THE SPD PROJECT AT NICA

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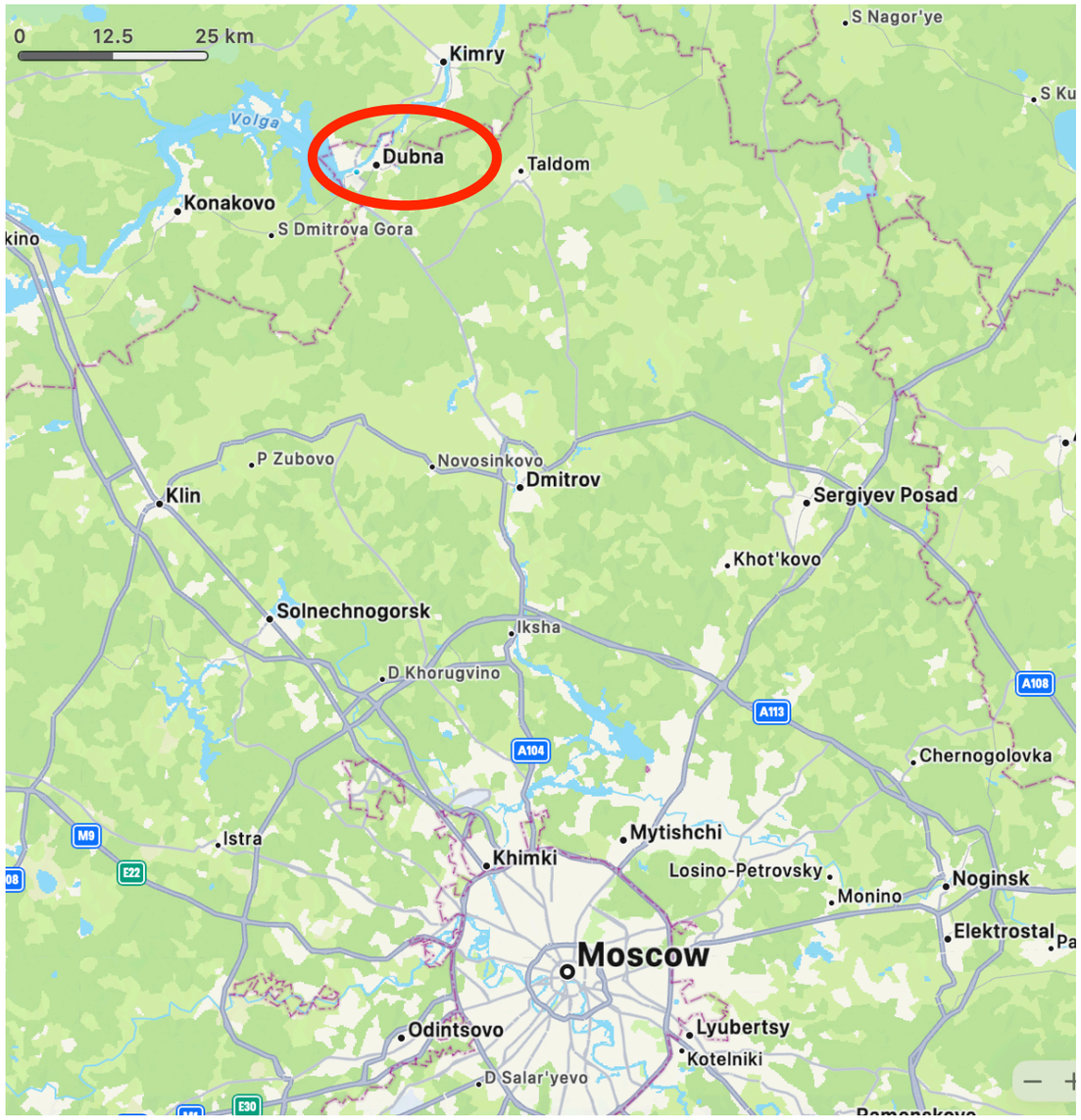
Hefei
12.11.2024

THE JOINT INSTITUTE FOR NUCLEAR RESEARCH, DUBNA, RUSSIA



The Joint Institute for Nuclear Research is an international intergovernmental scientific research organization in the science city Dubna of the Moscow region (Russia)

NICA facility at JINR

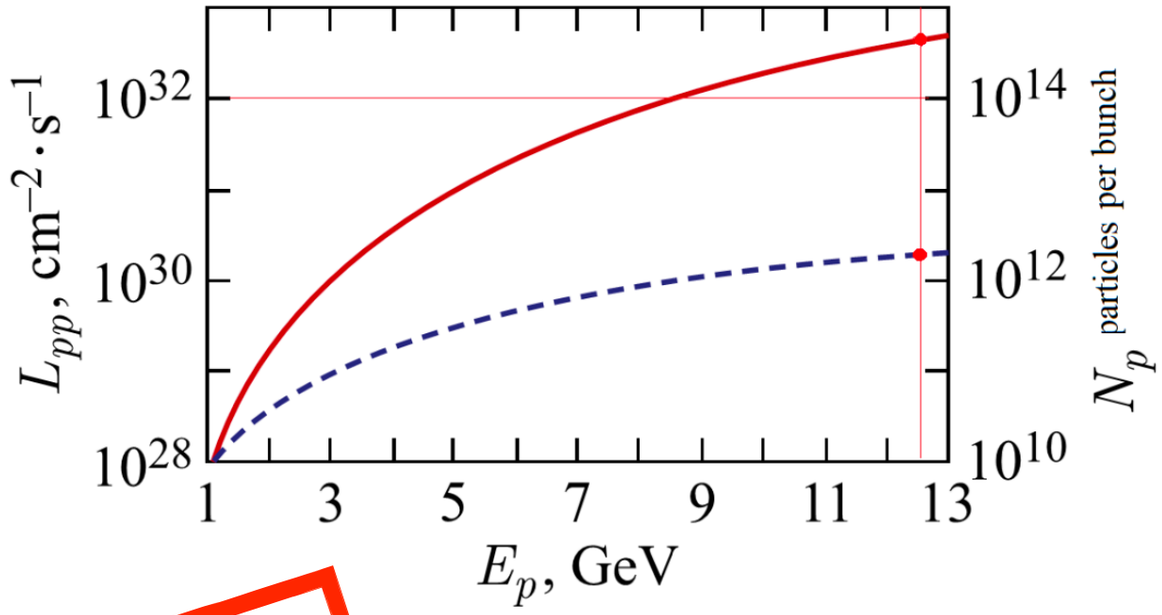
NICA - Nuclotron-based Ion Collider fAcility

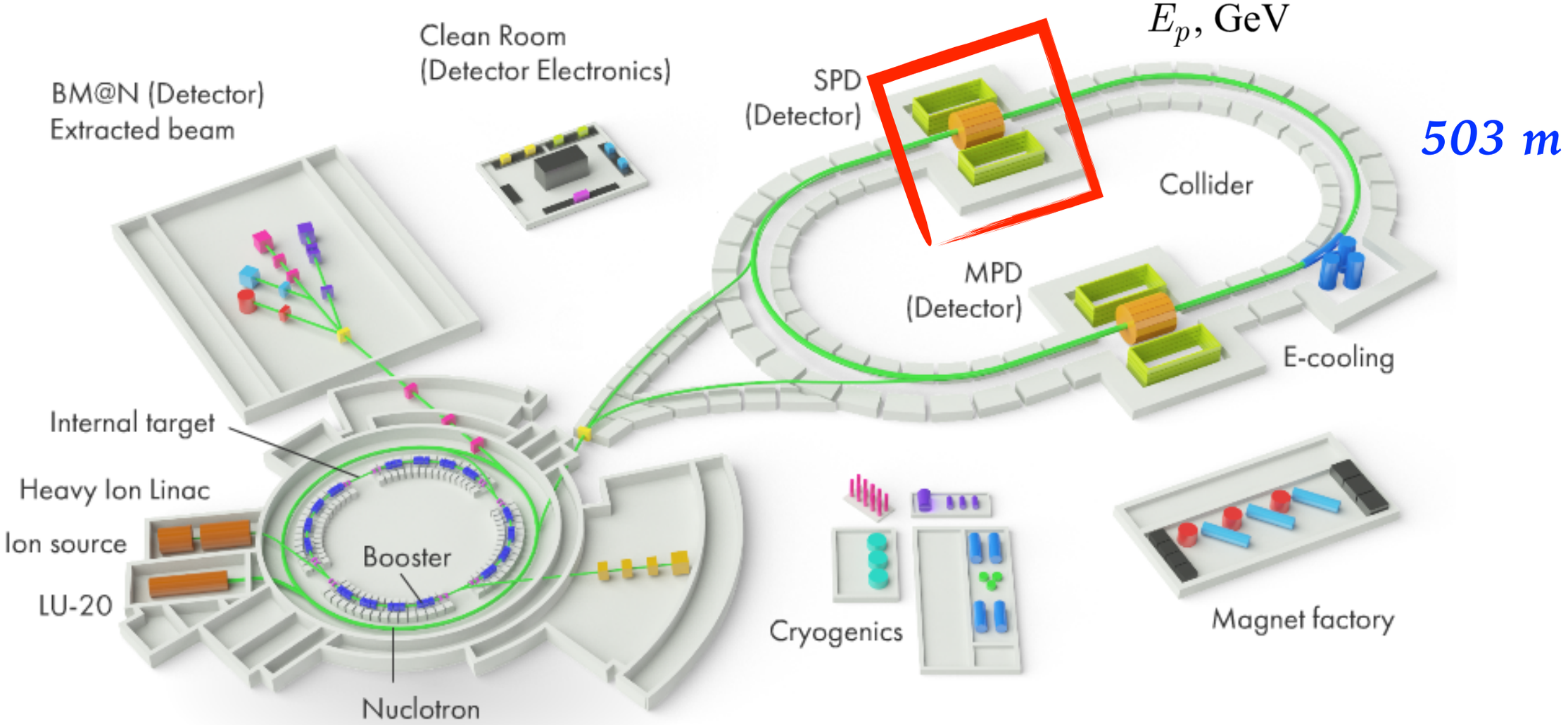
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

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

U, L, T

$|P| > 70\%$





NICA landscape

NICA landscape

- 13.6.24 - NICA technological launch
- Beam circulation - July 2025

Polarized beams at NICA

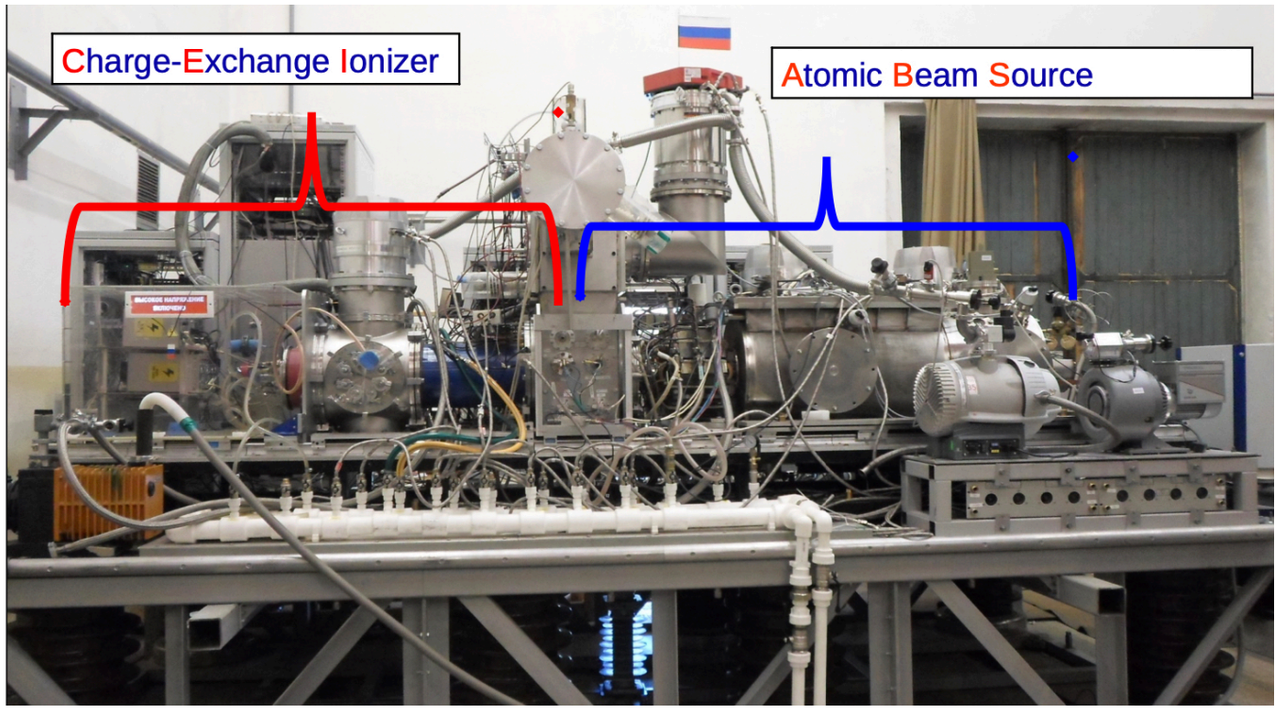
d↑- was accelerated in 1986 (Synchrophasotron) and 2002 (Nuclotron). It is quite simple procedure: there is just 1 depolarizing spin resonance at 5.6 GeV.

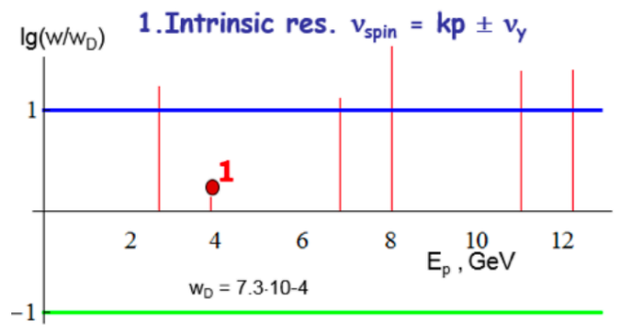
p↑- was first obtained only in 2017.

Source of Polarized Ions:

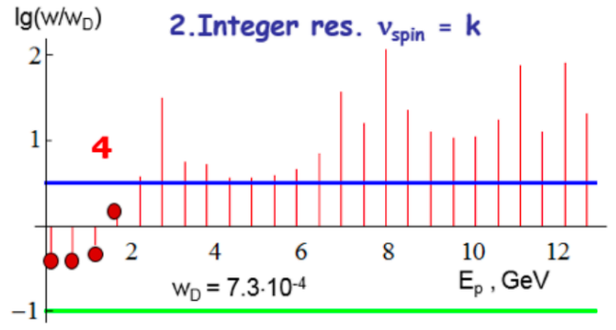
$$H^0 \uparrow + D^+ \rightarrow H^+ \uparrow + D^0$$

$$D^0 \uparrow + H^+ \rightarrow D^+ \uparrow + H^0$$

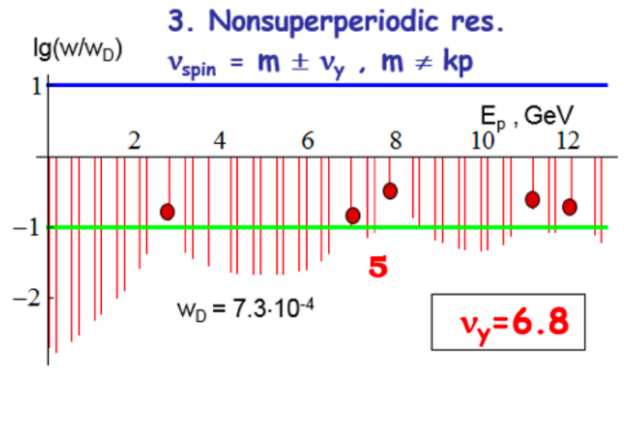


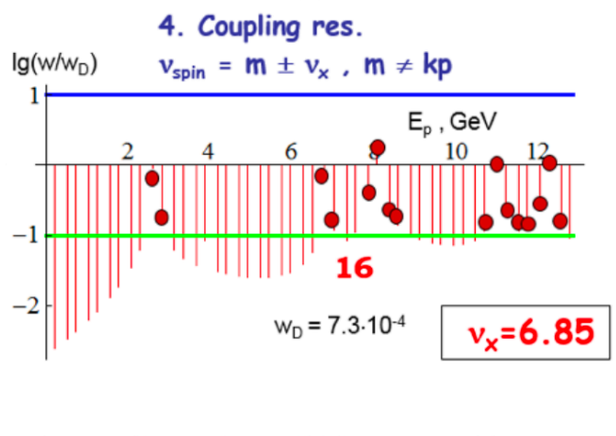


(a)



(b)





- Longitudinal polarization in the IP can be supported at the integer spin-resonances
  - For protons: E_{kin}=(0.108+0.523·n) [GeV]
  - For deuterons: E_{kin}=(5.62+6.56·n) [GeV/u]

- Transverse polarization at any energies

SPD Physics Program

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

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

A. Arbuzov [a], A. Bacchetta [b,c], M. Butenschoen [d], F.G. Celiberto [b,c,e,f], U. D'Alesio [g,h], M. Deka [a], I. Denisenko [a], M.G. Echevarria [i], A. Efremov [a], N.Ya. Ivanov [a,j], A. Guskov [a,k,*], A. Karpishkov [l,a], Ya. Klopot [a,m], B.A. Kniehl [d], A. Kotzinian [j,o], S. Kumano [p], J.P. Lansberg [q], Keh-Fei Liu [r], F. Murgia [h], M. Nefedov [l], B. Parsamyan [a,n,o], C. Pisano [g,h], M. Radici [c], A. Rymbekova [a], V. Saleev [l,a], A. Shipilova [l,a], Qin-Tao Song [s], O. Teryaev [a]

