Spin Physics Detector

SPD NICA

SPD NICA: Physics at the First Stage

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SPD at NICA (JINR, Dubna)

NICA:
Nuclotron-based Ion Collider fAcility

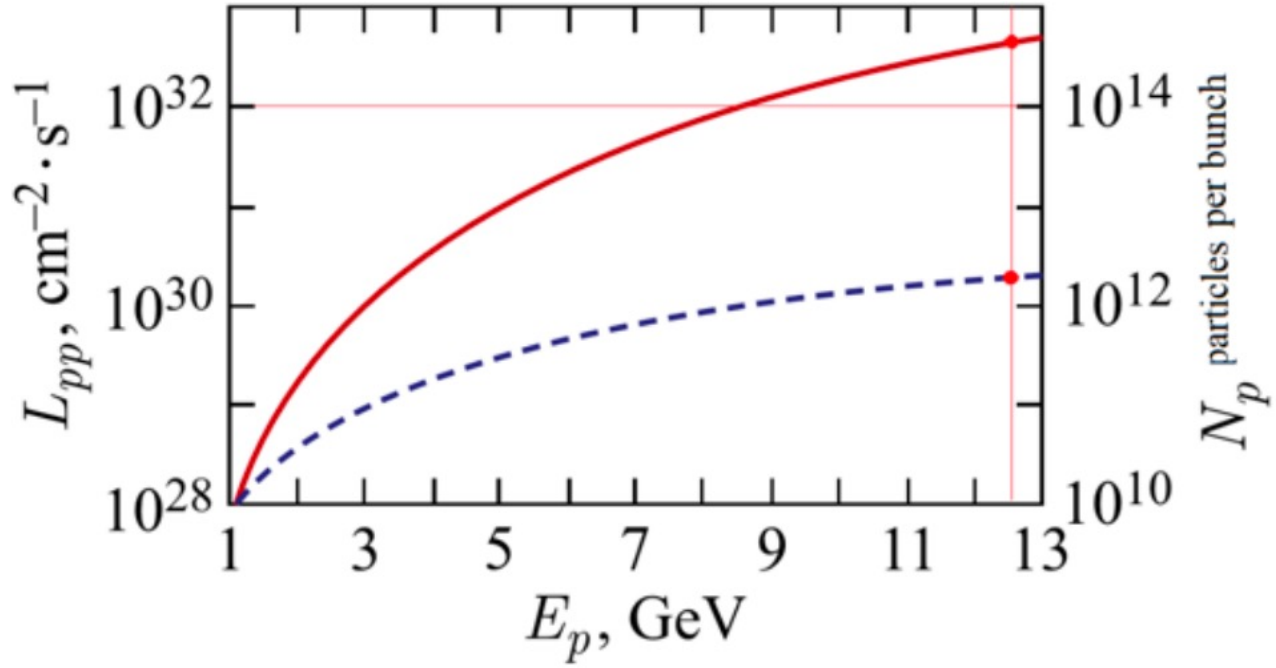
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$

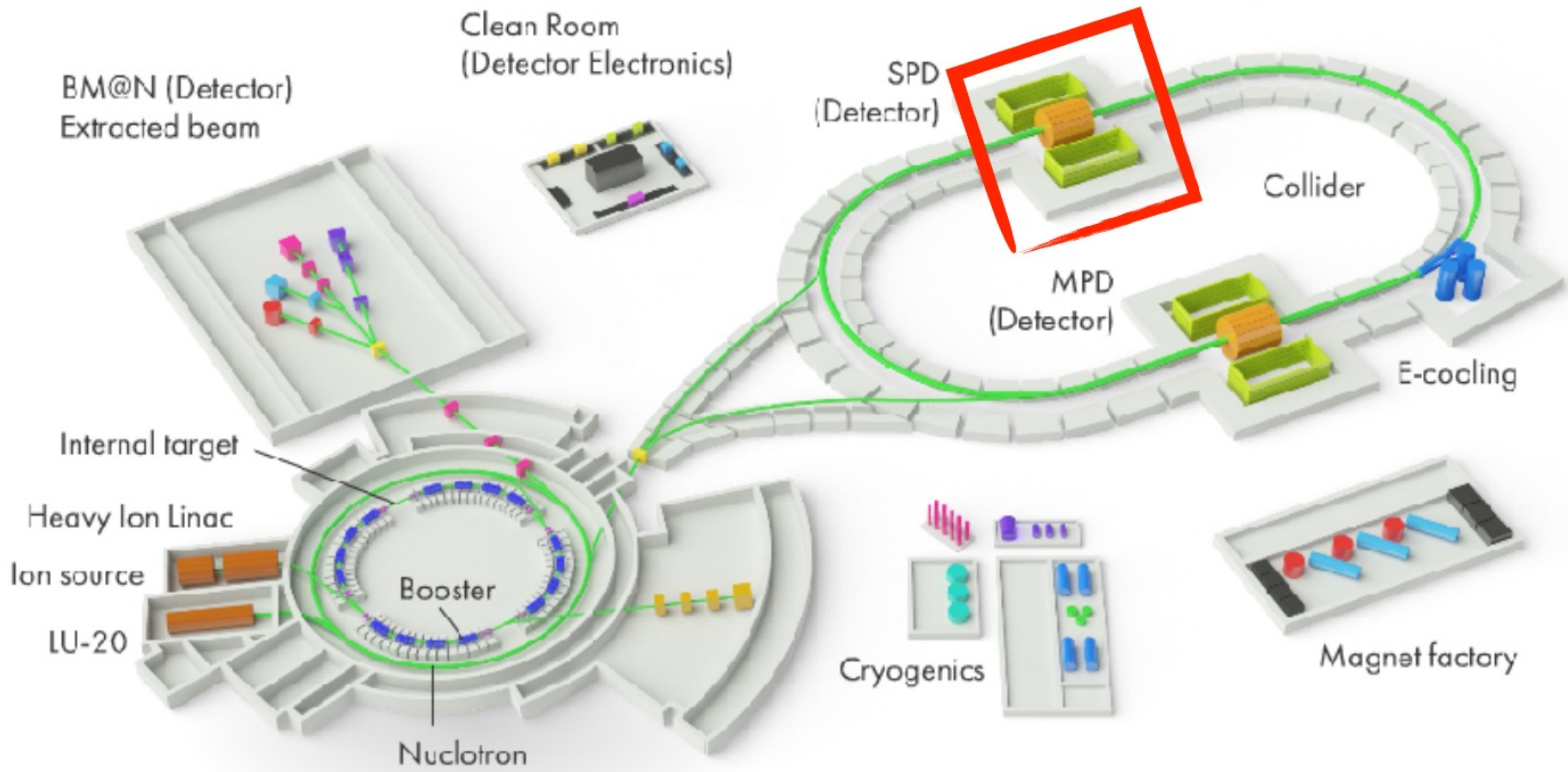
$d^{\uparrow}d^{\uparrow} : \sqrt{s} \leq 13.5\ GeV$

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

U, L, T

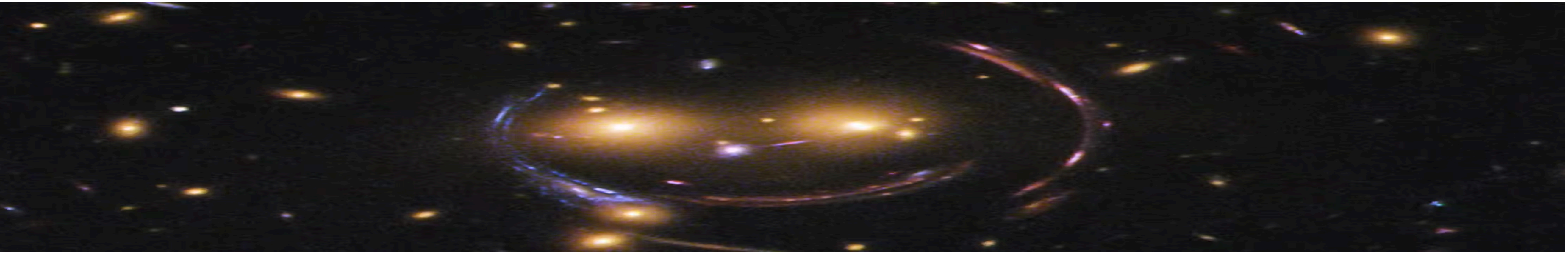
$|P| > 70\%$





JINR (Dubna): Accelerator Complex NICA

Why nucleon?



proton mass -> the visible Universe mass

Electroweak Higgs boson provides:
current quark masses m_U=3 MeV, m_D=7 MeV ➥ 2% proton mass

Spontaneous chiral symmetry breaking:
current quarks + vacuum condensates ➥ ➥ constituent quarks

m_U=3 MeV ➥ M_U ~ 400 MeV
m_D=7 MeV ➥ M_D ~ 400 MeV

➥ quark-gluon dynamics of nucleon structure provides:
~ 98% of the mass of the visible Universe!

