Polarized gluon structure of proton with SPD

Alexey Guskov, JINR

Spin Physic Detector @ NICA

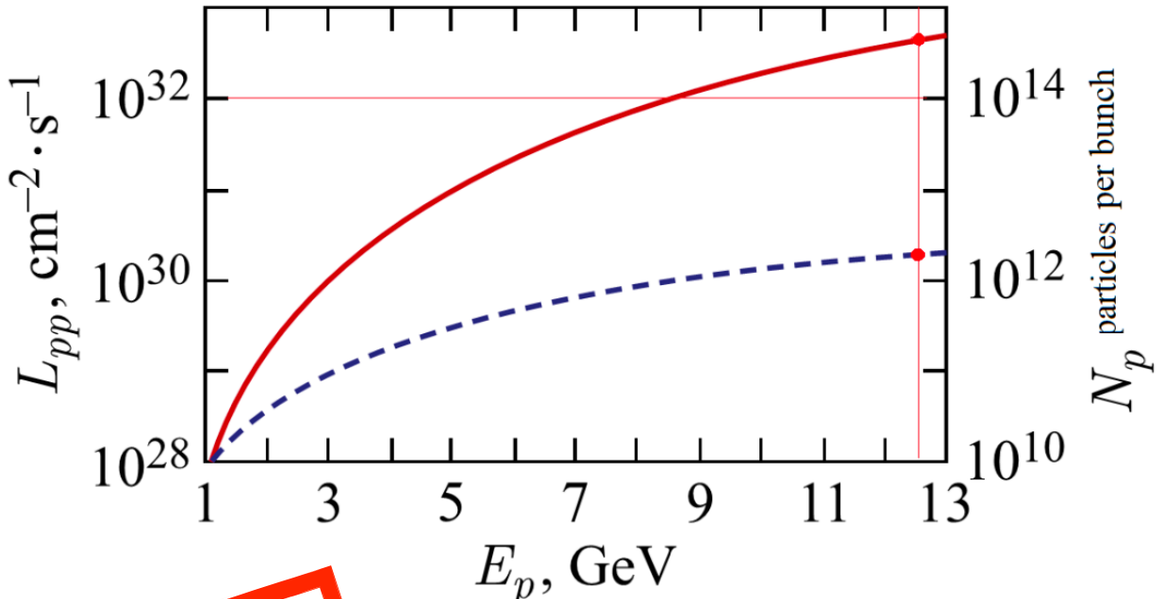
NICA - Nuclotron-based Ion Collider fAcility

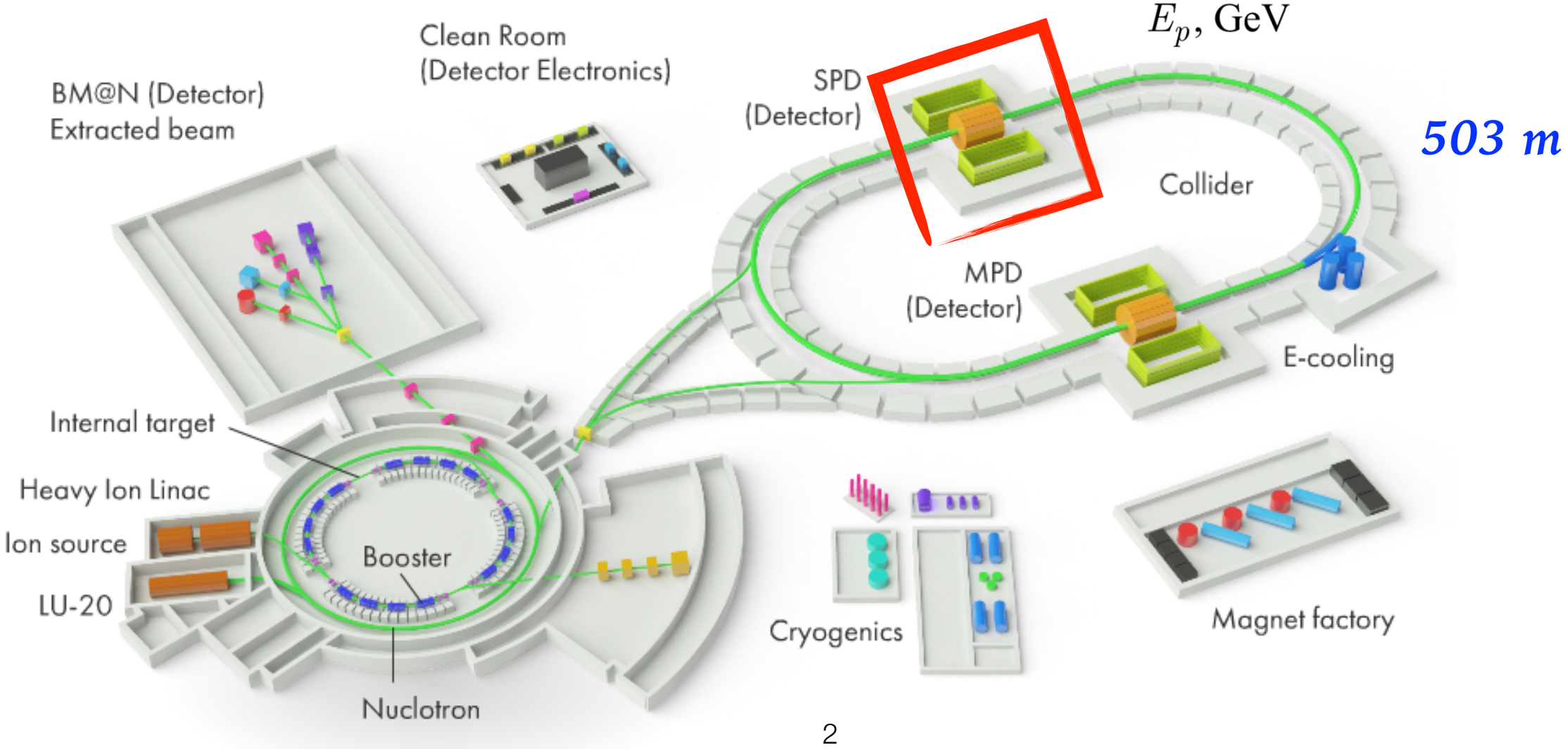
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