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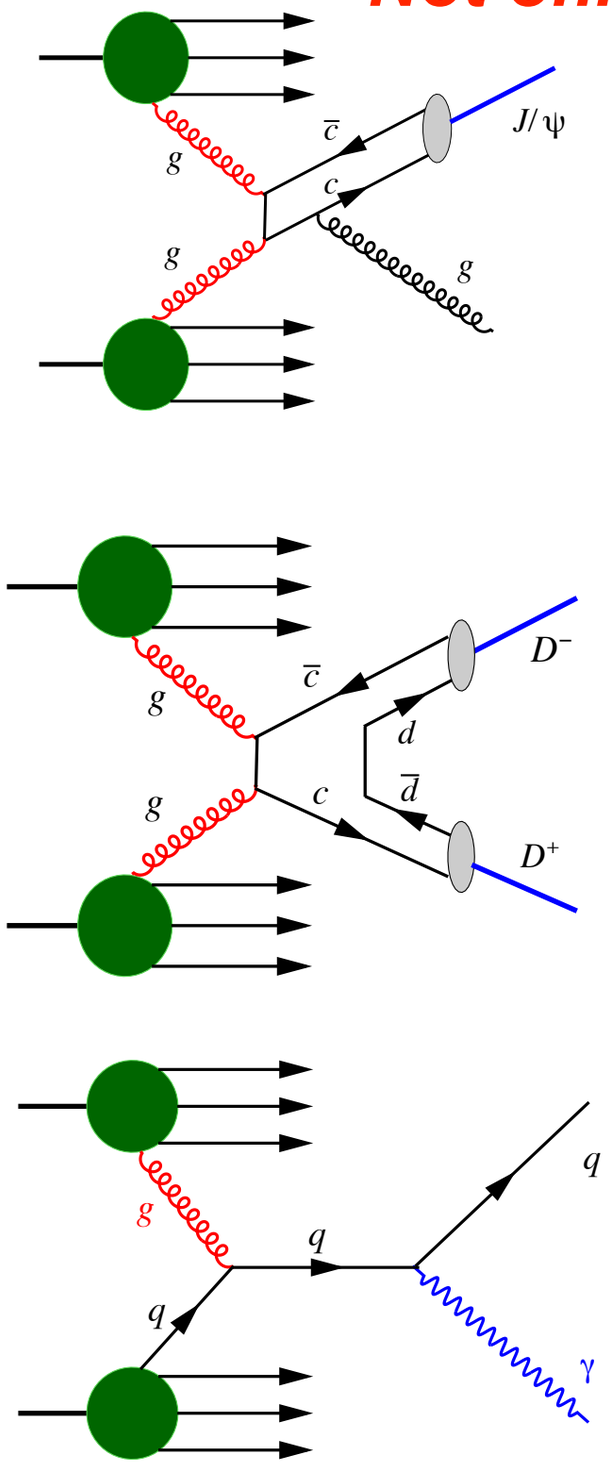
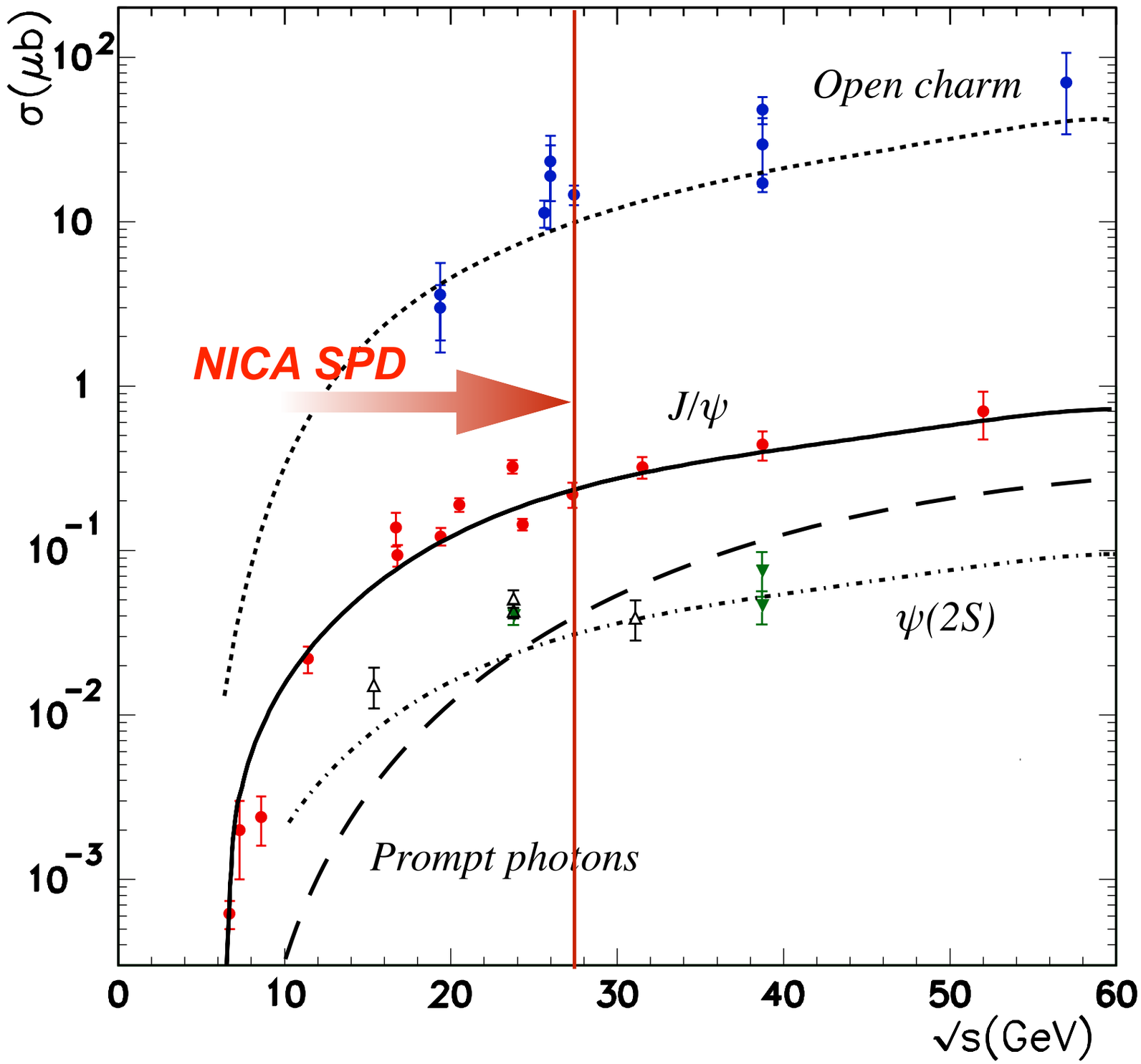
Prog.Part.Nucl.Phys. 119 (2021) 103858

arXiv:2011.15005

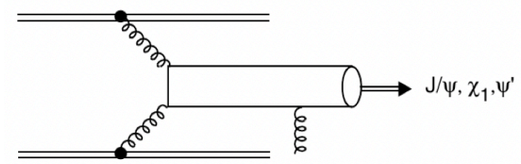
SPD and gluon structure of nucleon

Not only J/ψ!

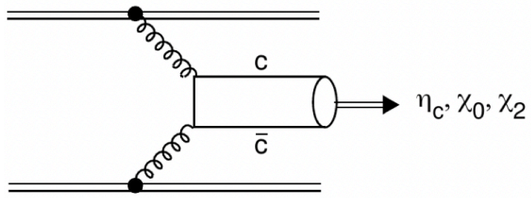


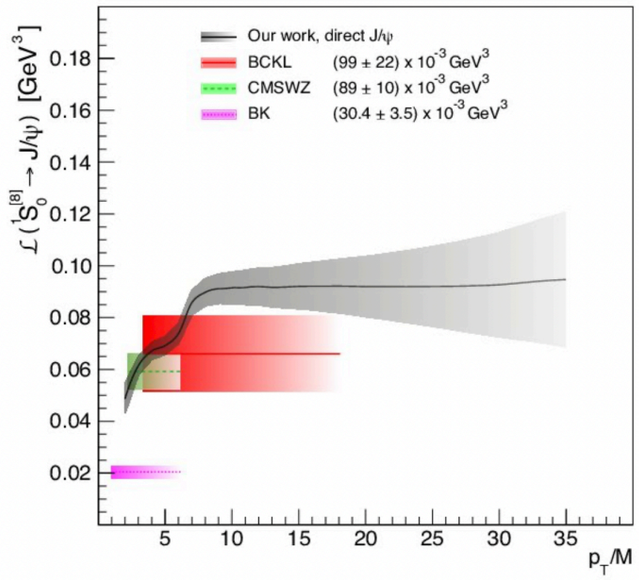


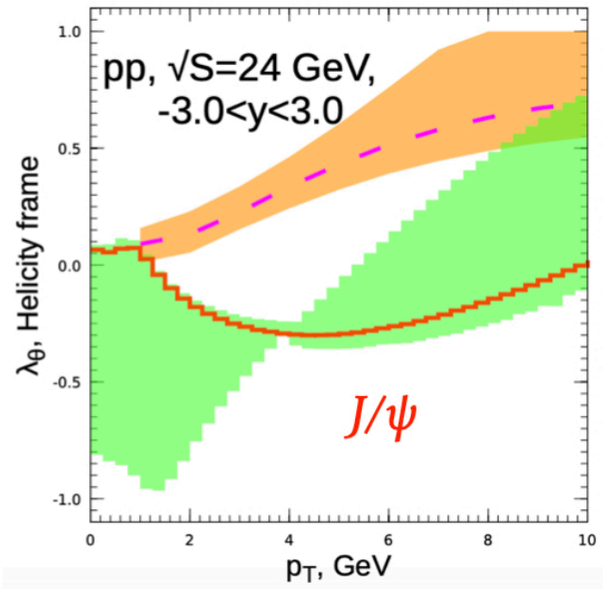
Unpolarized production



NRQCD — LDMEs

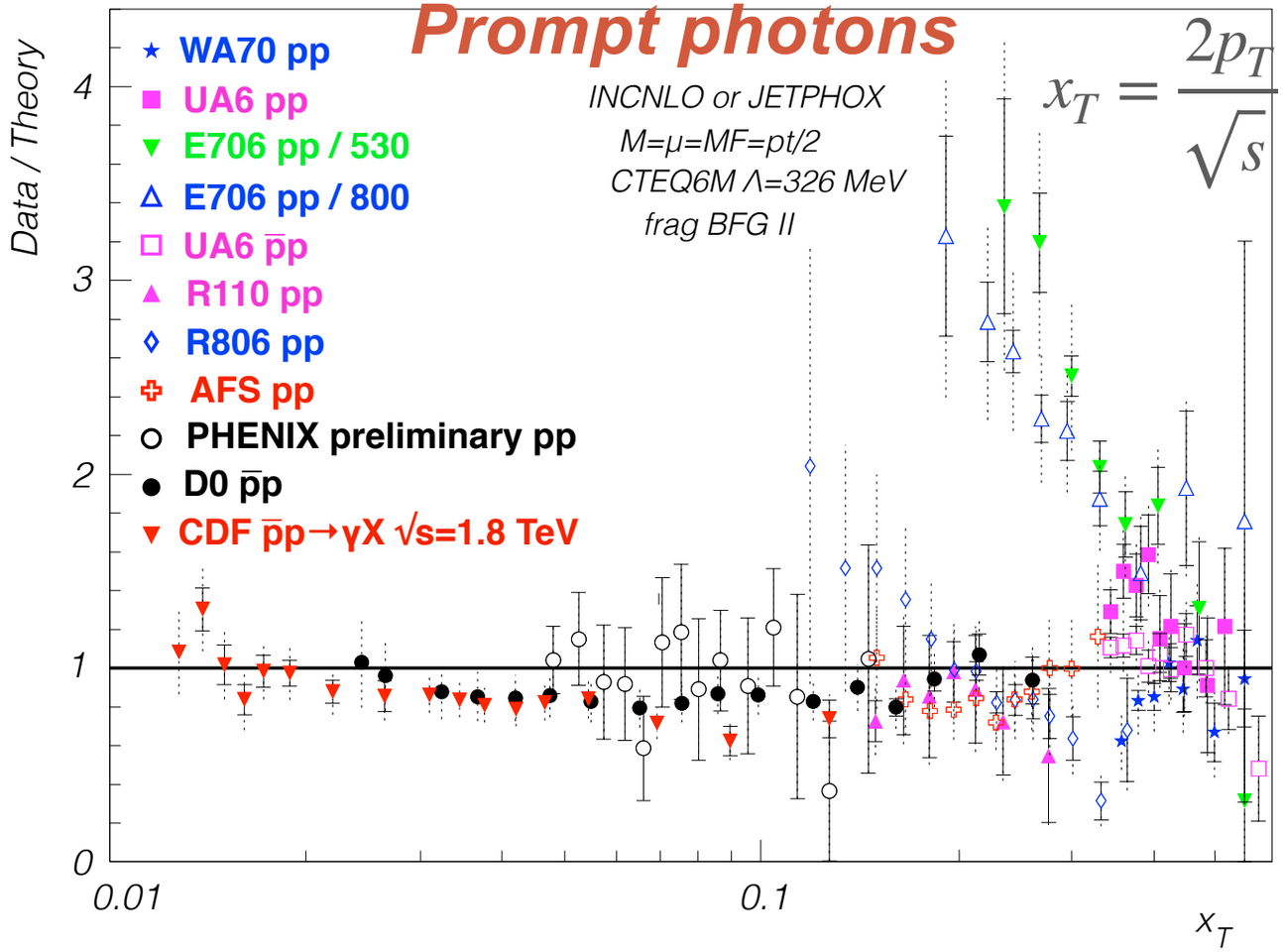


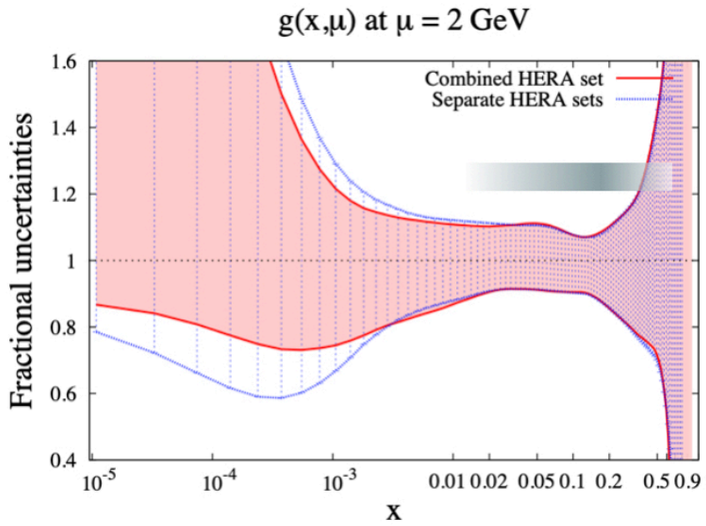




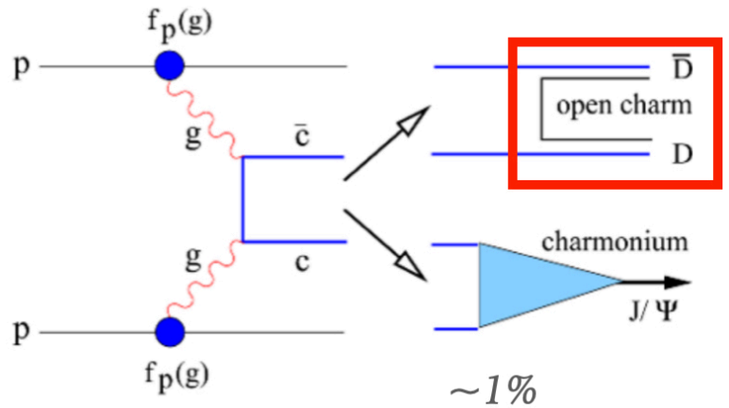
Charmonia

Prompt photons

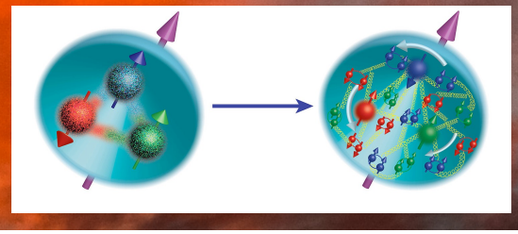




Open charm

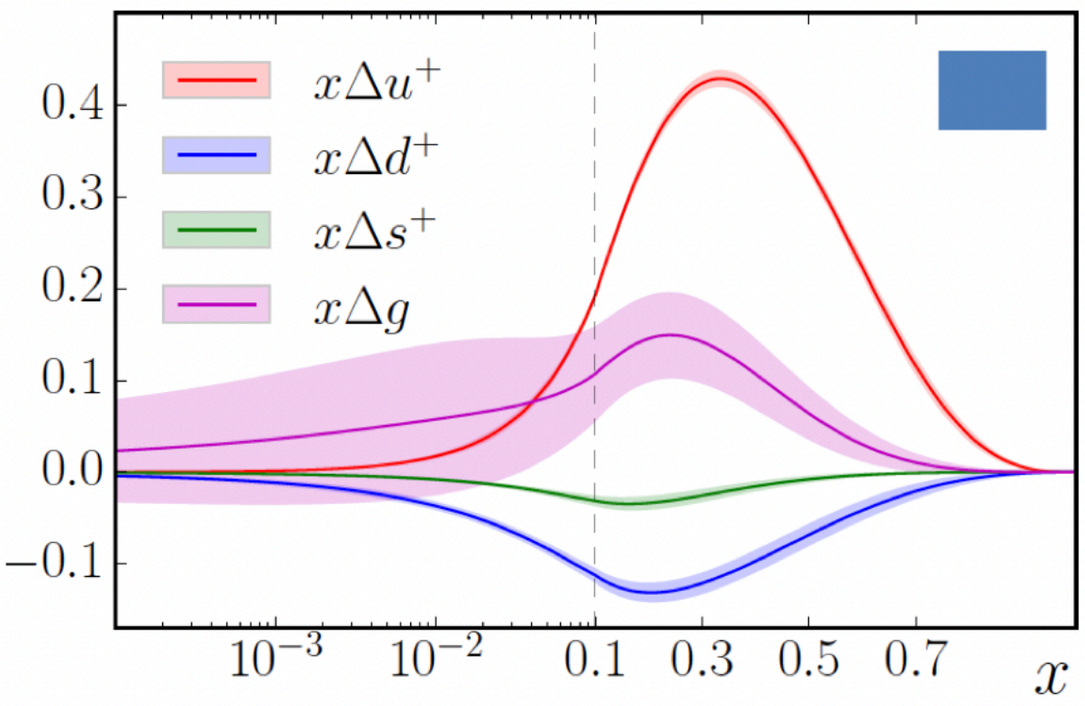


Gluon helicity

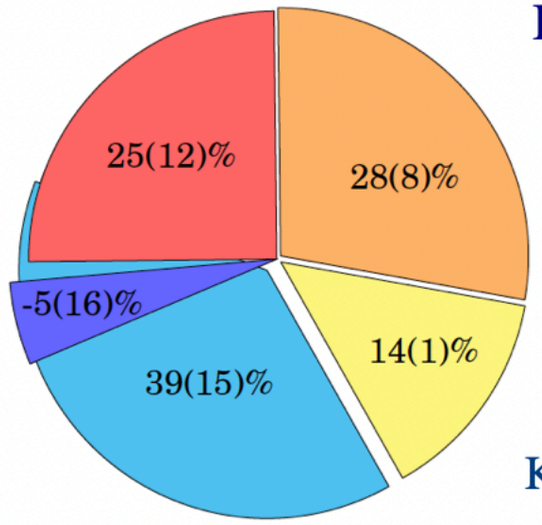


$$J = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

~30% ~10-20% ? ?



JAM Collaboration, PRD (2016).

