The SPD (Spin Physics Detector) experiment at NICA

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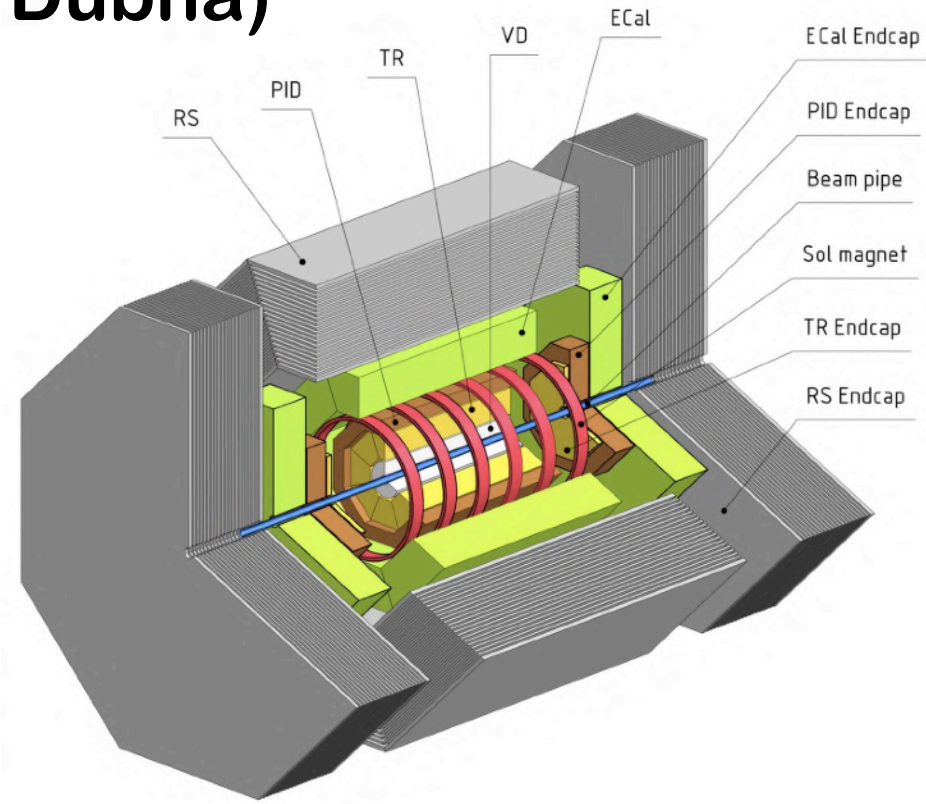
~300 authors from 23 institutes from 10 countries + individual contributors

SPD project at NICA (JINR, Dubna)

