Diffractive dijet production from the CGC

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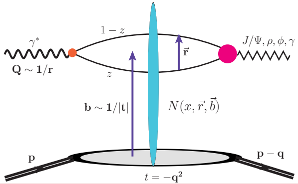
Outline

- Motivation:
  - Diffractive vector meson production and saturation effects.
  - Diffractive photo-production of VM at the LHC and saturation effects.
- Diffractive dijet in DIS at small-x, and CGC/saturation signature.
- Diffractive photo-production of dijet at the LHC.

This talk is mainly based on:

Altinoluk, Armesto, Beuf and Rezaeian, PLB 758, arXiv:1511.07452.
Armesto and Rezaeian, PRD 90, arXiv:1402.4831.

Exclusive diffractive process: $\psi^{\gamma}_{q\bar{q}} \otimes \mathcal{N} \otimes \phi^{V}_{q\bar{q}}$

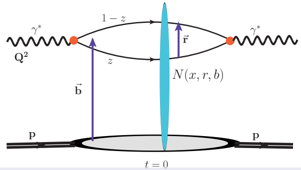


$$\mathcal{A}^{\gamma^* p \to Vp}_{T,L}(x, Q, \Delta) = 2\mathrm{i} \int \mathrm{d}^2\vec{r} \int_0^1 \mathrm{d}z (\Psi^*_E \Psi)_{T,L} \int \mathrm{d}^2\vec{b}\, \mathrm{e}^{-\mathrm{i}[\vec{b}-(1-z)\vec{r}]\cdot\vec{\Delta}} N(x, r, b)$$

$$\frac{\mathrm{d}\sigma^{\gamma^* p \to Ep}_{T,L}}{\mathrm{d}t} = \frac{1}{16\pi} \left|\mathcal{A}^{\gamma^* p \to Ep}_{T,L}\right|^2 \qquad t = -\Delta^2$$

- With corrections from the real part of the amplitude and skewedness effect $x \neq x'$
- $(b \to 1/|t|)$: t-distributions access impact-parameter distribution of interactions

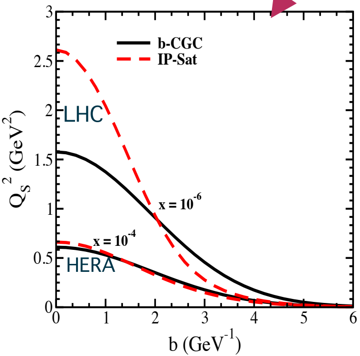
Inclusive deep-inelastic scattering (DIS): $\psi^{\gamma}_{q\bar{q}} \otimes \mathcal{N} \otimes \psi^{\gamma}_{q\bar{q}}$

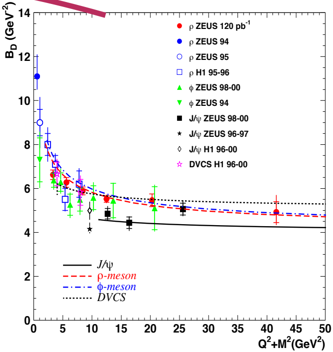


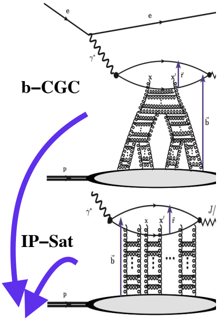
$$\sigma^{\gamma^* p}_{L,T}(Q^2, x) = Im\, \mathcal{A}^{\gamma^* p \to \gamma^* p}_{T,L}(x, Q, \Delta = 0)$$
$$= 2 \int \mathrm{d}^2\vec{r} \int_0^1 dz\, |\Psi_{L,T}(r, z; Q^2)|^2 \int \mathrm{d}^2\vec{b}\, N(x, r, b)$$

- DIS is less sensitive to the b-dependence compared to exclusive diffractive process

and **does not** probe $b \approx 0$, but $b \approx 2 \div 3\,\mathrm{GeV}^{-1}$.







$$\frac{d\sigma_{T,L}^{\gamma^* p\to Ep}}{dt} \approx e^{-B_D|t|} \text{ (large } Q^2) \Longleftrightarrow Q_s^2(x,b) \approx Q_s^2(x)e^{-b^2/2B_D}$$

- At a fixed Q^2, the typical dipole size is bigger for lighter vector meson $\Longrightarrow$ validity of the above asymptotic expression is postponed to a higher Q^2.
- **t-slope B_D gives the width of saturation scale distribution in proton**.

