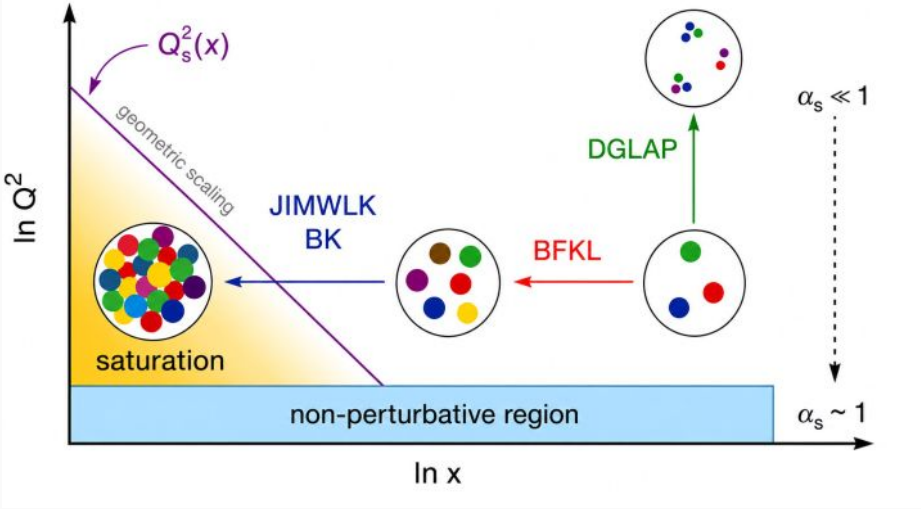
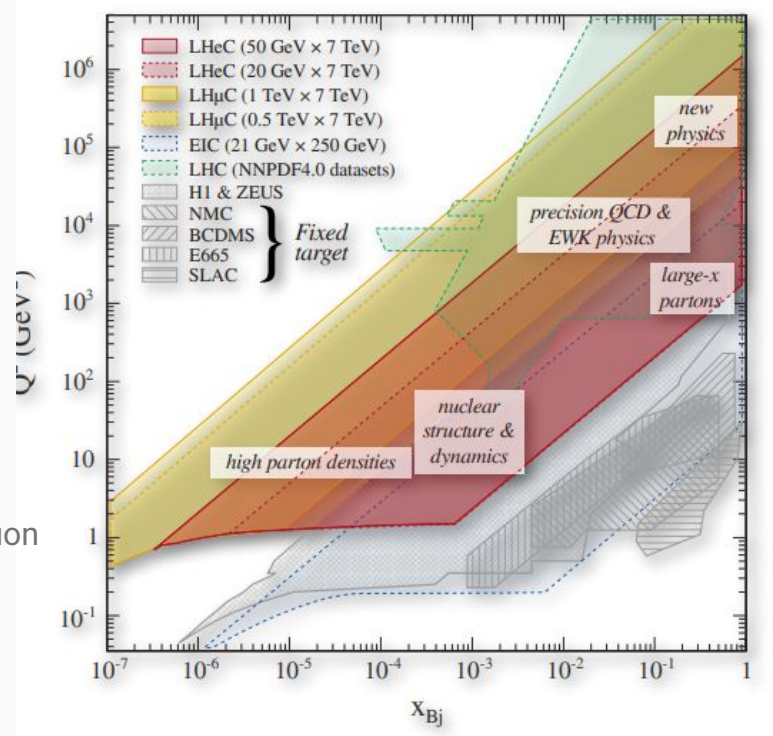
WG2: Small *x*, Diffraction, and Vector Mesons

Jani Penttala, Michael Pitt, and Cristovão Vilela

Small-*x* physics and gluon saturation



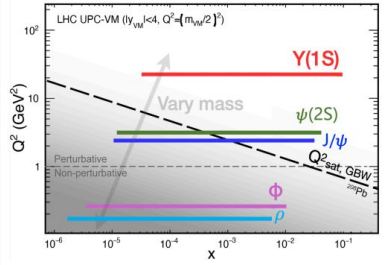


- Small-x physics addresses the high-energy limit of QCD, where gluon densities become large and nonlinear dynamics emerge.
- This working group focused on how this growth is controlled: from BFKL/JIMWLK/BK evolution and CGC phenomenology, to diffraction, vector meson production, UPCs, and future EIC/LHeC/FCC-eh opportunities.

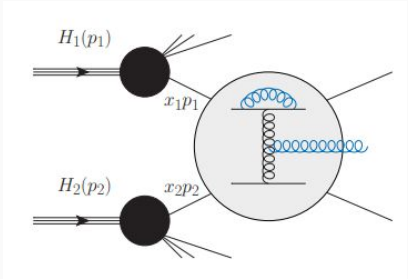
Overview of the working group

- 47 talks: 10 experimental, 37 theoretical
- Many topics discussed

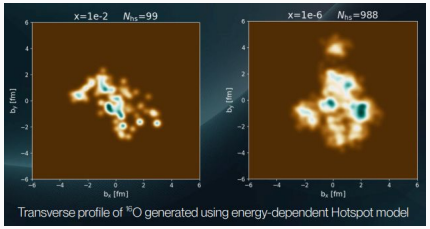
Vector meson production



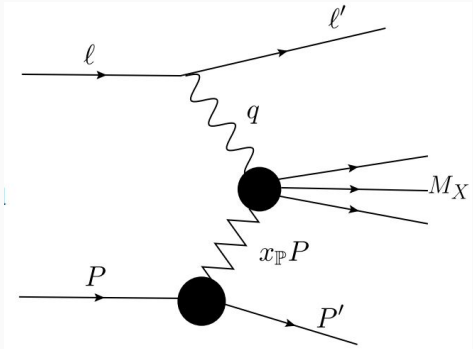
NLO phenomenology



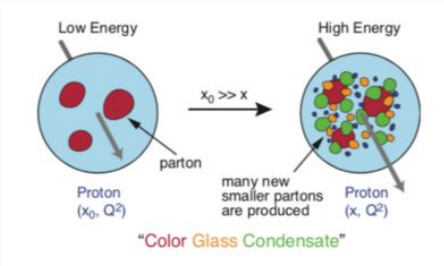
Ion structure



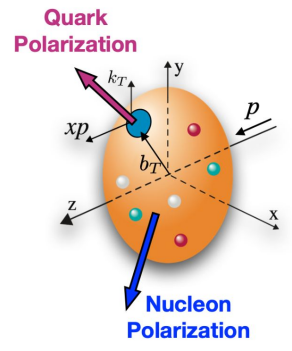
Diffraction



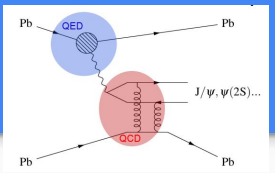
CGC



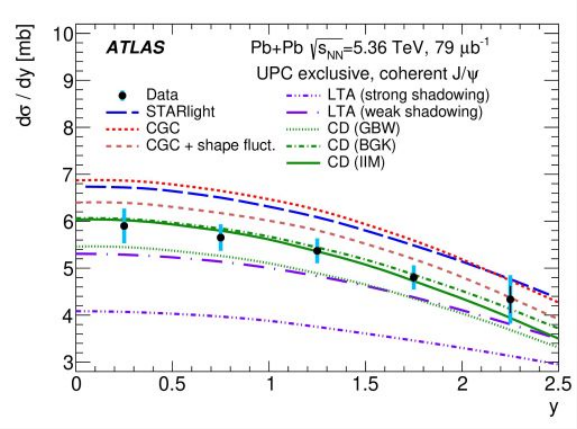
TMD



Vector meson production in γPb collisions

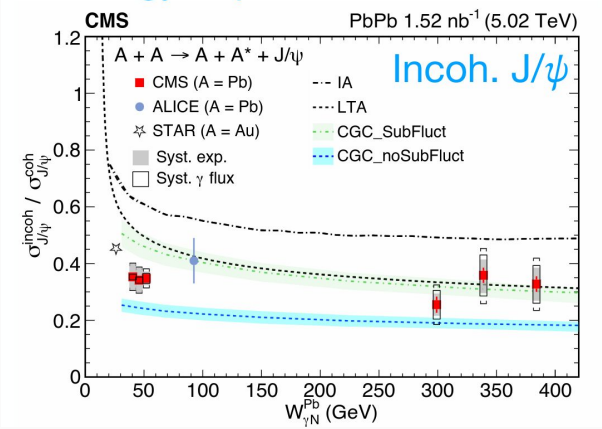


Agnieszka Ogrodnik



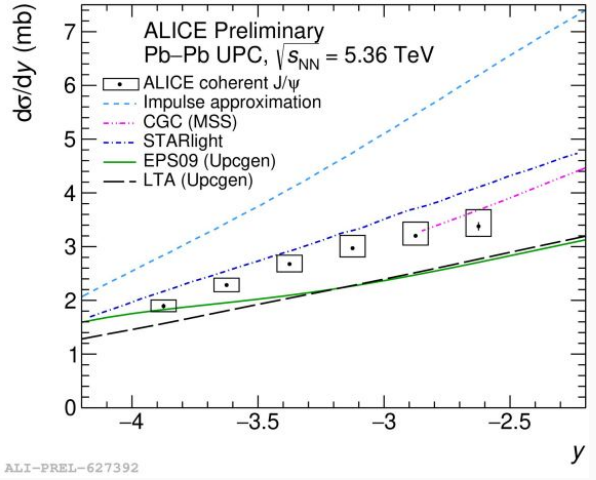
Wide rapidity range from ATLAS (tension with Run2 ALICE at y<0.5)

