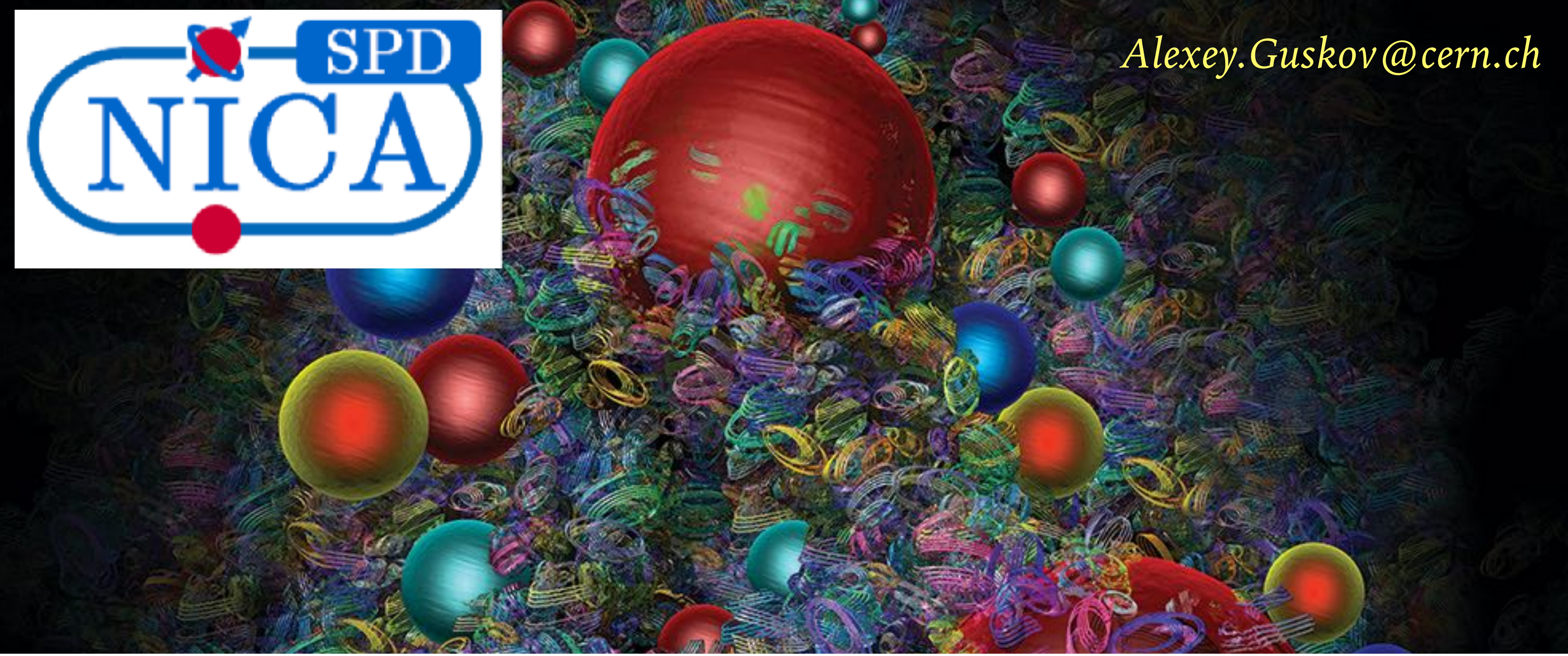


Alexey.Guskov@cern.ch

Spin Physics Detector at NICA as a universal facility for study of polarized and unpolaried gluon content of proton and deuteron.

A. Guskov (DLNP, JINR) on behalf of the working group:

A. Arbuzov, I. Denisenko, A. Efremov, A. Guskov, N. Ivanov, Ya. Klopot, A. Kotzinian, M. Nefedov, B. Parsamyan, A. Rymbekova, A. Shipilova, V. Saleev, O. Teryaev

15.05.2020

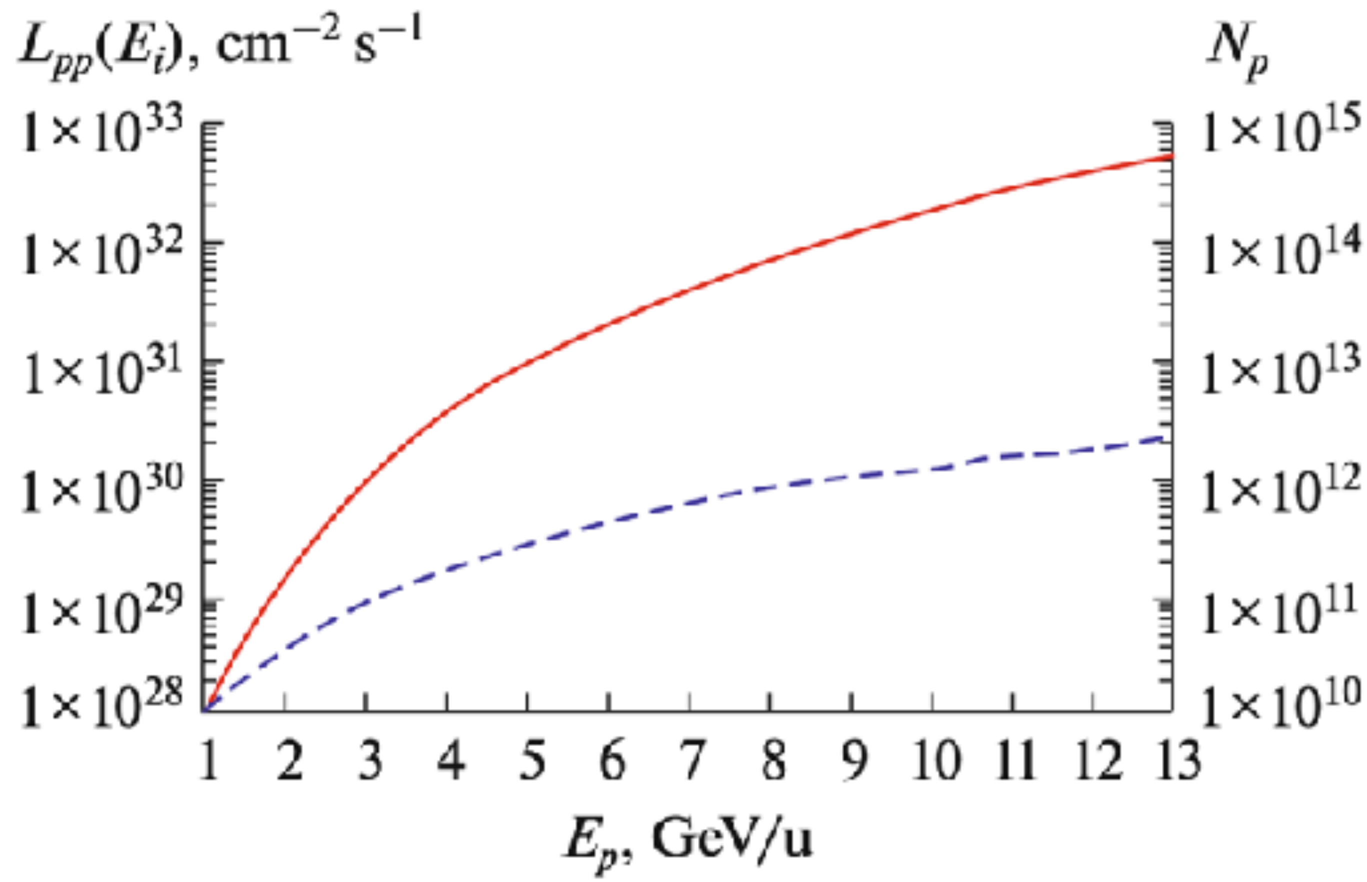
THE NICA PROJECT AT JINR

Nuclotron-based
Ion **C**ollider f**A**cility
in the **Joint Institute for Nuclear Research** (JINR),
Dubna, Russia

Two interaction points:
MPD -**M**ulti**P**urpose **D**etector for heavy ion physics
SPD - **S**pin **P**hysics **D**etector for physics with polirized beams

SPD – EXPERIMENTAL CONDITIONS

circumference	- 503 m,
number of collision points (IP)	- 2,
beta function β_{min} in the IP	- 0.35 m,
number of protons per bunch	- $\sim 1 \cdot 10^{12}$,
number of bunches	- 22,
RMS bunch length	- 0.5 m,
incoherent tune shift, $\Delta_{Lasslett}$	- 0.027,
beam-beam parameter, ξ	- 0.067,
beam emittance ε_{nrm} (normalized) at 12.5 GeV, π mm mrad	- 0.15.



Beam energies:

$p\uparrow p\uparrow(\sqrt{s_{pp}}) = 12 \div \geq 27$ GeV ($5 \div \geq 12.6$ GeV of proton kinetic energy),

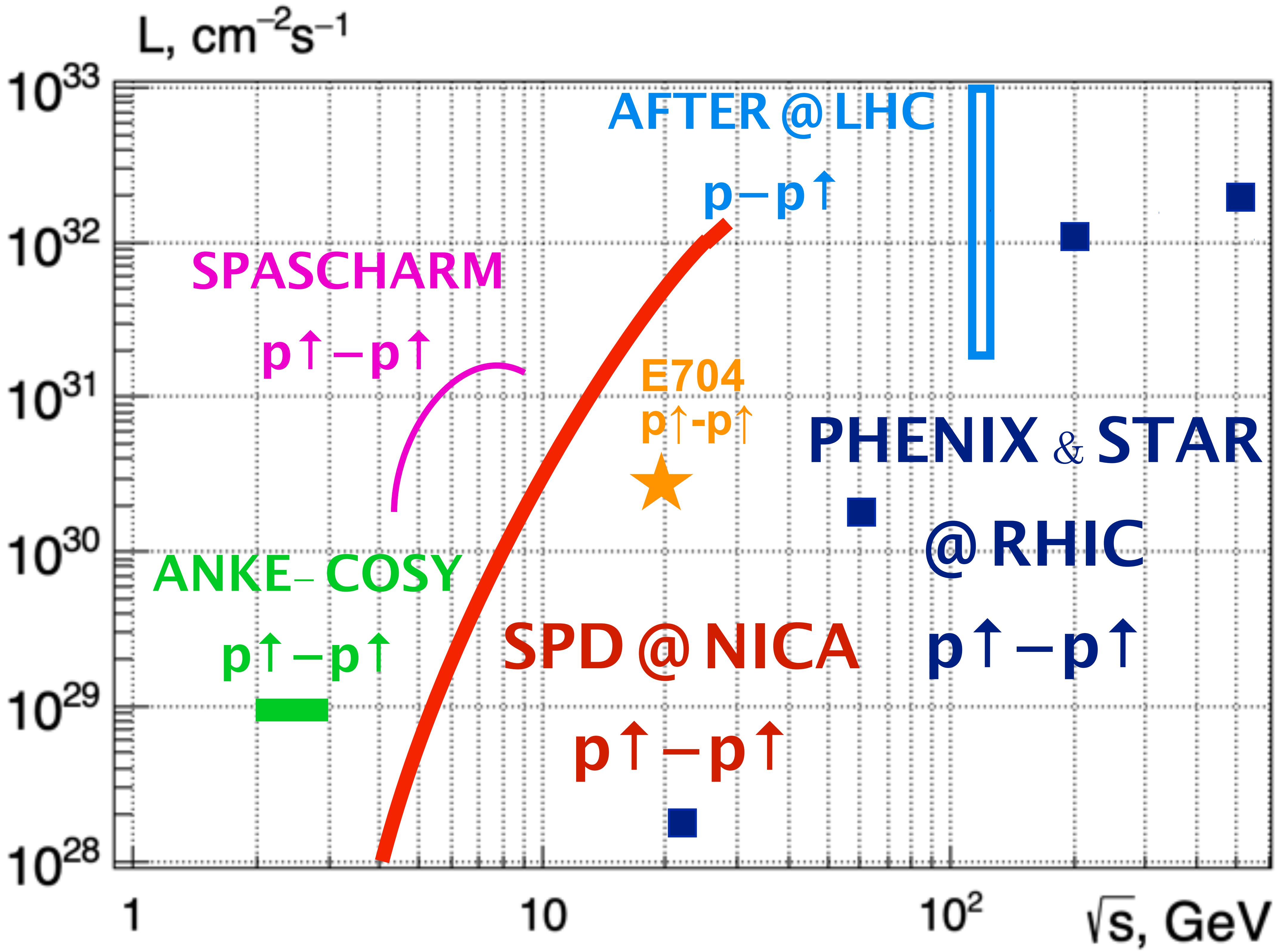
$d\uparrow d\uparrow(\sqrt{s_{NN}}) = 4 \div \geq 13.8$ GeV ($2 \div \geq 5.9$ GeV/u of ion kinetic energy).

Unique possibility!

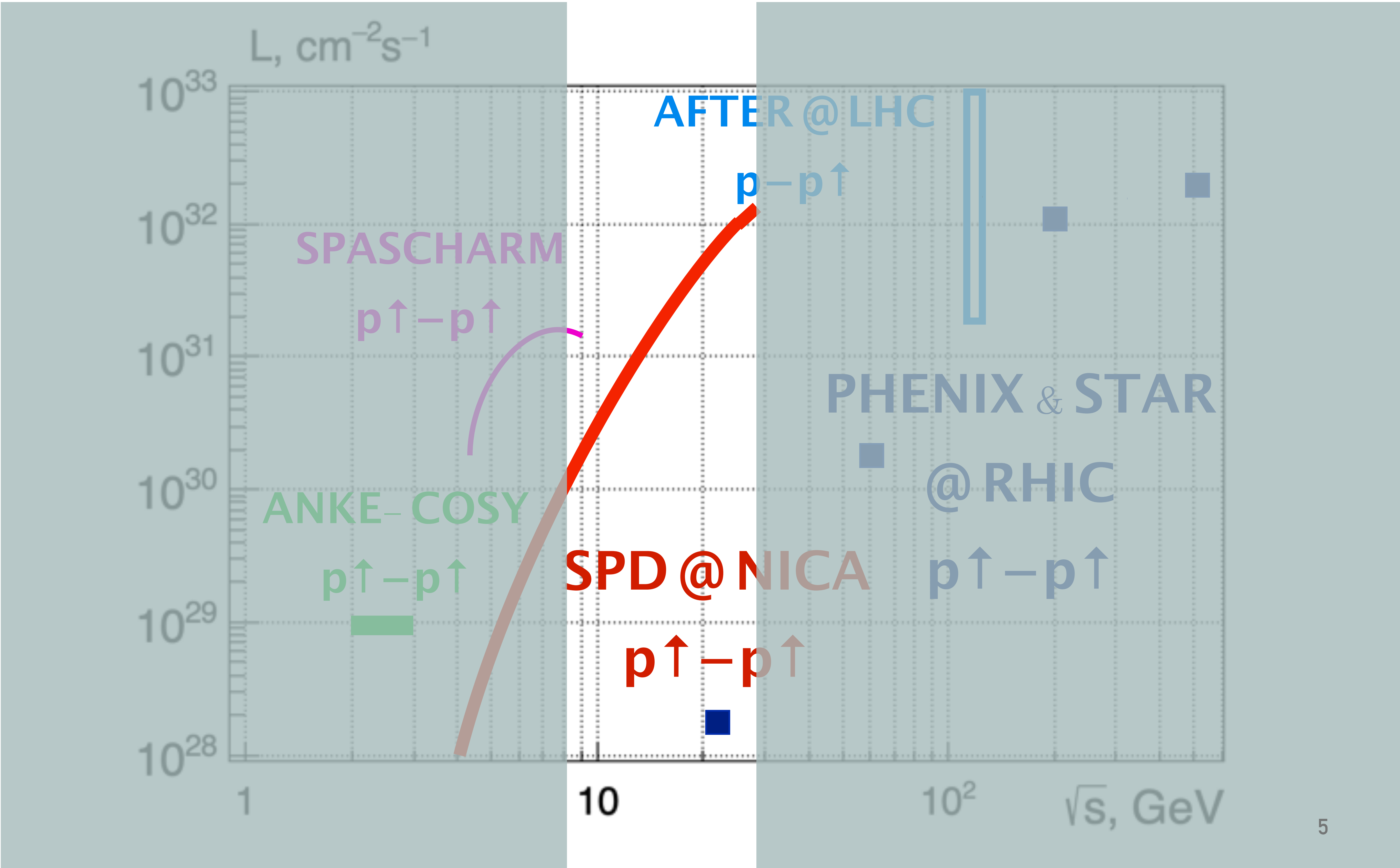
All combinations of collisions are possible -

UU, LL, TT, UL, UT, LT

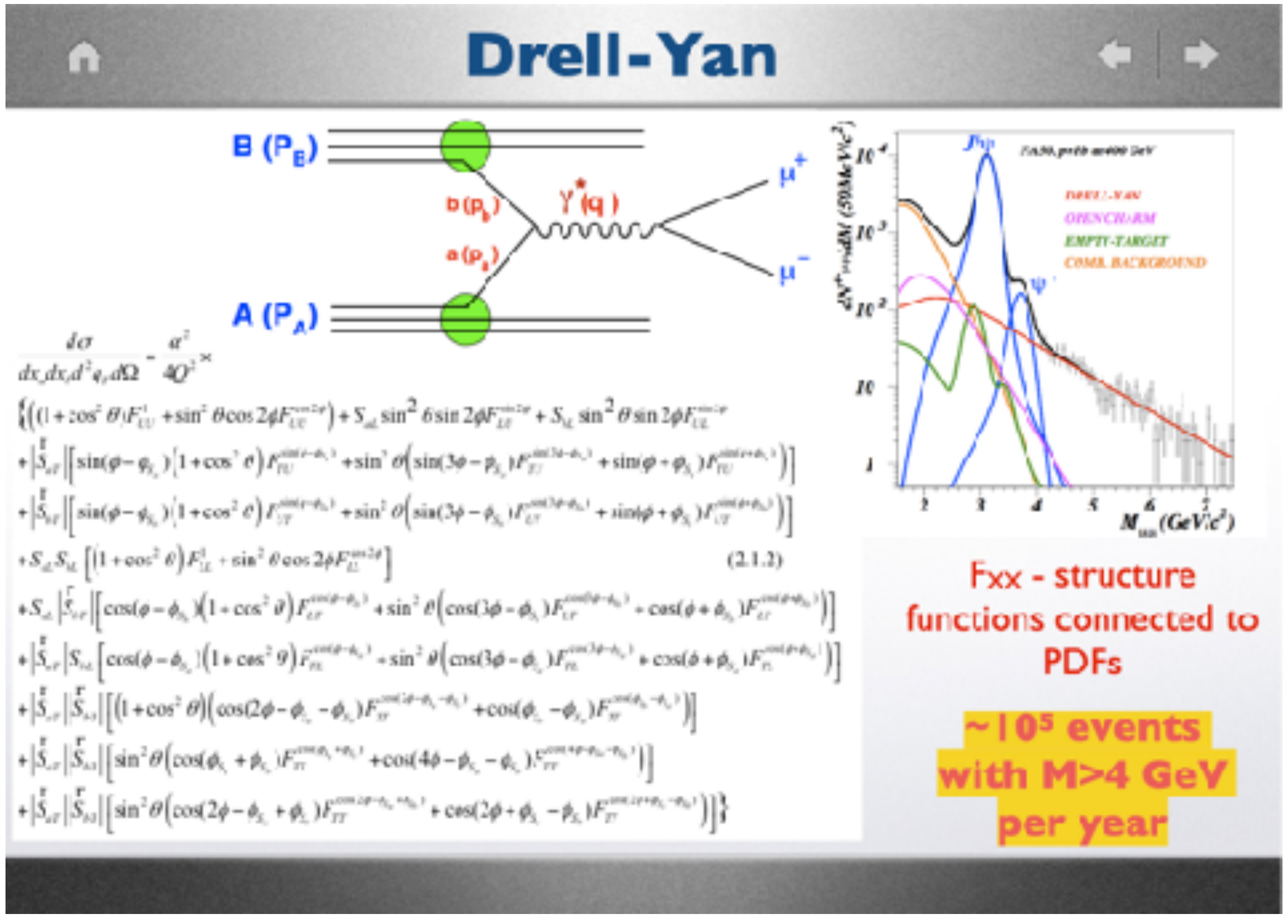
SPD – VS OTHER POLARIZED p-p EXPERIMENTS

