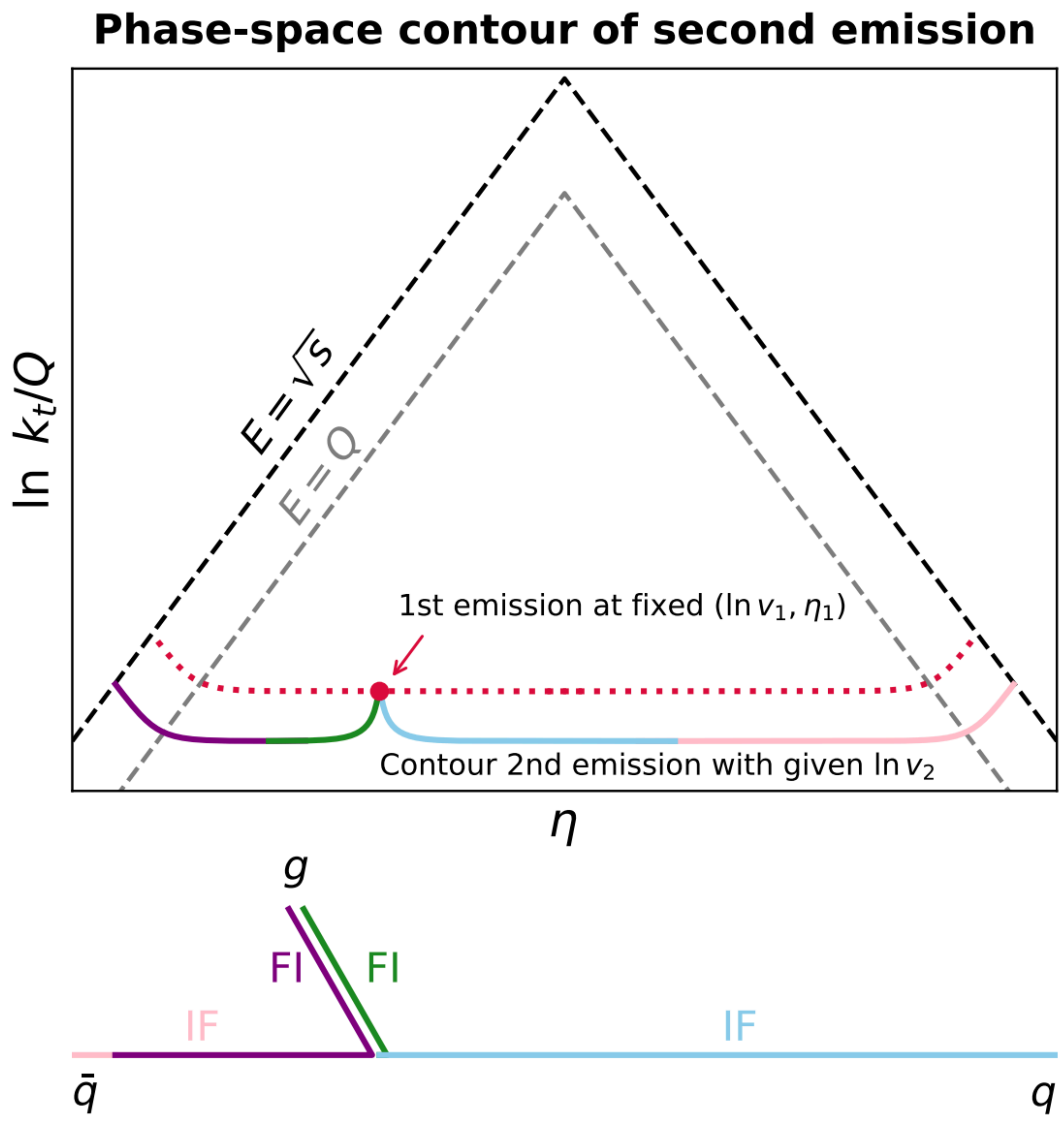


$B^{\mu\nu}$ ⇒

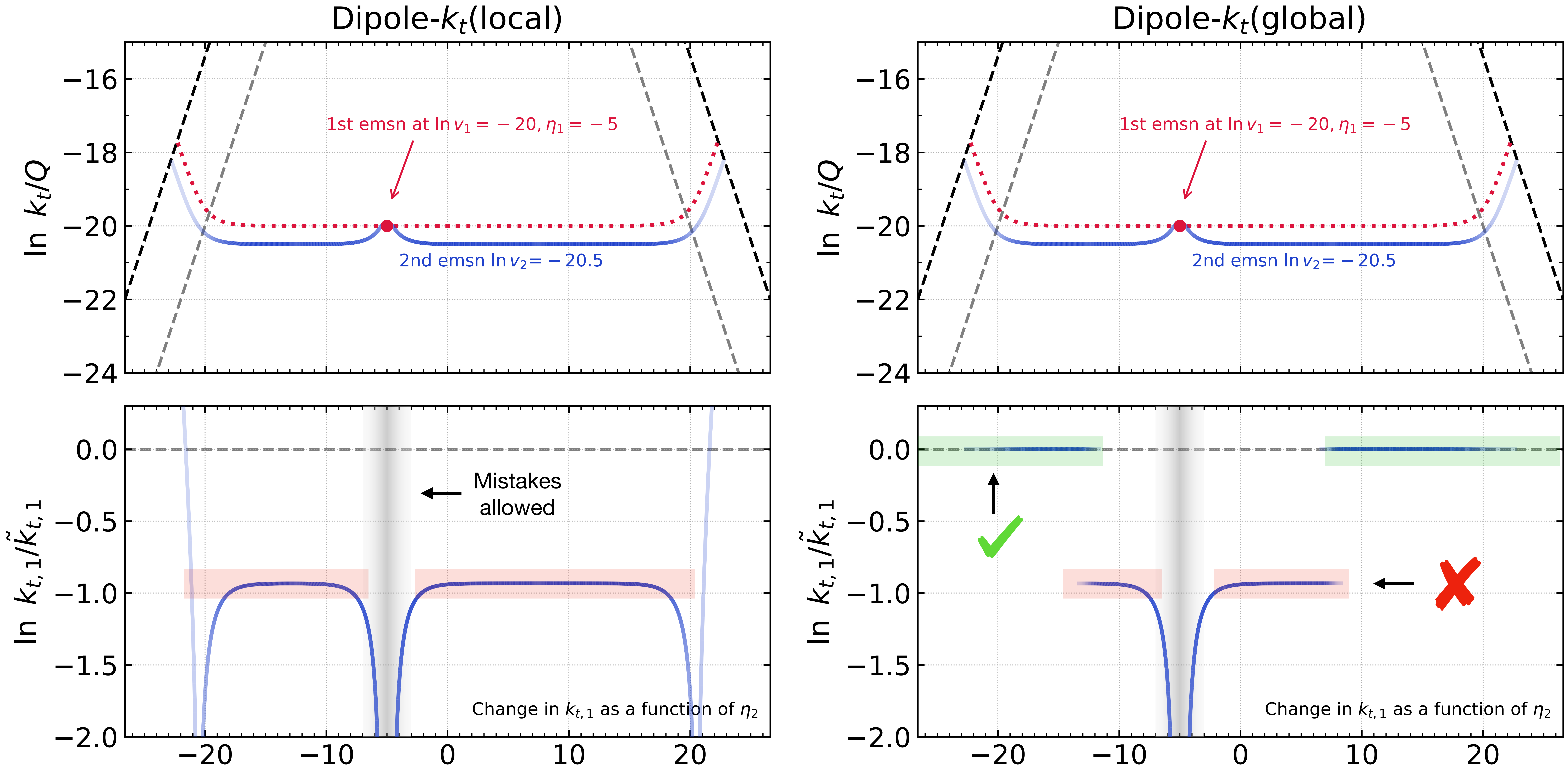


Dipole-k_t: Fixed-order tests



