Instituto de Física Teórica UAM-CSIC

Inclusive three jet production at the LHC as a new BFKL probe

Grigorios Chachamis, IFT - UAM/CSIC Madrid

In collaboration with F. Caporale, B. Murdaca and A. Sabio Vera

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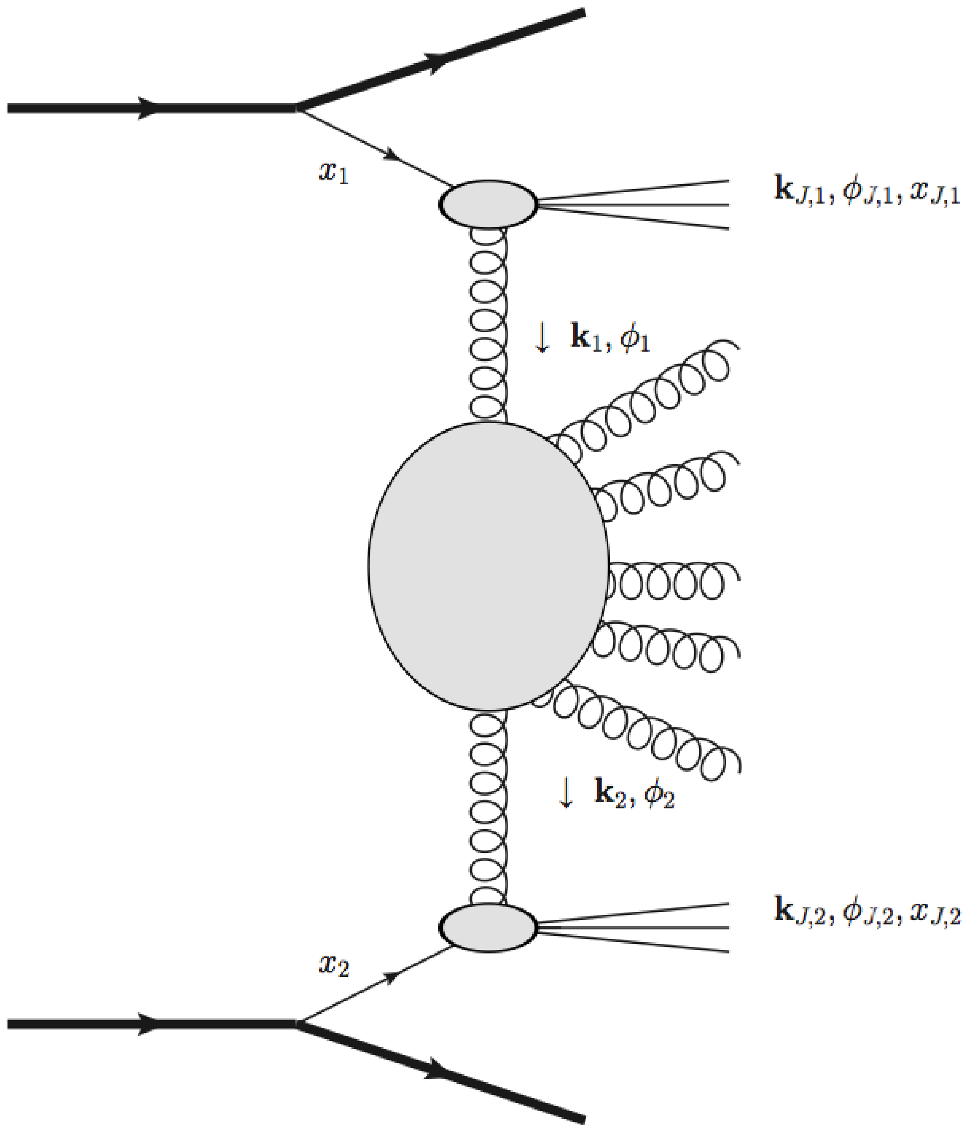
BFKL phenomenology

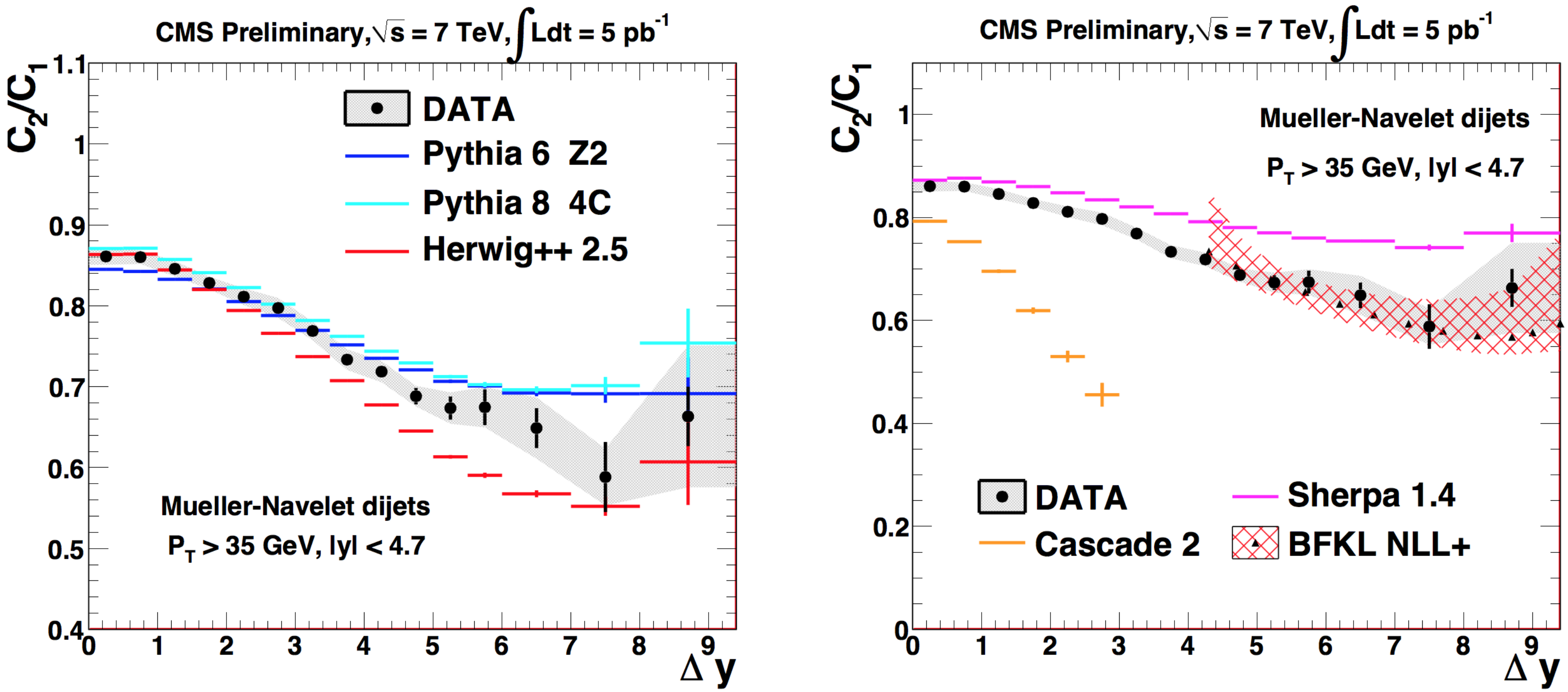
- LHC has produced and will further produce an abundance of data
- This is the best time to investigate the applicability of the BFKL resummation program within the context of a hadron collider
- In the last years: the big hit from the theory/experimental side was the study of Mueller-Navelet jets
- We need new observables: apart from the usual “growth with energy” signal, we should consider azimuthal angle dependencies