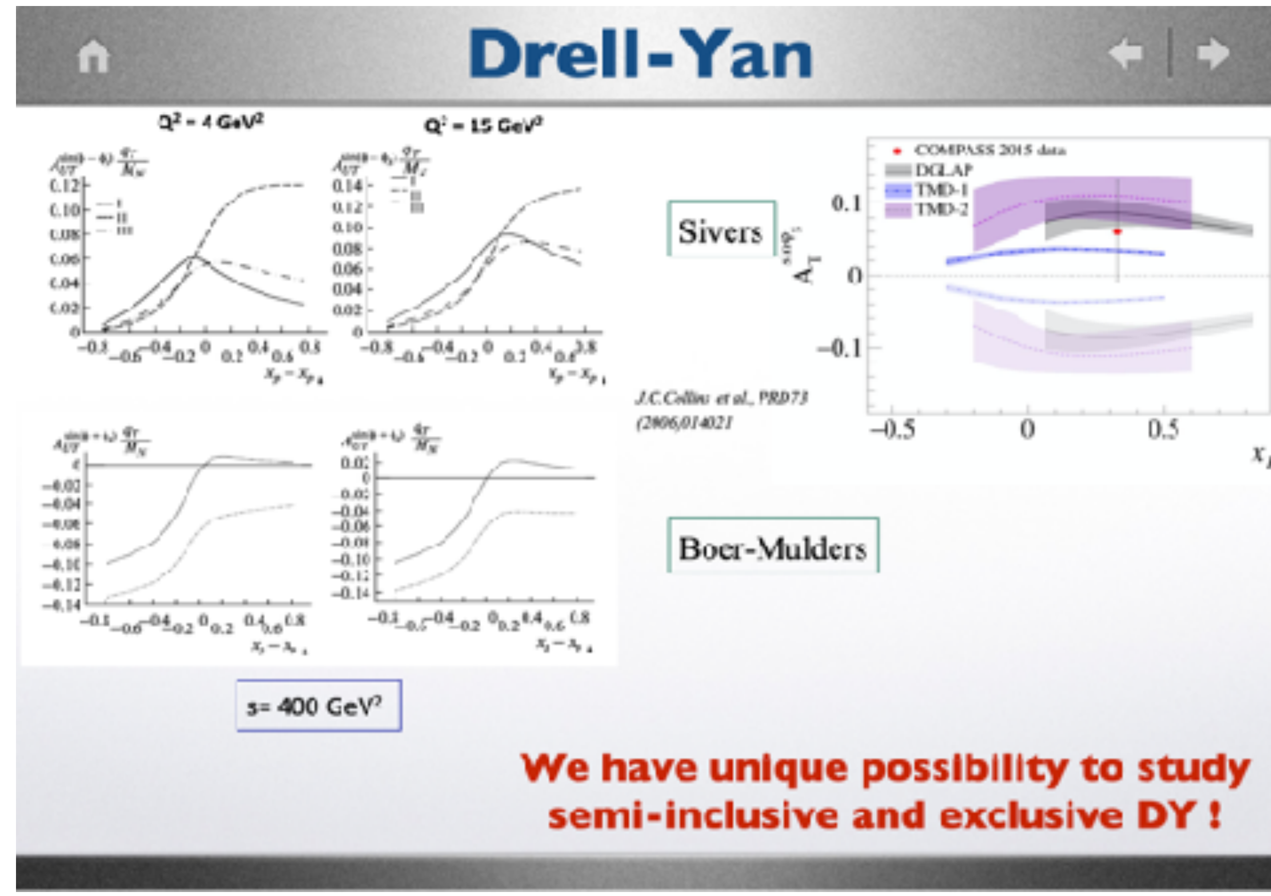


SPD – VS OTHER N-N EXPERIMENTS



DRELL-YAN - FORMER KEY POINT OF THE SPD PHYSICS PROGRAM

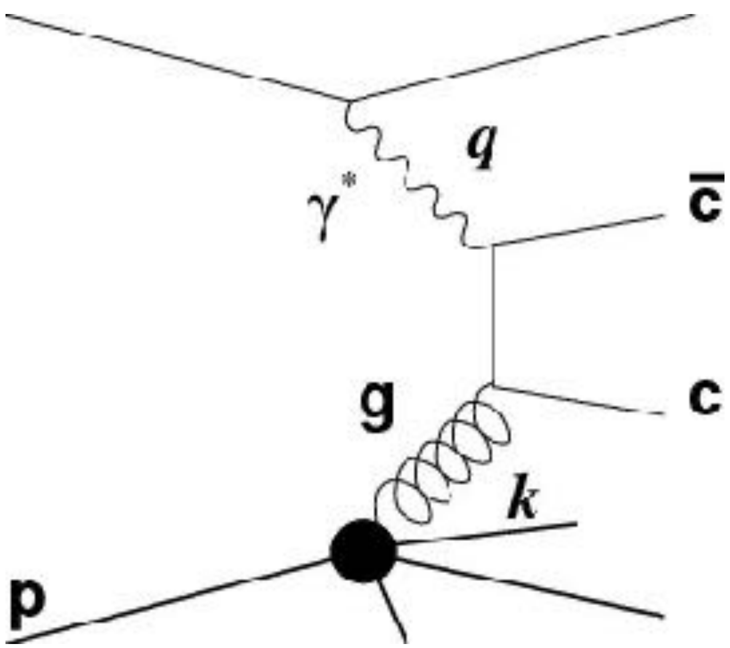


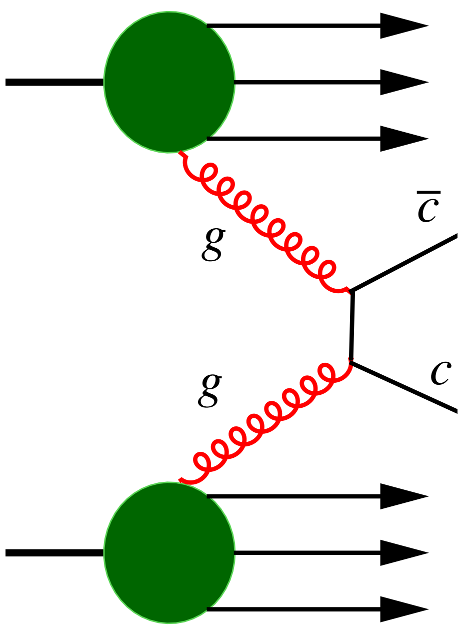


In spite of very competitive DY physics program we will not be able to extract experimentally the DY signal from combinatorial background.

WHY GLUONS?

Without DY we cannot compete with SIDIS experiments in the study of the quark content of the nucleon





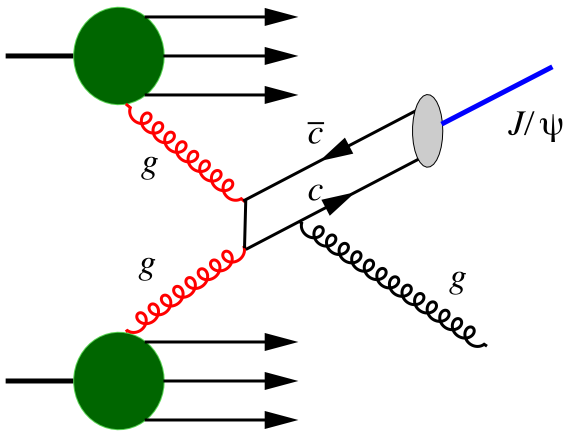
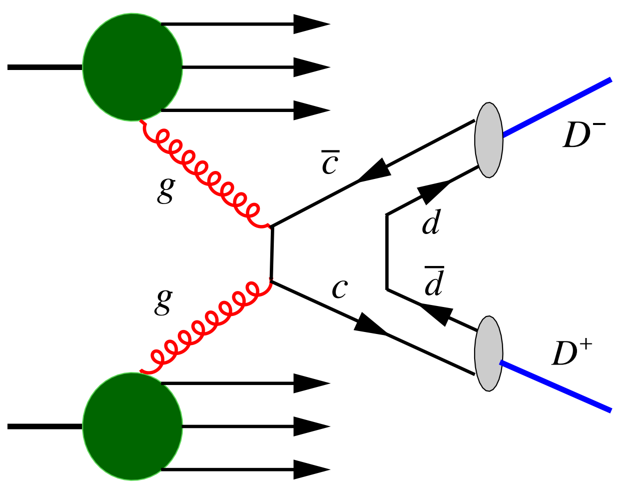
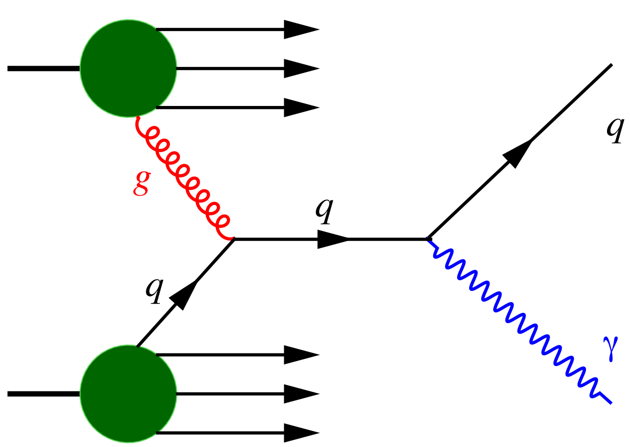
SIDIS

$$\sigma \sim \alpha^2 \alpha_s$$

Hadroproduction

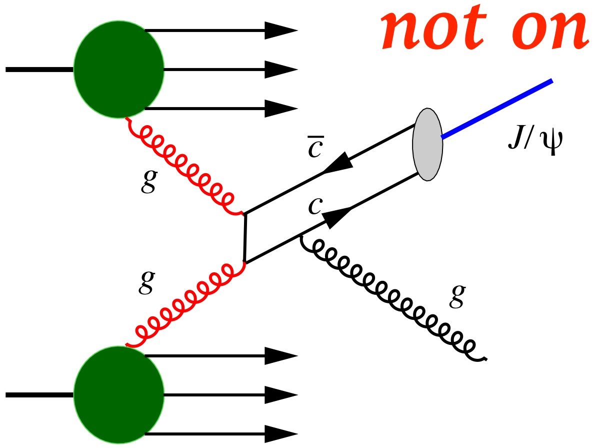
$$\sigma \sim \alpha_s^2$$

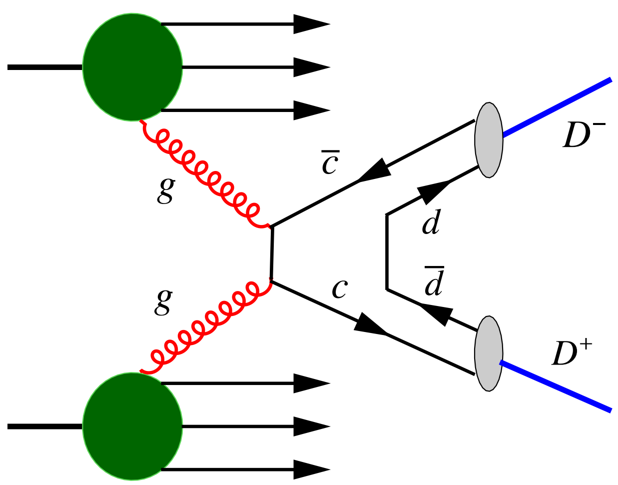
GLUON PROBES AT SPD

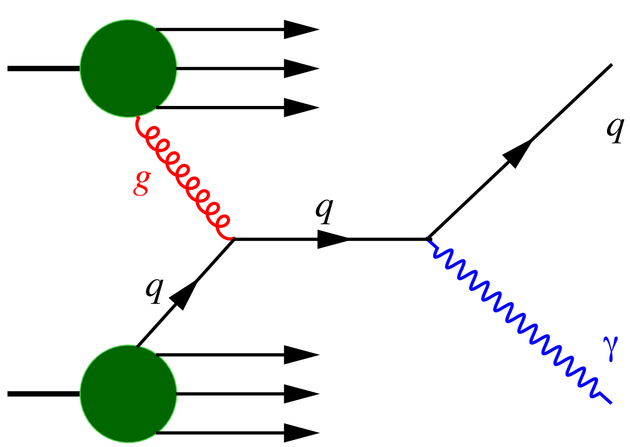
	Sharp signal Relatively large cross section	Model-dependent probability for $c\bar{c} \to J/\psi$
	Largest cross section	Challenging experimental requirements Model-dependent fragmentation functions
	Almost no fragmentation	Strong background at low p_T

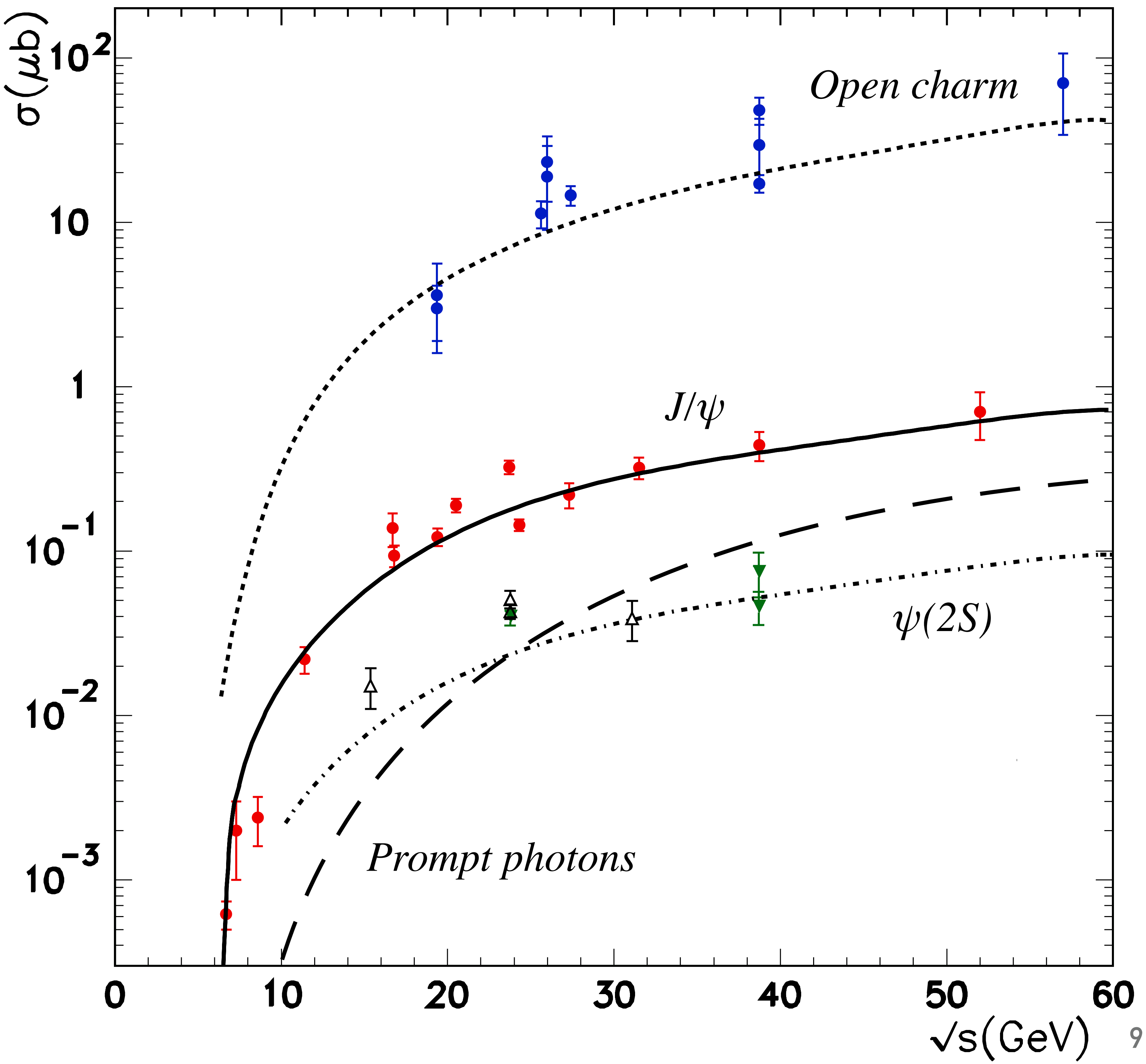
GLUON PROBES AT SPD

not only J/ψ!









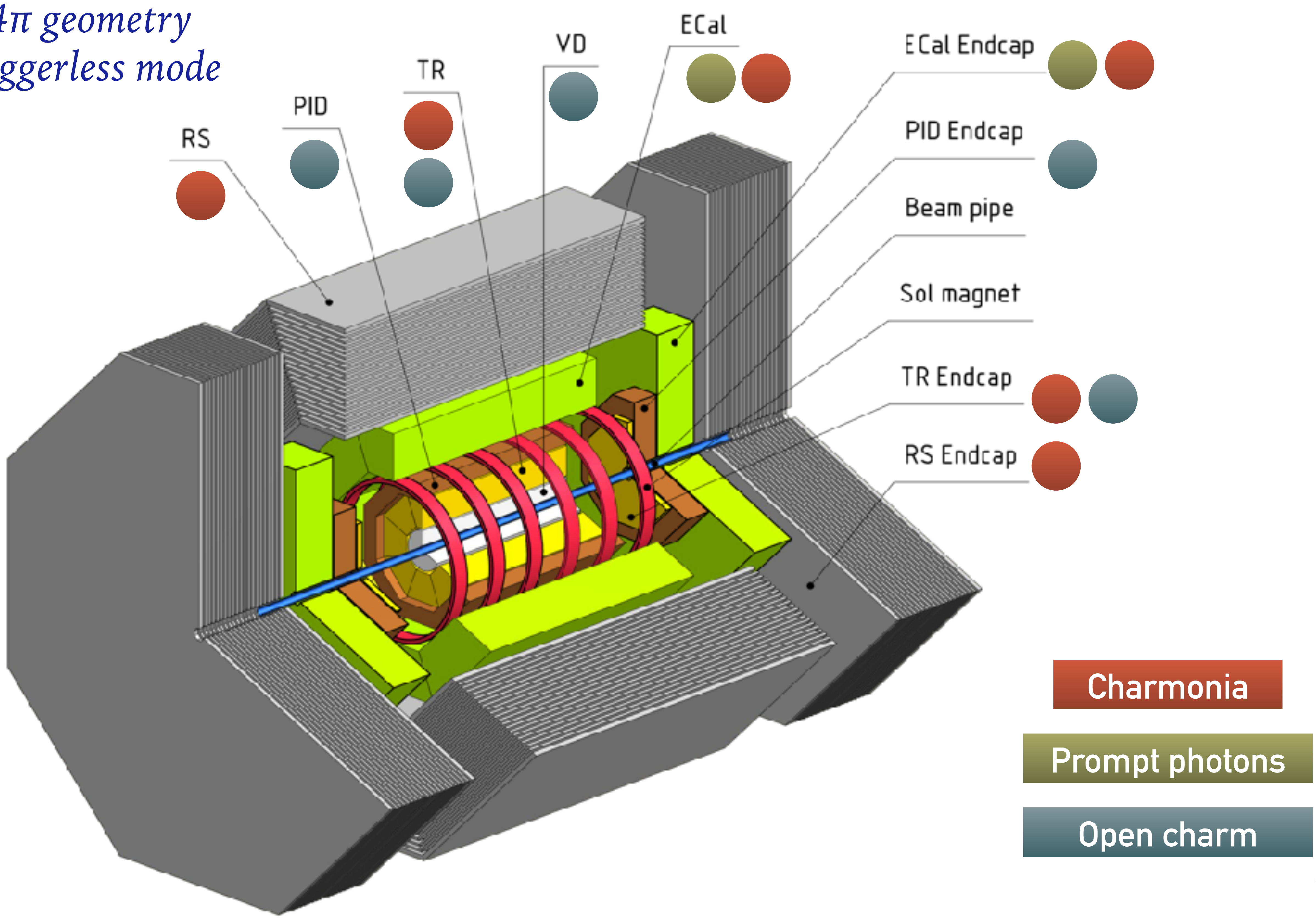
EXPECTED STATISTICS AFTER 1 YEAR OF DATA TAKING (10^7 s)

Probe	σ_{27GeV}, nb ($\times$BF)	$\sigma_{13.5GeV}$, nb ($\times$BF)	N_{27GeV}, 10^6	$N_{13.5GeV}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
$J/\psi \to$	200	60		
$\mu^+\mu^-$	12	3.6	12	0.36
$\psi(3686) \to$	25	5		
$J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\mu^+\mu^-$	0.2	0.04	0.2	0.004
Open charm: $D\bar{D}$ pairs	1×10^4	1300	40	0.6
Single D-mesons				
$D^+ \to \pi^+K^-\pi^+$	940	120	940	12
$D^0 \to K^-\pi^+$	400	52	400	5.2

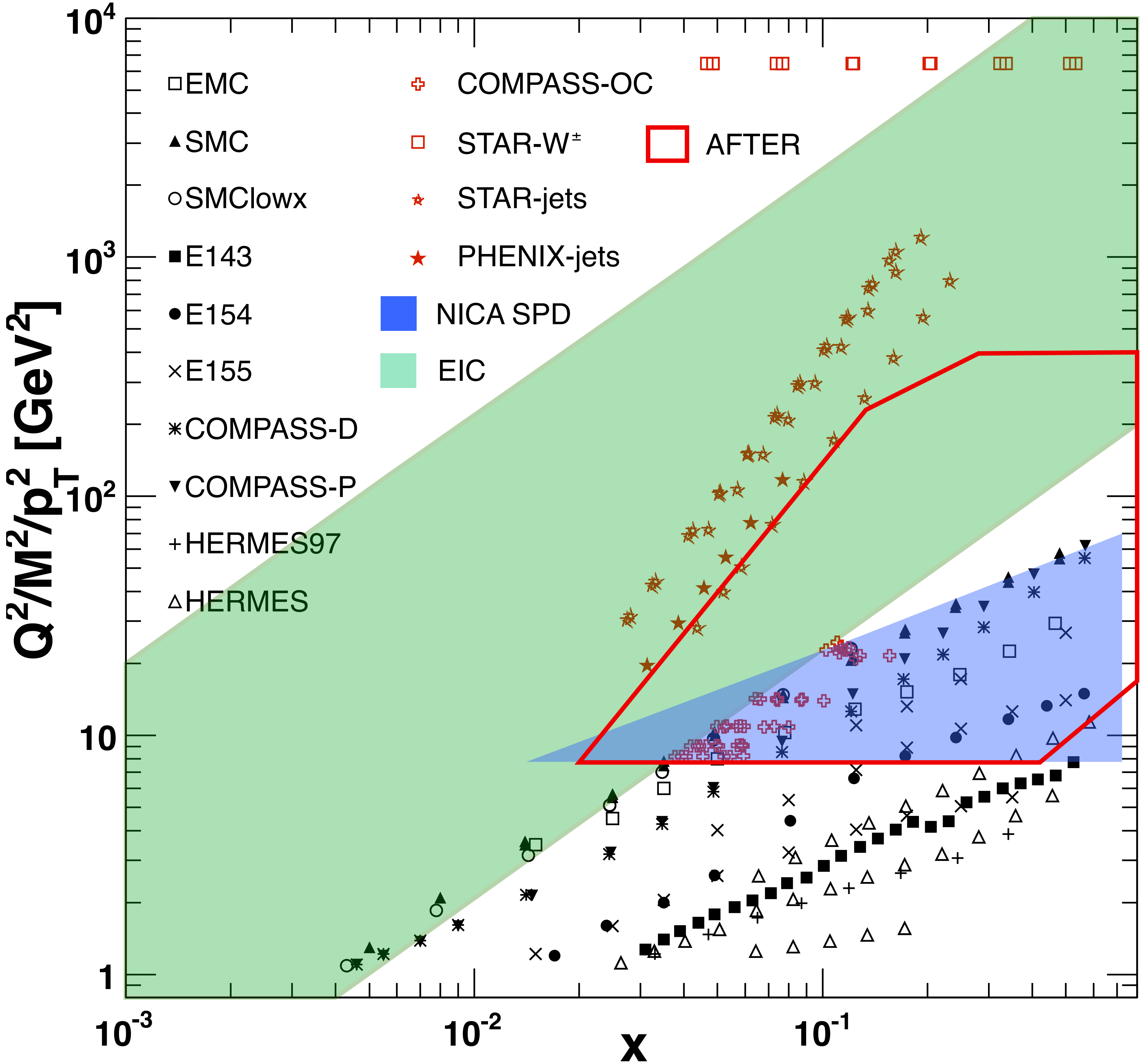
Drell-Yan (M>4 GeV) (μμ) *0.1* *0.005* *0.1* *0.0005*

WHAT SPD HAS FOR OPERATION WITH SUCH PROBES?

