Forward jets - selected recent developements

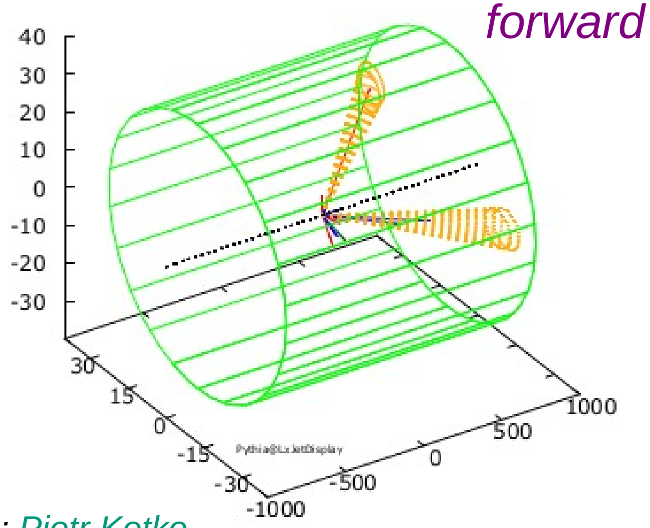
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

Krzysztof Kutak

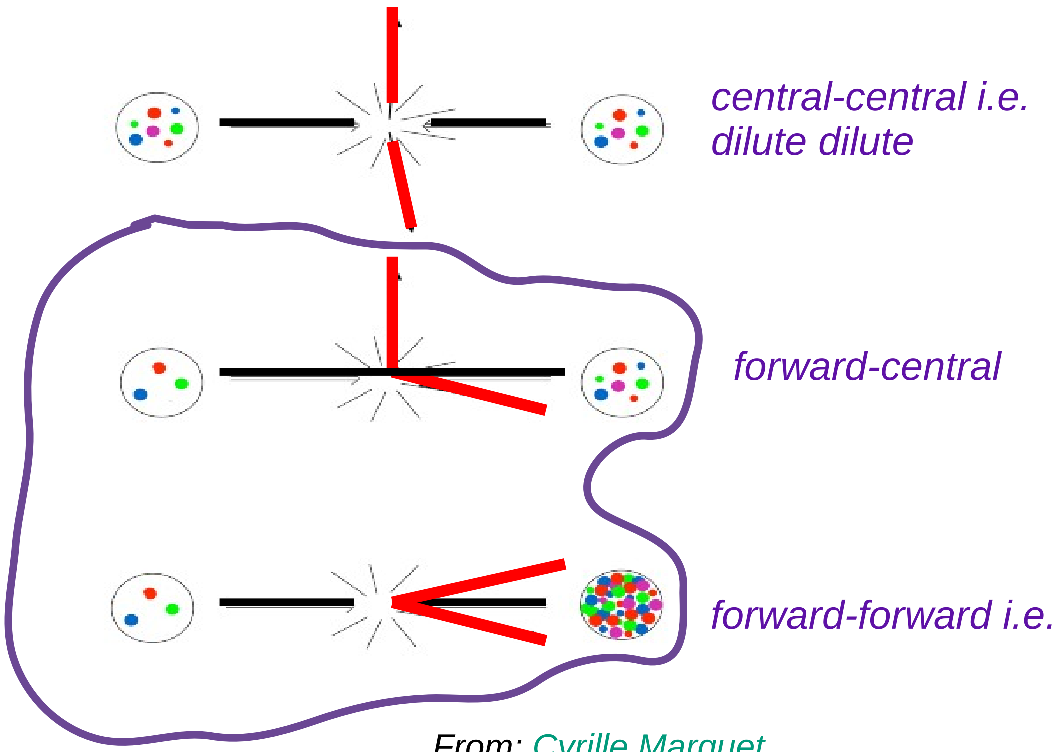
NCN

HORIZON 2020

Forward jets



From: Piotr Kotko

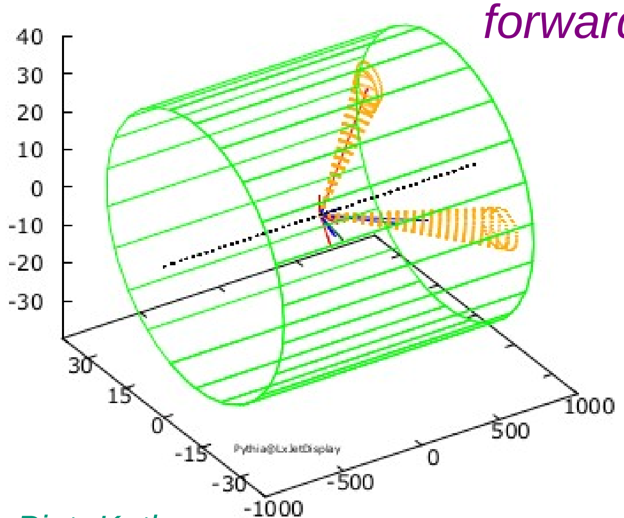


From: Cyrille Marquet

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

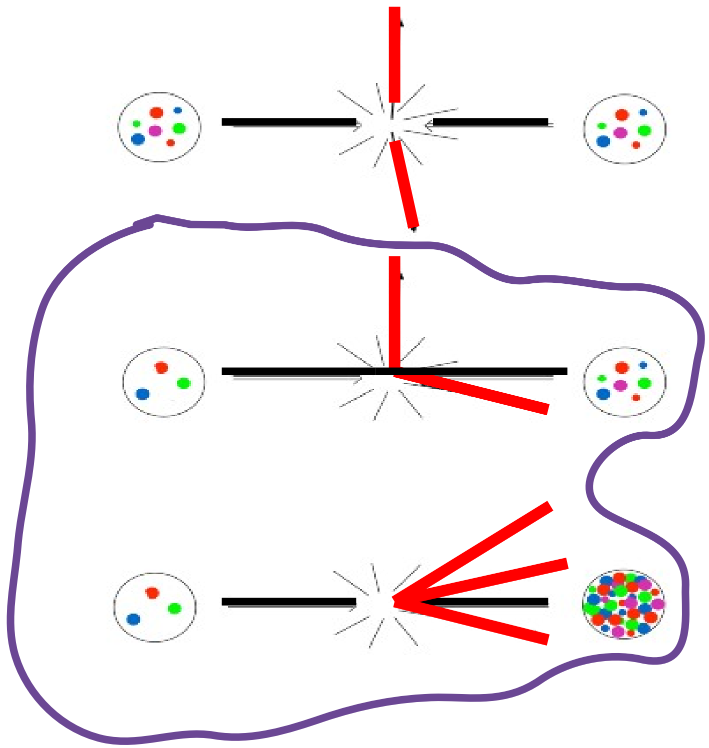
Forward jets

forward region



From: Piotr Kotko

central region



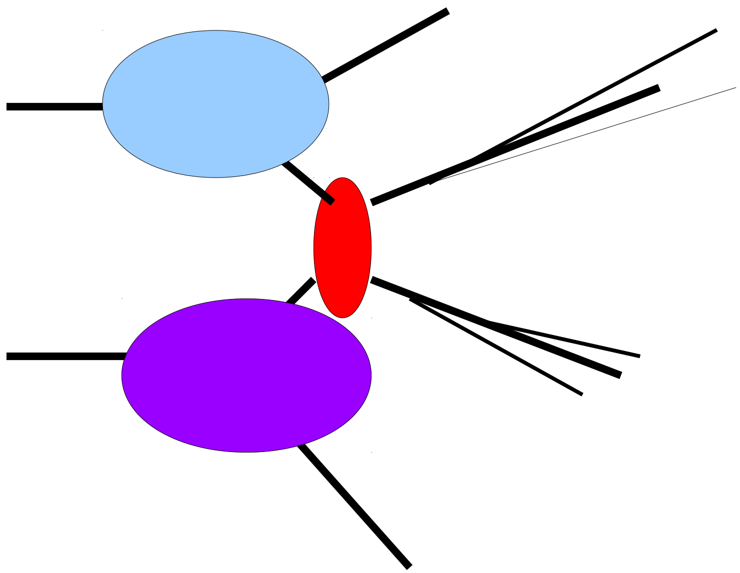
central-central i.e. dilute dilute

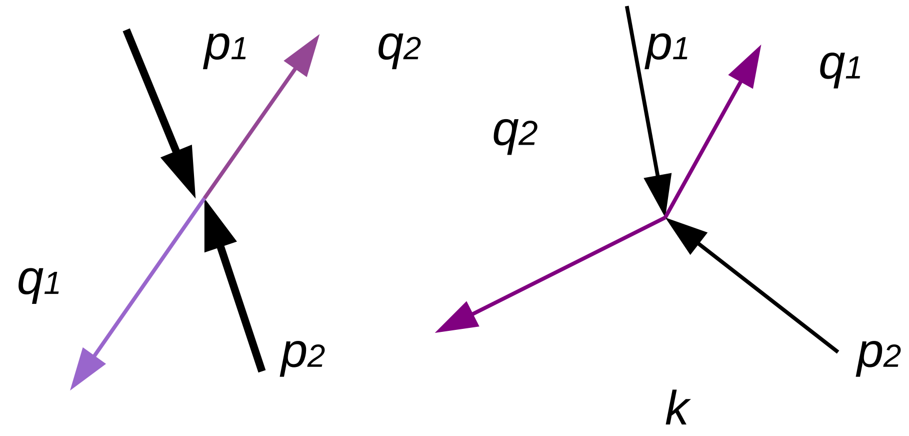
forward-central

forward-forward i.e.

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 – k_t factorization





$p_1+p_2=q_1+q_2$ $p_1+p_2=q_1+q_2+k$

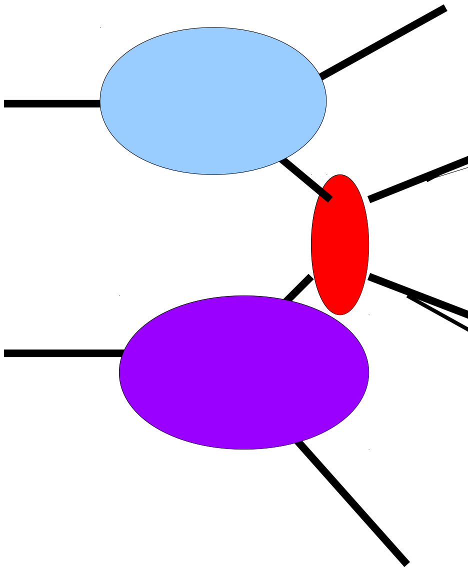
Schematic formula for cross section

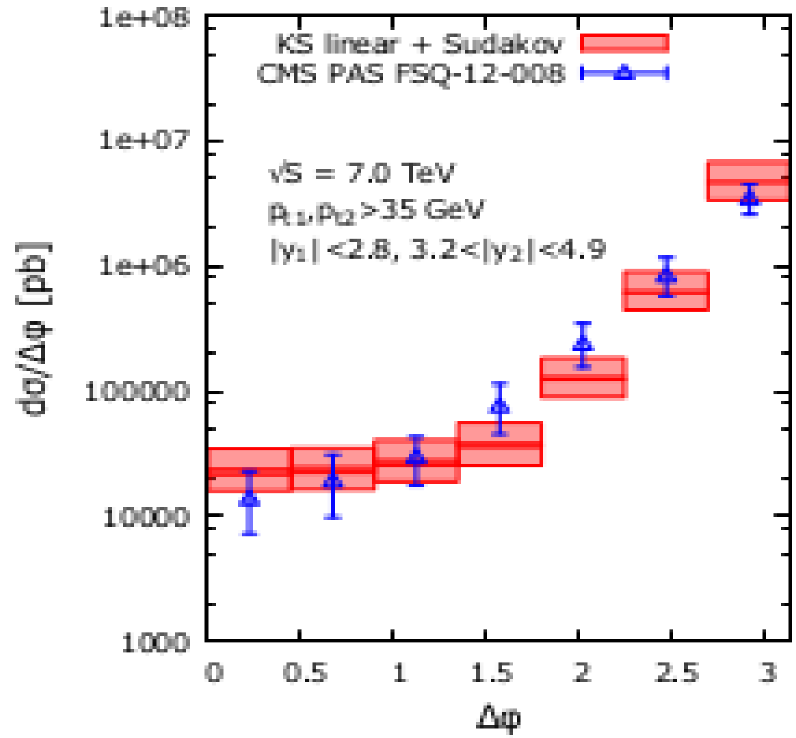
$$\frac{d\sigma}{dPS} \propto xf(x_1,\mu) \otimes \hat{\sigma}(x_1,x_2,k_T) \otimes \mathcal{F}(x_2,k_T)$$

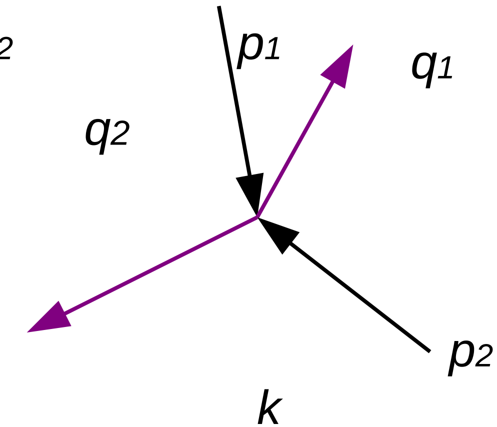
Ciafaloni, Catani, Hautman '93
Collins, Ellis '93
Lipatov '95

New helicity based methods for ME
van Hameren, Kotko, K.Kutak, JHEP 1301 (2013) 078

QCD at high energies – k_t factorization







$p_1+p_2=q_1+q_2+k$

Schematic formula fo

$$\frac{d\sigma}{dPS} \propto xf(x_1,\mu) \otimes \ldots$$

Ciafaloni, Catani, Hautman '93
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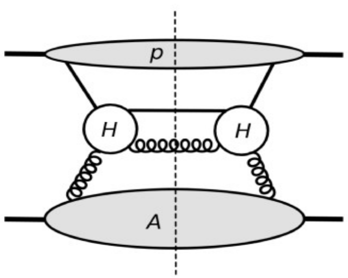
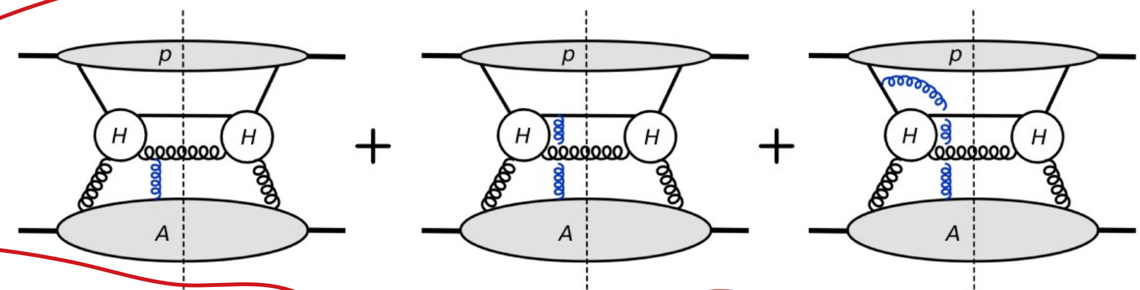
New helicity based methods for ME
van Hameren, Kotko, K.K, JHEP 1301 (2013) 078

