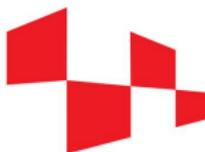


Isolated photon-hadron production in high energy pp and pA collisions

Sanjin Benić (University of Zagreb)

SB, Garcia-Montero, Perkov, 2203.01685

DIS2022, Spain, May 4, 2022



HRZZ

Hrvatska zaklada
za znanost

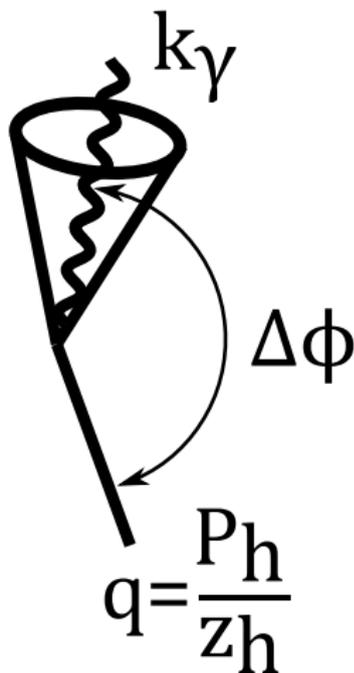
Motivations

- γh angular correlations as a probe of high energy nuclear wavefunction
- imbalance momentum

$$k_{\perp} \equiv k_{\gamma\perp} + \frac{P_{h\perp}}{z_h}$$

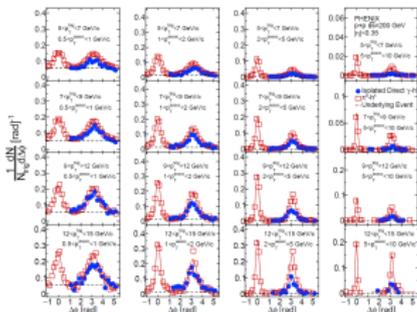
$$k_{\perp}^2 \sim Q_S^2 \sim A^{1/3}$$

- **complements hh productions**
→ see previous talk by Cyrille Marquet



Motivations

- recent data on isolated γh^\pm from PHENIX and ALICE at mid-rapidity



PHENIX (pp)

$\sqrt{s} = 200, 510$ GeV

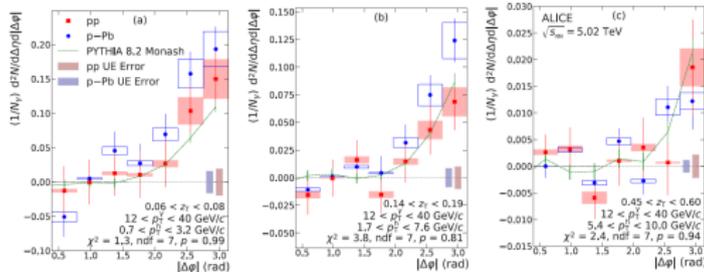
$k_{\gamma\perp} = 5 - 15$ GeV

$P_{h\perp} = 0.5 - 10$ GeV

PHENIX, PRD 95, no. 7, 072002 (2017)

PHENIX, PRD 98, no. 7, 072004 (2018)

ALICE, PRC 102, 044908 (2020)



ALICE (pp & pPb)

$\sqrt{s} = 5.02$ TeV

$k_{\gamma\perp} = 12 - 40$ GeV

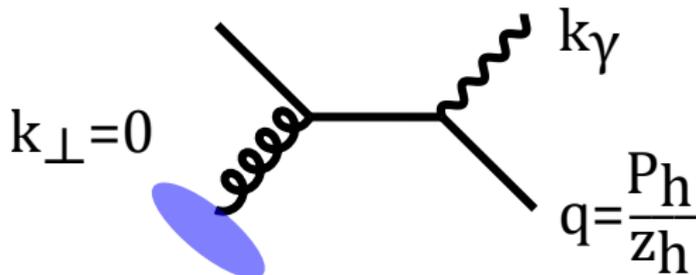
$P_{h\perp} = 0.5 - 10$ GeV

Motivations

- $x_{\text{RHIC}} \sim 10^{-2}$ $x_{\text{LHC}} \sim 10^{-3}$
→ small- x effects → CGC
- imbalance momentum: $k_{\perp} \equiv k_{\gamma\perp} + \frac{P_{h\perp}}{z_h}$
- hard scale: $Q \sim k_{\text{trig}\perp}$
- for kinematics when $Q \gg k_{\perp}$
→ Sudakov (double) logs $\alpha_S \log^2(Q^2/k_{\perp}^2)$
important
- try to interpret the PHENIX and ALICE data in the context of CGC + Sudakov

