WG2: Small-x, Diffraction and Vector Mesons

Theory Summary
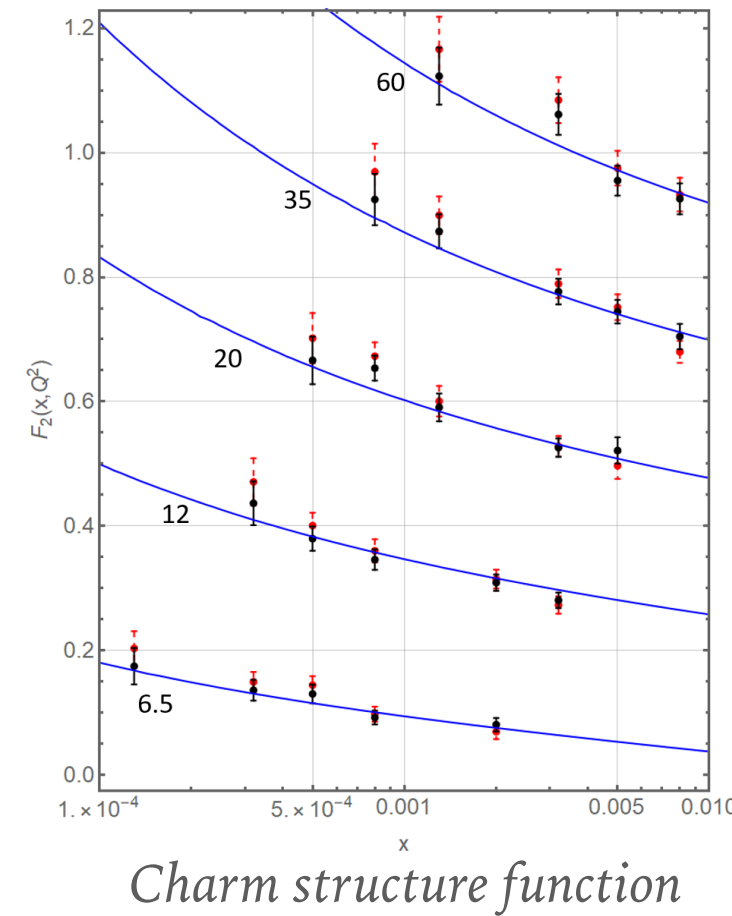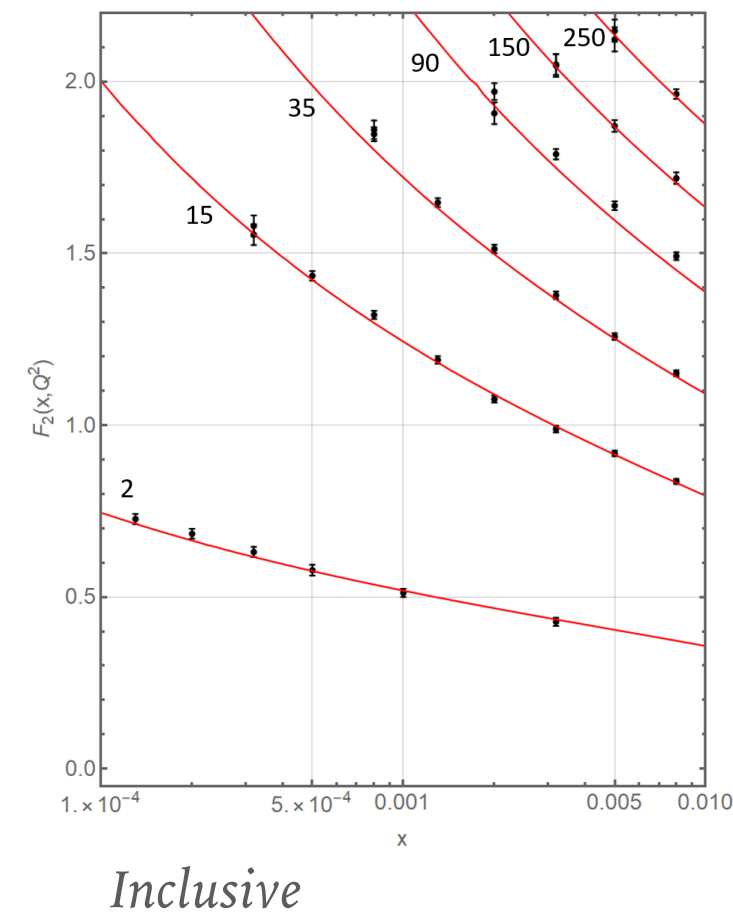
Guillaume Beuf

National Centre for Nuclear Research (NCBJ), Warsaw

Fits to DIS structure functions at small x

A. Stasto

Inclusive

Charm structure function
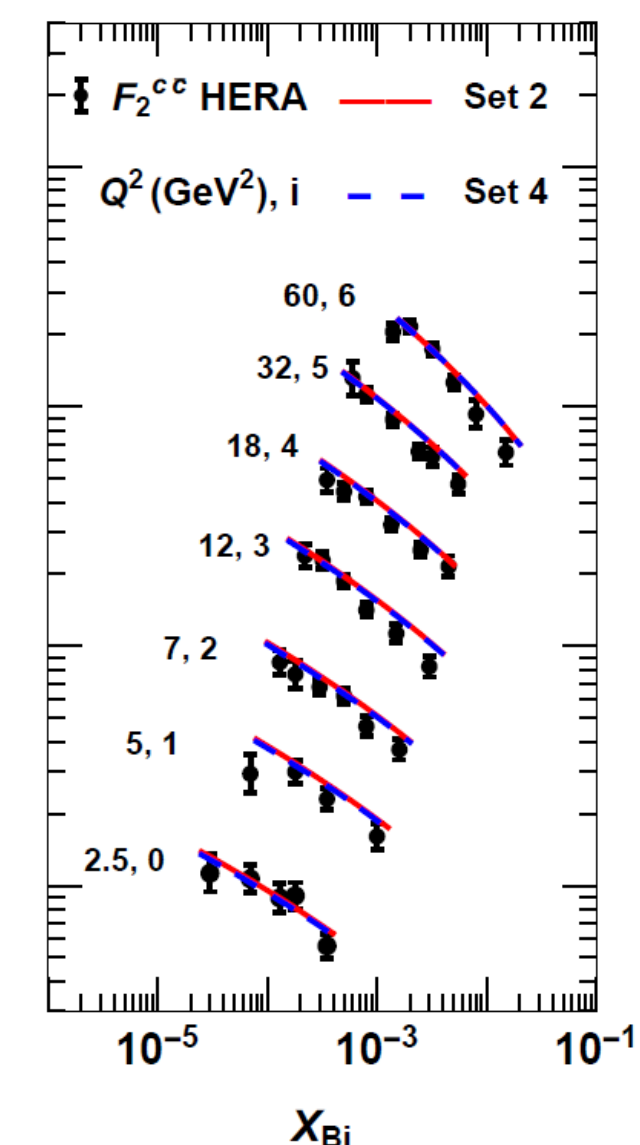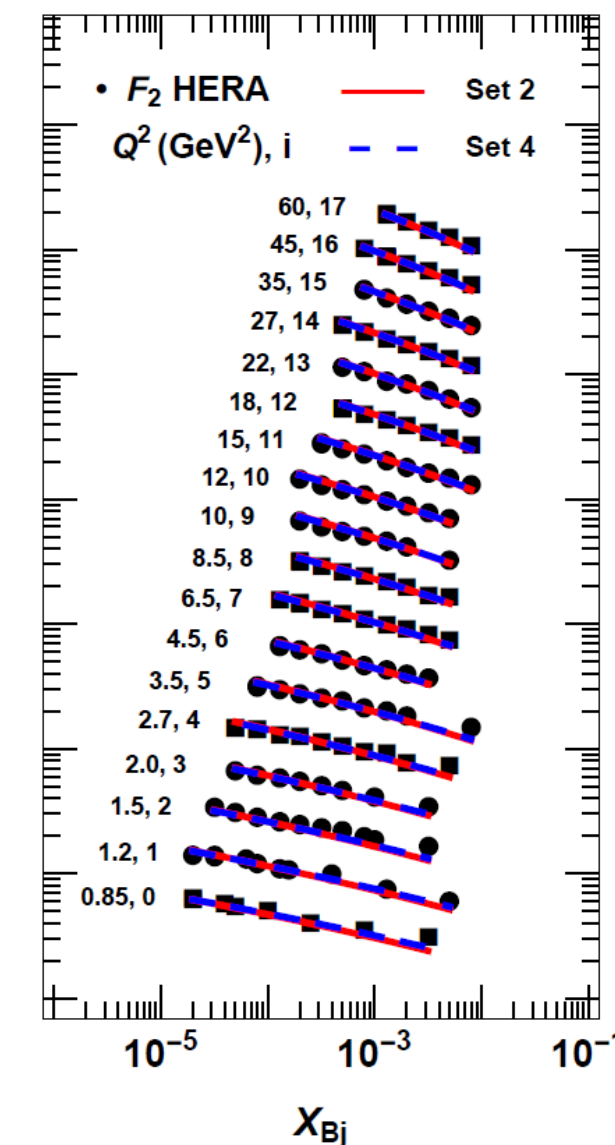
- Fits of F_2 and F_2^c using NLL BFKL with collinear resummation the CCSS scheme

- Exact kinematics is used in the high energy factorization formula

M. Sanhueza

- DIS fits using an approximate version of NLL BFKL with collinear resummations, and saturation effects

- Different models for large b behavior of the saturation scale Q_s are tested in the fits.

PDFs at small x

G. Chirilli

- Gluon Ioffe time distribution is computed in the high energy OPE.

- Gluon pseudo-PDFs and quasi PDFs are derived from this result.

- At low-x, very different behaviors for pseudo- PDF and quasi-PDF are observed.

- Pseudo-PDFs have the expected behavior at low-x.

- For Quasi-PDFs, the BFKL pomeron exponential is missing and higher twist power corrections are enhanced at low x.

K. Xie
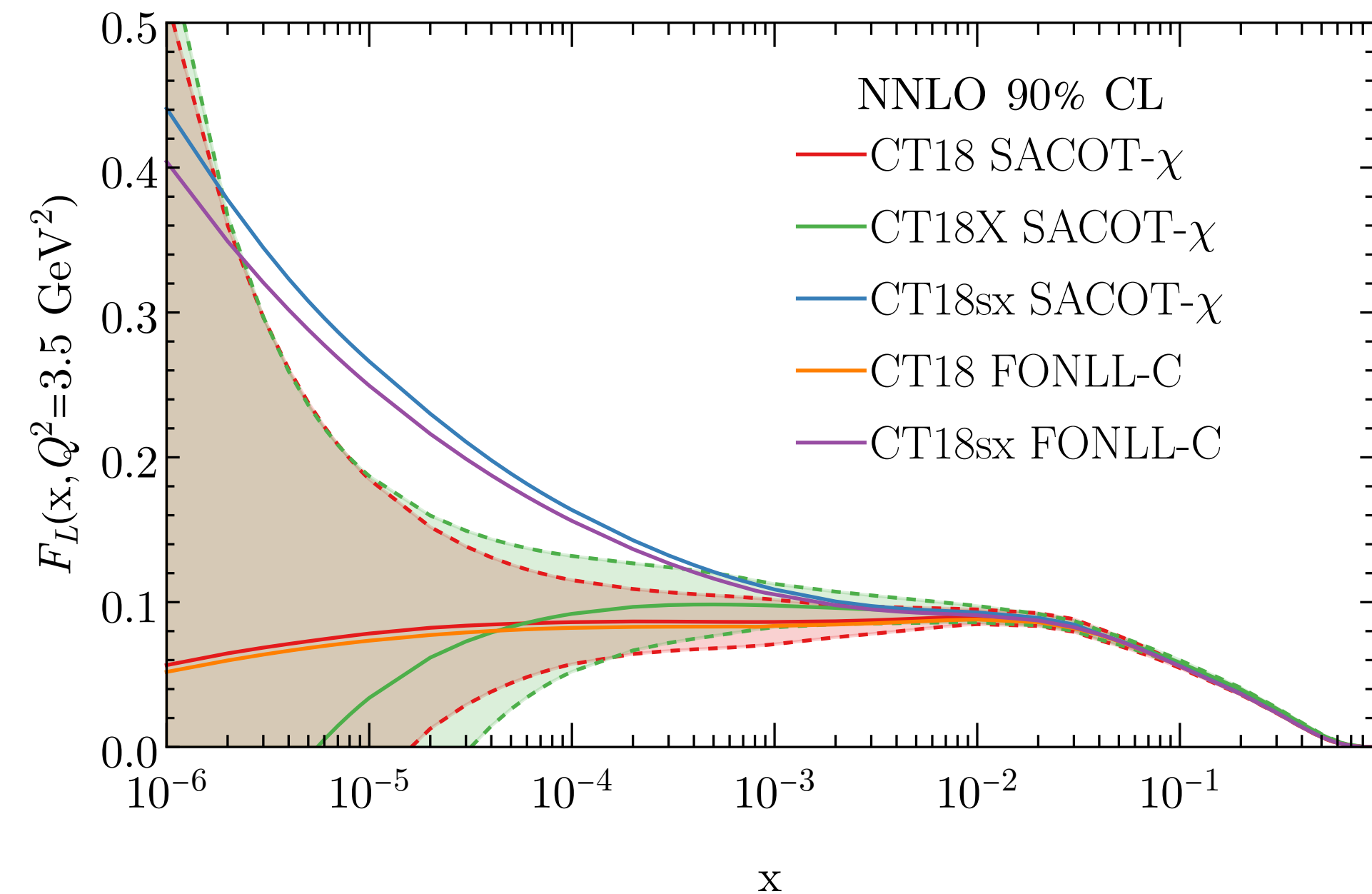
- Comparison of DGLAP fits with either BFKL resummation or a choice of factorization scale simulating saturation effects

