WG2 summary

Small x, diffraction and vector mesons

Cristian Baldenegro (Sapienza), Renaud Boussarie (CPHT),
Pieter Taels (Antwerp)

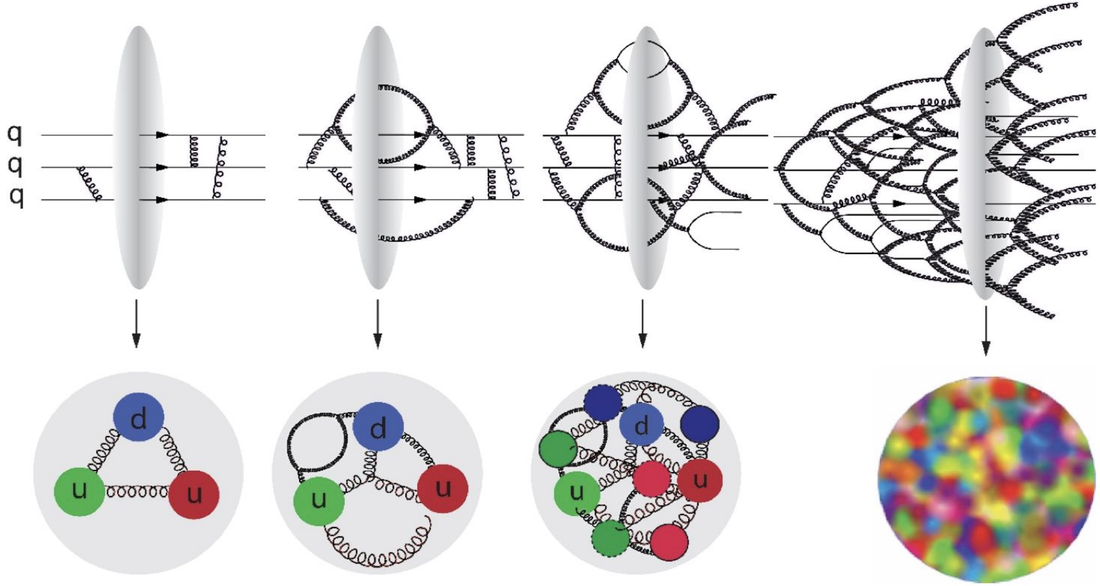
WG2 Small x, diffraction, and vector mesons

- 41 talks: 10 experimental talks + 31 pheno/theory talks

- Color Glass Condensate (CGC) developments, resummation, factorization, subeikonal corrections, and how we can use e.g. ultraperipheral collisions (UPC)

QCD at low *x*

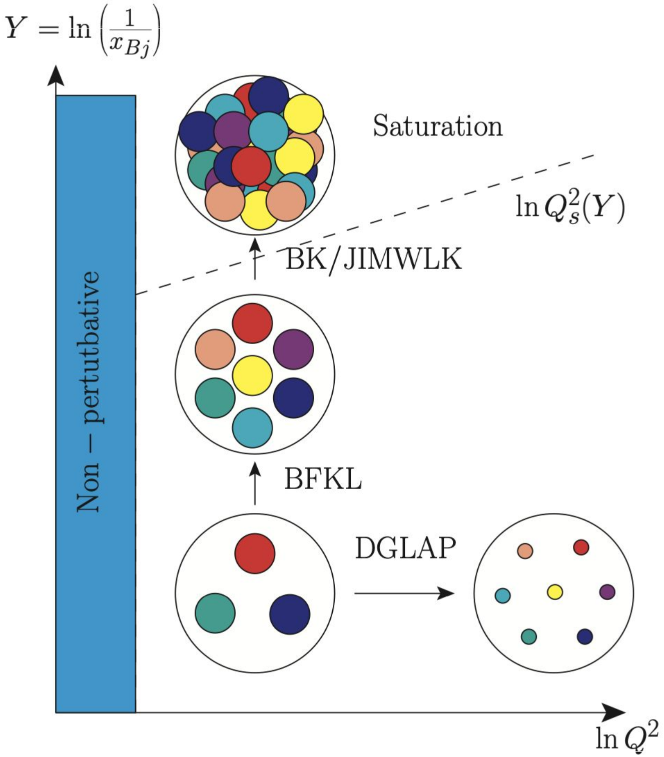
- Probed at asymptotic energies, or small momentum fraction *x*, the proton or nucleus structure is dominated by gluons
- Saturation predicted for a probe scale below $Q_s^2(x) \approx (A/x)^{1/3} \times Q_{s0}^2$

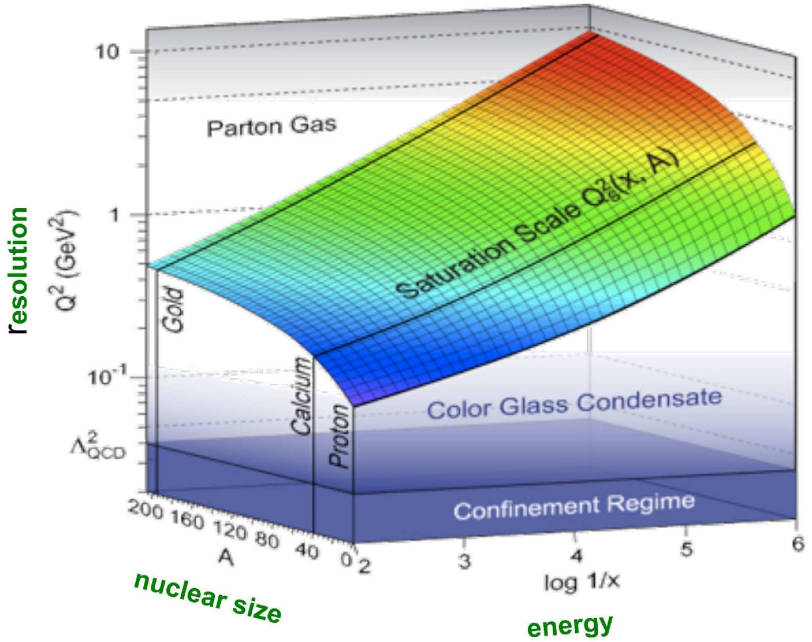


Kong Tu

Saturation

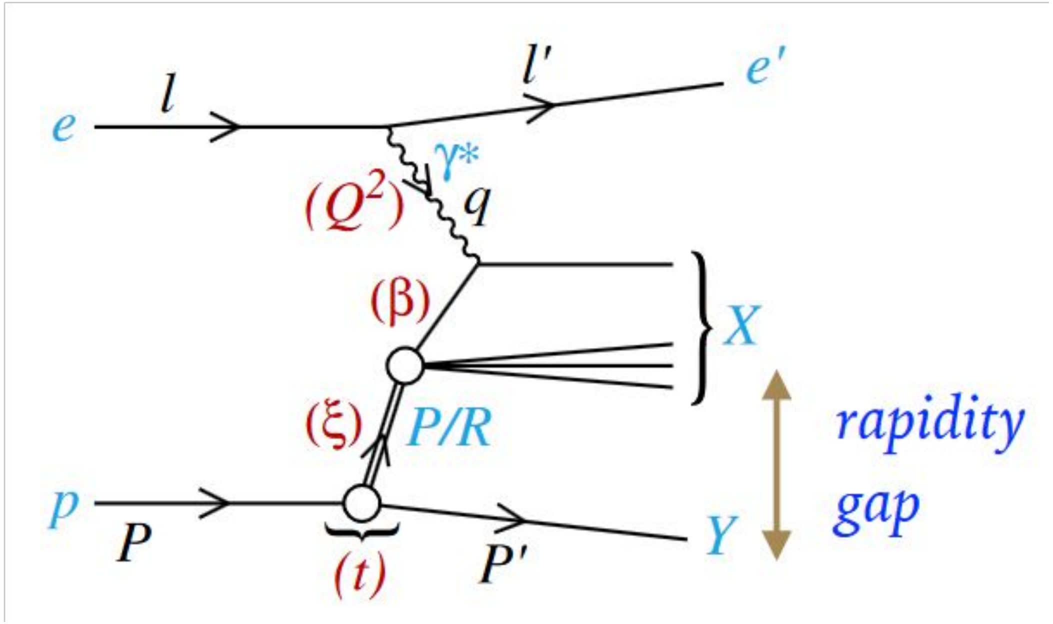
$$Q_s^2(x) \approx (A/x)^{1/3} \times Q_{s0}^2$$





Diffraction

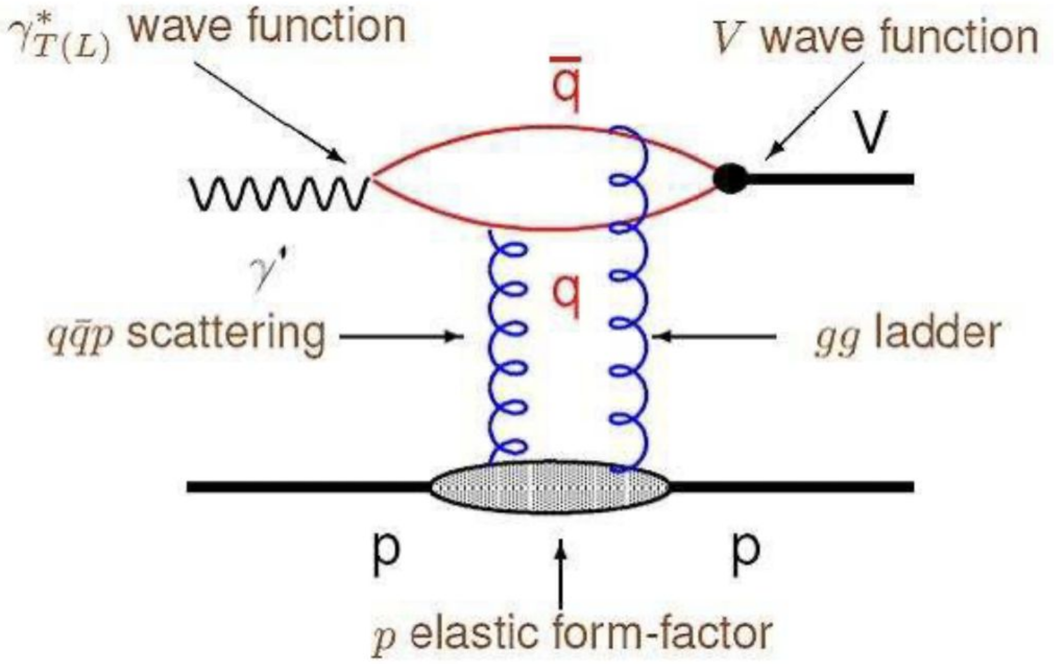
- Rapidity gap explained by colorless QCD exchange (Pomeron-Odderon)
- At very low *x* very sensitive to saturation



