Vector meson production at large t in eA collisions

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Outline:

Introduction

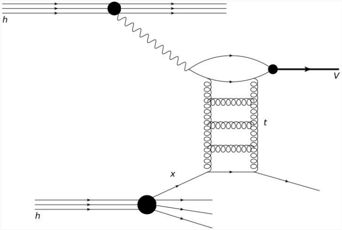
Formalism

Results & Conclusions

Introduction

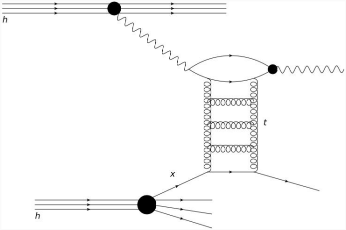
Motivations

- Diffractive process and rapidity gaps
- Exchange of the BFKL Pomeron in high momentum transfer to study the QCD dynamics at LHC
- Diffractive production of mesons (ρ, J/ψ and Υ) in LHC: Gonçalves, Sauter, Phys.Rev. D81 (2010) 074028, Eur.Phys.J. A47 (2011) 117, Phys. Lett B776 (2017) 424



Motivations

- Diffractive process and rapidity gaps
- Exchange of the BFKL Pomeron in high momentum transfer to study the QCD dynamics at LHC
- Diffractive production of mesons (ρ, J/ψ and Υ) in LHC: Gonçalves, Sauter, Phys.Rev. D81 (2010) 074028, Eur.Phys.J. A47 (2011) 117, Phys. Lett B776 (2017) 424
- Photo-production of photons. Gonçalves, Sauter, Phys.Rev. D87 (2013) 5, 054035

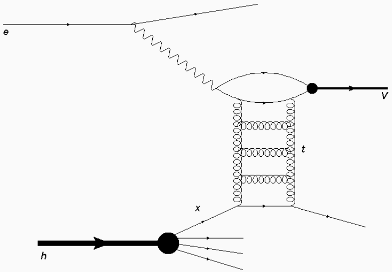


Motivations for EIC

- Production of vector mesons as observer of QCD dynamics: linear (DGLAP/BFKL) and non-linear (BK)
- Have a clean experimental signature: more precise kinematic variable determination
- Previous measurements in HERA have a limited rapidity acceptance.
- EIC will access a new kinematic regime in eA scattering

Motivations for EIC

Quick calculation:
Change the projectiles to eA and use more recent nuclear PDFs



Formalism

Previous

The calculation is based on

- Forshaw, Ryskin. *Z. Phys* C68, 137 (1995)
- Bartels, Forshaw, Lotter, Wüsthoff. *PLB* 375 (1996) 301
- Enberg, Motyka, Poludniowski *EPJ* C26, 219 (2002)

J/ψ in pA collisions:

- Frankfurt, Strickman, Zhalov *PLB* 640(2006)162, *PLB*670 (2008) 32

More recent:

- BFKL Loops in J/ψ & Υ production: Kotko, Motyka, Sadzikowski & Staśto: *JHEP*07(2019)129
- In EiC for ep: Deák, Staśto and Strickman *PRD*103, 014022 (2021)

Cross sections

- Photo inducted particle production.
- Coherent production: almost real photon
- Presence of rapidity gaps
- Large momentum transfer: dissociation of the target
- BFKL Pomeron exchange, but have a limited kinematic window

Cross sections

The differential and total cross sections: for the diffractive particle photoproduction at large momentum transfer reads

$$\frac{d\sigma_{\gamma h \to VX}}{dt} = \int_{x_{\min}}^{1} dx_j \, \frac{d\sigma}{dtdx_j}, \quad \sigma_{\text{tot}} = \int_{t_{\min}}^{t_{\max}} dt \, \frac{d\sigma_{\gamma h \to VX}}{dt}$$

where h denote a hadron, V the vector meson (J/ψ), X the hadron fragments and

$$\frac{d\sigma}{dtdx_j} = \left[\frac{81}{16} G(x_j, |t|) + \sum_j (q_j(x_j, |t|) + \bar{q}_j(x_j, |t|)) \right] \frac{d\hat{\sigma}}{dt}.$$

The pomeron couples with individual partons in hadron. Moreover, G, q and $\bar{q}$ are parton distribution functions. Previous we used CTEQ6L (for vectors) and MSTW2008LO (for photons) parton parametrization in proton-proton collisions and EKS for the ion-ion case.