- Both give comparable description of HERA data

- At very small-x BFKL resummation leads to an enhancement of F_L whereas the saturation model reduces F_L

Improvements of the NLO CGC

T. Lappi - NLO structure functions in CGC at low-x with massive quarks in dipole factorization:

$q\bar{q}$ state in γ^* $q\bar{q}g$ state in γ^*
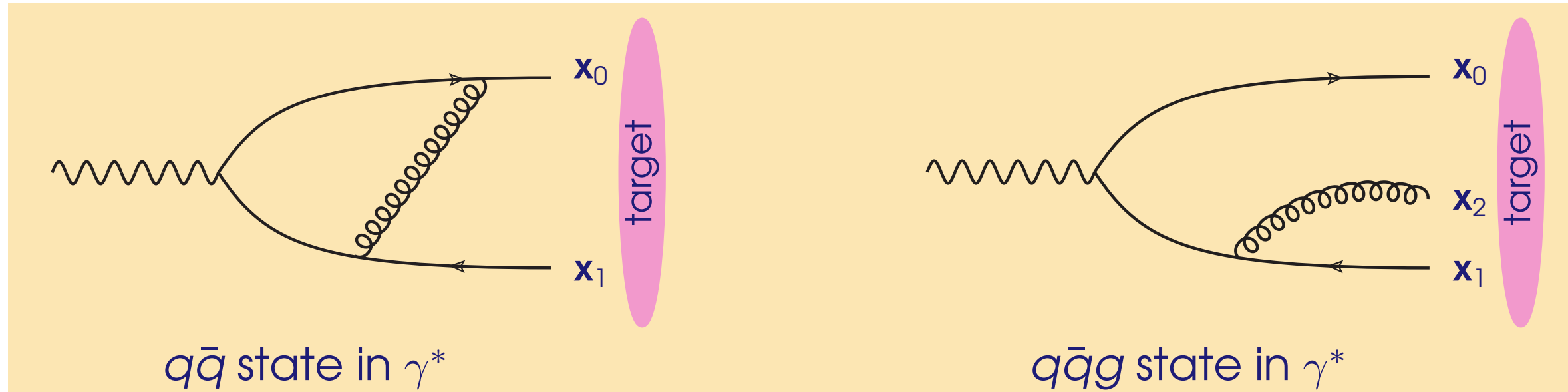
- Calculated in LFPT both for γ_L^* and γ_T^*

- Required solving longstanding LFPT problem of mass renormalization

- All ingredients for fully accurate NLO CGC fits are now available

L. Dai - NLO JIMWLK with massive quarks:

- Contribution of massive quark loops to the NLO JIMWLK Hamiltonian calculated in LFPT.

- Two types of diagrams (quark loop either across or fully outside the shock)

- Massive quark loops can induce gluon mass in LFPT but a specific counter term can prevent this issue.

P. Korcyl - Collinearly improved JIMWLK equation

- Numerical study of the Langevin form of JIMWLK

- New lattice implementation with finite volume and lattice spacing effects fully under control.

- Collinear improvement of JIMWLK implemented numerically for the first time. However, extremely demanding in computing power.

Further studies of nonlinear low-x evolution

L. Motyka - Twist decomposition of non-linear effects in BK evolution

- Twist decomposition of the proton structure functions from LL BK equation is performed with a single iteration of the nonlinear term
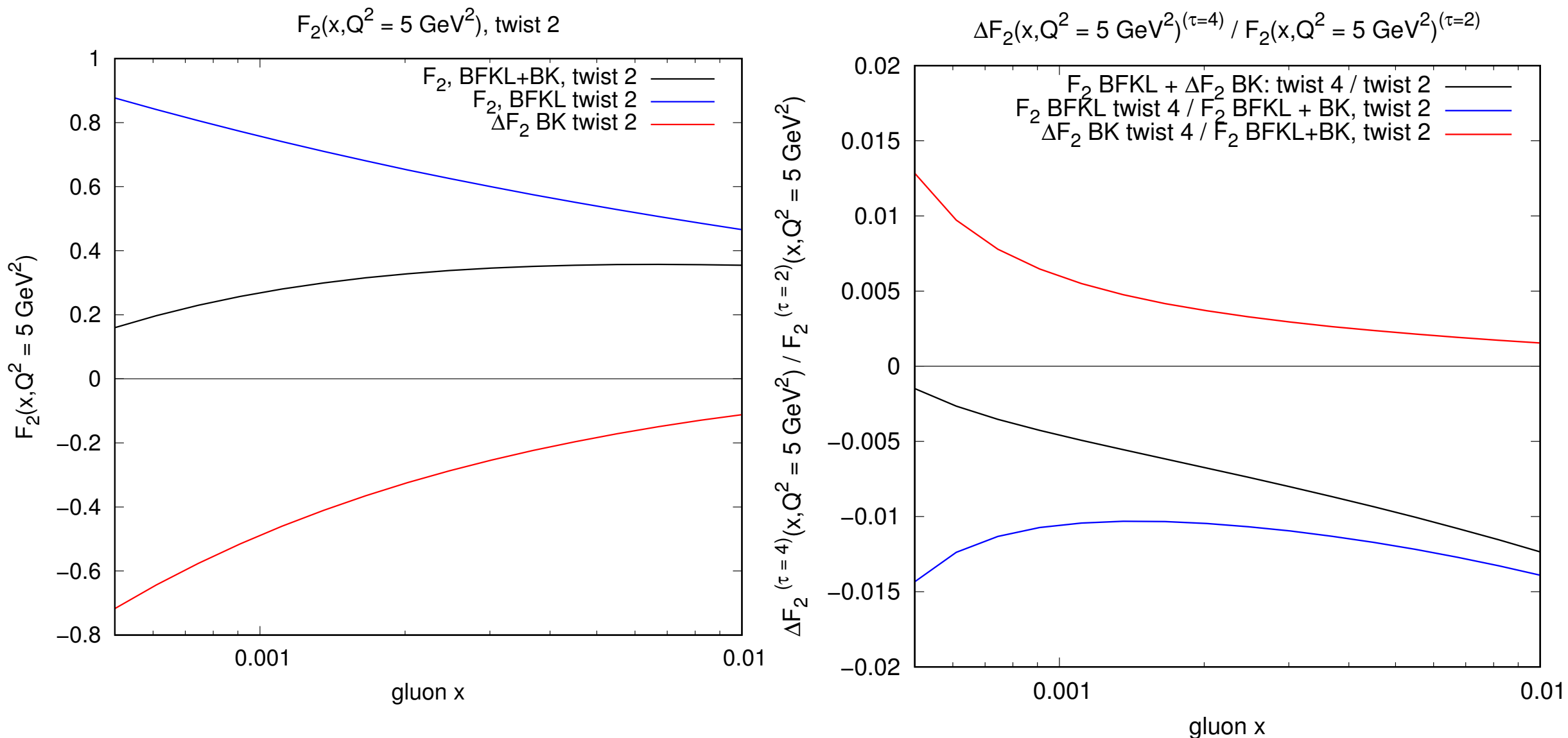
- Strong effect of gluon saturation corrections at twist 2

- Nonlinear evolution introduces small higher twist correction in F_2 and moderate corrections in F_L

M. Lublinsky - Reggeon Field Theory in zero transverse

- Toy model study in order to understand unitarity constraints and the transition from dilute to dense for the incoming hadrons

- Construction of a unitarized toy model with multiple emissions to approach the dense-dense regime in RFT

S. Bondarenko - Balitsky hierarchy from Lipatov effective action

- Expansion of Wilson lines around a classical background and calculation of the propagator of fluctuations in the background

- This formalism in principle can be extended to derive further corrections to low-x evolution (NNLL BFKL?)

CGC beyond eikonal accuracy

A. Tymowska - DIS dijet production at NEik order

- Calculation of the full NEik corrections from the gluon background field

- NEik correction beyond infinite time dilation of the target considered for the first time, allowing light-cone momentum exchange with the target.

- NEik corrections stemming from transverse motion within the target is accounted for, beyond the shockwave approximation

M.G. Santiago - Boer-Mulders TMDs at small-x

- Low-x evolution equation for the Boer-Mulders TMD is derived

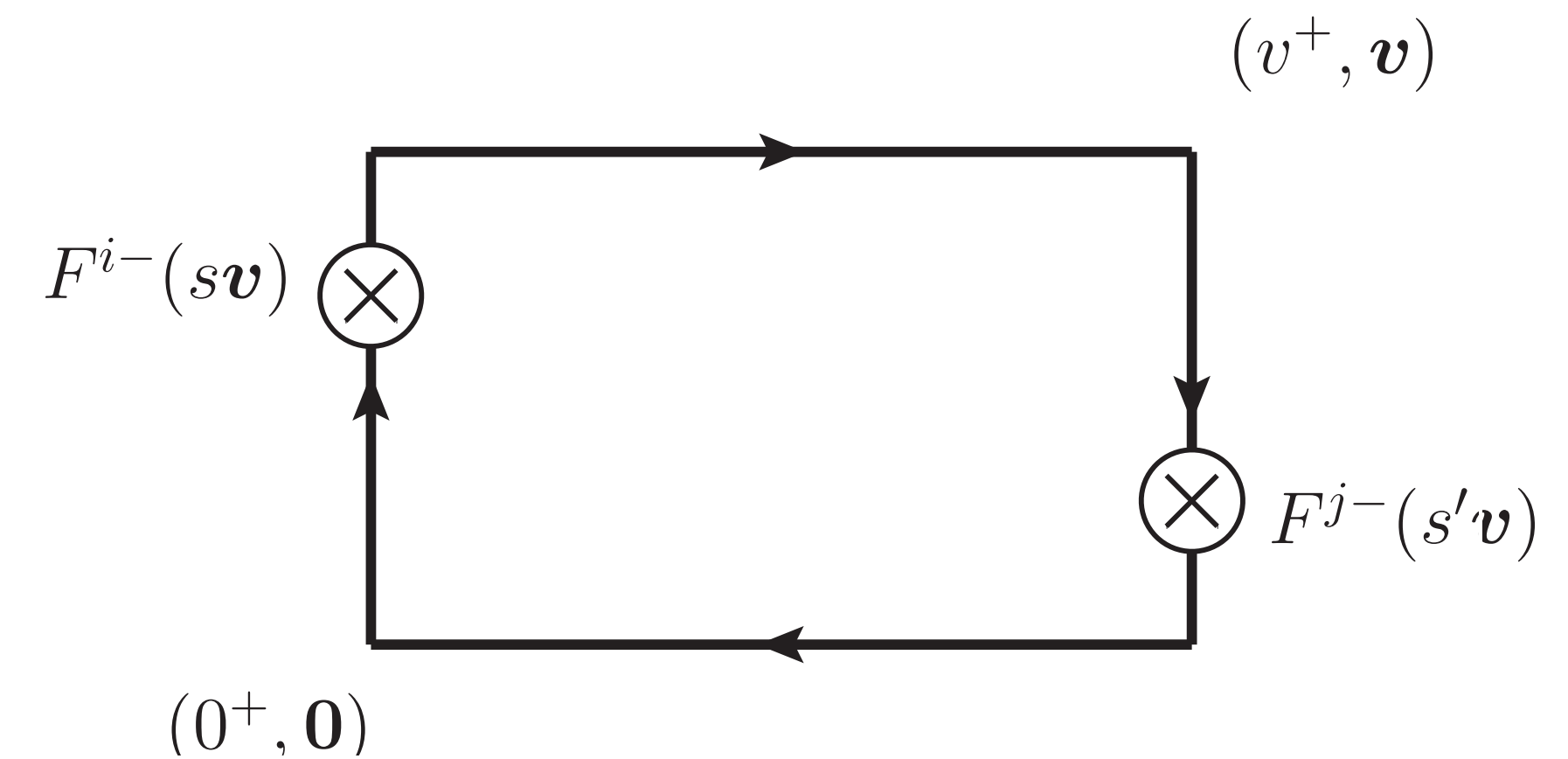- In the non-singlet case solution is shown to scale at low-x as

$$h_1^{\perp\,NS}(x, k_\perp) \propto \left(\frac{1}{x}\right)^{-1}$$

Naive sub-sub-eikonal scaling unchanged by α_s correction
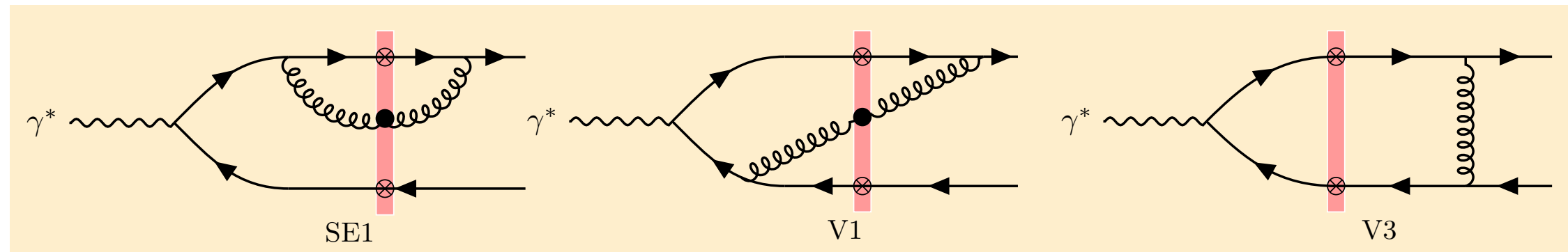
R. Boussarie - Twist expansion for DDVCS

An interpolating expression between the Regge-Gribov and Bjorken limits is derived for DDVCS amplitude.

