Saturation effects in exclusive vector meson production in DIS

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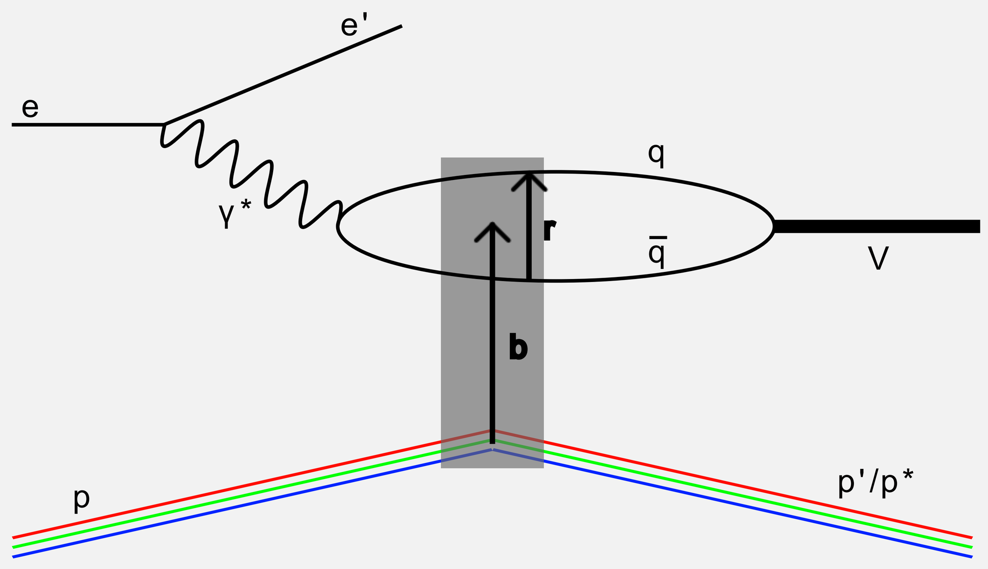
Motivation

- **Deep inelastic scattering (DIS)** allows for high-resolution probing of the (transverse) internal structure of protons/nuclei
- **Saturation** of the gluon densities is proposed by effective theoretical frameworks, e.g., the **Color Glass Condensate (CGC)**
  → **dense (saturated) hadron vs. dilute hadron**

Theoretical Models

- **Exclusive vector meson production in DIS** with a **color dipole probe** (using the **dipole picture**)
  → **b** is impact parameter, and **r** is size of the dipole



- **Scattering amplitude**
  $A^{\gamma^* p \to Vp}(Q^2, \Delta)$

$$\propto \iint d^2\mathbf{r}\, d^2\mathbf{b} \int_0^1 dz\, (\psi^* \psi_V)(Q^2, \mathbf{r}, z)\, \exp\{-i[\mathbf{b} + (\tfrac{1}{2} - z)\mathbf{r}]\Delta\}\, \frac{d\sigma_{\mathrm{dip}}^{\mathrm{p}}}{d^2\mathbf{b}}(\mathbf{b}, \mathbf{r})$$

  → $\psi^* \psi_V$: wave function overlap (photon and dipole)
  → $\frac{d\sigma_{\mathrm{dip}}^{\mathrm{p}}}{d^2\mathbf{b}}$: dipole cross section
  → $\frac{d\sigma_{\mathrm{dip}}^{\mathrm{p}}}{d^2\mathbf{b}}$ is sole quantity dependent on the proton model
  → energy transfer $\Delta = \sqrt{-t}$ is Fourier conjugate of impact parameter **b**