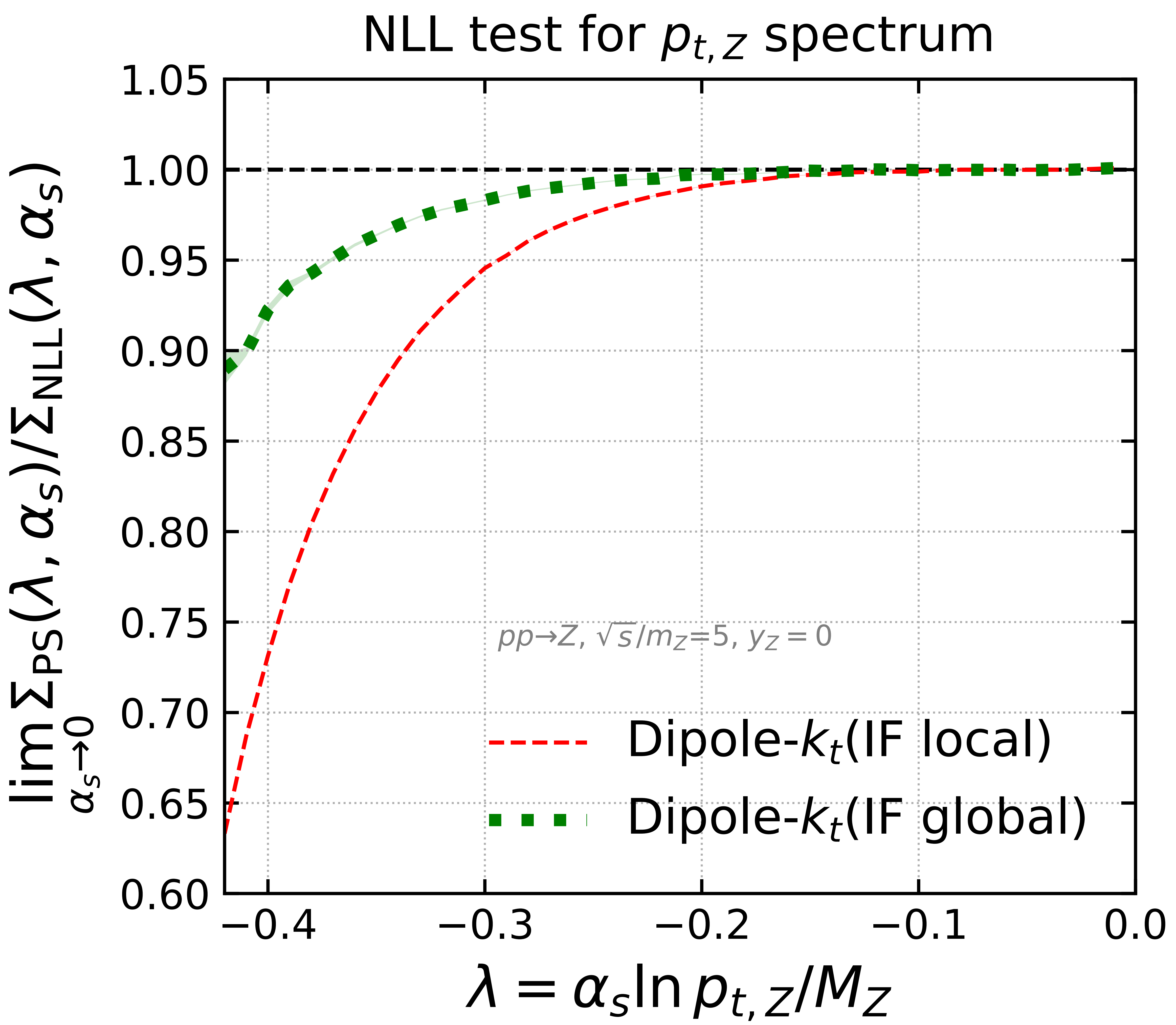


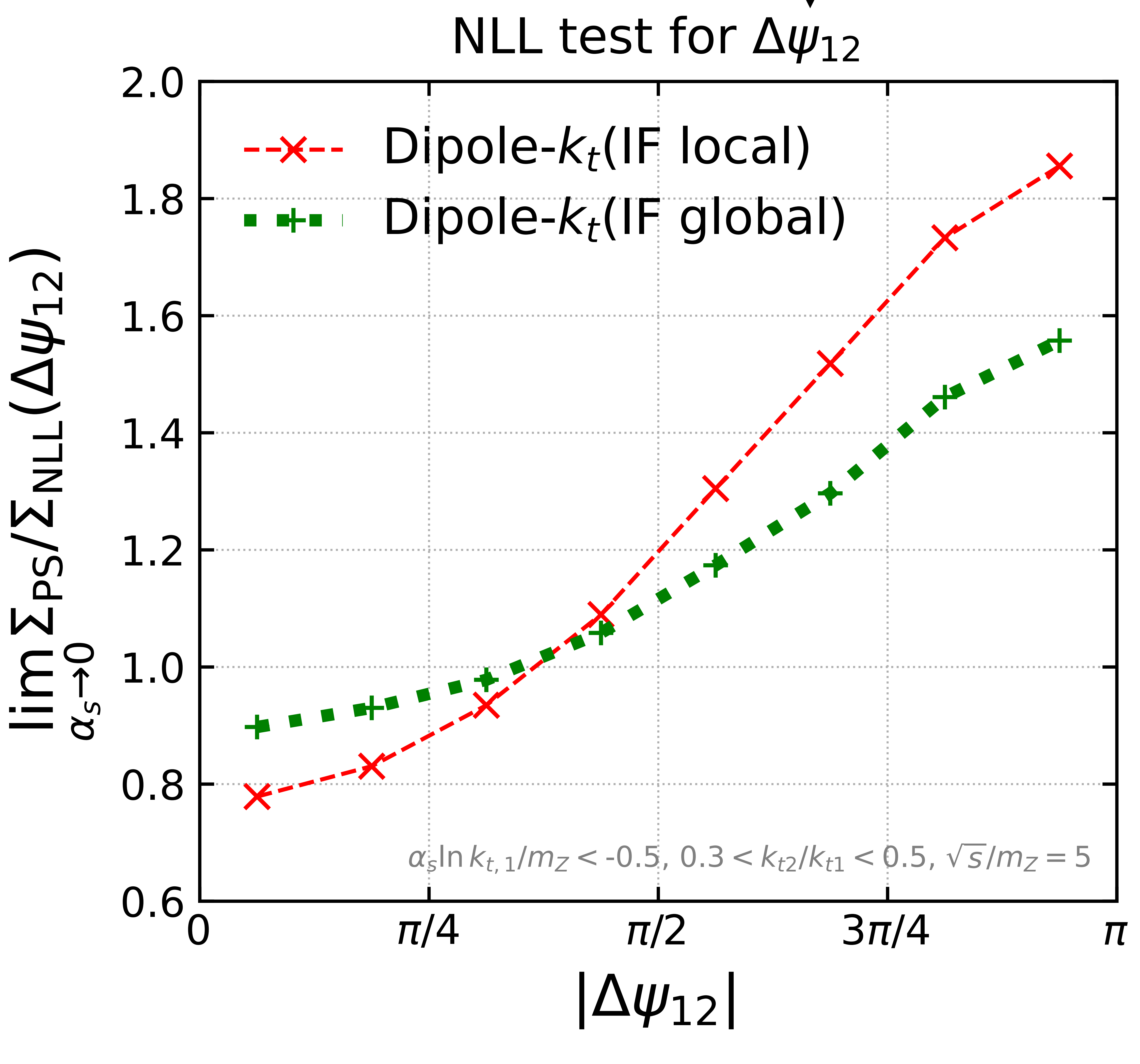
Dipole-k_t: Fixed-order tests



