New BFKL probes at the LHC

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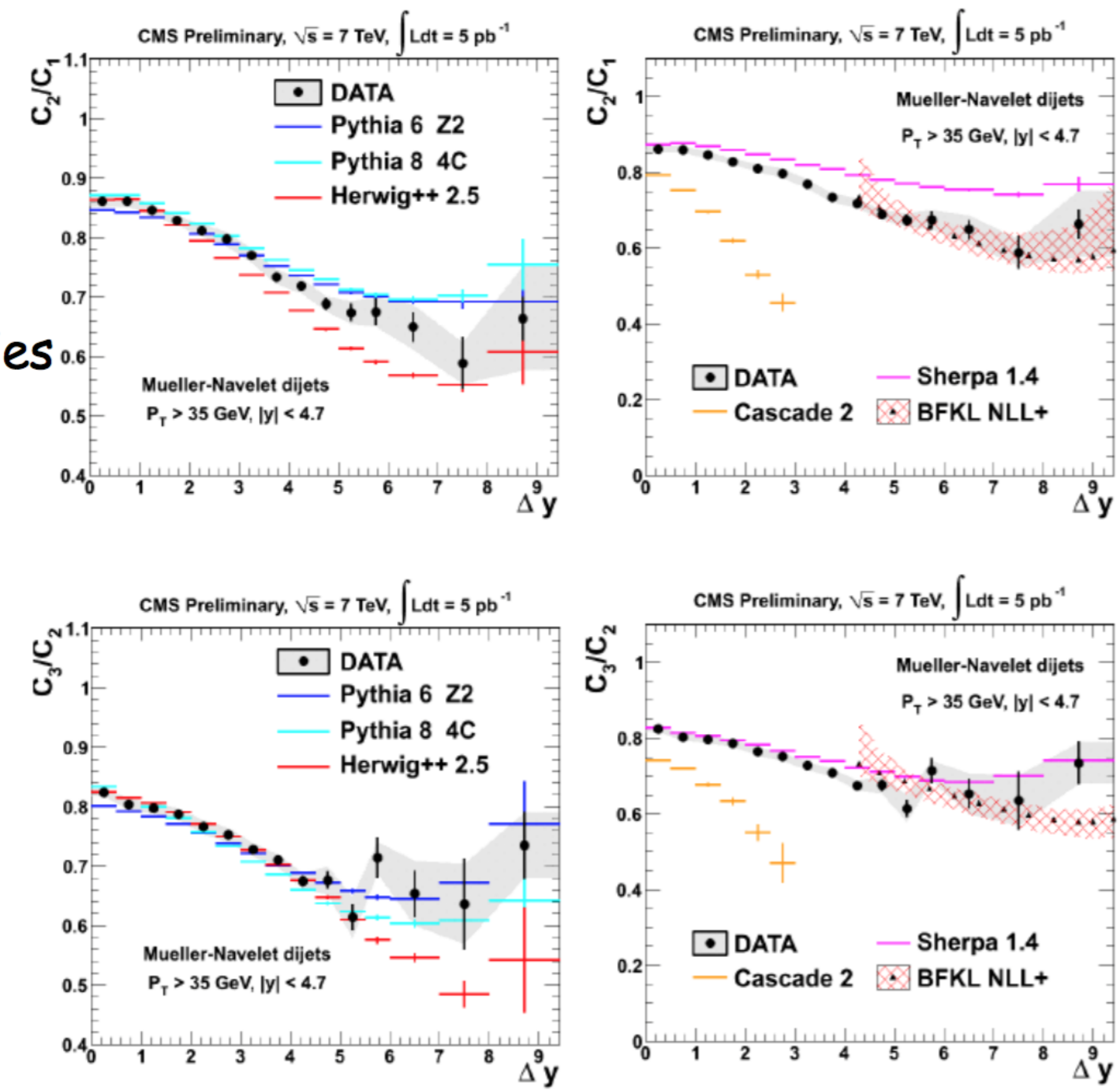
BFKL phenomenology

