Probing gluon number density with electron-dijet correlations at EIC

The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences

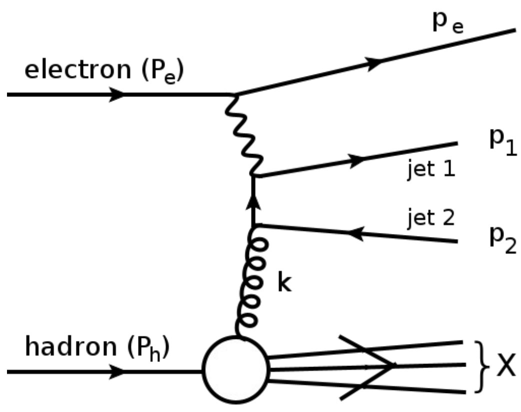
Krzysztof Kutak

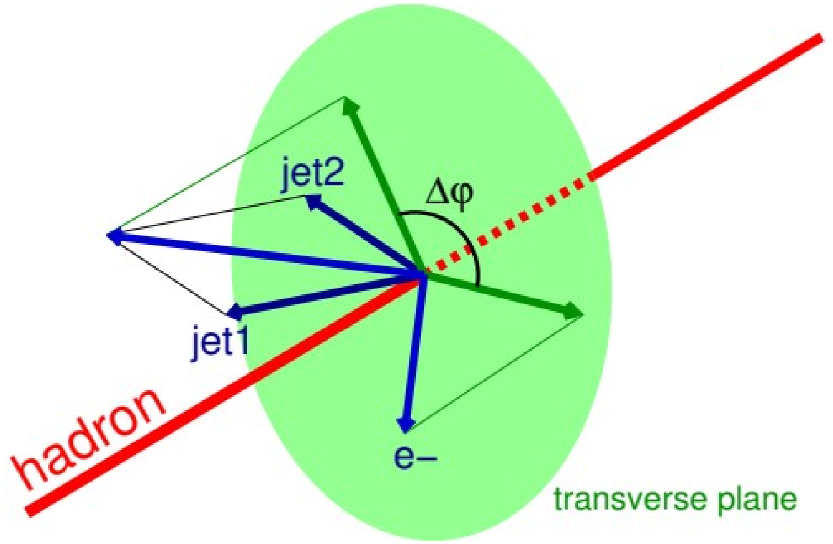
NCN

Based on:
EPJC 81, 741 (2021)
P. Kotko, S. Sapeta, A. van Hameren, E. Zarow

arxiv 2110.06156
Hentschinski, Kutak

The di-jet in DIS





$$k^\mu = xP_h^\mu + k_T^\mu$$

iTMD = *small x Improved Transverse Momentum Dependent factorization*

- *counts for saturation*
- *correct gauge structure i.e. uses gauge links to define TMD's*
- *takes into account kinematical effects – the whole phase space is available at LO*
- *is implemented in MC event generator KaTie by van Hameren , LxJet by Kotko*
- *valid in region $p_T > Qs$, k_T can by any. p_T is hard final state momentum, k_T is inbalance*

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

A. van Hameren, P. Kotko, K. Kutak, C. Marquet, E. Petreska
JHEP 12 (2016) 034

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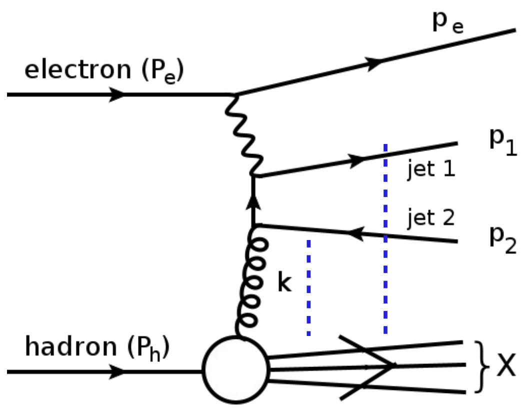

$$k^\mu = xP_h^\mu + k_T^\mu$$

The same gauge link structure and as in TMD 's

F. Dominguez, B. Xiao, F. Yuan
Phys.Rev.Lett. 106 (2011) 022301

F. Dominguez, C. Marquet, B. Xiao, F. Yuan
Phys.Rev. D83 (2011) 105005

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JHEP 1509 (2015) 106
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JHEP 12 (2016) 034

Derivation within CGC

T. Altinoluk, R. Boussarie, P. Kotko JHEP 1905 (2019) 156
T. Altinoluk, R. Boussarie, JHEP10(2019)208

Role of transverse gauge links

Boussarie, Mehtar- Tani Phys. Rev. D 103, 094012 (2021)

Set of basic TMD's for 2, 3 and 4 jets (unpolarized)

Bury, Kotko, Kutak '18

$$\mathcal{F}_{qg}^{(1)}(x,k_T) = \mathrm{F.T.}\left\langle \mathrm{Tr}\left[\hat{F}^{i+}(\xi)\,\mathcal{U}^{[-]\dagger}\hat{F}^{i+}(0)\,\mathcal{U}^{[+]}\right]\right\rangle$$

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Set of basic TMD's for 2, 3 and 4 jets

Bury, Kotko, Kutak '18

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dipole gluon

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WW gluon

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same direction pointing Wilson lines

