The NICA-Spin Physics Detector project: a new tool to investigate the HADRON structure

Egle Tomasi-Gustafsson

egle.tomasi@cea.fr

CEA, IRFU, DPhN

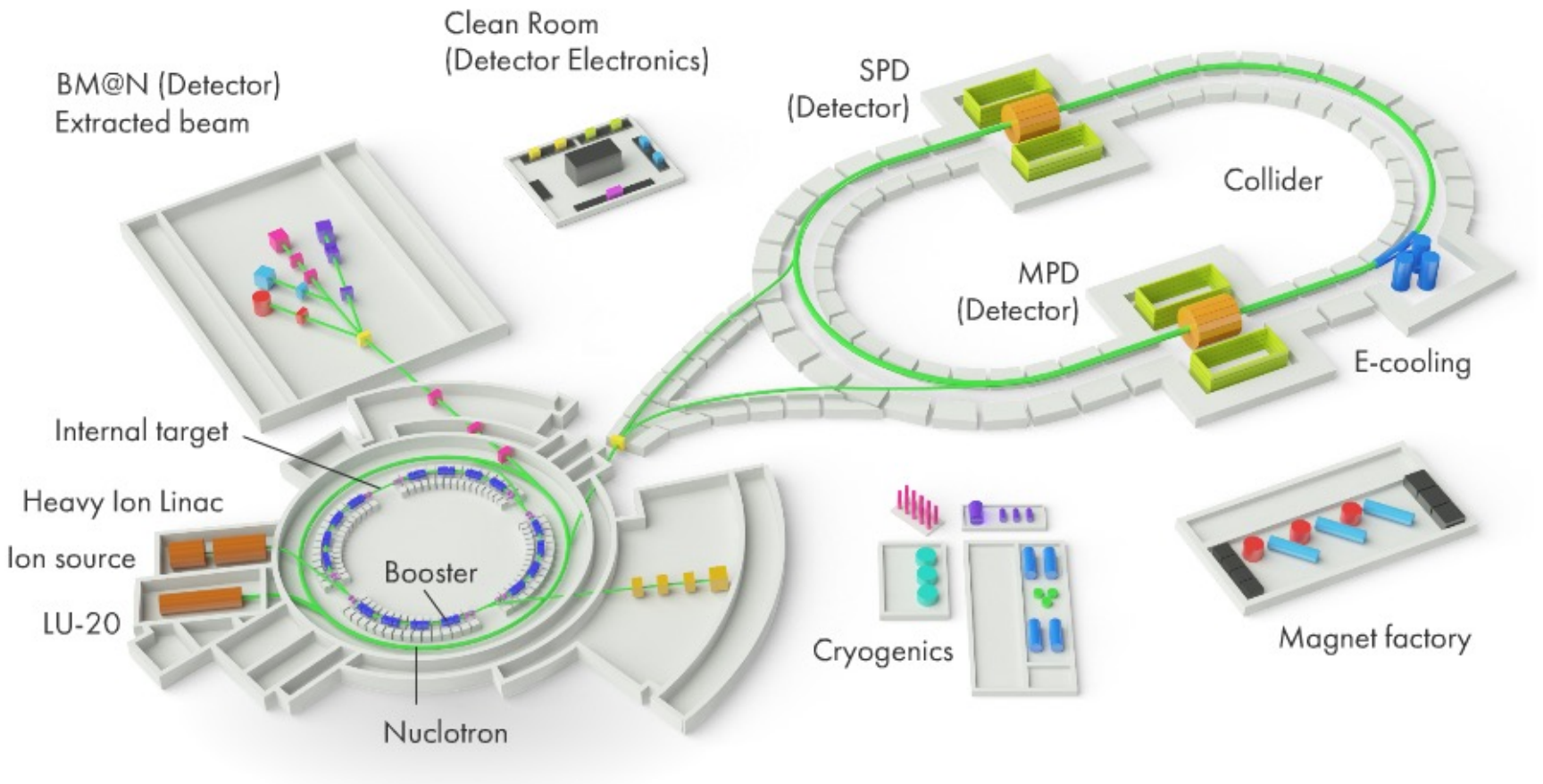
and

Université Paris-Saclay, France

on behalf of the SPD collaboration

SPD and the NICA Complex

NICA - Nuclotron-based Ion Collider fAcility *at the Joint Institute for Nuclear Research, Dubna, Moscow Region*

