SPD PROJECT AT JINR
PHYSICS CASE

1st meeting of the SPD DAC

A. Guskov

Alexey.Guskov@cern.ch

21.5.2021

SPD AT NICA

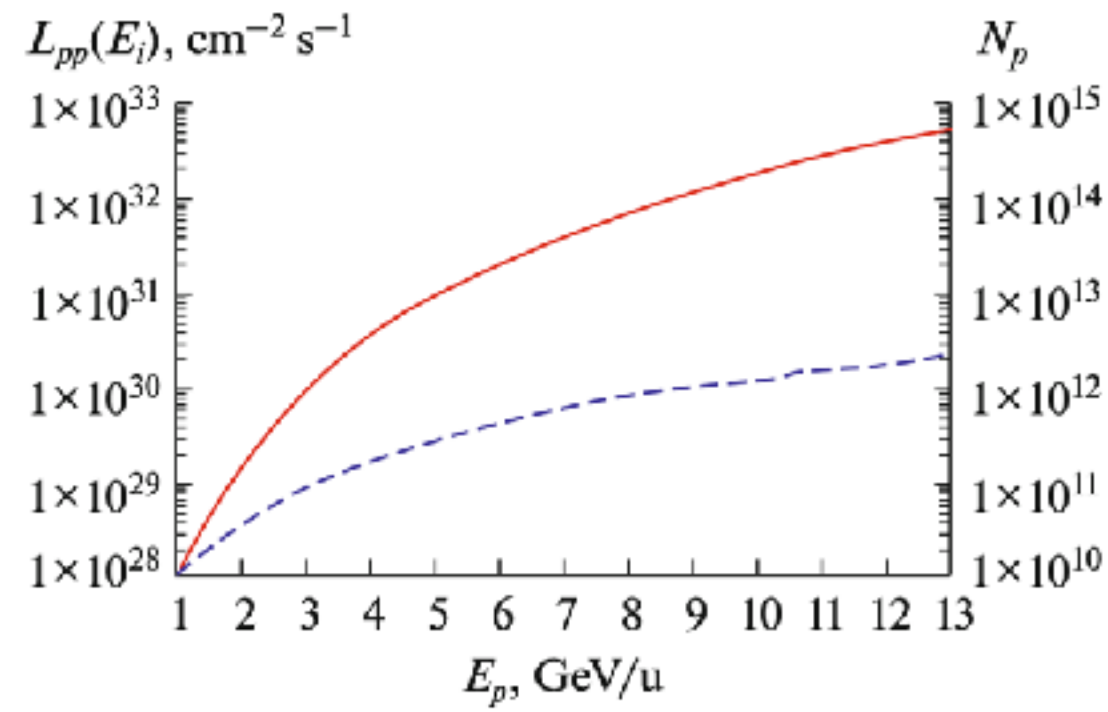
$p^{\uparrow}p^{\uparrow}: \sqrt{s} \leq 27\ GeV$

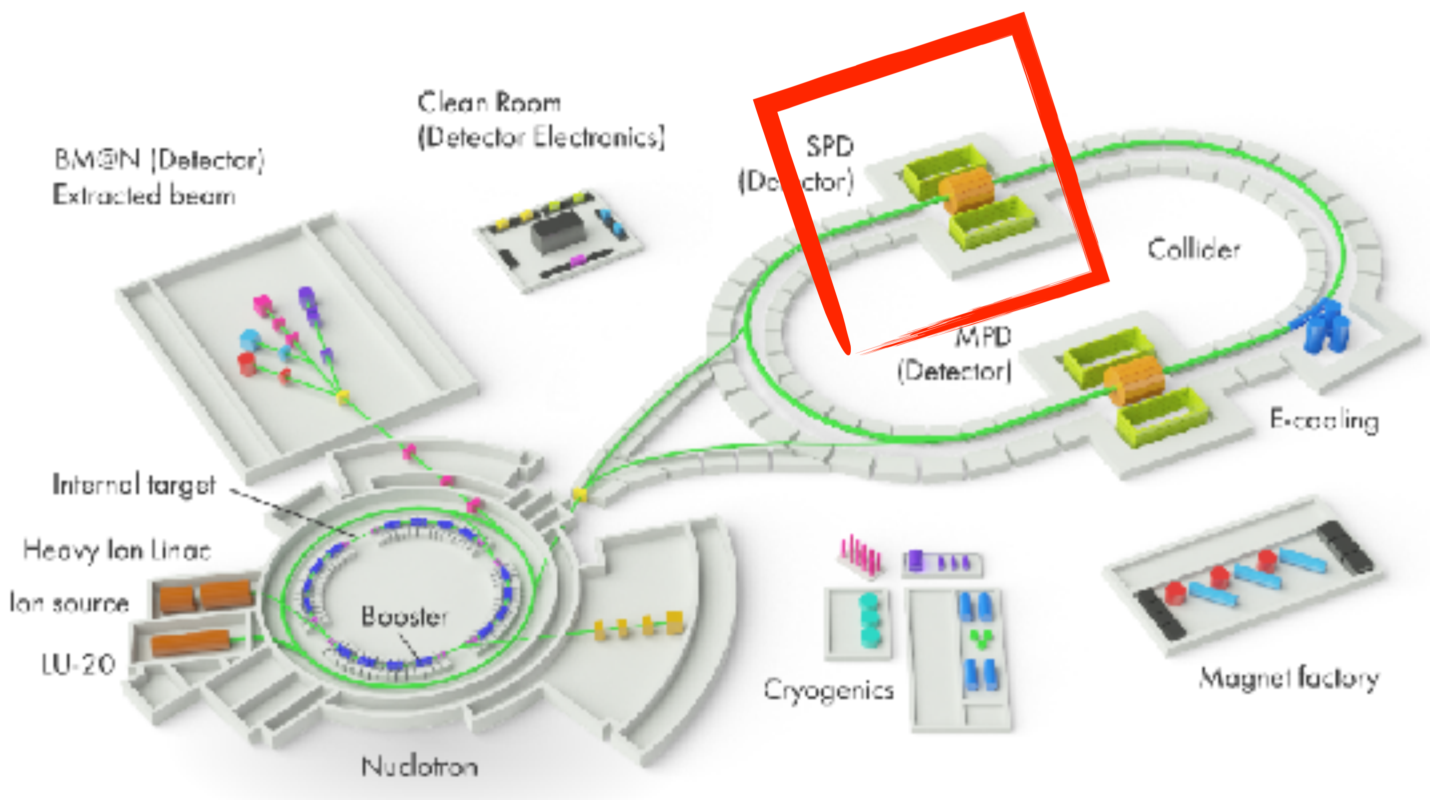
$d^{\uparrow}d^{\uparrow}: \sqrt{s} \leq 13.5\ GeV$

$d^{\uparrow}p^{\uparrow}: \sqrt{s} \leq 19\ GeV$

U, L, T

$|P| > 70\%$





2021, January: CDR presented [*arXiv:2102.00442*](https://arxiv.org/abs/2102.00442)

2021, June: report of the International Detector Advisory Committee (under formation)

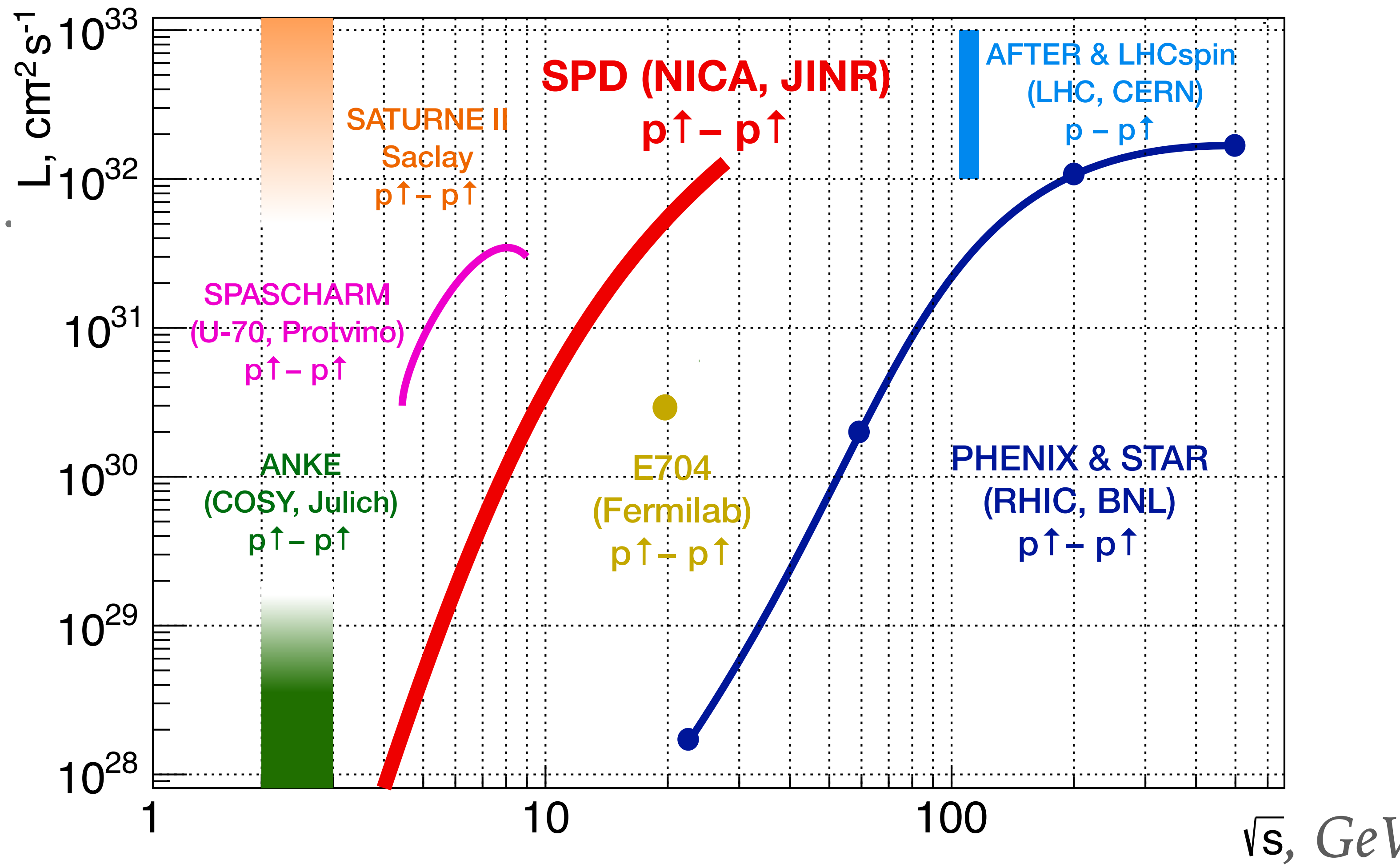
2022, January: Technical Design Report

2025+: Operation

The SPD international collaboration is forming now

SPD – VS OTHERS

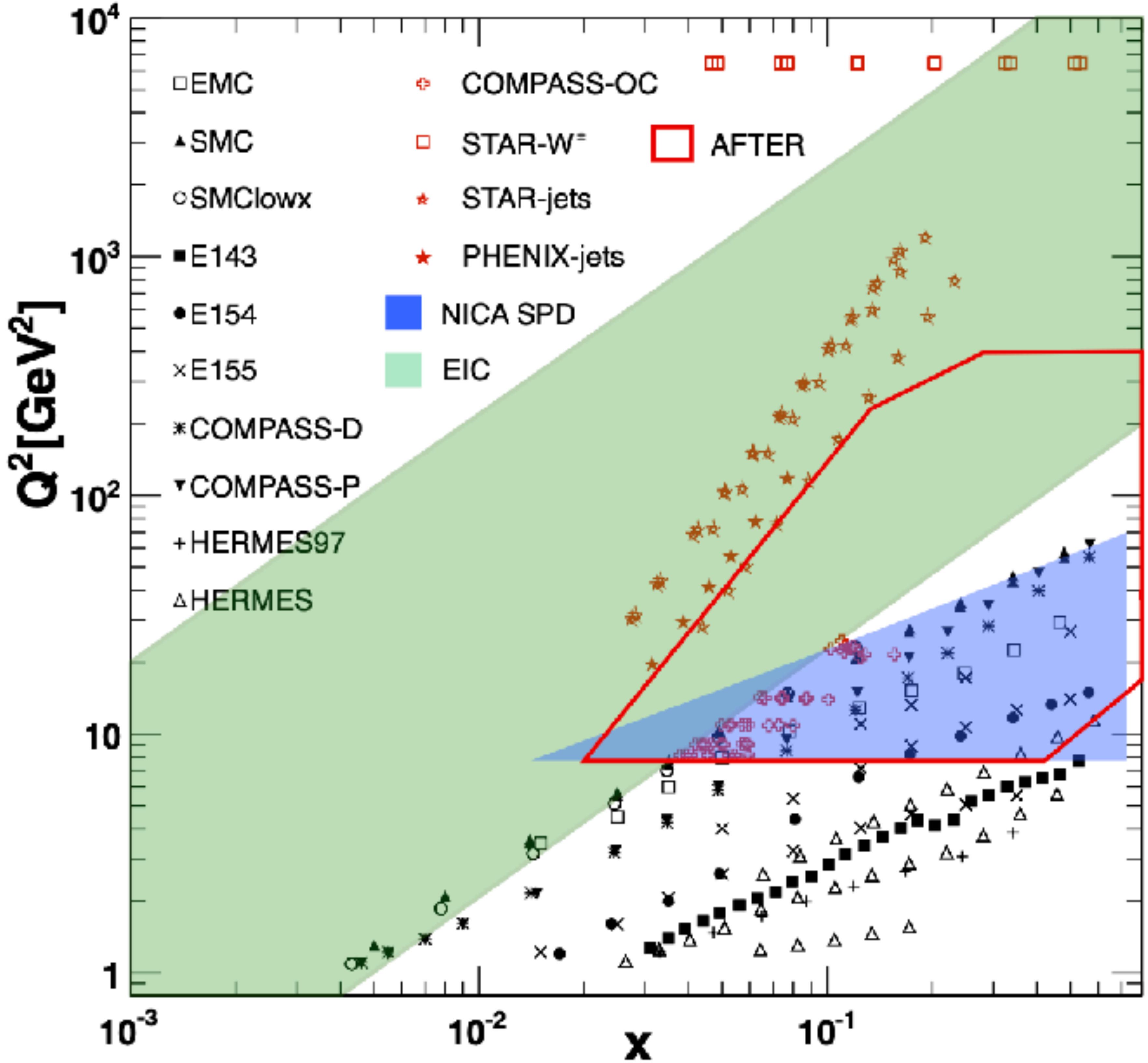
In the $p^{\uparrow}p^{\uparrow}$ mode:



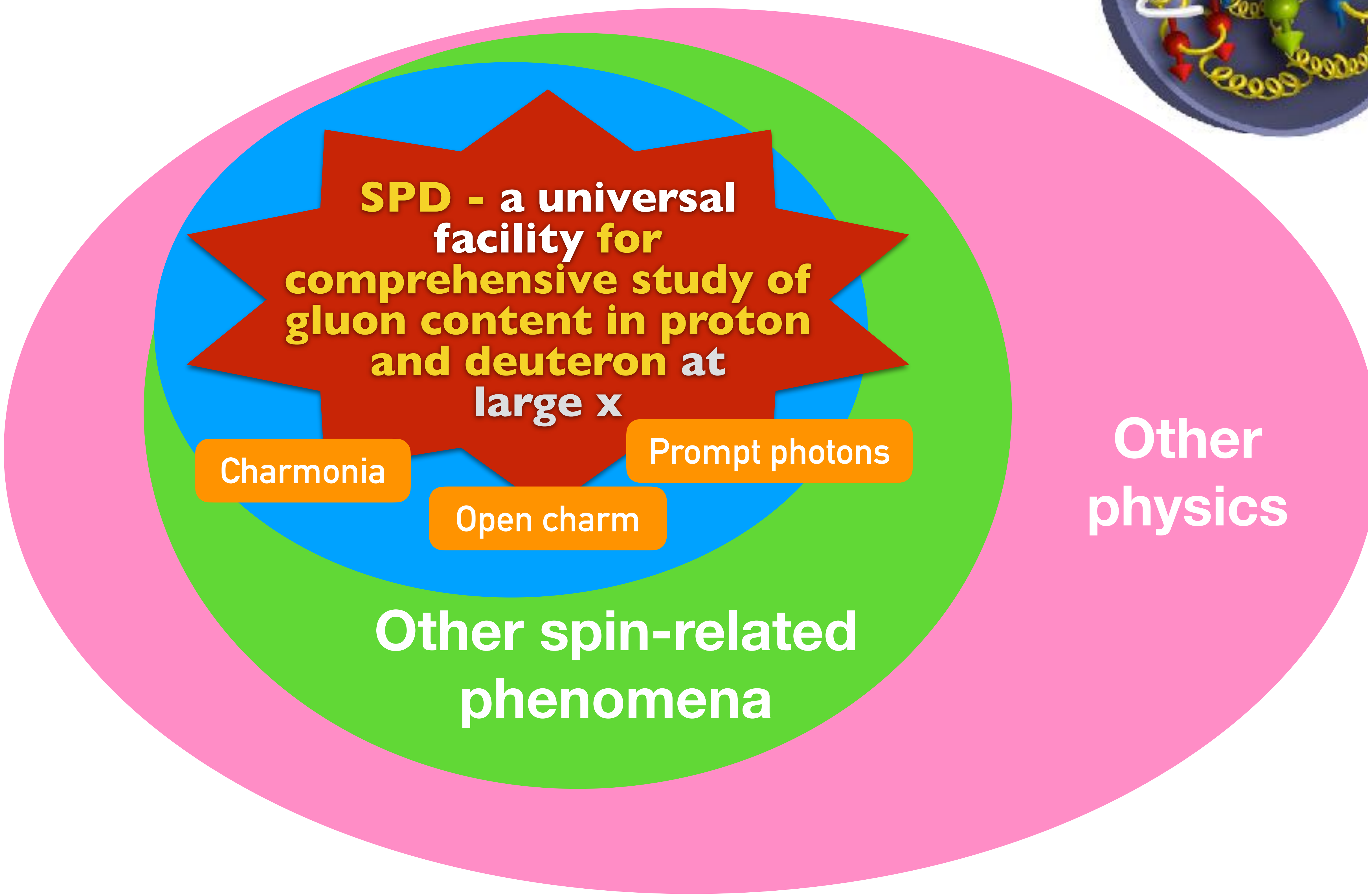
Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^\uparrow$-$p^\uparrow$ $\boxed{d^\uparrow\text{-}d^\uparrow}$ $p^\uparrow$-d, p-$d^\uparrow$	$p^\uparrow$-$p^\uparrow$	$e^\uparrow$-$p^\uparrow$, $d^\uparrow$,^{3}He$^\uparrow$	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

