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A new BFKL probe: inclusive three jet production at the LHC

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Outline

- Motivation
- BFKL dynamics at LLA
- Kinematics
- 3-jet production within the BFKL framework
- New observables relevant to 3-jet production
- Conclusions and outlook

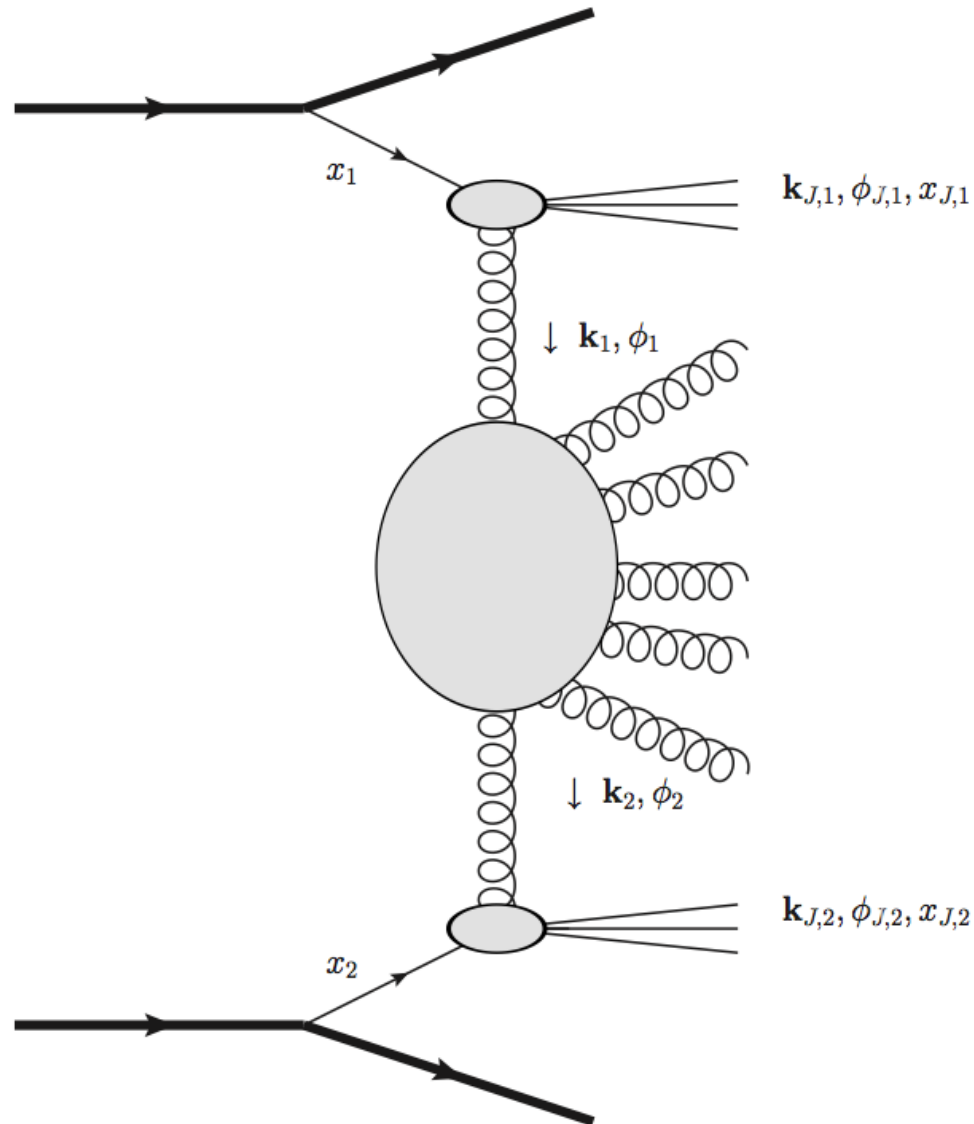
BFKL phenomenology

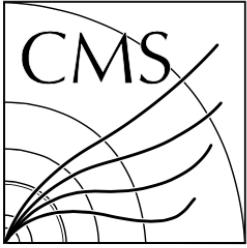
- LHC has produced and will further produce an abundance of data
- This is the best time to investigate the applicability of the BFKL resummation program within the context of a hadron collider
- In the last years: the big hit from the theory/experimental side was the study of Mueller-Navelet jets (dijets). We only touch here one subfield for which BFKL is relevant, small- x physics/forward physics is much richer of course: Diffraction, Saturation, DPI etc.

Brief introduction (LL)

- BFKL formalism: in high energy scattering terms like $\alpha_s^n \log^n(s) \sim \alpha_s^n (y_A - y_B)^n$ need to be resummed.
- $$\sigma(Q_1, Q_2, Y) = \int d^2\vec{k}_A d^2\vec{k}_B \underbrace{\phi_A(Q_1, \vec{k}_A) \phi_B(Q_2, \vec{k}_B)}_{\text{PROCESS-DEPENDENT}} \underbrace{f(\vec{k}_A, \vec{k}_B, Y)}_{\text{UNIVERSAL}}$$
- $\phi_{A,B}(Q_{1,2}, \vec{k}_{A,B})$ are the process-dependent impact factors
- The gluon Green's function $f(\vec{k}_A, \vec{k}_B, Y)$ is universal and depends on the scales $\vec{k}_{A,B}$ and the energy $\sim e^{Y/2}$