Formula for TMD gluon and gauge links

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





Valid for large transversal momentum and was obtained in a specific gauge

From S. Sapeta

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

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

Hard part defines the path of the gauge link

$$\mathcal{U}^{[C]}(\eta;\xi) = \mathcal{P}\exp\left[-ig\int_C \mathrm{d}z\cdot A(z)\right]$$

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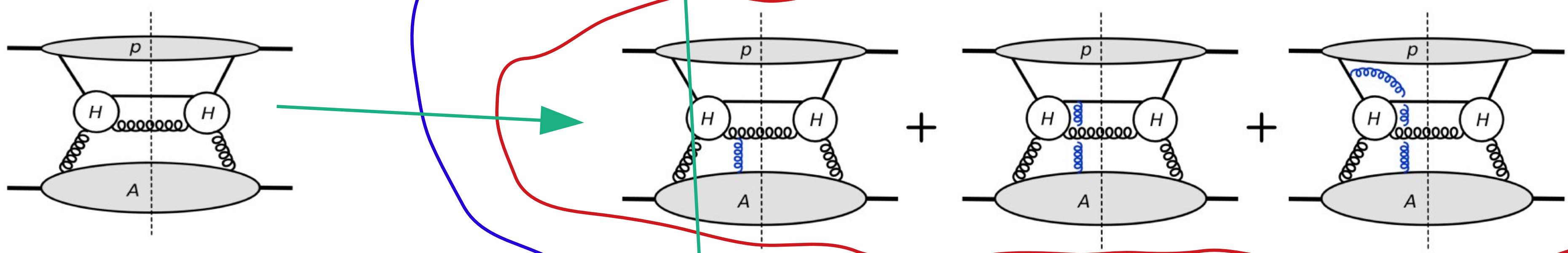

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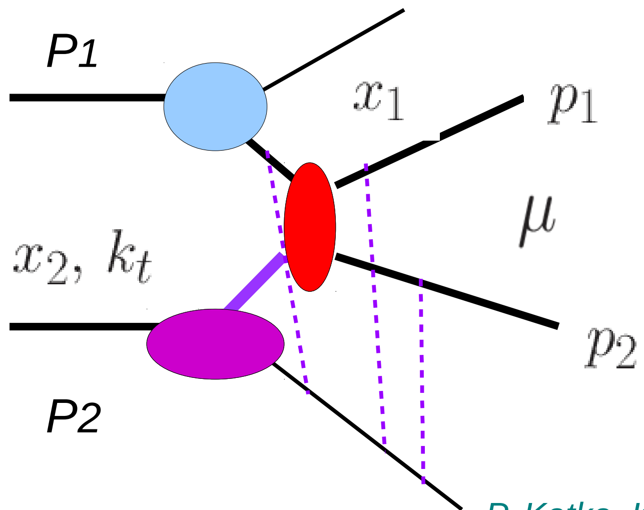
Improved Transverse Momentum Dependent Factorization



The same gauge link structure as in
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

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

Can be obtained from CGC
T. Altinoluk, R. Boussarie, Piotr Kotko
JHEP 1905 (2019) 156
Comparison between CGC and ITMD
Marquet, Fujii, Watanabe
JHEP12(2020)181

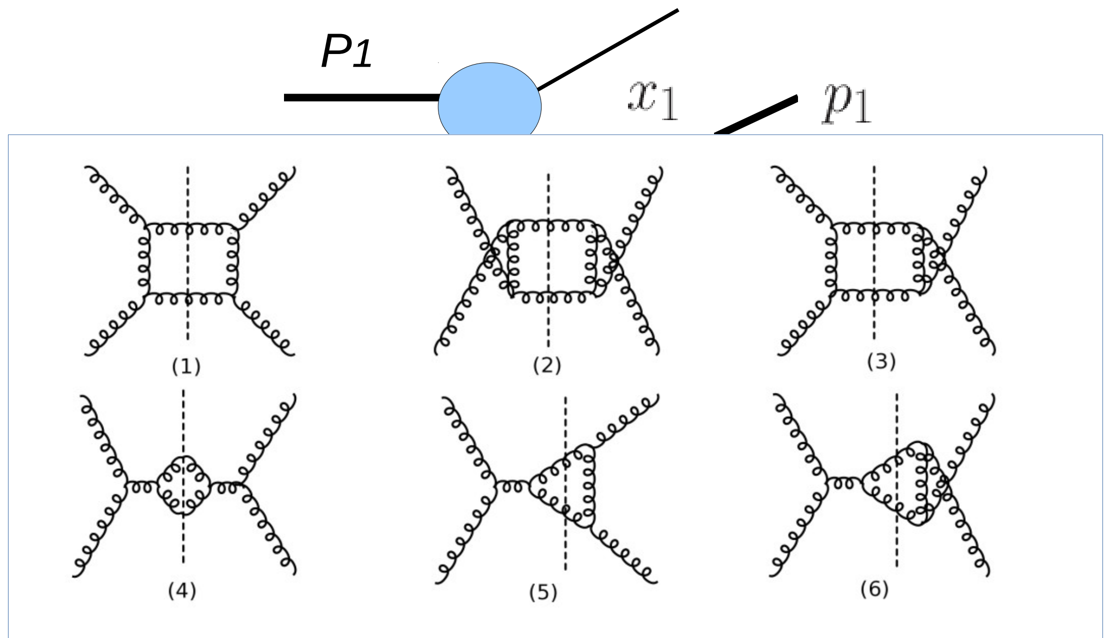
gauge invariant amplitudes with k_t and TMDs

Formalism implemented in Monte Carlo programs by A. van Hameren KaTie and P. Kotko LxJet

Example for g g → g g*

$$\frac{d\sigma^{pA\to ggX}}{d^2P_t d^2k_t dy_1 dy_2} = \frac{\alpha_s^2}{(x_1 x_2 s)^2}\, x_1 f_{g/p}(x_1,\mu^2) \sum_{i=1}^{6} \mathcal{F}_{gg}^{(i)} H_{gg\to gg}^{(i)}$$

Improved Transverse Momentum Dependent Factorization



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

Appropriate in any configuration
Can be obtained from CGC

T. Altinoluk, R. Boussarie, Piotr Kotko JHEP 1905 (2019) 156

Comparison between CGC and ITMD
Marquet, Fujii, Watanabe JHEP12(2020)181

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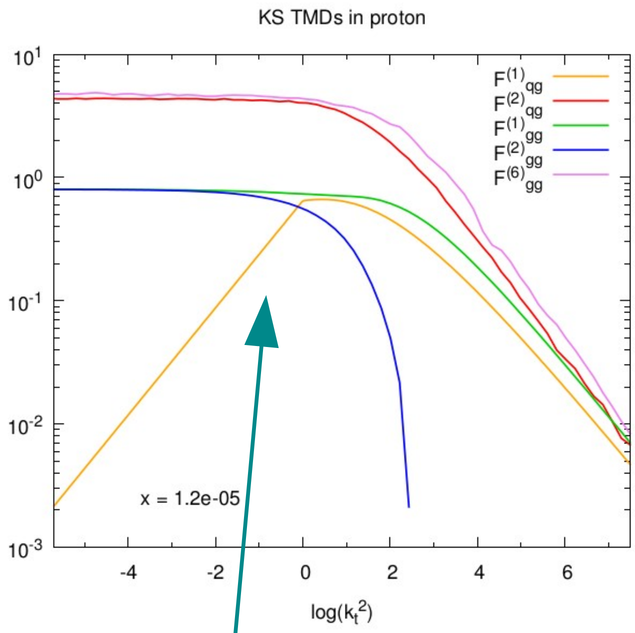
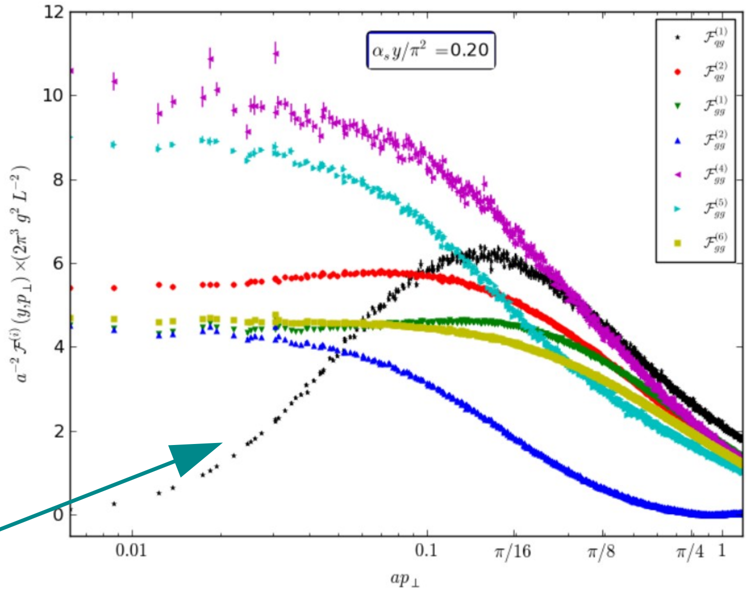
Plots of ITMD gluons





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

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

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

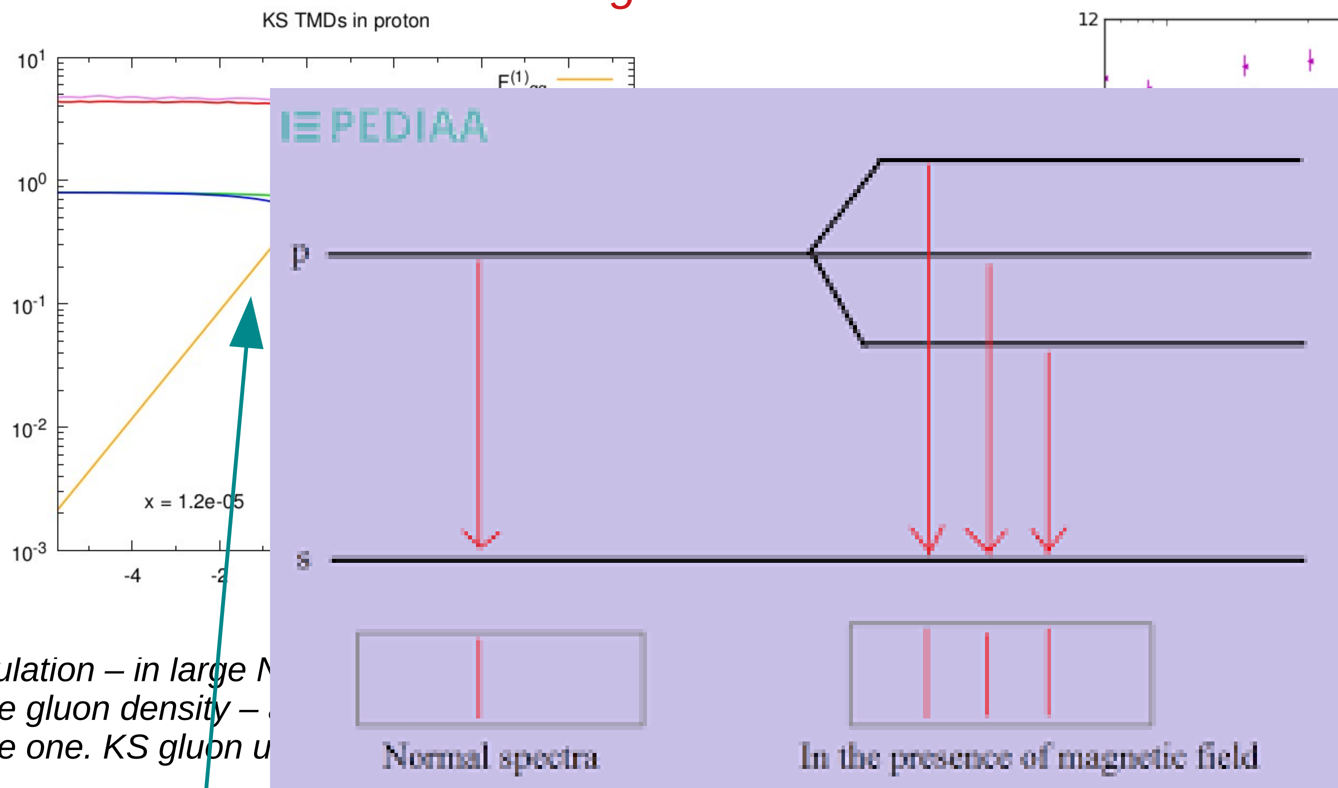
Dipole gluon density (solution of BK)

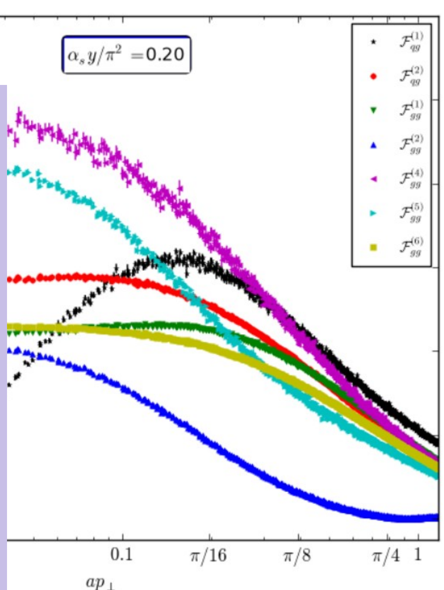
The other densities are flat at low k_t → less saturation

