# SPD project at NICA

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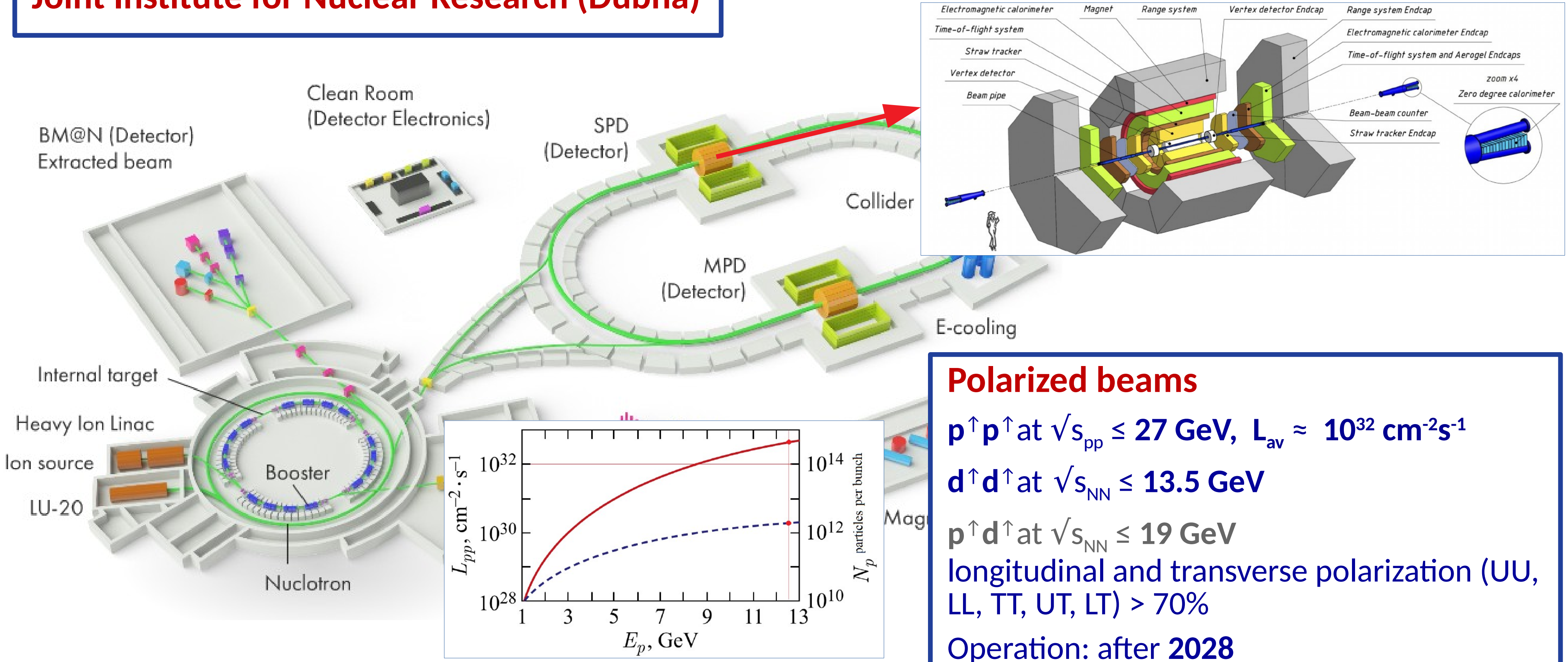
Joint 20-th International Workshop on Hadron Structure and Spectroscopy and 5-th workshop on Correlations in Partonic and Hadronic Interactions

30.09.24 – 04.10.24

# Nuclotron-based Ion Collider fAcility (NICA)

**Joint Institute for Nuclear Research (Dubna)**

## Spin Physics Detector (SPD)



**Polarized beams**

**$p^{\uparrow}p^{\uparrow}$ at $\sqrt{s_{pp}} \leq 27$ GeV, $L_{av} \approx 10^{32}$ cm$^{-2}$s$^{-1}$**

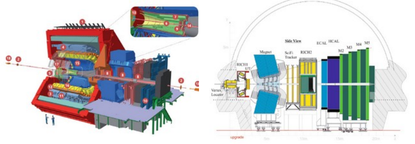
**$d^{\uparrow}d^{\uparrow}$ at $\sqrt{s_{NN}} \leq 13.5$ GeV**

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

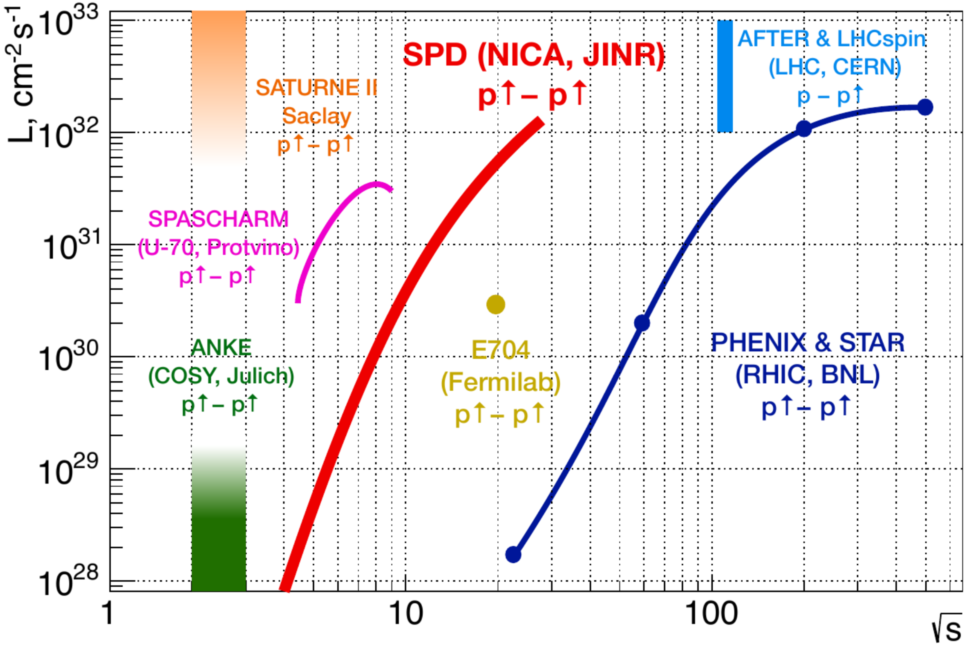
longitudinal and transverse polarization (UU, LL, TT, UT, LT) > 70%

Operation: after **2028**

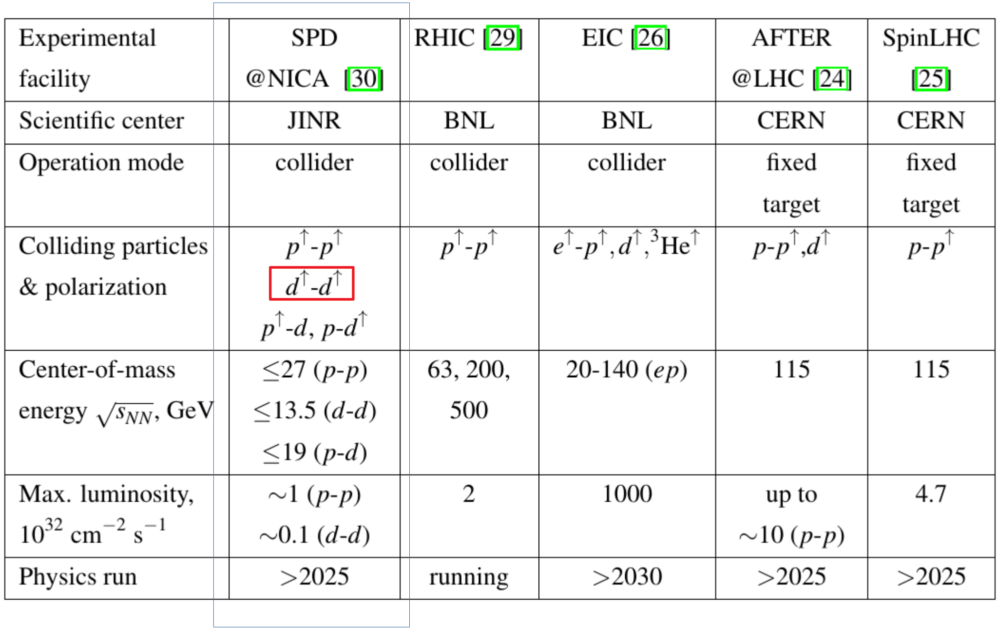
# NICA and other facilities



SPD CDR (arXiv:2102.00442)



p↑p↑ 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 | $p^\uparrow$-$p^\uparrow$<br>$d^\uparrow$-$d^\uparrow$<br>$p^\uparrow$-$d$, $p$-$d^\uparrow$ | $p^\uparrow$-$p^\uparrow$ | $e^\uparrow$-$p^\uparrow$,$d^\uparrow$,$^3$He$^\uparrow$ | $p$-$p^\uparrow$,$d^\uparrow$ | $p$-$p^\uparrow$ |
| Center-of-mass energy $\sqrt{s_{NN}}$, GeV | ≤27 ($p$-$p$)<br>≤13.5 ($d$-$d$)<br>≤19 ($p$-$d$) | 63, 200, 500 | 20-140 ($ep$) | 115 | 115 |
| Max. luminosity, $10^{32}$ cm$^{-2}$ s$^{-1}$ | ~1 ($p$-$p$)<br>~0.1 ($d$-$d$) | 2 | 1000 | up to ~10 ($p$-$p$) | 4.7 |
| Physics run | >2025 | running | >2030 | >2025 | >2025 |

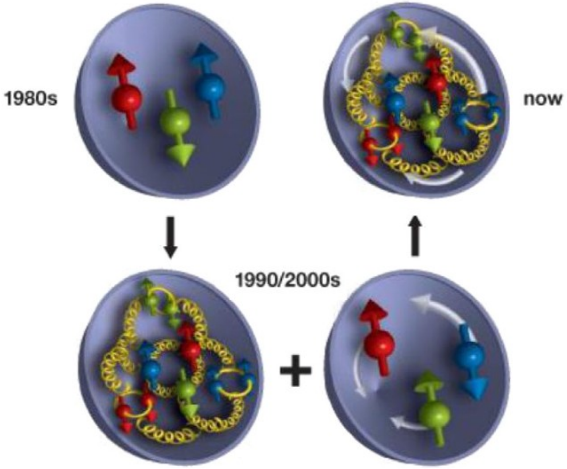
NICA is unique for double polarized d↑d↑ collisions at these energies.

# Nucleon structure

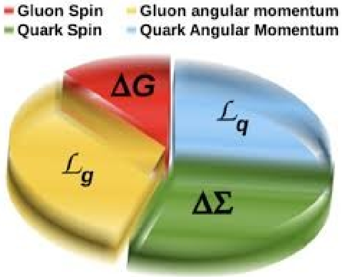
**Hadron structure is one of the keys to understand bound states in QCD.**

**Nucleon tomography aims to understand how hadrons are build in terms of elementary degrees of freedom in QCD.**

- How quarks and gluons, and their spins are distributed in a nucleon in transverse positional space and transverse momentum space?
- How nucleon spin emerges from spin and internal motion of valence and see quarks and gluons?



