Статус эксперимента SPD на ускорительном комплексе NICA

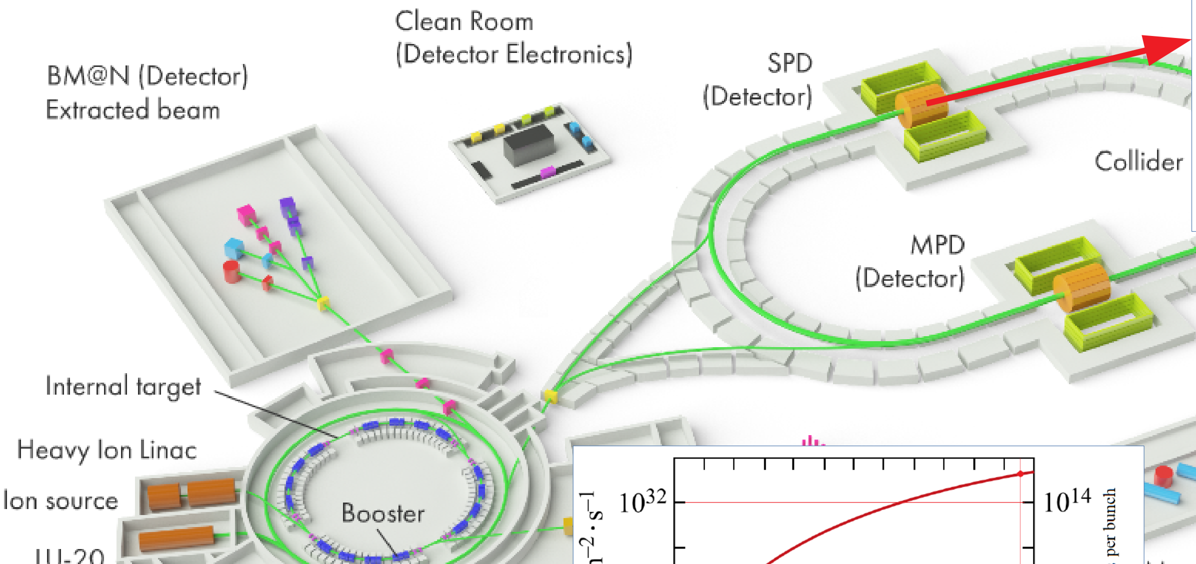
Игорь Денисенко
iden@jinr.ru

57-я Зимняя Школа НИЦ КИ ПИЯФ

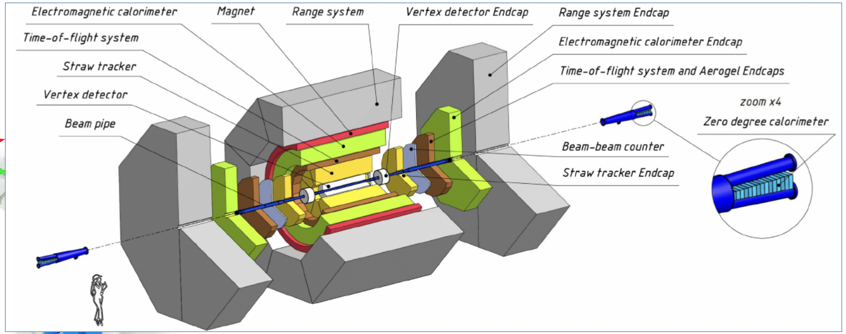
18.03.2025

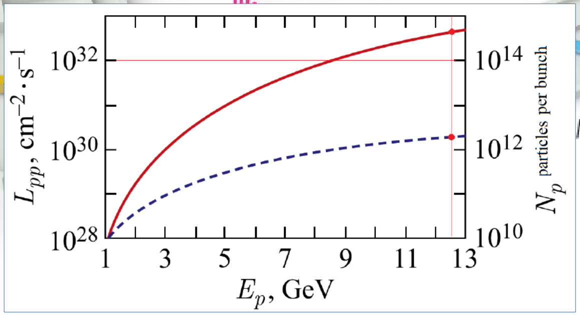
Nuclotron-based **I**on **C**ollider f**A**cility (NICA)

Joint Institute for Nuclear Research (Dubna)



Spin **P**hysics **D**etector (SPD)





Polarized beams

p$^{\uparrow}$**p**$^{\uparrow}$at $\sqrt{s_{pp}}$ ≤ **27 GeV, L**$_{av}$ ≈ **10**^{32} **cm**$^{-2}$**s**$^{-1}$

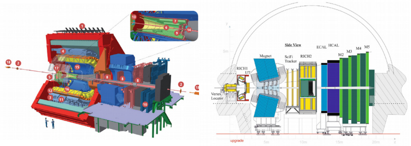
d$^{\uparrow}$**d**$^{\uparrow}$at $\sqrt{s_{NN}}$ ≤ **13.5 GeV**

p$^{\uparrow}$**d**$^{\uparrow}$at $\sqrt{s_{NN}}$ ≤ **19 GeV**

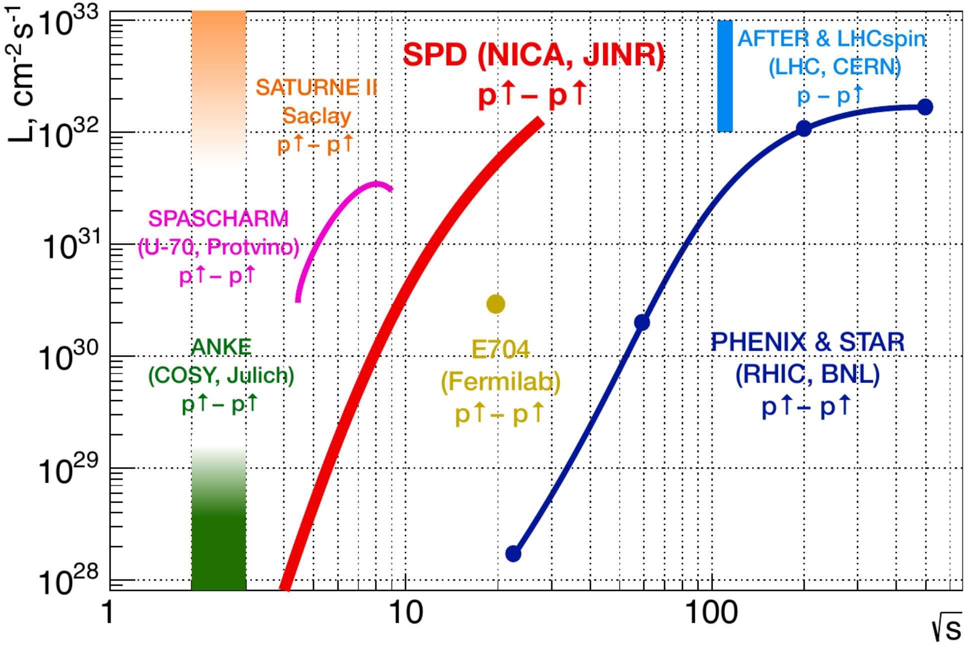
longitudinal and transverse polarization (UU, LL, TT, UT, LT) > 70%

Operation: after **2028**

NICA and other facilities



SPD CDR (arXiv:2102.00442)



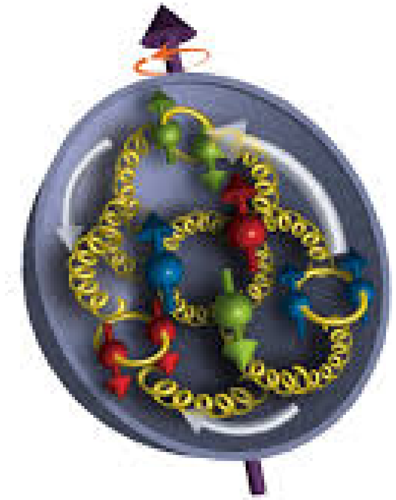
$p^{\uparrow}p^{\uparrow}$ collision mode

Experimental facility	SPD @NICA [30]	RHIC [29]	EIC [26]	AFTER @LHC [24]	SpinLHC [25]
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^{\uparrow}$-$p^{\uparrow}$ $d^{\uparrow}$-$d^{\uparrow}$ $p^{\uparrow}$-d, p-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, $^3He^{\uparrow}$	p-$p^{\uparrow}$, $d^{\uparrow}$	p-$p^{\uparrow}$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	$\leq$27 (p-p) $\leq$13.5 (d-d) $\leq$19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	$\sim$1 (p-p) $\sim$0.1 (d-d)	2	1000	up to $\sim$10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025

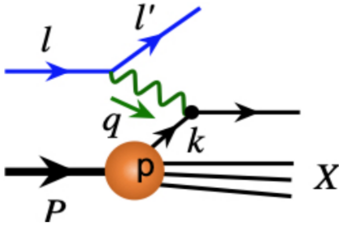
NICA is unique for double polarized $d^{\uparrow}d^{\uparrow}$ collisions at these energies.

Hadron structure

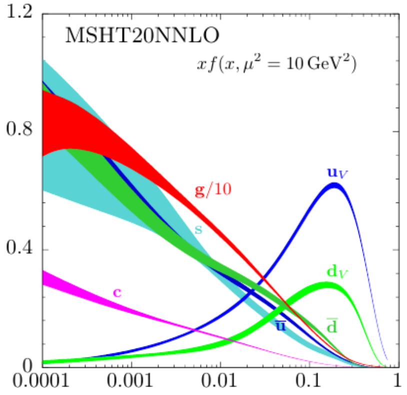
- Without understanding how bound states are formed in QCD we can’t say we understand this theory.
- Exploring hadron structure is way to understand how hadrons are build in terms of the fundamental degrees of freedom in QCD.
- Nucleons are the fundamental building blocks of nature, which make up essentially all visible matter in the universe.
- Nucleons has complex and dynamic internal structure to be reviled in modern experiments.



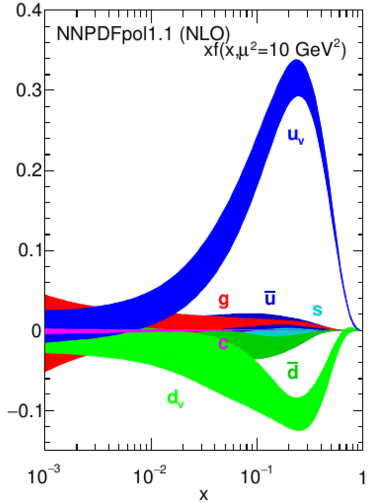
Collinear nucleon structure



$$E' \frac{d\sigma_{ep\to e'X}}{d^3 l'} \approx \sum_i \int d\xi\, f_{i/p}(\xi)\, E' \frac{d\hat{\sigma}_{ei\to e'X}}{d^3 l'}$$



- DIS process and QCD factorization
- collinear PDFs $f_{i/p}$ can be interpreted as probability densities of partons (quarks and gluons) carrying momentum fraction ξ *(usually x)* in hadron
- Polarized PDFs depend on nucleon spin (unpolarized, helicity and transversity PDFs)
    - $\Delta f_i = f_i^{\rightarrow} - f_i^{\leftarrow}$ (longitudinally polarized proton)
    - $h_{1i} = f_i^{\uparrow} - f_i^{\downarrow}$ (transversely polarized proton)



Spin crises: how spin of nucleon is build from its constituents?

Infinite-momentum frame decomposition
(Jaffe-Manohar sum rule)

$$J = \frac{1}{2}\Delta\Sigma + L_q^{JM} + \Delta G + L_G,$$

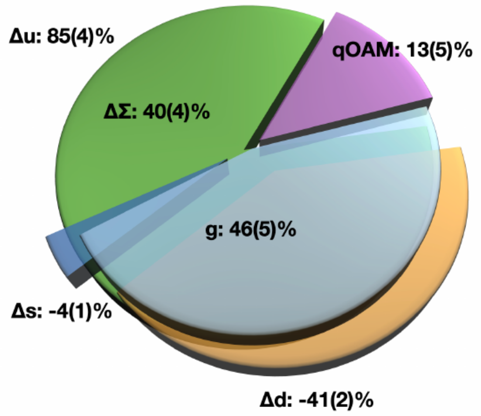
$q, \bar{q}$ spin (valence and sea) | $q, \bar{q}$ OAM | gluons spin | gluons OAM

Frame independent decomposition
(Ji's sum rule)

$$J = \frac{1}{2}\Delta\Sigma + L_q^{Ji} + J_G,$$

gluons total AM

Lattice calculations
arXiv:2112.08416



- ~38-46% gluons
- ~13-18% from quark OAM

(with very large uncertainties)

- EMC experiment $\Rightarrow \int_0^1 dx\Delta\Sigma(x) \approx 0.06$

[E. Leader and M. Anselmino, Z. Phys. C 41 , 239 (1988)]

- COMPASS, HERMES $\Rightarrow \int_0^1 dx\Delta\Sigma(x) \approx 0.3$

[V. Y. Alexakhin et al. (COMPASS Collaboration), Phys.Lett. B 647, 8 (2007)]
[A. Airapetian et al. (HERMES Collaboration), Phys.Rev. D 75, 012007 (2007)]

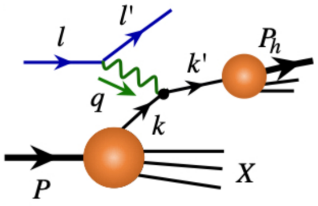
- PHENIX, STAR, COMPASS $\Rightarrow \int_{0.05}^{0.2} dx\Delta G(x) \approx 0.2$

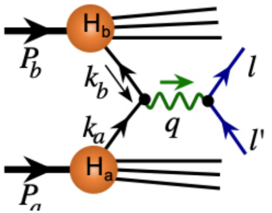
[D. de Florian et al (DSSV Collaboration). Phys Rev. Lett. 113, 012001 (2014)]
[E. R. Nocera et al. (NNPDF Collaboration), Nuc. Phys. B 887, 276 (2014)]

