Factorization and forward production

Grigorios Chachamis, LIP Lisbon

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Key considerations

- When high energy (low x) QCD is relevant? Is it relevant for the FPF physics program?

- Can we study the high energy limit of QCD at the FPF?

- Can we combine the FPF with ATLAS to take complementary measurements and probe high energy QCD?

lots of references in the following not shown,
I will be happy to provide them to whoever is interested

The streetlight effect

https://sketchplanations.com/looking-under-the-lamppost

Evolution equations in the low x regime

- Balitsky-Fadin-Kuraev-Lipatov (BFKL) → linear
- Gribov-Levin-Ryskin Mueller-Qiu (GLR-MQ) → non-linear
- Ciafaloni-Catani-Fiorani-Marchesini (CCFM)
- Balitsky-Kovchegov (BK) → non-linear
- Jalilian Marian-Iancu-MacLerran-Weigert-Leonidov-Kovner (JIMWLK) → non-linear
- Various “improved” versions

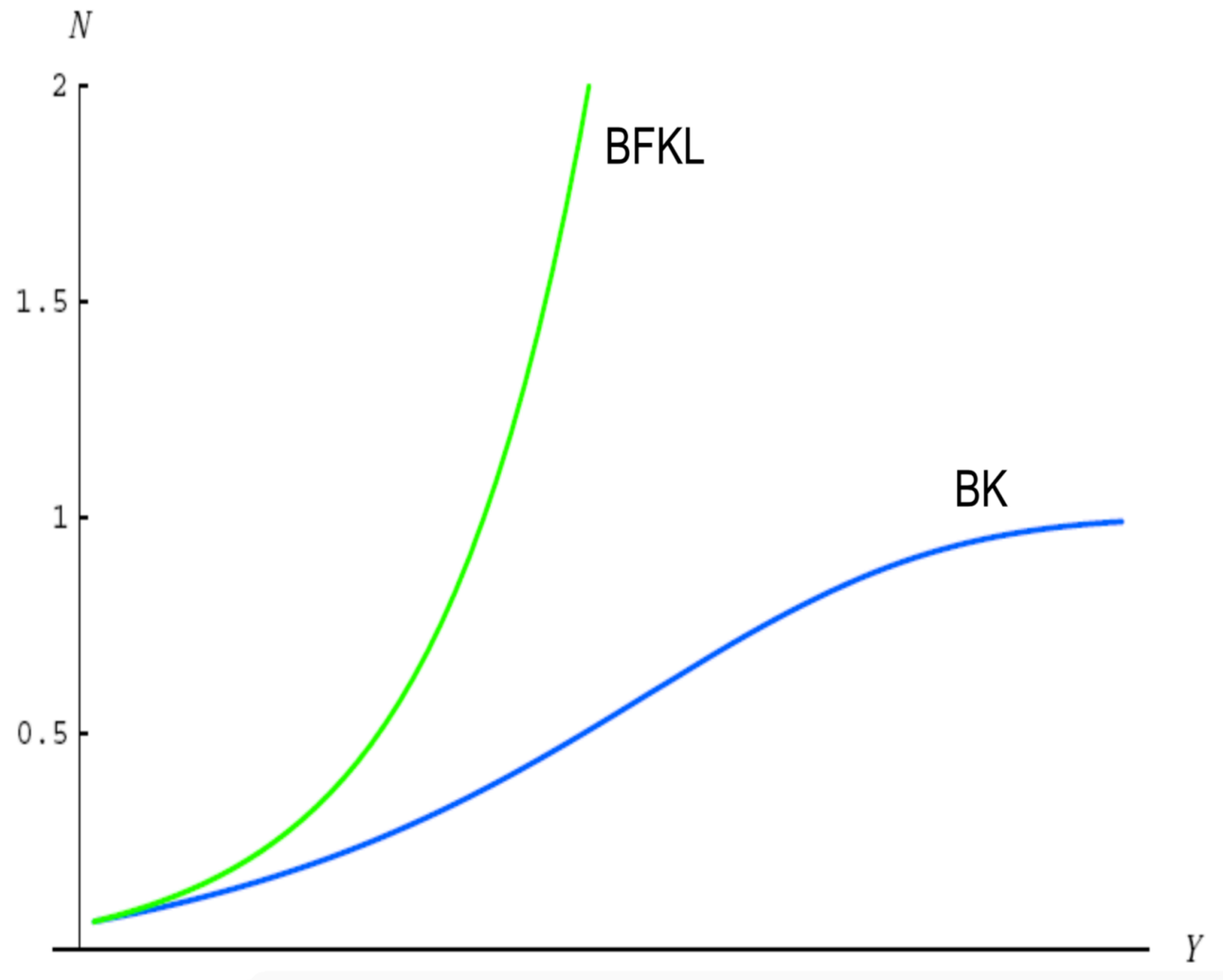
Choose the simplest way to probe high energy QCD

