Azimuthal decorelations in forward-central dijet production

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Based on:arXiv 1404.6204

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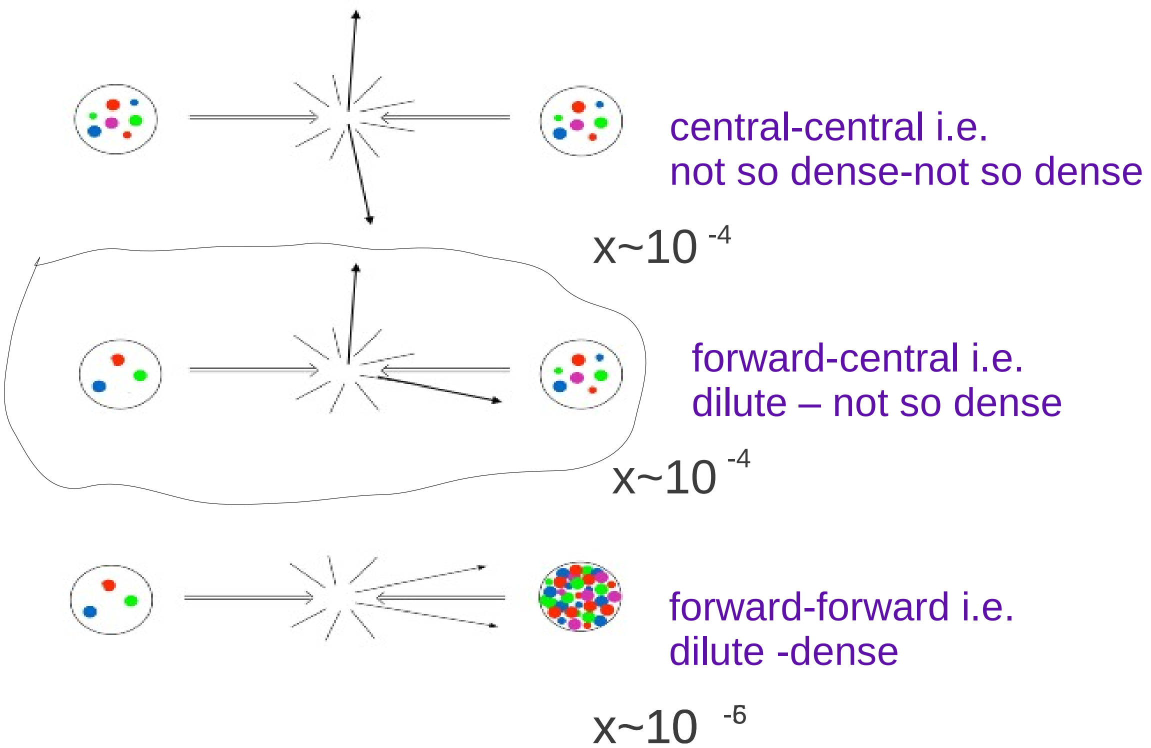
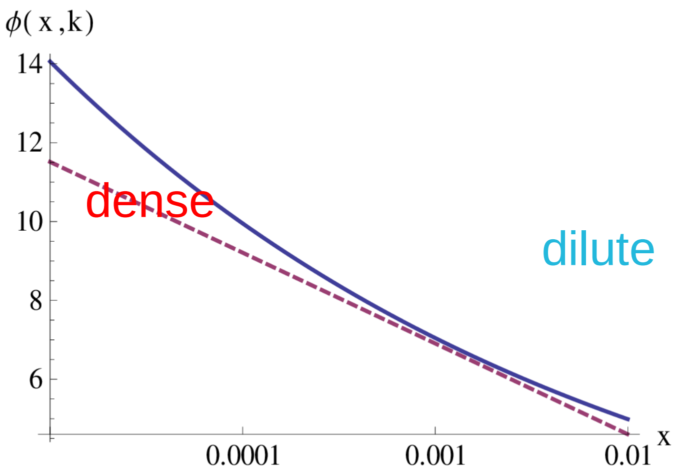
LHC as a scanner of gluon





See Pedro Cipriano, talk
See Piotr Kotko talk

QCD at high energies – high energy factorization

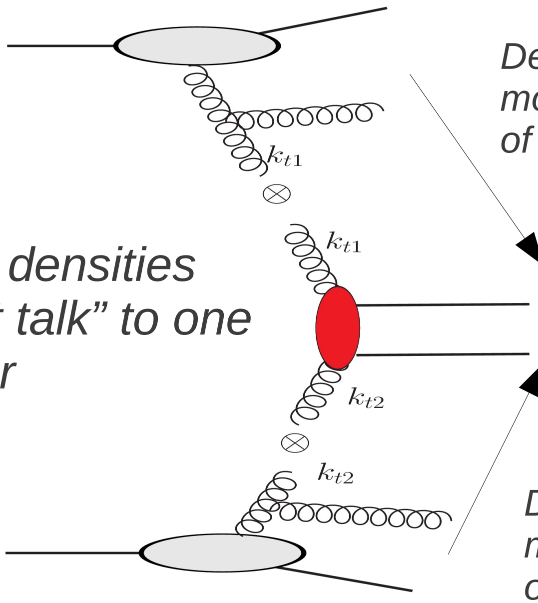
$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1t} d^2p_{2t}} = \sum_{a,b,c,d} \int \frac{d^2k_{1t}}{\pi}\frac{d^2k_{2t}}{\pi}\frac{1}{16\pi^2(x_1x_2S)^2}\overline{|\mathcal{M}_{ab\to cd}|^2}\delta^2(\vec{k}_{1t}+\vec{k}_{2t}-\vec{p}_{1t}-\vec{p}_{2t}) \times \mathcal{F}_{a/A}(x_1,k_{1t}^2,\mu^2)\,\mathcal{F}_{b/B}(x_2,k_{2t}^2,\mu^2)\,\frac{1}{1+\delta_{cd}}$$

$$k_1^\mu = x_1 P_1^\mu + \bar{x}_1 P_2^\mu + k_{1t}^\mu \qquad k_2^\mu = x_2 P_2^\mu + \bar{x}_2 P_1^\mu + k_{2t}^\mu$$

$$\bar{x}_1 = \frac{k_1^2 + \mathbf{k}^2}{Sx_1} \qquad \bar{x}_2 = \frac{k_2^2 + \mathbf{k}^2}{Sx_2}$$

Parton densities “do not talk” to one another

$$|\mathcal{M}_{ab\to cd}|^2 = \frac{2x_1 k_1^{\mu_1} k_1^{\nu_1}}{k_1^2}\frac{2x_2 k_2^{\mu_2} k_2^{\nu_2}}{k_2^2}\mathcal{M}_{ab\to cd\,\mu_1\nu_1}\mathcal{M}^*_{ab\to cd\,\mu_2\nu_2}$$



