Using Jet Substructure for QCD

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AJL, I. Moult, D. Neill 1501.04596

BOOST 2015, August 10, 2015

Goal of this talk:
Use methods and insight from jet substructure to make progress on fundamental problems in QCD

Goal of this talk:
Use jet substructure to understand
non-global logarithms

Goal of this talk:
Use jet substructure to understand non-global logarithms

What are non-global logarithms?

Global Observables

Examples:

$$\tau = \frac{1}{Q} \sum_{i \in \text{event}} \left| \mathbf{p}_i \cdot \hat{t} \right|$$

$$\not{E}_T = \left| \sum_{i \text{ visible}} \mathbf{p}_{Ti} \right|$$

$$Q_T = - \sum_{i \in \text{hadrons}} \mathbf{p}_{Ti}$$

$$\sigma\left(pp \to H + X\right)$$

$$\sigma\left(pp \to t\bar{t} + X\right)$$

High-precision calculations:

$$\frac{d\sigma}{d\tau}$$

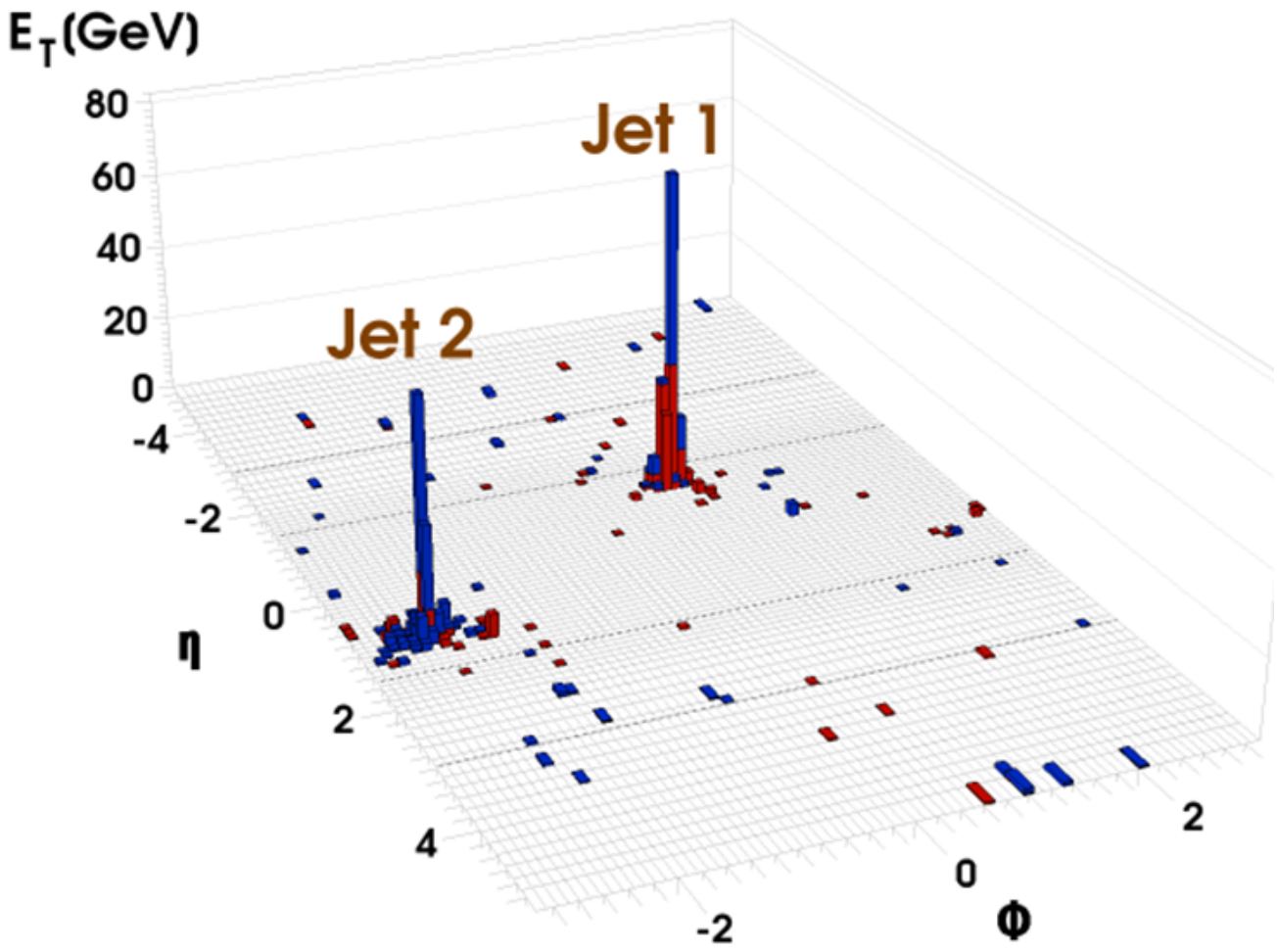
$$\sigma(gg \to H + X)$$

N³LL + N³LO
Becher, Schwartz 0803.0342
Abbate, Fickinger, Hoang, Mateu, Stewart 1006.3080

N³LO
Anastasiou, Duhr, Dulat, Herzog, Mistlberger 1503.06056

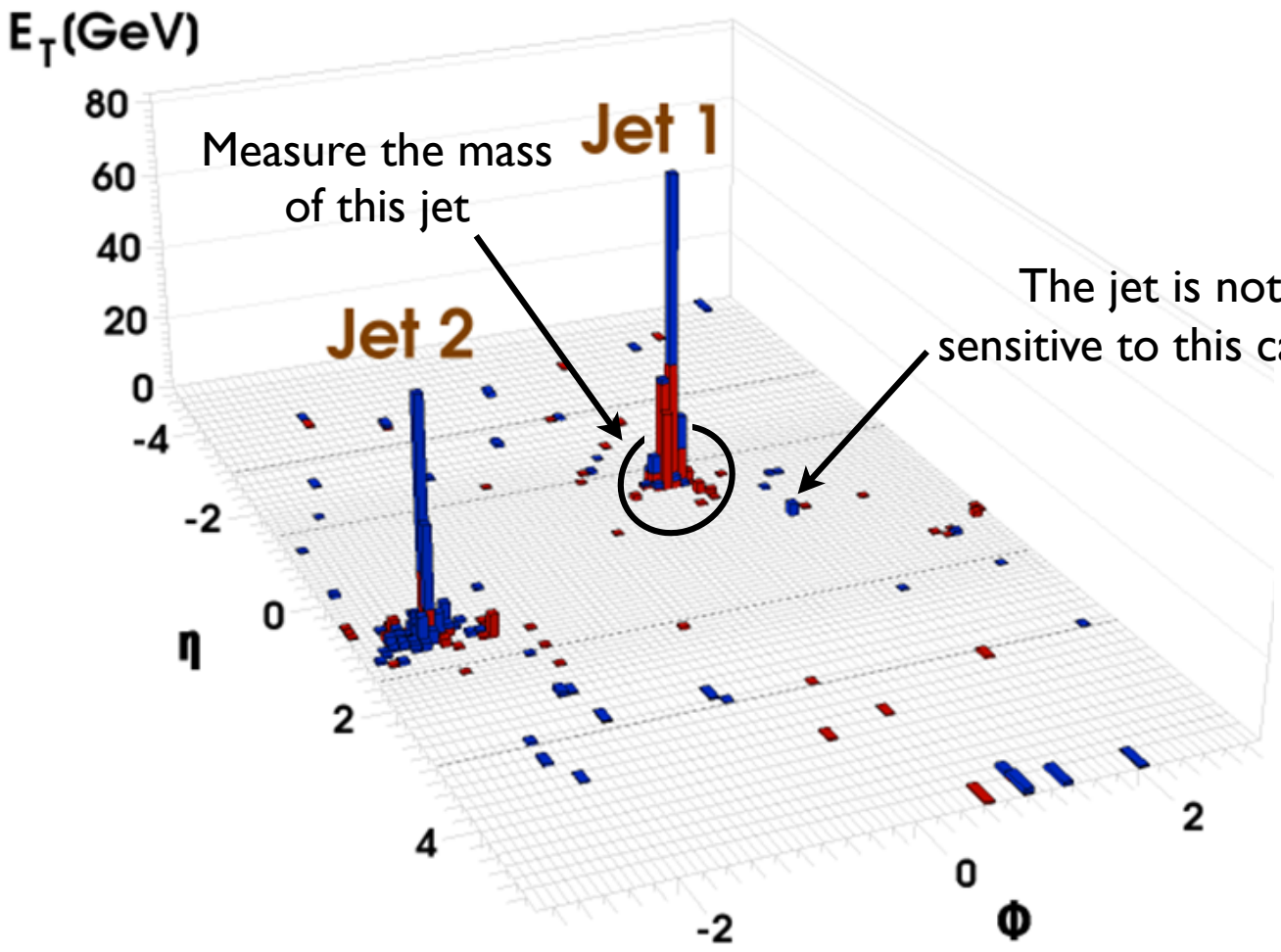
*Fiducial cross sections are considered global