Our understanding of nucleon structure



Spin decomposition of proton

Figure credit: Physics Reports 911, 2021, 1

# Nucleon tomography

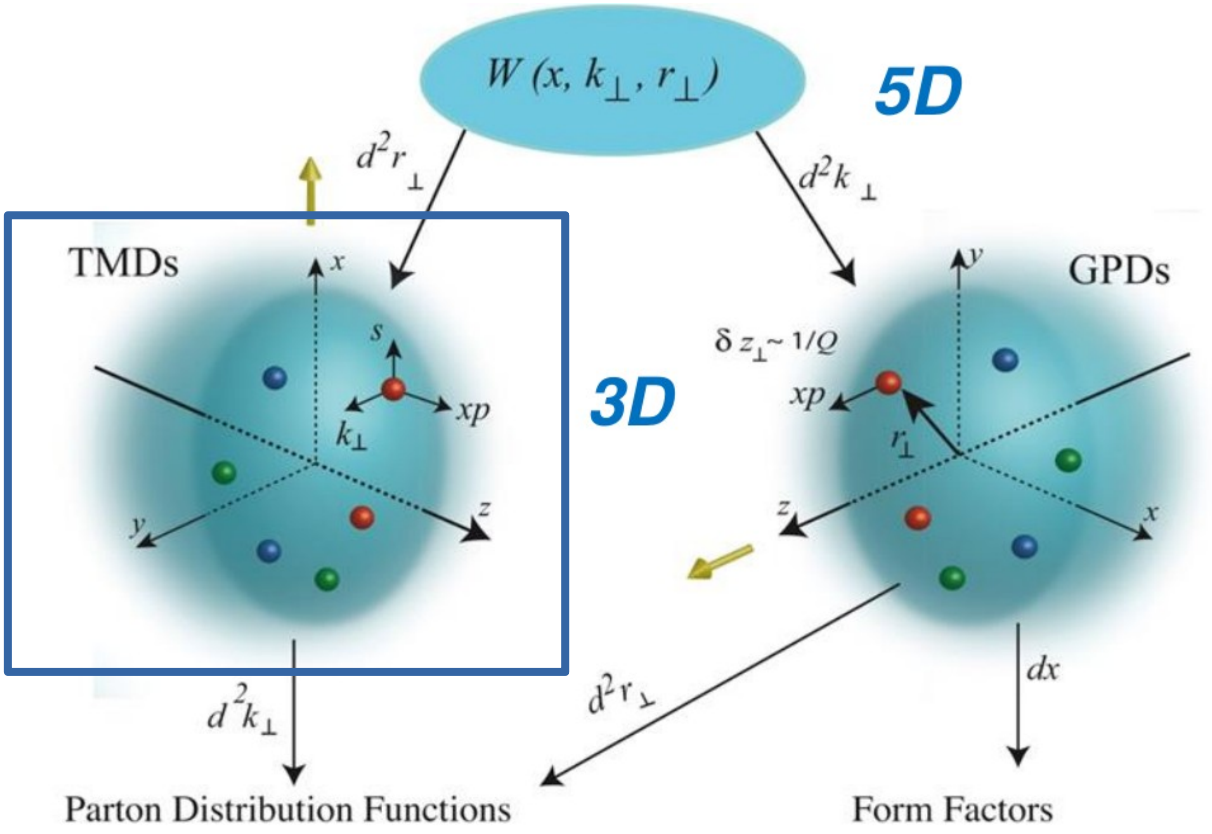
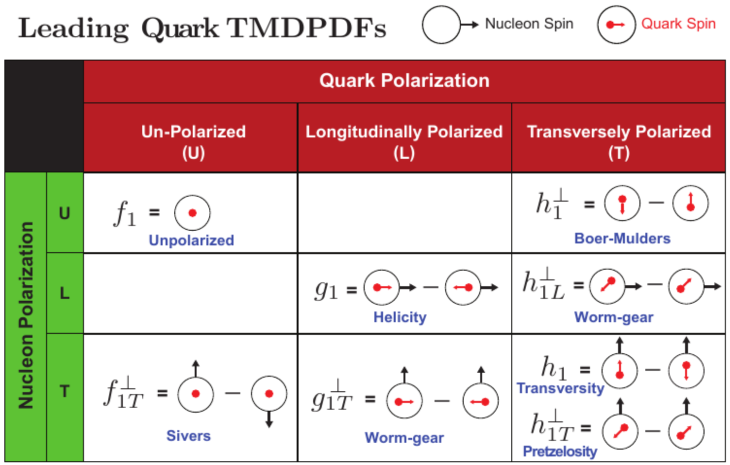


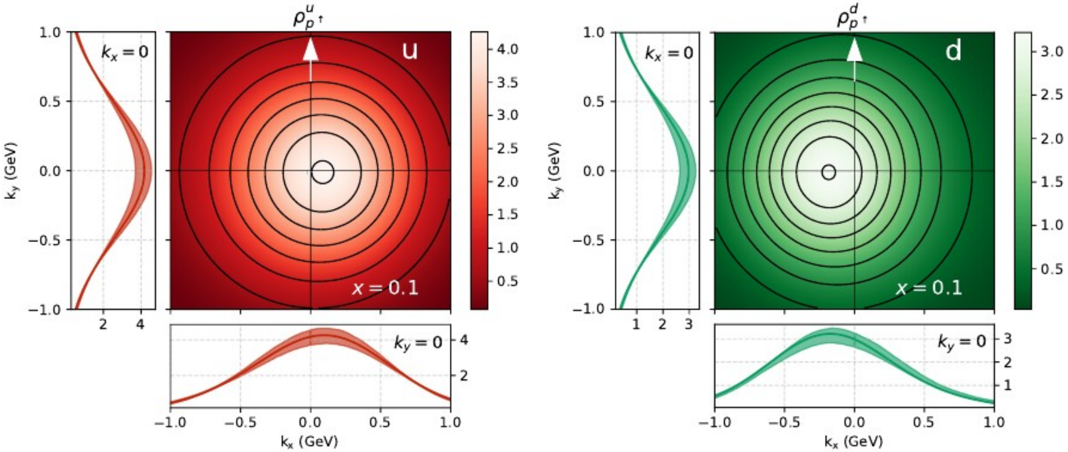
Figure credit: J.-P. Cheng

# Quark TMDs



Leading Quark TMDPDFs — Nucleon Spin — Quark Spin

| | | Quark Polarization | | |
|---|---|---|---|---|
| | | Un-Polarized (U) | Longitudinally Polarized (L) | Transversely Polarized (T) |
| Nucleon Polarization | U | $f_1$ =<br>Unpolarized | | $h_1^{\perp}$ = −<br>Boer-Mulders |
| | L | | $g_1$ = −<br>Helicity | $h_{1L}^{\perp}$ = −<br>Worm-gear |
| | T | $f_{1T}^{\perp}$ = −<br>Sivers | $g_{1T}^{\perp}$ = −<br>Worm-gear | $h_1$ = −<br>Transversity<br>$h_{1T}^{\perp}$ = −<br>Pretzelosity |



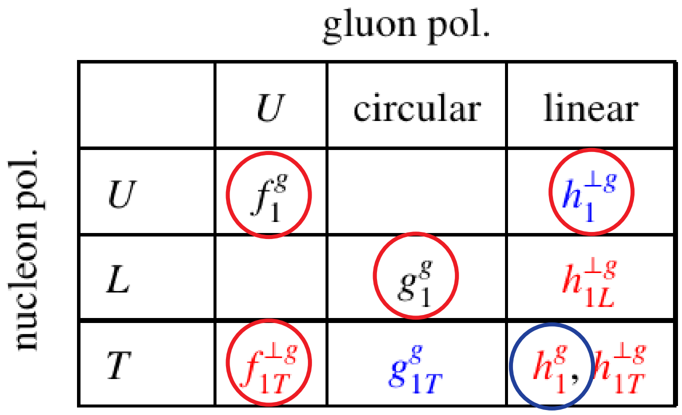
**Significant progress** on **quark TMD**s over the last decades (for details see e.g. TMD Handbook, PLB 827, 136961 (2022)).

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))

Overviewed by Alessandro Bacchetta on Tuesday

# Gluon TMDs and the SPD experiment

**Our knowledge on gluon TMD remains rather scarce.**



gluon pol.

nucleon pol.

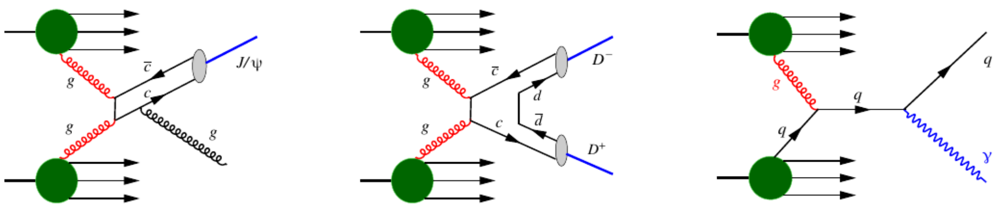
| | U | circular | linear |
|---|---|---|---|
| U | $f_1^g$ | | $h_1^{\perp g}$ |
| L | | $g_1^g$ | $h_{1L}^{\perp g}$ |
| T | $f_{1T}^{\perp g}$ | $g_{1T}^g$ | $h_1^g, h_{1T}^{\perp g}$ |

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

$h^g_1$ is nonzero only for deuteron.

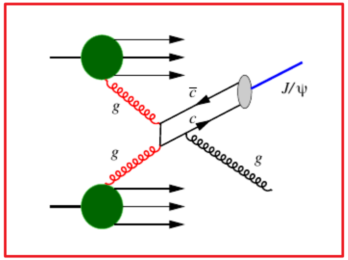
**Main goal of the experiment – spin-dependent gluon structure of proton and deuteron.**

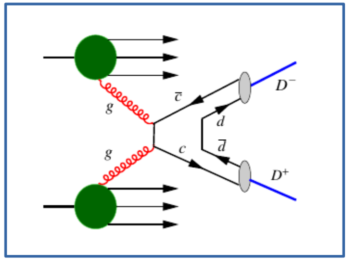
- Three probes of gluon structure chosen in this energy range:

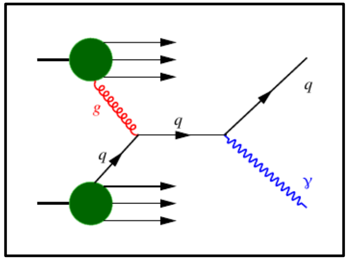


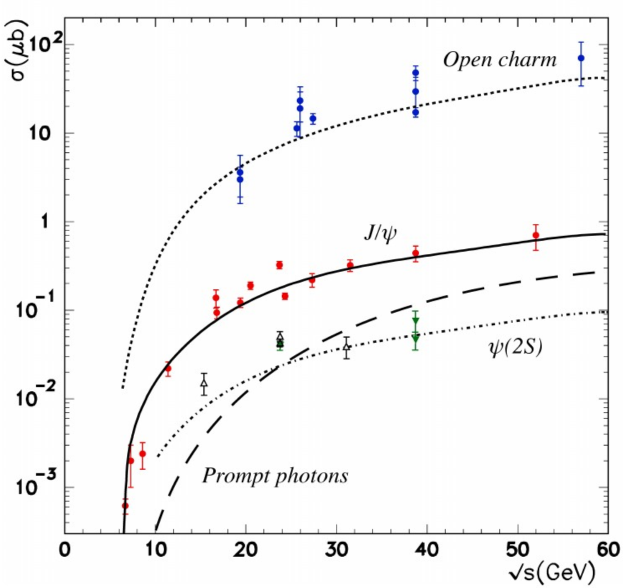
- Measurements at SPD should help to improve our understanding of QCD and resolve spin and mass crises.
- Many other aspects of QCD to be studied in such collisions.