Most of the slide taken from Llilet Calerdo Dias (IWHSS-CPHI24)

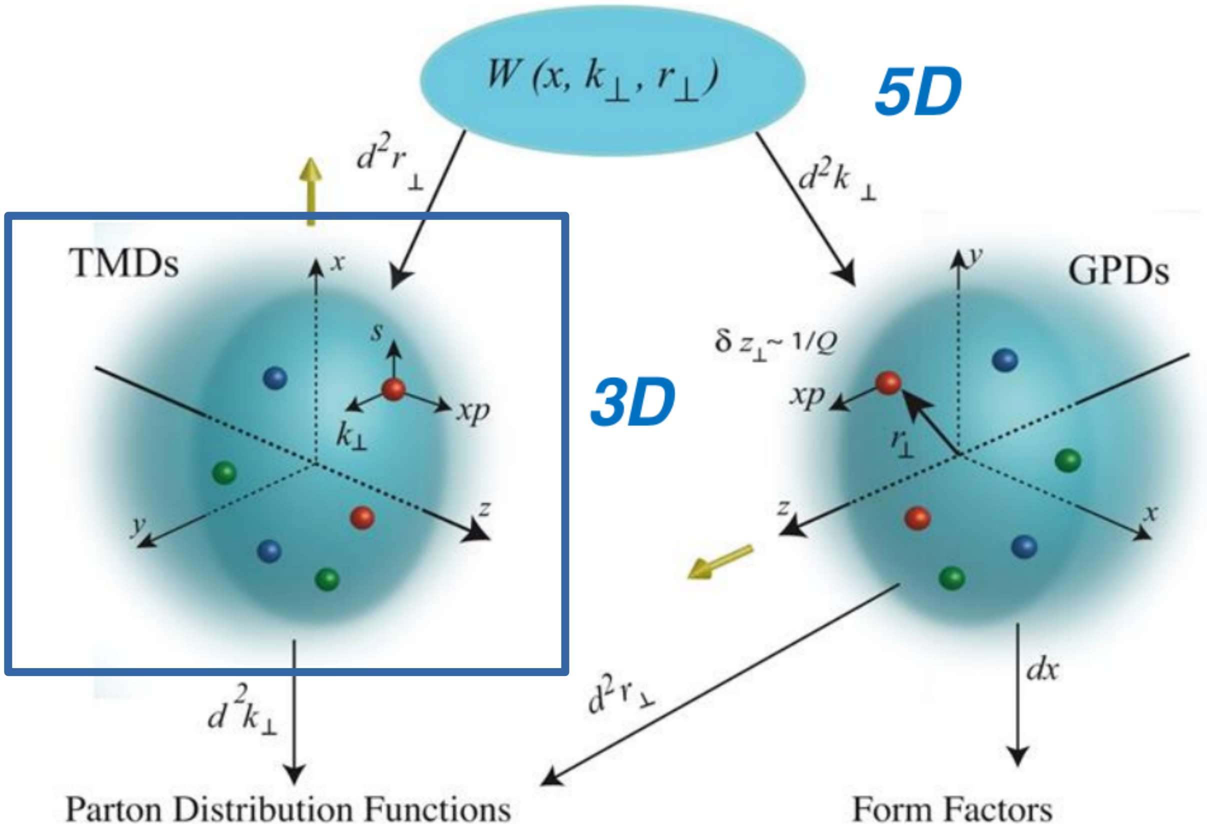
Nucleon tomography

For quarks:





For gluons see next slides!



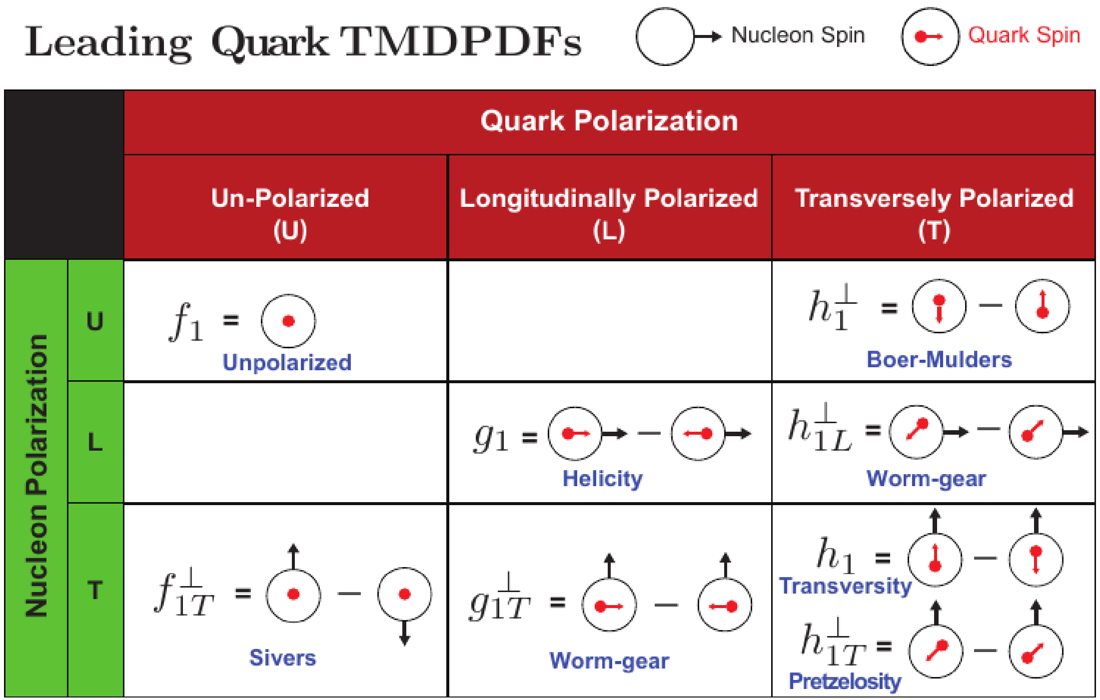
DVCS, DVMP,...

Figure credit: J.-P. Cheng

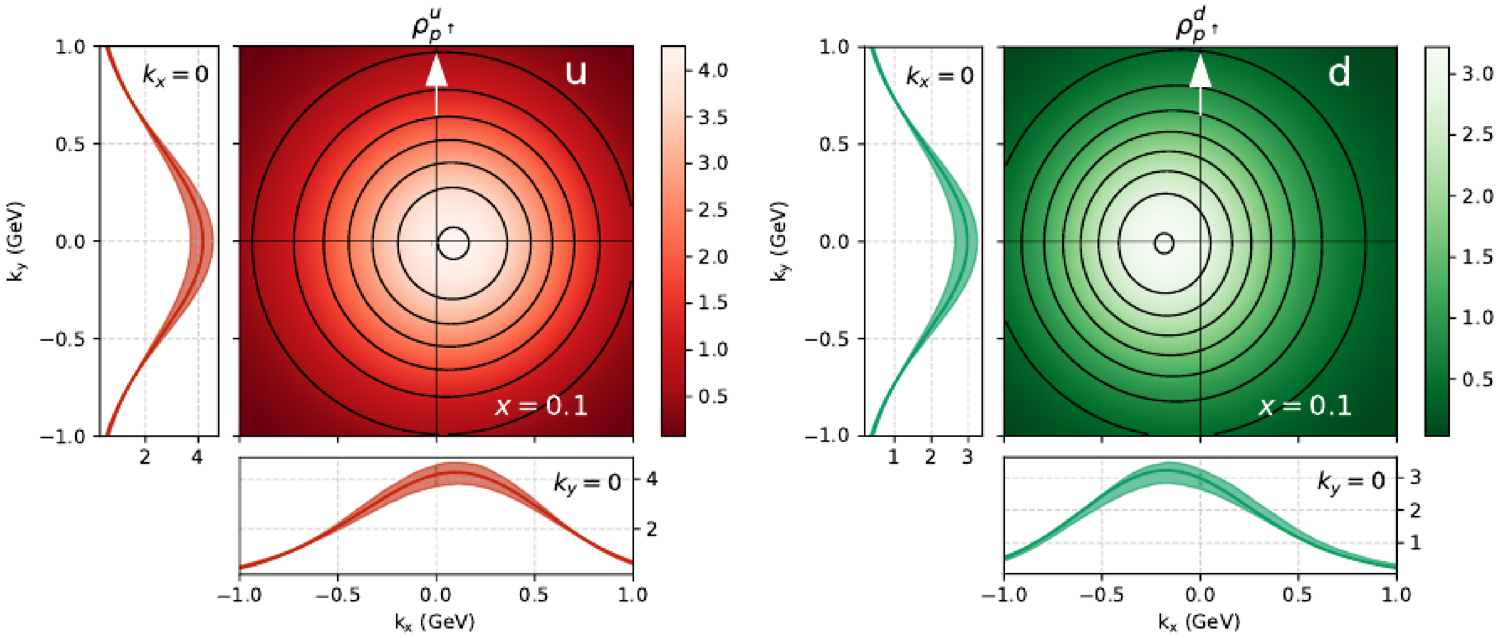
TMD distributions

- QCD factorization for TMD PDFs is proven for some processes (DY, SIDIS, higgs production,…)

- **Significant progress** on **quark TMD**s over the last decades (for details see e.g. TMD Handbook, PLB 827, 136961 (2022))

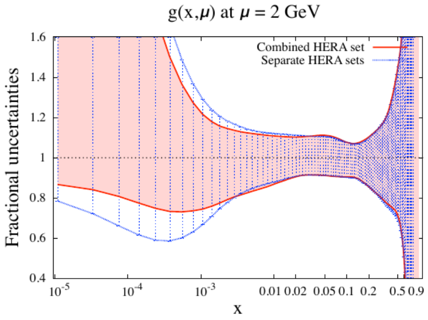


Quark TMDs

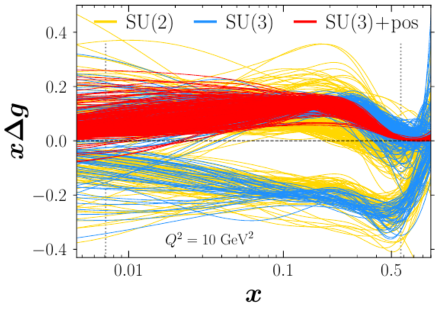


The density distribution of an unpolarized quark with flavor a in a proton polarized along the +y direction and moving towards the reader as a function of (k_x , k_y) at Q^2 = 4 GeV^2 (PLB 827, 136961 (2022))

What do we know about gluons?



Uncertainty of unpolarized gluon PDF based on HERA data PRD82, 074024 (2010)



Extraction of gluon helicity distributions by the JAM Collaboration (2022)

Alessandro Bacchetta at IWHSS-CPHI24:

- Good knowledge of x-dependence of f_1 and g_{1L}
- Some hints on the k_T dependence of f_1

Our knowledge on gluon TMD remains rather scarce.

gluon pol.

nucleon pol.	U	circular	linear
U	f_1^g		$h_1^{\perp g}$
L		g_1^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	$h_1^g, h_{1T}^{\perp g}$

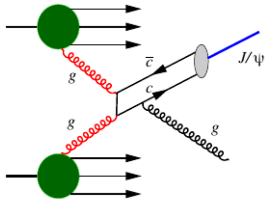
Leading twist gluon TMD PDFs
(**two times more** due to proper gauge link choice)

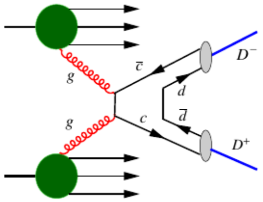
h^g_1 is nonzero only for deuteron.

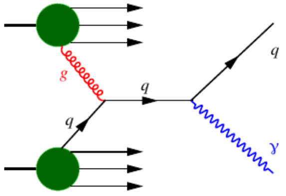
Gluon TMDs and the SPD experiment

Main goal of the experiment – spin-dependent gluon structure of proton and deuteron.

- Three probes of gluon structure chosen in this energy range:







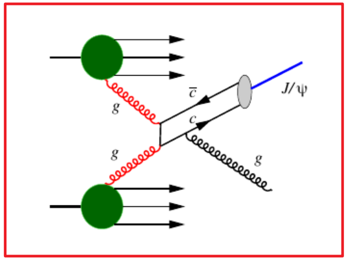
- Measurements at SPD should help to improve our understanding of QCD and resolve spin crisis.
- Many other aspects of QCD to be studied in such collisions.

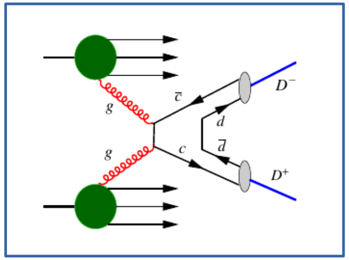
gluon pol.

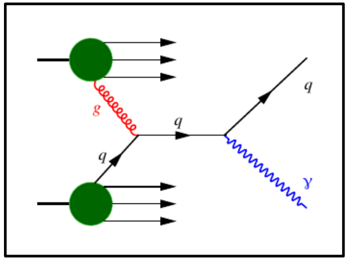
nucleon pol.	U	circular	linear
U	f_1^g		$h_1^{\perp g}$
L		g_1^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	h_1^g, $h_{1T}^{\perp g}$

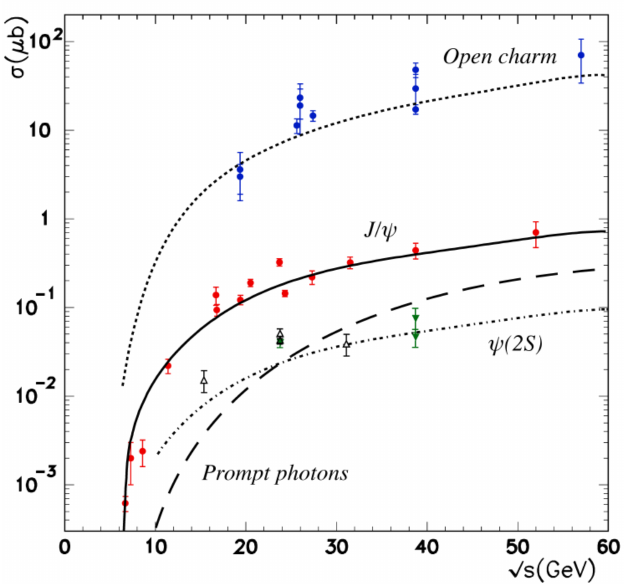
h^g_1 is nonzero only for deuteron.

