



SPD EXPERIMENT





Igor Savin
7.12.1930-8.7.2023

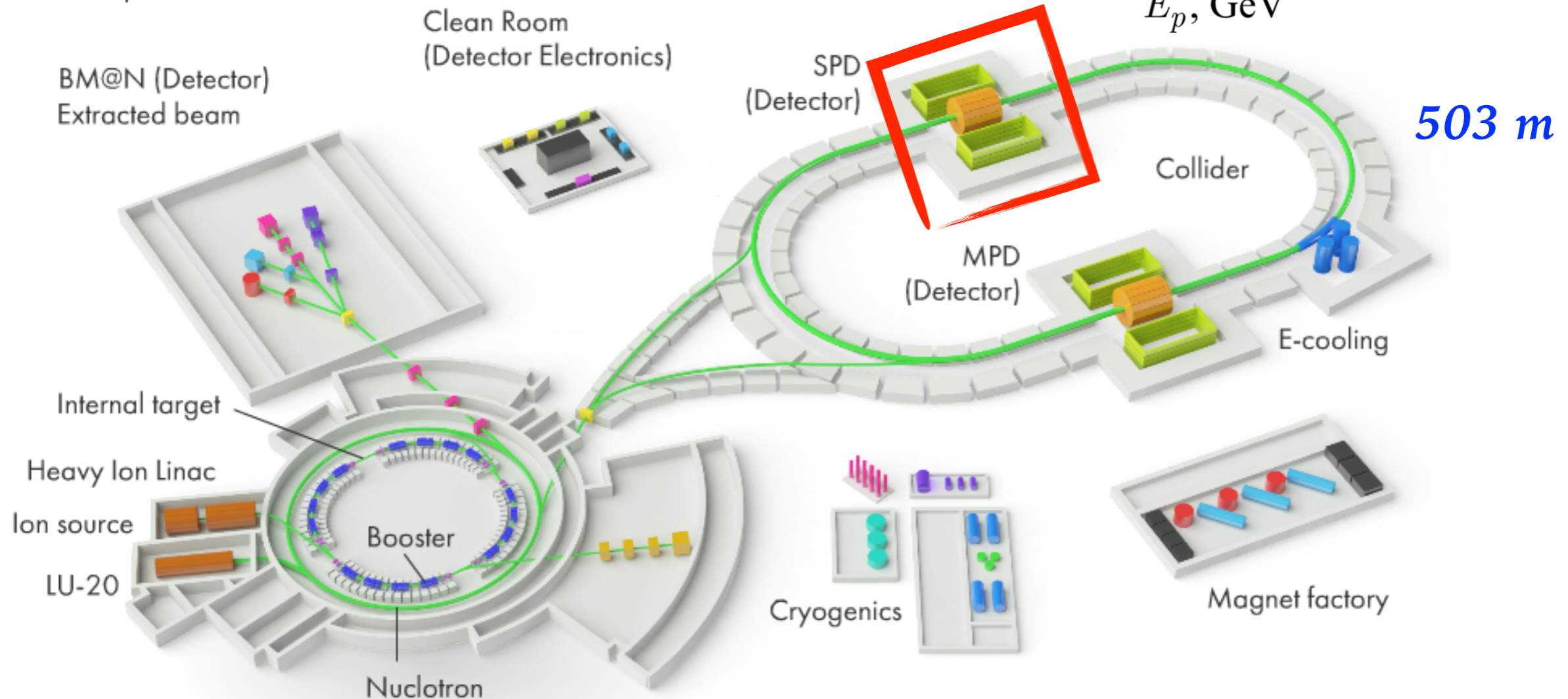
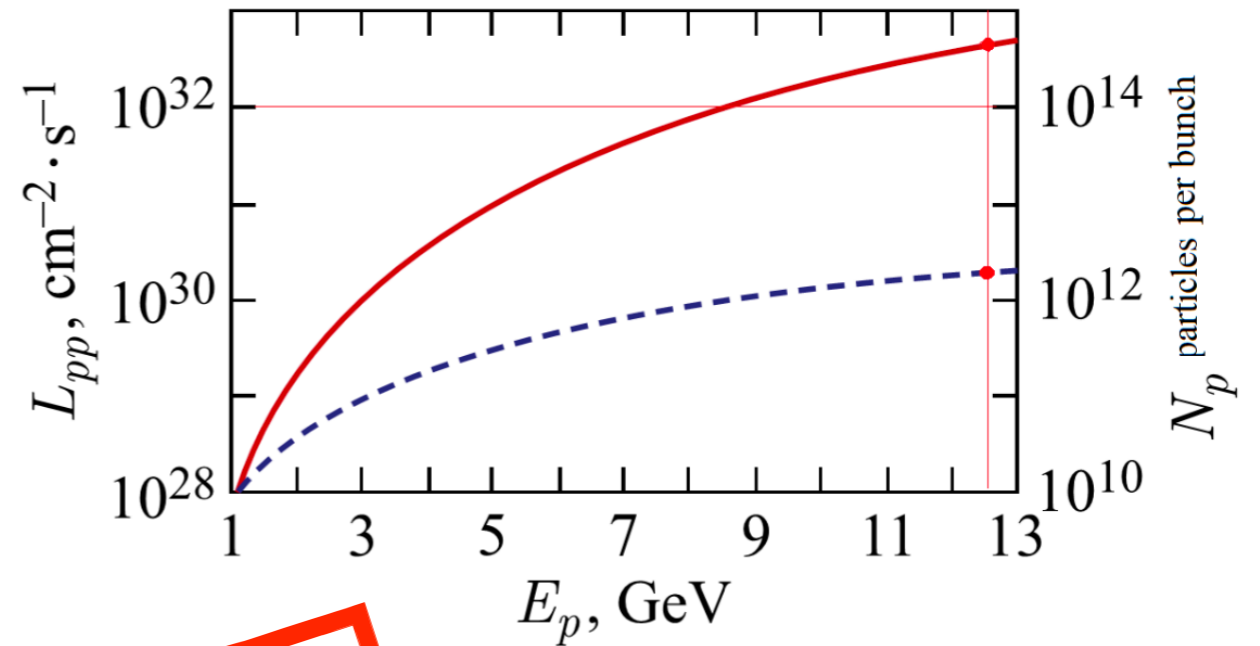
Spin Physics Detector @ NICA

NICA - Nuclotron-based Ion Collider fAcility

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

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

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



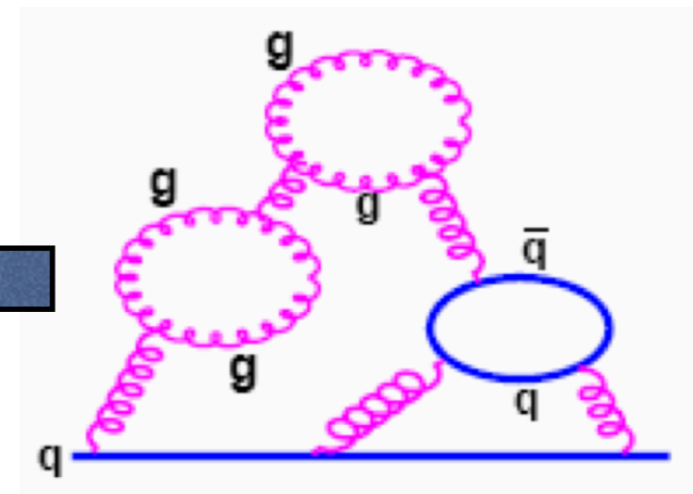
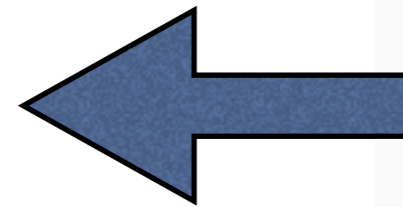
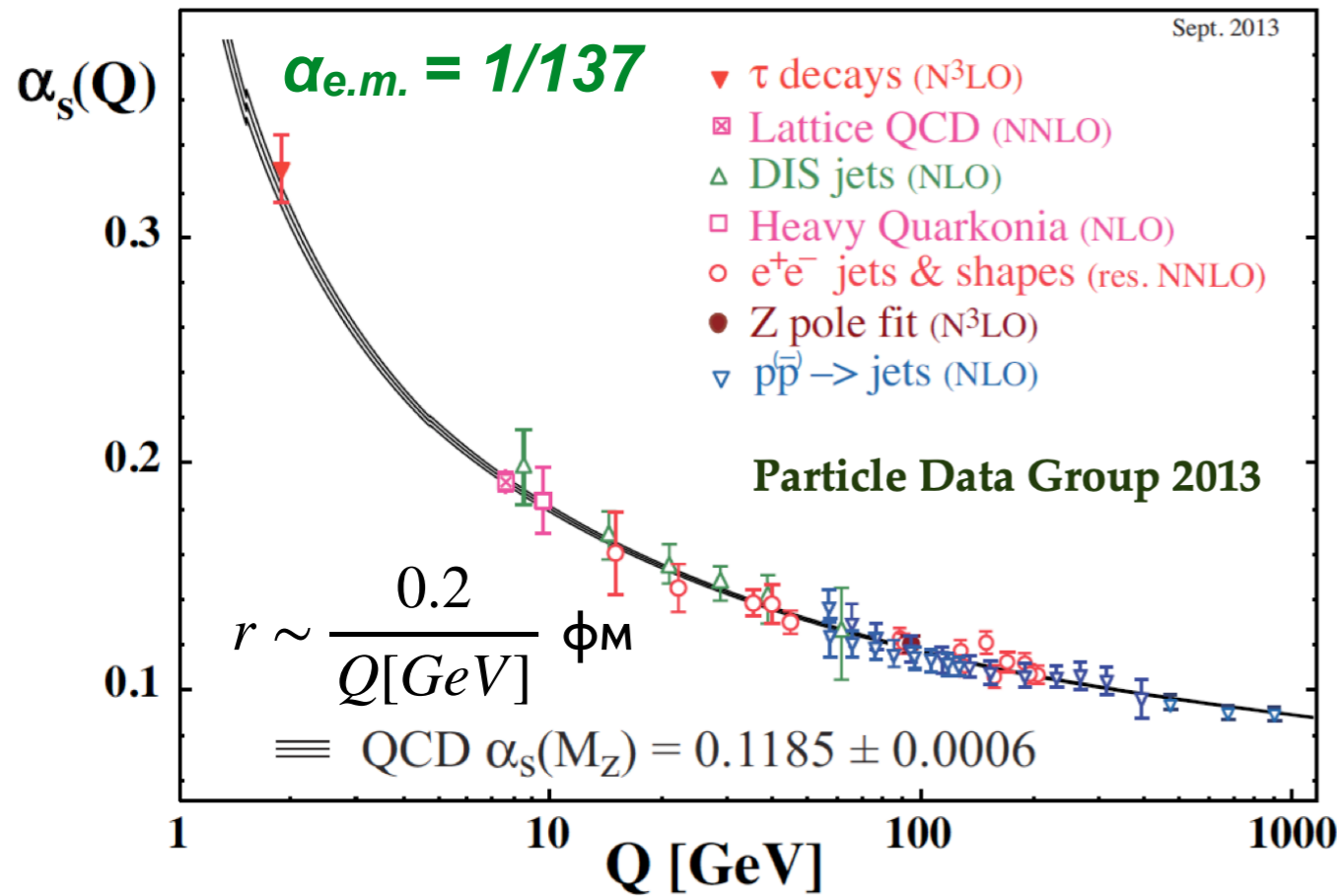
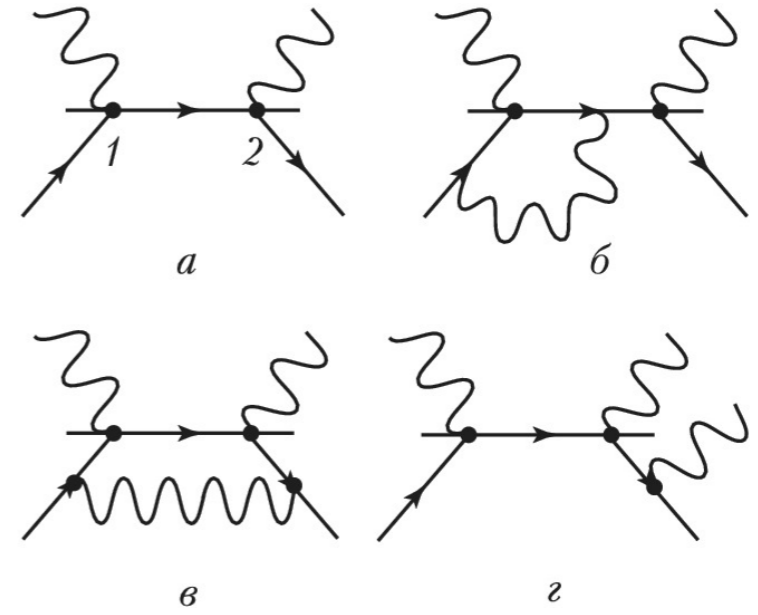
Problem to describe hadrons *ab initio*

Feynman diagrams - perturbative approach

$$\sigma \sim \sum_n c_n \alpha^n$$

α - interaction constant

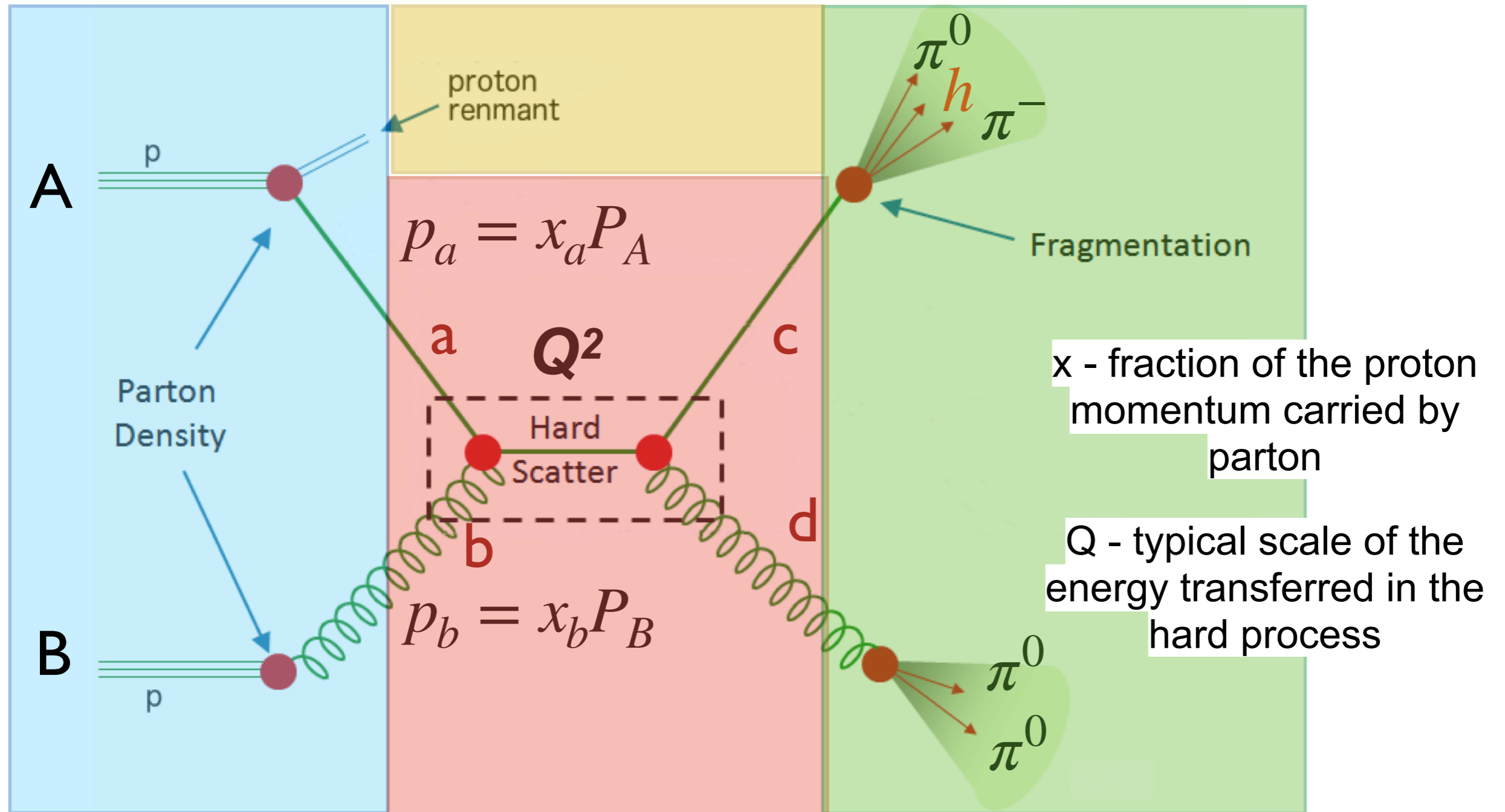
Fast convergence for $\alpha \ll 1$



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

Confinement is not strictly proven!

