Finding the Nuclear Suppression Factor using asymmetric beams

Ronan McNulty
University College Dublin

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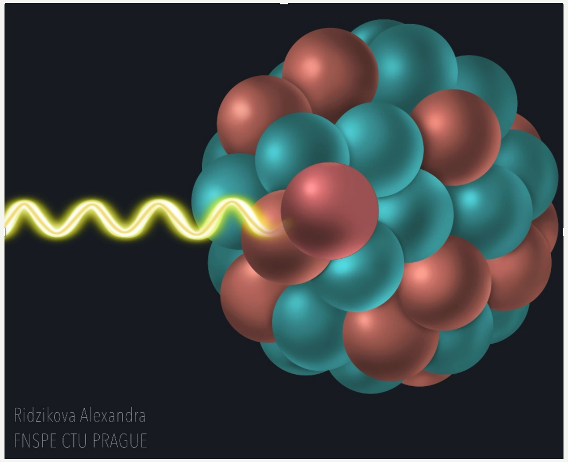
Overview

- Motivation
- Theory
- Pseudo-data validation and expectations
- Conclusions

R.McNulty and W. Schafer, Vector meson photoproduction on the nucleus and the extraction of the nuclear suppression factor using asymmetric beams, arXiv:2607.04228 [hep-ph]

Graphic from A. Ridzikova



Motivation

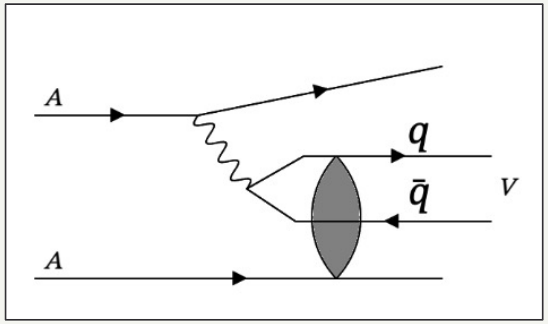
Naively, $\sigma_{\gamma A \to VA}$ scales from $\sigma_{\gamma p \to Vp}$ with the number of nucleons: $\sim A^{4/3}$.

Impulse Approximation (IA) calculated using nuclear form-factor

Nuclear effects alter this:

- shadowing $g_A(x, Q^2) < A g_p(x, Q^2)$
- rescattering (elastic/inelastic Glauber/Gribov)
- possibly saturation

Nuclear suppression quantified: $S^2 = \frac{\sigma_{\gamma A \to VA}}{\sigma^{IA}_{\gamma A \to VA}}$



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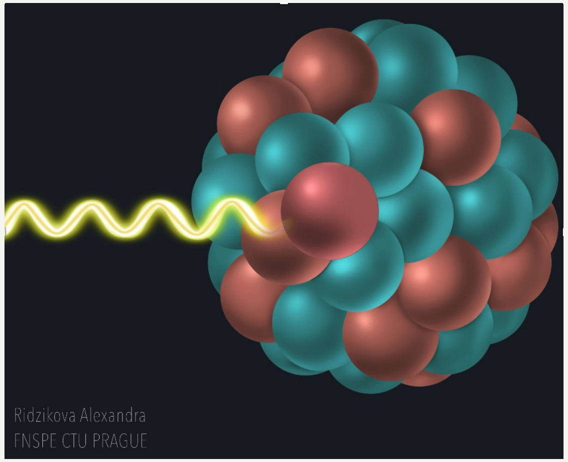
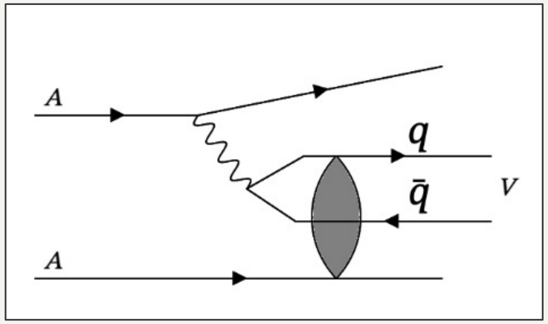