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 – magnetic field





Calculation – in large N
dipole gluon density –
dipole one. KS gluon u

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

Dipole gluon density (solution of BK)

of evolution equation which
MWLK equation used to obtain
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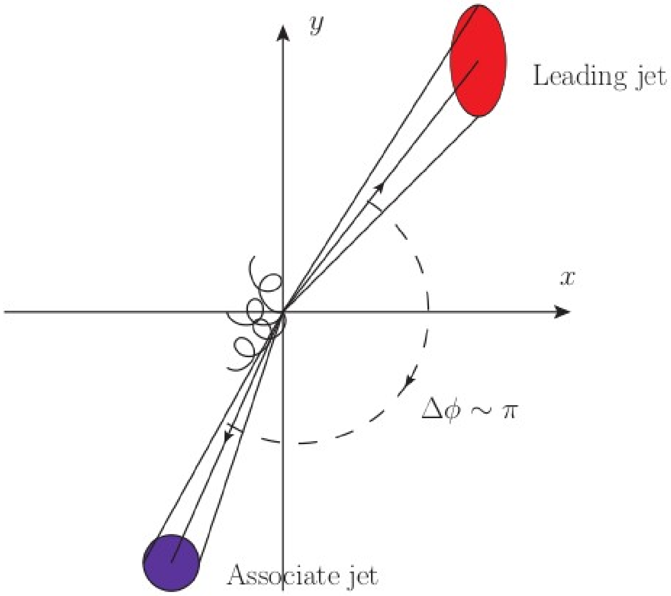
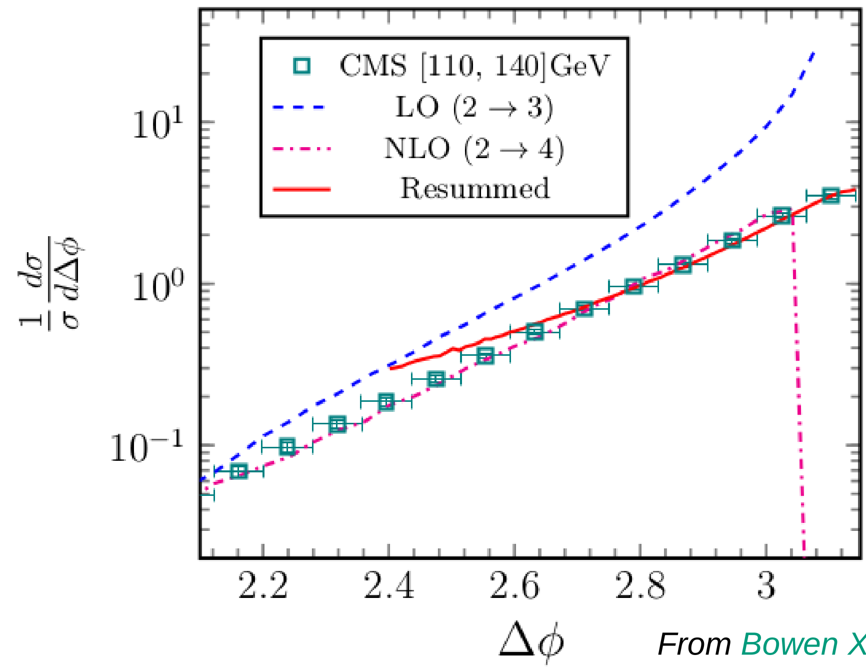
Sudakov, back-to-back jets and collinear physics





From Bowen Xiao lecture at QCD 2019 master class

In collinear physics at LO for 2 → 2 we get delta function since the colliding partons do not carry transverse momentum.   Adding more jet we get some improvement 2 → 3, 2 → 4. The unobserved partons can be soft and can introduce large logs. Note: k_t factorization also smears the delta function but it takes into account low x effects

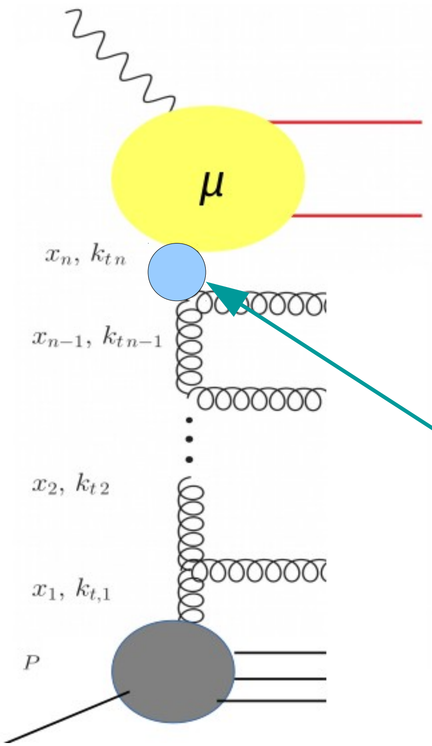
$$p_t >> k_t$$

divergence $L \sim \ln^2 \frac{p_t^2}{k_t^2}$ *needs to be resummed*

leading jet

imbalance between leading jet and associated jet – in forward jet scenario this can be linked to k_t of incoming parton

Sudakov and KMRW



includes plus prescription

$$\frac{\partial a(x,\mu^2)}{\ln \mu^2} = \frac{\alpha_s}{2\pi} \sum_{a'=q,g} \int_x^1 dz P_{aa'}(z,\mu^2) a'\left(\frac{x}{z},\mu^2\right)$$

one introduces cutoff and rewrites the equation as

$$\frac{\partial a(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_S}{2\pi}\left[\sum_{a'} \int_x^{1-\Delta} P_{aa'}(z)\, a'\left(\frac{x}{z},\mu^2\right) dz - a(x,\mu^2)\, V^a(\Delta)\right]$$

$$V^a(\Delta) = \sum_{a'} \int_0^{1-\Delta} P_{a'a}(z)\, dz$$

unregulated

virtual contribution

$$T^a(k_t,\mu) = \exp\left(-\int_{k_t^2}^{\mu^2} \frac{dk_t'^2}{k_t'^2} \frac{\alpha_S(k_t'^2)}{2\pi} V^a(\Delta)\right)$$

$$\Delta \equiv 1 - z_{\max} = \frac{k_t}{\mu + k_t}$$

$$f_a(x,k_t^2,\mu^2) \equiv \frac{\partial}{\partial \ln k_t^2}\left[a(x,k_t^2)\, T_a(k_t^2,\mu^2)\right]$$

$$= T^a(k_t,\mu)\left[\frac{\alpha_S(k_t^2)}{2\pi} \sum_{a'} \int_x^{1-\Delta} P_{aa'}(z)\, a'\left(\frac{x}{z},k_t^2\right) dz\right]$$

M. A. Kimber, A. D. Martin, M. G. Ryskin
Phys.Rev.D63:114027,2001
Phys.Rev.D64:094017,2001

A. Martin, M. Ryskin, G. Watt
Phys.Rev.D70:014012,2004

B. Guiot
Phys. Rev. D 101, 054006 (2020)

K. Golec-Biernat, A. Stasto
Phys.Lett.B 781 (2018) 633-638

M. Nefedov, V. Saleev
2009.13188

Eur.Phys.J.C 78 (2018) 2, 137
M. Bury, A van Hameren, H. Jung, K. Kutak, S. Sapeta

Sudakov and TMD gluon density

- *Survival probability of the gap * without emissions re-weighting of observable taking into account Sudakov and preserving total cross-section*

observable

function defining observable: cuts etc.

$$\mathcal{O} = \frac{\sigma}{W}\sum_i w_i F_i^{\mathcal{O}}(X_i)$$

$$\mathcal{O} \sim \sum_i w_i F_i^{\mathcal{O}}(X_i)\Theta(\mu_i > k) + \sum_j w_j F_i^{\mathcal{O}}(X_i)\Theta(k_j > \mu_i)$$

total cross-section

$$\bar{\mathcal{O}} \sim \sum_i w_i F_i^{\mathcal{O}}(X_i) T(k_i, \mu_i)\Theta(\mu_i > k) + \sum_j w_j F_i^{\mathcal{O}}(X_i)\Theta(k_j > \mu_i)$$

van Hameren, Kotko, Kutak, Sapeta PLB '14

total weight

- *KS hardscale unintegrated ** gluon density with Sudakov preserving normalisation*

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

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

Kutak PRD '14

ITMD and HEF for dijets

$$\frac{d\sigma^{pA\to ggX}}{d^2P_t d^2k_t dy_1 dy_2} = \frac{\alpha_s^2}{(x_1 x_2 s)^2}\; x_1 f_{g/p}(x_1,\mu^2) \sum_{i=1}^{6} \mathcal{F}_{gg}^{(i)} H_{gg\to gg}^{(i)}$$

moderate x almost linear regime hybrid HEF

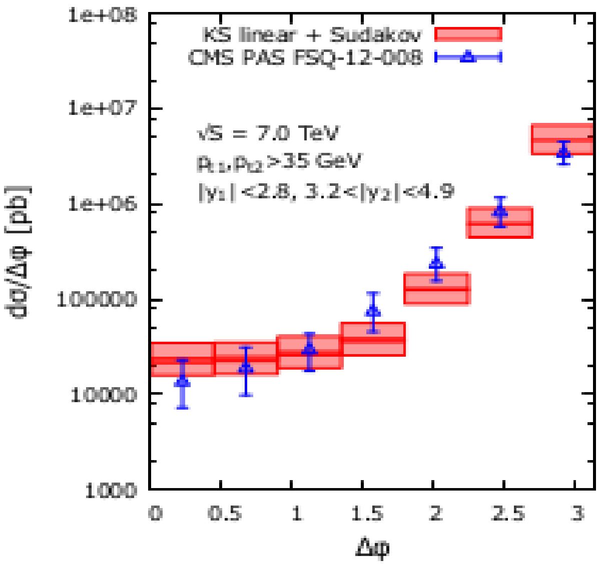
A, Dumitru, A. Hayashigaki J. Jalilian-Marian Nucl.Phys. A765 (2006) 464-482M.

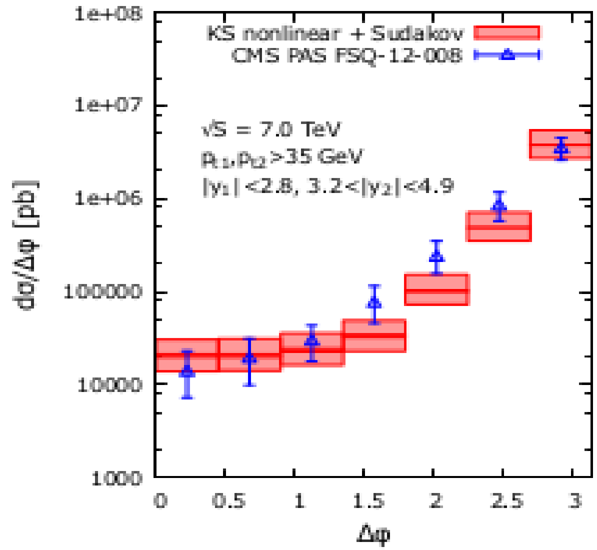
Marquet Nucl.Phys.A 796 (2007) 41-60

Deak, F. Hautmann, H. Jung, K. Kutak JHEP 0909 (2009) 121

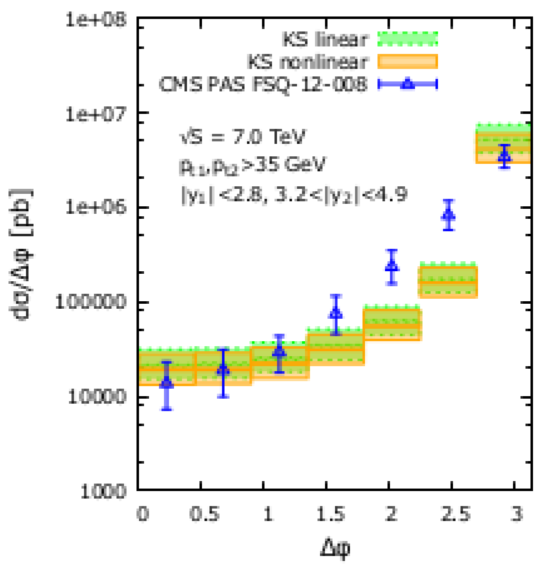
$$\frac{d\sigma_{\rm SPS}^{P_1P_2\to {\rm dijets}+X}}{dy_1 dy_2 dp_{1t} dp_{2t} d\Delta\phi} = \frac{p_{1t}p_{2t}}{8\pi^2(x_1x_2s)^2} \sum_{a,c,d} x_1 f_{a/P_1}(x_1,\mu^2)\, |\overline{\mathcal{M}_{ag^*\to cd}}|^2 \;\; \mathcal{F}_{g/P_2}(x_2,k_t^2) \frac{1}{1+\delta_{cd}}$$