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

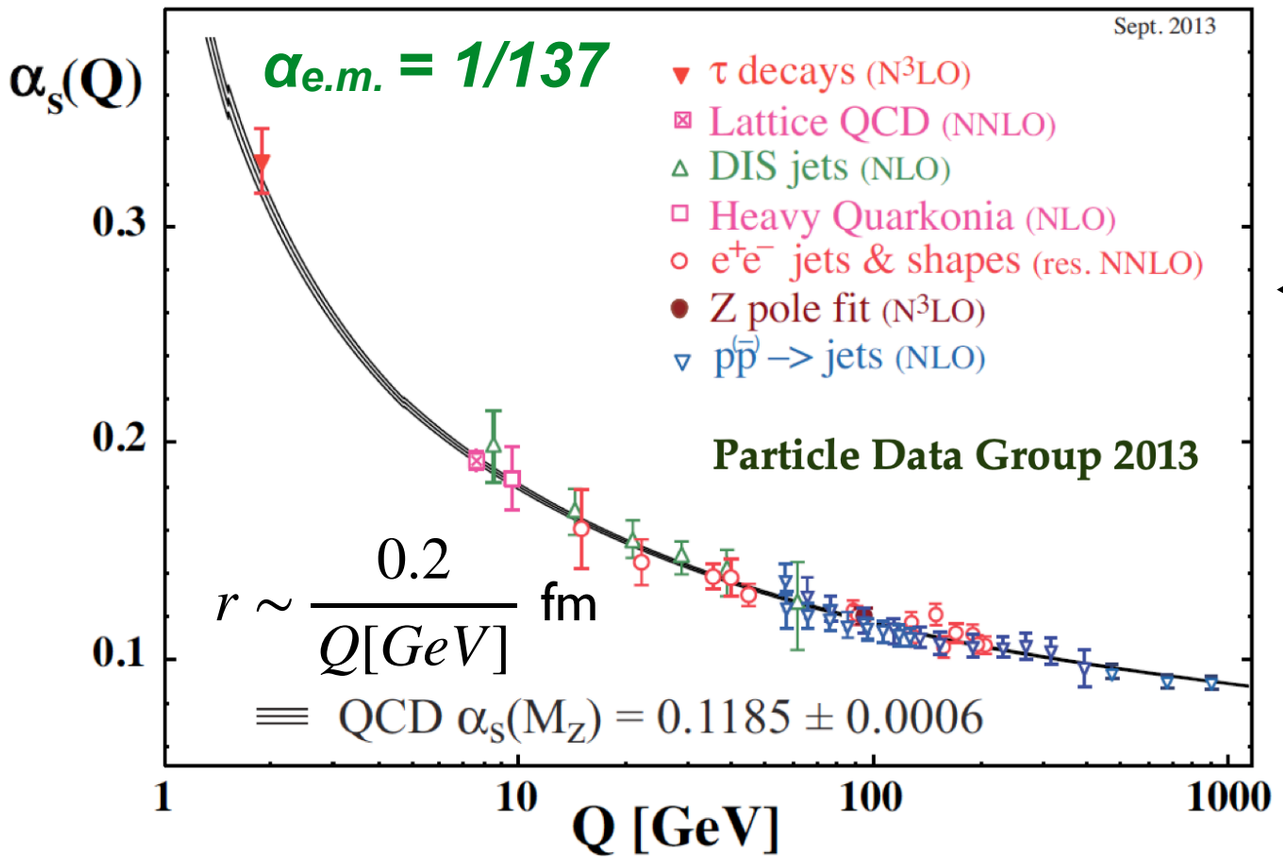
U, L, T

$|P| > 70\%$

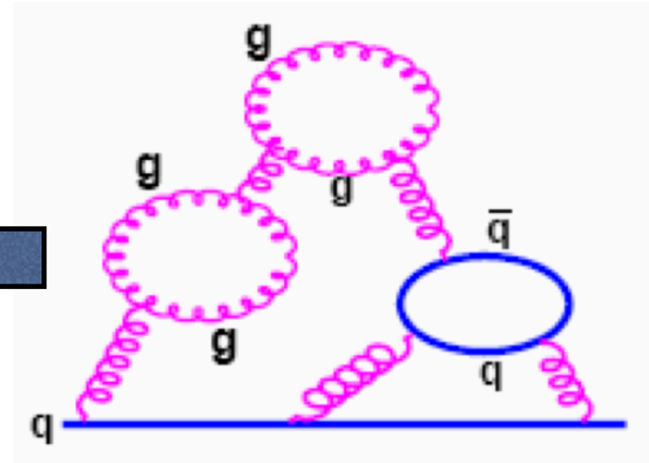




Problem to describe hadrons ab initio

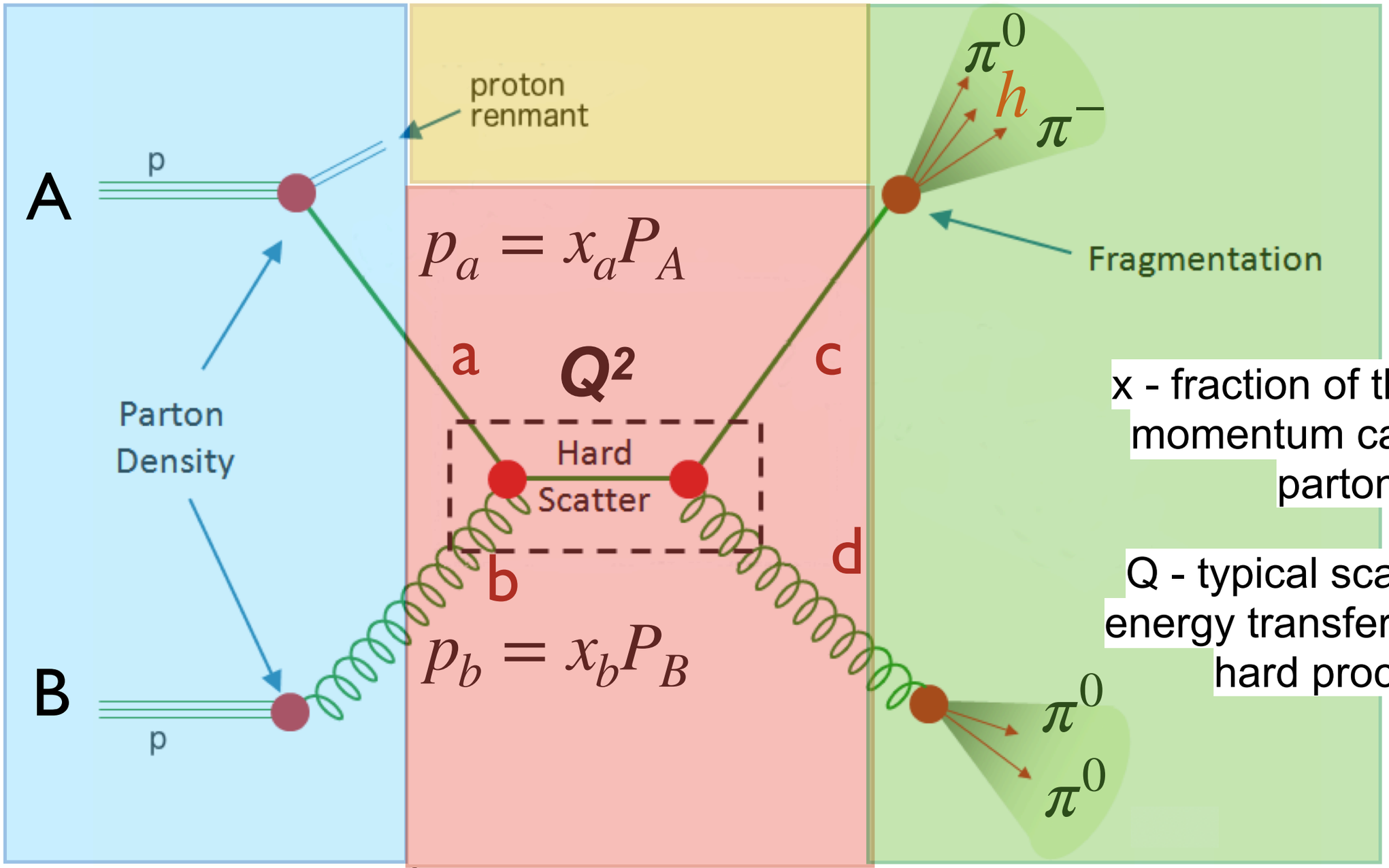


Confinement is not strictly proven!



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

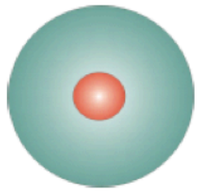
$$\sigma_{AB\to hX} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f(x_a, Q^2) f(x_b, Q^2) \times \hat{\sigma}_{ab\to cd}(x_a, x_b, Q^2) \times D_{cd\to h}$$

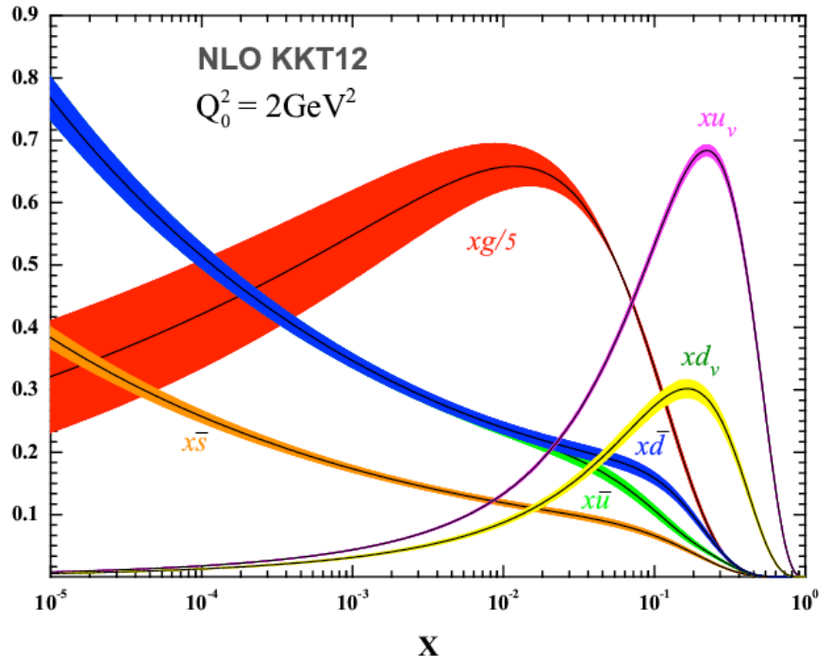
$Q^2 >> 1$ GeV$^2/c^2$

Partonic structure of proton

f(x)

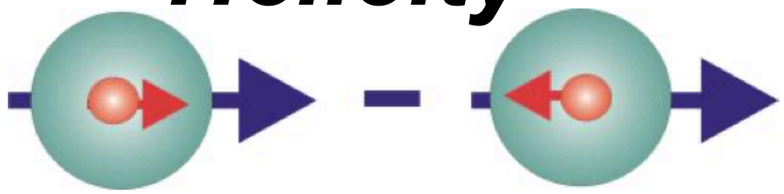
Unpolarized





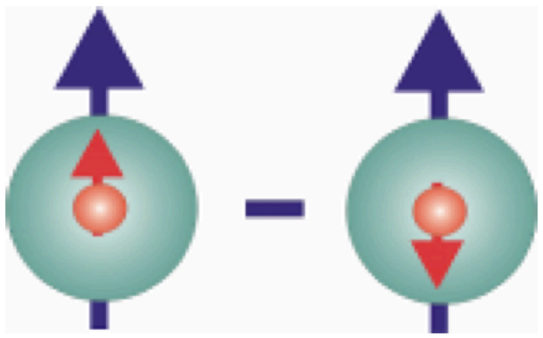
Δf(x)

