Rapidity correlations in multiperipheral models and high energy QCD

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in collaboration with
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Outline

- Multiparticle production 50-60 years ago
- The emergence of the so-called multiperipheral models and the concept of clusters in the 60s and 70s
- An important tool that comes from the past: two particle correlations
- How do these old ideas fare in the QCD era and are there useful at all?
- To answer that, go to a certain kinematical limit (multi-Regge kinematics) and use Monte Carlo techniques (**BFKLex**)
- Results

~50 years ago

CORRELATIONS AND MULTIPLICITY DISTRIBUTIONS IN MULTIPARTICLE PRODUCTION

BY M. LE BELLAC

University of Nice*

(Presented at the XIII Cracow School of Theoretical Physics, Zakopane, June 1–12, 1973)

A general discussion of Short Range Order hypothesis and its comparison with experimental data on correlations in inclusive spectra is given.

1. Introduction

In the absence of a theory of strong interactions, one of the main purposes of the present experiments on multiparticle production is to discover empirical regularities in the experimental data, in the hope that these regularities will be useful later for a more fundamental understanding of hadrodynamics. Some of these empirical regularities have

Chew, G. F., 'Multiperipheralism and the Bootstrap,' Comments on Nuclear and Particle Physics 2 (1968), 163–168.

Multiperipheralism and the Bootstrap

The adjective "peripheral", when applied to hadronic reactions, characterizes a correlation between large angular-momentum values that produces a smooth and persistent momentum-transfer dependence favoring small angles. The best-known example is the so called "forward diffraction peak" in elastic scattering, but almost all two-hadron reactions have exhibited similar forward peaking, with widths in momentum transfer that change only slowly with energy. The widths vary from one reaction to another but usually are well below 0.5 GeV. Although "peripheralism" at first sight may seem an unsurprising phenomenon, close study has revealed profound theoretical implications that touch on the very origin of the hadrons. One crucial inference is that multiple-production reactions should be "multiply-peripheral". This note proposes briefly to survey multiperipheralism, together with the related hypothesis of multi-Regge-poles. It will be seen that a new class of bootstrap constraints is implied.

Sergio Fubini
Comments Nucl.Part.Phys. 4 (1970) 3, 102-106

Multiperipheral Model

Work in the multiperipheral model was started almost ten years ago. It is pleasant to realize that the model in its different forms retains the attention of many physicists and that some of its general predictions seem to be in good agreement with experiment.[1]

Although a detailed study of the model requires a rather involved mathematical apparatus, most of the main results can be understood in a simple intuitive way.

The multiperipheral model is based on the idea that multiple production at high energy is dominated by the graphs shown in Fig. 1.

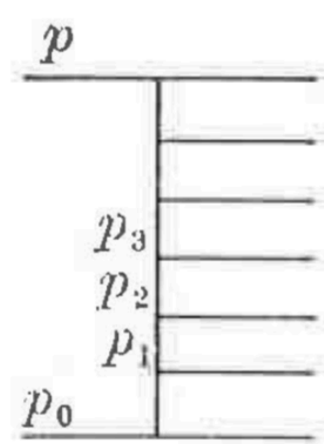


FIGURE 1

The different versions of the model differ in the choice of what object (particle, Regge poles $\cdots$) corresponds to the peripheral lines of momentum $p_1, p_2 \cdots$.

Notion of Clusters (70s)

Progress of Theoretical Physics, Vol. 53, No. 3, March 1975

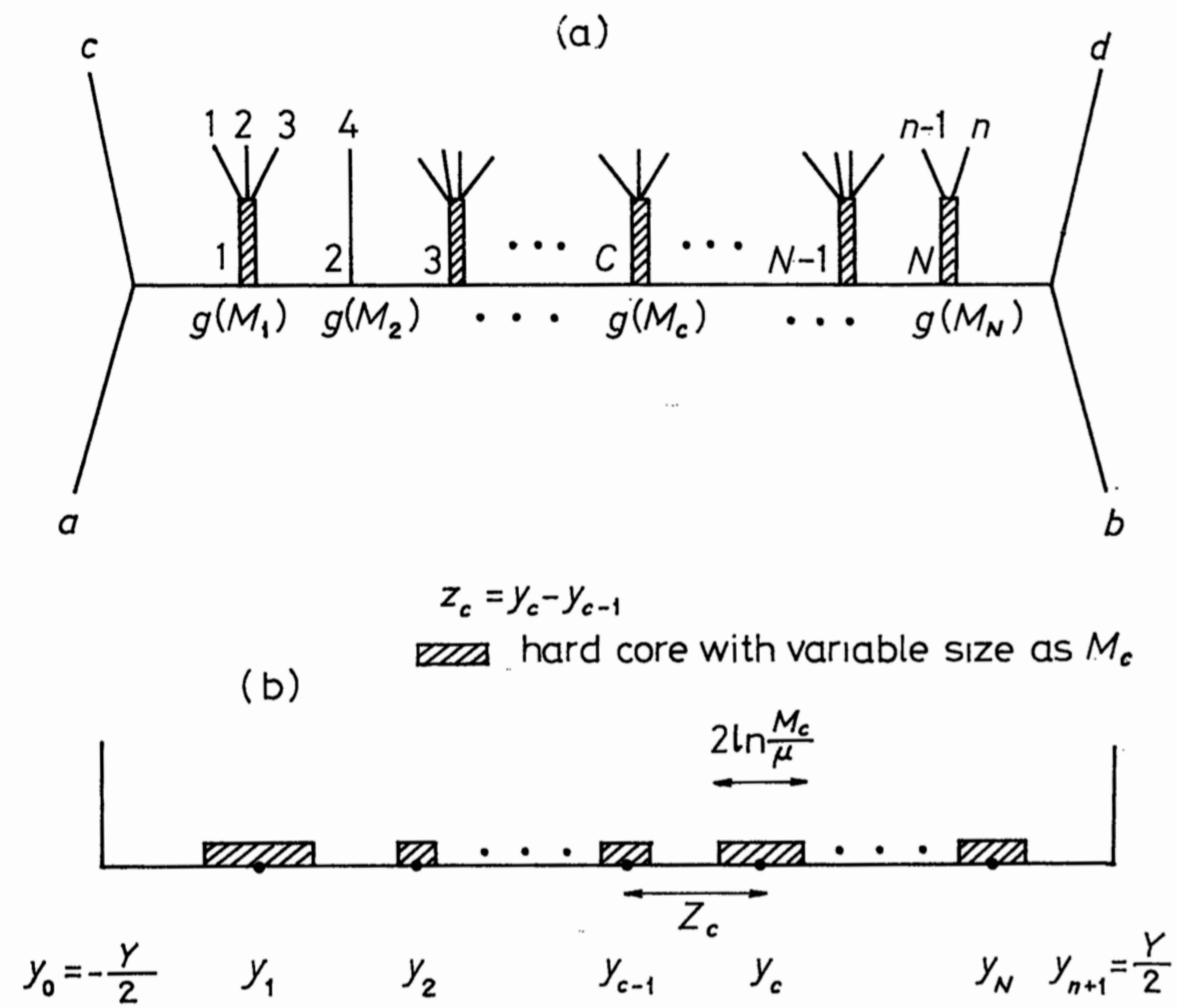


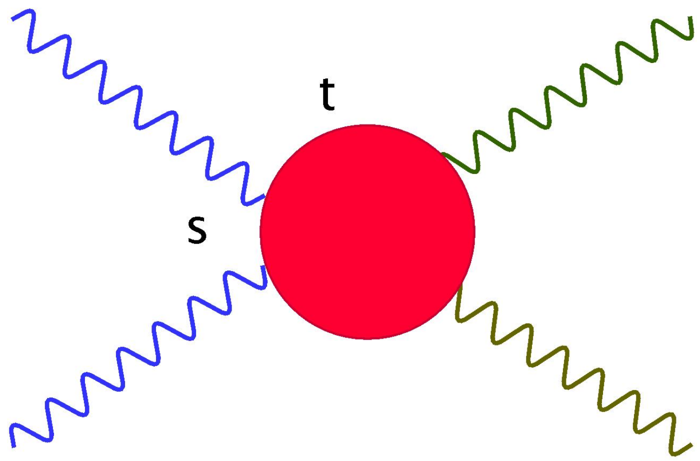
Fig. 1 (a) Multiperipheral chain of our cluster emission model. (b) Rapidity space configuration of clusters with variable mass M_c. Each cluster has a hard core of length $2\ \ln(M_c/\mu)$.