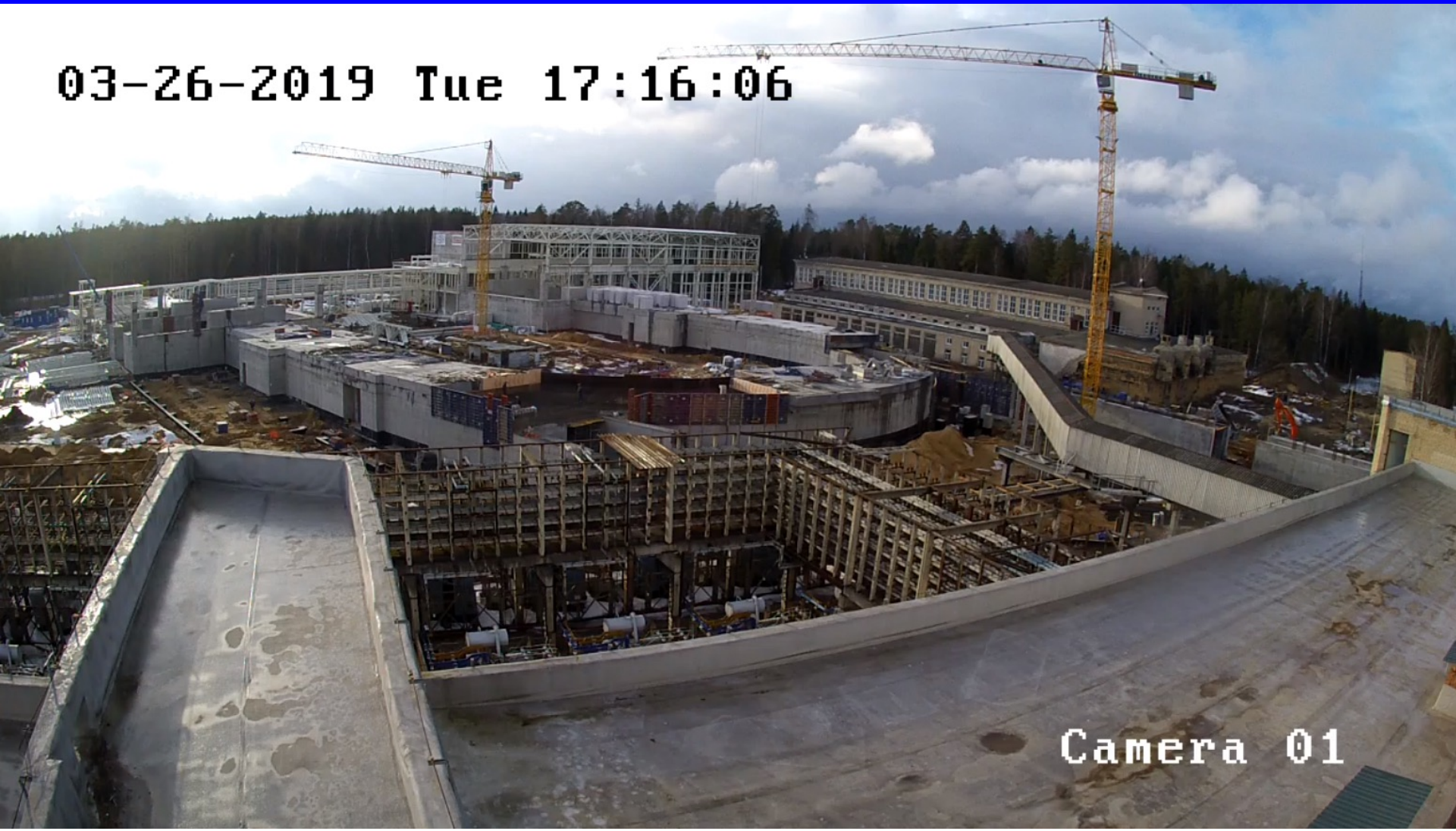


May 2021

July 2021

http://nucloweb.jinr.ru/nucloserv/205corp.htm

March 2019



http://nucloweb.jinr.ru/nucloserv/205corp.htm

Spin Physics Detector

SPD NICA

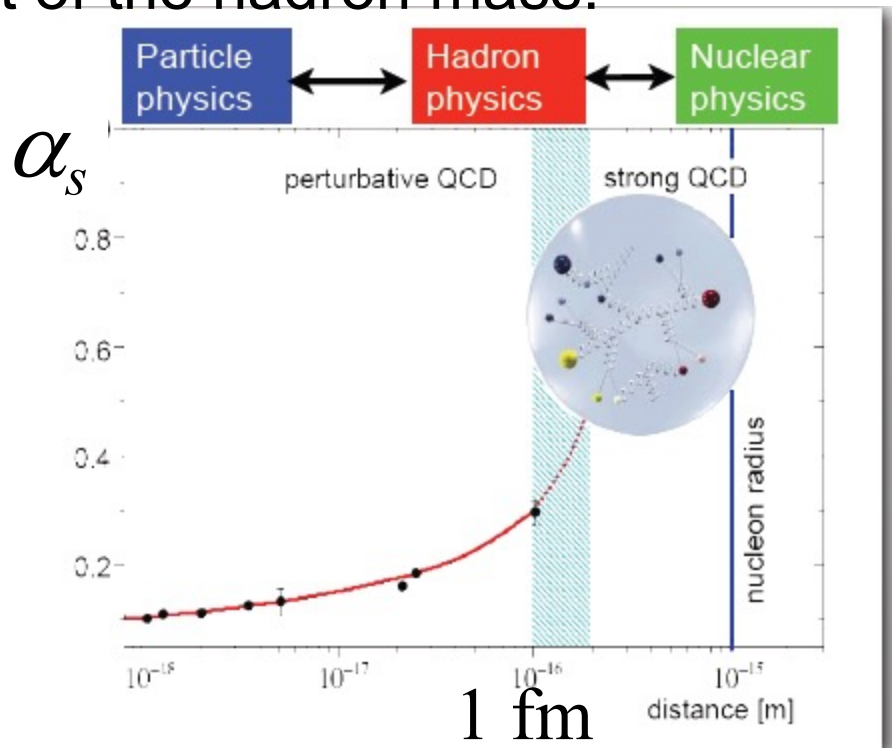
The NICA-SPD Collaboration, July 2021

Armenia
Belarus
Chile
China
Cuba
Czechia
Egypt
France
Italy
Poland
Russia
Serbia
South Africa
Ukraine

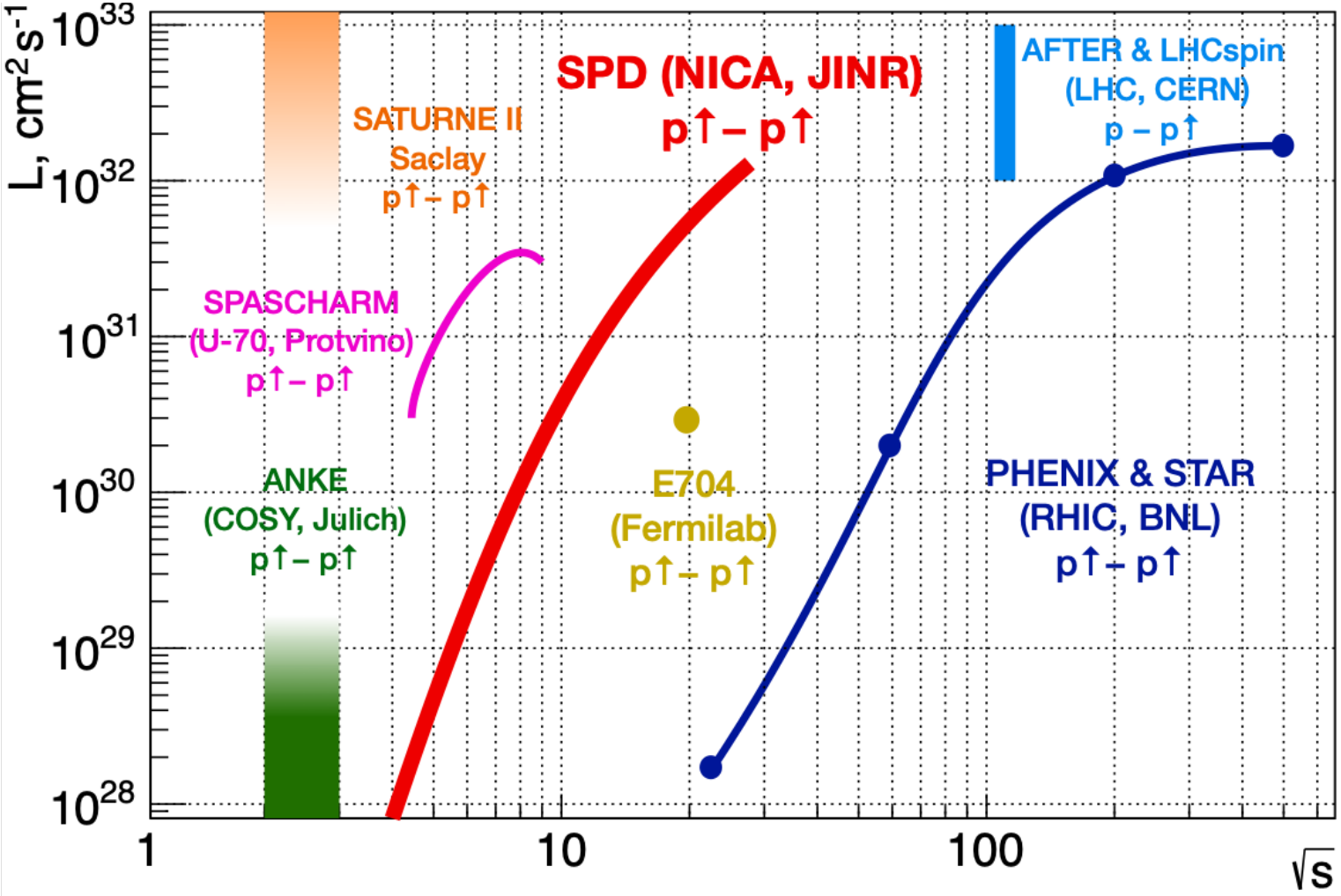
33 laboratories and individual contributors from 14 countries

Purpose of SPD

- Contribute to the world effort in understanding the strong interaction using unpolarized and polarized *pp* *pd* and *dd* collisions at $\sqrt{s} \leq 27$ GeV.
- Origin of the hadron mass: the Higgs mechanism accounts for some percent of the hadron mass: gluon dynamics
- Multiquark states
- Structure of the nucleon (charge, magnetic, spin distributions) and of light nuclei
- *Open questions in light nuclei structure - spin observables*

