fct Fundação para a Ciência e a Tecnologia

LIP LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

A comparative study of rapidity-azimuthal angle correlations in pp collisions and the ridge effect

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The near-side ridge effect

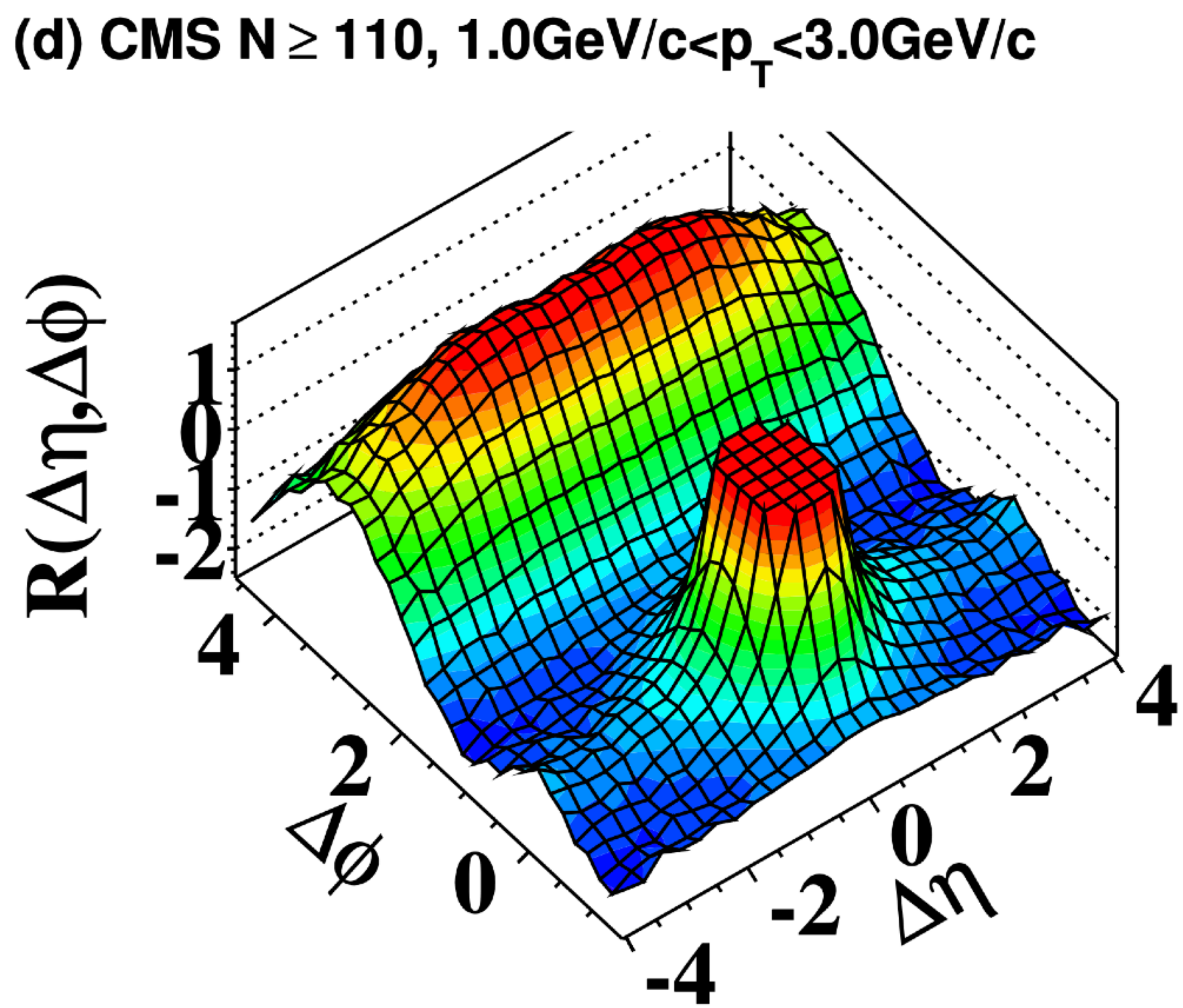
- The study of two-particle correlations is a powerful tool in exploring the underlying mechanisms of particle production.
- How do ridge-like structures emerge in perturbative Quantum Chromodynamics (QCD) in multiparticle production?
- Up to which degree can the ridge effect in proton-proton collisions be explained by the first principles of QCD and how does it generalize to heavy ion collisions?

The near-side ridge effect

- The study of the Δη-Δϕ correlation functions for proton-proton, proton-ion and ion-ion collisions, has drawn lots of attention in the last years. The correlation functions appear to have similar characteristics.

- Two "ridge-like structures", the important here is the enhancement on the near side, relative azimuthal angle $\Delta\phi \approx 0$, that extends over a wide range in relative pseudorapidity ($|\Delta\eta| \approx$ up to 4).

- That long-range near-side correlation is known as the "ridge".



CMS Collaboration, *JHEP* 09 (2010) 091

The near-side ridge effect

- There are two mainstream mechanisms (and many others) that give an explanation of the ridge effect in small systems (proton-proton and proton-ion collisions)
- The glasma correlation in the initial state described by the Color Glass Condensate effective field theory (CGC).
- The final state evolution described by hydrodynamics. Collectivity that implies a strongly coupled quark gluon plasma (QGP) that flows.

Correlation functions

- The two-particle correlation function is often defined in pseudorapidity and azimuthal space as $C(\Delta\eta, \Delta\phi) = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$

- S denotes the signal distribution which is built with particle pairs from the same event. B stands for the background distribution which involves particle pairs taken from different events; $\Delta\eta = \eta_1 - \eta_2$ and $\Delta\phi = \phi_1 - \phi_2$ are the pseudorapidity and azimuthal angle differences respectively between the particles with indices 1 and 2 which are labelling the trigger and associate particles.