CINEMATIC RANGE



CONCEPT OF THE SPD PHYSICS PROGRAM



GLUON PDFs

arXiv:2011.15005

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

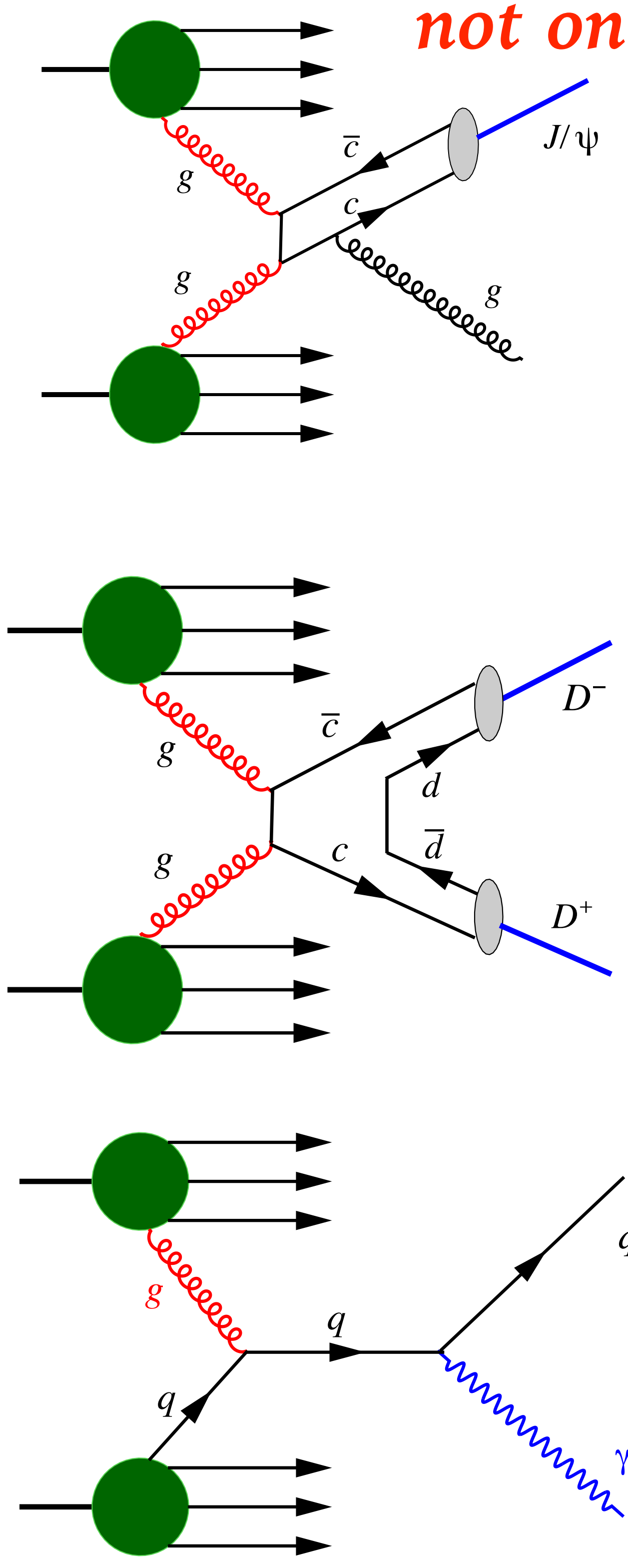
Gluon Sivers function

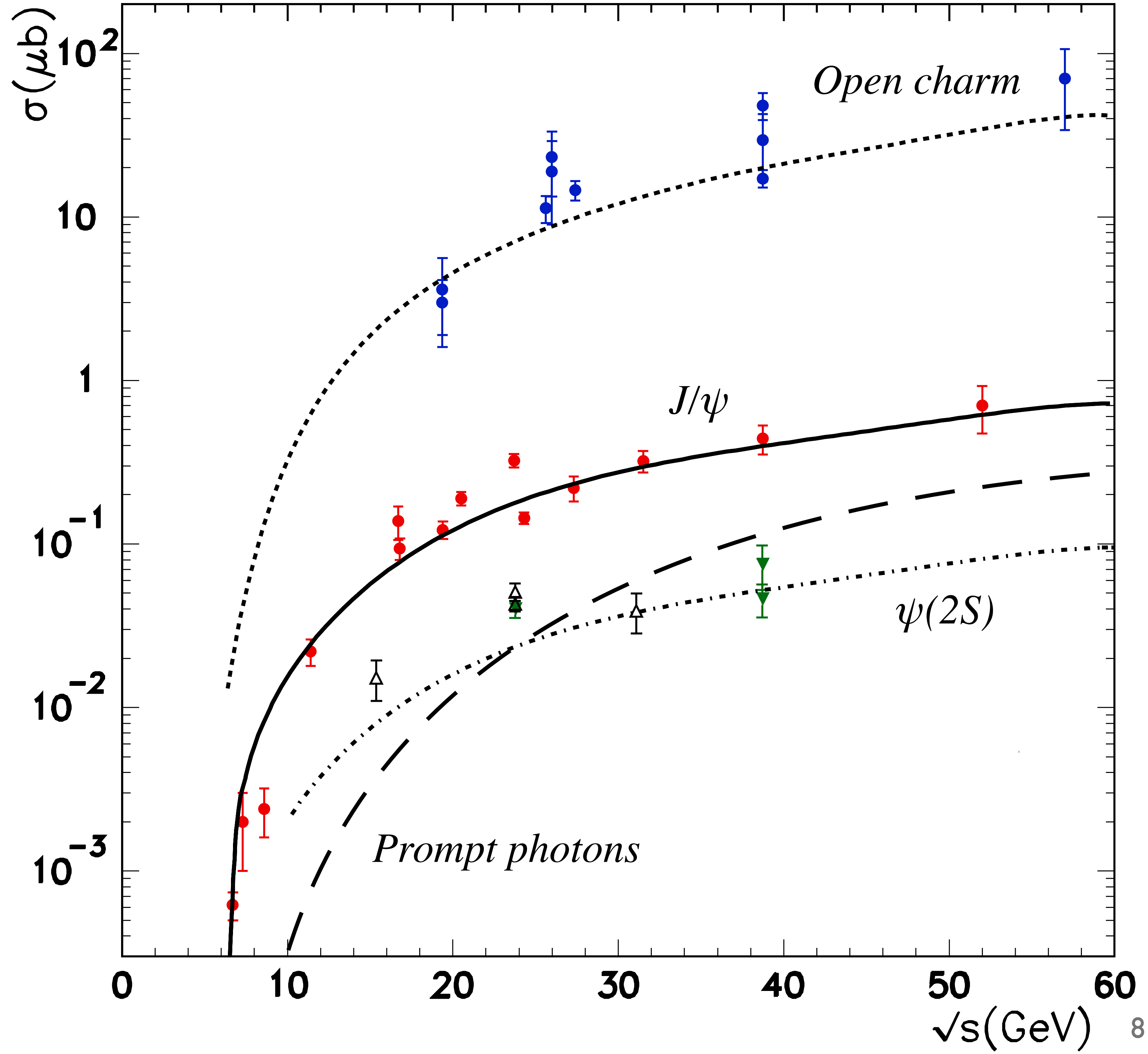
Gluon transversity in deuteron

GLUON PROBES AT SPD

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

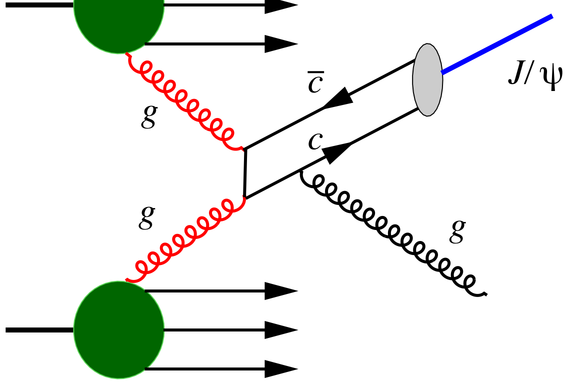
not only J/ψ!





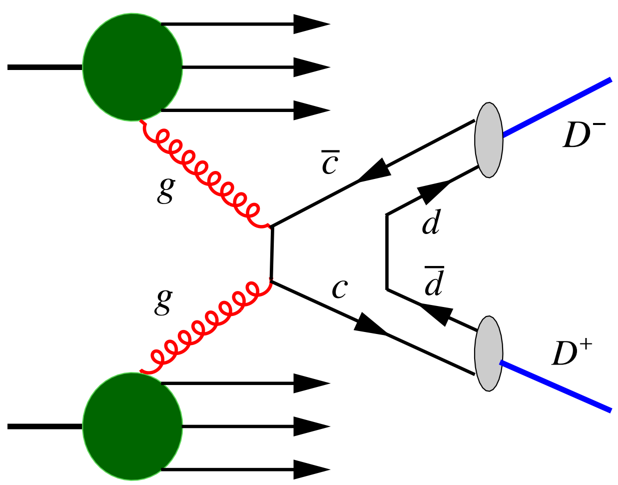
GLUON PROBES AT SPD

not only J/ψ!



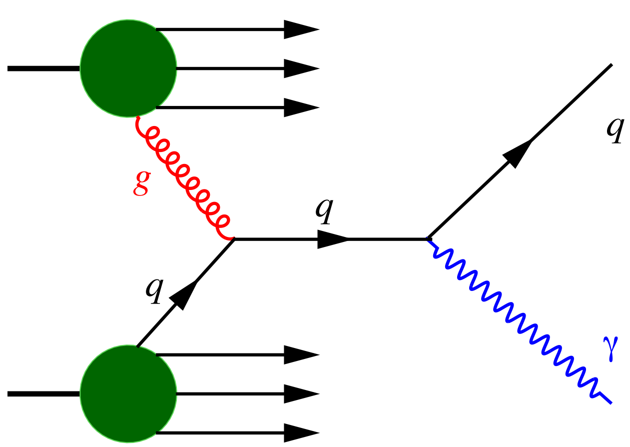
Sharp signal
Relatively large cross section

Model-dependent probability for $c\bar{c} \rightarrow [c\bar{c}]$



Largest cross section

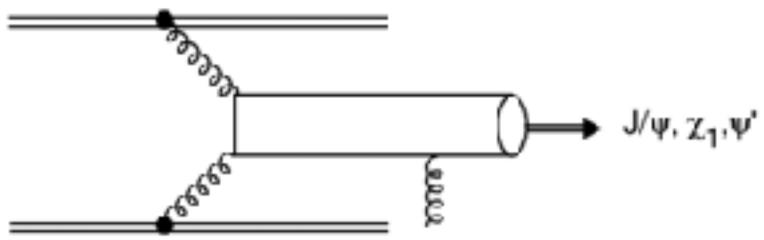
Challenging experimental requirements
Model-dependent fragmentation functions

