ZPW 2014 Monte Carlo Simulation & 2nd Mini-Workshop on Advances in the Matrix Element Methods - January 8 2014

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Nikhef

Towards LHC Phenomenology with Vincia

work in collaboration with D.A. Kosower, P. Skands

Vincia Inventors: W. Giele, D. A. Kosower, P. Skands

Further work on Vincia: A. Gehrmann-De Ridder, L. Hartgring, E. Laenen, A. Larkoski, J.J. Lopez-Villarejo, MR

Overview

motivation & basics

spotlight on recoil

summary and outlook

Context

there are several widely used and actively developed event generators with one or more parton shower modules:

Sherpa

S. Schumann, F. Krauss 0709.1027

J.-C. Winter, F. Krauss 0712.3913

Herwig

M. Bähr, S. Gieseke, M.A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Plätzer, P. Richardson, M.H. Seymour, A. Sherstnev, B.R. Webber 0803.0883

S. Plätzer, S. Gieseke 1109.6256

Pythia

T. Sjöstrand, S. Mrenna, P. Skands 0710.3820

next two slides: why add another one?

The Vincia Parton Shower

W. Giele, D.A. Kosower, P. Skands
0707.3652, 1102.2126

is a plugin to Pythia 8[1]

does efficient matching to fixed-order

estimates its uncertainty comprehensively

(and can do error bands)

is fully functional for e^+ - e^- collisions

[1] T. Sjöstrand, S. Mrenna, P. Skands
0710.3820

Matching

general idea: the parton shower is the phase space generator

unweighted events matched to several consecutive tree-level matrix elements, no sample merging step

can use identified helicities to avoid the evaluation of helicity-summed matrix elements

A. Larkoski, J.J. Lopez-Villarejo, P. Skands
1301.0933

extension to one-loop matching started ($Z \to 3$ jets)

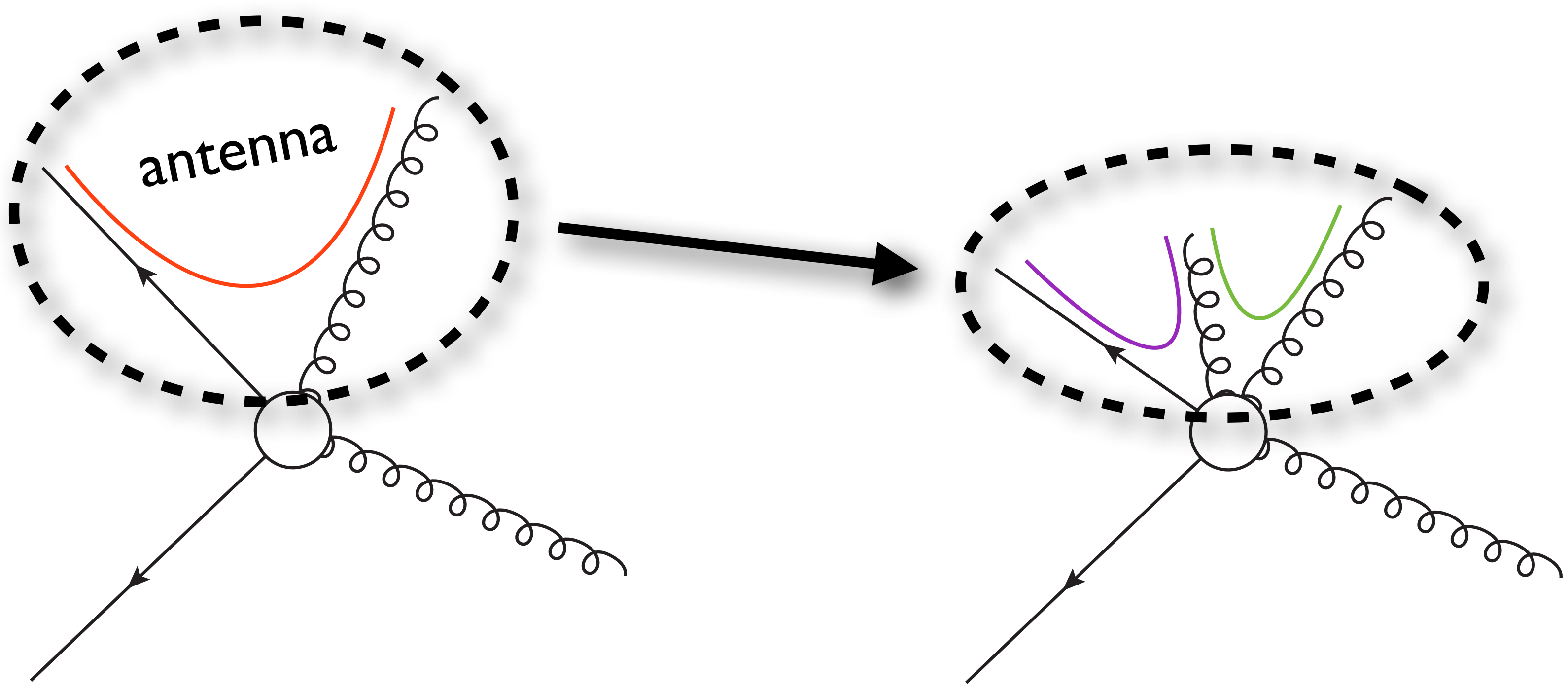
(still directly producing unweighted events)