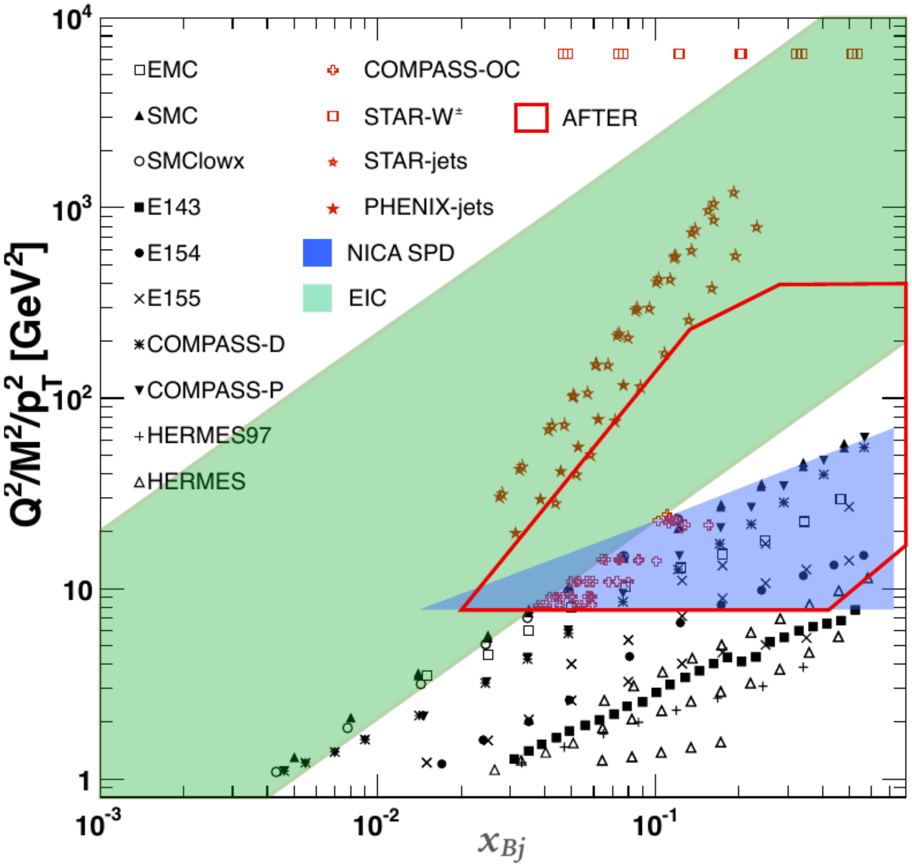
SPD kinematic coverage





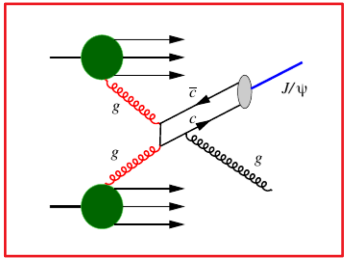


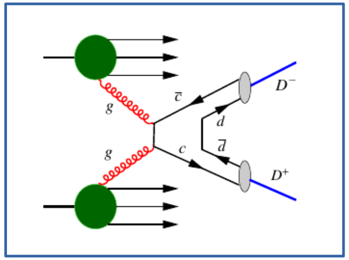


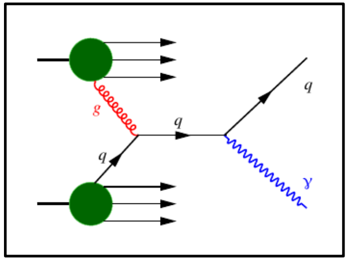


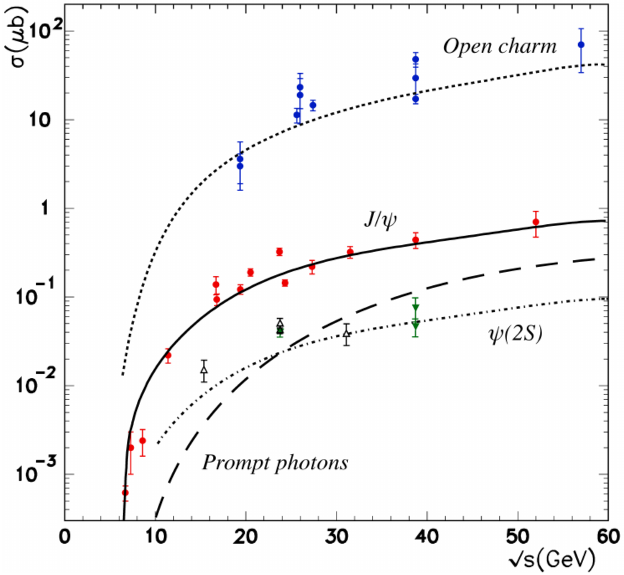
arXiv:2011.15005

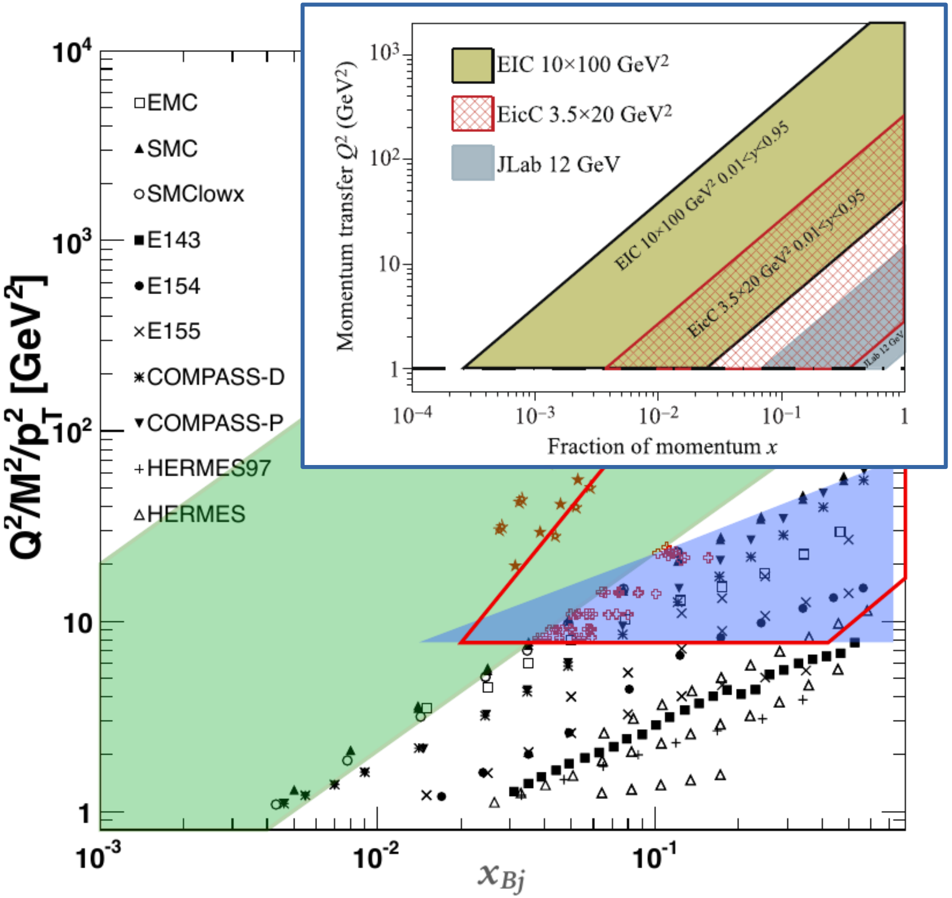
SPD kinematic coverage





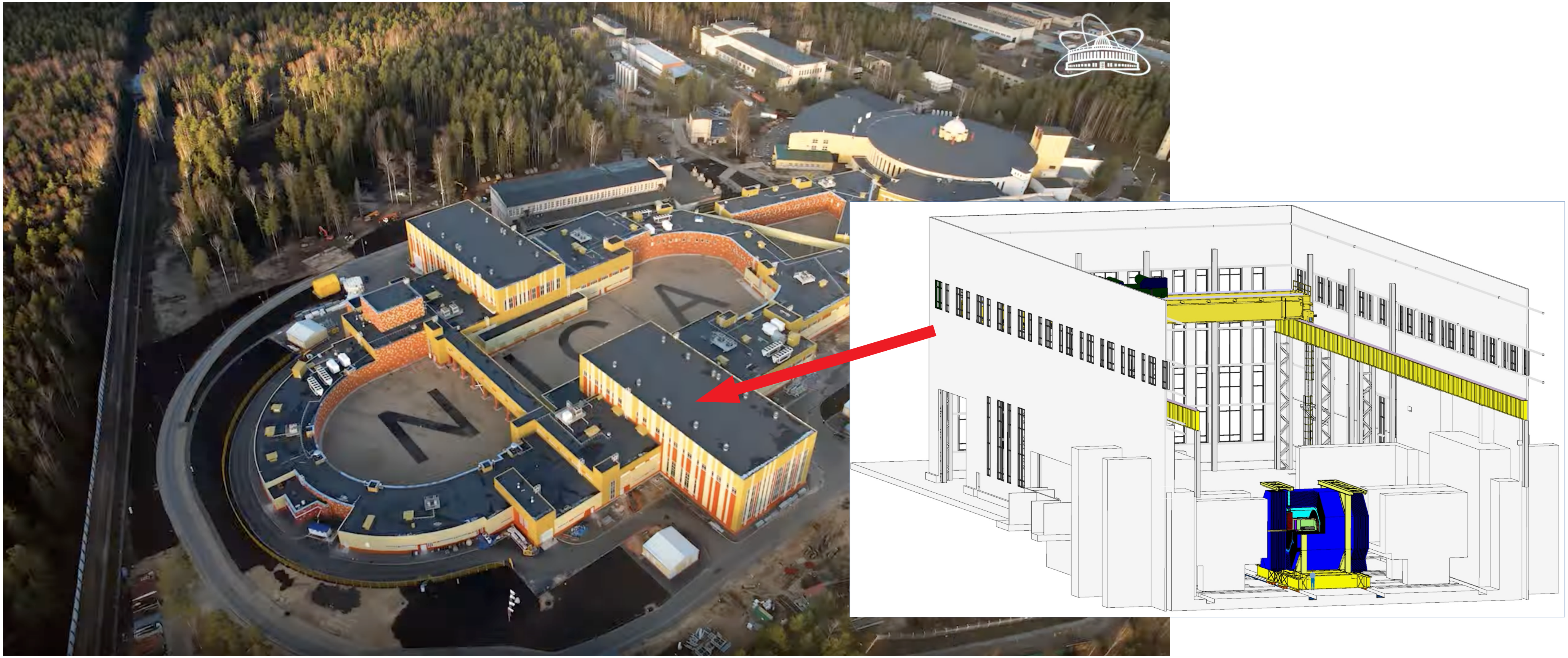




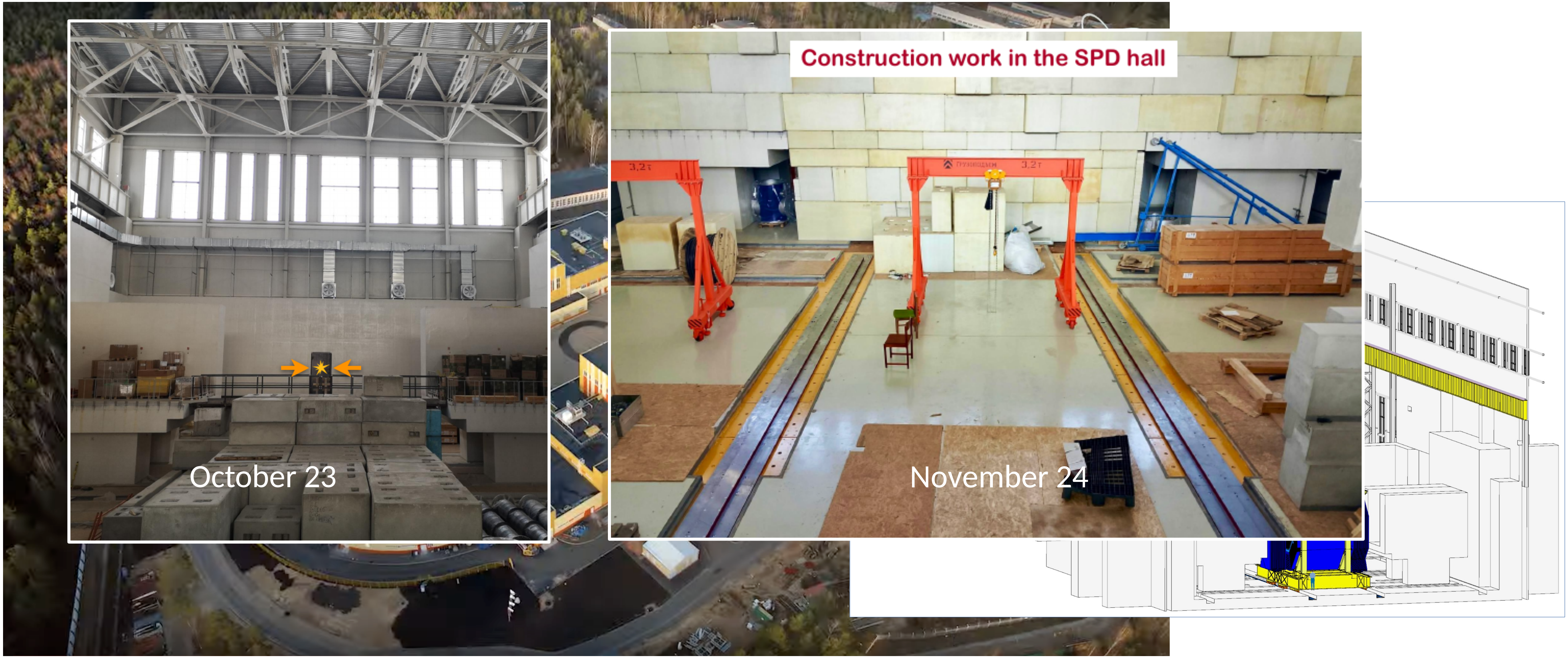


arXiv:2011.15005

Construction site



SPD hall

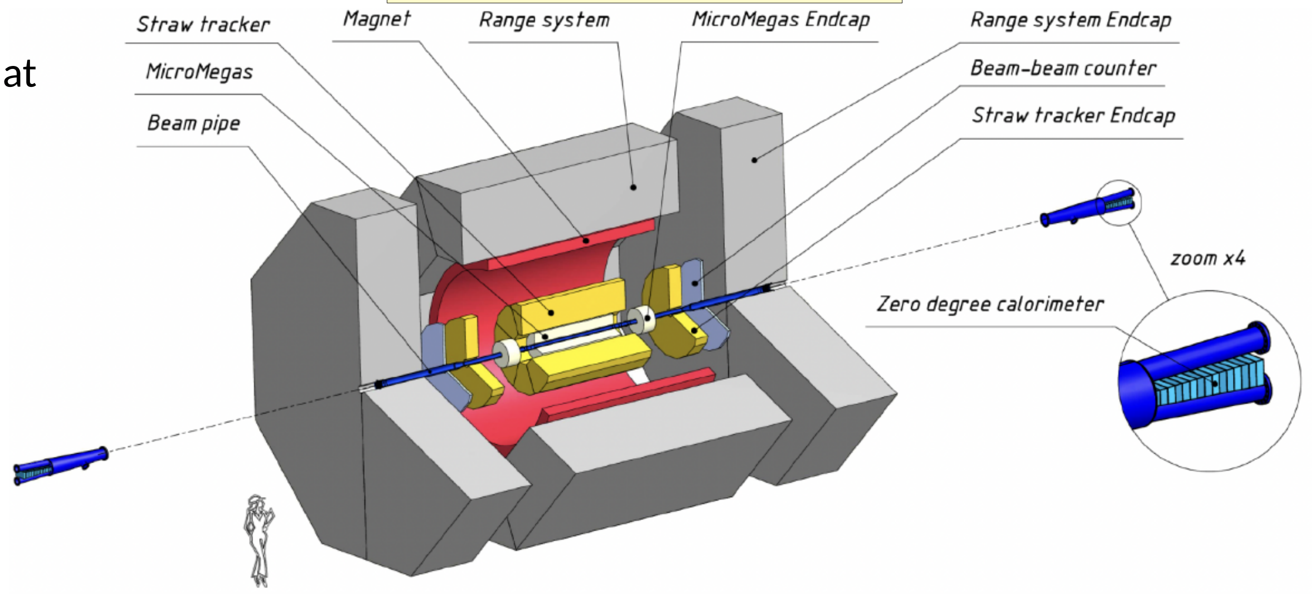


SPD initial stage

SPD TDR: Natural Science Review 1 1 (2024) (arXiv:2404.08317)

Magnetic field up to **1.2 T**

- Polarized and unpolarized phenomena at **low energies** (3.4 GeV < $\sqrt{s_{pp}}$ < 9.4 GeV) and **reduced luminosity**
- p-p, d-d, and ion collisions (up to Ca)
- Simplified detector set-up
- Up to 2 years of data taking



Range System
muon identification and coarse hadron calorimetry

Straw tracker:
- **σ ~ 150 μm**
- **σ(dE/dx) = 8.5%**

Micromegas central tracker:
σ ~ 150 μm

BBC and **ZDC** for online polarimetry

SPD initial stage

Physical program:

- spin effects in p-p and d-d scattering
- spin effects in hyperon production
- multiquark correlations
- color transparency in quasi elastic pd
- large pT hadron production to study diquark structure of proton
- dibaryon resonances
- hypernuclei
- physics of light and intermediate nuclei collisions
- open charm and charmonia production near threshold
- antiproton production measurements for astrophysics and BSM search
- ...

ISSN 1063-7796, Physics of Particles and Nuclei, 2021, Vol. 52, No. 6, pp. 1044–1119. © Pleiades Publishing, Ltd., 2021.

Possible Studies at the First Stage of the NICA Collider Operation with Polarized and Unpolarized Proton and Deuteron Beams

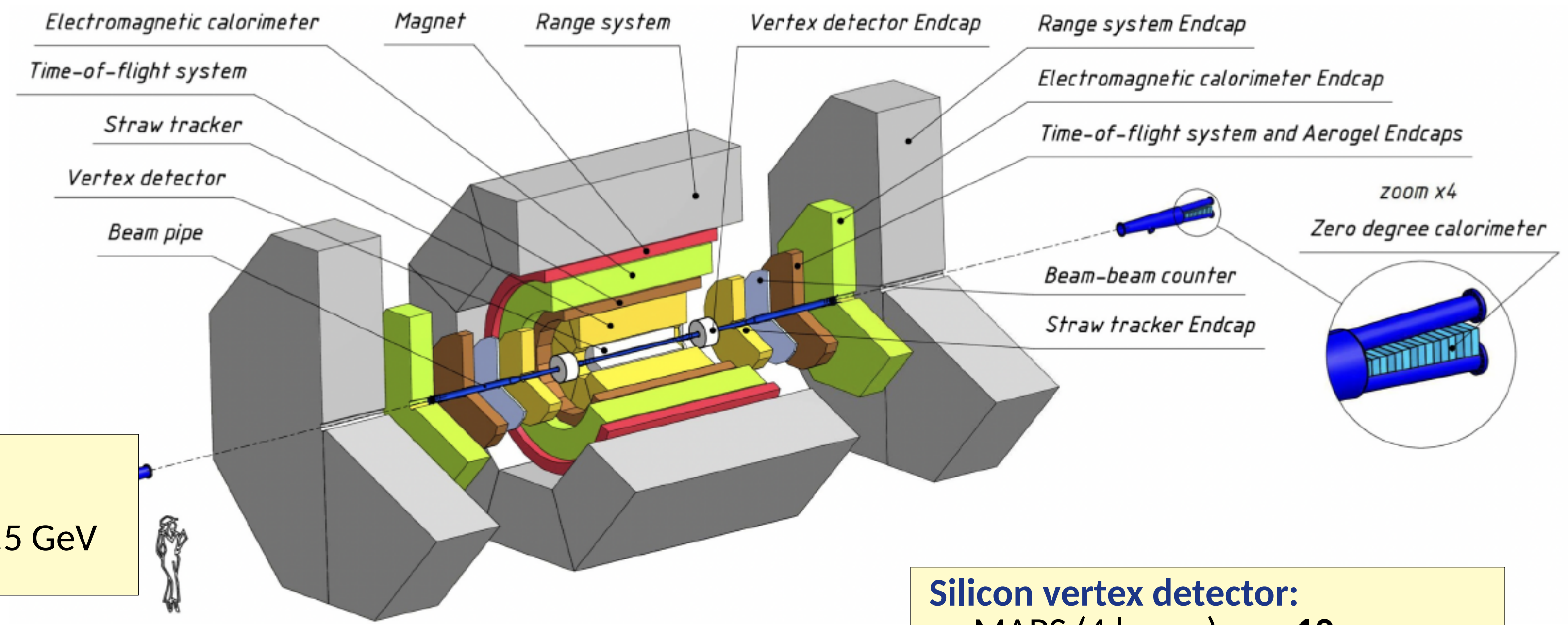