- Let us keep things simple by considering only linear evolution: BFKL

- Keep in mind: no saturation without BFKL

- Unitarization is of course needed and saturation does change things in DIS setups, however BFKL can describe F_2 data

- We can always introduce saturation at a later time



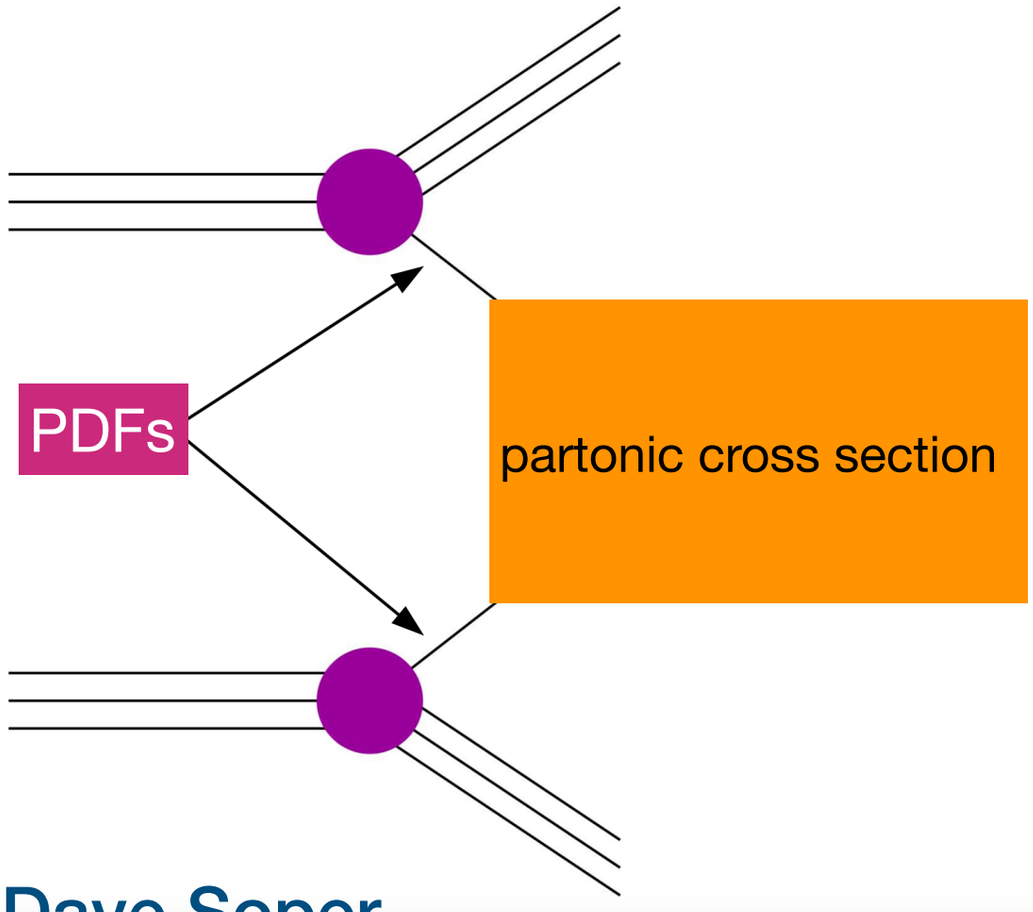
Collinear factorization scheme

Collins Soper Sterman 1989

$$\sigma(s) = \sum_{i,j} \int dx_1\, dx_2\, f_i(x_1)\, f_j(x_2)\, \hat{\sigma}_{ij}(x_1 x_2 \hat{s})$$