L. Hartgring, E. Laenen, P. Skands
1303.4974

Basics of Vincia

based on 2 → 3 splittings, as pioneered by Ariadne[1]

interference between emitters taken into account by construction (at leading colour)



[1] G. Gustafson, U. Pettersson
Nucl.Phys.B306:746,1988

Basics of Vincia

based on 2 → 3 splittings, as pioneered by Ariadne[1]

interference between emitters taken into account by construction (at leading colour)

related to antenna subtraction[2, 3, ...]

[2] A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover
hep-ph/0505111

[3] A. Daleo, T. Gehrmann, D. Maître
hep-ph/0612257

Basics of Vincia

use exact 2 → 3 factorization (same type as dipole factorization)

3 post-branching momenta ↙

$$\int \frac{\mathrm{d}x_a}{x_a}\frac{\mathrm{d}x_b}{x_b}\mathrm{d}\Phi_{2\to n+1} = \underbrace{\int \frac{\mathrm{d}x_A}{x_A}\frac{\mathrm{d}x_B}{x_B}\mathrm{d}\Phi_{2\to n}}_{\text{as in } \mathrm{d}\sigma_{2\to n}} \mathrm{d}\Phi_{\text{ant}}$$

$(a, b, A, B$ incoming$)$

three types according to where the radiators are:

final-final (carries over from e^+ - e^-)

initial-final

initial-initial

Basics of Vincia

specify algorithm by probability Δ that an antenna does not branch when evolving between two scales

$$\Delta\left(Q_{\text{start}}, Q_{\text{branch}}\right) = \exp\left[-\mathcal{A}\left(Q_{\text{start}}, Q_{\text{branch}}\right)\right]$$

$$\mathcal{A}\left(Q_{\text{start}}, Q_{\text{branch}}\right) = \int_{Q_{\text{branch}}}^{Q_{\text{start}}} a_c \, \frac{f_a(x_a, Q)}{f_A(x_A, Q)} \frac{f_b(x_b, Q)}{f_B(x_B, Q)} \, d\Phi_{\text{ant}}$$

$$Q = Q\left(\{p\}_{\text{ant}}\right)$$

resolution measure
several choices implemented for e^+ - e^-

antenna function
unifies splitting functions & soft eikonal factors
in GGG terms: sub-antenna function

Recoil in Initial-Initial Branchings

generate daughter invariants s_{aj}, s_{jb}

construct momenta with $p_a - p_j + p_b = p_A + p_B$

boost to align p_a, p_b with the beams

$\Rightarrow$ R gets recoil (e. g. Z gets $p_\perp$)

Recoil in Initial-Initial Branchings

daughter invariants don't fix the momenta

$\Rightarrow$ need to fix a mapping ($\equiv$ recoil strategy)

$$p_A = f_1 p_a - f_2 p_j + f_3 p_b$$
$$p_B = (1 - f_1) p_a - (1 - f_2) p_j + (1 - f_3) p_b$$

$\left(f_i = f_i\left(s_{aj}, s_{jb}, s_{ab}\right)\right)$

$p_A^2 = p_B^2 = 0 \Rightarrow$ one free parameter (select f_2)

collinear limits: $p_A \xrightarrow{p_j \to z p_a} (1 - z) p_a$ is not automatic

$\Rightarrow$ need to impose $f_2 \xrightarrow{j \| a/b} 1/2$

(antenna subtraction has $f_2 \equiv 1/2$)

Recoil in Initial-Initial Branchings

explicit factorization

$$\int \frac{\mathrm{d}x_a}{x_a}\frac{\mathrm{d}x_b}{x_b}\mathrm{d}\Phi_2\left(a,b\to j,R\right) =$$

$$\int \frac{\mathrm{d}x_a}{x_a}\frac{\mathrm{d}x_b}{x_b}\frac{1}{8\pi}\frac{1}{s_{ab}}\mathrm{d}s_{aj}\mathrm{d}s_{jb}\delta\left(s_{ab}-s_{aj}-s_{jb}-m_R^2\right)\frac{\mathrm{d}\phi}{2\pi}$$

change to $x_A \equiv r_a x_a$, $x_B \equiv r_b x_b$

$r_y = r_y(s_{aj}, s_{jb}, s_{ab})$ equivalent to choice of f_2

defined such that $r_a r_b = (s_{ab} - s_{aj} - s_{jb})/s_{ab} \equiv s_{AB}/s_{ab}$

