Spin Physics Detector

Статус Эксперимента SPD

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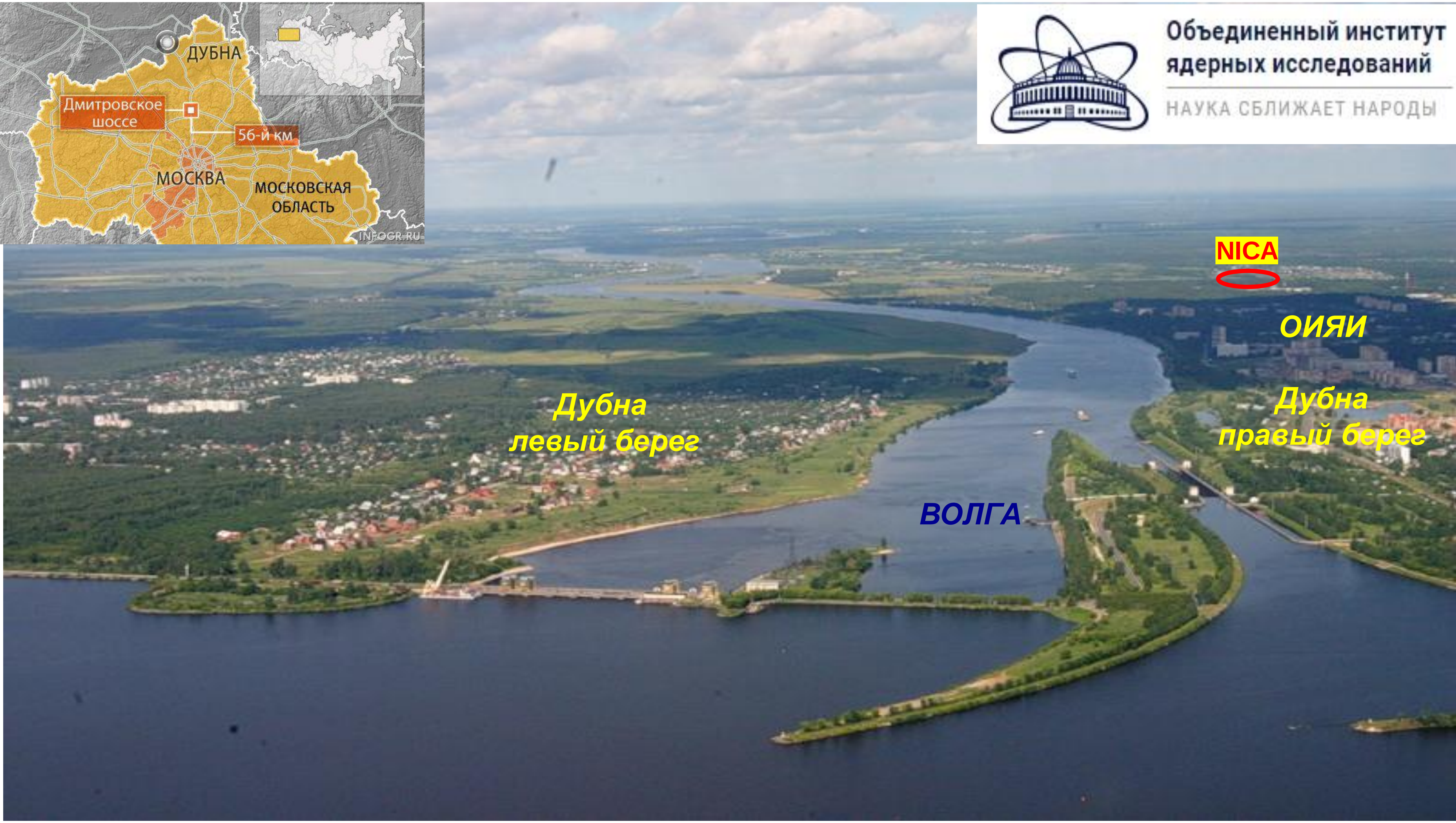
Ускорительный Комплекс NICA @ОИЯИ, Дубна



Ускорительный Комплекс NICA @ОИЯИ, Дубна

Тяжелые ионы (до Au) $\sqrt{s_{NN}}$ = 4 - 11 ГэВ **светимость L ~10^{27} см$^{-2}$ с$^{-1}$**

(не) поляризованные p↑(d↑)&p(d) $\sqrt{s_{NN}}$= 8(4) - 27(13,5) ГэВ **светимость L~10^{32} см$^{-2}$ с$^{-1}$**

Ускорительный Комплекс NICA @ОИЯИ, Дубна

SPD at NICA Collider (JINR, Dubna)

NICA:
Nuclotron-based Ion Collider fAcility

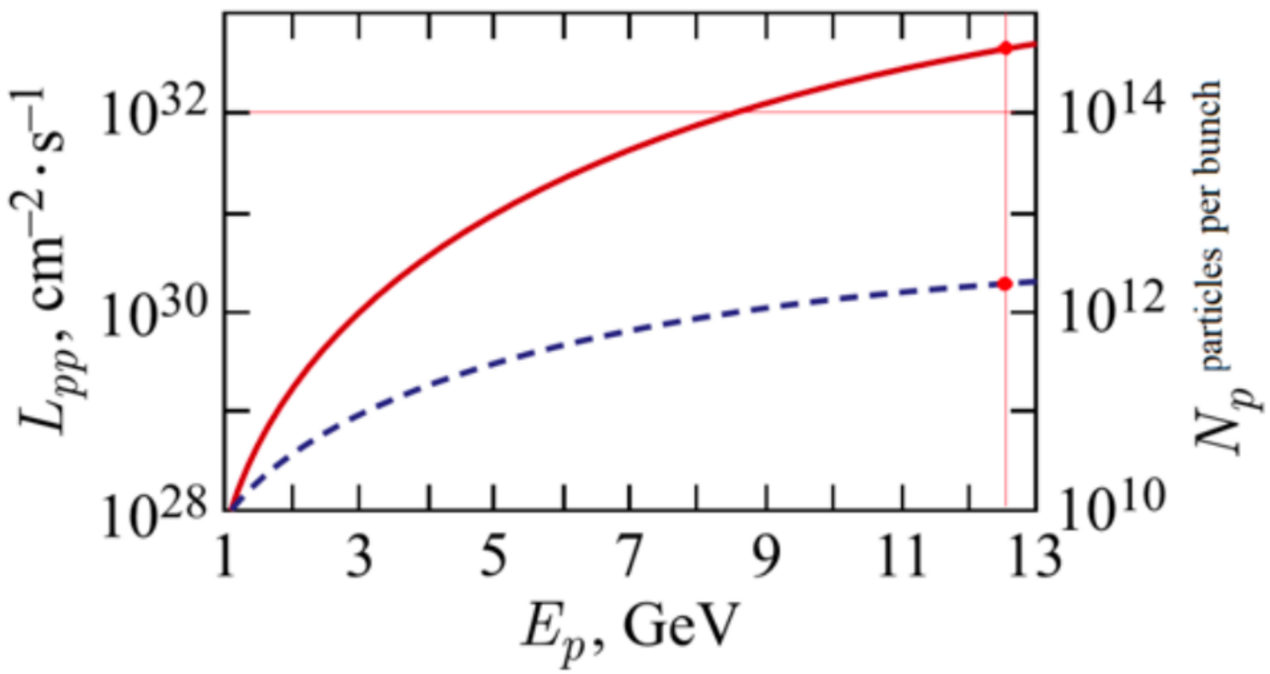
$$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$$

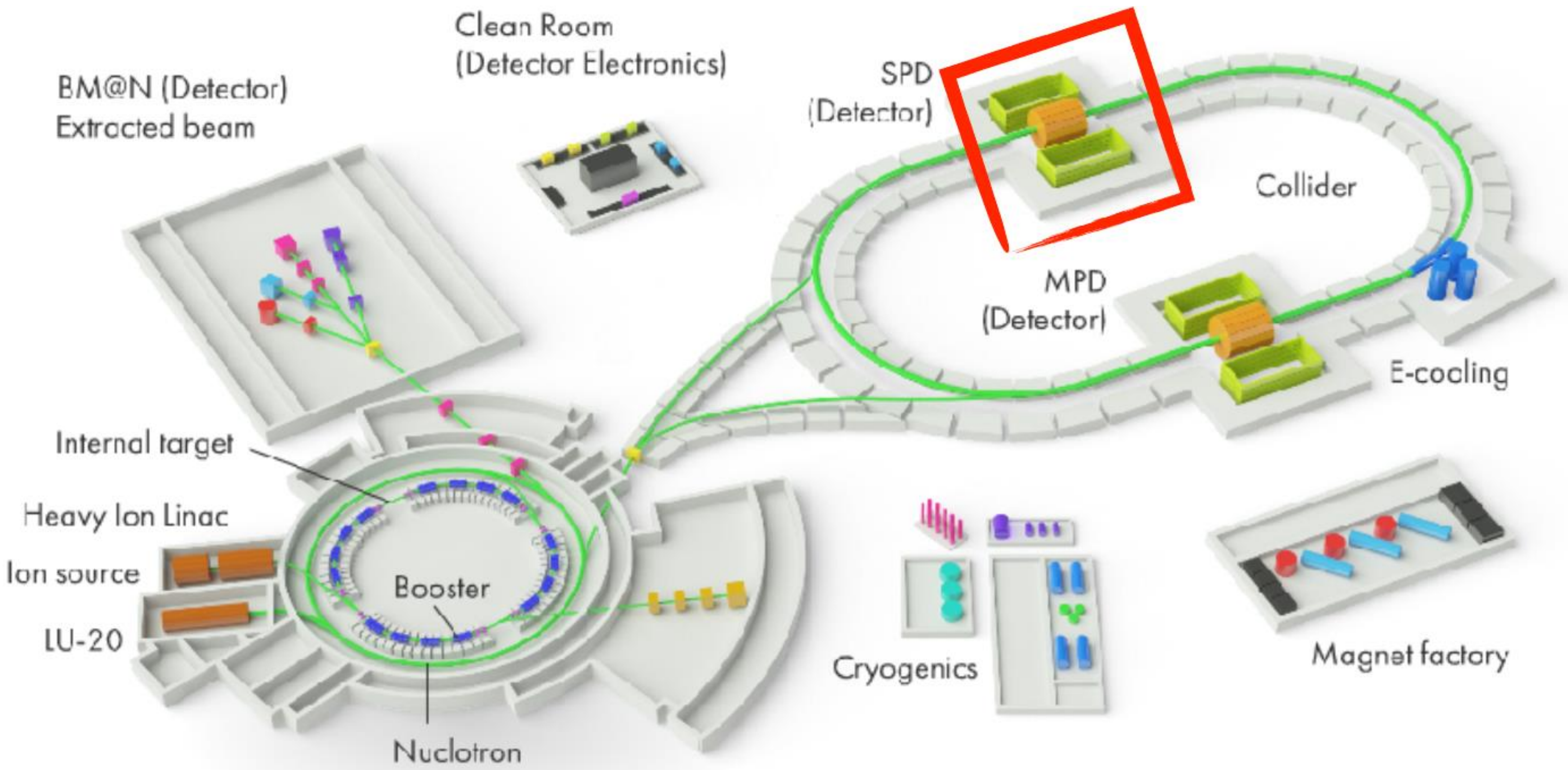
$$d^{\uparrow}d^{\uparrow} : \sqrt{s} \leq 13.5\ GeV$$

$$d^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 19\ GeV$$

U, L, T

$|P| > 70\%$





Основные цели эксперимента SPD

Spin Physics Detector (SPD) (http://spd.jinr.ru):
универсальный детектор на коллайдере NICA

➥ **Основные цели SPD:**
- понимание сильных взаимодействий используя интенсивные поляризованные и неполяризованные pp- и dd- соударения $\sqrt{s}$ < 27 ГэВ
- 3D структура протона и дейтрона -> глюонные TMD PDF при средних и больших x: чармоний, фотоны и т. п.

A. Arbuzov et al. ,Prog. Part. Nucl.Phys. 119 (2021) 103858 e-Print: 2011.15005 [hep-ex]

➥ **Первая стадия работы SPD: программа для широкой области исследований физики адронов и ядерной физики**

V.V. Abramov et al., Phys. Part. 52 (2021) 1044, e-Print: 2102.08477 [hep-ph]

Transverse momentum distribution (TMD) –
партонные распределения с учетом поперечного импульса
Parton distribution function (PDF) – функции распределения партонов

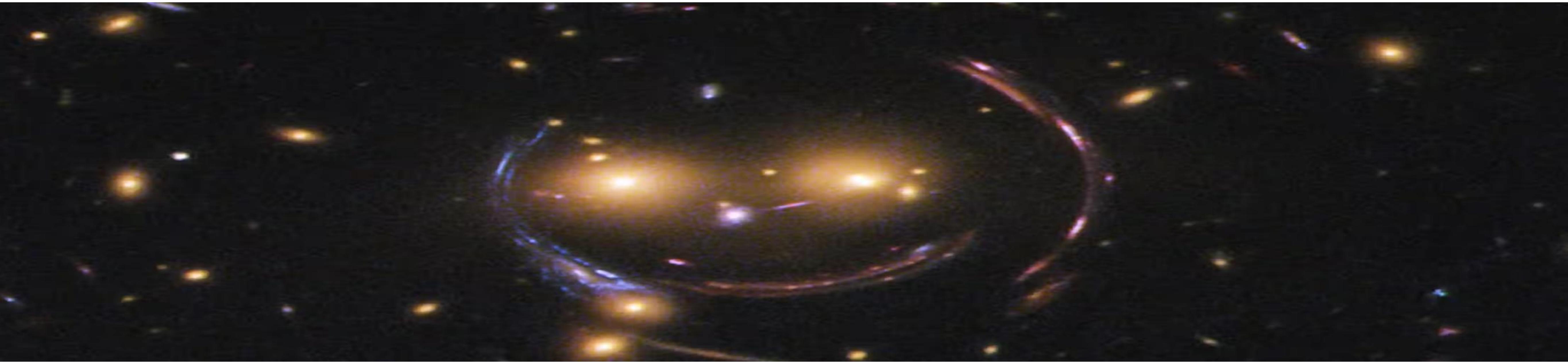
Почему Спиновая Физика Нуклона?

Поиски Новой Физики:

► Поиски новых частиц и взаимодействий
за пределами Стандартной Модели

► Поиски новой динамики Стандартной Модели

Почему Структура Нуклона?



- Масса протона -> масса видимой Вселенной

Электрослабый бозон Браута-Энглера-Хиггса:

масса кварков ~ 15 MeV ≃ 2% массы видимой Вселенной

➥ кварк-глюонная динамика нуклона:

~ 98% массы видимой Вселенной!

Загадка:

- Размер нуклона:

кварковая модель ➥

превышает величину ЭДМ нейтрона на > 10^12

Почему Спин?

Спин: чисто квантовая характеристика

спин: нет классических аналогов

спиновые наблюдаемые

➥ **волновые функции адронов**

➥ **амплитуды процессов**

“Спиноыфй кризис протона”:
кварковая модель ➥ <1/3 спина протона

Почему NICA?

Сильные взаимодействия:
асимптотическая свобода при больших энергиях

Динамические эффекты

➥ **уменьшаются при больших энергиях**

Энергии NICA

➥ **оптимальные для целей SPD**

Спин: challenging delicate properties

"Experiments with spin have killed more theories than any other single physical parameter"

Elliot Leader, Spin in Particle Physics, Cambridge U. Press (2001)

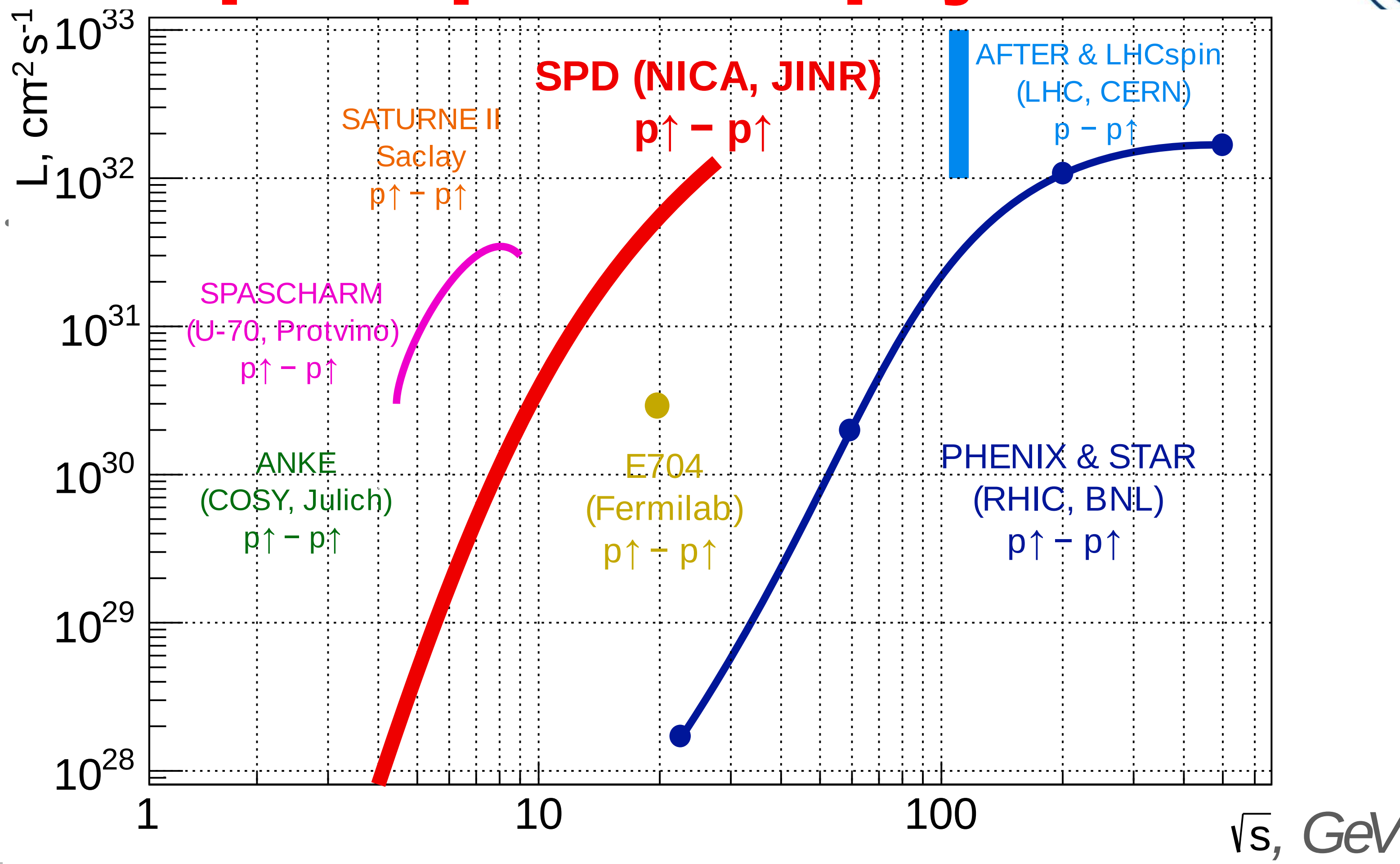
"Polarisation data has often been the graveyard of fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection."

J. D. Bjorken, Proc. Adv. Research Workshop on QCD Hadronic Processes, St. Croix, Virgin Islands (1987).

V. Mochalov (NRC KI - IHEP)

SPD in World landscape of polarized physics

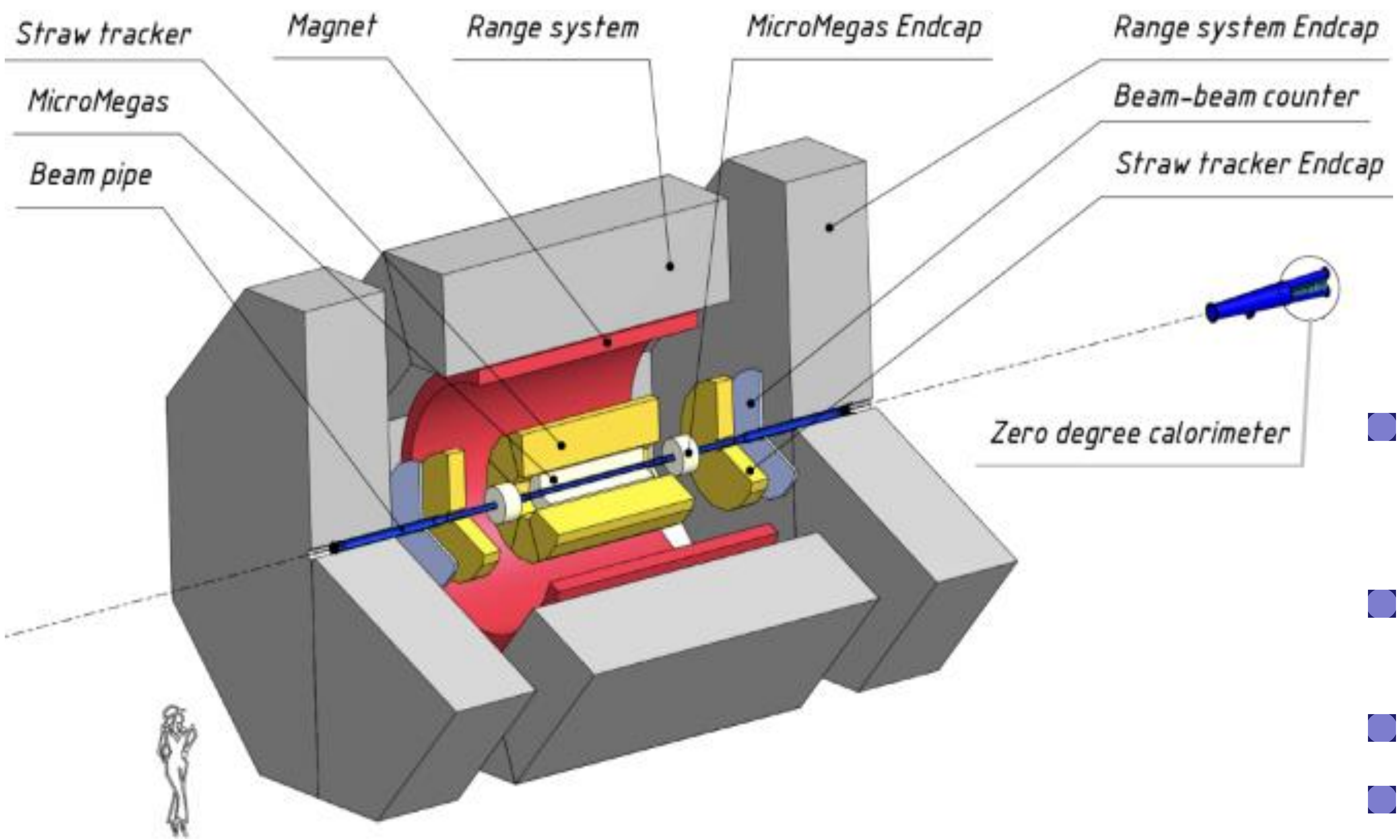
p↑ p↑-mode →



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	$p^{\uparrow}$-$p^{\uparrow}$ $\boxed{d^{\uparrow}\text{-}d^{\uparrow}}$ $p^{\uparrow}$-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

← SPD is unique in d↑ d↑-mode!

