



NICA Machine Advisory Committee

# SPD – STATUS AND PLANS

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12.11.2021



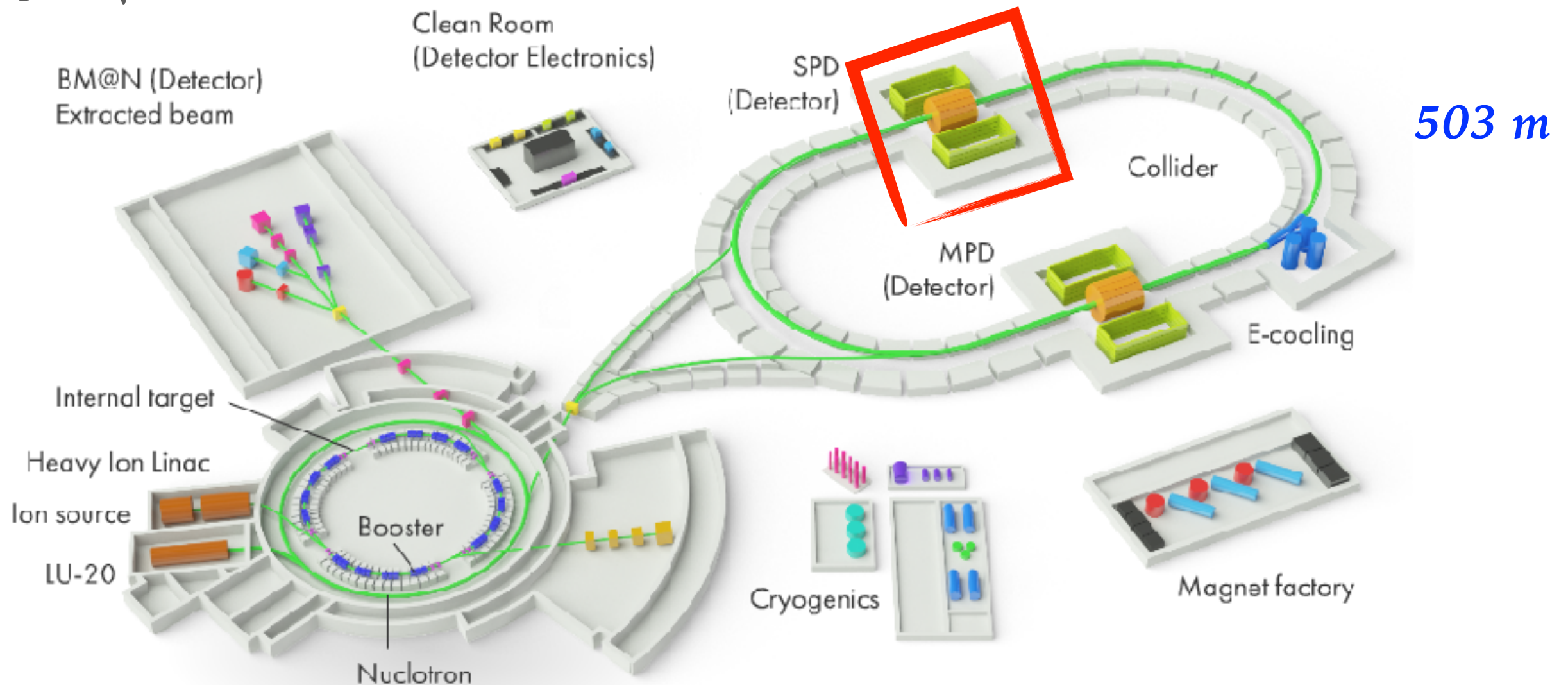
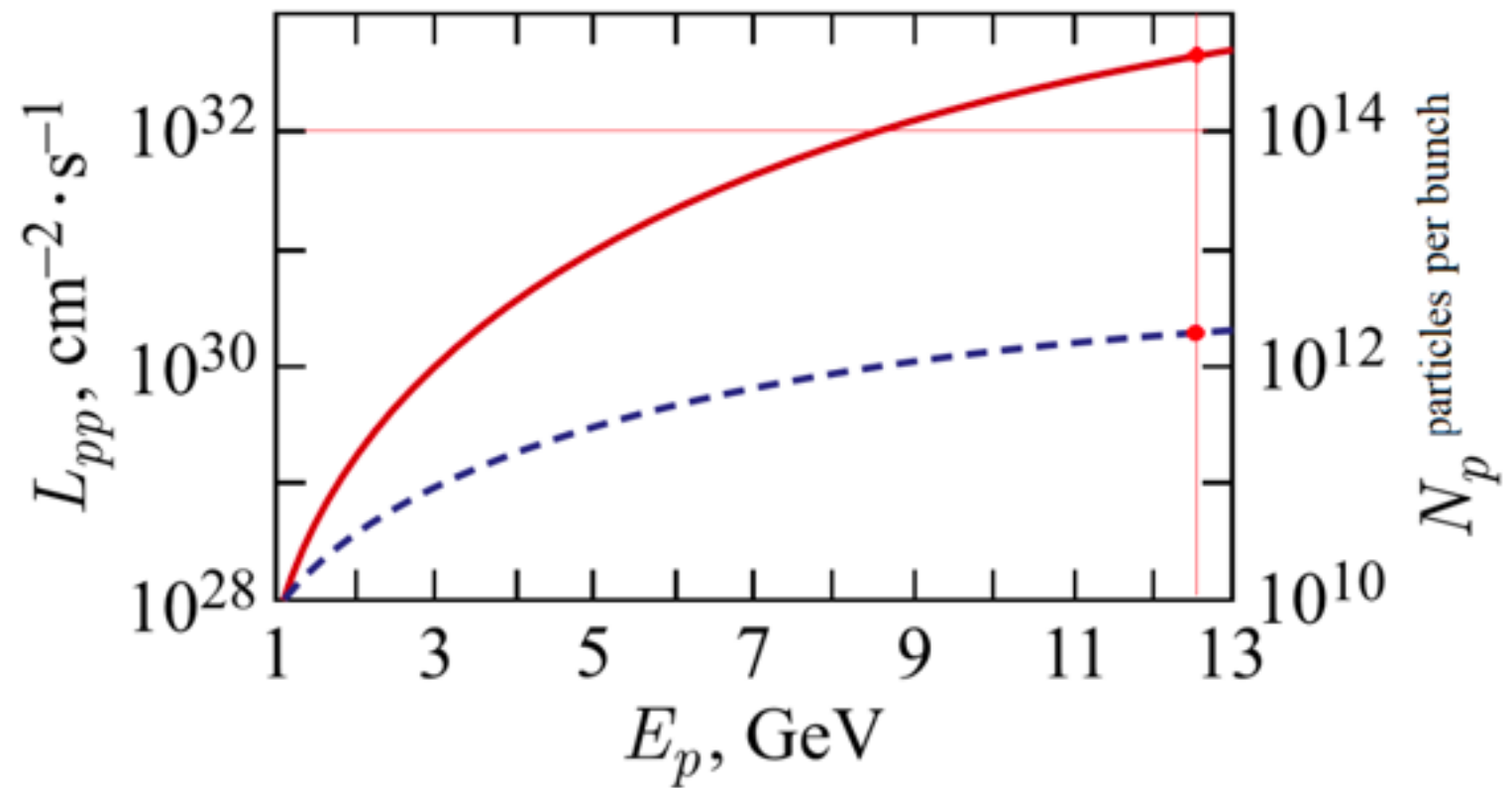
# SPD AT NICA

