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Production of forward jets in high energy factorization

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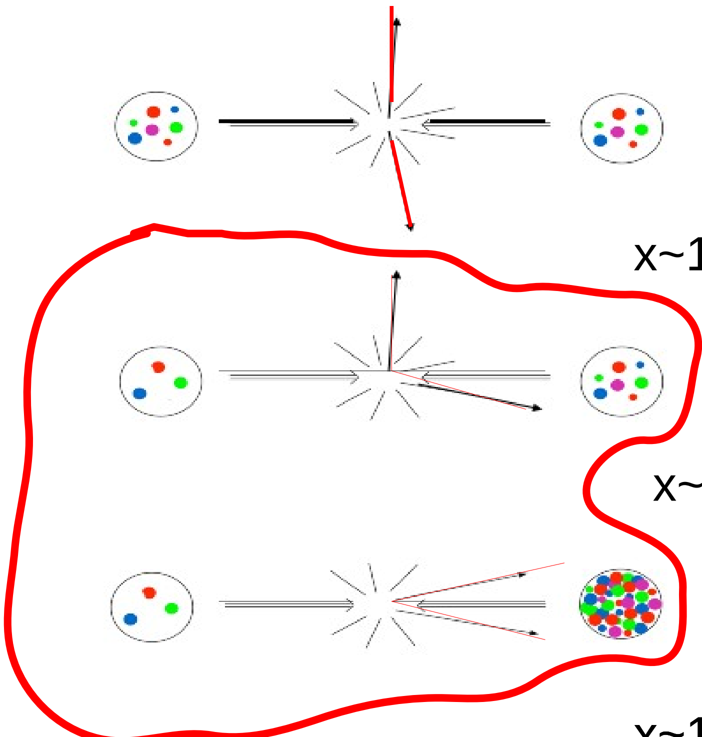
Based on:
1409.3822 K.Kutak
Phys.Lett. B737 (2014) 335-340, A. van Hameren, P. Kotko, K. Kutak, S. Sapeta
Phys. Rev. D 89, 094014 (2014), A. van Hameren, P. Kotko, K. Kutak, C. Marquet, S. Sapeta
Phys. Rev. D 86, 094043 (2012), Krzysztof Kutak, Sebastian Sapeta

LHC as a scanner of gluon



central-central i.e. dilute dilute

x~10 $^{-4}$

forward-central i.e. dilute – dense

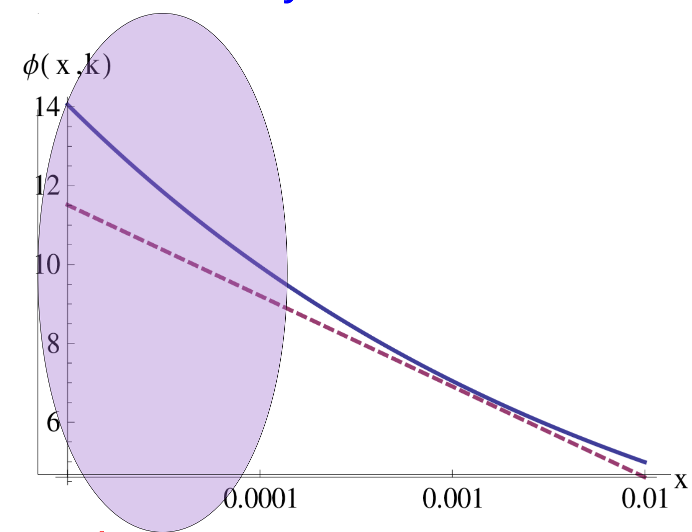
x~10 $^{-4}$

forward-forward i.e. dilute - dense

x~10 $^{-6}$

Plot from
Cyrille Marquet

Gluon density



dense

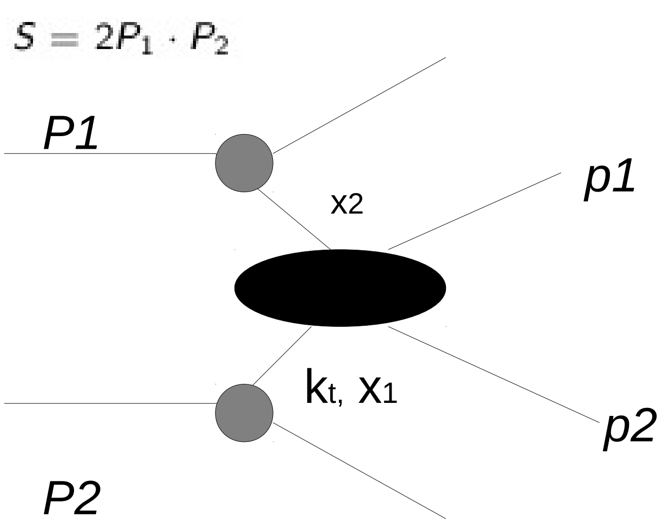
dilute

Hybrid factorization and dijets

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

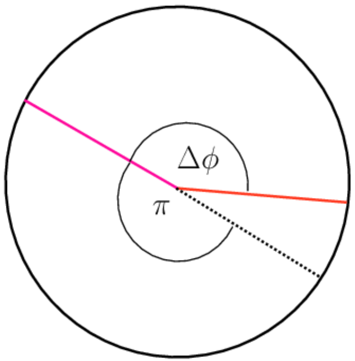
Can be obtained from CGC after neglecting nonlinearities
In that limit gluon density is just the dipole gluon density

Deak, Jung, KK,Hautmann '09
Deak, Jung,KK, Hautmann' 10



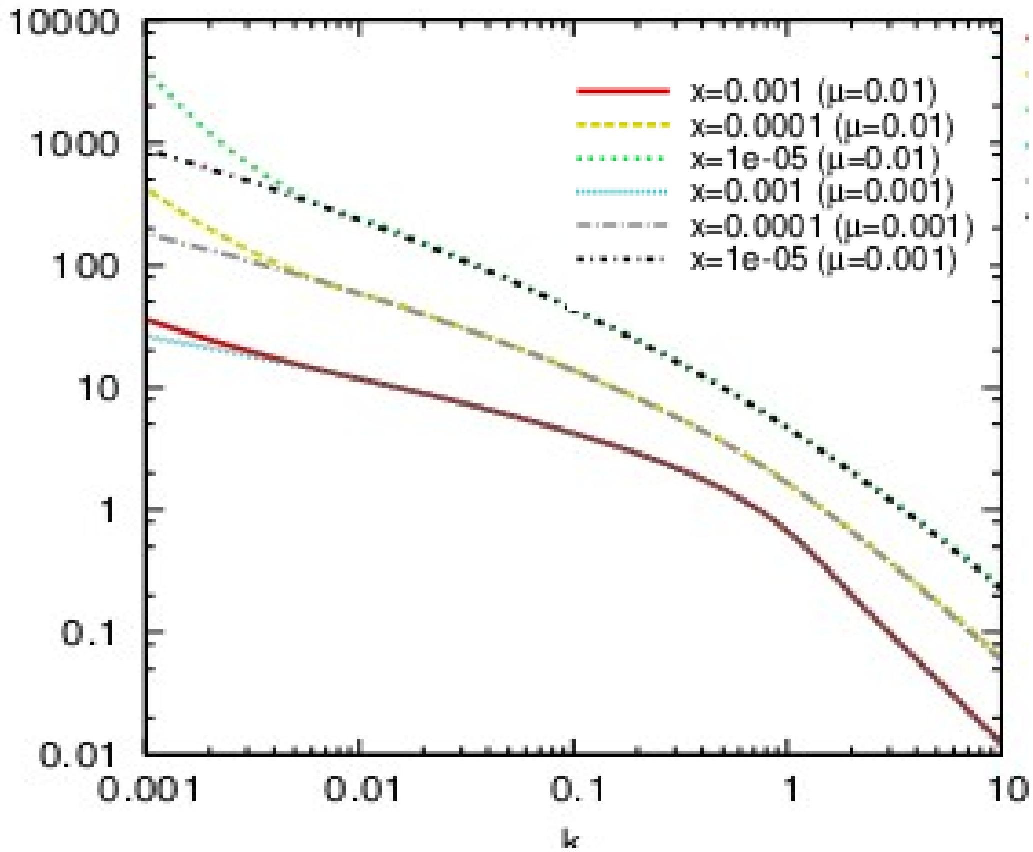
$$\mathcal{F}(x,k^2) = \frac{N_c}{\alpha_s (2\pi)^3} \int d^2 b \int d^2 r\, e^{ik\cdot r} \nabla_r^2 N(r,b,x)$$