Generic considerations

- $qg \rightarrow q\gamma$ in collinear pQCD



$$\frac{d\sigma}{d^2k_{\gamma\perp} d\eta_\gamma d^2P_{h\perp} d\eta_h} = \sum_q e_q^2 \int \frac{dz_h}{z_h^2} D_q(z_h, \mu^2) x_p f_q(x_p, \mu^2) x_A f_g(x_A, \mu^2) \alpha_S \hat{\sigma} \delta^{(2)}(k_\perp)$$

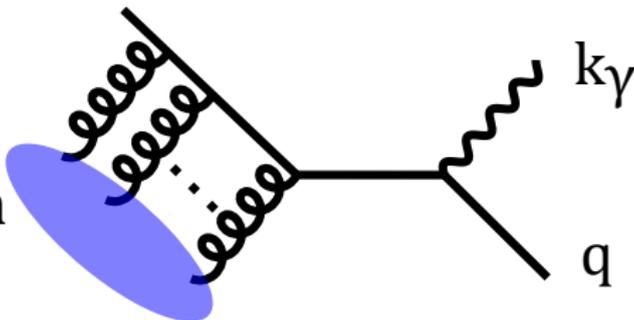
→ γh emerge back-to-back

Generic considerations

- $qg \rightarrow q\gamma$ in CGC

$$k_{\perp} \sim Q_S$$

$Q_S =$ saturation
scale



$$\frac{d\sigma}{d^2k_{\perp} d\eta_{\gamma} d^2P_{h\perp} d\eta_h}$$

$$= (\pi R_A^2) \sum_q \int_0^1 \frac{dz_h}{z_h^2} D_q(z_h, \mu^2) \frac{e_q^2 N_c}{8\pi^4} x_p f_q(x_p, \mu^2) k_{\perp}^2 \tilde{N}_{A, Y_A}(k_{\perp}) \hat{\sigma}$$

$$\tilde{N}_{A, Y_A}(k_{\perp}) \equiv \int d^2b_{\perp} e^{ik_{\perp} \cdot b_{\perp}} \text{tr} \left\langle \tilde{U}(b_{\perp}) \tilde{U}^{\dagger}(0) \right\rangle_{Y_A} / N_c$$

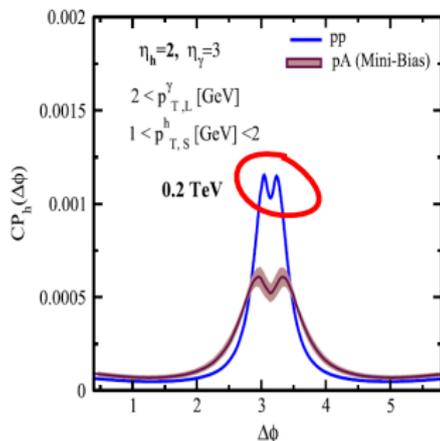
→ broadening of the away side peak

Kopeliovich, Tarasov, Schafer, PRC **59**, 1609-1619 (1999)

Gelis, Jalilian-Marian, PRD **66** 014021 (2002)

Baier, Mueller, Schiff, NPA **741** 358-380 (2004)

Previous phenomenological works



- a generic feature:
dip at $\Delta\phi = \pi$
- due to dipole UGD

$$\varphi_{\text{DP}}(k_{\perp}) \sim k_{\perp}^2 \tilde{\mathcal{N}}(k_{\perp}) \sim k_{\perp}^2 / Q_S^2$$

Jalilian-Marian, Rezaeian, PRD **86** 034016 (2012)

Stasto, Xiao, Zaslavsky, PRD **86** 014009 (2012)

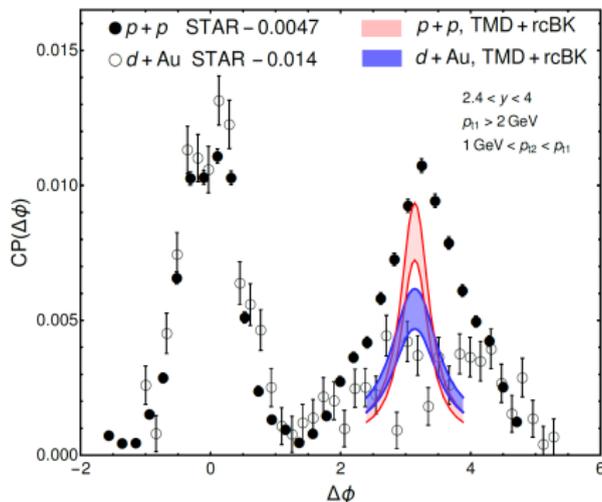
Rezaeian, PRD **86** 094016 (2012)