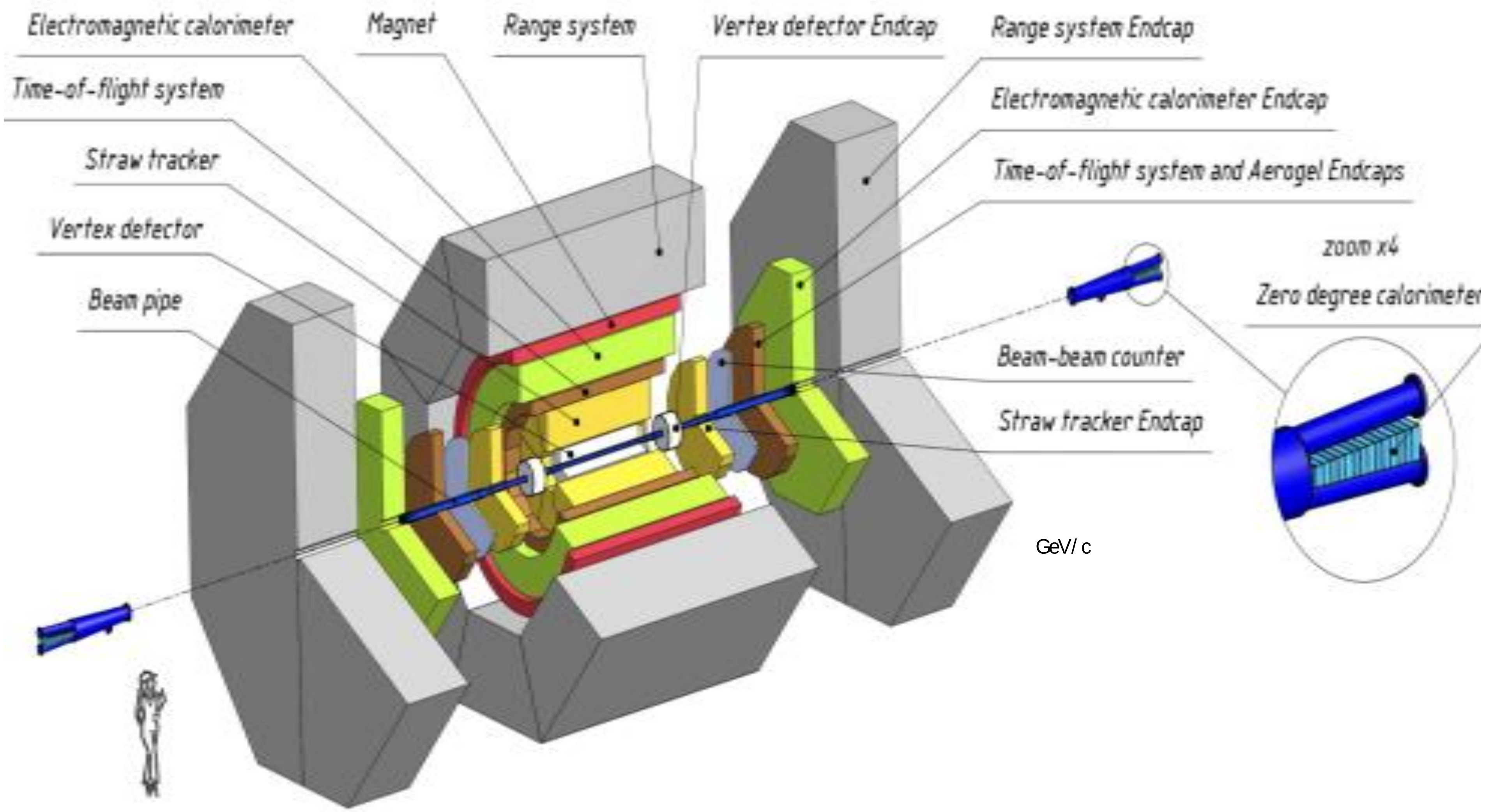
SPD detector at the Stage I



- Trackers:charged track and momentum, limited PID
- Range System:rough hadronic calorimeter, muon/ hadron separation

- Possible light ion collisions alongside *pp, dd*
- Up to $\sqrt{s} = 10$ GeV and reduced luminosity
- Solenoidal field $B \sim 1$ T
- BBC and ZDC for online polarimetry
- Micromegas central tracker
- Straw Tracker $\delta \sim 150\ \mu$m, $\delta(\frac{dE}{dx}) = 8.5\%$

SPD detector at the Stage II



- Event rate at peak luminosity and energy ⇠ 3 MHz
- Silicon vertex detector : MAPS/ DSSD
- Time of flight (TOF) for PID (δ_t ⇠ 50 ps), ⇡/ K separation upto 1.5 GeV/ c
- Electromagnetic calorimeter (ECAL) $(\frac{\delta_E}{E} = \frac{5\%}{\sqrt{E}} + 1\%)$
- Aerogel counter in endcaps, extends ⇡/ K separation upto 2.5 GeV/ c

- Improved vertex detector for short lived particle decays
- TOF+ AGel for better PID
- ECAL for $\gamma, e^{\pm}$ identification

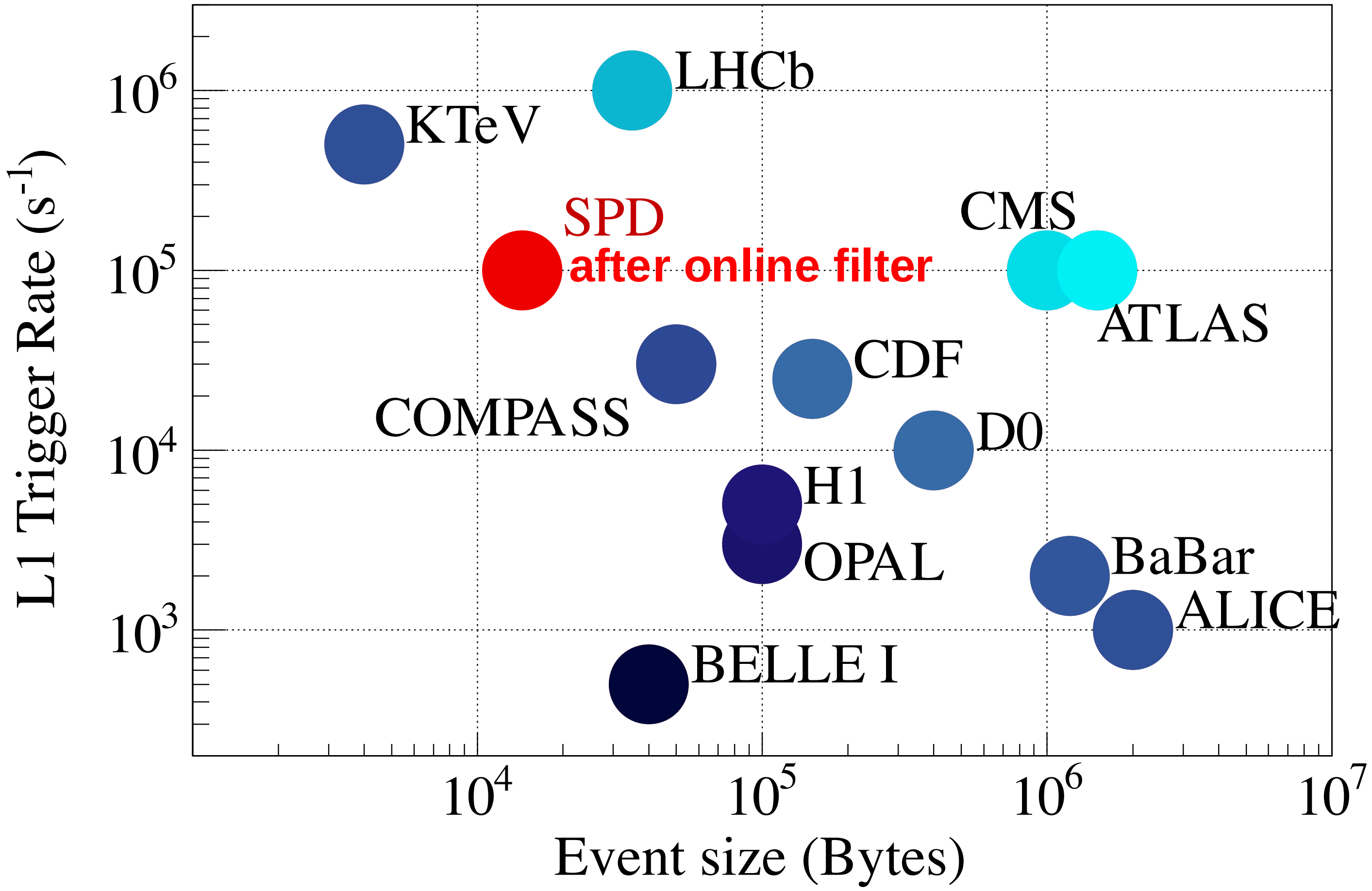
SPD detector data flow

No hardware trigger at the SPD detector to avoid a possible bias:
3 MHz event/s at 10^{32} cm^2/s design luminosity
20 GB/s ➡ 3 10^3 events/year ➡ 200 PB/year

The SPD setup is a medium scale detector in size,
but a large scale one in data rate!
Comparable in data rate with ATLAS and CMS at LHC

Considerations of SPD Tier-1 at PNPI

SPD data rate after online filter



SPD: Requested Computing Resources

Computing resources	Distribution by year				
	1st year	2nd year	3rd year	4th year	5th year
Data storage (TB) - EOS - Tapes	1500 0	2000 2000	5000 10000	7000 14000	10000 20000
Tier 1 (CPU corehours)	17 520 000	43 800 000	87 600 000	131 140 000	175 200 000
Tier 2 (CPU corehours)	1 752 000	4 380 000	8 760 000	13 114 000	17 520 000
SC Govorun (CPU core hours)	1 752 000	4 380 000	8 760 000	8 760 000	8 760 000

Considerations of SPD Tier-1
for the SPD 2nd Stage at NRC KI – PNPI, Gatchina

SPD project timeline

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

2014 SPD Letter of Intent is approved by JINR PAC

2016, 2018 SPD-oriented workshops in Prague

2019 SPD project is approved by JINR PAC (up to 2022)
The 1st SPD proto-Collaboration meeting

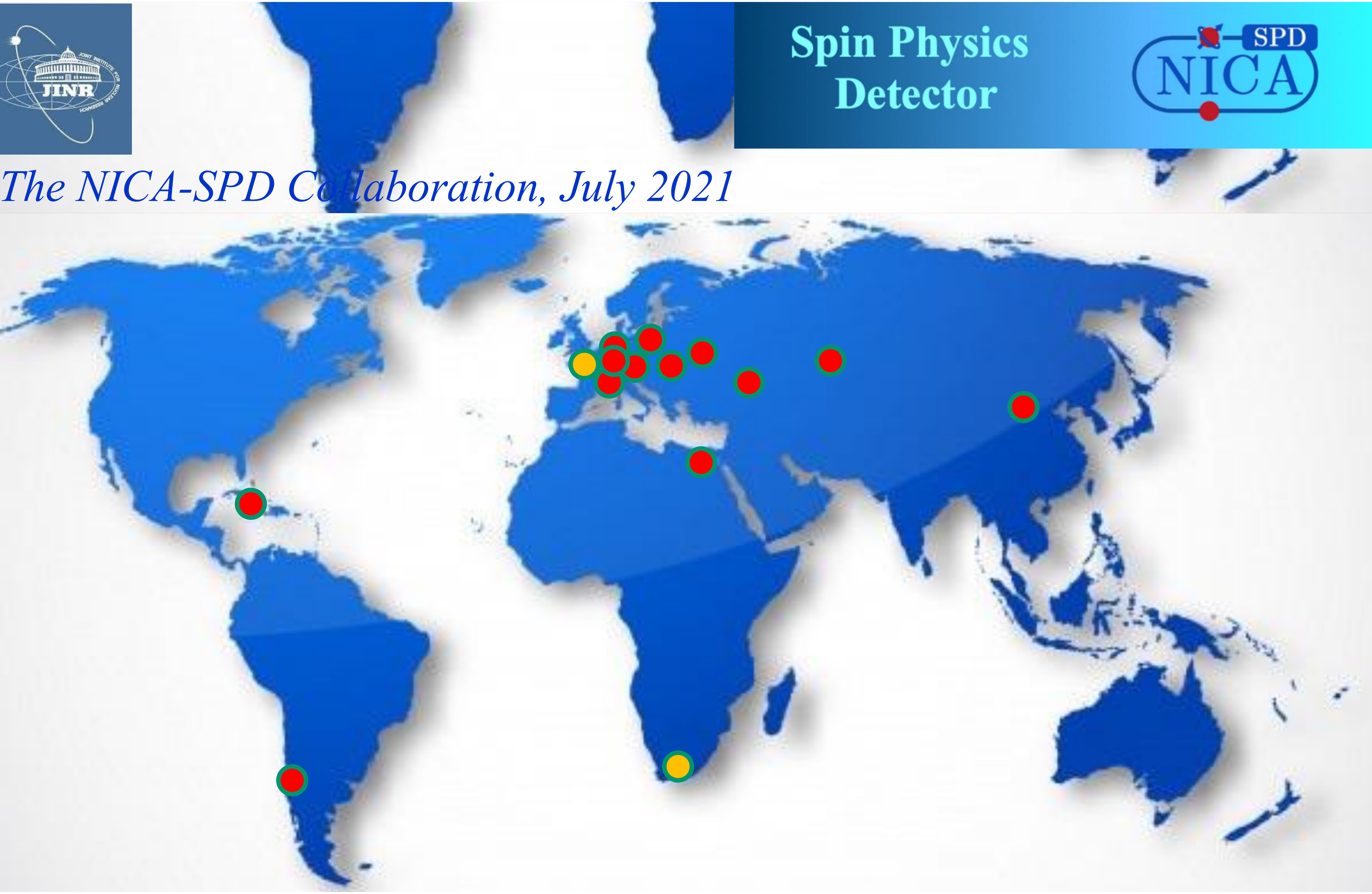
2020 Completion of SPD Conceptual Design Report (CDR)
http://arxiv.org/abs/2102.00442

2021 SPD Collaboration is established
Two SPD-physics papers were published

2024 SPD Technical Design Report (TDR): *http://spd.jinr.ru*
approved by JINR PAC June 2024

the SPD 1st Stage: included to the JINR 7-year Plan 2024-2030

SPD Collaboration: established in July 2021



SPD Collaboration: Organization

35 organizations from 15 countries *> 400 participants*

Signed MoU (16):

NRC "Kurchatov Institute" - PNPI, Gatchina
Alikhanov National Science Laboratory (Yerevan Physics Institute), Yerevan
Samara National Research University, Samara
Peter the Great Saint Petersburg Polytechnic University, St. Petersburg
Saint Petersburg State University, St. Petersburg
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow
Lebedev Institute of Physics RAS, Moscow
Institute for Nuclear Research RAS, Moscow
Institute of Nuclear Physics (INP RK), Almaty
Tomsk State University, Tomsk
National Research Nuclear University MEPhI, Moscow
Belgorod State University, Belgorod
Institute of Nuclear Problems, Belorussian State University, Minsk
Budker Institute of Nuclear Physics RAS, Novosibirsk
Higher School of Economics, Moscow
Higher Institute of Technologies and Applied Sciences, Havana
in signing: I-Temba Labs (South Africa), Univ. Cairo (Egypt)

SPD Spokespersons:
A.V. Guskov (JINR) & V.T. Kim (NRC KI - PNPI)

CB Chair: A. Tumasyan (ANSL, Yerevan)

SPD Collaboration Meetings:

2023: Dubna (April)
Samara (October)
2024: Almaty (May)
Dubna (November)
2025: Yerevan (April?)
Dubna (October?)

SPD Collaboration Meeting
at Kazakh-British Technical University (KBTU), Almaty, 20 - 24 May 2024

SPD Physics:

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

ArXiv e-Print: 2011.15005 [hep-ex]

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], F. Murgia [h], M. Nefedov [l], B. Parsamyan [a, n, o], C. Pisano [g, h], M. Radici [c], A. Rymbekova [a], V. Saleev [l, a], A. Shipilova [l, a], Qin-Tao Song [s], O. Teryaev [a]

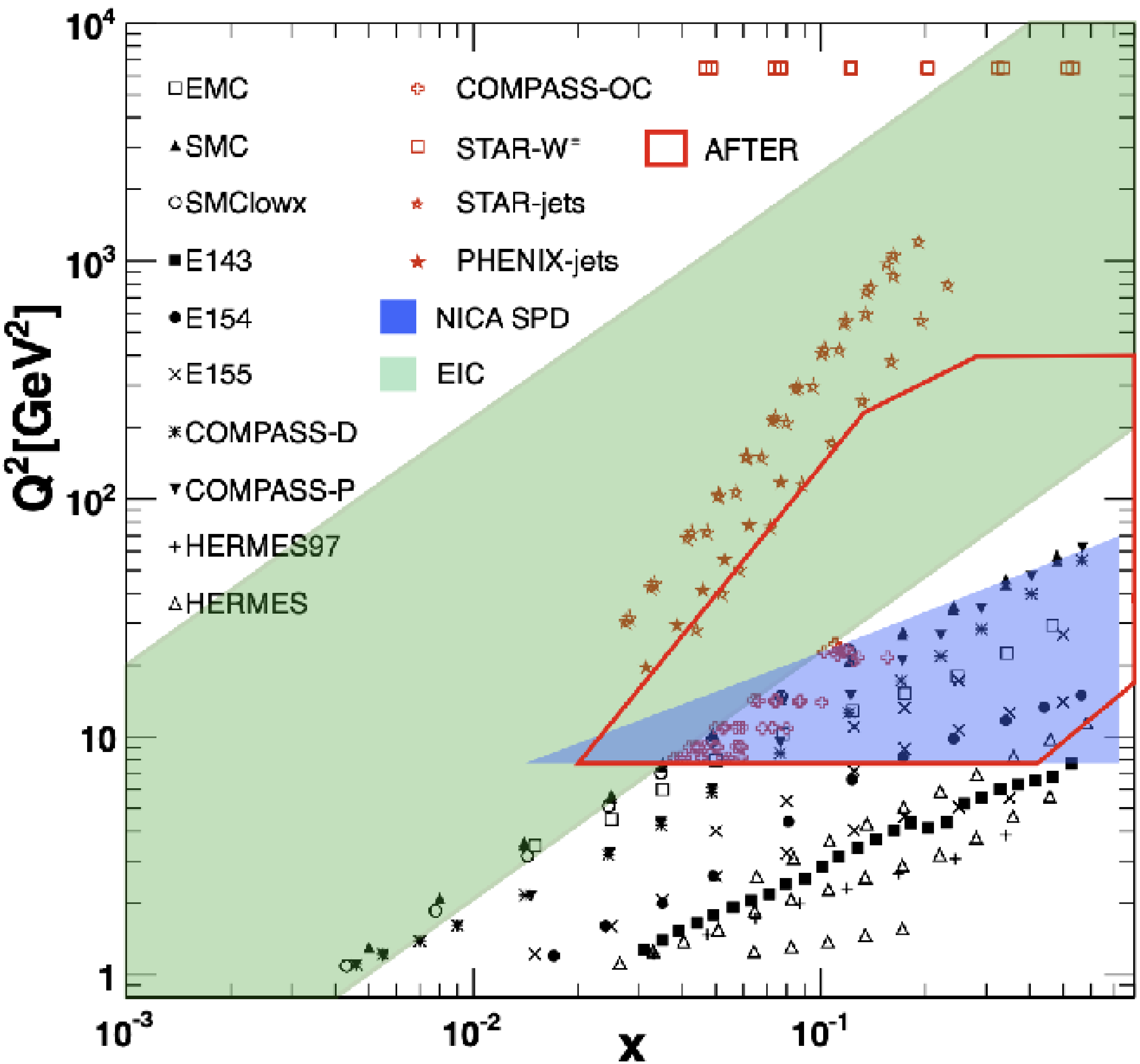
Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams

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 [7, 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]

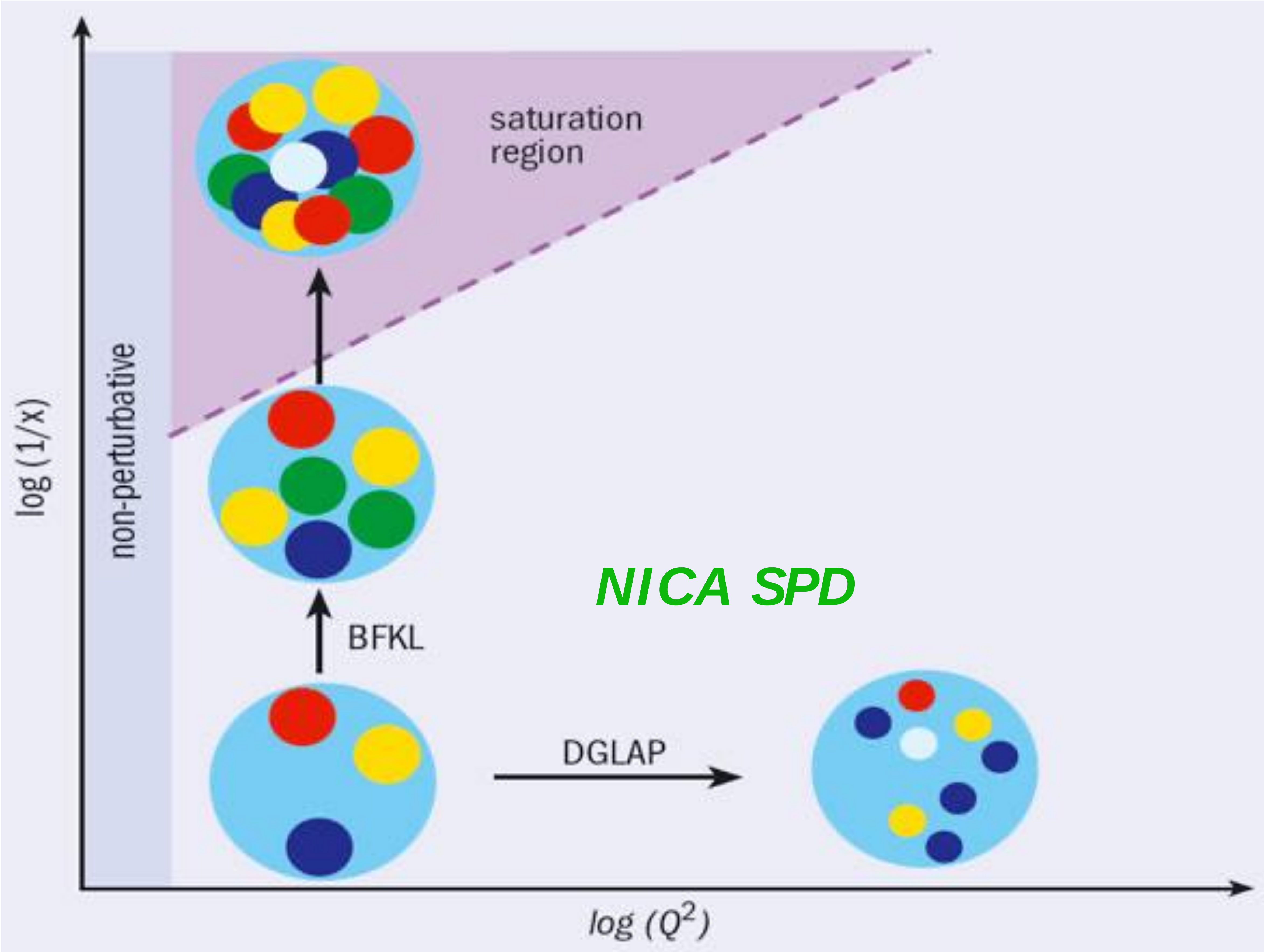
Phys. Part. Nucl. Vol.52, 2021, 1044

ArXiv e-Print: 2102.08477 [hep-ph]

