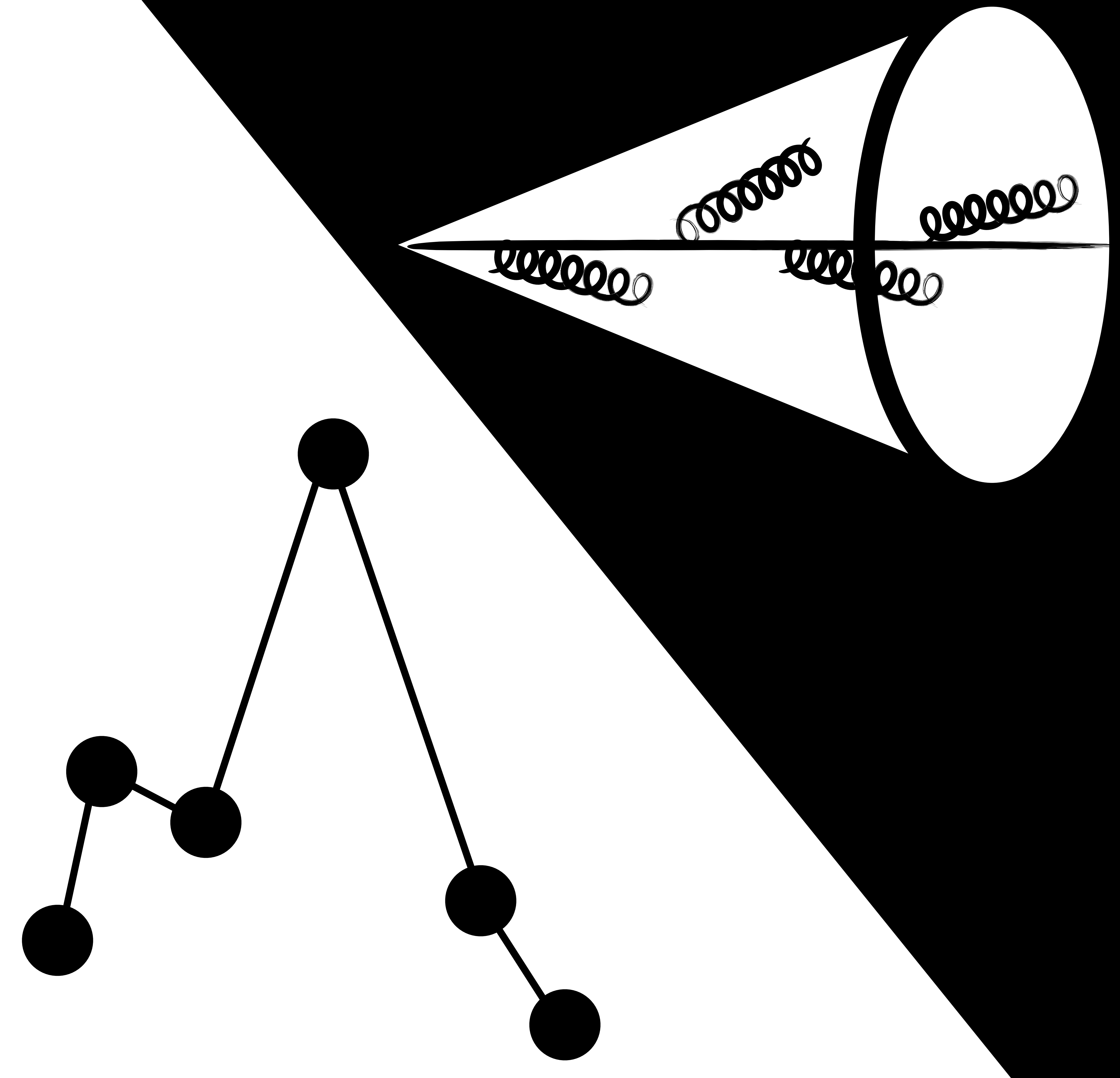
UNIVERSIDAD DE GRANADA

Jets in the Lund plane



Alba Soto Ontoso

LHC-EW WG: Jets and EW bosons

CERN, 18th September, 2024

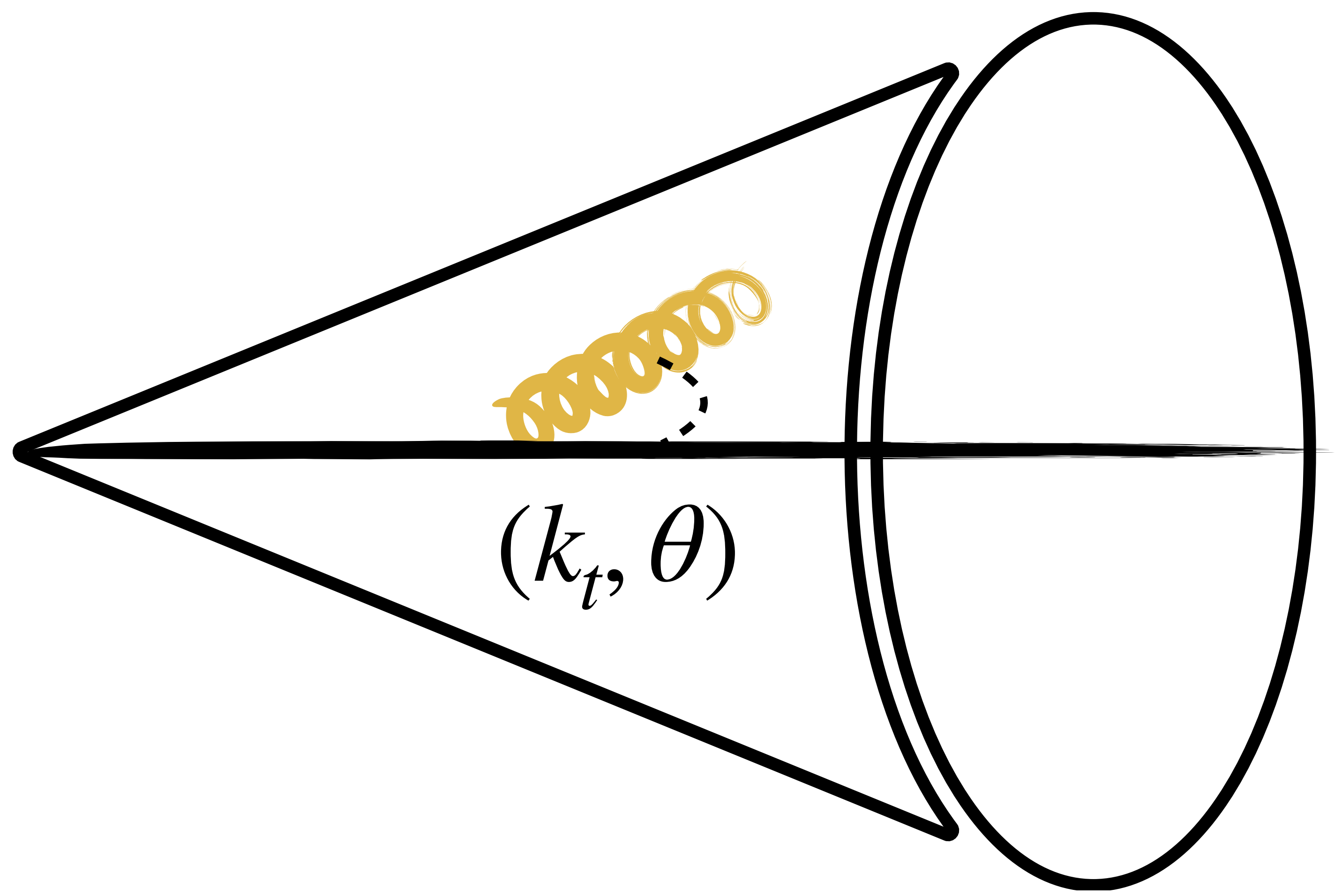
Definition of Lund-based observables

INPUT

Anti-k_t jet

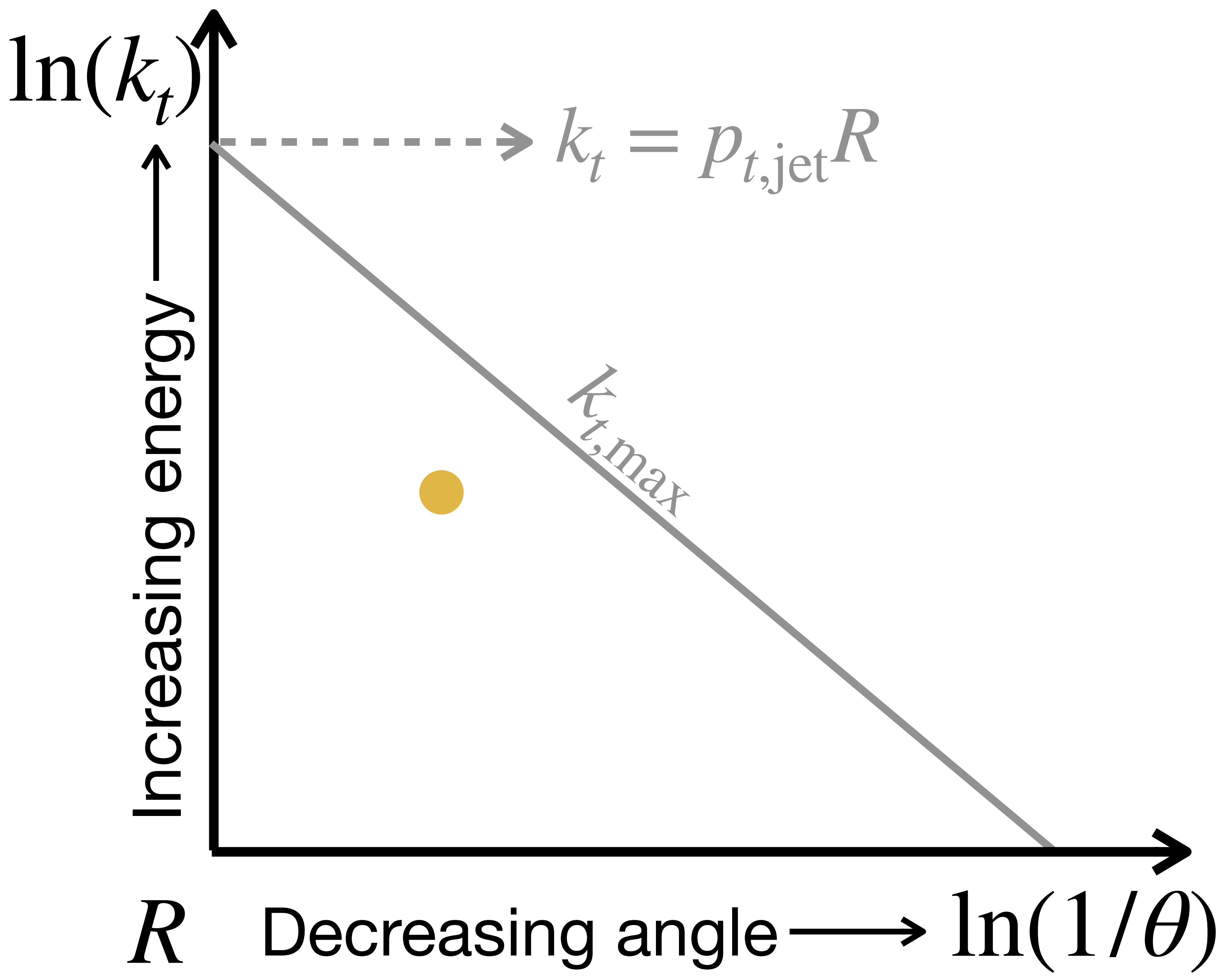
Hemisphere in e^+e^-

...