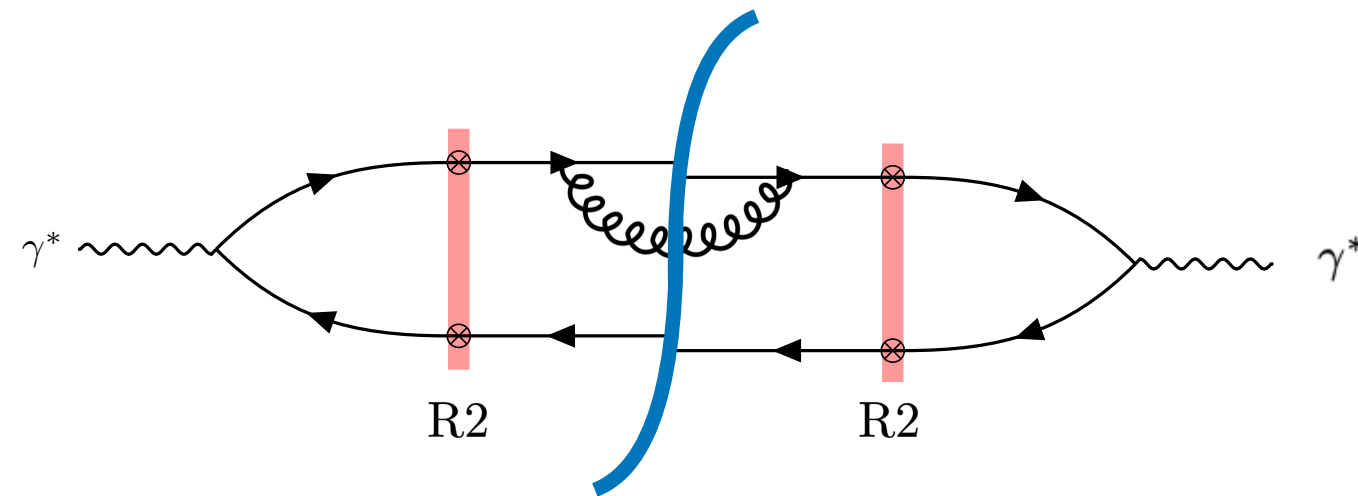It involves a GTMD defined from decorated Wilson loop with F^{i-} insertions.

$(v^+, \boldsymbol{v})$

$F^{i-}(s\boldsymbol{v})$ ⊗

⊗ $F^{j-}(s'\boldsymbol{v})$

$(0^+, \boldsymbol{0})$

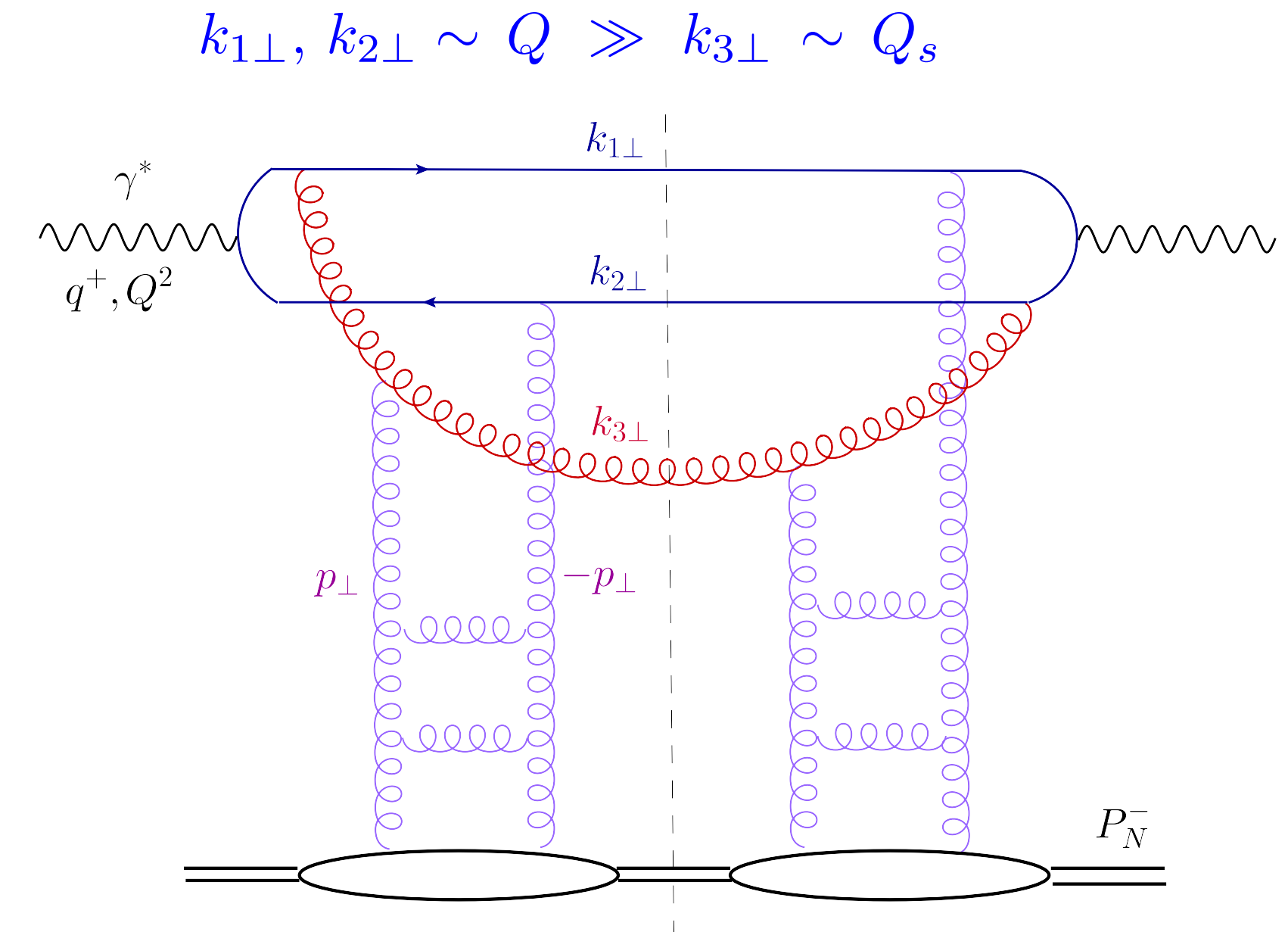**F. Salazar -** DIS dijet production at NLO

$Q^2 = 0$

- Cancellation of soft and UV divergences between diagrams

$Q^2 = 0$

- Collinear divergences treated with jet definition in small R limit

- Rapidity divergences treated with JIMWLK evolution of quadrupoles and dipoles.

- Sudakov double logs with the wrong sign are obtained in the back-to-back limit in the absence of kinematical improvement of JIMWLK

$$\int_{z_f}^{z_j} \frac{dz_g}{z_g} \mu^\varepsilon \int \frac{d^2}{(}$$

$$\mathcal{C}_{qg,\perp}^2 \leq \mathcal{C}_{qg,\perp}^2|_{\max} = R^2 \boldsymbol{p}_j^2 \min\left(\frac{z_g^2}{z_j^2}, \frac{(z_j - z_g)^2}{z_j^2}\right)$$

E. Iancu - Diffractive production of 2+1 jets in DIS

$$k_{1\perp},\ k_{2\perp} \sim Q \gg k_{3\perp} \sim Q_s$$

- TMD-like factorization obtained in this regime involving Pomeron UGD

- Strong sensitivity to gluon saturation

J. Jalilian-Marian - DIS dihadron production at NLO

- Similar calculation as dijet production with the same diagrams. / - Collinear divergences are absorbed into fragmentation functions instead of jets.

$$\frac{d\sigma_{R2\times R2 \text{ dijet in cone}}^\lambda}{d^2\boldsymbol{k}_{1\perp}d\eta_1 d^2\boldsymbol{k}_{2\perp}d\eta_2} \frac{\alpha_s C_F}{\pi} \frac{d\sigma_{LO,\varepsilon}^\lambda}{d^2\boldsymbol{k}_{1\perp}d\eta_1 d^2\boldsymbol{k}_{2\perp}d\eta_2} \left\{\left(\frac{3}{4} - \ln\left(\frac{z_{J1}}{z_f}\right)\right) \frac{2}{\varepsilon}\right.$$
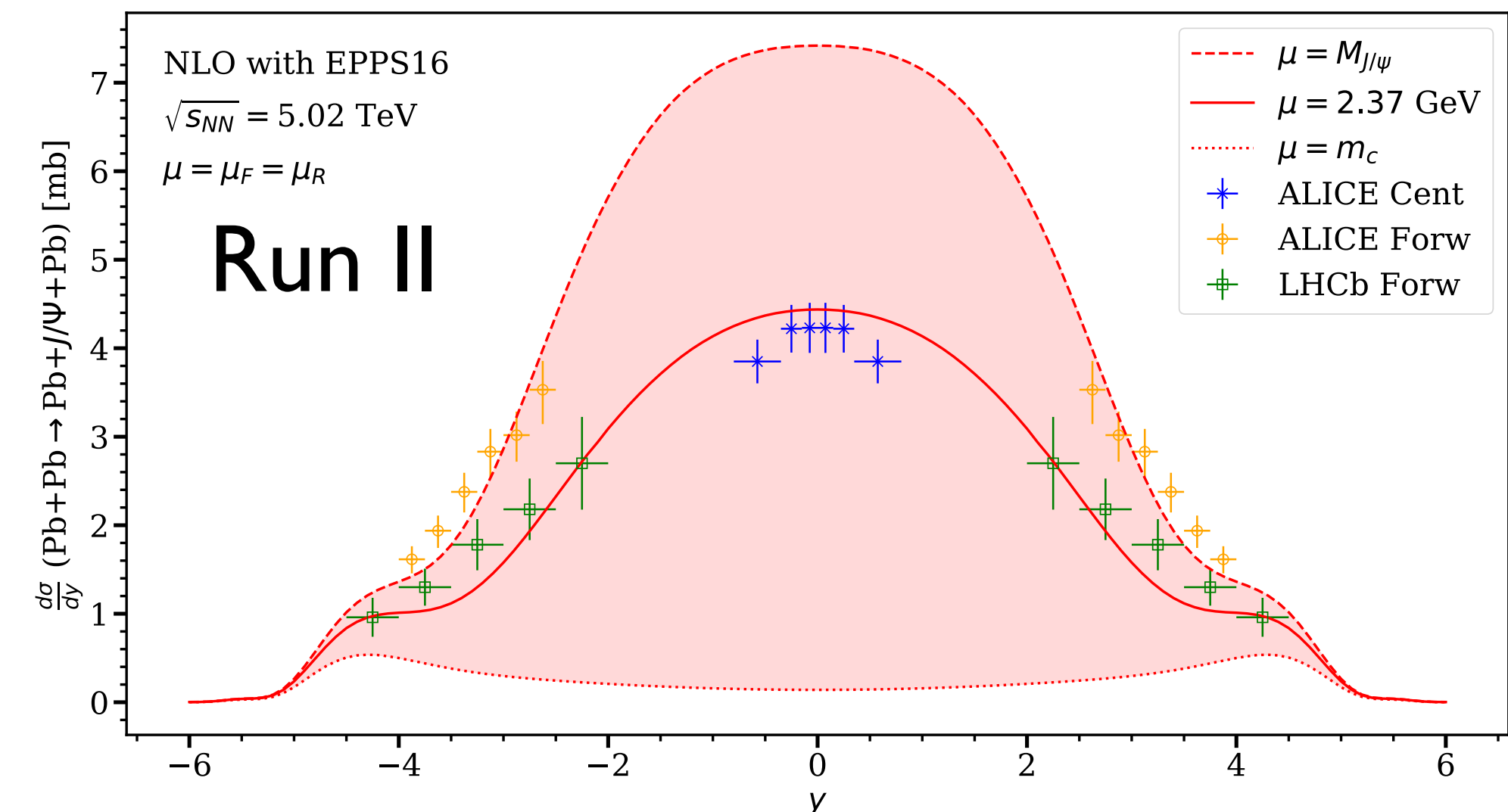
Exclusive vector meson production (1)

