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Production of forward jets at high energies

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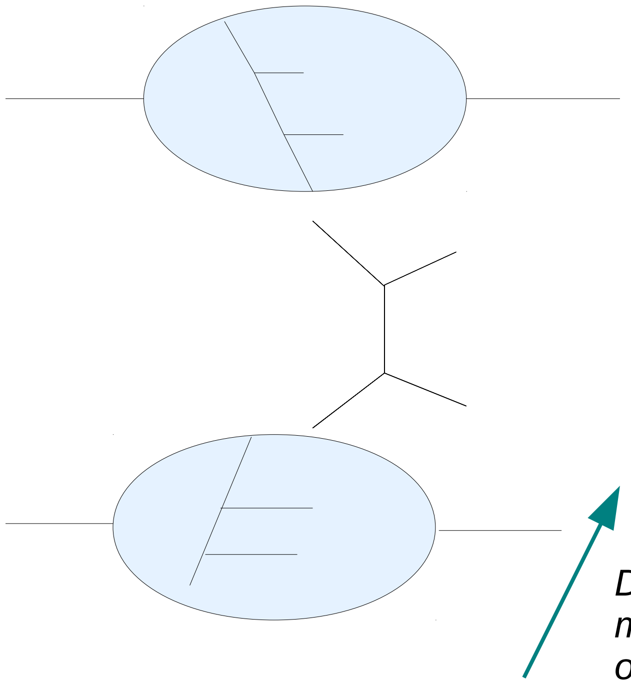
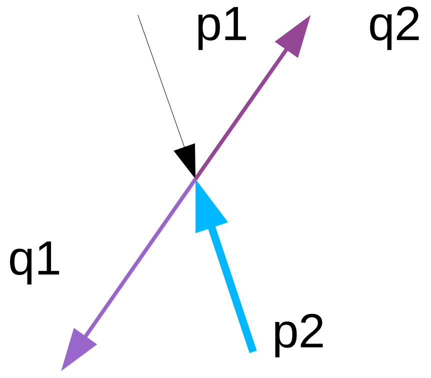
Based on:
1409.3822 K.Kutak
Phys.Lett. B737 (2014) 335-340, A. van Hameren, P. Kotko, K. Kutak, S. Sapeta
Phys. Rev. D 89, 094014 (2014), A. van Hameren, P. Kotko, K. Kutak, C. Marquet, S. Sapeta
Phys. Rev. D 86, 094043 (2012), Krzysztof Kutak, Sebastian Sapeta
To be published soon results on Z + jet with P. Kotko and A. van Hameren

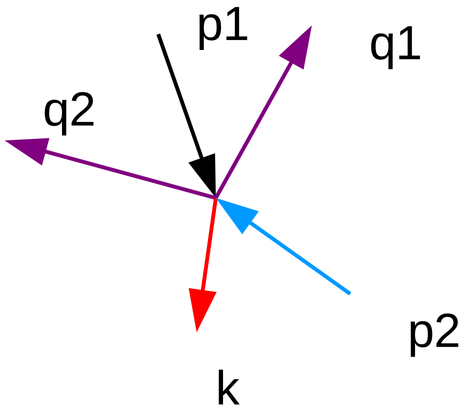
QCD at high energies – high energy factorization



Decreasing longitudinal momentum fractions of off-shell partons



p1+p2=q1+q2



p1+p2=q1+q2+k

Monte Carlo generators → aim to describe fully processes
In general many parameters → tunings
My point of view → ME + parton densities in kt factorization
Gain: less parameters.
Physics motivated approach to dense system

New helicity based methods for ME
K.K , van Hameren, Kotko, '12

Theory
Gribov, Levin, Ryskin '81
Ciafaloni, Catani, Hautman '93
Collins, Ellis '93

Phenomenology
Jung, Hautmann; Szczurek, Maciuła; KK, Kotko, van Hameren Staśto...

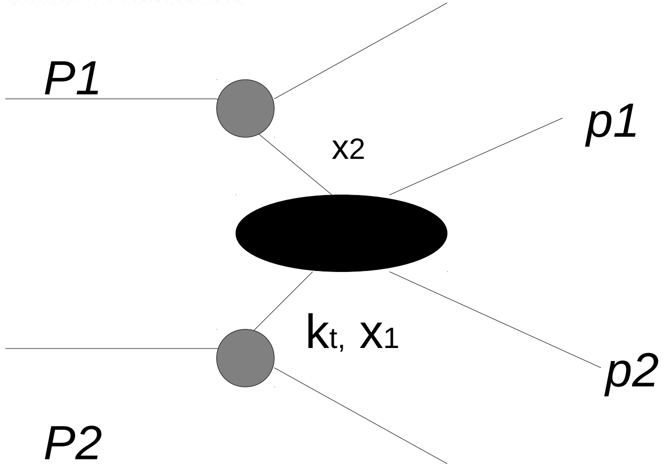
Hybrid factorization and dijets

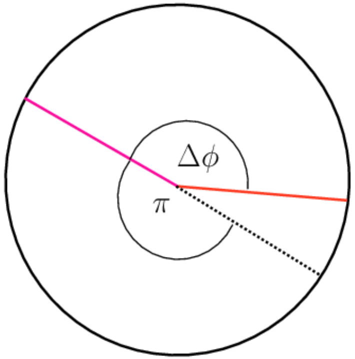
$$\frac{d\sigma}{dy_1 dy_2 dp_{1t} dp_{2t} d\Delta\phi} = \sum_{a,c,d} \frac{p_{t1} p_{t2}}{8\pi^2 (x_1 x_2 S)^2} |\mathcal{M}_{ag\to cd}|^2 x_1 f_{a/A}(x_1,\mu^2)\, \mathcal{F}_{g/B}(x_2,k^2) \frac{1}{1+\delta_{cd}}$$

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

$S = 2P_1 \cdot P_2$





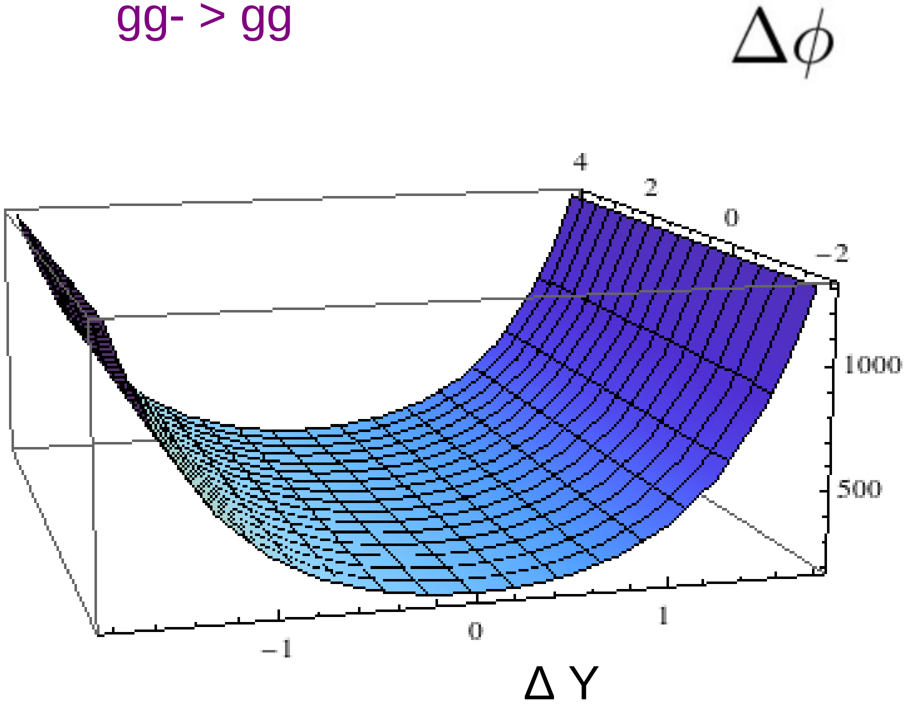
$$\mathcal{F}(x,k^2) = \frac{N_c}{\alpha_s (2\pi)^3} \int d^2b \int d^2r\, e^{ik\cdot r} \nabla_r^2 N(r,b,x)$$