~4π geometry
Triggerless mode



MAIN PLAYERS IN POLARIZED GLUON PHYSICS



SPD can cover this range for polarised gluon studies in p↑-p↑ interactions!

Open charm

charmonia

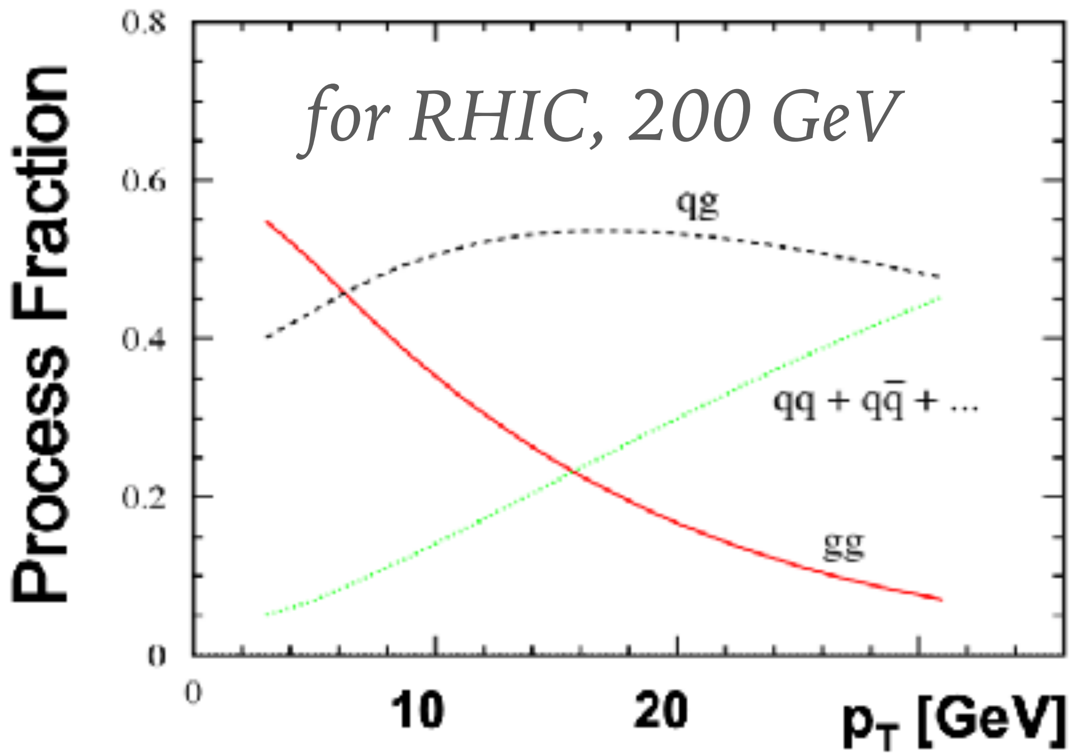
high-p_T prompt photons

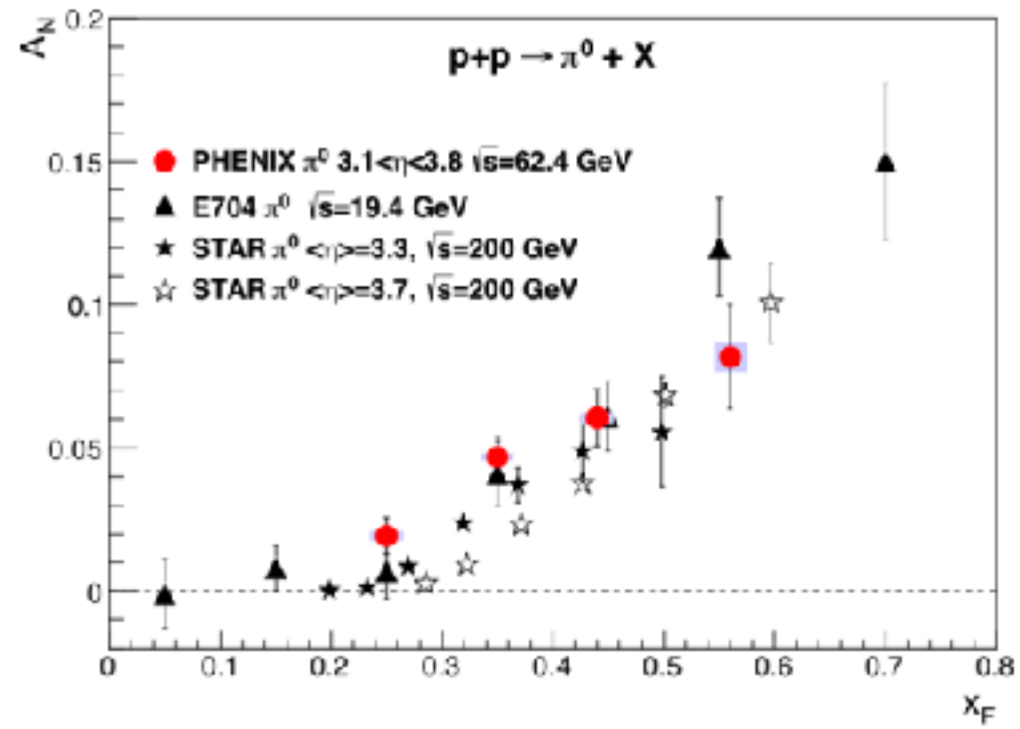
MAIN PLAYERS IN POLARIZED GLUON PHYSICS

Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC
Scientific center	JINR	BNL	BNL	CERN
Operation mode	collider	collider	collider	fixed target
Colliding particles & polarization	$p^{\uparrow}$-$p^{\uparrow}$ $d^{\uparrow}$-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$A^{\uparrow}$	p-$p^{\uparrow}$,$d^{\uparrow}$,A
Center-of-mass energy $\sqrt{s}$, GeV	$\leq$27 (p-p) $\leq$13.5 (d-d)	63, 200, 500	20-140 (ep)	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	$\sim$1 (p-p) $\sim$0.1 (d-d)	2	1000	up to $\sim$10 (p-p)
Physics run	>2025	running	>2030	>2025

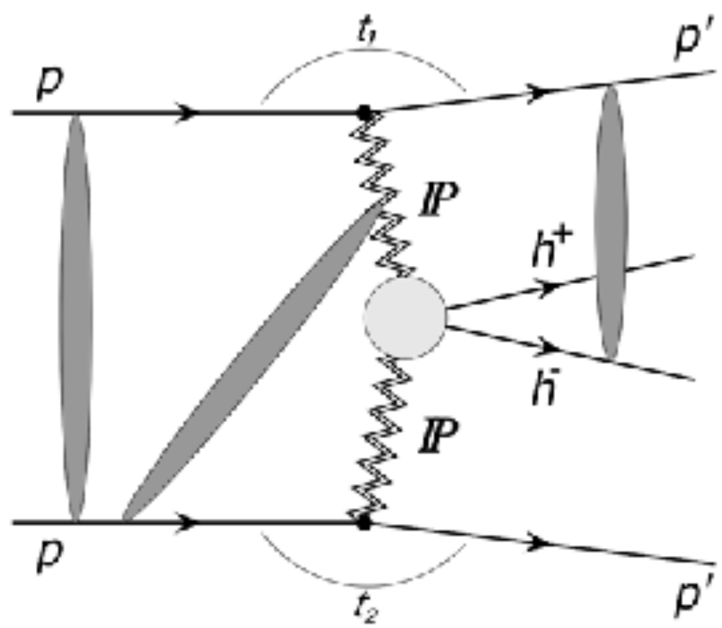
OTHER PROBES ?

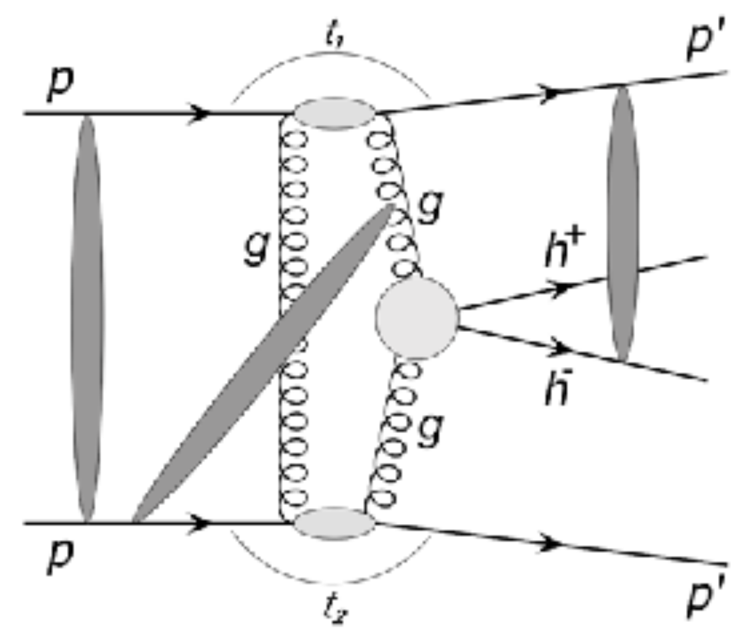
$$pp \to \pi^0 X$$





Central production





There is no detailed studies for our energies

but we will have sizable statistics at SPD for sure

GLUON PDFs

Unpolarized gluons at high x in proton and deuteron

Gluon helicity

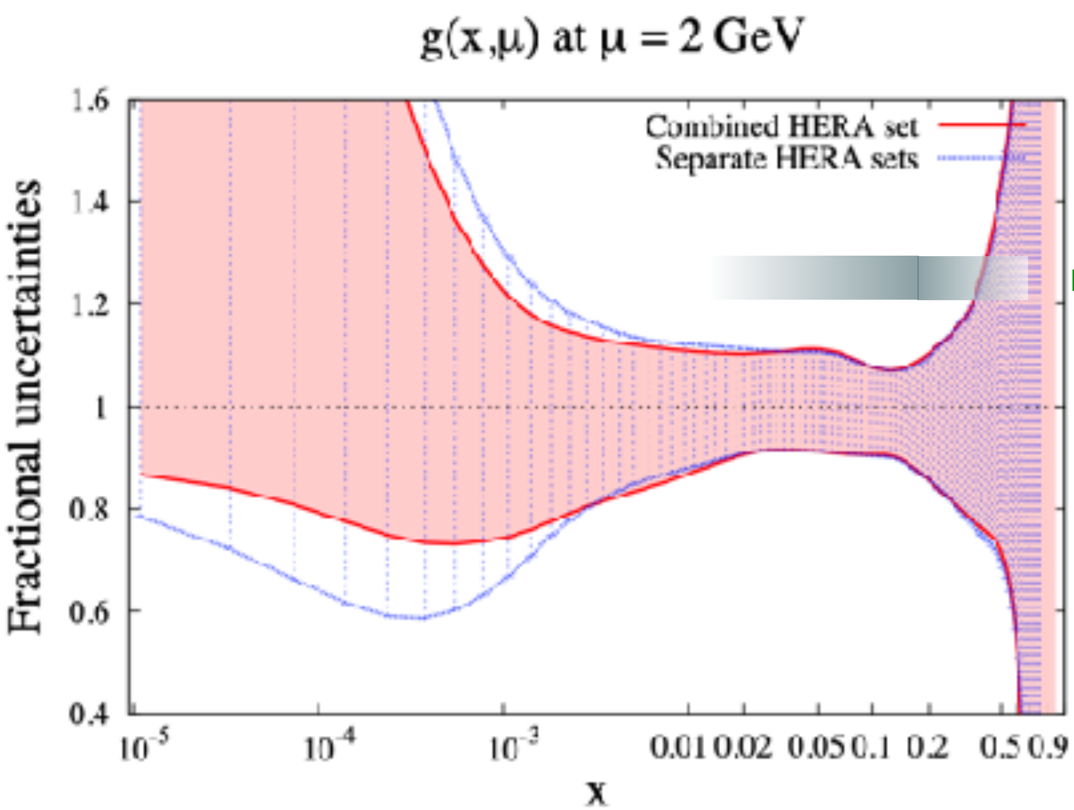
Gluon Boer-Mulders function

GLUONS	*unpolarized*	*circular*	*linear*
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	h_{1T}^g, $h_{1T}^{\perp g}$