Saturation scale: $$Q_S^2 = Q_0^2 \left(\frac{x_0}{x}\right)^\lambda$$

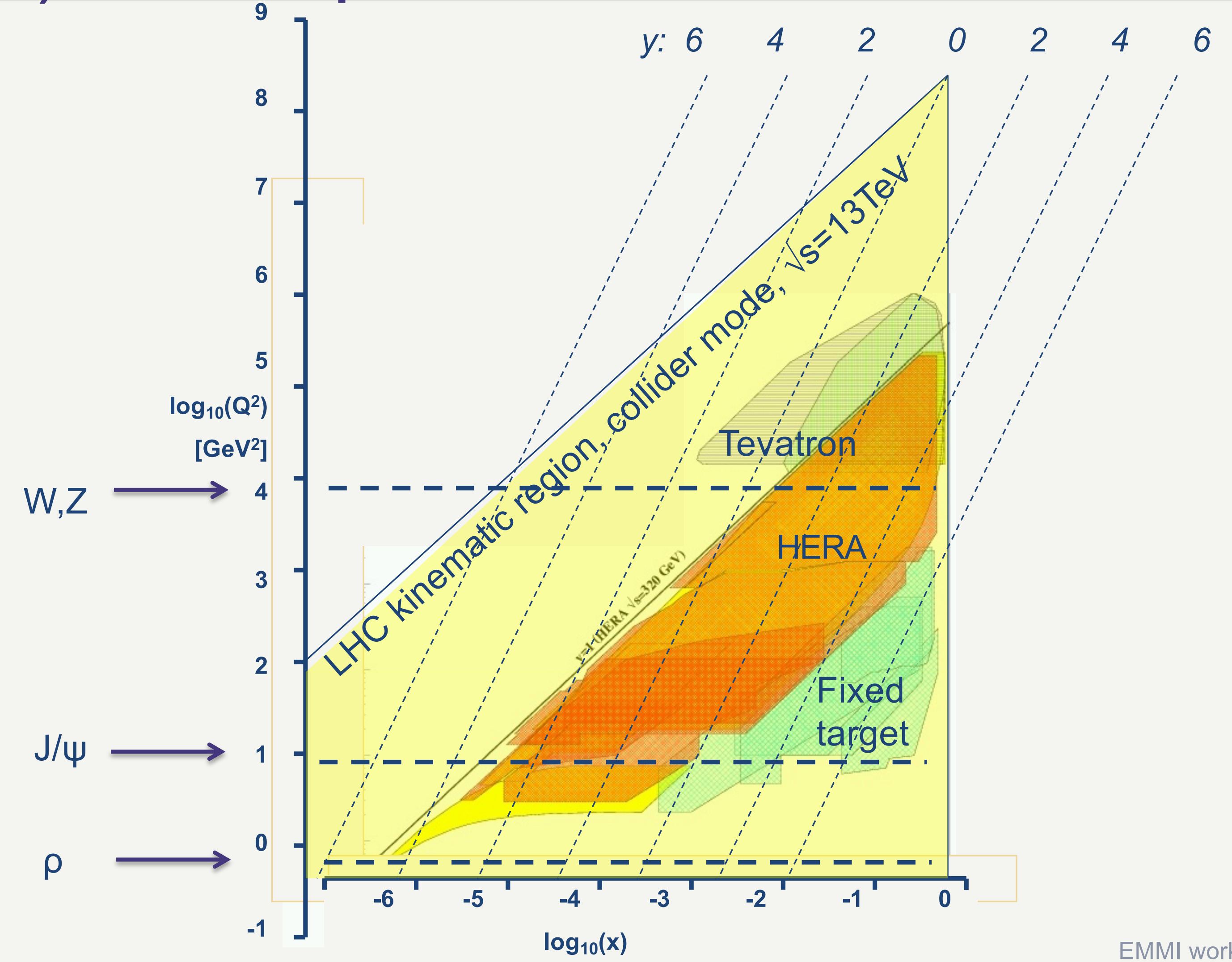
K.J. Golec-Biernat, M. Wusthoff, PRD, 59:014017 (1998)

- For J/ψ, saturation might appear $x \sim 10^{-7}$
- For ρ, saturation at $x \sim 10^{-4}$