- The partonic cross section is convoluted with the PDFs

$$\frac{\partial f_i(x,Q^2)}{\partial \log(Q^2)} = \sum_j \int_x^1 \frac{dz}{z} P_{j\to i}(z) f_j\left(\frac{x}{z}, Q^2\right)$$



See next talk by Dave Soper

k_T-factorization scheme

- Very large c.o.m energy squared, s—> infinity
- There is a hard scale allowing for perturbative approach, formally t (or Q^2)
- $s >> |t|$ (or Q^2) $>> \Lambda^2$: the Regge limit
- Large logarithms in energy, $\ln(s/Q^2) \sim \ln(1/x) >> 1$
- $(\alpha_s \ln(s))^n \sim 1$, resummation is needed: use BFKL

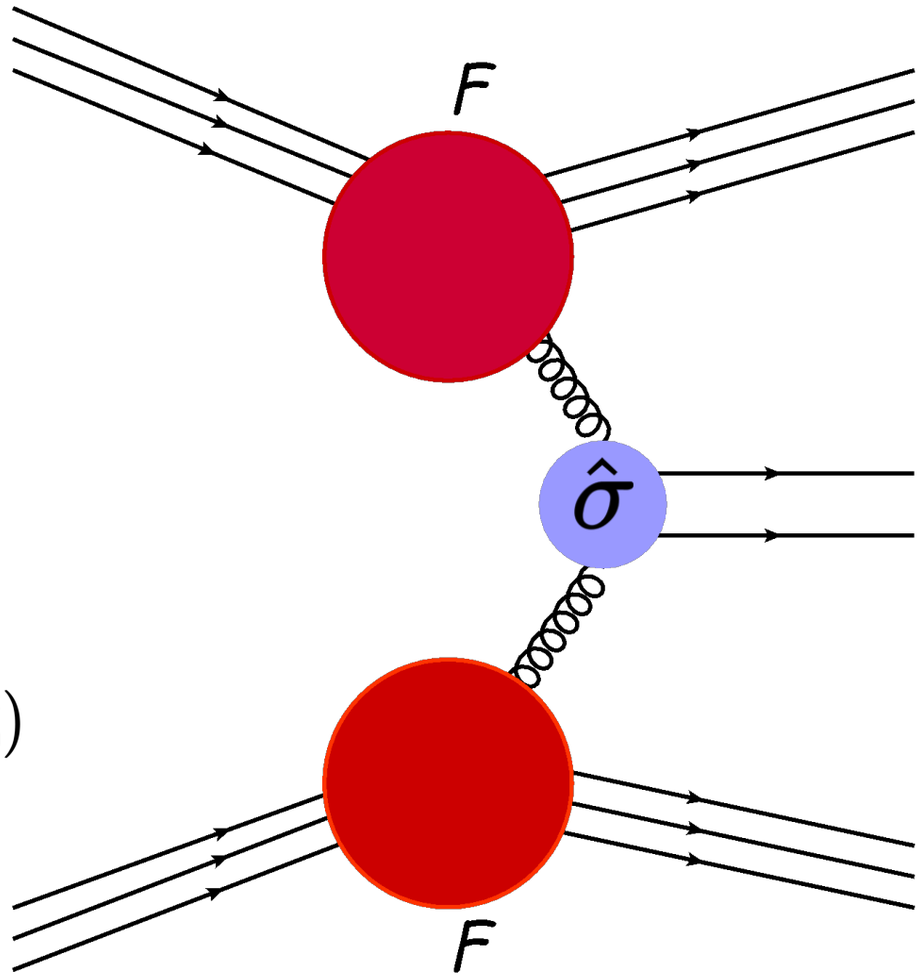
k_T-factorization scheme

$$\sigma(s) = \int d^2k_{1\perp} \frac{dx_1}{x_1} \mathcal{F}(x_1, k_{1\perp})\, d^2k_{2\perp} \frac{dx_2}{x_2} \mathcal{F}(x_2, k_{2\perp})\, \hat{\sigma}(x_1 x_2 s,\, k_{1\perp},\, k_{2\perp})$$