Mueller-Navelet jets: azimuthal decorrelation





CERN-PH-EP/2015-309
2016/01/26

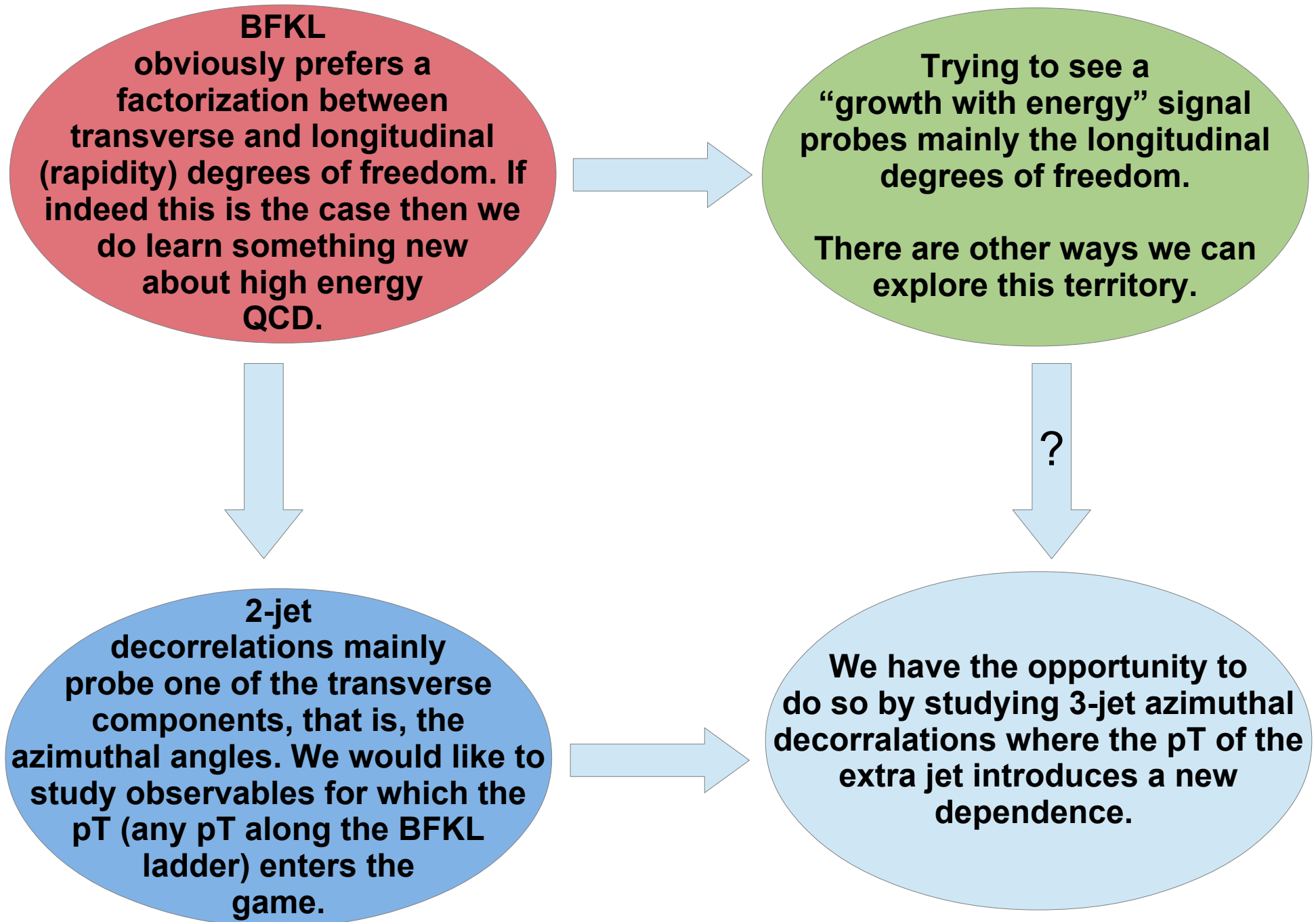
CMS-FSQ-12-002

Azimuthal decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

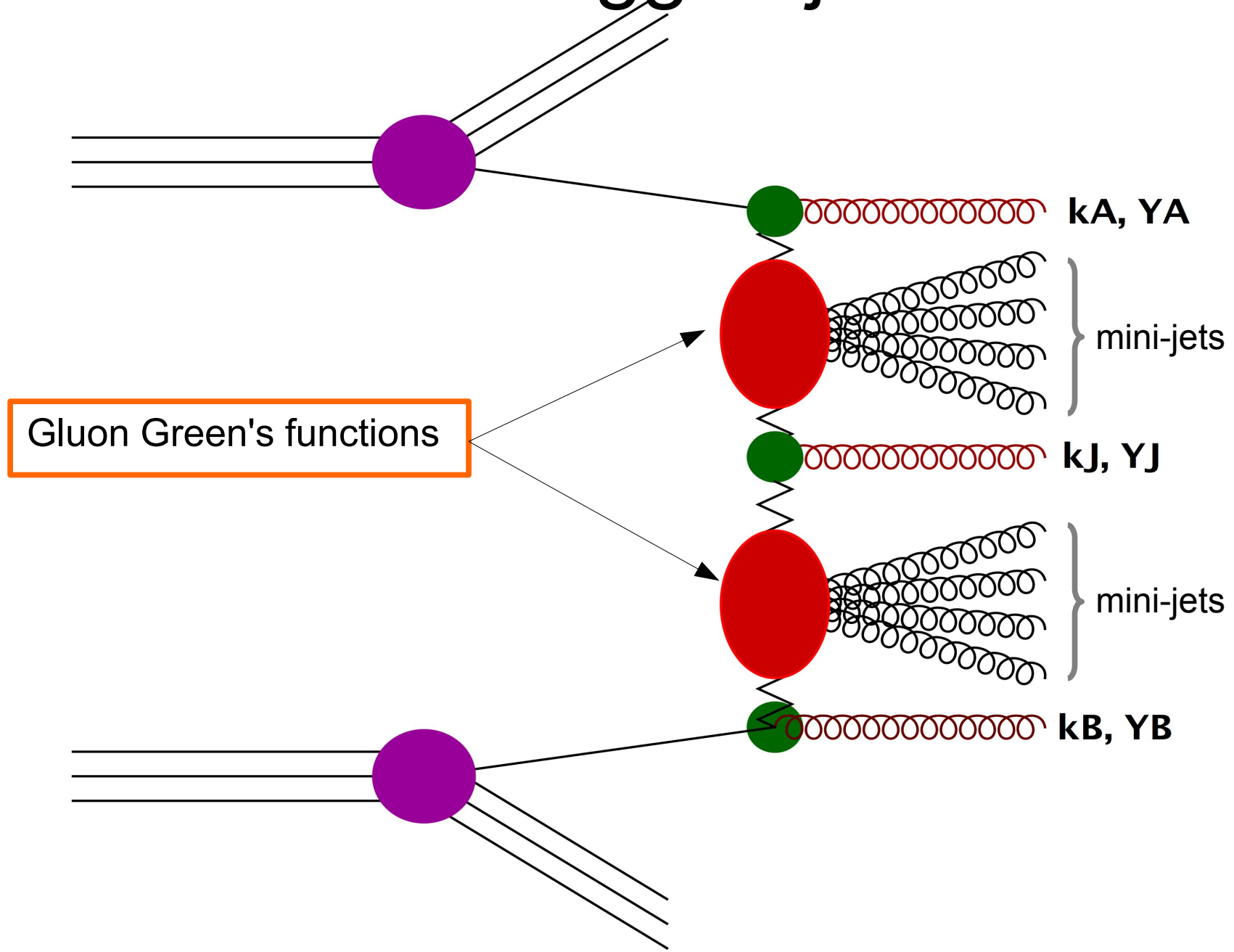
The CMS Collaboration*

... Therein, in the section Conclusions it reads:

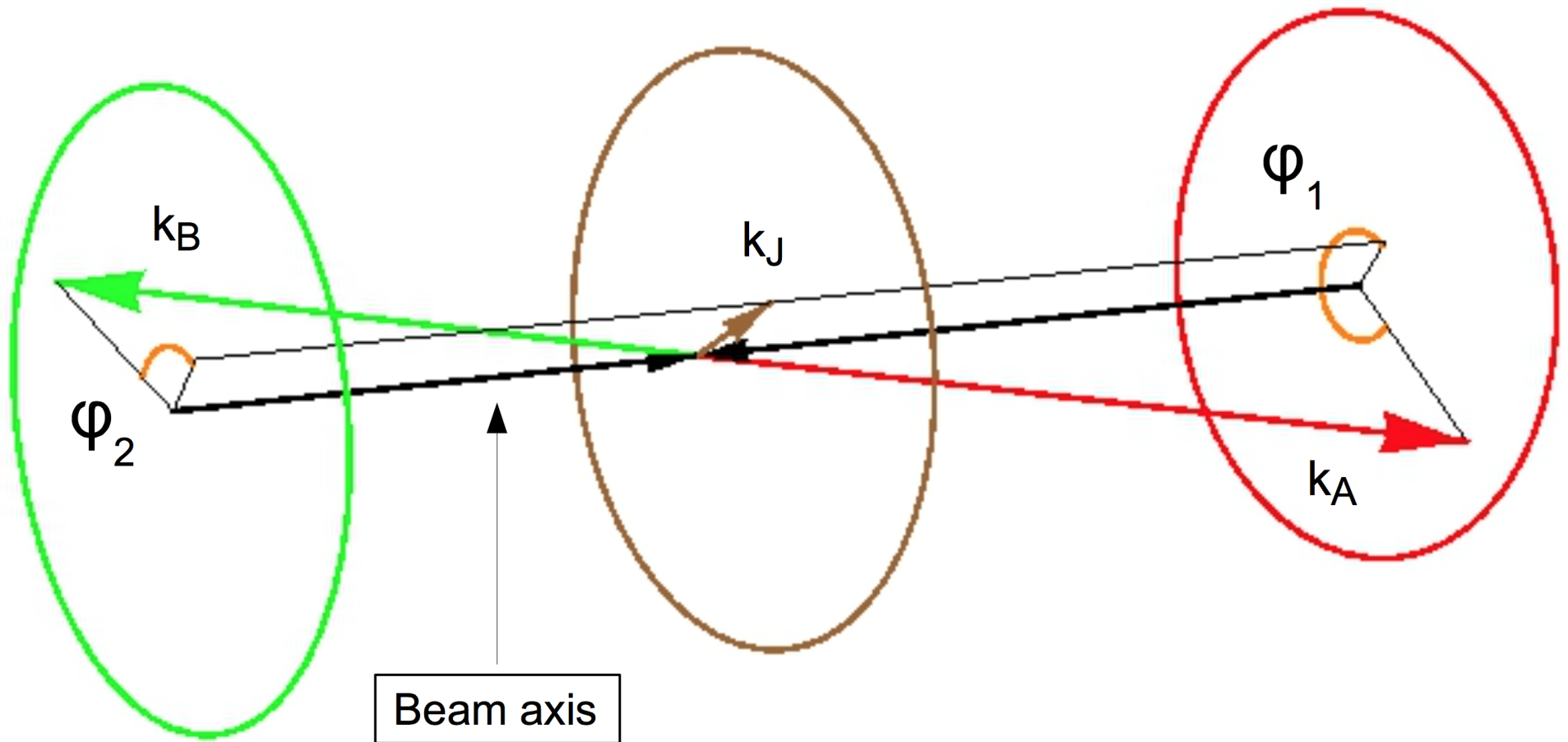
The observed sensitivity to the implementation of the colour-coherence effects in the DGLAP MC generators and the reasonable data-theory agreement shown by the NLL BFKL analytical calculations at large Δy , may be considered as indications that the kinematical domain of the present study lies in between the regions described by the DGLAP and BFKL approaches. Possible manifestations of BFKL signatures are expected to be more pronounced at increasing collision energies.



