ПРОЕКТ SPD НА КОЛЛАЙДЕРЕ NICA

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26.4.24

Spin Physic Detector @ NICA

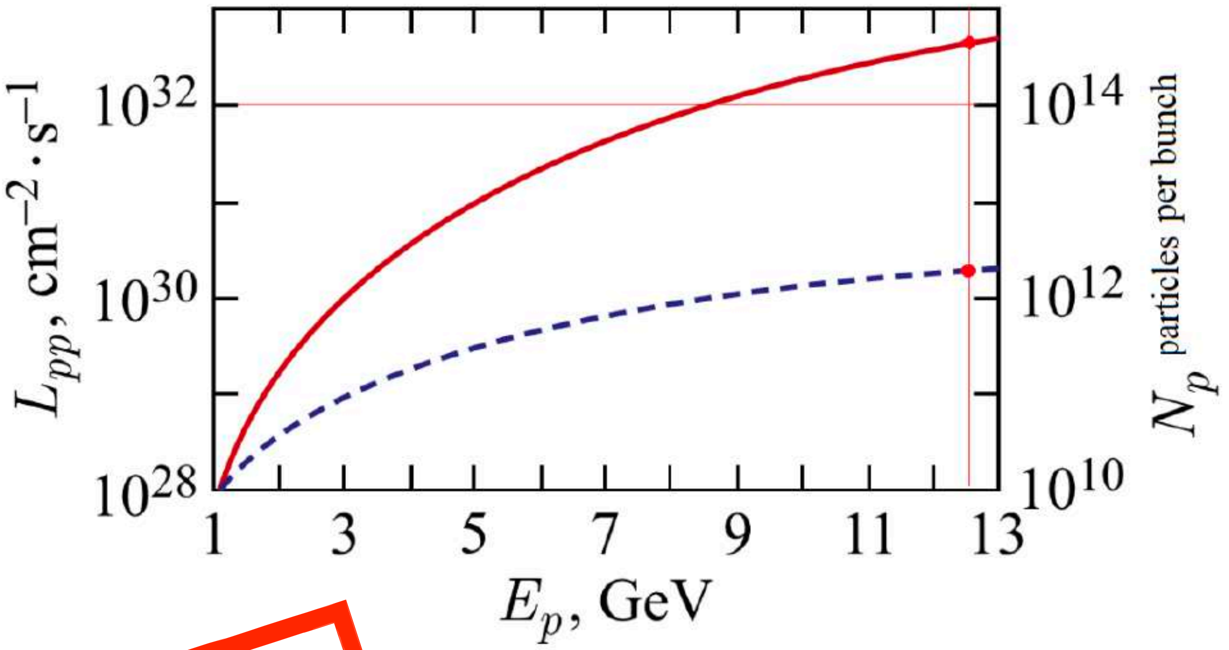
NICA - Nuclotron-based Ion Collider fAcility

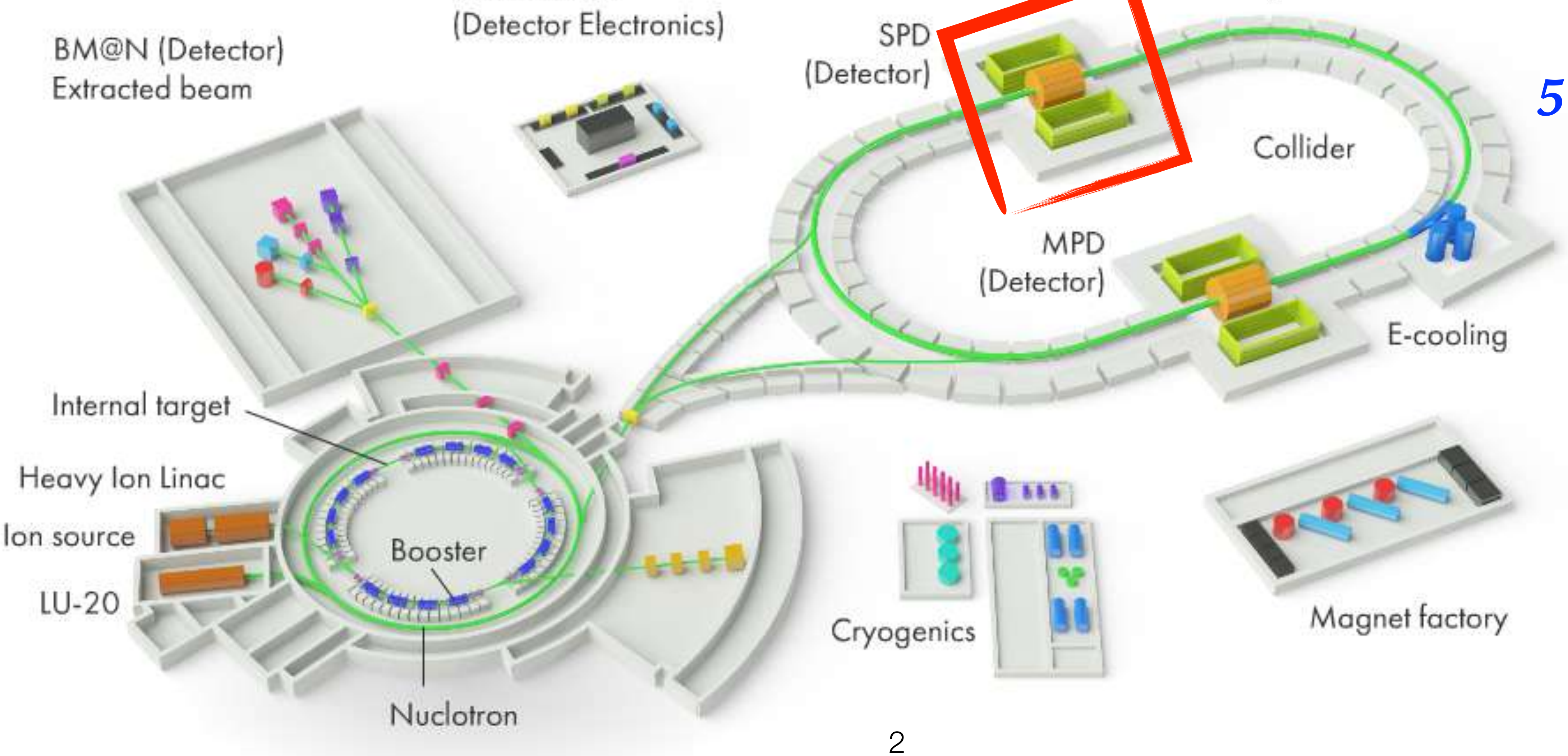
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

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

U, L, T

|P|>70%



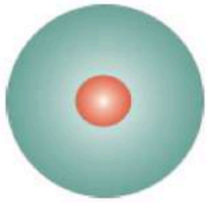


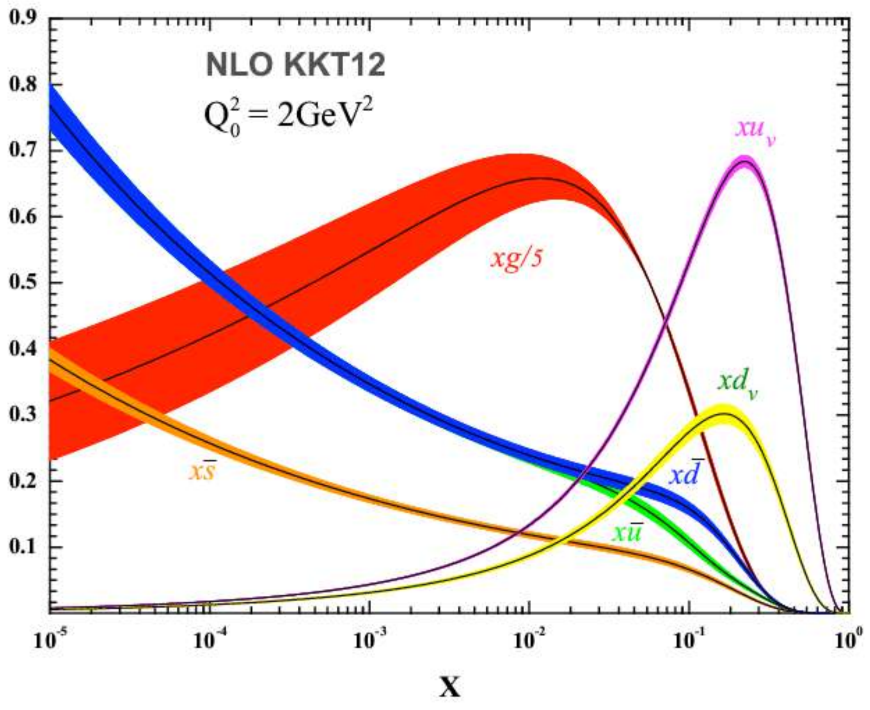
503 m

Partonic structure of proton

f(x)

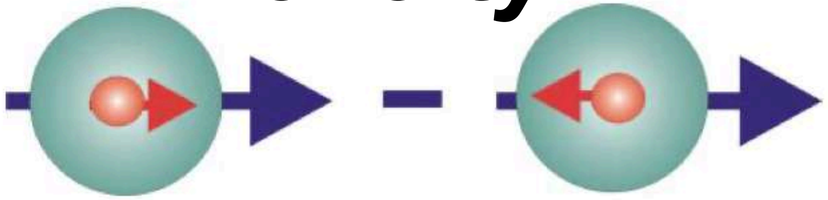
Unpolarized





Δf(x)

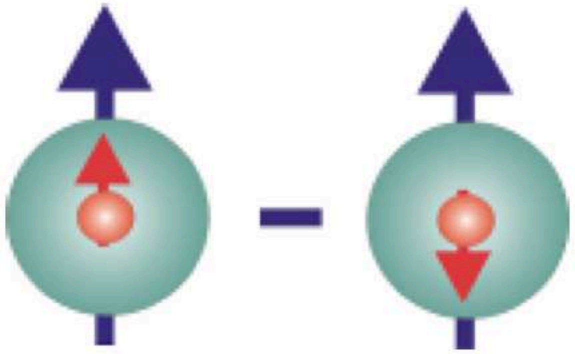
Helicity



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

Transversity

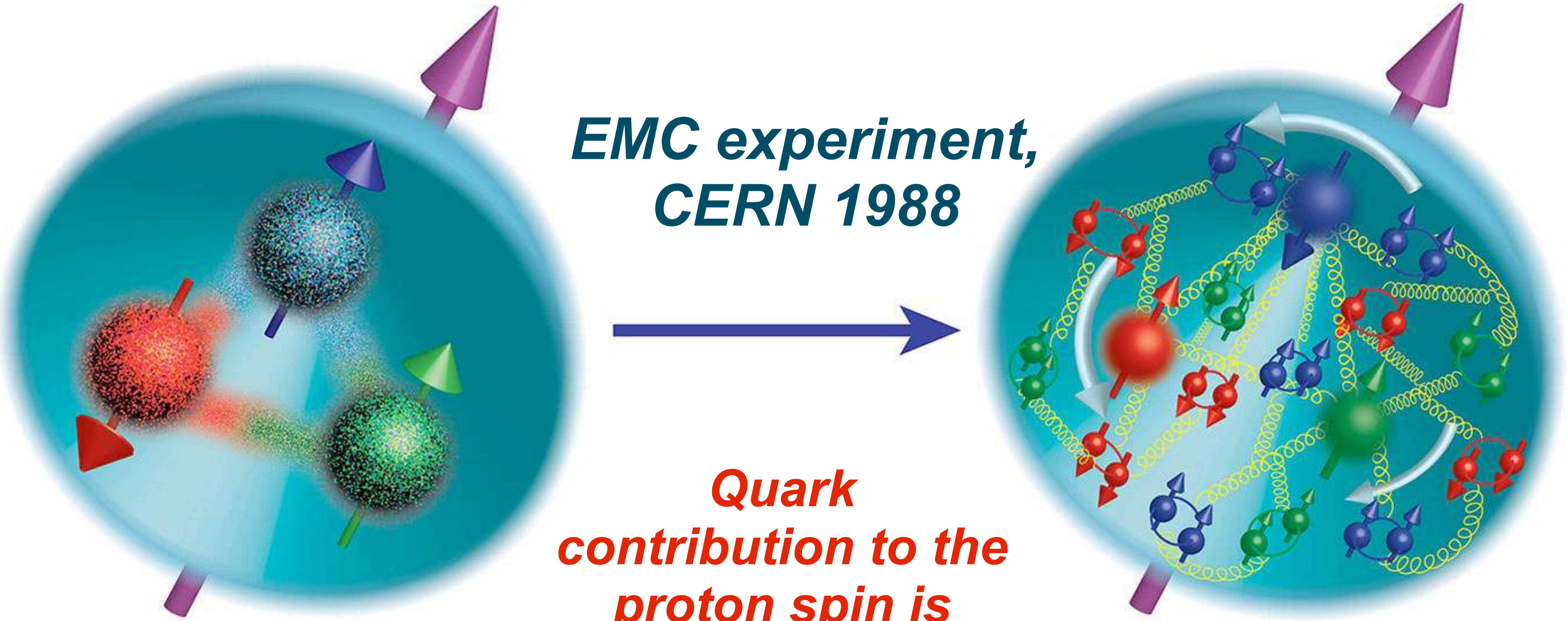
Δ_Tf(x)



Angular asymmetries

p

Spin crisis



EMC experiment, CERN 1988

Quark contribution to the proton spin is below 30%!

Naive quark model

Real situation

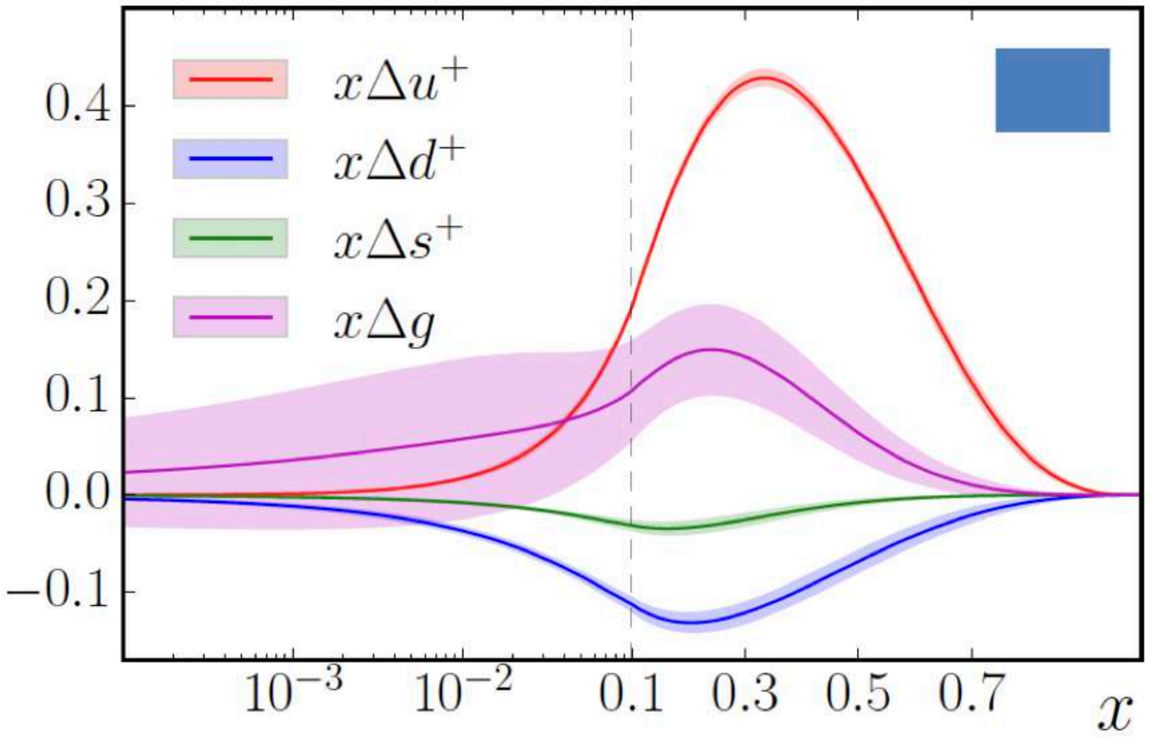
$$\frac{1}{2} = \sum_{q=u,u,d} (\frac{\vec{1}}{2})$$