NICA - Nuclotron-based Ion Collider fAcility

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

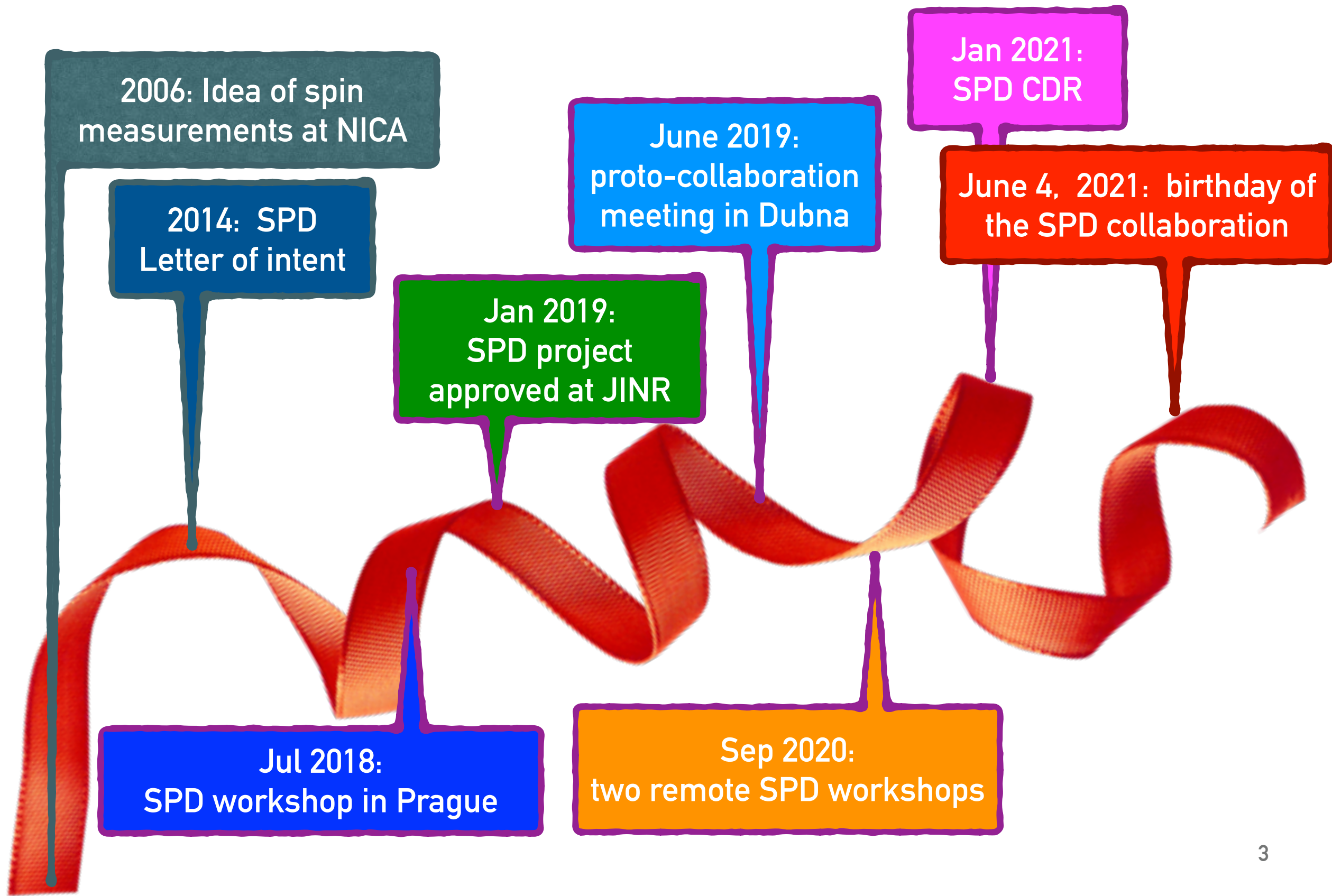
$d^\uparrow d^\uparrow : \sqrt{s} \leq 13.5 \text{ GeV}$  **U, L, T**

$d^\uparrow p^\uparrow : \sqrt{s} \leq 19 \text{ GeV}$  **|P| > 70%**



# BRIEF HISTORY OF THE SPD PROJECT

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# SPD international collaboration



*32 institutes from 14 states,  
~300 members*







February 3, 2021

## SPD CONCEPTUAL DESIGN REPORT IS PRESENTED:

[arXiv:2102.00442](https://arxiv.org/abs/2102.00442)

Conceptual design of the Spin Physics Detector

Version 1.0

The SPD proto-collaboration



**Andrea Bressan, INFN/University of Trieste (chair),  
Peter Hristov, CERN  
Pasquale di Nezza, INFN, Frascati**

## SPD PHYSICS PROGRAM IS PUBLISHED



[arXiv:2011.15005](https://arxiv.org/abs/2011.15005)

Review

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

A. Arbuzev<sup>a</sup>, A. Bacchetta<sup>b,c</sup>, M. Bultmann<sup>d</sup>, E.G. Celiberto<sup>b,c,e,f</sup>, U. D'Alesio<sup>b,h</sup>, M. Deka<sup>a</sup>, I. Denisenko<sup>a</sup>, M.G. Echevarria<sup>i</sup>, A. Efremov<sup>a</sup>, N.Ya. Ivanov<sup>a,j</sup>, A. Guskov<sup>a,k,l,m</sup>, A. Karpishkov<sup>k,p</sup>, Ya. Klopot<sup>q,m</sup>, B.A. Kniehl<sup>d</sup>, A. Kotzinian<sup>b,c</sup>, S. Kumano<sup>r</sup>, J.P. Lansberg<sup>q</sup>, Keh-Fei Liu<sup>r</sup>, ... O. Teryaev<sup>a</sup>

Prepared for Physics of Elementary Particles and Atomic Nuclei. Theory

[arXiv:2102.08477](https://arxiv.org/abs/2102.08477)

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

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

<sup>1</sup> NRC "Kurchatov Institute" - IHEP, Prctvino 142281, Moscow region, Russia