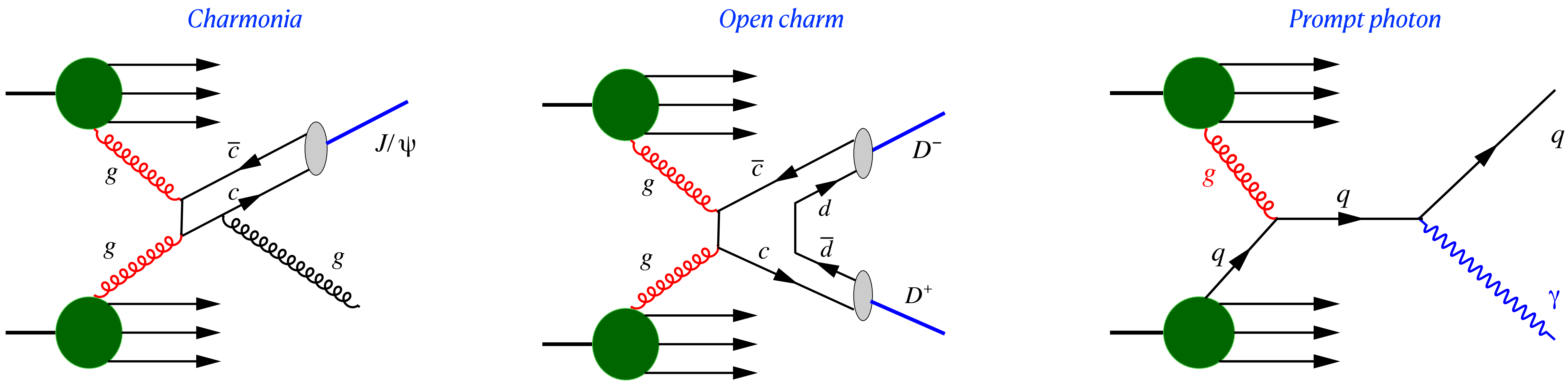


- SPD (Spin Physics Detector) is a universal facility with the primary goal to study unpolarized and polarized gluon content of proton and deuteron
- SPD project was approved by PAC and had its first proto-collaboration meeting in 2019
- Conceptual Design Report (CDR) has been prepared at the end of 2020, *arXiv:2102.00442*
- Interaction with Detector Advisory Committee in 2021
- Technical Design Report (TDR) of SPD to be prepared in 2021-2022
- Beginning of datataking for SPD after 2025