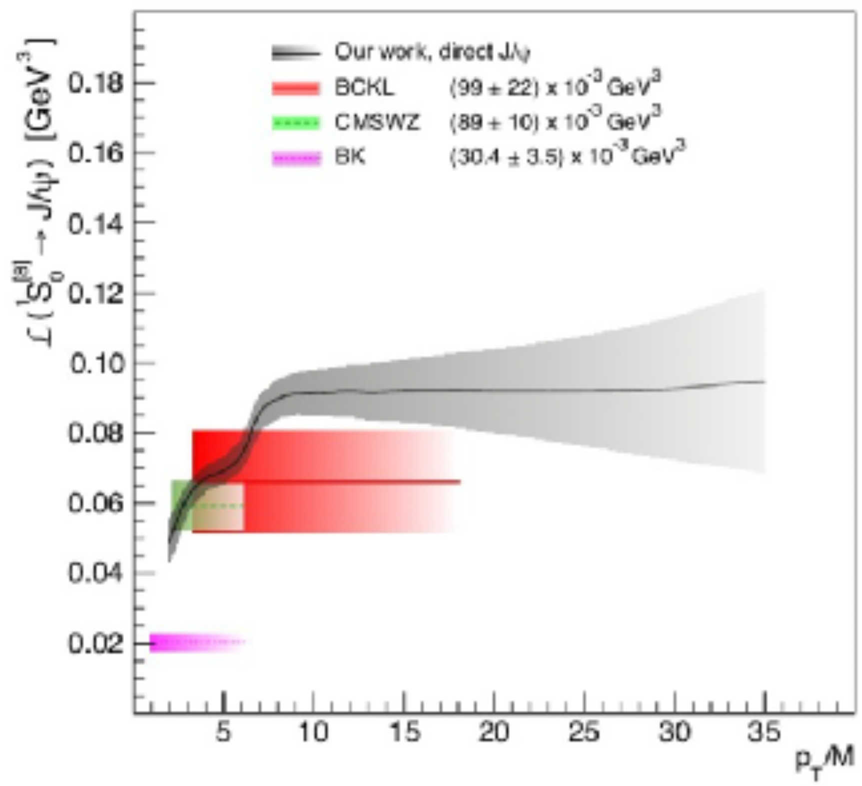


Almost no fragmentation

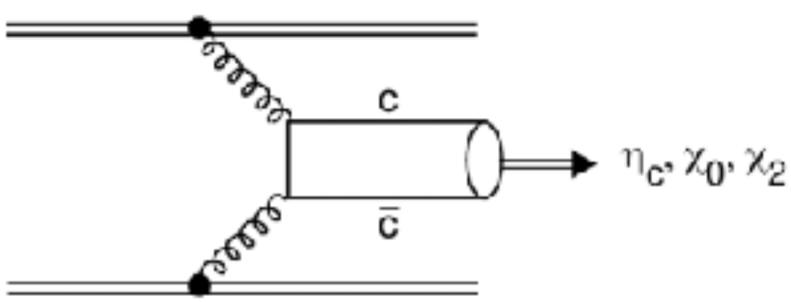
Strong background especially at low p_T

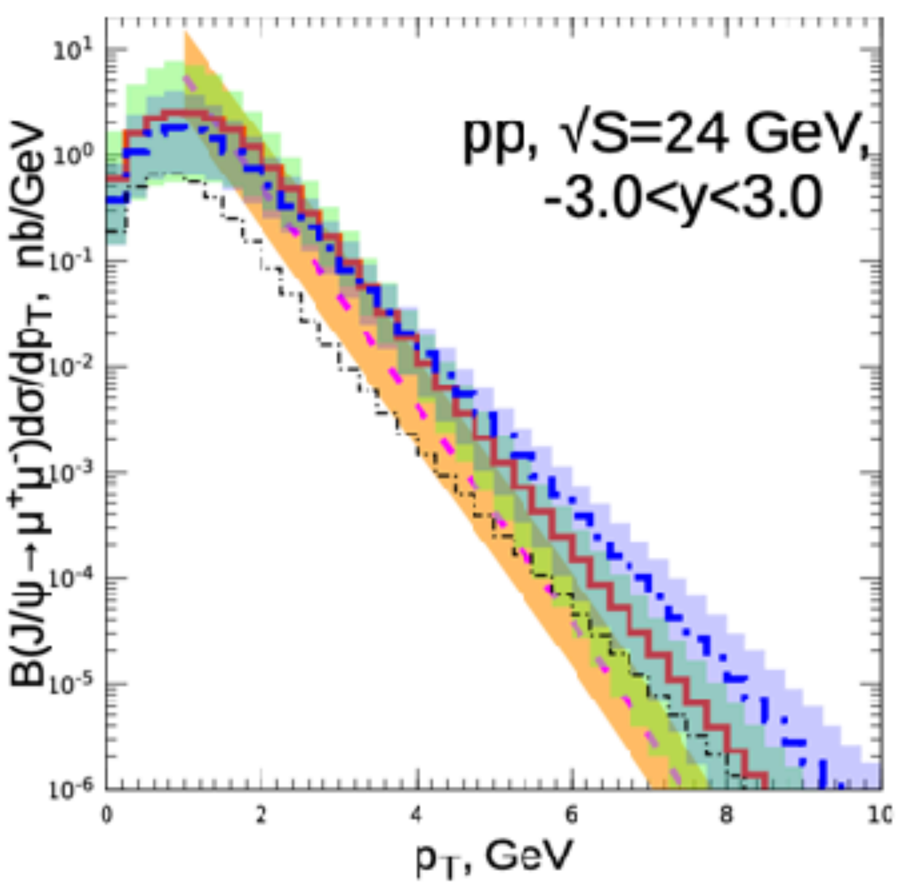
CHARMONIA PRODUCTION

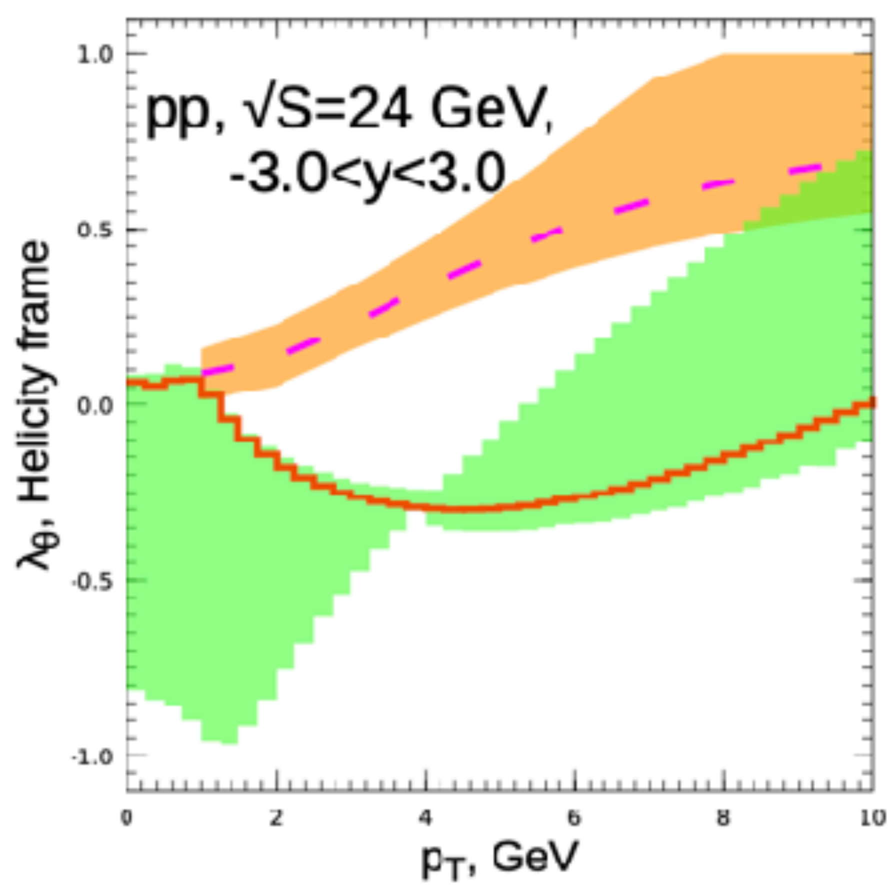


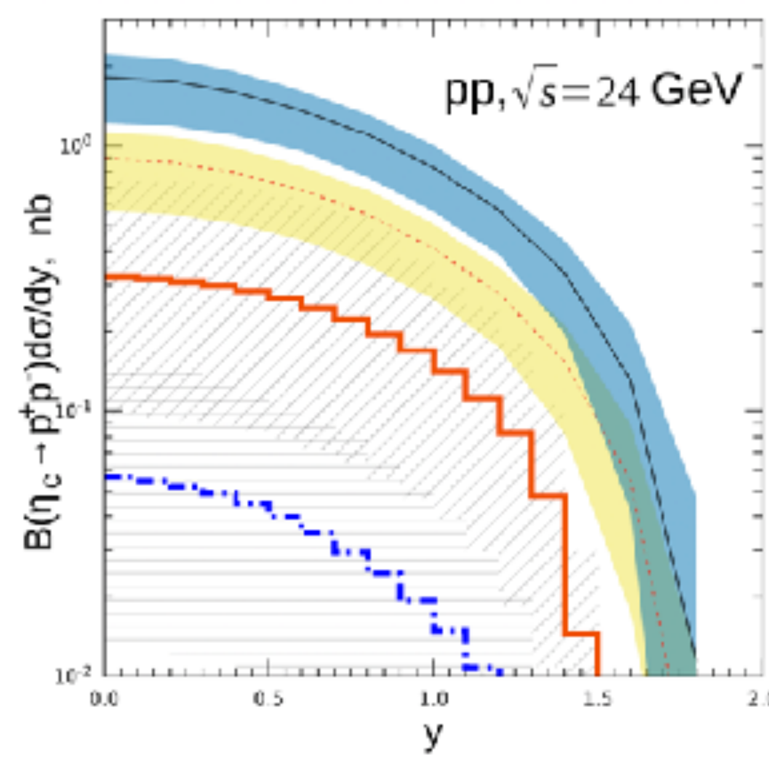


NRQCD — LDMEs

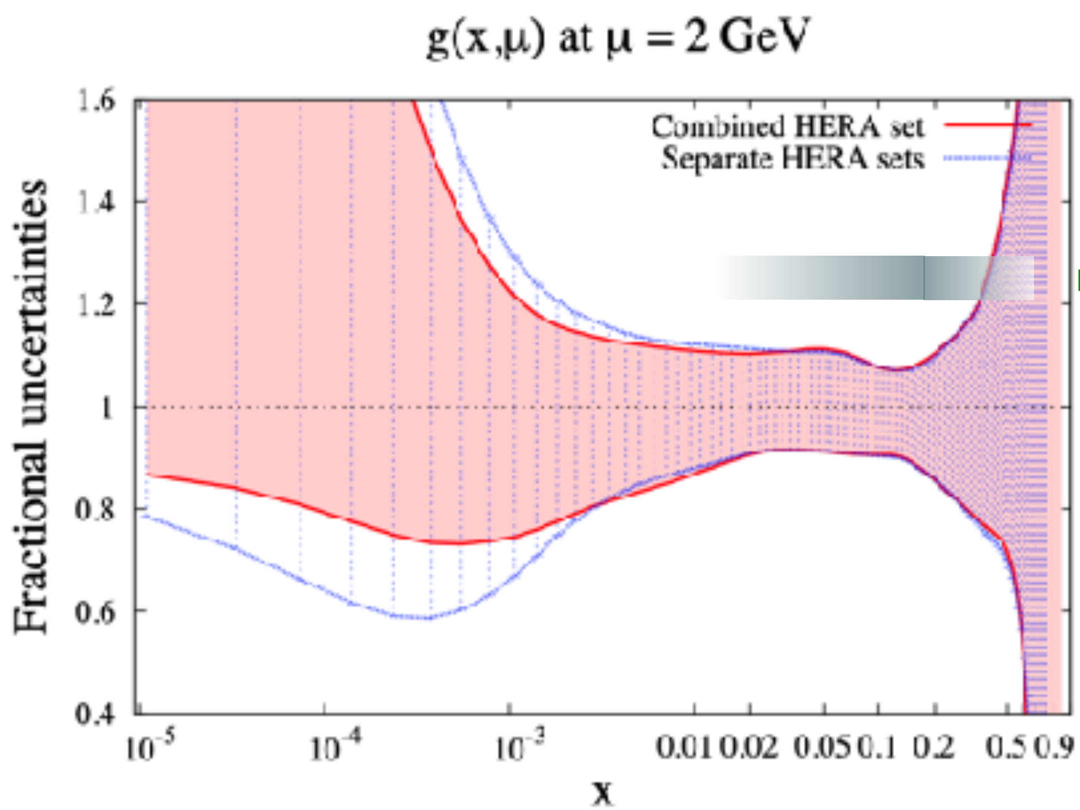




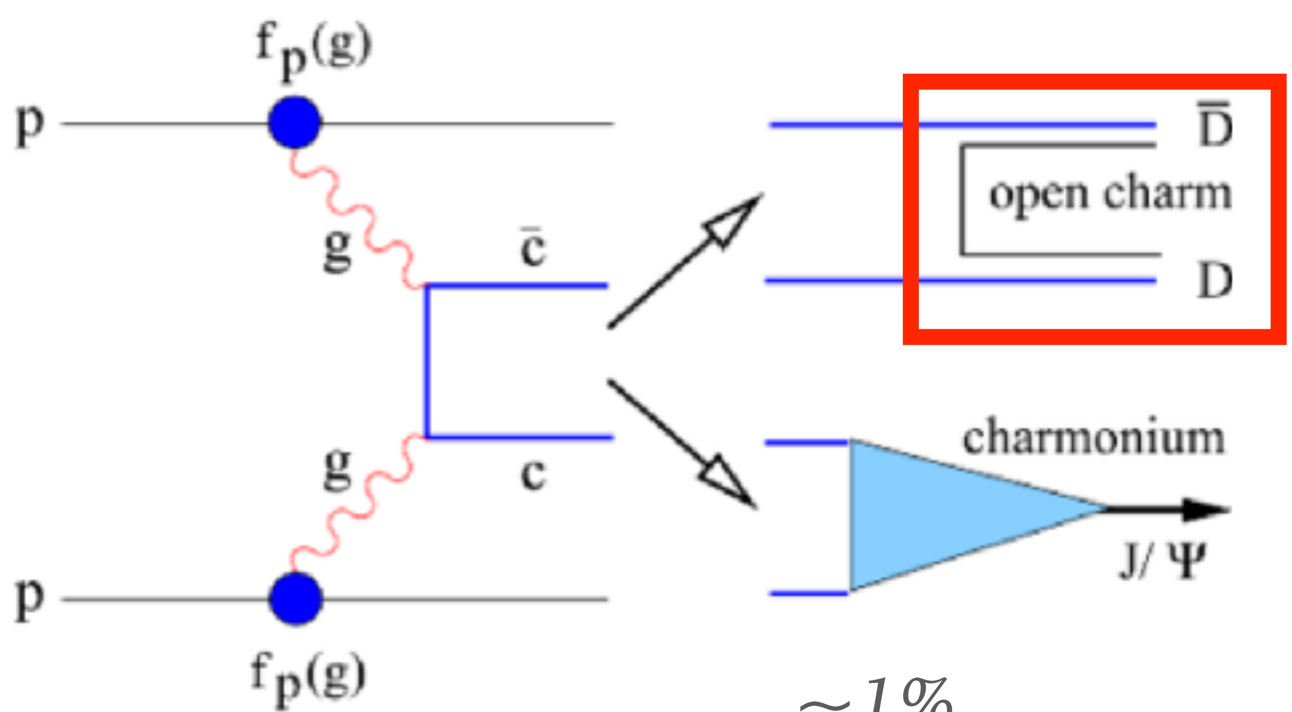




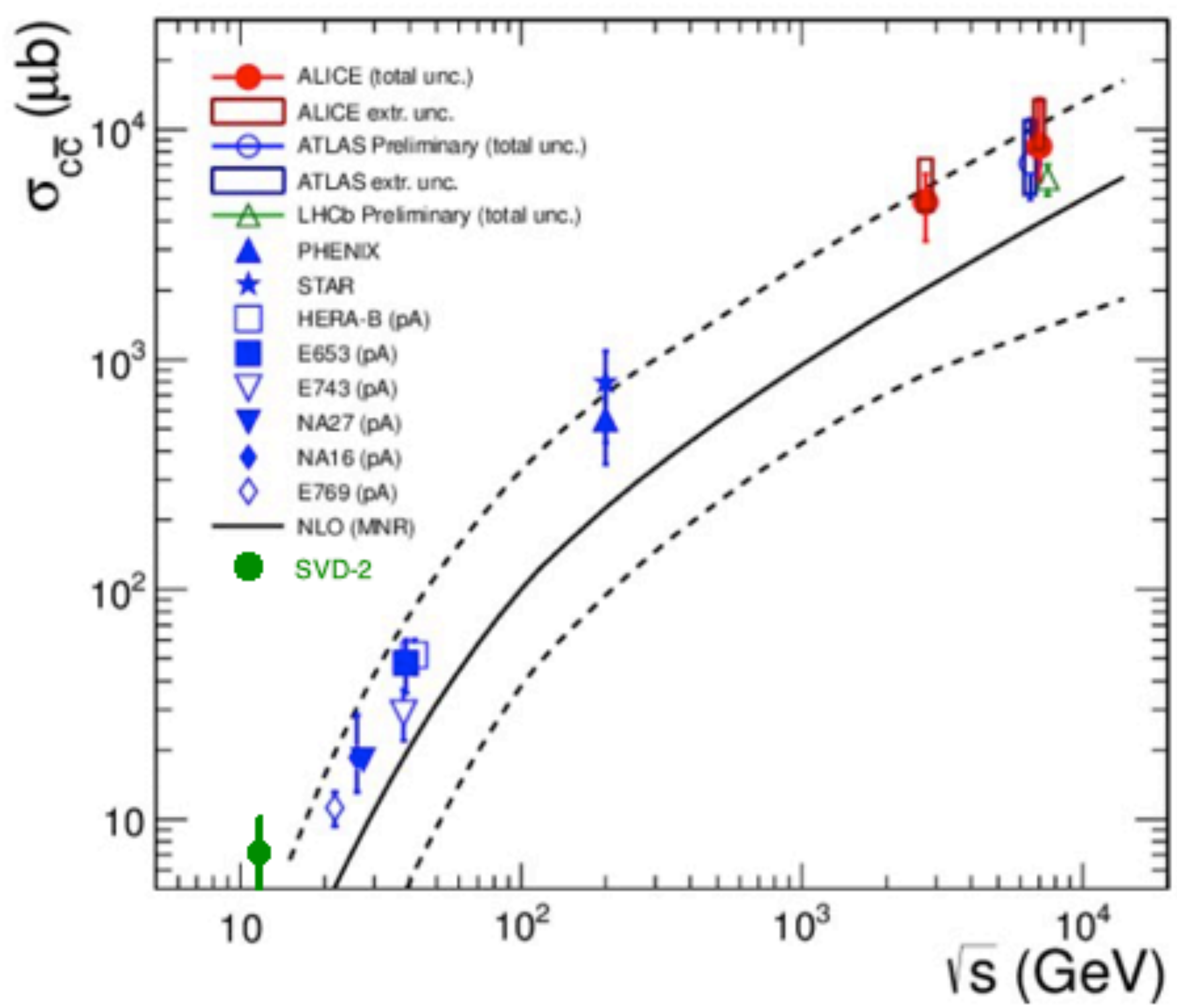
UNPOLARIZED GLUONS IN PROTON AT HIGH x



Good opportunity for SPD



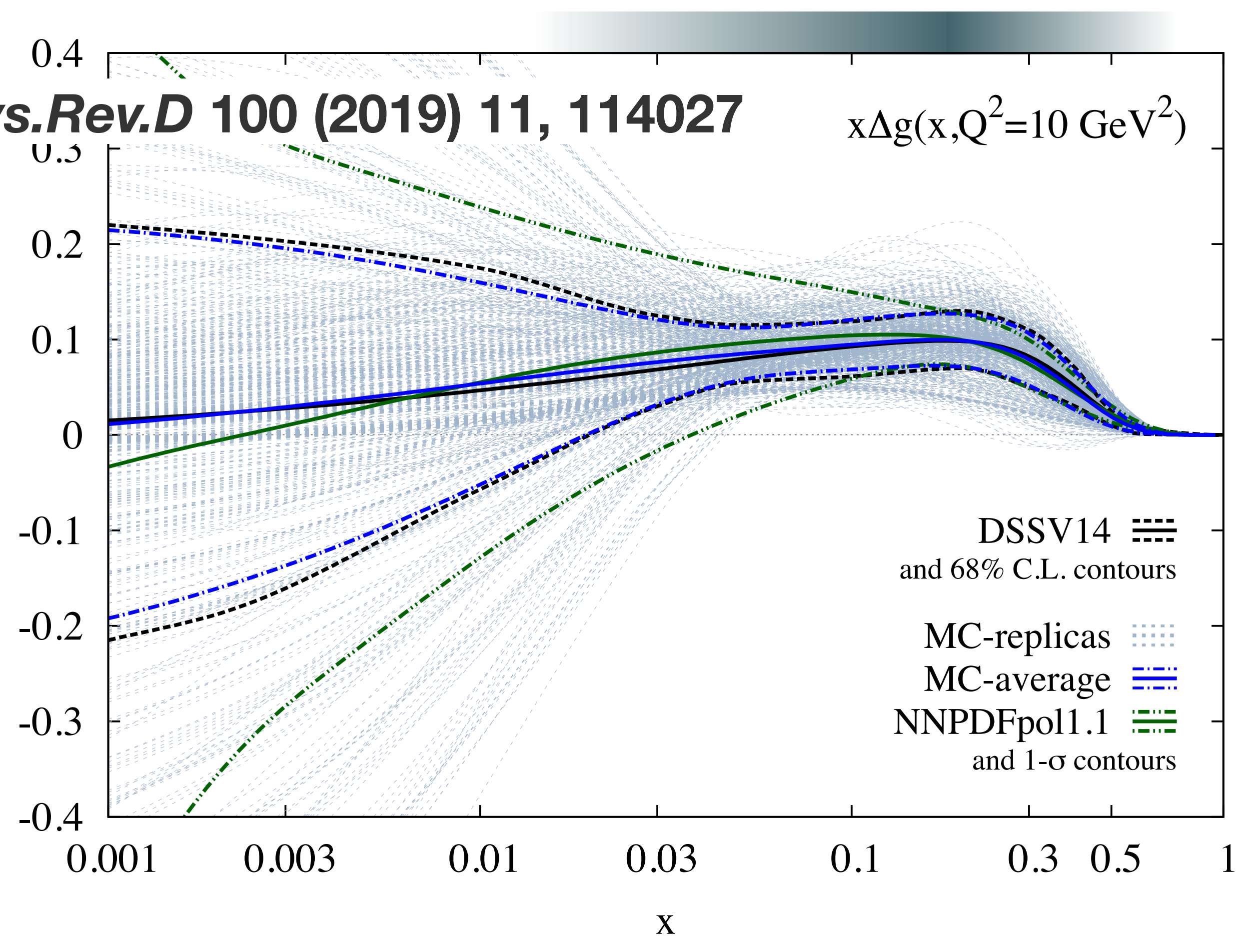
~1%



GLUON HELICITY FUNCTION $\Delta g(x)$

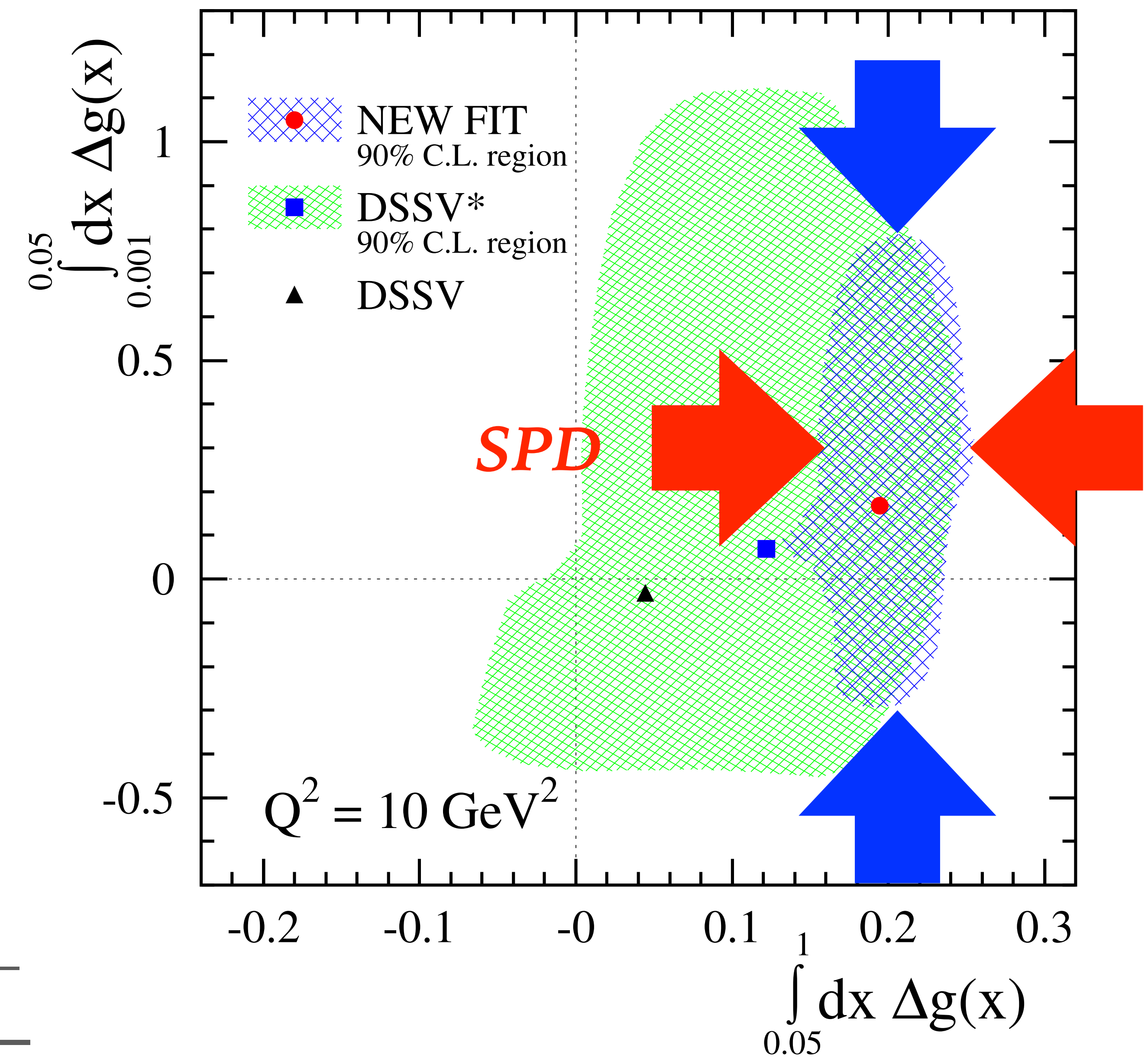
accessible with SPD

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



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

EIC

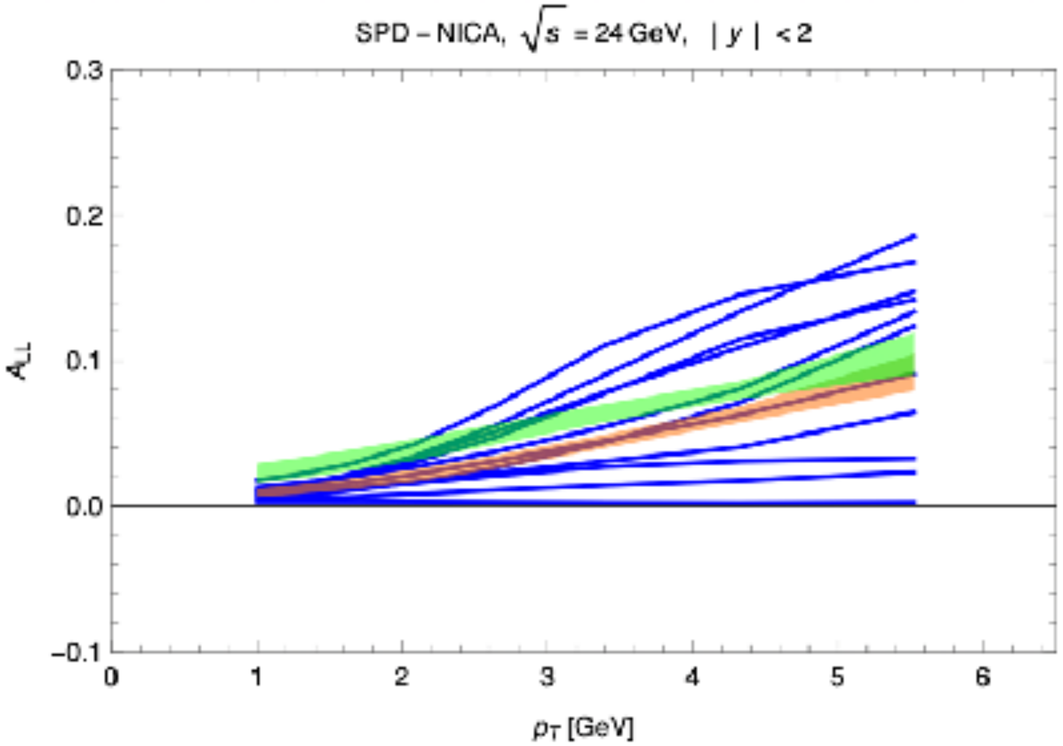