Shuai Yang



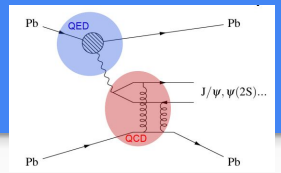
- First measurement of incoherent J/ψ
- Flat ratio of coherent/incoherent

Nazar Burmasov

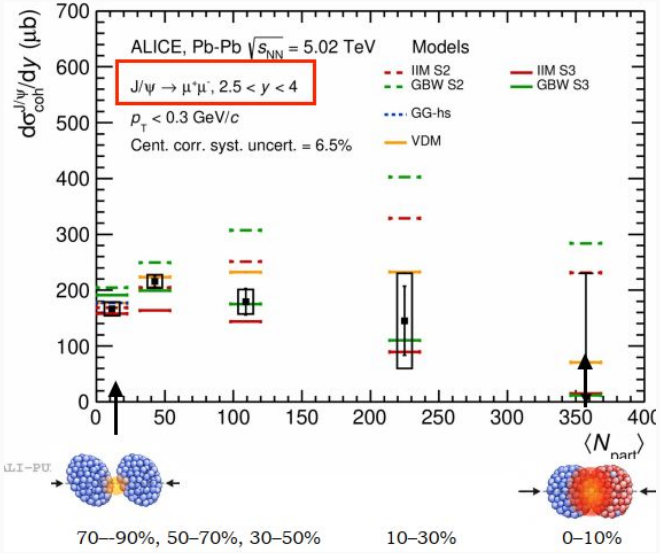


Strong nuclear effects observed in coherent J/ψ and ψ(2S)
Missing NLO corrections in J/ψ?

Vector meson production in γPb collisions

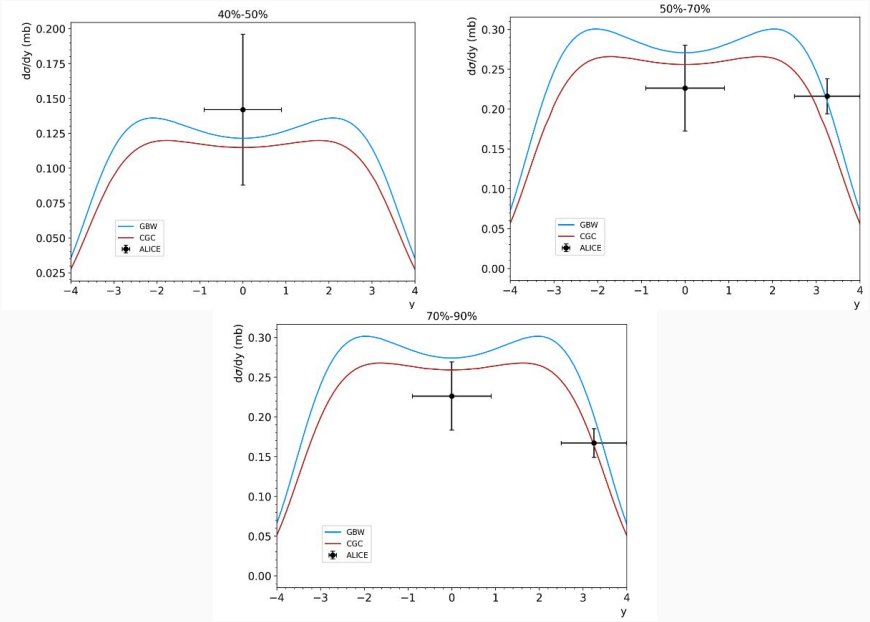


Dukhishyam Mallick



Coherent J/ψ in peripheral (70-90%), similar y-dependence and polarization to UPC

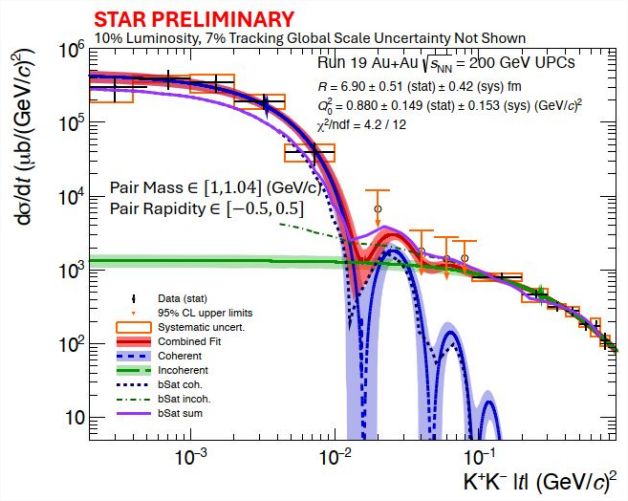
M. Beatriz Gay Ducati



dσ/dy predictions for J/ψ photoproduction at different centralities

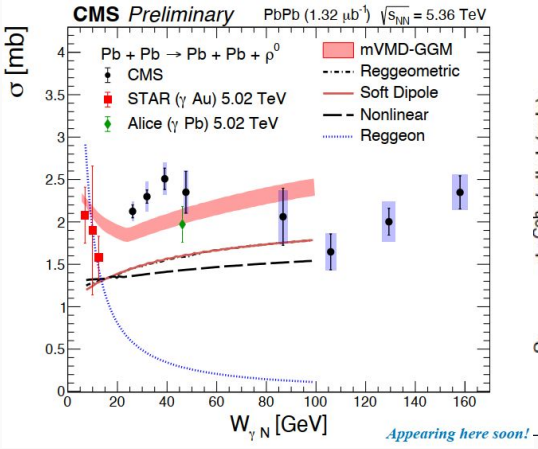
Vector meson production in γPb collisions

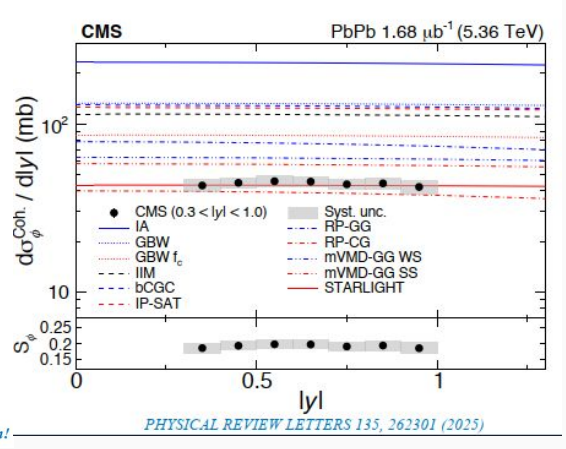
Xihe Han



First differential measurement of ϕ meson in UPC at STAR.

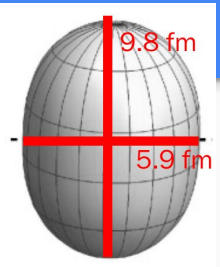
Pranjal Verma



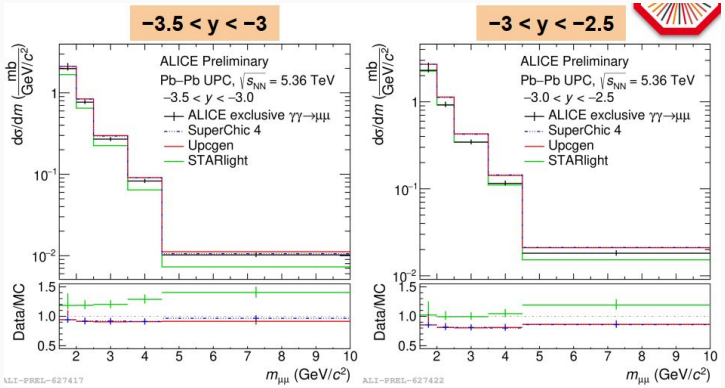


- First energy-dependent measurement of coherent ρ from CMS.
- For ρ and ϕ nuclear shadowing models describe the data better than calculations based on Regge theory

Photon-induced processes (γγ →ll)



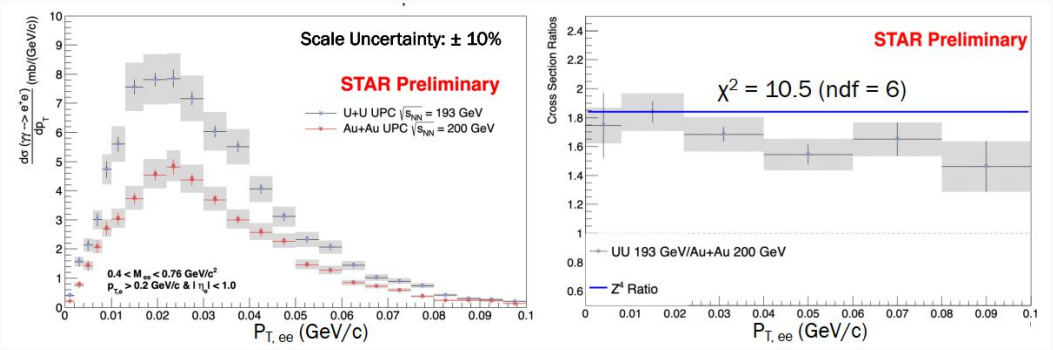
Nazar Burmasov



ALICE measured γγ →μμ in wide rapidity range

Careful treatment of photon fluxes important

Nicholas Jindal



STAR demonstrated the sensitivity of Breit-Wheeler process to nuclear geometry

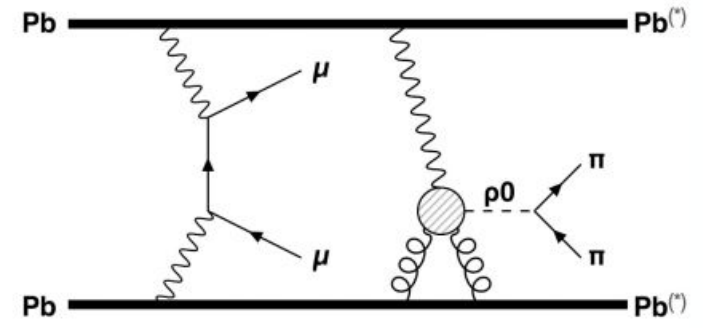
Data/MC agreement improved with adjusted charge density of the target