High energy scattering at hadron colliders

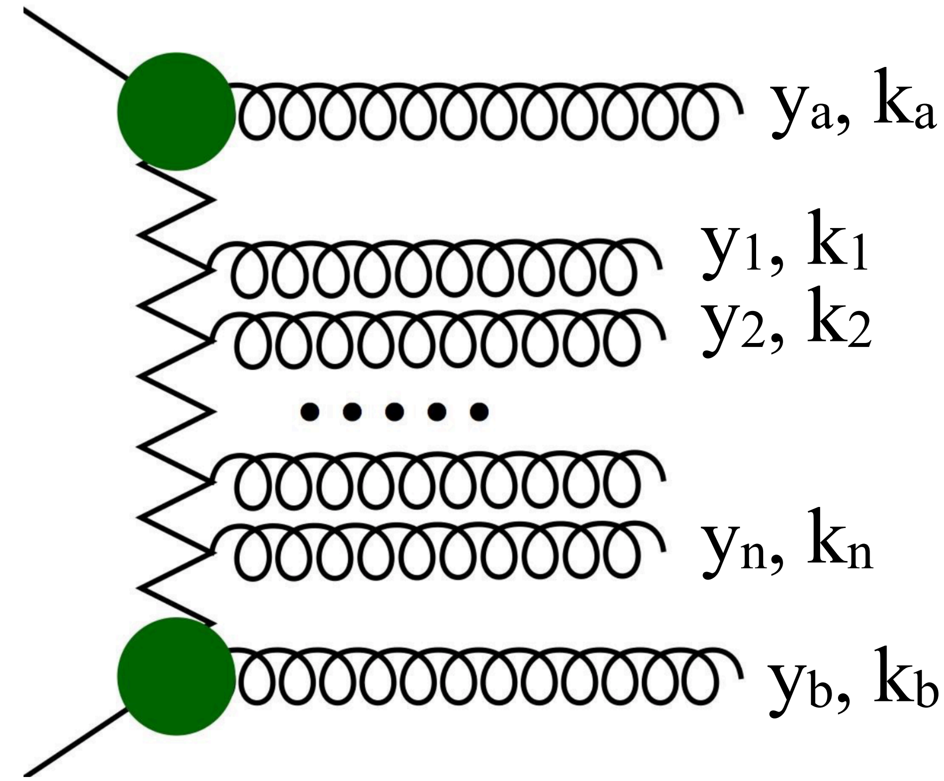
- The first hadron collider was the 1-km-circumference proton–proton (pp) **Intersecting Storage Rings (ISR)**,1 commissioned at CERN in 1971. Its beam energies ranged from 12 to 31 GeV. Experiments at the ISR revealed the logarithmic rise of the pp total scattering cross section at energies where it was expected to have levelled off.
- Ten years later, CERN's **Super Proton Synchrotron (SPS)**, until then a fixed-target accelerator, became the **SppS**, a proton–antiproton collider with Ecm up to 630 GeV. By the end of 1983, the collaborations that ran the large UA1 and UA2 detectors at the collider's beam-crossing points had **discovered the heavy W± and Z0** bosons that mediate the weak interactions
- Next, Fermilab's pp **Tevatron** collider had a Ecm of 1.8 TeV; eventually it reached 2 TeV. **1995 top quark discovery**
- Currently: **LHC** era

https://physicstoday.scitation.org/doi/10.1063/PT.3.2010

The high energy or *Regge* limit



$$\boxed{s \gg -t \gg m^2}$$



$$y_b \ll y_n \ll \cdots \ll y_2 \ll y_1 \ll y_a$$

$$|k_{b\perp}| \simeq |k_{n\perp}| \simeq \cdots \simeq |k_{2\perp}| \simeq |k_{1\perp}| \simeq |k_{a\perp}|$$

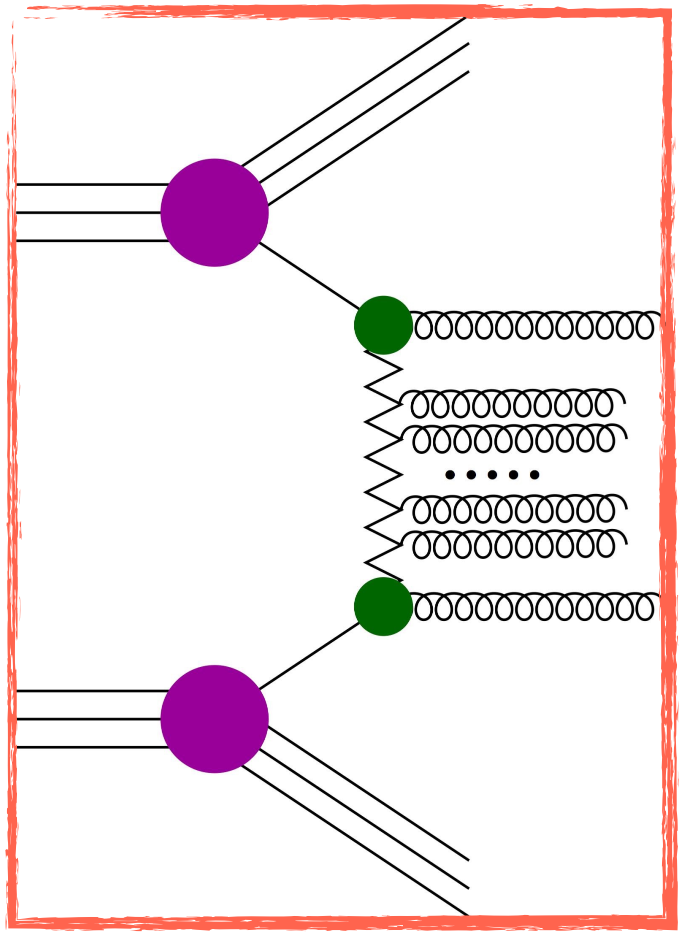
n+2 particle production in multi-Regge kinematics:

- strong ordering in rapidity
- similar transverse momenta
- Use *Balitsky-Fadin-Kuraev-Lipatov* (BFKL) dynamics. BFKL resums to all orders diagrams that carry **large logarithms** in energy.

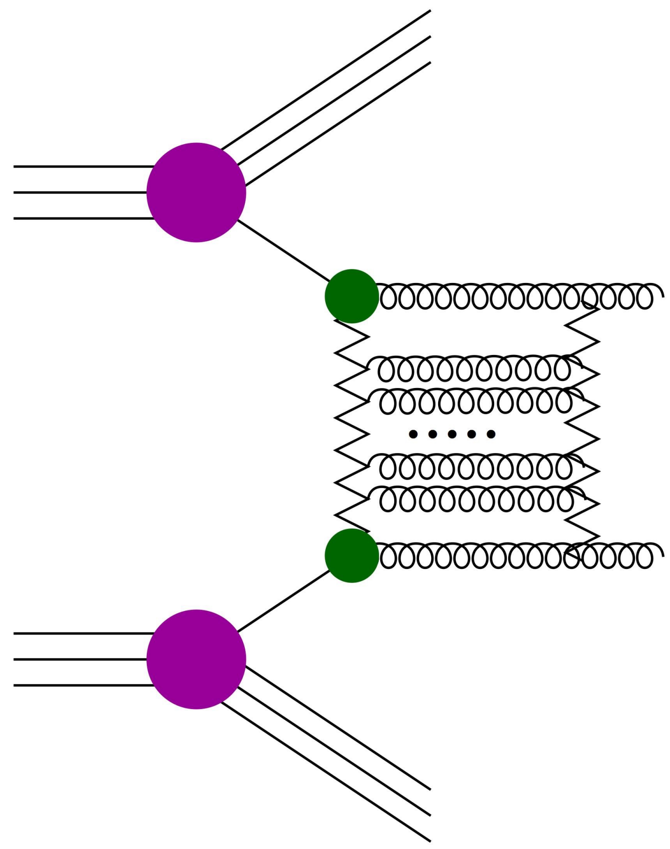
High energy scattering QCD

multi-Regge kinematics at colliders

Mueller-Navelet jets



rapidity gaps



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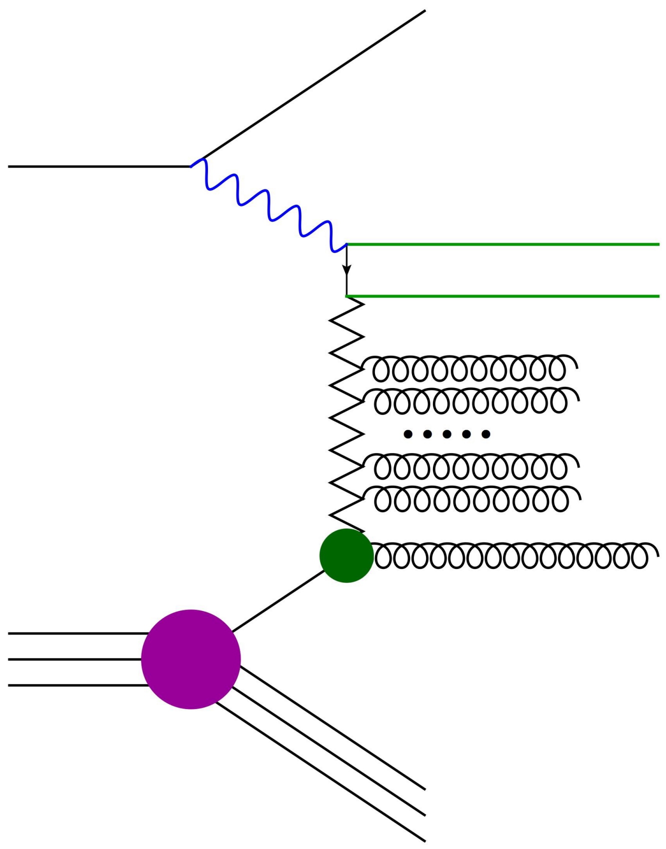


Multiperipheral models vs perturbative QCD

- The key idea is to **use** an old multiperipheral model, namely the **Chew-Pignotti model** (*Phys.Rev. 176 ,1968*) as used by DeTar (*Phys. Rev. D, 3 1971*) for **multi-jet final states at the LHC** assuming that the **jet multiplicity is fixed** and rather large and the total rapidity interval is large (similar to Mueller-Navelet jets).
- By jets in this context we really mean final state gluons before parton shower and before hadronization
- Produce **jet rapidity distributions** and **jet-jet rapidity correlations**
- We then want to produce the same distributions with **BFKLex** and compare the two approaches