Dipole-k_t: All-order tests

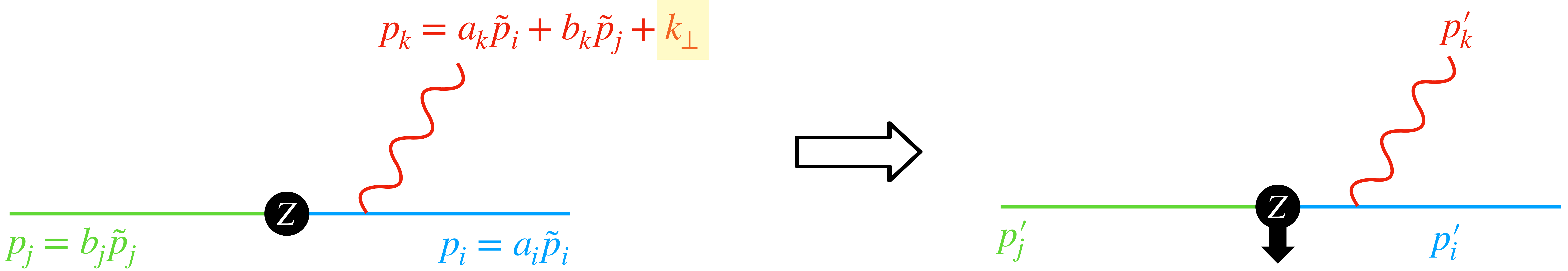
Azimuthal angle between the leading jets



