SPD EXPERIMENT

A. Guskov, avg@jinr.int

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Spin Physic Detector @ NICA

NICA - Nuclotron-based Ion Collider fAcility

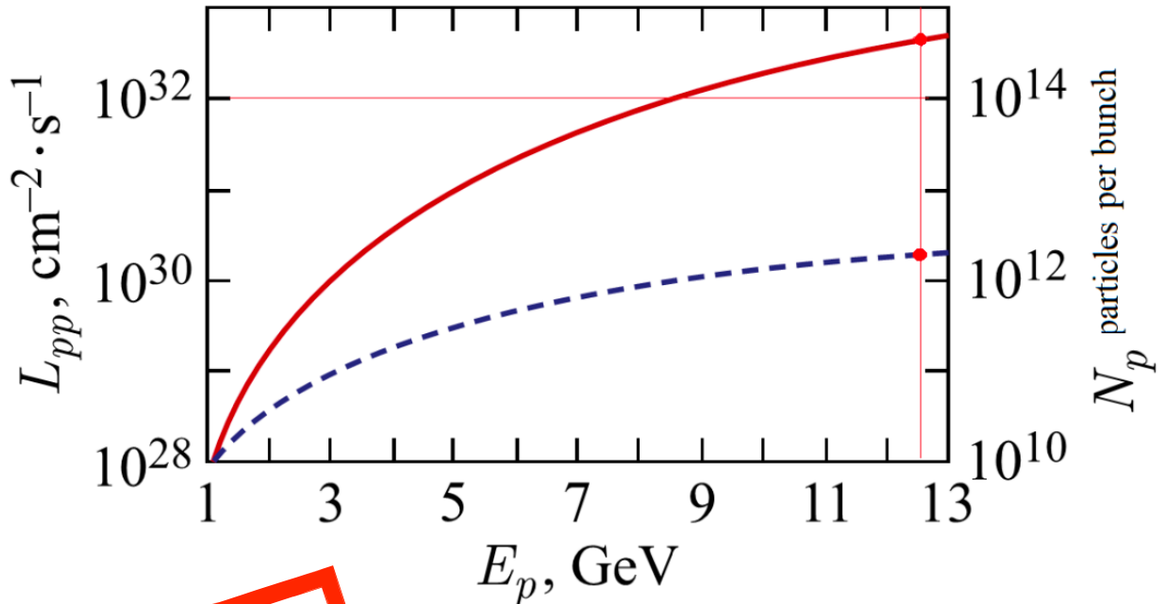
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

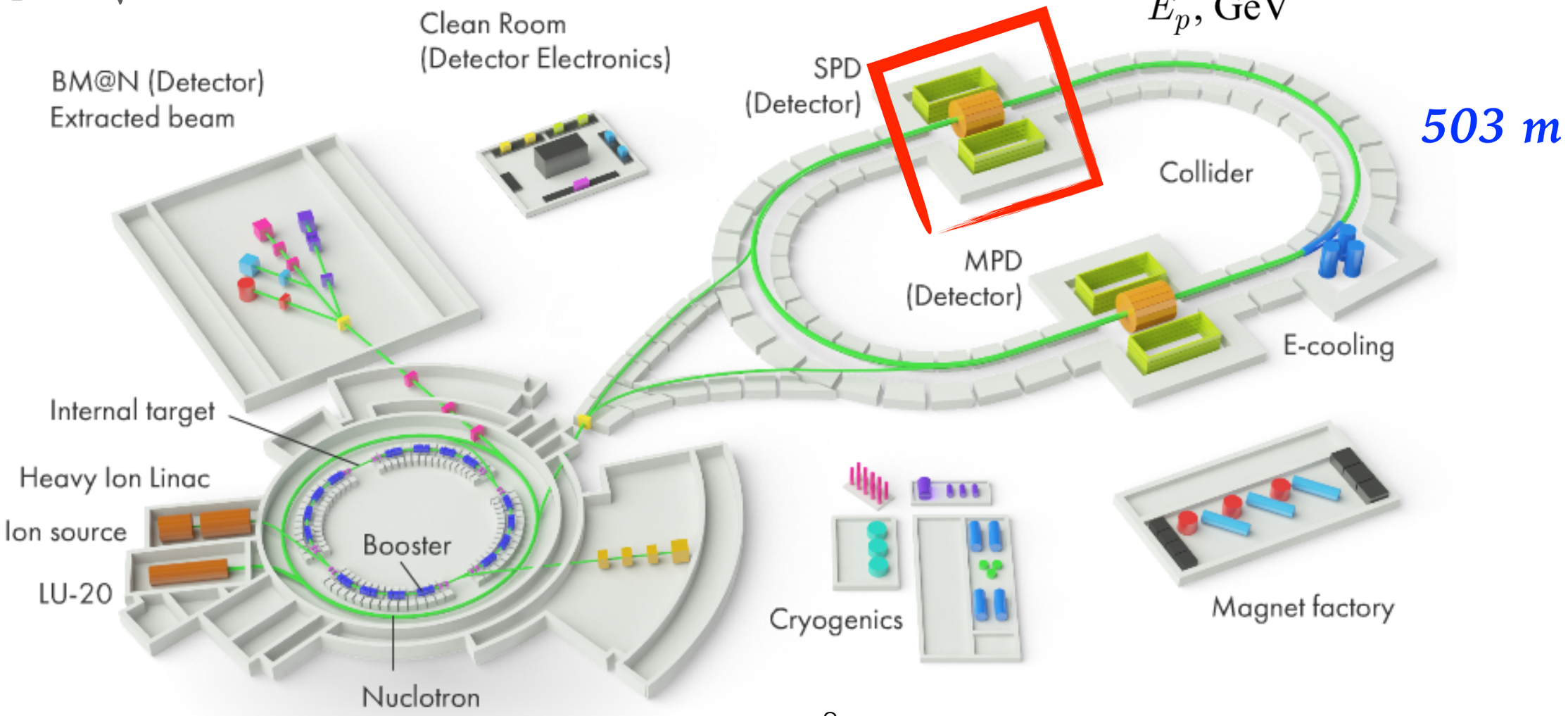
$d^{\uparrow}d^{\uparrow} : \sqrt{s} \leq 13.5\ GeV$

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

U, L, T

$|P| > 70\%$





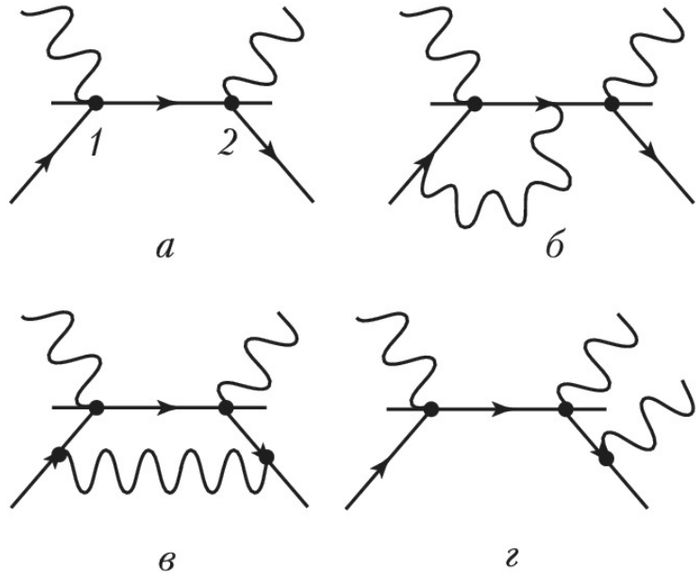
Problem to describe hadrons ab initio

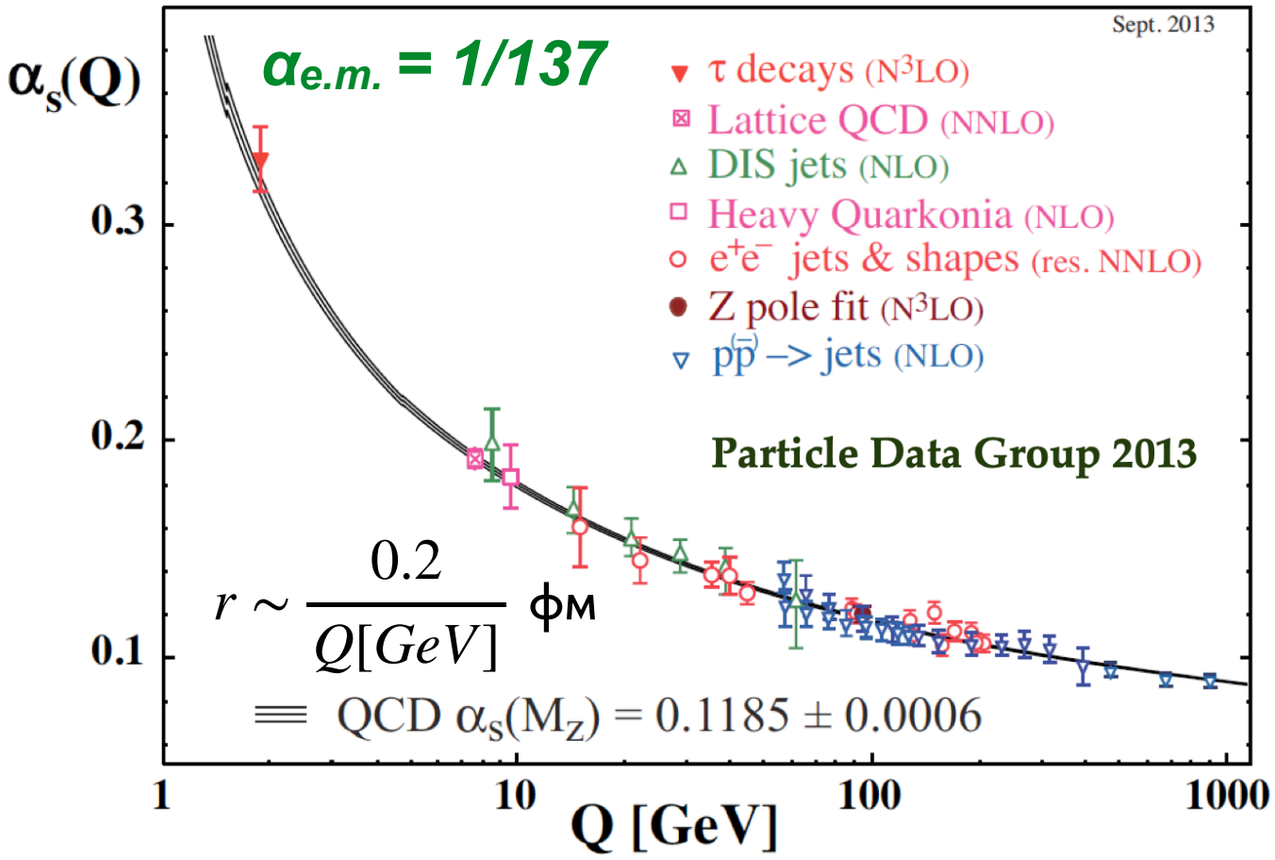
Feynman diagrams - perturbative approach