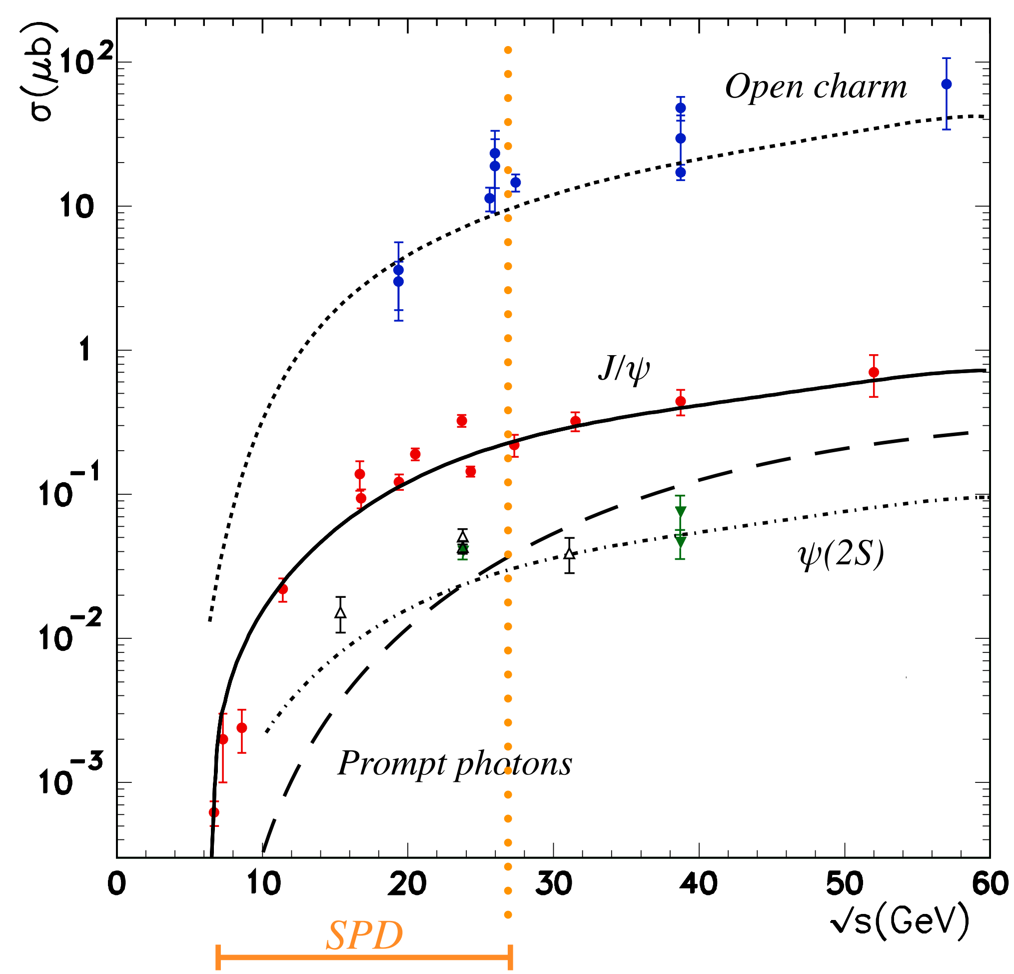
Physics program of SPD

- A.Arbuzov et al, *On the physics potential to study the gluon content of proton and deuteron at NICA SPD*, *arXiv:2011.15005*
    - Probe gluon distributions in production of charmonia, open charm and prompt photons
- V.Abramov et al, *Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams*, *arXiv:2102.08477*
    - Spin effects in elastic scattering and hyperon production, study of multiquark correlation, dibaryon resonances, exclusive reactions, open charm and charmonia near threshold, …