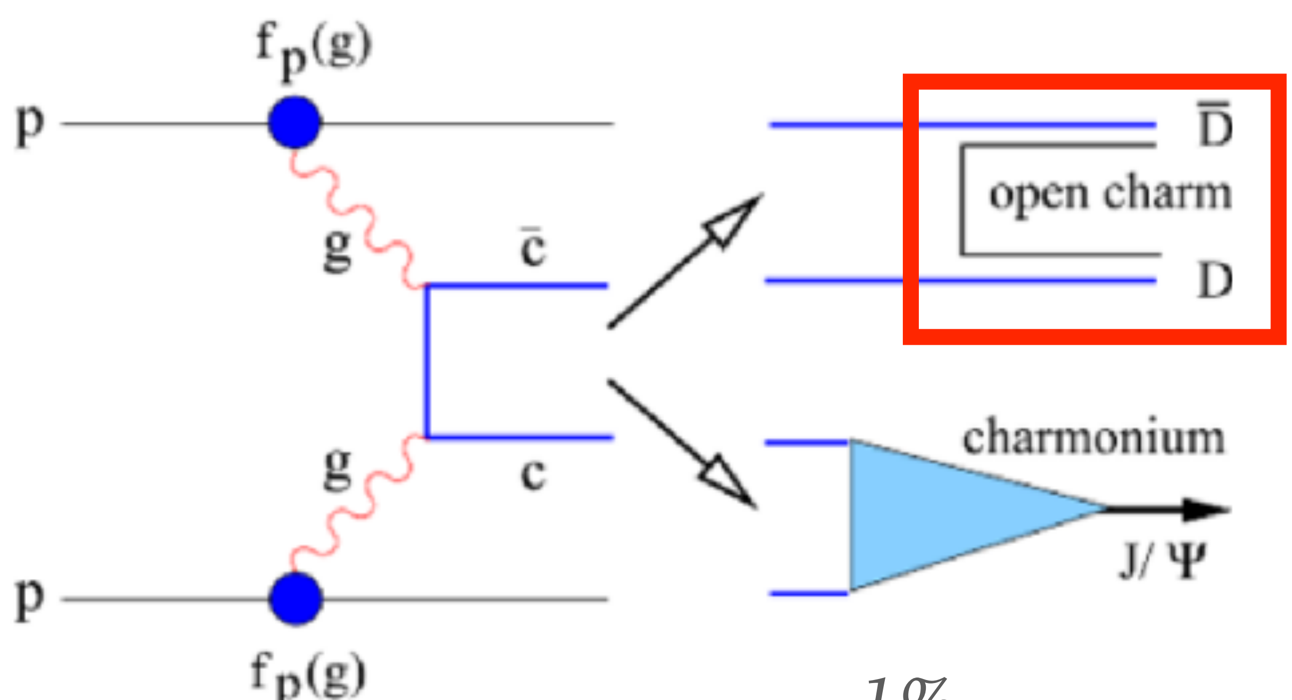
Gluon Sivers function

Gluon transversity in deuteron

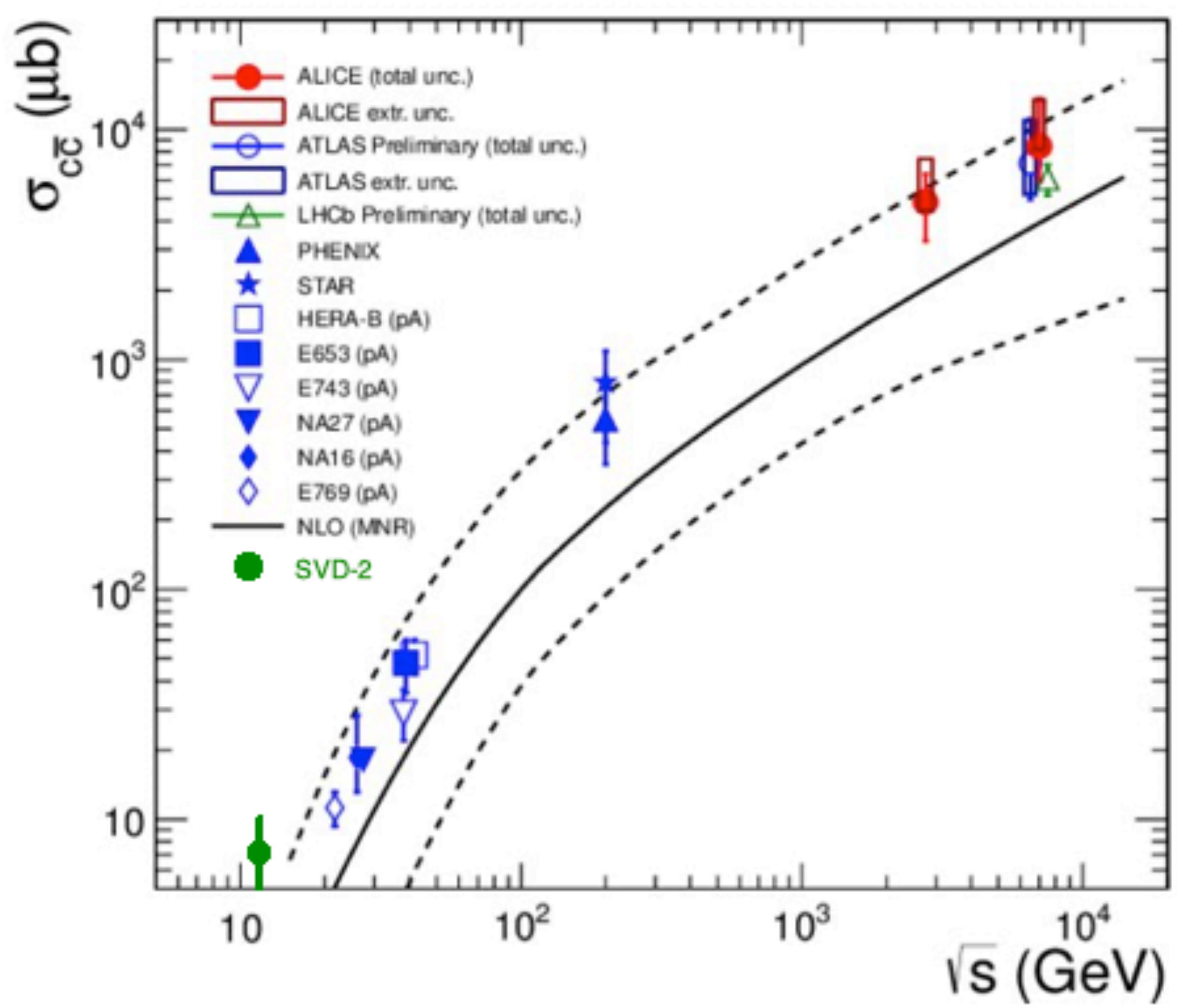
UNPOLARIZED GLUONS IN PROTON AT HIGH x



Good opportunity for SPD

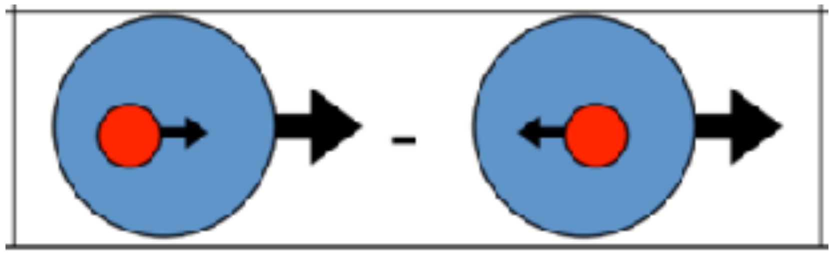


∼1%

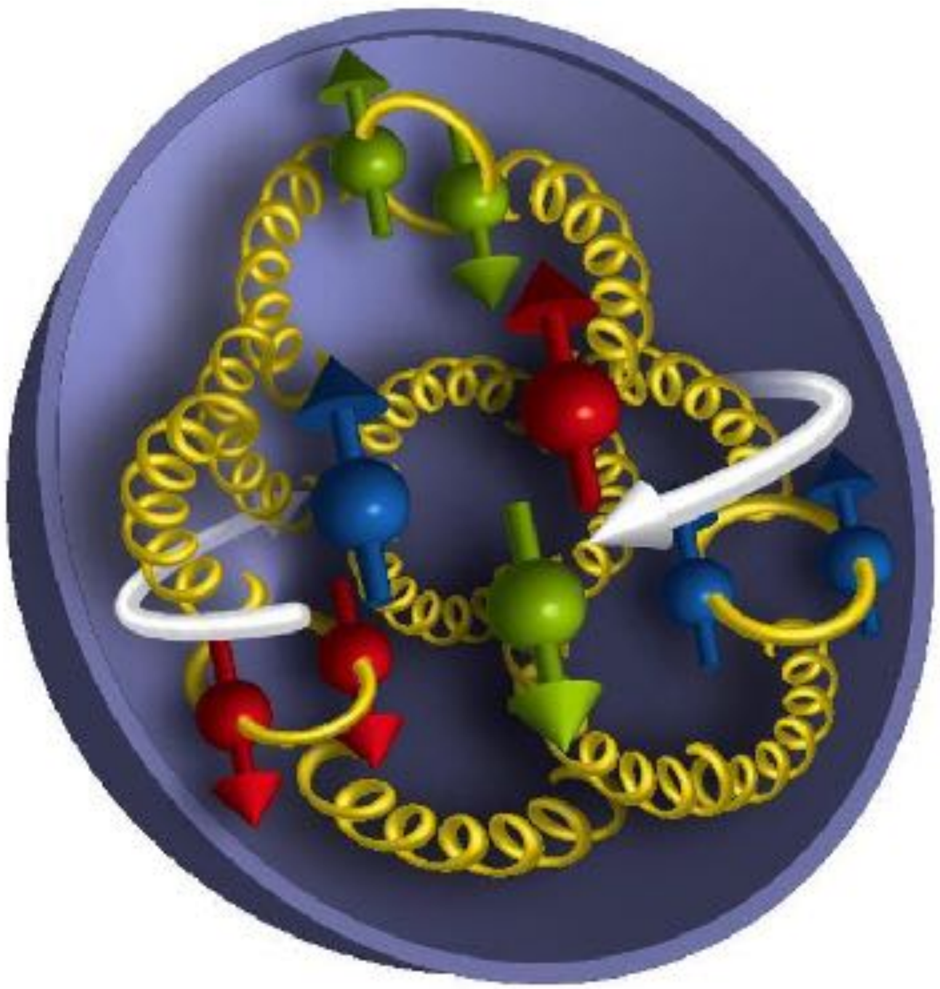


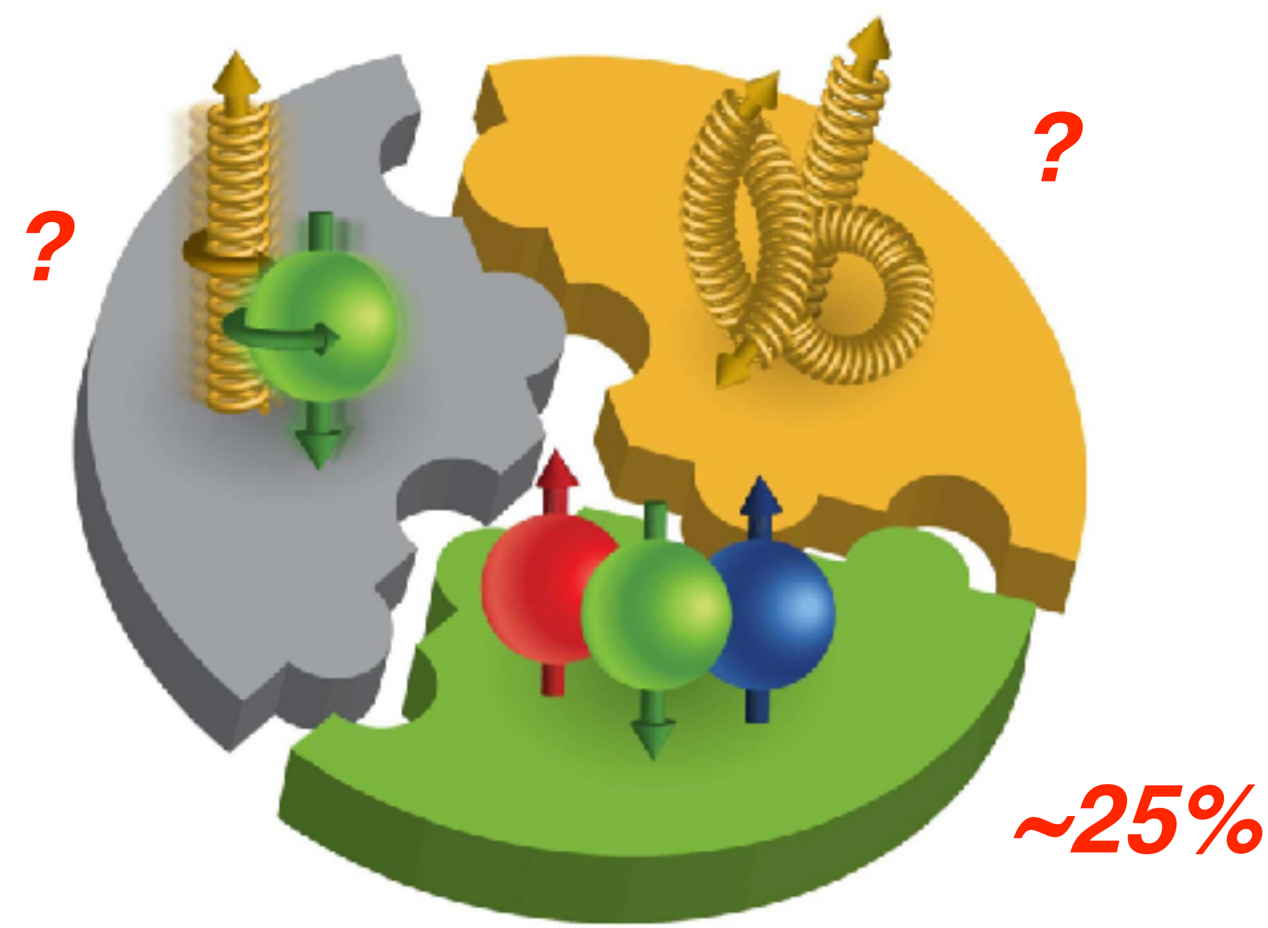
GLUON HELICITY FUNCTION Δg(x) : SPIN CRISIS

Δg(x) :



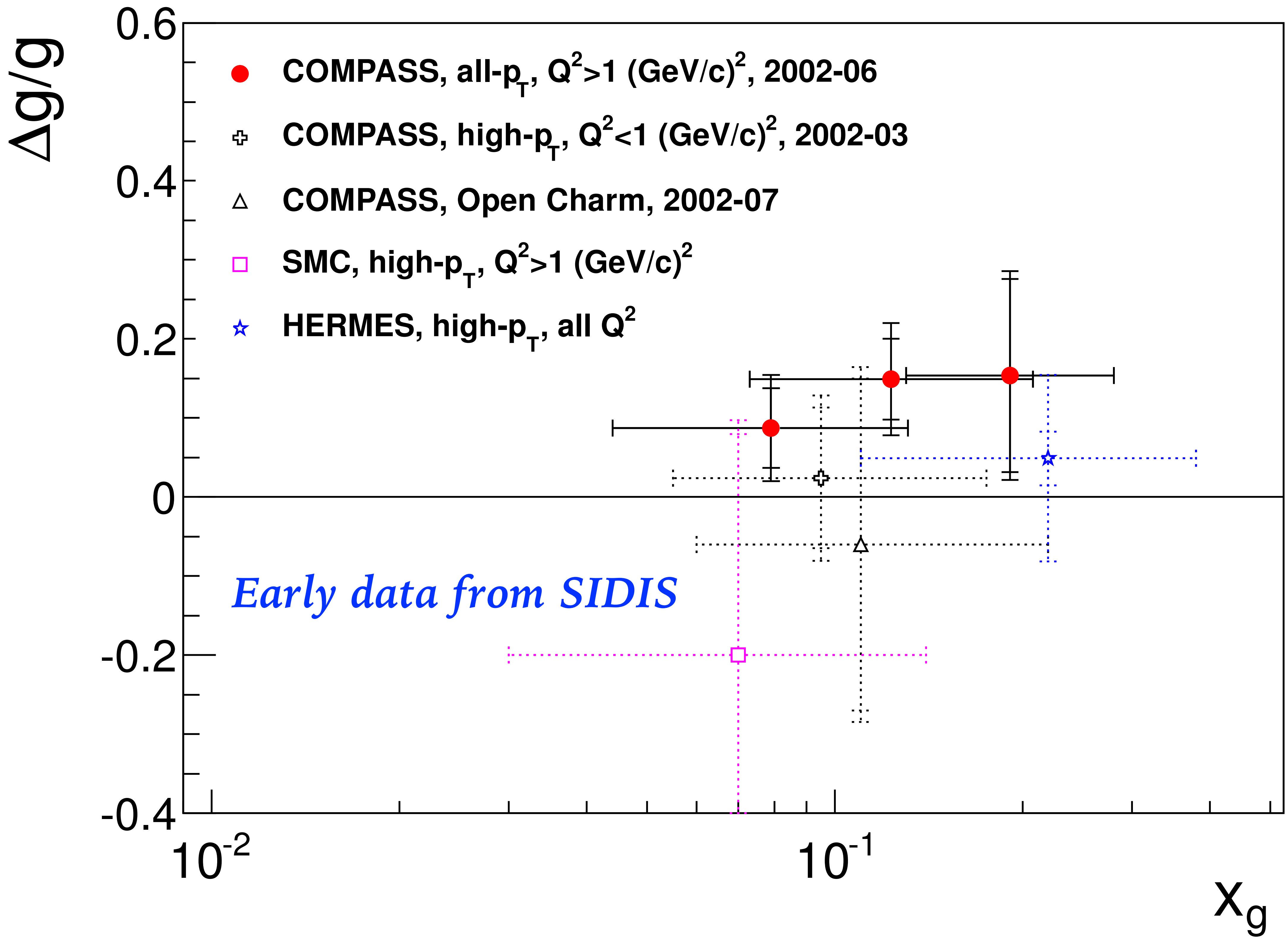
$$\Delta G = \int_0^1 \Delta g(x) dx$$





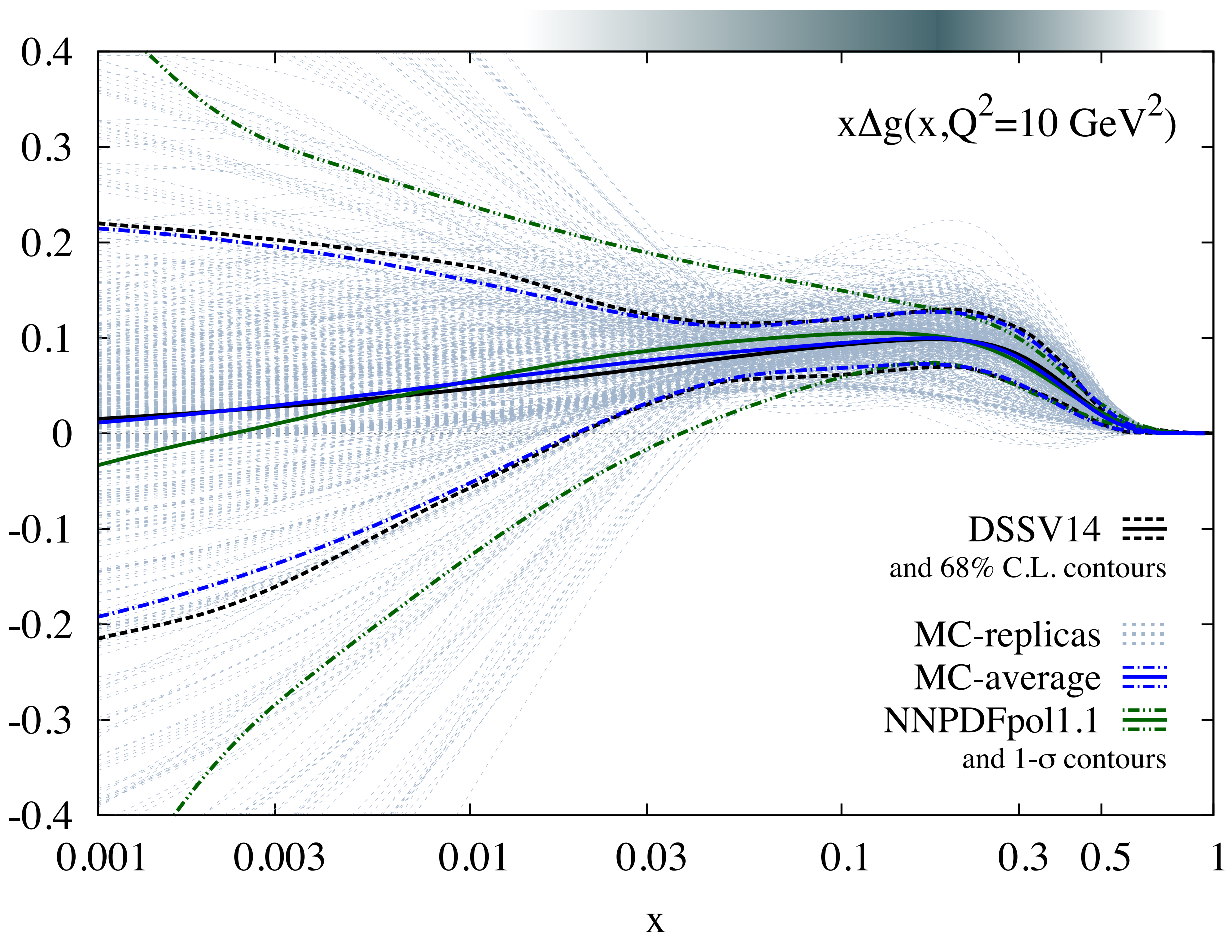
$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

GLUON HELICITY FUNCTION Δg(x)



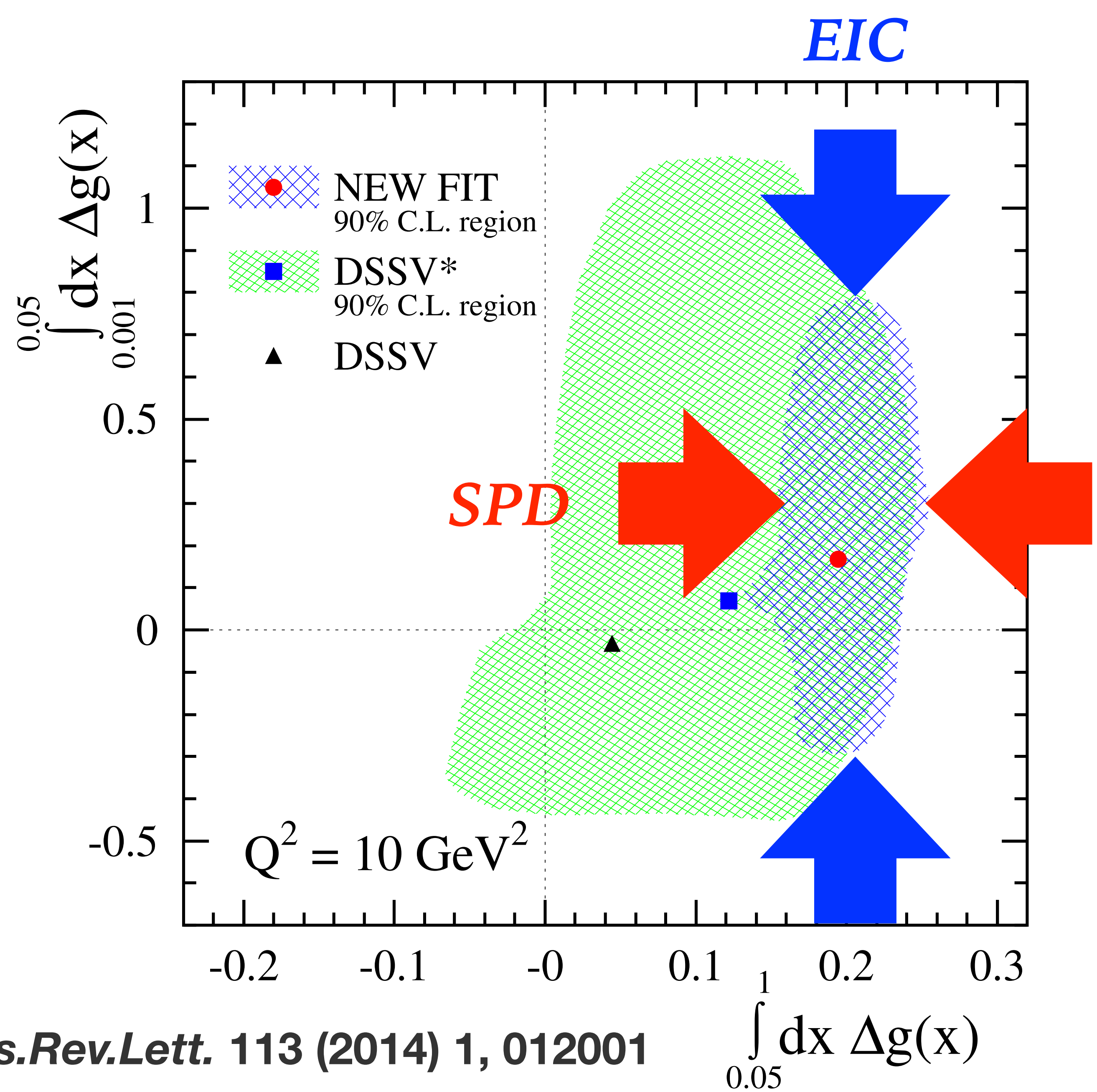
GLUON HELICITY FUNCTION $\Delta g(x)$

accessible with SPD



Phys.Rev.D 100 (2019) 11, 114027

EIC



***Phys.Rev.Lett.* 113 (2014) 1, 012001**

SPD could help to reduce uncertainty of ΔG at large x

GLUON HELICITY FUNCTION Δg(x) : HOW TO ACCESS?