A. Stasto

Vector mesons

Bound states have an intrinsic transverse ‘width’, light states $\leftrightarrow$ large widths $\leftrightarrow$ large dipoles $\leftrightarrow$ sensitive to saturation



A.Levy

Theory overview

Theoretical topics addressed during DIS2024

Determination of modern observables for saturation

Towards precision at small x
- Loop and log corrections
- Evolution and input
- Power corrections

Low x asymptotics of spin

Theoretical topics addressed during DIS2024

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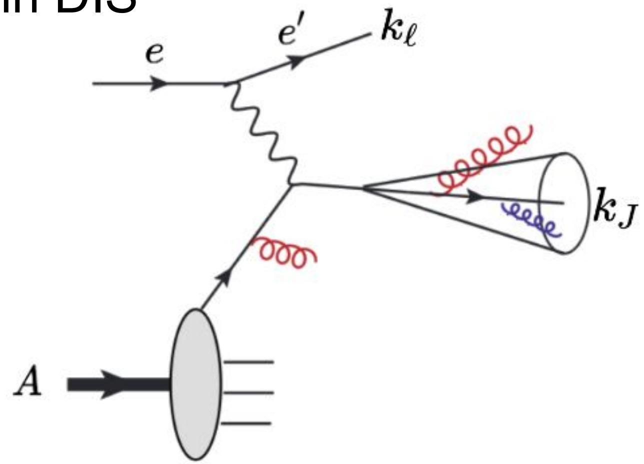
Low x asymptotics of spin

Modern observables for saturation effects

Lepton-jet correlation in DIS

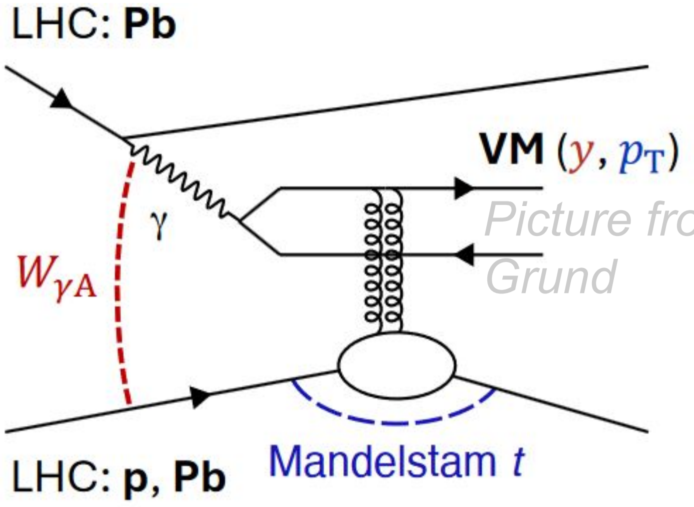


Transverse Energy-Energy Correlators (TEEC)
Jani Penttala

Anisotropy (angular harmonics)
Xuan-bo Tong

Modern observables for saturation effects

Vector meson production in ultraperipheral Pb Pb collisions



Picture from David Grund

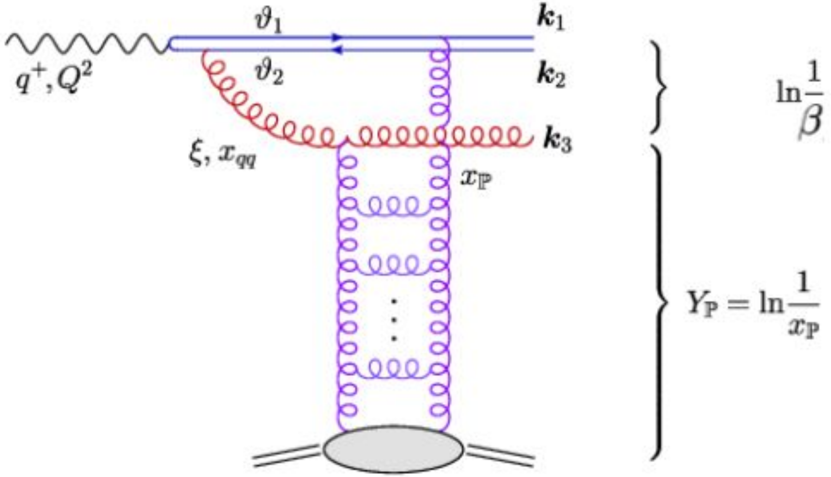
New ratio to distinguish saturation and shadowing effects *Kong Tu*

$$R_{\mathrm{UPC}} = \frac{\left[\sigma_{\mathrm{el}}^{\mathrm{VM}} / \left(\mathrm{d}\sigma_{\mathrm{inclusive}}^{\mathrm{hadron/jet}} / \mathrm{d}^2 p_{\mathrm{T}}\right)\right]_{\gamma A}}{\left[\sigma_{\mathrm{el}}^{\mathrm{VM}} / \left(\mathrm{d}\sigma_{\mathrm{inclusive}}^{\mathrm{hadron/jet}} / \mathrm{d}^2 p_{\mathrm{T}}\right)\right]_{\gamma p}}$$

Effects from target geometry and from saturation
Heikki Mantysaari

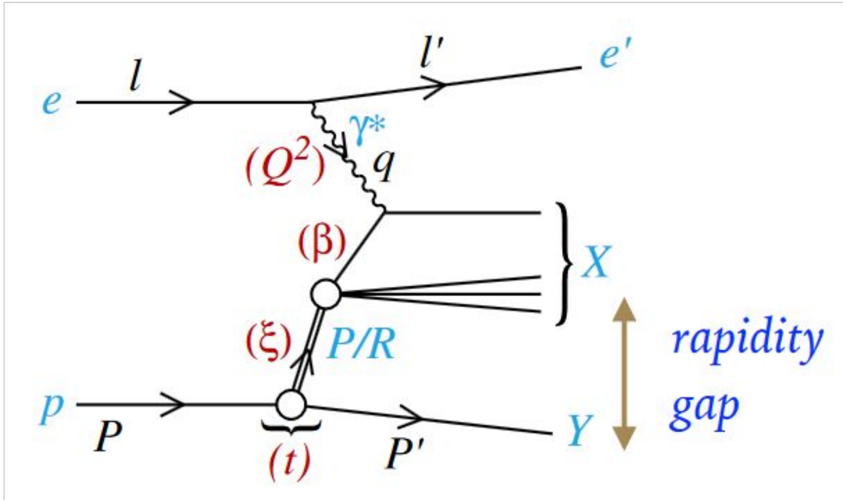
Modern observables for saturation effects

'Diffractive TMD' in semi-inclusive diffractive observables *Siggi Hauksson*

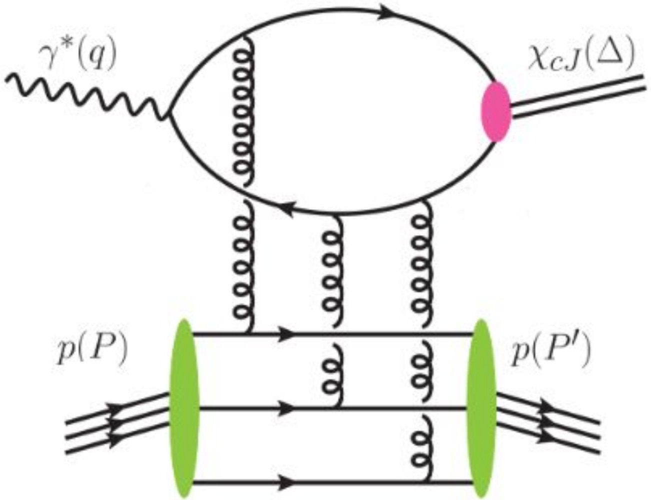


Constraining Reggeons, Pomerons and Odderons

Reggeon and Pomeron contributions to diffractive PDFs: HERA fit and EIC pseudodata *Anna Stasto*



Predictions for Odderon exchange at the EIC in exclusive C+ quarkonium production *Sanjin Benic*



Theoretical topics addressed in WG2

Determination of modern observables for saturation

Towards precision at small x
- Loop and log corrections
- Evolution and input
- Power corrections

Low x asymptotics of spin

Towards precision

Loop and log corrections

Properties of the evolution equation

Properties of the non-perturbative inputs

Energy-suppressed power corrections

Loop and log corrections: e.g. meson production in DIS

$$\mathcal{A} = \int \mathrm{d}^2\mathbf{r}\mathrm{d}^2\mathbf{b} \int_0^1 \frac{\mathrm{d}z}{2\pi} (\Psi_\gamma(z,\mathbf{r},Q^2)\Psi_V(z,\mathbf{r},Q^2)) \mathrm{e}^{-i\mathbf{b}\cdot\mathbf{\Delta}} N(z,\mathbf{b},\mathbf{r})$$