Decreasing longitudianl momentum fractions of off-shell partons

Decreasing longitudianl momentum fractions of off-shell partons

Gribov, Levin, Ryskin '81
Ciafaloni, Catani, Hautman '93

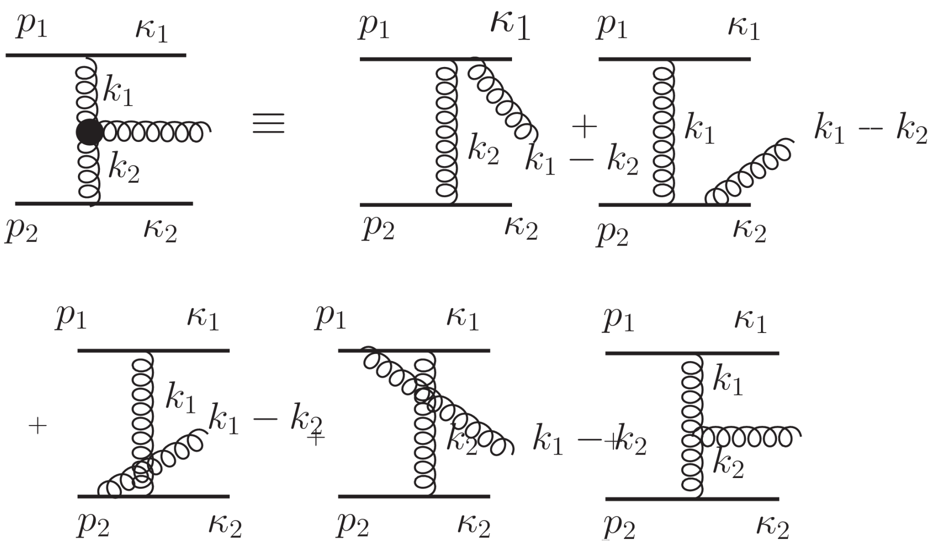
Originally derived for heavy quarks in final state.
Therefore no problem of division into density and ME
Gluons more tricky. Possible double counting

Some trials to generalized to p-A
Dominguez, Huan, Marquet,Xiao '10

Does not take into account MPI as formulated in DGLAP i.e. emissions from independent chains

The BFKL evolution

Balitsky, Fadin, Kuraev, Lipatov '77



$$1 \gg \alpha_1 \gg \alpha_2$$

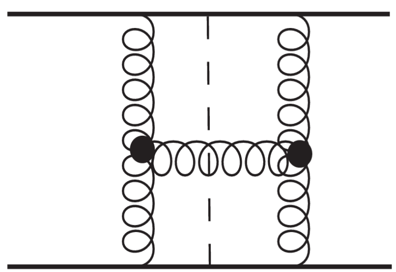
$$1 \gg |\beta_1| \gg |\beta_2|$$

$$k_1 = \alpha_1 p_1 + \beta_1 p_2 + k_{1t}$$

$$k_2 = \alpha_2 p_1 + \beta_2 p_2 + k_{2t}$$

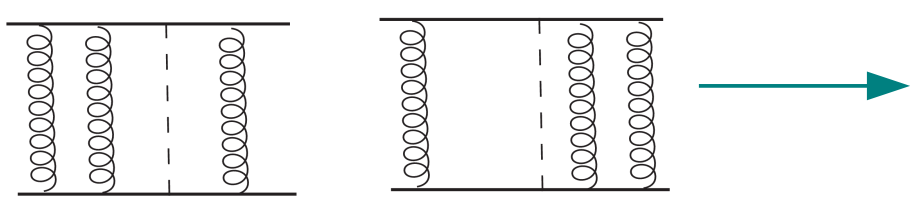
$$iA^\rho_{2\to3} = (-2ig_2 p_1^\mu) t^a_{mj} \left(\frac{-i}{k_1^2}\right) f_{abc} g_s \Gamma^\rho_{\mu\nu}(k_1,k_2) \left(\frac{-i}{k_2^2}\right) (-2ig_s p_2^\nu) t^b_{nl}$$

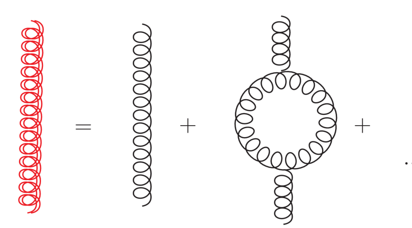
- *Known also for SM YM*
- *Studied also in context of AdS/CFT*
- *Known up to NLO*
- *No saturation*
- *No applicable to final states: "evolution without observer"*