Why nucleon structure?

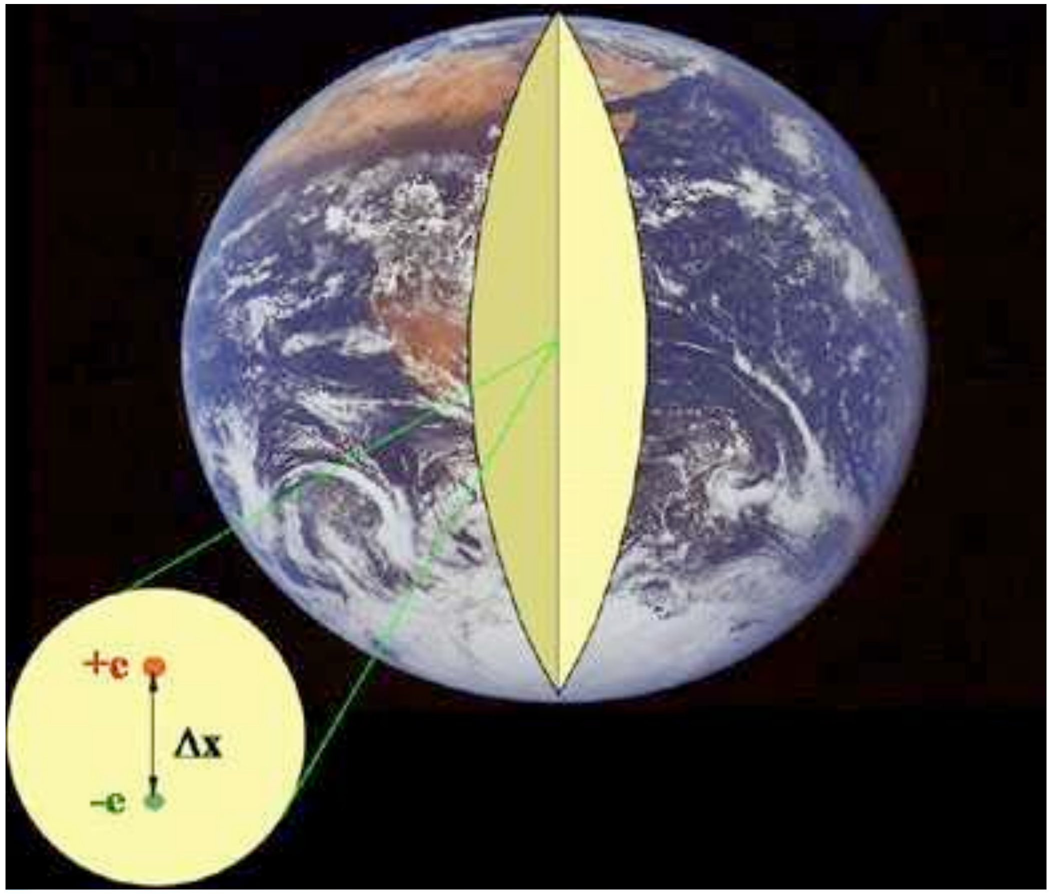
nucleon size ~ 1 Fm = 10^{-13} cm

(naïve) quark model expectations ➥
neutron electric dipole moment $EDM_N = 10^{-13}$ e·cm
EDM_N exp. limit $< 10^{-28}$ e·cm

exceeding by factor 10^{15} the observed limit!

If neutron size would be increased up to Earth diameter

➥ neutron dipole size < 10 nm



Why Spin?

Spin: pure quantum characteristics

spin: no classical analog

➥ **quantum entanglement,**
quantum computers, ….

spin observables

➥ **hadron wave functions**
process amplitudes

"proton spin crisis" :

naïve quark model (valence quarks)

➥ **only 1/3 of proton spin !**

valence quarks define
all proton quantum numbers except spin!?

Spin: 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)

Spin physics: not very high energy?