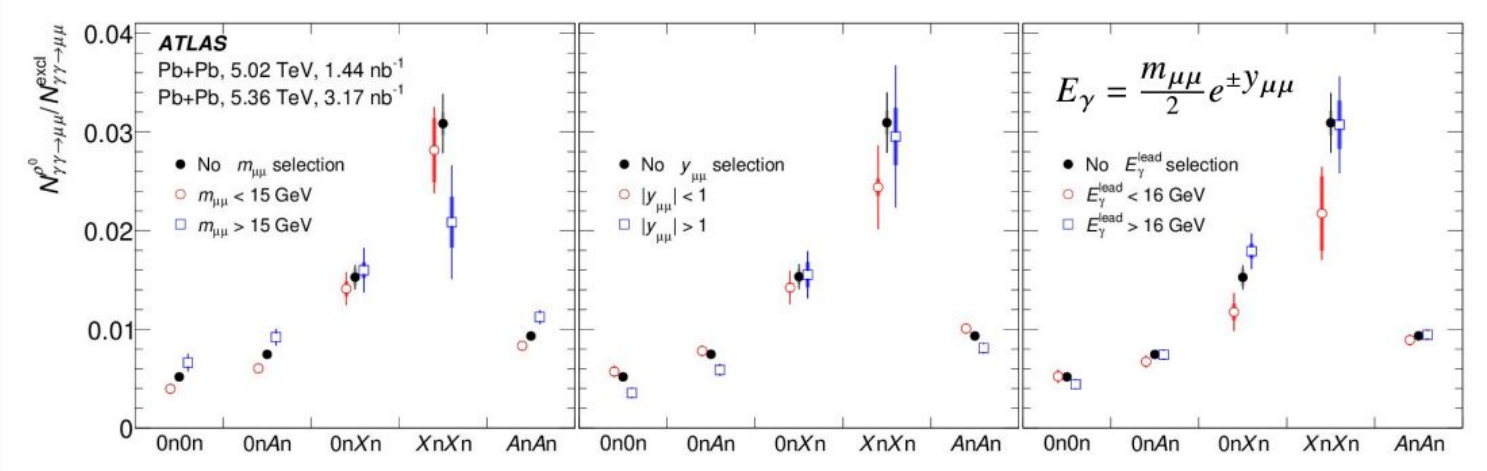
More UPC from LHC

Agnieszka Ogrodnik

ATLAS measured first double scattering of dileptons and ρ

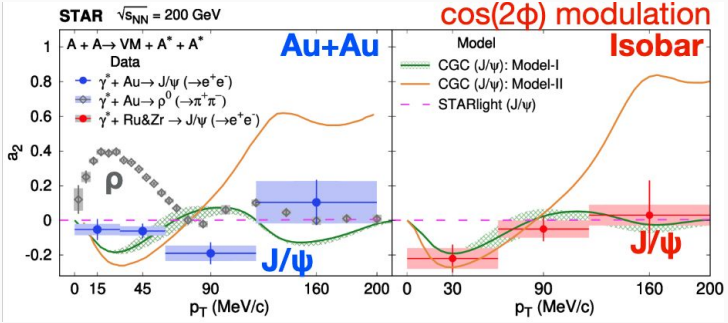
1% of UPC di-lepton events have ρ

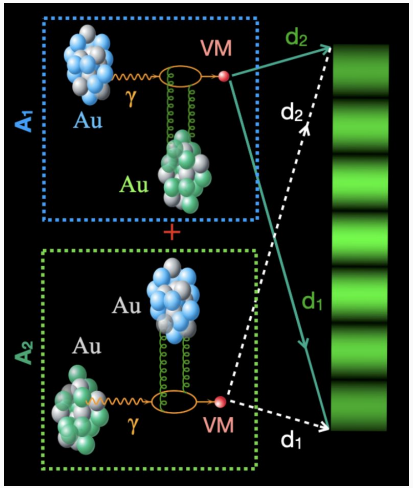




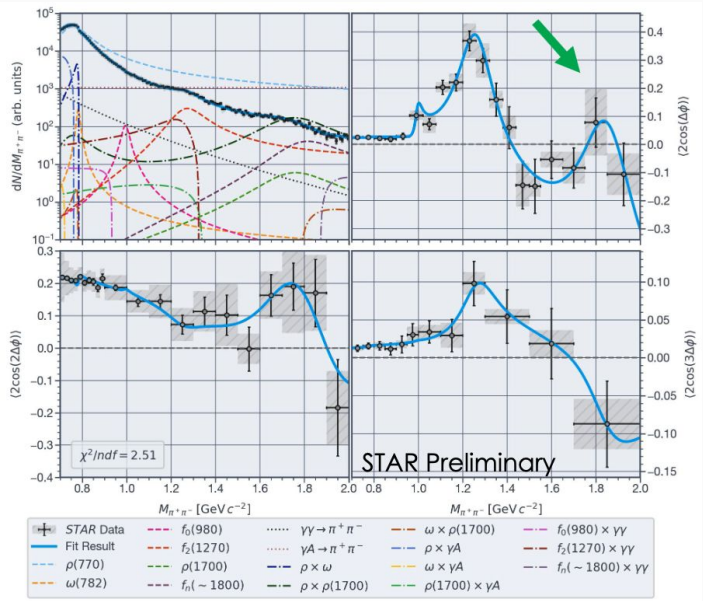
Spin interference measurements at STAR

Prithwish Tribedy





Samuel Corey



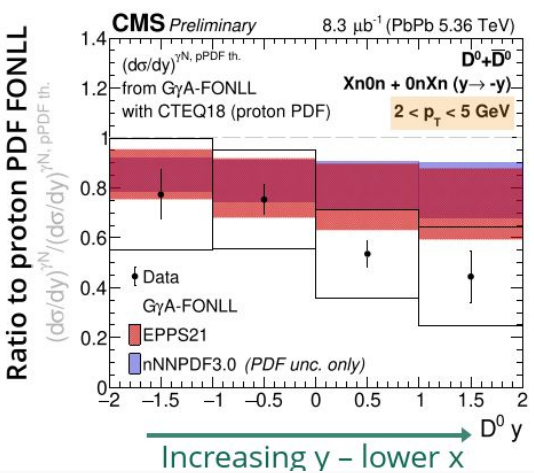
Spin interference ⇒ New phase-sensitive tool for comparisons to saturation-model predictions

Interference observed in $J/\Psi \rightarrow e^+e^-$ with opposite sign of previously observed $\varrho \rightarrow \pi^+\pi^-$

Use spin interference in addition to reconstructed mass to measure $\gamma\gamma$ continuum in UPC di-pion events.

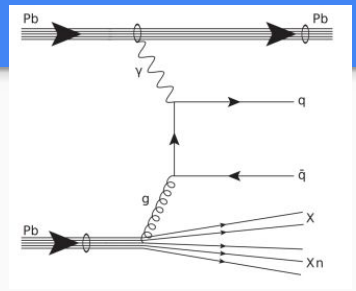
Using qqbar production in UPC to constrain nPDFs

Balazs Kovacs (CMS)

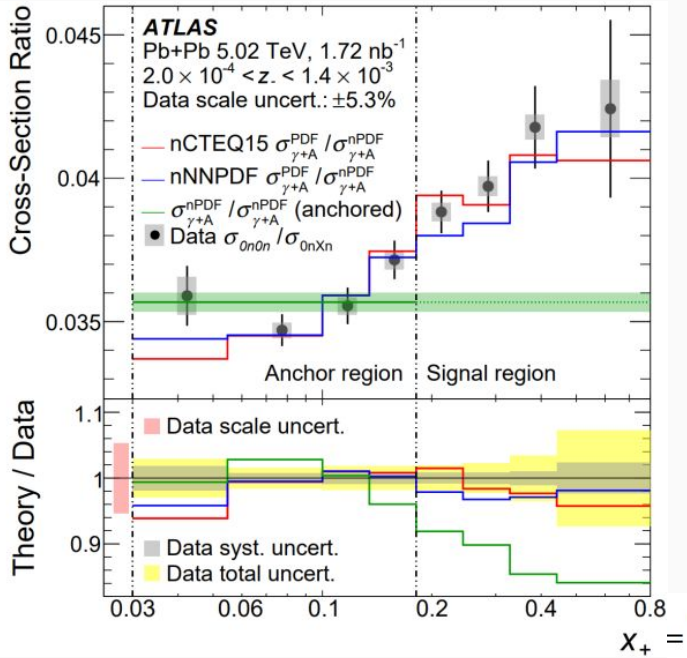


CMS: First inclusive D^0 measurement, with more data can use in nPDF fits

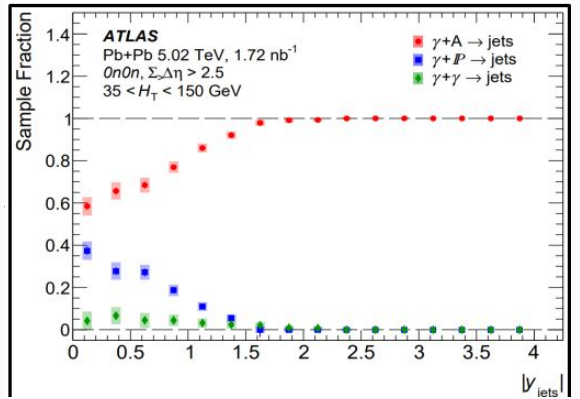
Ben Gilbert (ATLAS)