L - orbital moments of quarks and gluons

$$\boxed{S_N = ½ = ½\,\Delta\Sigma + \Delta G + L}$$

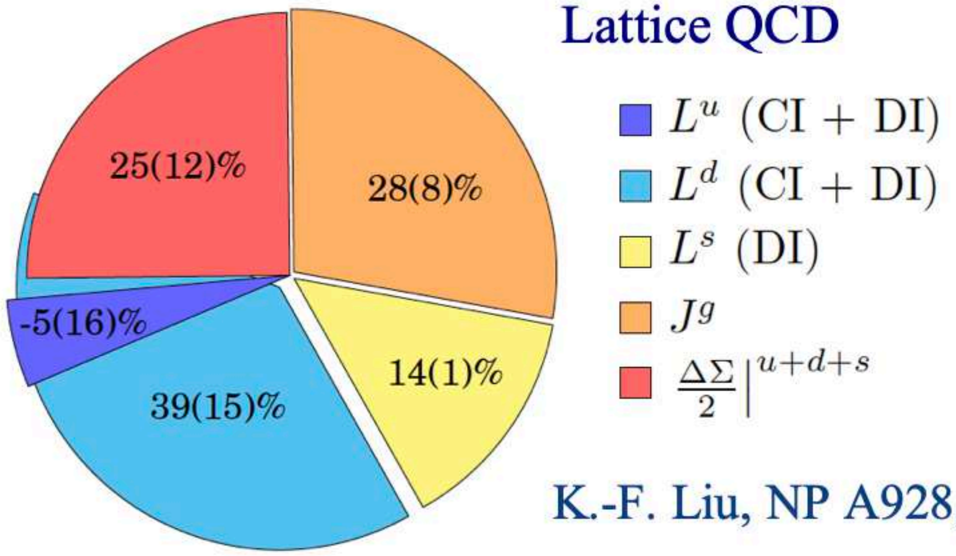
Spin balance

$$J = \frac{1}{2}\overset{\sim 30\%}{\Delta\Sigma} + \underset{\sim 10\text{-}20\%}{\Delta G} + \boxed{\overset{?}{L_q} + \overset{?}{L_g}}$$



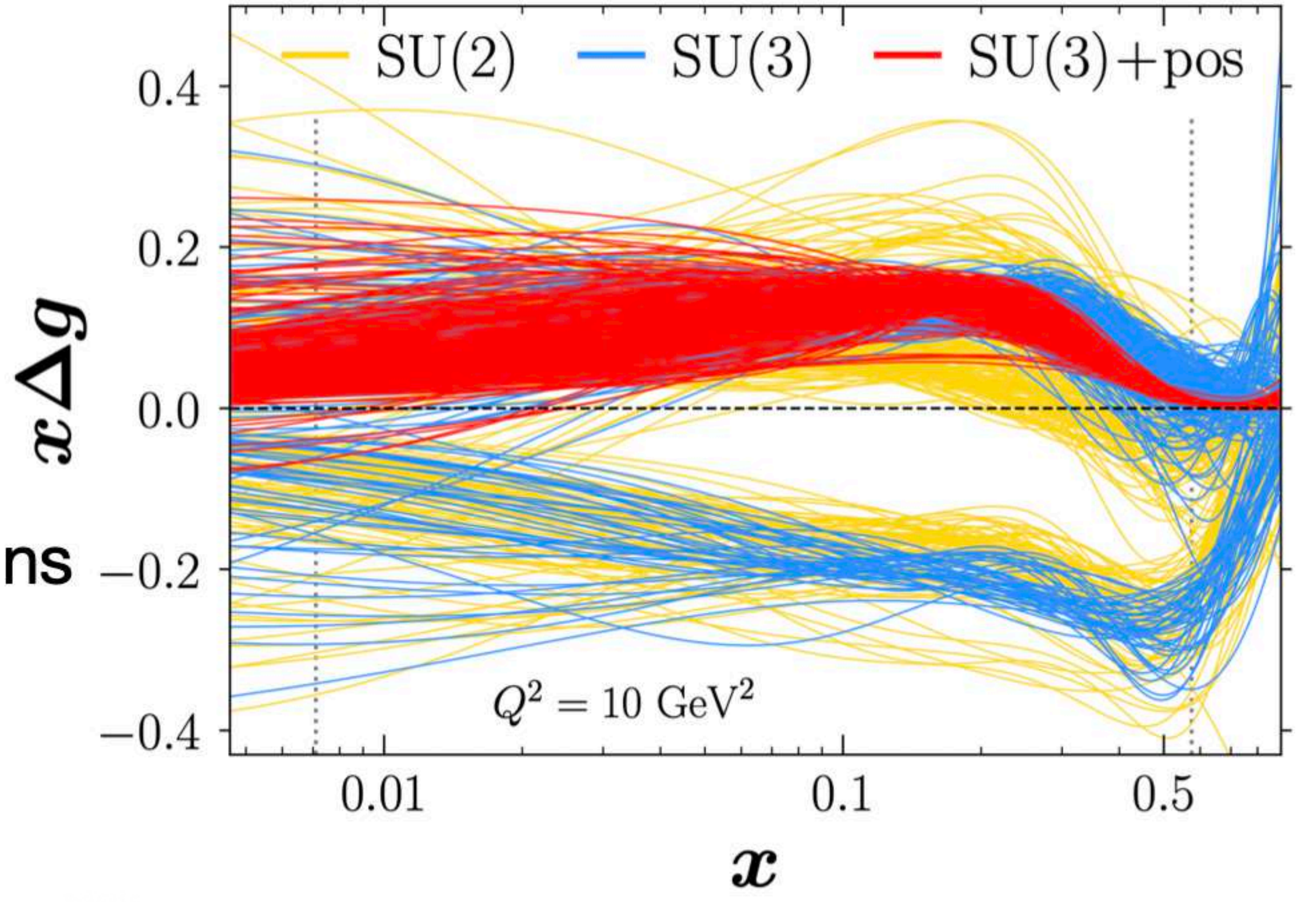
JAM Collaboration, PRD (2016).

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

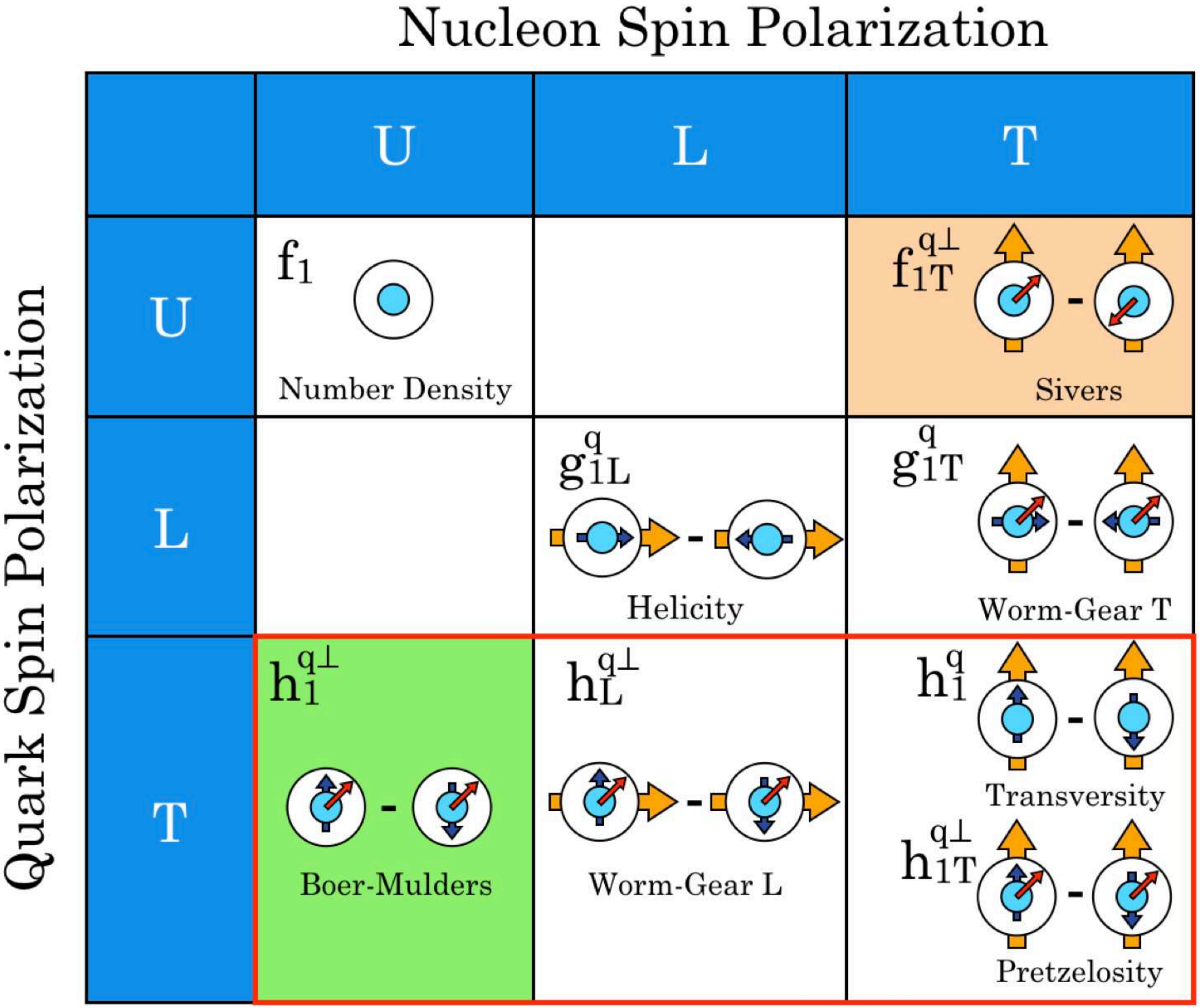


K.-F. Liu, NP A928, 99 (2014).

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



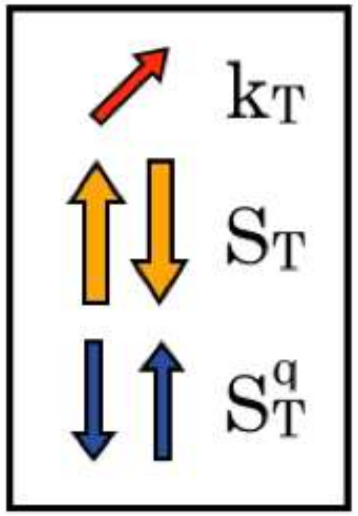
Proton in 3D: TMD PDFs



Nucleon Spin Polarization

Quark Spin Polarization

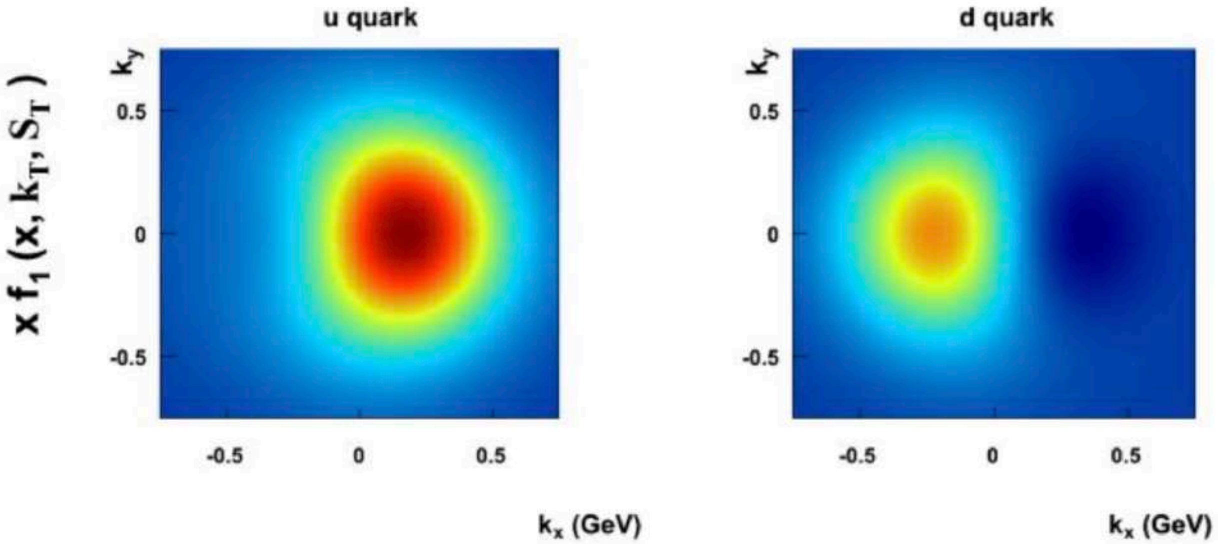
	U	L	T
U	f_1 Number Density		$f_{1T}^{q\perp}$ Sivers
L		g_{1L}^{q} Helicity	g_{1T}^{q} Worm-Gear T
T	$h_1^{q\perp}$ Boer-Mulders	$h_L^{q\perp}$ Worm-Gear L	h_1^{q} Transversity $h_{1T}^{q\perp}$ Pretzelosity