J. Penttala

- Full NLO calculation with massive quarks of the exclusive heavy vector meson production in the CGC

- Vector meson Light Front wave function obtained from nonrelativistic expansion in NRQCD

- First relativistic correction is also included in the computation
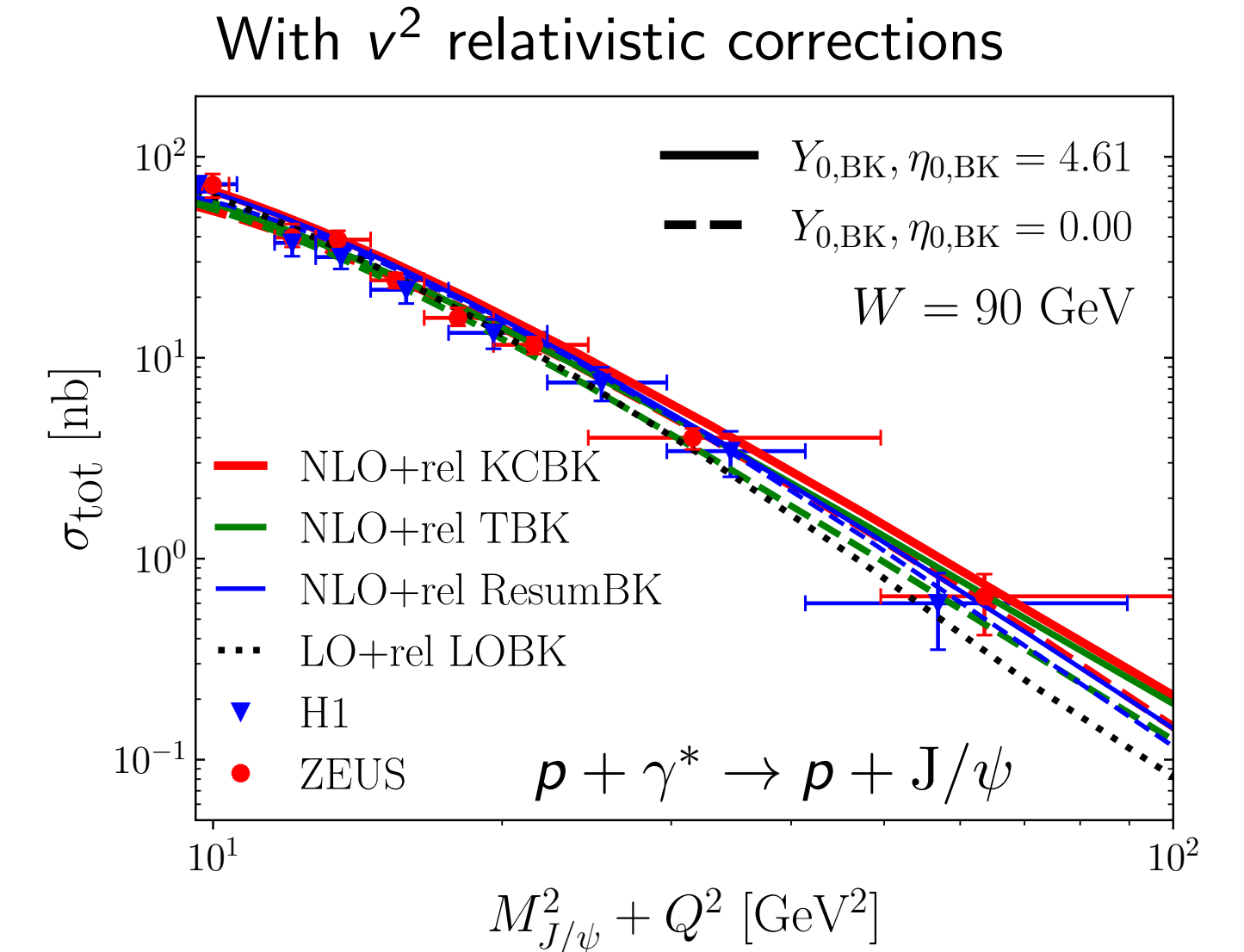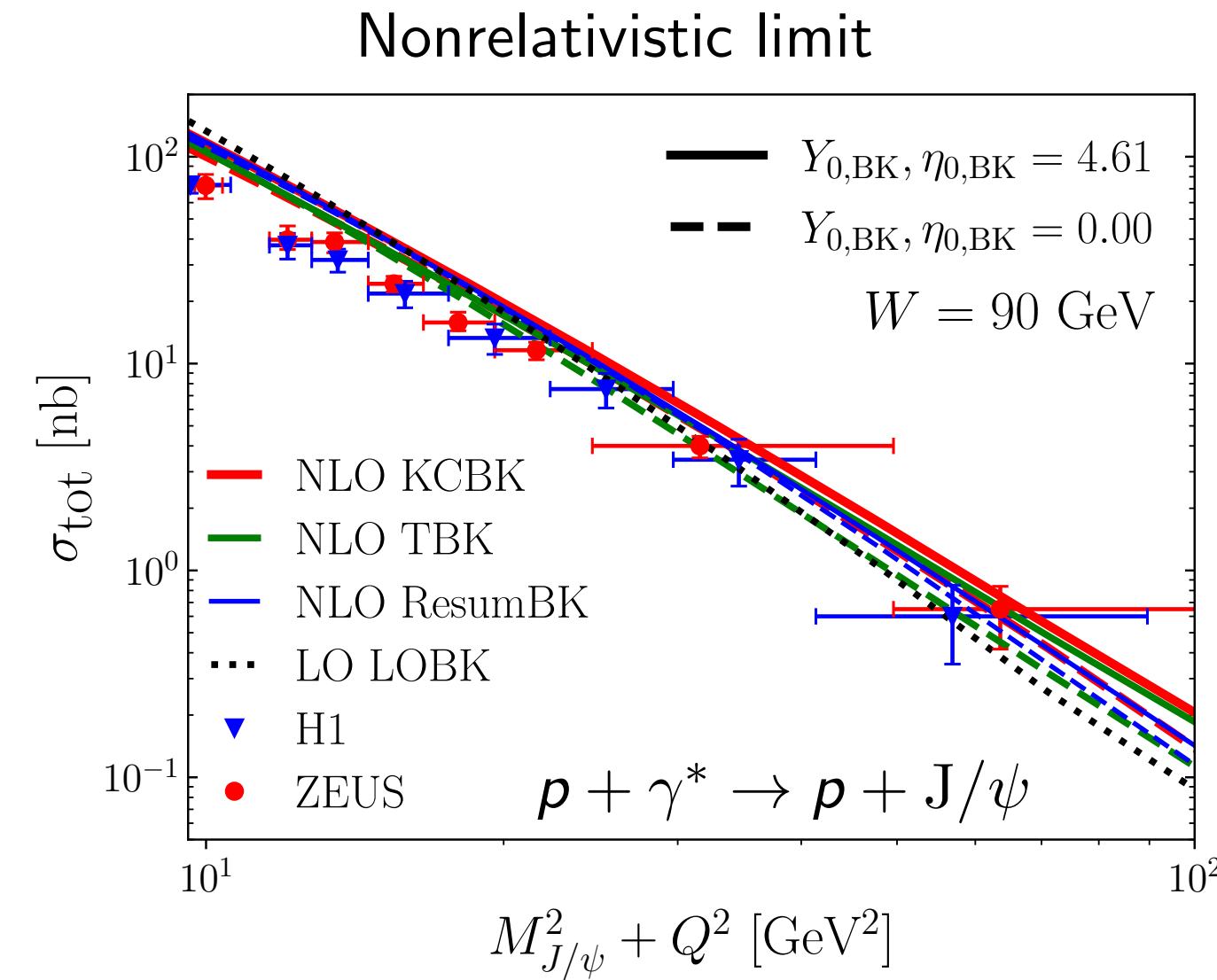
C. Flett

- Implementation of NLO collinear factorization + NRQCD to exclusive photoproduction of J/Ψ in Pb-Pb UPCs

- Large scale dependence encountered

- At mid-rapidity, quarks dominate at NLO due cancelation of gluon contributions

- Some ideas have been proposed to resolve these issues

Exclusive vector meson production (2)

F. Celiberto

- Exclusive forward ρ-meson production is computed in BFKL formalism and results for HERA and EIC are presented
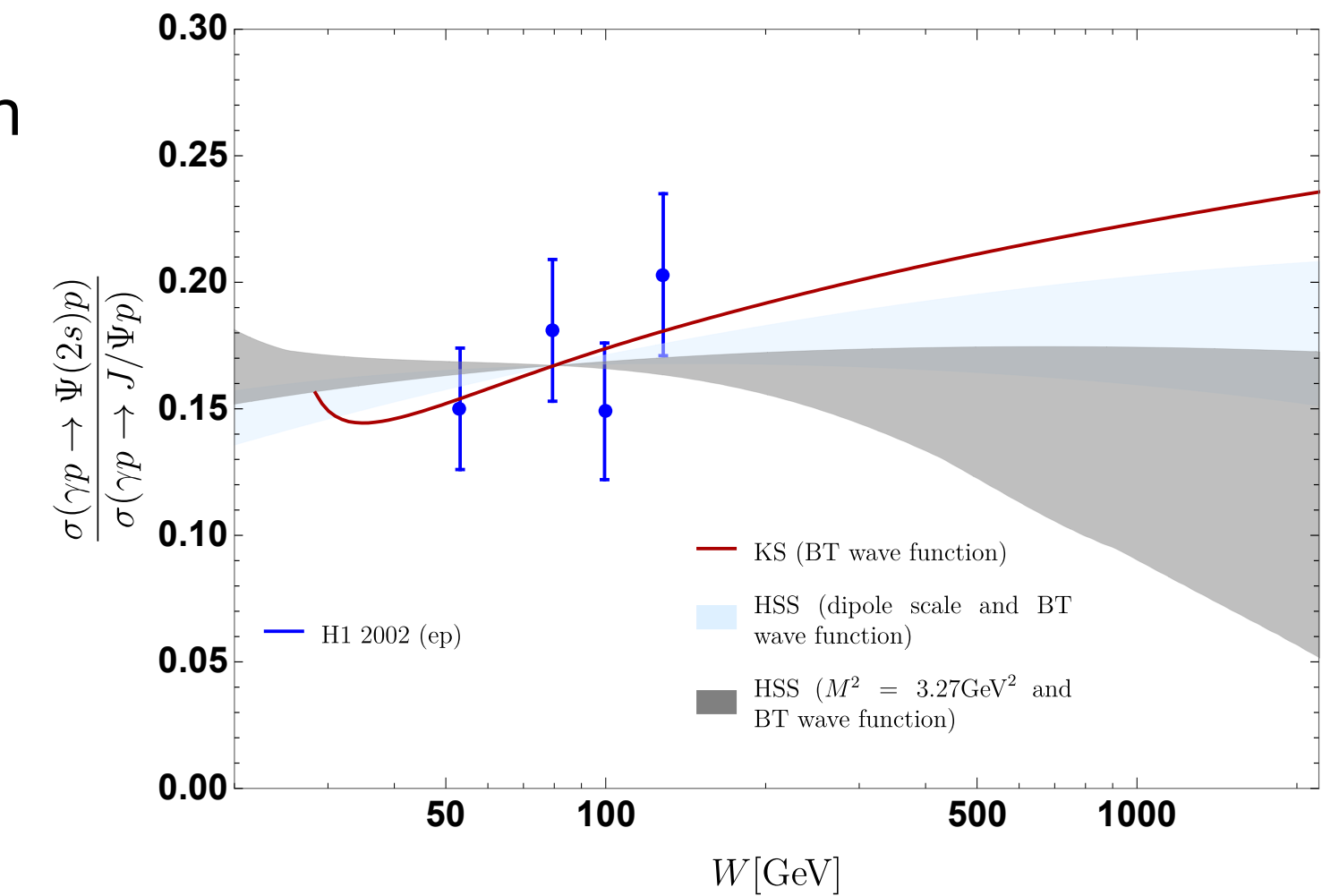
- Further constraints on UGD is possible with this process $\sigma_L/\sigma_T(Q^2)$
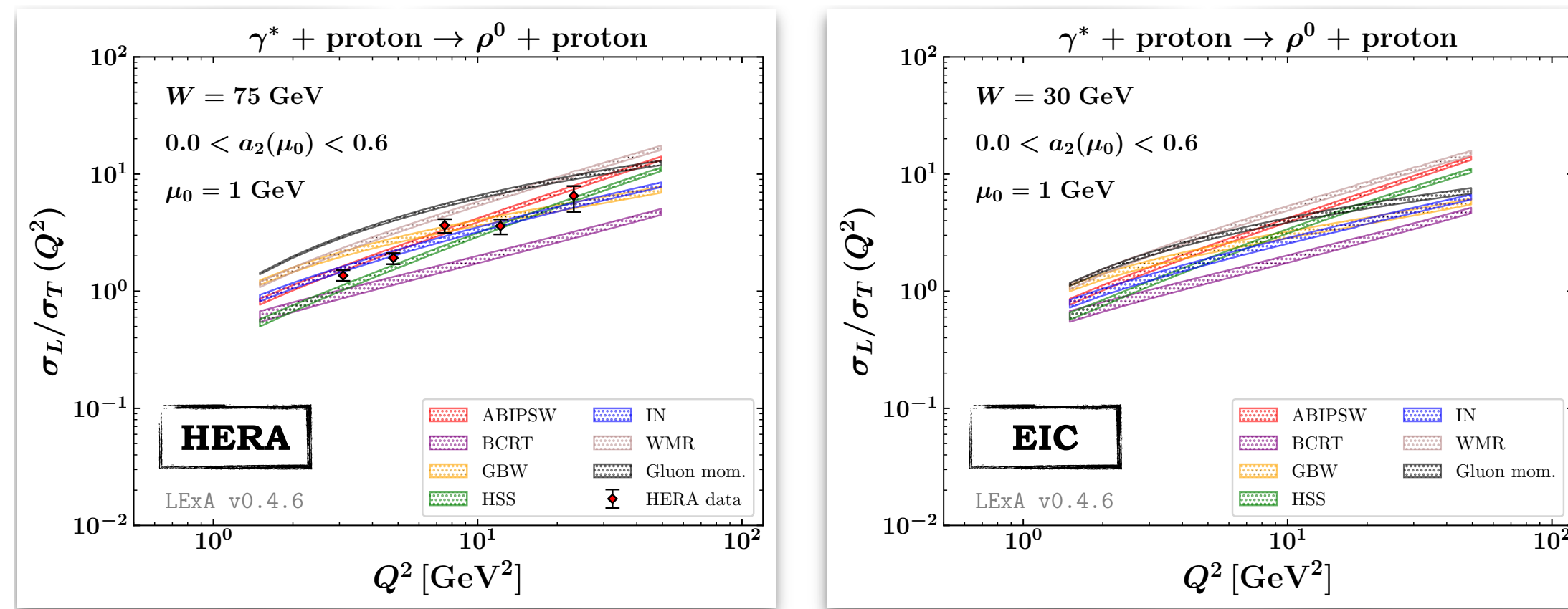
M. Hentschinski