  A first comparison can be found in

  Nucl.Phys.B 971 (2021) 115518, N. Bethencourt de León, GC and A. Sabio Vera

BFKLex

- A Monte Carlo code for the iterative solution of the BFKL equation
- The big advantage of a MC code is that differential information regarding the rapidities and momenta of the final state gluons can be booked and differential distributions for a large number of observables can be produced.
- Already, BFKLex was used to propose new observables in order to search for BFKL related effects at the LHC.
- We can run the code to compute the gluon Green's function omitting the bounding jets, PDFs, impact factors etc. (partonic level)
- We can run the code including all the omissions of the previous step (full-run)

Definition of the two-particle rapidity-rapidity correlation function

$$C_2(y_1, p_{\perp 1}, y_2, p_{\perp 2}) = \frac{1}{\sigma_{in}} \frac{d^6\sigma}{dy_1 d^2p_{\perp 1} dy_2 d^2p_{\perp 2}} - \frac{1}{\sigma_{in}^2} \frac{d^3\sigma}{dy_1 d^2p_{\perp 1}} \frac{d^3\sigma}{dy_2 d^2p_{\perp 2}}$$

We integrate over p_T

$$\rho_1(y) = \frac{1}{\sigma_{in}} \int d^2p_\perp \frac{d^3\sigma}{dy d^2p_\perp}$$

$$\rho_2(y_1, y_2) = \frac{1}{\sigma_{in}} \int d^2p_{\perp 1} d^2p_{\perp 2} \frac{d^6\sigma}{dy_1 d^2p_{\perp 1} dy_2 d^2p_{\perp 2}}$$

to get:

$$C_2(y_1, y_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma}{dy_1 dy_2} - \frac{1}{\sigma_{in}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2} \equiv \rho_2(y_1, y_2) - \rho_1(y_1)\rho_1(y_2)$$

$$R_2(y_1, y_2) = \frac{C_2(y_1, y_2)}{\rho_1(y_1)\rho_1(y_2)} = \frac{\rho_2(y_1, y_2)}{\rho_1(y_1)\rho_1(y_2)} - 1$$

Signal

Background

Rapidity distributions in the Chew-Pignotti model

Single differential distribution

$$\boxed{\frac{d\sigma^{(l)}_{N+2}}{dy_l} = \alpha^{N+2}\frac{\left(\frac{Y}{2}-y_l\right)^{N-l}}{(N-l)!}\frac{\left(y_l+\frac{Y}{2}\right)^{l-1}}{(l-1)!}}$$

Double differential distribution

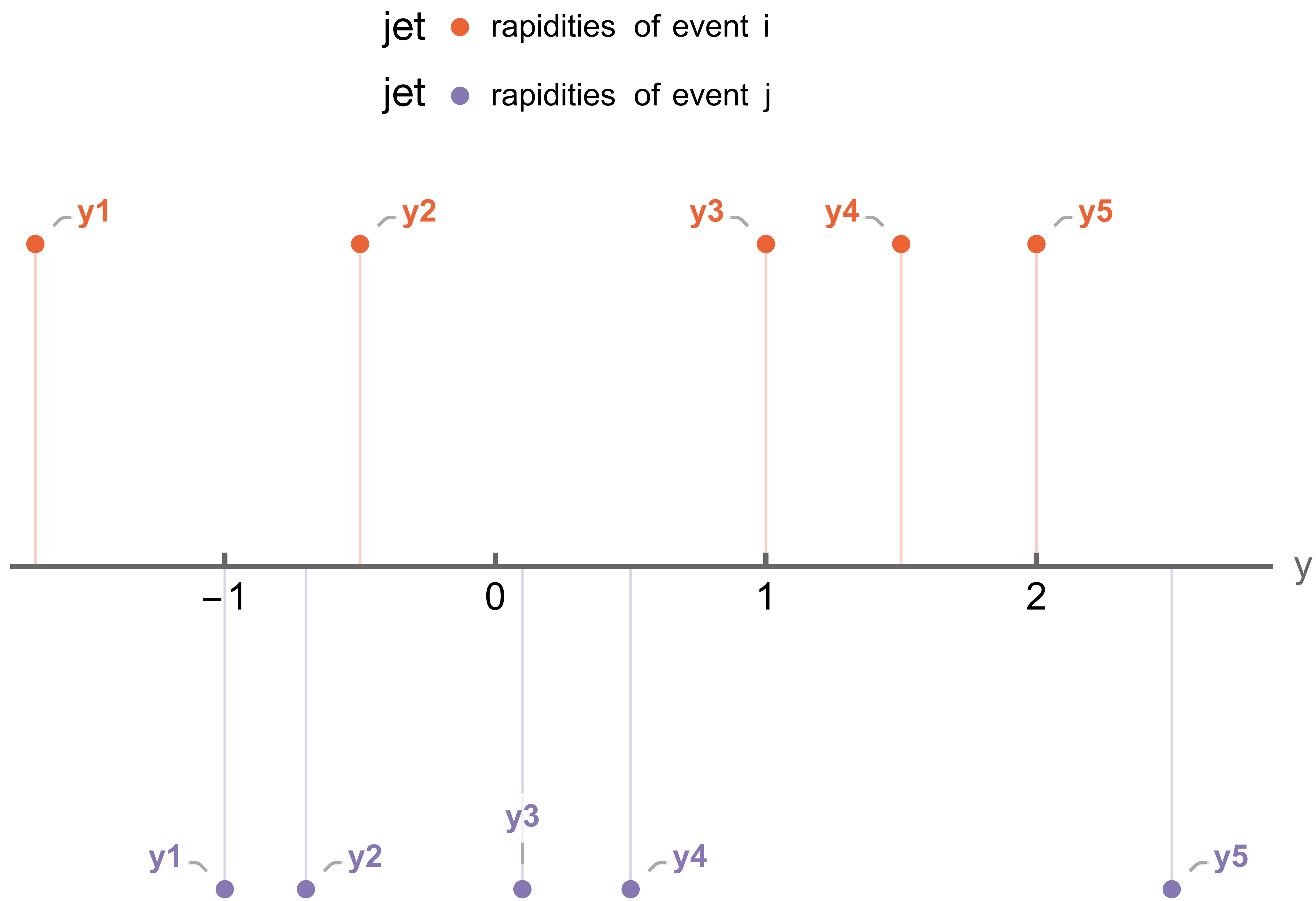
$$\boxed{\frac{d^2\sigma^{(l,m)}_{N+2}}{dy_l dy_m} = \alpha^{N+2}\frac{\left(\frac{Y}{2}-y_l\right)^{N-l}}{(N-l)!}\frac{(y_l-y_m)^{l-m-1}}{(l-m-1)!}\frac{\left(y_m+\frac{Y}{2}\right)^{m-1}}{(m-1)!}}$$

- The key point in the Chew-Pignotti model is that longitudinal and transverse degrees of freedom decouple.
- One of the standard ways to show double differential distributions and correlation functions is with contour plots