A unified description of combined inclusive HERA data & diffractive data in CGC

Rezaeian, Siddikov, Van de Klundert, Venugopalan, arXiv:1212.2974; Rezaeian, Schmidt, arXiv:1307.0825

The dipole scattering amplitude is the main ingredient with 3 or 4 free parameters fixed via a fit to the reduced cross–section.

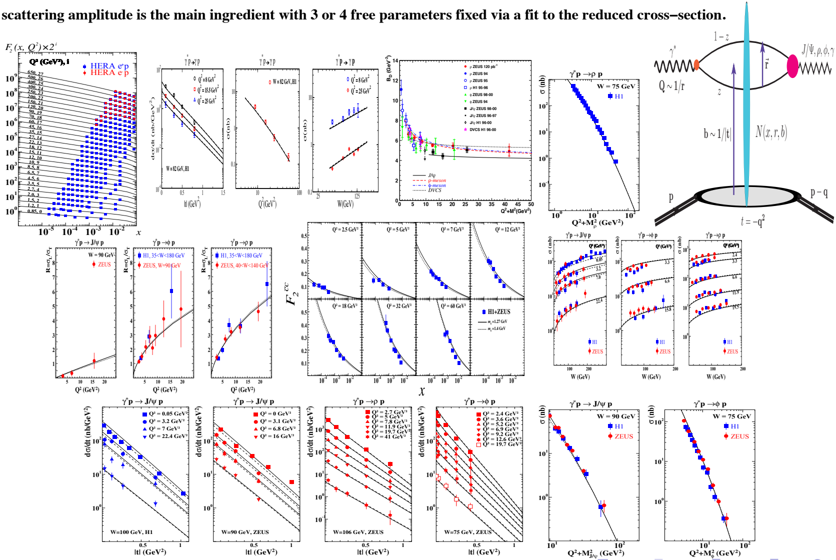
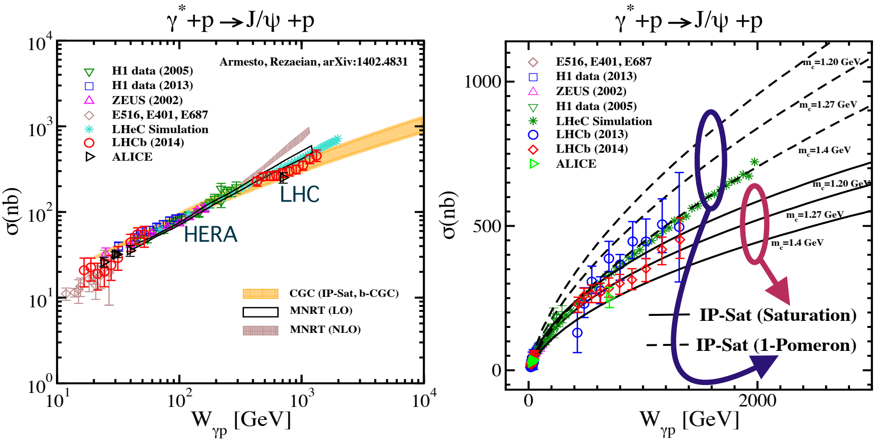
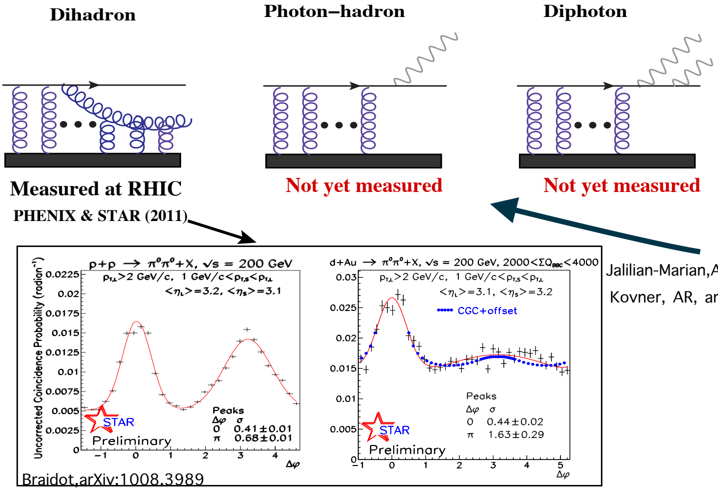


