Spin Physics Detector project at NICA

Elena Zemlyanichkina on behalf of the SPD collaboration

The joint "21st International Workshop on Hadron Structure and Spectroscopy" and 6th workshop on the "QCD Structure of the Nucleon"

1-5 September 2025, San Sebastián, Spain

Nuclotron-based Ion Collider fAcility at JINR

- Collisions:

$p^{\uparrow}p^{\uparrow}$ up to $\sqrt{s} = 27$ GeV

$d^{\uparrow}d^{\uparrow}$ up to $\sqrt{s_{NN}} = 13.5$ GeV

U, L, T; $|P| > 70\,\%$

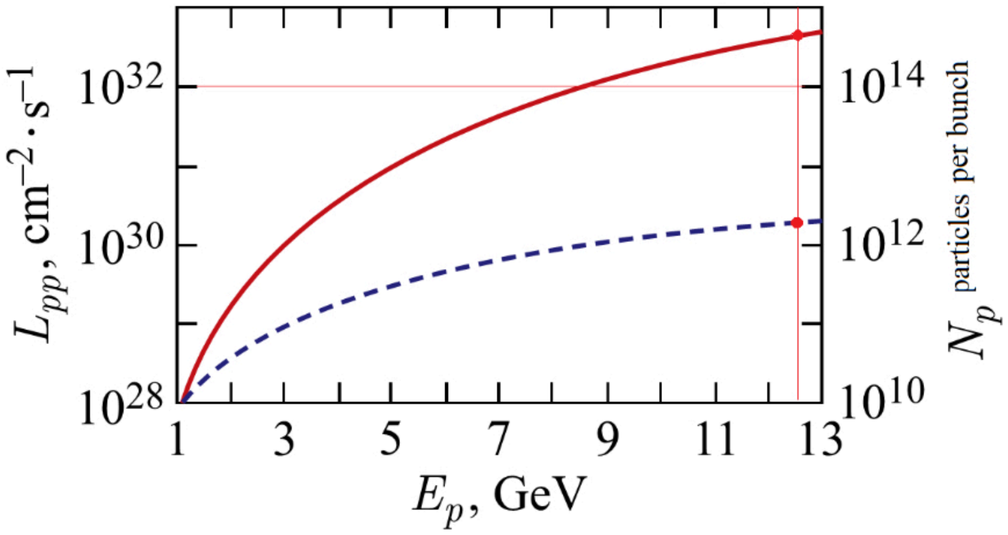
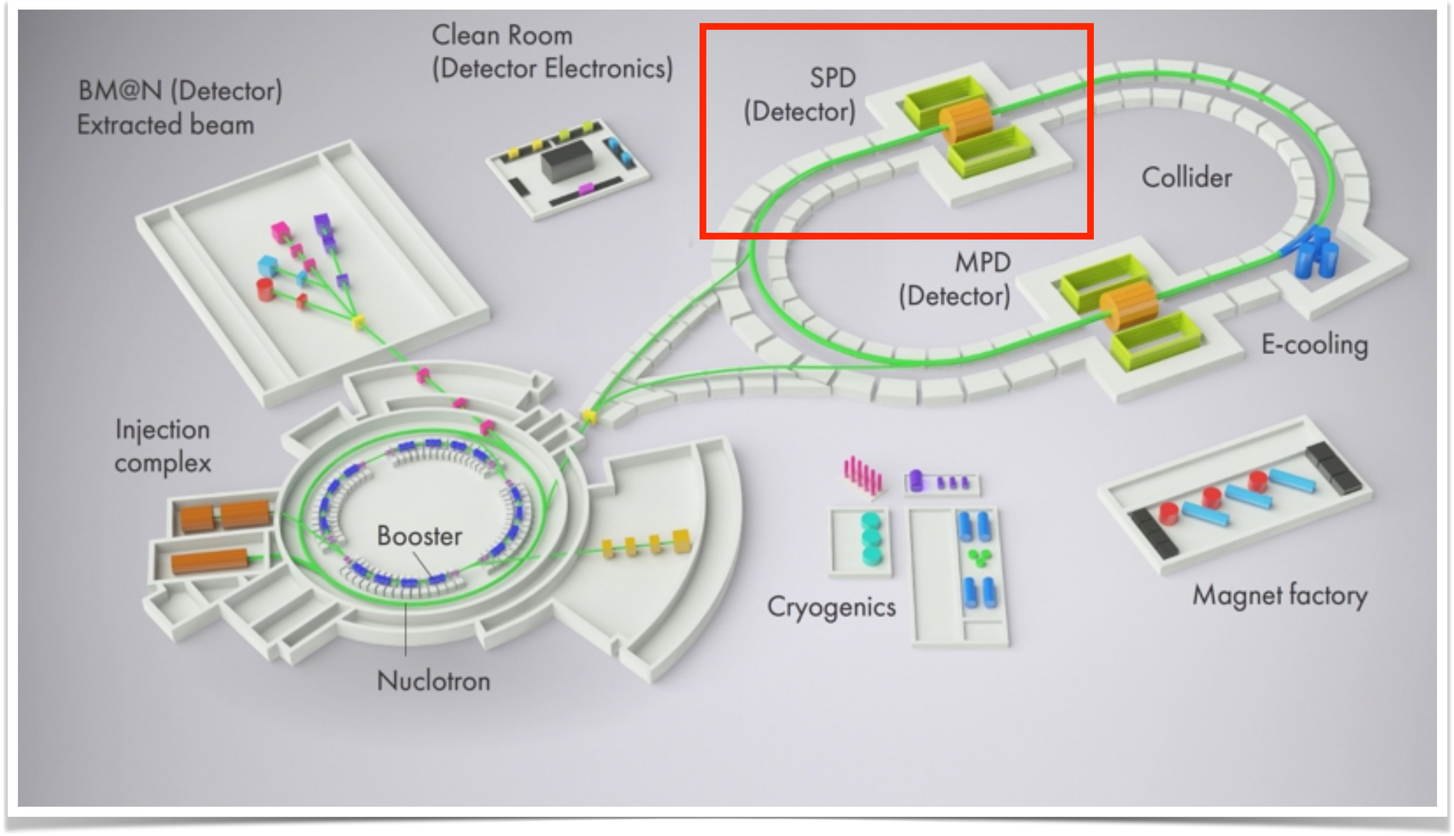


Fig.: Luminosity and bunch intensity : SPD TDR



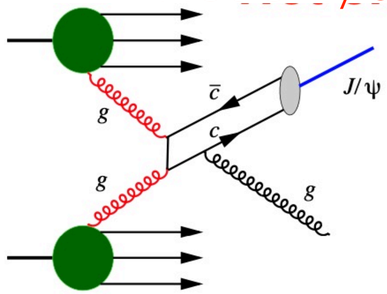
NICA technological launch: 13.06.2024

NICA beam circulation: end of 2025

NICA landscape

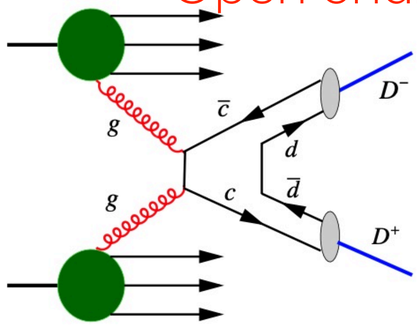
SPD Physics Program

Not only J/ψ !