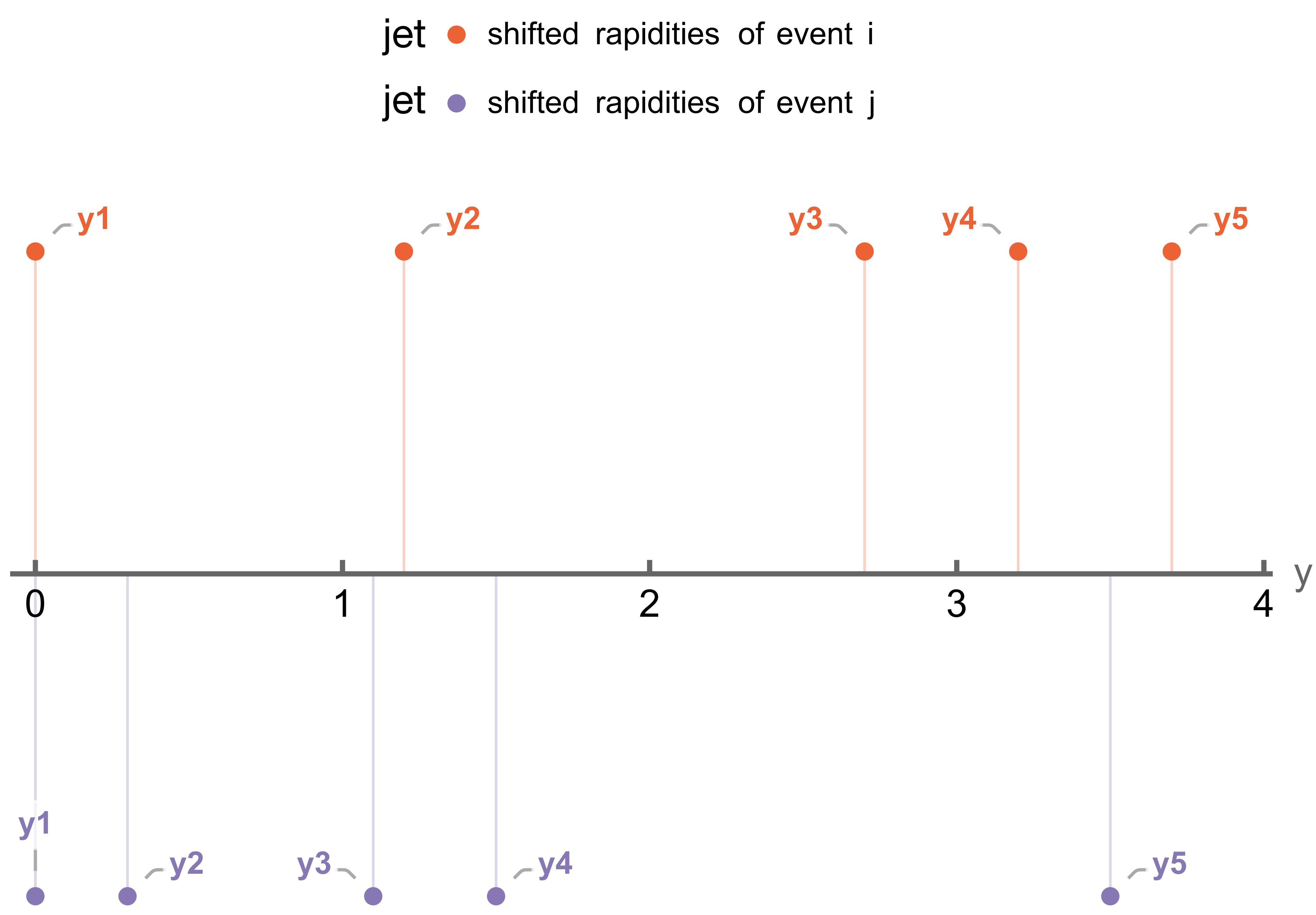
Kinematics

- Consider events with fixed jet multiplicity N=3+2, 4+2, 5+2
- Jets in the events must have a $pT > 20$ GeV to be considered, jets with $pT<20$ GeV do not contribute to the jet multiplicity
- The bounding jets (the most forward/backward jets) have $20<pT<30$ GeV and $30<pT<40$ GeV (and the reverse)
- The jets can have rapidity y such that $-4.7<y<4.7$
- The rapidity separation of the outermost jets was selected to be $3<\Delta Y<4$ and in one case $3.9<\Delta Y<4$
- anti-kT with R=0.4 was used as implemented in fastjet
- MSTW2008nnlo PDF (no particular reason, was used in MN studies)

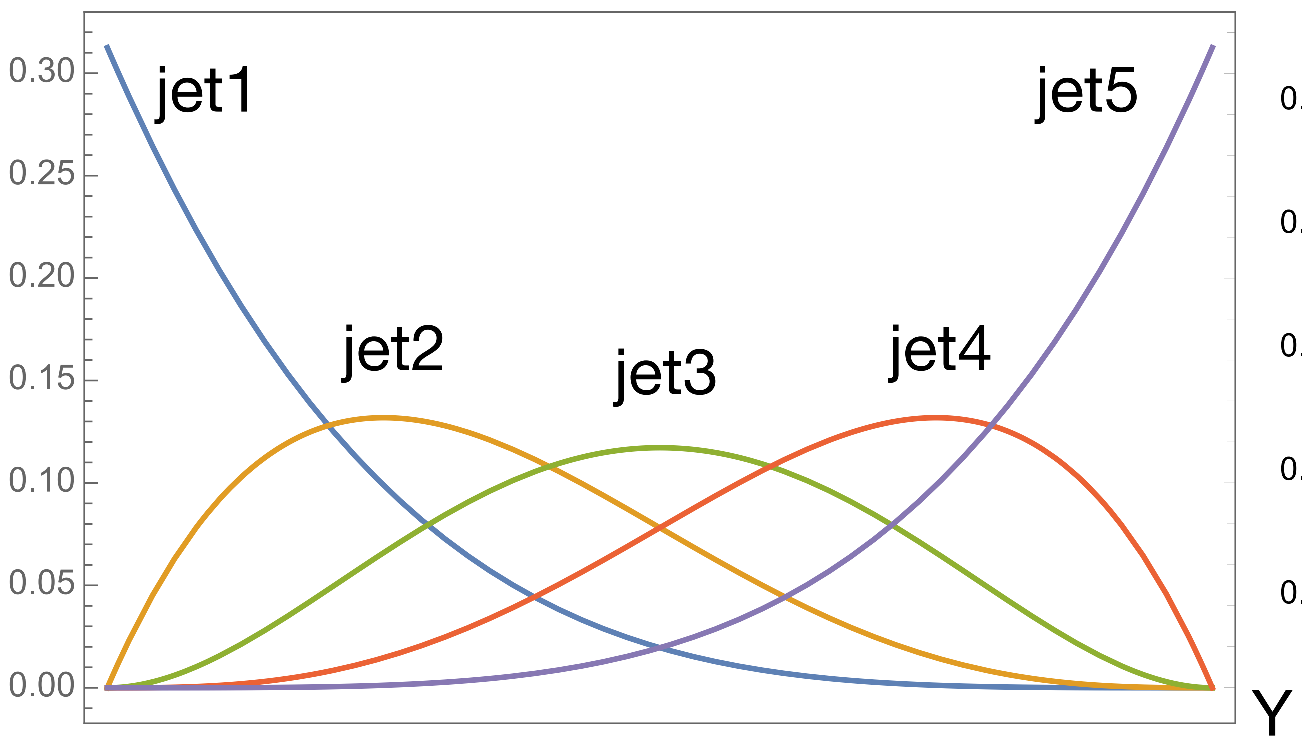
An example with N=5 (3+2)