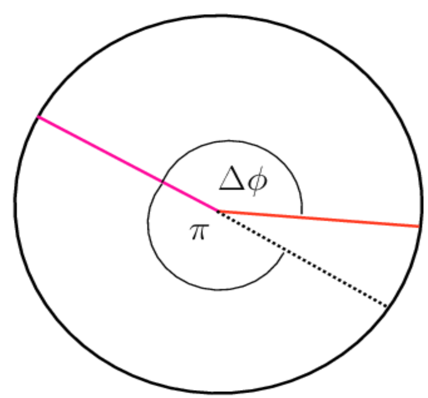
Decorelations inclusive scenario





No saturation but visible Sudakov effects





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

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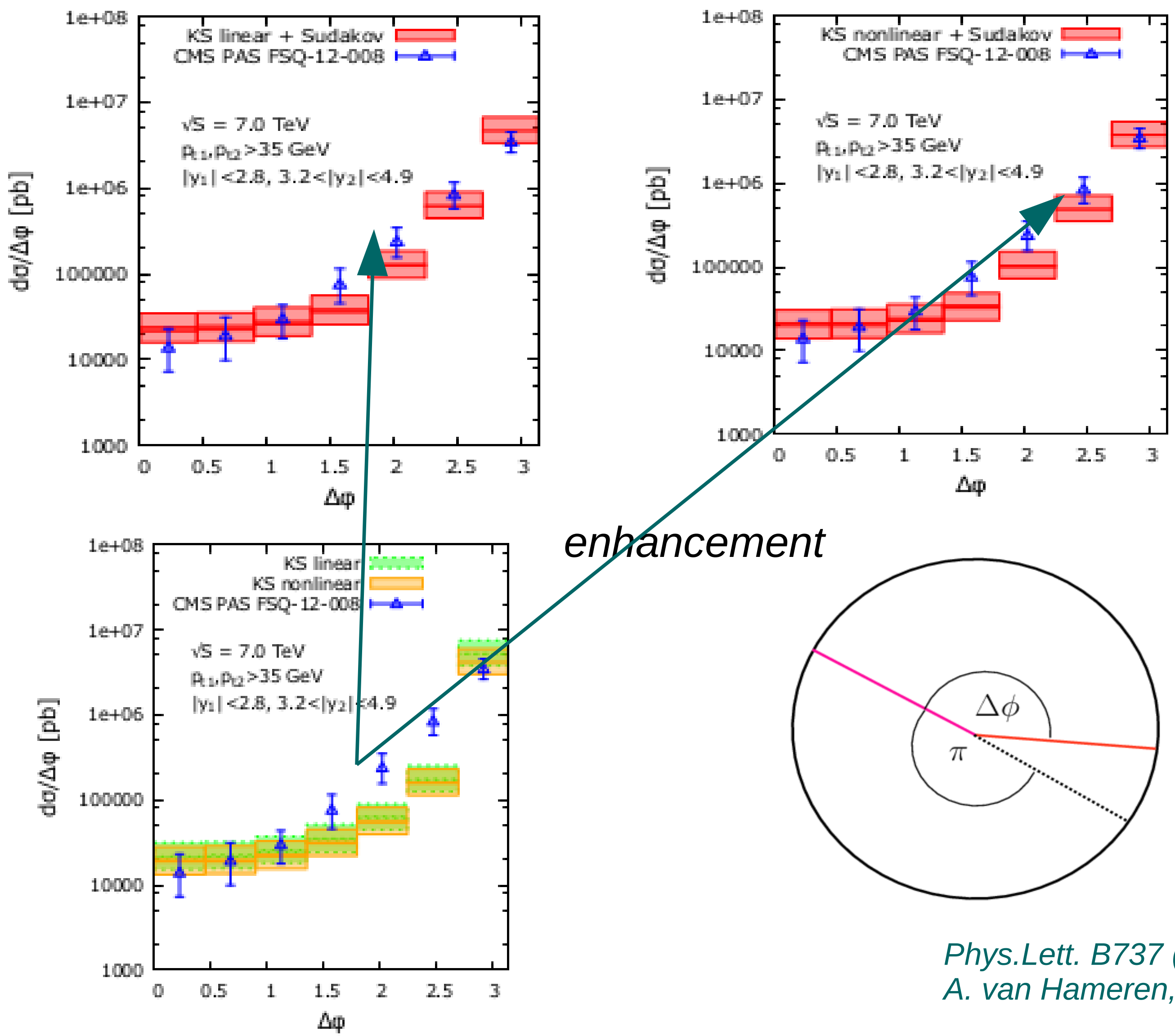

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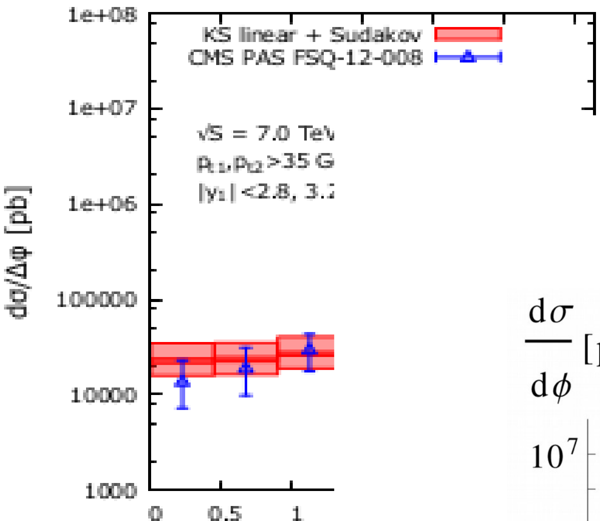
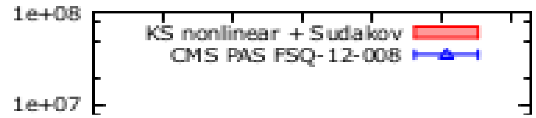
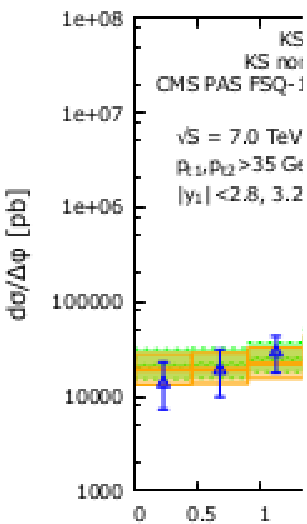
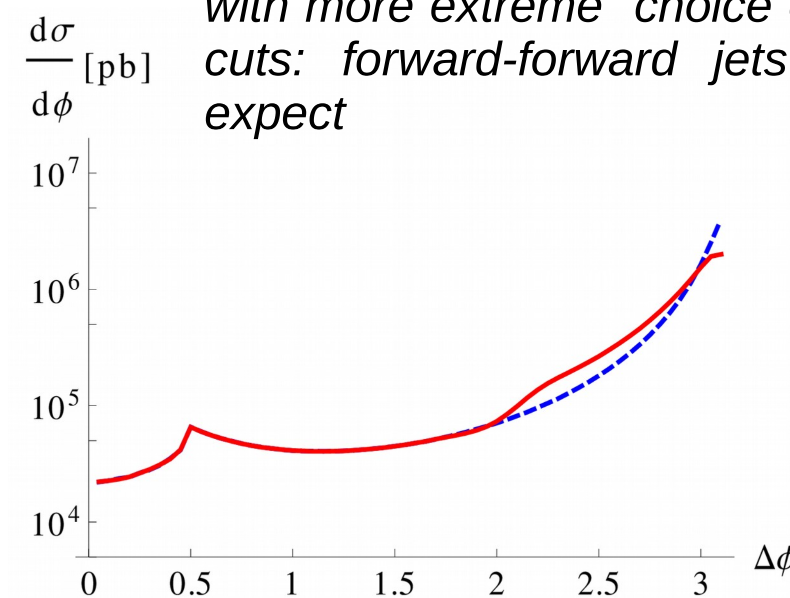




No saturation…
Visible Sudakov effects



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

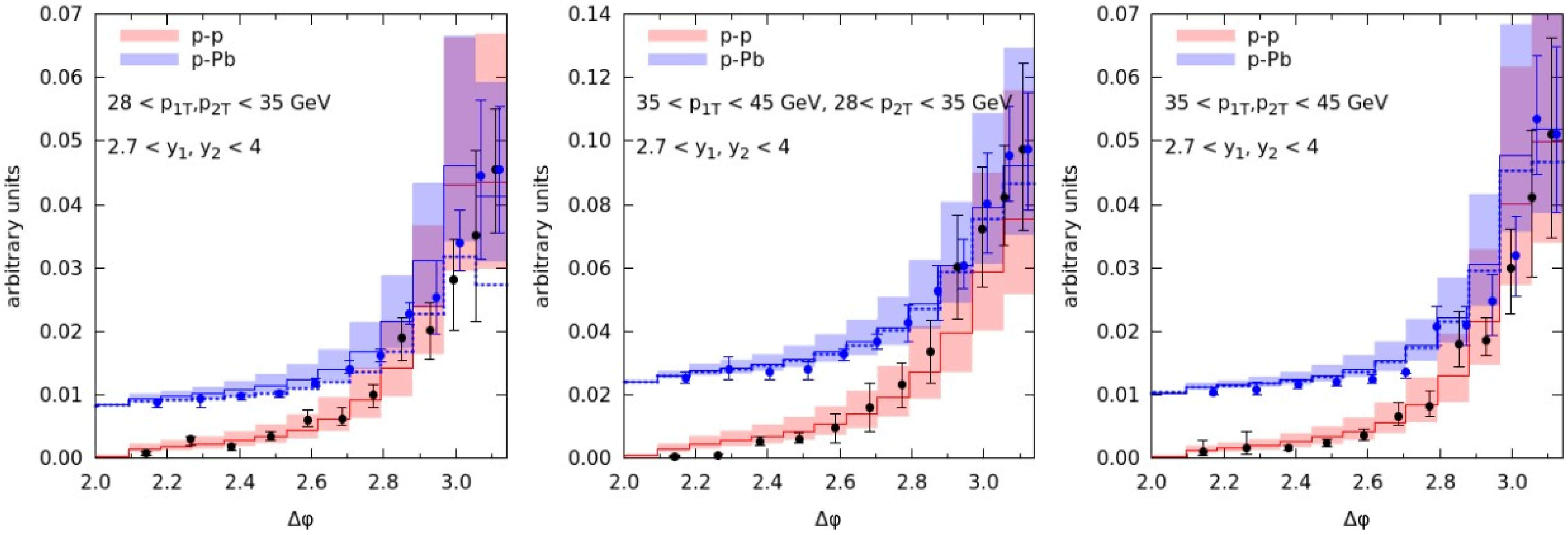


K. Kutak
Phys.Rev. D91 (2015) no.3, 034021

Signature of broadening in forward-forward dijets

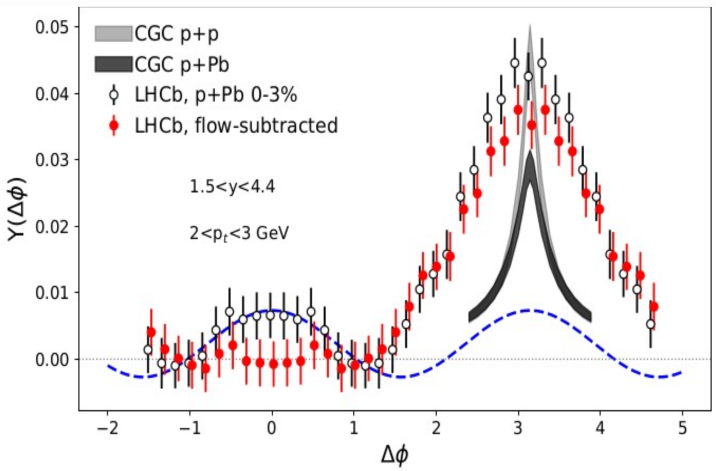
ATLAS Phys.Rev. C100 (2019) no.3, 034903

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

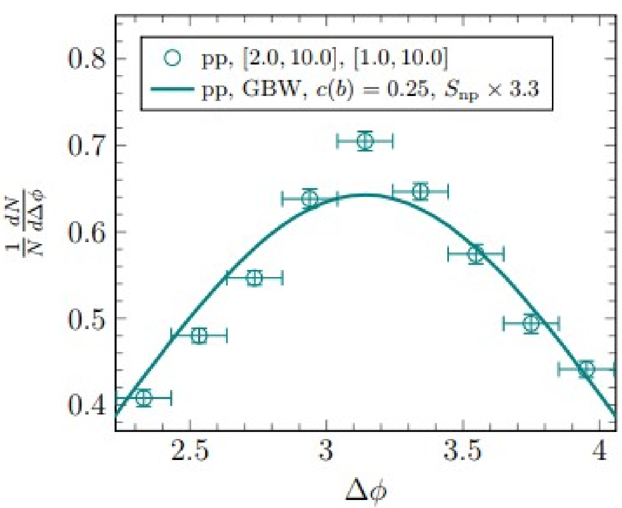
Di-hadrons production

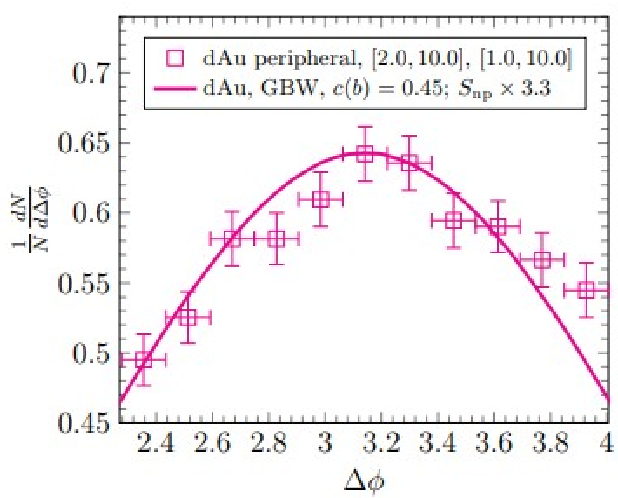


ITMD no Sudakov

Expectation: Sudakov will broaden the distribution

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





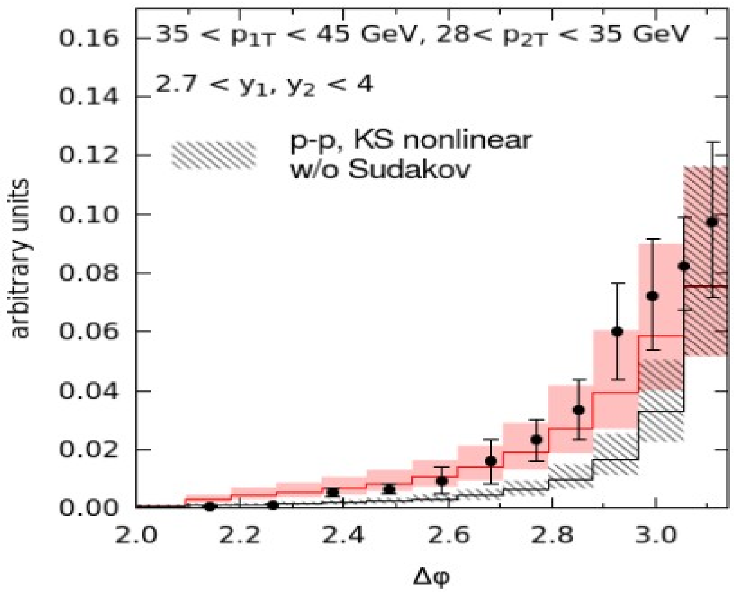
Correlation limit of CGC + Sudakov

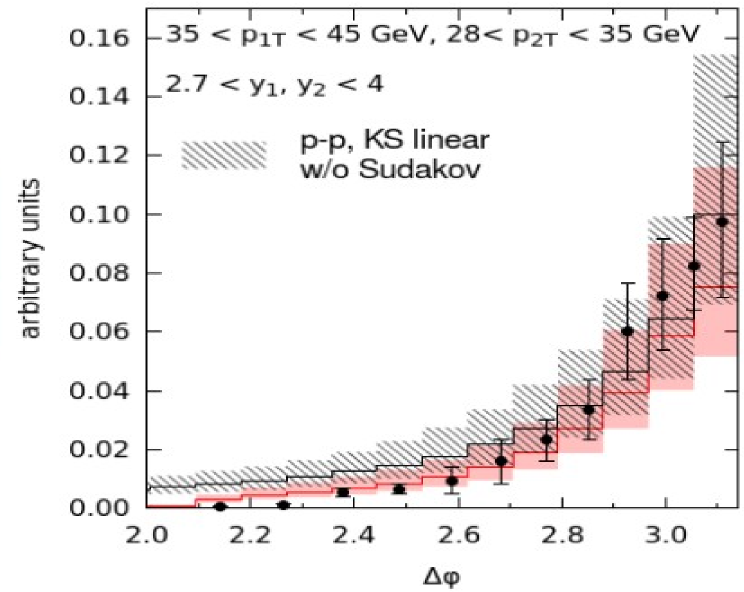
A.Stasto, S. Wei, B. Xiao, F. Yuan Phys.Lett. B784 (2018) 301-306