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

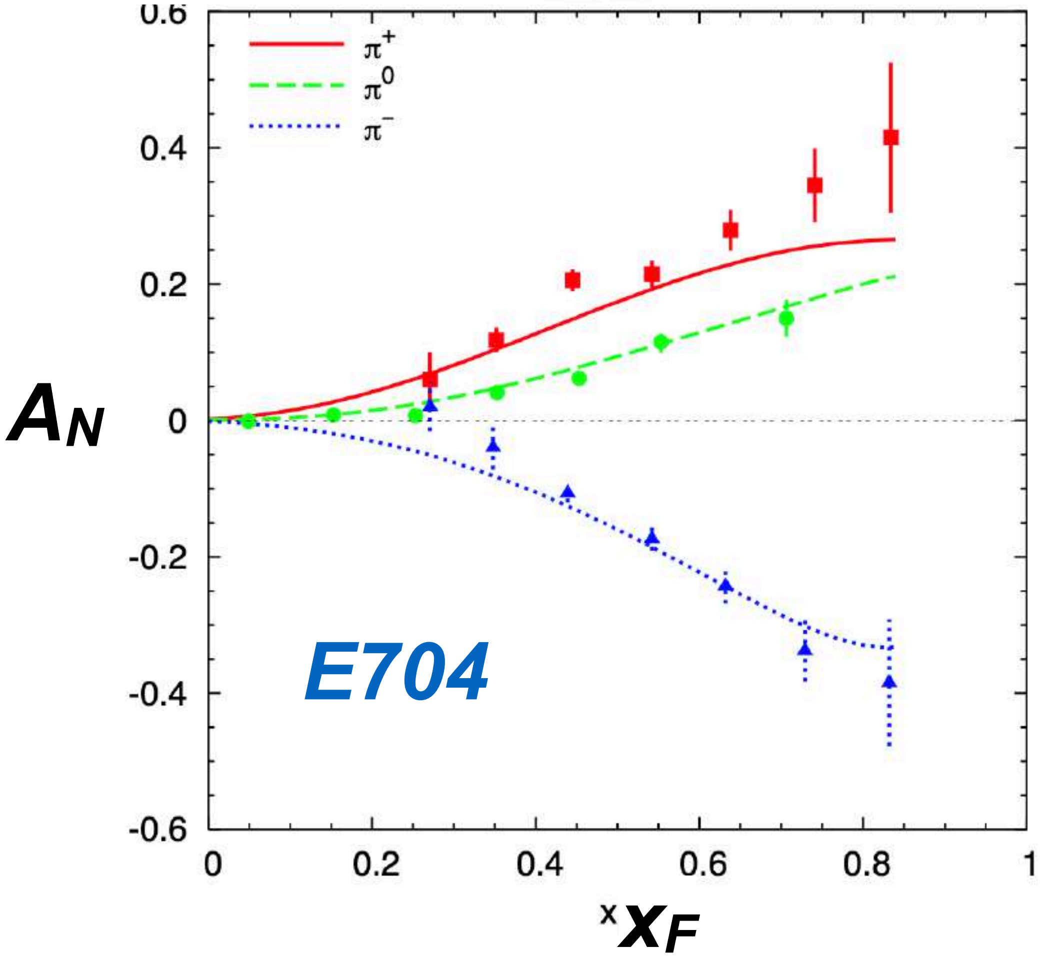
TMD effects: Sivers effect

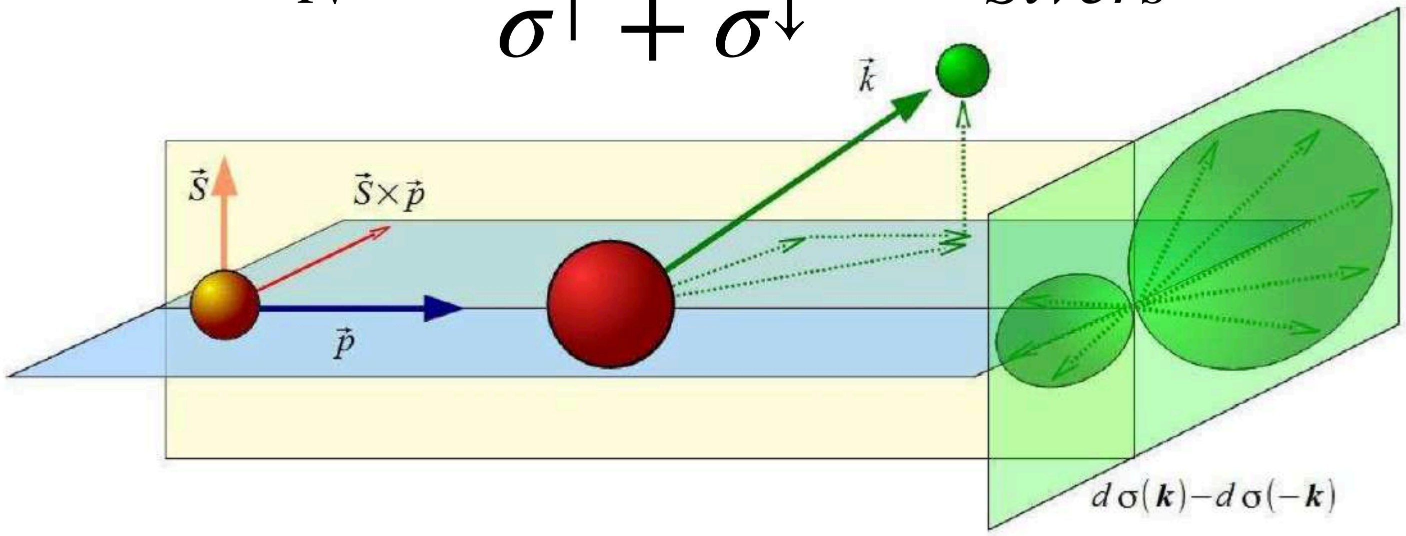
Probabilities to meet in a transversely polarized proton a parton moving to the ***left*** ***and to the*** ***right*** ***with respect to the*** $(\vec{S},\vec{p})$ ***plane are different!***



x=0.1

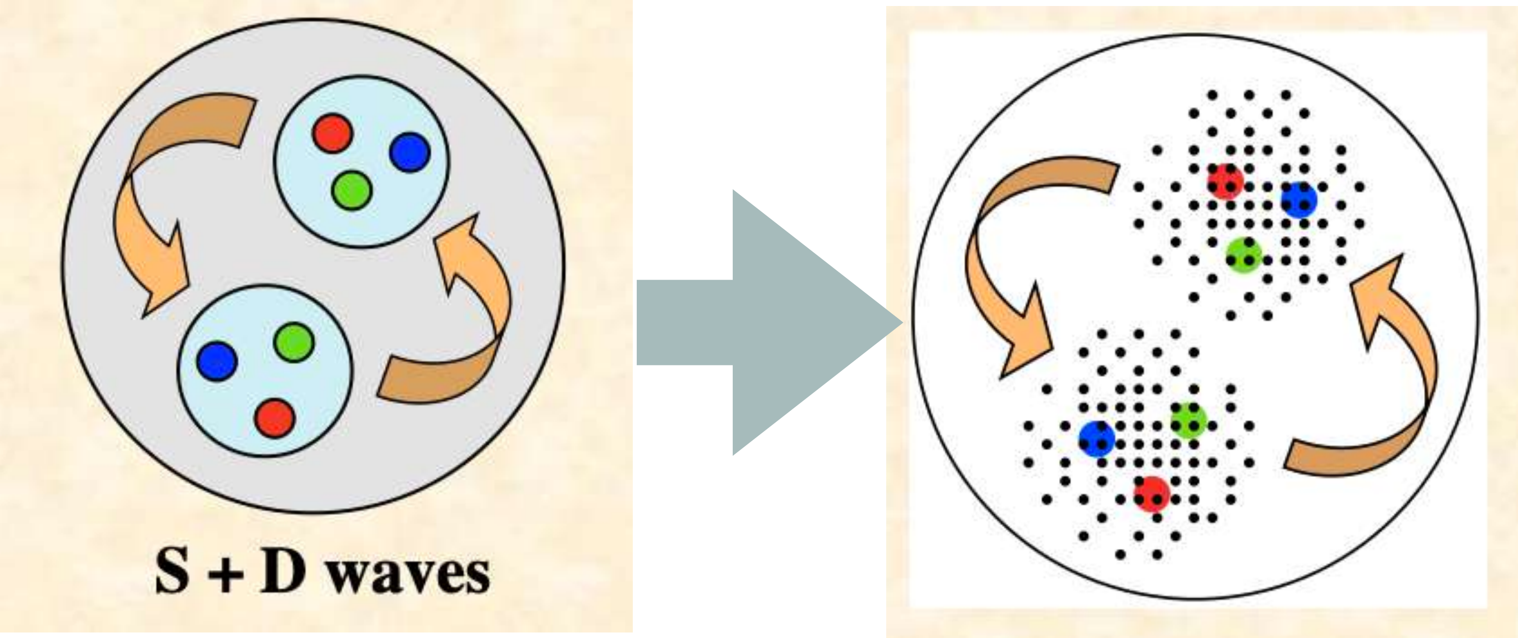
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim f_{Sivers}$$





The Sievers effect is usually observed together with the Collins effect, an asymmetry arising from the fragmentation of the final state.

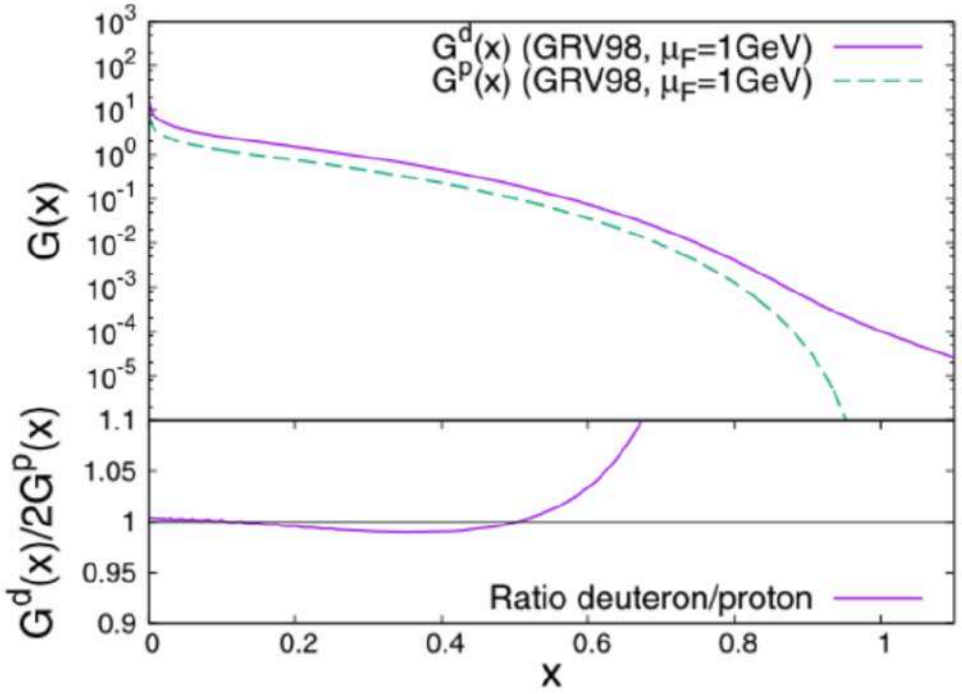
Deuteron



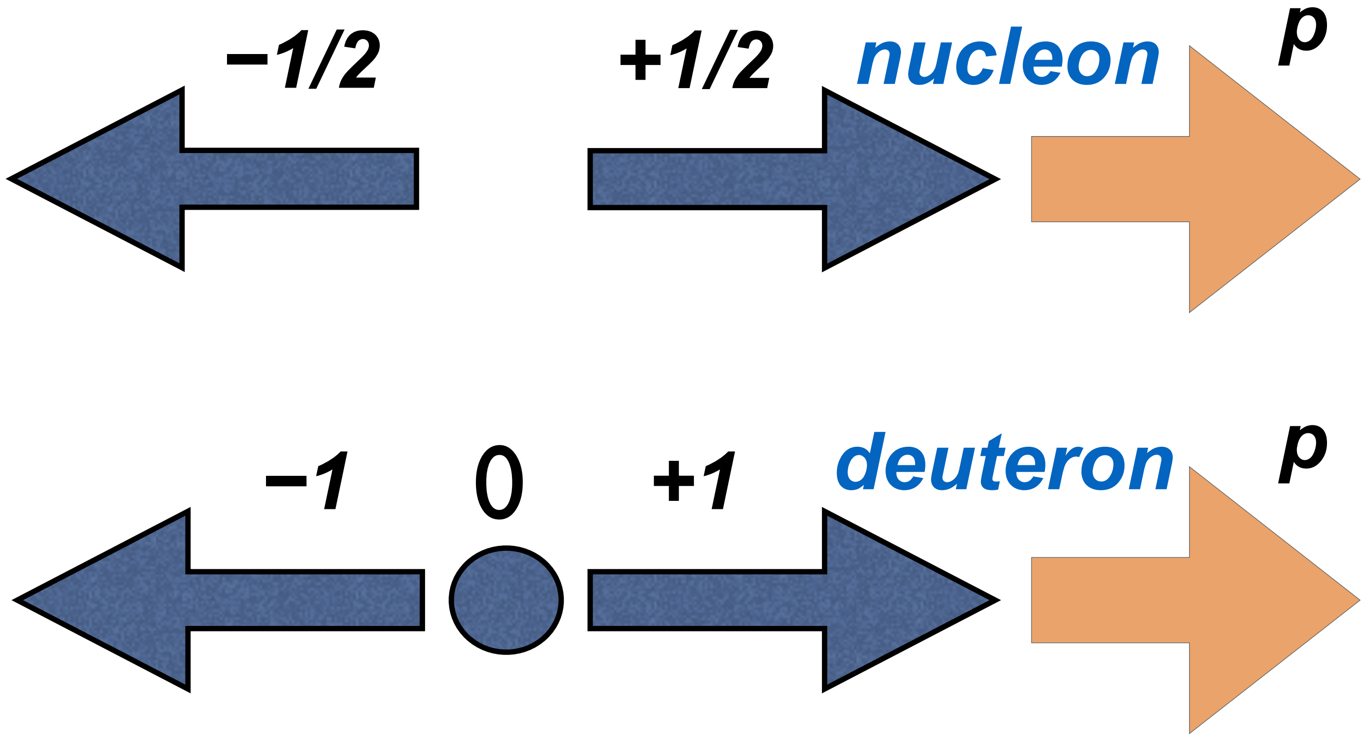
$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + \boxed{c_3|CC\rangle}$$

hidden color

Deuteron is not just proton + neutron!



More gluons at large x with respect to nucleon?



