Global Recoil in Initial-Final Antennae

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In collaboration with Peter Skands & Ronald Kleiss

Work in progress

IMAPP
Nikhef
Radboud University

Introduction

Giele, Kosower, Skands:1102.2126

Gehrmann, Ritzmann, Skands:1108.6172

Parton shower: Vincia, plugin for Pythia based on antenna factorization

Backward evolution for initial state radiation
$\longrightarrow$ Recoil imparted on the entire final state

Most dipole-like showers: Global recoil in II and IF

- Sherpa Höche, Schumann, Siegert: 0912.3501
- Herwig Platzer, Gieseke: 0909.5593
- Dire Höche,Prestel:1506.05057

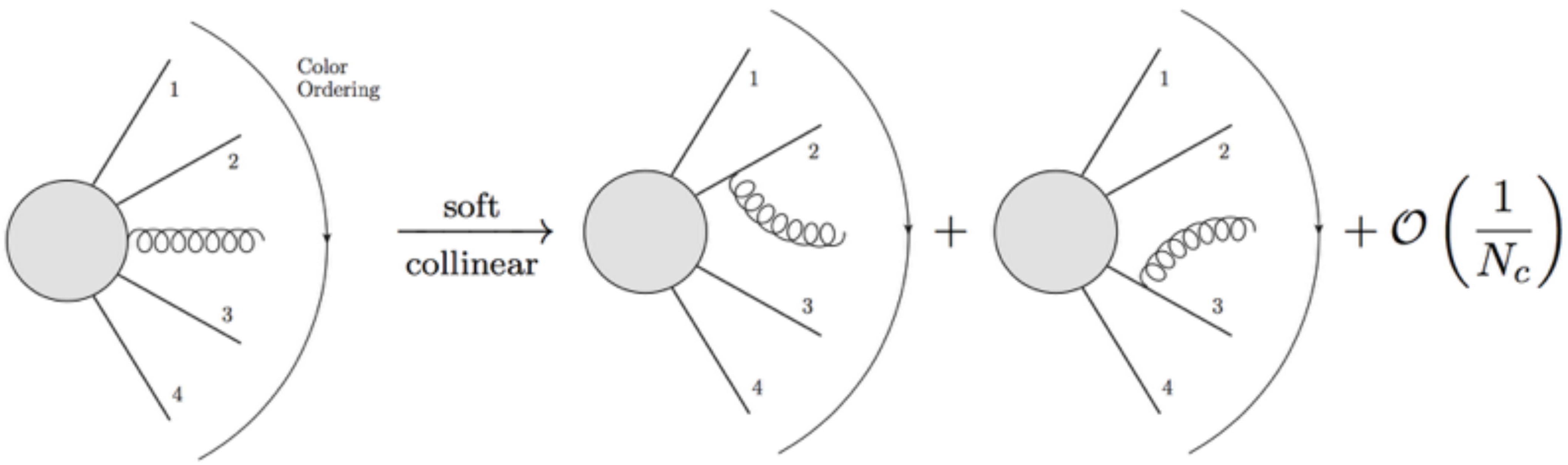
Vincia: only global recoil for II connections

Antenna Factorization

$$|M(..,p_a,k,..)|^2 \xrightarrow{p_a \| k} g^2 C \frac{P(z)}{p_a \cdot k} |M(..,p_a+k,..)|^2$$

$$|M(..,p_a,k,p_b,..)|^2 \xrightarrow{k\to 0} g^2 C \left[\frac{2 p_a \cdot p_b}{(p_a \cdot k)(k \cdot p_b)} - \frac{m_a^2}{(p_a \cdot k)^2} - \frac{m_b^2}{(p_b \cdot k)^2} \right] |M(..,p_a,p_b,..)|^2$$

$$|M(..,p_a,k,p_b,..)|^2 \approx g^2 C \, a_e^{QCD}(p_a,k,p_b) |M(..,p'_a,p'_b,..)|^2$$



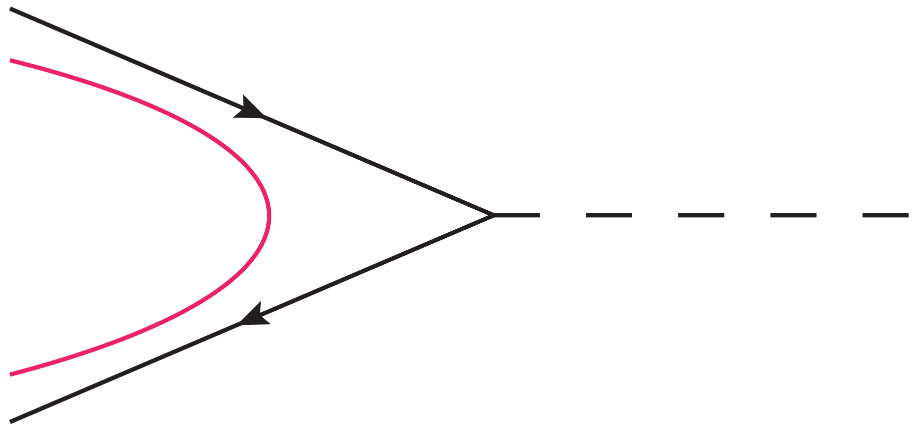
Phase Space Factorization

Exact factorization of phase space

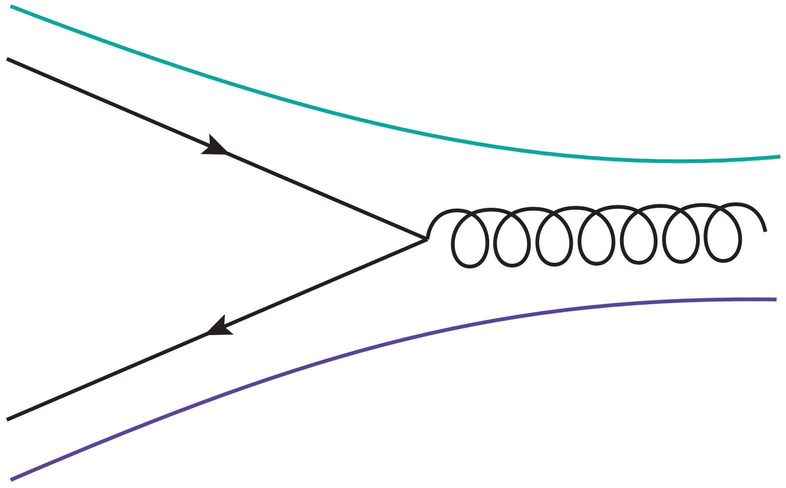
$$\frac{dx_a}{x_a}\frac{dx_b}{x_b}d\Phi_n = \frac{dx_A}{x_A}\frac{dx_B}{x_B}d\Phi_{n-1}d\Phi_{\text{ant}}$$

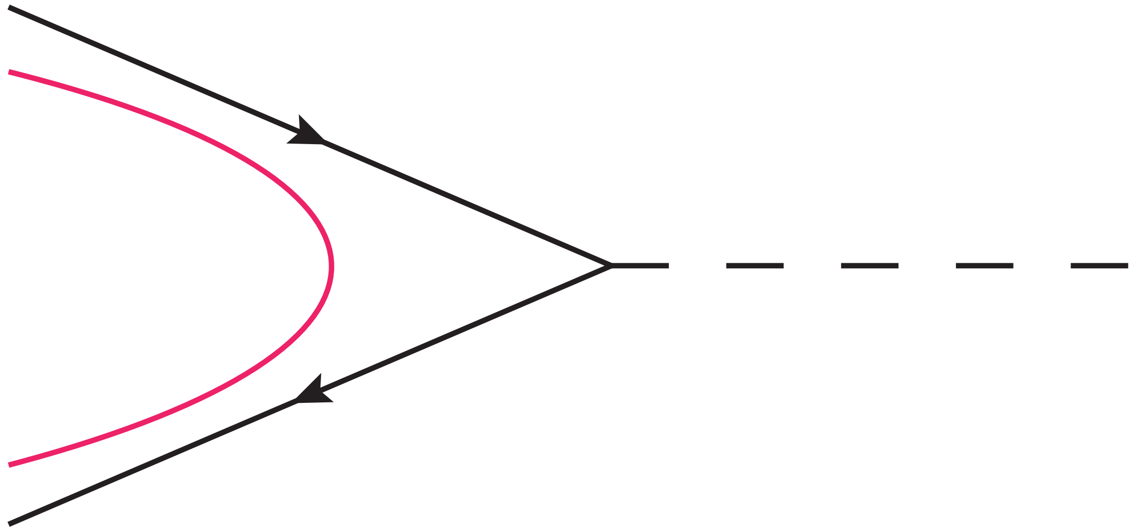
On-shell momenta with exact momentum conservation

