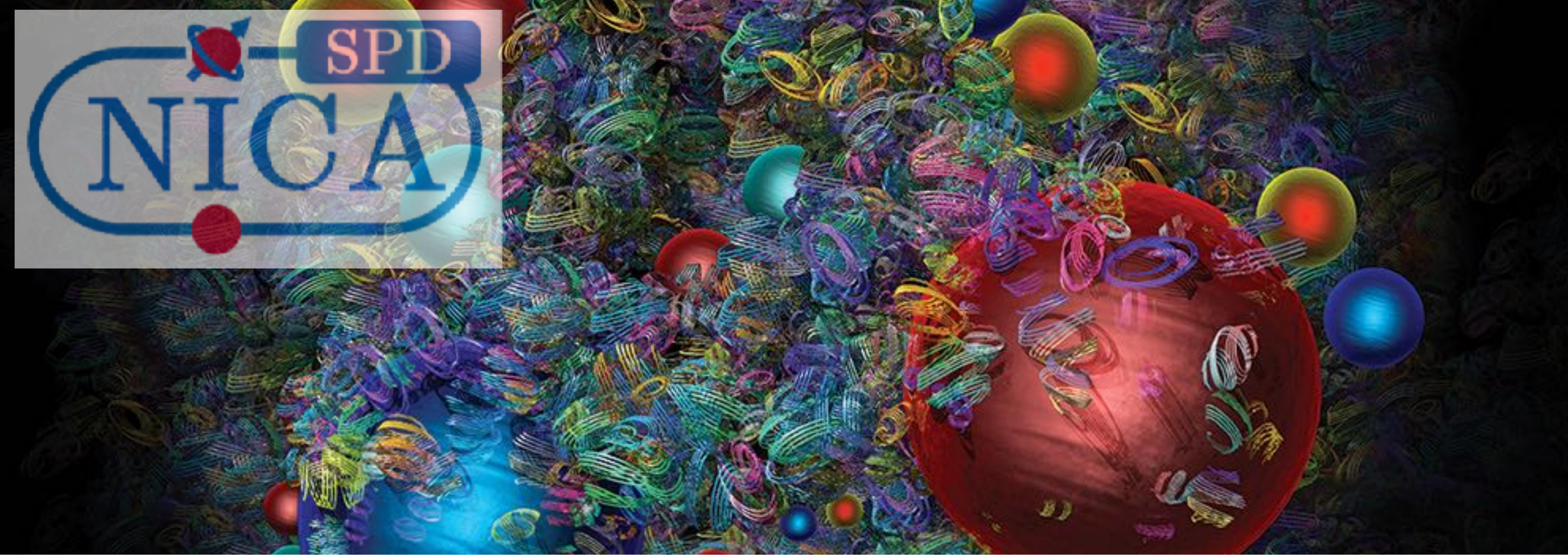


OVERVIEW OF THE SPD GLUON PROGRAM

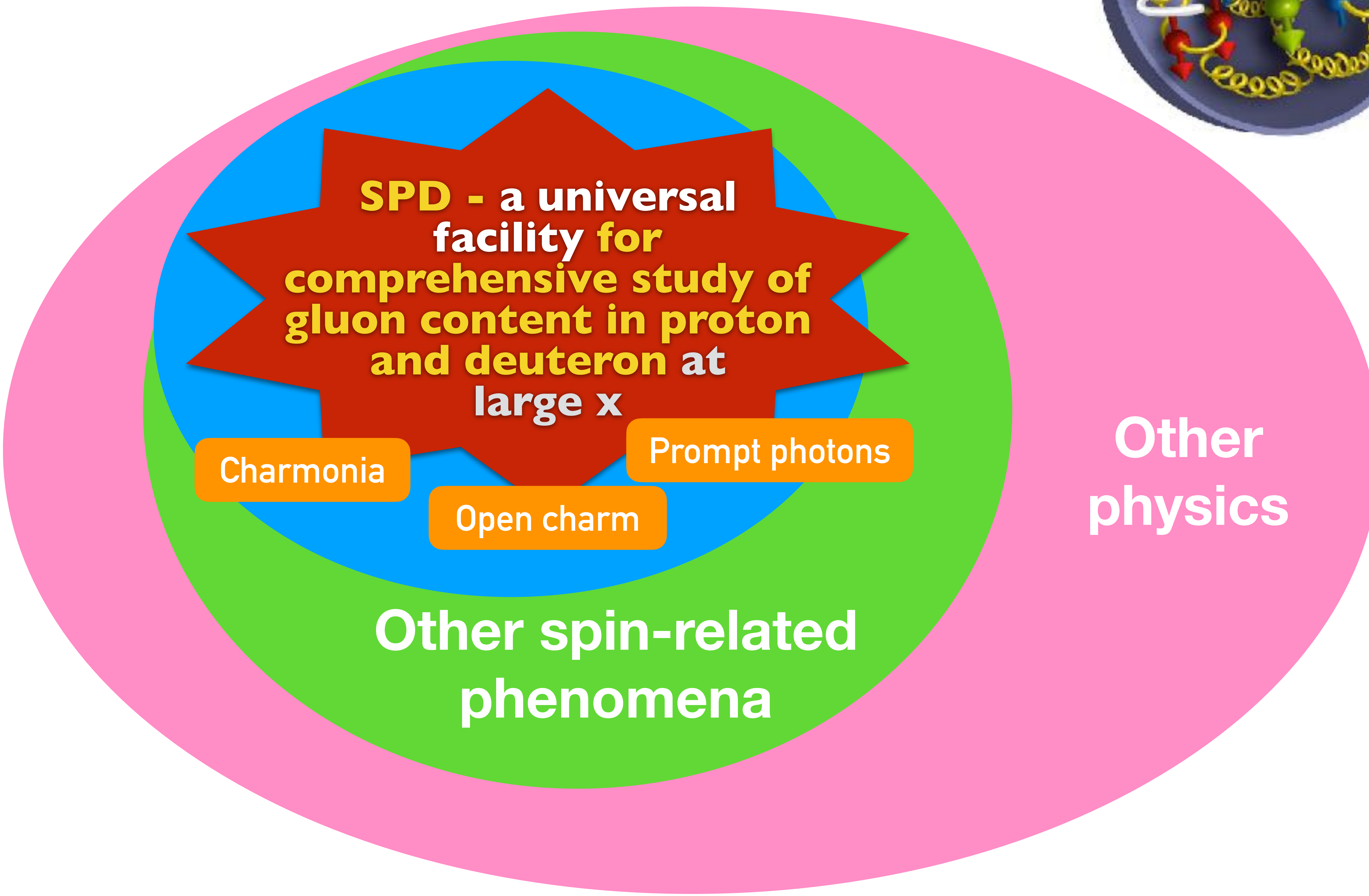
Alexey Guskov, JINR

Alexey.Guskov@cern.ch

9.6.2021

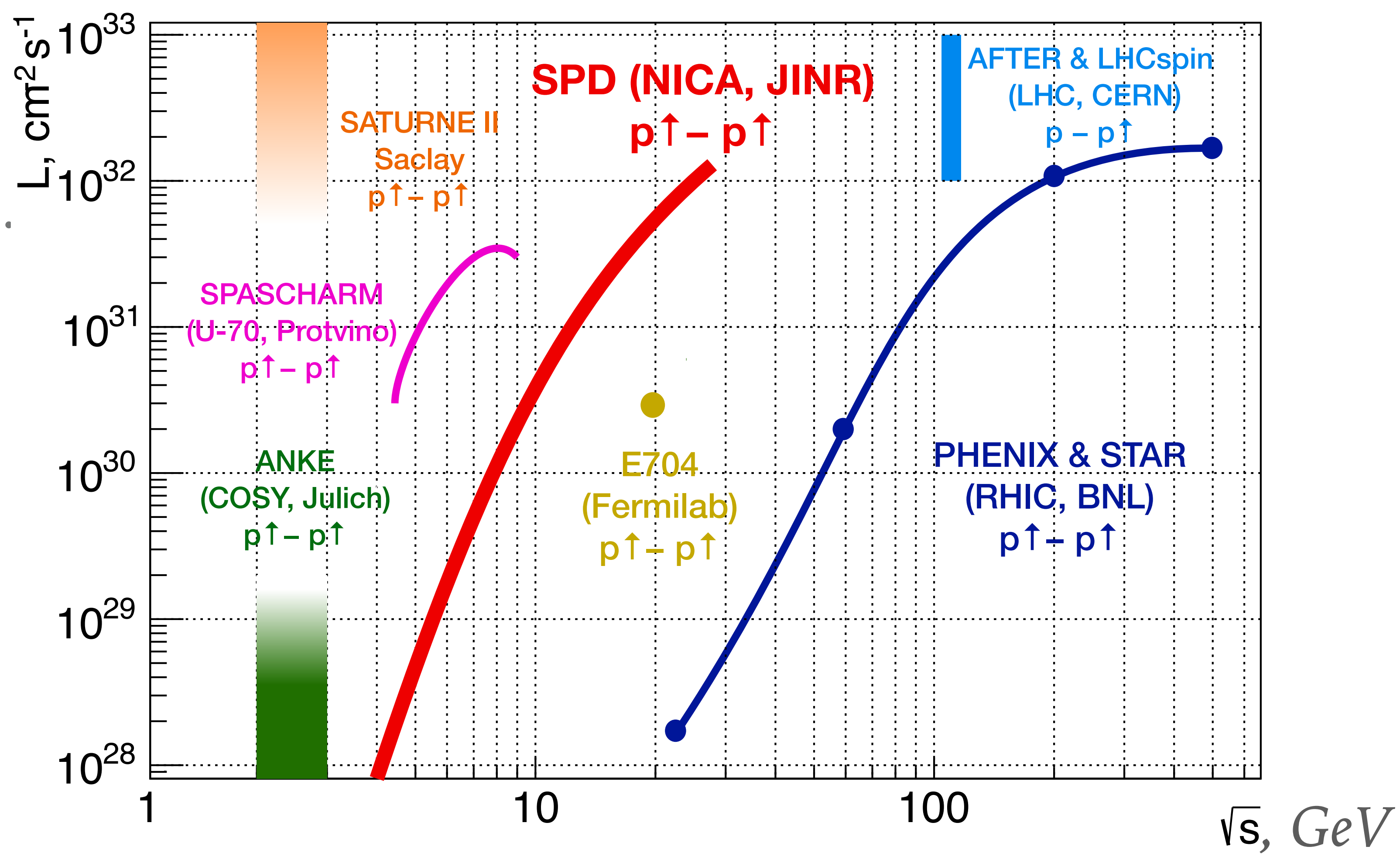

SPD

CONCEPT OF THE SPD PHYSICS PROGRAM



SPD – VS OTHERS

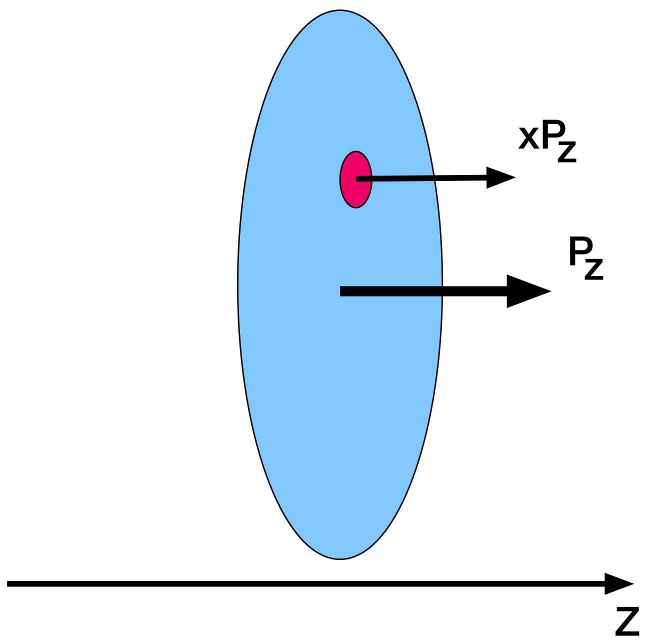
In the $p^{\uparrow}p^{\uparrow}$ mode:



Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^{\uparrow}$-$p^{\uparrow}$ $d^{\uparrow}$-$d^{\uparrow}$ $p^{\uparrow}$-d, p-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, $^3He^{\uparrow}$	p-$p^{\uparrow}$, $d^{\uparrow}$	p-$p^{\uparrow}$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	≤27 (p-p) ≤13.5 (d-d) ≤19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	~1 (p-p) ~0.1 (d-d)	2	1000	up to ~10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025

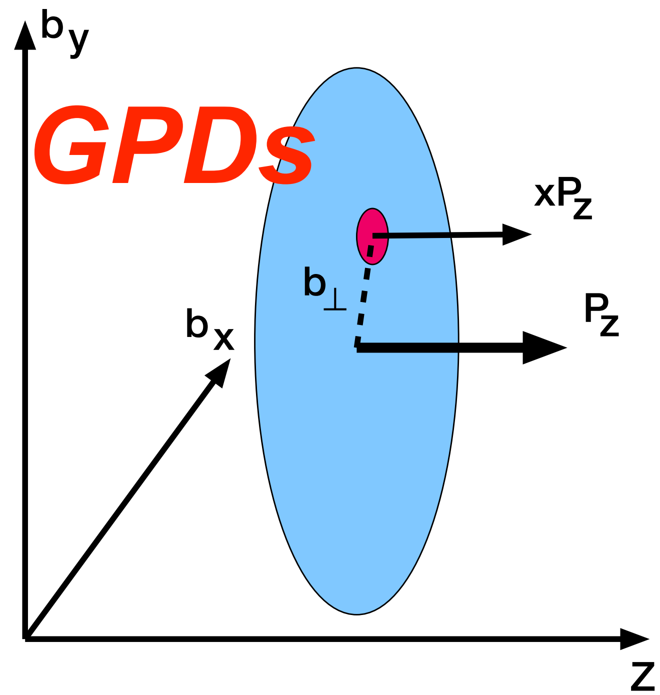
In the $d^{\uparrow}d^{\uparrow}$ mode we are unique

3D STRUCTURE OF THE PROTON

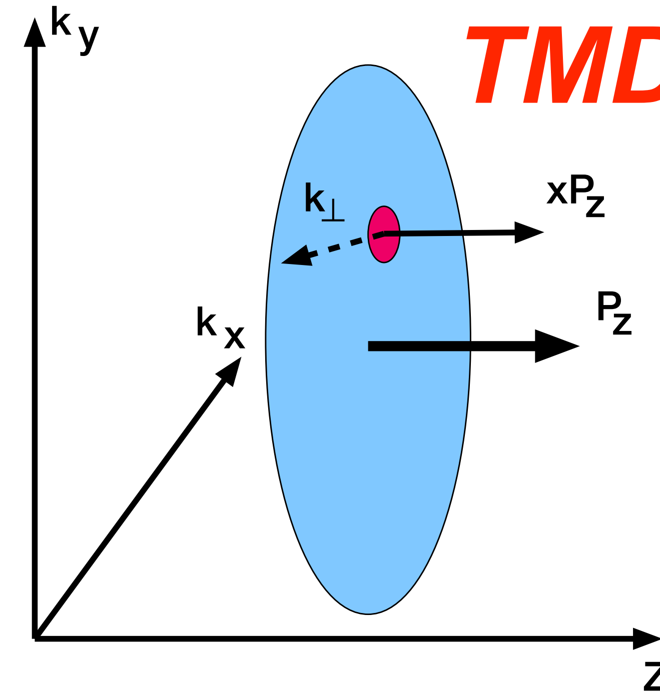


Collinear approximation

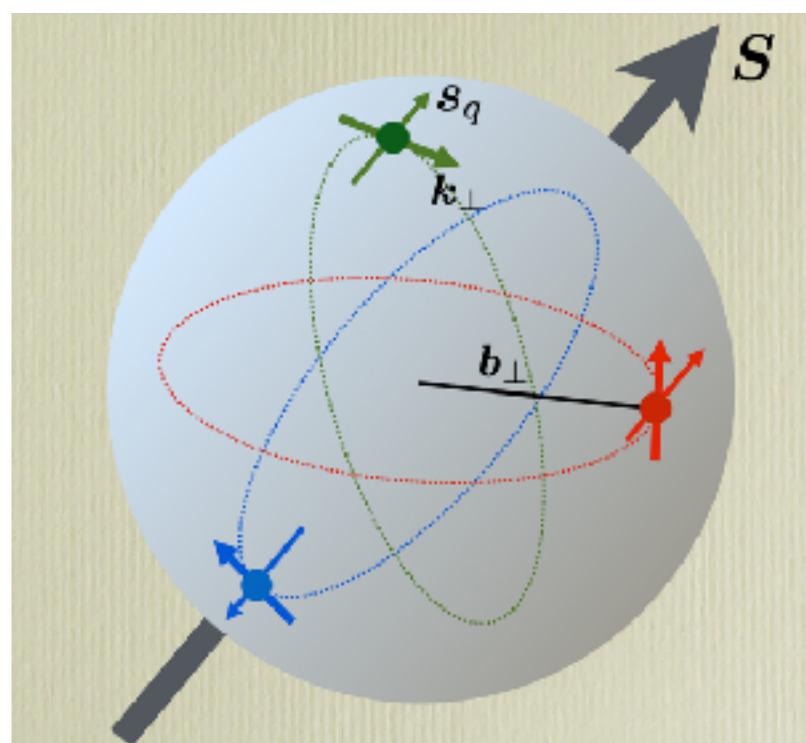
(common PDF)