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$$\tilde{\rho}(y, \vec{p}_T) = \frac{1}{\sigma_{\rm in}} \frac{d^3\sigma}{d^3p} = \frac{1}{\sigma_{\rm in}} \frac{d^3\sigma}{dy d^2p_T} = \frac{1}{2\sigma_{\rm in}} \frac{d^3\sigma}{dy d\phi dp_T^2}$$

$$\tilde{\rho}_2(y_1, \vec{p}_{T1}, y_2, \vec{p}_{T2}) = \frac{1}{\sigma_{\rm in}} \frac{d^6\sigma}{d^3p_1 d^3p_2} = \frac{1}{\sigma_{\rm in}} \frac{d^6\sigma}{dy_1 d^2p_{T1} dy_2 d^2p_{T2}} = \frac{1}{4\sigma_{\rm in}} \frac{d^6\sigma}{dy_1 d\phi_1 dp_{T1}^2 dy_2 d\phi_2 dp_{T2}^2}$$

$$C(1,2) = \frac{\tilde{\rho}_2(1,2)}{\tilde{\rho}(1)\tilde{\rho}(2)} \qquad C(\Delta y, \Delta\phi) = \frac{s(\Delta y, \Delta\phi)}{b(\Delta y, \Delta\phi)}$$

BFKLex, a BFKL Monte Carlo

- The main goal was to have a tool that calculates the gluon Green's function (GGF) and other differential observables.
- The GGF is the solution to the BFKL equation. Use the iterative form:

$$f = e^{\omega\left(\vec{k}_A\right)Y}\left\{\delta^{(2)}\left(\vec{k}_A-\vec{k}_B\right)+\sum_{n=1}^{\infty}\prod_{i=1}^{n}\frac{\alpha_s N_c}{\pi}\int d^2\vec{k}_i\frac{\theta\left(k_i^2-\lambda^2\right)}{\pi k_i^2}\right.$$
$$\left.\int_0^{y_{i-1}}dy_i e^{\left(\omega\left(\vec{k}_A+\sum_{l=1}^{i}\vec{k}_l\right)-\omega\left(\vec{k}_A+\sum_{l=1}^{i-1}\vec{k}_l\right)\right)y_i}\delta^{(2)}\left(\vec{k}_A+\sum_{l=1}^{n}\vec{k}_l-\vec{k}_B\right)\right\}$$

$\omega\left(\vec{q}\right)=-\frac{\alpha_s N_c}{\pi}\log\frac{q^2}{\lambda^2}$ is the gluon Regge trajectory

The implementation of the **BFKLex** is in C++, G.C & A. Sabio Vera

Why a Monte Carlo approach?

- We don't always know the analytic solution
- Even if we know it, we still want to store and analyze information about “differential” quantities (e.g. rapidities, transverse momenta, angles) that will be lost once we perform the integrations analytically.

  We want this for two reasons:

  1. Because then we can compare theoretical predictions to a greater set of observables
  2. Because there are lots of things we can still learn about concepts we use every day and maybe we don't fully understand
- We want to have a common language with people that work and are familiar with fixed order calculations and who are the majority in the “pheno” community – the interaction will help both sides
- We want to work in momentum space
- Connect to Heavy Ion physics
- Connect to physics of Cosmic Rays

Some results with BFKLex

A Comparative study of small x Monte Carlos with and without QCD coherence effects
G. C, M. Deak, A.Sabio Vera, P. Stephens
Nucl.Phys. B849 (2011) 28-44

The Colour Octet Representation of the Non-Forward BFKL Green Function
G. C, A. Sabio Vera.
Phys.Lett. B709 (2012) 301-308

The NLO N =4 SUSY BFKL Green function in the adjoint representation
G. C, A.Sabio Vera
Phys.Lett. B717 (2012) 458-461

Bootstrap and momentum transfer dependence in small x evolution equations
G. C, A. Sabio Vera, C. Salas
Phys.Rev. D87 (2013) no.1, 016007

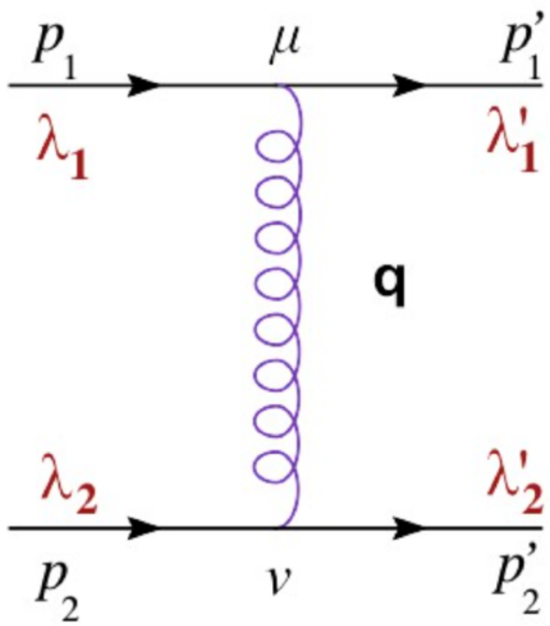
A study of the diffusion pattern in N = 4 SYM at high energies
F. Caporale, G. C, J.D. Madrigal, B. Murdaca, A. Sabio Vera
Phys.Lett. B724 (2013) 127-132

Monte Carlo study of double logarithms in the small x region
G. C, A. Sabio Vera
Phys.Rev. D93 (2016) no.7, 074004