Catani, Ciafaloni, Hautmann 1991, Collins Ellis 1991

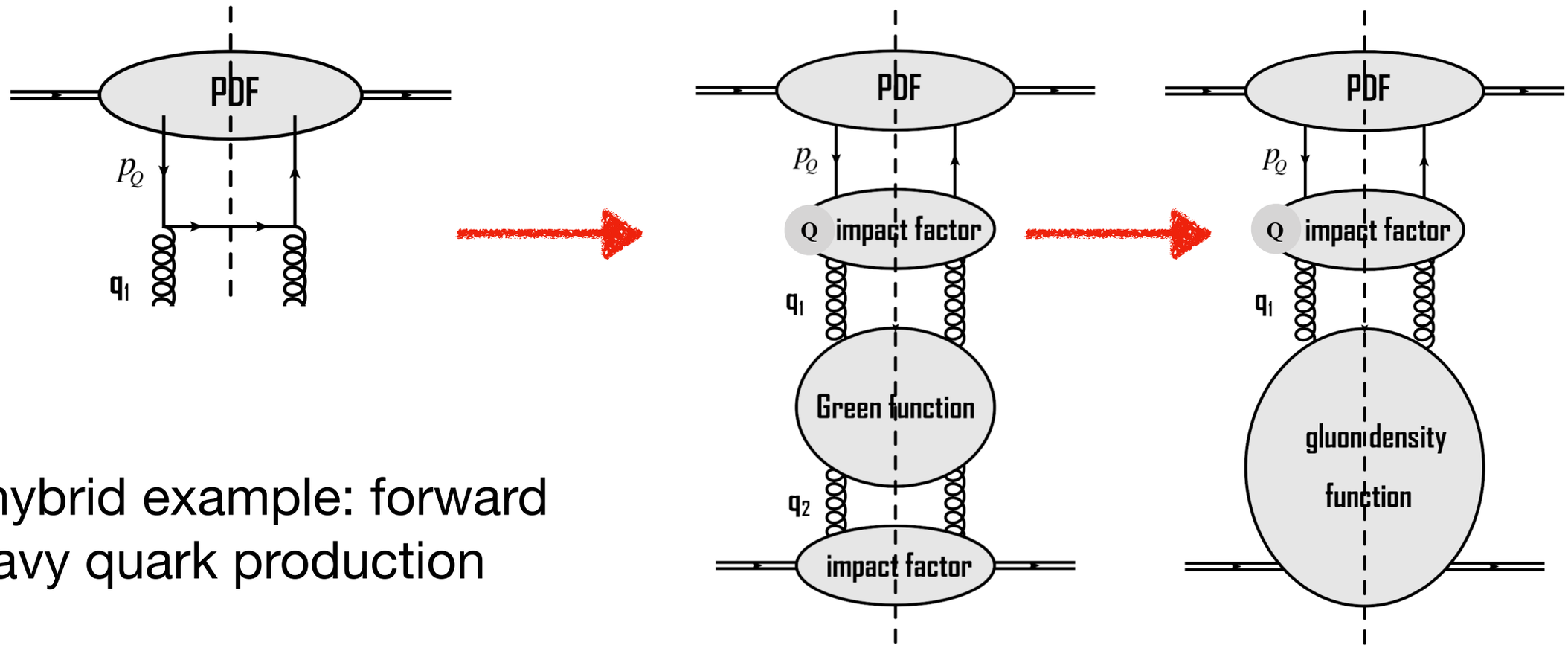
- The partonic cross section is convoluted with unintegrated gluon densities F

$$\mathcal{F}(x, k_{1\perp}) = \int \frac{d^2k_{2\perp}}{k_{2\perp}^2} \mathcal{G}^{\mathrm{BFKL}}(x, k_{1\perp}, k_{2\perp}) \Phi_p\left(k_{2\perp}, Q_0^2\right)$$



k_T-factorization scheme (and hybrids)