V. V. Abramov[a], A. Aleshko[b], V. A. Baskov[c], E. Boos[b], V. Bunichev[b], O. D. Dalkarov[c], R. El-Kholy[d], A. Galoyan[e], A. V. Guskov[f], V. T. Kim[g, h], E. Kokoulina[e, i], I. A. Koop[k, l, m], B. F. Kostenko[m], A. D. Kovalenko[e, †], V. P. Ladygin[e], A. B. Larionov[o, n], A. I. L'vov[c], A. I. Milstein[j, k], V. A. Nikitin[e], N. N. Nikolaev[p, z], A. S. Popov[j], V. V. Polyanskiy[c], J.-M. Richard[q], S. G. Salnikov[j], A. A. Shavrin[r], P. Yu. Shatunov[j, k], Yu. M. Shatunov[j, k], O. V. Selyugin[n], M. Strikman[s], E. Tomasi-Gustafsson[t], V. V. Uzhinsky[m], Yu. N. Uzikov[f, u, v, *], Qian Wang[w], Qiang Zhao[x, y], and A. V. Zelenov[g]

[a] *NRC "Kurchatov Institute"—IHEP, Protvino, Moscow oblast, 142281 Russia*
[b] *Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, 119991 Russia*
[c] *Lebedev Physical Institute, Moscow, 119991 Russia*
[d] *Astronomy Department, Faculty of Science, Cairo University, Giza, 12613 Egypt*
[e] *Veksler and Baldin Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, Moscow oblast, 141980 Russia*
[f] *Dzhelepov Laboratory of Nuclear problems, Joint Institute for Nuclear Researches, Dubna, Moscow oblast, 141980 Russia*
[g] *Petersburg Nuclear Physics Institute, NRC KI, Gatchina, Russia*
[h] *St. Petersburg Polytechnic University, St. Peterburg, Russia*
[i] *Sukhoi State Technical University of Gomel, Gomel, 246746 Belarus*
[j] *Budker Institute of Nuclear Physics of SB RAS, Novosibirsk, 630090 Russia*

Physics of Particles and Nuclei 52, 1044 (2021) arXiv:2102.08477

SPD final layout

SPD TDR: Natural Science Review 1 1 (2024) (arXiv:2404.08317)



Electromagnetic calorimeter:
$\sigma E/E = 5\%/\sqrt{E} \oplus 1\%$

Time of flight system:
σ = 50 ps
3σ π/K separation for p < 1.5 GeV

FARICH in *endcaps* for pion/kaon separation for particle momentum up to **5.5 GeV**

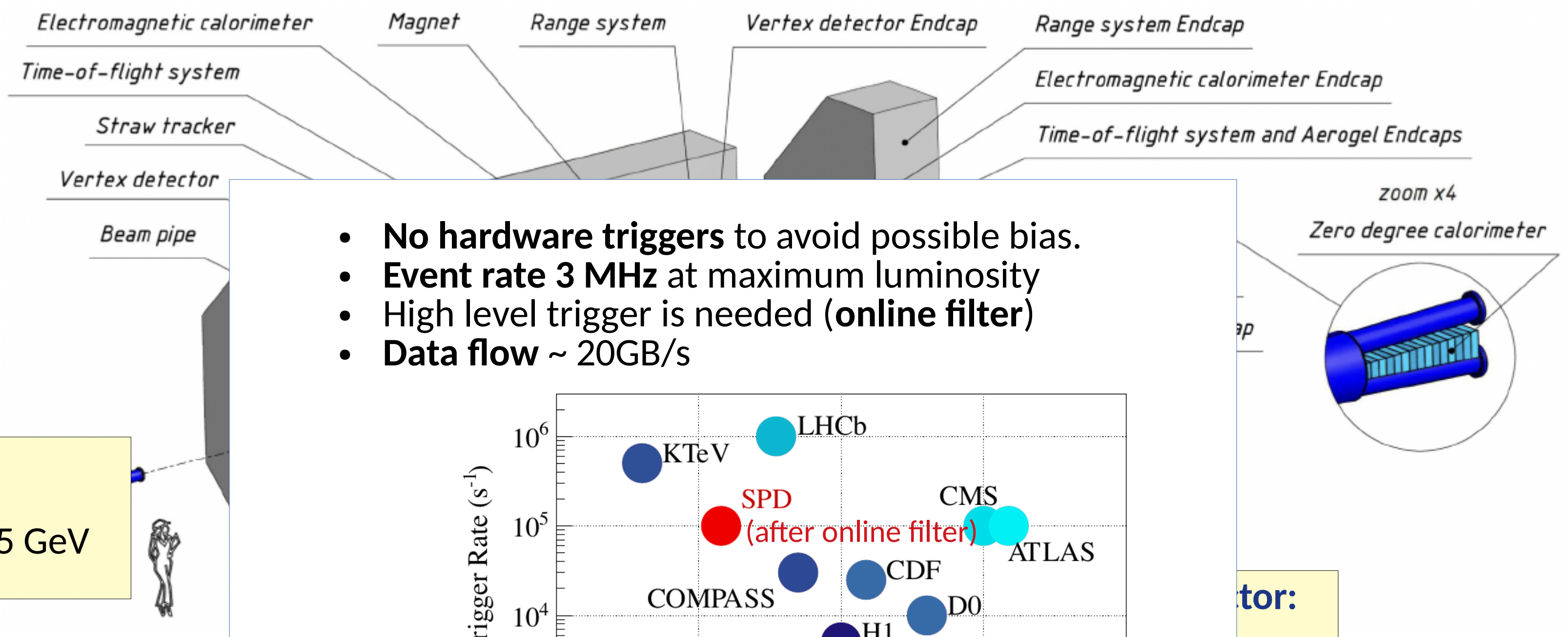
Silicon vertex detector:
- MAPS (4 layers): **σ = 10 μm**
- DSSD (3 layers): **σ_φ = 27.4 μm, σ_z = 81.3 μm**

SPD final layout

SPD TDR can be found at http://spd.jinr.ru/spd-cdr/

Electromagnetic calorimeter:
$\sigma E/E = 5\%/\sqrt{E} \oplus 1\%$

Time of flight system:
σ = 50 ps
3σ π/K separation for p < 1.5 GeV



- **No hardware triggers** to avoid possible bias.
- **Event rate 3 MHz** at maximum luminosity
- High level trigger is needed (**online filter**)
- **Data flow** ~ 20GB/s