C/A reclustered jet

OUTPUT



Unwinding the parton shower history

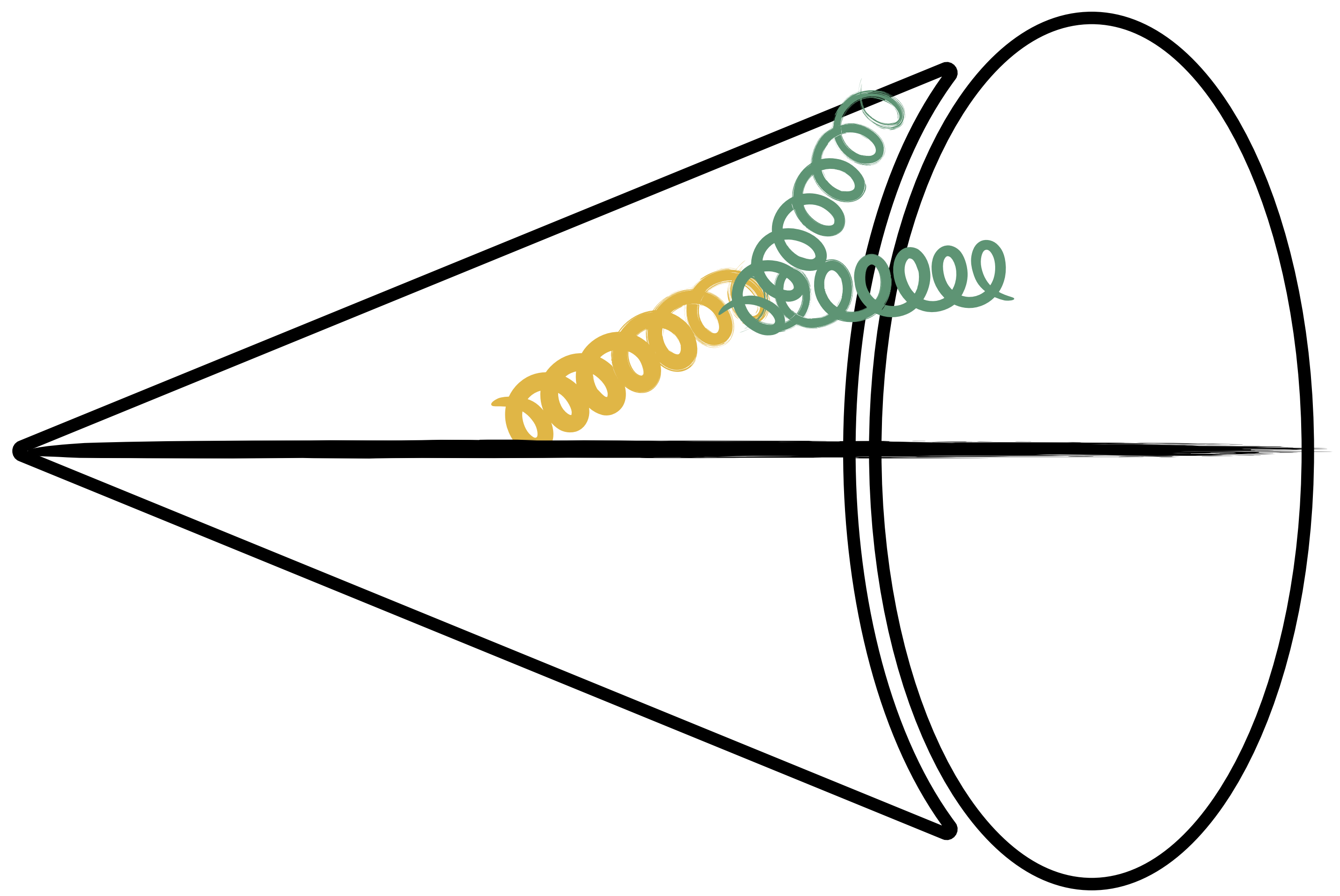
Definition of Lund-based observables

INPUT

Anti-k_t jet

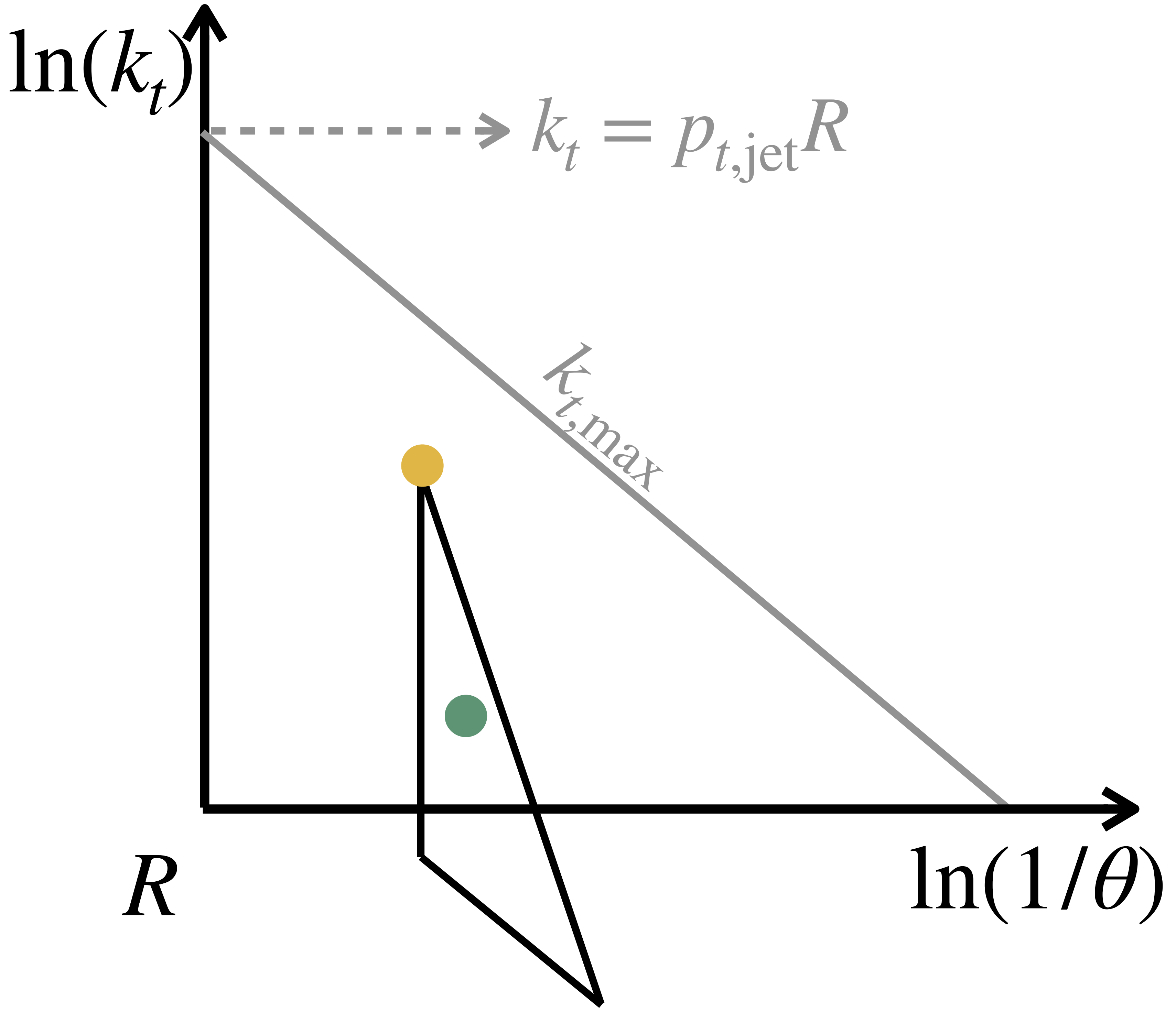
Hemisphere in e^+e^-

...



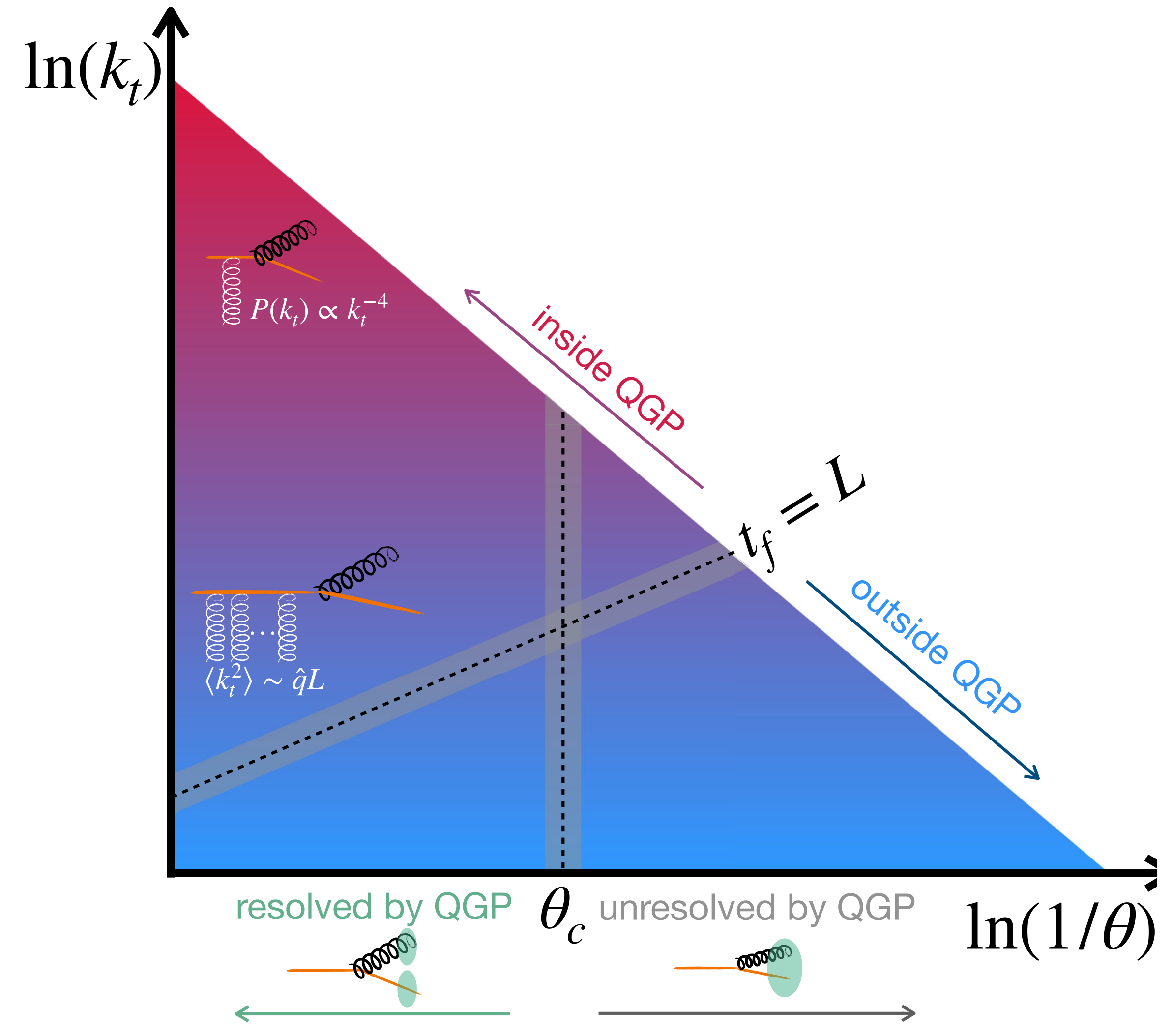
C/A reclustered jet

OUTPUT



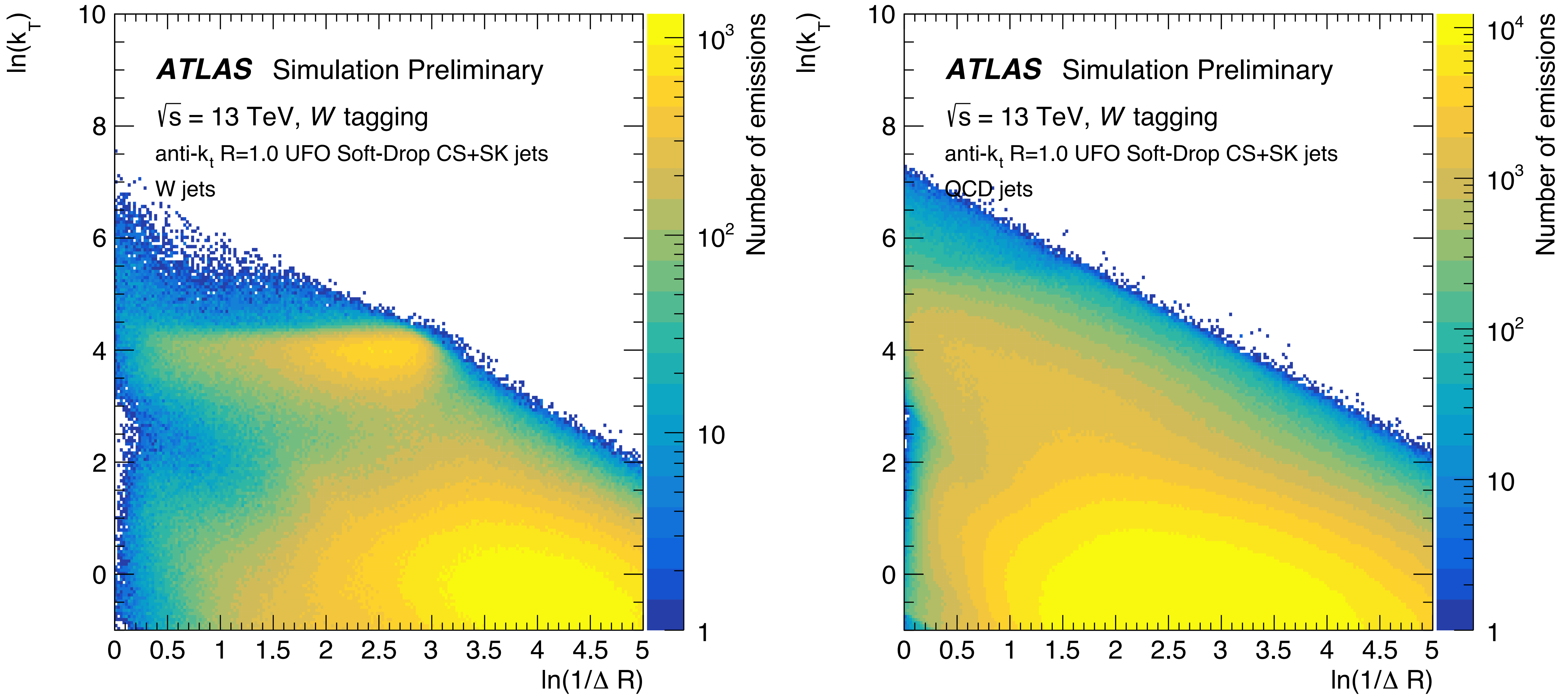
The Lund-plane: central tool for HEP

Heavy-ions



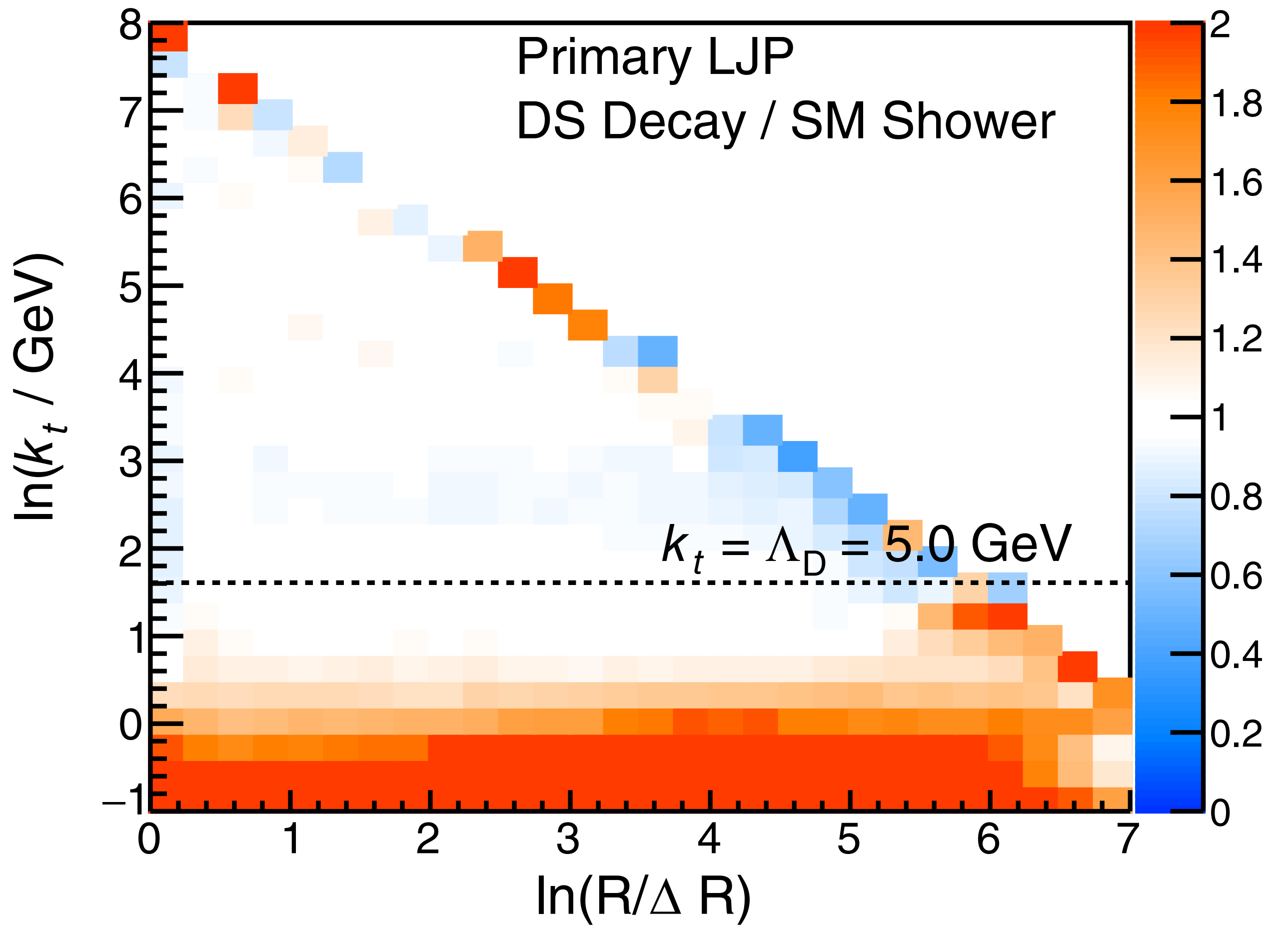
[Cunqueiro et al. PRD 110 (2024) 1, 014015]