Helicity



Transversity

$\Delta_T f(x)$

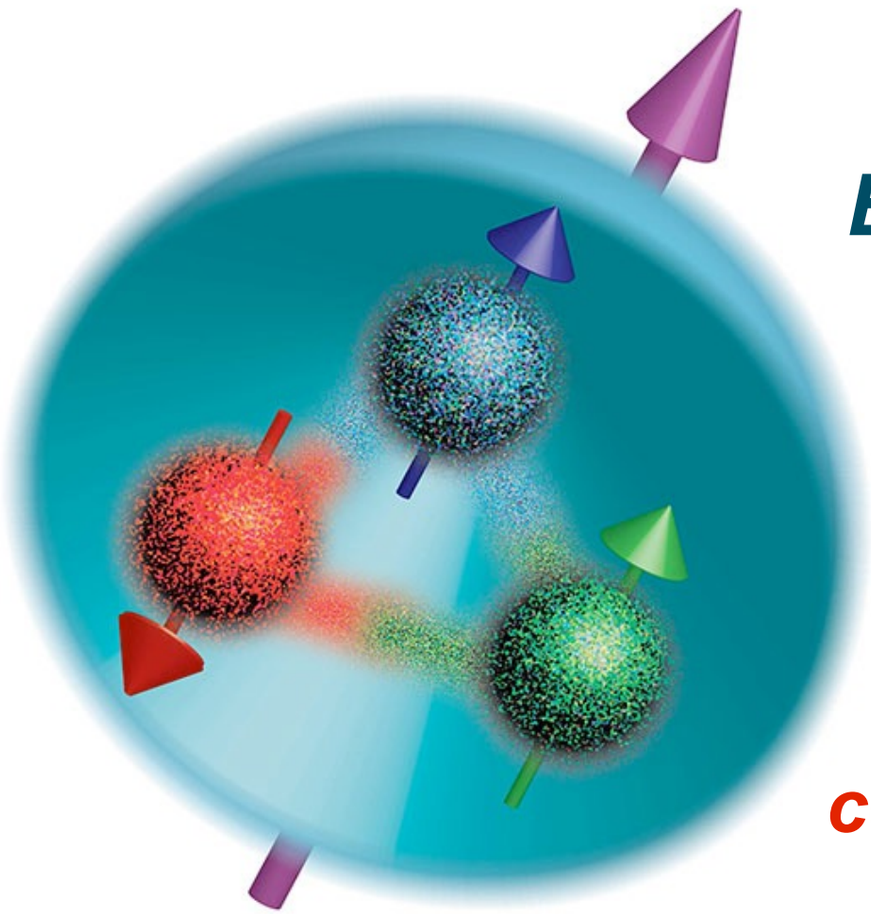


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \sim \Delta f$$

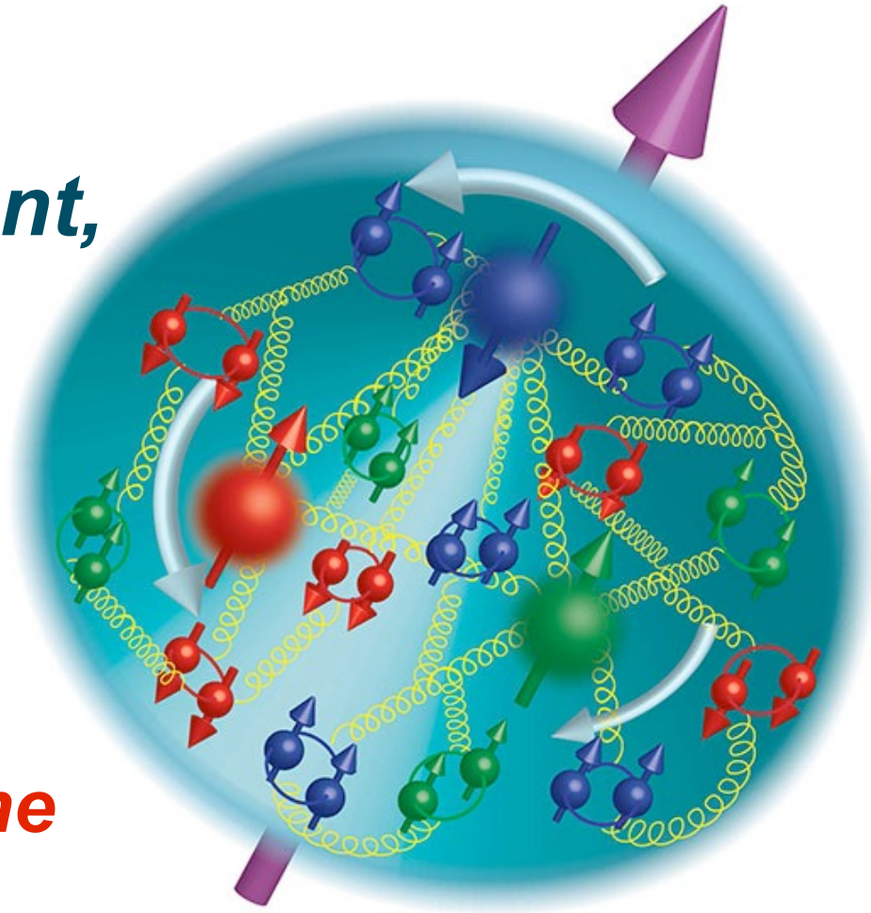
Angular asymmetries

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

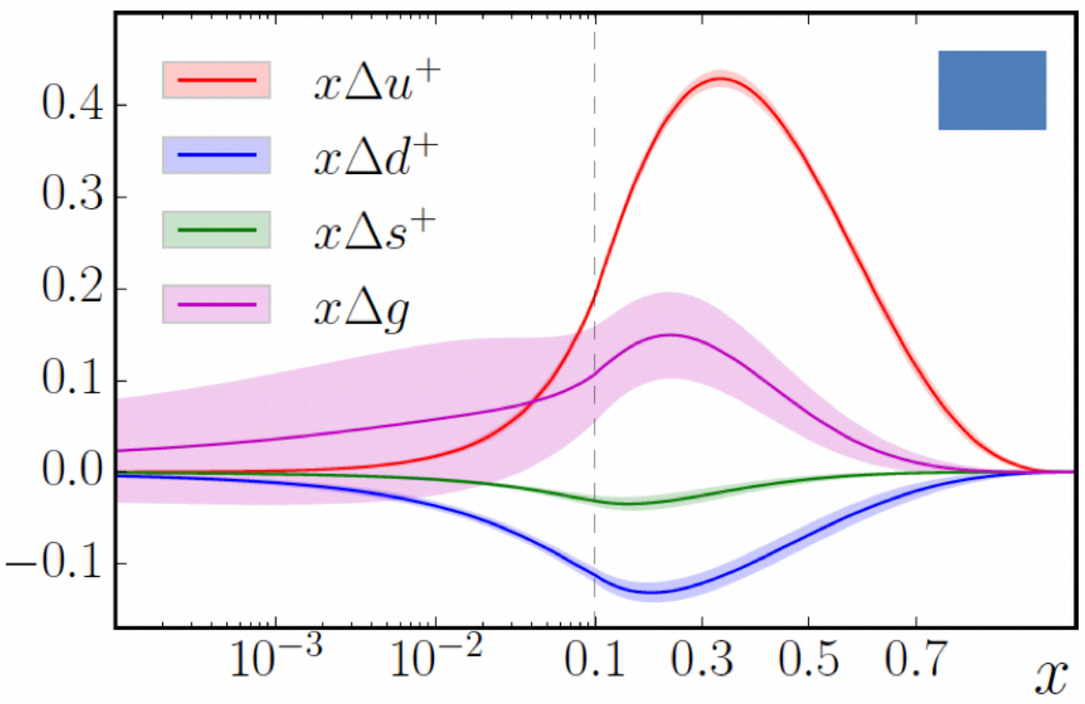
L - orbital moments of quarks and gluons

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

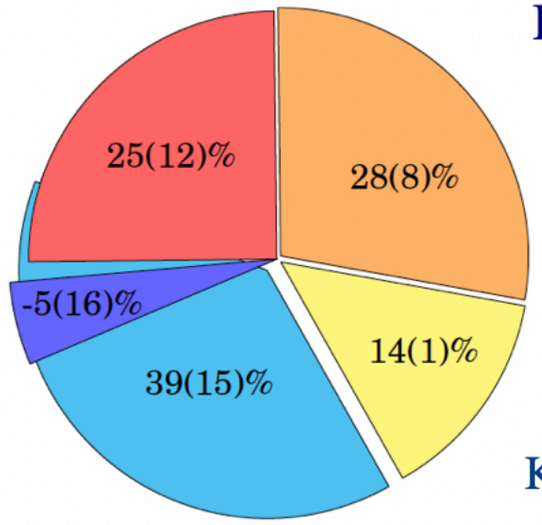
Spin balance

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

~30% for $\frac{1}{2}\Delta\Sigma + \Delta G$; ~10-20% for $L_q + L_g$; L_q, L_g marked with ?



JAM Collaboration, PRD (2016).

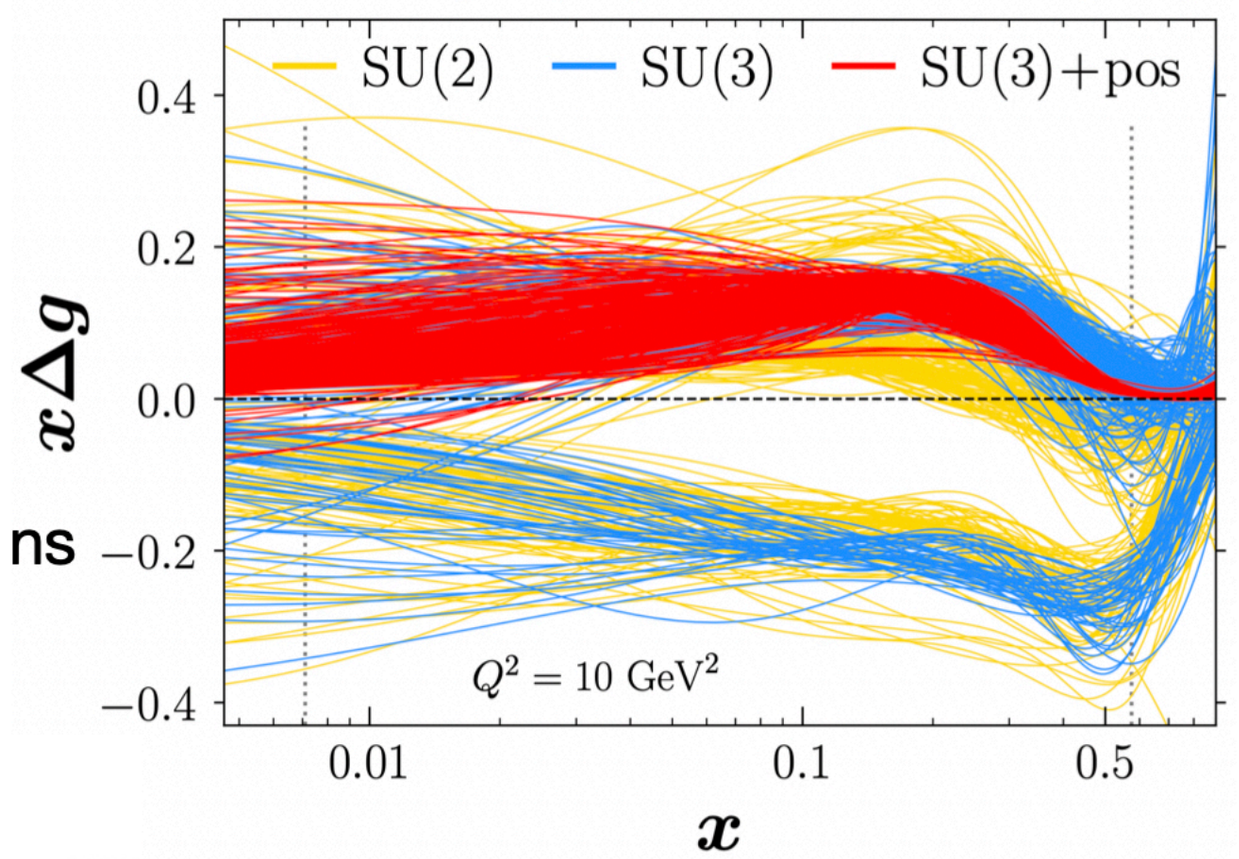


Lattice QCD

- 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)



