Transversal momentum dependence and di-jets in p-p, p-Pb and Pb-Pb collisions

The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences

Krzysztof Kutak

NCN

HORIZON 2020

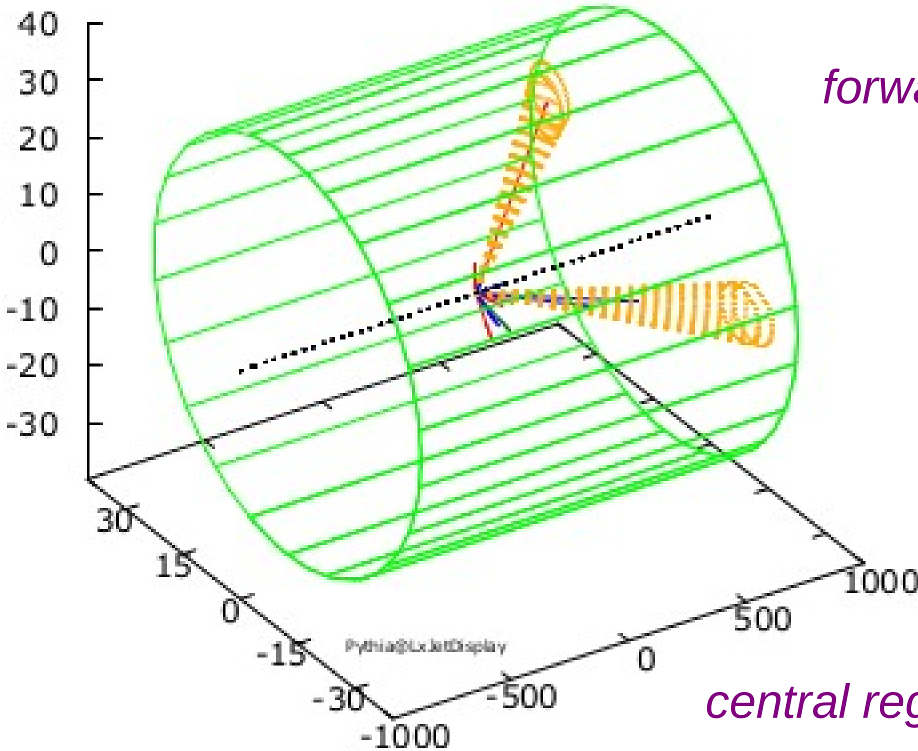
Based on
Phys.Lett. B795 (2019) 511-515
A. van Hameren, P. Kotko, K. Kutak, S. Sapeta

1811.06390 by Kutak, Płaczek, Straka

1911. XXXX van Hameren, Kutak, Płaczek, Rohrmoser, Tywoniuk

p-p and p-Pb

p – A (dilute-dense) forward-forward di-jets



forward region

central region

The collisions we consider:

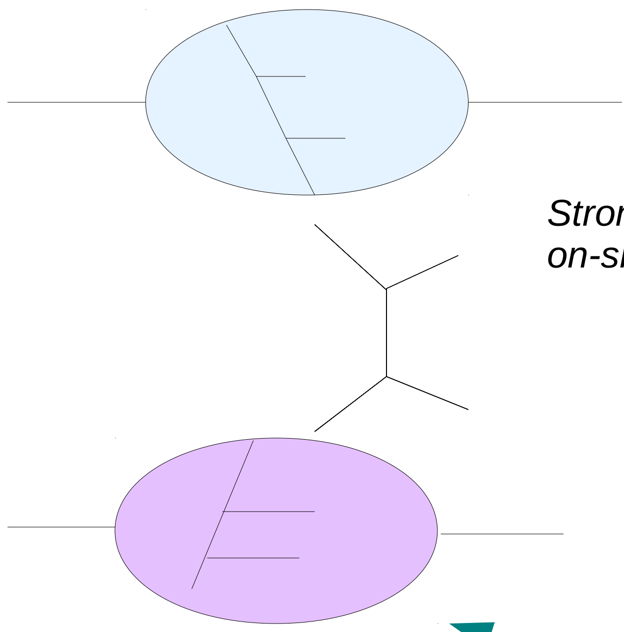
e.g minimal p_T 28 GeV

both jets are forward → 4 > y > 2.7

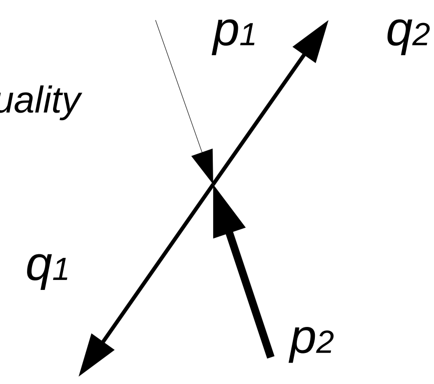
From: Piotr Kotko
LxJet

There is certain class of processes where one can assume that partons in one of hadrons are just collinear with hadron and in other are not

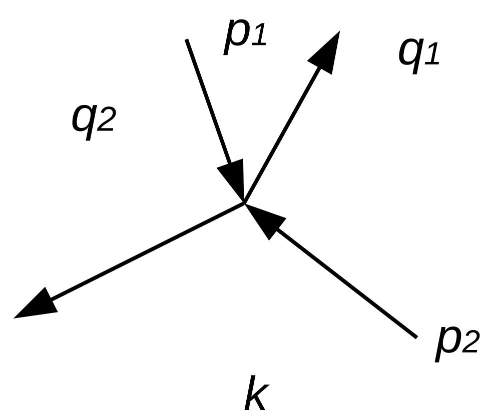
QCD at high energies – hybrid factorization



Strongly decreasing in virtuality
on-shell partons large x



$p_1+p_2=q_1+q_2$



$p_1+p_2=q_1+q_2+k$

Strongly decreasing
in longitudinal momentum
fractions of off-shell partons

$$\frac{d\sigma_{\rm SPS}^{P_1P_2\to {\rm dijets}+X}}{dy_1dy_2dp_{1t}dp_{2t}d\Delta\phi} = \frac{p_{1t}p_{2t}}{8\pi^2(x_1x_2s)^2}\sum_{a,c,d} x_1 f_{a/P_1}(x_1,\mu^2)\,|\overline{\mathcal{M}_{ag^*\to cd}}|^2 \quad \mathcal{F}_{g/P_2}(x_2,k_t^2)\frac{1}{1+\delta_{cd}}$$

New helicity based methods for ME

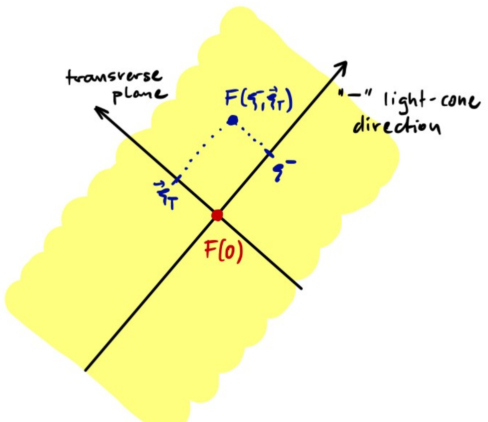
Kotko, K.K, van Hameren, '12

Definition of TMD – gauge links

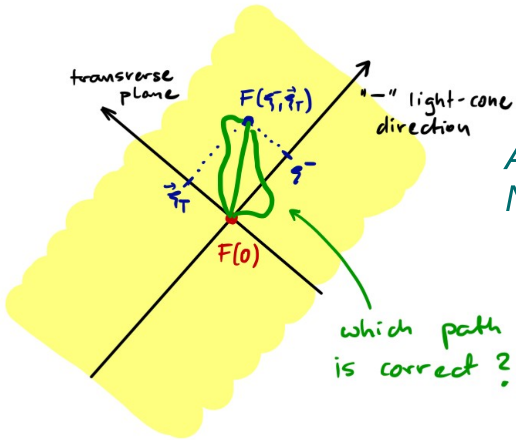
The formula for HEF is strictly valid for large transverse momentum and is kind of conjectured. The gluon density Is defined in terms of evolution equation. Recent developments with formal approaches start from definition of what parton density is.

$$\mathcal{F}(x,k_T) = 2\int \frac{d\xi^- d^2\xi_T}{(2\pi)^3 P^+} e^{ixP^+\xi^- - i\vec{k}_T\cdot\vec{\xi}_T} \langle P|\,\mathrm{Tr}\left\{\hat{F}^{i+}(0)\,\hat{F}^{i+}\left(\xi^+=0,\xi^-,\vec{\xi}_T\right)\right\}|P\rangle$$

naive definition of gluon distribution



from P. Kotko, Bialasówka 2019



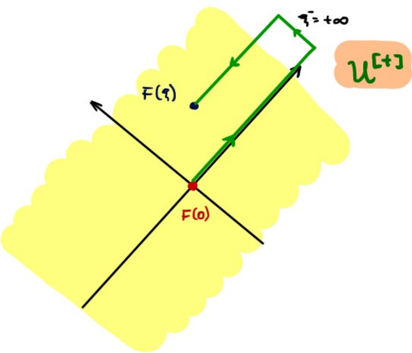
A. Belitsky, X. Ji, F. Yuan
Nucl.Phys. B656 (2003) 165-198

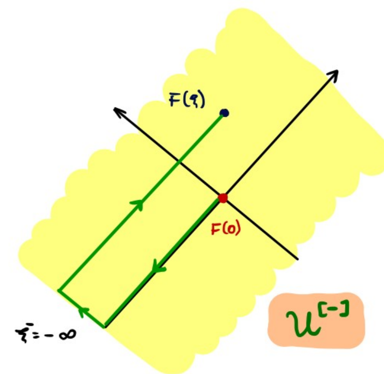
One needs also gauge link which accounts for exchange of collinear gluons between the soft and hard parts

$$\mathcal{F}(x,k_T) = 2\int \frac{d\xi^- d^2\xi_T}{(2\pi)^3 P^+} e^{ixP^+\xi^- - i\vec{k}_T\cdot\vec{\xi}_T} \langle P|\,\mathrm{Tr}\left\{\hat{F}^{i+}(0)\,\mathcal{U}_{C_1}\hat{F}^{i+}(\xi)\,\mathcal{U}_{C_2}\right\}|P\rangle$$

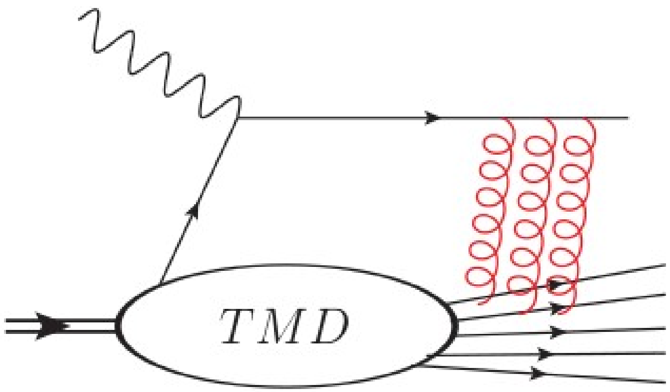
Definition of TMD – gauge links

Two basic structures arise:



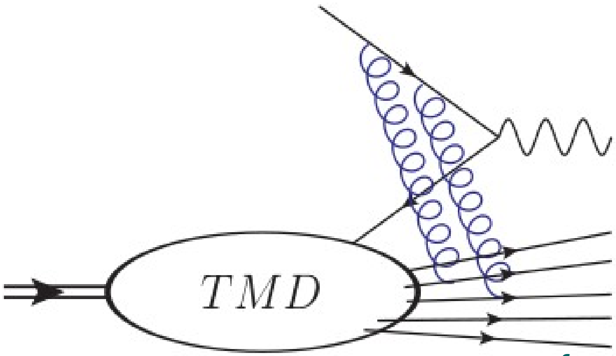


Semi Inclusive DIS



final state interactions

Drell-Yan



initial state interactions

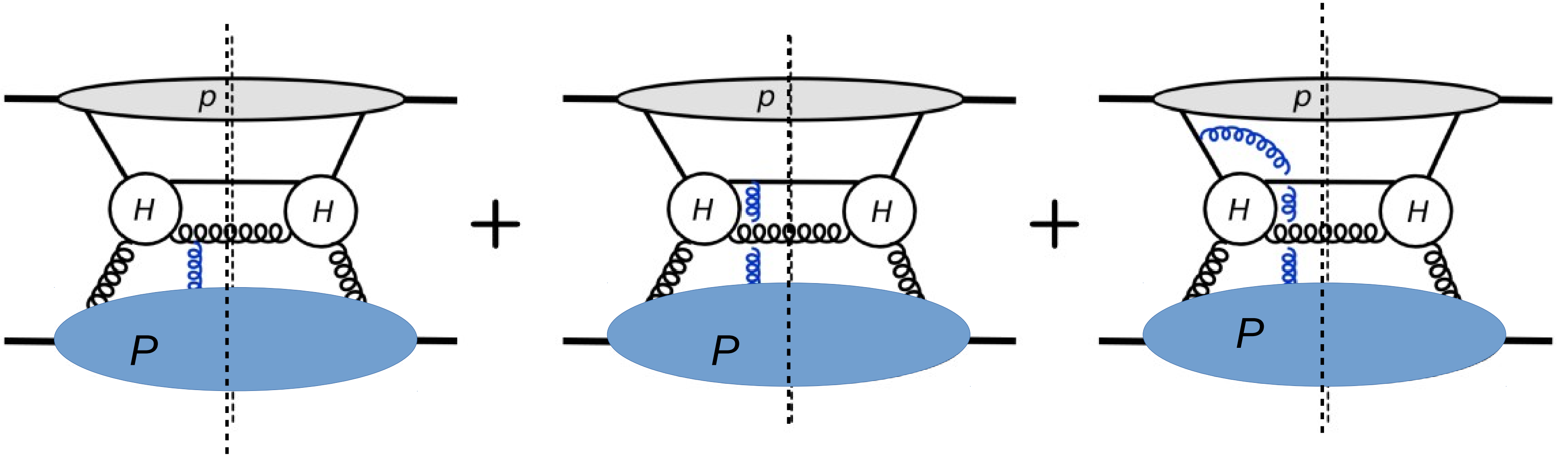
from R. Boussarie Initial Stages 2019

$$\Phi_q^{[+]}(x,p_T) = \int \frac{\mathrm{d}(\xi\cdot P)\mathrm{d}^2\xi_T}{(2\pi)^3}\, e^{ip\cdot\xi}\, \langle H|\,\overline{\psi}(0)\,\mathcal{U}^{[+]}\,\psi(\xi)\,|H\rangle$$

C.J. Bomhof, P.J. Mulders, F. Pijlman Eur.Phys.J. C47 (2006) 147-162

$$\mathcal{U}^{[\pm]} = U^n_{[(0^-,\mathbf{0}_T);(\pm\infty^-,\mathbf{0}_T)]}\, U^T_{[(\pm\infty^-,\mathbf{0}_T);(\pm\infty^-,\boldsymbol{\infty}_T)]}\, U^T_{[(\pm\infty^-,\boldsymbol{\infty}_T);(\pm\infty^-,\boldsymbol{\xi}_T)]}\, U^n_{[(\pm\infty^-,\boldsymbol{\xi}_T);(\xi^-,\boldsymbol{\xi}_T)]}$$