Generalized Parton Distributions



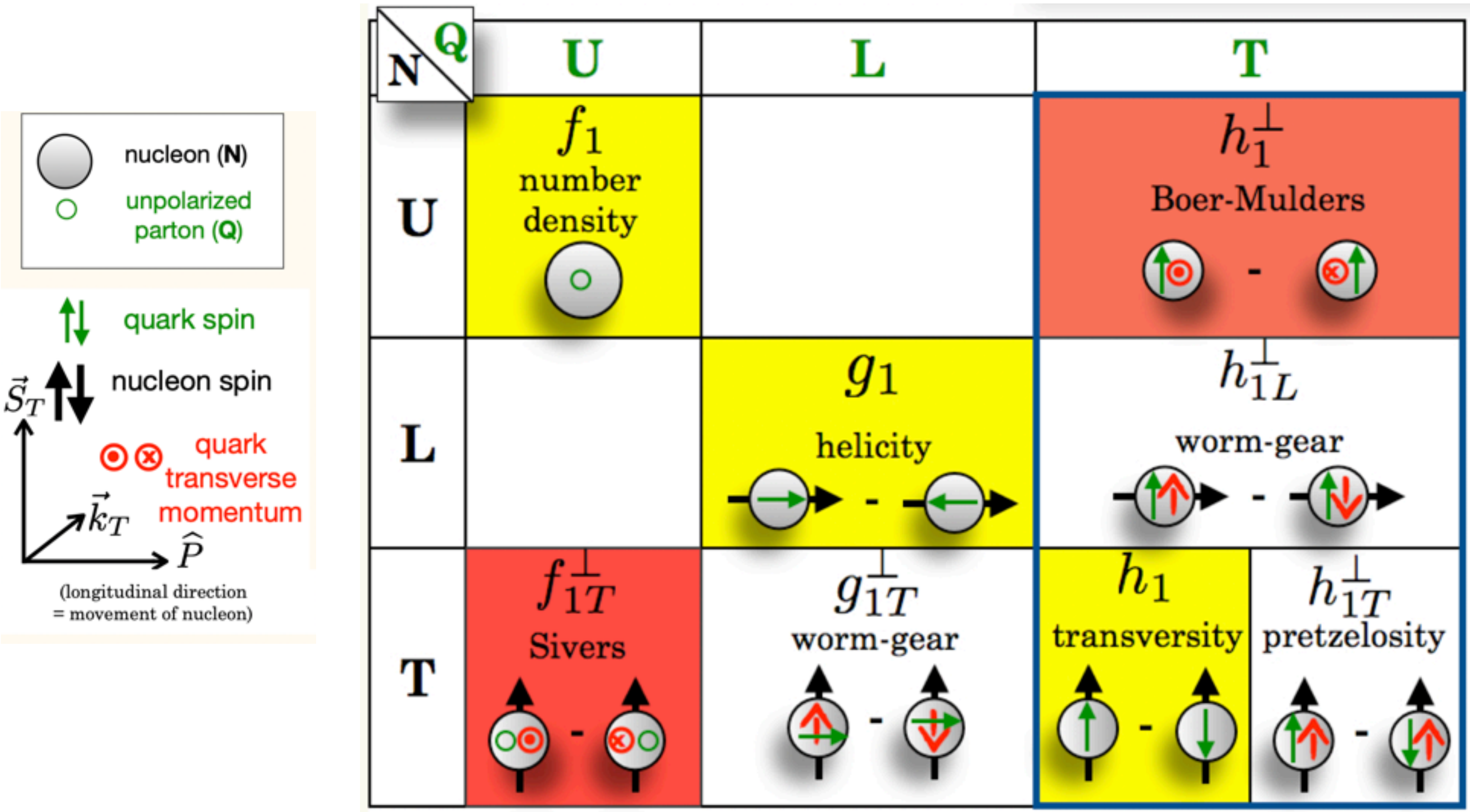
Transverse Momentum Dependent PDFs



3D structure of nucleon

connection to orbital moment

TMD PDFS



nucleon (N)
unpolarized parton (Q)
quark spin
nucleon spin
$\vec{S}_T$
quark transverse momentum
$\vec{k}_T$
$\widehat{P}$
(longitudinal direction = movement of nucleon)
N
Q
U
L
T
U
L
T
f_1
number density
$h_1^\perp$
Boer-Mulders
g_1
helicity
$h_{1L}^\perp$
worm-gear
$f_{1T}^\perp$
Sivers
$g_{1T}^\perp$
worm-gear
h_1
transversity
$h_{1T}^\perp$
pretzelosity

GLUON PDFs at SPD

arXiv:2011.15005
Prog.Part.Nucl.Phys. 119 (2021) 103858

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, $h_{1T}^{\perp g}$

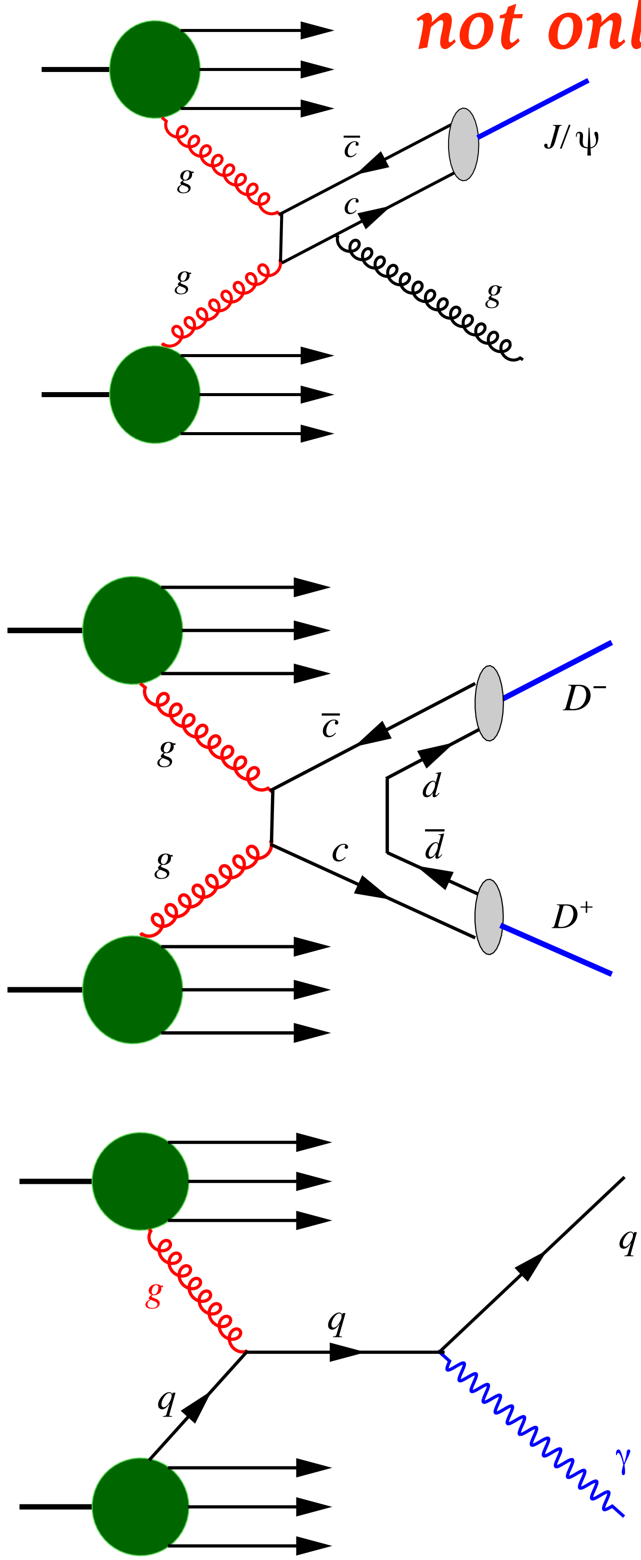
Gluon Sivers function

Gluon transversity in deuteron

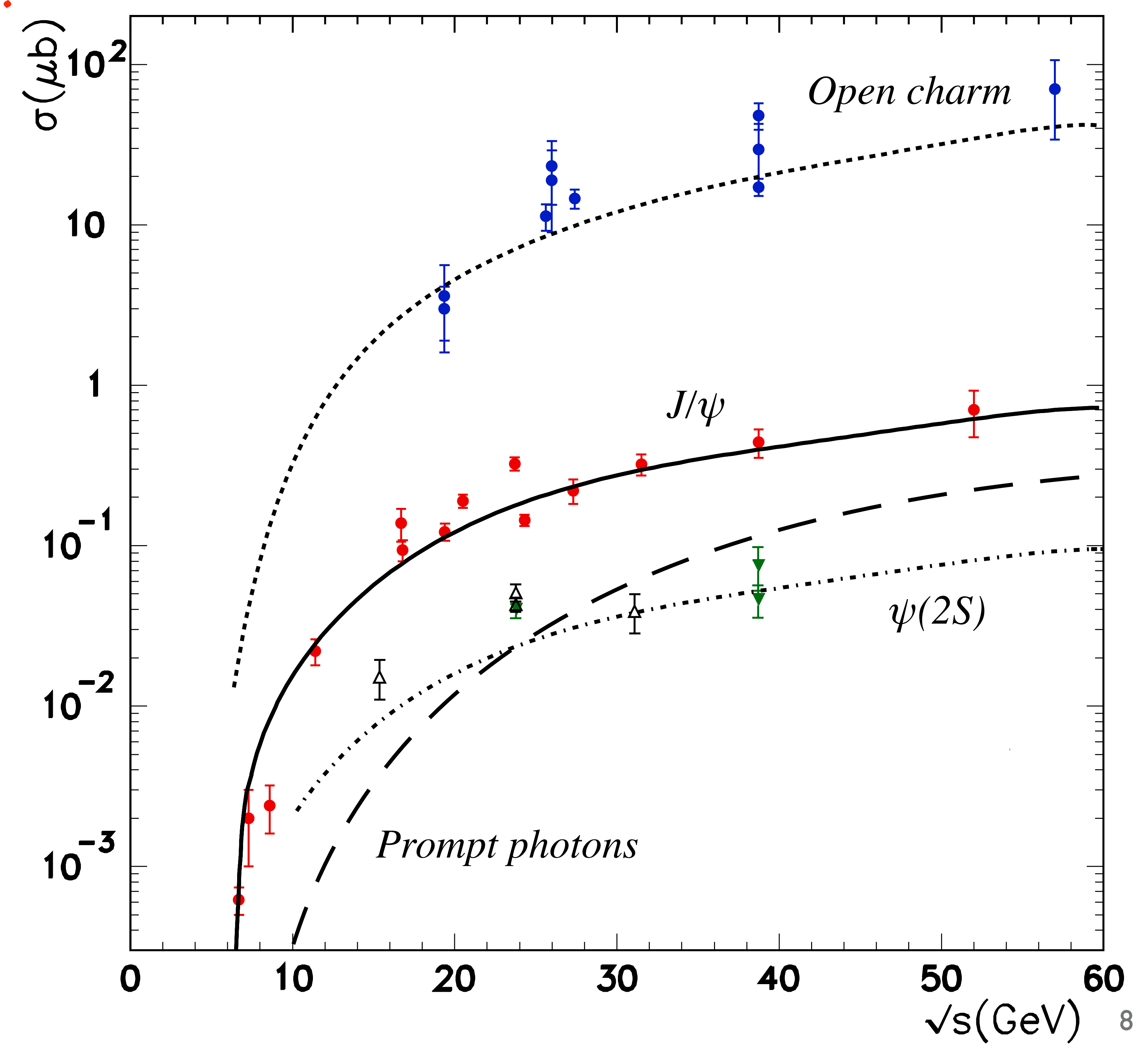
$\sigma(x_F,p_T)$ $A_{LL}(x_F,p_T)$ $A_{TT}(x_F,p_T)$ $A_N(x_F,p_T)$

GLUON PROBES AT SPD

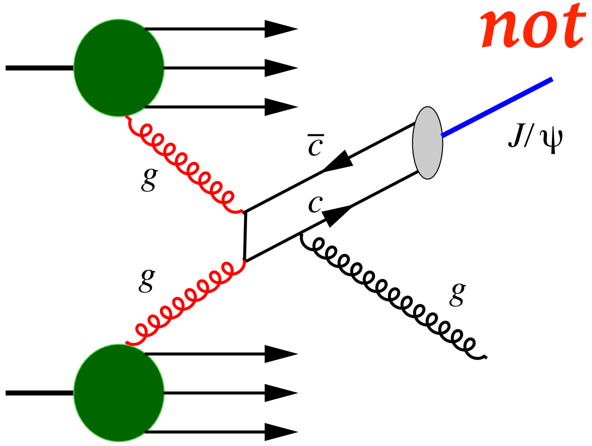
not only J/ψ!



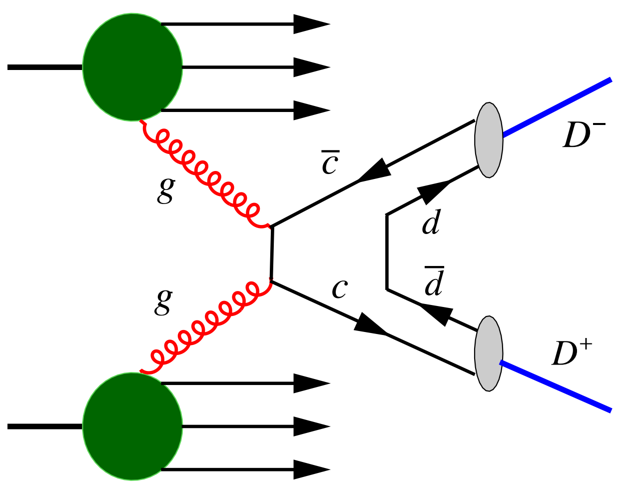
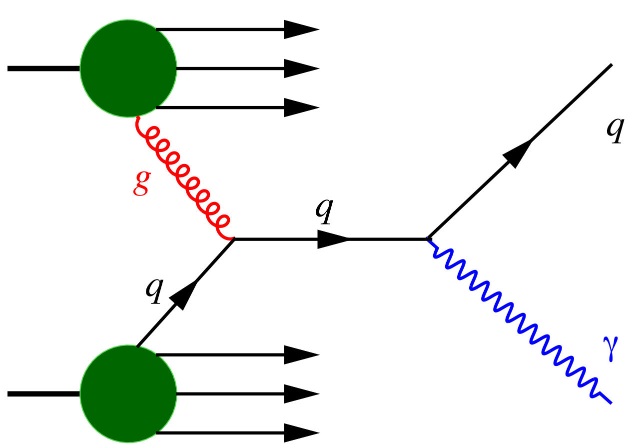
$$\sigma = PDF_1 \otimes PDF_2 \otimes \hat{\sigma}_{12}$$