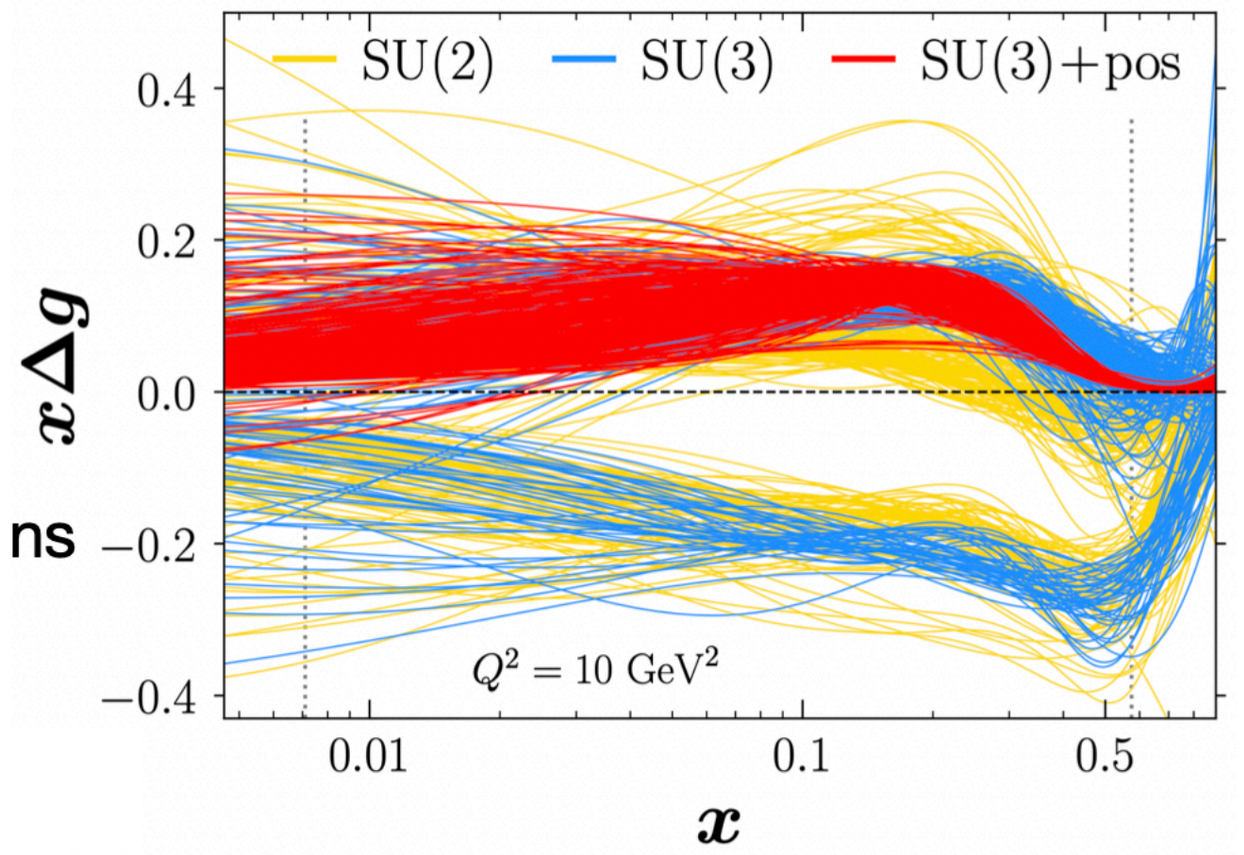


Lattice QCD

- L^u (CI + DI)
- L^d (CI + DI)
- L^s (DI)
- J^g
- $\frac{\Delta\Sigma}{2}\Big|^{u+d+s}$

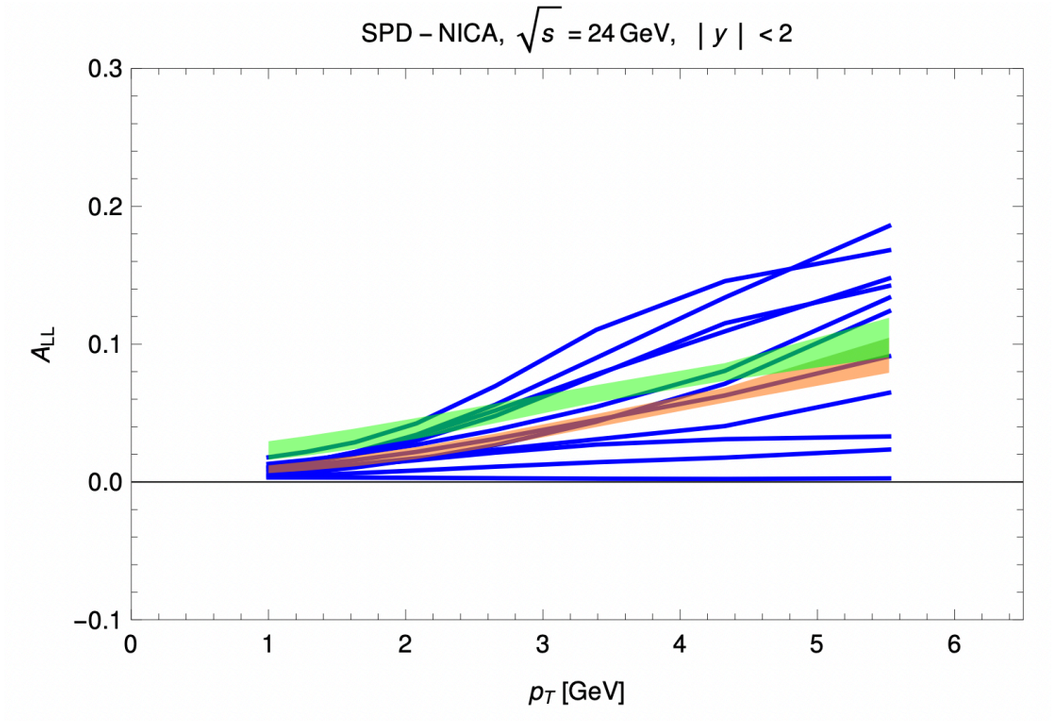
K.-F. Liu, NP A928, 99 (2014).

Y. Zhou et al (JAM) Phys. Rev. D 105, 074022 (2022)



To access angular momenta info about 3D structure is needed!

Gluon helicity function $\Delta g(x)$: expectations for A_{LL} at NICA energies



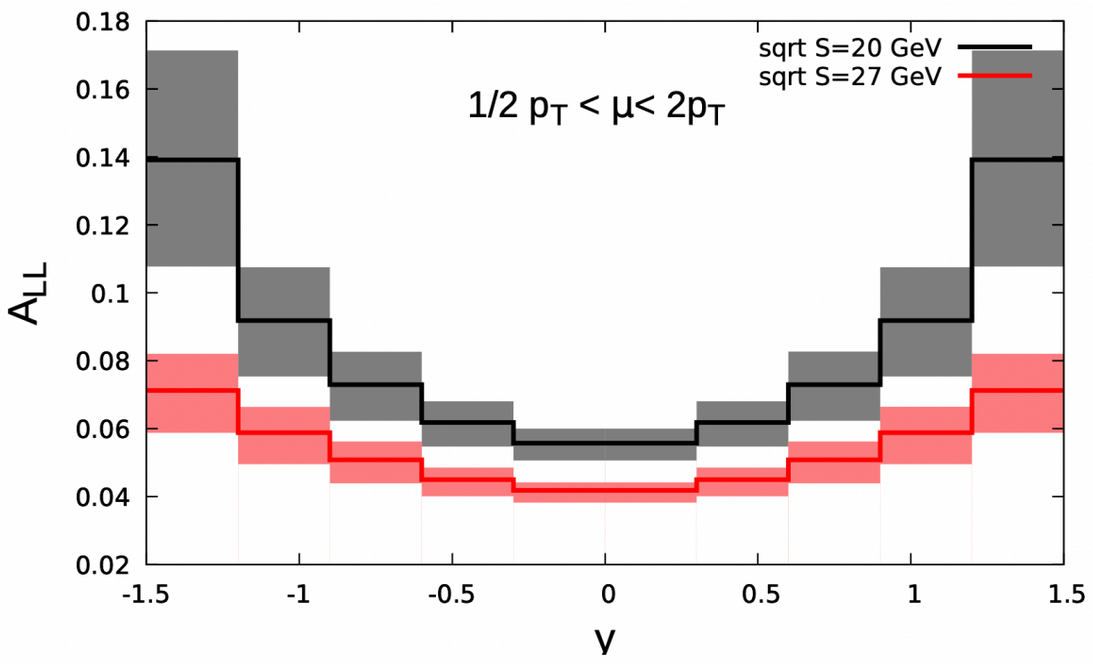
$gg \to J/\psi g$

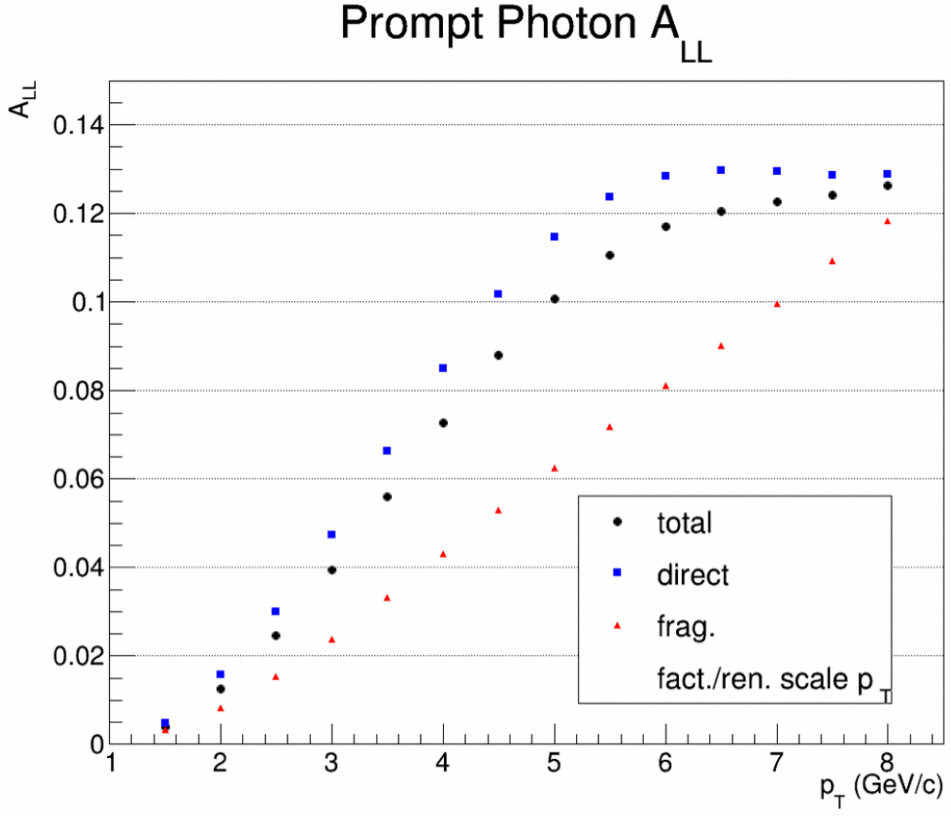
M. Nefedov

W. Vogelsang

A. Shipilova

$qg \to q\gamma$



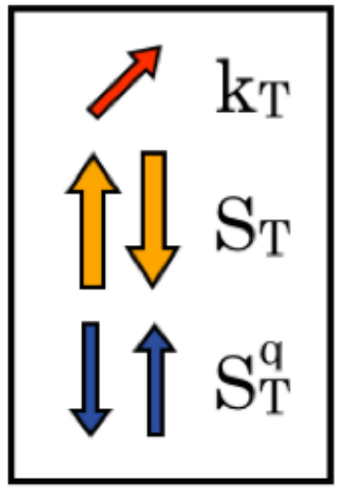


Proton in 3D: TMD PDFs

Nucleon Spin Polarization

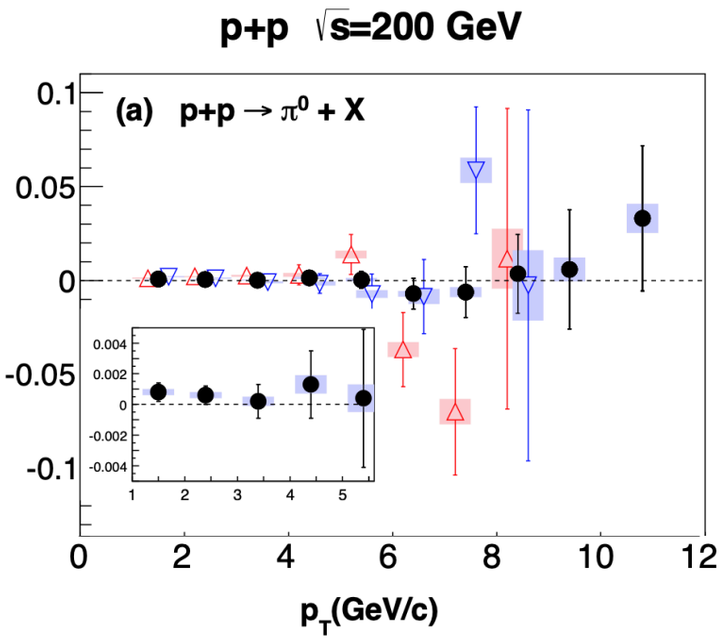
Quark Spin Polarization

	U	L	T
U	f_1 Number Density		$f_{1T}^{q\perp}$ Sivers
L		g_{1L}^{q} Helicity	g_{1T}^{q} Worm-Gear T
T	$h_1^{q\perp}$ Boer-Mulders	$h_L^{q\perp}$ Worm-Gear L	h_1^{q} Transversity; $h_{1T}^{q\perp}$ Pretzelosity



5 additional (TMD) functions describing the correlation between the nucleon spin, parton spin, and parton transverse momentum.