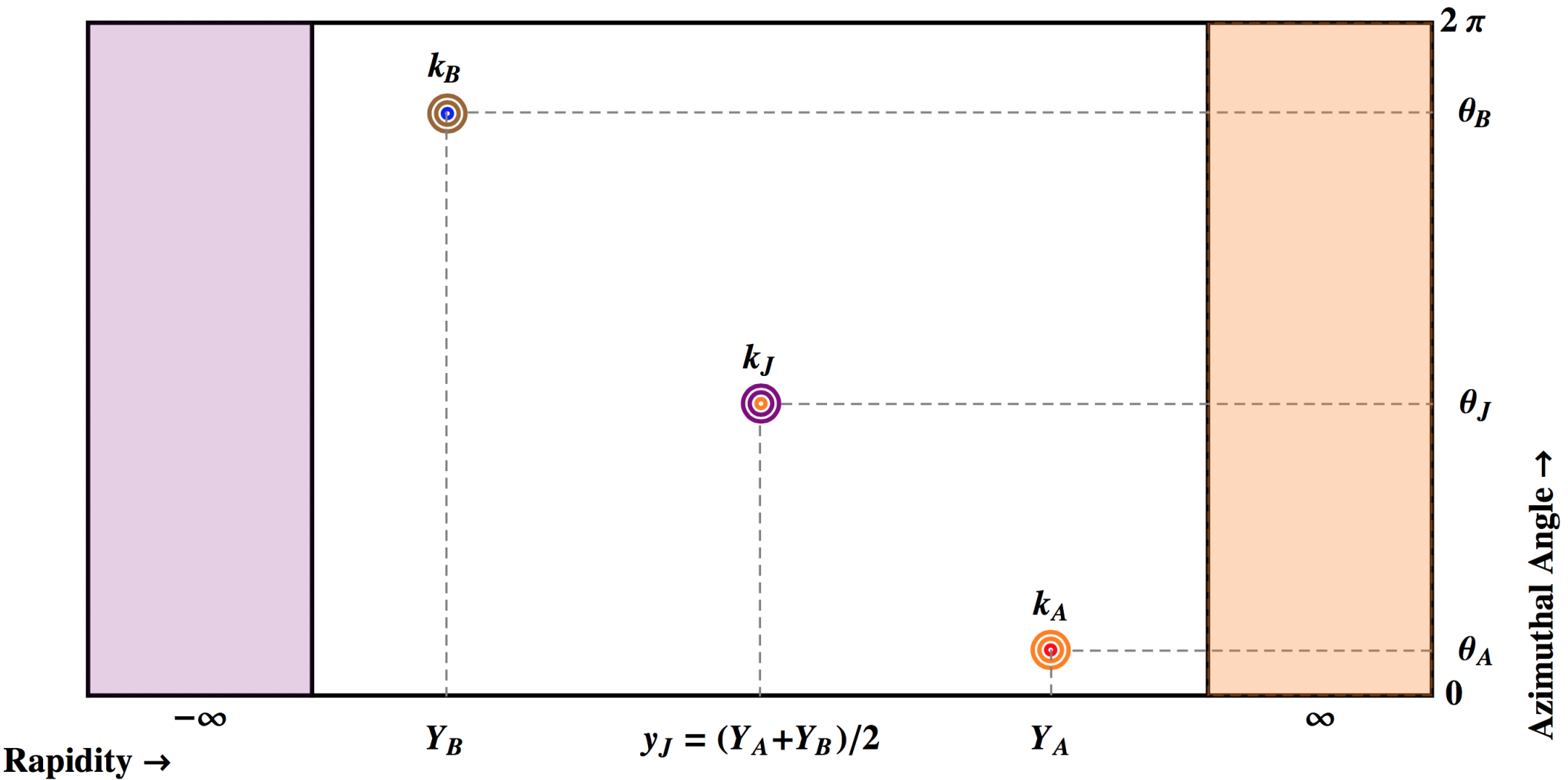
Now, let us move to events with three tagged jets



An event with three tagged jets

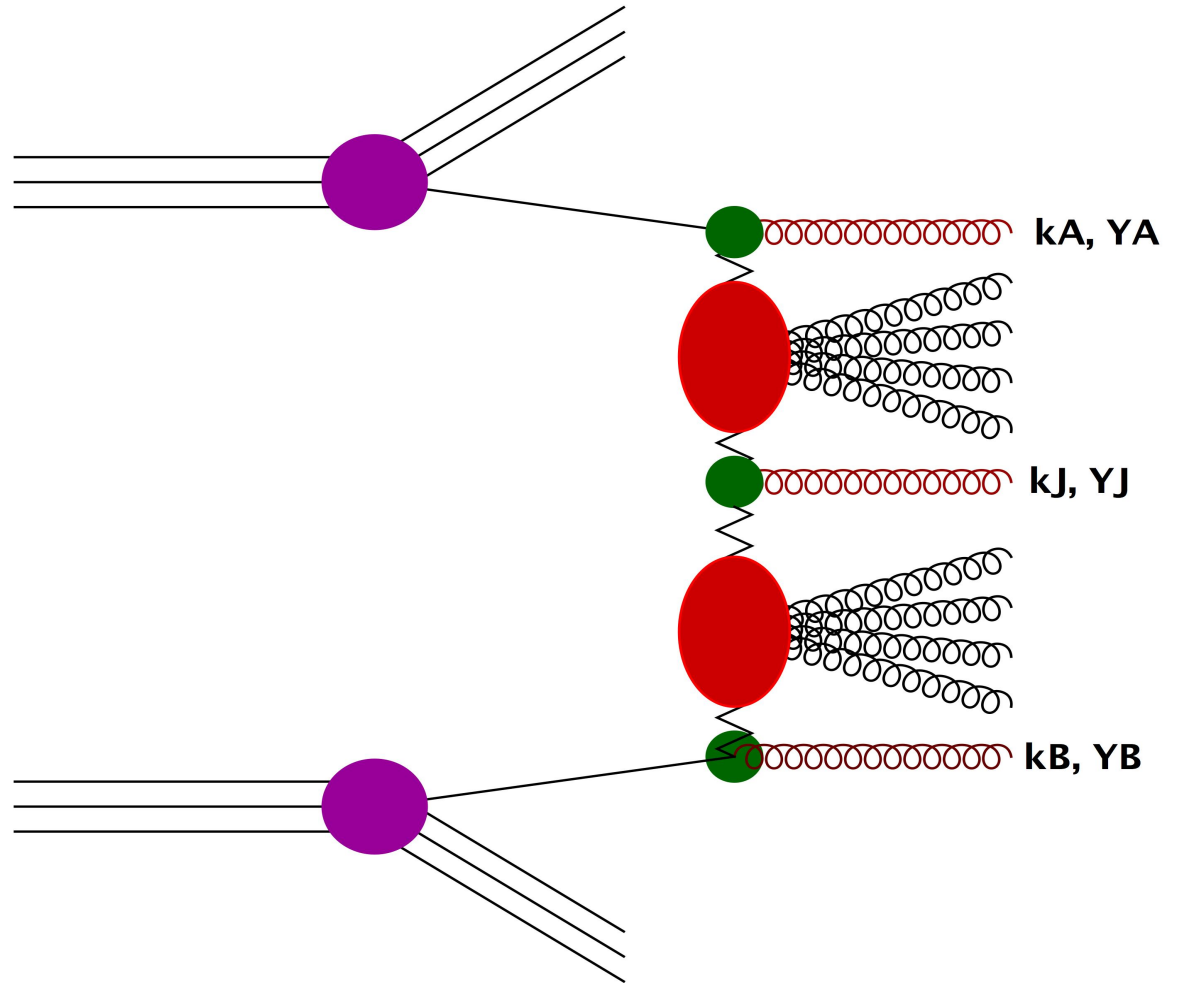


A primitive lego-plot (3-jets)



3-jets partonic cross section

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:



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

Starting point...
THEN:

The main idea 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. We are after “averages of angle differences” between the three jets.