Double longitudinal spin asymmetry:

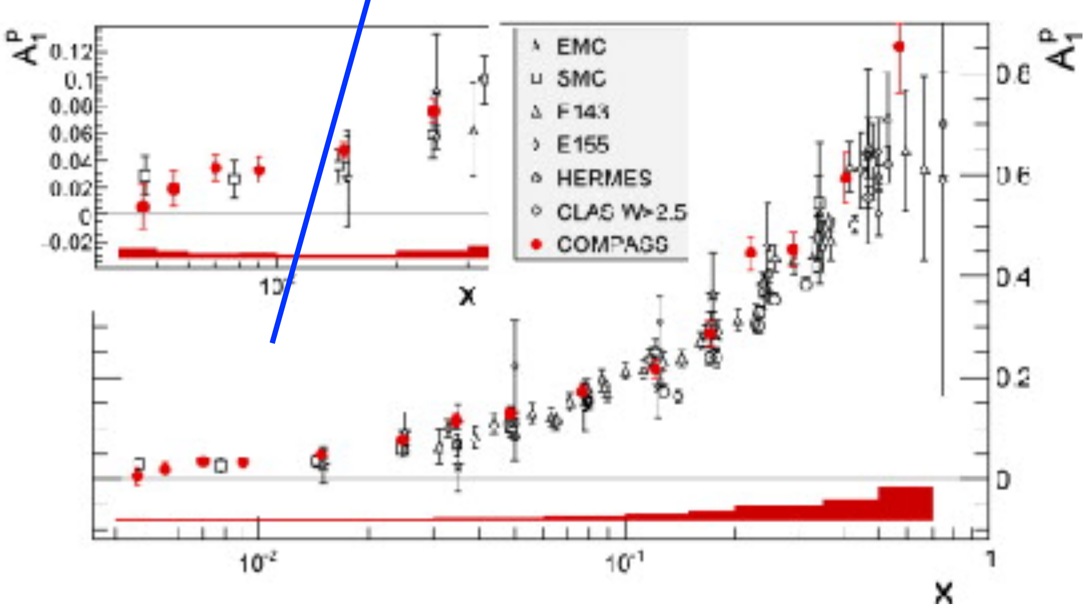
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

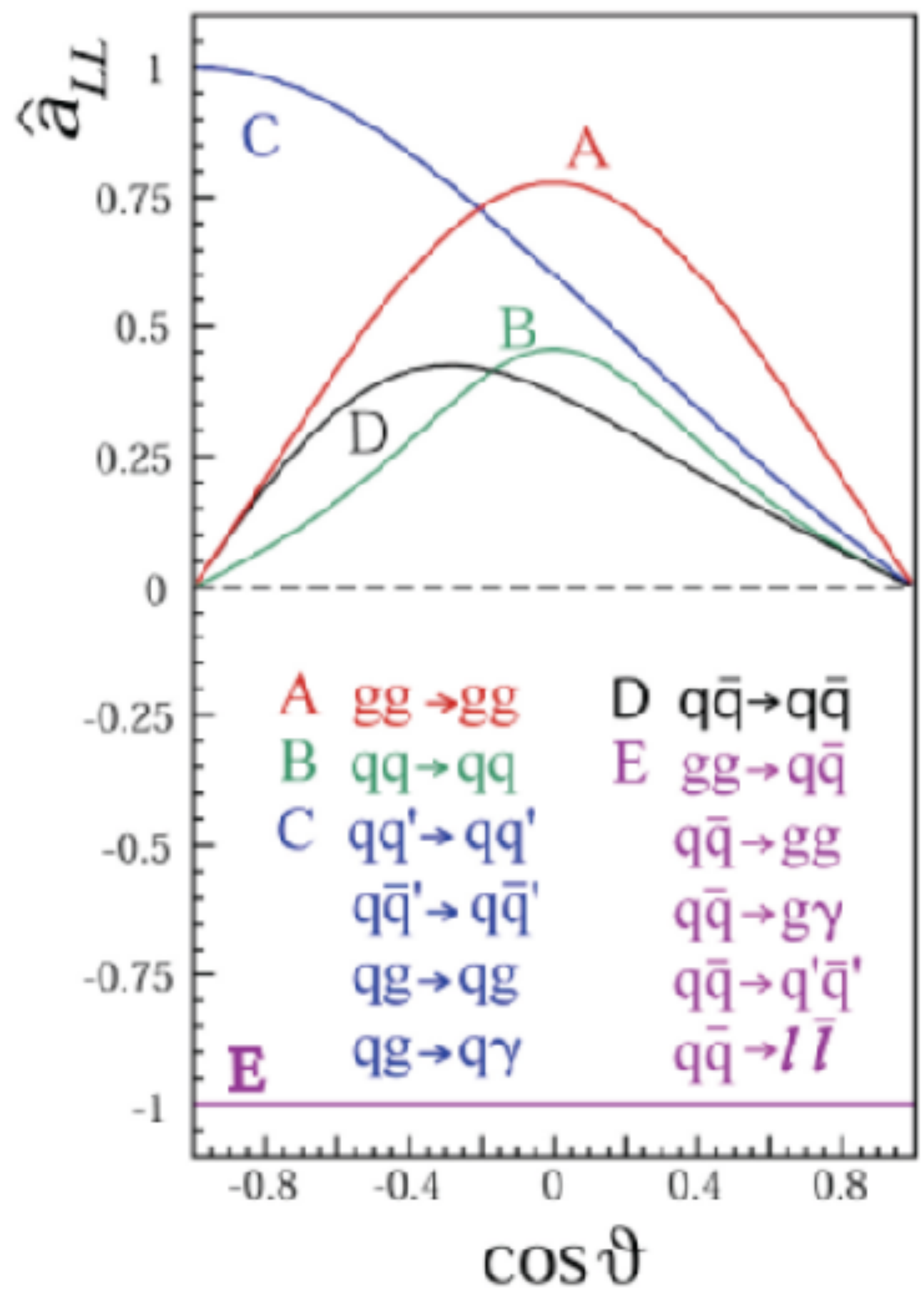
$$A_{LL}^{c\bar{c}} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg\to c\bar{c}X}$$

- ***quadratic* sensitivity to Δg**

$$A_{LL}^{\gamma} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes A_{1p}(x_2) \otimes \hat{a}_{LL}^{gq(\bar{q})\to\gamma q(\bar{q})} + (1 \leftrightarrow 2)\,.$$

- ***sensitivity to the sign of Δg***

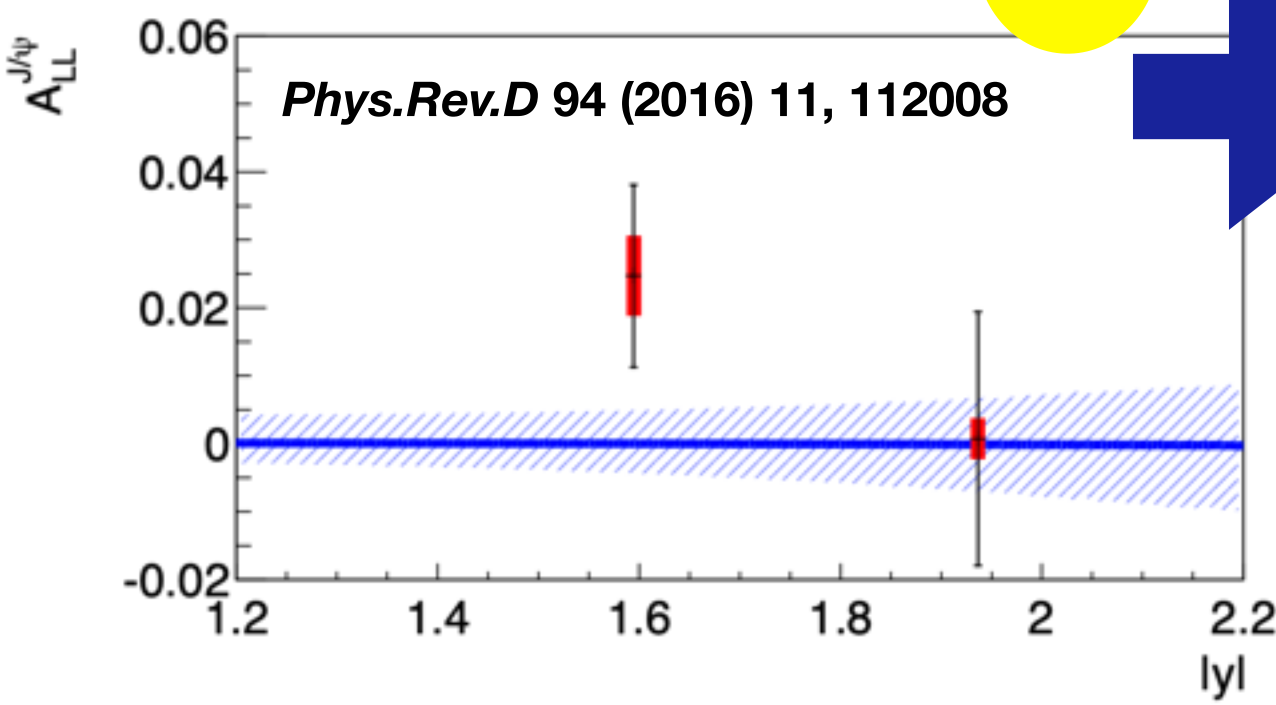


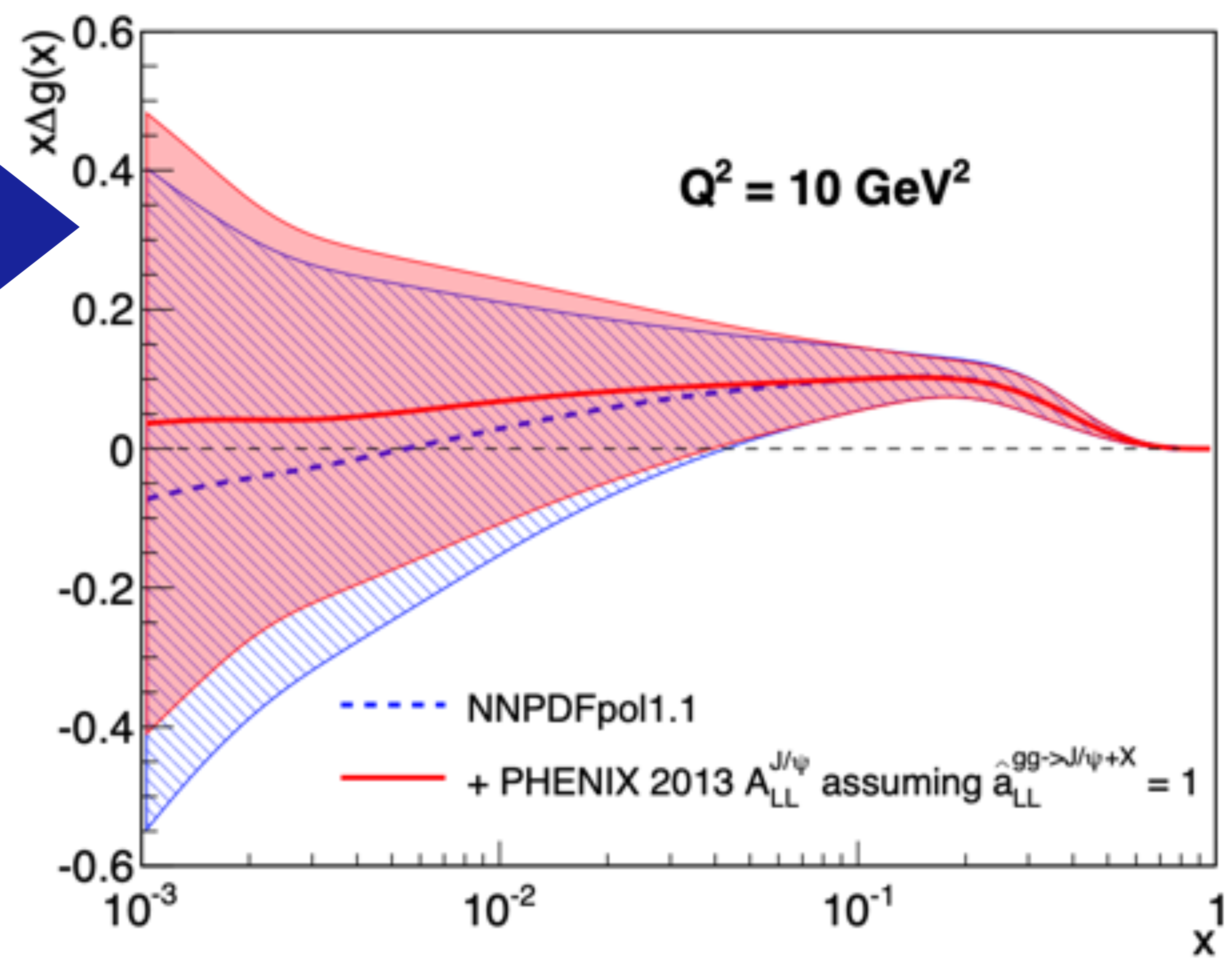


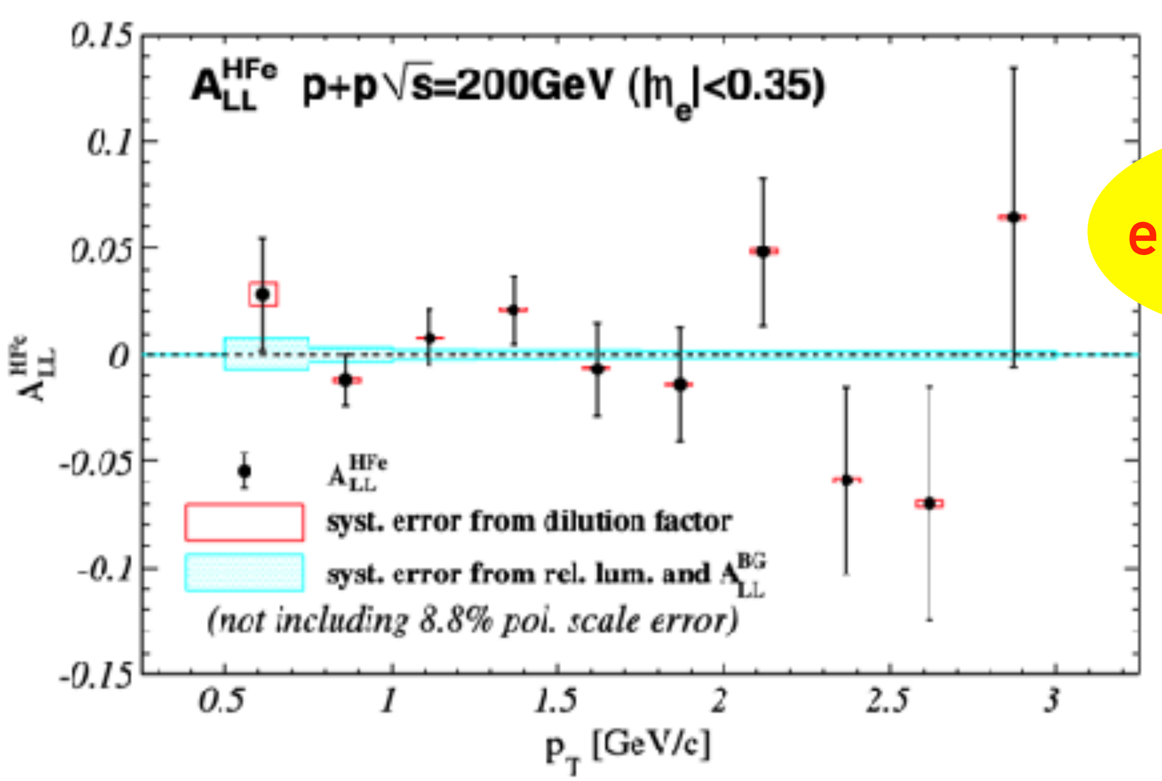
GLUON HELICITY FUNCTION Δg(x) : EXISTING RESULTS FOR A_{LL}

PHENIX, 510 GeV

J/ψ







e from HF

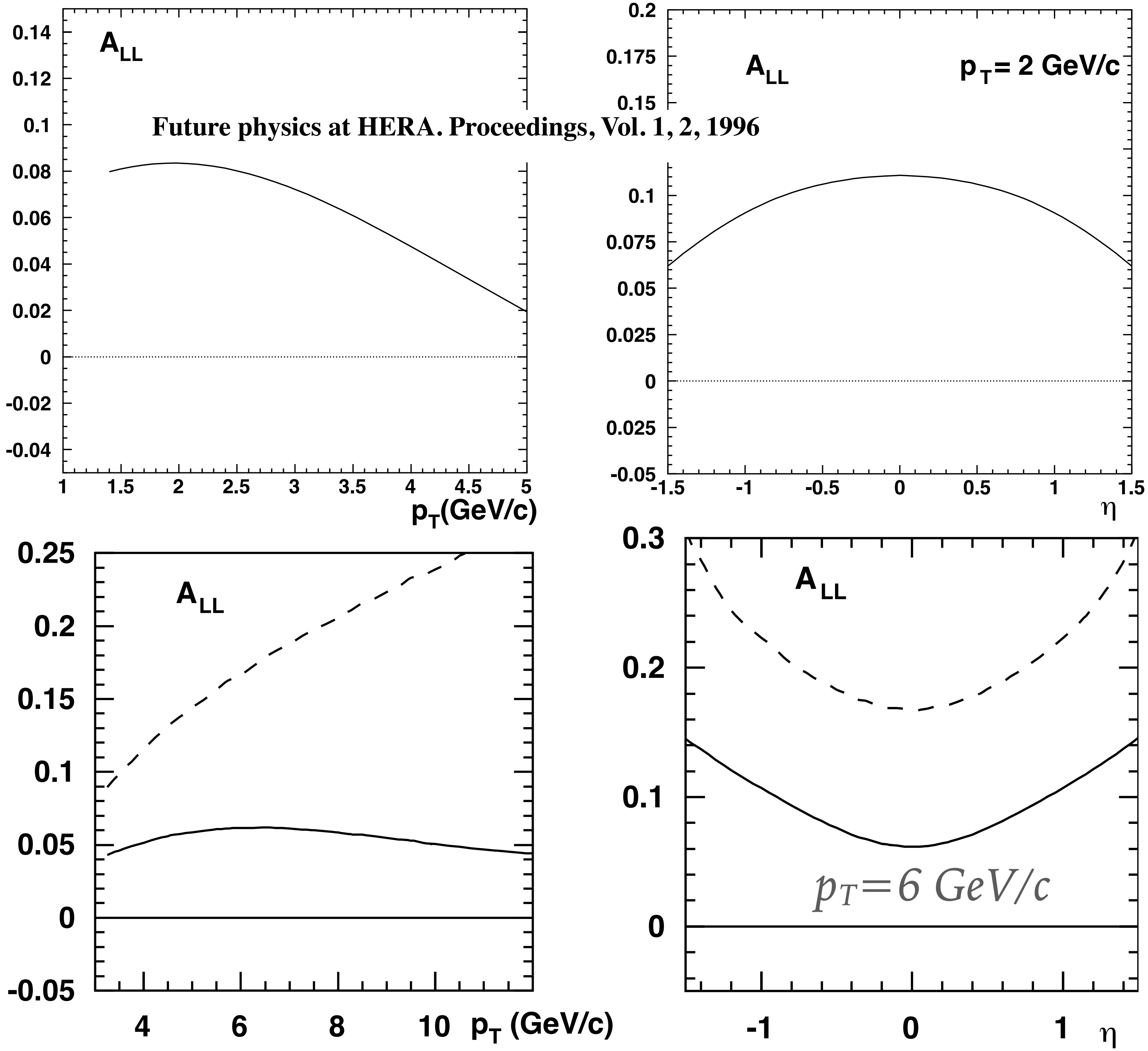
Also π^0, η, jets

PHENIX, 200 GeV

Phys.Rev.D 87 (2013) 1, 012011

GLUON HELICITY FUNCTION $\Delta g(x)$: EXPECTATIONS

Future physics at HERA. Proceedings, Vol. 1, 2, 1996



$$gg \rightarrow J/\psi g$$

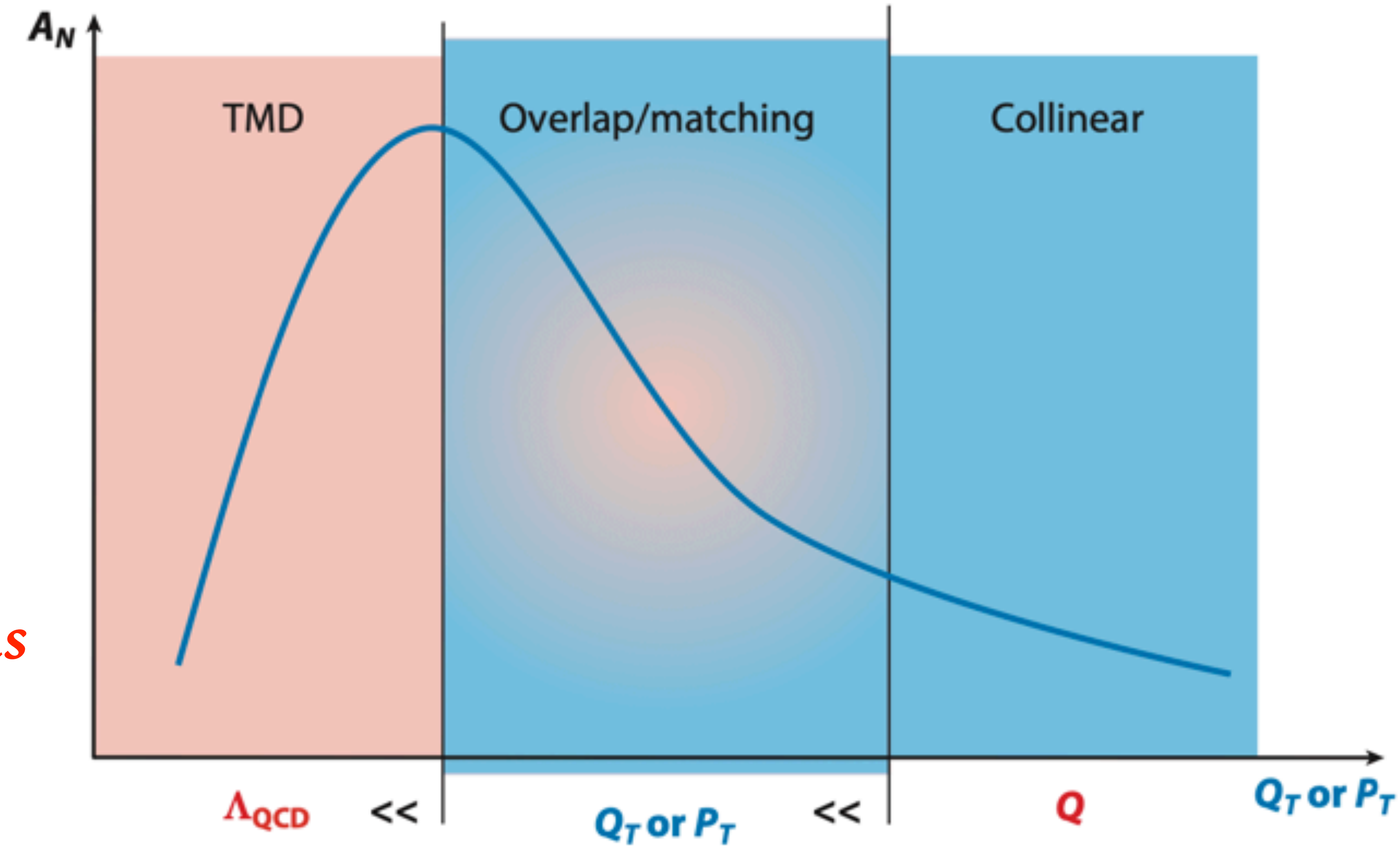
$$\sqrt{s} = 39\ GeV$$

$$qg \rightarrow q\gamma$$

GLUON-INDUCED TMD EFFECTS : TWO APPROACHES

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Different $<k_T>$ for quarks and gluons!