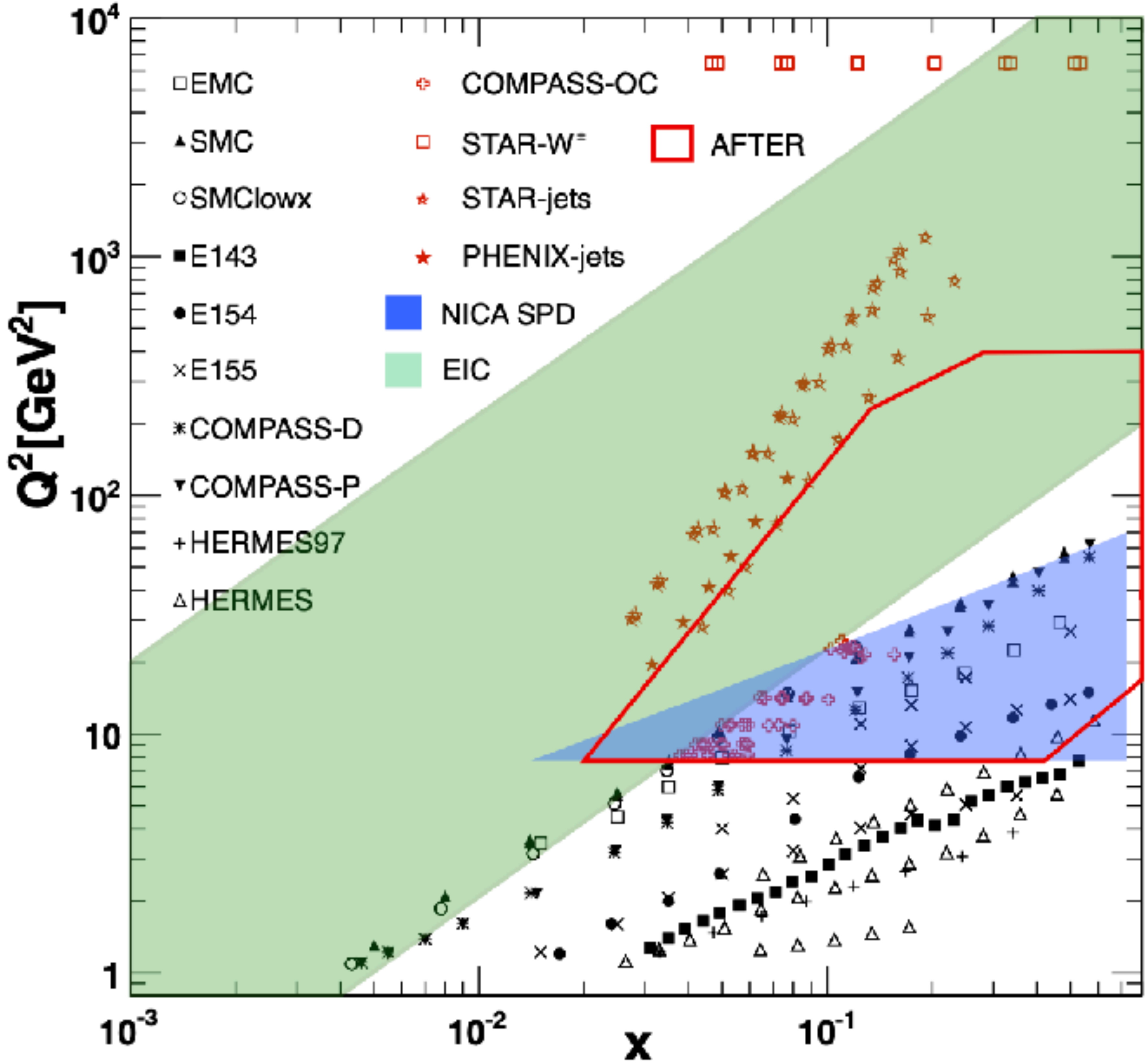
GLUON PROBES AT SPD



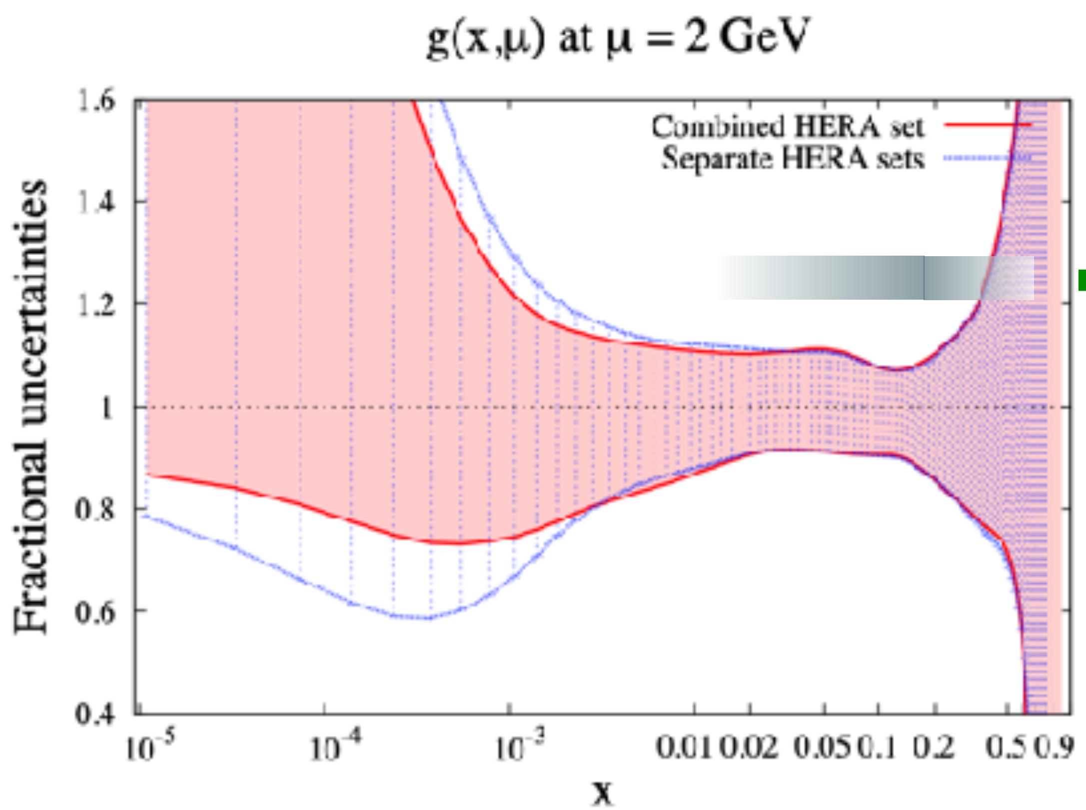
not only J/ψ!

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

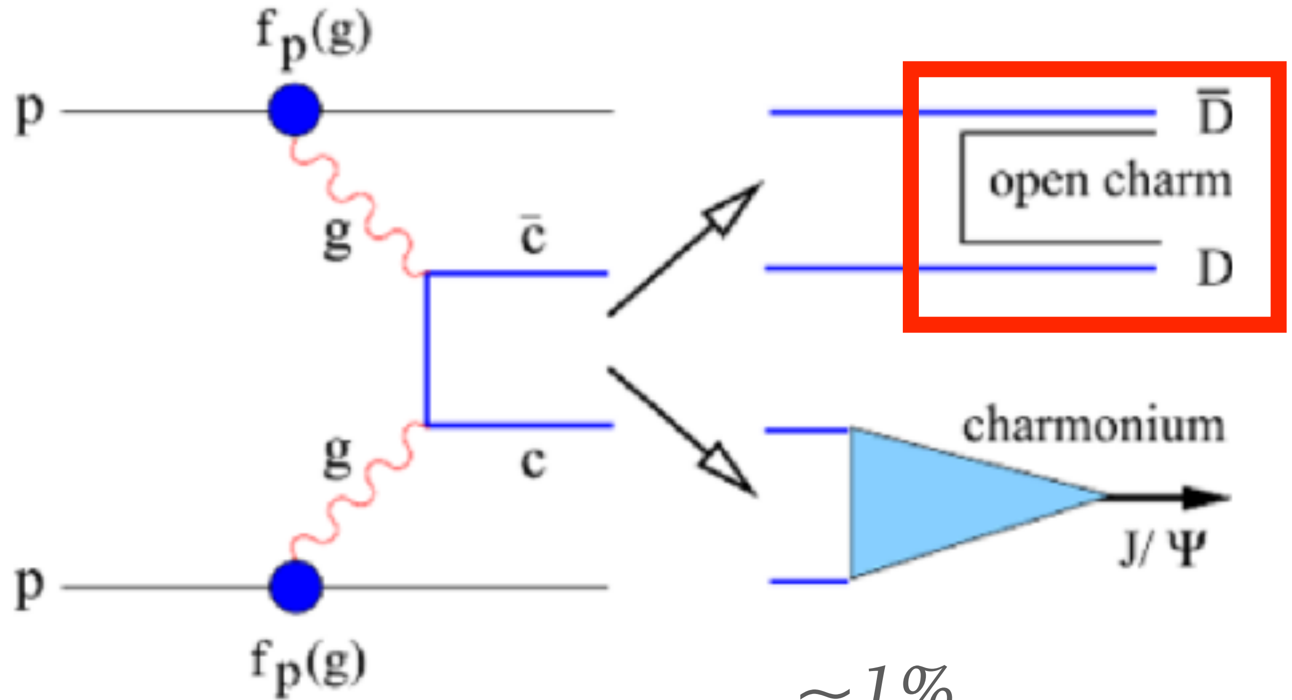
CINEMATIC RANGE



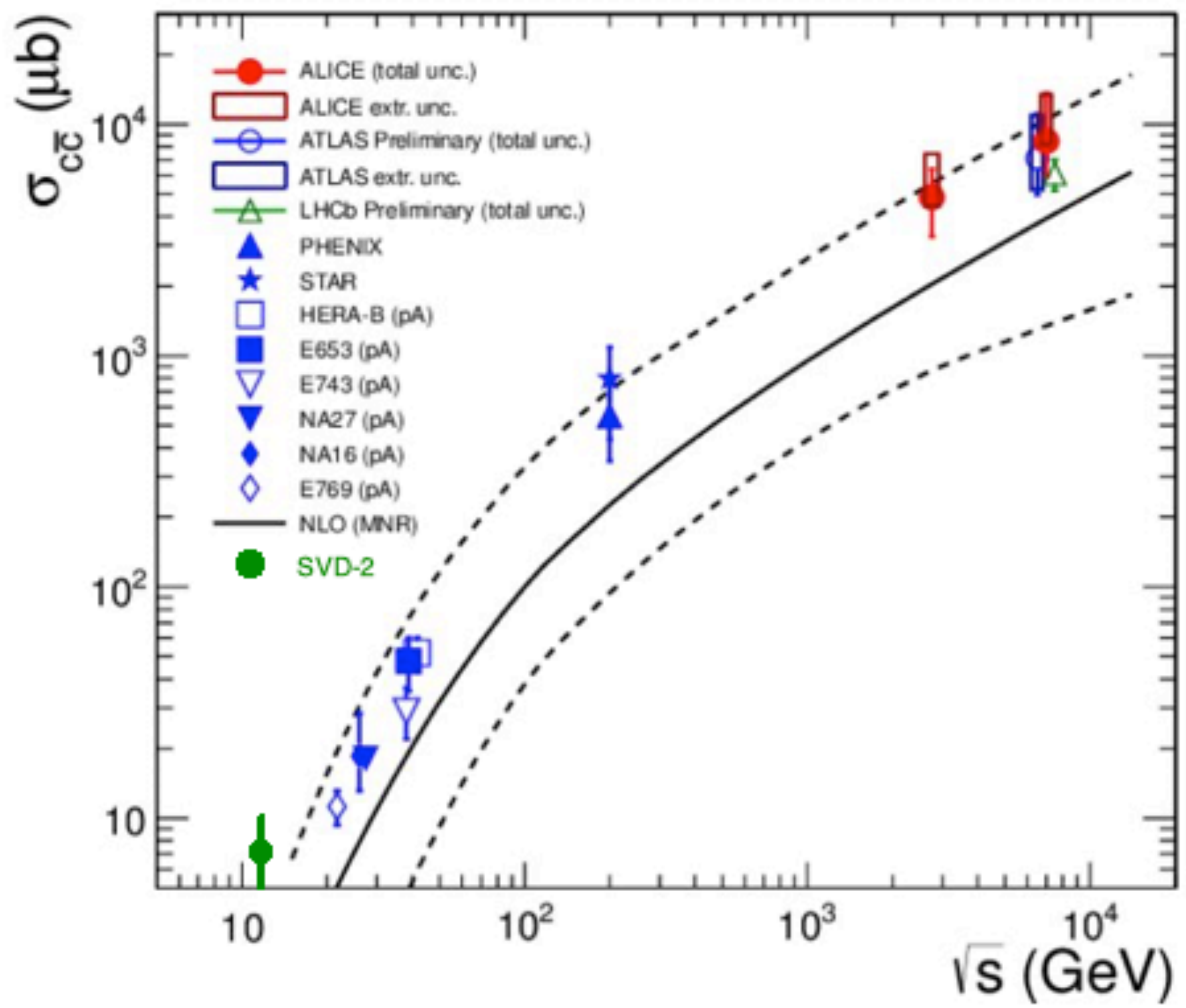
UNPOLARIZED GLUONS IN PROTON AT HIGH x



Good opportunity for SPD

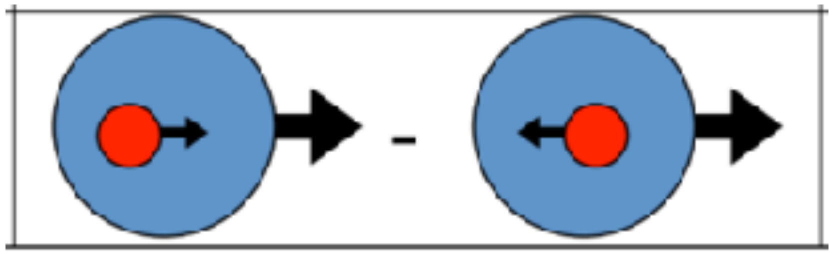


$\sim 1\%$

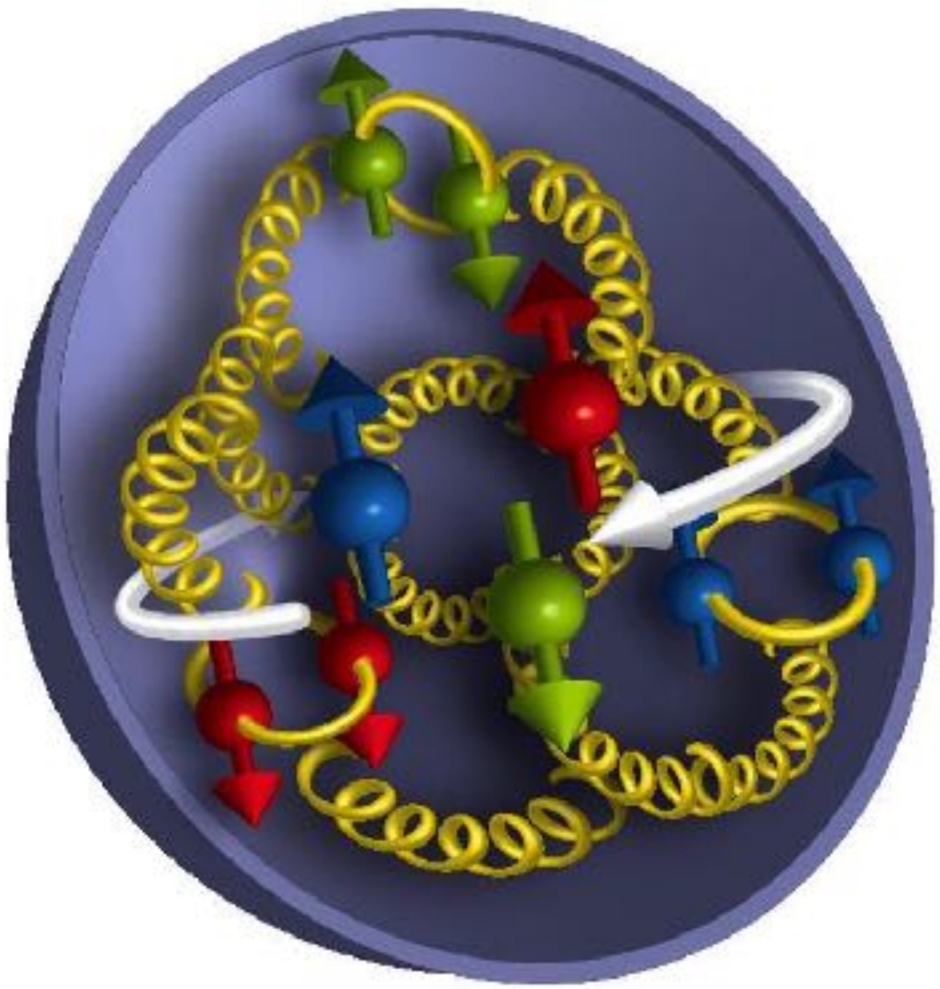


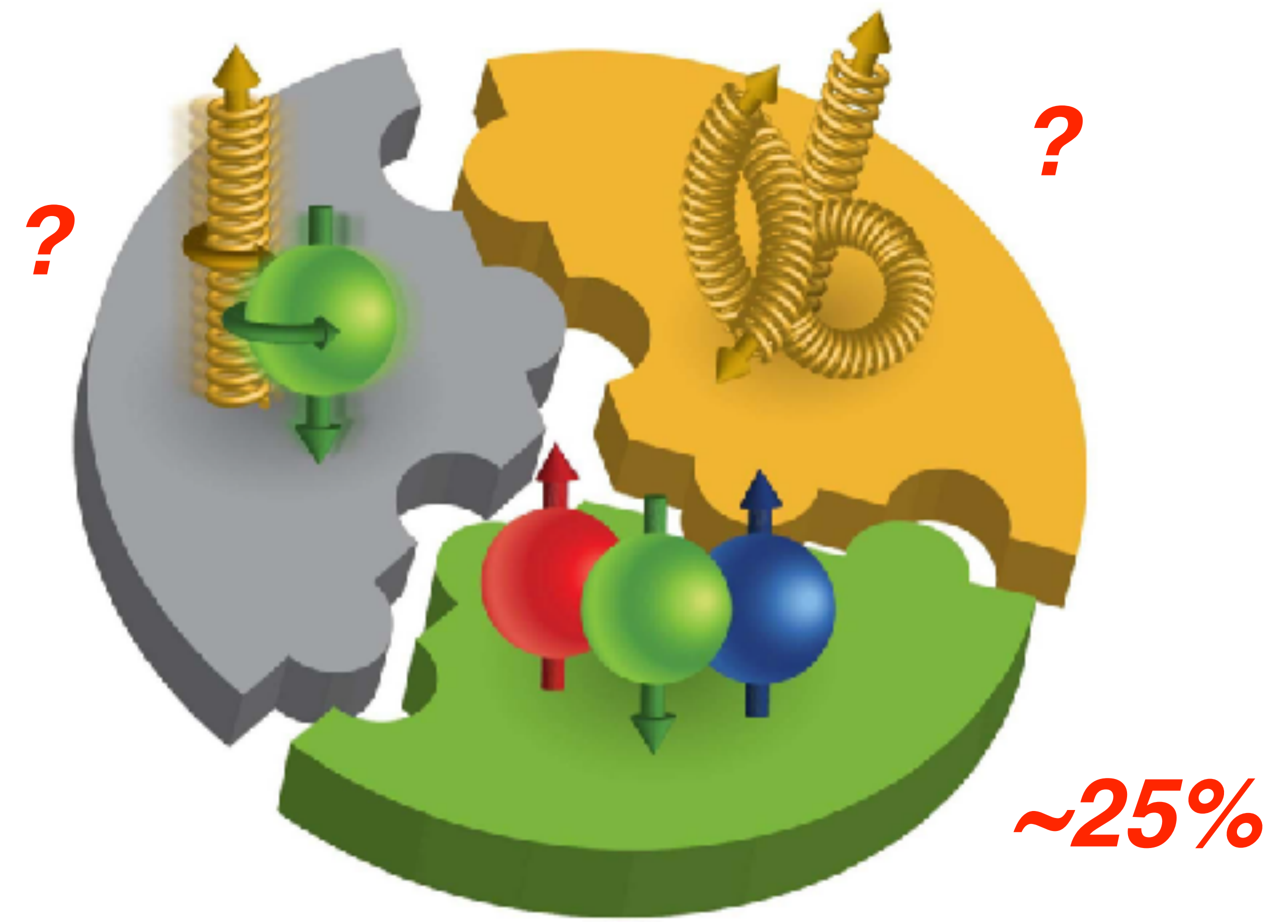
GLUON HELICITY FUNCTION Δg(x) : SPIN CRISIS

Δg(x) :