Photo-production of J/ψ from HERA to the LHC



- The LHCb and ALICE data seem to favor the CGC/Saturation predictions.
- The uncertainties related to the charm mass is very large.

Back-to-back decorrelations in inclusive production in the CGC



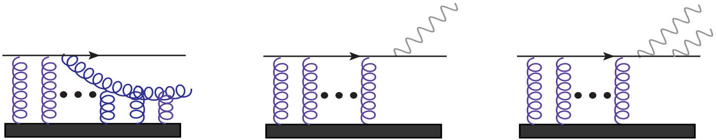
Jalilian-Marian,AR,arXiv:1110.281

Kovner, AR, arXiv:1404.5632

- Back-to-back correlation gets suppressed due to the saturation scale. This is universal to all **inclusive** two-particle production shown above.

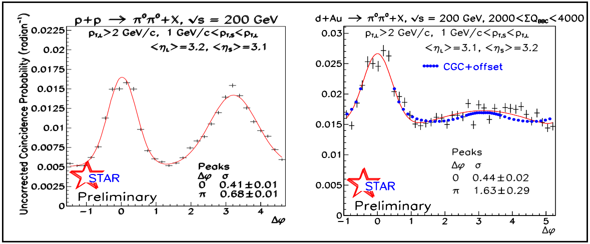
Back-to-back decorrelations in inclusive production in the CGC

Dihadron **Photon−hadron** **Diphoton**



Measured at RHIC **Not yet measured** **Not yet measured**

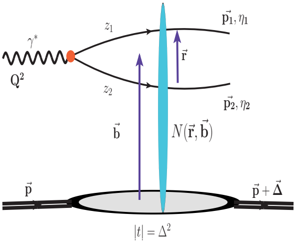
PHENIX & STAR (2011)



- Back-to-back correlation gets suppressed due to the saturation scale. This is universal to all **inclusive** two-particle production shown above.

What about diffractive production?, suppression or enhancement?.

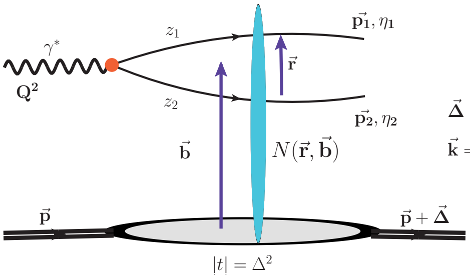
Diffractive (averaging over color at amplitude level): $\sigma \propto |\langle \mathcal{M} \rangle_\rho|^2$
Inclusive (averaging over color at cross-section level): $\sigma \propto \langle |\mathcal{M}|^2 \rangle_\rho$



$$\sigma^{\text{Diffractive dijet}} \propto \psi^{\gamma}_{q\bar{q}} \otimes \mathcal{N}(\vec{r}, \vec{b}) \otimes \mathcal{N}(\vec{r'}, \vec{b'}) \neq \psi^{\gamma}_{q\bar{q}} \otimes [\mathcal{N}(r, b)]^2$$
$$\sigma^{\text{Inclusive dijet}} \propto \psi^{\gamma}_{q\bar{q}} \otimes [\mathcal{N}(\vec{r}, \vec{b}) + S^{\text{Quadrupole}}(\vec{r}, \vec{r\prime}, \vec{b}, \vec{b'})]$$
$$\sigma^{\text{Inclusive DIS}} \propto \psi^{\gamma}_{q\bar{q}} \otimes \mathcal{N}(\vec{r}, \vec{b}) \otimes \psi^{\gamma}_{q\bar{q}}$$

- In contrast to inclusive dijet production, diffractive dijet production only depends on the dipole amplitude (not WW gluon distribution) at LO.