split off $2 \to 1$ phase space

Recoil in Initial-Initial Branchings

explicit factorization

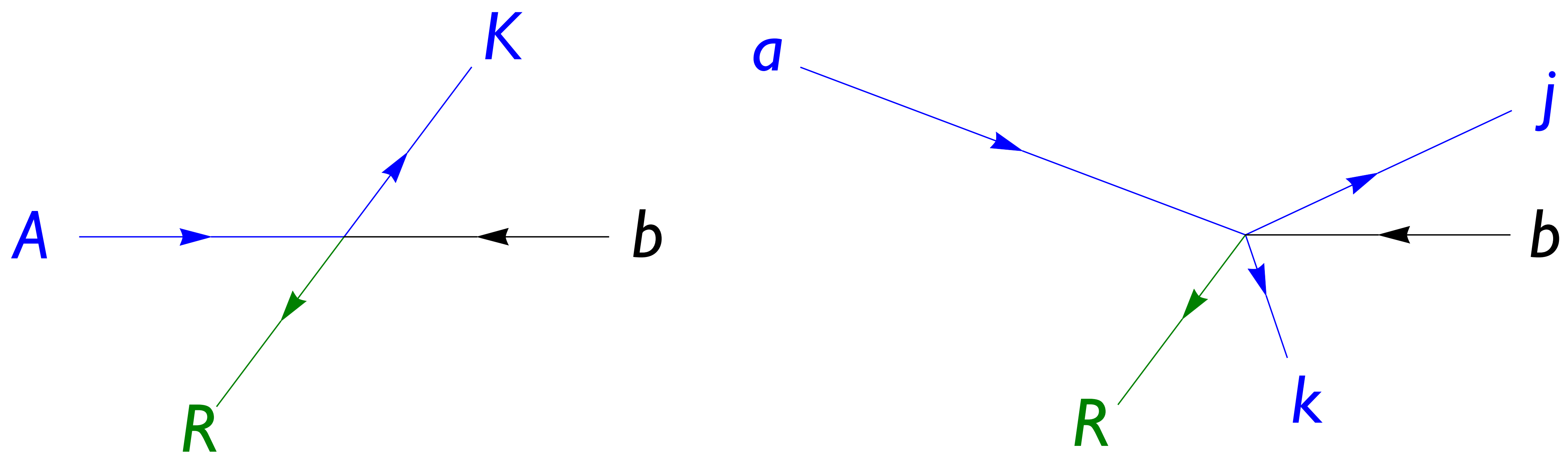
arrive at

$$\int \frac{dx_A}{x_A}\frac{dx_B}{x_B}\overbrace{2\pi\delta\left(s_{AB}-m_R^2\right)}^{d\Phi_1(A,B\to R)}$$

$$\underbrace{\frac{1}{16\pi^2}\frac{s_{AB}}{s_{ab}^2}\theta\left(r_a-x_A\right)\theta\left(r_b-x_B\right)ds_{aj}ds_{jb}\frac{d\phi}{2\pi}}_{d\Phi_{\mathrm{ant}}^{\mathrm{ii}}}$$

integration region depends on mapping

Recoil in Initial-Final Branchings



generate daughter invariants s_{aj}, s_{jk}

construct momenta with $p_a - p_j - p_k = p_A - p_K$

boost to align p_a with the beam (b stays)

$\Rightarrow$ R gets recoil

Recoil in Initial-Final Branchings

as before, write down general mapping

$$p_A = f_1 p_a - f_2 p_j - f_3 p_k$$
$$p_K = (1 - f_1) p_a - (1 - f_2) p_j - (1 - f_3) p_k$$

antenna/dipole subtraction: $f_2 \equiv 0 \Leftrightarrow p_a \parallel p_A$

due to initial-final kinematics, requiring that every physical $2 \to 3$ point corresponds to a physical $2 \to 2$ point restricts the choice of the mapping substantially (e.g. rules out crossing of final-final mapping)

Recoil in Initial-Final Branchings

explicit factorization

$$\int \frac{dx_a}{x_a} d\Phi_3 \left(a, b \to j, k, R\right) =$$

$$\int \frac{dx_a}{x_a} \frac{1}{s_{ab}} \frac{1}{256\pi^3} \left(\frac{2}{\pi} \frac{ds_{AK} ds_{ajb} ds_{aj} ds_{jk}}{\sqrt{-\Delta_4}} \right) \frac{d\phi}{2\pi}$$

change from x_a to x_A using $p_A = f_1 p_a - f_2 p_j - f_3 p_k$

observe $(-\Delta_4) = s_{AK}^2 / (f_1 - f_2)^2 \left(s_{ajb}^{\max} - s_{ajb}\right) \left(s_{ajb} - s_{ajb}^{\min}\right)$

$$s_{AK} = -(p_a - p_j - p_k)^2$$

$$s_{ajb} = \left(p_a - p_j + p_b\right)^2$$

Δ_4 : Gram determinant

Recoil in Initial-Final Branchings

explicit factorization

arrive at

$$\int \frac{dx_A}{x_A}\frac{1}{8\pi}\frac{1}{s_{Ab}}ds_{AK}\frac{d\phi}{2\pi}$$

$$\left[\frac{1}{16\pi^2}\frac{s_{Ab}^2}{s_{ab}^2}\frac{1}{s_{AK}}ds_{aj}ds_{jk}\left(\frac{1}{\pi}\frac{ds_{ajb}}{\sqrt{s_{ajb}^{\max}-s_{ajb}}\sqrt{s_{ajb}-s_{ajb}^{\min}}}\right)\right]$$