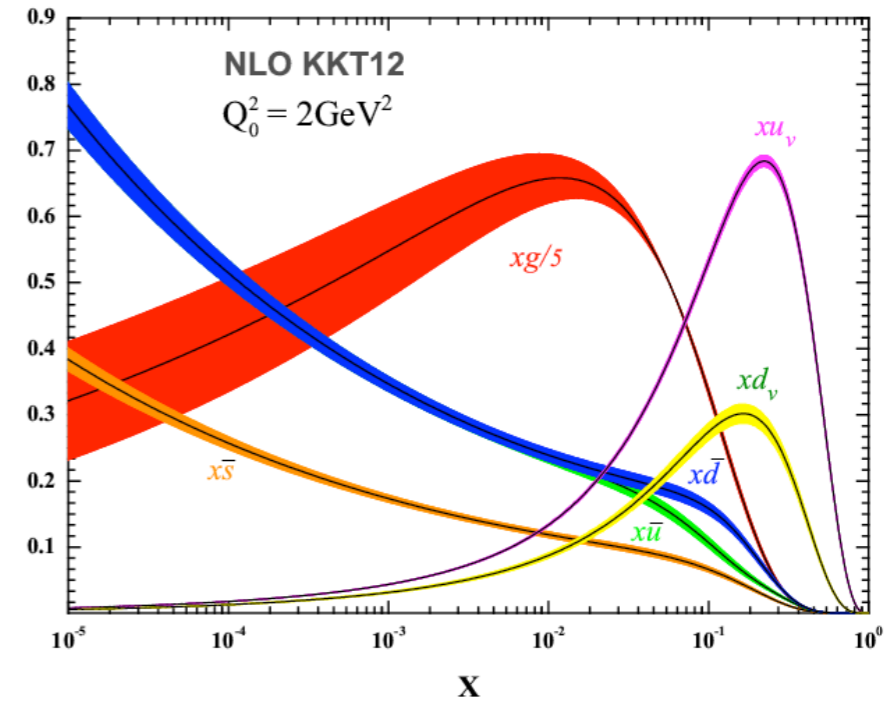
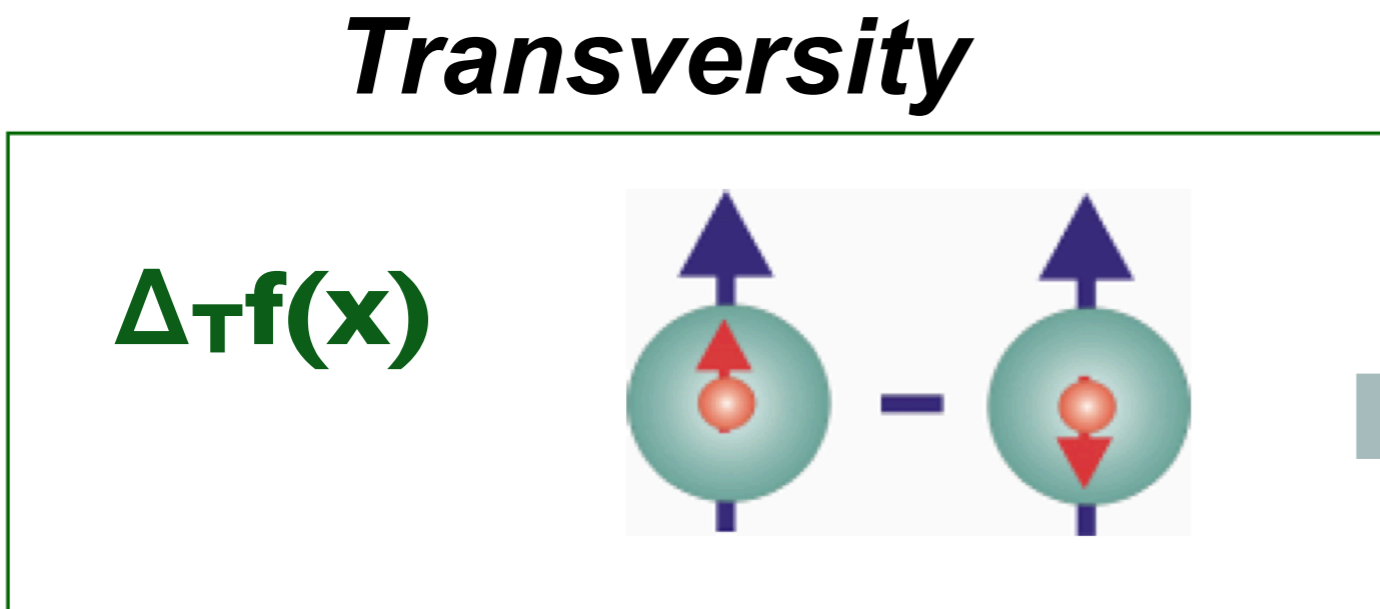
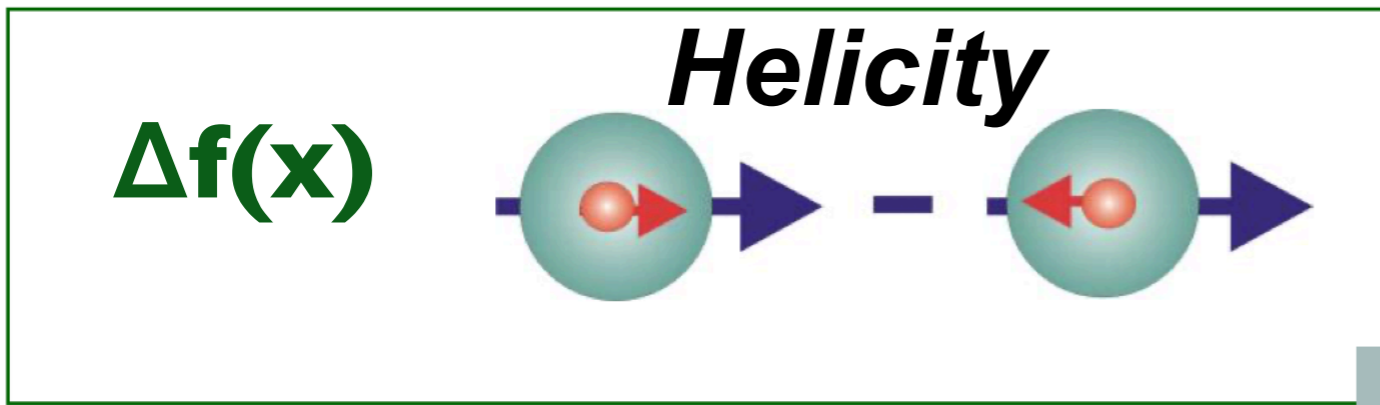
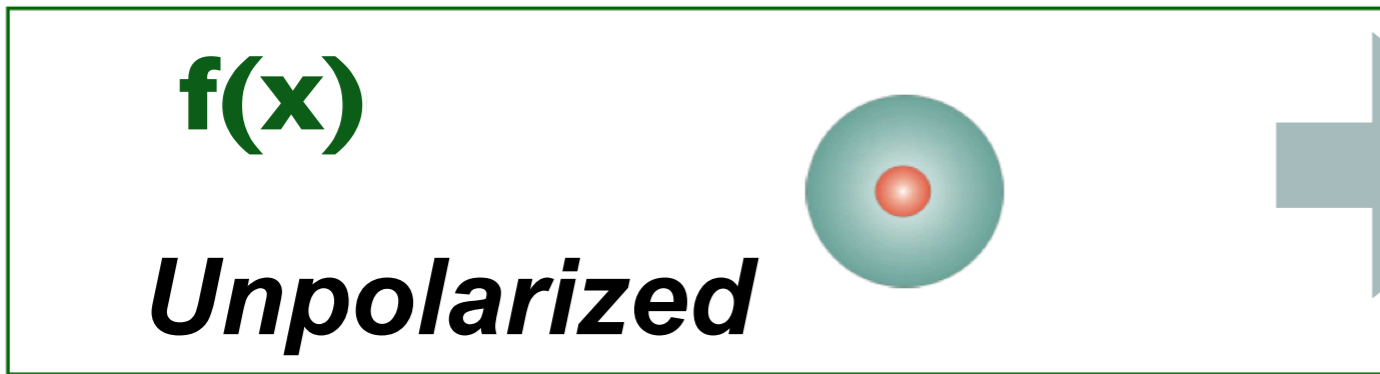
Factorization theorem