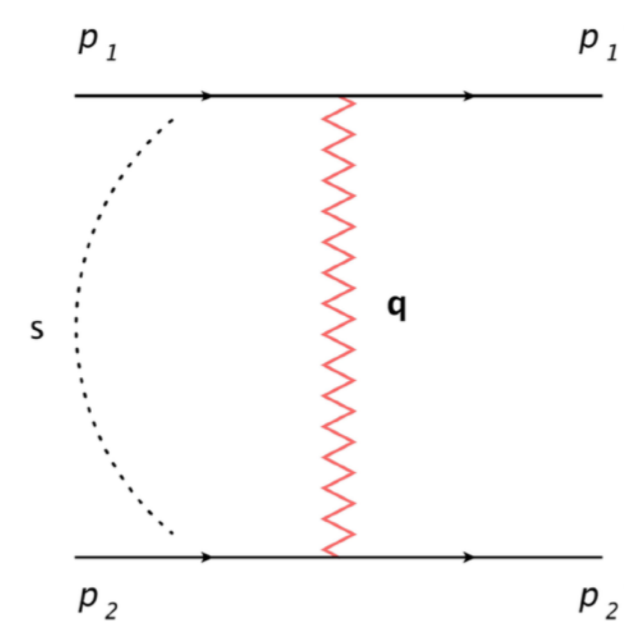
The high-energy radiation pattern from BFKLex with double-log collinear contributions
G. C, A. Sabio Vera
JHEP 1602 (2016) 064

Large logs from virtual corrections

At leading logarithmic accuracy we resum terms of the form $(\alpha_s \log(s))^n$



A normal gluon propagator: $D_{\mu\nu}(s, q^2) = -i\frac{g_{\mu\nu}}{q^2}$



The reggeized gluon is a gluon with modified propagator:

$$D_{\mu\nu}(s, q^2) = -i\frac{g_{\mu\nu}}{q^2} \left(\frac{s}{\mathbf{k}^2}\right)^{\omega(q^2)}$$

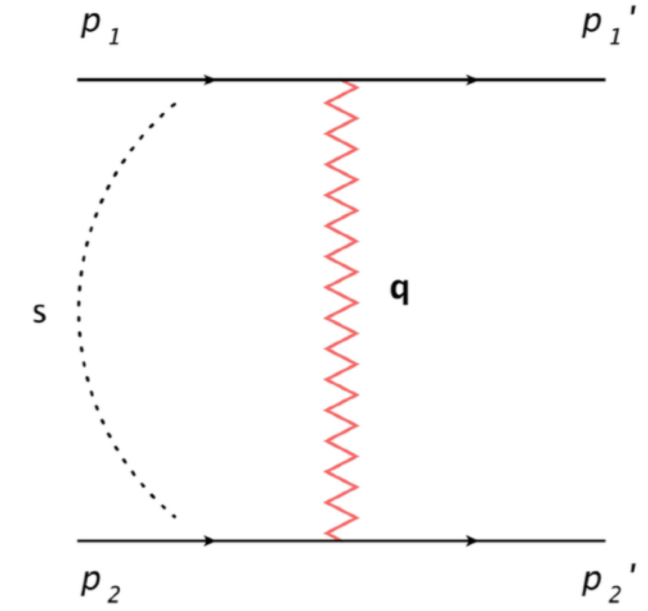
The Reggeon

All the virtual corrections that carry leading-logs in s are accounted for

The reggeized gluon is a gluon with modified propagator:

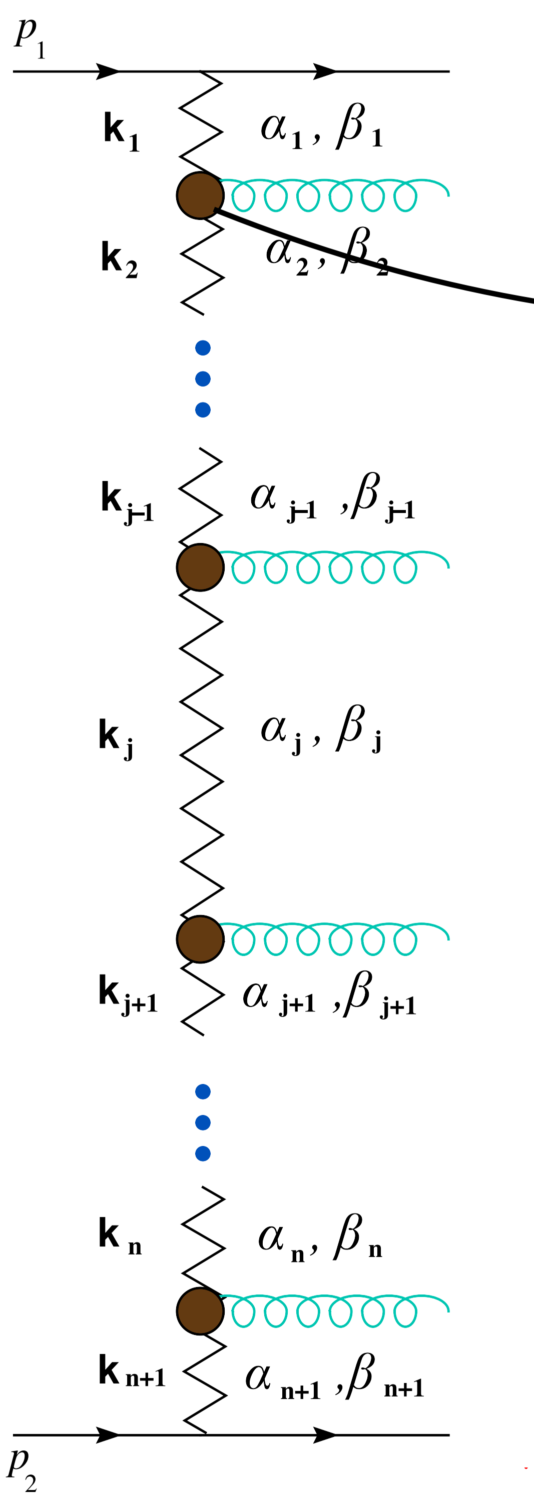
$$D_{\mu\nu}(s,q^2) = -i\frac{g_{\mu\nu}}{q^2}\left(\frac{s}{\mathbf{k}^2}\right)^{\omega(q^2)}$$