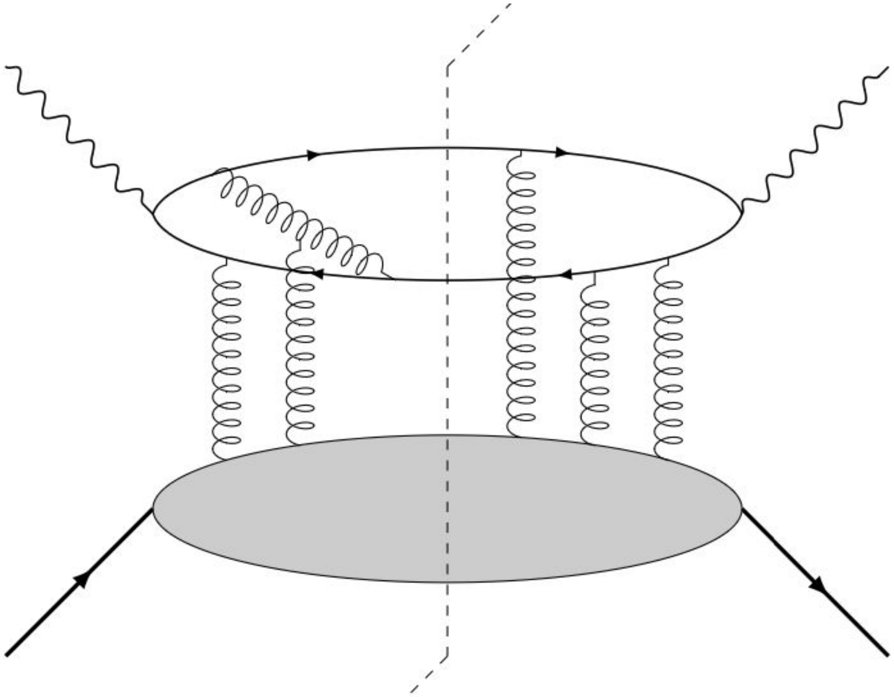
Wave functions: calculable with perturbative techniques

- Loop corrections to wave functions and overlaps

Non-perturbative input (dipole-proton scattering)

- Model building and fits for initial conditions
- NLL corrections to the evolution
- Logarithm resummations in the kernel

Next-to-leading order (NLO) calculations



Dealing with infinite twists:

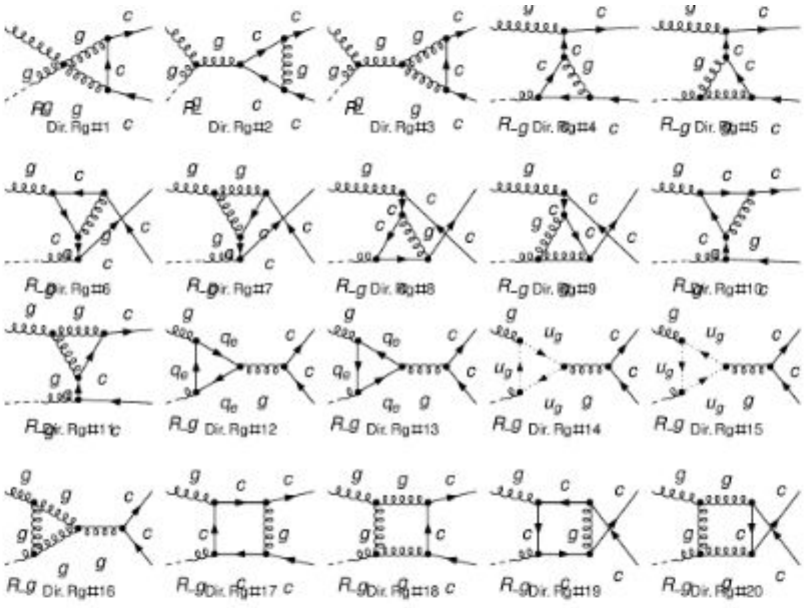
- Kinematic $k_\perp^2/Q^2$
- Genuine (many-body correlators)

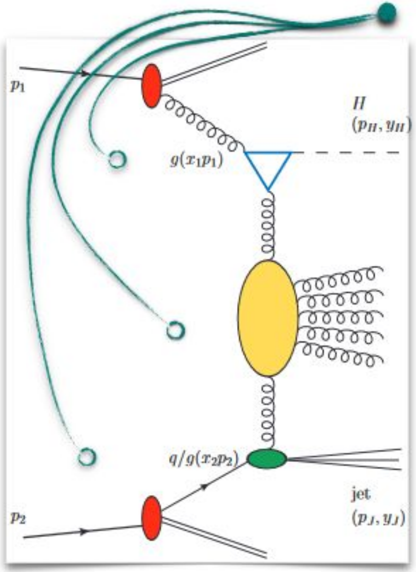
Balitsky-Fadin-Kuraev-Lipatov (BFKL) framework

Color Glass Condensate (CGC)

NLO impact factors and amplitudes in a ‘dilute’ framework

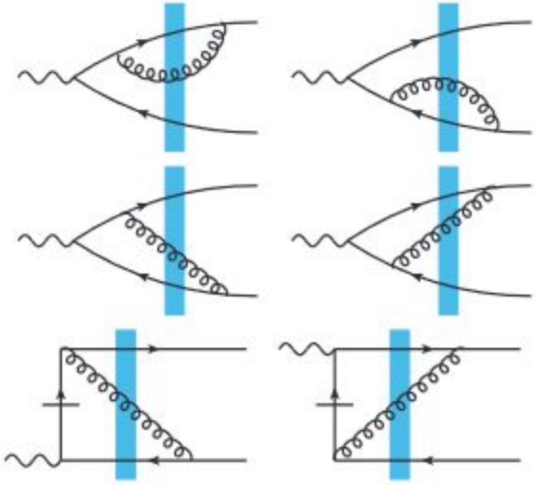
Hadroproduction of η_c *Maxim Nefedov* Higgs+jet in pp *Francesco G. Celiberto*





NLO impact factors accounting for saturation

- Diffractive dihadron leptoproduction, deeply virtual meson production
  Michael Fucilla
- Diffractive DIS structure functions *Tuomas Lappi*
- Hadroproduction of a photon - jet pair *Yair Mulian*
- SIDIS and dihadron production in DIS
  Jamal Jalilian-Marian



Precision in the evolution kernel (beyond pure NLL)

- Resummation of DGLAP logarithms in the JIMWLK kernel *Michael Lublinsky*

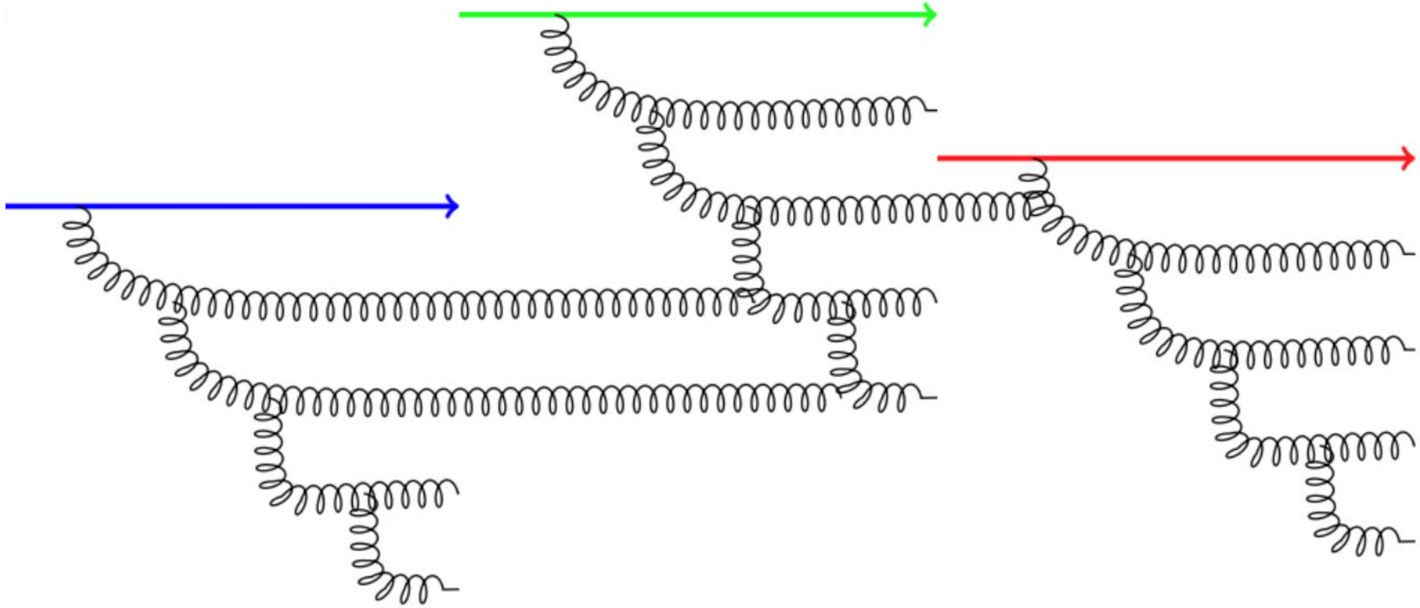
- Implementation of kinematic constraints in JIMWLK *Piotr Korcyl*

- Interpolation between DGLAP/CSS and BFKL evolutions *Swagato Mukherjee*

- Improved BFKL scheme for a full observable $(\gamma^*\gamma^* \to X)$ *Dimitri Colferai*

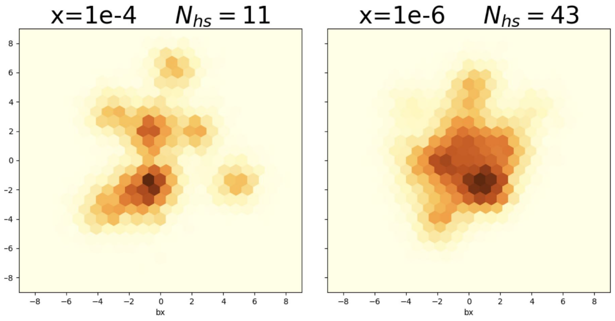
Understanding the evolution equations

- B-JIMWLK, its truncation BK, corresponds to BFKL in the linear regime
- (Non)linear evolution equations in $\ln 1/x \sim \ln s/Q^2$

