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Probing the transverse spin asymmetry in the inelastic J/Psi photoproduction at hadronic colliders

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Outline

- Vector meson photoproduction at hadronic colliders
- Transverse single - spin asymmetries and the gluon Sivers function
- Predictions for the J/Psi photoproduction in $p^{\uparrow}p$ and $p^{\uparrow}Au$ collisions at the RHIC energies

RHIC and LHC = Photon colliders

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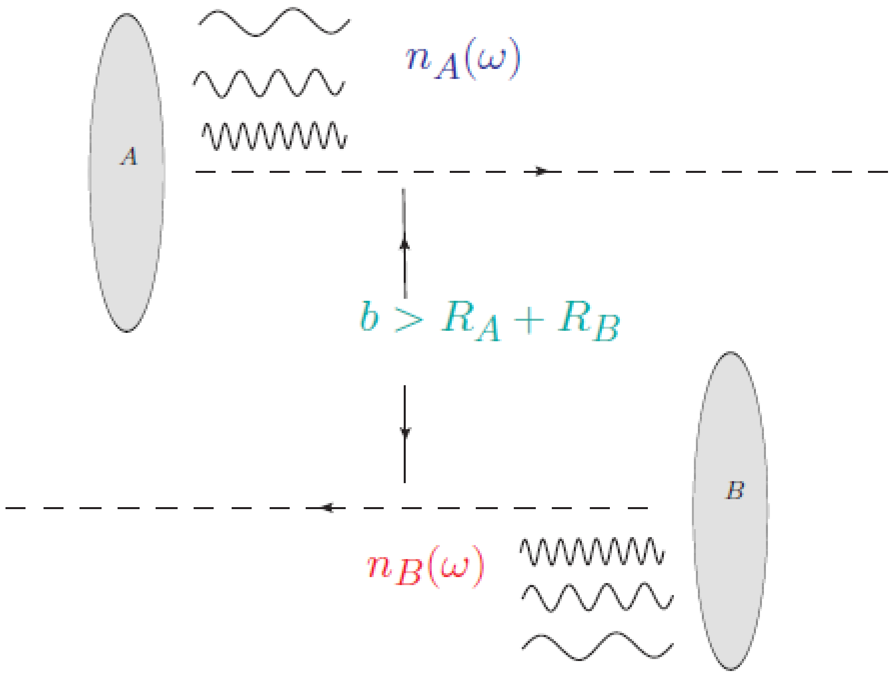
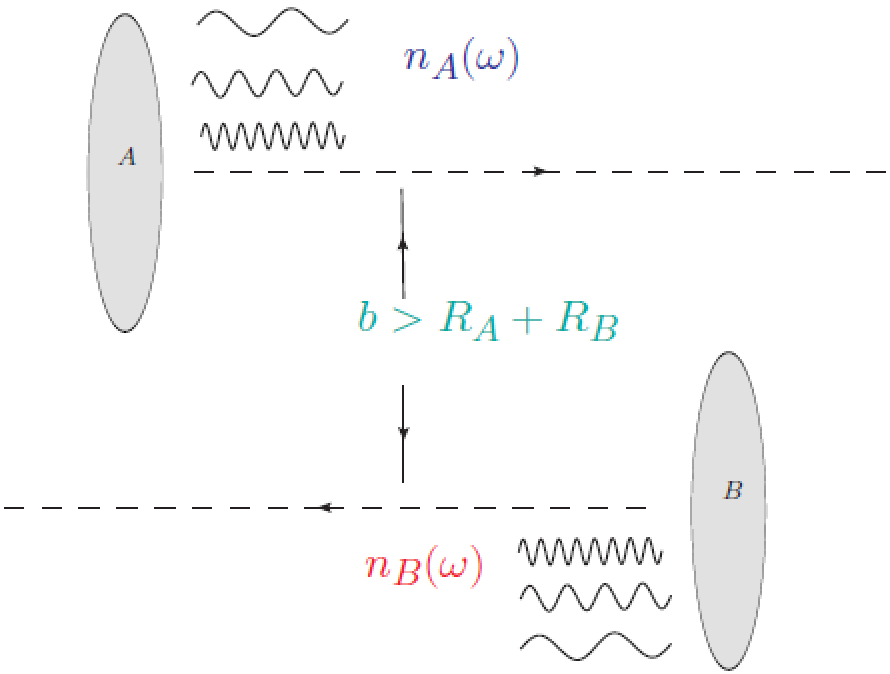


