



THE SPIN PHYSIC DETECTOR PROJECT AT NICA



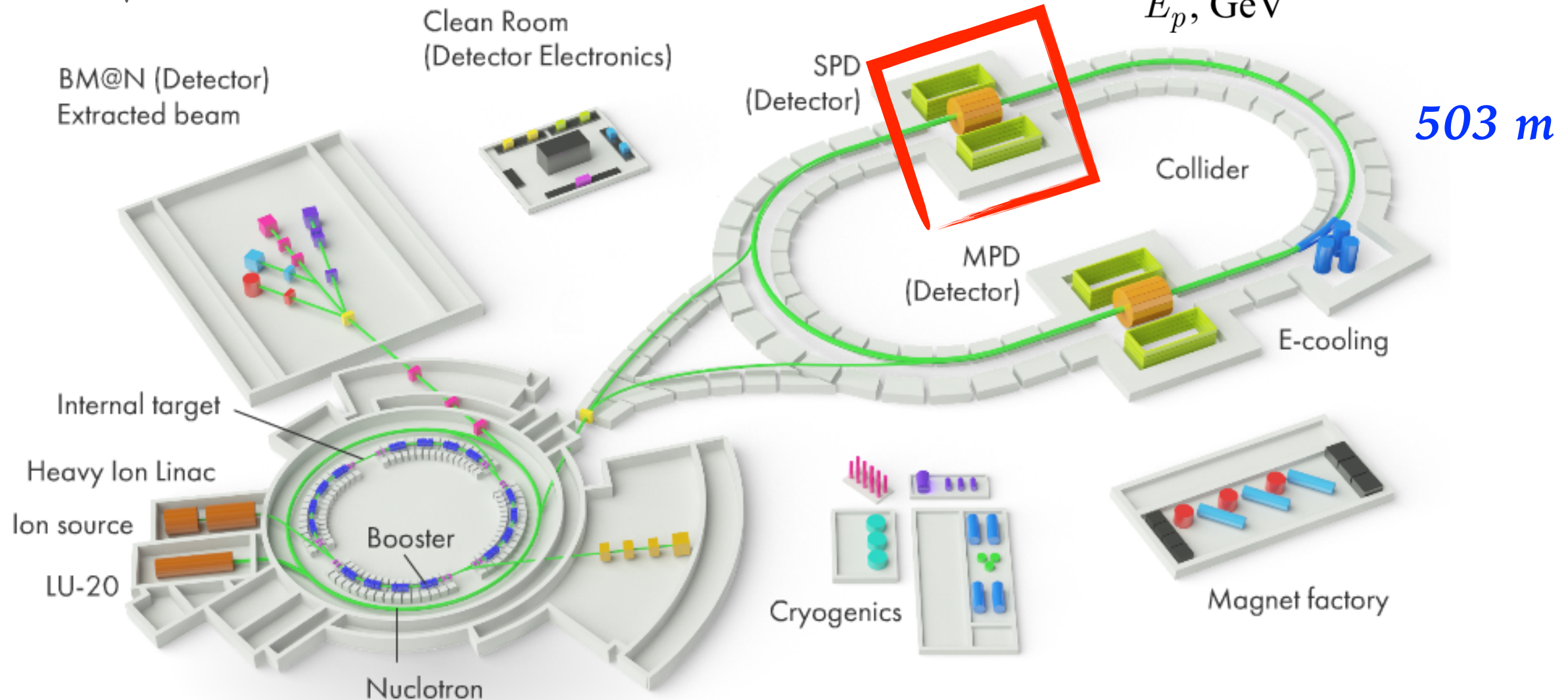
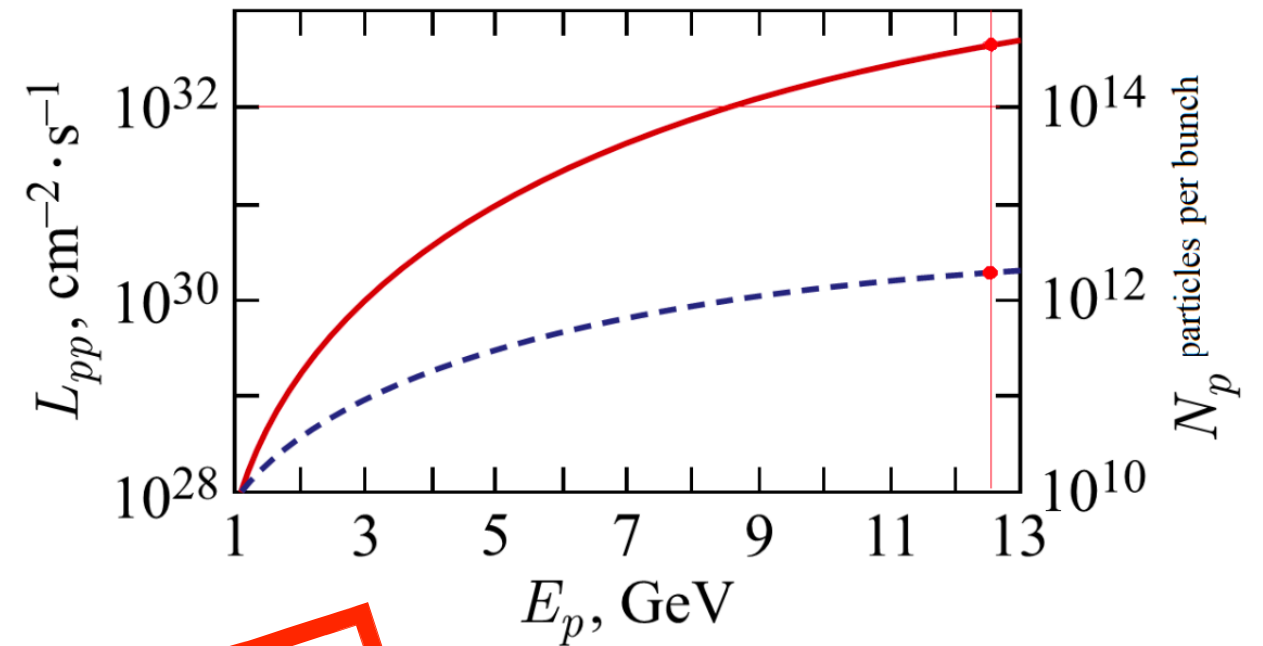
Spin Physics Detector @ NICA