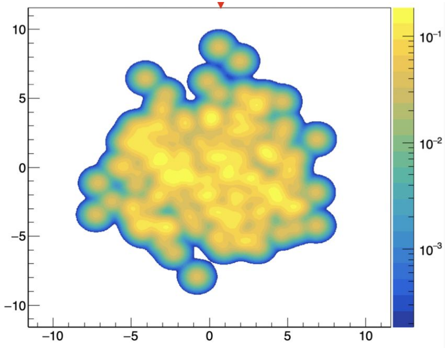


Understanding the evolution equations

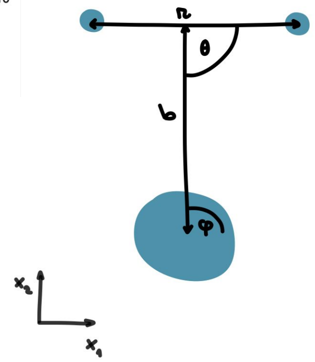
Modeling initial conditions with ‘hot spots’



Alexandra Ridzikova



Tobias Toll



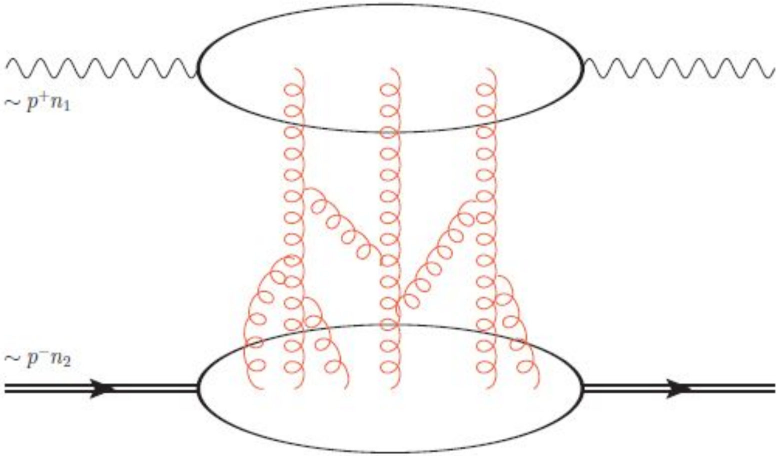
Solving (target-side) BK with full impact parameter dependence *Matej Vaculčiak*

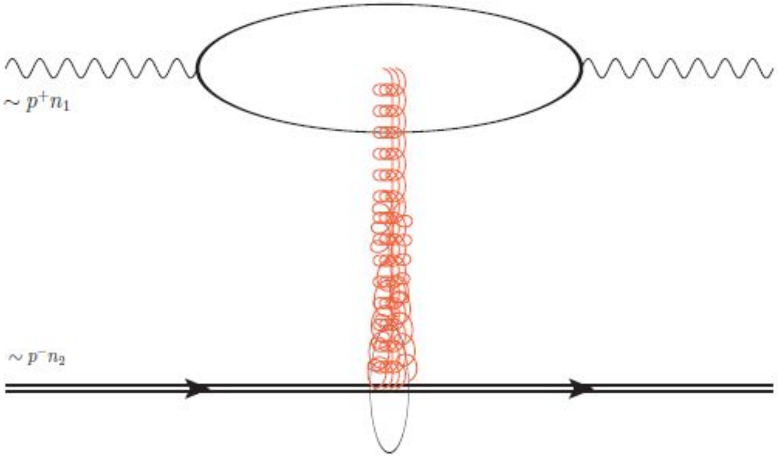
Validating prescriptions for NLO BK against HERA data *Jose Garrido*

Powerful rewriting of the eigenvalues, towards NNLL BFKL *Alex Prygarin*

Corrections to the eikonal approximation

Semi-classical effective description of small-x amplitudes in the eikonal limit: the target is comprised of highly boosted classical gluon fields





$$A^\mu(z) = \gamma^{-1} A^+(\gamma z^+, \gamma^{-1} z^-, \boldsymbol{z}) n_1^\mu + \gamma A^-(\gamma z^+, \gamma^{-1} z^-, \boldsymbol{z}) n_2^\mu + A_\perp^\mu(\gamma z^+, \gamma^{-1} z^-, \boldsymbol{z})$$

$$A^\mu(z) \sim_{\gamma \sim \sqrt{s} \to \infty} \delta(z^+) a^-(\boldsymbol{z}_\perp) n_1^\mu$$

Corrections to the eikonal approximation

Pedro Agostini, Guillaume Beuf, Swaleha Mulani, Gabriel Santiago, Josh Tawabutr

$$A^{\mu}(z) = \delta(z^{+})a^{-}(\boldsymbol{z}_{\perp})n_1^{\mu} + O(s^{-1/2})$$

- Extension of the longitudinal support beyond 0
- Contribution from classical quark fields Mulani, Santiago, Tawabutr and from transverse fields Beuf, Santiago, Tawabutr
- Longitudinal momentum transfer Beuf
- Comparison to QCD factorization in the leading Mulani and first subleading twist limits Beuf

Theoretical topics addressed during DIS2024

Determination of modern observables for saturation

Towards precision at small x
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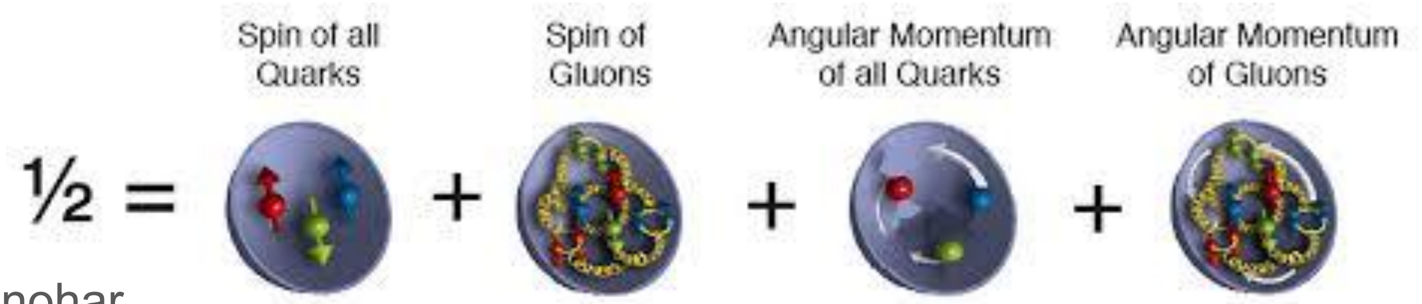
Low x asymptotics of spin

Low x contribution to the proton spin decomposition



Jaffe-Manohar sum rule

S_q S_G L_q L_G

$$S_q(Q^2 = 10\ \mathrm{GeV}^2) \approx \frac{1}{2}\int_{0.001}^{1} dx\, \Delta\Sigma(x, 10\ \mathrm{GeV}^2) \in [0.15, 0.20]$$

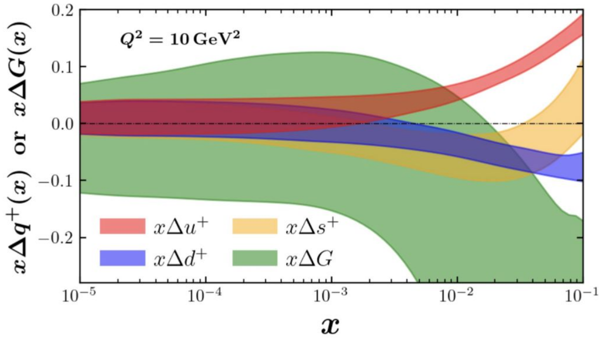
$$S_G(Q^2 = 10\ \mathrm{GeV}^2) \approx \int_{0.05}^{1} dx\, \Delta G(x, 10\ \mathrm{GeV}^2) \in [0.13, 0.26]$$

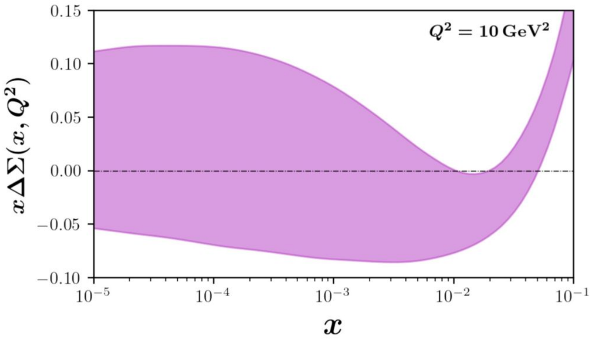
Y. Tawabutr

Spin distributions at small x

Leading Twist Quark TMDs				
		Quark Polarization		
		U	L	T
Nucleon Polarization	U	$f_1^{\mathrm{S}} \sim x^{-\frac{4\alpha_s N_c}{\pi}\ln(2)}$		$h_1^{\perp\mathrm{S}} \sim x$
	L		$g_1^{\mathrm{S}} \sim x^{-3.66\sqrt{\alpha_s N_c/2\pi}}$	$h_{1L}^{\perp\mathrm{S}} \sim x$
	T	$f_{1T}^{\perp\mathrm{S}} \sim x^{-2.9\sqrt{\alpha_s N_c/4\pi}}$	$g_{1T}^{\mathrm{S}} \sim x^{-2.9\sqrt{\alpha_s N_c/4\pi}}$	$h_1^{\mathrm{S}} \sim h_{1T}^{\perp\mathrm{S}} \sim x^{1-2\sqrt{\frac{\alpha_s N_c}{2\pi}}}$