Goncalves, Lima, Pasechnik, Sumera, PRD **101** no. 9 094019 (2020)

- in contrast to hh correlations that probe the WW UGD

$$\varphi_{\text{WW}}(k_{\perp}) \sim \log(Q_S^2/k_{\perp}^2)$$

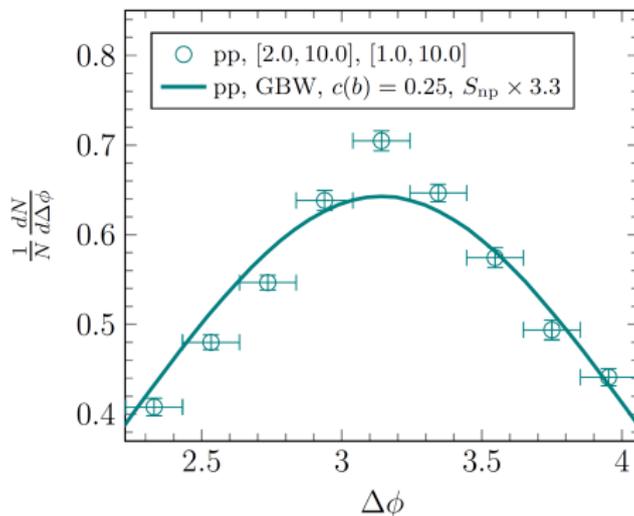
Lesson from hh correlations



Albacete, Giacalone, Marquet, Matas, PRD **99** 014002 (2019)

- Giacalone et al: **away side peak is too narrow** in comparison to the data
- see also previous talk by Cyrille Marquet

Lesson from hh correlations



Stasto, Wei, Xiao, Yuan, PLB **784** 301-306 (2018)

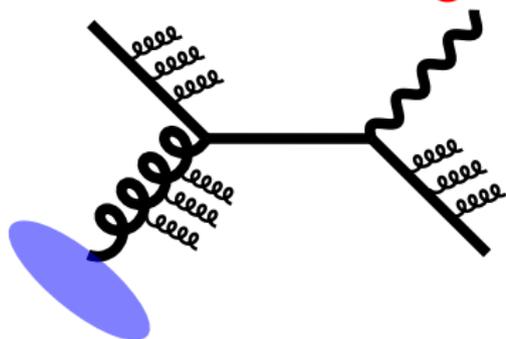
- Wei et al: **Sudakov resummation broadens the away side peak** → agrees with the data!
- see also previous talk by Cyrille Marquet

Sudakov resummation

- two particle production: two scale problem
→ imbalance k_{\perp} and a hard scale $\equiv Q$

$$Q^2 \equiv x_p x_{AS} \sim k_{\text{trig}\perp}^2$$

- account for **soft gluon radiations**



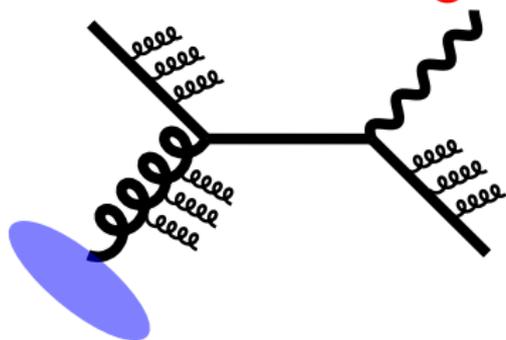
$$\frac{d\sigma^{(0)}}{d^2k_{\perp}} \propto \delta^{(2)}(k_{\perp})$$

Sudakov resummation

- two particle production \rightarrow two scale problem
 \rightarrow imbalance k_{\perp} and a hard scale $\equiv Q$

$$Q^2 \equiv x_p x_{A_S} s \sim k_{\text{trig}\perp}^2$$

- account for **soft gluon radiations**



$$\frac{d\sigma^{(1)}}{d^2k_{\perp}} \propto \int_{k_{g\perp}} \frac{\alpha_S}{k_{g\perp}^2} \log \frac{Q^2}{k_{g\perp}^2} \times \delta^{(2)}(k_{g\perp} + k_{\perp})$$

- enhanced when $Q^2 \gg k_{\perp}^2$
 \rightarrow **Sudakov resummation**

Collins, Soper, Sterman, NPB 250 199-224 (1985)