<sup>2</sup> Skobel'syn Institute of Nuclear Physics, MSU, Moscow, 119991 Russia

<sup>3</sup> P.N. Lebedev Physical Institute, Leninsky prospec: 53, 119991 Moscow, Russia

## SPD DETECTOR ADVISORY COMMITTEE IS FORMED

**NOW SPD WORKS ON THE TECHNICAL PROJECT**

# CONCEPT OF THE **SPD** PHYSICS PROGRAM

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**SPD - a universal facility for comprehensive study of gluon content in proton and deuteron at large  $x$**

Charmonia

Prompt photons

Open charm

Other spin-related phenomena

Other physics

# PARTONIC STRUCTURE OF PROTON AND DEUTERON

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

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

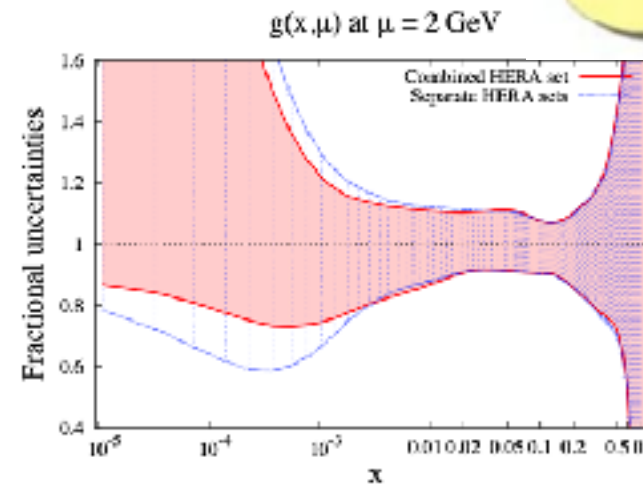
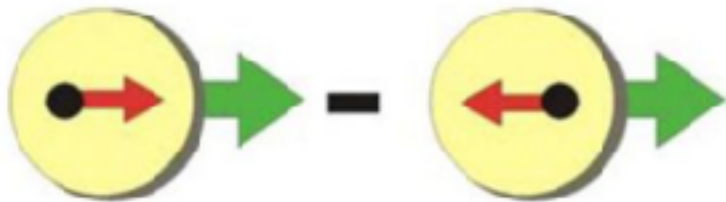
Unpolarized gluons in  
proton and deuteron at  
high  $x$ :



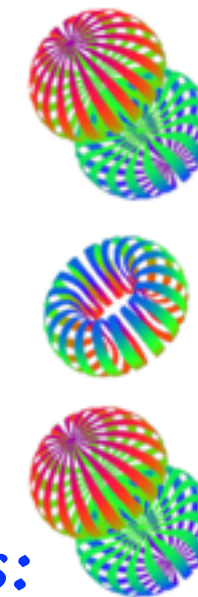
Tensor structure  
of deuteron:

Spin crisis:

Gluon helicity



Spin-1  
System



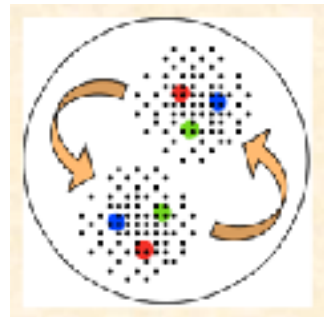
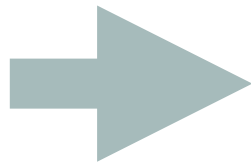
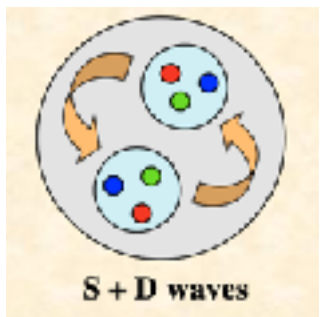
$m = +1$

$m = 0$

$m = -1$

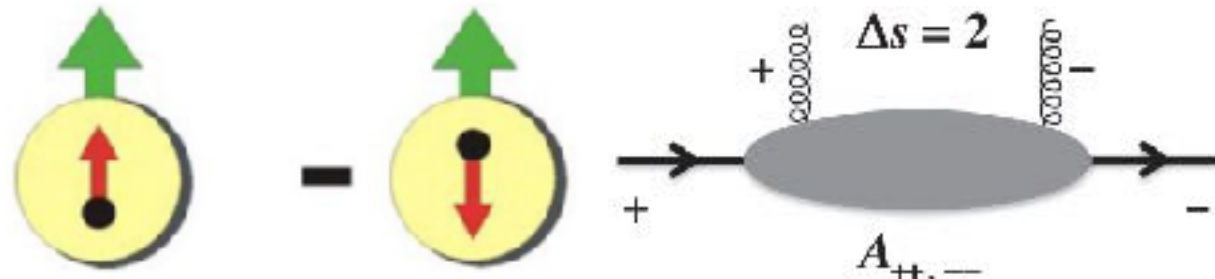


Nonbaryonic content of deuteron:

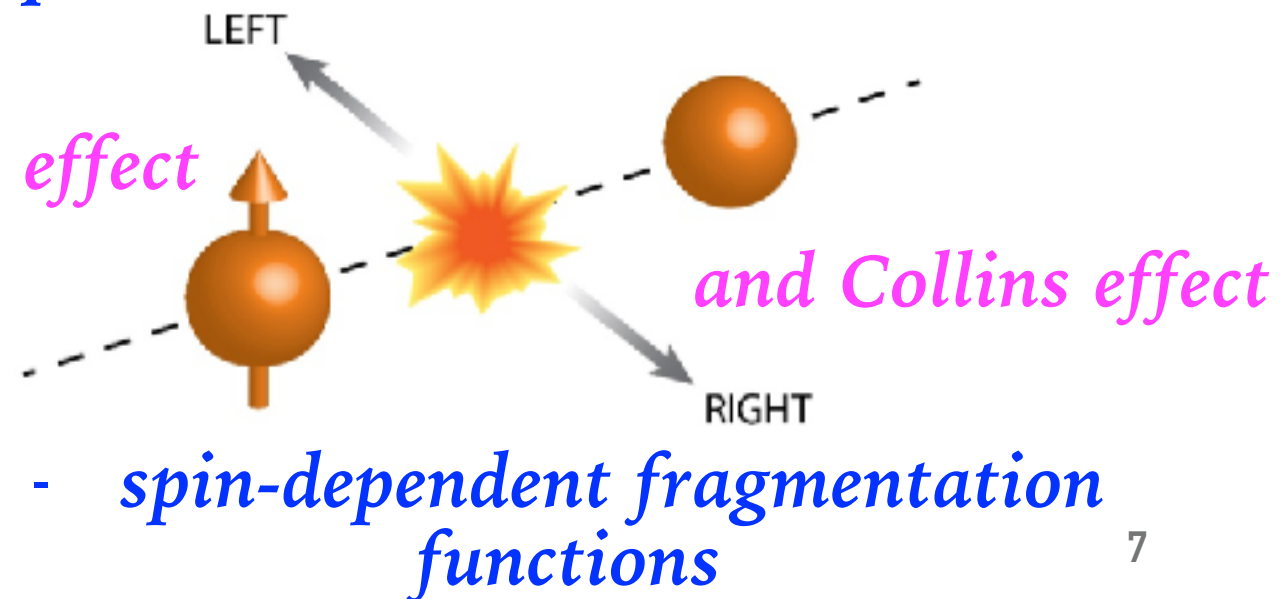


Gluon and quark TMD PDFs:

Gluon transversity



Sivers effect





# PHYSICS OF THE FIRST STAGE OF **SPD** RUNNING

*Non-perturbative QCD*

*Perturbative QCD*

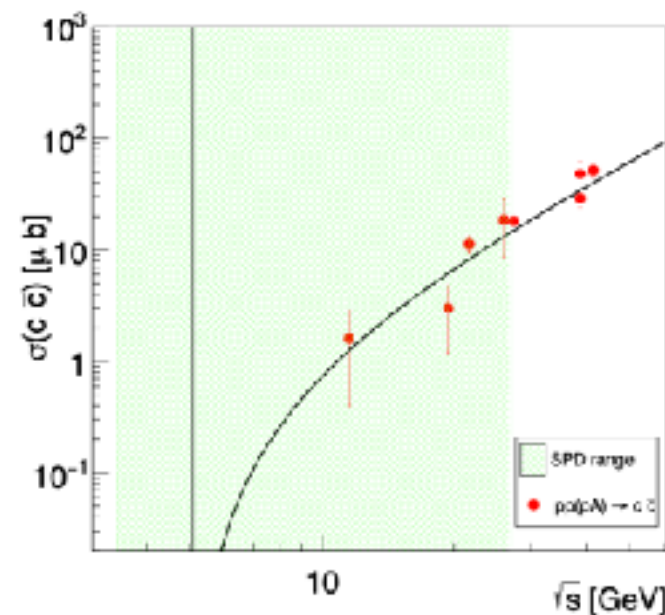
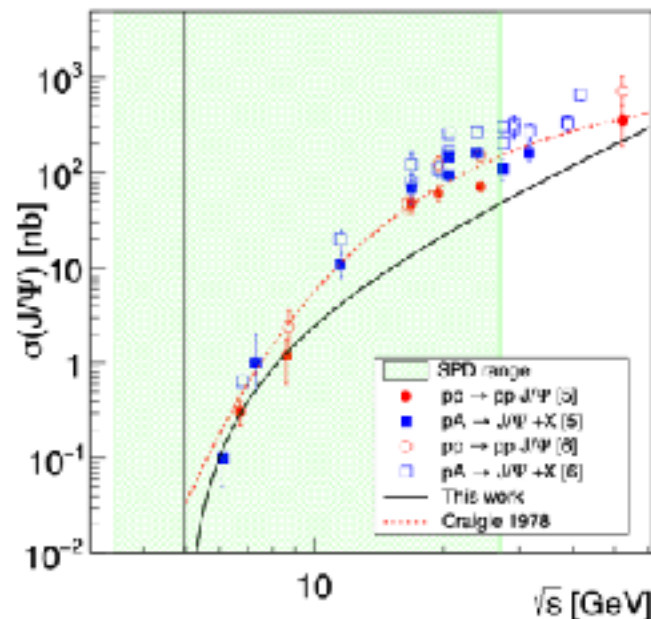
- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperon production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collisions
- Exclusive reactions
- Hypernuclei
- Open charm and charmonia near threshold

$$pp \rightarrow (6q)^* \rightarrow NN \text{ Mesons,}$$

$$dd \rightarrow K^+ K^+ \Lambda\Lambda^4 n,$$

$\sqrt{s}$

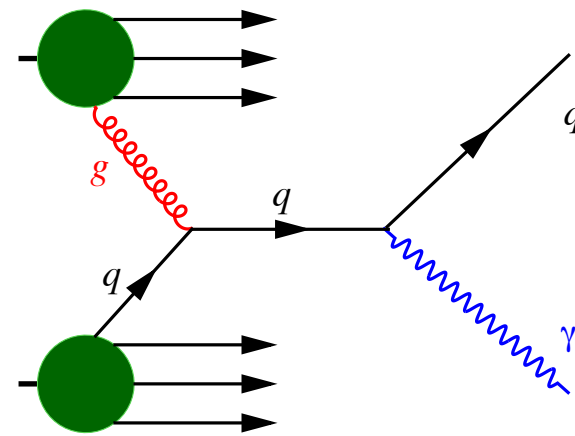
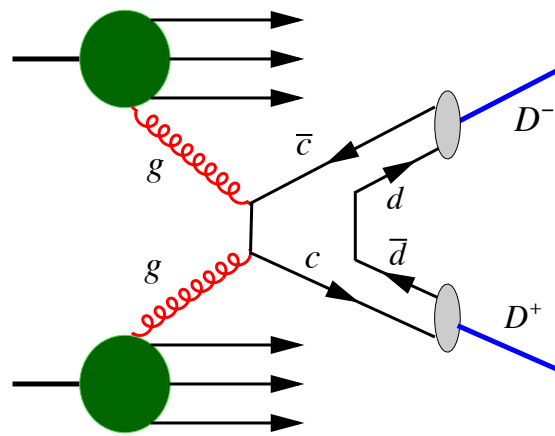
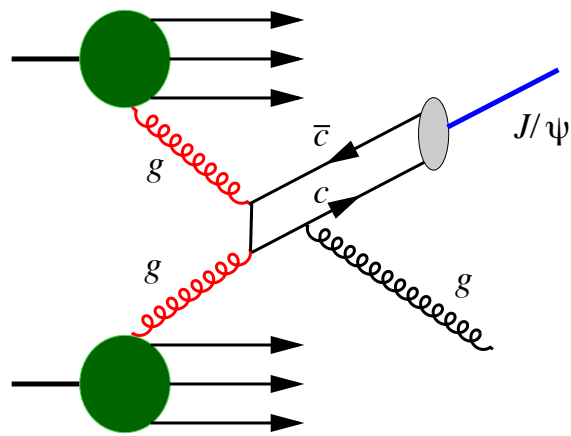
*Reduced luminosity  
and beam energy.*