Mueller-Navelet jets



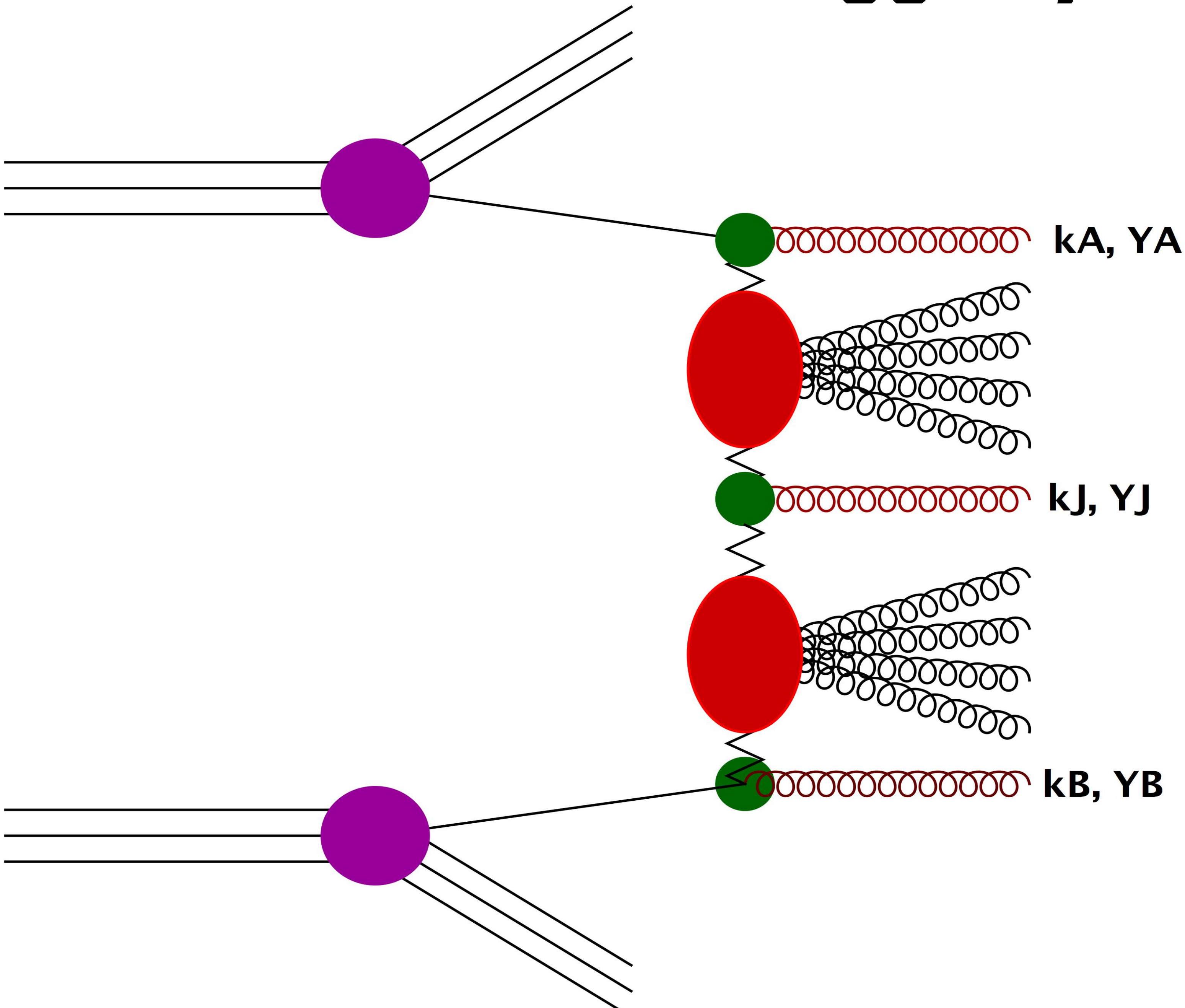
Colferai, Schwennsen, Szymanowski, Wallon 2010