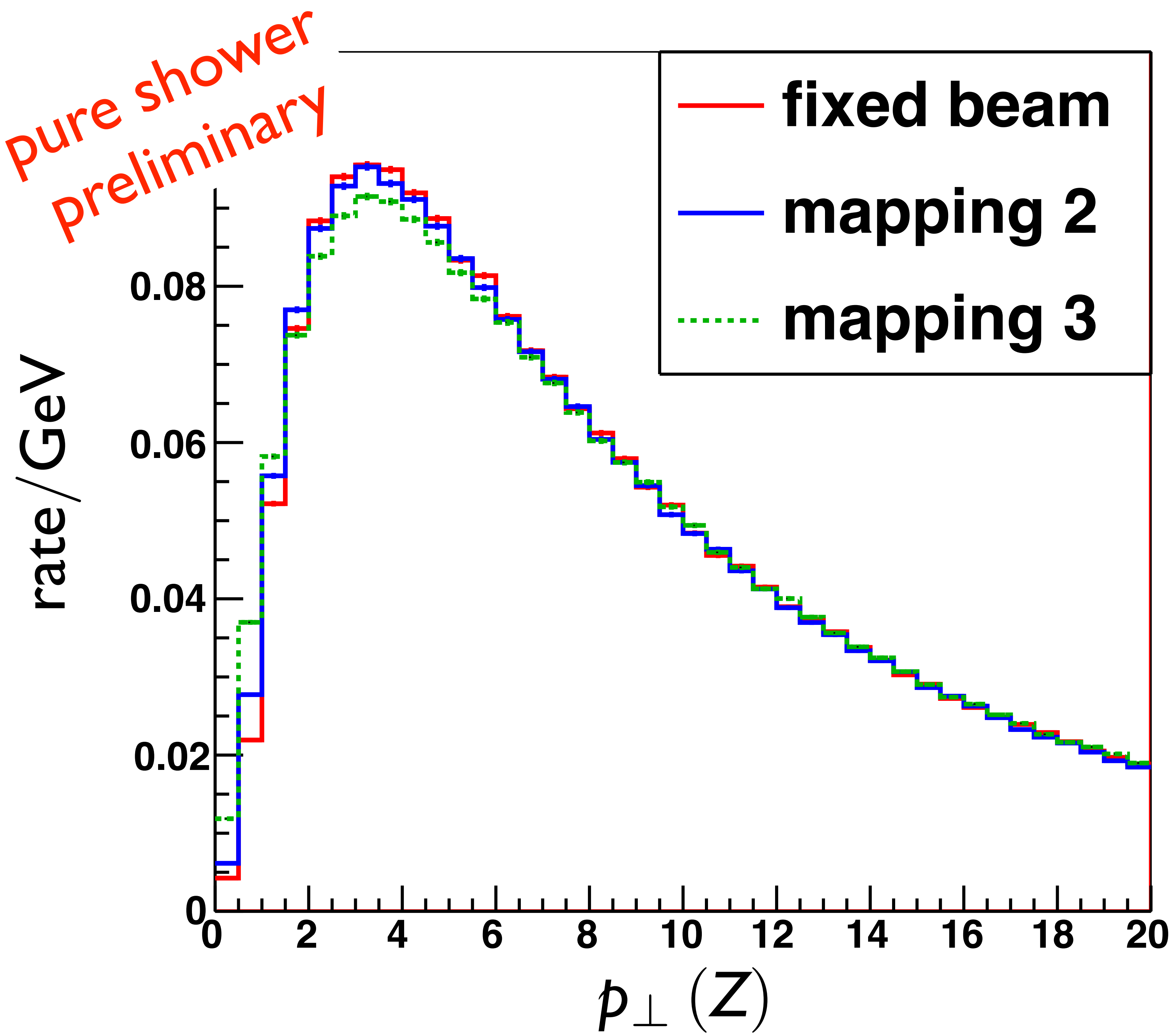
$$x_a = x_a\left(s_{aj}, s_{jk}, s_{ajb}\right)$$

note: $x_A < x_a \,\forall\, p_a, p_j, p_k$ not true for arbitrary mappings

f_2 found have : $f_2 \leq 0$, $f_2 \xrightarrow{s_{aj}\to 0} 0$, $f_2 \xrightarrow{s_{ak}\to 0} 0$