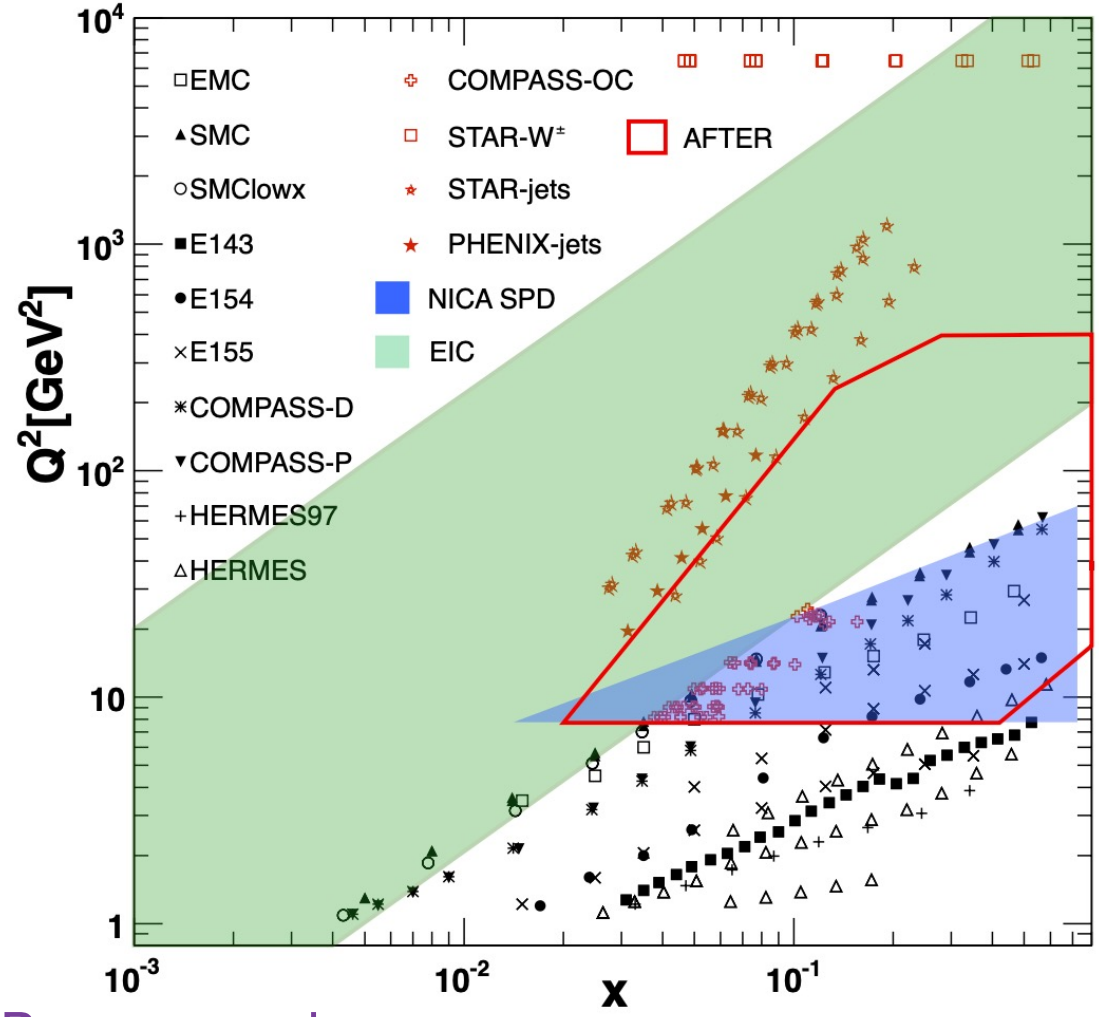


SPD and the World Facilities $p^{\uparrow}p^{\uparrow}$ (I)



$d^{\uparrow}d^{\uparrow}$ only at SPD!

Kinematical range



Contribute to the world effort in understanding gluon dynamics

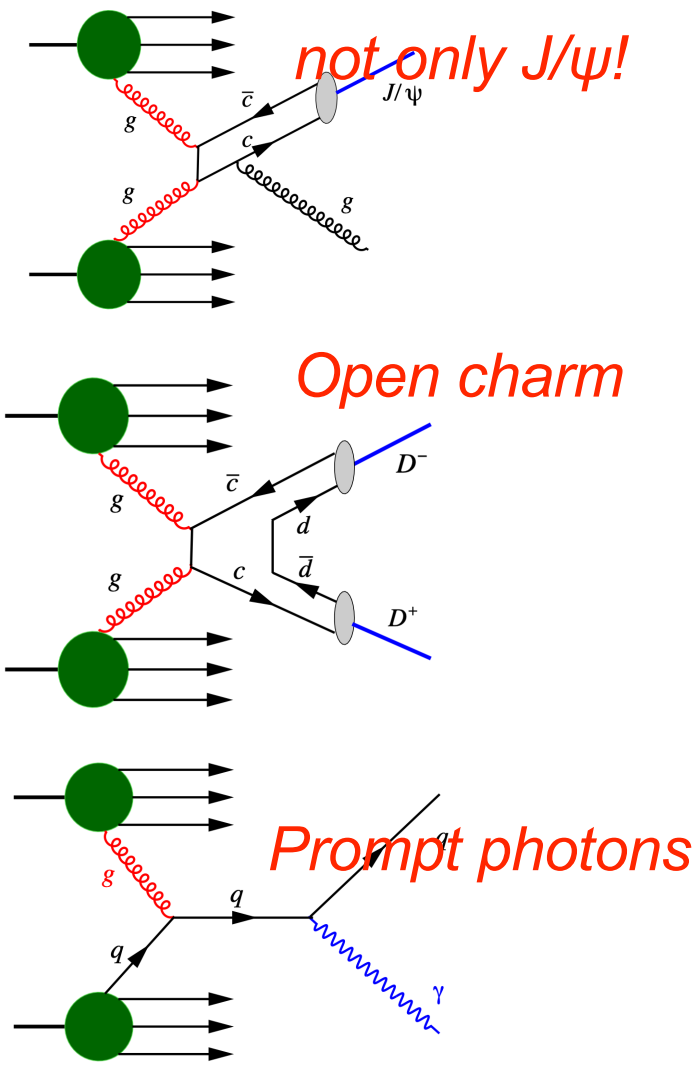
Investigate polarized elementary reactions, elastic and inelastic vector, strange, charmed meson production