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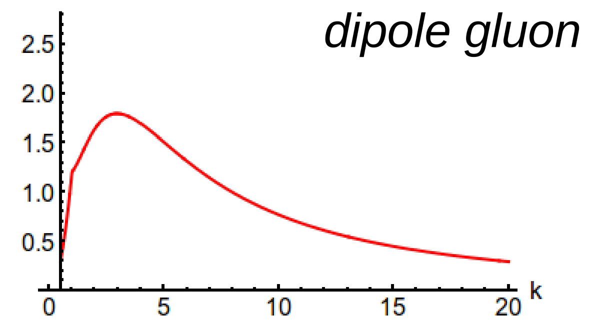
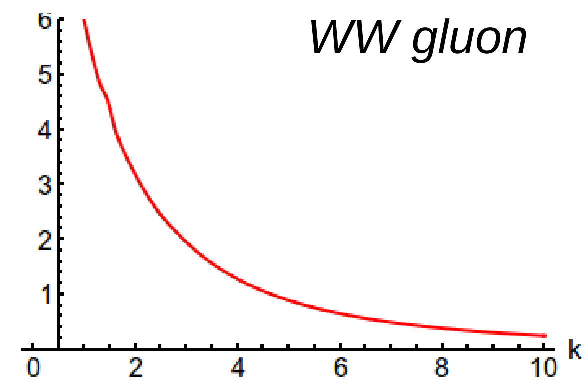
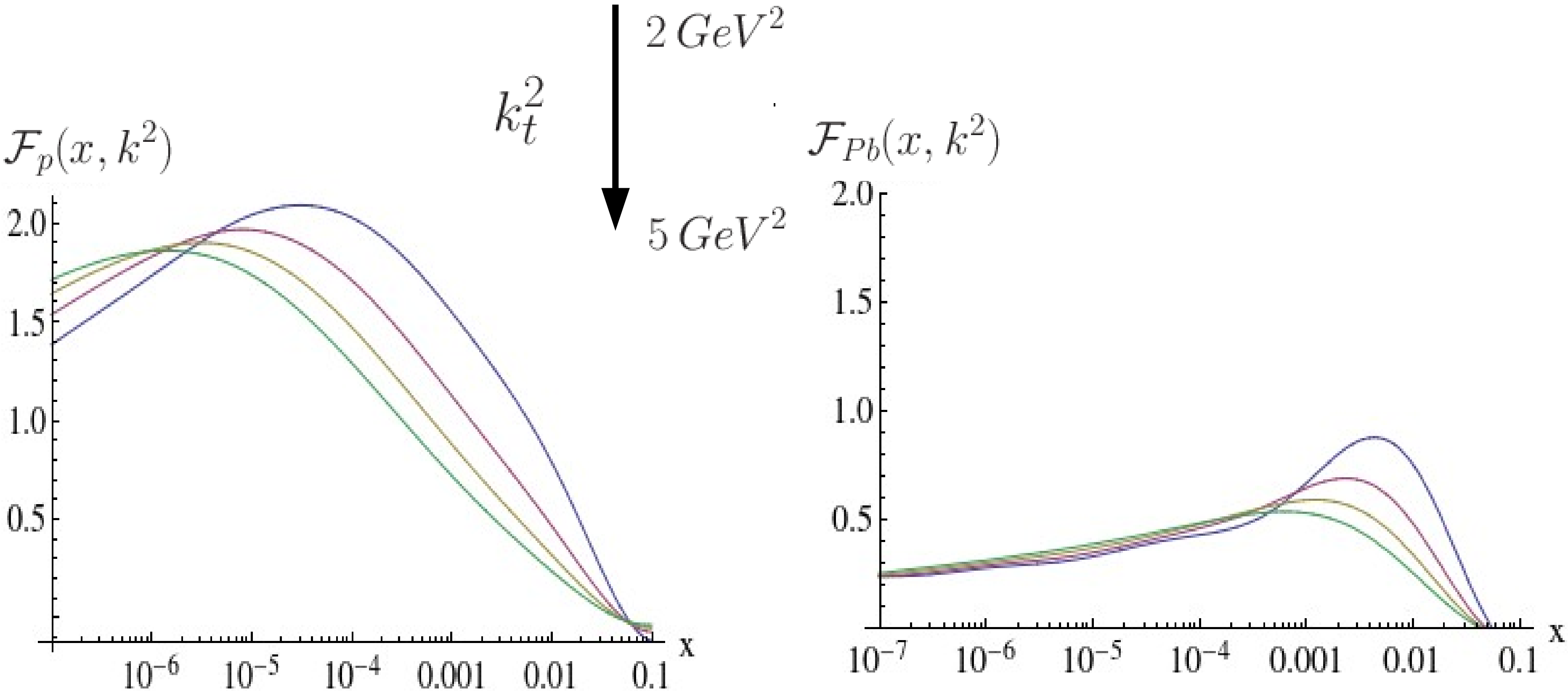


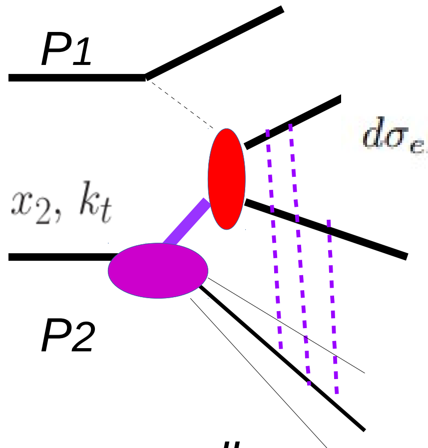


Glue from BK in p vs. glue in Pb – dipole gluon



Maximum signalize emergence of saturation scale

ITMD with Sudakov for dijets in DIS



P. Kotko, KK. S. Sapeta, A. van Hameren, E. Zarow, EPJC

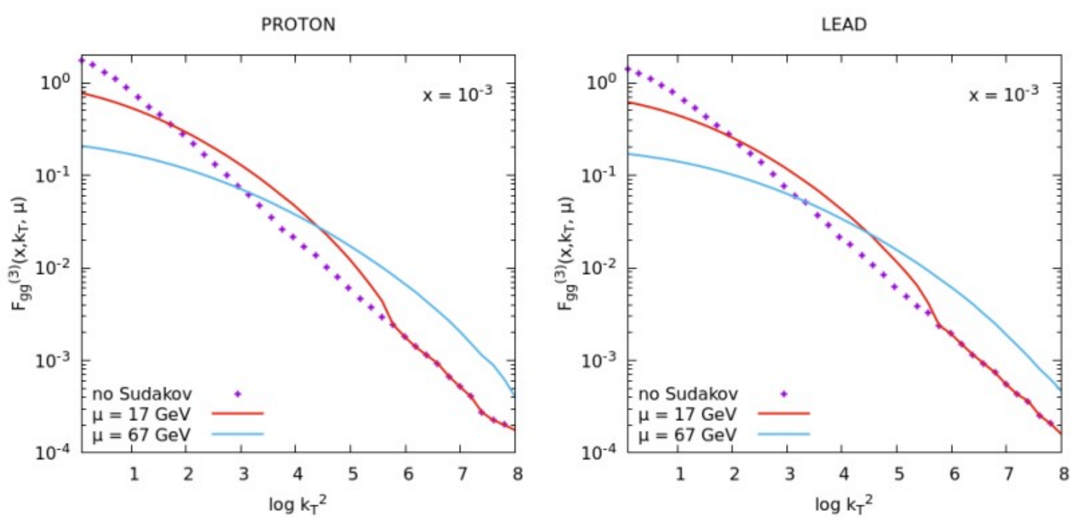
$$d\sigma_{eh\to e'+2j+X} = \int \frac{dx}{x}\frac{d^2k_T}{\pi} \mathcal{F}_{gg}^{(3)}(x,k_T,\mu) \frac{1}{4xP_e\cdot P_h} d\Phi(P_e,k;p_e,p_1,p_2)\,|\overline{M}_{eg^*\to e'+2j}|$$

$$S_{\rm Sud}^{g\to q\bar{q}}(\mu,b_T) = \frac{\alpha_s N_c}{4\pi}\ln^2\frac{\mu^2 b_T^2}{4e^{-2\gamma_E}}$$

A. Mueller, B-W. Xiao, F. Yuan, 2013

This process allows
to probe the Weizsacker-Williams TMD

The Weizsacker-Williams TMD with Sudakov resummation
to account for soft emissions



Related studies for dijet/dihadron at EIC

Back-to-back regime using MV model + Sudakov
L. Zheng, E.C. Aschenauer, J.H. Lee, B-W. Xiao, 2014