Mueller-Navelet dijets azimuthal decorrelations

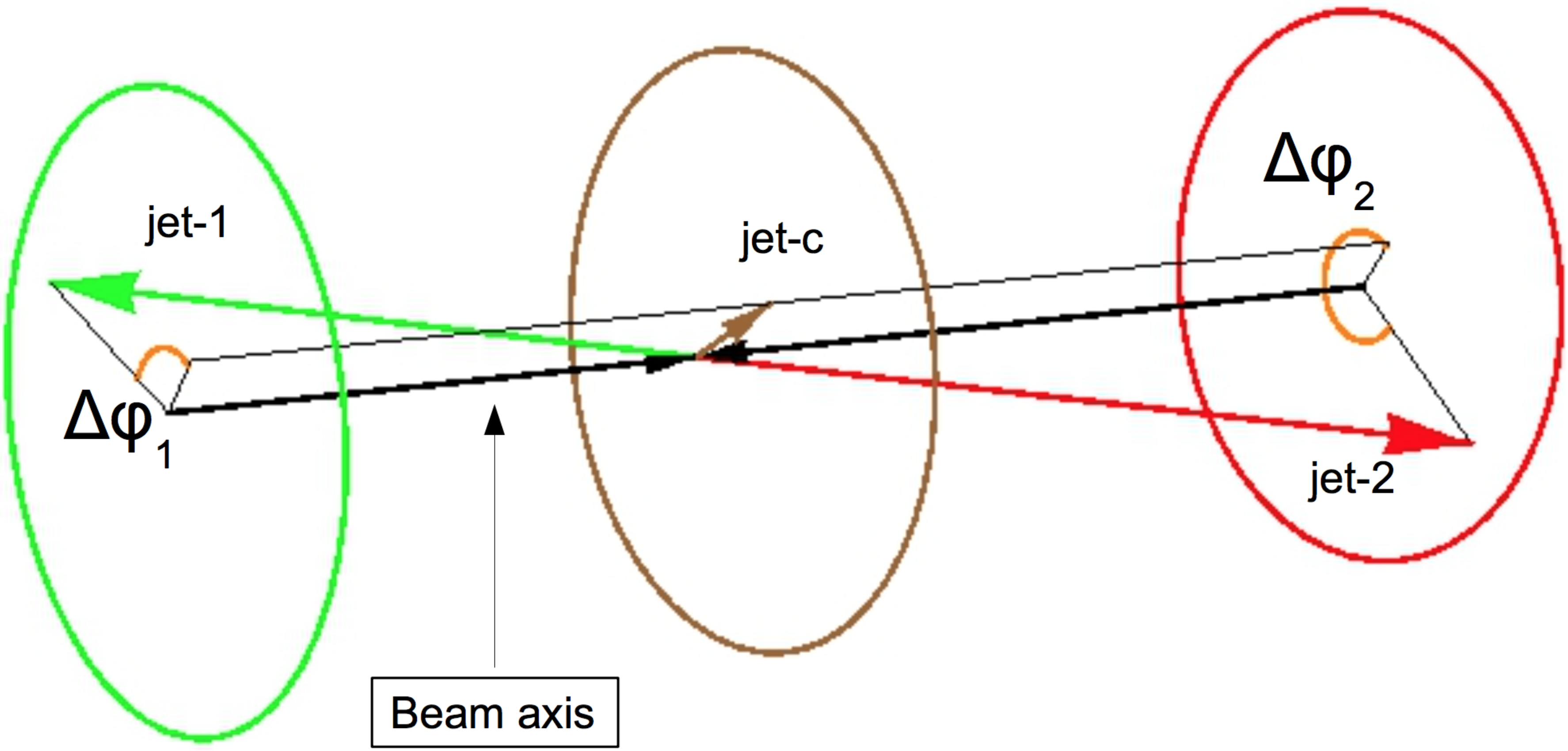


$$C_n = \langle \cos(n(\pi - \Delta\phi)) \rangle$$

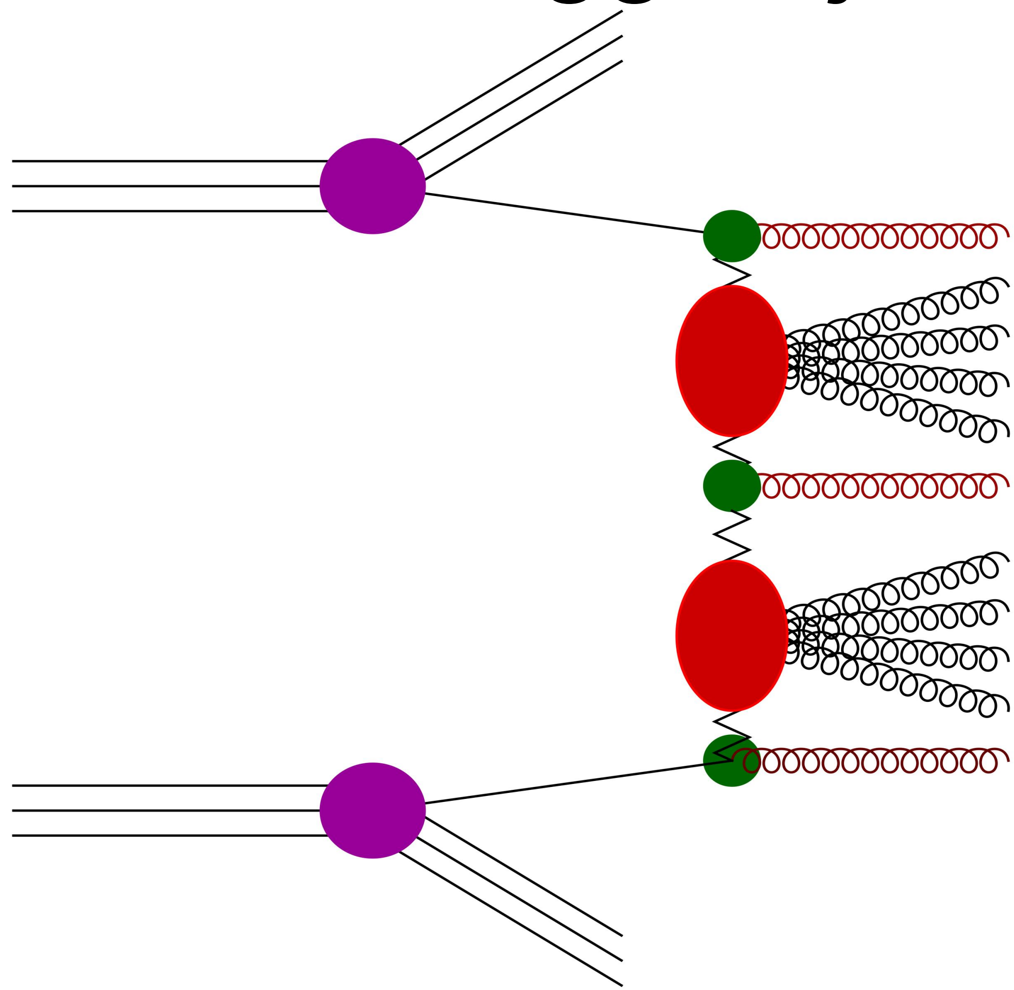
An event with three tagged jets



An event with three tagged jets



An event with three tagged jets



Assuming that $Y_A > y_J > Y_B$ and also that k_A and k_B are fixed we can write for the differential cross section:

$$\frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J} = \frac{\bar{\alpha}_s}{\pi k_J^2} \int d^2\vec{p}_A \int d^2\vec{p}_B \, \delta^{(2)}\left(\vec{p}_A + \vec{k}_J - \vec{p}_B\right) \times \varphi\left(\vec{k}_A, \vec{p}_A, Y_A - y_J\right) \varphi\left(\vec{p}_B, \vec{k}_B, y_J - Y_B\right)$$

Starting point

What to do next?

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1. Integrate over the angle difference of k_A and k_B and also over the angle of the central jet

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$$\int_0^{2\pi} d\Delta\phi\, \cos\left(M\Delta\phi\right)\int_0^{2\pi} d\theta_J\, \frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J}$$
$$= \bar{\alpha}_s \sum_{L=0}^{M}\int_0^{\infty} dp^2 \int_0^{2\pi} d\theta \frac{(-1)^M \binom{M}{L} \left(k_J^2\right)^{\frac{L-1}{2}} \left(p^2\right)^{\frac{M-L}{2}} \cos\left(L\,\theta\right)}{\sqrt{\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta\right)^M}}$$
$$\times \phi_M\left(p_A^2, p^2, Y_A - y_J\right)\phi_M\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta, p_B^2, y_J - Y_B\right)$$

$$\Delta\phi \equiv \theta_A - \theta_B - \pi$$

1. Integrate over the angle difference of k_A and k_B and also over the angle of the central jet

$$
\int_0^{2\pi} d\Delta\phi \, \cos\left(M\Delta\phi\right) \int_0^{2\pi} d\theta_J \, \frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J}
$$

$$
= \bar{\alpha}_s \sum_{L=0}^{M} \int_0^{\infty} dp^2 \int_0^{2\pi} d\theta \frac{(-1)^M \binom{M}{L} \left(k_J^2\right)^{\frac{L-1}{2}} \left(p^2\right)^{\frac{M-L}{2}} \cos\left(L\,\theta\right)}{\sqrt{\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta\right)^M}}
$$

$$
\times \phi_M\left(p_A^2, p^2, Y_A - y_J\right) \phi_M\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta, p_B^2, y_J - Y_B\right)
$$

where:

$$
\phi_n\left(p_A^2, p_B^2, Y\right) = 2\int_0^{\infty} d\nu \cos\left(\nu \ln\frac{p_A^2}{p_B^2}\right) \frac{e^{\bar{\alpha}_s \chi_{|n|}(\nu) Y}}{\pi\sqrt{p_A^2 p_B^2}},
$$

$$
\chi_n\left(\nu\right) = 2\psi(1) - \psi\left(\frac{1+n}{2} + i\nu\right) - \psi\left(\frac{1+n}{2} - i\nu\right)
$$

1. Integrate over the angle difference of k_A and k_B and also over the angle of the central jet

$$\int_0^{2\pi} d\Delta\phi \cos(M\Delta\phi) \int_0^{2\pi} d\theta_J \frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J}$$