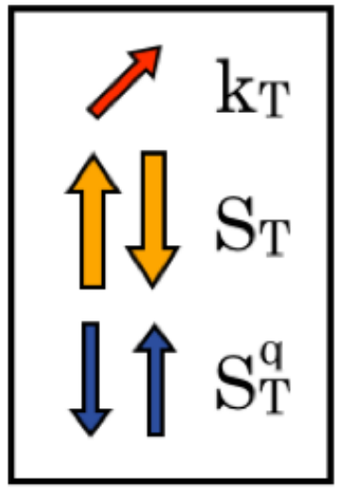
To access angular momenta info about 3D structure is needed!

Proton in 3D: TMD PDFs

Nucleon Spin Polarization

Quark Spin Polarization

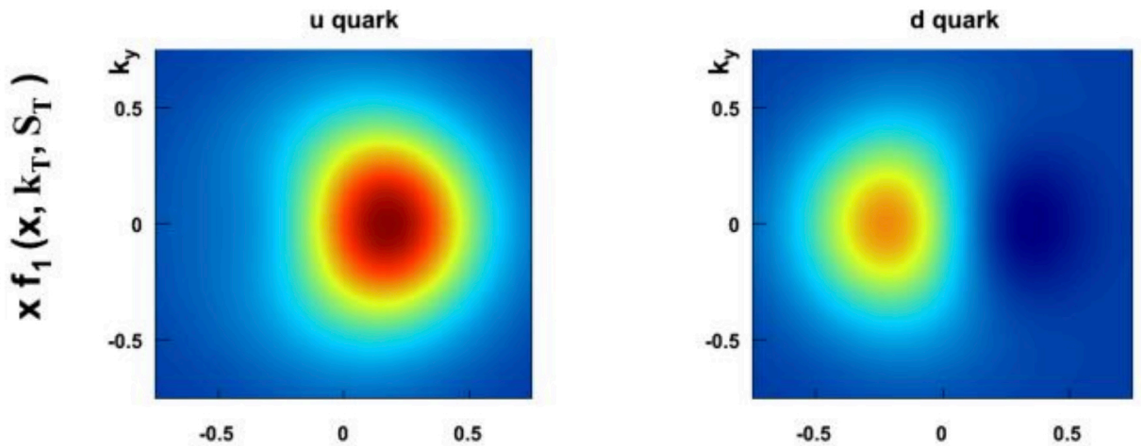
	U	L	T
U	f_1 Number Density		$f_{1T}^{q\perp}$ Sivers
L		g_{1L}^{q} Helicity	g_{1T}^{q} Worm-Gear T
T	$h_1^{q\perp}$ Boer-Mulders	$h_L^{q\perp}$ Worm-Gear L	h_1^{q} Transversity; $h_{1T}^{q\perp}$ Pretzelosity



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

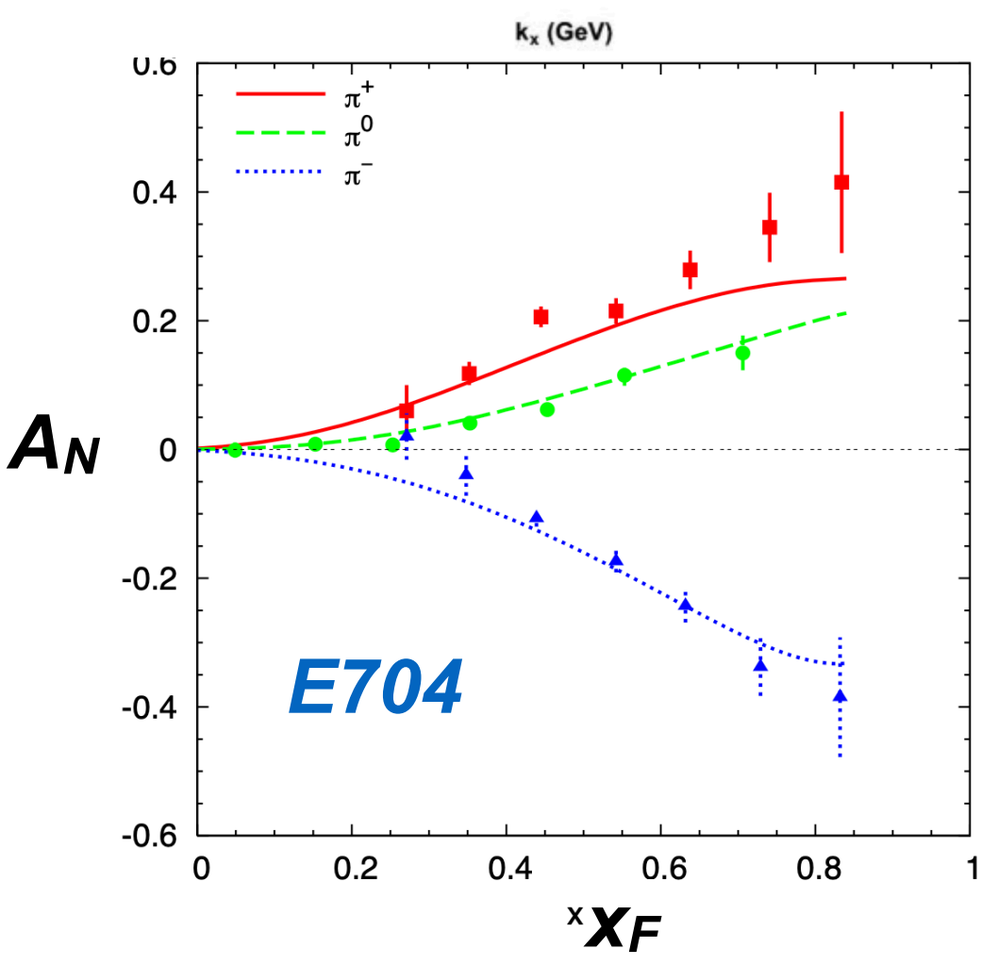
TMD effects: Sivers effect

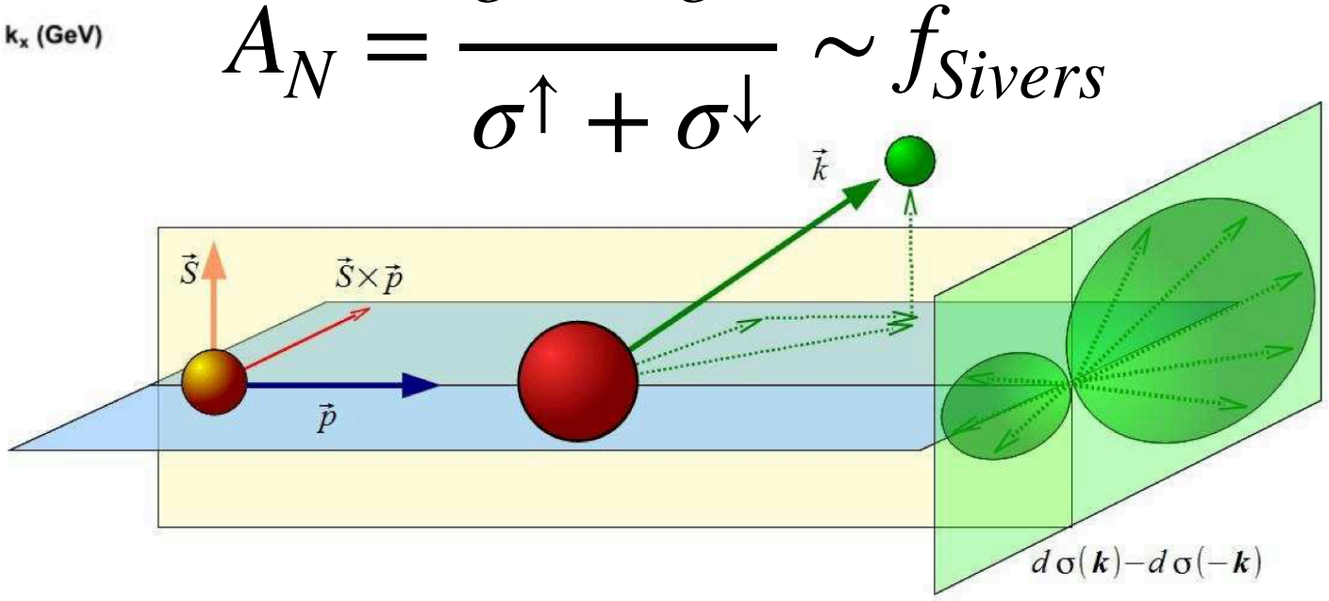
Probabilities to meet in a transversely polarized proton a parton moving to the left and to the right with respect to the $(\vec{S}, \vec{p})$ plane are different!