Sudakov resummation

- Sudakov effect on top of CGC

Mueller, Xiao, Yuan, PRL **110** 082301 (2013)

Stasto, Wei, Xiao, Yuan, PLB **784** 301-306 (2018)

Marquet, Wei, Xiao, PLB **802** 135253 (2020)

Zhao, Xu, Chen, Zhang, Wu, PRD **104**, no. 114032 (2021)

van Hameren, Kotko, Kutak, Sapeta, PLB **814** 136078 (2021)

- employed in b_{\perp} -space

$$k_{\perp}^2 \tilde{\mathcal{N}}_{A, \gamma_A}(k_{\perp}) D_q(z_h, \mu^2) f_q(x_p, \mu^2)$$

$$\rightarrow \int d^2 b_{\perp} e^{i k_{\perp} \cdot b_{\perp}} \partial_{b_{\perp}}^2 \tilde{\mathcal{N}}_{A, \gamma_A}(b_{\perp}) D_q(z_h, \mu_b^2) f_q(x_p, \mu_b^2) e^{-S_{\text{Sud}}(b_{\perp}, Q)}$$

- Sudakov factor

$$S_{\text{Sud}}(b_{\perp}, Q) = \int_{\mu_b^2}^{Q^2} \frac{d\bar{\mu}^2}{\bar{\mu}^2} \left[A \log \left(\frac{Q^2}{\bar{\mu}^2} \right) + B \right]$$

- A and $B \rightarrow$ channel dependent coefficients
- for $qg \rightarrow q\gamma$

$$A = \frac{\alpha_S(\bar{\mu}^2)}{\pi} \left(C_F + \frac{C_A}{2} \right) \quad B = -\frac{\alpha_S(\bar{\mu}^2)}{\pi} \frac{3}{2} C_F$$

Computation setup

- $D_q(z_h, \mu^2) \rightarrow$ DSS

de Florian, Sassot, Stratmann, PRD **75**, 114010 (2007)

- $x_p f_q(x_p, \mu^2) \rightarrow$ CTEQ6M

Pumplin, Stump, Huston, Lai, Nadolsky, Tung, JHEP **07**, 012 (2002)

- $\tilde{N}_{A, \gamma_A}(k_\perp) \rightarrow$ AAMQS

Albacete, Armesto, Milhano, Quiroga-Arias, Salgado, EPJC **71**, 1705 (2011)

- b^* prescription $\mu_b > 2e^{-\gamma_E}/b_{\max}$

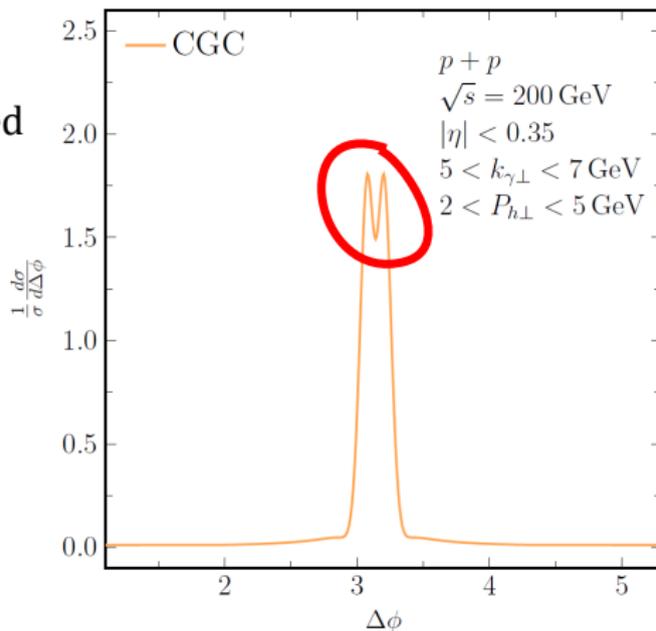
$$S_{\text{Sud}}(b_\perp, Q) \rightarrow S_{\text{Sud}}(b_\perp, Q) + S_{\text{non-pert}}(b_\perp, Q)$$

- $S_{\text{non-pert}}(b_\perp, Q) \rightarrow$ SIYY

Sun, Isaacson, Yuan, Yuan, IJMPA **33** no. 11, 1841006 (2018)