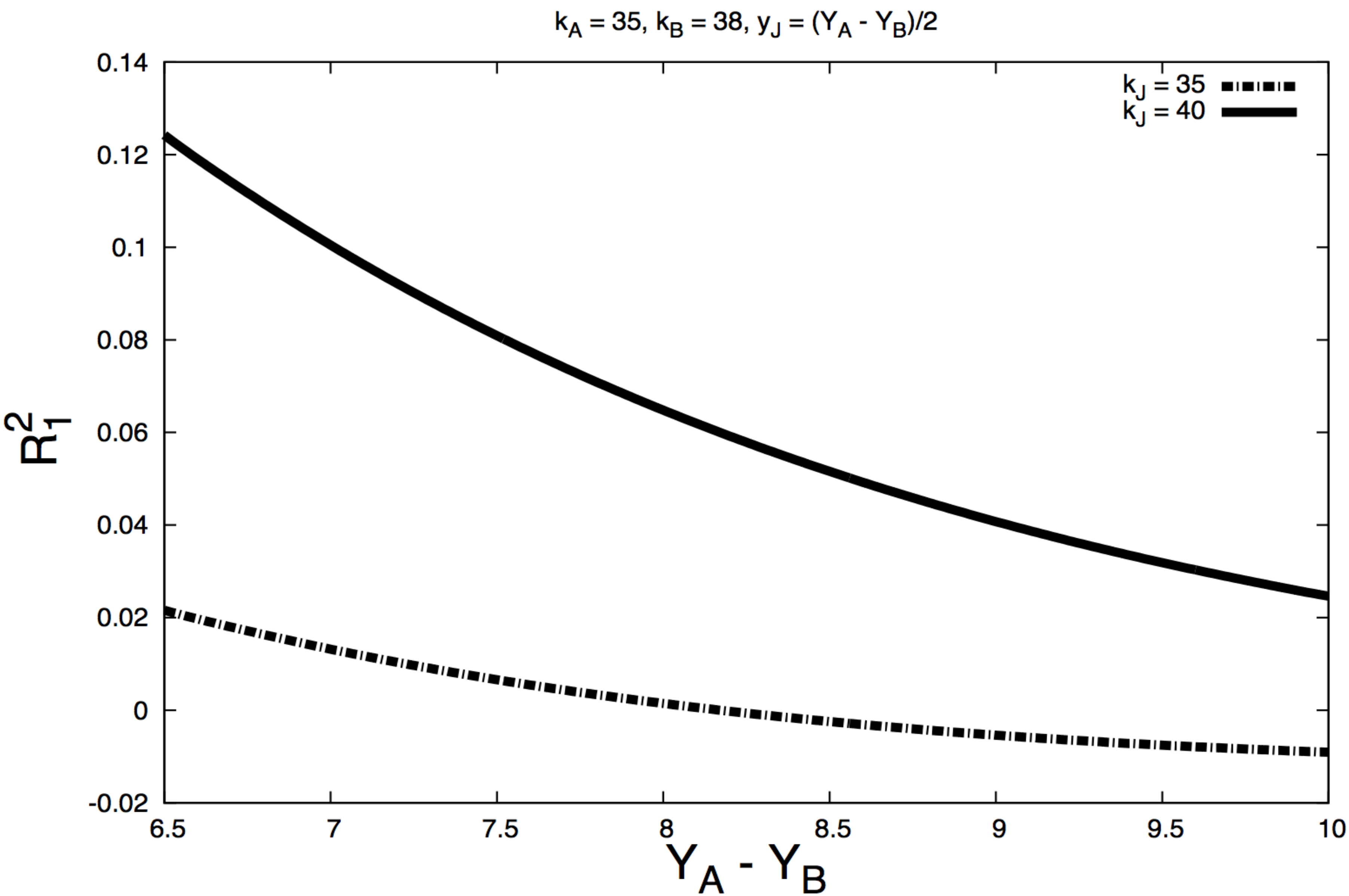
$$= \bar{\alpha}_s \sum_{L=0}^{M} \int_0^{\infty} dp^2 \int_0^{2\pi} d\theta \frac{(-1)^M \binom{M}{L} (k_J^2)^{\frac{L-1}{2}} (p^2)^{\frac{M-L}{2}} \cos(L\theta)}{\sqrt{\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta\right)^M}}$$

$$\times \phi_M\left(p_A^2, p^2, Y_A - y_J\right) \phi_M\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta, p_B^2, y_J - Y_B\right)$$

$$\langle \cos(M(\theta_A - \theta_B - \pi))\rangle = \frac{\int_0^{2\pi} d\Delta\phi \cos(M\Delta\phi) \int_0^{2\pi} d\theta_J \frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J}}{\int_0^{2\pi} d\Delta\phi \int_0^{2\pi} d\theta_J \frac{d^3\sigma^{3-\text{jet}}}{d^2\vec{k}_J dy_J}}$$

$$\mathcal{R}_N^M = \frac{\langle \cos(M(\theta_A - \theta_B - \pi))\rangle}{\langle \cos(N(\theta_A - \theta_B - \pi))\rangle}$$

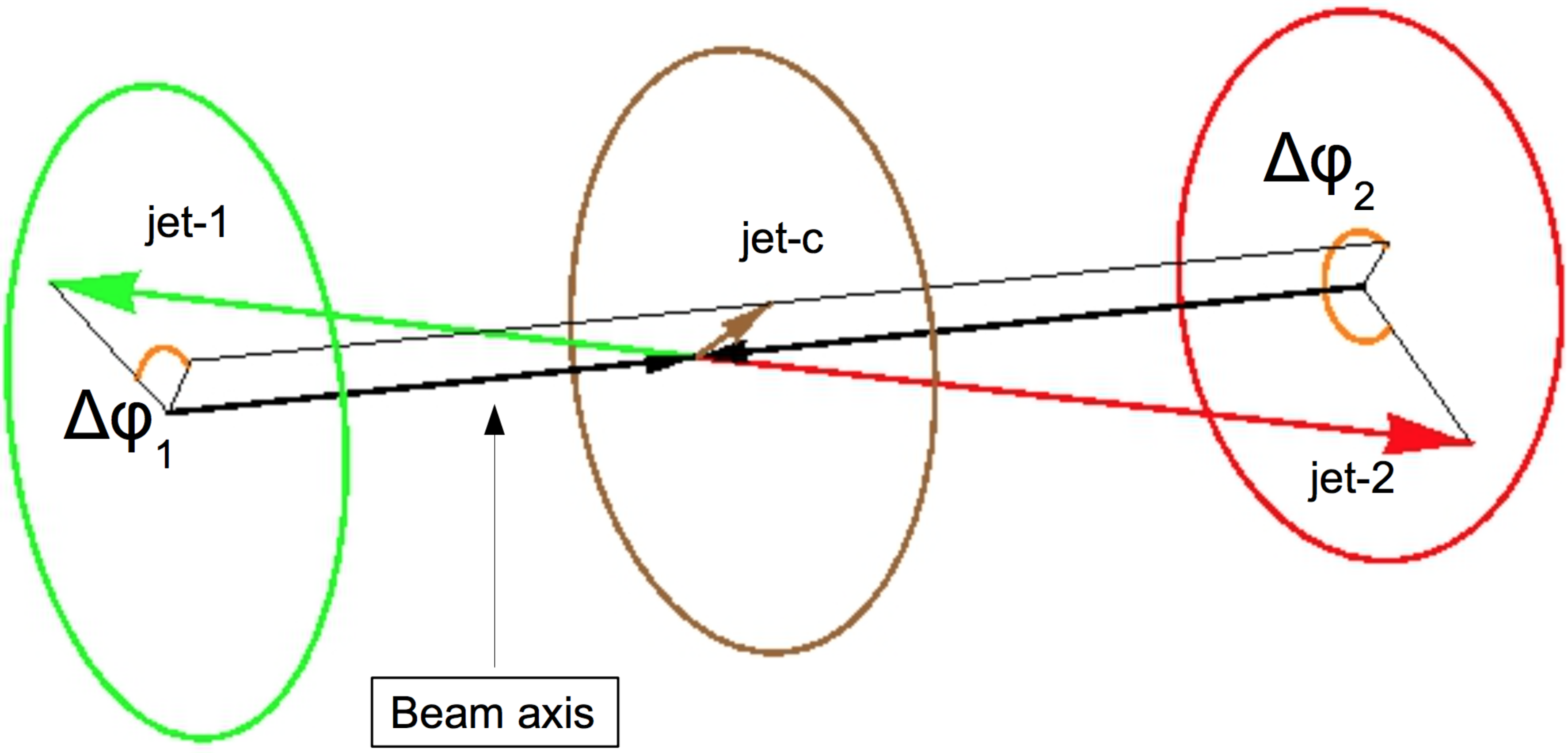
1. ...and then plot for different k_J



What to do next?