PDF kinematic range

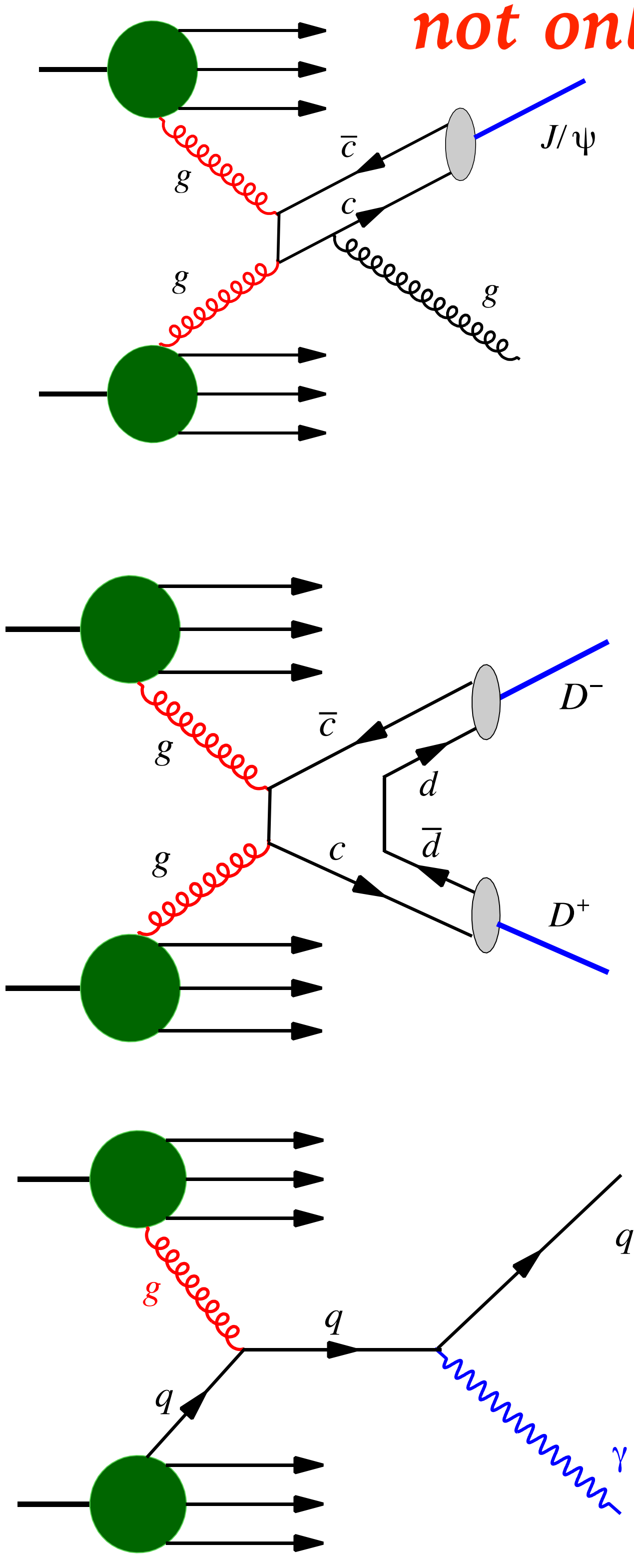


Dynamics kinematic range

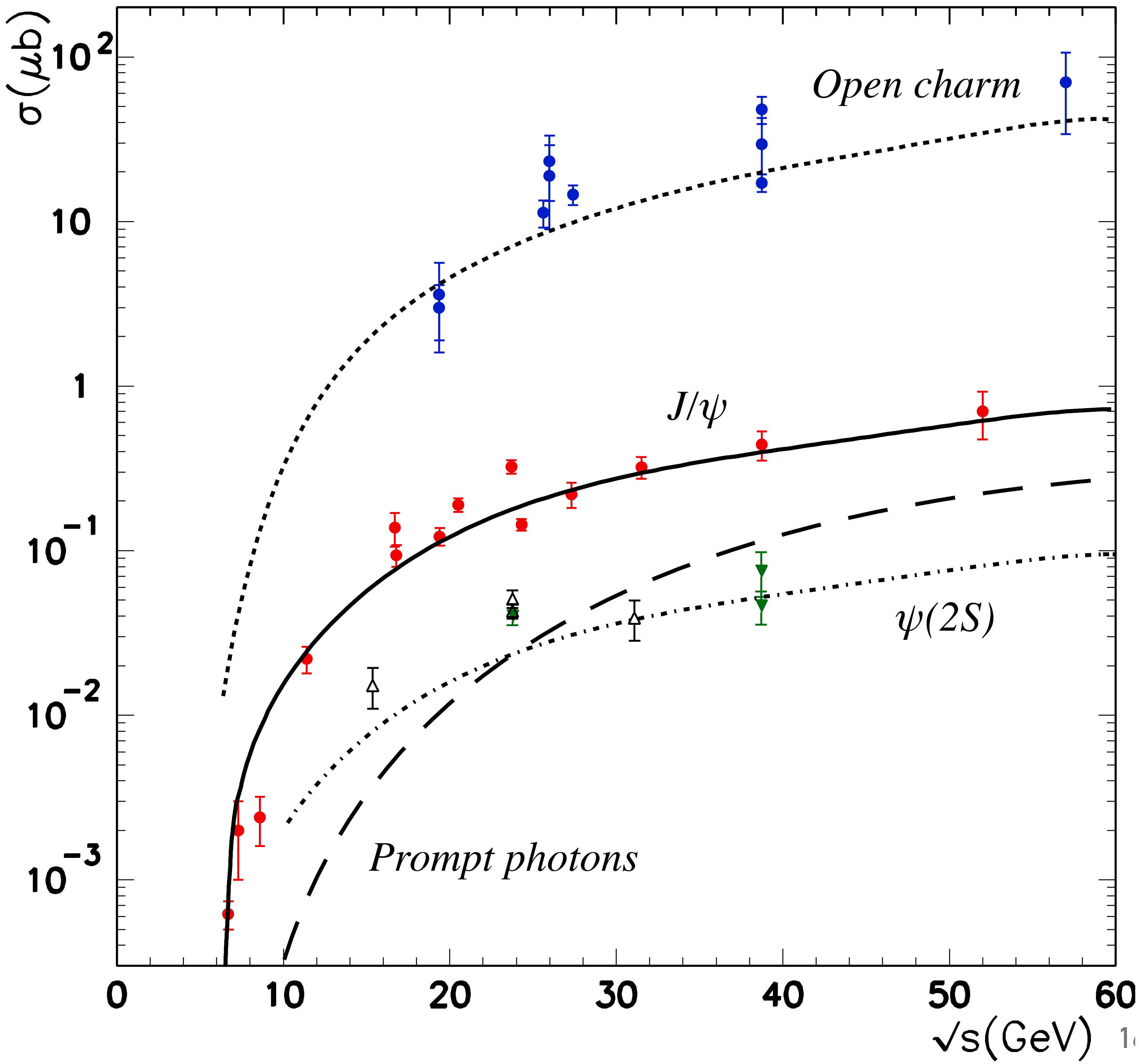


Gluon probes at SPD: charmonia, open charm, direct photons

not only J/ψ!

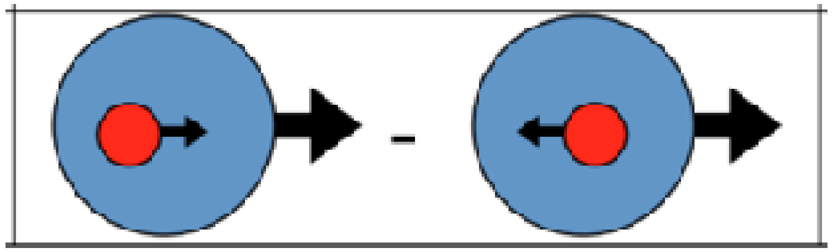


$$\sigma = PDF_1 \otimes PDF_2 \otimes \hat{\sigma}_{12}$$

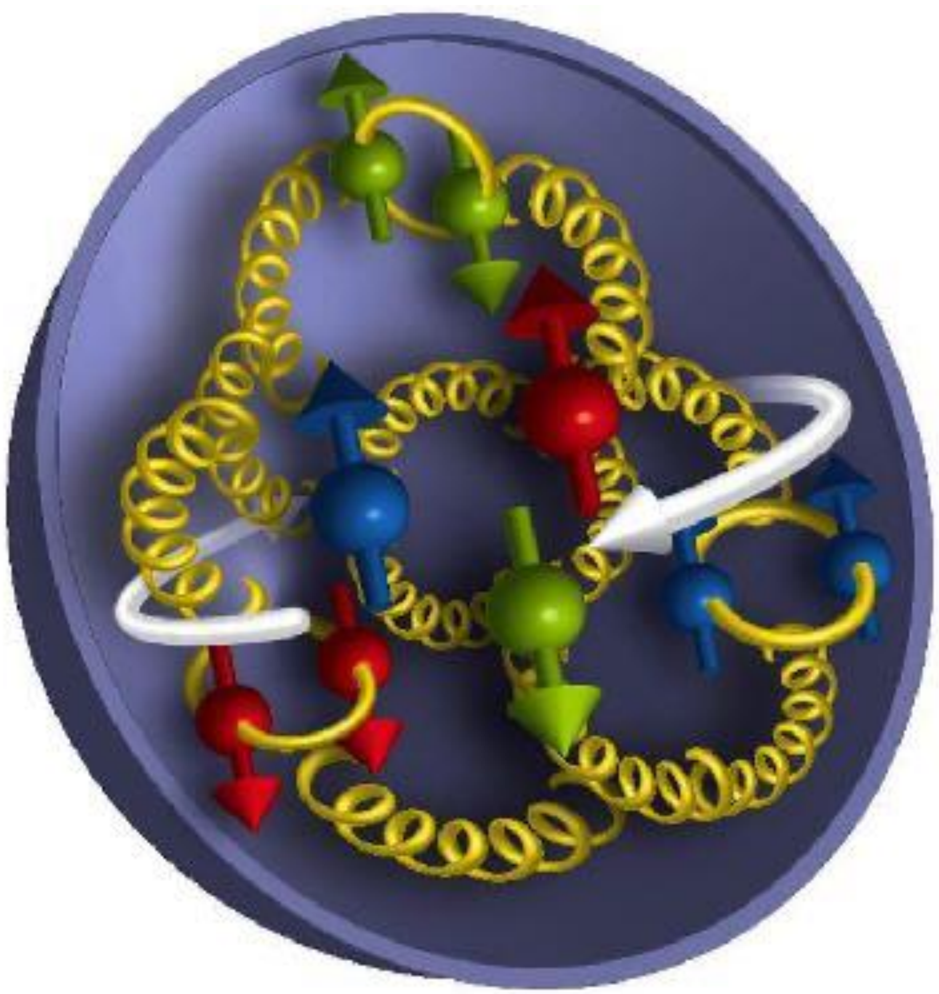


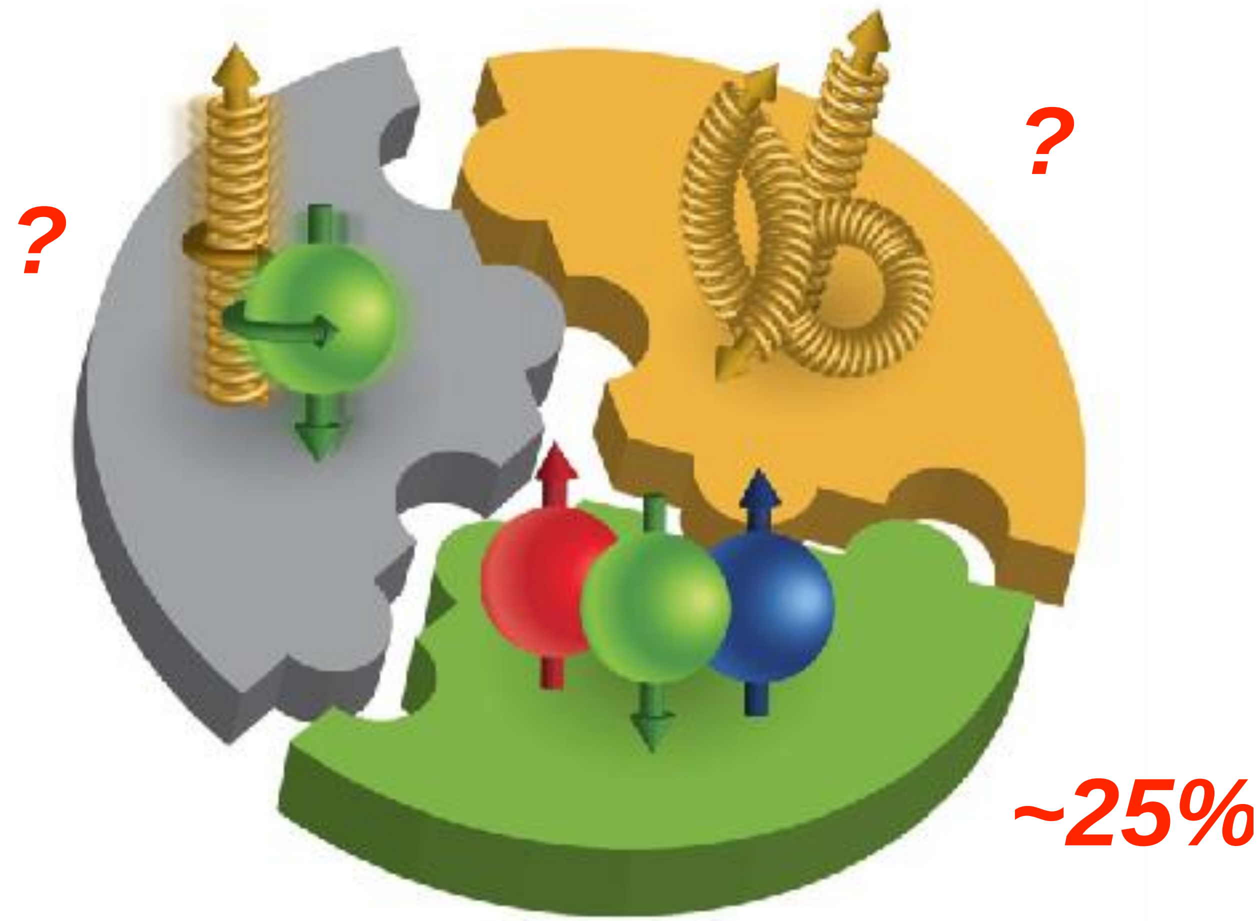
Helicity gluon PDF Δg(x): Spin Crisis

$\Delta g(x)$:



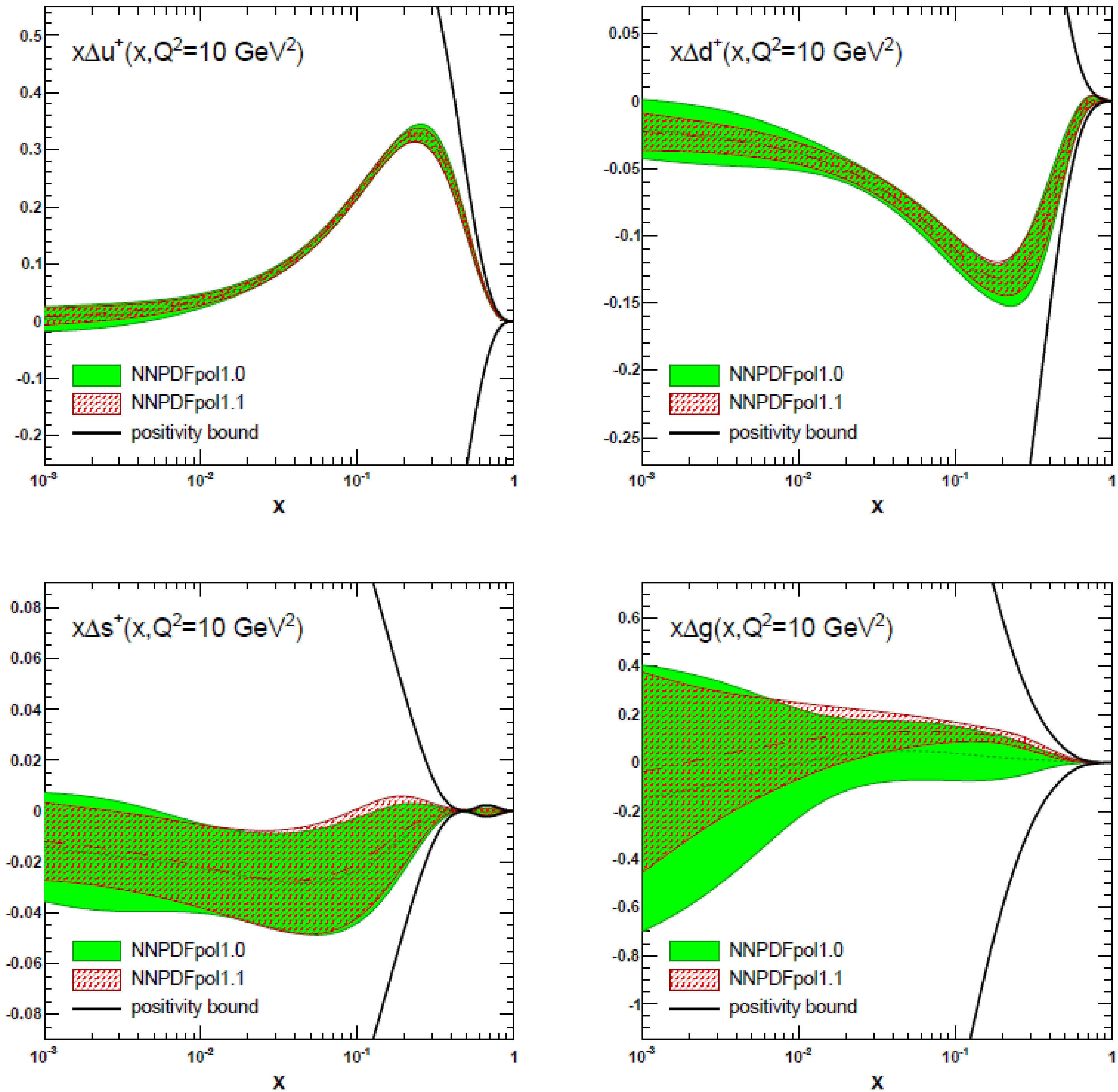
$$\Delta G = \int_0^1 \Delta g(x)dx$$





$$S_N = \tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + \Delta G + L$$

NNPDF Coll.: quark and gluon helicity PDFs of proton



NNPDF Coll.:
E. Nocera et al. (2014)

Quark helicity PDF:
few percent level uncertainties

It is measured with
high precision in DIS

Gluon helicity PDF:
still rather high uncertainties!

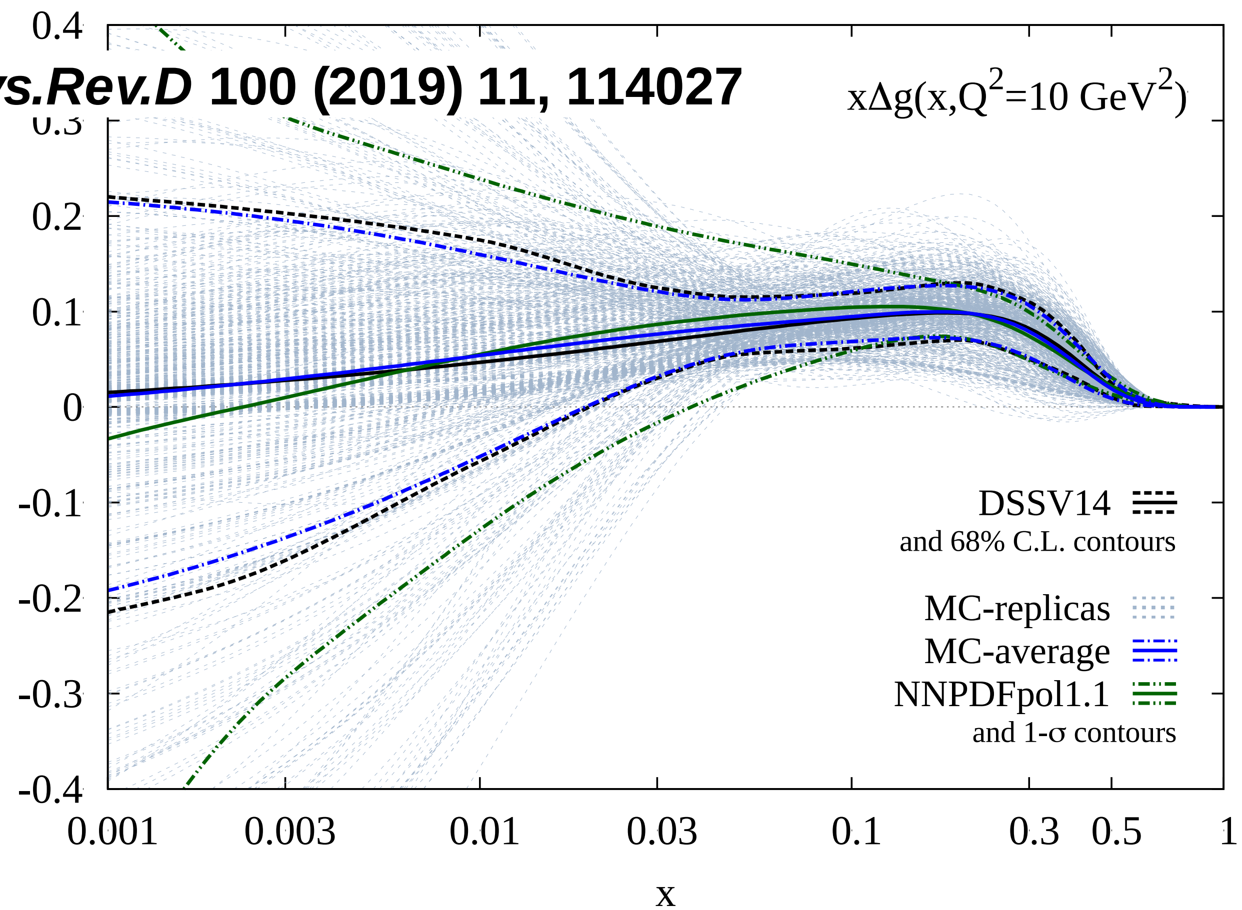
Hadron collisions have a better
sensitivity to measure it.

← SPD has a good opportunity!

