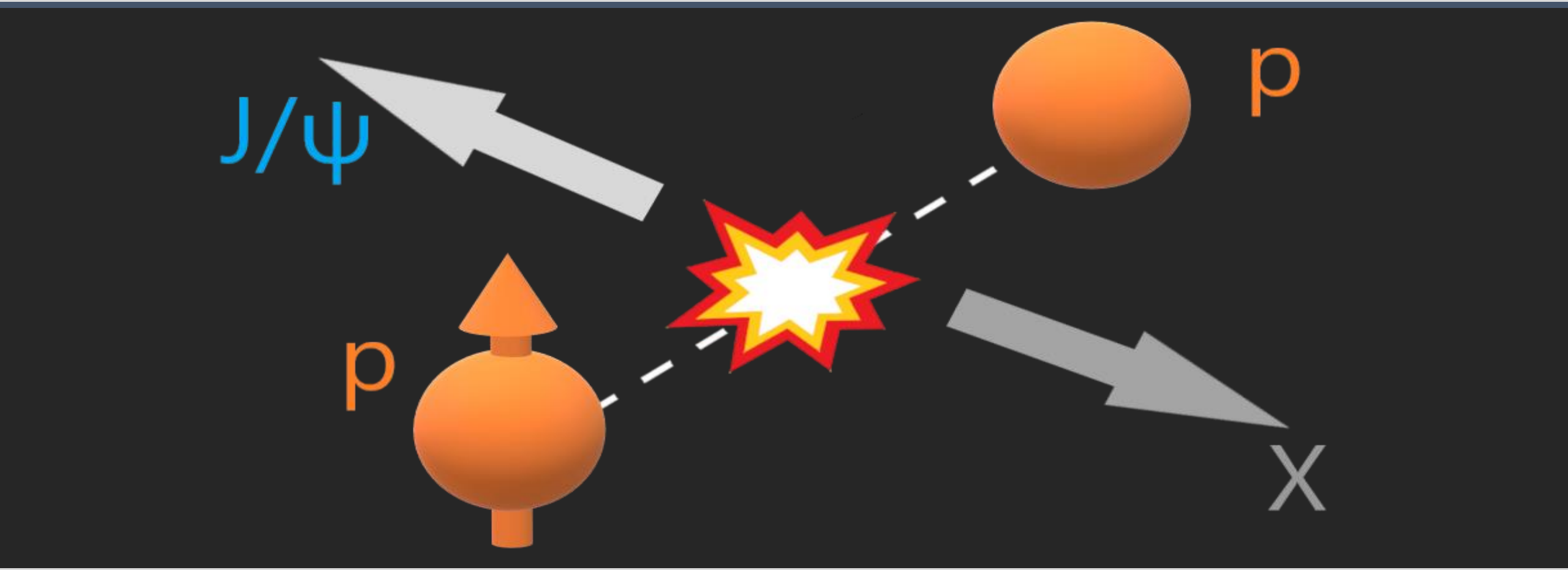
SSAs in $pp \to J/\psi\, X$: the gluon Sivers function and its process dependence



Luca Maxia
Università di Cagliari – INFN CA

@Quarkonia as tools 2021

Date: 25/03/2021

OUTLINE

- Introduction to TMDs
- Introduction to Heavy quark production models
- Phenomenological TMD approaches: GPM and CGI-GPM
- Estimates of SSAs at RHIC
- Expected SSAs for future experiments (LHC fixed target and NICA)

In collaboration with: U. D'Alesio, F. Murgia, R. Sangem, C. Pisano

Transverse Momentum Dependent PDFs (TMDs)

Leading twist TMDs

Parton polar. / Nucleon polar.	Unpolarized	Longitudinal/ Circular	Transverse/ Linear
Unpolarized	f_1		$h_1^\perp$
Longitudinal		g_{1L}	$h_{1L}^\perp$
Transverse	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

Sivers Function

Quark Sivers Function

Great phenomelogical and theoretical understanding

Access through SIDIS process

HERMES COMPASS JLAB

Gluon Sivers Function

Still poorly known

Access through different process

pions at mid y

D production (open charm)

quarkonium production
$(pp^\uparrow \to J/\psi + X)$

di-jet production

...

Heavy Quarkonium Production (HQP)

Hadronization is a non perturbative process → Different models

- Color Singlet Model (CSM)

$$\mathrm{d}\sigma[\mathcal{Q}] = \sum_{i,j} \int \mathrm{d}x_i \mathrm{d}x_j \, f(x_i)\, f(x_j) \mathrm{d}\hat{\sigma}_{i+j\to Q\bar{Q}+\mathrm{X}} \, |R(0)|^2$$

R. Baier & R. Ruckl, Z.Phys.C 19 (1983) 251

E. L. Berger & D. L. Jones, Phys. Rev. D 23, 1521 (1981)

- Non Relativistic QCD (NRQCD)

$$\mathrm{d}\sigma[\mathcal{Q}] = \sum_{i,j;n} \int \mathrm{d}x_i \mathrm{d}x_j \, f(x_i)\, f(x_j) \mathrm{d}\hat{\sigma}_{i+j\to (Q\bar{Q})_n+\mathrm{X}} < \mathcal{O}_{\mathcal{Q}}[n] >$$

Universal (in principle)

G.T. Bodwing et al., PR D55, 5853 (1997)