NICA - Nuclotron-based Ion Collider fAcility

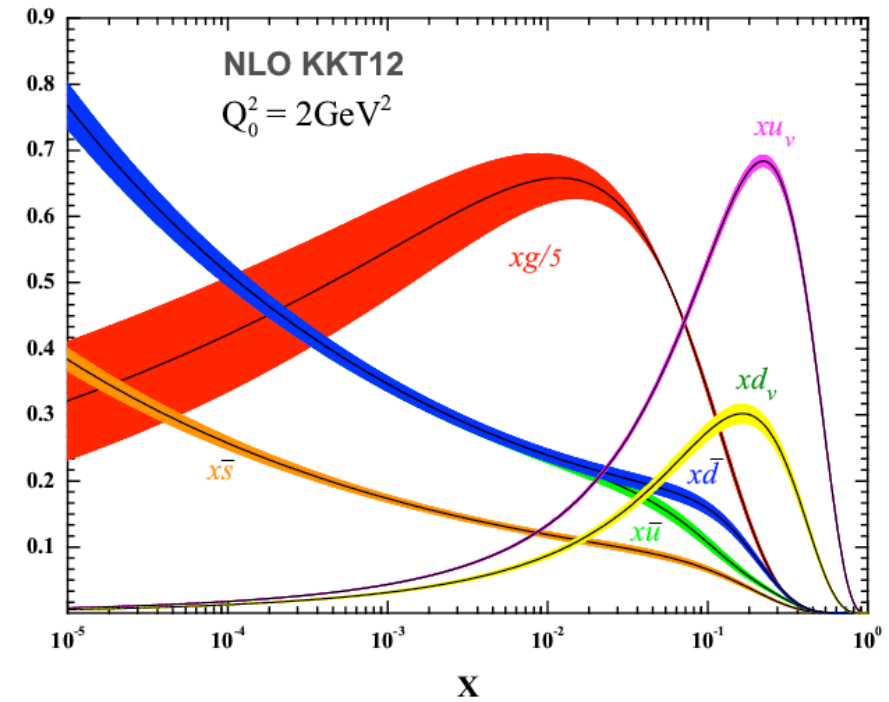
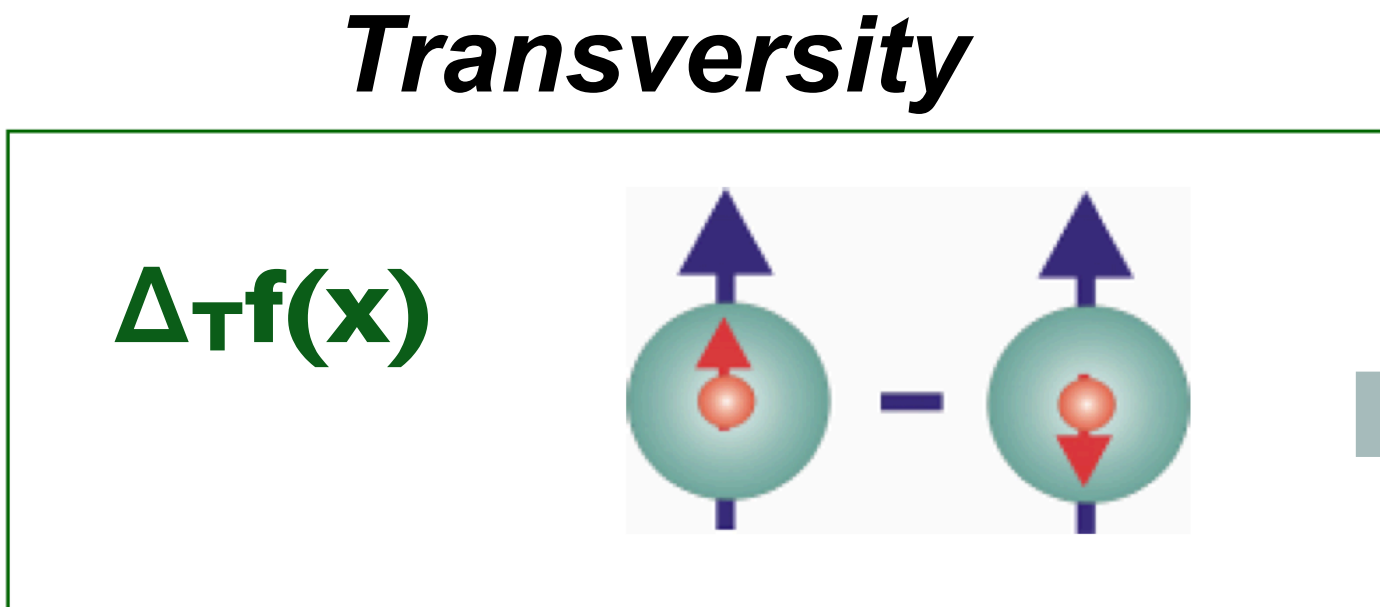
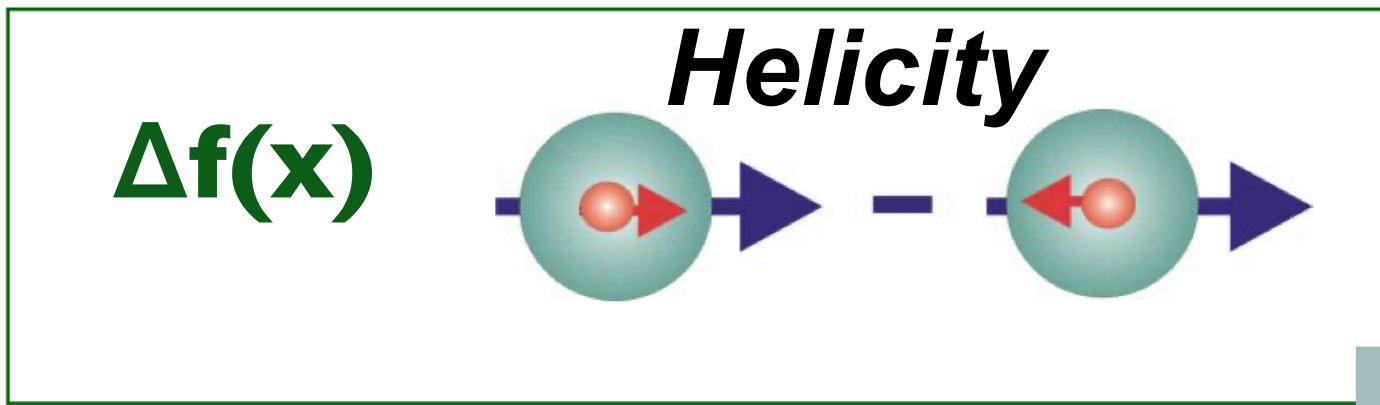
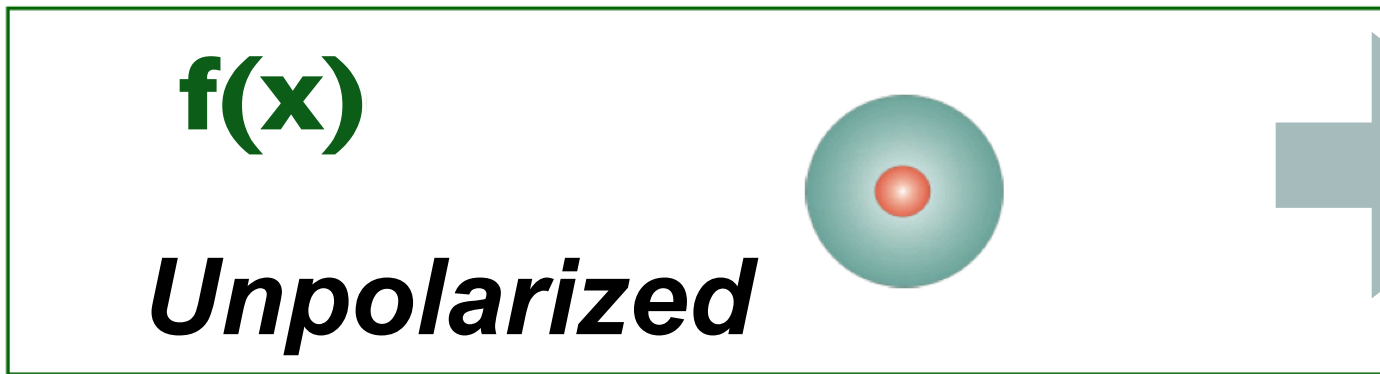
$$p^\uparrow p^\uparrow : \sqrt{s} \leq 27 \text{ GeV}$$