$$J^\mu = -ig\bar{u}(p_1+q)\gamma^\mu u(p_1) \approx -2ig_s p_1^\mu$$

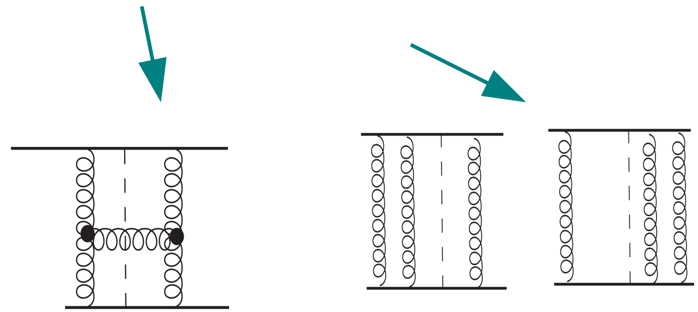
reggeized gluon

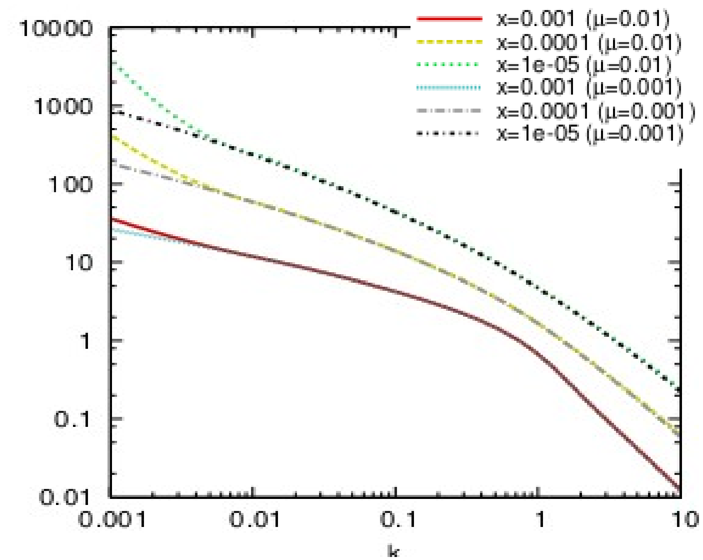


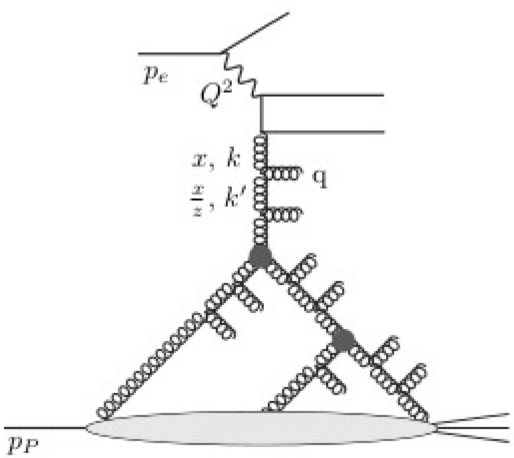


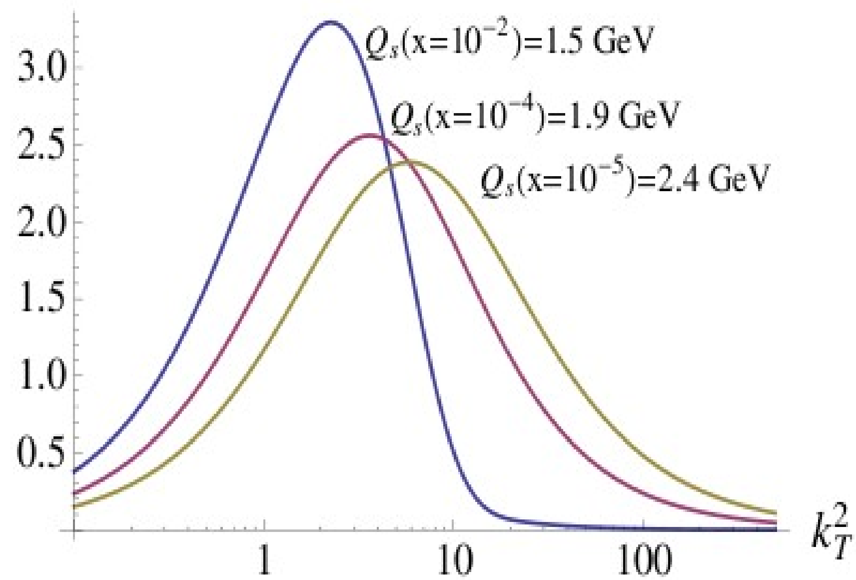
The BFKL and BK evolutions - solutions

$$\mathcal{F}(x,k^2) = \mathcal{F}_0(x,k^2) + \overline{\alpha}_s \int_{x/x_0}^{1} \frac{dz}{z} \int_0^\infty \frac{dl^2}{l^2}\left[\frac{l^2\mathcal{F}(x/z,l^2) - k^2\mathcal{F}(x/z,k^2)}{|k^2-l^2|} + \frac{k^2\mathcal{F}(x/z,k^2)}{\sqrt{(4l^4+k^4)}}\right]$$









$$\mathcal{F}(x,k^2) = \mathcal{F}_0(x,k^2) + \overline{\alpha}_s \int_{x/x_0}^{1} \frac{dz}{z} \int_0^\infty \frac{dl^2}{l^2}\left[\frac{l^2\mathcal{F}(x/z,l^2) - k^2\mathcal{F}(x/z,k^2)}{|k^2-l^2|} + \frac{k^2\mathcal{F}(x/z,k^2)}{\sqrt{(4l^4+k^4)}}\right]$$

$$-\frac{2\alpha_s^2\pi}{N_c R^2}\int_{x/x_0}^{1}\frac{dz}{z}\left\{\left[\int_{k^2}^{\infty}\frac{dl^2}{l^2}\mathcal{F}(x/z,l^2)\right]^2 + \mathcal{F}(x/z,k^2)\int_{k^2}^{\infty}\frac{dl^2}{l^2}\ln\left(\frac{l^2}{k^2}\right)\mathcal{F}(x/z,l^2)\right\}$$

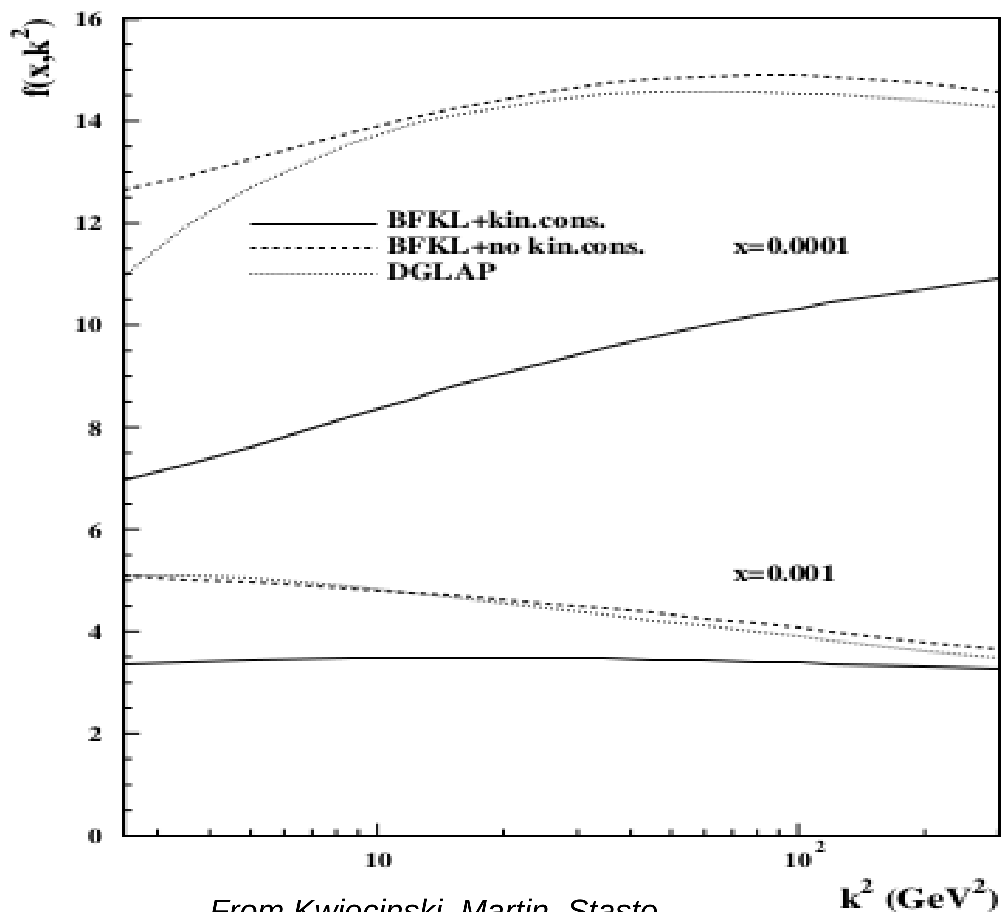
BFKL with subleading corrections
Kwiecinski, Martin, Staśto prescription