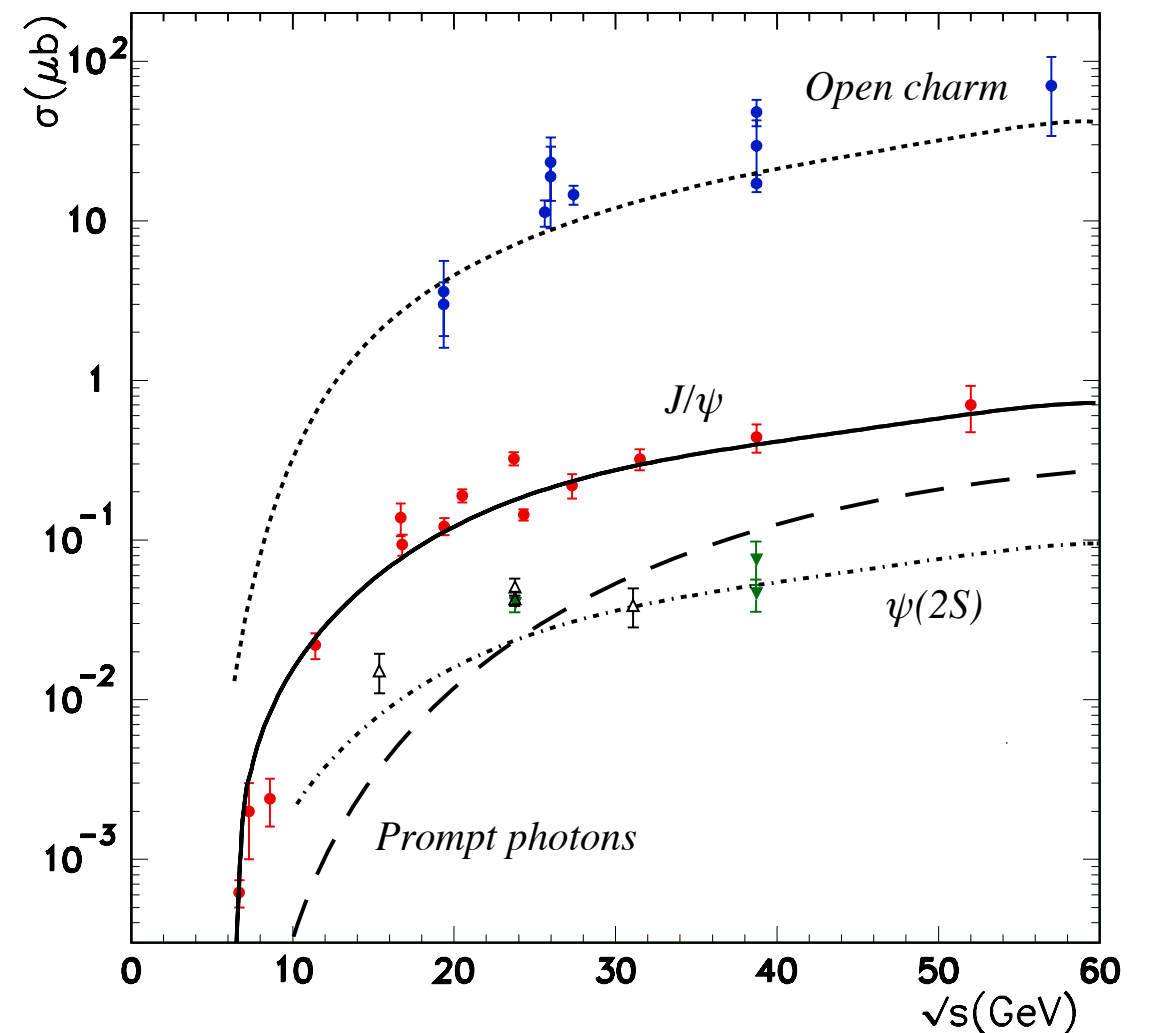
- Auxiliary measurements for Dark Matter search in astrophysical experiments
- ...



# RATES FOR MAIN PROBES



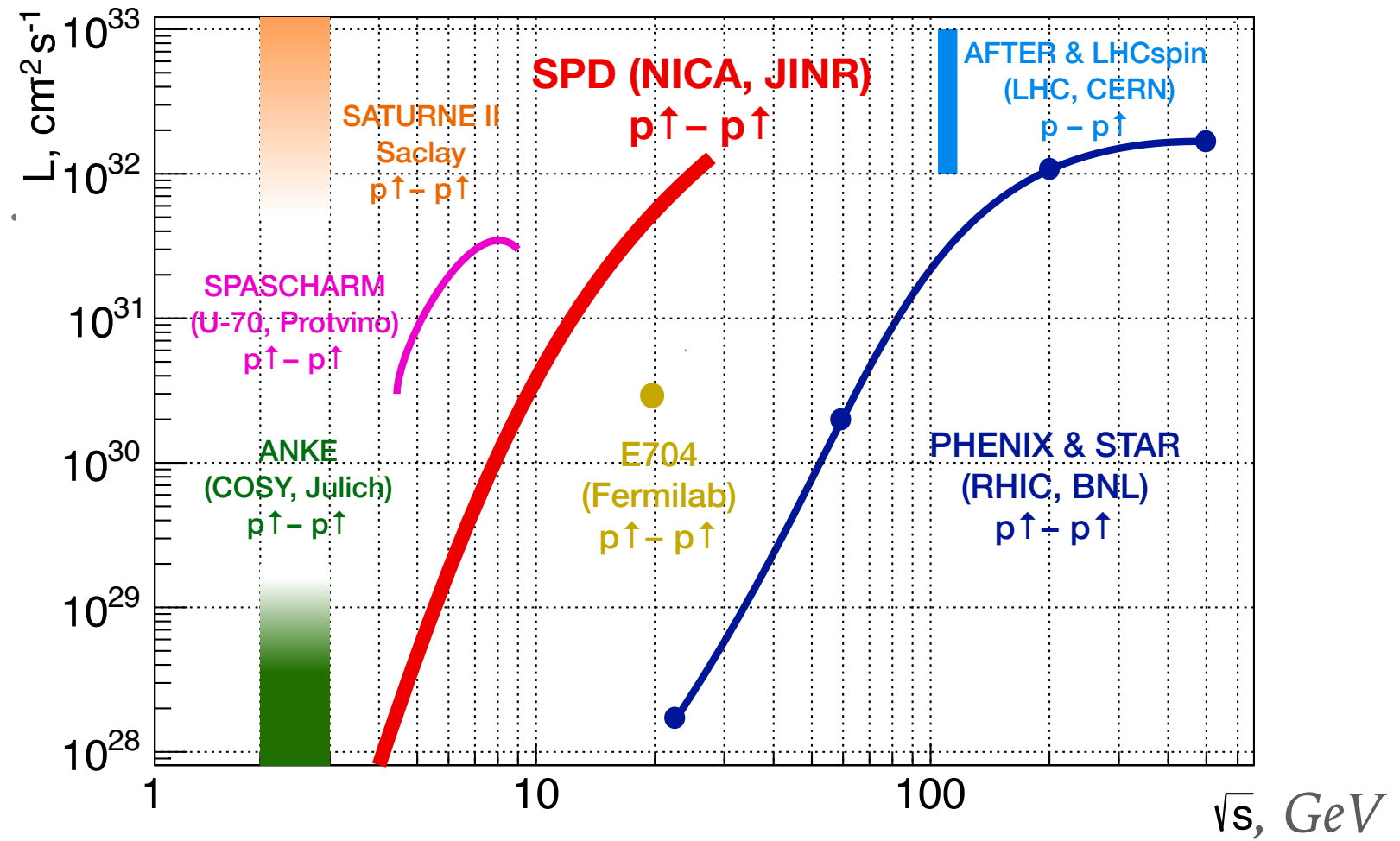
Probe	$\sigma_{27\text{ GeV}}$ , nb ( $\times\text{BF}$ )	$\sigma_{13.5\text{ GeV}}$ , nb ( $\times\text{BF}$ )	$N_{27\text{ GeV}}$ , $10^6$	$N_{13.5\text{ GeV}}$ , $10^6$
Prompt- $\gamma$ ( $p_T > 3\text{ GeV}/c$ )	35	2	35	0.2
$J/\psi$ $\rightarrow \mu^+\mu^-$	200 12	60 3.6	12	0.36
$\psi(2S)$ $\rightarrow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