$$d^\uparrow d^\uparrow : \sqrt{s} \leq 13.5 \text{ GeV} \quad U, L, T$$

$$d^\uparrow p^\uparrow : \sqrt{s} \leq 19 \text{ GeV} \quad |P| > 70\%$$



Polarized proton

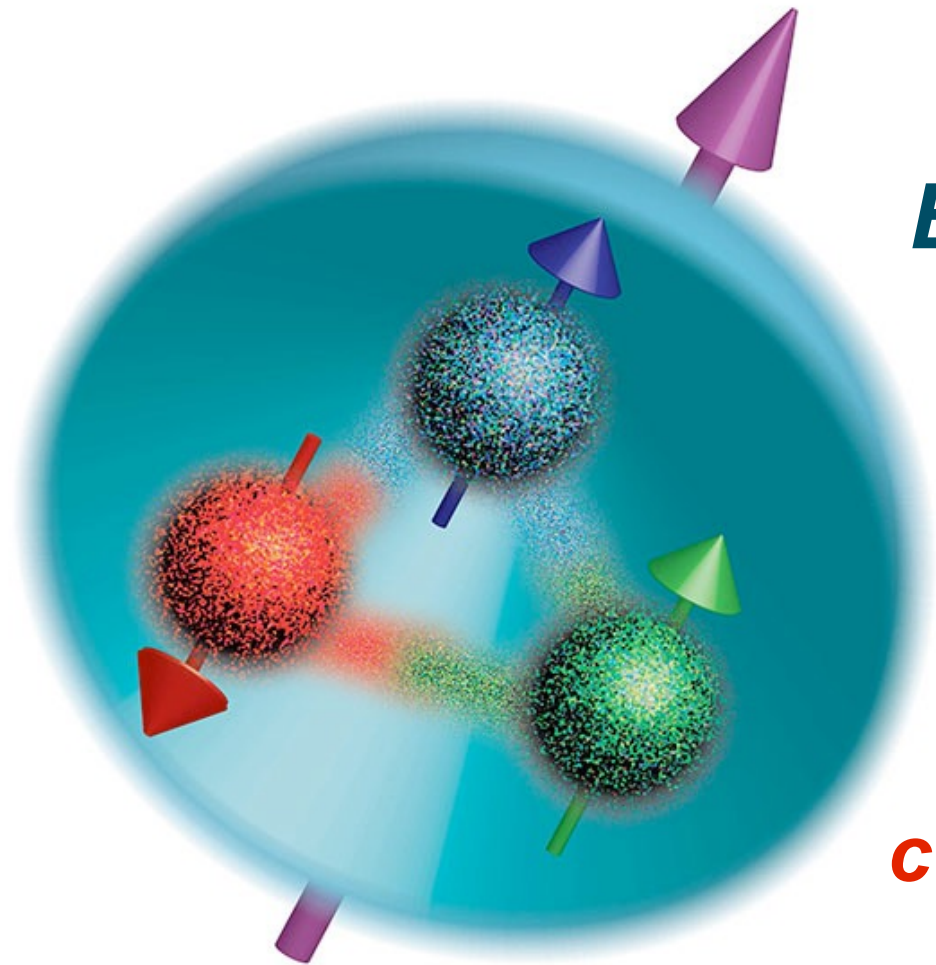


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \sim \Delta f$$

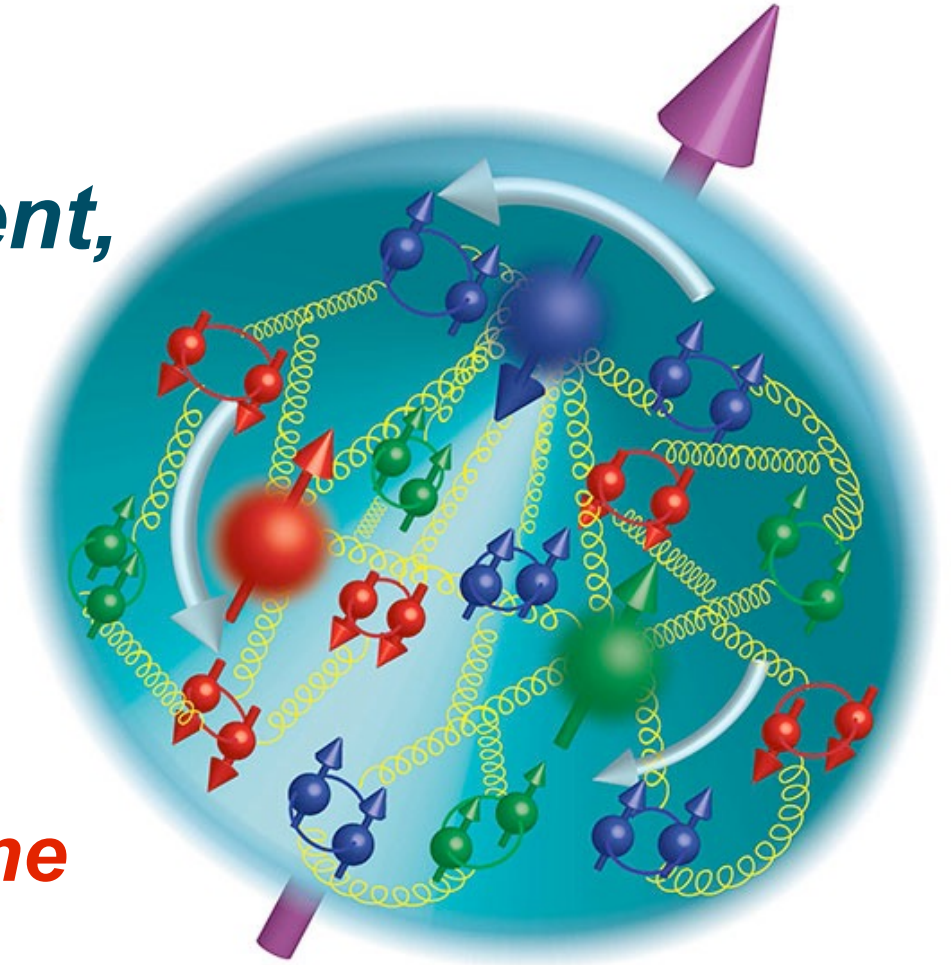
Angular asymmetries

P

Spin crisis



**EMC experiment,
CERN 1988**



**Quark
contribution to the
proton spin is
below 30%!**

Naive quark model

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

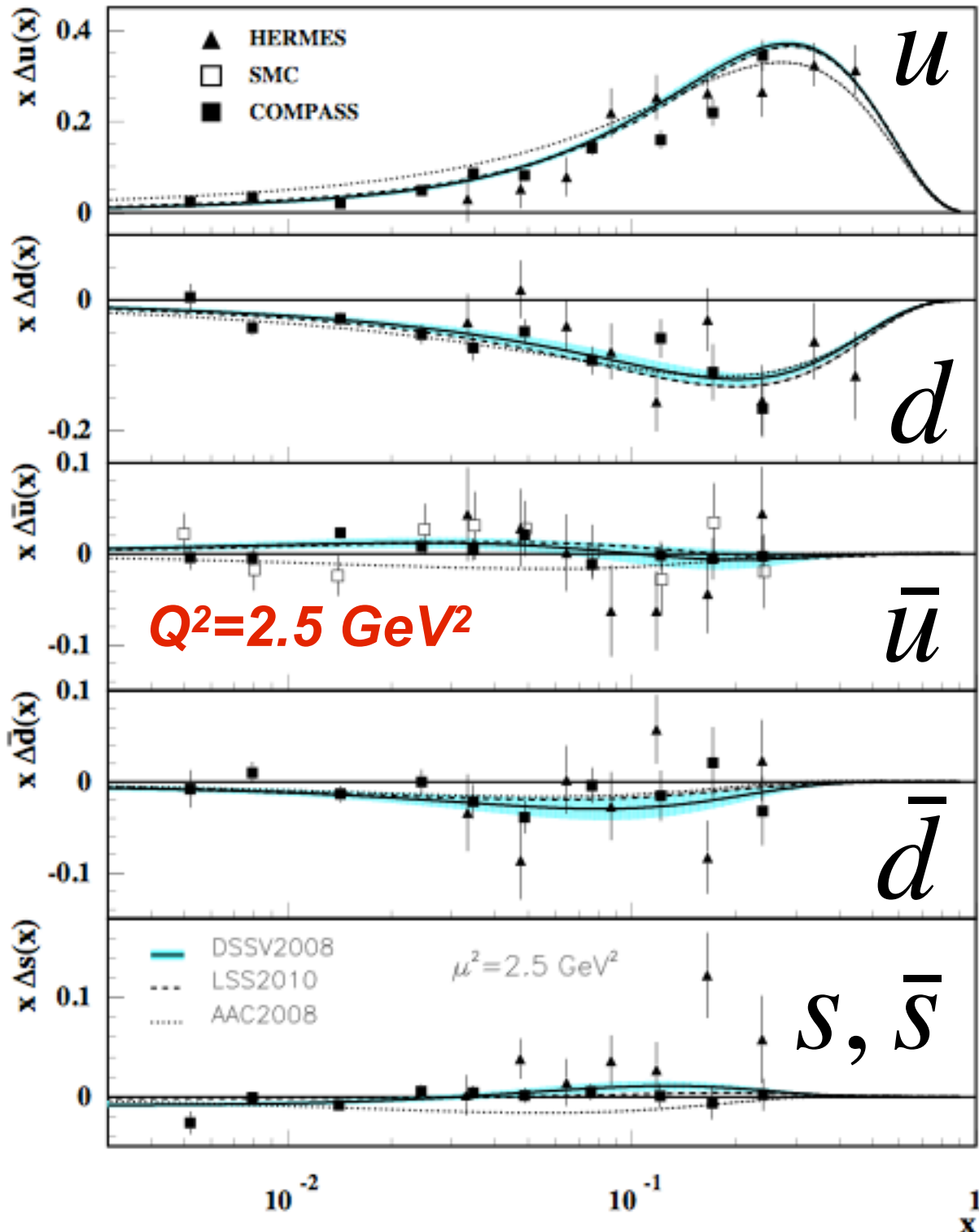
Real situation

**L - orbital moments of quarks
and gluons**

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

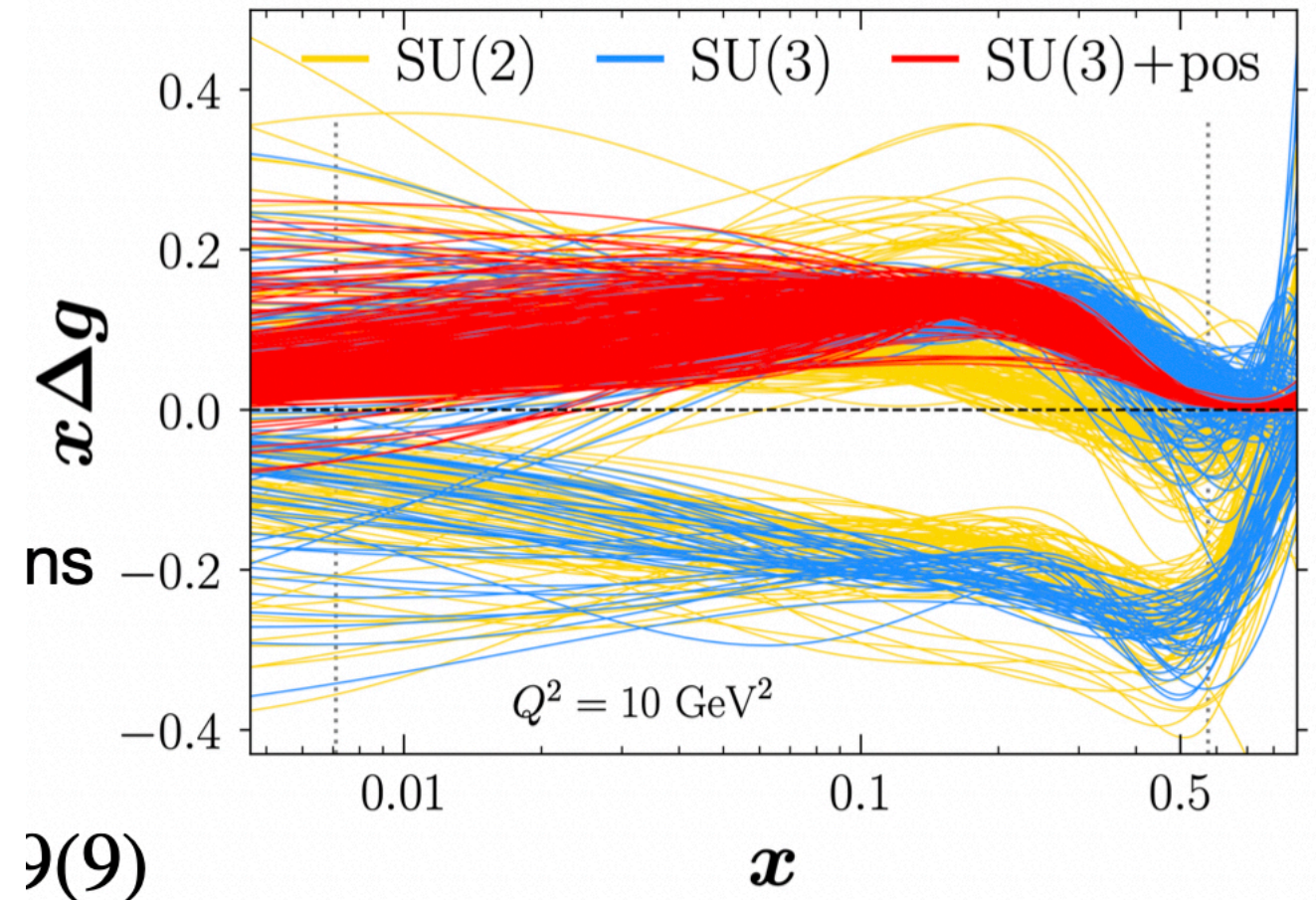
Spin crisis

Longitudinal polarization of quarks:



... and gluons:

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



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


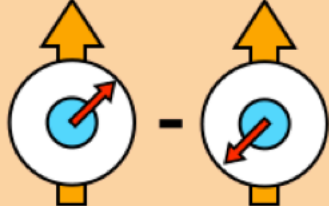
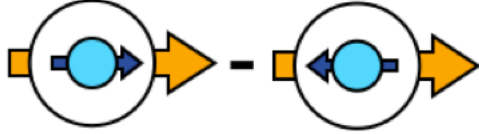
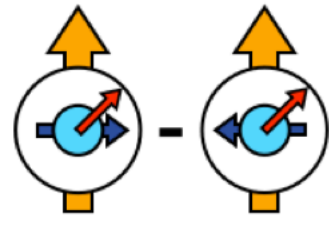

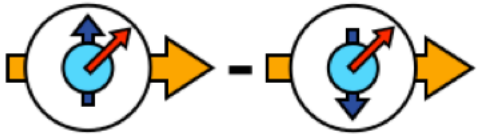
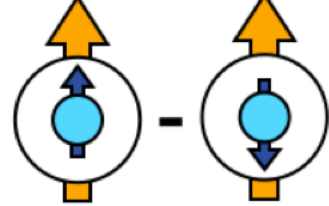
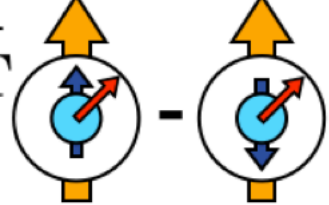
~30%

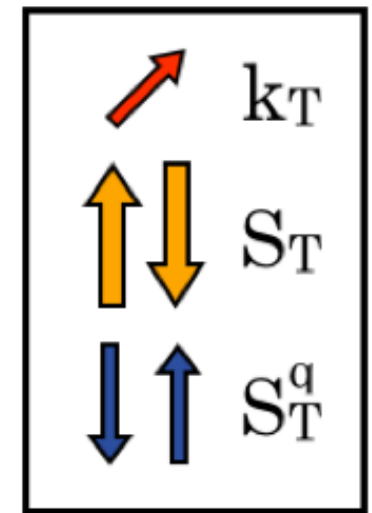
~ ?