Gluon Sivers function $\Delta^g_N(x,k_T)$

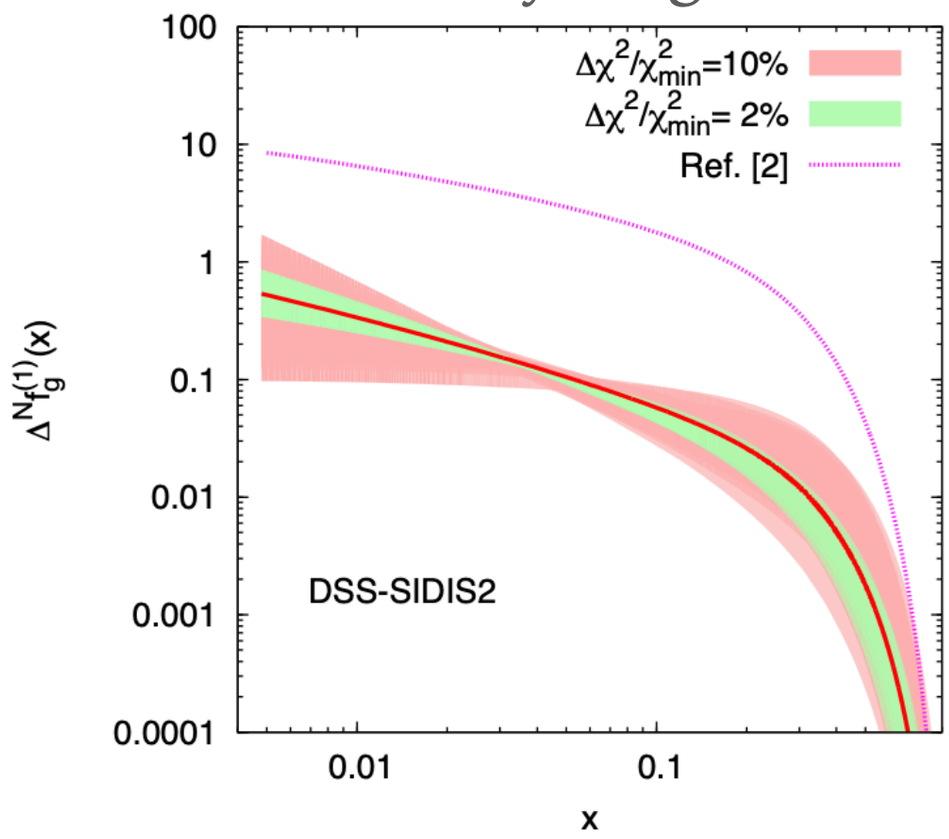


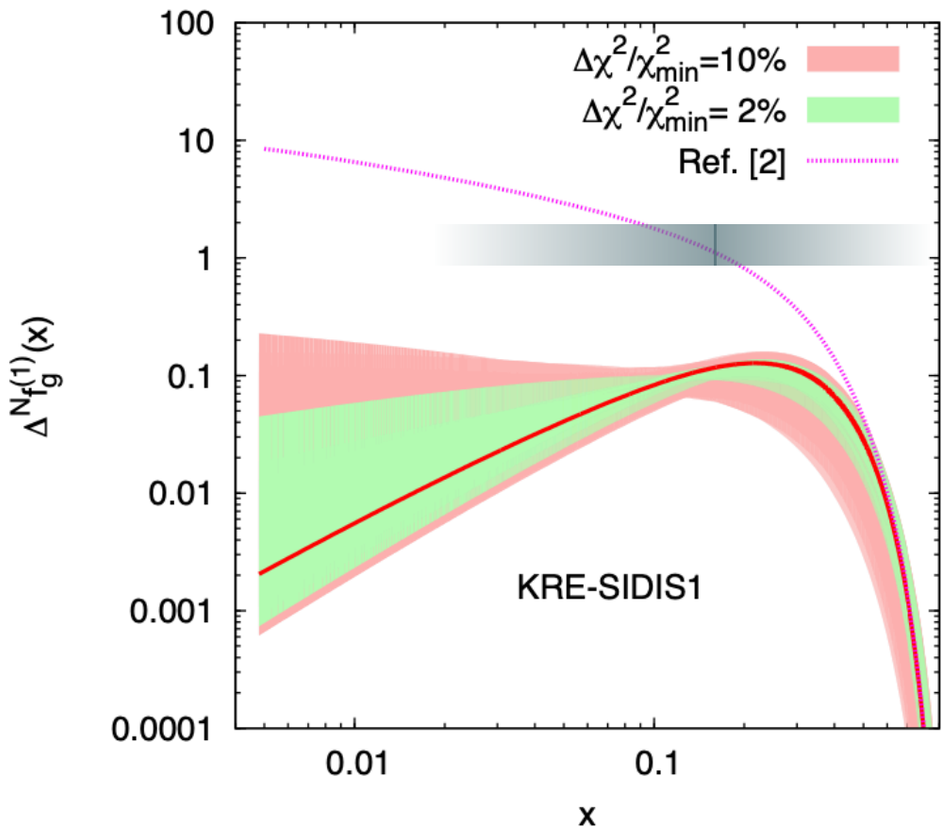
Phys.Rev.D **90 (2014) 1, 012006**

PHENIX

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

JHEP 09 (2015) 119

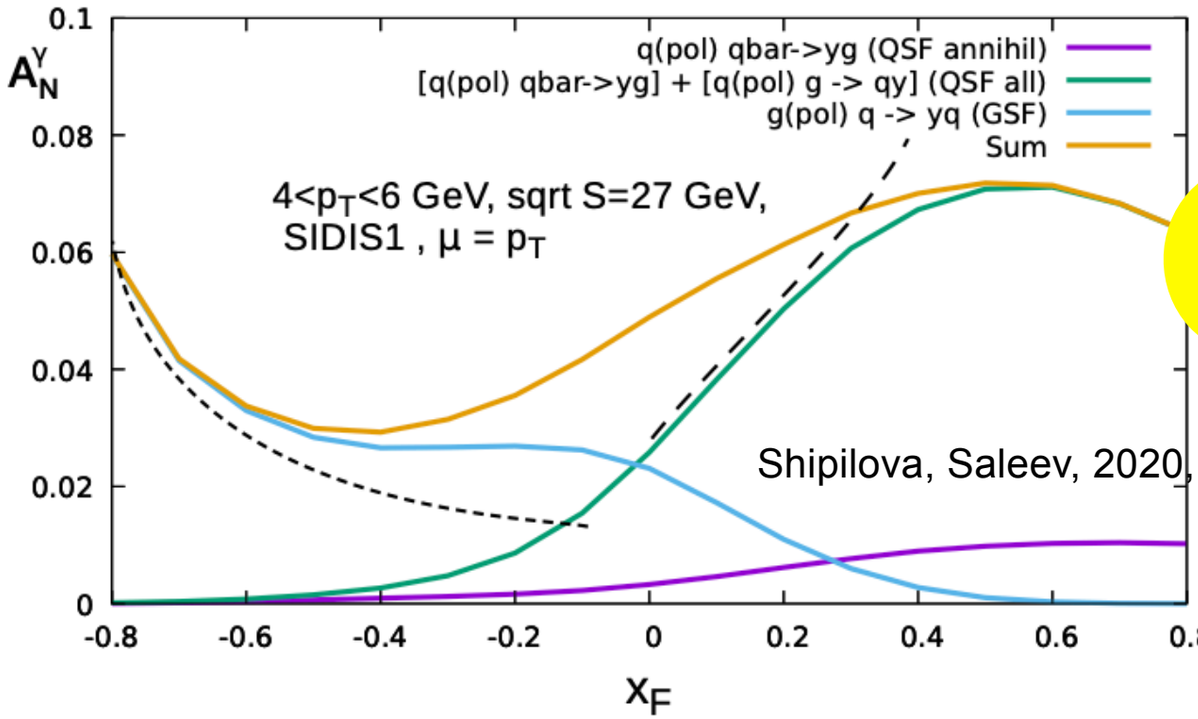


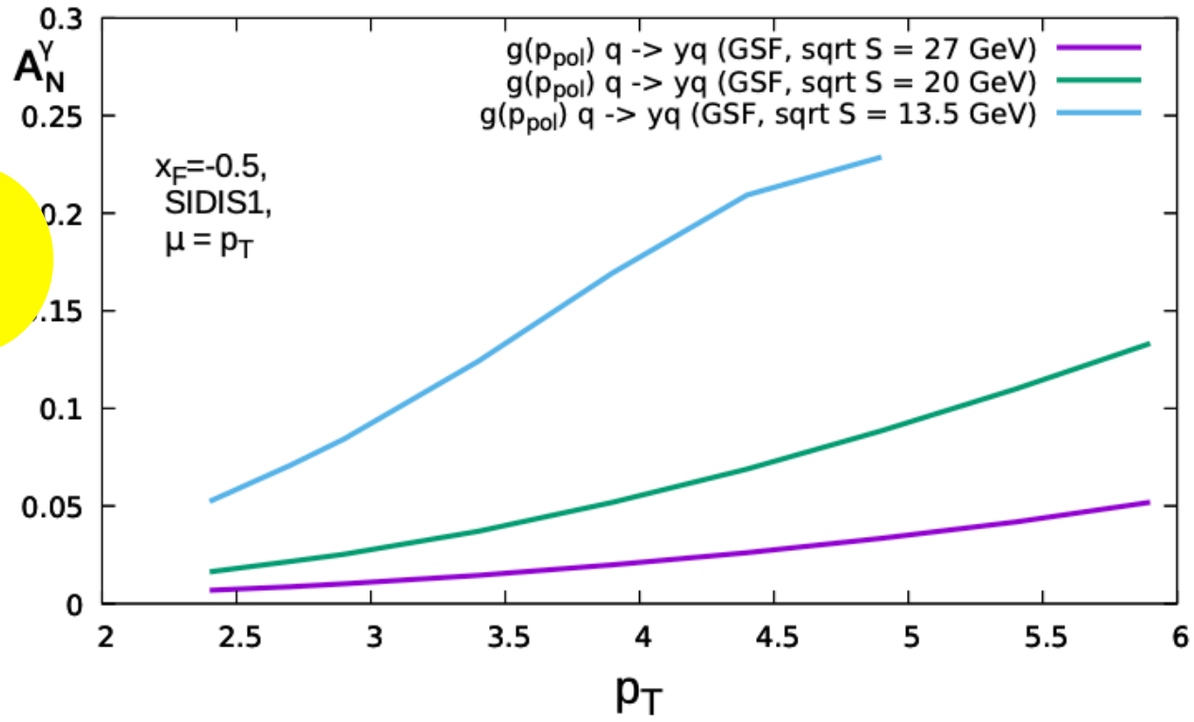


SPD

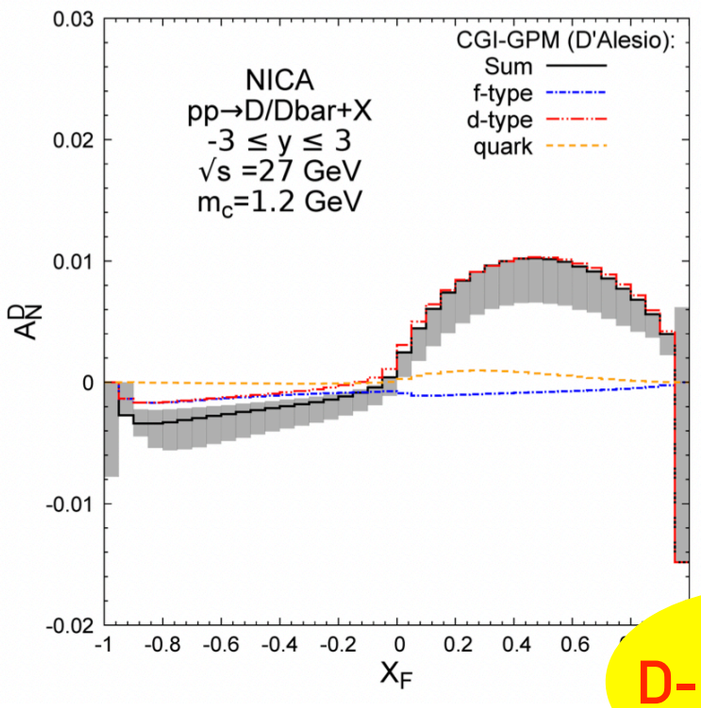
Gluon-induced TMD effects: expectations for A_N

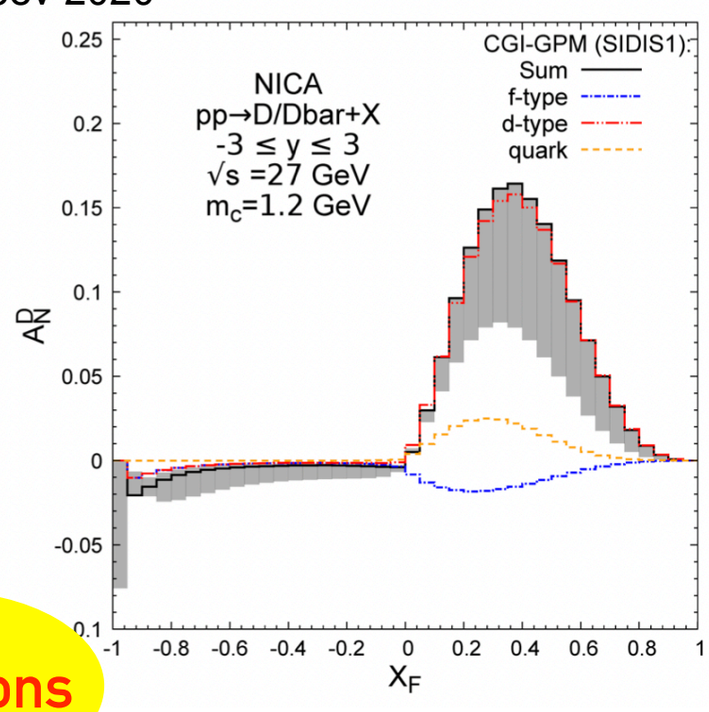
Sivers effect contribution



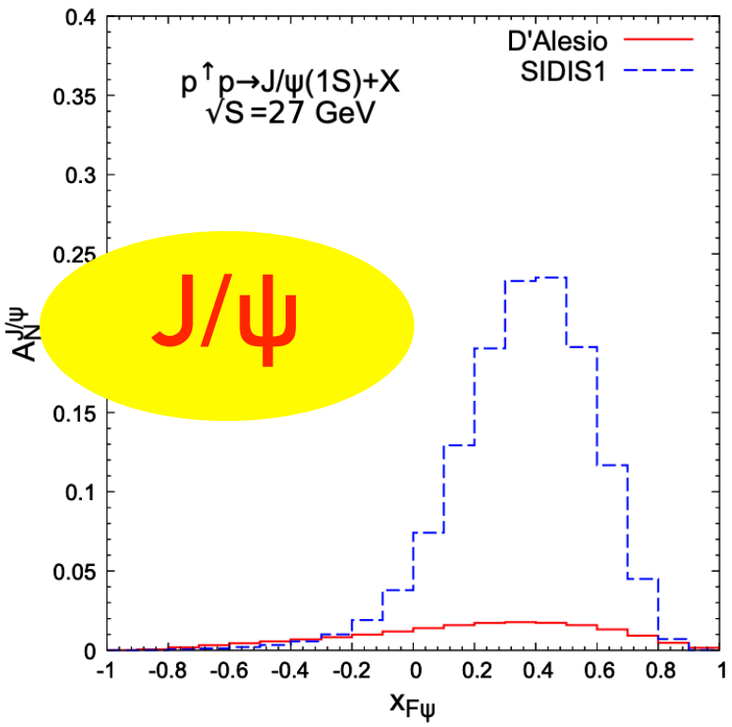


Saleev 2020





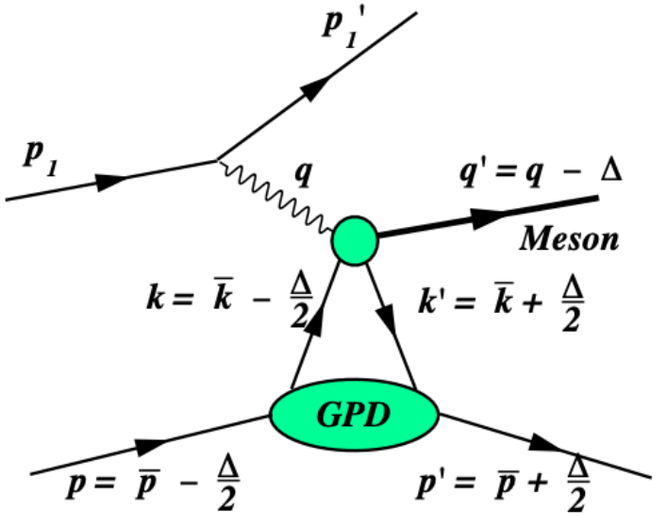
D-mesons

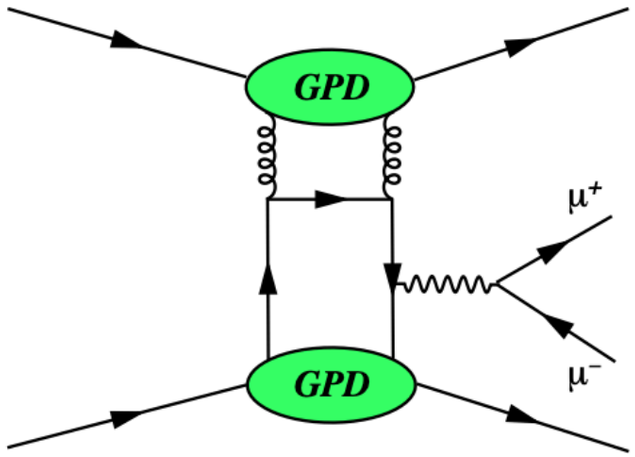


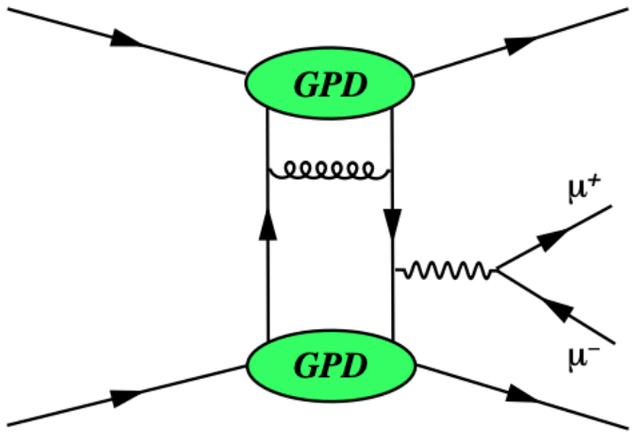
GPDs at SPD

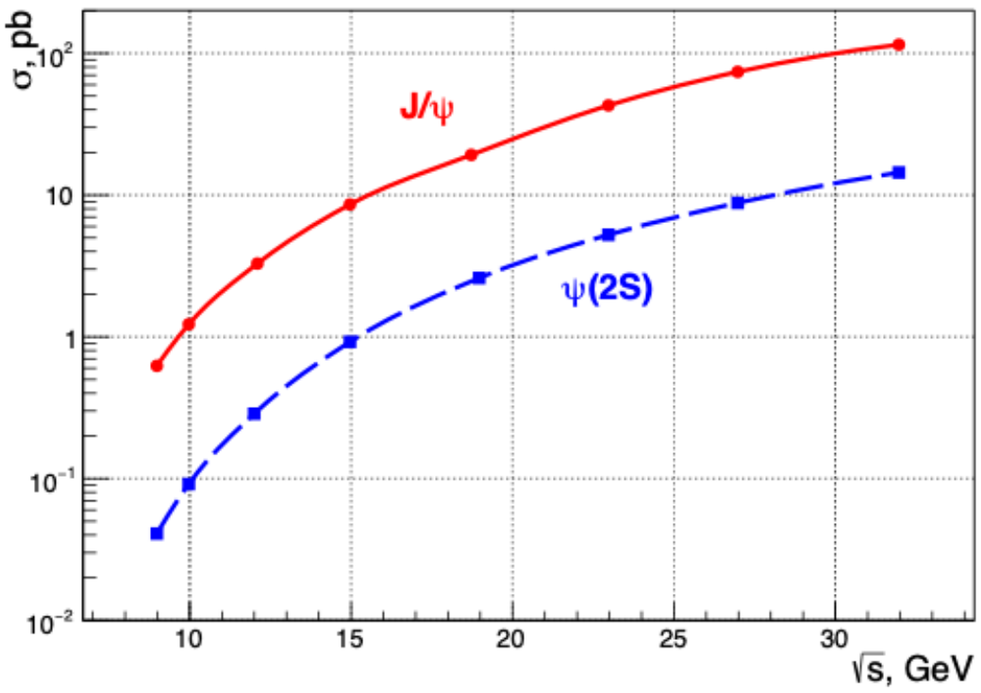
GPDs is not a priority goal at SPD but potentially they could be accessed:

Exclusive Drell-Yan







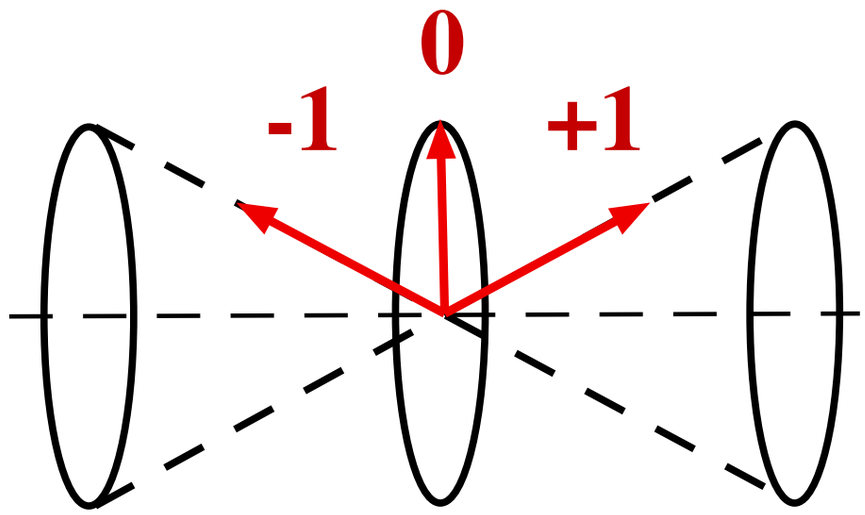


$$d\sigma/dQ^2 \sim 5\ pb/(GeV/c)^2$$

$$at\ \sqrt{s} = 24\ GeV\ and\ Q^2 = 5\ (GeV/c)^2$$

Deuteron

$\sigma(x_F, p_T)$, vector and tensor angular asymmetries



Nonbaryonic content of deuteron:

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

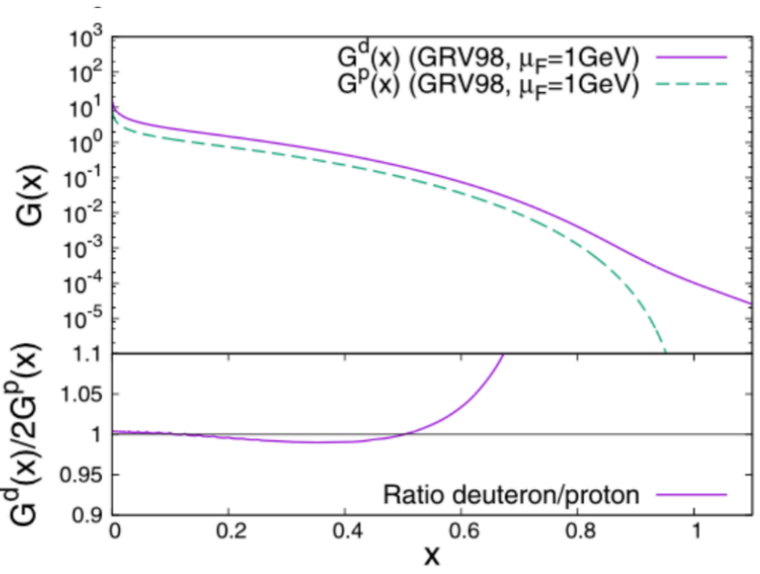
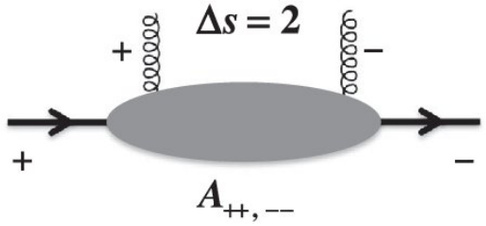
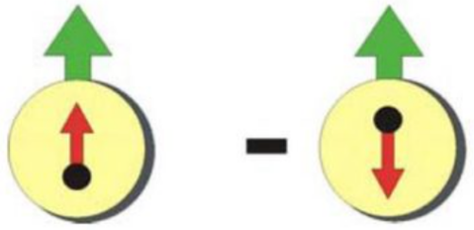


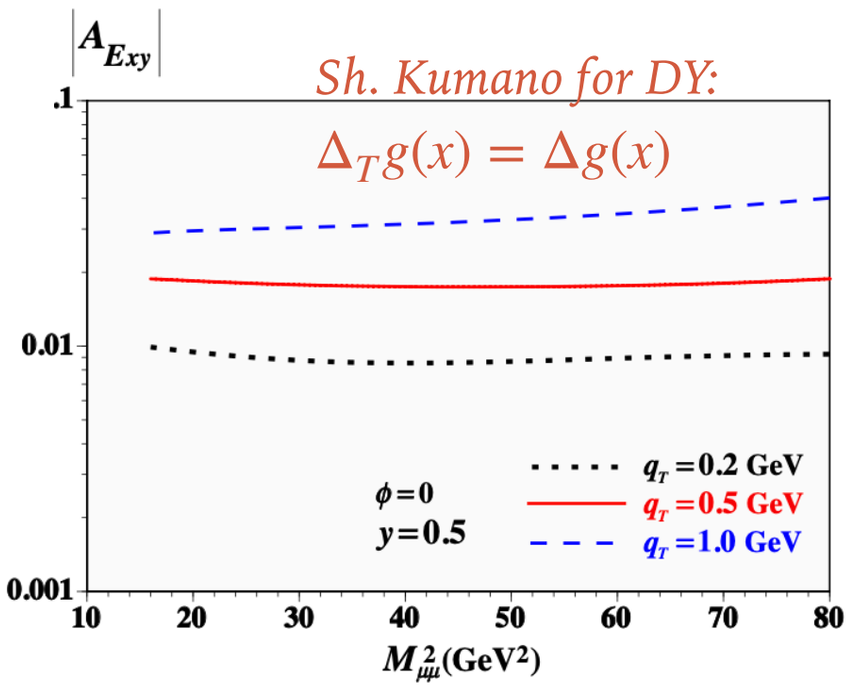
Fig. 6. Gluon PDF in the deuteron and in the nucleon.