Partonic cross section

Partonic cross section for vector meson production: is given by

$$\frac{d\hat{\sigma}}{dt}(\gamma q \to Vq) = \frac{1}{16\pi}|\mathcal{A}_V(s,t)|^2.$$

Meson production:

$$\mathcal{A}_V(s,t) = \frac{2}{9\pi^2}\int d\nu \frac{\nu^2}{(\nu^2+1/4)^2}\left(\frac{s}{\Lambda^2}\right)^{\omega(\nu)} I_\nu^{\gamma V}(Q_\perp) I_\nu^{qq}(Q_\perp)^*,$$

The quantities I's are related with the impact factors of $\gamma \to V$ and $q \to q$,

$$I_\nu^{\gamma V_i}(Q_\perp) = -\mathcal{C}_i\,\alpha_s \frac{16\pi}{Q_\perp^3}\frac{\Gamma(1/2-i\nu)}{\Gamma(1/2+i\nu)}\left(\frac{Q_\perp^2}{4}\right)^{i\nu}\int_{1/2-i\infty}^{1/2+i\infty}\frac{du}{2\pi i}\left(\frac{Q_\perp^2}{4M_{V_i}^2}\right)^{1/2+u} \times \frac{\Gamma^2(1/2+u)\Gamma(1/2-u/2-i\nu/2)\Gamma(1/2-u/2+i\nu/2)}{\Gamma(1/2+u/2-i\nu/2)\Gamma(1/2+u/2+i\nu/2)}.$$

The quark impact factor is given by

$$I_\nu^{qq}(Q_\perp) = -\frac{4\pi\alpha_s}{Q_\perp}\left(\frac{Q_\perp^2}{4}\right)^{i\nu}\frac{\Gamma(\frac{1}{2}-i\nu)}{\Gamma(\frac{1}{2}+i\nu)}.$$

BFKL (LO)

BFKL characteristic function:
From BFKL equation:

$$\omega(\nu) = \overline{\alpha}_s \chi(\gamma), \quad \overline{\alpha}_s = (N_c \alpha_s)/\pi, \quad \gamma = 1/2 + i\nu$$

At leading order: the BFKL function $\chi(\gamma)$ is given by

$$\chi^{\mathrm{LO}}(\gamma) = 2\psi(1) - \psi(\gamma) - \psi(1-\gamma)$$

where $\psi(z)$ is the digamma function. In what follows this expression is used in our calculations of the vector meson production at large-t.

Problems in LO:

- the energy scale Λ is arbitrary;
- α_s is fixed at LO BFKL;
- the power growth with energy violates s-channel unitarity at large rapidities.

BFKL (NLO)

Original NLO BFKL kernel obtained by Fadin, Ciafaloni:

$$\chi(\gamma) = \chi^{\mathrm{LO}}(\gamma) + \overline{\alpha}_s \chi^{\mathrm{NLO}}(\gamma), \quad \bar{\alpha}_s = N_c \alpha_s / \pi,$$

Several problems:

- the choice of energy scale;
- the renormalization scheme;
- large correction;

Alternatives:

- Brodsky, Fadin, Kim, Lipatov, Pivovarov (1999) : BLM optimal scale + MOM renormalization scheme
- Sabio-Vera (2005) *All-poles*: collinearly improved BFKL kernel characteristic function: $\Rightarrow$ resum collinear effects

Results & Conclusions

Vector mesons:[1]

Strongly depend on

- coupling constant: $\alpha_s = 0.21$
- energy scale with free parameters $\Lambda \equiv s_0 = \beta M_V^2 + \gamma|t|$