This Conference



CMS DP-2010/014

This Conference

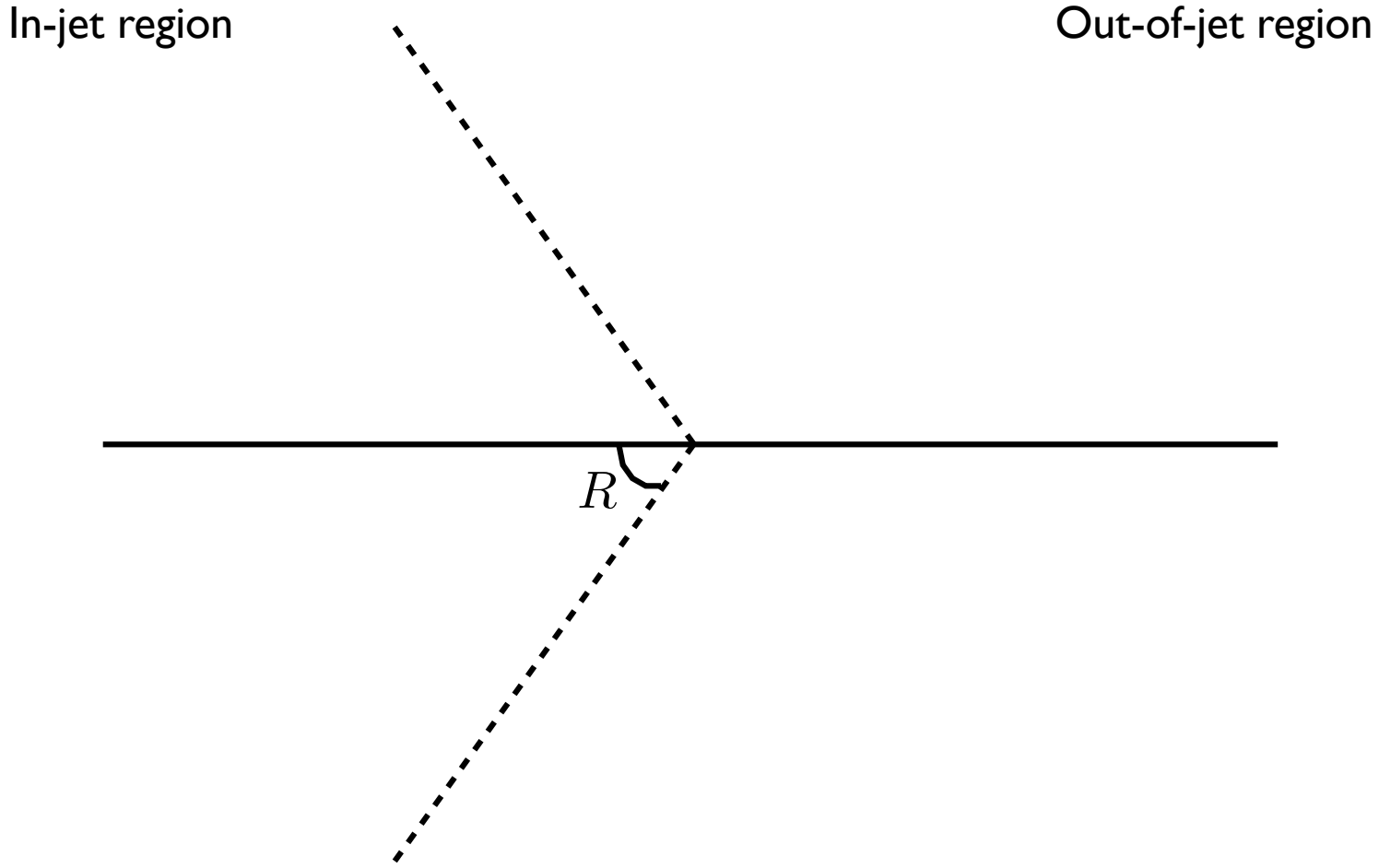


Indirect sensitivity = Non-global effects

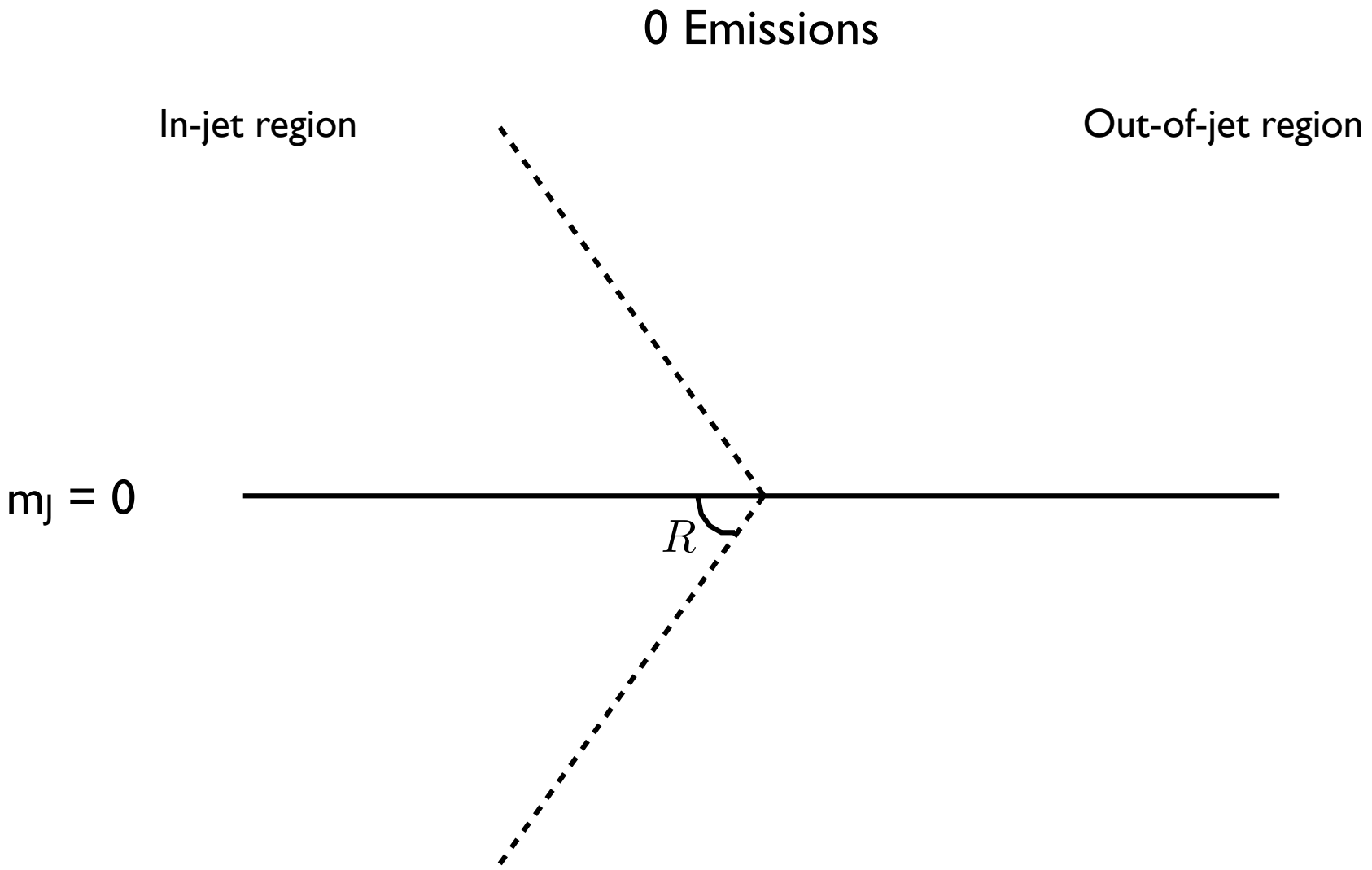
CMS DP-2010/014

Simple Picture of Non-Global Effects

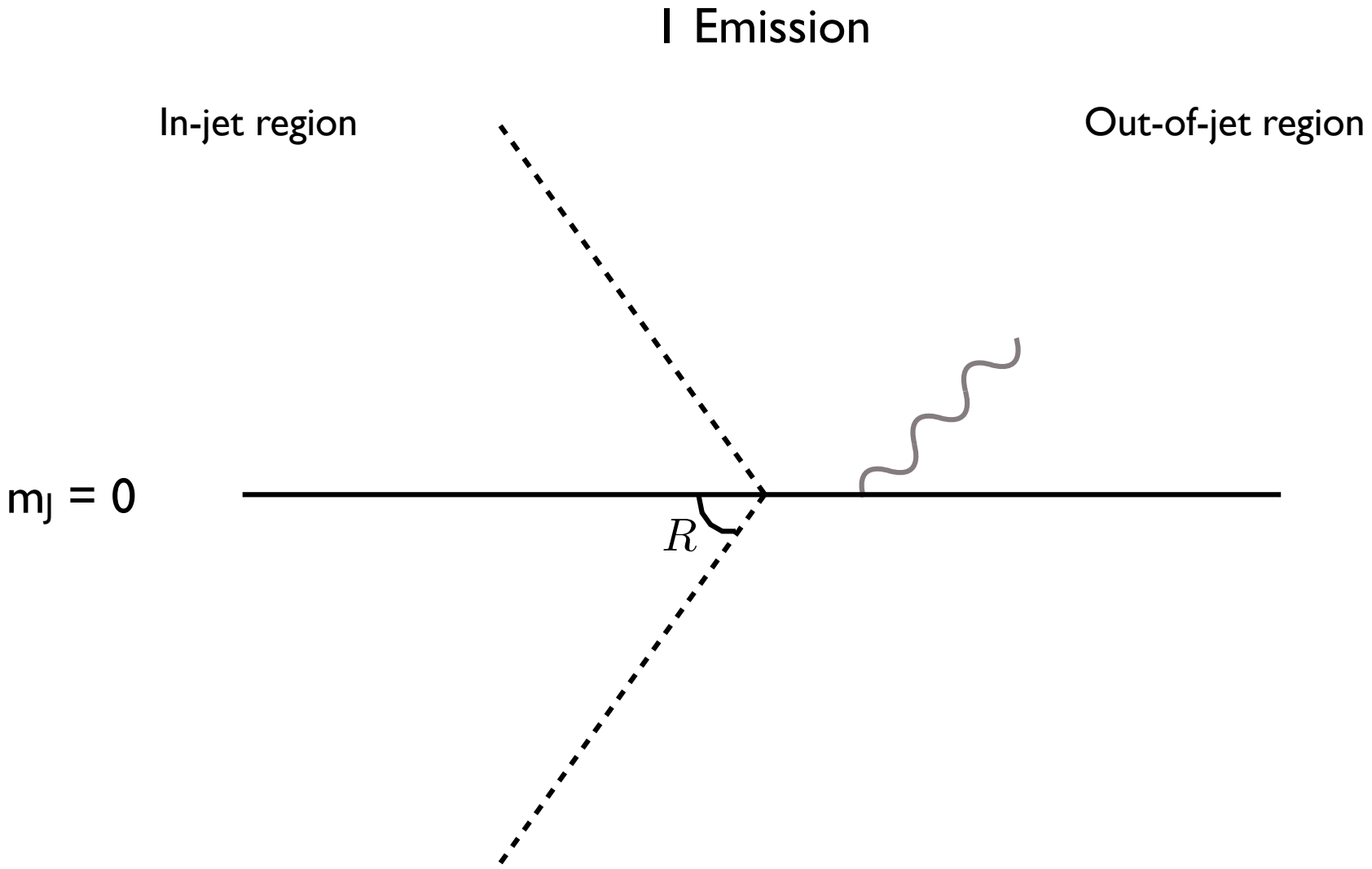
$$e^+e^- \to jj$$



Simple Picture of Non-Global Effects

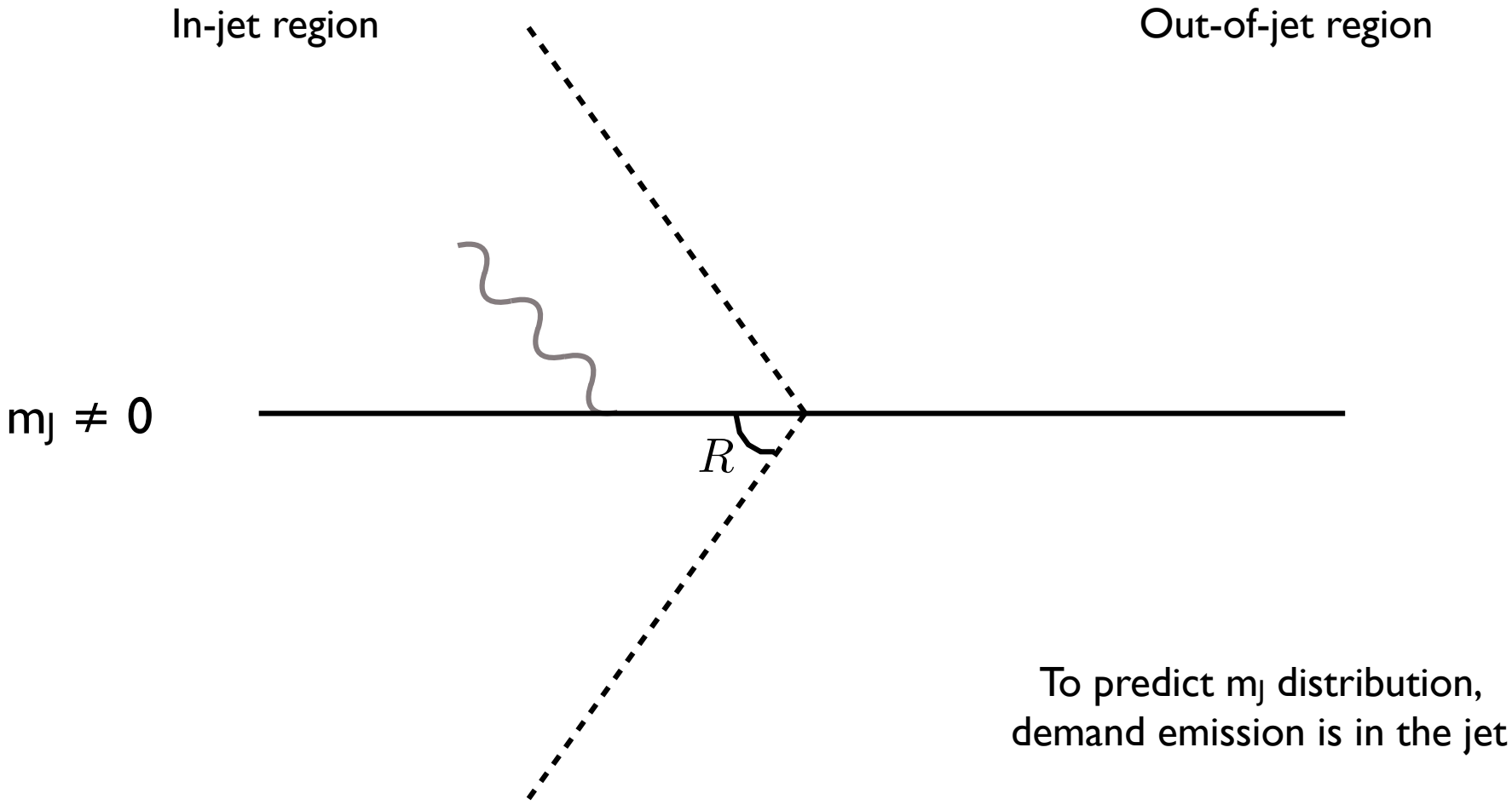


Simple Picture of Non-Global Effects



Simple Picture of Non-Global Effects

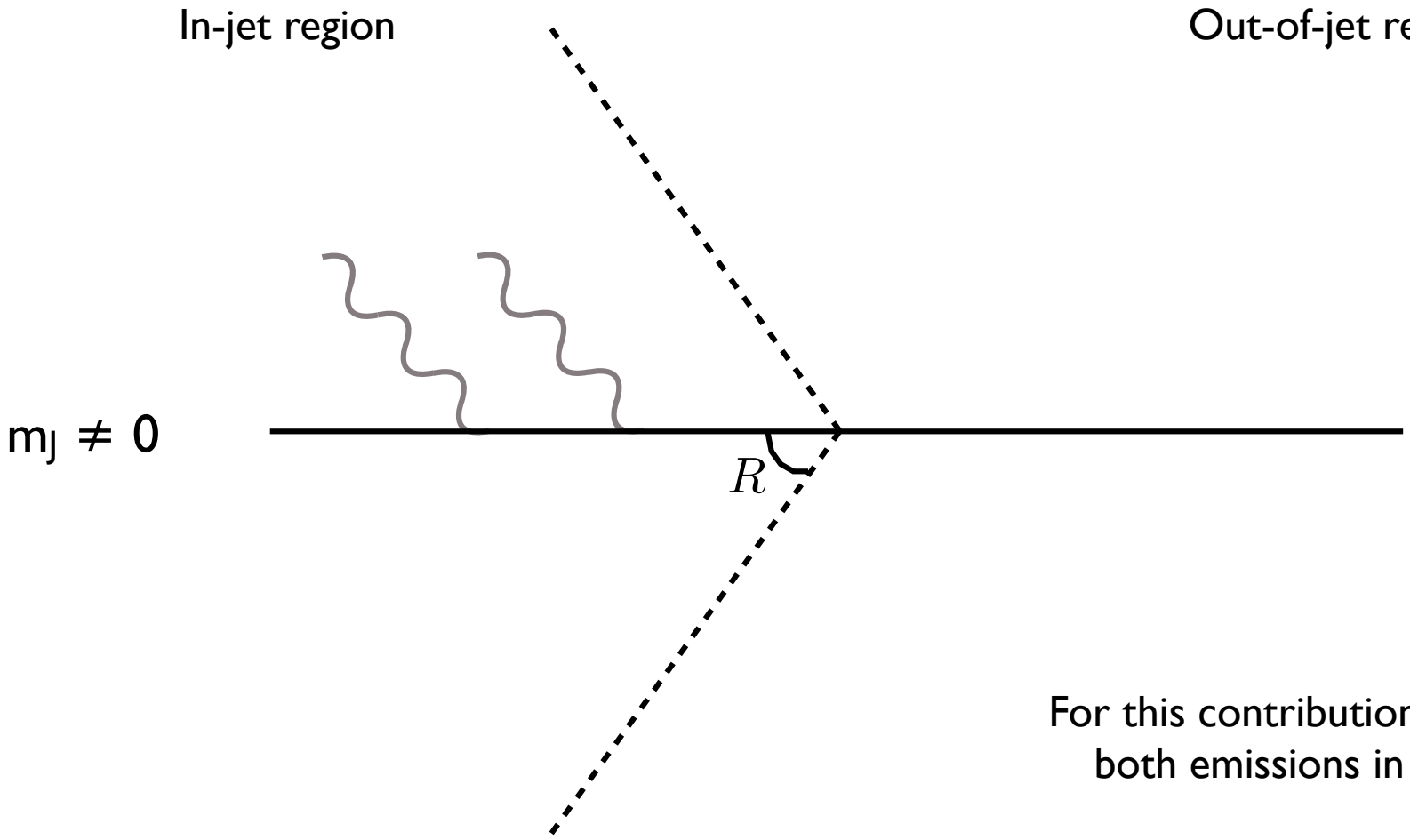
1 Emission



To predict m_J distribution,
demand emission is in the jet

Simple Picture of Non-Global Effects