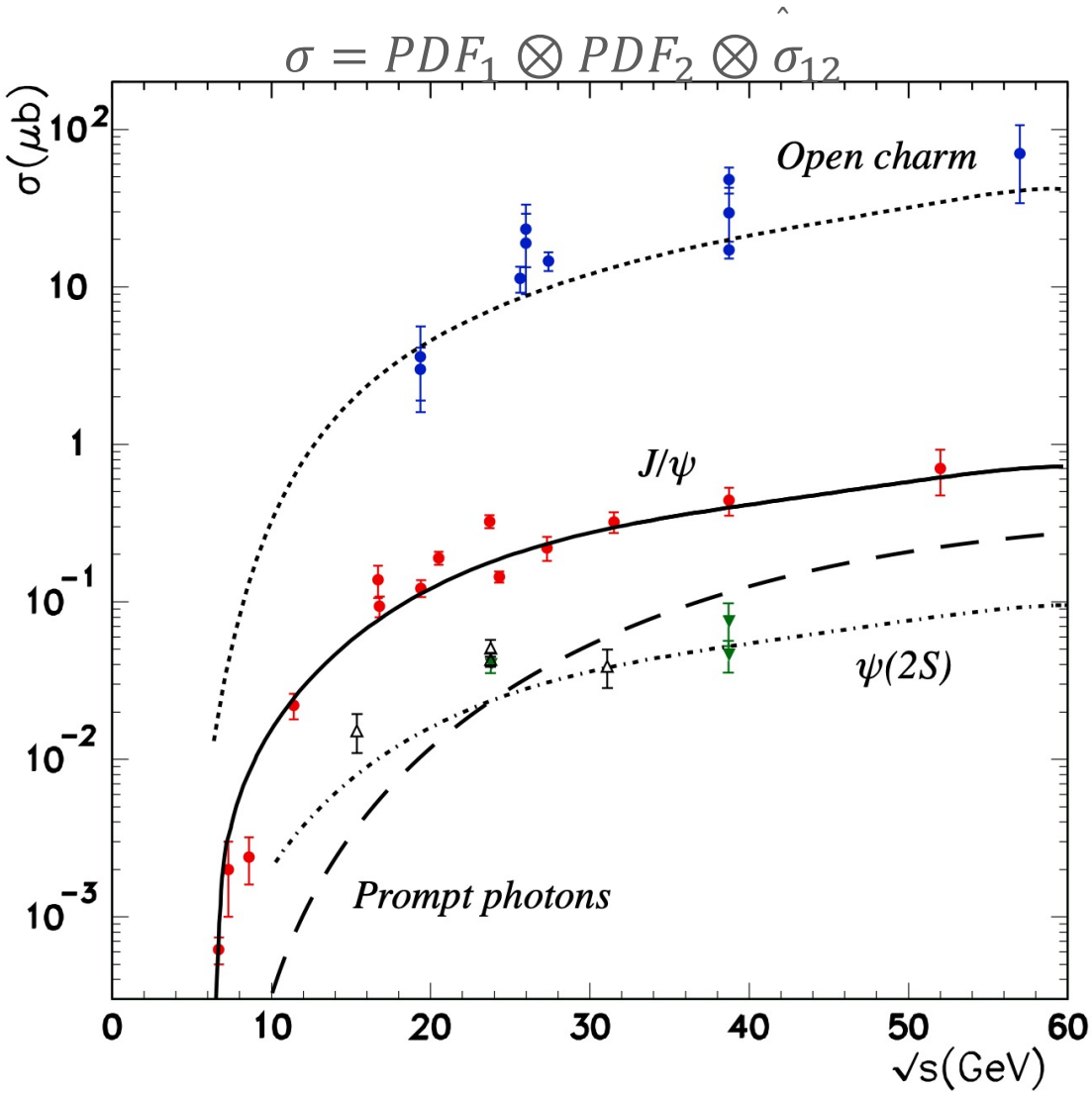
Beam energies:

p↑p↑($\sqrt{s_{pp}}$) = 12 ÷ ≥ 27 GeV (5 ÷ ≥12.6 GeV of proton kinetic energy),

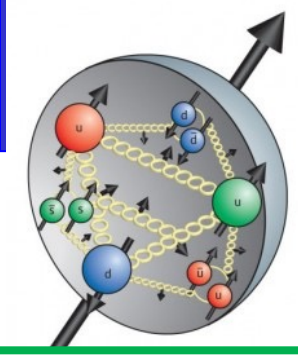
d↑d↑($\sqrt{s_{NN}}$) = 4 ÷ ≥13.8 GeV (2 ÷ ≥5.9 GeV/u of ion kinetic energy).

Gluon probes at spd





The SPIN of the proton

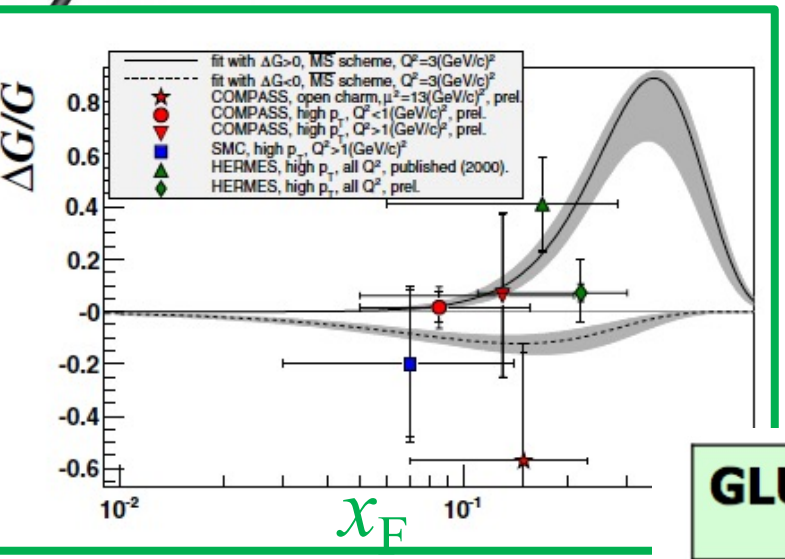


$S = 1/2$ measured: $\sim 1/4$

$\Delta\Sigma + \Delta G + L$

Quarks. gluons

orbital momentum



$\sigma(x_F,p_T)$ $A_{LL}(x_F,p_T)$ $A_{TT}(x_F,p_T)$ $A_N(x_F,p_T)$

GLUONS	unpolarized	circular	linear
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	h_{1T}^g, $h_{1T}^{\perp g}$

in deuteron only

Gluon content of proton and deuteron: Transverse Momentum-Dependent PDFs

Gluon physics at SPD

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

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], U. D'Alesio[e,f], M. Deka[a], I. Denisenko[a], M. G. Echevarria[g], A. Efremov[a], N.Ya. Ivanov[a,h], A. Guskov[a,i], A. Karpishkov[j,a], Ya. Klopot[a,k], B. A. Kniehl[d], A. Kotzinian[h,m], S. Kumano[n], J.P. Lansberg[o], Keh-Fei Liu[p], F. Murgia[f], M. Nefedov[j], B. Parsamyan[a,l,m], C. Pisano[e,f], M. Radici[c], A. Rymbekova[a], V. Saleev[j,a], A. Shipilova[j,a], Qin-Tao Song[q], O. Teryaev[a]

Contact: Alexey.Guskov@cern.ch

Physics of the first stage of SPD

- Study of the NN interaction: *spin amplitudes of NN elastic scattering*
- *Di-quarks* dynamics
- *Vector meson production* (strange, charm...) :

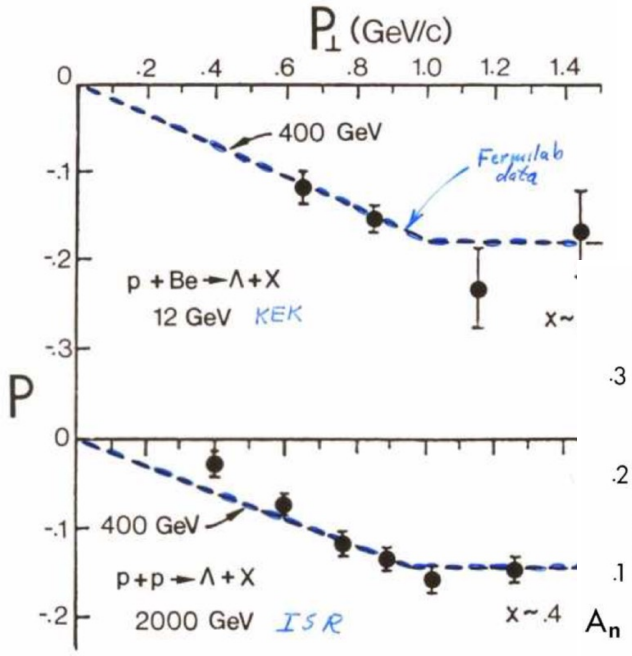
  spin-isospin effects, backward emission…
- *Deuteron wave function* at short distances
- …….