Gauge links and dijets



+ *similar diagrams with 2,3,….gluon exchanges.*

All this need to be resummed

C.J. Bomhof, P.J. Mulders, F. Pijlman
Eur.Phys.J. C47 (2006) 147-162

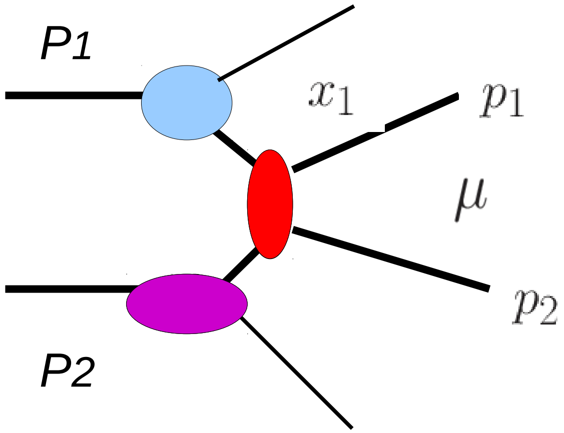
$$\mathcal{F}\left(x,k_T\right)=2\int\frac{d\xi^- d^2\xi_T}{(2\pi)^3\,P^+}\,e^{ixP^+\xi^- - i\vec{k}_T\cdot\vec{\xi}_T}\,\left\langle P\right|\mathrm{Tr}\left\{\hat{F}^{i+}\left(0\right)\mathcal{U}_{C_1}\hat{F}^{i+}\left(\xi\right)\mathcal{U}_{C_2}\right\}\left|P\right\rangle$$

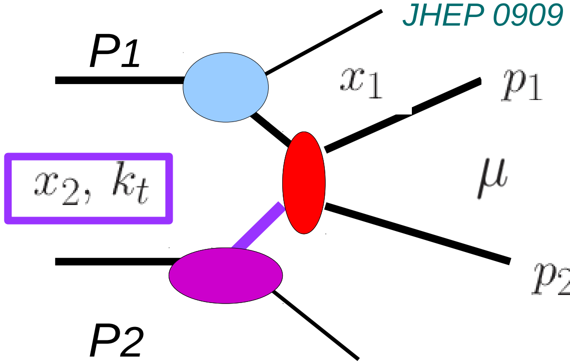
Hard part defines the path of the gauge link $\mathcal{U}^{[C]}(\eta;\xi)=\mathcal{P}\exp\Big[-ig\int_C \mathrm{d}z\cdot A(z)\Big]$

Improved Transversal Momentum Dependent Factorization

$$\frac{d\sigma_{\rm SPS}^{P_1P_2\to {\rm dijets}+X}}{dy_1dy_2dp_{1t}dp_{2t}d\Delta\phi}=\frac{p_{1t}p_{2t}}{8\pi^2(x_1x_2s)^2}\sum_{a,c,d}x_1f_{a/P_1}(x_1,\mu^2)\,|\overline{\mathcal{M}_{ag^*\to cd}}|^2\quad\mathcal{F}_{g/P_2}(x_2,k_t^2)\frac{1}{1+\delta_{cd}}$$

A, Dumitru, A. Hayashigaki J. Jalilian-Marian Nucl.Phys. A765 (2006) 464-482M. Deak, F. Hautmann, H. Jung, K. Kutak JHEP 0909 (2009) 121





Generalization of hybrid formula but no k_t in ME
Fabio Dominguez, Bo-Wen Xiao, Feng Yuan Phys.Rev.Lett. 106 (2011) 022301

F. Dominguez, C. Marquet, Bo-Wen Xiao, F. Yuan Phys.Rev. D83 (2011) 105005
Appropriate in back-to-back configuration

Using HEF motivated sum over polarization for low x gluons we included k_t in ME

Conjecture P. Kotko K. Kutak , C. Marquet , E. Petreska , S. Sapeta, A. van Hameren, JHEP 1509 (2015) 106
Appropriate in any configuration

gauge invariant amplitudes with k_t and TMDs

Can be obtained from CGC
T. Altinoluk, R. Boussarie, Piotr Kotko JHEP 1905 (2019) 156

Example for $g^*\, g \to g\, g$

$$\frac{d\sigma^{pA\to ggX}}{d^2P_td^2k_tdy_1dy_2}=\frac{\alpha_s^2}{(x_1x_2s)^2}\;x_1f_{g/p}(x_1,\mu^2)\sum_{i=1}^{6}\mathcal{F}_{gg}^{(i)}\,H_{gg\to gg}^{(i)}$$

Improved Transversal Momentum Dependent Factorization

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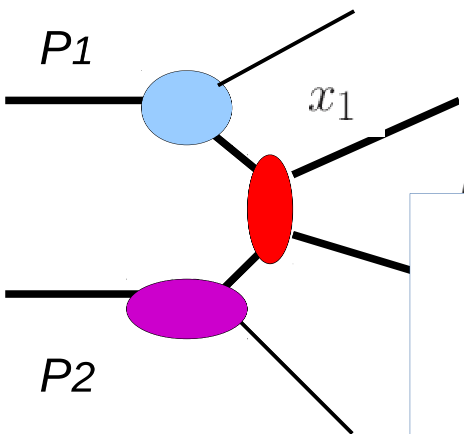

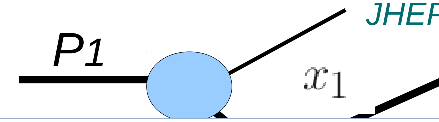

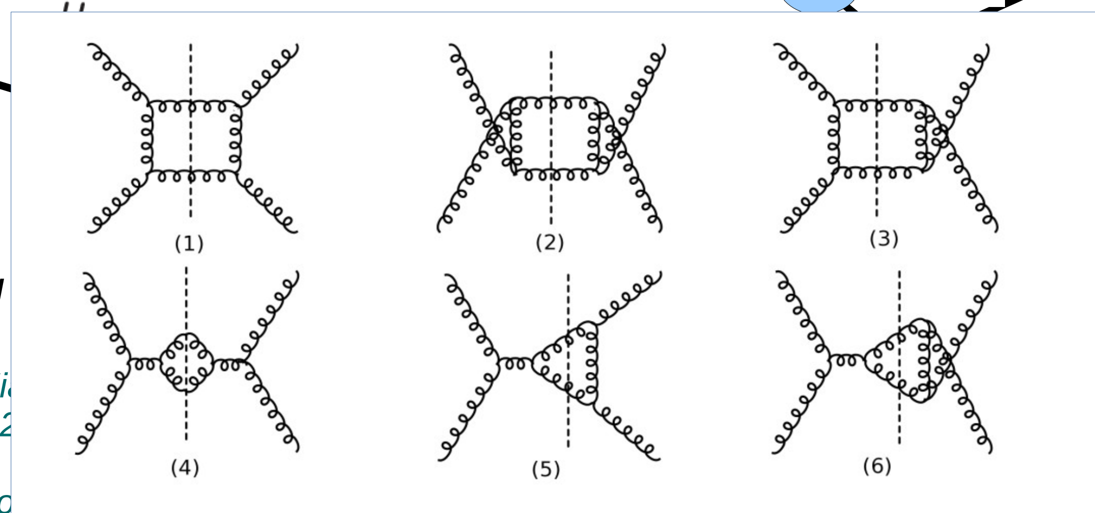

Generalization of hybrid
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Phys.Rev.Lett. 106 (2011) 022

F. Dominguez, C. Marquet, Bo
Phys.Rev. D83 (2011) 105005
Appropriate in back-to-back configuration

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Marquet , E. Petreska , S. Sapeta,
A. van Hameren, JHEP 1509 (2015) 106
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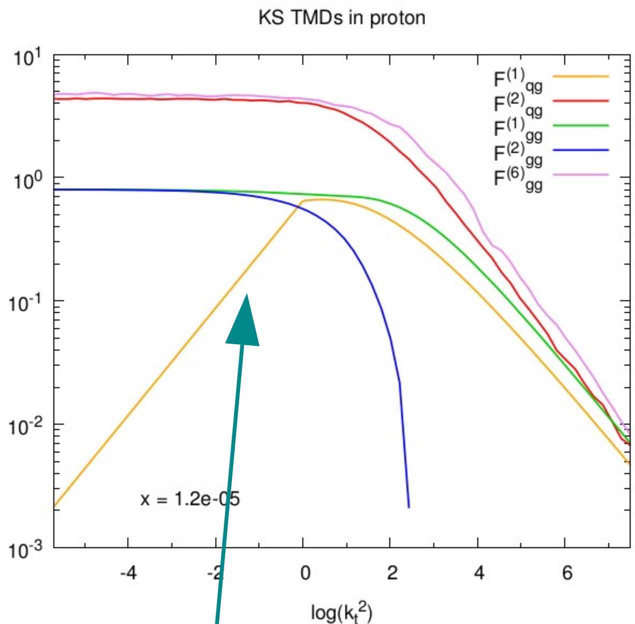
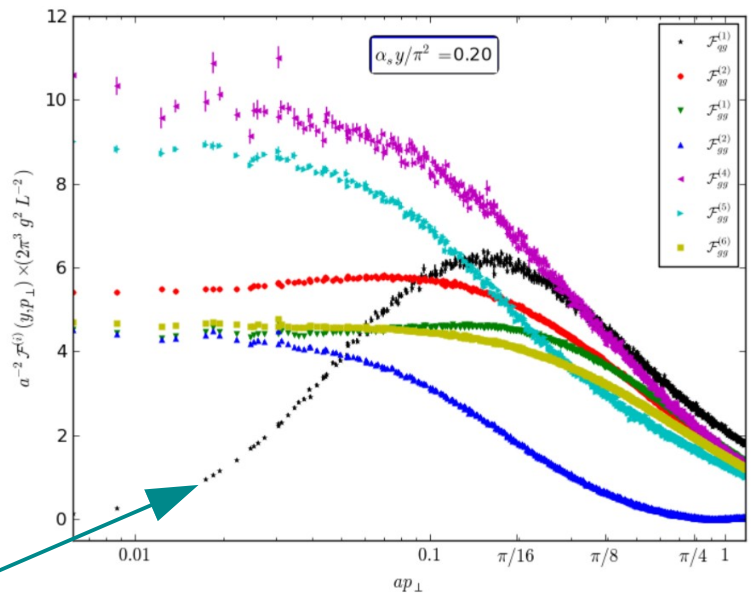
Plots of ITMD gluons





Calculation – in large Nc approximation with analitic model for dipole gluon density – all gluons can be calculated from the dipole one. KS gluon used.

Kotko, K.K, Marquet, Petreska, Sapeta, van Hameren JHEP 1612 (2016) 034

Standard HEF gluon density

Obtained from solutions of evolution equation which accounts for finite Nc. JIMWLK equation used to obtain Evolved gluon densities.

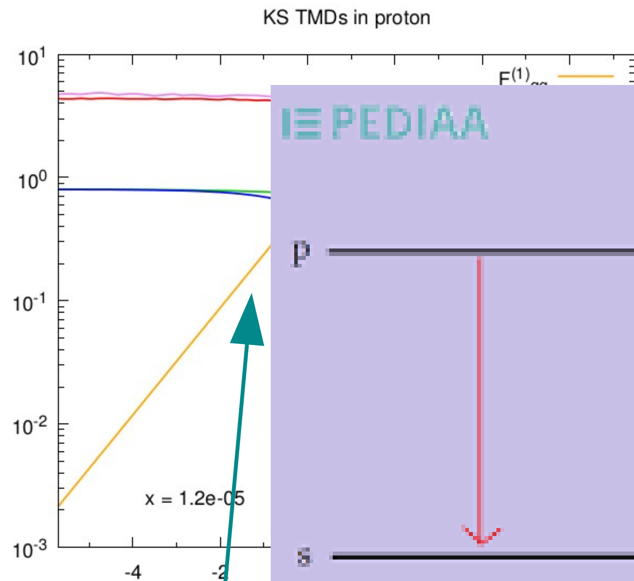
The JIMWLK equation is a renormalization group equation for the Wilson lines, obtained by integrating out the quantum fluctuations at smaller and smaller Bjorken-x.
C. Marquet, E. Petreska, C. Roiesnel
JHEP 1610 (2016) 065

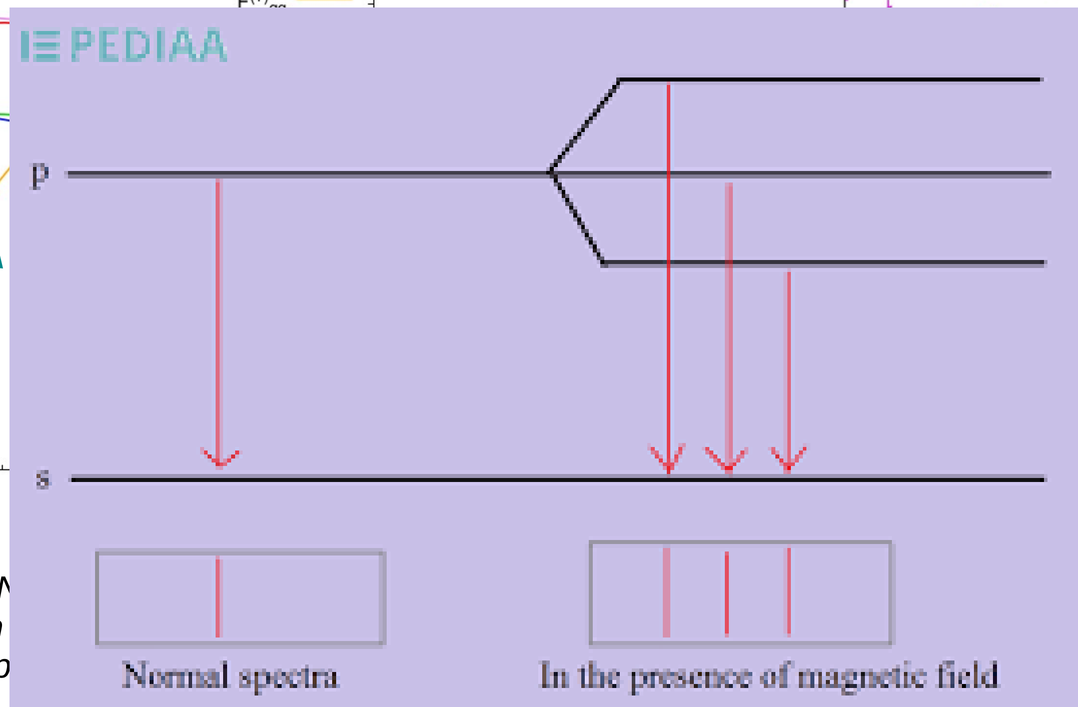
The other densities are flat at low k_t → less saturation

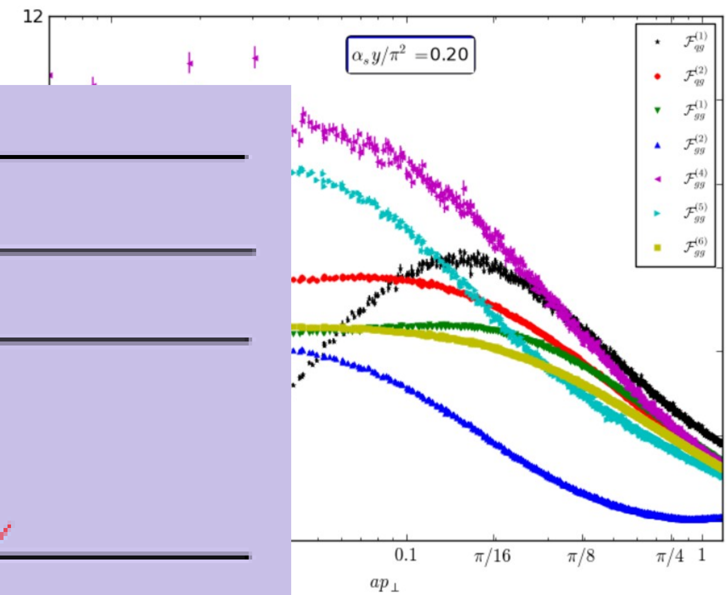
Not negligible differences at large k_t → differences at small angles