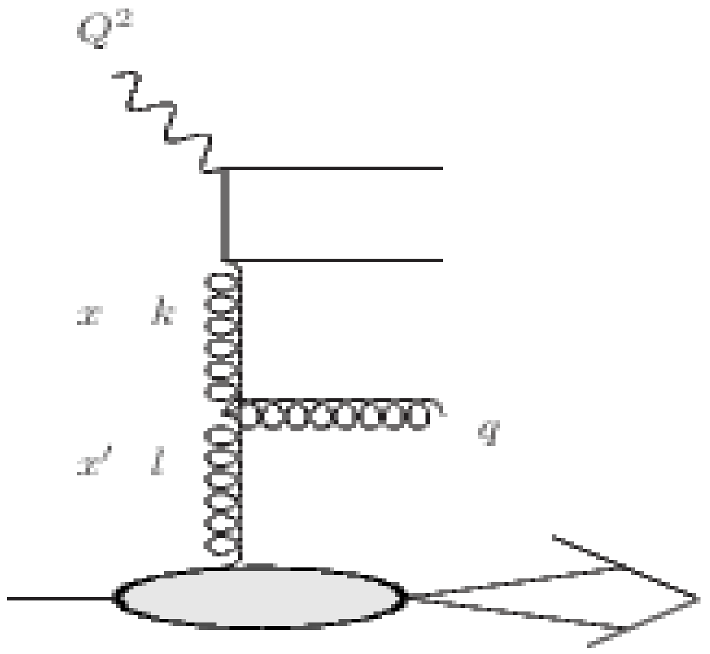
Consistent with definition of gluon density from
Dominguez, Marquet, Xiao, Yuan '10



- *Resummation of logs of x and logs of hard scale*
- *Knowing well parton densities at large x one can get information about low x physics*

The BFKL equation





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

when k>>l →

$$\mathcal{F}(x,k^2) = \mathcal{F}_0(x,k^2) + \bar{\alpha}_s \int_{x/x_0}^{1} \frac{dz}{z} \int_{k_0^2}^{k^2} dl^2 \frac{\mathcal{F}(x/z,l^2)}{k^2}$$

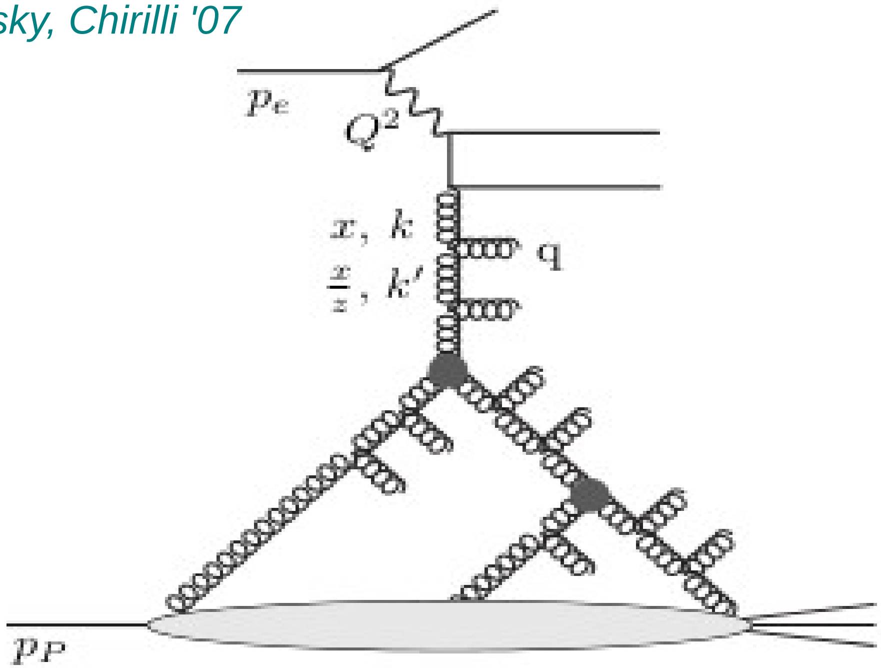
The BK equation for unintegrated gluon density