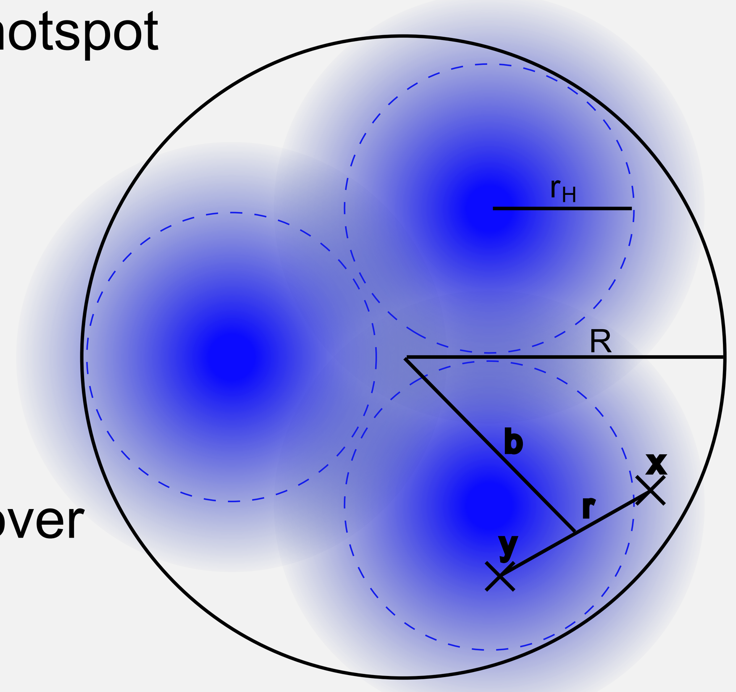
- **Elastic (coherent) and dissociative (incoherent) cross sections** in the Good-Walker picture [1]
  → coherent: $\frac{d\sigma^{\gamma^* p \to Vp}}{dt} = \frac{1}{16\pi}\left|\left\langle\left\langle A^{\gamma^* p \to Vp}\right\rangle\right\rangle\right|^2$
  → incoherent: $\frac{d\sigma^{\gamma^* p \to Vp^*}}{dt} = \frac{1}{16\pi}\left\langle\left\langle\left|A^{\gamma^* p \to Vp}\right|^2\right\rangle\right\rangle - \frac{d\sigma^{\gamma^* p \to Vp}}{dt}$
  → averages refer to the CGC color and hotspot average respectively
  → incoherent cross section can be separated into contributions from color fluctuations and hotspot fluctuations [2]

- **Hotspot proton model** with **Monte-Carlo approach**
  → Gaussian density profile for each hotspot

$$T_H(\mathbf{b}) = \frac{1}{2\pi r_H^2} \exp\left\{-\frac{\mathbf{b}^2}{2r_H^2}\right\}$$

  → hotspot positions are **randomly sampled** for each event with distribution

$$T(\mathbf{b}) = \frac{1}{2\pi R^2} \exp\left\{-\frac{\mathbf{b}^2}{2R^2}\right\}$$



  → resulting proton thickness is sum over hotspot thicknesses

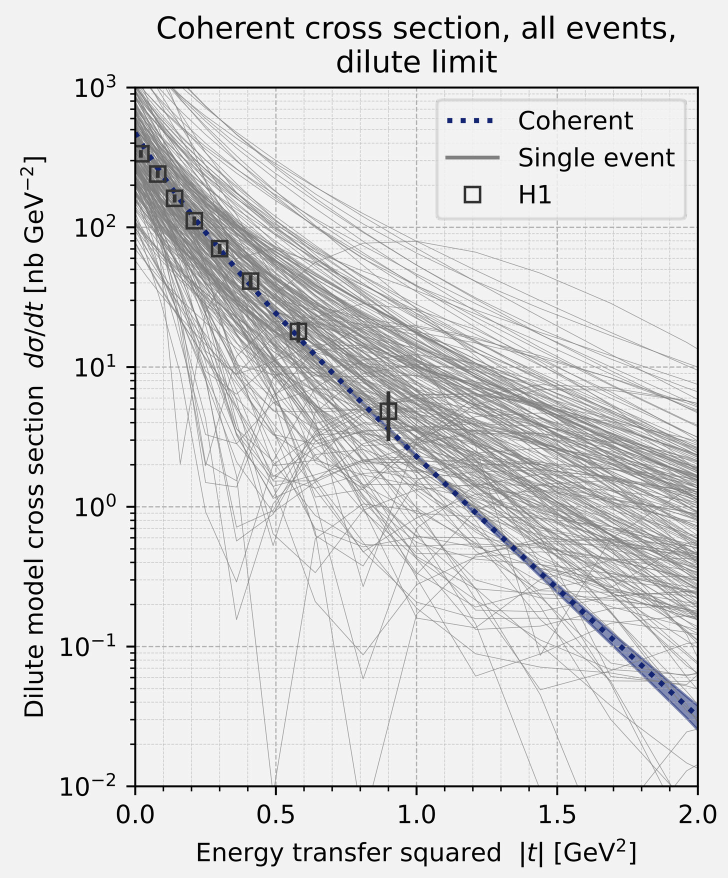
$$T_p(\mathbf{b}) = \sum_{i=1}^{N_H} T_H(\mathbf{b} - \mathbf{b}_i)$$