Plots of ITMD gluons

rough analogy to splitting of spectral lines in presence of a new scale







Calculation – in large N
model for dipole gluon
calculated from the dip

Kotko, K.K, Marquet, Petreska, Sapeta, van Hameren
JHEP 1612 (2016) 034

Standard HEF gluon density

of evolution equation which
MWLK equation used to obtain
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C. Marquet, E. Petreska, C. Roiesnel
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The other densities are flat at low k_t → less saturation

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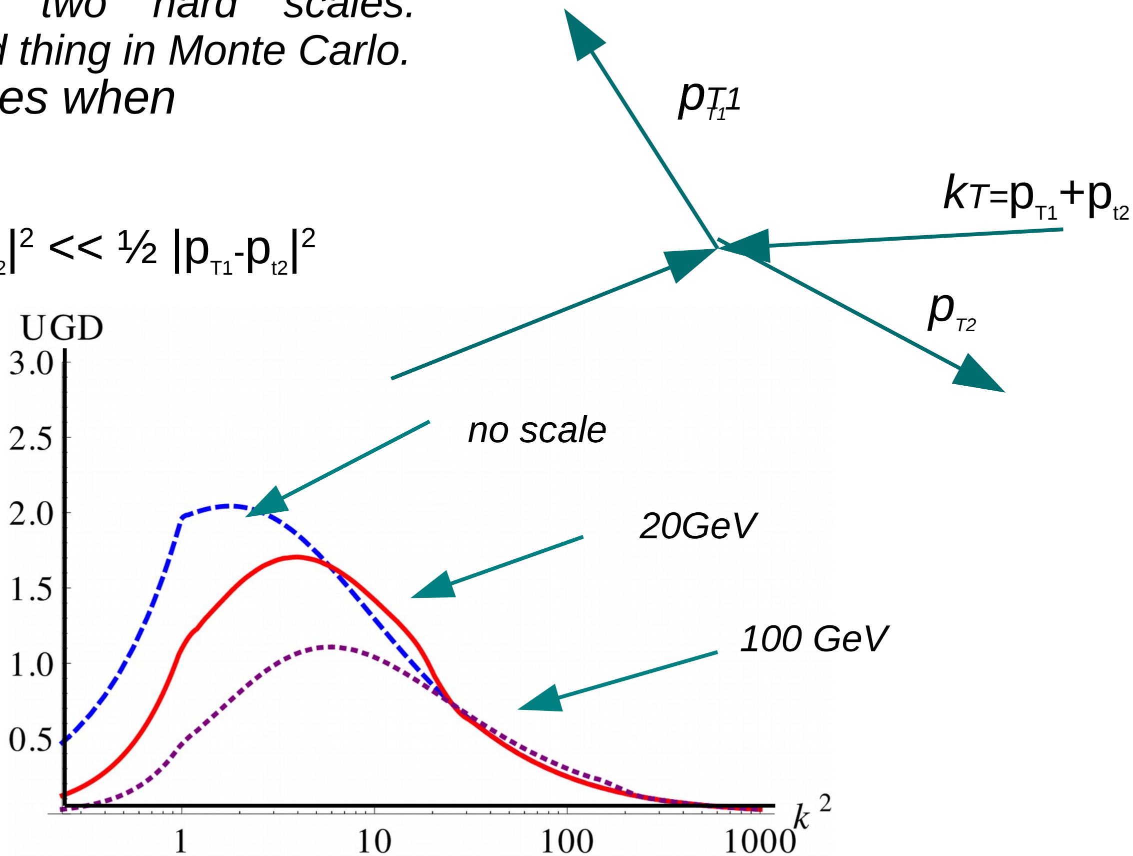
Forward physics and Sudakov form factor

Sudakov - no emision probability between two hard scales. Standard thing in Monte Carlo.

Applies when

$|p_{T1}+p_{t2}|^2 << \frac{1}{2} |p_{T1}-p_{t2}|^2$

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



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

A. H. Mueller, Bo-Wen Xiao, Feng Yuan
Phys.Rev.Lett. 110 (2013) no.8, 082301

Phys. Rev. D 88, 114010 (2013)
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Phys.Lett. B737 (2014) 335-340
A. van Hameren, P. Kotko, K. Kutak, S. Sapeta

K. Kutak
Phys.Rev. D91 (2015) no.3, 034021

I. Balitsky, A. Tarasov
JHEP 1510 (2015) 017

A.H. Mueller, Lech Szymanowski, Samuel Wallon, Bo-Wen Xiao, Feng Yuan
JHEP 1603 (2016) 096

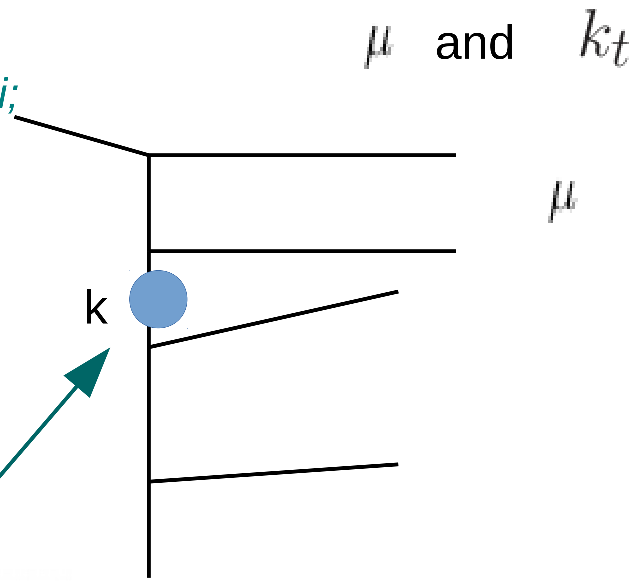
Nucl.Phys. B921 (2017) 104-126
B. Xiao, F. Yuan, J. Zhou.

Motivated by Catani, Ciafaloni, Fiorani Marchesini and Kwiecinski, Kimber, Martin, Stasto.

Sudakov form factor

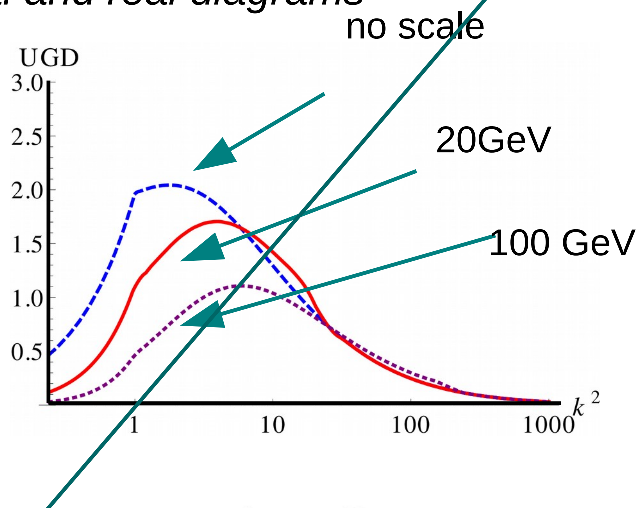
The relevance in low x physics
at linear level recognized by:
Catani, Ciafaloni, Fiorani,Marchesini;
Kimber,Martin,Ryskin;
Collins, Jung

Sudakov - no emision probability.
Resumes unresloved real and
virtual emissions. Standard thing
in Monte Carlo.
Comes from misscancelation
of virtual and real diagrams



hard scale

Survival probability of the gap without emissions



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

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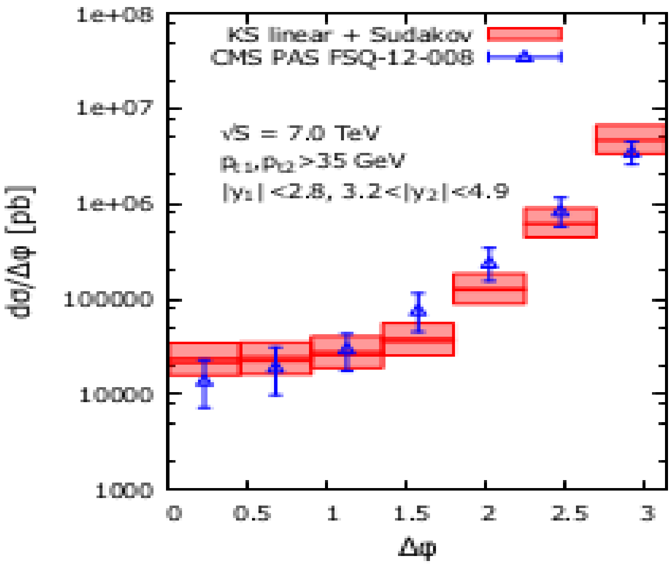
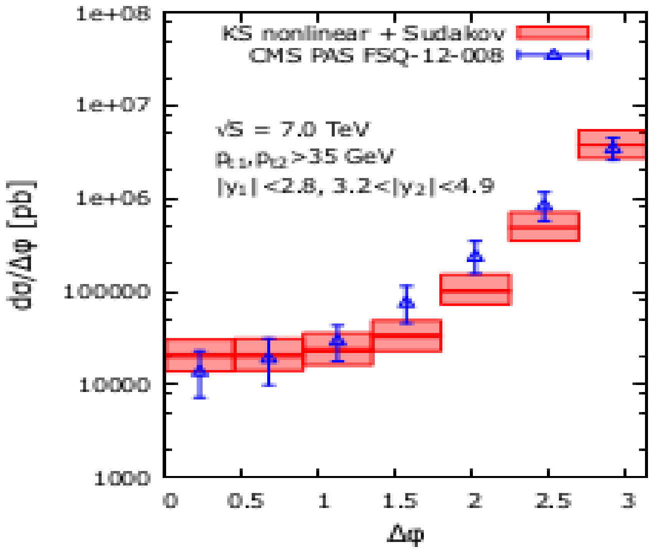
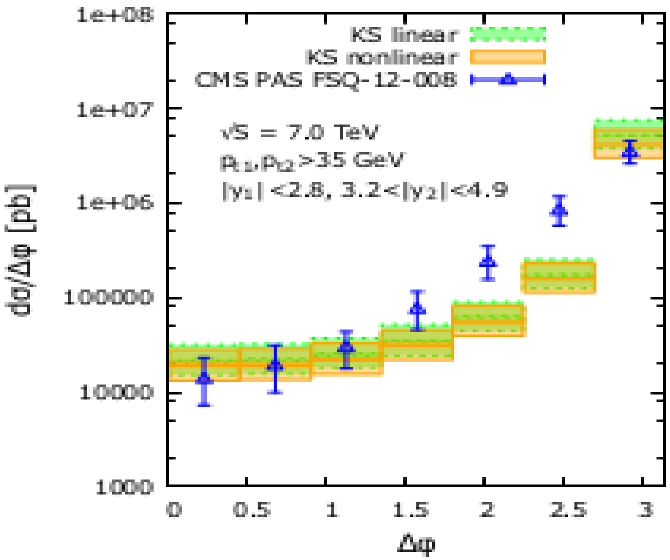
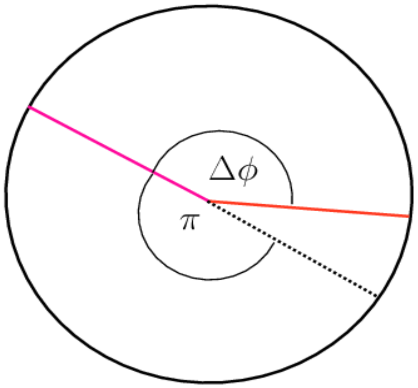
Decorelations inclusive scenario-central forward





No saturation…
visibleSudakov effects





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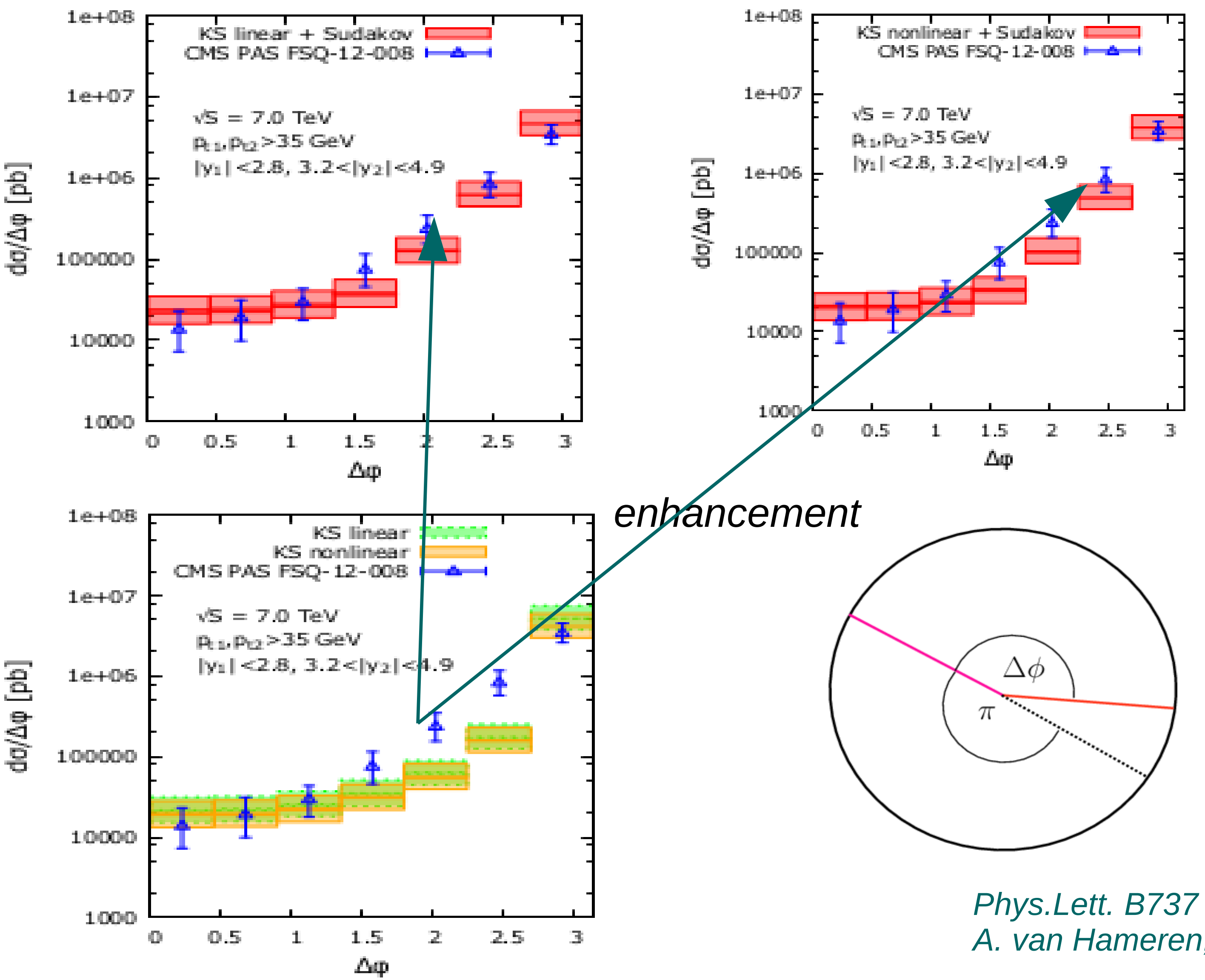