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

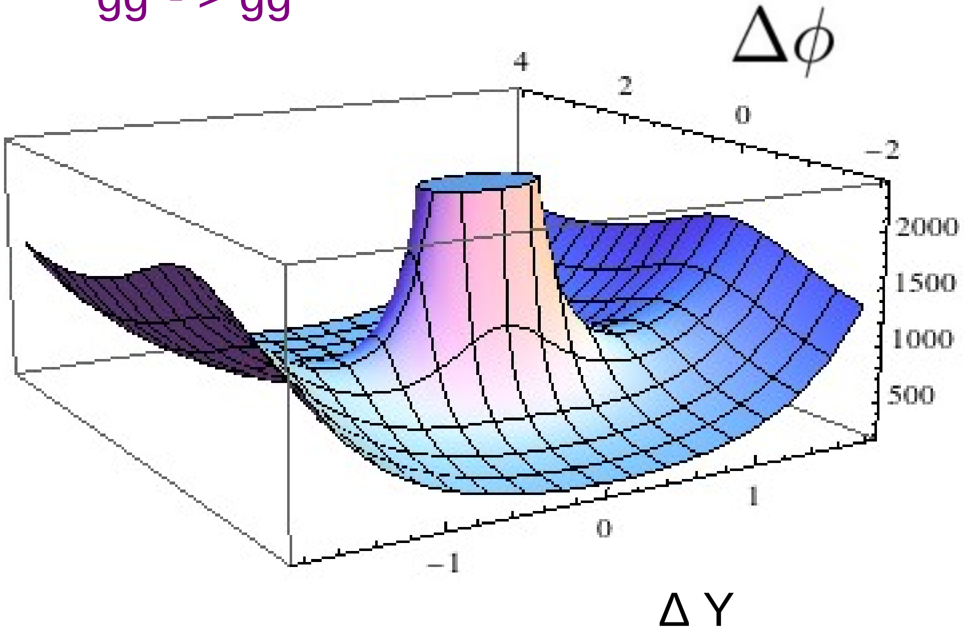
- *Resummation of logs of x and logs of hard scale*
- *Knowing well parton densities at large x one can get information about low x physics*
- *Gluon density we use includes corrections of higher orders*

Collinear vs. off-shell ME

gg- > gg



gg*- > gg



One off-shell parton 2->2 ME

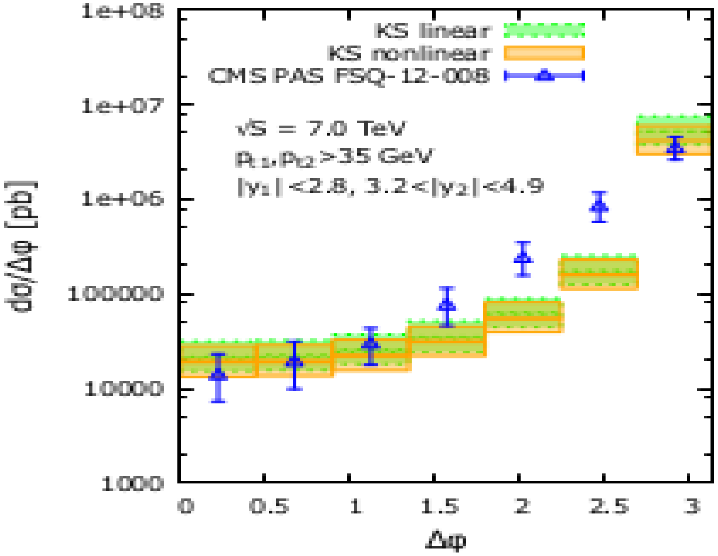
Collinear 2->2 ME

$$M= \frac{32\,\pi^2\,\alpha^2\,\left(e^{-\Delta y}+1\right)^2\left(e^{\Delta y}\left(e^{\Delta y}+1\right)+1\right)^2\,\mathrm{Nc}^2\,(-2\cosh(\Delta y)-1)}{\left(e^{\Delta y}+1\right)^2\left(\mathrm{Nc}^2-1\right)(-\cosh(\Delta y)-1)}$$

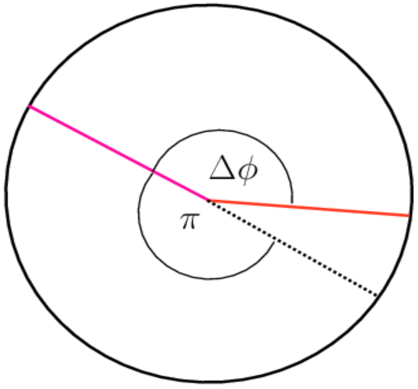
$$M= \frac{32\,\pi^2\,\alpha^2\,e^{-2\,\Delta y}\,\mathrm{Nc}^2\,\left(\mathrm{pt1}+e^{\Delta y}\,\mathrm{pt2}\right)^2\left(e^{2\,\Delta y}\,\mathrm{pt1}^2+e^{\Delta y}\,\mathrm{pt1}\,\mathrm{pt2}+\mathrm{pt2}^2\right)^2\,(\cos(\Delta\mathrm{phi})-2\cosh(\Delta y))}{\left(\mathrm{Nc}^2-1\right)\mathrm{pt1}^2\,\mathrm{pt2}^2\left(e^{\Delta y}\,\mathrm{pt1}+\mathrm{pt2}\right)^2\,(\cos(\Delta\mathrm{phi})-\cosh(\Delta y))}$$

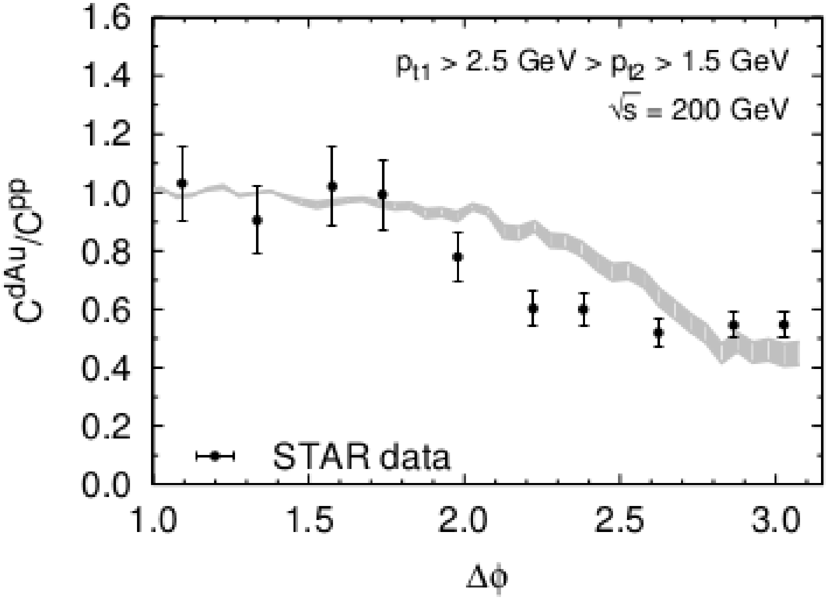
Forward-central decorelations inclusive scenario