x=0.1

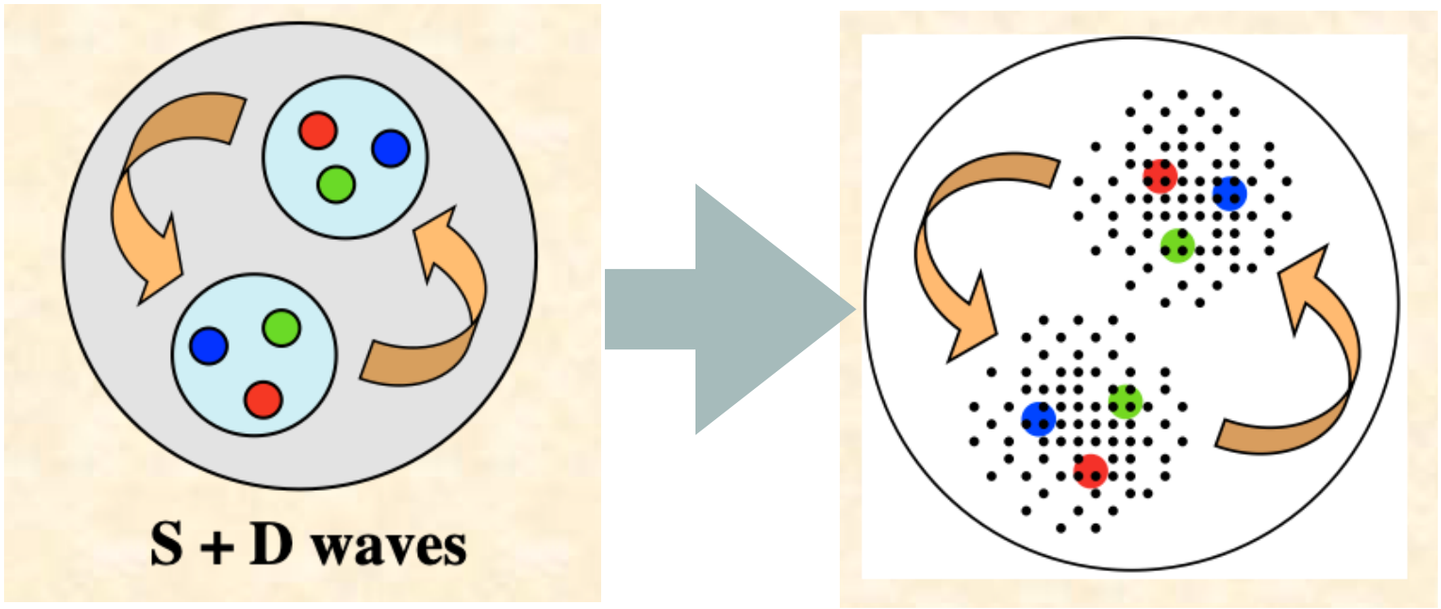
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim f_{Sivers}$$





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

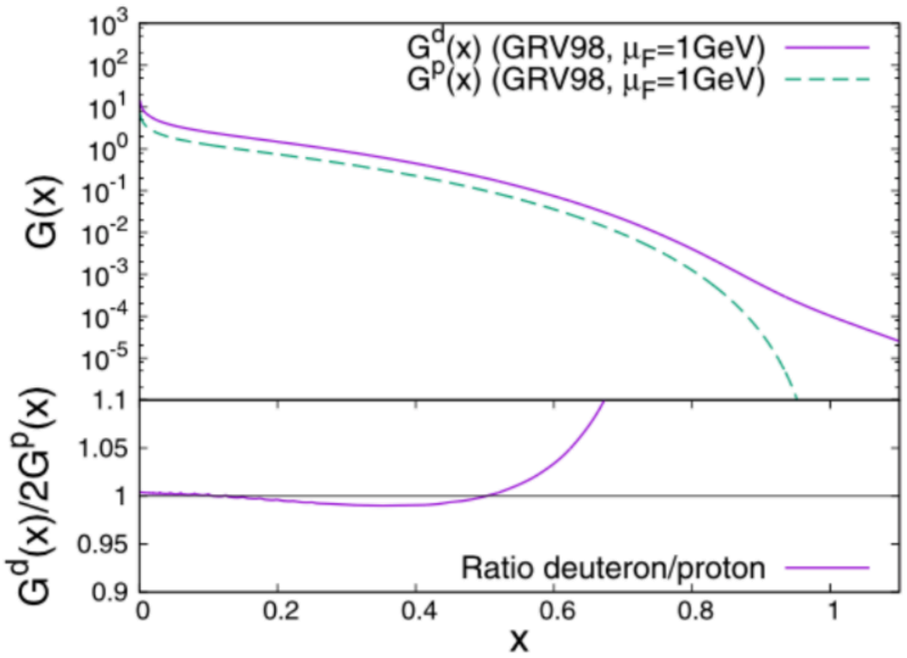
Deuteron



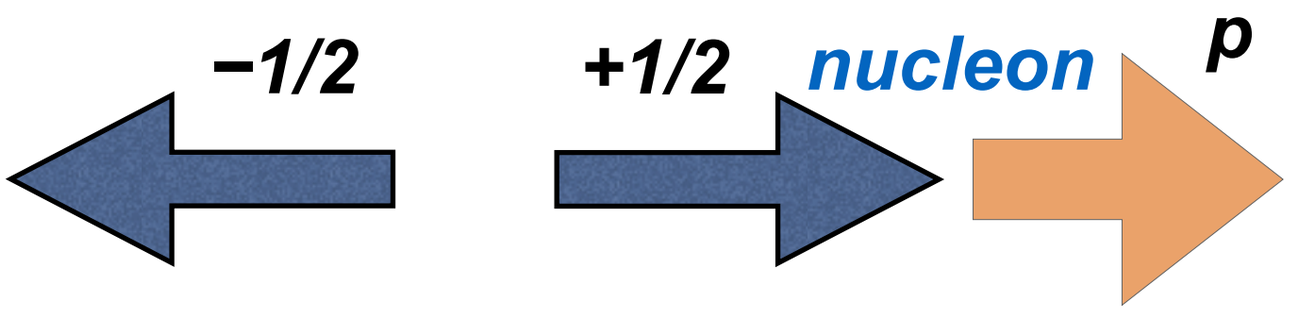
$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + \boxed{c_3|CC\rangle}$$

hidden color

Deuteron is not just proton + neutron!



More gluons at large x with respect to nucleon?

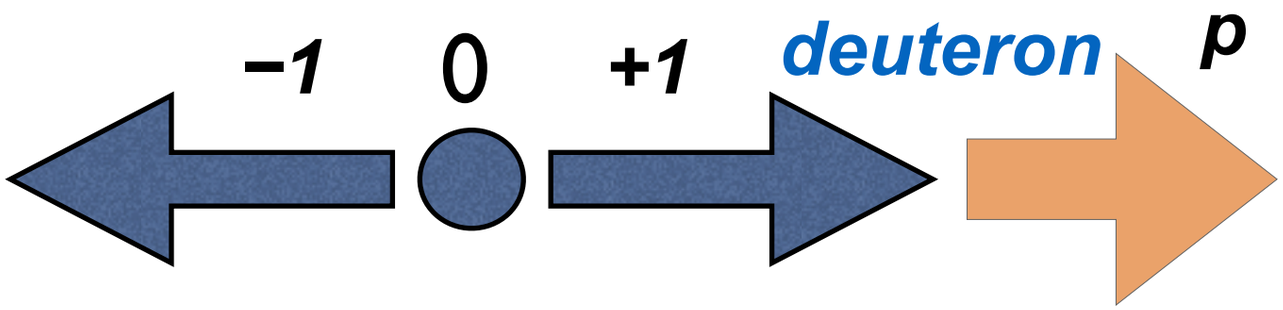


Vector polarization

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

Tensor polarization

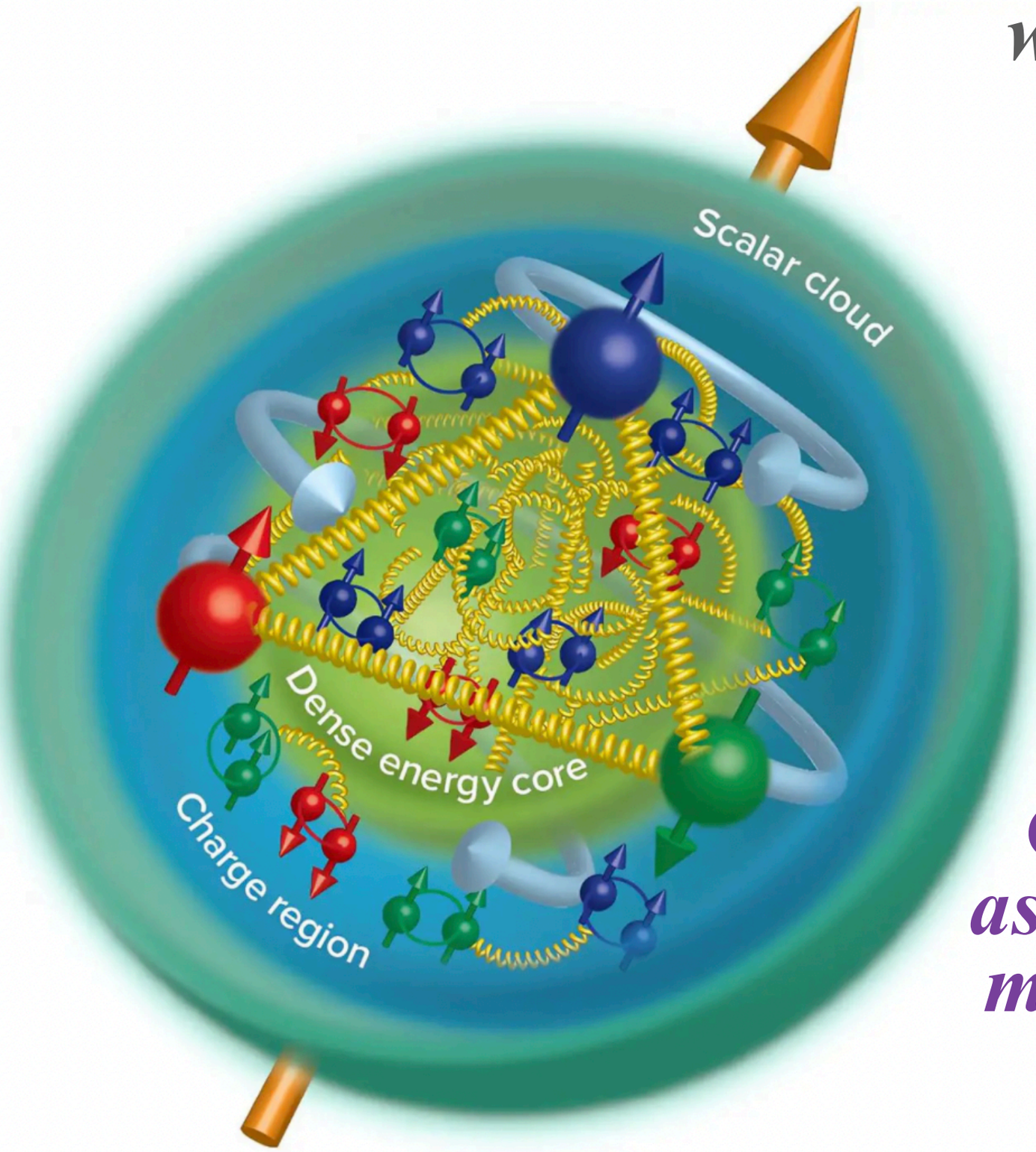
$$\frac{2N_0 - (N_{-1} + N_1)}{2N_0 + N_{1/2} + N_{-1/2}}$$