Nonsingular pieces of splitting function

Kinematical effects i.e. Momentum of gluon dominated by it's transversal component

Running coupling

In principle not applicable to final states since no hard scale dependence

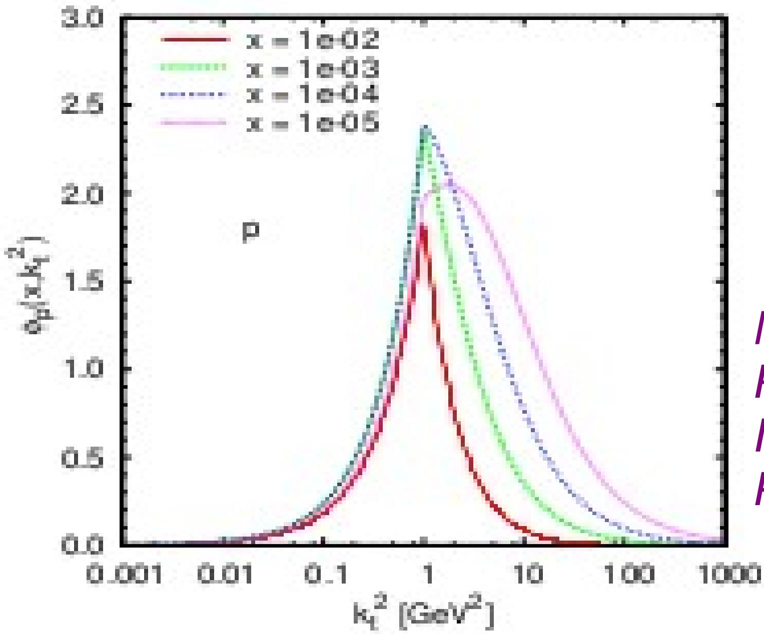


From Kwiecinski, Martin, Stasto
Phys.Rev. D56 (1997) 3991-4006

$$f(x,k^2) = k^2 \mathcal{F}(x,k^2)$$

$$\begin{aligned}\mathcal{F}_p(x,k^2) &= \mathcal{F}_p^{(0)}(x,k^2) \\ &+ \frac{\alpha_s(k^2)N_c}{\pi}\int_x^1 \frac{dz}{z}\int_{k_0^2}^{\infty}\frac{dl^2}{l^2}\left\{\frac{l^2\mathcal{F}_p(\frac{x}{z},l^2)\,\theta(\frac{k^2}{z}-l^2)\,-\,k^2\mathcal{F}_p(\frac{x}{z},k^2)}{|l^2-k^2|}+\frac{k^2\mathcal{F}_p(\frac{x}{z},k^2)}{|4l^4+k^4|^{\frac{1}{2}}}\right\} \\ &+ \frac{\alpha_s(k^2)}{2\pi k^2}\int_x^1 dz\left(P_{gg}(z)-\frac{2N_c}{z}\right)\int_{k_0^2}^{k^2} dl^2\,\mathcal{F}_p(\frac{x}{z},l^2)\end{aligned}$$

Unintegrated gluon density from BK with corrections



Nonlinear equation for unintegrated gluon density.
Related to BK via Fourier transform
Includes corrections of higher order Kwiecincki, KK 2002
Fitted to latest HERA data Sapeta, KK 2011

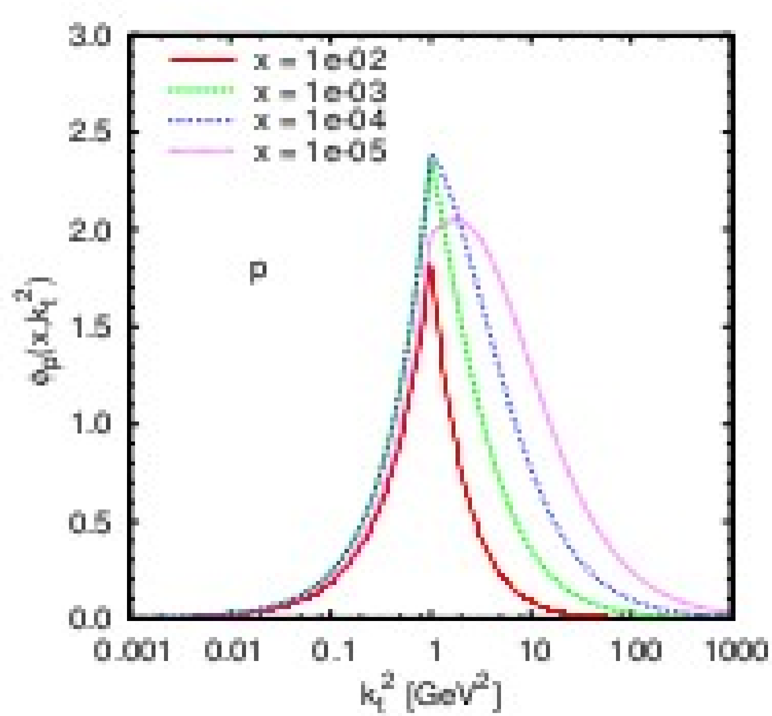
$$\begin{aligned}\mathcal{F}_p(x,k^2) \;=\; & \mathcal{F}_p^{(0)}(x,k^2) \\ & + \frac{\alpha_s(k^2)N_c}{\pi}\int_x^1 \frac{dz}{z}\int_{k_0^2}^{\infty}\frac{dl^2}{l^2}\left\{\frac{l^2\mathcal{F}_p(\frac{x}{z},l^2)\,\theta(\frac{k^2}{z}-l^2)-k^2\mathcal{F}_p(\frac{x}{z},k^2)}{|l^2-k^2|}+\frac{k^2\mathcal{F}_p(\frac{x}{z},k^2)}{|4l^4+k^4|^{\frac{1}{2}}}\right\} \\ & + \frac{\alpha_s(k^2)}{2\pi k^2}\int_x^1 dz\left(P_{gg}(z)-\frac{2N_c}{z}\right)\int_{k_0^2}^{k^2} dl^2\,\mathcal{F}_p(\frac{x}{z},l^2) \\ & - \frac{2\alpha_s^2(k^2)}{R^2}\left[\left(\int_{k^2}^{\infty}\frac{dl^2}{l^2}\mathcal{F}_p(x,l^2)\right)^2+\mathcal{F}_p(x,k^2)\int_{k^2}^{\infty}\frac{dl^2}{l^2}\ln\left(\frac{l^2}{k^2}\right)\mathcal{F}_p(x,l^2)\right]\end{aligned}$$