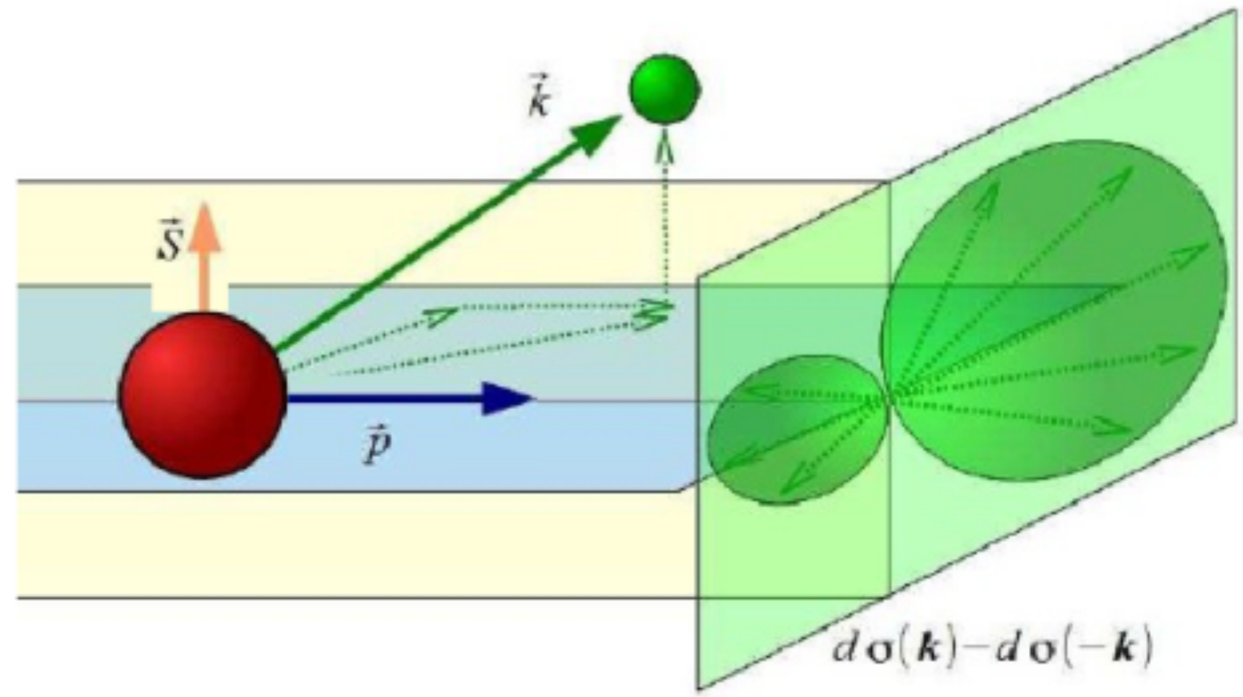


1) Collinear factorization + three-parton correlations in twist-3

2) TMD factorization

GLUON-INDUCED TMD EFFECTS : GLUON SIVERS FUNCTION $\Delta_N^g(x,k_T)$

Sivers effect: left-right asymmetry of unpolarized k_T distribution in transversely polarized nucleon



Sivers effect

Collins effect

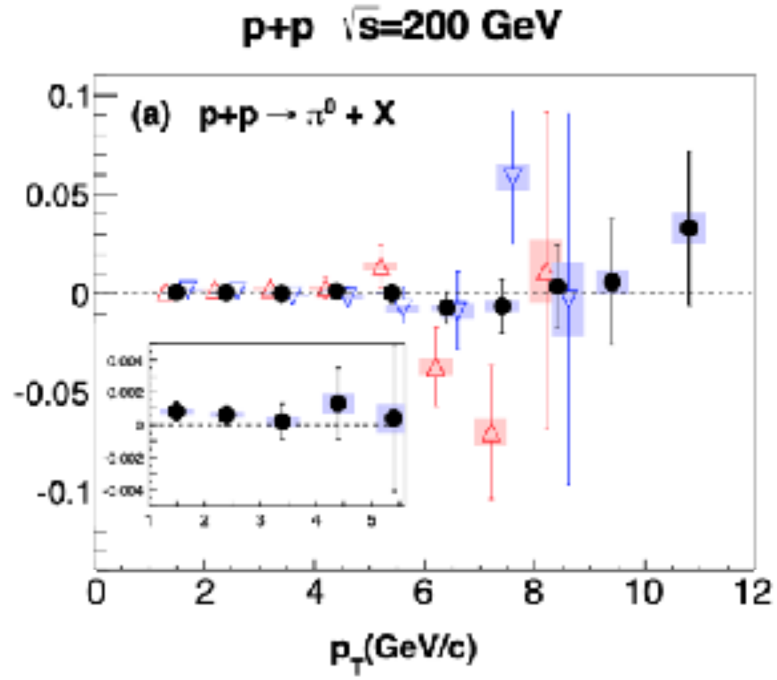
A_N

- due to fragmentation of polarized quark

Collins effect in the first approximation is absent for chamonia and prompt-photon production:

$$\sigma^\uparrow - \sigma^\downarrow = \sum_i \int_{x_{min}}^1 dx_a \int d^2\mathbf{k}_{Ta} d^2\mathbf{k}_{Tb} \frac{x_a x_b}{x_a - (p_T/\sqrt{s})\, e^y} \left[q_i(x_a, \mathbf{k}_{Ta}) \Delta_N G(x_b, \mathbf{k}_{Tb}) \times \frac{d\hat{\sigma}}{d\hat{t}}(q_i G \to q_i \gamma) + G(x_a, \mathbf{k}_{Ta}) \Delta_N q_i(x_b, \mathbf{k}_{Tb}) \frac{d\hat{\sigma}}{d\hat{t}}(G q_i \to q_i \gamma) \right]$$

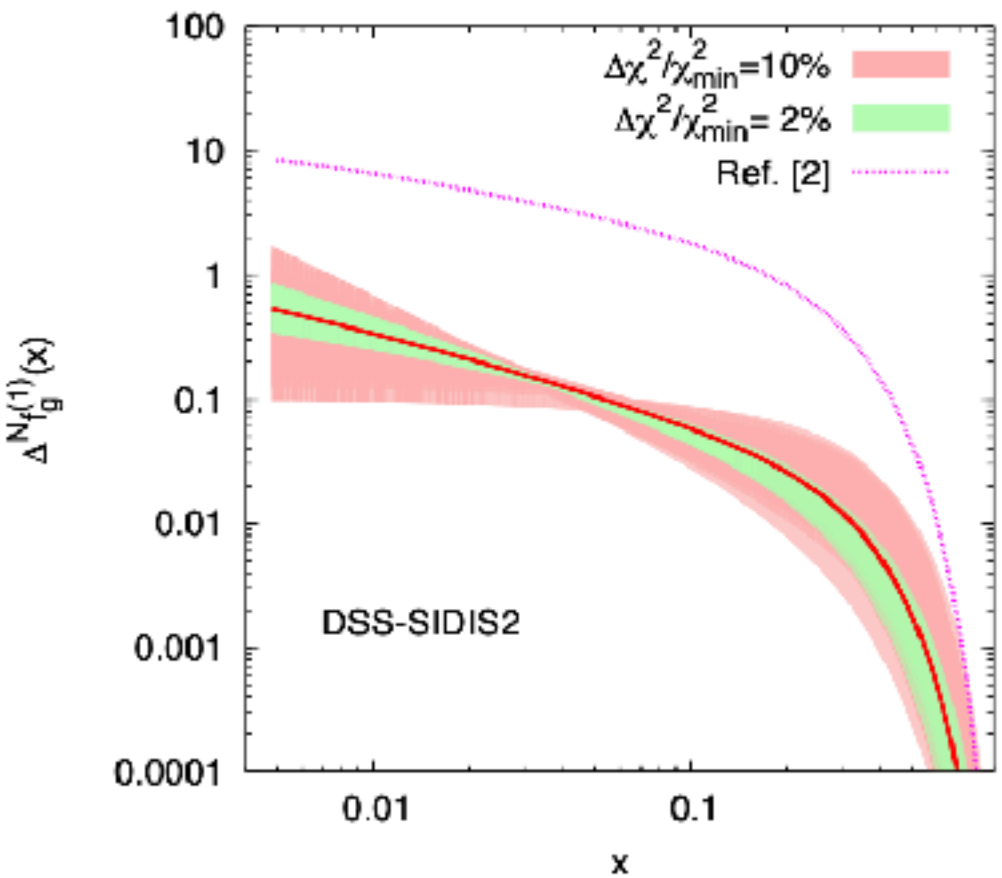
GLUON SIVERS FUNCTION $\Delta_N^g(x,k_T)$



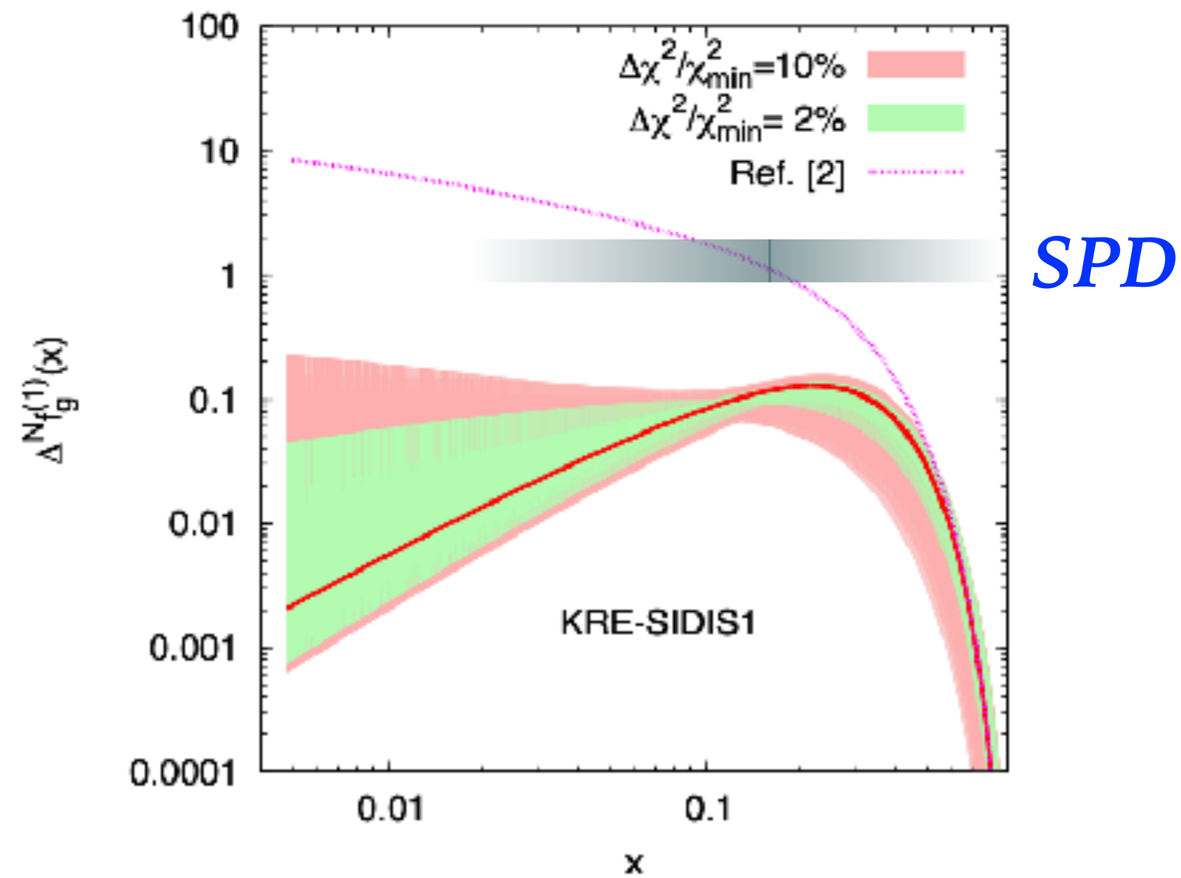
Phys.Rev.D **90 (2014) 1, 012006**

PHENIX

First k⊥-moment of the gluon Sivers function

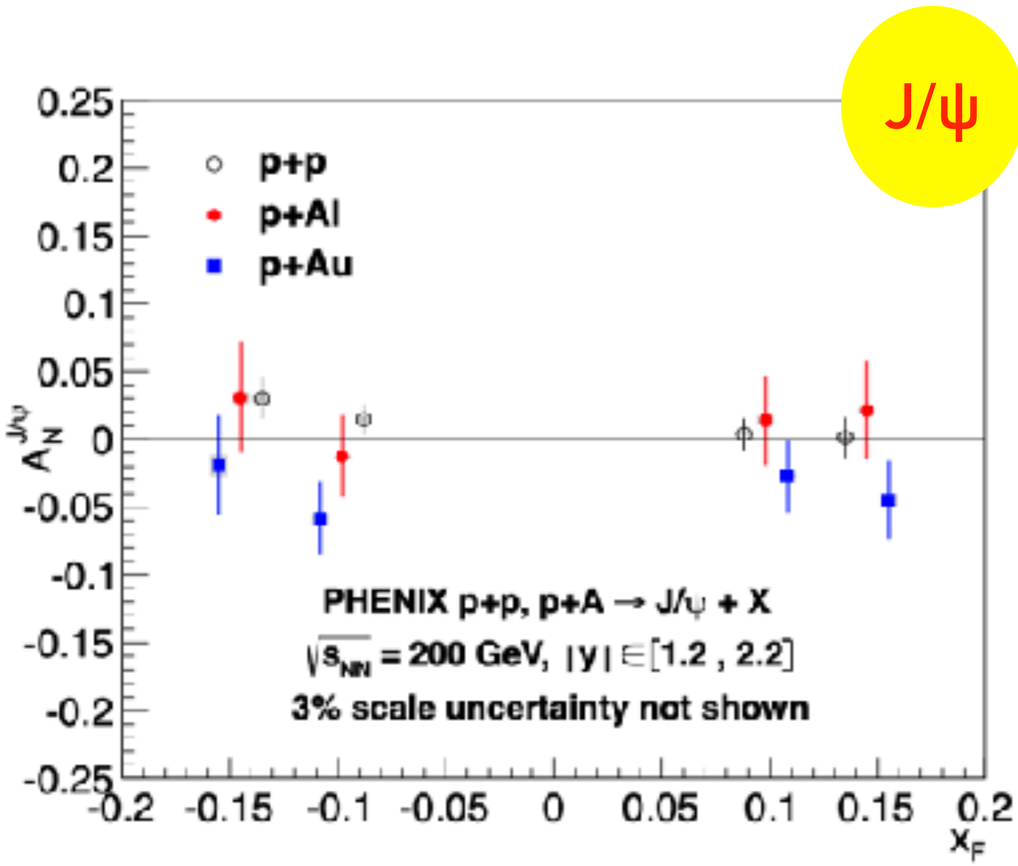


JHEP **09 (2015) 119**

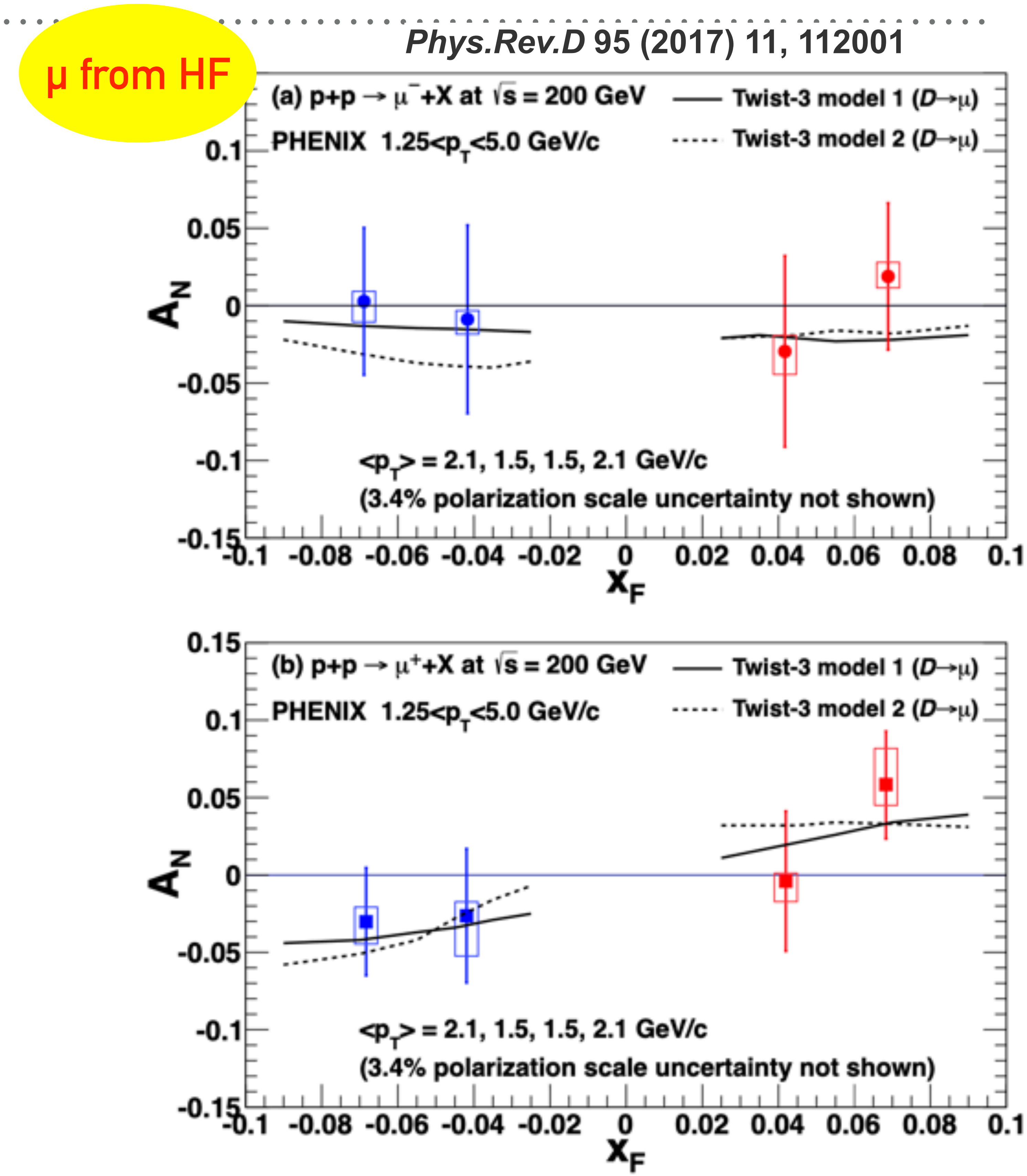


GLUON-INDUCED TMD EFFECTS : EXISTING RESULTS FOR A_N

Phys.Rev.D 98 (2018) 1, 012006



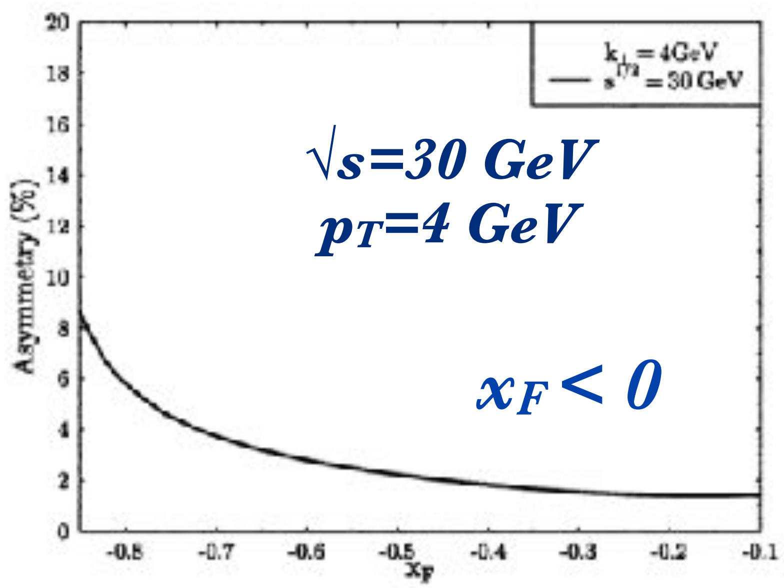
Phys.Rev.D 95 (2017) 11, 112001



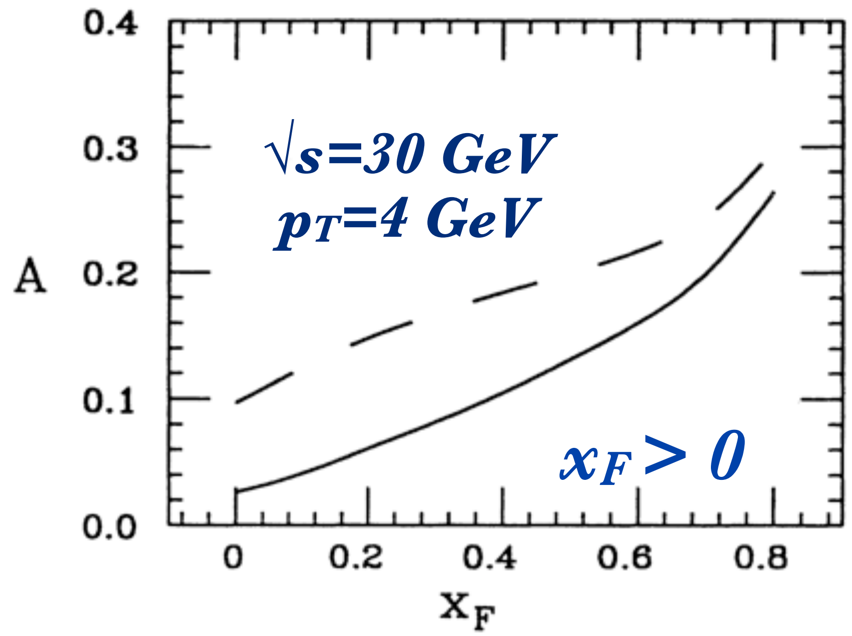
GLUON-INDUCED TMD EFFECTS : EXISTING RESULTS FOR A_N