- 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

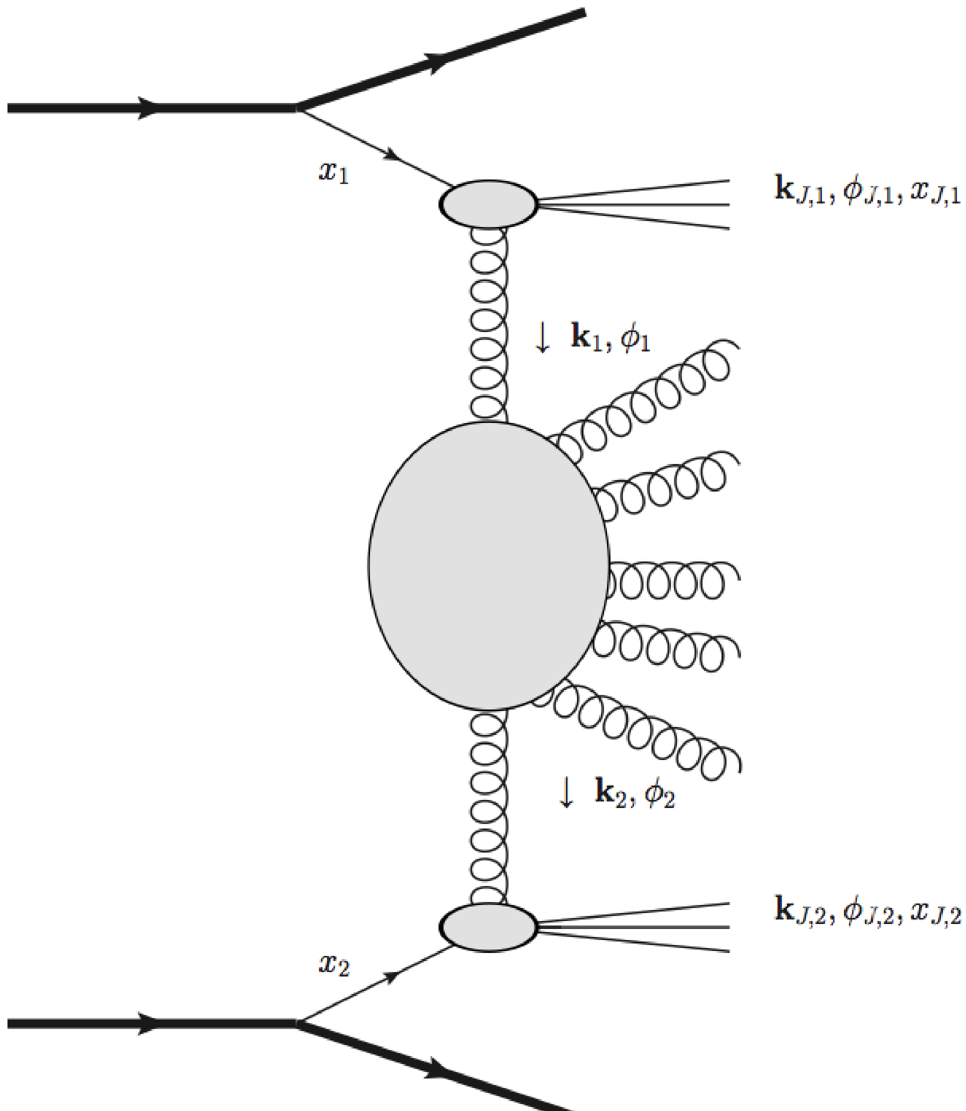
MN dijets azimuthal decorellations

- In ratios DGLAP contributions are suppresed
- Pythia/Herwig good agreement at low Δy, at large Δy discrepancies
- Sherpa is above the data
- Cascade is far below the data
- BFKL NLL calculation describes well the ratios, especially C_2/C_1



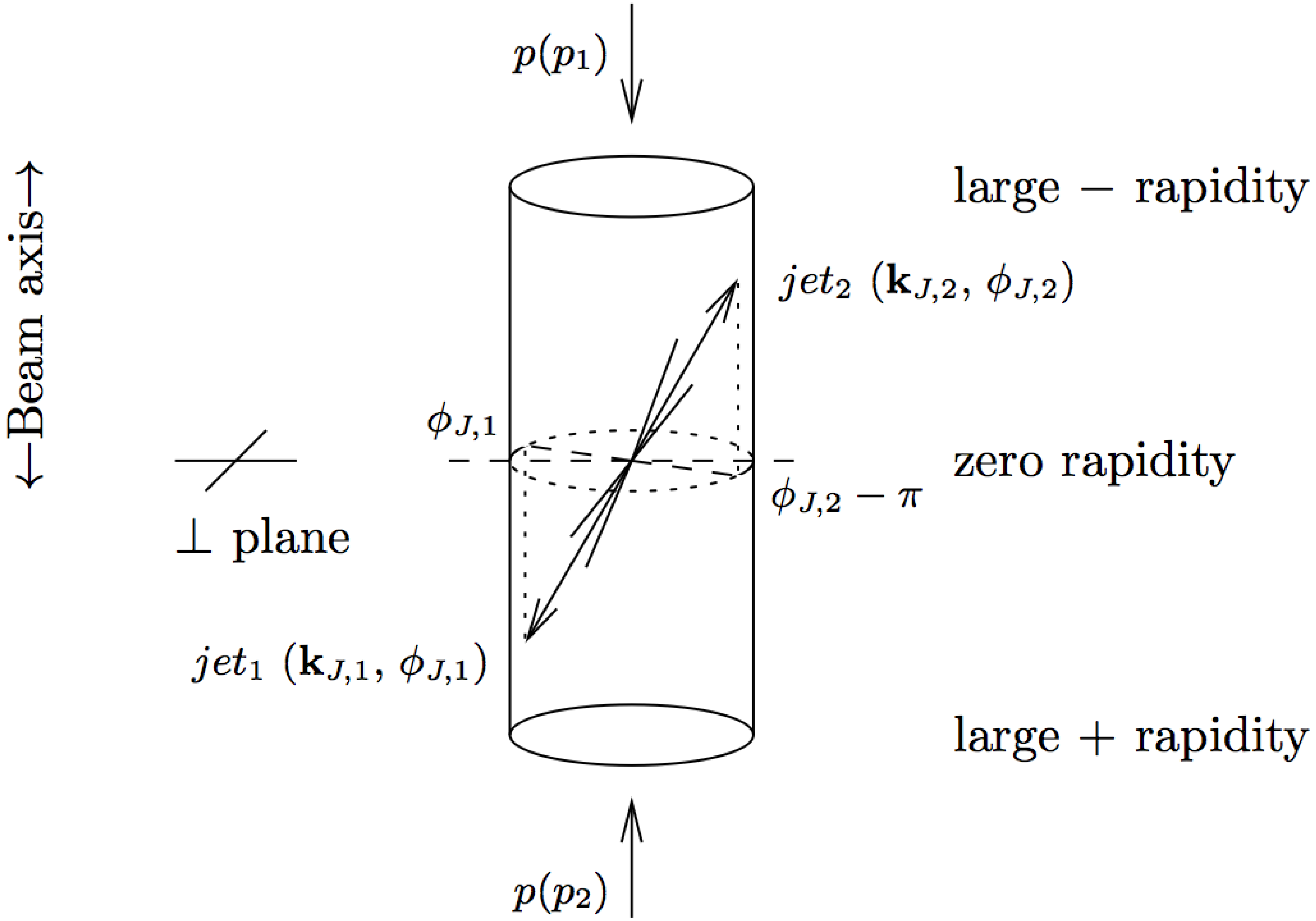
Slide taken from a talk by Grzegorz Brona (Low x meeting 2014)

