Elastic vector meson production

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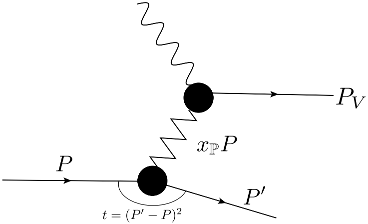
June 28, 2018
Electrons for the LHC - LHeC/FCCeh and PERLE Workshop

Diffractive vector meson production as a probe of small x

Exclusive production of a vector meson

$$\gamma p \to Vp$$
$$\gamma A \to VA$$



Pocket formula for diffraction (2-gluon exchange, LO)

$$\left.\frac{\mathrm{d}\sigma^{\gamma^* T \to VT}}{\mathrm{d}t}\right|_{t=0} = \frac{16\pi^3 \alpha_s^2 \Gamma_{ee}}{3\alpha_{\mathrm{em}} M_V^5} \left[\mathbf{xg(x, Q^2)}\right]^{\mathbf{2}}$$

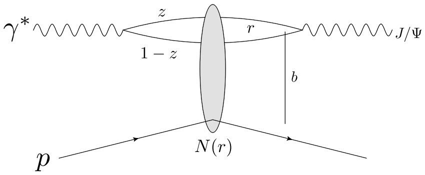
Ryskin, 1993

- Diffraction is very sensitive to (small-x) gluons $\Rightarrow$ saturation effects
- In exclusive process we also have t = Fourier conjugate to b_T
  - Access to impact parameter dependence

Vector meson production in the dipole picture

High energy factorization:

1. $\gamma^* \to q\bar{q}$: $\Psi^\gamma(r, Q^2, z)$
2. $q\bar{q}$ dipole scatters elastically
   Amplitude N
3. $q\bar{q} \to J/\Psi$: $\Psi^V(r, Q^2, z)$



Diffractive scattering amplitude

$$\mathcal{A}^{\gamma^* p \to Vp} \sim \int \mathrm{d}^2 b \, \mathrm{d}z \, \mathrm{d}^2 r \Psi^{\gamma*} \Psi^V(r, z, Q^2) \mathbf{e}^{-\mathbf{i}\mathbf{b}\cdot\mathbf{\Delta}} N(r, x, b)$$

- Access to the spatial structure: Fourier transform to momentum space
- $N(r, x, b)$ satisfies perturbative evolution equation, known from CGC, Non-perturbative input from F_2 data fits

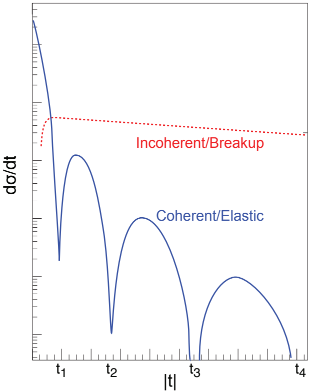
Two components – two target averages

Coherent diffraction:

Target remains in the same quantum state

Probes average density

$$\frac{\mathrm{d}\sigma^{\gamma^* p \to Vp}}{\mathrm{d}t} \sim |\langle \mathcal{A}^{\gamma^* p \to Vp} \rangle|^2$$



Good, Walker, PRD 120, 1960
Miettinen, Pumplin, PRD 18, 1978
Kovchegov, McLerran, PRD 60, 1999
Kovner, Wiedemann, PRD 64, 2001

$\langle\,\rangle$: average over target configurations [N(r, **b**)]

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Incoherent/target dissociation:

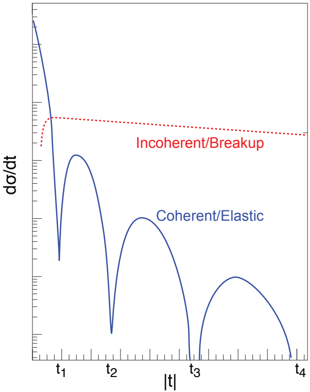
Total diffractive − coherent cross section

Target breaks up

$$\frac{\mathrm{d}\sigma^{\gamma^* p \to Vp^*}}{\mathrm{d}t} \sim \langle |\mathcal{A}^{\gamma^* p \to Vp}|^2 \rangle - |\langle \mathcal{A}^{\gamma^* p \to Vp} \rangle|^2$$

Variance, measures the amount of fluctuations!