Photoproduction of jets and 0n0n/0nXn ratio



First measurement of photo-diffractive component

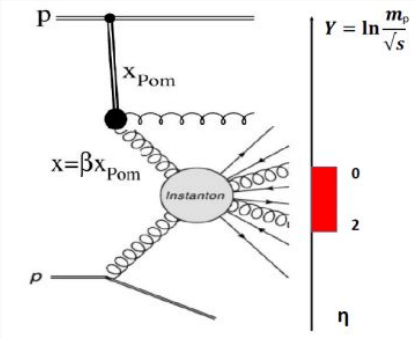


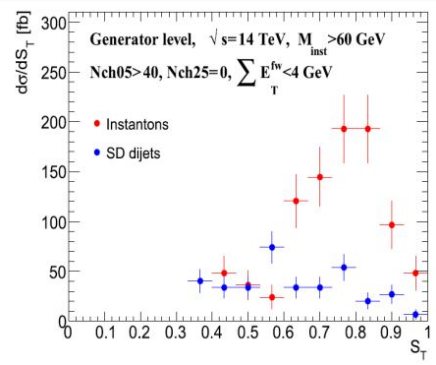
$$x_+ = \frac{m_{jets} e^{+|y_{jets}|}}{\sqrt{s_{NN}}}$$

Soft QCD studies

Marek Taševský

Imanol Corredoira





QCD instanton searches in diffractive events
Event sphericity suggested as a strong discriminating variable

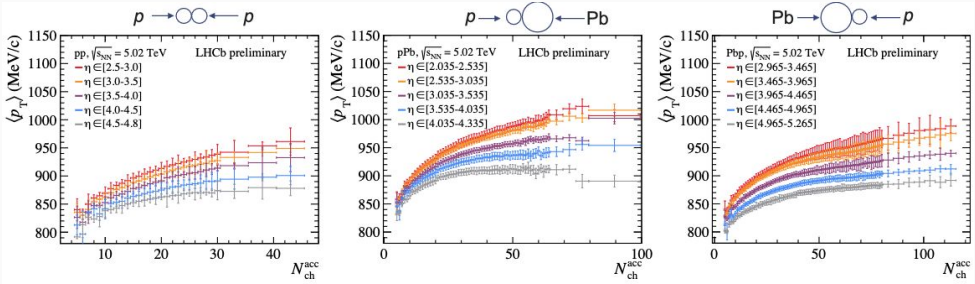
New LHCb results

Elliptic flow shows no Bjorken-x dependence.

ϱ cross-section measured in UPC PbPb overestimated by all models.

First observation of pseudorapidity dependence of $\langle p_T \rangle$ in high-multiplicity pp and pPb collisions

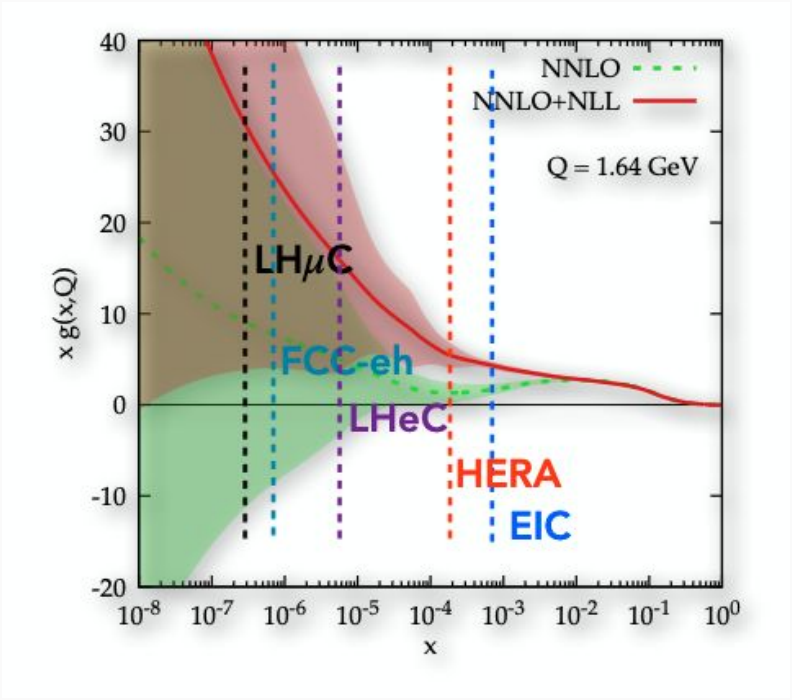
New strategy to measure Drell-Yan at $M_{\mu\mu} < 10$ GeV

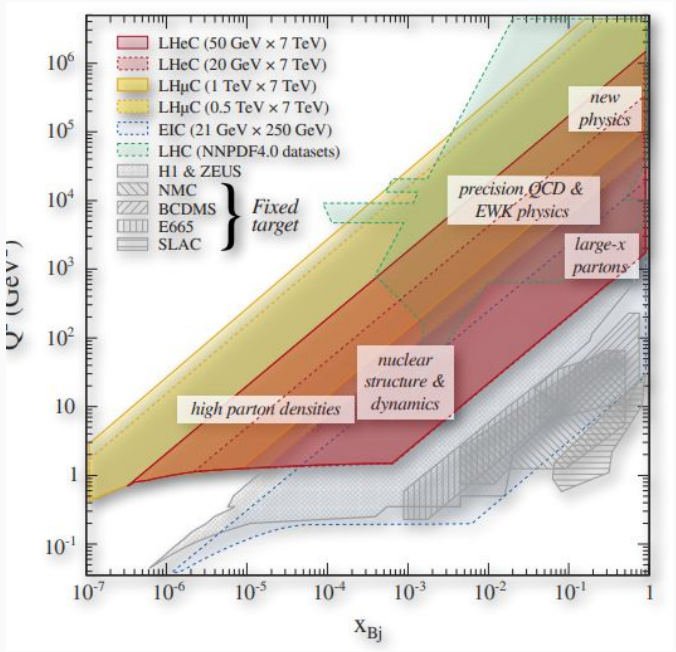


New proposals for small-x physics

Piotr Kotko

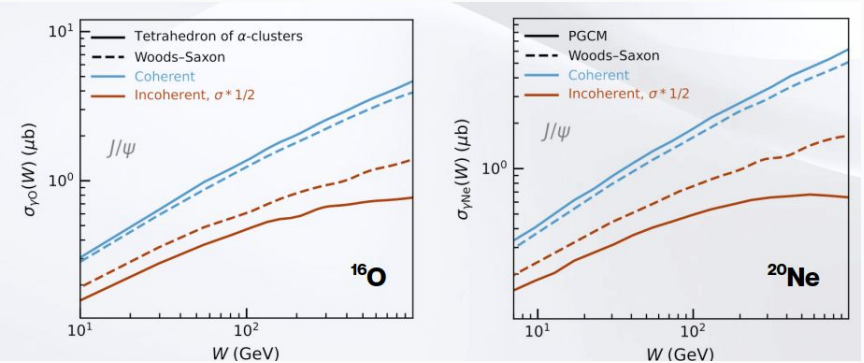
LHμC is an opportunity for small-x physics in the not-so-distant future.