Vector polarization

$$\frac{N_{1/2} - N_{-1/2}}{N_{1/2} + N_{-1/2}}$$

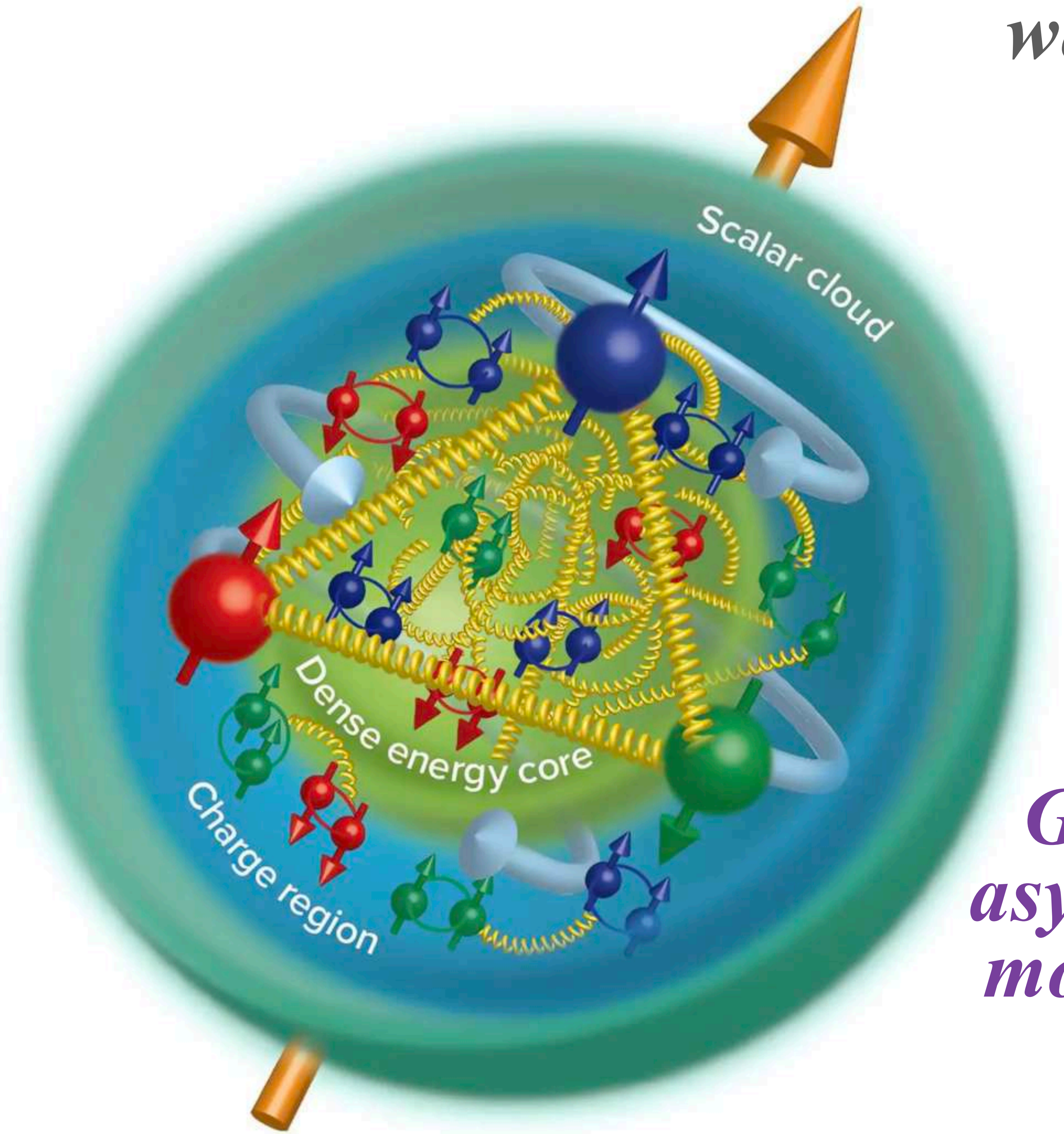
Tensor polarization

$$\frac{2N_0 - (N_{-1} + N_1)}{2N_0 + N_{1/2} + N_{-1/2}}$$

New “tensor” PDFs, mostly unknown

Gluon transversity PDF

Spin Physics @ NICA



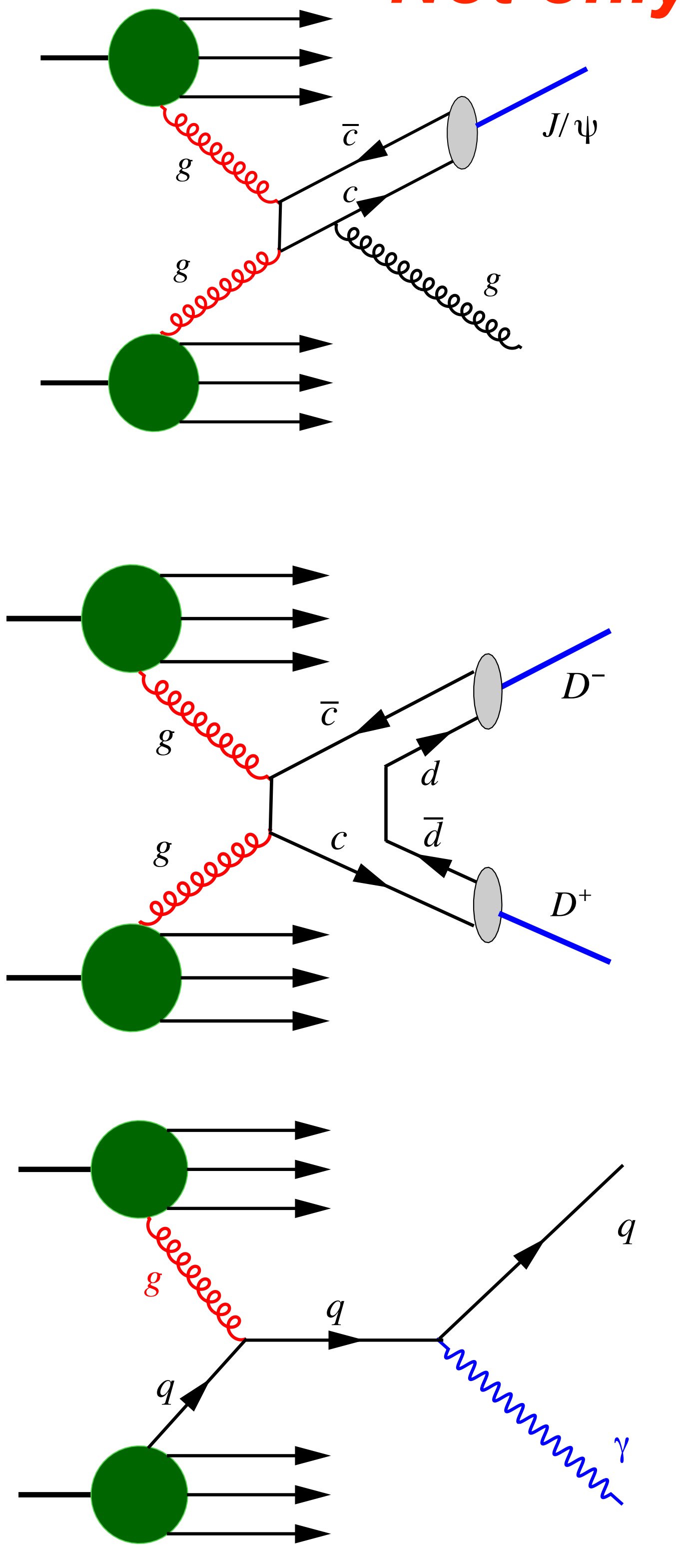
we plan to study how the proton and deuteron spin!

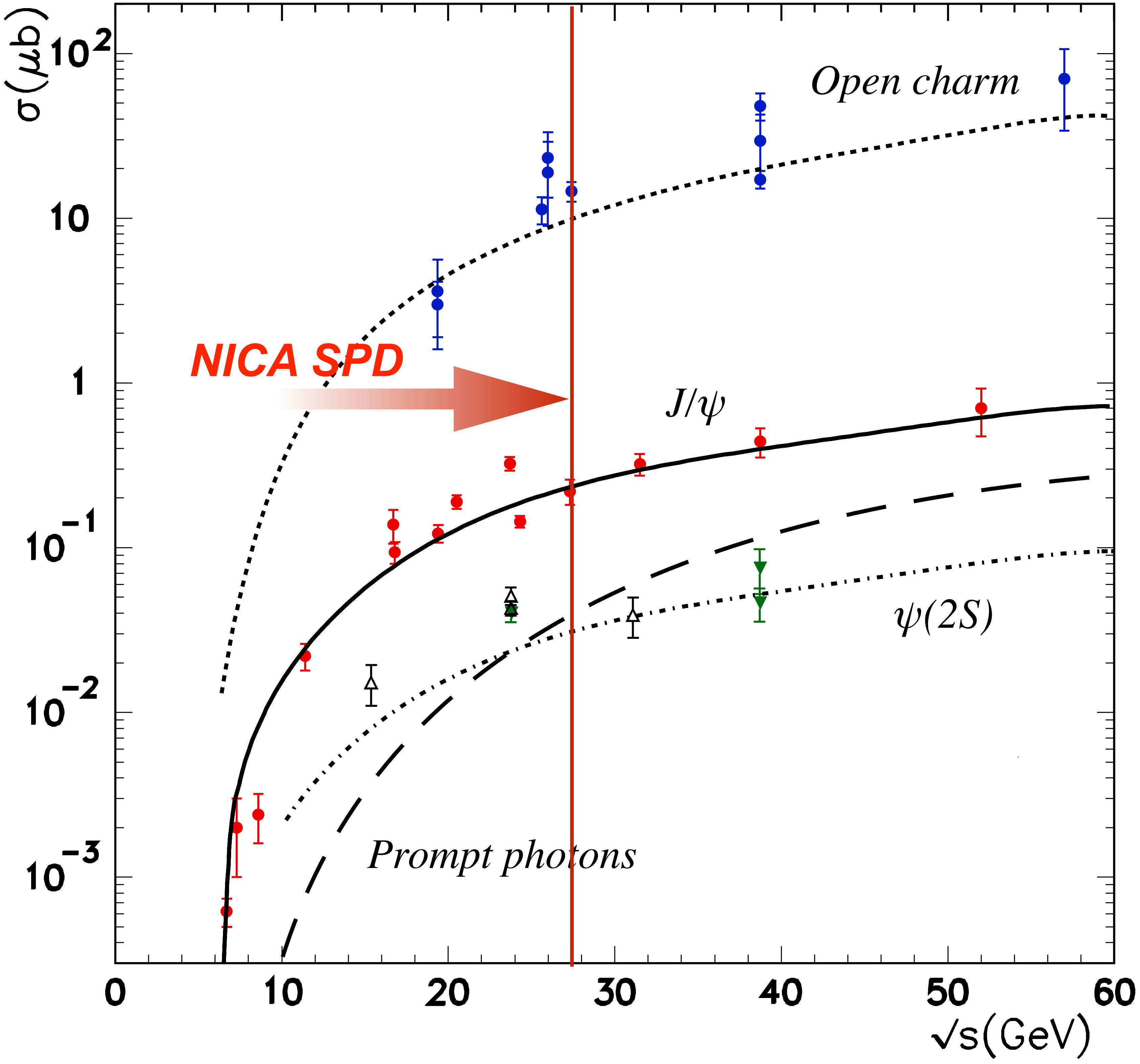
especially their gluon component!

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

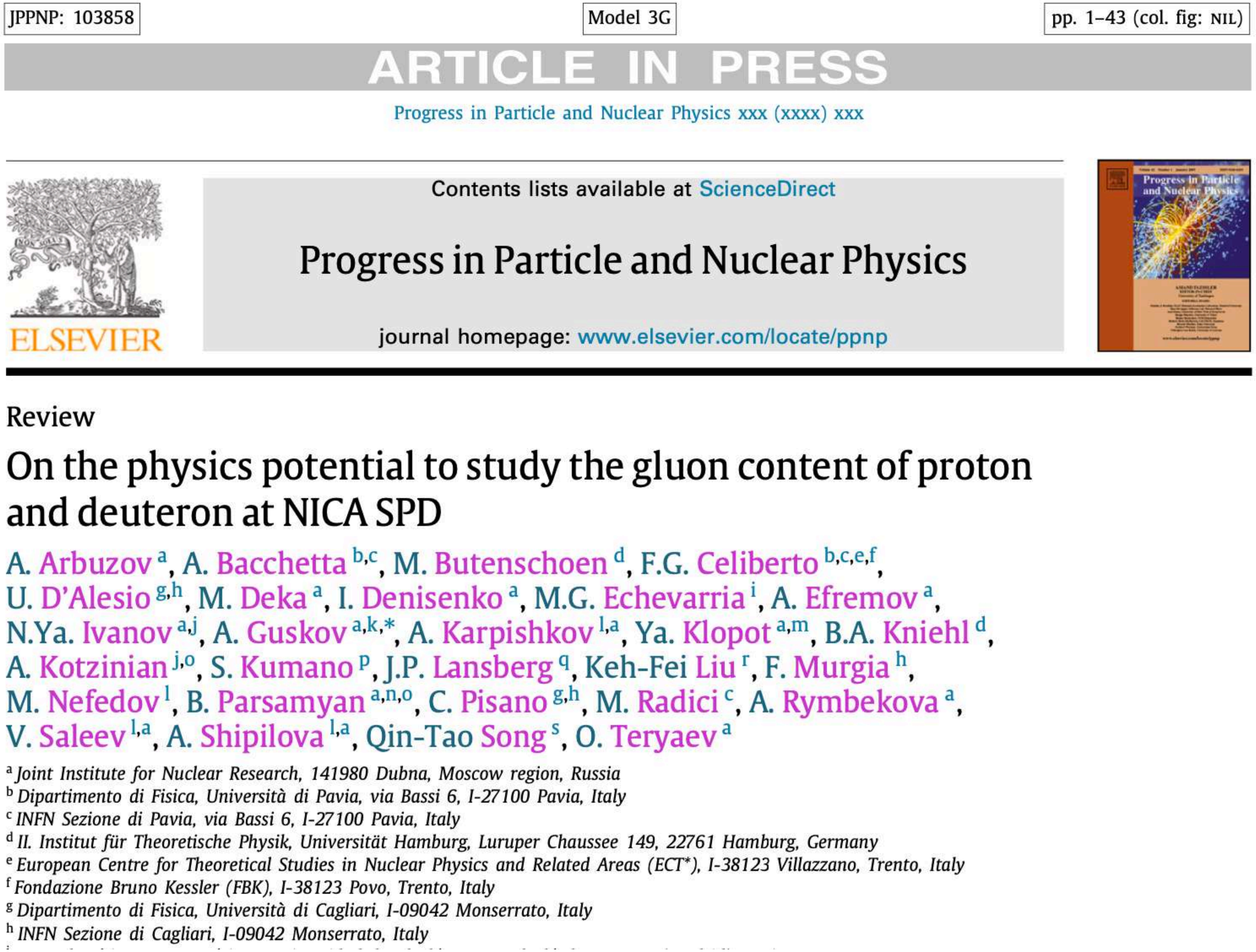
SPD and gluon structure of nucleon

Not only J/ψ!





SPD gluon program



JPPNP: 103858 Model 3G pp. 1–43 (col. fig: NIL)

ARTICLE IN PRESS

Progress in Particle and Nuclear Physics xxx (xxxx) xxx

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Progress in Particle and Nuclear Physics

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

Review

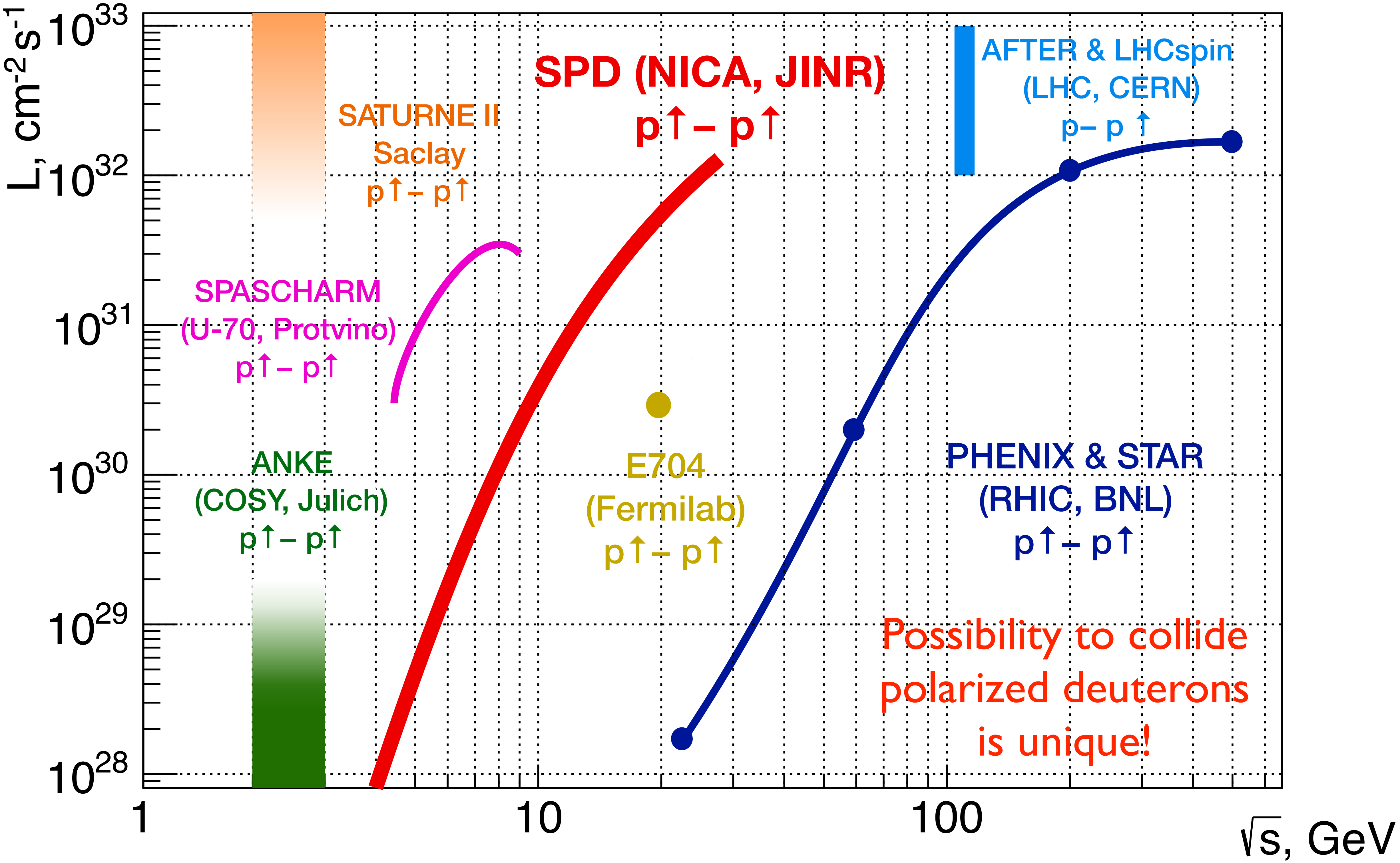
On the physics potential to study the gluon content of proton and deuteron at NICA SPD

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]

[a] Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
[b] Dipartimento di Fisica, Università di Pavia, via Bassi 6, I-27100 Pavia, Italy
[c] INFN Sezione di Pavia, via Bassi 6, I-27100 Pavia, Italy
[d] II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
[e] European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), I-38123 Villazzano, Trento, Italy
[f] Fondazione Bruno Kessler (FBK), I-38123 Povo, Trento, Italy
[g] Dipartimento di Fisica, Università di Cagliari, I-09042 Monserrato, Italy
[h] INFN Sezione di Cagliari, I-09042 Monserrato, Italy