Recoil for Initial-Final branchings

Dependence of Z $p_\perp$ on recoil strategy (mapping)

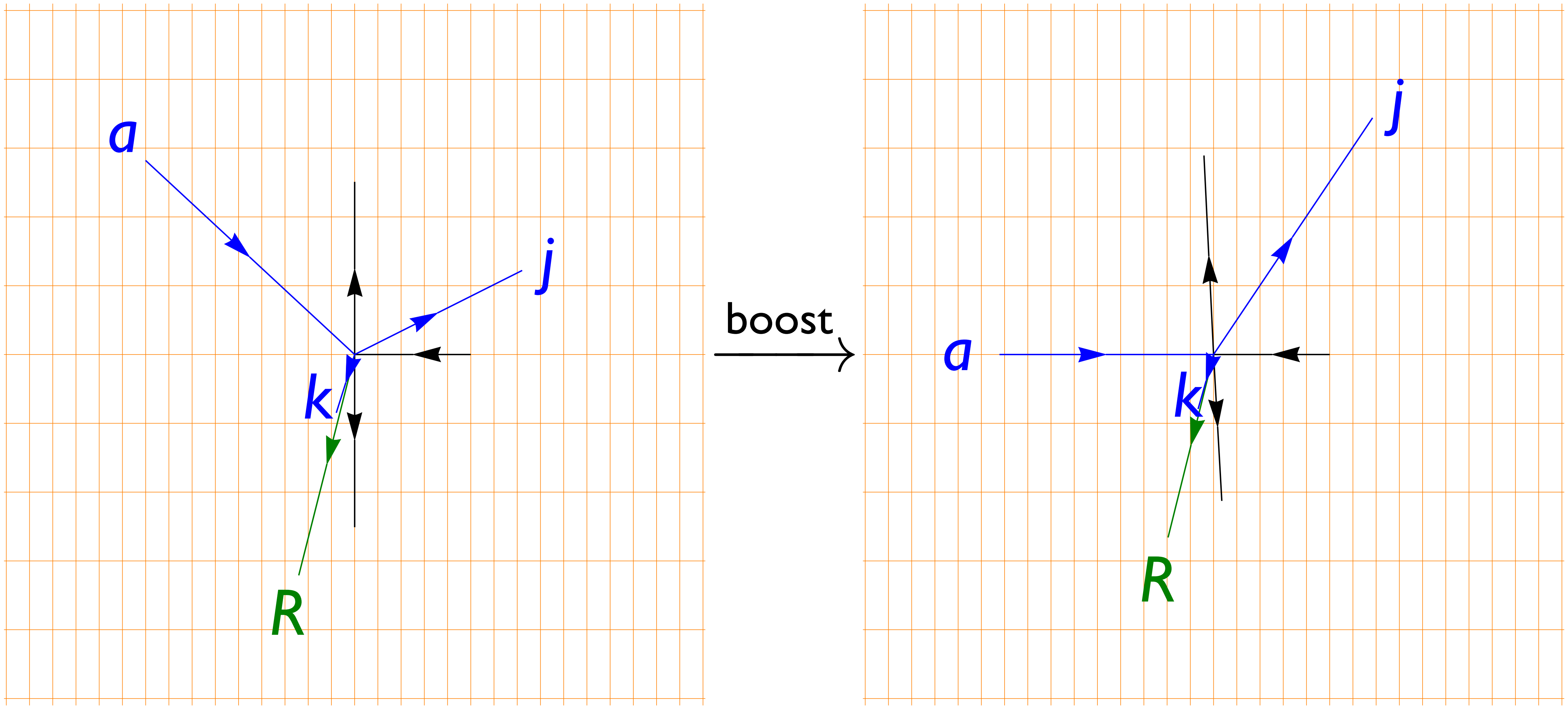


Recoil for Initial-Final branchings

Dependence of Z $p_\perp$ on recoil strategy (mapping)