- Energy dependence of the ratio of $\psi(2s)$ over J/Ψ exclusive cross $\Psi(2s)$ sections found to depend noticeably on gluon saturation.
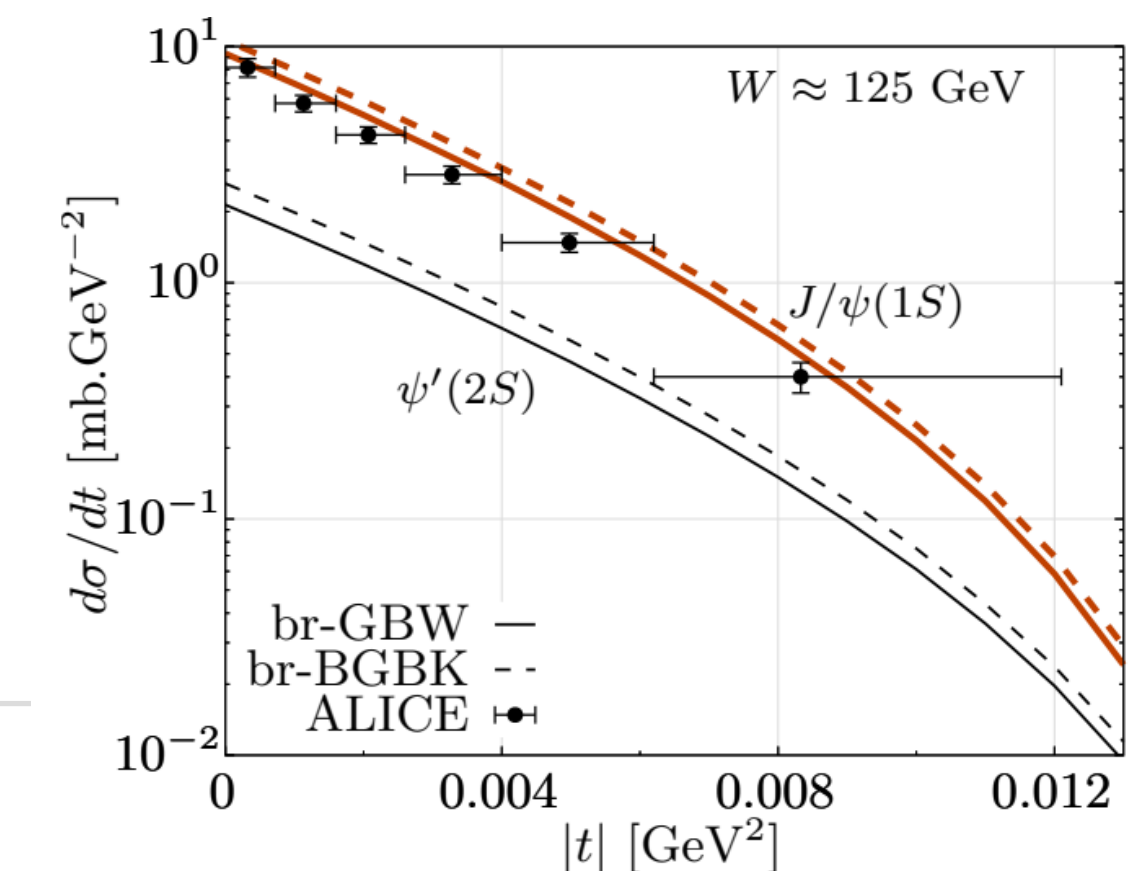
- Flat for linear BFKL evolution

- Rising with W for nonlinear BK evolution

M. Krelina

- Photoproduction of heavy quarkomium on nuclei

- t-dependent calculation in the dipole formalism including various corrections in particular gluon shadowing and shorter lived higher Fock components in the photon

Proton shape fluctuations

Fluctuating proton necessary in order to describe both coherent and incoherent exclusive VM production at HERA: *hot-spot model*
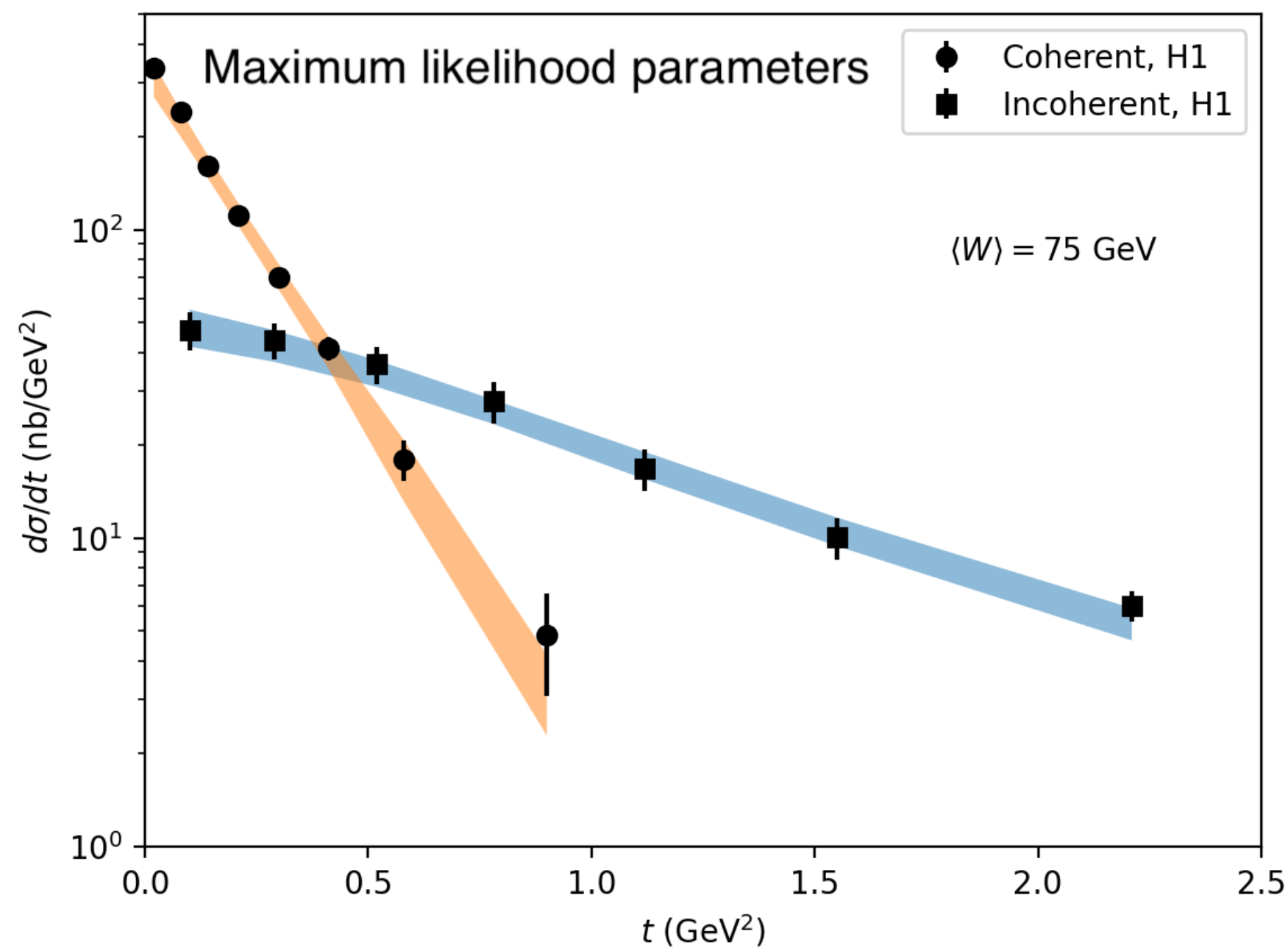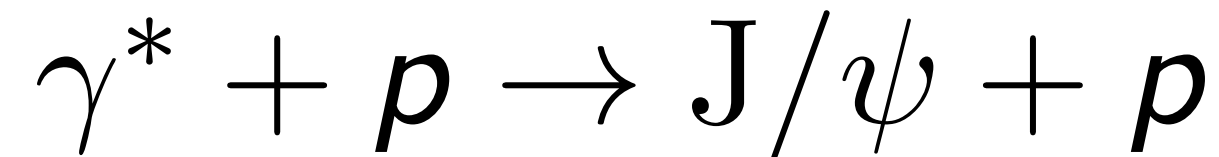
$$\sigma_{\text{coherent}} \sim |\langle \mathcal{A} \rangle_\Omega|^2 \qquad \text{and} \qquad \sigma_{\text{incoherent}} \sim \langle |\mathcal{A}|^2 \rangle_\Omega - |\langle \mathcal{A} \rangle_\Omega|^2$$
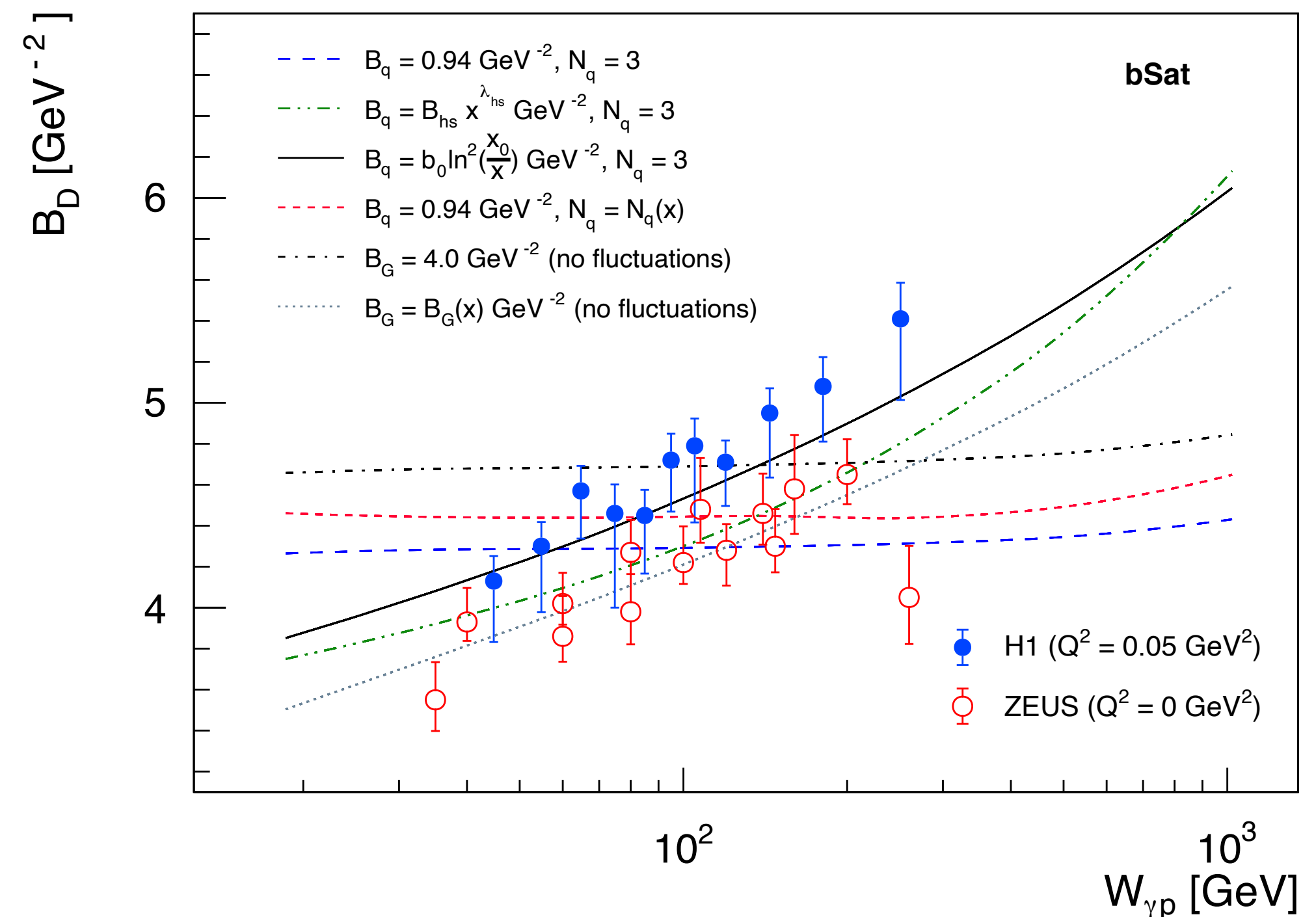
H. Mantysaari - First Bayesian analysis to extract hot-spot model parameters from diffractive J/Psi data.