Mueller-Navelet jets



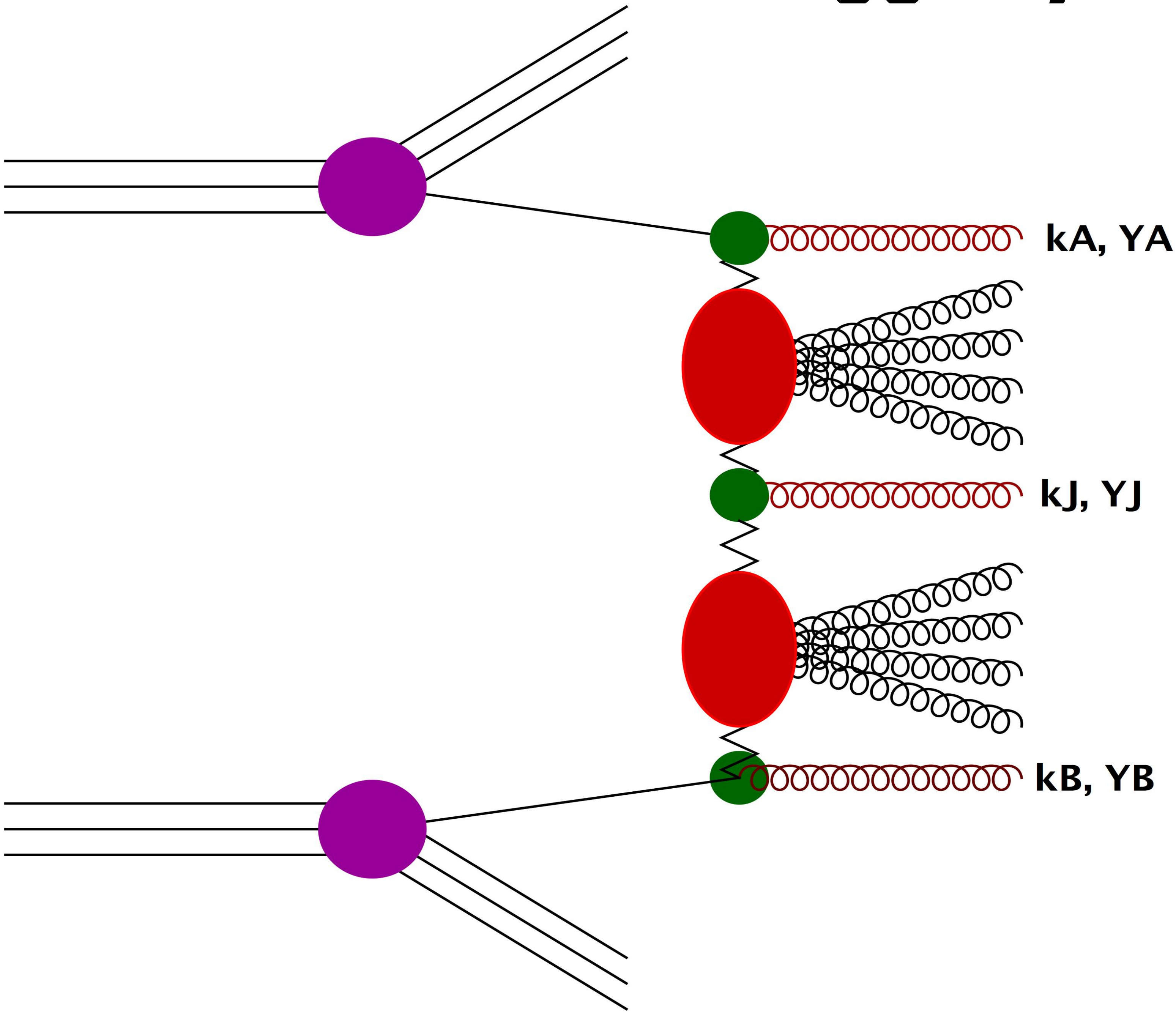
Colferai, Schwennsen, Szymanowski, Wallon 2010