Three-parton correlations in twist-3

γ

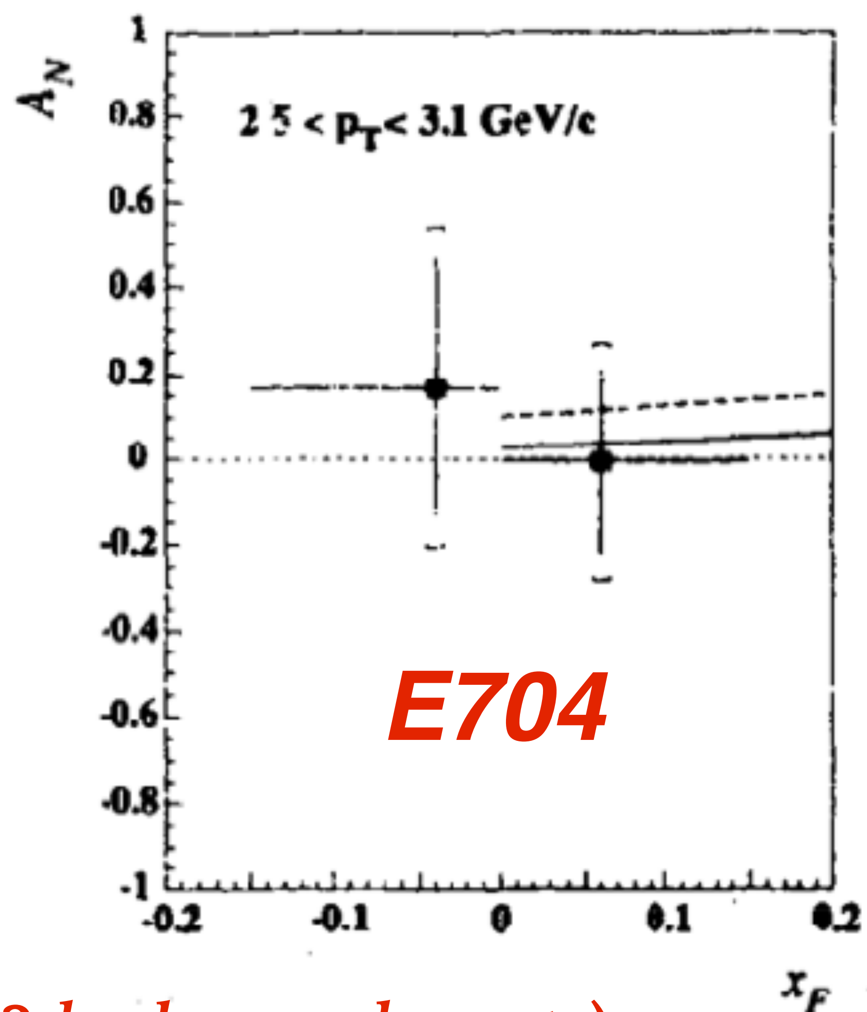


N. Hammon et al.
J. Phys. G: Nucl. Part. Phys. 24 991(1998)



J. Qui and G. Sterman, Phys. Rev. Lett. 67 (1991) 2264

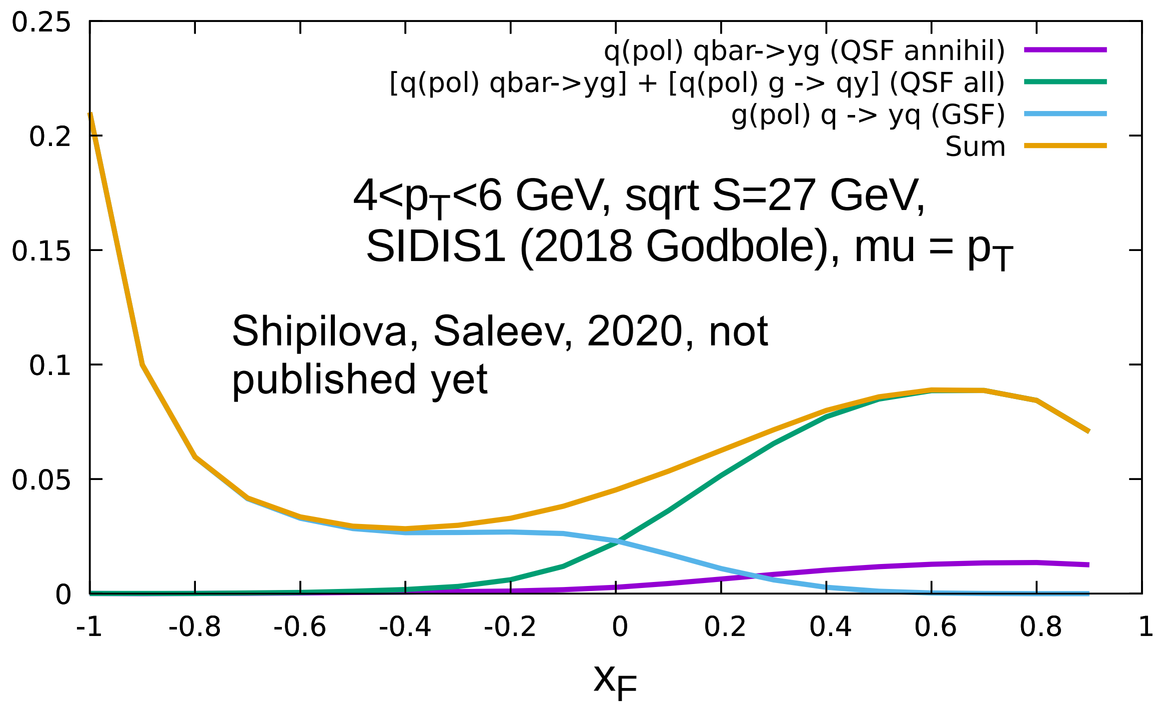
Phys. Lett. B 345 (1995)



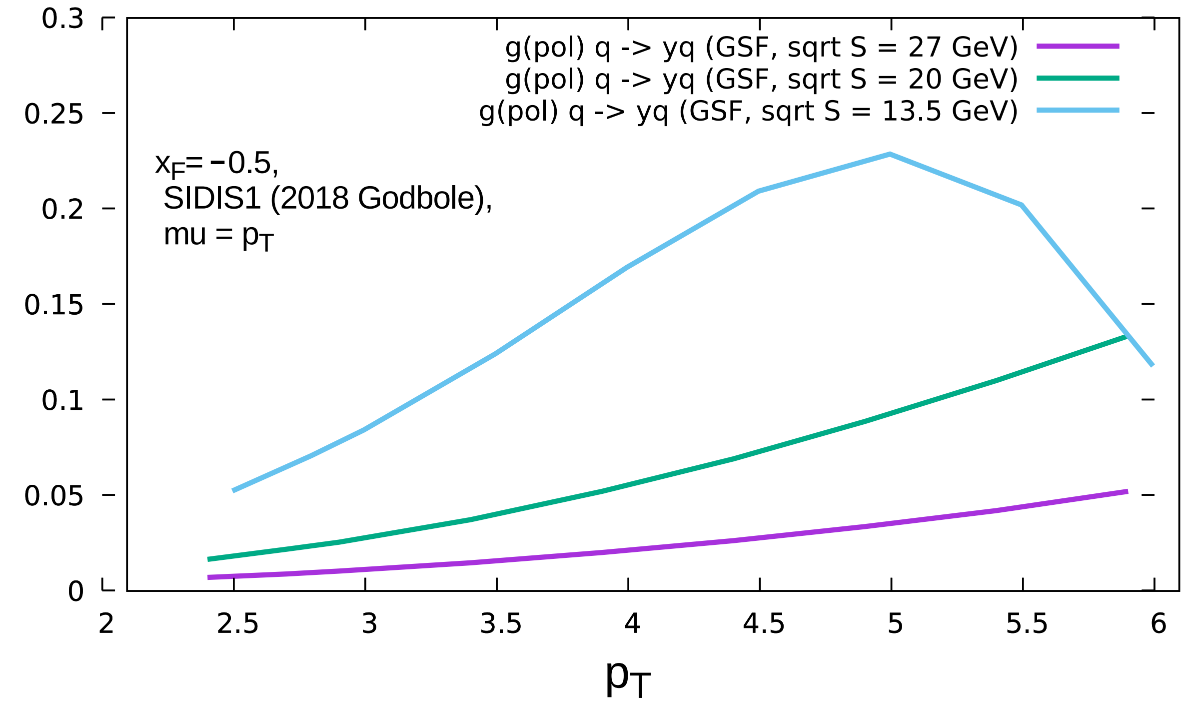
- *Fixed target;*
- *Polarized proton beam from Λ decay;*
- *2.5 GeV/c <p_T< 3.1 GeV/c;*
- *473 prompt photon candidates (including 220+-22 background events)*

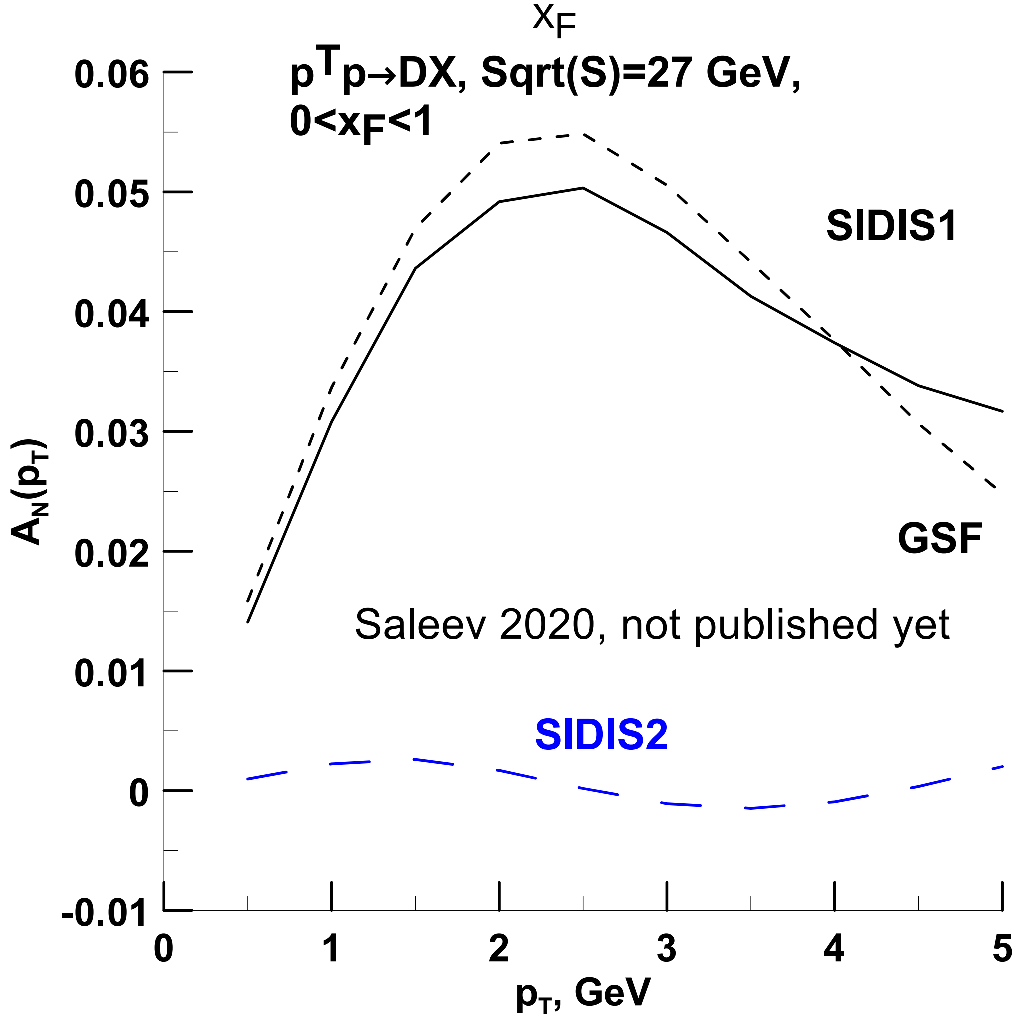
GLUON-INDUCED TMD EFFECTS: EXPECTATIONS FOR A_N

Sivers effect contribution

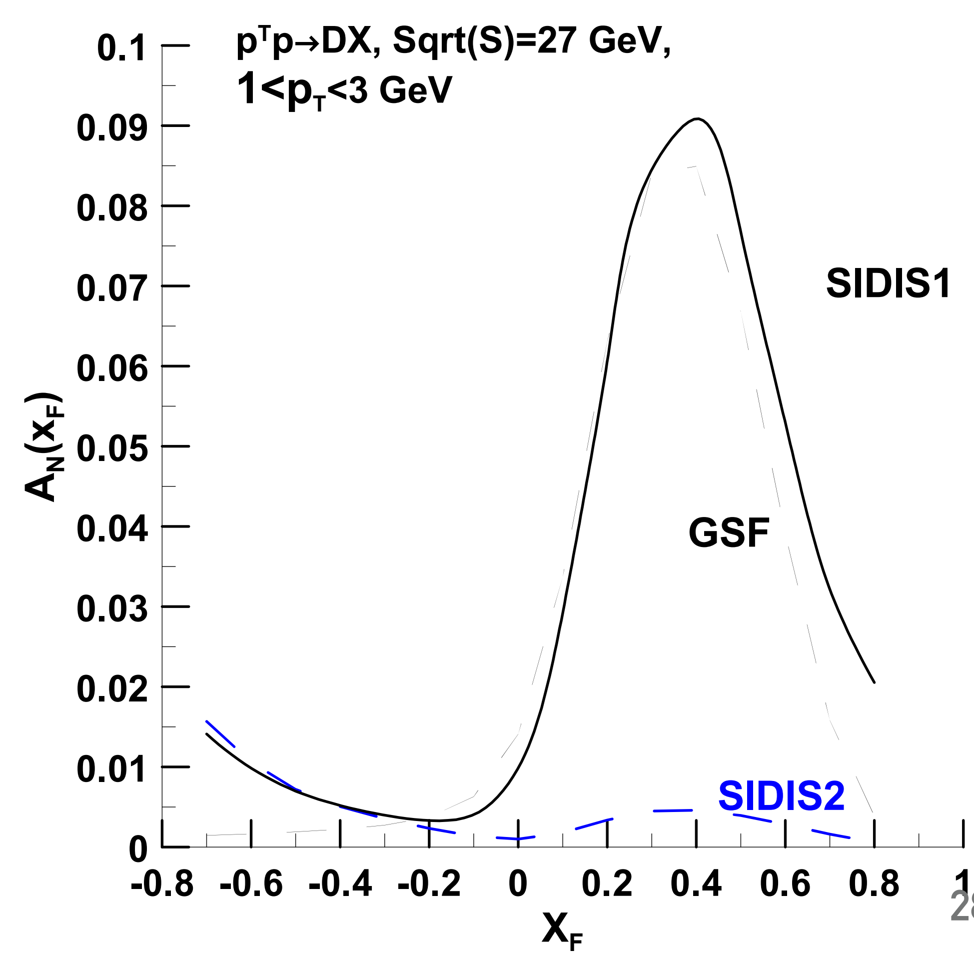


γ





D-mesons



GLUON-INDUCED TMD EFFECTS : BOER-MULDERS FUNCTION $h_1^{\perp g}(x,k_T)$

$gg \to D\bar{D}, \gamma\gamma, J/\psi\gamma, \ldots$

The hadronic cross section can be written with corrections of order $\mathcal{O}(\infty/S)$ in the form [D. Boer, P. Mulders, C. Pisano, 2008]

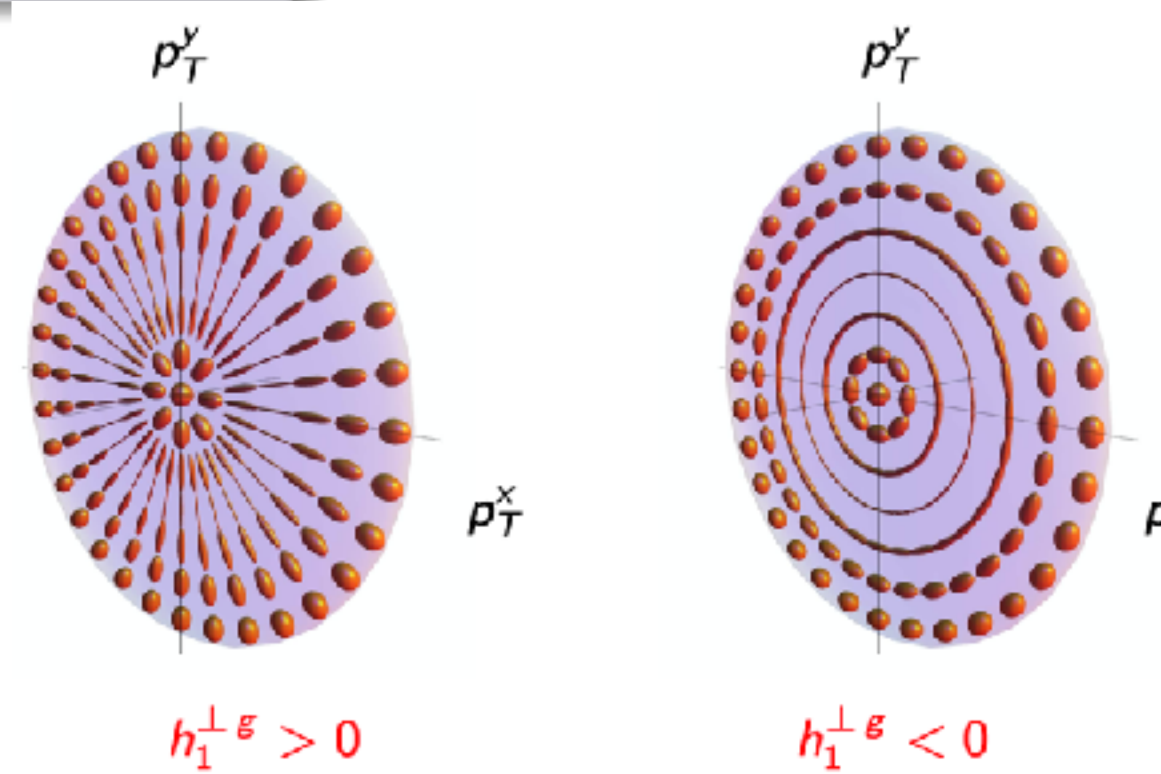
$$\frac{d\sigma(pp \to D\bar{D}X)}{d\eta_1 d\eta_2 d^2k_{1T} d^2k_{2T}} = \frac{\alpha_S}{SK_T^2}\Big[A(Q_T^2) + B(Q_T^2)Q_T^2 \cos 2(\phi_T - \phi_\perp) + \boxed{+C(Q_T^2)Q_T^4 \cos 4(\phi_Q - \phi_K)}\Big]$$

$$\vec{Q}_T = \vec{k}_{1T} + \vec{k}_{2T}, \qquad \vec{K}_T = (\vec{k}_{1T} - \vec{k}_{2T})/2$$

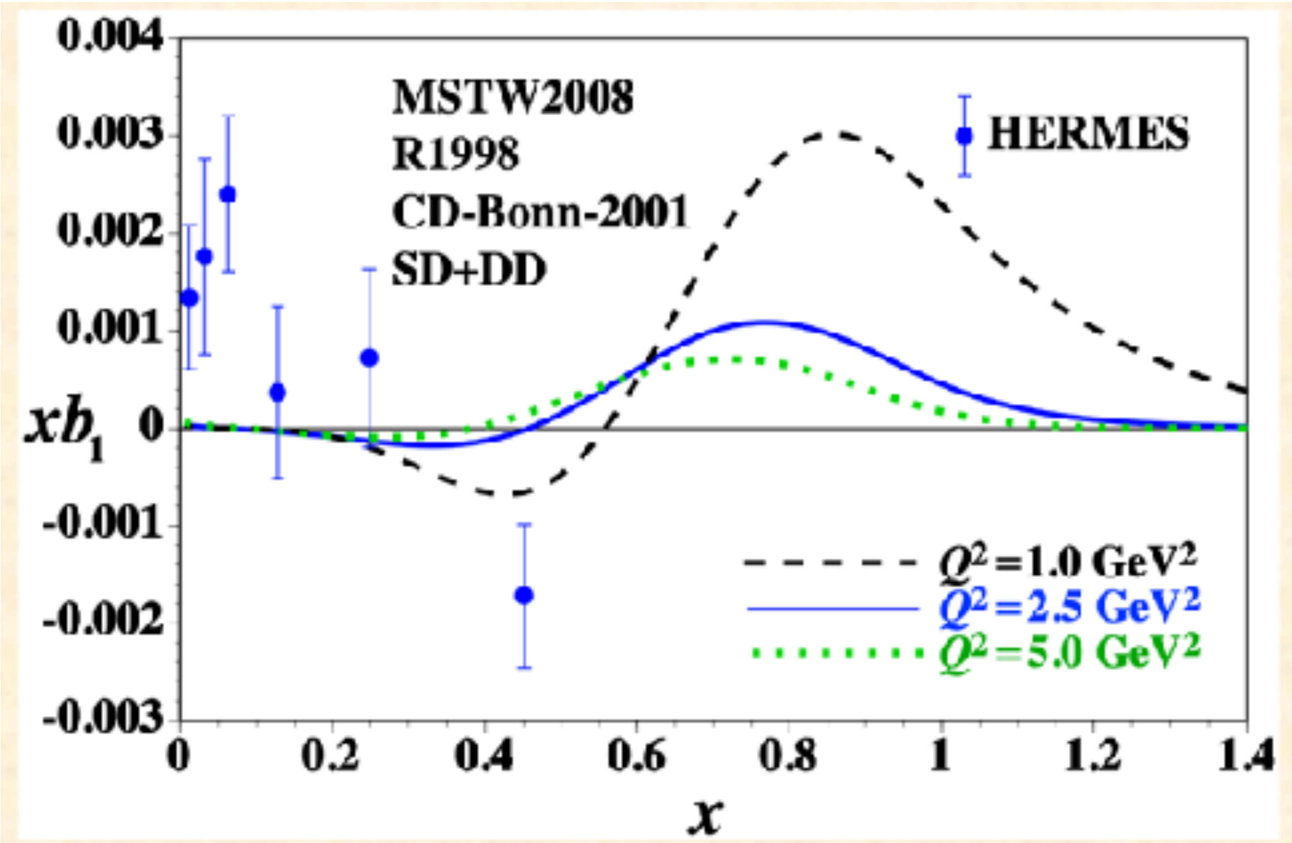
$$A: \quad f_1^q \otimes f_1^{\bar{q}},\ f_1^g \otimes f_1^g,$$

$$B: \quad h_1^{\perp q} \otimes h_1^{\perp \bar{q}},\ \frac{M_Q^2}{M_\perp^2} f_1^g \otimes h_1^{\perp g},$$