TMD PDF

Nucleon Spin Polarization

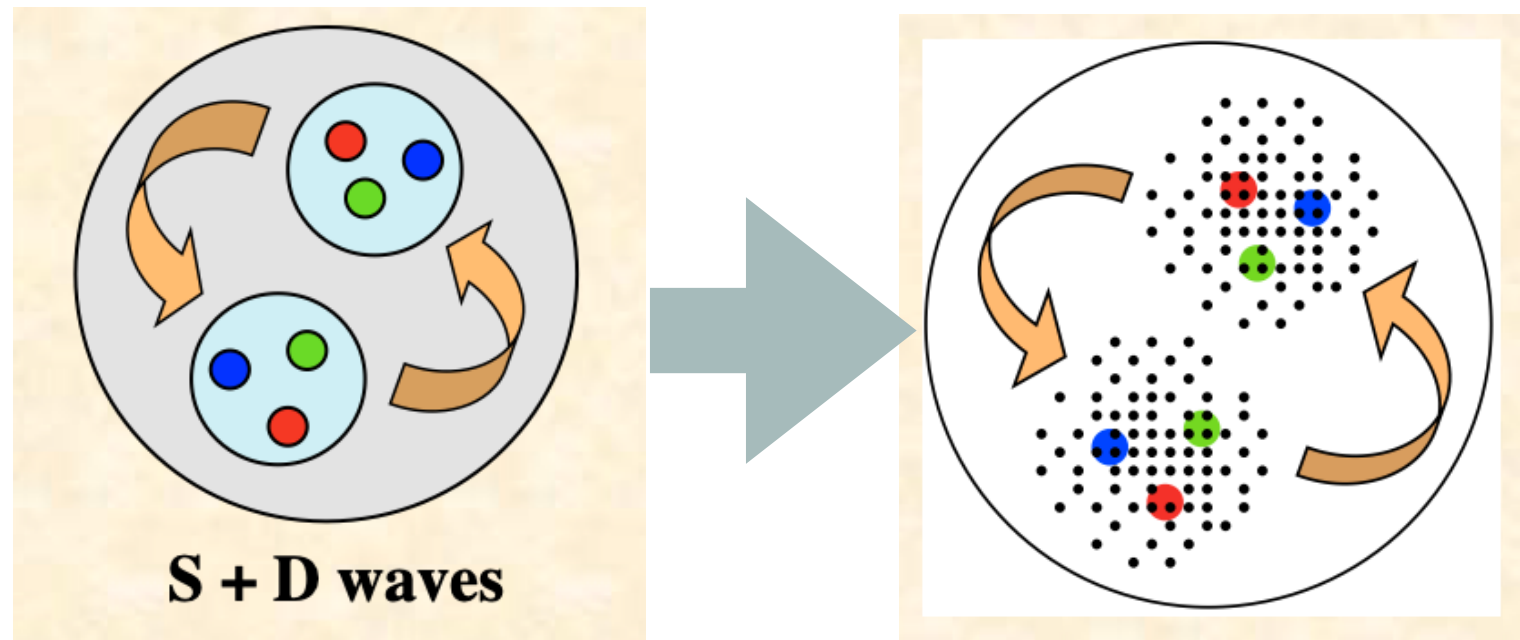
Quark Spin Polarization

	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

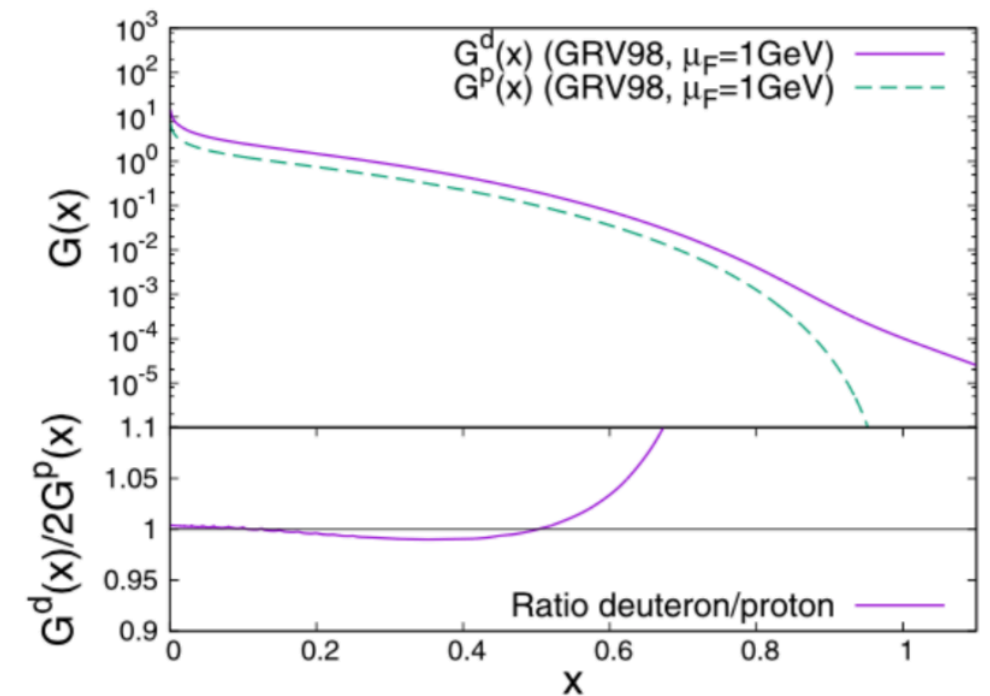


5 additional (TMD) functions describing the correlation between the nucleon spin, parton spin, and parton transverse momentum.

Deuteron

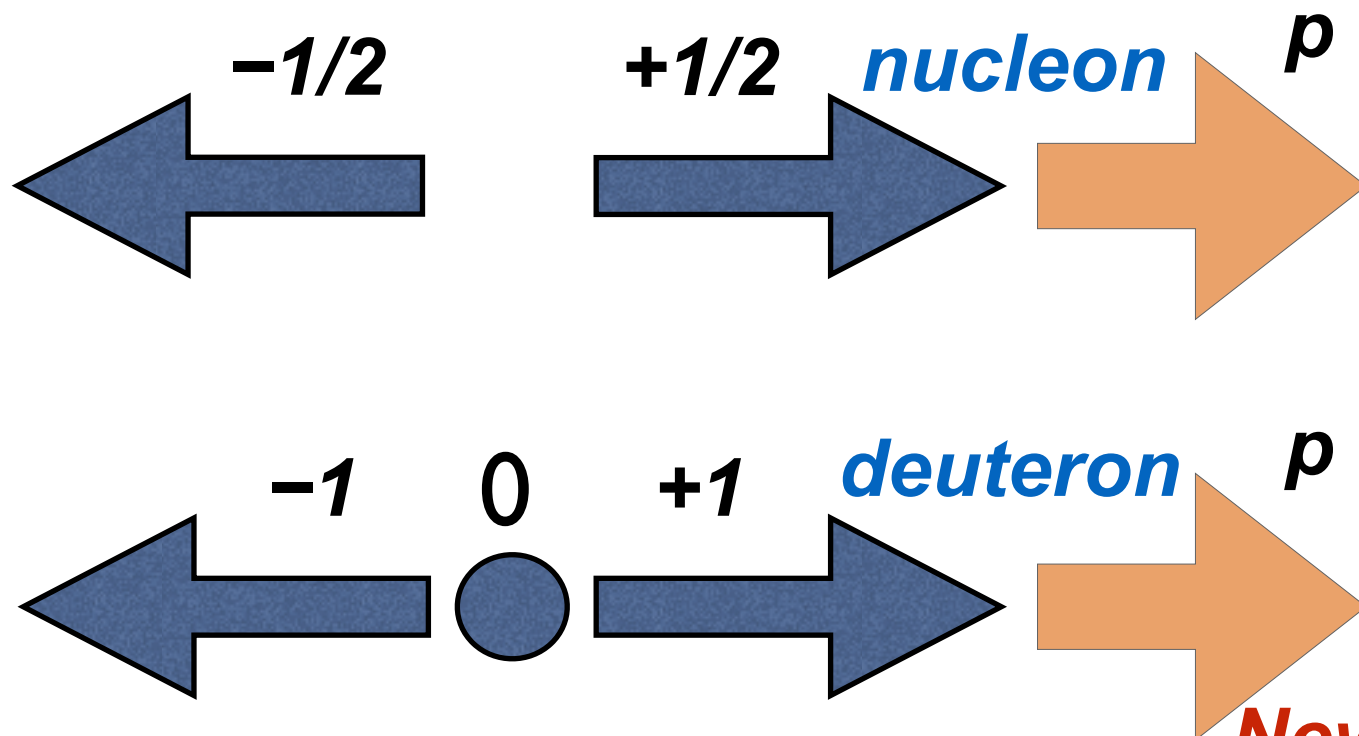


Deuteron is not just proton + neutron!