Spin effects in QCD: size value

naïve expectations for spin effects in pQCD

➥ current quark: few MeV

$m_q/m_N \sim 1\%$

Spontaneous symmetry breaking

➥ constituent quark mass: few hundred MeV

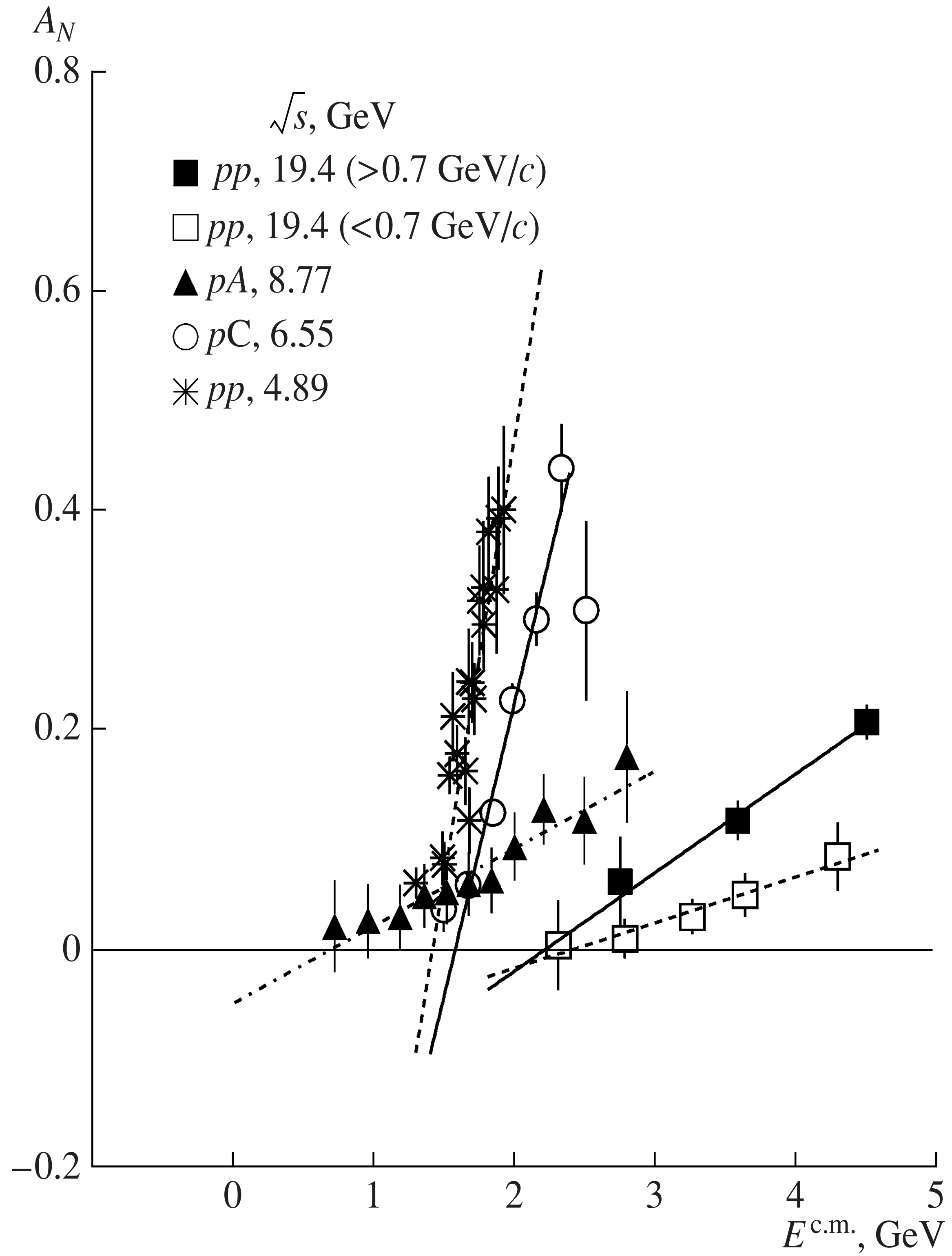
$m_Q/m_N \sim 40\%$

polarized PDF evolution:

➥ twist-2 & twist-3 (1/Q)

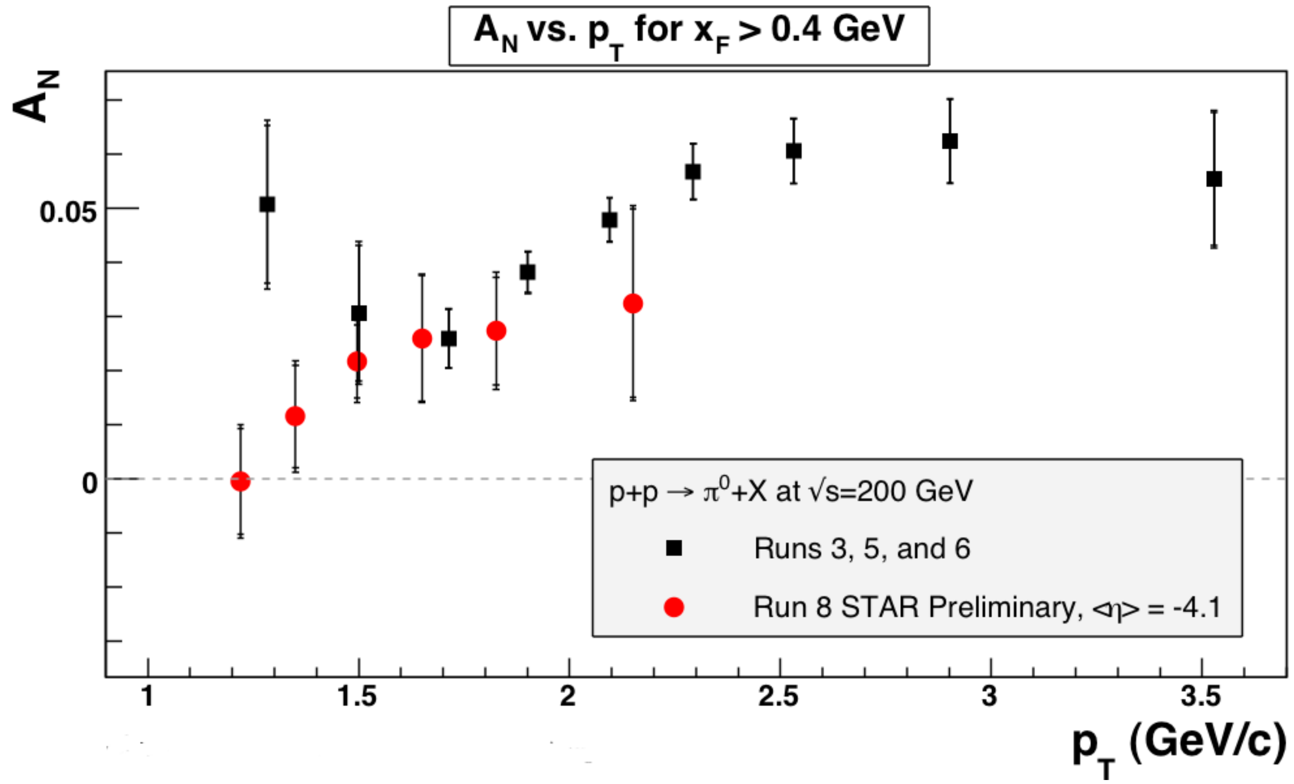
NICA energies: optimal for spin physics!

NICA energies: optimal for spin physics



Single-spin asymmetry A_N as a function of $E^{c.m.}$ for reactions of the type $p^{\uparrow}p(A) \to \pi^{+}X$

RHIC: √s=200 GeV **E_{CM} = 100 GeV**



Main goals of SPD Experiment

Spin Physics Detector (SPD) (http://spd.jinr.ru):
Universal setup at collider NICA

➥ **Main SPD goals:**
understanding strong interactions using polarized and unpolarized pp- and dd- collsions $\sqrt{s}$ < 27 GeV

- 3D structure of proton and deutron, PDF and TMD at moderate and large x

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

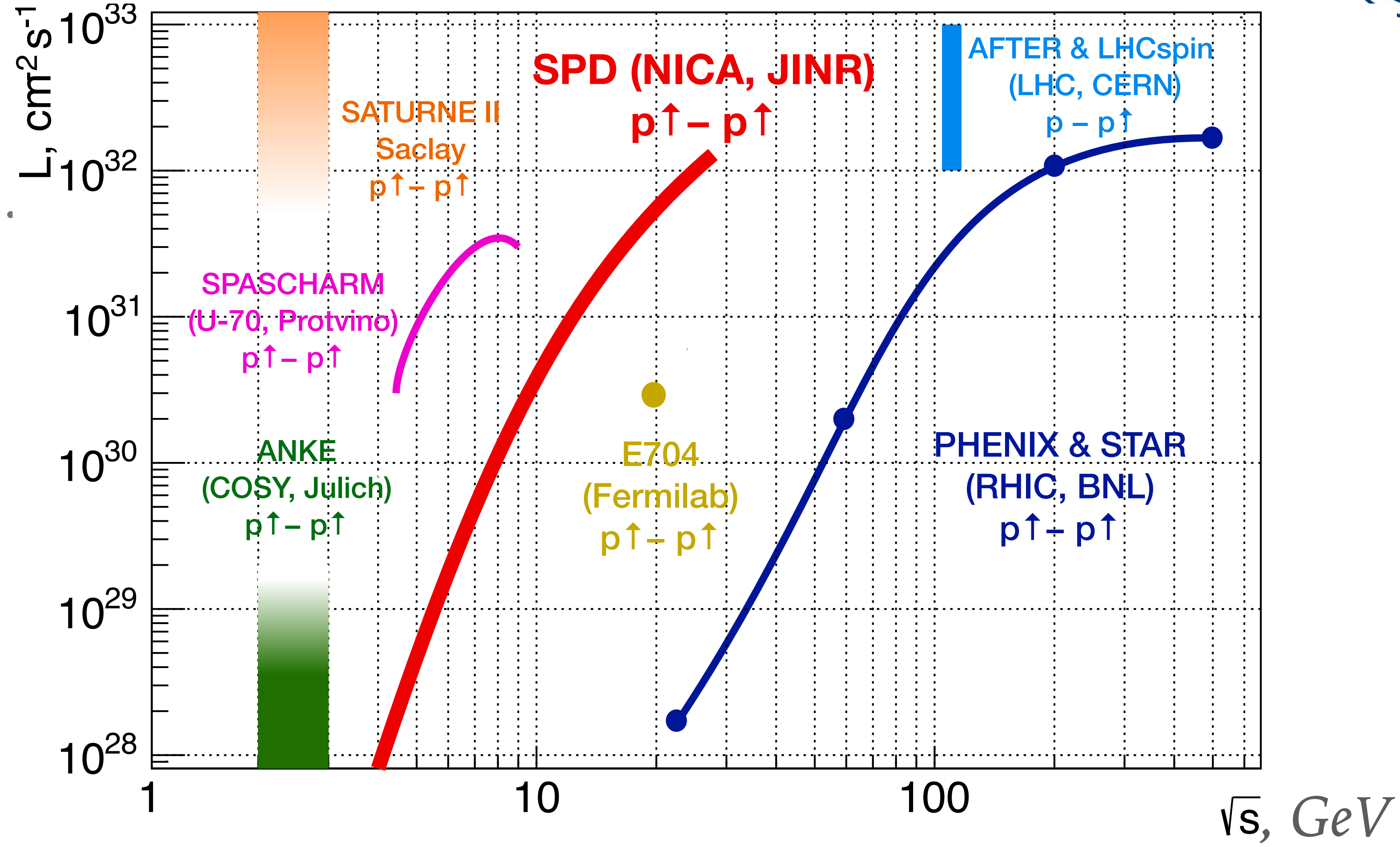
➥ **Reasearch program at the First Stage of SPD covers a broad scope of particle and nuclear physics**