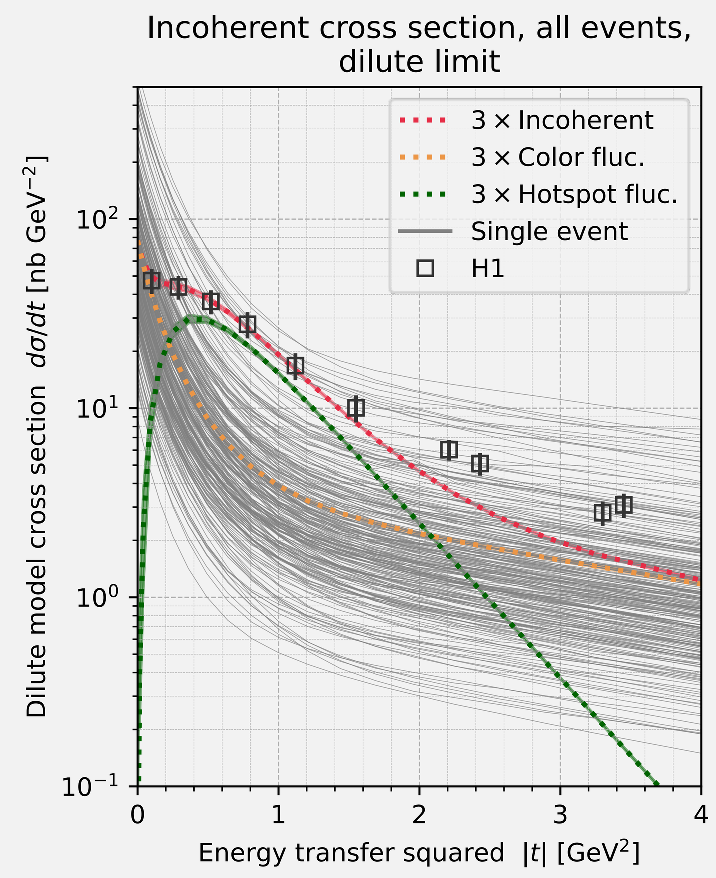
  → $\mathbf{b}_i$: position of hotspot i
  → N_H: number of hotspots
  → color charge density in each hotspot is proportional to hotspot thickness