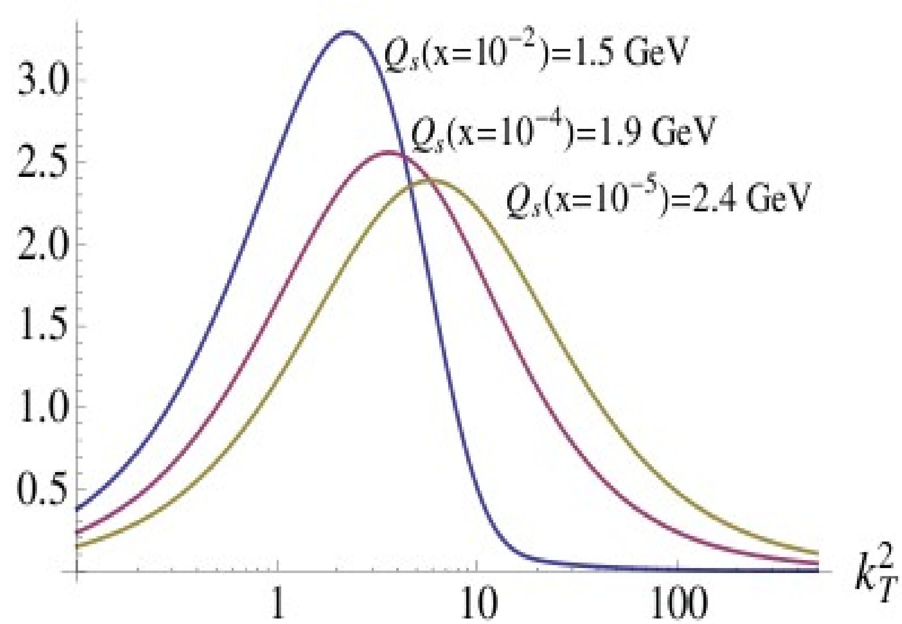
Originally formulated in "x" space

Balitsky '96, Kovchegov'99

Now at NLO accuracy

Balitsky, Chirilli '07



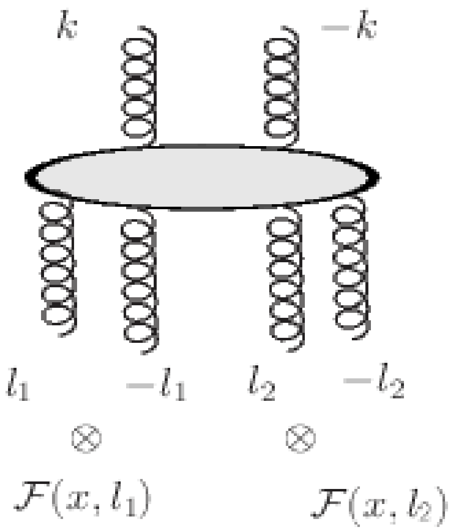


$$\mathcal{F}(x,k^2) = \mathcal{F}_0(x,k^2) + \overline{\alpha}_s \int_{x/x_0}^{1} \frac{dz}{z} \int_0^\infty \frac{dl^2}{l^2} \left[\frac{l^2\mathcal{F}(x/z,l^2) - k^2\mathcal{F}(x/z,k^2)}{|k^2-l^2|} + \frac{k^2\mathcal{F}(x/z,k^2)}{\sqrt{(4l^4+k^4)}} \right]$$
$$-\frac{2\alpha_s^2\pi}{N_c R^2} \int_{x/x_0}^{1}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

Kwiecinski, KK '01

Nikolaev, Schafer '06

The BK equation



$$\mathcal{V}(k,-k;l_1,-l_1,l_2,-l_2) = \frac{\pi\alpha_s^2}{N_c R^2}\Big[2\theta(l_1^2-k^2)\theta(l_2^2-k^2) + k^2\ln\frac{l_1^2}{l_2^2}\delta(l_1^2-k^2)\theta(l_2^2-l_1^2)$$
$$+k^2\ln\frac{l_2^2}{l_1^2}\delta(l_2^2-k^2)\theta(l_1^2-l_2^2)\Big]$$

Bartel,KK '07

Anticollinear pole dominates
TPV is 0 in DLL

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

when k>>l

$$\mathcal{F}(x,k^2) = \mathcal{F}_0(x,k^2) + \bar{\alpha}_s\int_{x/x_0}^1\frac{dz}{z}\int_{k_0^2}^{k^2} dl^2\,\frac{\mathcal{F}(x/z,l^2)}{k^2}$$

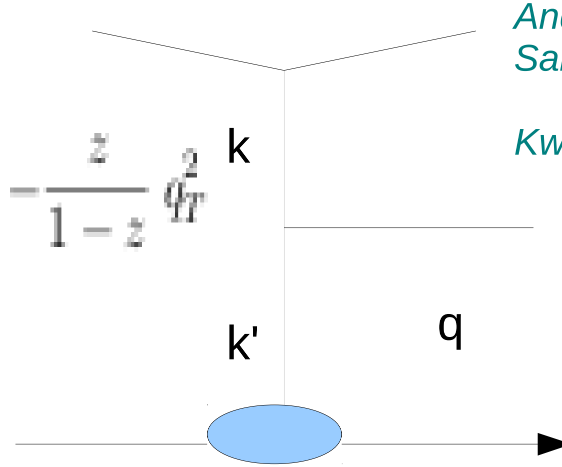
The kinematical constraint effects

Andersson,Gustafson
Samuelsson, Kharraziha '96

Kwiecinski, Martin, Sutton '97

$$k^2 = k^+k^- - k_T^2 \qquad k_T^2 > |k^+k^-|$$

$$k^+k^- \simeq -\frac{k^+}{q^+} q_T^2 = -\frac{k^+}{k'^+ - k^+} q_T^2 = -\frac{z}{1-z} q_T^2$$