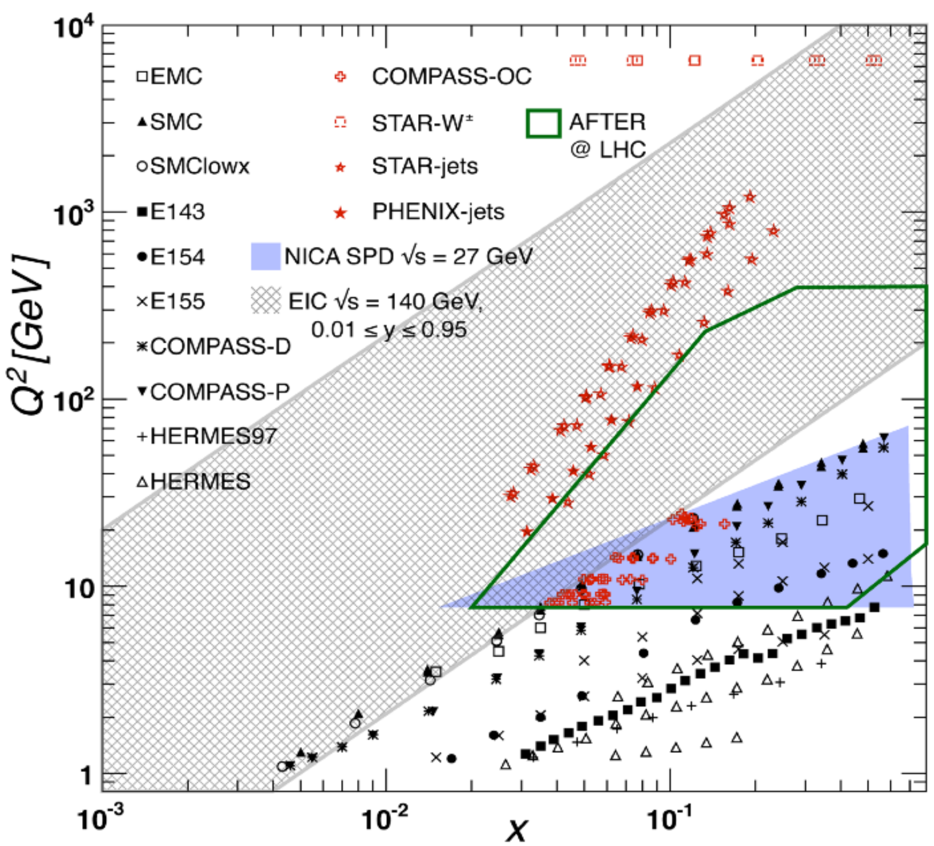
Gluon probes at SPD



- A.Arbuzov et al, *On the physics potential to study the gluon content of proton and deuteron at NICA SPD*, arXiv:2011.15005
- Tests of TMD factorization
- Linearly polarized gluons in unpolarized nucleon
- Hadron structure and heavy charmonia production mechanisms
- Non-nucleonic degrees of freedom in deuteron
- Gluon polarization Δg with longitudinally polarized beams
- Gluon-related TMD and twist-3 effects with transversely polarized beams
- Gluon transversity in deuteron
- Deuteron tensor polarization and shear forces