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

Parton distribution function (PDF): parton longitudinal momentum distributions
Transverse momentum distribution (TMD) – parton distribution with unintegrated transverse momenta

SPD in World landscape of polarized physics

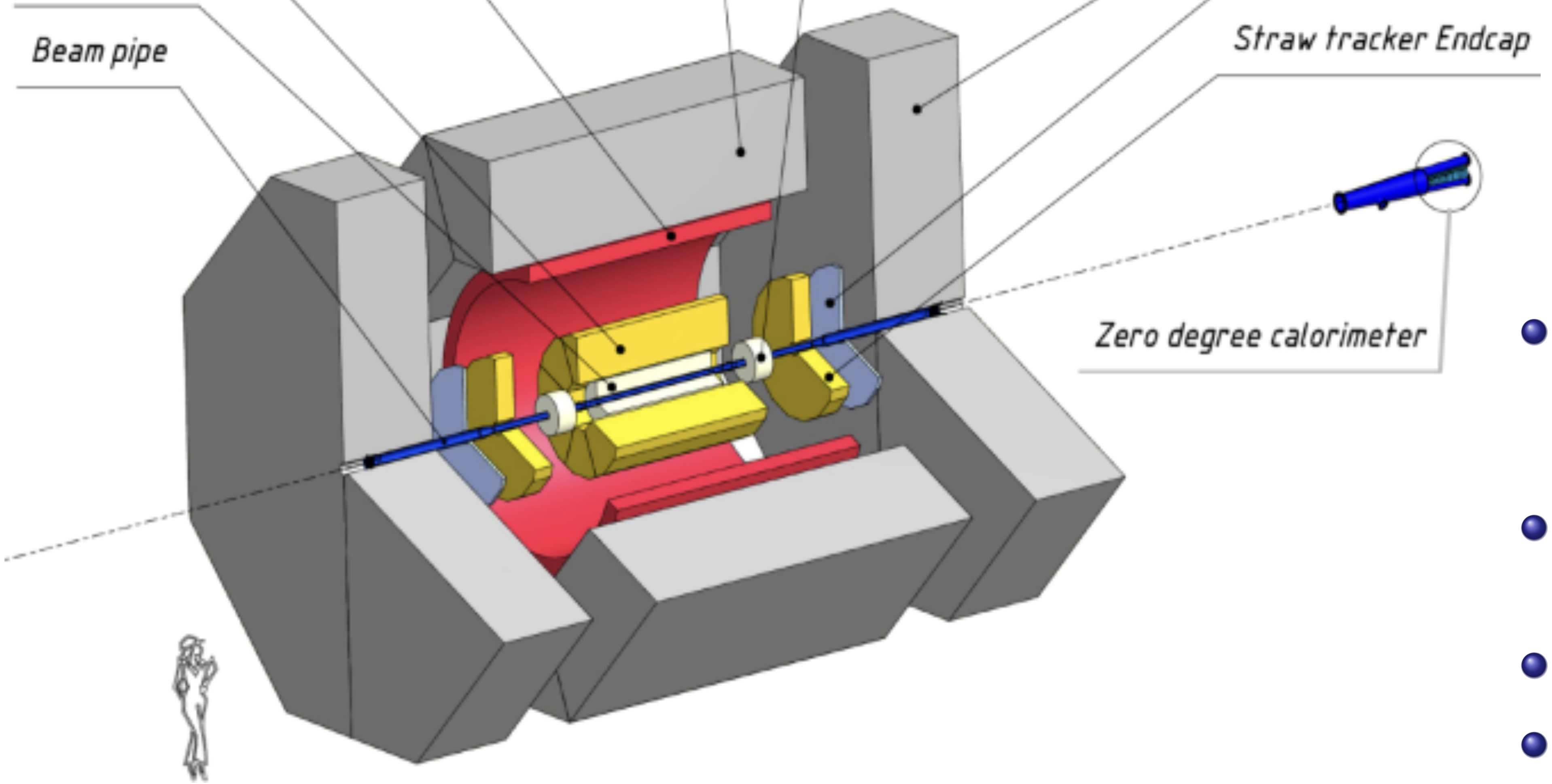
p↑ p↑-mode ➡️



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	$p^\uparrow$-$p^\uparrow$ $d^\uparrow$-$d^\uparrow$ $p^\uparrow$-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

⬅️ SPD is unique in d↑ d↑-mode!

SPD detector at the Stage I



- 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, $\delta(\frac{dE}{dx}) = 8.5\%$