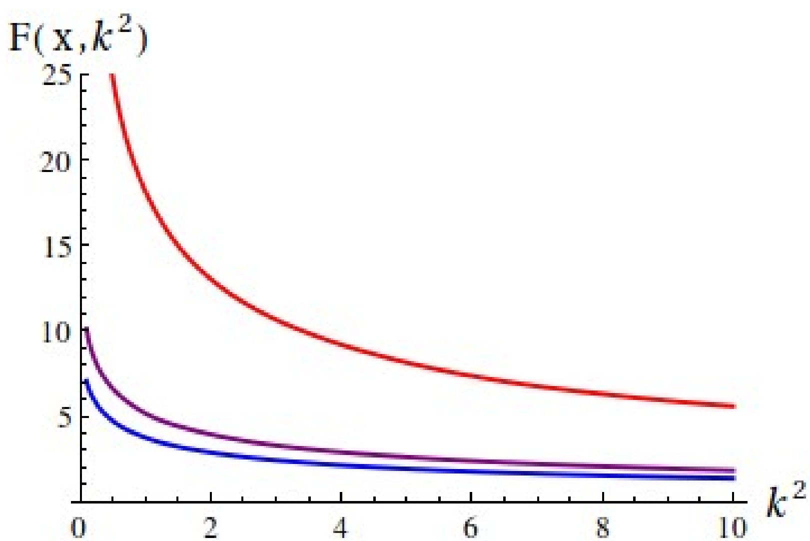


$$\theta\left(\frac{k_T^2}{q_T^2} - z\right)$$

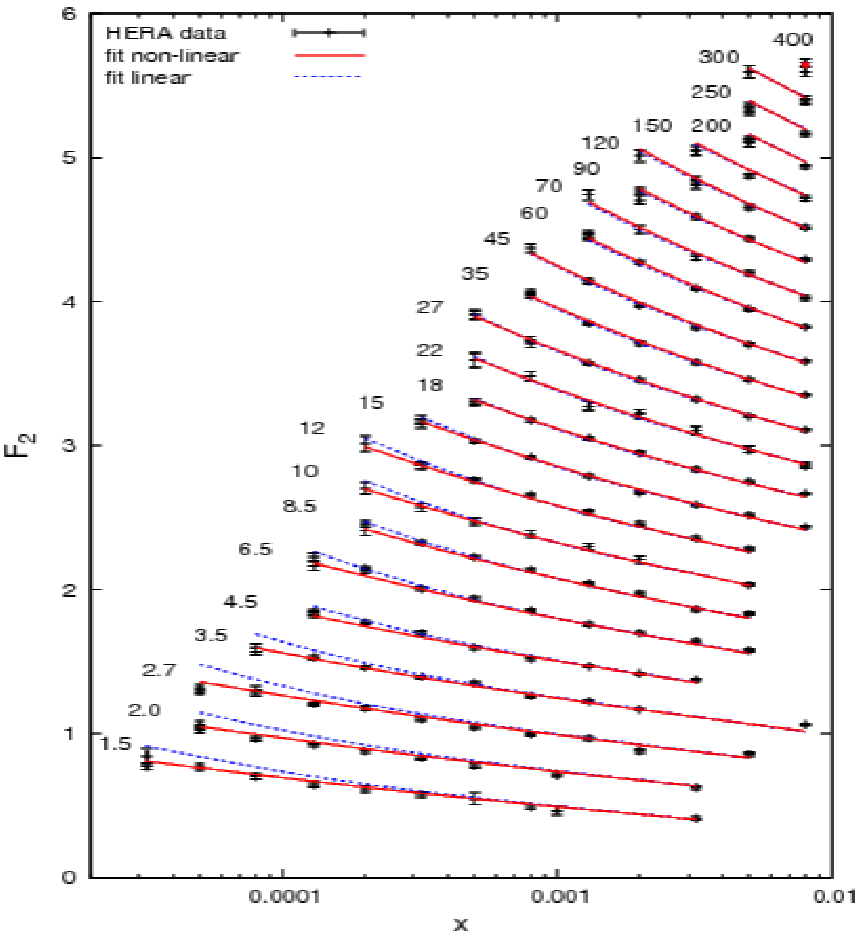
antilollinear limit

$$l \gg k \qquad \theta\left(\frac{k_T^2}{l_T^2} - z\right)$$

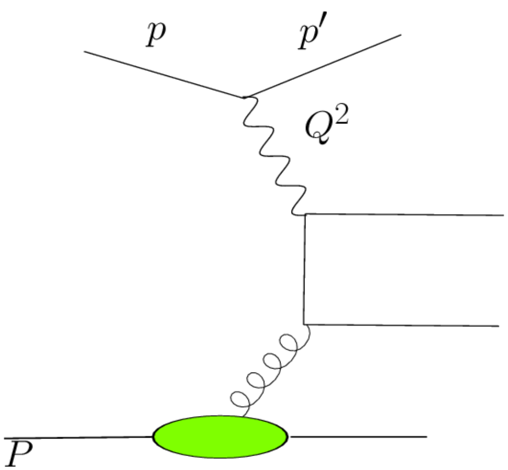
$$f(x,k^2) = f_0(x,k^2) + \bar{\alpha}_s \int_x^1 \frac{dz}{z} \int_0^\infty \frac{dl^2}{l^2} \left[\frac{\theta(k^2/l^2 - z) f(x/z, l^2) - f(x/z, k^2)}{|k^2 - l^2|} + \frac{f(x/z, k)}{\sqrt{(4l^4 + k^4)}} \right]$$