Tagging



[ATLAS et al. ATL-PHYS-PUB-2023-017]

BSM



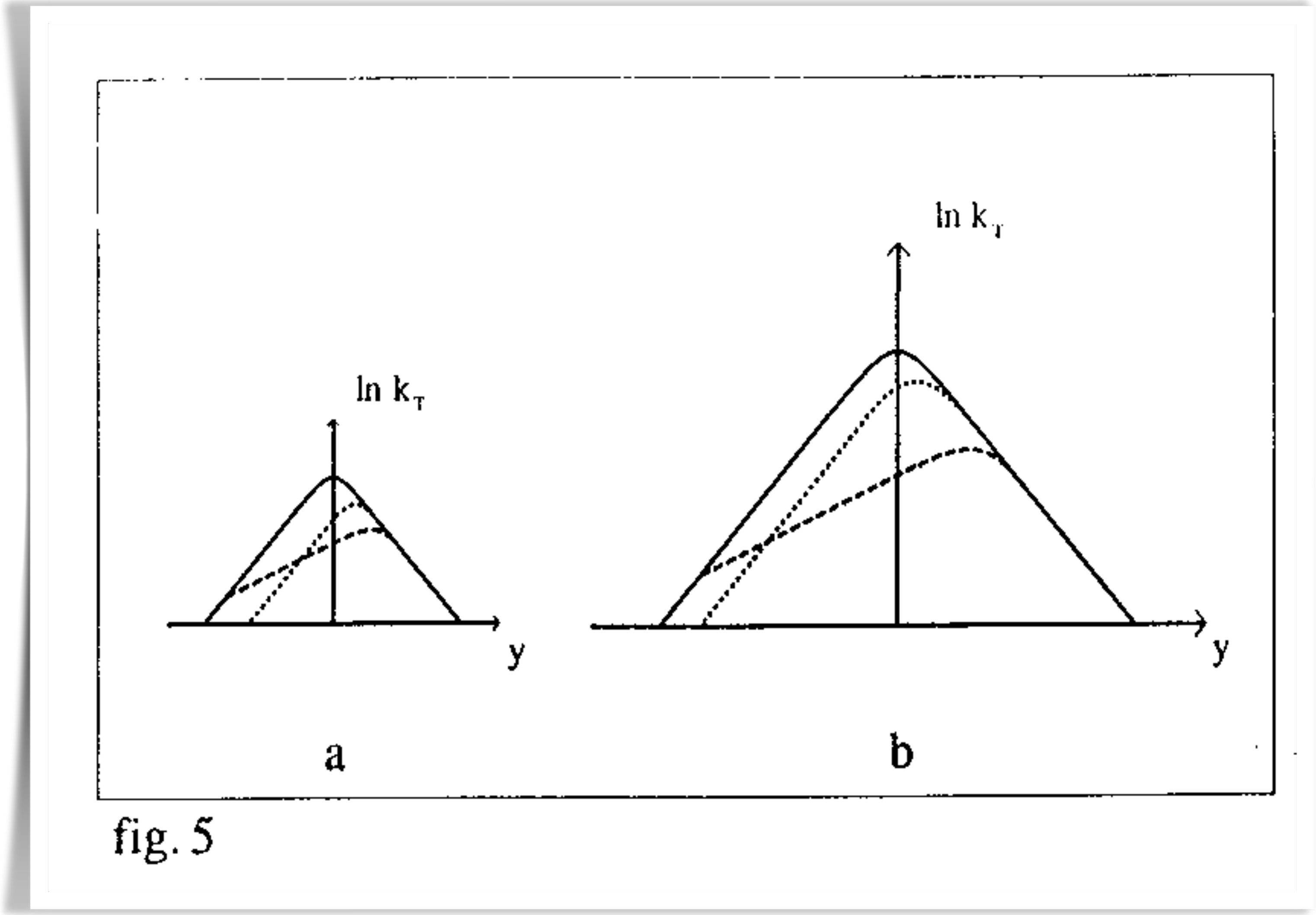
[Cohen et al. PRD 108 (2023) 3, L031501]

The Lund jet plane is used in a broad array of high-energy physics topics

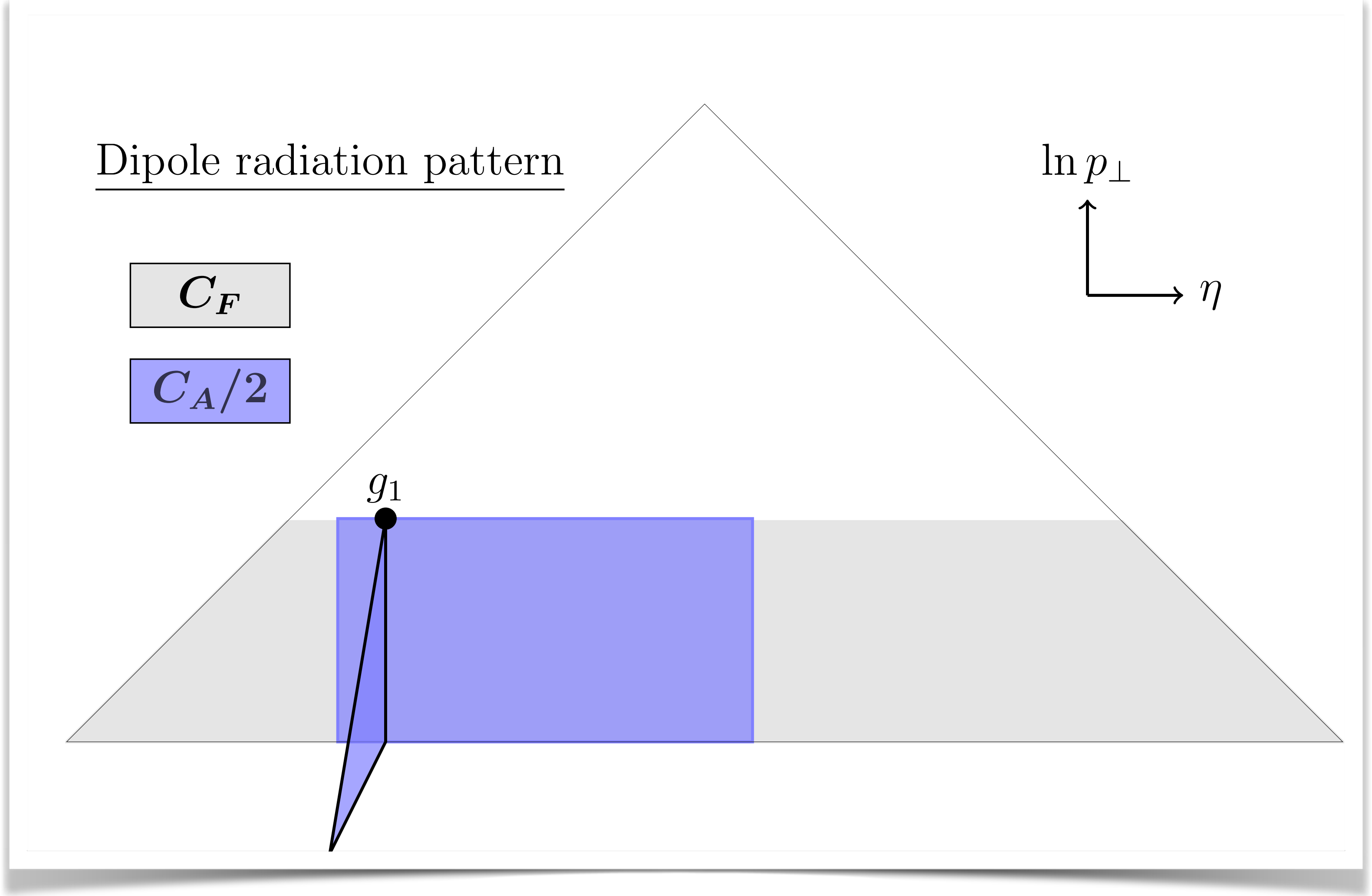
The Lund-plane: central tool for pQCD

Parton showers

[Andersson et al. Z.Phys.C 43 (1989) 625]

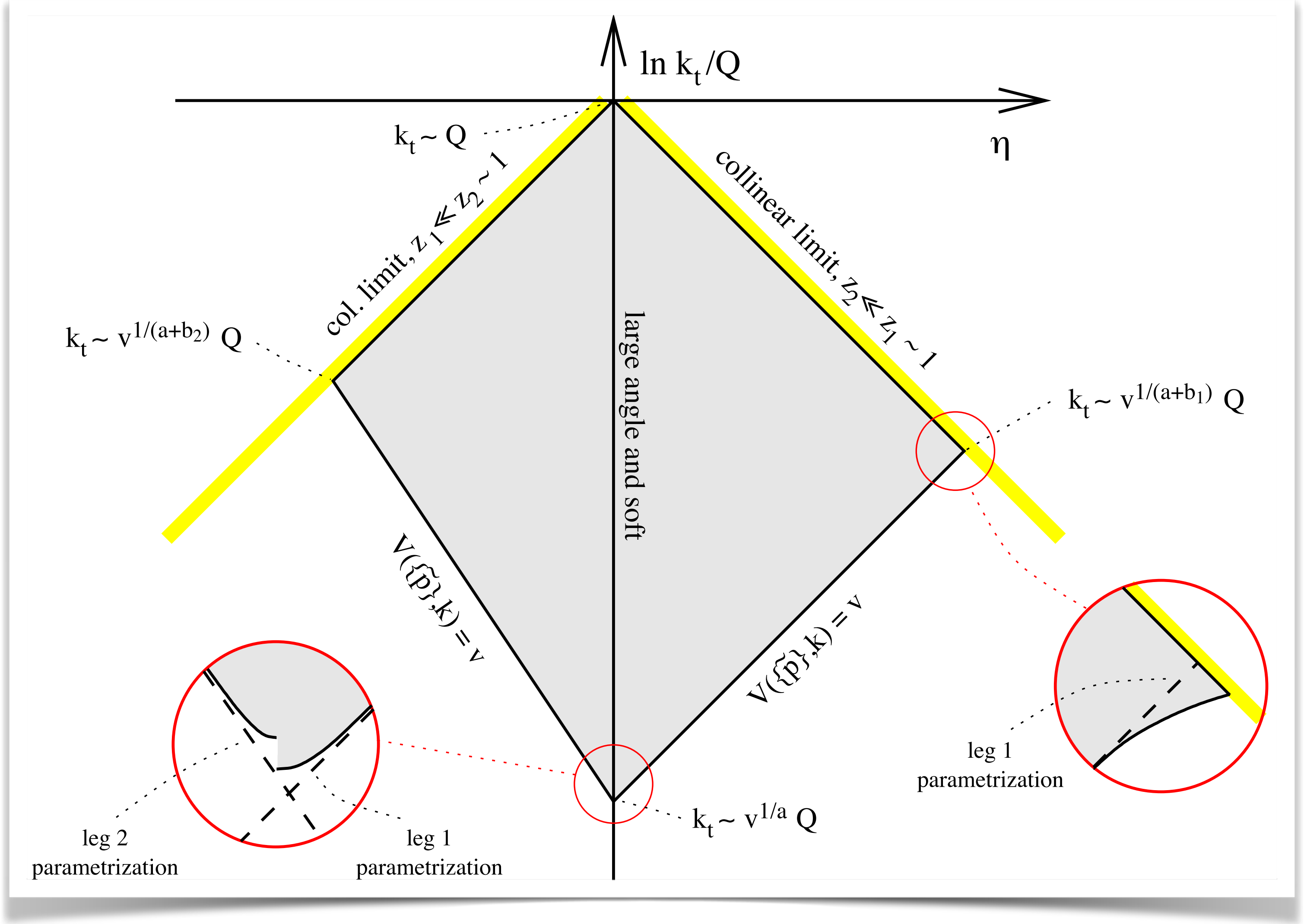


[Dasgupta et al. JHEP 09 (2018) 033]

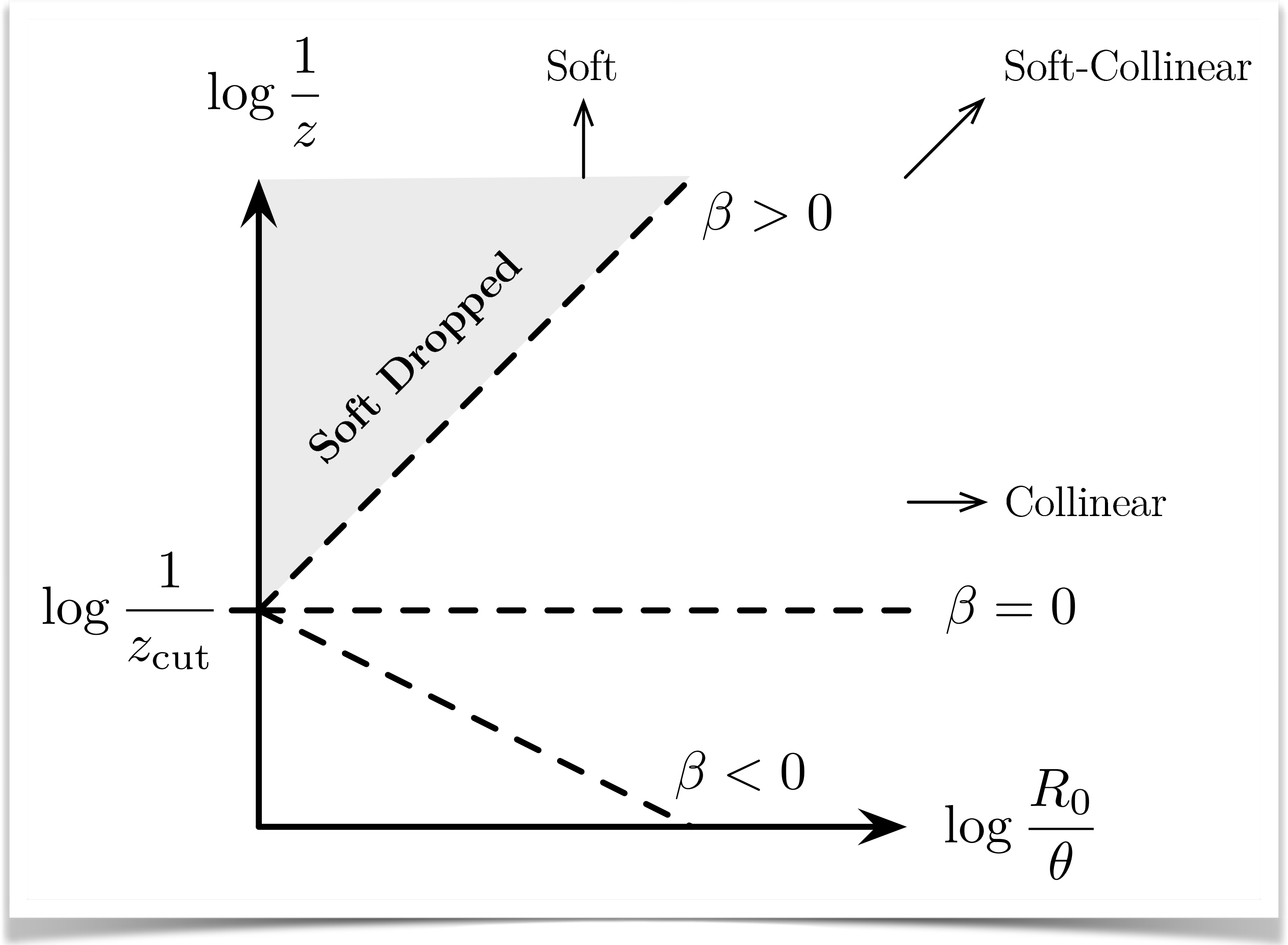


Resummation

[Banfi, Salam, Zanderighi, JHEP 03 (2005) 073]