Initial-initial



Initial-final





Initial-Initial

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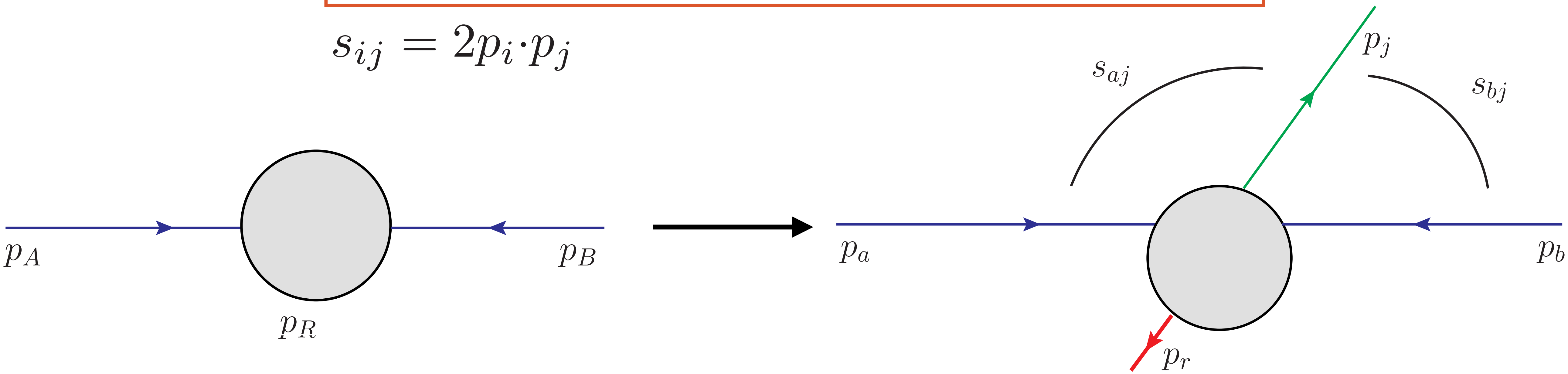
Phase Space Factorization - II

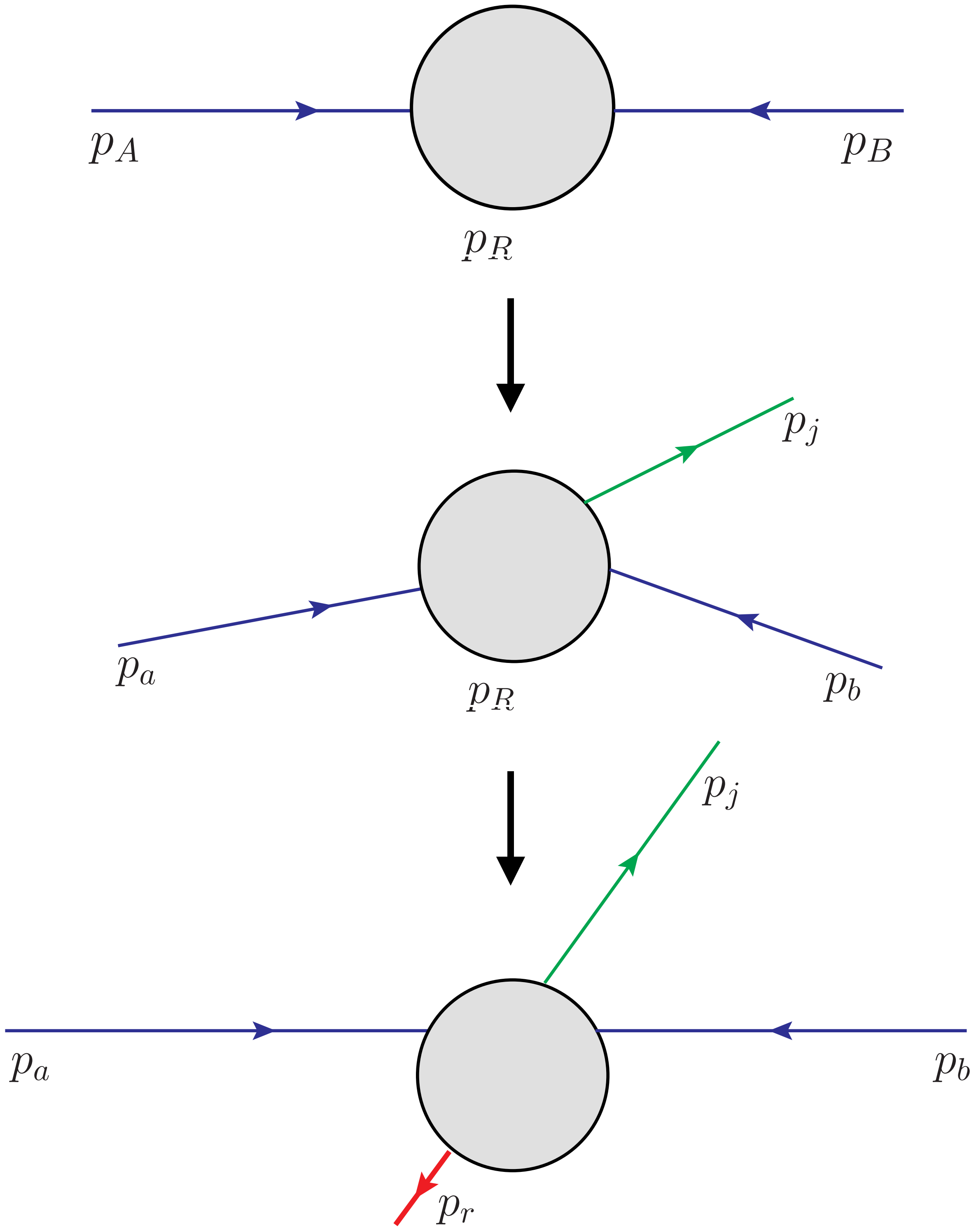
$$\frac{dx_a}{x_a}\frac{dx_b}{x_b} d\Phi_2(p_a + p_b \to p_j + p_r)$$
$$= \frac{dx_A}{x_A}\frac{dx_B}{x_B} d\Phi_1(p_A + p_B \to p_R)\, d\Phi_{\text{ant}}$$

$$d\Phi_{\text{ant}} = \frac{1}{16\pi^2}\frac{1}{s_{AB}}\left(\frac{x_A}{x_a}\frac{x_B}{x_b}\right)^2 ds_{aj}ds_{bj}\frac{d\varphi}{2\pi}$$

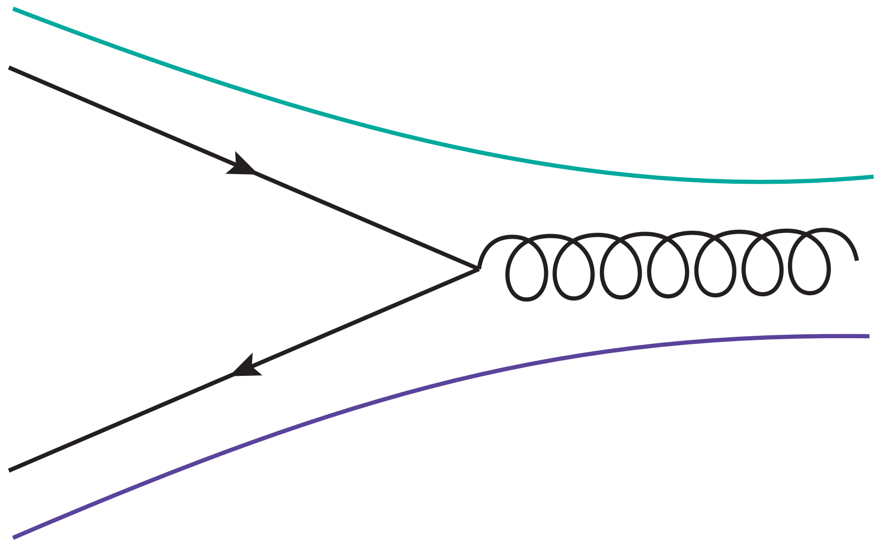
$$s_{ij} = 2p_i{\cdot}p_j$$



Phase Space Factorization - II



$$
\begin{aligned}
p_a &= c_1 p_A \\
p_b &= c_2 p_B \\
p_j &= c_3 p_A + c_4 p_B + c_5 p_\perp(\varphi) \\
p_r &= p_a + p_b - p_j
\end{aligned}
$$