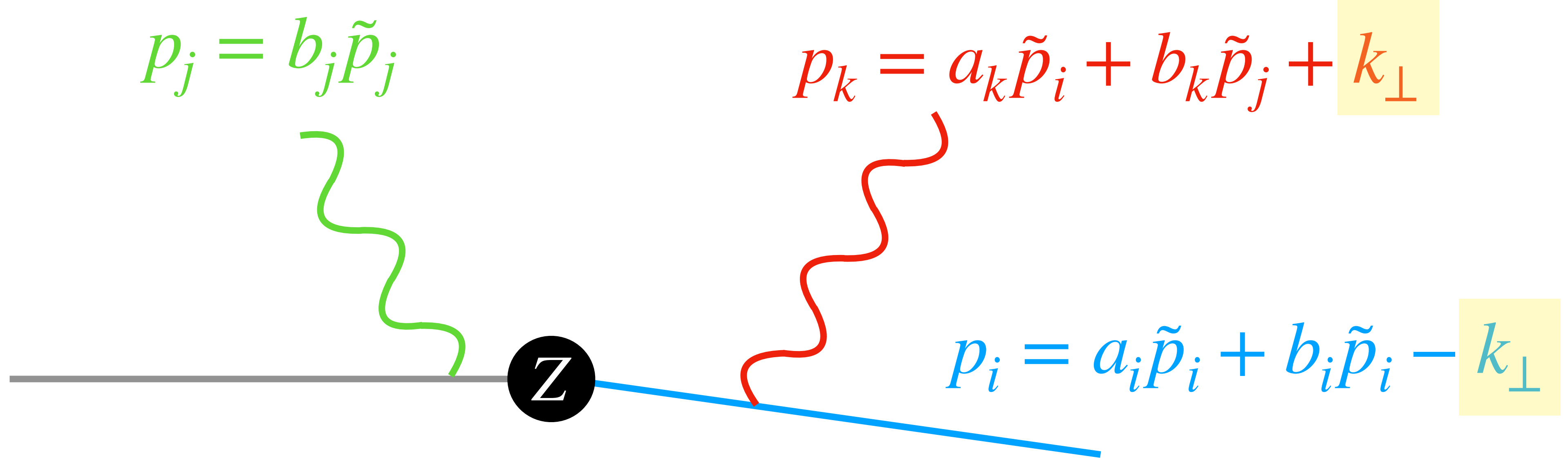


The PanScales showers

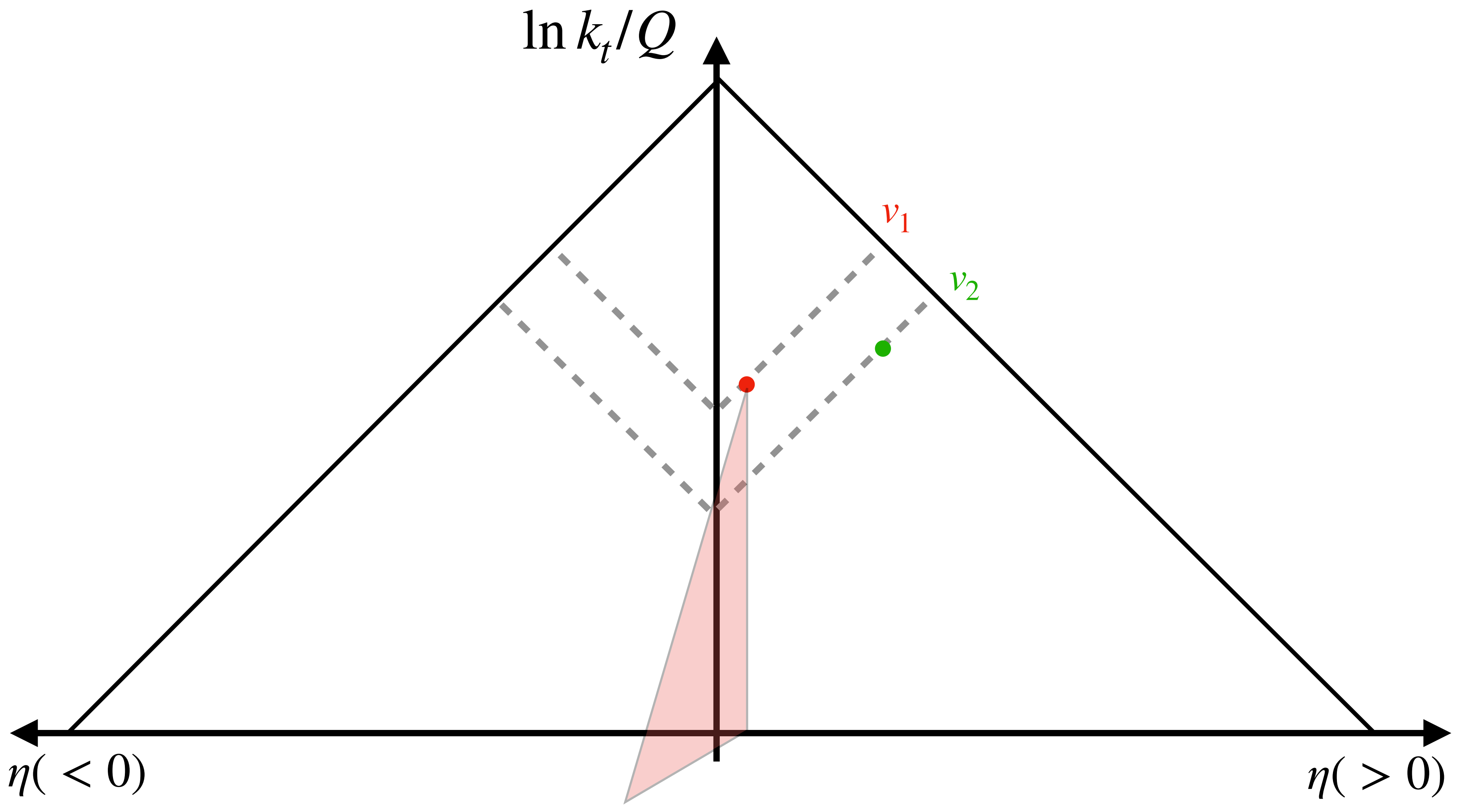
PanGlobal: Always distribute recoil globally



