THE SPD PROJECT AT NICA

INDIA-JINR WORKSHOP ON PARTICLE, NUCLEAR, NEUTRINO PHYSICS AND ASTROPHYSICS

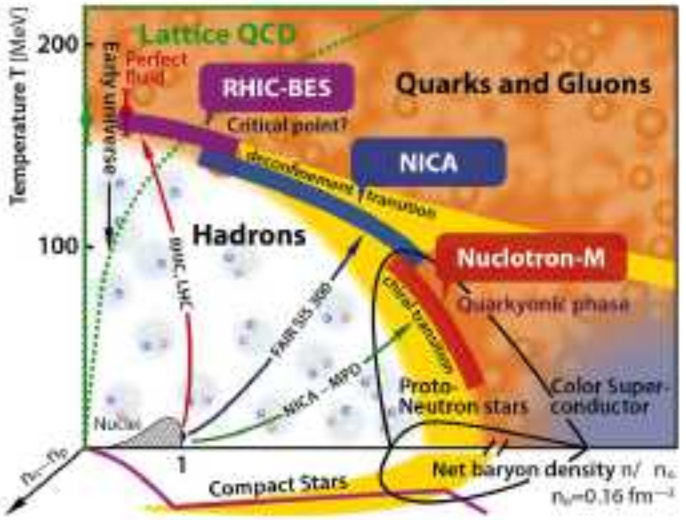
Alexey Guskov
JINR

avg@jinr.int

11.11.2025

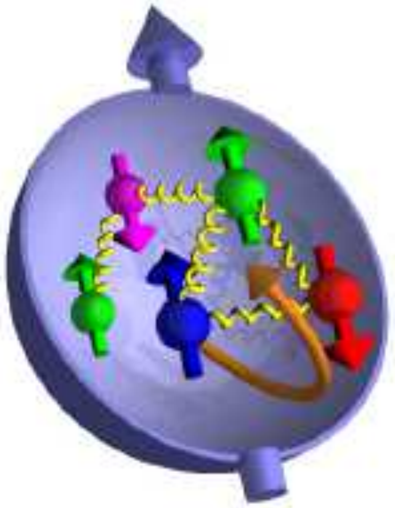
NICA facility at JINR

NICA (Nuclotron-based Ion Collider fAcility)



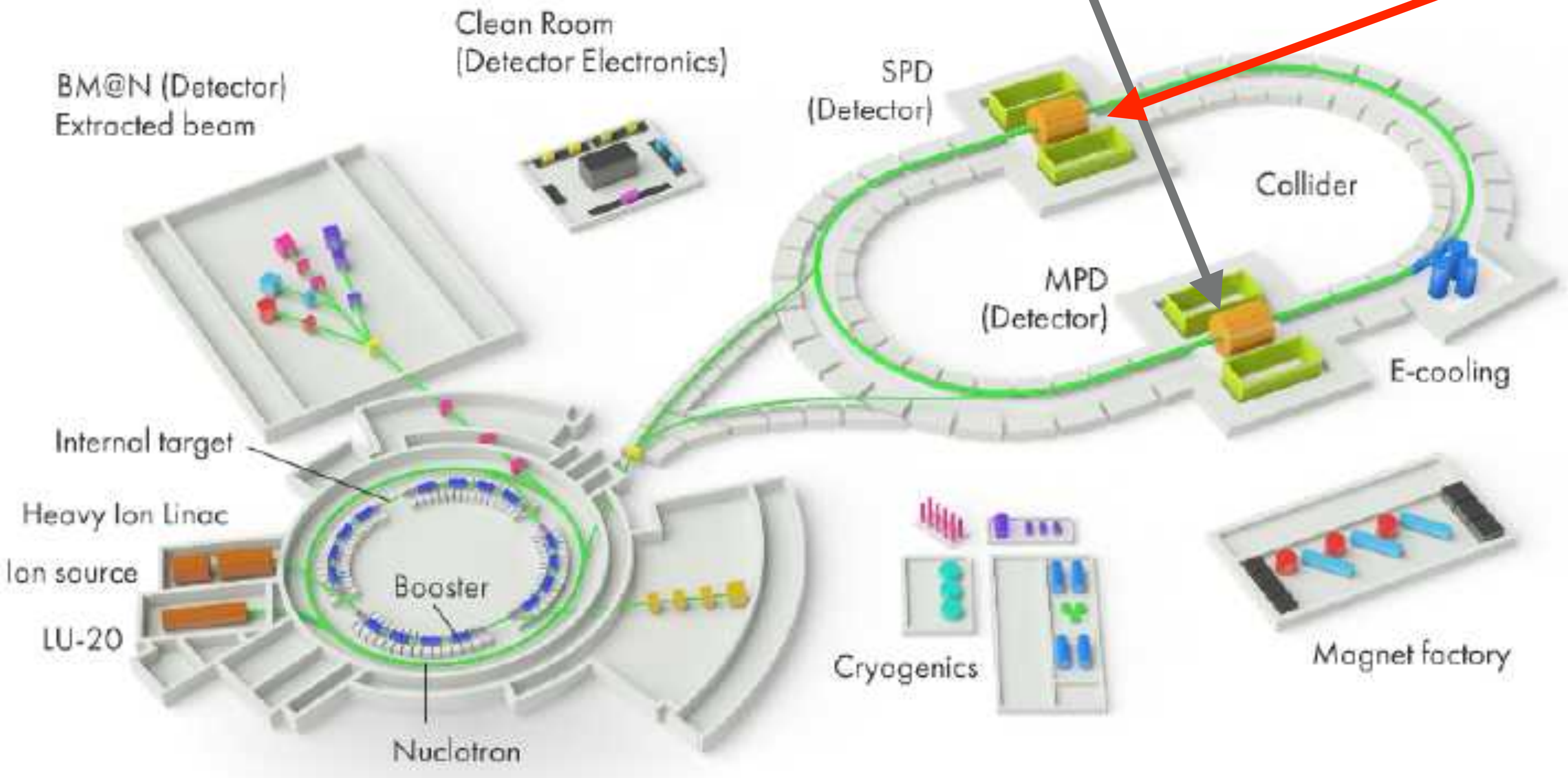
Stage 1

Hot hadronic matter in extremal conditions with heavy-ion beams



Stage 2

Proton and deuteron spin structure with polarized beams



503 m

NICA for spin physics

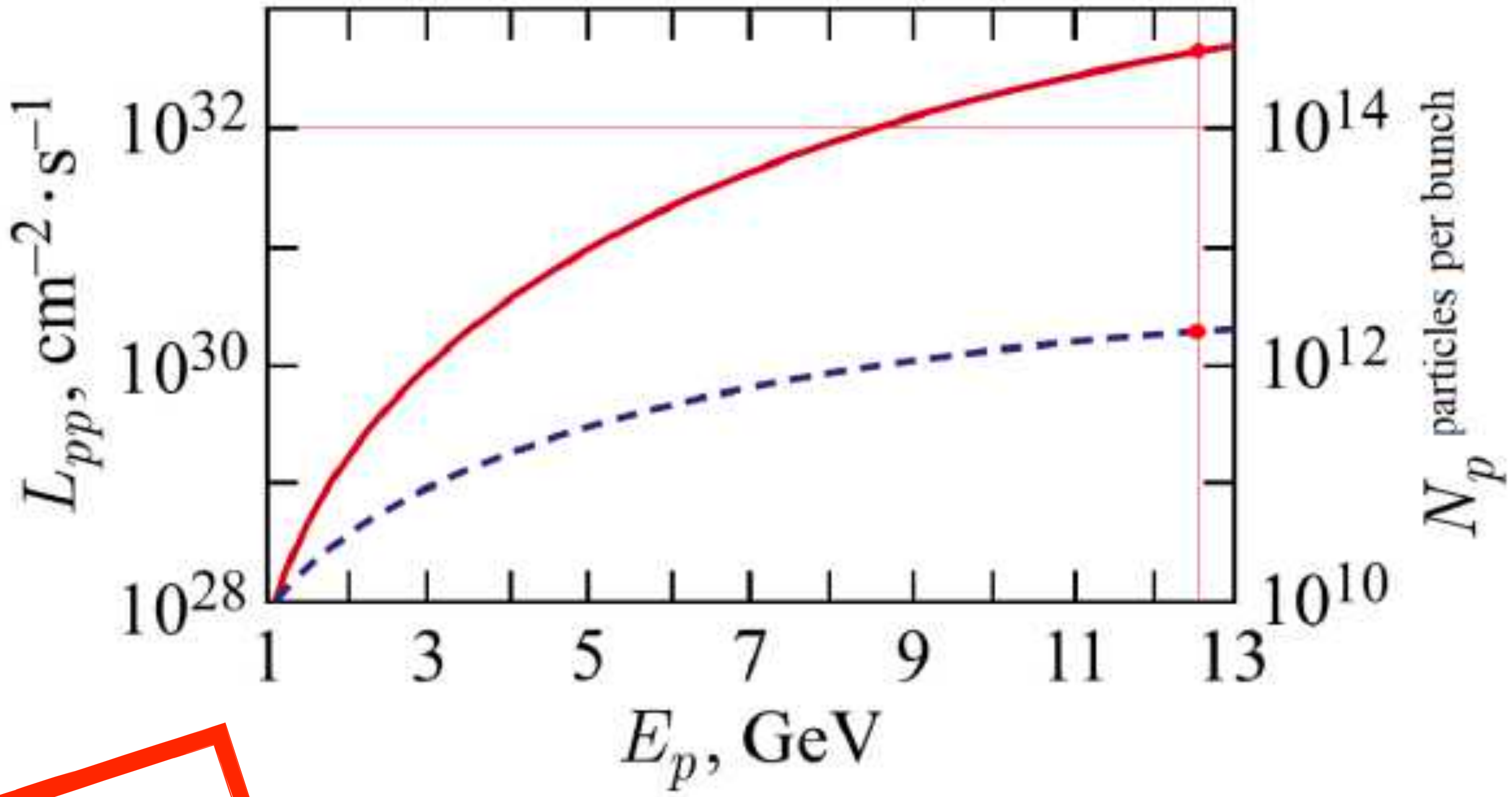
Polarized proton and deuteron beams:

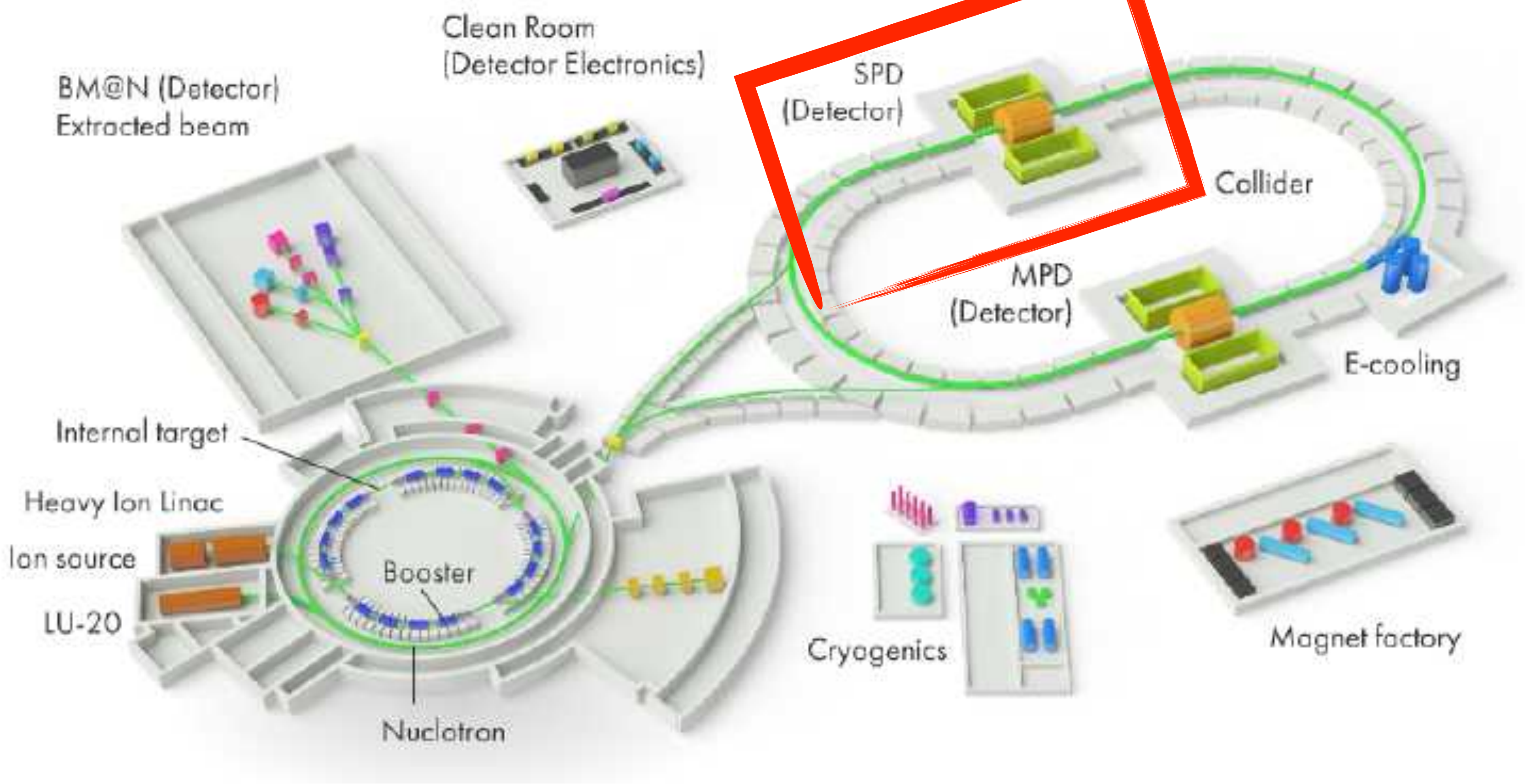
$$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$$

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

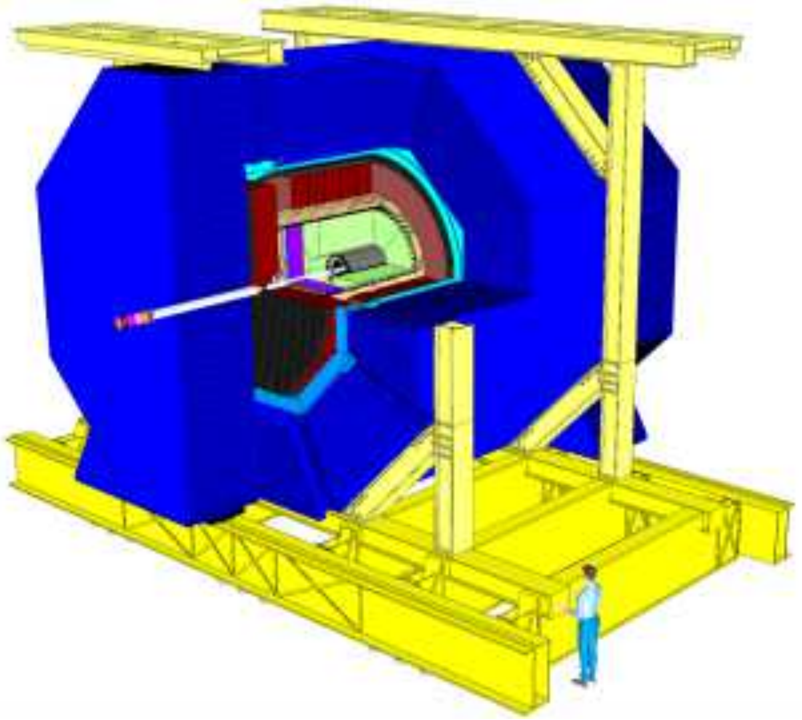
U, L, T |P|>70%

Polarized ^{3}**He** beams are also possible





***S**pin **P**hysics **D**etector*



NICA landscape

Polarized beams at NICA

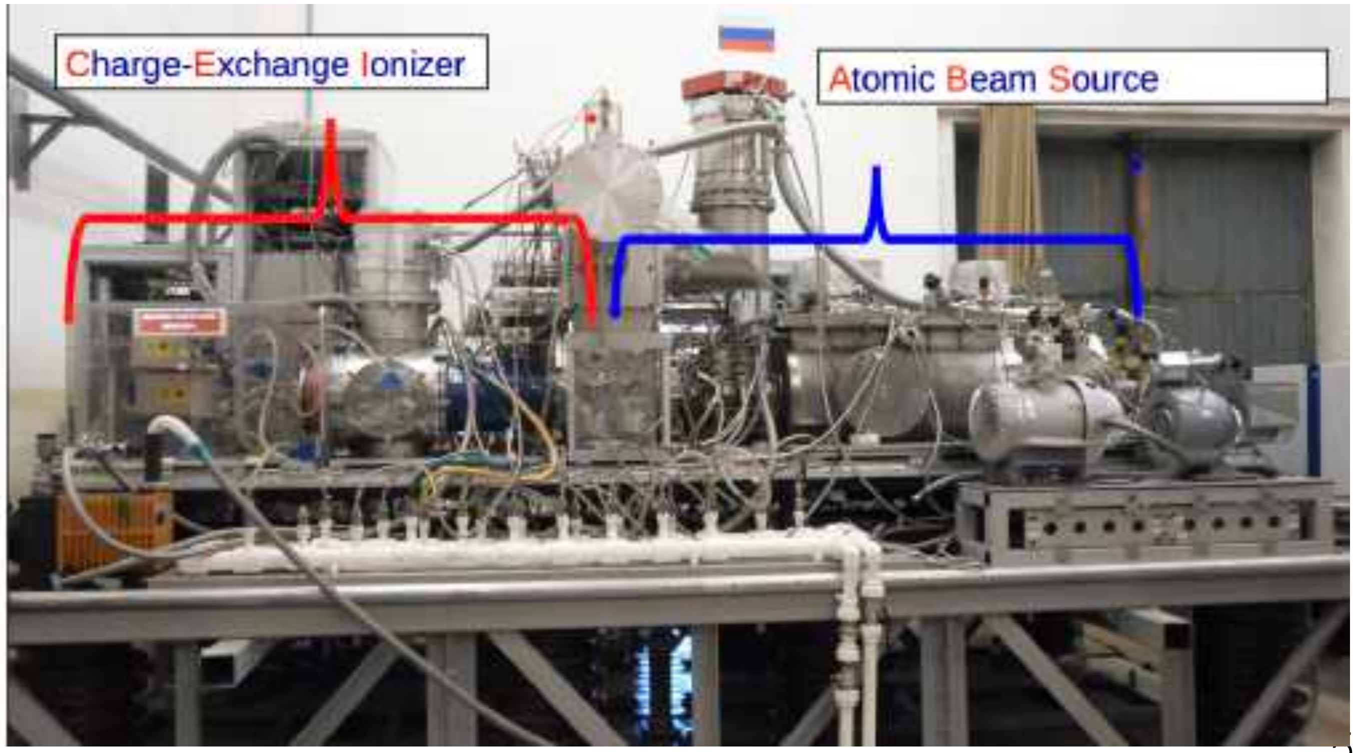
d↑- was accelerated in 1986 (Synchrophasotron) and 2002 (Nuclotron). It is quite simple procedure: there is just 1 depolarizing spin resonance at 5.6 GeV.