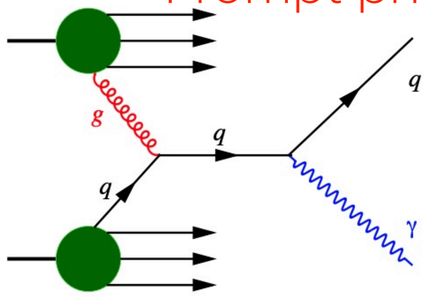
Primarily via dimuon decay chanel

Open charm



Highest statistic, but also very high background

Prompt photons



cleanest channel for interpretation

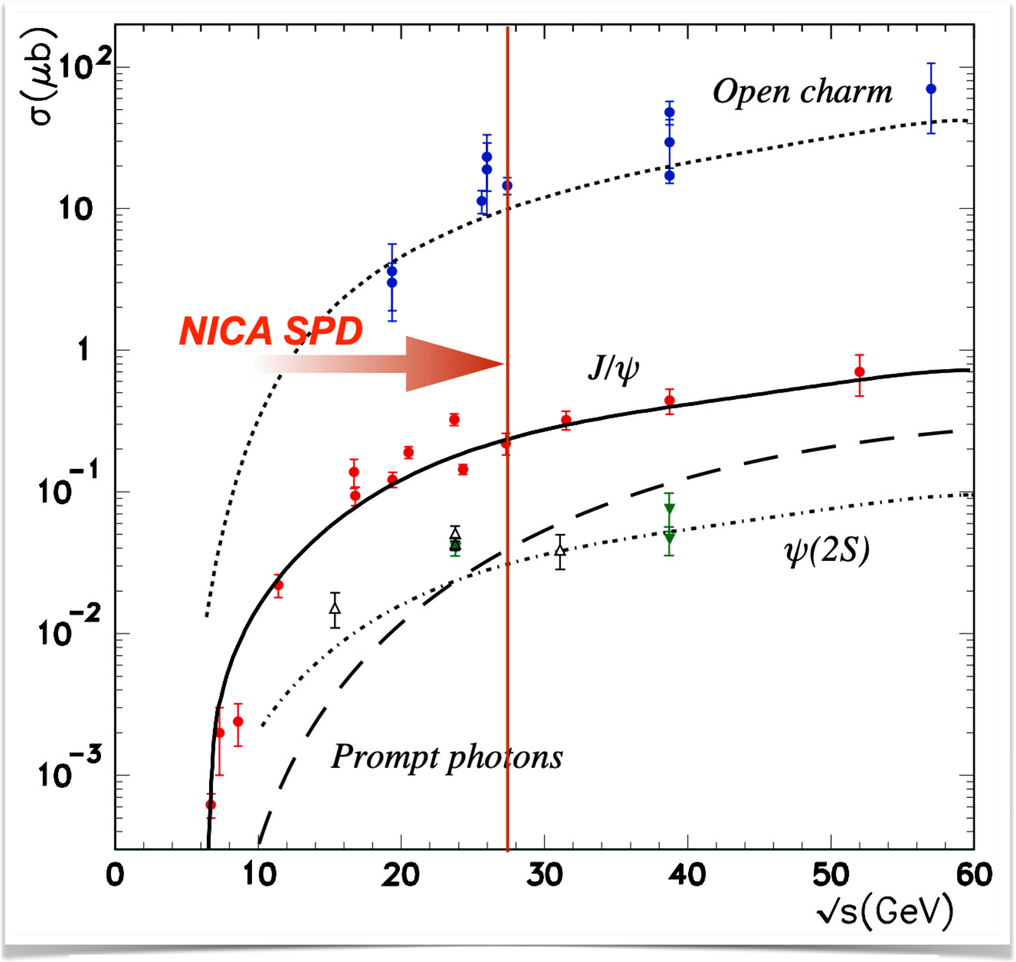


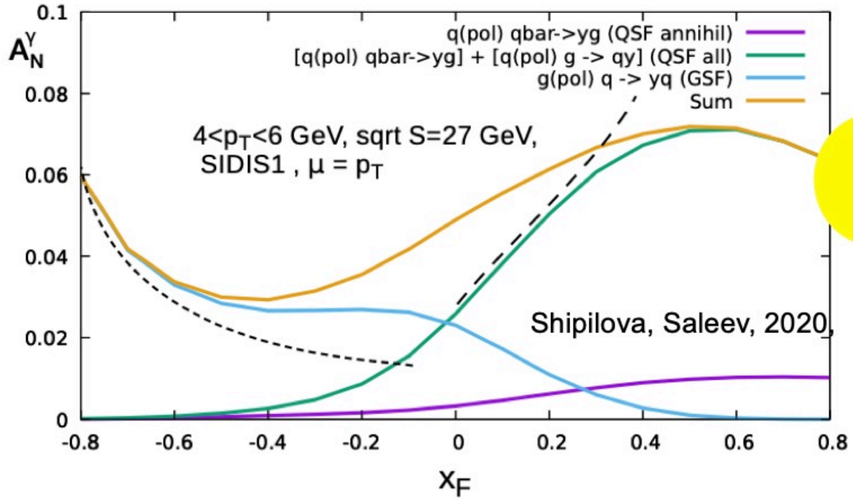
Fig.: Partonic sub-process cross-sections from p-p vs. collision energy