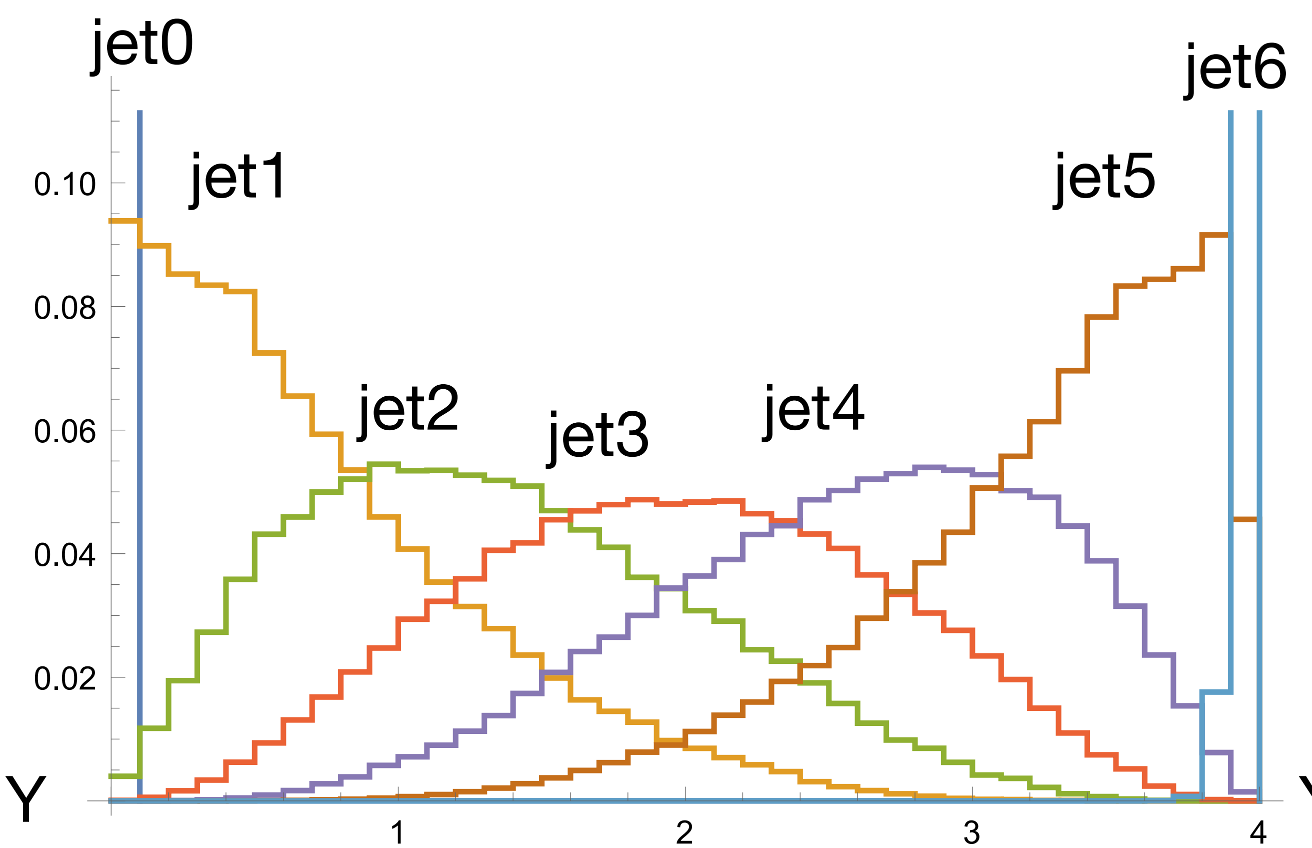
Shift the rapidities such that $y_1=0$



Rapidity distributions for N=5+2
3.9<ΔY<4

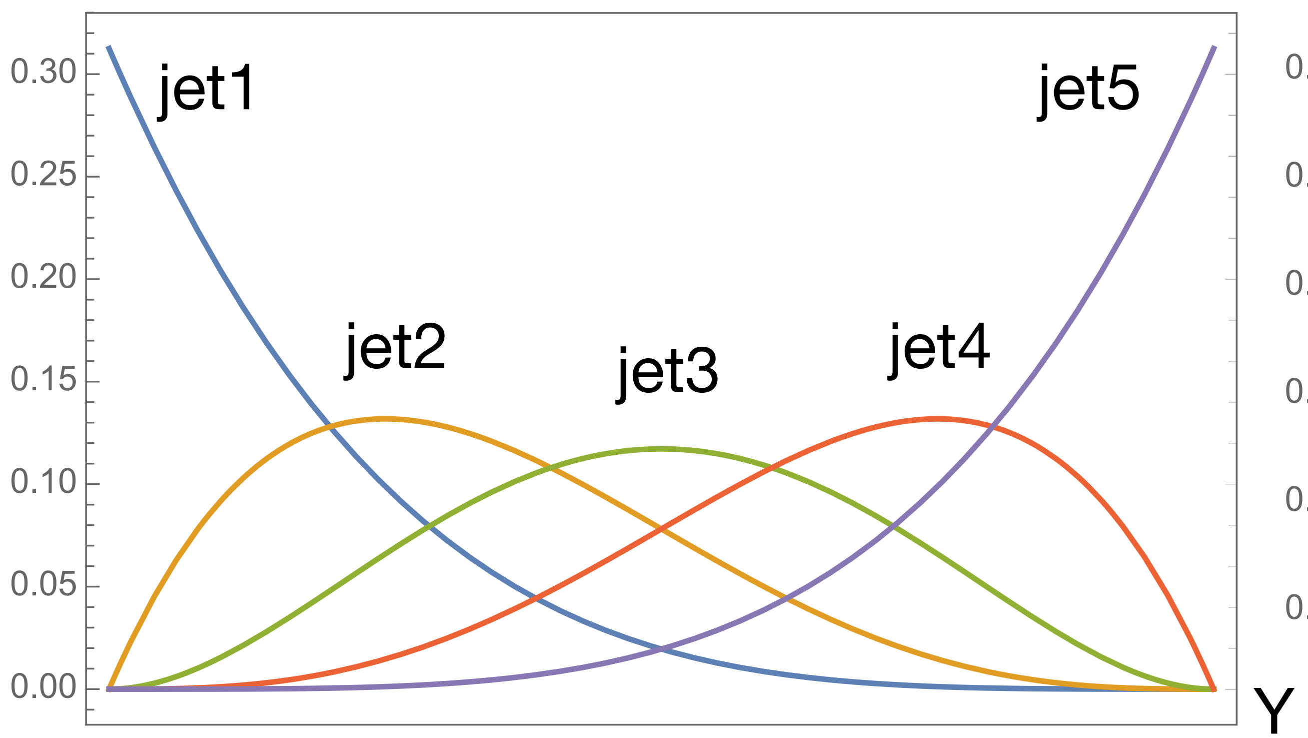


Chew-Pignotti, N = 5+2

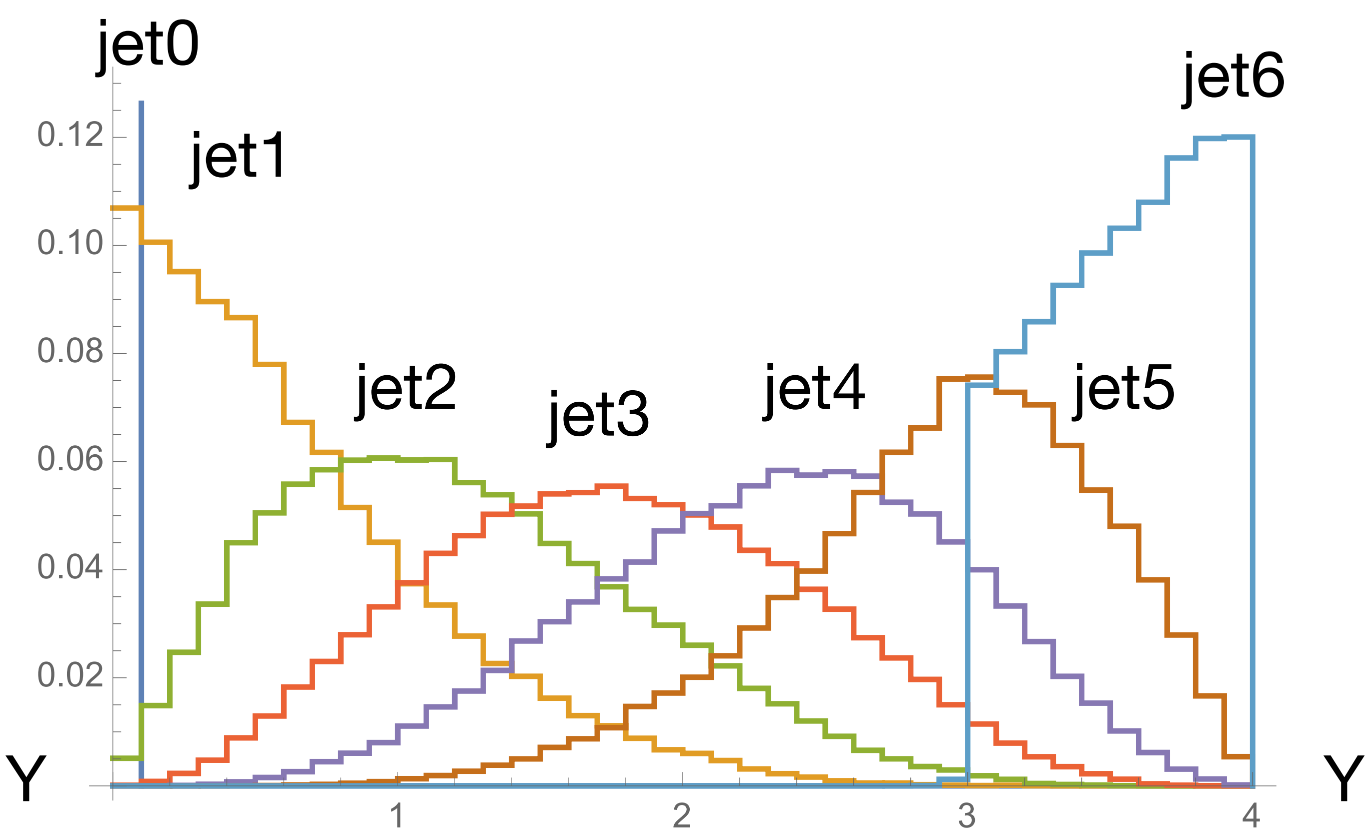