P. Cho & K. Leibovich, PRD53, 150 (1996)

- Color Evaporation Model (CEM)

$$\mathrm{d}\sigma[\mathcal{Q}] = \mathcal{P}_{\mathcal{Q}} \int_{2m_{\mathcal{Q}}}^{2m_H} \frac{\mathrm{d}\sigma[Q\bar{Q}]}{\mathrm{d}m_{Q\bar{Q}}} \mathrm{d}m_{Q\bar{Q}}$$

H. Fritzsch, PL 67B (1977) 217-221

F. Halzen, PL 69B (1977) 105-108

- k_T factorization

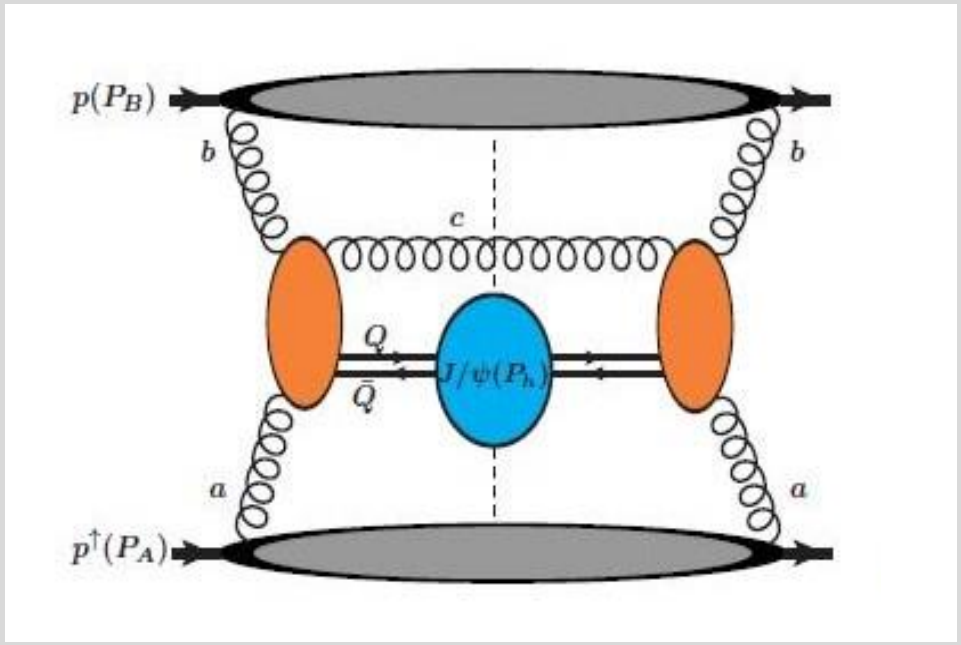
$$\mathrm{d}\sigma = \int^{k^2_{\max}} \mathrm{d}x_1 \, \mathrm{d}x_2 \, \mathrm{d}^2k_{1T} \, \mathrm{d}^2\mathrm{k}_{2\mathrm{T}} \, F(x_1, k_{1T}) \, F(x_2, k_{2T}) \mathrm{d}\hat{\sigma}(x_1, x_2, k_{1T}, k_{2T}, p_T)$$

J. Collins & R.K. Eliis, Phys. Rev. B360 (1991)

S. Catani et al, Phys. Rev. B366 (1991)

Generalized Parton Model (GPM)

- Inclusion of spin and transverse momentum effects in a natural way
- Infrared divergences regulated by partons intrinsic motion in the hard part
- Assumption of TMD factorization



$gg \to J/\psi\, g$ in GPM

EXAMPLE OF GPM APPLICATION:

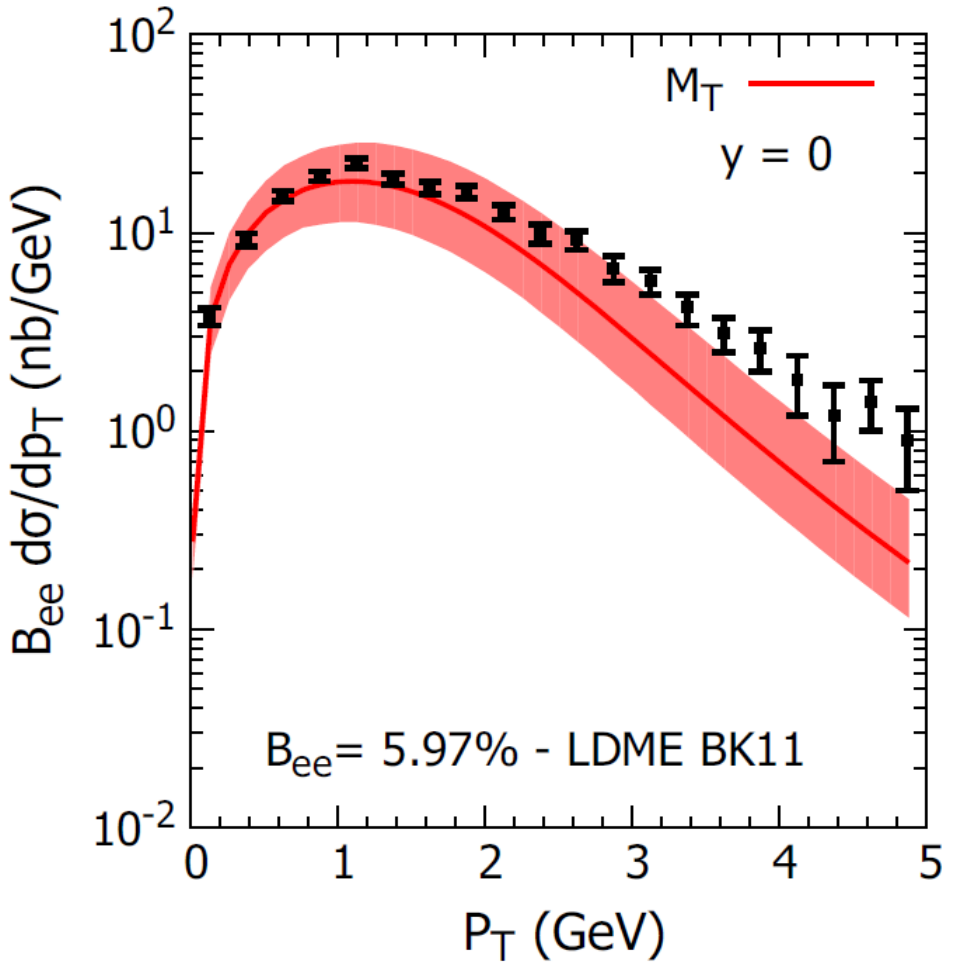
Unpolarized cross section for $pp \to J/\psi + X$ in the GPM + NRQCD (or +CSM) scheme:

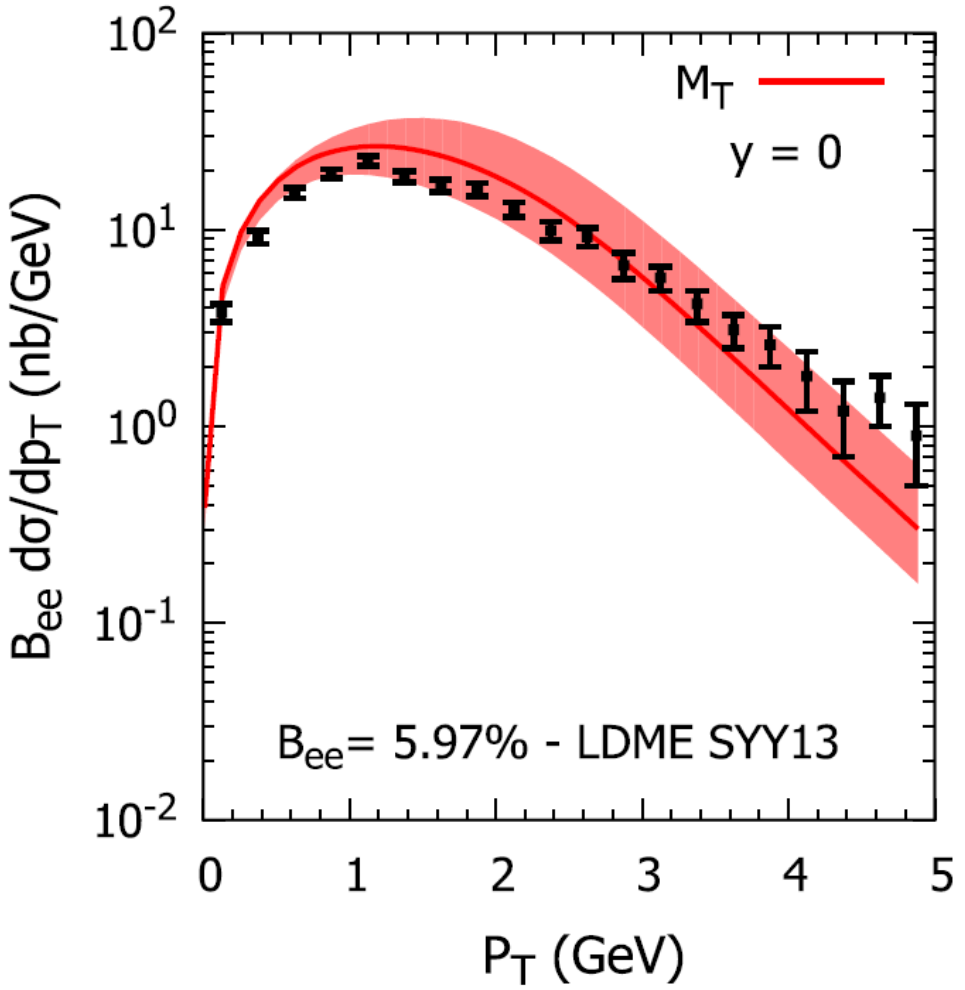
$$\frac{\mathrm{d}^3\sigma}{\mathrm{d}^3\boldsymbol{P}_h} \propto \sum_{a,b} \int \frac{\mathrm{d}x_a}{x_a}\frac{\mathrm{d}x_b}{x_b}\mathrm{d}^2\boldsymbol{k}_{\perp a}\mathrm{d}^2\boldsymbol{k}_{\perp b}$$

$$f_{a/p}(x_a, k_{\perp a})\, f_{b/p}(x_b, k_{\perp b})\, \left|\mathrm{H}^{\mathrm{U}}_{J/\psi}\right|^2 \delta(\hat{s} + \hat{t} + \hat{u} - M_\psi^2)$$

Generalized Parton Model (GPM)

D'Alesio Murgia Sangem Pisano, EPJ (2019)





Unpolarised gluon TMD extraction from $pp \to J/\psi + X$ data

Single Spin Asymmetry (SSA) in J/ψ production

SSA for $p^{\uparrow}p \to J/\psi + X$: $A_N = \dfrac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$