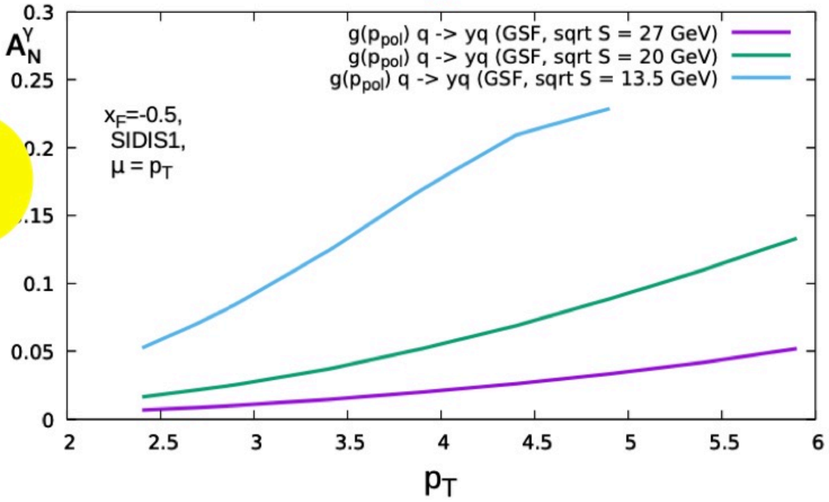
- The main goal of the SPD physics program is to study the contribution of partons to the spin structure of nucleons and deuterons
- particularly focusing on their gluonic components
- Gluon's TMD PDFs through measurements of asymmetries and angular modulations in scattering cross sections

Prog.Part.Nucl.Phys. 119 (2021) 103858; arXiv:2011.15005

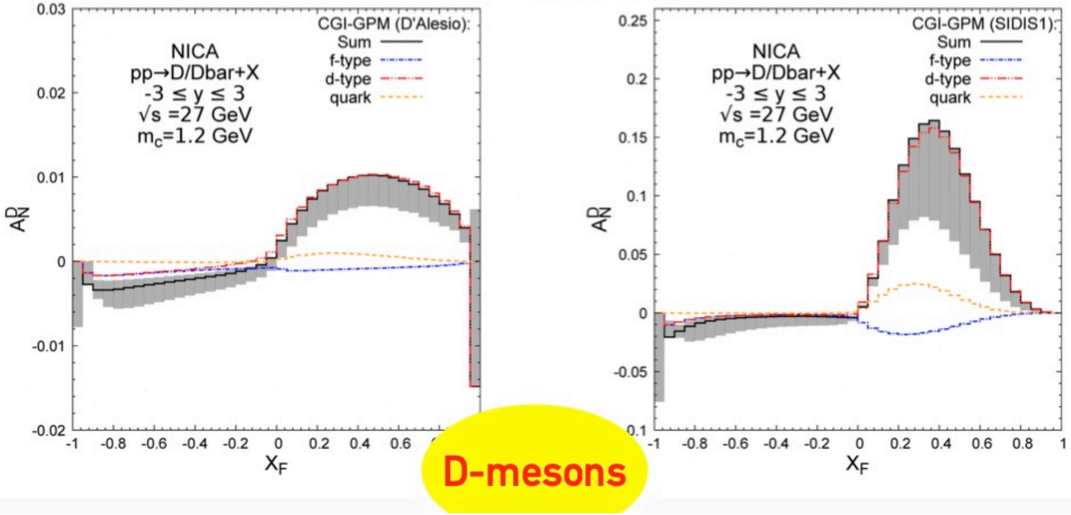
Predictions for SPD kinematics

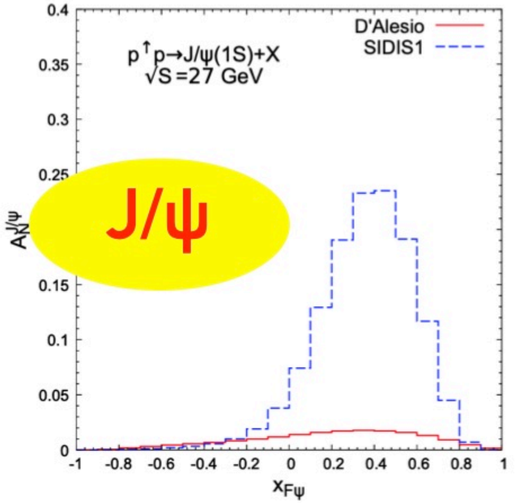
Sivers effect contribution





Saleev 2020





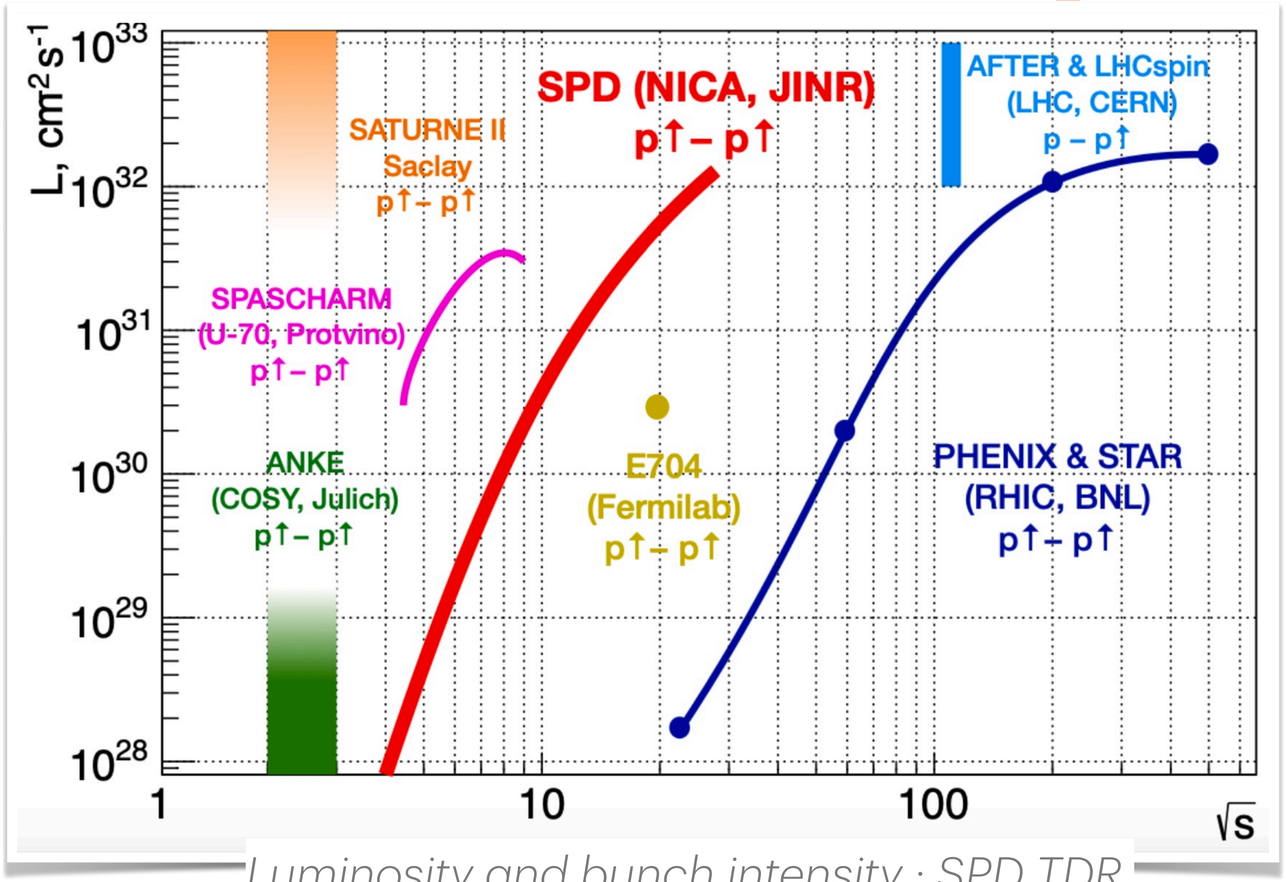
highlight substantial model dependance when using different combinations of PDFs and hadronization models.