Non-perturbative QCD — Perturbative QCD

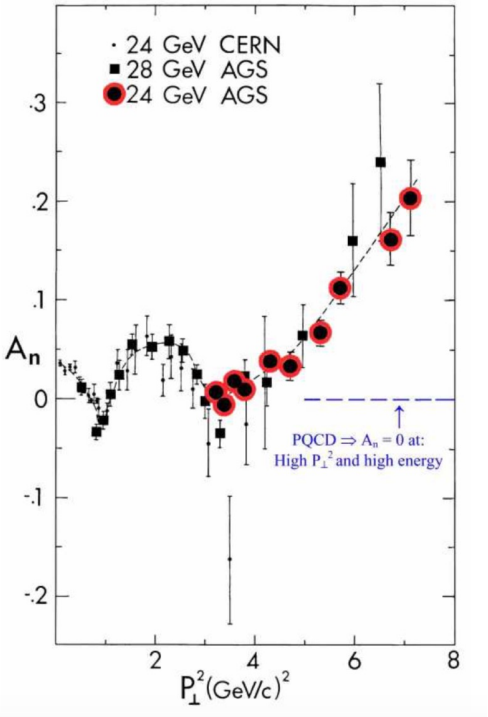
$\sqrt{s}$

Investigating (unexplained) spin effects

Hyperon polarization

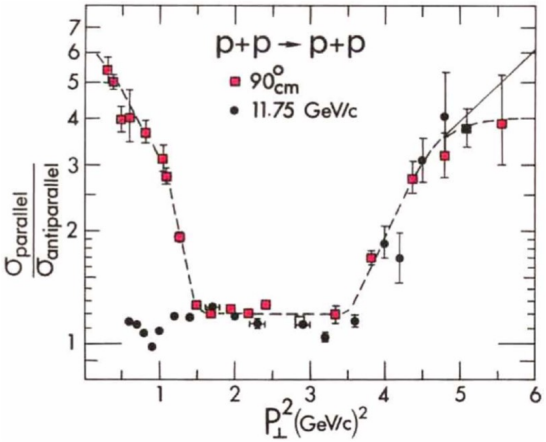


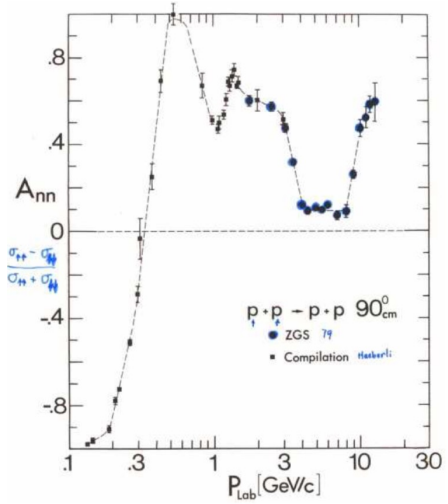
PRL 51 (1983) 2025



Large angle *pp* scattering

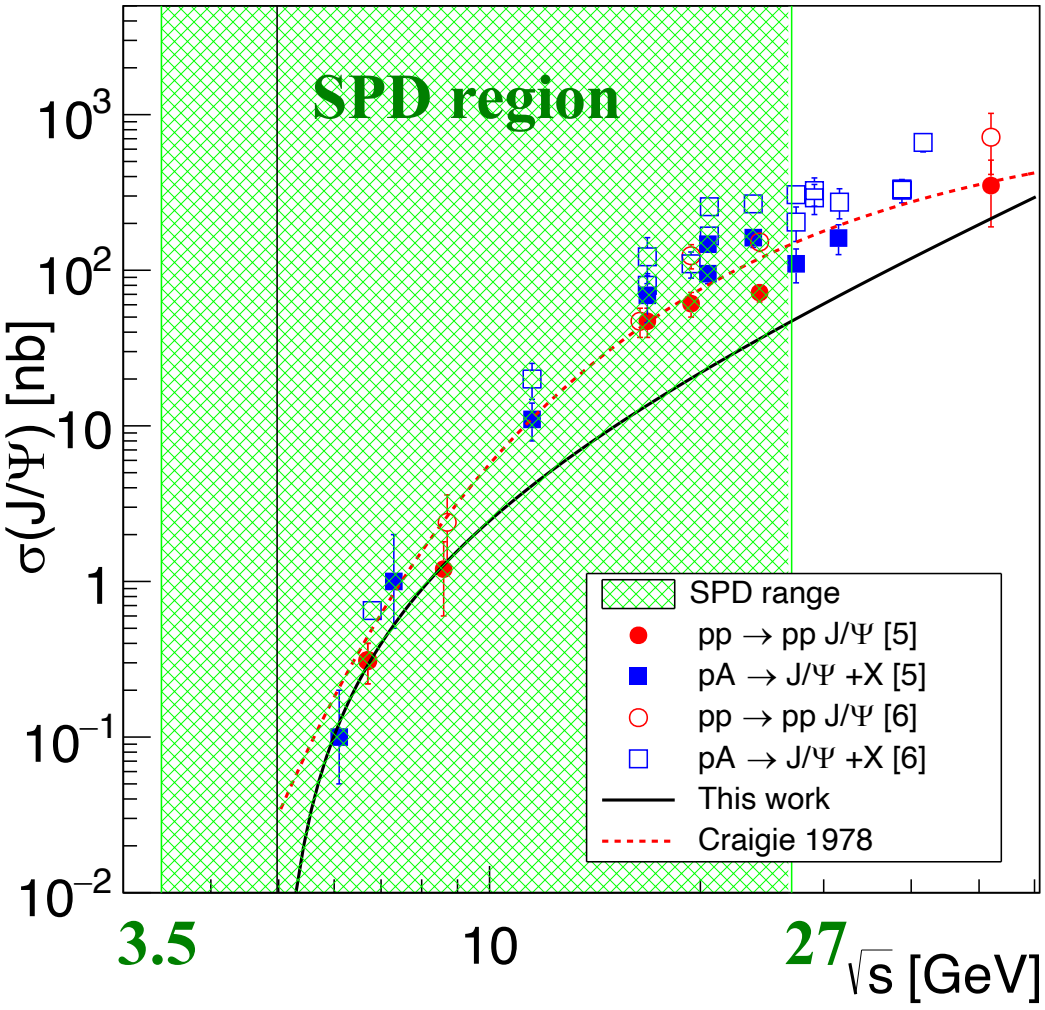
PRD 23 (1981) 600





J/Ψ production

M.P. Rekalo, E.T.-G.. New J. Phys., 4,68(2002).