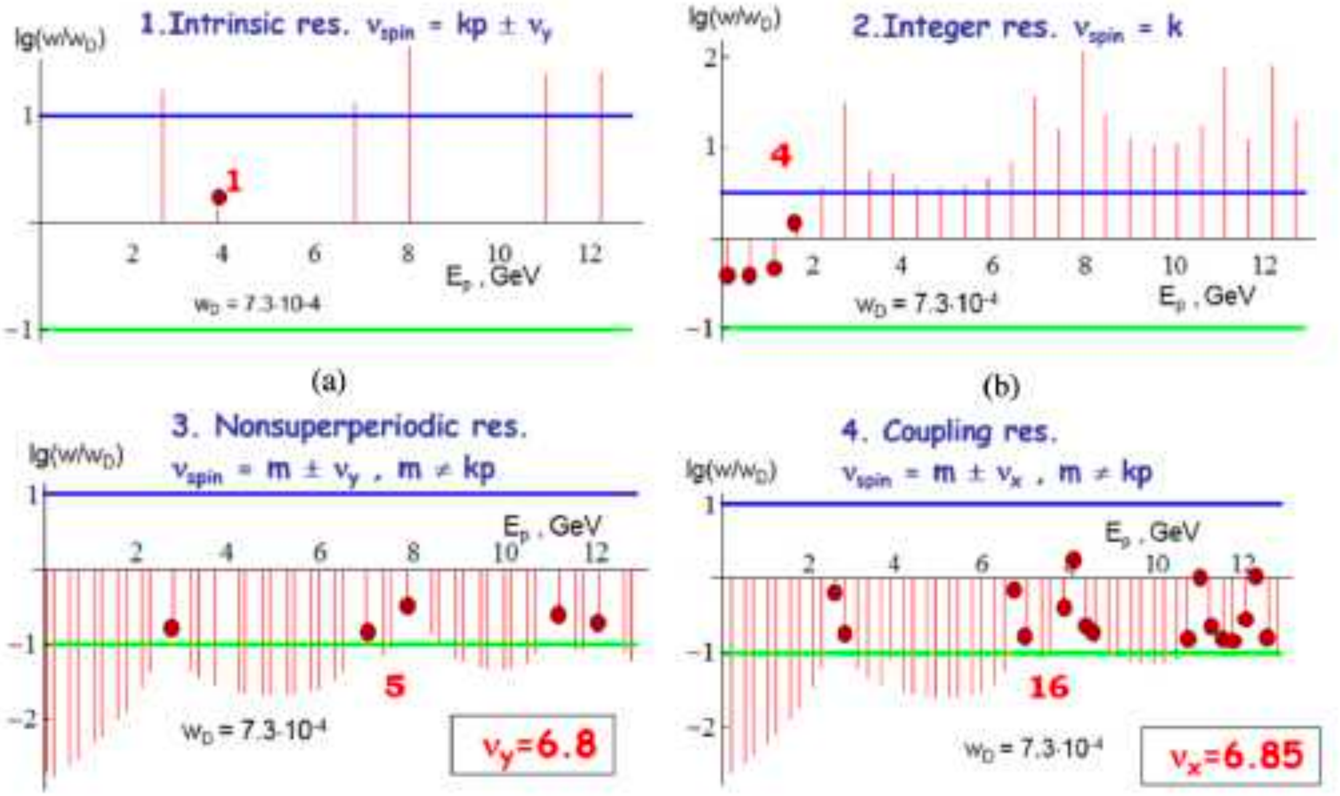
p↑- was first obtained only in 2017.

Source of Polarized Ions:

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

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

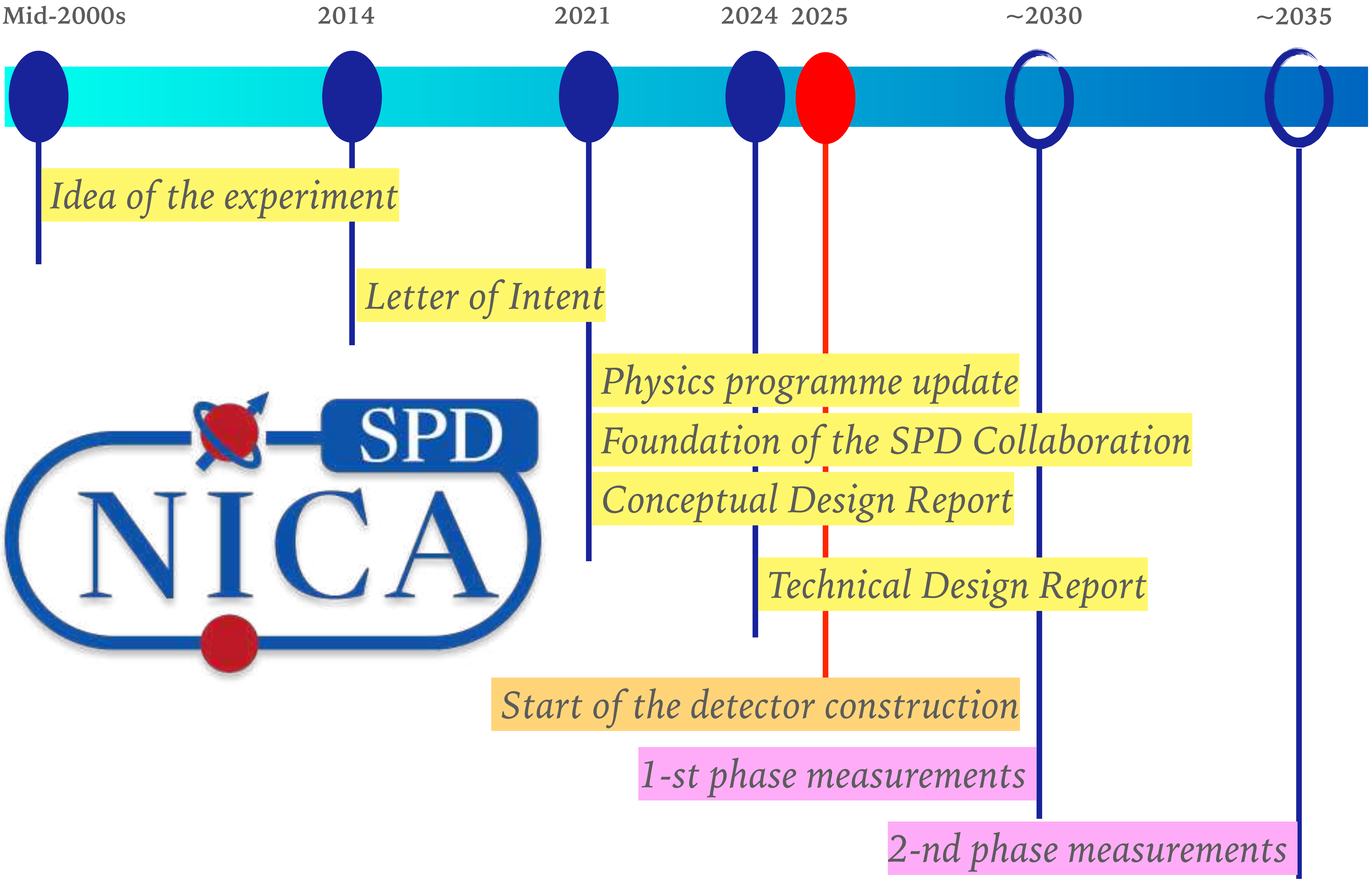




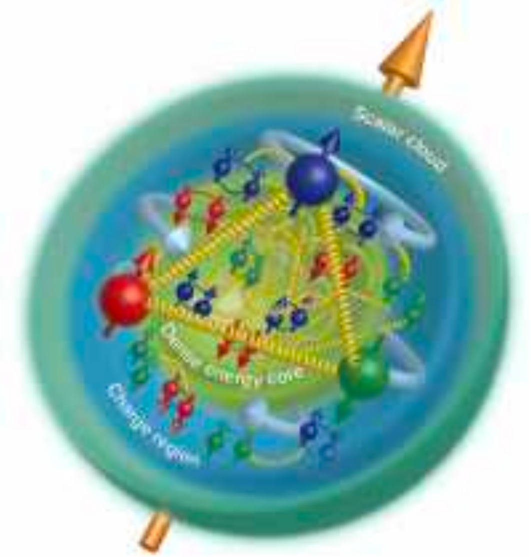
- Longitudinal polarization in the IP can be supported at the integer spin-resonances
  - For protons: E_{kin}=(0.108+0.523·n) [GeV]
  - For deuterons: E_{kin}=(5.62+6.56·n) [GeV/u]

- Transverse polarization at any energies

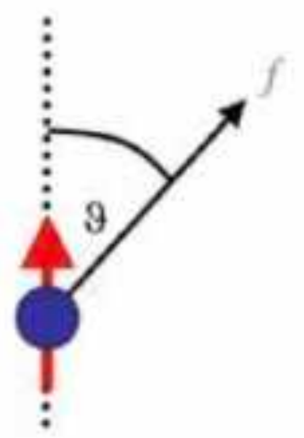
Spin Physics Detector project



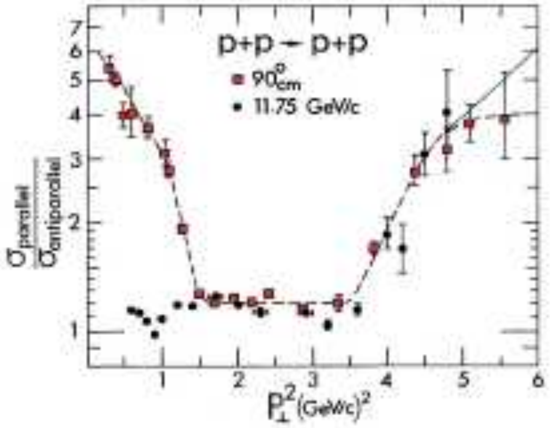
Physics @ SPD



- *Gluon polarized PDFs (TMDs and helicity)*
- *Quark polarized PDFs*
- *Deuteron tensor PDFs*



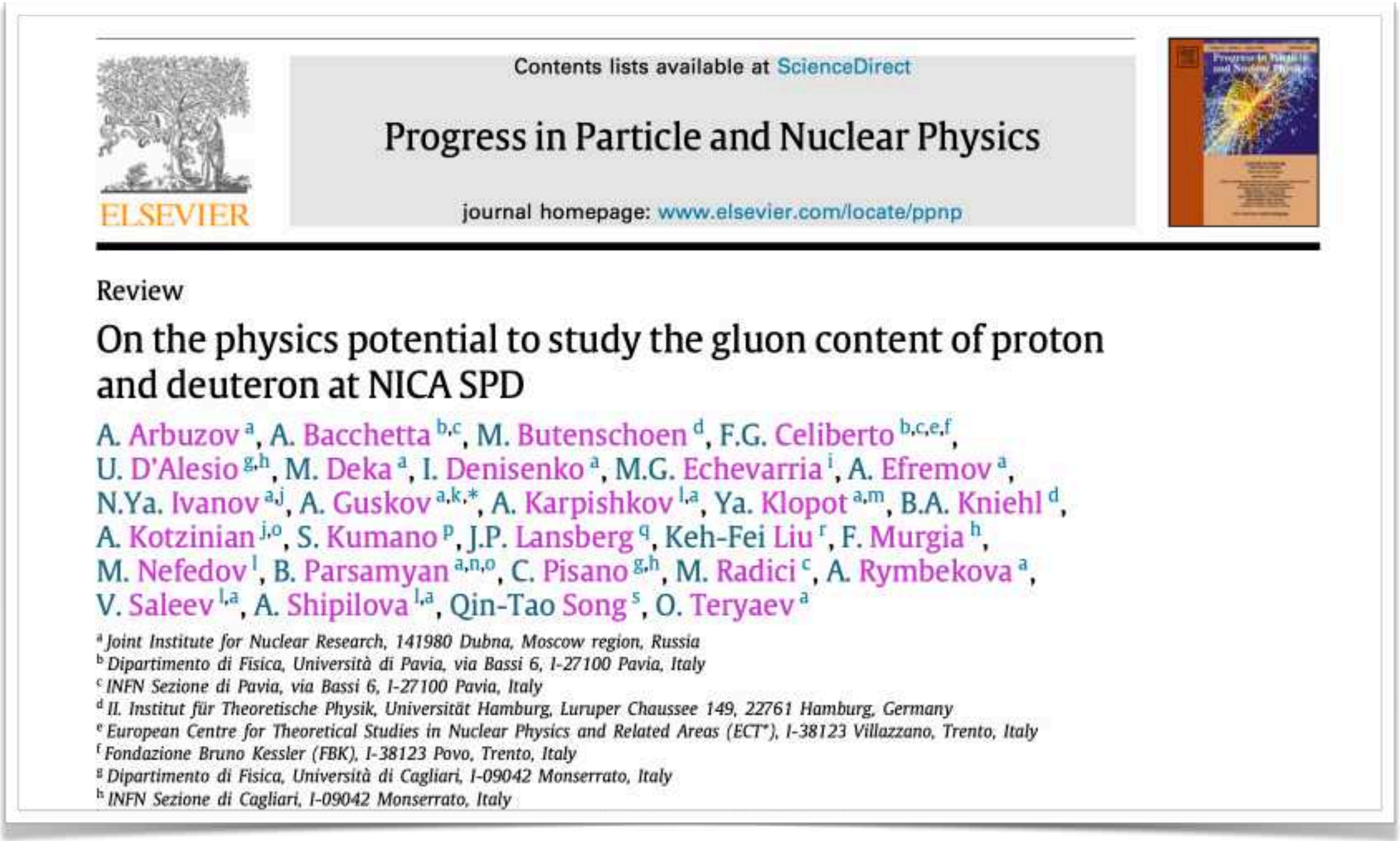
- *Spin effects in hadroproduction*
- *Polarization of hyperons and charmonia*
- *Spin correlations*



- *Other spin-dependent phenomena*

- *Unpolarized physics*

SPD gluon physics programme



Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

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

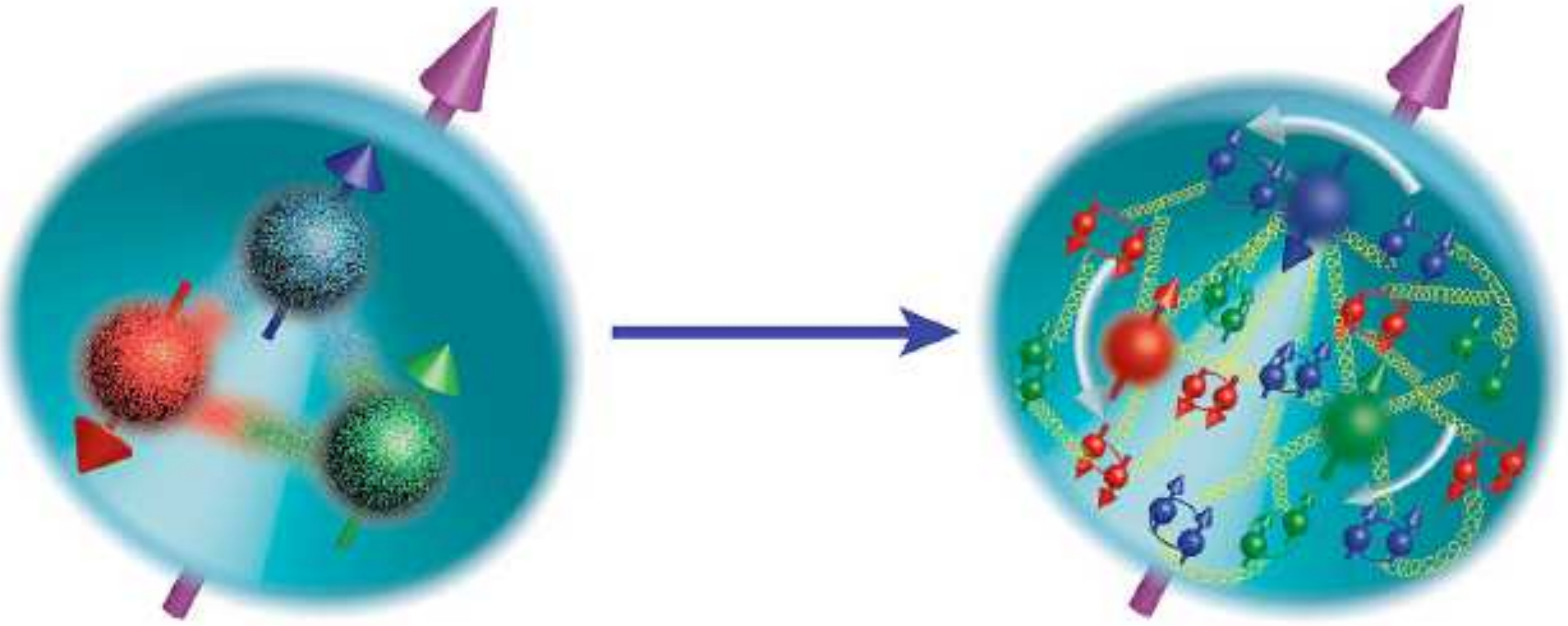
A. Arbuzov [a], A. Bacchetta [b,c], M. Butenschoen [d], F.G. Celiberto [b,c,e,f], U. D'Alesio [g,h], M. Deka [a], I. Denisenko [a], M.G. Echevarria [i], A. Efremov [a], N.Ya. Ivanov [a,j], A. Guskov [a,k,*], A. Karpishkov [l,a], Ya. Klopot [a,m], B.A. Kniehl [d], A. Kotzinian [j,o], S. Kumano [p], J.P. 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]

[a] Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
[b] Dipartimento di Fisica, Università di Pavia, via Bassi 6, I-27100 Pavia, Italy
[c] INFN Sezione di Pavia, via Bassi 6, I-27100 Pavia, Italy
[d] II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
[e] European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), I-38123 Villazzano, Trento, Italy
[f] Fondazione Bruno Kessler (FBK), I-38123 Povo, Trento, Italy
[g] Dipartimento di Fisica, Università di Cagliari, I-09042 Monserrato, Italy
[h] INFN Sezione di Cagliari, I-09042 Monserrato, Italy