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

$$Q^2 \gg 1 \text{ GeV}^2/c^2$$

Polarized proton

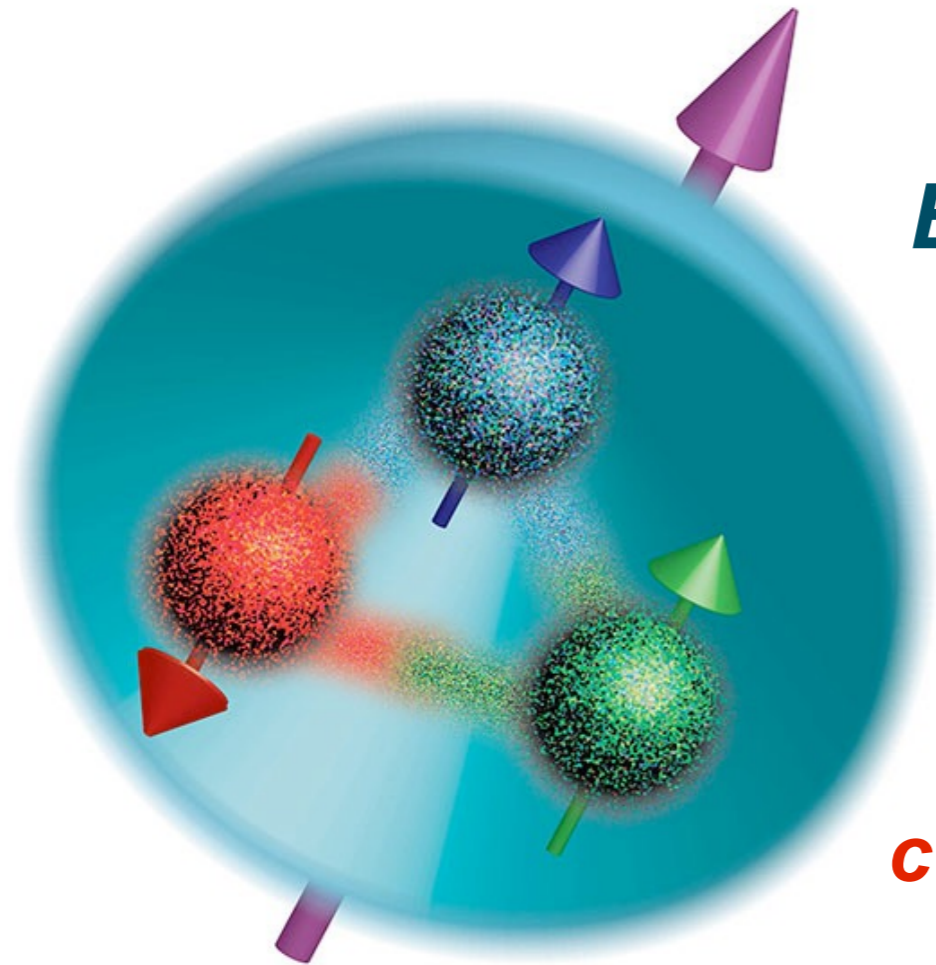


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \sim \Delta f$$

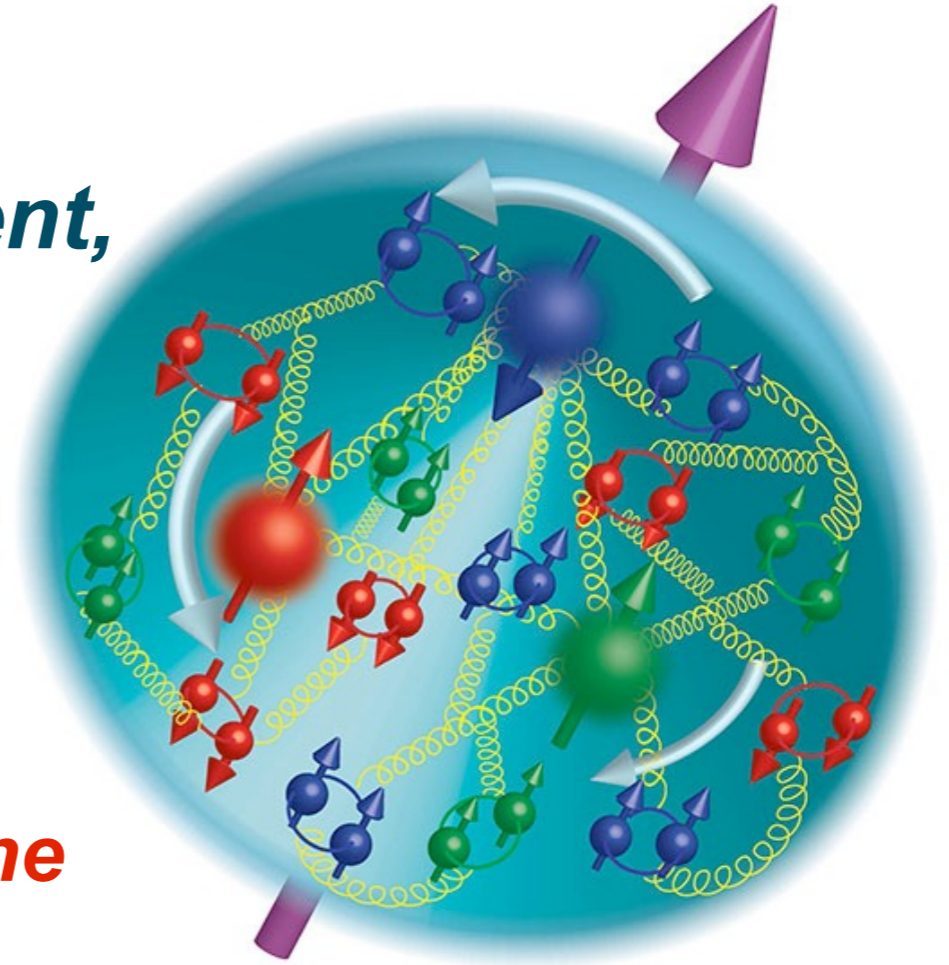
Angular asymmetries

\vec{P}

Spin crisis



**EMC experiment,
CERN 1988**



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

Naive quark model

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

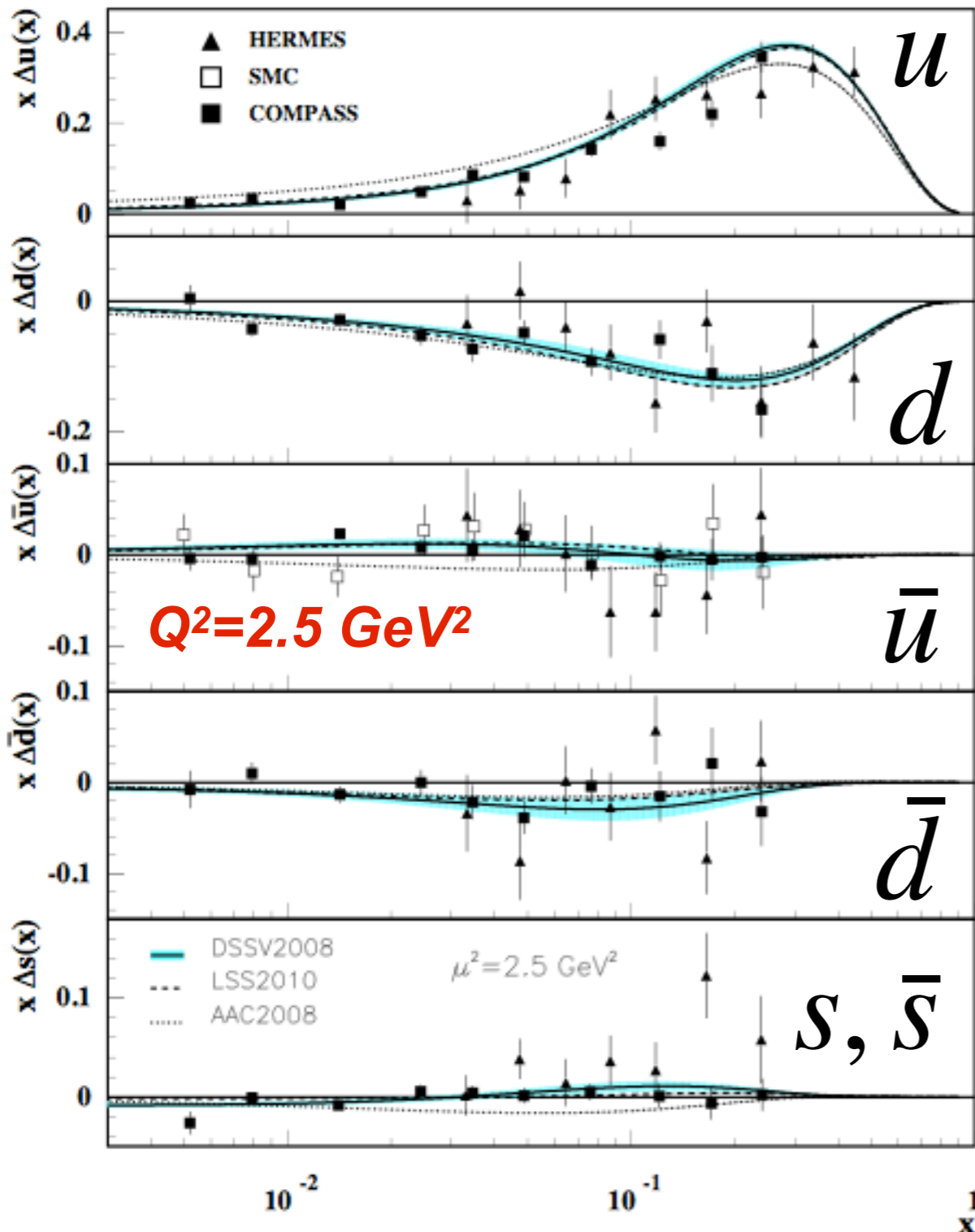
Real situation

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

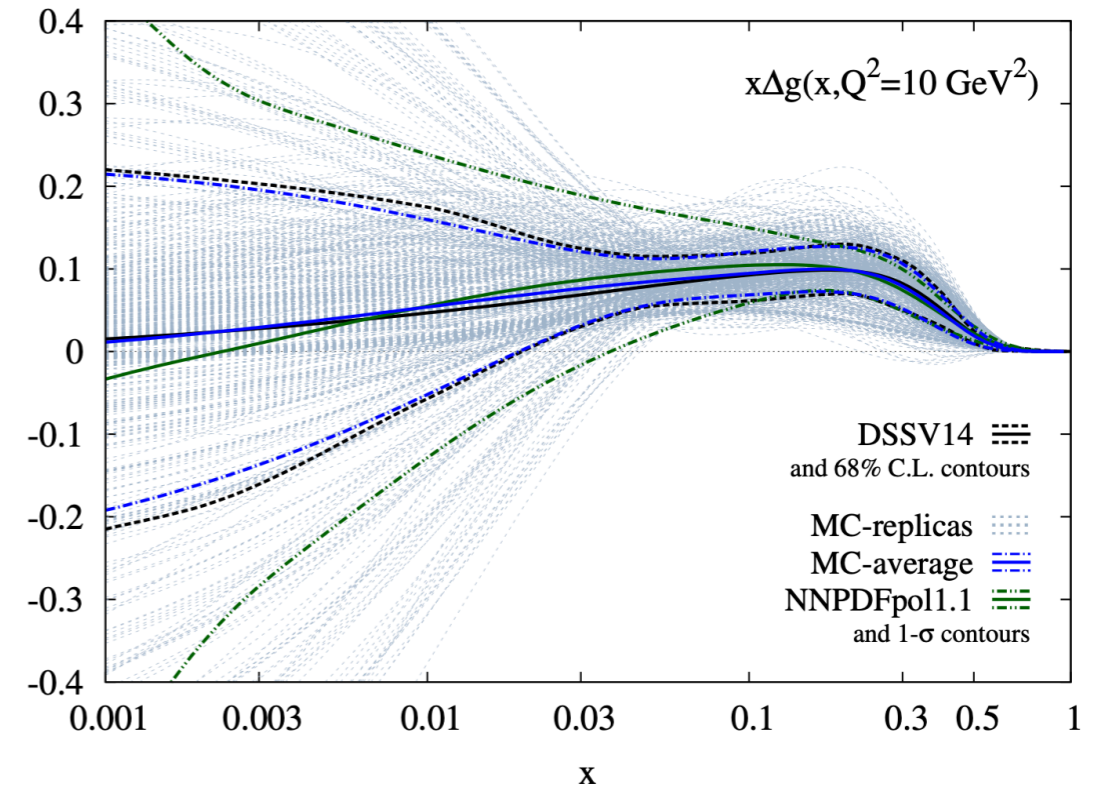
$$S_N = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L$$

Spin crisis

Longitudinal polarization of quarks:



... and gluons:



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


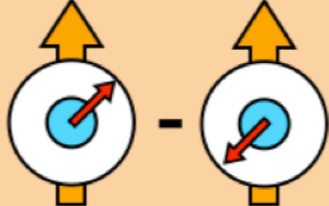
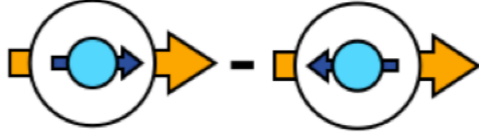
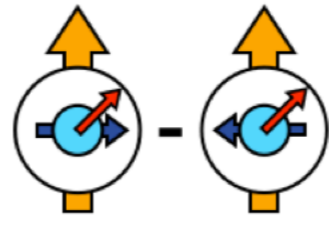

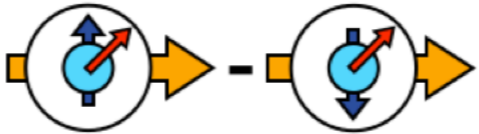
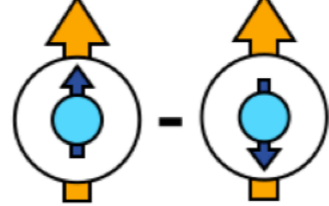
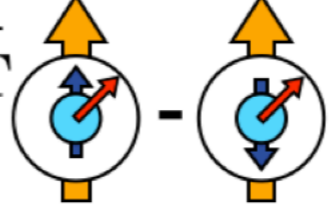
~30%

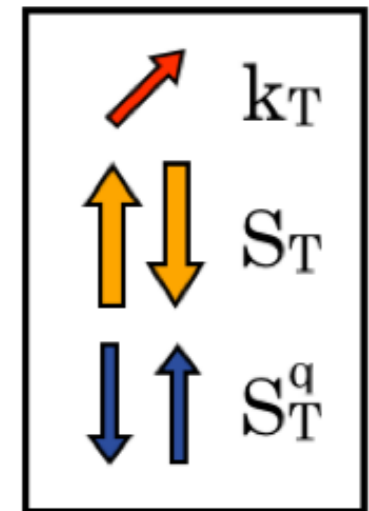
~?

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

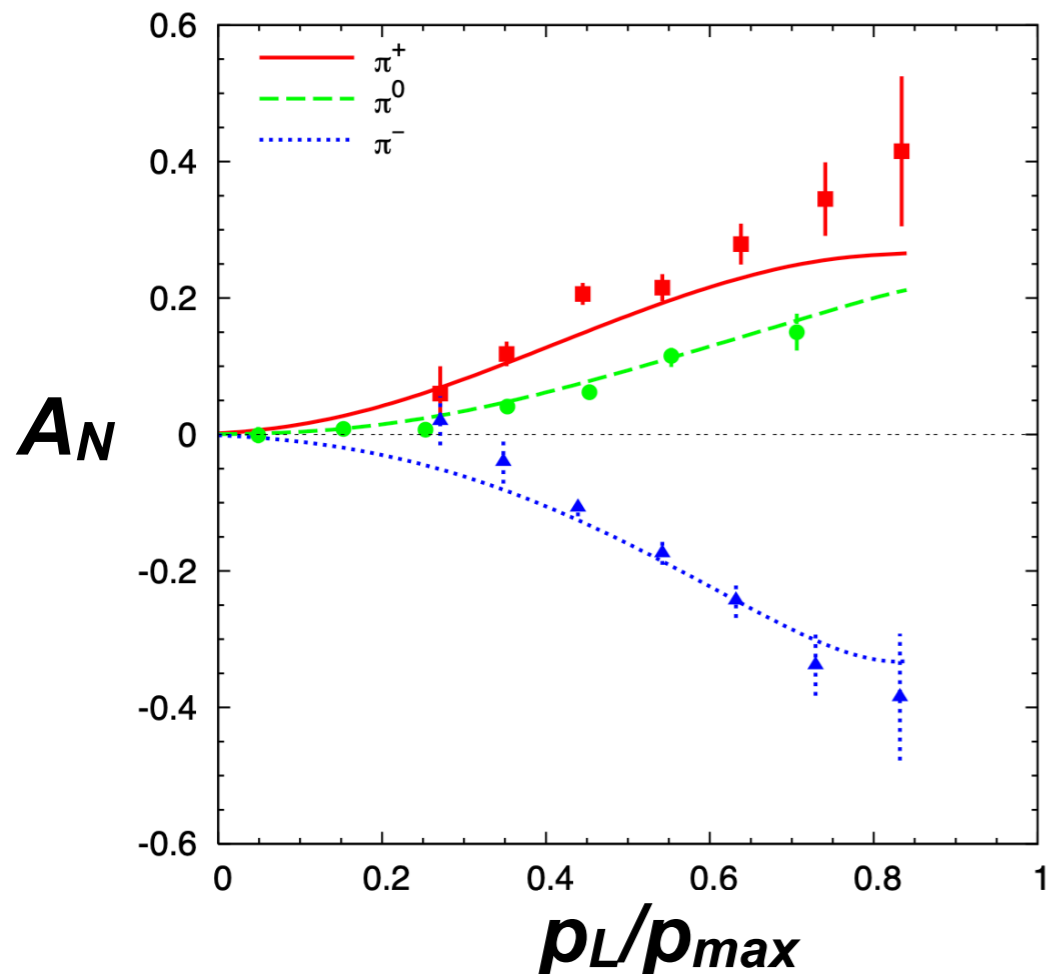
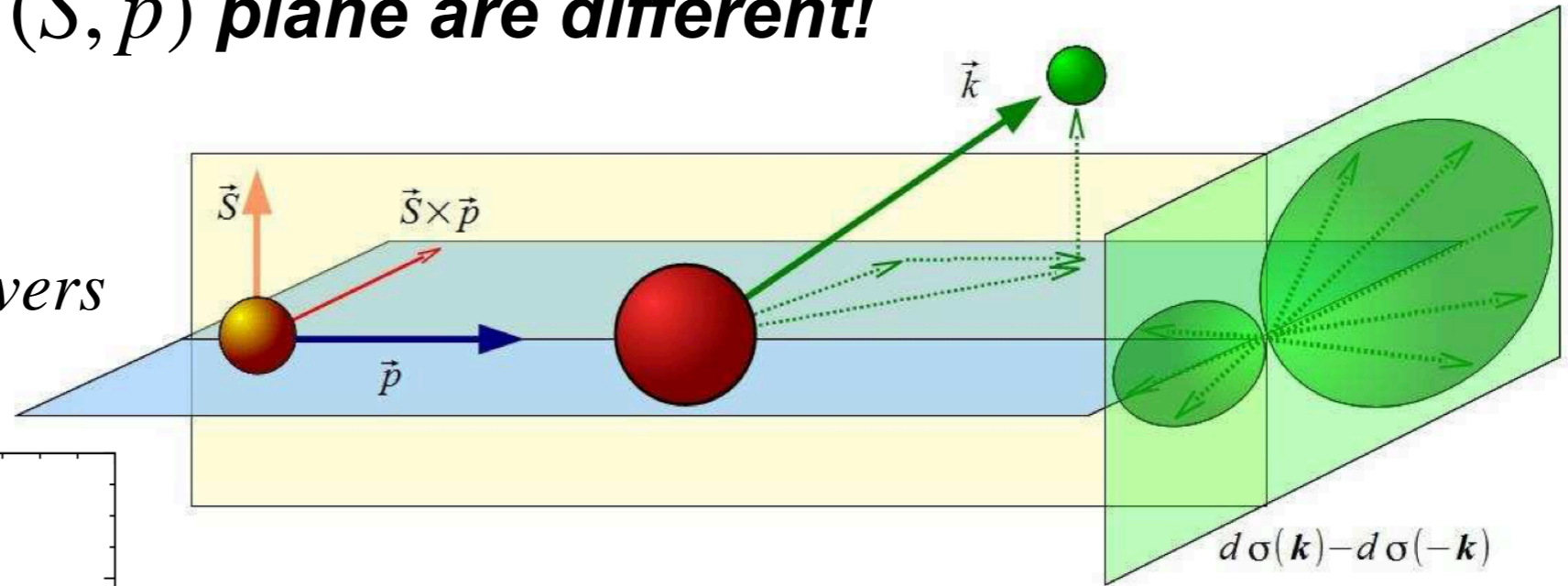


5 additional (TMD) functions describing the correlation between the nucleon spin, parton spin, and parton transverse momentum.

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!

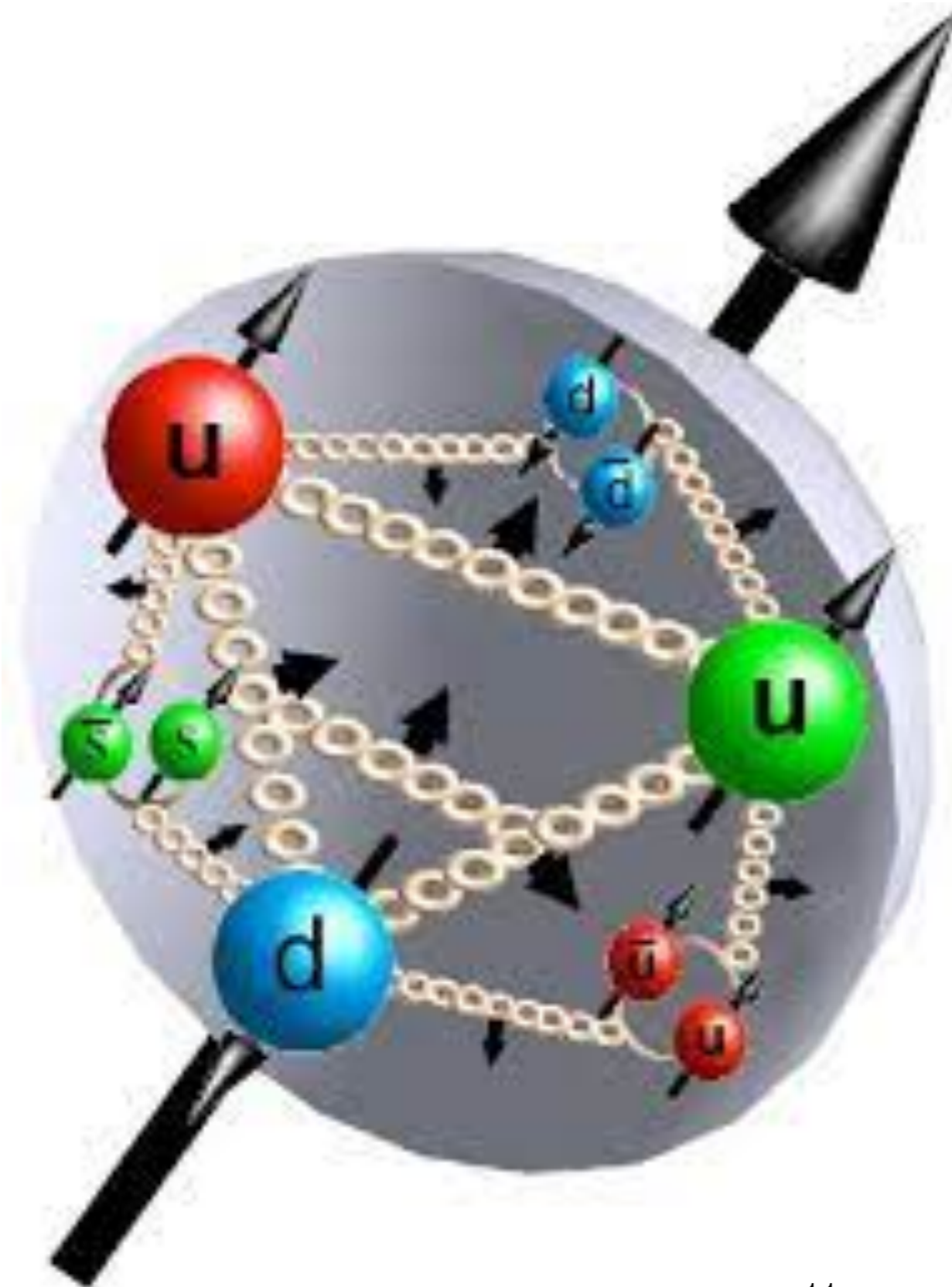
$$A_N = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \sim f_{Sivers}$$