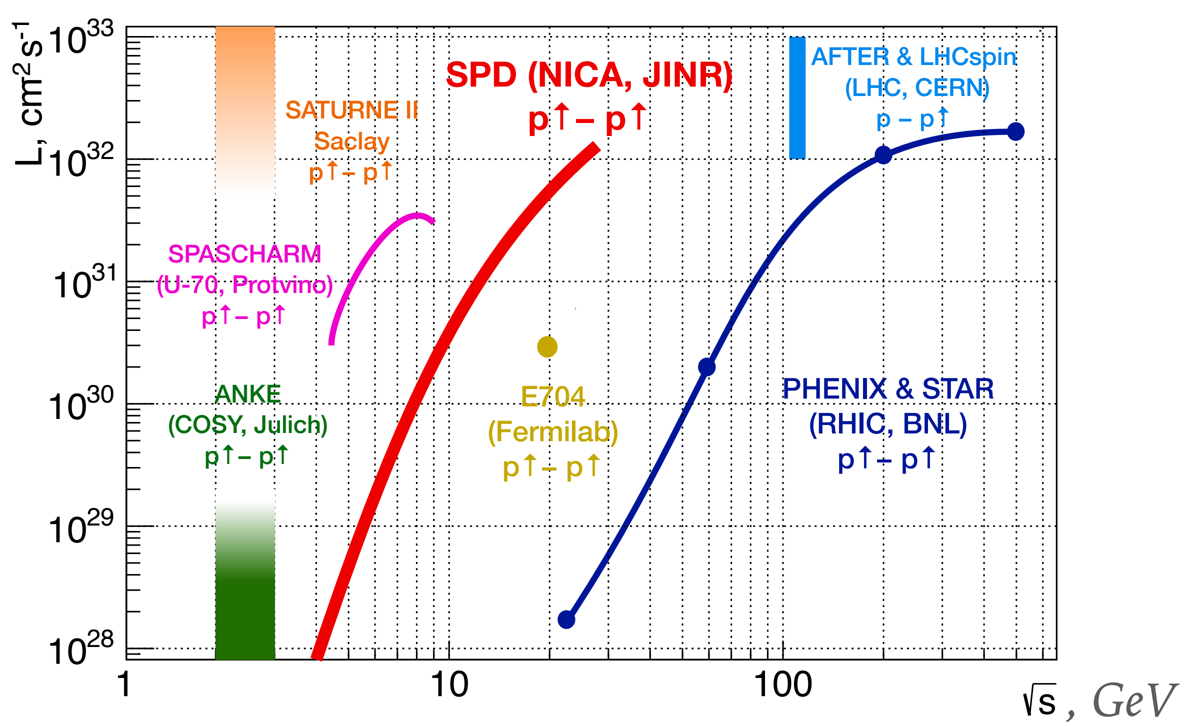


SPD compared to other spin experiments



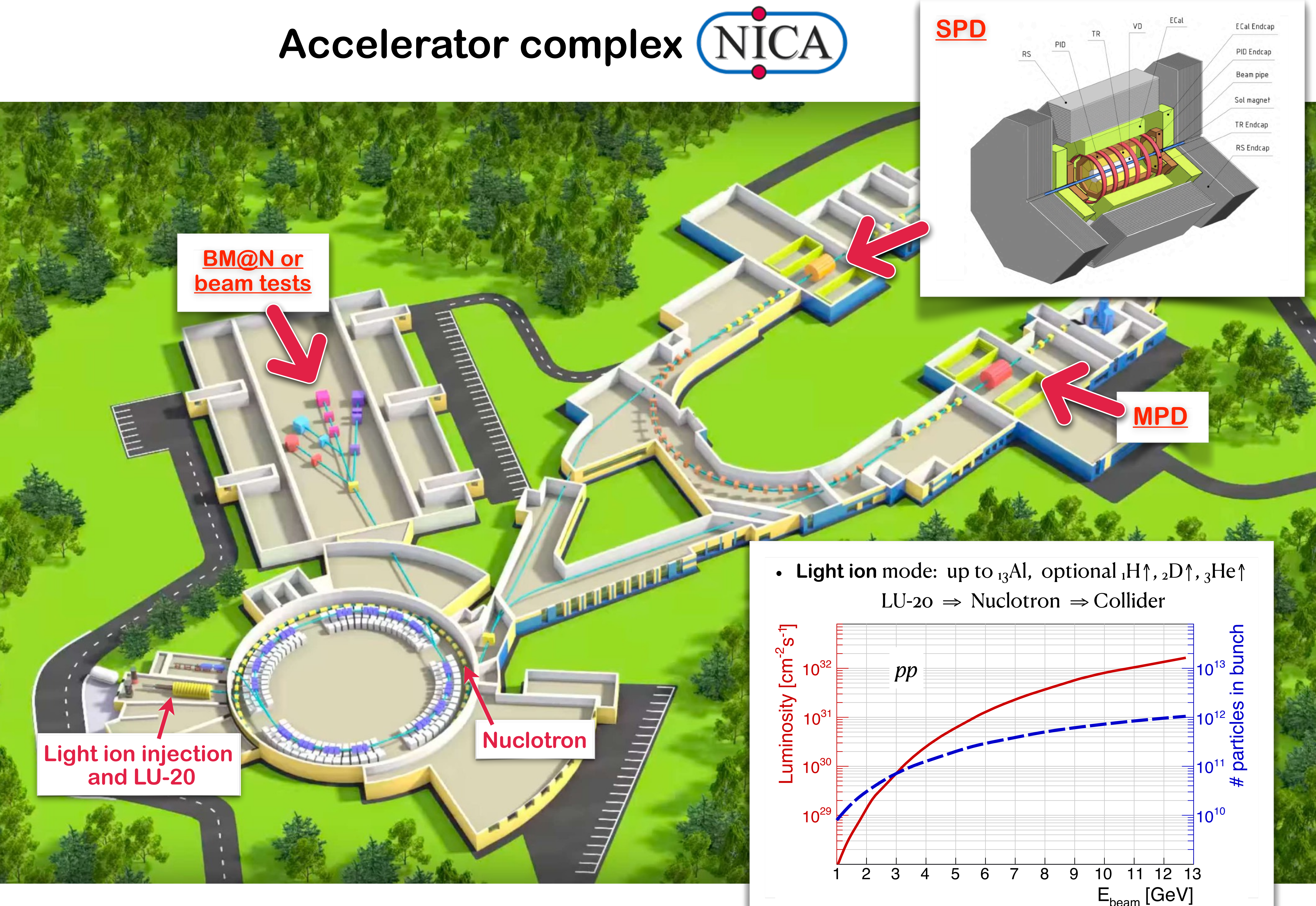
Main present and future gluon-spin-physics experiments

Experimental facility	SPD @NICA [41]	RHIC [45]	EIC [36]	AFTER @LHC [34]	LHCspin [35]
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