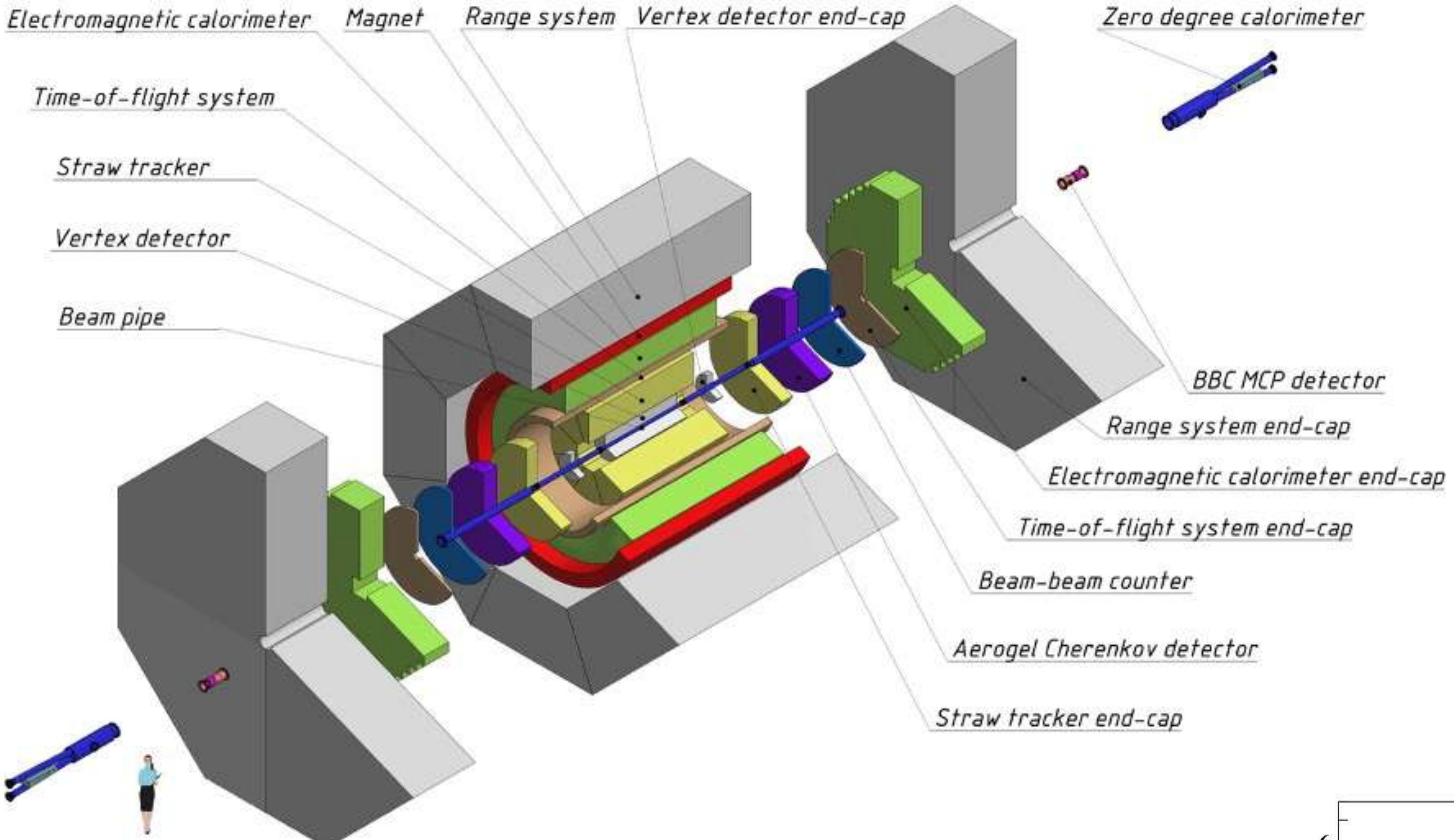
arXiv:2011.15005

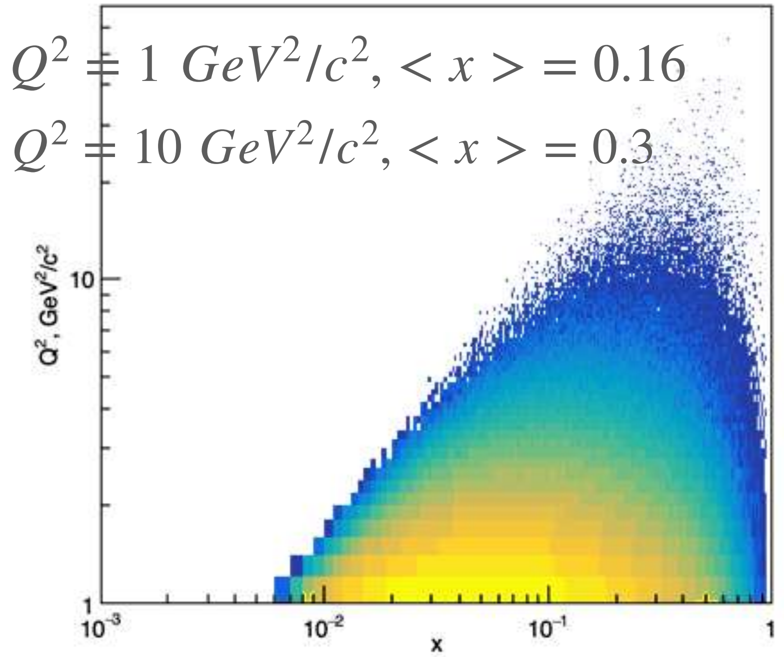
SPD and others



Possibility to collide polarized deuterons is unique!

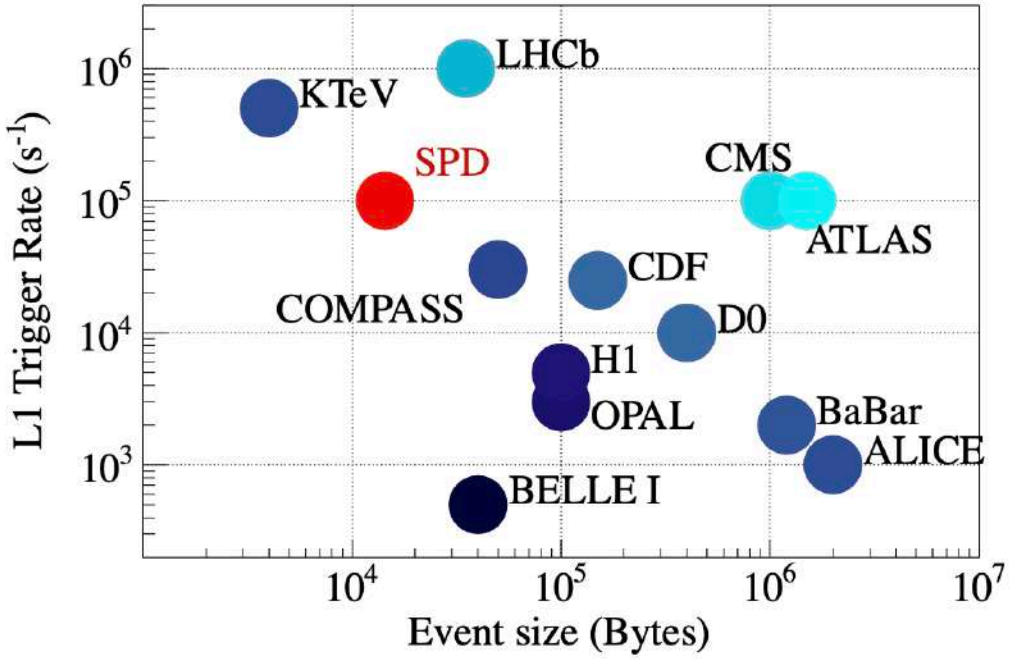
SPD setup




$Q^2 = 1\ GeV^2/c^2, <x> = 0.16$

$Q^2 = 10\ GeV^2/c^2, <x> = 0.3$

Free-running DAQ



Physic of the first stage

arXiv:2102.08477

Non-perturbative QCD **Perturbative QCD**

$\sqrt{s}$

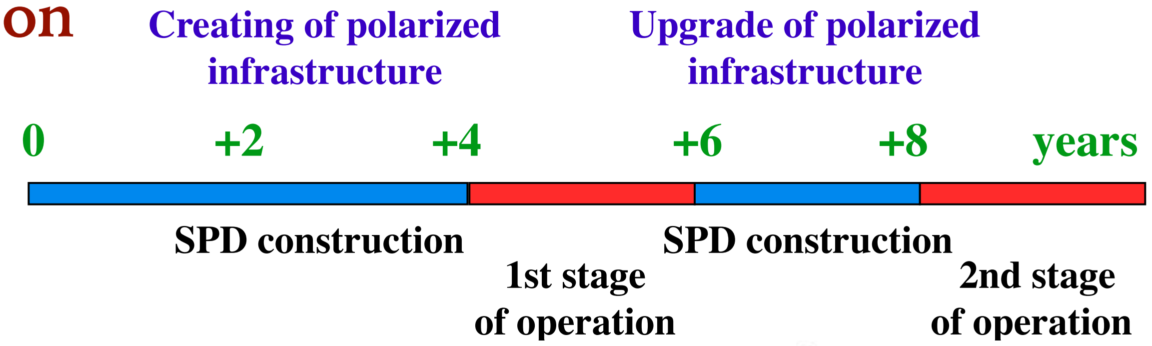
- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances

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

- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernucei

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

- Open charm and charmonia near threshold



Creating of polarized infrastructure

Upgrade of polarized infrastructure

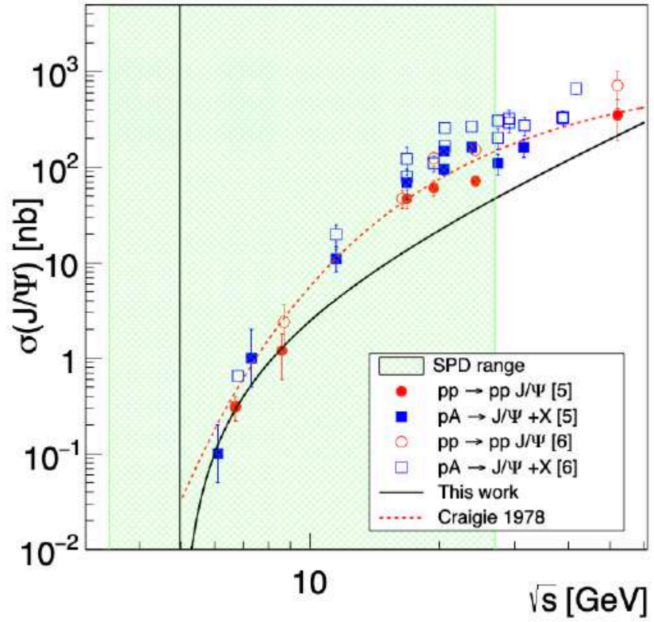
0 +2 +4 +6 +8 years

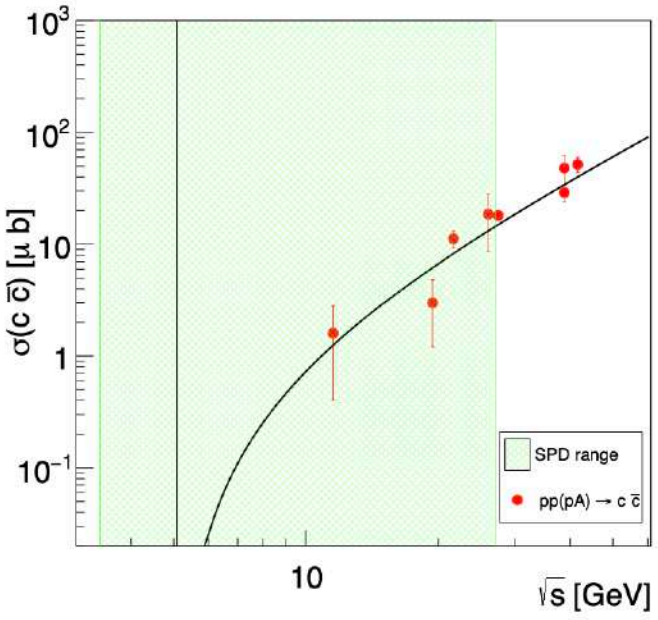
SPD construction

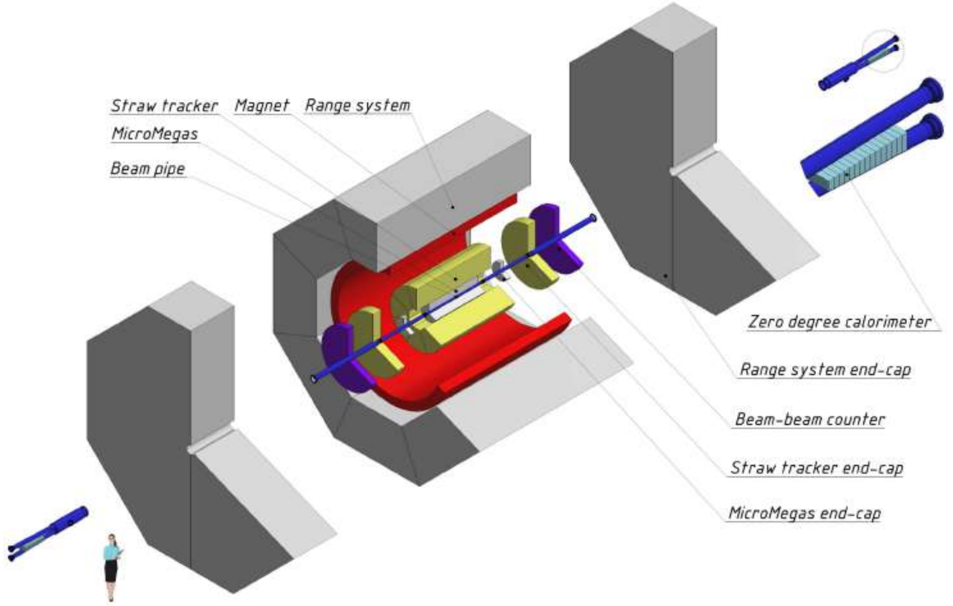
1st stage of operation

SPD construction

2nd stage of operation







- Auxiliary measurements for astrophysics
- ...

SPD collaboration

A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute), Yerevan
NRC “Kurchatov Institute” - PNPI, Gatchina
Samara National Research University (Samara University), Samara
Saint Petersburg Polytechnic University St. Petersburg
Saint Petersburg State University, St. Petersburg
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow
Tomsk State University, Tomsk
Belgorod State University, Belgorod
Lebedev Physical Institute of RAS, Moscow
Institute for Nuclear Research of the RAS, Moscow
National Research Nuclear University MEPhI, Moscow
Institute of Nuclear Physics (INP RK), Almaty
Institute for Nuclear Problems of BSU, Minsk
Budker Institute for Nuclear Physics, Novosibirsk

MoU signed

NRC “Kurchatov Institute”, Moscow (NRC KI)
Higher Institute of Technologies and Applied Sciences, Havana
iThemba LABS, SA

MoU under preparation or signing

>30 institutes
~400 members

http://spd.jinr.ru/

Present status of the 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, is updated in 2024 and should pass via the international expertise this year.

https://arxiv.org/abs/2404.08317

SPD: 14 countries, 32 institutes, ~300 participants

- SPD CDR was approved in Jan'2022;
- detectors prototyping/tests are ongoing;
- new version of TDR – Jan'2024;
- start of operation (Stage-I) – 2028;
- 50 papers and 70 conference reports.