Unpolarized gluons at high x:

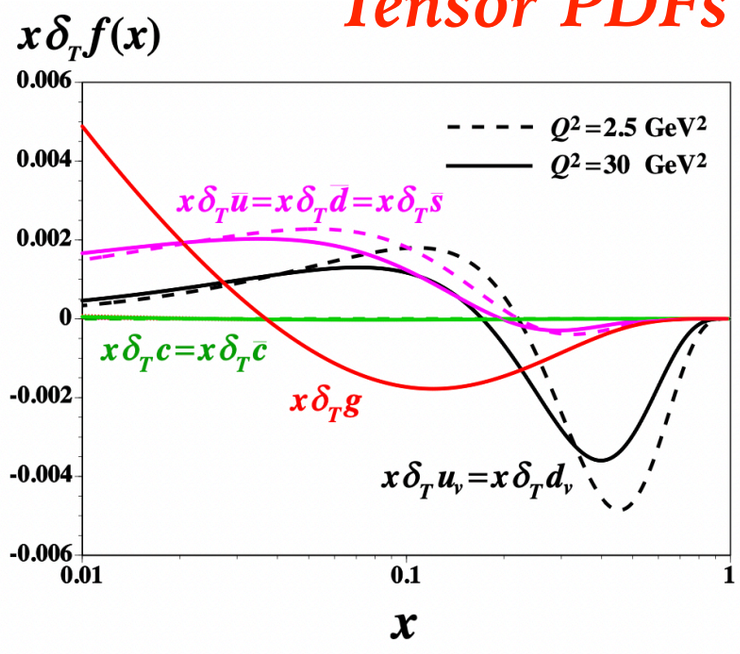
Gluon transversity



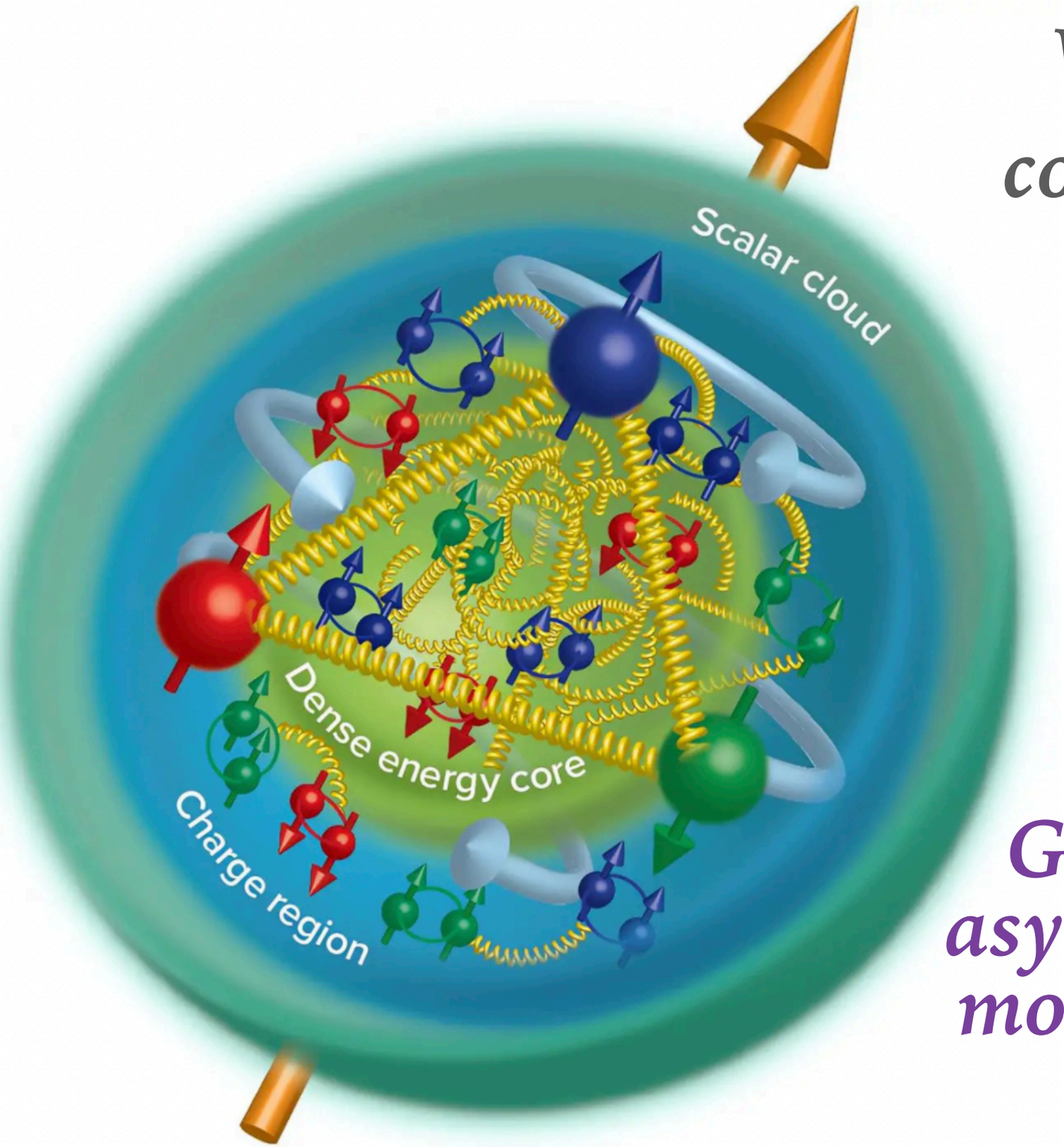




Tensor PDFs



Spin Physics @ NICA

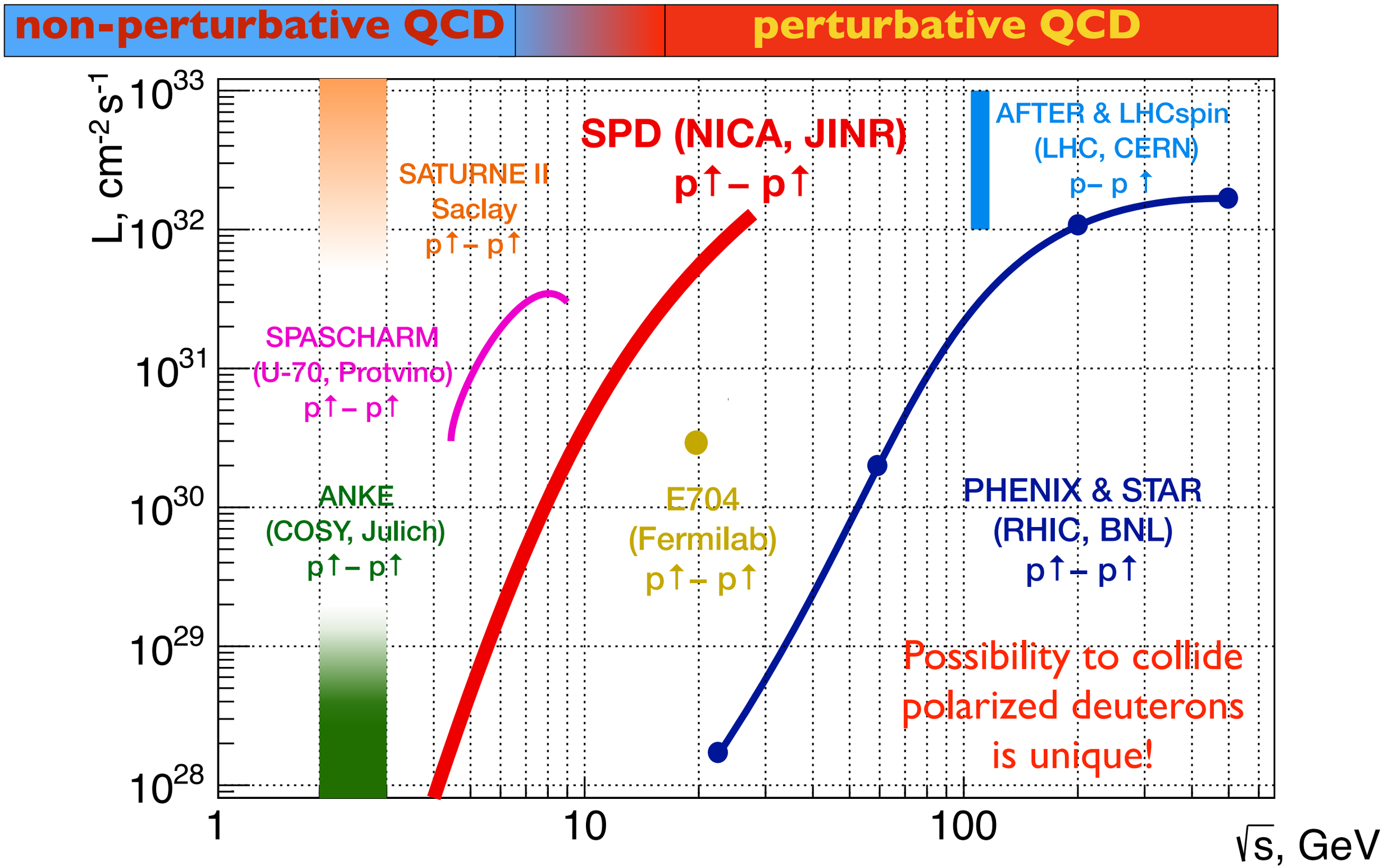


We plan to study the contribution of partons to the nucleon and deuteron spins

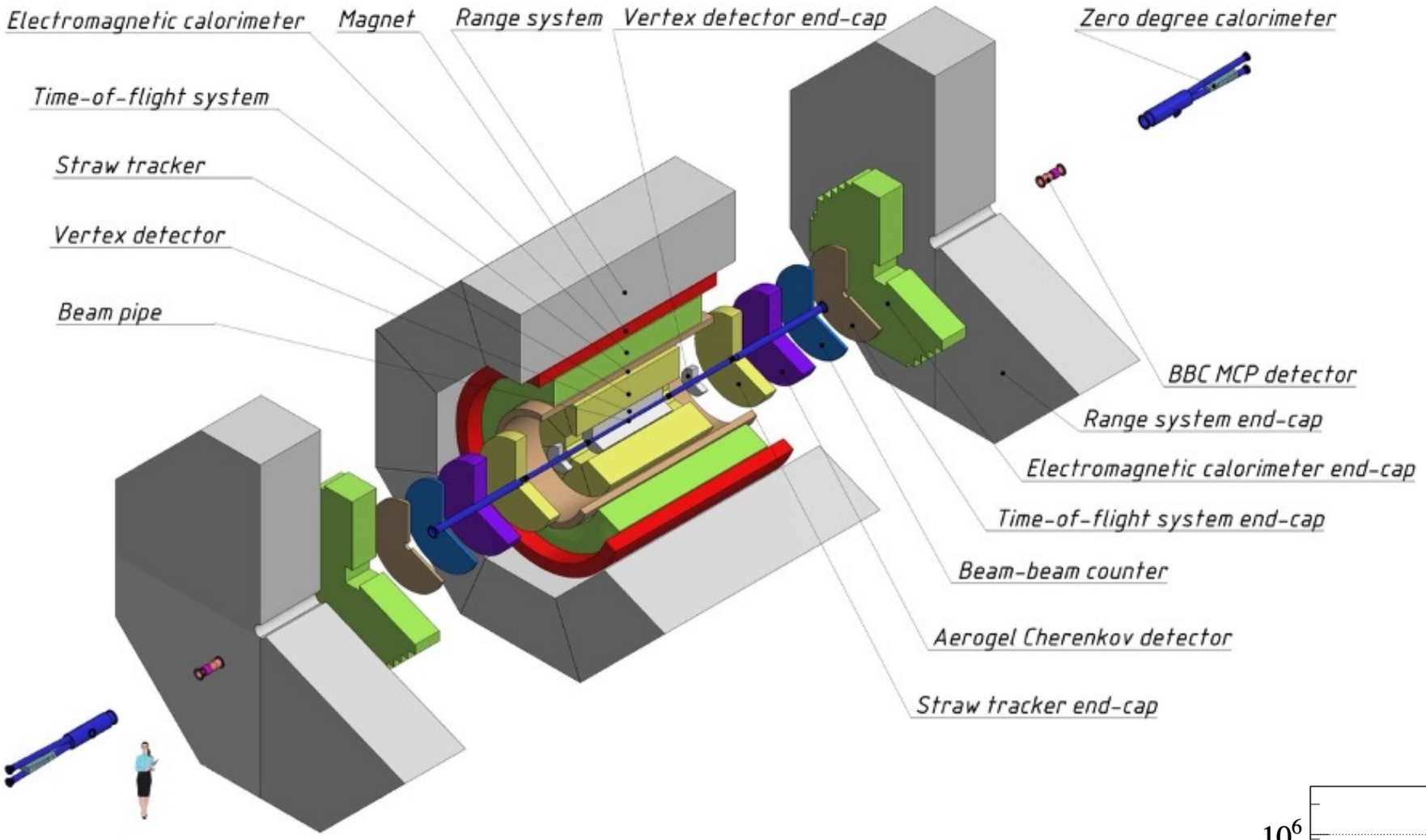
especially their gluon component!

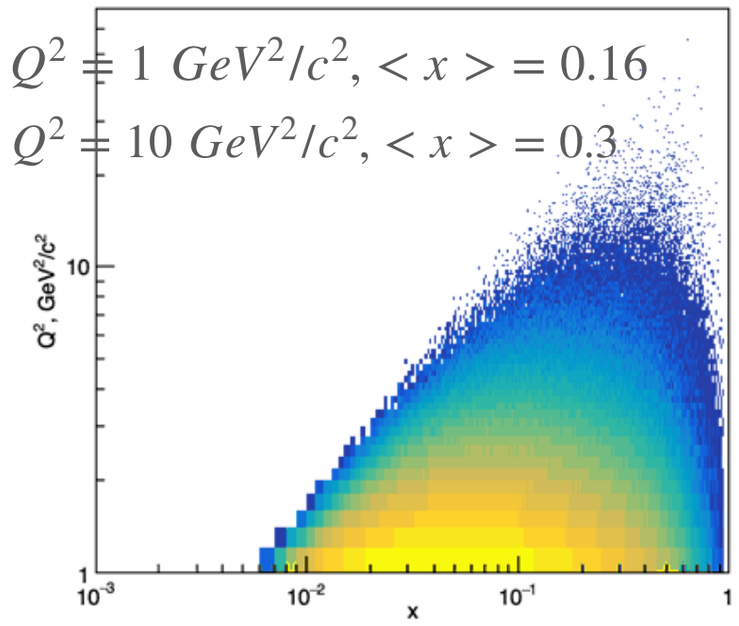
Gluon TMD PDFs via asymmetries and angular modulations in the cross sections

SPD and others



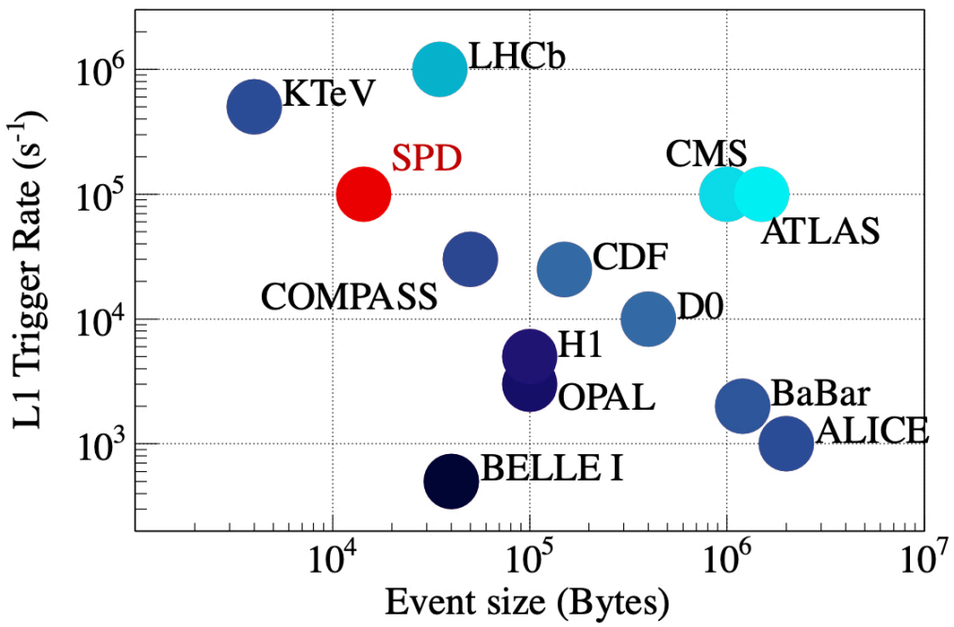
SPD setup





SPD NICA

Free-running DAQ



Physic of the first stage

arXiv:2102.08477

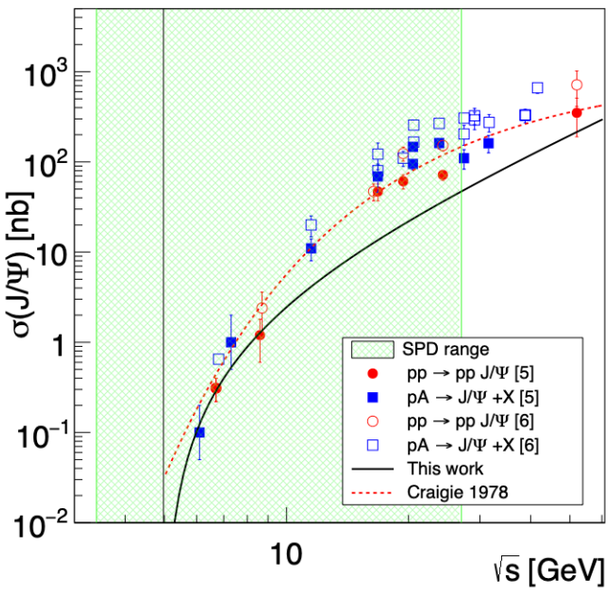
Non-perturbative QCD — *Perturbative QCD*