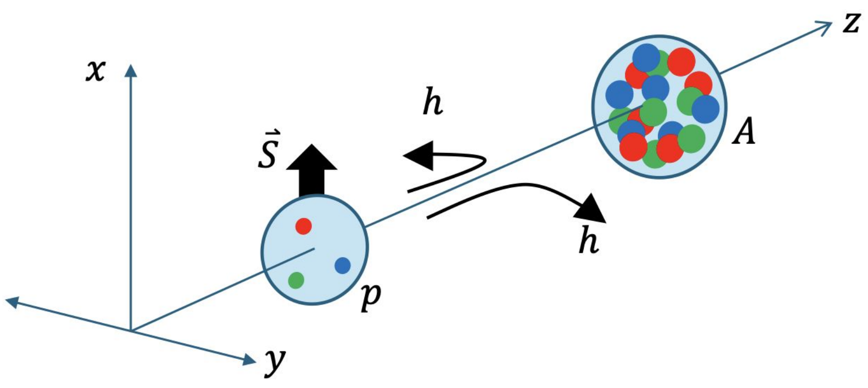
Gabriel Santiago

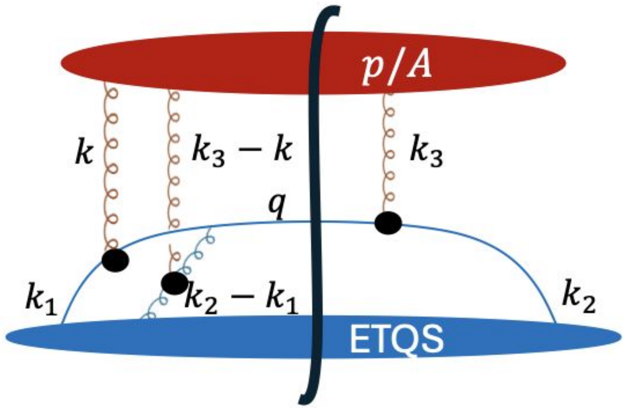




Josh Tawabutr

Transverse single spin asymmetries (TSSA)





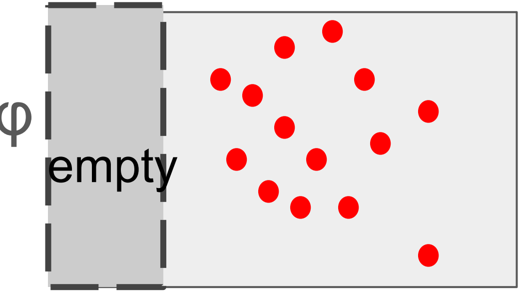
Contribution to TSSA from Odderon exchanges at small x

Eric Vivoda

Experimental overview

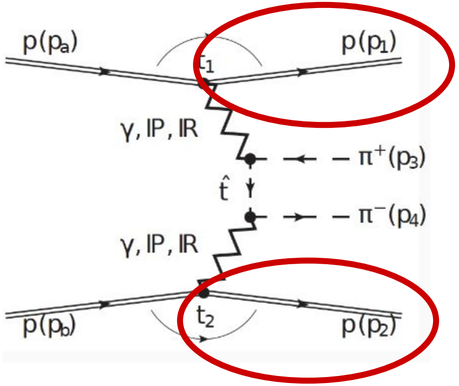
Experimentalist toolbox for diffraction & photoproduction

pp, pA, AA



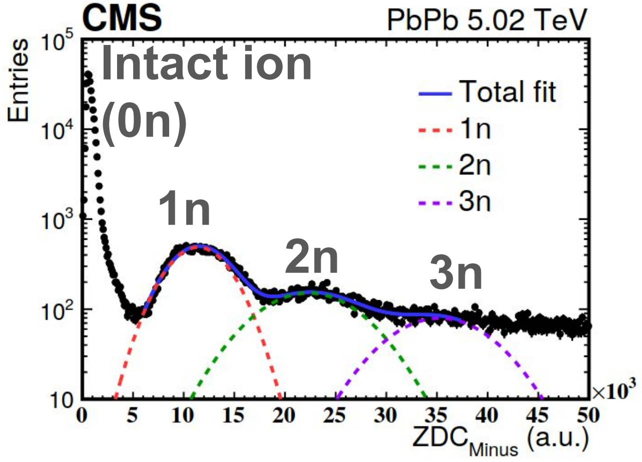
Rapidity gaps
(no particle activity)

pp, pA?



Tagging outgoing hadron
(e.g., Roman pots in
ATLAS, CMS/TOTEM)

pA, AA



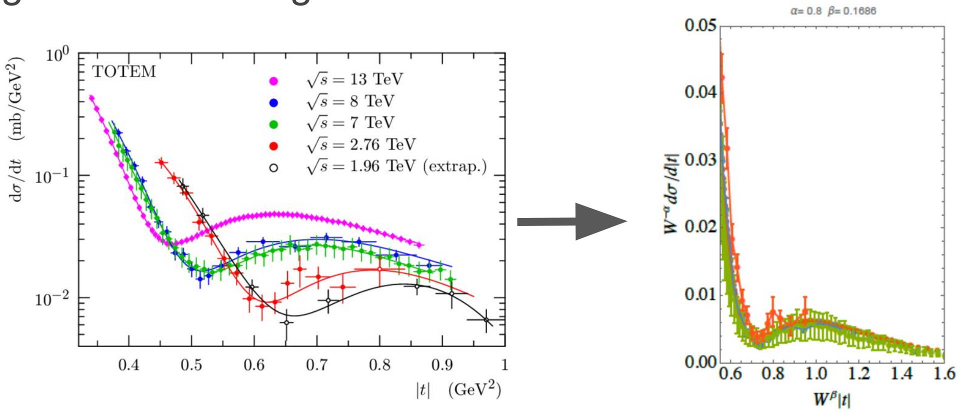
Tagging neutron emissions from giant dipole resonances
(Zero degree calorimeters in CMS, ATLAS, ALICE, STAR)

“Simple” final states help isolate signal further (e.g., pair of back-to-back tracks)

See *Ronan McNulty’s* plenary

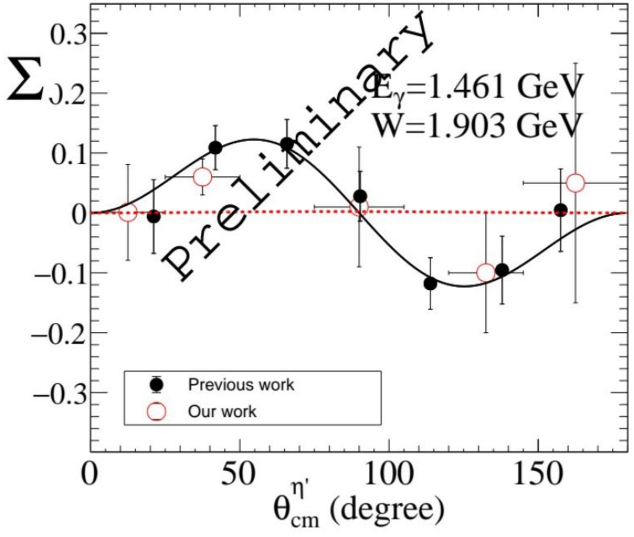
Soft diffraction & low-energy photoproduction

Energy-invariant features in pp→pp scattering at ISR & LHC, geometric scaling in data? ***Michał Praszałowicz***



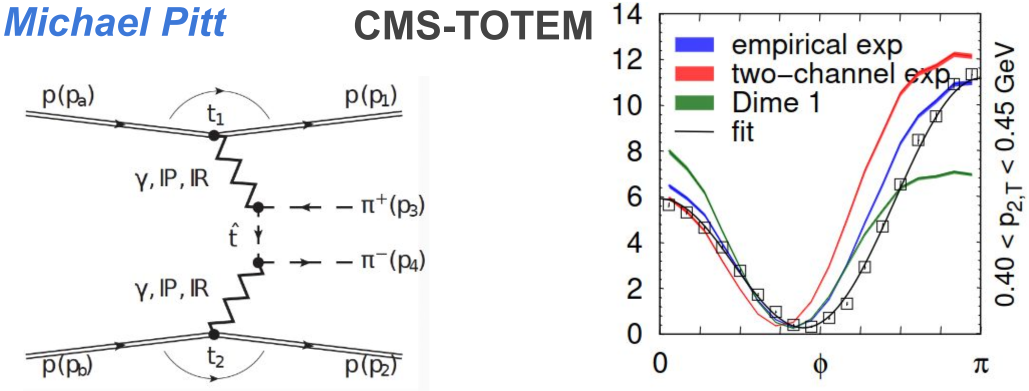
η’-photoproduction to constrain nucleon resonances at Graal γ^{*}n →η’ n (**experiment @ Grenoble!**),

Antonio Riggio

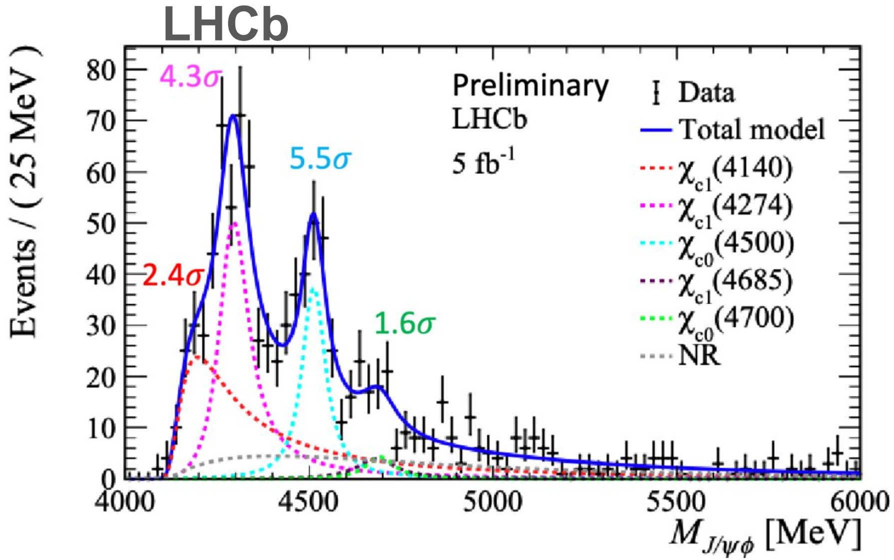


Nonresonant pp→p h^+h^- p, **triple-differential** cross section

Michael Pitt **CMS-TOTEM**



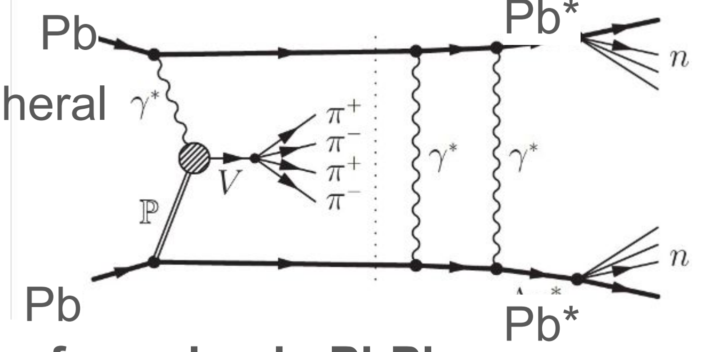
Exotic states & new PDG inputs



Sharp signatures of exotic states in exclusive production!