2. A second idea and by far more interesting is to integrate over all angles after using the projections on the two azimuthal angle differences between the central jet and k_A and k_B respectively

Back to the basic picture



2. Integrate over all angles after using projections

$$\frac{d^3\sigma^{3-\mathrm{jet}}}{d^2\vec{k}_J dy_J} = \frac{\bar{\alpha}_s}{\pi k_J^2}\int d^2\vec{p}_A \int d^2\vec{p}_B\, \delta^{(2)}\left(\vec{p}_A + \vec{k}_J - \vec{p}_B\right) \times \varphi\left(\vec{k}_A, \vec{p}_A, Y_A - y_J\right)\varphi\left(\vec{p}_B, \vec{k}_B, y_J - Y_B\right)$$

$$\int_0^{2\pi} d\theta_A \int_0^{2\pi} d\theta_B \int_0^{2\pi} d\theta_J \cos\left(M\left(\theta_A - \theta_J - \pi\right)\right) \cos\left(N\left(\theta_J - \theta_B - \pi\right)\right)\frac{d^3\sigma^{3-\mathrm{jet}}}{d^2\vec{k}_J dy_J}$$

$$= \bar{\alpha}_s \sum_{L=0}^{N} \binom{N}{L} \left(k_J^2\right)^{\frac{L-1}{2}} \int_0^{\infty} dp^2 \left(p^2\right)^{\frac{N-L}{2}} \int_0^{2\pi} d\theta \frac{(-1)^{M+N}\cos\left(M\theta\right)\cos\left((N-L)\theta\right)}{\sqrt{\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta\right)^N}} \times \phi_M\left(p_A^2, p^2, Y_A - y_J\right)\phi_N\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta, p_B^2, y_J - Y_B\right)$$

2. Integrate over all angles after using projections

$$\int_0^{2\pi} d\theta_A \int_0^{2\pi} d\theta_B \int_0^{2\pi} d\theta_J \cos\left(M\left(\theta_A-\theta_J-\pi\right)\right) \cos\left(N\left(\theta_J-\theta_B-\pi\right)\right)\frac{d^3\sigma^{3-\mathrm{jet}}}{d^2\vec{k}_J dy_J}$$

$$= \bar{\alpha}_s \sum_{L=0}^{N} \binom{N}{L} \left(k_J^2\right)^{\frac{L-1}{2}} \int_0^{\infty} dp^2 \left(p^2\right)^{\frac{N-L}{2}} \int_0^{2\pi} d\theta \frac{(-1)^{M+N}\cos\left(M\theta\right)\cos\left((N-L)\theta\right)}{\sqrt{\left(p^2+k_J^2+2\sqrt{p^2k_J^2}\cos\theta\right)^N}}$$

$$\times\, \phi_M\left(p_A^2, p^2, Y_A-y_J\right)\phi_N\left(p^2+k_J^2+2\sqrt{p^2k_J^2}\cos\theta, p_B^2, y_J-Y_B\right)$$

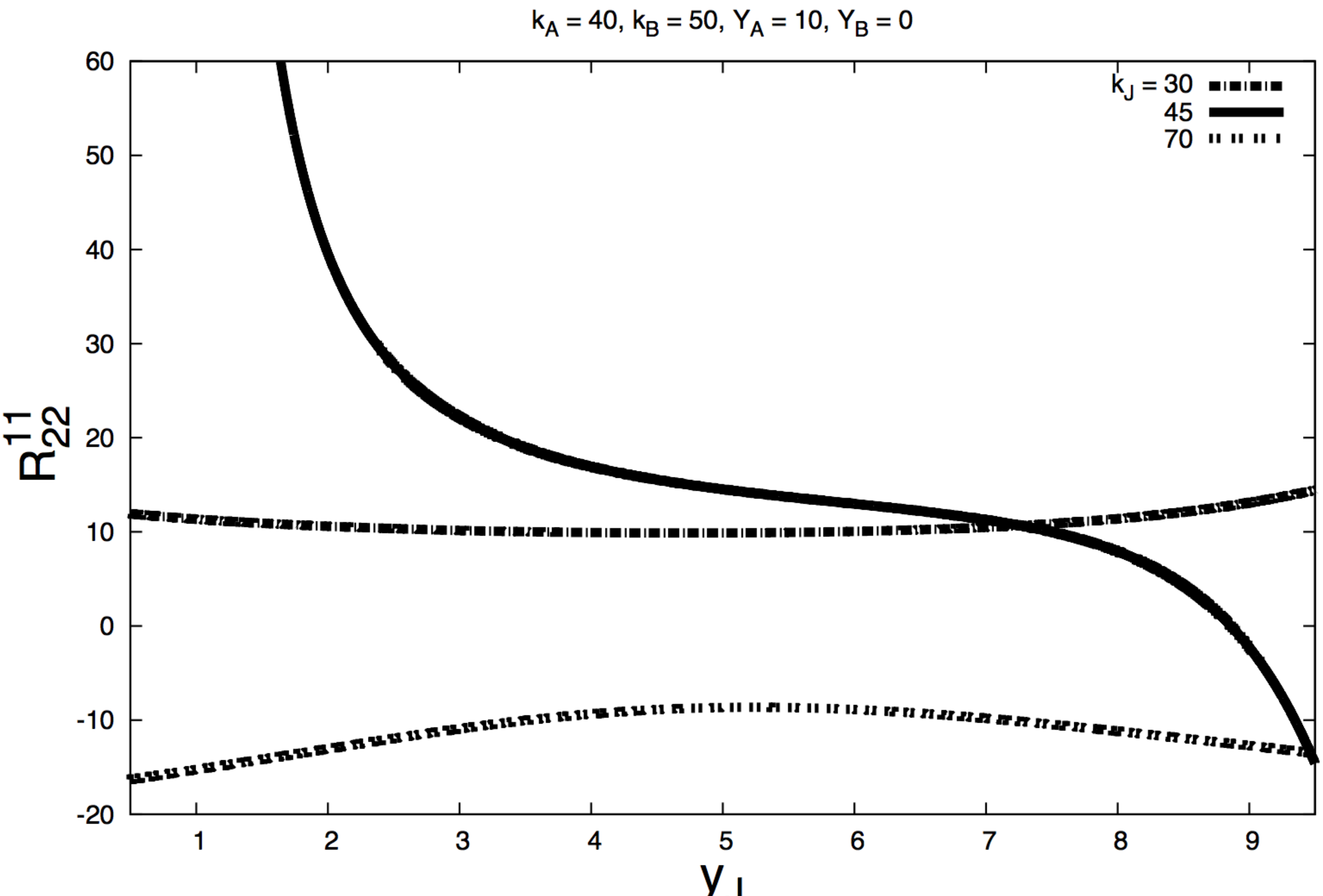
$$\left\langle \cos\left(M\left(\theta_A-\theta_J-\pi\right)\right)\cos\left(N\left(\theta_J-\theta_B-\pi\right)\right)\right\rangle$$

$$= \frac{\int_0^{2\pi} d\theta_A d\theta_B d\theta_J \cos\left(M\left(\theta_A-\theta_J-\pi\right)\right)\cos\left(N\left(\theta_J-\theta_B-\pi\right)\right)\frac{d^3\sigma^{3-\mathrm{jet}}}{d^2\vec{k}_J dy_J}}{\int_0^{2\pi} d\theta_A d\theta_B d\theta_J \frac{d^3\sigma^{3-\mathrm{jet}}}{d^2\vec{k}_J dy_J}}$$

2. ... so that you can define new observables:

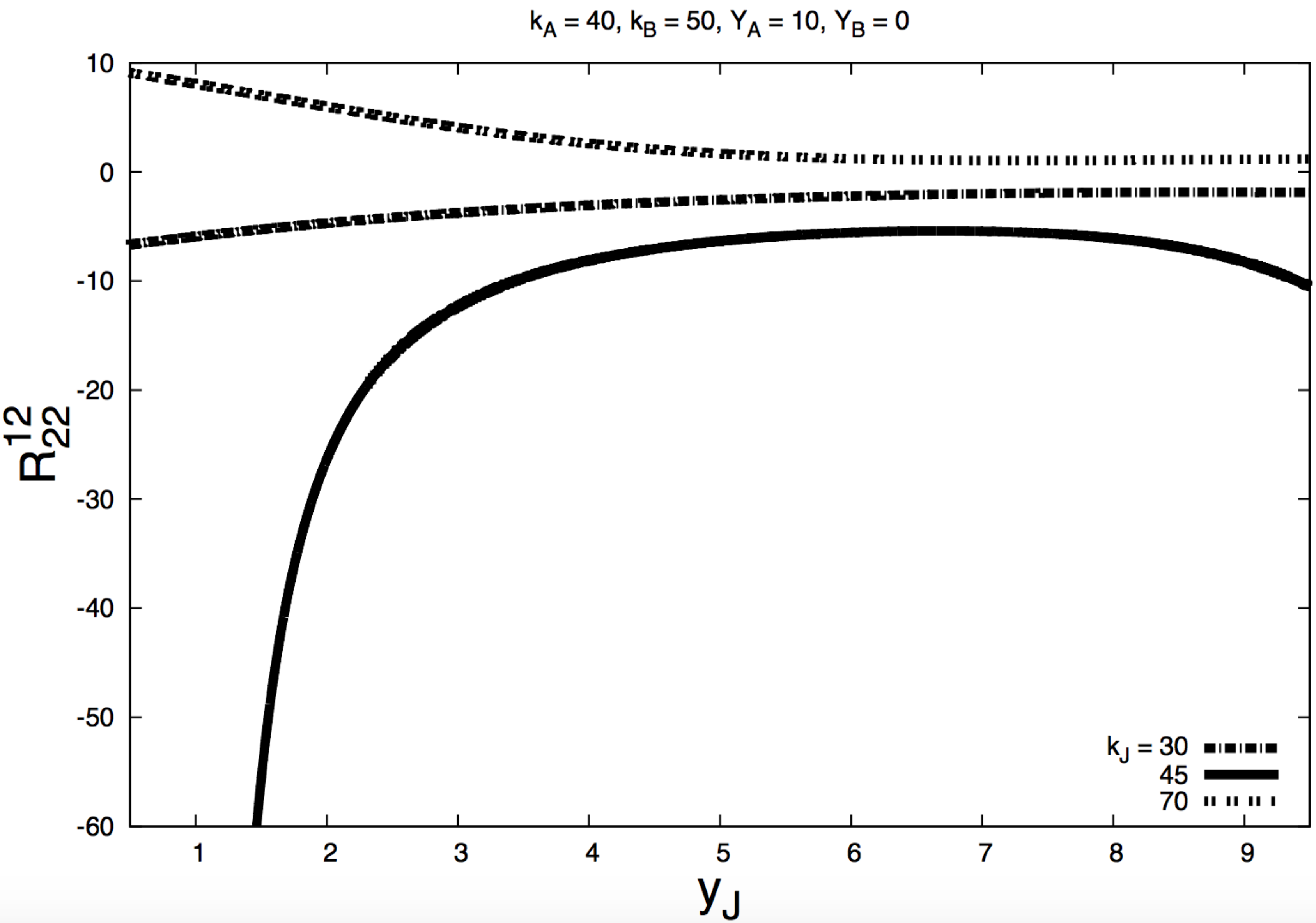
$$\mathcal{R}_{P,Q}^{M,N} = \frac{\langle \cos\left(M\left(\theta_A - \theta_J - \pi\right)\right)\cos\left(N\left(\theta_J - \theta_B - \pi\right)\right)\rangle}{\langle \cos\left(P\left(\theta_A - \theta_J - \pi\right)\right)\cos\left(Q\left(\theta_J - \theta_B - \pi\right)\right)\rangle}$$

R^{11}_{22}

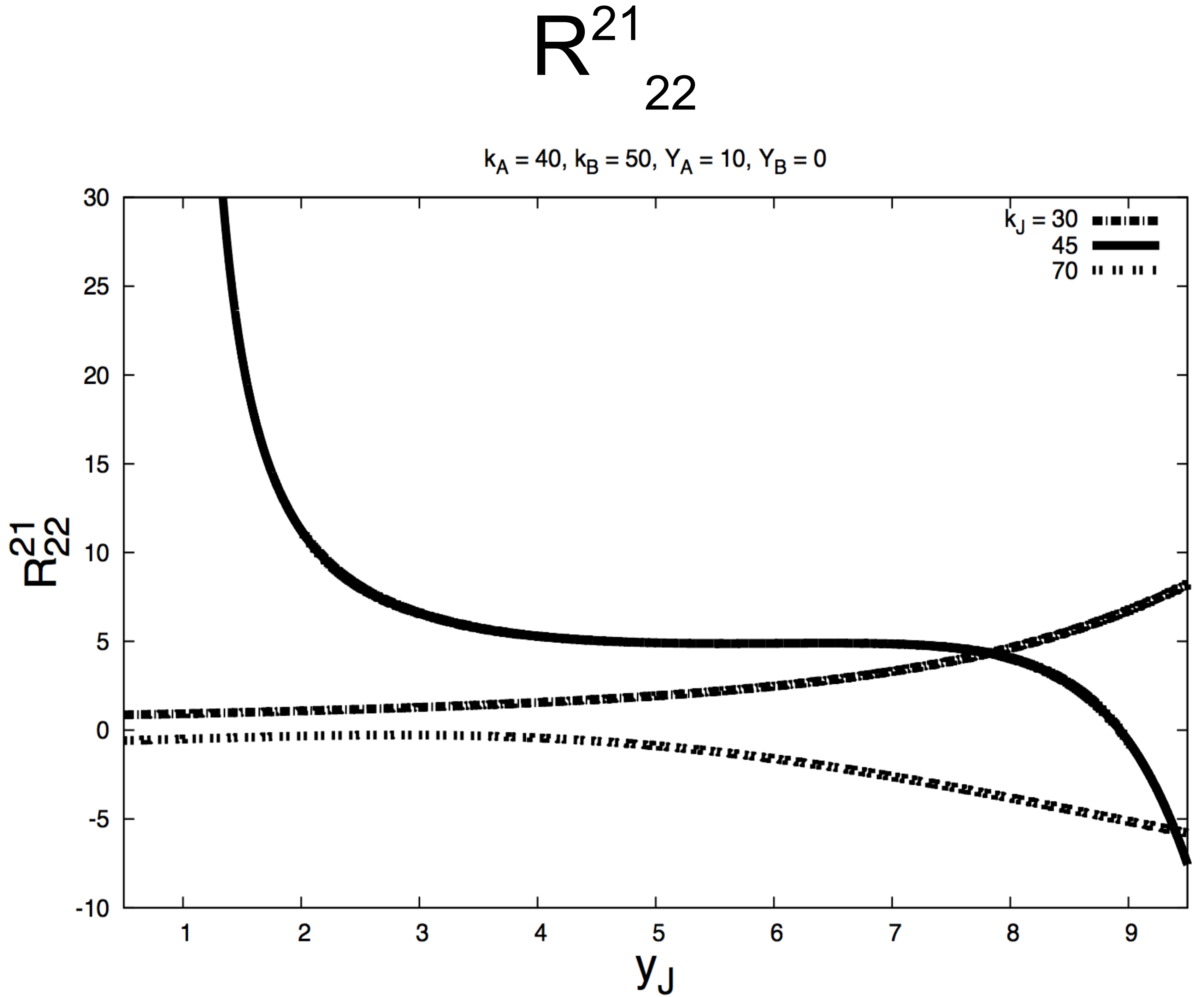


$k_A = 40$, $k_B = 50$, $Y_A = 10$, $Y_B = 0$
$k_J = 30$
45
70
R^{11}_{22}
y_J
60
50
40
30
20
10
0
-10
-20
1
2
3
4
5
6
7
8
9