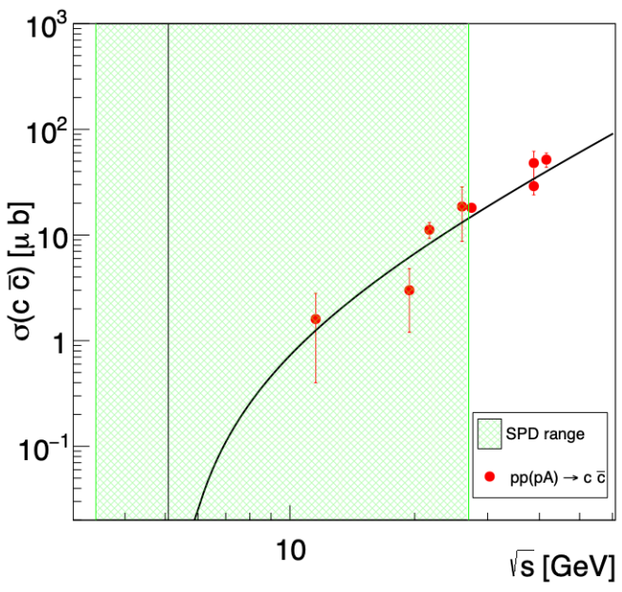
$\sqrt{s}$

- 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
- Hypernucei
- Open charm and charmonia near threshold
- Auxiliary measurements for astrophysics

$$pp \to (6q)^* \to N\,N\,Mesons,$$

$$dd \to K^+\,K^+\,{}^{4}_{\Lambda\Lambda}\mathrm{n},$$



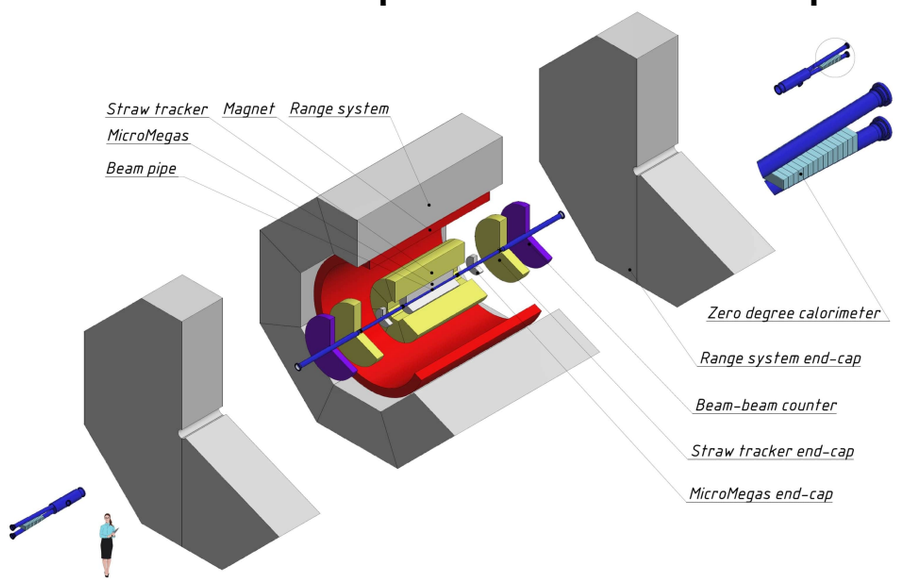


Creating of polarized infrastructure — **Upgrade of polarized infrastructure**

0 +2 +4 +6 +8 years

SPD construction — **SPD construction**

1st stage of operation — **2nd stage of operation**



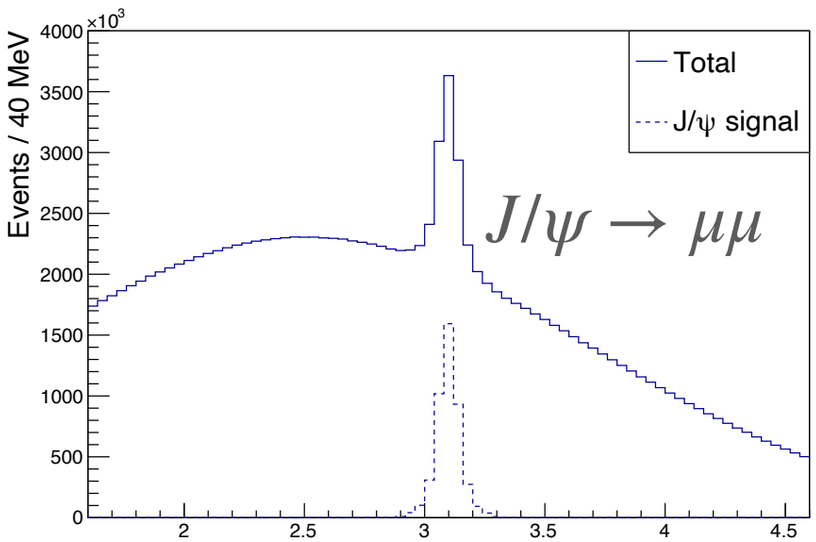
SPD setup: basic properties

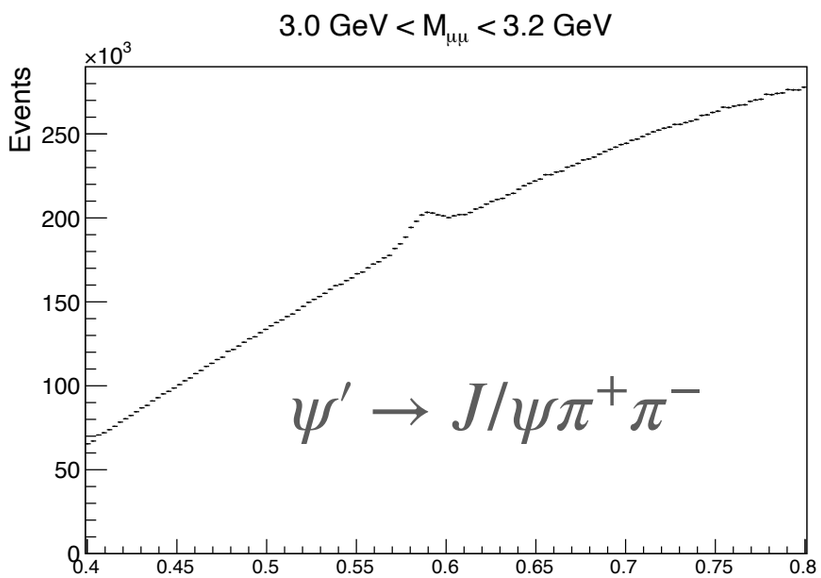
	Stage I	Stage II
Maximum luminosity, 10^{32} cm^{-2} s^{-2}	up to 0.1	1
Interaction rate, MHz	up to 0.4	4
Magnetic field at IP, T	up to 1.0	1.0
Track momentum resolution $\frac{\delta p}{p}$ at 1 GeV/c, %	~1.7	~1.0
Photon energy resolution, %		$5/\sqrt{E} \oplus 1$
$D^0 \to K\pi$ vertex spatial resolution, μm		60 for MAPS
		80 for DSSD
PID capabilities	dE/dx, RS	dE/dx, ECal, RS, TOF, FARICH
Number of channels, 10^3	170	294 for MAPS)
	210	397 for DSSD
Raw data flow, GB/s	up to 1	up to 20
Total weight, t	1236*	1240
Power consumption, kW	77	113 for MAPS
		90 for DSSD

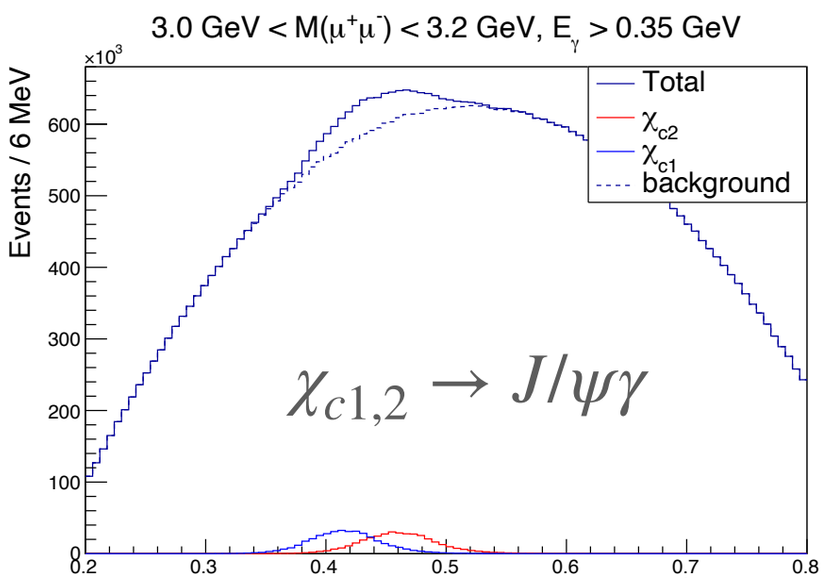
Detector	Spatial resolution	Time resolution	Energy resolution	Signal length
RS	3 mm (wires), 1 cm (strips)	150 ns	$90\%/\sqrt{E}$ (p, n)	250÷500 ns
ECal	5 mm (γ, 1 GeV)	1 ns	$5\%/\sqrt{E} \oplus 1\%$	
TOF	10 cm	50 ps	–	
FARICH		<1 ns	$d\beta/\beta < 10^{-3}$	10 ns
Straw	150 μm	1 ns	$8.5\%(dE/dx)$	120 ns
SVD MAPS	5 μm	–	–	
SVD DSSD	27.4 μm (ϕ)	–	–	
	81.3 μm (z)			
MCT	150 μm	10 ns	–	~ 300 ns
BBC inner	1.5 mm	50 ps	–	
BBC outer	~ 10 cm	400 ps	–	
ZDC	~ 1 cm	150 ps at 0.4 GeV	$50\%/\sqrt{E} \oplus 30\%$ (n)	
			$20\%/\sqrt{E} \oplus 9\%$ (γ)	

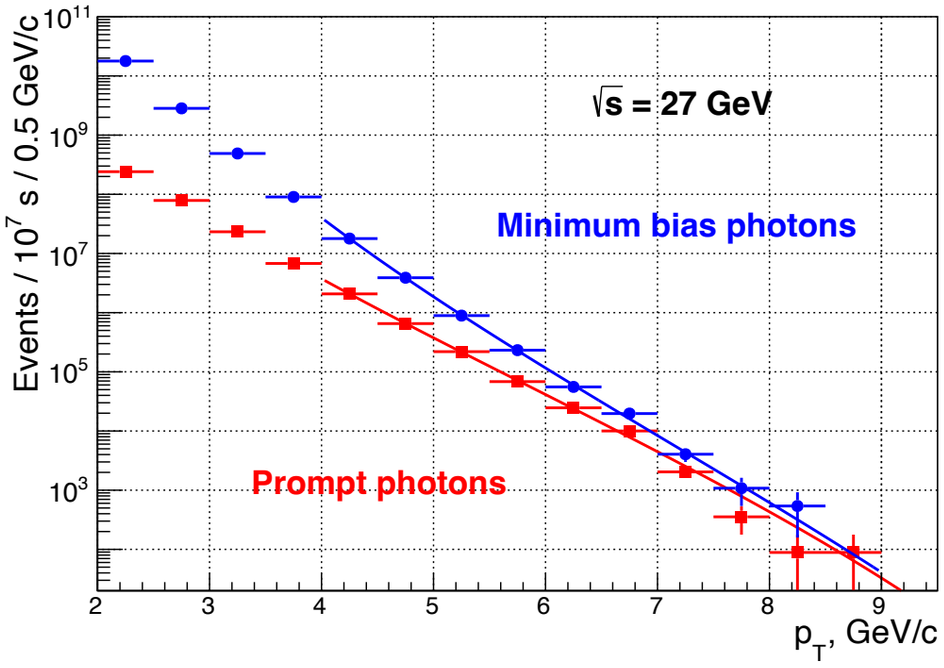
Physics performance: gluon probes

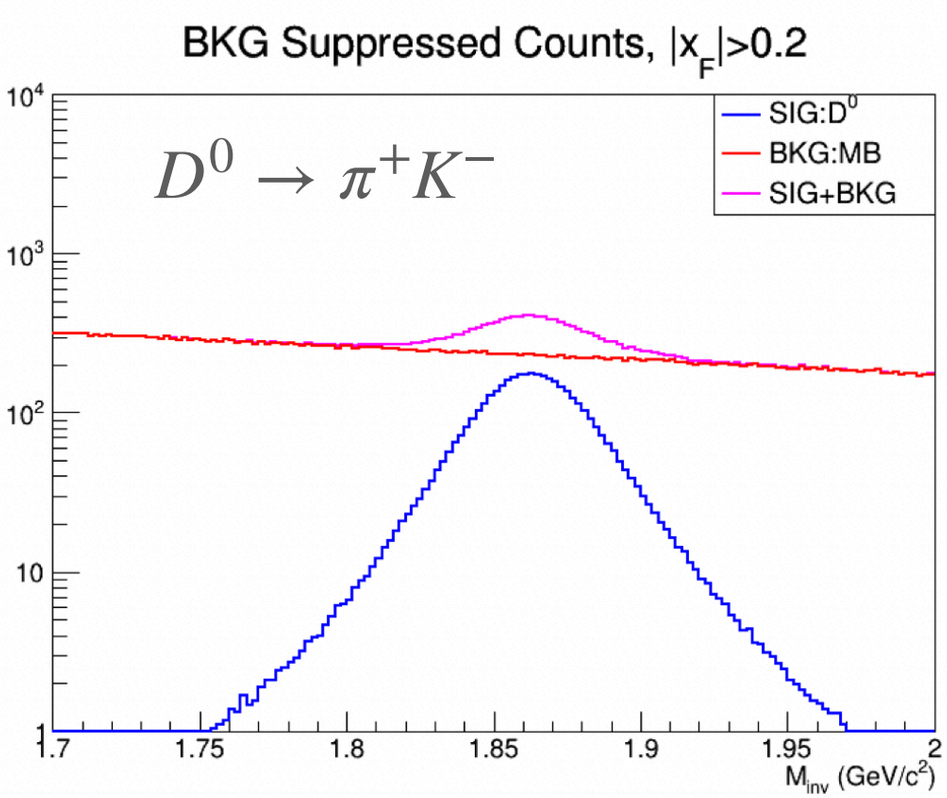
(1 year=10^7 s, 27 GeV)