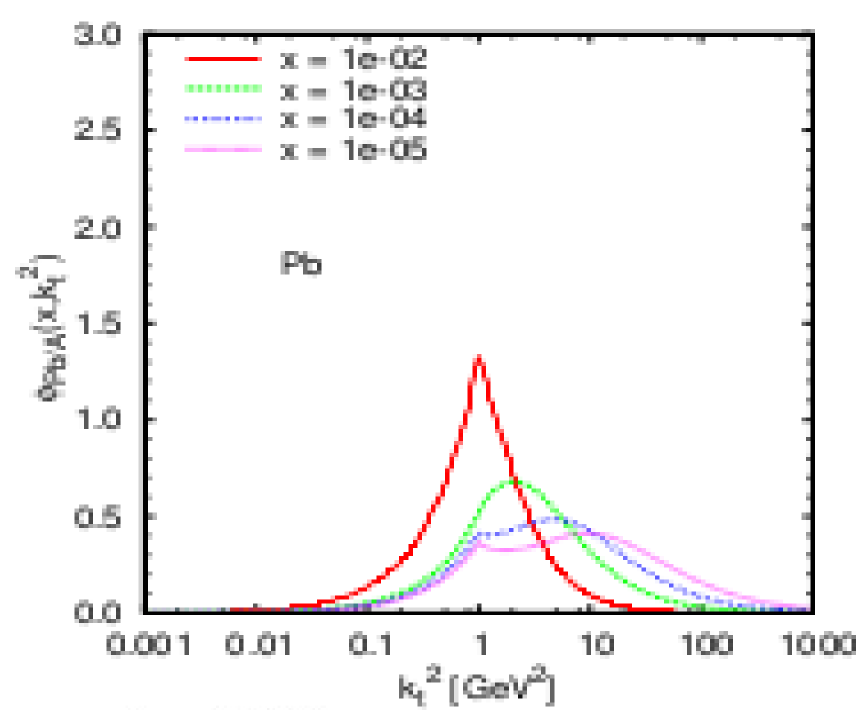
Kwiecinski, KK '03

Corrections
of higher orders
Included.
Kin. Constr
DGLAP spf

Andersson, Gustafson,Sammuelsson '96
Kwiecinski, Martin, Stasto '96,

Glue in p vs. glue in Pb





$R_A = R\,A^{1/3}$

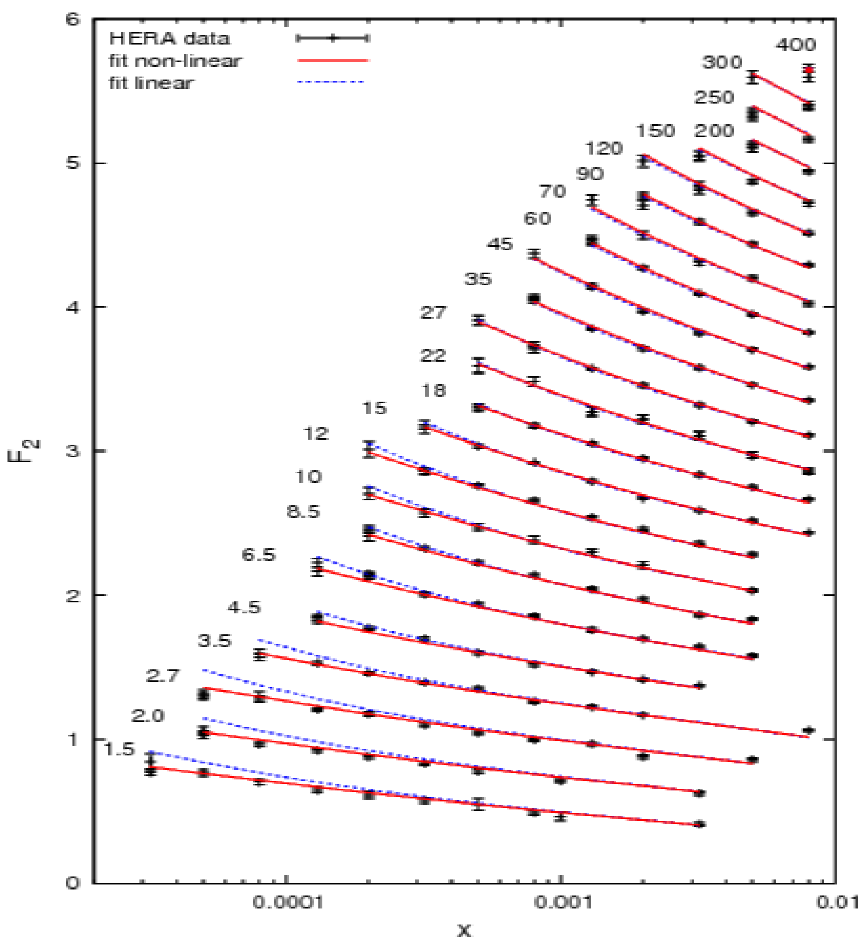
Nonlinear equation for unintegrated gluon density.

Related to BK via Fourier transform

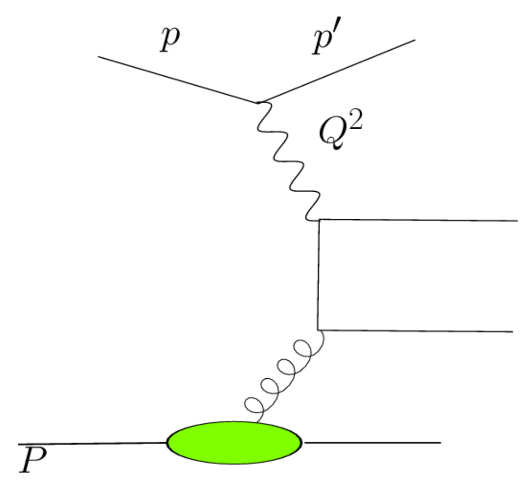
Includes corrections of higher order Kwiecincki, KK 2002

Fitted to latest HERA data Sapeta, KK 2011

BFKL applied to DIS - some recent results



Sapeta, KK '12



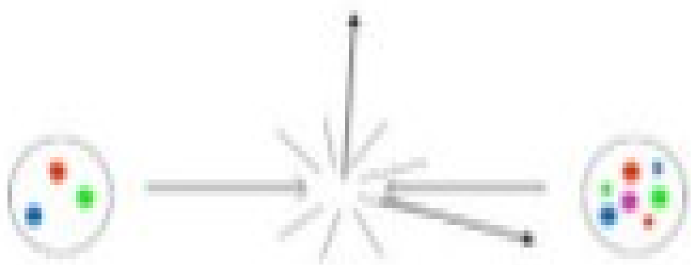
FromBK equation with corrections of higher order

High energy prescription and forward-central di-jets

Deak, Jung, Hautmann Kutak
JHEP 0909:121,2009

$$\frac{d\sigma}{dy_1 dy_2 dp_{1t} dp_{2t} d\Delta\phi} = \sum_{a,c,d} \frac{p_{t1} p_{t2}}{8\pi^2 (x_1 x_2 S)^2} |\mathcal{M}_{ag\to cd}|^2 x_1 f_{a/A}(x_1,\mu^2)\, \mathcal{F}_{g/B}(x_2,k^2) \frac{1}{1+\delta_{cd}}$$