BM@N: 5 countries, 13 institutes, >200 participants

BM@N setup for heavy ions (2022)

4th NICA run (2022-2023)

- 550M events Xe+CsI at 3.0A, 3.8A G
- analysis is ongoing;
- so far: 80 publications and 80 repor including "Quark Matter", "Strangeness in Quark Matter", etc

BM@N setup for SRC

First observation of the Short-Range Correlations in inverse kinematics:

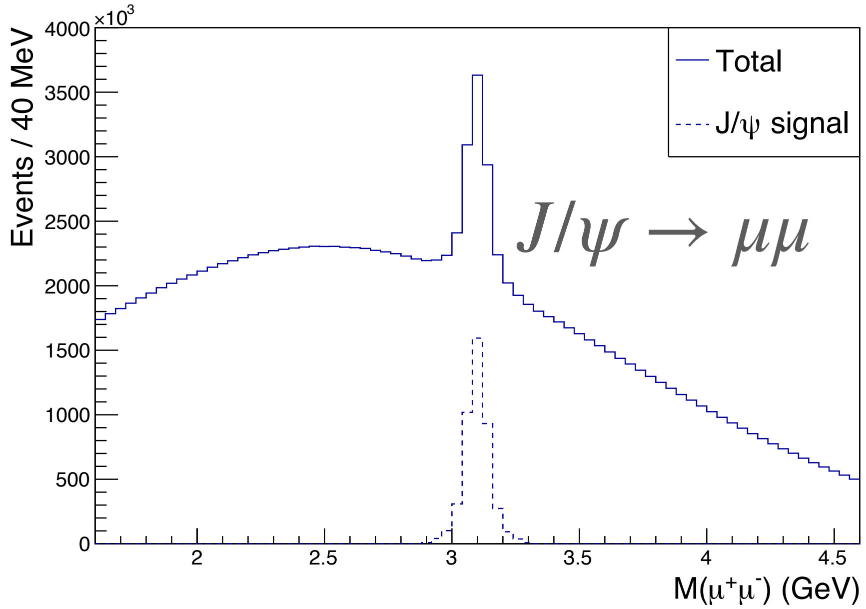
The **first phase** of the SPD project is included into the JINR's 7-year plan (2024-2030)

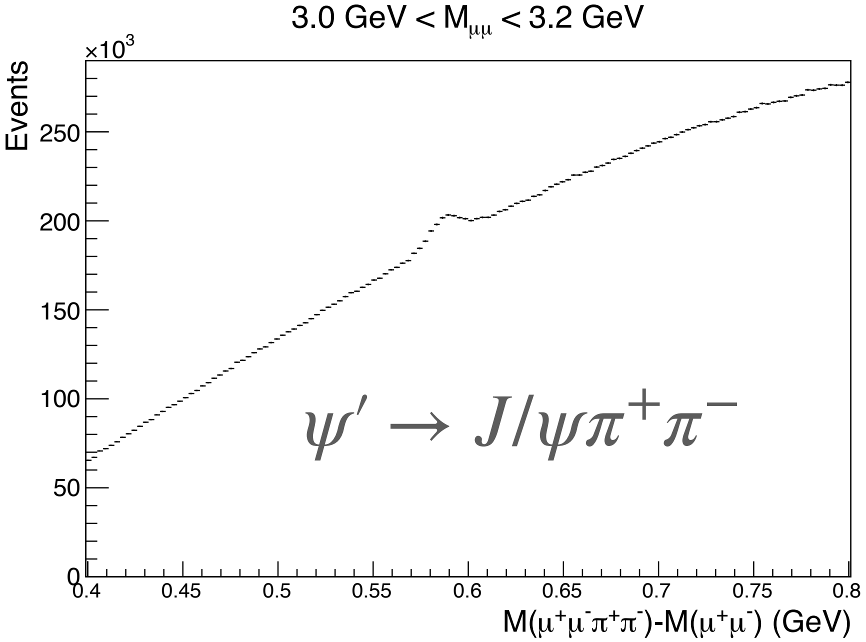
Summary

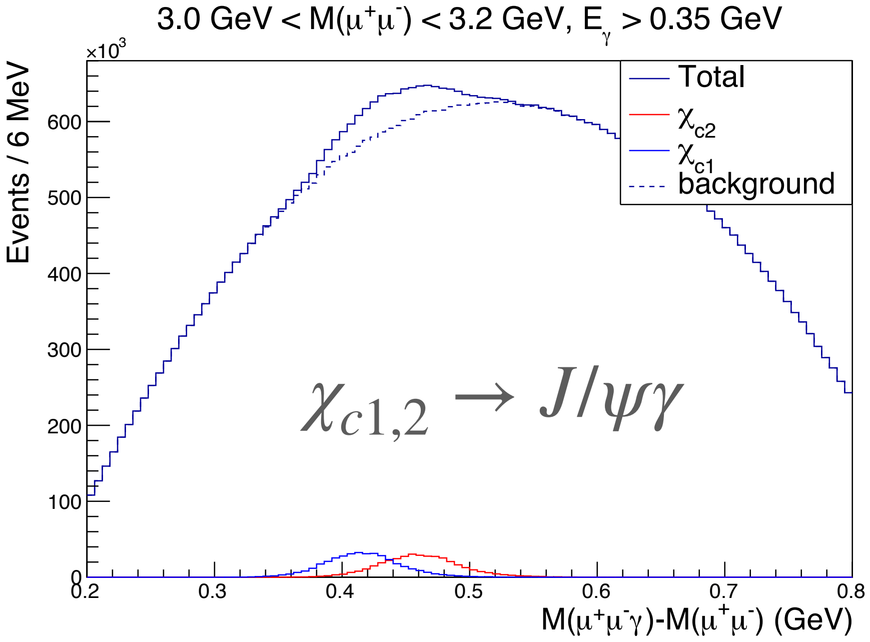
- The **Spin Physics Detector** at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized **gluon content of proton and deuteron**; in polarized high-luminosity **p-p** and **d-d** collisions at $\sqrt{s} \leq 27\ GeV$;
- Complementing main probes such as **charmonia** (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;
  - ○ …
- 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) and mesons (AMBER, EIC);**
- More information including **SPD CDR** and **TDR** could be found at http://spd.jinr.ru .

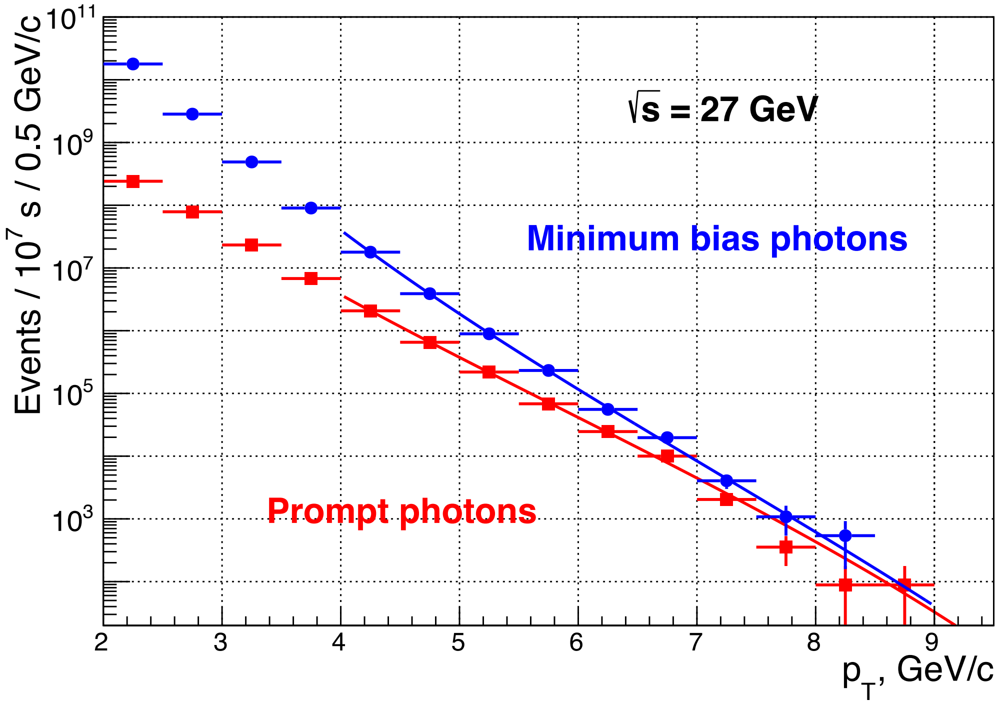
BACKUP SLIDES

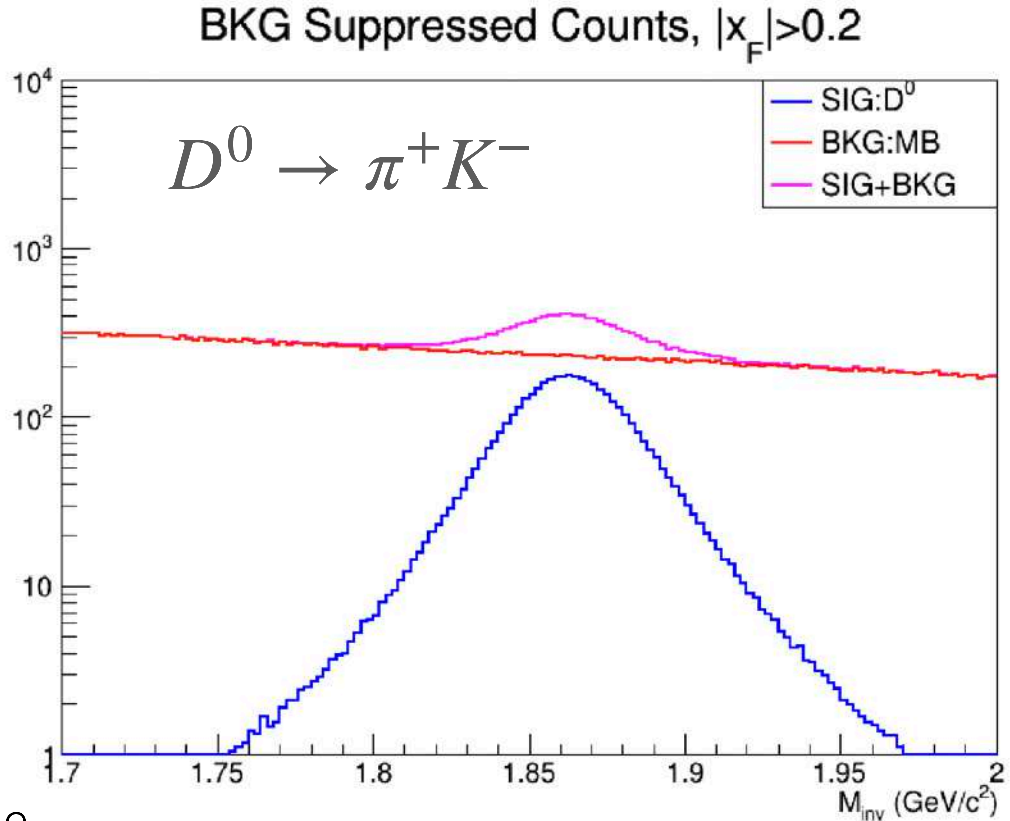
Physics performance: gluon probes (1 year=10^7 s)





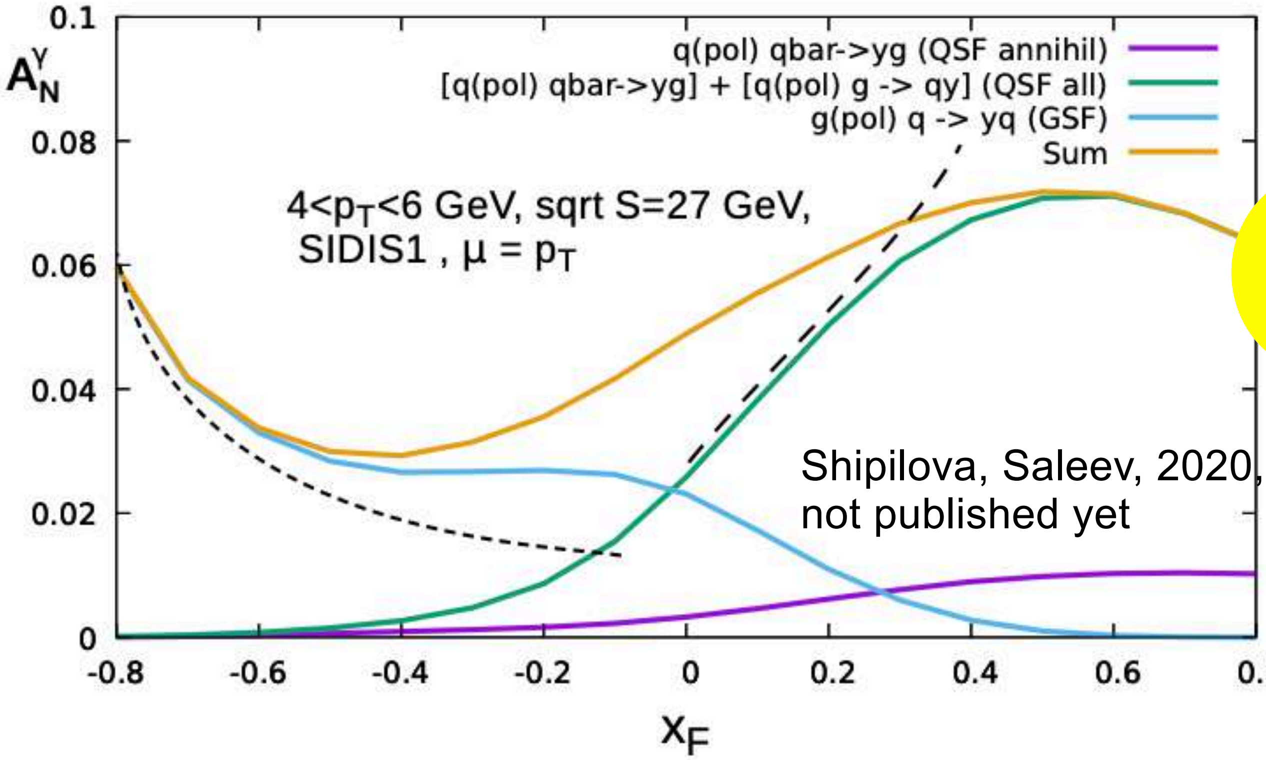






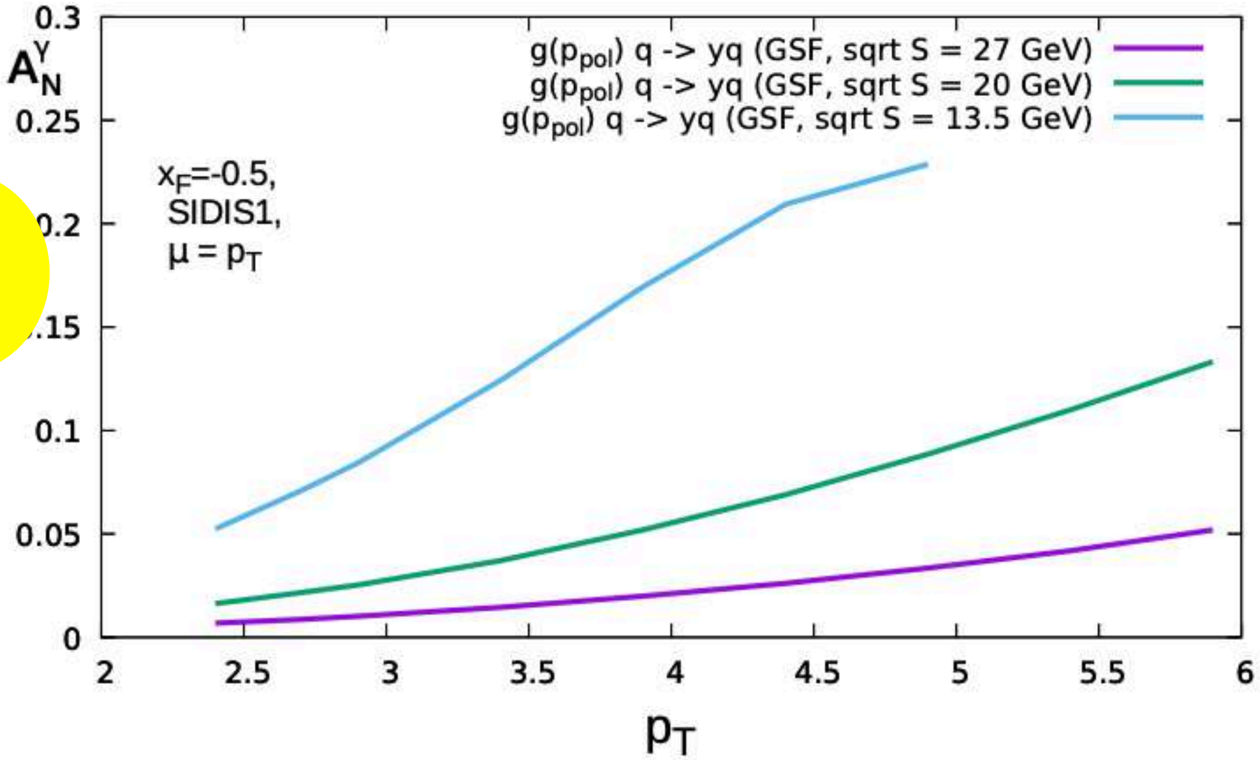
Gluon-induced TMD effects: expectations for A_N