Enhancement $N_A^{1/3}$ in nuclear collisions

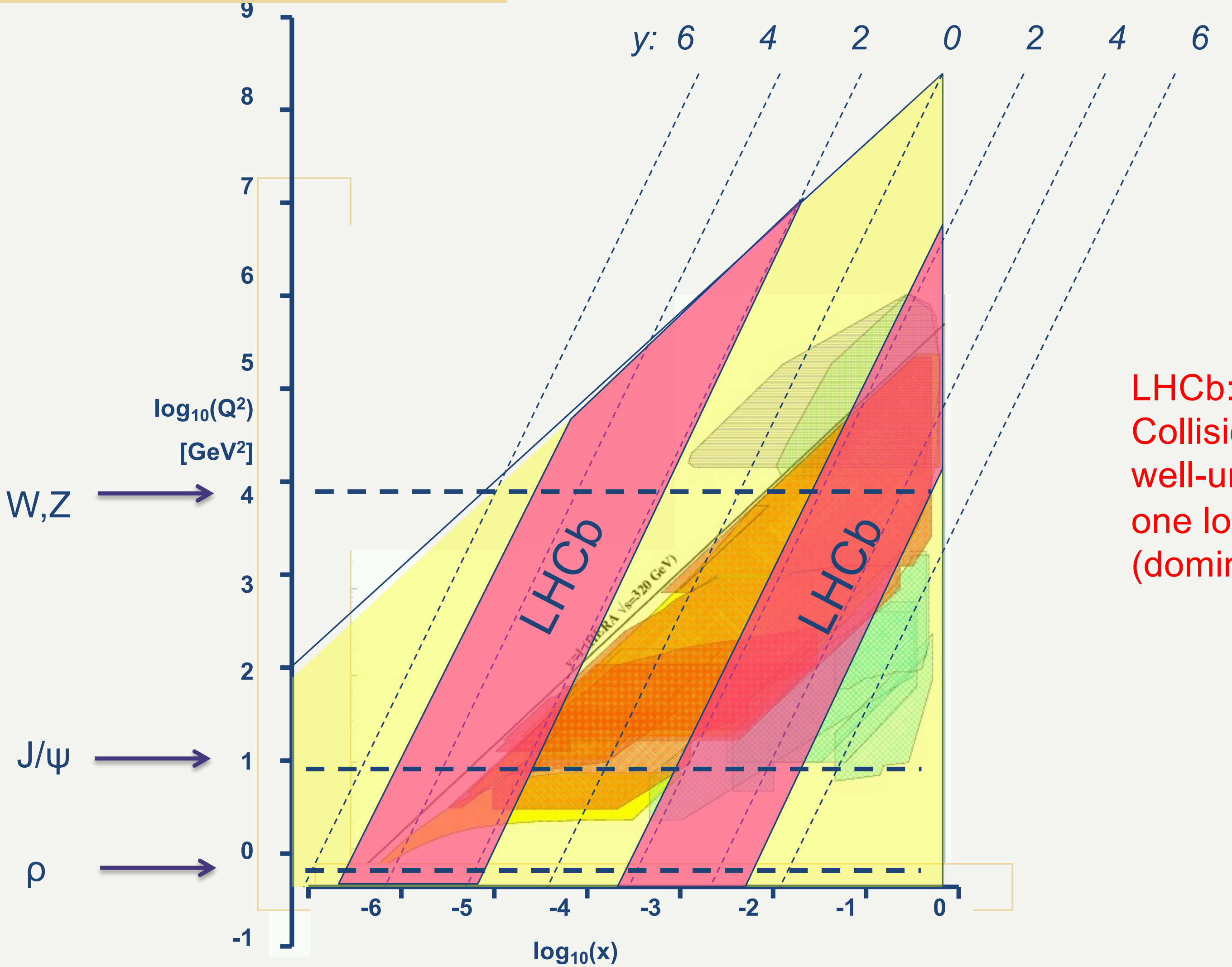


(x,Q^2) values probed at LHC, HERA, Tevatron



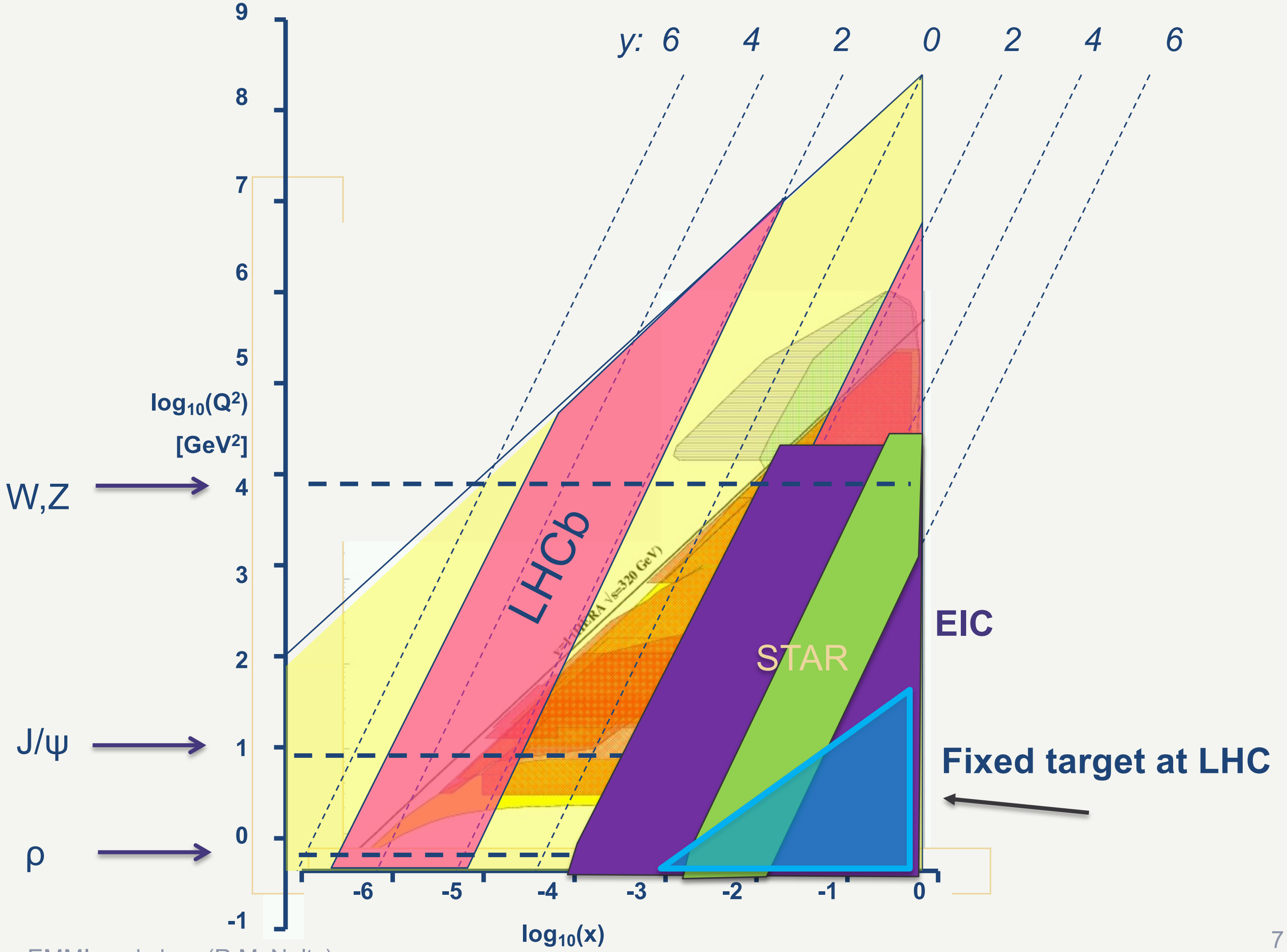
Low-x & Forward physics

$$\sigma(s)_{pp\to X} = \sum_{ab}\int dx_a dx_b f_{a/A}(x_a,Q^2) f_{b/B}(x_b,Q^2)\hat{\sigma}_{ab\to X}(\alpha_s(Q), x_1 x_2 s)$$



LHCb:
Collision between one well-understood and one low-x parton (dominated by gluons)

Low-x & Forward physics



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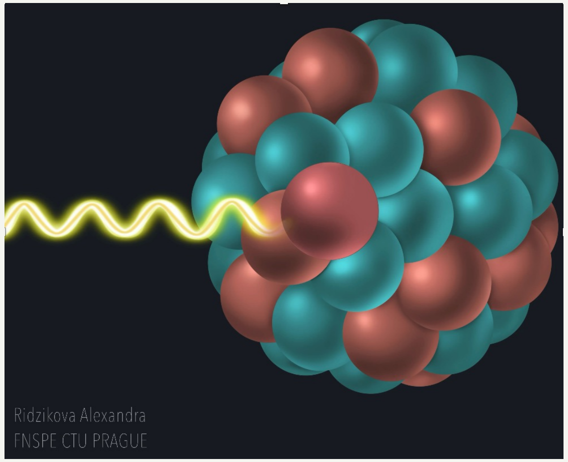

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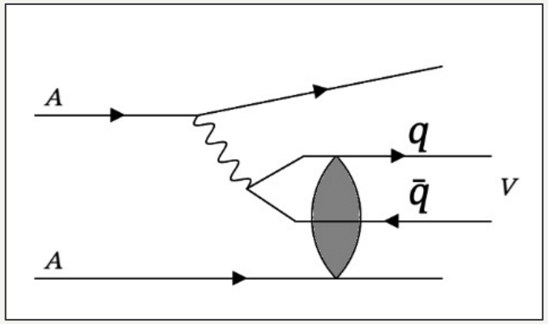
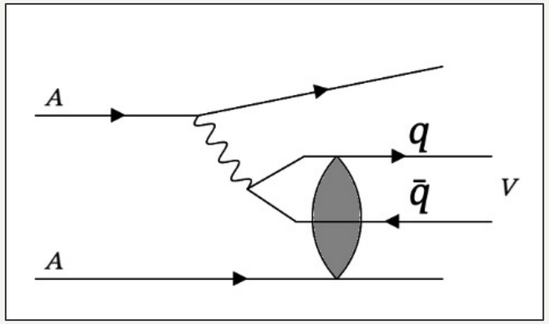


Best chances are nuclear collisions in forward region at the LHC

Motivation



$\sigma_{\gamma A \to VA}$ usually measured in ion-ion collisions

Two-fold ambiguity as to which ion is the photon emitter.