Cesar da Silva

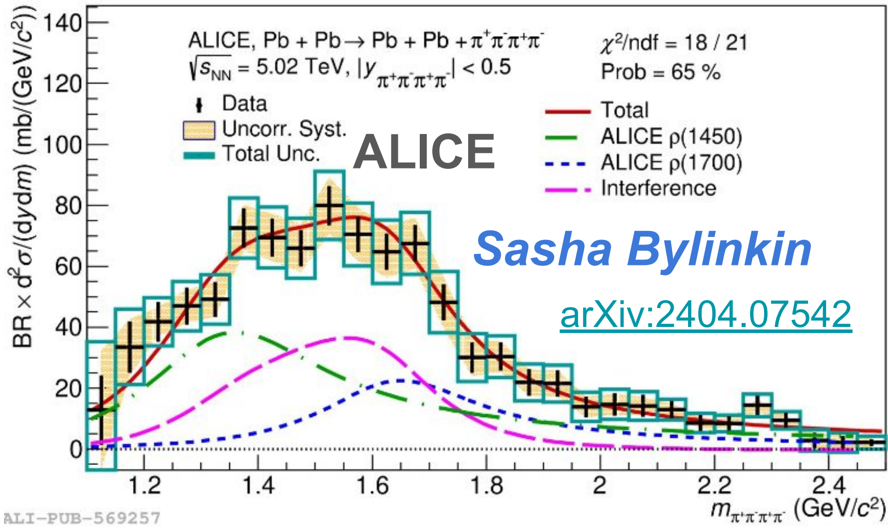
Ultraperipheral
(b ≳ 2R)



Exclusive four-pion in PbPb

Interference of $\varrho(1450)$ and $\varrho(1700)$ states

\+ **new inputs to PDG for mass & width**

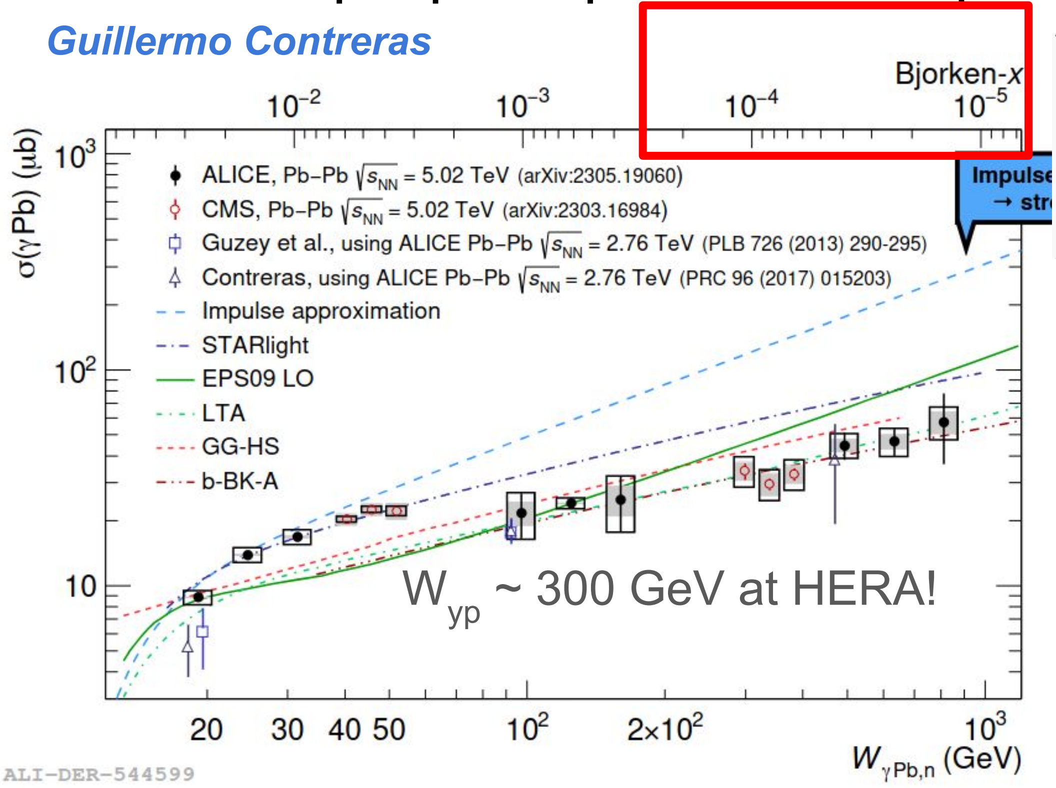


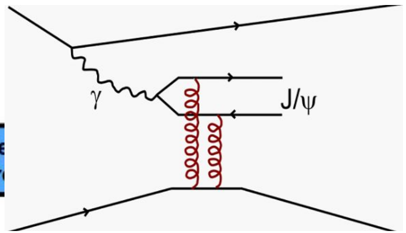
Sasha Bylinkin

arXiv:2404.07542

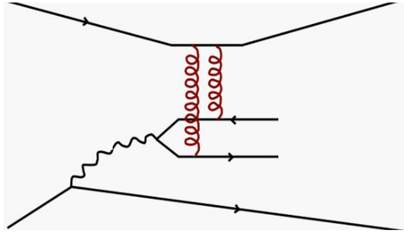
Coherent J/psi photoproduction in photon-nucleus frame

Guillermo Contreras





or



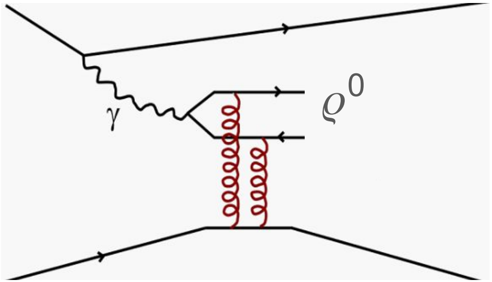
- Two-way ambiguity in symmetric PbPb system; has been overcome w/ the use of ZDC!
- Strong suppression with respect to Wyp cross section scaled to number of nucleons
- no single model describes globally the data at small-x & high-x

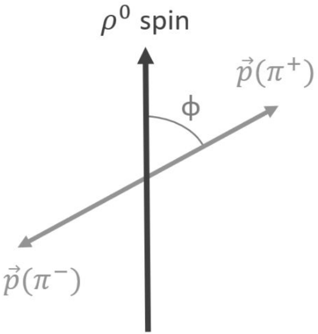
CMS&ALICE overcoming two-way ambiguity in PbPb!

Crucial to disentangle small-x evolution

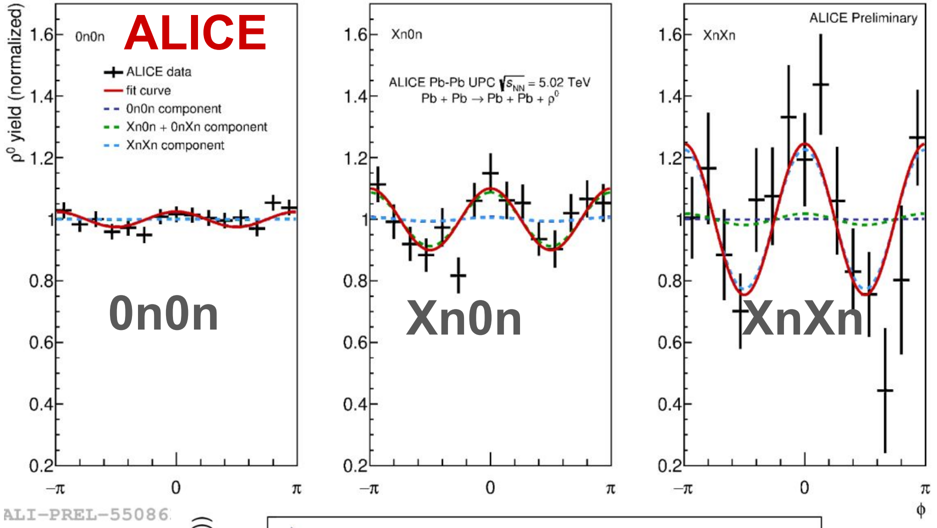
Azimuthal anisotropy in exclusive ρ^0 photoproduction (**evolution with ZDC activity**)

Andrea Riffero



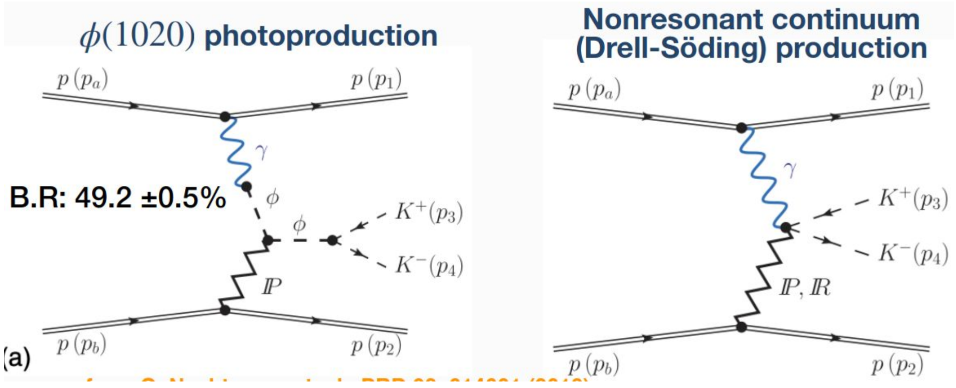


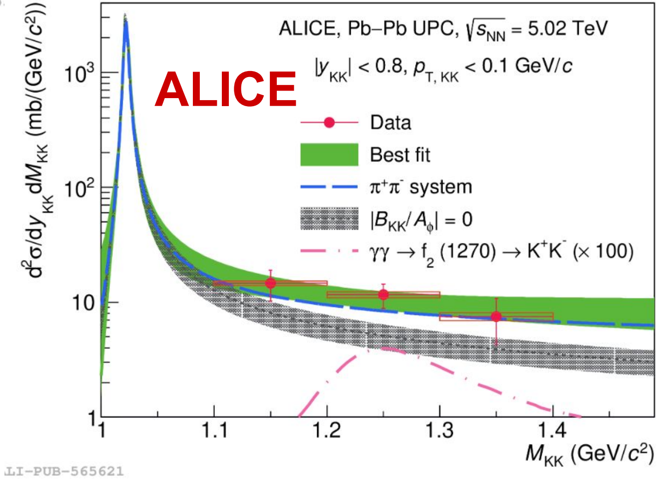
Large → small impact parameter



Exclusive K^+K^- photoproduction in PbPb,

Minjung Kim

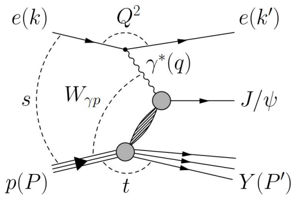




Incoherent J/ψ photoproduction in photon-proton & photon-nucleus

Constrains subnucleonic fluctuations ("hotspots") expected from saturation models