E704

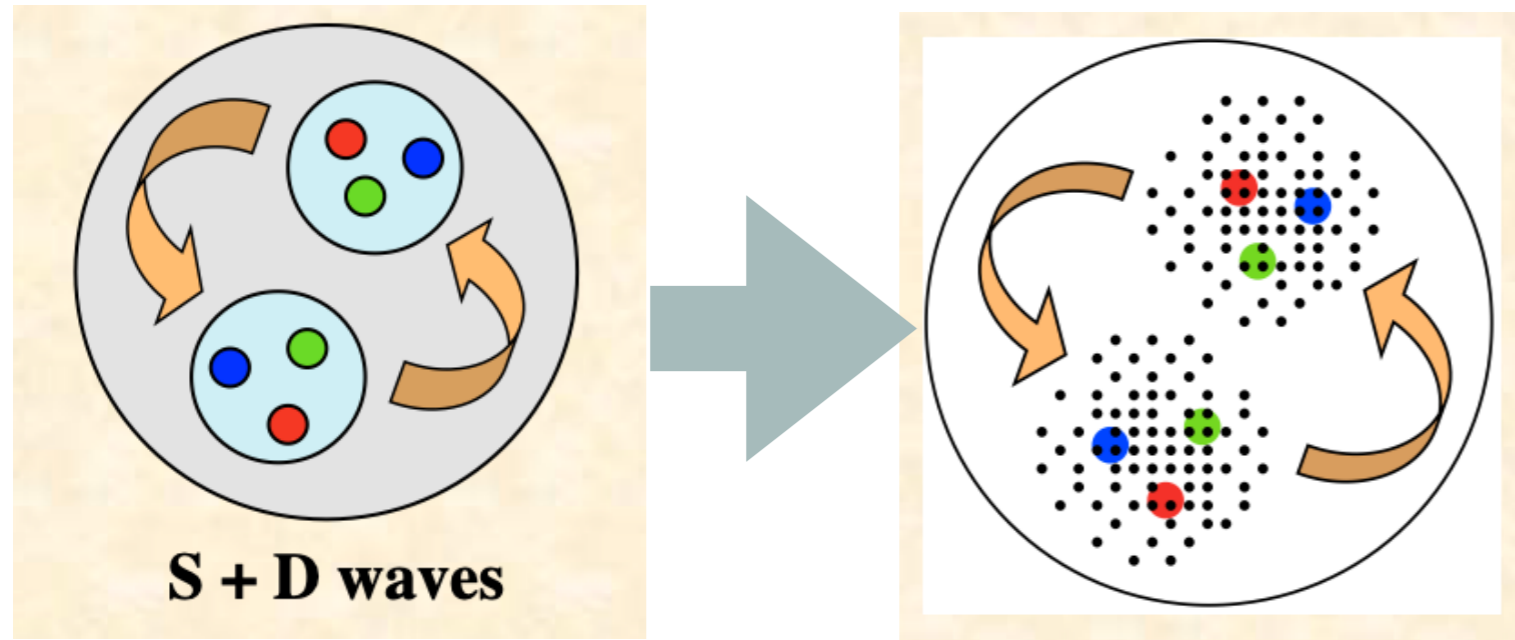
The **Sivers effect** is usually observed together with the **Collins effect**, an asymmetry arising from the fragmentation of the final state.

SPD experiment

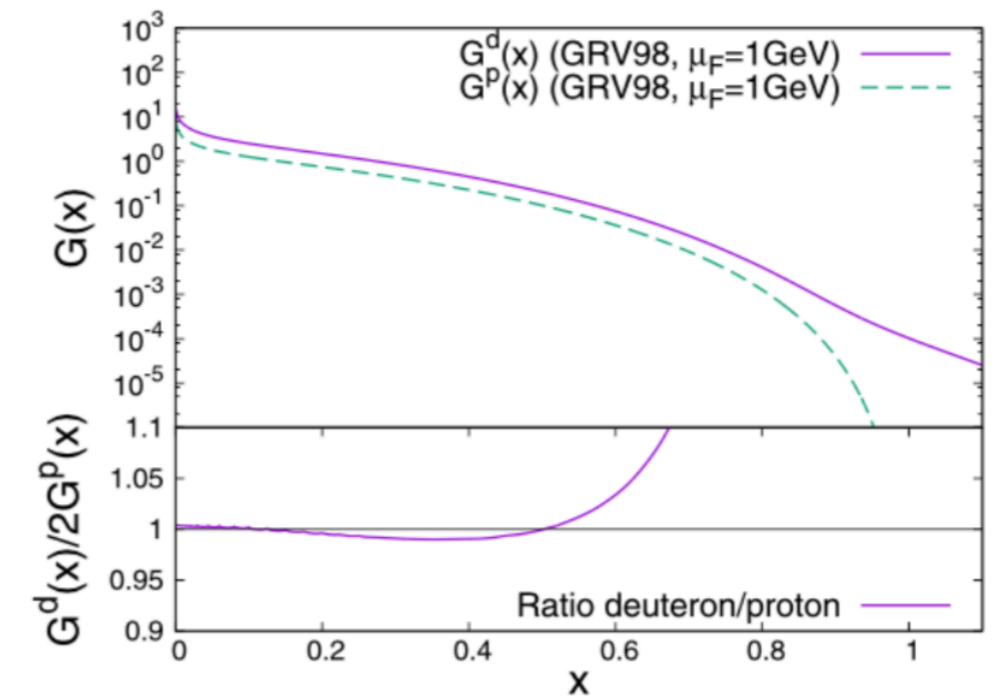


*NICA SPD:
we plan to study
how the proton
spins*

Deuteron

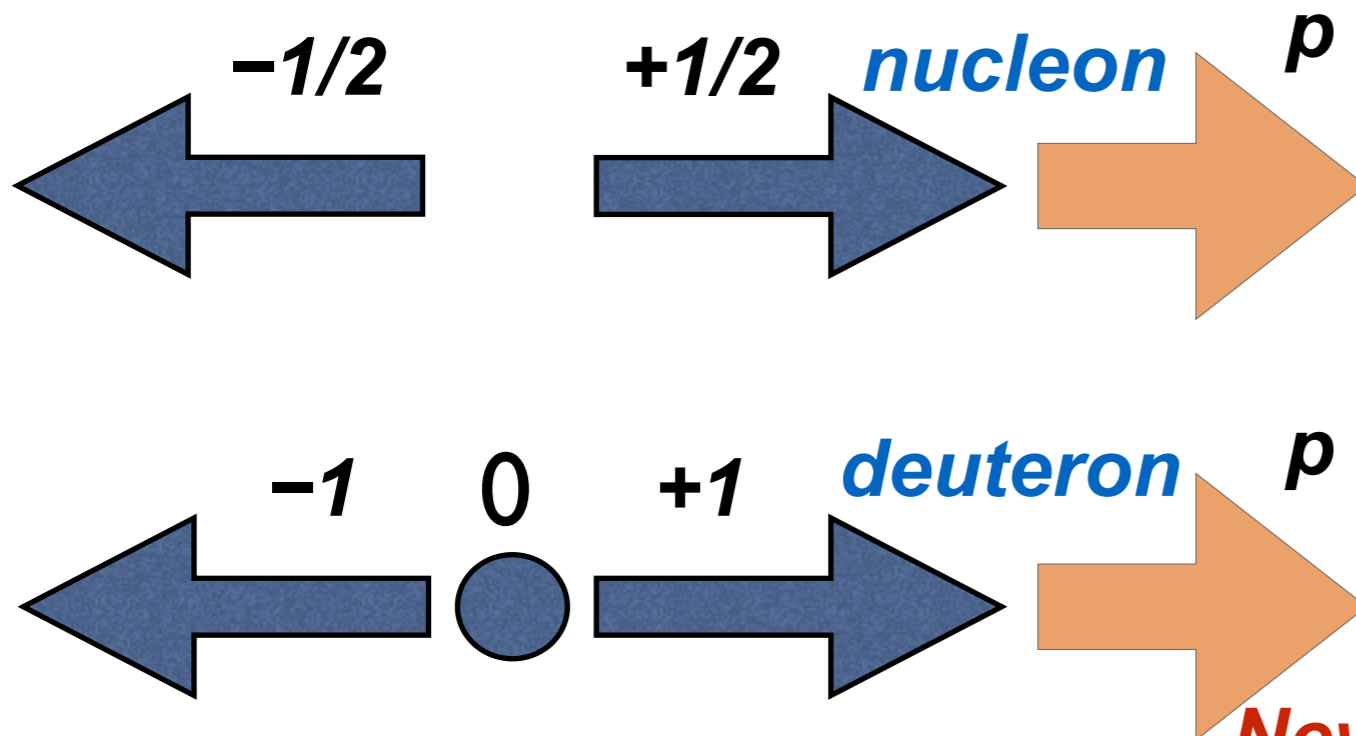


Deuteron is not just proton + neutron!



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

hidden color



More gluons at large x with respect to nucleon?

Vector polarization

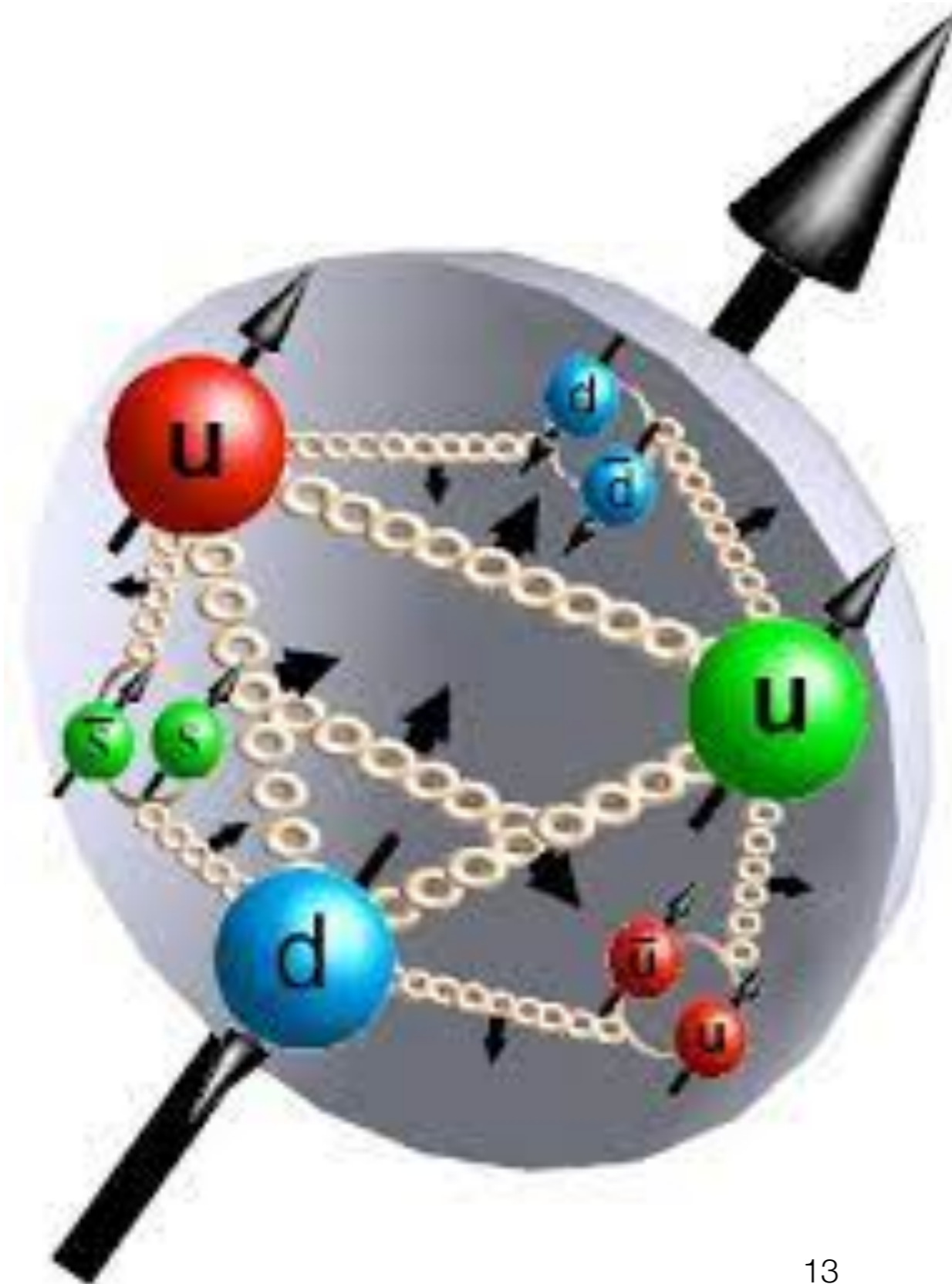
$$\frac{N_{1/2} - N_{-1/2}}{N_{1/2} + N_{-1/2}}$$

Tensor polarization

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

New "tensor" PDFs, mostly unknown

SPD experiment

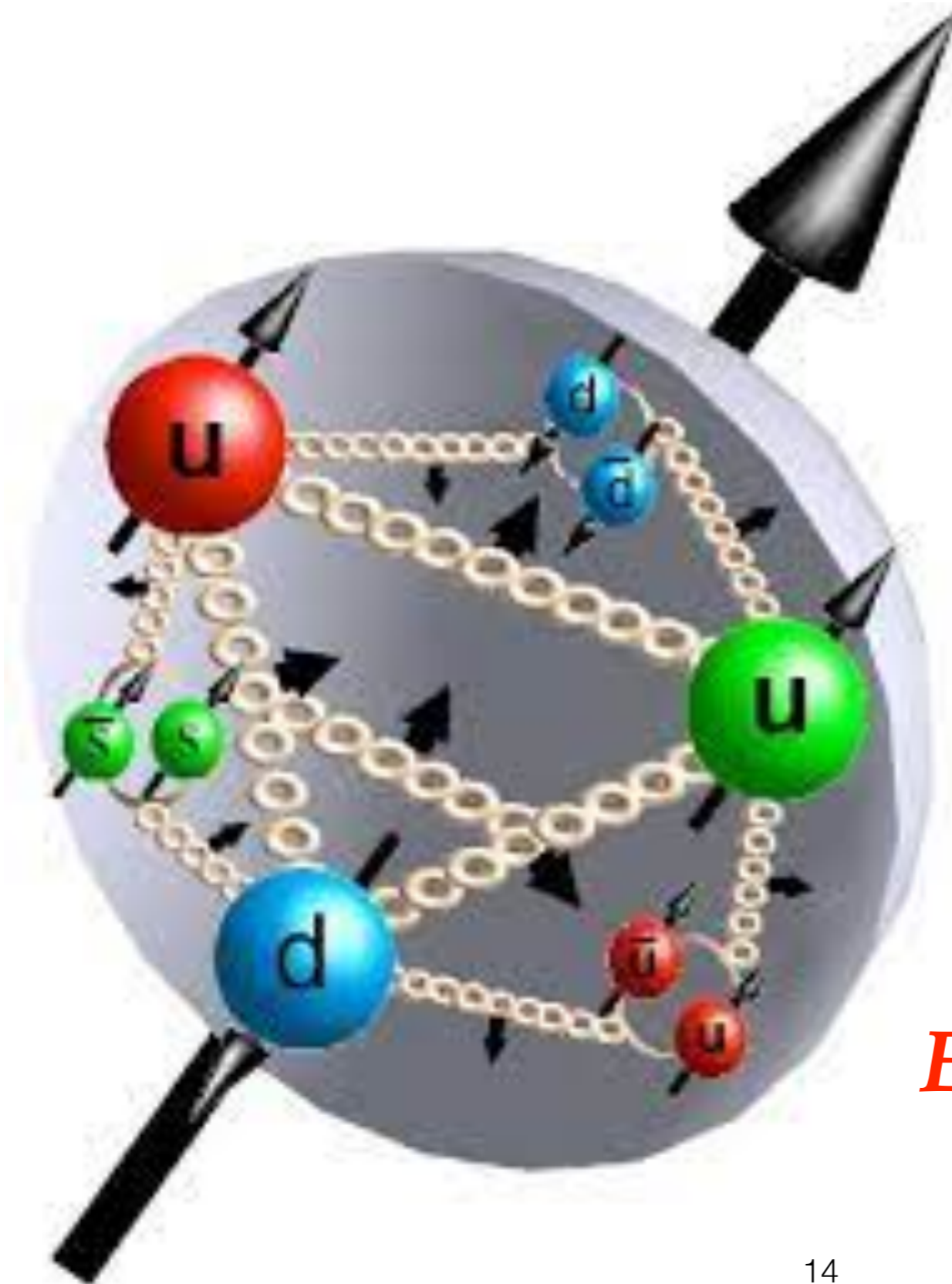


NICA SPD:

*we plan to study
how the proton
spins*

and the deuteron!