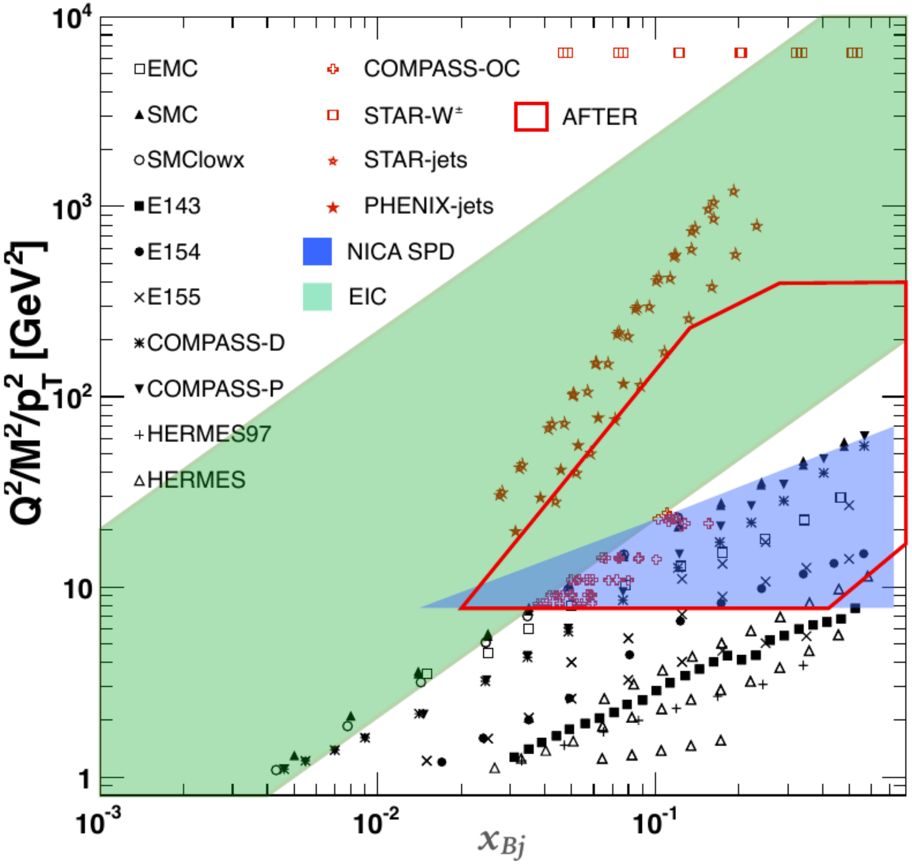
# SPD kinematic coverage





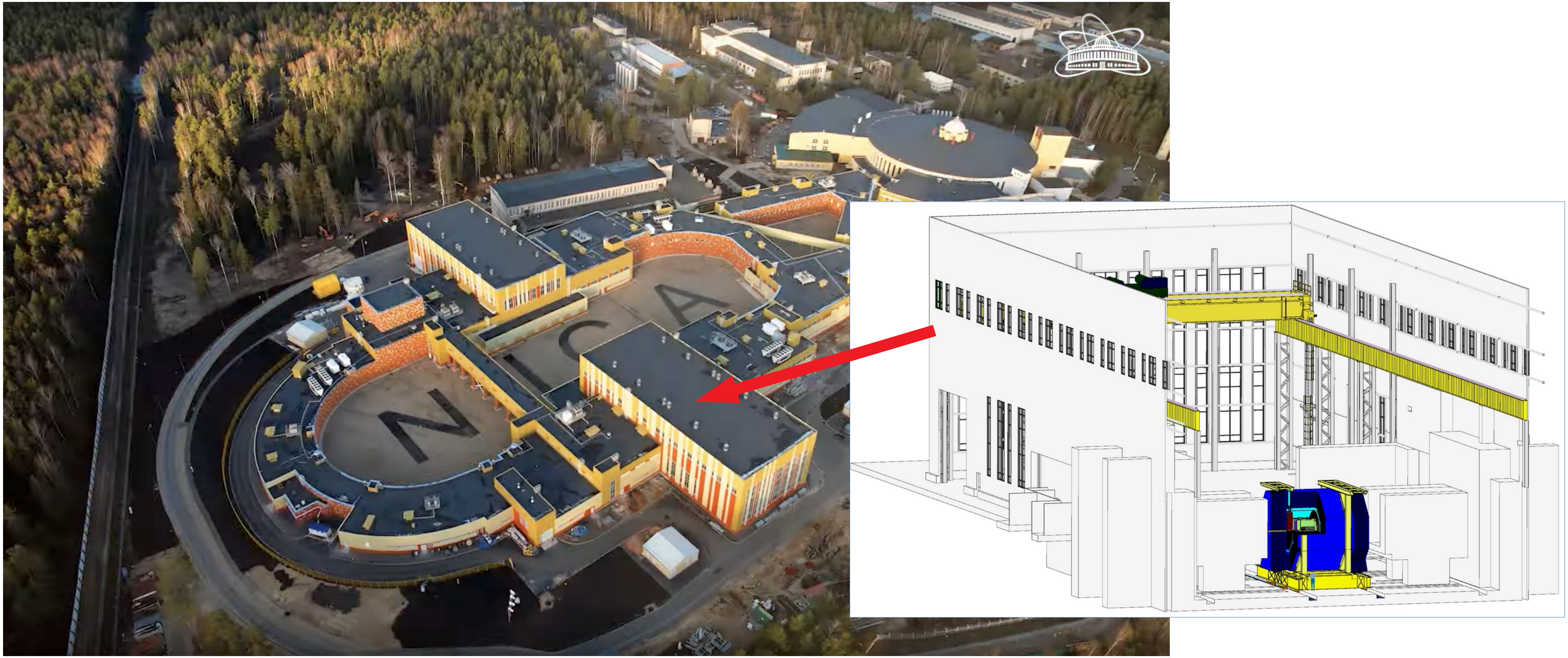






arXiv:2011.15005

# Construction site

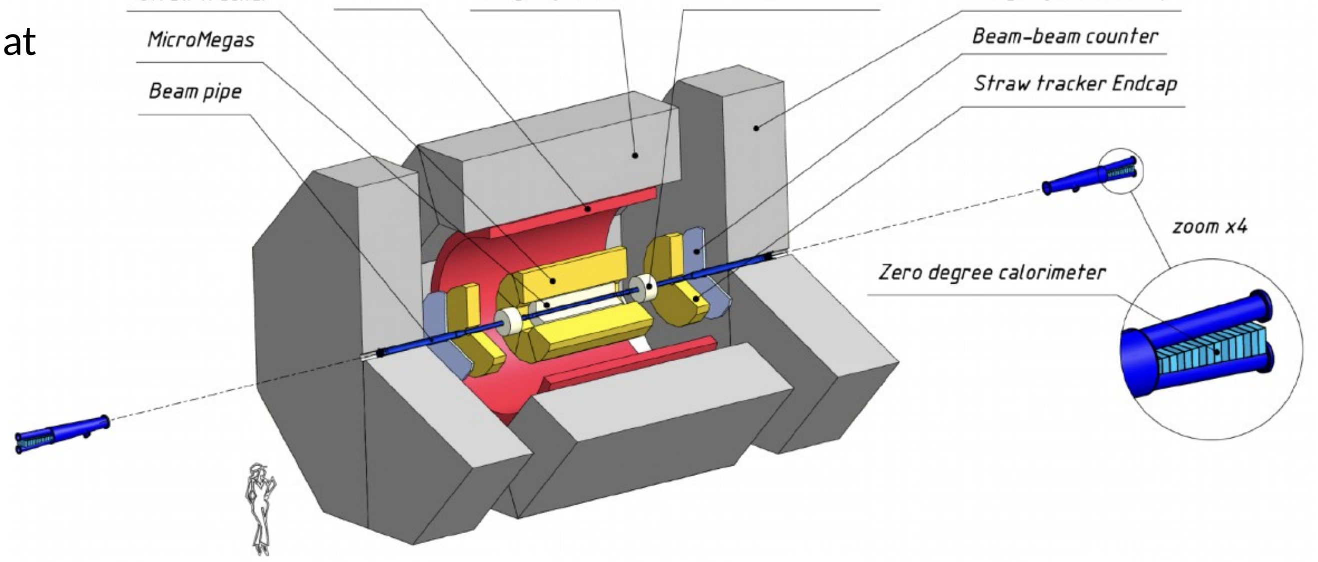


# SPD initial stage

The SPD TDR can be found at 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**:
- **$\sigma \sim 150$ μm**
- **$\sigma(dE/dx) = 8.5\%$**

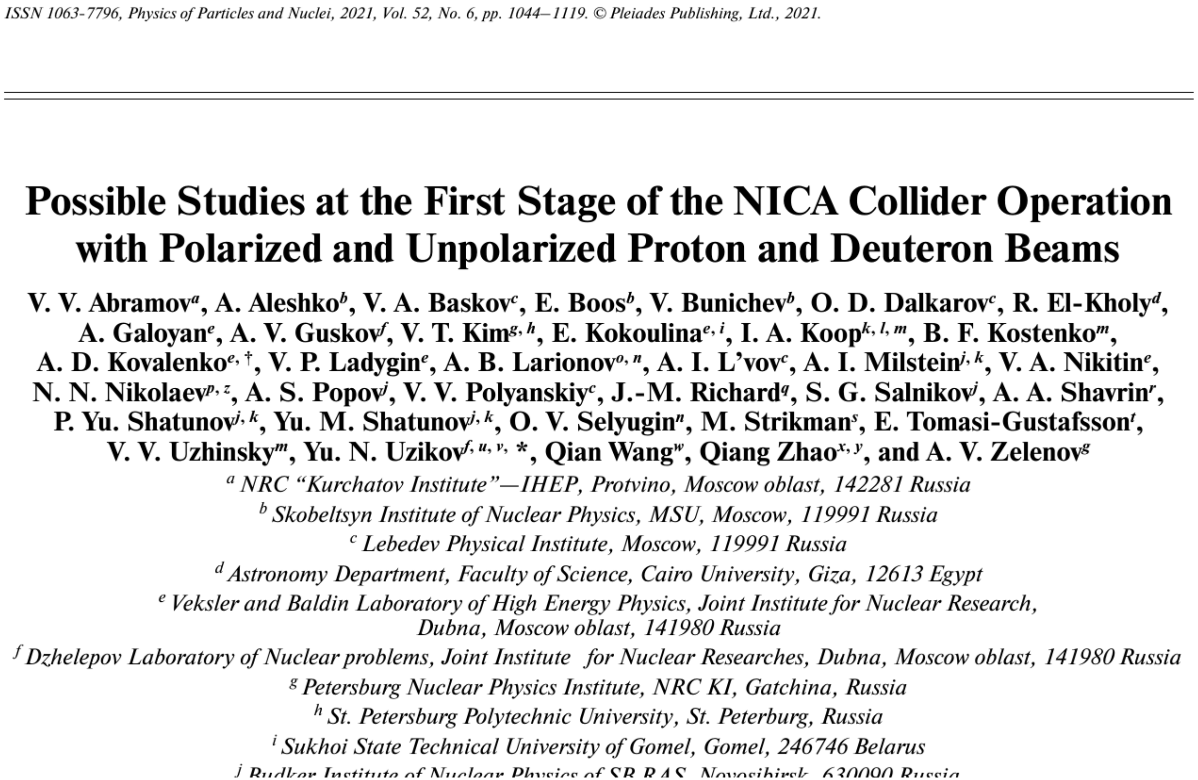
**Micromegas central tracker**:
**$\sigma \sim 150$ μm**

**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 (SRC)
- 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
- ...