New "tensor" PDFs, mostly unknown

Gluon transversity PDF

Spin Physics @ NICA



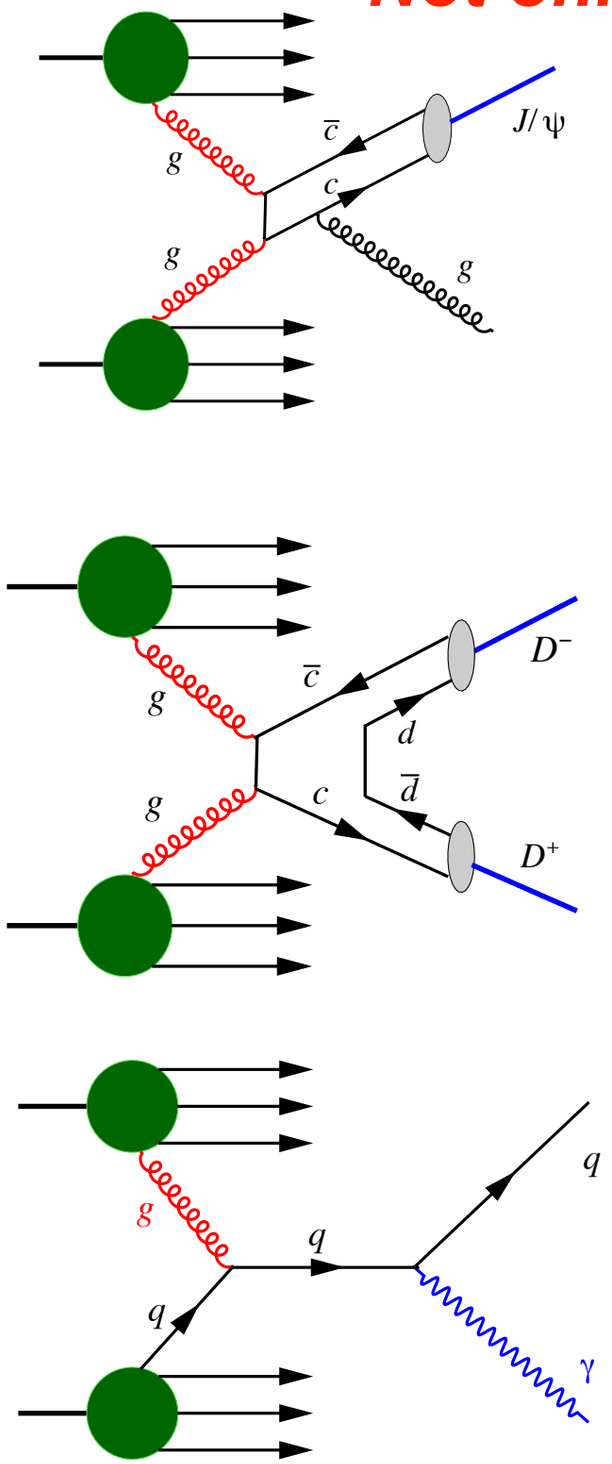
we plan to study how the proton and deuteron spin!

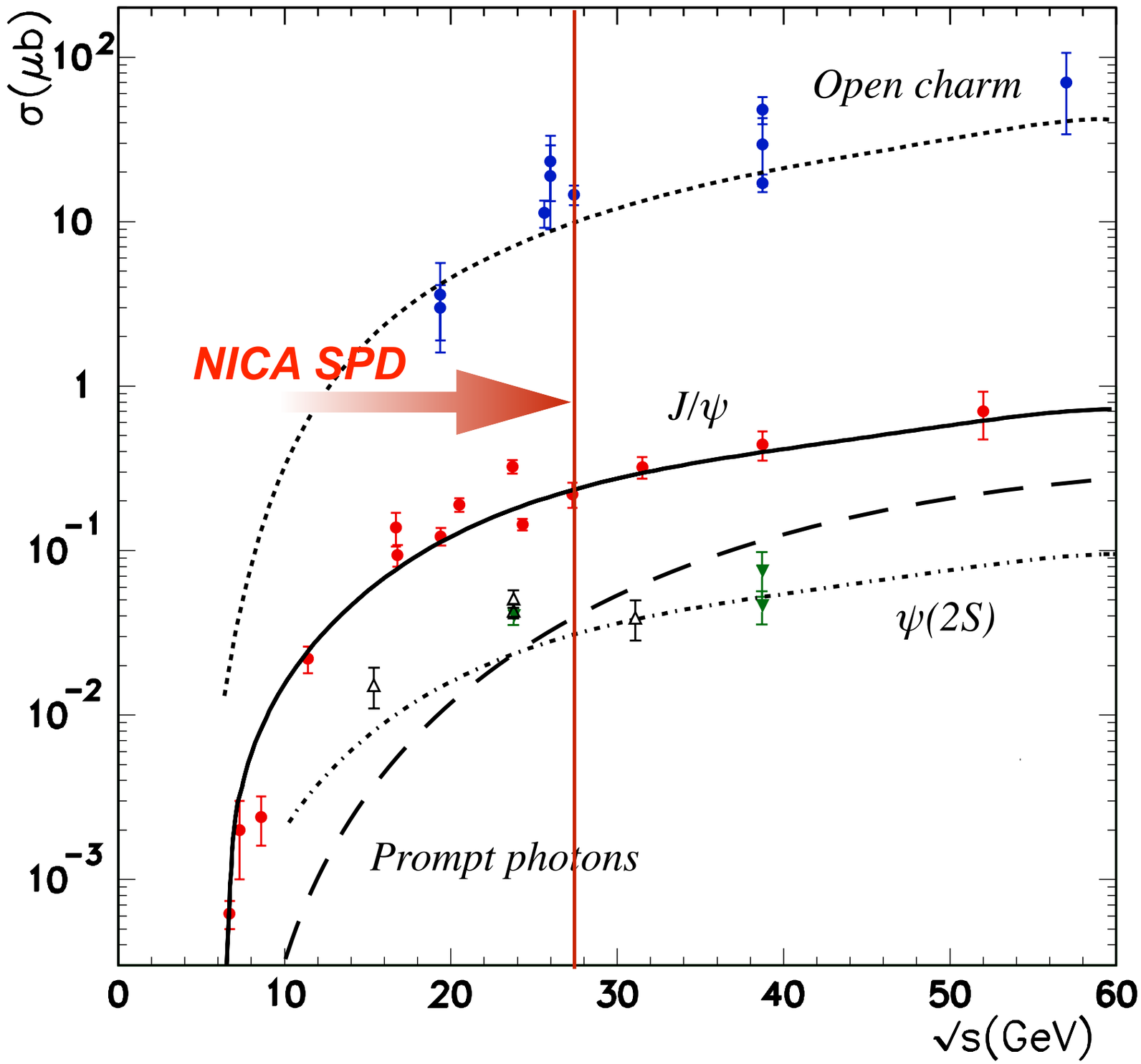
especially their gluon component!