For instance, asymmetry predictions obtained with SIDIS1 and d'Alesio parametrizations differ by approximately one order of magnitude.

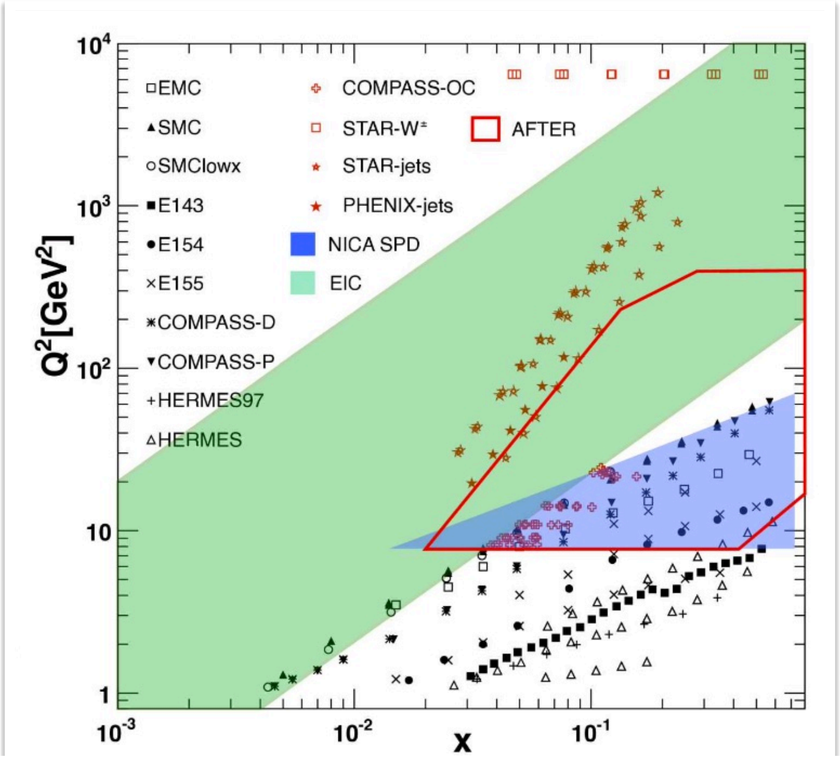
Precise measurements conducted by SPD could play a critical role in reducing such model dependencies in future analyses!

Prog. Part. Nucl. Phys. 2021, 119, 103858

SPD in World landscape of polarised physics



Luminosity and bunch intensity : SPD TDR

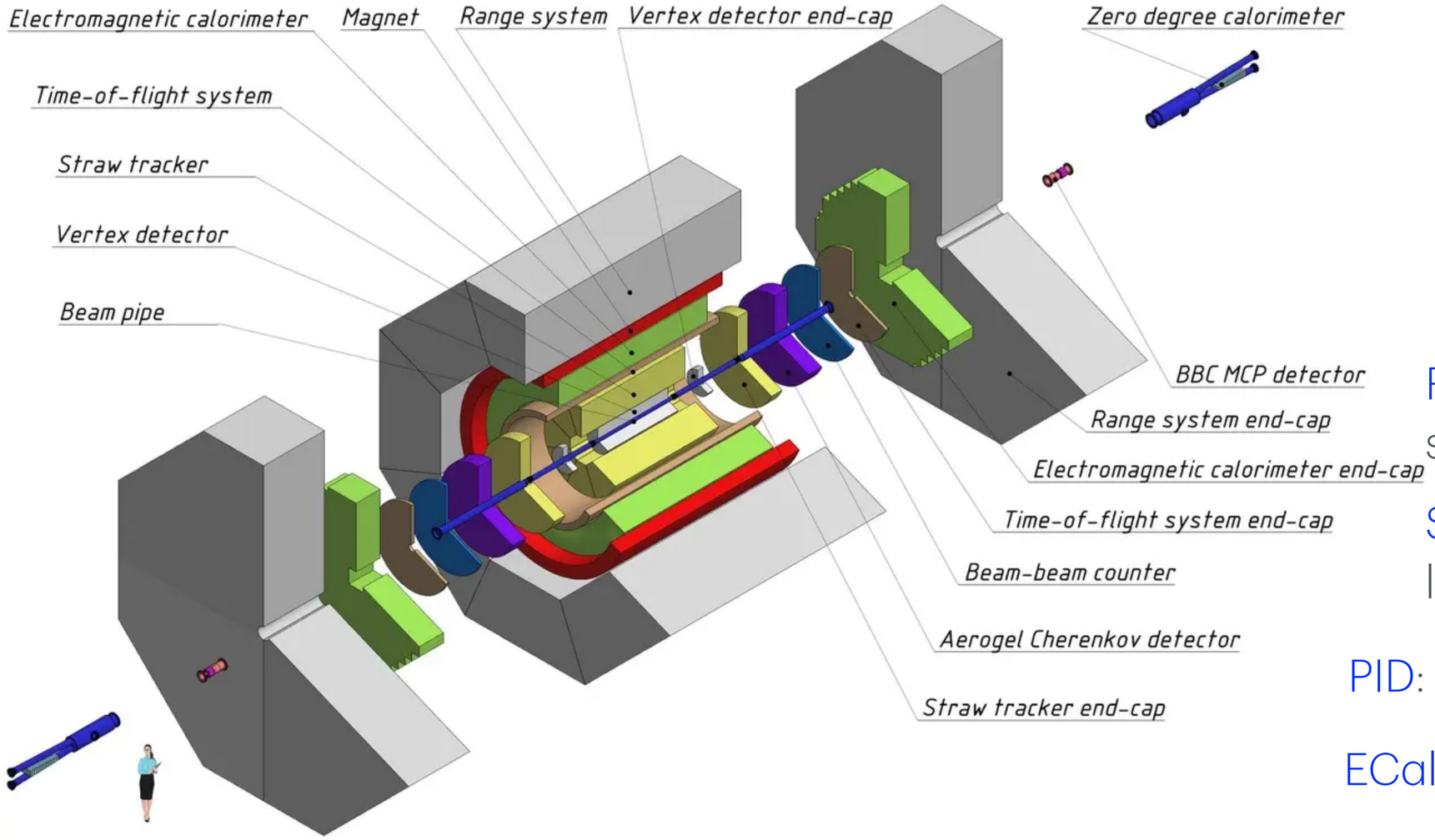


Kinematical coverage for major probes at the SPD: charmed mesons, high-p_T photons, charmonia

At NICA, there will be a unique opportunity to utilize polarized deuteron beams!