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## 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]**

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*[b] Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, 119991 Russia*
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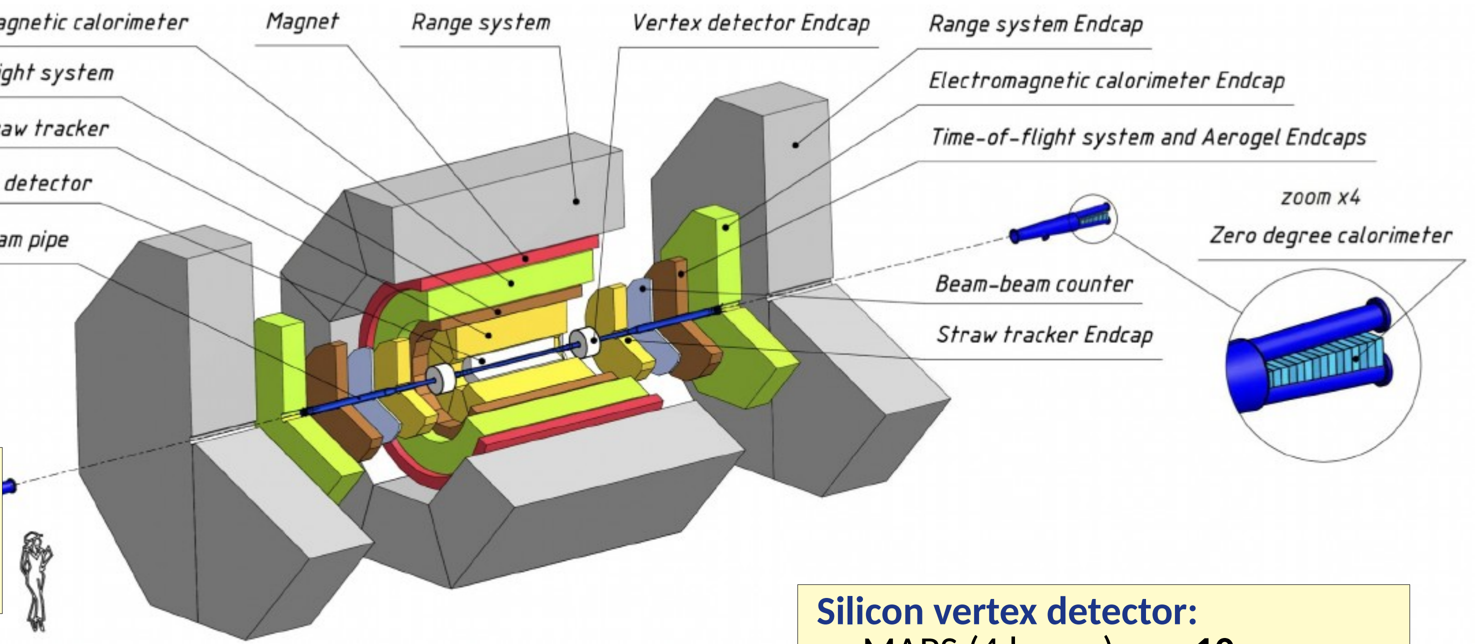
*[d] Astronomy Department, Faculty of Science, Cairo University, Giza, 12613 Egypt*
*[e] Veksler and Baldin Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, Moscow oblast, 141980 Russia*
*[f] Dzhelepov Laboratory of Nuclear problems, Joint Institute for Nuclear Researches, 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

The SPD TDR can be found at arXiv:2404.08317

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



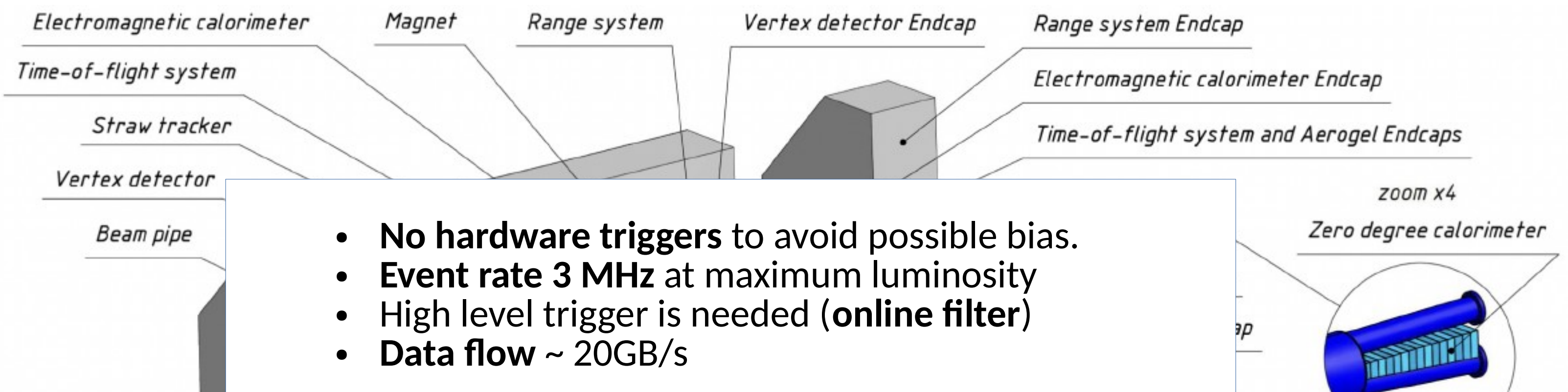
**Time of flight system:**
**$\sigma$ = 50 ps**
**3$\sigma$** $\pi$/K separation for p < 1.5 GeV

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

**Silicon vertex detector:**
- MAPS (4 layers): **$\sigma$ = 10 µm**
- DSSD (3 layers): **$\sigma_\varphi$ = 27.4 µm, $\sigma_z$ = 81.3 µm**

# SPD final layout

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



**Electromagnetic calorimeter:**
**σE/E = 5%/√E⊕1%**

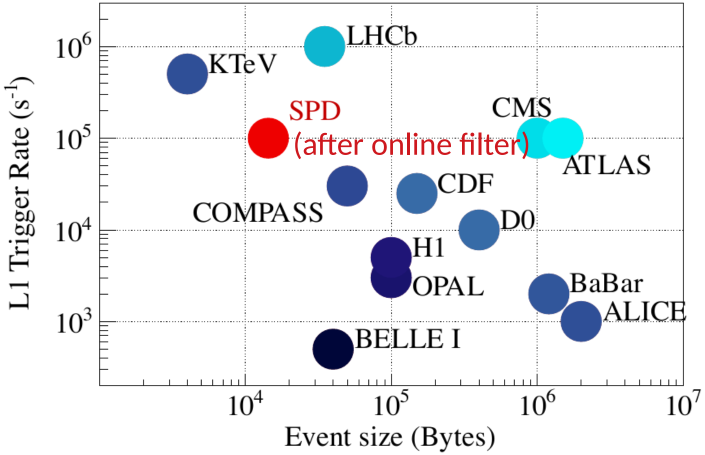
**Time of flight system:**
**σ = 50 ps**
**3σ** π/K separation for p < 1.5 GeV

**Threshol**
for pion k
range **1.0**

**tor:**

**μm,**
**μm**

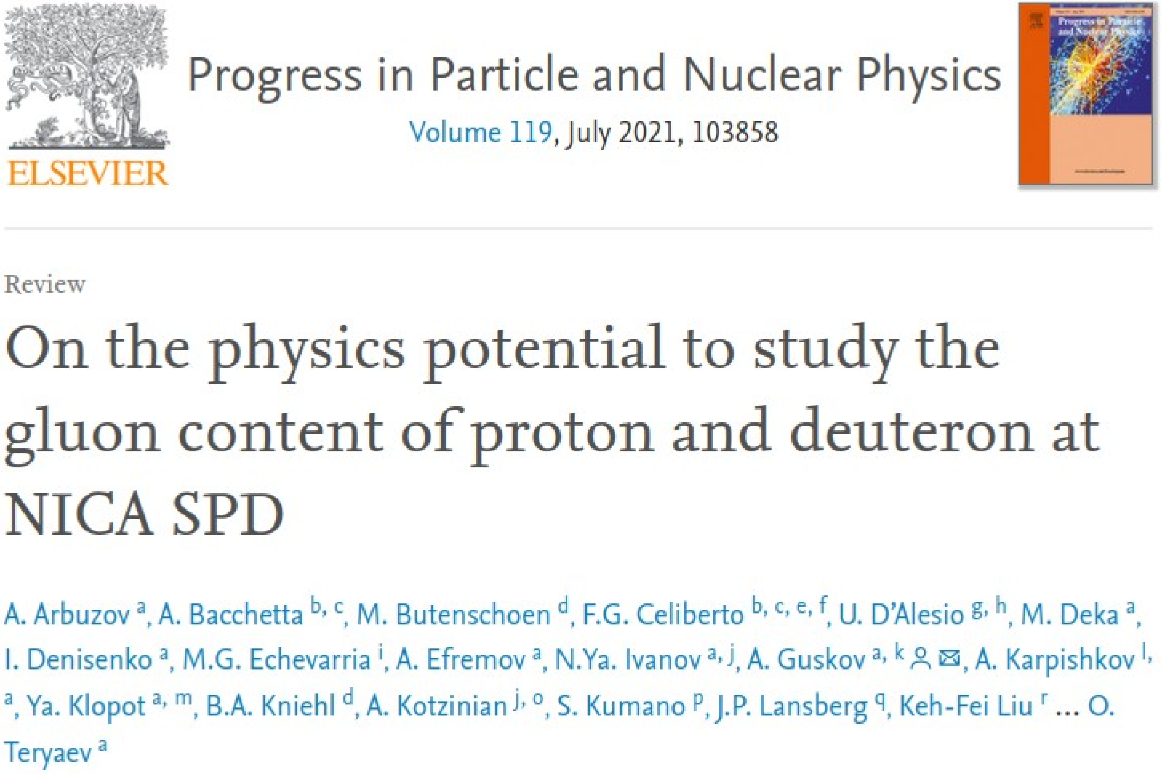
- **No hardware triggers** to avoid possible bias.
- **Event rate 3 MHz** at maximum luminosity
- High level trigger is needed (**online filter**)
- **Data flow** ~ 20GB/s



# 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

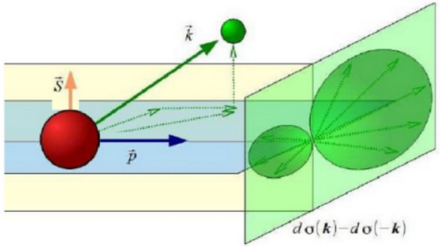
Volume 119, July 2021, 103858

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]

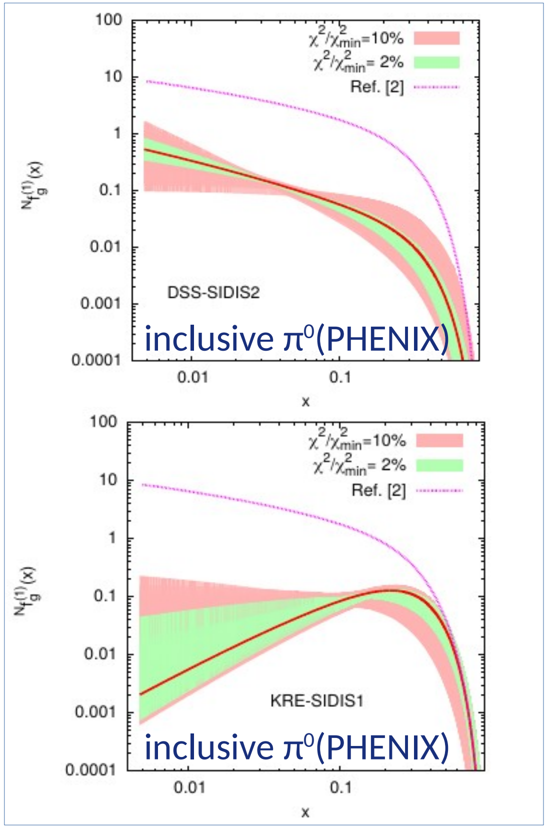
# Gluon Sivers function



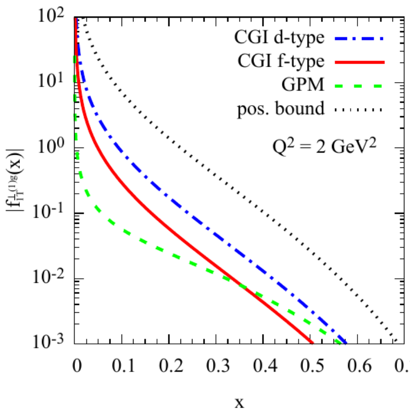
- GSF – correlation between transverse spin and gluon $k_T$
- Can be indirectly related to gluon OAM
- Probed by TSSA

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

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



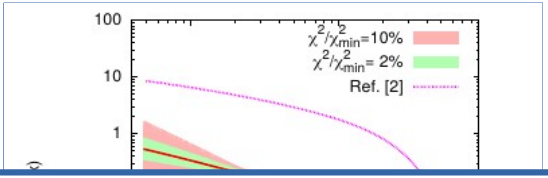
First kT moments for GSF, GPM (JHEP09(2015)119))