Boost Effect in Initial-Final

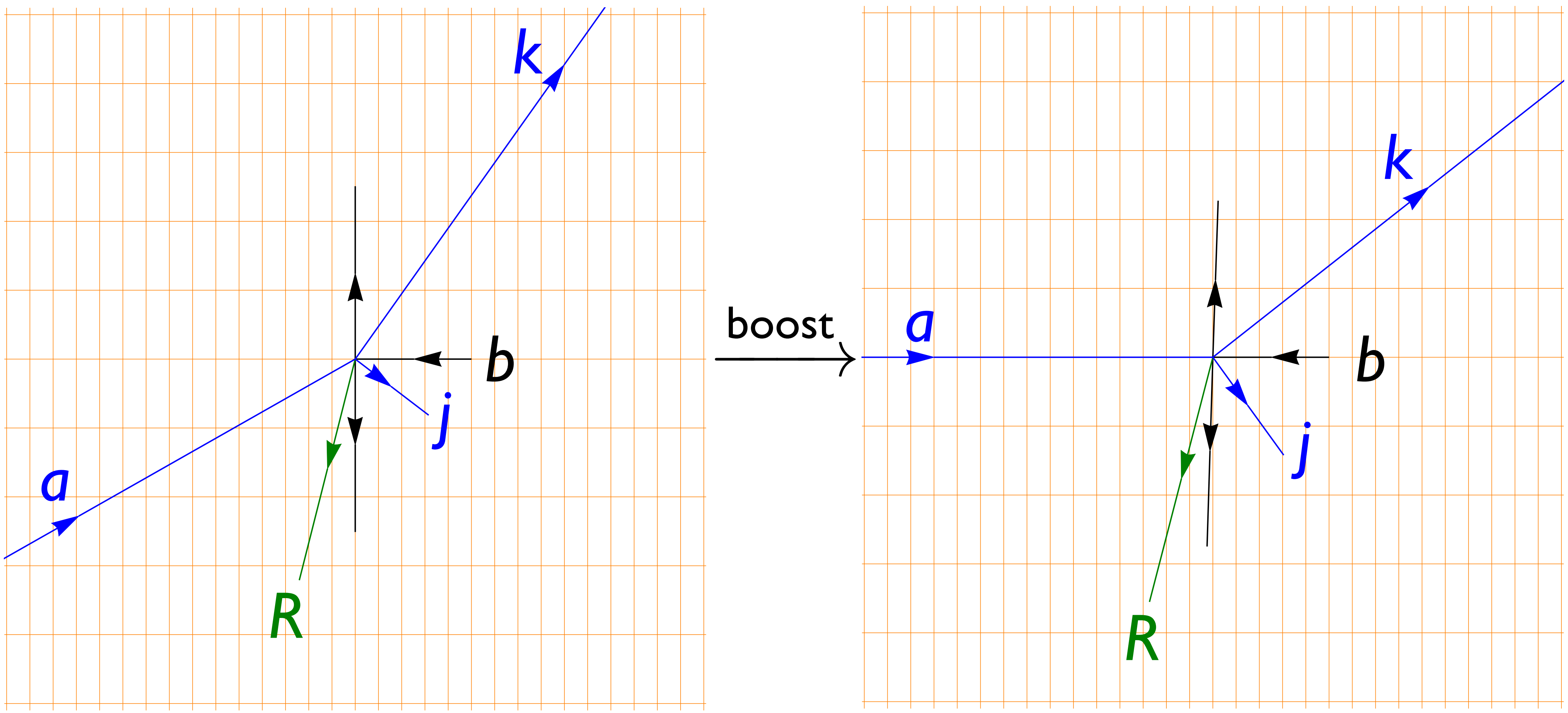
example configuration with $s_{ajb} = s_{ajb}^{\min}(s_{aj}, s_{jb}, \dots)$



$$x_a/x_A \approx 1.9, \quad p_\perp(R')/p_\perp(R) \approx 0.83$$

Boost Effect in Initial-Final

same example configuration but with $s_{ajb} = s_{ajb}^{\max}(s_{aj}, s_{jb}, \ldots)$



$$x_a/x_A \approx 4.8, \quad p_\perp(R')/p_\perp(R) \approx 1.11$$

pdf suppression $\Rightarrow$ much more likely to shrink $p_\perp$

Summary & Outlook

Vincia has been extended to hadron collisions

still to do: alternative Q definitions, some validation (in particular interplay with Pythia 8), ...

afterwards: carry over matching

Thanks

Backup - Uncertainty Bands

The veto algorithm

generate trial scales Q by inverting $\boldsymbol{\Delta}_t$ (which has been chosen such that this inversion is simple)

$$\Delta_t\left(Q_s^2, Q_b^2\right) \equiv P\left[\text{no trial branching between } Q_s \text{ and } Q_b\right]$$
$$= \exp\left[-\int_{Q_b^2}^{Q_s^2} a_t\left(Q^2\right) dQ^2\right]$$

$$Q_s \equiv Q_{\text{start}}, \quad Q_b \equiv Q_{\text{branch}}$$

accept a trial with probability $a_{p(hysical)}/a_{t(rial)}$

continue at scale of rejected trial

The veto algorithm

what is the resulting non-branching probability?

$$\Delta\left(Q_s^2, Q_b^2\right) = \sum_{k=0}^{\infty} P\left[\text{k rejected trials}\right] = \sum_{k=0}^{\infty} p_k$$

$$p_k = \int_{Q_b^2}^{Q_s^2} \overbrace{\Delta_t\left(Q_s^2, Q_1^2\right) a_t\left(Q_1^2\right)}^{\text{trial density}} \overbrace{\left(1 - a_p/a_t\right)\left(Q_1^2\right)}^{\text{reject probability}} \dots$$

$$\Delta_t\left(Q_{k-1}^2, Q_k^2\right) a_t\left(Q_k^2\right)\left(1 - a_p/a_t\right)\left(Q_k^2\right)\Delta_t\left(Q_k^2, Q_b^2\right)$$

$$\theta\left(Q_1^2 > \dots > Q_k^2\right) \mathrm{d}Q_1^2 \dots \mathrm{d}Q_k^2$$