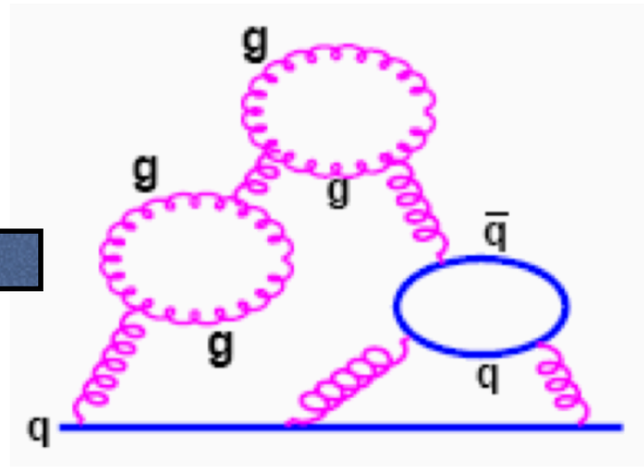
$$\sigma \sim \sum_{n}^{\infty} c_n \alpha^n$$

α - interaction constant

Fast convergence for α<<1



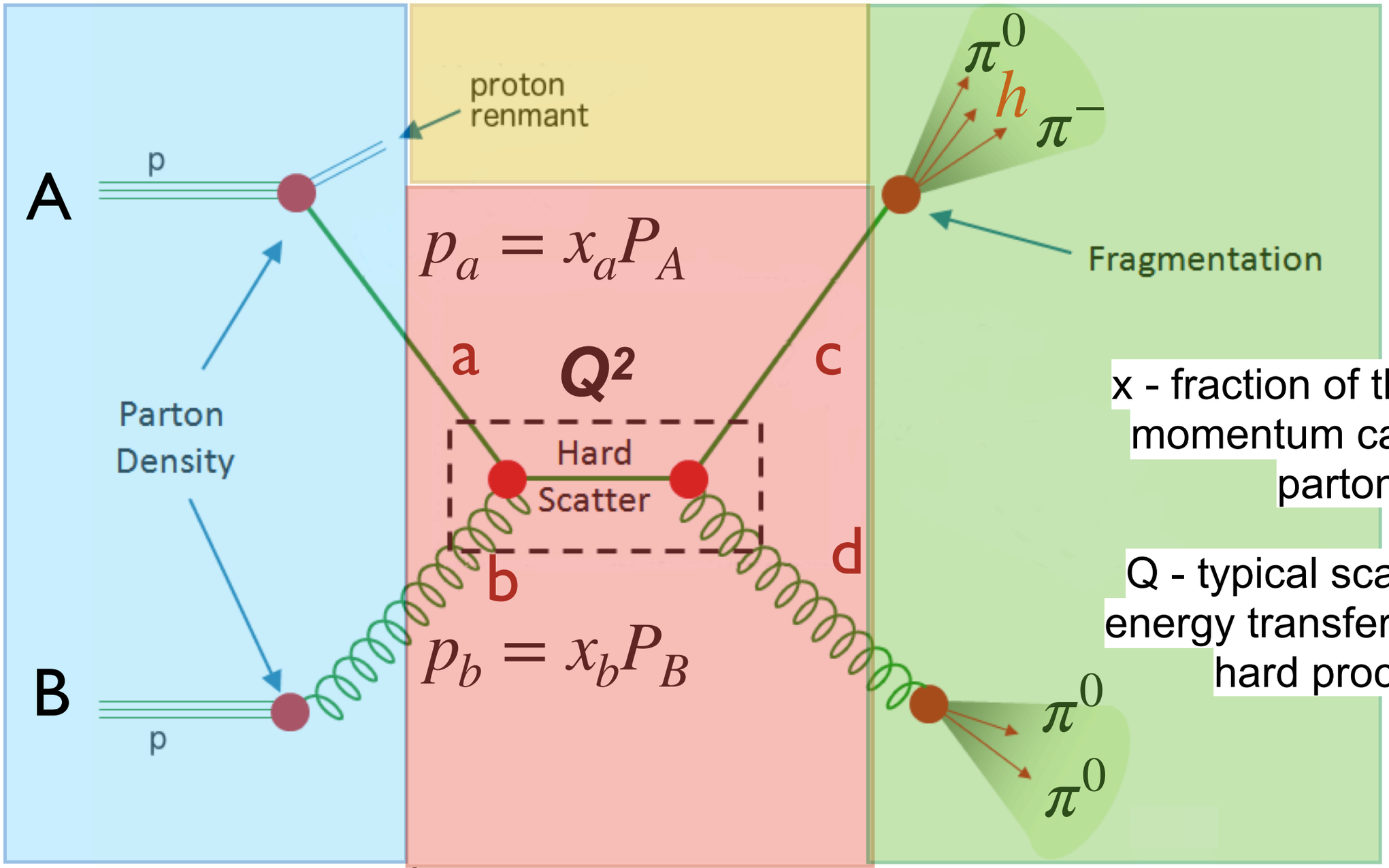




Confinement is not strictly proven!

Unlike the hydrogen atom, we cannot (yet?) describe from first principles the structure of hadrons and their interactions at low energies

Factorization theorem



x - fraction of the proton momentum carried by parton

Q - typical scale of the energy transferred in the hard process

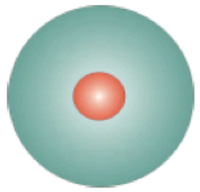
$$\sigma_{AB\to hX} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f(x_a, Q^2) f(x_b, Q^2) \times \hat{\sigma}_{ab\to cd}(x_a, x_b, Q^2) \times D_{cd\to h}$$

$Q^2 >> 1$ GeV$^2/c^2$

Polarized proton

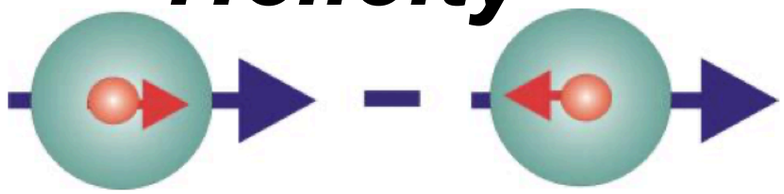
f(x)

Unpolarized



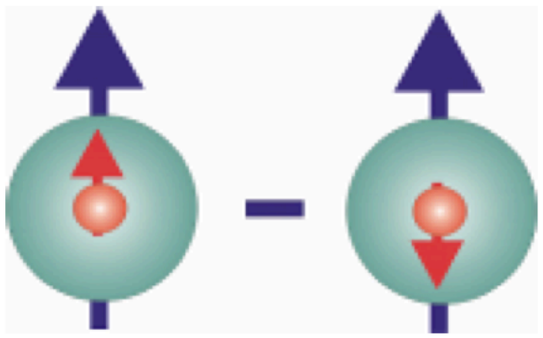
Δf(x)