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



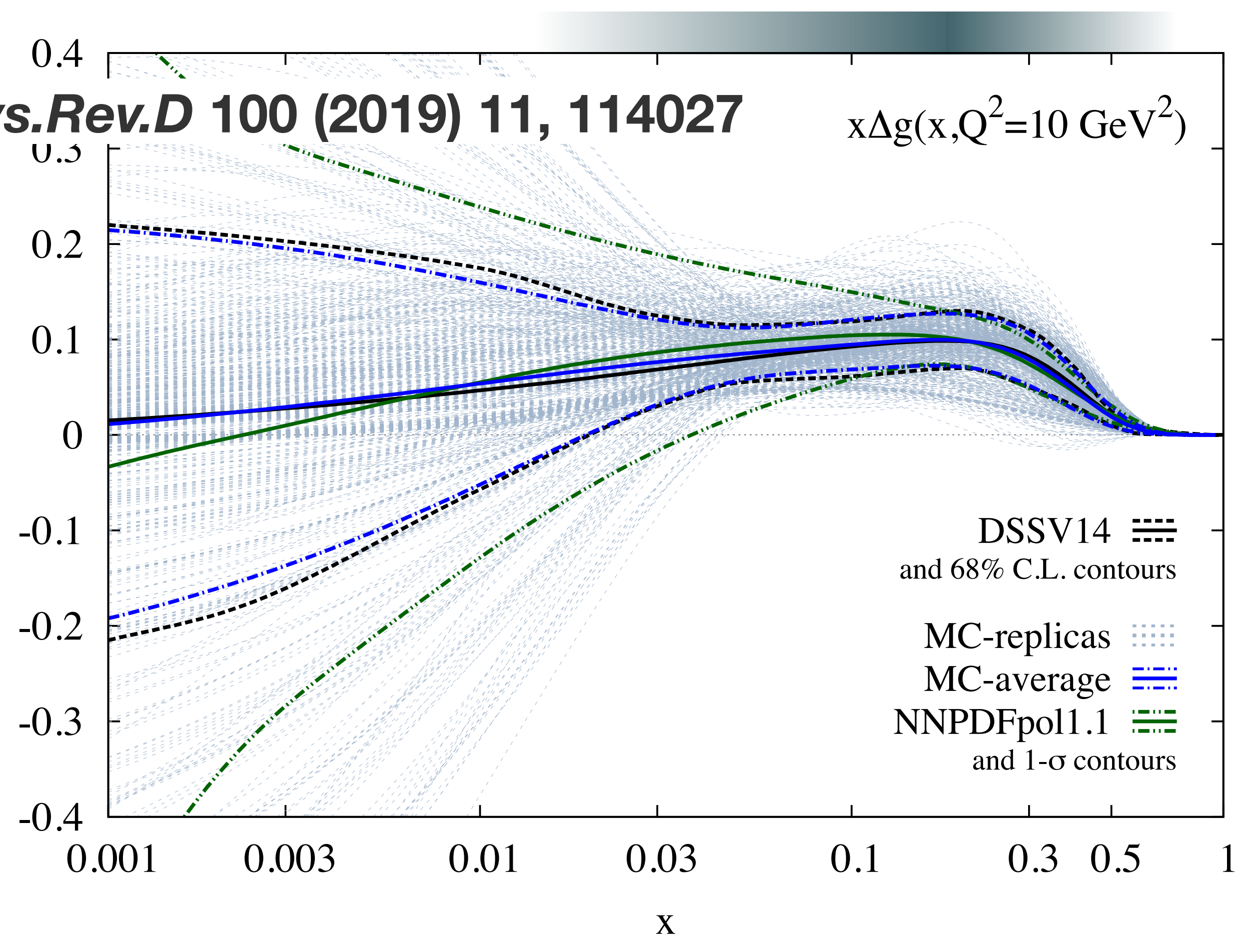


$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

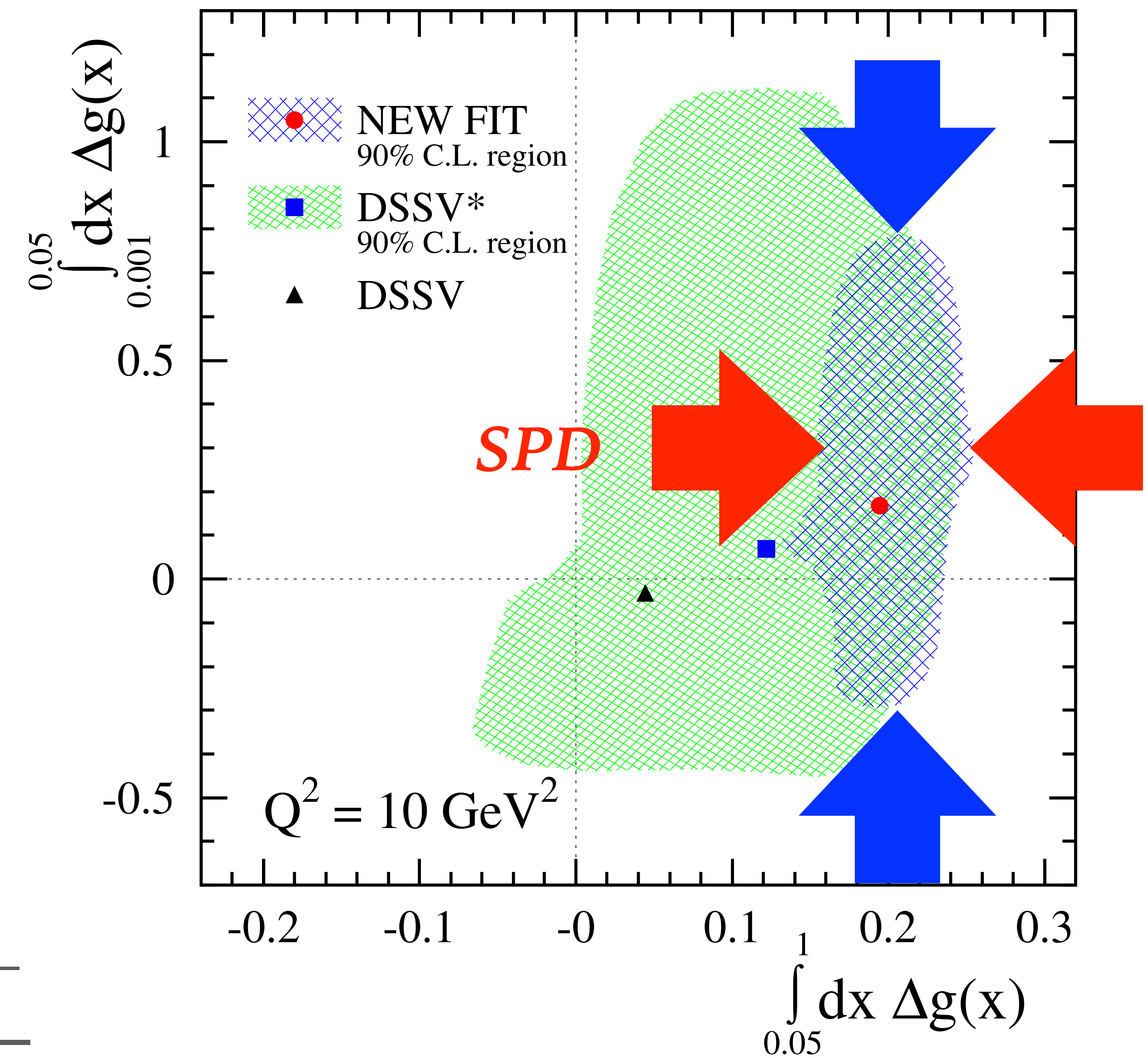
GLUON HELICITY FUNCTION Δg(x)

accessible with SPD

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



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

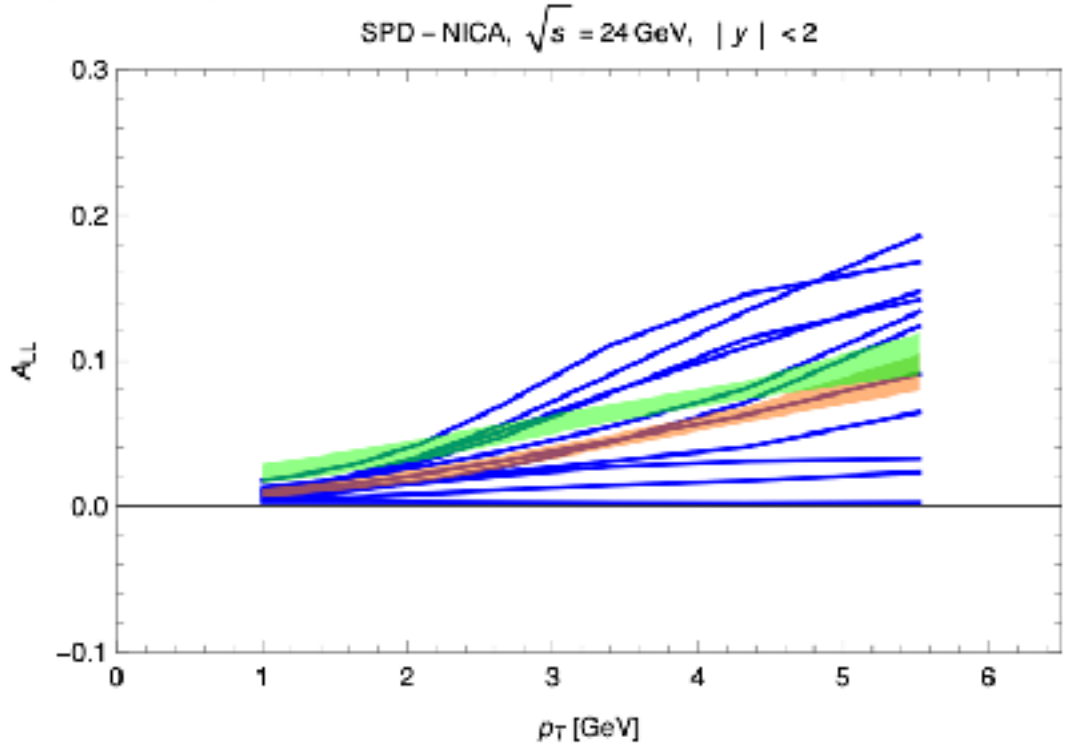


SPD could help to reduce uncertainty of ΔG at large x

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

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

GLUON HELICITY FUNCTION $\Delta g(x)$: EXPECTATIONS FOR A_{LL}



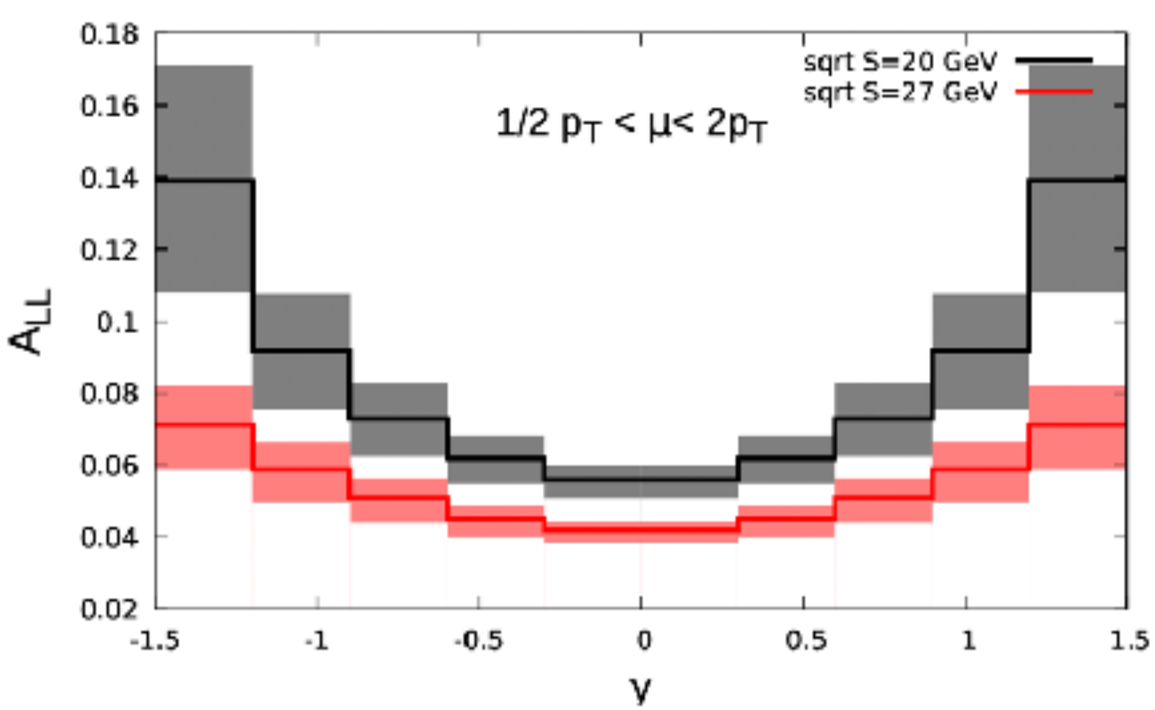
$$gg \to J/\psi g$$

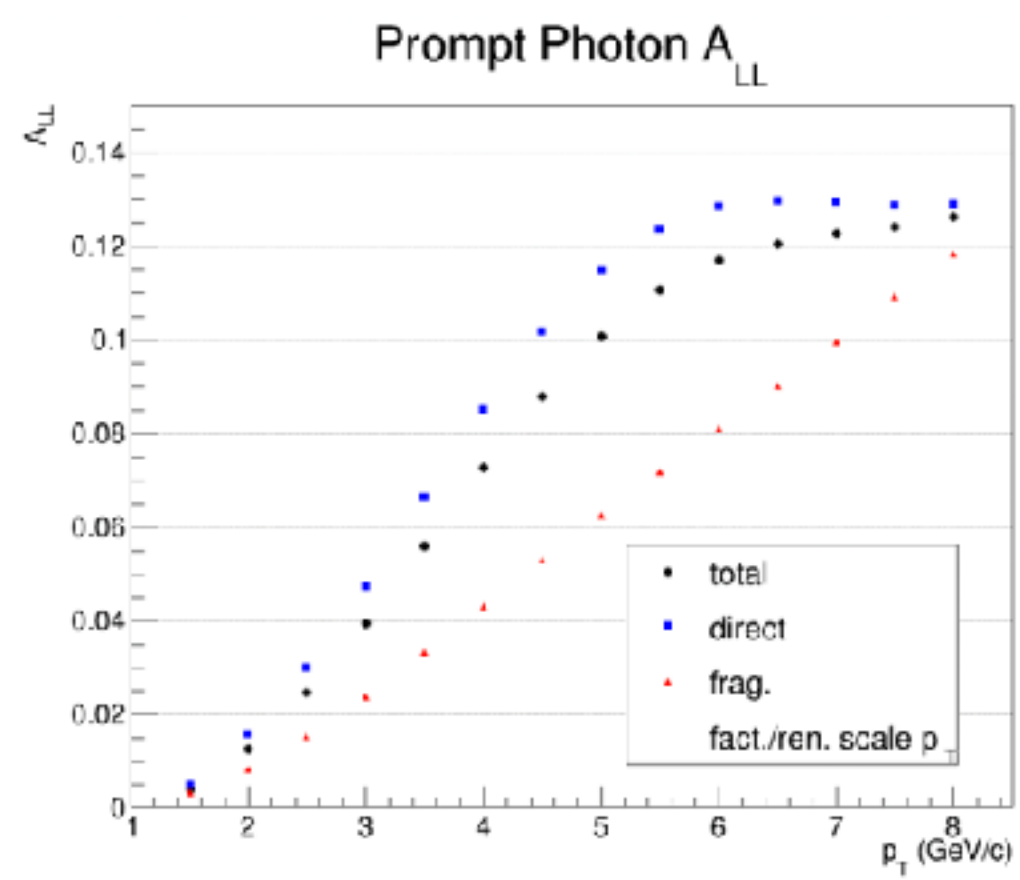
M. Nefedov

W. Vogelsang

$$qg \to q\gamma$$

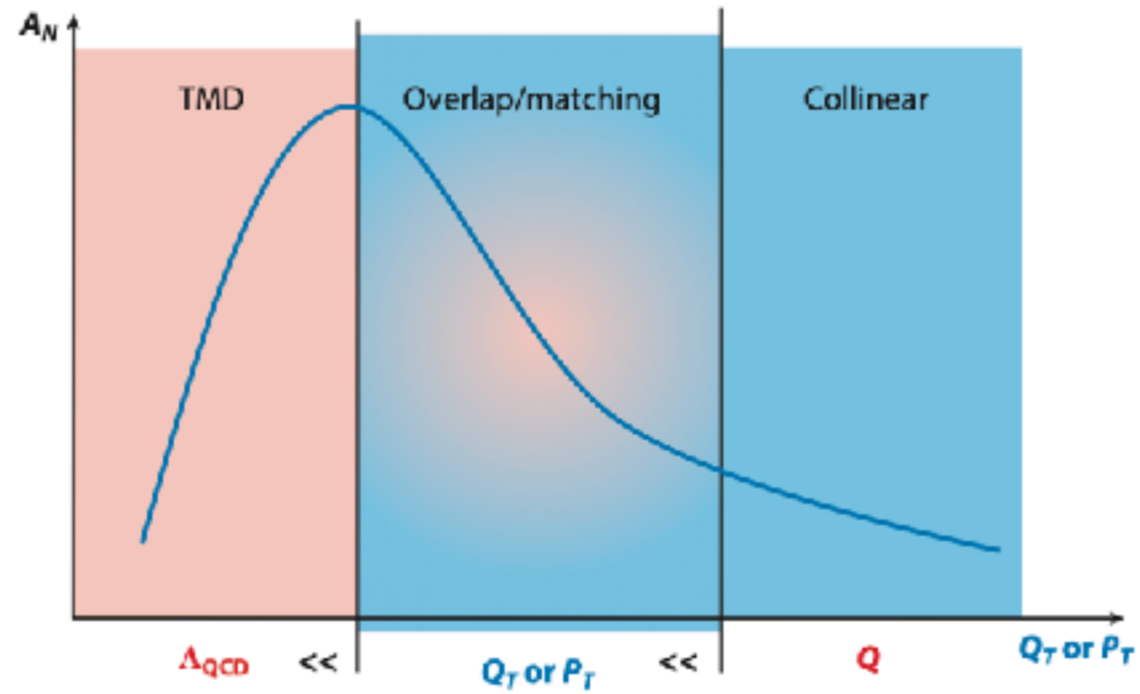
A. Shipilova





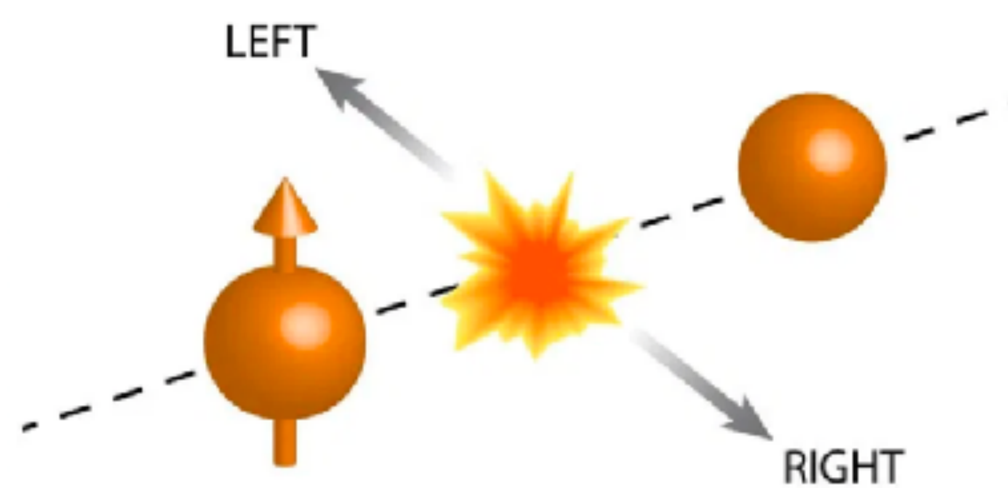
GLUON-INDUCED TMD EFFECTS : GLUON SIVERS FUNCTION $\Delta_N^g(x,k_T)$

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



Different <k_T> for quarks and gluons?