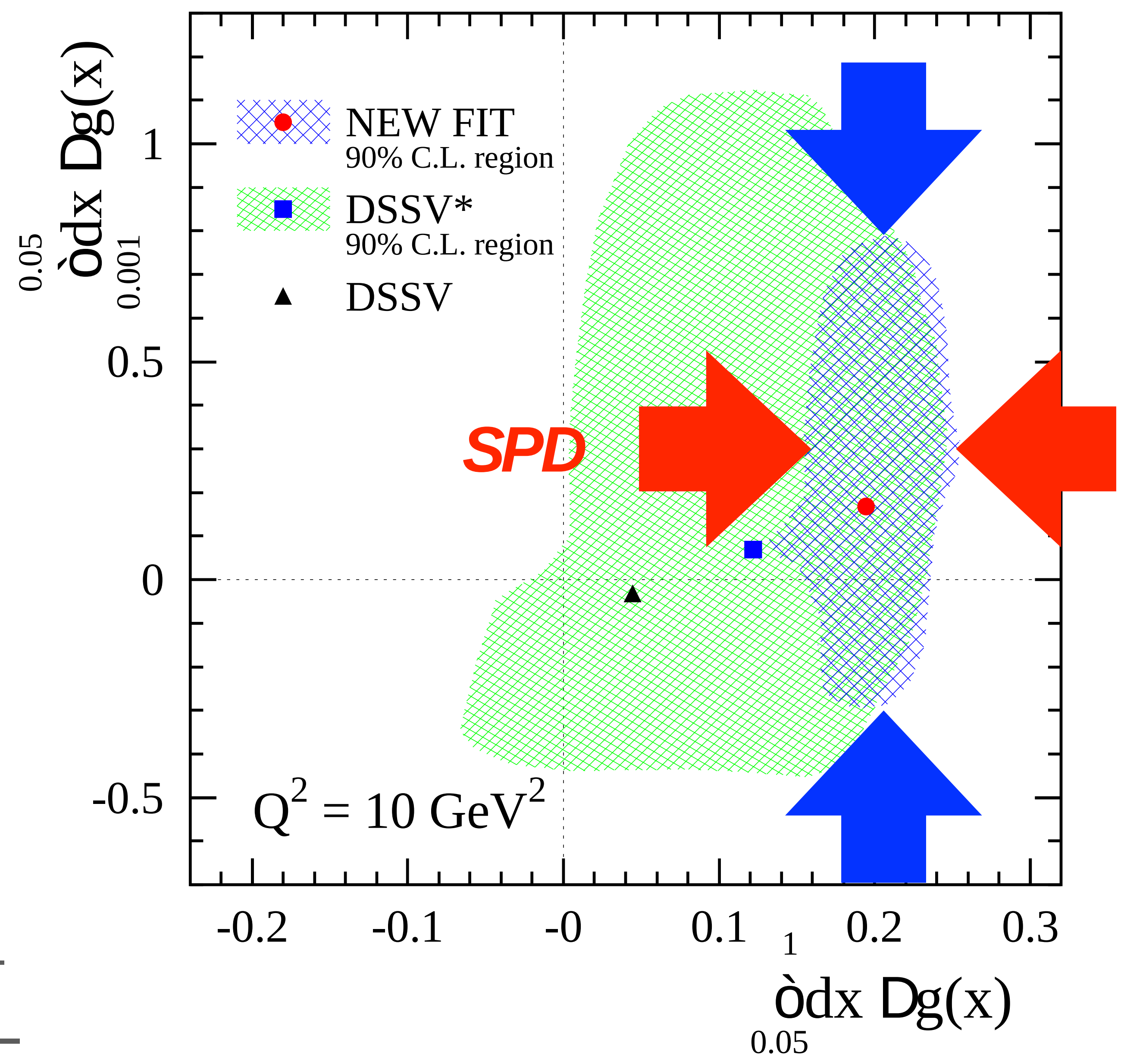
Helicity gluon PDF $\Delta g(x)$:

accessible with SPD

Phys.Rev.D 100 (2019) 11, 114027



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

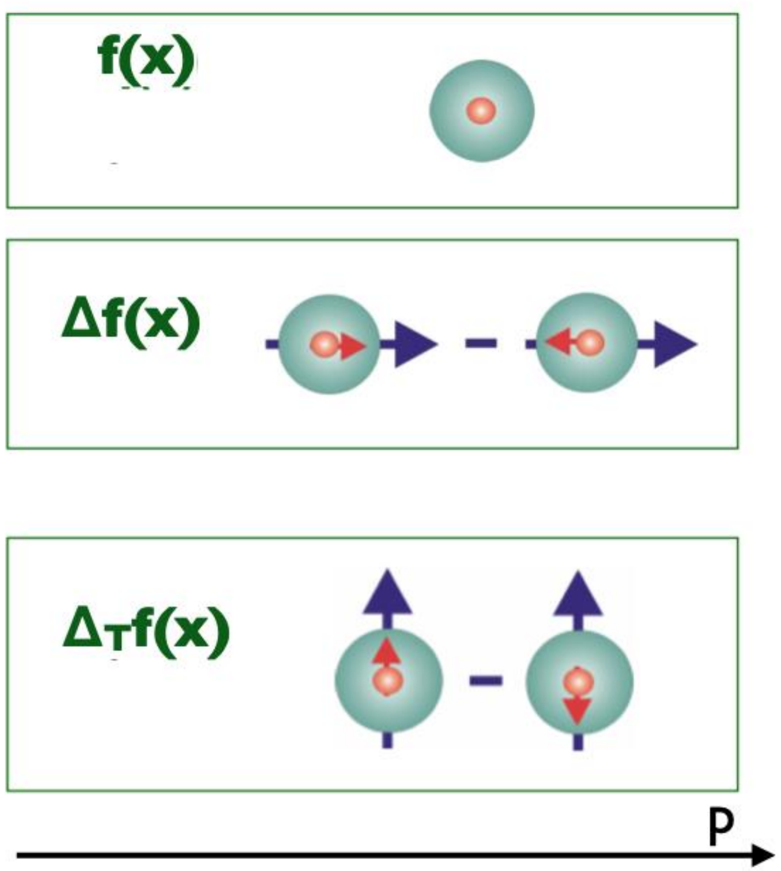


SPD could help to reduce uncertainty of ΔG at large x

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

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

Spin of proton

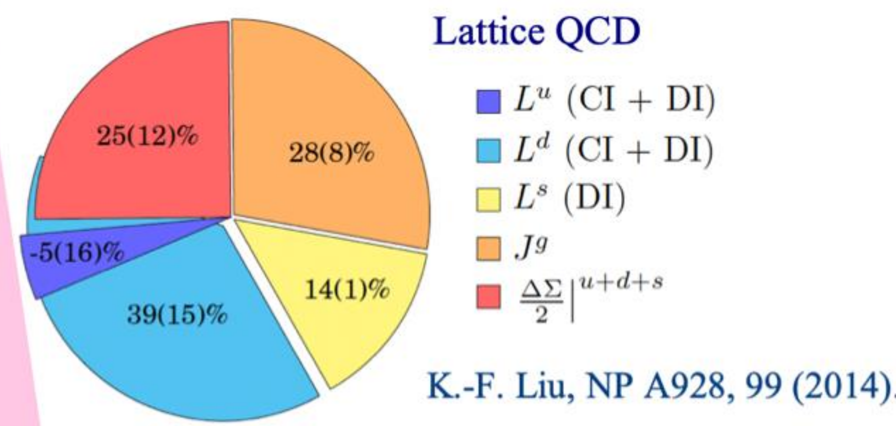


Unpolarized PDF

Helicity

Transversity

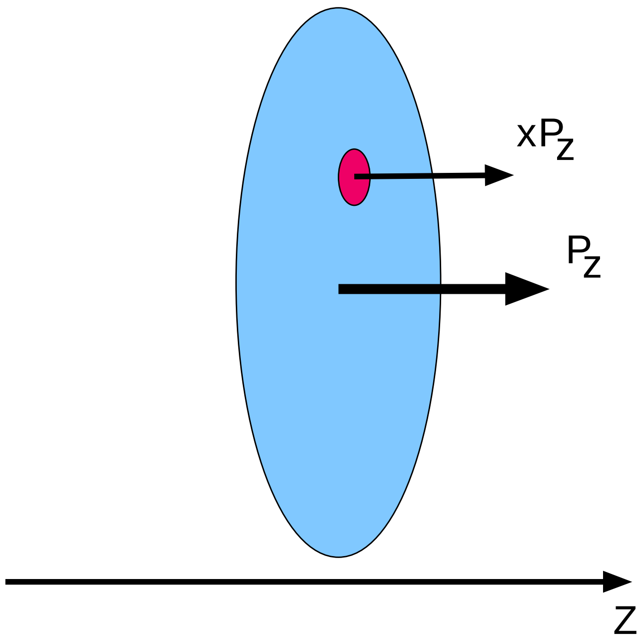
$$J = \overset{\sim 30\%}{\frac{1}{2}\Delta\Sigma} + \underset{\sim 10\text{-}20\%}{\Delta G} + \boxed{\overset{?}{L_q} + \overset{?}{L_g}}$$



K.-F. Liu, NP A928, 99 (2014).

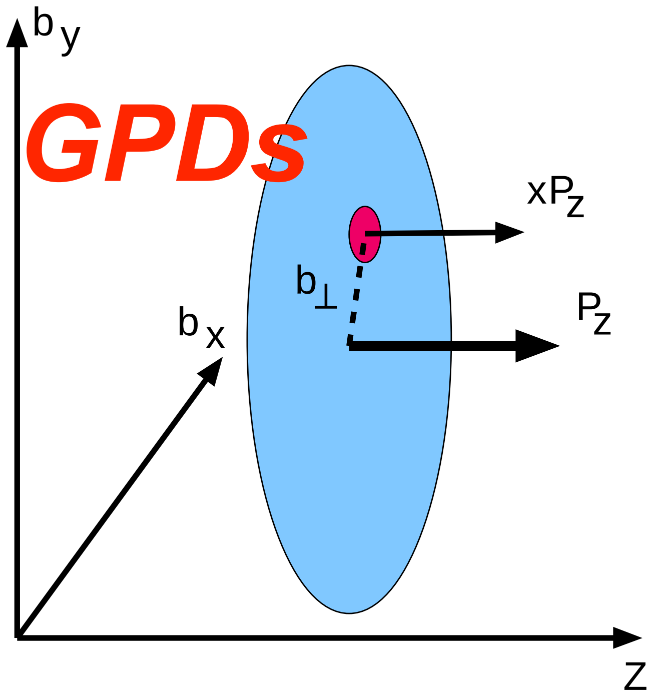
To access angular momenta info about 3D structure is needed!

SPD: towards 3D-structure of nucleon



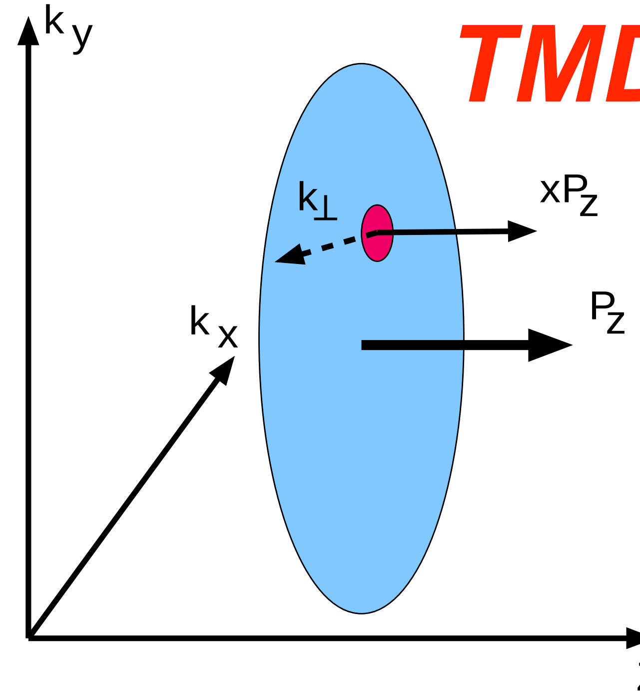
Collinear approximation

(common PDF)

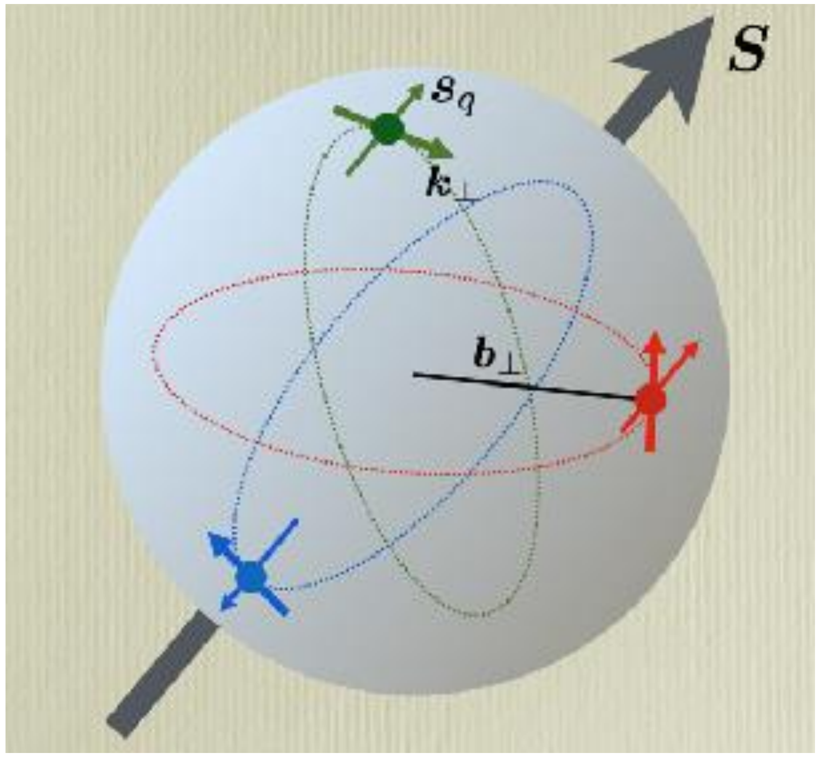


Generalized Parton Distributions

TMD PDFs



Transverse Momentum Dependent PDFs



3D structure of nucleon

connection to orbital moment

13

Parton Distribution Functions (PDFs): 1D ➡ 3D

Parton 1D-distribitions:

Integrated over kT PDF: f(x; logQ^2) ⟵ **modulo logQ^2 - DGLAP evolution**

Extension to parton 3D-distribitions:

- **Generalized parton distributions (GPDs): G(x, b, n; logQ^2)**
  b - impact parameter, n – unit vector

- **Unintegrated over kT PDF: Φ(x, kT, n; logQ^2) (two theory approaches):**
  - ➥ **Unintegrated collinear PDF (uPDF)**
  - ➥ **Transverse momentum distribution (TMD)**

TMD: quarks in polarized nucleon

Nucleon (N) with momentum P and spin polarization S=(U,L,T)

New information in quark TMD of nucleon: $\Phi^q(x, P, S)$

$\Phi^q(x, P, S)$ contains time-even functions:

$f^q(x, kT)$ ← unpolarized quarks in unpolarized N ← density

$g^q_L(x, kT)$ ← L-polarized (chiral) quarks in L-polarized N ← helicity

$g^q_T(x, kT)$ ← L-polarized (chiral) quarks in T-polarized N ← worm-gear

$h^q_T(x, kT)$ ← T-polarized quarks in T-polarized N ← pretzelocity

and time-odd functions (spin-orbital correlations):

$f^{\perp q}_L(x, kT)$ ← unpolarized quarks in T-polarized N ← Sivers f.

$h^{\perp q}_T(x, kT)$ ← T-polarized quarks in unpolarized N ← Boer-Mulders f.

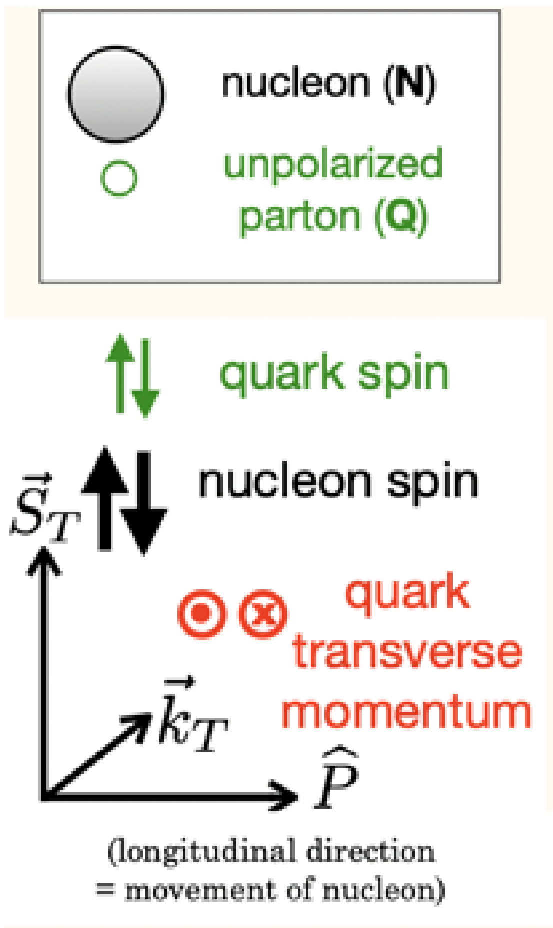
Integrated over kT quark TMDs:

$f^q(x) = q(x) = q_{L=+}(x) + q_{L=-}(x)$

$g^q_L(x) = \Delta q(x) = q_{L=+}(x) - q_{L=-}(x)$ ← helicity (chirality)

$h^q_T(x) = \delta q(x) = q_{T=+}(x) - q_{T=-}(x)$ ← transversity

TMDs: quarks in nucleon



N \ Q	U	L	T
U	f_1 number density		$h_1^\perp$ Boer-Mulders
L		g_1 helicity	$h_{1L}^\perp$ worm-gear
T	$f_{1T}^\perp$ Sivers	$g_{1T}^\perp$ worm-gear	h_1 transversity; $h_{1T}^\perp$ pretzelosity

Gluon TMD with SPD

Unpolarized gluons at high x in proton and deuteron

Gluon helicity

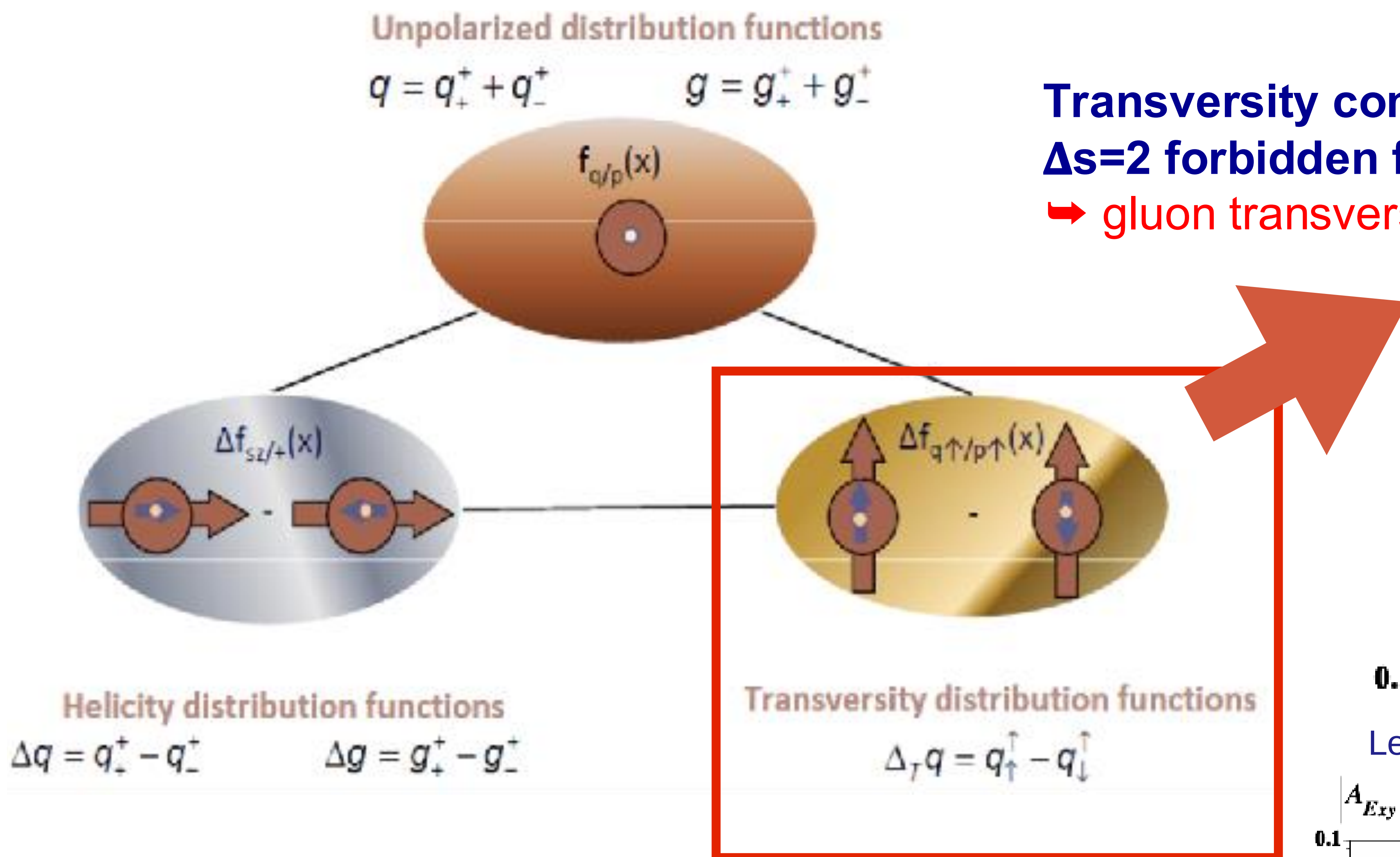
Gluon Boer-Mulders function

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	$\boxed{h_{1T}^g}, h_{1T}^{\perp g}$

Gluon Sivers function

Gluon transversity in deuteron

Gluon transversity of deuteron

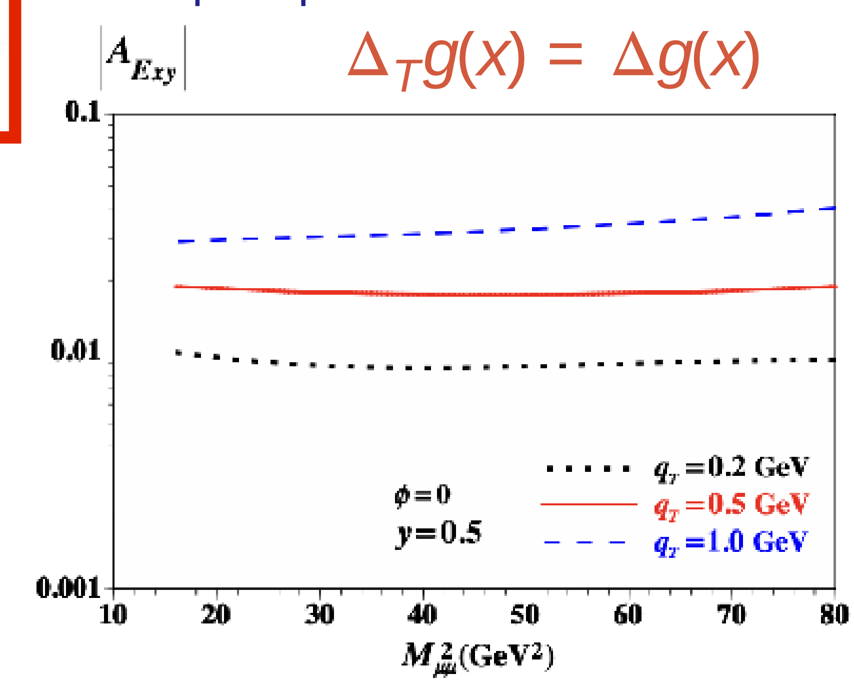


Transversity comes from spin-flip:
Δs=2 forbidden for spin-½ nucleon in LO
➥ gluon transversity in nucleon ≈ 0

0.