Full CGC calculations (no Sudakov)
A. Dumitru, V. Skokov, 2018

H. Mantysaari, N. Mueller, F. Salazar, B. Schenke, 2019
F. Salazar, B. Schenke, 2020

R. Boussarie, H. Mäntysaari, F. Salazar, B. Schenke
JHEP 09 (2021) 178

Y. Zhao et . Al 2105.08818

Marquet, Taels, Altinoluk, JHEP 06 (2021) 085

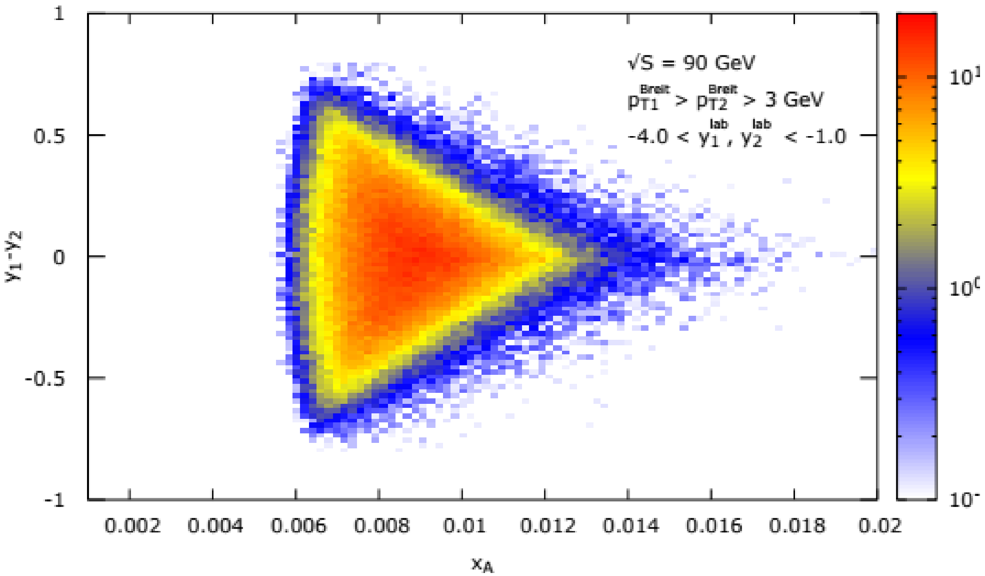
We do not take into account
linearly polarised gluons

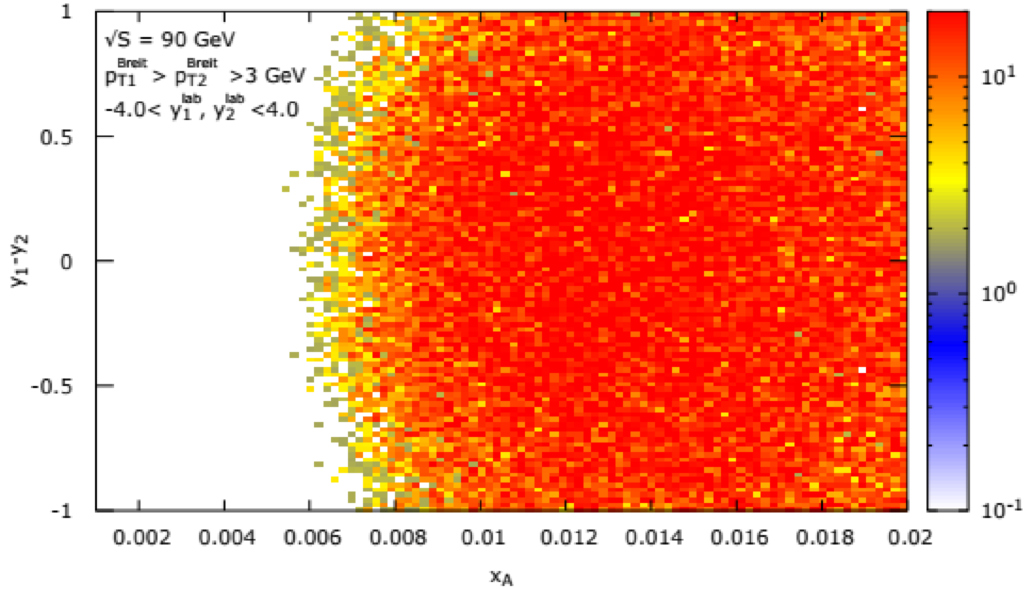
Low x region

P. Kotko, KK. S. Sapeta, A. van Hameren, E. Zarow, ‘20 EPJC

For clarity:

$k = P\,x_A + k_T \quad x_{Bj} = Q^2/(P.q)$





The asymmetric rapidity cuts guarantee good focusing of the cross section around smaller values of x required by the formalism.

x_{Bj} VS x_A

P. Kotko, KK. S. Sapeta, A. van Hameren, E. Zarow, '20 EPJC

For clarity:

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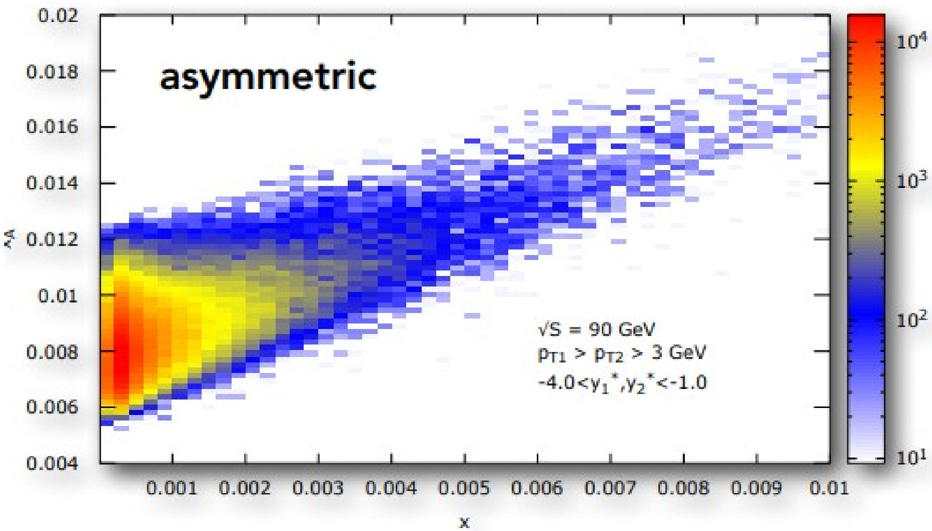
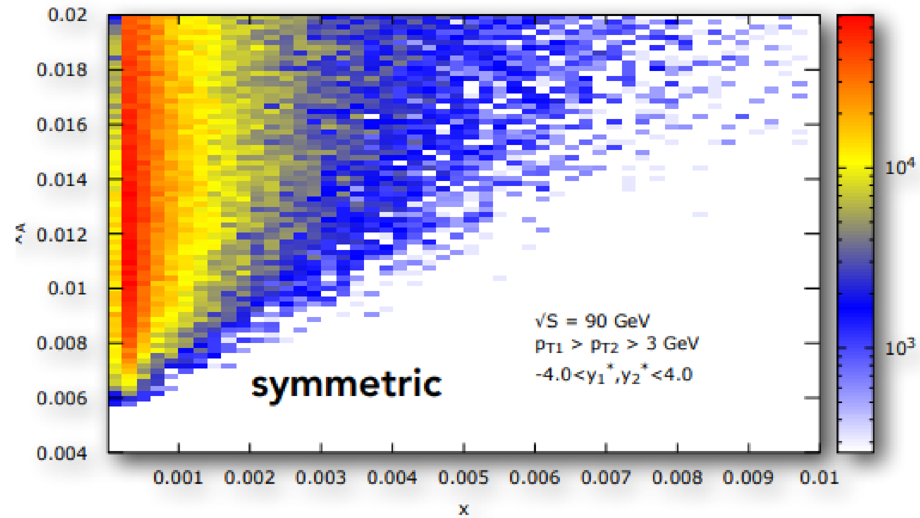