BFKLex, N = 5+2

Rapidity distributions for N=5+2
3<ΔY<4

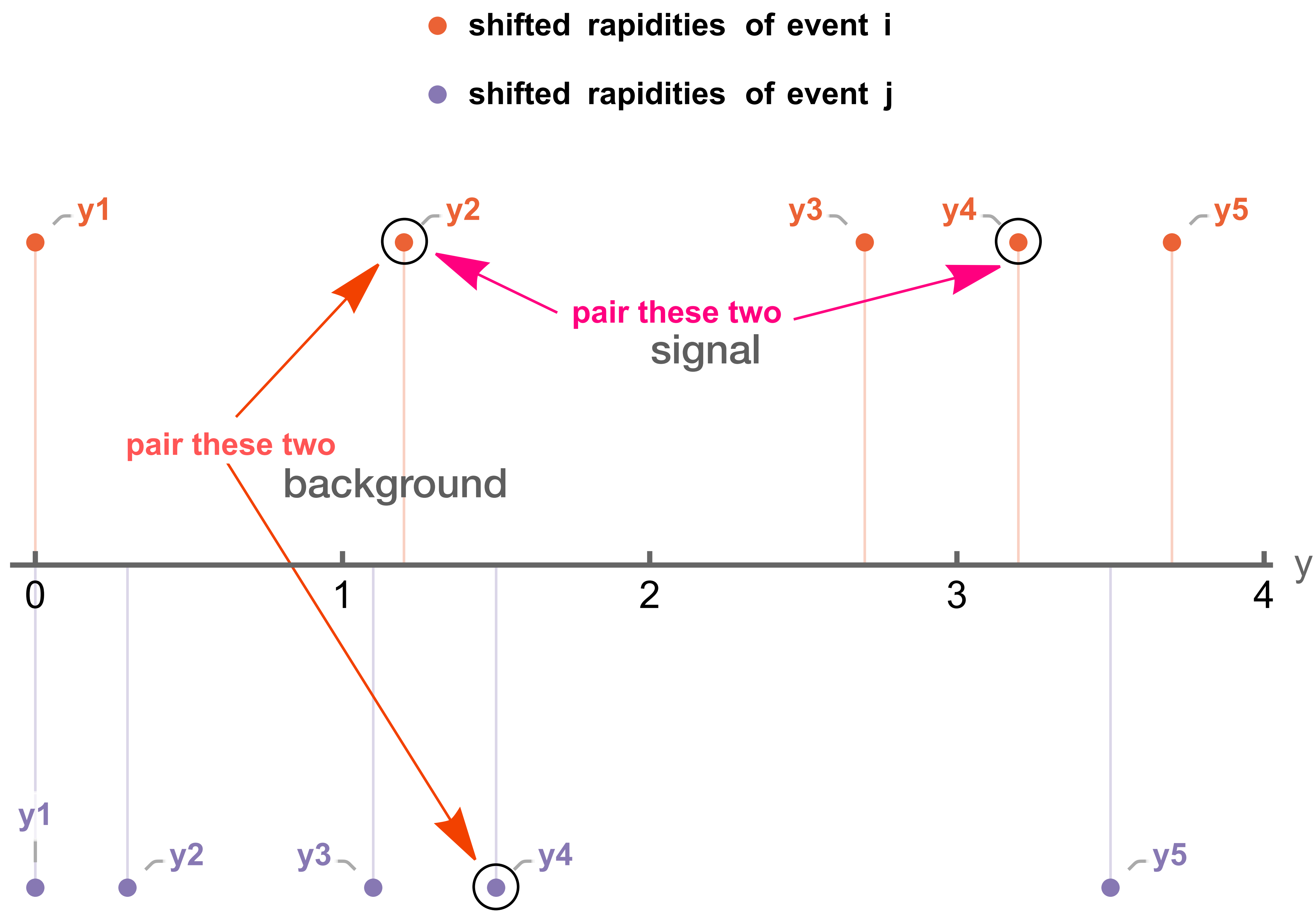


Chew-Pignotti, N = 5+2

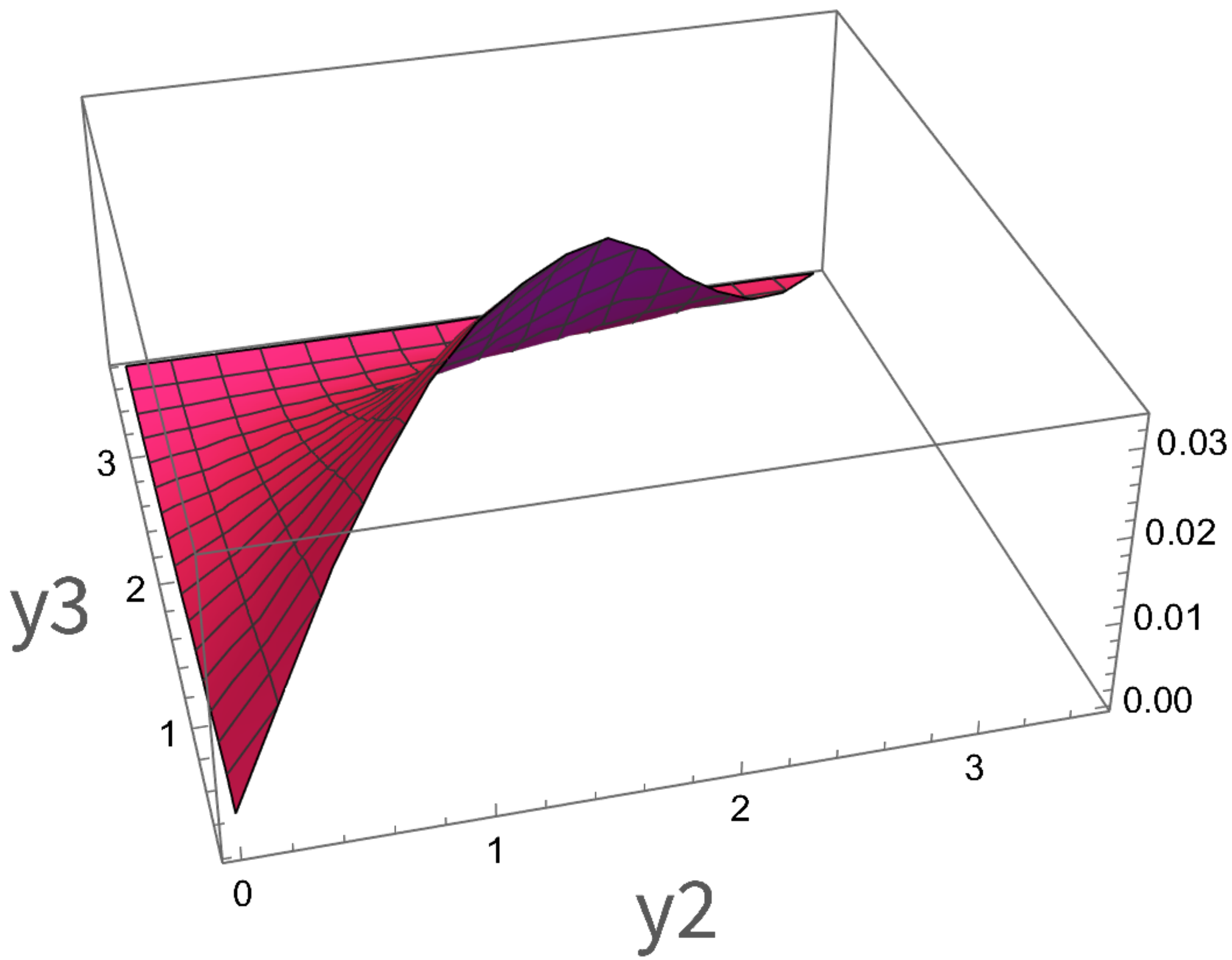


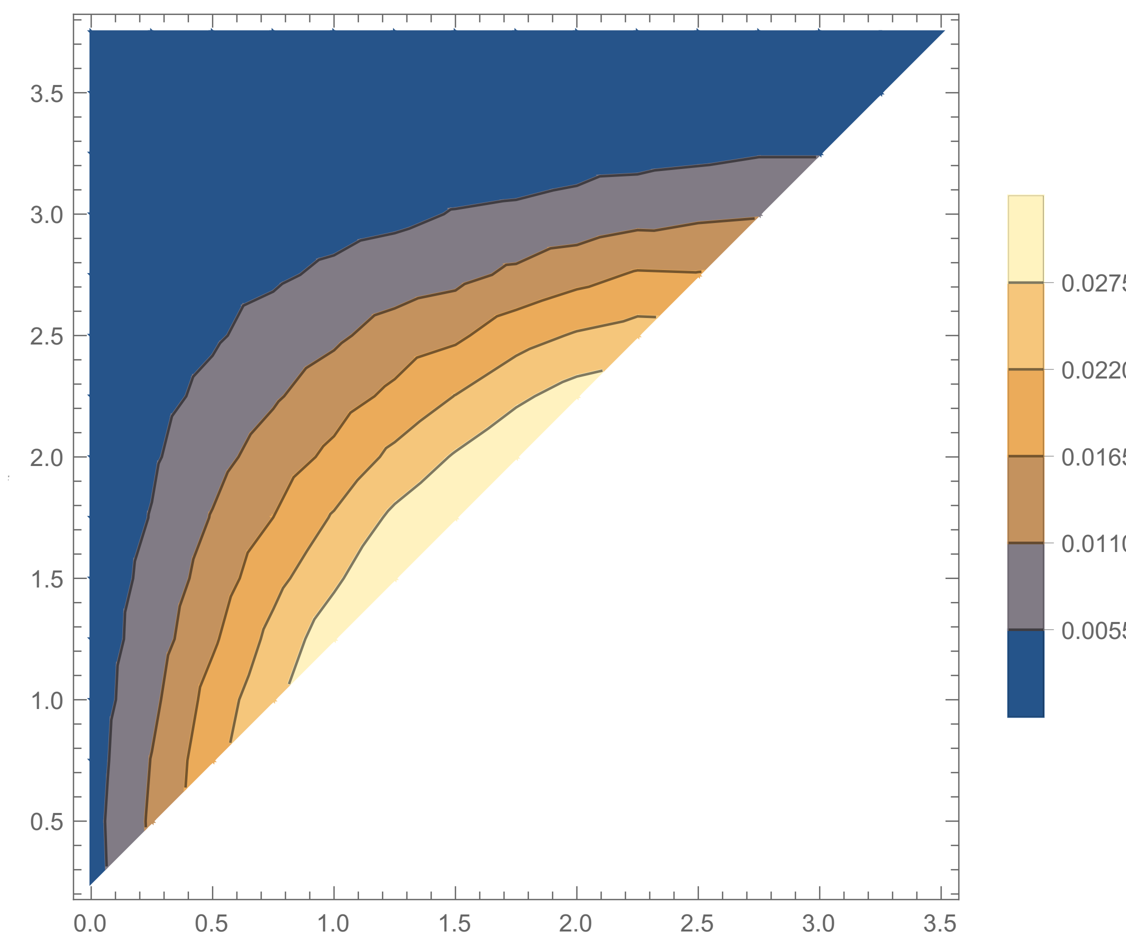
BFKLex, N = 5+2

Signal and background distributions