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

hidden color



More gluons at large x with respect to nucleon?

Vector polarization

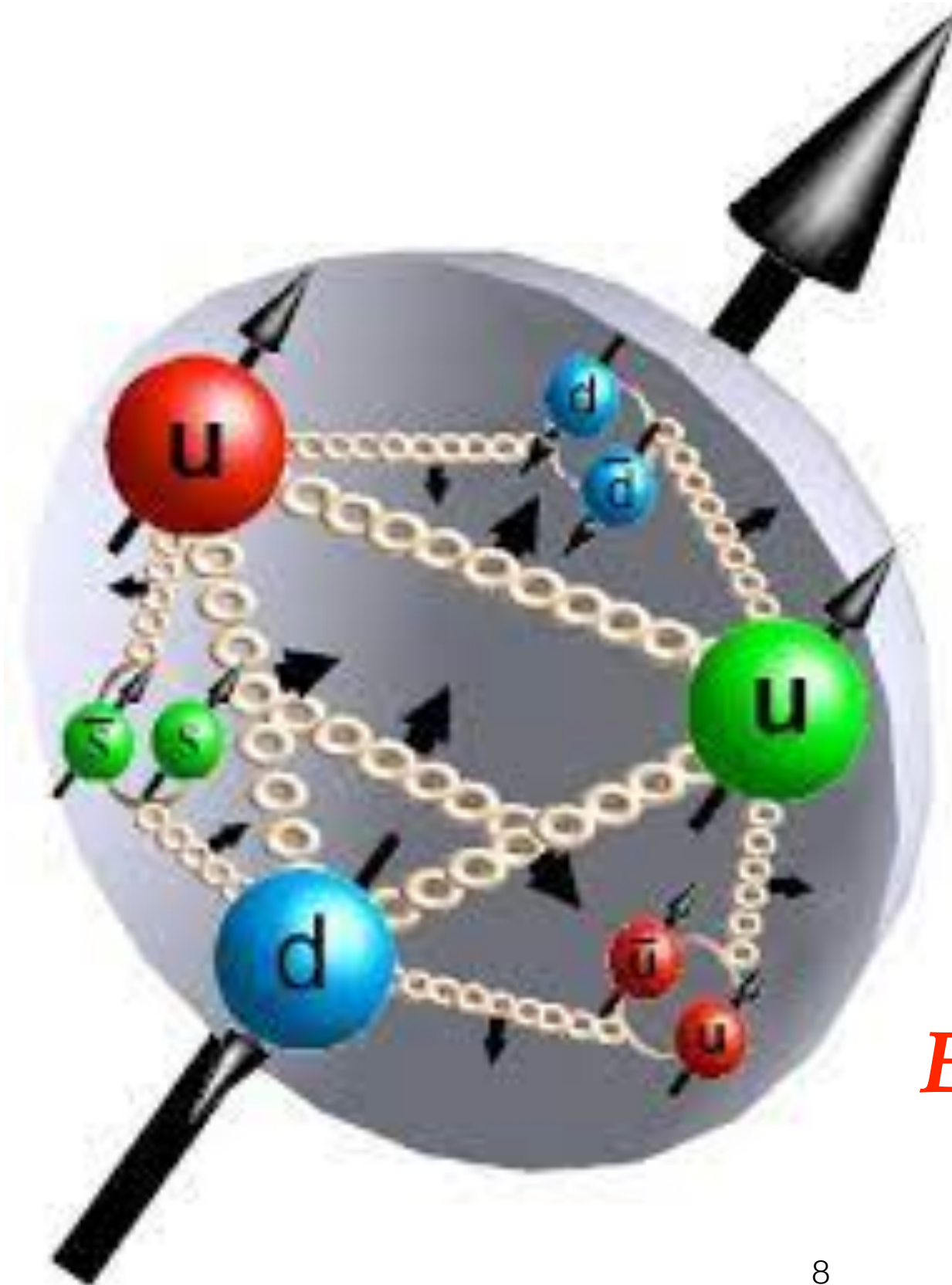
$$\frac{N_{1/2} - N_{-1/2}}{N_{1/2} + N_{-1/2}}$$

Tensor polarization

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

New "tensor" PDFs, mostly unknown

SPD experiment



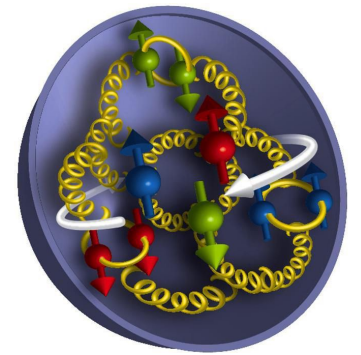
NICA SPD:

*we plan to study
how the proton
spins*

and the deuteron!

*Especially their gluon
component!*

Concept of the **SPD** physics program



SPD - a universal
facility for
comprehensive study of
gluon content in proton
and deuteron at
large x

Charmonia

Prompt photons

Open charm

Other spin-related
phenomena

Other
physics

SPD gluon program

JPPNP: 103858

Model 3G

pp. 1–43 (col. fig: NIL)

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Review

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

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On the physics potential to study the gluon content of proton and deuteron at NICA SPD #1

A. Arbuzov (Dubna, JINR), A. Bacchetta (Pavia U. and INFN, Pavia), M. Butenschoen (Hamburg U., Inst. Theor. Phys. II), F.G. Celiberto (Pavia U. and INFN, Pavia and ECT, Trento and Fond. Bruno Kessler, Povo), U. D'Alesio (Cagliari U. and INFN, Cagliari) et al. (Nov 30, 2020)

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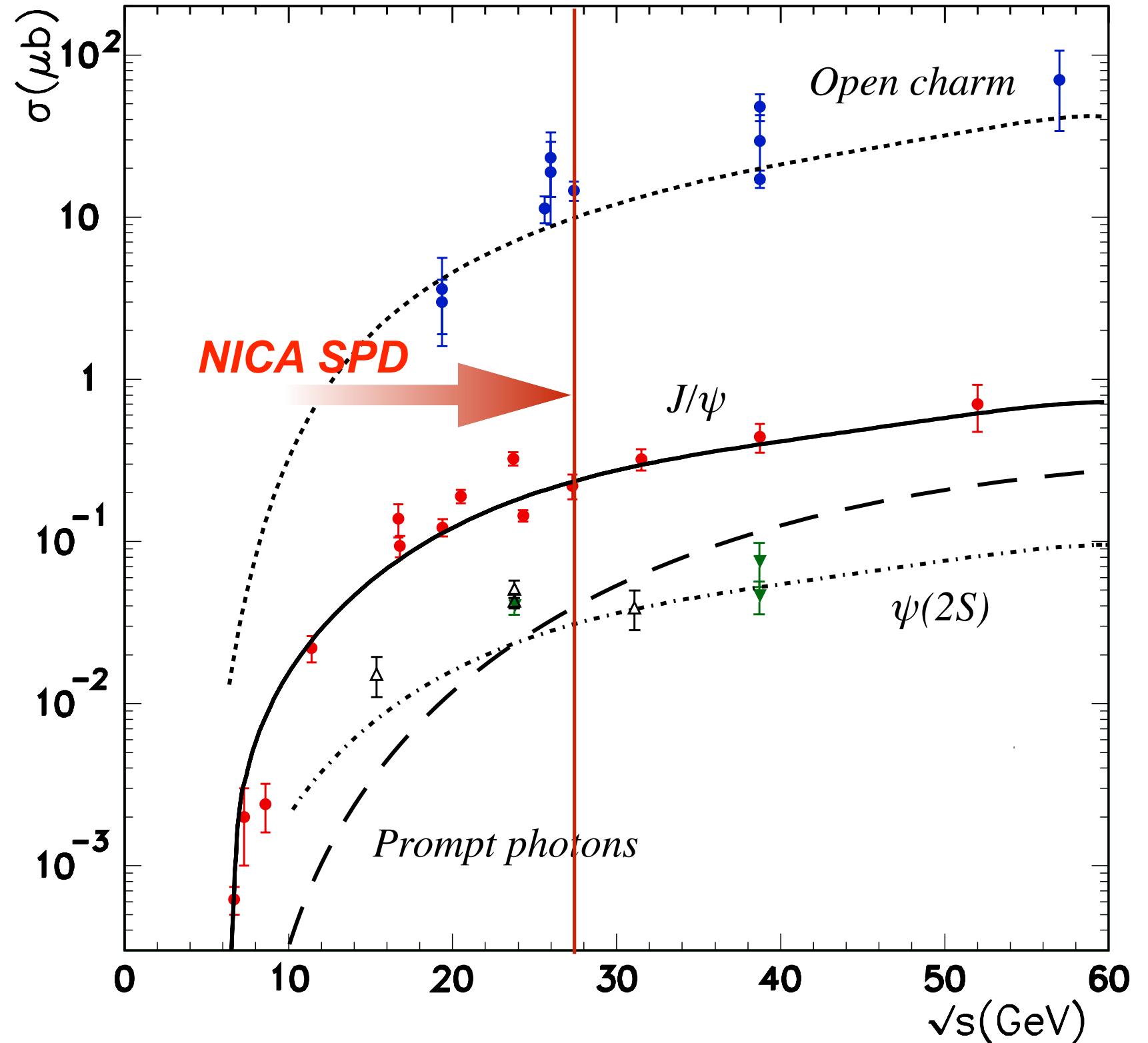
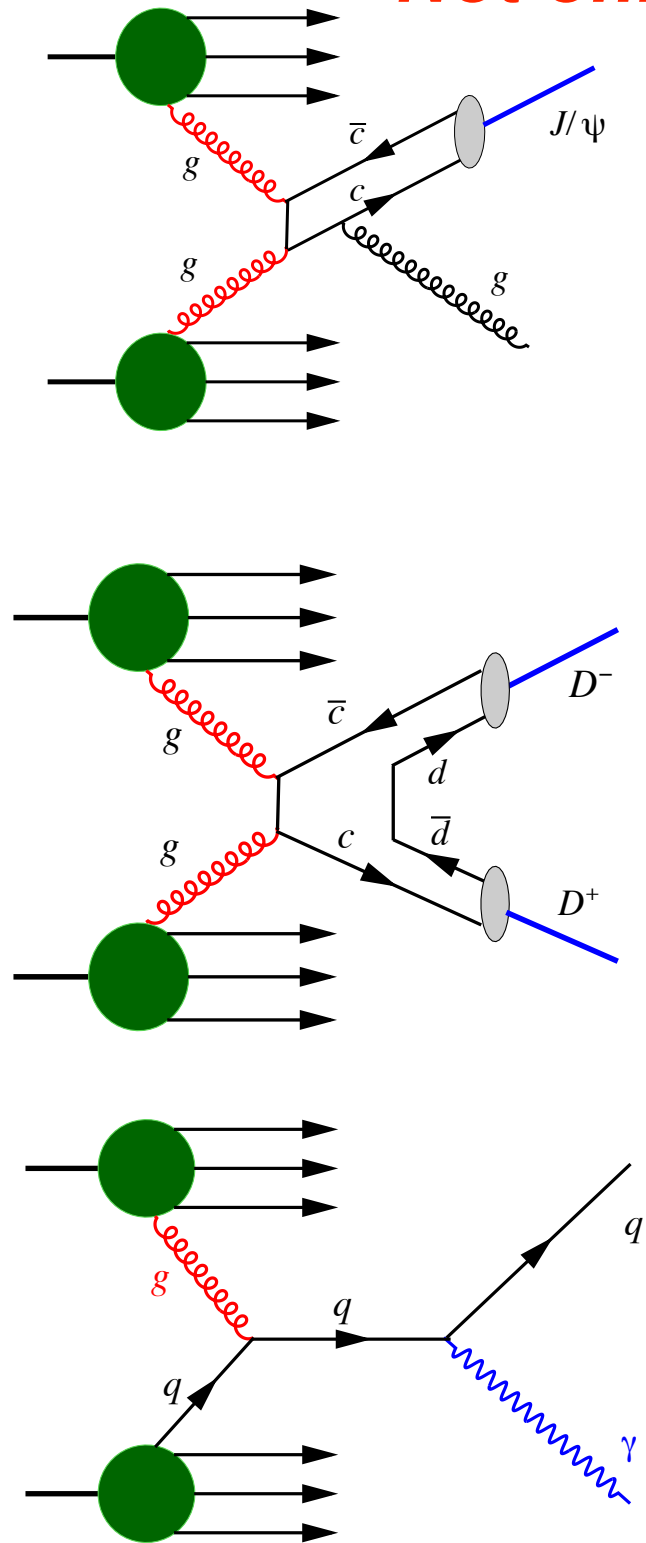
claim