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

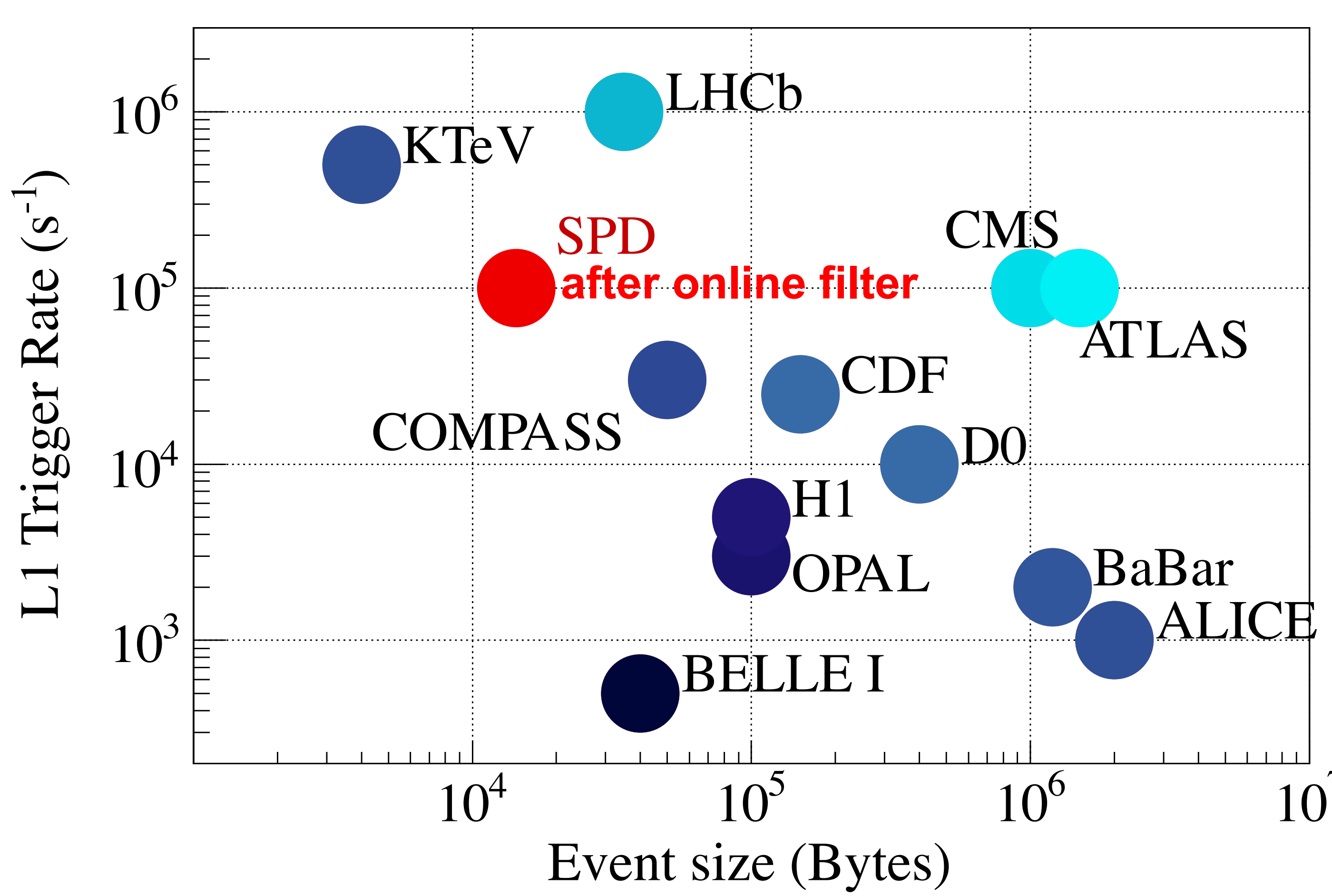
SPD detector data flow

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 at the Second Stage!
Comparable in data rate with ATLAS and CMS at LHC RUN1

SPD Tier-1:
NRC KI - PNPI, Gatchina ?
NRC KI, Moscow ?

SPD data rate after online filter



SPD Collaboration: established in July 2021

SPD Spokespersons:

Alexey Guskov (JINR, Dubna) Victor Kim (NRC KI - PNPI) Gatchina)

SPD Collaboration Board Chair:

Egle Tomasi-Gustafsson (CEA, Saclay)
deputy: Armen Tumasyan, (ANNL, Yerevan)

SPD Coordinators:

Hardware: Alexander Korzenev (JINR)
Software: Alexey Zhemchugov (JINR)
deputy: Danila Oleynik (JINR)
Software: Igor Denisenko (JINR)
deputy: Amaresh Datta (JINR)

36 organizations from 15 countries ~ 400 participants

The Fist Stage of SPD: R&D

- The 1-st Stage of SPD included to 7-year plan of JINR 2024-2030
- SPD TDR: *http://spd.jinr.ru* is under review (approval: June 2024?)
- SPD R&D: optimization of physics signals,
  design optimization,
  subdetector prototype production and testing,
  preparation to production

SPD R&D: Straw Tracker

JINR (Dubna), NRC KI - PNPI (Gatchina) and INP ME (Almaty)
T.L. Enik (JINR) and E.V. Kuznetsova (PNPI)
R&D straw tubes ASIC: solutions for readout electronics

- **Straw Stracker R&D: SPD/SHiP/Dune/DRD1 at CERN SPS and PS to define requirements to the readout electronics**

Test measurements for ASIC: VMM3,VMM3a, Tiger
- 2021 (1 SPS beam), 2022 (3 SPS beams), 2023 (3 SPS beams), 2024 (2 SPS and 2 PS beams)
- SPD TDR based on the measurements

SPD Physics Highlights at the First Stage

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

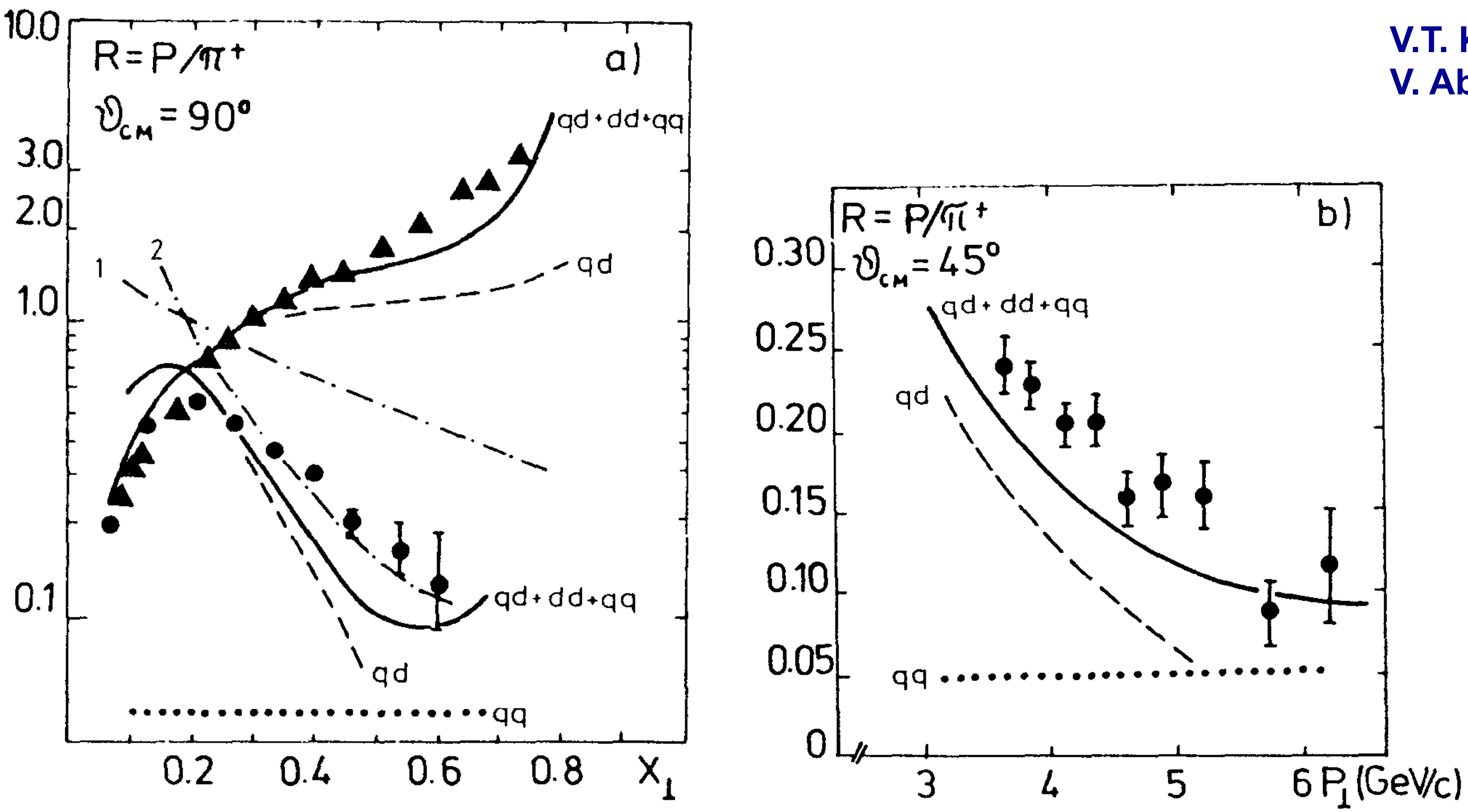
Comprehensive and rich physics program at the initial stage of SPD data taking:

- ► **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: diquarks

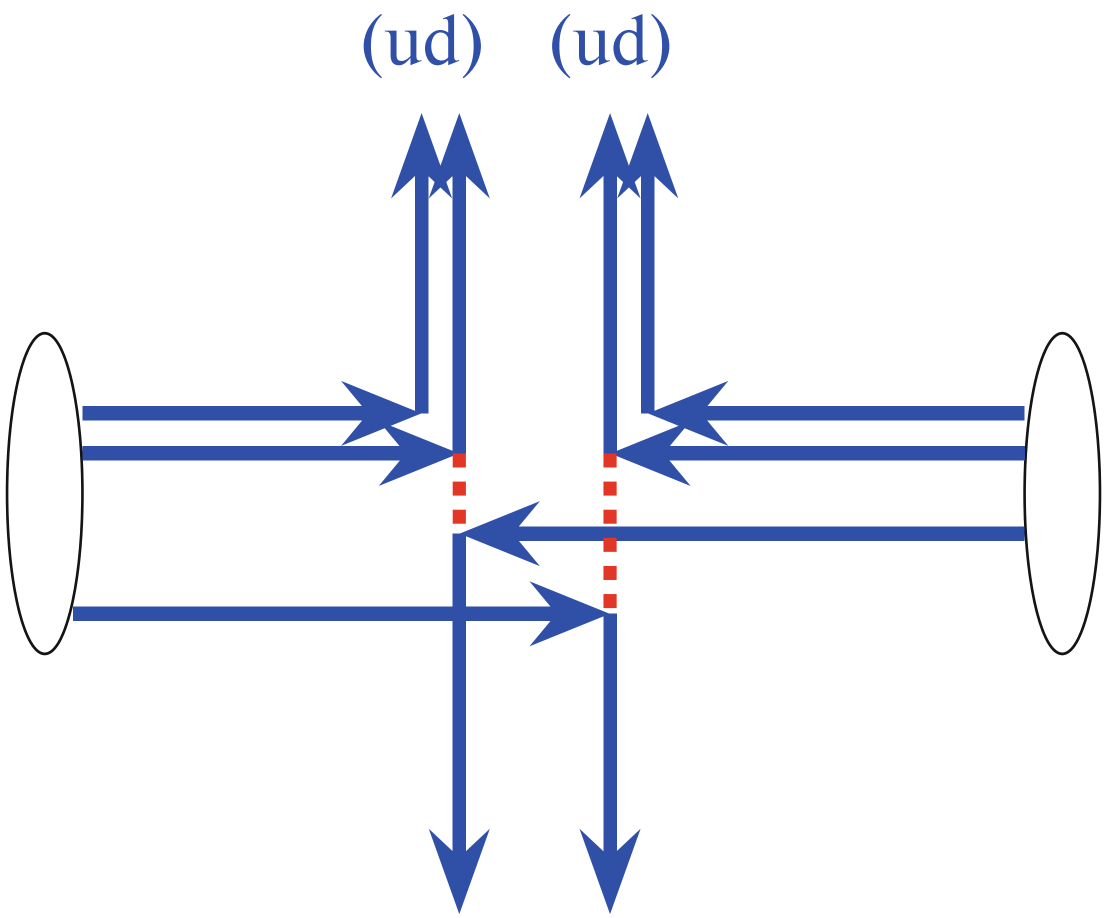
Strong scaling violation in p/pi ratio: diquarks