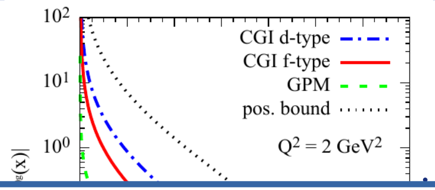


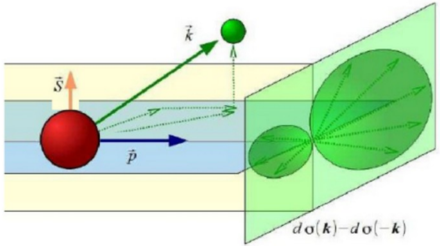
inclusive $\pi^0$ and inclusive D ($p^\uparrow p \to \mu^\pm X$)

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

# Gluon Sivers function







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

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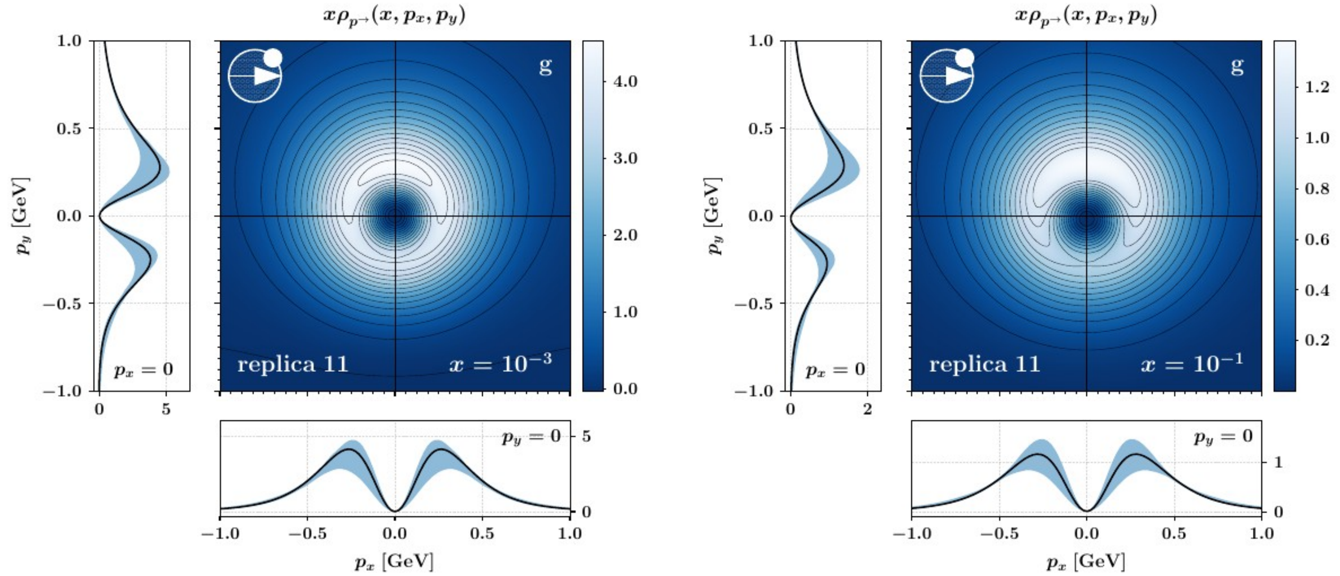
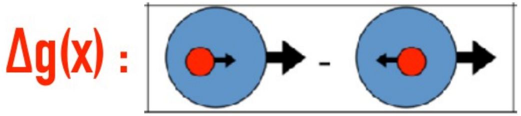
## Spectator model calculations

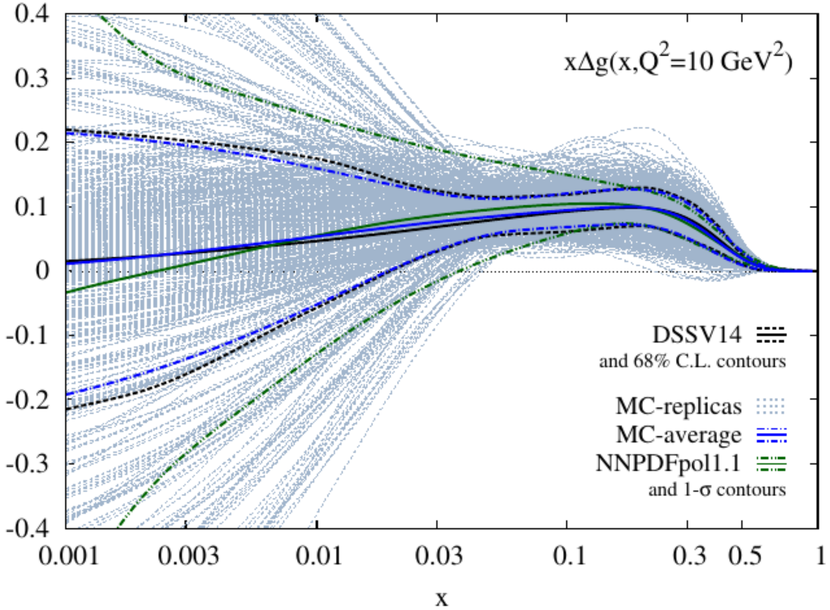


Unpolarized gluon density for a transvsersely polarized nucleon along X-axis, (Q=1.64 GeV) in the **spectator model -** Bacchetta, Celiberto, Radici (EPJC 84 (2024) 6, 576)

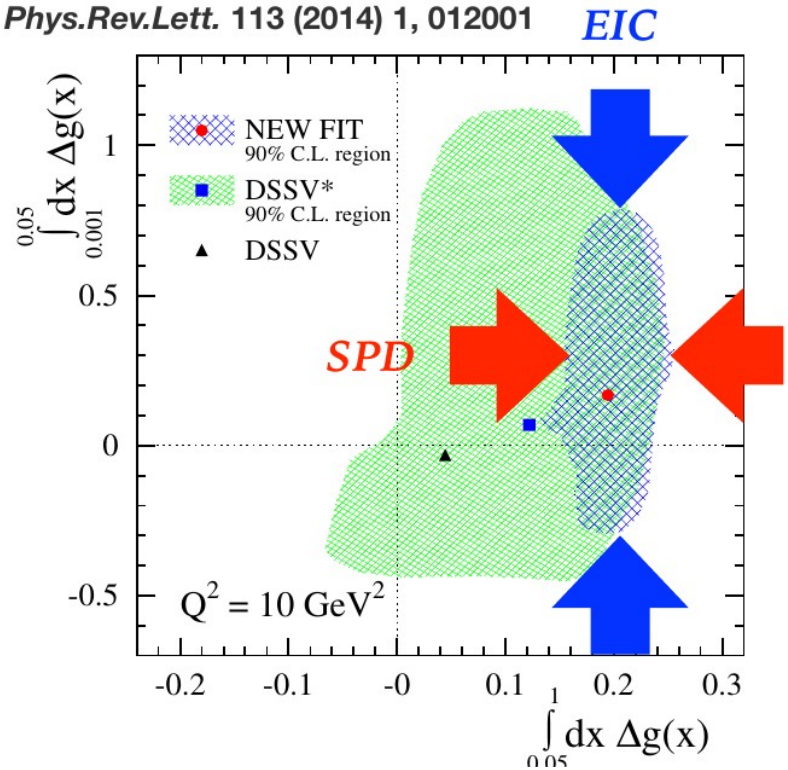
# Gluon helicity distribution



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



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**

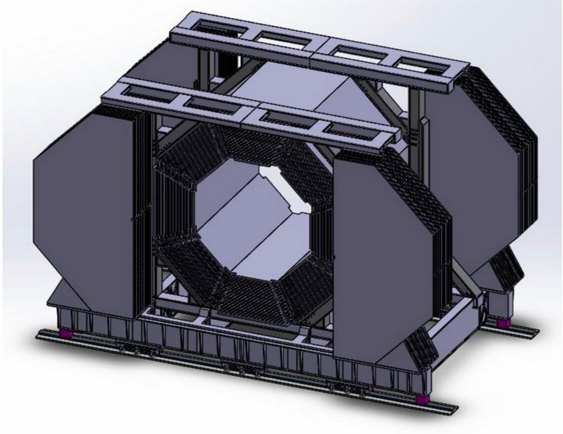
- dominated by gluon-gluon fusion
- high cross-section
- J/ψ can be easily reconstructed from the $\mu^+\mu^-$ decay, ψ(2S) and $\chi_{cJ}$ can be reconstructed based on this decay
- hadronization of $c\bar{c}$ pair is not well understood theoretically:
  - (Improved) Color Evaporation Model
  - CSM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

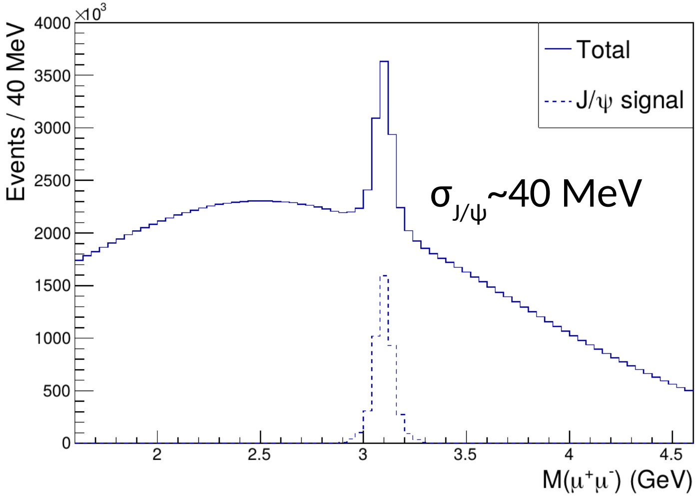
**Charmonia production at SPD**

- High statistics, wide kinematic coverage
- Ability to measure also production properties of ψ(2S), $\chi_{c1}$ and $\chi_{c2}$
- 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)

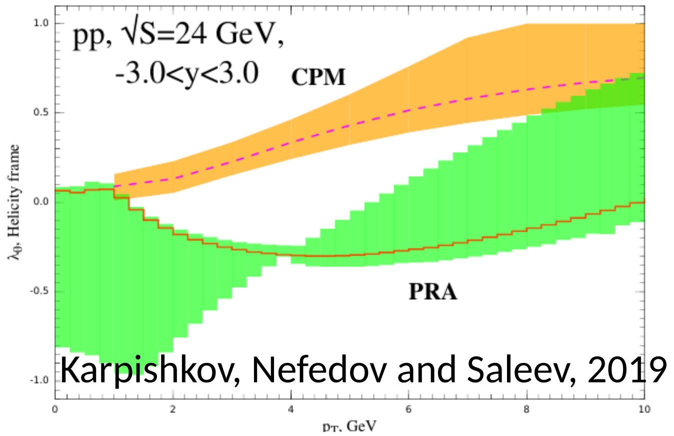
Discussed in details by Cristian Pisano on Tuesday