$d\sigma^{\uparrow} - d\sigma^{\downarrow} \propto f_{1T}^{\perp}$

$d\sigma^{\uparrow} + d\sigma^{\downarrow} = 2d\sigma^{\mathrm{unp}}$

Main contributions coming from $gg \to J/\psi\, g$ and $gg \to J/\psi$ channels → Access to GSF

Within CSM or NRQCD approach:

Denominator (unpolar. cross section) → GPM scheme

Numerator → GPM scheme or CGI scheme*

GPM scheme:
- one and universal quark Sivers function
- one and universal gluon Sivers function

CGI scheme*:
- one quark Sivers function
- two gluon Sivers function

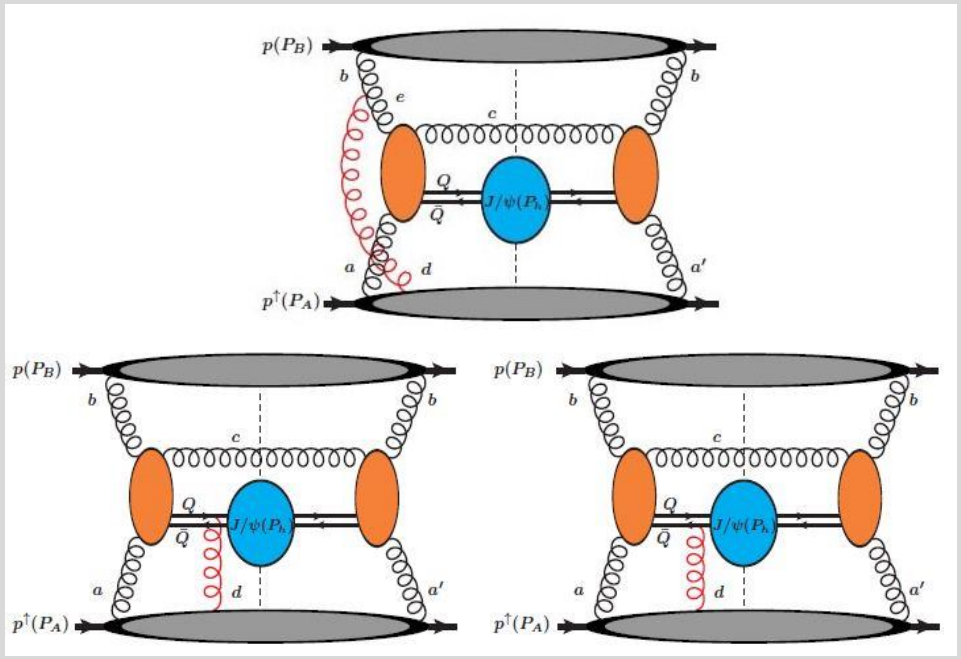
*(described in the next slide)

Color Gauge Invariant – GPM (CGI-GPM)

- Initial- and Final-state interactions (ISIs and FSIs) are taken into account
- Process dependence of the Sivers function

L. Gamberg & Z. B. Kang, PL B696 (2014)

D'Alesio Murgia Pisano Taels, PRD96 (2017)



$gg \to J/\psi\, g$ in CGI

Color flow is modified by the presence of the extra gluon

$$M_i^{\mathrm{CGI}} M_j^{\mathrm{CGI}*} = \frac{C_I + C_F}{C_{\mathrm{U}}} M_i^{\mathrm{U}} M_j^{\mathrm{U}*}$$

1 way to neutralize color in (anti-)quark subprocess

$\mathcal{N}_c\, t_{ij}^a$ $\qquad \mathcal{N}_c = \frac{2}{N_c^2-1}$

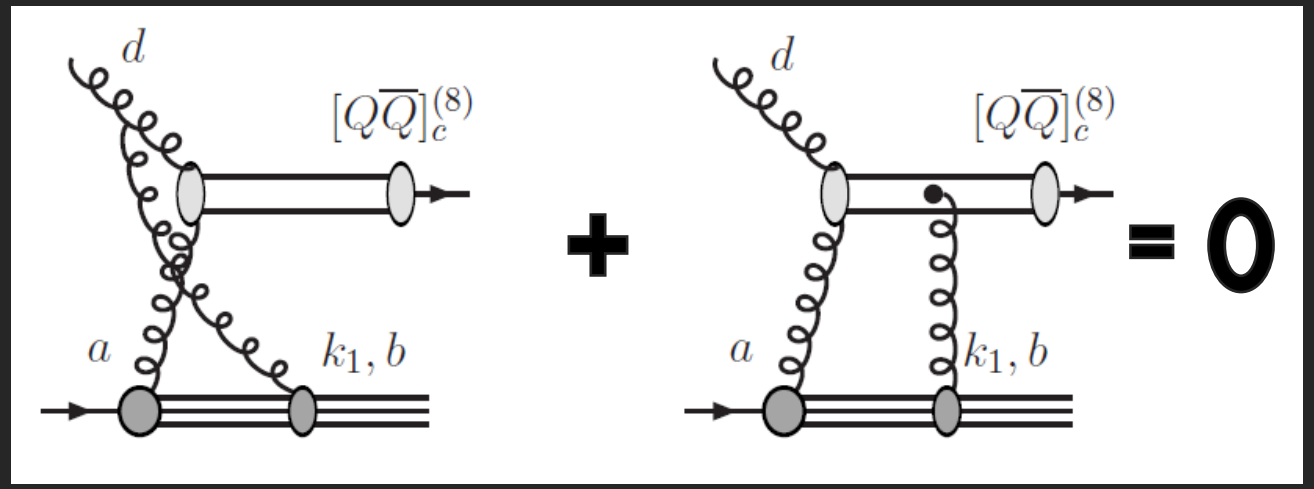
2 way to neutralize color in gluon subprocess