Sivers effect contribution

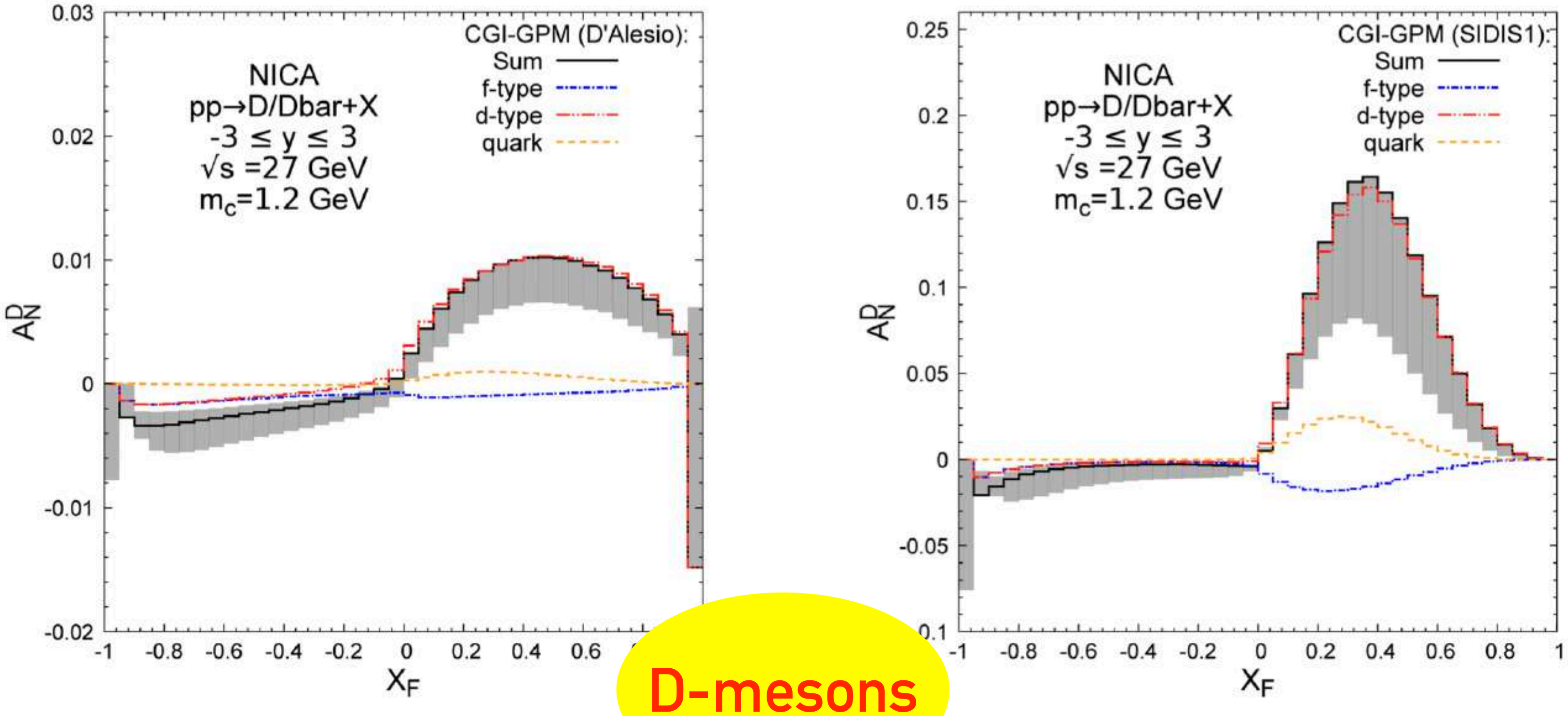


Shipilova, Saleev, 2020,
not published yet

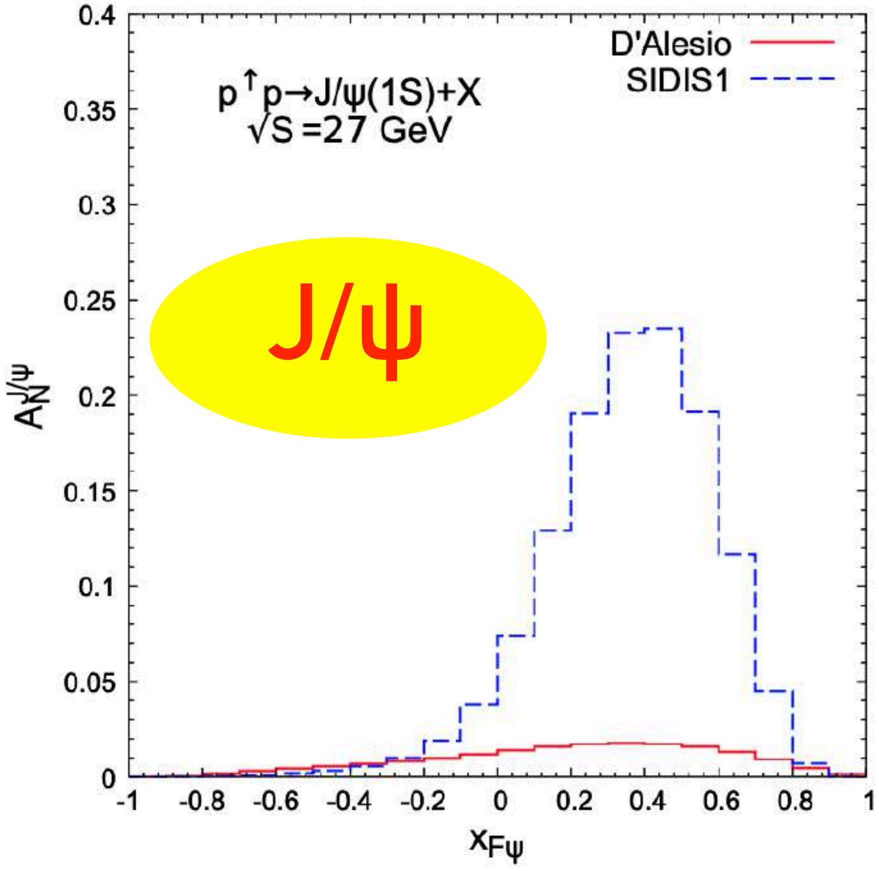
γ



Saleev 2020

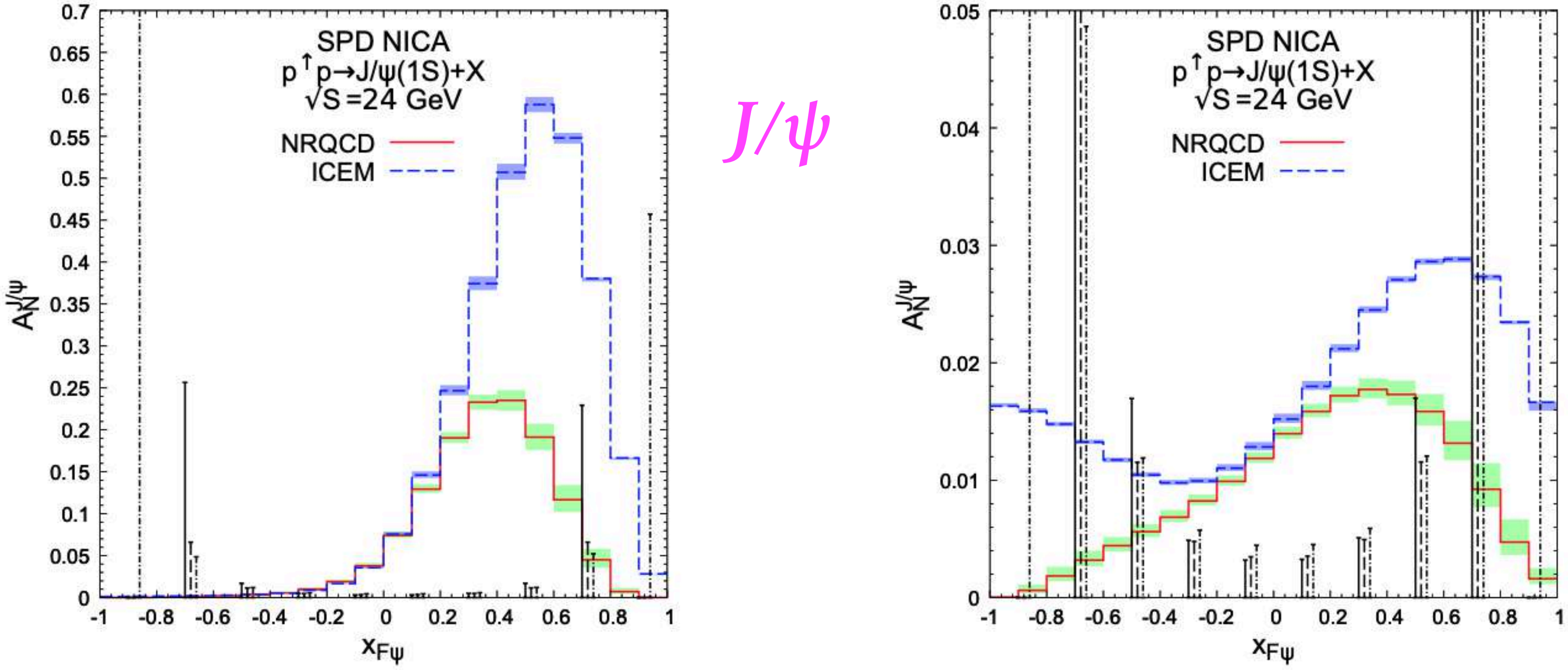


D-mesons



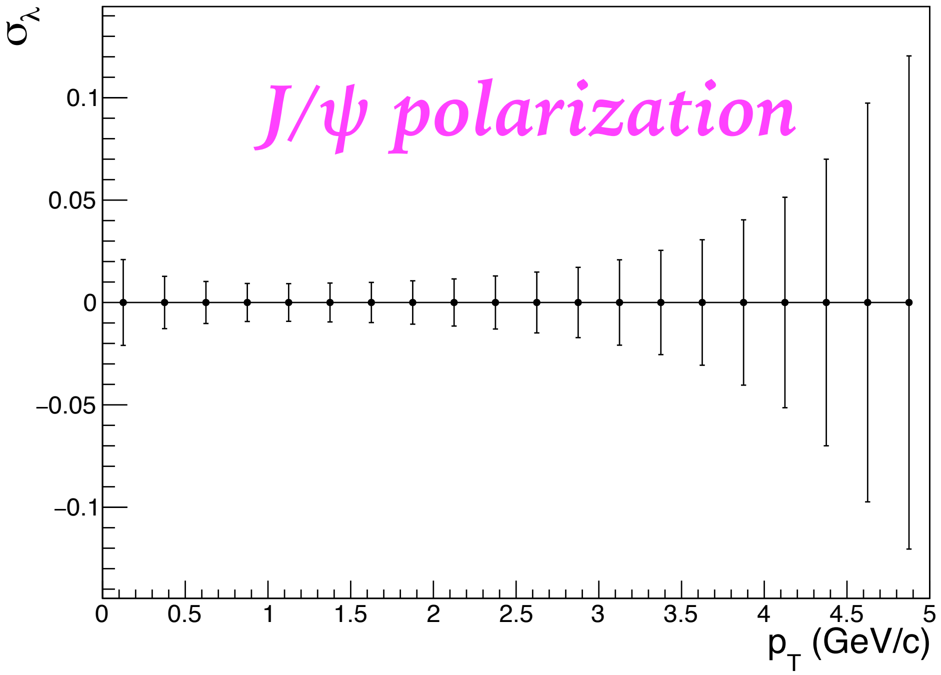
J/ψ

Physics performance: accuracies

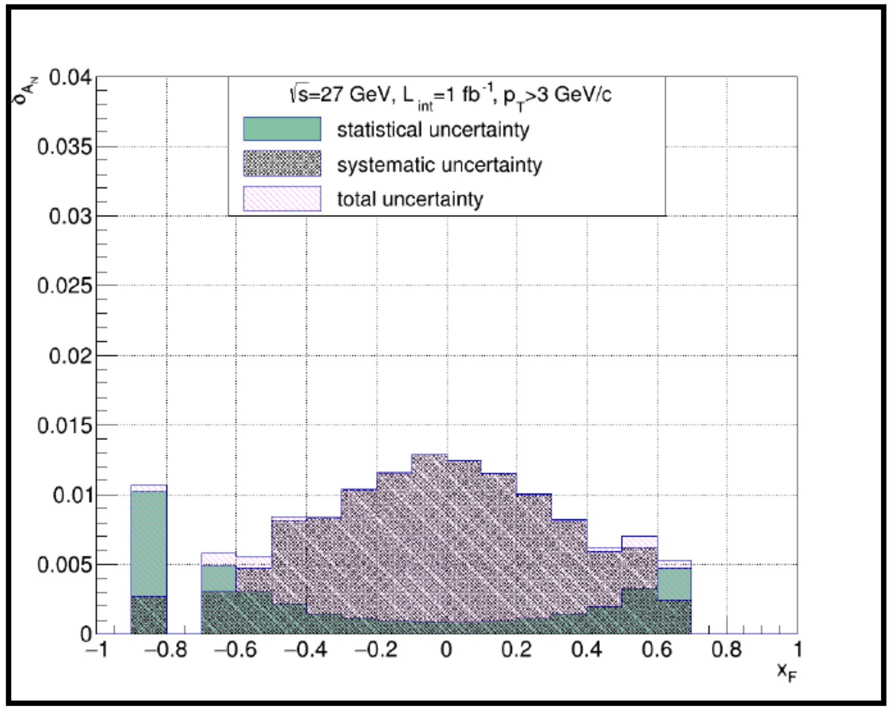


J/ψ

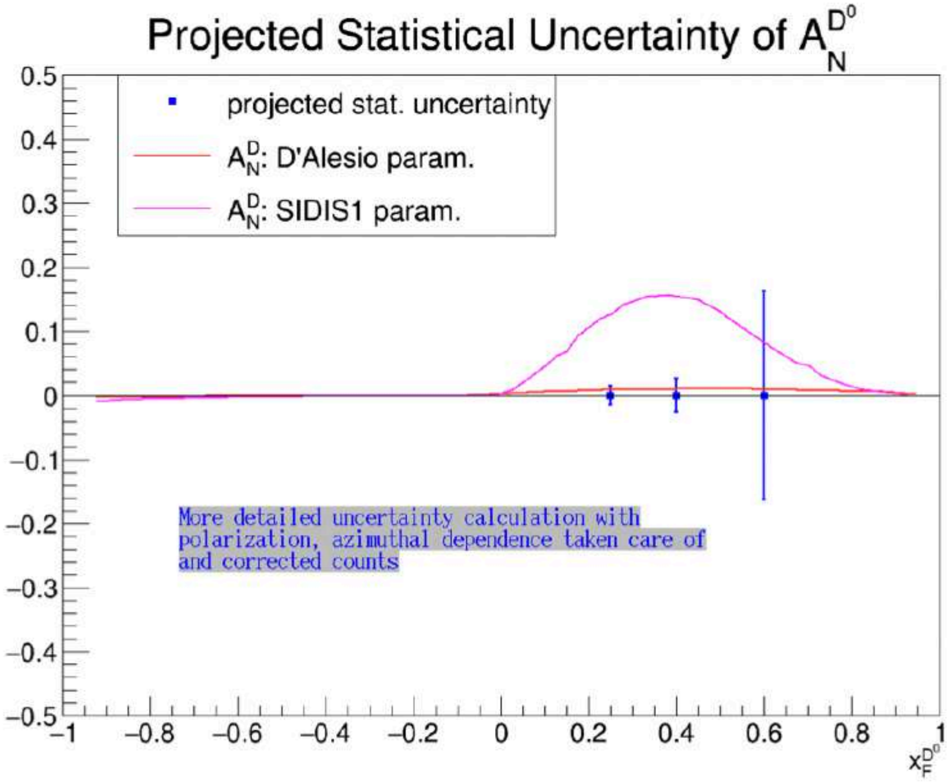
Different inputs for gluon Sivers function