Lepton pairs S. Kumano

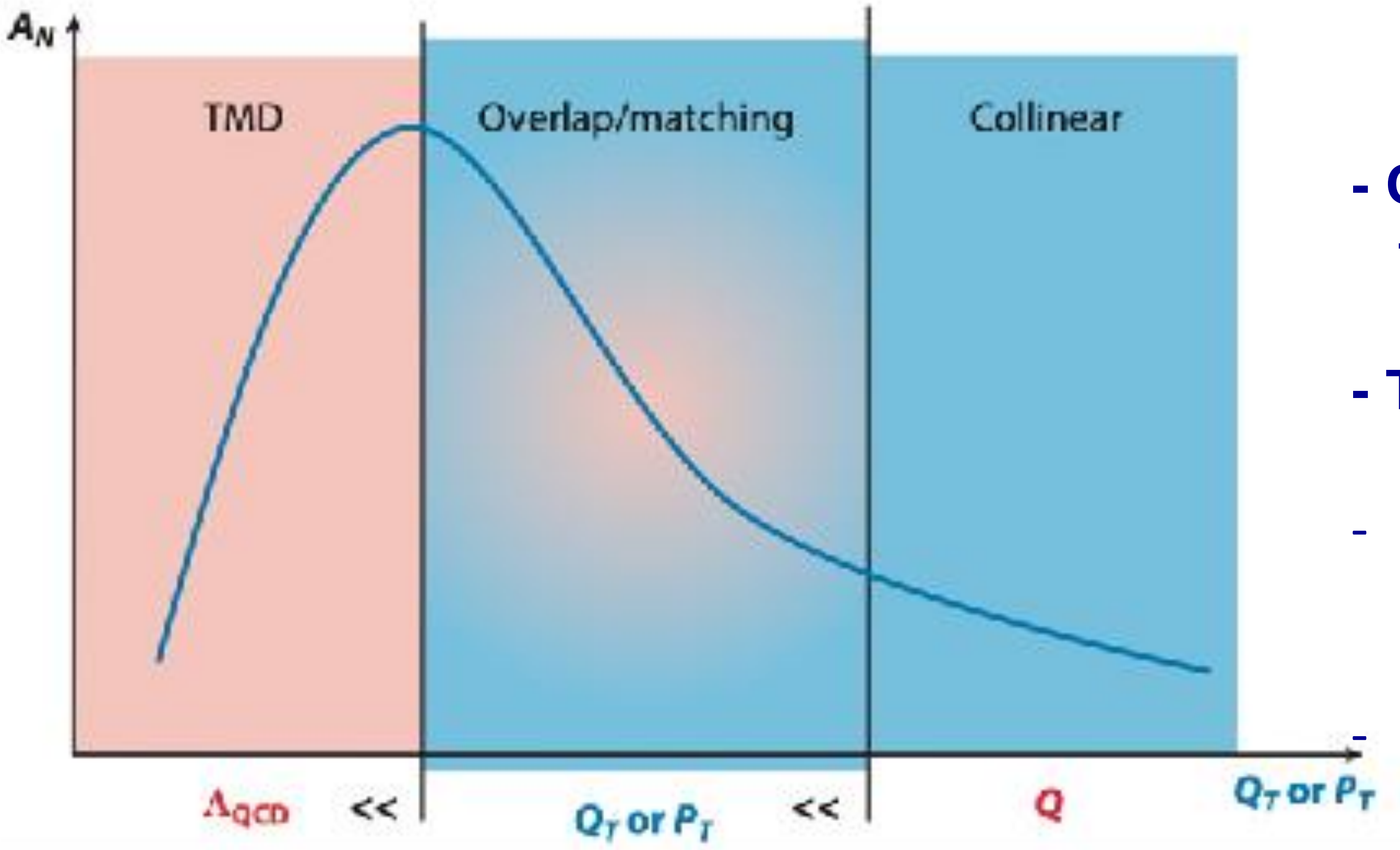
$\Delta_T g(x) = \Delta g(x)$



SPD has a unique opportunity to measure
gluon transversity in deuteron for the first time!

To probe new non-nucleonic degrees of freedom in deuteron!

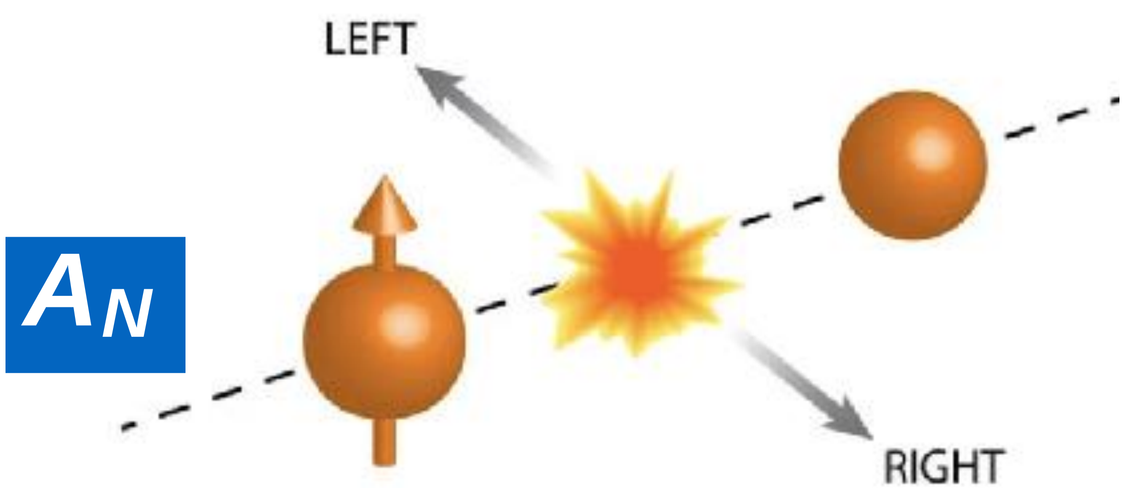
Gluon TMD effects: gluon Sivers function



- Collinear factorization:
  twist-2 and twist-3
- TMD-factorization
- Overlap/matching region
- Nontrivial x and kT correlation?

Sivers effect: L-R asymmetry of unpolarized kT-distribution in T-polarized nucleon

Collins effect: due to fragmentation of polarized parton



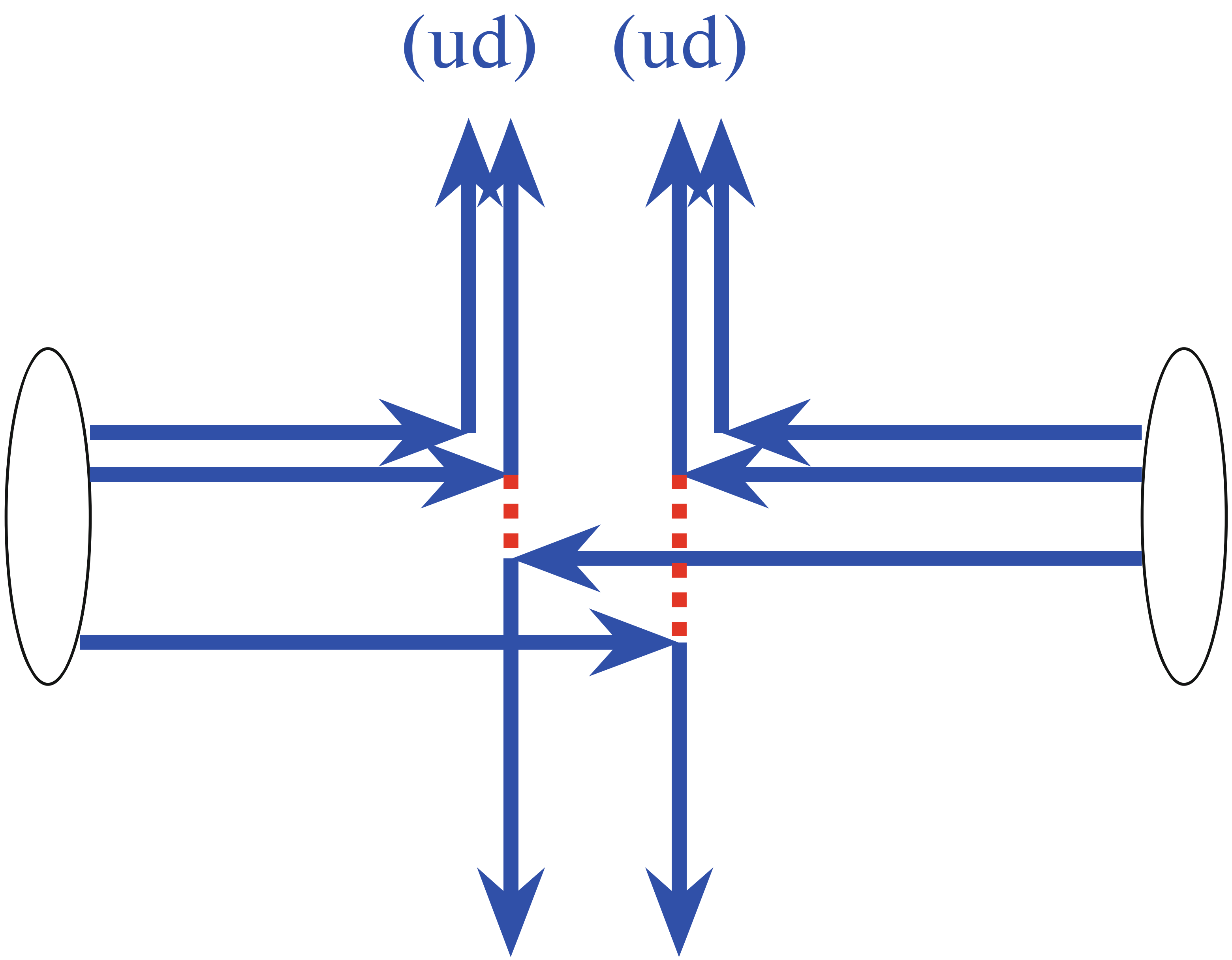
SPD Physics at the initial Stage I

V.V. Abramov et al., Phys. Part. Nucl. 52(2021) 1044, e-Print: 2102.08477 [hep-ph]

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

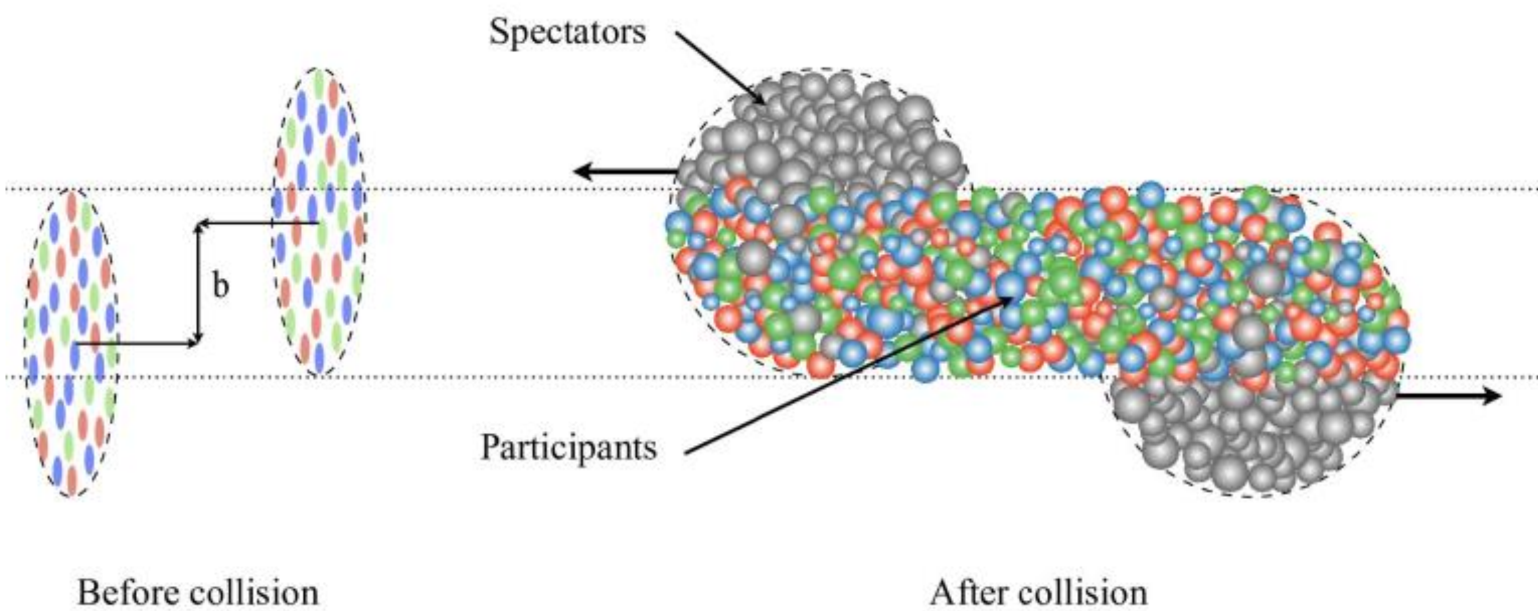
- **Spin effects in pp-, pd- and dd- (quasi)elastic scattering**
- **Spin effects in hyperon production**
- **Search for exotic states (glueball, penta- and tetra- quarks)**
- **Multiquark correlations (SRC) in deuteron and light nuclei**
- **Dibaryon resonances**
- **Hypernucleus production**
- **Open charm and charmonia production near threshold**
- **Large-pT hadron production to study diquark structure of proton**
- **Large-pT hadron production to study multiparton scattering**
- **Antiproton production measurement for astrophysics and BSM search**
- **…**

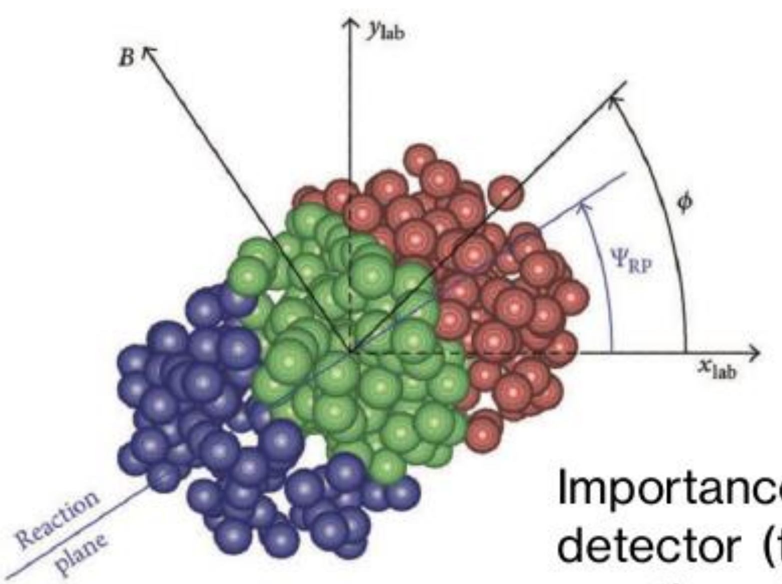
SPD Physics at the initial Stage: exotic states pentaquark, dihyperon, etc. production



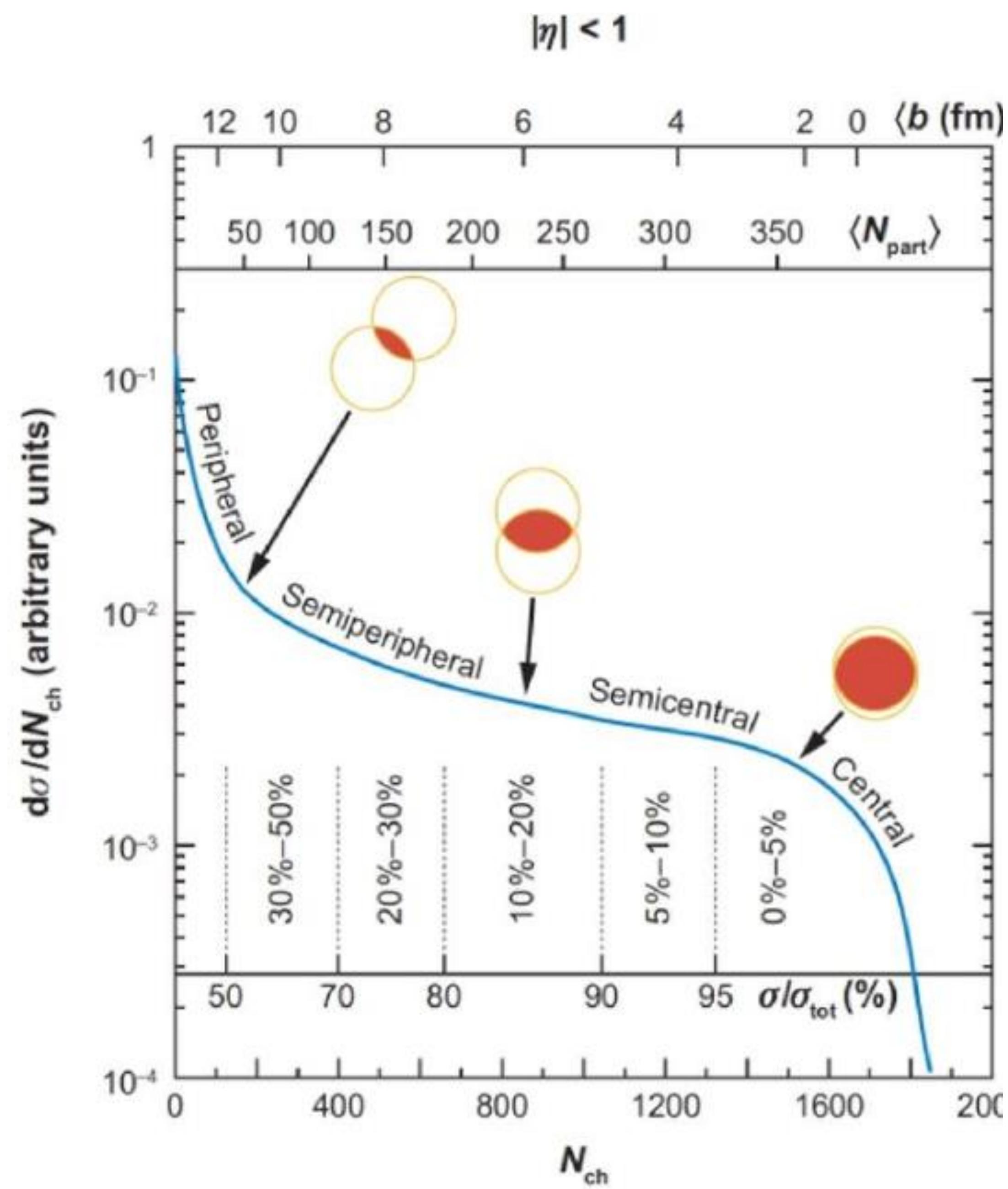
A. Efremov, V. Kim 1987
V. Abramov et al 2021

SPD Physics at the Stage-1: ion-ion collisions

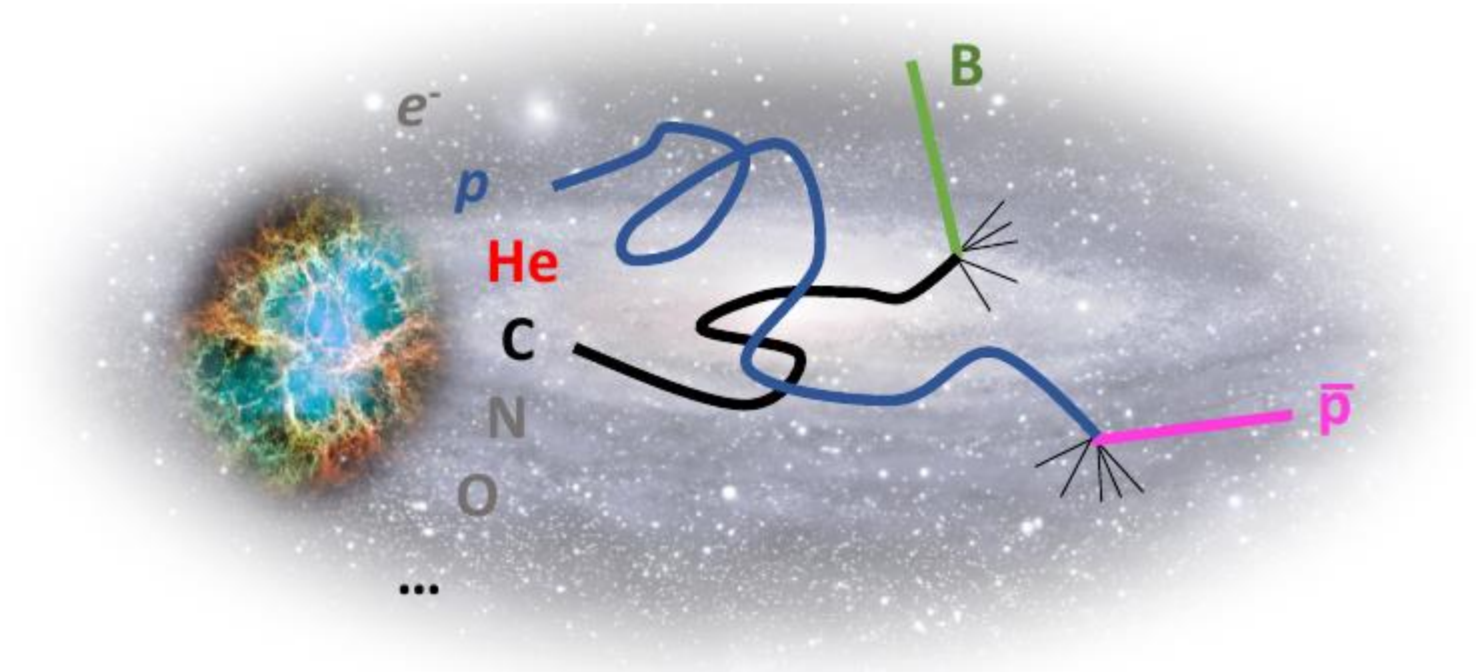




Importance of granular BBC detector (to reconstruct reaction plane angle)



SPD Physics at the Stage-1: antiproton production



ASTROPHYSICS

AMS-02 in International Space Station

AMS-02 search for Dark Matter:
antiproton flux   precision ~5%

Contemporary high energy physics experiments
antiproton production ~25%

Precision antiproton production measurements needed:
energy range 5 GeV < ECM < 100 GeV with precision ~5%

SPD: from R&D to Production Stage

SPD TDR   https://spd.jinr.ru/physics-detector/

version 1.0 (April 2024):   https://arxiv.org/abs/2404.08317
Current version: to be published in new journal Natural Science Review

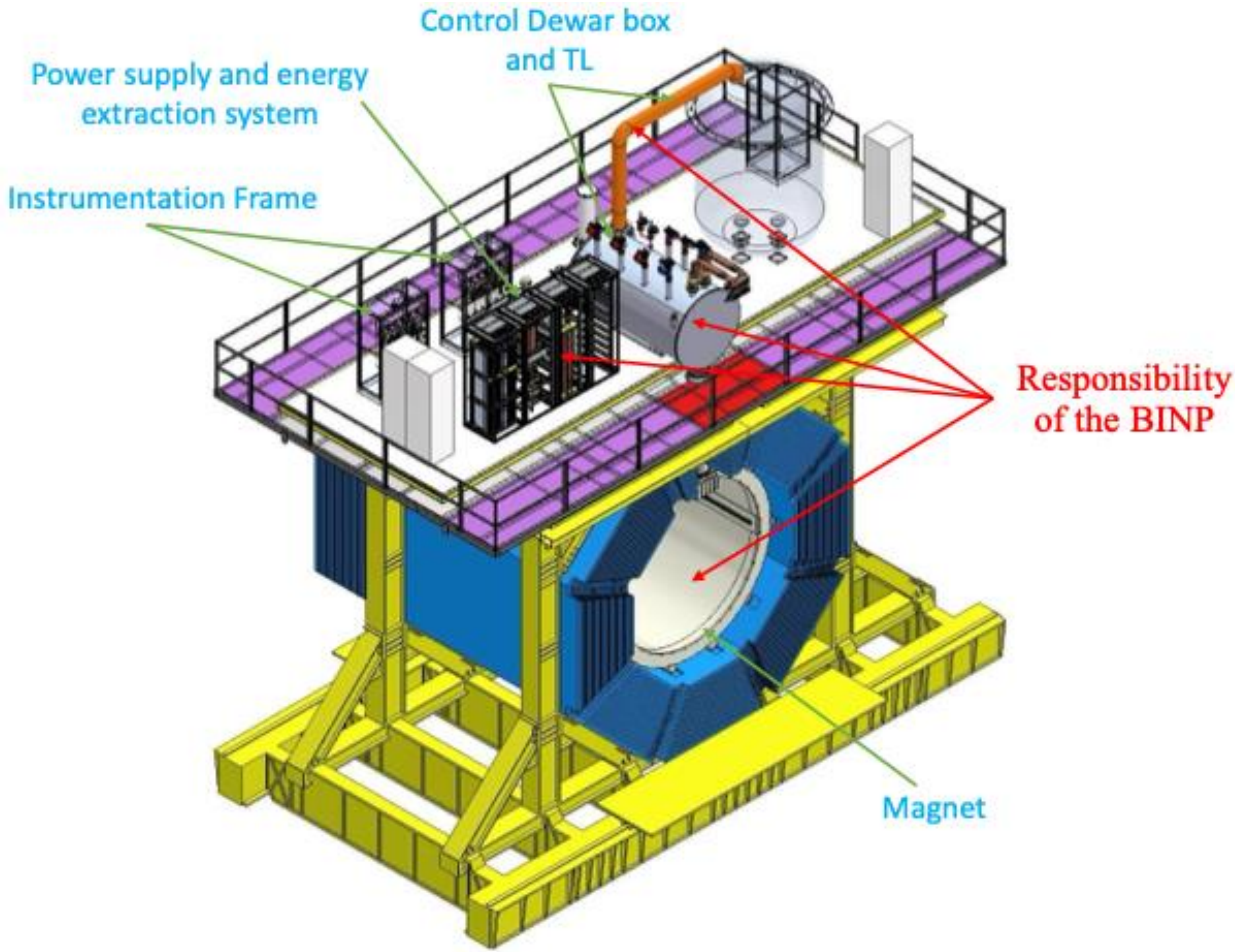
JINR PAC Approval after SPD DAC review: June 2024