Other approaches

nonlinearity
no Sudakov

too narrow
distribution



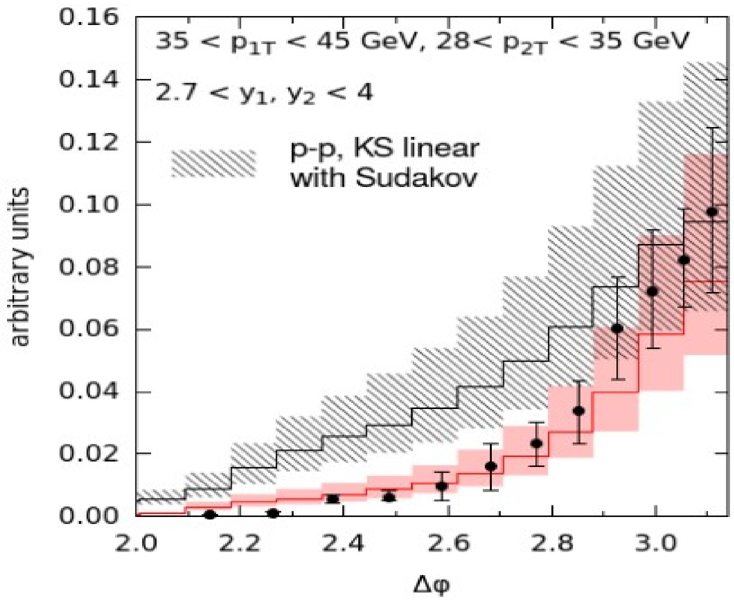


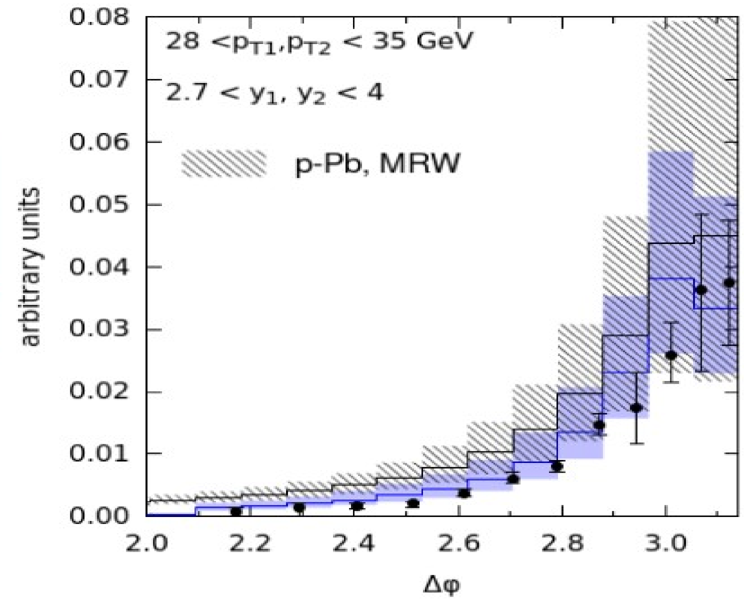
linear
no Sudakov

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

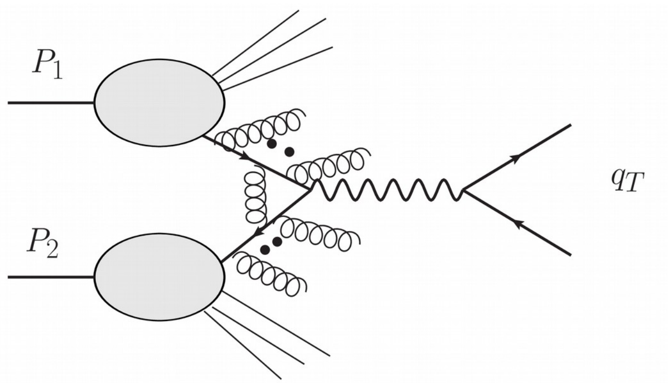
Drell-Yan and Sudakov in coordinate space

zero transverse momentum

$$\frac{d\sigma}{dQ^2 d^2 p_T} = \sum_q \int \frac{dx_1 dx_2}{x_1 x_2 S} q(x_1) q(x_2) \hat{\sigma}(q\bar{q} \to l^+ l^-) \int d^2 b_\perp e^{-p_T \cdot b_\perp}$$

$$Y = \frac{1}{2} \ln \frac{x_1}{x_2} \qquad x_1 = \frac{Q}{\sqrt{S}} e^{Y} \qquad x_2 = \frac{Q}{\sqrt{S}} e^{-Y}$$

invariant mass



$$\frac{dP}{d^2 q_T} = \frac{\alpha_s C_F}{2\pi^2} \frac{1}{q_T} \int_0^{1-\frac{q_T^2}{Q^2}} dz \frac{1+z^2}{1-z} \frac{\alpha_s C_F}{\pi^2} \frac{1}{q_T} \ln \frac{Q^2}{q_T^2}$$

process studied a lot in TMD factorization framework see also recent low x papers by
Marquet, Wei, Xiao
Phys.Lett.B 802 (2020) 135253
Golec-Biernat, Stebel
Eur. Phys. J. C (2020) 80:455

resummation of all soft emissions leads to

$$\frac{d\sigma}{dQ^2 d^2 p_T} = \sum_q \int d^2 b_\perp e^{-p_T \cdot b_\perp} e^{-S(b_T)} \int \frac{dx_1 dx_2}{x_1 x_2 S} q(x_1,\mu) q(x_2,\mu) \hat{\sigma}(q\bar{q} \to l^+ l^- + X)$$

It is usually referred as the Sudakov form factor for which can be interpreted as the probability for emitting no gluons with transverse momentum greater than p_T. The momenta of emitted gluons should add up to p_T the transverse momentum conservation for arbitrary number of gluon radiations.

KS gluon with b space Sudakov

Befor addressing the di-jets in forward-forward which are sensitive to both Sudakov and saturation we want to see what different Sudakov give.

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

Phys. Rev. D 88, 114010 (2013)
A. H. Mueller, Bo-Wen Xiao, Feng Yuan

A. Stasto, S. Wei, B. Xiao, F. Yuan,
Phys.Lett.B 784 (2018) 301-306

$$\mathcal{F}^{ag\to cd}_{g*/B}(x,k_T,\mu) = \frac{-N_c}{2\pi\alpha_s}\int \frac{d^2 b_T}{2\pi} e^{-ik_T\cdot b_T} e^{-S(\mu,b_T)_{Sud}} \nabla^2_{b_T}(1-N(x,b_T))$$

$$S_p^{gg\to gg}(Q,b_\perp) = \int_{\mu_b^2}^{Q^2}\frac{d\mu^2}{\mu^2}\left[4C_A\frac{\alpha_s}{2\pi}\ln\left(\frac{Q^2}{\mu^2}\right) - 3C_A\beta_0\frac{\alpha_s}{\pi}\right]$$

hard scale

$$S_p^{qg\to qg}(Q,b_\perp) = \int_{\mu_b^2}^{Q^2}\frac{d\mu^2}{\mu^2}\left[2(C_F+C_A)\frac{\alpha_s}{2\pi}\ln\left(\frac{Q^2}{\mu^2}\right) - \left(\frac{3}{2}C_F + C_A\beta_0\right)\frac{\alpha_s}{\pi}\right]$$

Arises due to incomplete cancelation of collinear singularities

Arises due to incomplete cancelation of soft divergencies

.

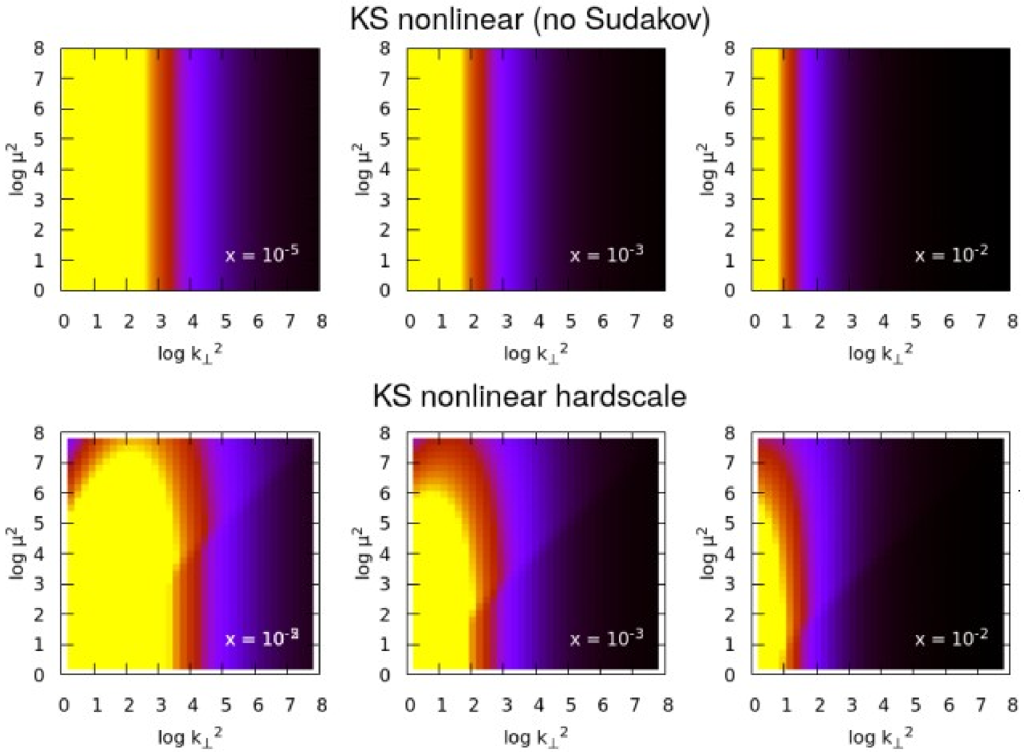
$$\mathcal{F}^{ab\to cd}_{g^*/B}(x,k_\perp,\mu) = \int db_\perp \int dk'_\perp\, b_\perp\, k'_\perp\, J_0(b_\perp k'_\perp)\, J_0(b_\perp k_\perp)\, \mathcal{F}_{g^*/B}(x,k'_\perp)\, e^{-S^{ab\to cd}_{\rm Sud}(\mu,b_\perp)}$$

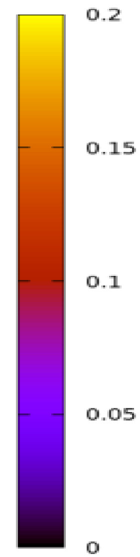
van Hameren, Kotko, Kutak, Sapeta
to appear soon

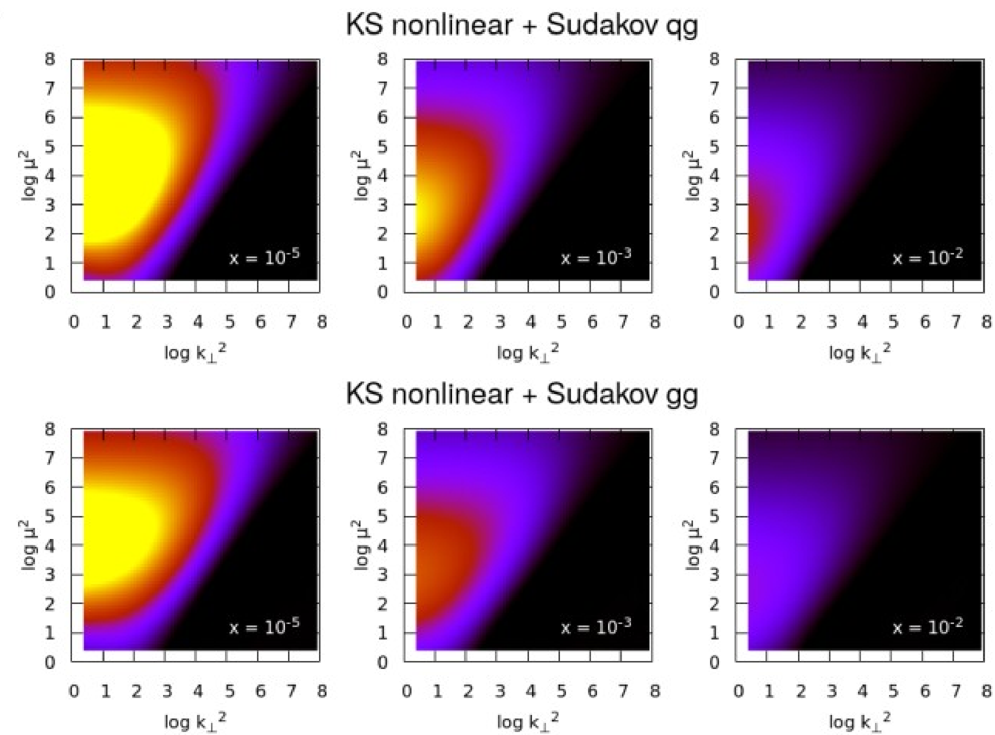
Solution of BK with kinematical constraint and nonsingular pieces of DGLAP splitting function