The veto algorithm

what is the resulting non-branching probability?

$$\Delta\left(Q_s^2, Q_b^2\right) = \sum_{k=0}^{\infty} P\left[\text{k rejected trials}\right] = \sum_{k=0}^{\infty} p_k$$

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$$\Delta_t\left(Q_{k-1}^2, Q_k^2\right) a_t\left(Q_k^2\right)\left(1 - a_p/a_t\right)\left(Q_k^2\right) \Delta_t\left(Q_k^2, Q_b^2\right)$$

$$\theta\left(Q_1^2 > \ldots > Q_k^2\right) \mathrm{d}Q_1^2 \ldots \mathrm{d}Q_k^2$$

The veto algorithm

what is the resulting non-branching probability?

$$\Delta\left(Q_s^2, Q_b^2\right) = \sum_{k=0}^{\infty} P\left[\text{k rejected trials}\right] = \sum_{k=0}^{\infty} p_k$$

$$p_k = \Delta_t\left(Q_s^2, Q_b^2\right) \int_{Q_b^2}^{Q_s^2} \prod_{i=1}^{k} \left[a_t\left(Q_i^2\right) - a_p\left(Q_i^2\right)\right]$$

$$\theta\left(Q_1^2 > \ldots > Q_k^2\right) dQ_1^2 \ldots dQ_k^2$$

The veto algorithm

what is the resulting non-branching probability?

$$\Delta\left(Q_s^2, Q_b^2\right) = \sum_{k=0}^{\infty} P\left[\text{k rejected trials}\right] = \sum_{k=0}^{\infty} p_k$$

$$p_k = \Delta_t\left(Q_s^2, Q_b^2\right) \frac{1}{k!}\left[\int_{Q_b^2}^{Q_s^2} a_t\left(Q^2\right) - a_p\left(Q^2\right)\right]^k$$

$$\Delta_t\left(Q_s^2, Q_b^2\right) = \exp\left[-\int_{Q_b^2}^{Q_s^2} a_t\left(Q^2\right) dQ^2\right]$$

$$\Rightarrow \sum p_k = \exp\left[-\int_{Q_b^2}^{Q_s^2} a_p\left(Q^2\right)\right]$$

Uncertainties

produce weighted set for $a_{\mathrm{v(ariant)}}$

$$\text{accept} \to w = w \cdot a_v / a_p, \quad \text{reject} \to w = w \cdot \frac{1 - a_v/a_t}{1 - a_p/a_t}$$

$$\Delta_v\left(Q_s^2, Q_b^2\right) = \sum_{k=0}^{\infty} p_k w_k$$

$$p_k w_k = \int_{Q_b^2}^{Q_s^2} \overbrace{\Delta_t\left(Q_s^2, Q_1^2\right) a_t\left(Q_1^2\right)}^{\text{trial density}} \overbrace{\left(1 - a_p/a_t\right)\left(Q_1^2\right)}^{\text{reject probability}} \overbrace{\frac{1 - a_v/a_t}{1 - a_p/a_t}\left(Q_1^2\right)}^{\text{weight}}$$

$$(\text{same for } Q_2, \ldots, Q_k)$$

$$\Delta_t\left(Q_k^2, Q_b^2\right) \theta\left(Q_1^2 > \ldots > Q_k^2\right) dQ_1^2 \ldots dQ_k^2$$

Uncertainties

produce weighted set for $a_{\mathrm{v(ariant)}}$

$$\text{accept} \rightarrow w = w \cdot a_\mathrm{v}/a_\mathrm{p}, \quad \text{reject} \rightarrow w = w \cdot \frac{1 - a_\mathrm{v}/a_\mathrm{t}}{1 - a_\mathrm{p}/a_\mathrm{t}}$$

$$\Delta_\mathrm{v}\left(Q_\mathrm{s}^2, Q_\mathrm{b}^2\right) = \sum_{k=0}^{\infty} p_k w_k$$

$$p_k w_k = \int_{Q_\mathrm{b}^2}^{Q_\mathrm{s}^2} \overbrace{\Delta_\mathrm{t}\left(Q_\mathrm{s}^2, Q_1^2\right) a_\mathrm{t}\left(Q_1^2\right)}^{\text{trial density}} \overbrace{\cancel{\left(1 - a_\mathrm{p}/a_\mathrm{t}\right)}\left(Q_1^2\right)}^{\cancel{\text{reject probability}}} \overbrace{\frac{1 - a_\mathrm{v}/a_\mathrm{t}}{\cancel{1 - a_\mathrm{p}/a_\mathrm{t}}}\left(Q_1^2\right)}^{\text{weight}}$$

$$(\text{same for } Q_2, \ldots, Q_k)$$

$$\Delta_\mathrm{t}\left(Q_k^2, Q_\mathrm{b}^2\right) \theta\left(Q_1^2 > \ldots > Q_k^2\right) \mathrm{d}Q_1^2 \ldots \mathrm{d}Q_k^2$$

$$\text{derivation as before} \Rightarrow \Delta_\mathrm{v} = \exp\left[-\int_{Q_\mathrm{b}^2}^{Q_\mathrm{s}^2} a_\mathrm{v}\left(Q^2\right)\right]$$