The high-energy $W_{\gamma n}$ is particularly difficult to access, and this corresponds to low x, where saturation may be present.

Ambiguity can be broken:

- At y=0 !
- Using neutron emission *V. Guzey, M. Strikman, M. Zhalov. Eur. Phys. J. C, 74(7):2942, 2014*
  - Statistical rather than event-by-event
  - Uncertainties in modelling neutron emission.
- Peripheral collisions: measurements at two different impact parameters. *J.G. Contreras, Phys.Rev.C 96 (2017) 1, 015203*

$$Q_S^2 = Q_0^2 \left(\frac{x_0}{x}\right)^\lambda$$

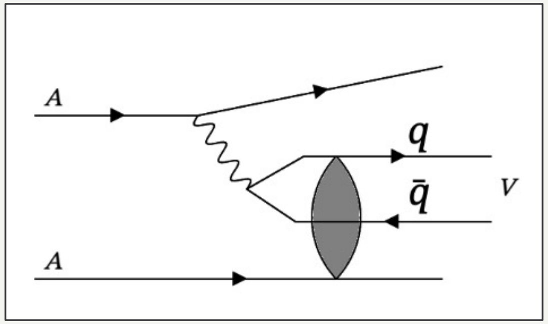
$x_0=10^{-4}$
$Q_0=1$GeV
$\lambda=0.3$

K.J. Golec-Biernat, M. Wusthoff, PRD, 59:014017 (1998)

$$x \sim 10^{-7} \;\; (J/\psi)$$
$$x \sim 10^{-4} \;\; (\rho)$$

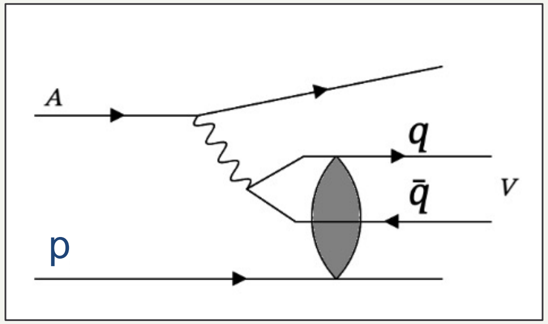
$$W^2 = 2k\sqrt{s_{NN}}$$
$$k = me^{+y}/2$$
$$x \approx me^{-y}/\sqrt{s_{NN}}$$