R. Vogt. Phys. Rept., 310, 197 (1999).

1) Hard process at parton level
2) Formation of $c\bar{c}$ pairs
   (not pre-existing in the proton)
3) Hadronization of cc pairs into J/Ψ
4) FSI

1) Effective proton size: $r_c \approx 1/m_c$
2) Large isotopic effects :
   $\sigma_{np} >> \sigma_{pp}$
3) Polarization phenomena

arXiv:2102.08477

Physics of Elementary Particles and Nuclei

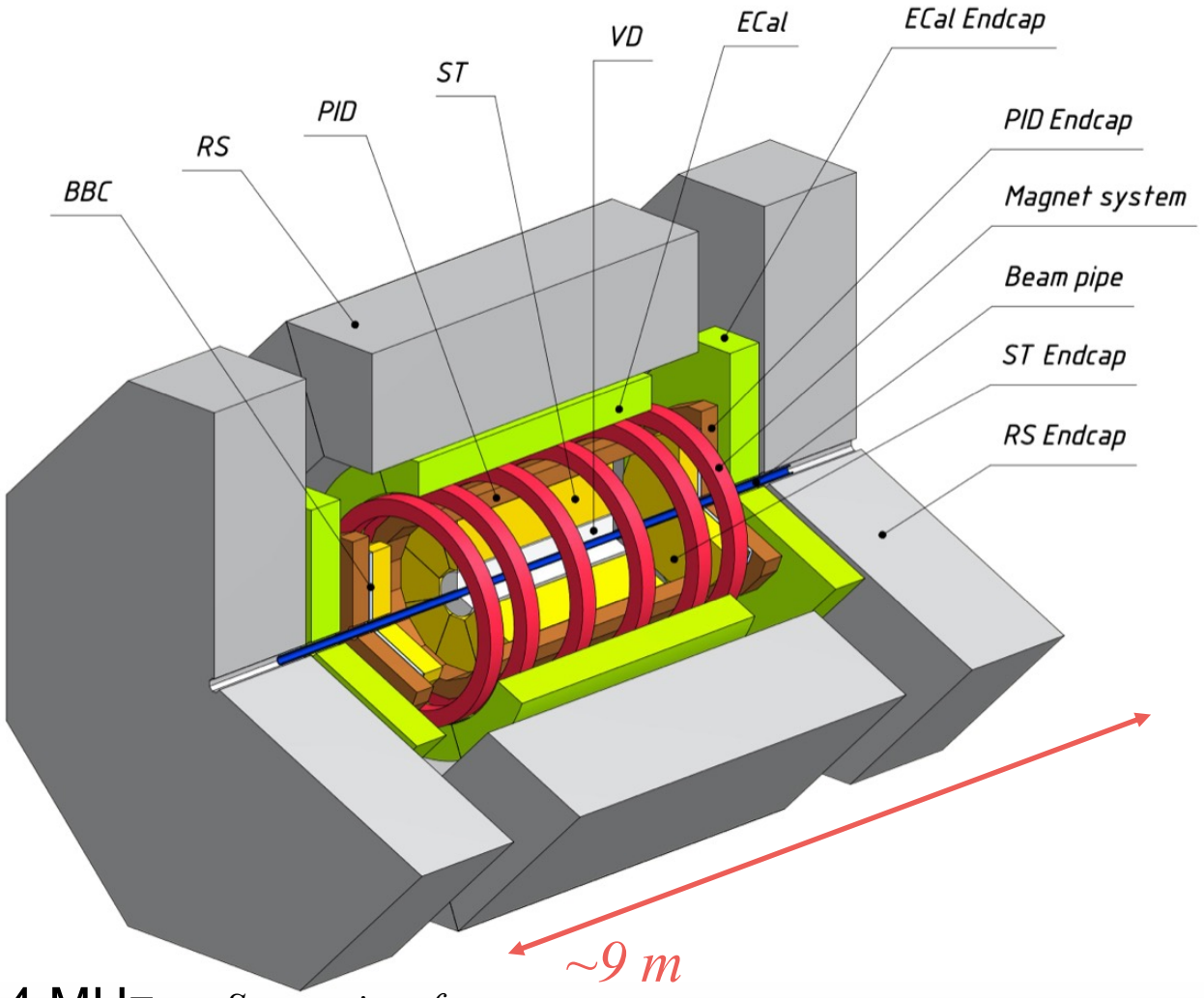
Prepared for Physics of Elementary Particles and Atomic Nuclei. Theory

Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams

V.V. Abramov[1], *A. Aleshko*[2], *V.A. Baskov*[3], *E. Boos*[2], *V. Bunichev*[2], *O.D. Dalkarov*[3], *R. El-Kholy*[4], *A. Galoyan*[5], *A.V. Guskov*[6], *V.T. Kim*[7,8], *E. Kokoulina*[5,9], *I.A. Koop*[10,11,12], *B.F. Kostenko*[13], *A.D. Kovalenko*[5], *V.P. Ladygin*[5], *A. B. Larionov*[14,15], *A.I. L'vov*[3], *A.I. Milstein*[10,11], *V.A. Nikitin*[5], *N. N. Nikolaev*[16,26], *A. S. Popov*[10], *V.V. Polyanskiy*[3], *J.-M. Richard*[17], *S. G. Salnikov*[10], *A.A. Shavrin*[18], *P. Yu. Shatunov*[10,11], *Yu.M. Shatunov*[10,11], *O.V. Selyugin*[14], *M. Strikman*[19], *E. Tomasi-Gustafsson*[20], *V.V. Uzhinsky*[13], *Yu.N. Uzikov*[6,21,22,*], *Qian Wang*[23], *Qiang Zhao*[24,25], *A.V. Zelenov*[7]