The contributions of SPD to polarized gluon distribution studies will complement those from other existing and planned colliders and fixed-target experiments.

Spin Physics Detector setup



Range system: muon/hadron separation

Silicon vertex detector: for short lived particle decays

PID: TOF + FARICH + STRAW (dE/dx)

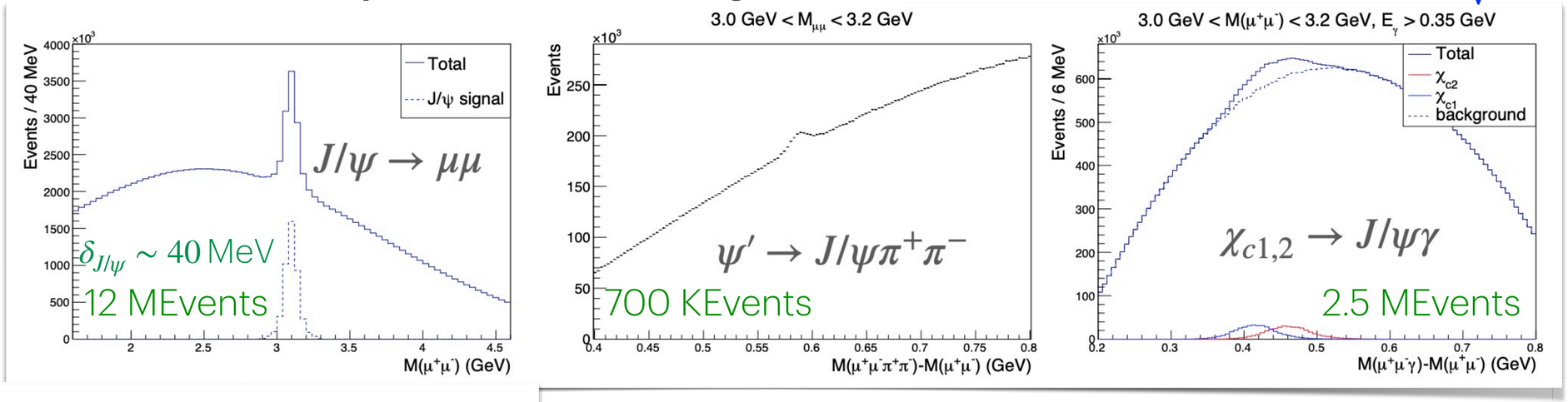
ECal: for prompt photons

SPD Technical Design Report: V.Abazov et al.(SPD Collaboration), Natural Sci.Rev. 1 (2024) 1.

Physics performance: gluon probes

Expected statistics for 1 year of data taking at SPD

1 year = $10^7\ s$, $\sqrt{s} = 27$ GeV



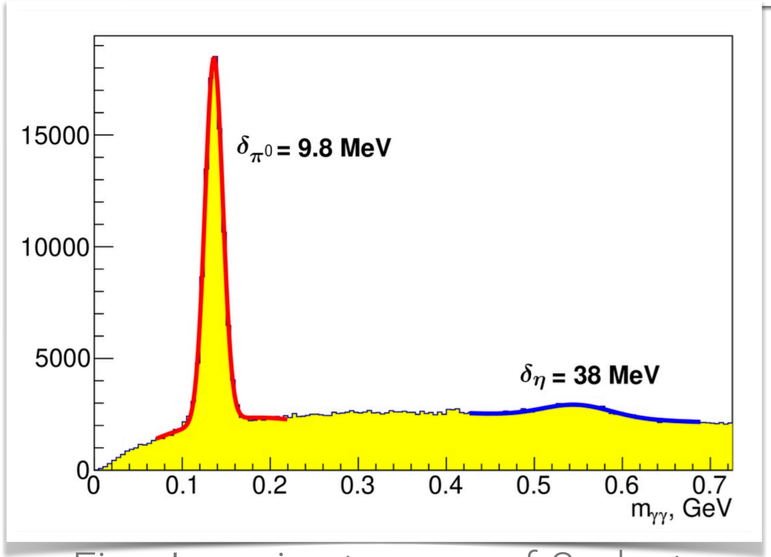
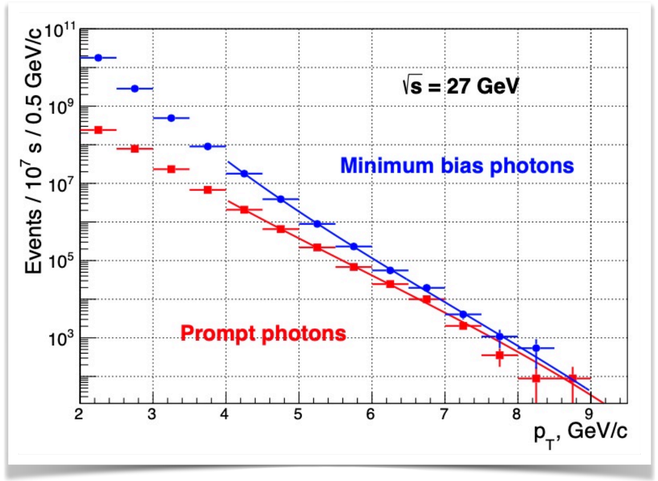
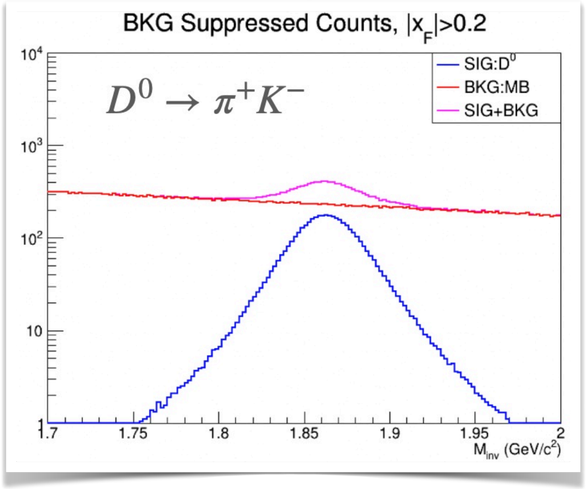