- Allows to control uncertainty propagation.

**T. Toll -** Test of energy dependence of parameters of the hot-spot model vs HERA data

- Preference for hot-spot number or proton size growing with energy.

A. Kumar

 - DIS processes with leading neutron can give accesses to DIS on pion.

 - By comparison to HERA data at low-x, the same dipole cross section is then obtained for pions and proton up to the normalization: universality of hadron structure at small-x.

 - t-dependence of exclusive vector meson production with leading neutron can probe both the spatial distribution of gluons in pion at large-t and the pion cloud of the proton at small t.
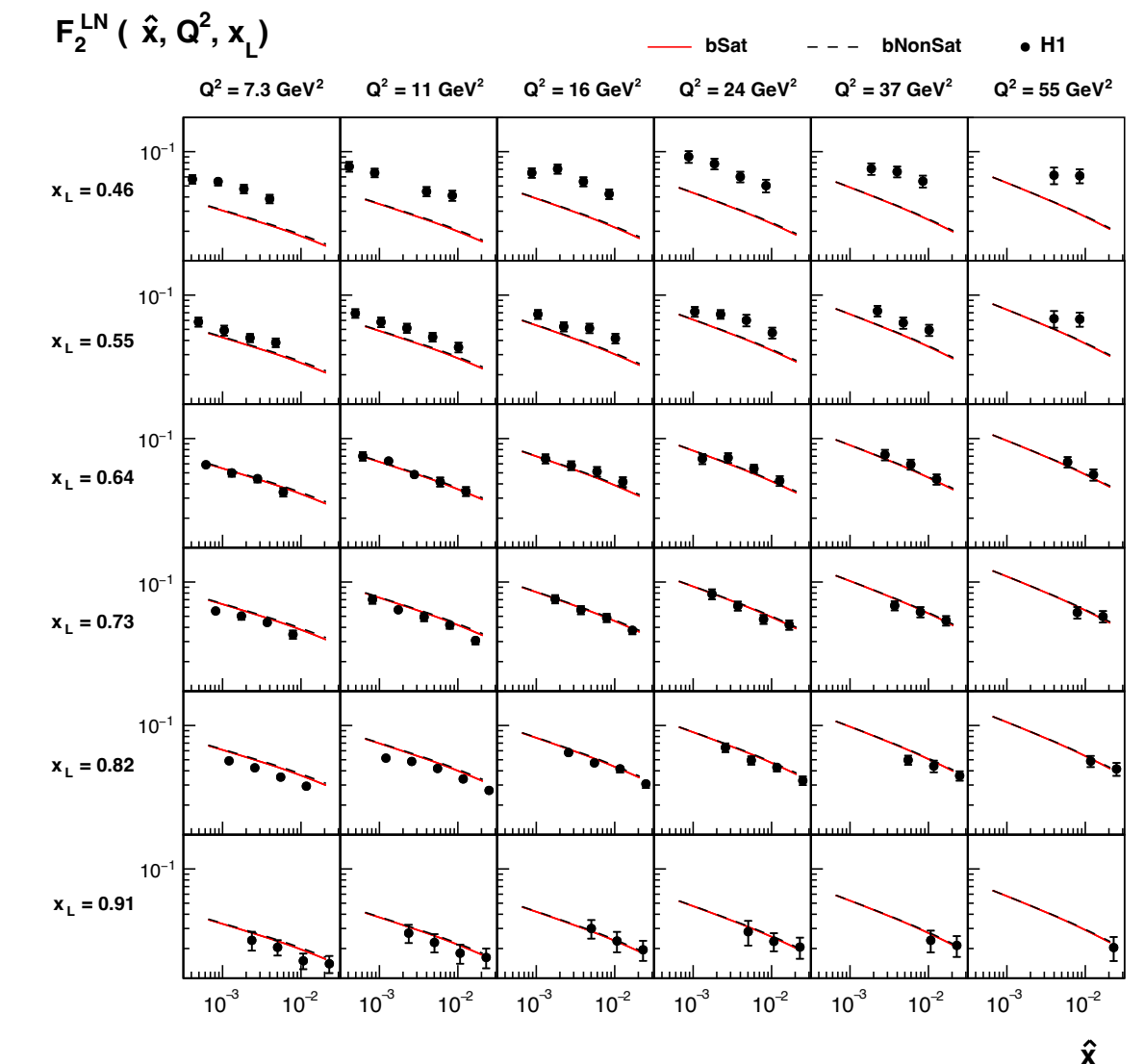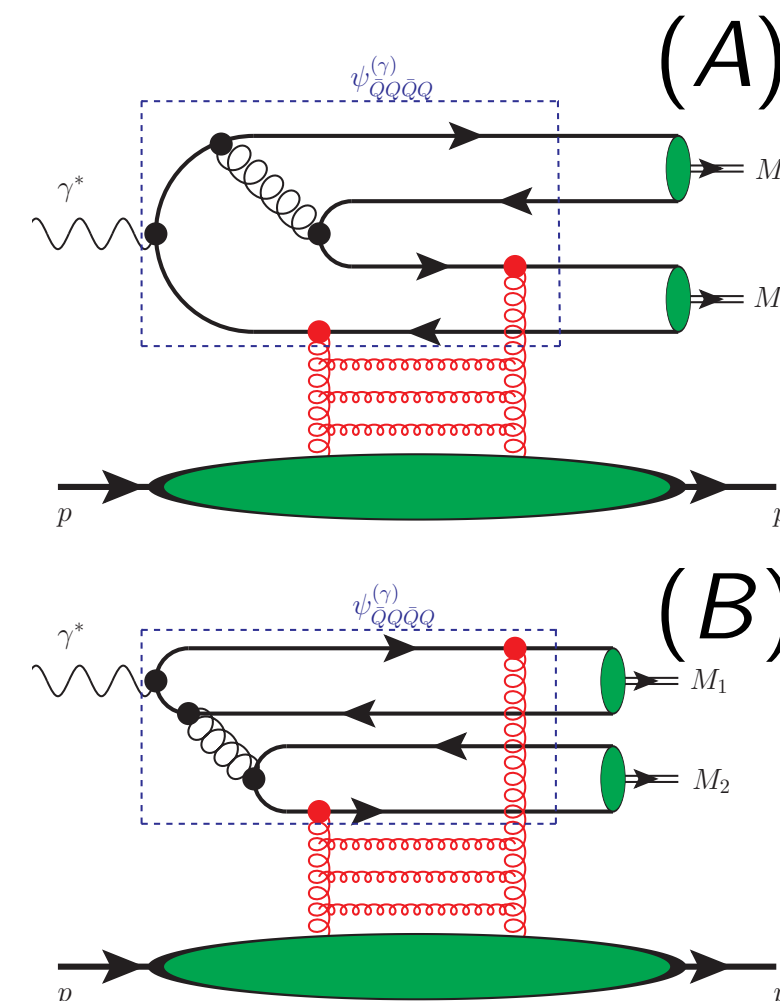

S. Nabeebaccus
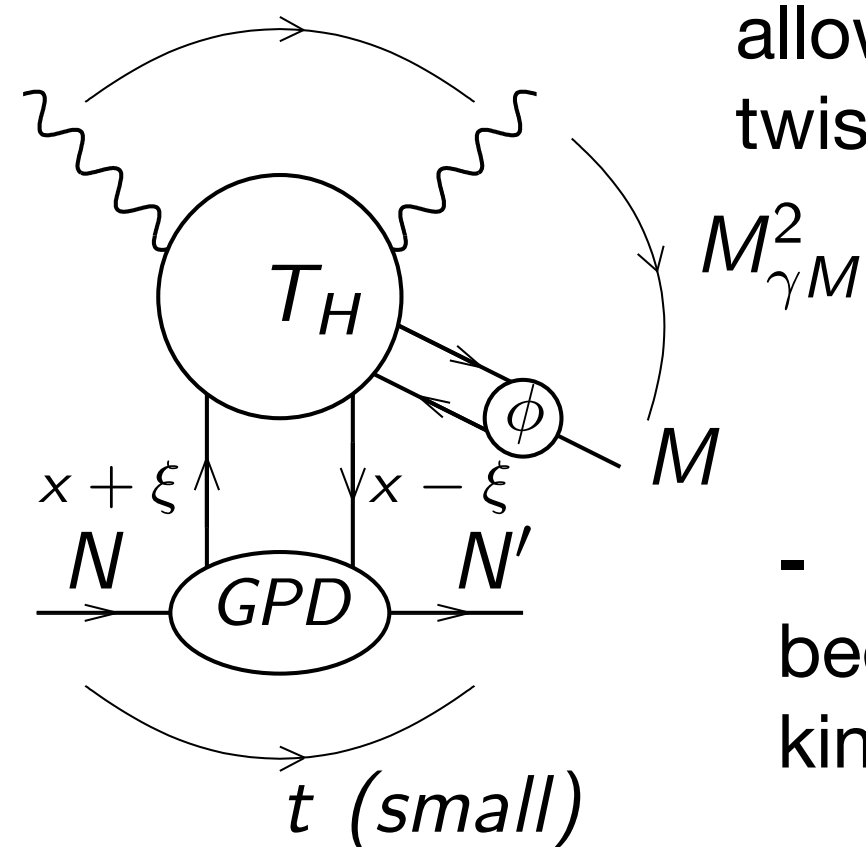
- $2 \to 3$ exclusive process with ρ_T production allows to access so far unknown chiral-odd twist 2 GPDs