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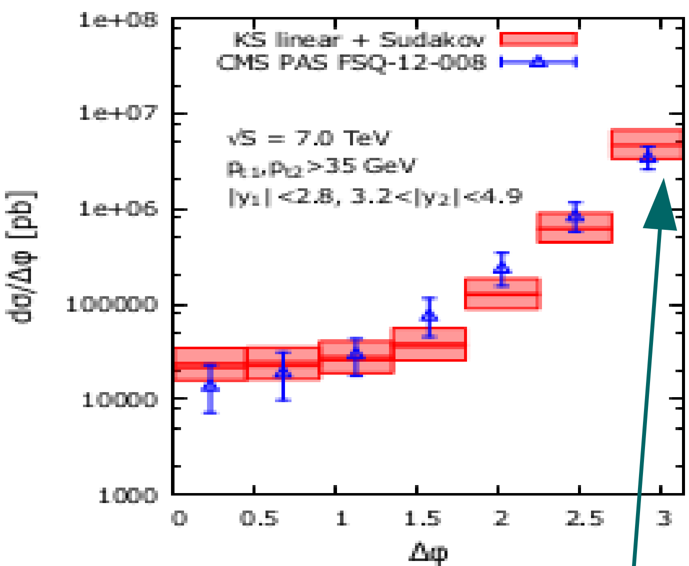
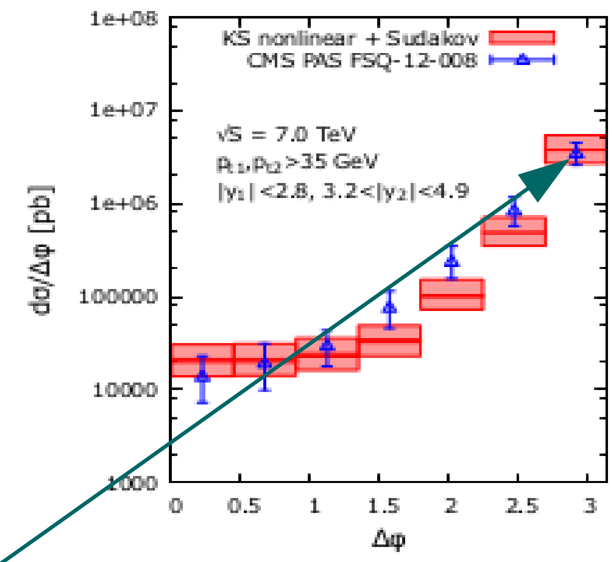
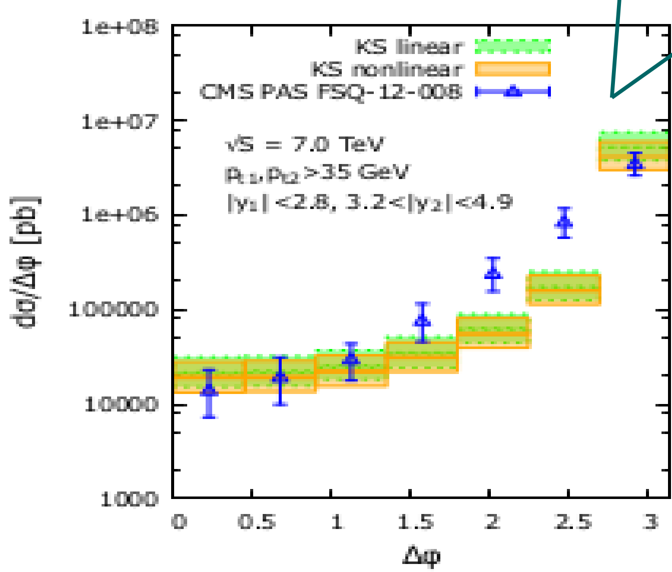
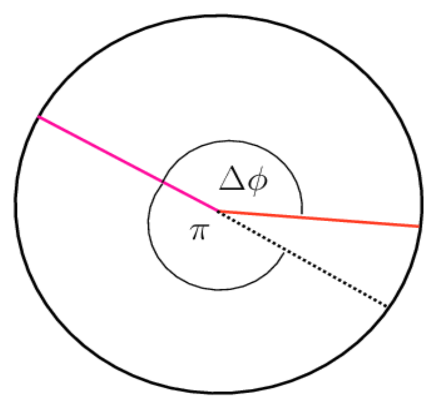




No saturation…
visibleSudakov effects

suppression





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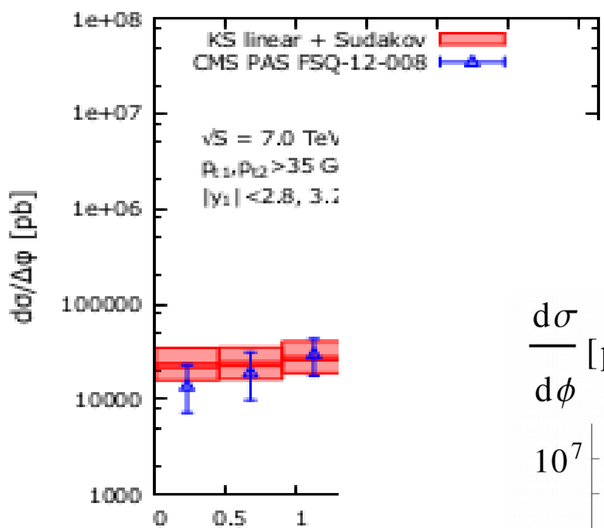
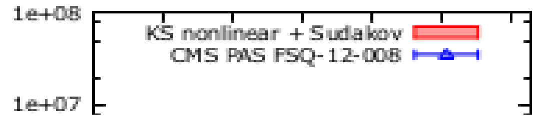
A. van Hameren, P. Kotko, K. Kutak, S. Sapeta

Decorelations inclusive scenario





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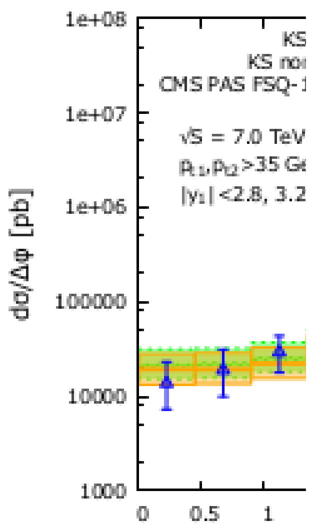
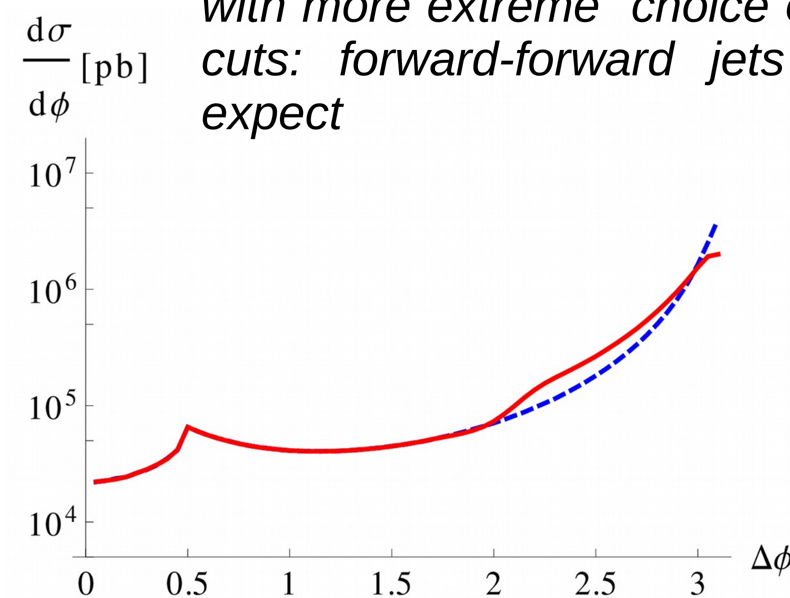


with more extreme choice of rapidity cuts: forward-forward jets we can expect



K. Kutak
Phys.Rev. D91 (2015) no.3, 034021

Forward-forward dijets- elements going into our prediction

The ITMD gluon's were obtained using:

Proton's KS gluon density – fitted to F_2 proton HERA data Balitsky-Kovchegov equation + kinematical constraint + subleading in low x, low z parts of splitting function.

Lead's KS gluon density – normalized to number of nucleons. Modified radius as compared to proton's radius

The Sudakov:

It has been was obtained from exponentiation of DGLAP splitting function

Total cross section is unchanged. Cross section at large angles is suppressed. Events with moderate angles are enhanced.

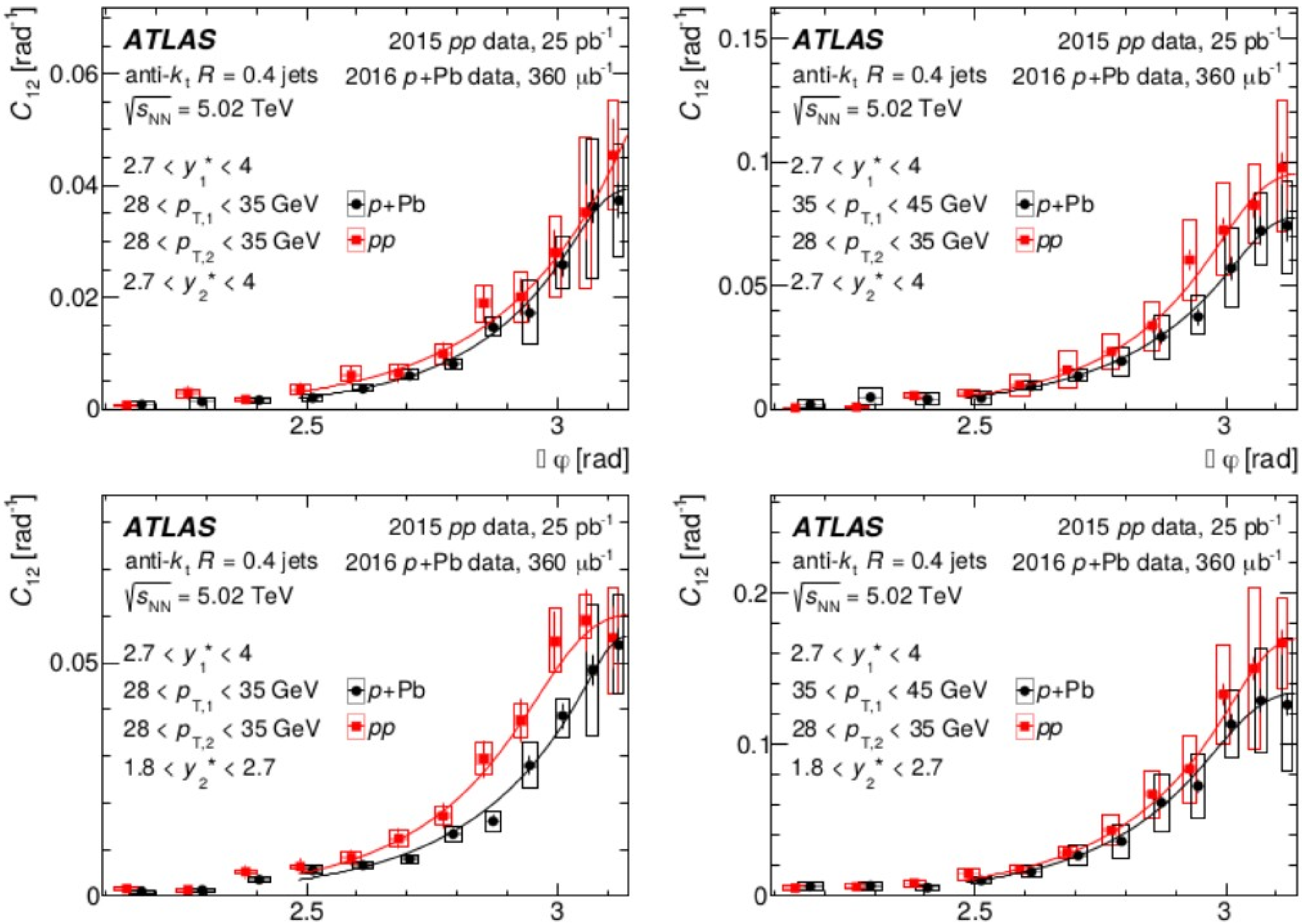
The cross section:

was calculated using:

- *KaTie Monte Carlo (van Hameren Comput.Phys.Commun. 224 (2018) 371-380)*
  - MC for p-p, p-A, soon DIS and A-A, calculates
  matrix elements in kt factorization and ITMD, matrix elements agree with the once obtained from Lipatov effectve action. Via merging with CASCADE accounts for ISR and FSR

- *cross-checked with LxJet Monte Carlo (Piotr Kotko) – dedicated MC for jets in kt factorization*

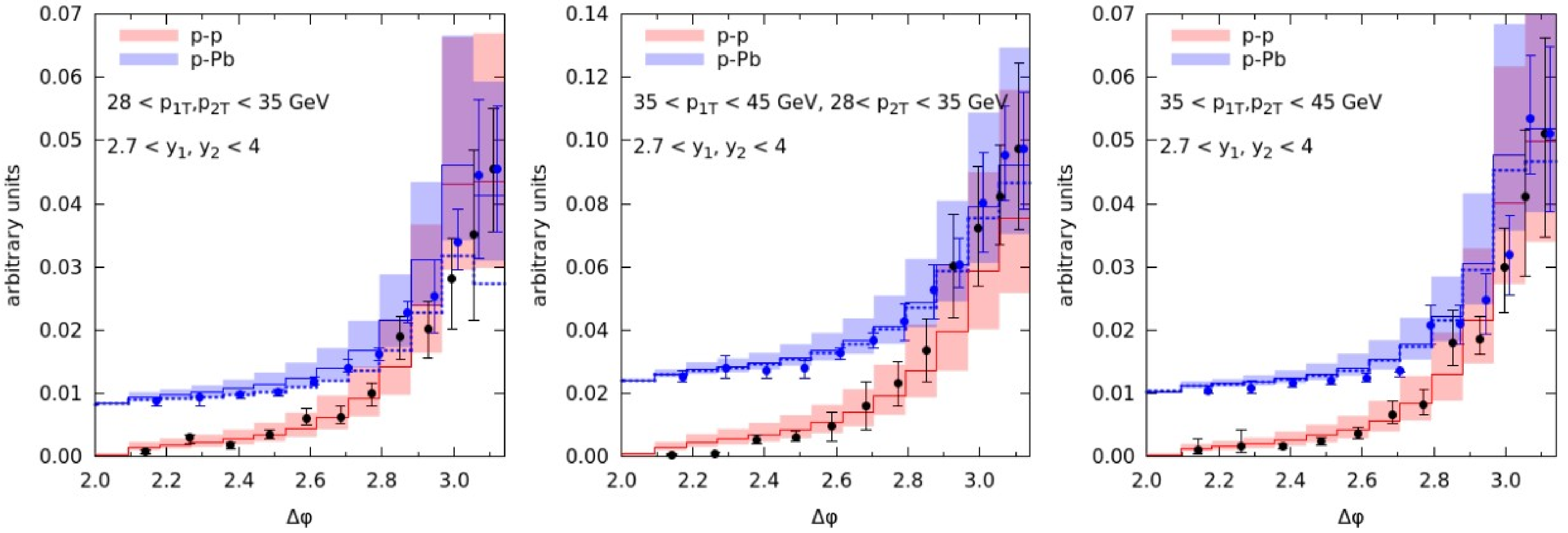
Data


ATLAS
2015 pp data, 25 pb-1
anti-kt R = 0.4 jets
2016 p+Pb data, 360 μb-1
√sNN = 5.02 TeV
2.7 < y1* < 4
28 < pT,1 < 35 GeV
28 < pT,2 < 35 GeV
2.7 < y2* < 4
p+Pb
pp
C12 [rad-1]
Δφ [rad]
35 < pT,1 < 45 GeV
1.8 < y2* < 2.7