$\mathcal{N}_T\, (-if_{caa'})$ $\qquad \mathcal{N}_T = \frac{1}{N_c(N_c^2-1)}$

$\mathcal{N}_D\, (d_{caa'})$ $\qquad \mathcal{N}_T = \frac{N_c}{(N_c^2-4)(N_c^2-1)}$

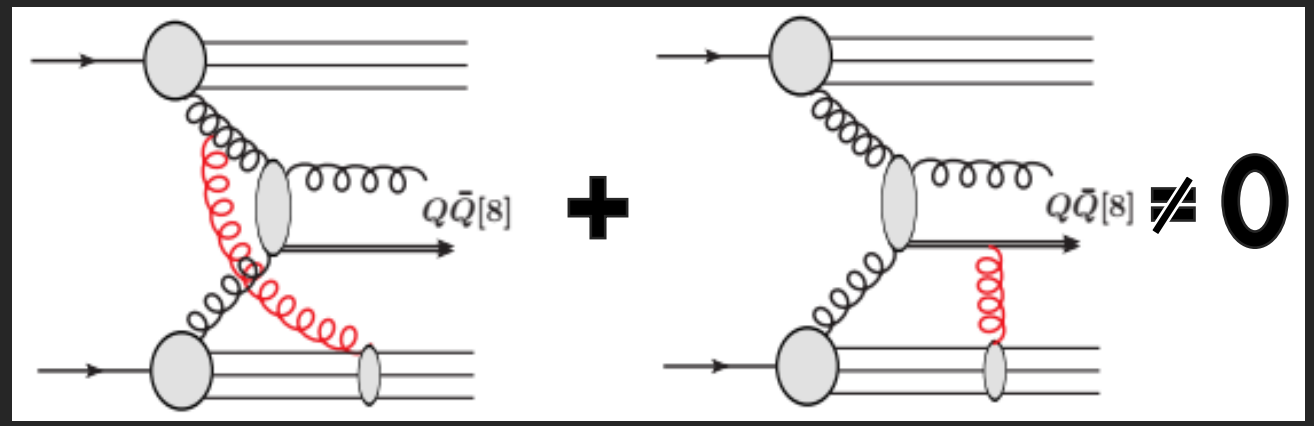
(*f*-type and *d*-type)

Color Gauge Invariant – GPM (CGI-GPM)



Asymmetry from $2 \to 1$ CO state is expected 0 for CGI scheme

F. Yuan, PRD 78 (2008)



$2 \to 2$ CO states give contribution to asymmetry in $pp^{\uparrow} \to J/\psi\, X$ process

D'Alesio LM Murgia Sangem Pisano, PRD102 (2020)

TMD parameterisation

TMD gaussian parameterisation

$$f_{a/p}(x_a, k_{\perp a}) = \frac{e^{-k_{\perp a}^2/<k_{\perp a}^2>}}{\pi < k_{\perp a}^2 >} f_{a/p}(x_a)$$

$\longrightarrow$ $< k_{\perp g}^2 >= 1\ \mathrm{GeV}^2 \quad < k_{\perp q}^2 >= 0.25\ \mathrm{GeV}^2$

$\Rightarrow$ no $k_\perp$ evolution

D'Alesio Murgia Pisano, JHEP (2015)

Anselmino Boglione D'Alesio Kotzinian Murgia , PRD (2005)

GSF factorized parameterisation

$$\Delta^N f_{g/p^\uparrow}(x_g, k_{\perp g}) = \left(-2\frac{k_{\perp g}}{M_p}\right) f_{1T}^{\perp g}(x_g, k_{\perp g}) = 2\, \mathcal{N}_g(x_g)\, h(k_{\perp g})\, f_{g/p}(x_g, k_{\perp g})$$

respects the positivity bound $\left|\Delta^N f_{a/p^\uparrow}(x_a, k_{\perp a})\right| \leq 2 f_{a/p}(x_a, k_{\perp a})$

GSF *saturated* form:

saturating x dependence

«maximizing» $h(k_{\perp g})$

$(\mathcal{N}_g = +1)$

(fulfilling positivity bound)

Results

- Maximized asymmetries
- Comparison with PHENIX data
- CGI-GPM vs GPM
- Prediction for LHC and NICA

PDF set chosen: CTEQL1 J. Pumplin et al., JHEP (2002) at scale $M_T = \left(M_\psi^2 + P_T^2\right)^{1/2}$

LDME considered:

M. Butenschoen & B. A. Kniehl, PRD 84 (2011) (BK11)

Low p_T cut ($\sim 3\mathrm{GeV}$)