Actually, we are after ratios of “averages of angle differences”

Integrate over all angles after using projections

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

$$\begin{aligned} &\int_0^{2\pi} d\theta_A \int_0^{2\pi} d\theta_B \int_0^{2\pi} d\theta_J \cos(M(\theta_A - \theta_J - \pi)) \\ &\quad \cos(N(\theta_J - \theta_B - \pi)) \frac{d^3\sigma^{3\text{-jet}}}{d^2\vec{k}_J dy_J} \\ &= \bar{\alpha}_s \sum_{L=0}^N \binom{N}{L} (k_J^2)^{\frac{L-1}{2}} \int_0^\infty dp^2 (p^2)^{\frac{N-L}{2}} \\ &\quad \int_0^{2\pi} d\theta \frac{(-1)^{M+N} \cos(M\theta) \cos((N-L)\theta)}{\sqrt{(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2} \cos \theta)}^N} \\ &\quad \times \phi_M(p_A^2, p^2, Y_A - y_J) \phi_N(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2} \cos \theta, p_B^2, y_J - Y_B) \end{aligned}$$

Integrate over all angles after using projections

$$\begin{aligned}
 & \int_0^{2\pi} d\theta_A \int_0^{2\pi} d\theta_B \int_0^{2\pi} d\theta_J \cos(M(\theta_A - \theta_J - \pi)) \\
 & \quad \cos(N(\theta_J - \theta_B - \pi)) \frac{d^3\sigma^{3\text{-jet}}}{d^2\vec{k}_J dy_J} \\
 &= \bar{\alpha}_s \sum_{L=0}^N \binom{N}{L} (k_J^2)^{\frac{L-1}{2}} \int_0^\infty dp^2 (p^2)^{\frac{N-L}{2}} \\
 & \quad \int_0^{2\pi} d\theta \frac{(-1)^{M+N} \cos(M\theta) \cos((N-L)\theta)}{\sqrt{(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2} \cos \theta)}^N} \\
 & \quad \times \phi_M(p_A^2, p^2, Y_A - y_J) \phi_N(p^2 + k_J^2 + 2\sqrt{p^2 k_J^2} \cos \theta, p_B^2, y_J - Y_B)
 \end{aligned}$$

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

... so that you can define new observables:

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

How would an experimentalist measure this*?

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

* Coming from theorists, this would appear to be more of a cooking recipe, apologies to our experimental colleagues in advance for any naivety here.

How would an experimentalist measure this?

1. For 7 (and 8) TeV energies, just pick up the data that were used for Mueller-Navelet studies.
2. From these data, isolate those events that have in addition a very central jet. DO THE SAME FOR 13 TeV.
3. Choose integers M, N, P, Q, e.g. M=1, N=3, P=1, Q=2
4. For each event, measure the azimuthal angle difference between the forward-central jets, $\Delta\theta_1 = (\theta_A - \theta_J - \pi)$, and the backward-central jets, $\Delta\theta_2 = (\theta_J - \theta_B - \pi)$.
5. For each event calculate two quantities:
num = $\text{Cos}(1 * \Delta\theta_1) * \text{Cos}^*(3 * \Delta\theta_2)$ and denom = $\text{Cos}(1 * \Delta\theta_1) * \text{Cos}^*(2 * \Delta\theta_2)$.
6. Calculate the average of num ($\langle \text{num} \rangle$) and denom ($\langle \text{denom} \rangle$) over all the events. Divide $\langle \text{num} \rangle$ over $\langle \text{denom} \rangle$ to have the quantity below:

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

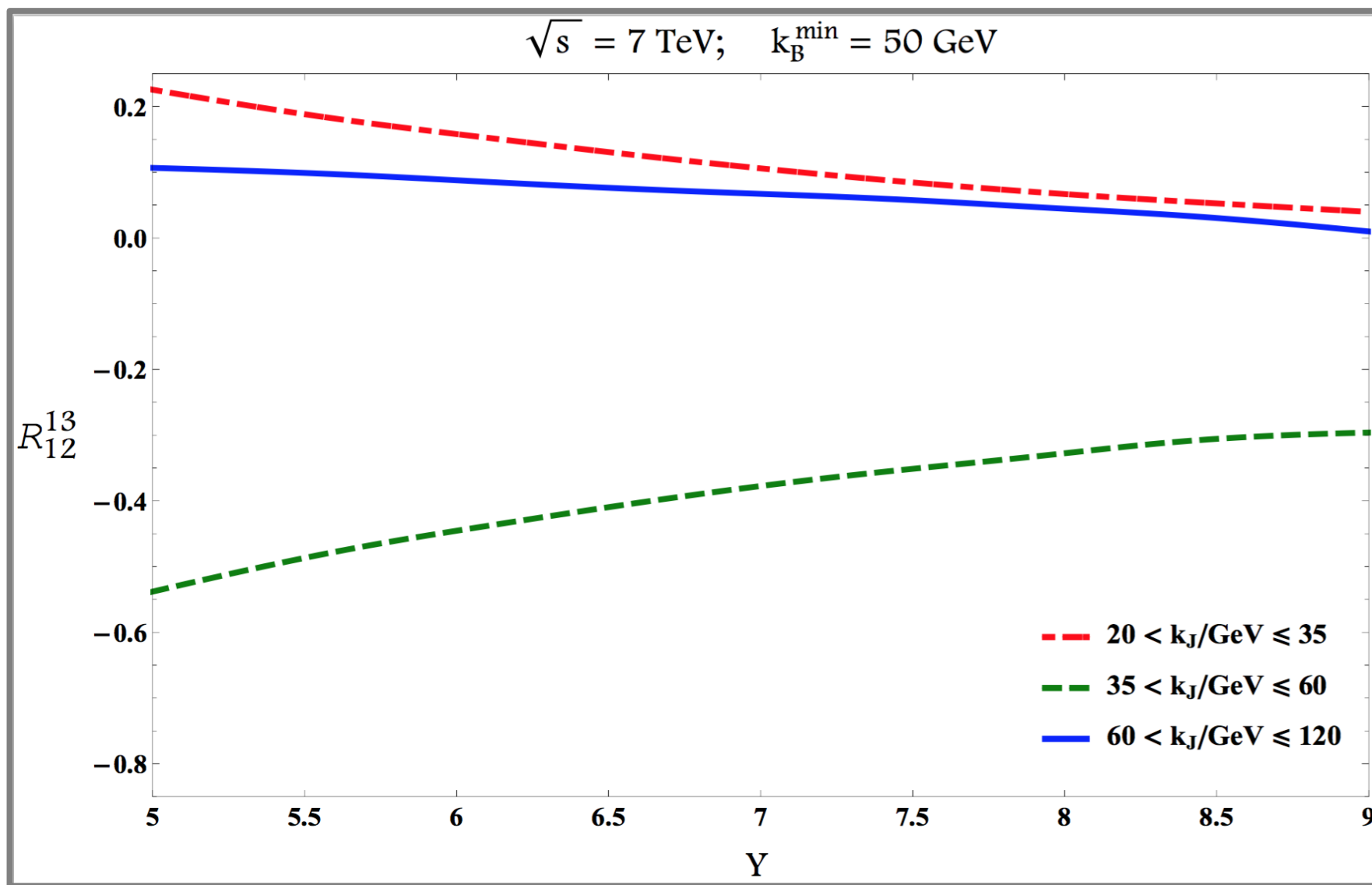
Now introduce PDF's and running of the strong coupling to get theoretical predictions on a hadronic level for various kinematical cuts