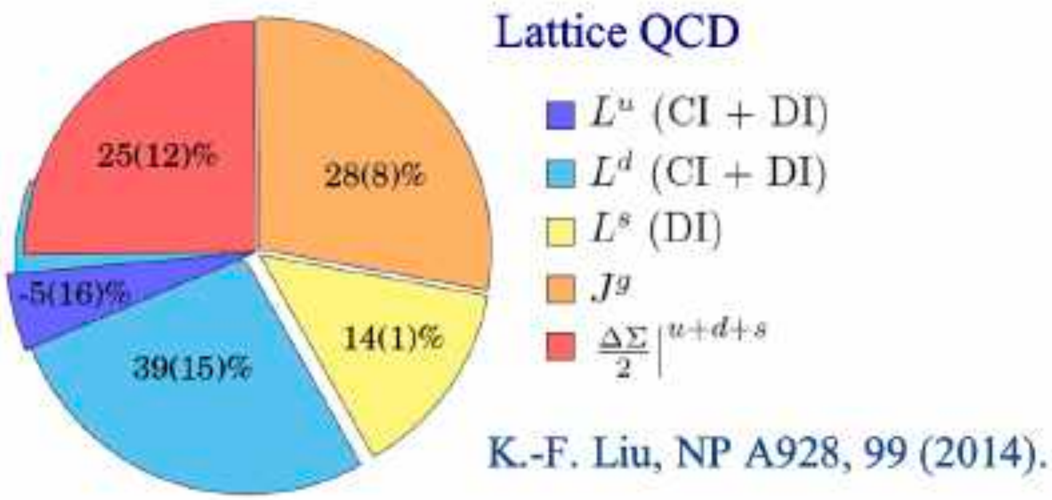
Prog.Part.Nucl.Phys. **119 (2021) 103858**

arXiv:2011.15005

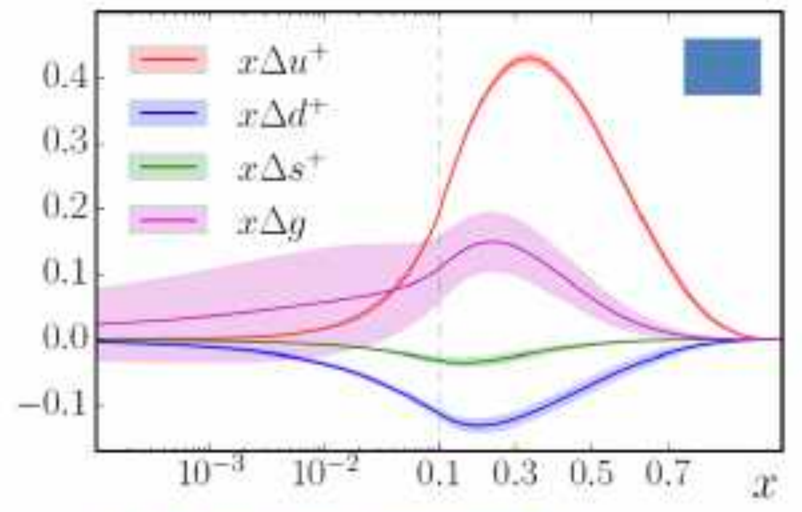
Proton spin crisis



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



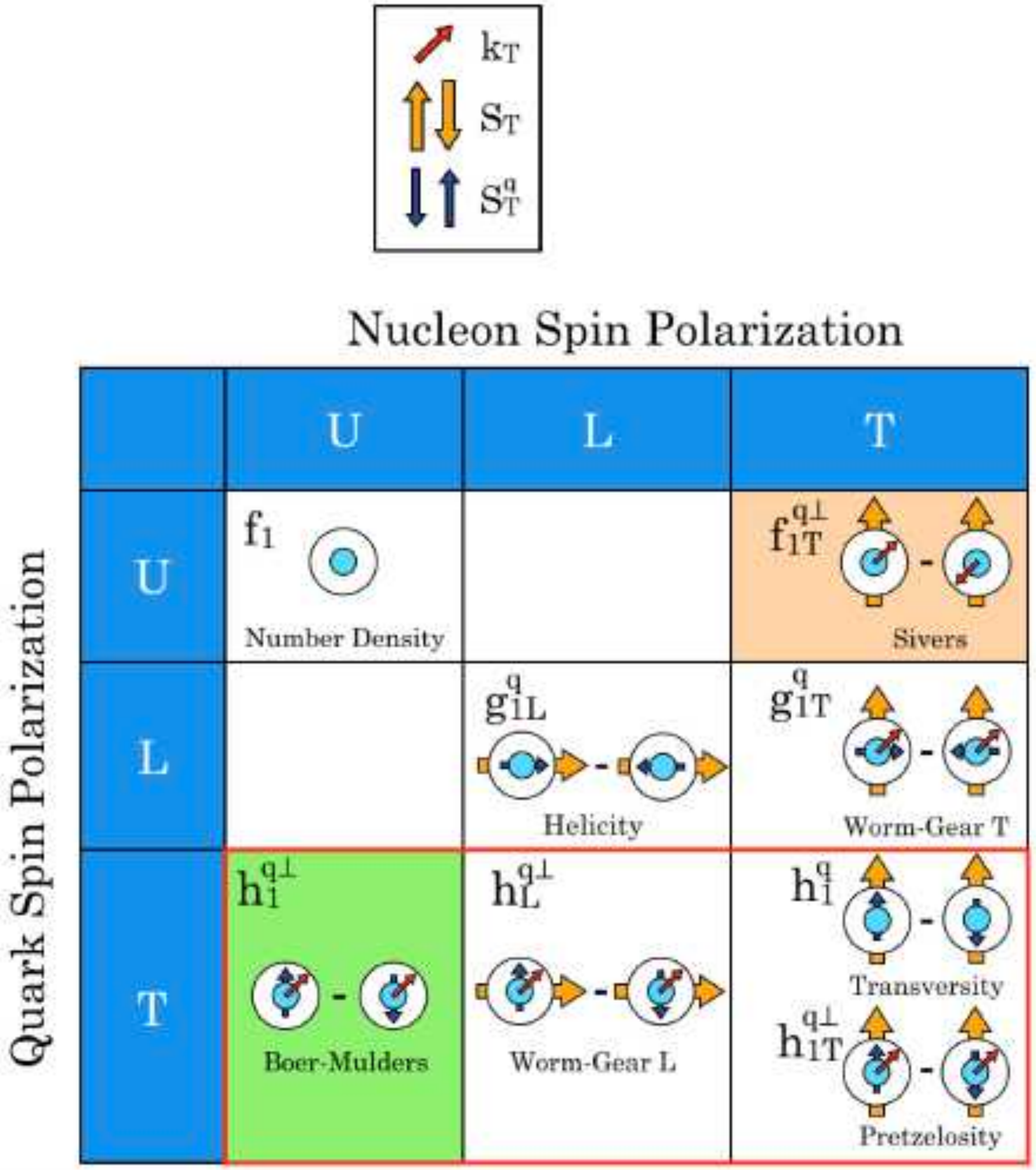
K.-F. Liu, NP A928, 99 (2014).



JAM Collaboration, PRD (2016).

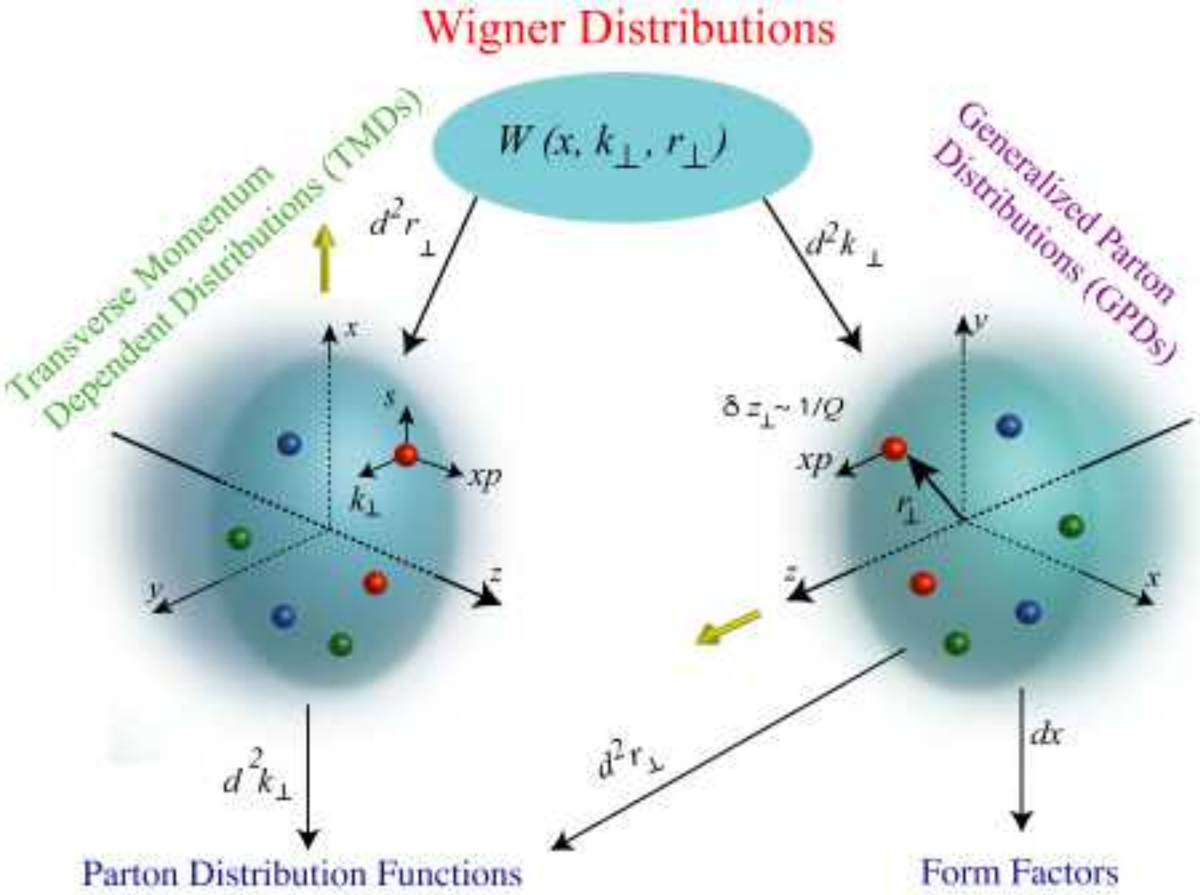
No chance to disentangle proton spin puzzle without understanding its 3D structure!

Proton in 3D: TMDs and GPDs



	U	L	T
U	f_1 Number Density		$f_{1T}^{q\perp}$ Sivers
L		g_{1L}^q Helicity	g_{1T}^q Worm-Gear T
T	$h_1^{q\perp}$ Boer-Mulders	$h_{1L}^{q\perp}$ Worm-Gear L	h_1^q Transversity $h_{1T}^{q\perp}$ Pretzelosity

TMD PDFs



Partonic structure of proton

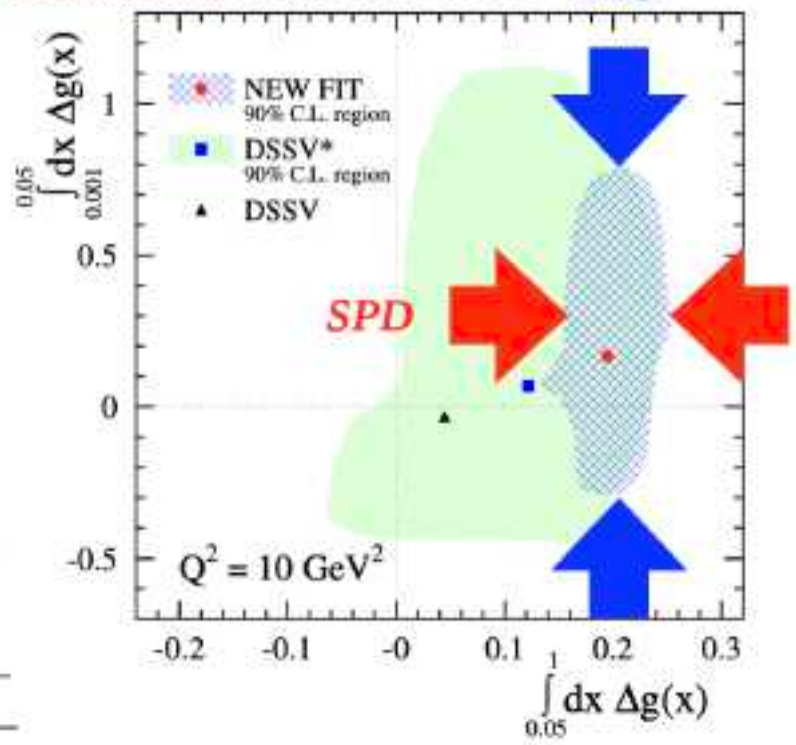
Prog.Part.Nucl.Phys. 119 (2021) 103858 arXiv:2011.15005

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

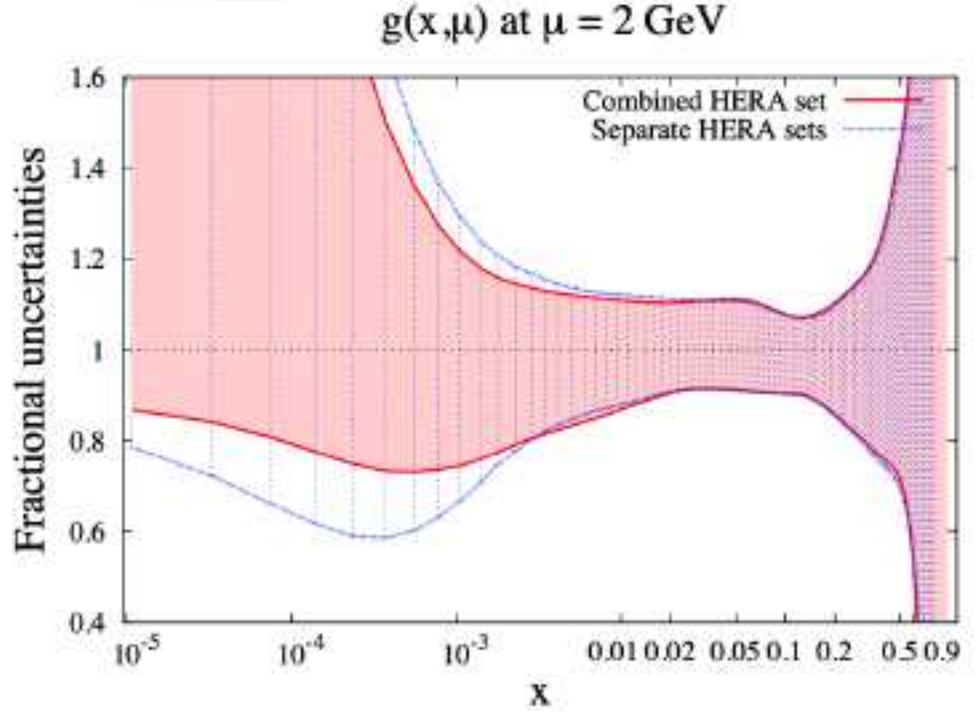
Spin crisis:

Gluon helicity

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

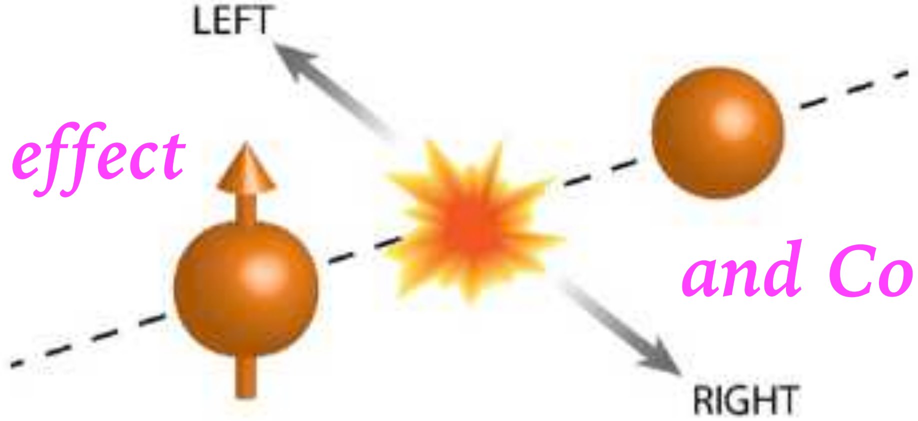


Unpolarized gluons in proton at high x:



Gluon and quark TMD PDFs:

Sivers effect

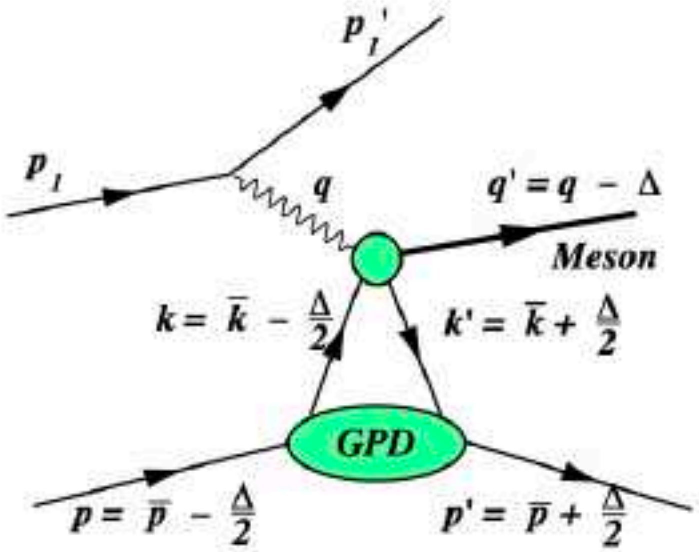


and Collins effect

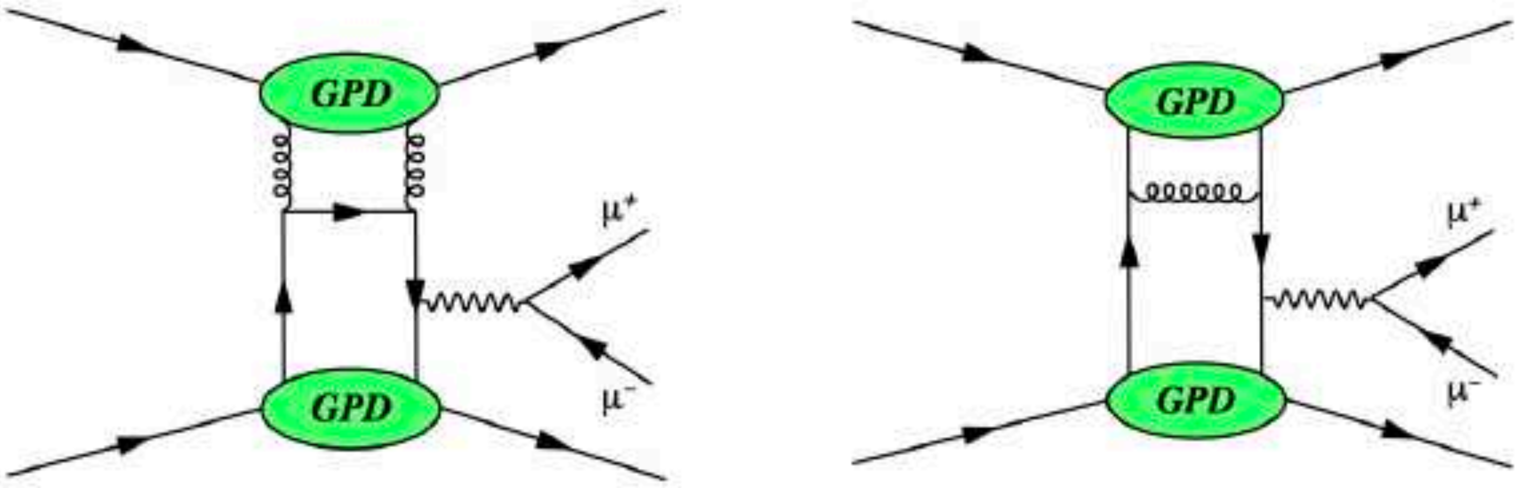
Spin-dependent fragmentation functions

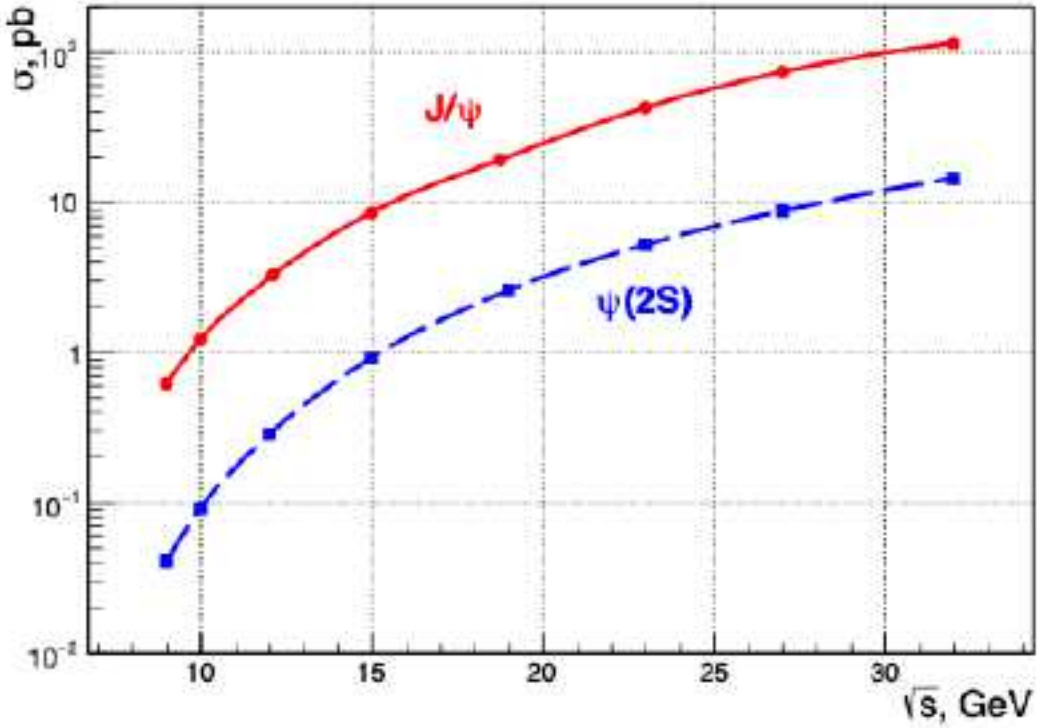
GPDs at SPD

GPDs is not a priority goal at SPD but potentially they could be accessed:



Exclusive Drell-Yan





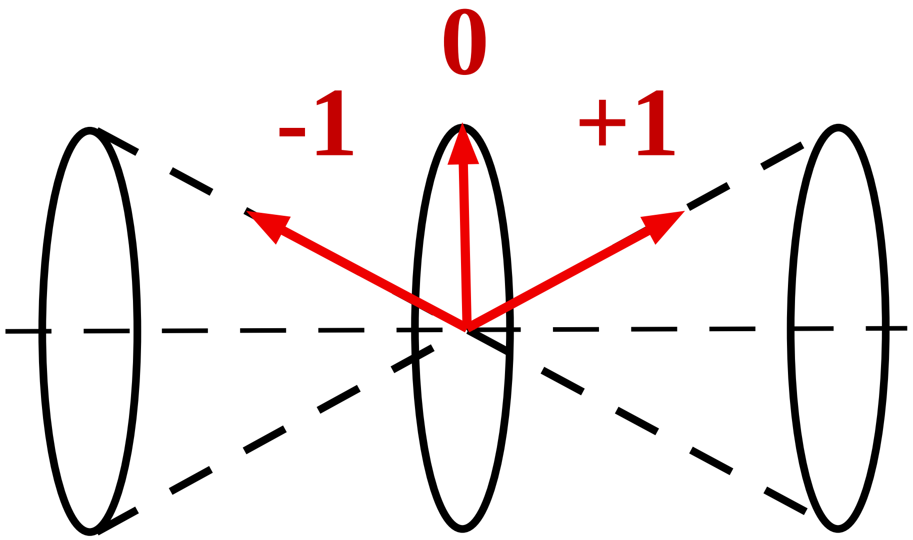
$$d\sigma/dQ^2 \sim 5\ pb/(GeV/c)^2$$
$$at\ \sqrt{s} = 24\ GeV\ and\ Q^2 = 5\ (GeV/c)^2$$

Deuteron

$\sigma(x_F,p_T)$, vector and tensor angular asymmetries

Nonbaryonic content of deuteron:

$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + c_3|CC\rangle$$



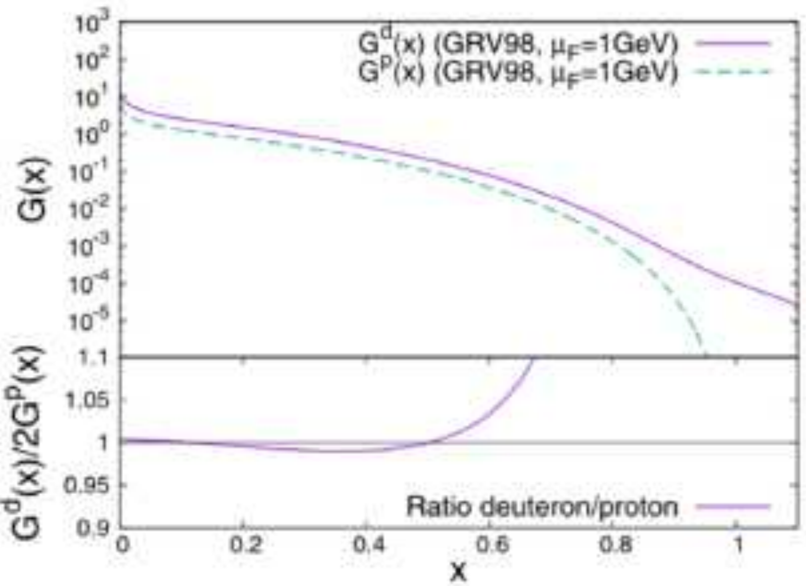
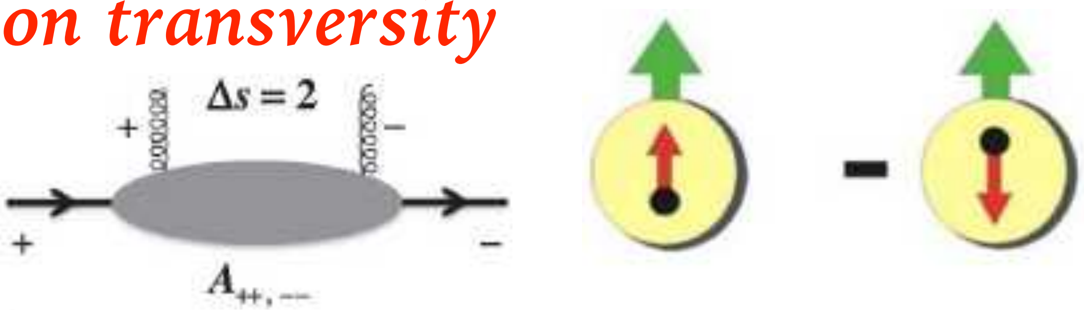


Fig. 6. Gluon PDF in the deuteron and in the nucleon.

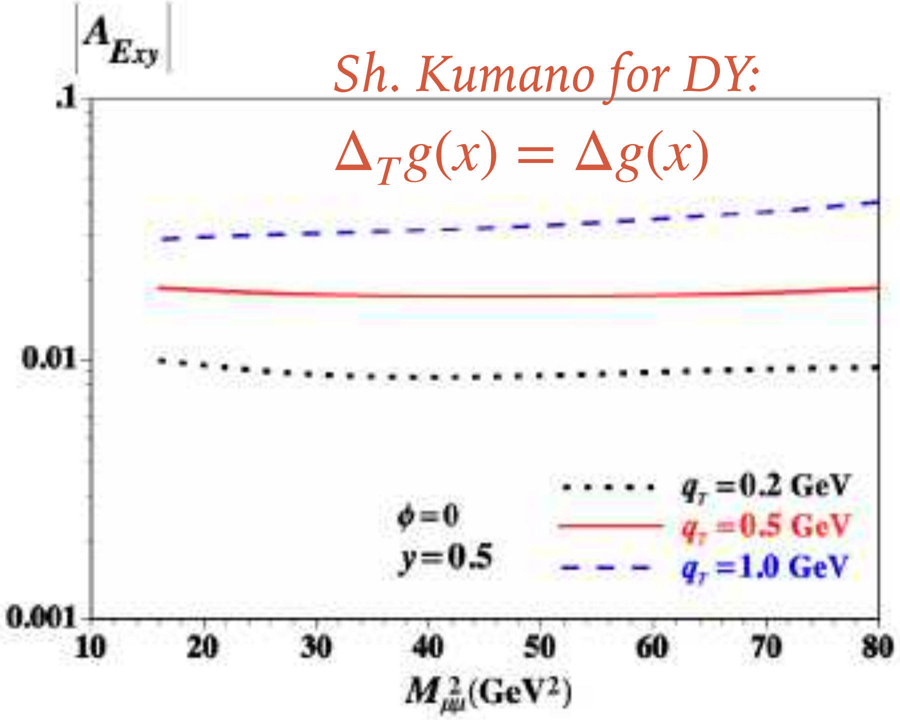
Unpolarized gluons at high x:

Gluon transversity

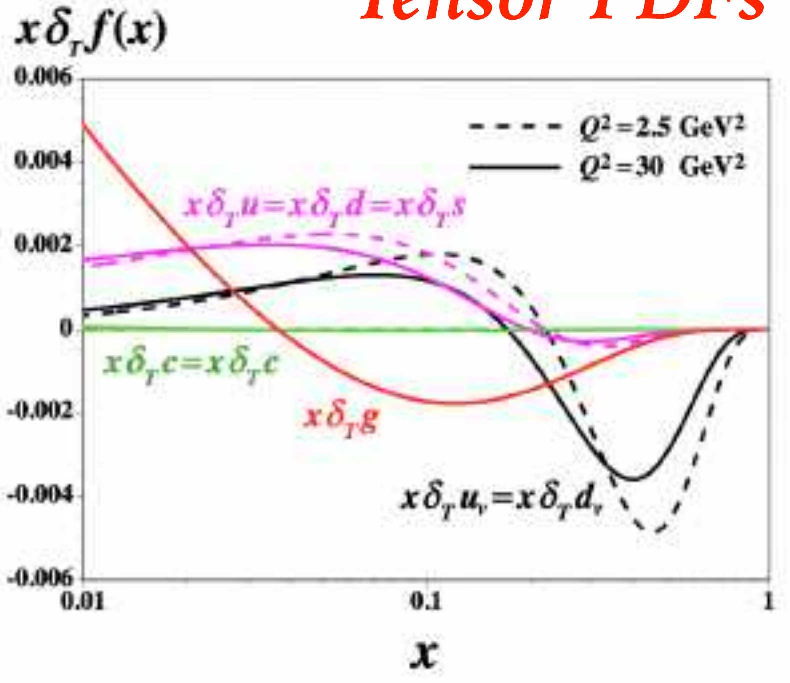


Sh. Kumano for DY:

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

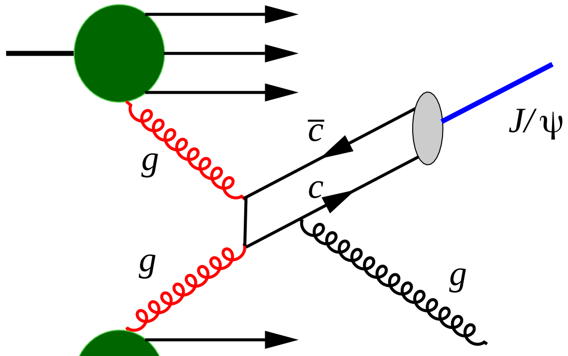


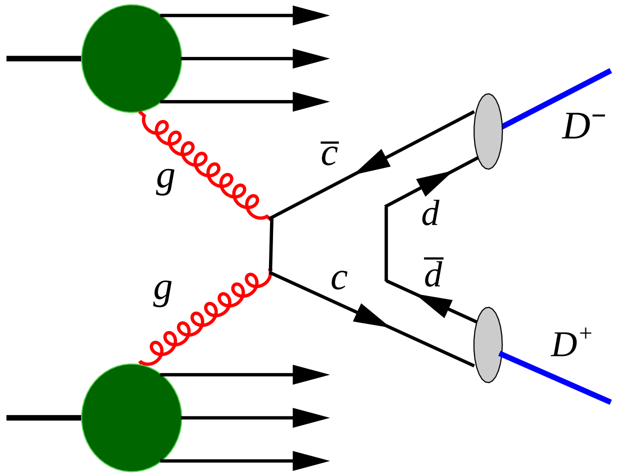
Tensor PDFs

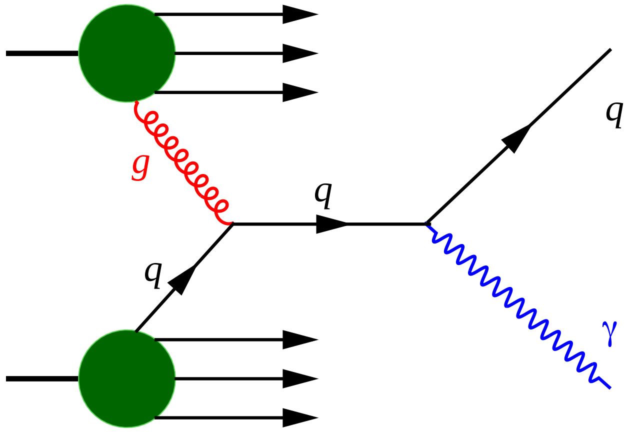


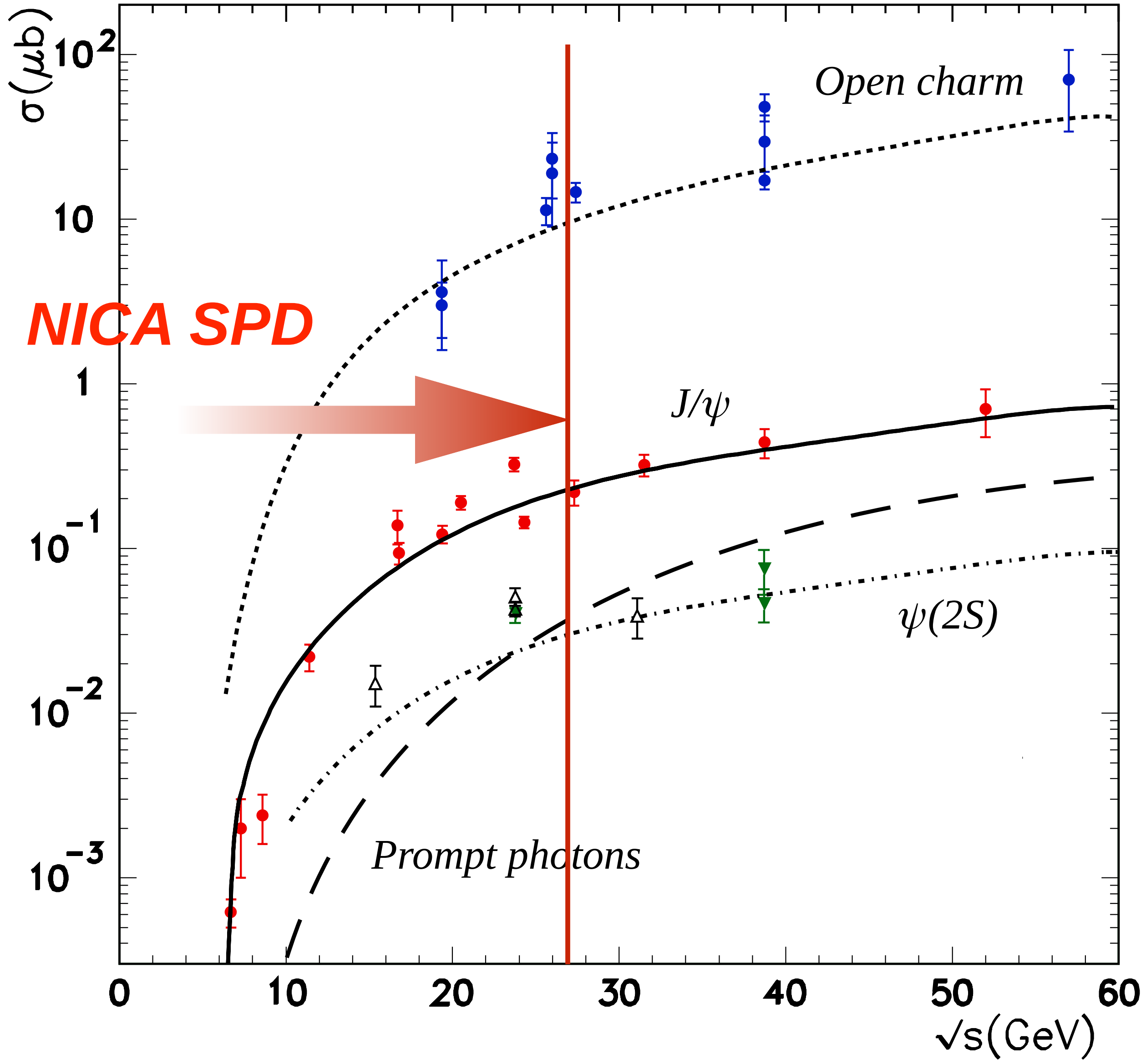
SPD golden probes

Not only J/ψ!



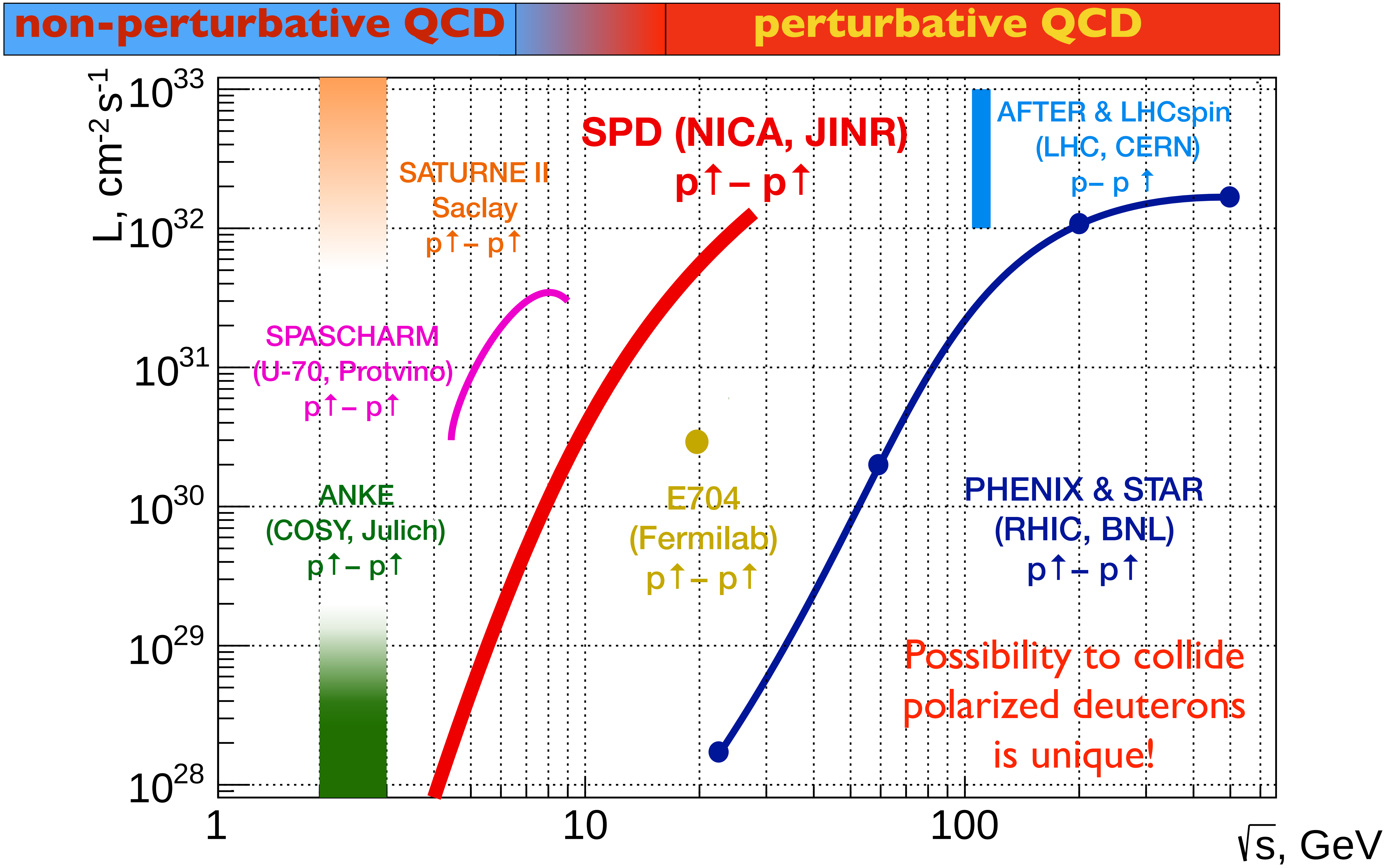






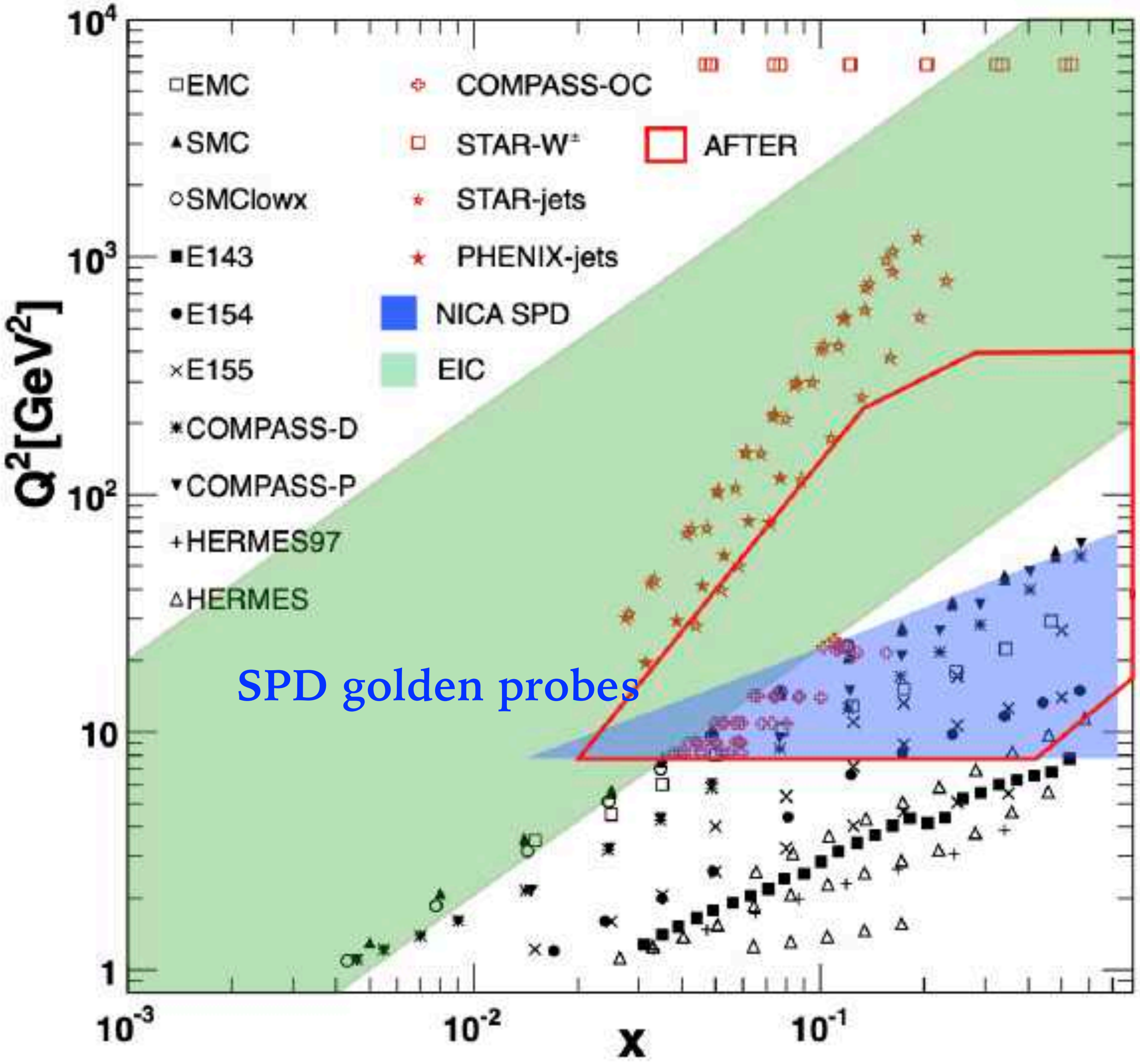
These golden probes define the layout of the SPD experimental setup.