reference search

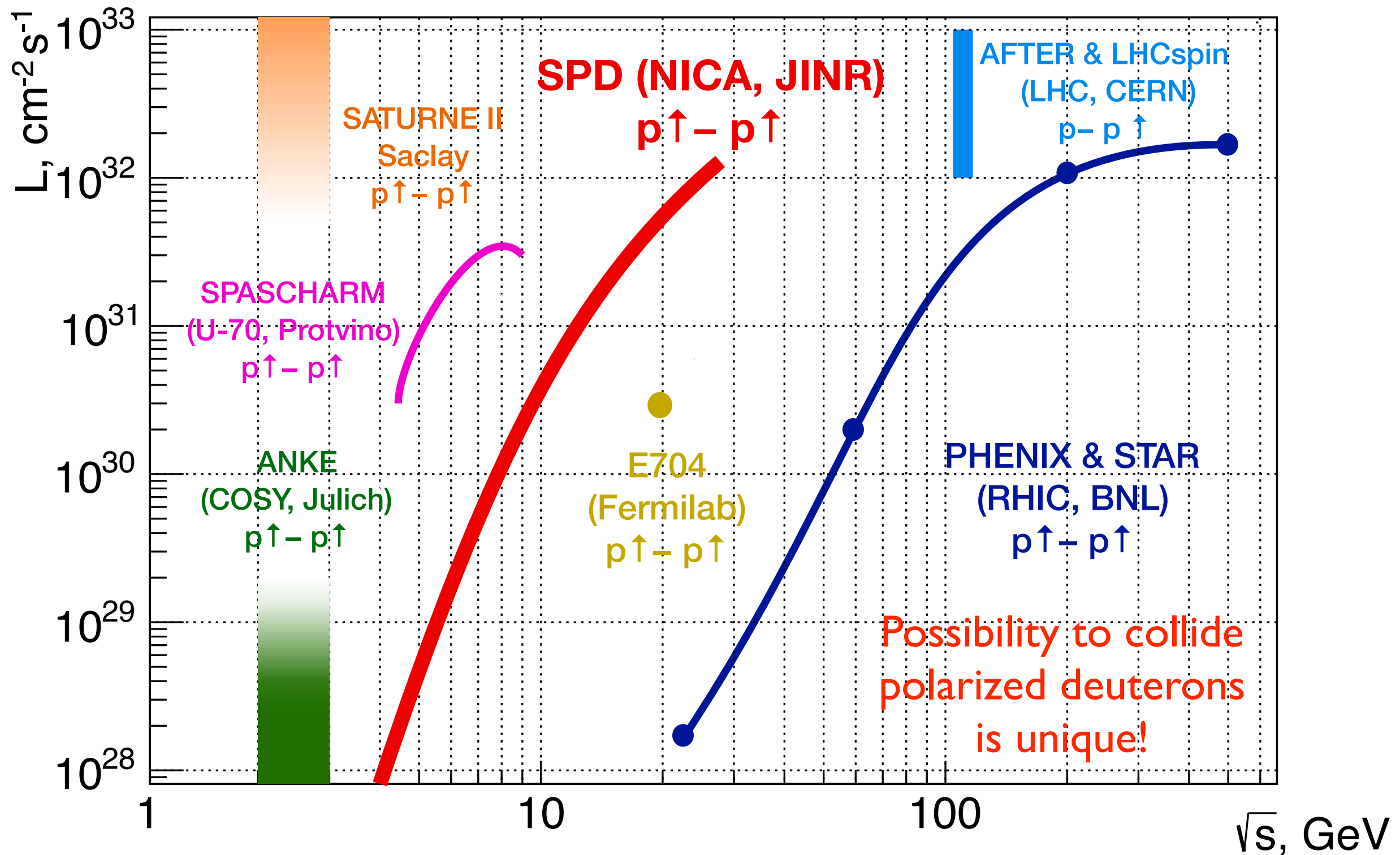
51 citations

SPD and *gluon* structure of nucleon

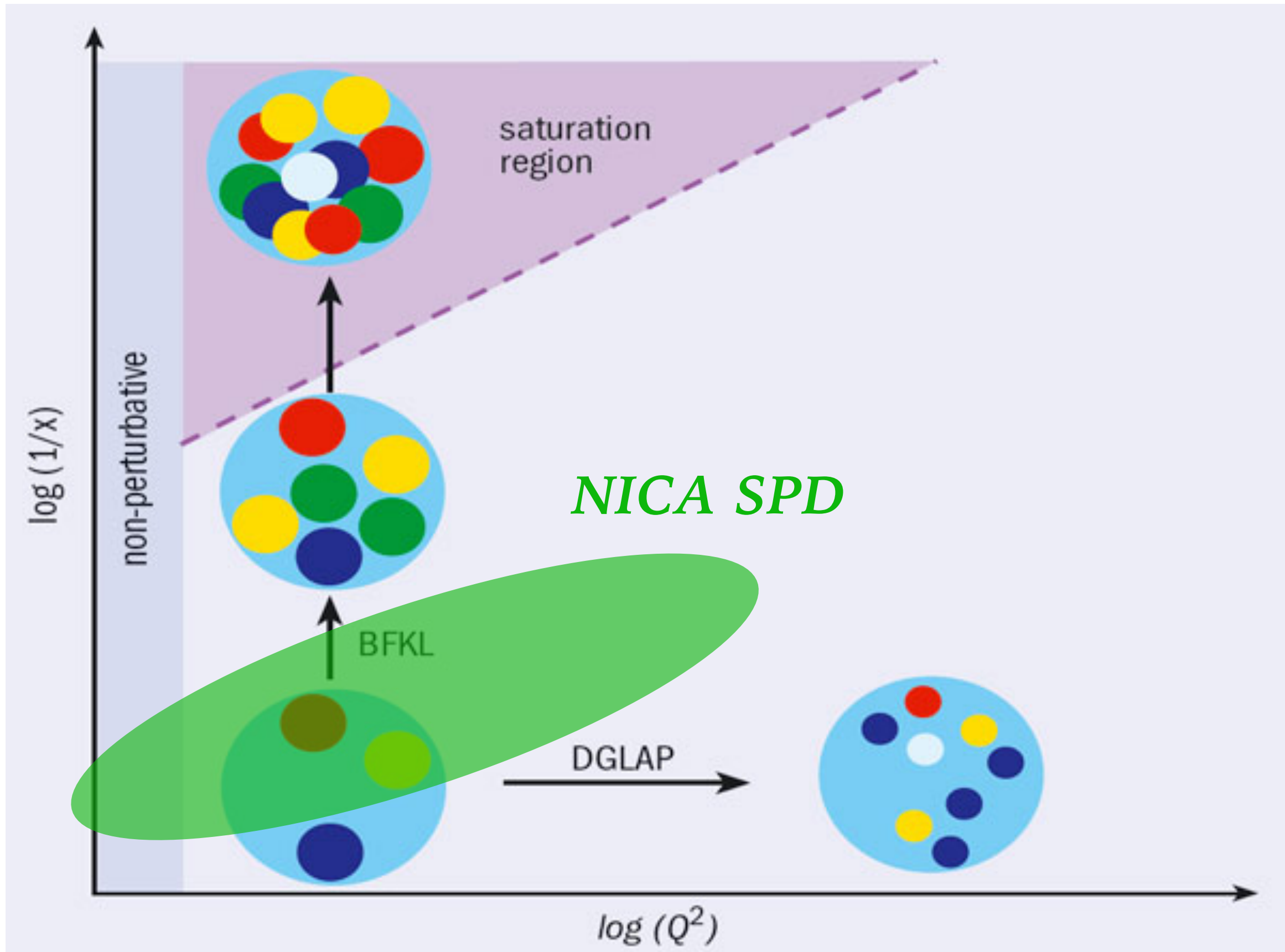
Not only J/ψ!