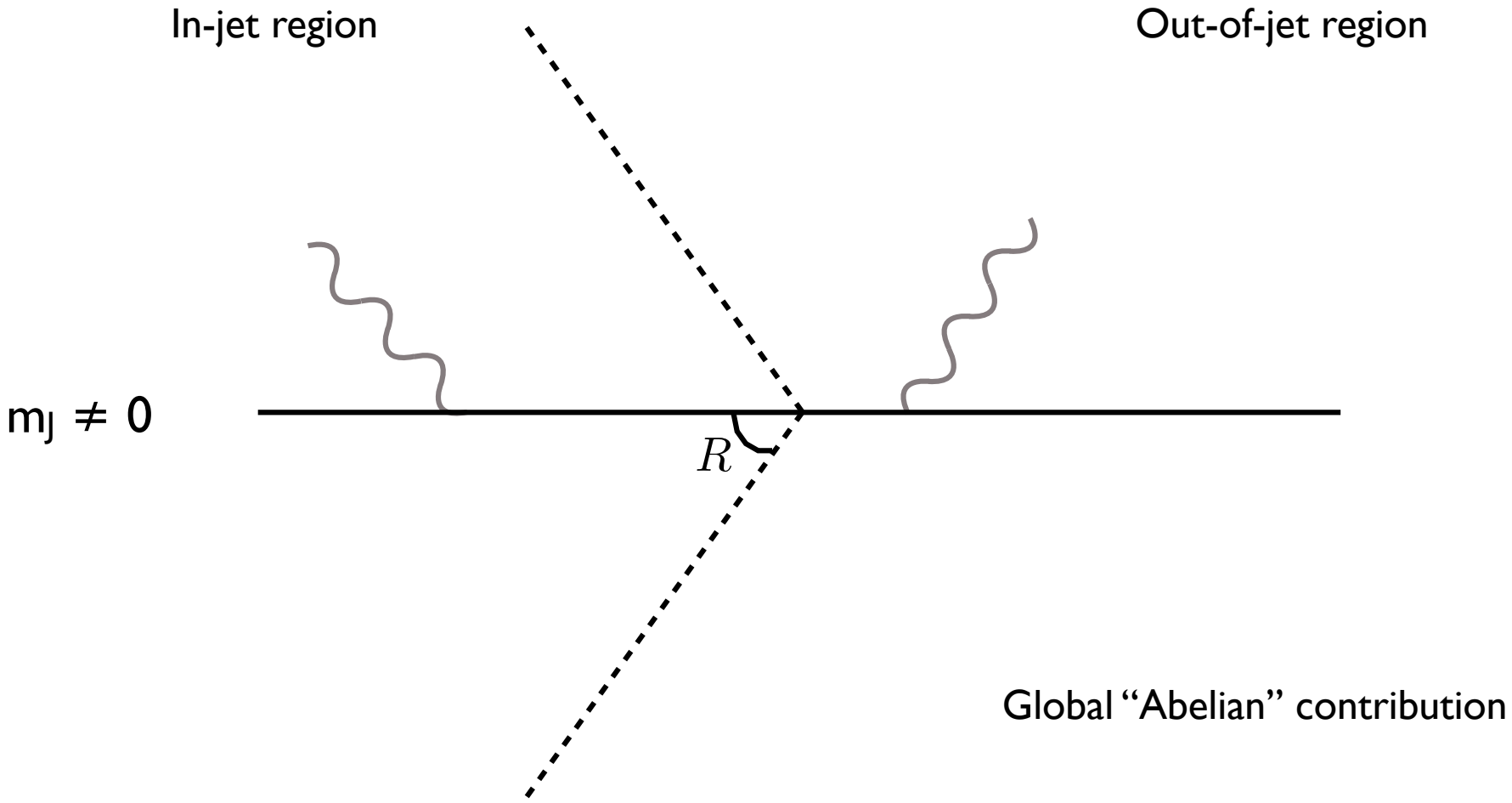
2 Emissions



For this contribution, demand both emissions in the jet

Simple Picture of Non-Global Effects

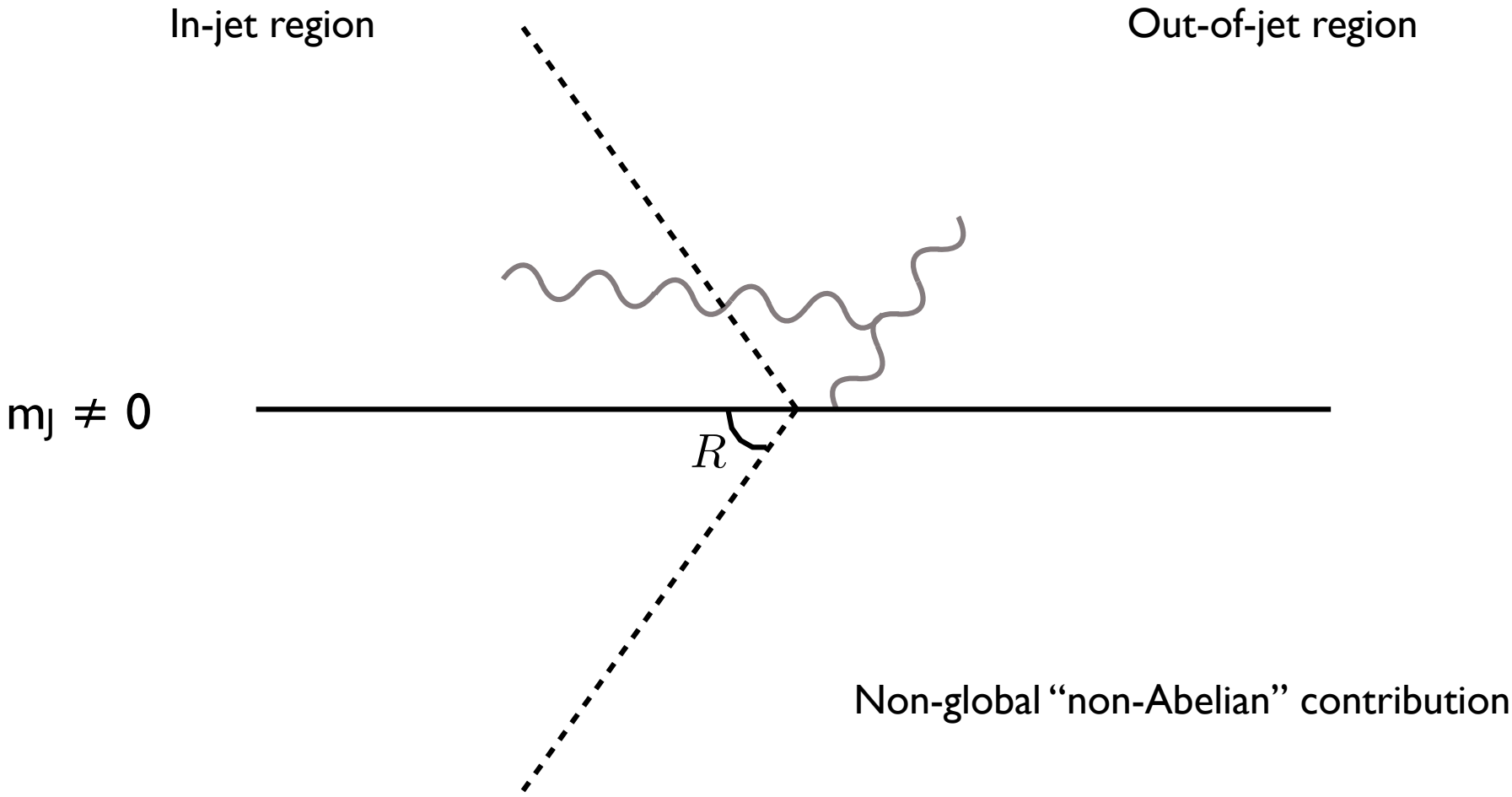
2 Emissions



Global "Abelian" contribution

Simple Picture of Non-Global Effects

2 Emissions



Non-global "non-Abelian" contribution

History of Non-Global Effects

Identified and defined by Dasgupta and Salam
Presented Monte Carlo for NLL resummation

Dasgupta, Salam 0104277

BMS non-linear evolution equation at NLL:

Banfi, Marchesini, Smye 0206076