BFKL applied to DIS - some recent results

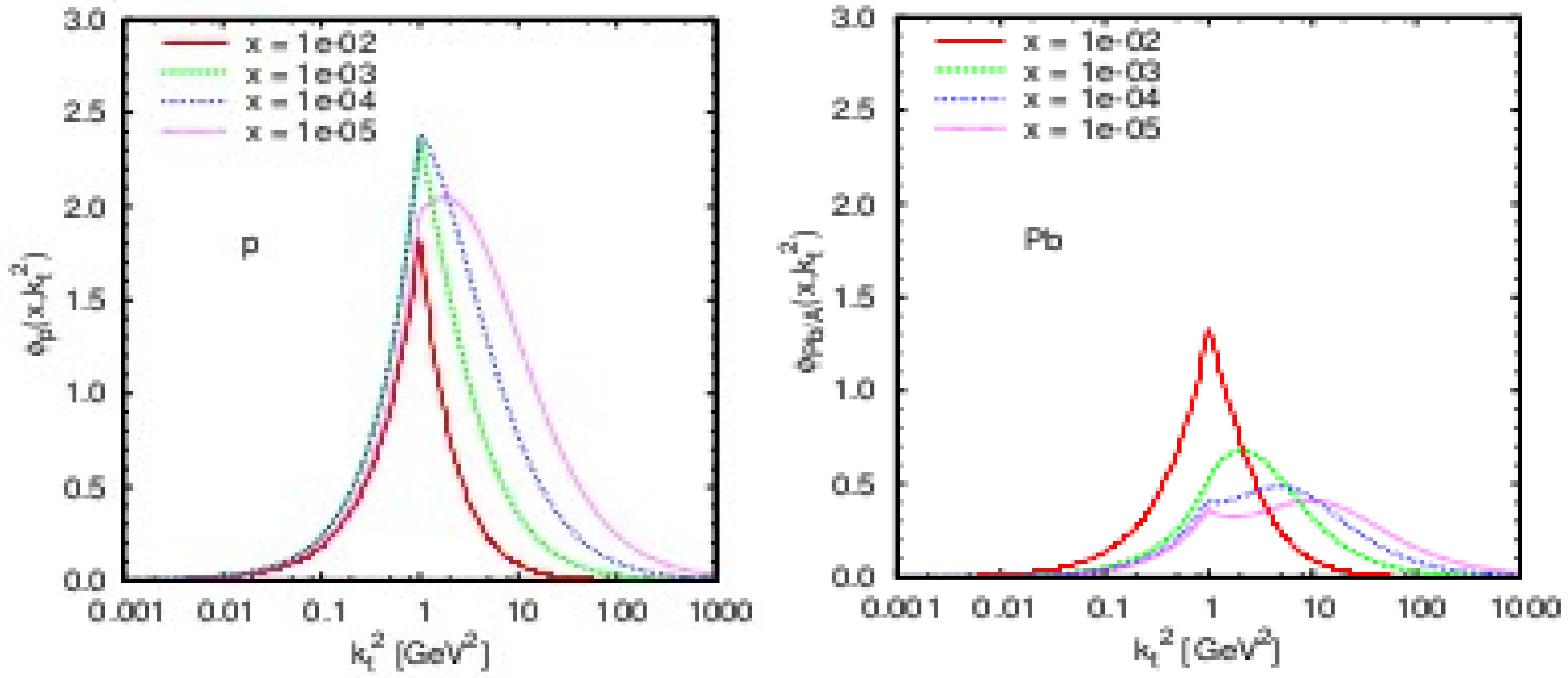


Sapeta, KK '12

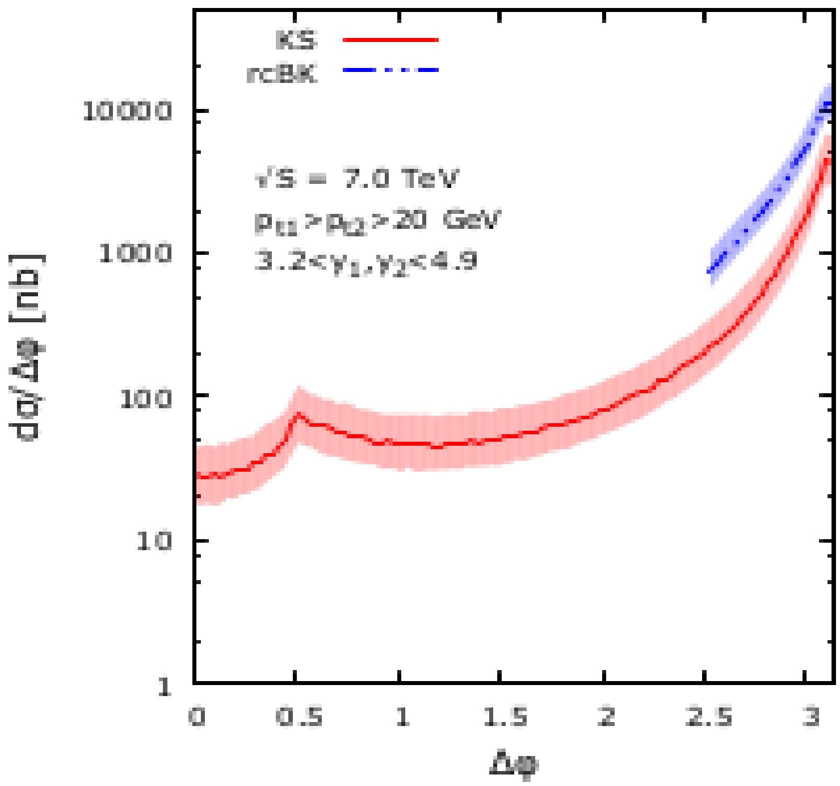


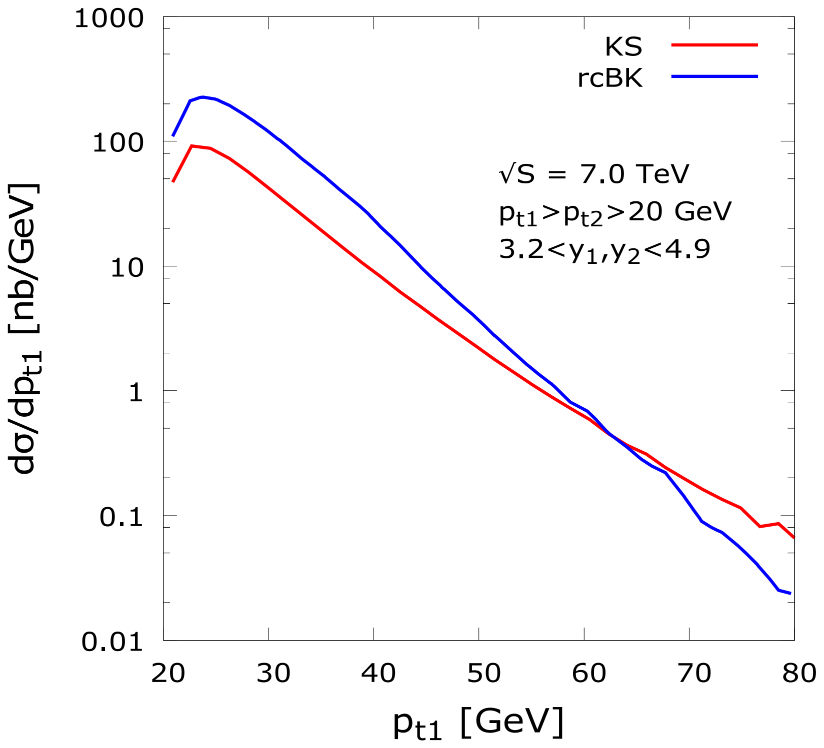
FromBK equation with corrections of higher order

Glue in p vs. glue in Pb



Results for decorelations



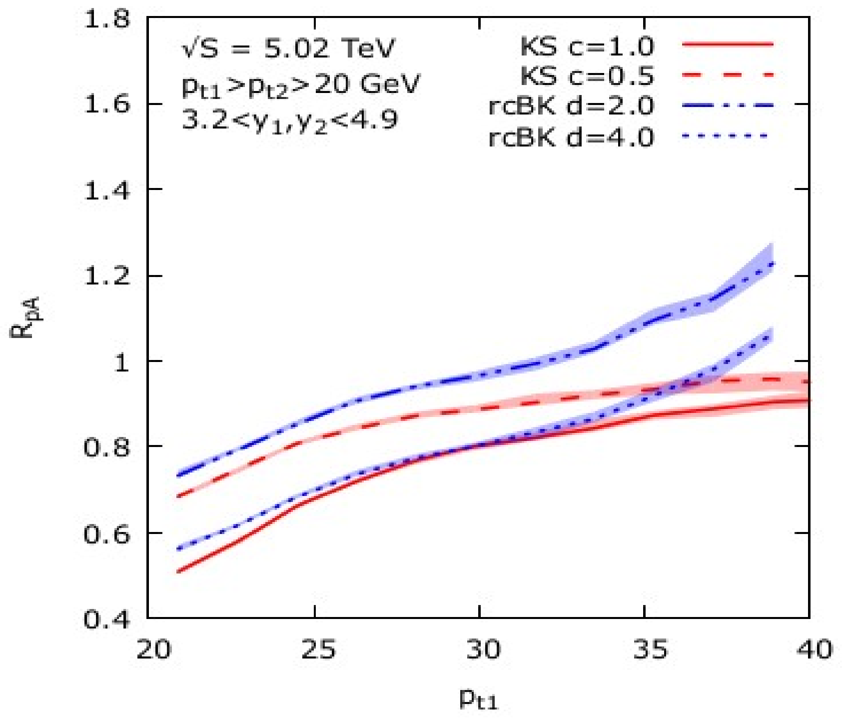


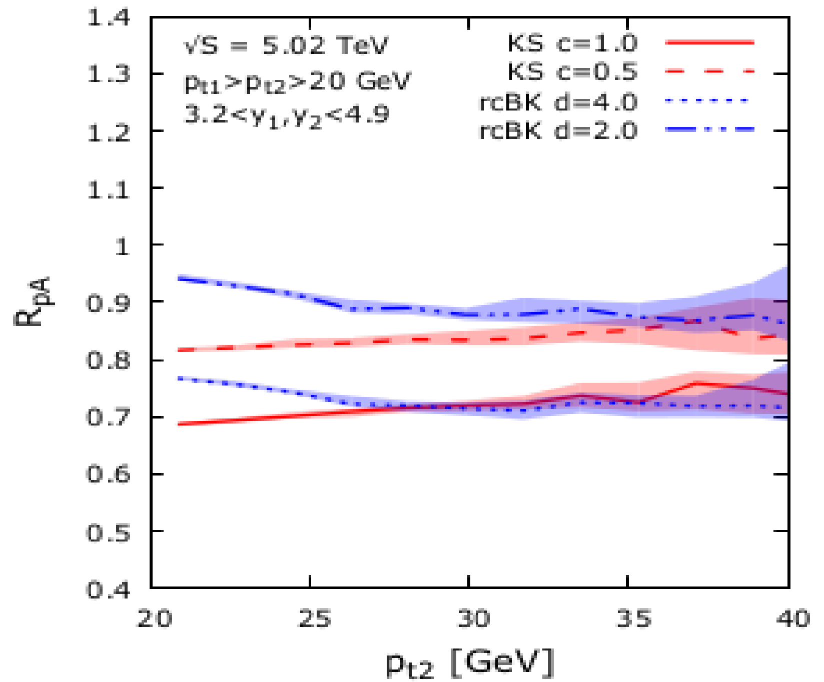
Results obtained with gluons coming from two prescriptions to improve the LL BK equation

Better behaviour of KS at large pt

Forward-forward dijets

A. van Hameren, Kotko,KK,Marquet, Sapeta '14



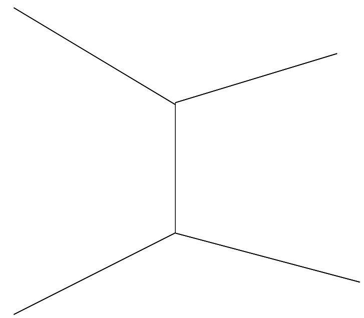


rcBK: not correct at large pt
KS: reaches unity at large pt

Studies of sub-leading jet gives more pronounced signal of nonlinear effects.