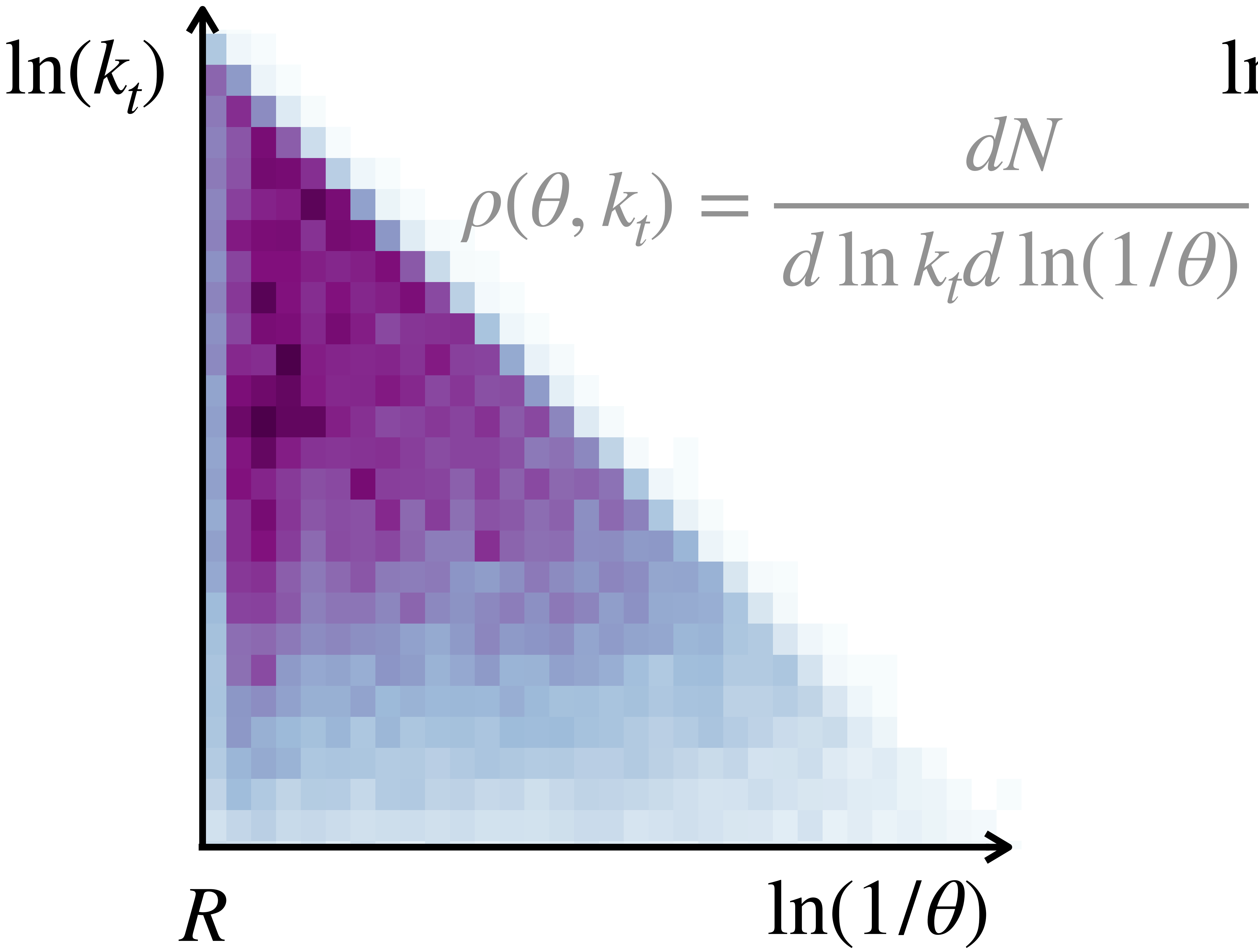


[Larkorski et al.,JHEP 05 (2014) 146]



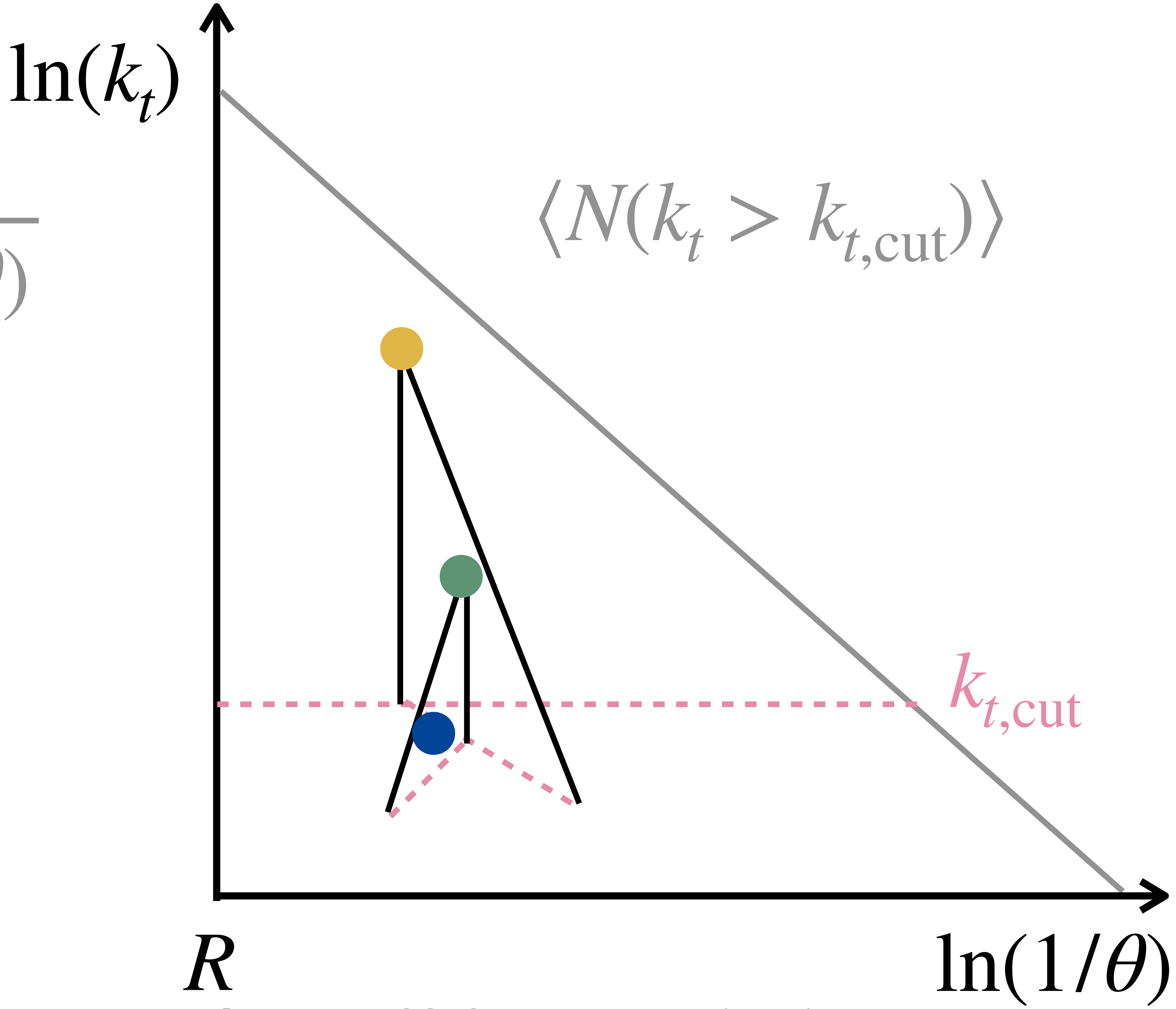
Two examples of Lund-based observables calculable in pQCD

Primary Lund-plane density



[Lifson, Salam, Soyez JHEP 10 (2020) 170]

Lund multiplicity



[Medves, ASO, Soyez, JHEP 10 (2022) 156, JHEP 04 (2023) 104]

The primary Lund-plane density: resummation structure

In the soft-and-collinear limit, the Lund plane density is simply given by

$$\rho_{\rm LO}(\theta, k_t) = \frac{2\alpha_s C_i}{\pi}$$

Beyond LO/LL, two sources of logarithmic enhancements appear

$$\alpha_s^{n+1} \ln^m \theta \ln^{n-m} \frac{p_t}{k_t} \quad \text{with} \quad 0 \leq m \leq n$$

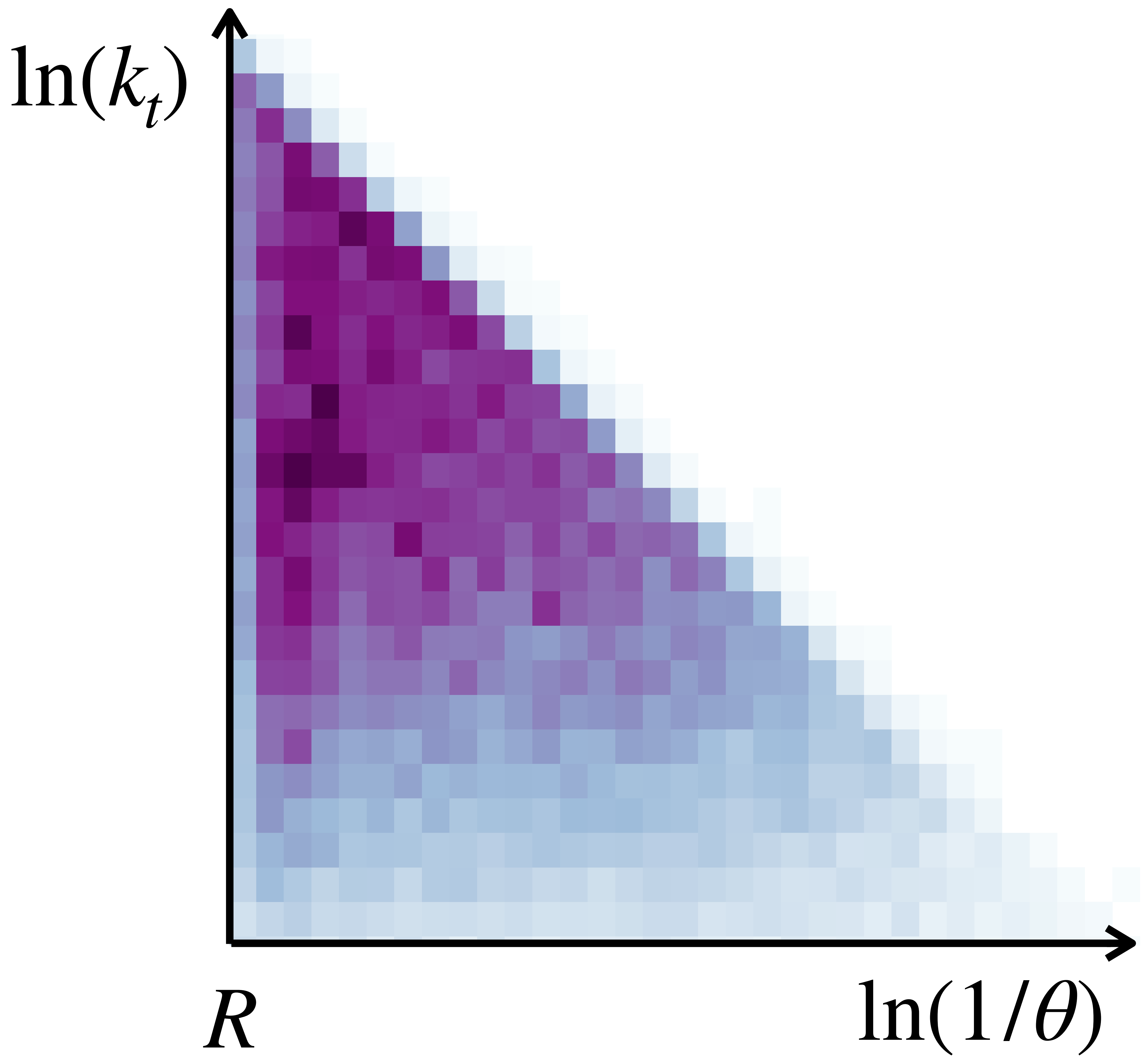
So far, the full set of single-logarithmic corrections has been computed

[Lifson, Salam, Soyez JHEP 10 (2020) 170]

The primary Lund-plane density: NLL resummation

1 Running coupling corrections

$$\rho_{\rm rc}(\theta, k_t) = \frac{2\alpha_s^{1\ell}(k_t)C_i}{\pi}$$



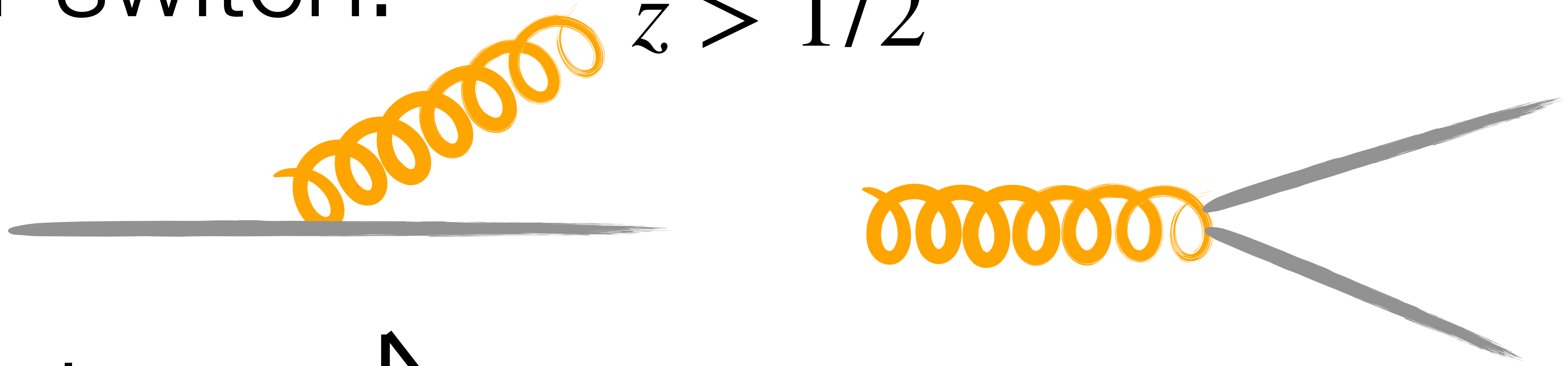
The primary Lund-plane density: NLL resummation