(where $\mathbf{k}^2$ is a hard scale in the process at hand)



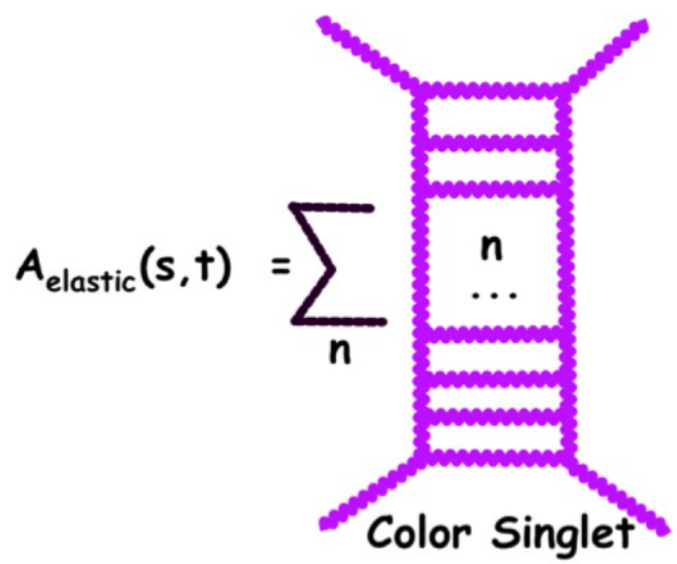
From now on, vertical propagators represent Reggeons

Large logs from real emission corrections



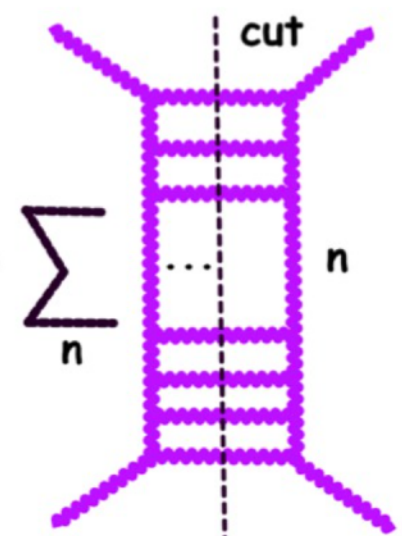
Lipatov's effective vertex

BFKL equation



Optical Theorem :

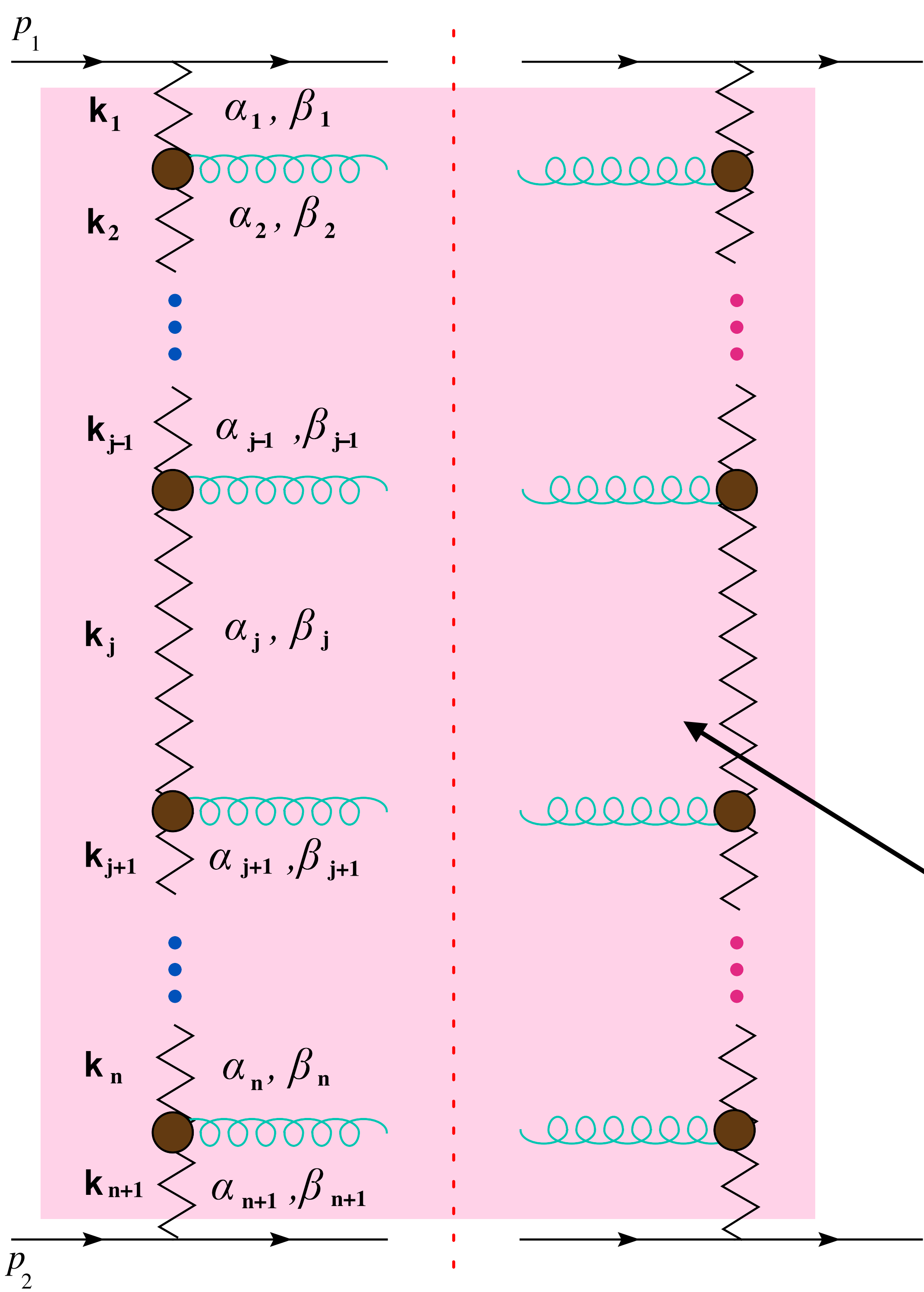
$$\sigma_{TOT} \simeq \frac{1}{s}\mathrm{Im}\mathcal{A}_{\mathrm{elastic}}(s, t=0) = \frac{1}{s}\sum_n$$