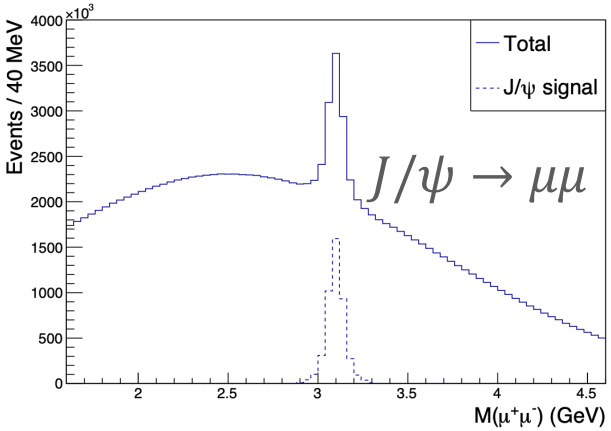
Contact: Yuri Uzikov; Uzikov@jinr.ru

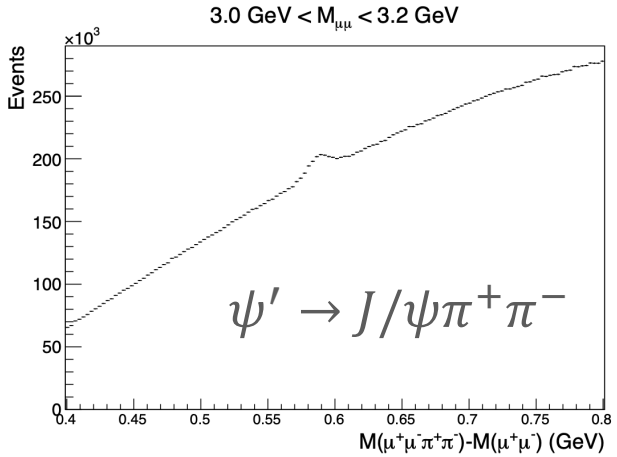
SPD detector

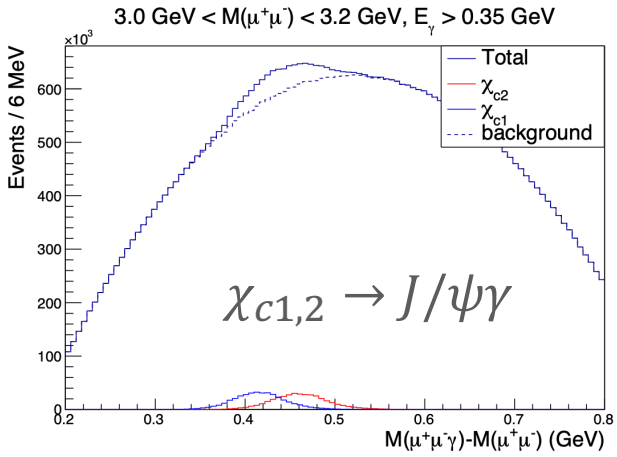


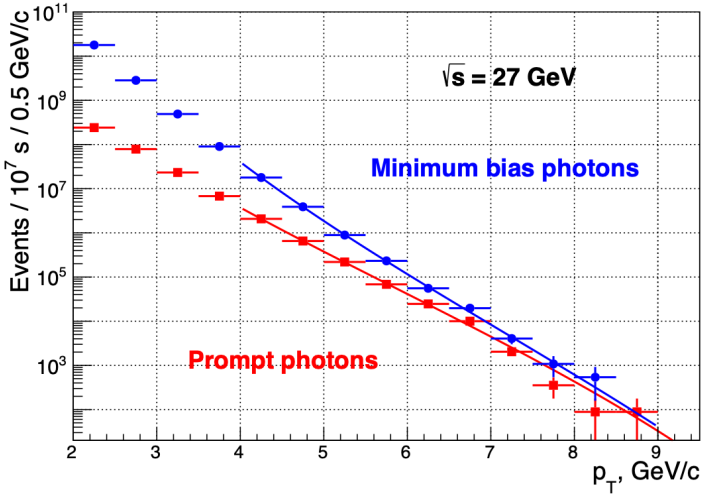
Collision rate ~4 MHz
Trigerless DAQ

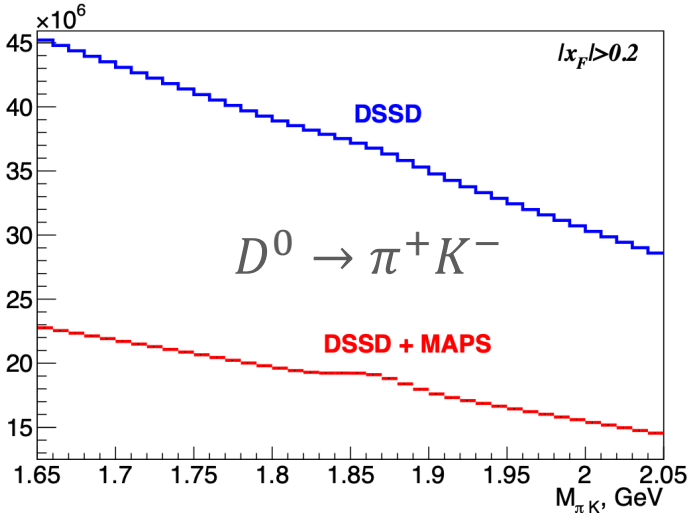
Physics performance: gluon probes



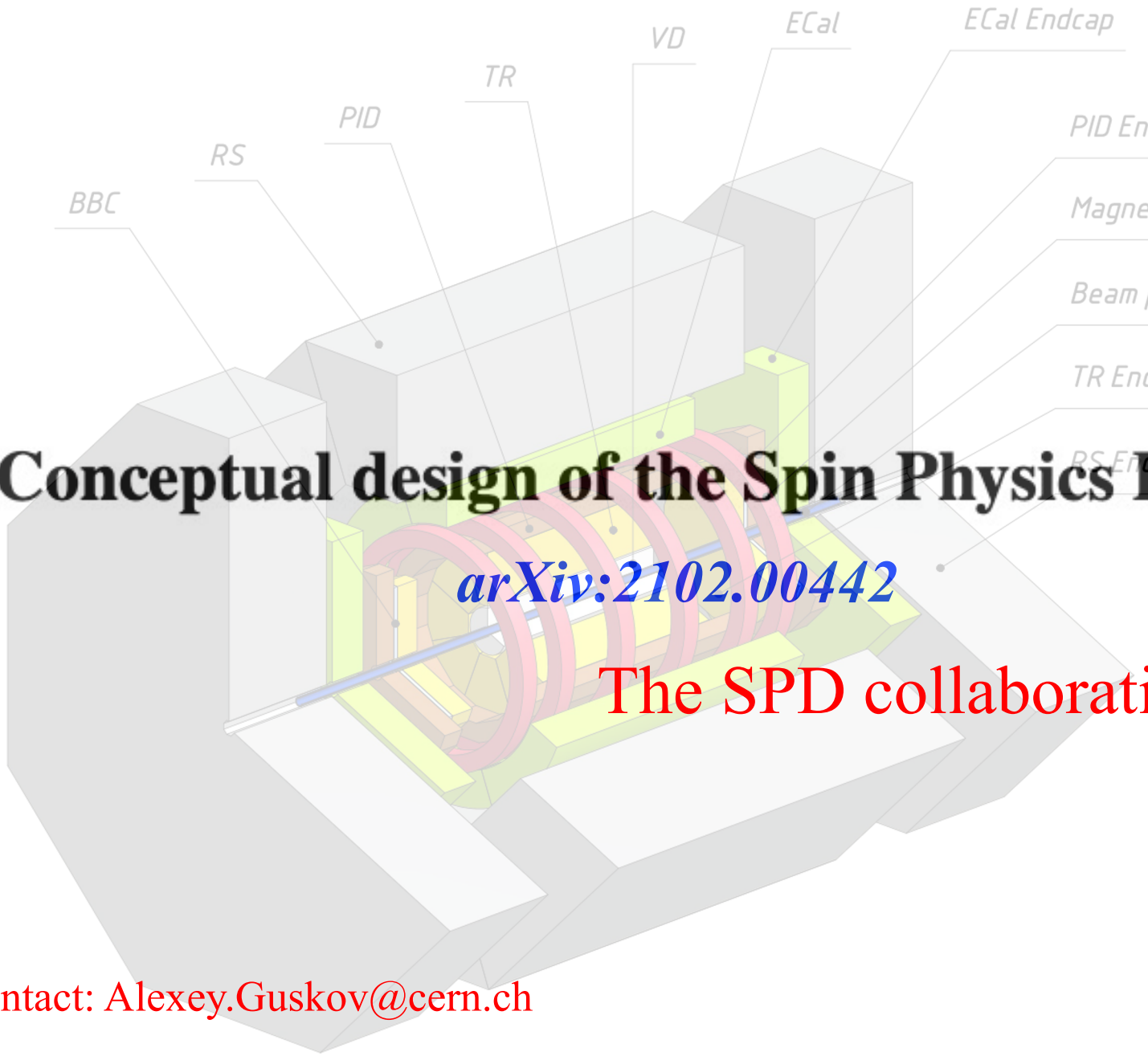








(1y=10^7s)