1 Running coupling corrections

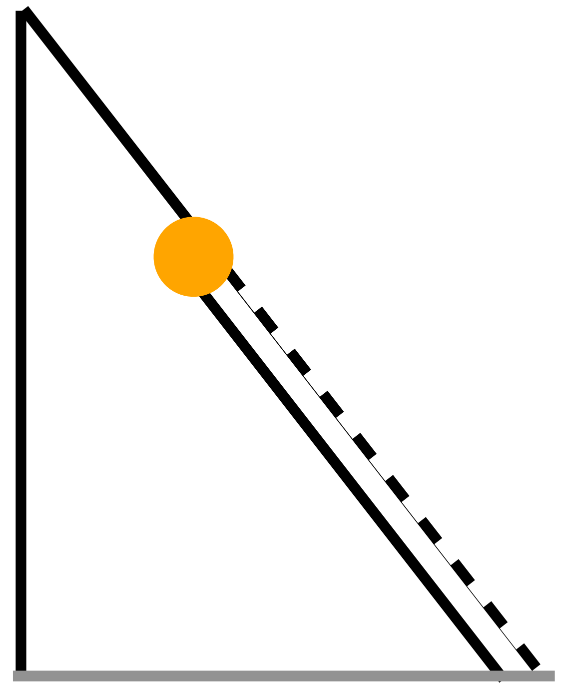
$$\rho_{\rm rc}(\theta, k_t) = \frac{2\alpha_s^{1\ell}(k_t)C_i}{\pi}$$

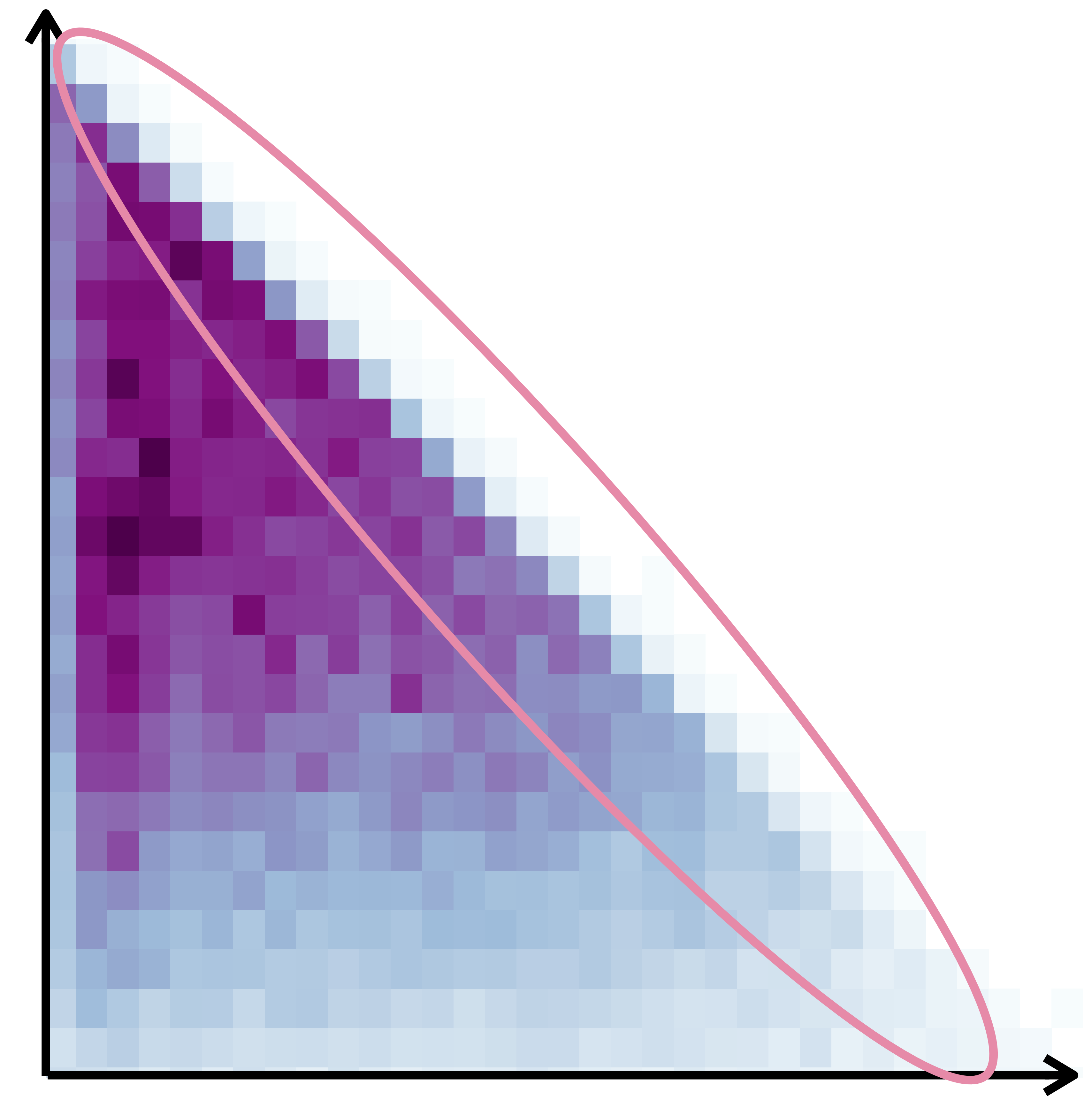
2 Hard-collinear corrections $\alpha_s^{n+1}\ln^n(1/\theta)$

a) Flavour switch:



b) Energy loss:





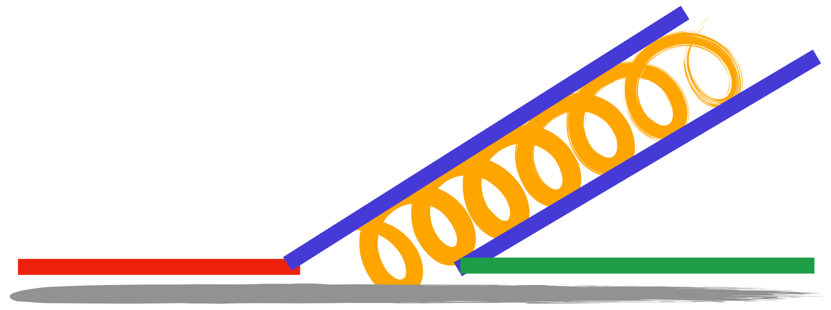
The primary Lund-plane density: NLL resummation

1 Running coupling corrections

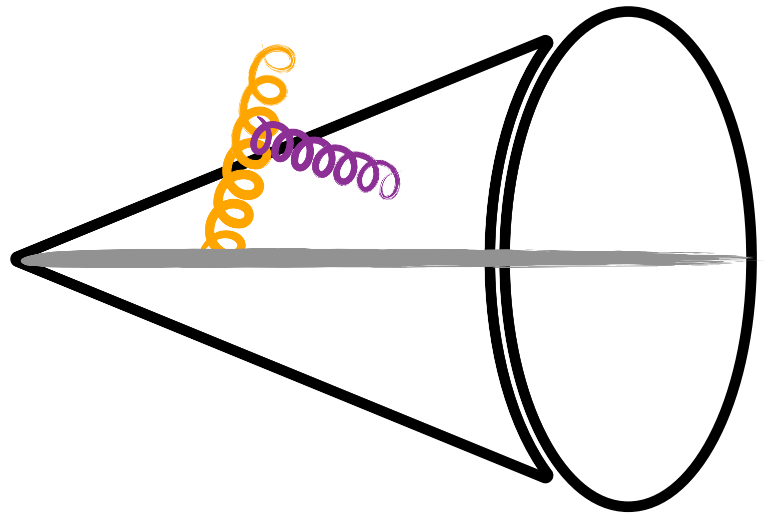
$$\rho_{\rm rc}(\theta, k_t) = \frac{2\alpha_s^{1\ell}(k_t) C_i}{\pi}$$

2 Hard-collinear corrections $\alpha_s^{n+1} \ln^n \theta$

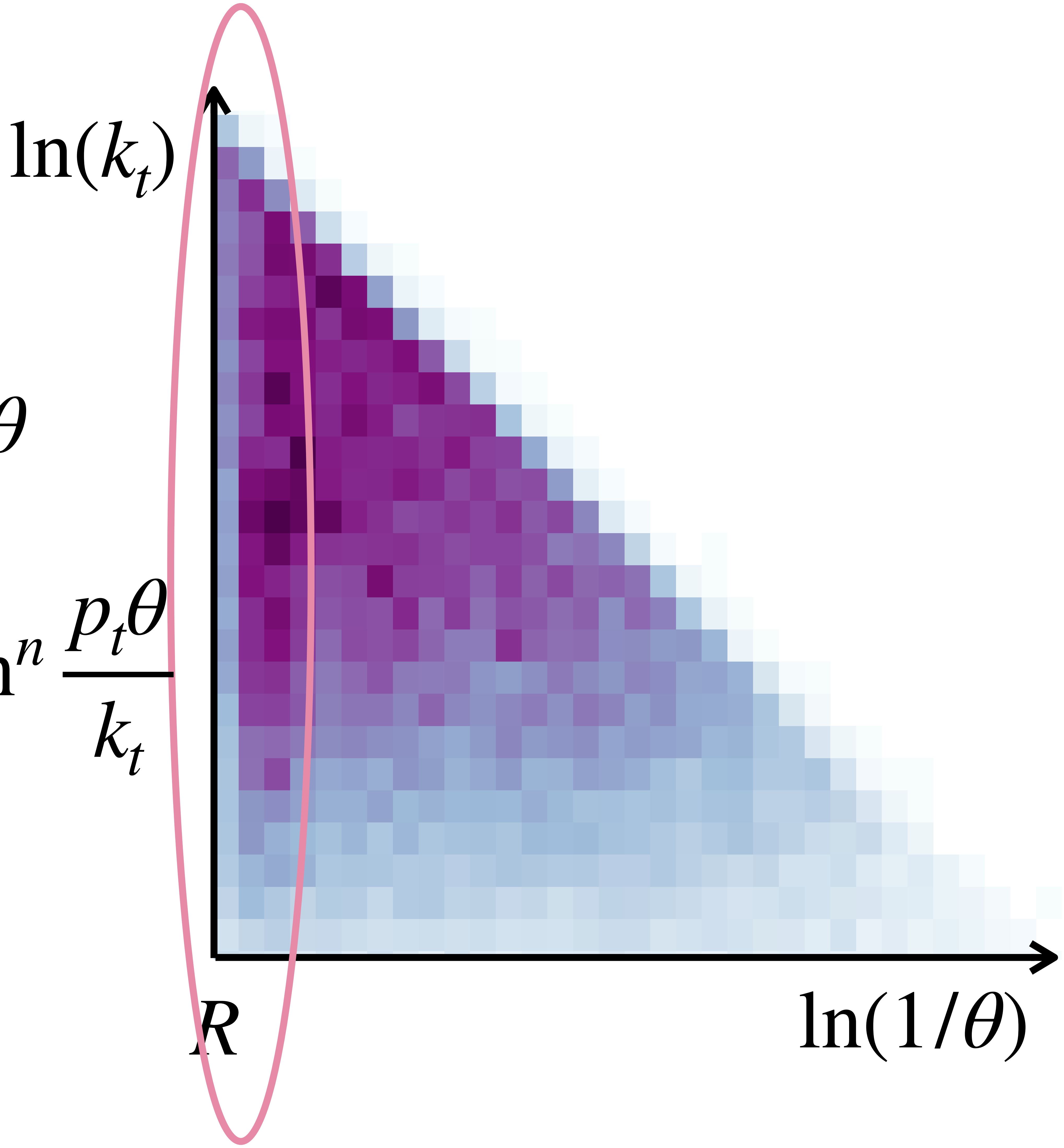
3 Soft, large-angle corrections $\alpha_s^{n+1} \ln^n \frac{p_t \theta}{k_t}$



[Ellis, Marchesini, Webber. Nucl.Phys.B 286 (1987) 643]