$$\partial_L g_{ab} = \int_{\text{out}} \frac{d\Omega_j}{4\pi} \mathcal{W}_{ab}^j [U_{abj} g_{aj} g_{jb} - g_{ab}]$$

Fixed-Order

Schwartz, Zhu 1403.4949
Khelifa-Kerfa, Delenda 1501.00475

Subleading Color

Weigert 0312050
Hatta, Ueda 1304.6930

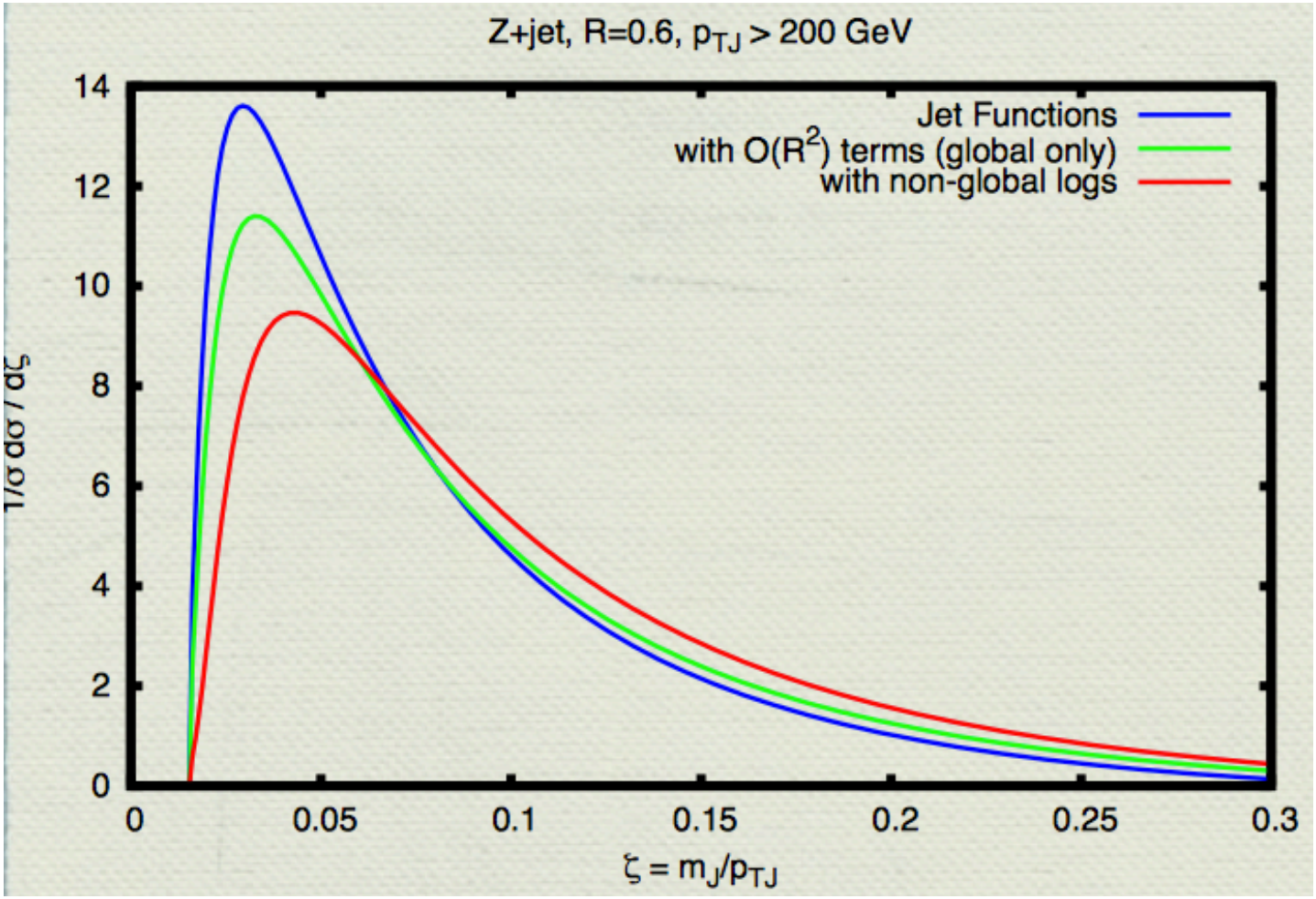
Subleading Fixed-Order Logarithms

Hornig, Lee, Stewart, Walsh, Zuberi 1105.4628

Higher-Order Evolution

Caron-Huot 1501.03754

Jet mass distribution:

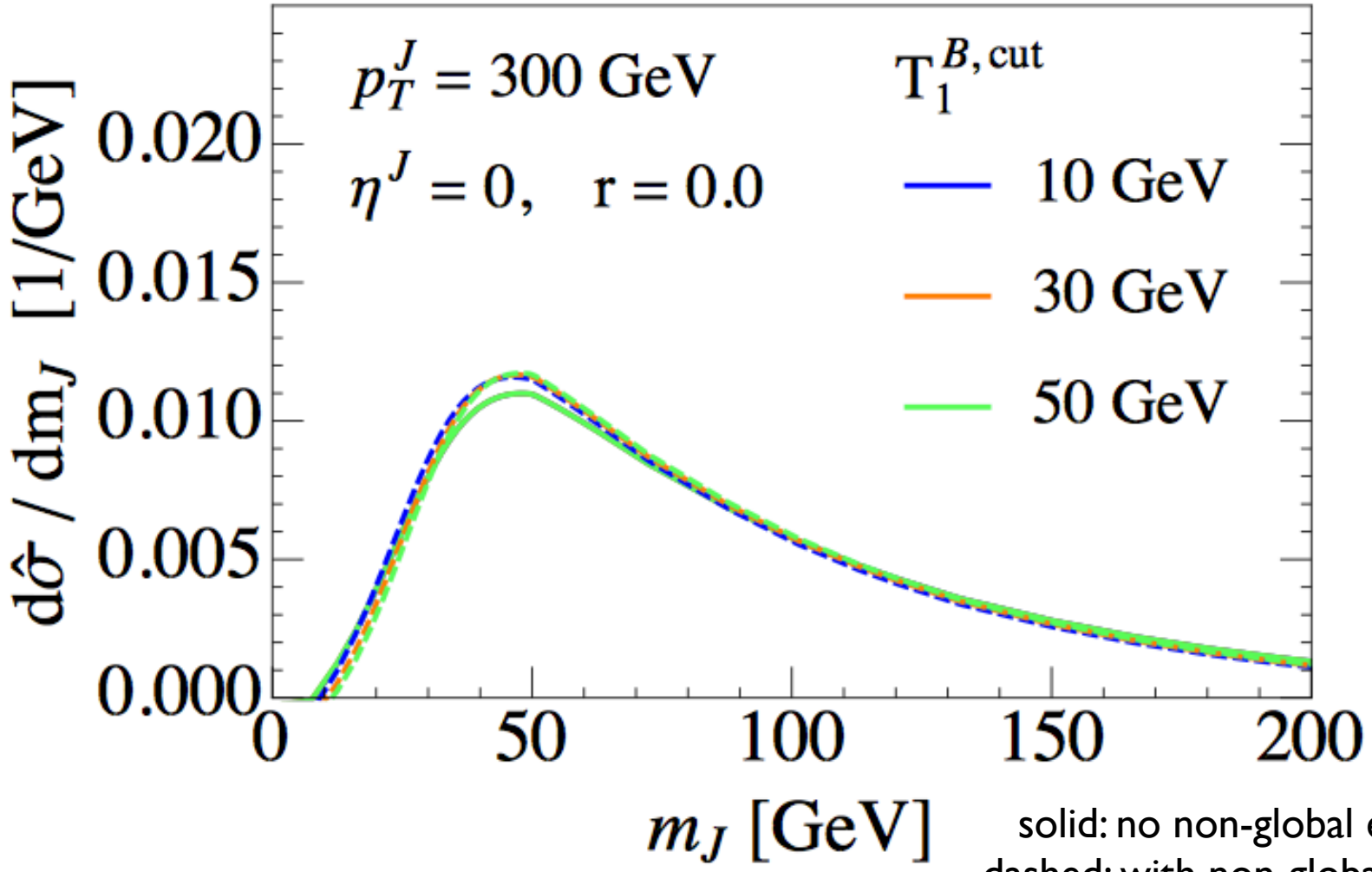


S. Marzani, BOOST 2012

Dasgupta, Khelifa-Kerfa, Marzani, Spannowsky 1207.1640

Large corrections from non-global effects

Jet mass distribution:



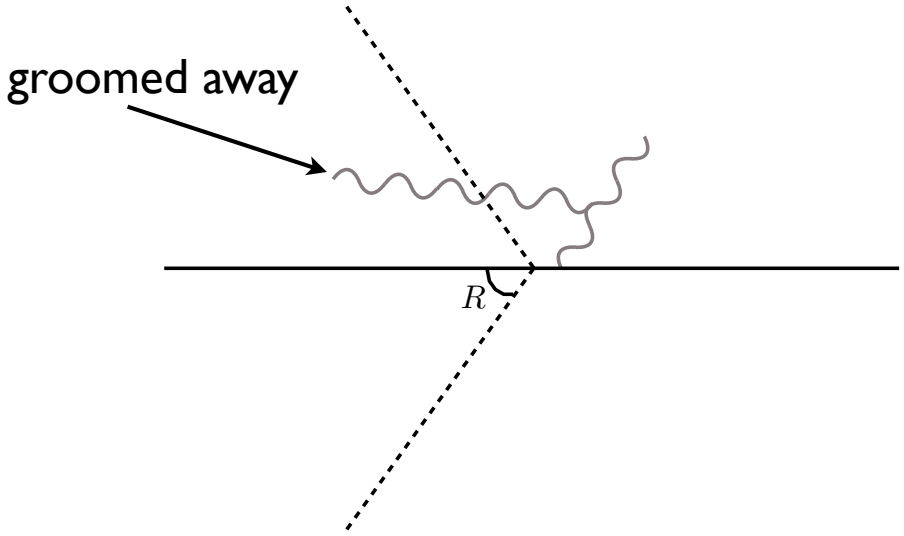
solid: no non-global effects
dashed: with non-global effects

I. Stewart, BOOST 2012

Jouttenus, Stewart, Tackmann, Waalewijn 1302.0846

$\mathcal{T}_N < \mathcal{T}_{\mathrm{cut}}$ Highly restricts out-of-jet radiation

Removing Non-Global Effects

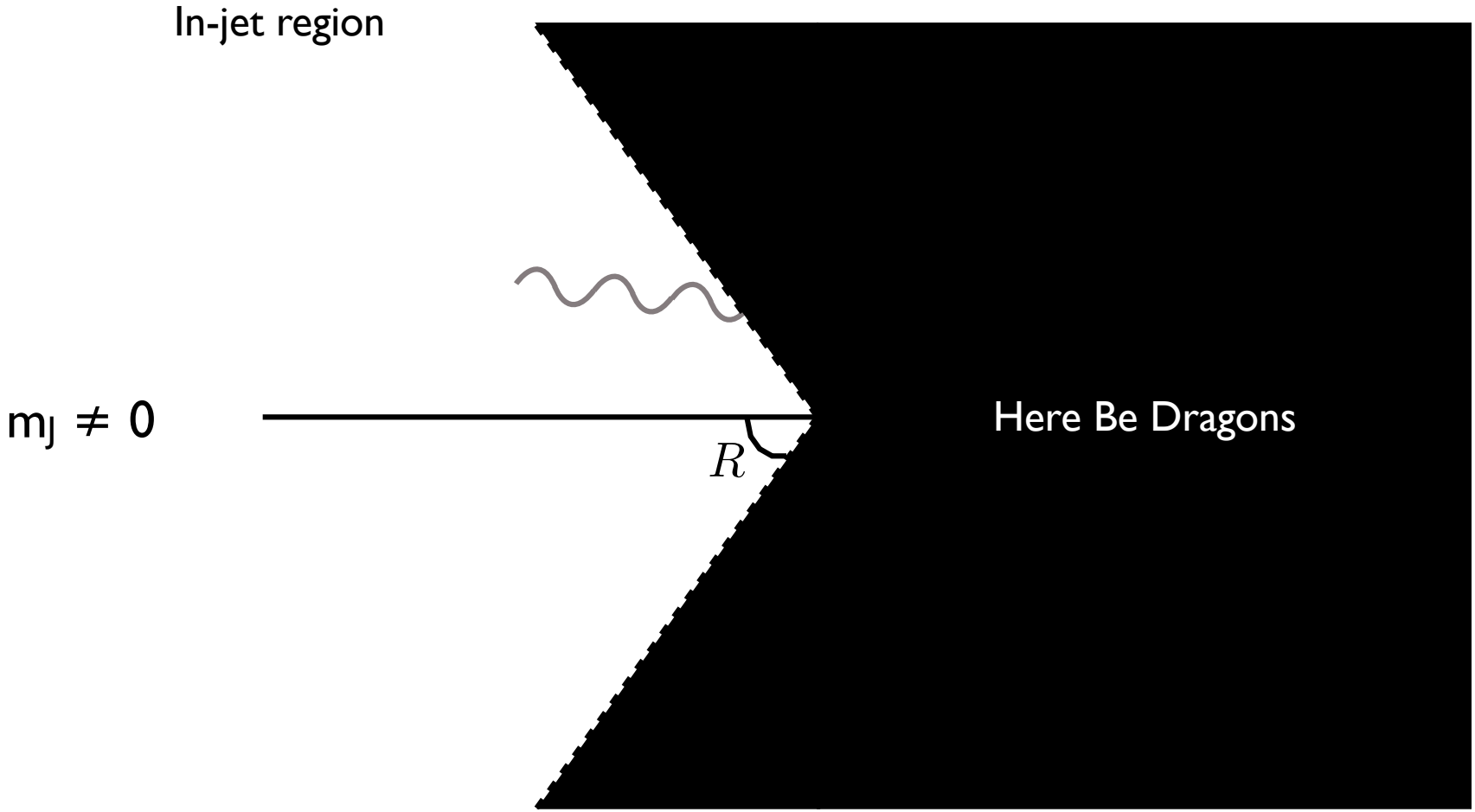


See talks by:
Salam and Marzani, BOOST 2013
Marzani, BOOST 2104

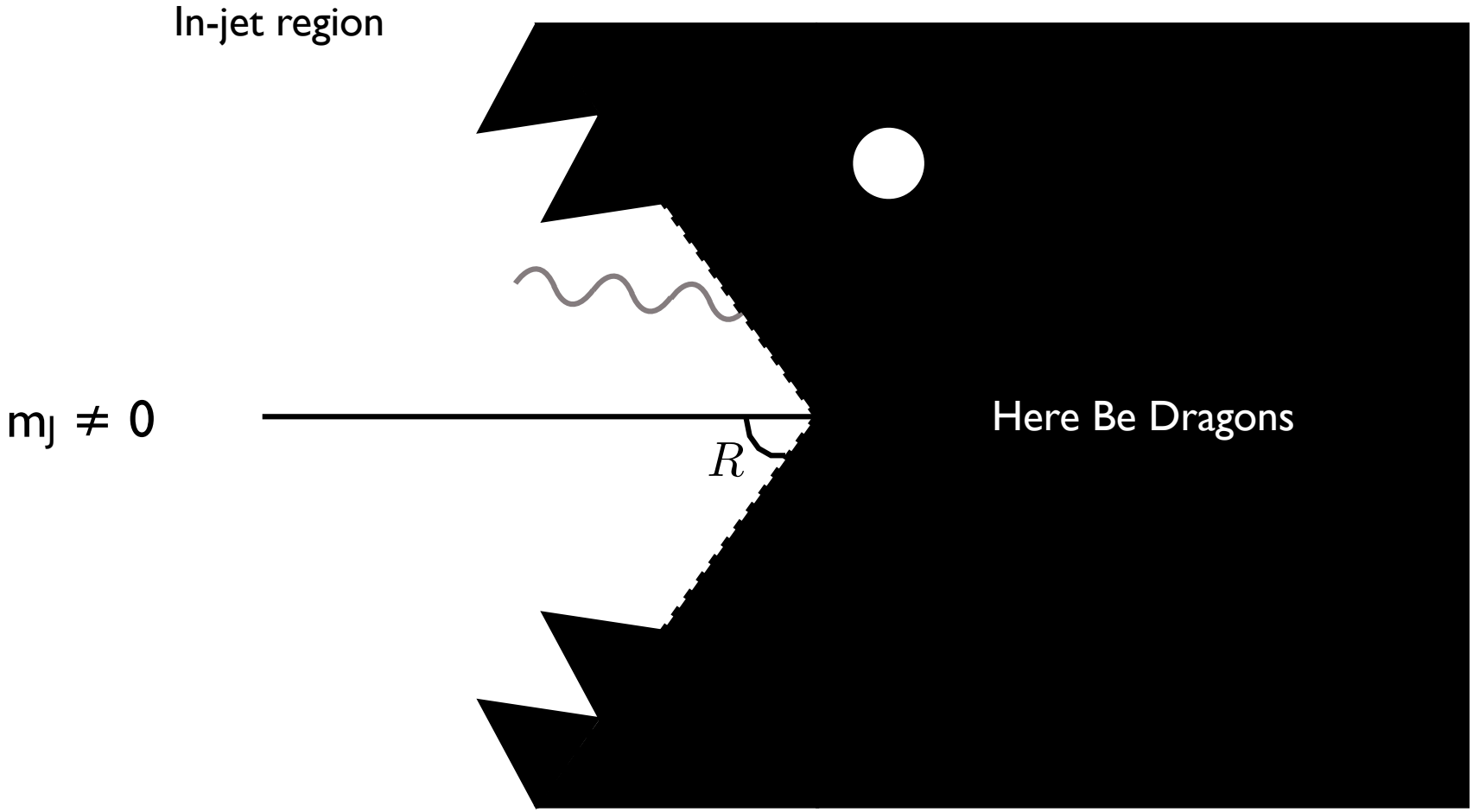
	highest logs	transition(s)	Sudakov peak	NGLs	NP: $m^2 \lesssim$
plain mass	$\alpha_s^n L^{2n}$	—	$L \simeq 1/\sqrt{\bar{\alpha}_s}$	yes	$\mu_{\rm NP}\, p_t\, R$
trimming	$\alpha_s^n L^{2n}$	$z_{\rm cut},\ r^2 z_{\rm cut}$	$L \simeq 1/\sqrt{\bar{\alpha}_s} - 2\ln r$	yes	$\mu_{\rm NP}\, p_t\, R_{\rm sub}$
pruning	$\alpha_s^n L^{2n}$	$z_{\rm cut},\ z_{\rm cut}^2$	$L \simeq 2.3/\sqrt{\bar{\alpha}_s}$	yes	$\mu_{\rm NP}\, p_t\, R$
MDT	$\alpha_s^n L^{2n-1}$	$y_{\rm cut},\ \frac{1}{4} y_{\rm cut}^2,\ y_{\rm cut}^3$	—	yes	$\mu_{\rm NP}\, p_t\, R$
Y-pruning	$\alpha_s^n L^{2n-1}$	$z_{\rm cut}$	(Sudakov tail)	yes	$\mu_{\rm NP}\, p_t\, R$
mMDT/soft drop	$\alpha_s^n L^{n}$	$y_{\rm cut}$	—	no	$\mu_{\rm NP}^2/y_{\rm cut}$

Dasgupta, Fregoso, Marzani, Salam 1307.0007
AJL, Marzani, Soyez, Thaler 1402.2657