KS gluon with Sudakov

van Hameren, Kotko, Kutak, Sapeta 2010.13066





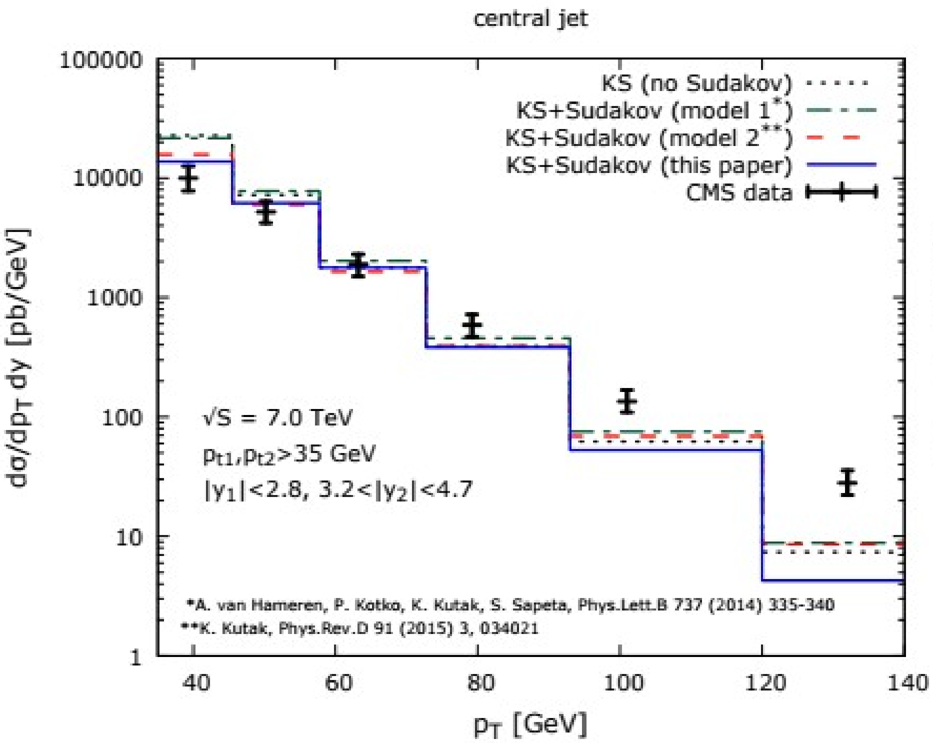


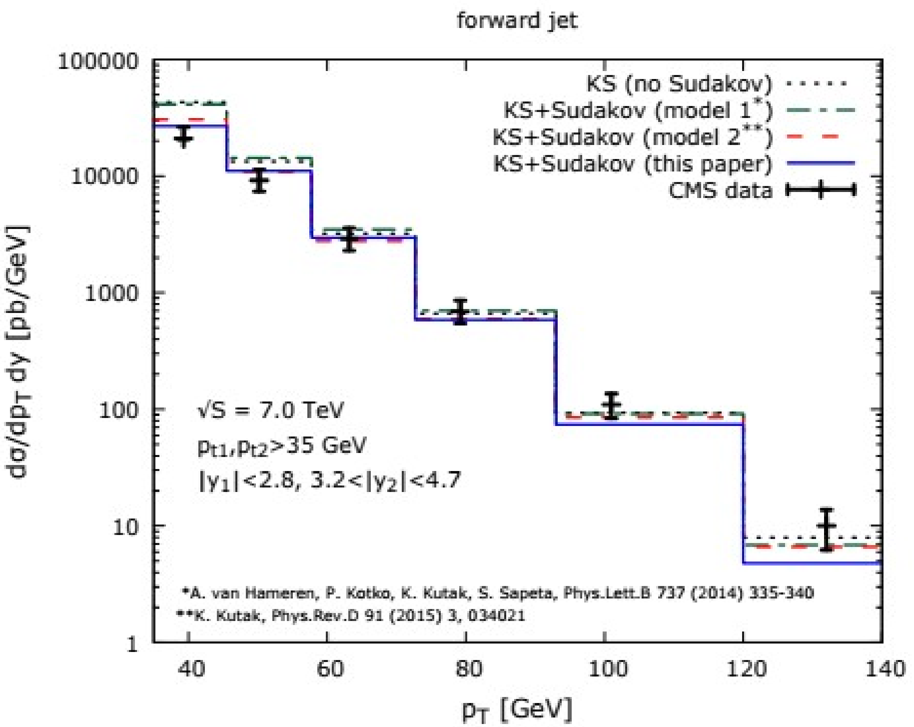
The messages

- *the "b" space Sudakov suppresses more*
- *the gluon density*
- *the gg Sudakov suppresses more than the qg Sudakov*

P_T spectra – no Sudakov vs. “b” space Sudakov vs. * model vs. ** model

van Hameren, Kotko, Kutak,Sapeta
2010.13066

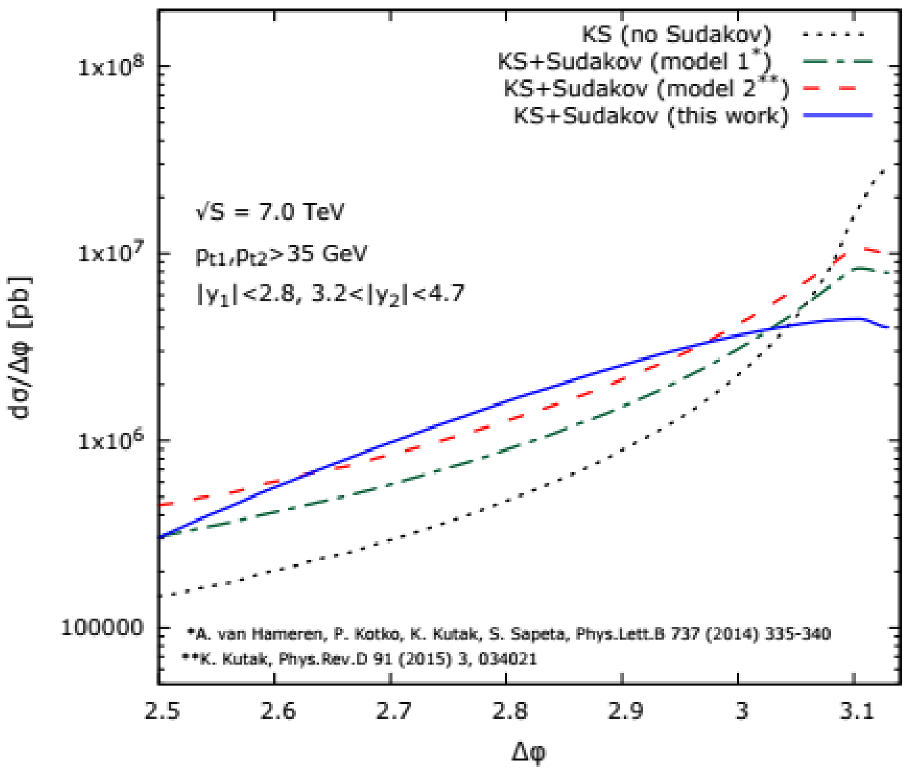


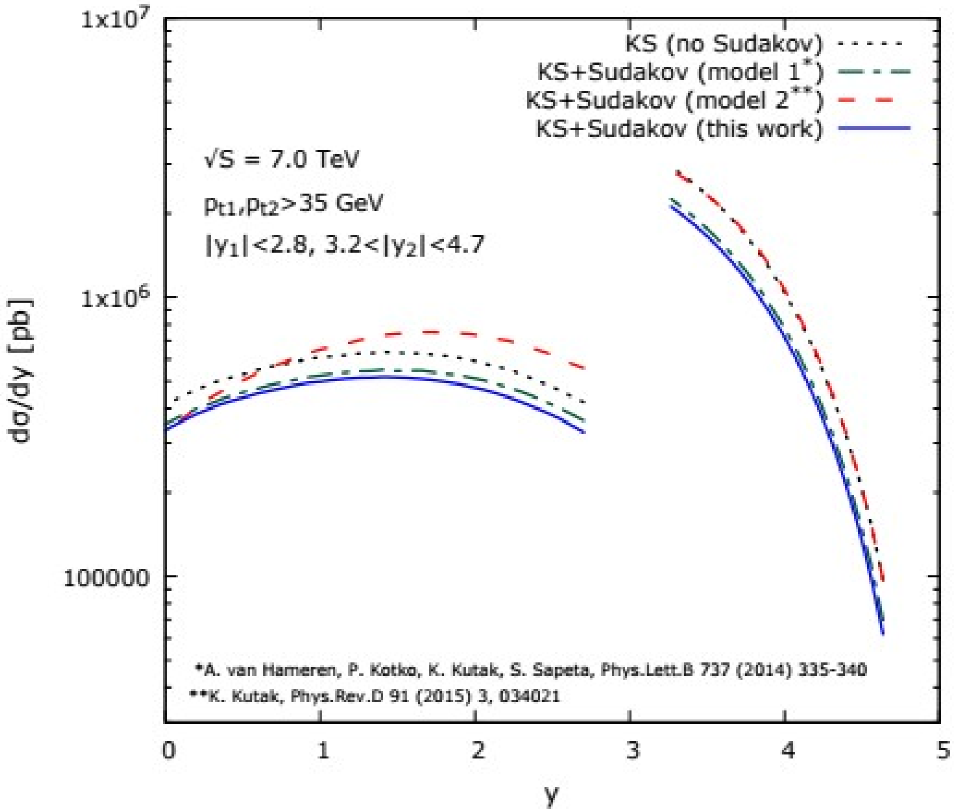


Pt spectra give similar description. Not very useful but confirm that the framework is in principle fine.
At larger p_T we expect the parton shower to play significant role.

Azimuthal angle decorelations and rapidity distributions

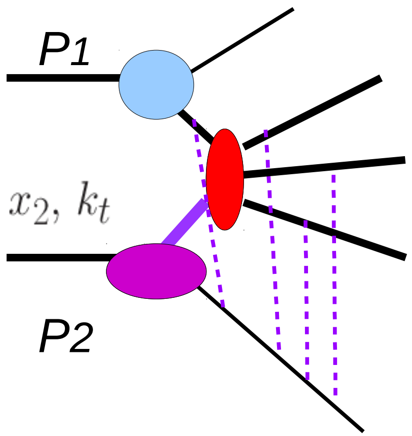
van Hameren, Kotko, Kutak,Sapeta
arxiv: 2010.13066





All approaches lead to suppression of the distribution at the back-to-back region and broadening of the cross-section.
Clearly the "b" space Sudakov suppresses cross section more than the DGLAP based one.
The shape of distribution away from back-to-back is very different: concave vs. convex.

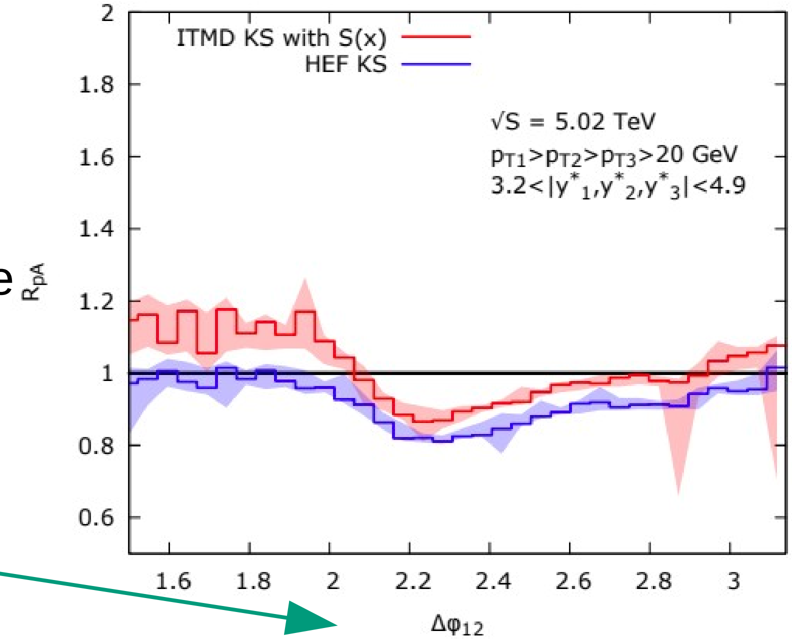
ITMD for three jets in p+p, p+A

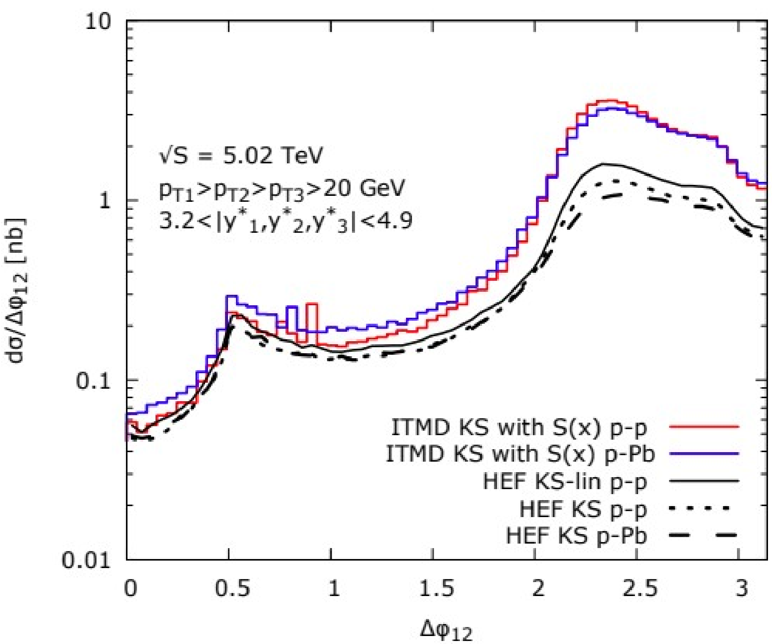


ratio p-A/p-p

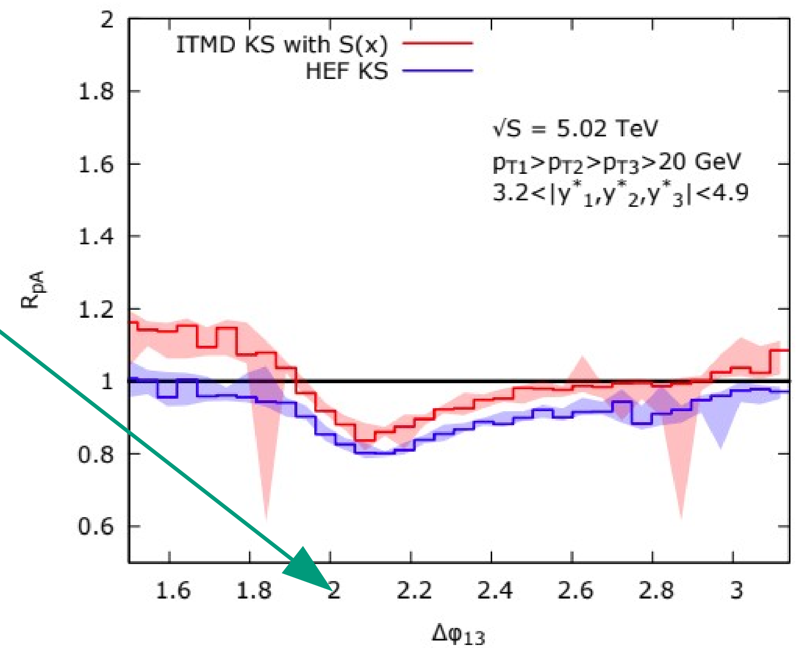
There are regions where $R_{pA} > 1$

angle between leading and subleading jet





angle between leading and softest jet



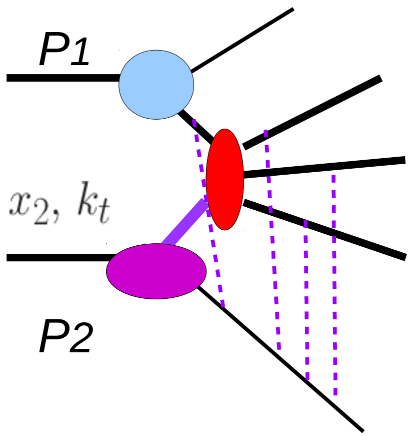
Bury, van Hameren, Kotko, Kutak JHEP09(2020)175