Signature of broadening in forward-forward dijets

ATLAS Phys.Rev. C100 (2019) no.3, 034903

A. Hameren, P. Kotko, K. Kutak, S. Sapeta
Phys.Lett. B795 (2019) 511-515



Data: number of dijets normalized to number of single inclusive jets. We can not calculate that.
We can compare shapes.
Procedure: fit normalization to p-p data.
Use that both for p-p and p-Pb. Shift p-Pb data
The procedure allows for visualization of broadening

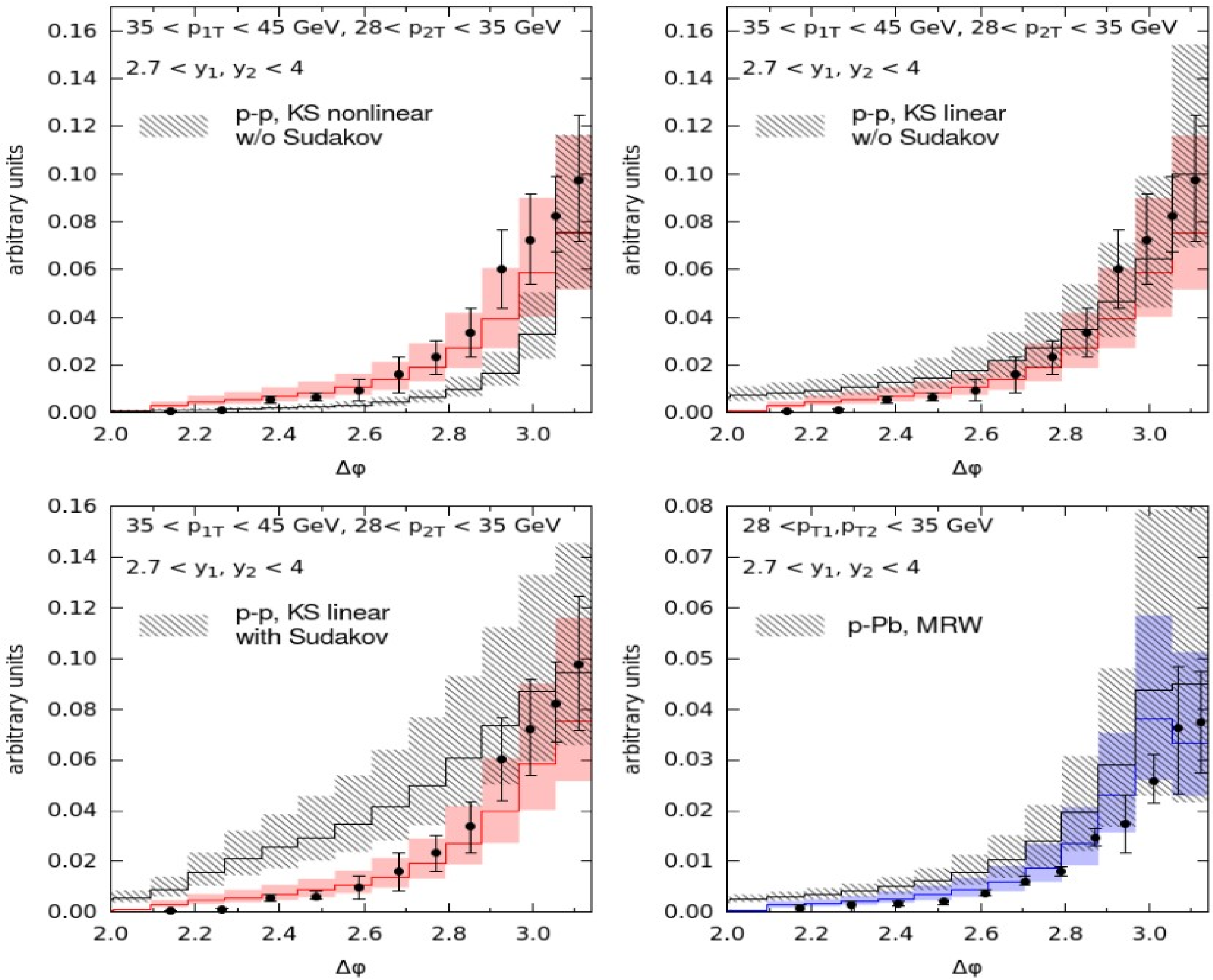
Other approaches

nonlinearity
no Sudakov

too narrow
distribution

linear
no Sudakov

not too bad
but
different
shape



linear

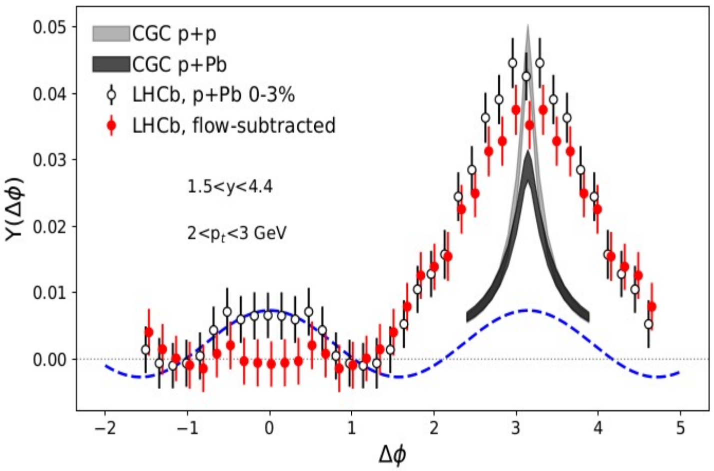
too wide
Sudakov
acts too much

Linear +
Sudakov

Ordering in
k_t

not too bad
but different
shape

Other calculations which support our result - di-hadrons production

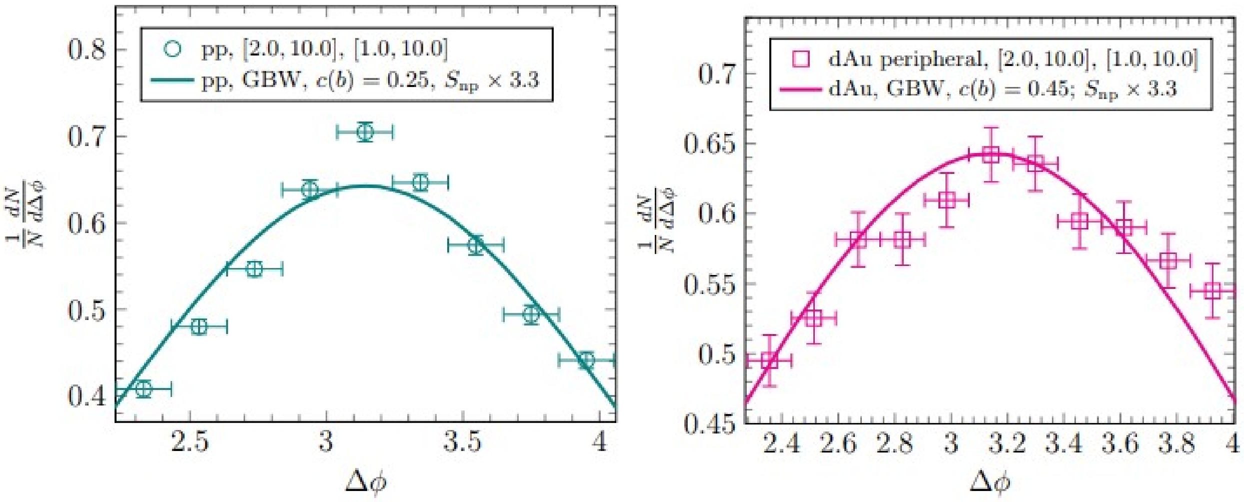


ITMD, no Sudakov

Expectation:
Sudakov
will broaden the distribution

G. Giacalone, C. Marquet, M. Matas
Phys.Rev. D99 (2019) no.1, 014002

J. Albacete, C, Marquet
Phys.Rev.Lett. 105 (2010) 162301

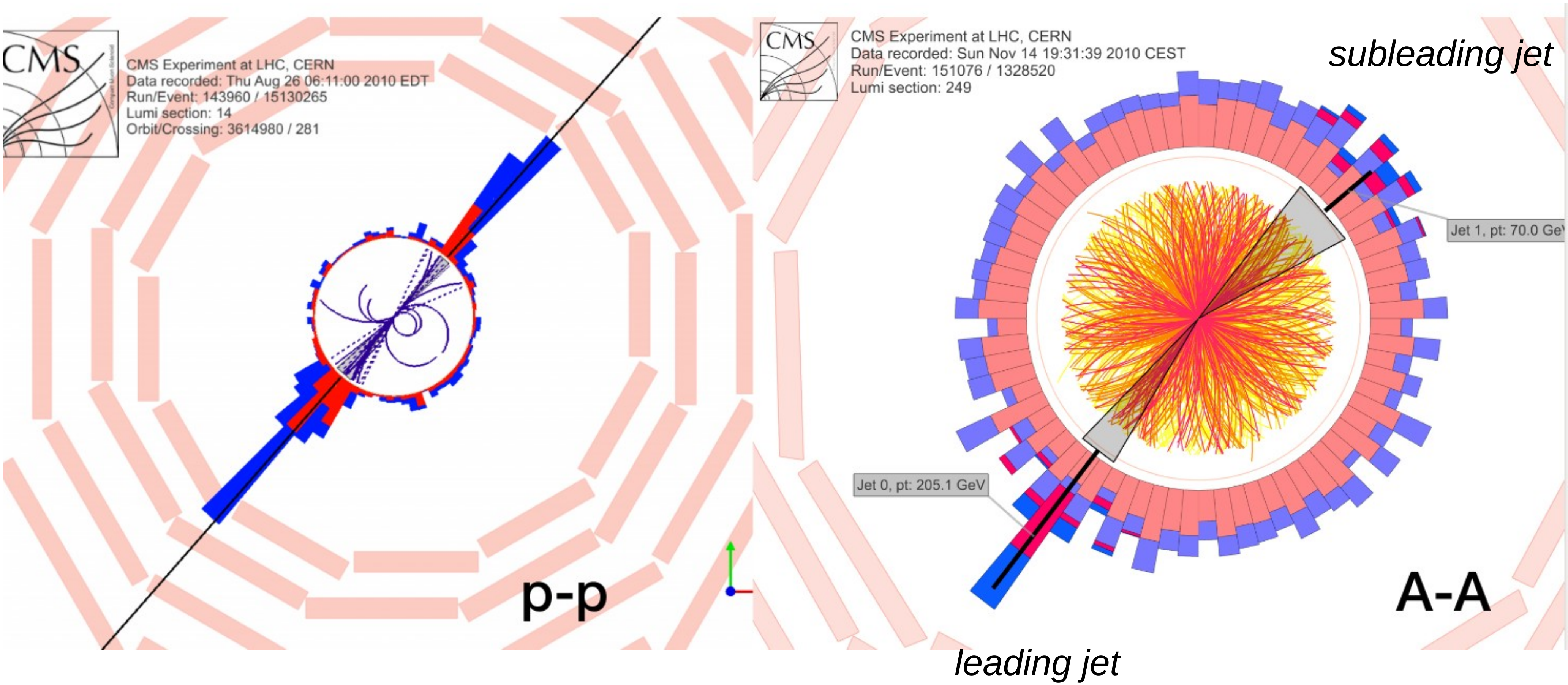


Correlation limit of CGC
+ Sudakov no k_t in ME

A.Stasto, S. Wei, B. Xiao, F. Yuan
Phys.Lett. B784 (2018) 301-306

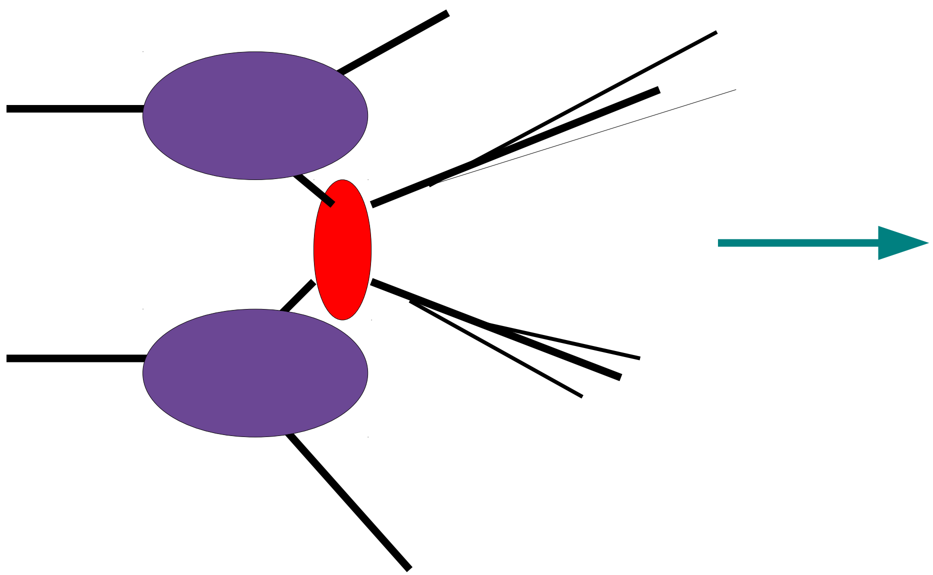
Pb-Pb

Jet quenching

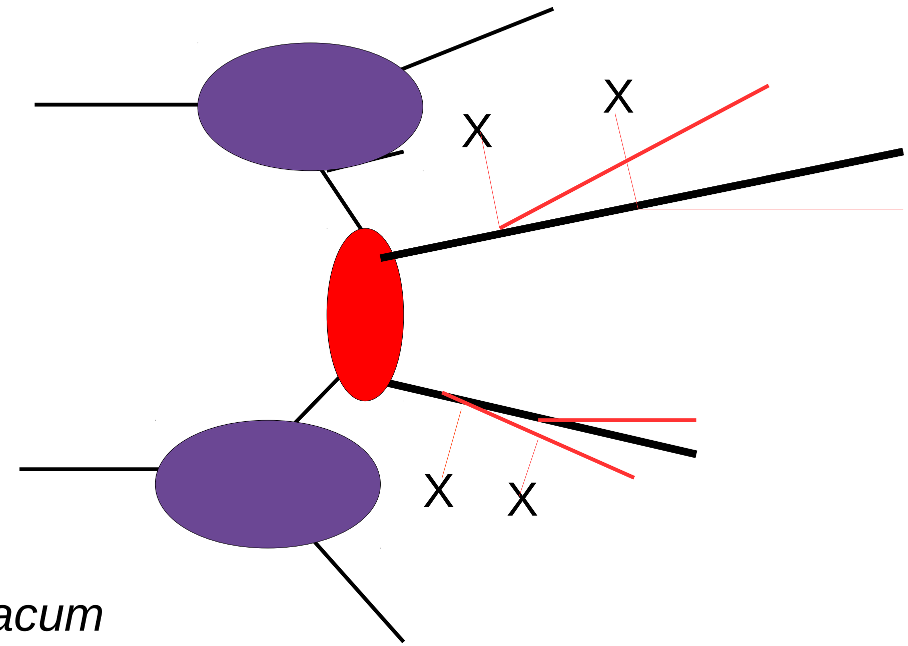


From vacuum to medium

vacuum



medium



*vacuum x-section = ME * pdf * fragmentaion in vacum*

*complete x-section = ME * pdf * fragmentaion in medium +*
*ME * pdf * fragmentation in vacum*

LPM and BDMPS-Z

Multiple soft scattering resummed to all orders. It is expected to be important for short mean free-path

Because medium-induced radiation can occur anywhere along the medium with equal probability, the radiation spectrum is expected to scale linearly with L.