# Inclusive J/ψ measurements





$\sigma_{J/\psi}$~40 MeV

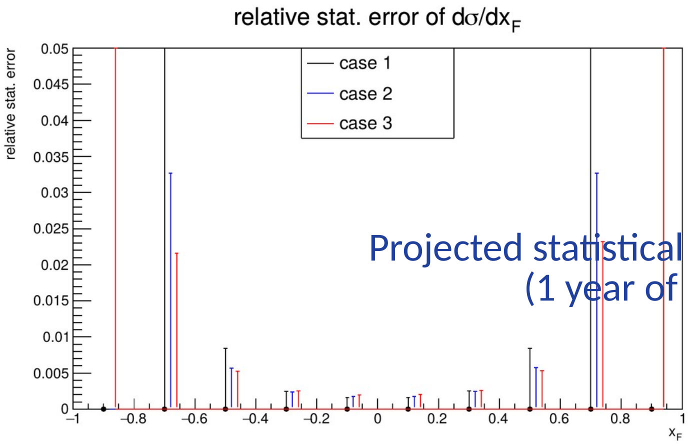


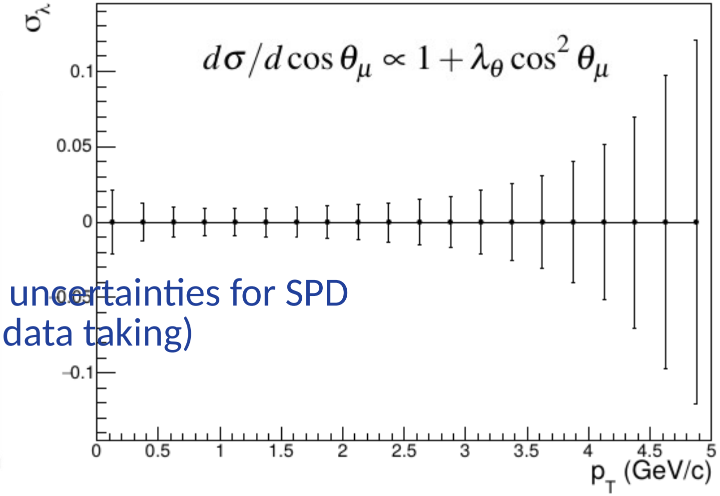
Karpishkov, Nefedov and Saleev, 2019

- 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

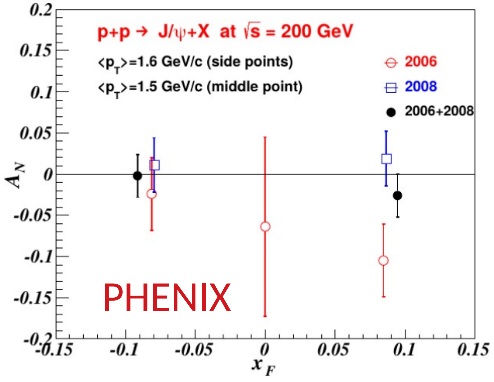




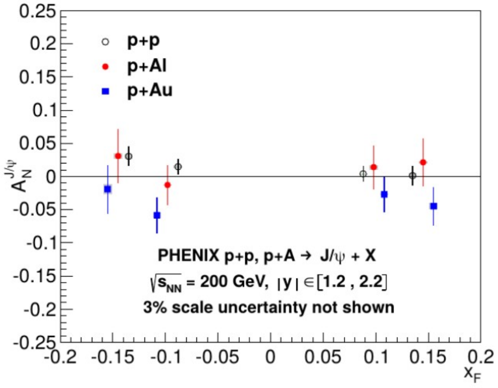
Projected statistical uncertainties for SPD
(1 year of data taking)

# $A_N$ for inclusive J/ψ production

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



PRD82, 112008 (2010)

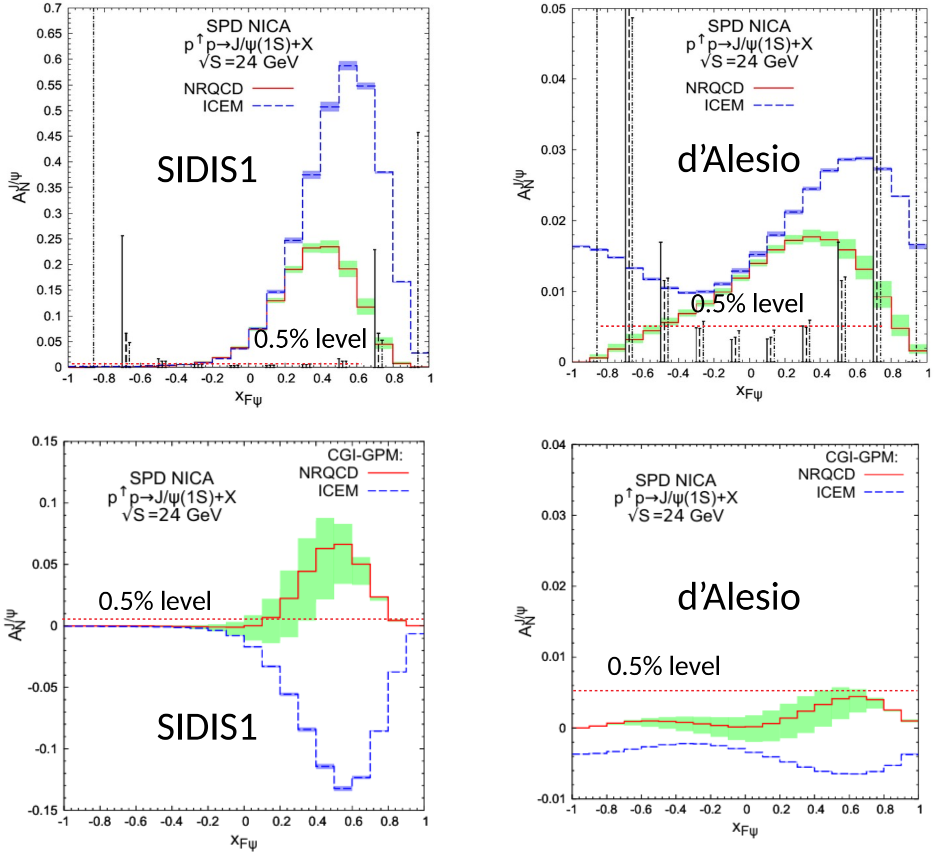


PRD98, 012006 (2018)

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

GPM

CGI-GPM

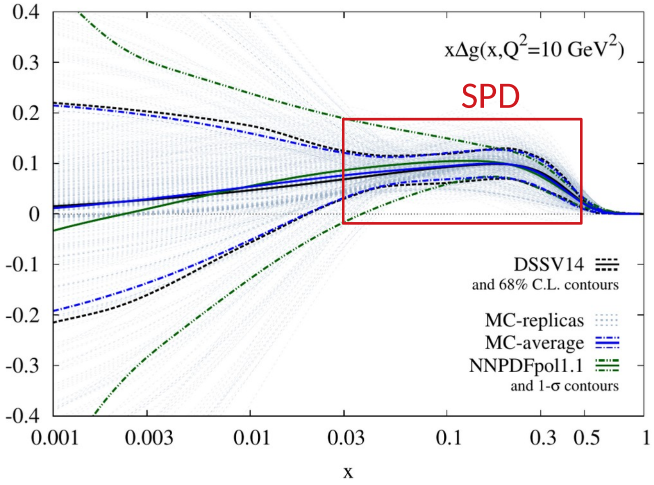


Here and in the following P = 0.7 and is assumed constant during the run.

# $A_{LL}$ for inclusive J/ψ production

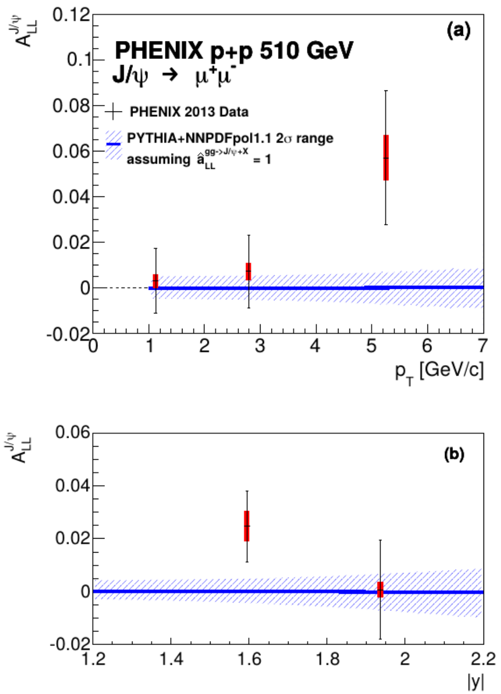
$$A_{LL}^{J/\psi} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

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



PRD100 114027 (2019)

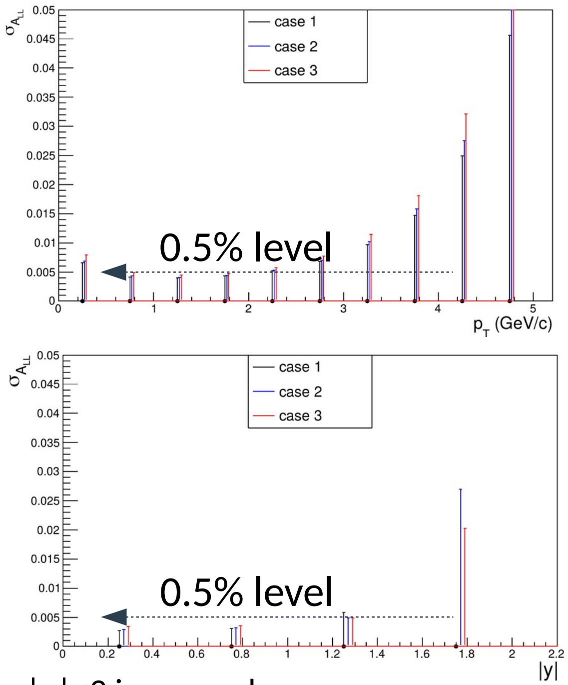
PRD94 112008 (2016)



$x_1$~5x10$^{-2}$

$x_2$~2x10$^{-3}$

Projected statistical uncertainties for SPD

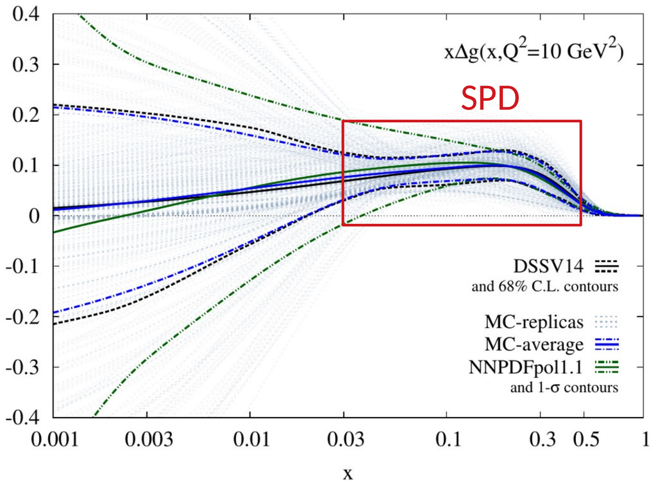


- |y|<2 is covered
- At SPD both Δg($x_1$) and Δg($x_2$) are expected to be close to the maximum
- A measurable $A_{LL}$ of the order of 1-10% can be expected

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

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

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

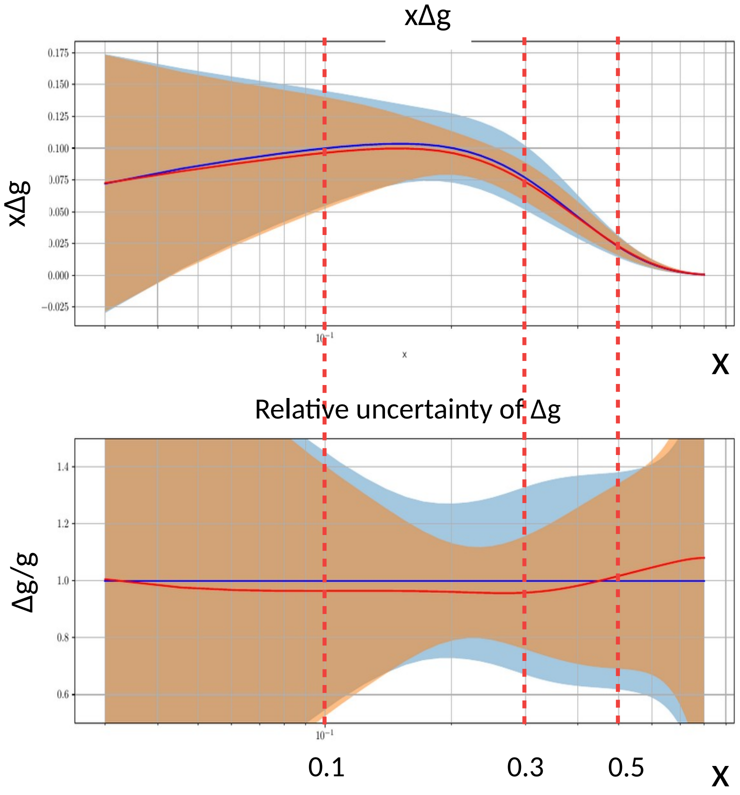


PRD100 114027 (2019)