Threshol
for pion k
range **1.0**

tor:
µm,
µm

SPD 2-nd stage

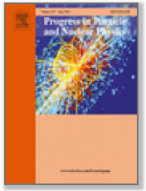
Physical program:

- unpolarized and polarized proton and deuteron structure:
  - gluon helicty
  - gluon TMDs (Sivers and Boer-Mulders)
  - gluon transversity and tensor polarized gluon distribution in deuteron
  - unpolarized proton and deuteron gluon PDF at high x
  - non-nucleonic degrees of freedom in deuteron…
- tests of QCD factorization
- charmonia production mechanisms
- …

ELSEVIER

Progress in Particle and Nuclear Physics

Volume 119, July 2021, 103858

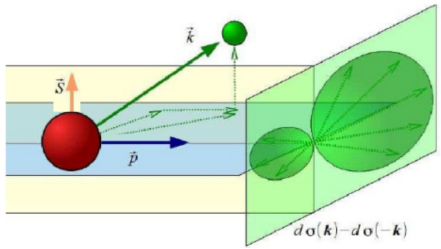


Review

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] … O. Teryaev [a]

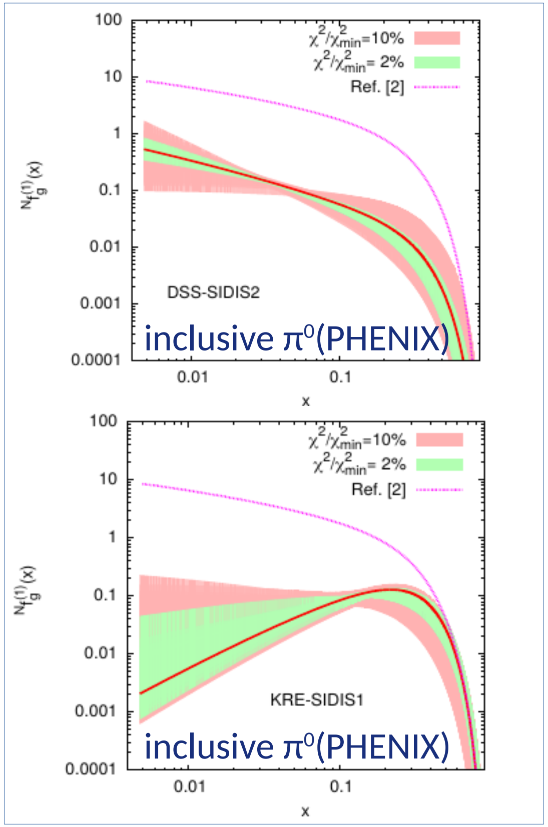
Gluon Sivers function



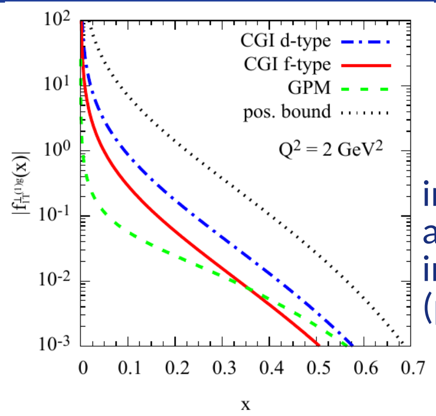
- GSF – correlation between transverse spin and gluon k_T
- Can be indirectly related to gluon OAM
- Probed by TSSA

$$\sigma(\phi) \propto 1 + P \cdot A_N \sin(\phi_{\rm pol} - \phi)$$

- Poorly known, extracted in GPM, CGI-GPM, and very recently TMD approaches (spectator model)



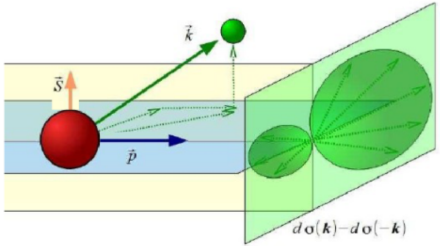
First kT moments for GSF, GPM (JHEP09(2015)119)

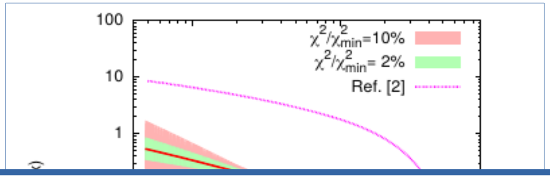


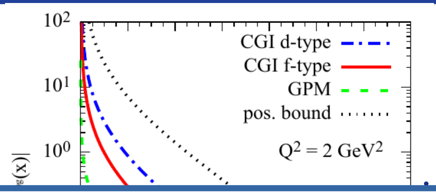
inclusive π^0 and inclusive D ($p^\uparrow p \to \mu^\pm X$)

Maximized first kT moments for GSF, CGI-GPM (PRD99, 036013 (2019))

Gluon Sivers function





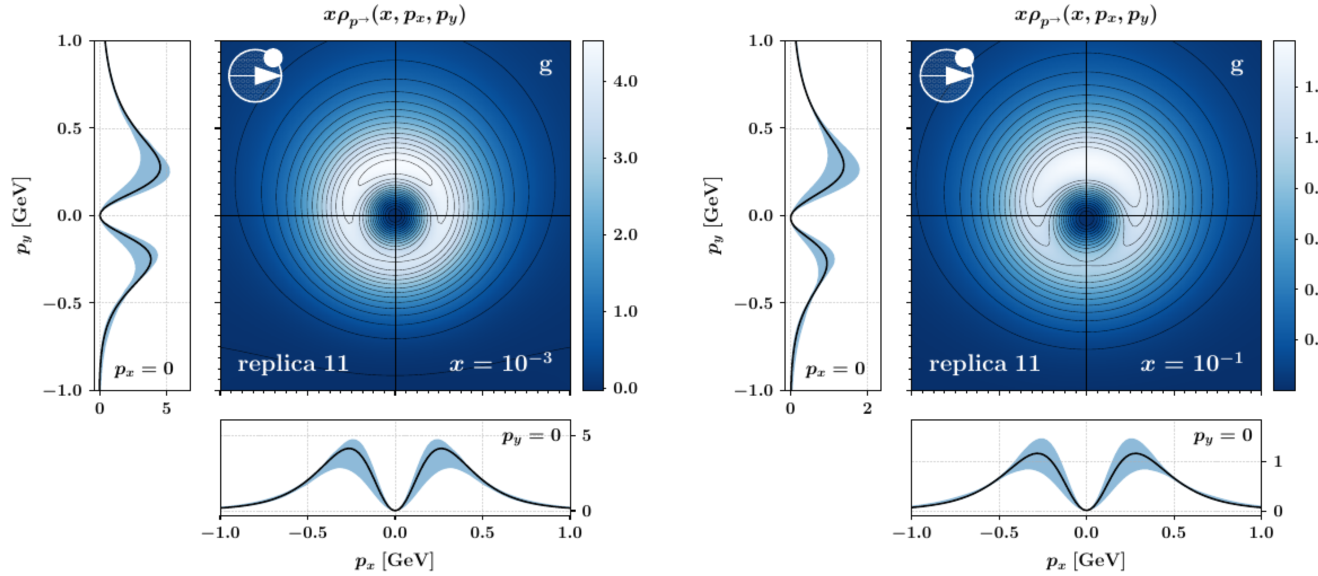


- GSF – correlation between transverse spin and gluon k_T
- Can be indirectly related to gluon OAM
- Probed by TSSA

$$\sigma(\phi) \propto 1 + P \cdot A_N \sin(\phi_{\text{pol}} - \phi)$$

- Poorly known, extracted in GPM, CGI-GPM, and very recently TMD approaches (spectator model)

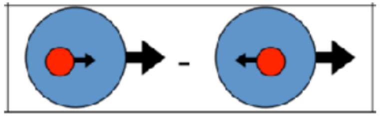
Spectator model calculations



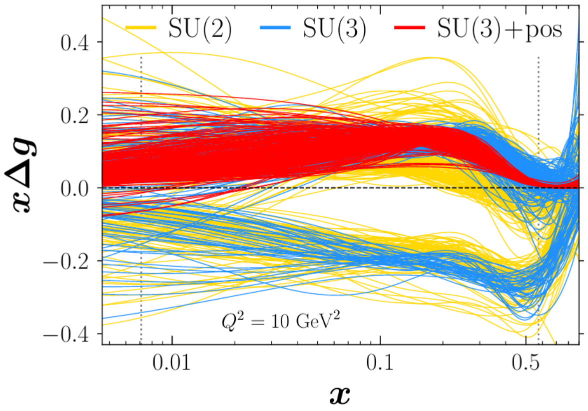
Unpolarized gluon density for a transvsersely polarized nucleon along X-axis, (Q=1.64 GeV) in the **spectator model** - Bacchetta, Celiberto, Radici (EPJC 84 (2024) 6, 576)

Gluon helicity distribution

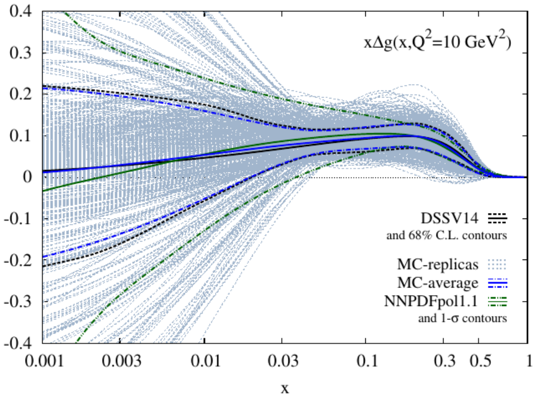
$\Delta g(x)$:



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

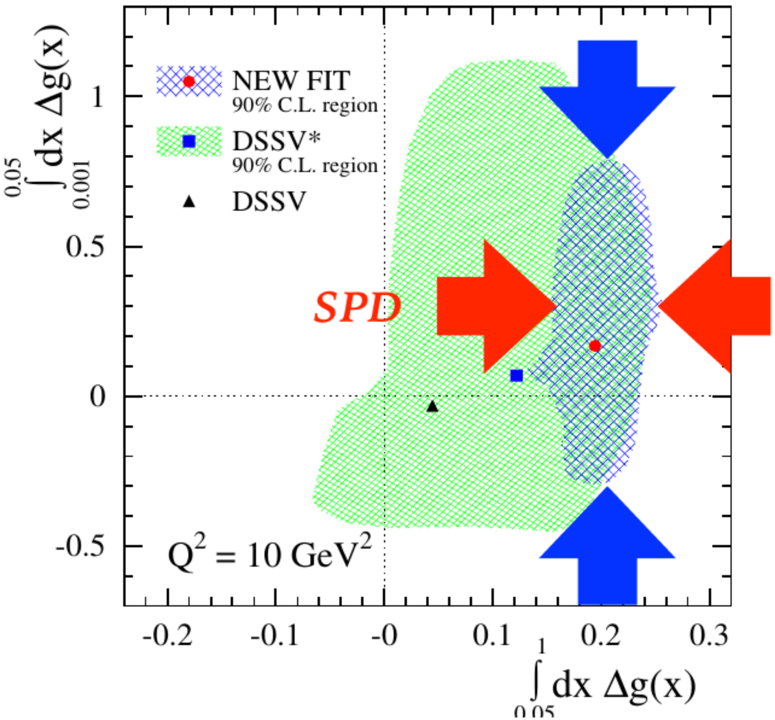


JAM Collaboration (2022)



Phys. Rev. D 100, 114027 (2019)

Phys.Rev.Lett. 113 (2014) 1, 012001



Other extractions: LSS15, JAM17

Charmonia production as a probe of gluon TMD PDFs

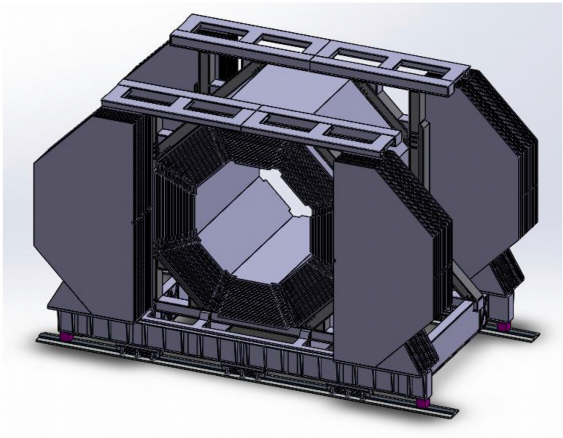
Charmonia production

- dominated by gluon-gluon fusion
- high cross-section
- J/ψ can be easily reconstructed from the $\mu^+\mu^-$ decay, $\psi(2S)$ and χ_{cJ} can be reconstructed based on this decay
- hadronization of $c\bar{c}$ pair is not well understood theoretically:
  - (Improved) Color Evaporation Model
  - CSM
  - NRQCD
- TMD factorization does not always hold
- η_c might be the best probe, but its observation is challenging experimentally
- the J/ψ signal is “contaminated” by feed-down contributions

Charmonia production at SPD

- High statistics, wide kinematic coverage
- Ability to measure also production properties of $\psi(2S)$, χ_{c1} and χ_{c2}
- Strategy is to obtain all possible measurements in the wide kinematic range
- Constrain both theoretical approaches and PDFs
- Our p_T are mostly below $M_{J/\psi}$
- NRQCD LDME → shape functions (Echevarria, 2019)