$$n_h(\omega) \propto Z^2$$

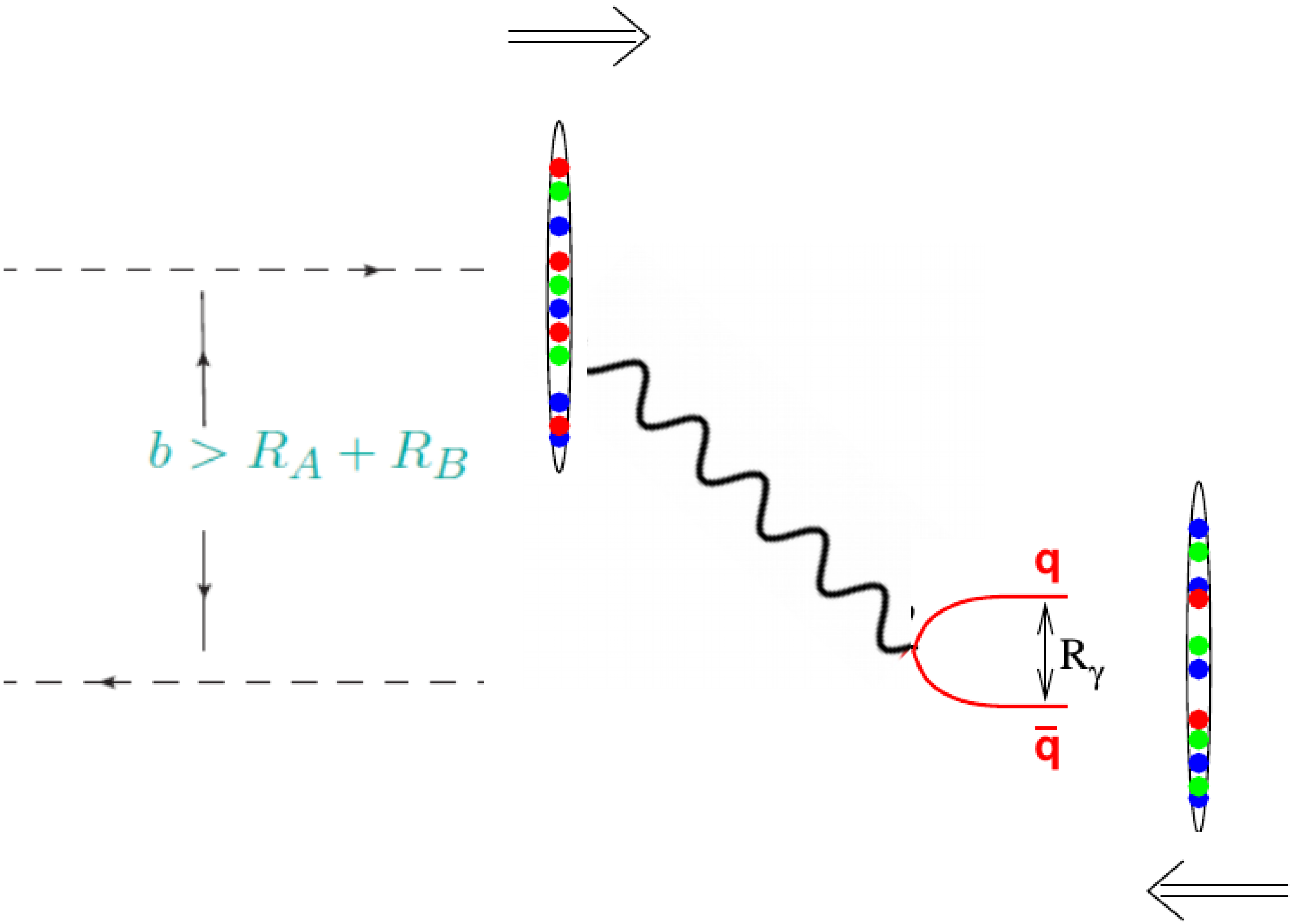
RHIC and LHC = Photon colliders



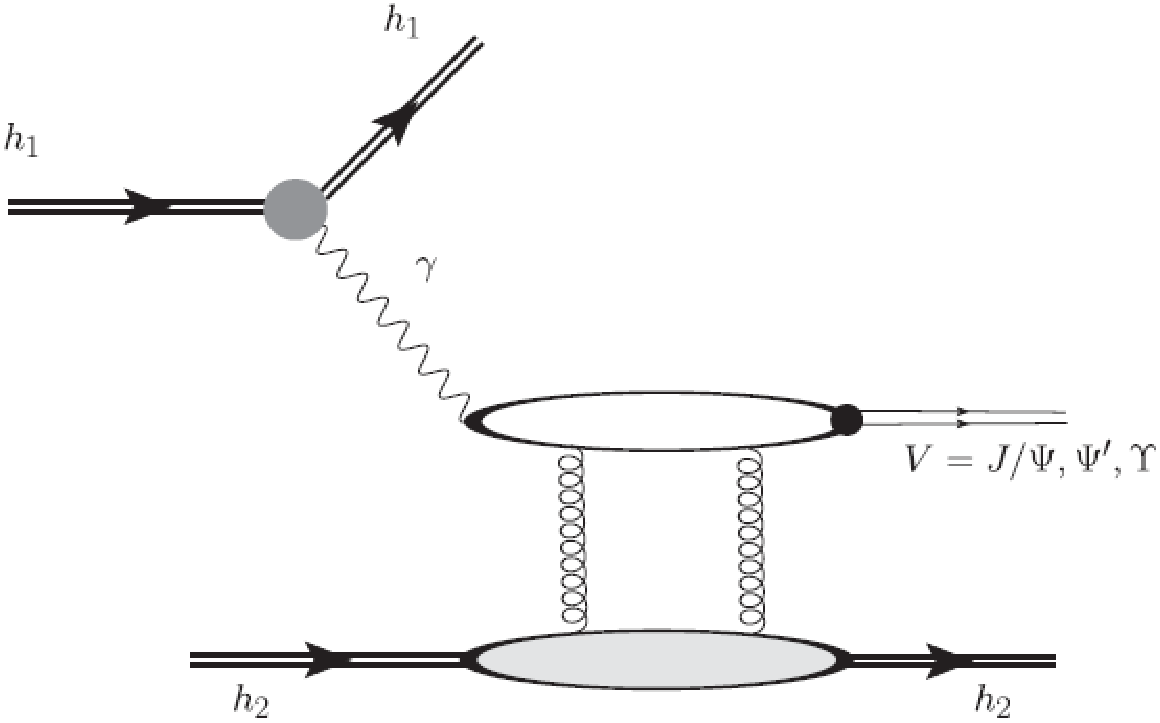
$$n_h(\omega) \propto Z^2$$

1. γh Processes: $\sigma(h_1 h_2 \rightarrow X) = n_h(\omega) \otimes \sigma^{\gamma h \rightarrow X}(W_{\gamma h})$
2. $\gamma\gamma$ Processes: $\sigma(h_1 h_2 \rightarrow X) = n_1(\omega) \otimes n_2(\omega) \otimes \sigma^{\gamma\gamma \rightarrow X}(W_{\gamma\gamma})$

Ultraperipheral Hadronic Collisions: Photon - hadron interactions



Exclusive vector meson photoproduction at hadronic colliders



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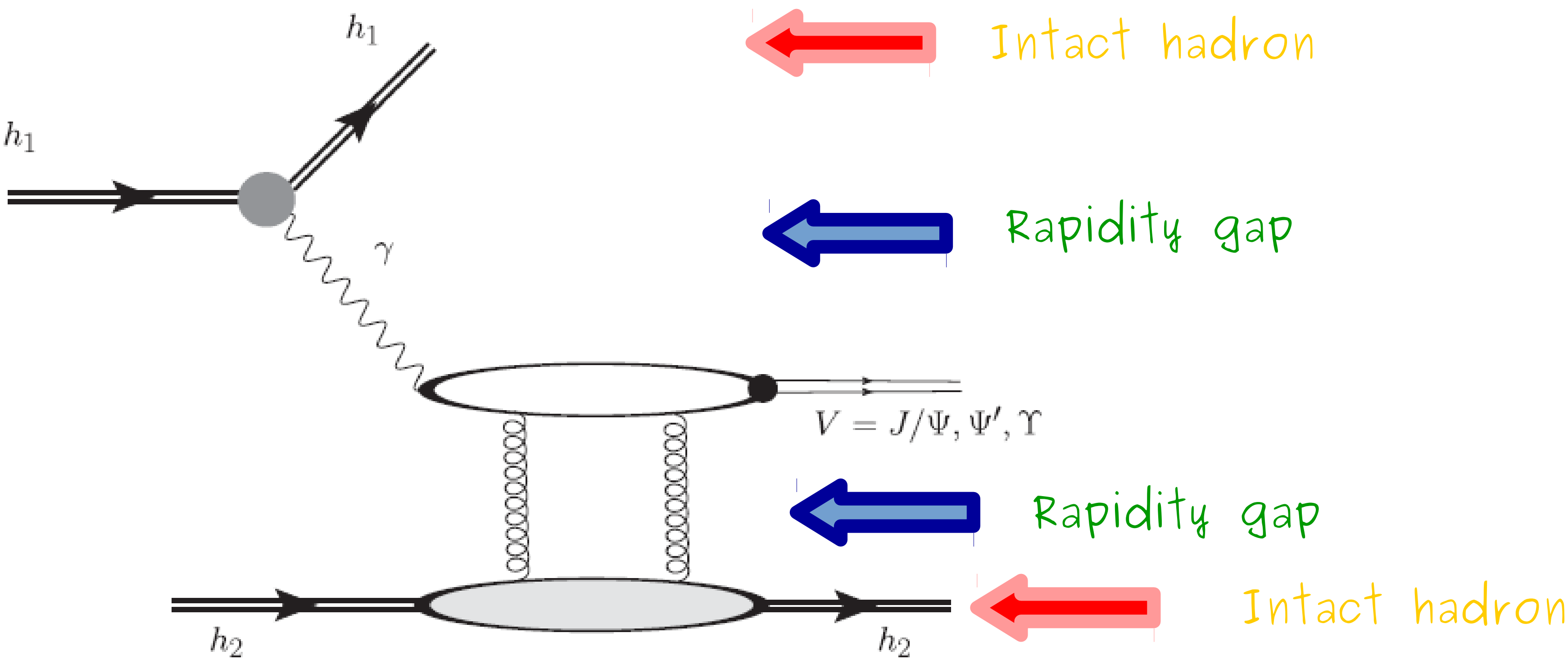

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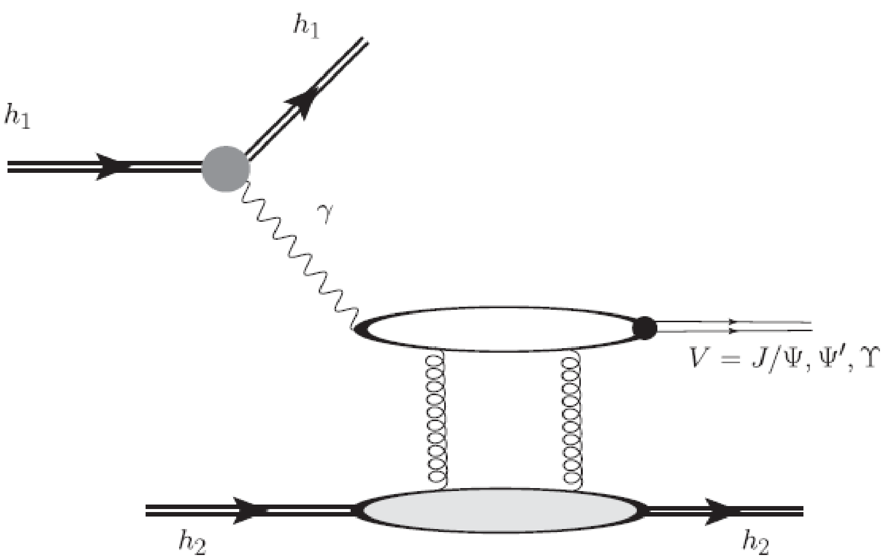