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



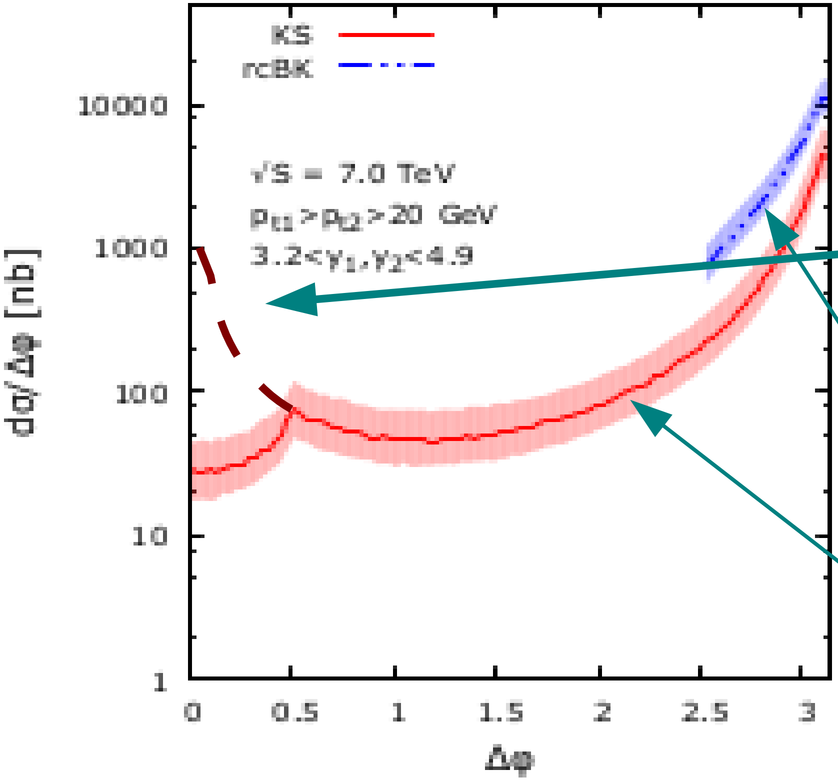
pt1,pt2 >35, leading jets
|y1|<2.8, 3.2<|y2|<4.7
No further requirement on jets

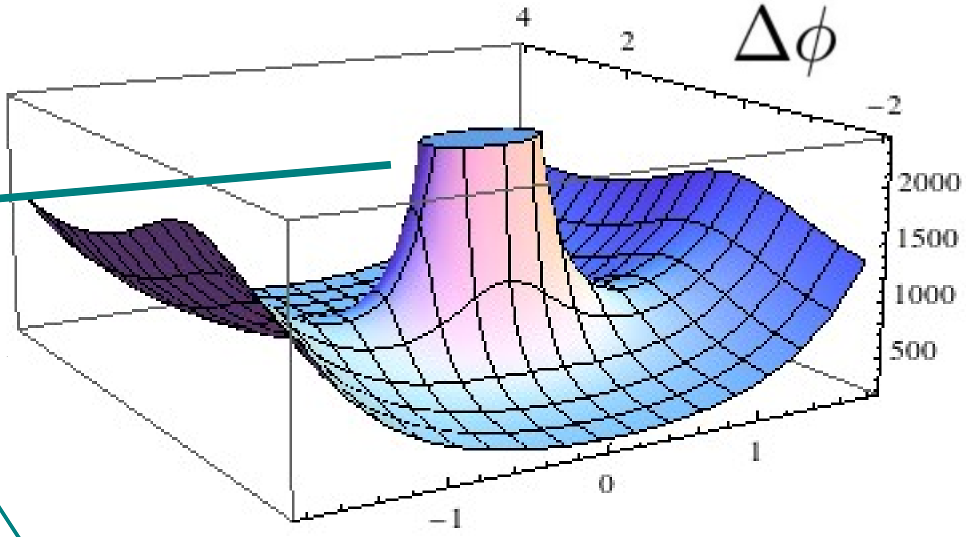




In pure DGLAP approach i.e 2 →2 + pdf one would get delta function at $\Delta\phi = \pi$

Results for decorelations forward-forward dijets

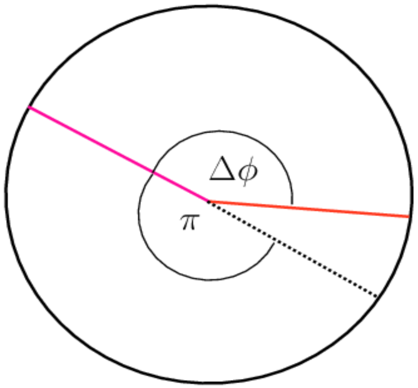




From rc BK

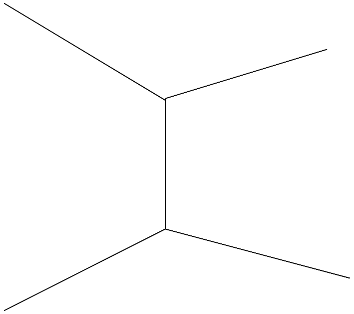
BK with
kinemtical constraint
h.o. corrections
to splitting function

Divergence regularized by
jet algorithm



CCFM evolution equation - evolution with observer

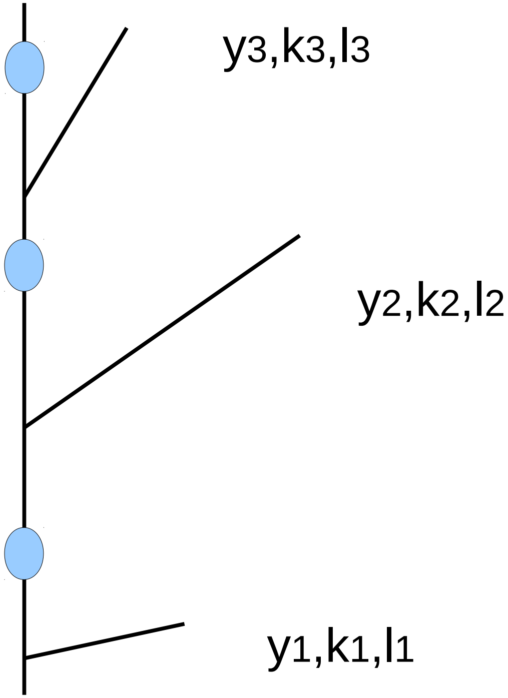
Catani,Ciafaloni, Fiorani, Marchesini '88



Constraint $l_i < L$

L given by the scale of the hard process

L~ pt1+pt2

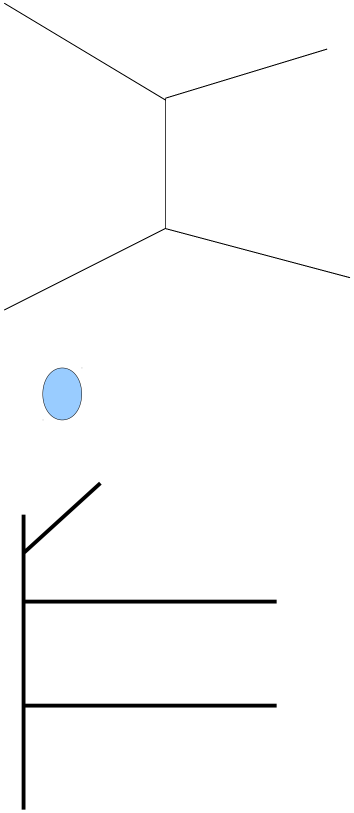


There is a region where emitted gluons are soft the the dominant contribution to the amplitude comes from the angular ordered region.