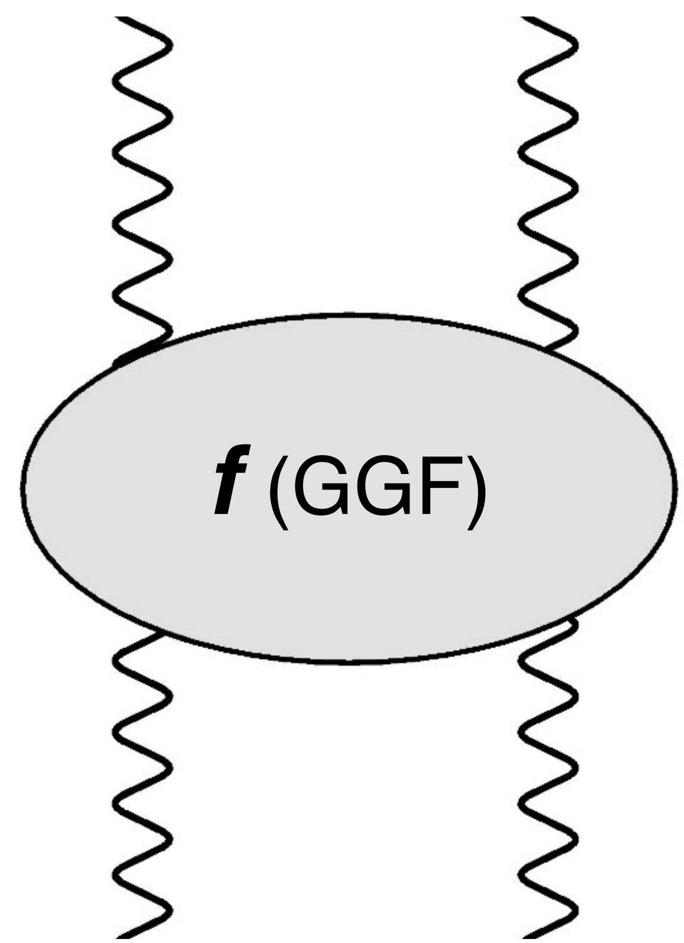
$$= \frac{1}{s}\sum_n |A_n(s,t)|^2$$

The Pomeron

From now on, ‘rungs’ instead of real emissions



BFKL
equation

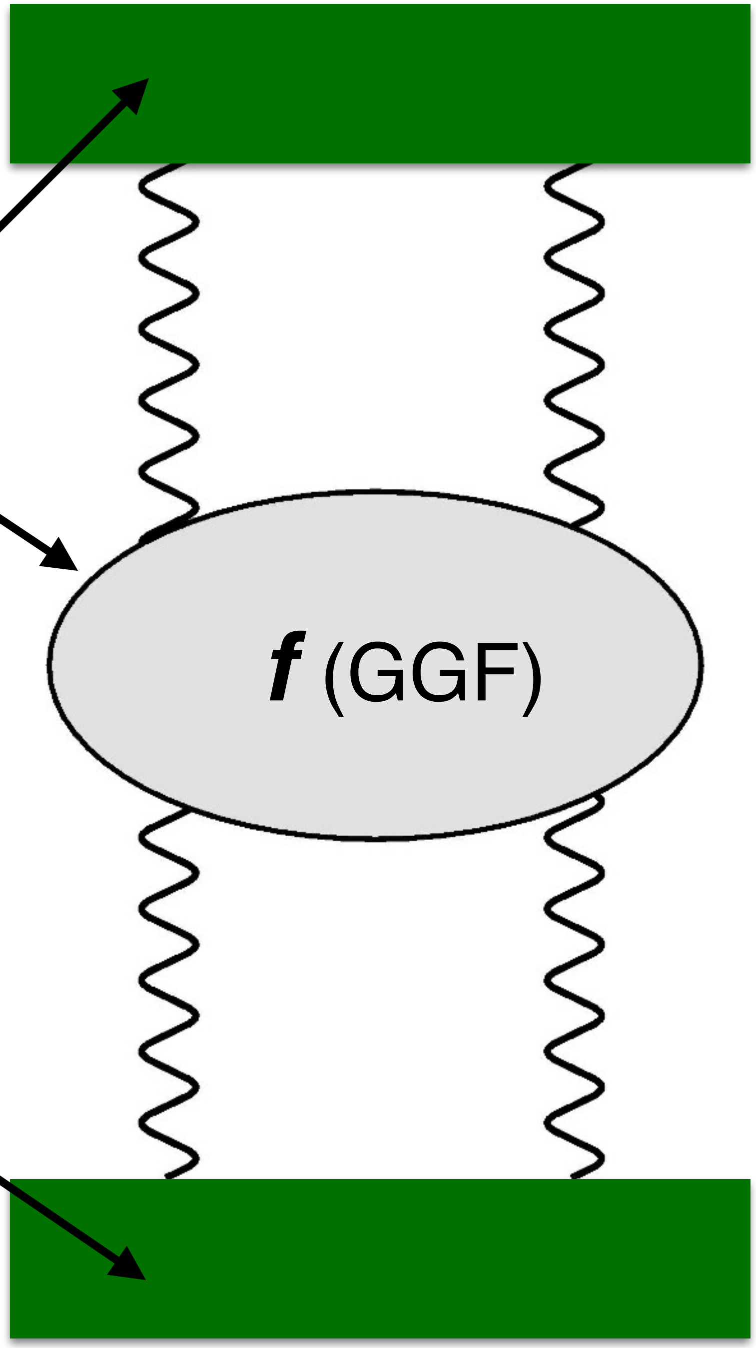