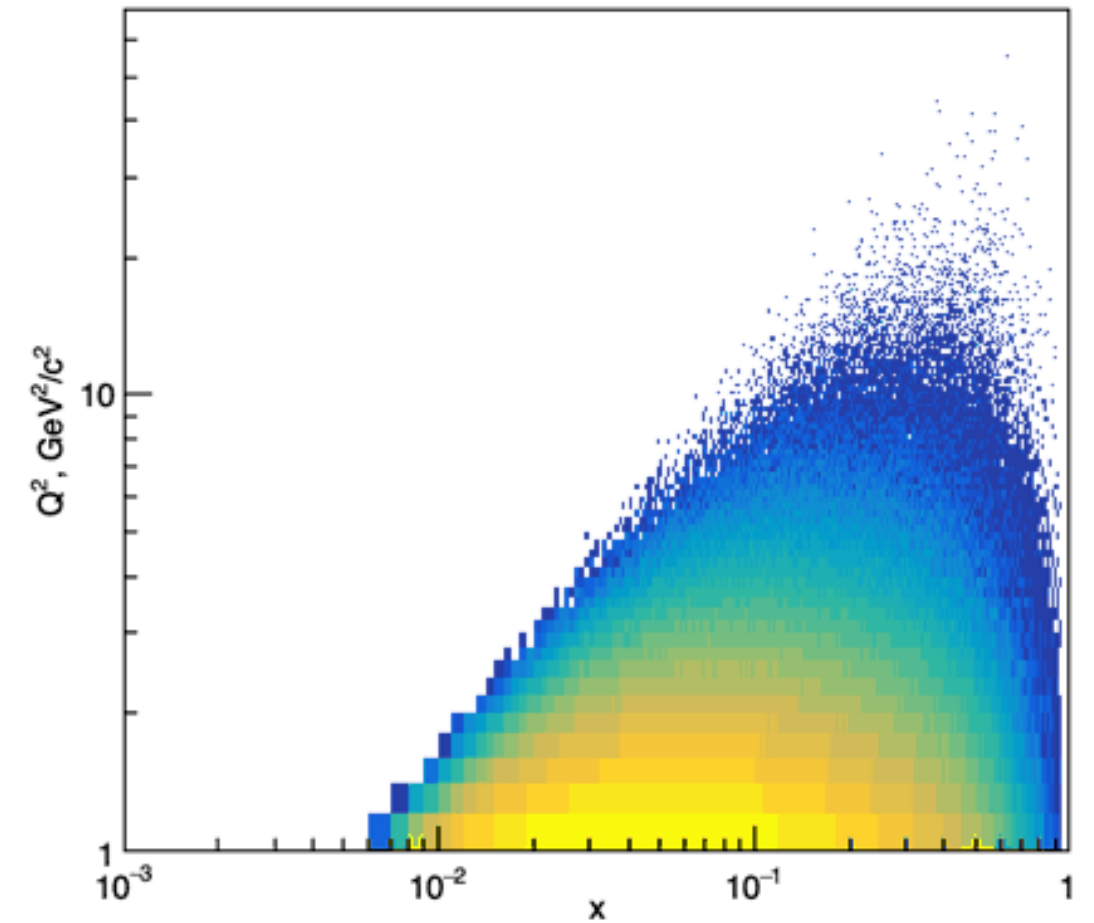
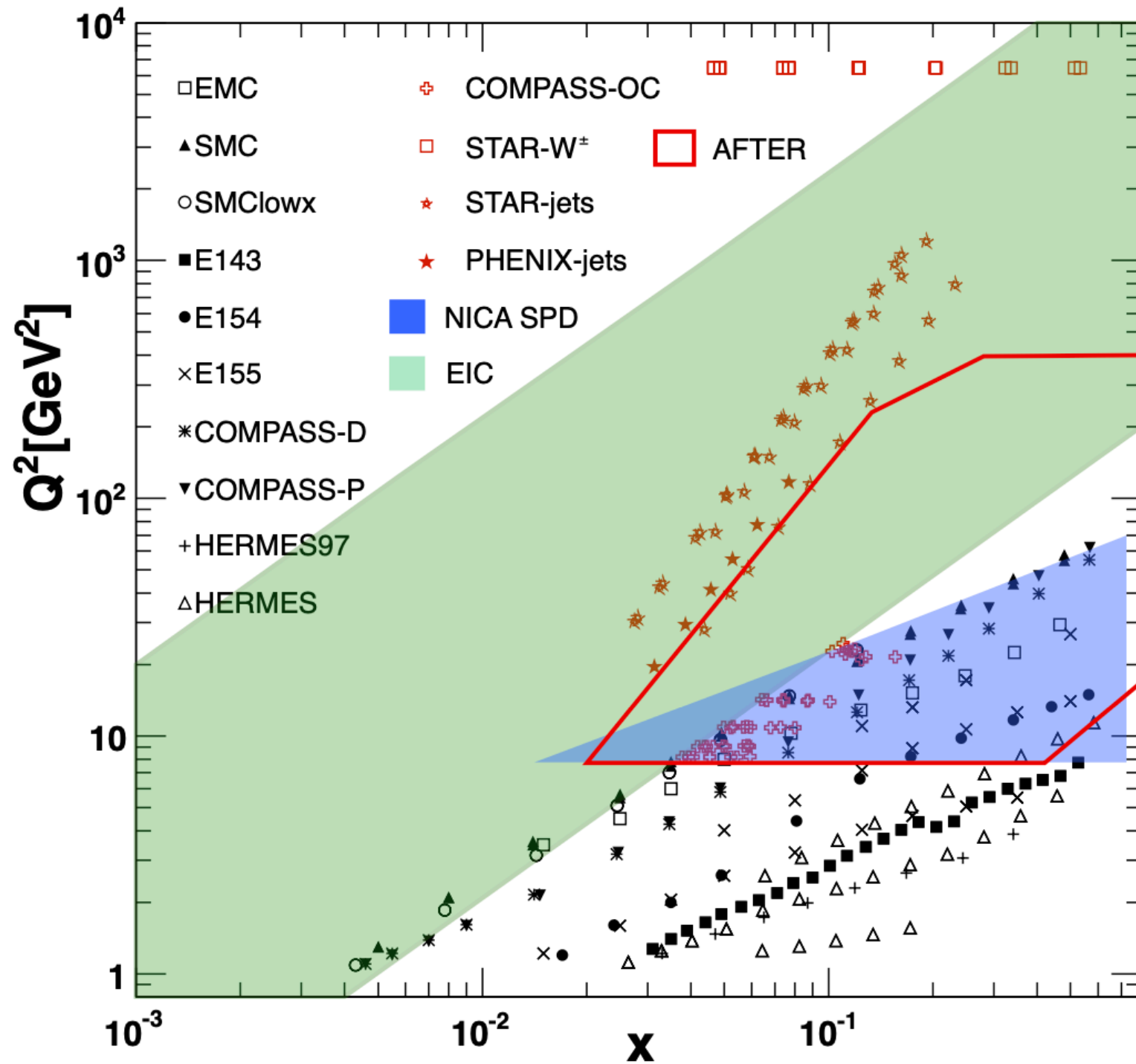
SPD and others



Proton structure: landscape



SPD and others



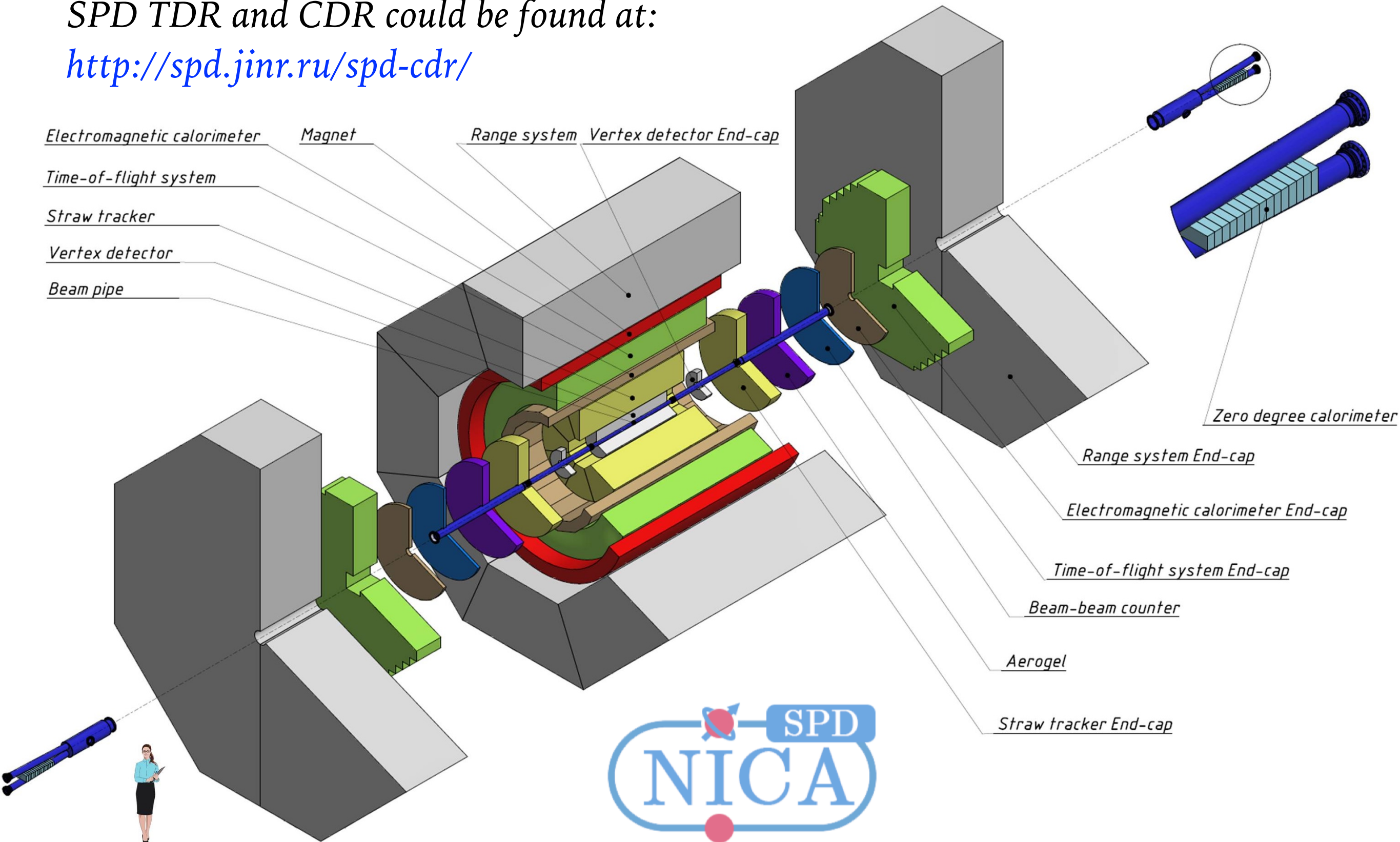
$$Q^2 = 1 \text{ GeV}^2/c^2, \langle x \rangle = 0.16$$