The same structure for x → 0 *although the softest emitted gluons are harder than internal.*

● *Probability of finding no real gluon between hard emissions*

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

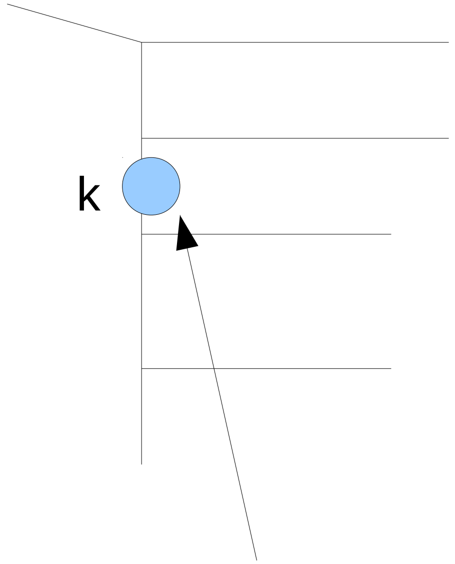
Probability of finding no real gluon between scales

Introducing hard scale dependence

Probability of finding no real gluon
Between scales μ and k

μ hard scale

Survival probability of the gap without emissions



Kutak '14

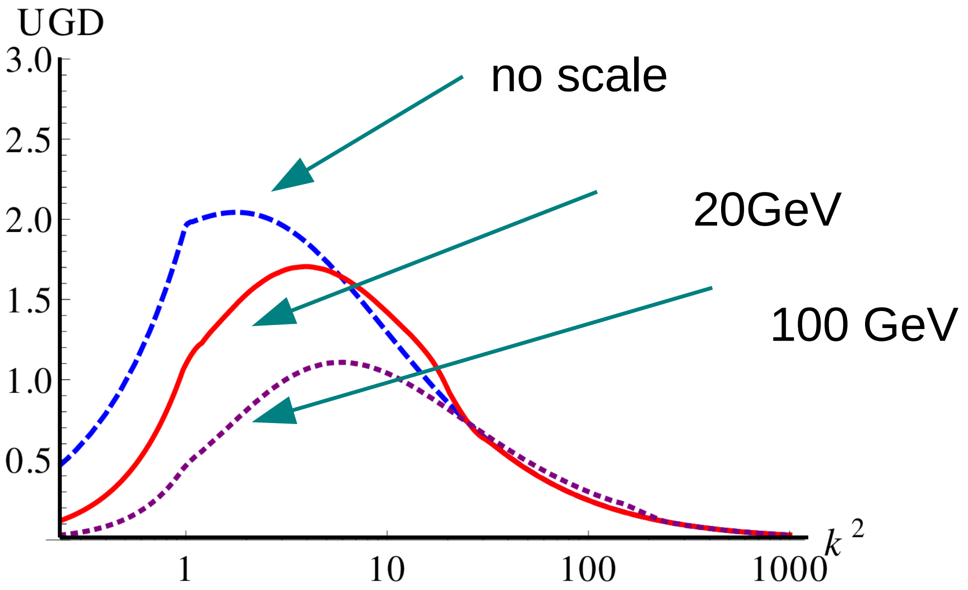
$$T_a(k_t,\mu) = \exp\left(-\int_{k_t^2}^{\mu^2} \frac{\alpha_s(p_t^2)}{2\pi}\,\frac{dp_t^2}{p_t^2}\sum_{a'}\int_0^{1-\Delta} P_{a'a}(z')\,dz'\right)$$

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

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

Saturation scale in equation with coherence forward-forward jets

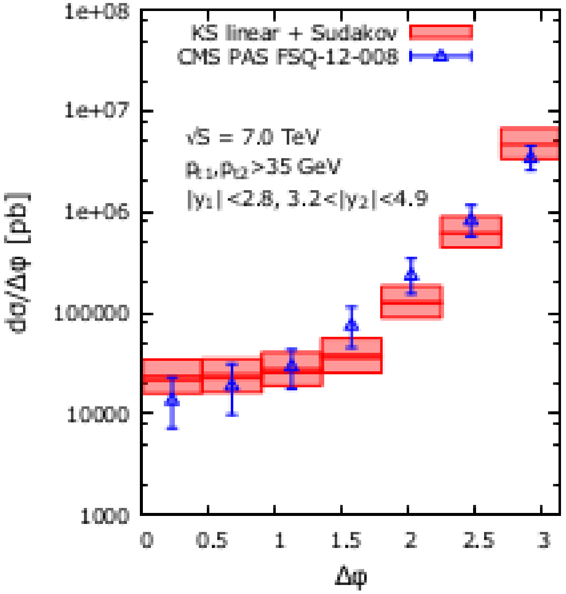
Kutak '14

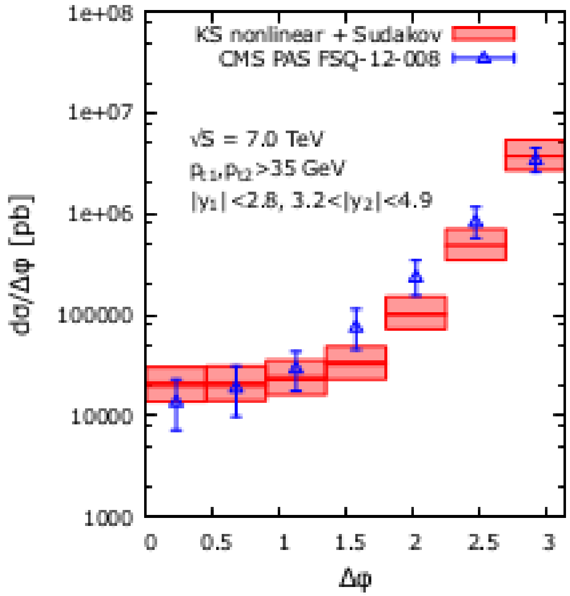


Low kt gluons are suppressed. The conservation of probability leads to change of shape of gluon density which depends on the hard scale

Decorelations inclusive scenario

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





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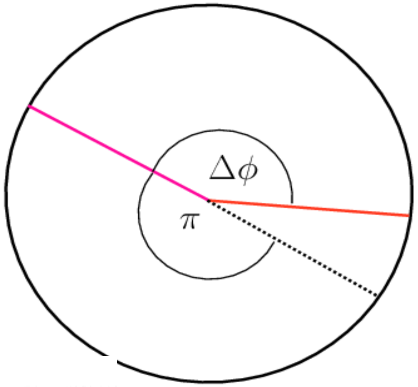
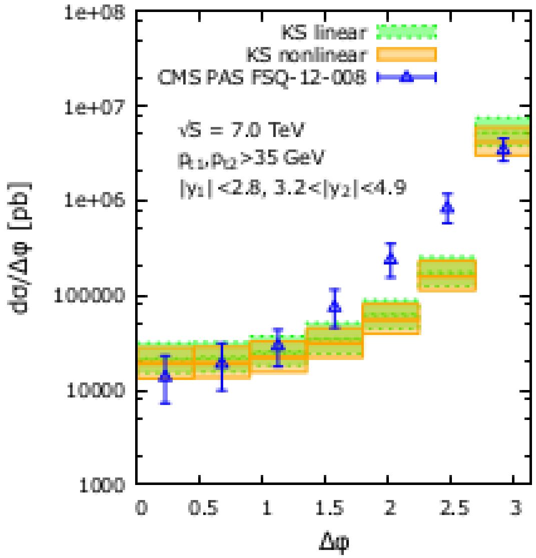


In pure DGLAP approach i.e 2 →2 + pdf one would get delta function at

$$\Delta\phi = \pi$$

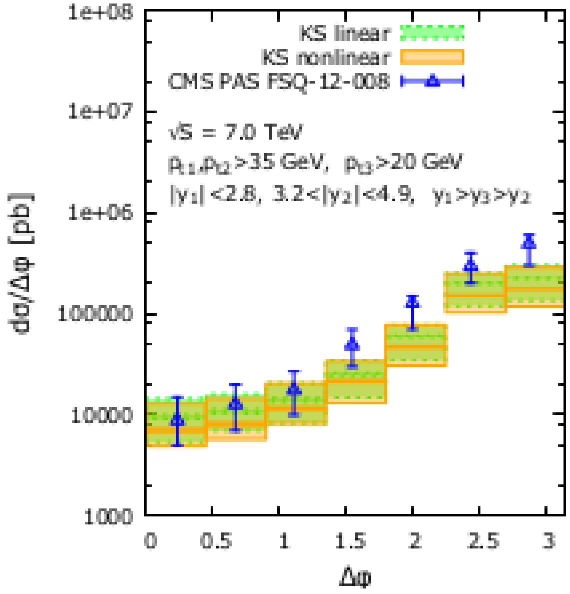


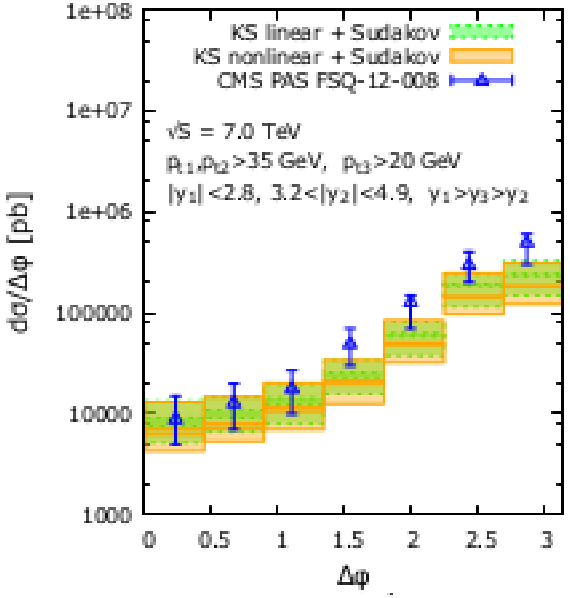
Sudakov effects by reweighing implemented in LxJet Monte Carlo P. Kotko