SPD and other polarized pp exps

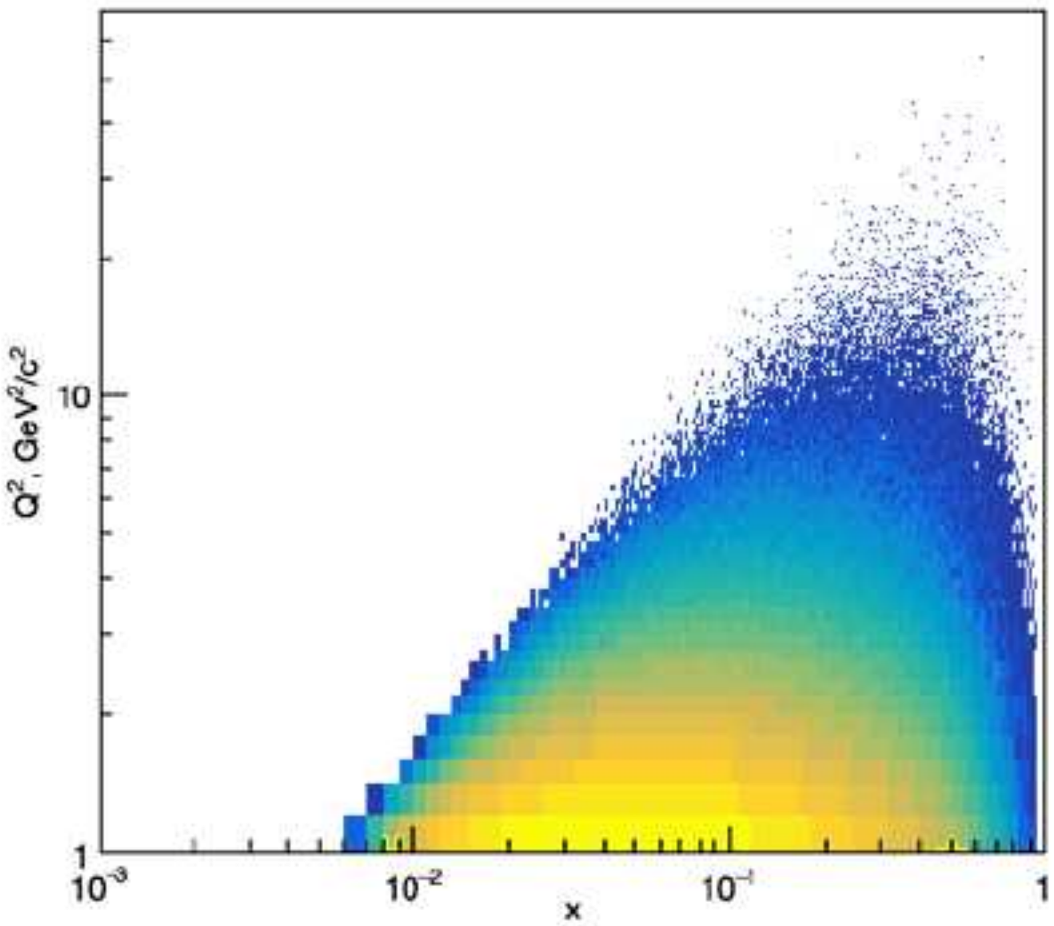


Possibility to collide polarized deuterons is unique!

SPD and others



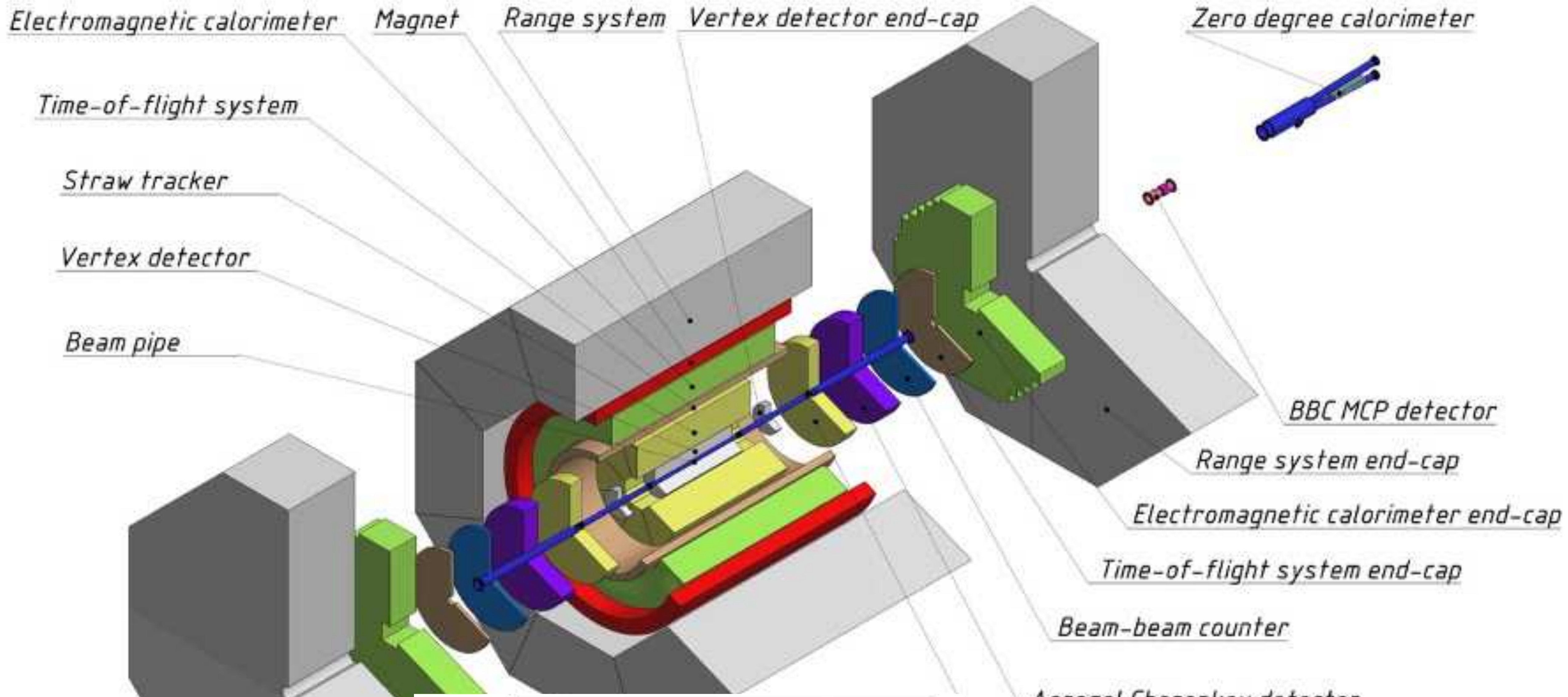
SPD golden probes

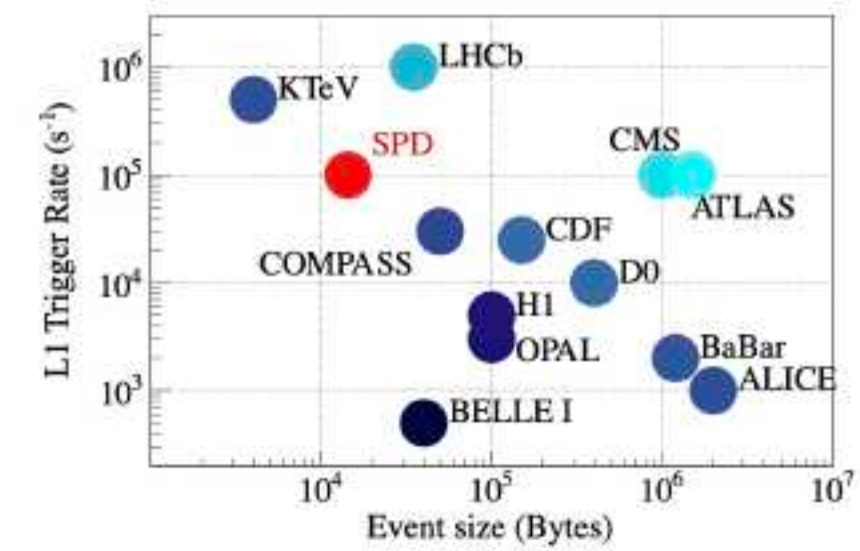


$$Q^2 = 1\ GeV^2/c^2, <x> = 0.16$$

$$Q^2 = 10\ GeV^2/c^2, <x> = 0.3$$

SPD setup

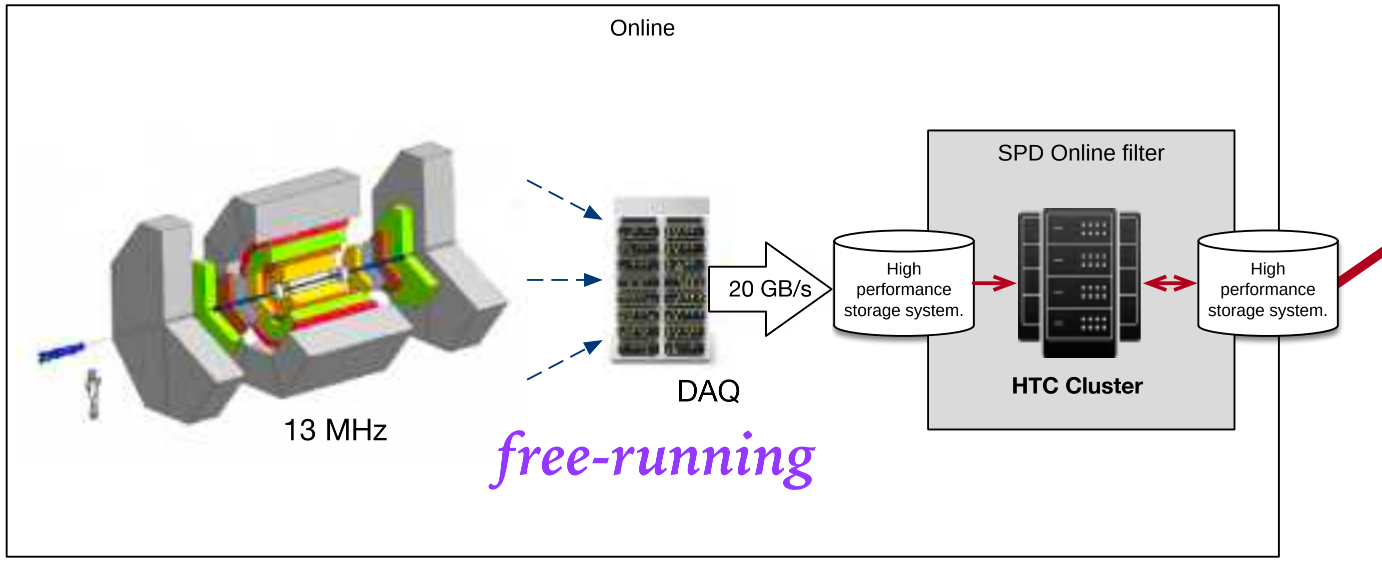




Free-running DAQ

IT infrastructure

SPD data flow



Online

13 MHz

DAQ

20 GB/s

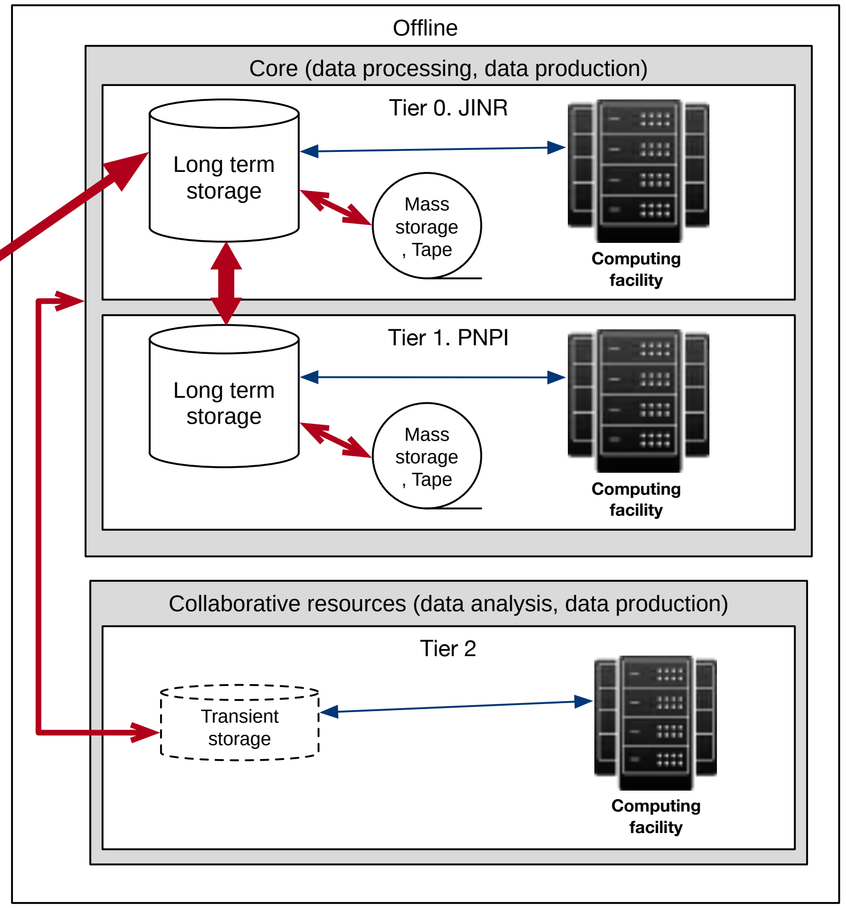
free-running

SPD Online filter

High performance storage system.

HTC Cluster

High performance storage system.



Offline

Core (data processing, data production)

Tier 0. JINR

Long term storage

Mass storage , Tape

Computing facility

Tier 1. PNPI

Long term storage

Mass storage , Tape

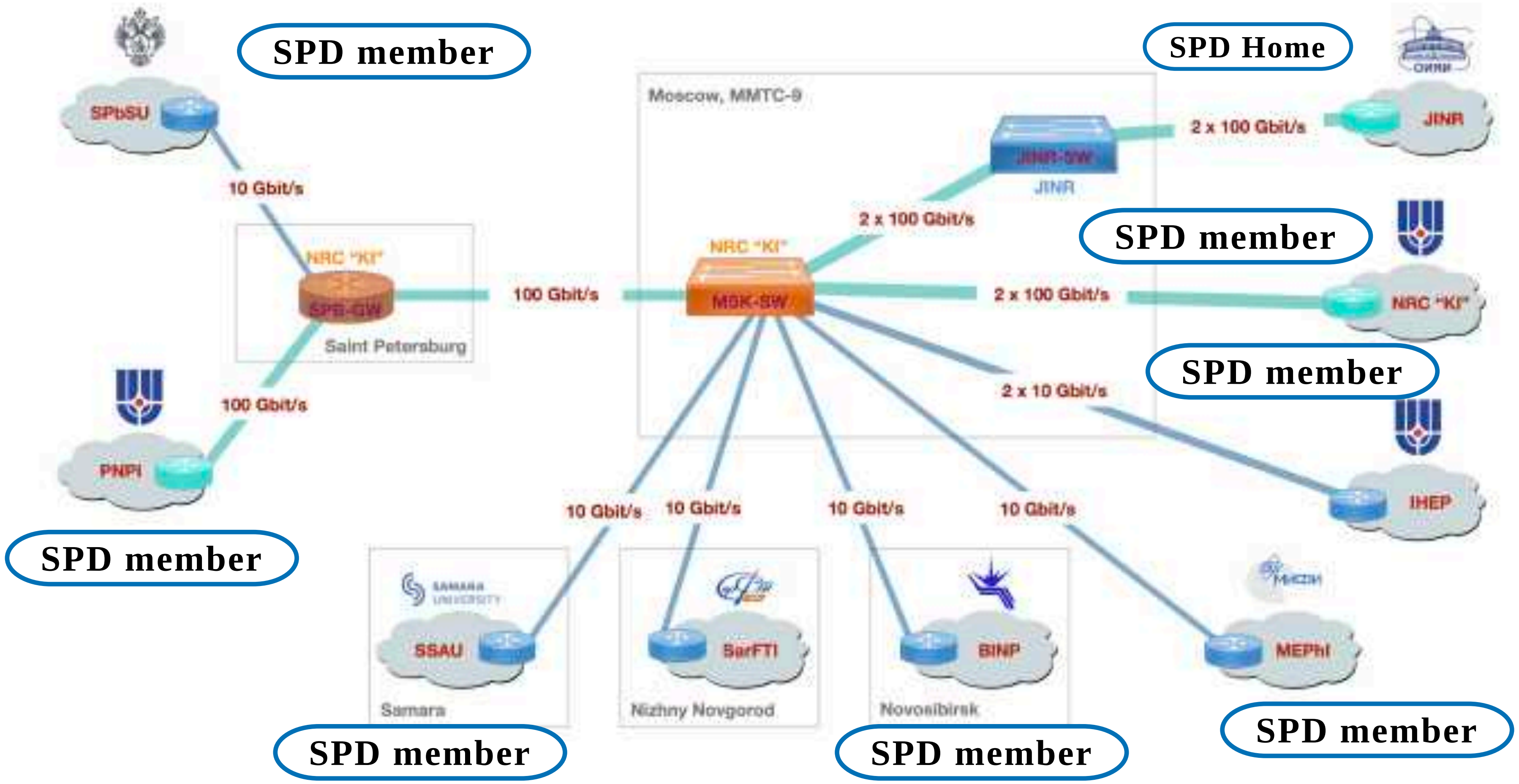
Computing facility

Collaborative resources (data analysis, data production)

Tier 2

Transient storage

Computing facility



SPD member

SPbSU

10 Gbit/s

NRC "KI" SPB-GW

Saint Petersburg

100 Gbit/s

PNPI

SPD member

Moscow, MMTC-9

JINR-SW

JINR

2 x 100 Gbit/s

SPD Home

JINR

2 x 100 Gbit/s

NRC "KI"