Mueller-Navelet jets

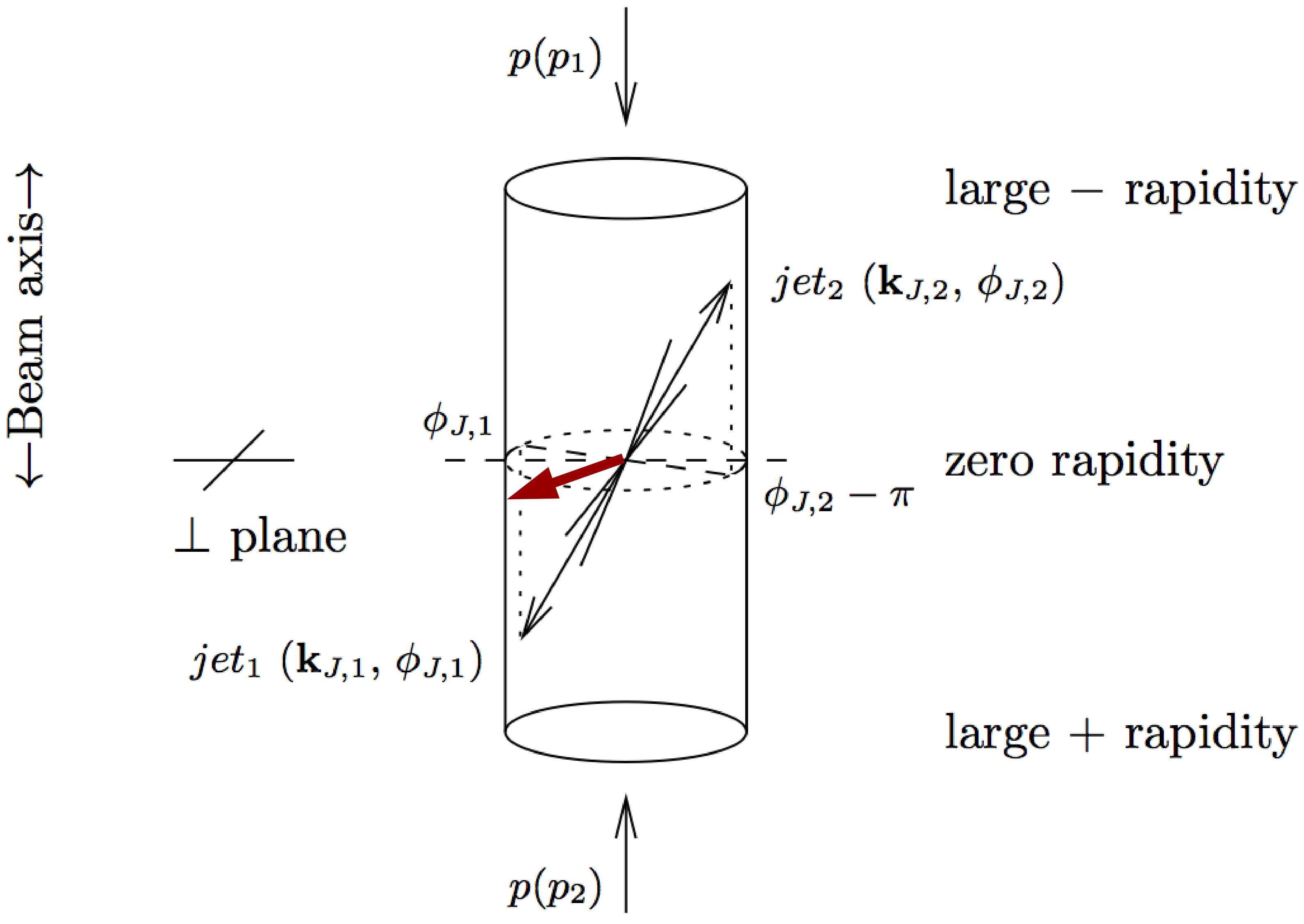


Colferai, Schwennsen, Szymanowski, Wallon 2010

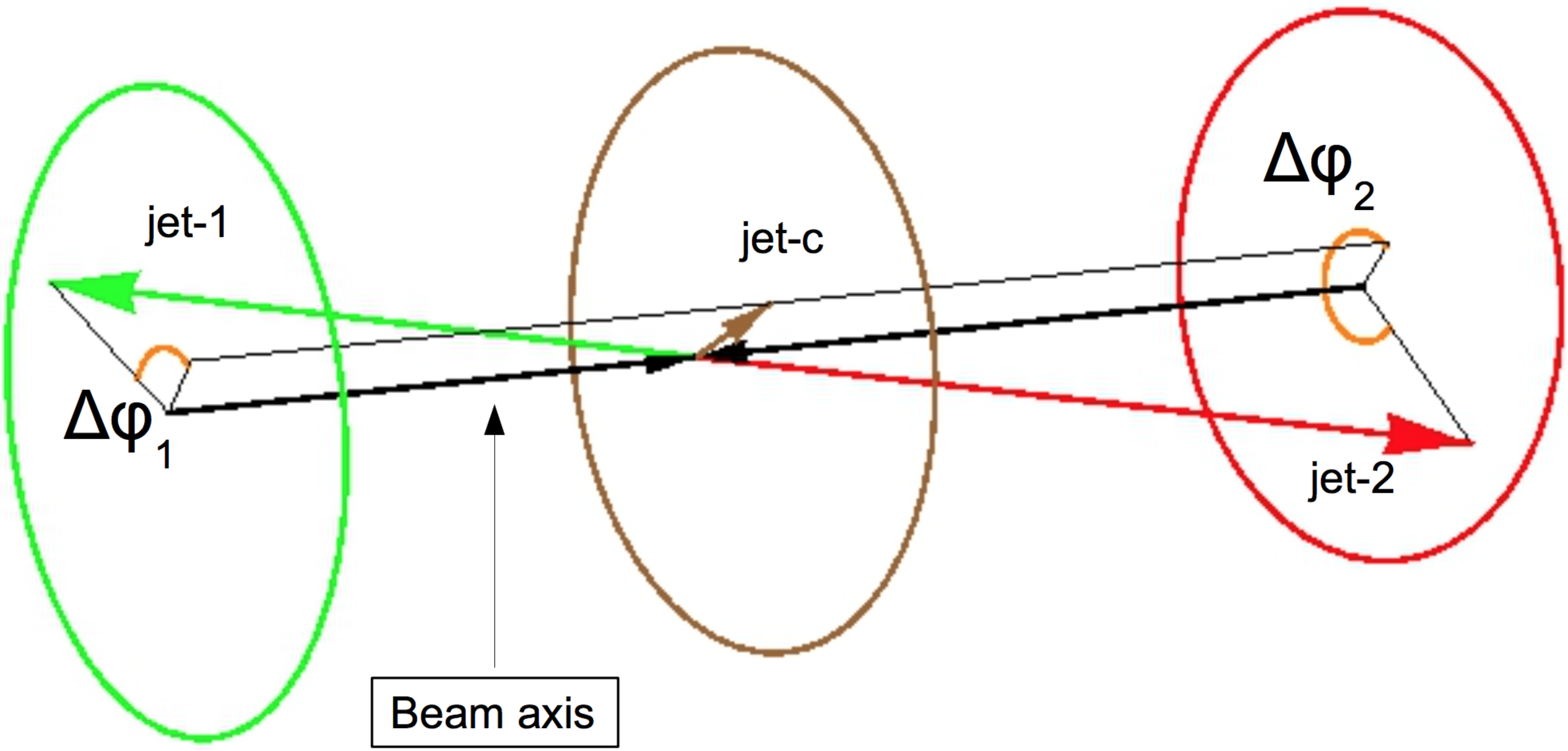
An event with three tagged jets



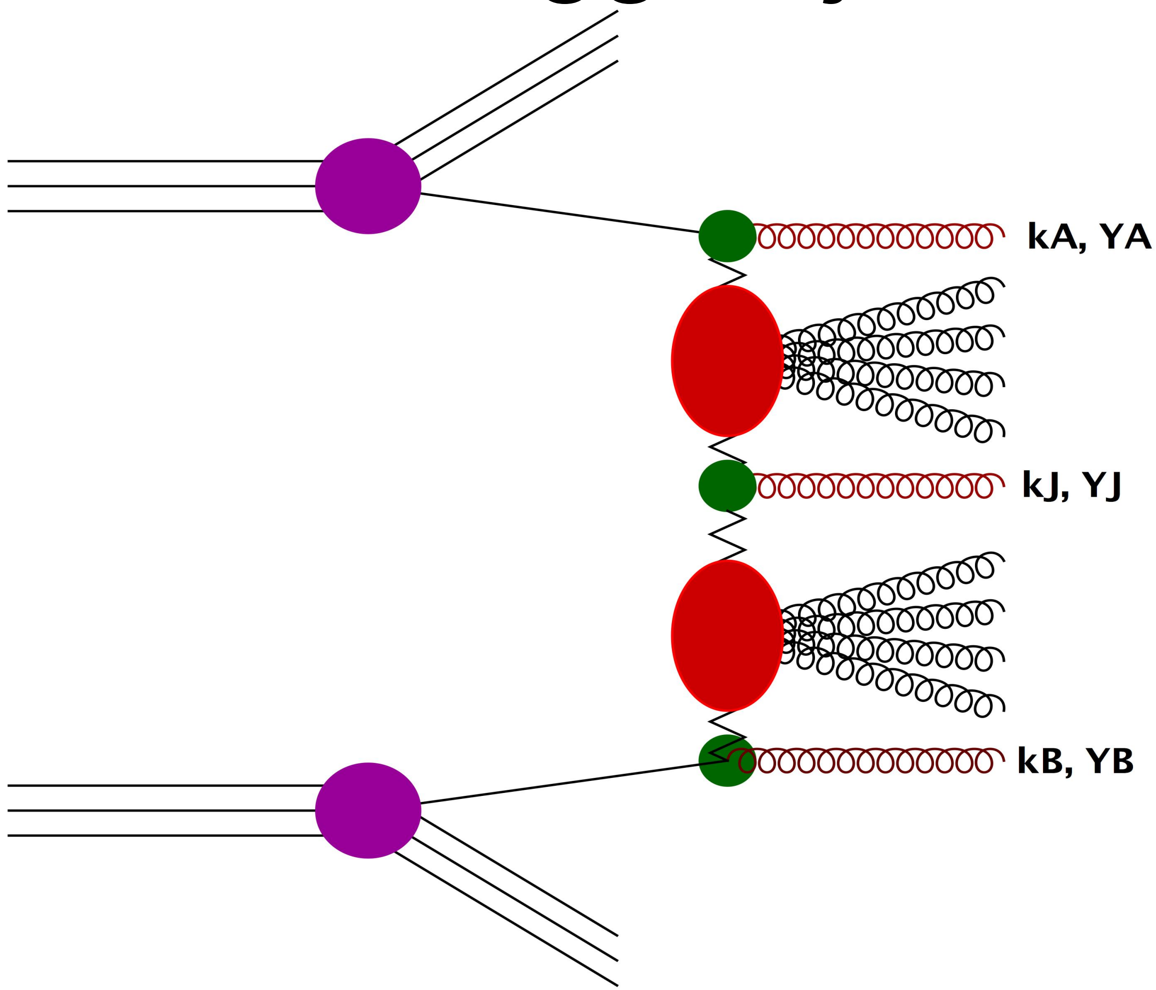
An event with three tagged jets



An event with three tagged jets



An event with three tagged jets



Assuming that
YA > YJ > YB and also that kA and kB are fixed we can write for the differential cross section:

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

Starting point

What to do next?

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1. Integrate over the angle difference of kA and kB and also over the angle of the central jet

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

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