At leading order in LL(1/x) approx.:

$$\left.\frac{d\sigma^{\gamma h \to V h}}{dt}\right|_{t=0} = \mathcal{N} \frac{\pi^3 \Gamma_{e^+e^-} M_V^3}{48 \alpha_{\rm em}} \left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g_h(x, \bar{Q}^2) \right]^2$$

Cross section is proportional to the square of the hadron gluon distribution at $x = 4\overline{Q}^2/W^2$

[a] VPG, Bertulani, PRC65, 054905 (2002)

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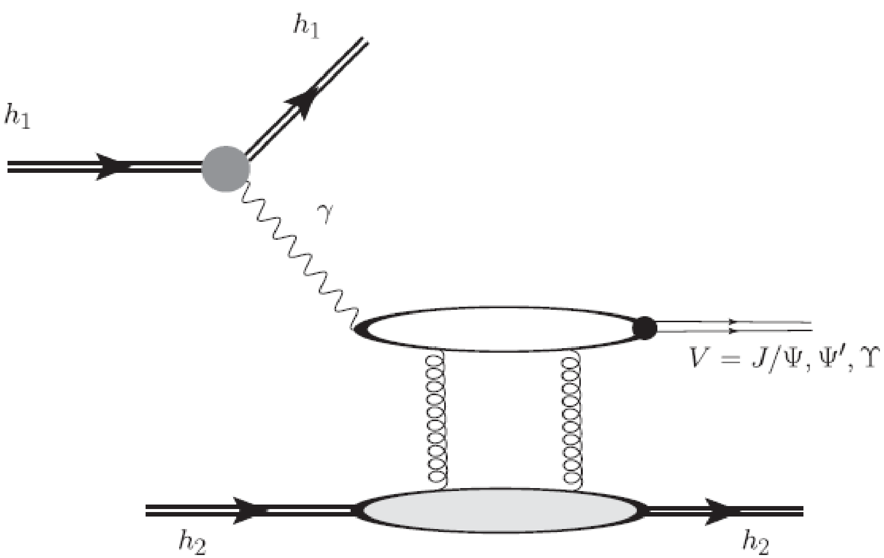

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Important probe of the QCD dynamics at high energies!

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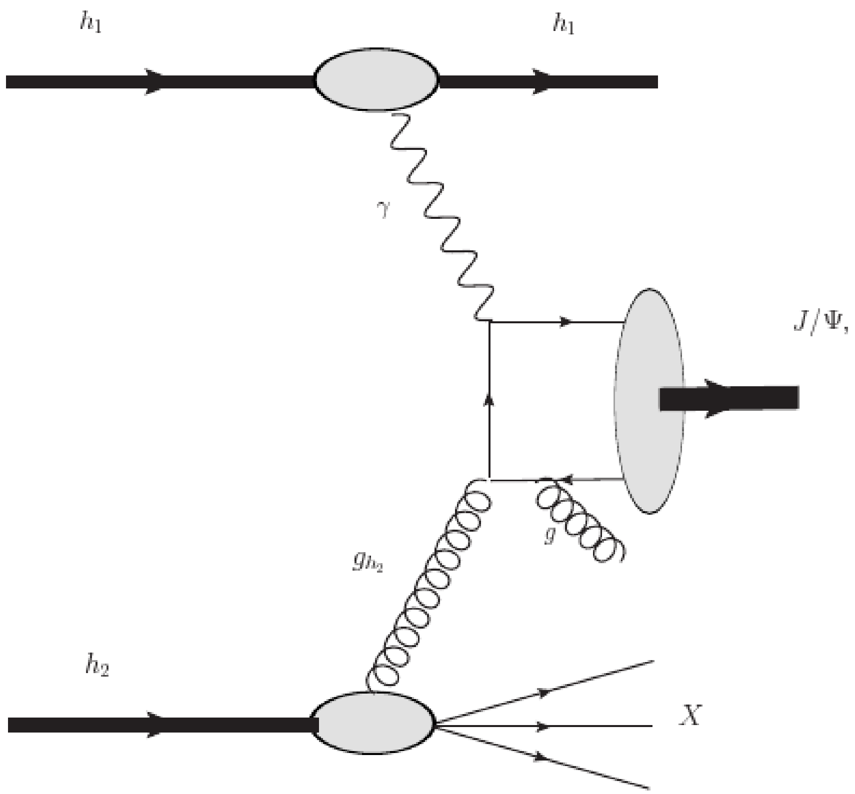
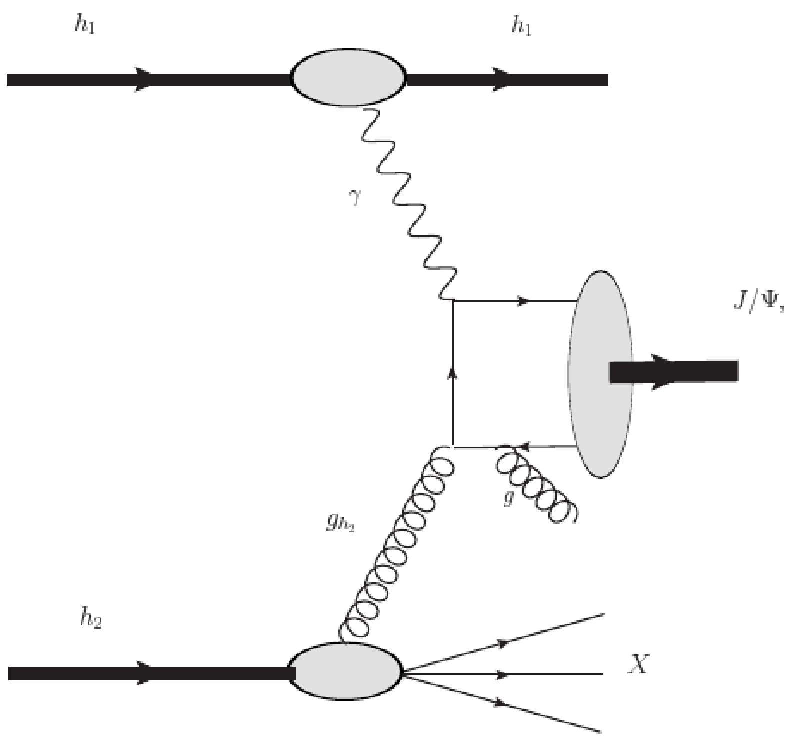


Inclusive vector meson photoproduction at hadronic colliders: Unpolarized target

$$\sigma(h_1 + h_2 \to h_1 \otimes J/\Psi + X) = \int d\omega \, n_{h_1}(\omega) \, \sigma(\gamma h_2 \to J/\Psi X)$$



At leading order:

$$\sigma(\gamma h_2 \to J/\Psi X) \propto \sigma(\gamma g \to J/\Psi) \cdot x g_{h_2}$$

- Cross section is proportional to the hadron gluon distribution.
- The predictions depend on the modelling of the quarkonium photoproduction (NRQCD, CSM, CEM, kT - factorization, ...)