Feed down included

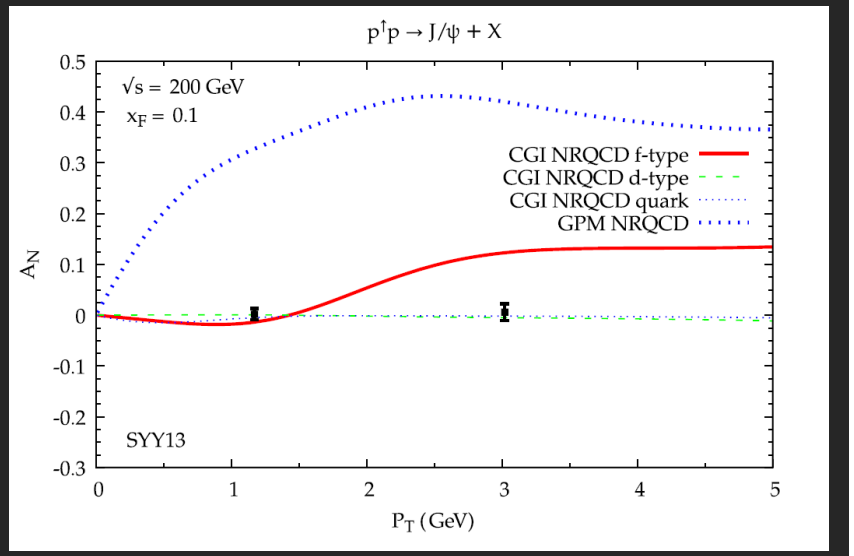
P. Sun, C. P. Yuan, and F. Yuan, PRD 88 (2013) (SYY13)

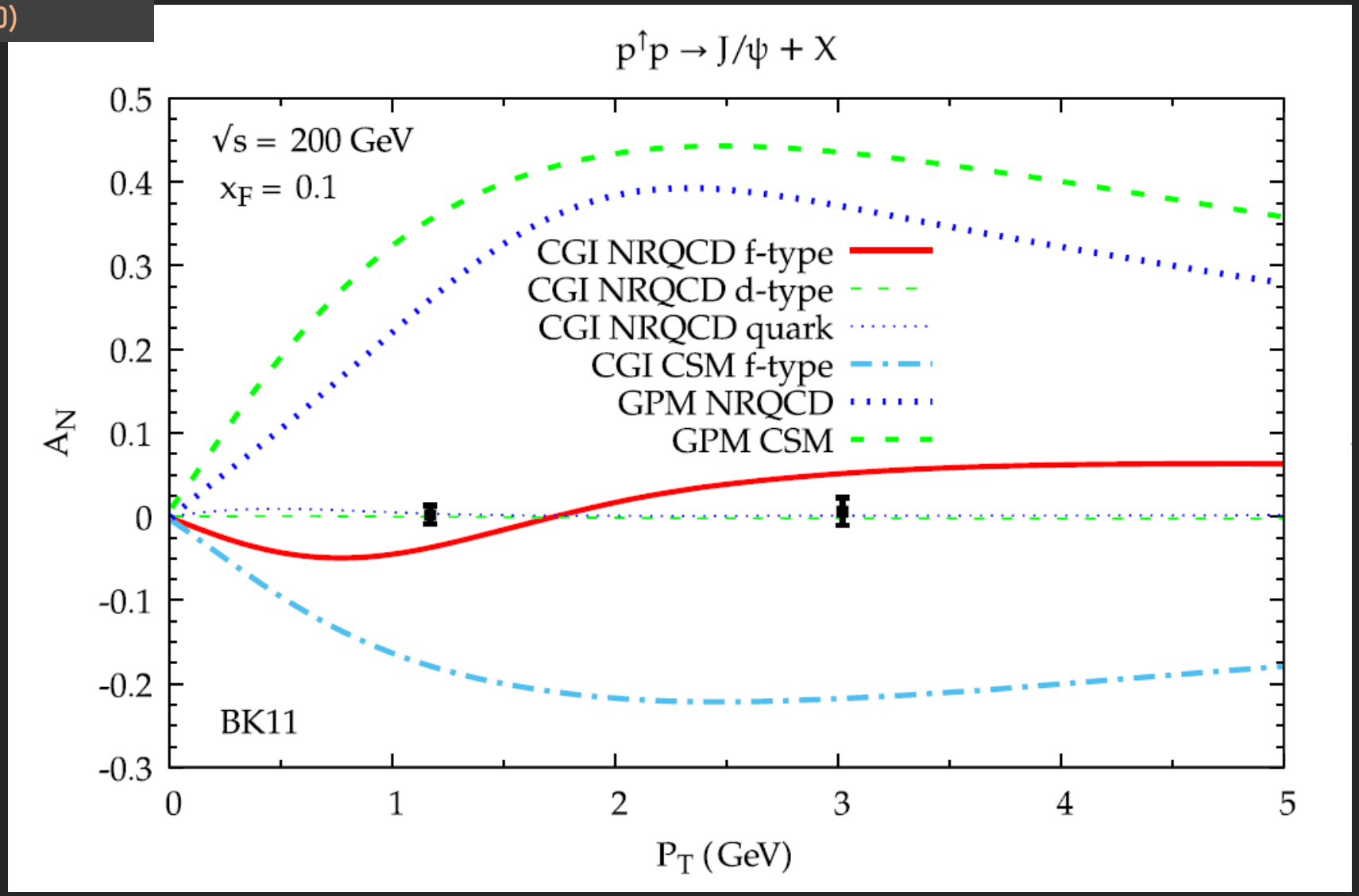
Extraction from $0\mathrm{GeV}$ to $5\mathrm{GeV}$

No CS contribution

Maximized asymmetry in GPM and CGI-GPM

D'Alesio LM Murgia Sangem Pisano, PRD102 (2020)