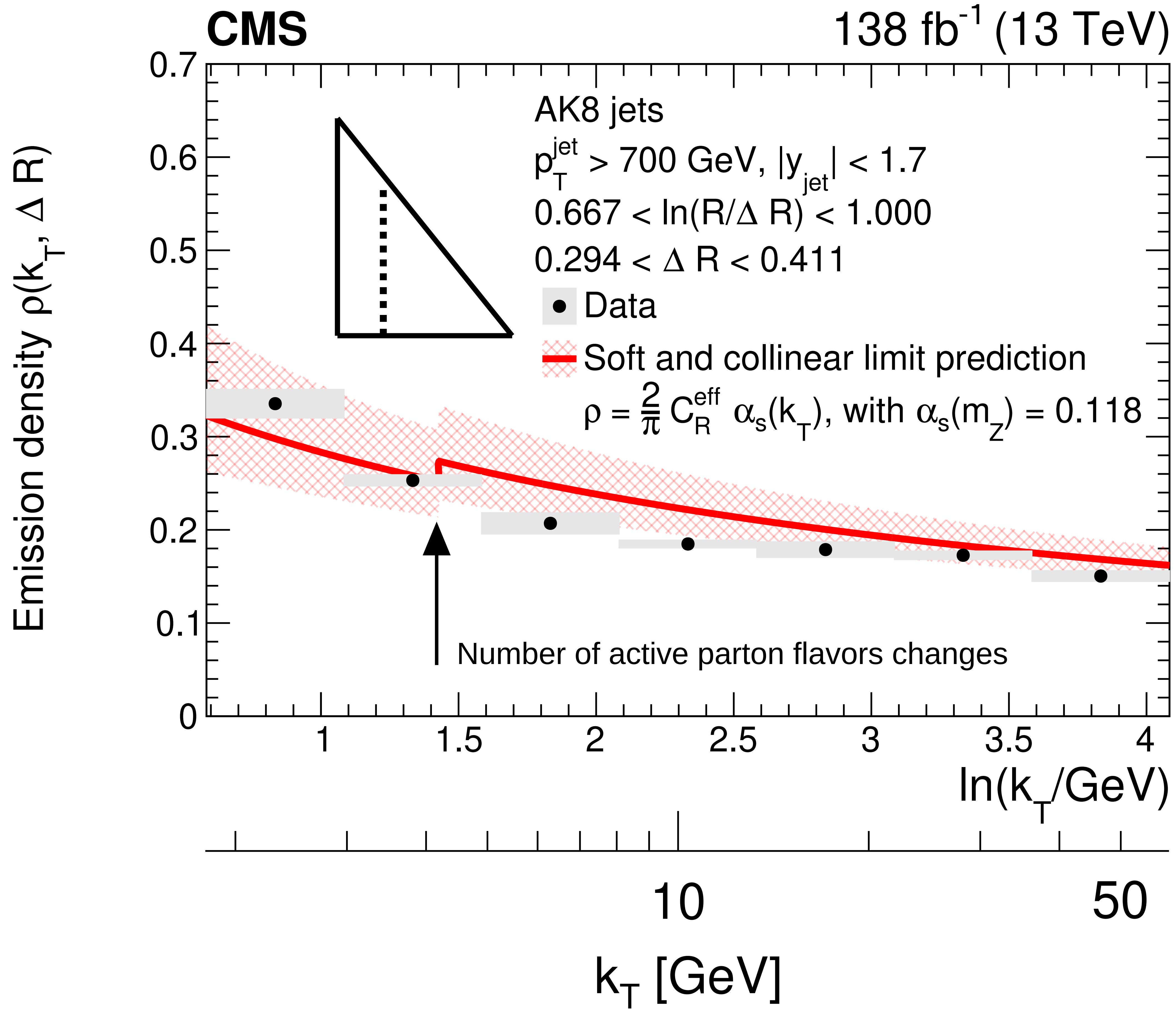


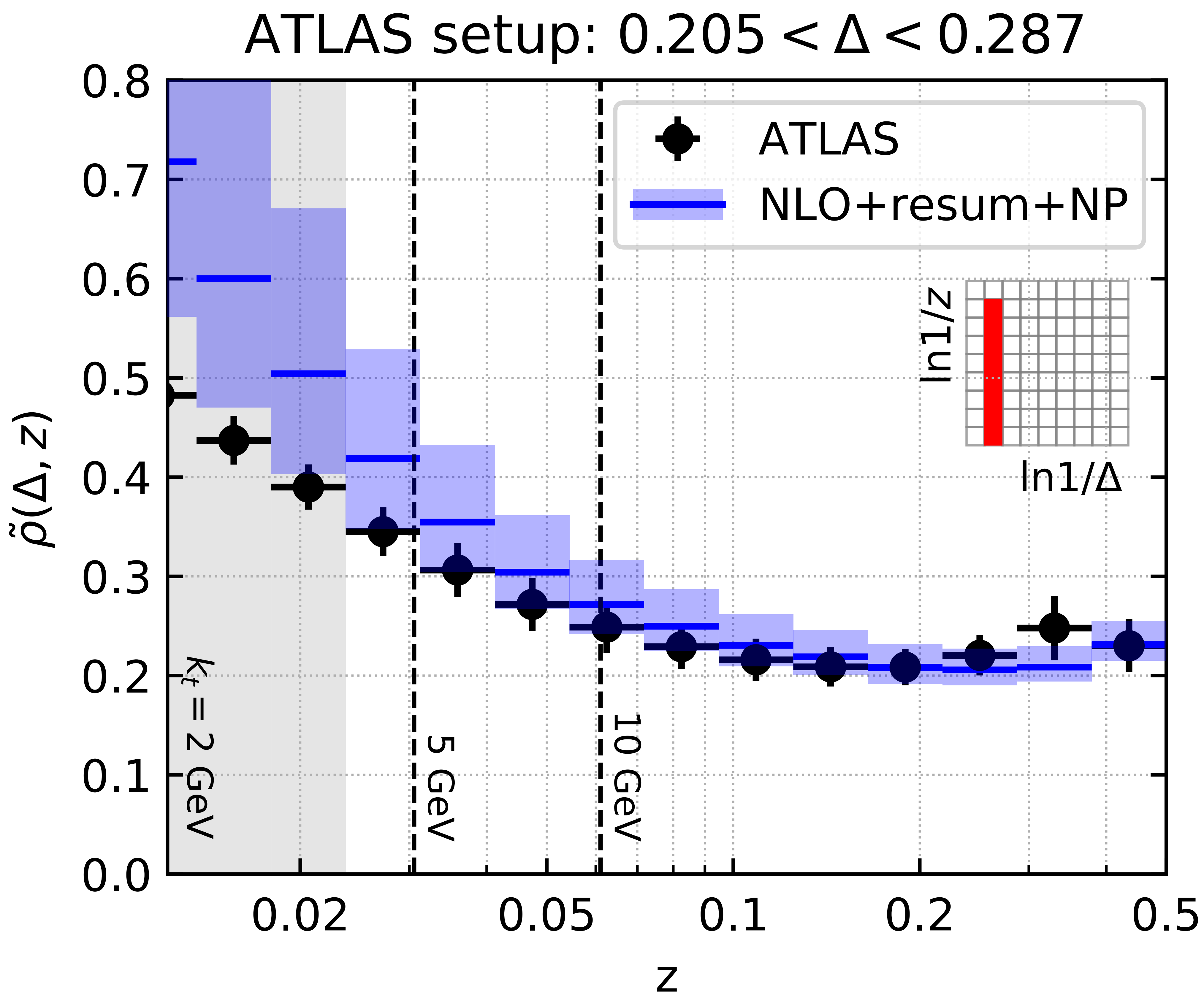
$\ln(R/(R-\theta))$



The primary Lund-plane density: theory-to-data

[CMS Collab JHEP 05 (2024) 116]





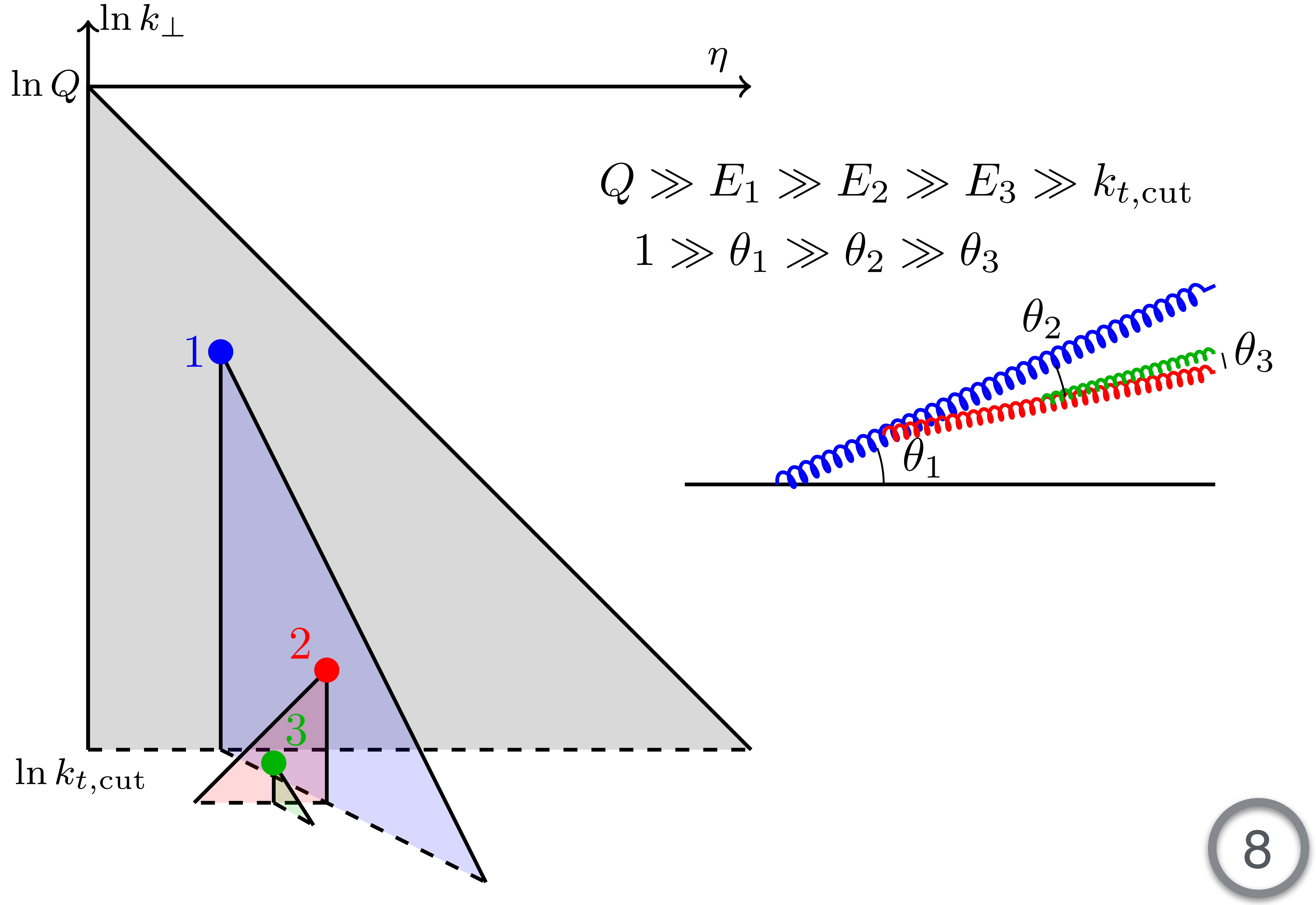
$\rho_{\rm LO}(\theta, k_t)$ agrees with data in bulk of LP. N^{k}LL terms required elsewhere

Lund multiplicity: DL resummation $(\alpha_s L^2)^n$

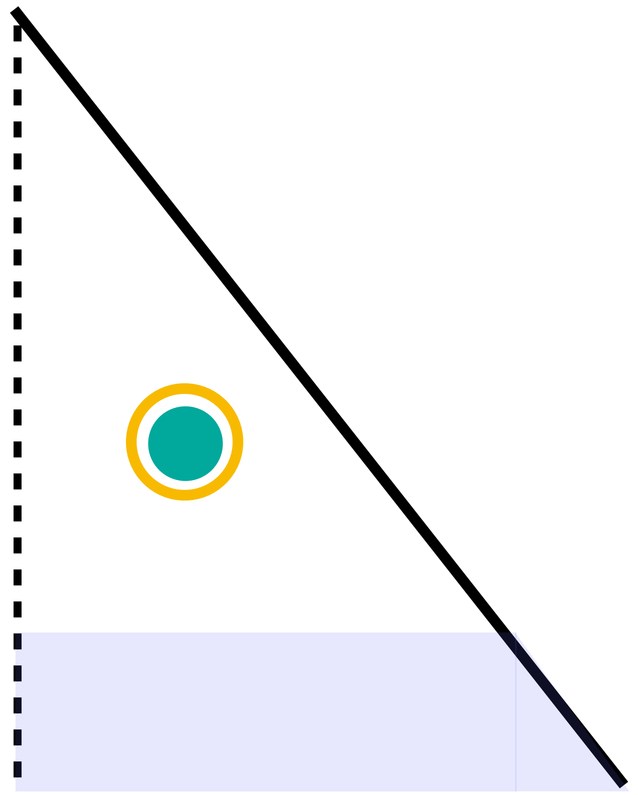
$$\langle N\rangle_{\rm DL} = 1 + \frac{C_i}{C_A}\sum_{n=1}^{\infty}\bar{\alpha}^n \underbrace{\int_0^\infty d\eta_1\int_{\eta_1}^\infty d\eta_2\ldots\int_{\eta_{n-1}}^\infty d\eta_n}_{\text{angular-ordering}} \underbrace{\int_0^1\frac{dx_1}{x_1}\int_0^{x_1}\frac{dx_2}{x_2}\ldots\int_0^{x_{n-1}}\frac{dx_n}{x_n}}_{\text{energy-ordering}} \underbrace{\Theta(x_n e^{-\eta_n} > e^{-L})}_{k_t > k_{t,\rm cut}}$$

$$\boxed{\langle N\rangle_{\rm DL} = 1 + \frac{C_i}{C_A}\left[\cosh\nu - 1\right]}$$

$$\nu = \sqrt{2\alpha_s C_A L^2/\pi}$$



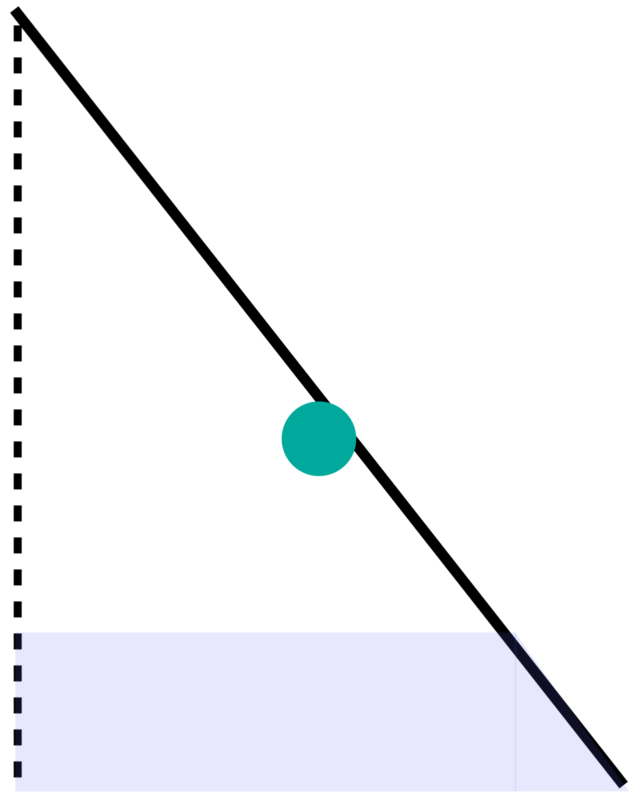
Lund multiplicity: NDL resummation $\alpha_s L(\alpha_s L^2)^n$