Many scattering centers act coherently during the radiation over time t_{coh} (<< t_{mfp}).

$$\omega \frac{\mathrm{d}I}{\mathrm{d}\omega} \simeq \alpha_s \frac{L}{t_{\mathrm{coh}}} = \alpha_s \sqrt{\frac{\omega_c}{\omega}}$$

$$t_{\mathrm{coh}} \equiv \sqrt{\frac{\omega}{\hat{q}}}$$

energy of observed gluon

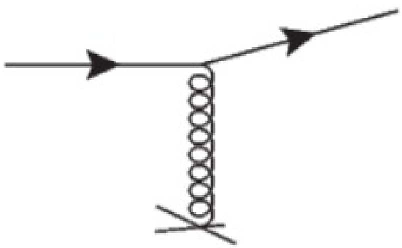
maximal energy that can be taken by single gluon

$$\omega \frac{\mathrm{d}I_{\mathrm{BH}}}{\mathrm{d}\omega} \simeq \alpha_s \frac{L}{\ell_{\mathrm{mfp}}} = \alpha_s N_{\mathrm{scatt}}$$

if $t_{coh} \sim t_{mfp}$ only one scattering is involved in radiation

Jet medium interaction

scattering...



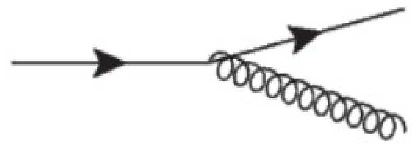
Transverse momentum transfer!

$p \to p + k_T$

Scattering Kernel: $C(k_T)$

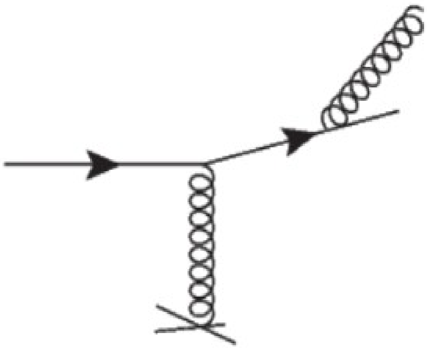
Average transfer: $\hat{q}$

...splitting...



Bremsstrahlung as in vacuum.

...induced radiation



Momentum distribution:

$p \to zp$

+Momentum transfer:

$p \to zp + k_T$

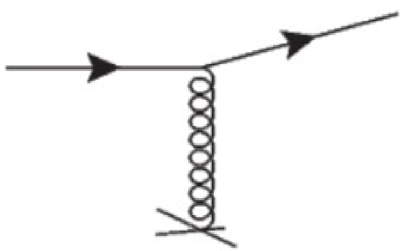
Kernel: $\mathcal{K}(z, k_T)$

from Martin Rohmoser

Jet medium interaction

we do not account for this now

scattering...



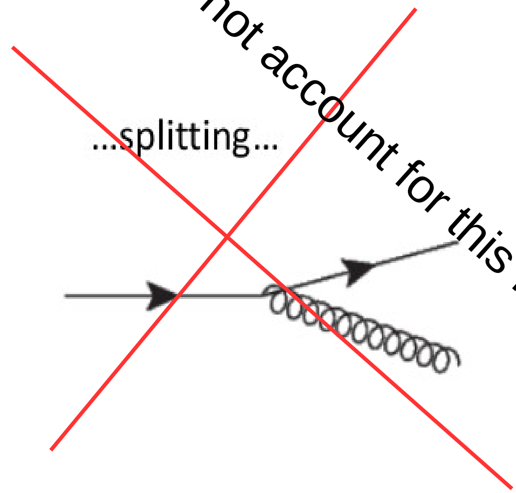
Transverse momentum transfer!

$p \rightarrow p + k_T$

Scattering Kernel: $C(k_T)$

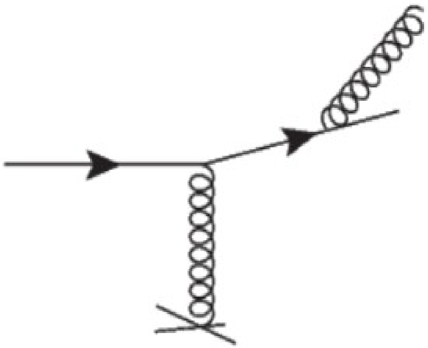
Average transfer: $\hat{q}$

...splitting...



Bremsstrahlung as in vacuum.

...induced radiation



Momentum distribution:

$p \rightarrow zp$

+Momentum transfer:

$p \rightarrow zp + k_T$

Kernel: $\mathcal{K}(z, k_T)$

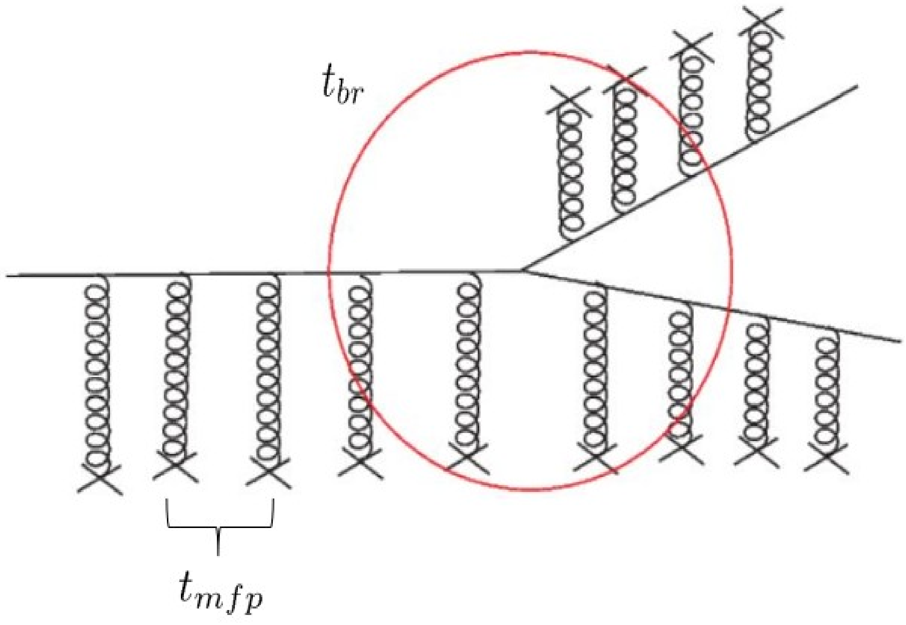
from Martin Rohmoser

LPM and BDMPS-Z

$t_{br} \sim \sqrt{\frac{2\omega}{\hat{q}}}$

$t_{br} \sim t_{mfp}$: one scattering + radiation
...Bethe-Heitler spectrum

$t_{br} \gg t_{mfp}$: coherent radiation



$\omega \frac{dI}{d\omega} \sim \alpha_s \frac{L}{t_{br}} = \alpha_s \sqrt{\frac{\omega_c}{\omega}}$

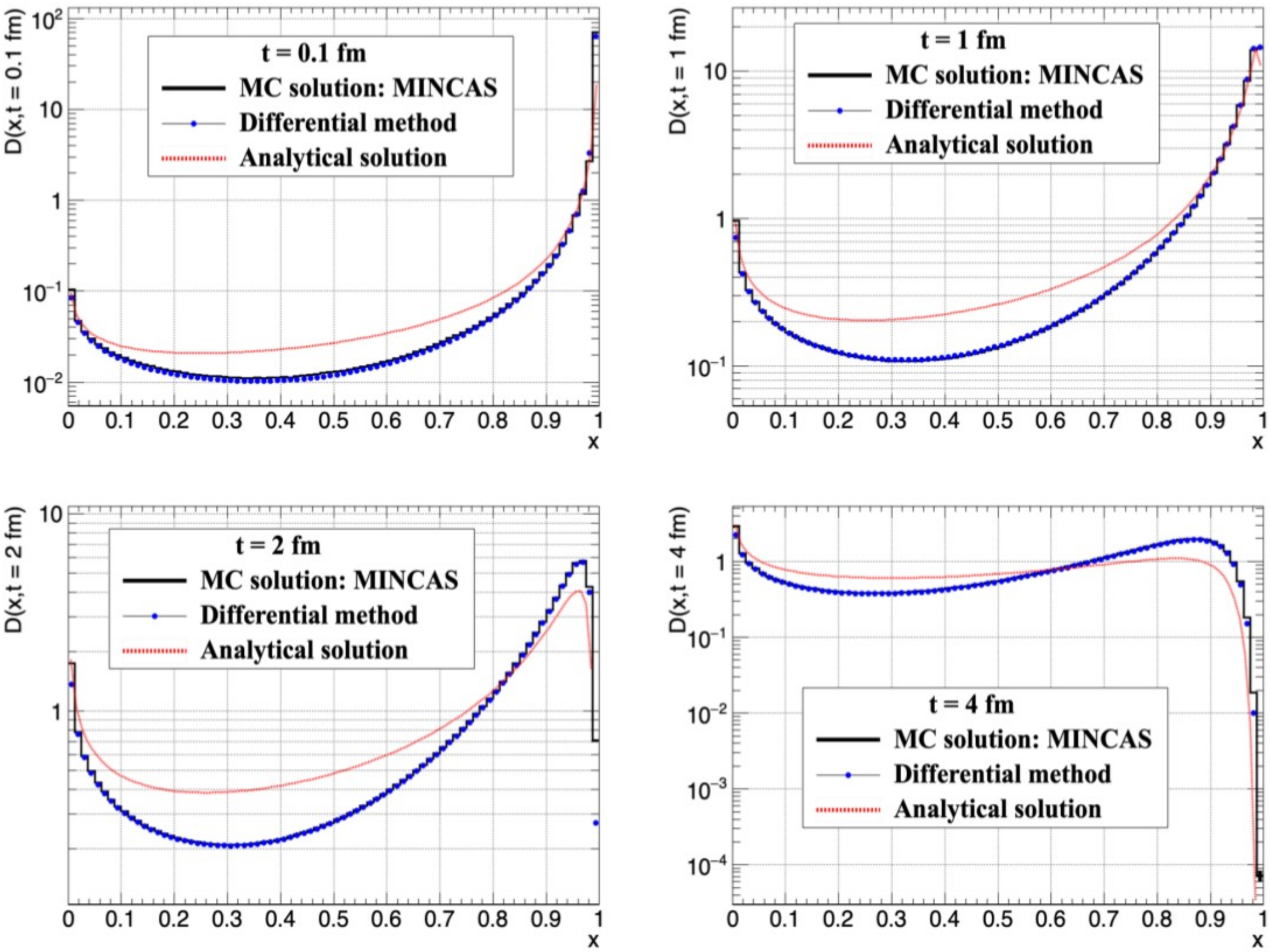
Look at range: $\omega_{BH} < \omega < \omega_c$

maximal energy that can be taken by single gluon

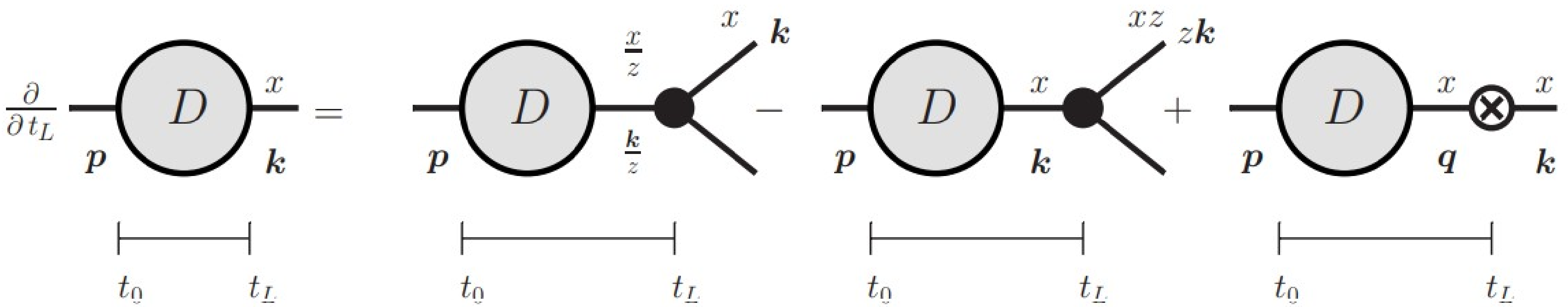
Energy distribution of radiated gluons

$$\frac{\partial}{\partial t} D(x,t) = \frac{1}{t^*} \int_0^1 dz\, \mathcal{K}(z) \left[\sqrt{\frac{z}{x}} D\left(\frac{x}{z}, t\right) \theta(z-x) - \frac{z}{\sqrt{x}} D(x,t) \right]$$

Solution for energy distribution – simplified kernel vs. complete kernel



The BDIM equation - generalization of BDMPS-Z



Blaizot, Dominguez, Iancu, Mehtar-Tani '12

$$\frac{\partial}{\partial t}D(x,\mathbf{k},t) = \frac{1}{t^*}\int_0^1 dz\,\mathcal{K}(z)\left[\frac{1}{z^2}\sqrt{\frac{z}{x}}D\left(\frac{x}{z},\frac{\mathbf{k}}{z},t\right)\theta(z-x) - \frac{z}{\sqrt{x}}D(x,\mathbf{k},t)\right]$$

Inclusive gluon distribution as produced by hard jet

$$+\int\frac{d^2\mathbf{q}}{(2\pi)^2}C(\mathbf{q})D(x,\mathbf{k}-\mathbf{q},t)$$

$$\frac{1}{t^*} = \frac{\bar{\alpha}}{\tau_{\rm br}(E)} = \bar{\alpha}\sqrt{\frac{\hat{q}}{E}}$$

$$C(\mathbf{q}) = w(\mathbf{q}) - \delta(\mathbf{q})\int d^2\mathbf{q}'\,w(\mathbf{q}')$$

$$\mathcal{K}(z) = \frac{[f(z)]^{5/2}}{[z(1-z)]^{3/2}} \qquad f(z) = 1 - z + z^2$$

Equation describes interplay of rescatterings and branching. This particular equation has k_t independent kernel. This is an approximation. The whole broadening comes from rescattering. Energy of emitted gluon is much larger than its transverse momentum

Rearrangement of the equation for gluon density

procedure almost the same as for energy distribution

$$\frac{\partial}{\partial t}D(x,\mathbf{k},t) = \frac{1}{t^*}\int_0^1 dz\,\mathcal{K}(z)\left[\frac{1}{z^2}\sqrt{\frac{z}{x}}D\left(\frac{x}{z},\frac{\mathbf{k}}{z},t\right)\theta(z-x) - \frac{z}{\sqrt{x}}D(x,\mathbf{k},t)\right] + \int\frac{d^2\mathbf{q}}{(2\pi)^2}C(\mathbf{q})\,D(x,\mathbf{k}-\mathbf{q},t),$$