Angular corr's: CGC vs CGC+Sud

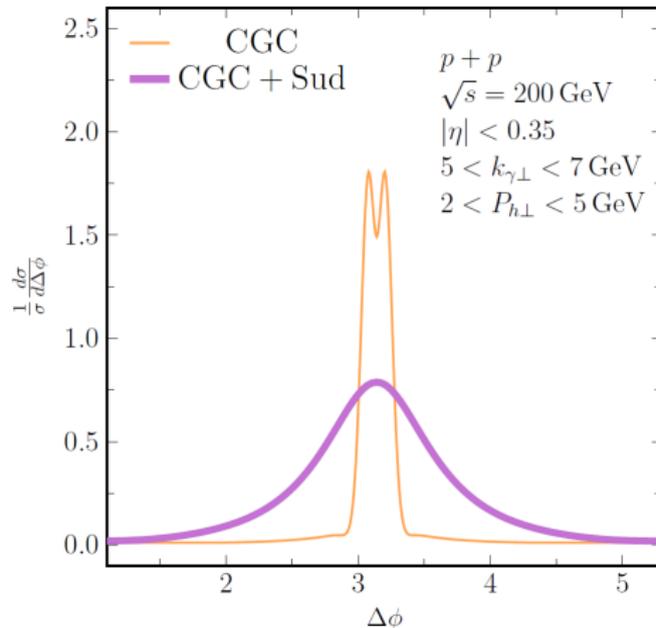
self-normalized
cross section



- **dip** at $\Delta\phi = \pi$ ($\varphi_{\text{DP}}(k_{\perp}) \sim k_{\perp}^2 / Q_S^2$)

SB, Garcia-Montero, Perkov, 2203.01685

Angular corr's: CGC vs CGC+Sud

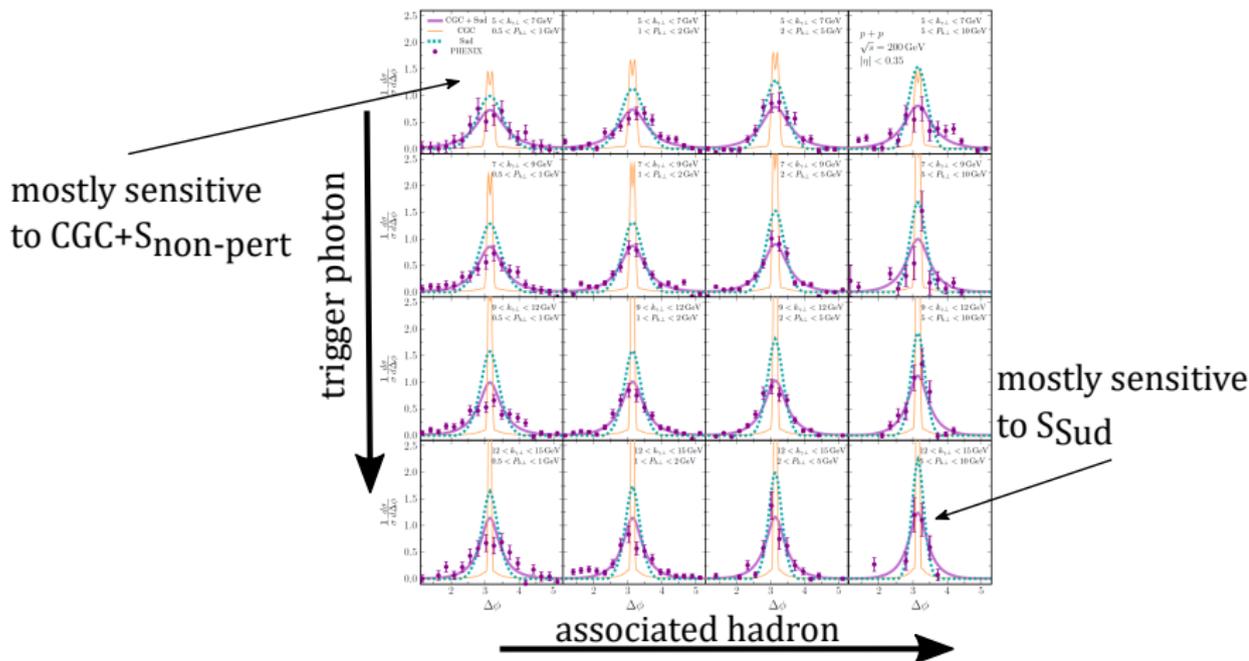


- washed away by Sudakov!!