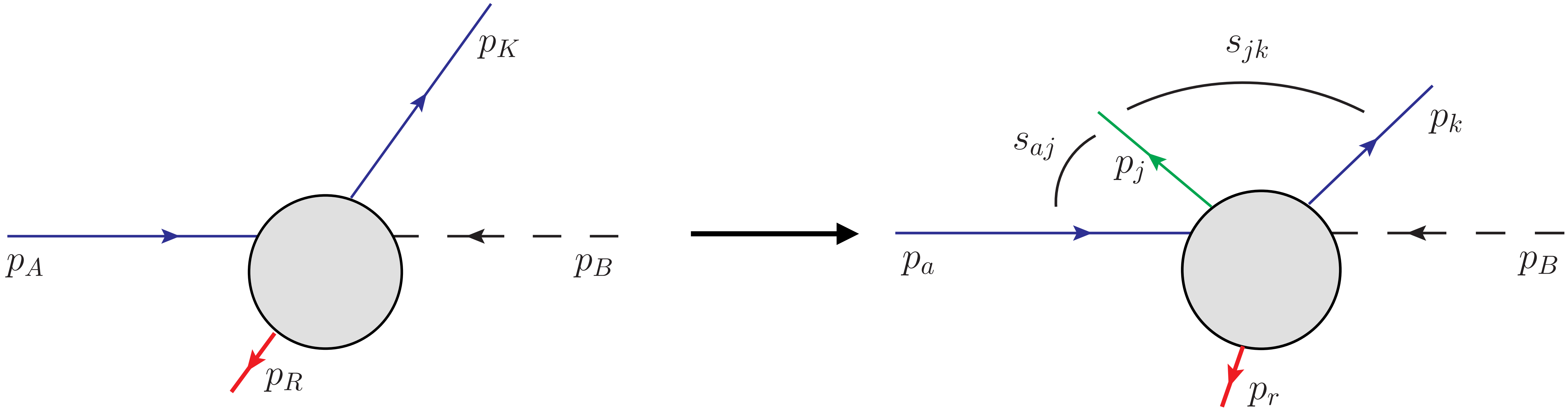


Initial-Final

Phase Space Factorization - IF

$$\frac{dx_a}{x_a}\frac{dx_B}{x_B}d\Phi_3(p_a+p_B\to p_j+p_k+p_r)$$
$$=\frac{dx_A}{x_A}\frac{dx_B}{x_B}d\Phi_2(p_A+p_B\to p_K+p_R)\,d\Phi_{\mathrm{ant}}$$

$$d\Phi_{\mathrm{ant}}=\frac{1}{16\pi^2}\frac{1}{s_{AK}}\frac{x_A^2}{x_a^2}ds_{aj}ds_{jk}\frac{d\varphi}{2\pi}$$



Initial - Final Mapping

Map 1: p_A retains its direction

$$p_a = \frac{s_{AK} + s_{jk}}{s_{jk}} p_A$$

$$p_j = \frac{s_{jk} s_{ak}}{s_{AK}(s_{AK} + s_{jk})} p_A + \frac{s_{aj}}{s_{AK} + s_{jk}} p_K + \frac{\sqrt{s_{jk} s_{aj} s_{ak}}}{s_{AK} + s_{jk}} p_\perp(\varphi)$$

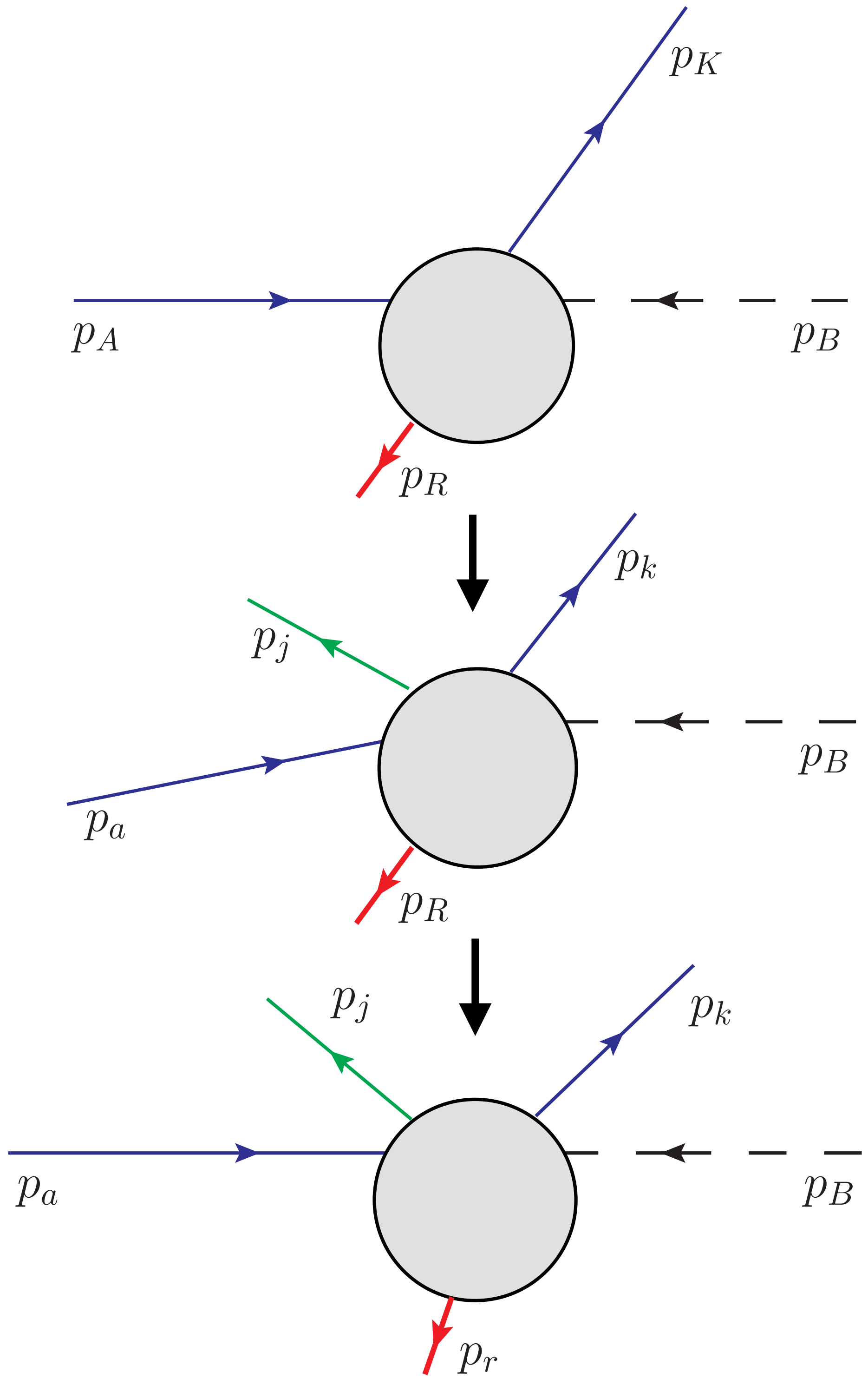
$$p_k = p_a - p_A + p_K - p_j$$

p_k emits p_j with p_a spectating

- No Lorentz boost required $\rightarrow$ p_R does not change
- Automatically $x_a > x_A$
- Correct collinear and soft behaviour
- Current default map in Vincia

$$d\Phi_{\text{ant}} = \frac{1}{16\pi^2} \frac{s_{AK}}{(s_{AK} + s_{jk})^2} ds_{aj} ds_{jk} \frac{d\varphi}{2\pi}$$

Initial - Final Mapping



Kinematics

$$p_a = c_1 p_A$$

$$p_j = c_2 p_A + c_3 p_K + c_4 p_R + c_5 p_\perp(\varphi)$$

$$p_k = c_6 p_A + c_7 p_K + c_8 p_R + c_9 p_\perp(\varphi)$$

$$p_r = p_a - p_A + p_K + p_R - p_j - p_k$$

Initial - Final Mapping

Map 2: p_K retains its direction

$$p_a = \frac{s_{ak}}{s_{AK} - s_{aj}} p_A + \frac{s_{aj} s_{sjk}}{s_{AK}(s_{AK} - s_{aj})} p_K + \frac{\sqrt{s_{jk} s_{aj} s_{ak}}}{s_{AK} - s_{aj}} p_\perp(\varphi)$$

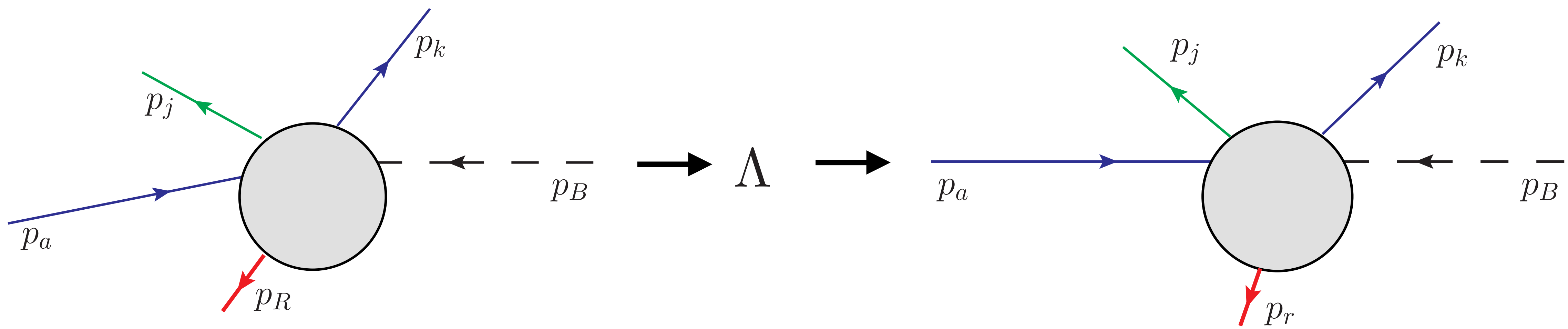
$$p_j = p_a - p_A + p_K - p_k$$

$$p_k = \frac{s_{AK} - s_{aj}}{s_{AK}} p_K$$

p_a emits p_j with p_k spectating

- Lorentz boost required to reallign $p_a \to p_R$ changes
- Not necessarily $x_a > x_A$
- Correct collinear and soft behaviour