For details see e.g. VPG, MM Machado, EPJA 50 (2014) 72

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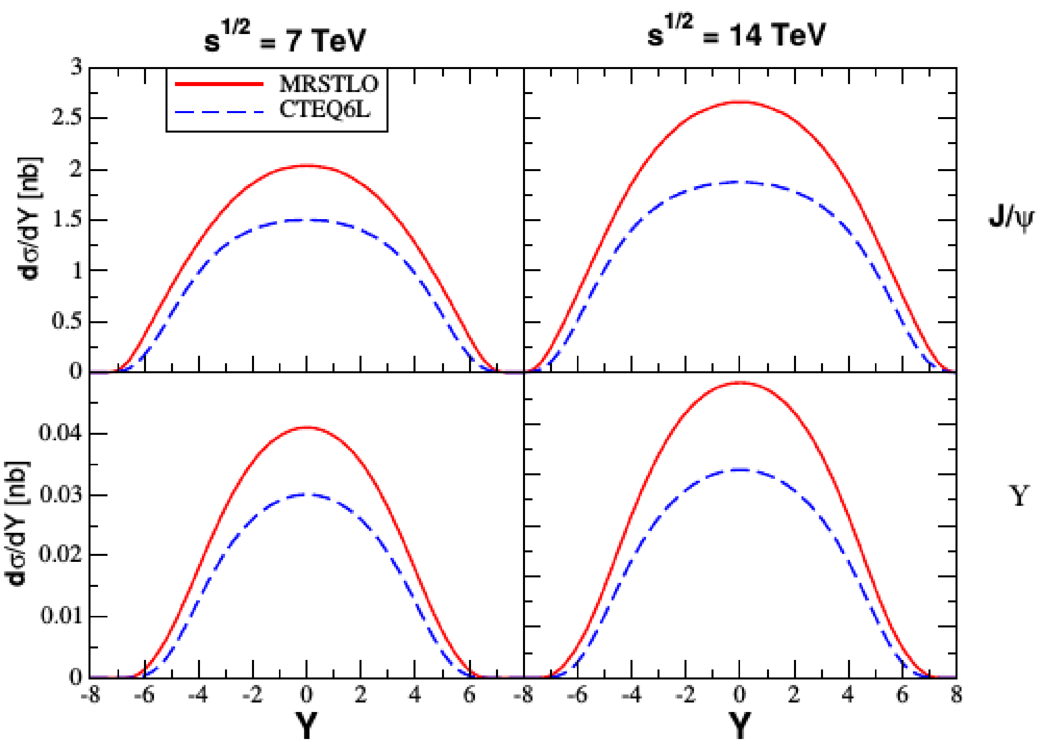


J/Ψ	MRSTLO	CTEQ6L
$\sqrt{s} = 7$ TeV	17.93 nb (1793×10^6)	13.18 nb (1318×10^6)
$\sqrt{s} = 14$ TeV	25.66 nb (2566×10^6)	18.40 nb (1840×10^6)
Υ	MRSTLO	CTEQ6L
$\sqrt{s} = 7$ TeV	0.30 nb (30×10^6)	0.21 nb (21×10^6)
$\sqrt{s} = 14$ TeV	0.47 nb (47×10^6)	0.33 nb (33×10^6)

For details see e.g. VPG, MM Machado, EPJA 50 (2014) 72

Inclusive vector meson photoproduction at hadronic colliders: Polarized target

$$\sigma_{hp^\uparrow \to hJ/\Psi X}(\sqrt{s}) = \int dx_\gamma d^2\boldsymbol{k}_{\perp\gamma}\; f_{\gamma/h}(x_\gamma, \boldsymbol{k}_{\perp\gamma}) \cdot \sigma_{\gamma p^\uparrow \to J/\Psi X}(W^2_{\gamma p})$$

Where:

– x_γ is the energy fraction of hadron carried by the photon with transverse momentum $\boldsymbol{k}_{\perp\gamma}$;

– $f_{\gamma/h}$ is TMD photon spectrum, which we asssume to be given by:

$$f_{\gamma/h}(x_\gamma, \boldsymbol{k}_{\perp\gamma}) = f_{\gamma/h}(x_\gamma)\exp\left(-\,k^2_{\perp\gamma}/\langle\, k^2_{\perp\gamma}\rangle\right)/(\pi\langle\, k^2_{\perp\gamma}\rangle)$$

For a proton:

$$f_{\gamma/p}(x_\gamma) = \frac{\alpha_{\rm em}}{2\pi}\frac{1+(1-x_\gamma)^2}{x_\gamma}\left(\ln\Omega - \frac{11}{6} + \frac{3}{\Omega} - \frac{3}{2\,\Omega^2} + \frac{1}{3\,\Omega^3}\right)$$

For a nucleus:

$$f_{\gamma/A}(x_\gamma) = \frac{\alpha_{em}Z^2}{\pi}\,\frac{1}{x_\gamma}\left[2\eta\, K_0\,(\eta)\, K_1\,(\eta) - \eta^2\,\mathcal{U}(\eta)\right]$$

For details see VPG, PRD97 (2018) 014001

Inclusive vector meson photoproduction at hadronic colliders: Polarized target

$$\sigma_{hp^\uparrow \to hJ/\Psi X}(\sqrt{s}) = \int dx_\gamma d^2\boldsymbol{k}_{\perp\gamma}\, f_{\gamma/h}(x_\gamma, \boldsymbol{k}_{\perp\gamma}) \cdot \sigma_{\gamma p^\uparrow \to J/\Psi X}(W^2_{\gamma p})$$

Quarkonium photoproduction: Color Evaporation Model

$$\sigma_{\gamma p^\uparrow \to J/\Psi X} = F_{J/\Psi}\, \overline{\sigma}_{\gamma p^\uparrow \to c\bar{c}X}$$

With:

$$\overline{\sigma}_{\gamma p^\uparrow \to c\bar{c}X} = \int_{4m_c^2}^{4m_D^2} dM^2_{c\bar{c}}\, dx_g\, d^2\boldsymbol{k}_{\perp g}\, f_{g/p^\uparrow}(x_g, \boldsymbol{k}_{\perp g})\, \frac{d\sigma[\gamma g \to c\bar{c}]}{dM^2_{c\bar{c}}}$$

The cross section is proportional to the number density of gluons in the proton with transverse polarization S and momentum P, which is usually parametrized as:

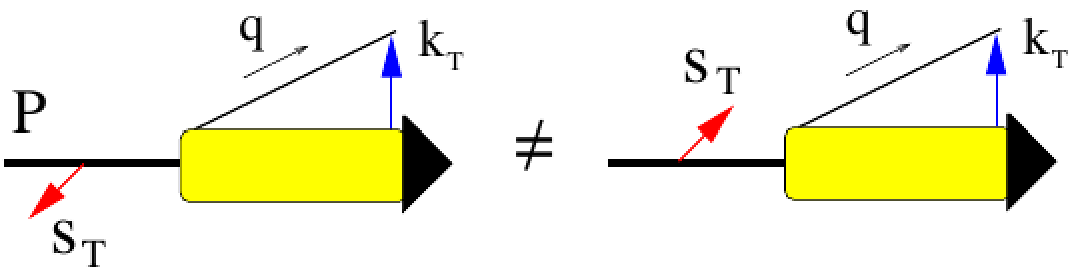
$$f_{g/p^\uparrow}(x_g, \boldsymbol{k}_{\perp g}, \boldsymbol{S}) \equiv f_{g/p}(x_g, k_{\perp g}) + \frac{1}{2}\Delta^N f_{g/p^\uparrow}(x_g, k_{\perp g})\hat{\boldsymbol{S}} \cdot (\hat{\boldsymbol{P}} \times \hat{\boldsymbol{k}_{\perp g}})$$

Unpolarized gluon TMD

Gluon Sivers function

Sivers effect

Sivers (90's) have proposed that the transverse momentum of the partons inside of hadrons can be correlated with the spin.



Gluon Sivers function: Unpolarized gluon in a polarized nucleon. Parametrizes the correlation between the azimuthal distribution of an unpolarized parton and the spin of its parent nucleon.