Kutak, Płaczek, Straka 19

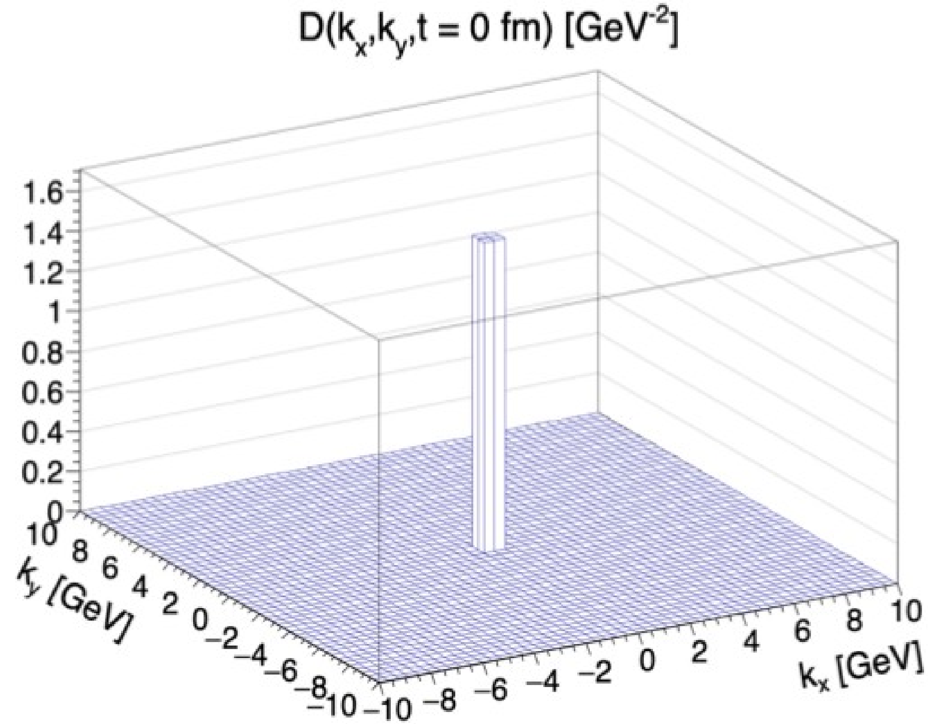
mathematics: transformation of differential equation to integral equation

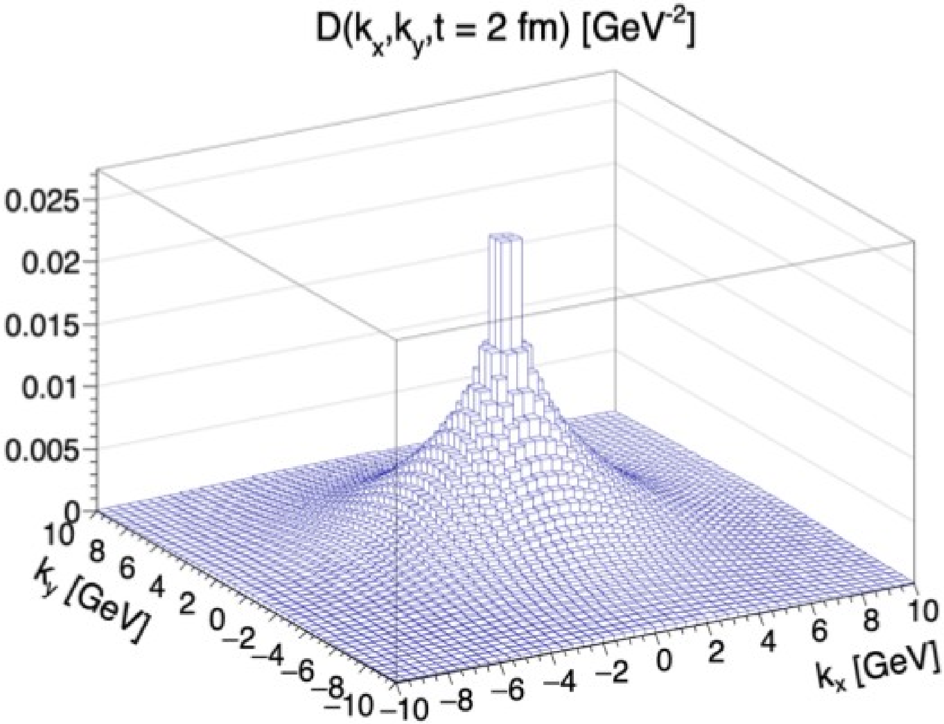
physics: resummation of virtual and unresolved real emissions

Sudakov form factor resumes virtual and unresolved real emissions

$$D(x,\mathbf{k},\tau) = e^{-\Psi(x)(\tau-\tau_0)}D(x,\mathbf{k},\tau_0) + \int_{\tau_0}^{\tau}d\tau'\int_0^1 dz\int_0^1 dy\int d^2\mathbf{k}'\int d^2\mathbf{q}\;\mathcal{G}(z,\mathbf{q}) \times \delta(x-zy)\,\delta(\mathbf{k}-\mathbf{q}-z\mathbf{k}')\,e^{-\Psi(x)(\tau-\tau')}D(y,\mathbf{k}',\tau')$$

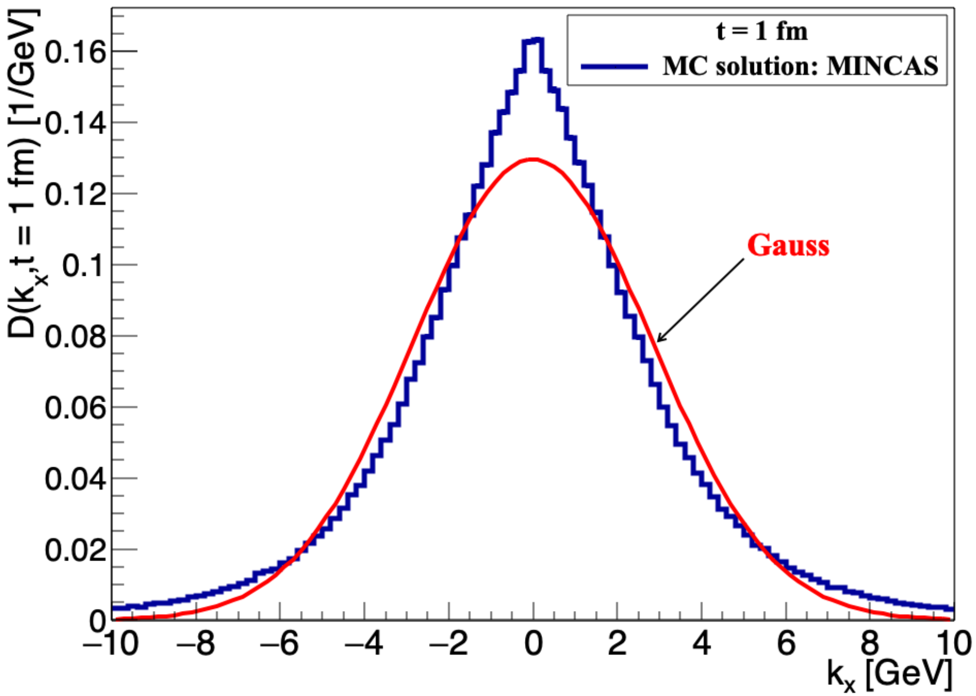
Broadening of jet

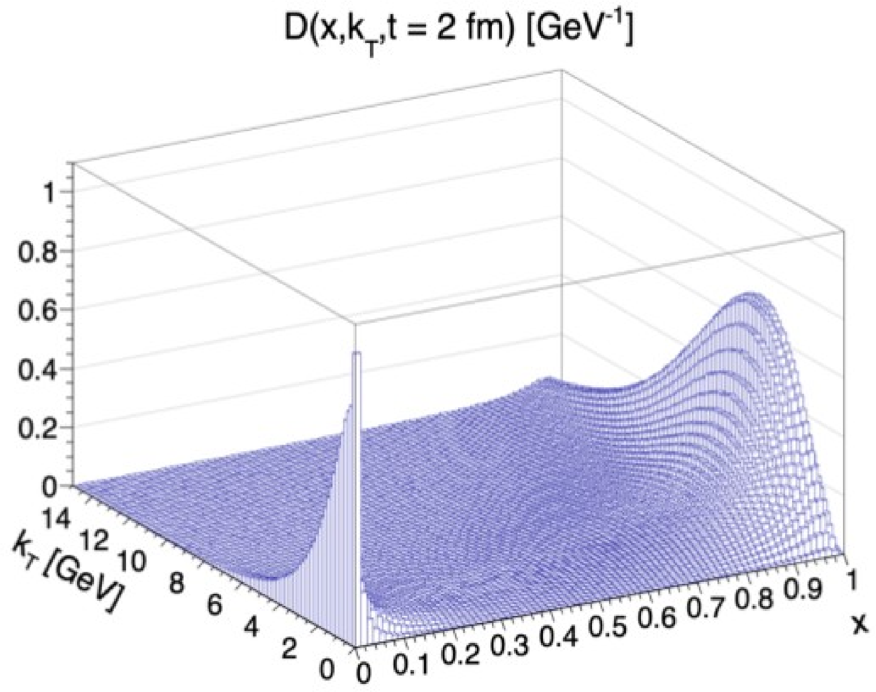




Such picture is not possible is fou assume strongly coupled plasma

Non gaussianity



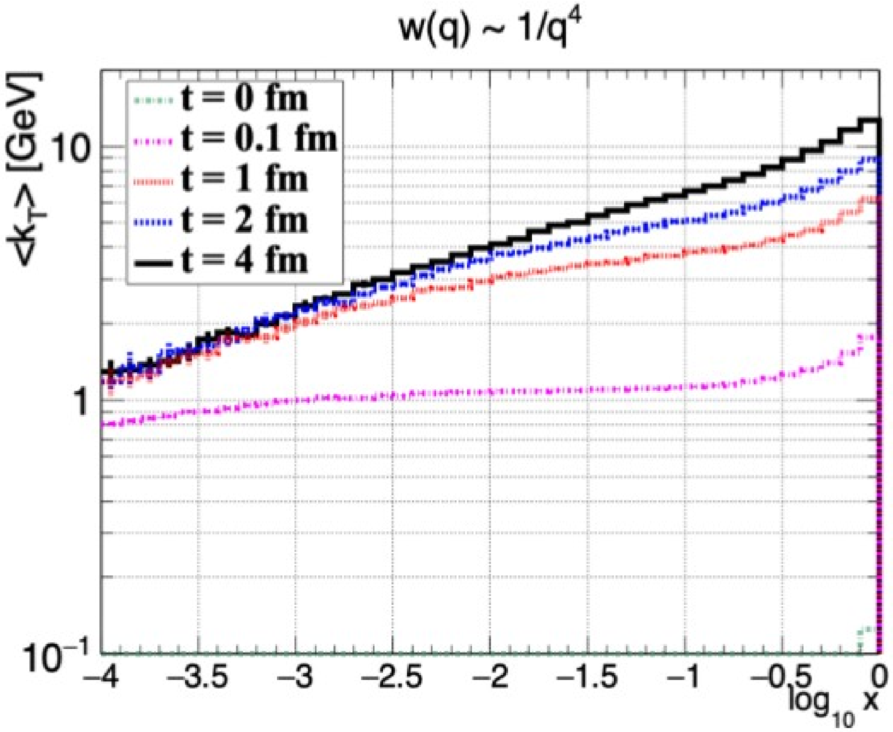


Sum of many gaussians with different width.

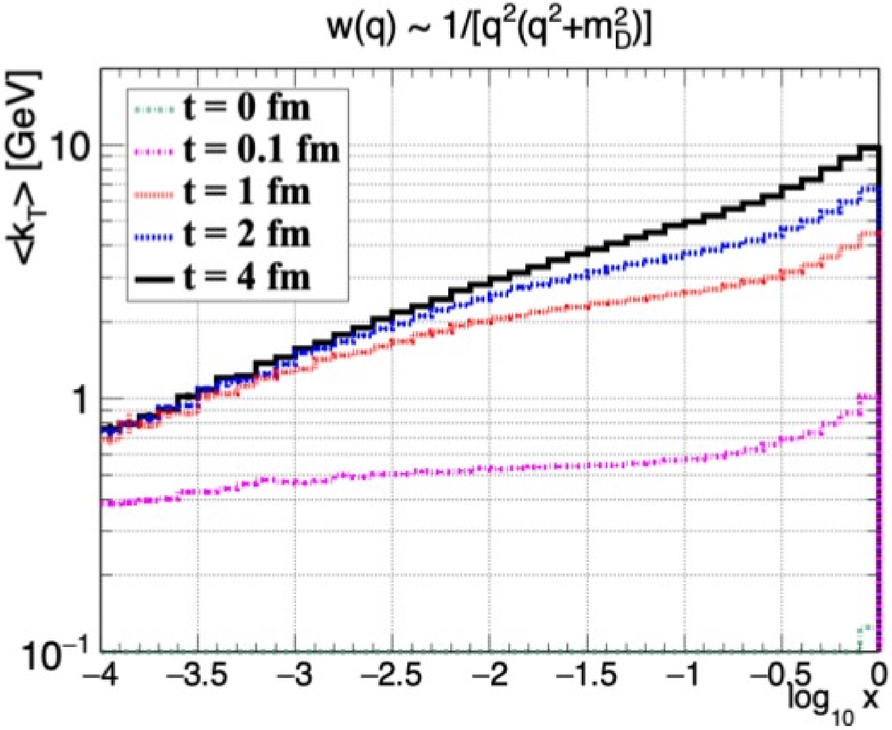
This is a result of the exact treatment of the gluon transverse-momentum broadening due to an arbitrary number of the collisions with the medium together with its shrinking due an arbitrary number of the emission branching.