MSK-SW

100 Gbit/s

SPD member

2 x 100 Gbit/s

NRC "KI"

SPD member

2 x 10 Gbit/s

IHEP

10 Gbit/s

10 Gbit/s

10 Gbit/s

10 Gbit/s

SSAU

Samara

SarFTI

Nizhny Novgorod

BINP

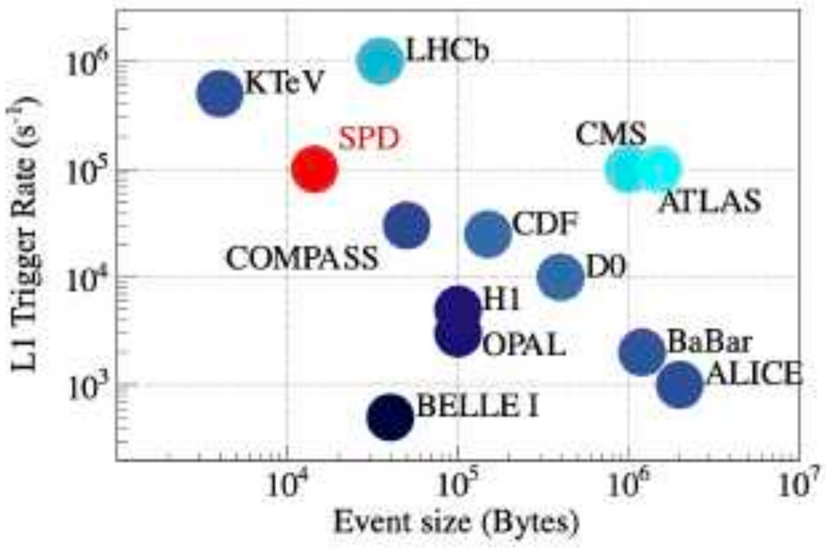
Novosibirsk

MEPhI

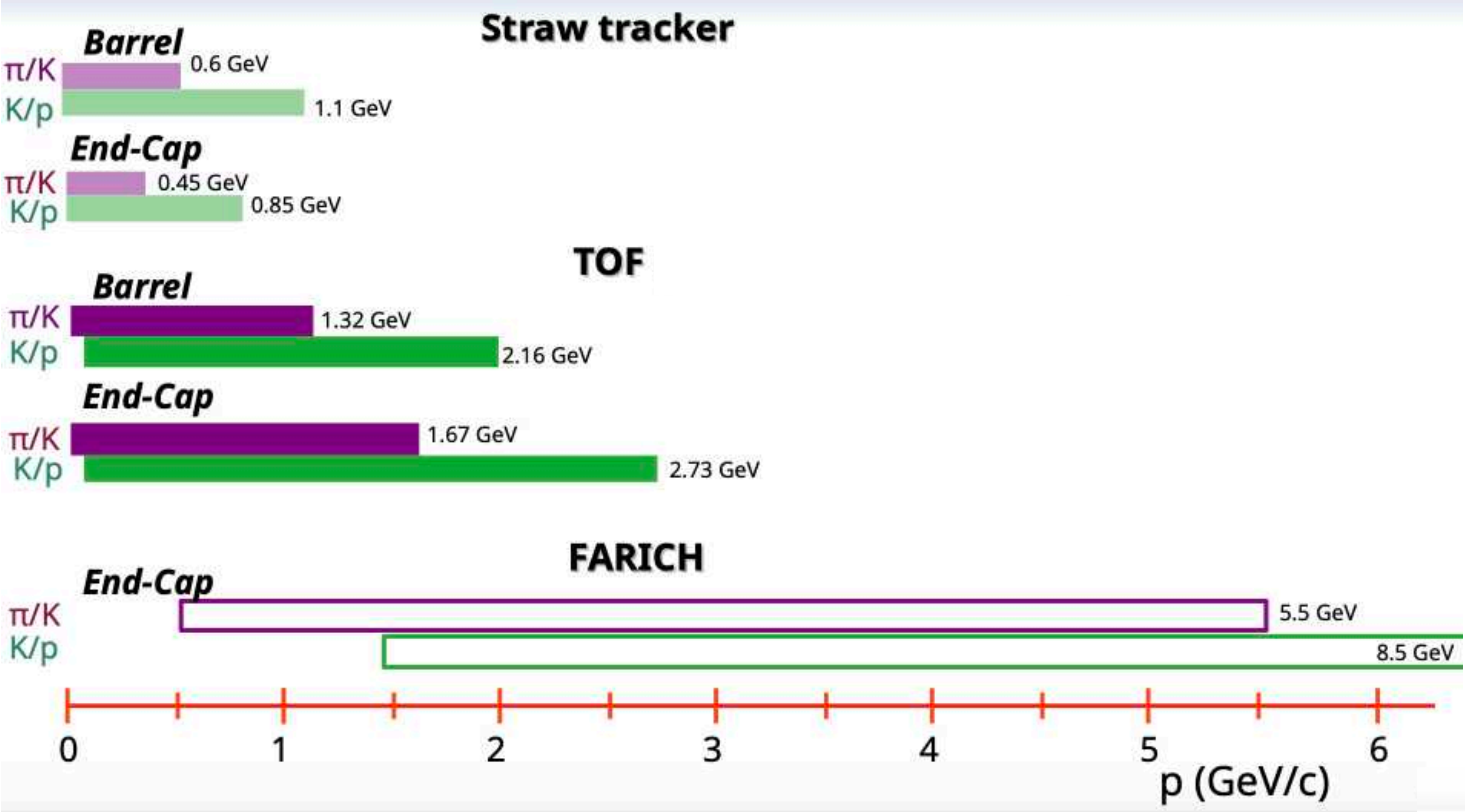
SPD member

SPD member

SPD member

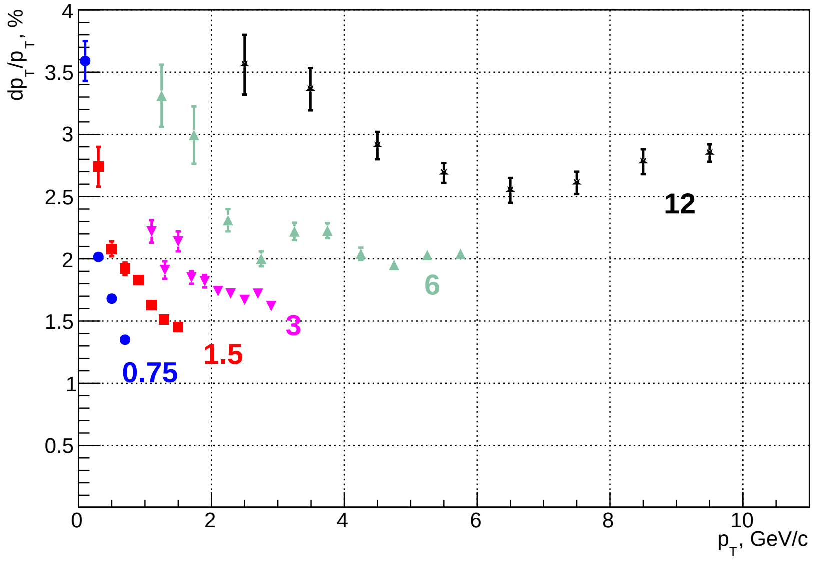


PID capabilities

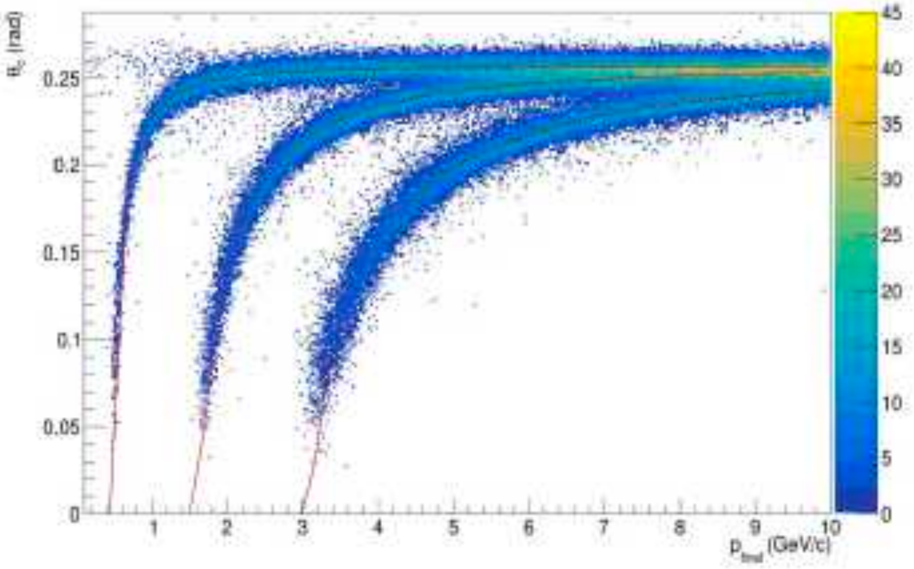


Detector performance

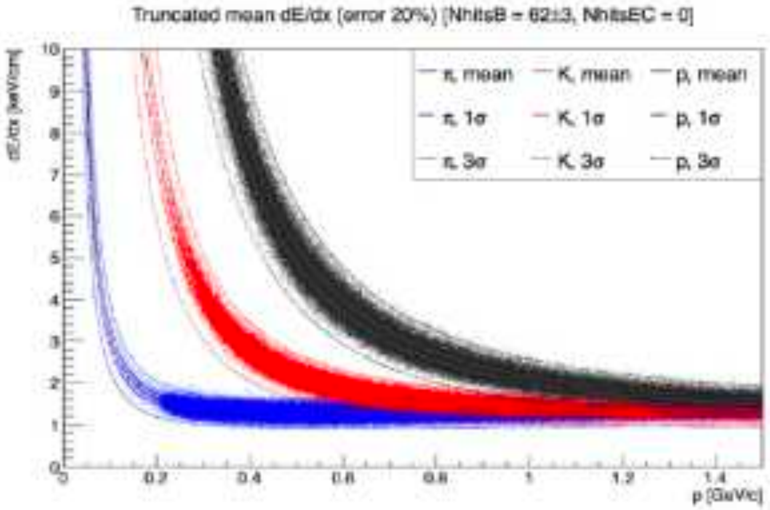
Momentum resolution

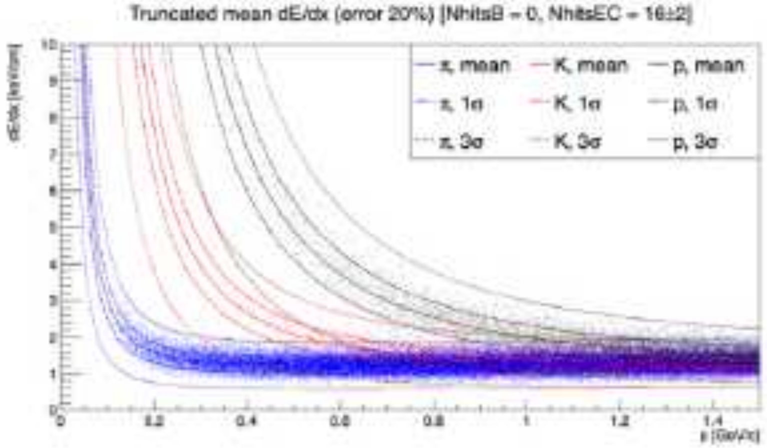


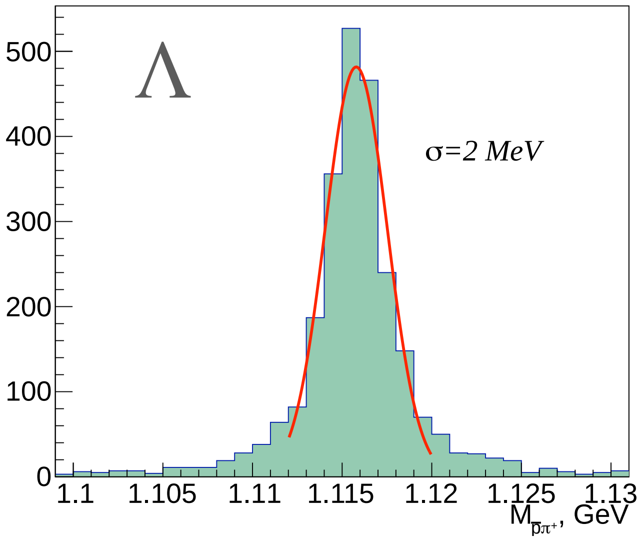
FARICH performance



dE/dx in Straw tracker

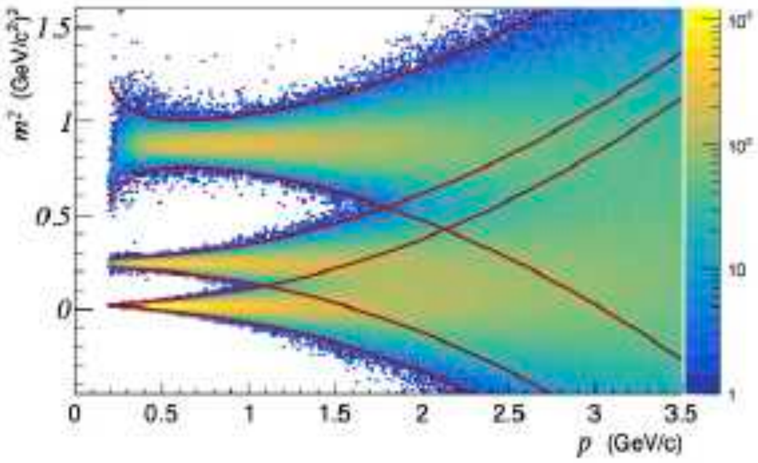




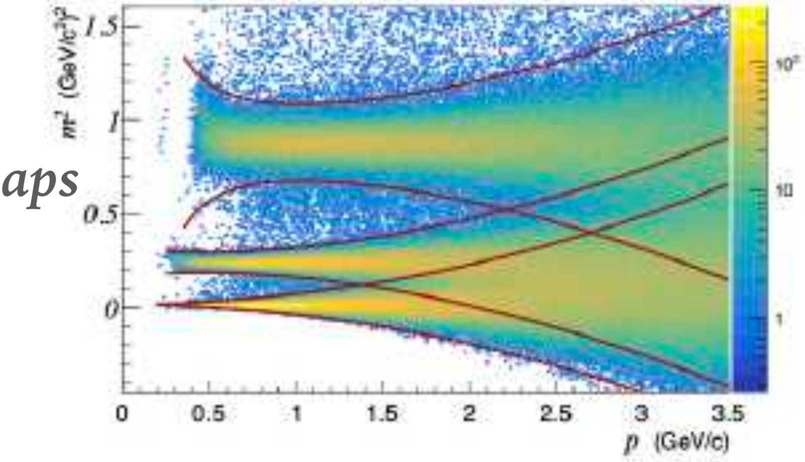


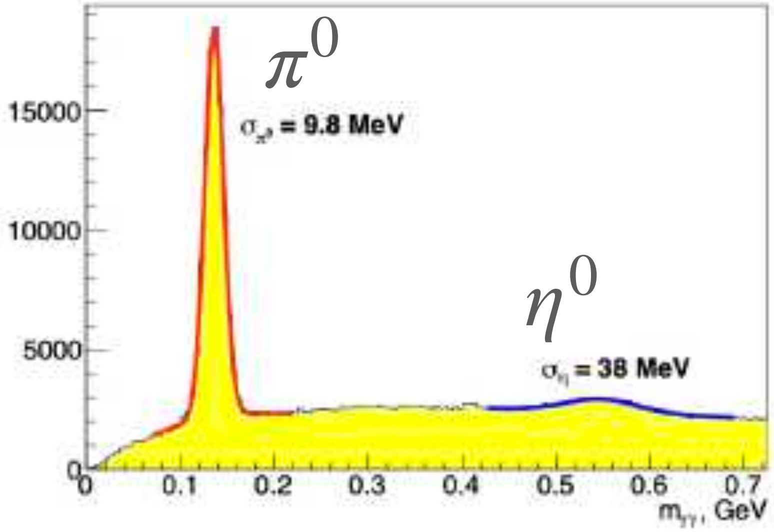
TOF performance