Nuclear geometry

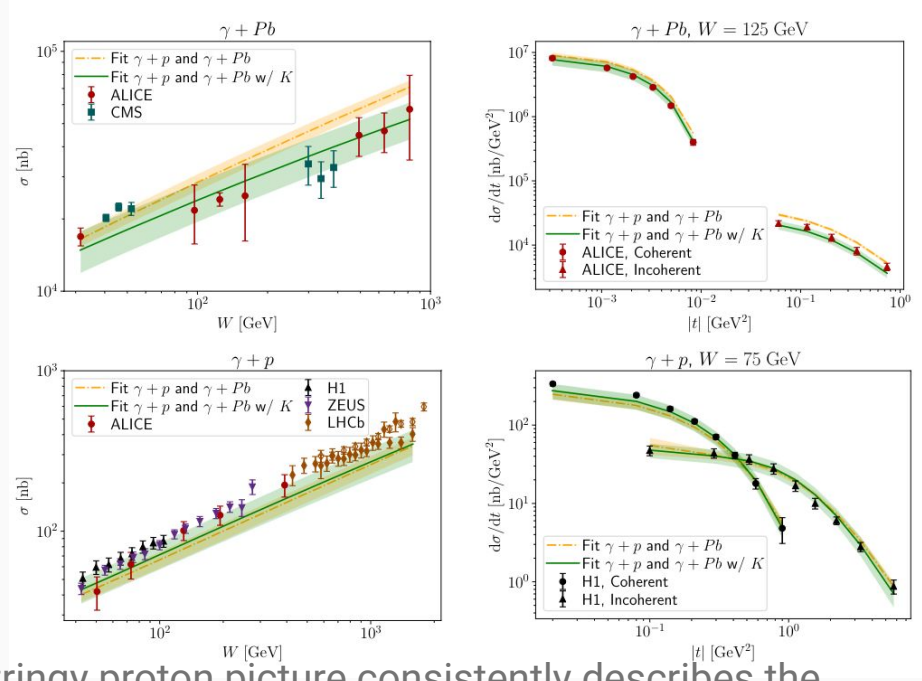
Alexandra Ridziková



Energy dependent hot-spot model

Extended to O/Ne ions, incoherent production sensitive to nuclear geometry

Hendrik Roch

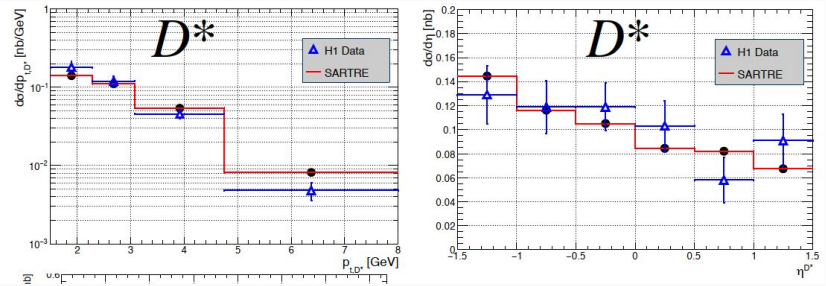


Stringy proton picture consistently describes the charge radius of the proton and diffractive J/ ψ data.

Event generators and geometric scaling

Tobias Toll

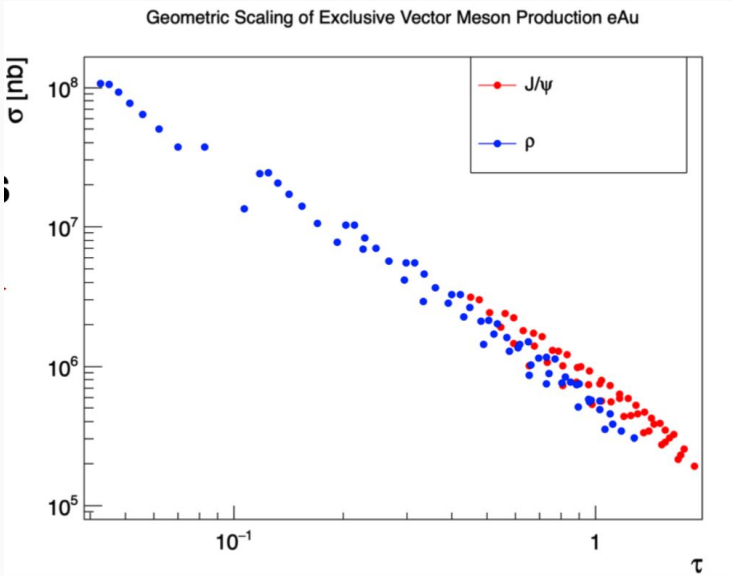
- Exclusive and inclusive diffraction with Sartre event generator



Upcoming:

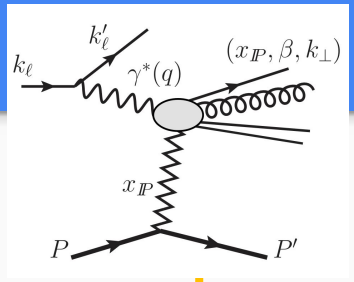
- UPC for heavy quarks for LHC
- *t*-dependence

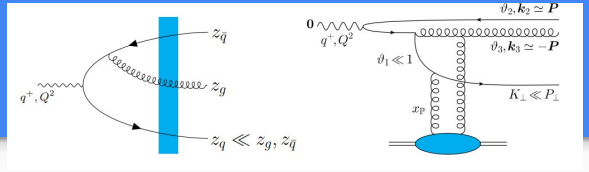
Rojae Mighty



Investigate geometric scaling in exclusive vector meson production in eA collisions at the EIC.

Inclusive diffraction in DIS



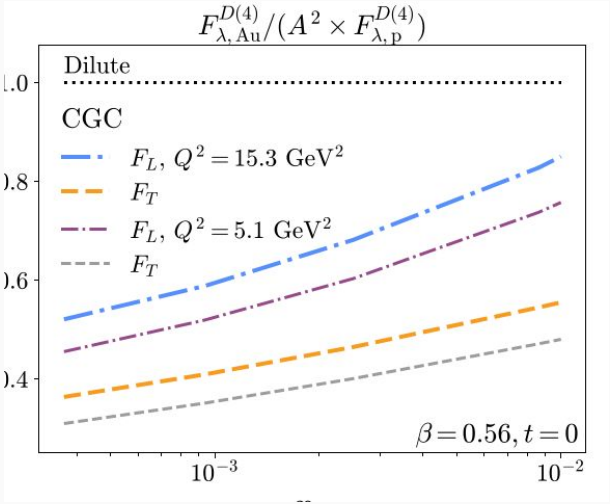


Pyry Runko

Abhiram Kaushik

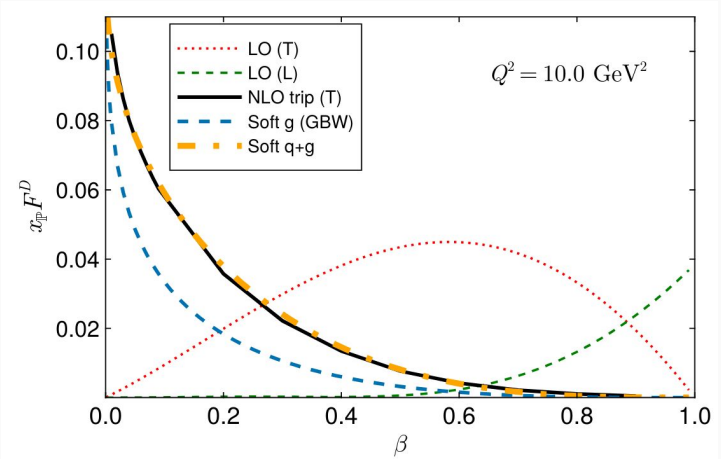
Diffractive Structure Functions from JIMWLK evolution

- $x_{I\!P}$ dependence from JIMWLK evolution
- Good description of HERA diffractive structure function data



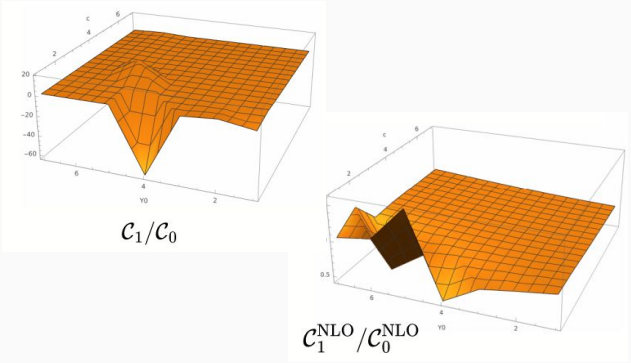
qqg contribution to diffractive DIS: numerically most challenging part of the full NLO

- NLO usually approximated by soft gluon
- Numerical results: soft quark also important



Small-*x* resummation

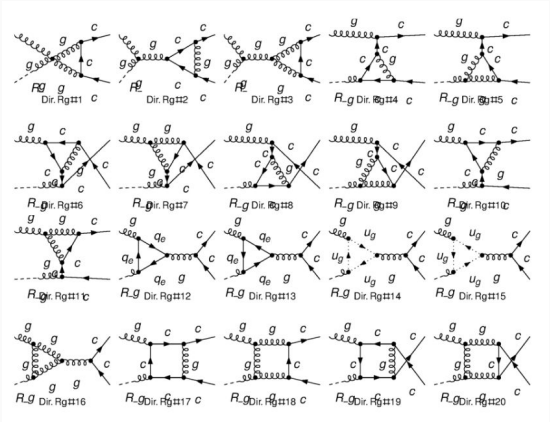
Ada Polizzi



New BFKL calculations with NLO eigenfunctions.

Applied to electroproduction of light vector meson pair and Mueller-Navelet jet production.

Michael Fucilla

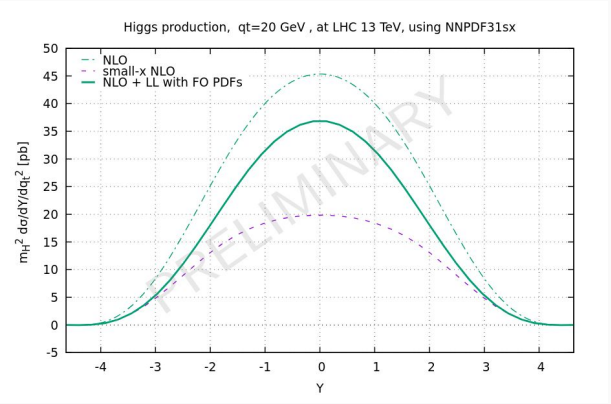


NLO impact factors for forward Quarkonium production

Instabilities in fixed order calculation without small-*x* resummation.