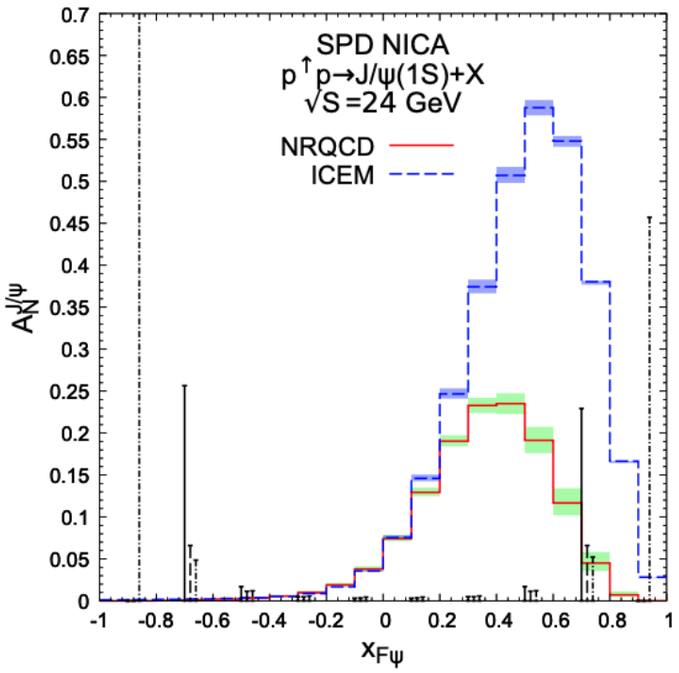




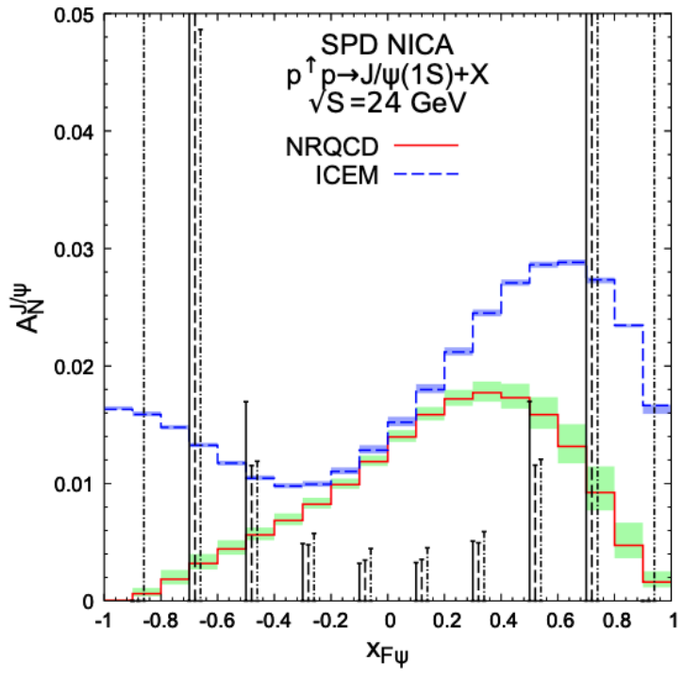


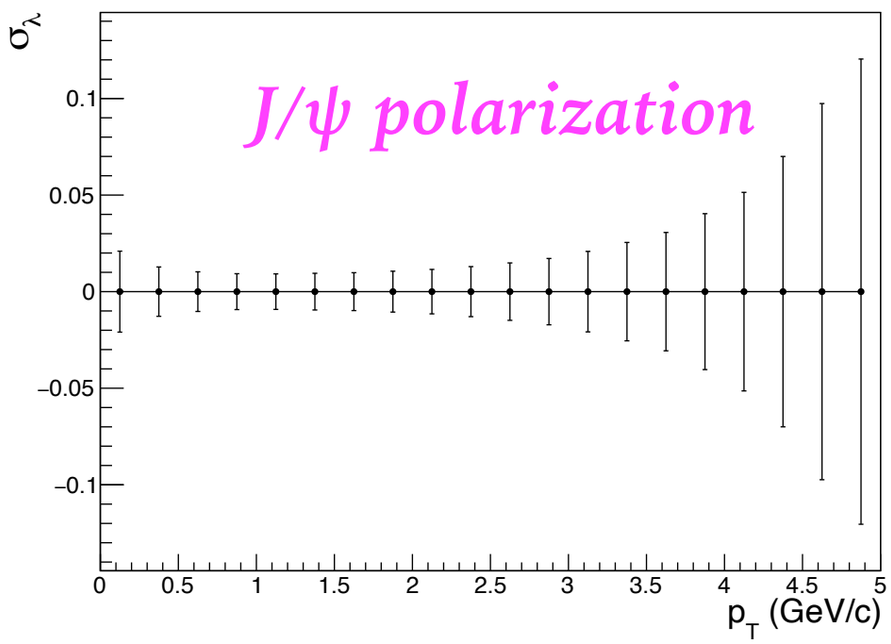


Physics performance: accuracies



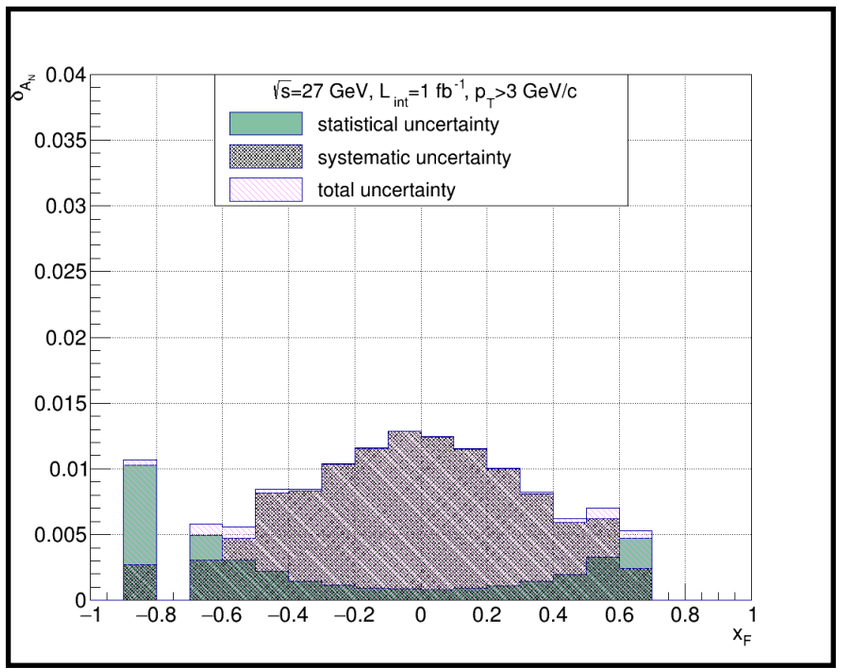
J/ψ



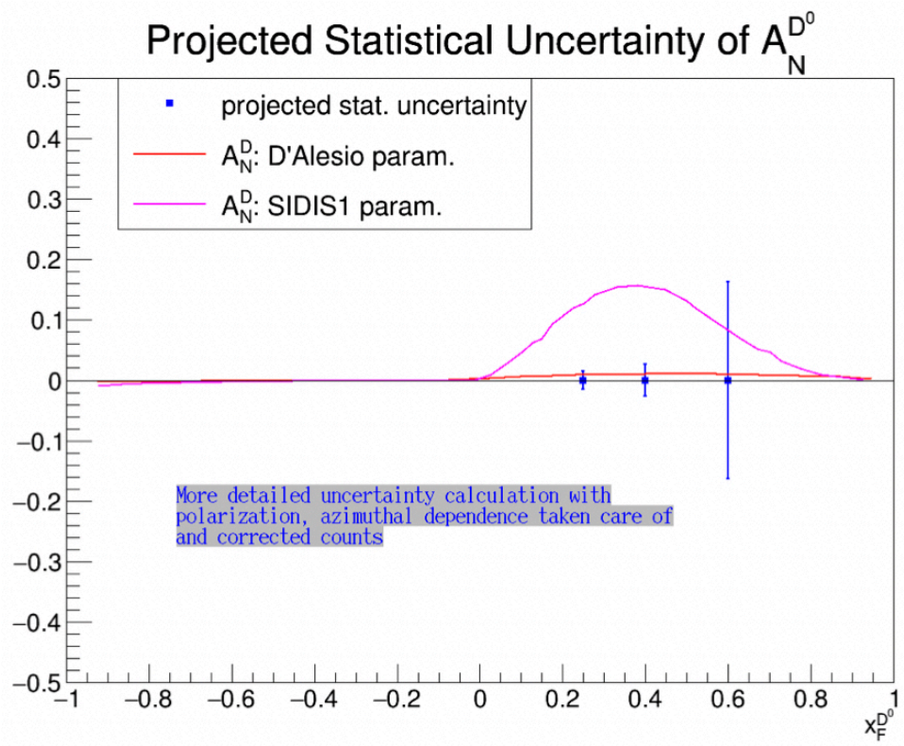


J/ψ polarization

Different inputs for gluon Sivers function

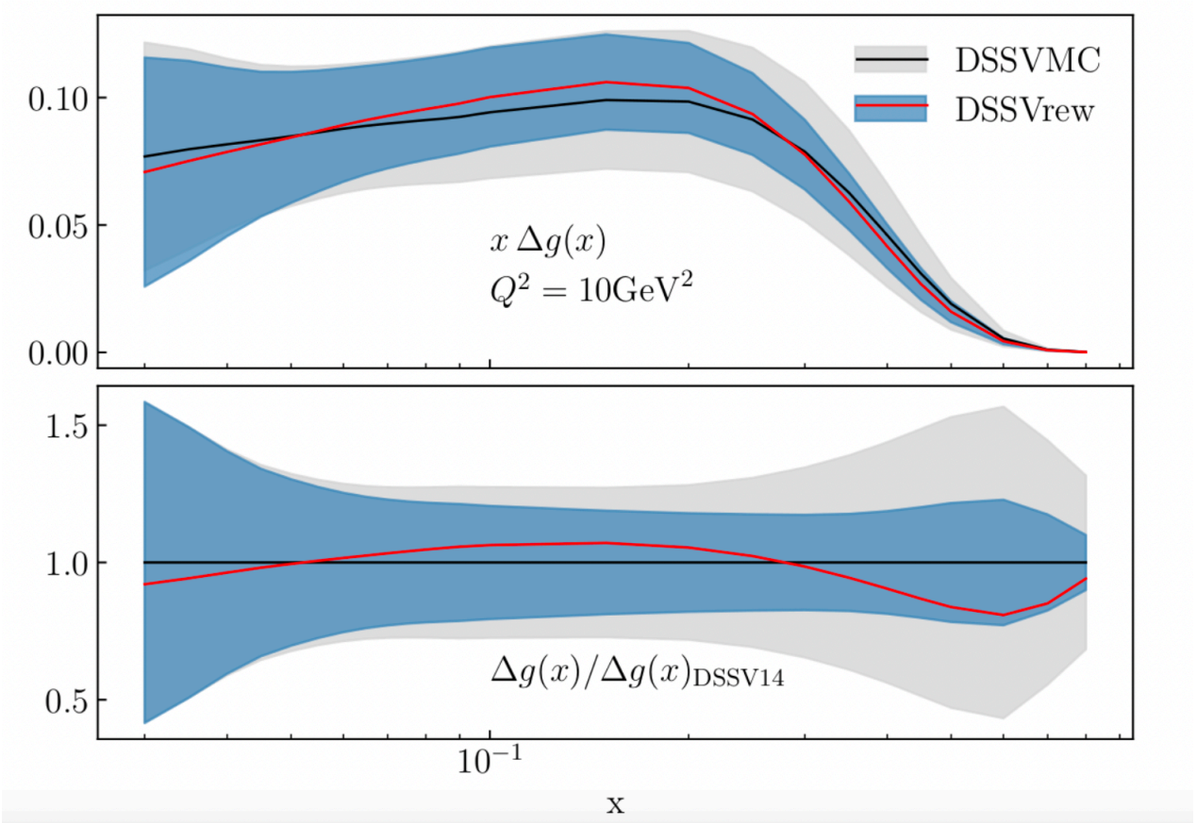


prompt-γ

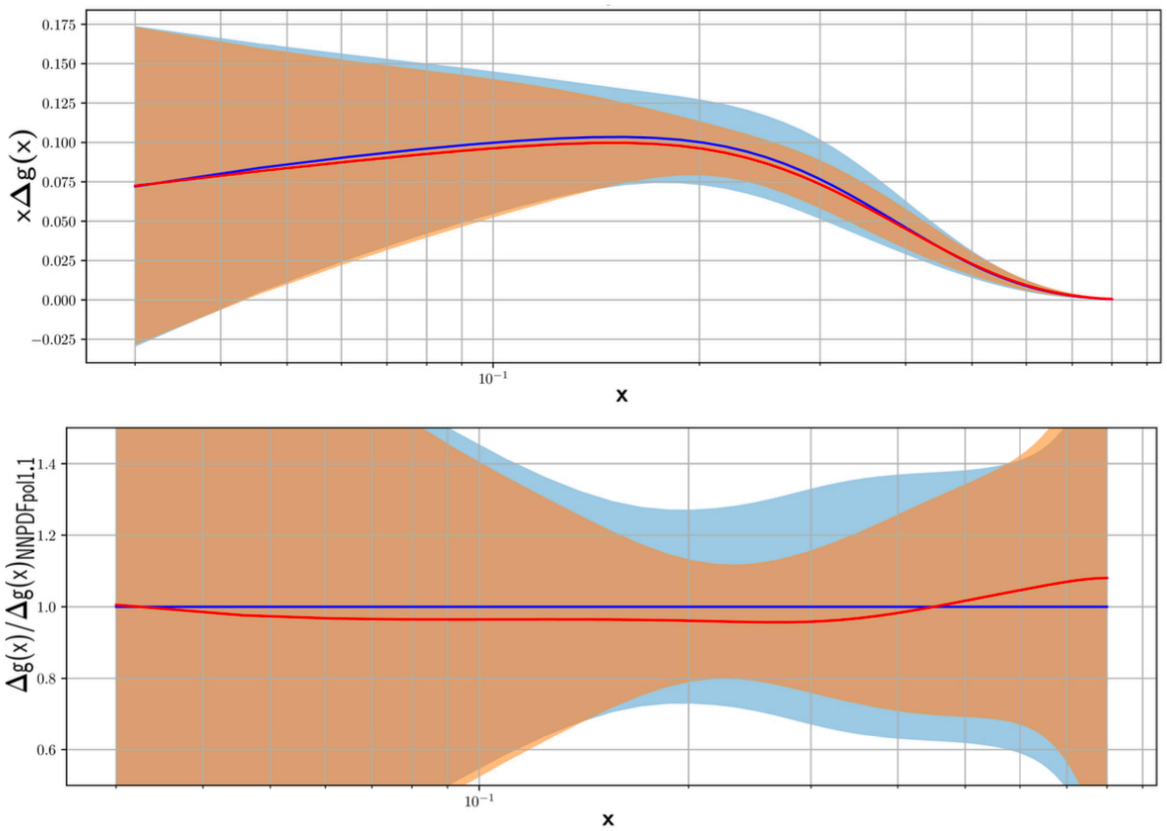


D^0

Impact of SPD measurements to the world data for $\Delta g(x)$

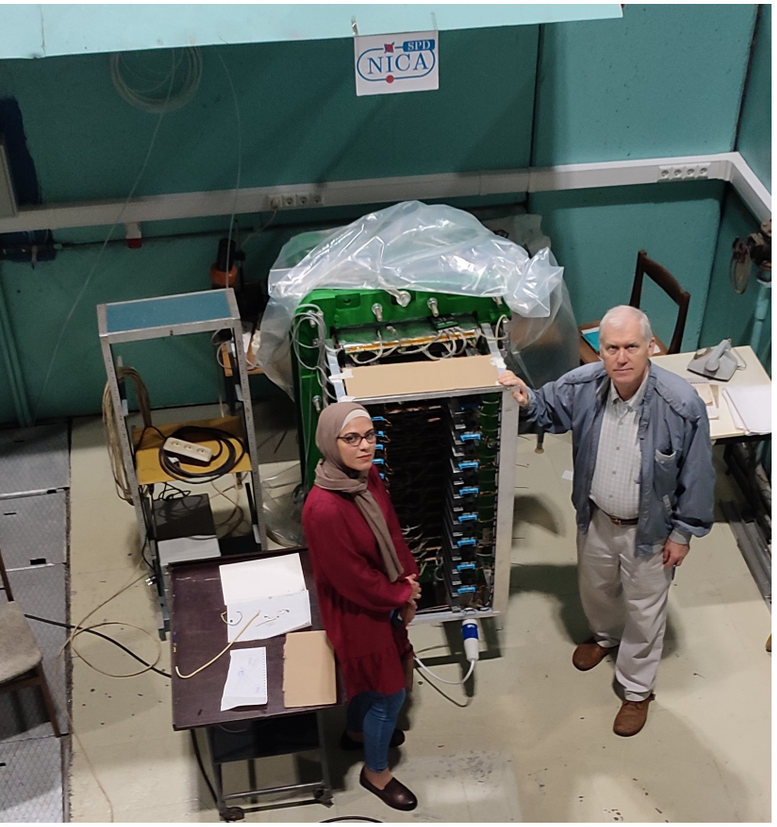


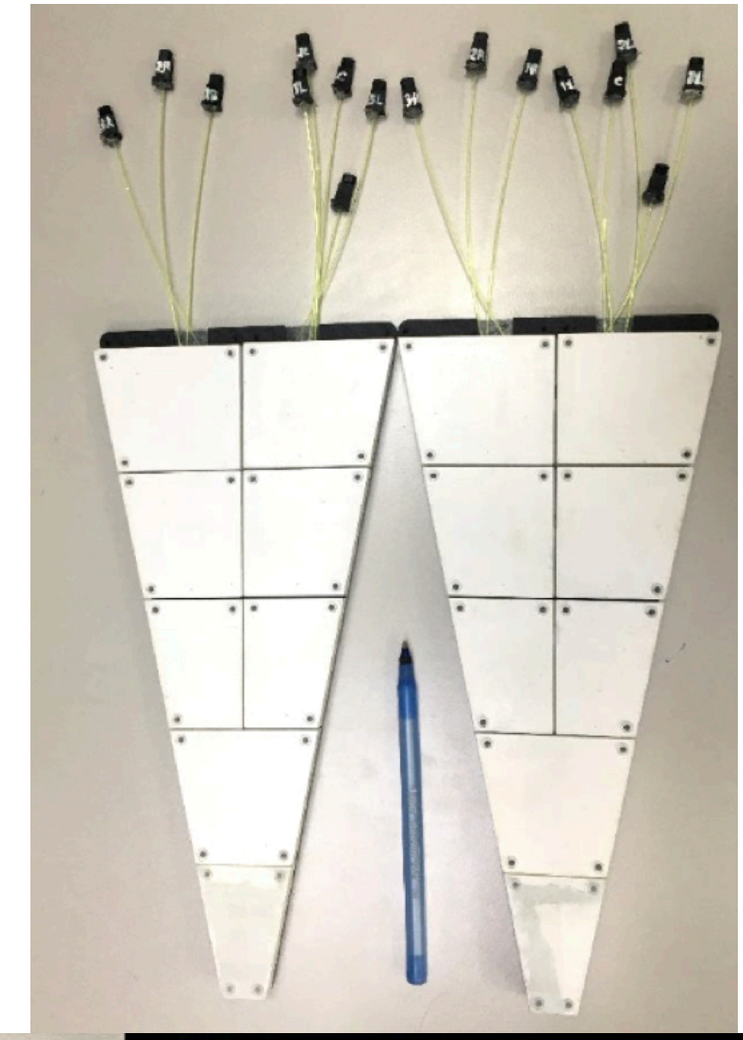
A_{LL} *for prompt photons*

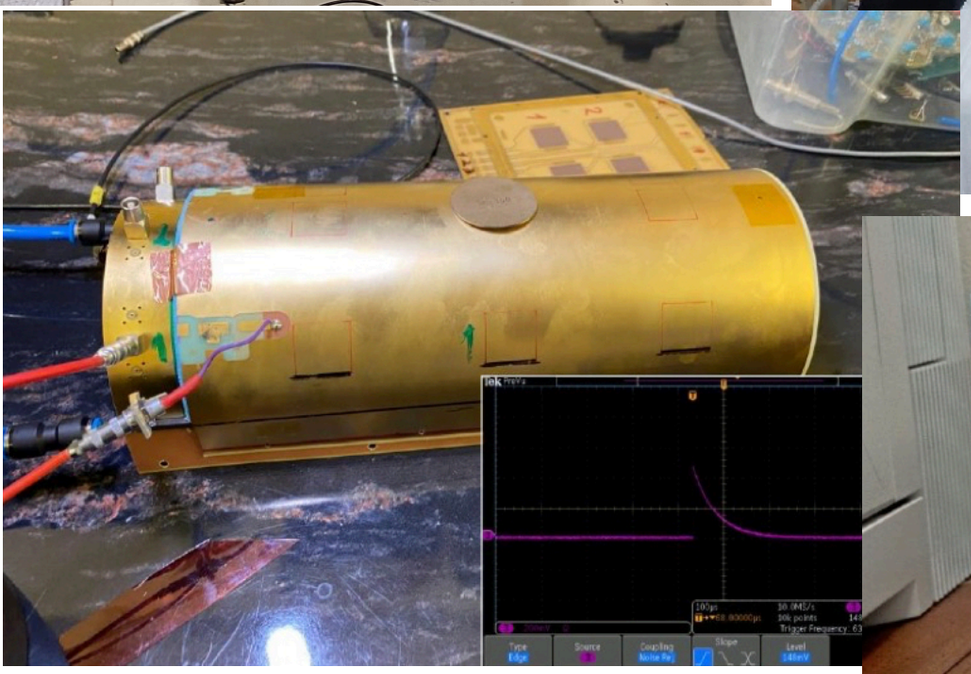


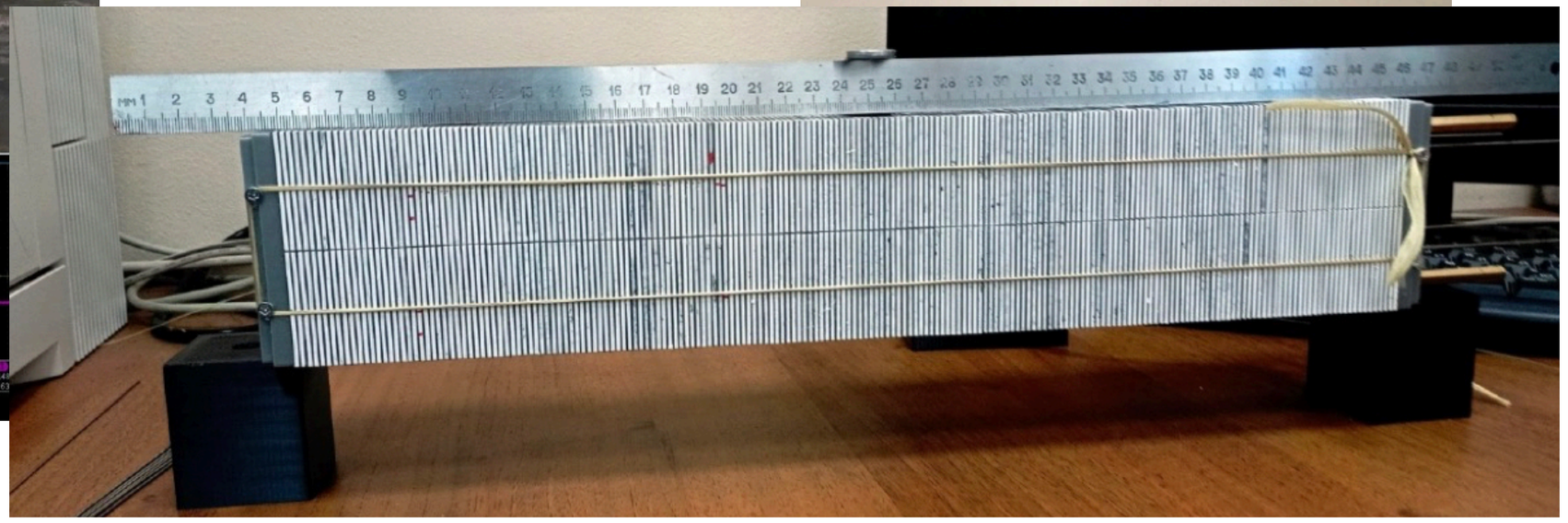
A_{LL} *for* J/ψ

Hardware


SPD
NICA






MM 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

SPD experimental hall

Status of the SPD project

SPD **Conceptual Design Report** was presented firstly in Jan 2021 and approved by the JINR PAC for Particle physics after an international expertise in Jan 2022

https://arxiv.org/abs/2102.00442

SPD **Technical Design Report** was presented firstly in Jan 2023, then was updated in 2024 and passed international expertise this year.

https://arxiv.org/abs/2404.08317

The **first phase** of the SPD project is included into the JINR's 7-year plan (2024-2030)

The **SPD international collaboration** established in 2021. Currently it consists of 35 institutes from 15 countries and more than 400 participants

Summary

- The **Spin Physics Detector** at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized **gluon cont** $\sqrt{s} \leq 27\ GeV$ **ent of proton and deuteron**; in polarized high-luminosity **p-p** and **d-d** collisions at ;
- 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;
  - …
- Comprehensive physics program for the first period of data taking: spin effects in p-p, p-d and d-d elastic scattering, spin effects in hyperon production, multiquark correlations, dibaryon resonances, physics of light and intermediate nuclei collisions, exclusive reactions, hypernuclei, open charm and charmonia near threshold, etc.;
- **The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC, AFTER, LHC-Spin, EIC, JLab experiments, EICC, …)**
- More information including **SPD CDR** and **TDR** can be found at http://spd.jinr.ru .