SB, Garcia-Montero, Perkov, 2203.01685

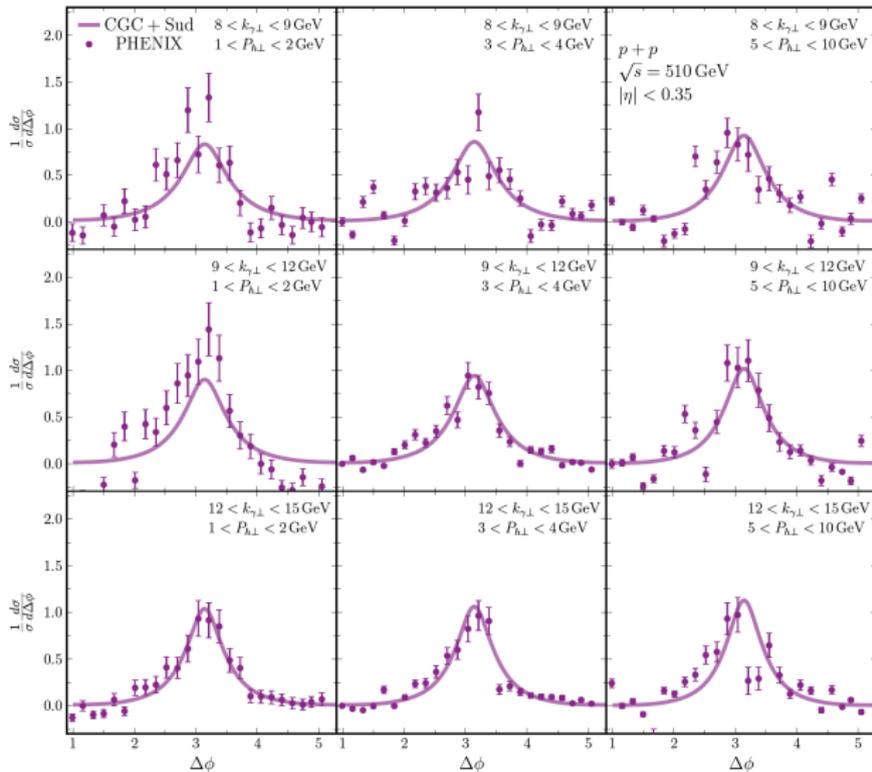
Angular corr's: PHENIX pp 200 GeV

- self-normalized results in $k_{\gamma\perp} \times P_{h\perp}$ bins



PHENIX, PRD **98**, no. 7, 072004 (2018)
SB, Garcia-Montero, Perkov, 2203.01685

PHENIX pp 510 GeV



PHENIX, PRD **95**, no. 7, 072002 (2017)

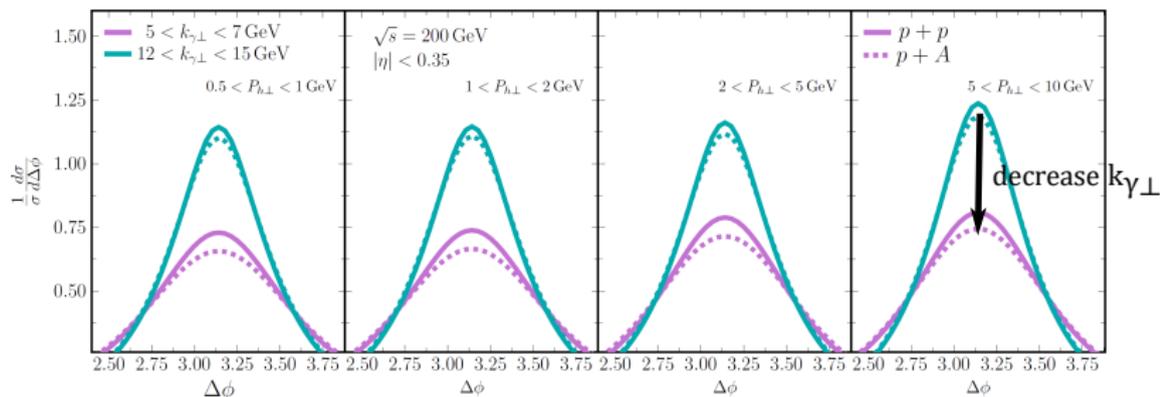
SB, Garcia-Montero, Perkov, 2203.01685

PHENIX predictions

- pp vs pA @ PHENIX:

lowest (5 – 7 GeV) & highest (12 – 15 GeV) $k_{\gamma\perp}$ bins

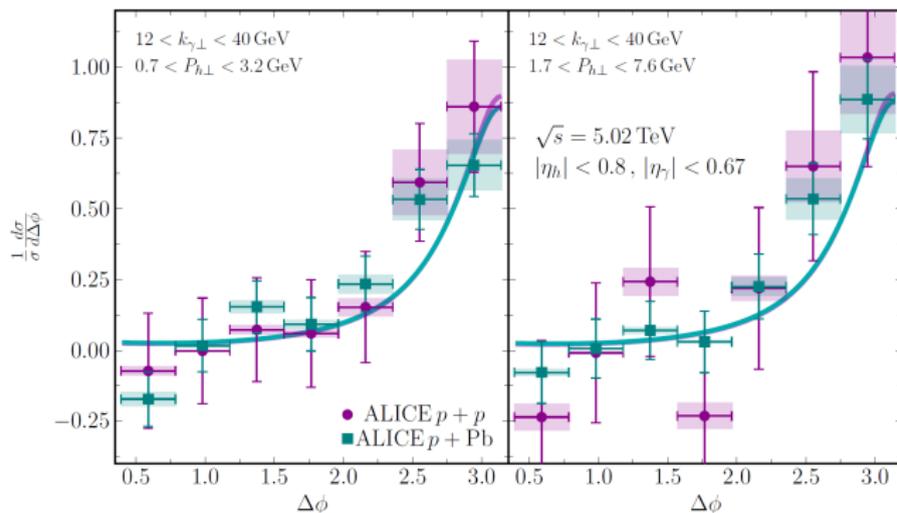
- $Q_{S0,A}^2 = 3Q_{S0,p}^2$



- nuclear effect at most $\sim 10\%$

SB, Garcia-Montero, Perkov, 2203.01685

ALICE pp and pA 5.02 TeV



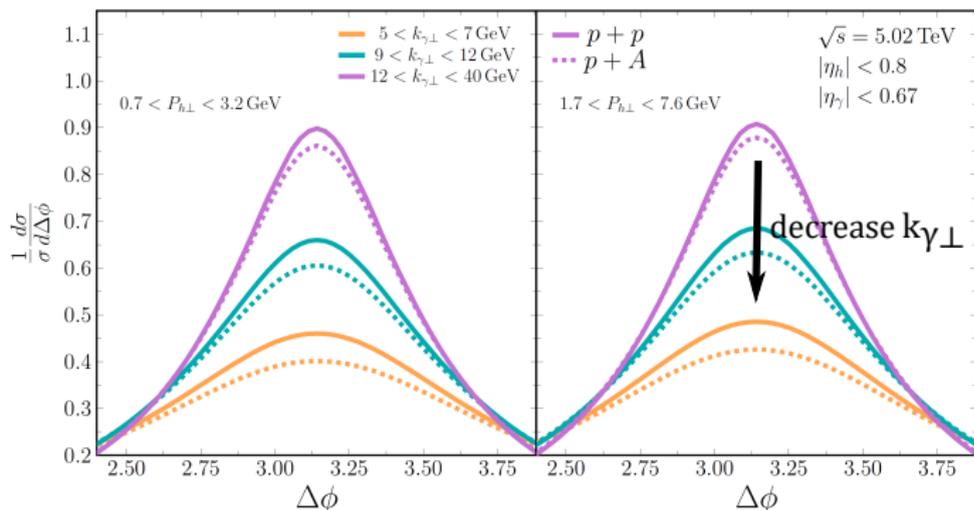
- $k_{\gamma\perp} = 12 - 40 \text{ GeV}$
→ nuclear effect barely visible for ALICE kinematics

ALICE, PRC 102, 044908 (2020)
SB, Garcia-Montero, Perkov, 2203.01685

ALICE - predictions

- pp vs pA @ ALICE

lower $k_{\gamma\perp} \rightarrow$ more symmetric kinematics



- nuclear effect at most $\sim 10\%$

SB, Garcia-Montero, Perkov, 2203.01685

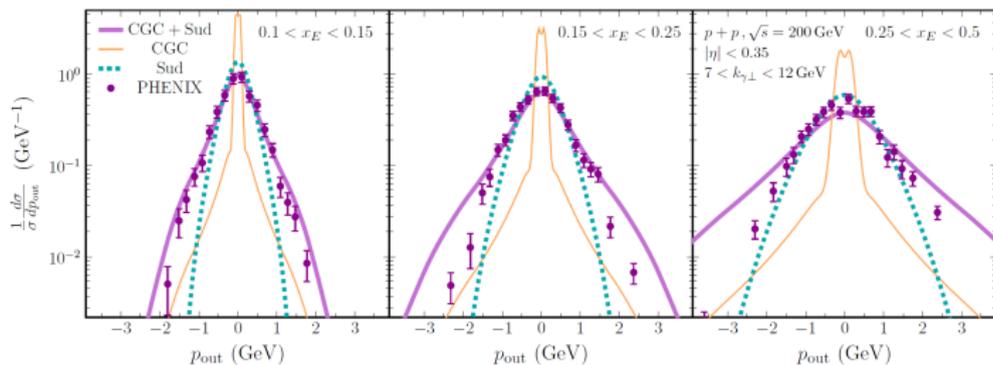
p_{out} -distributions: PHENIX

$$p_{\text{out}} \equiv P_{h\perp} \sin(\Delta\phi) \quad x_E \equiv -\frac{P_{h\perp}}{k_{\gamma\perp}} \cos(\Delta\phi)$$