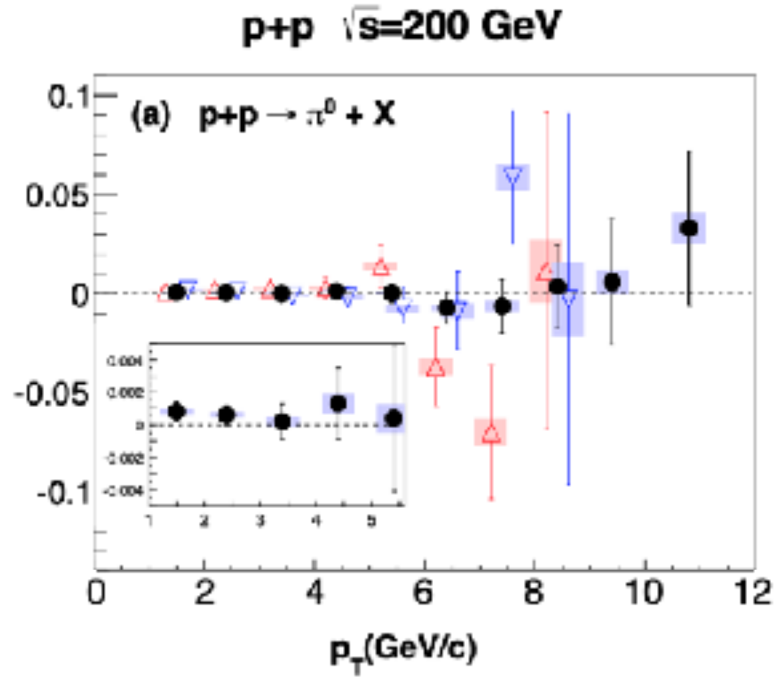
***Sivers effect**: left-right asymmetry of unpolarized k_T distribution in transversely polarized nucleon*



Sivers effect → A_N ← Collins effect

- due to fragmentation of polarized quark

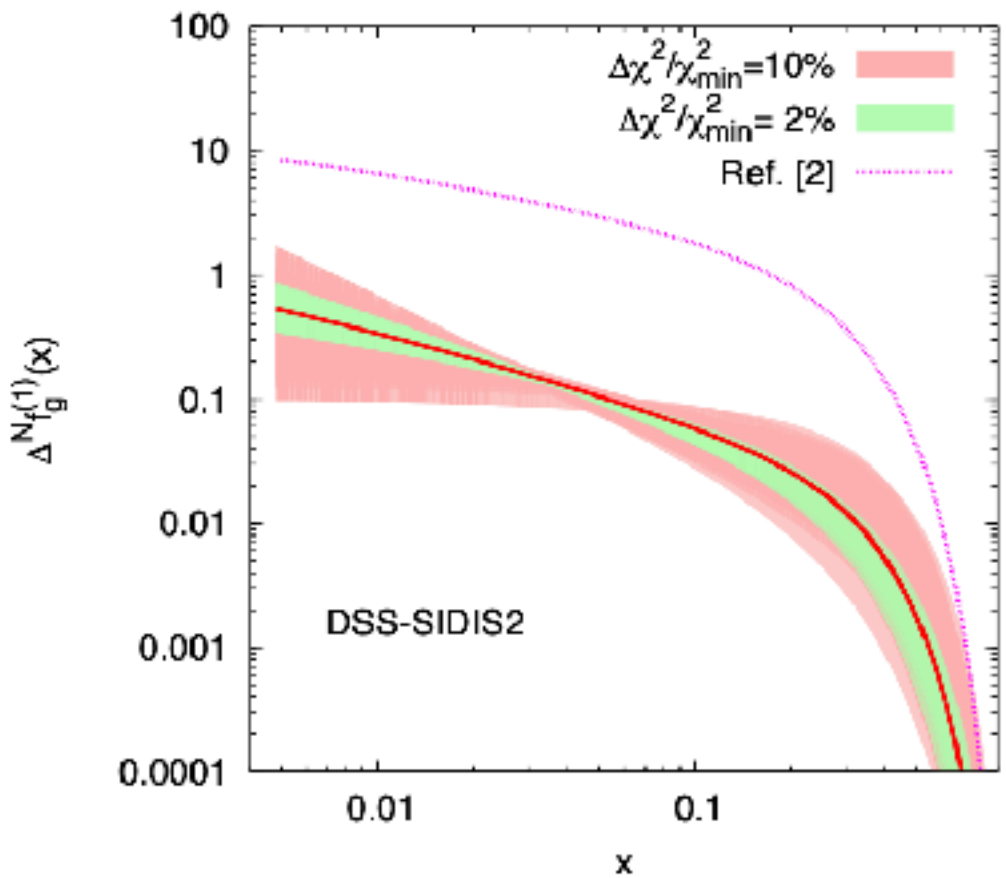
GLUON SIVERS FUNCTION $\Delta^{g}_{N}(x,k_T)$



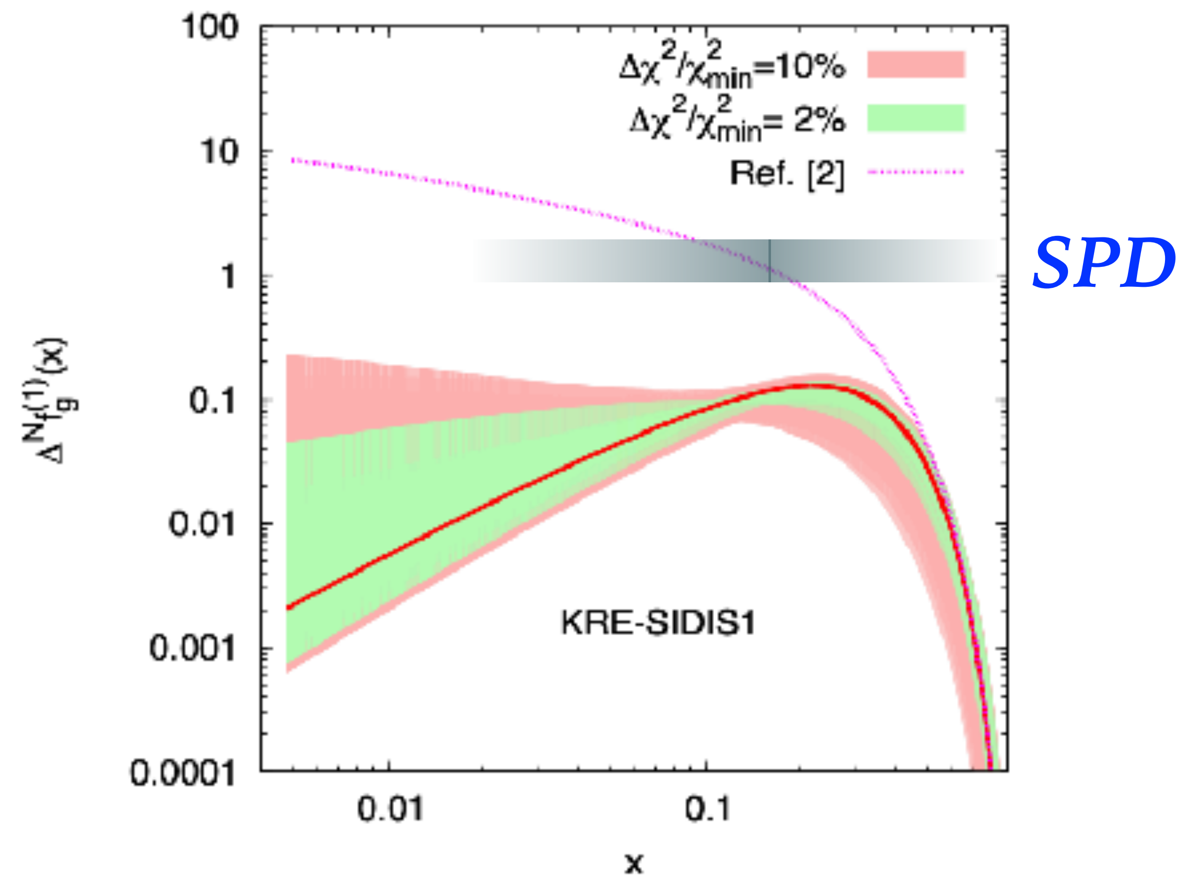
Phys.Rev.D **90 (2014) 1, 012006**

PHENIX

First $k_\perp$-moment of the gluon Sivers function

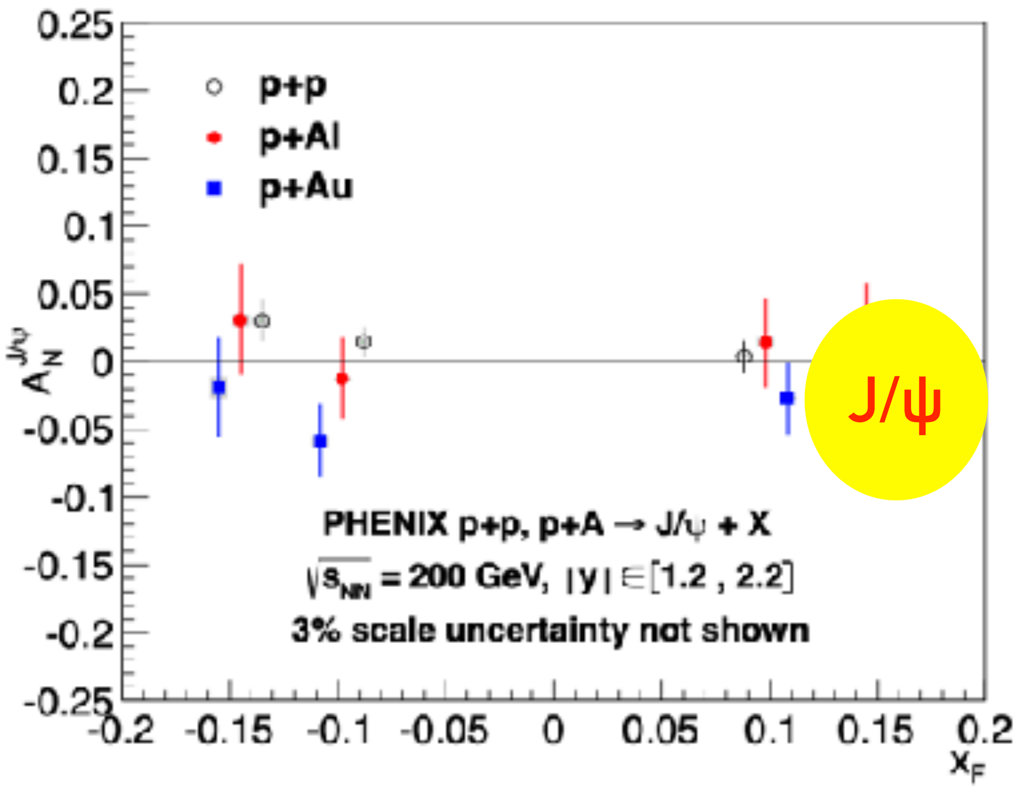


JHEP **09 (2015) 119**



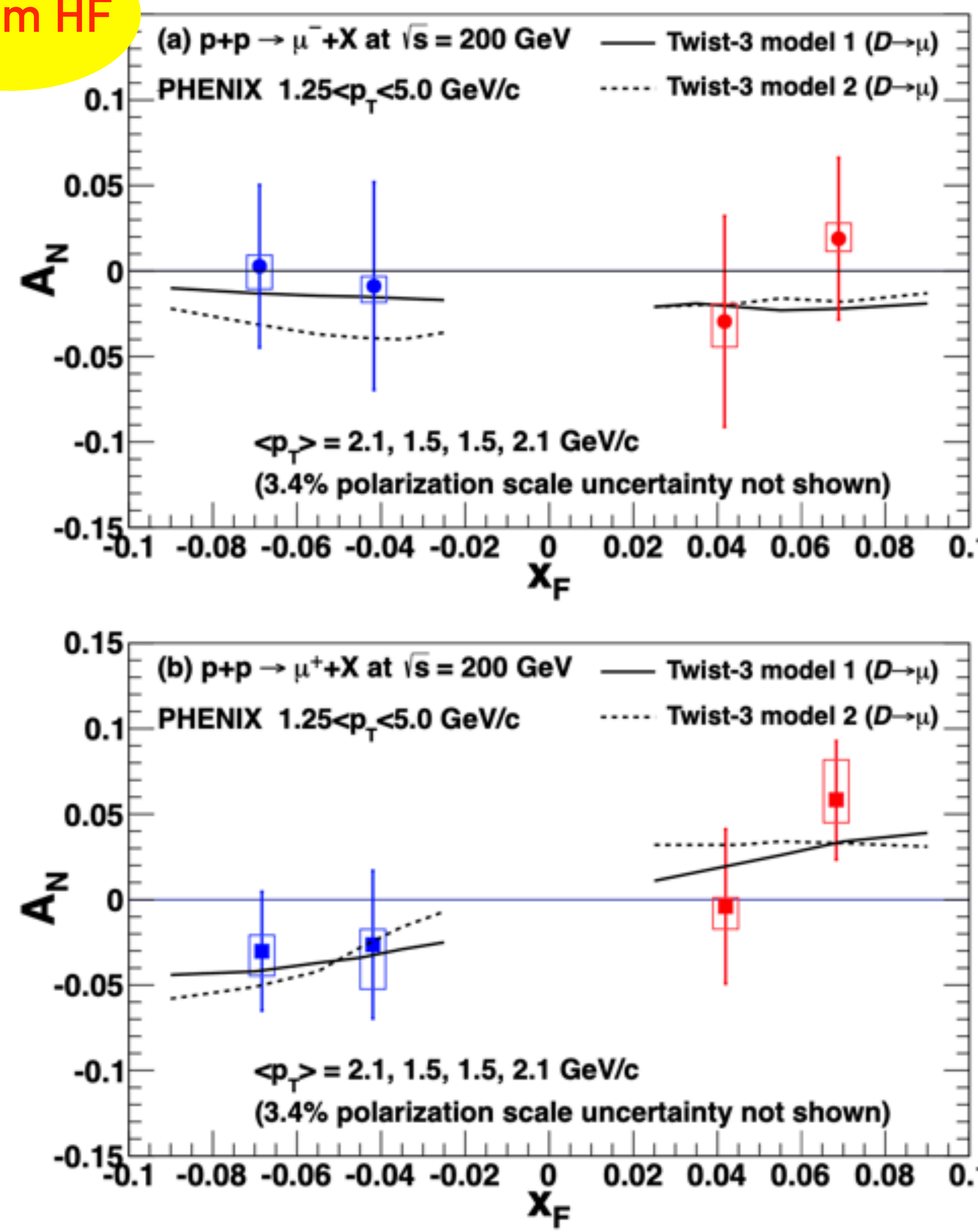
GLUON-INDUCED TMD EFFECTS : EXISTING RESULTS FOR A_N