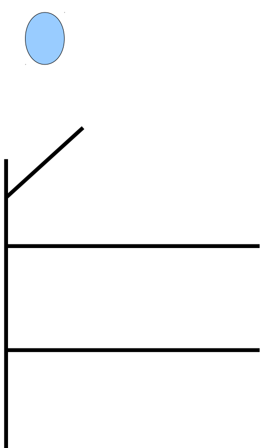
Introducing hard scale dependence

Nonlinear extension of CCFM not applied so far to phenomenology



provides hard scale

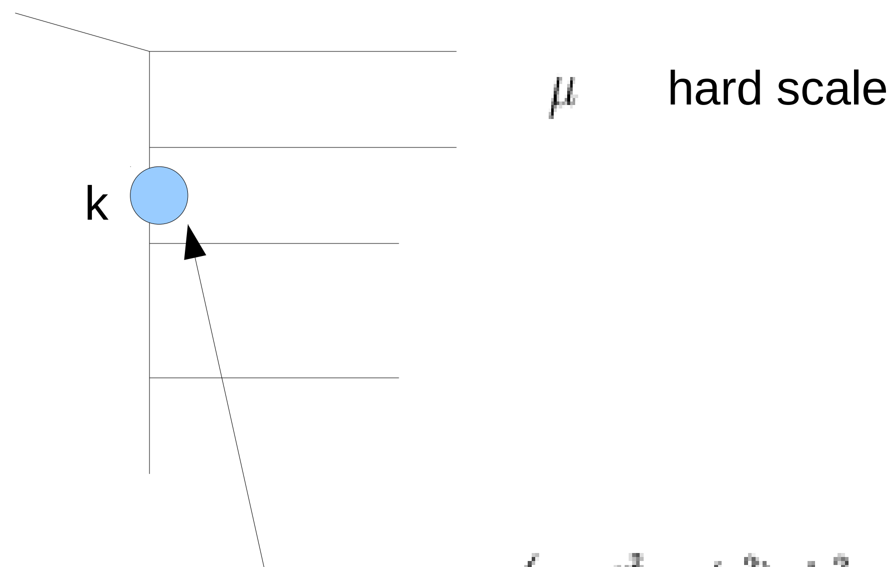
Include the effect in the last step of evolution



Probability of finding no real gluon between scales

Introducing hard scale dependence

Probability of finding no real gluon
Between scales μ and k



Survival probability of the gap without emissions

Kutak '14

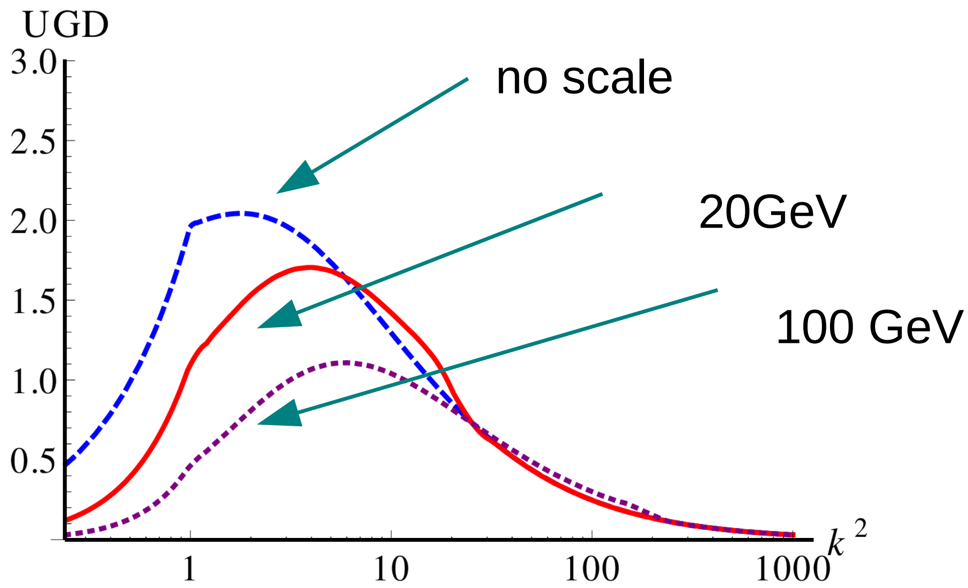
$$T_a(k_t,\mu) = \exp\left(-\int_{k_t^2}^{\mu^2} \frac{\alpha_s(p_t^2)}{2\pi}\,\frac{dp_t^2}{p_t^2}\sum_{a'}\int_0^{1-\Delta} P_{a'a}(z')\,dz'\right)$$

$$\mathcal{A}(x,k^2,\mu^2) = \theta(\mu^2-k^2)T_s(\mu^2,k^2)\frac{xg(x,\mu^2)}{xg_{hs}(x,\mu^2)}\mathcal{F}(x,k^2) + \theta(k^2-\mu^2)\mathcal{F}(x,k^2).$$

$$xg_{hs}(x,\mu^2) = \int^{\mu^2} dk^2 T_s(\mu^2,k^2)\mathcal{F}(x,k^2),\;\; xg(x,\mu^2) = \int^{\mu^2} dk^2\mathcal{F}(x,k^2)$$

Saturation scale in equation with coherence forward-forward jets

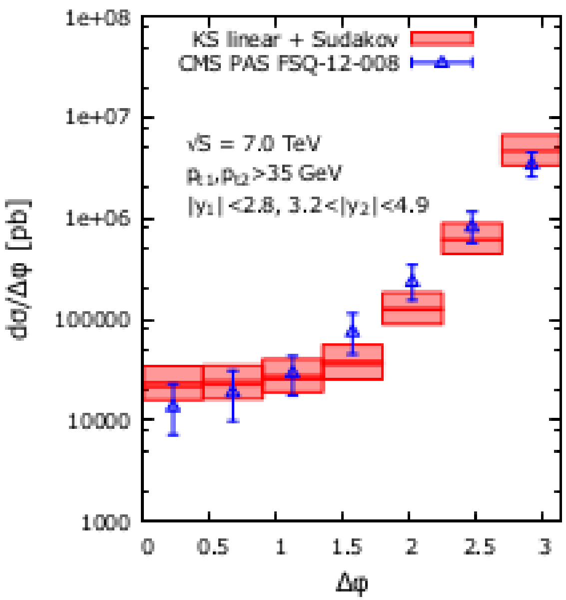
Kutak '14

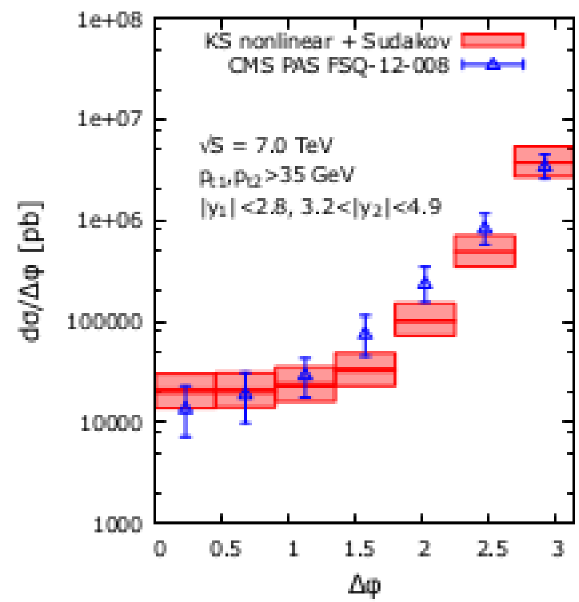


Low kt gluons are suppressed. The conservation of probability leads to change of shape of gluon density which depends on the hard scale