a) √s = 11.5 GeV and √s = 23.4 GeV
b) √s = 62 GeV

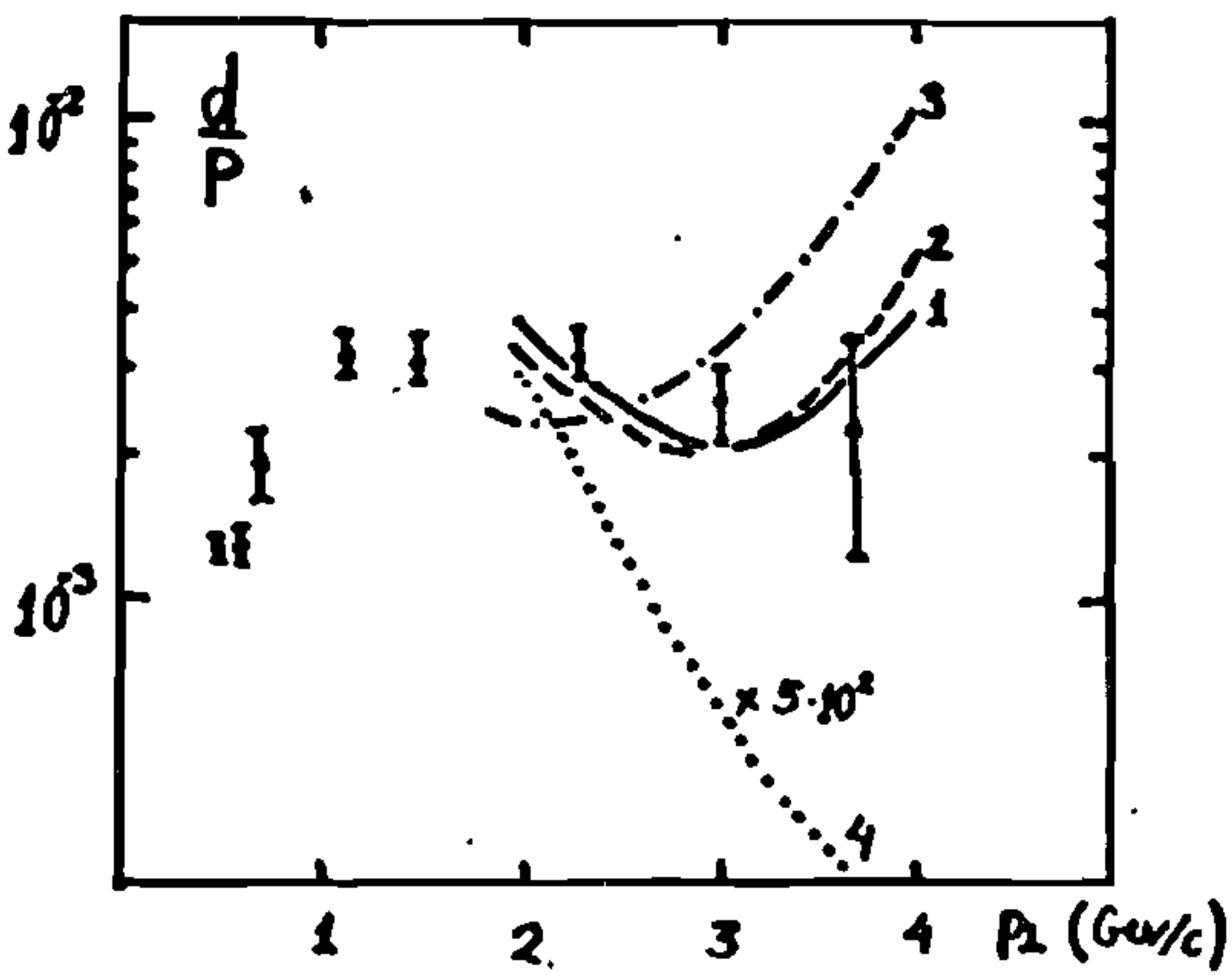


V.T. Kim 1988
V. Abramov et al 2021

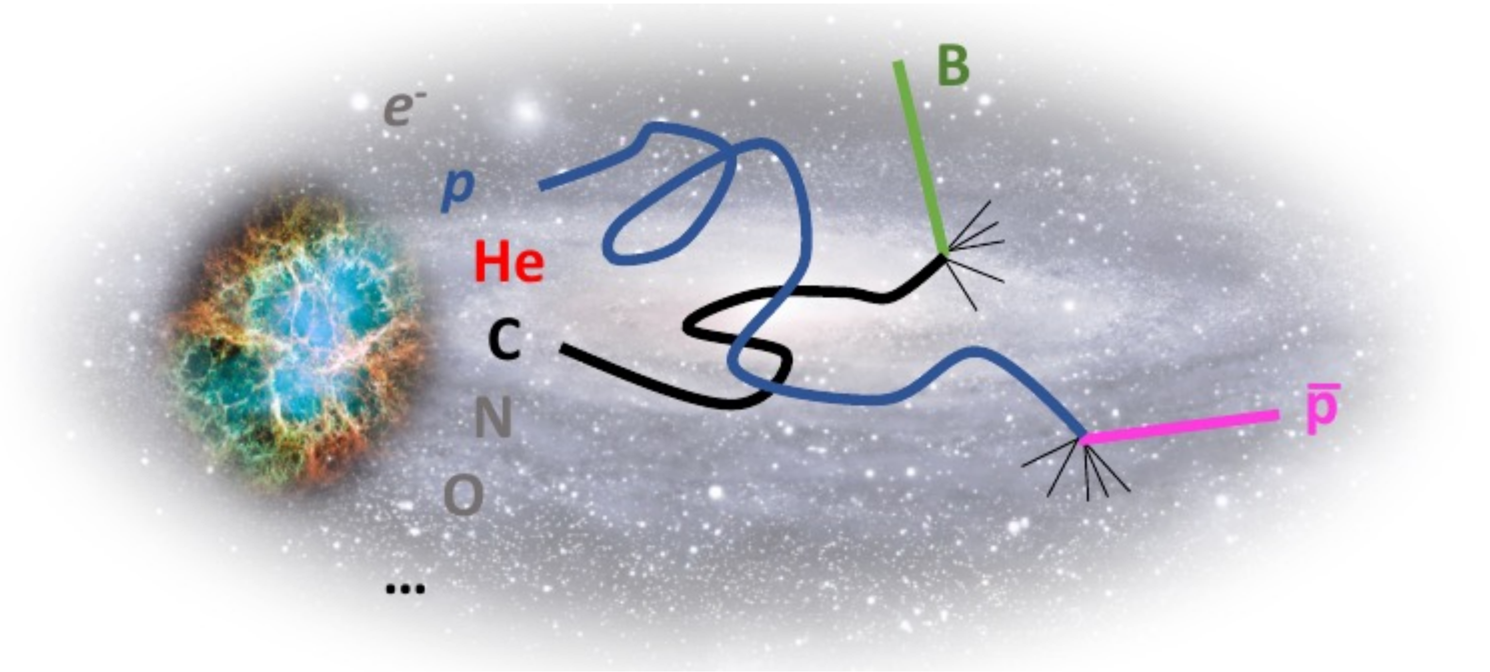
SPD Physics at the initial Stage: exotic states pentaquark, dihyperon, etc. production



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



SPD Physics at the Stage-1: antiproton production



ASTROPHYSICS

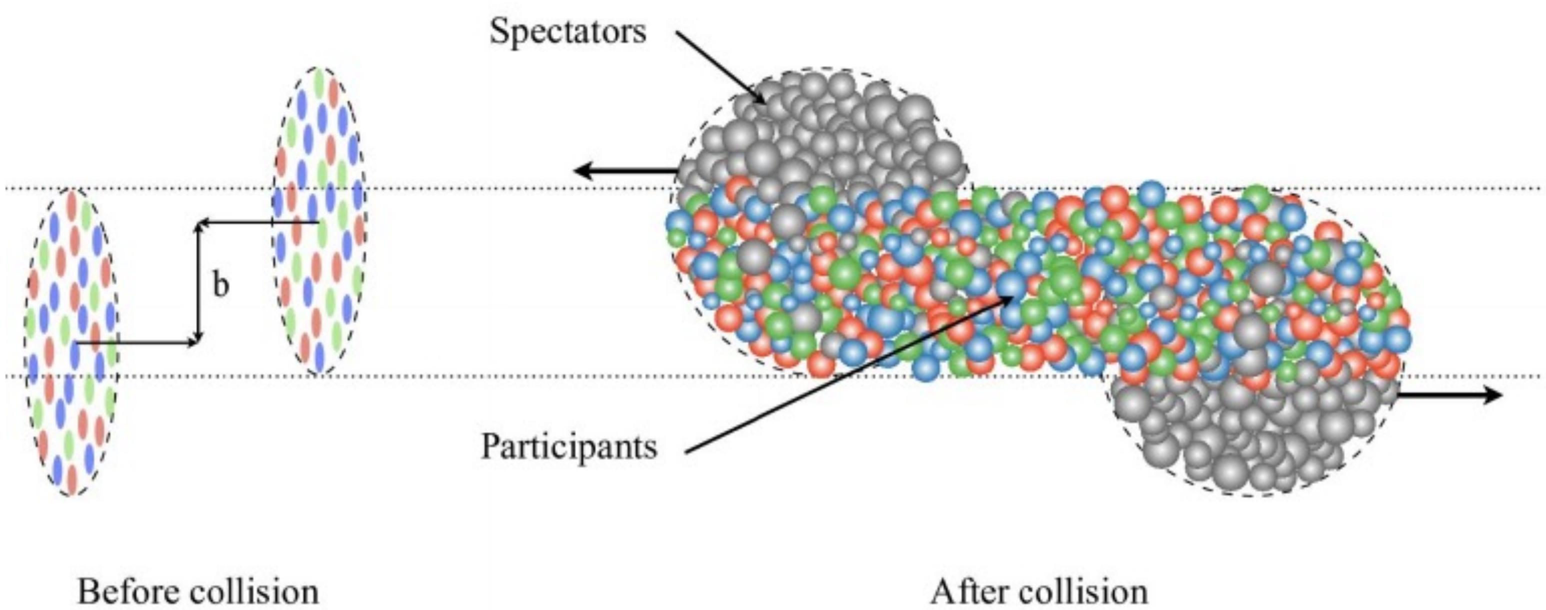
AMS-02 at International Space Station

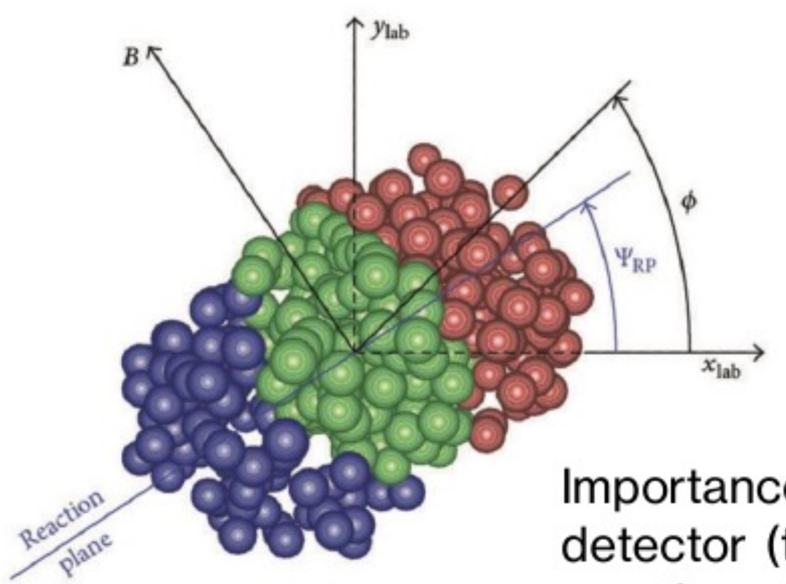
AMS-02 search for Dark Matter:
antiproton flux precision ~5%