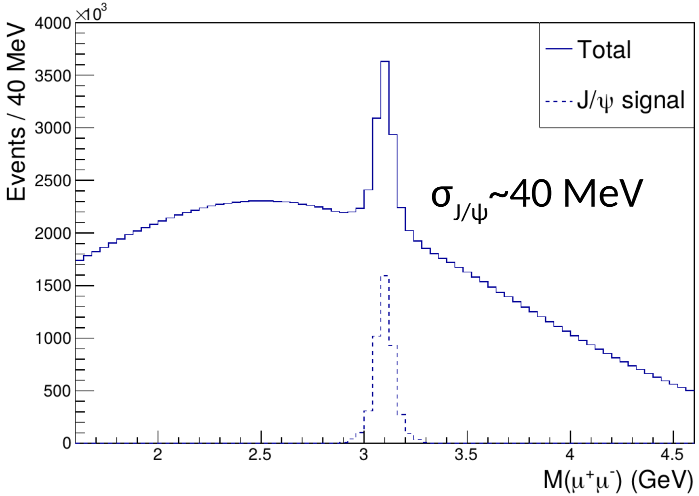
Inclusive J/ψ measurements

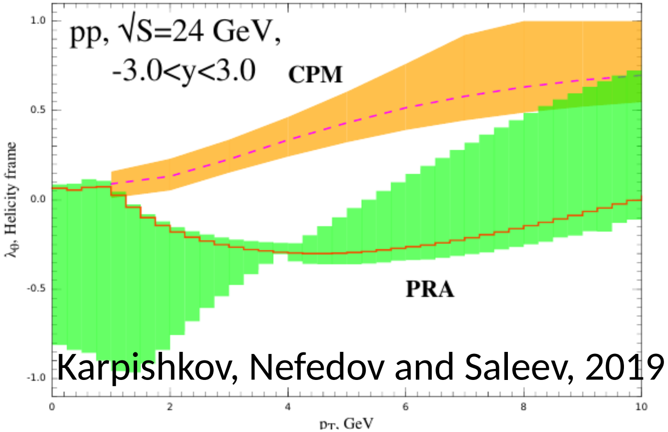


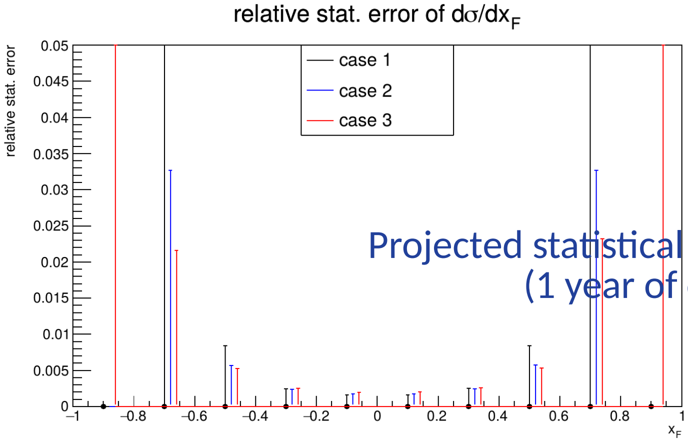
- Reconstruction efficiency: ~40%
- Statistics: ~ 4.5–5.0 M (selected events) per year
- Large background due to pion decays and muon misidentification in RS

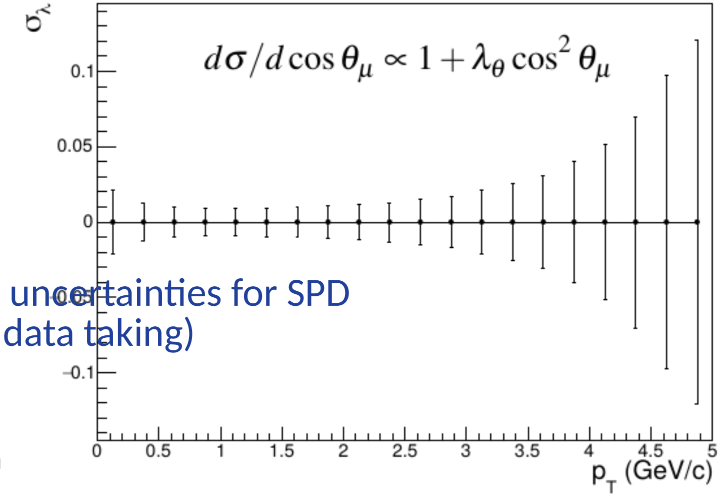
Observables:

- cross-section, p_T-, x_F-dependencies
- polarization
- asymmetries





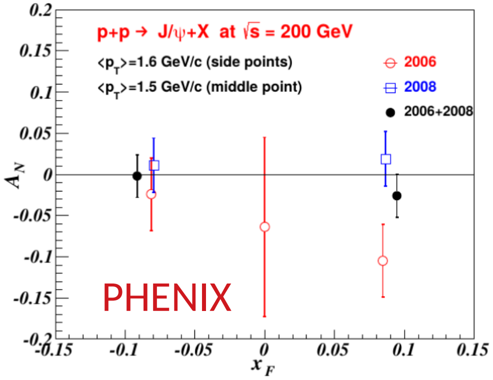




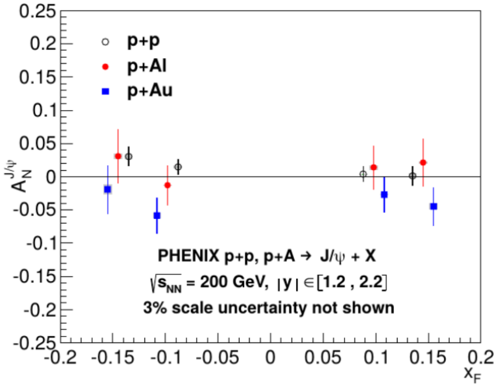
Projected statistical uncertainties for SPD
(1 year of data taking)

A_N for inclusive J/ψ production

$$\sigma(\phi) \propto 1 + P \cdot A_N \sin(\phi_{\rm pol} - \phi)$$



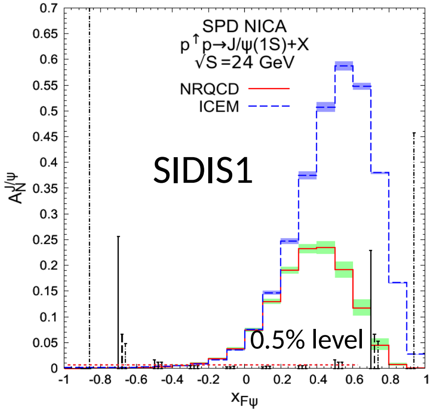
PRD82, 112008 (2010)

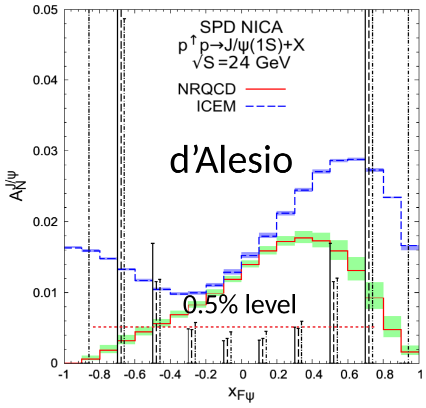


PRD98, 012006 (2018)

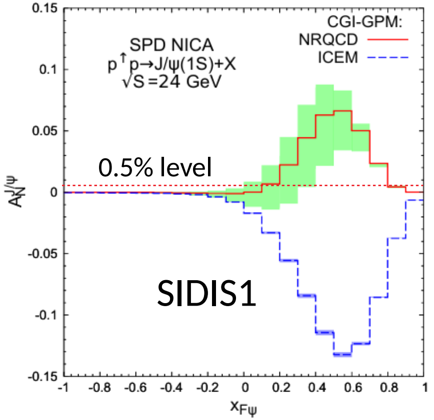
Projected stat. uncertainties and predictions from PRD104, 016008 (2021)

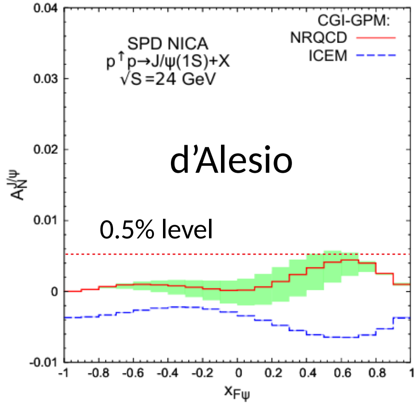
GPM





CGI-GPM

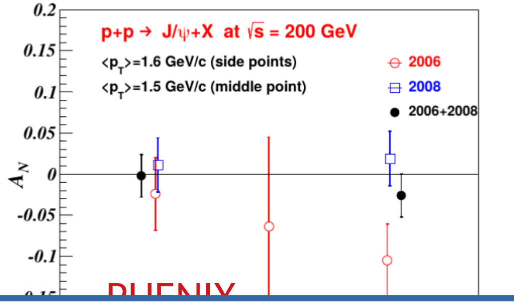




Here and in the following P = 0.7 and is assumed constant during the run.

A_N for inclusive J/ψ production

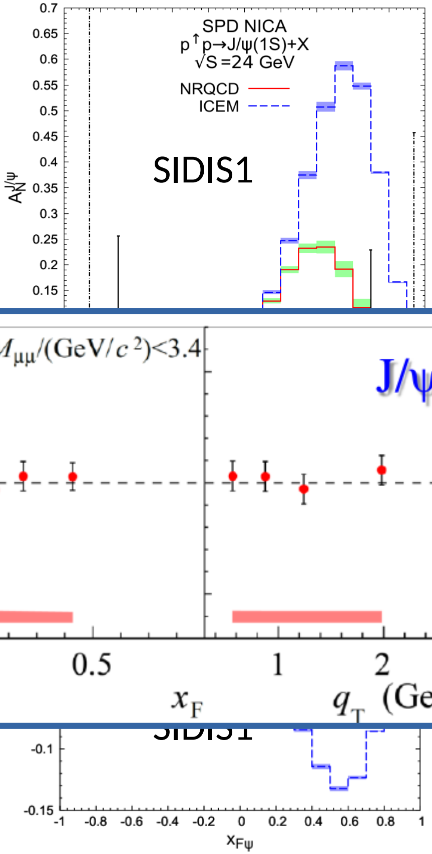
$$\sigma(\phi) \propto 1 + P \cdot A_N \sin(\phi_{\text{pol}} - \phi)$$

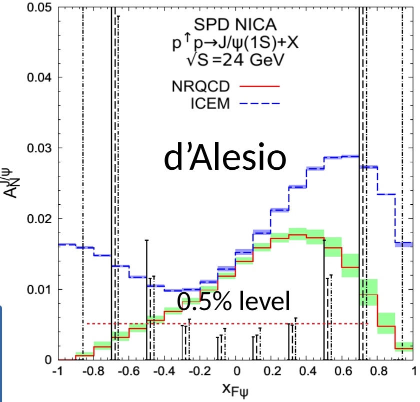


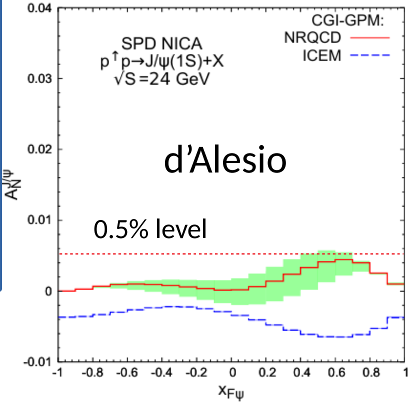
PRD98, 012006 (2018)

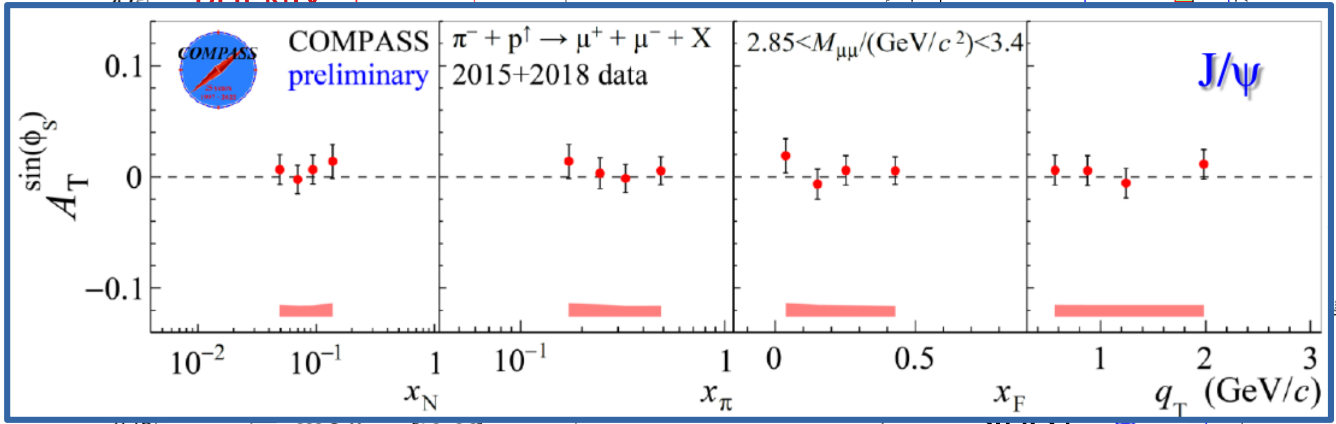
GPM

Projected stat. uncertainties and predictions from PRD104, 016008 (2021)







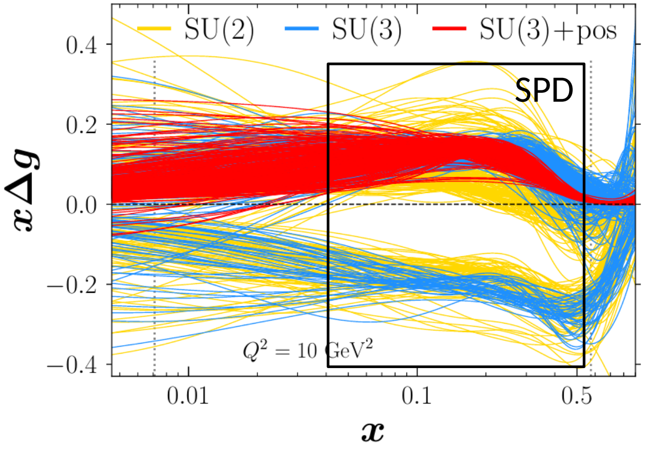


Here and in the following P = 0.7 and is assumed constant during the run.