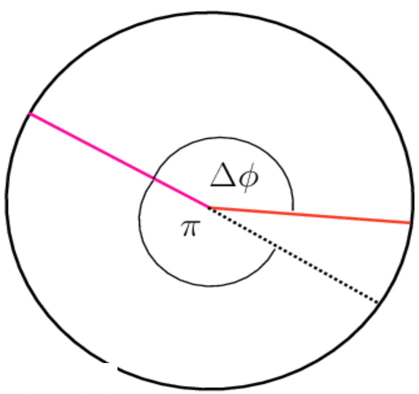
Decorelations inclusive scenario

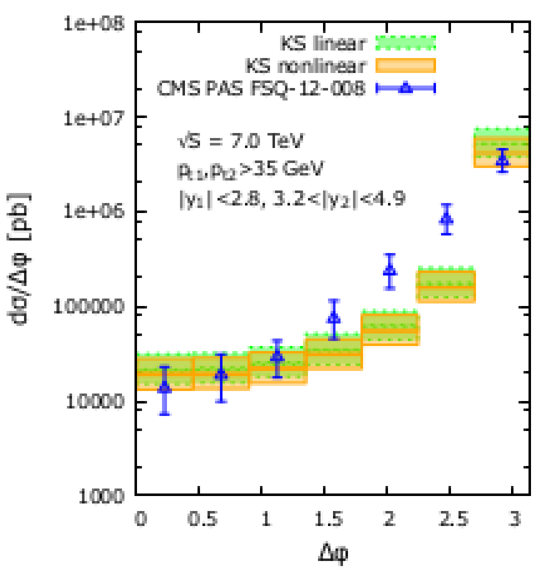
A.v.Hameren, P.Kotko, KK, S.Sapeta '14





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





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

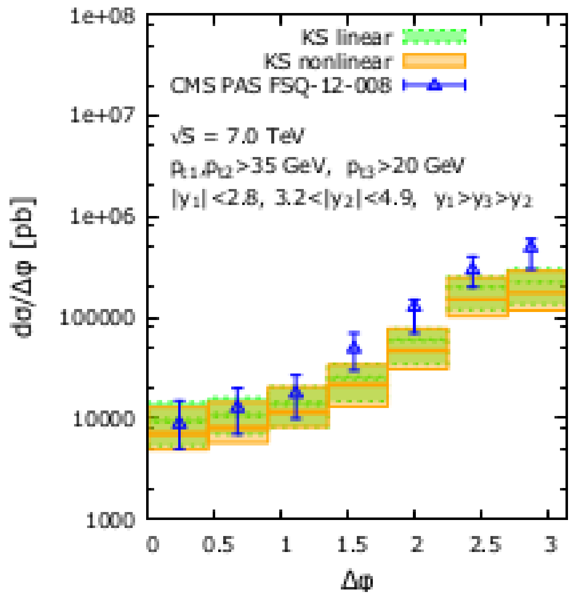
$$\Delta\phi = \pi$$

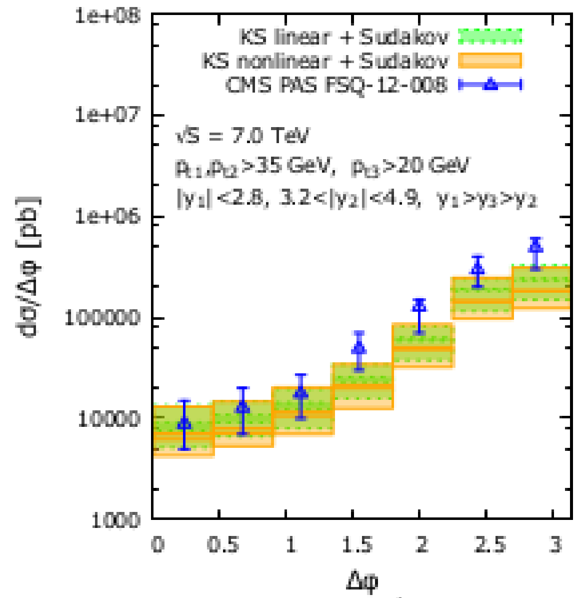
Sudakov effects by reweighing implemented in LxJet Monte Carlo P. Kotko

Studied also context of RHIC
Albacete, Marquet '10

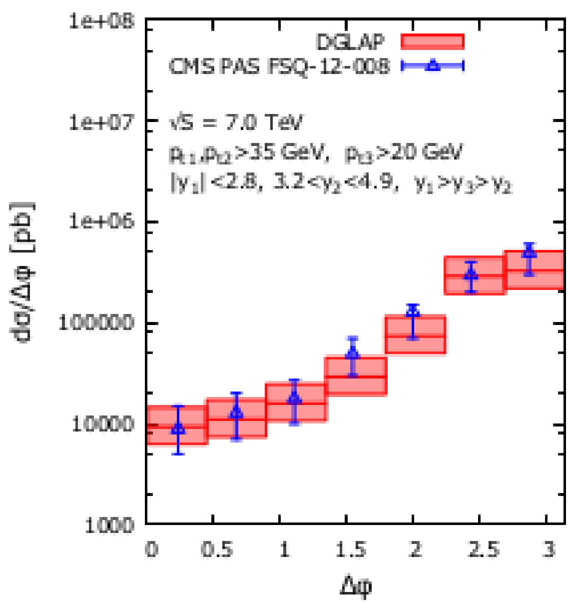
Decorelations inside jet tag scenario

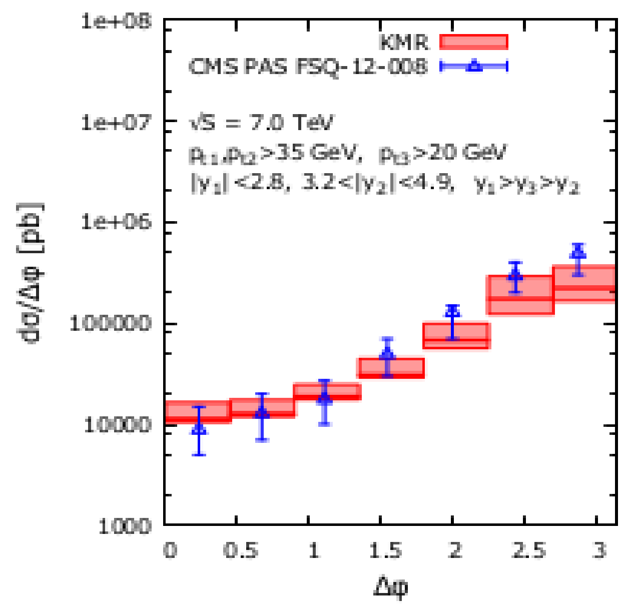
A.v.Hameren, P.Kotko, KK, S.Sapeta '14

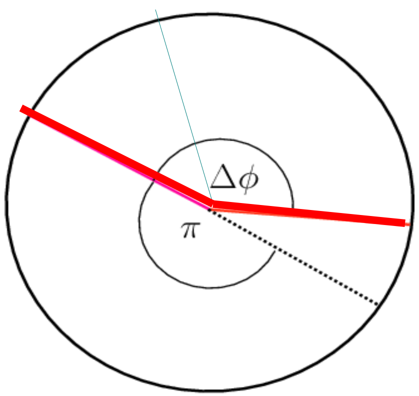




pt1, pt2 >35 GeV, leading jets |y1|<2.8, 3.2<|y2|<4.7 Third jet pt>20GeV. Between the forward and central region