Quenching line

Non-termalized medium



Termalized medium



Thermalized medium suppresses jets stronger
Universal behavior at larger times
The jet gets delocalized in transverse in transverse plane and lower and lower "x"

From cacum to medium

$$\frac{d\sigma_{pp}}{dy_1 dy_2 d^2q_{1T} d^2q_{2T}} = \int \frac{d^2k_{1T}}{\pi}\frac{d^2k_{2T}}{\pi}\frac{1}{16\pi^2(x_1x_2s)^2}\overline{|\mathcal{M}^{\mathrm{off-shell}}_{g^*g^*\to gg}|^2} \times \delta^2\left(\vec{k}_{1T}+\vec{k}_{2T}-\vec{q}_{1T}-\vec{q}_{2T}\right)\mathcal{F}_g(x_1,k^2_{1T},\mu^2_F)\,\mathcal{F}_g(x_2,k^2_{2T},\mu^2_F)$$

$$\frac{\mathrm{d}\sigma_{AA}}{\mathrm{d}\Omega_{p_1}\Omega_{p_2}} = \int \mathrm{d}^2\boldsymbol{q}_1 \int \mathrm{d}^2\boldsymbol{q}_2 \int_0^1 \frac{\mathrm{d}\tilde{x}_1}{\tilde{x}_1^2}\int_0^1 \frac{\mathrm{d}\tilde{x}_2}{\tilde{x}_2^2} D(\tilde{x}_1,\boldsymbol{p}_1-\boldsymbol{q}_1,\tau(p_1^+/\tilde{x}_1))D(\tilde{x}_2,\boldsymbol{p}_2-\boldsymbol{q}_2,\tau(p_2^+/\tilde{x}_2))$$

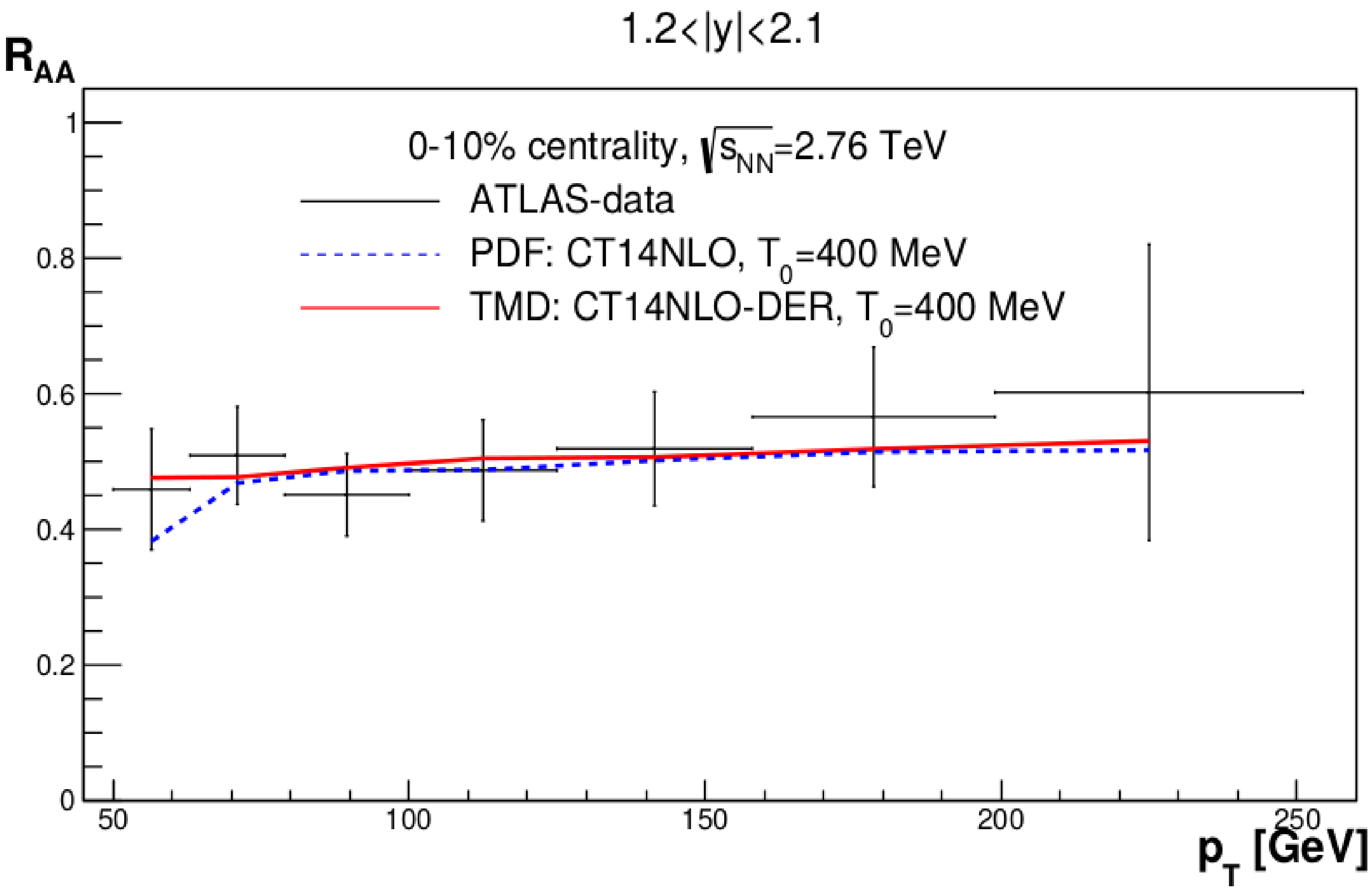
$$\left.\frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}q_1^+\mathrm{d}q_2^+\mathrm{d}^2\boldsymbol{q}_1\mathrm{d}^2\boldsymbol{q}_2}\right|_{q_1^+=p_1^+/\tilde{x}_1,\,q_2^+=p_2^+/\tilde{x}_2}$$

Our assumptions:

- *only gluonic jets*
- *uniform plasma*
- *we neglect shower outside of plasma*
- *we neglect vacum like emissions in plasma*
- *we assume bjorken model to tune the temperature to describe* R_{AA}

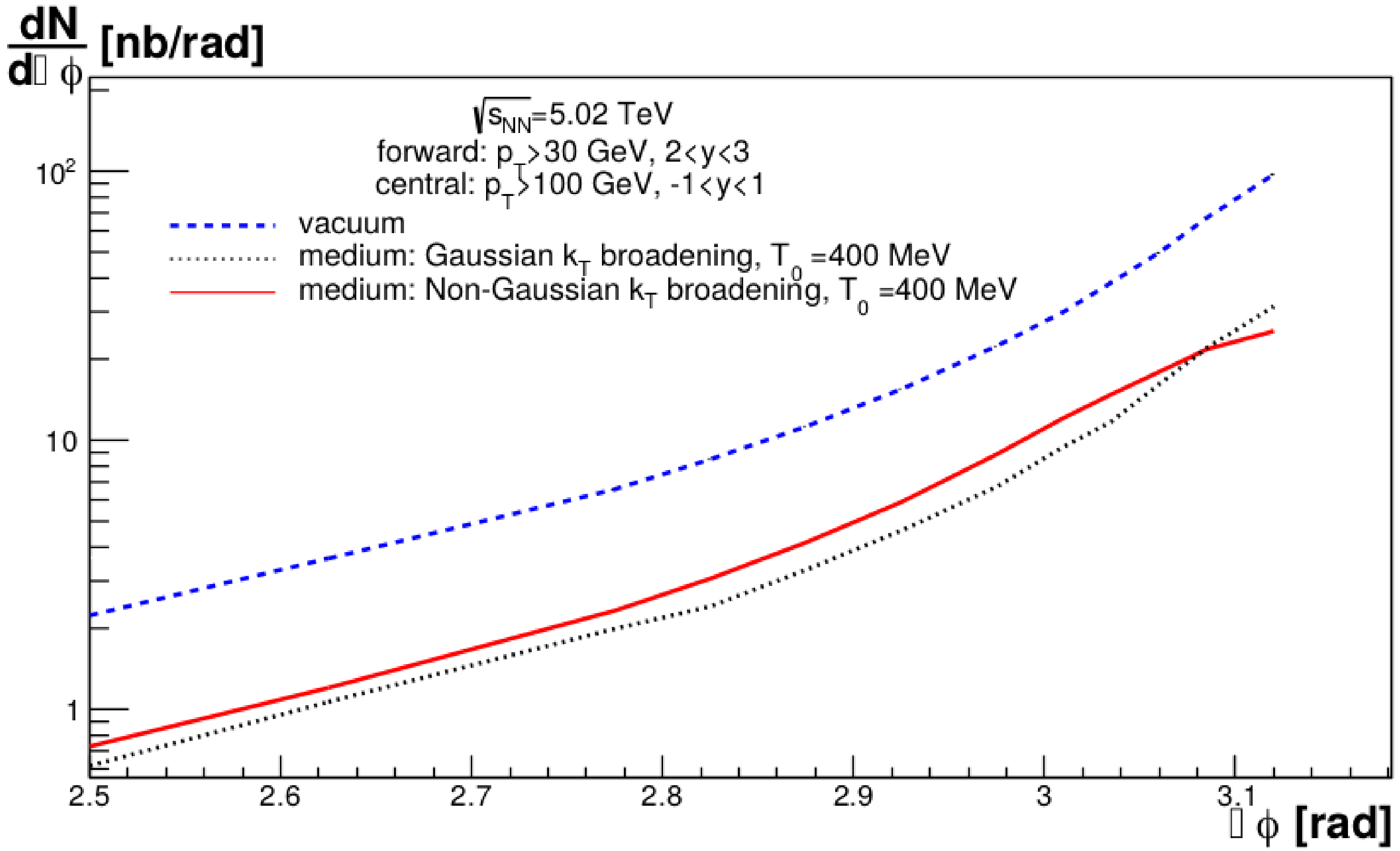
R $_{AA}$ nuclear modificatio ratio

1911.05463
Van Hameren, Kutak,Placzek, Rohrmoser



Azimutal decorelations

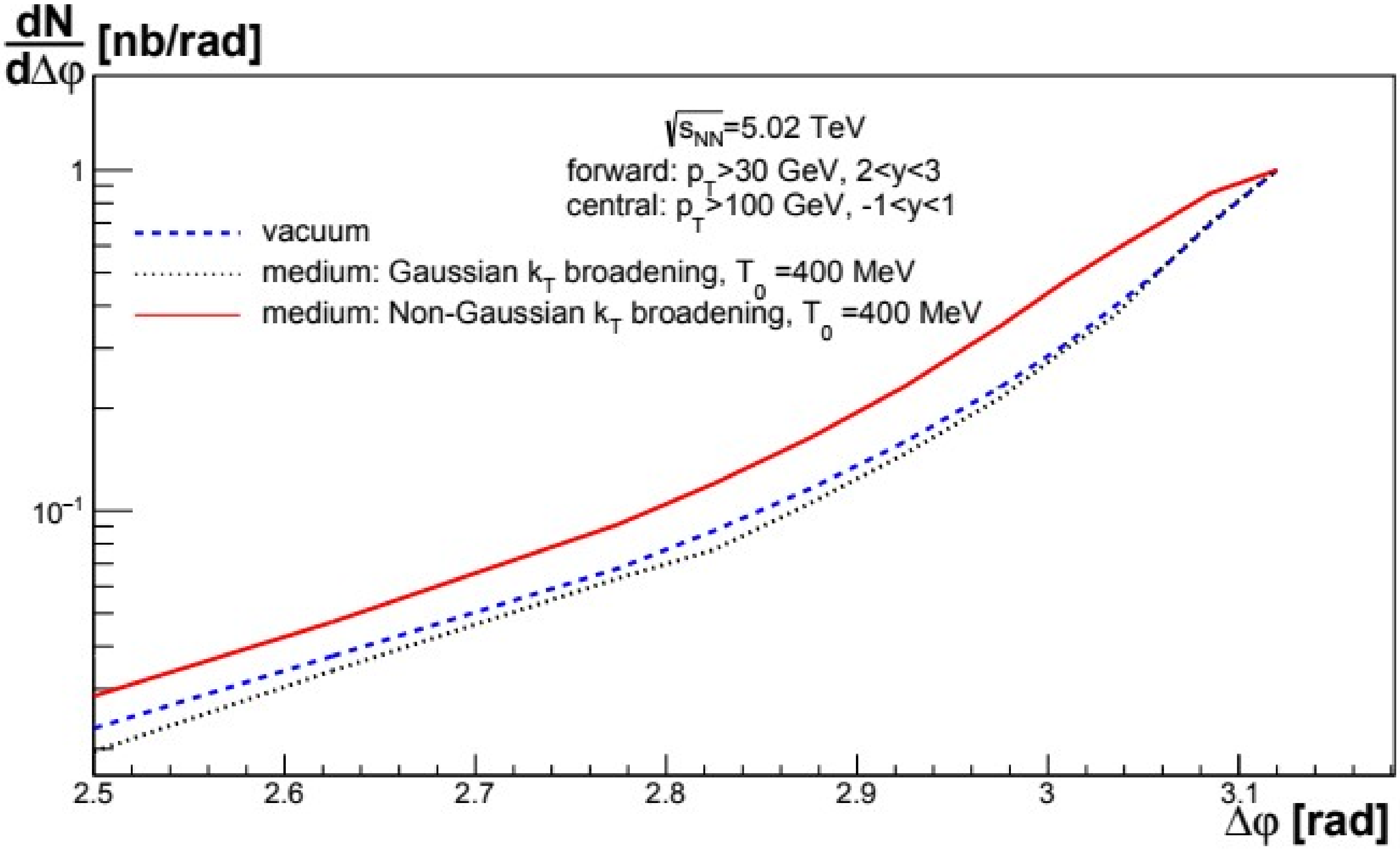
1911.05463
Van Hameren, Kutak,Placzek, Rohrmoser



Suppression at large angles
Enhancement at moderate angles

Azimutal decorelations - normalized to maximum

1911.05463
Van Hameren, Kutak,Placzek, Rohrmoser



Summary and outlook

P-p, p-A

New factorization formula for dilute-dense collision has been obtained

- *accounts for nonlinear evolution of low x gluon density*
- *accounts for correct gauge structure of the theory*
- *can be obtained from Color Glass Condensate in appropriate limit*

Evidence for need for Sudakov and saturation in forward jets has been found – visible broadening

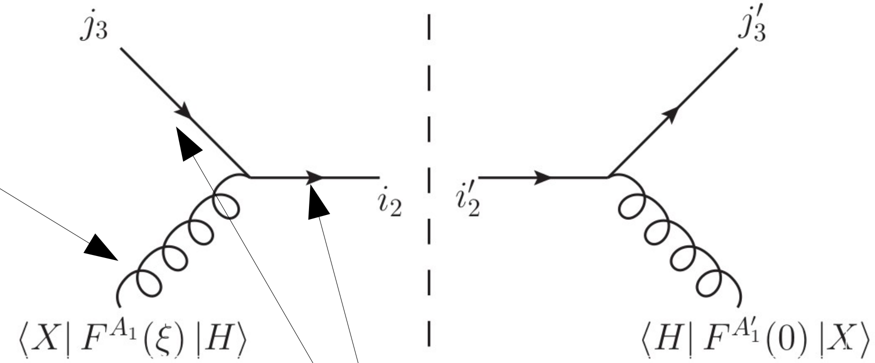
A-A

- *jet evolution based on coherent emission and scattering*
- *combination with of MINCAS with KATIE: allows for calculation of jet-observables*
- *results differ from pure Gaussian broadening…*

In the future we want to study more forward processes and in particular combine jet quenching and saturation

Example qg → q

We want to get TMD distribution of



Resummation

replacement of deltas with operators

We need to resum all collinear emissions from

$$\mathcal{M} = \left(t^{A_1}\right)^{i_2}_{j_3} \mathcal{A}(2,1,3)$$

$$\mathcal{M}^* \mathcal{M}\, \delta^{i_2 i_2'}\, \delta_{j_3 j_3'} = \left(t^{A_1}\right)^{i_2}_{j_3} \left(t^{A_1'}\right)^{j_3'}_{i_2'} \delta^{A_1 A_1'} \delta^{i_2}_{i_2'}\, \delta^{j_3'}_{j_3}\, \mathcal{A}^*(2,1,3)\mathcal{A}(2,1,3)$$

$$\left(t^{A_1}\right)^{i_2}_{j_3} \left(t^{A_1'}\right)^{j_3'}_{i_2'} \left(\mathcal{U}^{[+]}\right)^{i_2}_{i_2'} \left(\mathcal{U}^{[-]\dagger}\right)^{j_3'}_{j_3} F^{A_1'}(0) F^{A_1}(\xi) =$$

$$= \left(F(\xi)\right)^{i_2}_{j_3} \left(\mathcal{U}^{[-]\dagger}\right)^{j_3'}_{j_3} \left(F(0)\right)^{j_3'}_{i_2'} \left(\mathcal{U}^{[+]}\right)^{i_2}_{i_2'} = \mathrm{Tr}\left[F(\xi)\mathcal{U}^{[-]\dagger} F(0) \mathcal{U}^{[+]}\right]$$

$$\mathcal{F}^{(1)}_{qg}\left(x, k_T\right) = 2 \int \frac{d\xi^- d^2\xi_T}{(2\pi)^3 P^+} e^{ixP^+\xi^- - i\vec{k}_T\cdot\vec{\xi}_T} \left\langle \mathrm{Tr}\left[\hat{F}^{i+}\left(\xi\right) \mathcal{U}^{[-]\dagger} \hat{F}^{i+}\left(0\right) \mathcal{U}^{[+]}\right]\right\rangle$$