NLL accuracy imperative in small-*x* physics

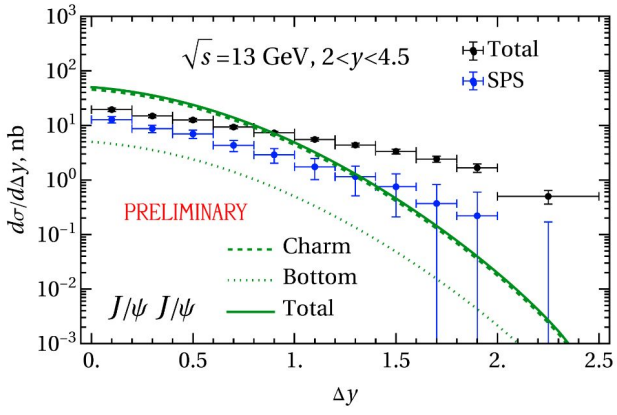
Benedetta Bernardini



Small-x resummation in the HELL language extended to fully differential Higgs production. Higgs production probes gluon dynamics at very small-x.

Heavy meson pairs

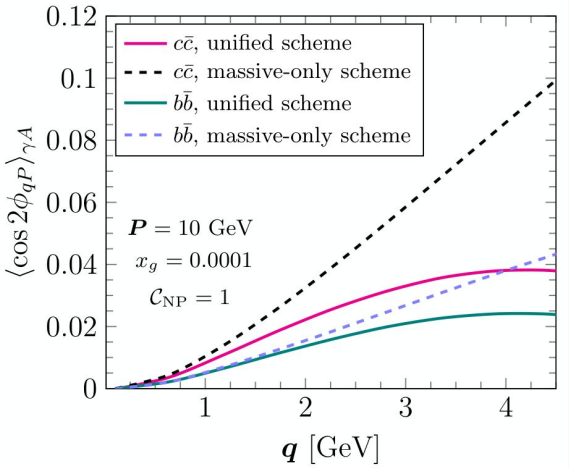
Benjamin Guiot



Calculation of double-fragmentation contribution to di-quarkonia production

Previously not taken into account

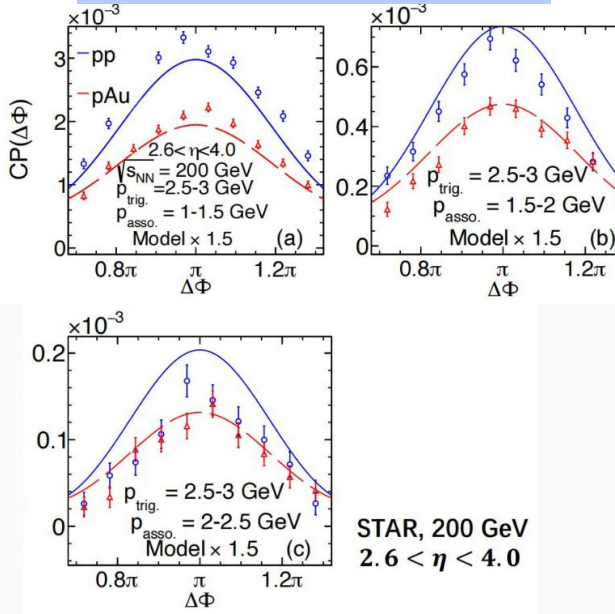
Yu Shi



New unified resummation of soft gluons for heavy quarks

Consistent description of different measurements of heavy hadron correlations

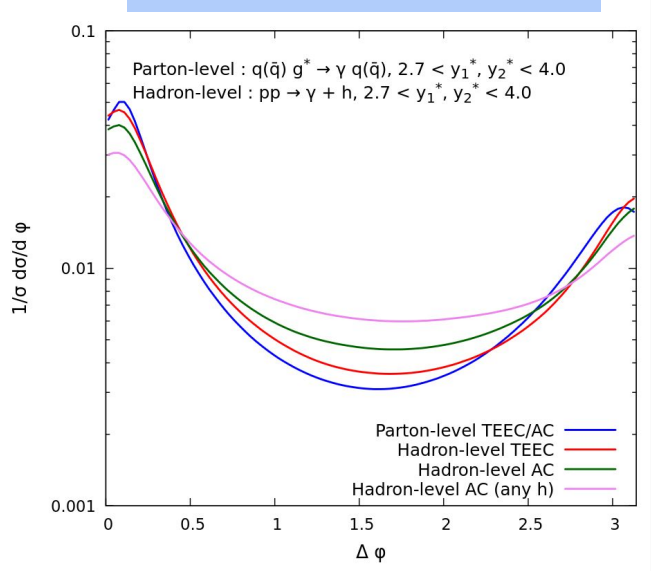
Wenbin Zhao



CGC model provides a good description of both dihadron correlations and inclusive production.

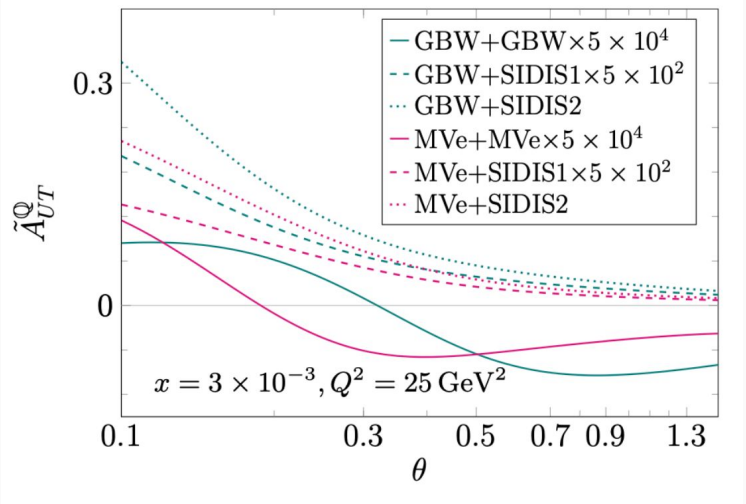
Energy correlators

Ishita Ganguli



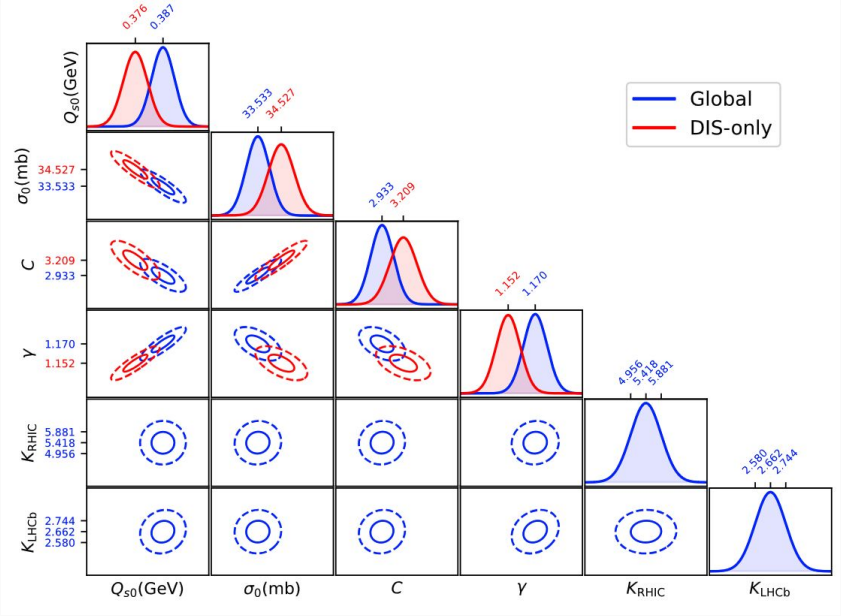
- Transverse energy–energy correlations as a probe for gluon saturation
- TEEC closer to parton level than hadron azimuthal correlations.

Xuan-Bo Tong



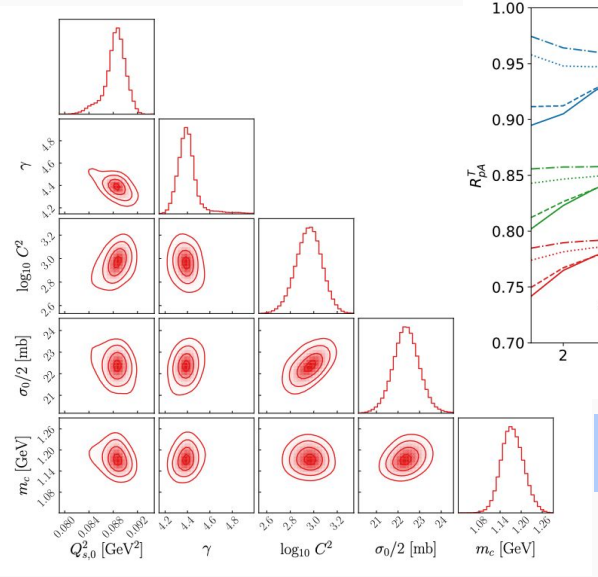
- Nucleon energy correlator as probe of the Odderon
- Connection between the spin-dependent odderon and the nucleon tomography in the target fragmentation region.

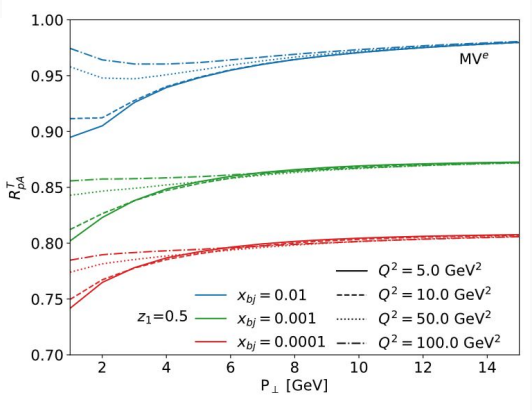
CGC fits



Truong My Hau Le

Investigate universal property of CGC framework with global fit to HERA and pp collisions.