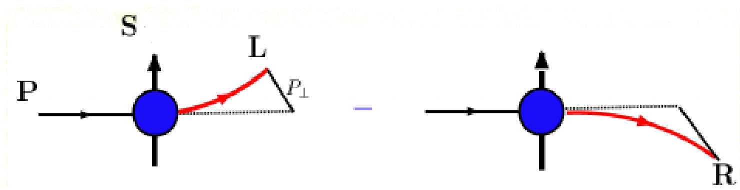
- While the quark Sivers function have been measured directly in many processes (e.g. SIDIS and DY), no direct clear measurements of the gluon Sivers function have been done.
- Potential probes: Quarkonium Electroproduction, J/Psi and D meson production in hadronic collisions, …

Inclusive J/Psi photoproduction in $p^{\uparrow}p$ and $p^{\uparrow}Au$ collisions at the RHIC energies: Probing the gluon Sivers function

Single Spin Asymmetry

In order to probe the gluon Sivers function, in what follows we will investigate the impact of different models for $\Delta^N f_{g/p^\uparrow}(x_g, k_{\perp g})$ in the rapidity dependence of the single spin asymmetry, defined as:

$$A_N(Y) = \frac{\frac{d\sigma^\uparrow}{dY} - \frac{d\sigma^\downarrow}{dY}}{\frac{d\sigma^\uparrow}{dY} + \frac{d\sigma^\downarrow}{dY}}$$



Where $\frac{d\sigma^\uparrow}{dY}$ and $\frac{d\sigma^\downarrow}{dY}$ are respectively the differential cross sections measured when the proton is transversely polarized up (↑) and down (↓) with respect to the scattering plane. One have that:

$$\frac{d\sigma^\uparrow}{dY} - \frac{d\sigma^\downarrow}{dY} = F_{J/\Psi} \int d\phi_{q_T} \int q_T dq_T \int_{4m_c^2}^{4m_D^2} dM_{c\bar{c}}^2 \int d^2\boldsymbol{k}_{\perp g}\, f_{\gamma/h}(x_\gamma, \boldsymbol{q}_T - \boldsymbol{k}_{\perp g})$$
$$\times \left[f_{g/p^\uparrow}(x_g, \boldsymbol{k}_{\perp g}) - f_{g/p^\downarrow}(x_g, \boldsymbol{k}_{\perp g})\right] \hat{\sigma}_0(M_{c\bar{c}}^2) \sin(\phi_{q_T} - \phi_S)$$

$$\frac{d\sigma^\uparrow}{dY} + \frac{d\sigma^\downarrow}{dY} = 2\, F_{J/\Psi} \int d\phi_{q_T} \int q_T dq_T \int_{4m_c^2}^{4m_D^2} dM_{c\bar{c}}^2 \int d^2\boldsymbol{k}_{\perp g}\, f_{\gamma/h}(x_\gamma, \boldsymbol{q}_T - \boldsymbol{k}_{\perp g})\, f_{g/p}(x_g, \boldsymbol{k}_{\perp g}) \hat{\sigma}_0(M_{c\bar{c}}^2)$$

Single Spin Asymmetry

In our calculations we will assume that:

- Unpolarized gluon TMD: Gaussian form

$$f_{g/p}(x_g, \boldsymbol{k}_{\perp g}) = f_{g/p}(x_g, \mu^2)\frac{1}{\pi\langle\, k_{\perp g}^2\rangle}e^{-\,k_{\perp g}^2/\langle\, k_{\perp g}^2\rangle}$$

- Proton is moving along z – axis with momentum P and transversely polarized along y – axis;

- The gluon Sivers function can be parametrized as follows:

$$\Delta^N f_{g/p^\uparrow}(x_g, k_{\perp g}) = 2N_g(x_g) f_{g/p}(x_g, \mu^2) h(k_{\perp g})\frac{e^{-\,k_{\perp g}^2/\langle\, k_{\perp g}^2\rangle}}{\pi\langle\, k_{\perp g}^2\rangle}$$

Where:

$$N_g(x_g) = N_g x_g^{\alpha}(1-x_g)^{\beta}\frac{(\alpha+\beta)^{(\alpha+\beta)}}{\alpha^{\alpha}\beta^{\beta}}$$

and

$$h(k_{\perp g})\frac{e^{-\,k_{\perp g}^2/\langle\, k_{\perp g}^2\rangle}}{\pi\langle\, k_{\perp g}^2\rangle} = \frac{\sqrt{2e}}{\pi}\sqrt{\frac{1-\rho}{\rho}}\,k_{\perp g}\frac{e^{-\,k_{\perp g}^2/\rho\langle\, k_{\perp g}^2\rangle}}{\langle\, k_{\perp g}^2\rangle^{3/2}}$$

Single Spin Asymmetry

Possible parametrizations:

D'Alesio et al. [JHEP1509,119 (2015)]: Obtained by fitting the PHENIX data and using the quark Sivers parameters extracted earlier from the SIDIS data.

SIDIS1	$N_g = 0.65$	$\alpha_g = 2.8$	$\beta_g = 2.8$	$\rho = 0.687$	$\langle k_\perp^2 \rangle = 0.25 GeV^2$
SIDIS2	$N_g = 0.05$	$\alpha_g = 0.8$	$\beta_g = 1.4$	$\rho = 0.576$	

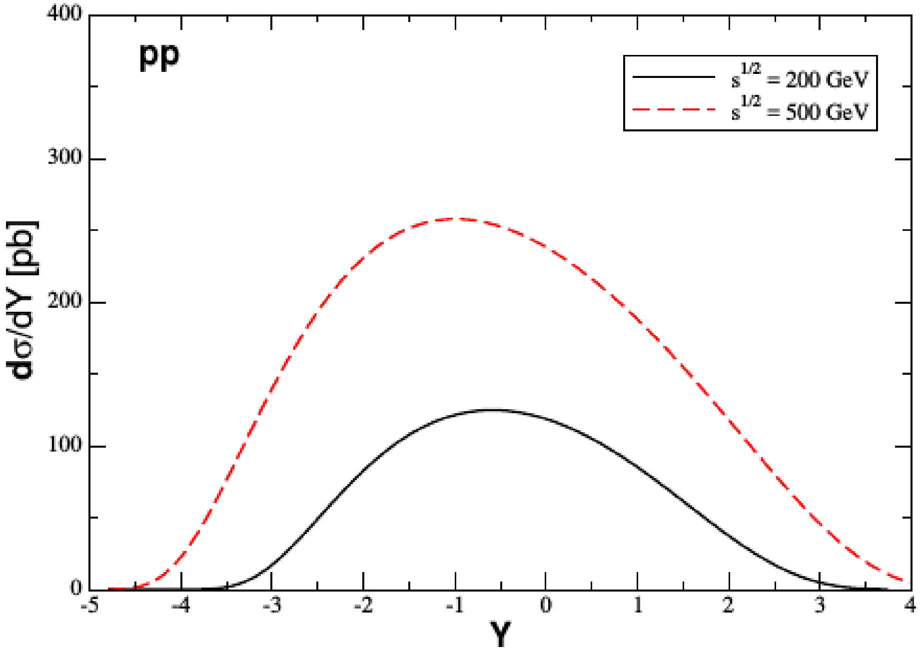
Boer and Vogelsang [PRD69, 094025 (2004)]: Proposed to express the gluon Sivers function in terms of the quark Sivers one.