Impact of SPD data is estimated by

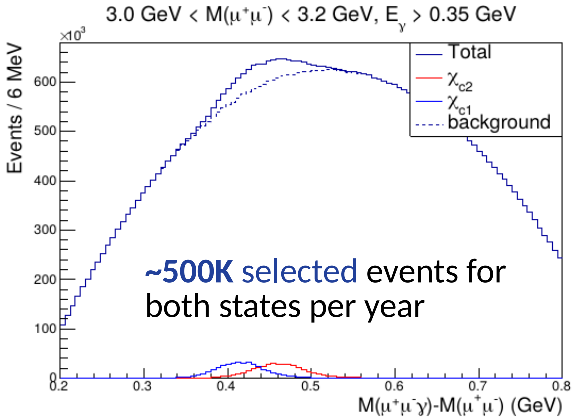
- generating "SPD data" according to NNPDFPol1.1
- prescribing **stat. errors** estimated for 1 year data taking at SPD with √s = 27 GeV
- Bayesian reweighing of MC replicas

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

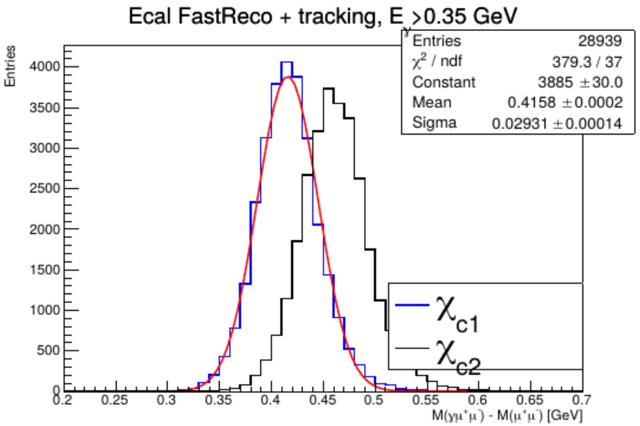


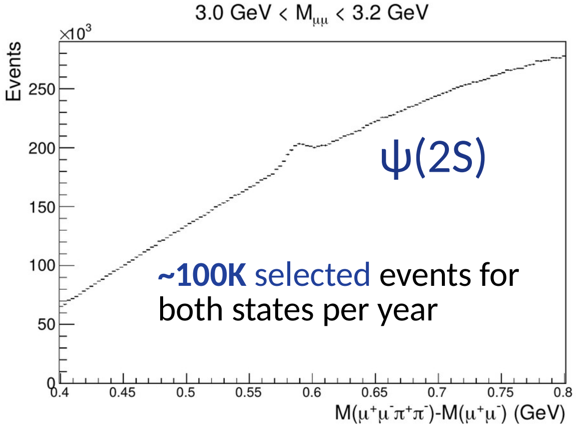
# On other measurements with charmonia

## $\chi_{c1}$ and $\chi_{c2}$



**~500K** selected events for both states per year





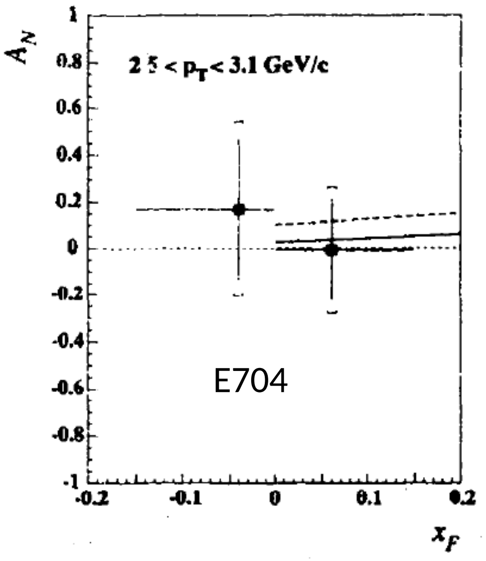
ψ(2S)

**~100K** selected events for both states per year

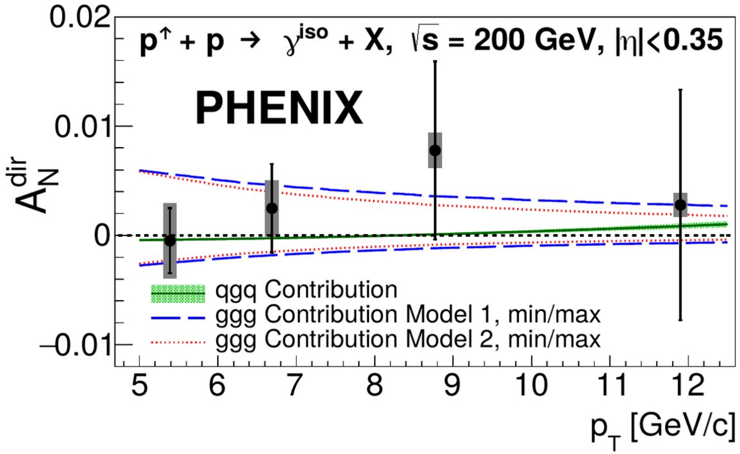
- $\eta_c \to p\bar{p}, \Lambda\bar{\Lambda}, \phi\phi$?
  - 500K selected events for $\eta_c \to p\bar{p}$
  - huge background
- Double J/ψ production
  - 50-100 events/year for both J/ψ dilepton decay modes
  - pT dependence complimentary to high energy experiments
- J/ψγ: limited statistics and large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

# Prompt photons: $A_N$

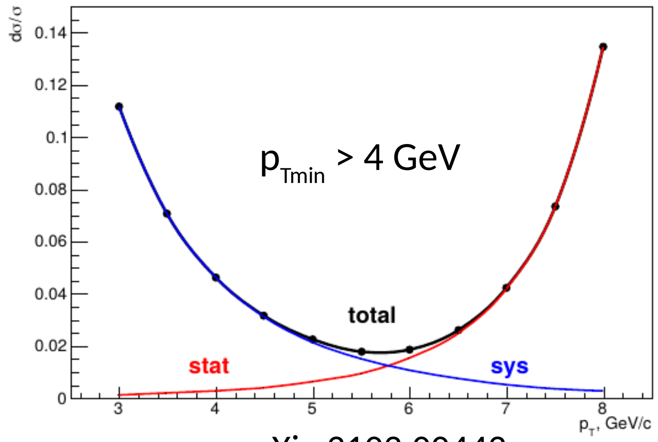
- Straightforward theoretical interpretation
- very challenging experimentally



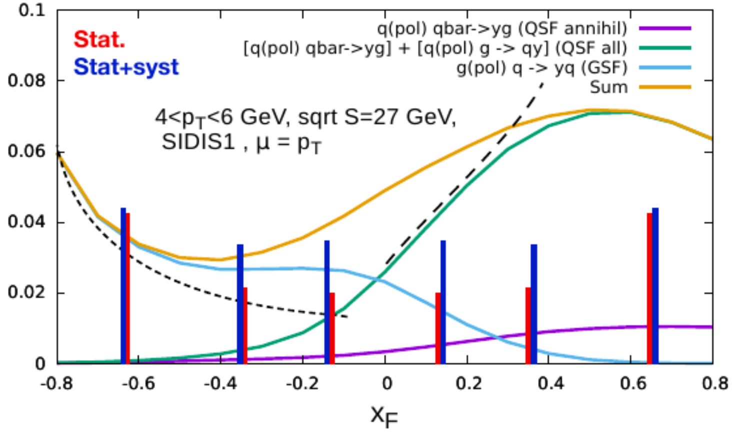
PLB345, 569 (1995)



Phys. Rev. Lett. 127, 162001



arXiv:2102.00442



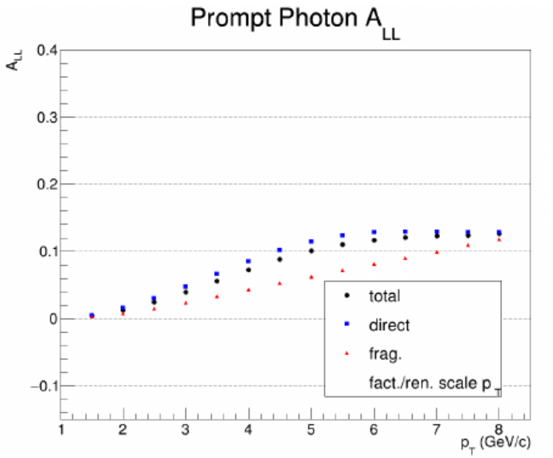
Predictions: Saleev, Shipilova, 2020

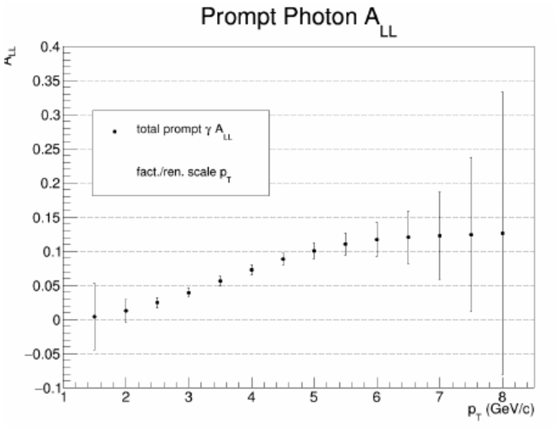
# Prompt photons: $A_{LL}$

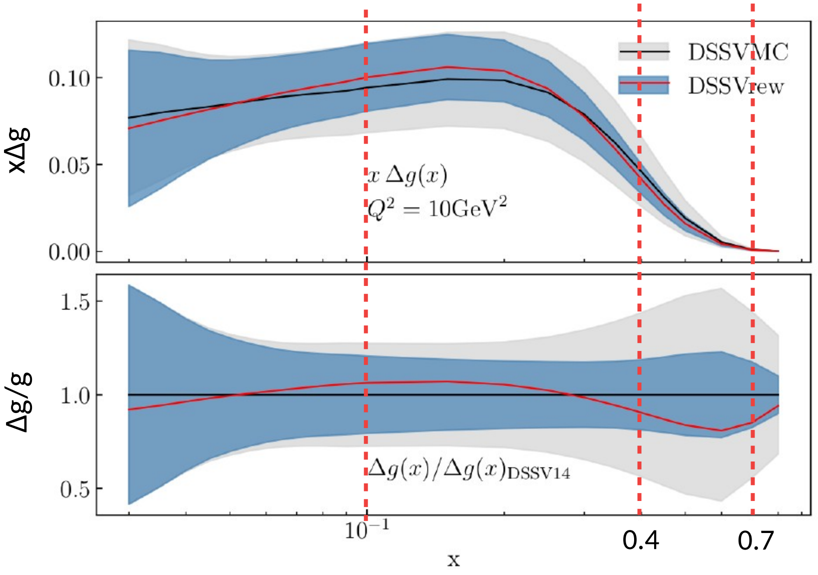
$$A_{LL}^{\gamma} \approx \frac{\Delta g(x_1)}{g(x_1)} \otimes A_{1p}(x_2) \otimes \hat{a}_{LL}^{gq(\bar{q})\to\gamma q(\bar{q})} + (1 \leftrightarrow 2)$$

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



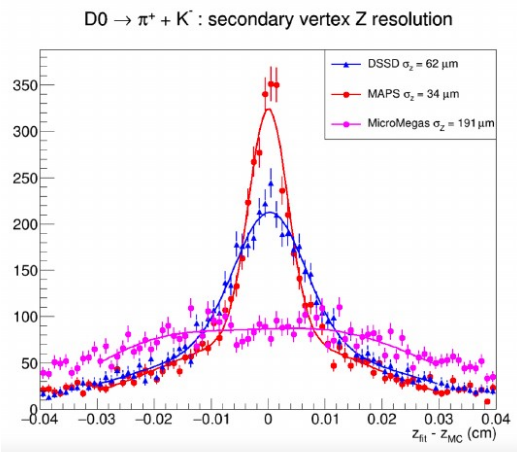


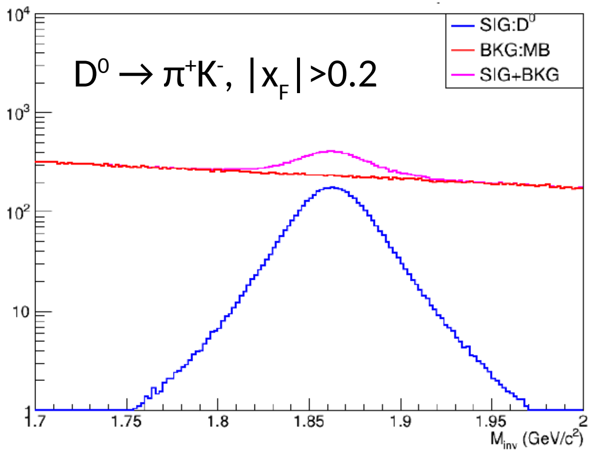


Predictions with new “data” added (top) and ration of the uncertainties (bottom). Courtesy R. Sassot, I. Borsa, 2021.