Swaleha Mulani

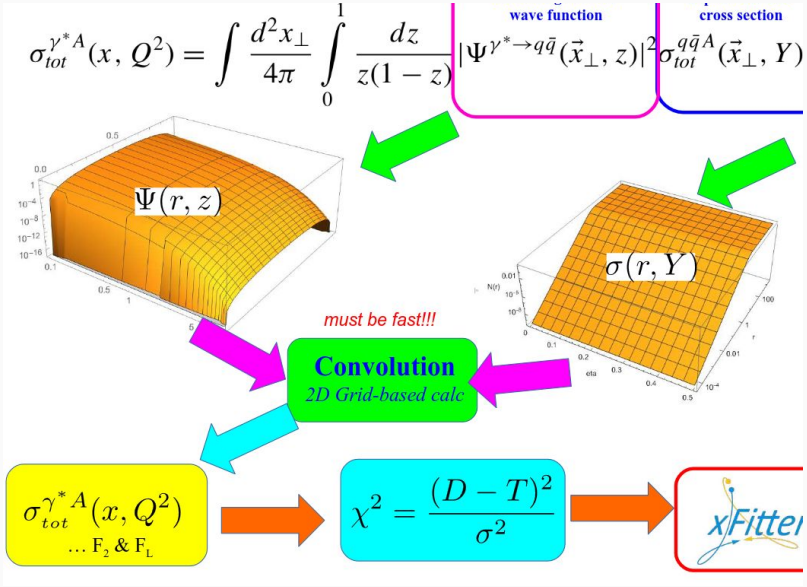
Carlisle Casuga

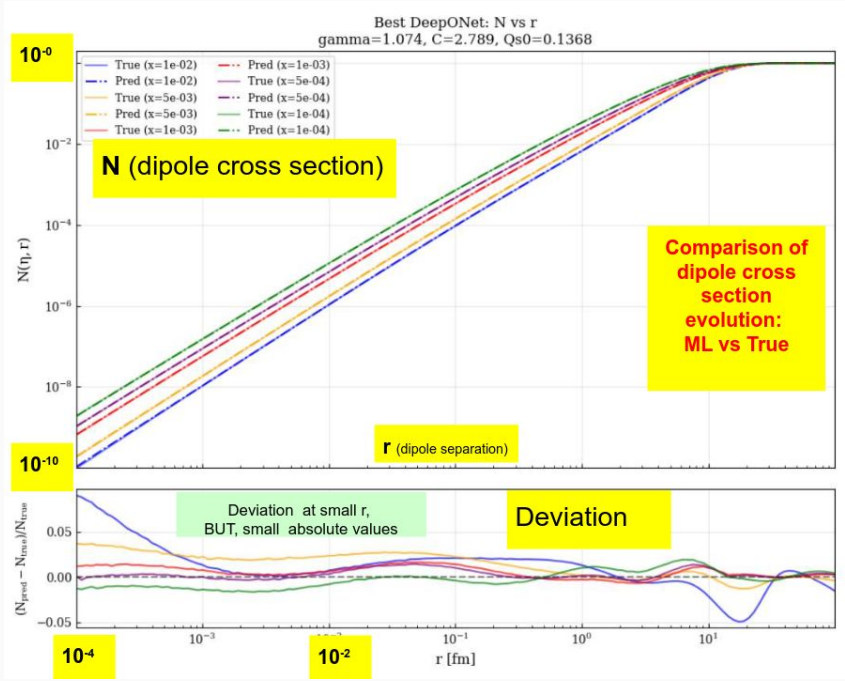
Dipole amplitude fitted to small-x inclusive DIS data at full NLO. Predictions for semi-inclusive hadron production at the EIC.

CGC fits

Fred Olness

Developing an efficient framework for small-x fitting





Machine learning model to skip the numerically heavy small-x evolution

Small-*x* evolution

Guillaume Beuf

Small-*x* calculations at NLO:

Problems with the standard cutoff regulator

Proposal: 3 versions of rapidity regularisation for CGC calculations at NLO:

Introduce a factor in the loop integrand (with gluon momentum k)

- regulator in k^+: $\left(\frac{k^+}{\nu_B^+}\right)^\eta$ (inspired by η and analytic regulators)
- regulator in k^-: $\left(\frac{\nu_B^-}{k^-}\right)^\eta \sim \left(\frac{2k^+\nu_B^-}{\mathbf{k}^2}\right)^\eta$
- pure rapidity regulator: $\left(\frac{k^+\,\nu_B^-}{k^-\,\nu_B^+}\right)^{\frac{\eta}{2}} \sim \left(\frac{2(k^+)^2\nu_B^-}{\mathbf{k}^2\nu_B^+}\right)^{\frac{\eta}{2}}$

Longitudinal DIS structure function at NLO with different regulators:

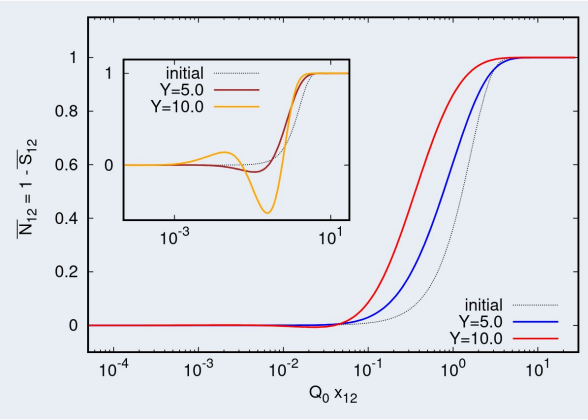
- New insights on (anti)collinear logs in BK/JIMWLK and their resummation?

Piotr Korcyl

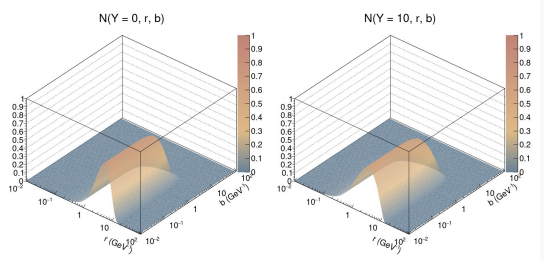
Double transverse logarithms in NLO BK: instability

"Rotation" of the dipole amplitude

⇒ Fixes the problem with double logarithms



Jan Cepila



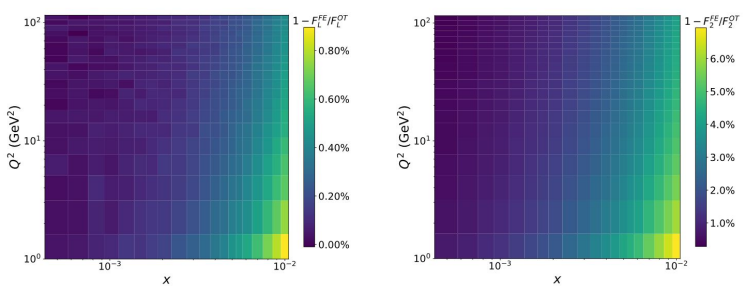
Most BK studies: dipole amplitude only depends on dipole size

Here also dipole orientation and impact parameter included

- Numerical instabilities with full NLO

Corrections at moderate *x*

Magnus Bertilsson

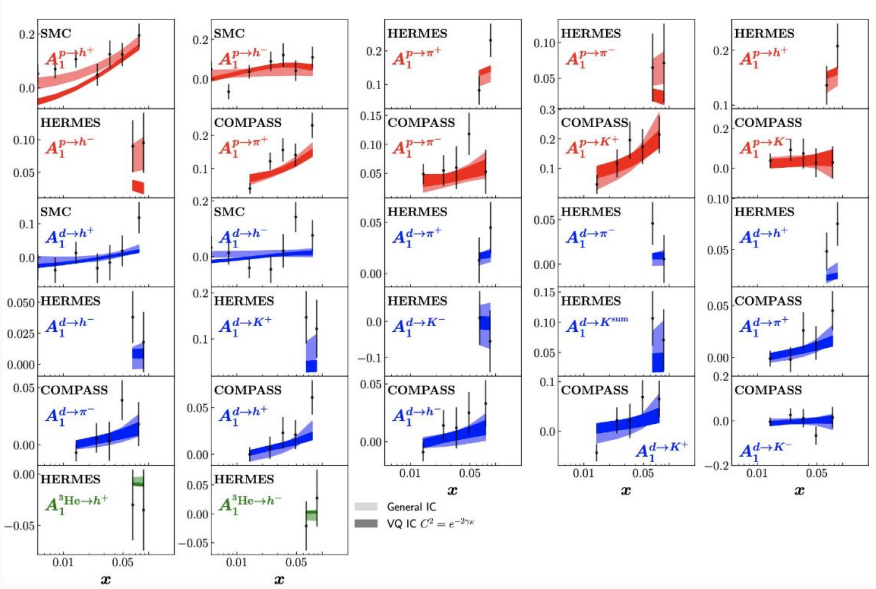


Kinematic constraint included to inclusive DIS:

- More important for F_2 than F_L
- More important to heavy quarks

Yossathorn (Josh) Tawabutr

- Small-*x* evolution needs nonperturbative initial condition
- Subeikonal corrections: constrain the initial condition with a physical valence quark model
- Fit shows promising signs of agreement