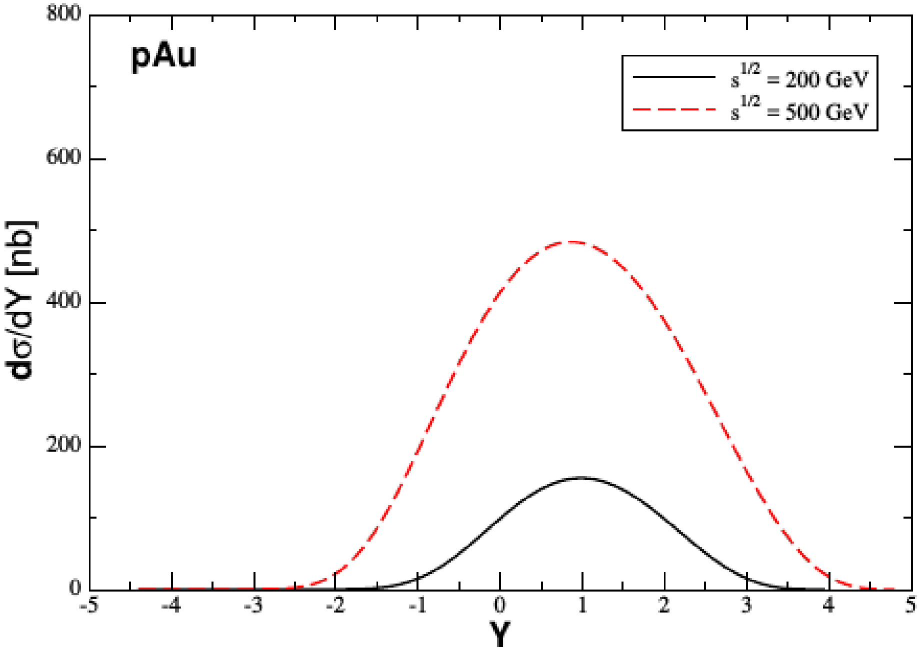
$$\mathcal{N}_g(x) = (\mathcal{N}_u(x) + \mathcal{N}_d(x))/2 \text{ (BV (A))}$$

$$\mathcal{N}_g(x) = \mathcal{N}_d(x) \text{ (BV (B))}$$

Results:

Rapidity distributions:



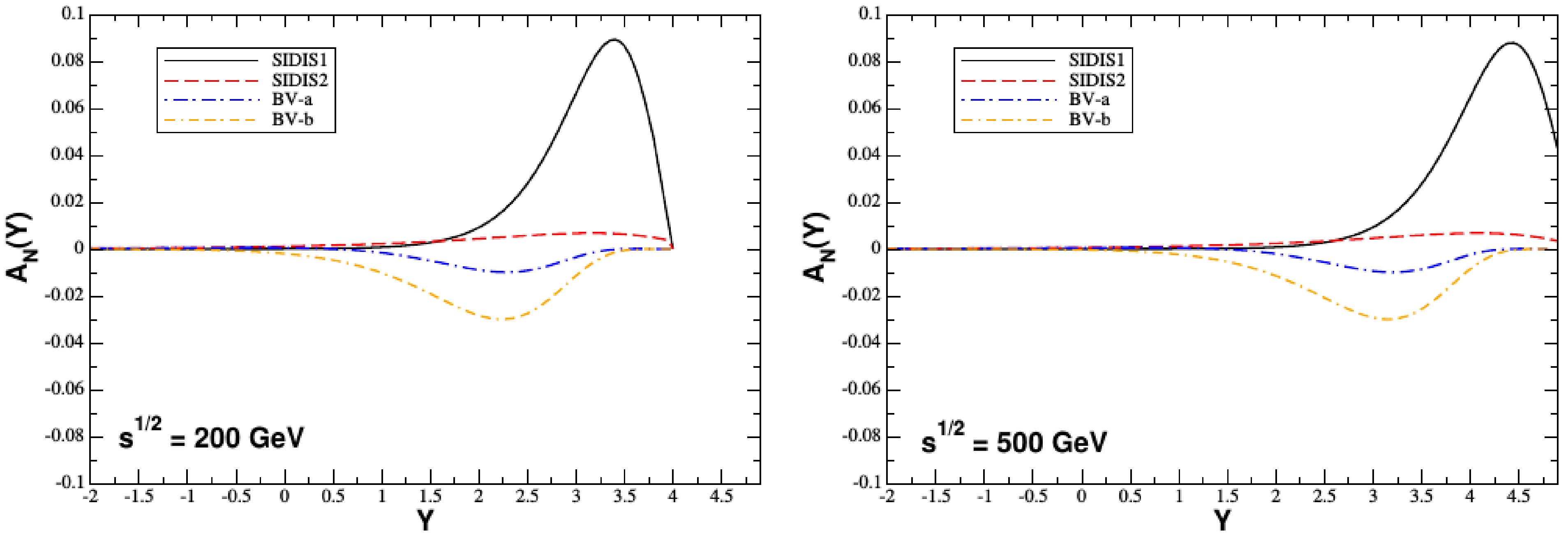


Total cross sections (in nb):

	$\sqrt{s} = 200$ GeV	$\sqrt{s} = 500$ GeV
$p^{\uparrow}p$	0.932	1.245
$p^{\uparrow}Au$	380.0	1664.5

Results:

pp collisions:



The magnitude and signal of $A_N(Y)$ is strongly dependent on the model used to describe the gluon Sivers function, with the position of peak occuring at larger values of Y with the increasing of energy.

Results:

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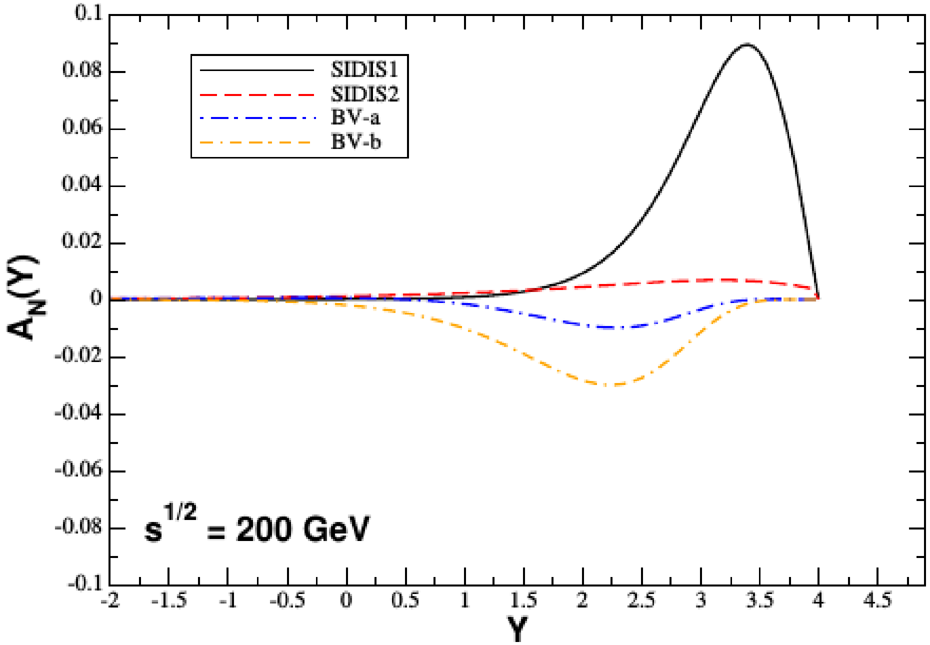

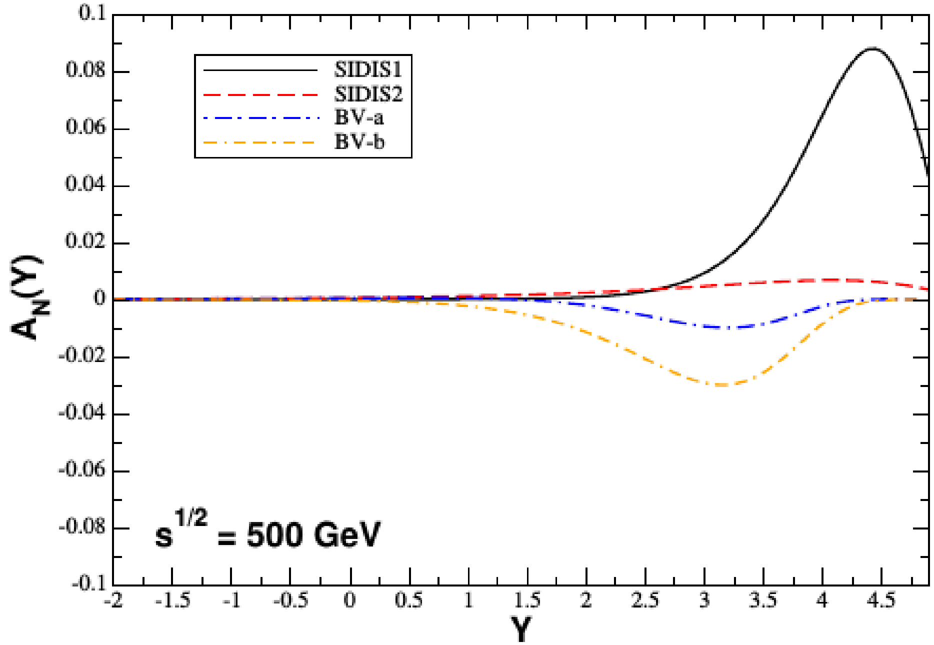

Similar results for $p^{\uparrow}$Au Collisions!