Uncertainties - Fine Print

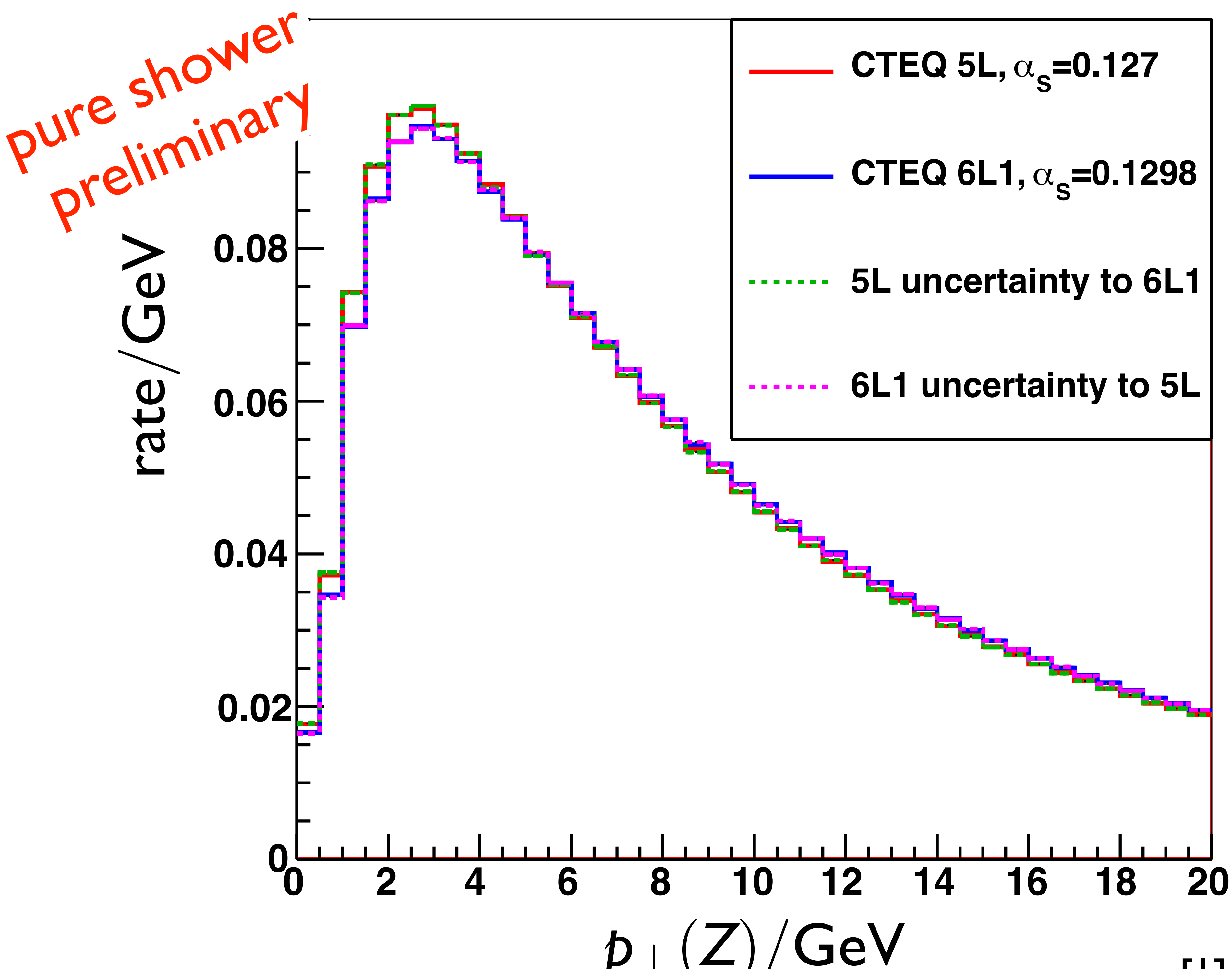
derivation independent of a_p / a_t, but $w \xrightarrow{a_p \to a_t} \infty$

far down in the shower cascade, we may lack the statistics to realize the cancellation
$\Rightarrow$ in practice, restrict range of weights (artificially)

only most, not all uncertainties can be accessed in this way

Uncertainties - Test

Drell-Yan[1] in Pythia 8.176 + Vincia



[1] pure parton shower