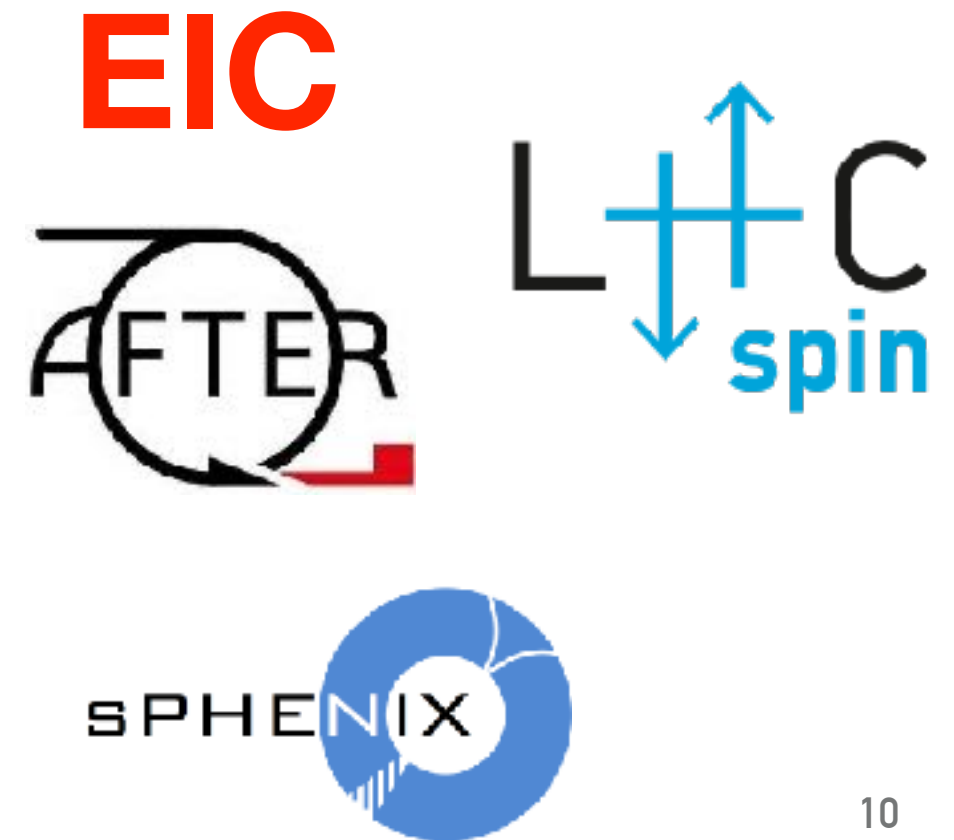
# SPD - VS OTHERS

In the  $p^\uparrow p^\uparrow$  mode:

In the  $d^\uparrow d^\uparrow$  mode we are unique

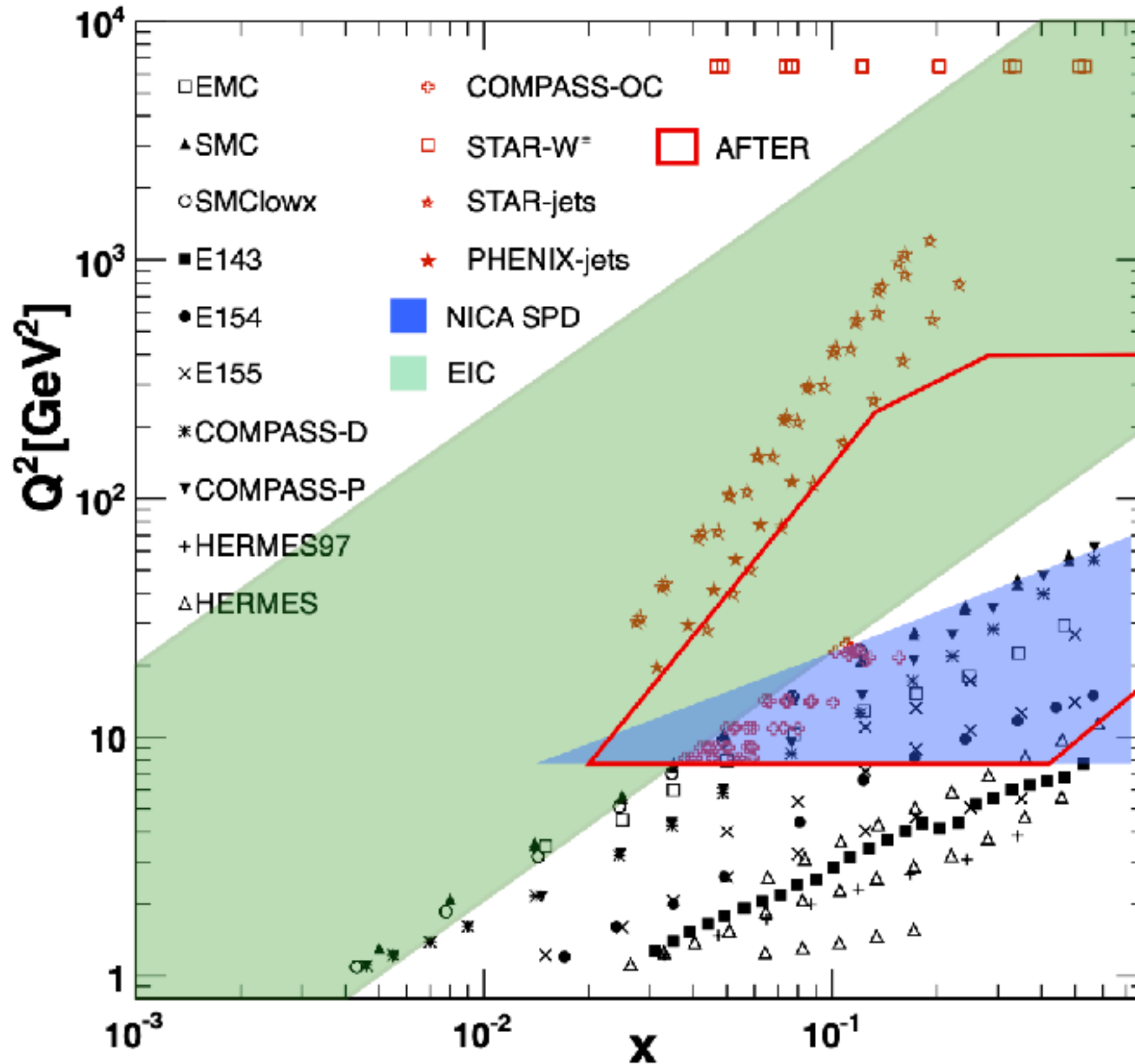


Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^\uparrow - p^\uparrow$ <b><math>d^\uparrow - d^\uparrow</math></b> $p^\uparrow - d$ , $p - d^\uparrow$	$p^\uparrow - p^\uparrow$	$e^\uparrow - p^\uparrow$ , $d^\uparrow$ , ${}^3\text{He}^\uparrow$	$p - p^\uparrow$ , $d^\uparrow$	$p - p^\uparrow$
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, $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$	$\sim 1$ ( $p-p$ ) $\sim 0.1$ ( $d-d$ )	2	1000	up to $\sim 10$ ( $p-p$ )	4.7
Physics run	>2025	running	>2030	>2025	>2025

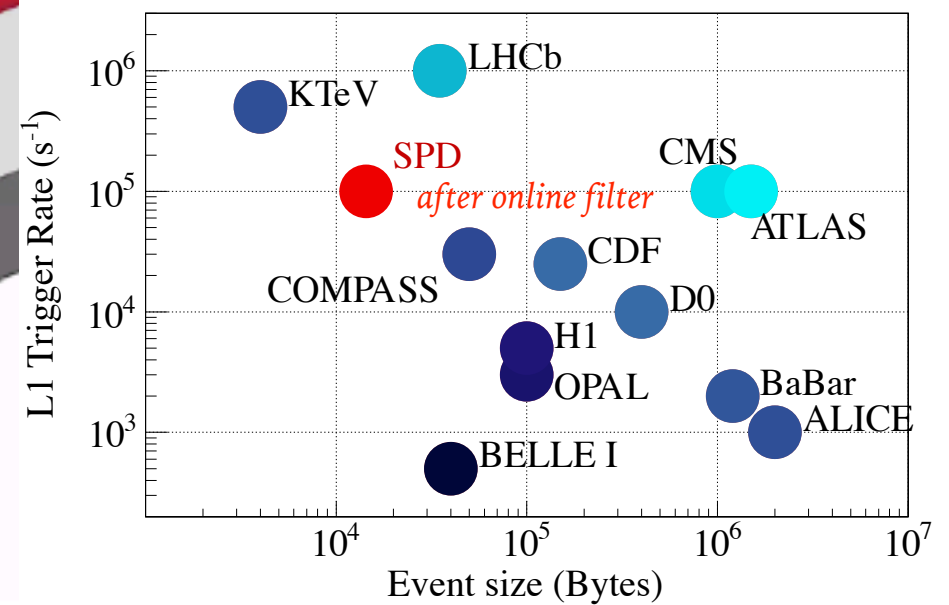
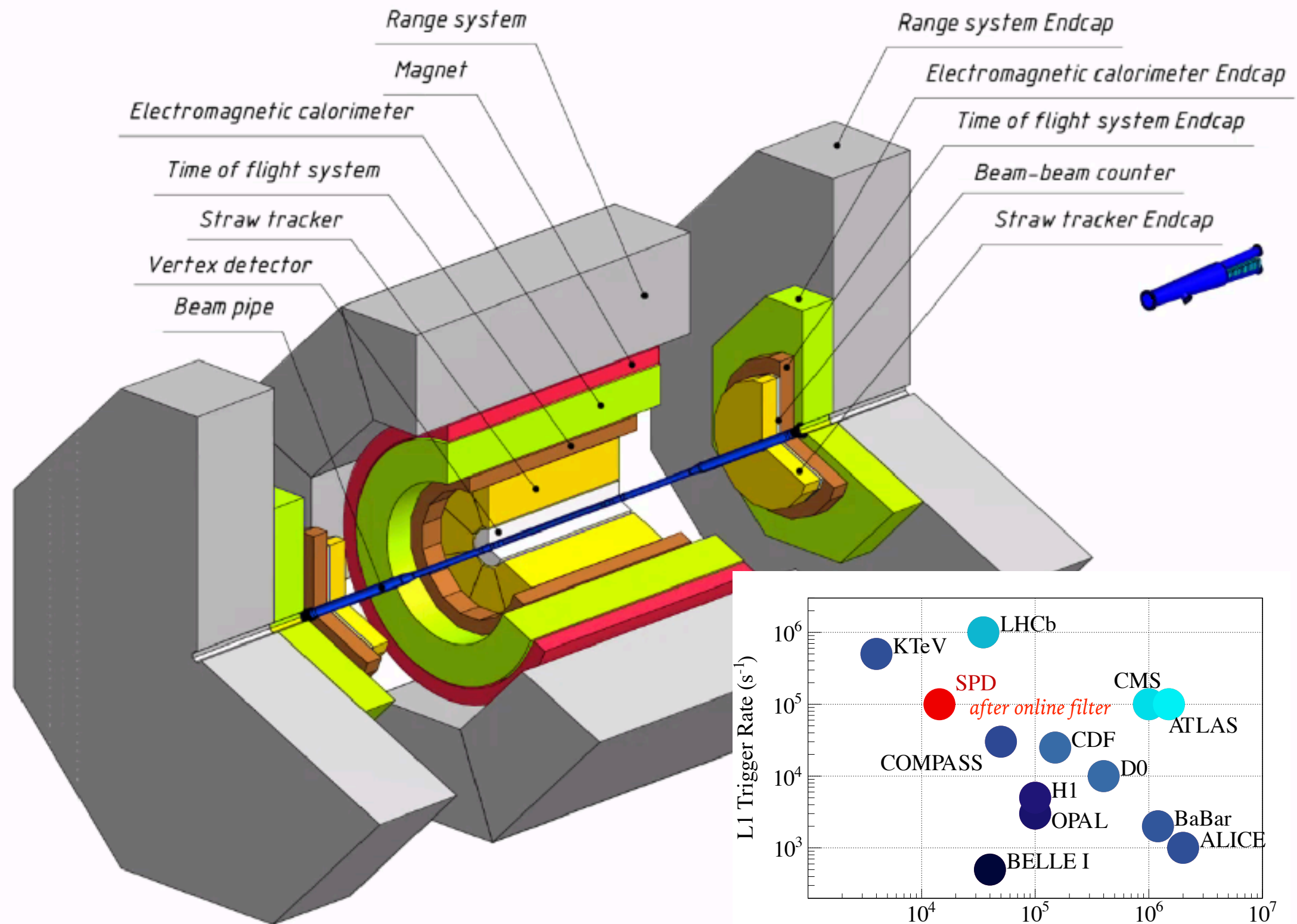