$$\mu^2(\mathbf{b}) = \mu_0^2 T_H(\mathbf{b})$$

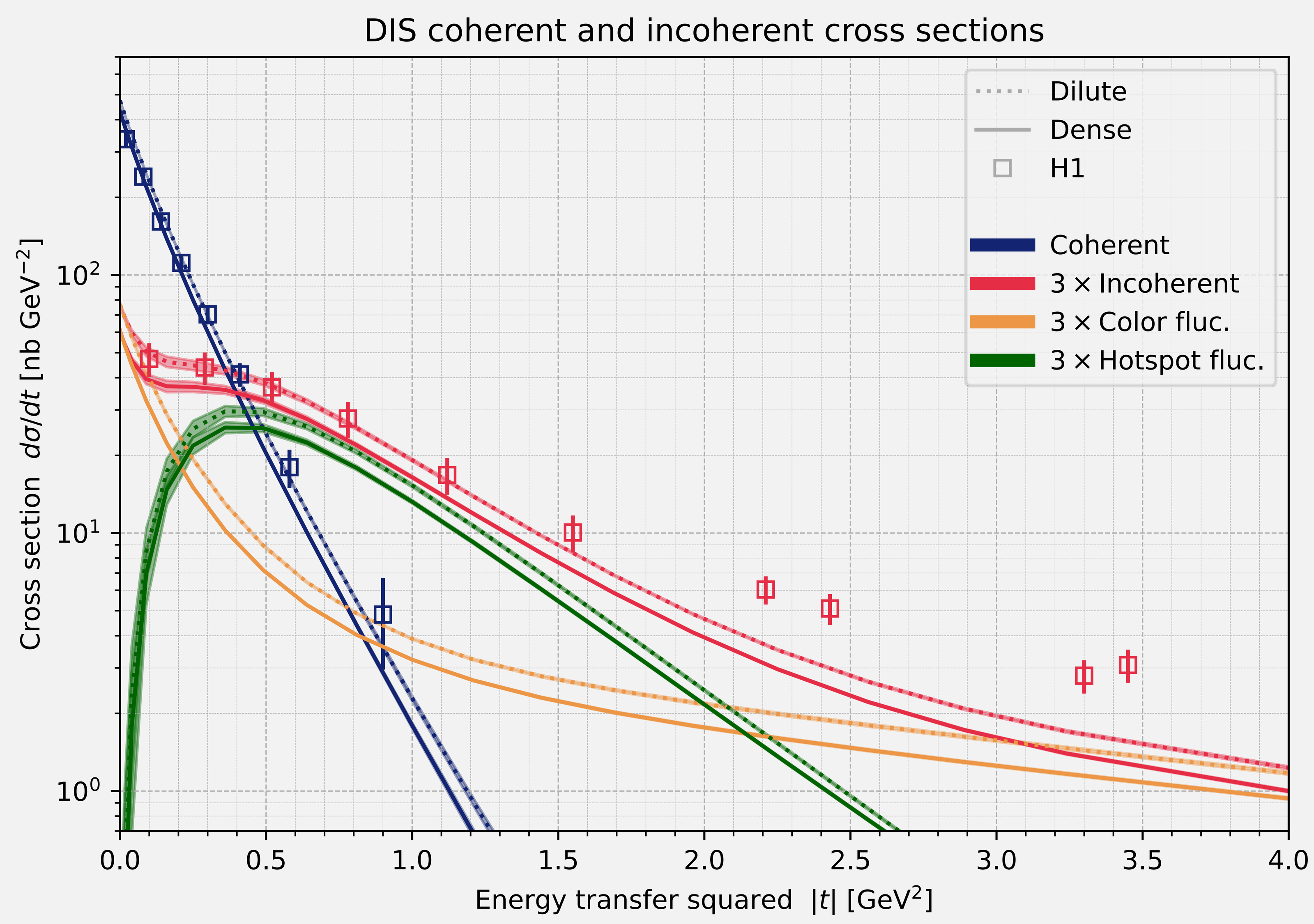
Results

- Monte-Carlo approach recovers average behaviour well

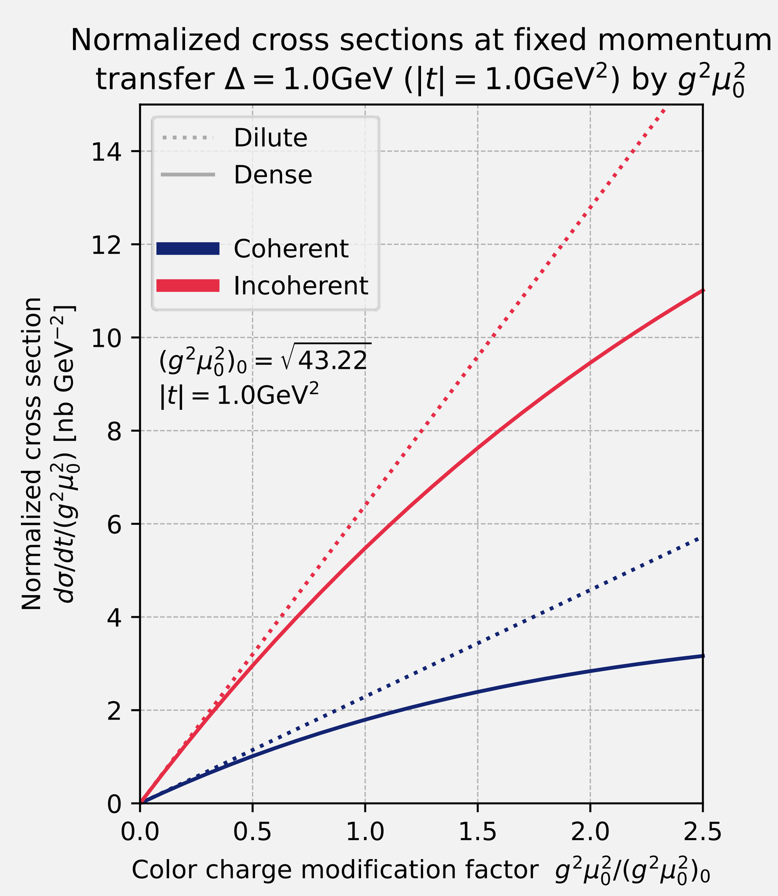




- **Saturation causes suppression** of scattering cross sections



- Strength of suppression is influenced by color charge density $g^2\mu_0^2$



→ suppression increases with color charge
→ different dependencies on the dipole correlation function $G_{\mathbf{xy}}$:

$$\left\langle \frac{d\sigma_{\mathrm{dip}}^{\mathrm{p,dilute}}}{d^2\mathbf{b}} \right\rangle_c = -2G_{\mathbf{xy}}$$

$$\left\langle \frac{d\sigma_{\mathrm{dip}}^{\mathrm{p,dense}}}{d^2\mathbf{b}} \right\rangle_c = 2\left(1 - e^{G_{\mathbf{xy}}}\right)$$

→ dense < dilute, because $G_{\mathbf{xy}} < 0\ \forall \mathbf{x}, \mathbf{y}$ and $G_{\mathbf{xy}} \propto g^2\mu_0^2$

Conclusion & Outlook

- Dense model not entirely sufficient for the description of ep-DIS with the given parameters, which are derived by dilute-model fits
  → more physically accurate fits using the dense model needed
- Dense model is relevant with larger systems/higher energies
  → electron-nucleus collisions (already supported by model)
- More research into other fluctuations necessary (normalization of incoherent)

References
[1] M. Good, W. Walker, Phys. Rev. 120 (1960), 1857-1860
[2] S. Demirci, T. Lappi, S. Schlichting, Phys. Rev. D 106 (2022) no.7, 074025
[3] C. Alexa et al. [H1], Eur. Phys. J. C 73 (2013) no.6, 2466