Studied also context of RHIC
Albacete, Marquet '10

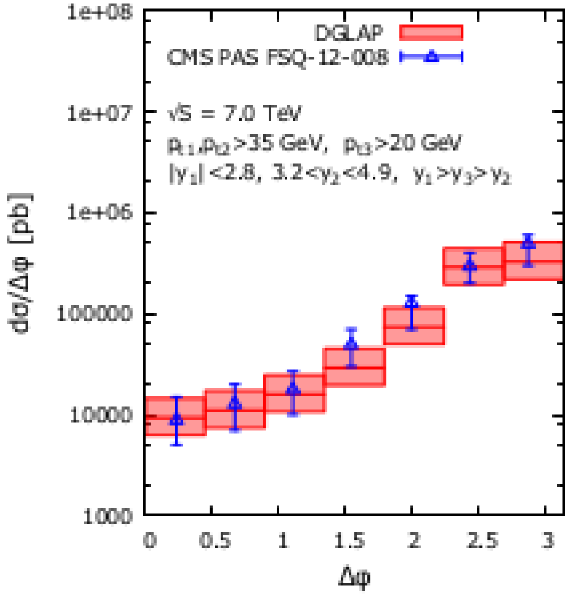
Decorelations inside jet tag scenario

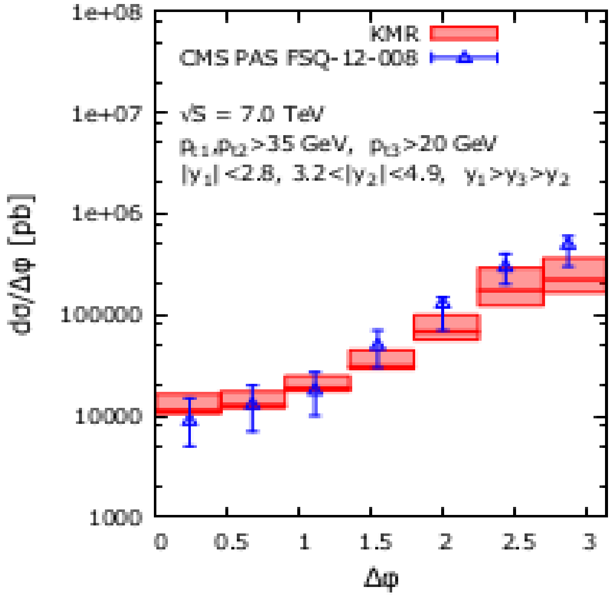
A.v.Hameren, P.Kotko, KK, S.Sapeta '14

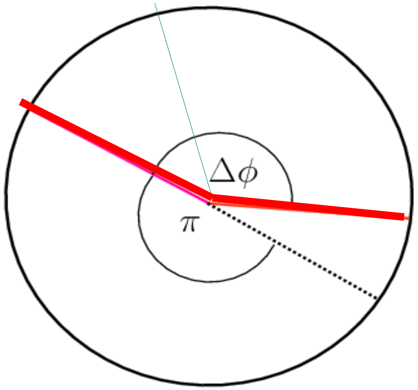




pt1, pt2 >35 GeV, leading jets |y1|<2.8, 3.2<|y2|<4.7 Third jet pt>20GeV. Between the forward and central region