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

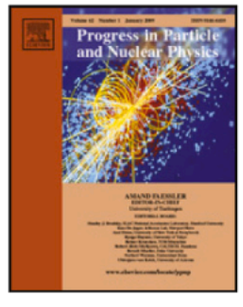
Progress in Particle and Nuclear Physics xxx (xxxx) xxx

arXiv:2011.15005

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

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



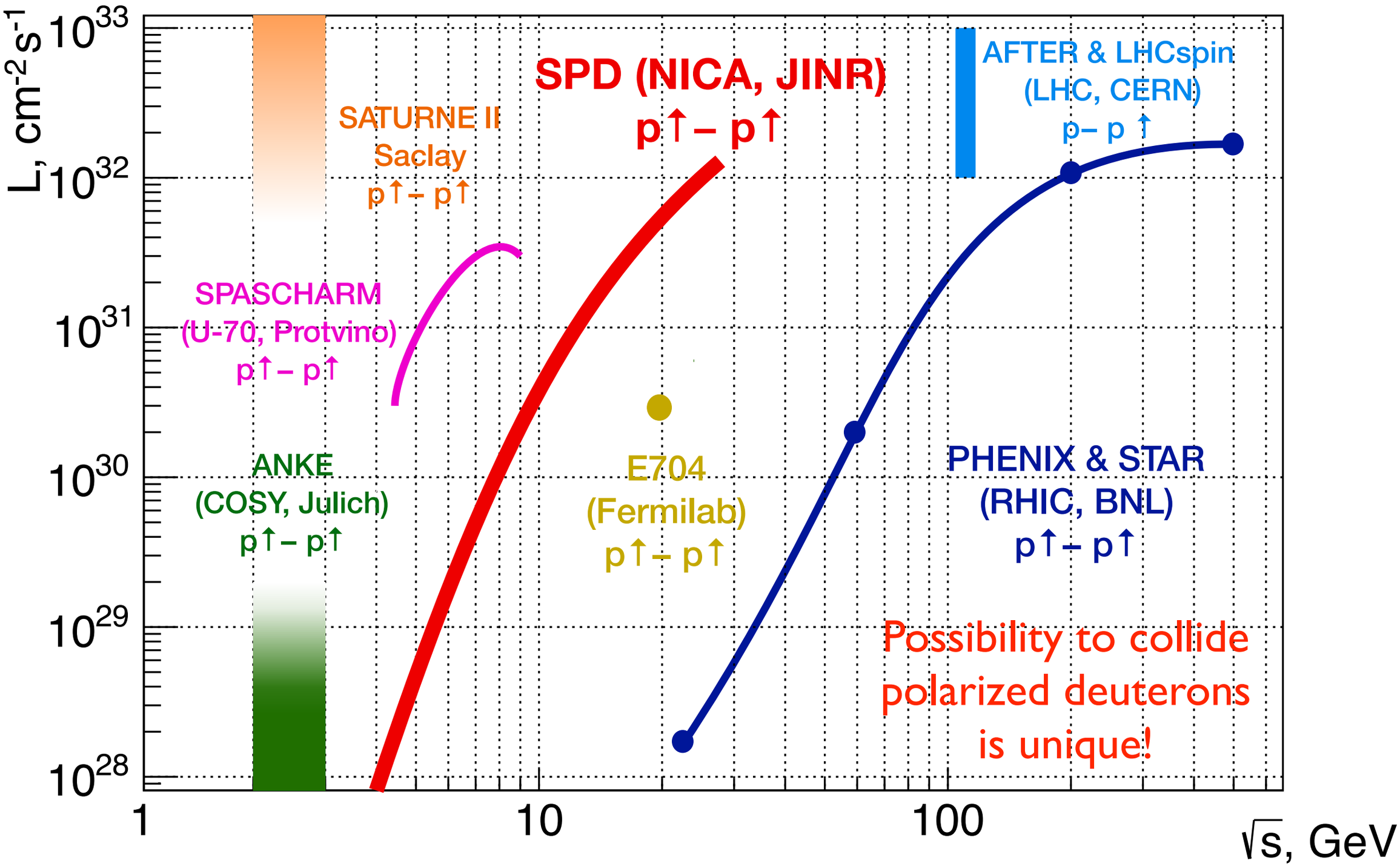
Review

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

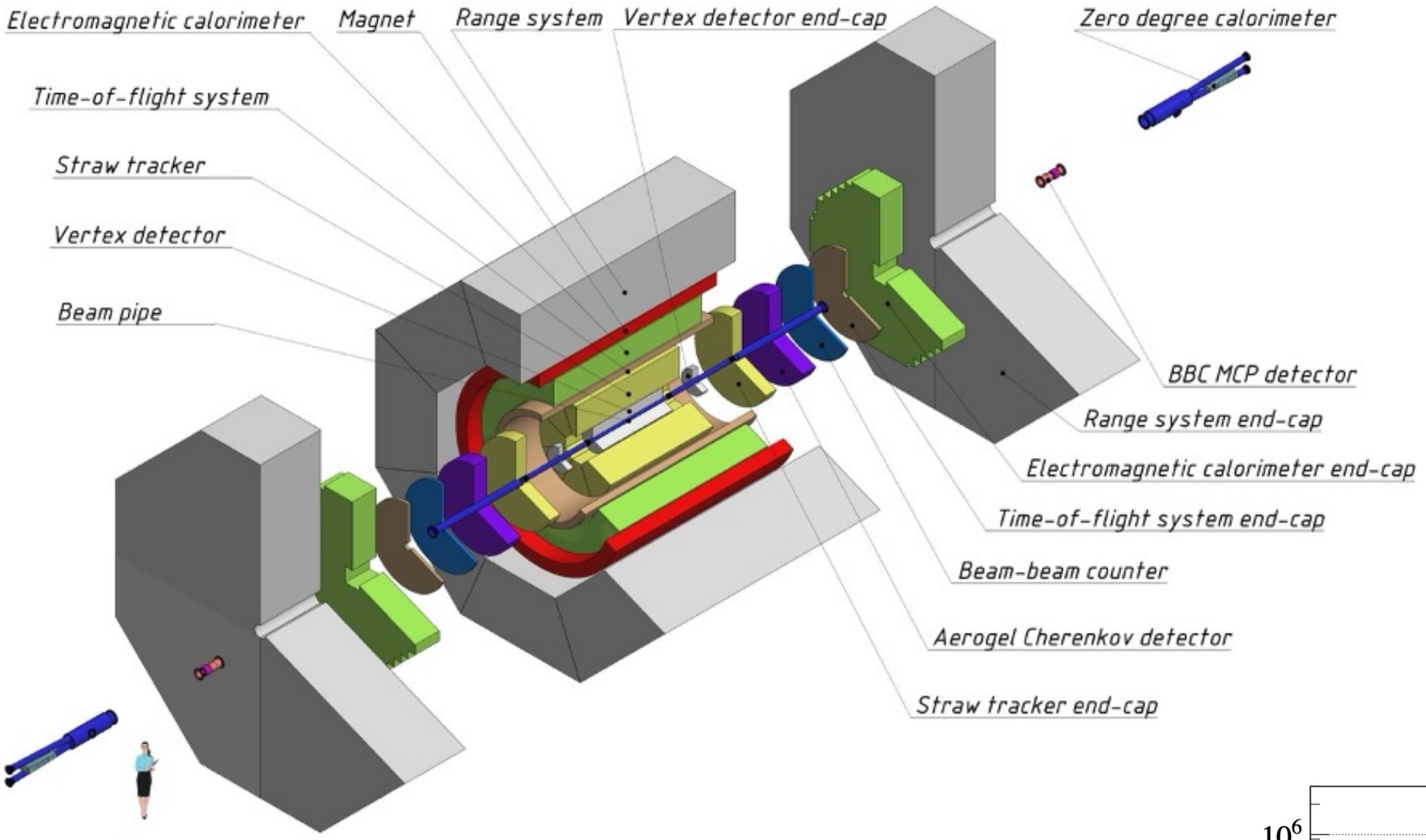
A. Arbuzov [a], A. Bacchetta [b,c], M. Butenschoen [d], F.G. Celiberto [b,c,e,f], U. D'Alesio [g,h], M. Deka [a], I. Denisenko [a], M.G. Echevarria [i], A. Efremov [a], N.Ya. Ivanov [a,j], A. Guskov [a,k,*], A. Karpishkov [l,a], Ya. Klopot [a,m], B.A. Kniehl [d], A. Kotzinian [j,o], S. Kumano [p], J.P. 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]

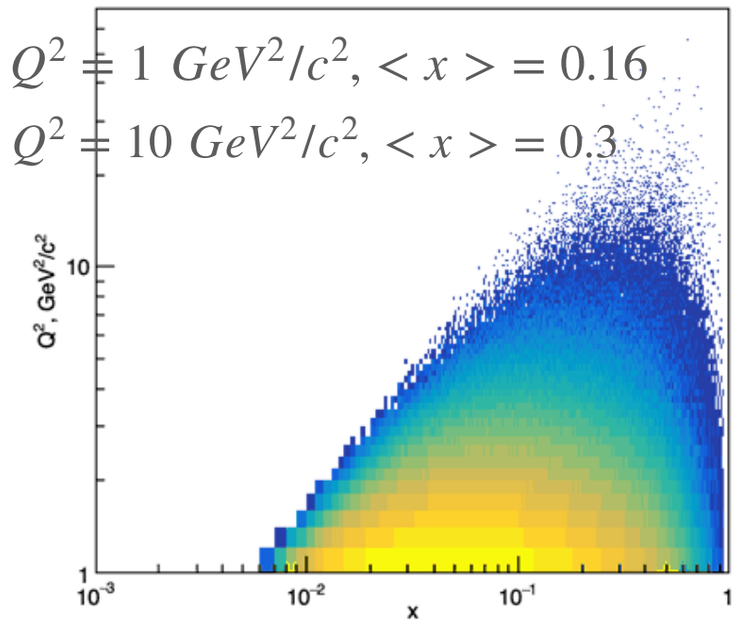
[a] *Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia*
[b] *Dipartimento di Fisica, Università di Pavia, via Bassi 6, I-27100 Pavia, Italy*
[c] *INFN Sezione di Pavia, via Bassi 6, I-27100 Pavia, Italy*
[d] *II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 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*