SPD: Moving from R&D to Production Preparation

Few examples …

SPD Superconductive Solenoid Magnet: 1 Testla

Budker INP SB RAS, Novosibirsk

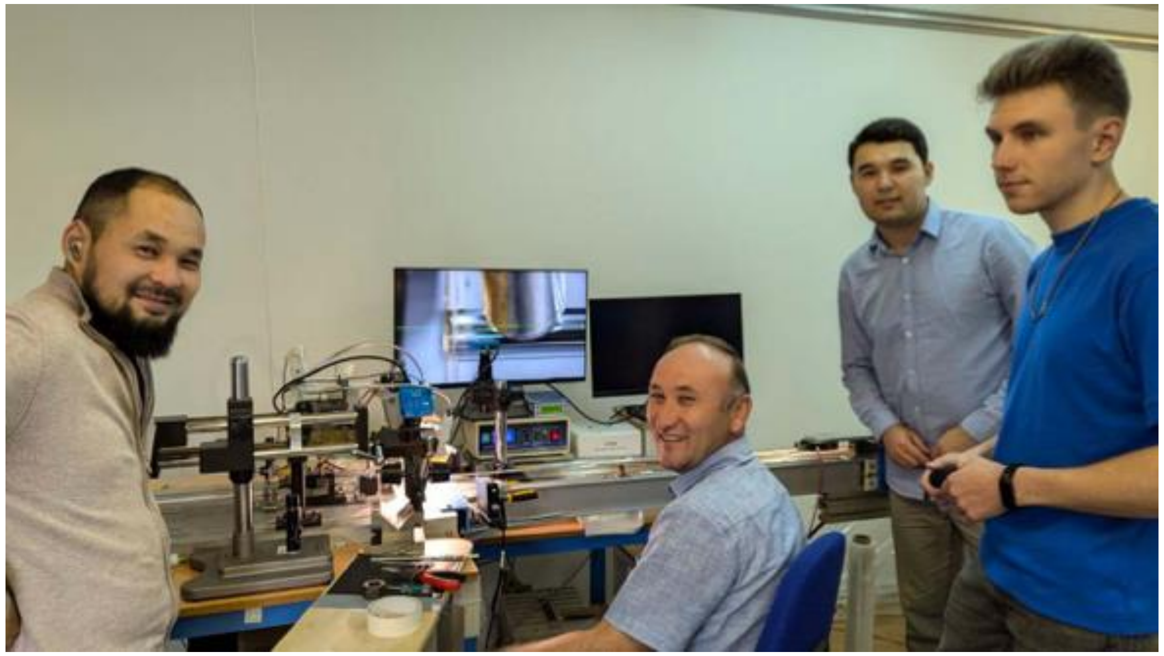


SPD Central Straw-Tracker: New Production Site @JINR

Straw productions sites: JINR (Dubna), NRC KI – PNPI (Gatchina) & INP KZ (Almaty) based on JINR ultrasonic welding technology

JINR, Dubna

► **Production Hall 200 sq. m, Clean Room 100 sq.m**



SPD Straw-Tracker: New Production Site @INP ME KZ (Almaty)

Straw productions sites: JINR (Dubna), NRC KI – PNPI (Gatchina) & INP KZ (Almaty) based on JINR ultrasonic welding technology

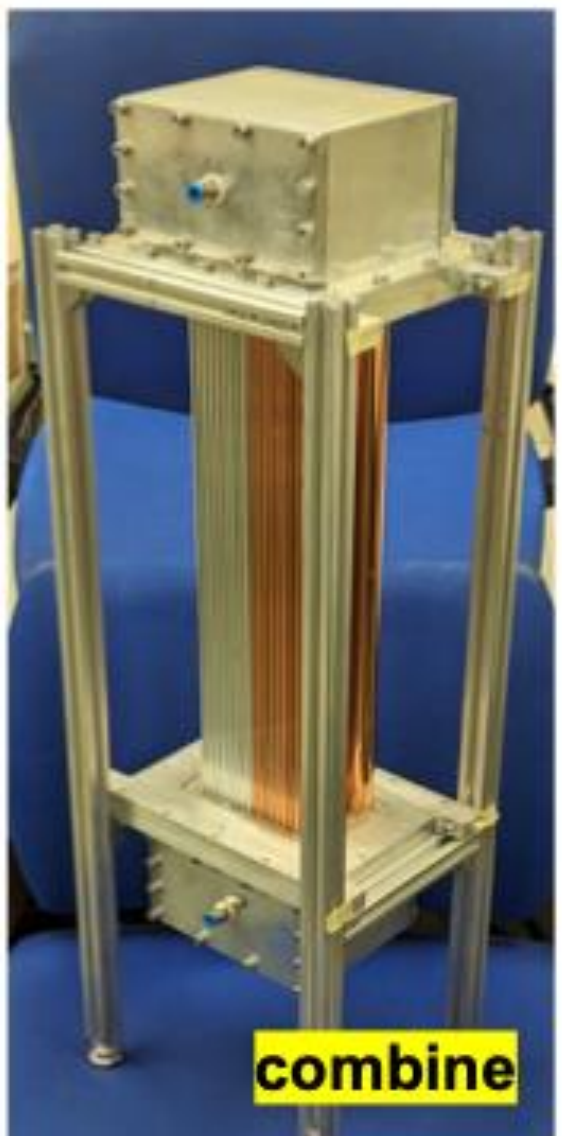
INP ME KZ (Almaty)

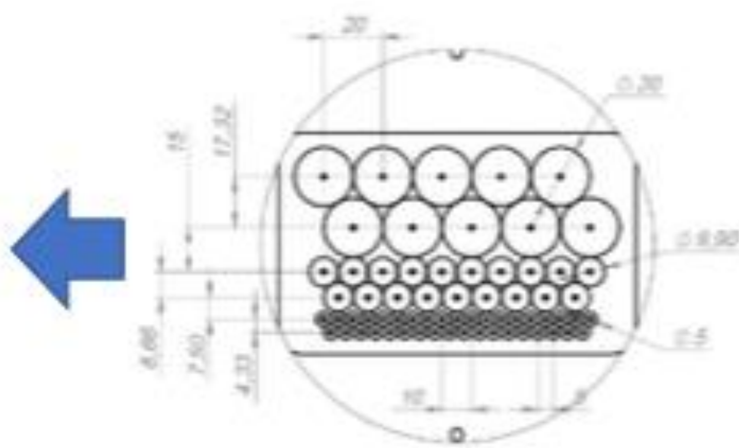
- **Two large halls for straw production**

SPD Central Straw-Tracker: Prototyping

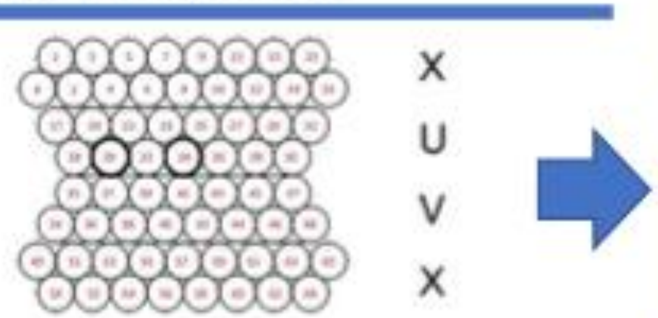
JINR (Dubna), NRC KI – PNPI (Gatchina) & INP KZ (Almaty)

- Small prototype production (lab and test beam straw and readout performance studies)
- development and prototyping of the construction elements (gas supply, sealing)
- development and optimization of the electrical

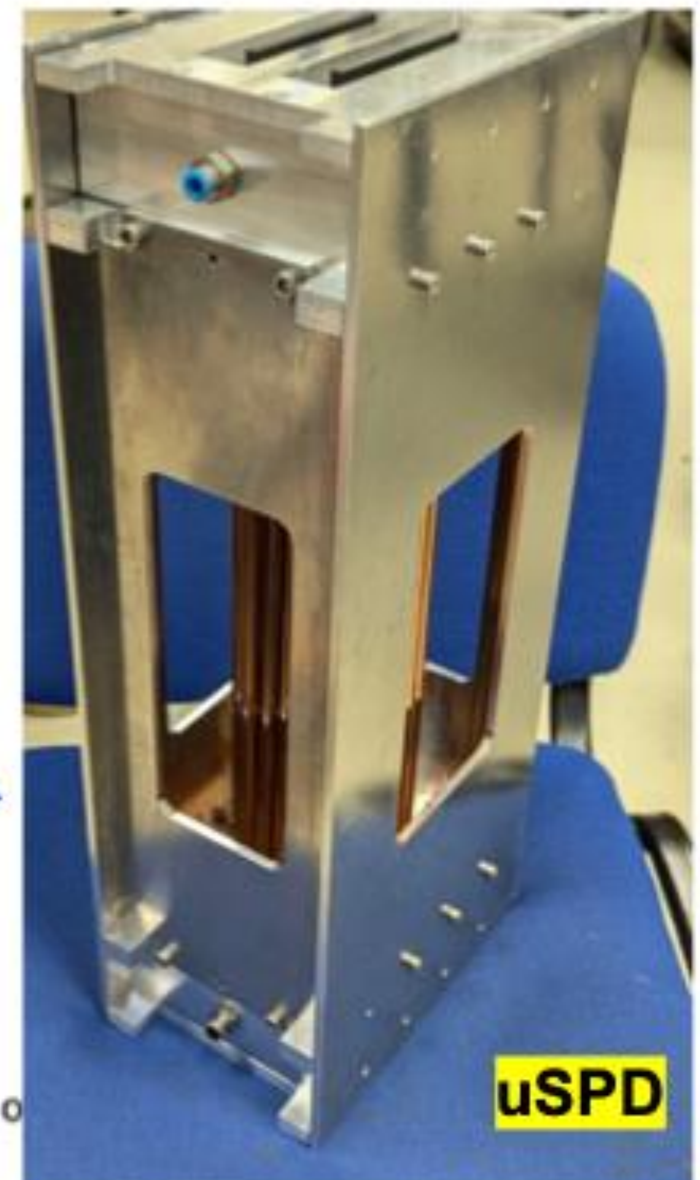


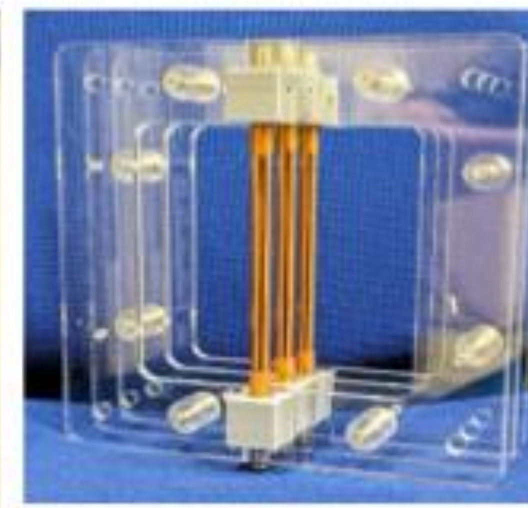


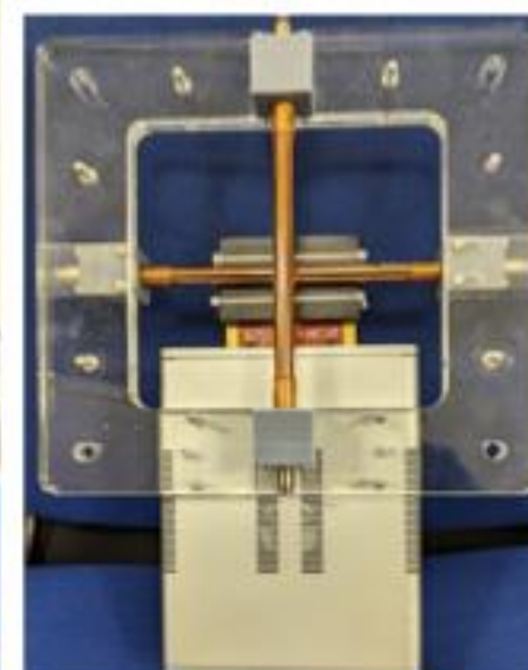
Prototype 1: 5 mm, 10 mm, and 20 mm tubes area



Prototype 2: 10 mm tube area only. Two planes of X, two planes of U (2°), two planes o V (−2°) and two planes of X.



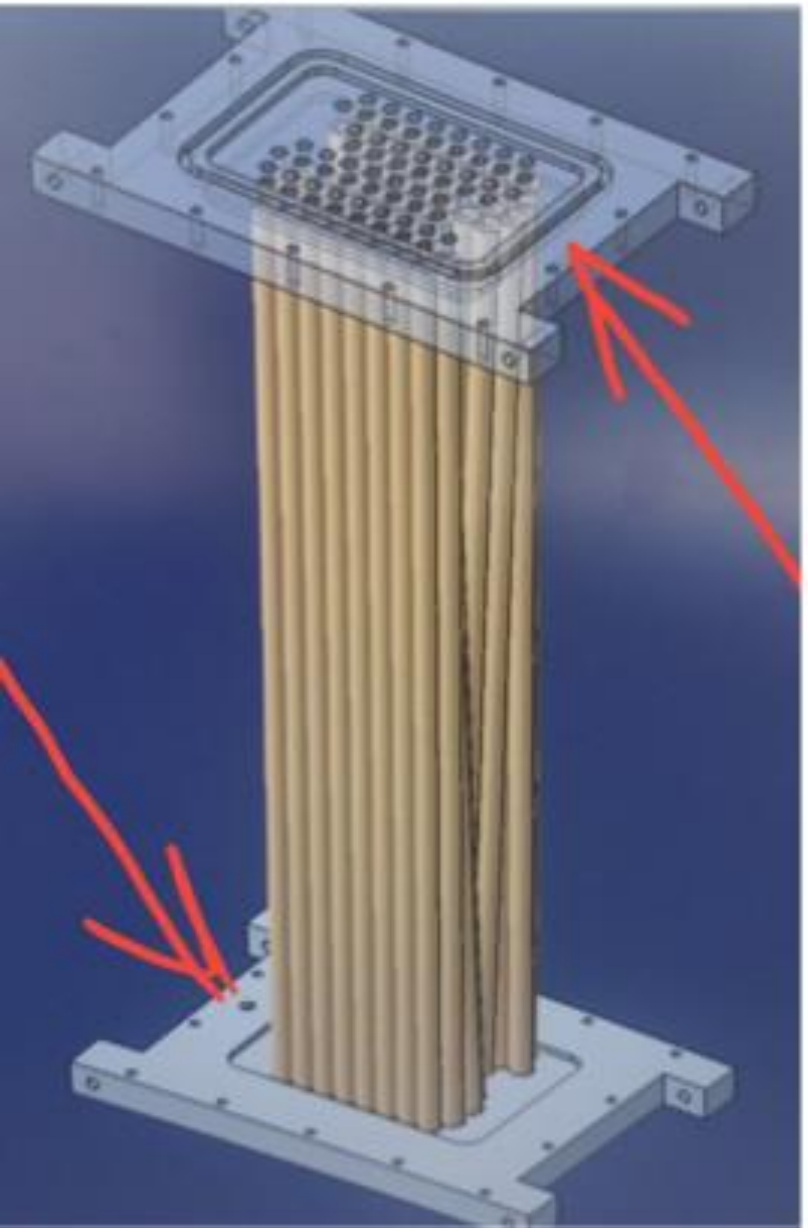


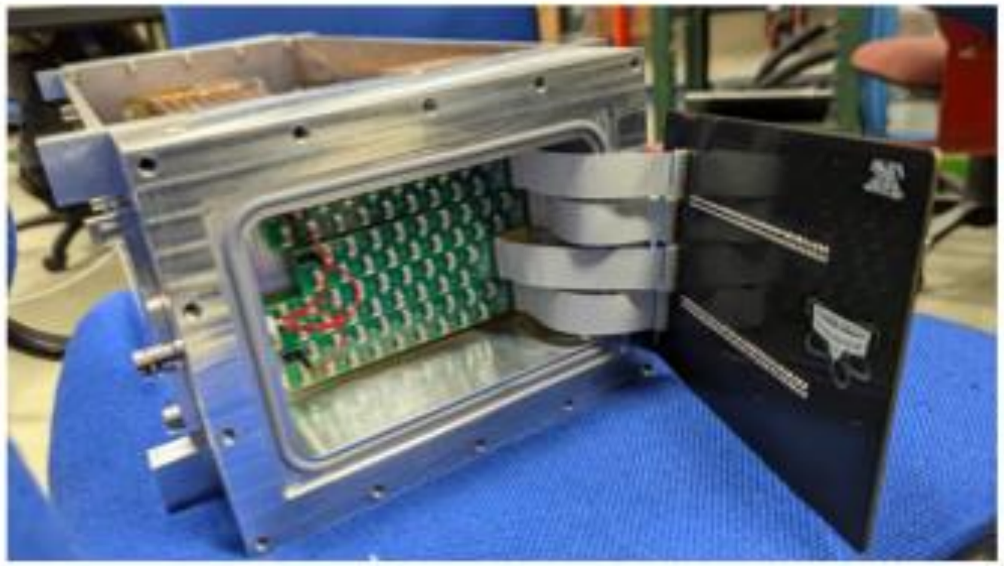


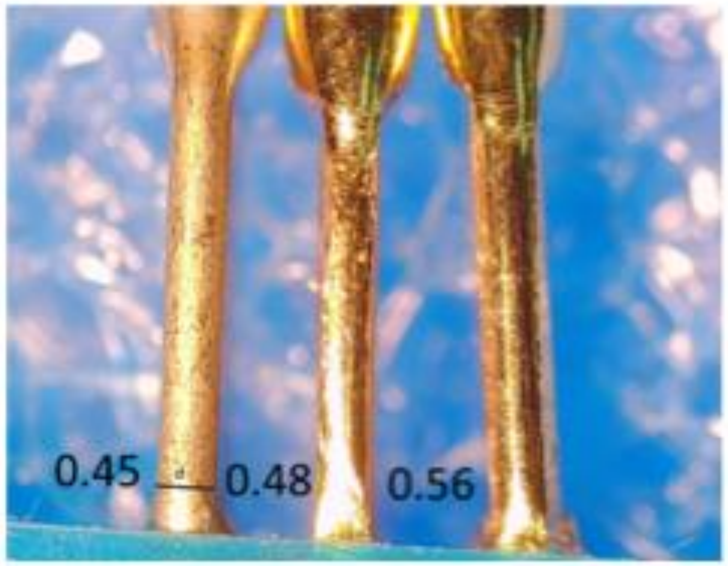
SPD Central Straw-Tracker: Prototyping

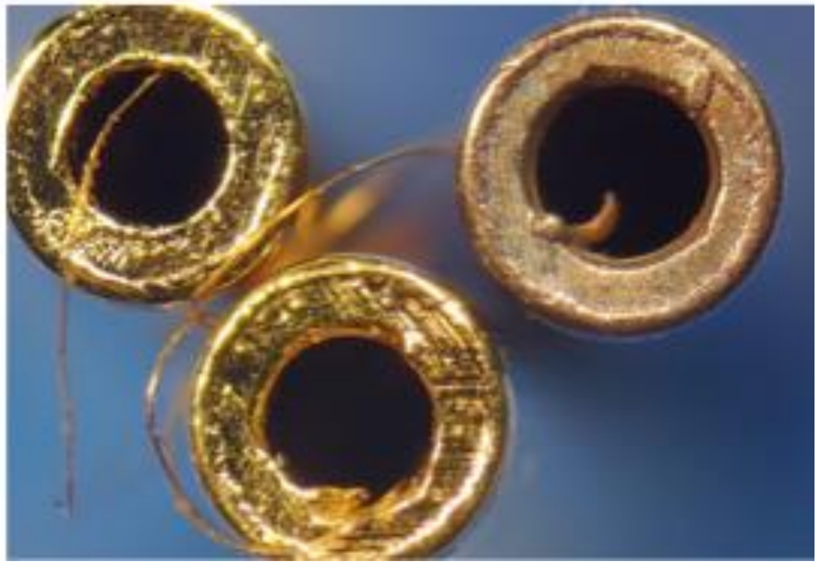
JINR (Dubna), NRC KI – PNPI (Gatchina) & INP KZ (Almaty)

Connectors, HV distribution board, new pin, assembling, grounding





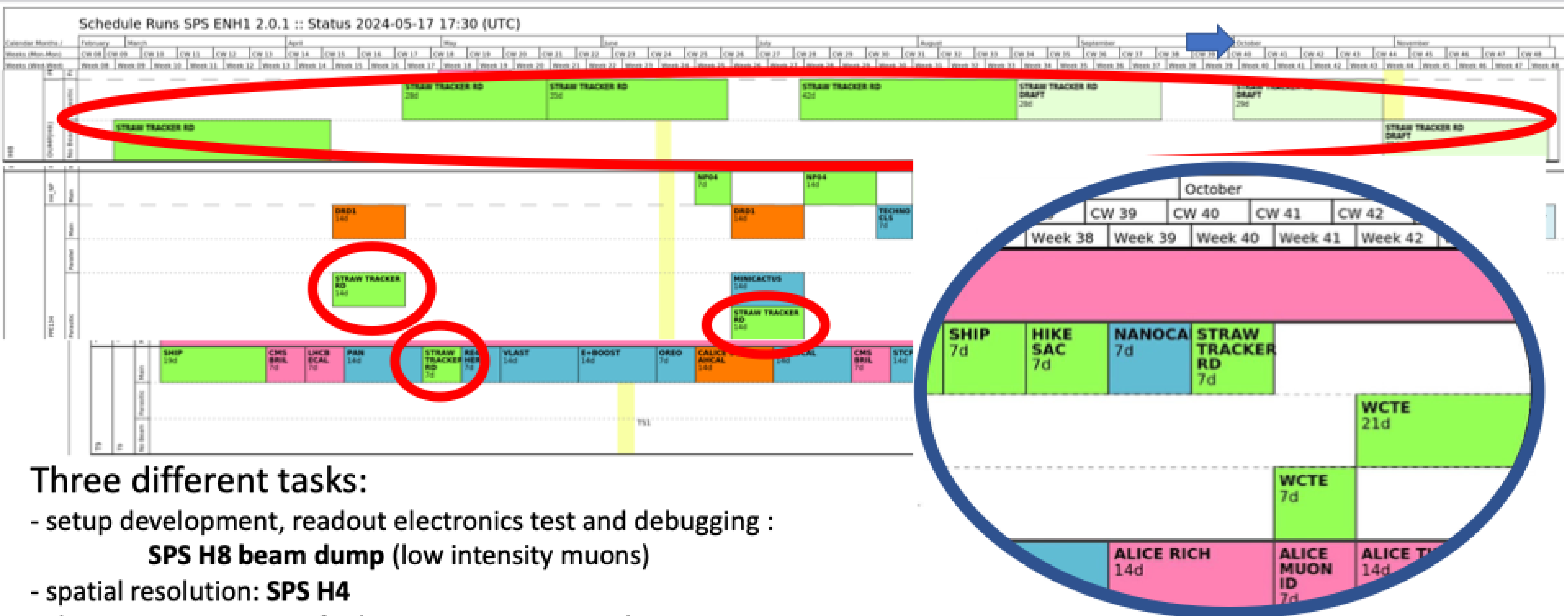




SPD Straw-Tracker: Prototype Testing at CERN SPS and PS

T. Enik (JINR) & E. Kuznetsova (PNPI)

JINR (Dubna), NRC KI – PNPI (Gatchina) & INP KZ (Almaty)