SPD experiment



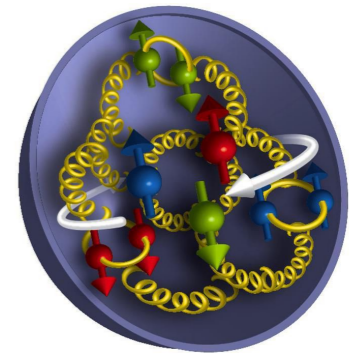
NICA SPD:

*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

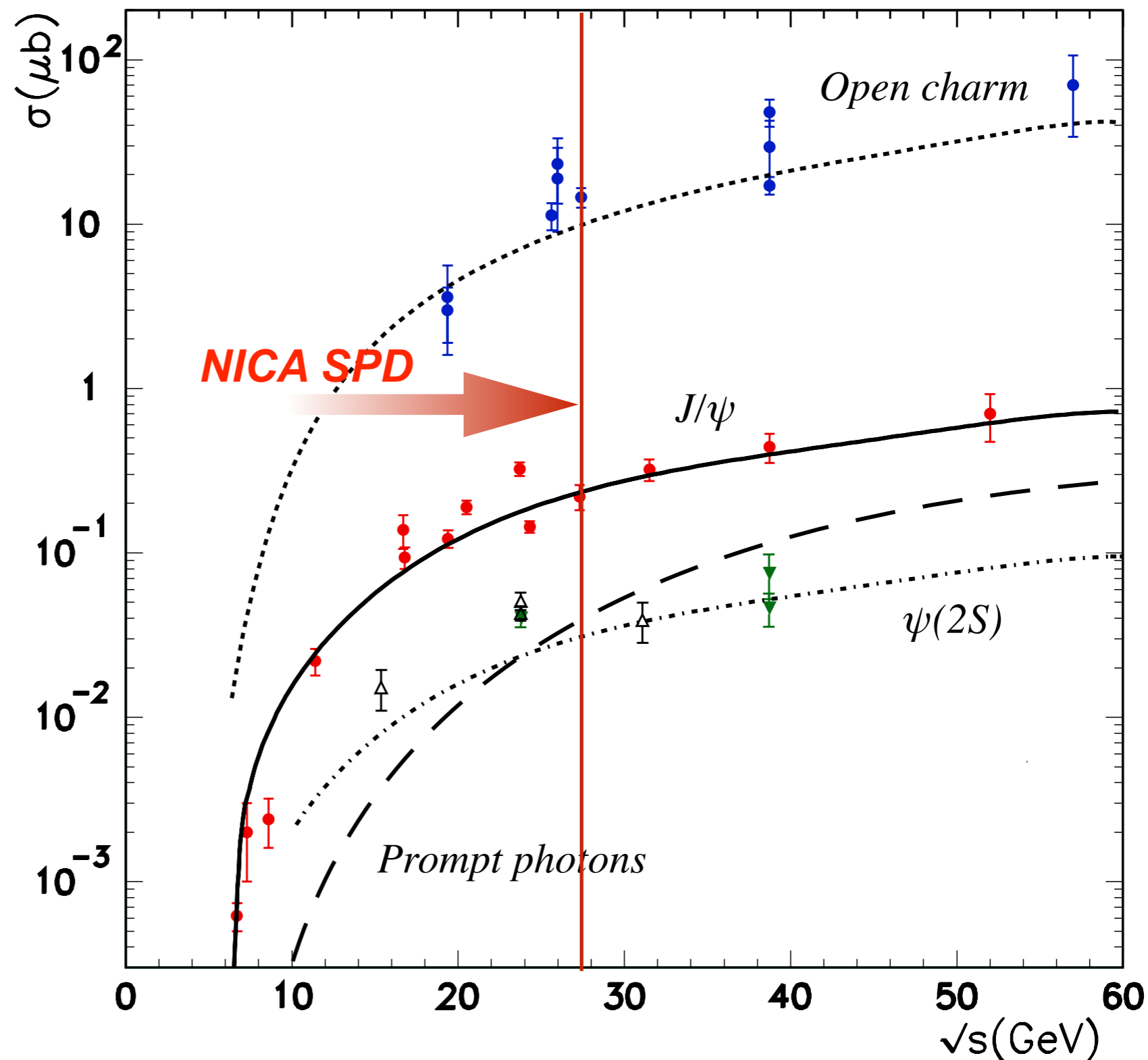
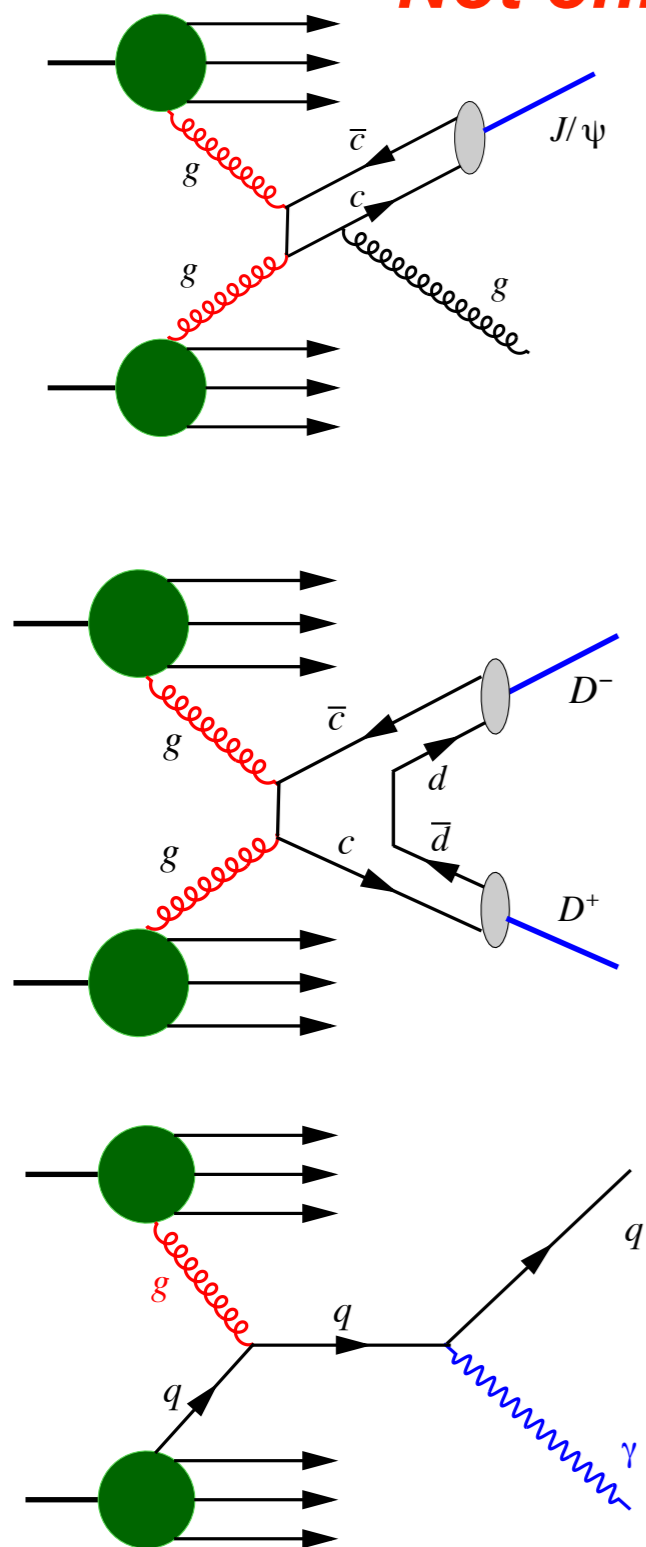
Open charm

Other spin-related
phenomena

Other
physics

SPD and *gluon* structure of nucleon

Not only J/ψ !



SPD gluon program

JPPNP: 103858

Model 3G

pp. 1–43 (col. fig: NIL)

ARTICLE IN PRESS

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arXiv:2011.15005



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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. Echevarriaⁱ, A. Efremov^a,
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M. Nefedov^l, B. Parsamyan^{a,n,o}, C. Pisano^{g,h}, M. Radici^c, A. Rymbekova^a,
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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)

Published in: *Prog.Part.Nucl.Phys.* 119 (2021) 103858 • e-Print: [2011.15005](https://arxiv.org/abs/2011.15005) [hep-ex]

pdf

DOI

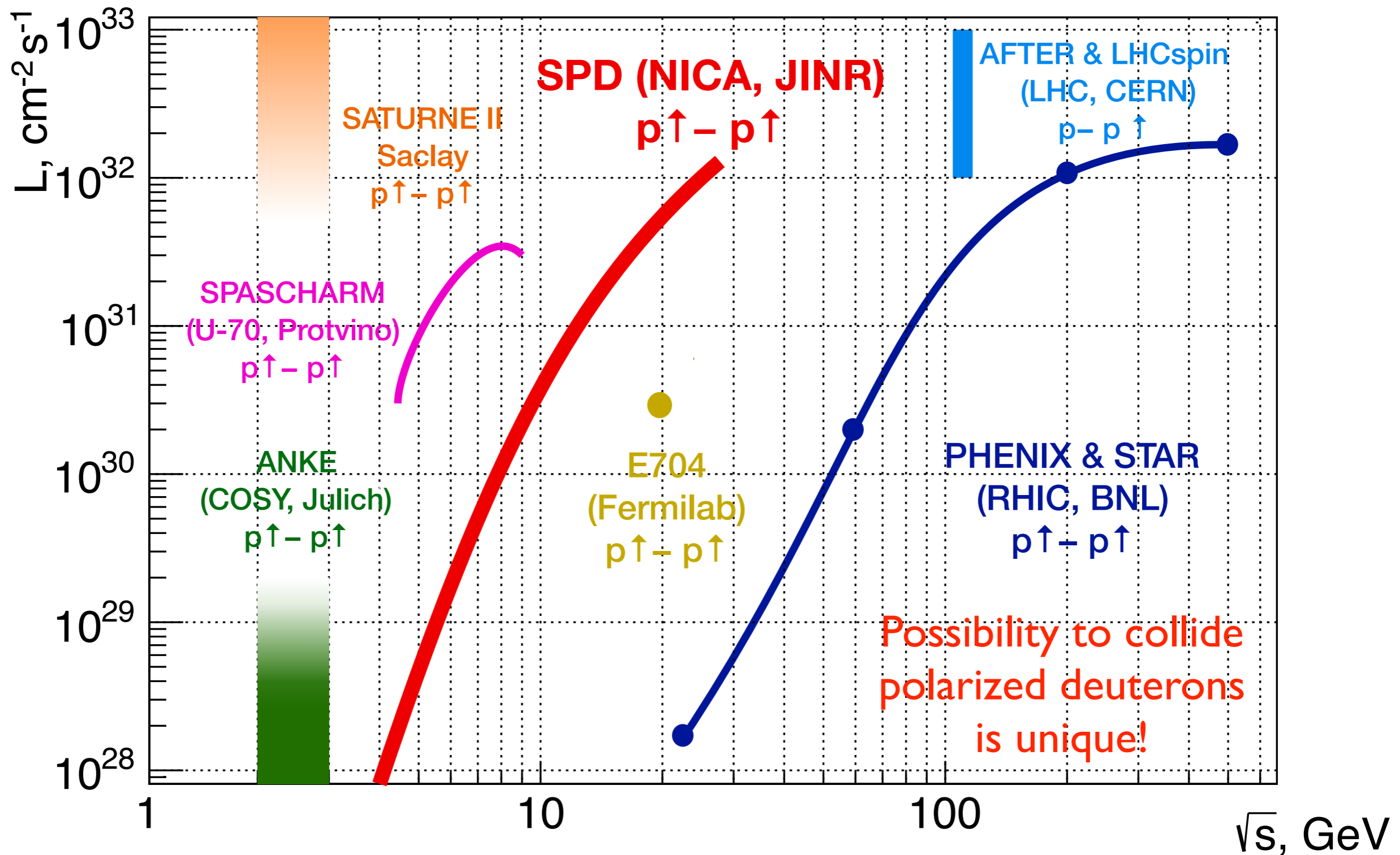
cite

claim

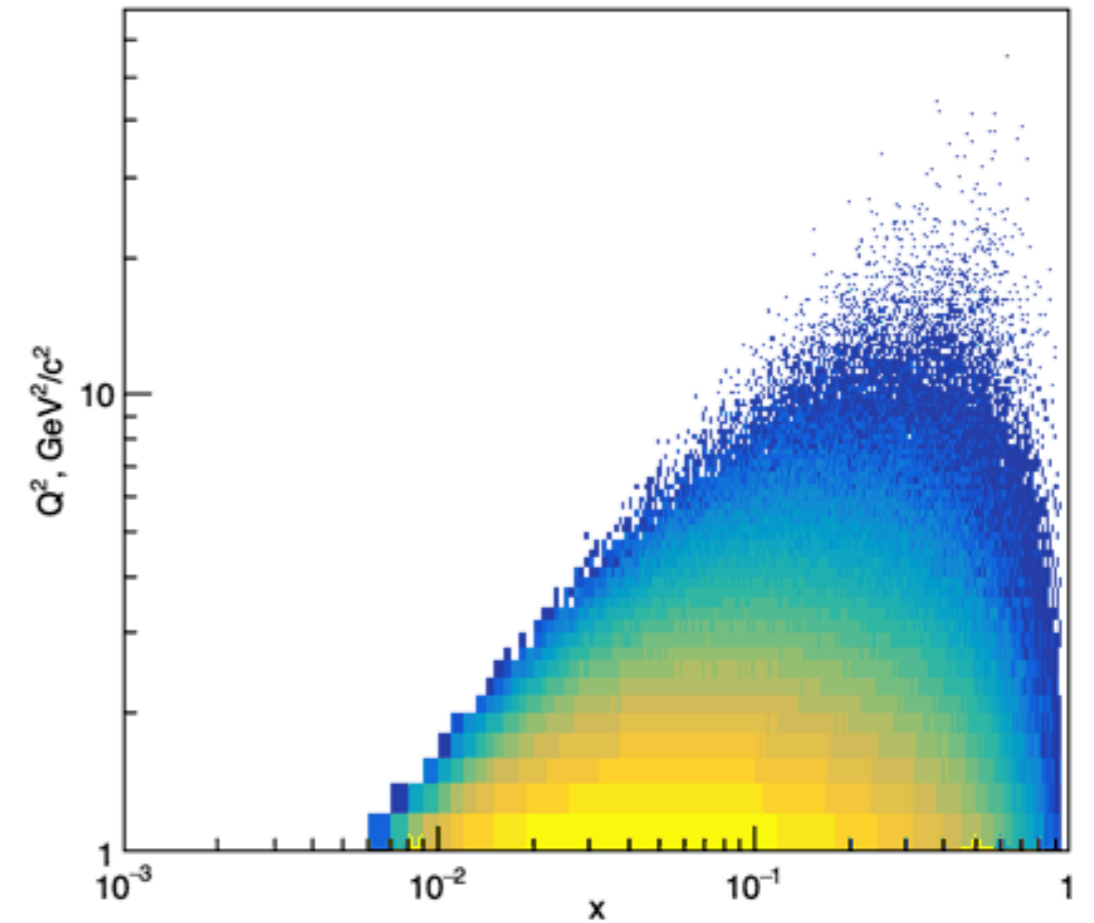
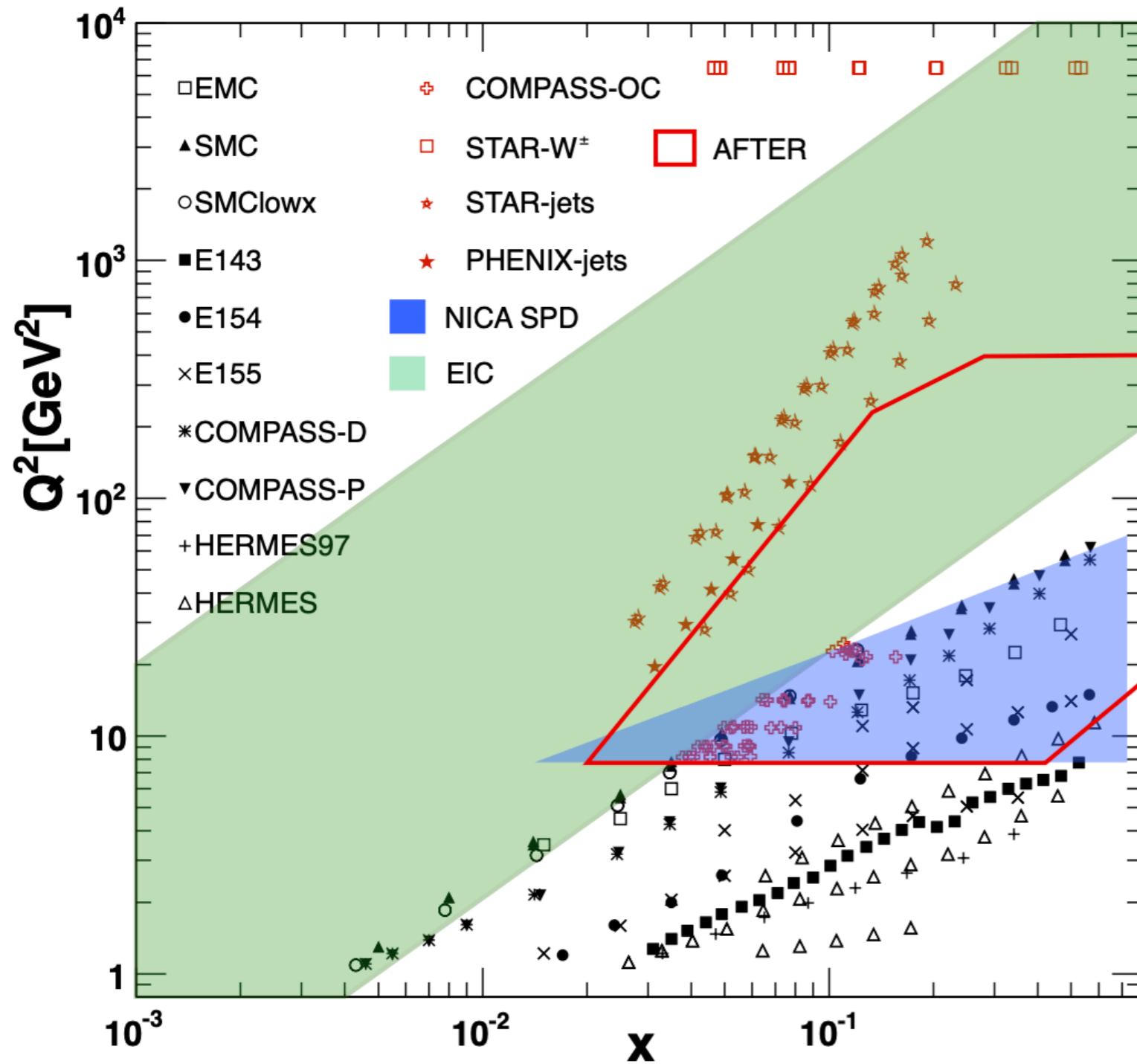
reference search