barrel



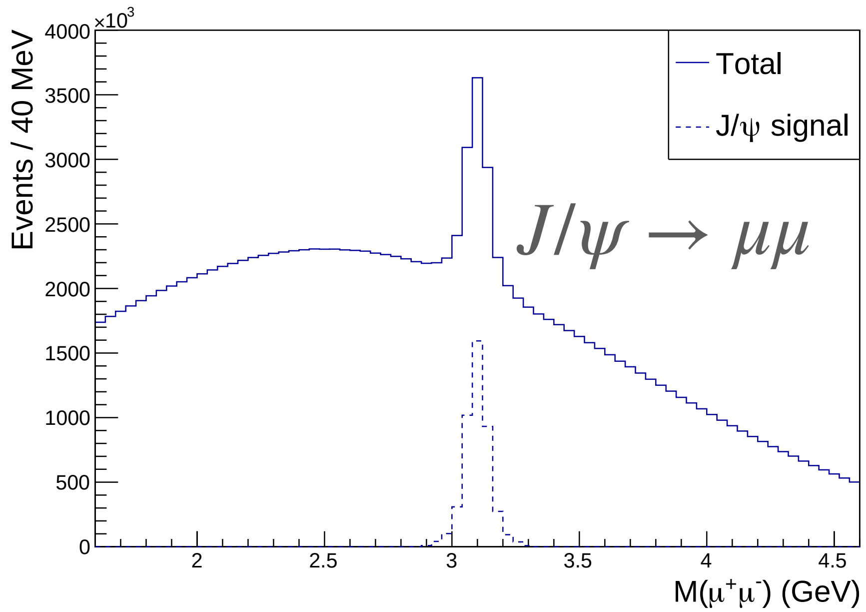
endcaps

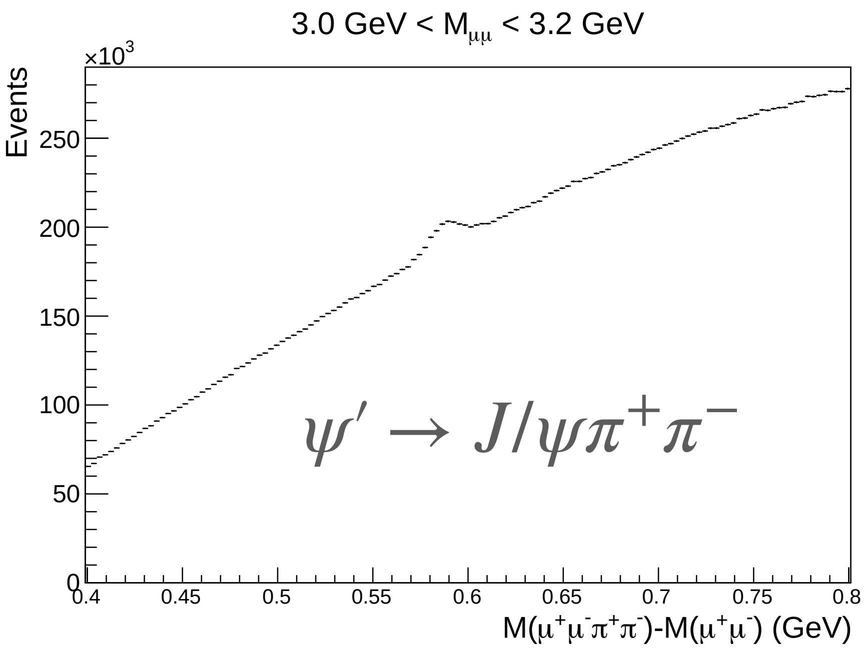


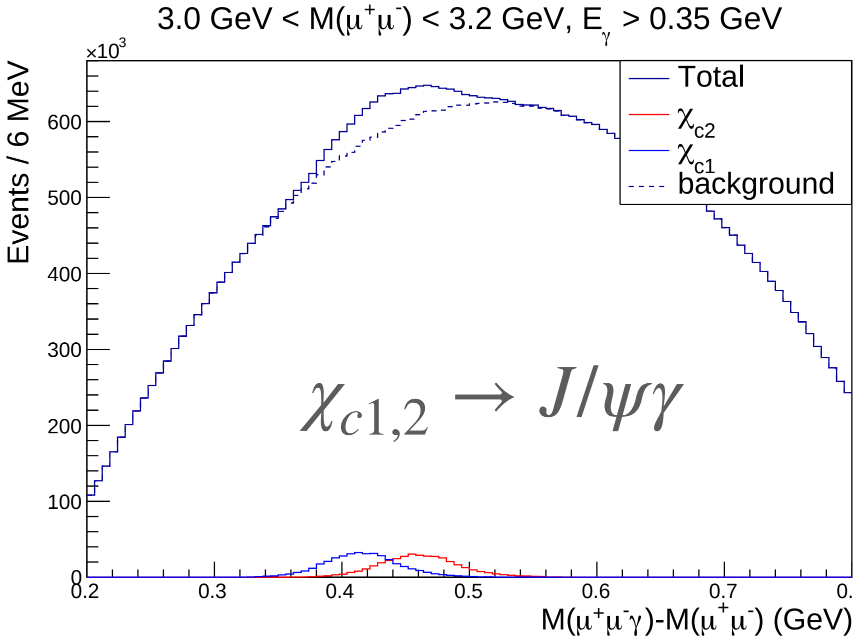


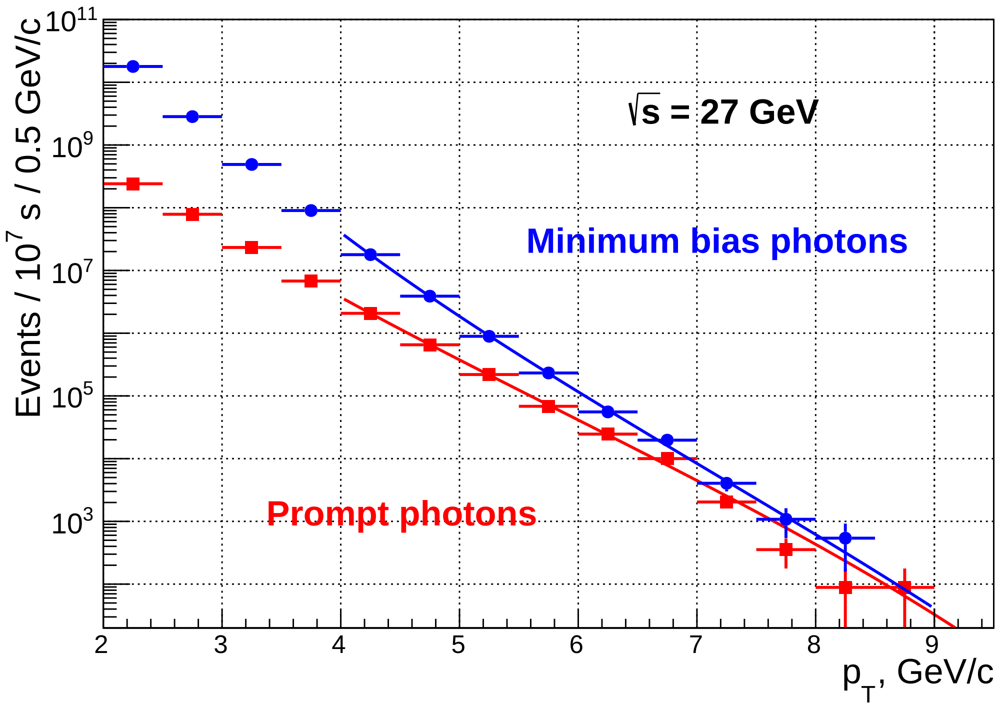
Physics performance: gluon probes

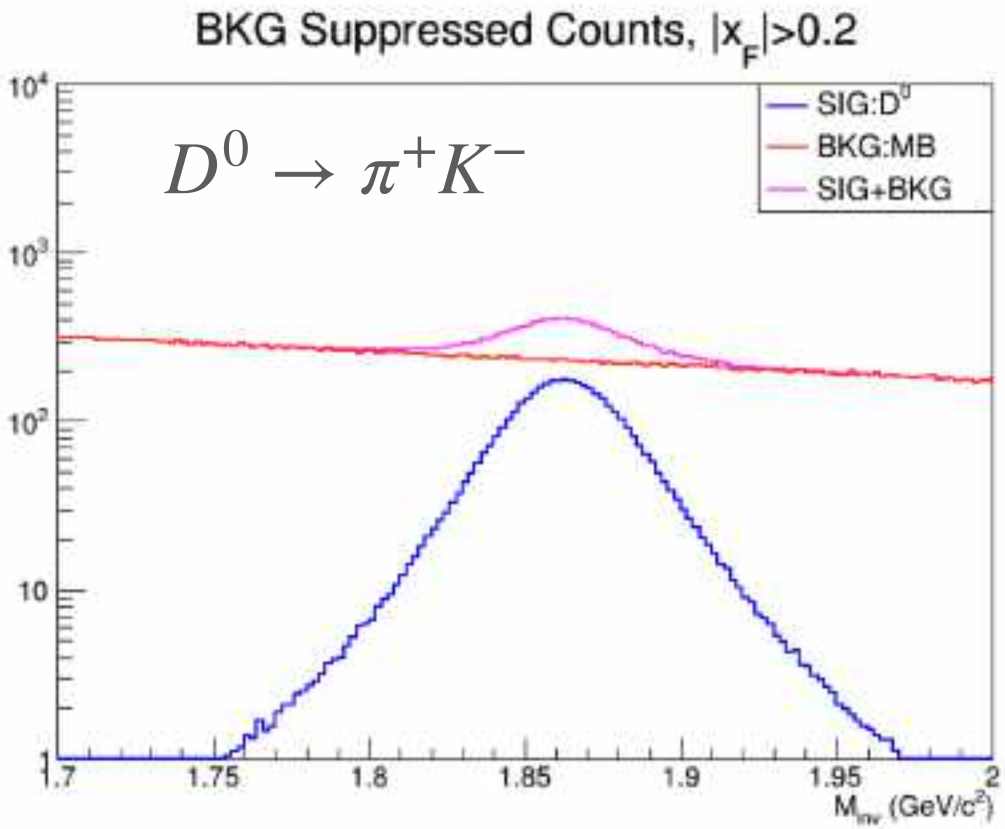
(1 year=10^7 s, 27 GeV)



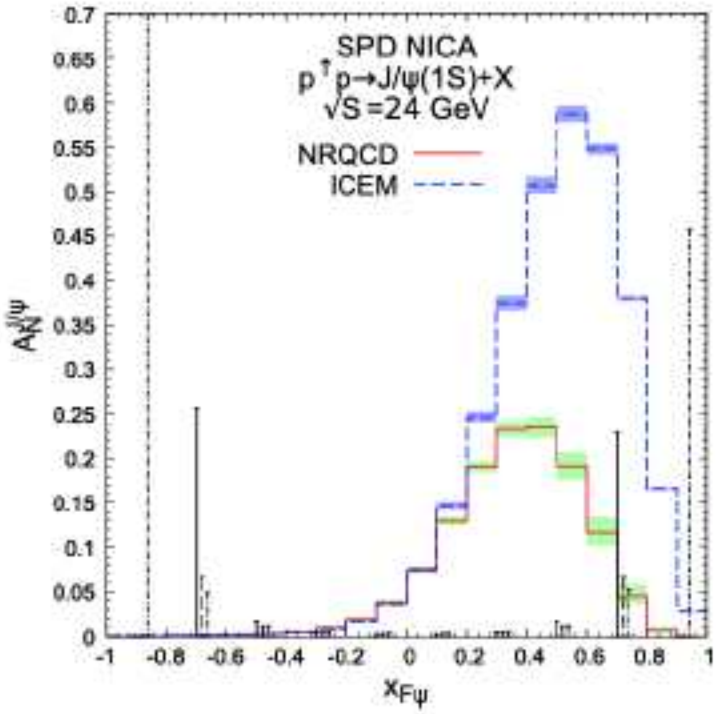




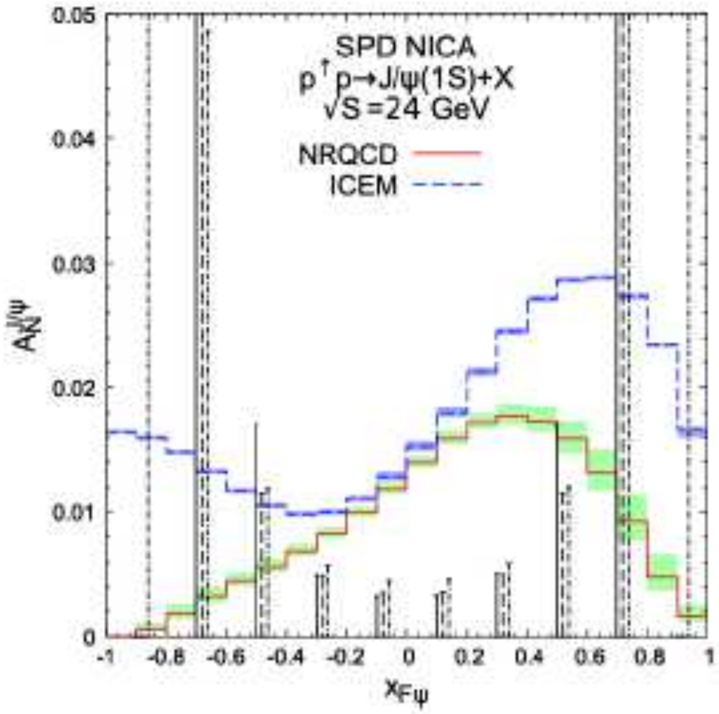




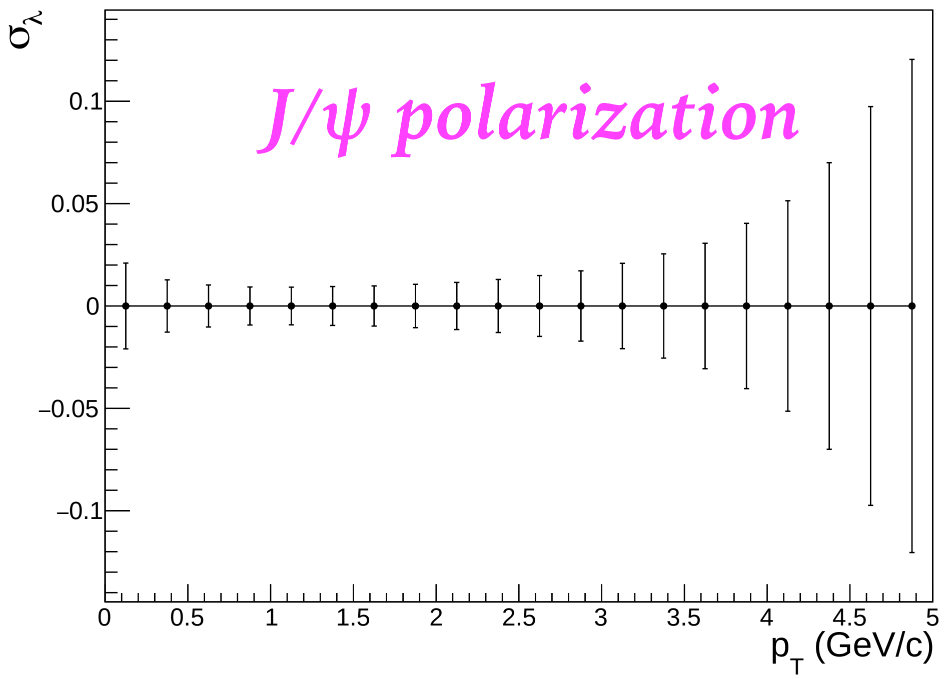
Physics performance: accuracies



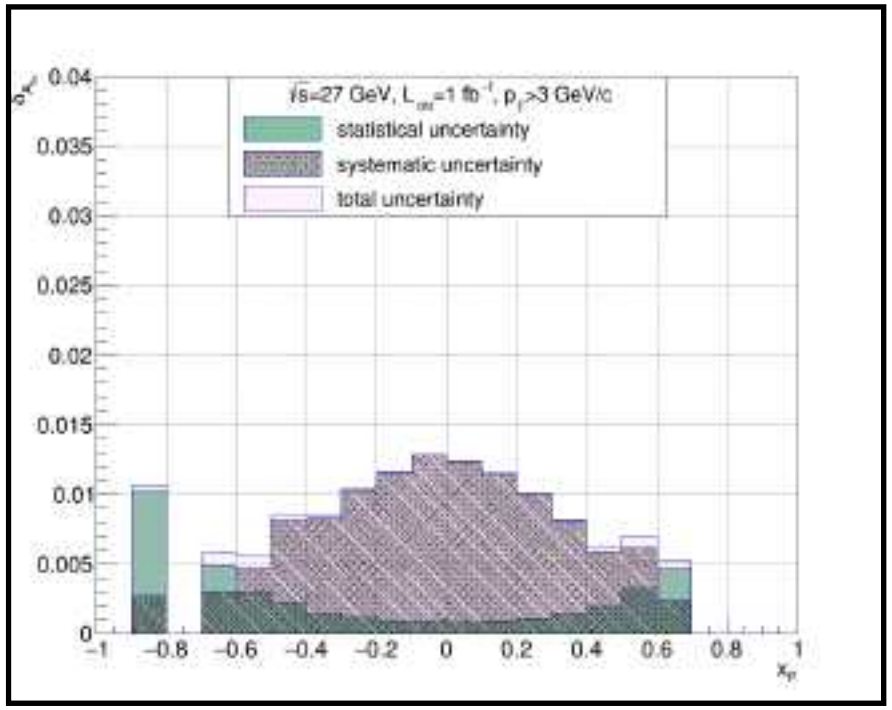
J/ψ



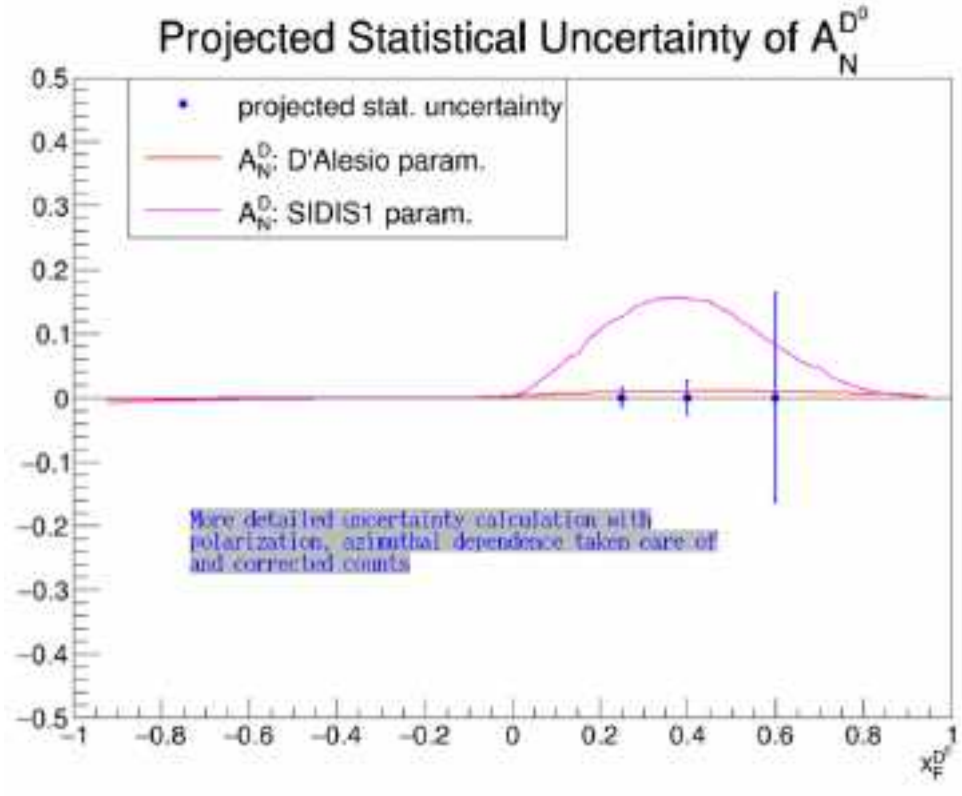
Different inputs for gluon Sivers function



J/ψ *polarization*



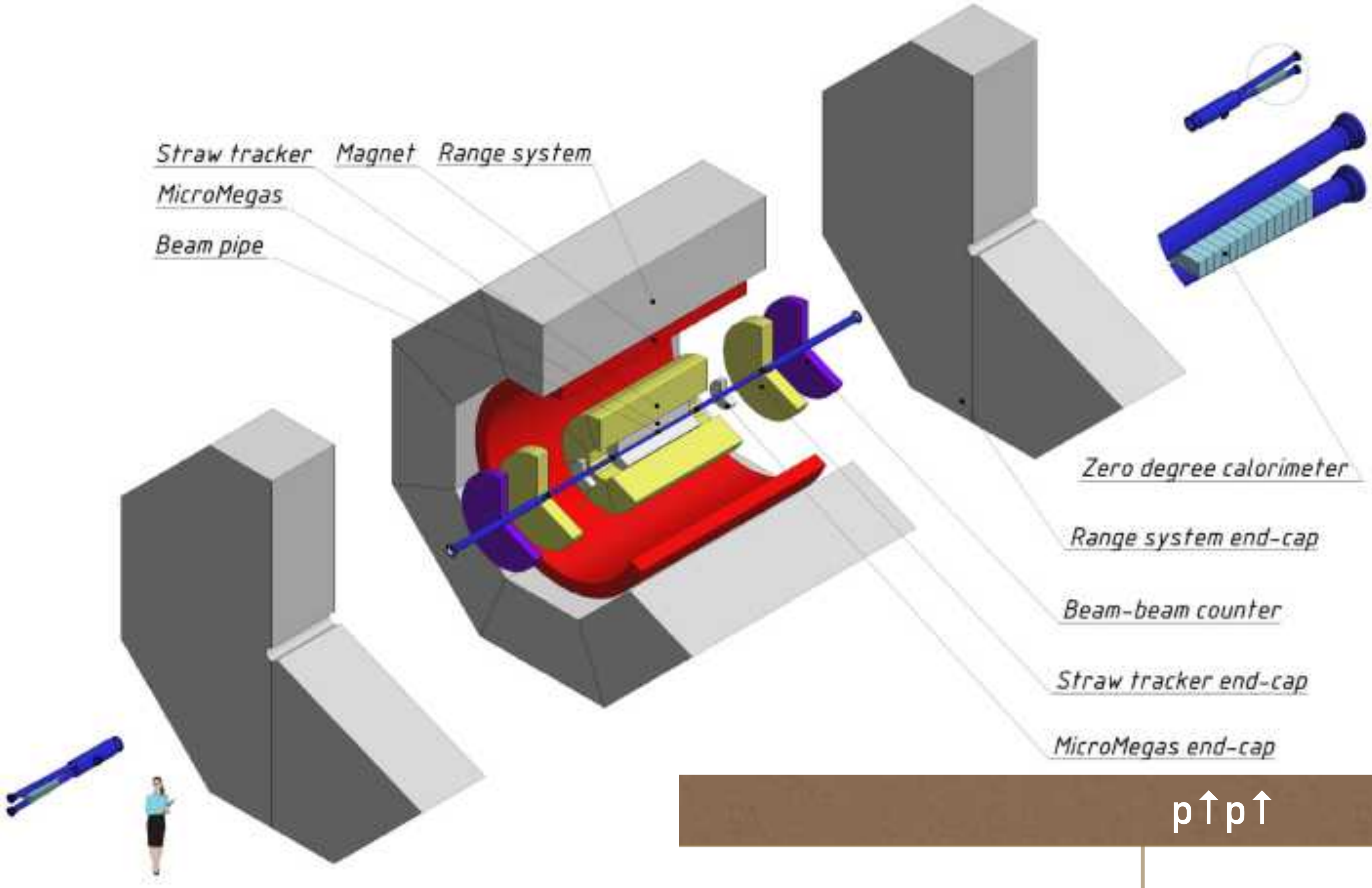
prompt-γ



More detailed uncertainty calculation with polarization, azimuthal dependence taken care of and corrected counts