Summary

We wait from theorists:

- *new brilliant ideas!*
- *predictions for SPD kinematics*
  - *polarized **p-p** collisions,* $\sqrt{s_{pp}} \leq 27\ GeV$
  - *polarized **d-d** collisions,* $\sqrt{s_{NN}} \leq 13.5\ GeV$
  - unpolarized **p-p**, **d-d**, and **light ions** collisions

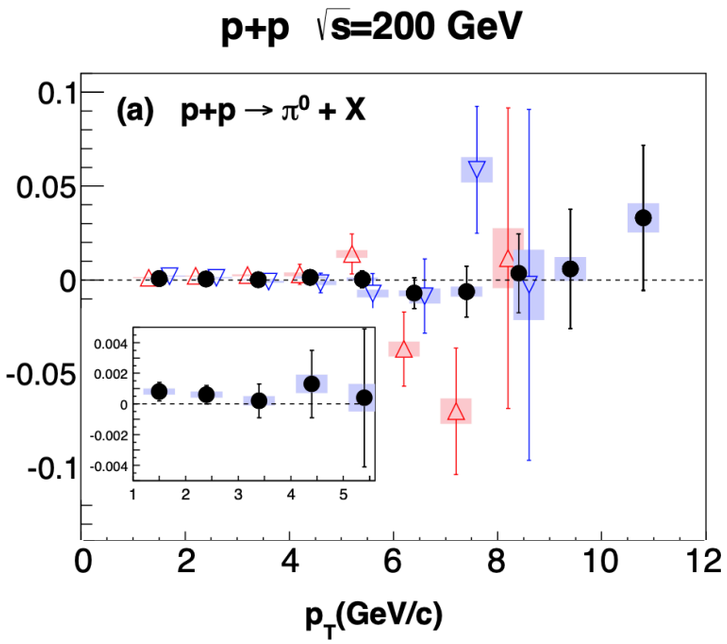
… from experimentalists:

- *joining the **SPD project** with their experience and enthusiasm*

You are welcome!

BACKUP SLIDES

Gluon Sivers function $\Delta^{g}_{N}(x,k_T)$

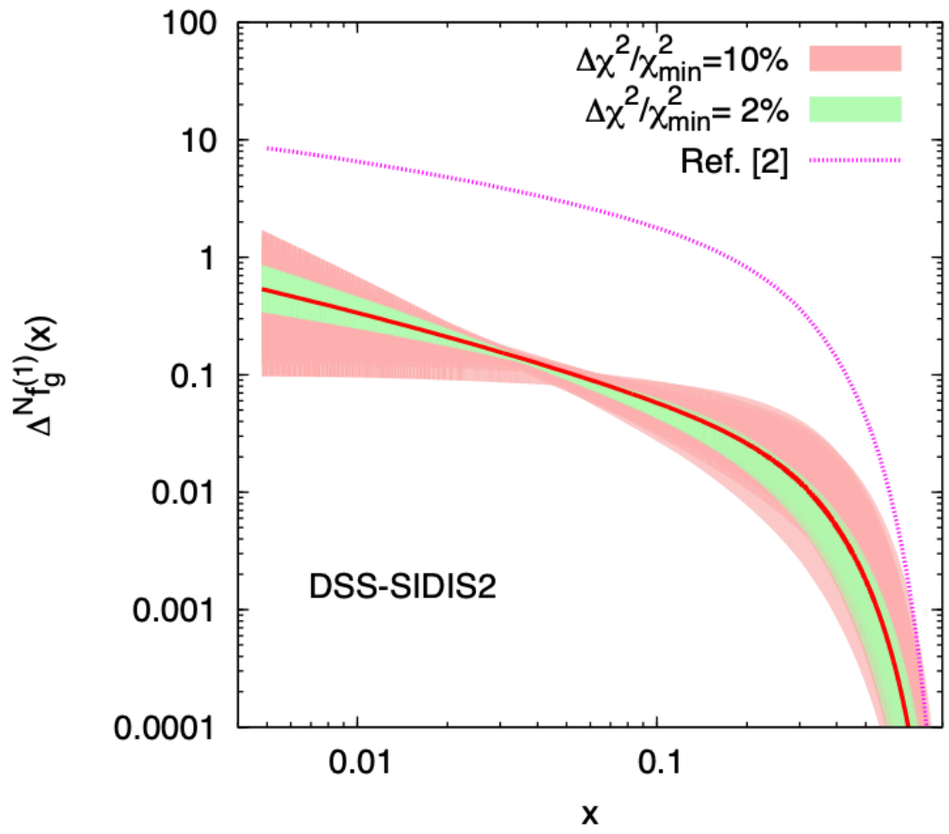


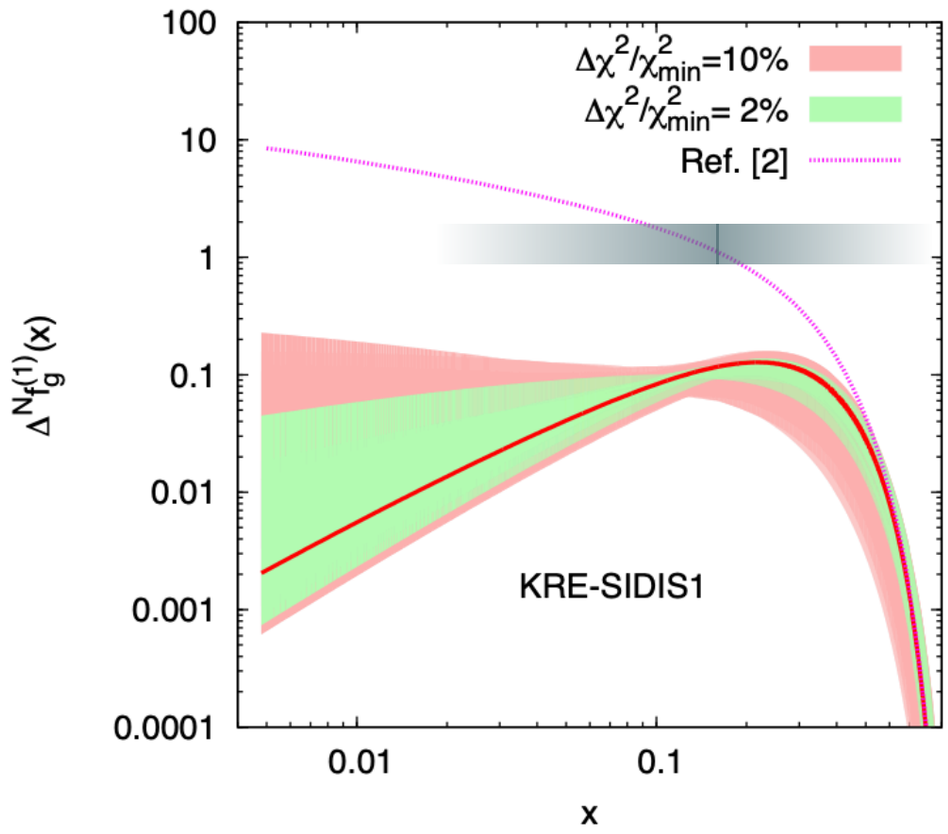
Phys.Rev.D **90 (2014) 1, 012006**

PHENIX

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

JHEP 09 (2015) 119

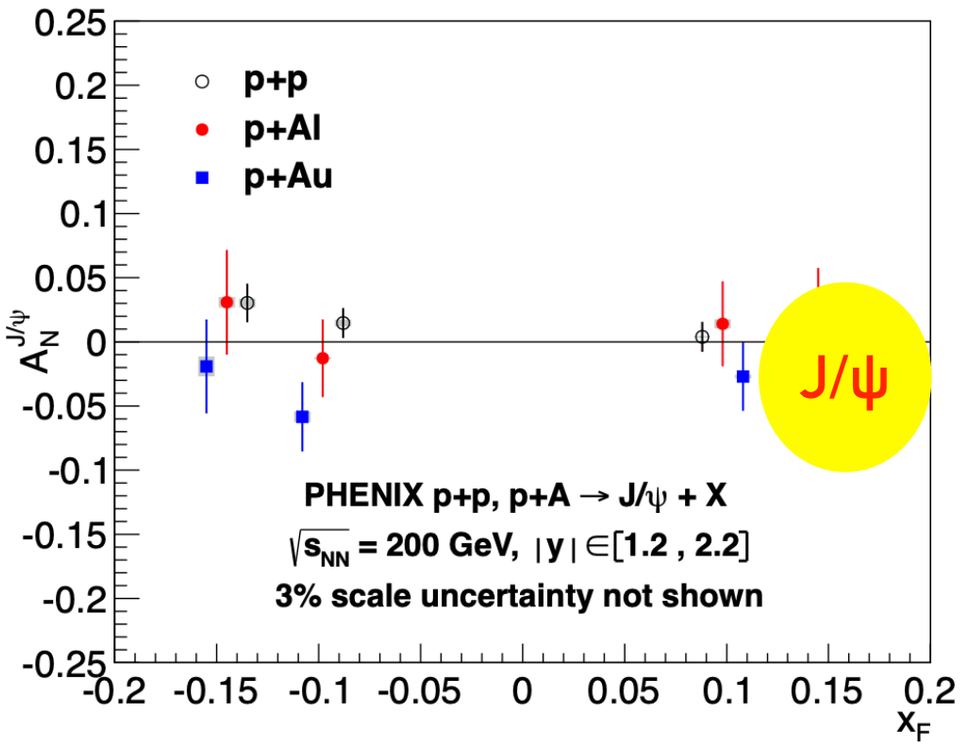


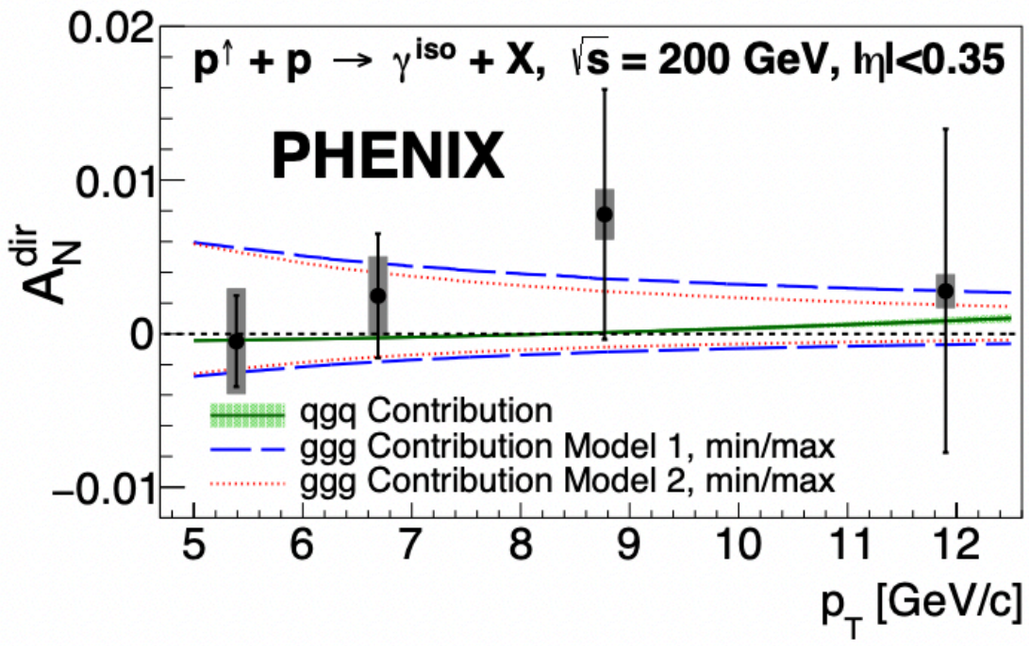


SPD

Gluon-induced TMD effects : existing results for A_N

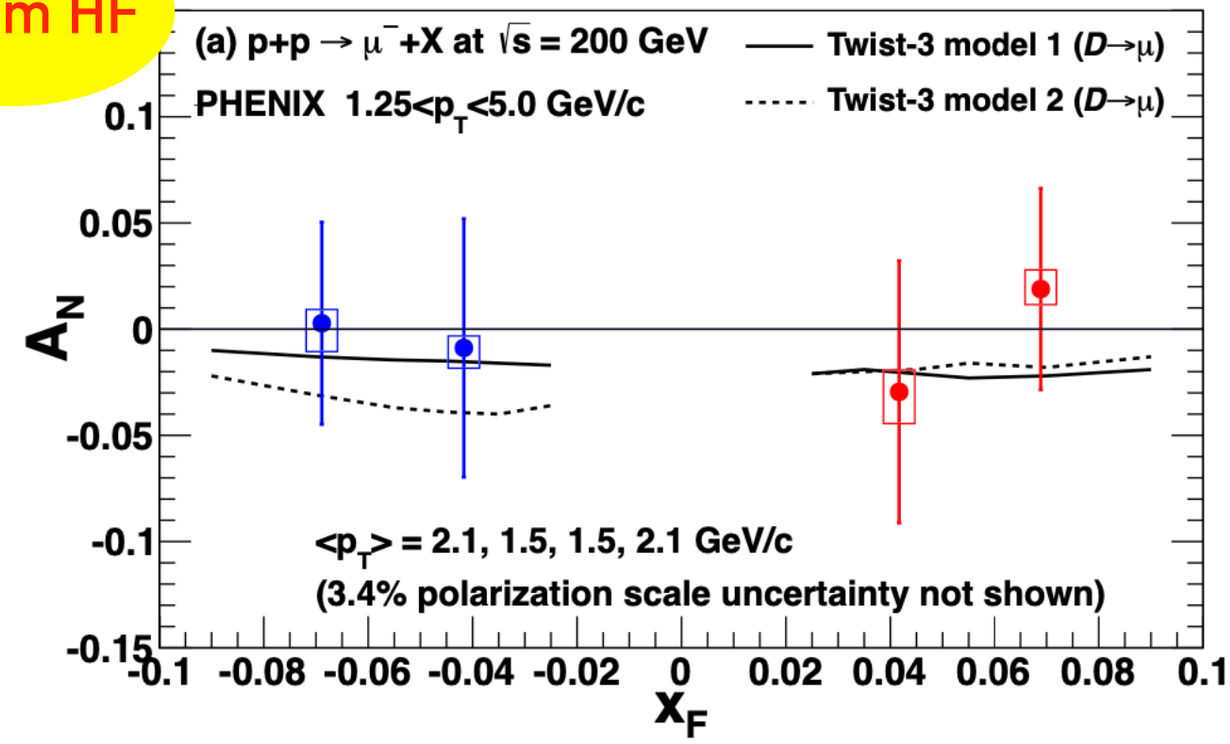
Phys.Rev.D 98 (2018) 1, 012006

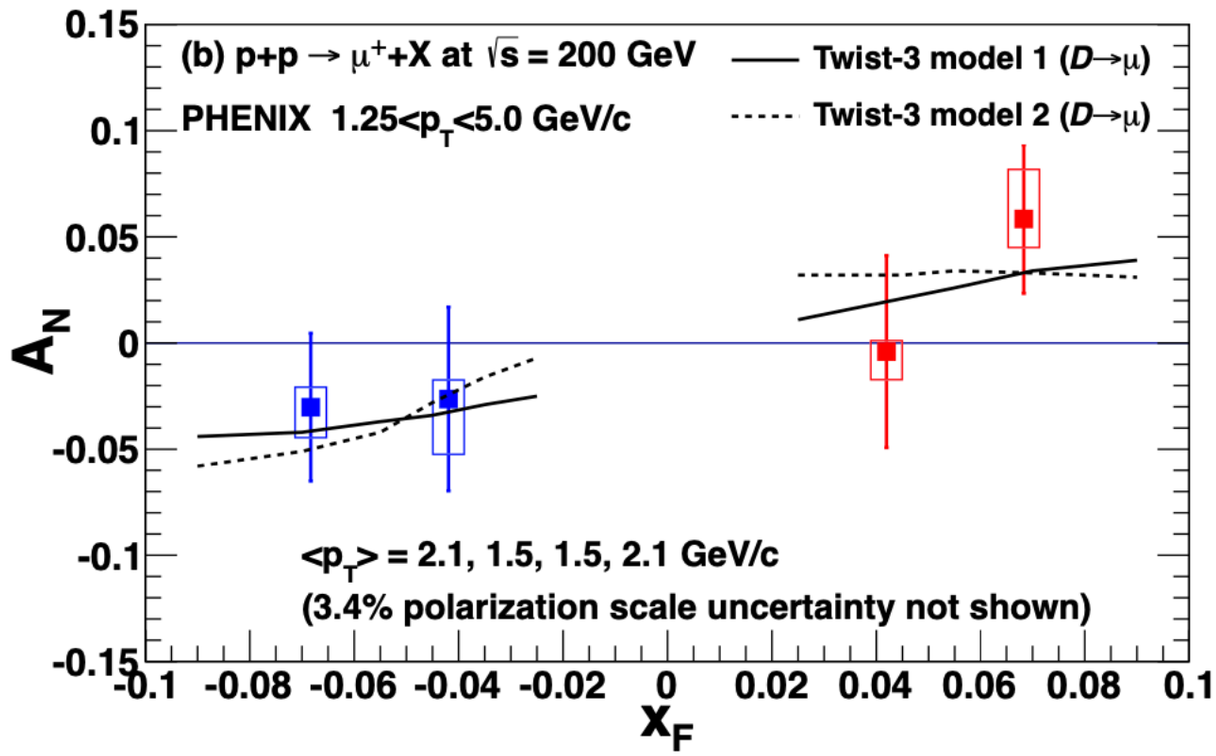




μ from HF

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





… and At NICA energies

Phys. Lett. B 345 (1995)