Lorentz boost



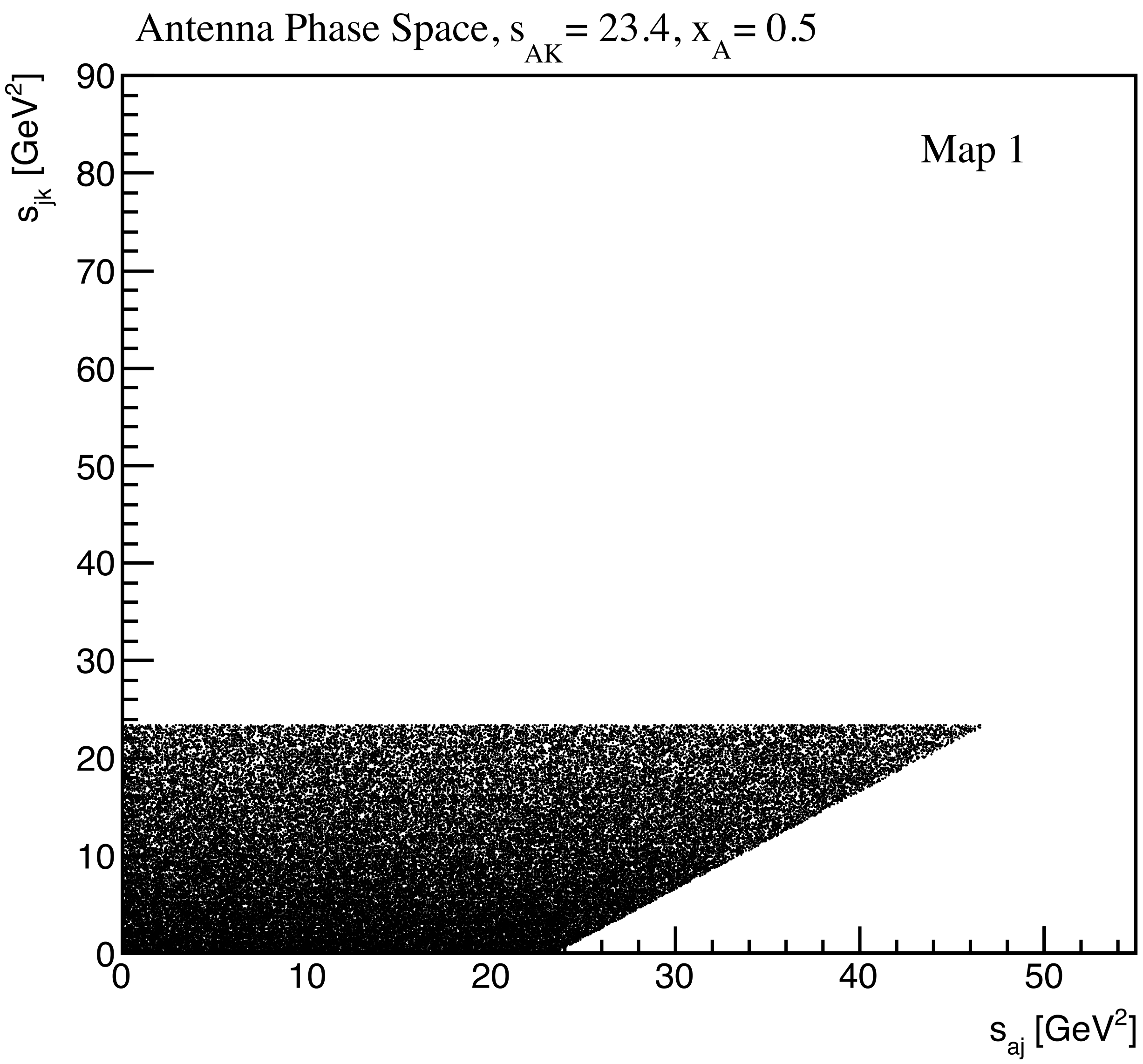
$$\Lambda^{\mu\nu} = g^{\mu\nu} + \frac{p_B^\mu p_a^\nu - p_a^\mu p_B^\nu}{p_a \cdot p_B} + \frac{p_A^\mu p_B^\nu - p_B^\mu p_A^\nu}{p_A \cdot p_B} + \frac{p_A \cdot p_a}{(p_A \cdot p_B)(p_a \cdot p_B)} p_B^\mu p_B^\mu$$