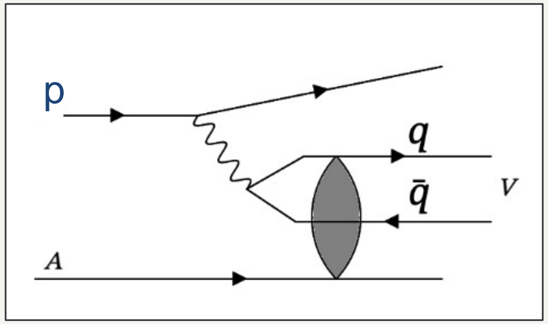
Theory



In AA collision: $$\frac{d\sigma_{\mathrm{AA}\to\mathrm{A}V\mathrm{A}}}{dy} = \left(k^{+}\frac{dN_\gamma}{dk^{+}}\right)\sigma_{\gamma A\to VA}(W^{+}) + \left(k^{-}\frac{dN_\gamma}{dk^{-}}\right)\sigma_{\gamma A\to VA}(W^{-}).$$

In pA collision: $$\frac{d\sigma_{\mathrm{pA}\to\mathrm{p}V\mathrm{A}}}{dy} = \left(k^{A}\frac{dN_\gamma}{dk^{A}}\right)^{A}\sigma_{\gamma p\to Vp}(W^{A}) + \left(k^{p}\frac{dN_\gamma}{dk^{p}}\right)^{p}\sigma_{\gamma A\to VA}(W^{p}).$$



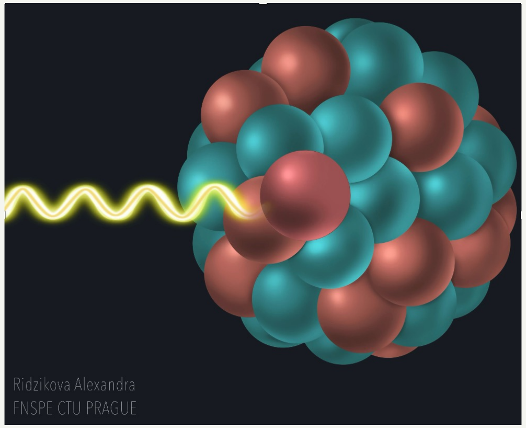


$$\left(k\frac{dN_\gamma}{dk}\right)^{A} = Z^2\left(k\frac{dN_\gamma}{dk}\right)^{p}$$

dominant term since photon couple with Z^2

Theory

Graphic from A. Ridzikova



In the Impulse Approximation

$$\sigma^{IA}_{\gamma A \to VA}(W) = \frac{d\sigma_{\gamma p \to Vp}}{dt}(W, t=0)\Phi_A(t_{min})$$

$$\Phi_A(t_{\min}) = \int_{t_{\min}}^{\infty} |F_A(t)|^2 dt$$

$$F_A(q) = \frac{4\pi}{q}\int_0^{\infty} r\sin(qr)\rho(r)dr$$

$$\rho_N(r) = \frac{\rho_0}{1+\exp((r-R)/d)}$$

$$\frac{d\sigma_{\gamma p \to Vp}}{dt} = \sigma_{\gamma p \to Vp} b_V e^{b_V t}$$

measured in ep collision at HERA
Note also Regge/Pomeron W dependence

$$\sigma \sim \left(\frac{W}{W_0}\right)^{\delta_{\mathcal{P}}} + f_{\mathcal{R}}\left(\frac{W}{W_0}\right)^{\delta_{\mathcal{R}}}$$

$$b_V = b_0 + 4\alpha' \log(W/W_0)$$

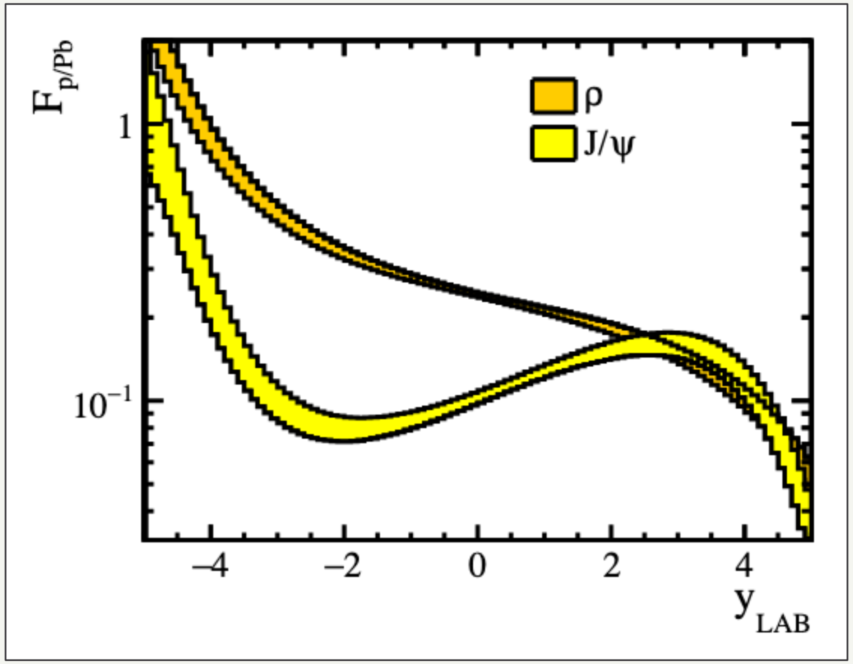
$$\frac{d\sigma_{\mathrm{pA}\to\mathrm{pVA}}}{dy} = Z^2\left(k_A\frac{dN_\gamma}{dk_A}\right)^p \sigma_{\gamma p\to Vp}(W_A) + \left(k_p\frac{dN_\gamma}{dk_p}\right)^p b_V\sigma_{\gamma p\to Vp}(W_p)\mathcal{S}^2\Phi_A(t_{min})$$