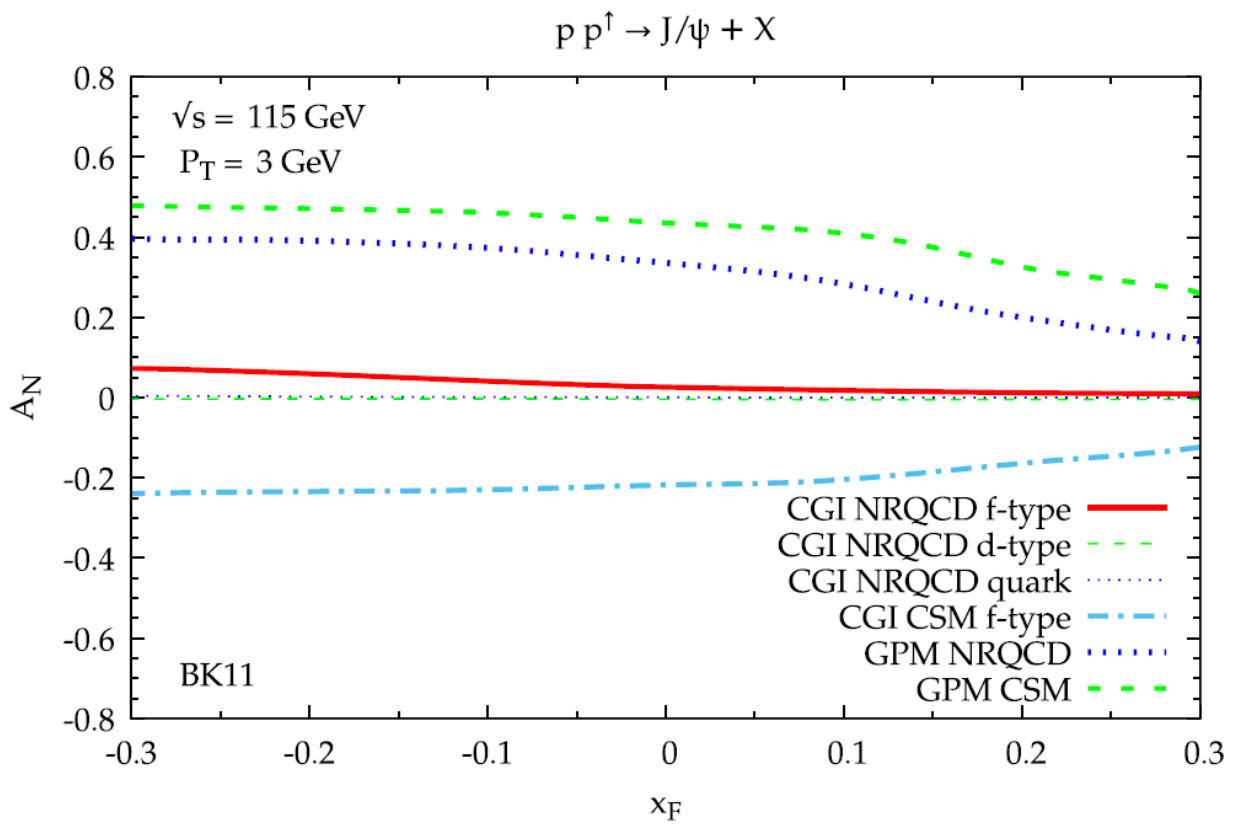


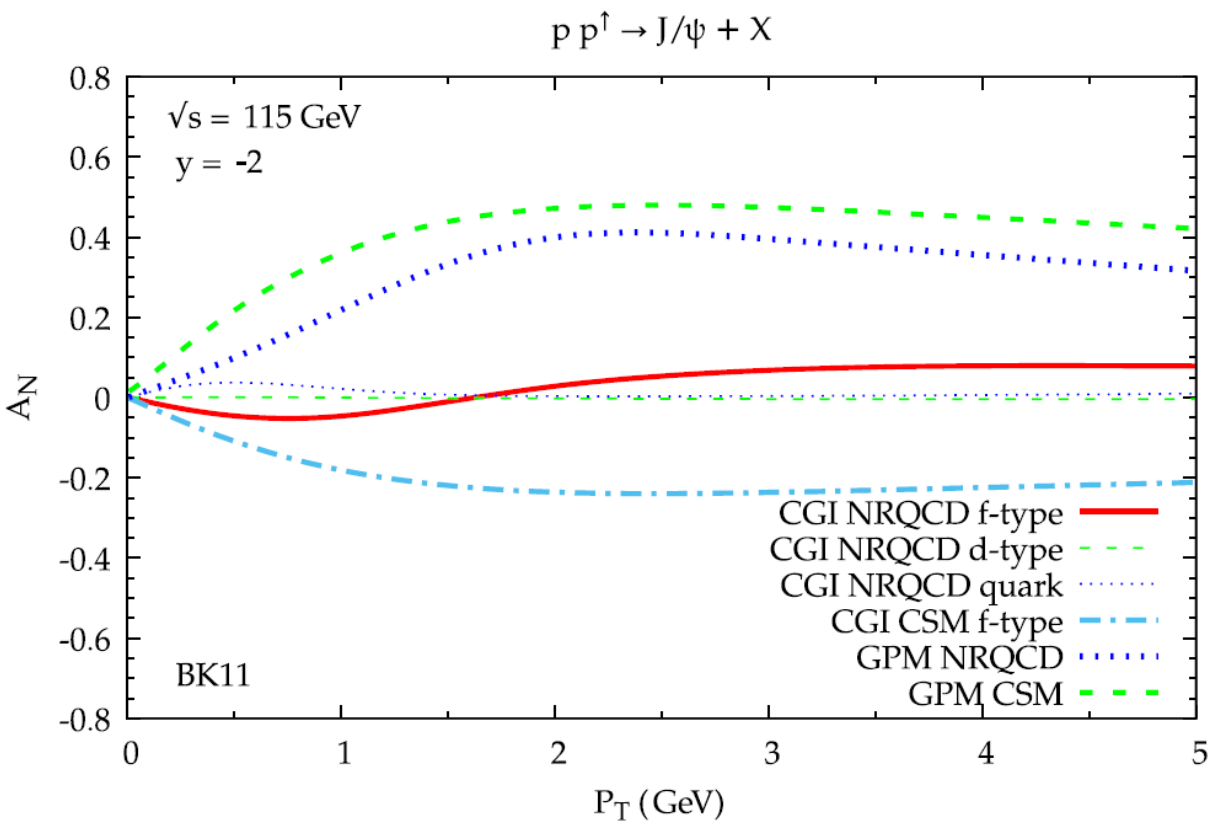
Data taken from PHENIX collab.