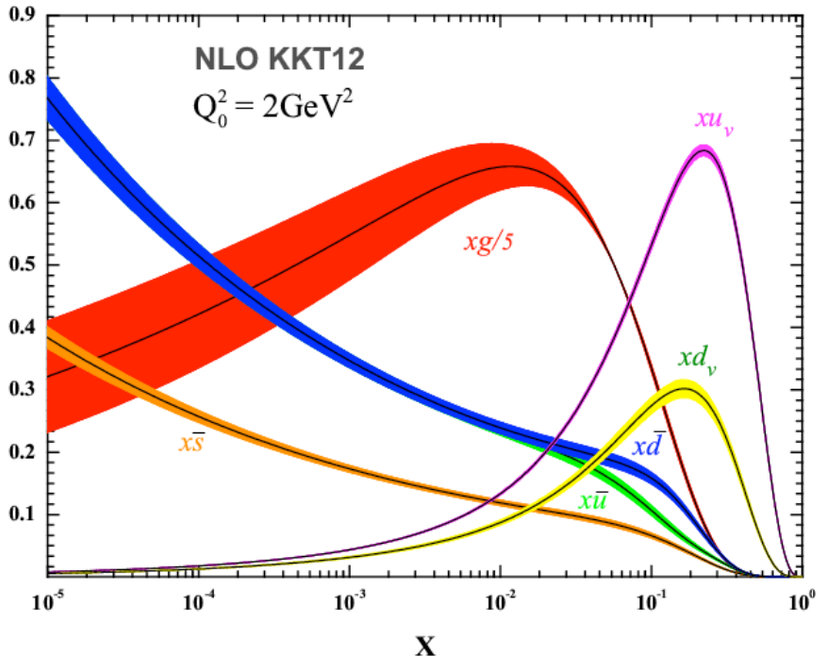
Helicity



Transversity

$\Delta_T f(x)$



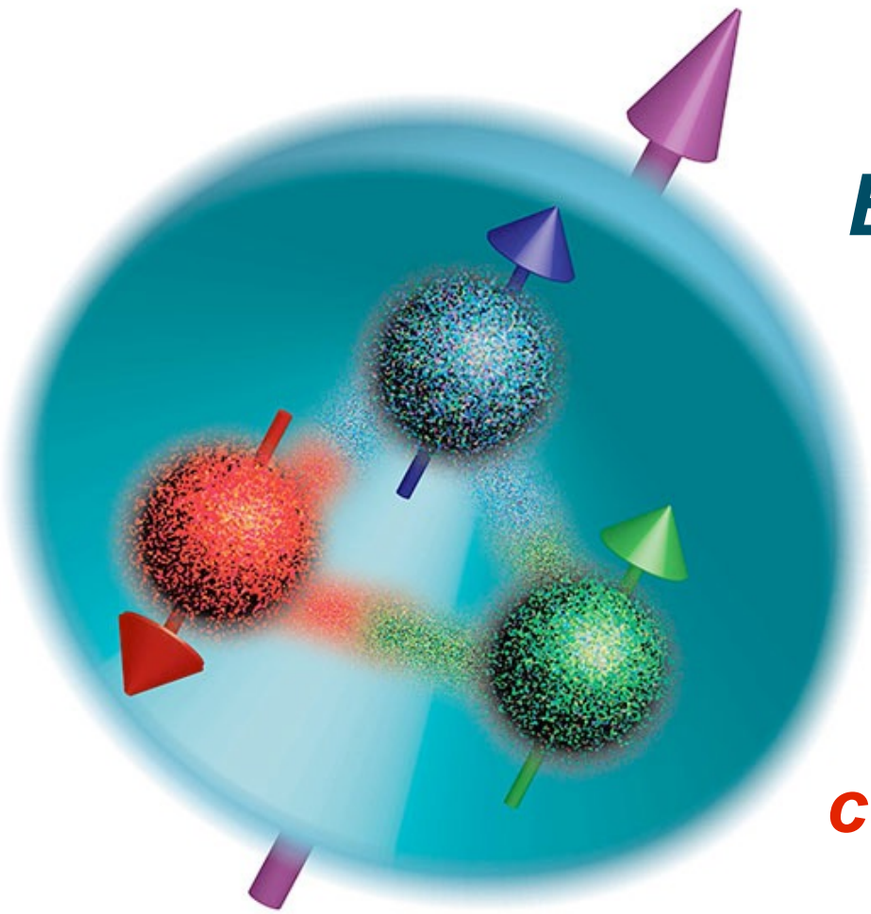


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \sim \Delta f$$

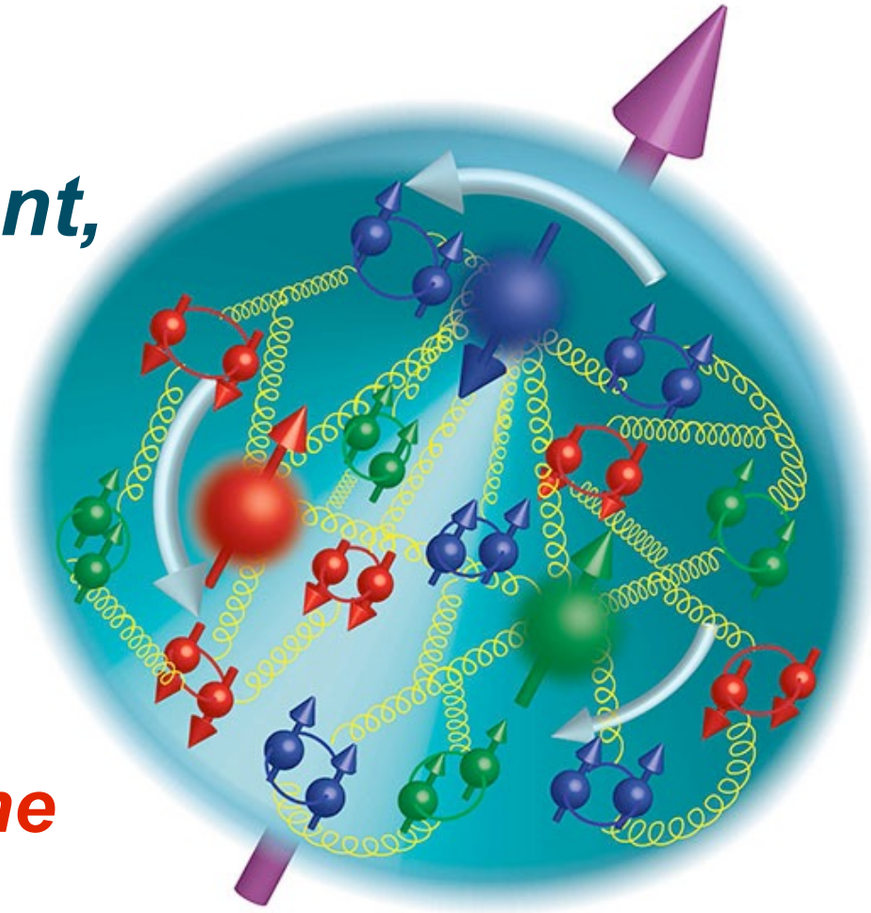
Angular asymmetries

P

Spin crisis



EMC experiment, CERN 1988



Quark contribution to the proton spin is below 30%!

Naive quark model

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

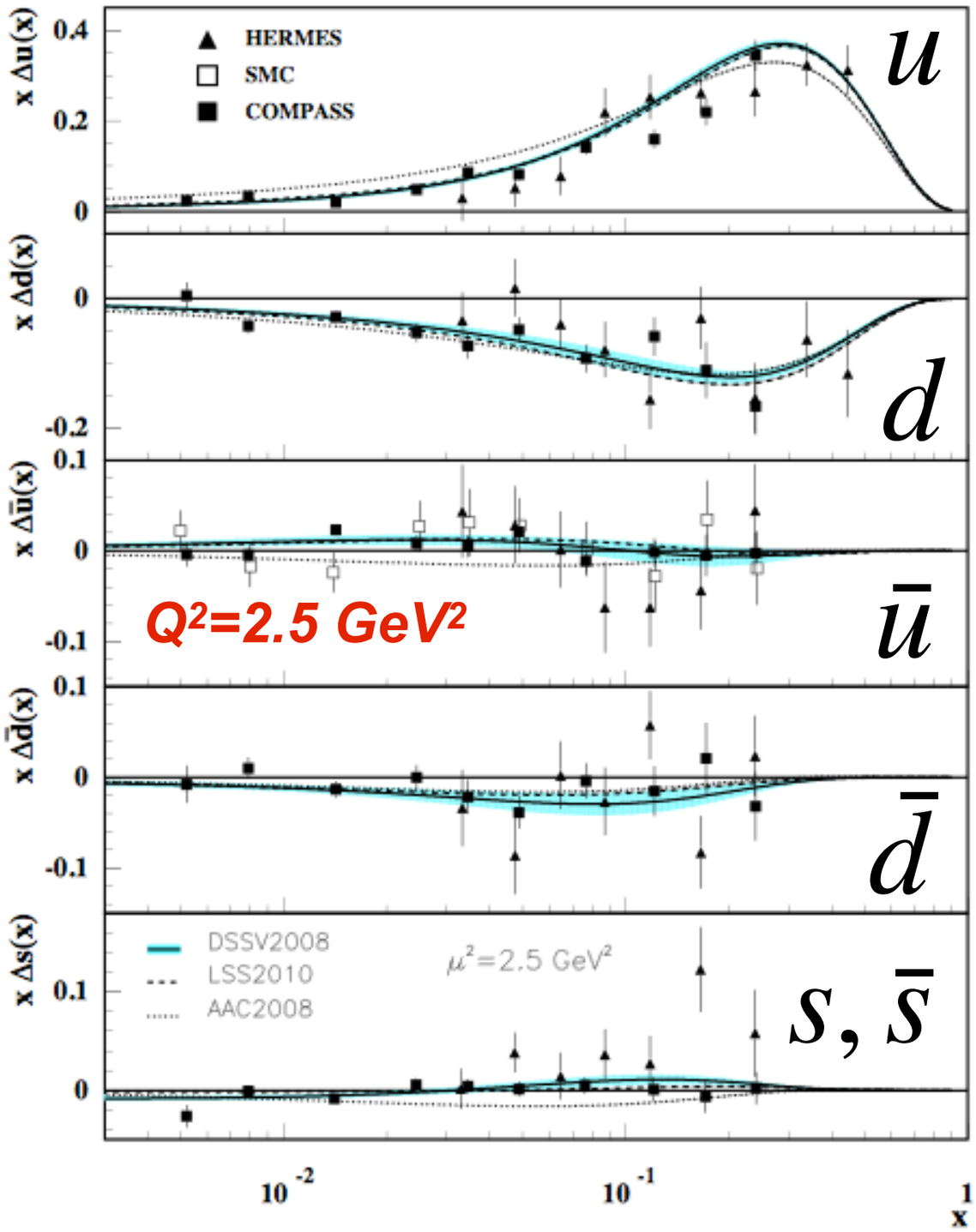
Real situation

L - orbital moments of quarks and gluons

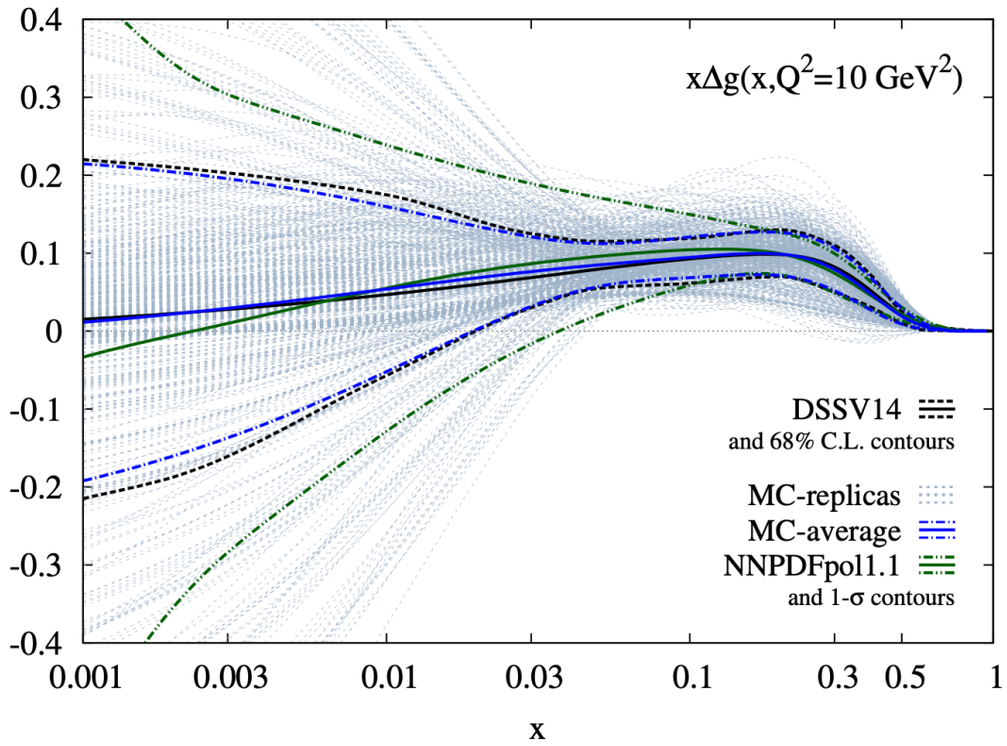
$$S_N = ½ = ½\,\Delta\Sigma + \Delta G + L$$

Spin crisis

Longitudinal polarization of quarks:



… and gluons:



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

~30%

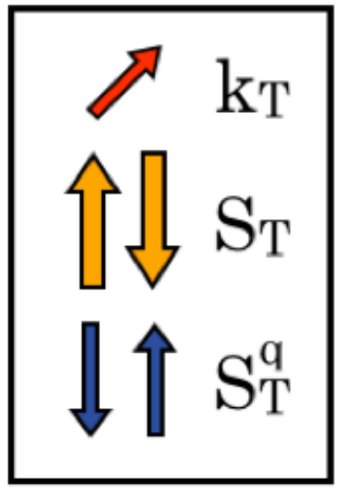
~ ?