51 citations

SPD and others



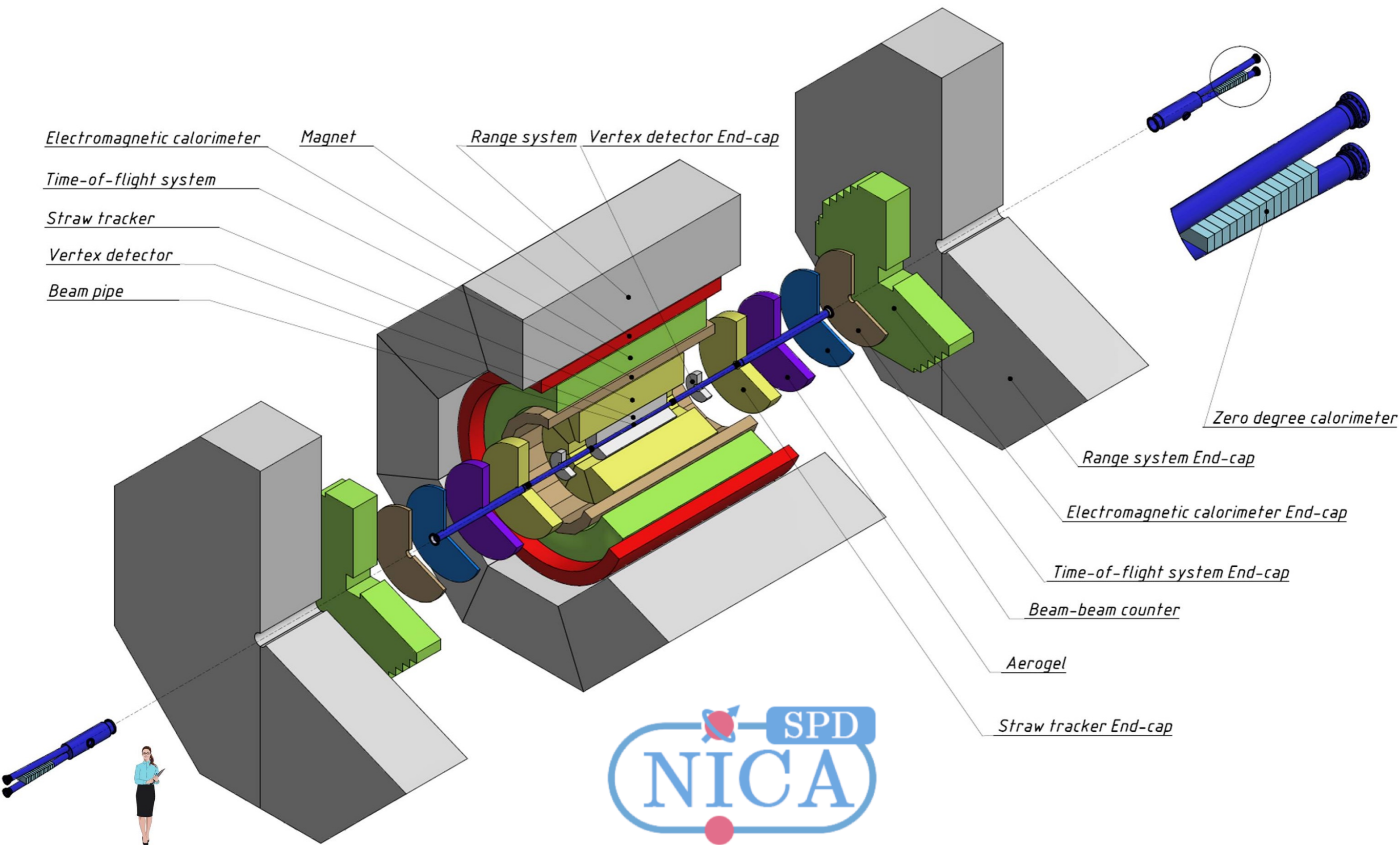
SPD and others



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

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

SPD setup



SPD: 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

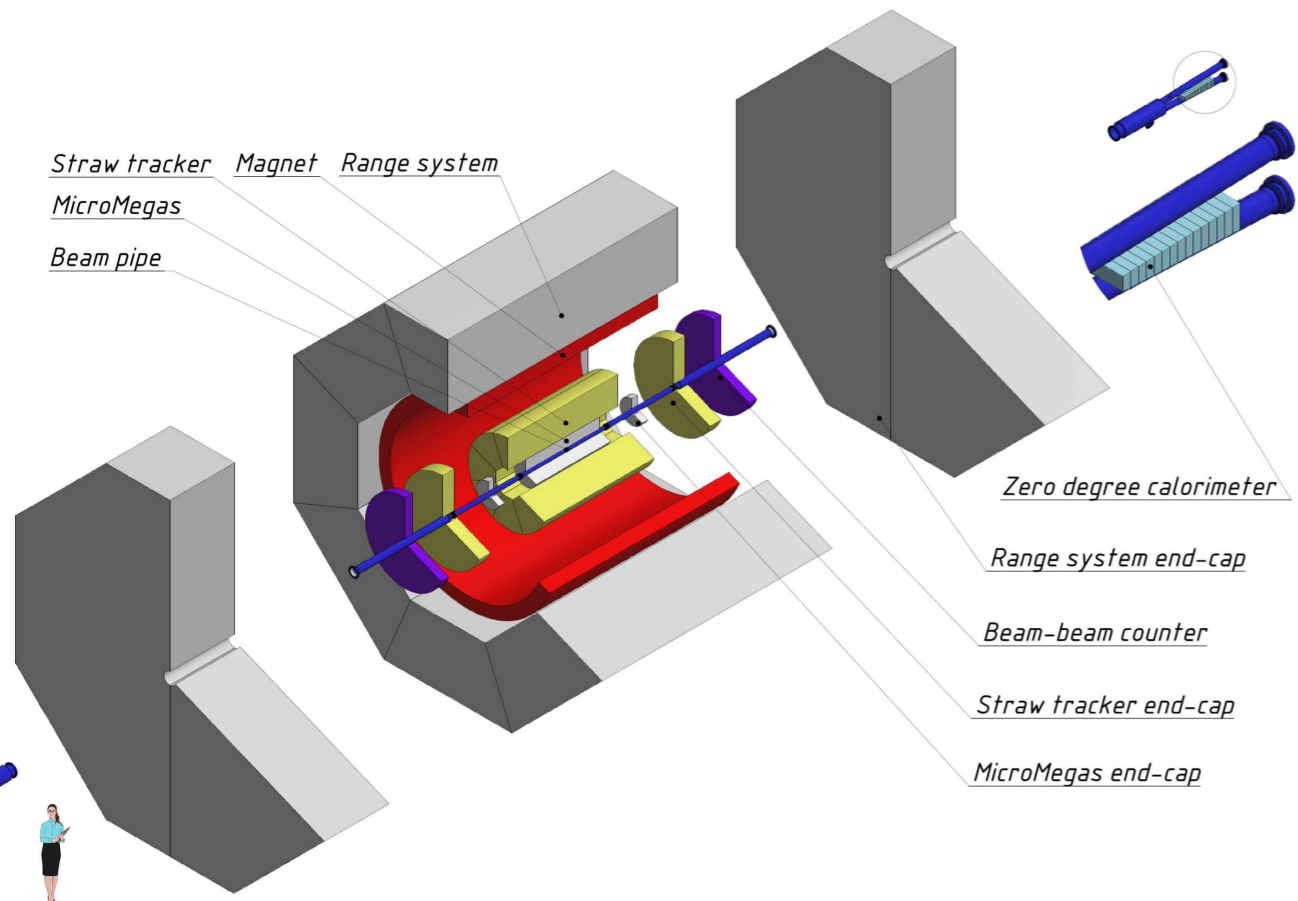
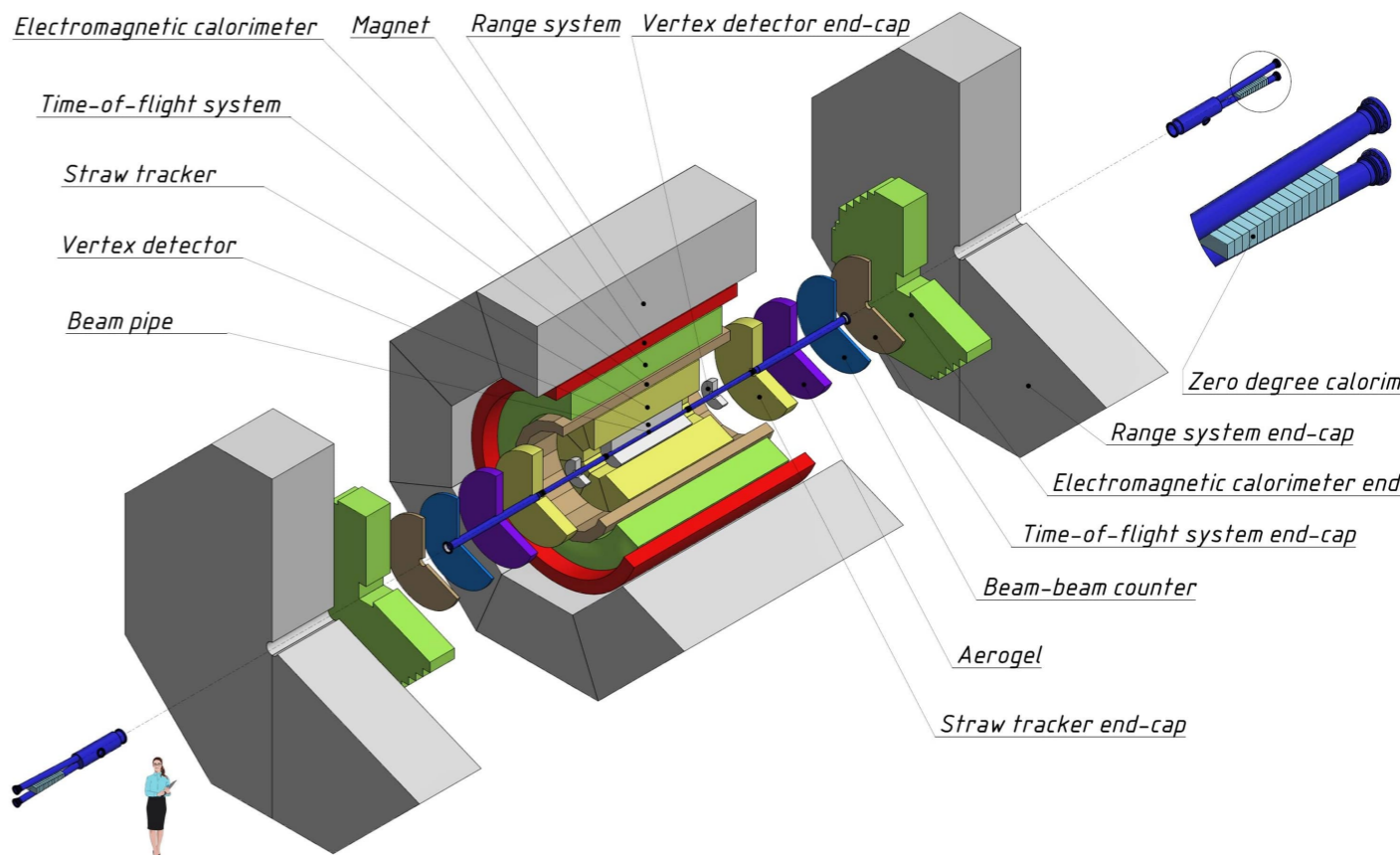
Zero degree calorimeter

Range system end-cap

Beam-beam counter

Straw tracker end-cap

MicroMegas end-cap



Physic of the first stage

Non-perturbative QCD

Perturbative QCD

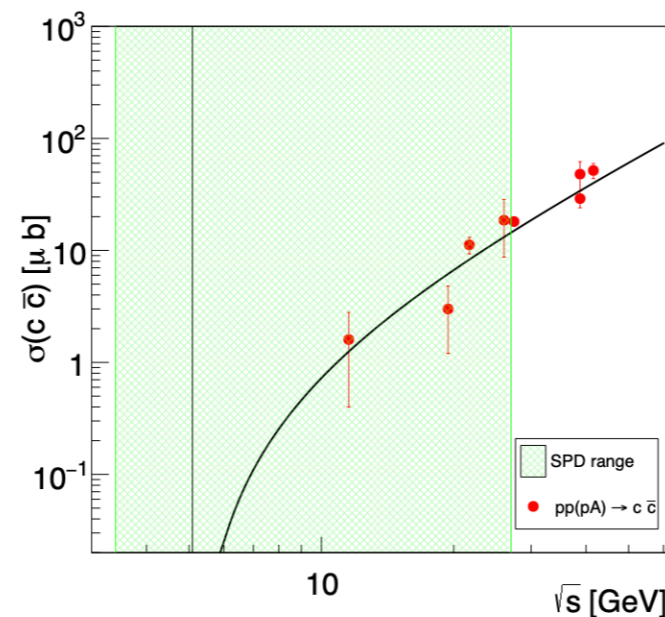
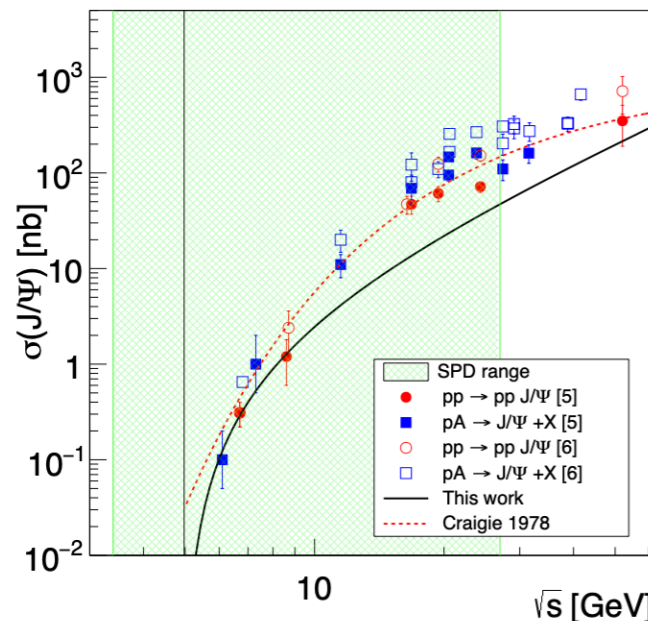
- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernuclei
- Open charm and charmonia near threshold