SPD could help to reduce uncertainty of ΔG at large x

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

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

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



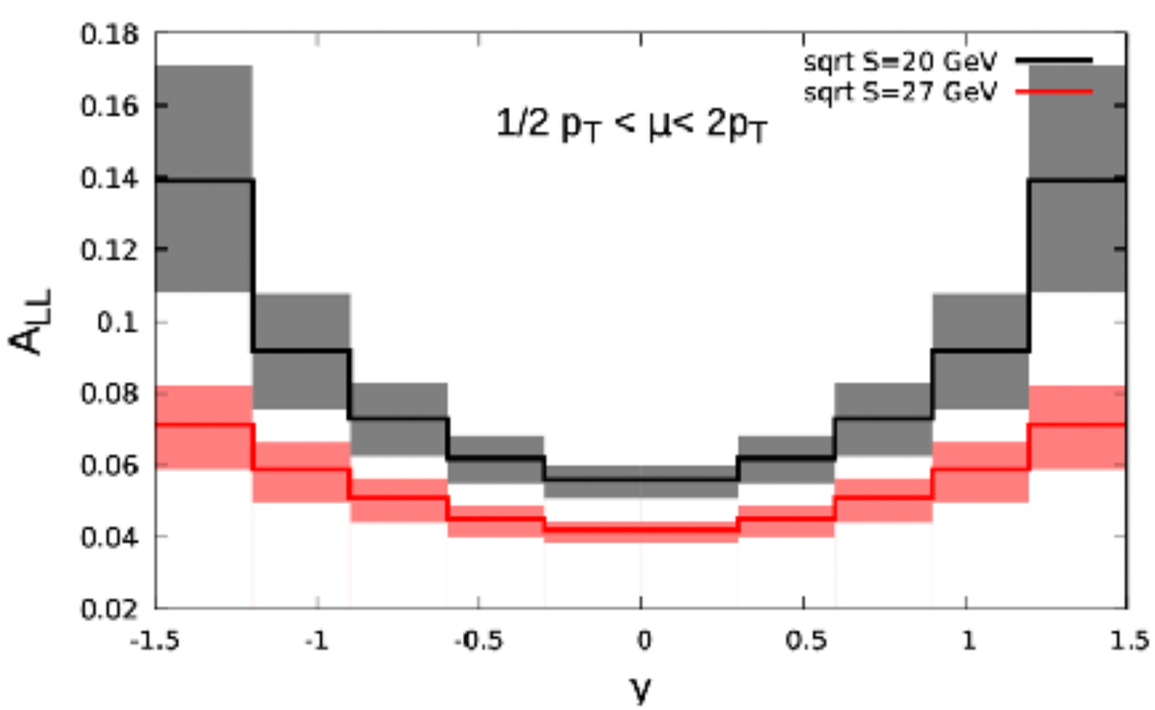
$$gg \to J/\psi g$$

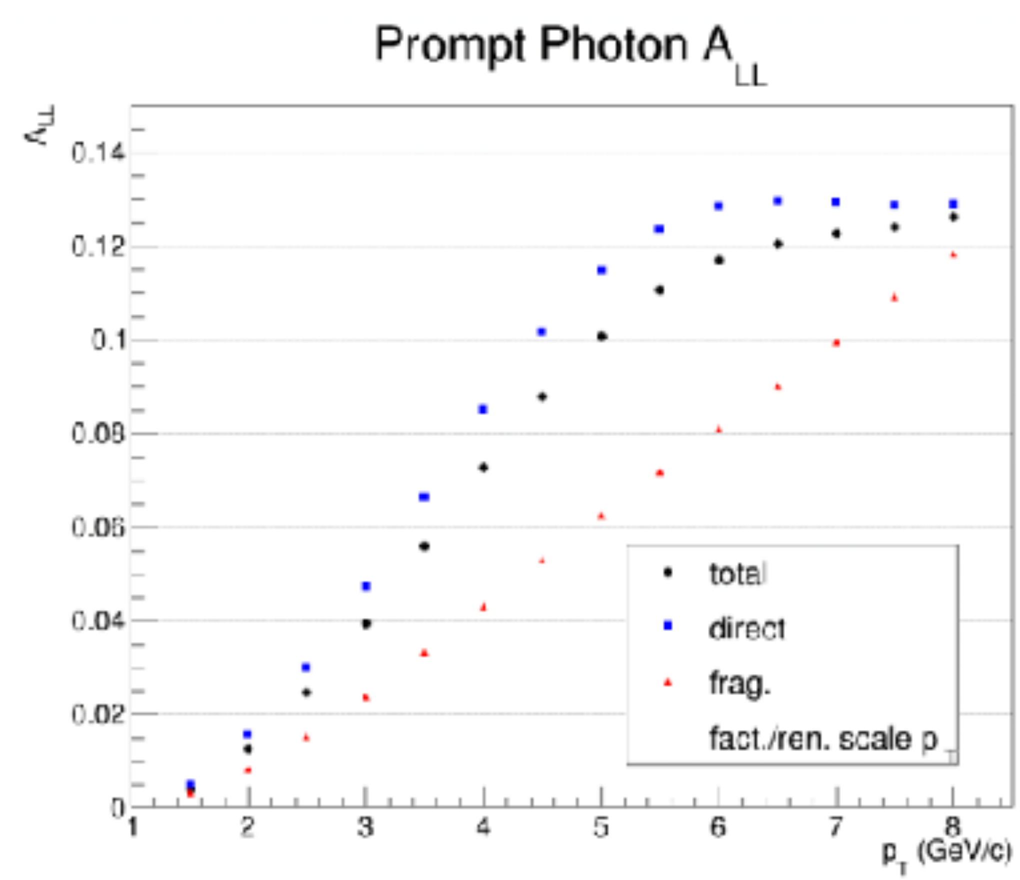
M. Nefedov

W. Vogelsang

A. Shipilova

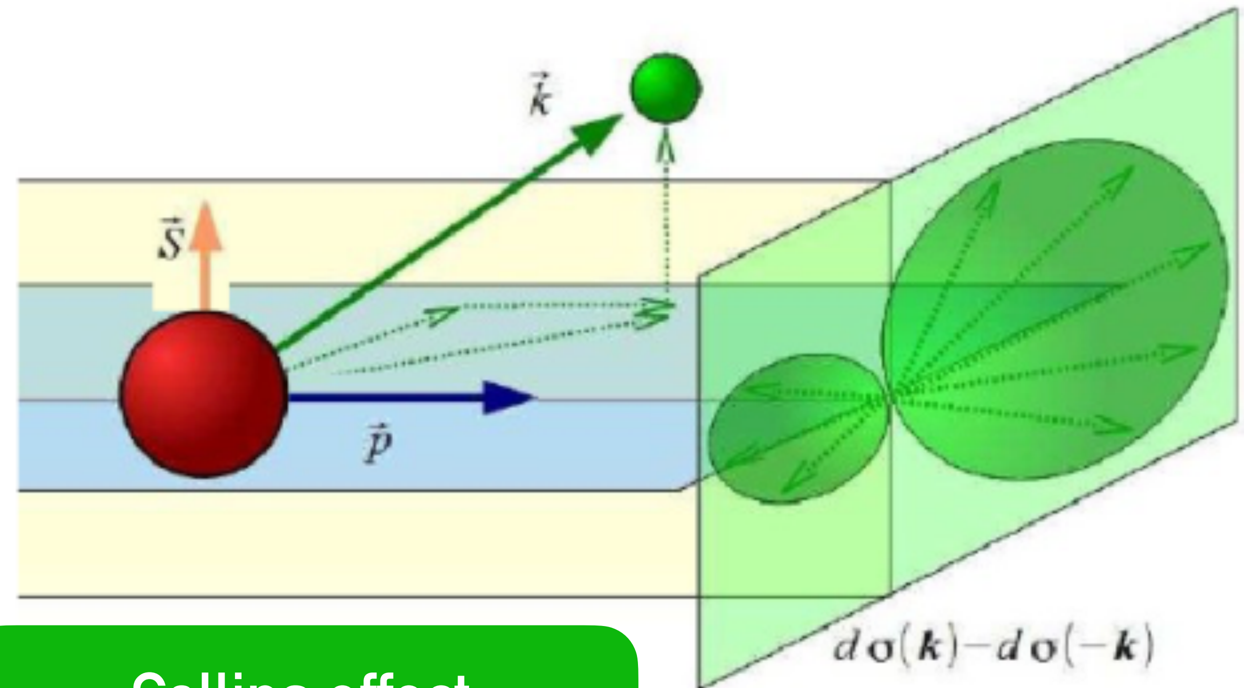
$$qg \to q\gamma$$





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*

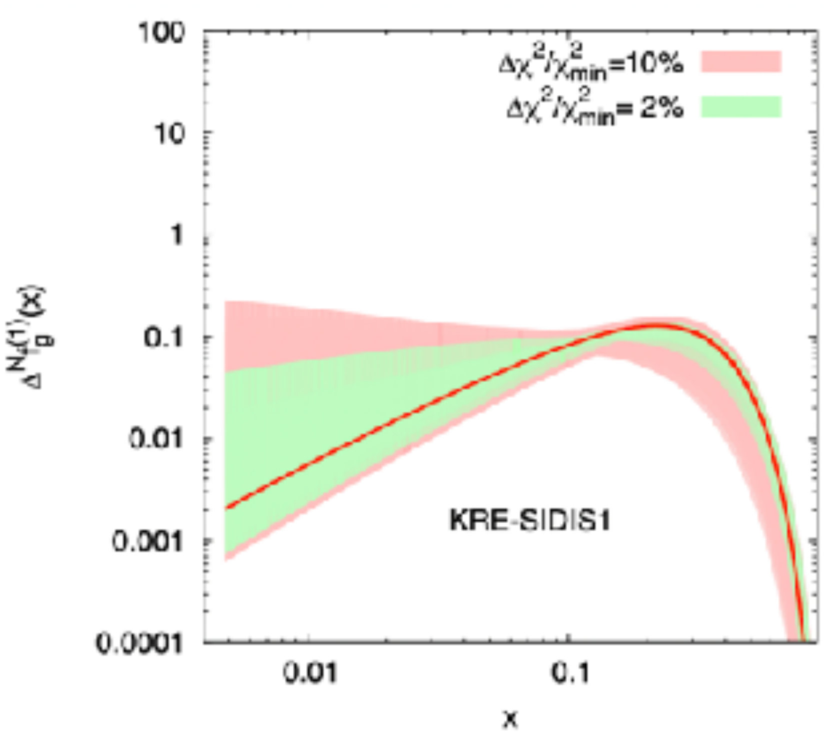


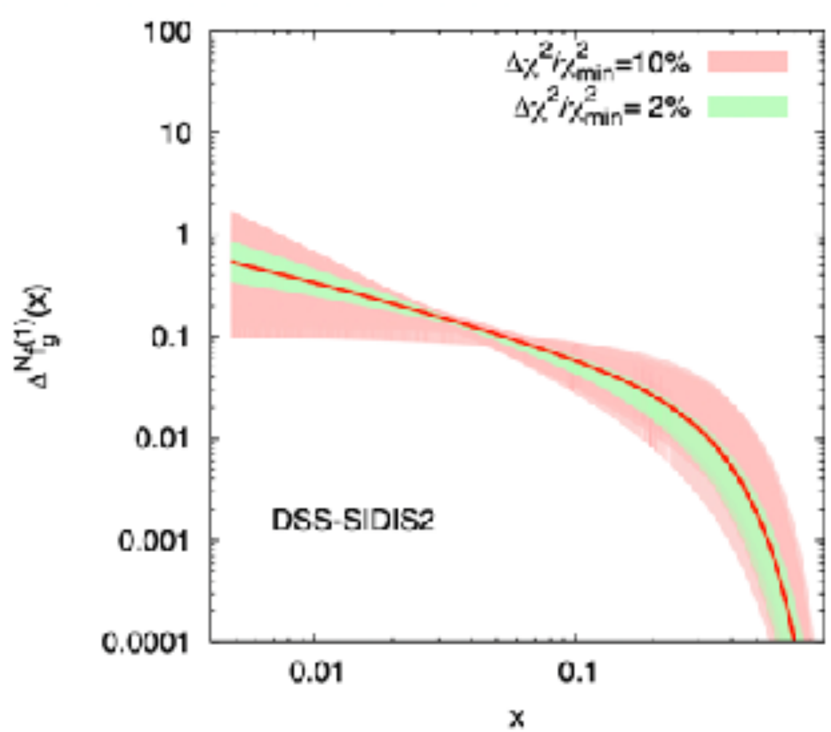
Sivers effect

Collins effect

A_N

- due to fragmentation of polarized quark

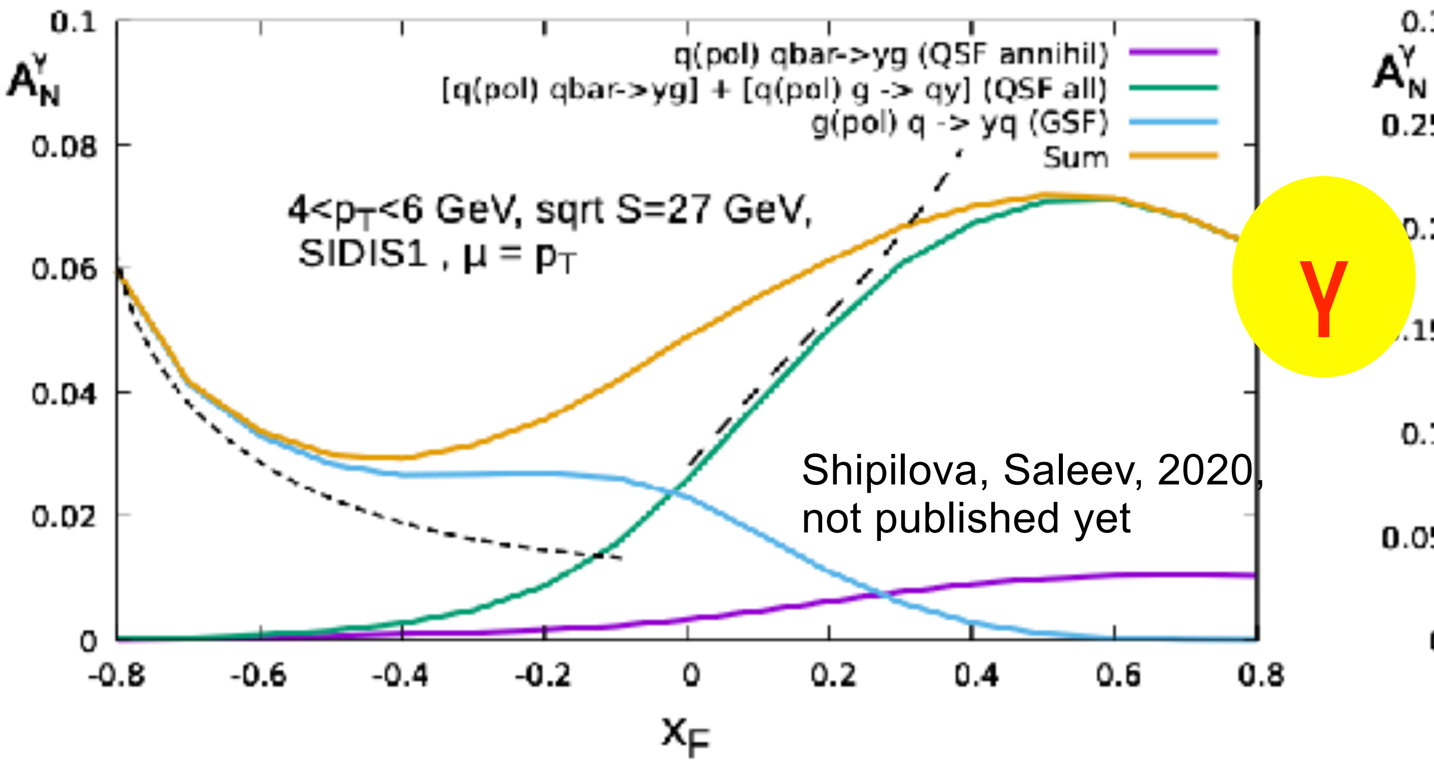


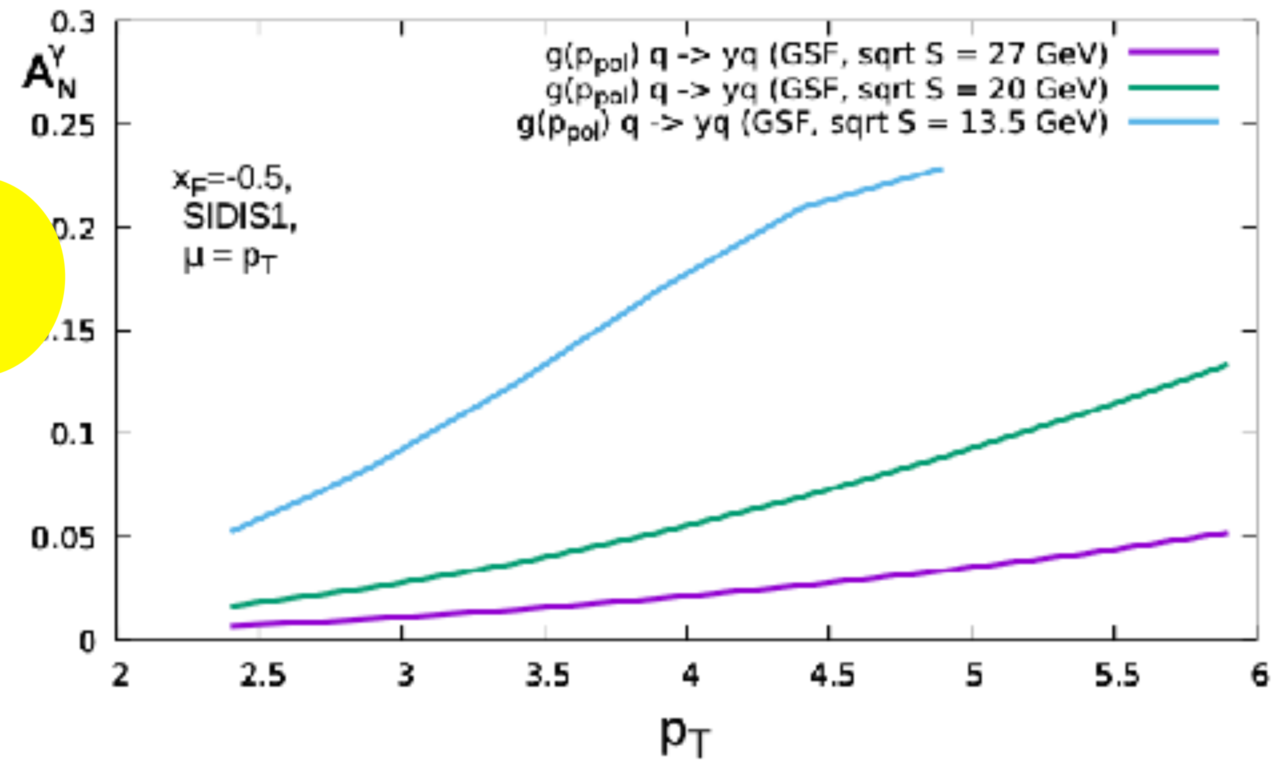


Collins effect in the first approximation is absent for chamonia and prompt-photon production:

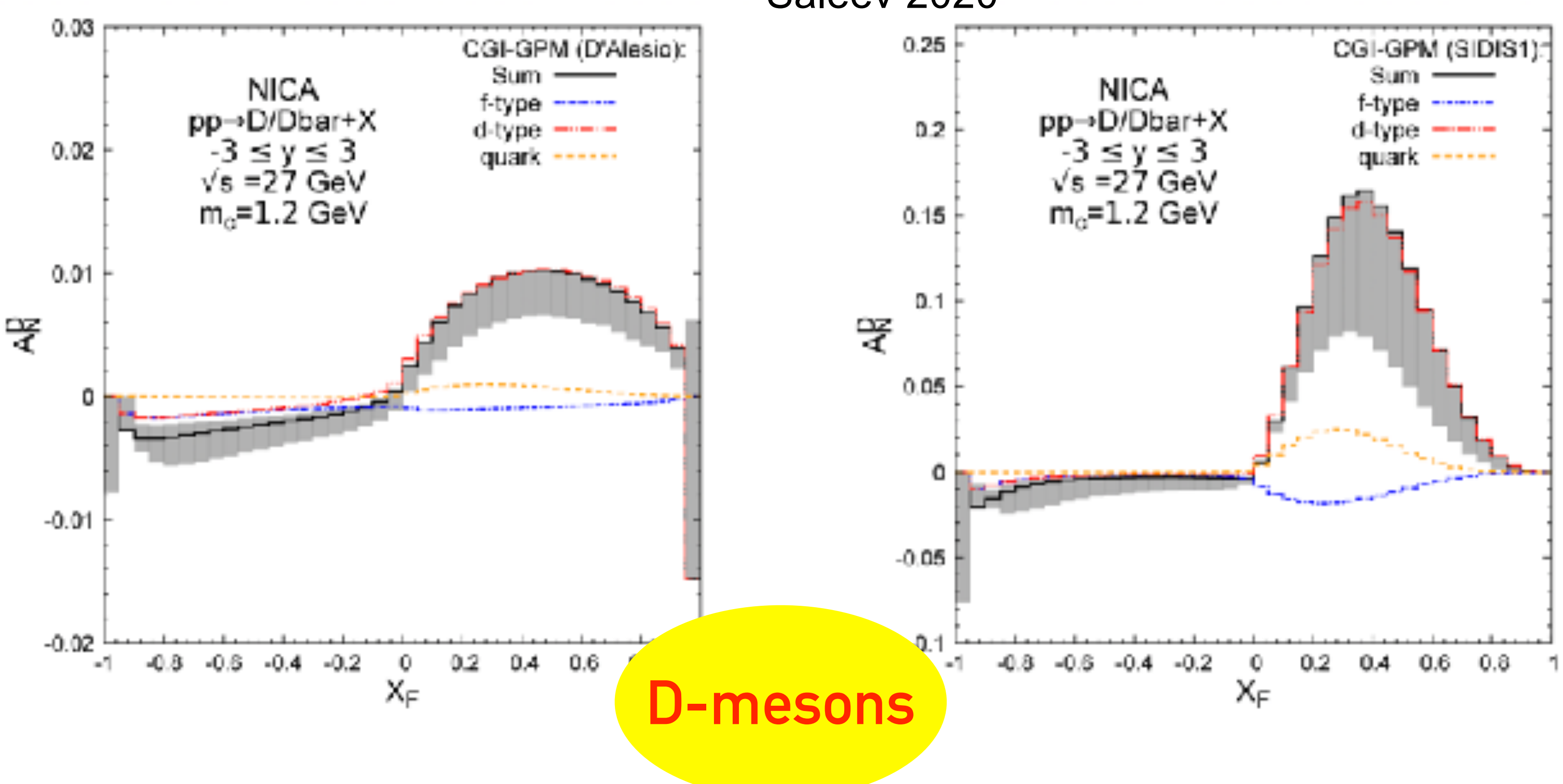
GLUON-INDUCED TMD EFFECTS: EXPECTATIONS FOR A_N

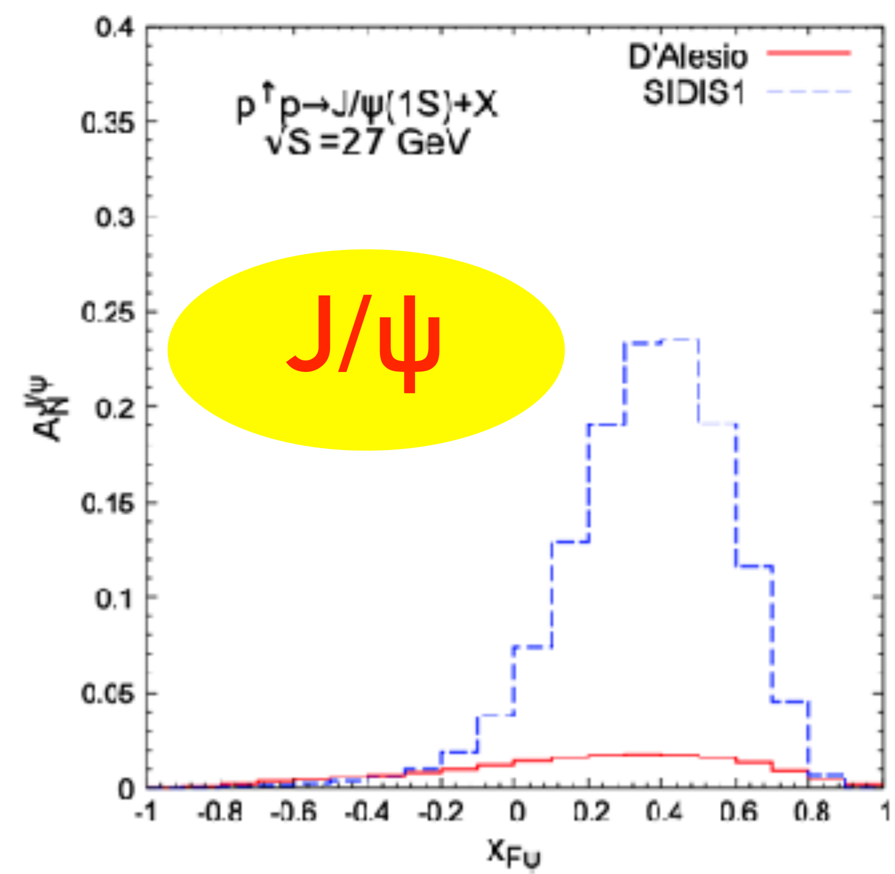
Sivers effect contribution





Saleev 2020





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]

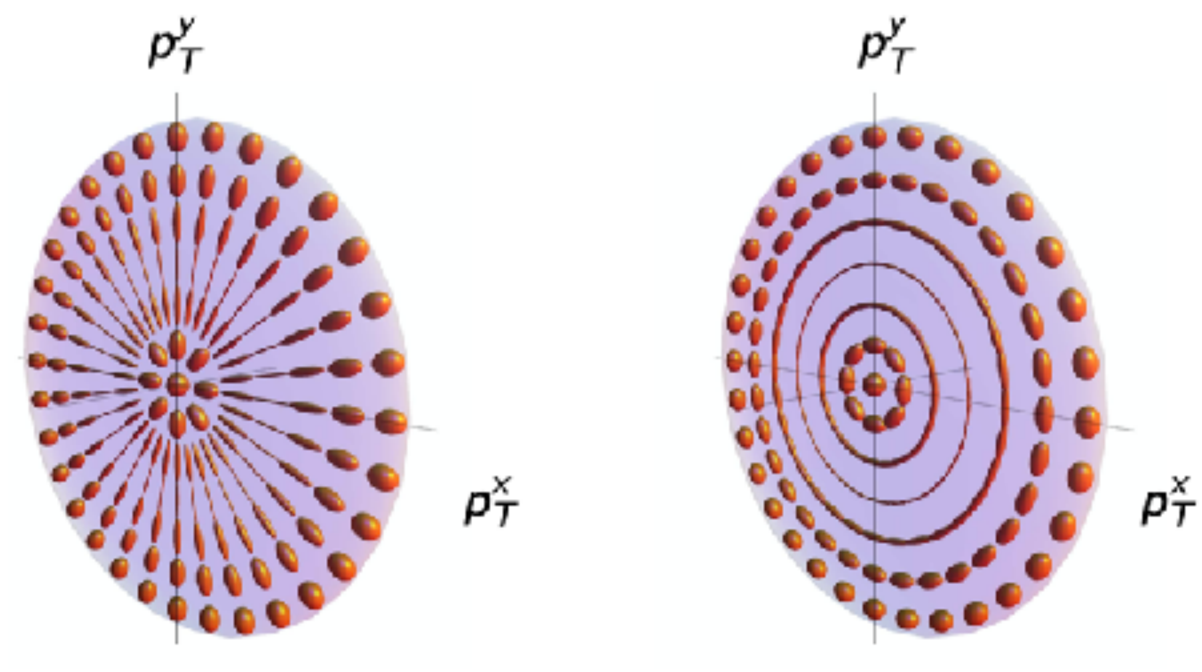
$$\frac{d\sigma(pp\to D\bar{D}X)}{d\eta_1\, d\eta_2\, d^2k_{1T}\, d^2k_{2T}} = \frac{\alpha_S}{SK_T^2}\Big[A(Q_T^2) + \boxed{B(Q_T^2)Q_T^2\cos 2(\phi_T - \phi_\perp)} + \boxed{+C(Q_T^2)Q_T^4\cos 4(\phi_Q - \phi_K)}\Big]$$

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

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

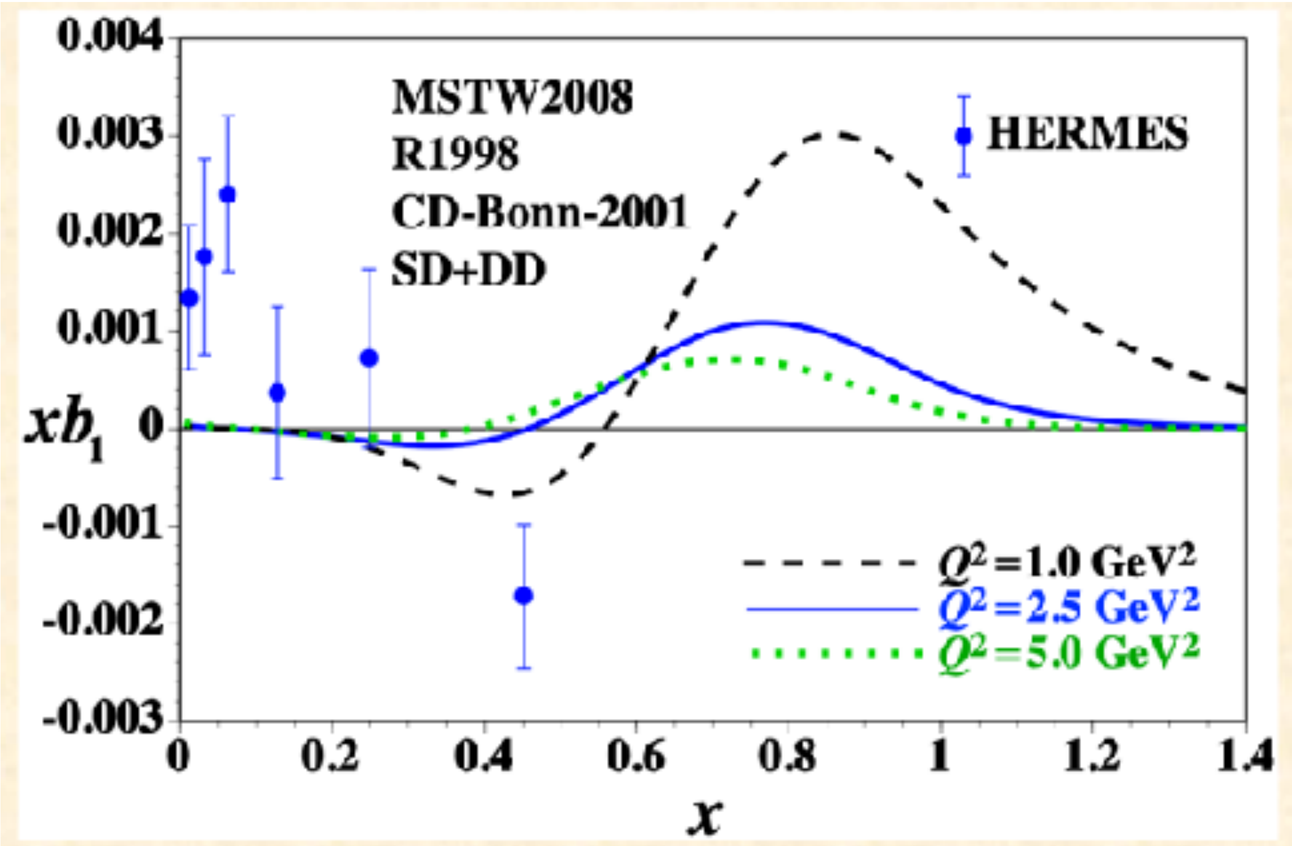
$$B: \quad h_1^{\perp\, q} \otimes h_1^{\perp\, \bar{q}},\; \frac{M_Q^2}{M_\perp^2} f_1^g \otimes h_1^{\perp\, g}\,,$$