PanLocal: Local recoil, but require $\beta_{\rm ps} > 0$



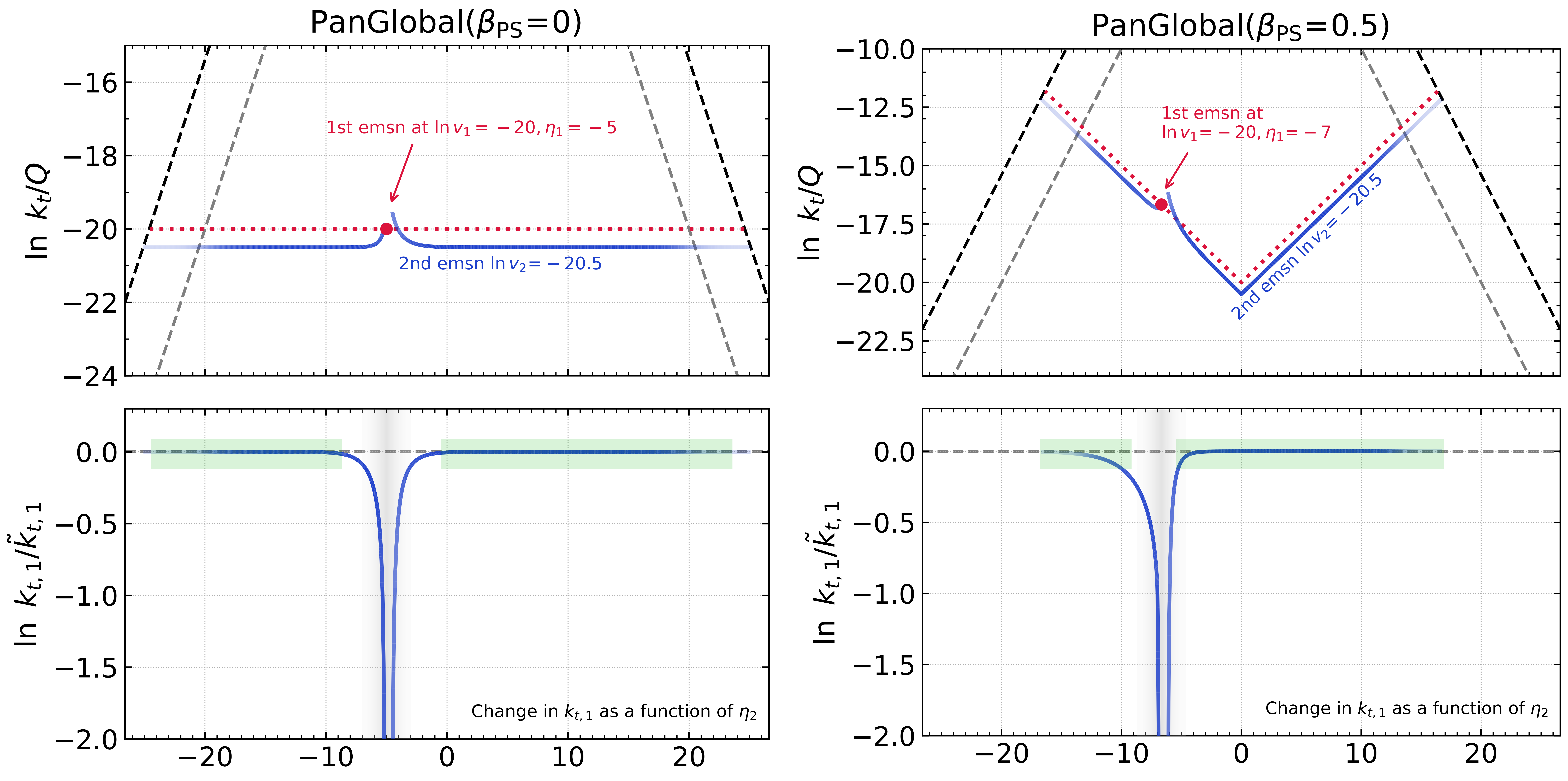
Require boost only if initial-state leg acquires $k_\perp$