We have used two kinematical cuts:

$$k_A^{\min} = 35 \text{ GeV}, k_B^{\min} = 35 \text{ GeV}, k_A^{\max} = k_B^{\max} = 60 \text{ GeV} \text{ (symmetric)}$$

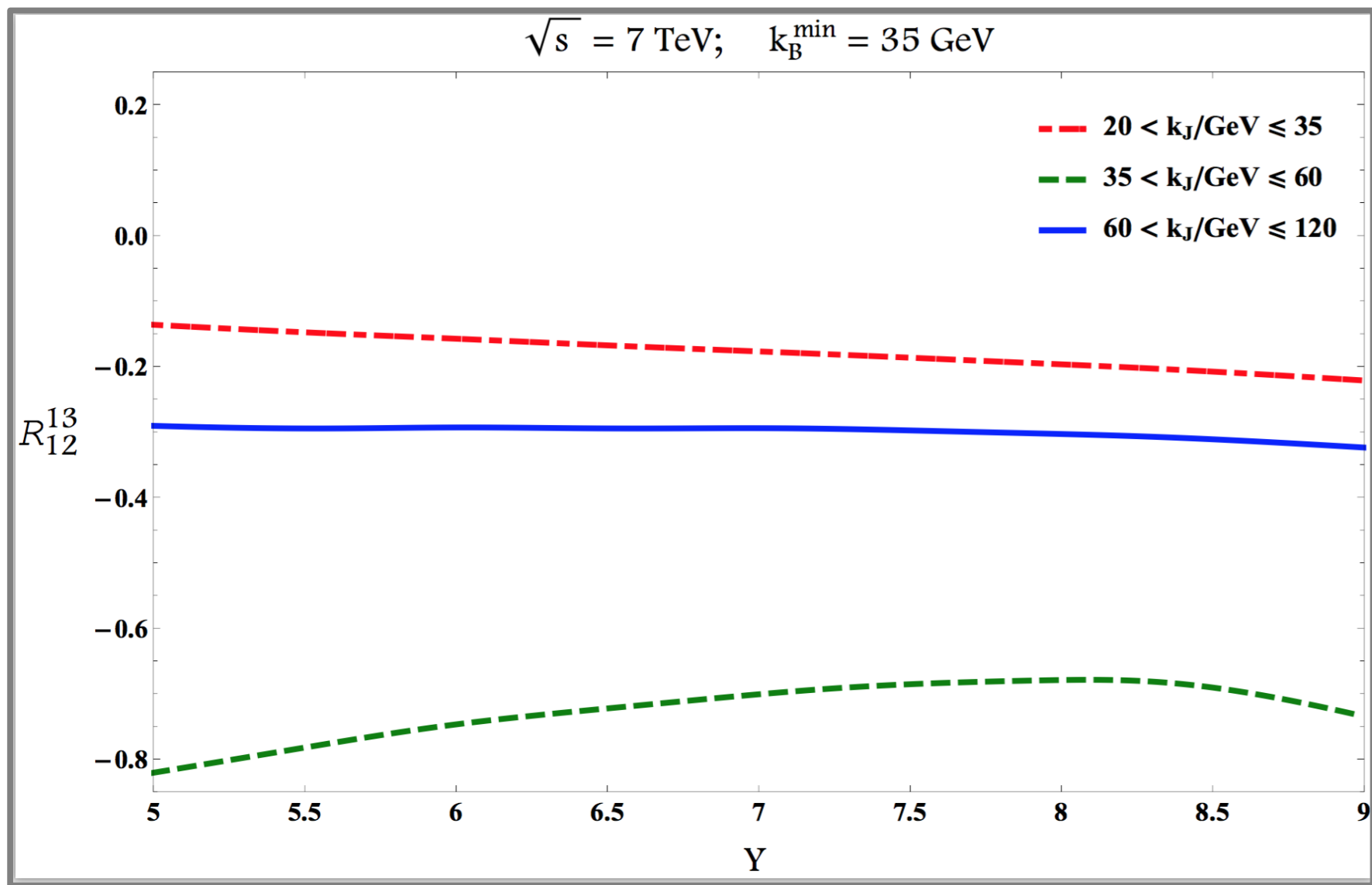
$$k_A^{\min} = 35 \text{ GeV}, k_B^{\min} = 50 \text{ GeV}, k_A^{\max} = k_B^{\max} = 60 \text{ GeV} \text{ (asymmetric)}$$