See also for results in correlation limit (no kt in ME)

Altinoluk, Boussarie, Marquet, Taels JHEP 07 (2020) 143

Iancu, Mulian Nucl.Phys.A 985 (2019) 66-127

ITMD for three jets in p+p, p+A



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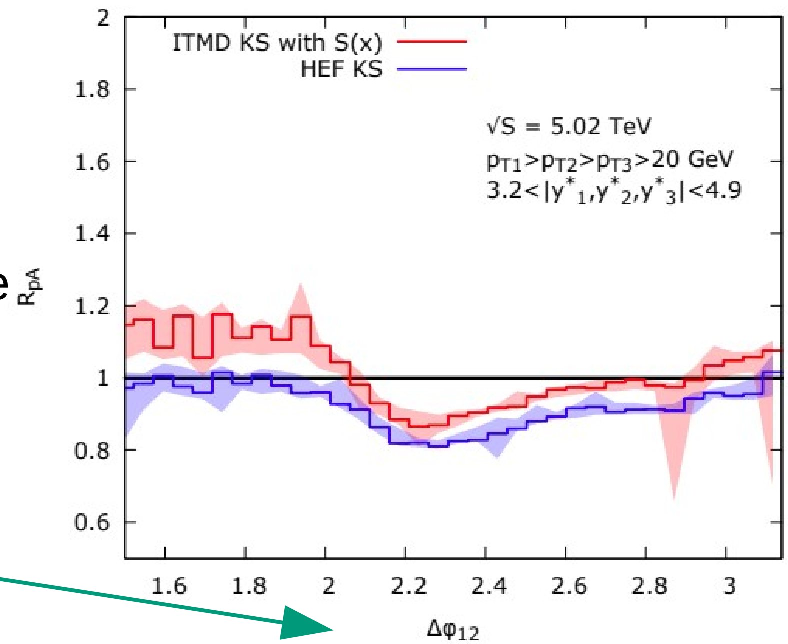
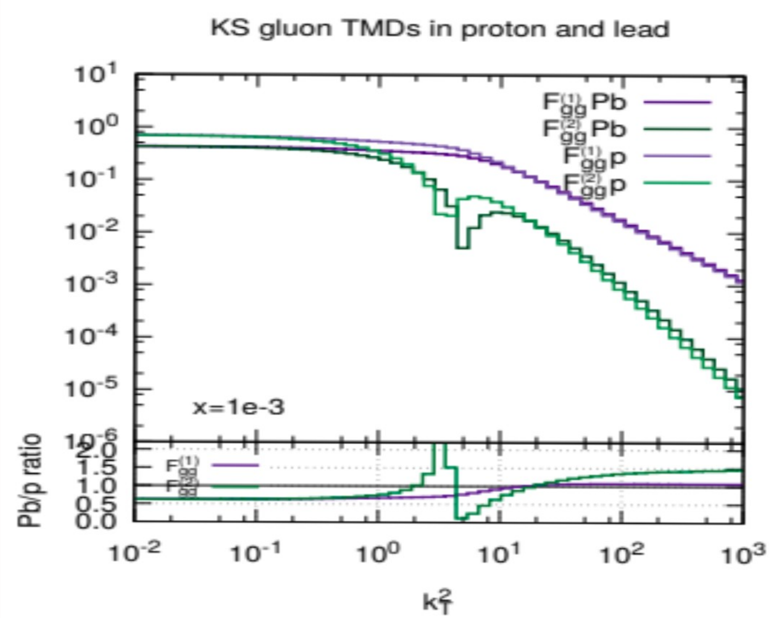
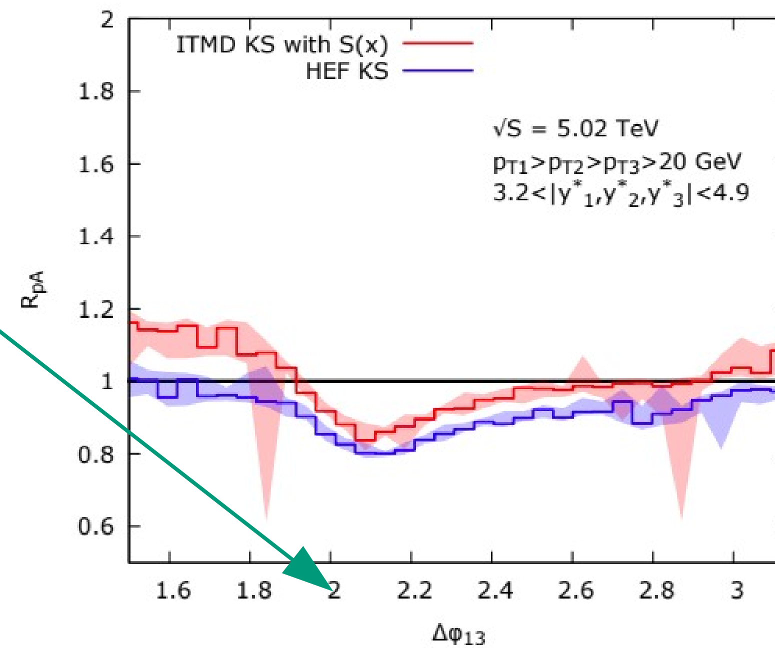




angle between leading and softest jet



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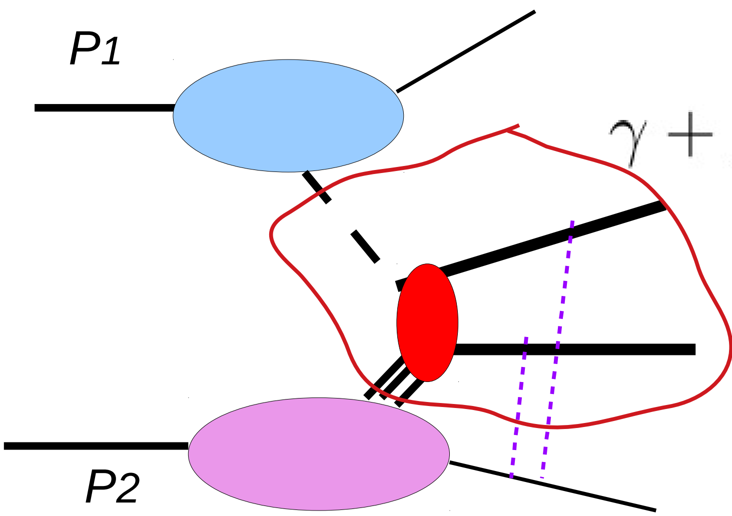
UPC collision of Pb-Pb

Direct relation relation to DIS

Flux of photons

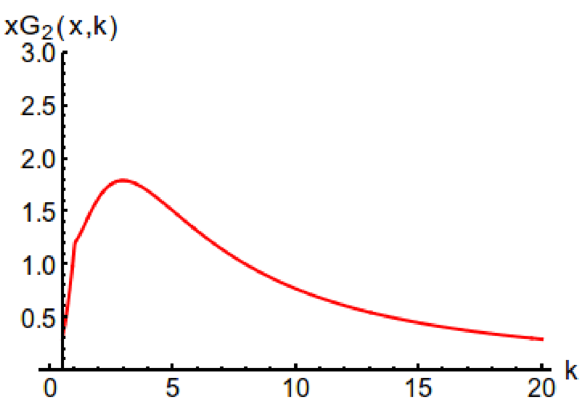


$$\gamma + g \rightarrow \bar{q}q$$

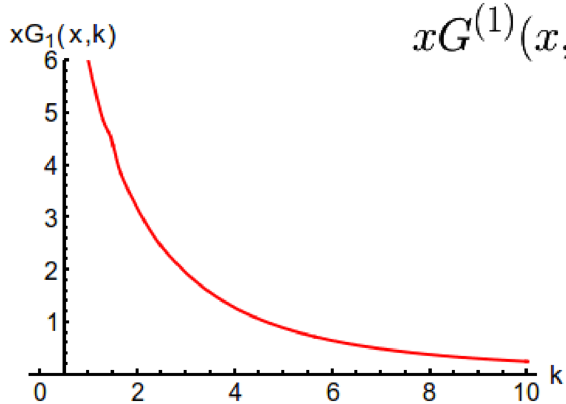
$$d\sigma_{AA\rightarrow 2jet+X} = \int dx_\gamma \frac{dN_\gamma}{dx_\gamma} d\sigma_{\gamma A\rightarrow 2jet+X}$$

$$d\sigma_{\gamma A\rightarrow 2\,\mathrm{jet}+X} = \sum_{\{q,\bar{q}\}} \int \frac{dx_A}{x_A} \int d^2k_T\, x_A G_1\left(x_A, k_T\right)\, d\sigma_{\gamma g^*\rightarrow q\bar{q}}\left(x_A, k_T\right)$$

Kotko, Kutak, Sapeta, Stasto, Strikman '16



dipole gluon density



$$xG^{(1)}(x, \mathbf{k}_t^2) \propto \int \frac{d^2\mathbf{x}}{(2\pi)^2} e^{-i\mathbf{k}_t\cdot\mathbf{x}} \frac{(1 - S_A(x, \mathbf{x}))}{\mathbf{x}^2}$$

$$S_A(x, \mathbf{x}) = [S(x, \mathbf{x})]^2$$

Weizacker-Williams gluon density

UPC collision of Pb-Pb

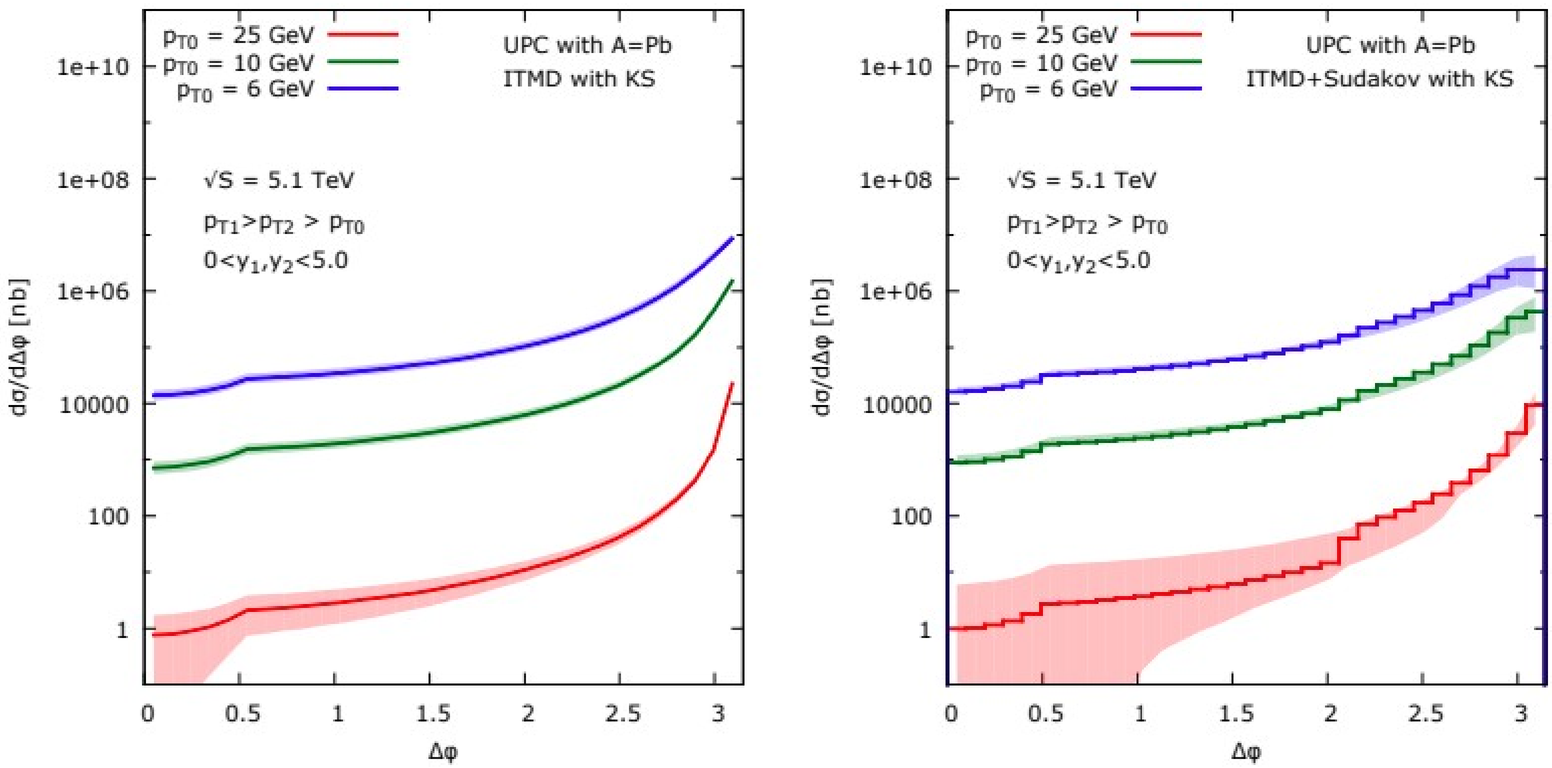
$$\gamma + g \rightarrow \bar{q}q$$

ıtons

P1

P2

Kotko, Kutɛ



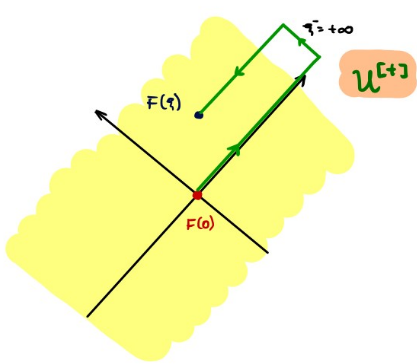
$\rightarrow q\bar{q}\ (x_A, k_T)$

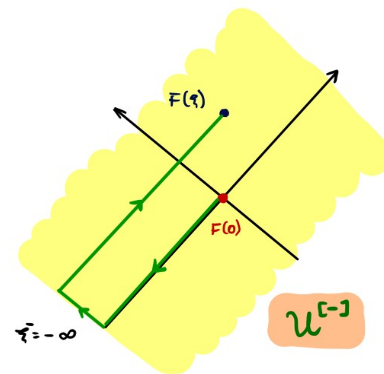
Summary and outlook

- *We obtained results for cross-section of dijets in central-forward and forward-forward configurations*
- *For central-forward the Sudakov effects were taken into account using b space and model Sudakov*
- *The results for the decorelations have different shape but both lead to broadening*
- *The results for three jet ITMD show that there is large potential in this observable for stauration search*
- *We have also results with Sudakov for inclusive dijet production in UPC*
- *future applications to dijets at EIC*
- *Possible NLO extension we have already forward Higgs production in hybrid approach*
  Hentschinski, KK, van Hameren 2011.03193