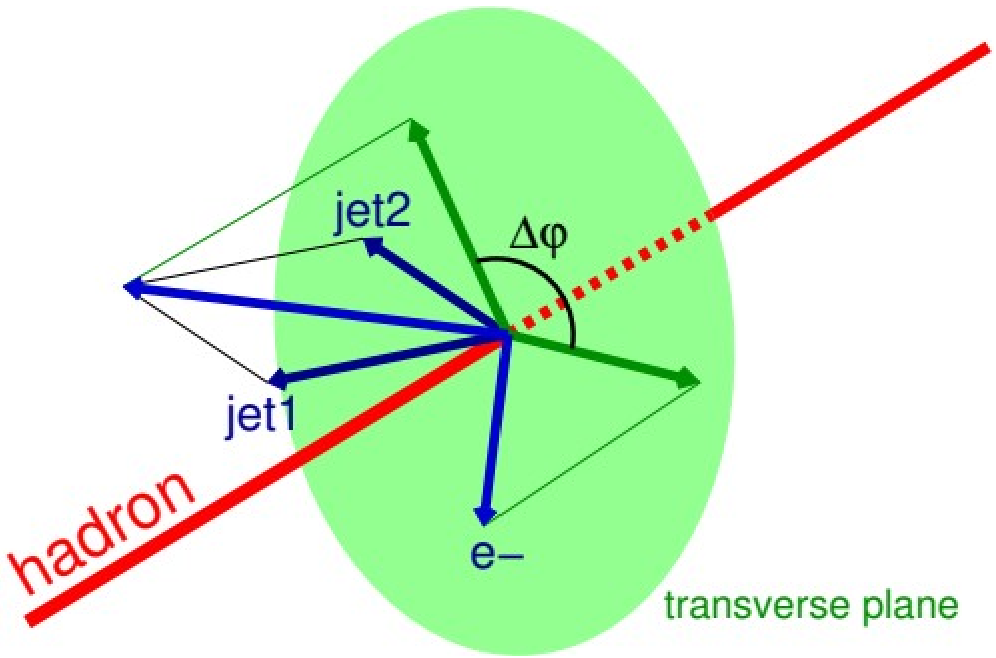


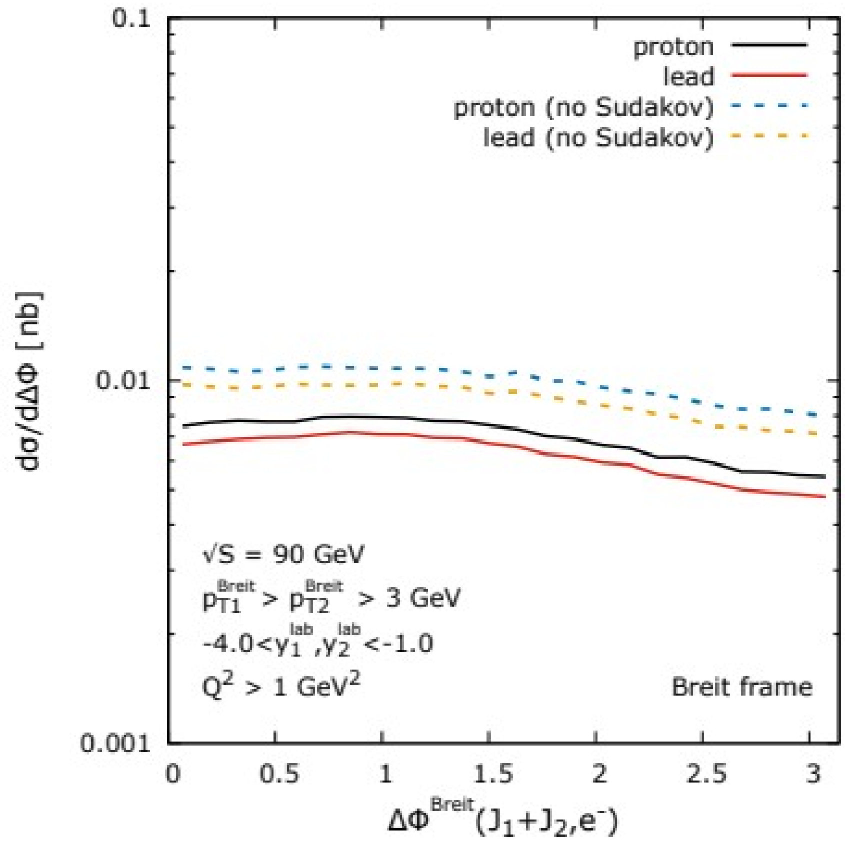
For asymmetric window $x_{Bj} \sim 10^{-4}$, $x_A \sim 5\ 10^{-3}$

From P. Kotko DIS 2021

Azimuthal correlations EIC kinematics

angle between di-jet and electron

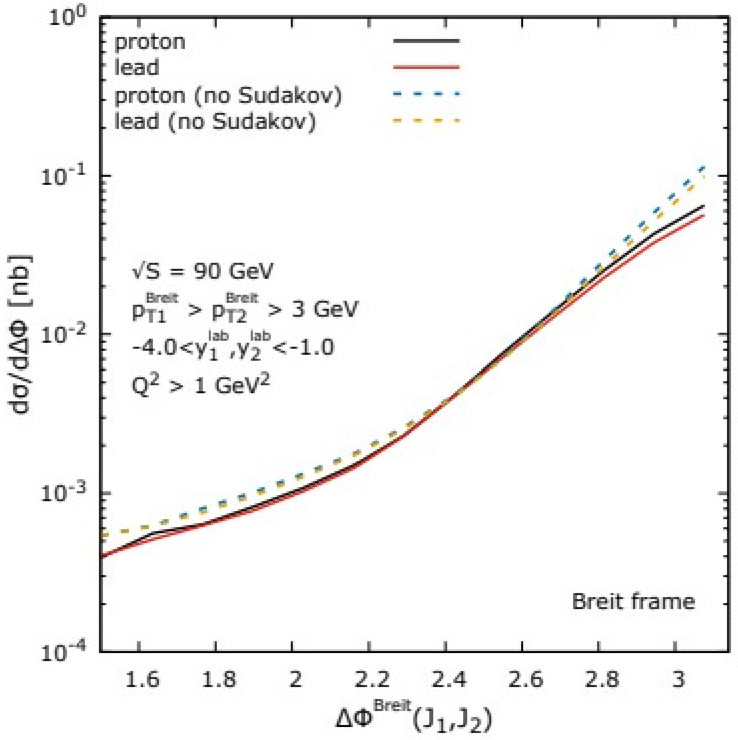




Large Sudakov effects.