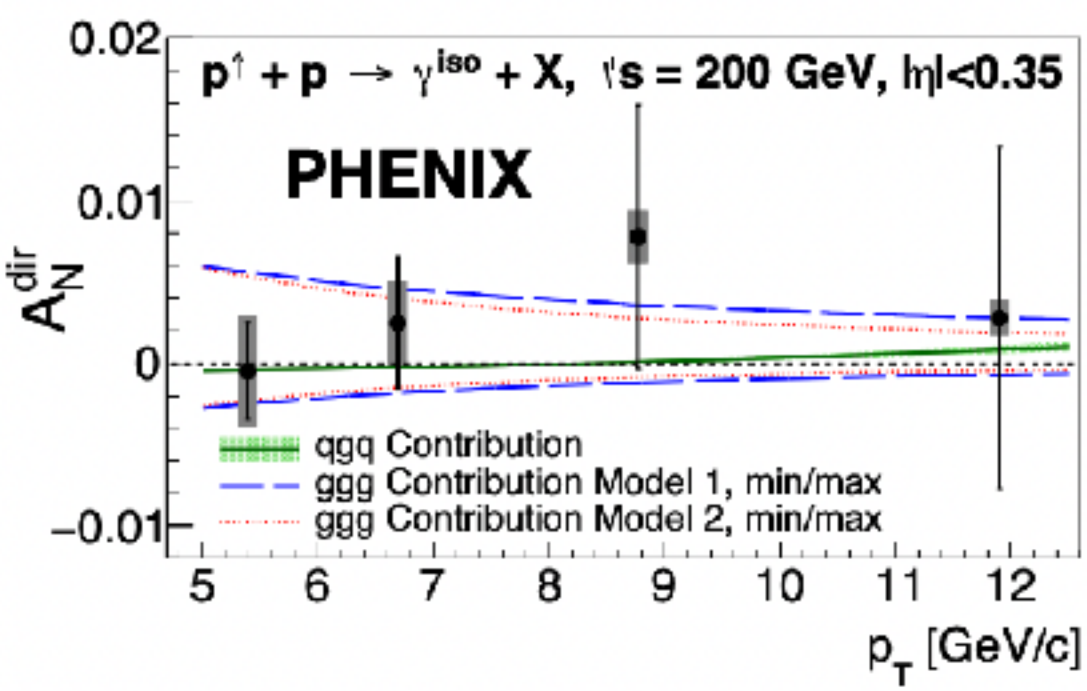
Phys.Rev.D 98 (2018) 1, 012006



μ from HF

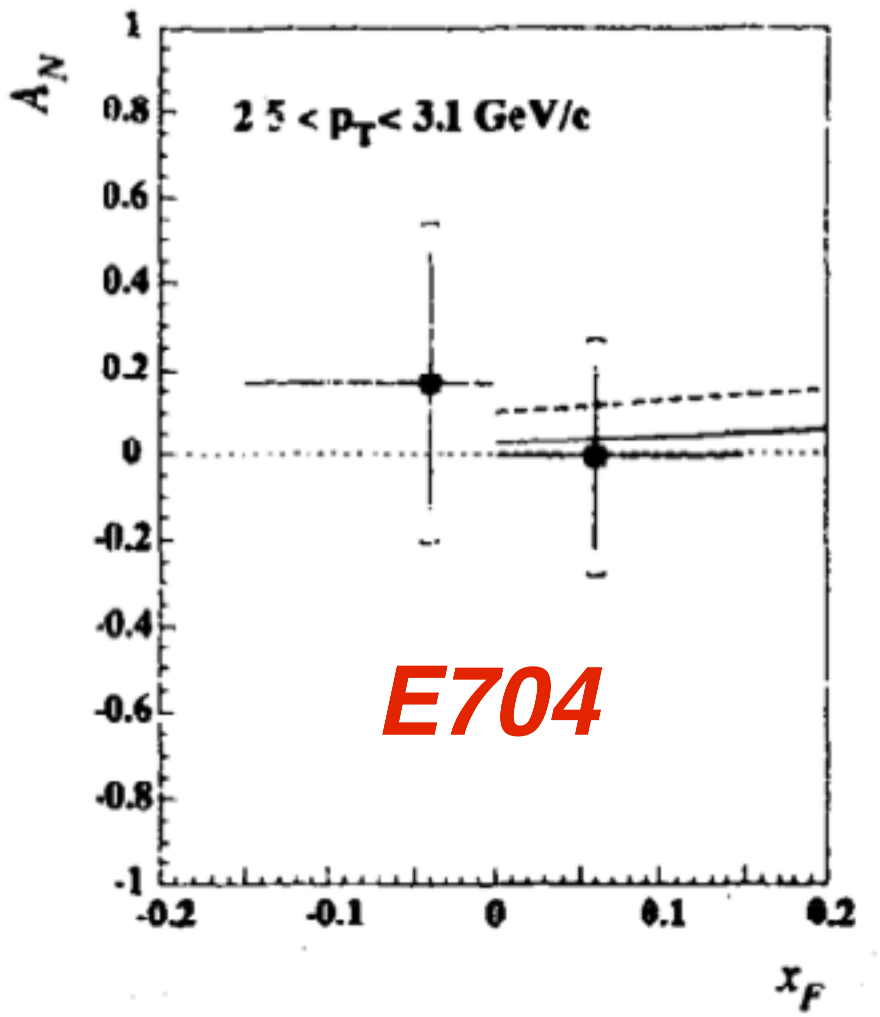
Phys.Rev.D 95 (2017) 11, 112001





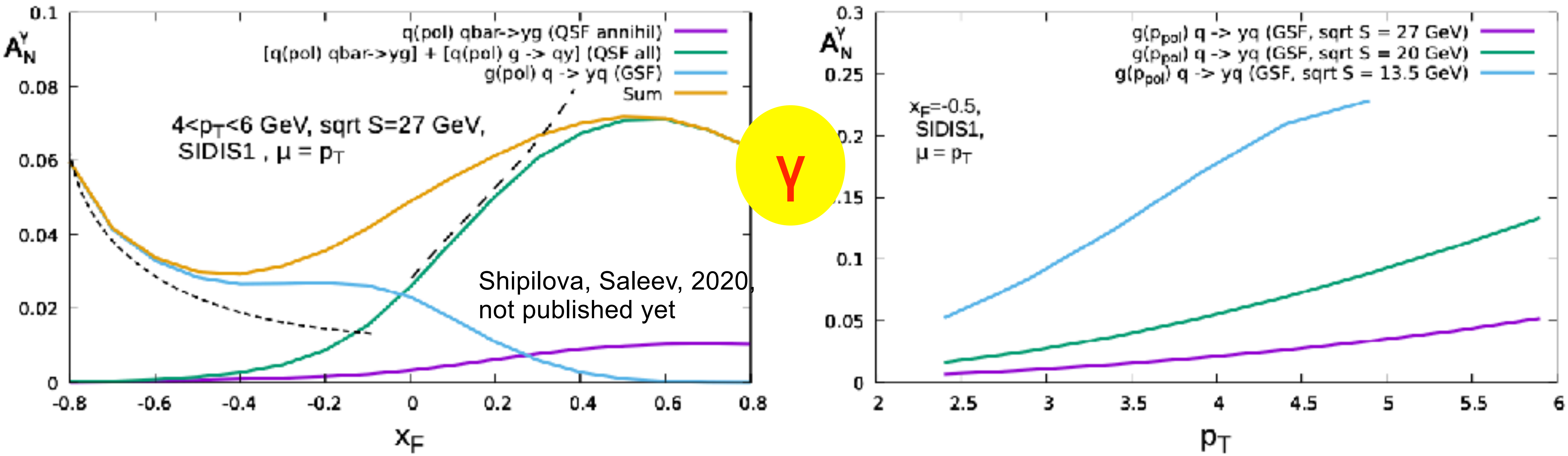
. . . AND AT NICA ENERGIES

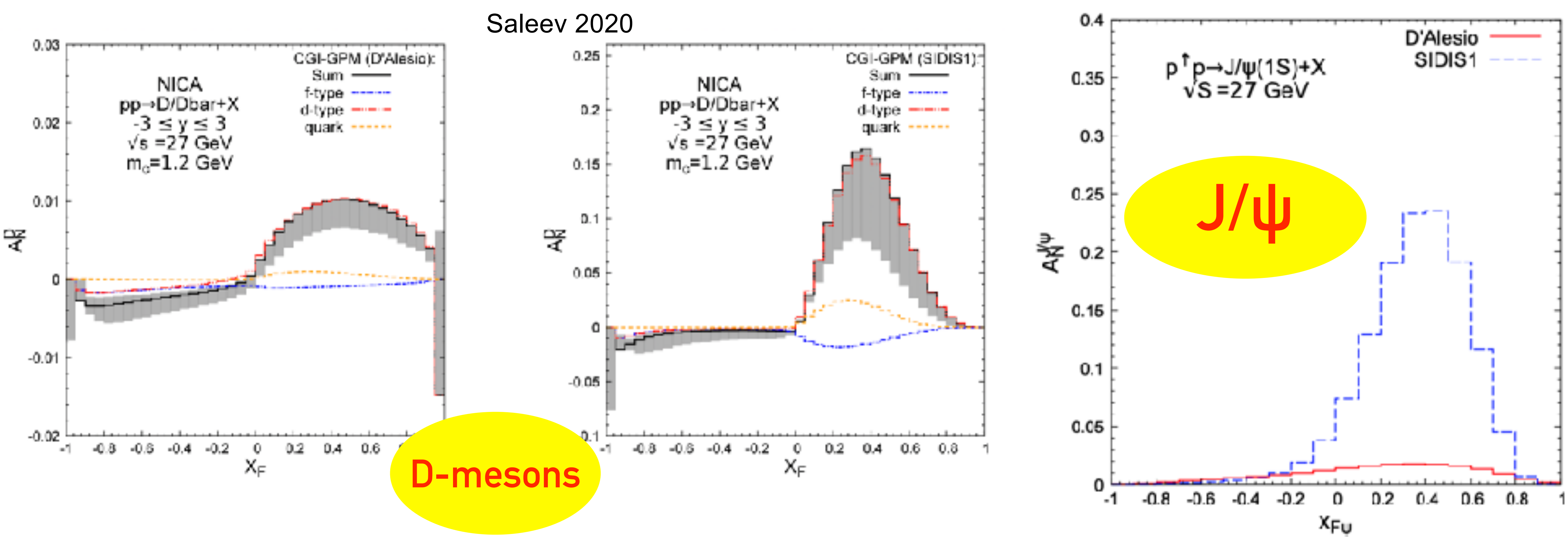
Phys. Lett. B 345 (1995)



GLUON-INDUCED TMD EFFECTS: EXPECTATIONS FOR A_N

Sivers effect contribution





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 $\mathcal{O}(\infty/\mathcal{S})$ in the form [D. Boer, P. Mulders, C. Pisano, 2008]

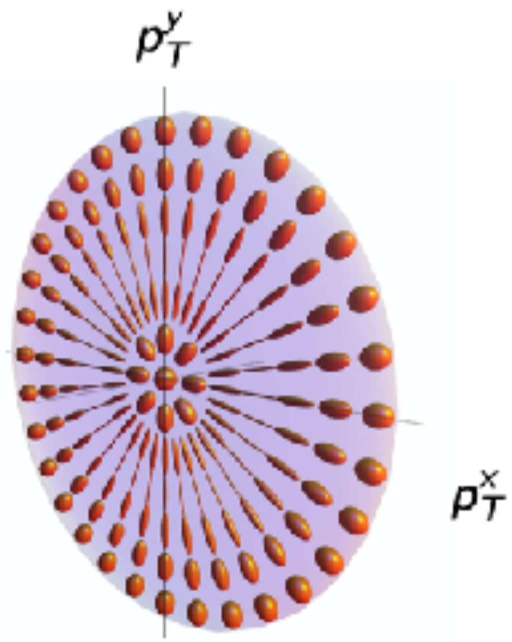
$$\frac{d\sigma(pp\to D\bar{D}X)}{d\eta_1 d\eta_2 d^2k_{1T}d^2k_{2T}} = \frac{\alpha_S}{SK_T^2}\Big[A(Q_T^2) + B(Q_T^2)Q_T^2\cos 2(\phi_T - \phi_\perp) + C(Q_T^2)Q_T^4\cos 4(\phi_Q - \phi_K)\Big]$$

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

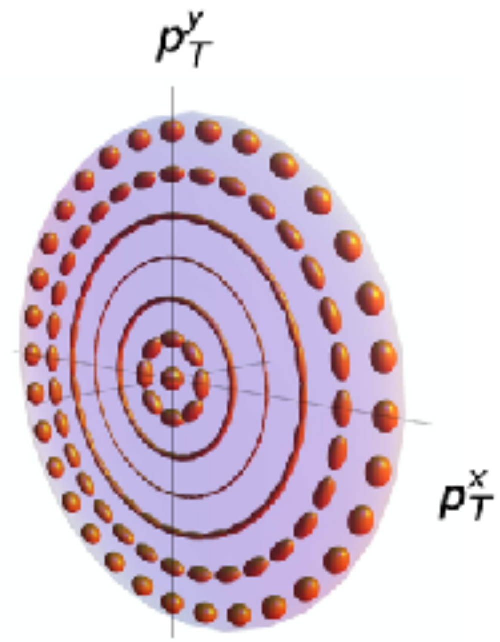
$$A: \quad f_1^q \otimes f_1^{\bar{q}}, \; f_1^g \otimes f_1^g\,,$$

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

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



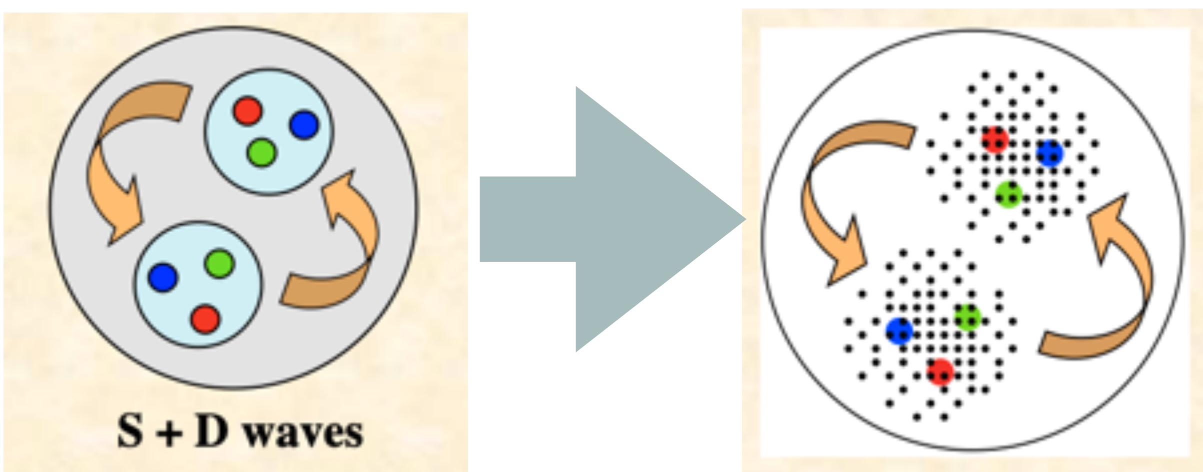
$h_1^{\perp g} > 0$



$h_1^{\perp g} < 0$

UNPOLARIZED GLUONS IN DEUTERON AT HIGH x

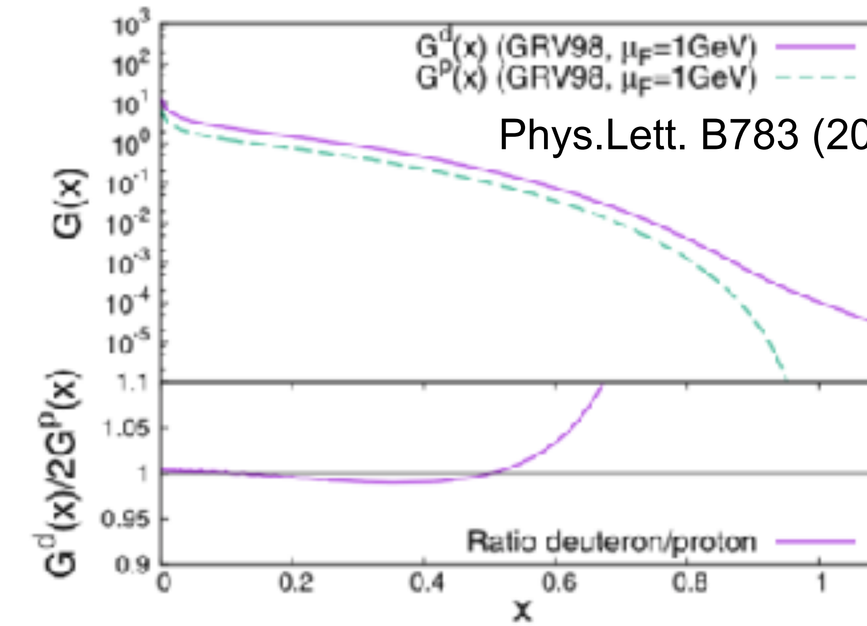
S. Kumano



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

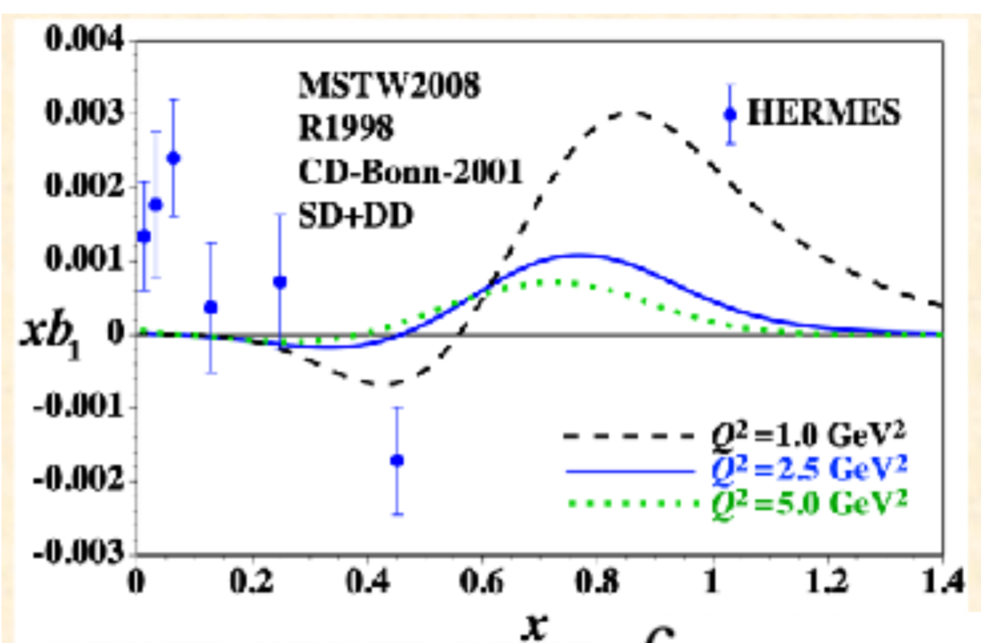
hidden color *up to 90% at some models!*