Three different tasks:

- setup development, readout electronics test and debugging :
  SPS H8 beam dump (low intensity muons)
- spatial resolution: **SPS H4**
- charge measurements for low momentum particles: **PS T09**

T9 PS		08/05-15/05				02/10-09/10
H4 SPS	10/04-24/04		26/06-10/07		18/09-02/10	
H8 SPS dump	10/04-26/10					

SPD Central Straw-Tracker: Prototype Testing @SPS&PS

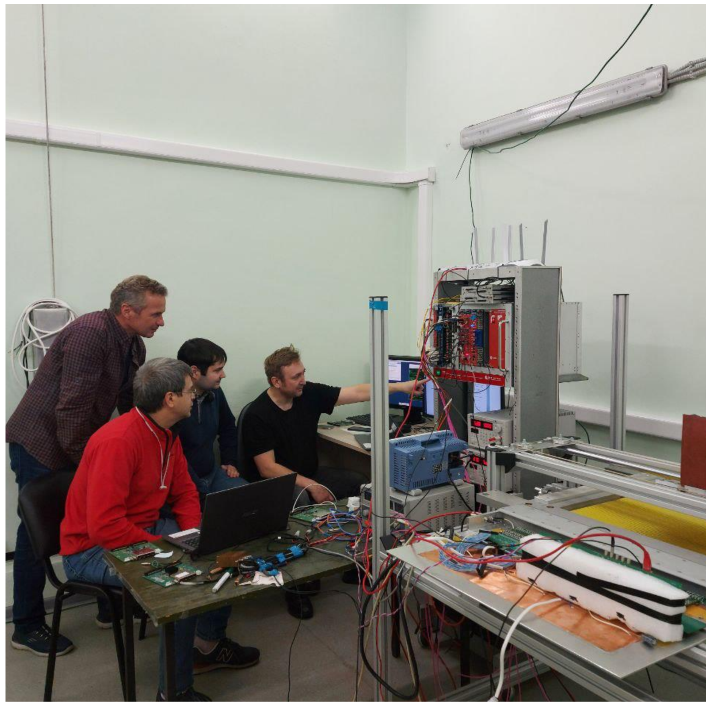
JINR (Dubna), NRC KI - PNPI (Gatchina) & INP RK (Almaty)

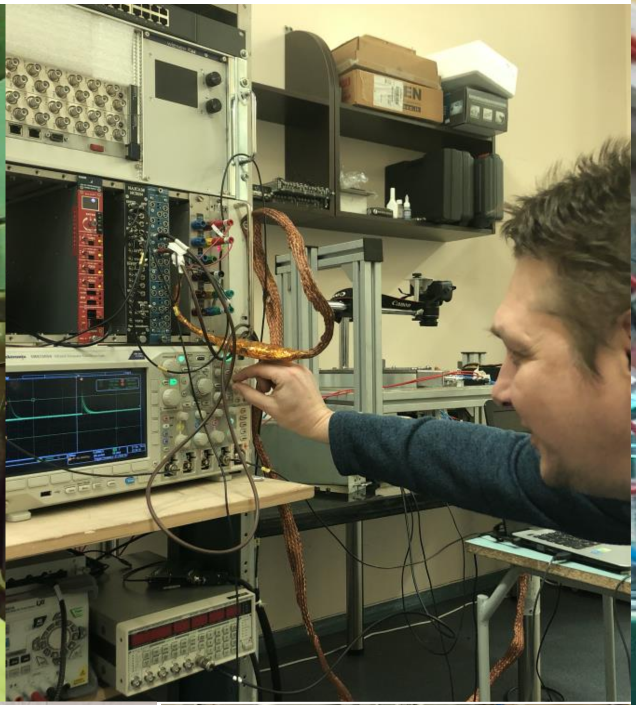
R&D: thin straw tubes with ASIC readout solution

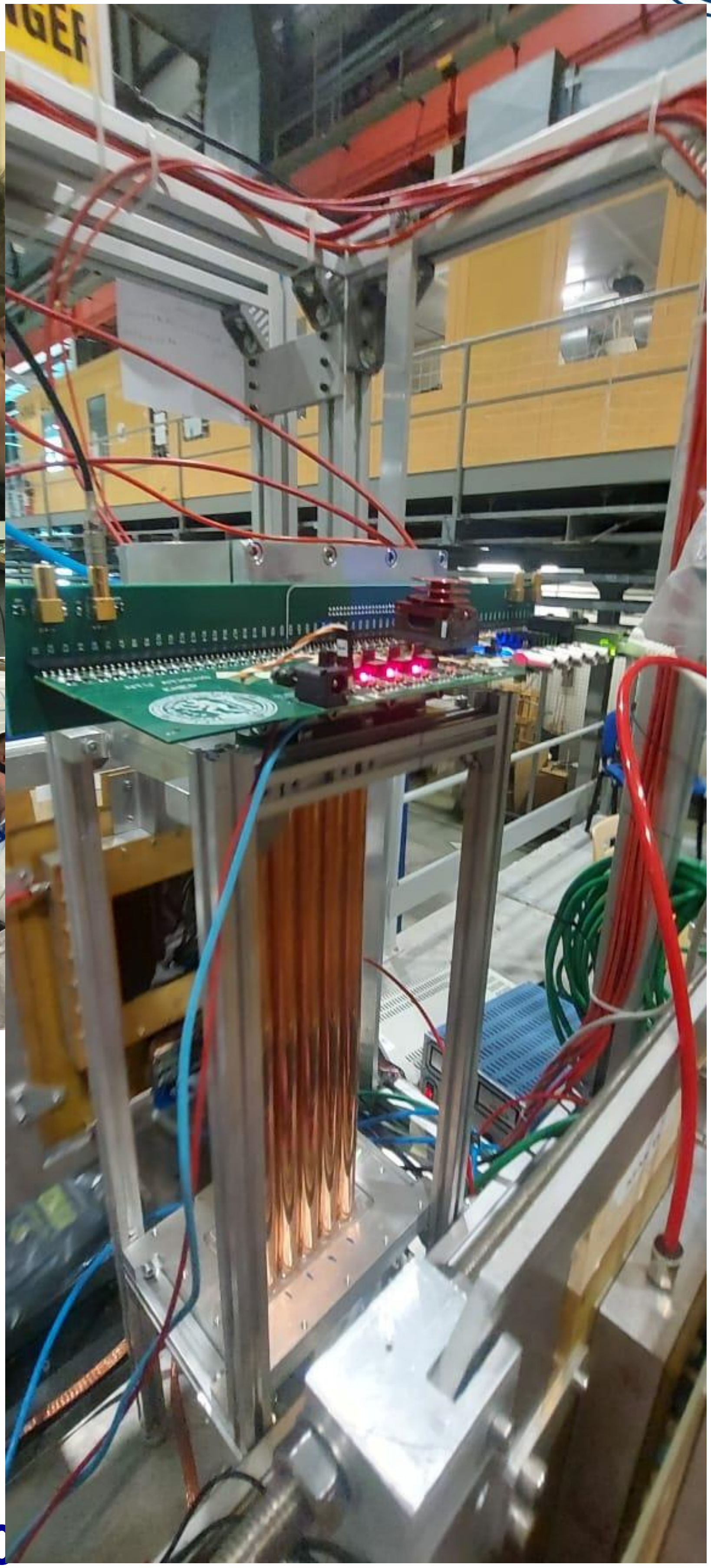
► **Straw R&D Test Stand for SPD/SHiP/Dune/DRD1 at SPS and PS (CERN) for definition of ASIC novel technology requirements**

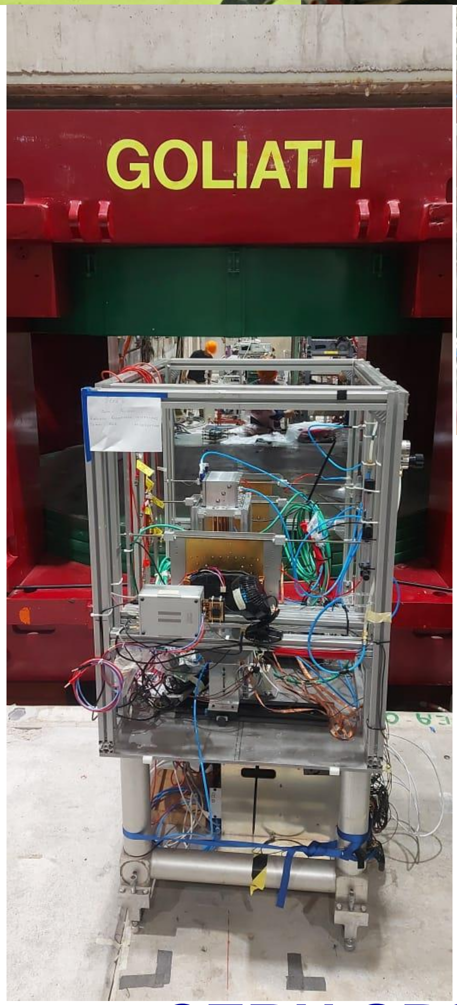
Test Runs with ASIC: VMM3,VMM3a, Tiger
- 2021 (1 Run), 2022 (3 Runs), 2023 (3 Runs), 2024 (3 Runs SPS, 2 Runs PS)
- most of results included to the SPD TDR

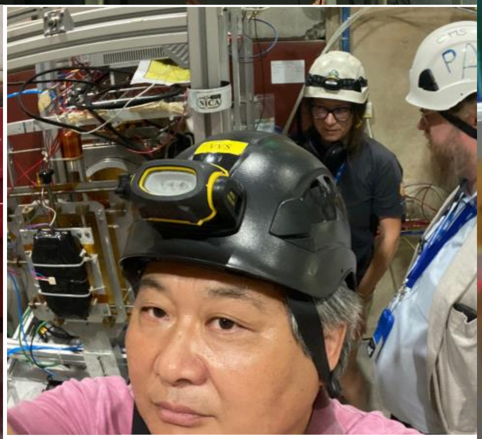
SPD R&Ds







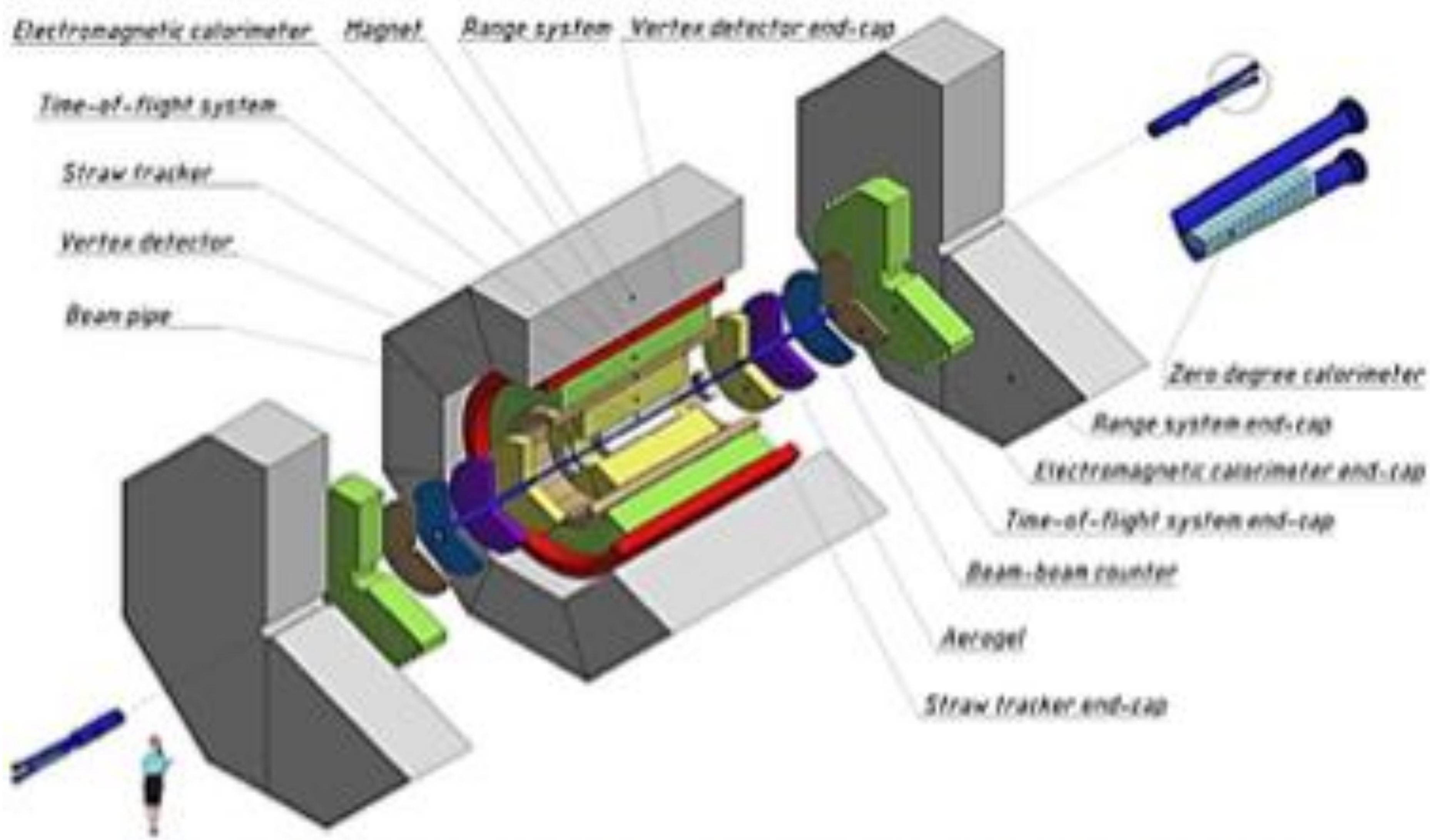




SPD Straw Tracker test beams: CERN SPS, PNPI SC-1000

SPD: Beam-Beam Counter (BBC)

JINR, Dubna & MEPhI, Moscow



The Beam-Beam Counters (BBC) for SPD

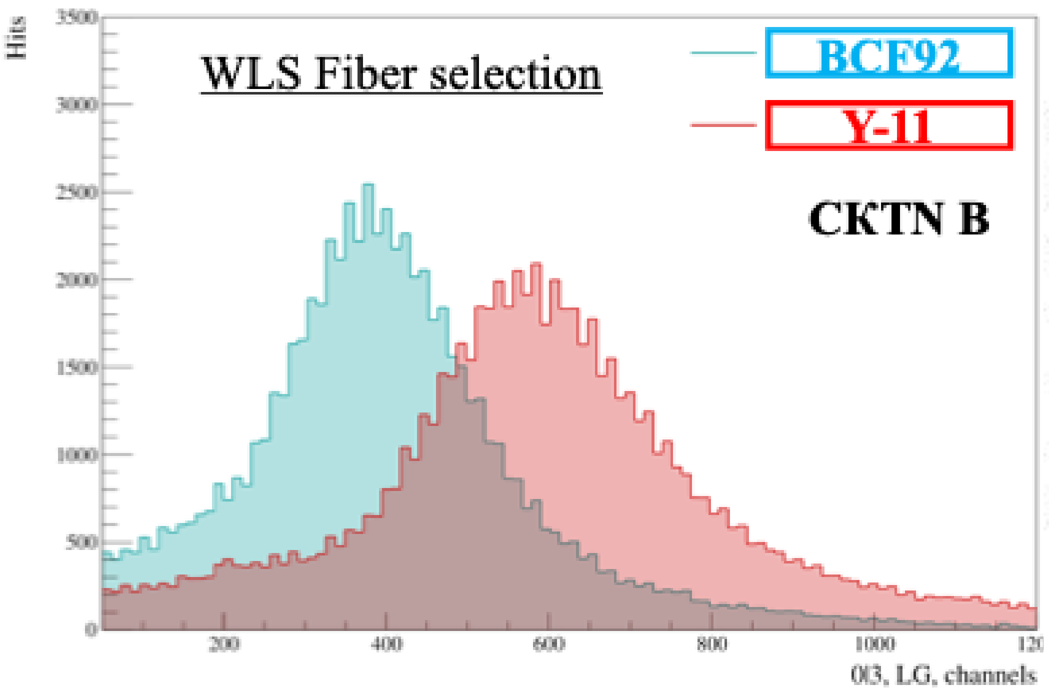
The main purpose of BBC is the permanent monitoring of the beam polarization using the azimuthal asymmetry of the inclusive charged particles yield.

+ event plane detector for HI physics.

- **Scintillator tiles part at the distance ~1.7 m**

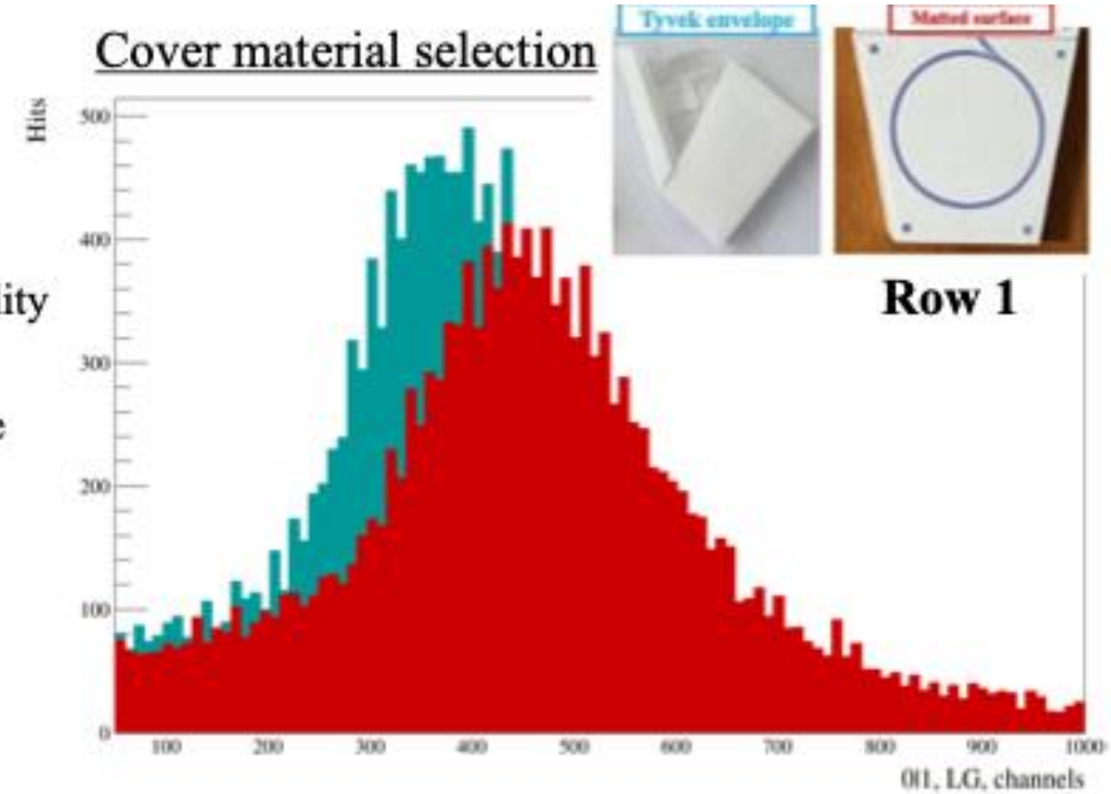
SPD BBC R&D: Material Selection

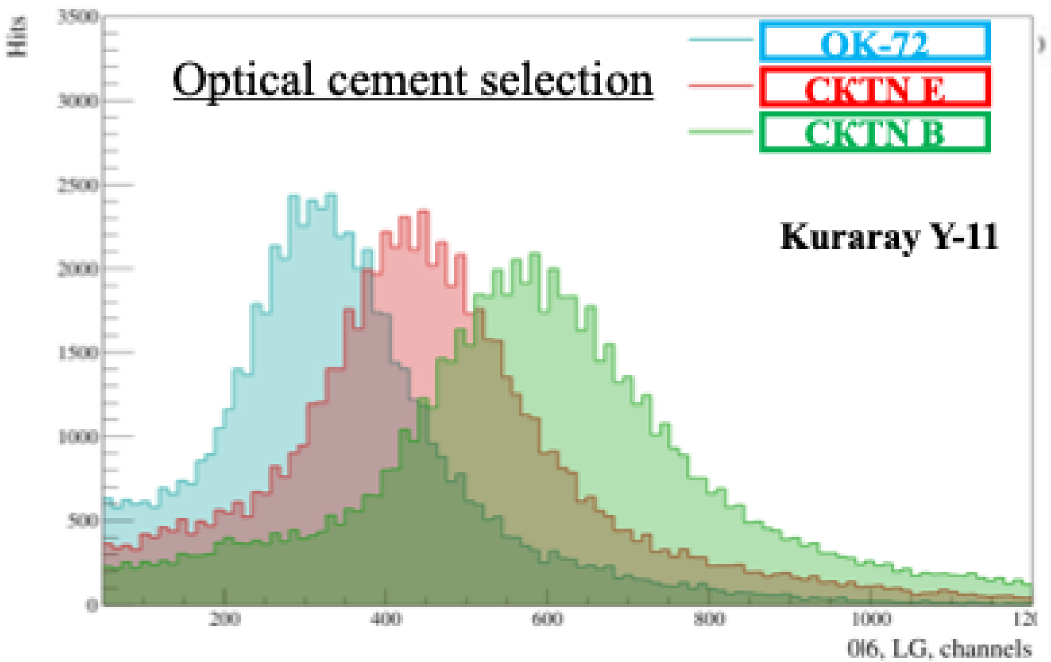
JINR, Dubna & MEPhI, Moscow



Selection criteria:

- Light collection
- Technological applicability
- Pricing
- Availability for purchase
- Radiation hardness
- Ageing etc





Materials selection and tests with different material combinations of tile prototype includes:

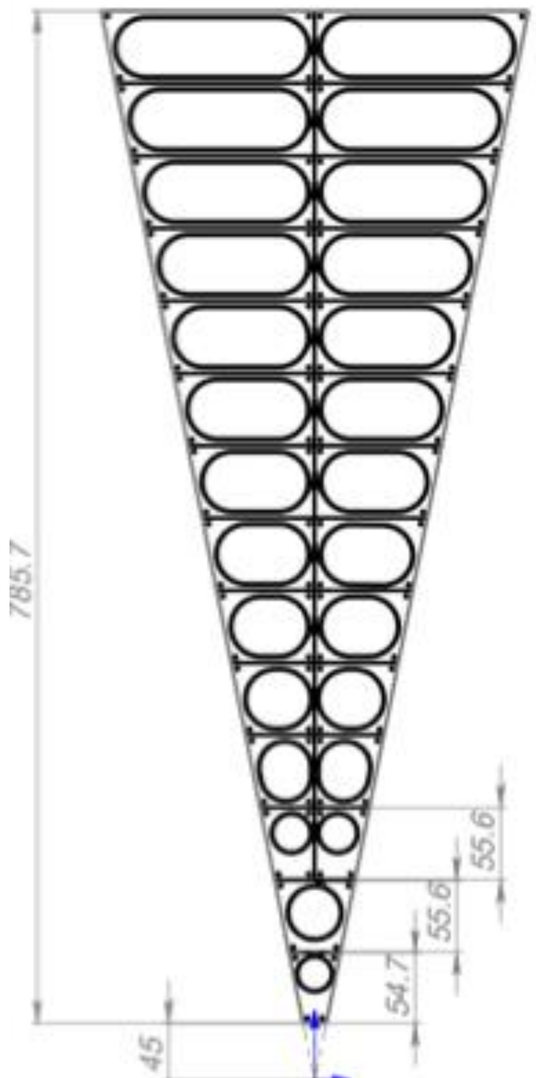
- Scintillator: **Matted** or Tyvek covered
- Optical cement: **CKTN MED** vs OK-72
- Fiber: Saint-Gobain Crystals vs **Kuraray** (Phase 1)
- SiPMs: 3x3 vs **1x1 mm² (currently: Hamamatsu)**