$$Q^2 = 10 \text{ GeV}^2/c^2, \langle x \rangle = 0.3$$

SPD setup

SPD TDR and CDR could be found at:

<http://spd.jinr.ru/spd-cdr/>



SPD: two stages

Creating of polarized infrastructure

Upgrade of polarized infrastructure

Start of NICA operation

+4 years

+6 years

+8 years



SPD construction

1st stage of operation

SPD upgrade

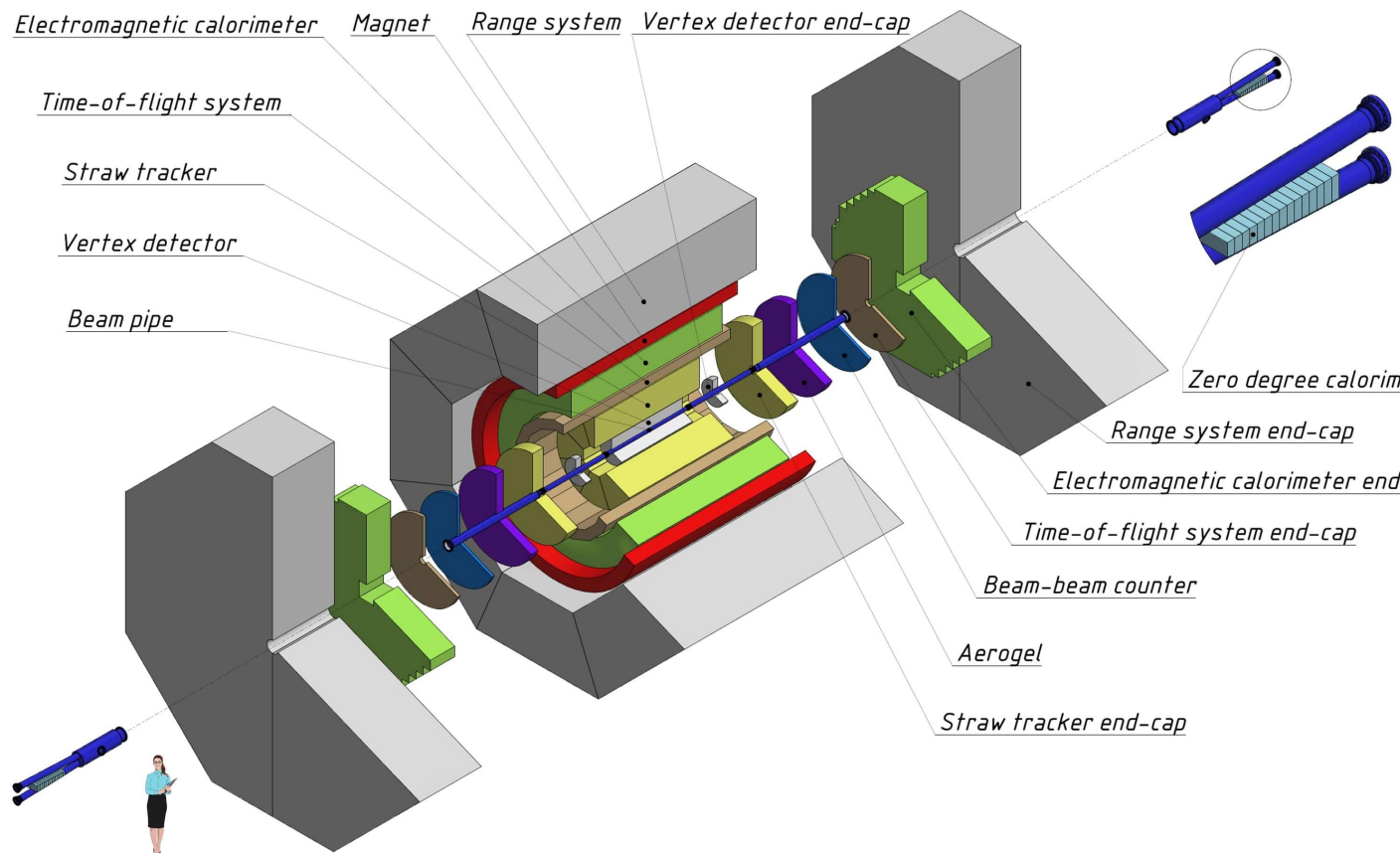
2nd stage of operation

Straw tracker
MicroMegas
Beam pipe

Electromagnetic calorimeter
Magnet
Range system
Vertex detector end-cap
Time-of-flight system
Straw tracker
Vertex detector
Beam pipe

Zero degree calorimeter
Range system end-cap
Electromagnetic calorimeter end-cap
Time-of-flight system end-cap
Beam-beam counter
Aerogel
Straw tracker end-cap

Zero degree calorimeter
Range system end-cap
Beam-beam counter
Straw tracker end-cap
MicroMegas end-cap



Physic of the first stage

Non-perturbative QCD

Perturbative QCD

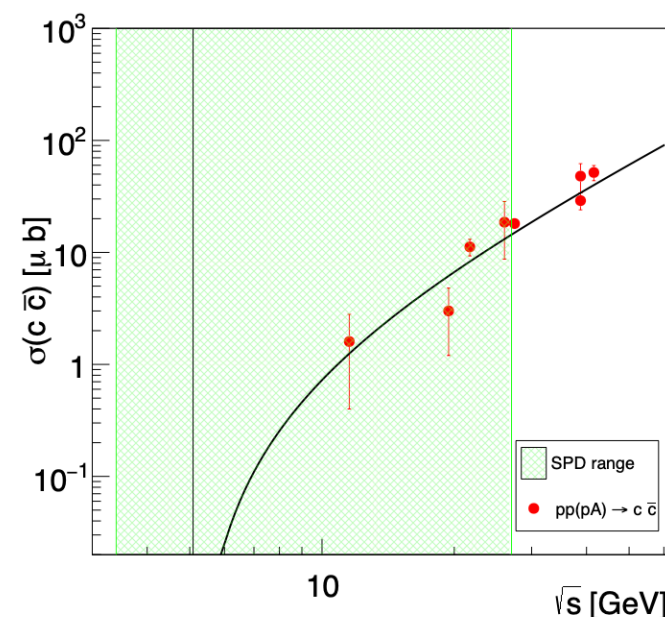
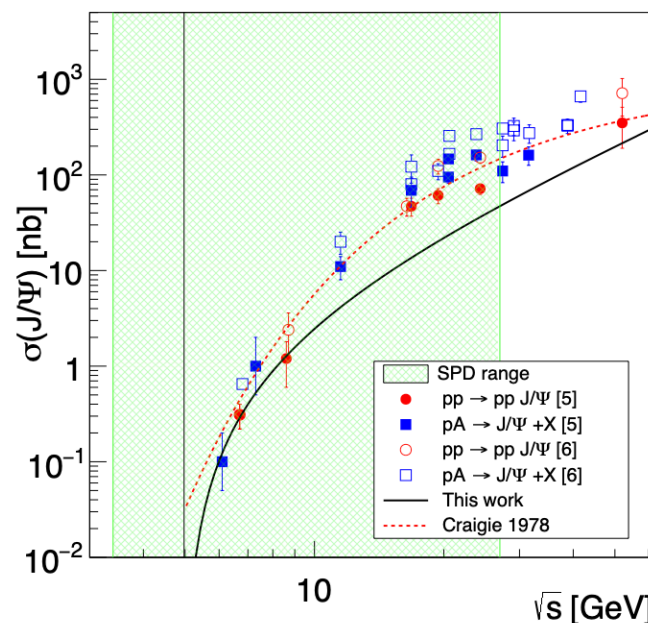
- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernuclei
- Open charm and charmonia near threshold

$$pp \rightarrow (6q)^* \rightarrow NN \text{ Mesons,}$$

$$dd \rightarrow K^+ K^+ \Lambda\Lambda n,$$

 \sqrt{s}

arXiv:2102.08477



- Auxiliary measurements for astrophysics

SPD international collaboration

35 institutes from 14 countries, ~300 members



We are open for new participants!

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 $\sqrt{s} \leq 27 \text{ GeV}$;
- 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> .