A_{LL} for inclusive J/ψ production

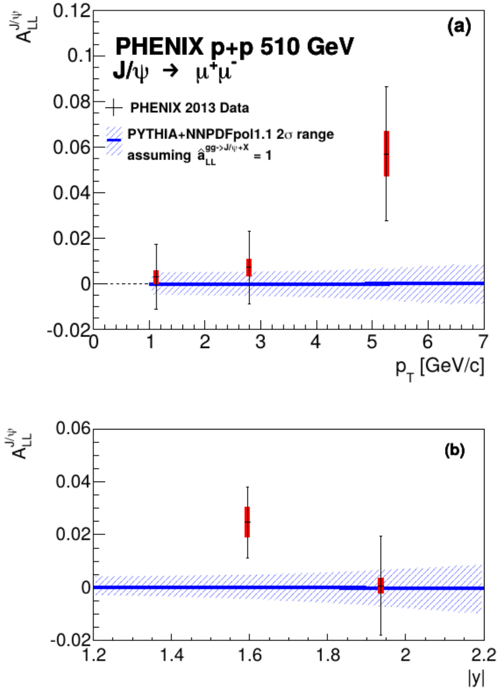
$$A_{LL}^{J/\psi} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL}^{J/\psi} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg\to J/\psi+X}$$



JAM (2022)

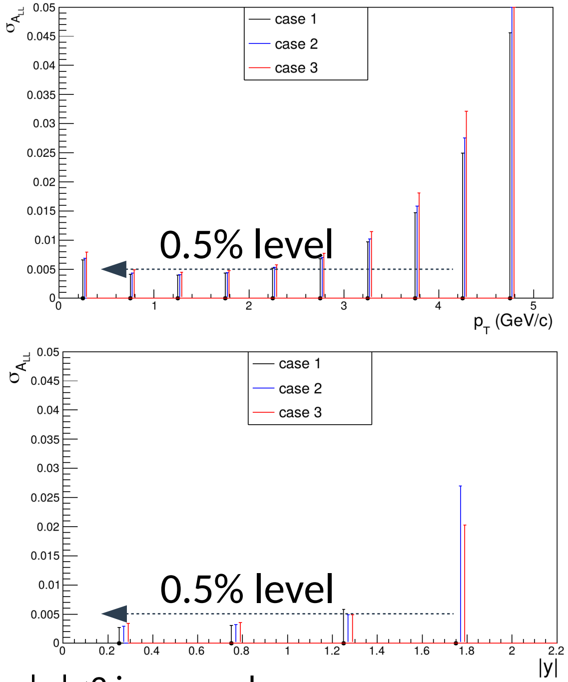
PRD94 112008 (2016)



x_1~5×10^{-2}

x_2~2×10^{-3}

Projected statistical uncertainties for SPD

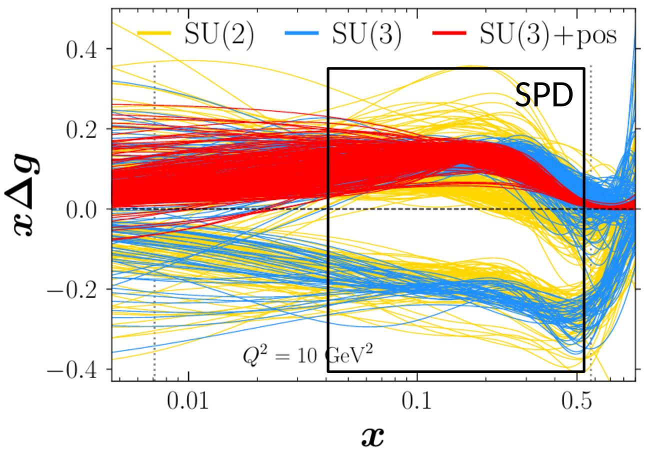


- |y|<2 is covered
- At SPD both $\Delta g(x_1)$ and $\Delta g(x_2)$ are expected to be close to the maximum
- A measurable A_{LL} of the order of 1-10% can be expected

A_{LL} for inclusive J/ψ production (impact of SPD measurements)

$$A_{LL}^{J/\psi} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL}^{J/\psi} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg\to J/\psi+X}$$

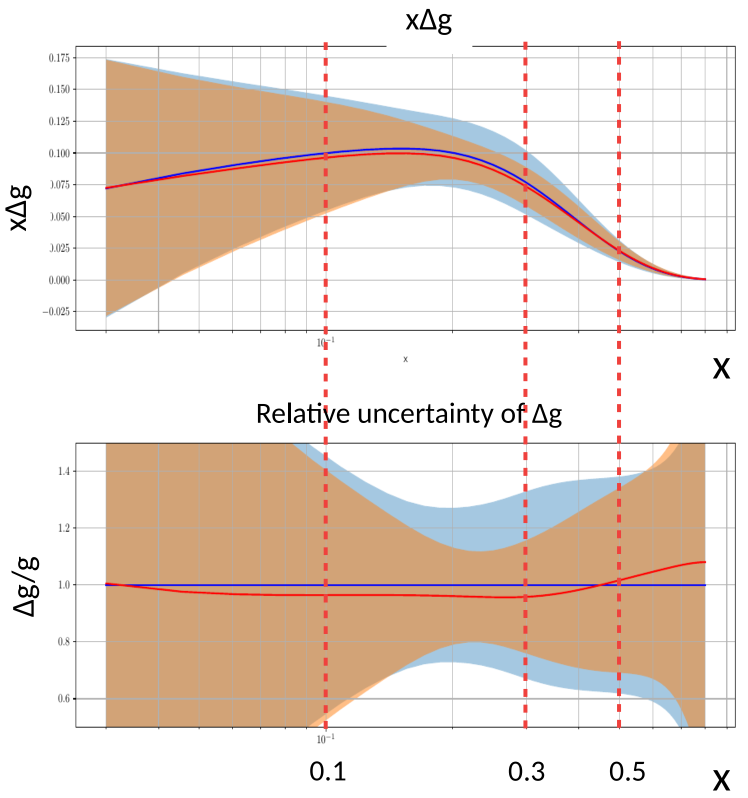


JAM (2022)

Impact of SPD data is estimated by

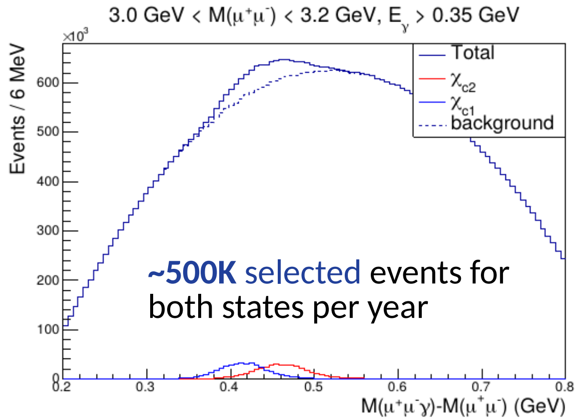
- generating "SPD data" according to NNPDFPol1.1
- prescribing **stat. errors** estimated for 1 year data taking at SPD with √s = 27 GeV
- Bayesian reweighing of MC replicas

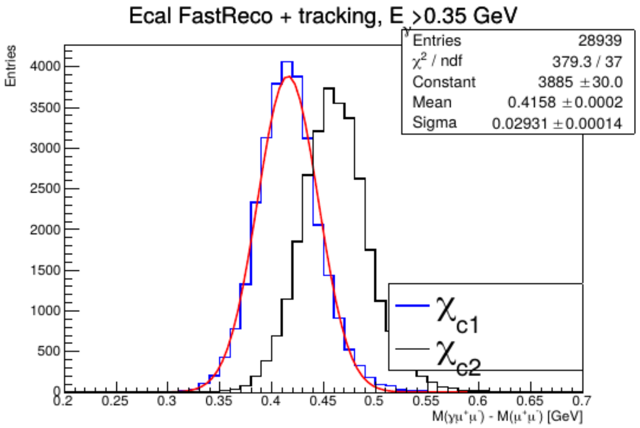
The relative uncertainty decreases by a factor of ~2 for x ~ 0.2-0.3.

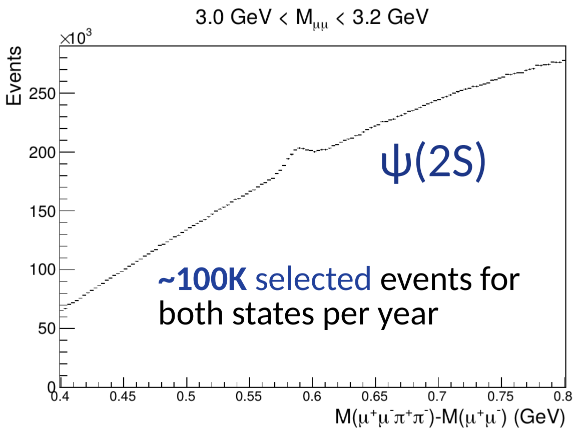


On other measurements with charmonia

χ_{c1} and χ_{c2}

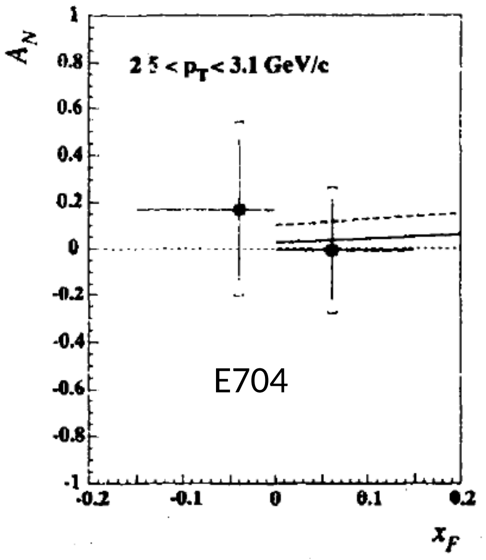






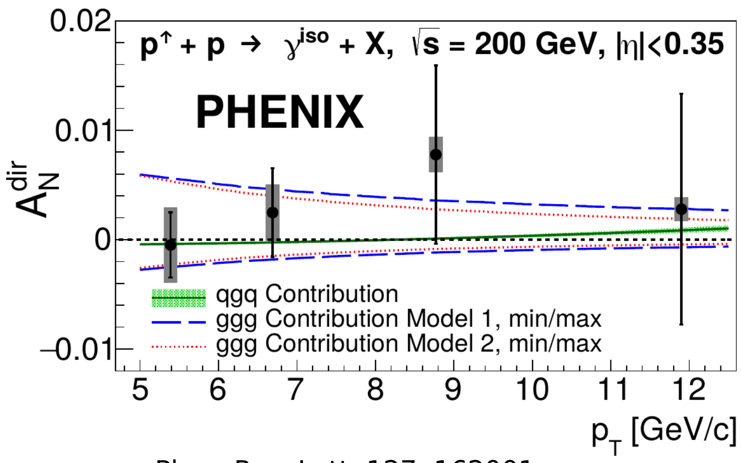
- $\eta_c \rightarrow p\bar{p}, \Lambda\bar{\Lambda}, \phi\phi$?
  - 500K selected events for $\eta_c \rightarrow p\bar{p}$
  - huge background
- Double J/ψ production
  - 50-100 events/year for both J/ψ dilepton decay modes
  - pT dependence complimentary to high energy experiments
- $J/\psi\gamma$: limited statistics and large background

Prompt photons: A_N

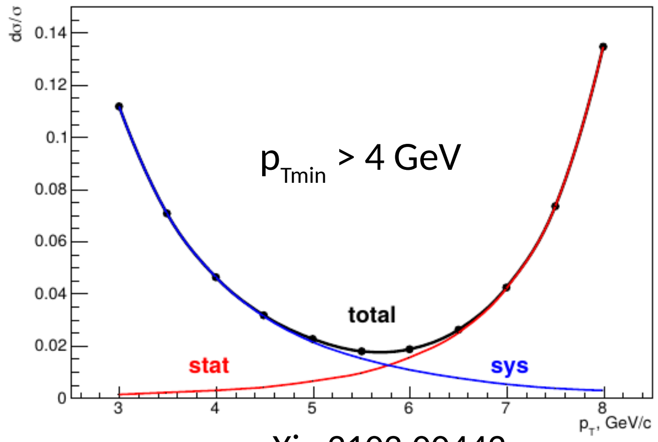


PLB345, 569 (1995)

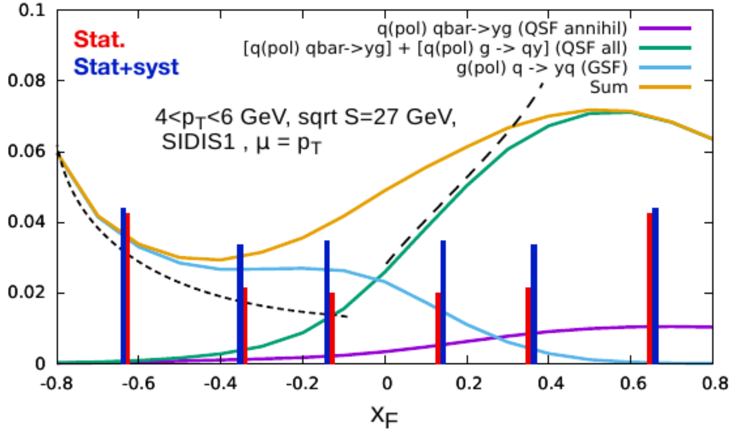
- Straightforward theoretical interpretation
- Sensitive to Δg sign
- very challenging experimentally