y*Pb → J/ψ+Pb*

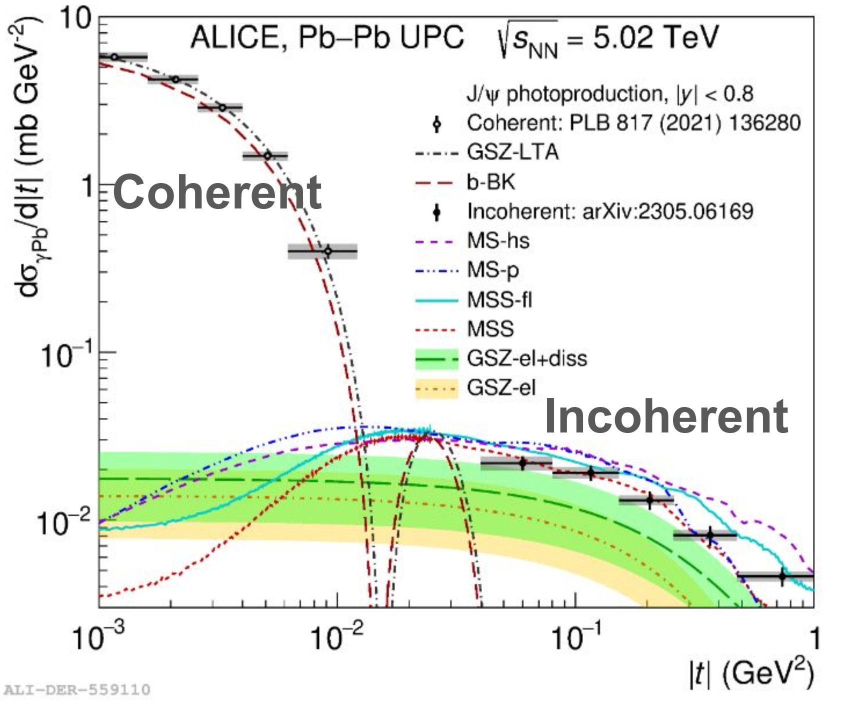


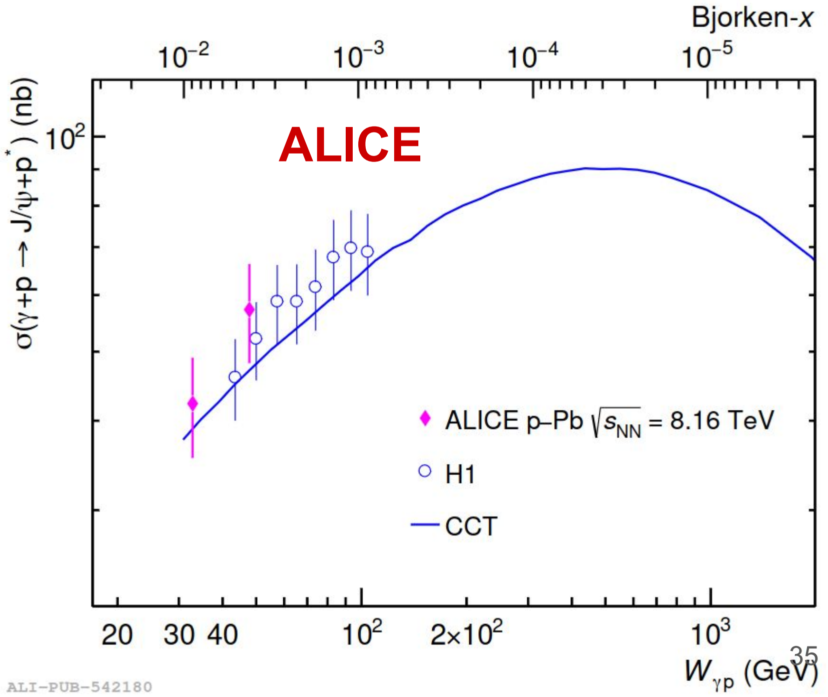
y* p → J/ψ+p* (dissociative)

2016 pPb data keeps giving!

Consistent with H1 data

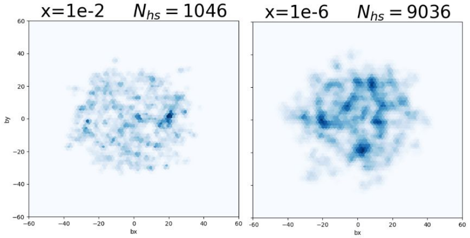
David Grund



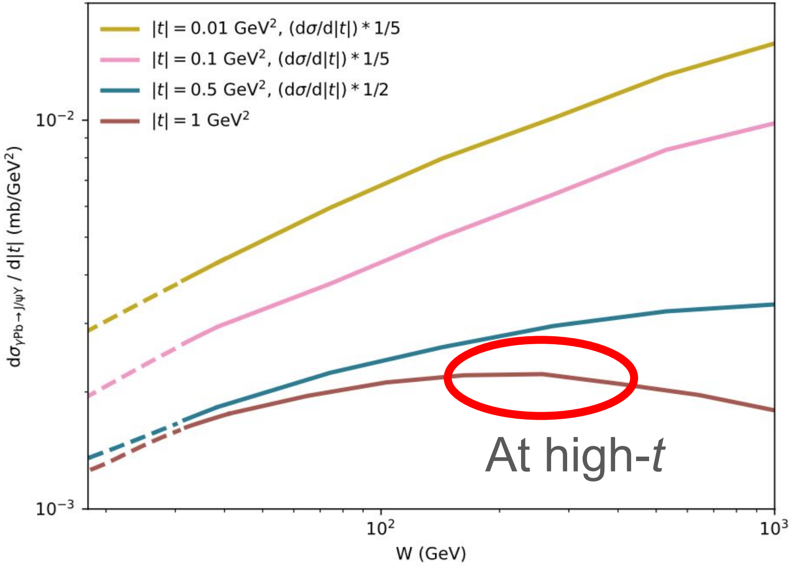


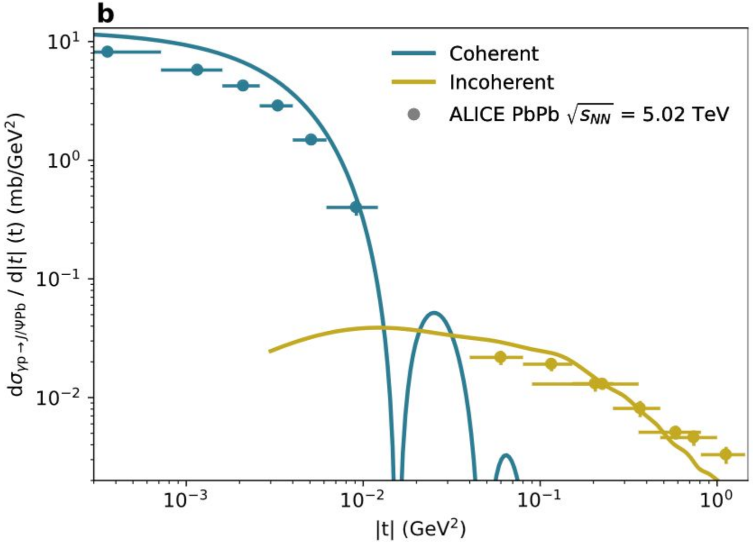
Onset of gluon saturation could be identified using incoherent J/ψ production (hotspot model)

Alexandra Ridziková



Hotspots in transverse plane

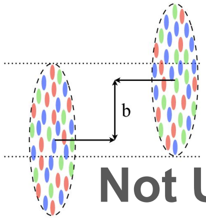




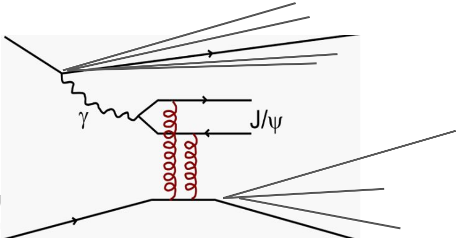
Saturation sets in “sooner” than for coherent J/psi photoproduction

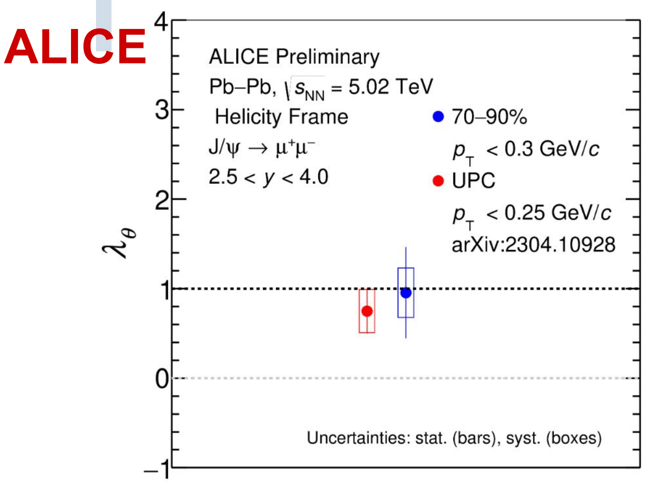
Beyond ***exclusive*** photoproduction…?