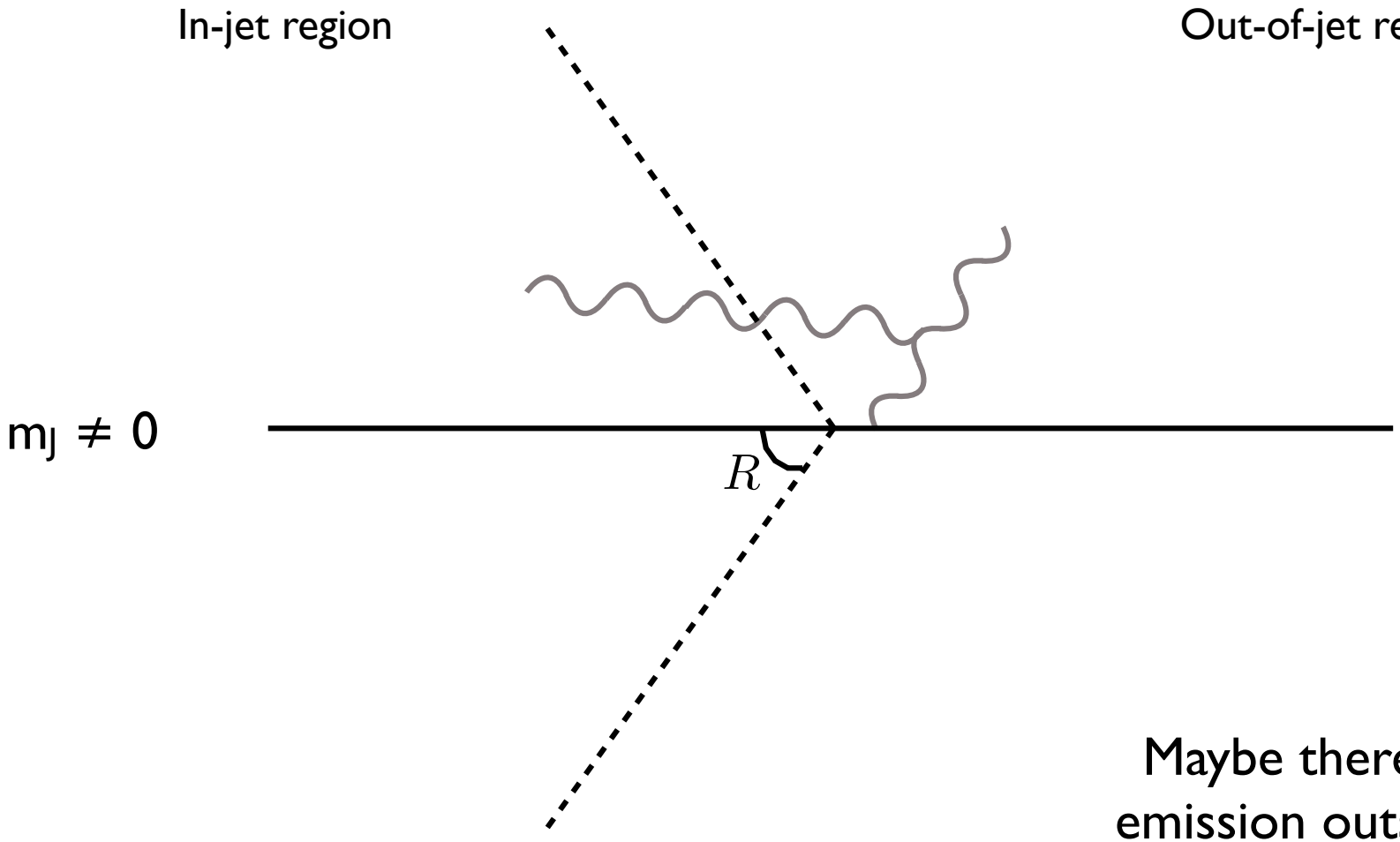
Rethinking Non-Global Effects



Rethinking Non-Global Effects

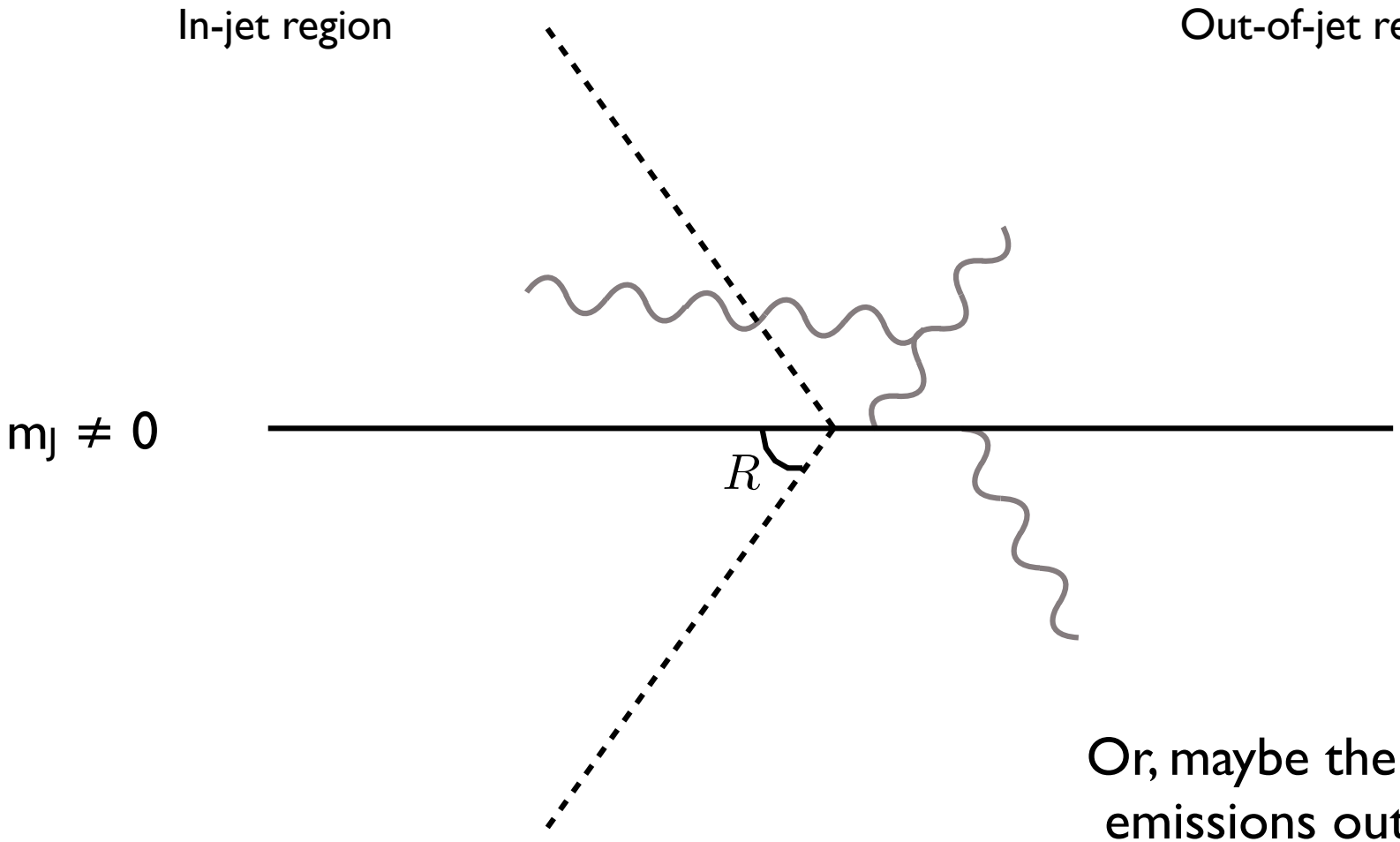


Rethinking Non-Global Effects



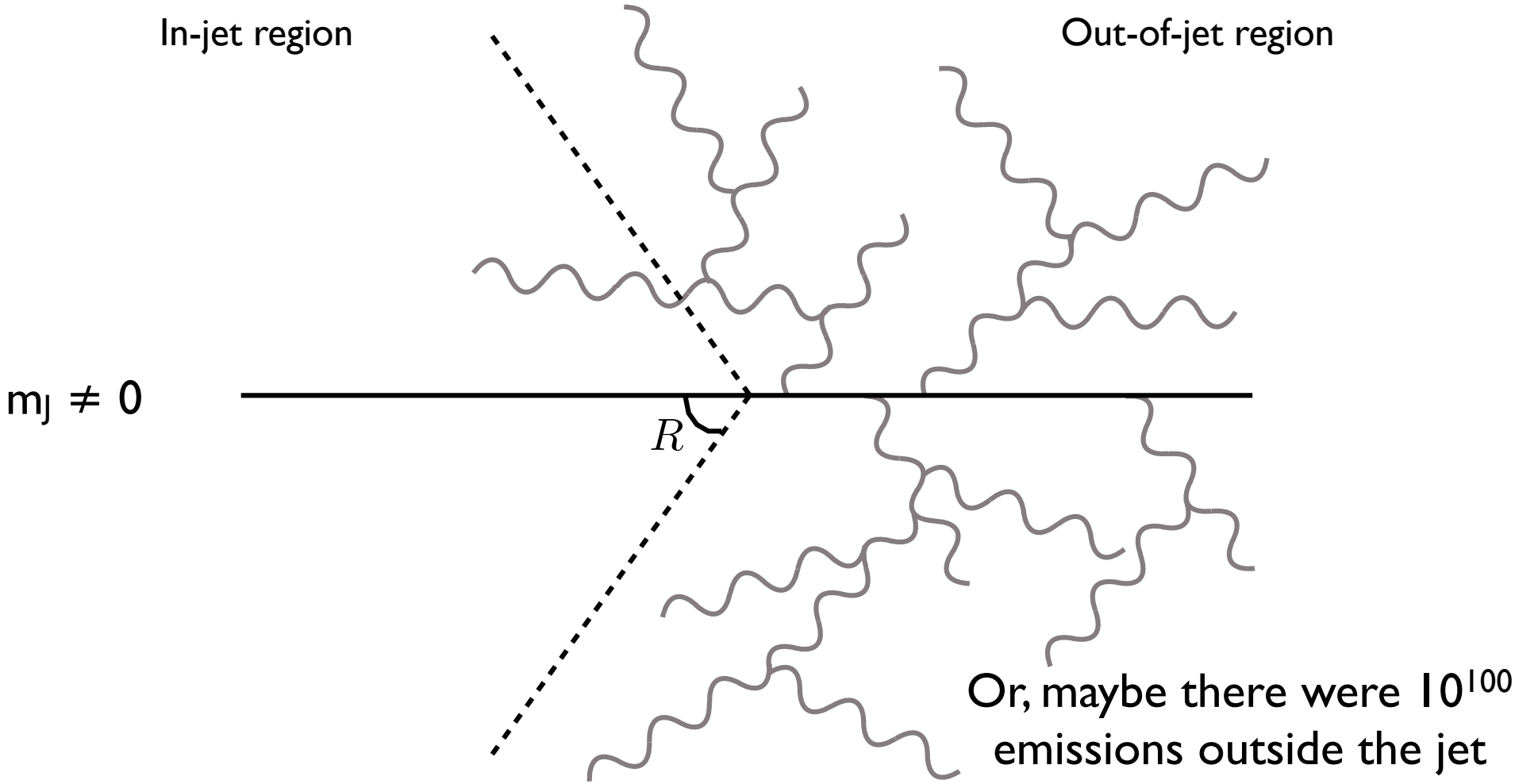
Maybe there was one emission outside the jet