Theory: Observable 1

$$F_{p/A}(y_{LAB}) \equiv \frac{N_{\gamma-from-p}(y_{LAB})}{N_{\gamma-from-A}(y_{LAB})} = \frac{b_V \mathcal{S}^2 \Phi_A(t_{min})}{Z^2} \frac{\sigma_{\gamma p \to Vp}(W_p)}{\sigma_{\gamma p \to Vp}(W_A)} \frac{\left(k_A \frac{dN_\gamma}{dk_A}\right)^p}{\left(k_p \frac{dN_\gamma}{dk_p}\right)^p}$$

$F_{p/A}$ **minimises experimental uncertainties**.

Events in pA and Ap collisions occur at the same detector location: efficiencies cancel in the ratio.



Theory: Observable 2

$$F^{\pm}_{p/A}(y) \equiv \frac{N_{\gamma-from-p}(y)}{N_{\gamma-from-A}(-y)} = \frac{b_V \mathcal{S}^2 \Phi_A(t_{min})}{Z^2}$$

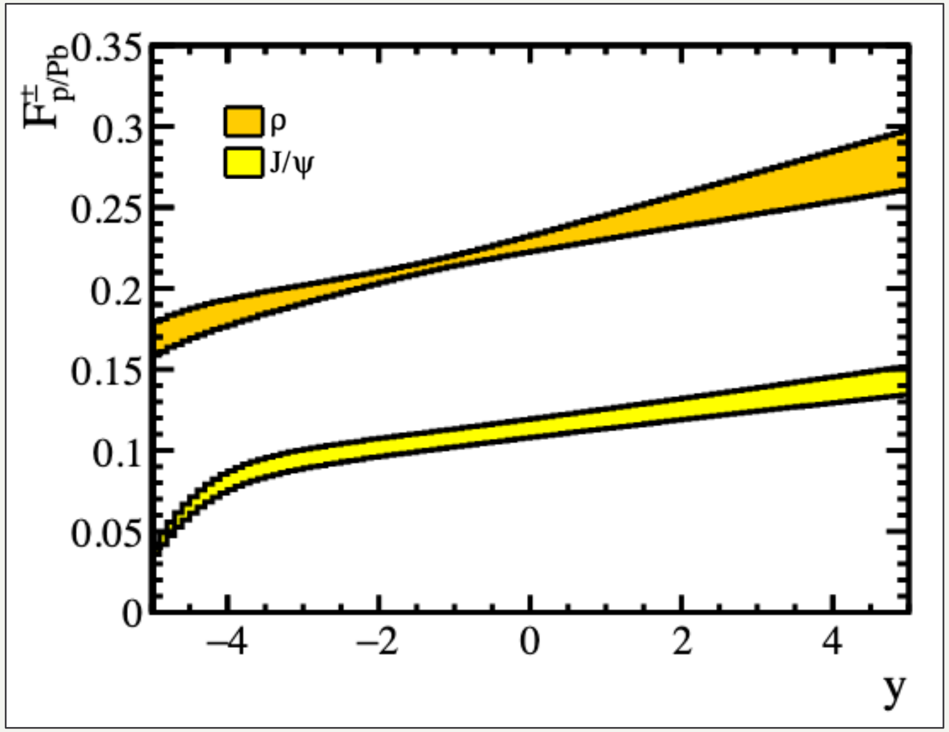
$F^{\pm}_{p/A}$ **minimises theoretical uncertainties**.
Just a function of:

- b, well measured at HERA or in LHC data itself
- Φ, the shape of the nucleus

Directly measures nuclear suppresion, $\mathcal{S}$.