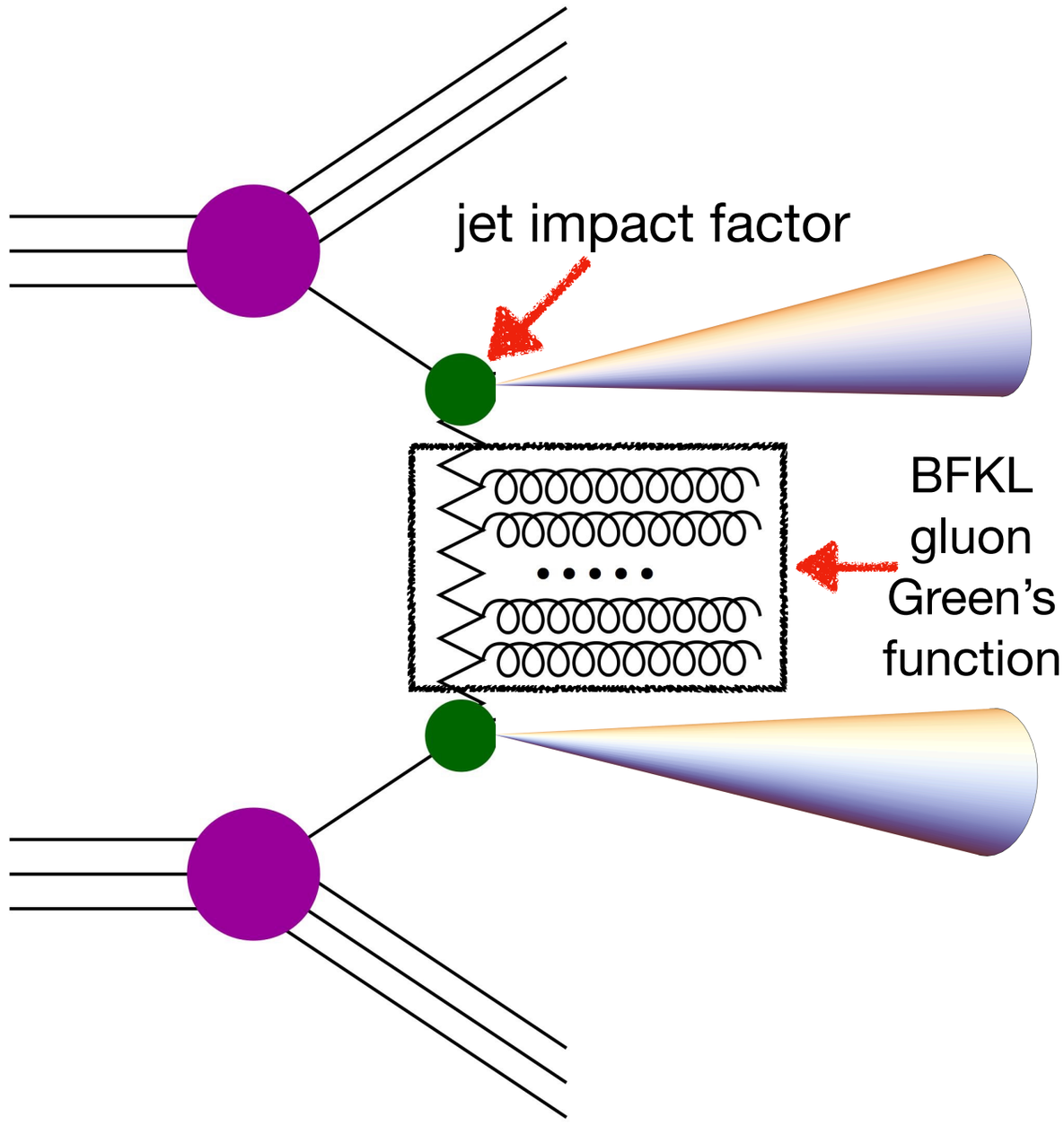
$$\sigma(s) = \int \frac{dx_1}{x_1} f_i(x_1)\, d^2k_{2\perp} \frac{dx_2}{x_2} \mathcal{F}(x_2, k_{2\perp})\, \hat{\sigma}(x_1 x_2 s,\, k_{1\perp} \to 0,\, k_{2\perp})$$



- A hybrid example: forward heavy quark production

Can BFKL live outside k_T-factorization?