Possible improvements and Open questions:

- ✓ Treatment of the quarkonium photoproduction (NLO corrections, NRQCD, …);
- ✓ Inclusion of the QCD evolution in the TMD gluon distribution;
- ✓ Extension for the expected kinematical range to be probed the AFTER @ LHC experiment;

Summary

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- ✓ The study of high energies processes involving polarized hadrons allows to improve our understanding of the polarized quark and gluon structure of hadrons;
- ✓ In particular, the analysis of transverse spin phenomena in hard processes is expected to provide a 3D picture of partons inside the nucleon;
- ✓ One of the current challenges is the description of the gluon Sivers distribution;
- ✓ In this contribution we have proposed to probe the gluon Sivers distribution considering the inelastic J/Psi photoproduction in pp and pAu collisions at the RHIC energies;
- ✓ Our exploratory analysis indicates that the signal and magnitude of asymmetry can be investigated by the analysis of the J/Psi production at forward rapidities;
- ✓ Similar dependence also is expect to be present in the case of D meson photoproduction.

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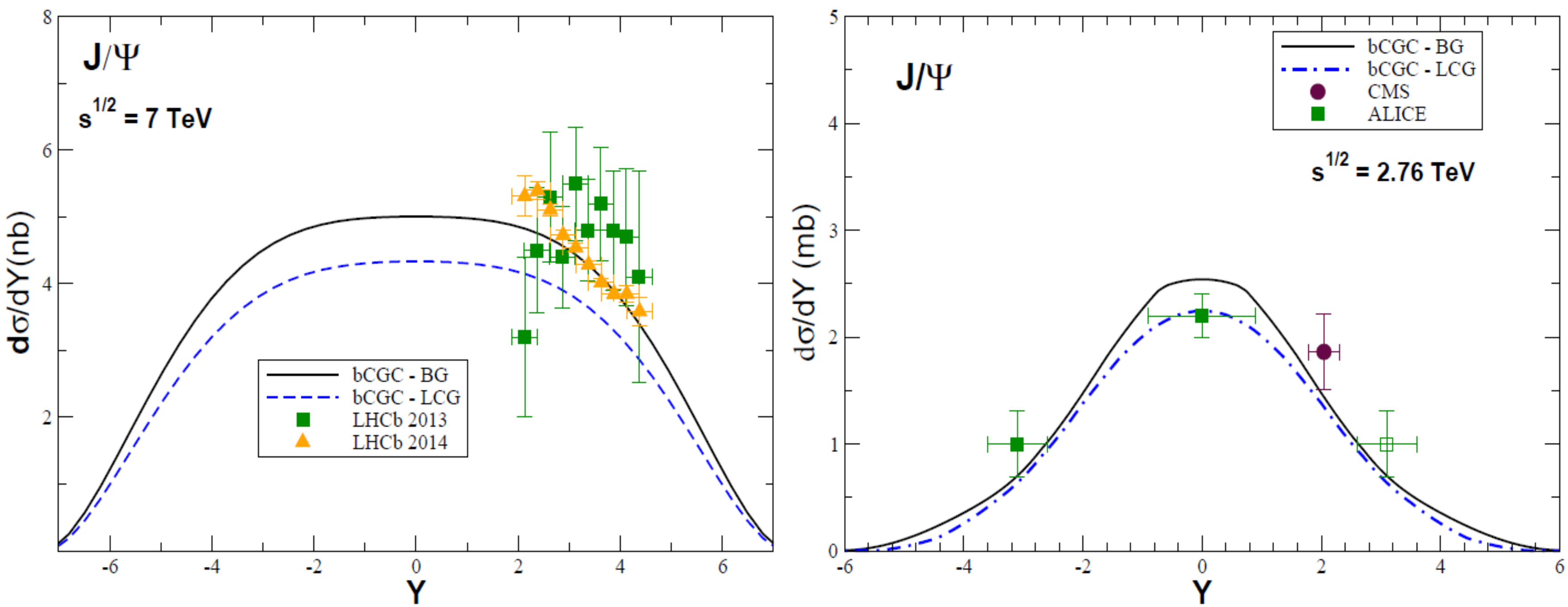
Thank you for your attention!

Extras

Comparison with the Run I data

- Diffractive J/Ψ photoproduction in hadronic collisions [a]



(a) VPG, Moreira, Navarra, PRC90, 015203 (2014)