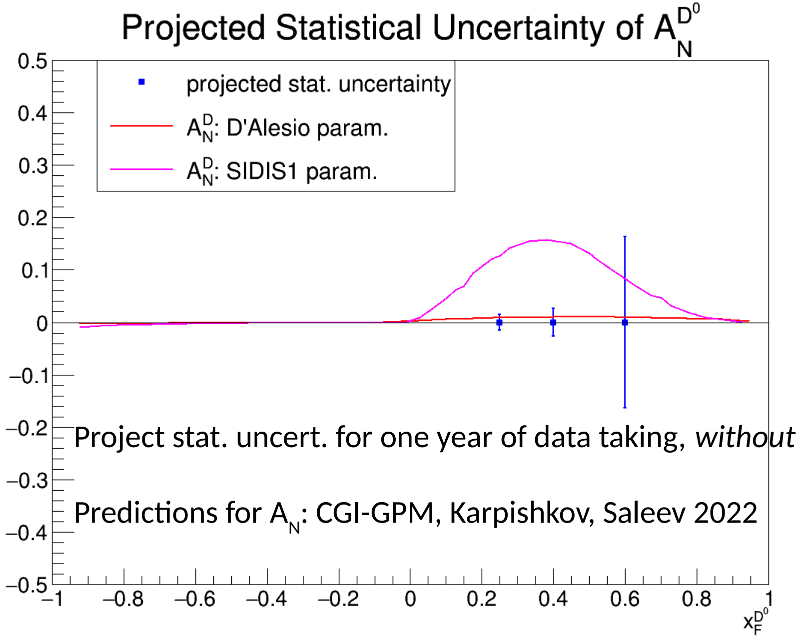
Uncertainties are reduced by factor of 2 for 0.4 < x < 0.7

# Measurements with D mesons





$D^0 \to \pi^+K^-$, $|x_F|>0.2$



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

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

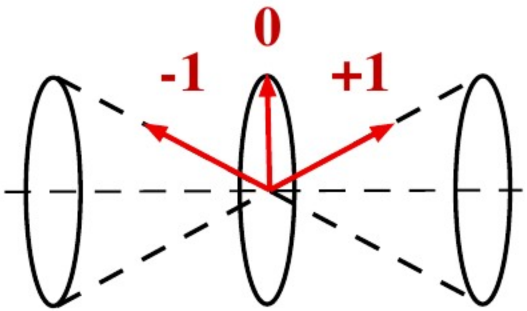
- The largest production cross-section (almost two orders of magnitude larger than for J/ψ)
- Small D-meson boost at our energies
- Interpretation requires c-quark FF
- Projected uncertainties shown for $D^0$ only
- D meson pair production – probe for Boer-Mulders function

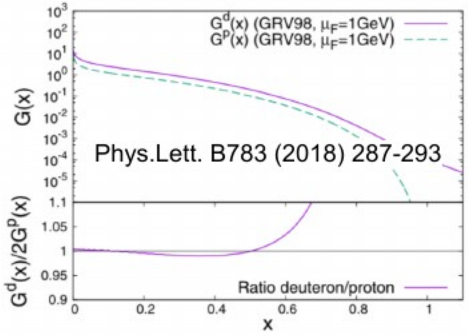
# Deuteron gluon structure

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

*Nonbaryonic content of deuteron:*

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

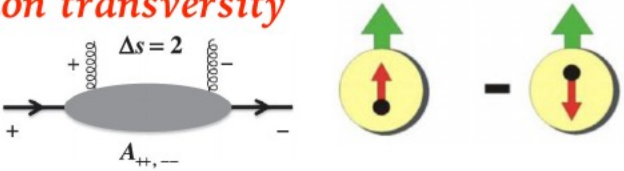




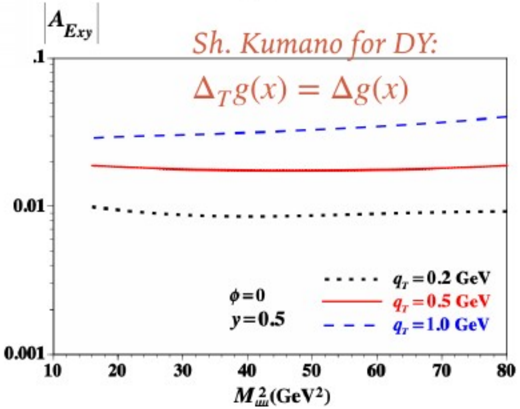
Phys.Lett. B783 (2018) 287-293

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

*Gluon transversity*



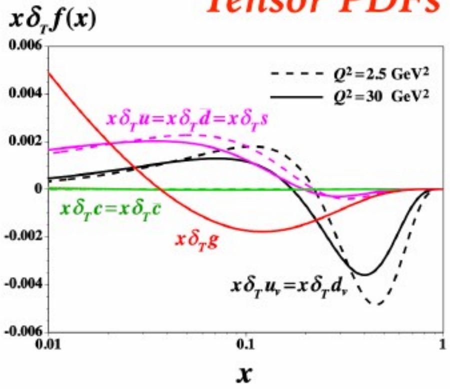
*Unpolarized gluons at high x:*



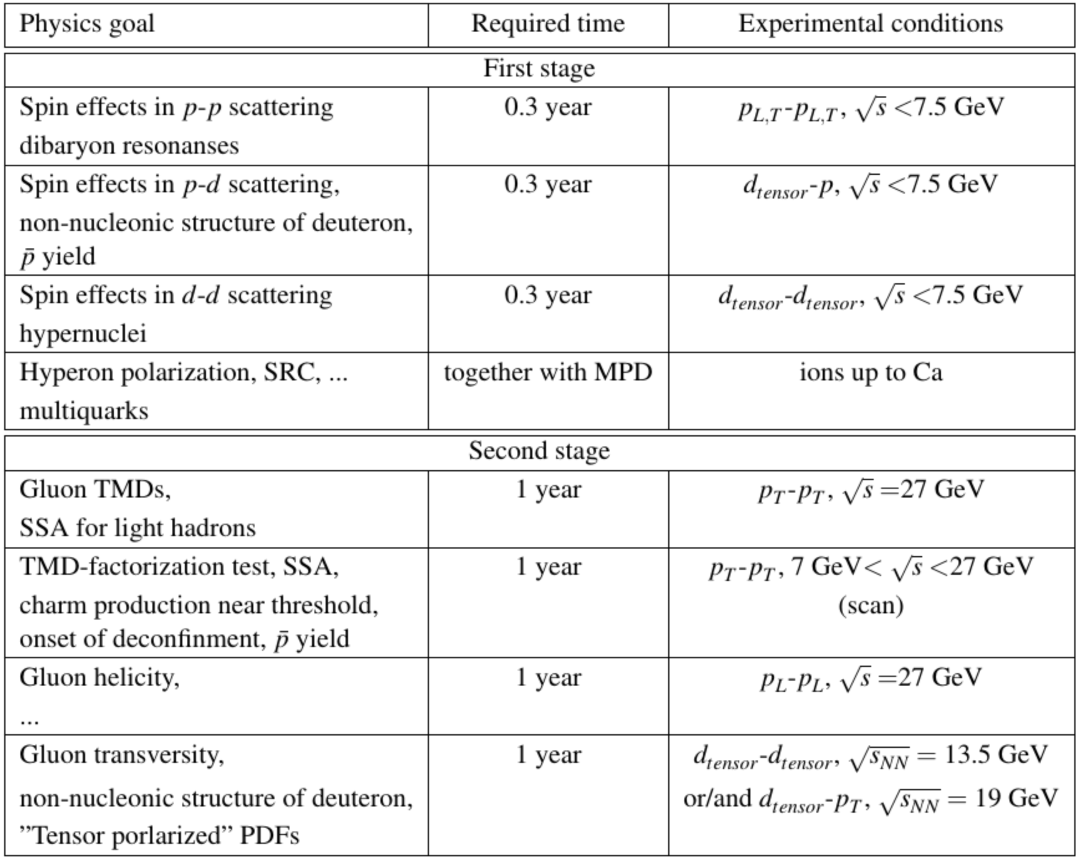
*Sh. Kumano for DY:*

$\Delta_T g(x) = \Delta g(x)$

*Tensor PDFs*



# Running strategy



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

SPD CDR

# SPD Collaboration

VII SPD Collaboration meeting, Almaty, May 2024

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

**MoU under prepartaion:**

- NRC “Kurchatov Institute”, Moscow (NRC KI)
- Higher Institute of Technologies and Applied Sciences, Havana
- 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

# 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

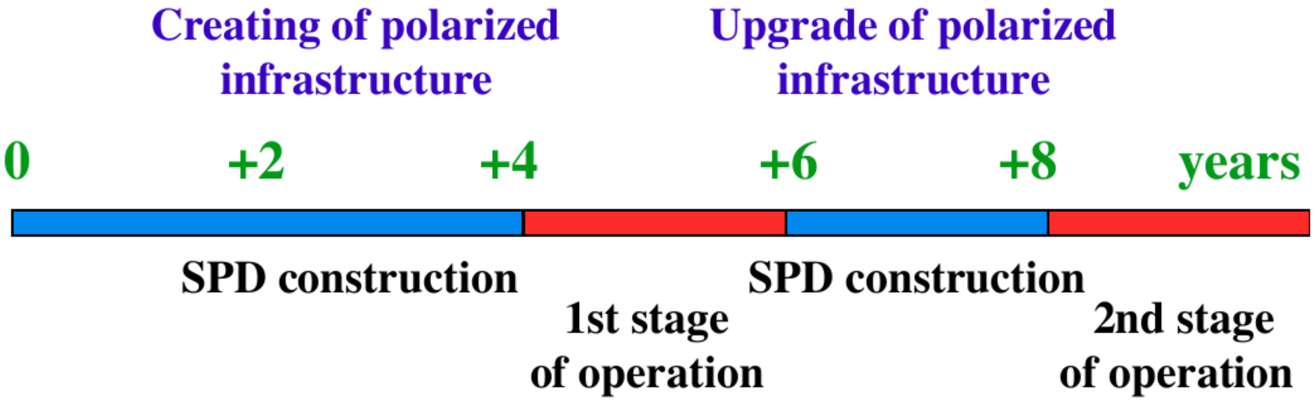
**2020:** Completion of SPD CDR (arXiv:2102.00442v3)

**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 **√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.