Contemporary high energy physics experiments
antiproton production ~25%

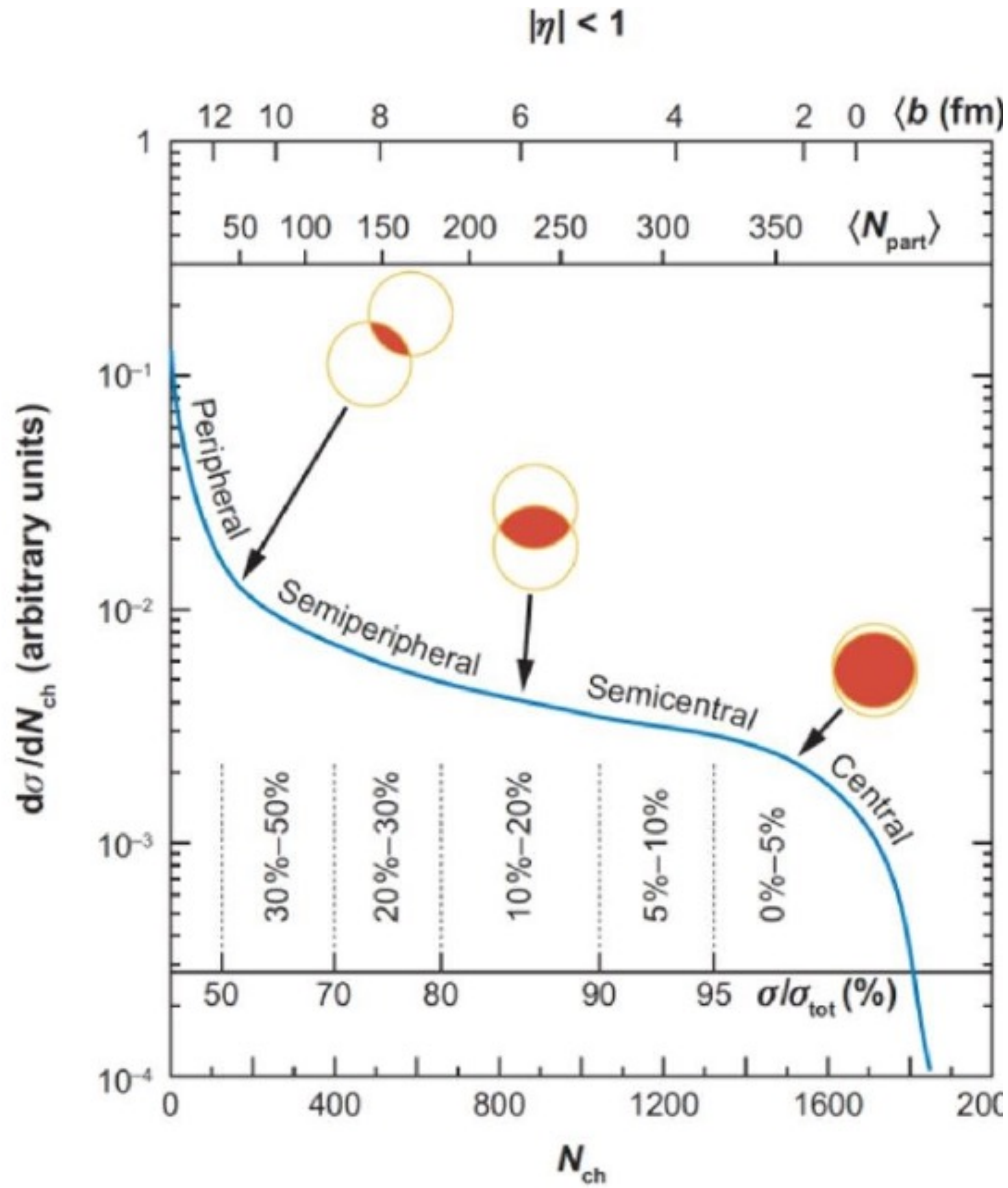
Precision antiproton production measurements needed:
energy range 5 GeV < ECM < 100 GeV with precision ~5%

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





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



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

SUMMARY: SPD Physics at the First Stage

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

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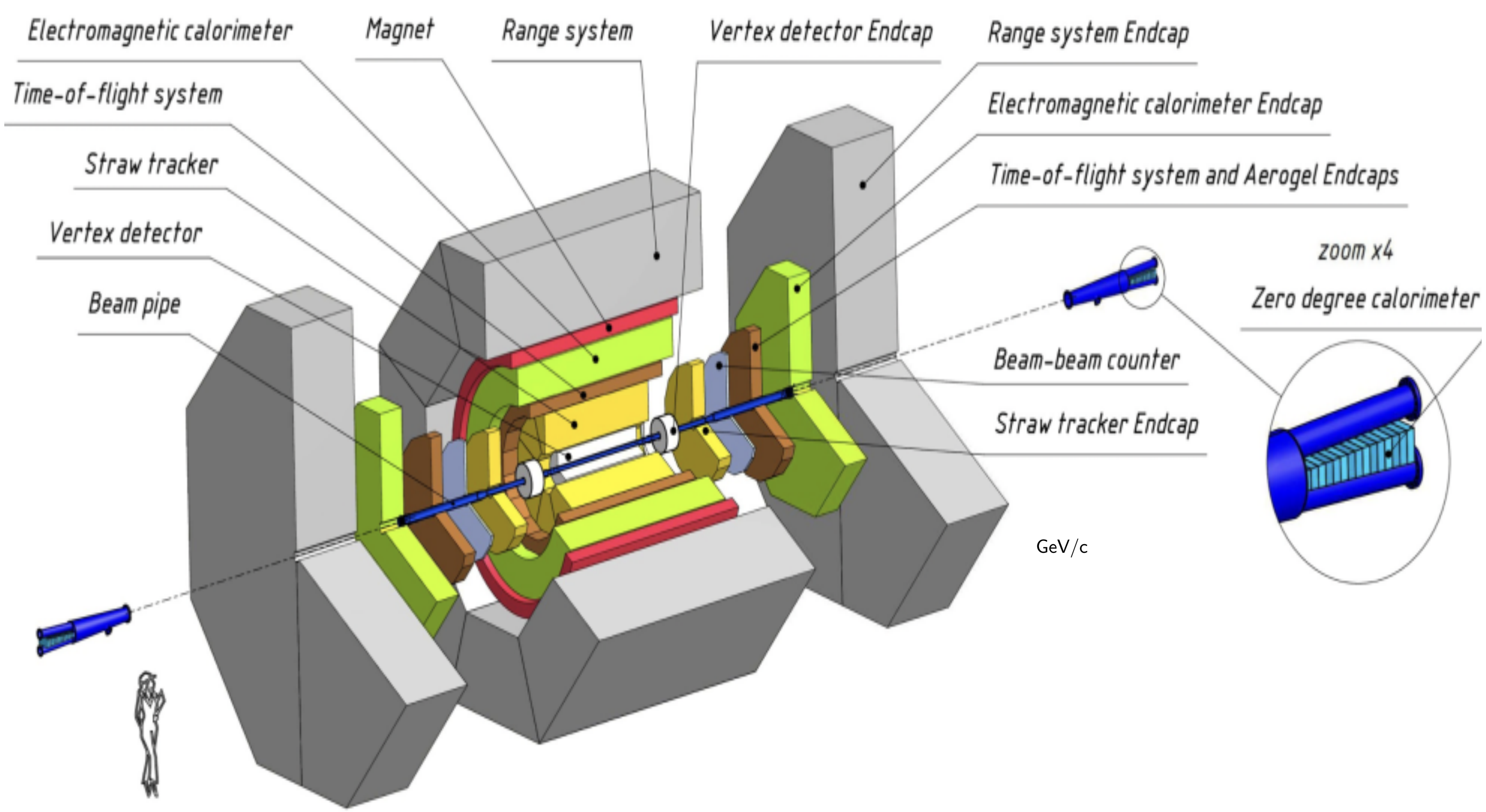
- **…**

We are looking forward for very interesting results!

BACKUP SLIDES

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 ($\delta_t \sim 50$ ps), π/K separation upto 1.5 GeV/c
- Electromagnetic calorimeter (ECAL) $(\frac{\delta_E}{E} = \frac{5\%}{\sqrt{E}} + 1\%)$
- Aerogel counter in endcaps, extends π/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 Physics:

ELSEVIER

Progress in Particle and Nuclear Physics

Volume 119, July 2021, 103858

ArXiv e-Print: 2011.15005 [hep-ex]

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], 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]

Dynamics kinematic range