Rethinking Non-Global Effects

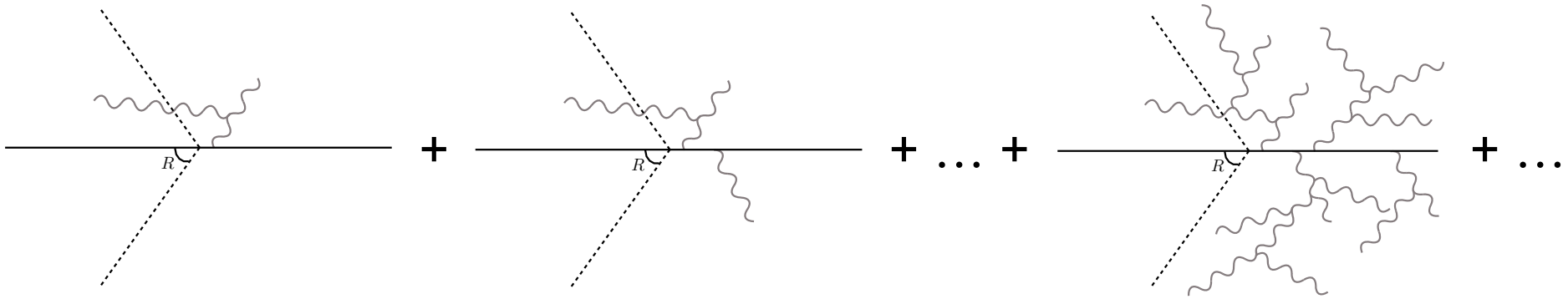


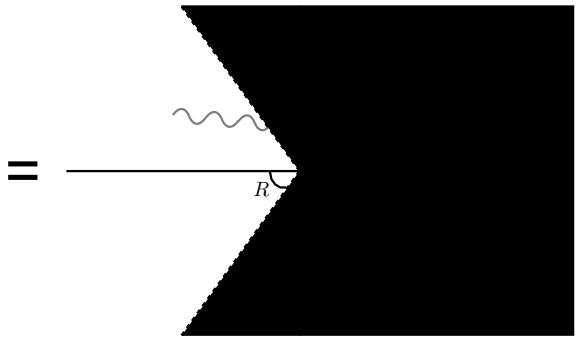
Or, maybe there were two emissions outside the jet

Rethinking Non-Global Effects



Rethinking Non-Global Effects

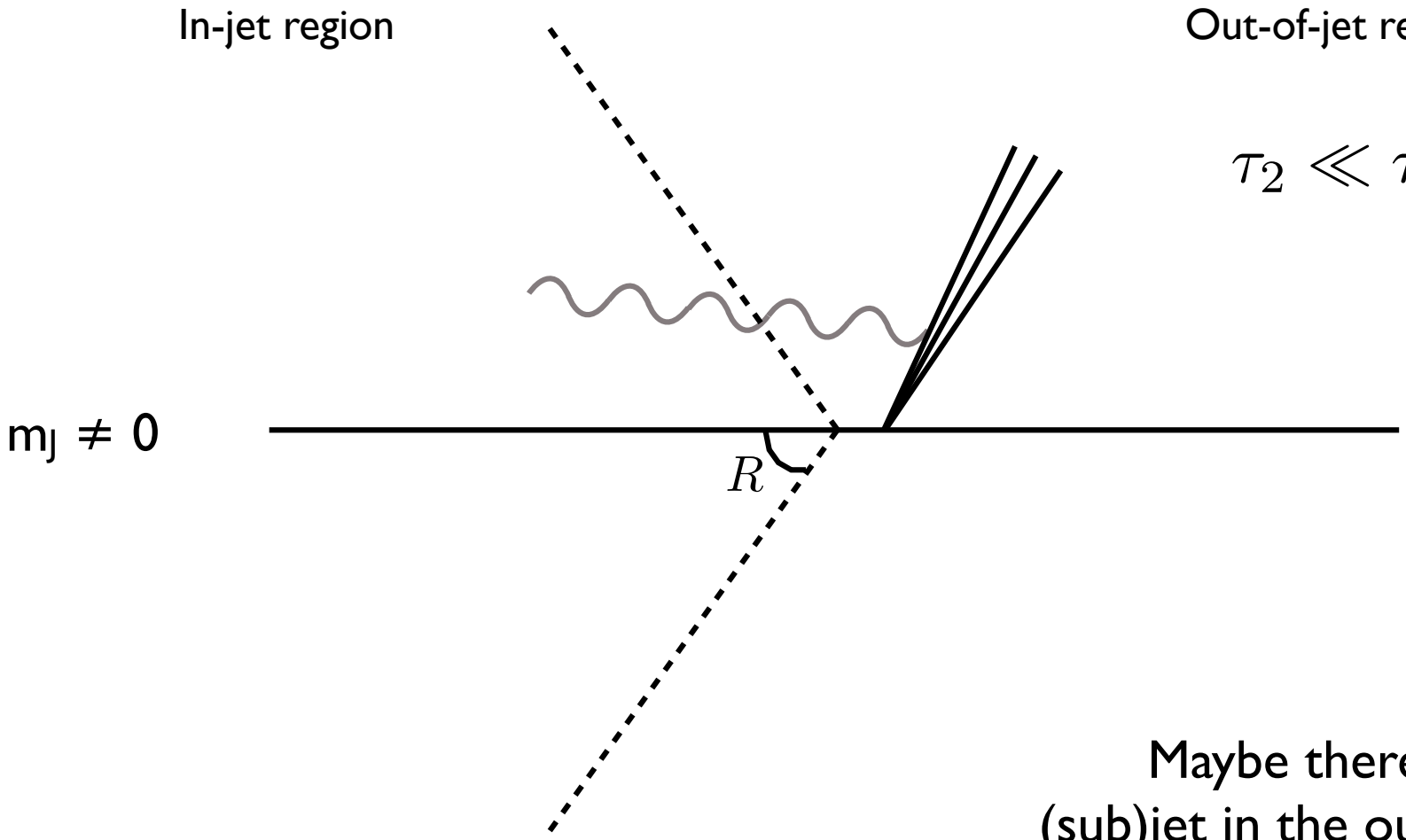




This is a complete basis for out-of-jet radiation, but is not an IRC safe basis

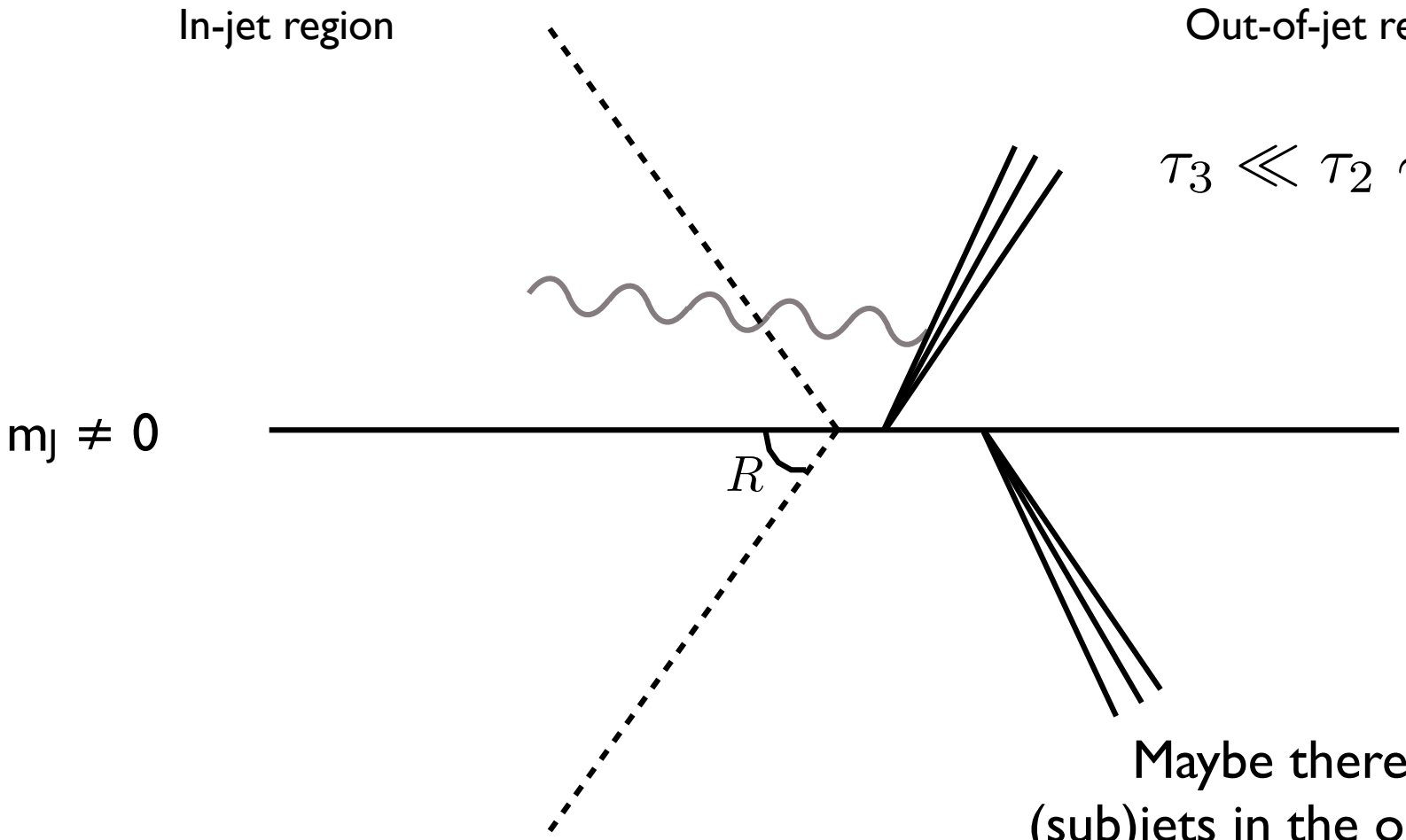
Count individual jets not individual particles!