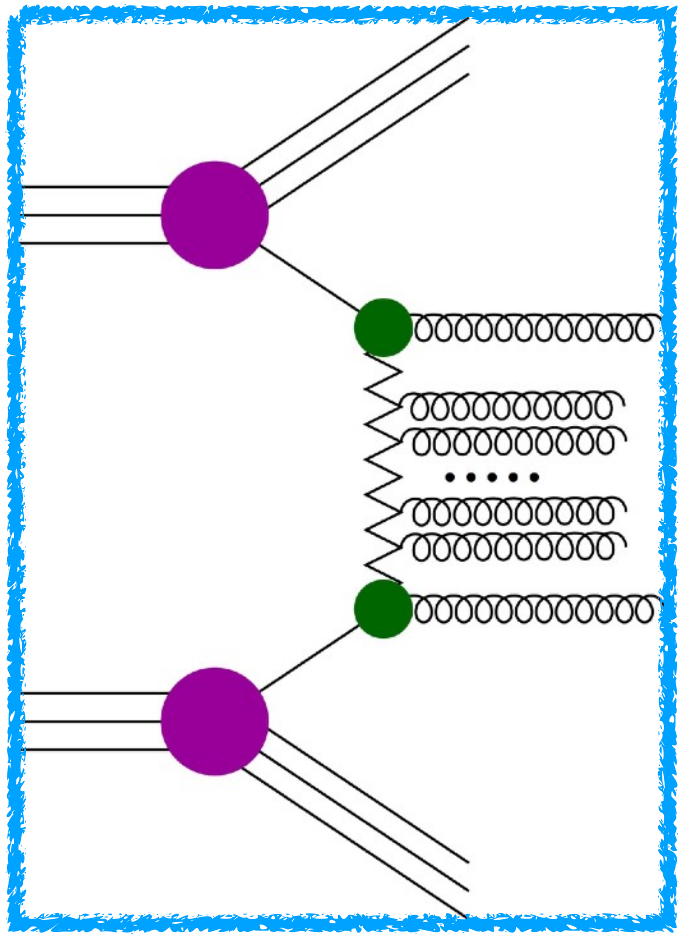
Many many
phase-space diagrams

Impact factors

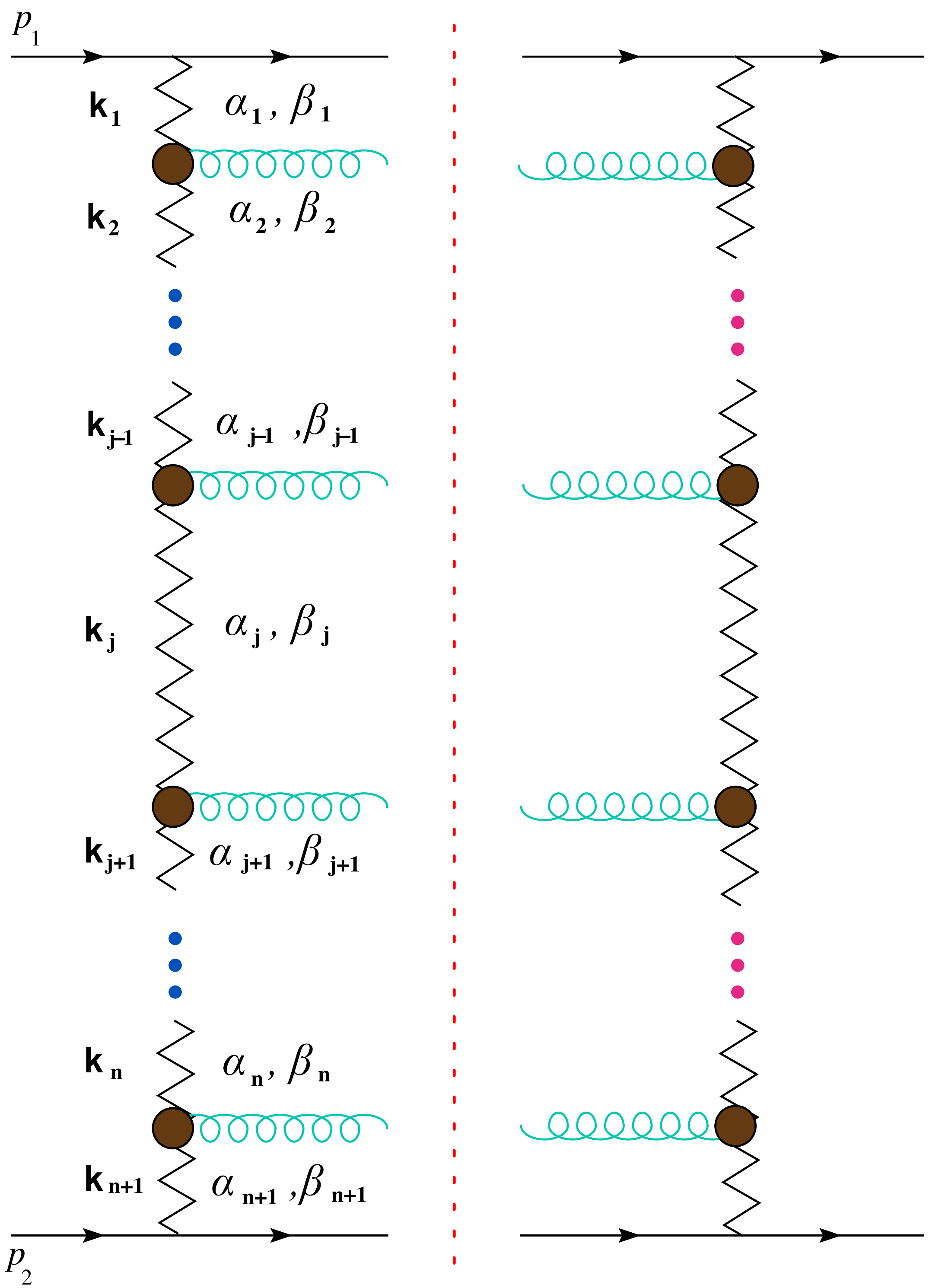
The gluon Green's function is process independent.