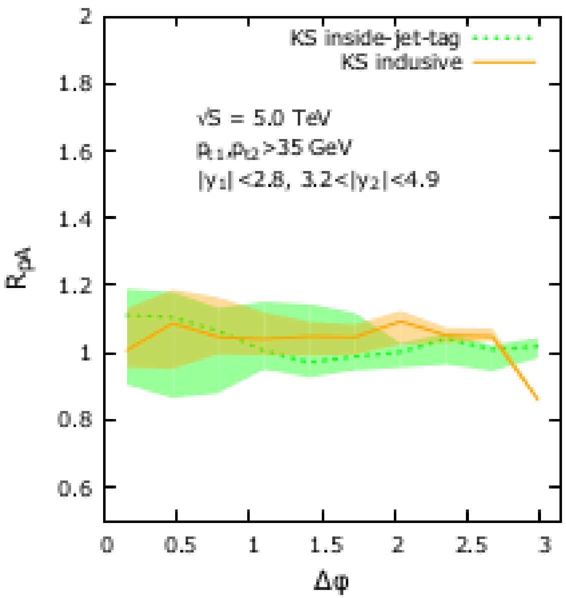


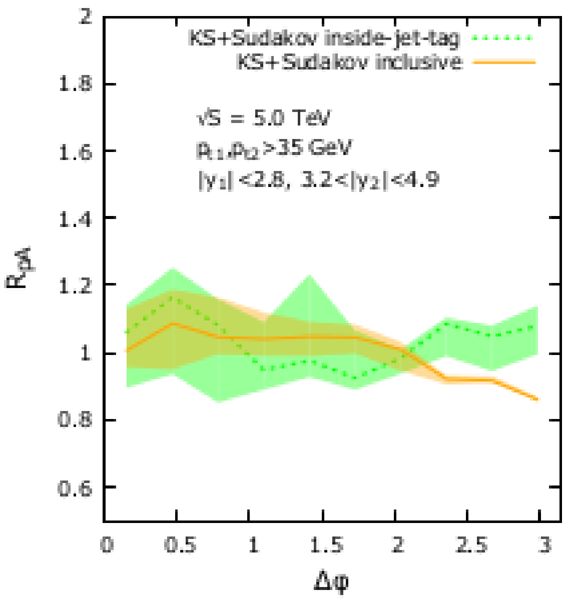


Sudakov effects by reweighting implemented in LxJet Monte Carlo P. Kotko

Predictions for p-Pb for forward-central

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

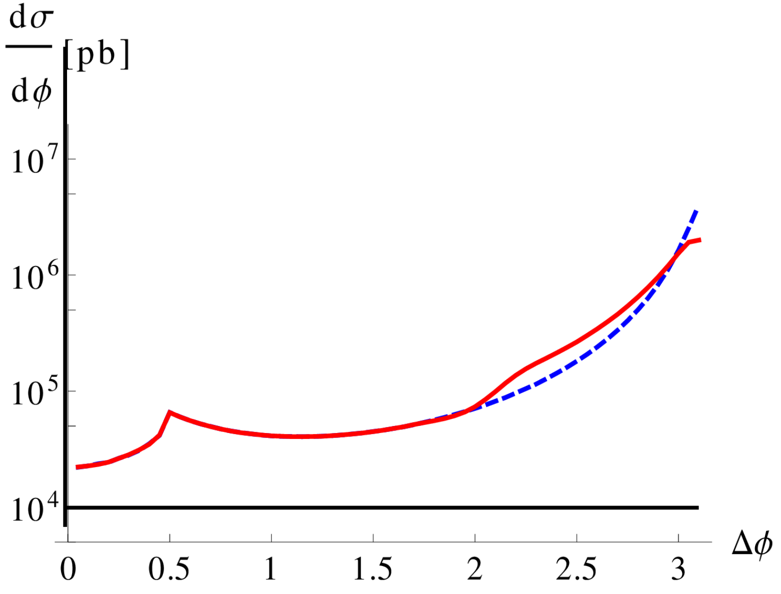


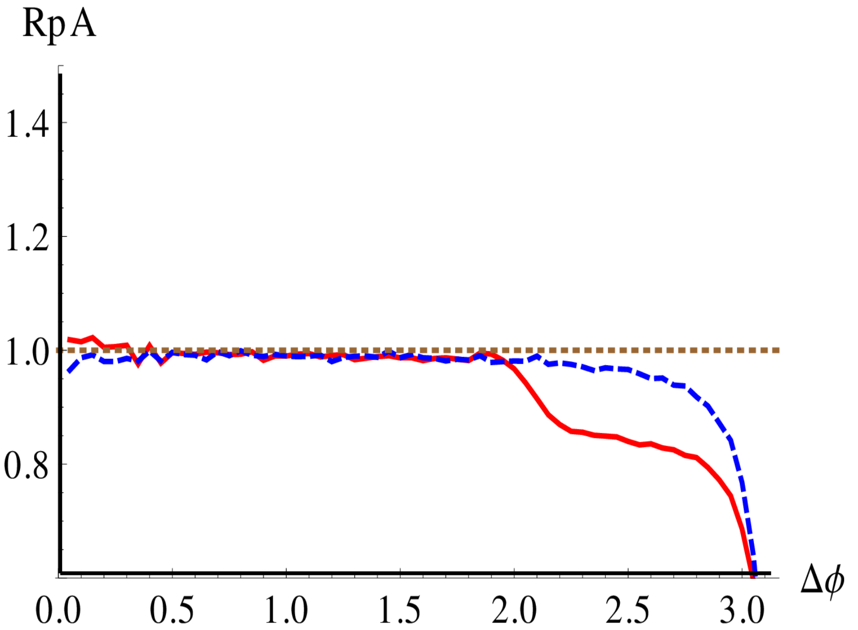


- *Sudakov enhances saturation effects*
- *However, saturation effects are rather weak for forward-central jets*

Predictions for p-Pb for forward-forward

Kutak '14





- *The hard scale effects make the potential signatures of saturation more pronounced.*
- *"Pb" affected more by saturation than "p" therefore we see more significant effect.*

Conclusions and outlook

- *Achieved good description of forward-central jet measurement*
- *Predictions for forward-forward dijets pPb are provided*
- *Open question – description of the decorelations within CCFM. It includes Sudakov and low x dynamics.*
- *Open question – description of the decorelations within nonlinear extension of CCFM*