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



$h_1^{\perp g} > 0$ $\qquad$ $h_1^{\perp g} < 0$

UNPOLARIZED GLUONS IN DEUTERON AT HIGH x



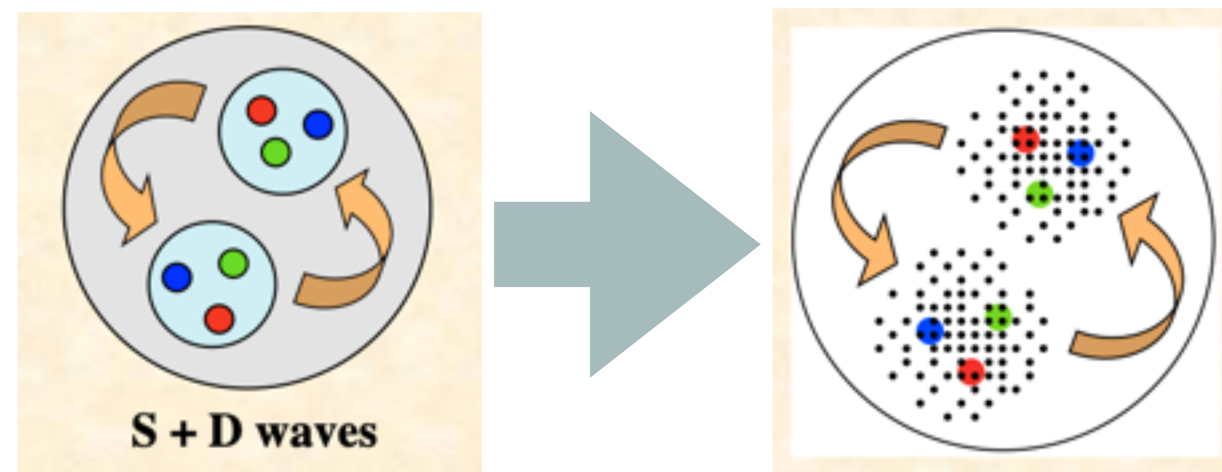
$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + c_3|CC\rangle$$

hidden color

up to 90% at some models!

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

S. Kumano



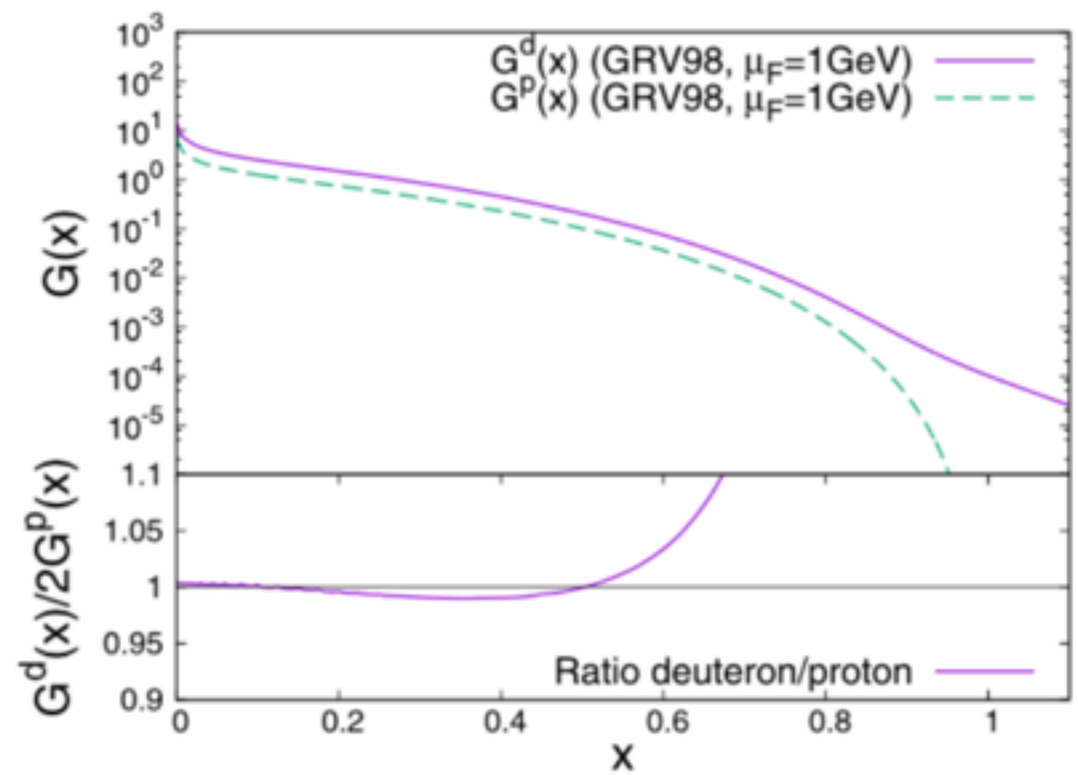
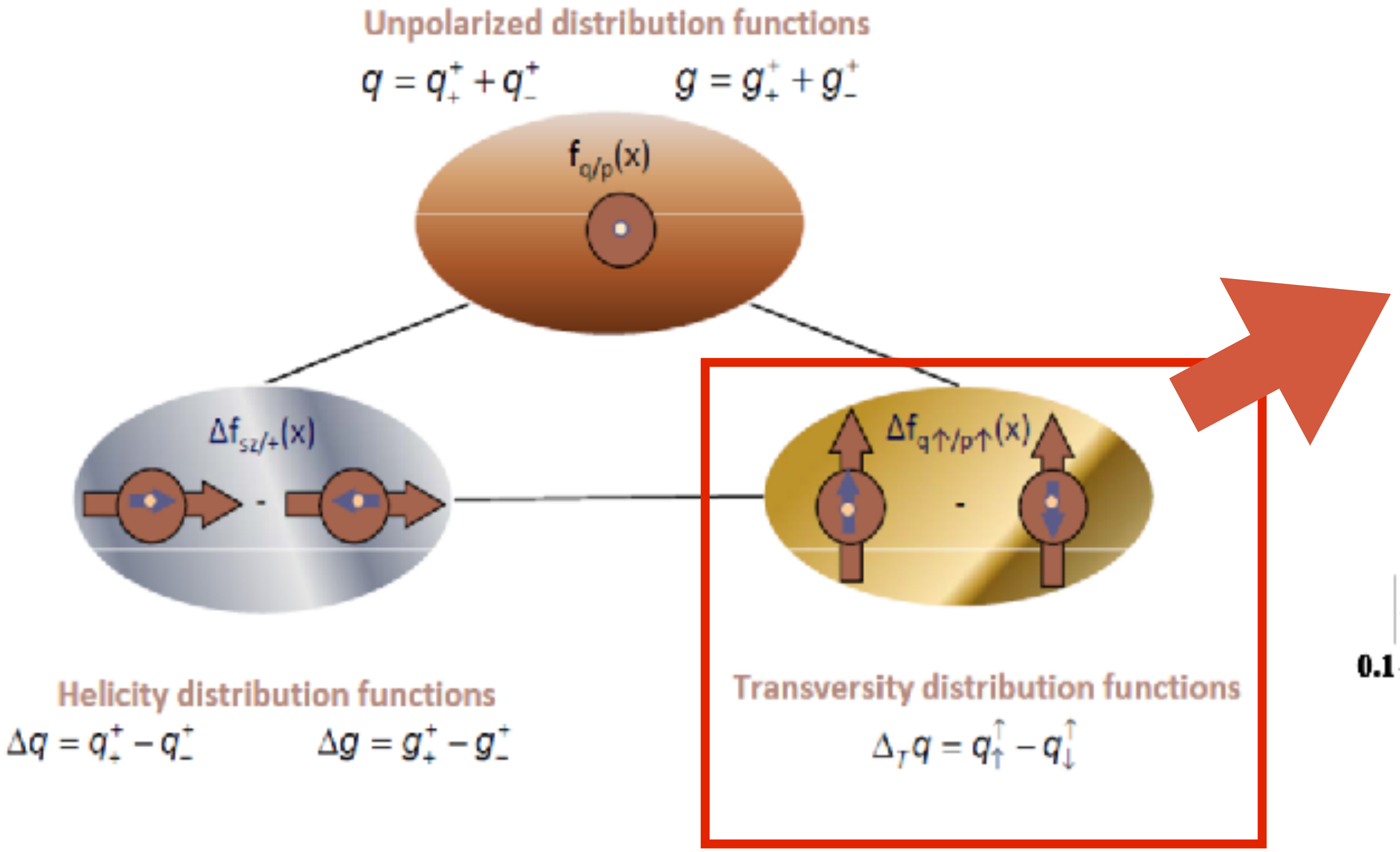


Fig. 6. Gluon PDF in the deuteron and in the nucleon.

Phys.Lett. B783 (2018) 287-293

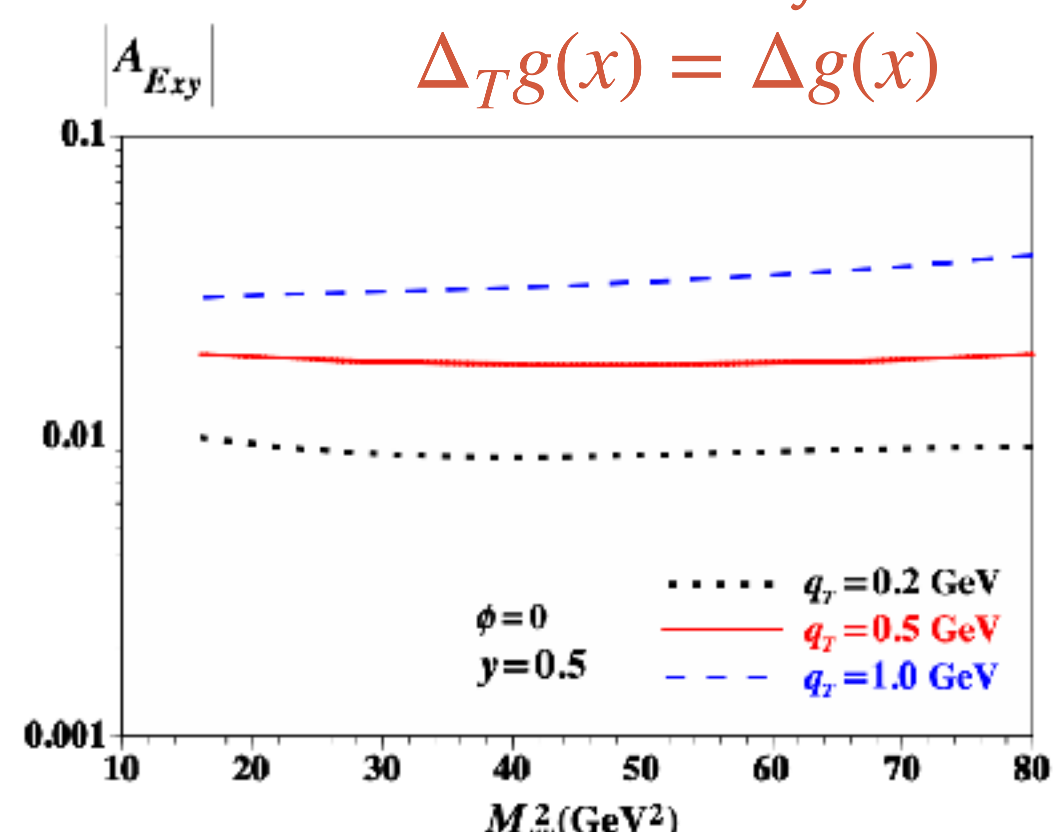
GLUON TRANSVERSITY $\Delta g_T(x)$ IN DEUTERON



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

Sh. Kumano for DY:

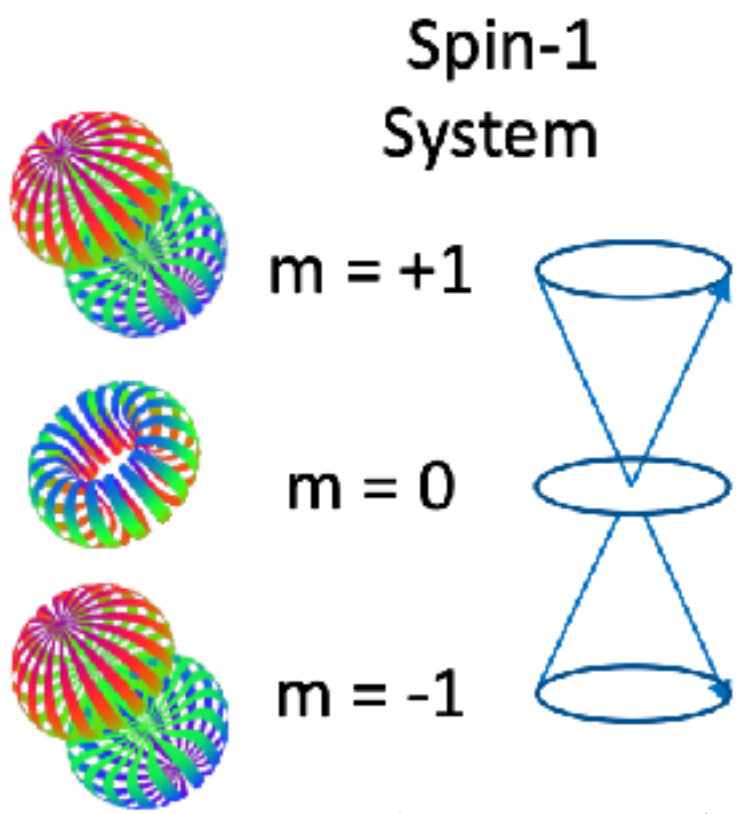
$\Delta_T g(x) = \Delta g(x)$



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!

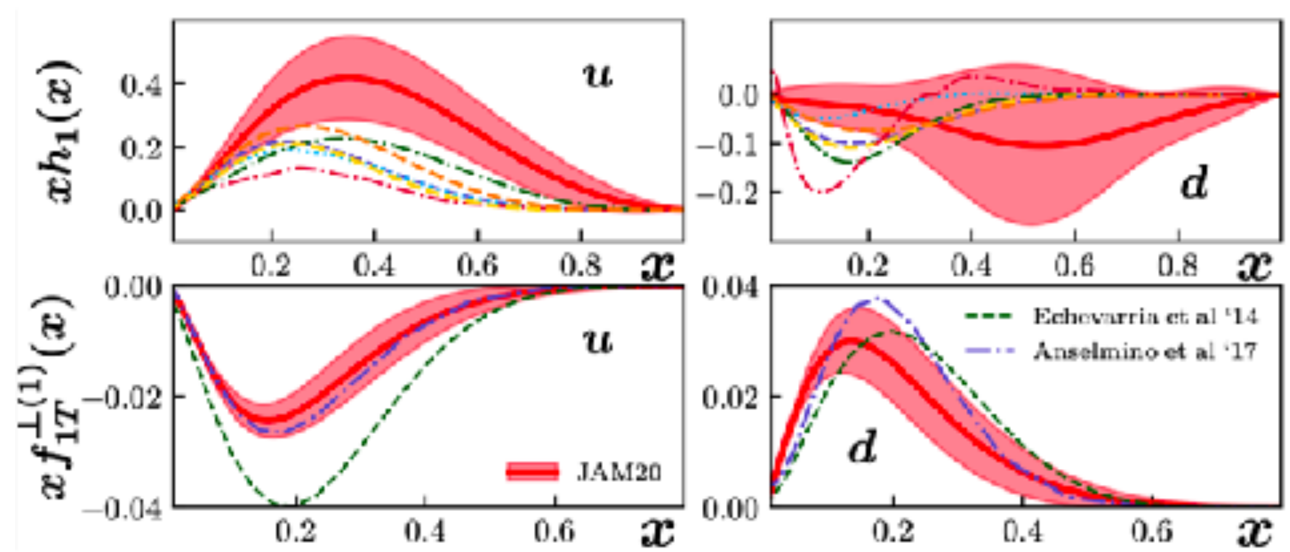
OTHER TASKS RELATED WITH THE PARTONIC STRUCTURE

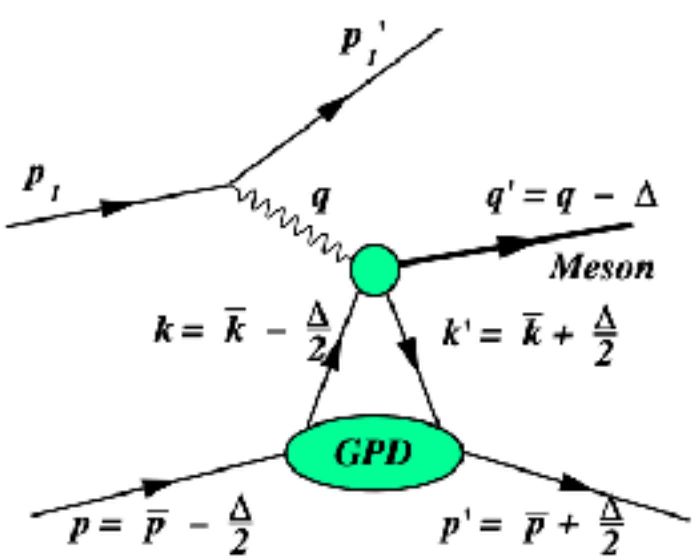
Tensor structure of deuteron:



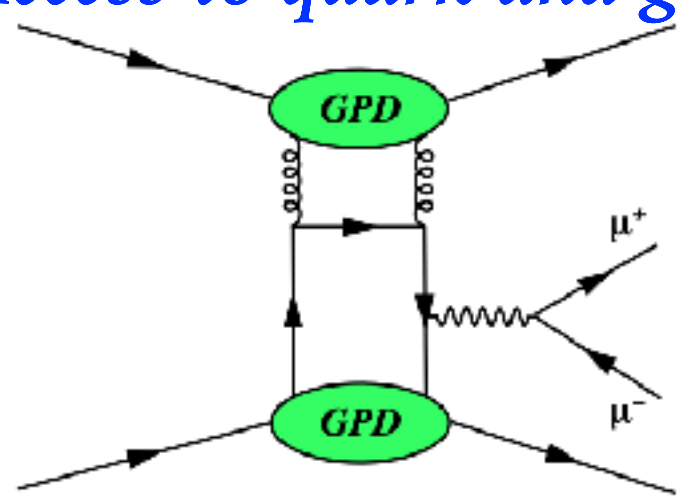
New structure functions: ***b*₁**, *b*₂, *b*₃, *b*₄

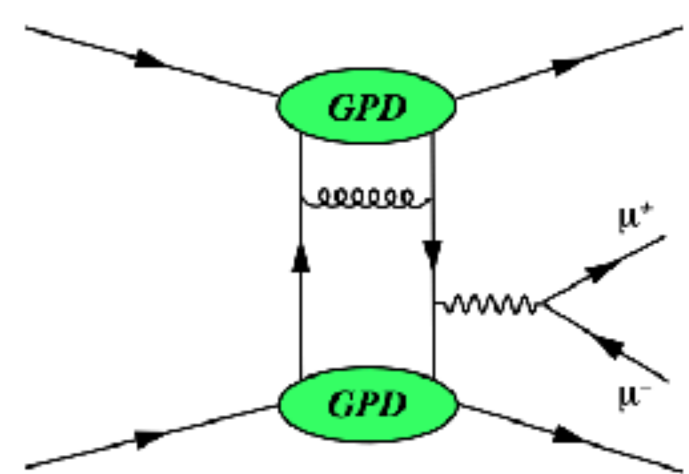
STSA with light hadrons — contribution to global fit of quark TMDs





Access to quark and gluon GPDs





PHYSICS OF THE FIRST STAGE OF SPD RUNNING

- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Open charm and charmonia near threshold
- Auxiliary measurements for astrophysics
- …

arXiv:2102.08477

RATES FOR MAIN PROBES

Probe	$\sigma_{27\,\text{GeV}}$, nb ($\times$BF)	$\sigma_{13.5\,\text{GeV}}$, nb ($\times$BF)	$N_{27\,\text{GeV}}$, 10^6	$N_{13.5\,\text{GeV}}$ 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

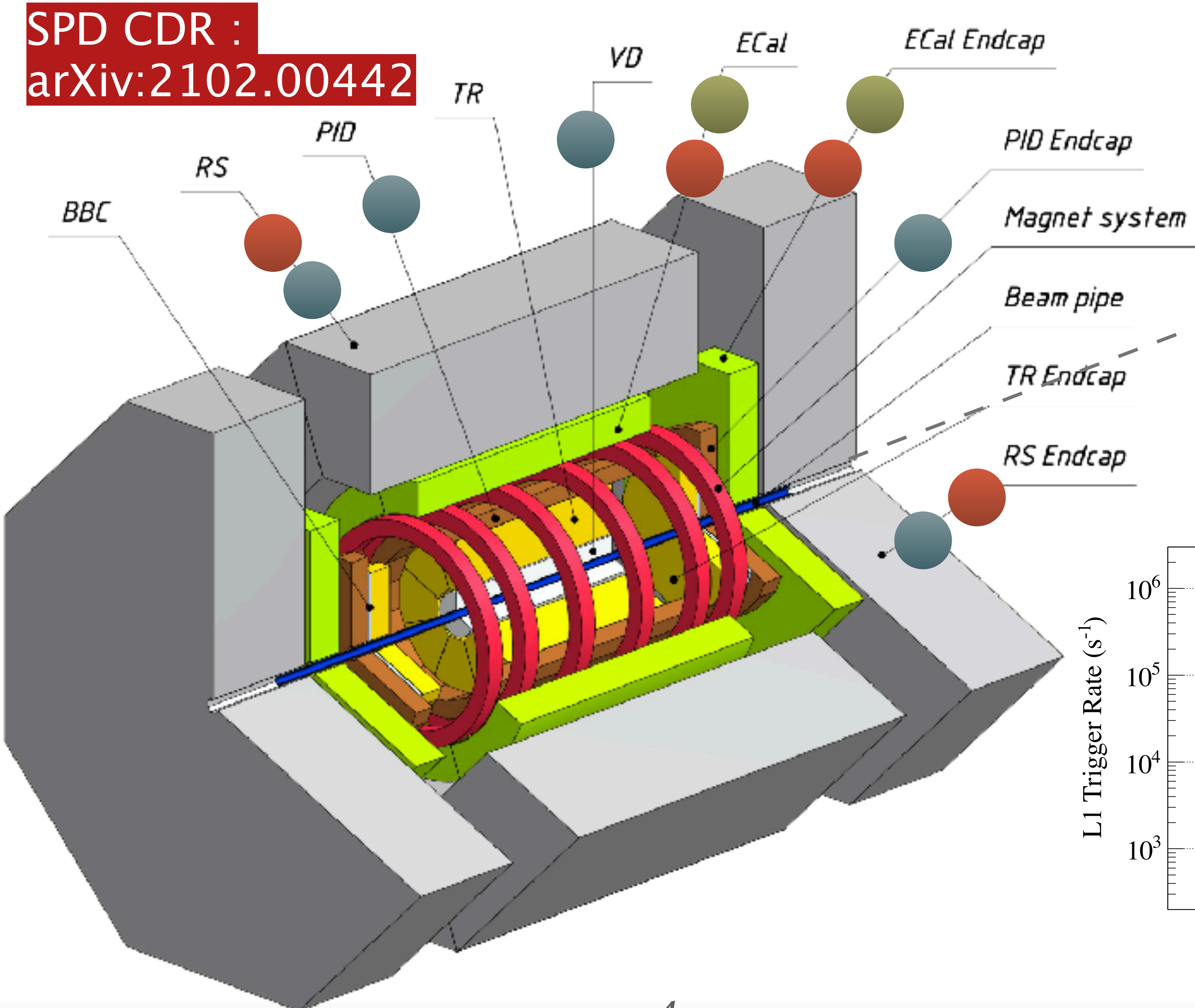
SPD DETECTOR

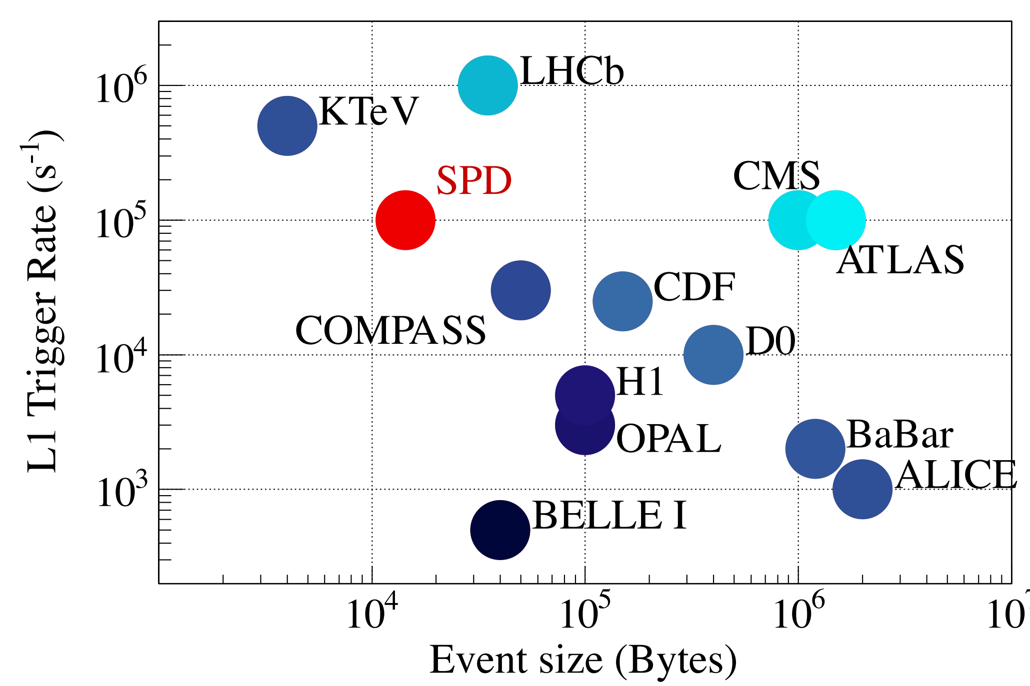
SPD CDR :
arXiv:2102.00442

Charmonia

Prompt photons

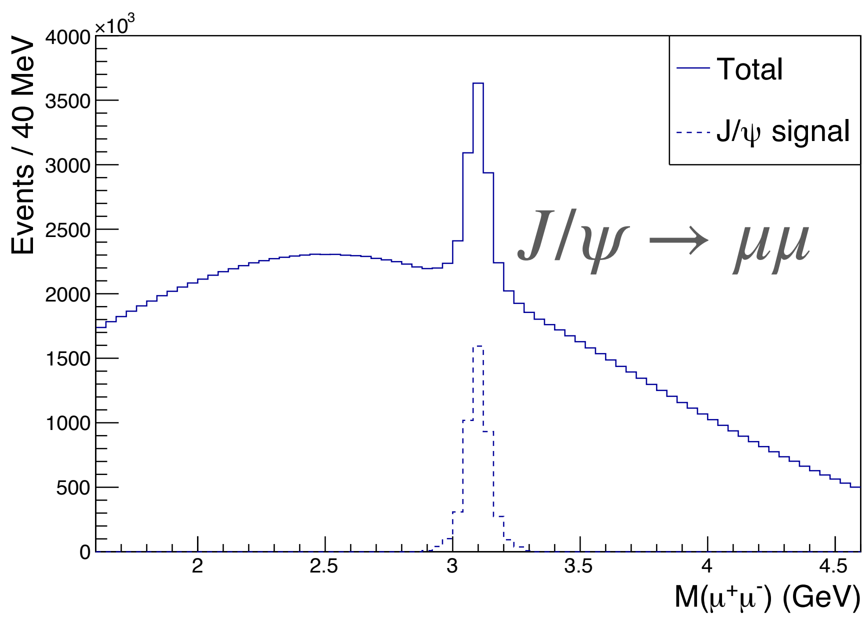
Open charm

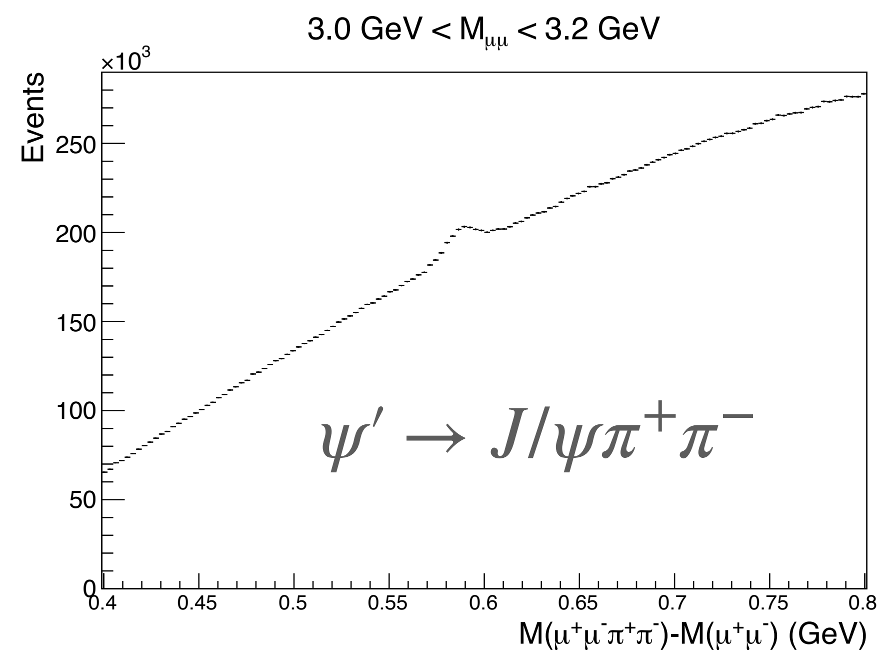


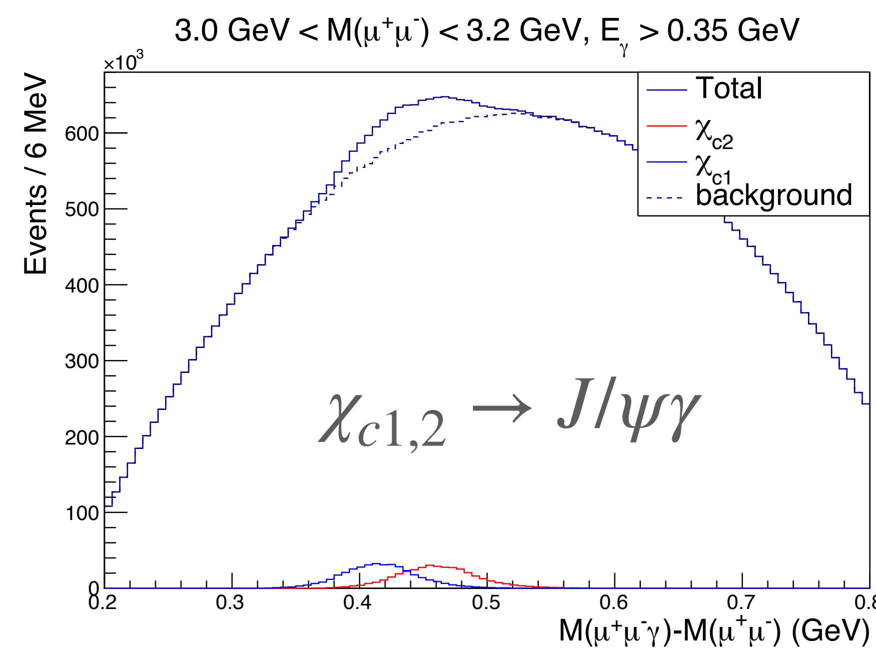


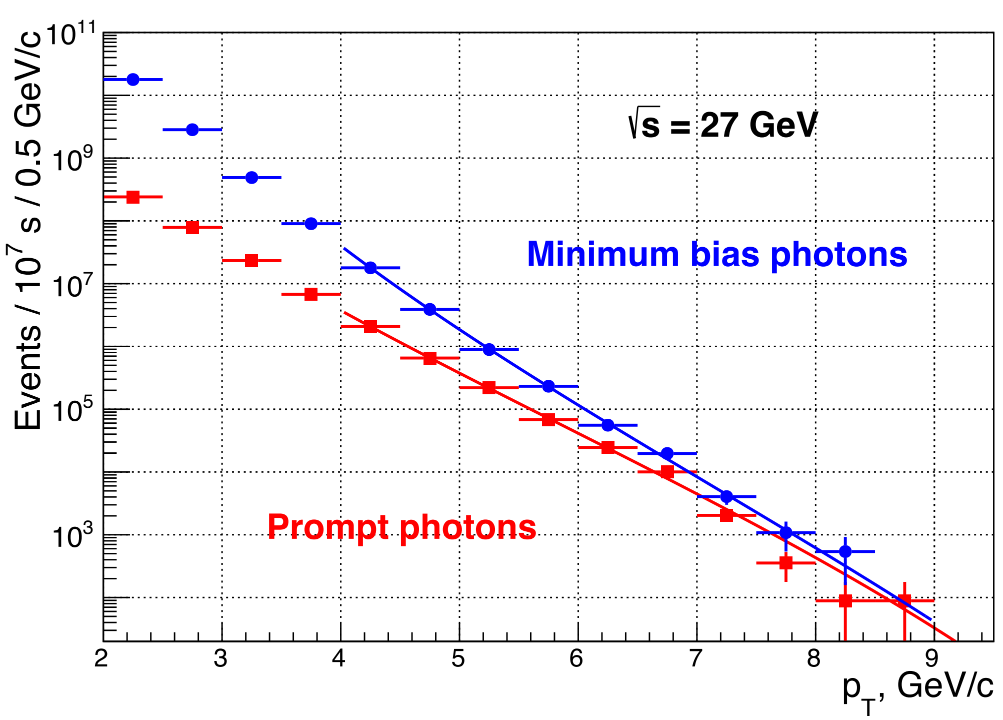
$\sim 4\pi$

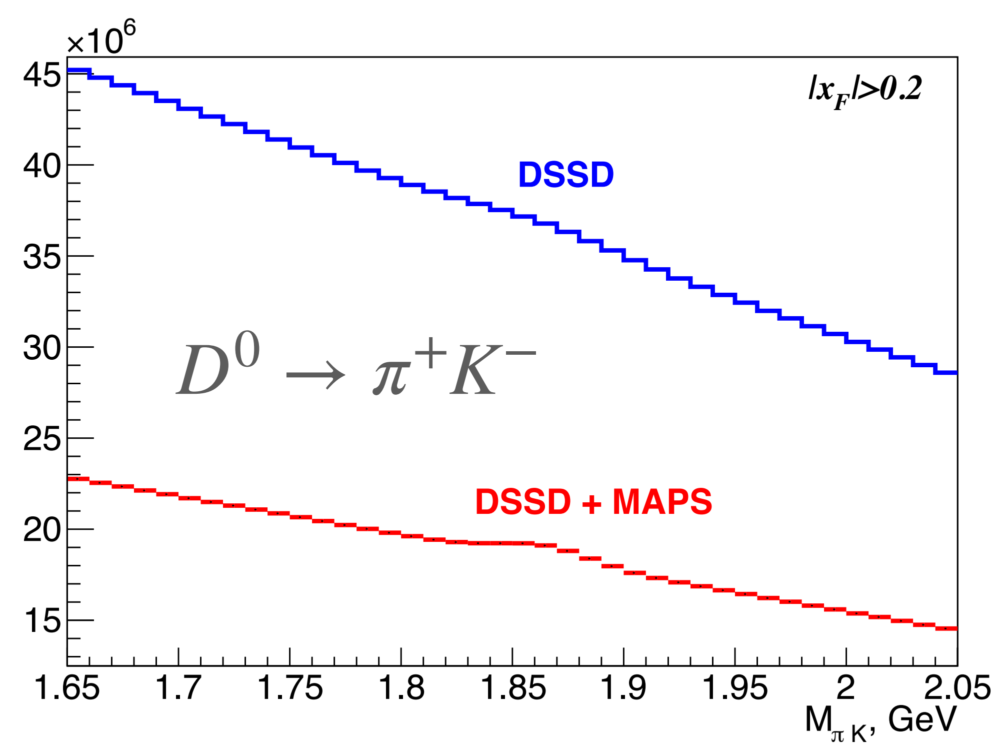
PHYSICS PERFORMANCE: GLUON PROBES (1 YEAR=10^7 S)