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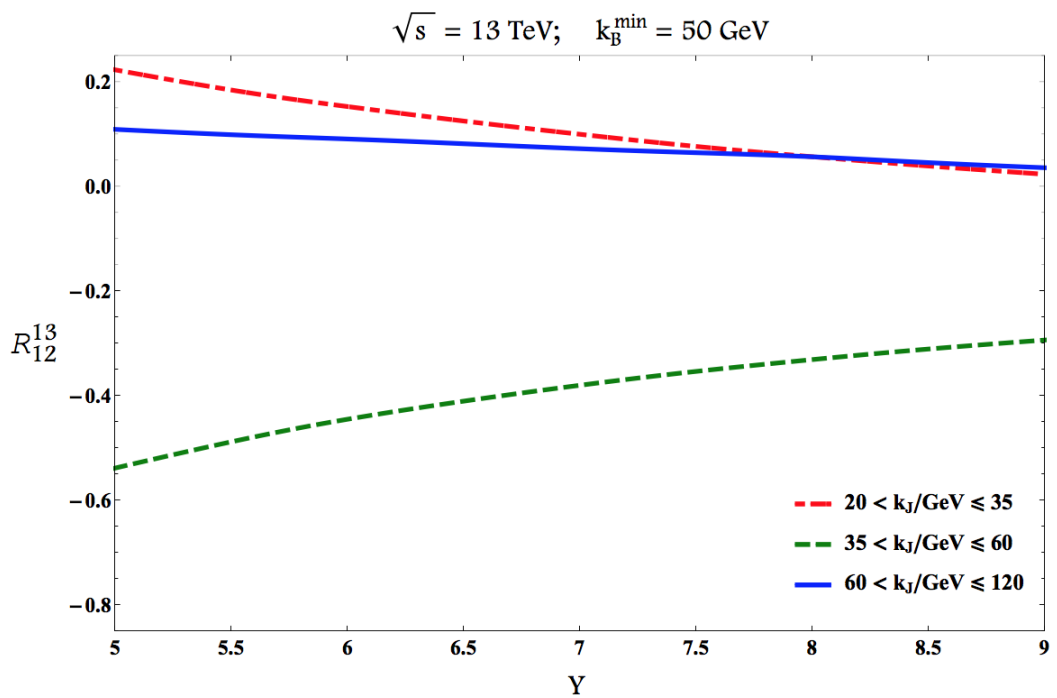
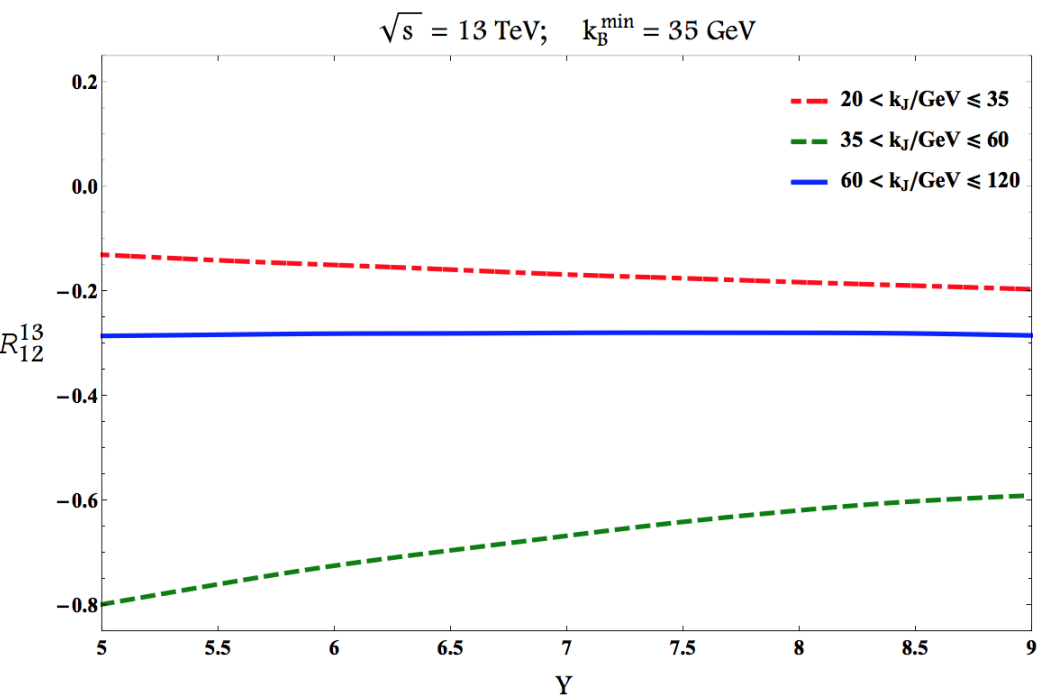
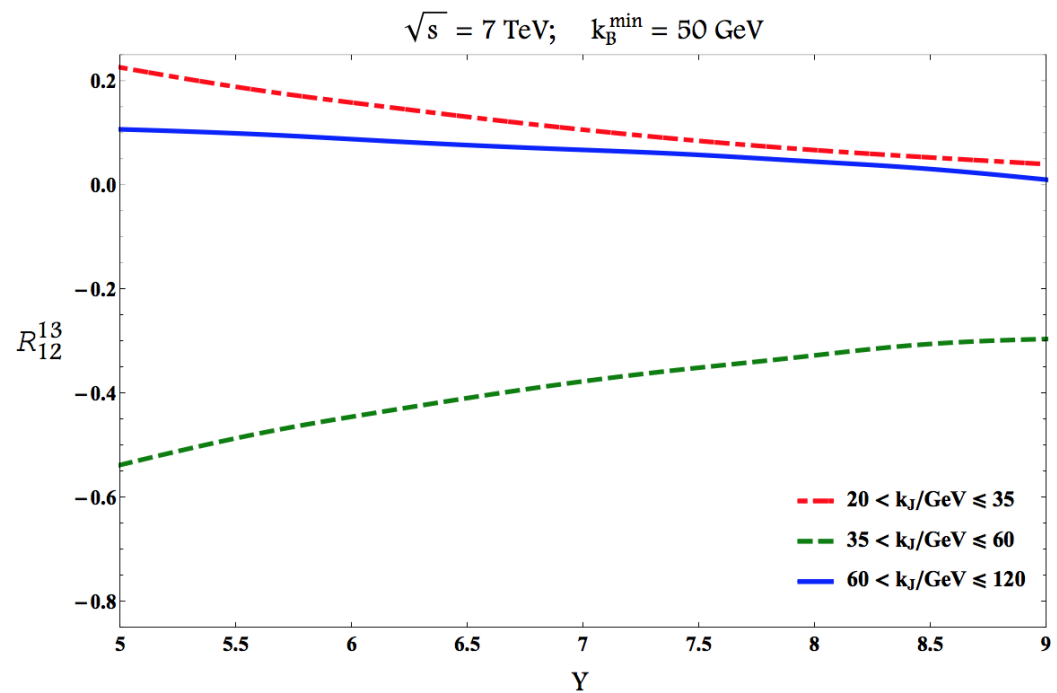
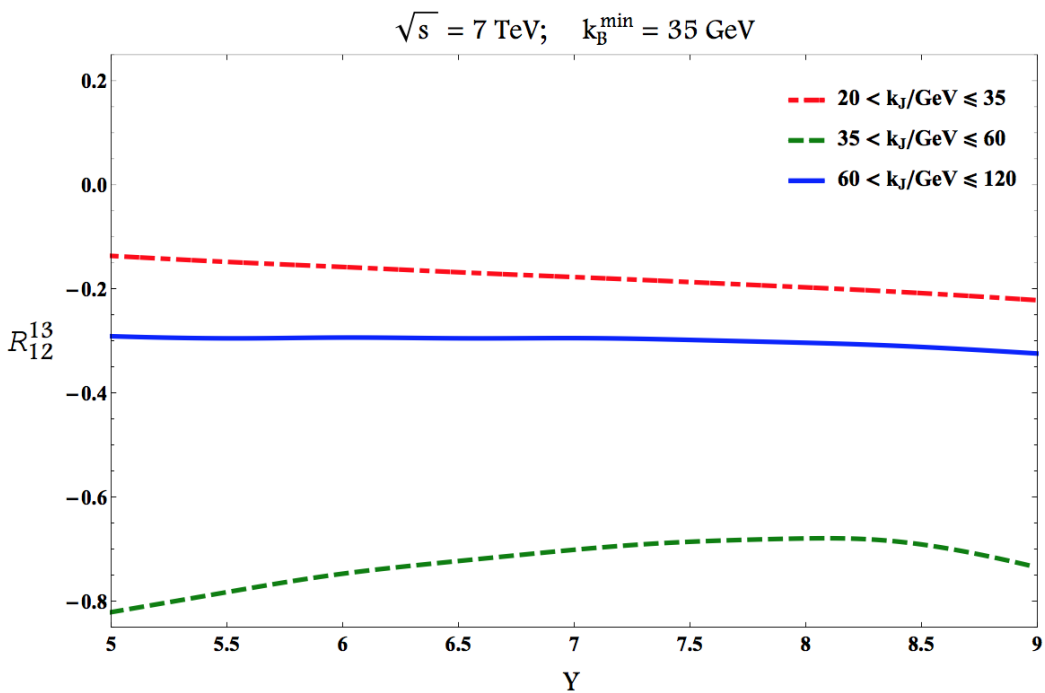