$\langle\,\rangle$: average over target configurations [N(r, **b**)]



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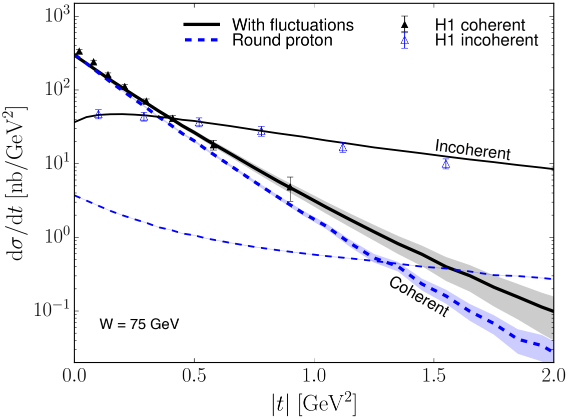
1. Proton targets

Accessing proton structure in $\gamma + p \to J/\Psi + p$

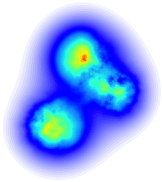
Proton structure (IP-Glasma)

- $\langle$Color charge density$\rangle \sim \sum$ three hot spots $\Rightarrow$ compute $N(r, x, b)$
- Free parameters: hot spot size and separation

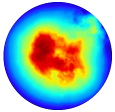


H.M, B. Schenke, 1607.01711

Fluctuations

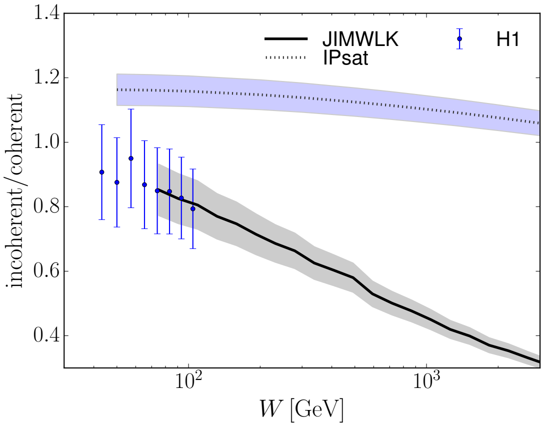


Round

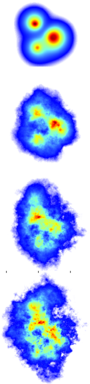


Energy evolution

Bjorken-x evolution by solving perturbative JIMWLK equation
Initial state geometry is lost in the evolution



$W = 75$ GeV:

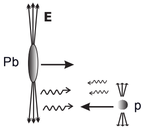


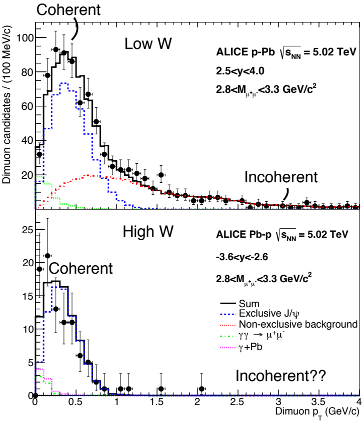
$W = 680$ GeV

Note: parameters fixed at $W = 75$GeV,
the rest is prediction H.M, B. Schenke, arXiv:1806.06783

Hints of shape evolution from UPC

Ultraperipheral $p + A$ at the LHC:
Photon flux $\sim Z^2 \Rightarrow \gamma + p$ dominates





ALICE: 1406.7819

Forward/backward rapidity J/Ψ
High/low W

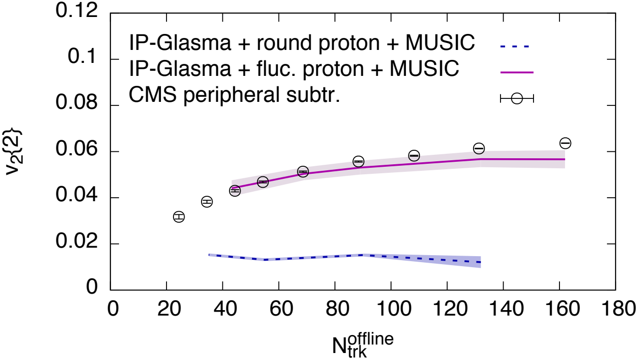
- Low W: significant coherent and incoherent contributions
- High W: no incoherent
  Black disk limit expectation

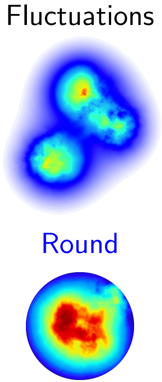
LHC disadvantage: $Q^2 = 0$
So far can not see target breakup