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

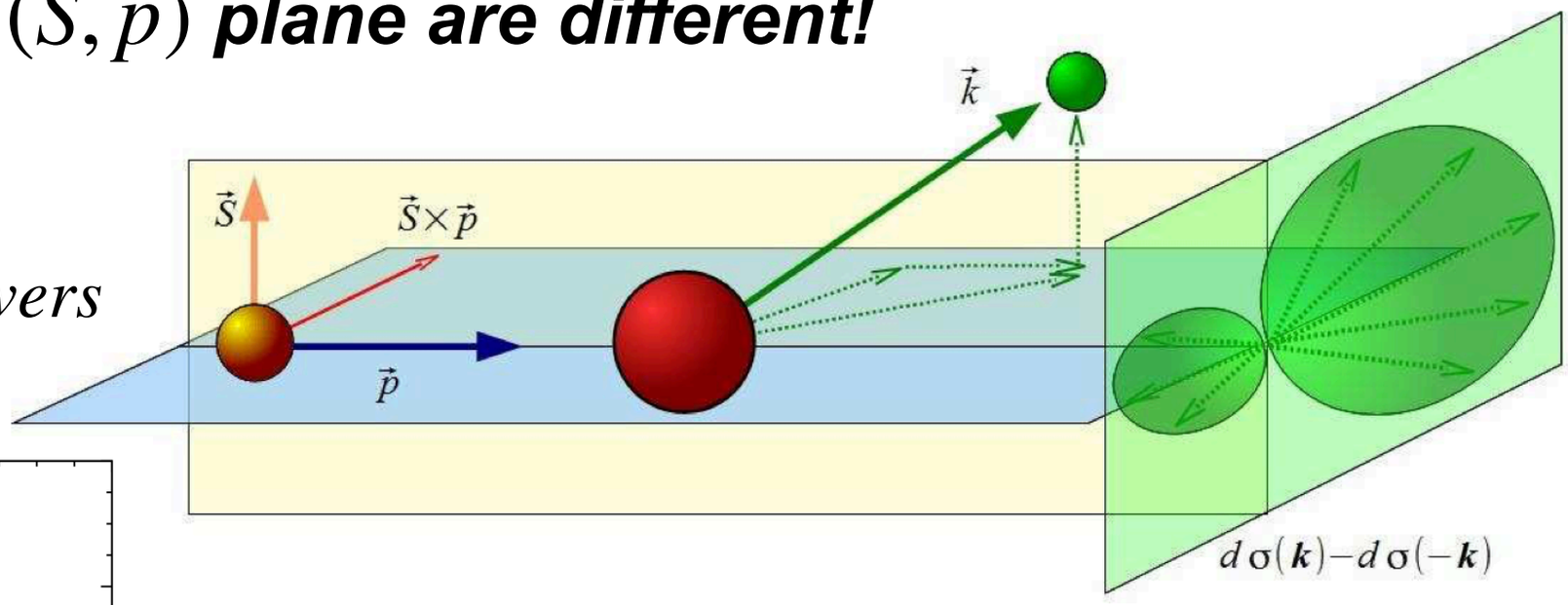


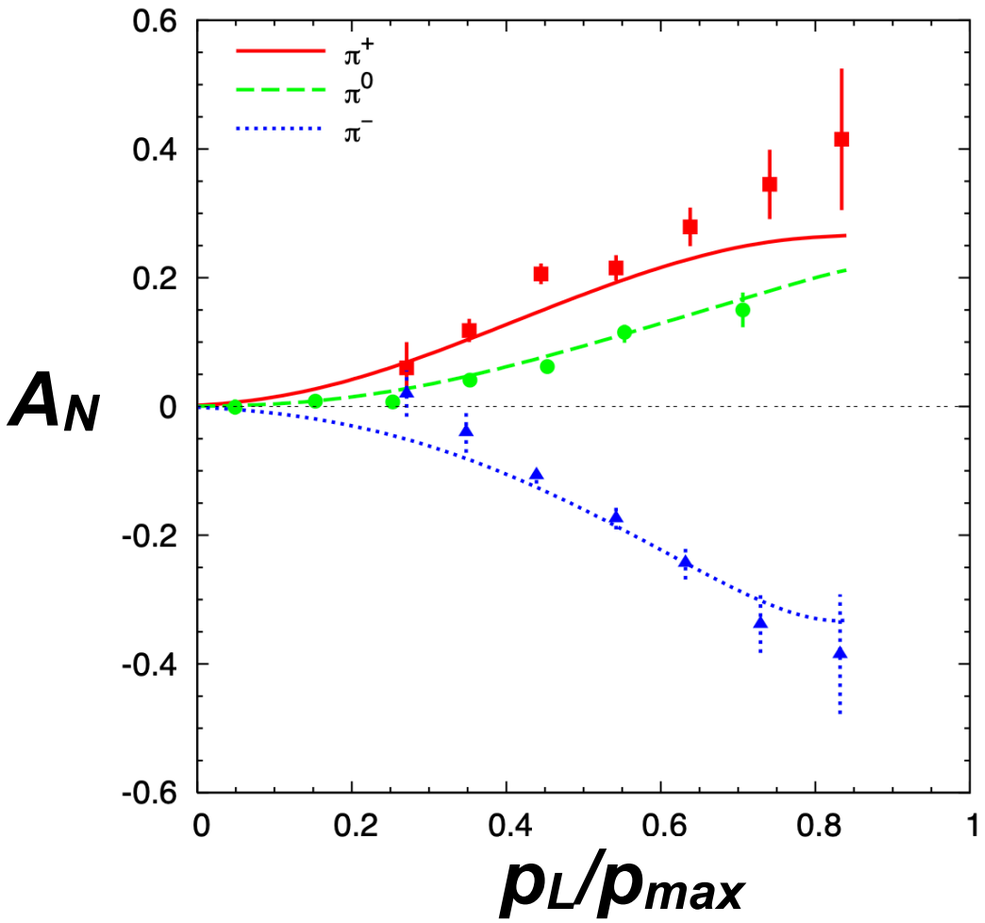
5 additional (TMD) functions describing the correlation between the nucleon spin, parton spin, and parton transverse momentum.

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!

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

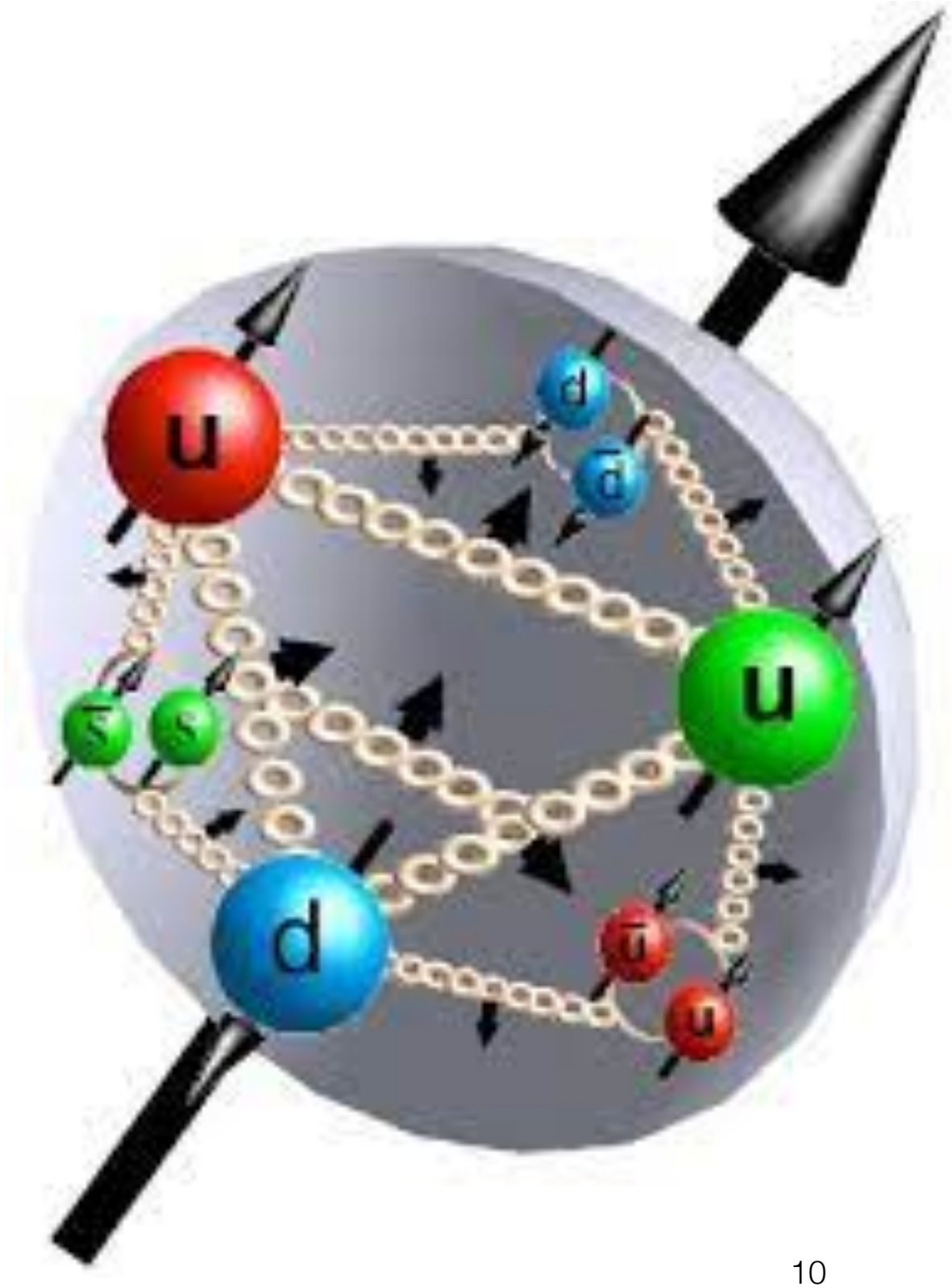




E704

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

SPD experiment

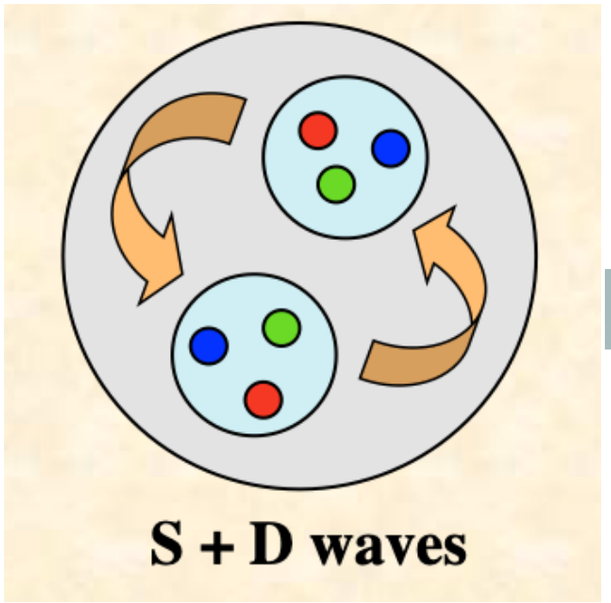


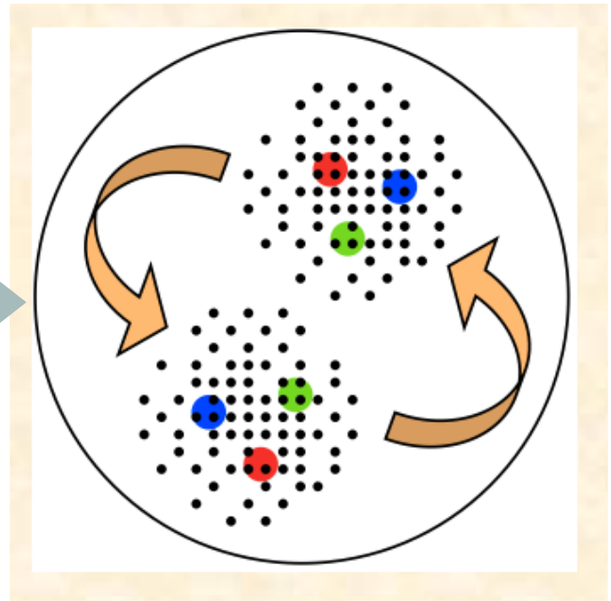
NICA SPD:

we plan to study

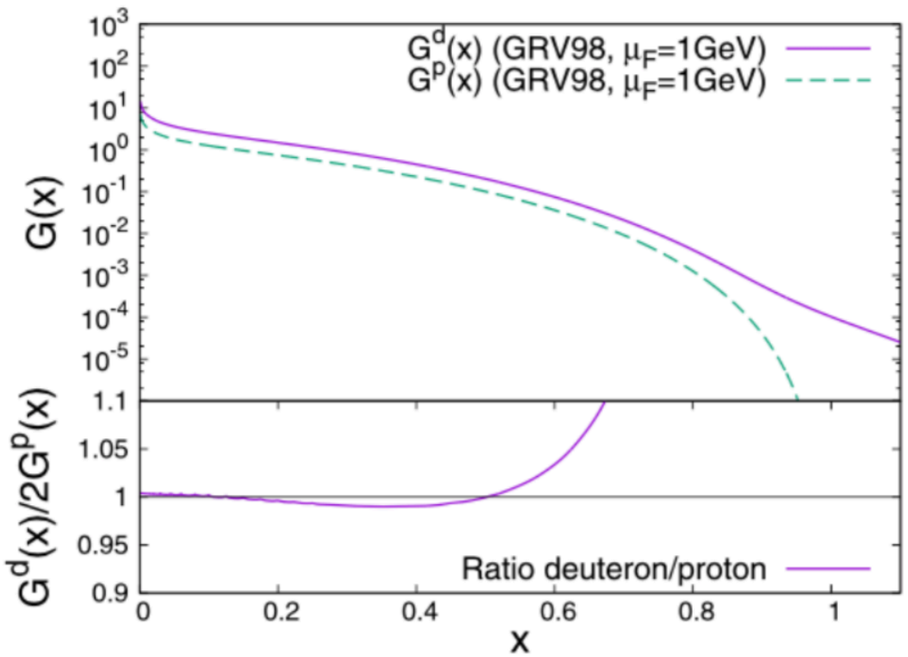
how the proton spins

Deuteron



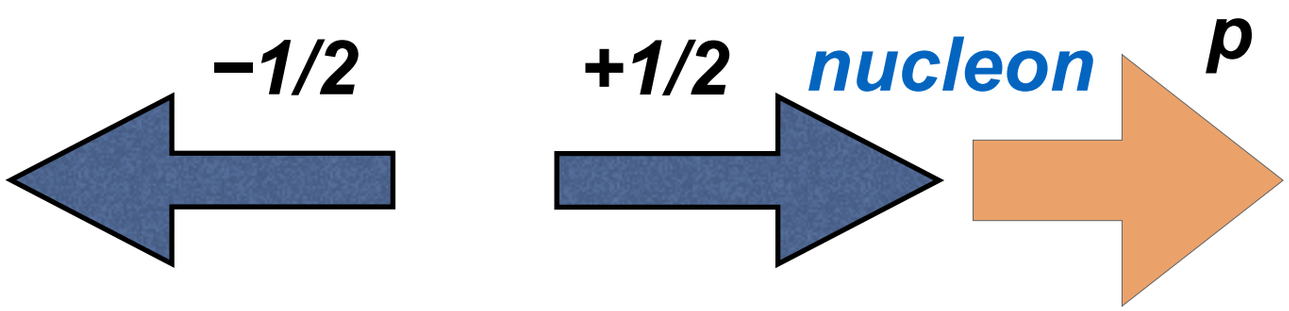


Deuteron is not just proton + neutron!



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

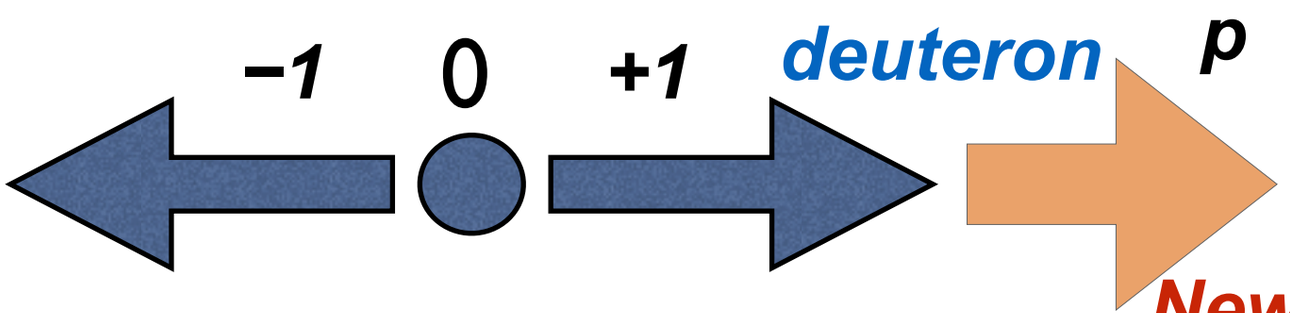
hidden color



More gluons at large x with respect to nucleon?

Vector polarization

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

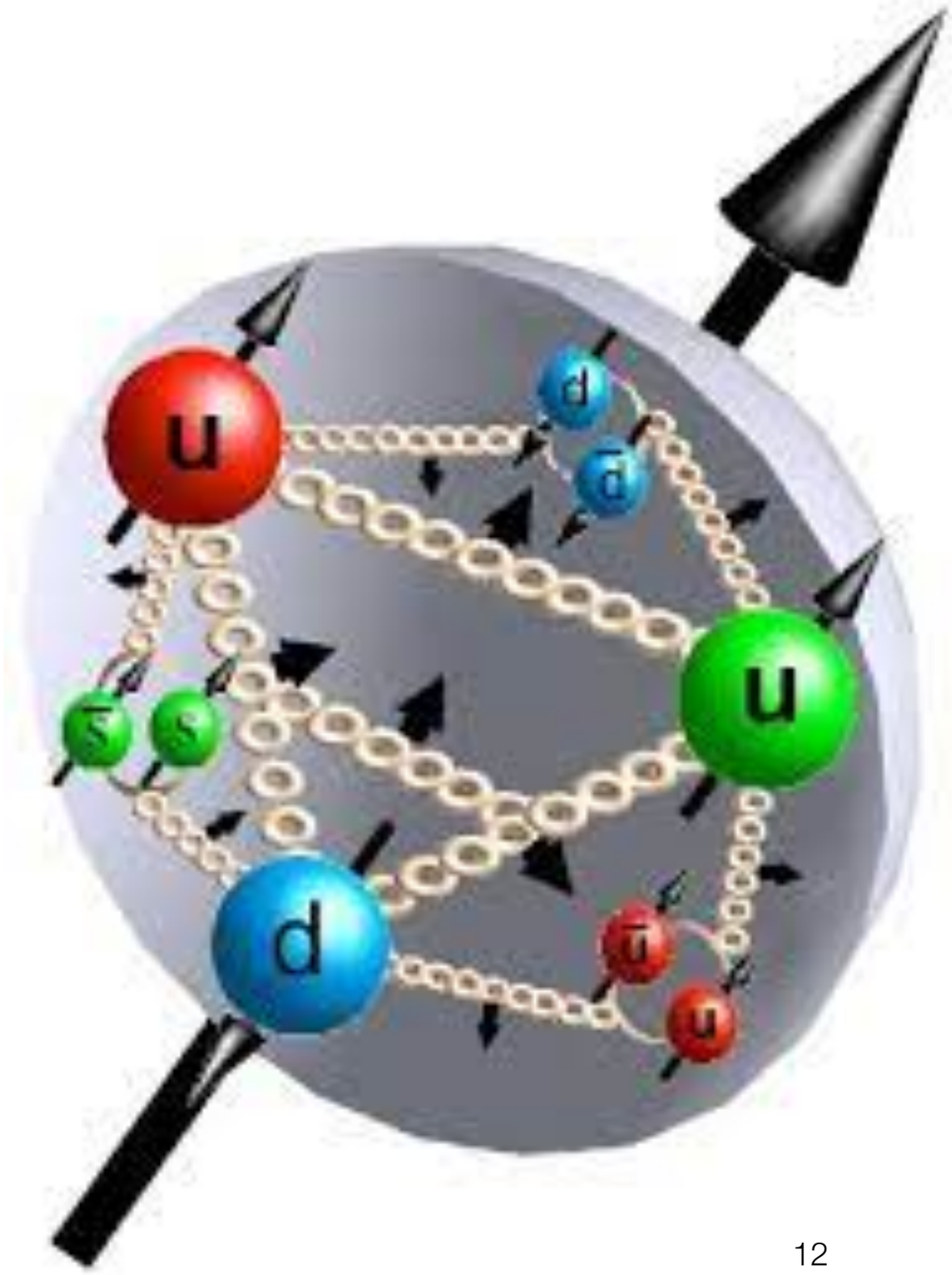


Tensor polarization

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

New "tensor" PDFs, mostly unknown

SPD experiment



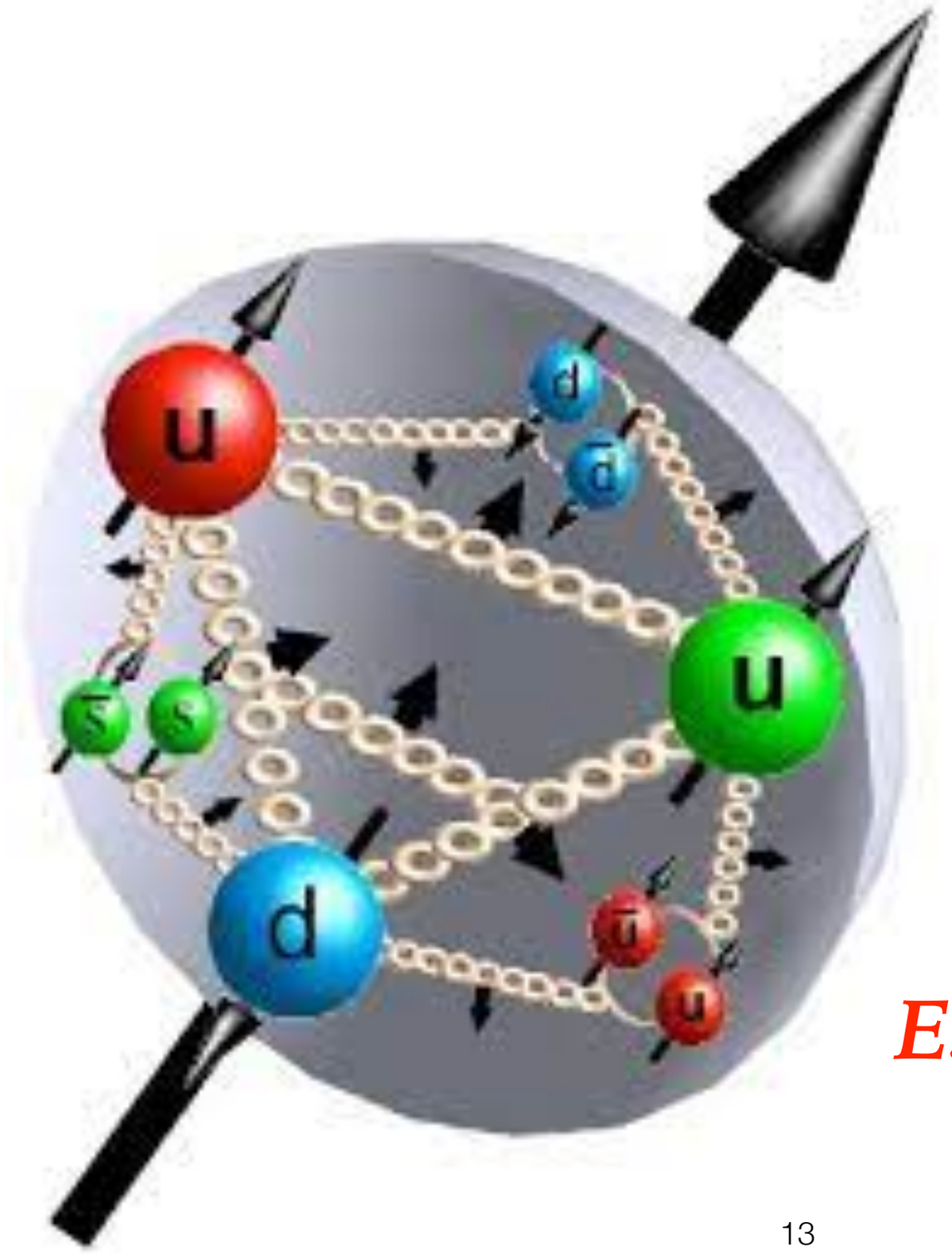
NICA SPD:

we plan to study

how the proton spins

and the deuteron!

SPD experiment



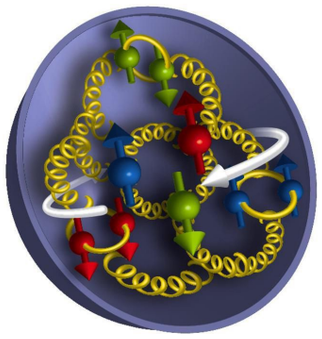
NICA SPD:

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

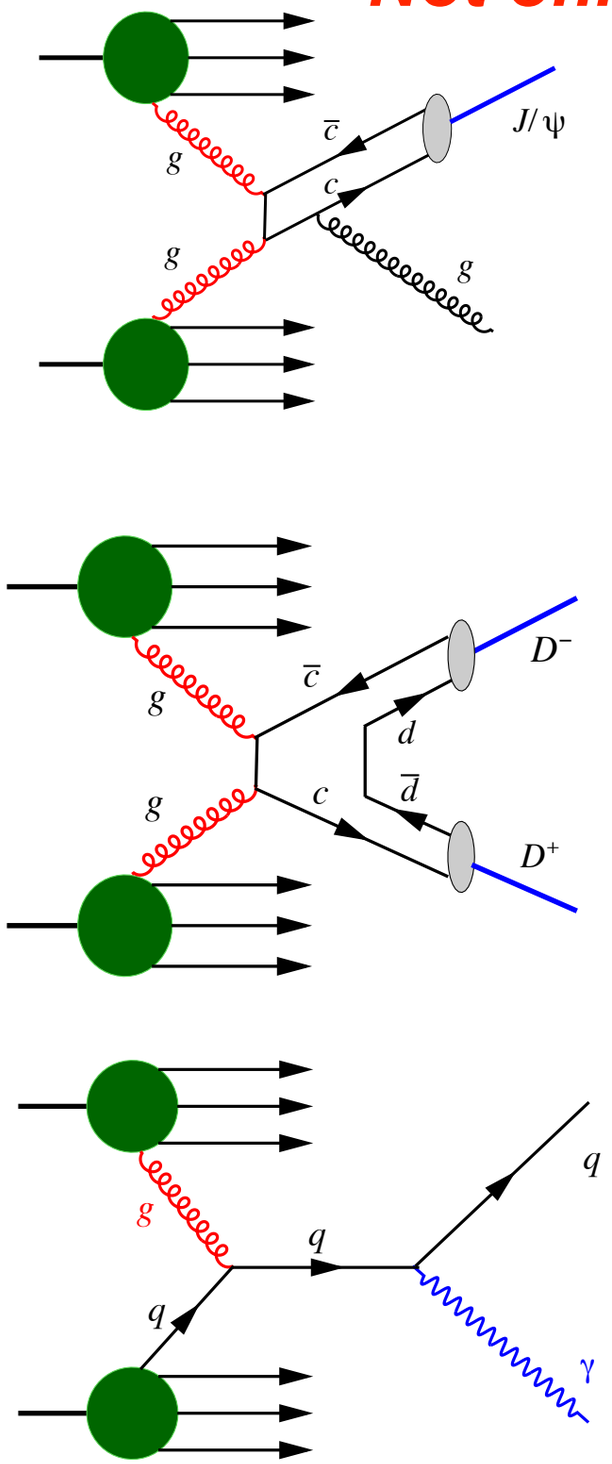
Open charm

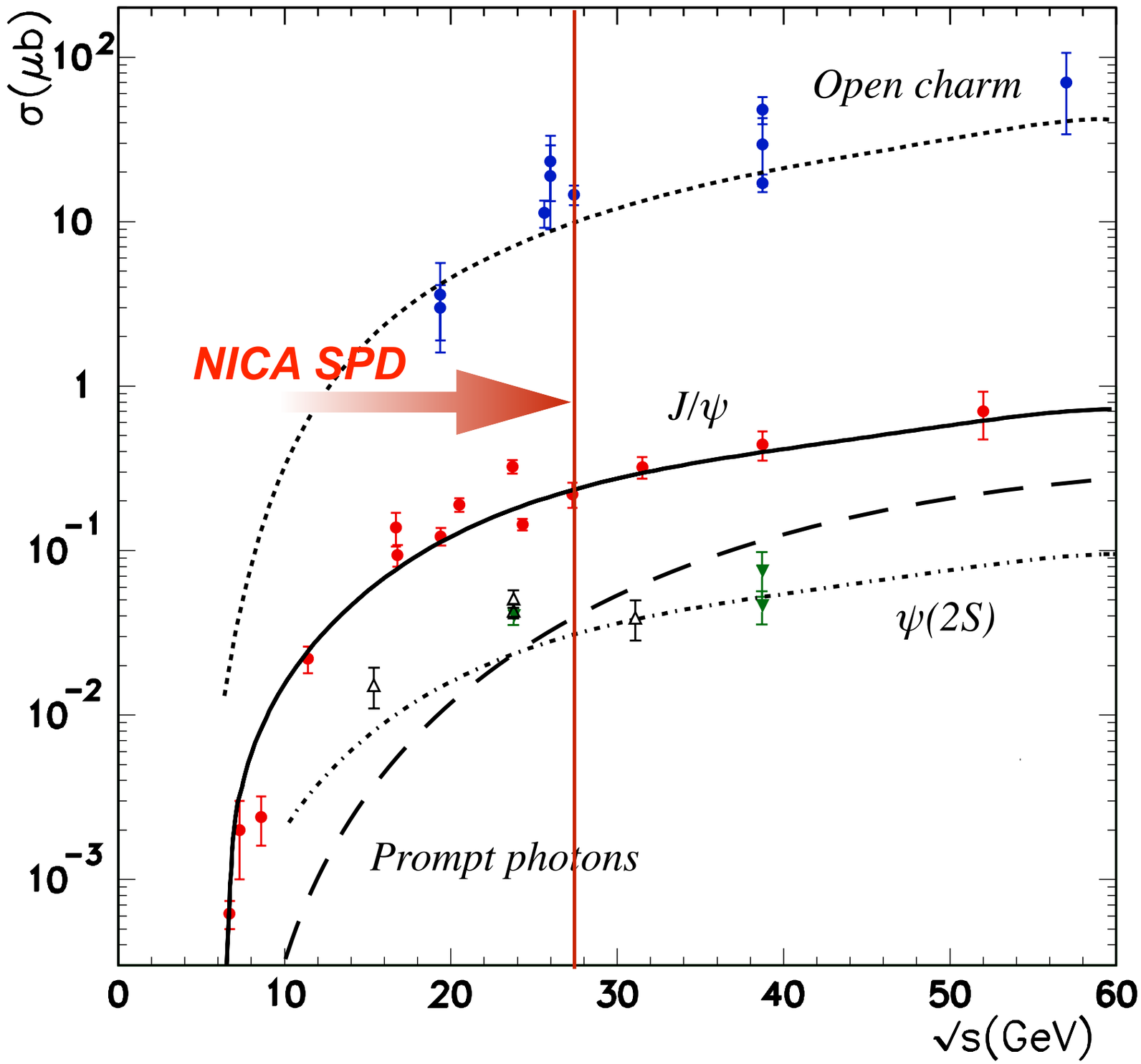
Other spin-related phenomena

Other physics

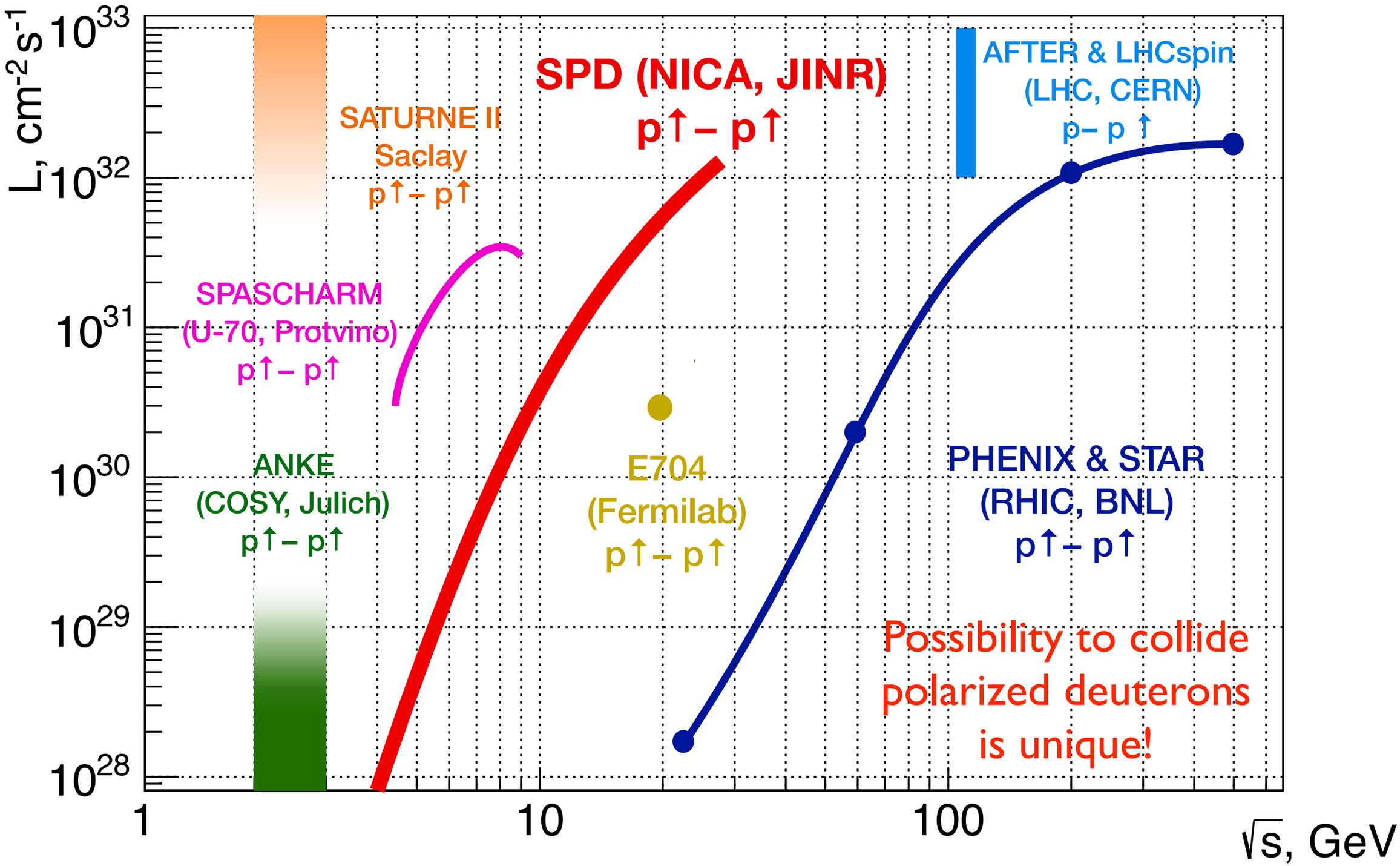
SPD and gluon structure of nucleon

Not only J/ψ!