Azimuthal correlations EIC kinematics

angle between dijets



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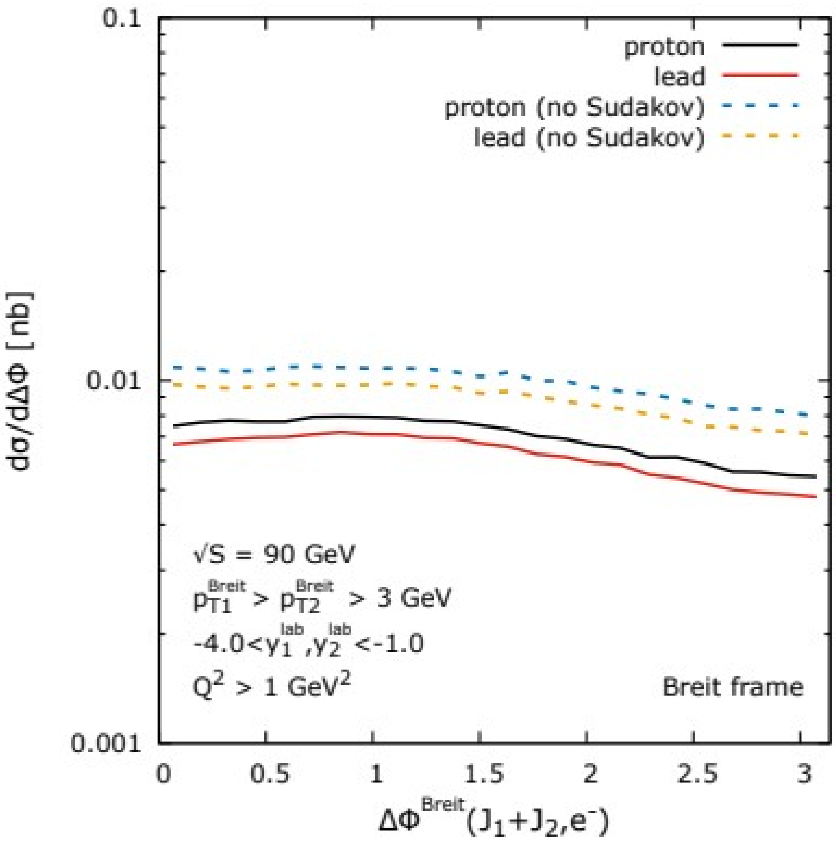
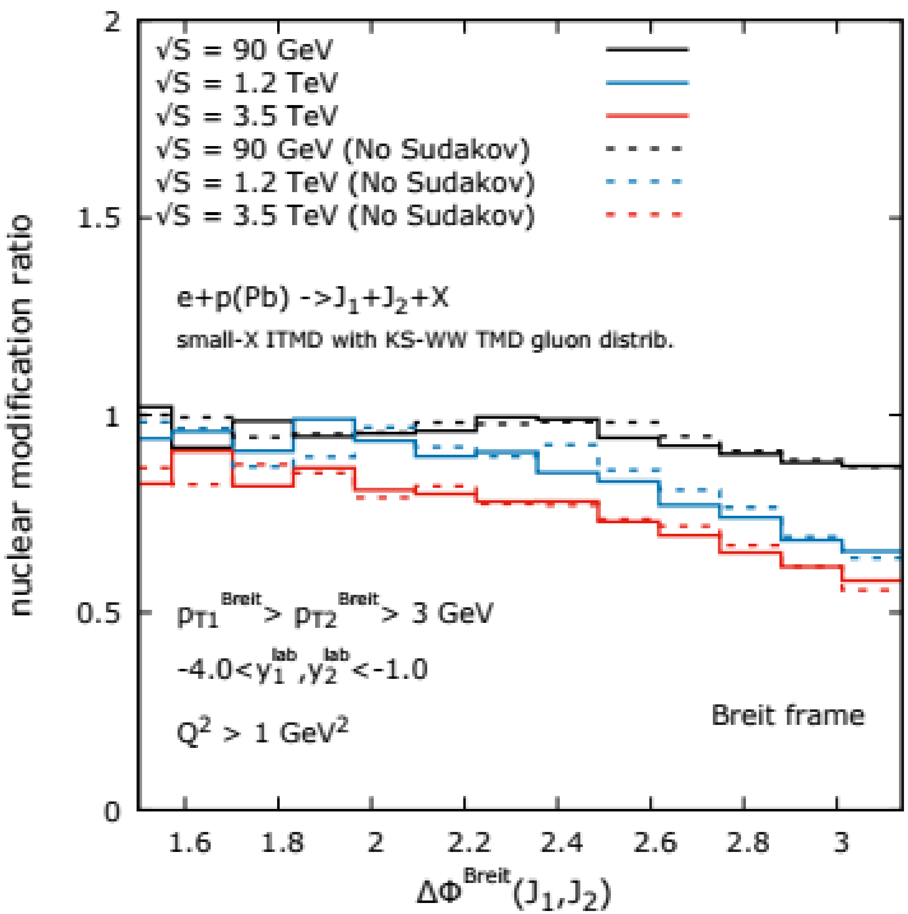
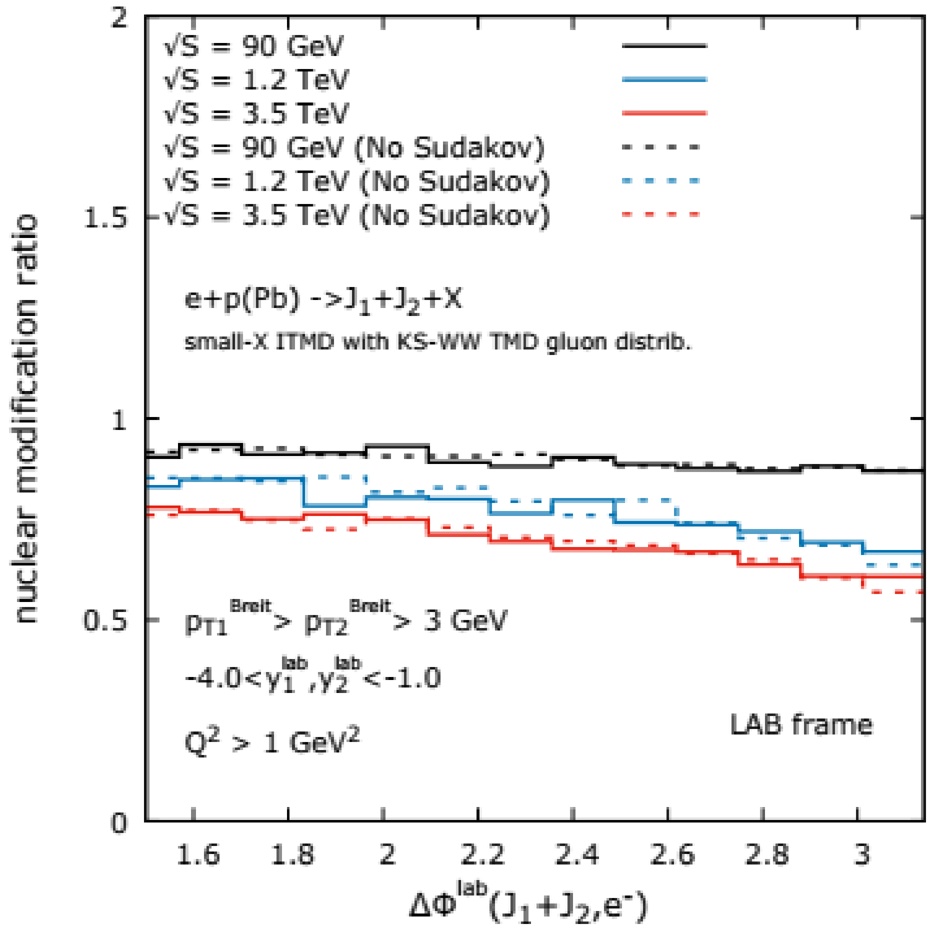


Large Sudakov effects.

Energy dependence of nuclear modification factor





Evidently the larger energy the more visible saturation effects are.
Sudakov effects in RpA cancel to large extent.