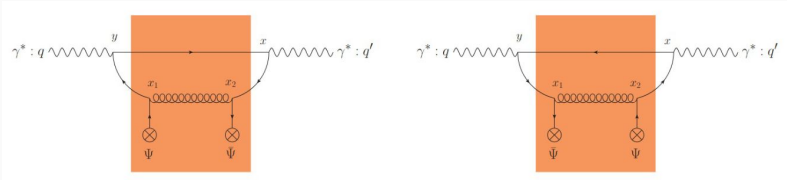
Next-to-Eikonal corrections at Next-to-Leading Order

Giovanni Chirilli

Evolution equations for different subeikonal quark operators

$$
\begin{aligned}
\frac{d}{d\eta}\mathcal{Q}^{f}_{1x} &= \frac{\alpha_s}{4\pi^2}\int \frac{d^2z}{(x-z)^2_\perp}\left[2C_F\mathcal{Q}^{f}_{1z} - N_c\mathcal{Q}^{f}_{1,zx} + \frac{1}{N_c}\Psi^{f}_{1,zx}\right] \\
\frac{d}{d\eta}\mathcal{Q}^{S}_{5x} &= \frac{\alpha_s}{4\pi^2}\int \frac{d^2z}{(x-z)^2_\perp}\left[2C_F\mathcal{Q}^{S}_{5z} - N_c\mathcal{Q}^{S}_{5,zx} + \frac{1}{N_c}\Psi^{S}_{5,zx} + 2N_f\mathcal{F}_{xz}\right] \\
\frac{d}{d\eta}\mathcal{Q}^{\mathrm{NS}}_{5x} &= \frac{\alpha_s}{4\pi^2}\int \frac{d^2z}{(x-z)^2_\perp}\left[2C_F\mathcal{Q}^{\mathrm{NS}}_{5z} - N_c\mathcal{Q}^{\mathrm{NS}}_{5,zx} + \frac{1}{N_c}\Psi^{\mathrm{NS}}_{5,zx}\right]
\end{aligned}
$$

Jules Favrel



NLO+NEik corrections to structure functions

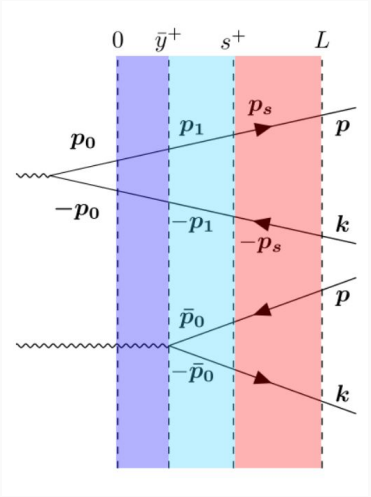
- UV and rapidity divergences identified

Sub-Eikonal corrections: Dijet production in DIS

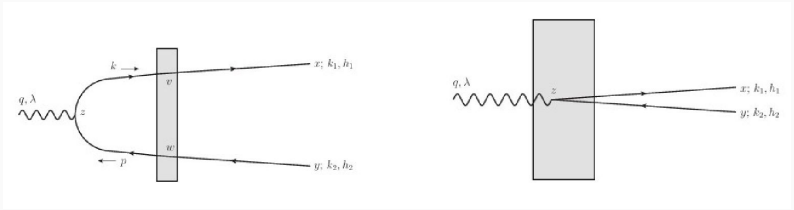
Adrián Romero

Kacper Gosławski

Relaxed the eikonal approximation to all orders in medium length



- Bridging CGC and TMD at the next-to-eikonal level
- 2-point and 3-point gluon field insertions
- Connection to TMDs studied



Need to go beyond next-to-eikonal to obtain non-zero corrections

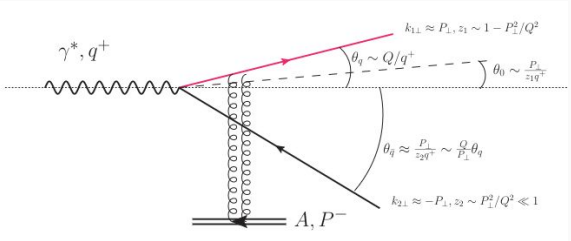
$$\left.\frac{d\sigma}{dP.S.}\right|_{\mathcal{F}^{\perp+}\mathcal{F}^{\perp+}\mathcal{F}^{\perp+}} \sim (\dots)\cdot\Phi(0,0,0,\Delta\mathbf{b}) + (\dots)\cdot\int_{-1}^{1} dx\delta'(x)\Phi(x,-\frac{x}{2},-\frac{x}{2},\Delta\mathbf{b}) + f^{abc}(\dots)\cdot\int_{-1}^{1} dx\delta'(x)\Phi(0,x,-x,\Delta\mathbf{b})$$
$$+(\dots)\cdot\int_{-1}^{1} dx\left[\frac{1}{(x+i\epsilon)^2}+\frac{1}{(x-i\epsilon)^2}\right]\Phi(x,-\frac{x}{2},-\frac{x}{2},\Delta\mathbf{b})$$

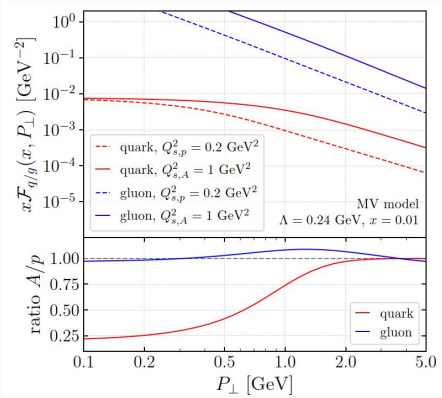
Small-*x* and TMD factorization

Paul Caucal

Jet definition in SIDIS:

- Jet algorithm important for correct Sudakov
- Emergence of the DGLAP and CSS evolutions from the small-x approach

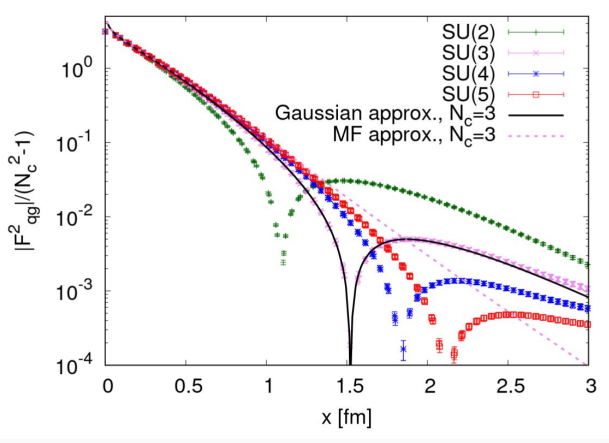




Small-*x* Factorization in the Target Fragmentation Region:

- First NLO calculation of $F_{UU,L}$ at small x and $P_T \ll Q$
- New window for saturation searches at the EIC?

Florian Cougoulic



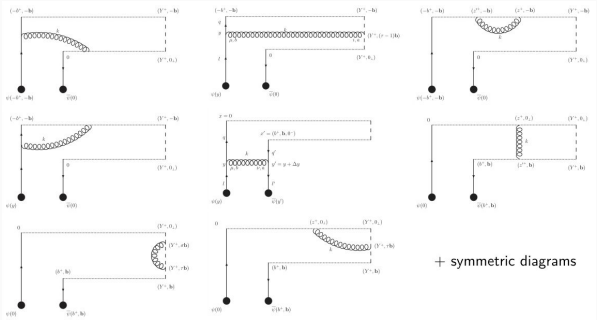
N_c-dependence of TMD's initial condition for JIMWLK evolution

- Gaussian approximation and mean-field limit vs exact
- Good agreement for small separation x
- Discrepancies at large size

TMD evolution

Mirja Tevio

NLO corrections to unpolarized quark TMD in the background field method



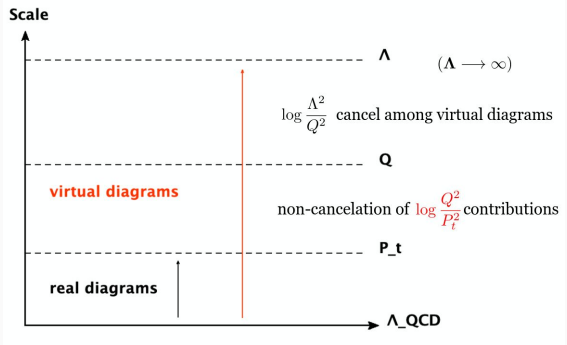
Goal: a unified framework to understand connections between the TMD and CGC approaches

Jamal Jalilian-Marian

Sudakov vs saturation in SIDIS:

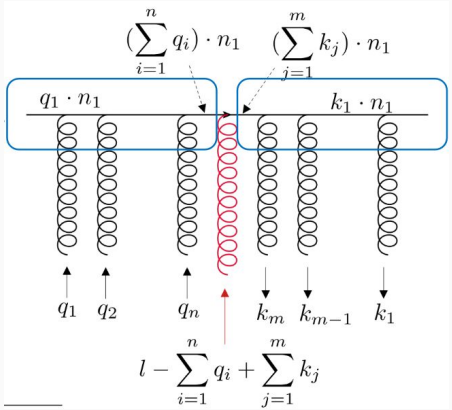
How to disentangle them?

avoid large Sudakov logs: $\mathbf{p_{t,h}^2 \sim Q^2}$



Andrea Simonelli

Connecting Regge Factorization with TMD evolution



Naive factorization breaks due to Glauber gluons
Fixed number of Glaubes:
Hoping to recover factorization
⇒ Promising results at 1 Glauber

Thanks to the organizers, speakers, scientific secretaries & attendees!