Calculation:
Impact factors and BFKL kernel at LO

The NLO BFKL correction is large

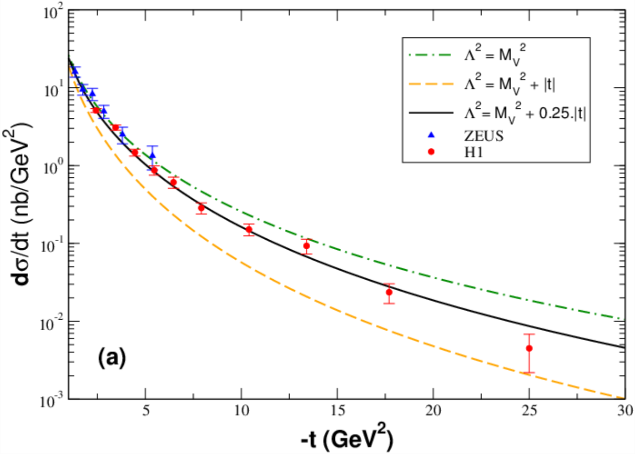
Fit to HERA data to fix the parameters

[1] Gonçalves, Sauter, Phys.Rev. D81 (2010) 074028, Eur.Phys.J. A47 (2011) 117

Vector mesons:[1]

$d\sigma/dt$ using to fixing the parameters (using HERA data):

J/ψ:



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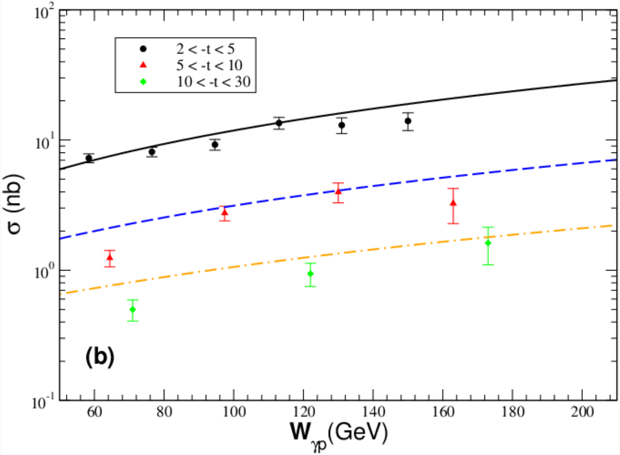
Vector mesons:[1]

σ_{tot} with the parameters fixed:

J/ψ (H1 & ZEUS03):



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Hadronic collisions

- Cross section:

$$\frac{d\sigma\left[h_1 + h_2 \to h_1 \otimes Y \otimes X\right]}{dy} = \int_{t_{\min}}^{t_{\max}} dt\ \omega \frac{dN_\gamma(\omega)}{d\omega}\ \frac{d\sigma_{\gamma h \to YX}}{dt}(\omega)$$

- Proton photon flux (Dress *et al.*):

$$\frac{dN_\gamma^{pp}(\omega)}{d\omega} = \frac{\alpha_{\rm em}}{2\pi\,\omega}\left[1 + \left(1 - \frac{2\,\omega}{\sqrt{S_{\rm NN}}}\right)^2\right]\left(\ln\Omega - \frac{11}{6} + \frac{3}{\Omega} - \frac{3}{2\,\Omega^2} + \frac{1}{3\,\Omega^3}\right)$$

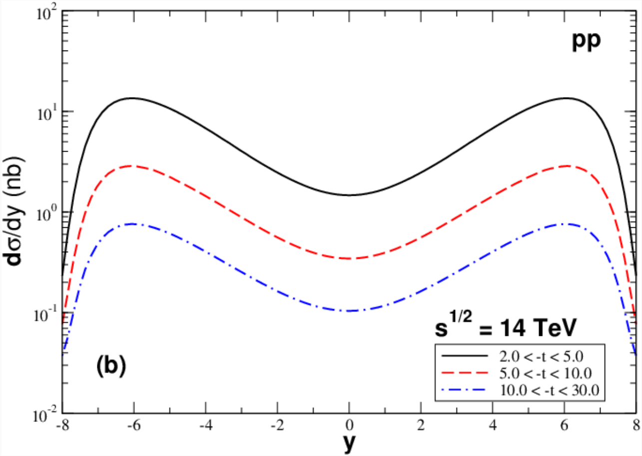
- Nucleus photon flux (Weissäcker/Williams):