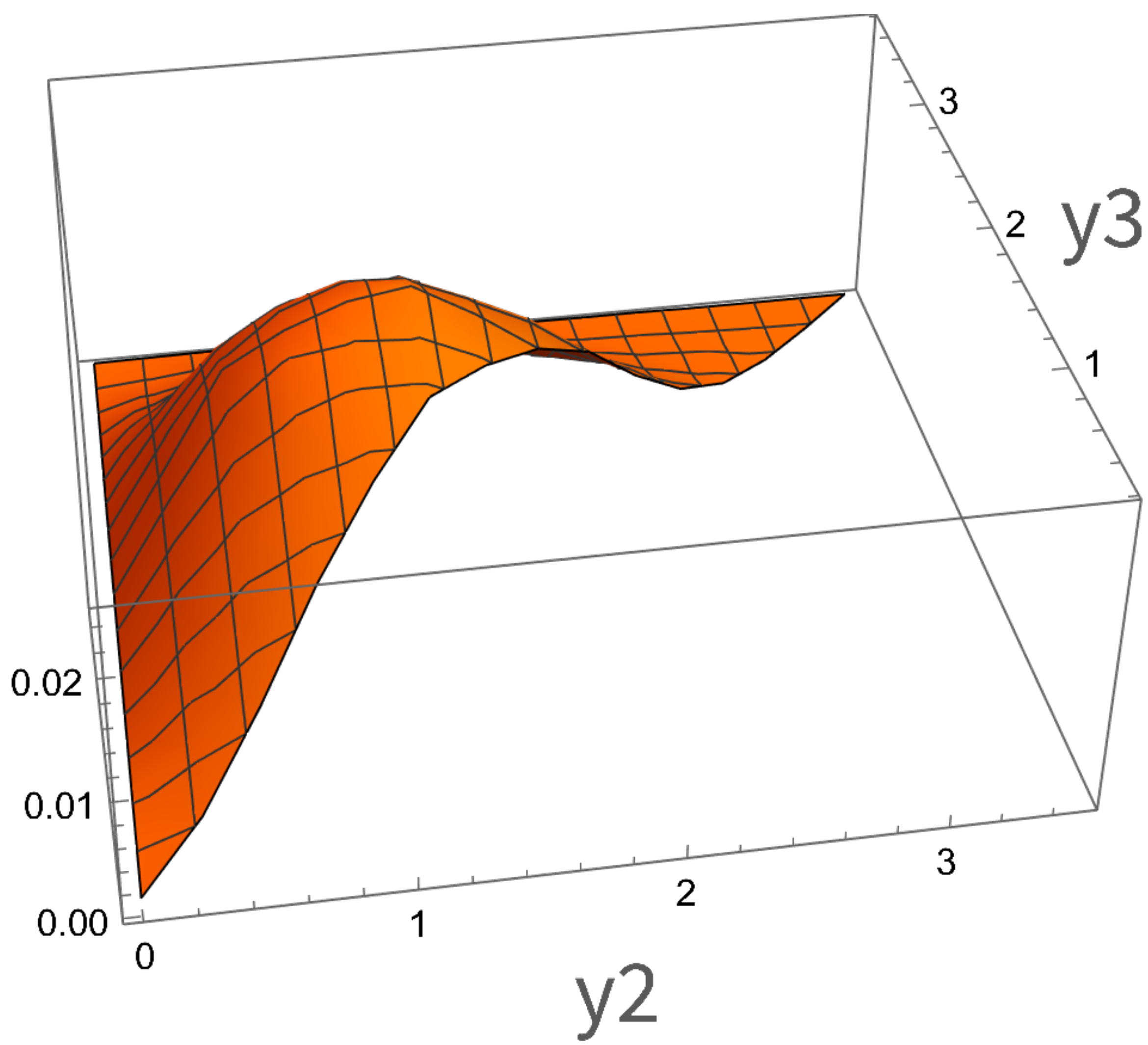
(y_2, y_3) signal distribution, N = 4+2

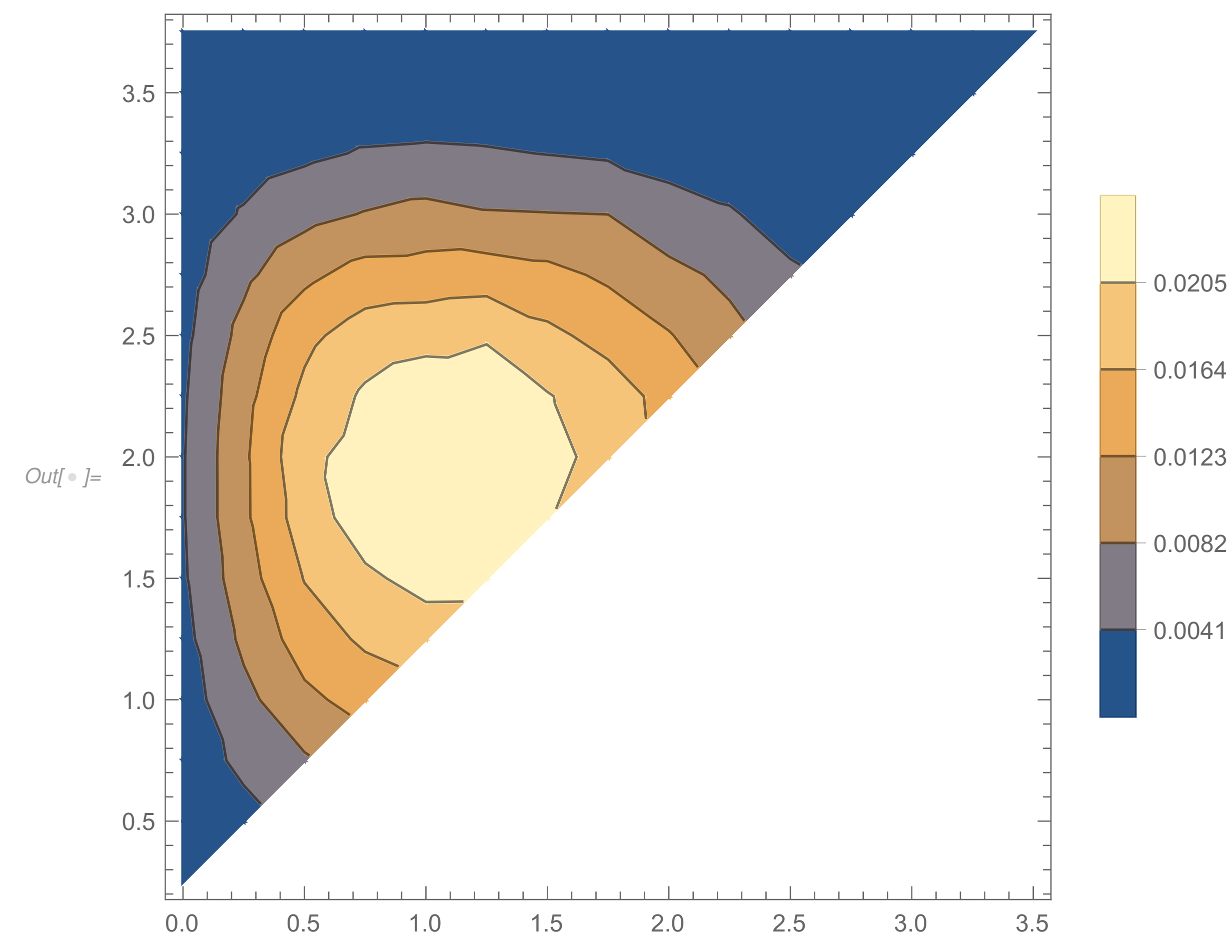




with
BFKLex

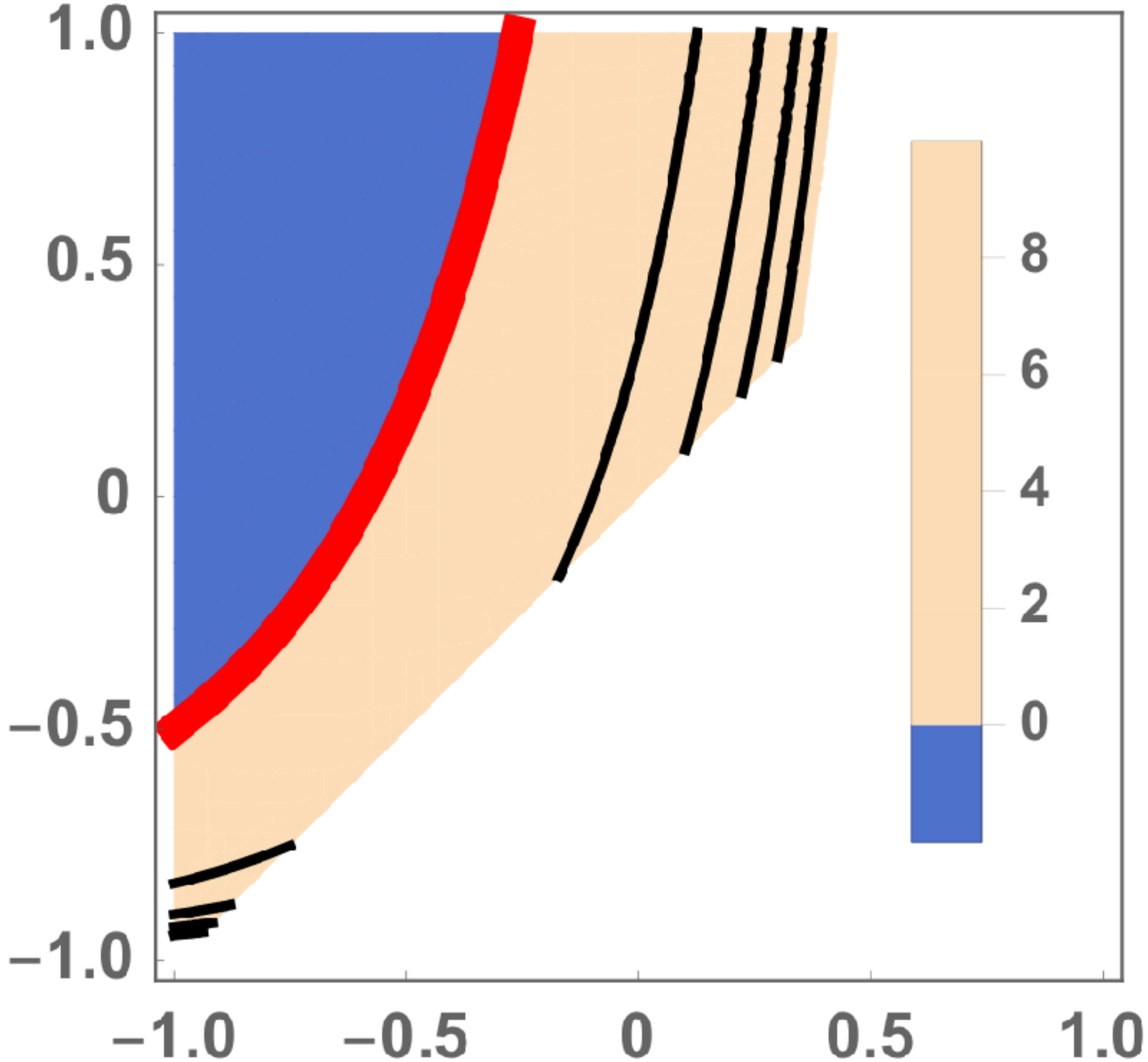
(y_2, y_3) background distribution
$N = 4+2$