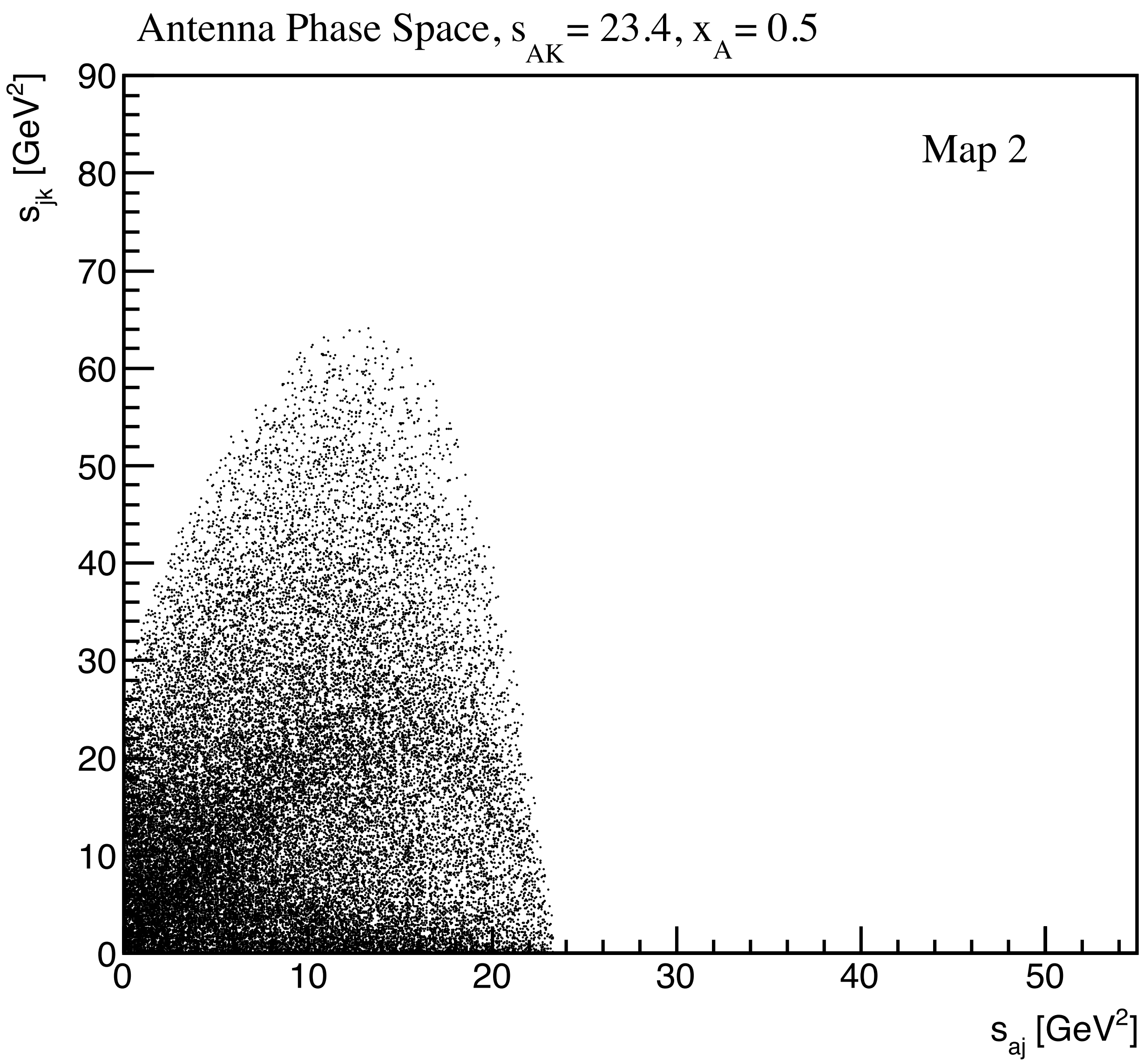
Properties: $(\Lambda p_B) = p_B$

$$(\Lambda p_a) = \frac{x_a}{x_A} p_A$$

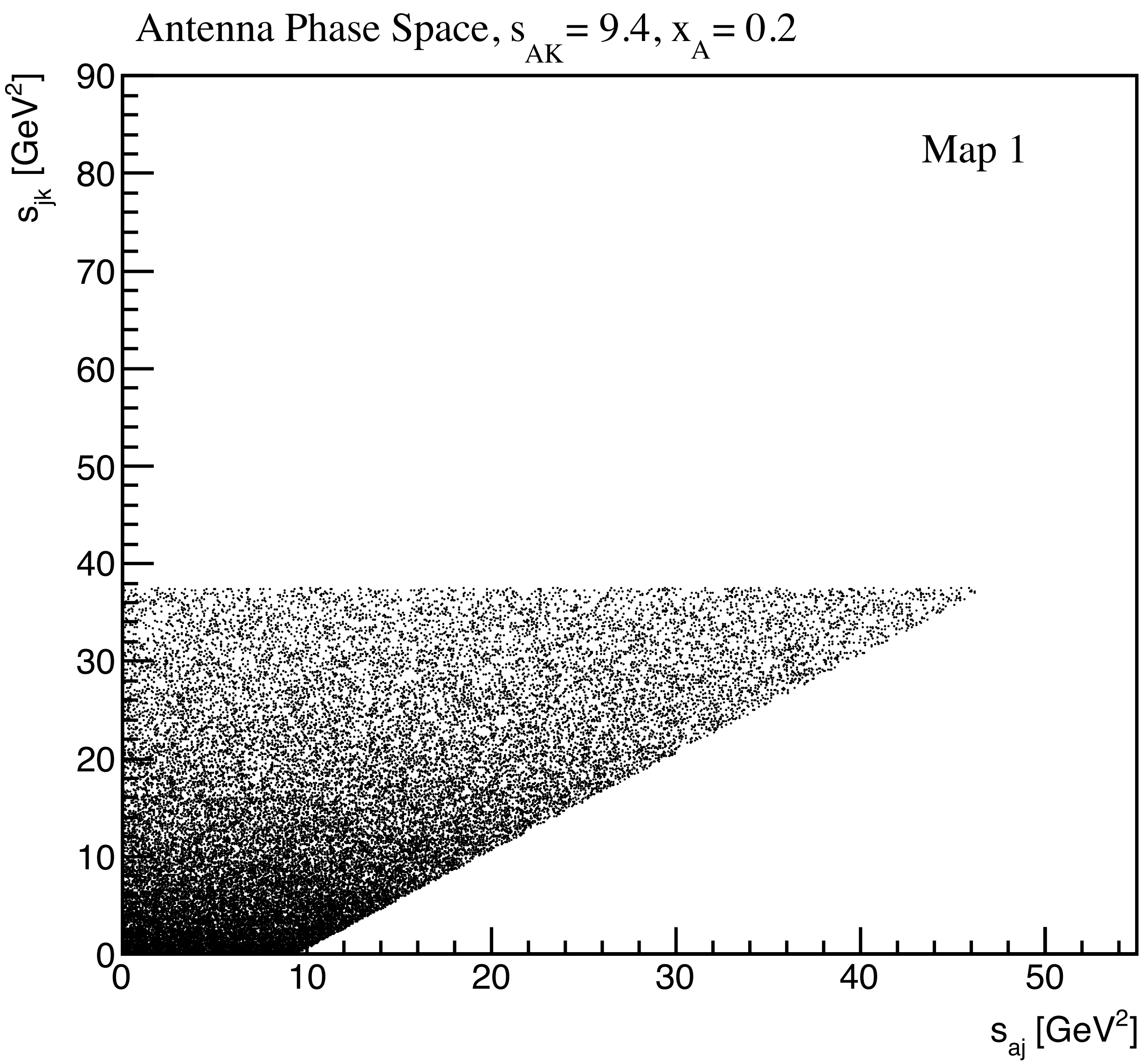
$$d\Phi_{\text{ant}} = \frac{1}{16\pi^2} \frac{1}{s_{AK}} \frac{s_{AB}^2}{s_{aB}^2} ds_{aj} ds_{jk} \frac{d\varphi}{2\pi}$$

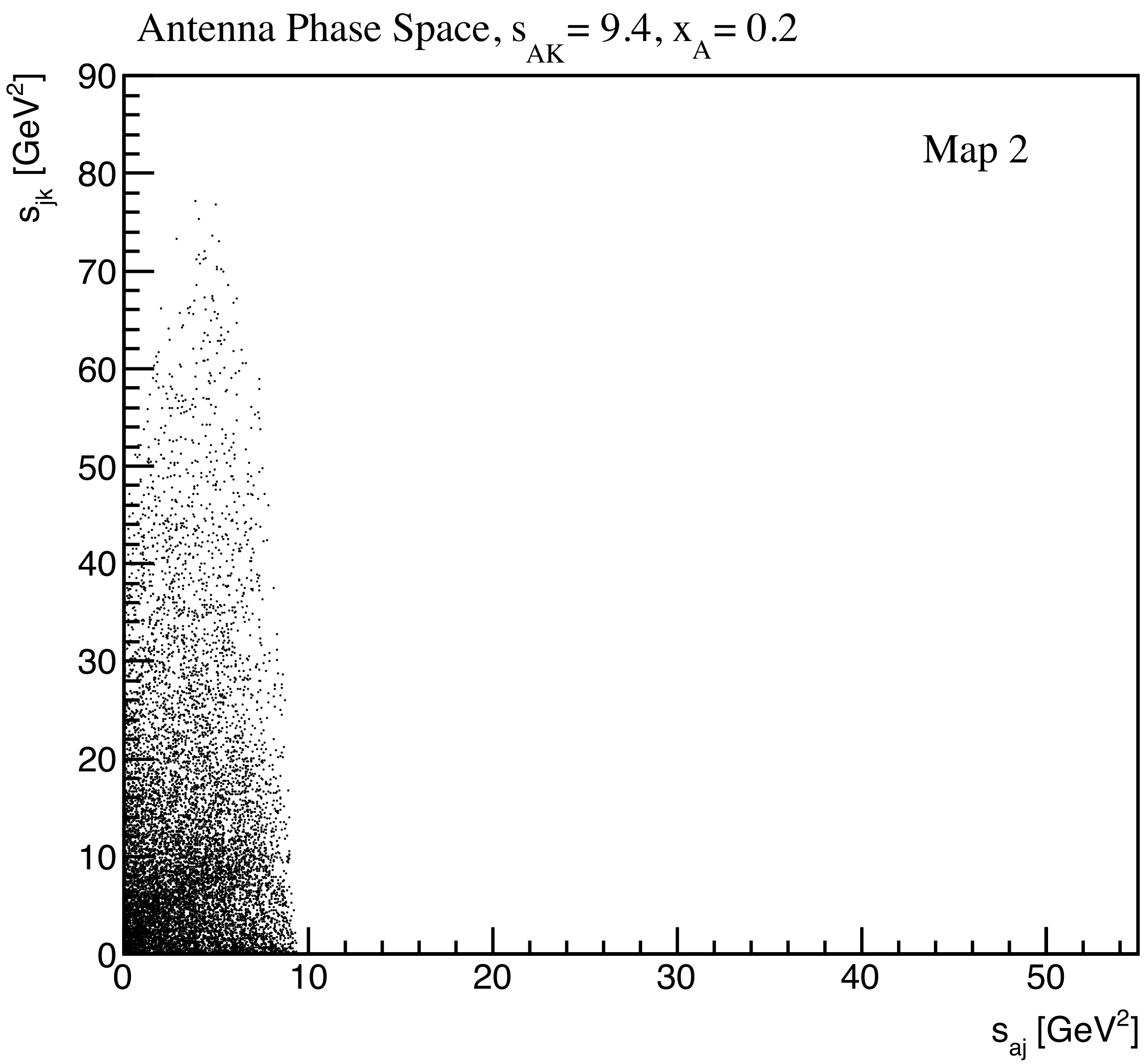
Phase Space


Antenna Phase Space, $s_{AK} = 23.4$, $x_A = 0.5$
Map 1
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90