SPD and others



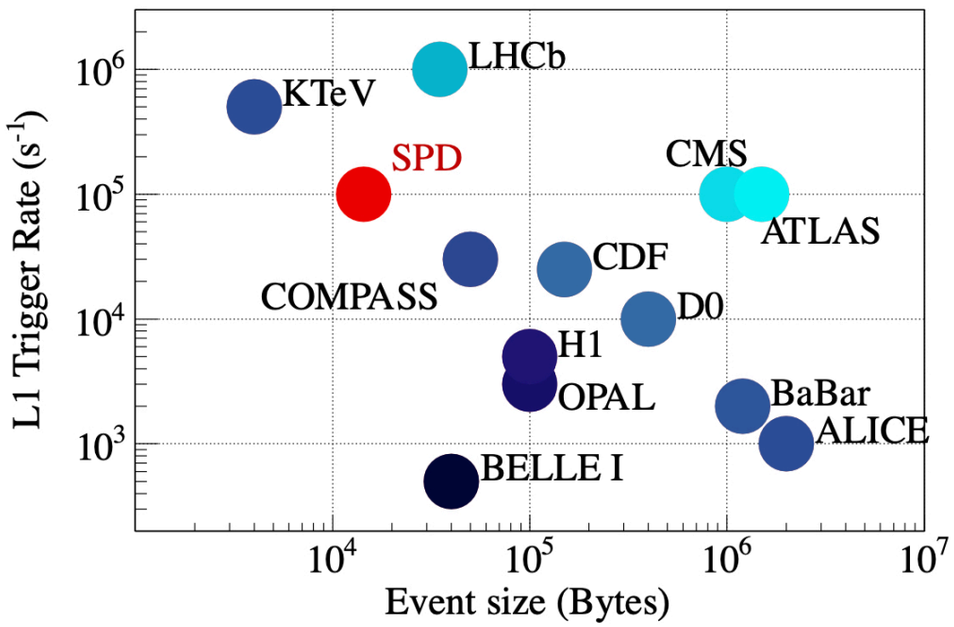
SPD setup





SPD NICA

Free-running DAQ



Physic of the first stage

arXiv:2102.08477

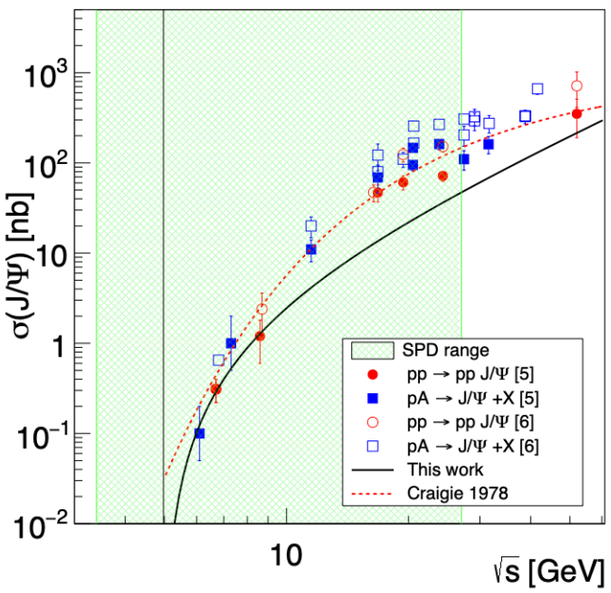
Non-perturbative QCD — *Perturbative QCD*

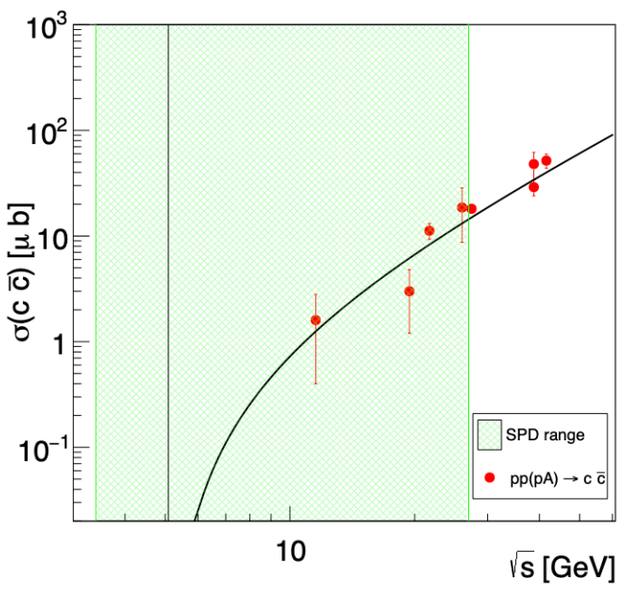
$\sqrt{s}$

- 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

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

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



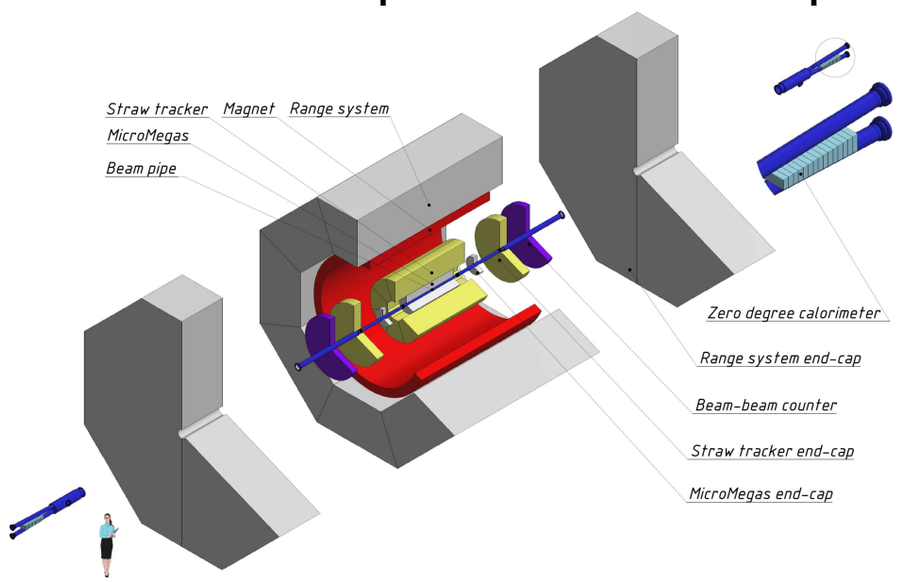


Creating of polarized infrastructure — **Upgrade of polarized infrastructure**

0 +2 +4 +6 +8 years

SPD construction — **SPD construction**

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



SPD 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
HSE University, Moscow

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

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

Proton structure: Hall of Fame

hermes

PHENIX

STAR

GLUEX

COMPASS

CLAS12

SeaQuest
E906

SPIN
QUEST

SoLID

sPHENIX

AFTER

LHC spin

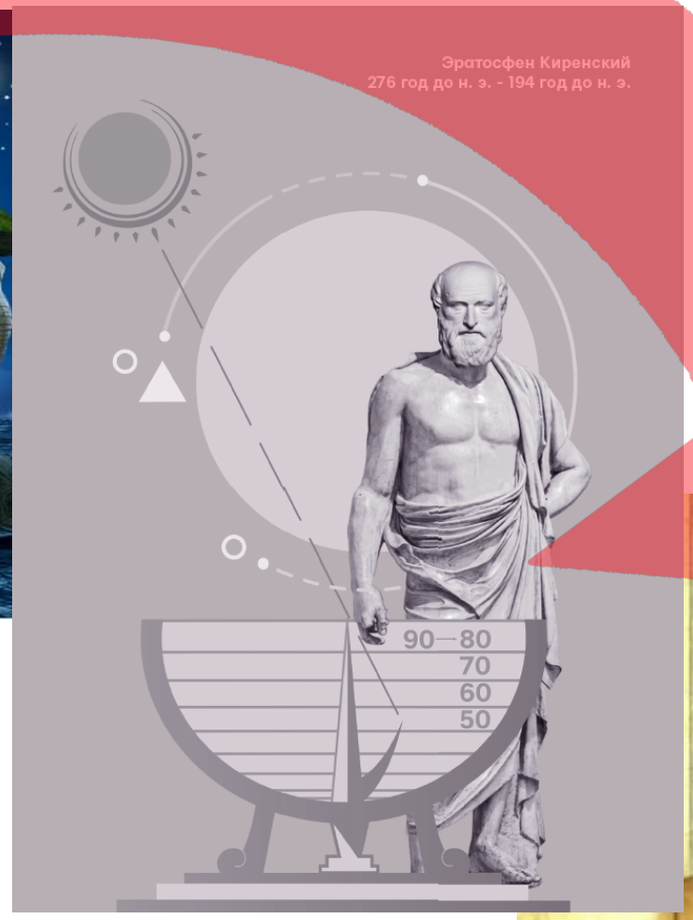
AMBER

SPD
NICA

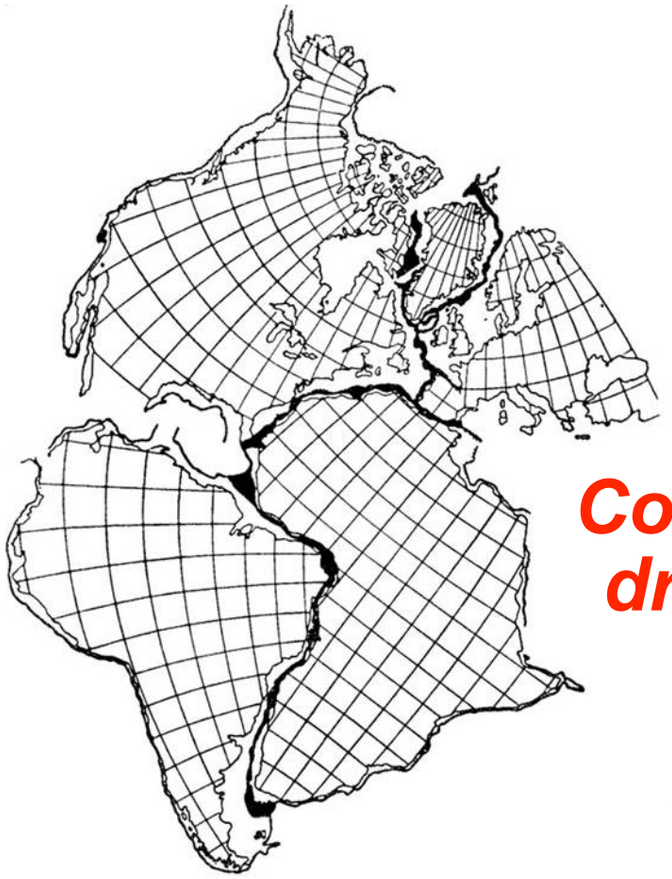
ECCE

Growth of Knowledge

Naive concepts



The Earth is a sphere!
II century B.C.



Continental drift, 1912

Age of Discoveries, XV-XIX centuries