Monte Carlo tools for k_T dependent initial states

KaTie *(A. van Hameren)* *Comput.Phys.Commun.Â 224Â (2018)Â 371-380*

- *Monte Carlo program for tree-level calculations e-p, p-p, p-A, A-A*
- *any process within the Standard Model (High Energy Factorization)*
- *dijets, trijets using iTMD*
- *initial-state partons on-shell or off-shell dependent on factorization framework*
- *employs numerical Dyson-Schwinger recursion to calculate helicity amplitudes*
- *automatic phase space optimization*
- *It can be used together with CASCADE to account for initial and final state state showers for example using PB TMD*

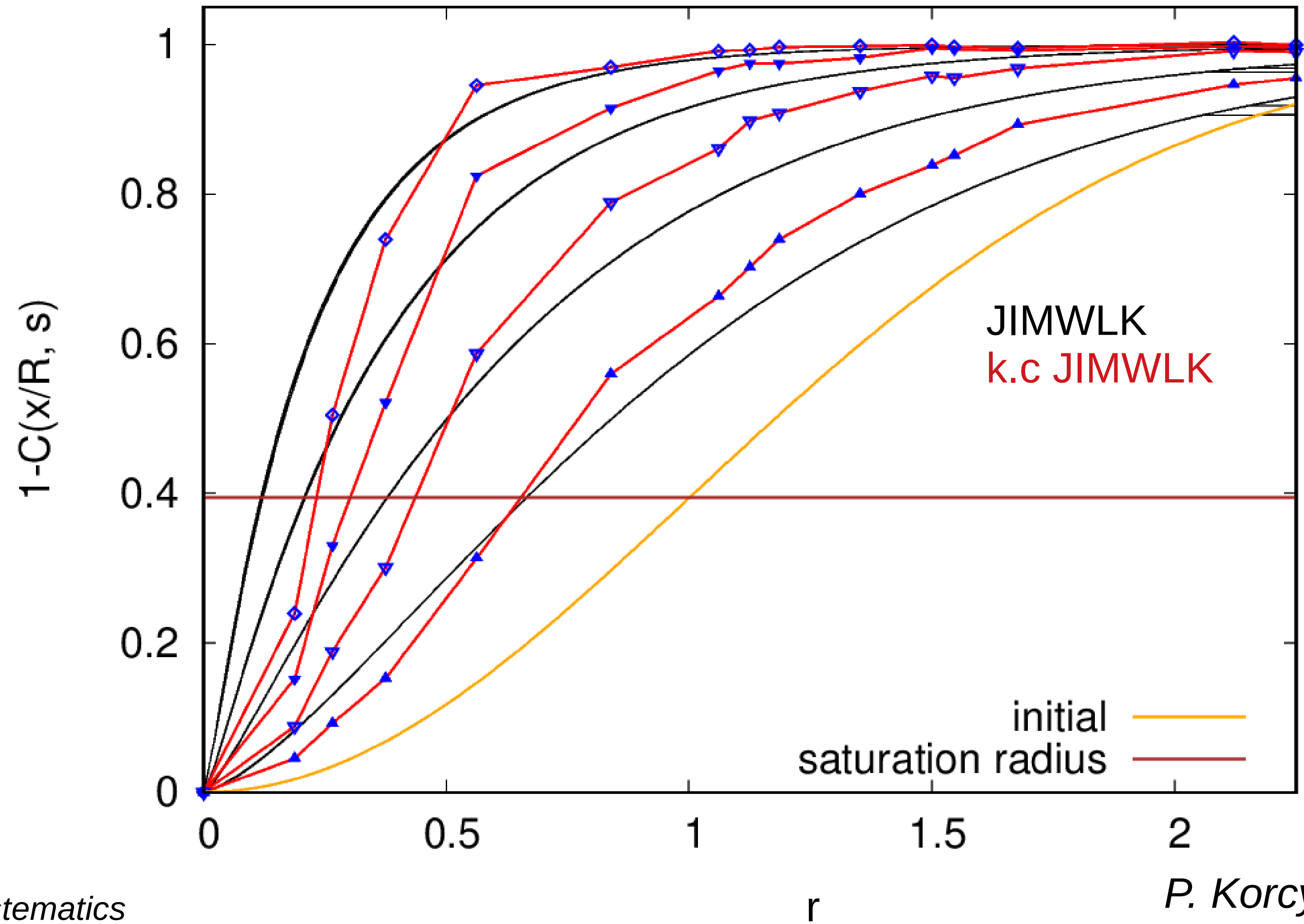
H. Van Haevermaet, A. Van Hameren, P. Kotko, K. Kutak, P. Van Mechelen
Eur.Phys.J.C 80 (2020) 7, 610

Ongoing work on developments at NLO accuracy

JIMWLK with kinematical-constraint

Proposal by Hatta, Iancu '16

See discussion by A. Stasto on Wednesday



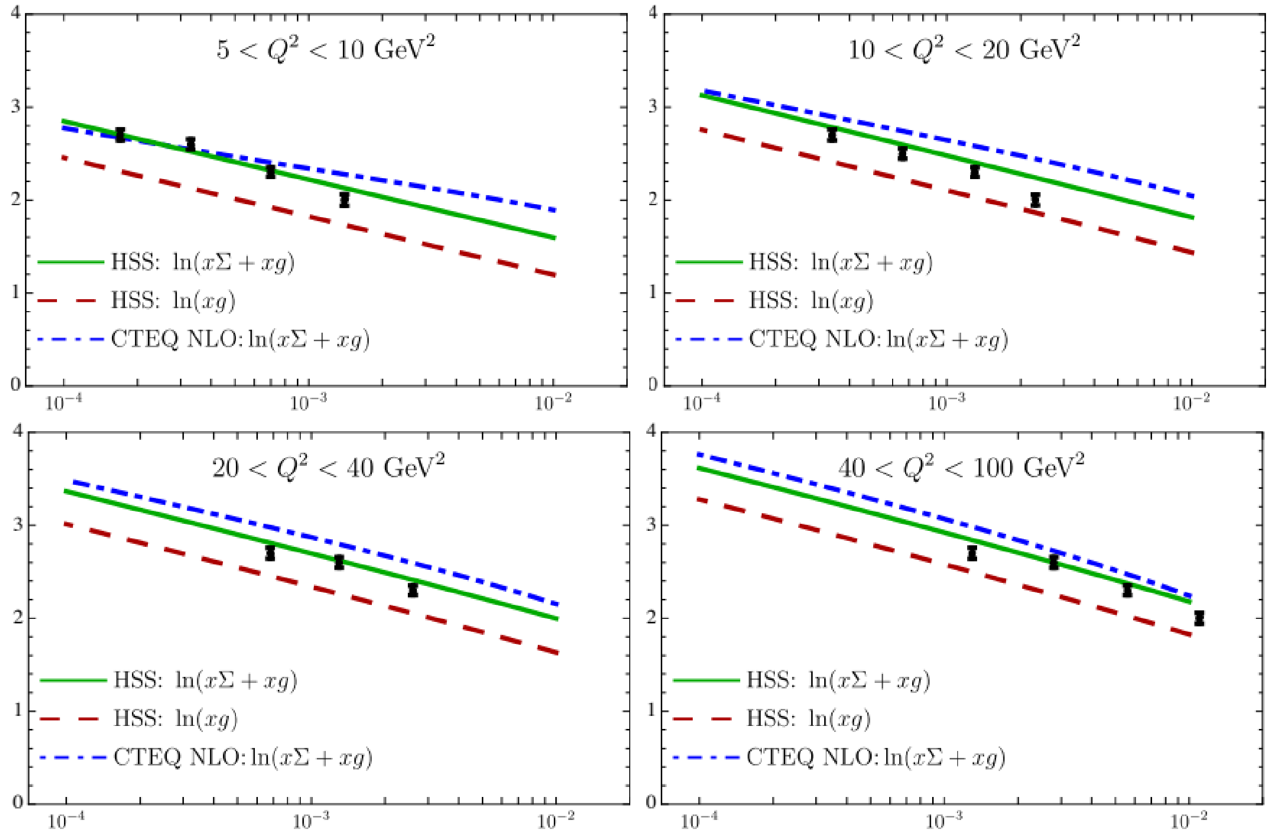
P. Korcyl, preliminary

JIMWLK systematics
Cali, Cichy, Korcyl, Kotko, Kutak, Marquet '20

New algorithm for MV initial conditions – results do not suffer from volume dependence *Korcyl '21*