$S = 2P_1 \cdot P_2$



- Resummation of logs of x and logs of hard scale
- Knowing well pdf at large x one can get information about low x physics
- Framework goes recently under name "hybride framework"

$$x_1 = \frac{1}{\sqrt{S}}\left(p_{t1} e^{y_1} + p_{t2} e^{y_2}\right) \xrightarrow{y_1 \sim 0,\, y_2 \gg 0} \sim 1$$

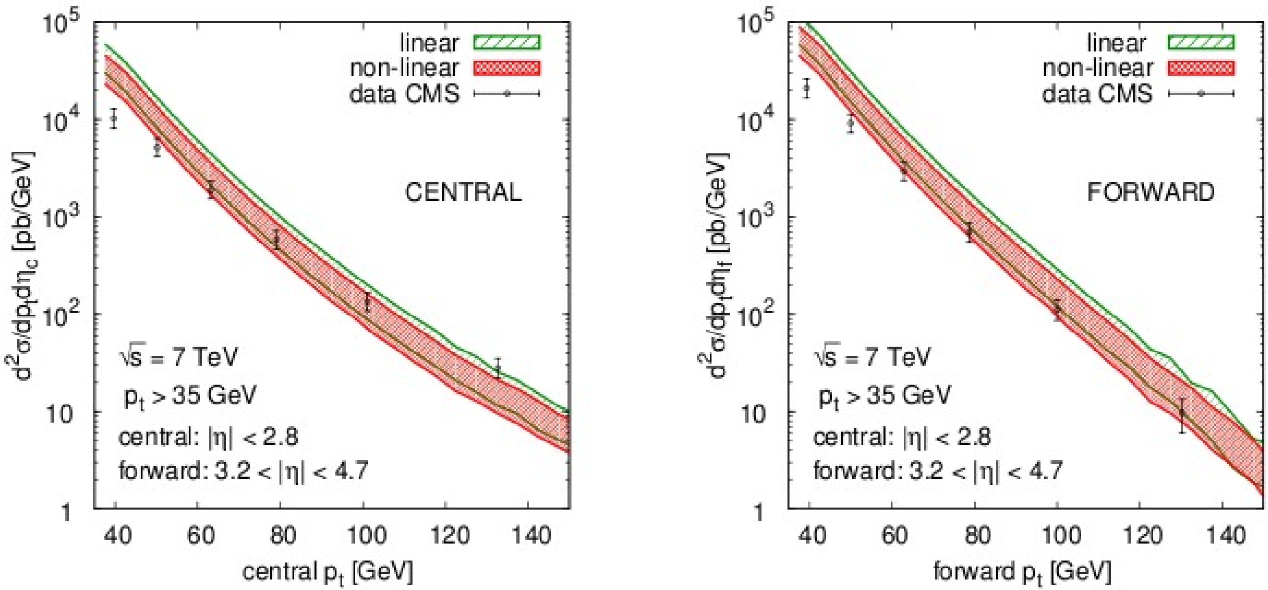
$$x_2 = \frac{1}{\sqrt{S}}\left(p_{t1} e^{-y_1} + p_{t2} e^{-y_2}\right) \qquad \ll 1$$

$$k_1^\mu = x_1 P_1^\mu$$

$$k_2^\mu = x_2 P_2^\mu + k_t^\mu$$

Di-jets p_t spectra

S.Sapeta. KK ,12

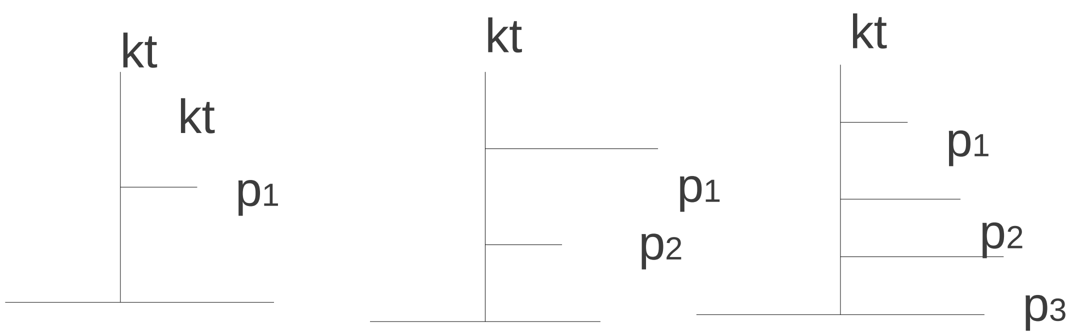


Reasonable agreement.

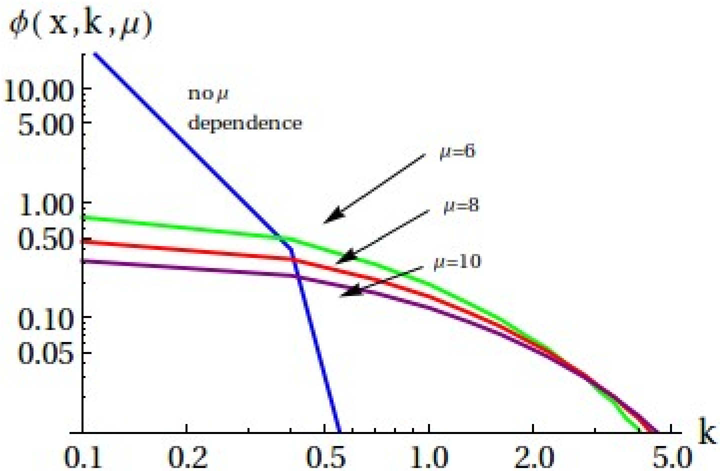
Gluon emissions are unordered in pt and udd up to $k_t = |p_1+p_2+.....p_n|$

During evolution time incoming gluon becomes off-shell

Crucial effect of higher order corrections

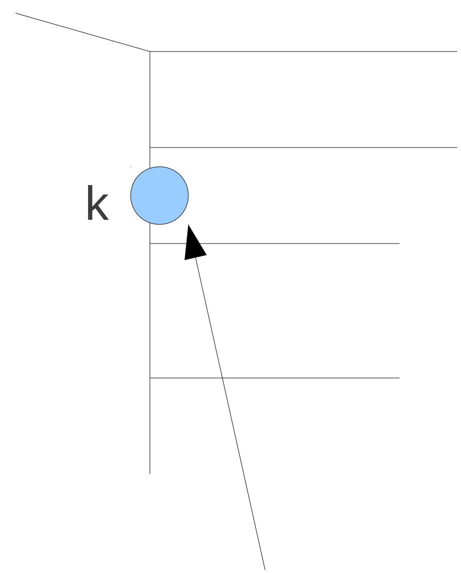


Final states via Sudakov effects - illustration



Two scale dependent gluon density vs. one scale dependent

Probability of finding no real gluon
Between scales μ



Survival probability of the gap without emissions

$$T_a(k_t,\mu) = \exp\left(-\int_{k_t^2}^{\mu^2} \frac{\alpha_s(p_t^2)}{2\pi}\,\frac{dp_t^2}{p_t^2}\sum_{a'}\int_0^{1-\Delta} P_{a'a}(z')\,dz'\right)$$