 - Models for this transversity GPDs have been used to make predictions at JLab kinematics
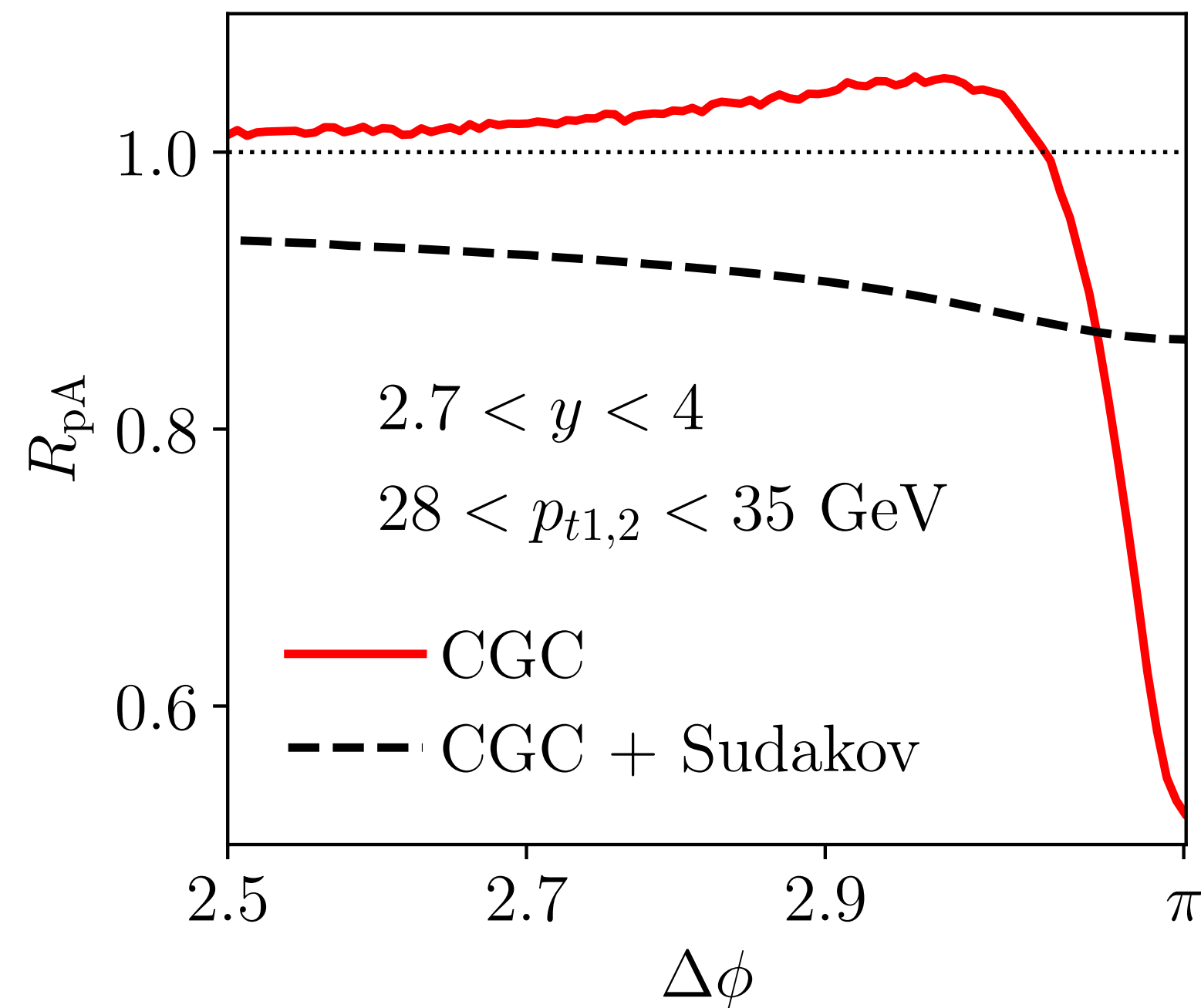
M. Siddikov

-Production of quarkonia pairs with opposite C-parity is dominated by photon-Pomeron fusion: Cross-section is not so small.

-This proces is calculated in the dipole model and the predictions for EIC, UPCs at LHC, LHeC and FCC have been presented.

Saturation

Gluon saturation

However, leads t

Cyrille Marquet

$2.7 < y < 4$

$28 < p_{t1,2} < 35 \text{ GeV}$

—— CGC

- - - CGC + Sudakov

mostly sensitive
to CGC+S$_{\text{non-pert}}$

trigger photon

associated hadron

mostly sensitive
to S$_{\text{Sud}}$
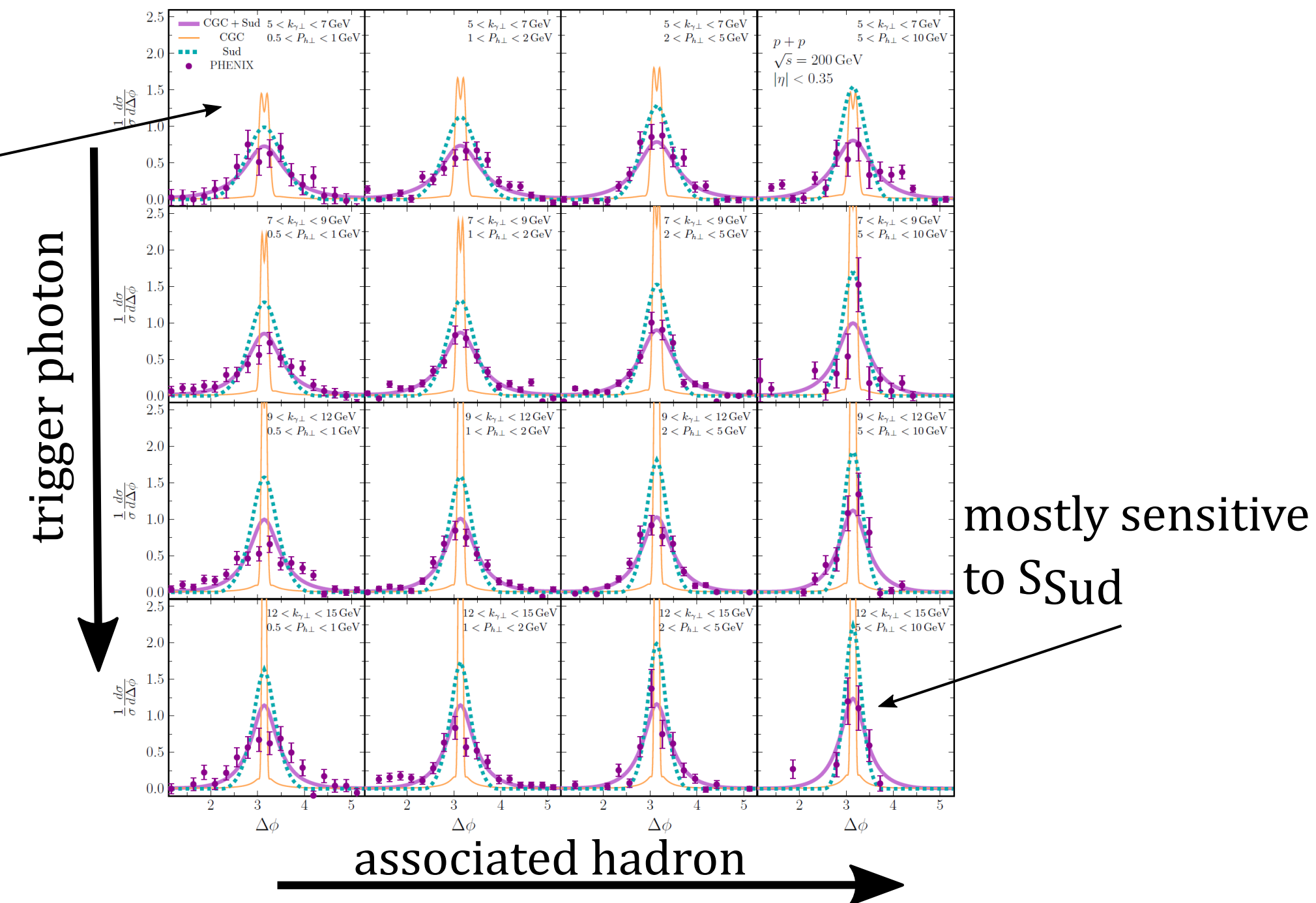
- At large pt: Sudakov resummation erase the sensitivity to saturation.
- At small pt: Sudakov resummation is non-perturtbative and leads to large uncertainties.

Jet production in low-x hadronic collisions

H. Liu - Forward single jet production at NLO in $\rho_{R,p_{J\perp}} \equiv \dfrac{d\sigma_{\text{full}}/dp_{J,\perp}}{d\sigma_{\text{small }R}/dp_{J,\perp}}$

- Jet production beyond the small R limit is implemented for the first time in the CGC.

- Full fledged anti-kt jet algorithm is used.

- Numerical study shows that small R jet definition is a good approximation for an extended domain in pt and in R.

- In the small R approximation the same semi-inclusive quark jet function is obtained as in collinear factorization.

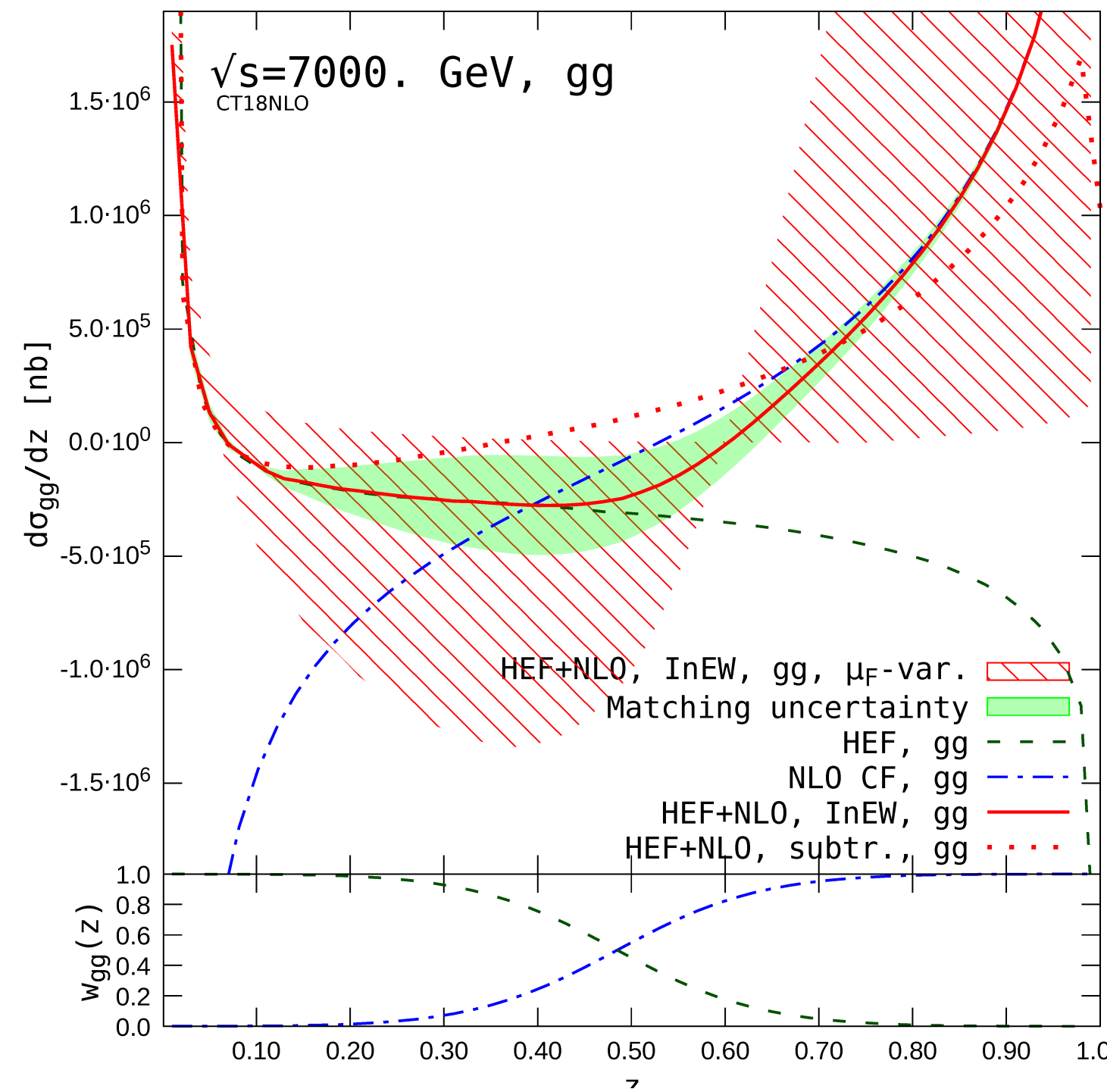 *Special thanks to Meijian Li for making this talk possible after all.*
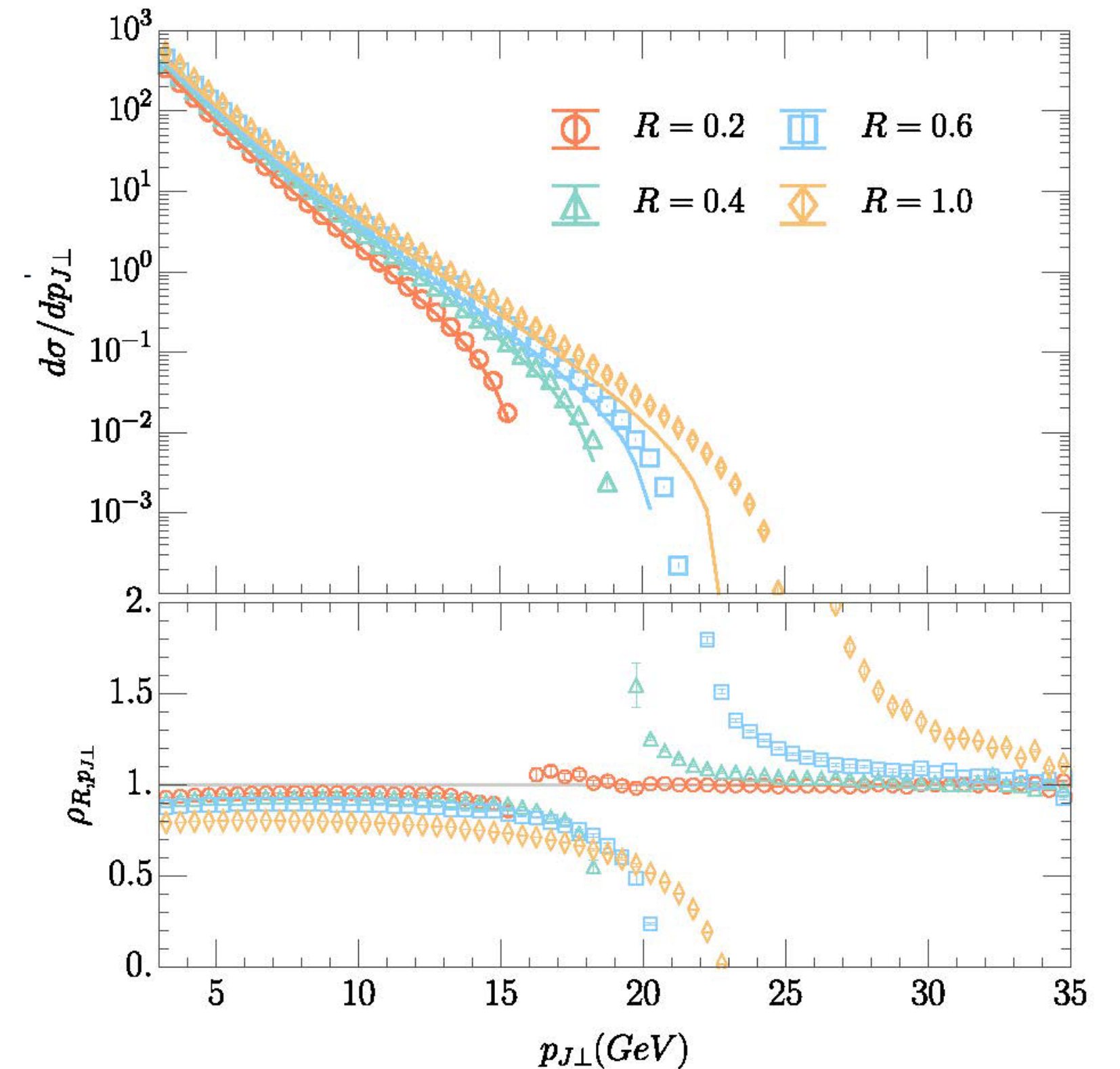
A. van Hameren - Hybrid k_T factorization at NLO