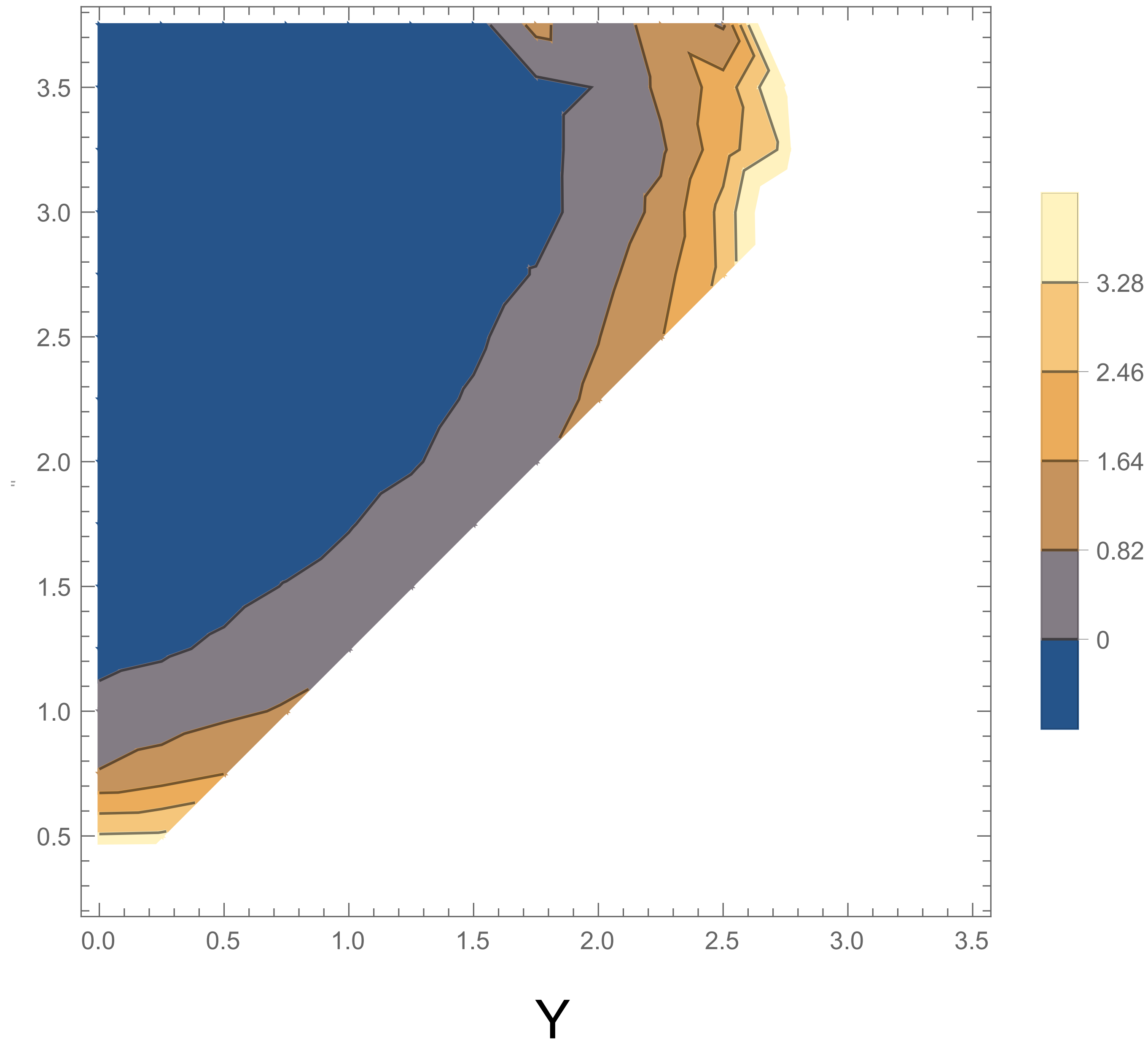




with
BFKLex

Full-run for (y_2,y_3) correlation
N = 4+2

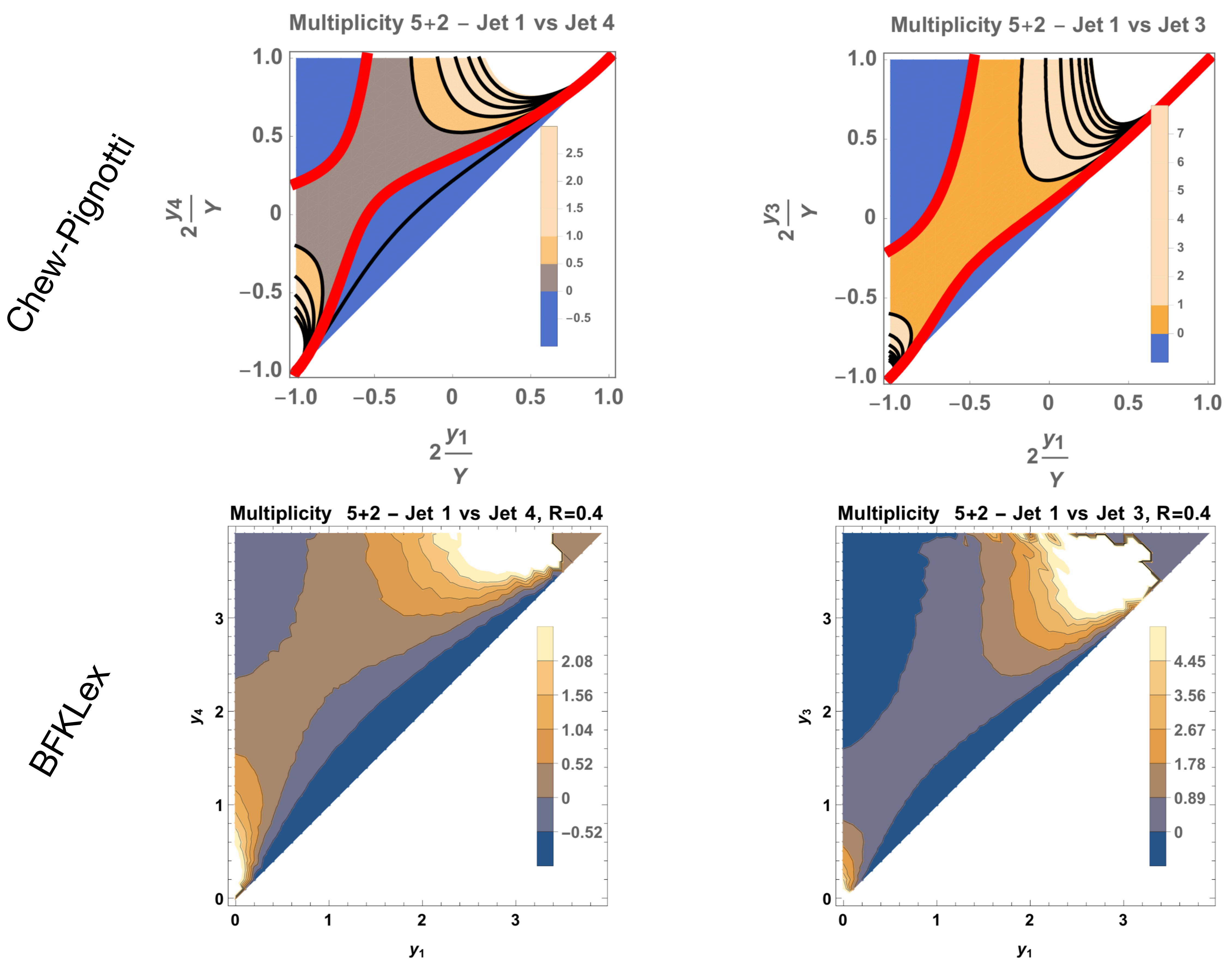




Chew-Pignotti

BFKLex

Partonic level run



Many thanks for your attention!