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

1. Integrate over the angle difference of kA and kB and also over the angle of the central jet

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

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

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

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 kA and kB and also over the angle of the central jet

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

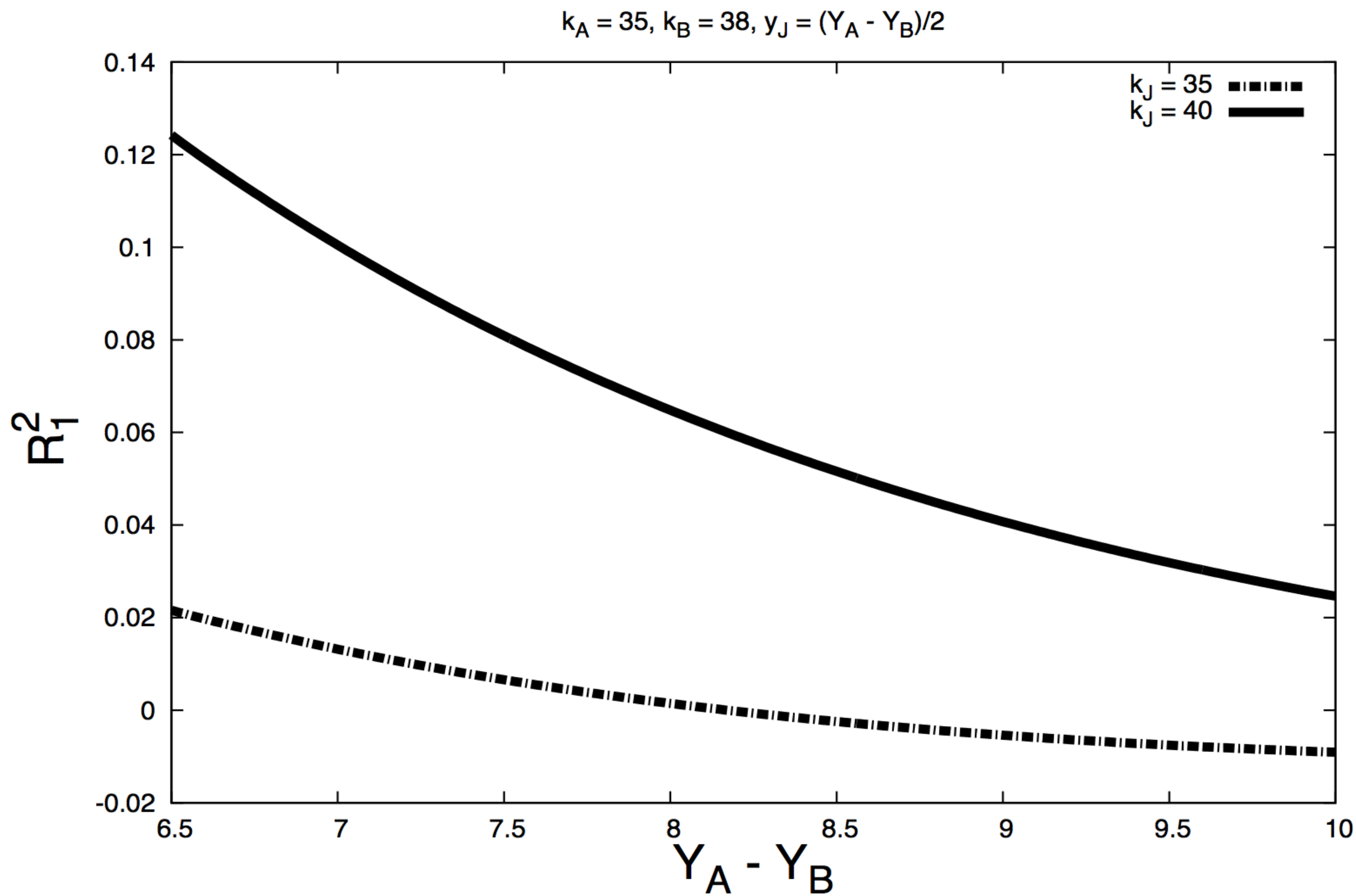
$$= \bar{\alpha}_s \sum_{L=0}^{M} \int_0^{\infty} dp^2 \int_0^{2\pi} d\theta \frac{(-1)^M \binom{M}{L} \left(k_J^2\right)^{\frac{L-1}{2}} \left(p^2\right)^{\frac{M-L}{2}} \cos\left(L\,\theta\right)}{\sqrt{\left(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2}\cos\theta\right)^M}}$$