Diffractive Dijet production in the CGC: $\gamma^* + p(A) \to q\bar{q} + p(A)$



$$\vec{\Delta} = \vec{p}_1 + \vec{p}_2$$

$$\vec{k} = \tfrac{1}{2}(\vec{p}_1 - \vec{p}_2)$$

$$\sigma = \psi^{\gamma}_{q\bar{q}} \otimes \mathcal{N}(\vec{r}, \vec{b}) \otimes \mathcal{N}(\vec{r'}, \vec{b'}) \neq \psi^{\gamma}_{q\bar{q}} \otimes [\mathcal{N}(r, b)]^2$$

$$\left(\frac{d\sigma_{\mathrm{T}}^{\mathrm{dijet}}}{dz_1 dz_2 d^2\mathbf{p}_1 d^2\mathbf{p}_2}\right) = (2\pi)^2 \delta(z_1 + z_2 - 1) N_c \alpha_{em} \sum_f e_f^2 \int \frac{d^2\mathbf{r}}{(2\pi)^2} \int \frac{d^2\mathbf{r}'}{(2\pi)^2} \int \frac{d^2\mathbf{b}}{(2\pi)^2} \int \frac{d^2\mathbf{b}'}{(2\pi)^2}$$
$$\times\ \mathbf{e}^{-\mathbf{i}(\mathbf{b}-\mathbf{b}')\cdot(\mathbf{p}_1+\mathbf{p}_2)} \mathbf{e}^{-\mathbf{i}(\mathbf{r}-\mathbf{r}')\cdot(\mathbf{p}_1-\mathbf{p}_2)/2} \mathcal{N}(\mathbf{r}, \mathbf{b})\ \mathcal{N}(\mathbf{r}', \mathbf{b}')\ 2[z_1^2 + z_2^2]\ \frac{\mathbf{r}\cdot\mathbf{r}'}{\mathbf{r}^2\mathbf{r}'^2}\ [\varepsilon|\mathbf{r}|K_1(\varepsilon|\mathbf{r}|)]\ \left[\varepsilon|\mathbf{r}'|K_1(\varepsilon|\mathbf{r}'|)\right]$$

- **Diffractive dijet production is a sensitive probe of the color-dipole orientation**.

Let's assume:

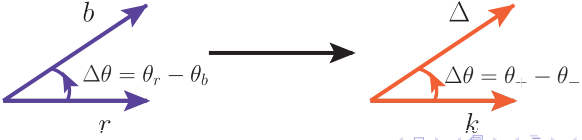
$$\mathcal{N}(\mathbf{r},\mathbf{b}) = \mathcal{N}(r,b,\theta_r-\theta_b) = 1 - e^{-\frac{Q_s^2(b)}{4}r^2\left(1+\mathbf{A}\cos^2(\theta_r-\theta_b)\right)}$$

θ_r, θ_b are the angles of vectors $\vec{r}$, $\vec{b}$ with respect to a reference vector, respectively. Assuming $Q_s^2 r^2 A/4 \ll 1$:

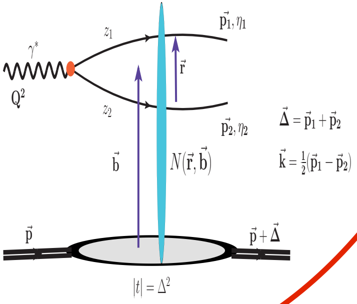
$$\int \frac{d^2\mathbf{r}}{(2\pi)^2}\int \frac{d^2\mathbf{b}}{(2\pi)^2} e^{-i\mathbf{b}\cdot(\mathbf{p}_0+\mathbf{p}_1)} e^{-i\mathbf{r}\cdot(\mathbf{p}_0-\mathbf{p}_1)/2}\mathcal{N}(\mathbf{r},\mathbf{b})K_0(\varepsilon|\mathbf{r}|) \simeq \int_0^{+\infty}\frac{dr}{2\pi}r\int_0^{+\infty}\frac{db}{2\pi}b\, J_0\left(b|\mathbf{p}_0+\mathbf{p}_1|\right) \times J_0\left(r\frac{|\mathbf{p}_0-\mathbf{p}_1|}{2}\right)\mathcal{N}(r,b,\theta_- - \theta_+)K_0(\varepsilon r)$$

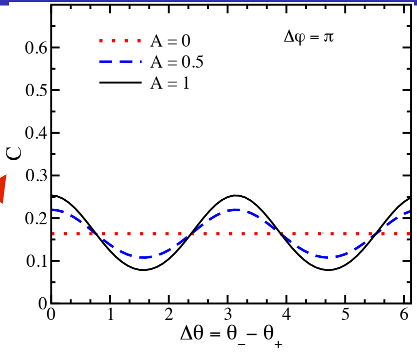
θ_+, θ_- denote the angles of vectors $\vec{\Delta} = \vec{p}_0 + \vec{p}_1$ and $\vec{k} = \frac{1}{2}(\vec{p}_0 - \vec{p}_1)$ with respect to a reference vector, respectively.

- **A nonzero A corresponding to the existence of $\vec{r} - \vec{b}$ correlations in the color dipole amplitude, induces azimuthal correlations between $\vec{\Delta}$ and $\vec{k}$.**



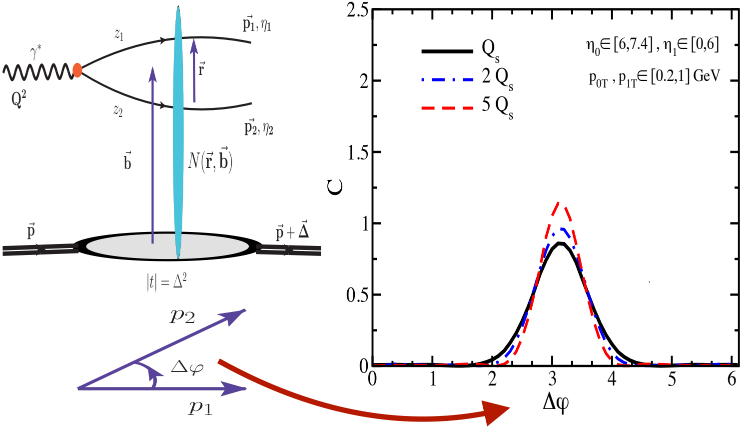
Diffractive dijet production as a probe of color-dipole orientation



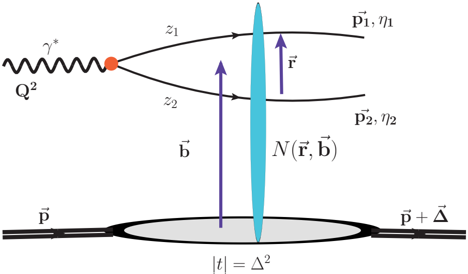


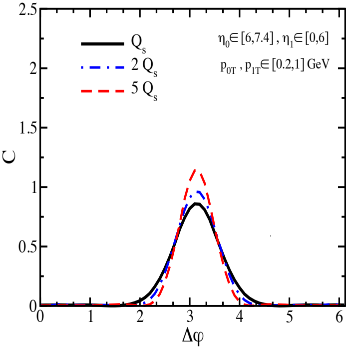
$$C(\Delta\theta) = \frac{d\sigma^{\gamma^\star p\to q\bar{q}p}}{d\mathbf{p}_0\,\mathbf{p}_1\,d\Delta\theta} \Bigg/ \int_0^{2\pi} d\Delta\theta\,\frac{d\sigma^{\gamma^\star p\to q\bar{q}p}}{d\mathbf{p}_0\,\mathbf{p}_1\,d\Delta\theta}$$