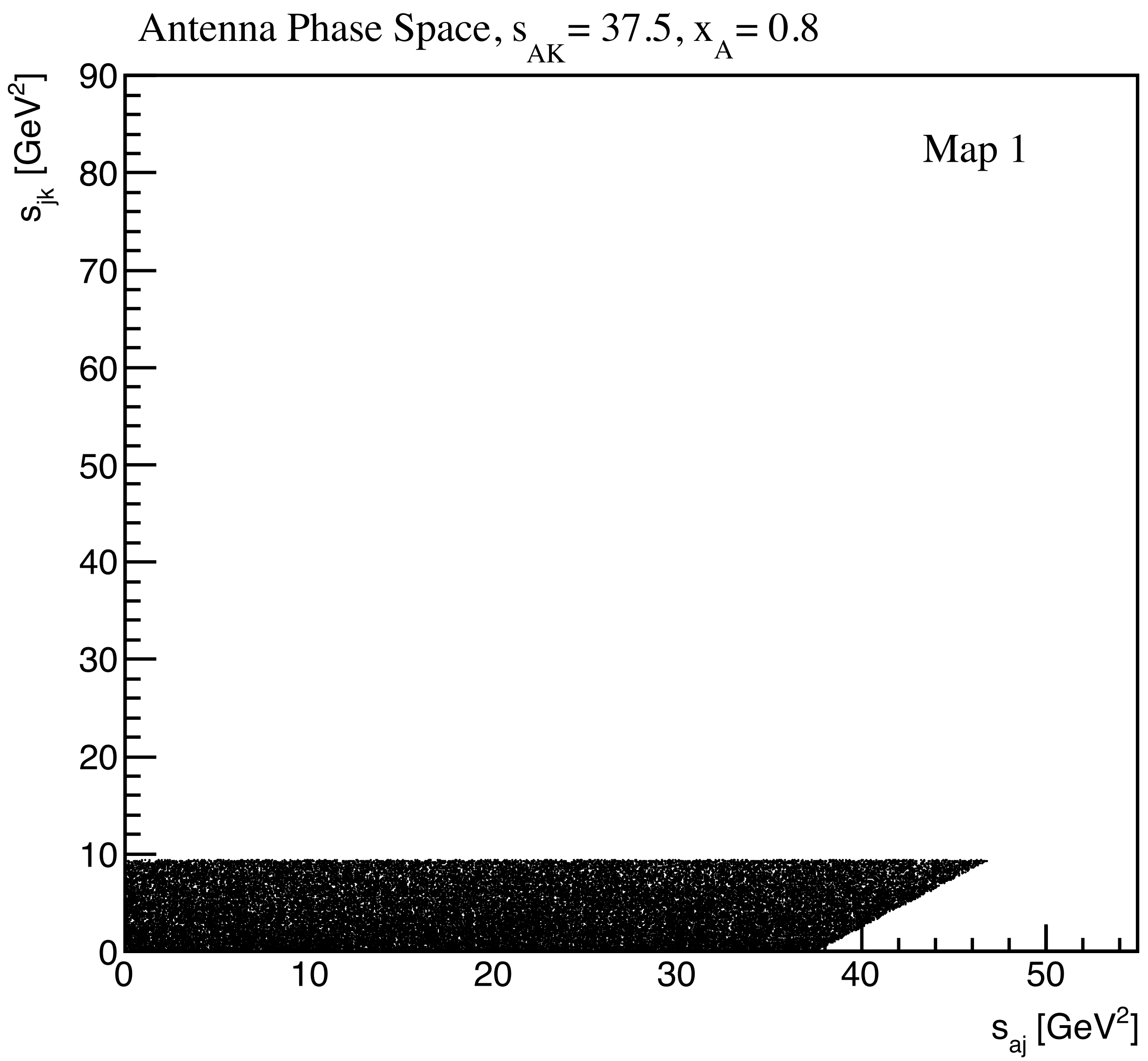

Antenna Phase Space, $s_{AK} = 23.4$, $x_A = 0.5$
Map 2
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90

Phase Space

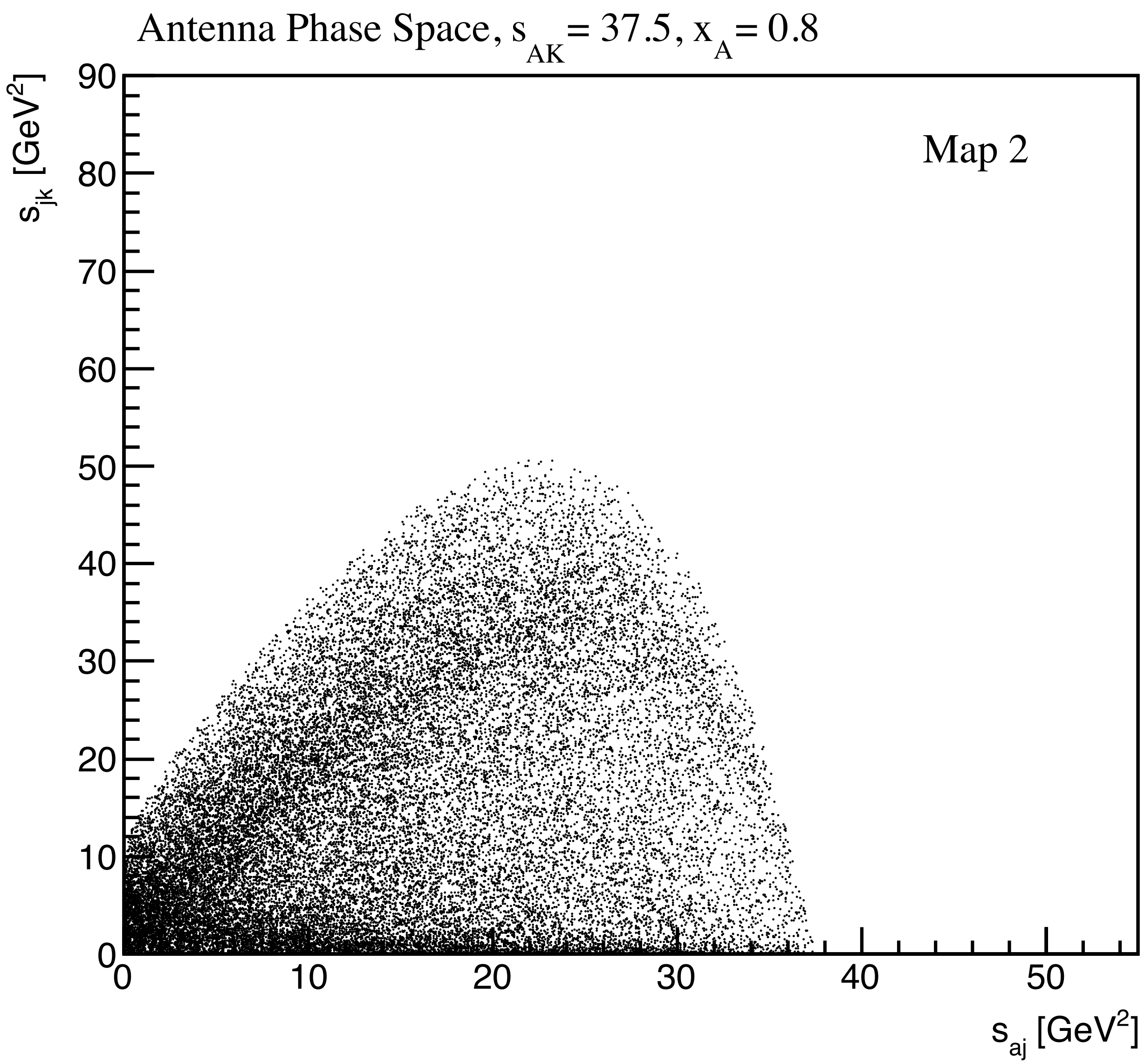

Antenna Phase Space, $s_{AK} = 9.4$, $x_A = 0.2$
Map 1
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90


Antenna Phase Space, $s_{AK} = 9.4$, $x_A = 0.2$
Map 2
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90

Phase Space



Antenna Phase Space, $s_{AK} = 37.5$, $x_A = 0.8$
Map 1
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
50



Antenna Phase Space, $s_{AK} = 37.5$, $x_A = 0.8$
Map 2
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
50

Implementation

Idea: Select maps probabilistically

$$P_1 = \frac{s_{aj}}{s_{aj} + s_{jk}}$$

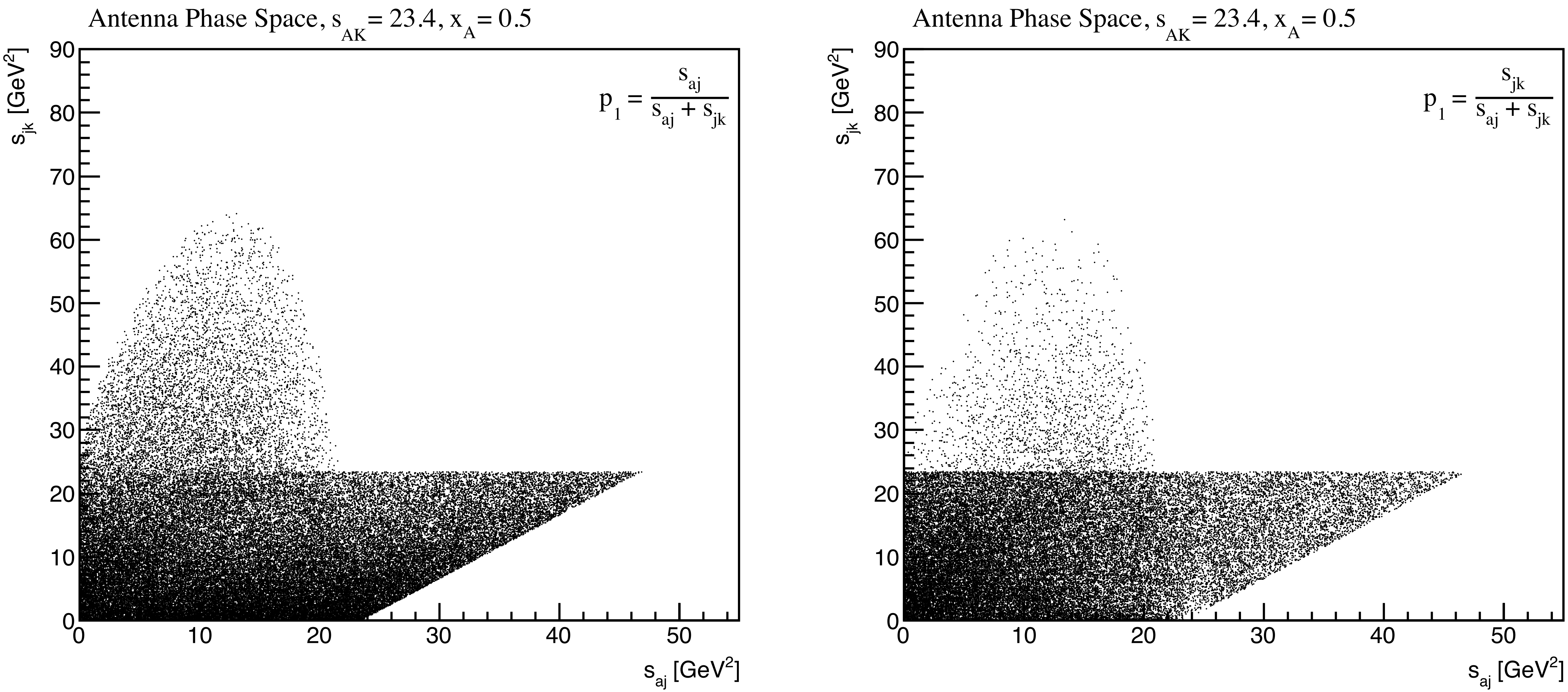
$$P_1 = \frac{s_{jk}}{s_{aj} + s_{jk}}$$