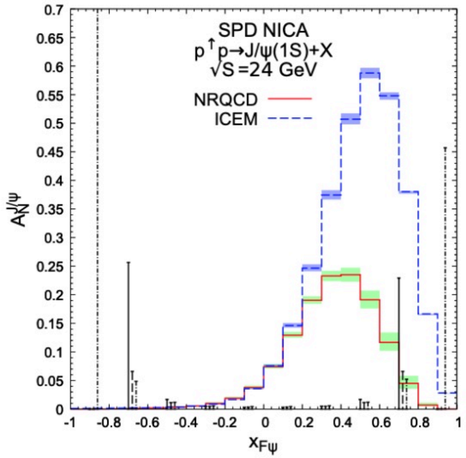
Fig.: Invariant mass of 2 photons



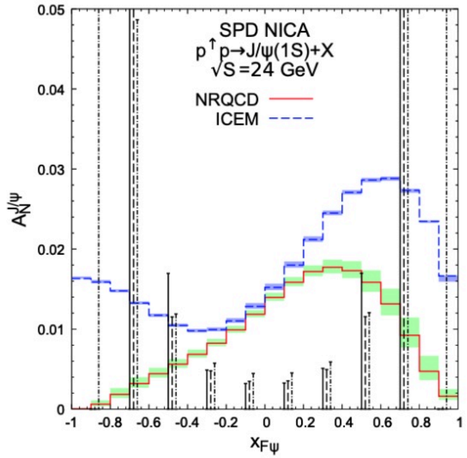


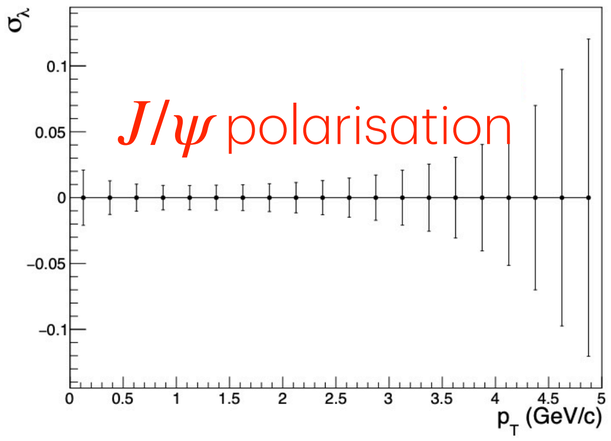
Monte Carlo simulation for the SPD

Physics performance: accuracies



J/ψ

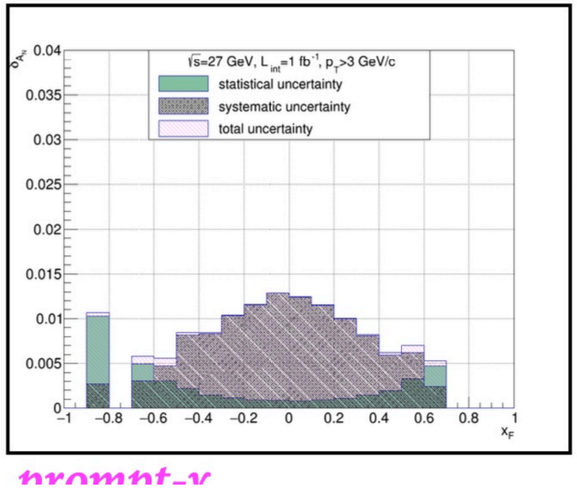




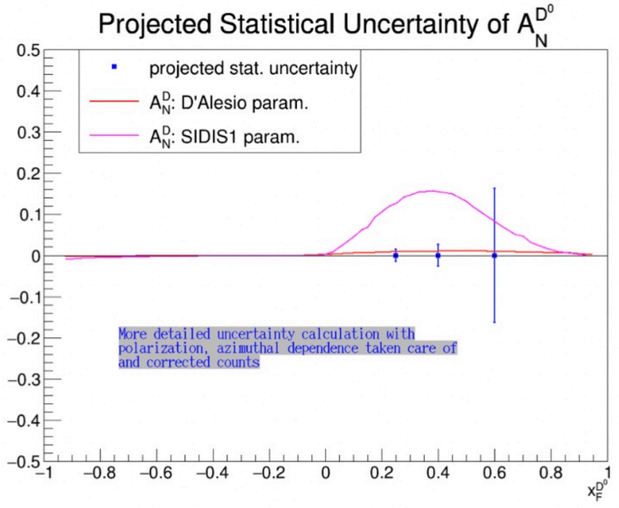
$A_N^{J/\psi}$ predictions for SPD kinematics (and projected uncertainties for one year of recorded data)

[Phys. Rev. D 104, 016008]

Different inputs for gluon Sivers function



Prompt γ



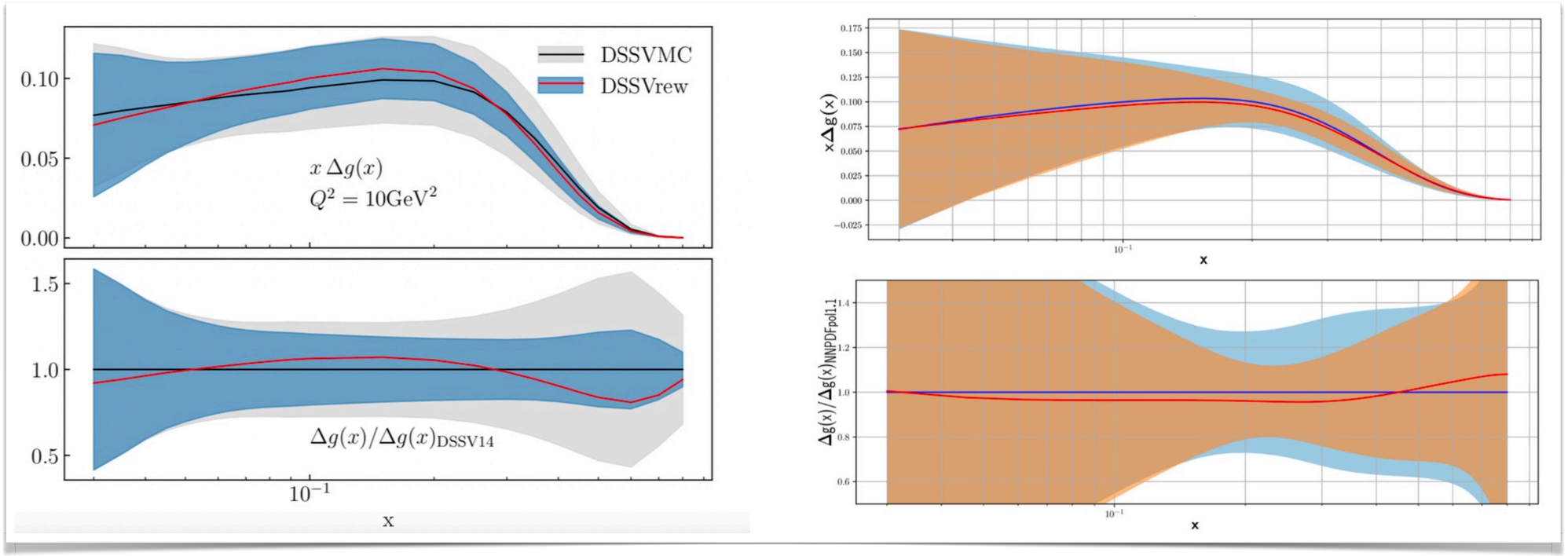
D^0

1 year = 10^7 s,

$\sqrt{s} = 27$ GeV

SPD measurements and precision can be crucial in restricting model dependence in future!