- Indeed, it can also live within the collinear factorization scheme as long as the BFKL gluon Green's function governs the partonic cross section, e.g. Mueller-Navelet jets



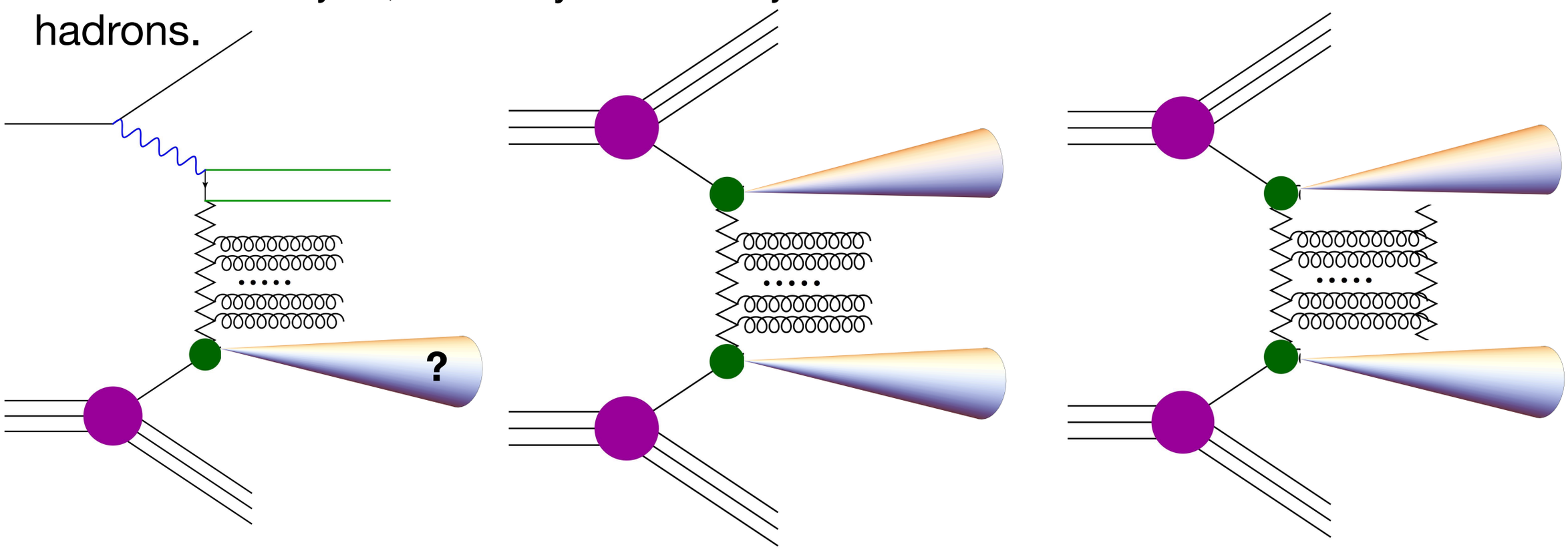
Where to look for BFKL related effects

BFKL is applicable in various scenarios, let us focus on two

1.Deep Inelastic Scattering (DIS) *

2.Production of two hard jets well separated in rapidity

Instead of two jets, one may have one jet and one hadron or even two hadrons.



Do we see BFKL related effects at the LHC?

- We know that after some energy, BFKL will be needed to stabilize the perturbative expansion and fixed order calculations within the collinear factorization scheme will not be enough.

- However, we do not know the energy window where BFKL is applicable

- Most promising channel at the LHC is ratios of azimuthal decorrelation quantities in Mueller-Navelet jet studies.

- However, this implies that we need differential information about the two jets (their azimuthal angle difference).

- One can also convincingly argue that PDFs at very low x need a BFKL inspired input.