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

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

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

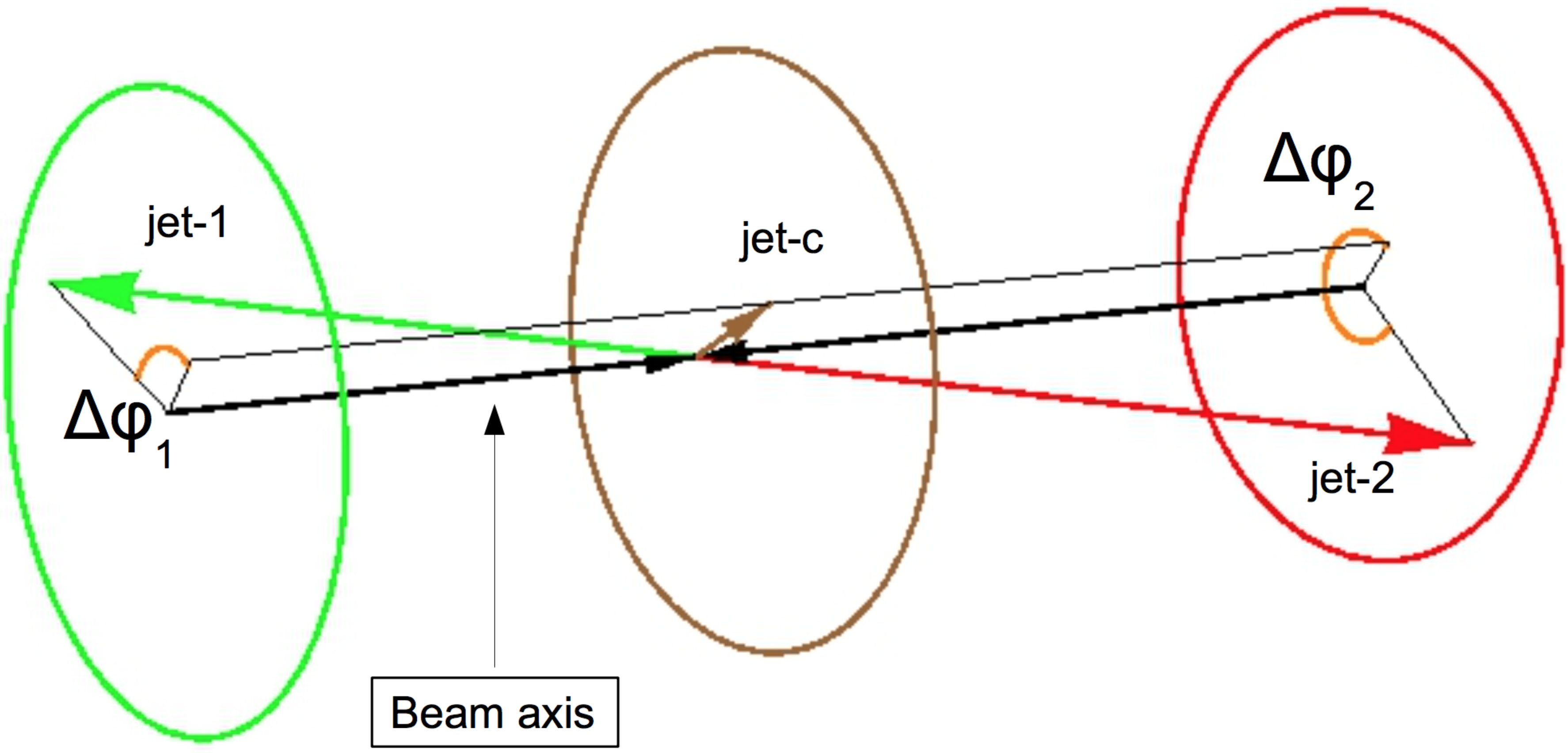
1. ...and then plot for different kJ



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 kA and kB respectively

Back to the basic picture



2. Integrate over all angles after using projections

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

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

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

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

2. Integrate over all angles after using projections

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