\sqrt{s}

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

arXiv:2102.08477

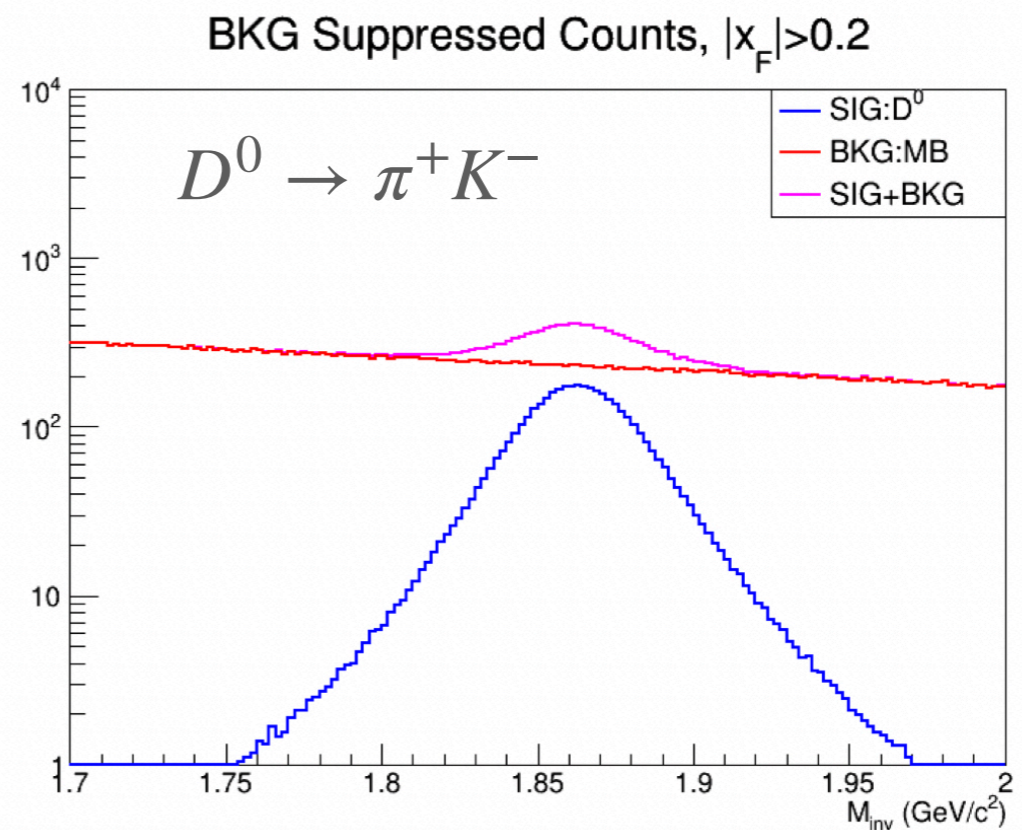
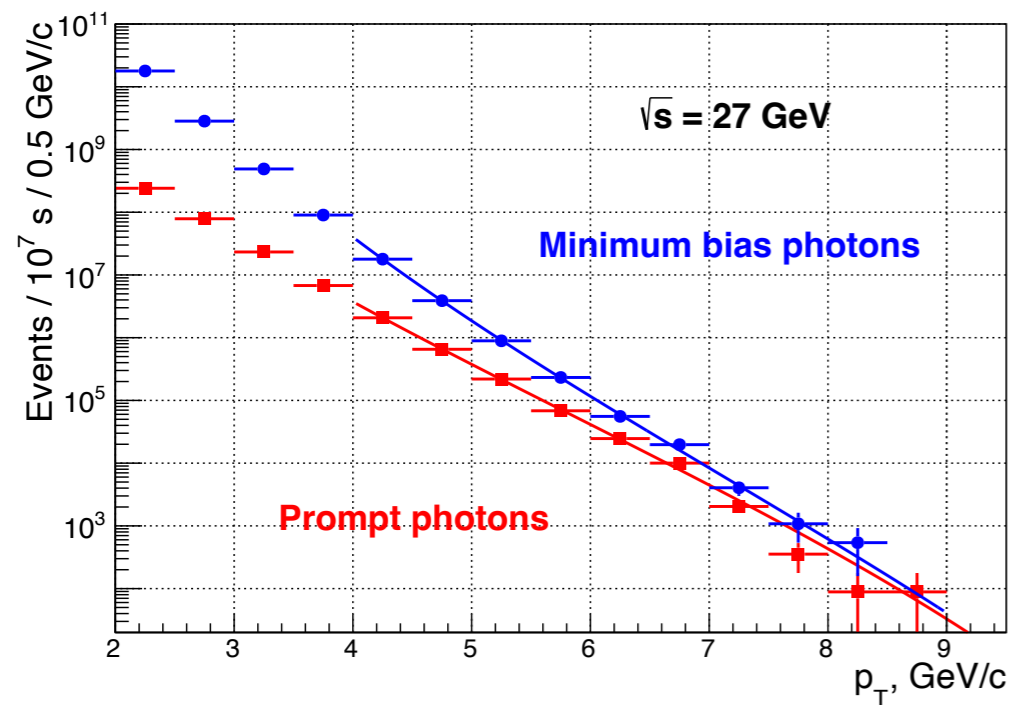
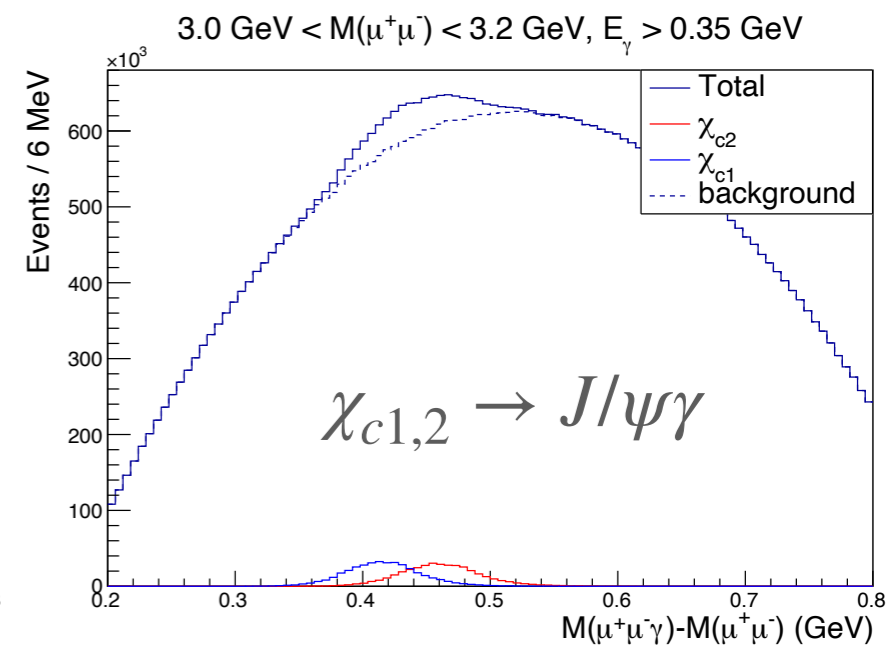
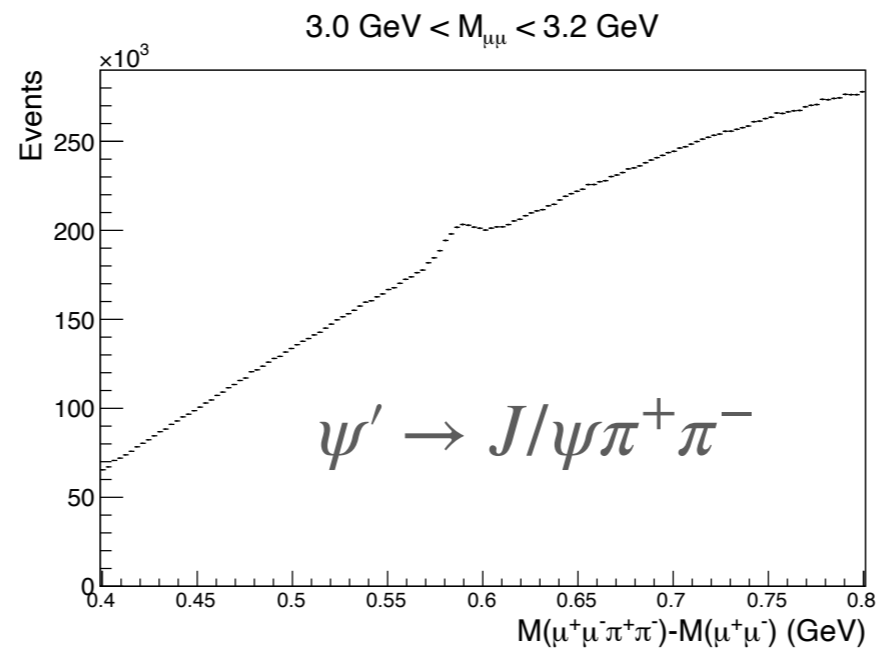
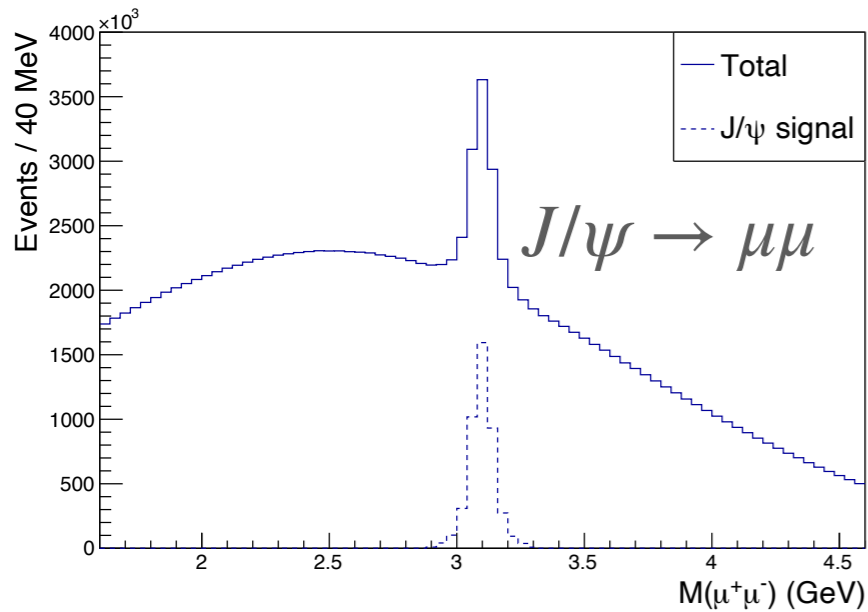
$$dd \rightarrow K^+ K^+ \Lambda\Lambda^4 n,$$



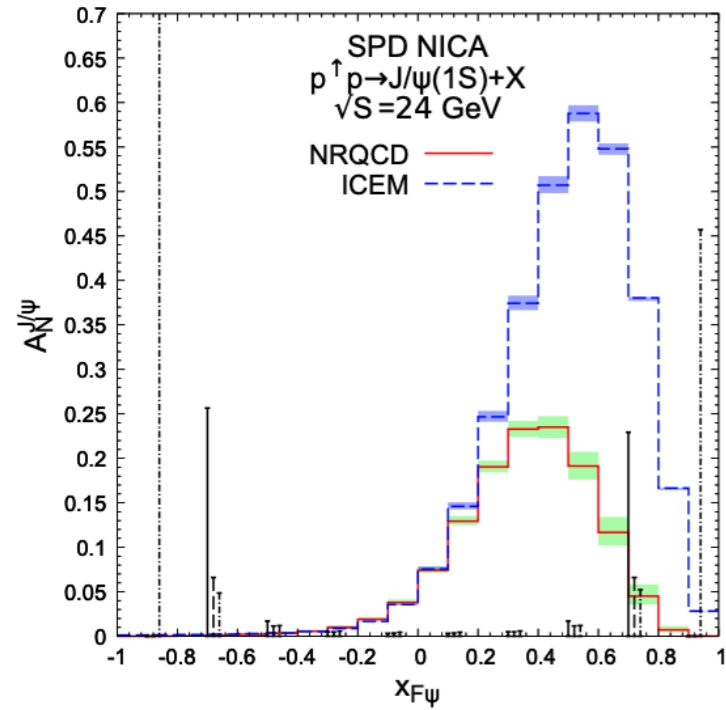
- Auxiliary measurements for astrophysics

Physics performance: gluon probes

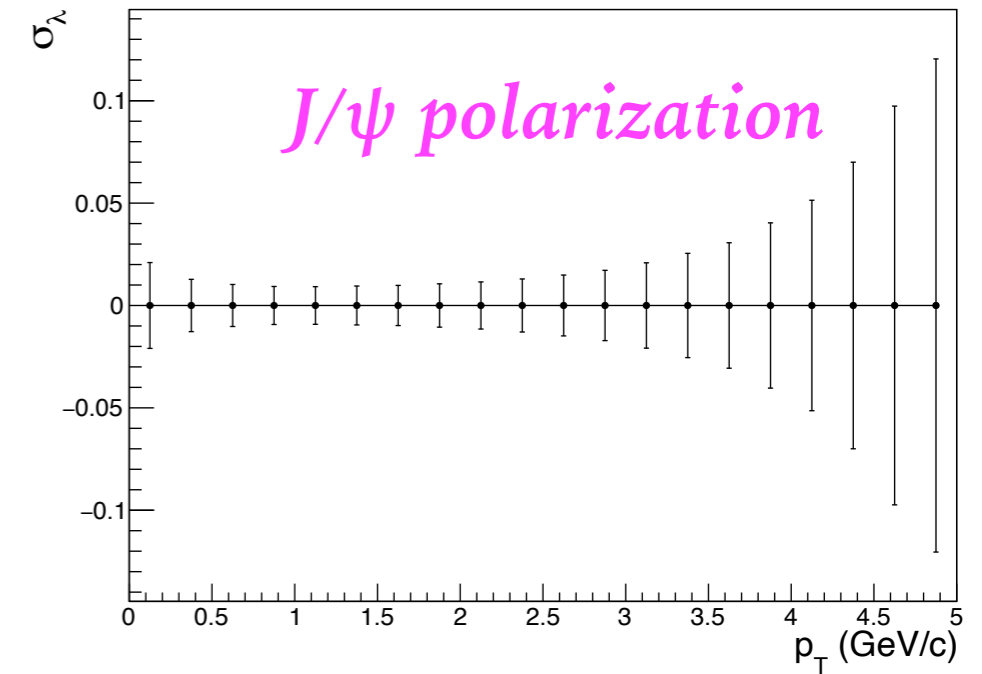
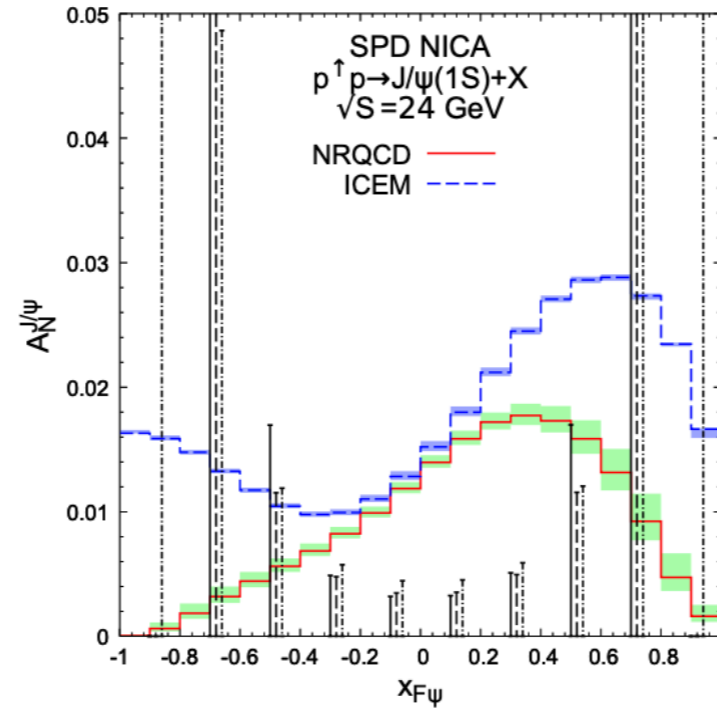
(1 year = 10^7 s)