Running coupling

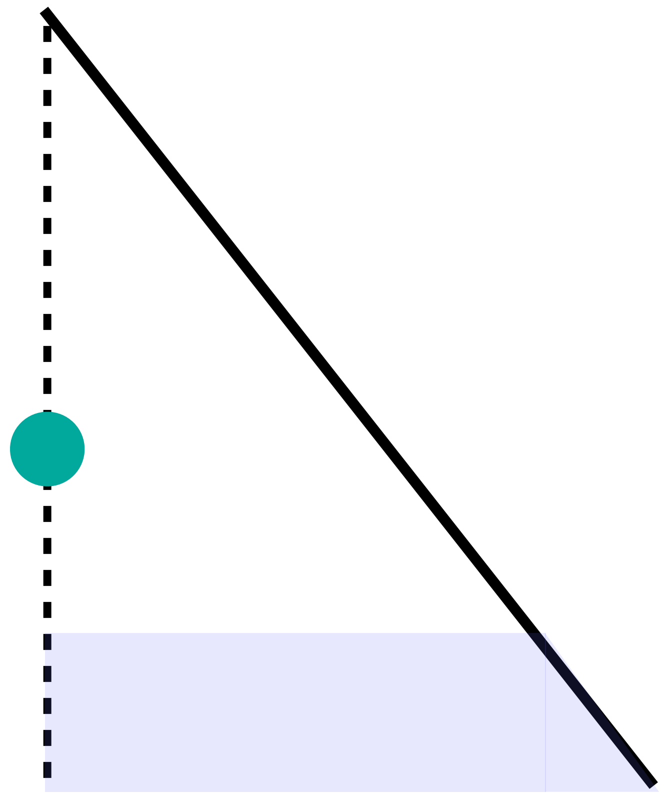
$$\alpha_s \to \alpha_s - 2\alpha_s^2 \beta_0 \ell + \mathcal{O}(\alpha_s^3)$$

with $\ell \equiv \ln(k_t/Q)$



Hard-collinear

$$\frac{1}{z} \to C_F \left(\frac{1-z}{z} + \frac{z}{2} \right)$$

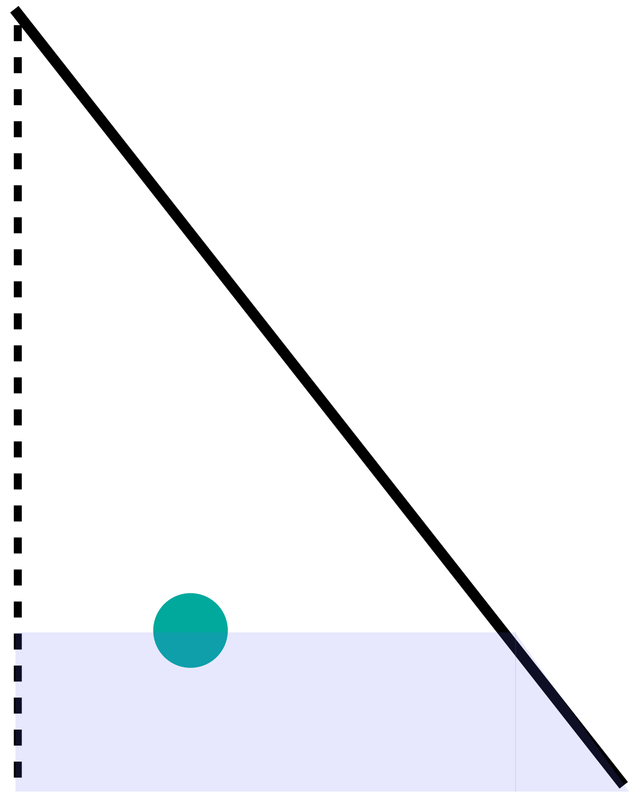


Large-angle

$$\frac{\mathrm{d}z}{z}\mathrm{d}\eta$$

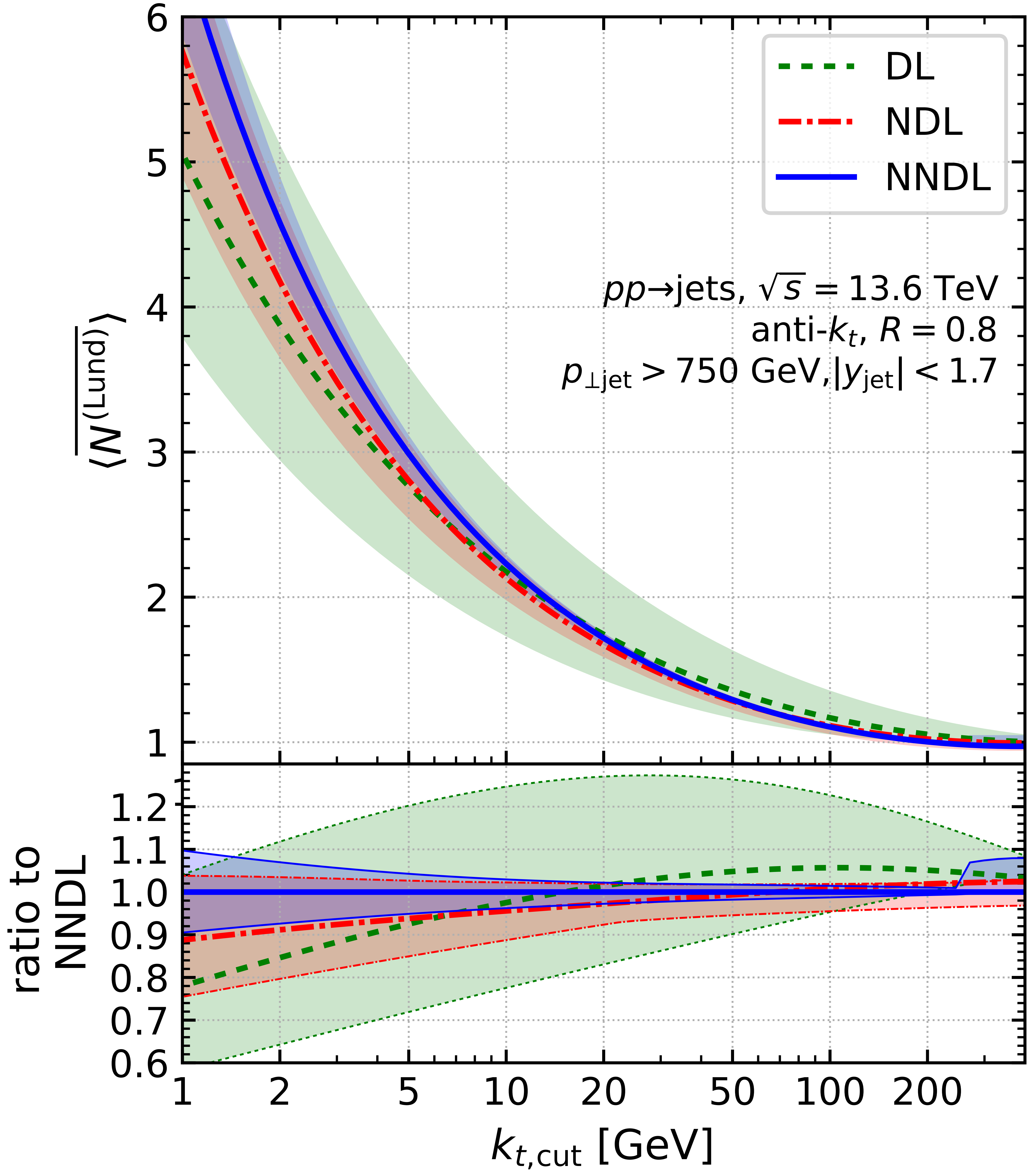
$$\downarrow$$

$$\frac{p_i \cdot p_j}{p_i \cdot p_k p_j \cdot p_k} \frac{\mathrm{d}\phi}{2\pi} \mathrm{d}\cos\theta$$



$k_t \sim k_{t,\mathrm{cut}}$

The importance of higher logarithmic accuracy

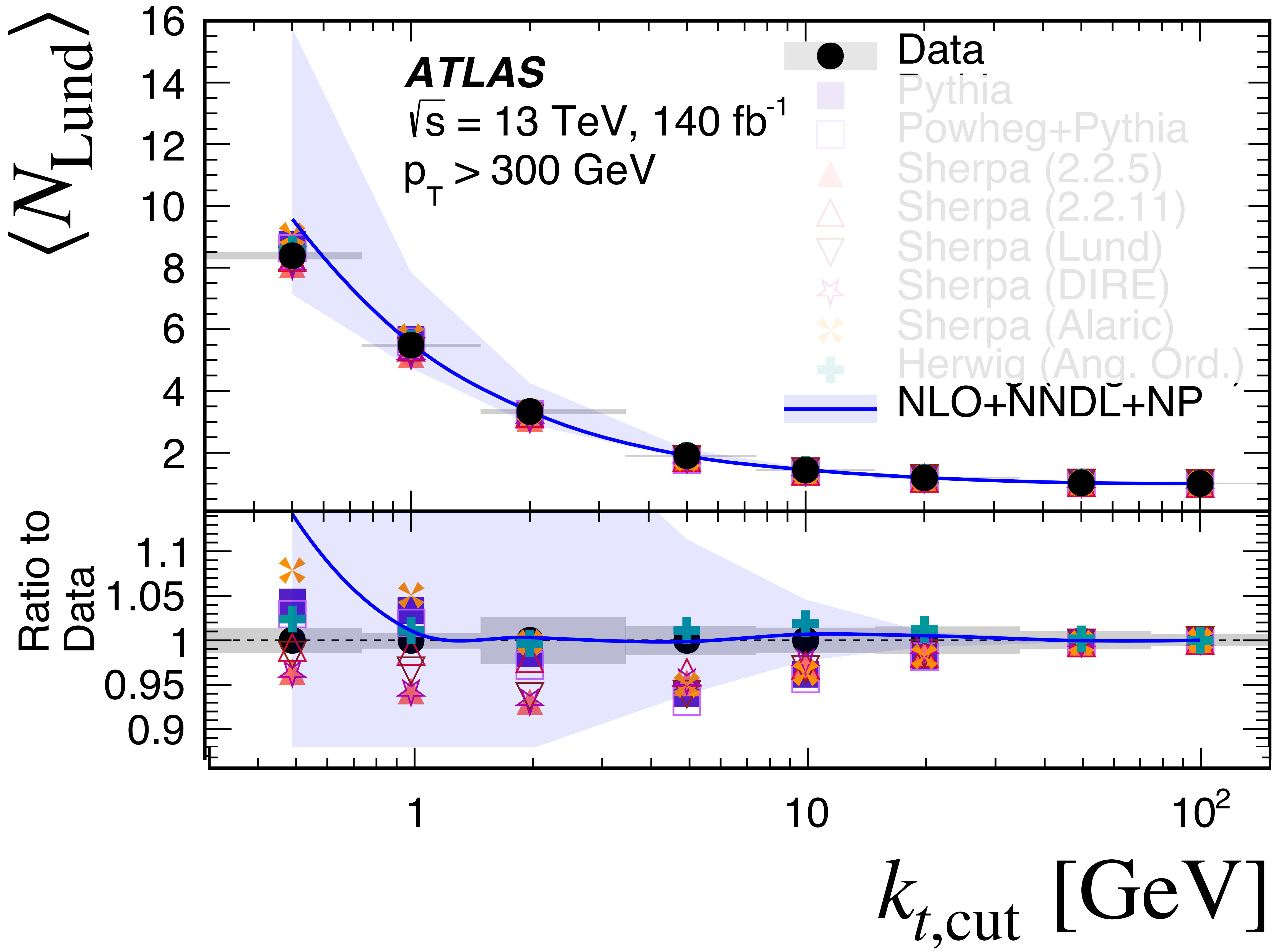


The uncertainty of the theoretical prediction at $k_{t,\mathrm{cut}} = 5$ GeV is

DL: $28\,\%$, NDL: $10\,\%$, NNDL: $5\,\%$

Theory-to-data and theory-to-theory comparisons

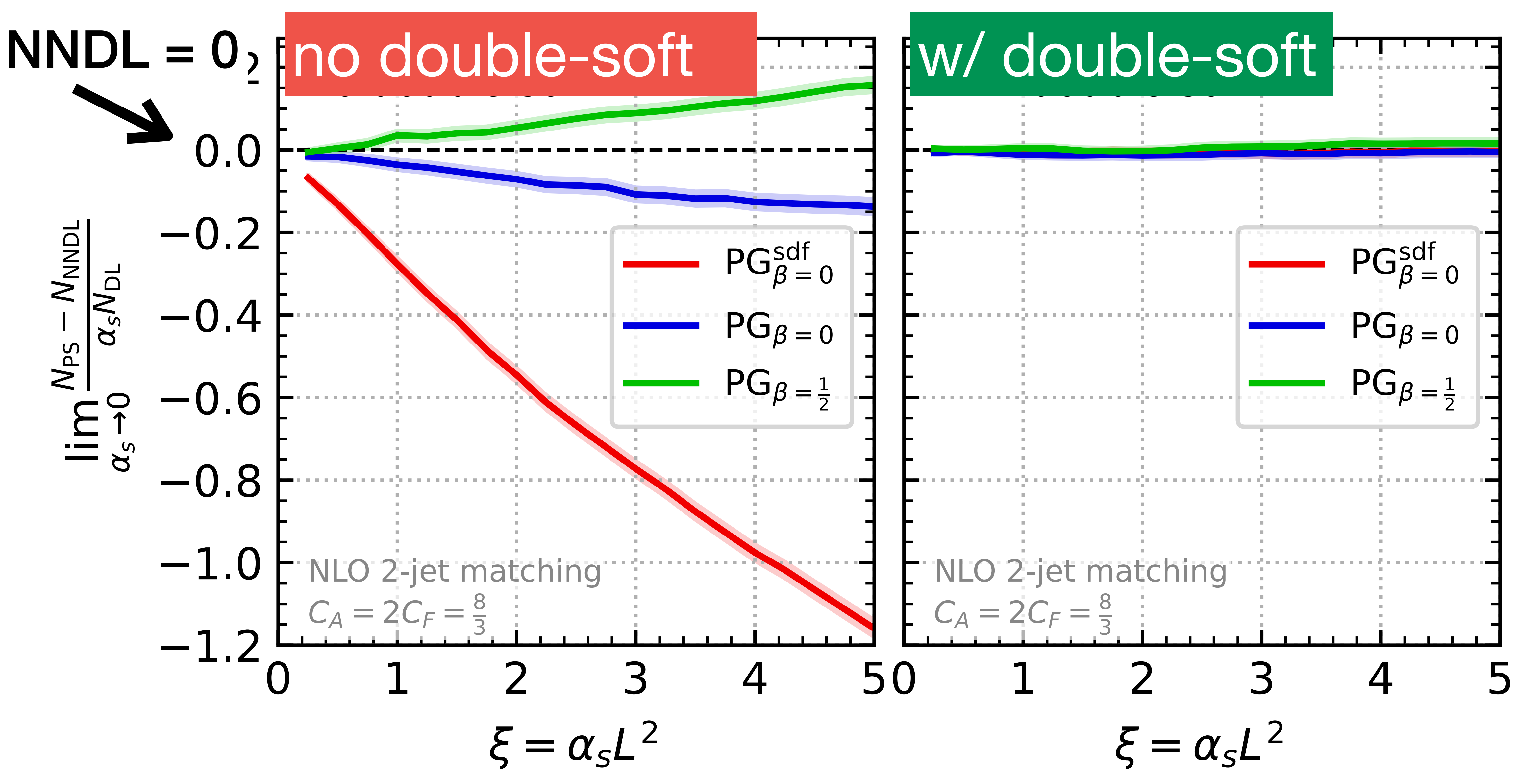
[ATLAS Collab arXiv:2402.13052]



Agreement with data within 10%

[Ferrario Ravasio et al. PRL 131 (2023) 16, 161906]