Entropy and BFKL

2110.06156 Hentschinski, Kutak



See alzo talk by D. Kharzeev on Thursday

Motivated by

Kharzeev, Levin '17
Tu, Kharzeev, Ullrich '20
Kharzeev, Levin '21

HSS gluon density used i.e. NLO BFKL + kinematical Improvements

Hentschinski, Sabio-Vera, Salas.
Phys.Rev.D 87 (2013) 7, 076005
Phys.Rev.Lett. 110 (2013) 4, 041601

$$S(x, Q^2) = \ln \left\langle n \left(\ln \frac{1}{x}, Q \right) \right\rangle$$

$$xg(x, Q) = \int_0^{Q^2} d\mathbf{k}^2 \mathcal{F}(x, \mathbf{k}^2)$$

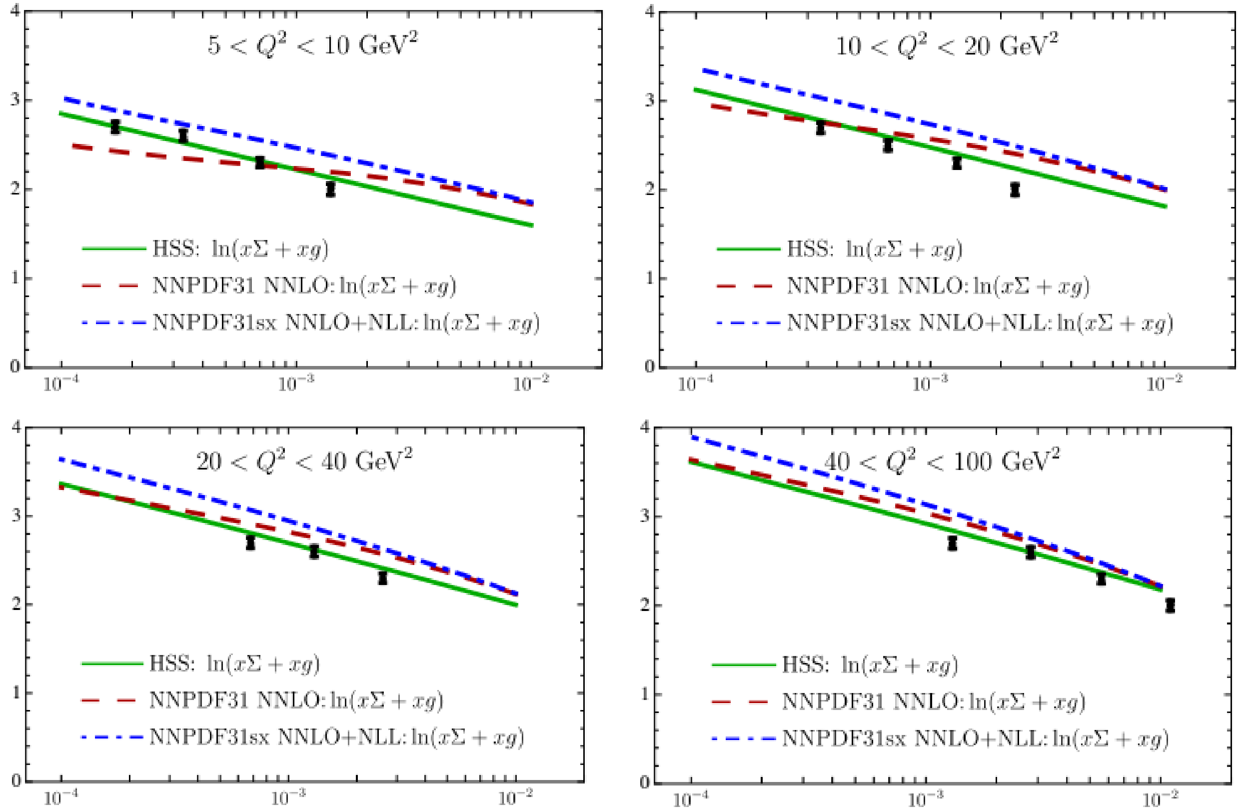
Our proposal

$$\left\langle n \left(\ln \frac{1}{x}, Q \right) \right\rangle = xg(x, Q) + x\Sigma(x, Q)$$

$$x\Sigma(x, Q) = P_{qg}(Q, \mathbf{k}) \otimes \mathcal{F}(x, \mathbf{k}^2)$$

Entanglement entropy and BFKL

2110.06156 Hentschinski, Kutak



Low x resummation is essential to get good description of data

HSS gluon density used i.e. NLO BFKL + kinematical Improvements

Hentschinski, Sabio-Vera, Salas.
Phys.Rev.D 87 (2013) 7, 076005
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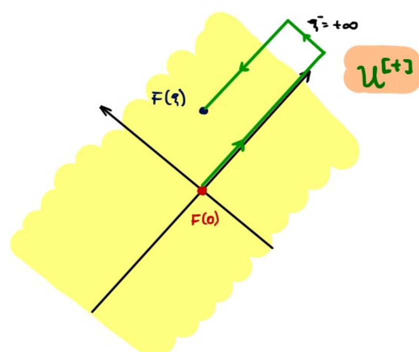
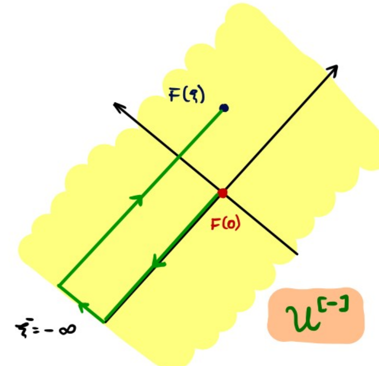
Back up

Definition of TMD – gauge links

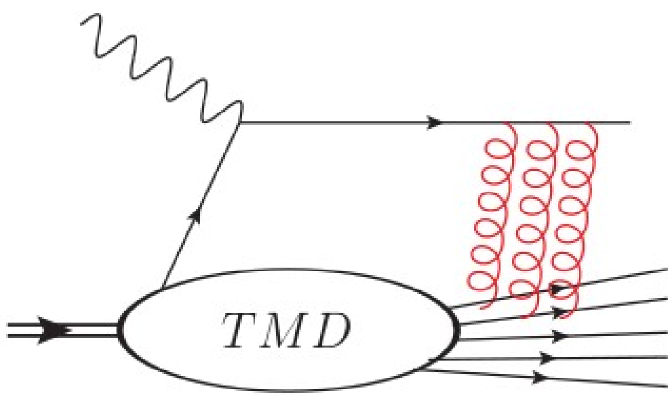
Two basic structures arise:





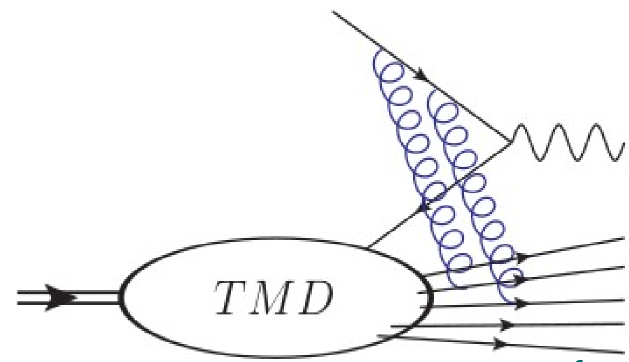
from P. Kotko, Bialasówka 2019

Semi Inclusive DIS



final state interactions

Drell-Yan



initial state interactions

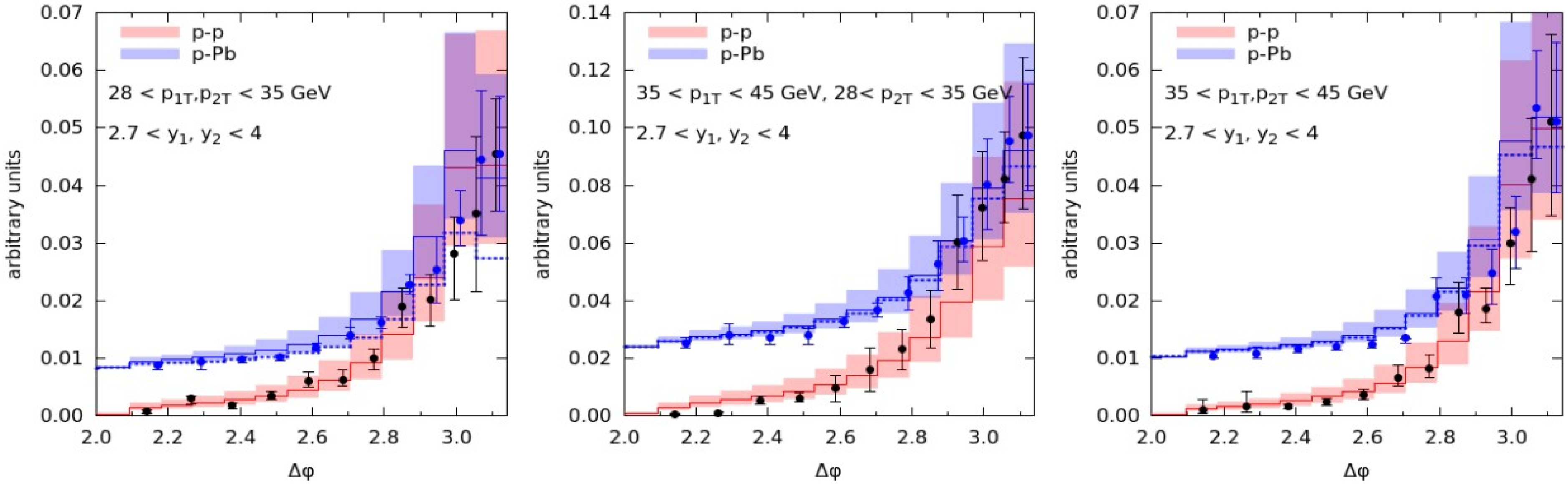
from R. Boussarie
Initial Stages 2019

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

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

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

The iTMD factorization for di-jets in p-p and p-Pb



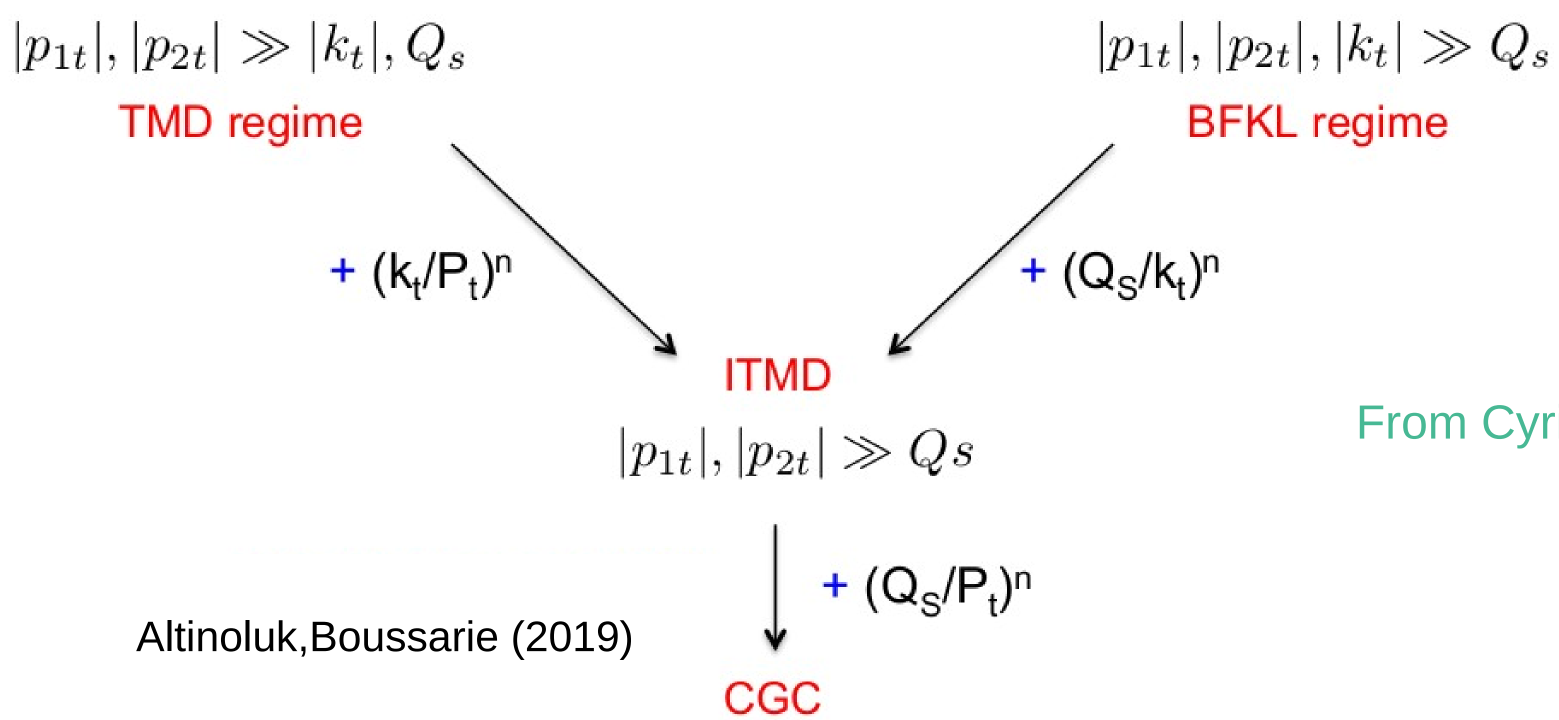
A. Hameren, P. Kotko, K. Kutak, S. Sapeta
Phys.Lett. B795 (2019) 511-515

To describe data we had to account both for Sudakov effects and for saturation.

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

ITMD from Color Glass Condensate

T. Altinoluk, R. Boussarie, P. Kotko JHEP 1905 (2019) 156
T. Altinoluk, R. Boussarie, JHEP10(2019)208



From Cyrille Marquet

Backup

Background

~ 0 p_T in Breit frame

$$2x_{\mathrm{Bj}}\vec{p} + \vec{q} = 0$$