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



A_{LL} *for prompt photons: (Phys.Rev.Lett.2014, 113, 012001.)* A_{LL} for J/ψ (Physics 2023, 5(3), 672-687)

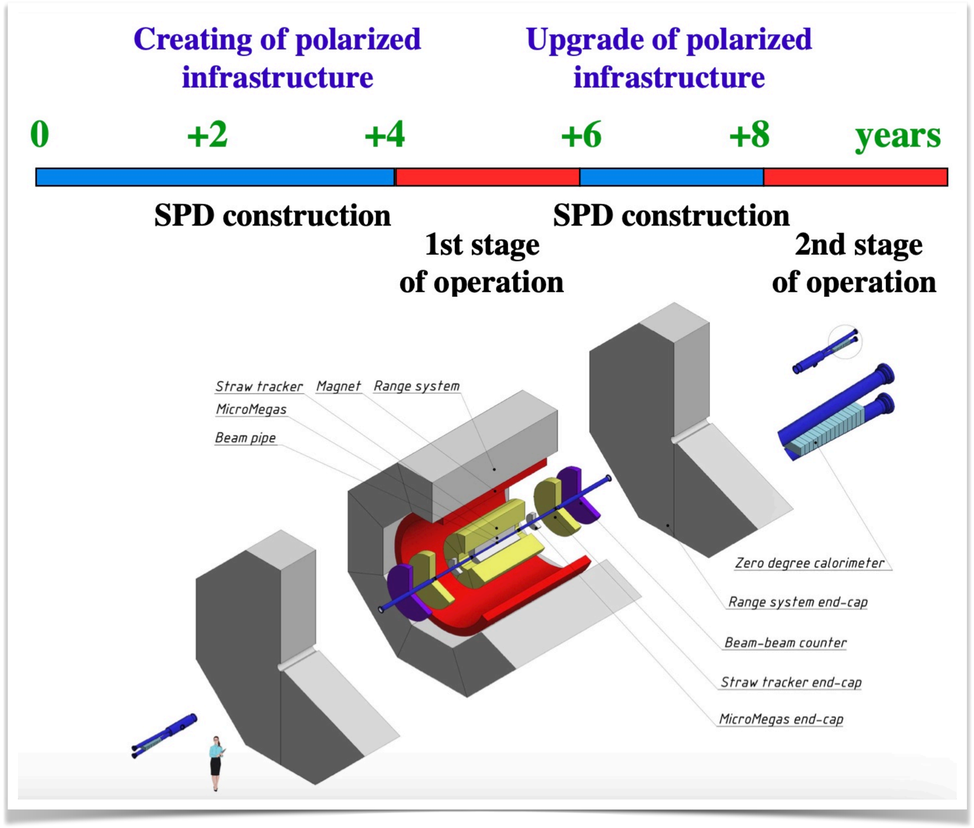
Lines show the mean of the replicas sets before and after the re-weighting, respectively.
Bands show the corresponding standard deviation uncertainties.
Measurements at the SPD can reduce uncertainties of gluon helicity at large x

Physic of the first stage

V.V. Abramov et al., Phys. Part. Nucl. 52(2021) 1044, arXiv:2102.08477

Comprehensive and rich physics program at the initial stage of SPD data taking:

- Spin effects in p-p and d-d elastic scattering
- Spin effects in hyperon production
- Multiquark correlations (SRC) in deuteron and light nuclei
- Dibaryon resonances
- Physics of light and intermediate nuclei collisions
- Exclusive reactions
- Hypernucleus production
- …



Status of the SPD project

- SPD Conceptual Design Report was presented firstly in January of 2021 and approved by the JINR PAC for Particle physics after an expertise in January of 2022
  https://arxiv.org/abs/2102.00442
- SPD Technical Design Report was presented firstly in January 2023, then was updated in 2024 and passed DAC expertise in 2024 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). The project is on track for development. We started preparation of the first phase of the spectrometer
- The SPD international collaboration established in 2021. Currently it consists of more than 400 physicist.

Summary

- The Spin Physics Detector at the NICA is a universal facility for comprehensive study of polarised and unpolarised gluon content of proton and deuteron in polarised high luminosity pp and dd collisions at $\sqrt{s} <= 27\,GeV$;

- SPD can contribute significantly to investigation of gluon helicity; gluon-induced TMD effects; unpolarised gluon PDFs at high-x in proton and deuteron; gluon transversity in deuteron; etc.;

- Comprehensive physics program for the first period of data taking: spin effects in p-p 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 productions near threshold, etc.

- More information including SPD CDR and TDR can be found at http://spd.jinr.ru

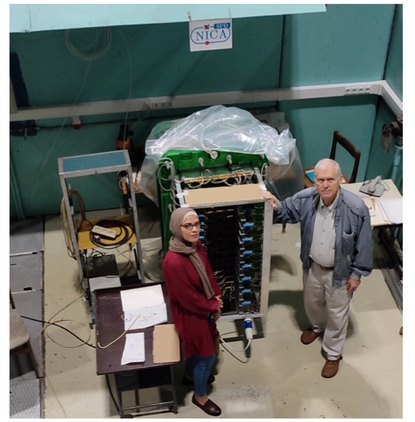
We are opened for new collaborators

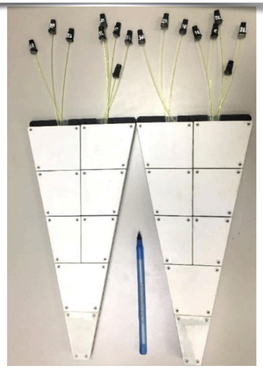
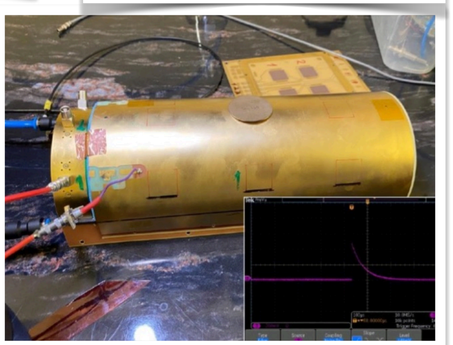
Thank you for your attention!