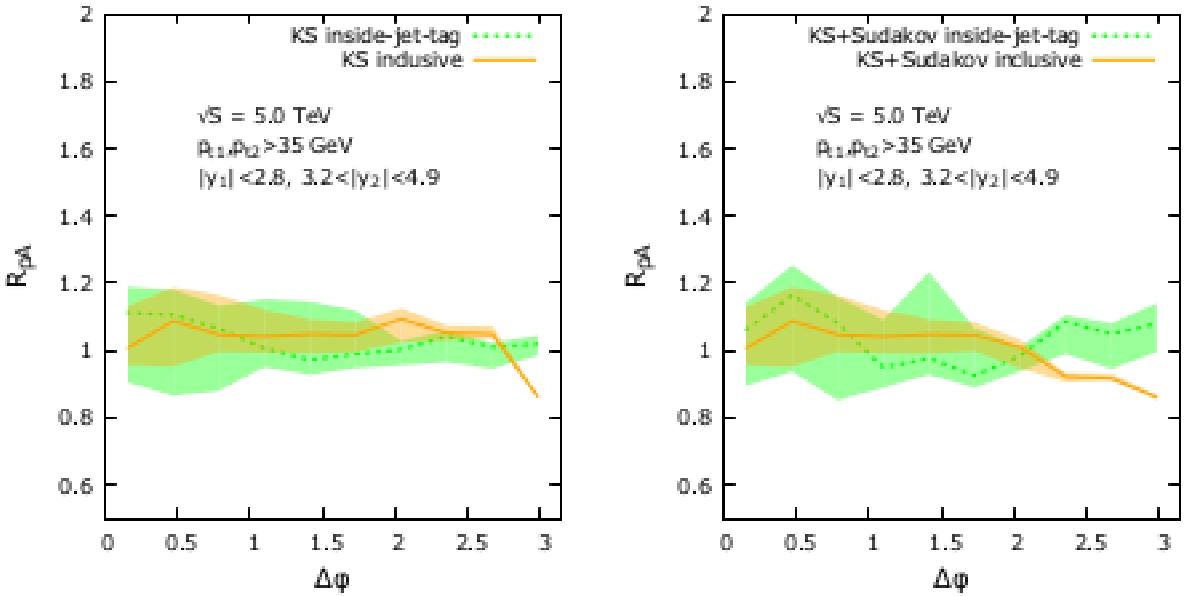




Sudakov effects by reweighting implemented in LxJet Monte Carlo P. Kotko

Predictions for p-Pb for forward-central

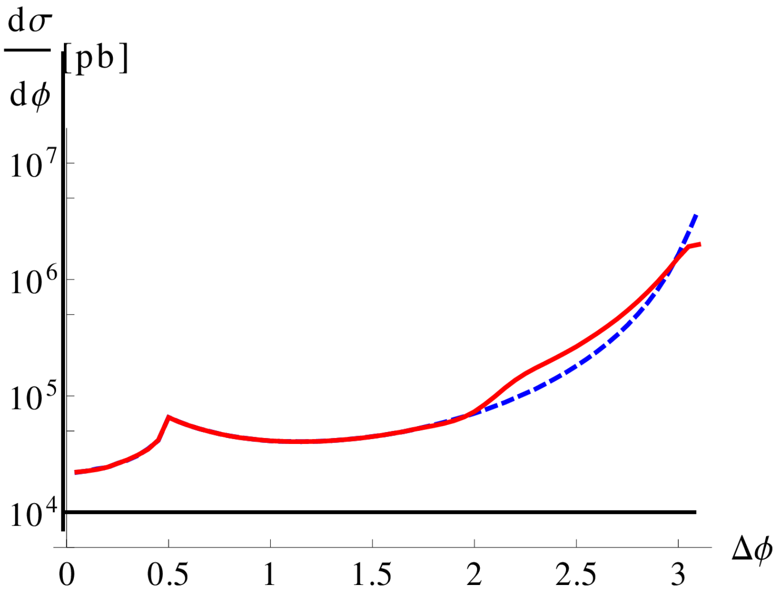
A.v.Hameren, P.Kotko, KK, S.Sapeta '14

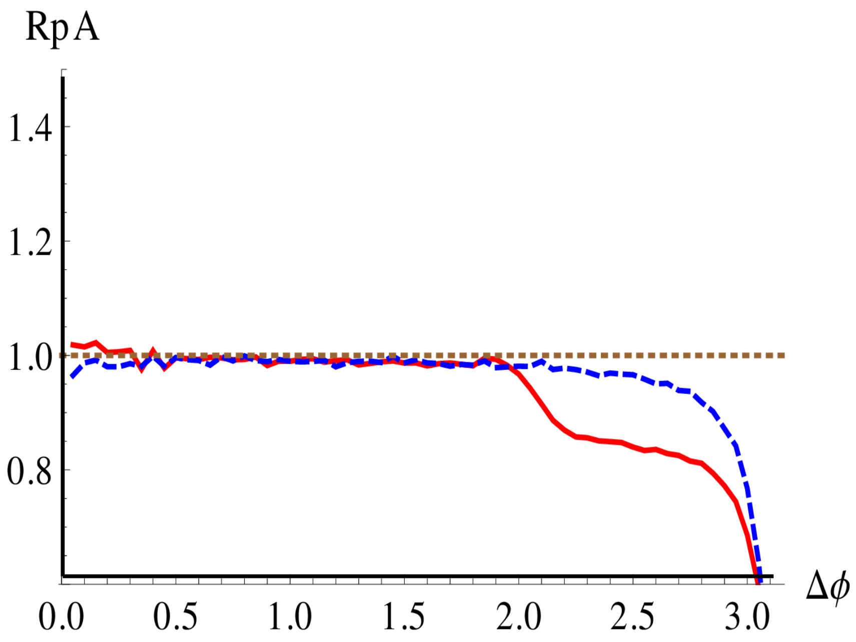


- *Sudakov enhances saturation effects*
- *However, saturation effects are rather weak for forward-central jets*

Predictions for p-Pb for forward-forward

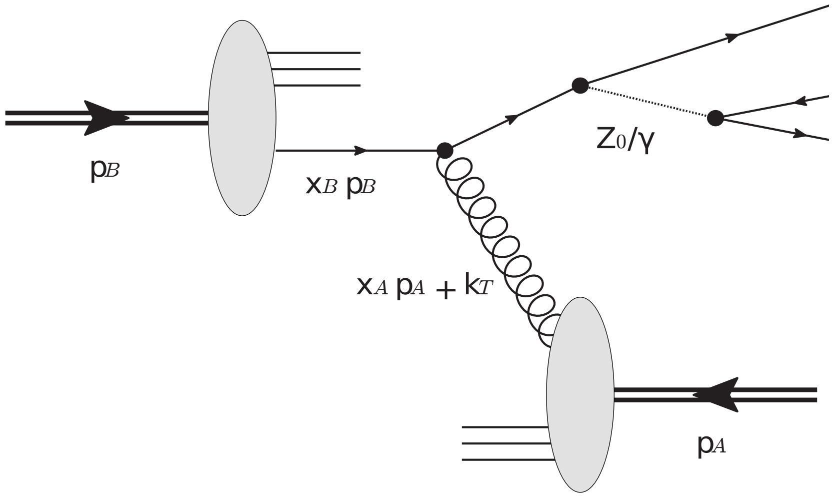
Kutak '14





- *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.*

Production of Z0 + jet



$\sqrt{S}$ = 7.0 TeV

$p_{Tj}>10$ GeV, $p_{T\mu1},p_{T\mu2}>20$ GeV

$2<y_j,y_{\mu1},y_{\mu2}<4.5$

60 GeV$<M_{\mu\mu}<$120 GeV

$$d\sigma_{AB\to\mu^+\mu^-+\text{jet}+X} = \int d^2k_{TA}\int\frac{dx_A}{x_A}\int dx_B \sum_b \mathcal{F}_{g^*/A}\left(x_A,k_{TA},\mu\right)\, f_b\left(x_B,\mu\right)\, d\hat{\sigma}_{g^*q_b\to q_b\mu^+\mu^-}\left(x_A,x_B,k_{TA},\mu\right)$$

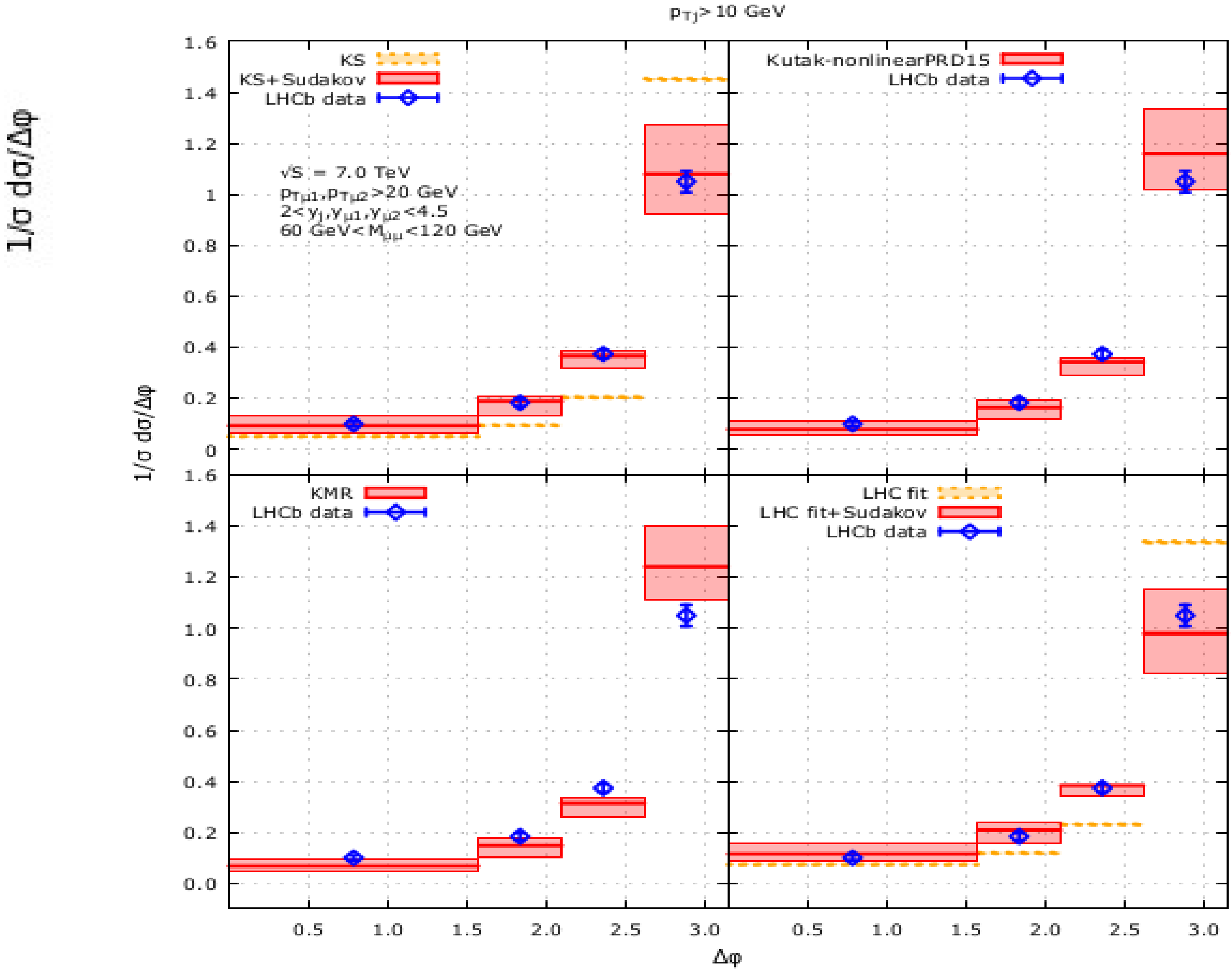
Less final state rescatterings as compared to dijet system