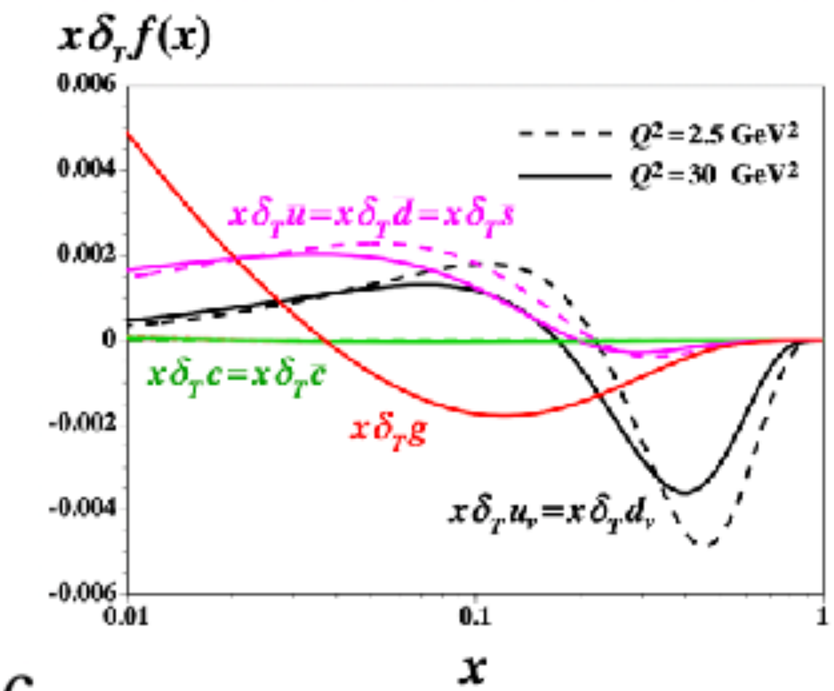
G. A. Miller, Phys.Rev. C89 (2014) no.4, 045203



Phys.Lett. B783 (2018) 287-293

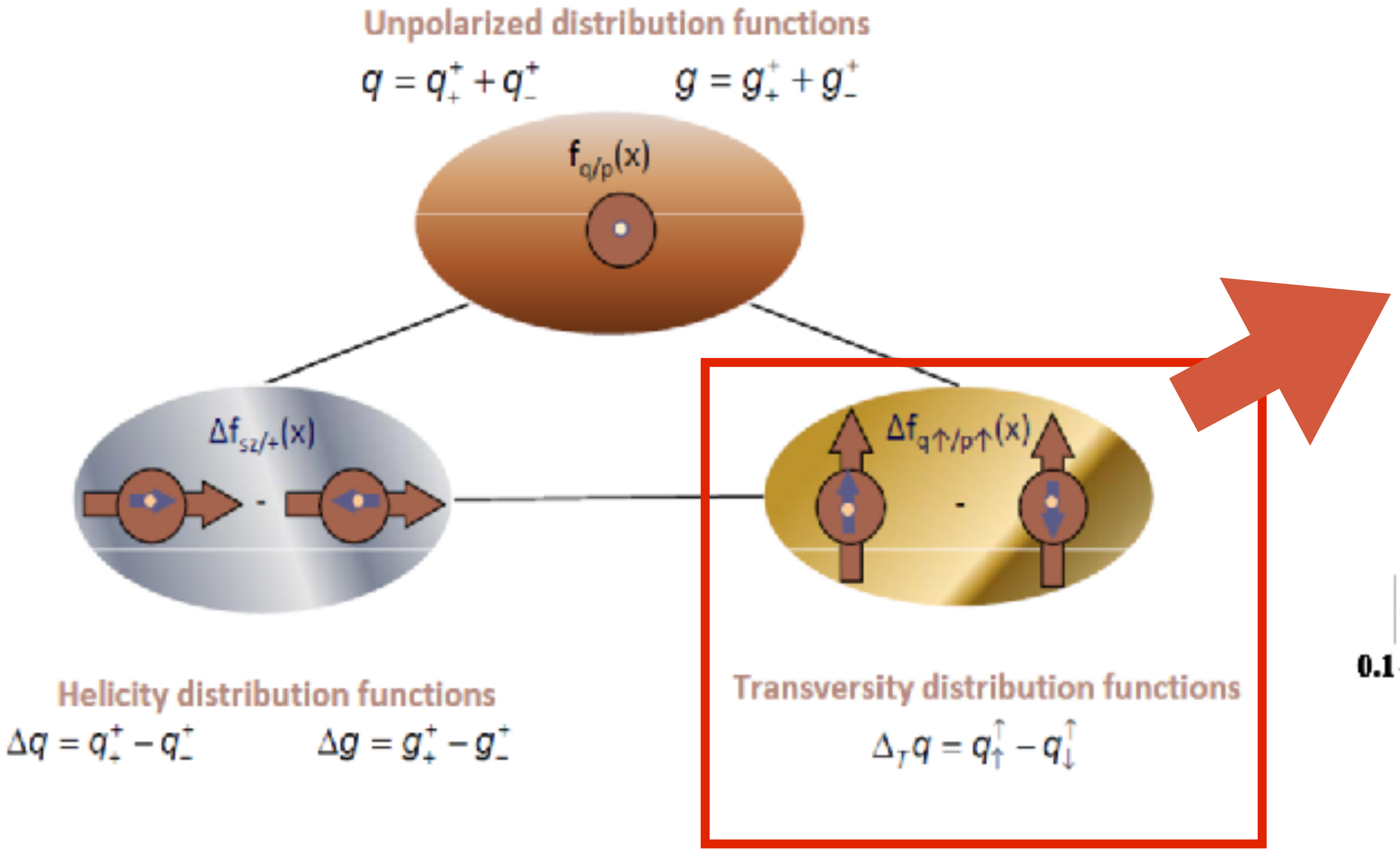
Fig. 6. Gluon PDF in the deuteron and in the nucleon.





$$\int dx\, b_1(x)_{LO} = -\frac{5}{24} \lim_{t\to 0} t\, F_Q(t) + \sum_i e_i^2 \int dx\, \delta_T \bar{q}_i(x),$$

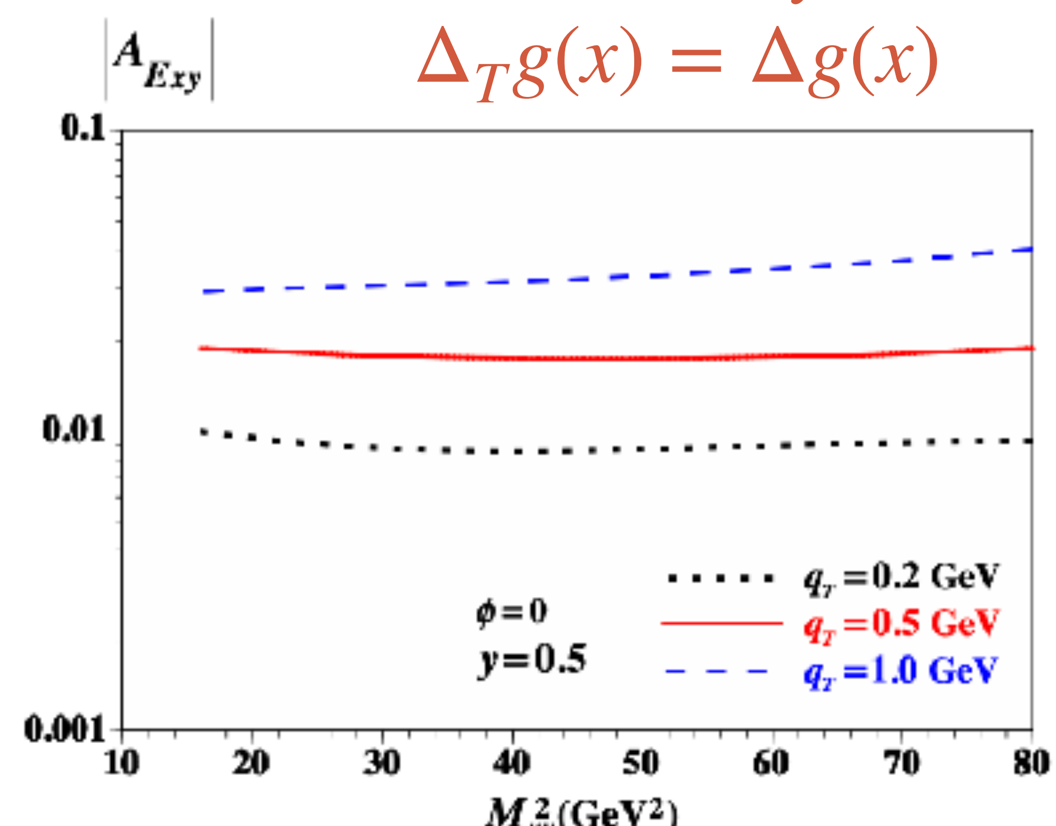
GLUON TRANSVERSITY $\Delta g_T(x)$ IN DEUTERON



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

Sh. Kumano for DY:

$\Delta_T g(x) = \Delta g(x)$



*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!*

RATES FOR MAIN PROBES

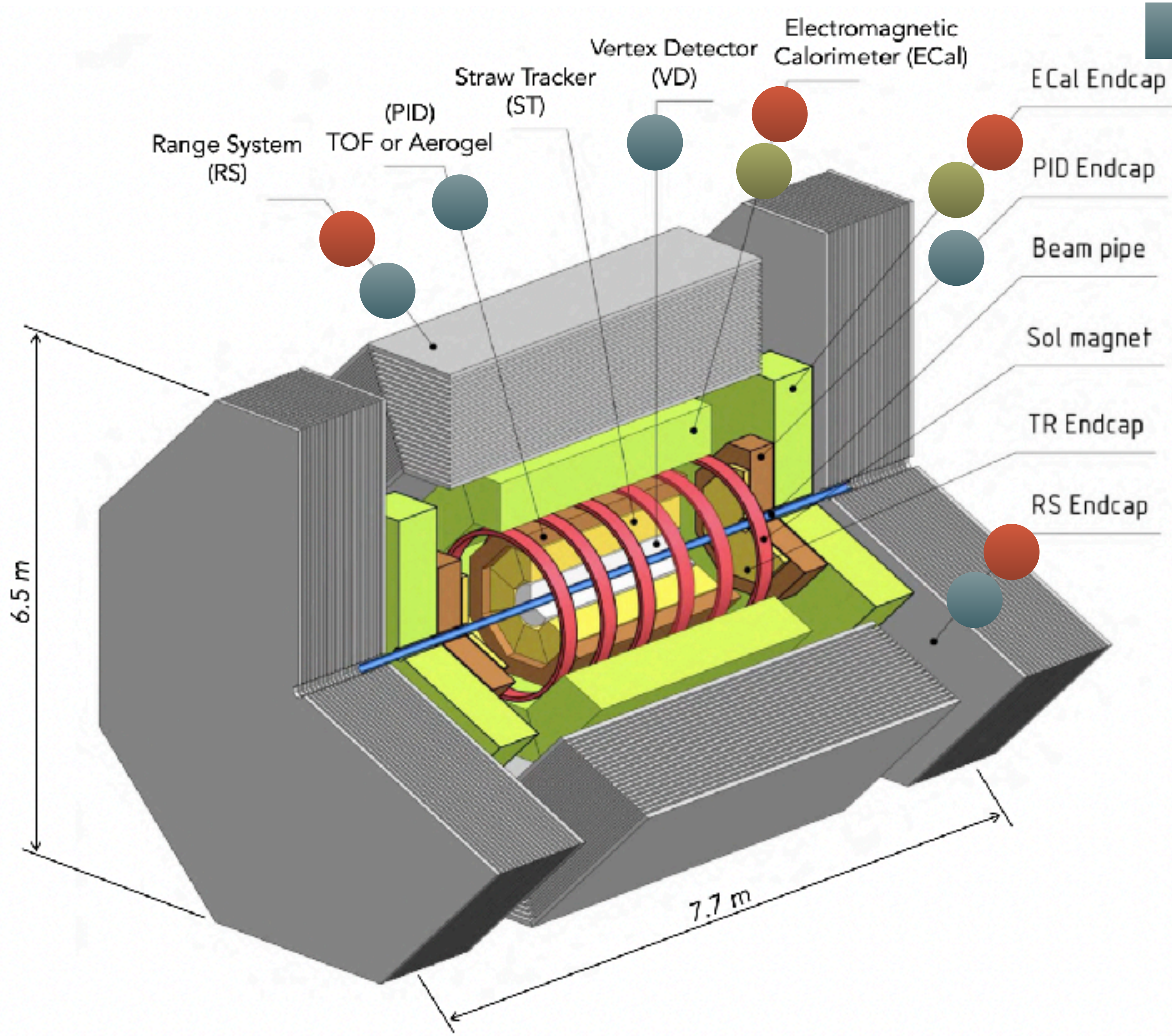
Probe	$\sigma_{27\,\mathrm{GeV}}$, nb ($\times$BF)	$\sigma_{13.5\,\mathrm{GeV}}$, nb ($\times$BF)	$N_{27\,\mathrm{GeV}}$, 10^6	$N_{13.5\,\mathrm{GeV}}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
J/ψ	200	60		
$\rightarrow \mu^+\mu^-$	12	3.6	12	0.36
$\psi(2S)$	25	5		
$\rightarrow J/\psi\pi^+\pi^- \rightarrow \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\rightarrow \mu^+\mu^-$	0.2	0.04	0.2	0.004
$\chi_{c1} + \chi_{c2}$	200			
$\rightarrow \gamma J/\psi \rightarrow \gamma\mu^+\mu^-$	2.4		2.4	
η_c	400			
$\rightarrow p\bar{p}$	0.6		0.6	
Open charm: $D\overline{D}$ pairs	14000	1300		
Single D-mesons				
$D^+ \rightarrow K^-2\pi^+$ ($D^- \rightarrow K^+2\pi^-$)	520	48	520	4.8
$D^0 \rightarrow K^-\pi^+$ ($\overline{D}^0 \rightarrow K^+\pi^-$)	360	33	360	3.3