Y is the rapidity difference between the most forward/backward jet

$$k_A^{\min} = 35 \text{ GeV}, k_B^{\min} = 35 \text{ GeV}, k_A^{\max} = k_B^{\max} = 60 \text{ GeV} \text{ (symmetric)}$$



Y is the rapidity difference between the most forward/backward jet

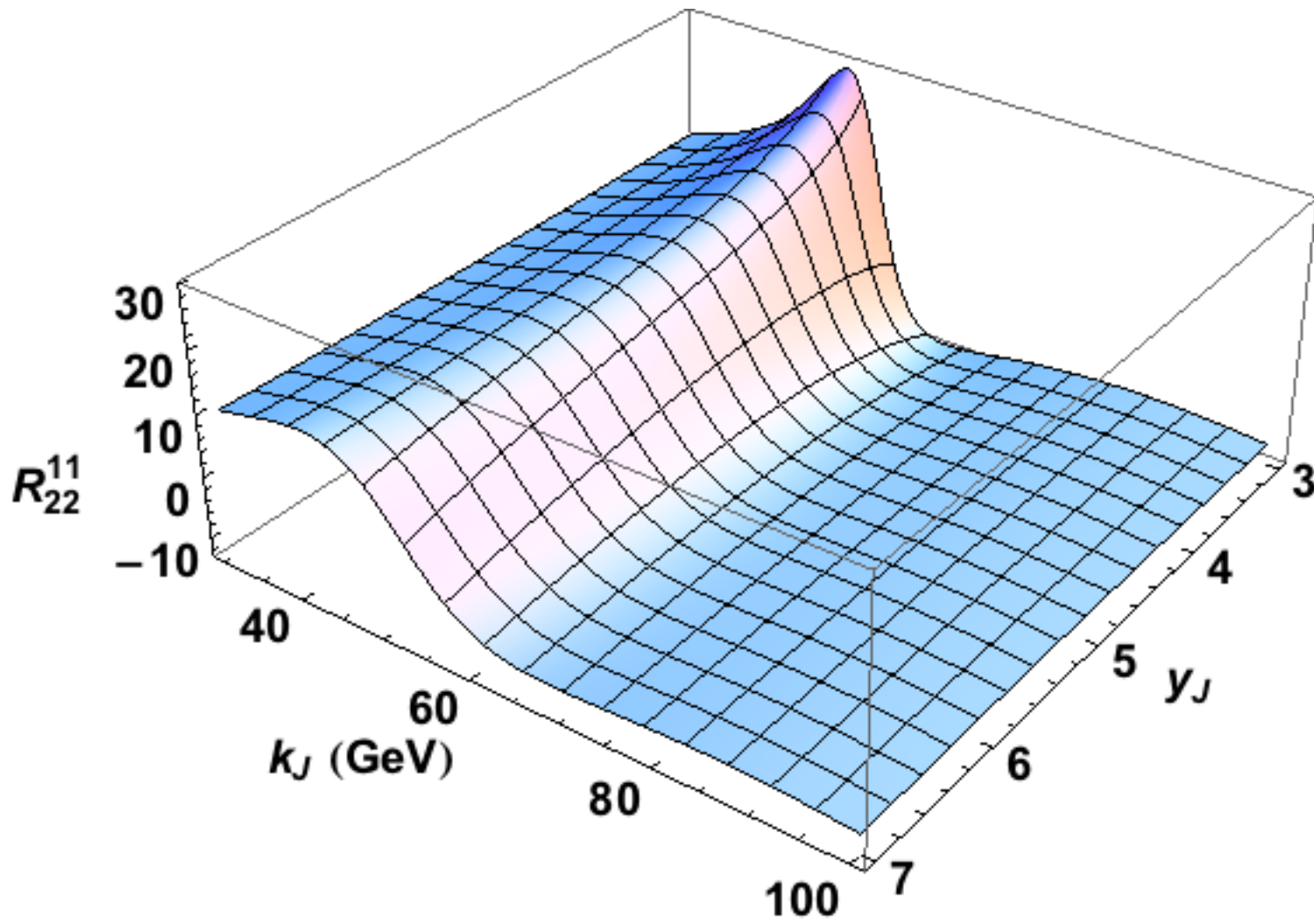


Conclusions & Outlook

- We use events with three tagged jets to propose new observables with a distinct signal of BFKL dynamics.
- We use ratios of correlation functions to minimize the influence of higher order corrections.
- We need to compare against experimental data to see whether these new BFKL probes deliver results that outline the window of applicability of the BFKL framework at the LHC.
- Any new input from the experimental side would be extremely valuable

Backup slides

3D plot for (partonic) R_{22}^{11}



$$k_A = 40 \text{ GeV}, k_B = 50 \text{ GeV}, Y_A = 10, Y_B = 0$$