Implications on heavy ion phenomenology: p+A

Hydro simulations with nucleon structure fluctuations from J/Ψ data:

- Compatible with the LHC p+A data



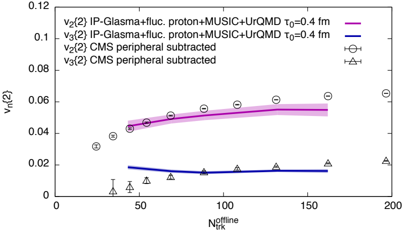


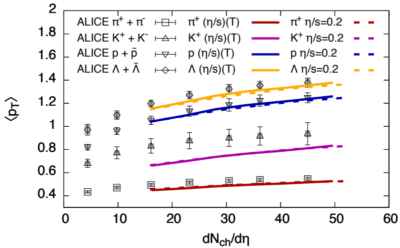
H.M, Schenke, Shen, Tribedy, 1705.03177

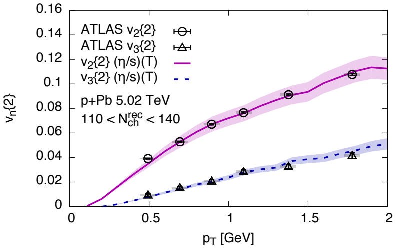
Also pure initial state models describe v_n e.g. Dusling, Mace, Venugopalan, 1705.00745

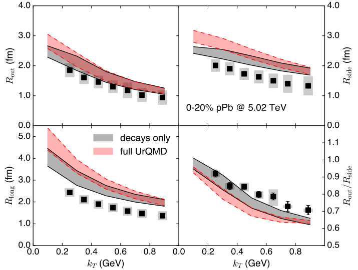
Implications on heavy ion phenomenology: p+A

Hydro + fluctuations from HERA J/Ψ data: success









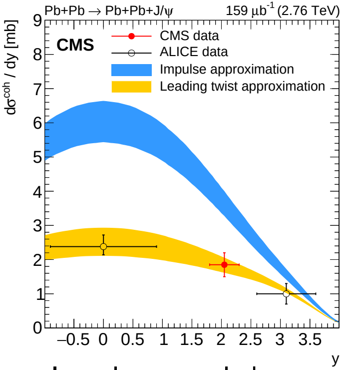
H.M, Schenke, Shen, Tribedy, 1705.03177

2. Nuclear targets

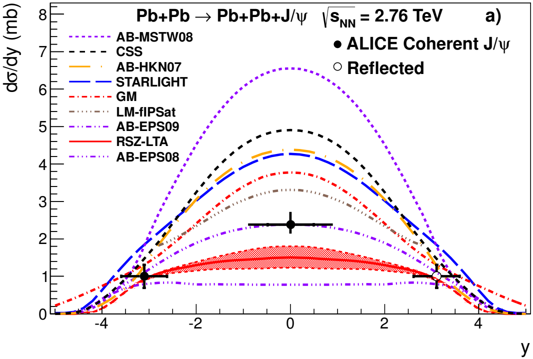
$$Q^2_{s,A} \sim A^{1/3} Q^2_{s,p}$$

Enhanced saturation effects in nuclei

Large nuclear suppression already seen in $A+A \to J/\Psi + A + A$



Impulse = scaled γp



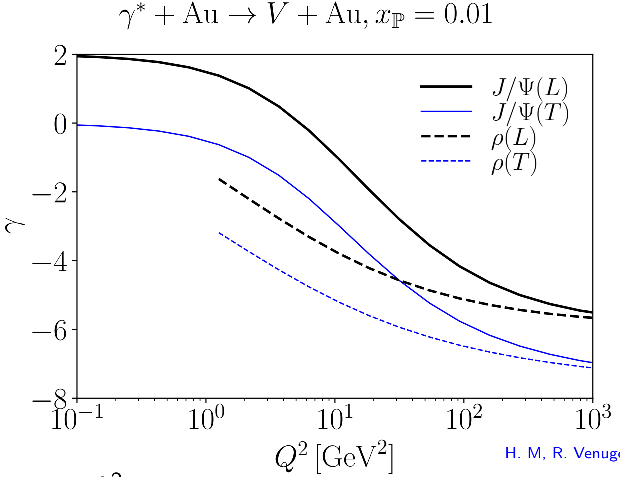
Calculations with nuclear PDF (EPS09) or saturation (IPsat) compatilbe