Comparison with the Run I data

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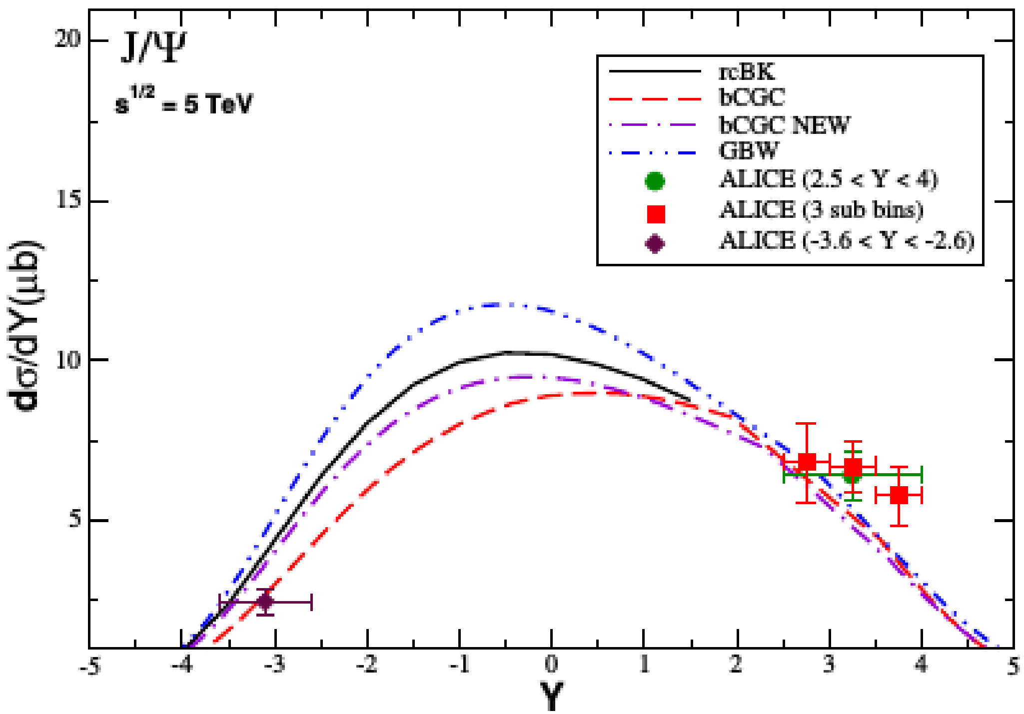
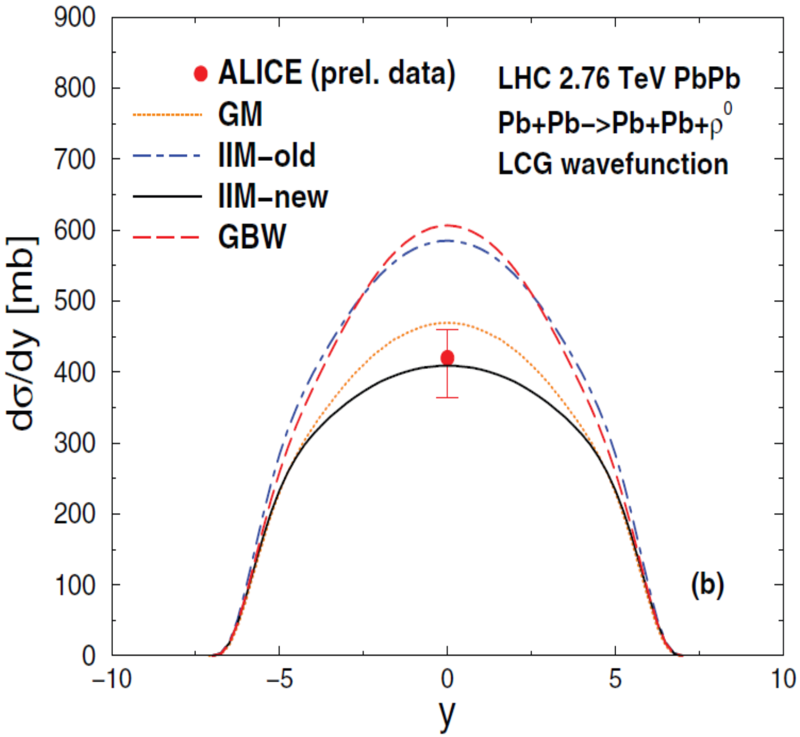
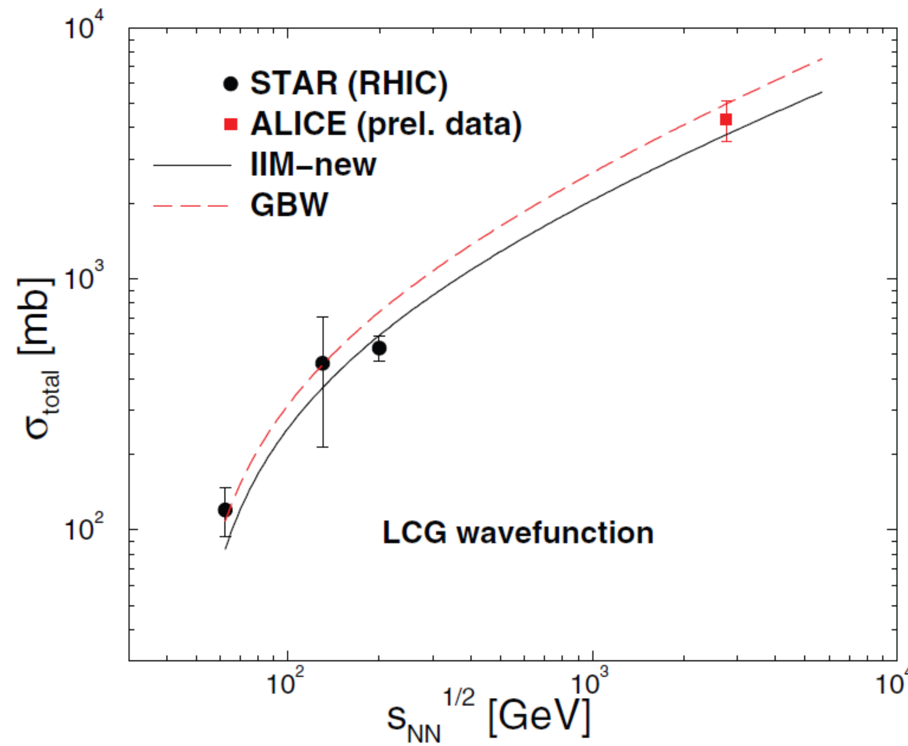


Comparison with the Run I data

- Diffractive ρ photoproduction in hadronic collisions [c]

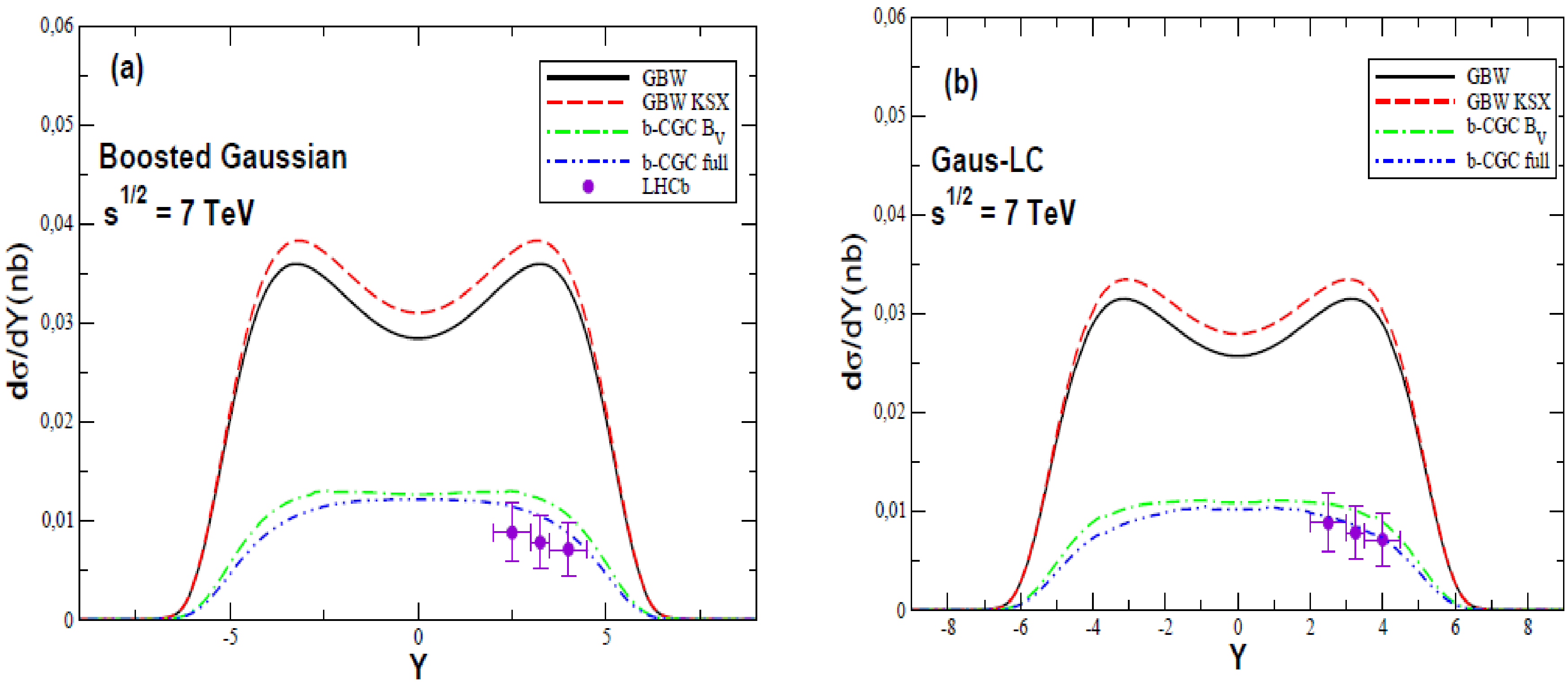




(c) VPG, Machado, EPJC 40, 519 (2005); PRC80, 054901 (2009); PRC84, 011902 (2011); Machado, dos Santos, PRC91, 025203 (2015)

Comparison with the Run I data

- Diffractive Υ photoproduction in hadronic collisions [b]



[b] VPG, Moreira, Navarra, PLB 472, 172 (2015)