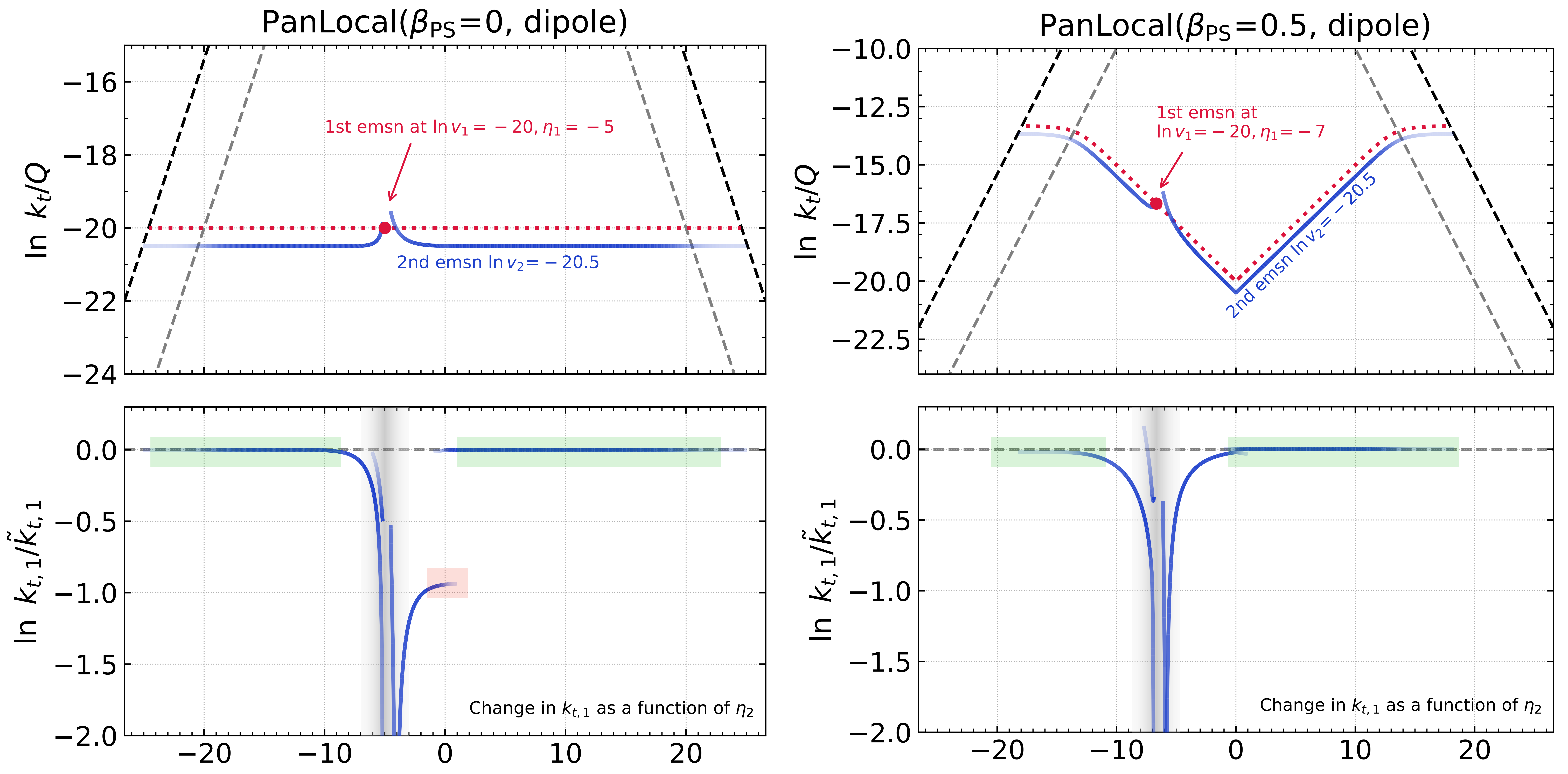
Emissions at large $|\eta|$ occur later

→ Recoil always taken from the hard leg

PanGlobal: Fixed-order tests

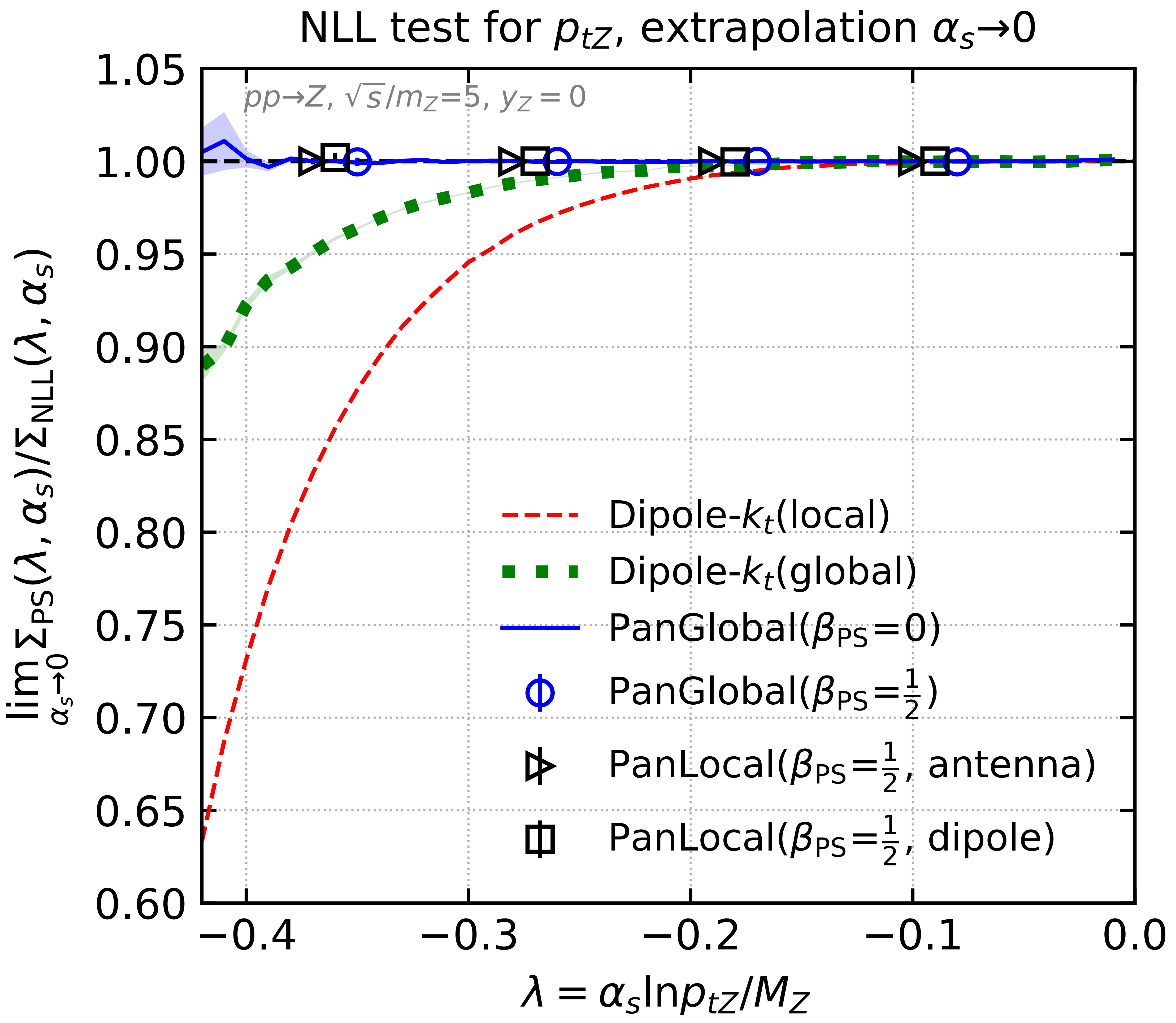


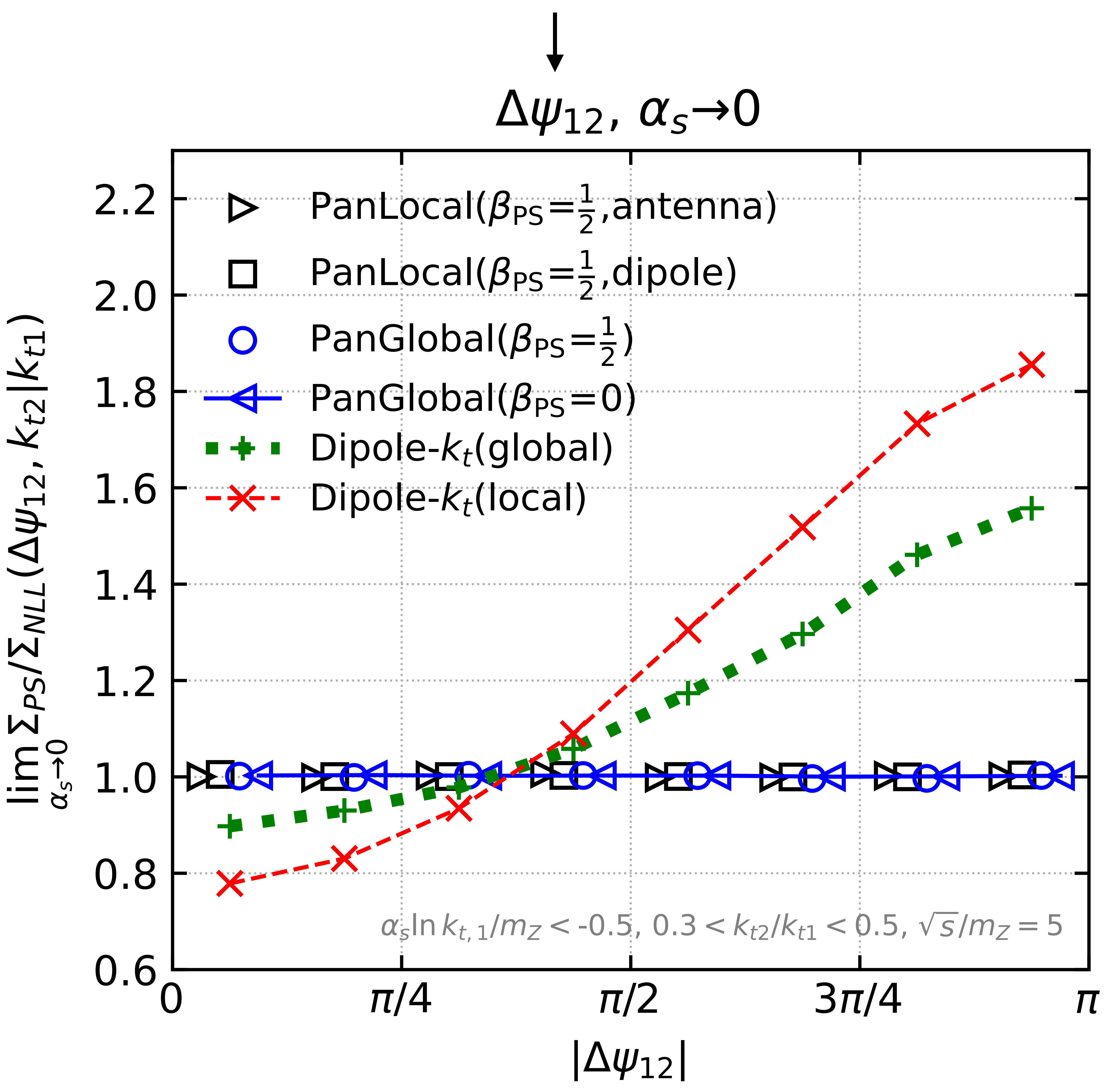
PanLocal: Fixed-order tests



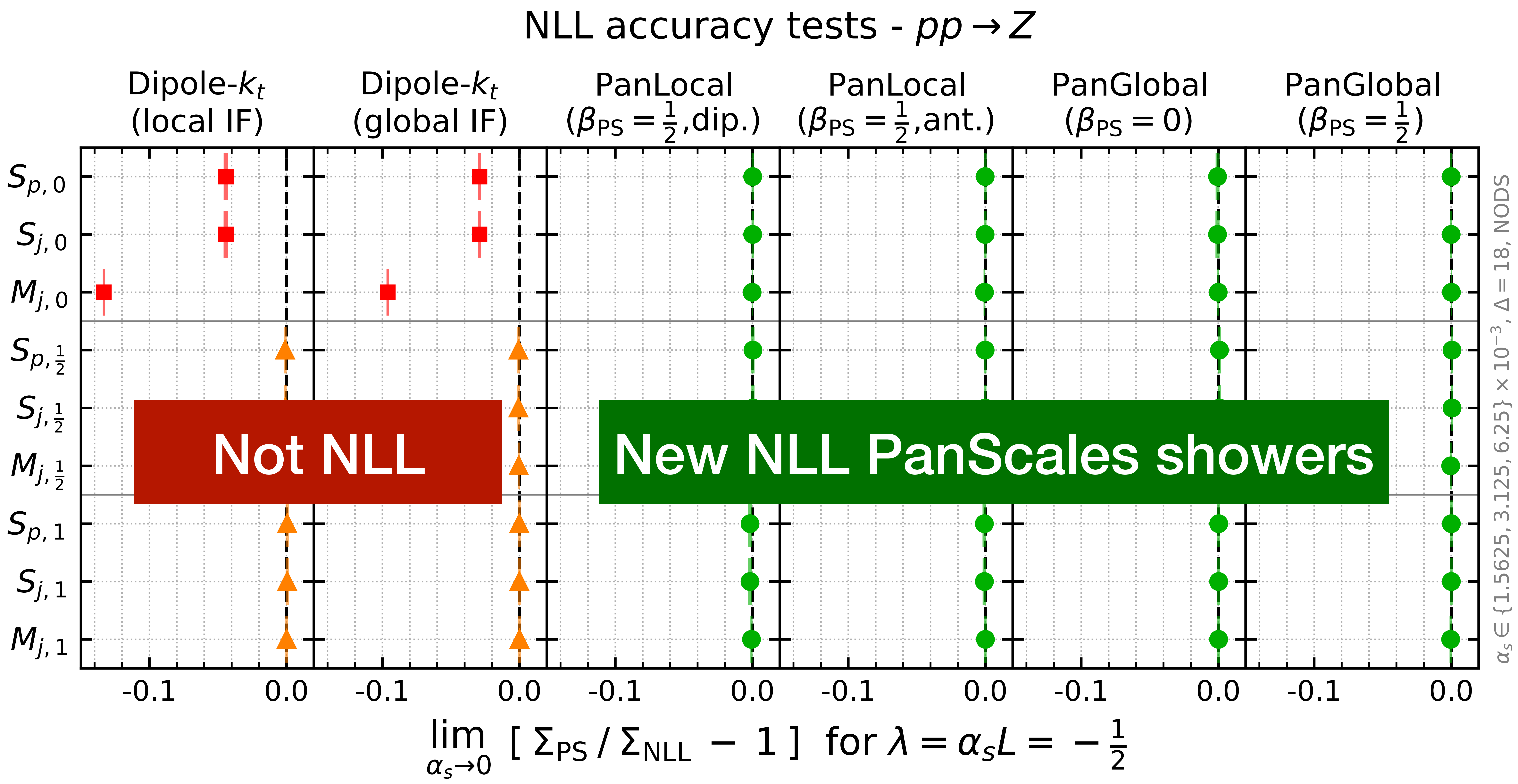
PanScales: All-order tests

Azimuthal angle between the leading jets





PanScales: All-order tests



$$S_{p,\beta_{obs}} = \sum_{i \in p} \frac{k_{t,i}}{Q} e^{-\beta_{obs}|\eta_i|} \qquad S_{j,\beta_{obs}} = \sum_{i \in j} \frac{k_{t,i}}{Q} e^{-\beta_{obs}|\eta_i|} \qquad M_{j,\beta_{obs}} = \max_{i \in j} \frac{k_{t,i}}{Q} e^{-\beta_{obs}|\eta_i|}$$