Similar to dipole approach

Correct Jacobian by veto with a factor

$$P_J = \frac{P_1 \left(\frac{x_{A1}}{x_{a1}}\right)^2 + (1 - P_1) \left(\frac{x_{A2}}{x_{a2}}\right)^2}{\left(\frac{x_{A1}}{x_{a1}}\right)^2}$$

Phase Space


Antenna Phase Space, $s_{AK} = 23.4$, $x_A = 0.5$
$p_1 = \frac{s_{aj}}{s_{aj} + s_{jk}}$
s_{jk} [GeV^2]
s_{aj} [GeV^2]
0
10
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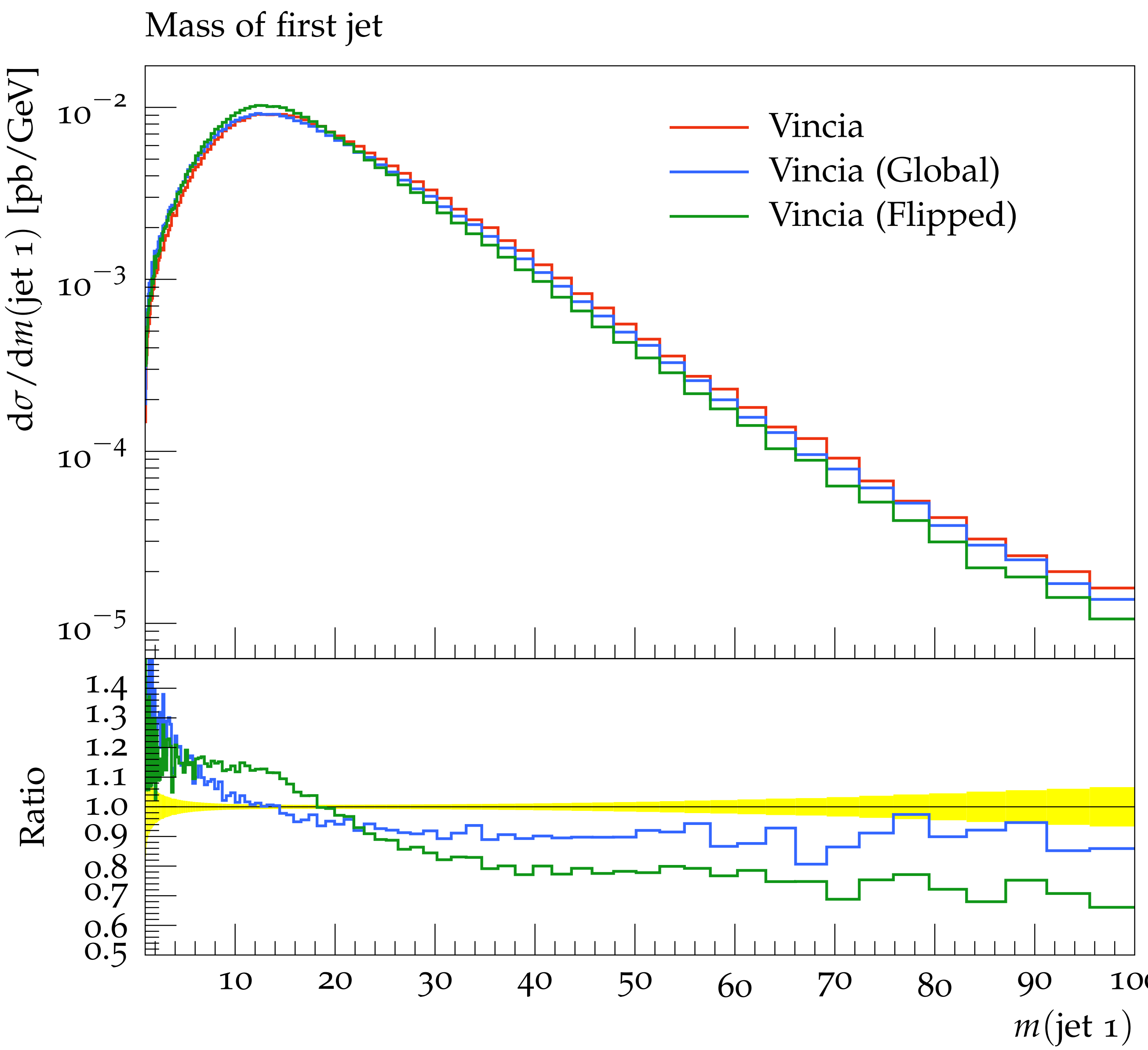
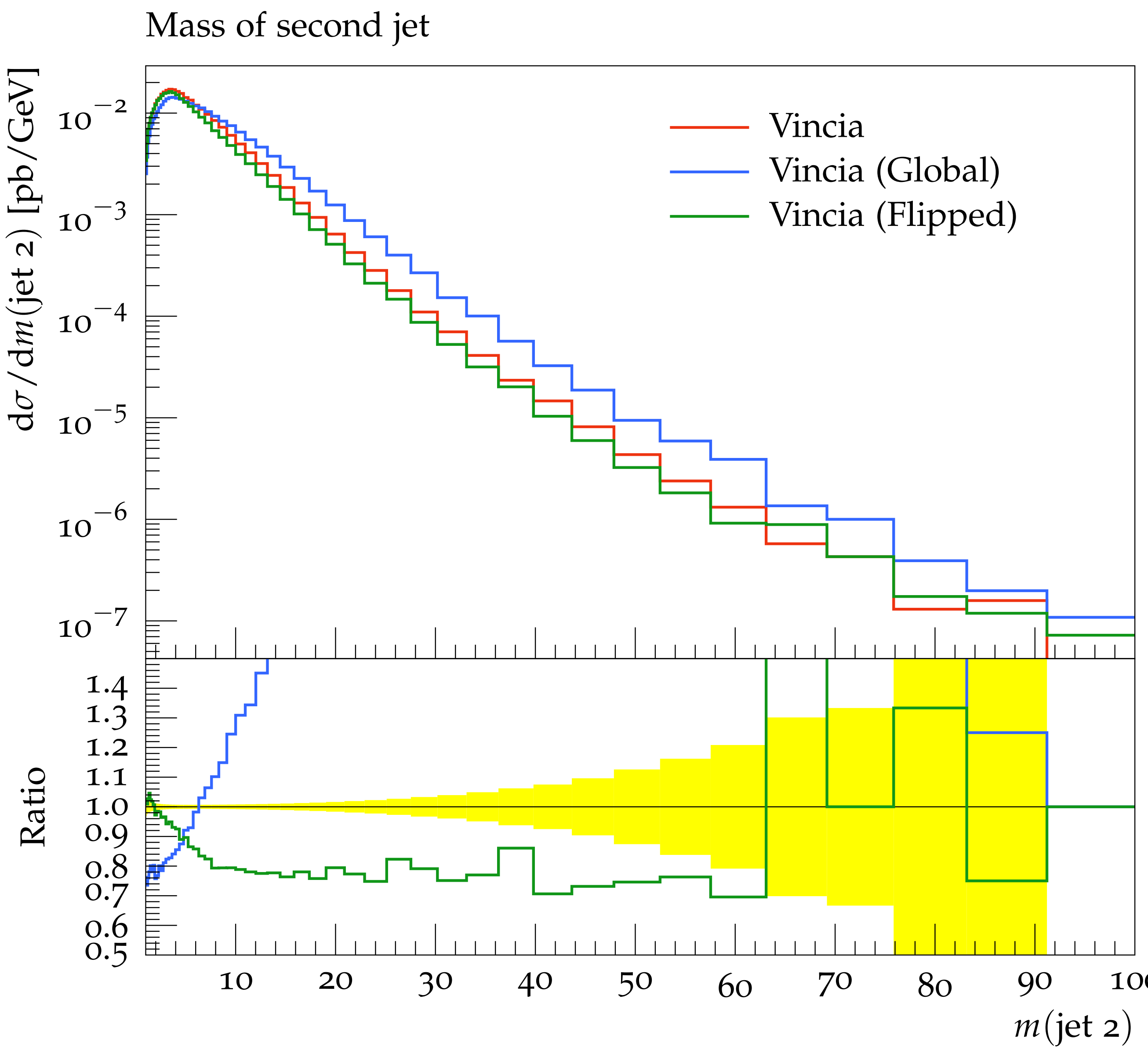
90
Antenna Phase Space, $s_{AK} = 23.4$, $x_A = 0.5$
$p_1 = \frac{s_{jk}}{s_{aj} + s_{jk}}$
s_{jk} [GeV^2]
s_{aj} [GeV^2]