R^{12}_{22}

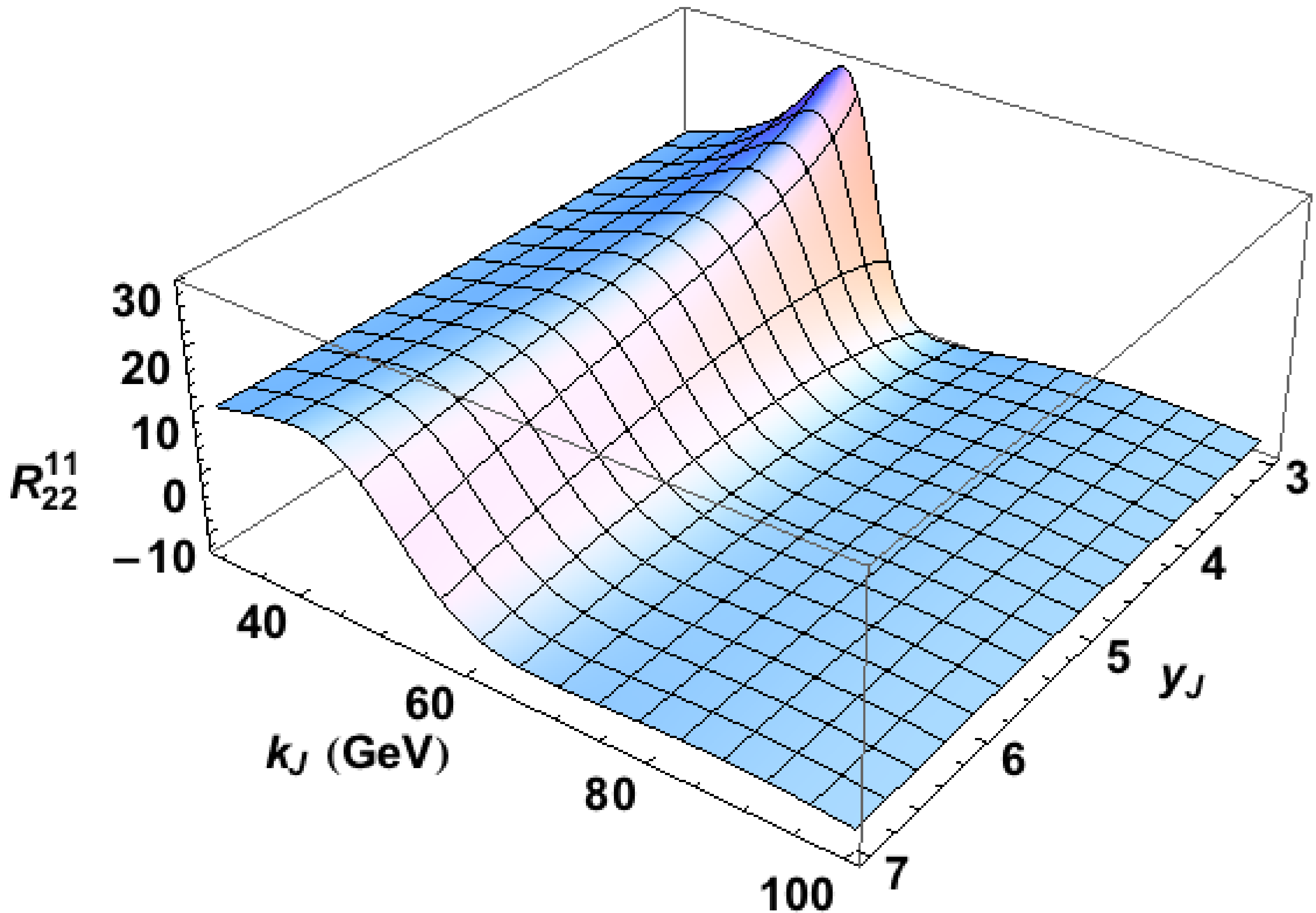


k_A = 40, k_B = 50, Y_A = 10, Y_B = 0
R^12_22
y_J
10
0
-10
-20
-30
-40
-50
-60
1
2
3
4
5
6
7
8
9
k_J = 30
45
70



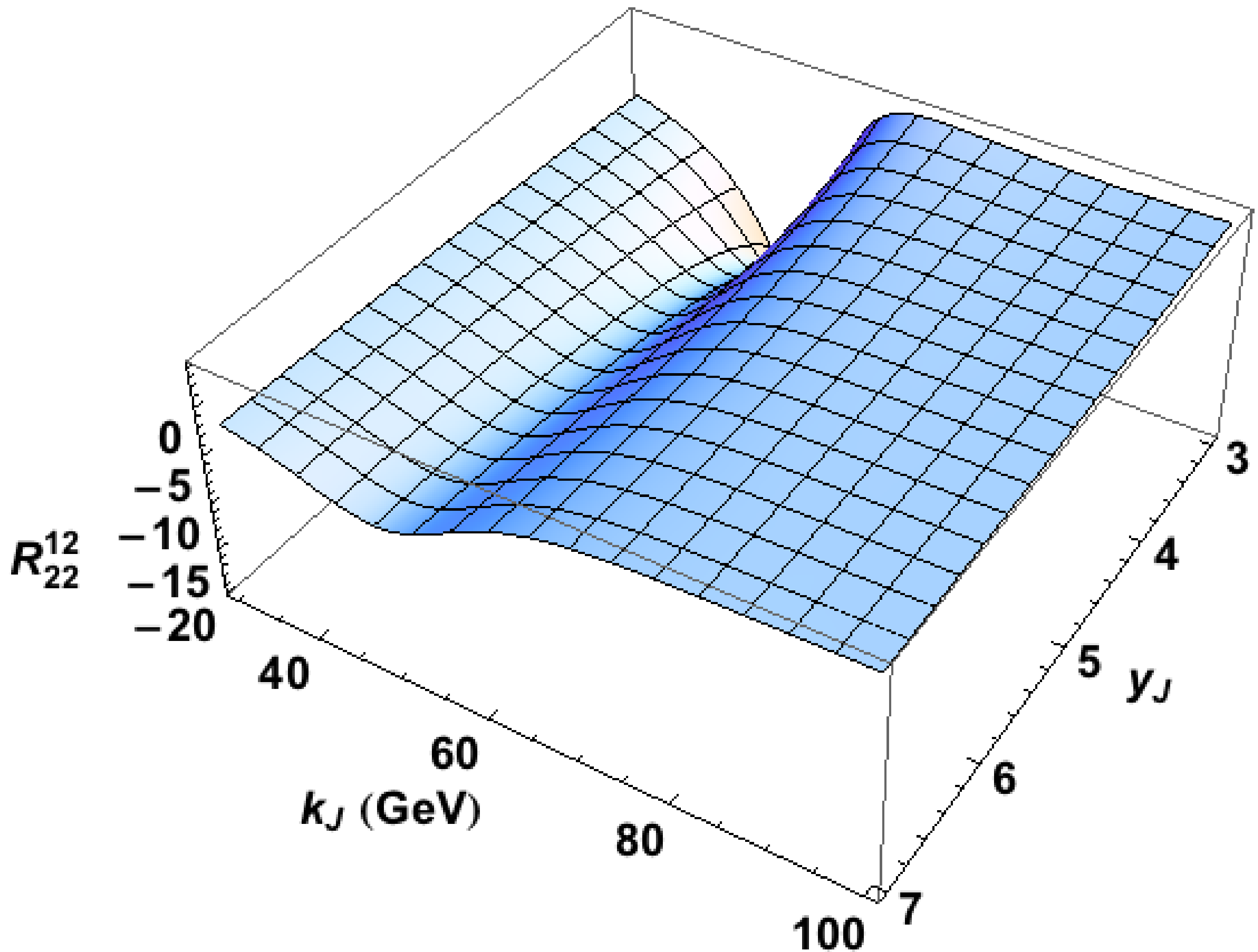
R^{21}_{22}
$k_A = 40, k_B = 50, Y_A = 10, Y_B = 0$
$k_J = 30$
45
70
30
25
20
15
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9
y_J
R^{21}_{22}

3D plot for R^{11}_{22}



k_A = 40 GeV, k_B = 50 GeV, Y_A = 10, Y_B = 0

3D plot for R^{12}_{22}



k_A = 40 GeV, k_B = 50 GeV, Y_A = 10, Y_B = 0

How about 4-jet events, is there something similar to be done there?

How about 4-jet events, is there something similar to be done there?

More generally, what about:

- Including PDF's?
- Jet clustering algorithms?

Other observables beyond azimuthal correlations?