$$\frac{dN_\gamma^{AA}(\omega)}{d\omega} = \frac{2\,Z^2\alpha_{em}}{\pi\,\omega}\left[\bar{\eta}\,K_0(\bar{\eta})\,K_1(\bar{\eta}) - \frac{\bar{\eta}^2}{2}\left(K_1^2(\bar{\eta}) - K_0^2(\bar{\eta})\right)\right]$$

where $\bar{\eta} = \omega\,(R_{h_1} + R_{h_2})/\gamma_L$

Using the previous parameters.

J/ψ:



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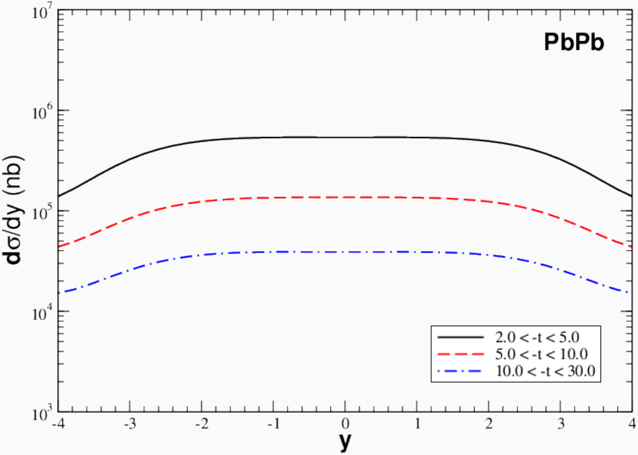
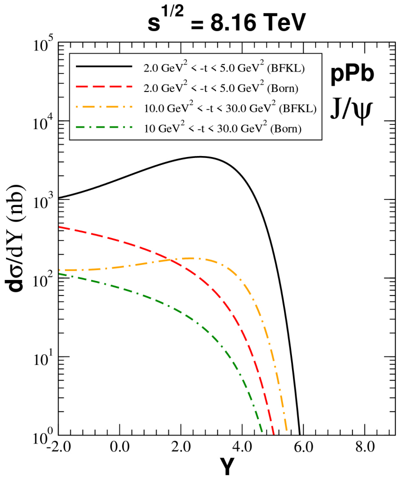
J/ψ:



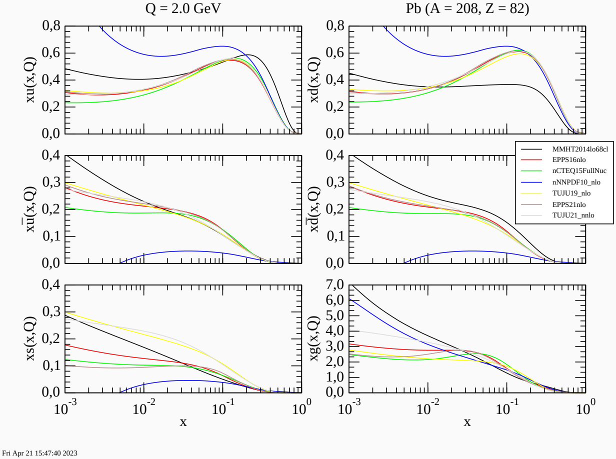
Comparison among Born level (2 gluons) and BFKL ladder:



Electron-Ion collisions

For $eA \to eVX$ process, I perform the same calculations as hh collisions, but replacing the proton PDF by a nuclear one **and** the photon luminosity.