Definition of TMD – gauge links

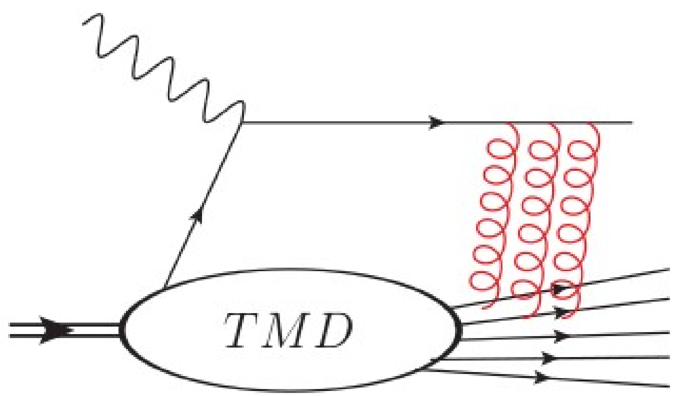
Two basic structures arise:





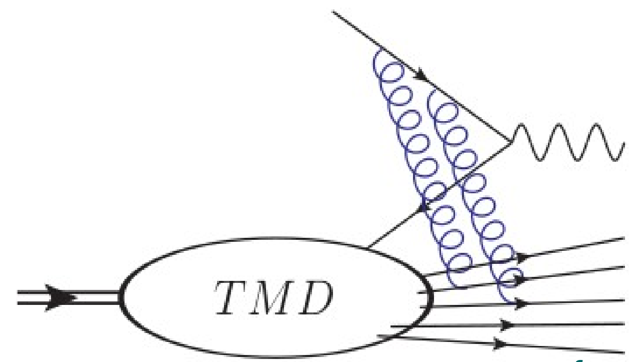
From P. Kotko,

Semi Inclusive DIS



final state interactions

Drell-Yan



initial state interactions

from R. Boussarie
Initial Stages 2019

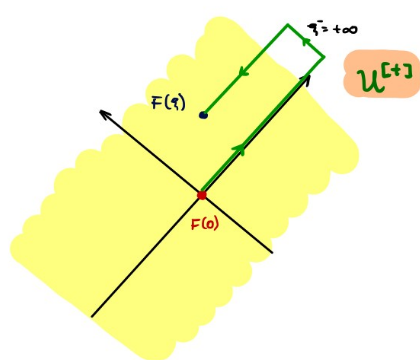
$$\Phi_q^{[+]}(x, p_T) = \int \frac{\mathrm{d}(\xi \cdot P)\mathrm{d}^2\xi_T}{(2\pi)^3}\, e^{ip\cdot\xi} \langle H | \overline{\psi}(0)\, \mathcal{U}^{[+]}\, \psi(\xi)\, | H \rangle$$

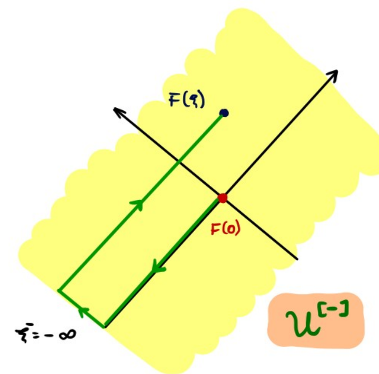
C.J. Bomhof, P.J. Mulders, F. Pijlman
Eur.Phys.J. C47 (2006) 147-162

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

Definition of TMD – gauge links

Two basic structures arise:





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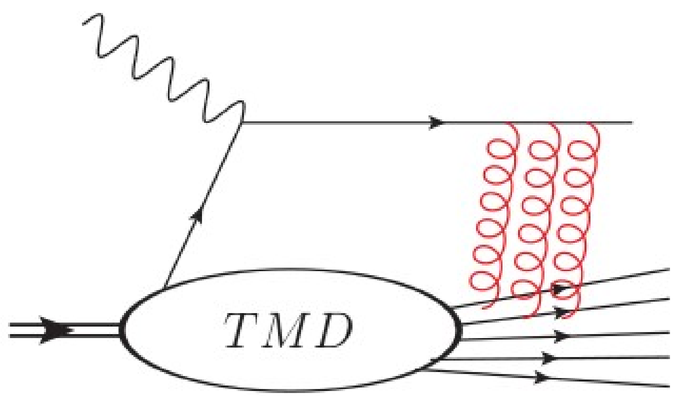
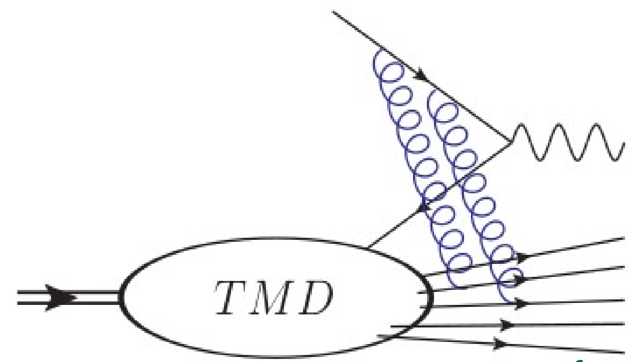


final state interactions

Drell-Yan



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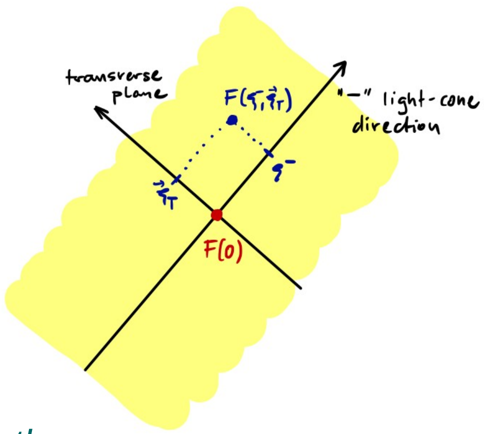
C.J. Bomhof, P.J. Mulders, F. Pijlman
Eur.Phys.J. C47 (2006) 147-162

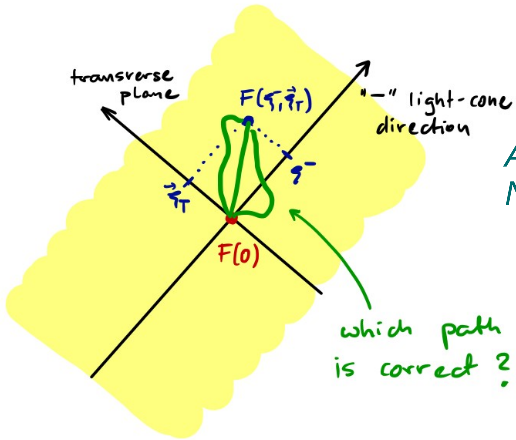
Definition of TMD – gauge links

The formula for TMD gluon density

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

naive definition of gluon distribution





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

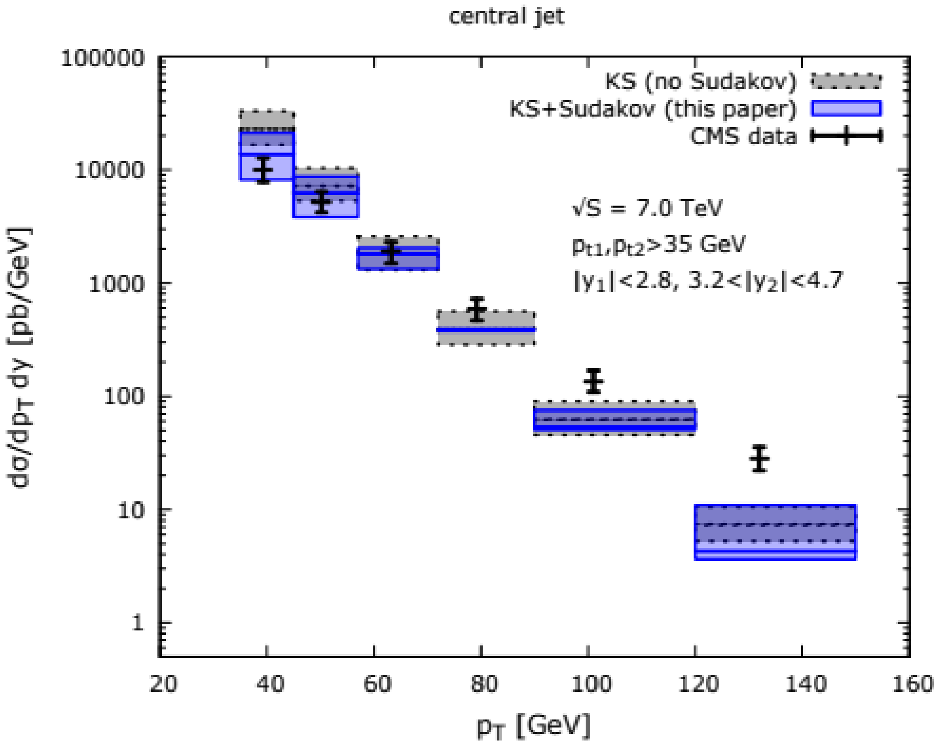
From P. Kotko,

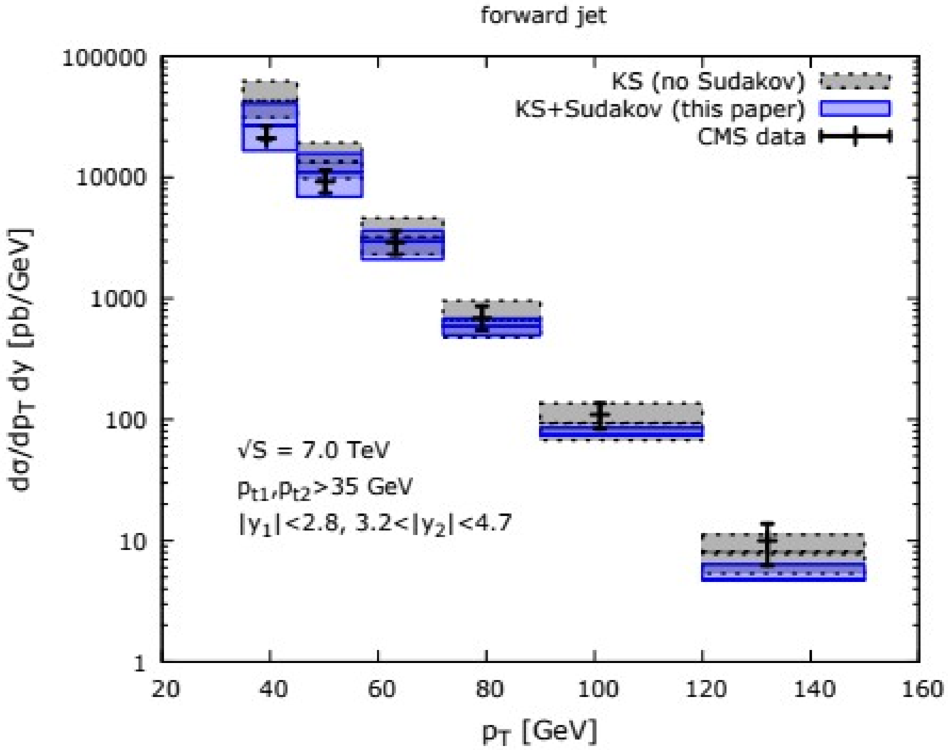
The generalization is achieved via gauge link which accounts for exchange of collinear gluons between the softand hard partsrenders the gluon density gauge invariant….

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

P_T spectra no-Sudakov vs. “b” space Sudakov and uncertainity

van Hameren, Kotko, Kutak,Sapeta
2010.13066





Good rescription of forward jet – probes small k_t part of the gluon density

Central jet requires Monte Carlo parton shower corrections - we do not account for them now since there is no shower available for KS gluons

Calculations have been done using KaTie van Hameren CPC. 224 (2018) 371-380
and LxJet Kotko *Monte Carlo programs*

BACKUP

observable

total cross-section

$$\mathcal{O} = \frac{\sigma}{W} \sum_i w_i F_i^{\mathcal{O}} (X_i)$$

function defining observable: cuts etc.

$$\mathcal{O} = \frac{\sigma}{W} \left[\sum_i w_i F_i^{\mathcal{O}} (X_i) \, \Theta (\mu_i > k_{Ti}) + \sum_j w_j F_j^{\mathcal{O}} (X_j) \, \Theta (k_{Tj} > \mu_j) \right]$$

$W = \sum_i w_i$ *total weight*

of order 1

$$\overline{\mathcal{O}} = \frac{\sigma}{\overline{W}} \left[\sum_i w_i \Delta (\mu_i, k_{Ti}) \, F_i^{\mathcal{O}} (X_i) \, \Theta (\mu_i > k_{Ti}) + \frac{\widetilde{W}}{W} \sum_j w_j F_j^{\mathcal{O}} (X_j) \, \Theta (k_{Tj} > \mu_j) \right]$$

$$\overline{W} = \sum_i w_i \Delta (\mu_i, k_{Ti}) \, \Theta (\mu_i > k_{Ti}) + \frac{\widetilde{W}}{W} \sum_j w_j \Theta (k_{Tj} > \mu_j)$$

modified weight