PanGlobal's NNDL accuracy test



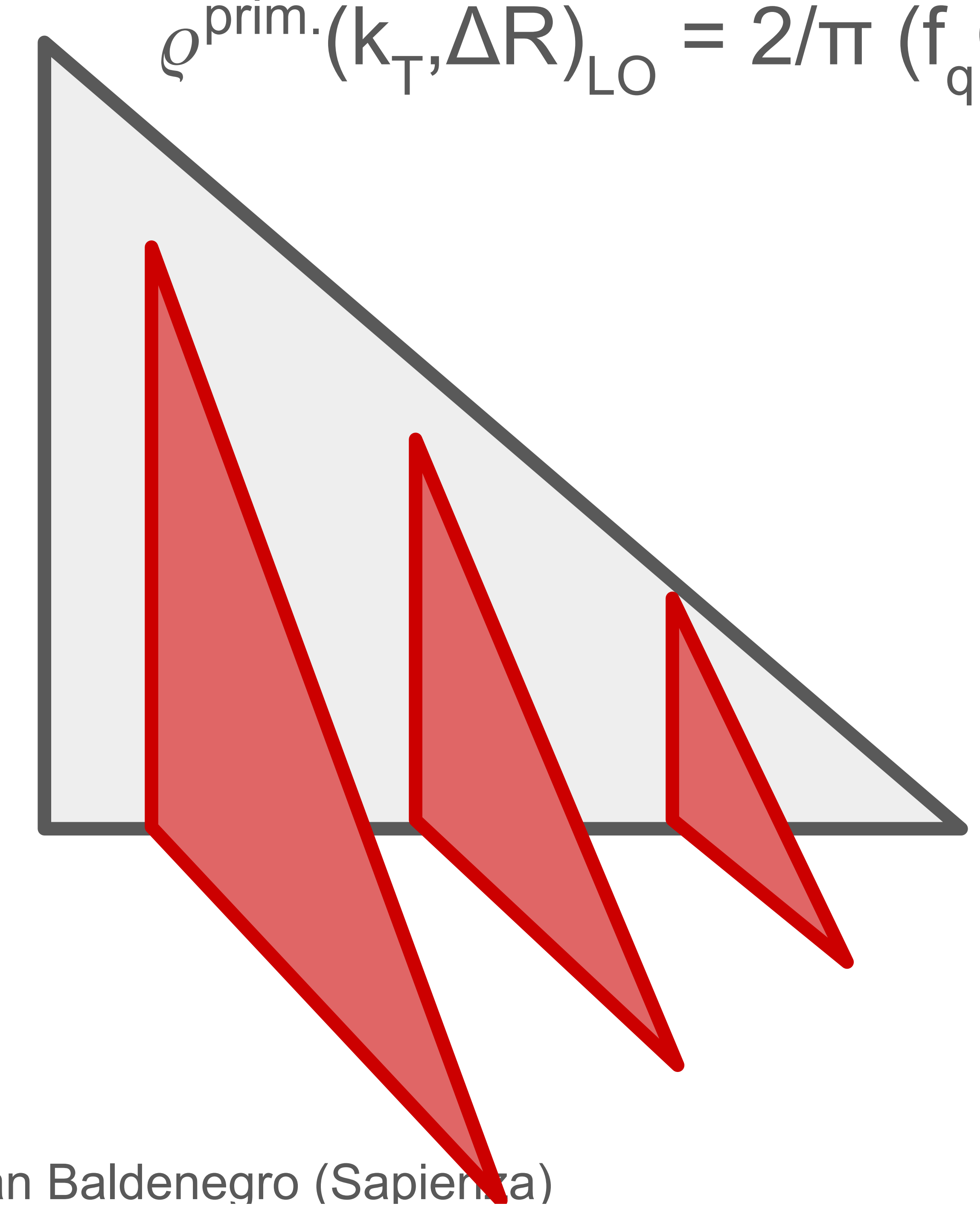
New application of resummation calculations: test of parton showers

New ideas: beyond the primary Lund plane

Primary Lund plane

Average map for **mixture** of quark/gluon jets at high-p_T

$\varrho^{prim.}(k_T,\Delta R)_{LO} = 2/\pi\ (f_q C_F + f_g C_A)\alpha_S(k_T)$

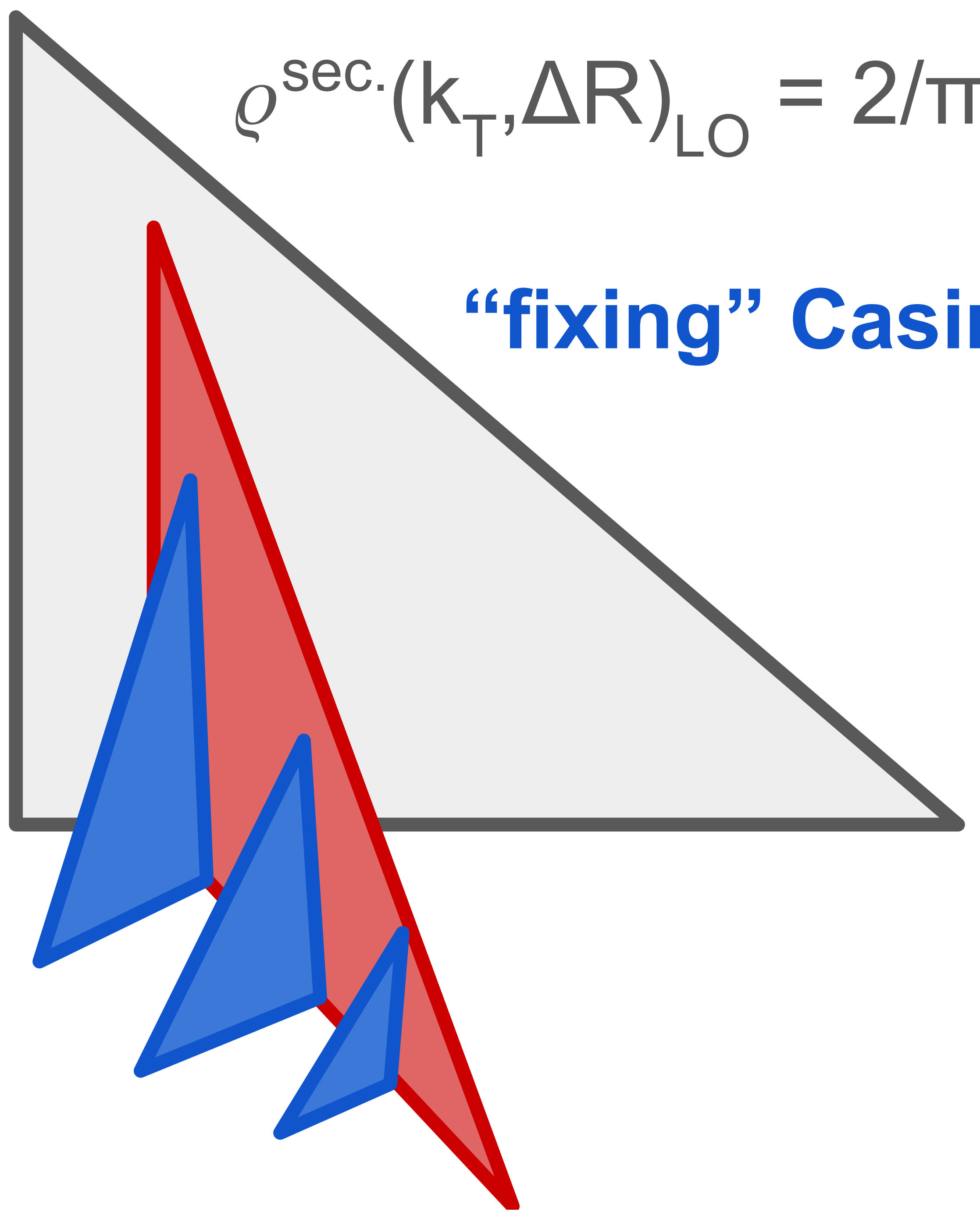


Secondary **Lund jet plane**

If **primary emission** is chosen judiciously, can obtain gluon-rich jet sample at a lower p_T

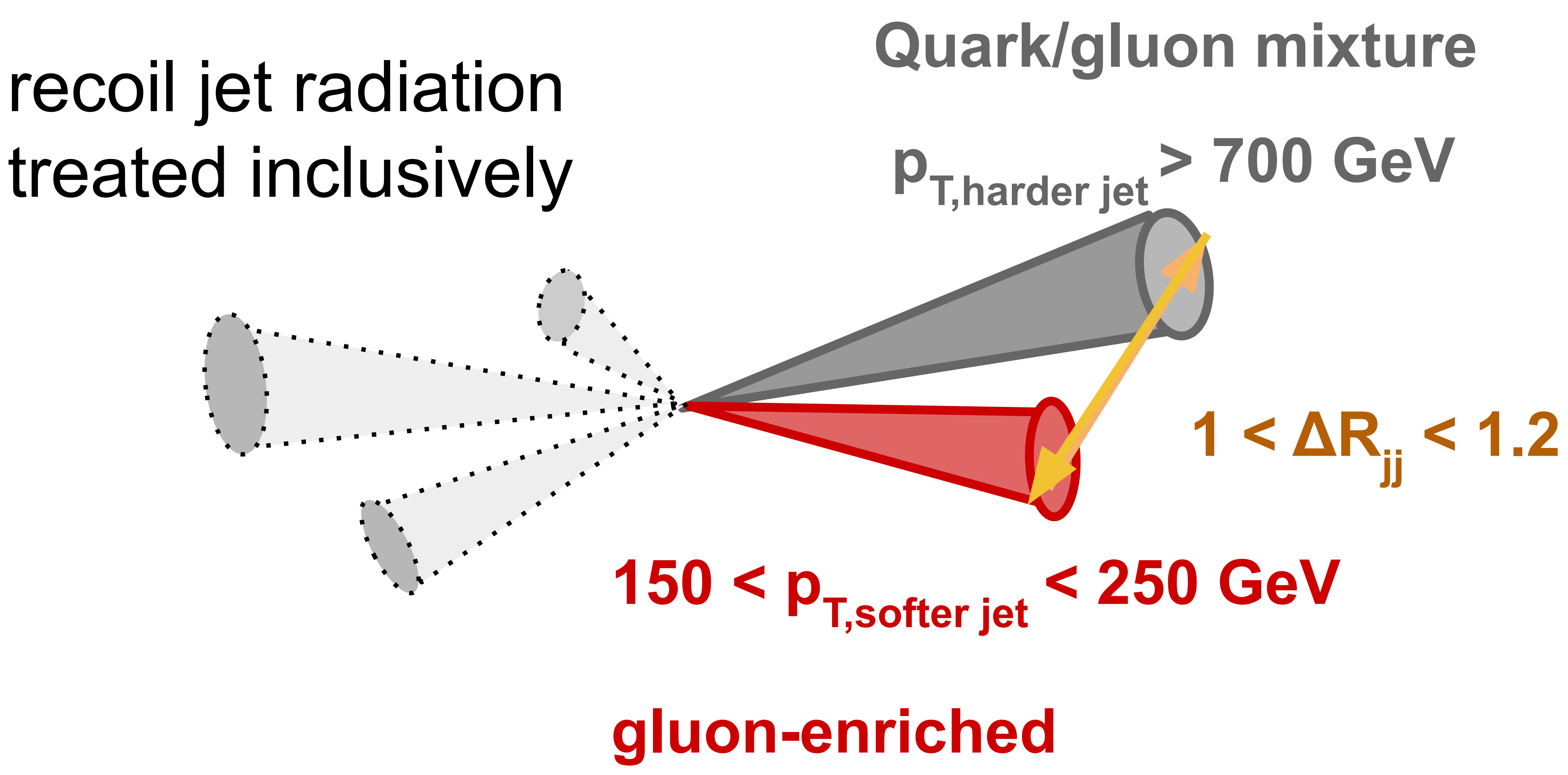
$\varrho^{sec.}(k_T,\Delta R)_{LO} = 2/\pi\ \boxed{C_A \alpha_S(k_T)}$

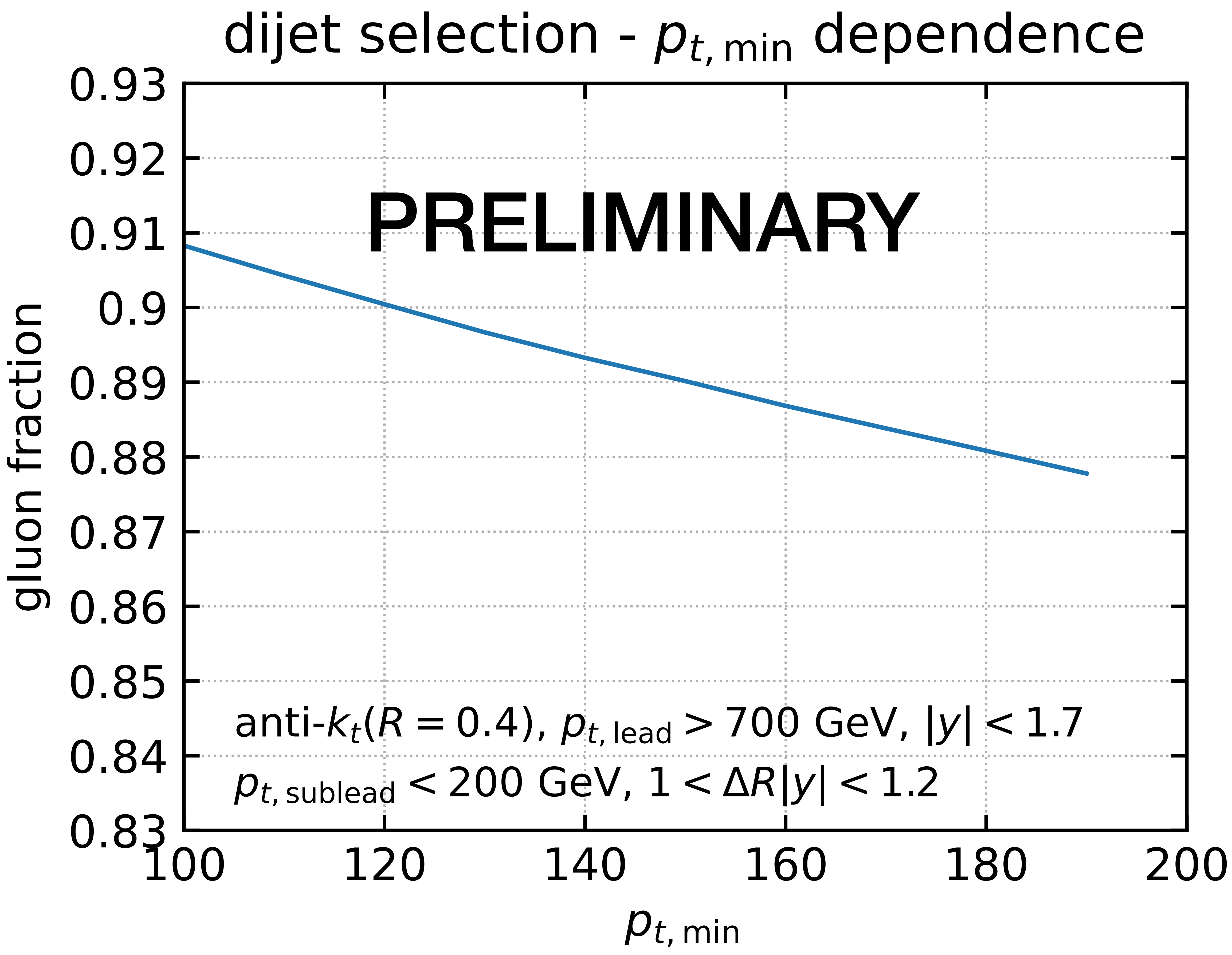
“fixing” Casimir factor



New ideas: beyond the primary Lund plane

[Baldenegro, Soyez, ASO, in preparation]





Potential of secondary Lund plane as a gluon-enriched sample