- close to the away side peak ($\Delta\phi \simeq \pi$):

$$p_{\text{out}} \simeq z_h k_{\perp} \quad x_E \simeq z_h$$

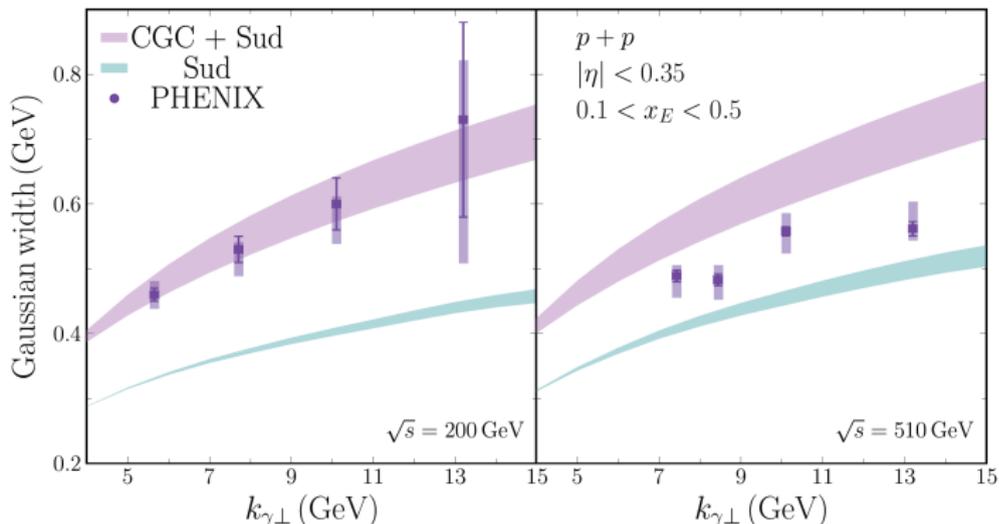
→ proxy for intrinsic k_{\perp}



PHENIX, PRD **98**, no. 7, 072004 (2018)
SB, Garcia-Montero, Perkov, 2203.01685

p_{out} -distributions: widths

- extracted by fitting to a Gaussian in the range $|p_{\text{out}}| < 1.1 \pm 0.2$ GeV



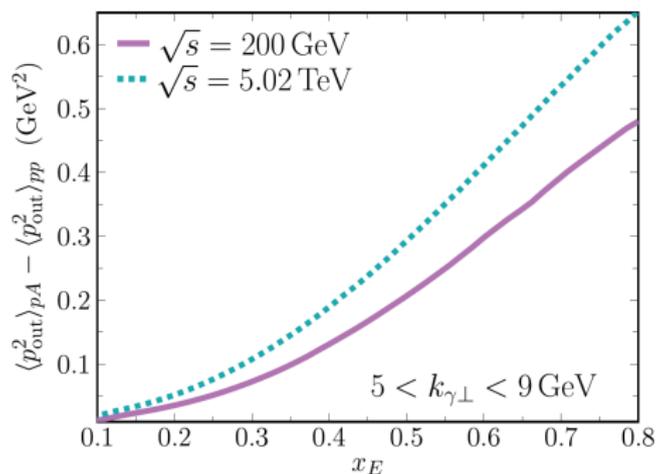
- best description with CGC+Sud

PHENIX, PRD **98**, no. 7, 072004 (2018)
SB, Garcia-Montero, Perkov, 2203.01685

Conclusions

- γh production in a CGC+Sud framework
→ a reasonable description of the data
- caveat: this may not be the only way to interpret the data
- modest nuclear effect $\sim 10\%$
- future works: Drell-Yan, NLO corrections, systematic errors etc..

Widths: pA vs. pp



- up to 0.15 GeV^2 broader widths² in pA vs pp for $x_E < 0.4$

SB, Garcia-Montero, Perkov, 2203.01685