D^0

SPD setup: 1st phase



	p↑p↑	d↑d↑	AA
	First phase		
$\sqrt{s_{NN}}$, GeV	< 9.4	< 4.5	< 4.5
L, 10^{30} cm^{-1} s^{-1}	< 10	< 1	< 0.001
	Second phase		
$\sqrt{s_{NN}}$, GeV	< 27	< 13.5	
L, 10^{30} cm^{-1} s^{-1}	< 100	< 10	

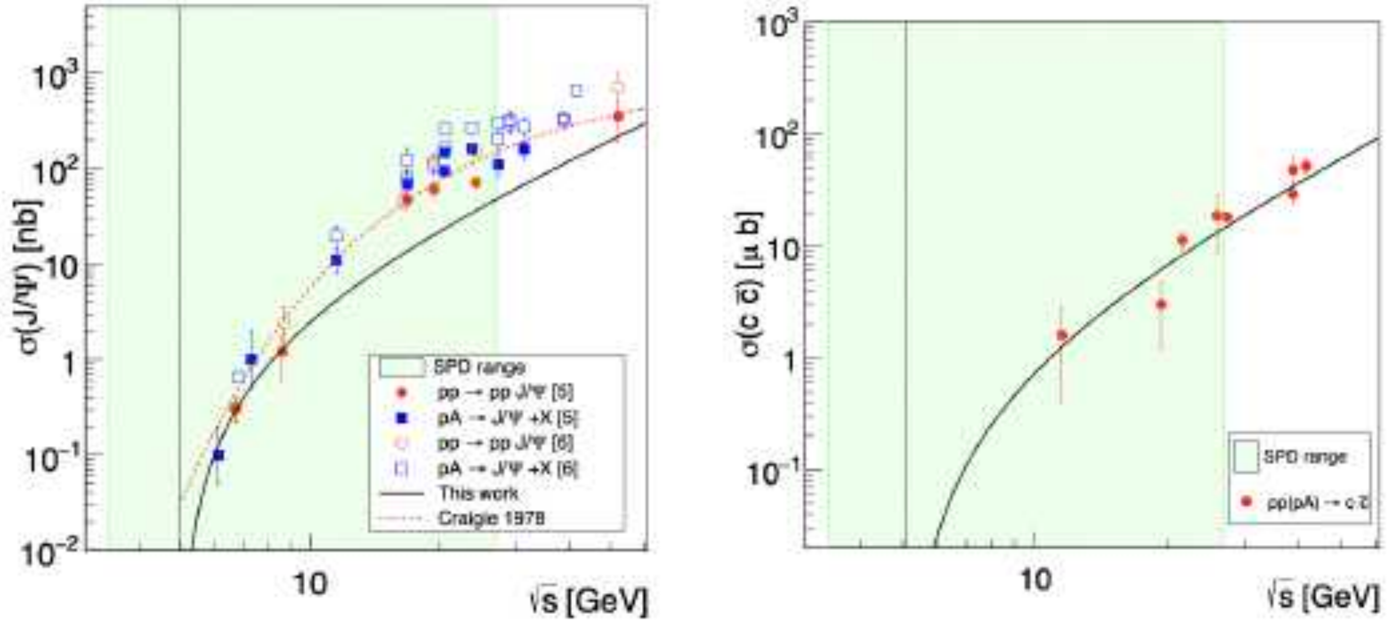
First-phase physics

arXiv:2102.08477 *Phys.Part.Nucl.* **52 (2021) 6, 1044-1119**

Non-perturbative QCD *Perturbative QCD*

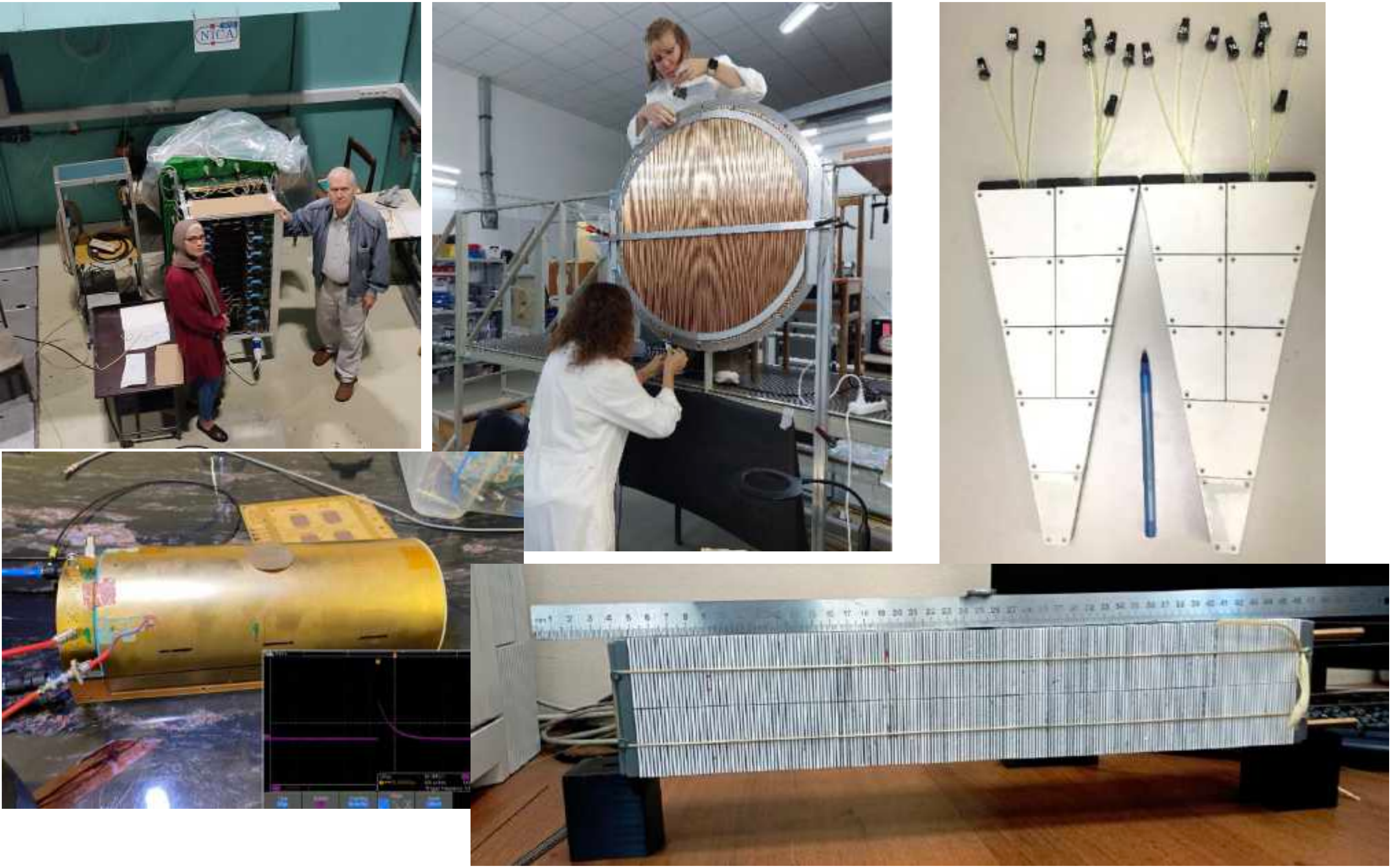
$\sqrt{s}$

- Spin effects in p-p, d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances $pp \to (6q)^* \to N\,N\,Mesons,$
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernucei $dd \to K^+ K^+ \, {}^{4}_{\Lambda\Lambda}\mathrm{n},$
- Open charm and charmonia near threshold



- Auxiliary measurements for astrophysics
- ...

Detector prototyping



Detector prototyping

SPD experimental hall

Status of the SPD project

SPD **Technical Design Report** passed international expertise and published:
Natural Sci. Rev. 1 1 (2024)
https://arxiv.org/abs/2404.08317

NATURAL
SCIENCE
REVIEW

ISSUE 1
DECEMBER 2024

nsr.jinr.int

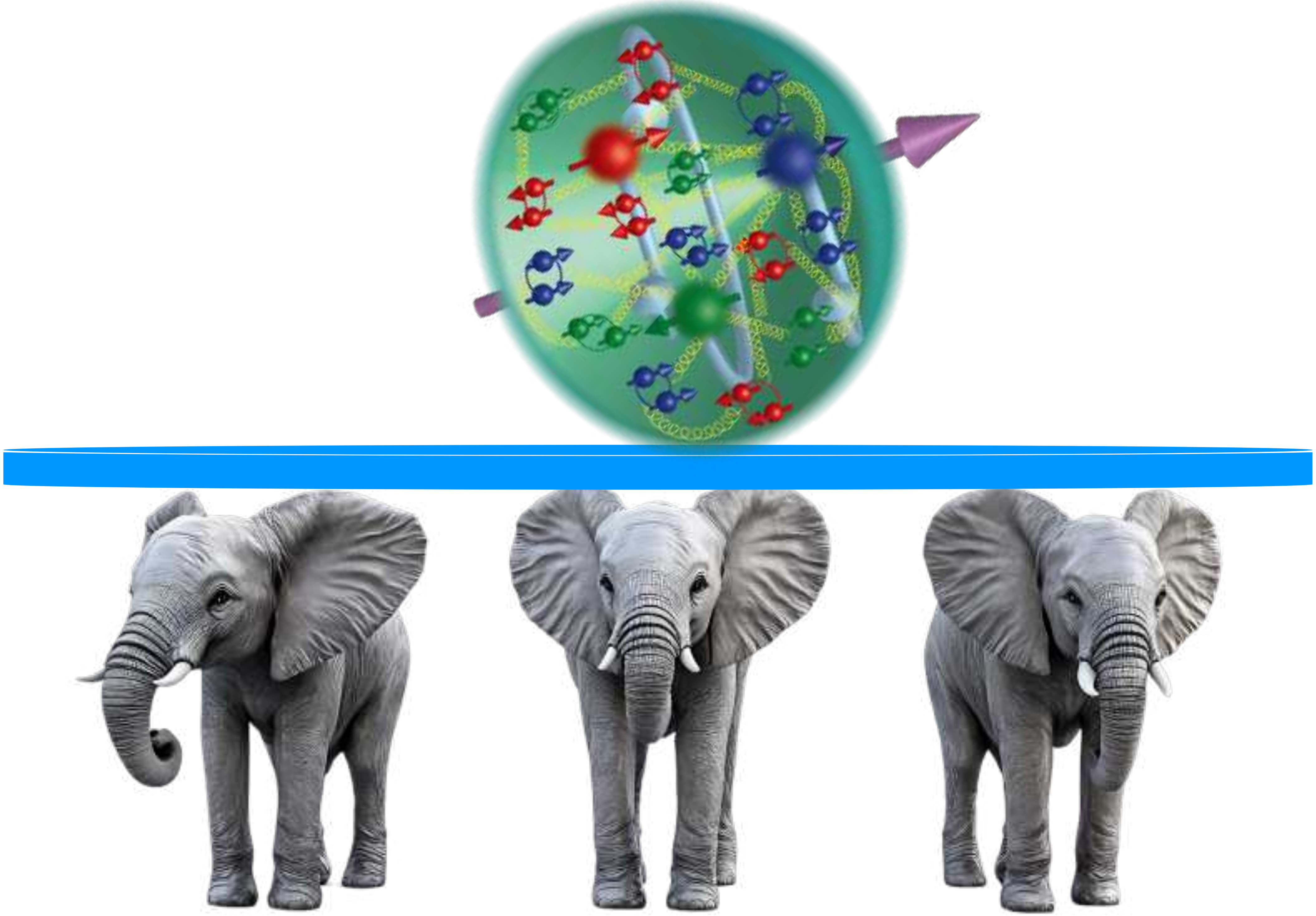
On the cover:
Spin
Physics
Detector
at NICA

© Published by JINR, 2024

The **first phase** of the SPD project is included into the JINR’s 7-year plan (2024-2030)

The **SPD collaboration** currently it consists of 36 institutes from 15 countries and more than 400 participants

Decade 2030+



DIS: Electron-ion colliders
EIC, EicC and JLAb

Fixed-target hadron
experiments: LHCspin, DY, etc.

Hadron colliders:
NICA SPD

Summary

- 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 $\sqrt{s} \leq 27\ GeV$;
- Complementing main probes such as **charmonia** (J/ψ and higher states), **open charm** and **prompt photons** will be used for that;
- SPD can contribute significantly to investigation of
  - ○ gluon helicity;
  - ○ gluon-induced TMD effects (Sivers and Boer-Mulders);
  - ○ unpolarized gluon PDFs at high-x in proton and deuteron;
  - ○ gluon transversity in deuteron;
  - ○ …
- 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 near threshold, etc.;
- **The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC exps, AFTER, LHC-Spin, EIC, JLab exps, EicC, …)**
- More information about the SPD project can be found at http://spd.jinr.ru .

Summary

We wait from theorists:

- *new brilliant ideas!*
- *predictions for SPD kinematics*
  - *polarized* ***p-p*** collisions, $\sqrt{s_{pp}} \leq 27\ GeV$
  - *polarized* ***d-d*** collisions, $\sqrt{s_{NN}} \leq 13.5\ GeV$
  - unpolarized **p-p**, **d-d**, and **light ions** collisions

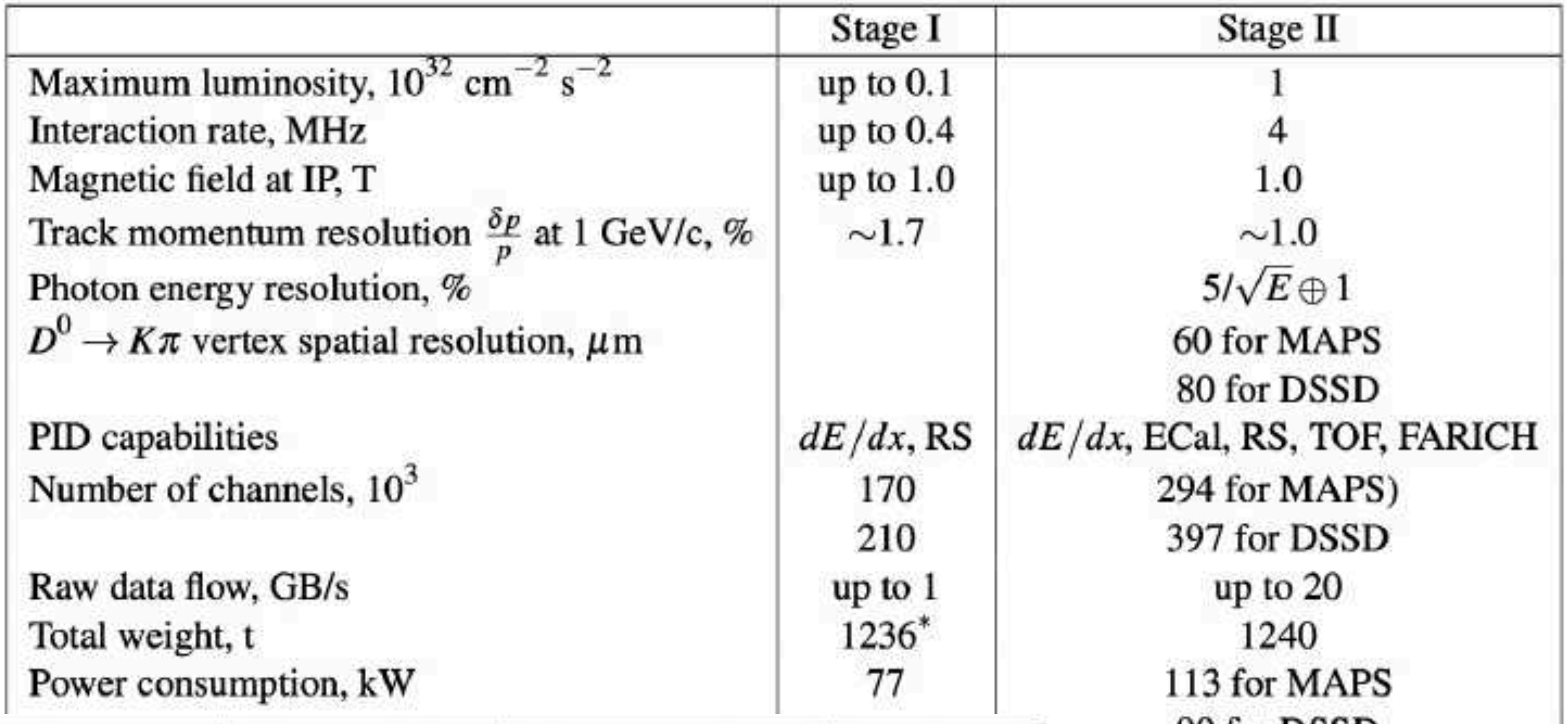
… from experimentalists:

- *joining the* ***SPD project*** *with their experience and enthusiasm*

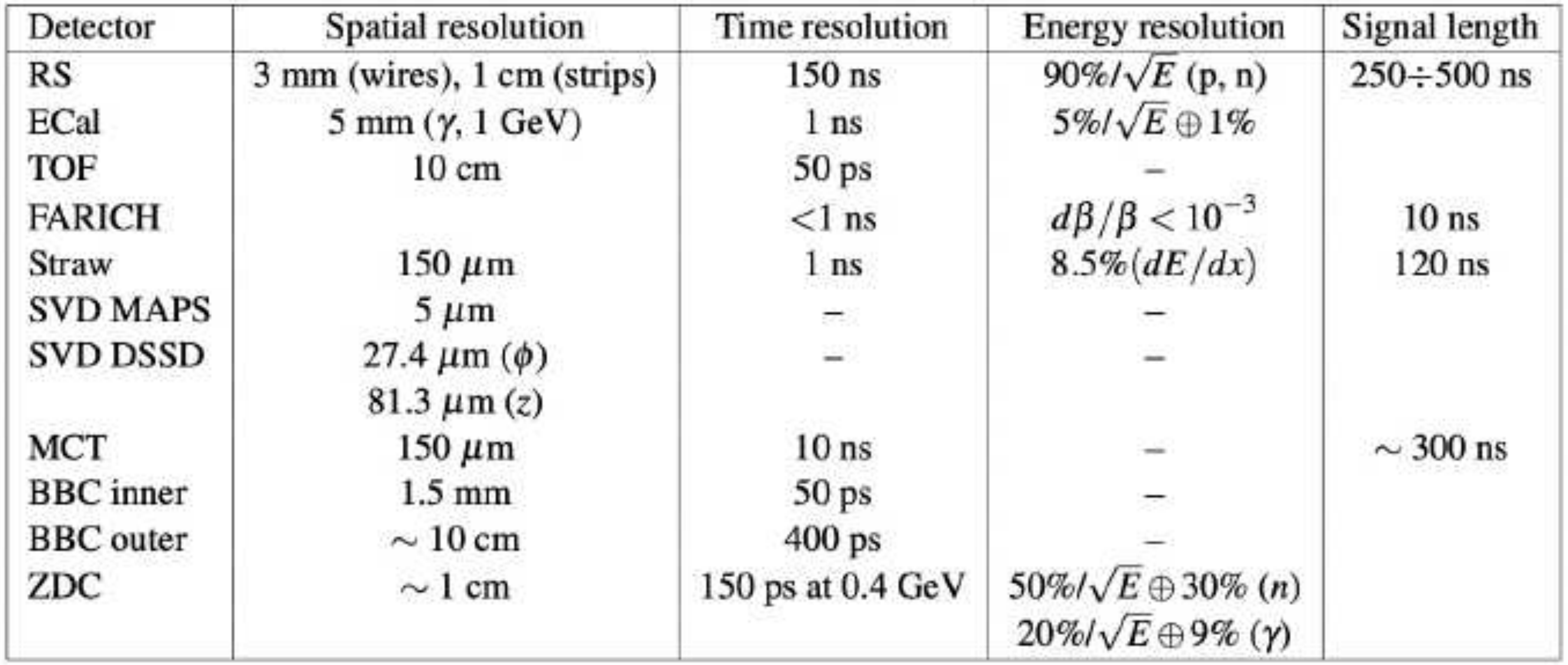
You are welcome!

BACKUP SLIDES

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	170 210	294 for MAPS) 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)	