Phys. Rev. Lett. 127, 162001



arXiv:2102.00442



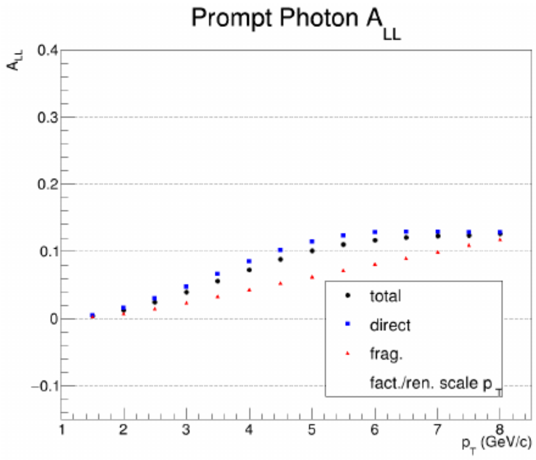
Predictions: Saleev, Shipilova, 2020

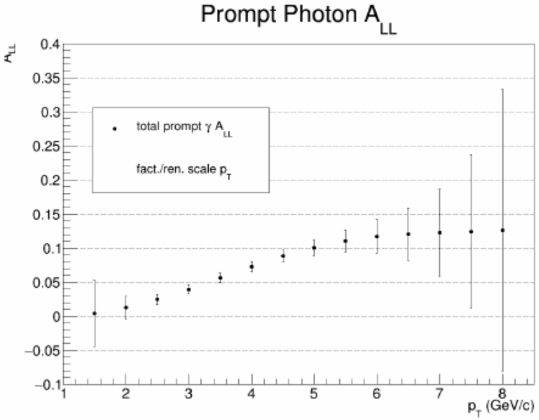
Prompt photons: A_{LL}

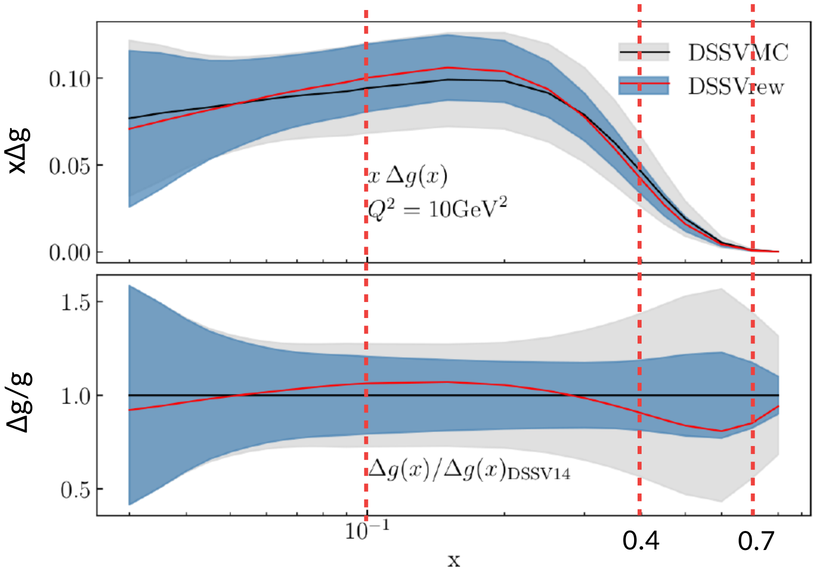
$$A_{LL}^{\gamma} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes A_{1p}(x_2) \otimes \hat{a}_{LL}^{gq(\bar{q})\to\gamma q(\bar{q})} + (1 \leftrightarrow 2)$$

Impact of SPD data is estimated by

- generating “SPD data” according to current PDFs (NLO, NNPDF3.0, DSSV2014) – W. Vogelsong, 2021
- prescribing errors estimated for 1 year data taking at SPD with √s = 27 GeV
- Bayesian reweighing of MC replicas



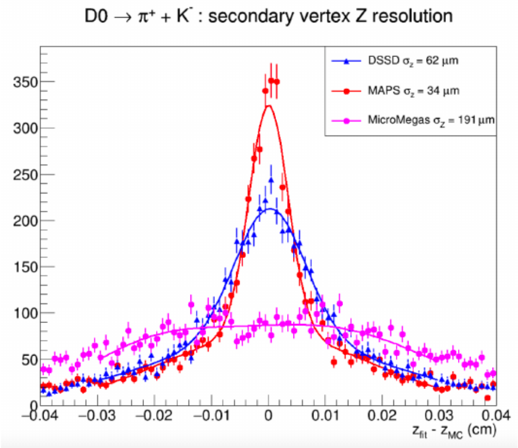


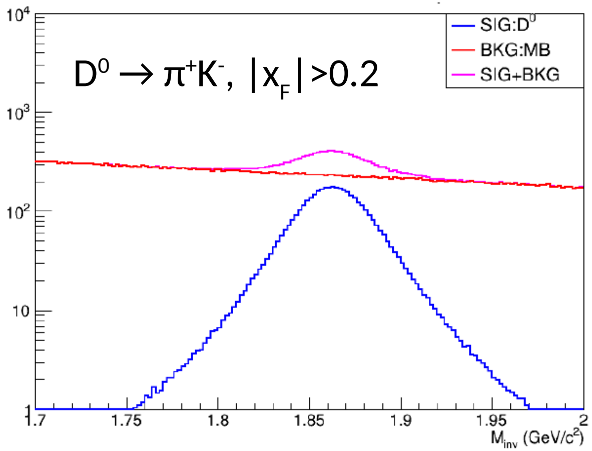


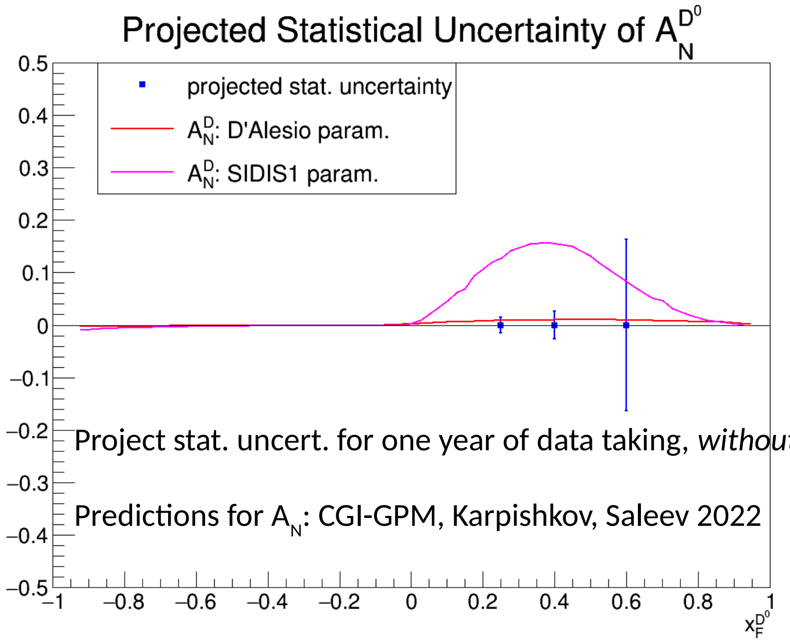
Predictions with new “data” added (top) and ration of the uncertainties (bottom). Courtesy R. Sassot, I. Borsa, 2021.

Uncertainties are reduced by factor of 2 for 0.4 < x < 0.7

Measurements with D mesons







Project stat. uncert. for one year of data taking, *without FARICH PID*

Predictions for A_N: CGI-GPM, Karpishkov, Saleev 2022

- The largest production cross-section (almost two orders of magnitude larger than for J/ψ)
- Small D-meson boost at our energies
- Interpretation requires c-quark FF
- Projected uncertainties shown for D^0 only
- D meson pair production – probe for Boer-Mulders function

Deuteron gluon structure

$\sigma(x_F,p_T)$, vector and tensor angular asymmetries

Nonbaryonic content of deuteron:

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

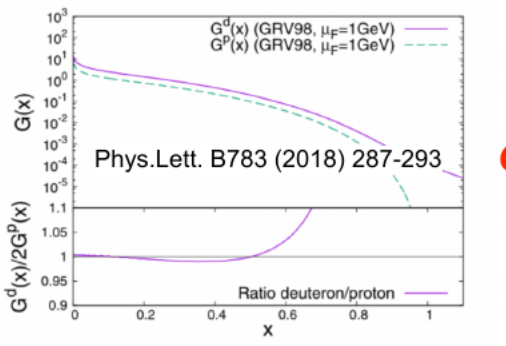
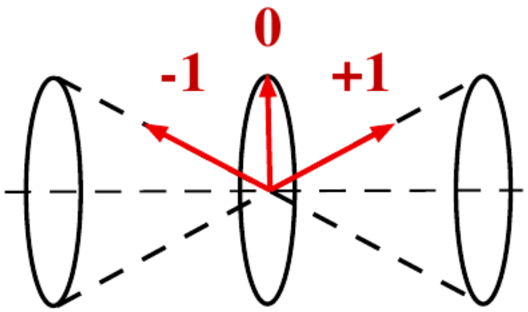
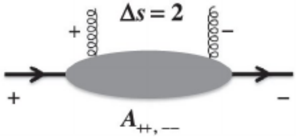


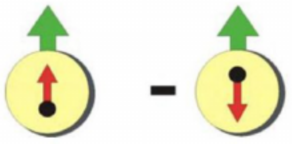
Fig. 6. Gluon PDF in the deuteron and in the nucleon.

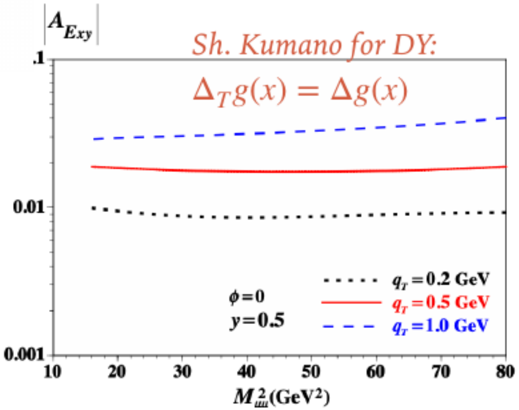


Unpolarized gluons at high x:

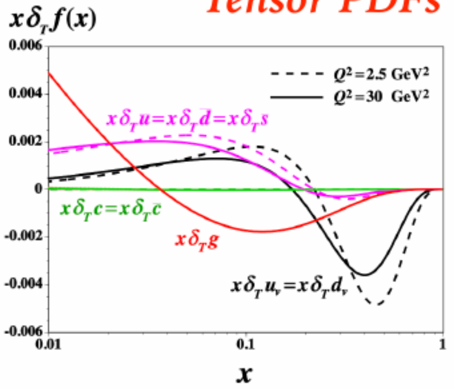
Gluon transversity







Tensor PDFs



Physics goal	Required time	Experimental conditions
First stage		
Spin effects in p-p scattering dibaryon resonanses	0.3 year	$p_{L,T}$-$p_{L,T}$, $\sqrt{s}$ <7.5 GeV
Spin effects in p-d scattering, non-nucleonic structure of deuteron, $\bar{p}$ yield	0.3 year	d_{tensor}-p, $\sqrt{s}$ <7.5 GeV
Spin effects in d-d scattering hypernuclei	0.3 year	d_{tensor}-d_{tensor}, $\sqrt{s}$ <7.5 GeV
Hyperon polarization, SRC, ... multiquarks	together with MPD	ions up to Ca
Second stage		
Gluon TMDs, SSA for light hadrons	1 year	p_T-p_T, $\sqrt{s}$ =27 GeV
TMD-factorization test, SSA, charm production near threshold, onset of deconfinment, $\bar{p}$ yield	1 year	p_T-p_T, 7 GeV< $\sqrt{s}$ <27 GeV (scan)
Gluon helicity, ...	1 year	p_L-p_L, $\sqrt{s}$ =27 GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor porlarized" PDFs	1 year	d_{tensor}-d_{tensor}, $\sqrt{s_{NN}}$ = 13.5 GeV or/and d_{tensor}-p_T, $\sqrt{s_{NN}}$ = 19 GeV

SPD CDR

SPD Collaboration

VIII SPD Collaboration meeting, Dubna, Novemeber 2024

Overall > 30 institutes, ~400 members
https://spd.jinr.ru

MoU under prepartaion:

- NRC "Kurchatov Institute", Moscow (NRC KI)
- iThemba LABS, SA
- HSE University, Moscow
- Cairo University, Cairo

MoU has been signed with

- 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
- Higher Institute of Technologies and Applied Sciences, Havana

SPD project timeline and tentative operating plan

2007: Idea of SPD project included to NICA activities at JINR

2014: SPD LoI approved by JINR PAC

2020: Completion of SPD CDR (arXiv:2102.00442v3)

2021: SPD Collaboration is established, preparation of TDR is started

Jan 2023: 1-st version of SPD TDR presented JINR PAC

Jun 2024: DAC recommended to approve the updated version of TDR (arXiv:2404.08317)

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

Summary

- The SPD experiment is a comprehensive facility to study **polarized** and **unpolarized gluon content** of **proton** and **deuteron** at **high x** in p-p and d-d collisions with **$\sqrt{s}$ up to 27 GeV**. The detector is optimized for three complementary probes: charmonia production, prompt photons, and D-meson production.
- SPD can contribute to:
  - gluon TMD (Sivers and Boer-Mulders)
  - gluon helicity PDF
  - gluon transversity in deuteron
  - unpolarized gluon PDFs of proton and deuteron
  - ...
- The SPD Collaboration is active and growing.
- Apart from that, the SPD physics program covers large variety of different aspects of QCD during the initial and final stages of the experiment.
- The physical program of SPD experiment with respect to nucleon gluon content is complementary to those of experiments at RHIC, EIC, and proposed fixed target program at LHC (AFTER, LHC-Spin) and EicC.
- We are extremely interested in new people (especially students) to be involved physics simulation, development of reconstruction algorithms, software development!

spd.jinr.ru