- Off-shell leg in an amplitude can be defined via auxiliary on-shell parton.

- NLO corrections to partonic cross sections with one off-shell leg are studied.

- Cancellation of the infrared poles requires small momentum fraction x carried by the off-shell leg.

- HEF emerge from kt-dependent factorization in the auxiliary parton method at NLO.


Inclusive heavy quarkonium production

M. Nefedov - η_c and η_b inclusive hadroproduction, …

M. Fucilla - Inclusive J/Ψ and Υ production in hybrid HEF/Collinear factorization

- Quarkonium production from single parton fragmentation as well as collinear PDF included in the impact factors

- Azimuthal angle correlation between quarkonium and jet is studied.

- NLO cross section in collinear factorization is unstable due to high energy logs

- HEF partonic cross section valid only in part of the integration range

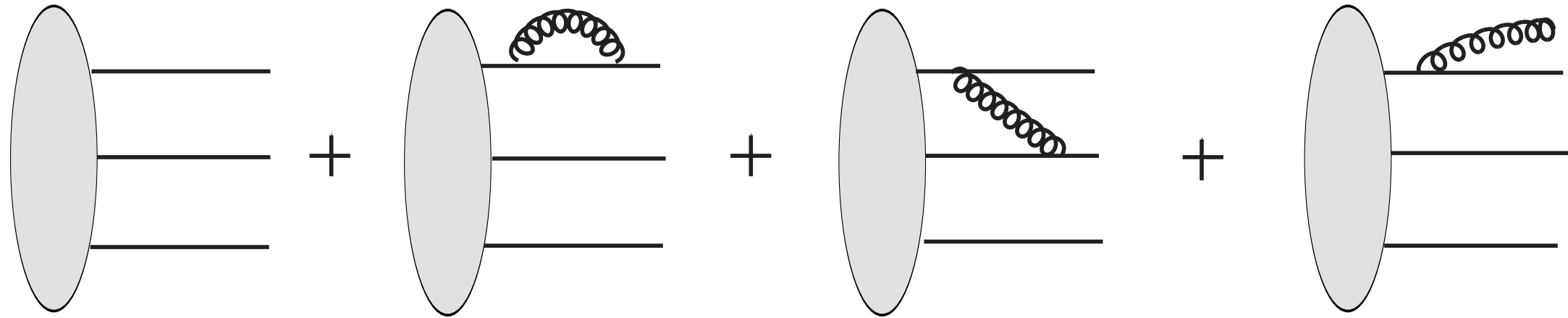- Matching between HEF and NLO CF is always required.
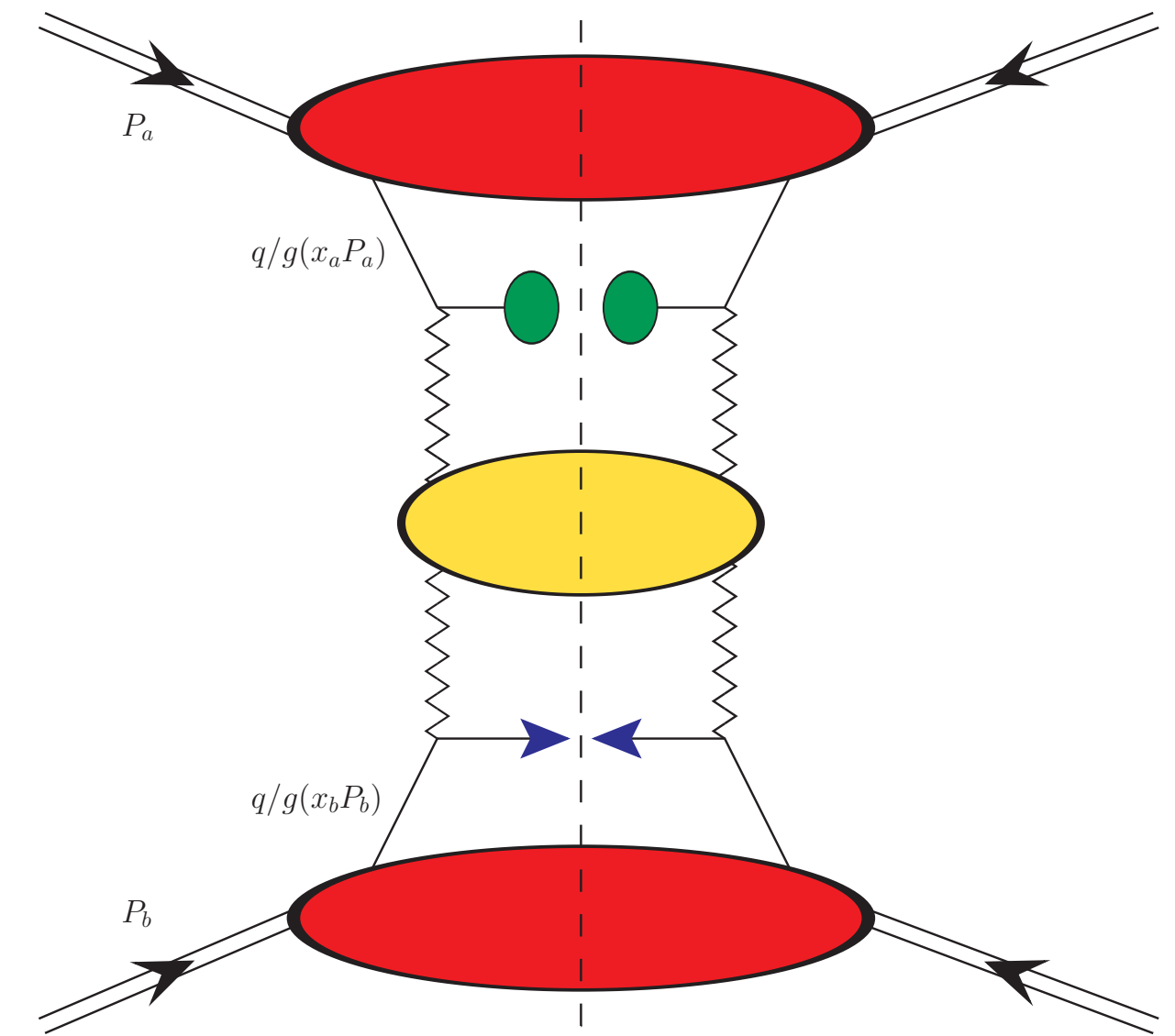
- Due to the weak dependence on renormalization/factorization scale, it is a promising channel to study BFKL physics.

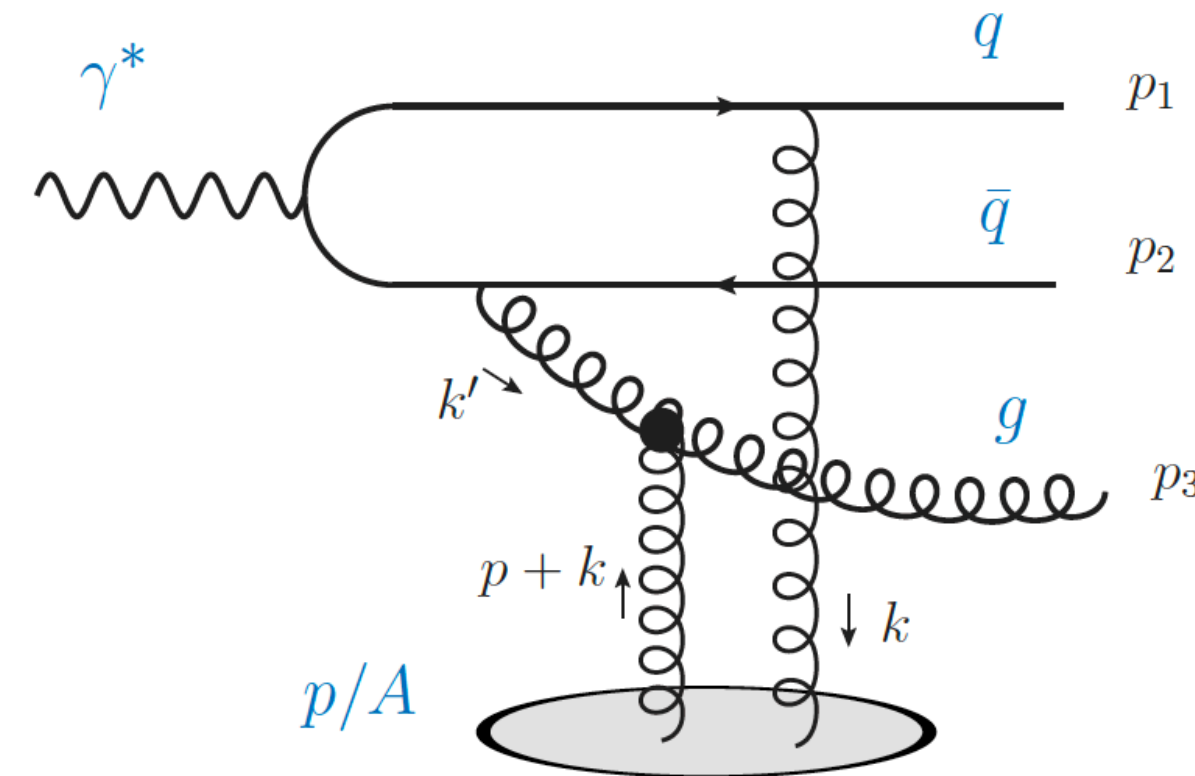# Correlations and entanglement in hadron wave function

A. Dumitru - C-odd color charge correlators:

- Model for proton state including perturbative |qqqg> component in addition to the |qqq> component:

– C-odd three color charge correlator is computed in this model.
– Should contribute to Odderon exchange and T-odd gluon TMDs.

M. Li - Bose correlations in DIS trijet production

Measure the correlation $C(\mathbf{p}_3, \boldsymbol{\Delta})$

$$\mathbf{k'} + \mathbf{k} + \mathbf{p}_1 + \mathbf{p}_2 = 0$$
$$\mathbf{p} \equiv \mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 \qquad \boldsymbol{\Delta} \equiv \mathbf{p}_1 + \mathbf{p}_2$$
$$|\mathbf{k'}| \ll |\mathbf{p}_3|$$

Demonstration that diffractive quark-antiquark singlet dijet + gluon jet in DIS has near-side ridge correlation that originates from the Bose correlations in the nuclear wave function.

K. Kutak - Conjecture of maximal entanglement at low-x:

"Hadronic entropy from charged particle multiplicity distribution is related log of the number of partons in the proton"

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

Indeed, observed at HERA for quark+gluon distributions with low-x resummation.