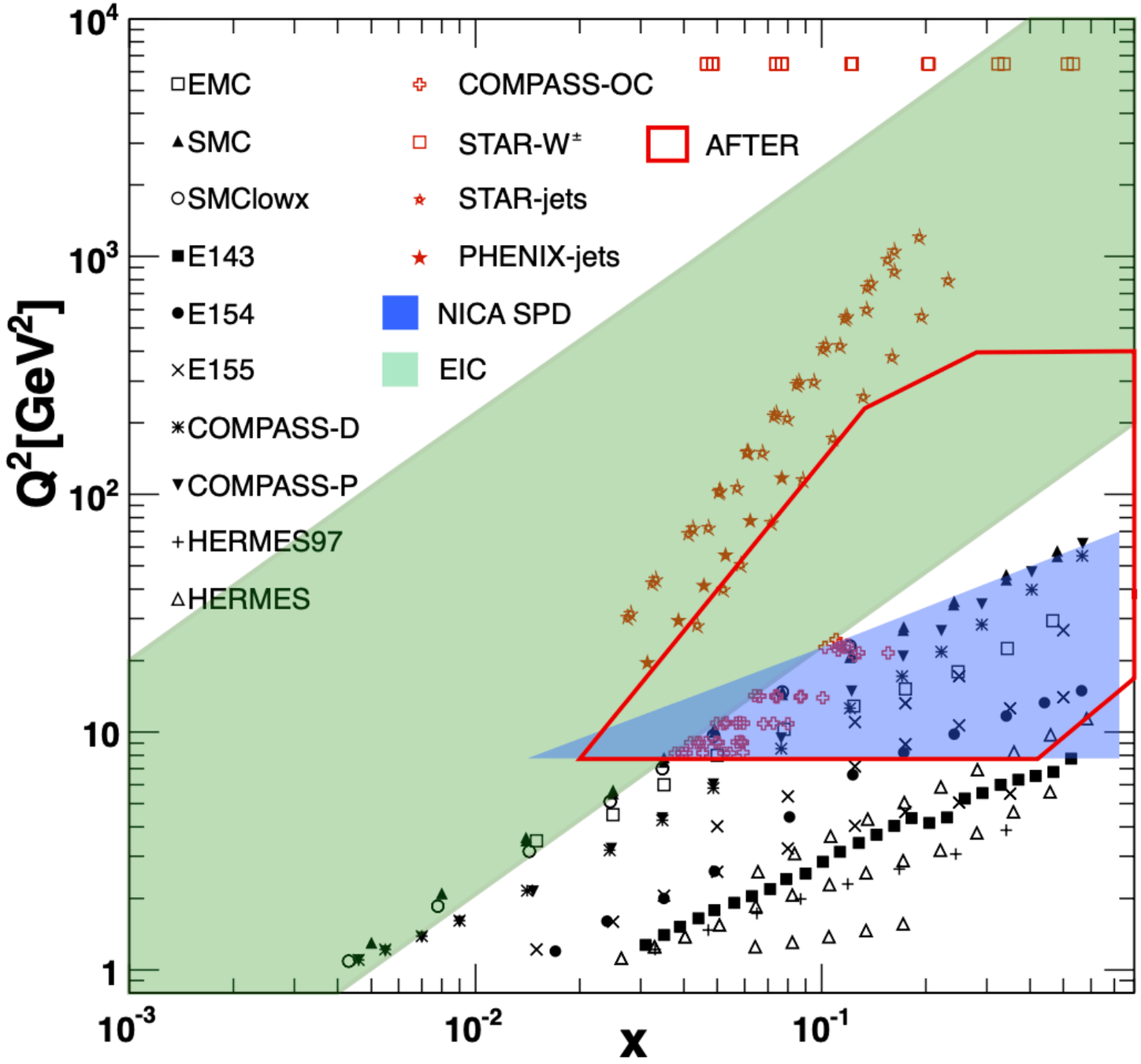


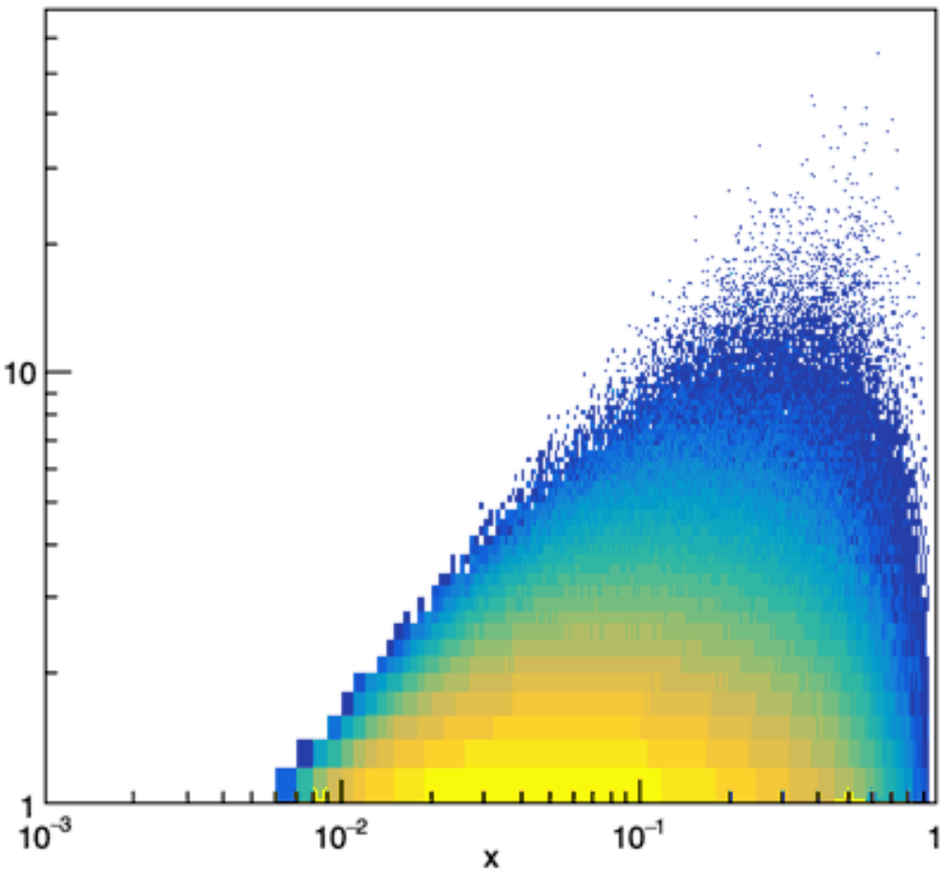


SPD and others



SPD and others

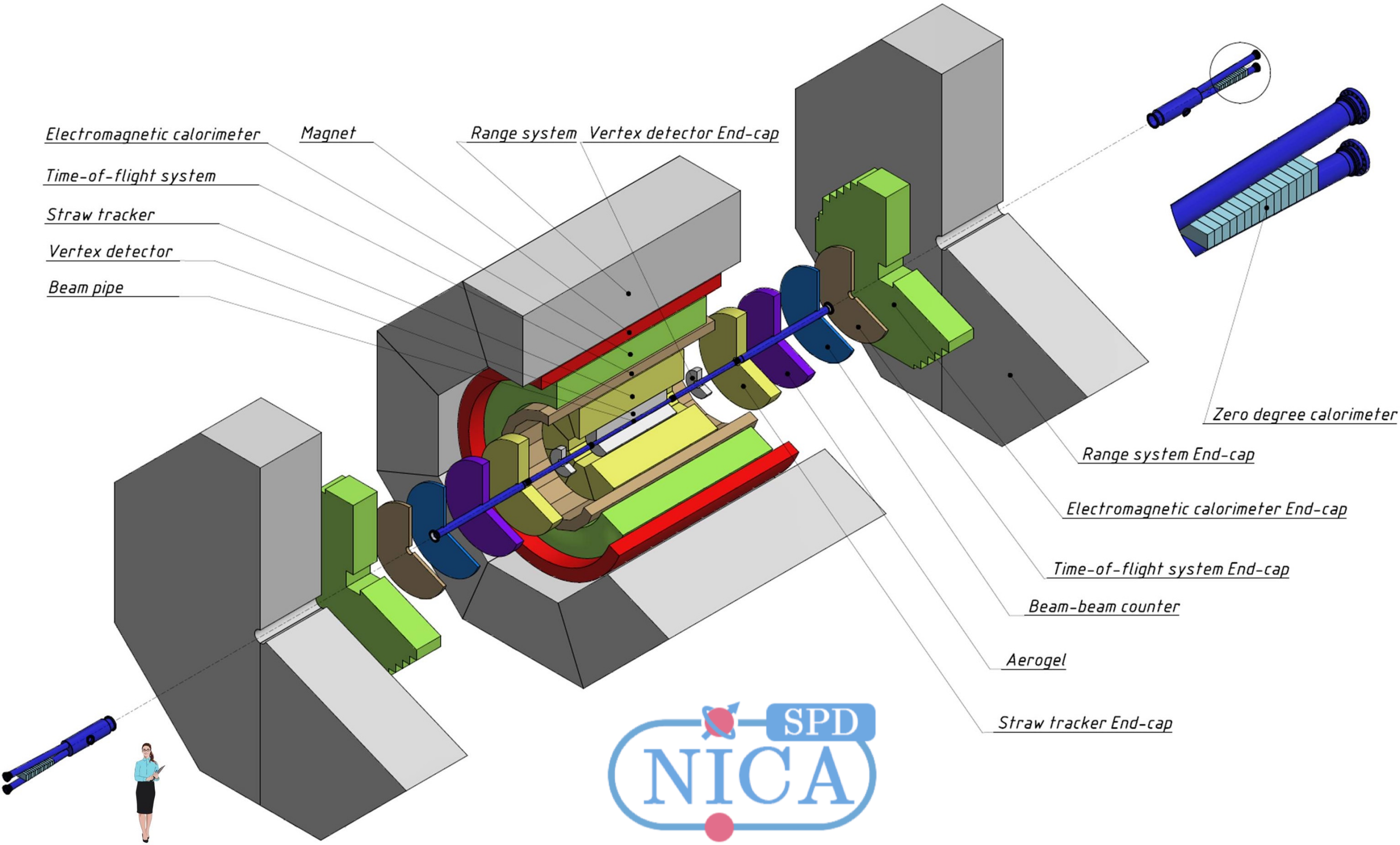




$Q^2 = 1\ GeV^2/c^2, < x > = 0.16$

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

SPD setup


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

SPD: two stages

Creating of polarized infrastructure

Upgrade of polarized infrastructure

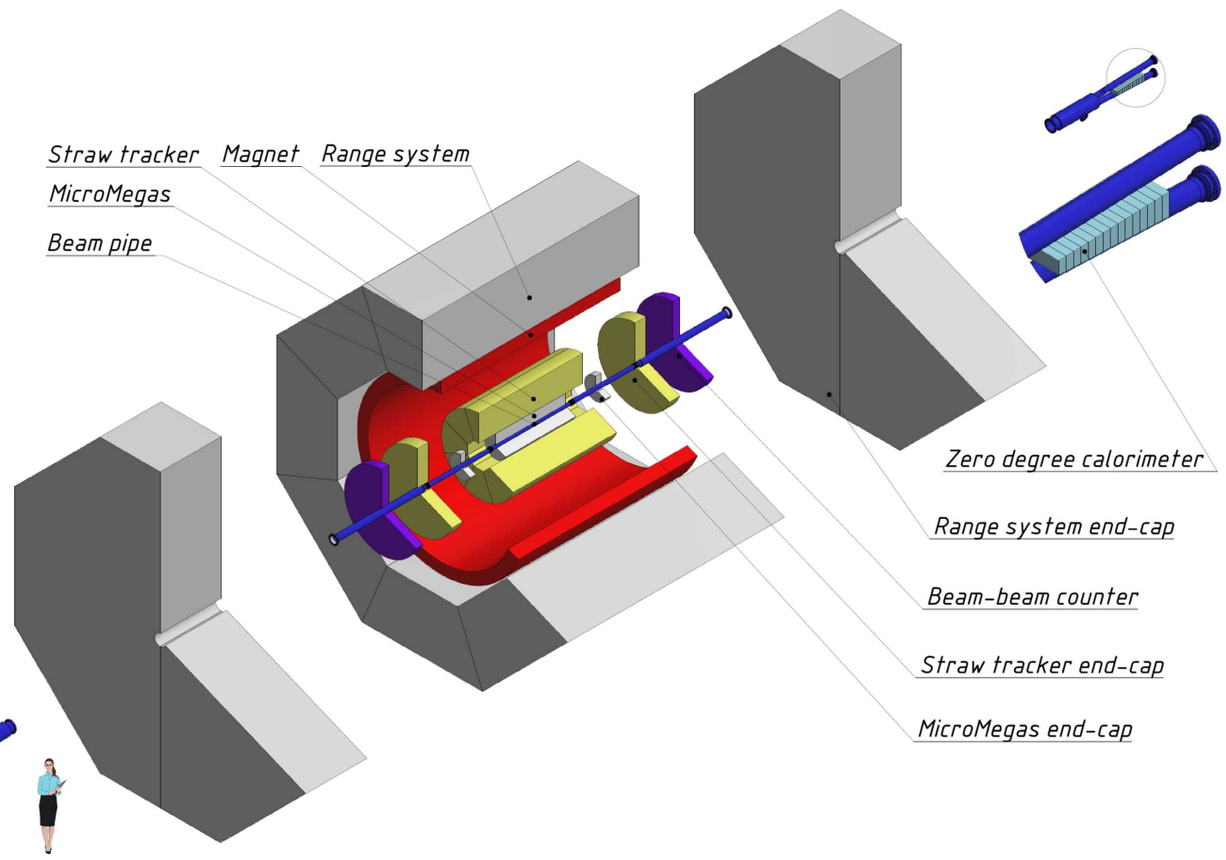
2023 **2026** **2028** **2030** **2032**

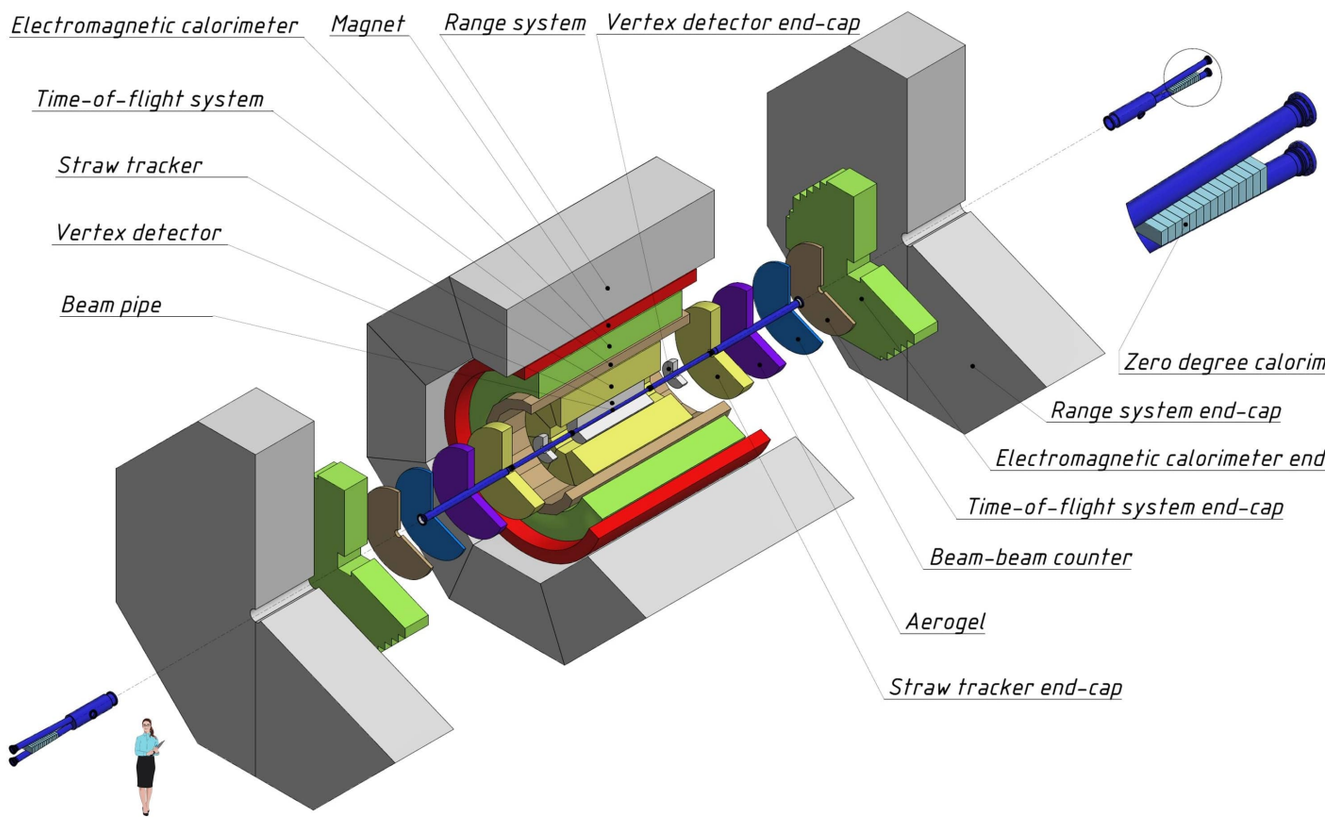
SPD construction

1st stage of operation