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

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

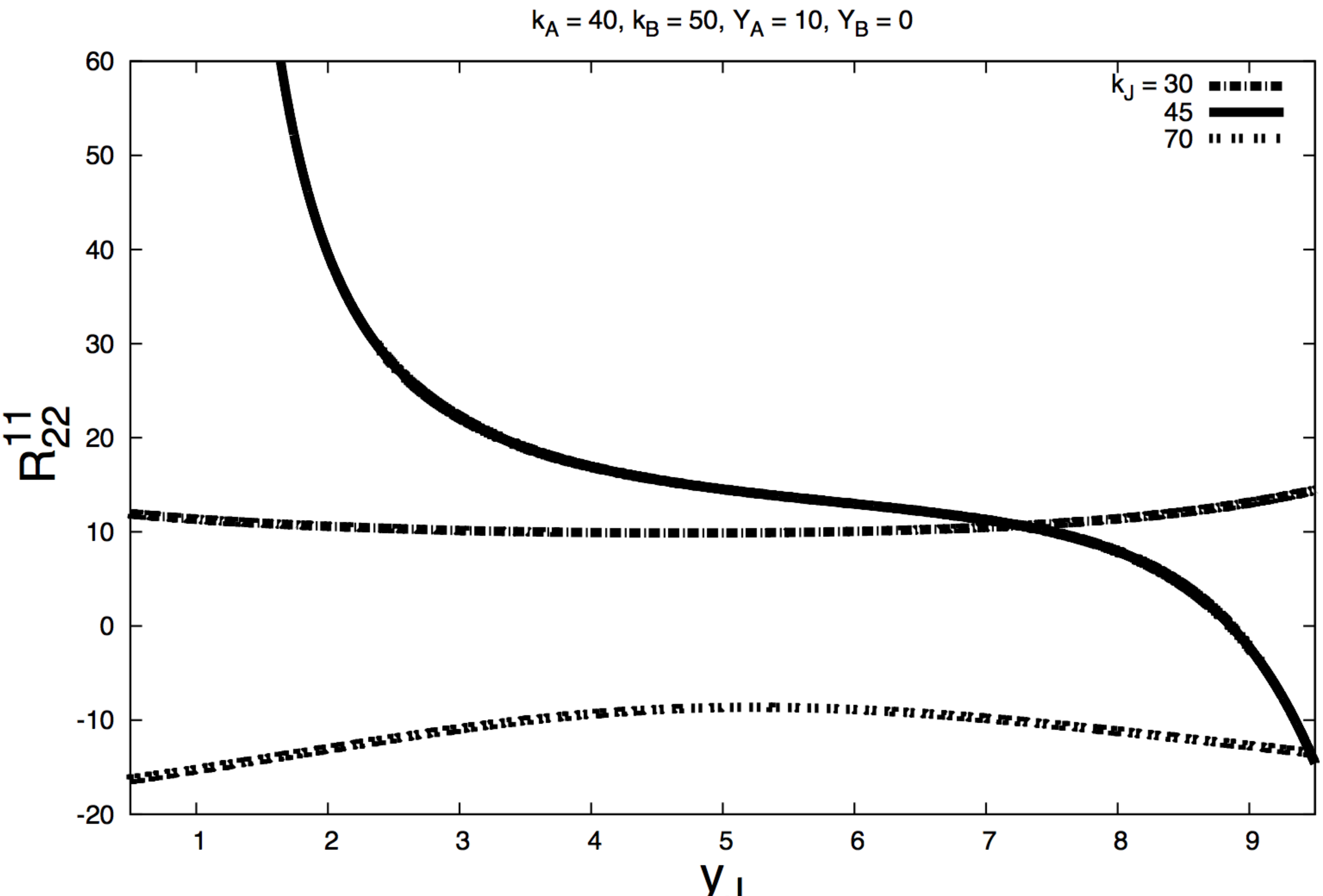
$$\left\langle \cos\left(M\left(\theta_A - \theta_J - \pi\right)\right) \cos\left(N\left(\theta_J - \theta_B - \pi\right)\right)\right\rangle$$

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

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

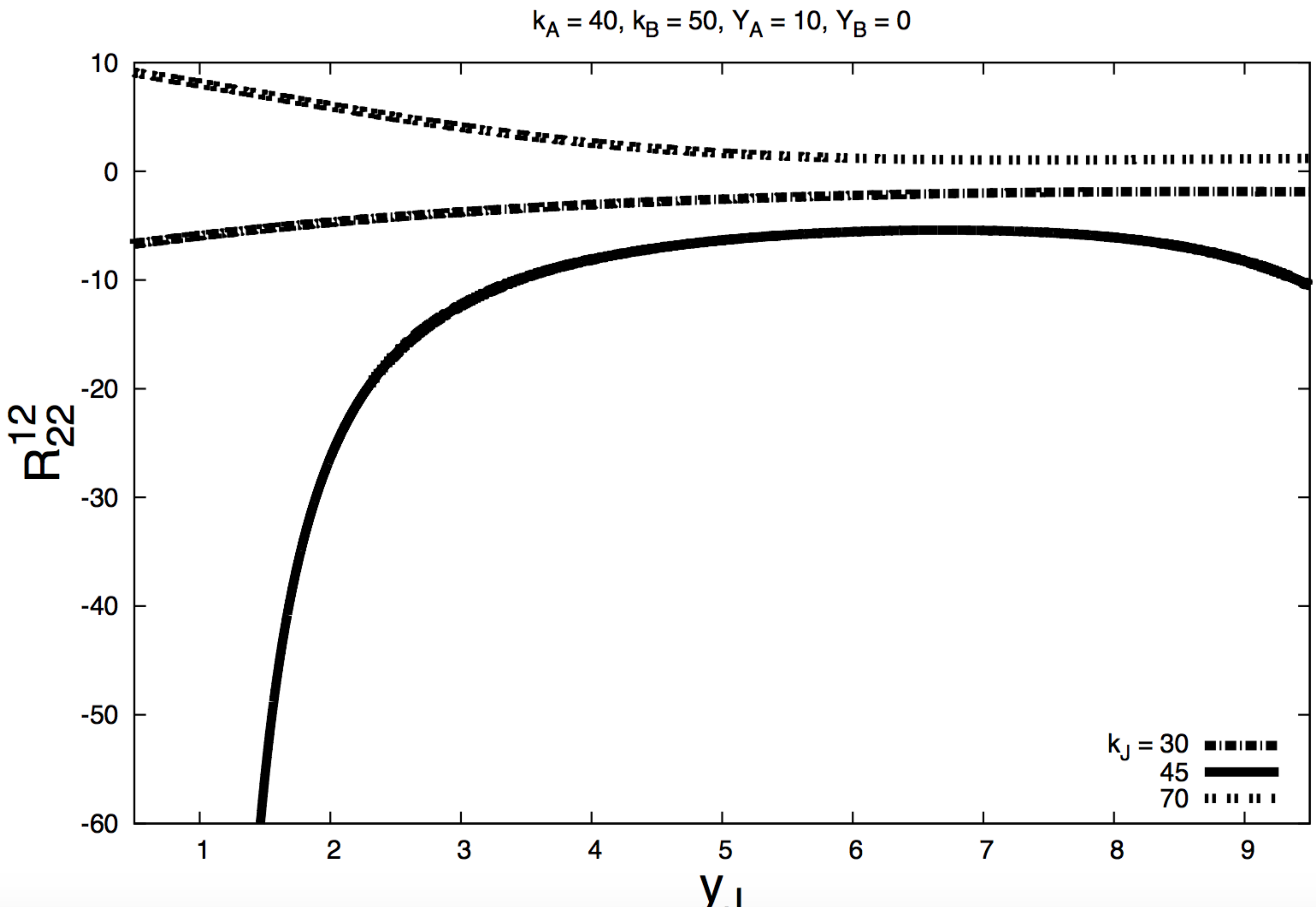
$$\mathcal{R}_{P,Q}^{M,N} = \frac{\langle \cos\left(M\left(\theta_A - \theta_J - \pi\right)\right) \cos\left(N\left(\theta_J - \theta_B - \pi\right)\right)\rangle}{\langle \cos\left(P\left(\theta_A - \theta_J - \pi\right)\right) \cos\left(Q\left(\theta_J - \theta_B - \pi\right)\right)\rangle}$$