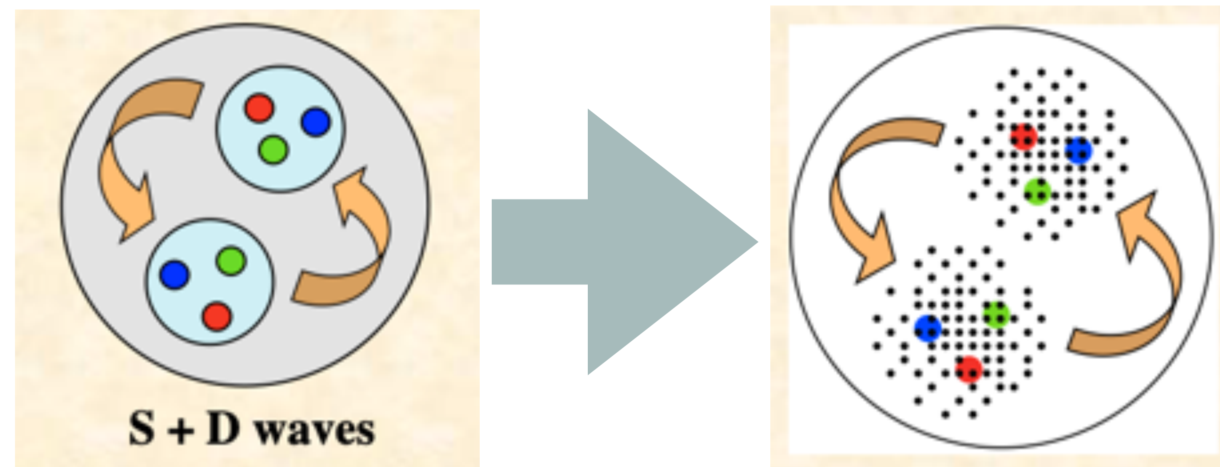
$$C: \quad h_1^{\perp g} \otimes h_1^{\perp g}.$$



UNPOLARIZED GLUONS IN DEUTERON AT HIGH x



S. Kumano



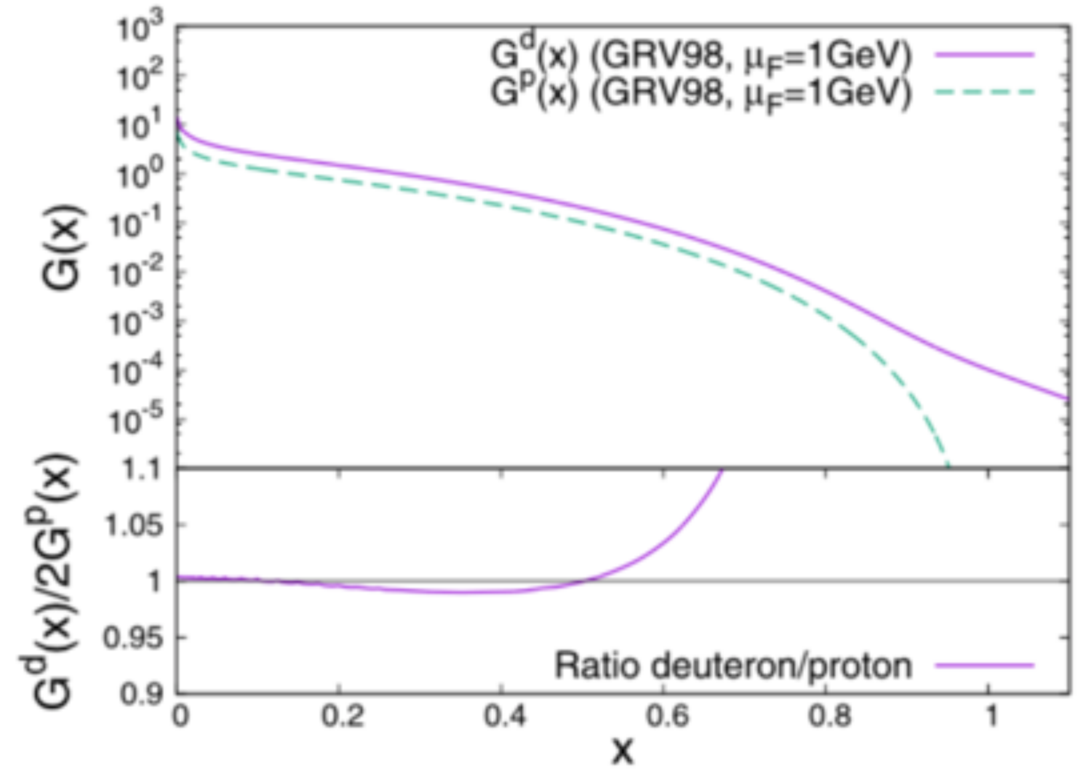


Fig. 6. Gluon PDF in the deuteron and in the nucleon.

$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + c_3|CC\rangle$$

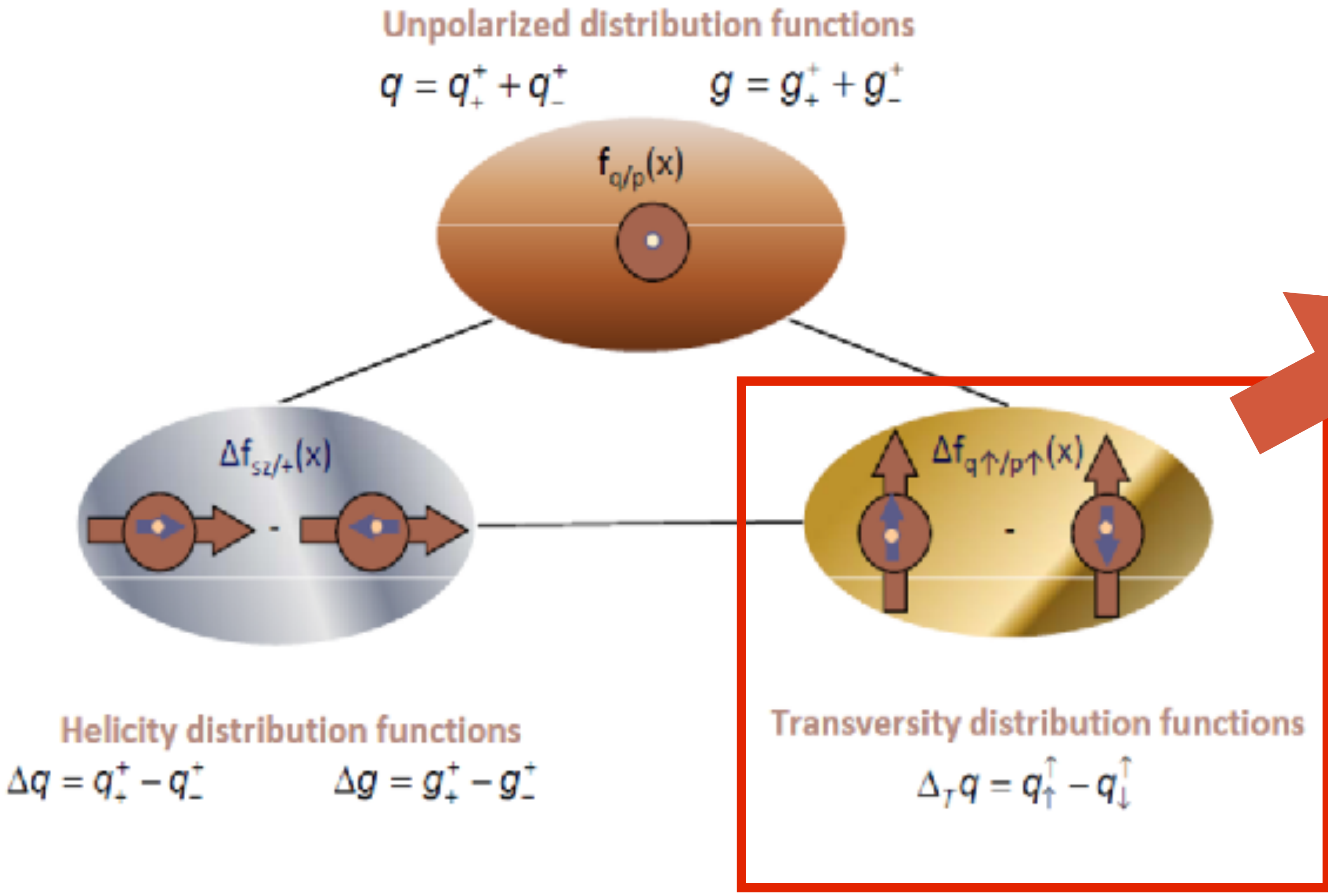
hidden color

up to 90% at some models!

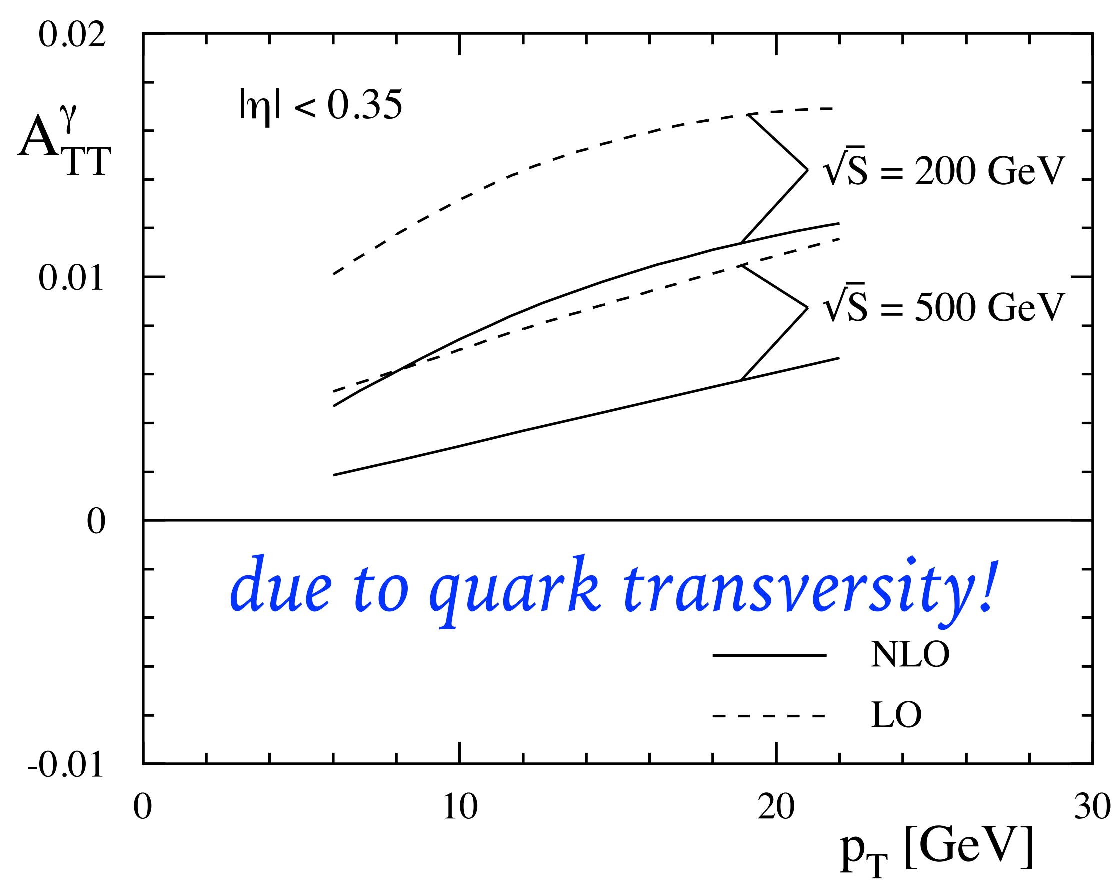
G. A. Miller, Phys.Rev. C89 (2014) no.4, 045203

Phys.Lett. B783 (2018) 287-293

GLUON TRANSVERSITY $\Delta g_T(x)$ IN DEUTERON



Transversity function is related to spin-flip amplitude but $\Delta s=2$ is impossible in LO for spin-1/2 hadron.

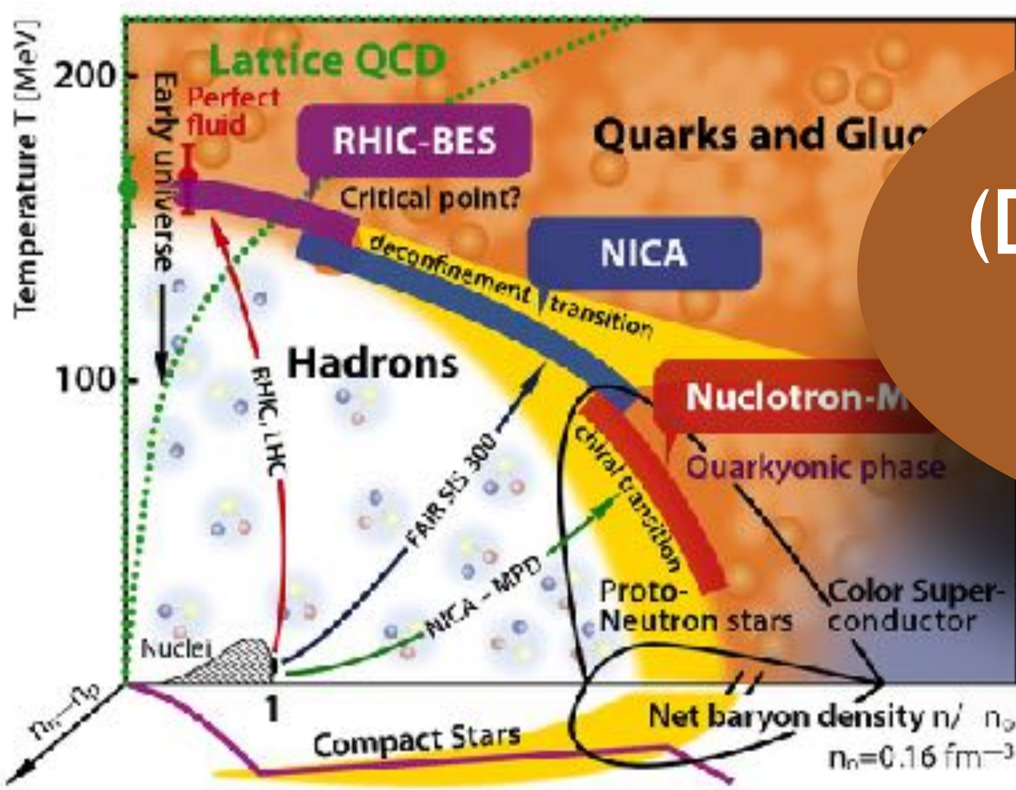


But it nonzero gluon transversity is possible already in LO in deuteron due to non-nucleonic gluon component! It could be accessed via double transverse spin asymmetry!

COMPLEMENTARITY OF STUDIES AT SPD AND MPD AT NICA

Partonic structure of deuteron − Partonic structure of nucleon = Non-baryonic matter in deuteron **SPD**

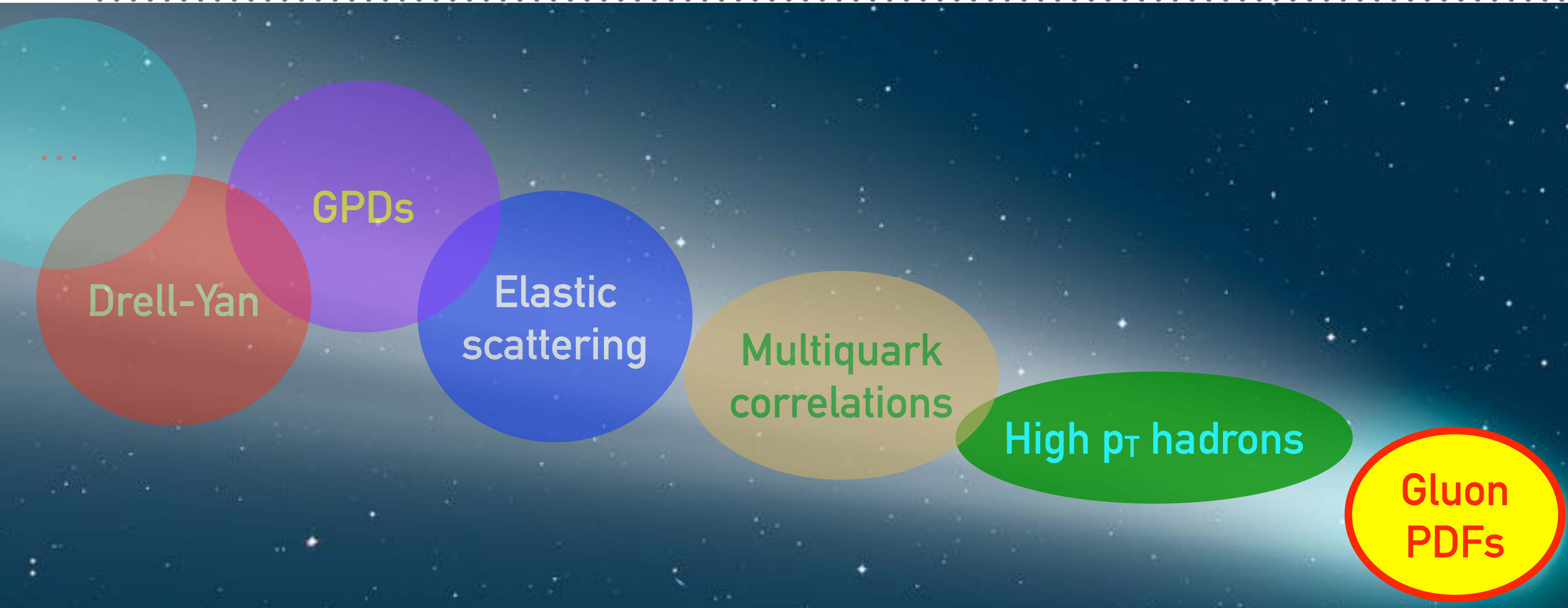
(De)confinement, mixed phase **MPD**



SUMMARY

Physics goal	Observable	Experimental conditions
Gluon helicity $\Delta g(x)$	A_{LL} asymmetries	p_L-p_L, $\sqrt{s}$ =27 GeV
Gluon Sivers PDF $\Delta_N^g(x, k_T)$, Gluon Boer-Mulders PDF $h_1^{\perp g}(x, k_T)$ TMD-factorization test	A_N asymmetries, Azimuthal asymmetries Diff. cross sections, A_N asymmetries	p_T-p, $\sqrt{s}$ =27 GeV p-p, $\sqrt{s}$ =27 GeV p_T-p, energy scan
Unpolarized gluon density $g(x)$ in deuteron Unpolarized gluon density $g(x)$ in proton	Differential cross sections	d-d, p-p, $\sqrt{s_{NN}}$ = 13.5 GeV p-p, $\sqrt{s} \leq$ 20 GeV
Gluon transversity $\Delta g_T(x)$	A_{TT} asymmetries	d_T-d_T, $\sqrt{s_{NN}}$ = 13.5 GeV

SUMMARY: SPD PHYSICS PROGRAM



The SPD Conceptual Design Report should be ready till the end of the year

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SUMMARY

- The **Spin Physics Detector** at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized **gluon content of proton and deuteron**; in polarized high-luminosity **p-p** and **d-d** collisions at $\sqrt{s} \leq 27\ GeV$
- Complementing main probes such as **charmonia** (J/ψ and higher states), **open charm** and **prompt photons** will be used for that;
- SPD can contribute significantly to investigation of
  - gluon helicity;
  - gluon-induced TMD effects (Sivers and Boer-Mulders);
  - unpolarized gluon PDFs at high-x in proton and deuteron;
  - gluon transversity in deuteron.
  - … **something else, please, propose!**
- **The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC, AFTER, EIC) and mesons (COMPASS++/AMBER, EIC).**

REVIEW PAPER IS IN PREPARATION

On the physics potential to study the gluon content of proton and deuteron at NICA SPD

list of authors and contributers

Abstract

The Spin Physics Detector at the future NICA collider at JINR (Dubna, Russia) aims for investigate the nucleon spin structure in collisions of longitudinally and transversely polarized protons and deuterons at $\sqrt{s}$ up to 27 GeV and luminosity up to 10^{32} cm^{-2} s^{-1}. It will operate as a universal facility for comprehensive study of unpolarized and polarized gluon content in the proton and deuteron. Such complementing probes as charmonia, open charm and prompt-photon production processes will be used for that. Possible physics tasks such as the access to the gluon helicity, gluon Sivers and Boer-Mulders function and gluon transversity in the deuteron via the measurement of single and double spin asymmetries and other gluon-related tasks will be discussed.

Welcome to participate!