Rethinking Non-Global Effects



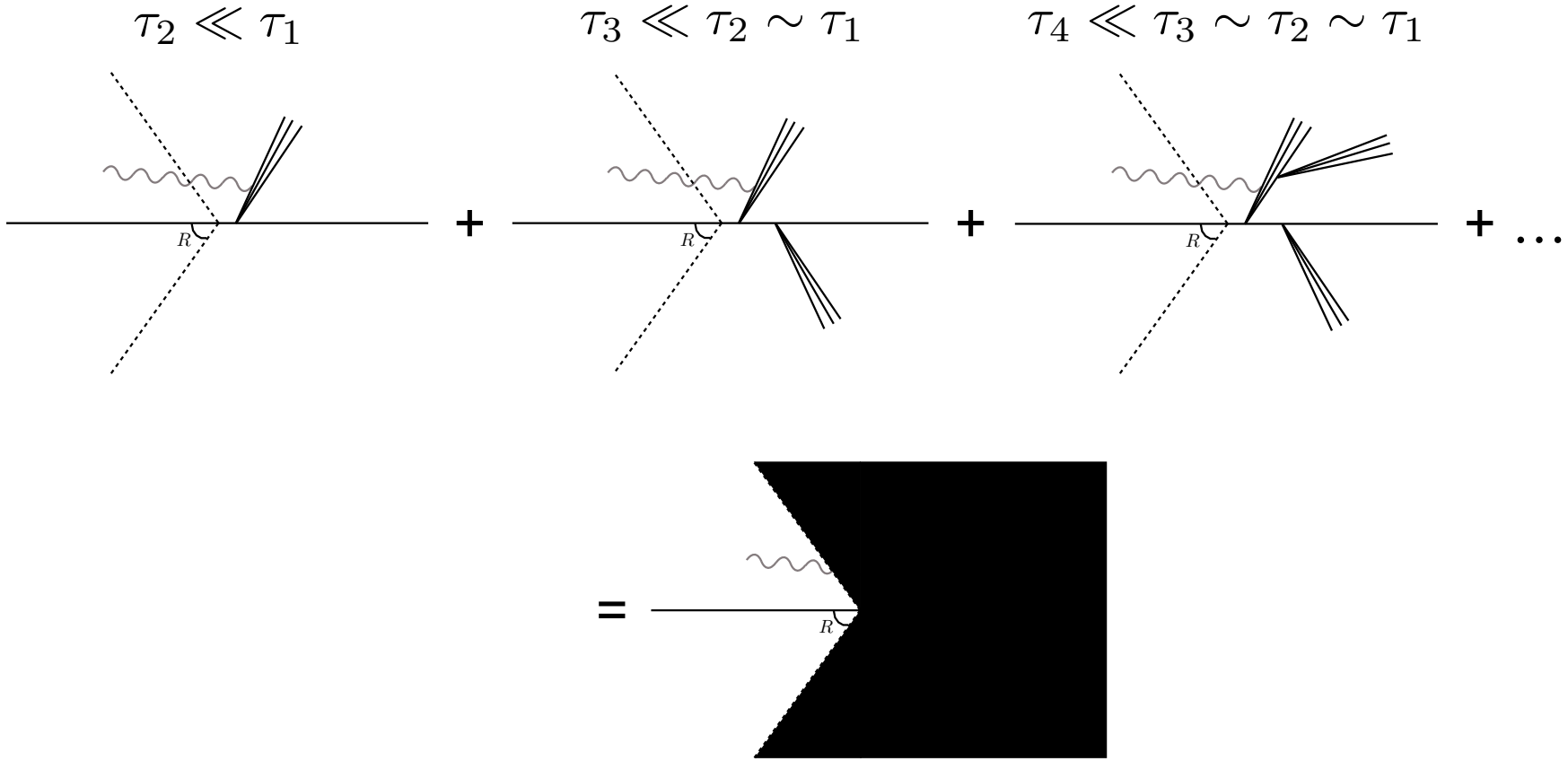
Maybe there was one
(sub)jet in the out-of-jet region

Rethinking Non-Global Effects



Maybe there were two
(sub)jets in the out-of-jet region

Rethinking Non-Global Effects

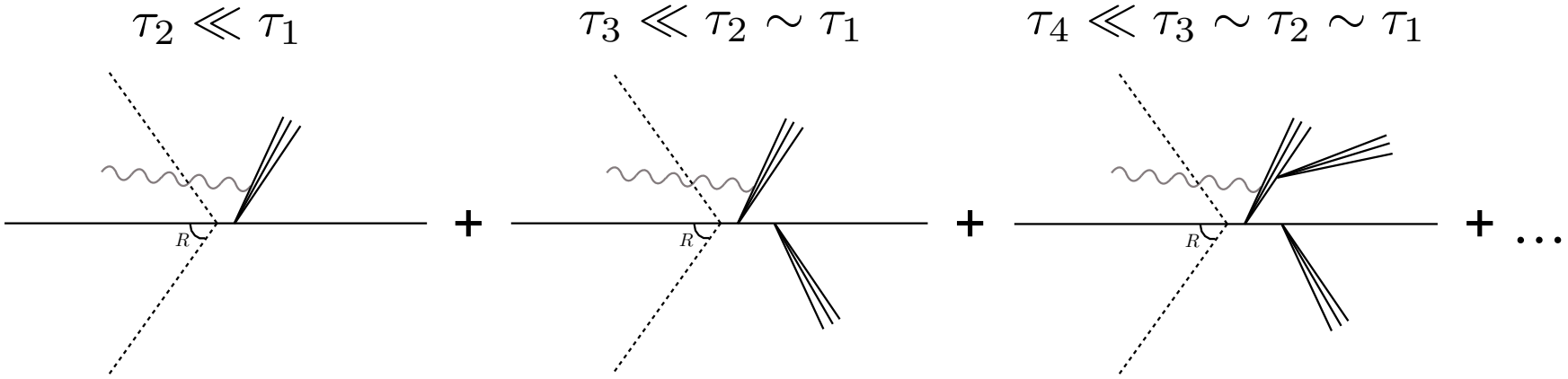


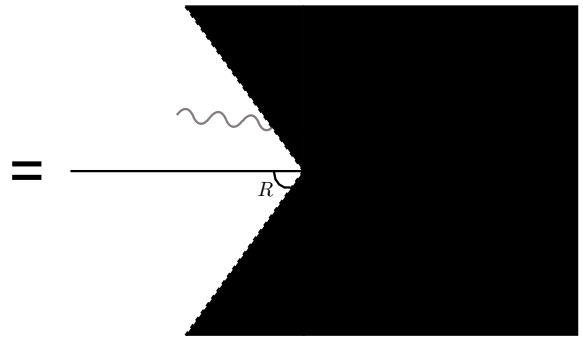
This is a complete and IRC safe basis for out-of-jet radiation

To isolate *N* (sub)jet contribution, require: $\tau_{N+1} \ll \tau_N \sim \ldots \sim \tau_1$

Each subjet configuration is systematically improvable to arbitrary accuracy!

Rethinking Non-Global Effects

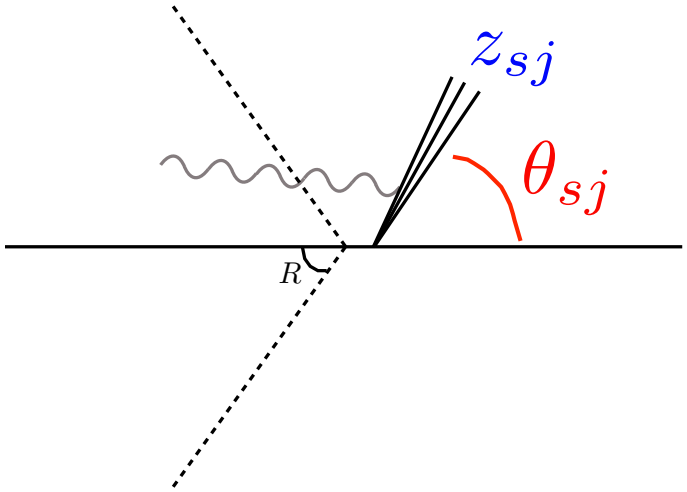




"Dressed Gluon Approximation"

Rigorous definition in terms of all-orders factorization theorems

One-Dressed Gluon Approximation



$$= W_{n\bar{n}}(z_{sj}, \theta_{sj}; R; \mu) G_{n\bar{n}n_{sj}}(B; R; \mu)$$

$$= \frac{\alpha_s C_F}{4\pi^2} \frac{2}{z_{sj} \sin^2 \theta_{sj}} \left(1 - \frac{\tan^2 \frac{\theta_{sj}}{2}}{\tan^2 \frac{R}{2}}\right)^{\frac{\alpha_s C_A}{\pi} \ln \frac{\mu}{\mu_i}}$$

out-of-jet mass

jet mass

subjet energy fraction

angle to jet boundary

Vanishes as subjet approaches boundary!

"Buffer region"

Dasgupta, Salam 0203009

Conclusions

Using insights from jet substructure, gained understanding of non-global effects

Dressed gluon expansion systematically organizes out-of-jet radiation into an IRC-safe and complete basis

Can be systematically improved to arbitrary perturbative accuracy

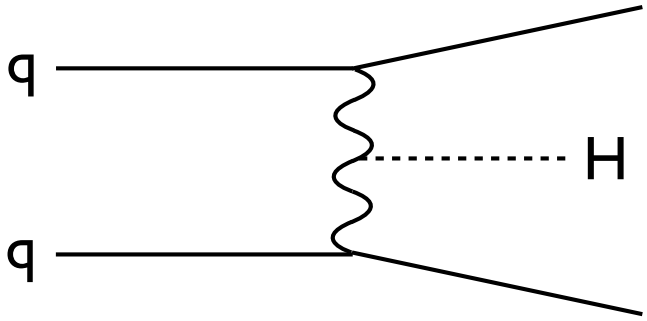
Where else can ideas from jet substructure be applied? Jet vetos? Fixed-order subtraction algorithms? High-accuracy parton showers?

Boughezal, Focke, Liu, Petriello 1504.02131
Gaunt, Stahlhofen, Tackmann, Walsh 1505.04794

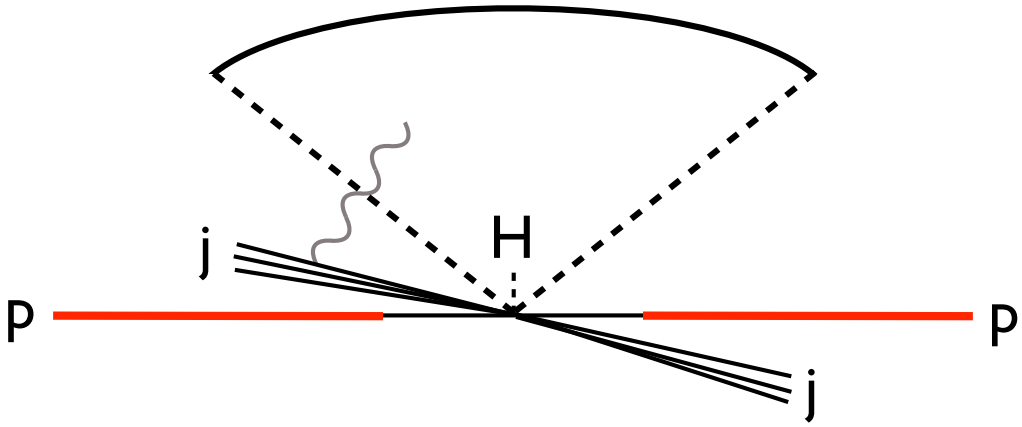
Bonus Slides

Other Non-Global Effects

Rapidity Gaps in VBF Higgs Production



Rapidity gap veto on hadronic radiation



$$\hat{s} = x_1 x_2 s = m_H^2$$

$x \gtrsim 10^{-4}$ at the LHC

$x \gtrsim 10^{-6}$ at a 100 TeV machine

Non-global effects in rapidity gaps related to factorization-violating effects

Forshaw, Kyrieleis, Seymour 0604094

Small-x BFKL evolution conformally related to non-global BMS evolution

Hatta 0810.0889

Consequences of Non-Global Effects

Out-of-Jet Buffer Region

In-jet region

Out-of-jet region

$\eta_{\rm buffer}$

$\tau_2 \ll \tau_1$

$m_J \neq 0$

R

$$\eta_{\rm buffer} \sim \log \frac{\tau_1 Q^2}{m_J^2}$$

Observed numerically in Monte Carlo

Dasgupta, Salam 0203009

Analytically verified in the dressed gluon approximation!