Events in pA and Ap collisions are separated by about one unit of rapidity,
since $y_{LAB} = y \pm \Delta y$ with $\Delta = \frac{1}{2}\ln\frac{Z}{A} = 0.465$

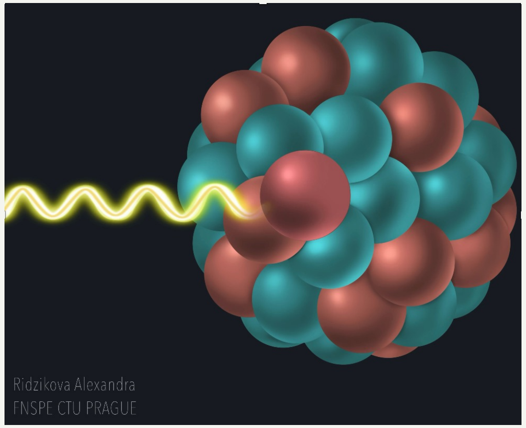
Good knowledge of acceptance and efficiency required.



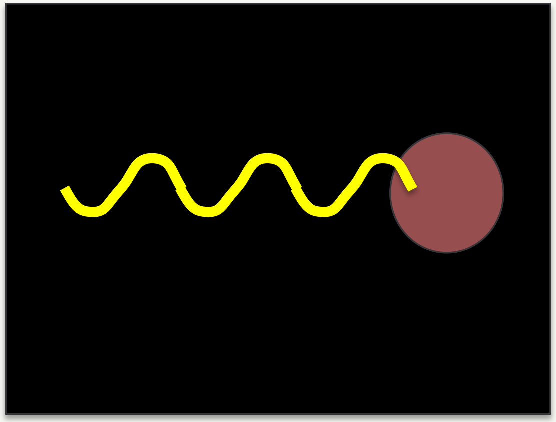
Feasibility using pseudo-data

$$\frac{d\sigma_{\mathrm{pA}\to\mathrm{pVA}}}{dy} = \left(k^A \frac{dN_\gamma}{dk^A}\right)^A \sigma_{\gamma p\to Vp}(W^A) + \left(k^p \frac{dN_\gamma}{dk^p}\right)^p \sigma_{\gamma A\to VA}(W^p)$$

How do you separate the photon-from-lead and photon-from-proton events?



$p_T \sim 1/R_A \sim 40$ MeV



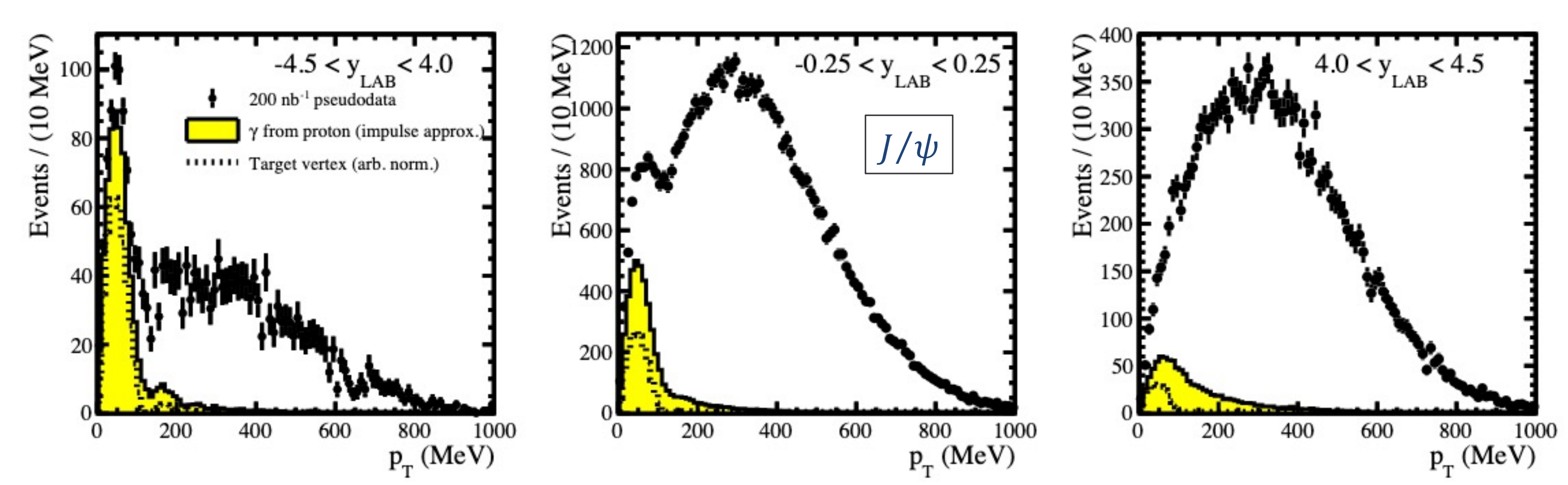
$p_T \sim 1/R_p \sim 250$ MeV

Calculate spectrum as Fourier transform of the shape of the target.
(Much smaller effect from p_T of the emitter)