Conclusions

- PanScales: a project to bring logarithmic understanding & accuracy to parton showers

- NLL accuracy has been achieved for e^+e^- and colour singlet production in pp

- Next steps include (not in order of priority):
  - **Matching to hard matrix elements:** essential for NNDL accuracy
  - **Heavy quarks:** needed for pheno + interesting resummation
  - **Interface to Pythia:** retuning of hadronisation model
  - **Extension of pp showers** to more complex processes, i.e. Z+jet and dijets
  - **NLL showers for deep-inelastic scattering**
  - **Towards NNLL showers:** higher-order kernels, i.e. double soft, triple collinear

Backup

Mapping from logarithmic to physical

Q [GeV]	$\alpha_s(Q)$	$p_{t,\min}$ [GeV]	$\xi = \alpha_s L^2$	$\lambda = \alpha_s L$	τ
91.2	0.1181	1.0	2.4	−0.53	0.27
91.2	0.1181	3.0	1.4	−0.40	0.18
91.2	0.1181	5.0	1.0	−0.34	0.14
1000	0.0886	1.0	4.2	−0.61	0.36
1000	0.0886	3.0	3.0	−0.51	0.26
1000	0.0886	5.0	2.5	−0.47	0.22
4000	0.0777	1.0	5.3	−0.64	0.40
4000	0.0777	3.0	4.0	−0.56	0.30
4000	0.0777	5.0	3.5	−0.52	0.26
20000	0.0680	1.0	6.7	−0.67	0.45
20000	0.0680	3.0	5.3	−0.60	0.34
20000	0.0680	5.0	4.7	−0.56	0.30

Extrapolation