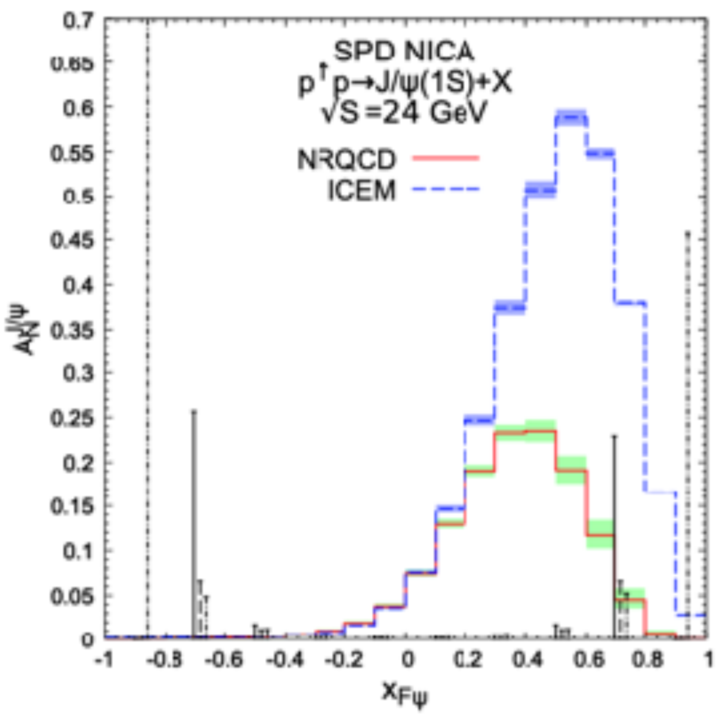




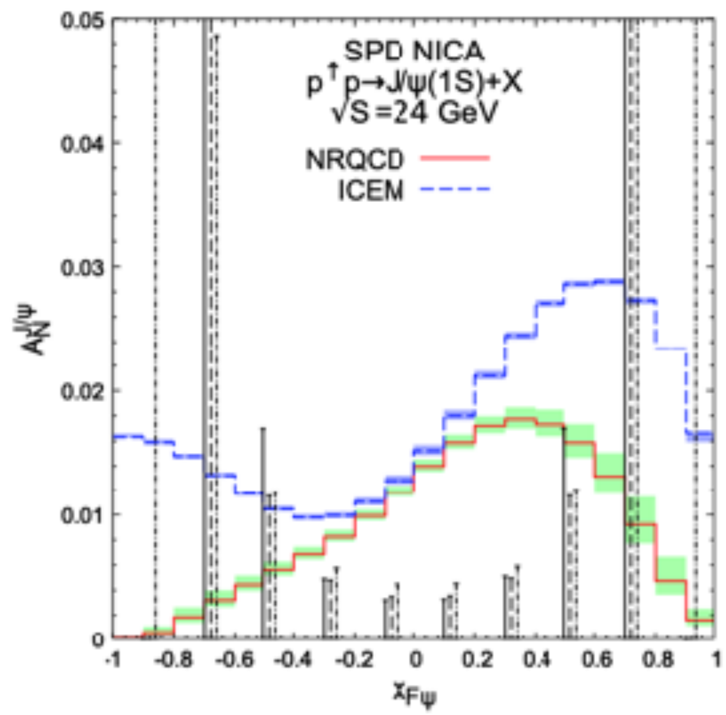


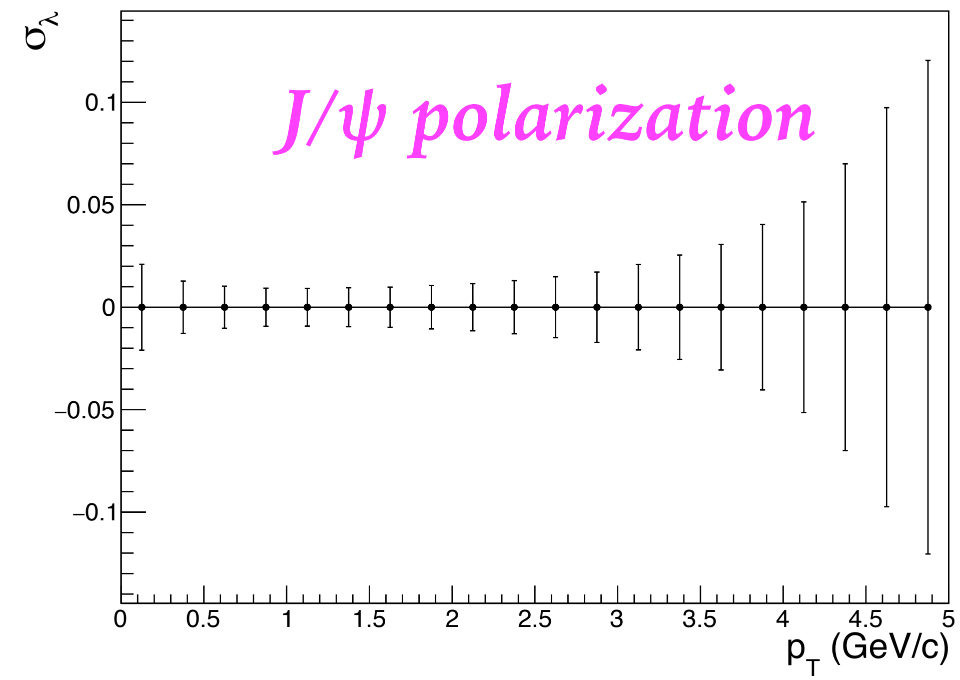


PHYSICS PERFORMANCE: ACCURACIES

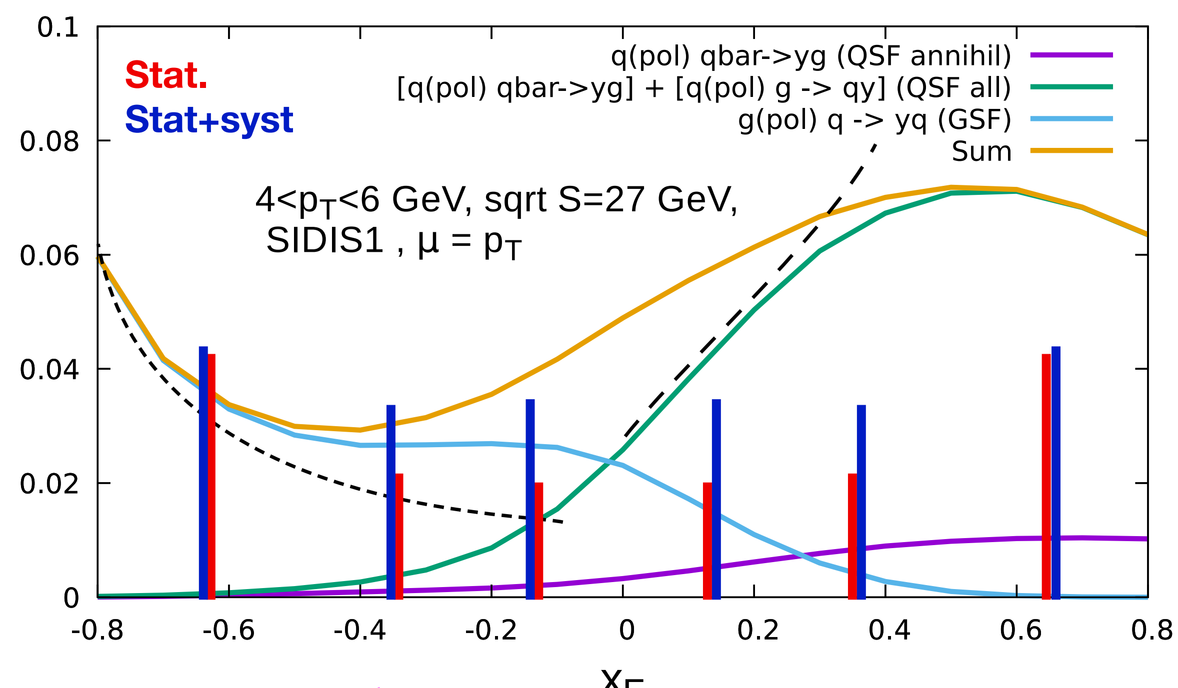


J/ψ

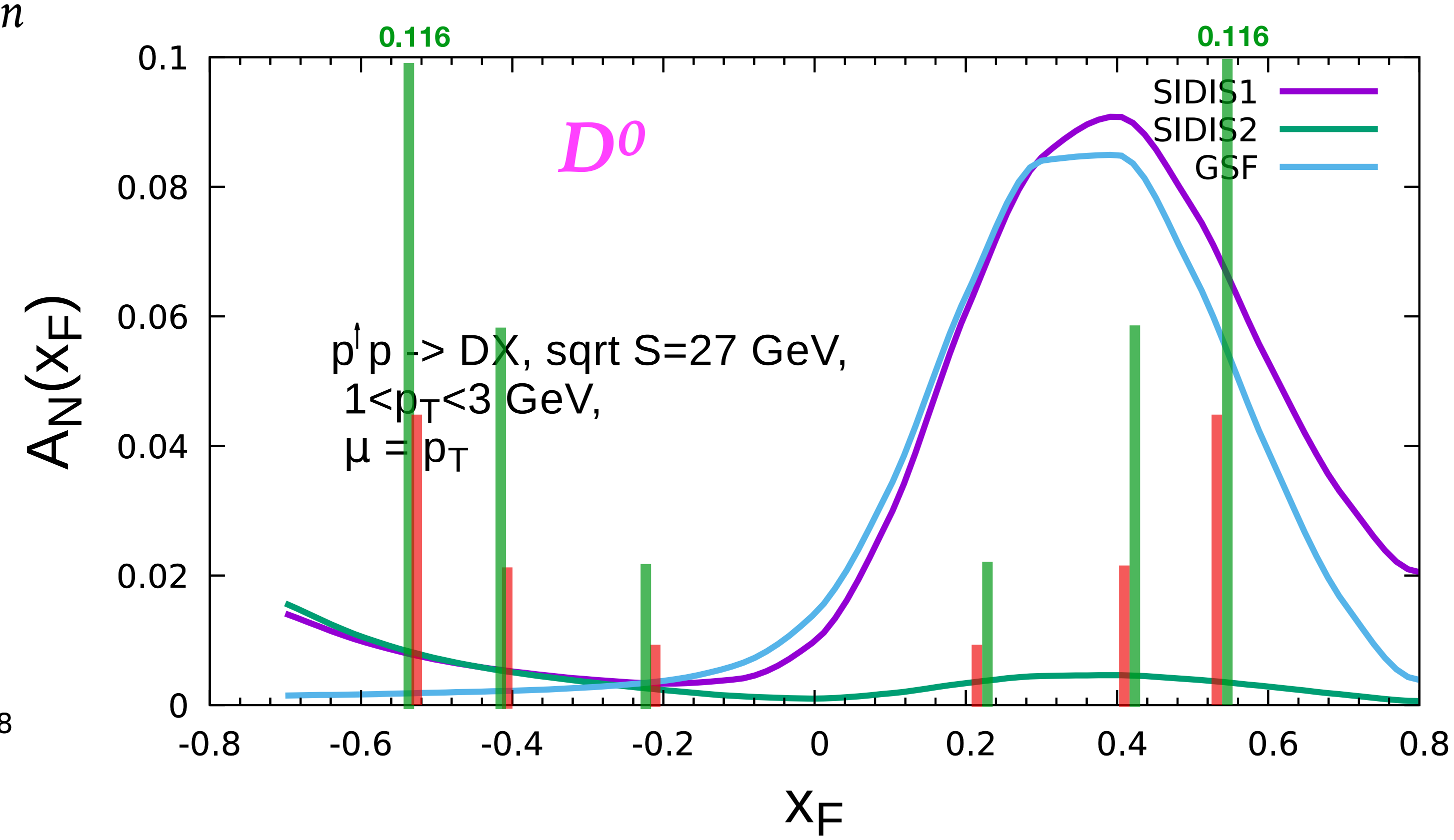




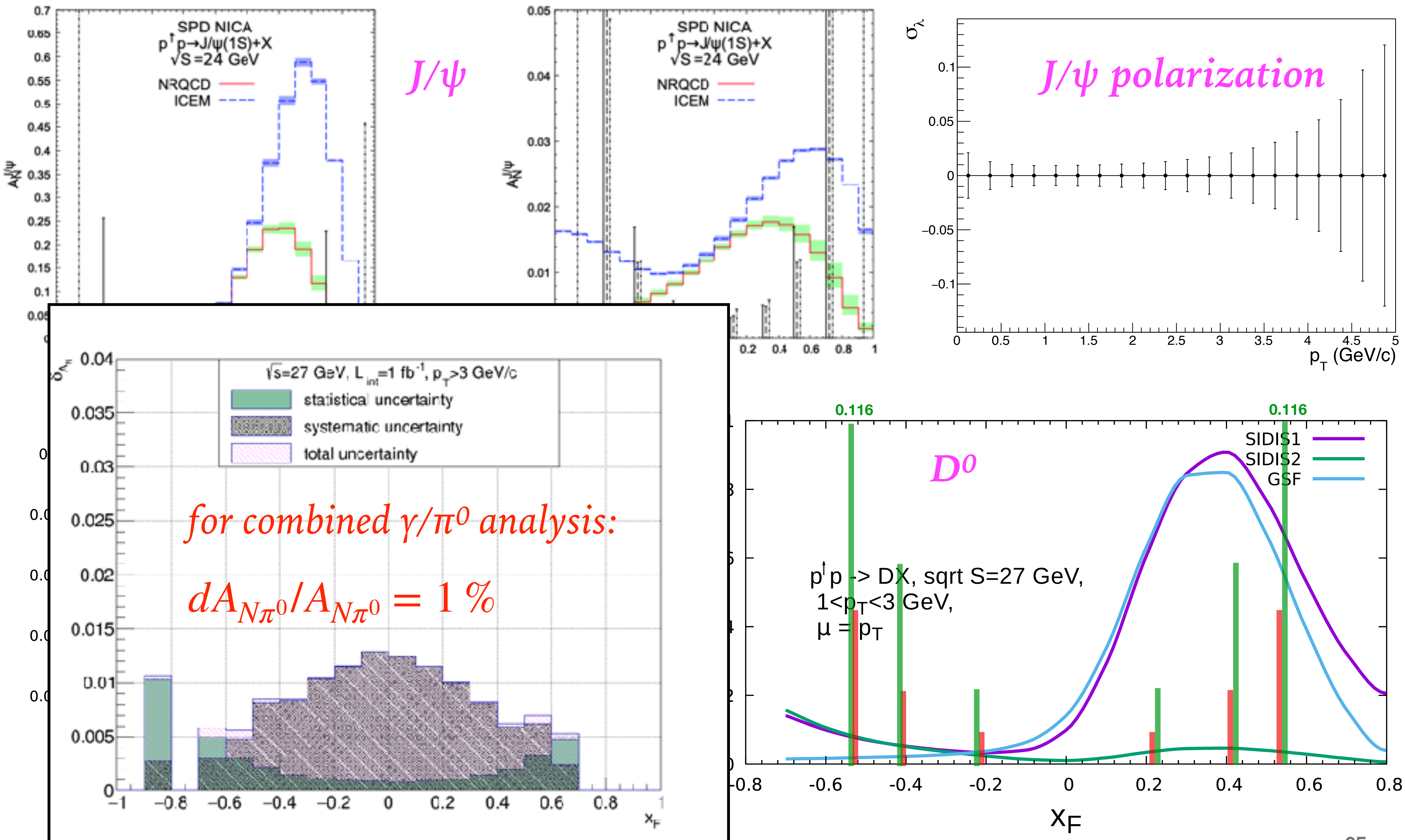
Different inputs for gluon Sivers function



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

COST ESTIMATION

	Subsystem	Option	Cost, M$
SPD setup	Vertex detector: – DSSD – DSSD+MAPS	 VD1 VD2	 9.4+6.5 (FE) 9.4+7.0 (FE)
	Straw tracker		2.4
	PID system: – RPC-based TOF – Scintillator-based TOF – Aerogel PID system	 PID1 PID2 PID3	 5 4 5
	Electromagnetic calorimeter		21.1
	Range system		14.2
	ZDC		2
	BBC		0.4
	Magnetic system		10
	Beam pipe		2
General infrastructure			5
Slow control system			0.8
Data acquisition system			1.6
Computing			10
TOTAL COST	VD2+PID2+PID3		94.9

+4.5 per year

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).**