SPD upgrade

2nd stage of operation





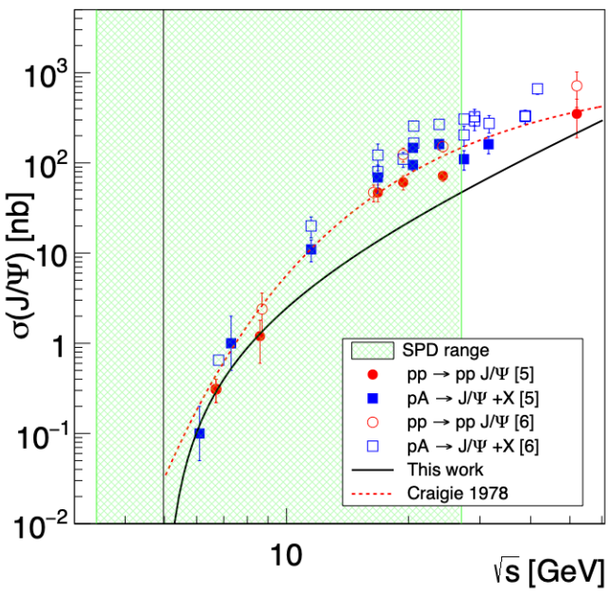
Physic of the first stage

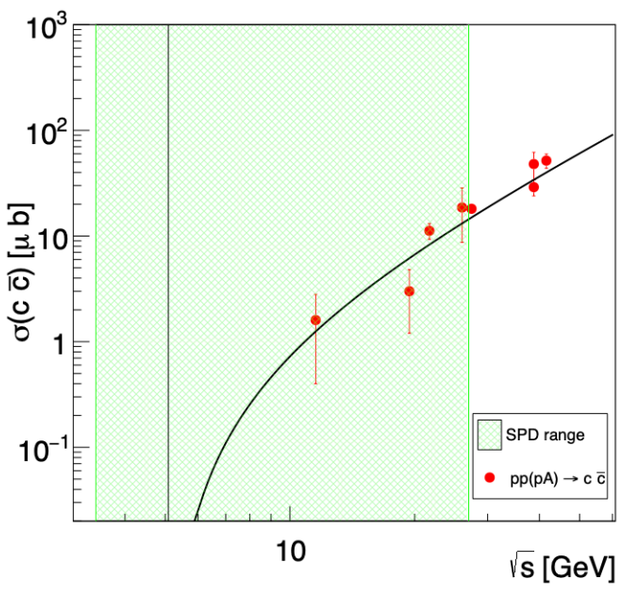
Non-perturbative QCD — *Perturbative QCD*

$\sqrt{s}$

- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations $pp \to (6q)^* \to N\,N\,Mesons,$
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernucei $dd \to K^+\,K^+\,{}^{4}_{\Lambda\Lambda}\mathrm{n},$
- Open charm and charmonia near threshold

arXiv:2102.08477





- Auxiliary measurements for astrophysics

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 .