CMS, 1605.06966

ALICE, 1305.1467

Dense ↔ dilute transition and the need for high energy

$$\sigma^{\gamma+A\to J/\Psi+A} \sim Q^{\gamma}$$

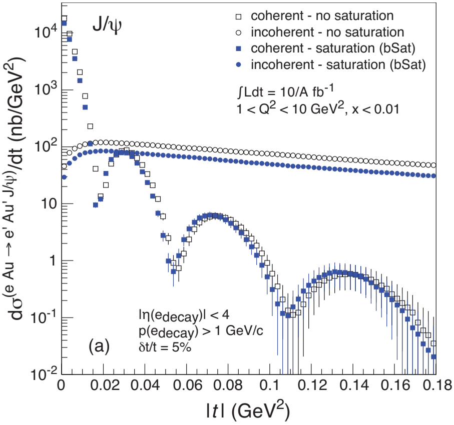


H. M, R. Venugopalan, 1712.02508

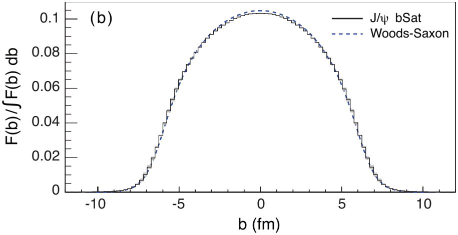
Large Q^2 lever arm needed to see the transition,
and to probe the x dependence!

Extract nuclear geometry

Full EIC simulation with expected uncertainties in $\gamma + A \to J/\Psi + A$



Coherent J/Ψ spectra $\Rightarrow$ FT
$\Rightarrow$ Density profile



Extract transverse density profile of small-x gluons — T. Toll, T. Ullrich, 1211.3048

Also: fluctuations at different length scales — H. M, B. Schenke, 1703.09256

Centrality in exclusive scattering: probe highest Q_s^2

Incoherent diffraction: largish p_T kick, localized to $\sim$ nucleon size

- A nucleon receives kick and scatters off other nucleons on its way out
- More "ballistic nucleons" in central events
- 2nd component: thermal emission in the rest frame
  - Different p_T spectra in the LAB frame

T. Lappi, H. M, R. Venugopalan, PRL 114 (2015) 082301

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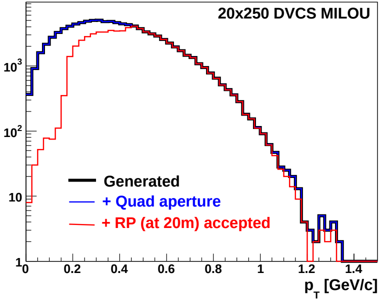
Centrality estimator

Centrality $\sim$ number of "ballistic protons" in the roman pot

EIC simulation:
Romat pot acceptance is good in $|t| \sim 0.5 \ldots 1\text{GeV}^2$



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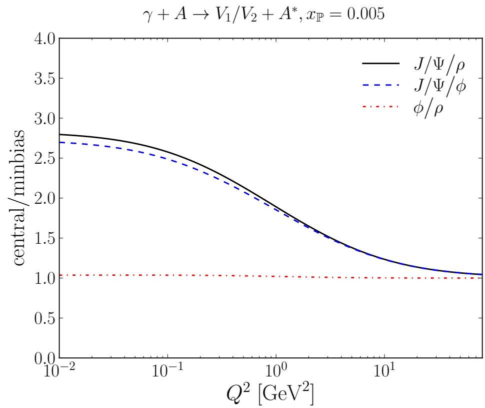
Centrality dependence of incoherent cross section

Double ratio $\frac{\sigma(V_1)/\sigma(V_2)|_{\text{central}}}{\sigma(V_1)/\sigma(V_2)|_{\text{minbias}}}$



Larger Q_s^2 in central events

- Light mesons are more suppressed in central events
  $\Rightarrow$ enhancement at low Q^2

T. Lappi, H. M, R. Venugopalan, PRL 114 (2015) 082301

Conclusions & outlook

Exclusive vector meson production is a powerful tool to study

- Geometric structure
- Structure fluctuations
- Saturation effects
- Initial condition for heavy ion collisions

LHeC/FCC-eh provides large x, Q^2 with precision

Additionally (not discussed here)

- Small-x nuclear DIS data: much tighter model constraints
- Large Q^2 range: study mostly unknown vector meson wave function
- Event-by-event fluctuations of the small-x nuclear structure
- And much more