J/ψ polarization



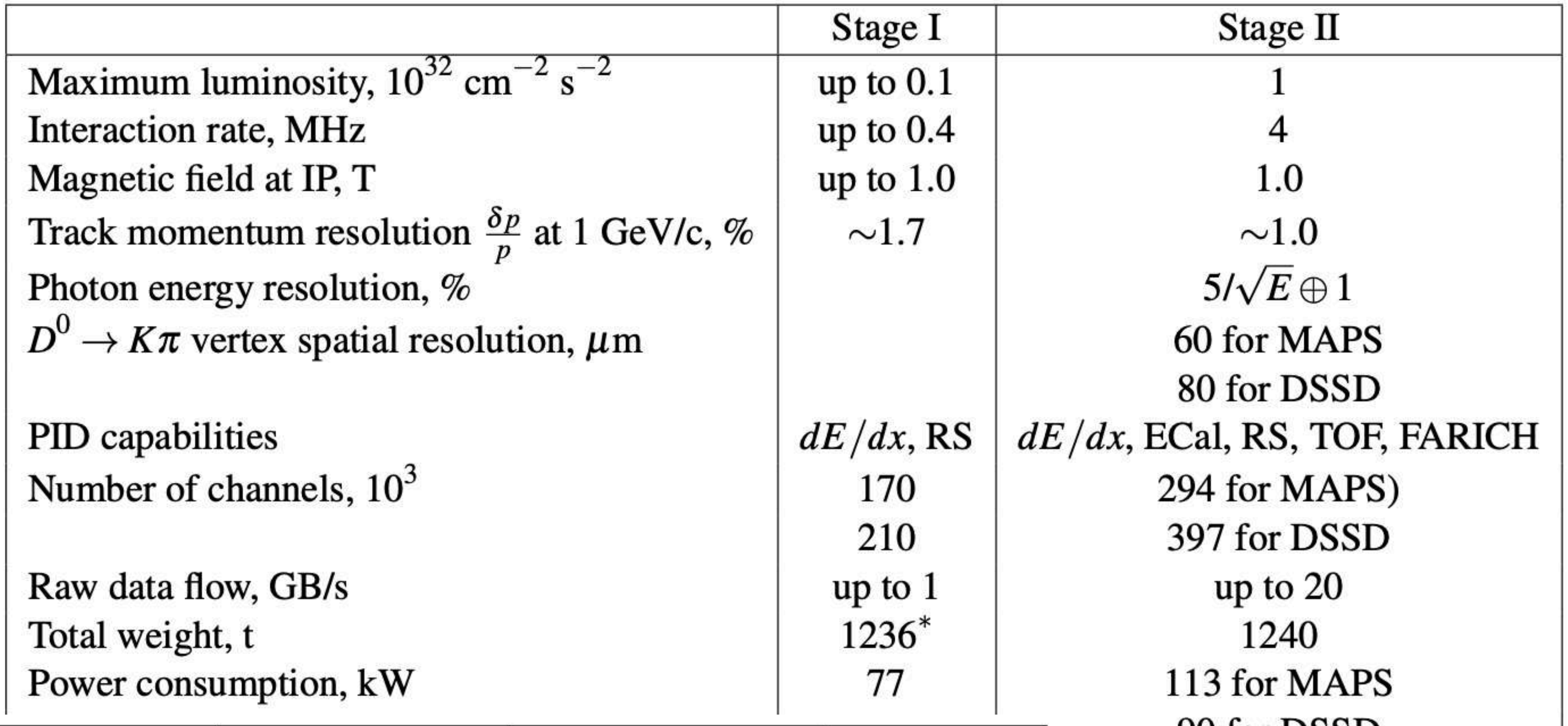
prompt-γ



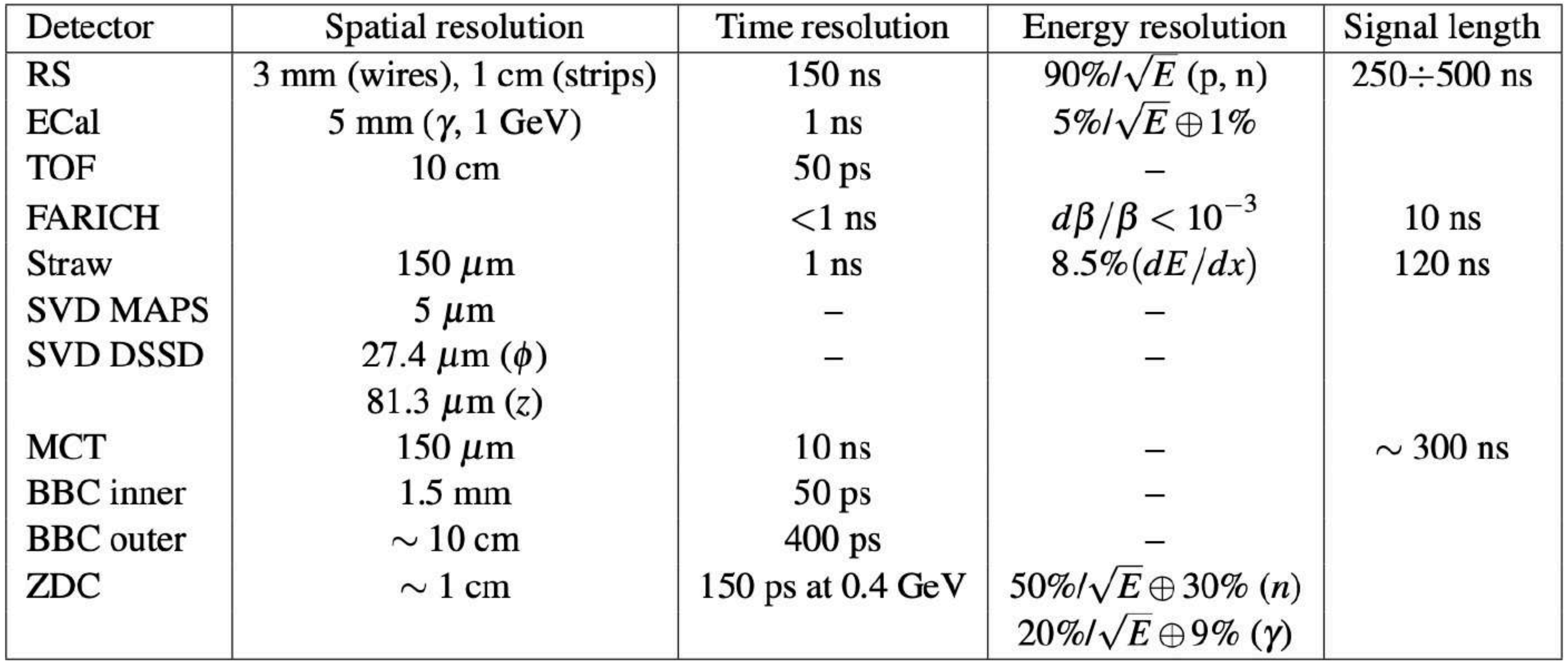
More detailed uncertainty calculation with polarization, azimuthal dependence taken care of and corrected counts

D⁰

SPD setup: basic properties

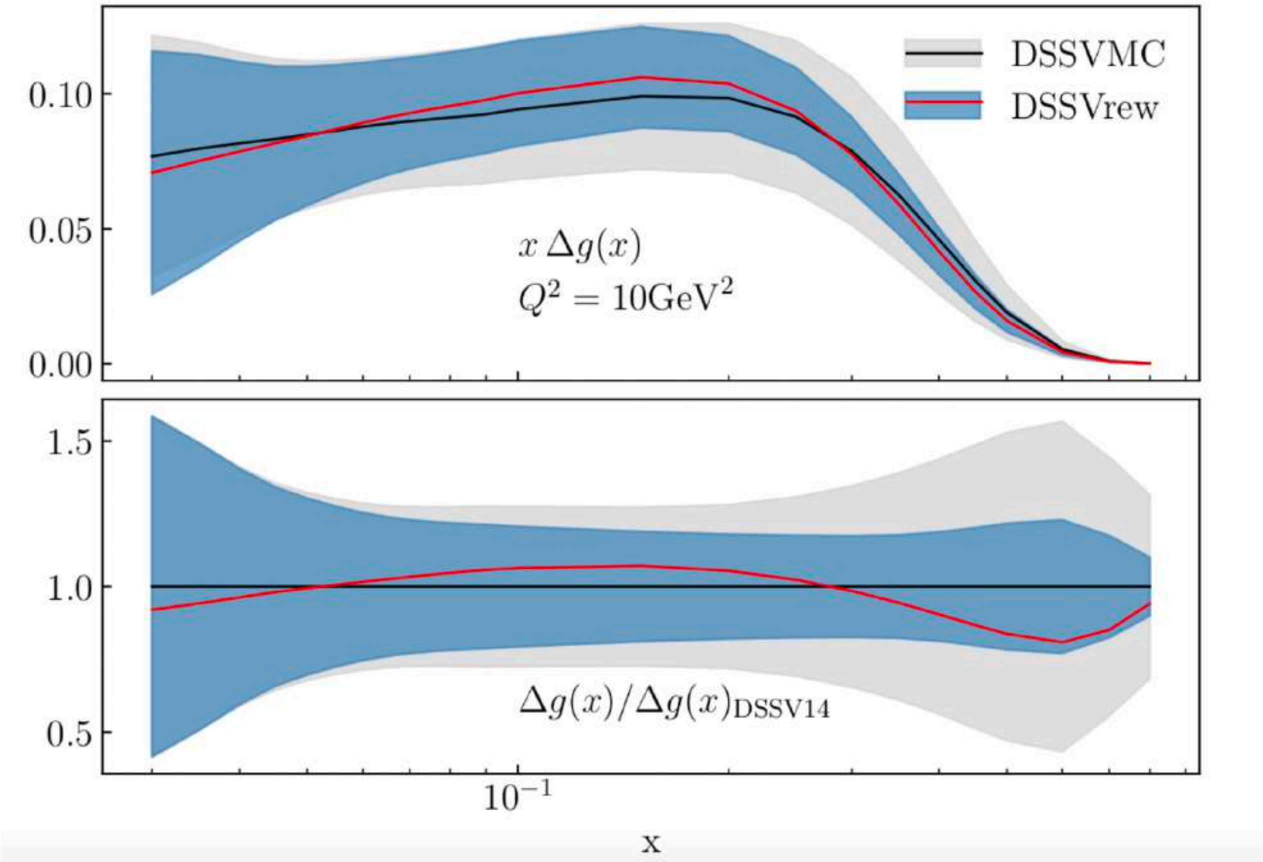


	Stage I	Stage II
Maximum luminosity, 10^{32} cm^{-2} s^{-2}	up to 0.1	1
Interaction rate, MHz	up to 0.4	4
Magnetic field at IP, T	up to 1.0	1.0
Track momentum resolution $\frac{\delta p}{p}$ at 1 GeV/c, %	$\sim$1.7	$\sim$1.0
Photon energy resolution, %		$5/\sqrt{E}\oplus 1$
$D^0 \to K\pi$ vertex spatial 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

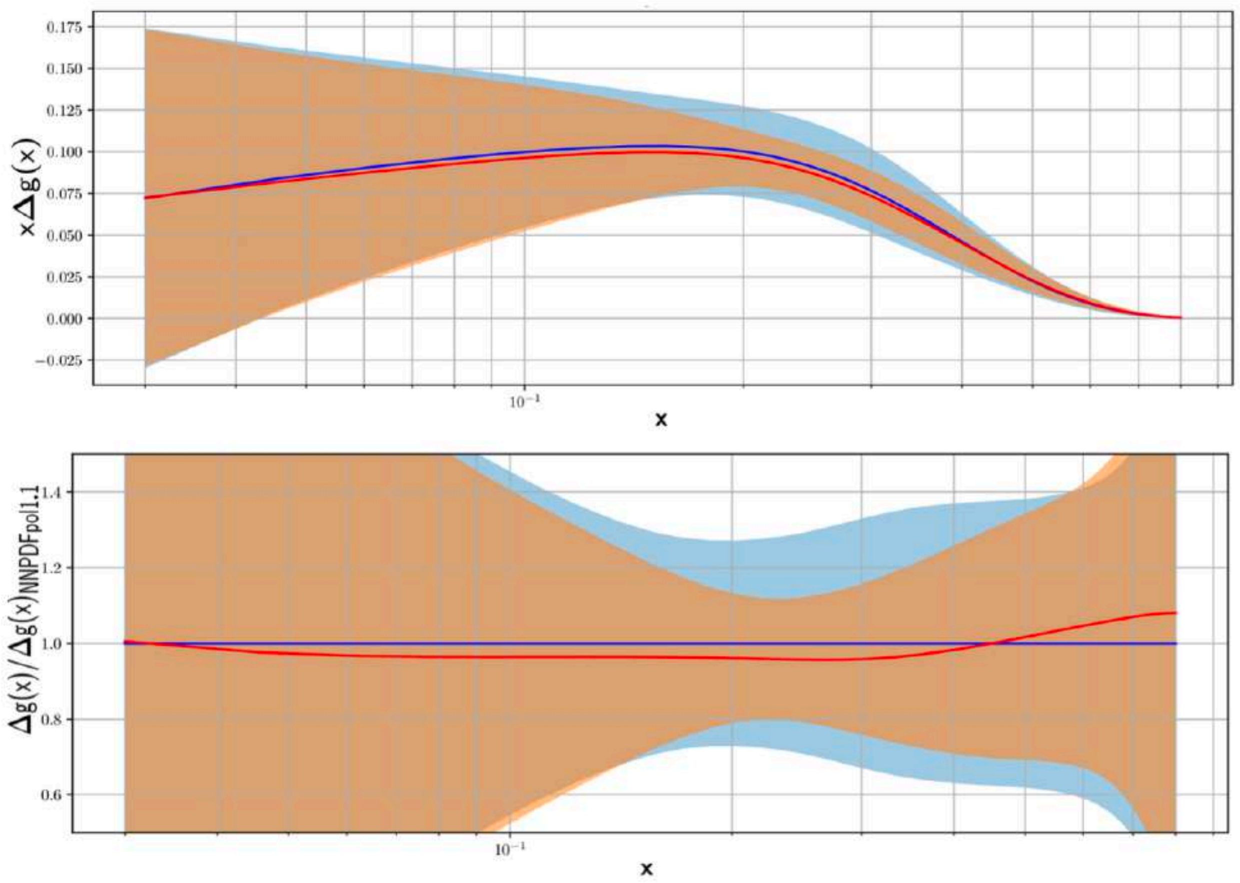


Detector	Spatial resolution	Time resolution	Energy resolution	Signal length
RS	3 mm (wires), 1 cm (strips)	150 ns	$90\%/\sqrt{E}$ (p, n)	250÷500 ns
ECal	5 mm (γ, 1 GeV)	1 ns	$5\%/\sqrt{E}\oplus 1\%$	
TOF	10 cm	50 ps	–	
FARICH		<1 ns	$d\beta/\beta < 10^{-3}$	10 ns
Straw	150 μm	1 ns	$8.5\%(dE/dx)$	120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

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



A_{LL} for prompt photons



A_{LL} for J/ψ