SPD DETECTOR

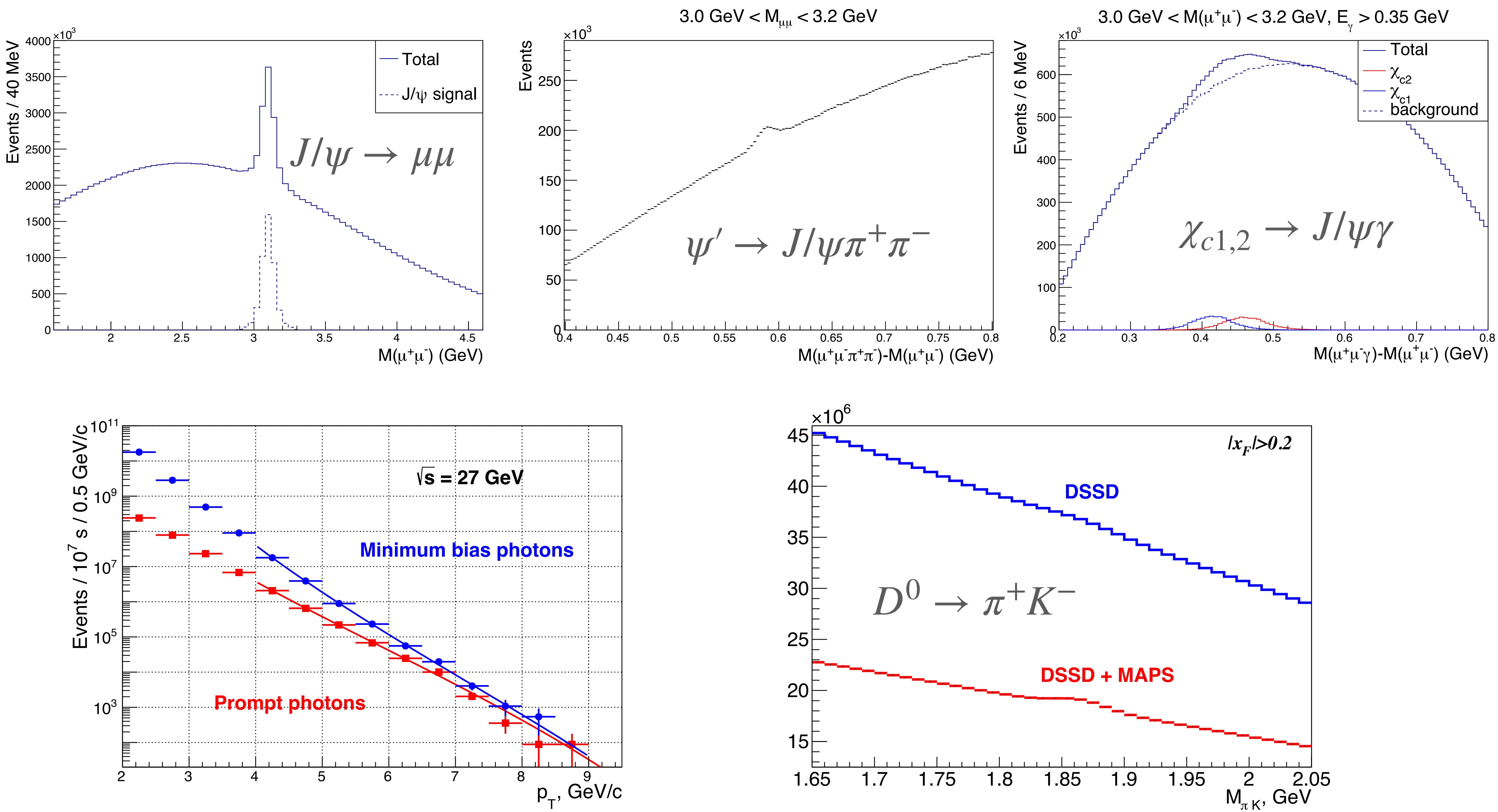
Charmonia

Prompt photons

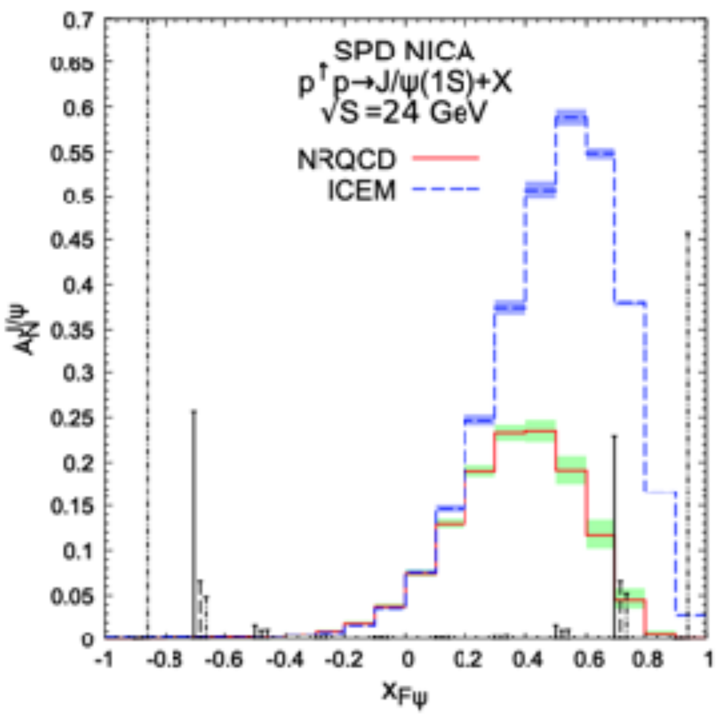
Open charm



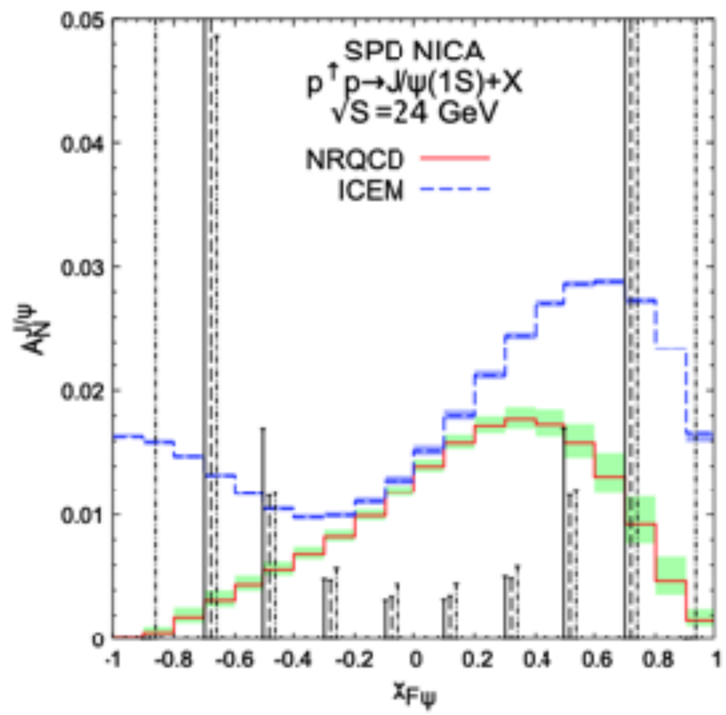
PHYSICS PERFORMANCE: GLUON PROBES (1 YEAR=10^7 S)

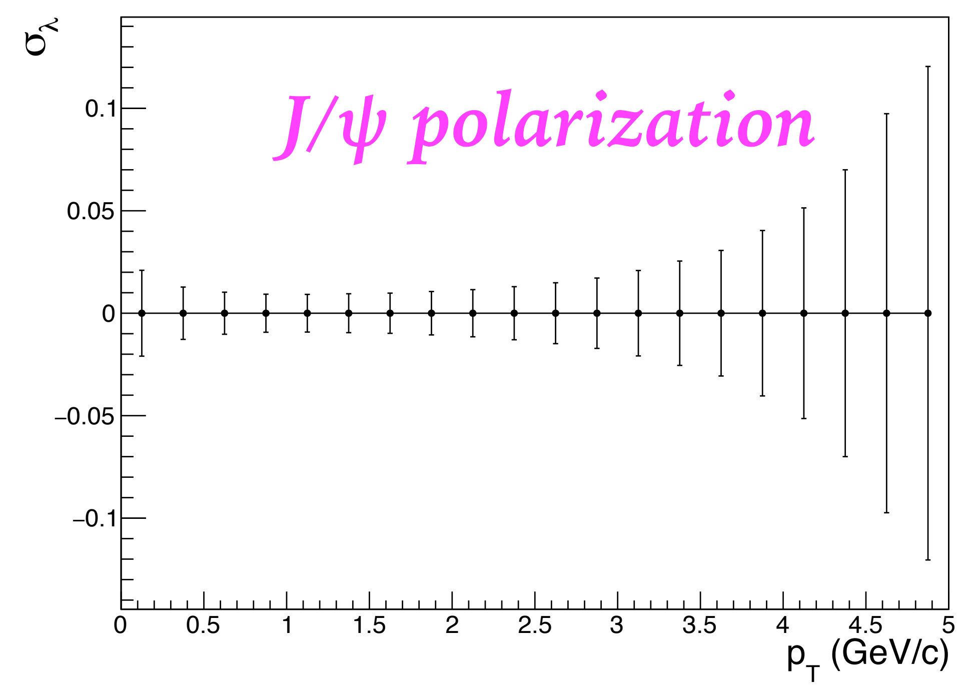


PHYSICS PERFORMANCE: ACCURACIES



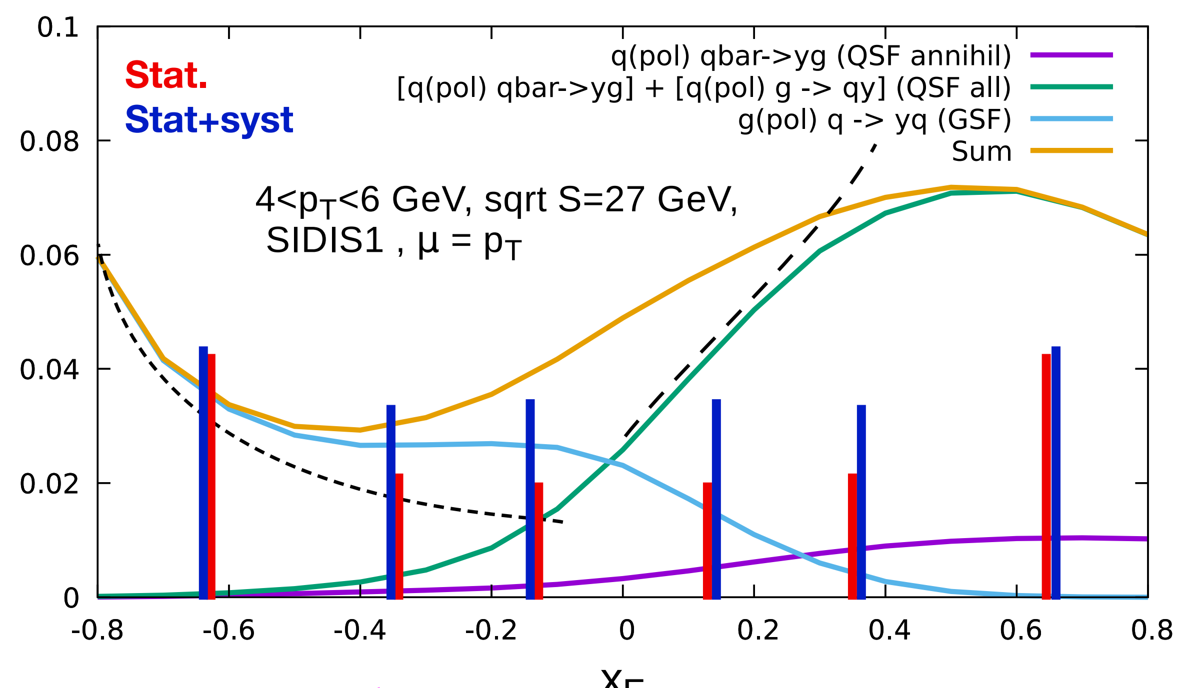
J/ψ



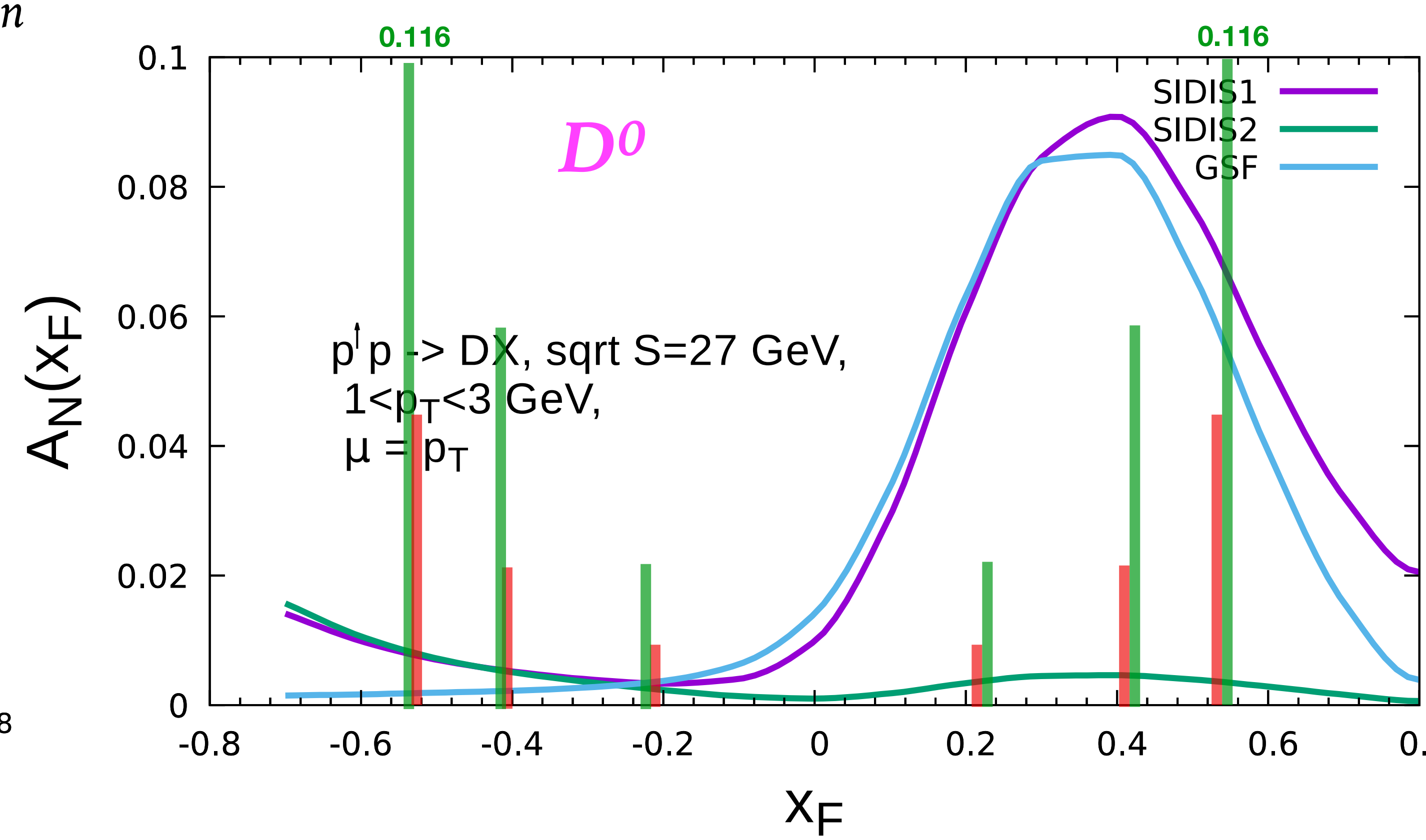


J/ψ polarization

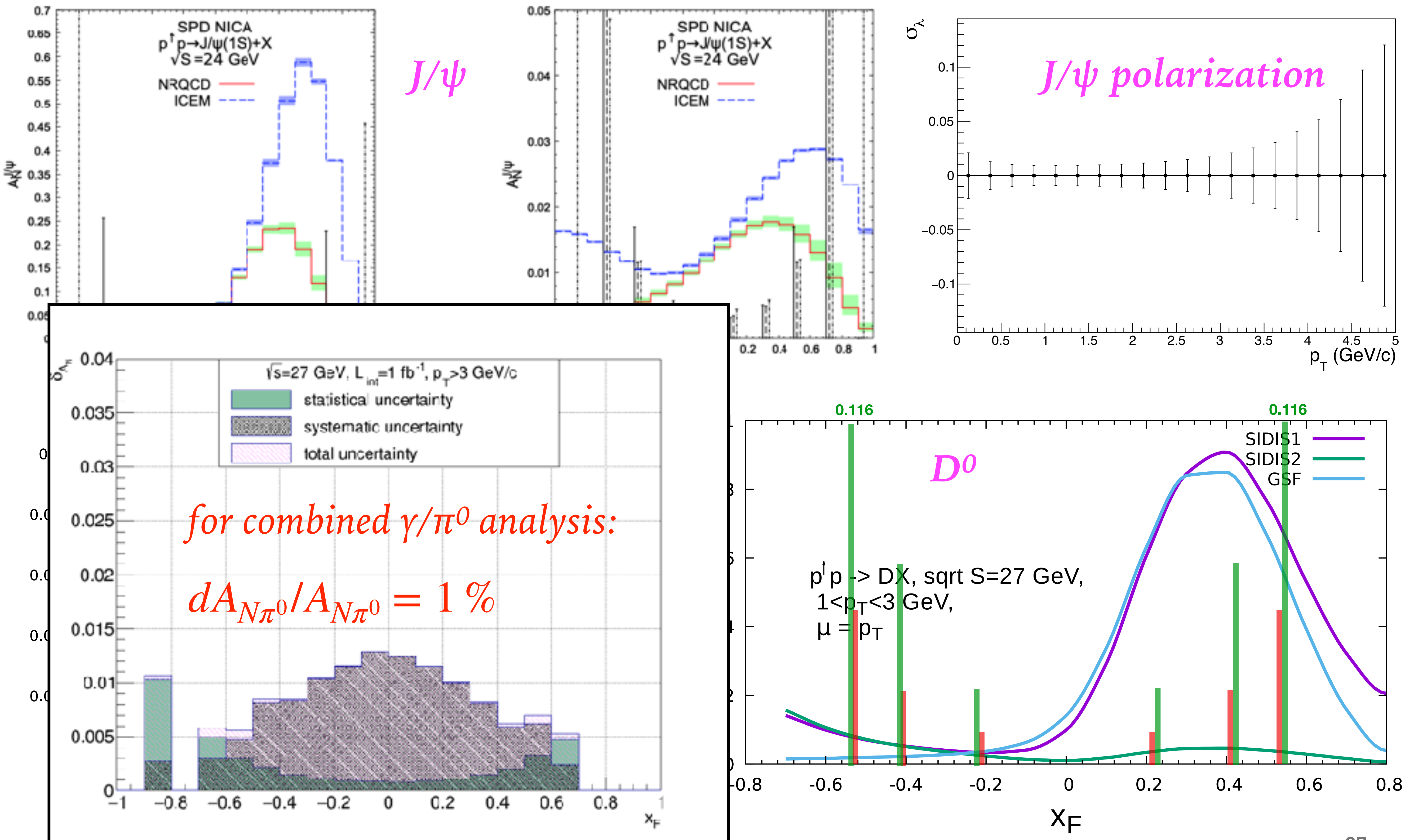
Different inputs for gluon Sivers function



prompt-γ



PHYSICS PERFORMANCE: ACCURACIES



TENTATIVE RUNNING PLAN

Physics goal	Required time	Experimental conditions
First stage		
Spin effects in p-p scattering dibaryon resonanses	0.3 year	$p_{L,T}$-$p_{L,T}$, $\sqrt{s}$ <7.5 GeV
Spin effects in p-d scattering, non-nucleonic structure of deuteron, $\bar{p}$ yield	0.3 year	d_{tensor}-p, $\sqrt{s}$ <7.5 GeV
Spin effects in d-d scattering hypernuclei	0.3 year	d_{tensor}-d_{tensor}, $\sqrt{s}$ <7.5 GeV
Hyperon polarization, SRC, ... multiquarks	together with MPD	ions up to Ca
Second stage		
Gluon TMDs, SSA for light hadrons	1 year	p_T-p_T, $\sqrt{s}$ =27 GeV
TMD-factorization test, SSA, charm production near threshold, onset of deconfinment, $\bar{p}$ yield	1 year	p_T-p_T, 7 GeV< $\sqrt{s}$ <27 GeV (scan)
Gluon helicity, ...	1 year	p_L-p_L, $\sqrt{s}$ =27 GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor porlarized" PDFs	1 year	d_{tensor}-d_{tensor}, $\sqrt{s_{NN}} = 13.5$ GeV or/and? d_{tensor}-p_T, $\sqrt{s_{NN}} = 19$ GeV

≥ 5 years of data taking

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.
  - …
- **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).**
- SPD CDR could be found at **arXiv:2102.00442** for more details.
- More information could be found at http://spd.jinr.ru