Kimber, Martin, Ryskin framework '01

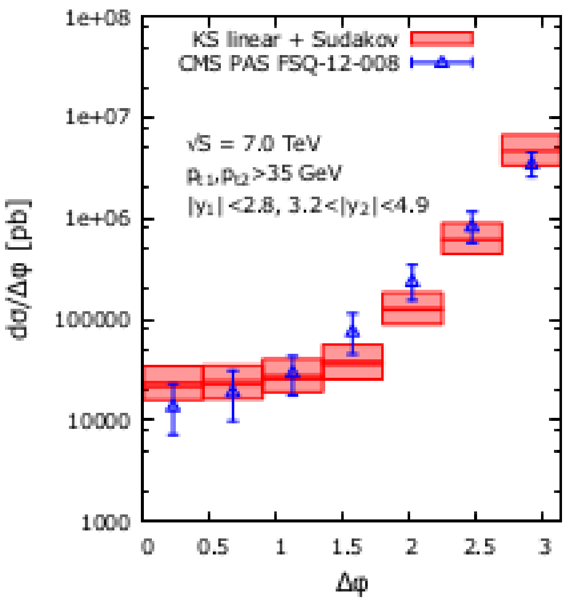
Mueller, Xiao, Huan ;13

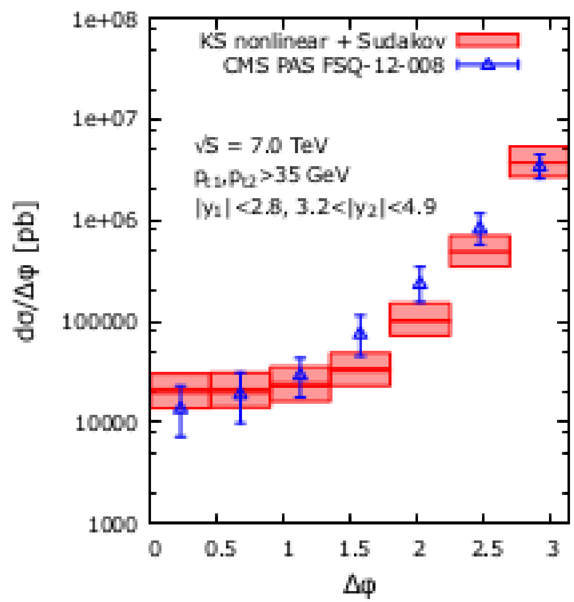
Tools to be used

- *General tool for matrix elements within HEF based on spinor helicity method (A. van Hameren)*
- *Gauge link based tool to evaluate matrix elements (OGIME P. Kotko)*
- *Monte Carlo for production of dijets, trijets within HEF with Sudakov effect LxJet (P. Kotko)*
- *Tool for forward dijets Forward (S. Sapeta)*

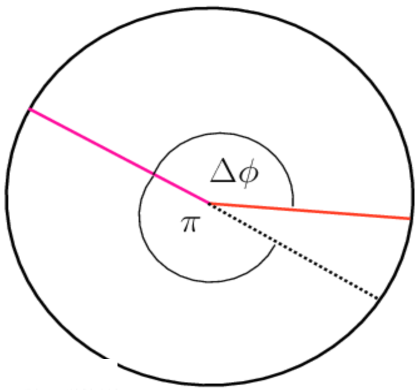
Decorelations inclusive scenario

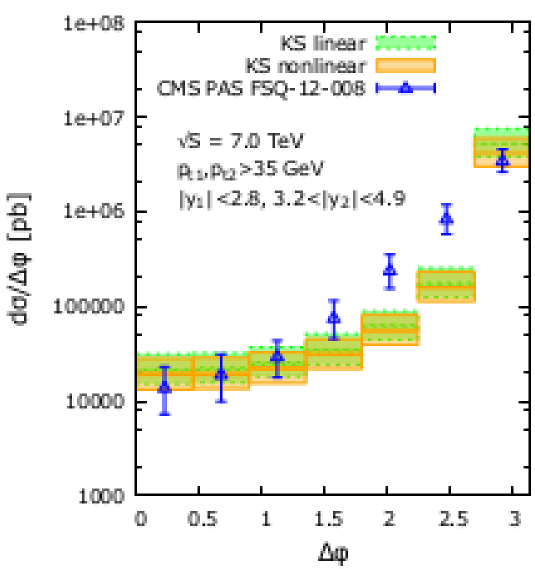
A.v.Hameren, P.Kotko, KK, S.Sapeta '14





pt1,pt2 >35, leading jets
|y1|<2.8, 3.2<|y2|<4.7
No further requirement on jets





In DGLAP approach
i.e 2 → 2 + pdf one would
Get delta function at

$$\Delta\phi = \pi$$

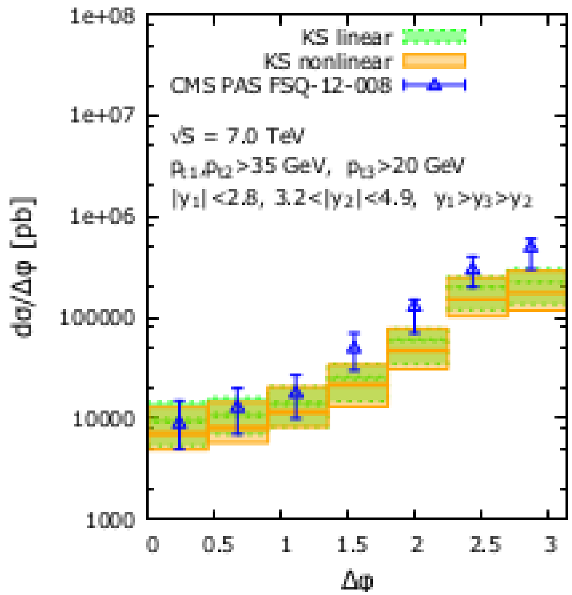
Sudakov effects by reweighting implemented in LxJet Monte Carlo P. Kotko