SPD setup: basic properties

	Stage I	Stage II
Maximum luminosity, 10^{32} cm^{-2} s^{-2}	up to 0.1	1
Interaction rate, MHz	up to 0.4	4
Magnetic field at IP, T	up to 1.0	1.0
Track momentum resolution $\frac{\delta p}{p}$ at 1 GeV/c, %	~1.7	~1.0
Photon energy resolution, %		$5/\sqrt{E} \oplus 1$
$D^0 \to K\pi$ vertex spatial resolution, μm		60 for MAPS
		80 for DSSD
PID capabilities	dE/dx, RS	dE/dx, ECal, RS, TOF, FARICH
Number of channels, 10^3	170	294 for MAPS)
	210	397 for DSSD
Raw data flow, GB/s	up to 1	up to 20
Total weight, t	1236*	1240
Power consumption, kW	77	113 for MAPS
		90 for DSSD

Detector	Spatial resolution	Time resolution	Energy resolution	Signal length
RS	3 mm (wires), 1 cm (strips)	150 ns	$90\%/\sqrt{E}$ (p, n)	250÷500 ns
ECal	5 mm (γ, 1 GeV)	1 ns	$5\%/\sqrt{E} \oplus 1\%$	
TOF	10 cm	50 ps	–	
FARICH		<1 ns	$d\beta/\beta < 10^{-3}$	10 ns
Straw	150 μm	1 ns	$8.5\%(dE/dx)$	120 ns
SVD MAPS	5 μm	–	–	
SVD DSSD	27.4 μm (ϕ)	–	–	
	81.3 μm (z)			
MCT	150 μm	10 ns	–	~ 300 ns
BBC inner	1.5 mm	50 ps	–	
BBC outer	~ 10 cm	400 ps	–	
ZDC	~ 1 cm	150 ps at 0.4 GeV	$50\%/\sqrt{E} \oplus 30\%$ (n)	
			$20\%/\sqrt{E} \oplus 9\%$ (γ)	




Polarised beams at NICA

$d^{\uparrow}$ - was accelerated in 1986 (Synchrophasotron) and in 2002 (Nuclotron).

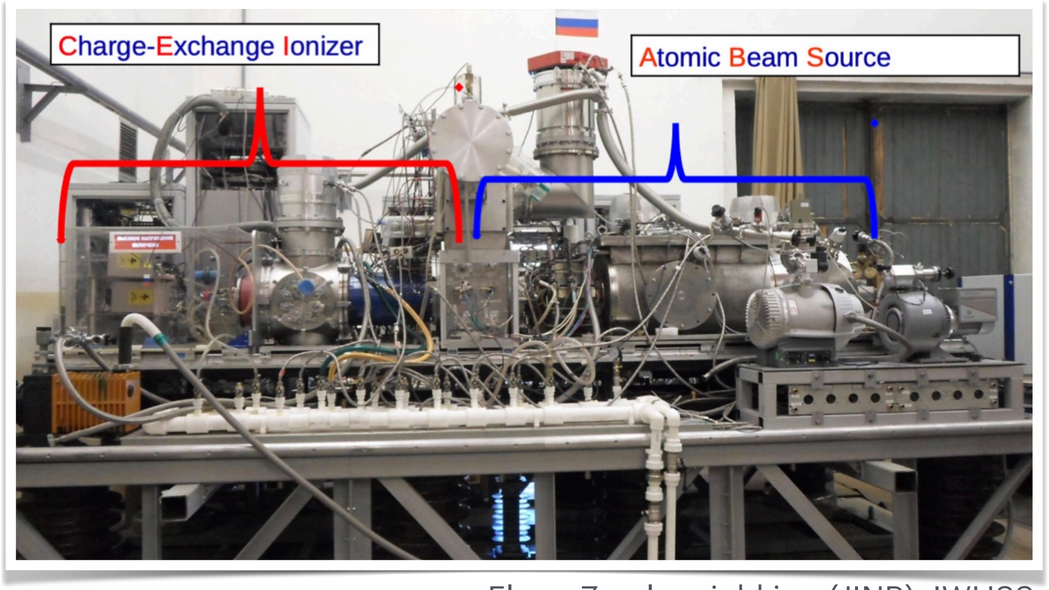
It is a quite simple procedure: there is just 1 depolarizing spin resonance at 5.6 GeV.

$p^{\uparrow}$ - was first obtained only in 2017.

Source of Polarized Ions:

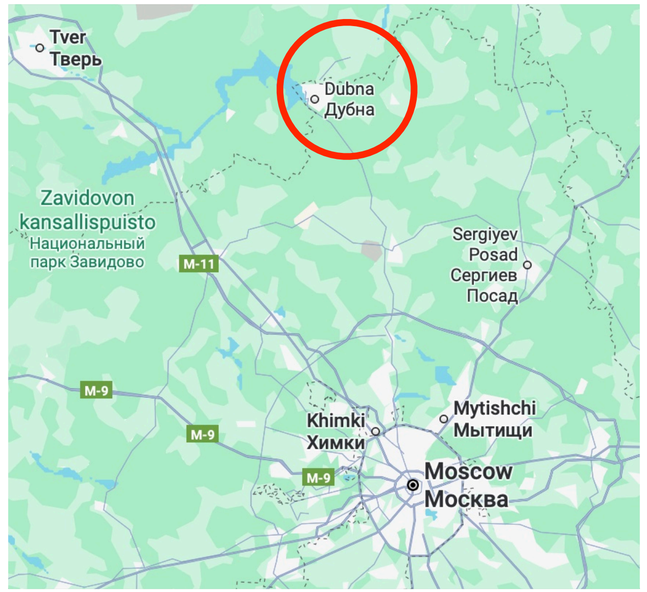
$$H^0 \uparrow + D^+ \rightarrow H^+ \uparrow + D^0$$

$$D^0 \uparrow + H^+ \rightarrow D^+ \uparrow + H^0$$



- Longitudinal polarisation in the IP can be supported at the integer spin-resonances
  - For protons: $E_{kin} = (0.108 + 0.523 \cdot n)$ [GeV]
  - For deuterons: $E_{kin} = (5.62 + 6.56 \cdot n)$ [GeV/u]
- Transverse polarisation at any energies

The Joint Institute for Nuclear Research



JINR is an international intergovernmental scientific research organisation situated in the science city Dubna of the Moscow region (Russia)