Decorelations in Z0 + jet

Preliminary

Kotko, van Hameren,KK

$g^* q \to q \mu^+ \mu^-, \; g^* \bar{q} \to \bar{q} \mu^+ \mu^-$



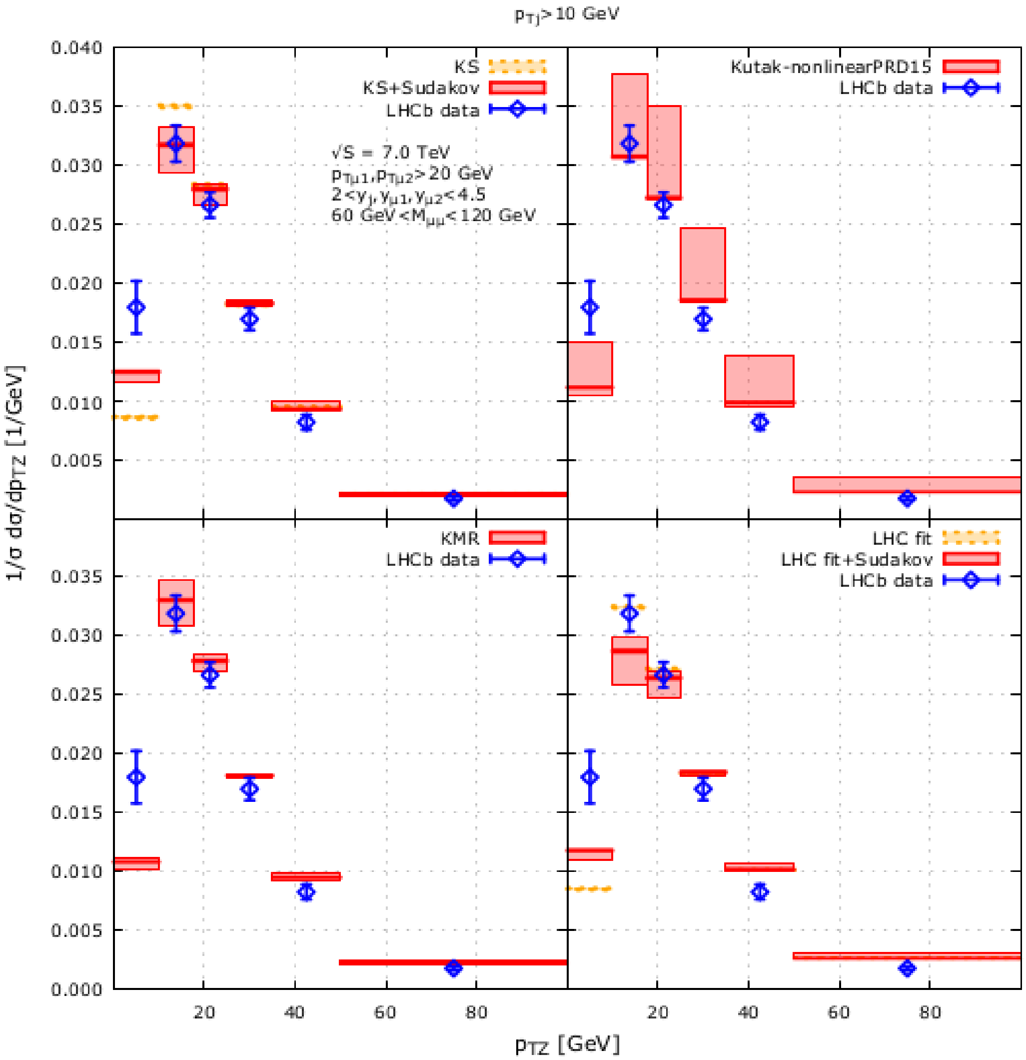
Possible contributions from MPI which add pedestal.

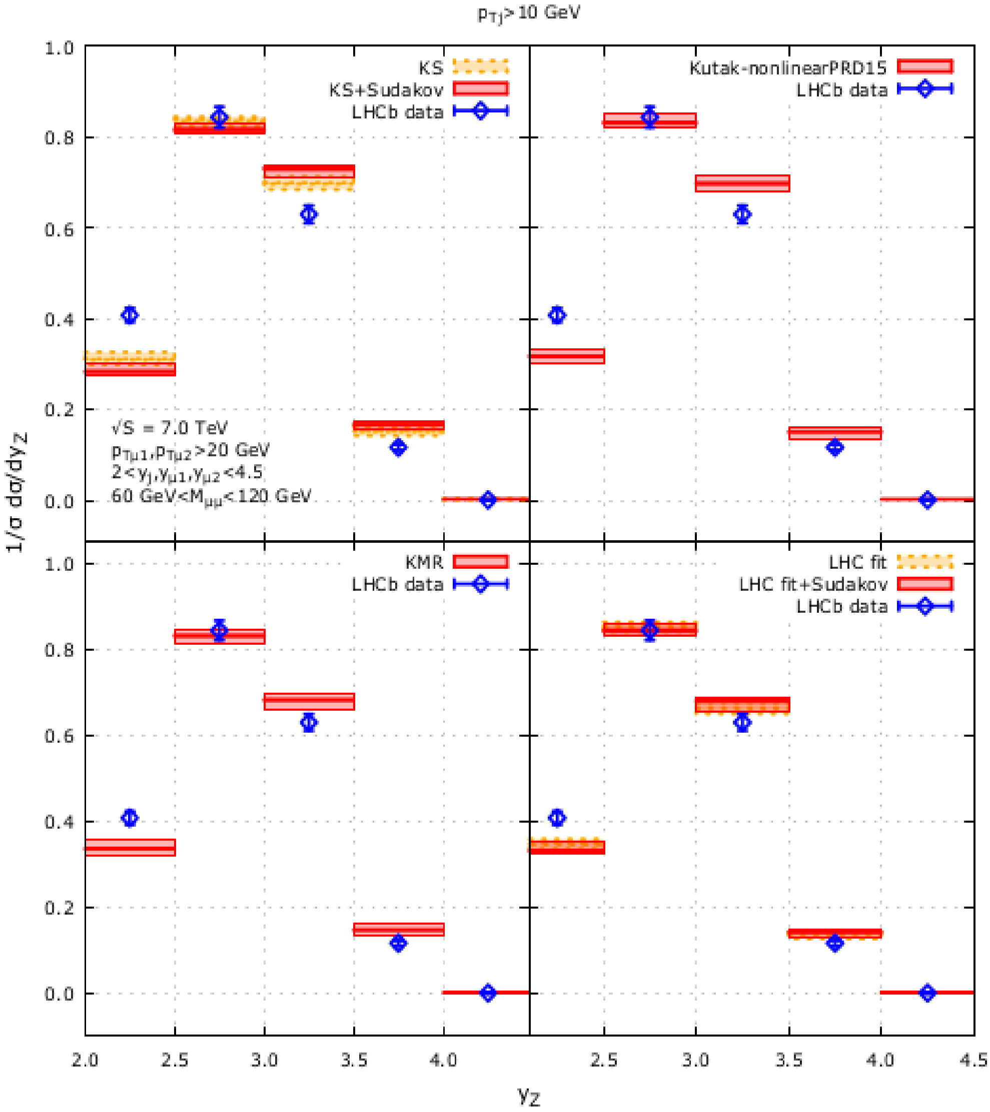
Total cross section:

Cut	$p_{T\,j} > 10\,\mathrm{GeV}$
Our result	$4.1^{+1.0}_{-0.7}\,\mathrm{pb}$
Data	$16.0 \pm 1.4\,\mathrm{pb}$

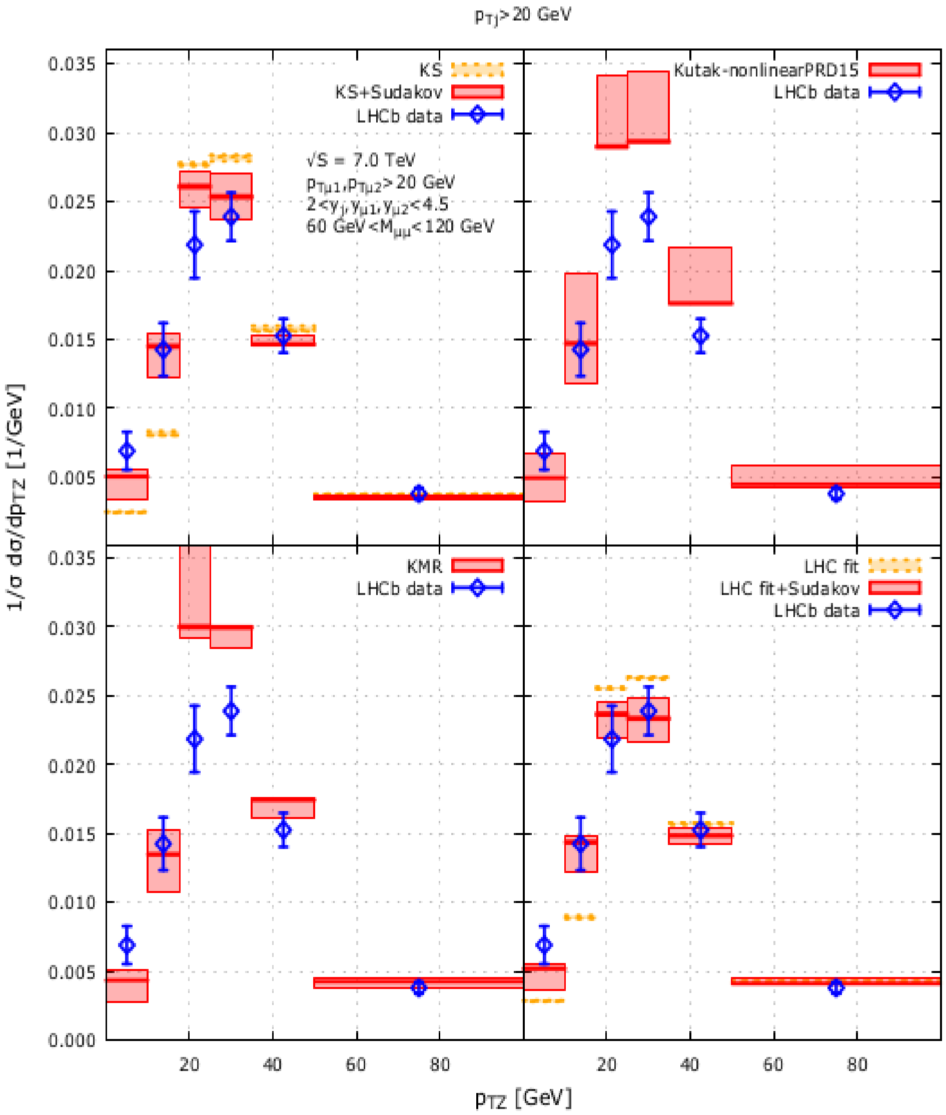
Simulated within LxJet by Kotko

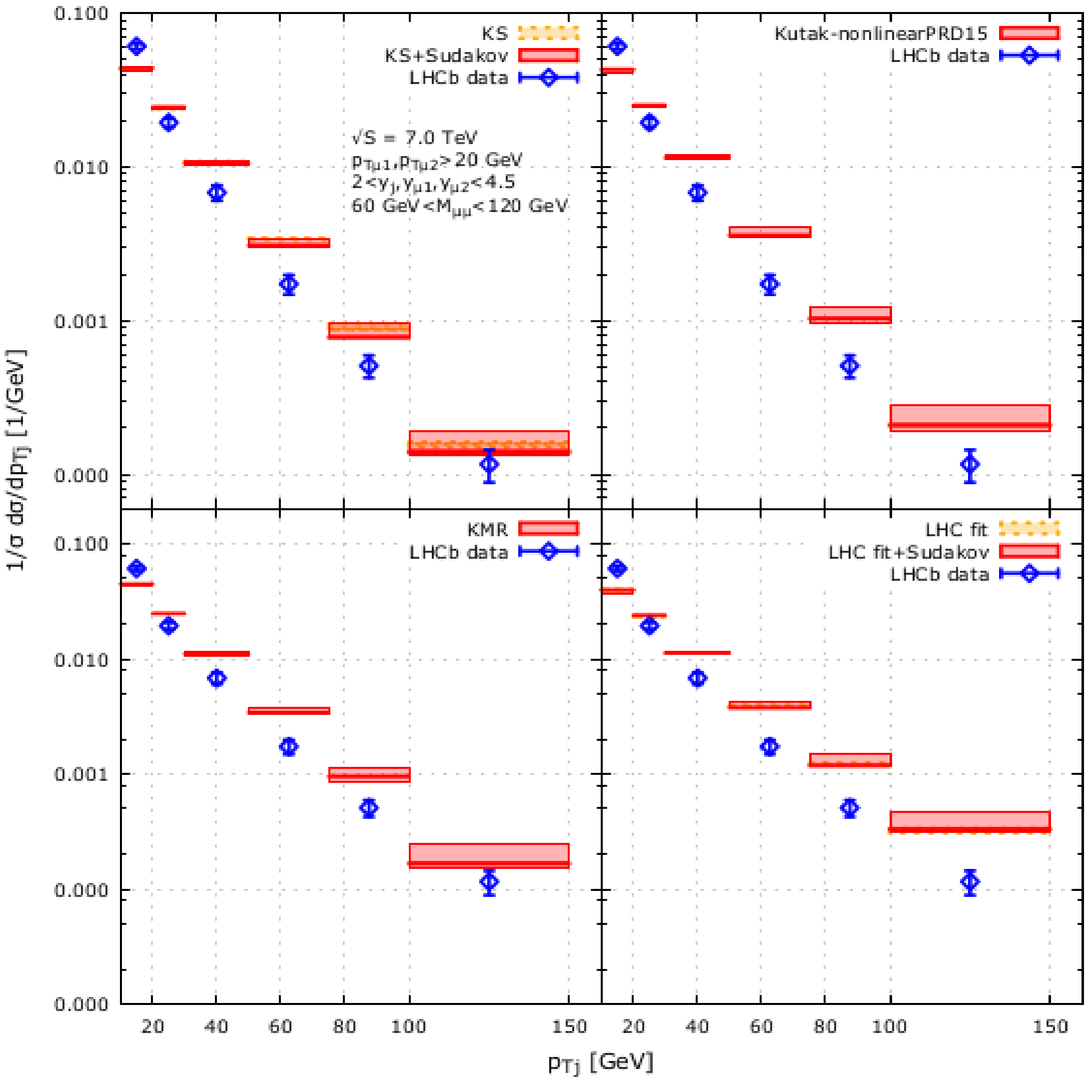
Pt and rapidity spectra of Z





Pt of Z vs. pt of jet





Worse results for jet as compared to Z.
Might be due to not taking into account in our description FSI

Conclusions and outlook

- *Achieved good description of forward-central jet measurement within approach based on linear evolution equations*

- *Predictions for forward-forward dijets pPb are provided*

- *Explicit evidence for need for hard scale dependence on top of low x equations*

- *Satisfactory description of shape in decorelations of Z and jet*

- *Satisfactory description of pt spectra of Z*

Open questions

- *MPI in Z + jet*

- *FSI in Z + jet*