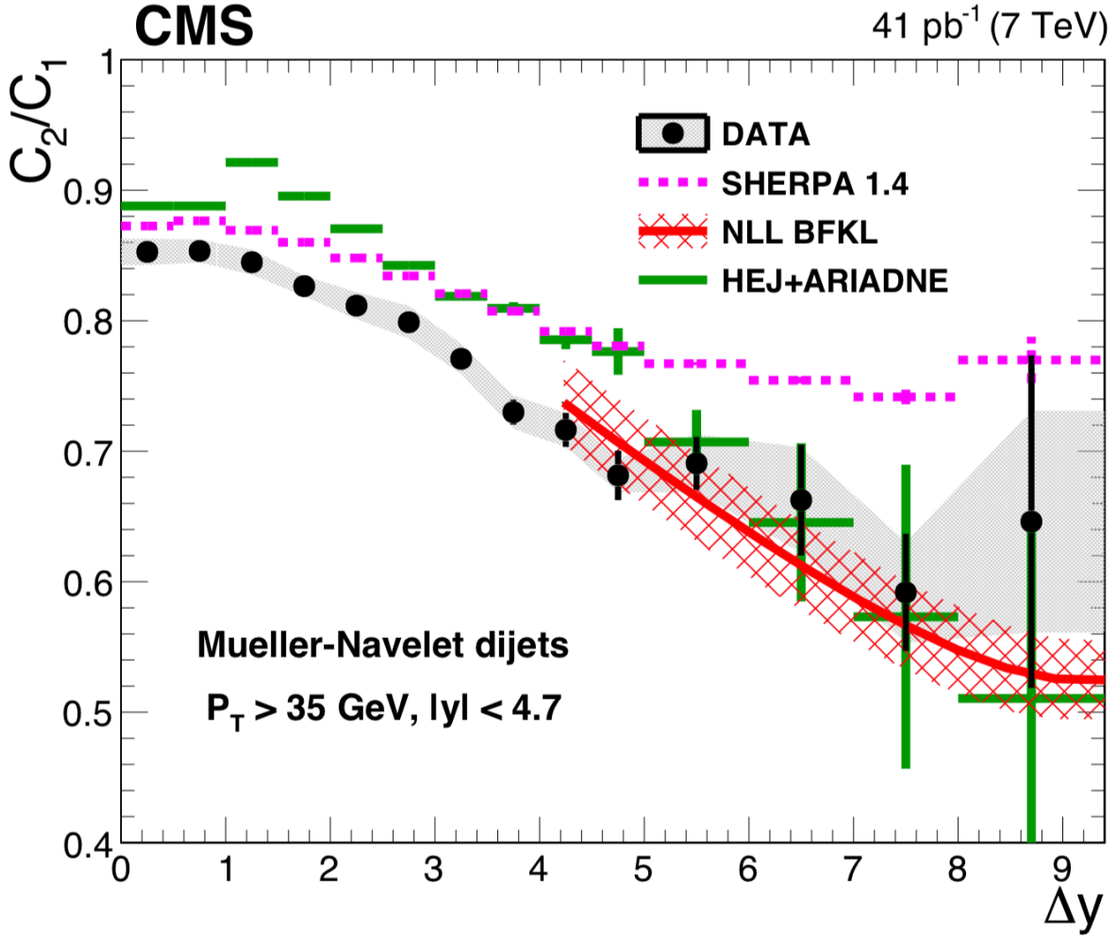
Do we see BFKL related effects at the LHC?

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}})\,\cos(n(\pi - \Delta\phi))\right]$$

- The normalized cross section for dijet production can be written as a Fourier series.

- The Fourier coefficients give the average cosines of (π-Δϕ): the decorralation angle.

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



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Could we search for BFKL signals using ATLAS and FPF?

- If we consider the case in which we have two hard scales in the final state well separated in rapidity, we need the transverse d.o.f of both in order to make predictions. If one of them is outside the ATLAS acceptance it will be really hard to “reconstruct” even if it is “detected” by the FPF. Moreover, to consider correlations in the azimuthal plane is impossible.

- However, heavy quark production in k_T-factorization with full mass effects is relevant, there is lots of work from the theory side to be done. See also talks by A. Stasto and M. V. Garzeli in the 2nd Forward Physics Facility meeting and the next talk by Dave Soper.

- DIS neutrino, could BFKL be relevant? See talk by J. Rojo today.

Should we study processes relevant for the FPF in the high energy limit?

- Yes we should. It could be that fixed order partonic cross sections (at sufficiently high order) convoluted with PDFs give stable predictions but there is a good chance that the perturbative expansion might have convergence issues.

- It will boost theoretical progress in computing and understanding within the k_T-factorization scheme at NLLA, there are still quite a few issues open (NLO impact factors with full mass dependence unknown, choice of renormalisation scale, collinear logs contamination, etc)

Back to those key considerations

- When high energy (low x) QCD is relevant? Is it relevant for the FPF physics program? ✅

- Should we really study the high energy limit of QCD at the FPF? ✅

- Can we combine the FPF with ATLAS to take complementary measurements and probe high energy QCD? ❓

Thanks a lot for your attention!