- **A nonzero A corresponding to the existence of $\vec{r}-\vec{b}$ correlations in the color dipole amplitude, induces sizeable azimuthal correlations for dijet between $\vec{\Delta}$ and $\vec{k}$.**

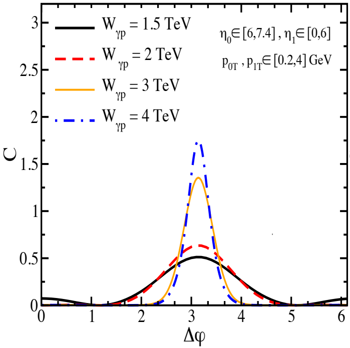


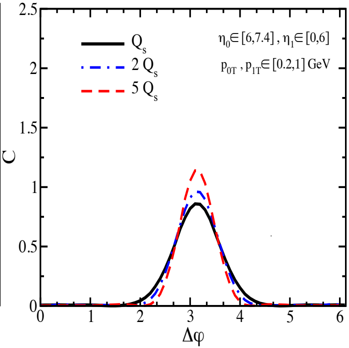
- In order to keep the color neutrality of the dijet system, required by its diffractive nature, the production becomes dominated by $q\bar{q}$ pairs of smaller transverse size with increasing saturation momentum.





- **Diffractive** dijet photoproduction:
  Back-to-back correlation gets **enhanced** due to the saturation scale.
  Balance between: $p_{1T}, p_{2T}, \vec{\Delta}, Q_s$
- **Inclusive** dijet:
  Back-to-back correlation gets **suppressed** due to the saturation scale.
  Balance between: p_{1T}, p_{2T}, Q_s





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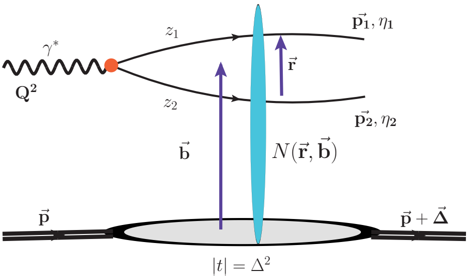
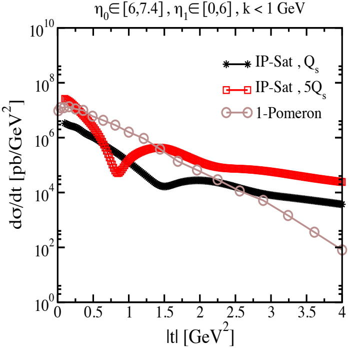
  Back-to-back correlation gets **suppressed** due to the saturation scale.
  Balance between: p_{1T}, p_{2T}, Q_s

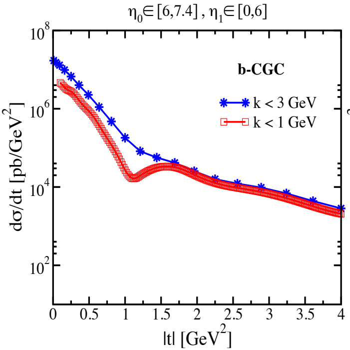
$$\vec{\Delta} = \vec{p_1} + \vec{p_2}, \quad \vec{k} = \frac{1}{2}(\vec{p_1} - \vec{p_2}), \quad |t| = \Delta^2, \ |t| \propto 1/b$$

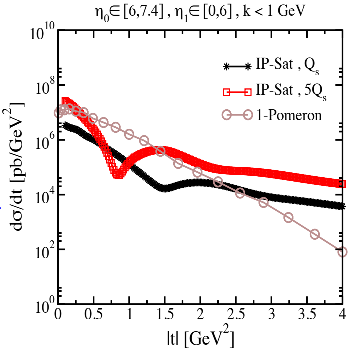




Diffractive dijet photoproduction:

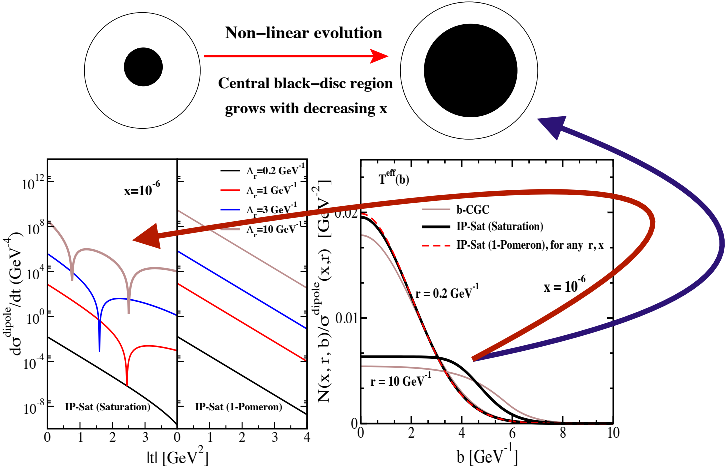
- $|t|$ distribution exhibits dips for the saturation models, similar to diffractive vector mesons.
- There is NO dips for the non-saturation models (i.e. 1-Pomeron).
- The dips become stronger by increasing the saturation scale.





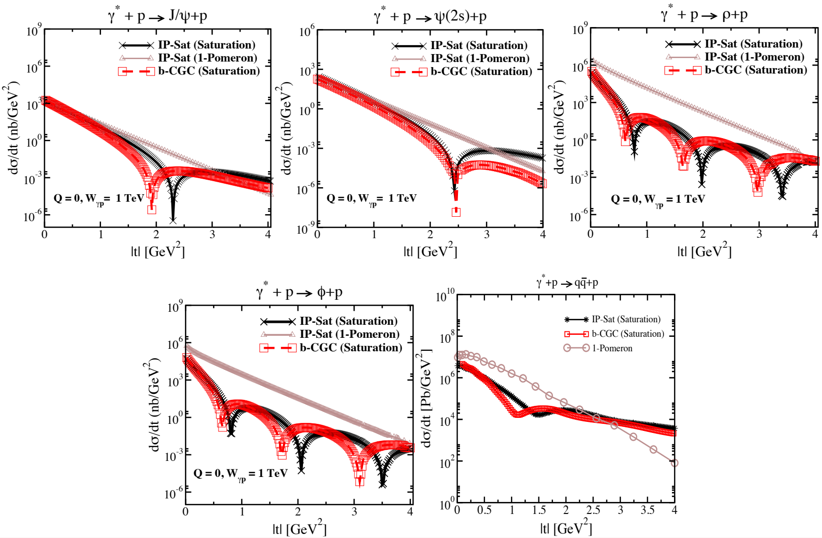
Diffractive dijet photoproduction:

- The dips become stronger by increasing the saturation scale: lowering x, decreasing k and increasing energy.



- Non-linear evolution $\Longrightarrow$ evolves any realistic profile in b, like a Gaussian or Woods-Saxon distribution, and makes it closer to a step-like function in the b-space at black-disc limit.

The universality of the diffractive dip at small-x



- The emergence of dip structure in the diffractive *t*-distribution is universal and does not depend on the details of the final-state particle wave functions.

Conclusion:

- Away-side correlations are enhanced in coherent diffractive processes in DIS and real (and virtual) photon-hadron ($\gamma^{(*)}$-h) collisions due to the saturation effects.
- Saturation and non-saturation models are very different at very small x and large $|t|$ ($x < 10^{-5}$ and $|t| > 1$):
  - Emergence of dips in the t-distribution of diffractive photoproduction of vector mesons and dijet in $\gamma^\star p$ collisions at large $|t|$ in the saturation models.
  - The t-distribution of diffractive production unambiguously discriminate among saturation and non-saturation models.
- **Diffractive dijet production** in dilute-dense scatterings is a sensitive probe of the color-dipole orientation:
  - Dipole orientation generates v_2: (Kopeliovich, Rezaeian and Schmidt, arXiv:0809.4327).
  - Dipole orientation induces Ridge effect (Levin and Rezaeian, arXiv:1105.3275).