The effective couplings to the colliding projectiles though which are called **Impact Factors** are process dependent and need to be calculated for each different process.





Large logs from real emission corrections in a Monte Carlo setup



- Assume Reggeons in the t-channel
- Assume you have only one real emission
- Do the phase-space integration —> res1
- Now assume you have two real emissions
- Do the phase-space integration —> res2
- Add the results: RES = res1+res2
- Now assume you have three real emissions
- Do the phase-space integration —> res3
- Add the results: RES = RES + res3
- Repeat until you have N real emissions with resN so tiny compared to RES such that you are allowed to claim convergence

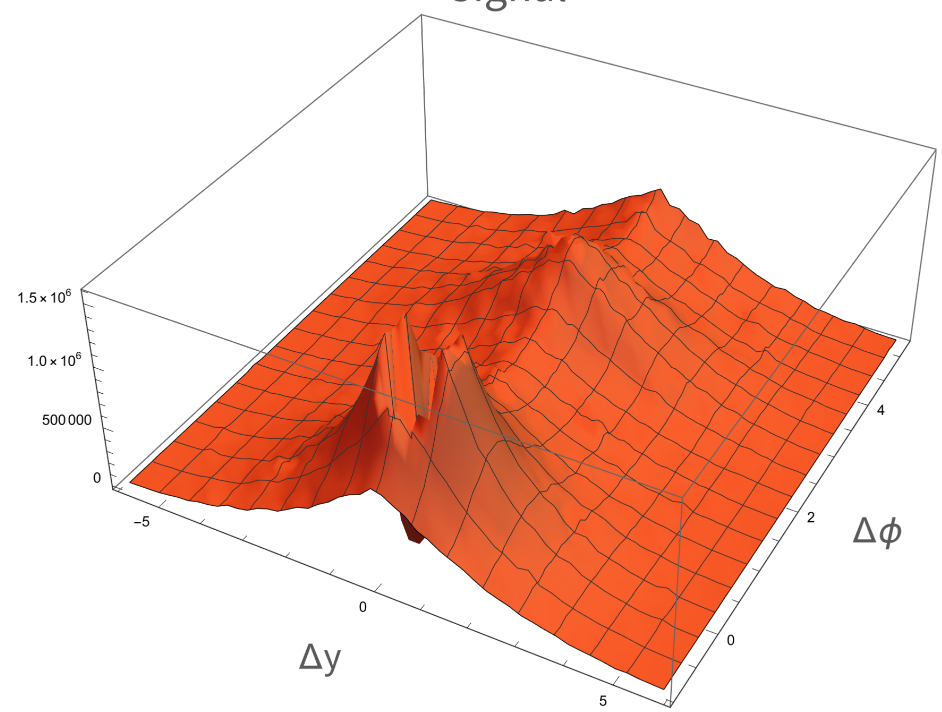
NOTE: The phase-space integration is over rapidity and transverse momenta.