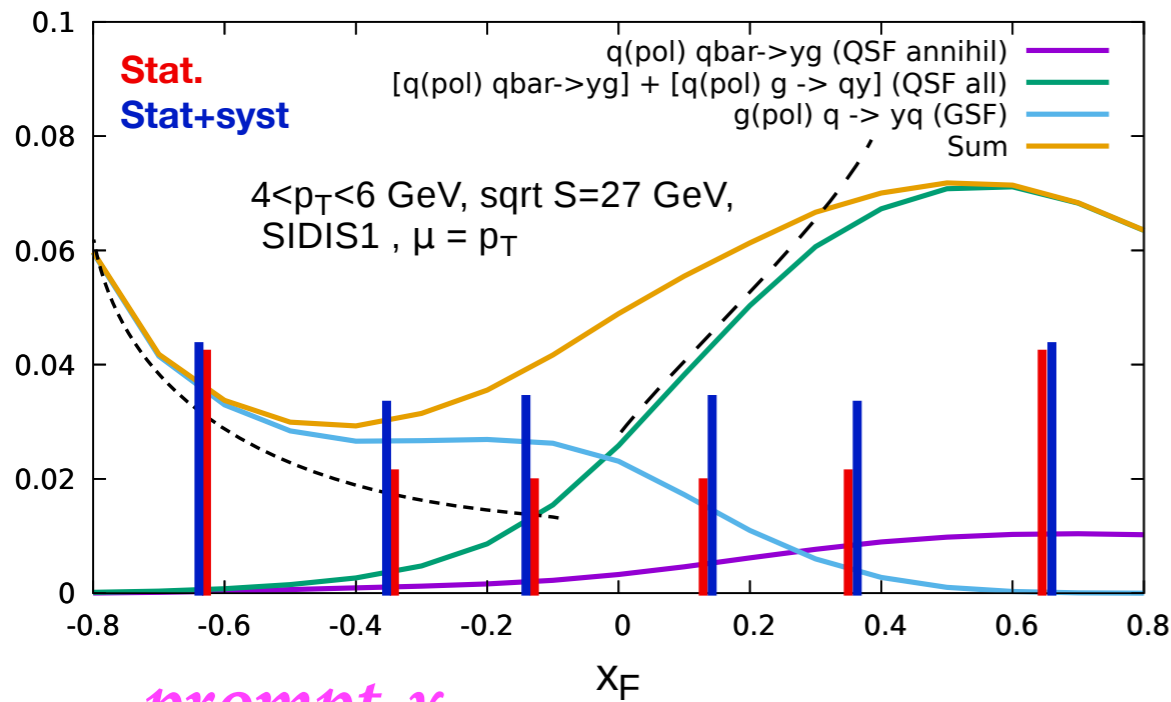
Physics performance: accuracies



J/ψ

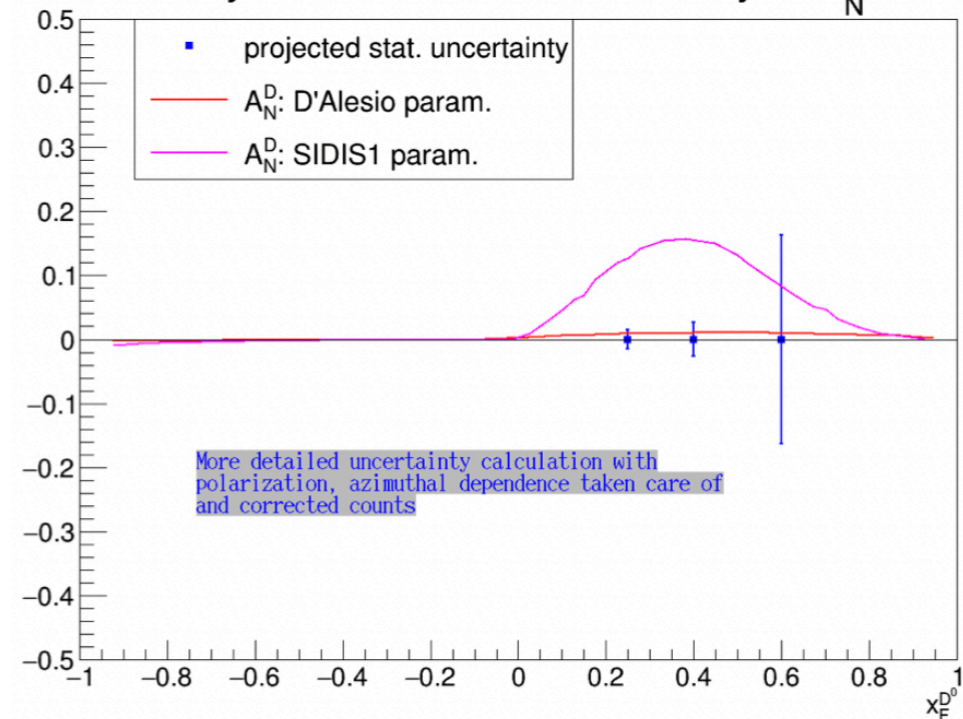


Different inputs for gluon Sivers function



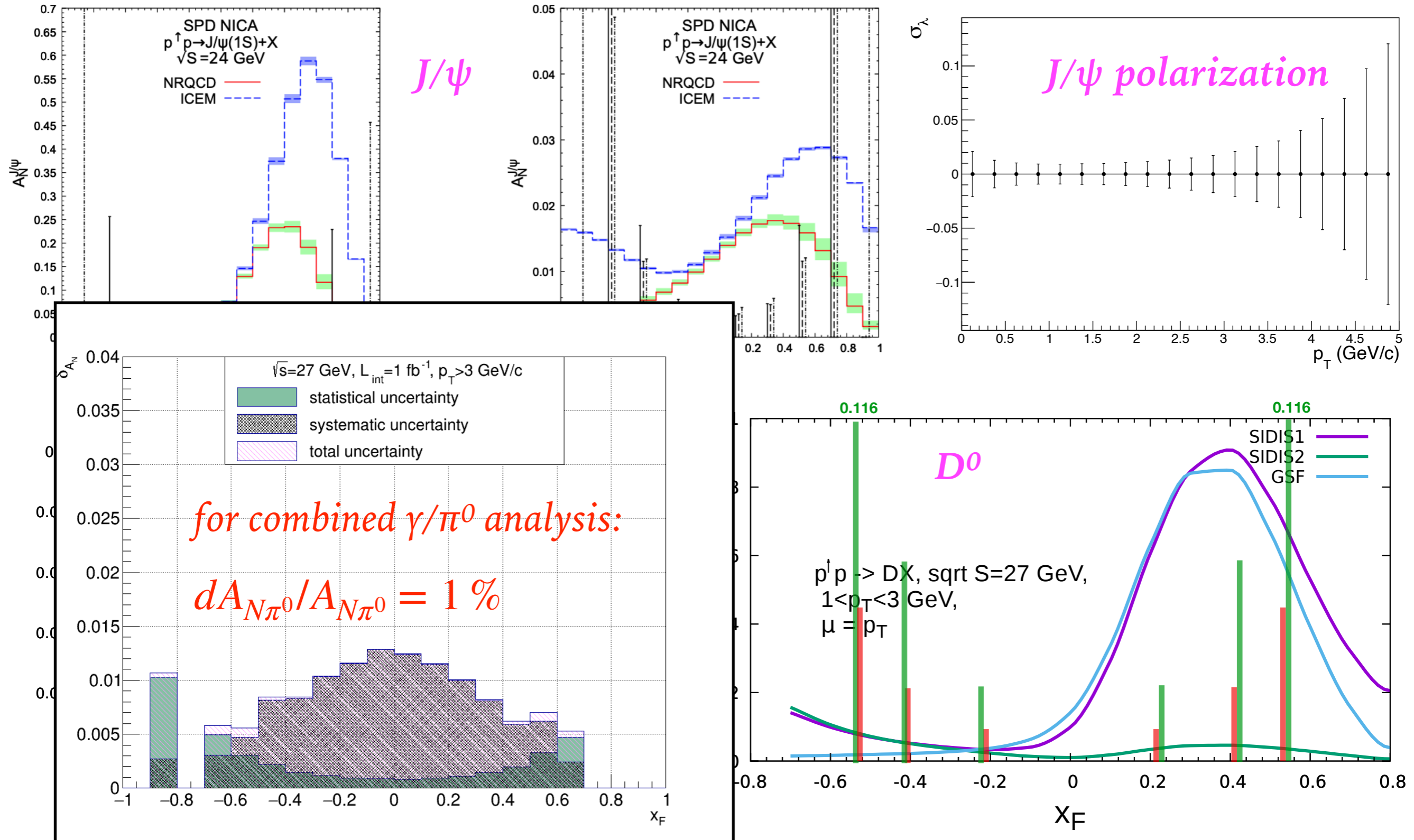
$prompt-\gamma$

Projected Statistical Uncertainty of $A_N^{D^0}$

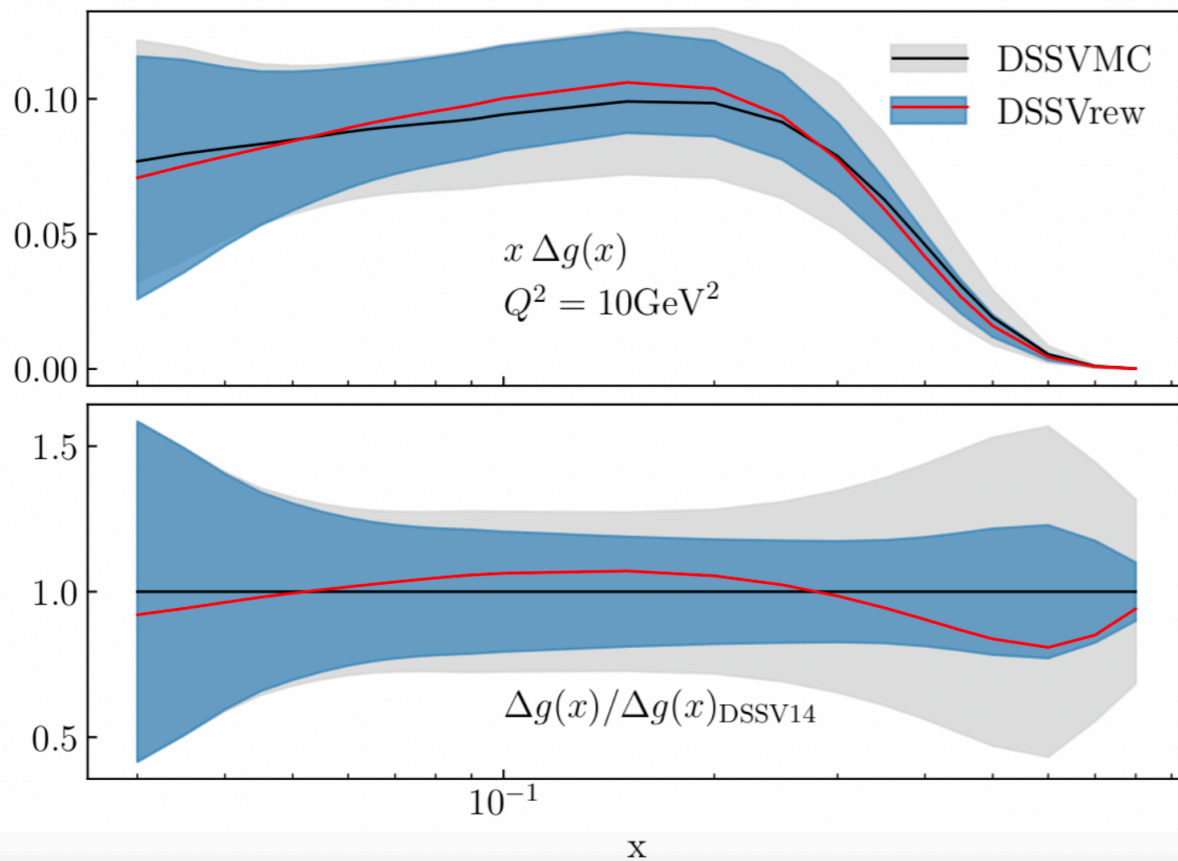


D^0

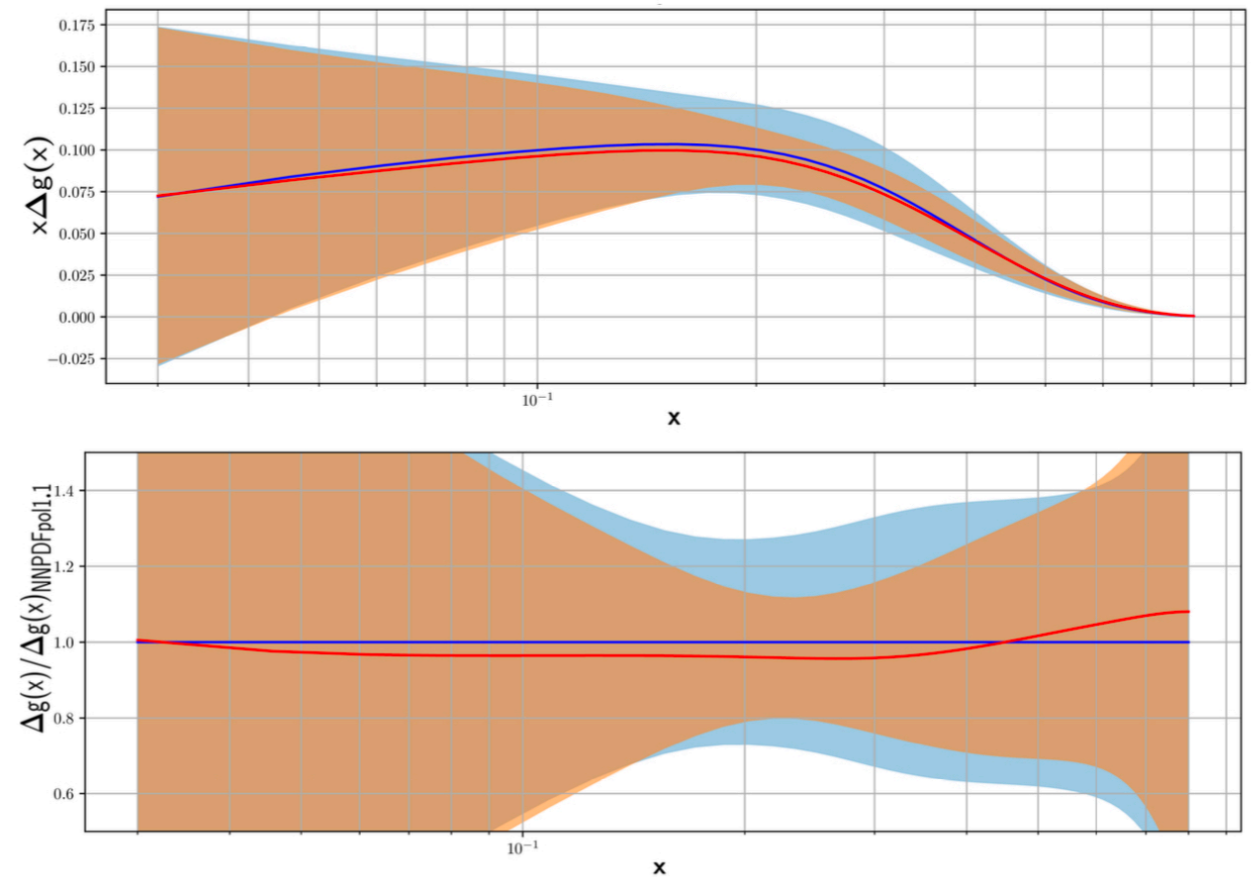
Physics performance: accuracies



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



A_{LL} for prompt photons



A_{LL} for J/ψ

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> .