The material selection for BBC is complete, final configuration – matted surface, Y-11 fiber, CKTN B optical cement

SPD BBC: Prototyping

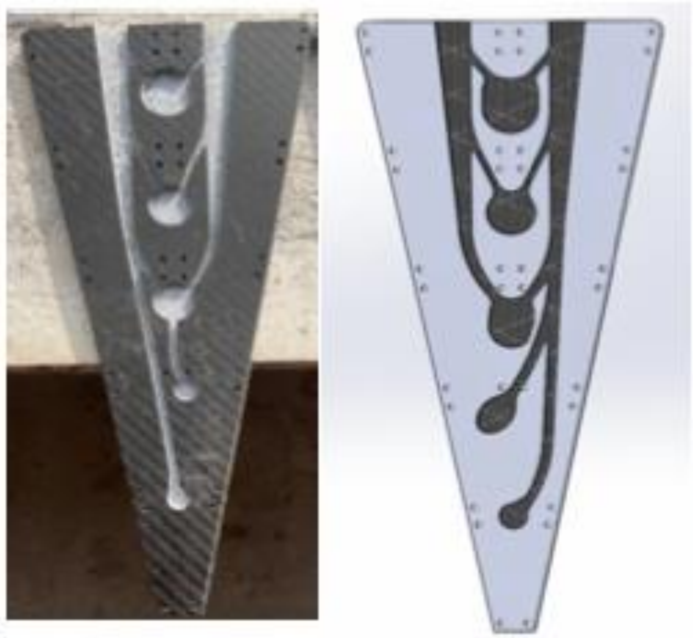
JINR, Dubna & MEPhI, Moscow

BBC Prototyping



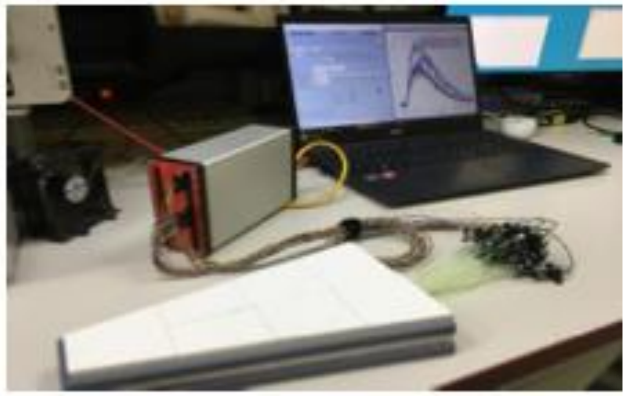
BBC Sector (Ring 1/16) design

WLS-SiPM test connector couple

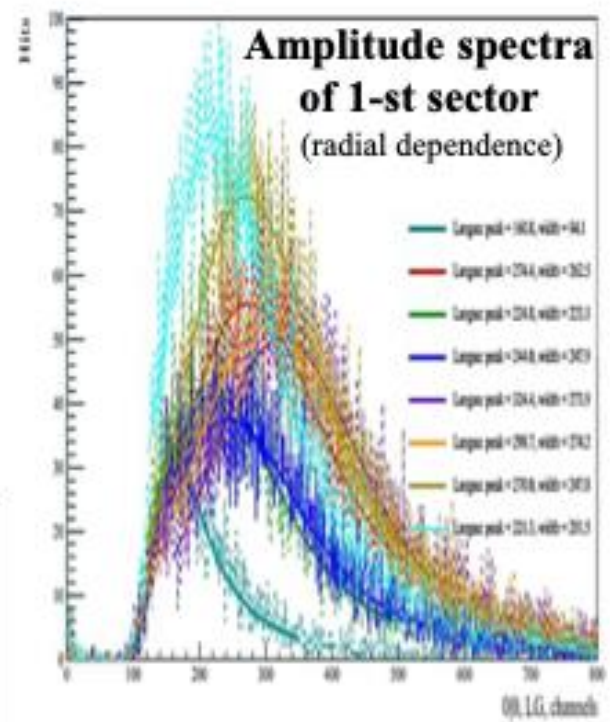


Grooved carbon fiber backplate v1 prototype and updated design

2x reduced sector prototype



Prototypes test with CAEN FERS-5200



✓ Currently we have in hands 2 small sector prototypes of 8 tiles with CKTN B and SG BCF92 fiber assembled on carbon fiber backplate

- We plan to produce a full **wheel with reduced sectors** in the middle of 2025

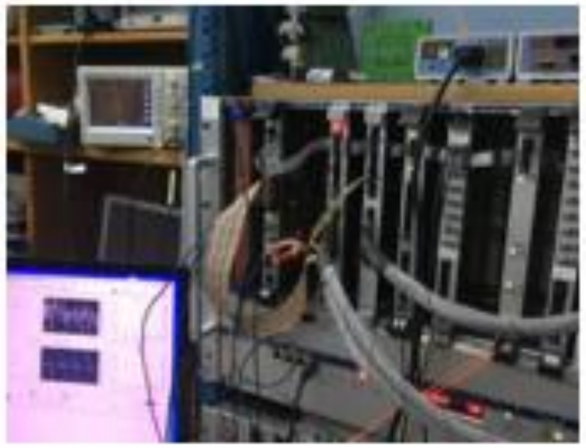
SPD BBC Stand: testing prototypes

JINR, Dubna & MEPhI, Moscow & INR RAS, Moscow

TRB-3 (10 ps)

Together with **V.Chmil (JINR), S.Morozov, E.Usenko (INR)**

The VME based DAQ



Isupov A.Yu. // EPJ Web Conf. 2019. V.10003. P.204

CAEN FERS 5200

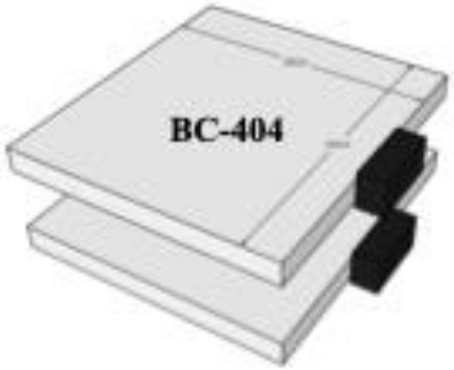
DT5202 (citiroc 1A chip)

DT5203 (picoTDC chip)

DT5215 (Concentrator)

The stand for BBC

External trigger by coincidence of two scintillators with PMTs readout



PMT Hamamatsu H10720-110

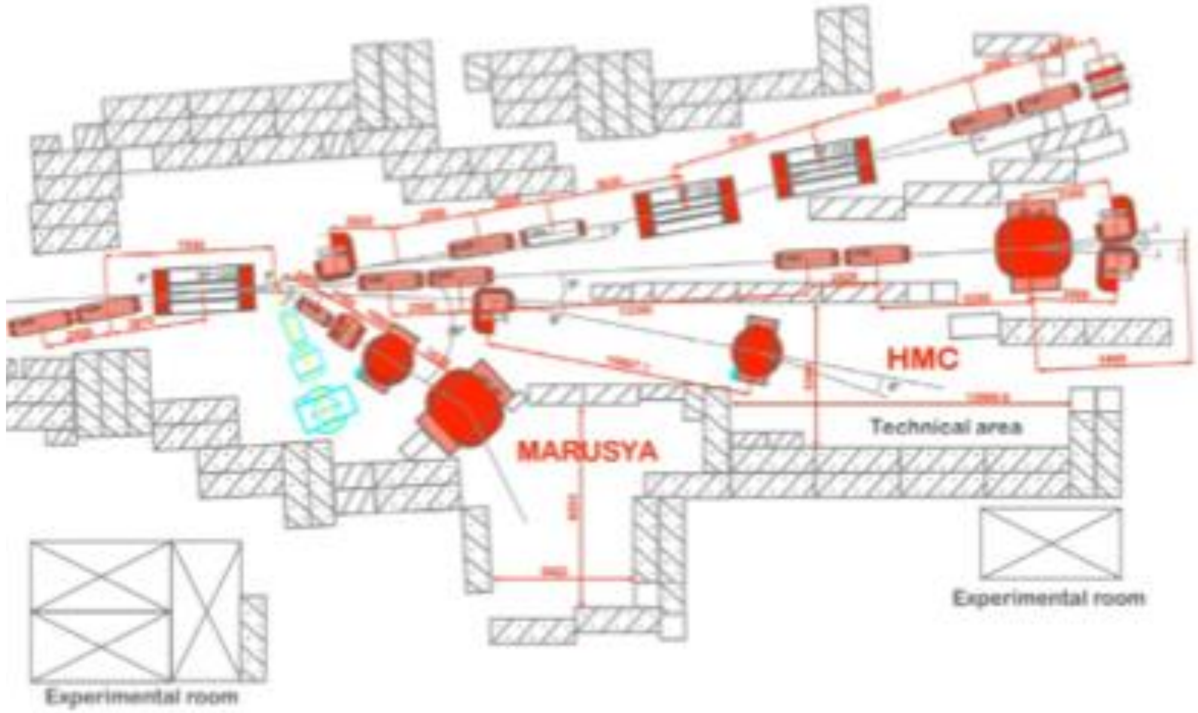
SPD: Test Zone @Nuclotron

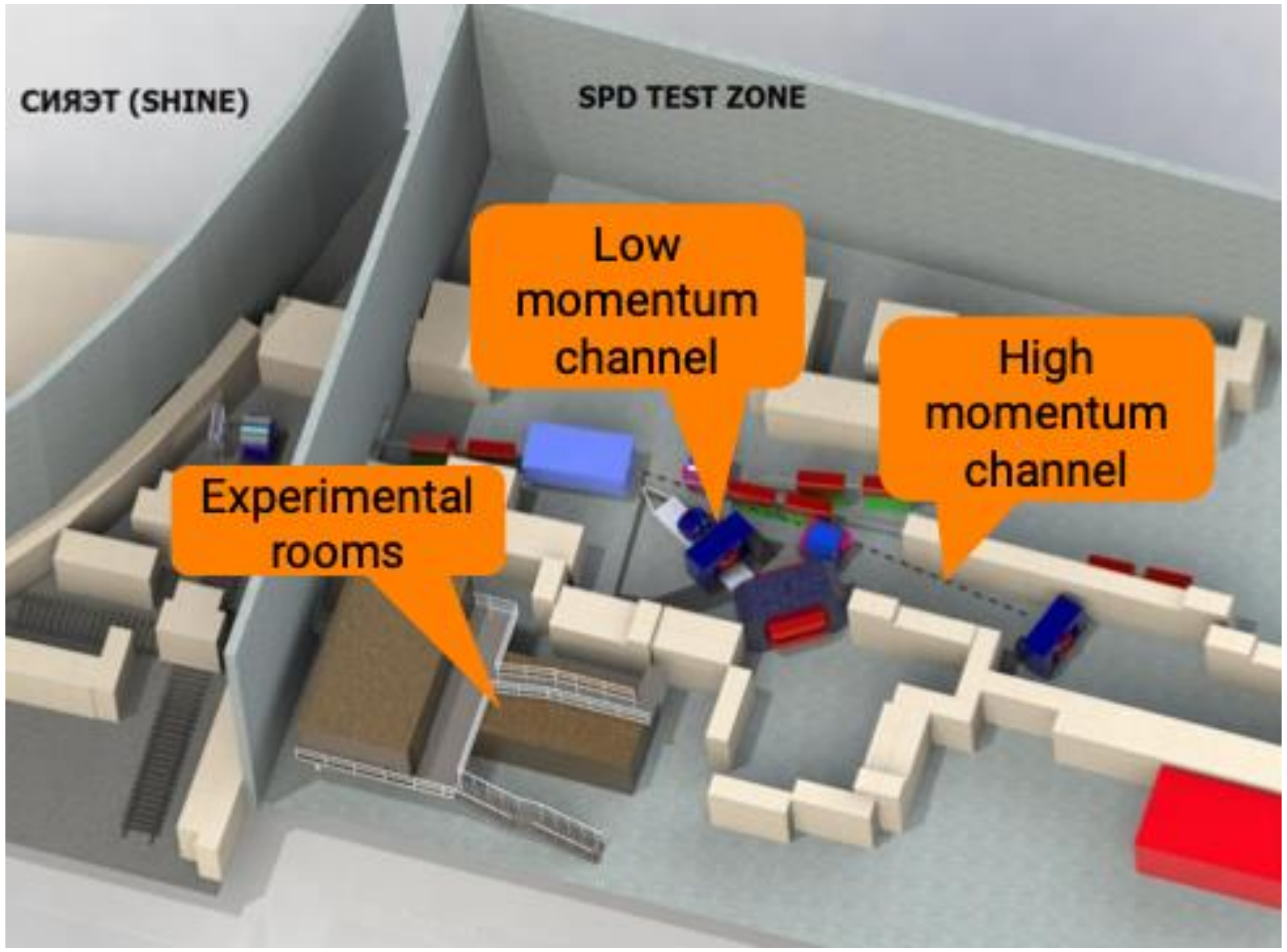
JINR, Dubna

JOINT INSTITUTE FOR NUCLEAR RESEARCH
International Intergovernmental Organization

SPD test zone has two channel:

- The low momentum channel (Marusya setup) should provide particle beams with a momentum range from 100 MeV/c to 2 GeV/c.
- The high momentum channel should provide particle beams with a momentum range from 1 GeV/c to 10 GeV/c.





SPD: Test Zone @Nuclotron

JINR, Dubna

JOINT INSTITUTE FOR NUCLEAR RESEARCH
International Intergovernmental Organization

SPD Test Zone: Muon Range System Prototype

JINR, Dubna

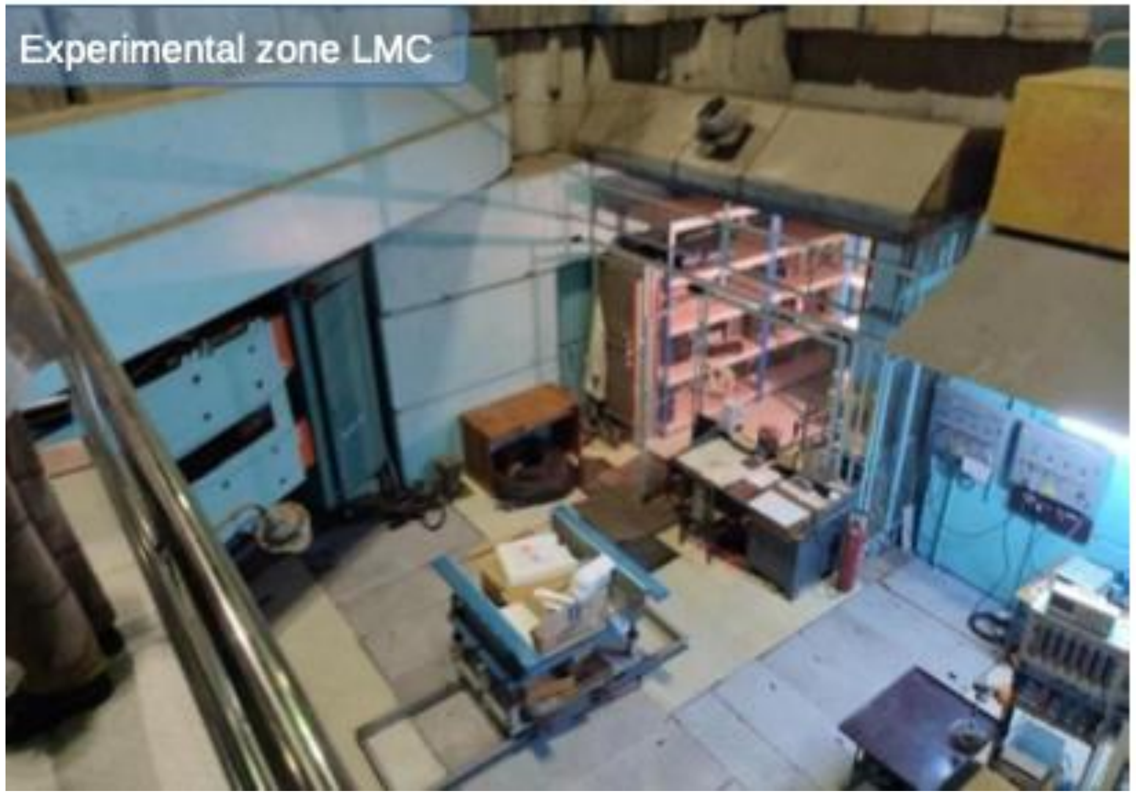
JOINT INSTITUTE FOR NUCLEAR RESEARCH
International Intergovernmental Organization

SPD Test Zone: Low Momentum Channel

JINR, Dubna

Energy of primary beam — up to 2 GeV/n

Commissioning date — 2025 year



Intensities from interaction deuteron 5GeV/n + carbon target

p, MeV/c	d	p,n	$\pi^{\pm}$	K^{+}	K^{-}	$\mu^{\pm}$	$e^{\pm}$
400	10^3	10^5	10^5	10^3	10^2	10^3	10^3
800	10^3	10^4	10^4	10^3	10^2	10^3	10^3
1500	10^2	10^4	10^4	10^3	10^2	10^2	10^2

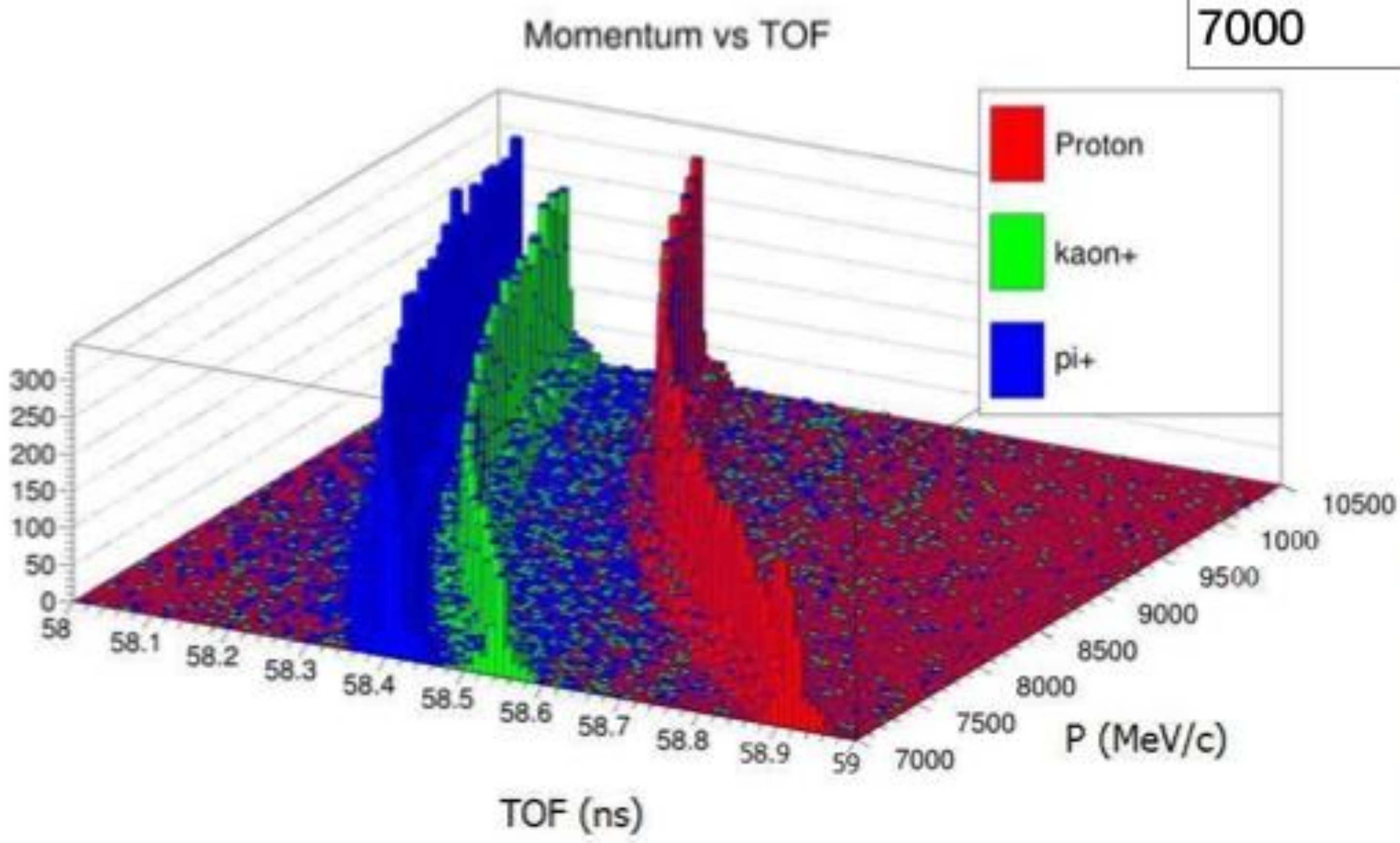
SPD Test Zone: High Momentum Channel

JINR, Dubna

JOINT INSTITUTE FOR NUCLEAR RESEARCH
International Intergovernmental Organization

Energy of primary beam — up to 10 GeV/n

Commissioning date — 2026 year



Intensities from interaction deuteron 5GeV/n + carbon target

p, MeV/c	d	p,n	$\pi^{\pm}$	K^{+}	K^{-}	$\mu^{\pm}$	$e^{\pm}$
2000	10^4	10^5	10^4	10^3	10^2	10^2	10^2
7000	10^4	10^6	10^3	10^3	10^2	10^2	10^2

Тестовая зона SPD: дополнительные возможности

Тестовая зона SPD :

Дополнительные возможности
на фиксированной мишени!

SPD Fixed Target & FITNEX

Straw-Tracker R&D тестовые испытания:
СЦ-1000 в 2024 г.

SPD Experiment: Running Strategy

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

ЗАКЛЮЧЕНИЕ

► **Spin Physics Detector (SPD) – универсальный детектор на коллайдере NICA: Детальное изучение поляризованной и неполяризованной (глюонной) структуры протона и дейтрона в pp- и dd- соударениях при высокой светимости до $\sqrt{s} < 27$ ГэВ**

► **Дополняющие друг друга пробники: кварконии (J/Psi и высшие состоянии), открытый чарм и прямые фотоны**

► **SPD должен улучшить понимание 3D глюонной структуры:**
- **поляризованные глюонные распределения**
- **неполяризованные PDF и TMD при высоких x в протоне и дейтроне**
- **глюонная трансверсити (transversity) в дейтроне …**

► **Физическая программа SPD является дополняющей исследования на COMPASS++/AMBER, RHIC, AFTER@LHC, LHC-spin, EIC**

► **Широкая программа на 1-й Стадии SPD:**
- **поиски экзотических резонансов (глюболы, пента- и тетра- кварки), …**
- **многокварковые флуктоны и малонуклонные корреляции …**

► **SPD TDR: *http://spd.jinr.ru* *опубликован в Natural Science Review 1 (2024) 1-325* утвержден международной экспертизой SPD DAC и JINR PAC (июнь 2024)**

► **1-я Стадия SPD включена в 7-летний план ОИЯИ 2024-2030 > 35 MUSD**

► **SPD R&D: оптимизация физических сигналов, оптимизация дизайна, изготовление и тестирование прототипов, подготовка к производству**

► **Тестовая зона SPD: новые возможности**