- Further understanding of coherent J/ψ photoproduction in ***peripheral*** **(70-90%)** PbPb collisions
  Afnan Shatat



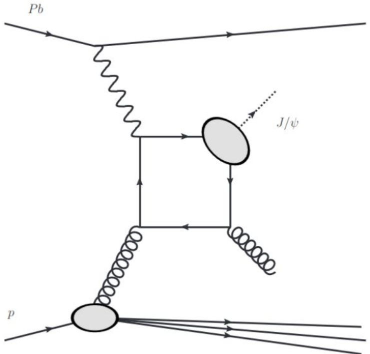
Not UPC!



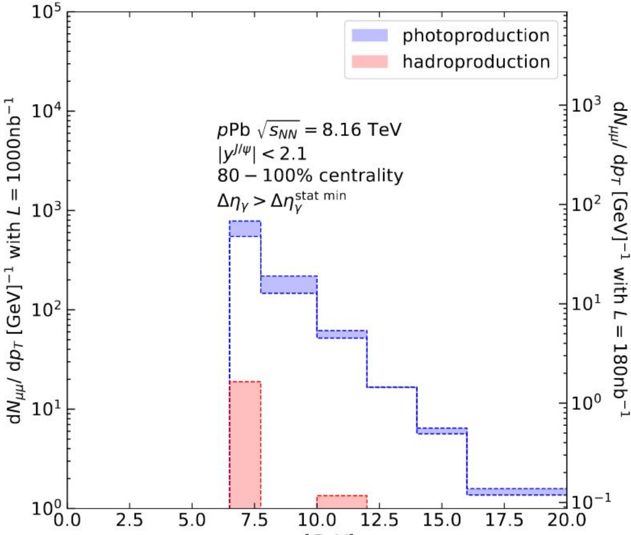


Polarization of J/psi in peripherals consistent with UPC J/psi's

- ***Inclusive*** J/ψ photoproduction is possible at the LHC!
  (***not yet measured at the LHC!***)
  Kate Lynch

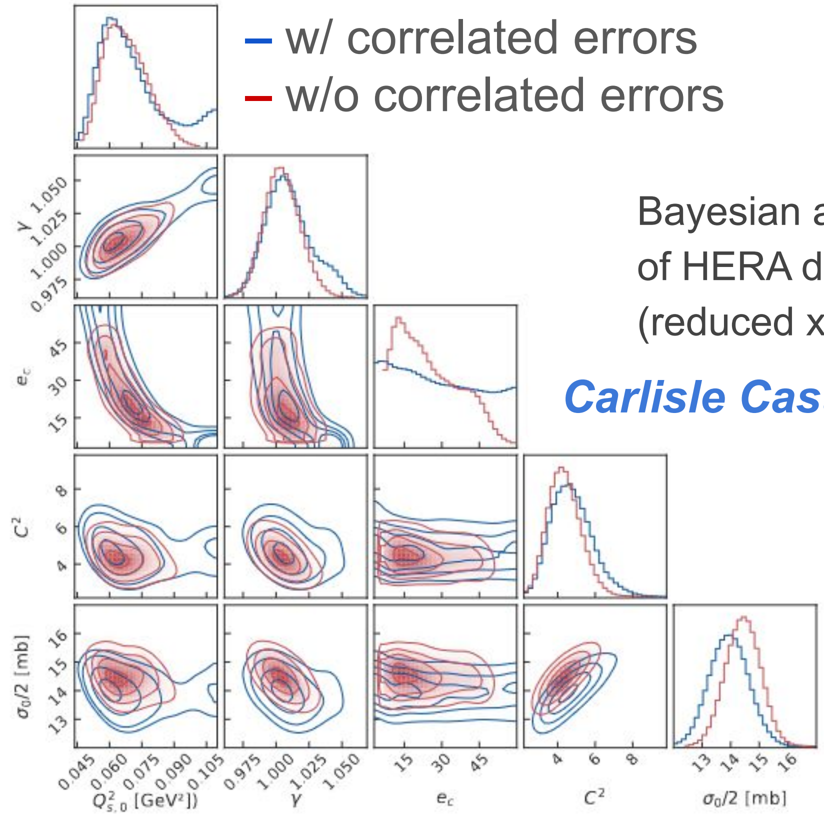


J/ψ p_T up to 20 GeV at the LHC
(p_T ~ 10 GeV@HERA)



HERA data fits

Posterior distributions of BK initial condition params.



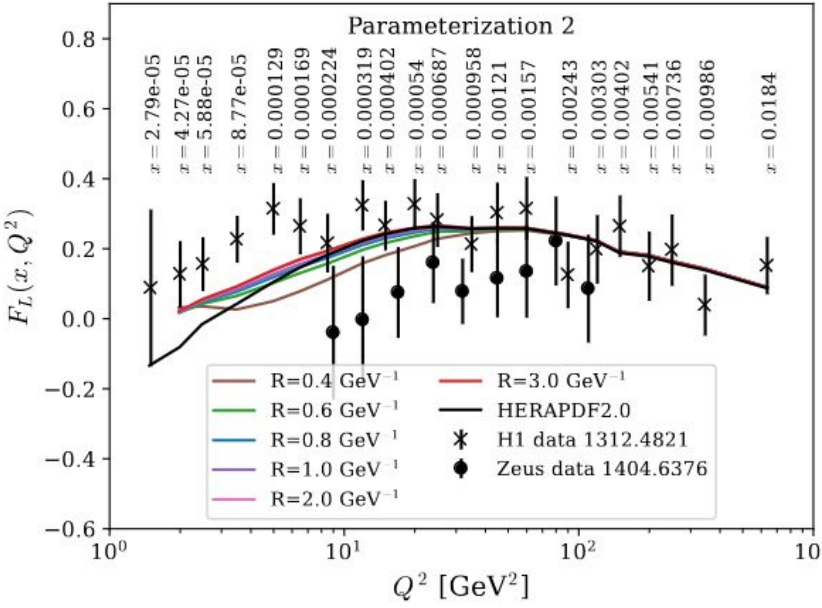
Bayesian analysis of HERA data (reduced xsec)

Carlisle Casuga

Global PDF fits with nonlinear corrections (HOPPET + xFitter)

No clear signs of gluon recombination

Pit Duwentäster



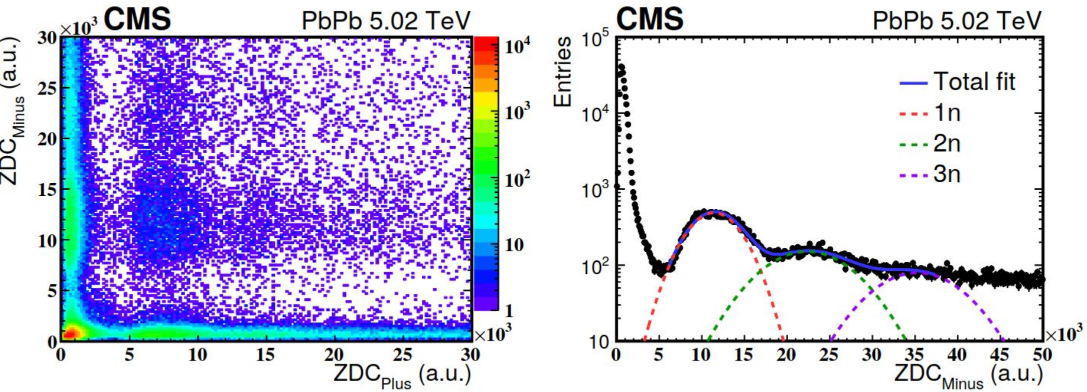
Crucial for experimentalists to provide covariance matrices!

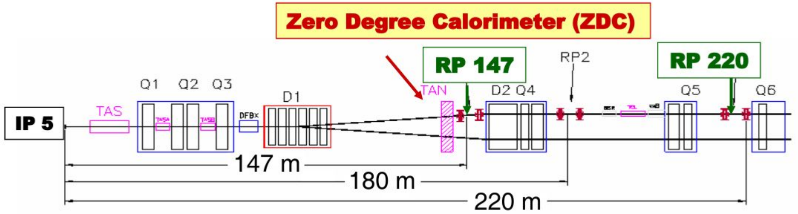
Thanks to the organisers, and to all the session speakers & attendees!

Backup

Forward neutron multiplicity ⇔ impact parameter "filter"

Softer photon-exchange in addition to hard scattering → forward neutrons from nuclear breakup
Events can be categorized w.r.t. Zero Degree Calorimeter (**ZDC**) activity (0n0n, 0nXn, XnX n, with X = 1, 2, ...)



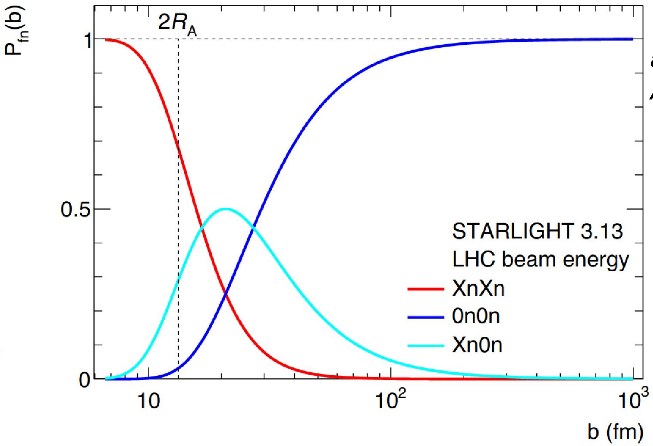


Phys. Rev. Lett. 127, 122001 (2021)

arXiv:2011.05239, Phys. Rev. Lett. 127, 122001 (2021)

Selection of a specific ZDC topology is also filtering on a range of impact parameters.

Xn0n or XnXn select smaller impact parameters than 0n0n!



arXiv:2005.01872, S. Klein, P. Steinberg, Ann. Rev. Nucl. Part. Sci. 70 (2020) 323