Using the LHAPDF interface: `EPPS21nlo, nCTEQ15, TUJU21nnlo`



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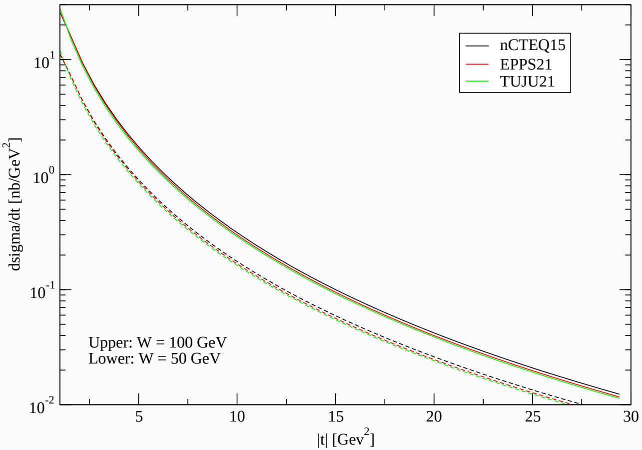
Electron photon flux (Frixione):

$$\frac{dN_\gamma(\omega)}{d\omega} = \frac{\alpha}{2\pi y}\left\{\left[1+(1-y)^2\right]\ln\left[\frac{Q^2_{\rm max}(1-y)}{m_e^2 y^2}\right] + 2\left[\frac{m_e^2 y^2}{Q^2_{\rm max}} - (1-y)\right]\right\}$$

$$y = \ln(2\omega/m_v), \quad Q^2_{\rm max} = 4\,\mathrm{GeV}^2$$

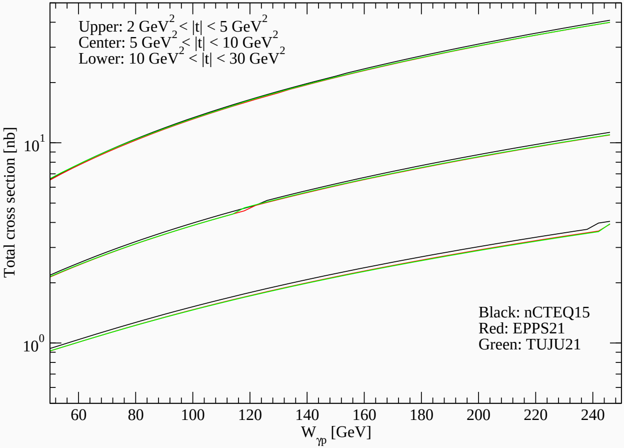
Electron-Ion collisions: PRELIMINARY RESULTS!

Differential cross-sections: same parameters of previous calculation.



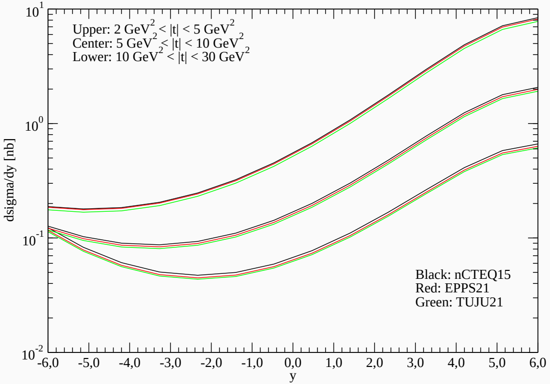
Electron-Ion collisions: PRELIMINARY RESULTS!

Total cross sections: same t intervals as pp and pA collisions in LHC



Electron-Ion collisions: PRELIMINARY RESULTS!

Rapidity distribution:



Conclusions

Our results:

1. BFKL formalism is able to describe the current experimental data of *ep* collisions at HERA with suitable choice of parameters
2. *pp* interactions at LHC $\Rightarrow$ able to constrain the QCD dynamics
3. complementary to the recent theoretical and phenomenological studies that use NLO BFKL Pomeron as $\gamma^*\gamma^*$, Mueller-Navelet jets.
4. The exploratory analysis done here is useful to indicate the potentiality of this process to probe the BFKL dynamics as well as to constrain the influence of the higher order corrections

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Other contributions: conformal spin (small effect); NLO BFKL; Other nuclei

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Thank you!