# CINEMATIC RANGE



# SPD DETECTOR





# RUNNING PLANS

2022

2024

2026

2028

TDR

Detector construction

Detector assembling

RUN

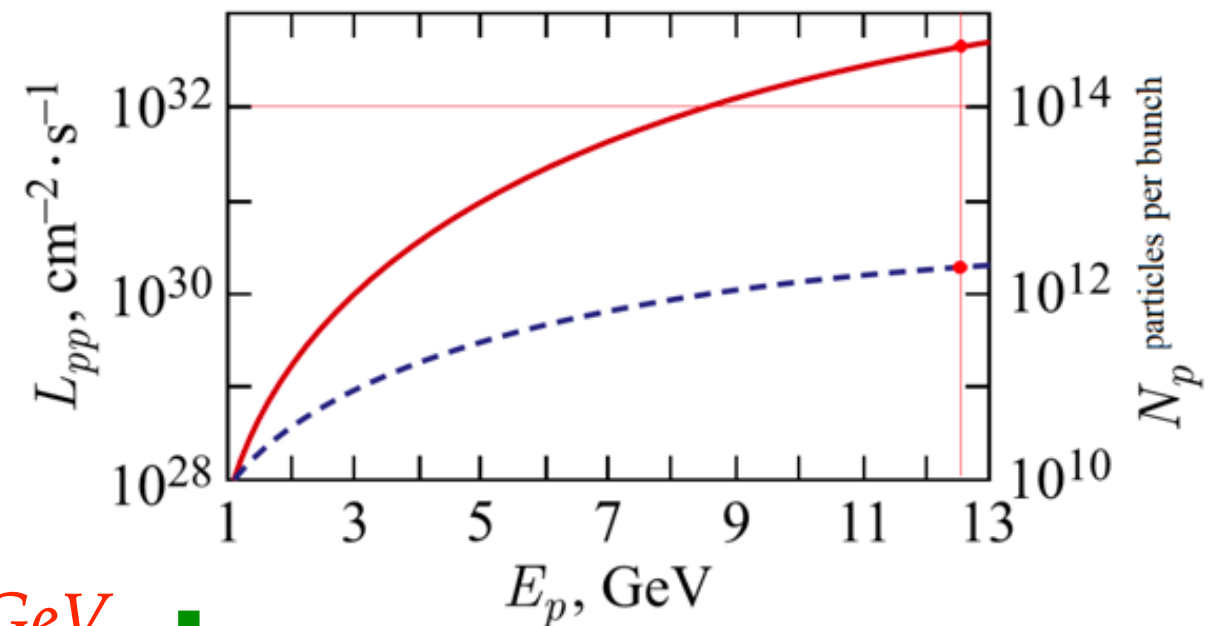
Physics goal	Required time	Experimental conditions
First stage		
Spin effects in $p$ - $p$ scattering dibaryon resonances	0.3 year	$p_{L,T}$ - $p_{L,T}$ , $\sqrt{s} < 7.5$ GeV
Spin effects in $d$ - $d$ scattering hypernuclei	0.3 year	$d_{tensor}$ - $d_{tensor}$ , $\sqrt{s} < 7.5$ GeV
Hyperon polarization, SRC, ... multiquarks	0.3 year	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 deconfinement, $\bar{p}$ yield	1 year	$p_T$ - $p_T$ , $7 \text{ GeV} < \sqrt{s} < 27 \text{ GeV}$ (scan)
Gluon helicity, ...	1 year	$p_L$ - $p_L$ , $\sqrt{s} = 27$ GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor polarized" PDFs	1 year	$d_{tensor}$ - $d_{tensor}$ , $\sqrt{s_{NN}} = 13.5$ GeV or/and $d_{tensor}$ - $p_T$ , $\sqrt{s_{NN}} = 19$ GeV

# WE EXPECT FROM ACCELERATOR: MODES

## Till 2028:

- polarized  $p$ - $p$  collisions,  $E_{\text{beam}} < 3.75$  GeV in spin transparency mode
- polarized  $d$ - $d$  collisions,  $E_{\text{beam}} < 1.3$  GeV/ $u$  in spin transparency mode
- both  $L$  and  $T$ -polarizations,  $T$ -polarization in vertical and horizontal planes
- absolute polarimetry for both  $p$ - $p$  and  $d$ - $d$
- $A$ - $A$  collisions

also  $L$ - $T$  mode



2 additional snakes +  
electron cooling in booster

## After 2028:

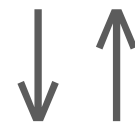
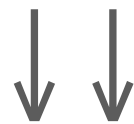
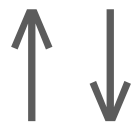
- $p$ - $p$  mode with  $T$ -polarization:  $E_{\text{beam}} < 12.6$  GeV,  
 $L$ -polarization:  $E_{\text{beam}} < 12.6$  GeV in resonances  
with step 0.5 GeV
- $d$ - $d$  mode with  $T$ -polarization:  $E_{\text{beam}} < 6.3$  GeV/ $n$ ,  
 $L$ -polarization:  $E_{\text{beam}} < 4.2$  GeV/ $u$



# WE EXPECT FROM ACCELERATOR

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*~ 10 s*



**SPIN FLIP**

*Radiofrequency in digital form*

**TIMING**

# SUMMARY

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- The **Spin Physics Detector** at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized **gluon content of proton and deuteron**; in polarized high-luminosity **p-p** and **d-d** collisions at  $\sqrt{s} \leq 27 \text{ GeV}$
- SPD CDR could be found at [arXiv:2102.00442](https://arxiv.org/abs/2102.00442) for more details.
- We hope to start running with minimal configuration in 2028
- We have formulated our requirements and we are in contact with accelerator people.