Conceptual design of the Spin Physics Detector

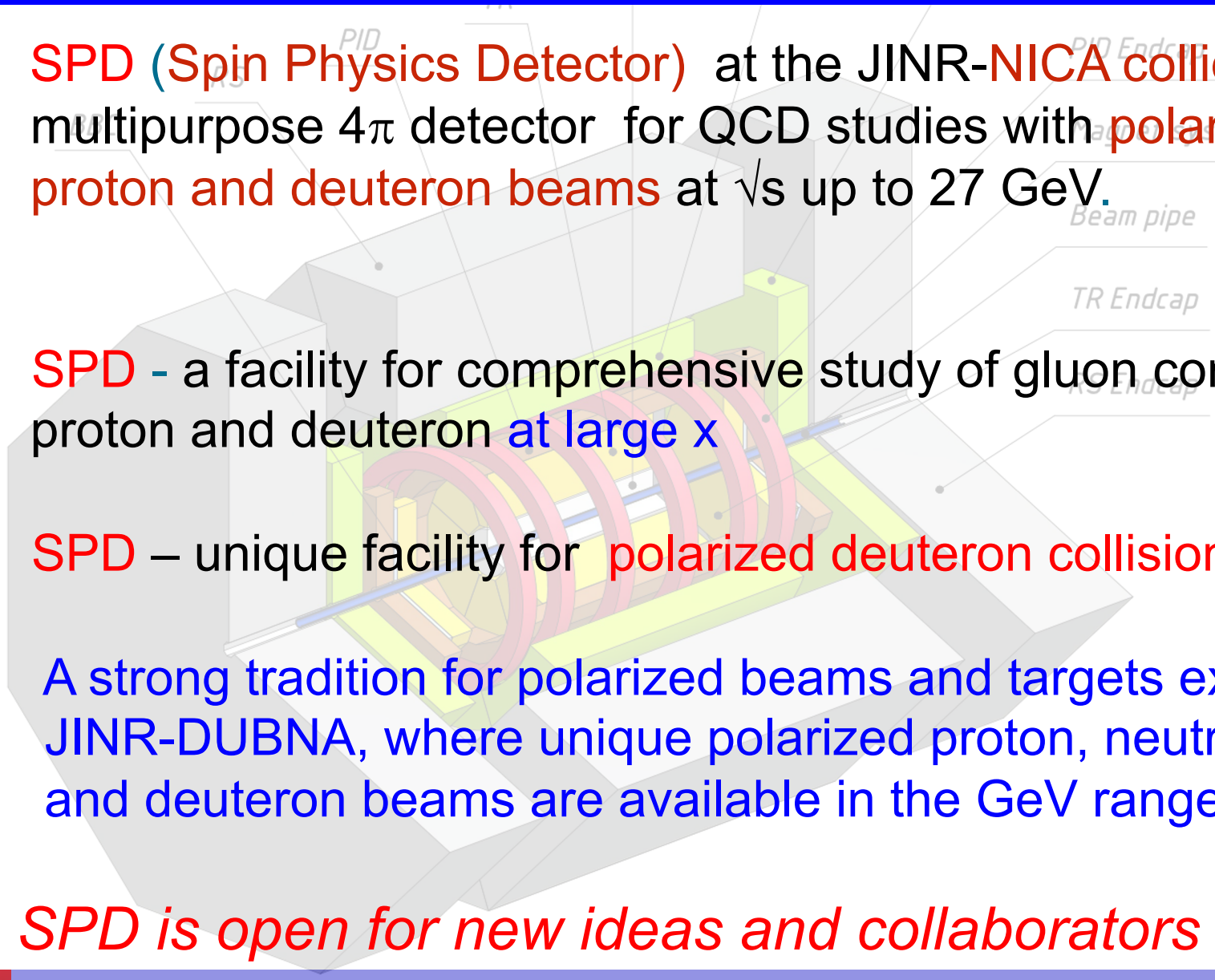
arXiv:2102.00442

The SPD collaboration

Contact: Alexey.Guskov@cern.ch

Conclusions

- SPD (Spin Physics Detector) at the JINR-NICA collider - a multipurpose 4π detector for QCD studies with polarized proton and deuteron beams at $\sqrt{s}$ up to 27 GeV.



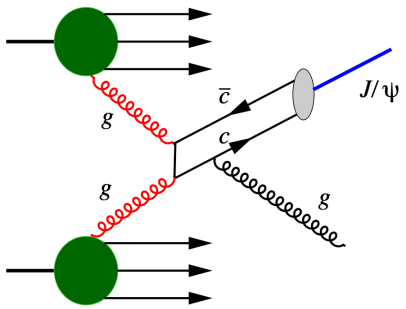
- SPD - a facility for comprehensive study of gluon content in proton and deuteron at large x
- SPD – unique facility for polarized deuteron collisions
- A strong tradition for polarized beams and targets exists at JINR-DUBNA, where unique polarized proton, neutron and deuteron beams are available in the GeV range.

SPD is open for new ideas and collaborators

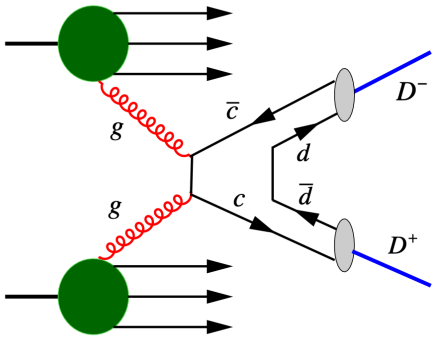
Thank you for the attention!

Gluon probes at spd

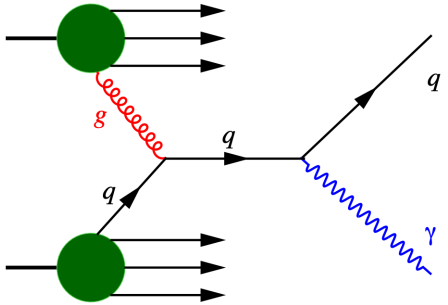
not only J/ψ!



Sharp signal **Relatively large cross section**	**Model-dependent probability for** $c\bar{c} \rightarrow [c\bar{c}]$



Largest cross section	**Challenging experimental requirements** **Model-dependent fragmentation functions**



Almost no fragmentation	**Strong background especially at low pT**

World facilities for polarized gluon physics

Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
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-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, ^{3}He$^{\uparrow}$	p-$p^{\uparrow}$, $d^{\uparrow}$	p-$p^{\uparrow}$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	≤27 (p-p) ≤13.5 (d-d) ≤19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	~1 (p-p) ~0.1 (d-d)	2	1000	up to ~10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025

RATES for the main probes

Probe	$\sigma_{27\,\mathrm{GeV}}$, nb (×BF)	$\sigma_{13.5\,\mathrm{GeV}}$, nb (×BF)	$N_{27\,\mathrm{GeV}}$, 10^6	$N_{13.5\,\mathrm{GeV}}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
J/ψ	200	60		
$\to \mu^+\mu^-$	12	3.6	12	0.36
$\psi(2S)$	25	5		
$\to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\to \mu^+\mu^-$	0.2	0.04	0.2	0.004
$\chi_{c1} + \chi_{c2}$	200			
$\to \gamma J/\psi \to \gamma\mu^+\mu^-$	2.4		2.4	
η_c	400			
$\to p\bar{p}$	0.6		0.6	
Open charm: $D\overline{D}$ pairs	14000	1300		
Single D-mesons				
$D^+ \to K^-2\pi^+$ ($D^- \to K^+2\pi^-$)	520	48	520	4.8
$D^0 \to K^-\pi^+$ ($\overline{D}^0 \to K^+\pi^-$)	360	33	360	3.3