Feasibility using pseudo-data

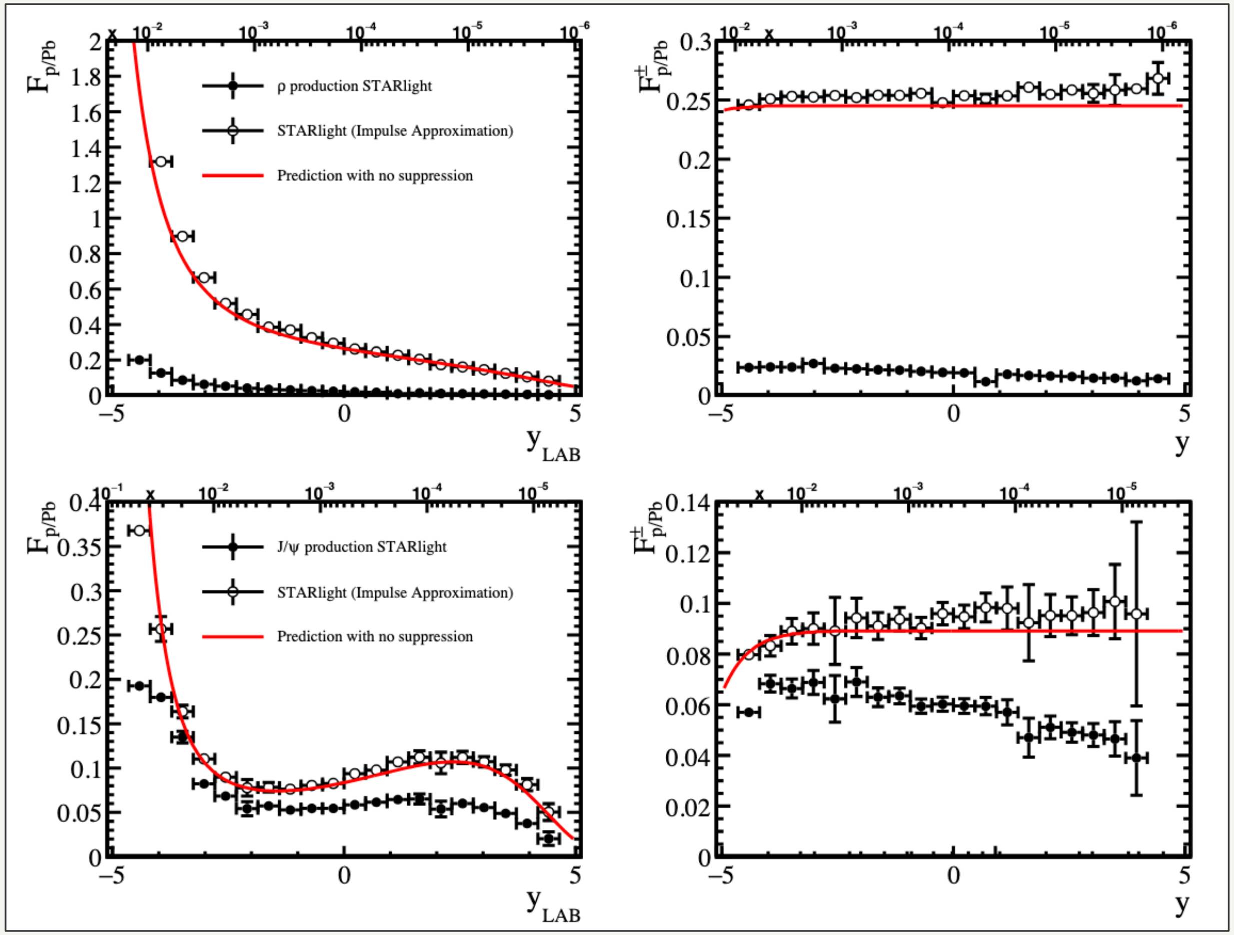
$$\frac{d\sigma_{\mathrm{pA}\to\mathrm{p}V\mathrm{A}}}{dy} = \left(k^A \frac{dN_\gamma}{dk^A}\right)^A \sigma_{\gamma p\to Vp}(W^A) + \left(k^p \frac{dN_\gamma}{dk^p}\right)^p \sigma_{\gamma A\to VA}(W^p)$$

Pseudo-data generated using STARlight generator *S. Klein et al., Comp. Phys. Comm. 212:258 2017*
200 nb^{-1} generated, corresponding to what ALTAS/CMS obtained in the 2016 pPb LHC run.
70% trigger & reconstruction efficiency assumed.



$p_T \sim 1/R_A \sim 40$ MeV $\qquad$ $p_T \sim 1/R_p \sim 250$ MeV

Results using pseudo-data



Generated data in Impulse Approximation agrees with theory predictions (using STARlight inputs for b)
This validates the methodology

Suppression present in default STARlight generation, due to Glauber mechanism, is clearly seen.

Nuclear Suppression is almost directly measured in $F^{\pm}_{p/A}$ with no ambiguity.

$$F^{\pm}_{p/A}(y) \equiv \frac{N_{\gamma-from-p}(y)}{N_{\gamma-from-A}(-y)} = \frac{b_V S^2 \Phi_A(t_{min})}{Z^2}$$

Conclusions

- Two observables, $F_{p/A}$, $F^{\pm}_{p/A}$ have been introduced that are measurable in asymmetric collisions (e.g. pPb at LHC).
- These directly measure the nuclear suppresion factor
  - $F_{p/A}$ minimises experimental uncertainties
  - $F^{\pm}_{p/A}$ minimises theoretical uncertainties
- Methodology has been validates using STARlight generator
- Nuclear suppression factor measurable with existing data with precision of:
  - ~10% for J/ψ
  - few % for ρ.
- <u>Future LHC heavy-ion runs should include asymmetric beams</u>