$$q + \bar{q} \to \gamma^*/Z + g$$





Conclusion

Goal: Incorporate global recoil for initial-final antennae in Vincia

Linear combination of dipole-like maps

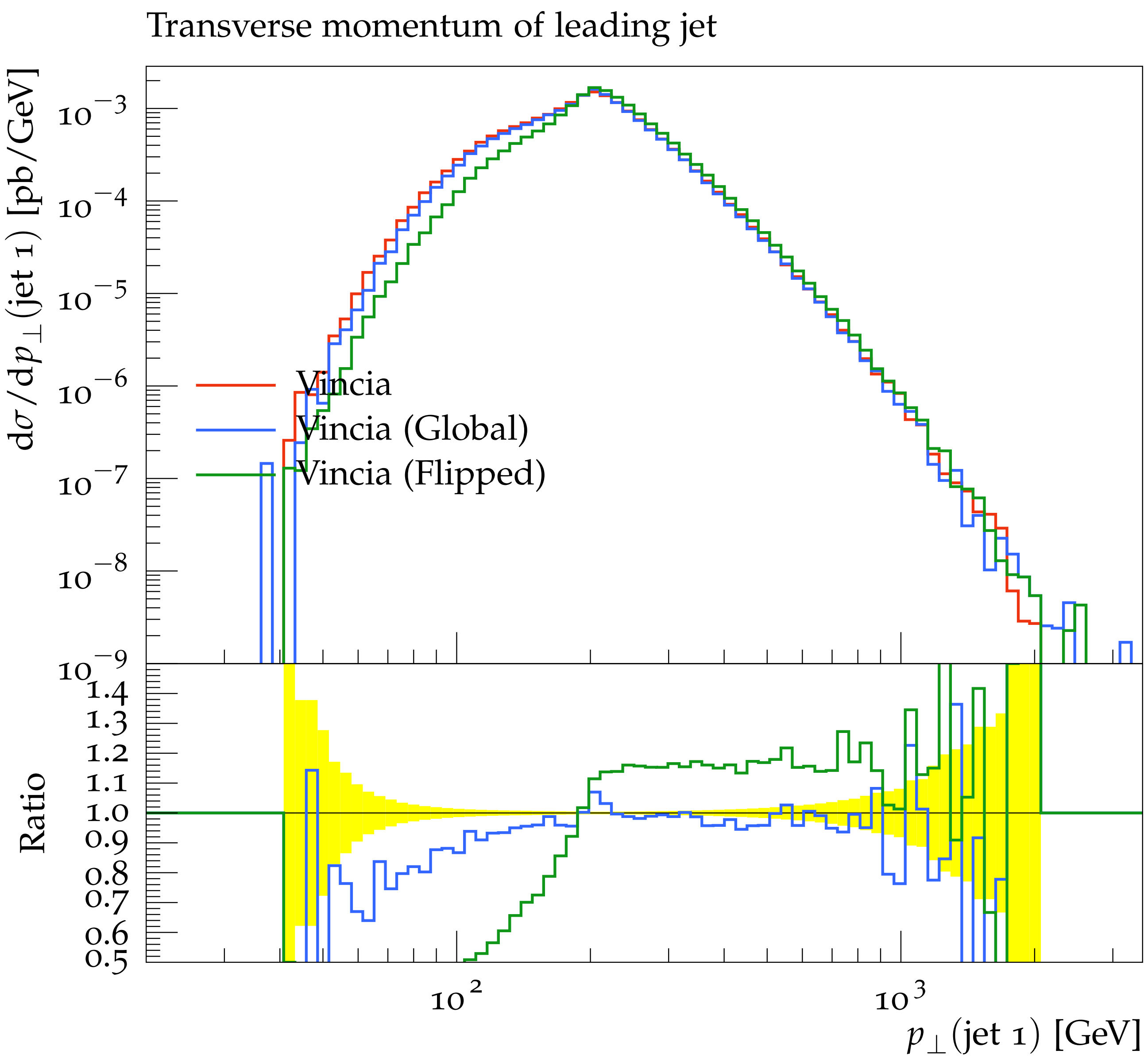
- Agnostic about emitter/spectator roles
- “Free parameter” selection probability

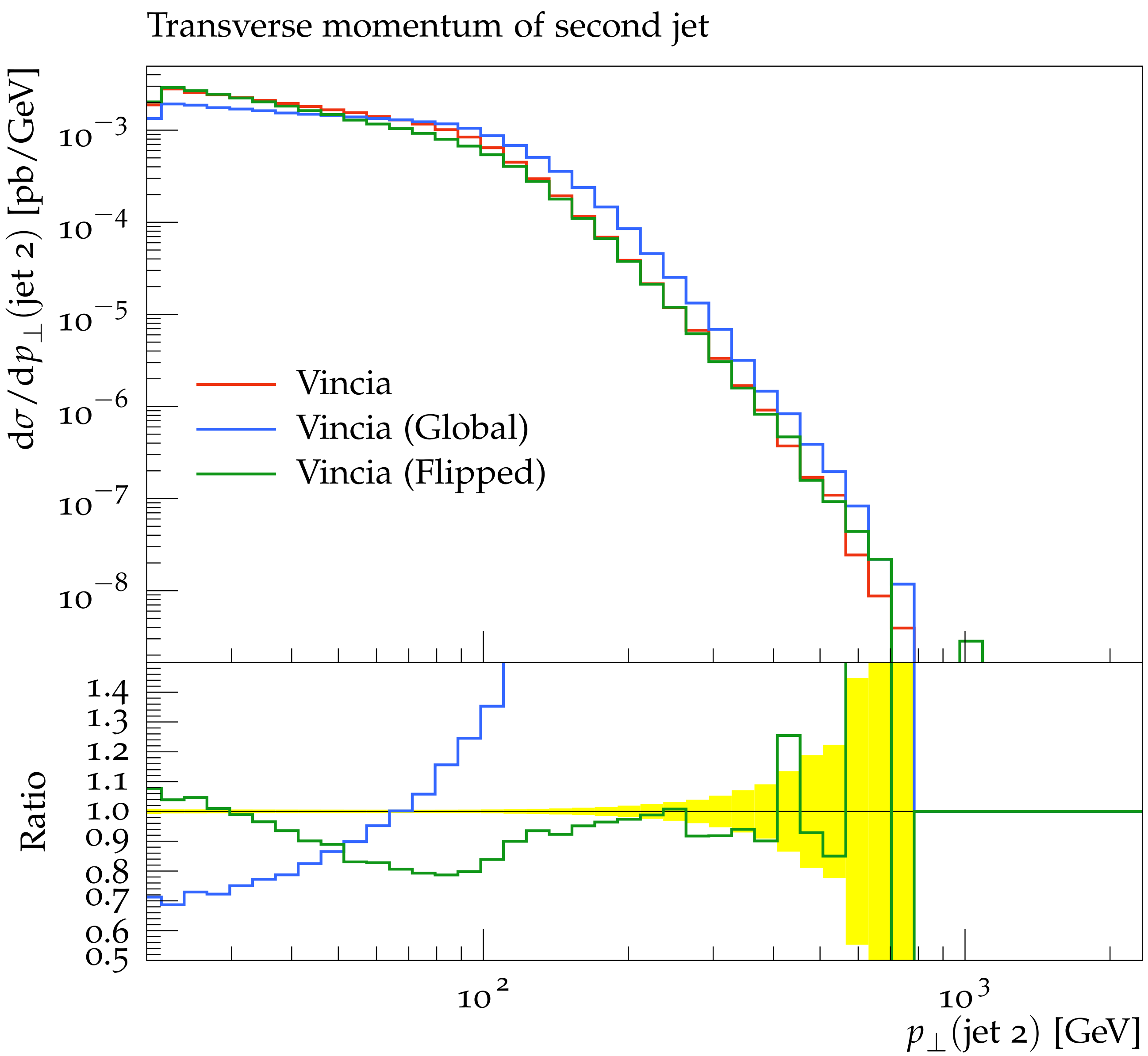
Outlook

- More efficient implementation
- Investigate influence of the selection probability

Phase Space

$$q + \bar{q} \rightarrow \gamma^* / Z + g$$





Phase Space

$$q + \bar{q} \rightarrow \gamma^*/Z + g$$