Correlation functions with BFKLex

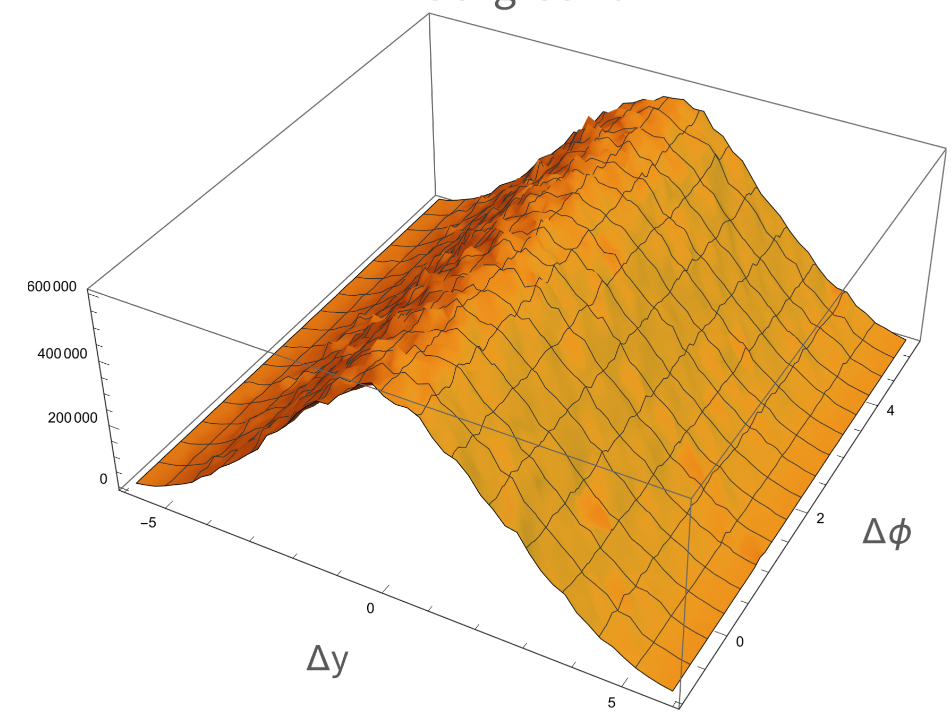
- We want to see whether any long-range near-side enhancement is observed from studying the correlations functions under the strong assumption that the relevant underlying dynamics is the BFKL dynamics.

First **Preliminary** Results

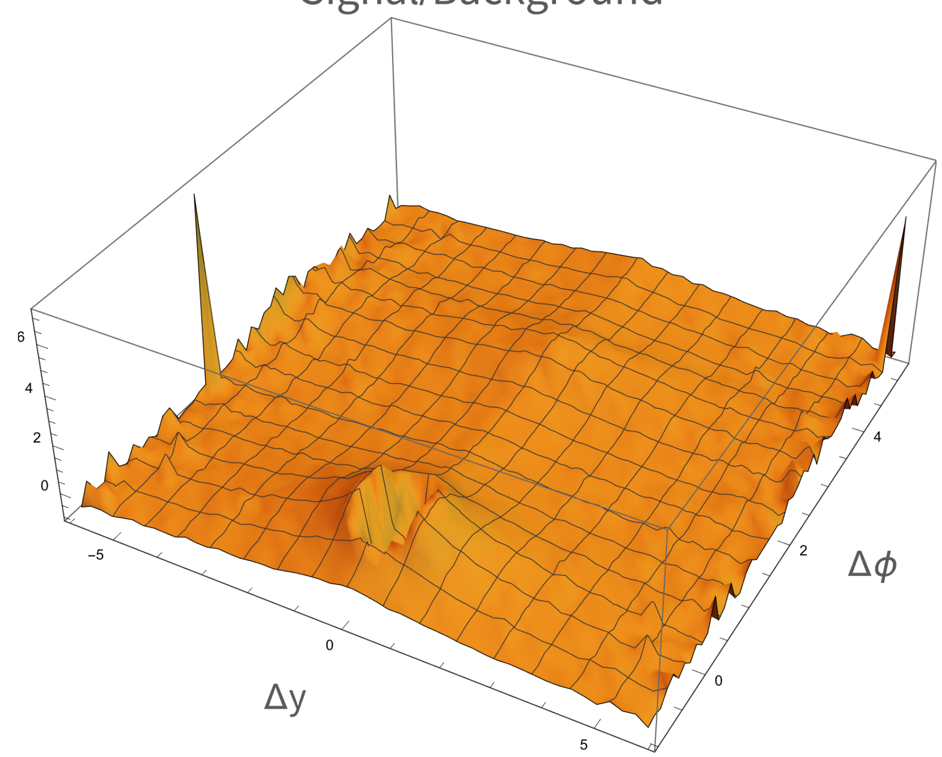
Signal

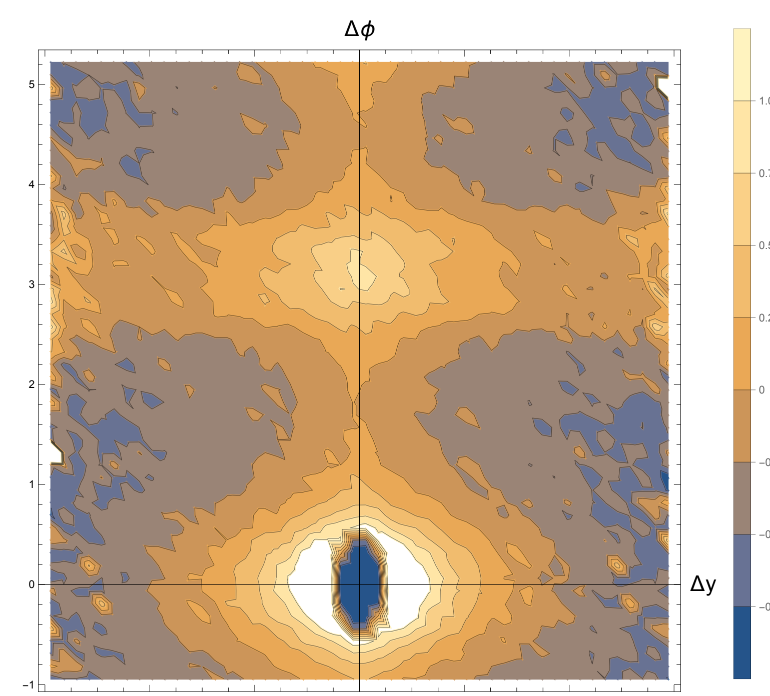


Background



Signal/Background





Conclusions

- The correlation function seems to get an enhancement for $\Delta\phi \sim 0$ and for long ranges of Δy
- Further runs are needed to make sure that the effect is really there
- Extremely important finding as there is no modelling, BFKLex contains “pure” high energy QCD dynamics