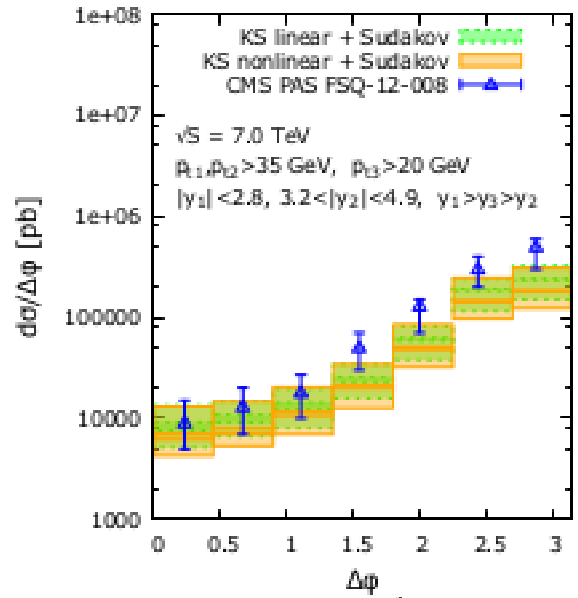
Observable suggested to study BFKL effects
Sabio-Vera, Schwensen '06

Studied also context of RHIC
Albacete, Marquet '10

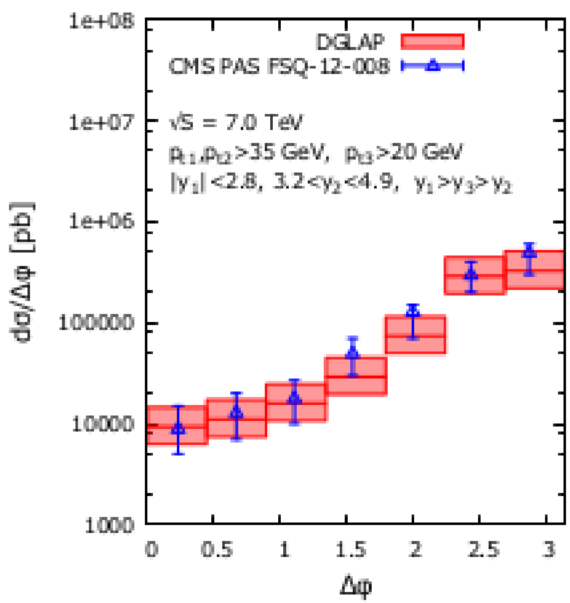
Decorelations inside jet tag scenario

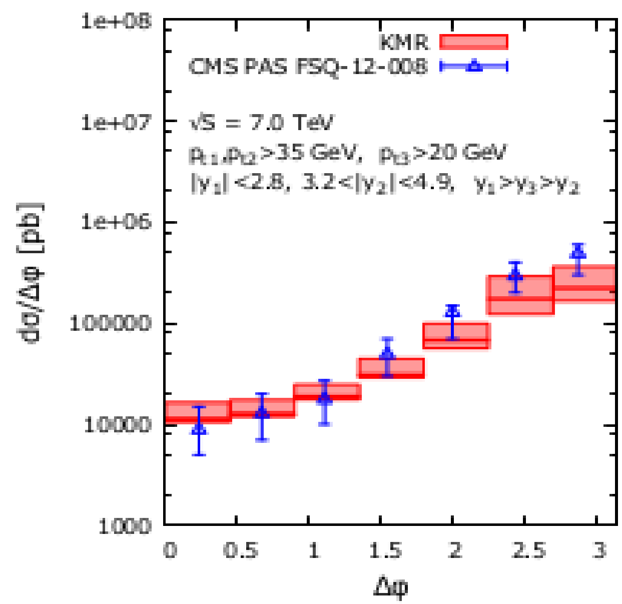
A.v.Hameren, P.Kotko, KK, S.Sapeta '14

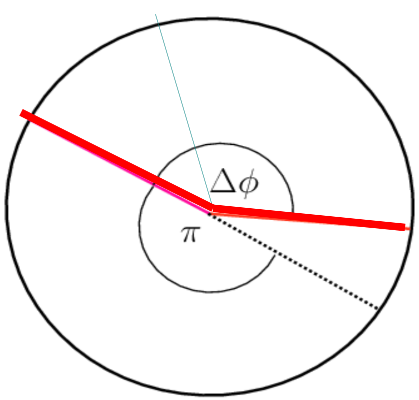




pt1, pt2 >35 GeV, leading jets |y1|<2.8, 3.2<|y2|<4.7 Third jet pt>20GeV. Between the forward and central region



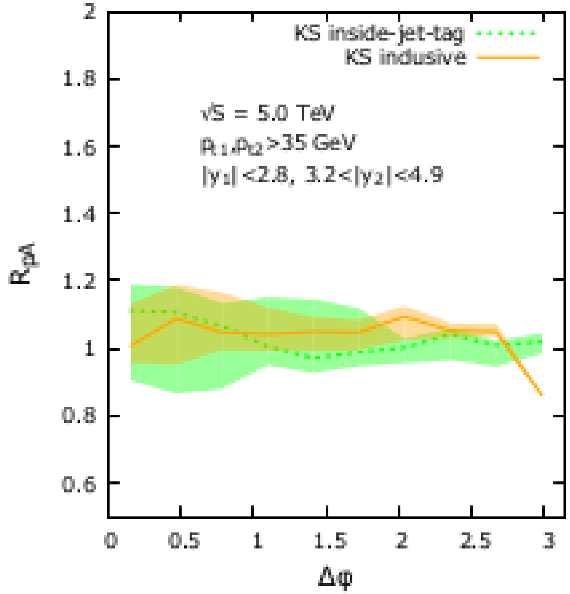


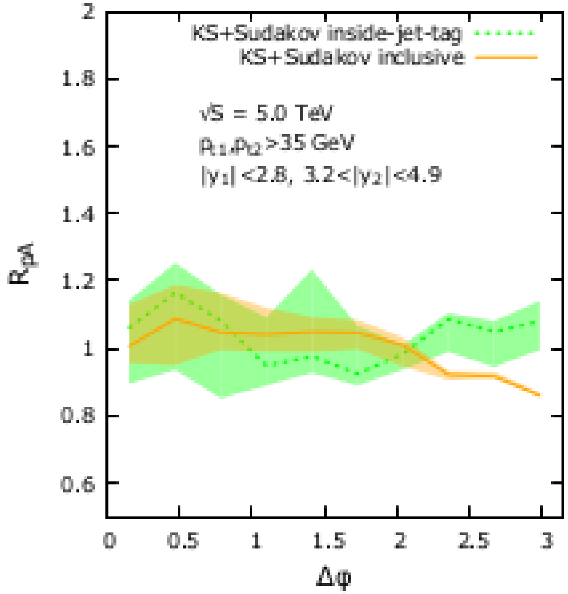


Sudakov effects by reweighting implemented in LxJet Monte Carlo P. Kotko

Predictions for p-Pb

A.v.Hameren, P.Kotko, KK, S.Sapeta '14





- *Sudakov enhance saturation effects*
- *Hawever, satuartion effects are rather weak*

Conclusions and outlook

- *Achieved very good description of forward-central jet measurement*
- *Predictions for pPb are robust*
- *Evidence for low x dynamics*
- *MC tool for calculations within HEF – LxJet has been upgraded to include Sudakov effects*
- *Open questions – description of the decorelations within CCFM. It includes Sudakov, and low x dynamics.*