C. Aidala et al., PRD98 (2018)

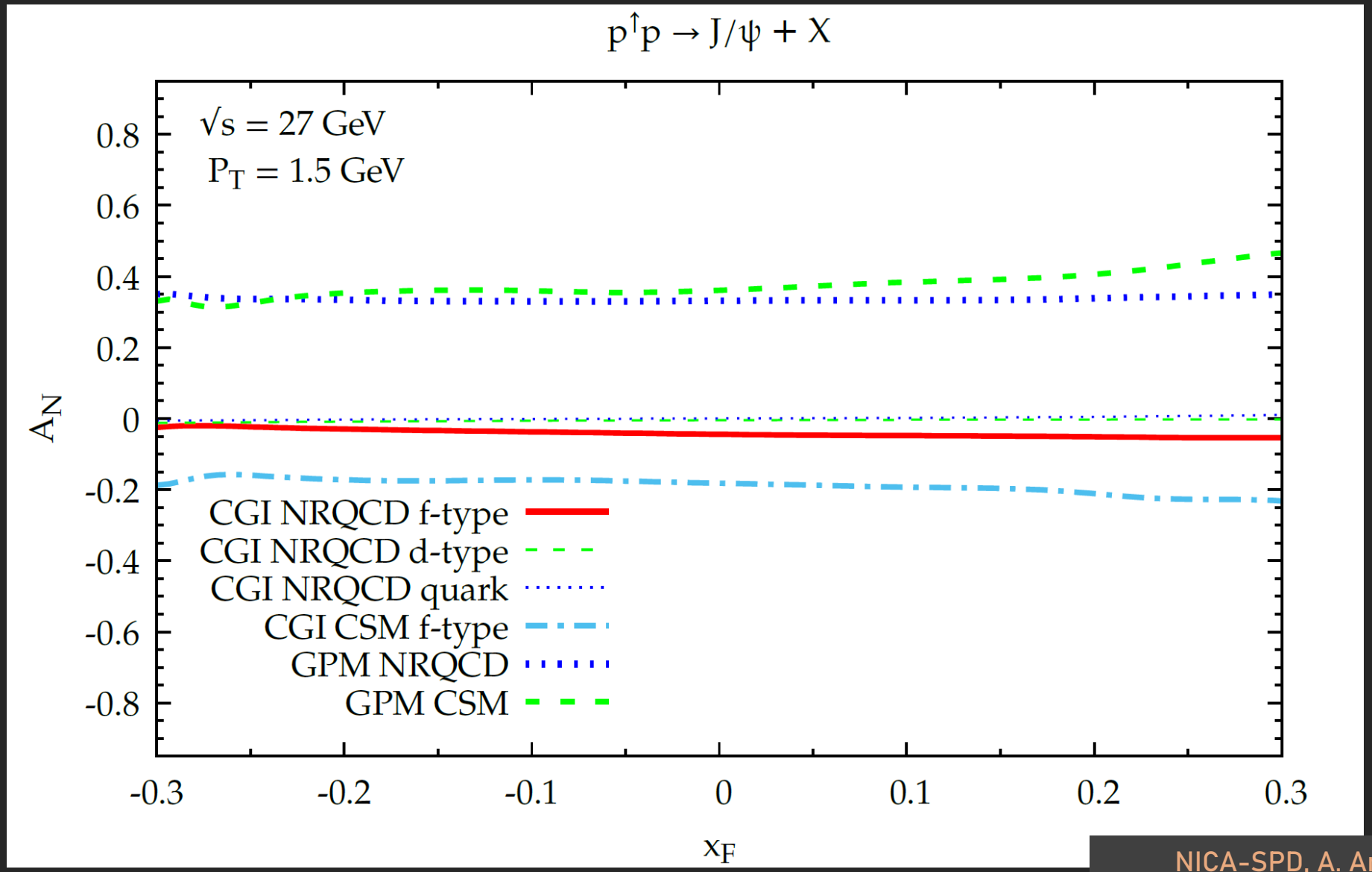
Future at LHC (fixed target)

D'Alesio LM Murgia Sangem Pisano, PRD102 (2020)





Future at NICA



NICA-SPD, A. Arbuzov et al., PPNP (in press)

CONCLUSIONS

- Features of GPM and CGI schemes
- Comparison between GPM and CGI maximized asymmetries at RHIC In different framework
- Comparison with PHENIX data (possible constraints)
- Prediction for LHC and NICA

Thanks for the attention