R^{11}_{22}

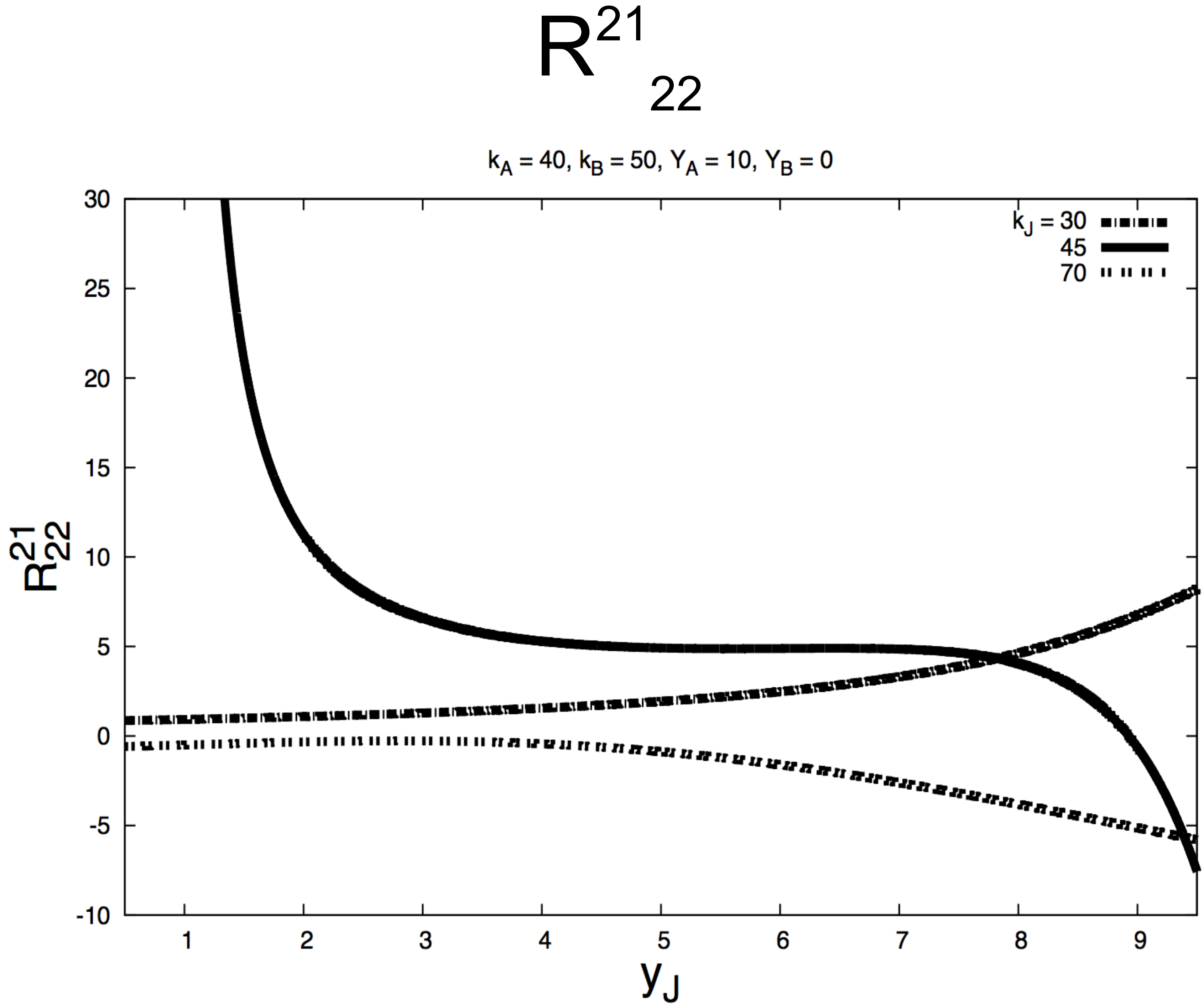


k_A = 40, k_B = 50, Y_A = 10, Y_B = 0
k_J = 30
45
70
R^11_22
y_J
60
50
40
30
20
10
0
-10
-20
1
2
3
4
5
6
7
8
9

R^{12}_{22}



k_A = 40, k_B = 50, Y_A = 10, Y_B = 0
10
0
-10
-20
-30
-40
-50
-60
1
2
3
4
5
6
7
8
9
R^12_22
y_J
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
R^{21}_{22}
y_J
30
25
20
15
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9

Conclusions

- We use three tagged jets to propose new observables with a distinct signal of BFKL dynamics
- We work at LL accuracy (with running coupling) but 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 kA, kB and introduce PDFs
- Comparison with BFKLex results and other Monte Carlo codes is underway