BFKLex Monte Carlo

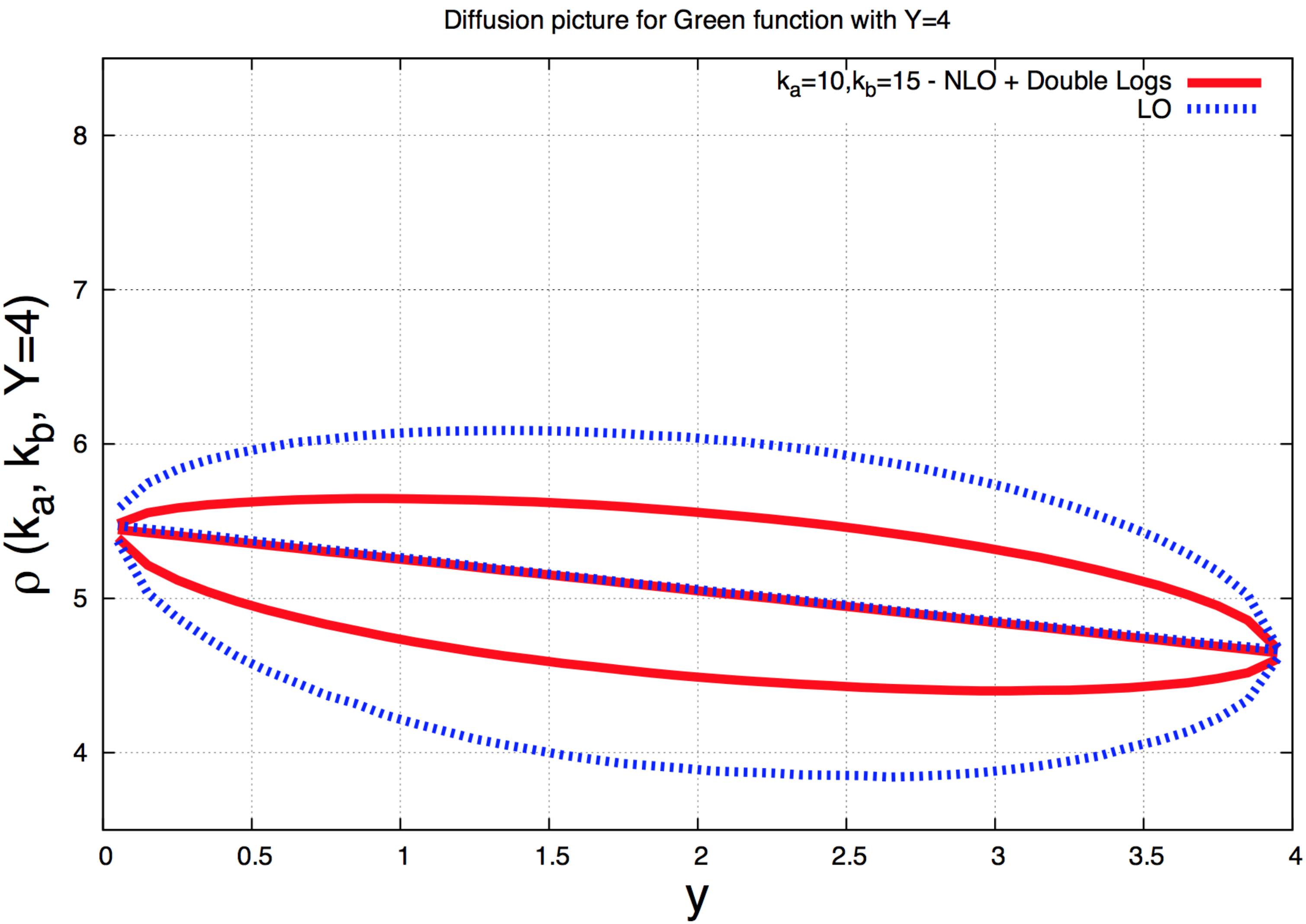
This is an implementation of the iterative solution of the BFKL equation as a Monte Carlo code.

GC, A. Sabio Vera, arXiv:1508:07711

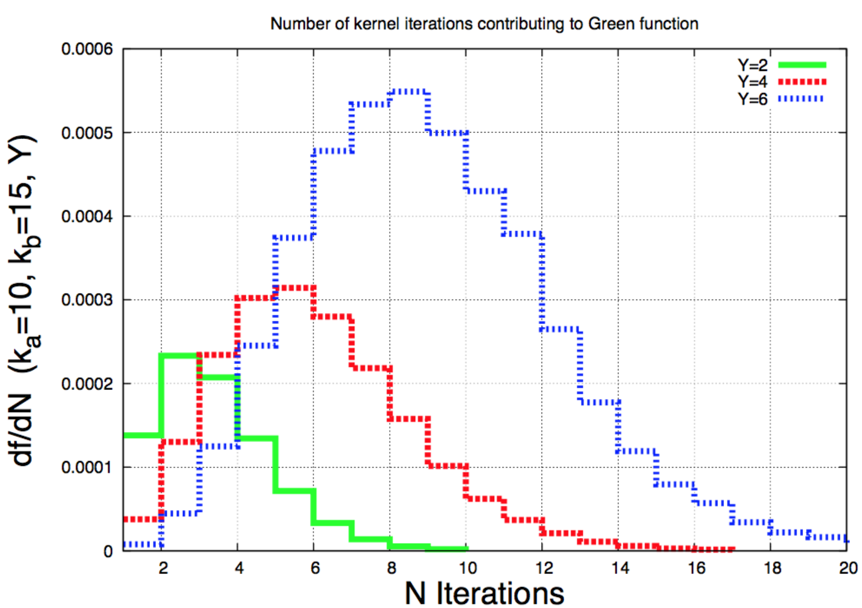
Present status:

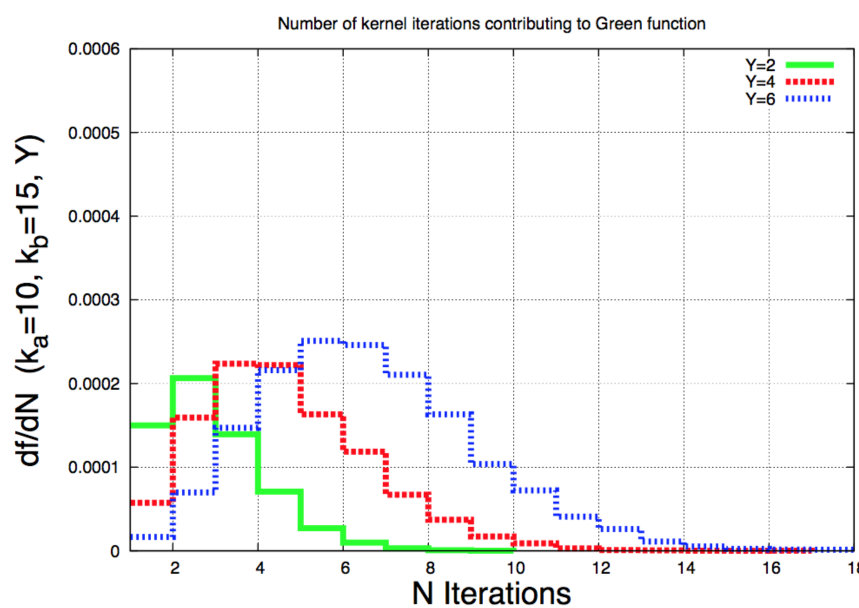
- NLO BFKL, collinearly improved
- Interfaced with PDF's and FastJet

BFKLex Monte Carlo interesting facts: Diffusion



BFKLex Monte Carlo interesting facts: “multiplicity”





Conclusions & Outlook

- We use three tagged jets to propose new observables with a distinct signal of BFKL dynamics, 4-jet case is also ready
- We use ratios of correlation functions to minimize the influence of higher order corrections
- For a realistic comparison against experimental data we need to integrate over a range of k_A and k_B and introduce PDFs and a jet algorithm
- Comparison with **BFKLex** results and other Monte Carlo codes is underway