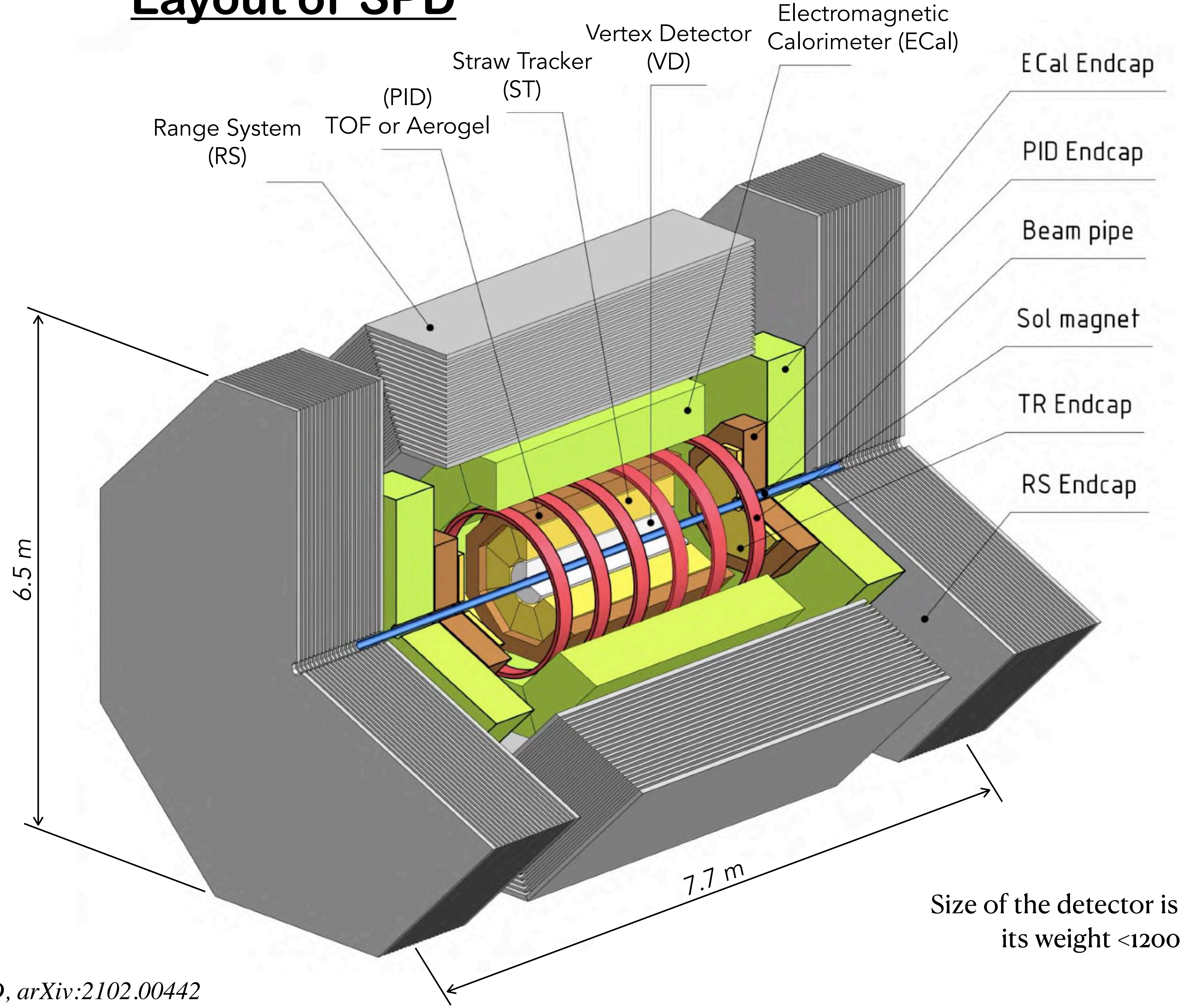


- Access to intermediate and high values of Bjorken x
- Low energy but collider experiment (compared to fixed target). Nearly 4π coverage
- Two injector complexes available ⇒ mixed combinations p↑-d and p-d↑ are possible

Accelerator complex NICA



Layout of SPD

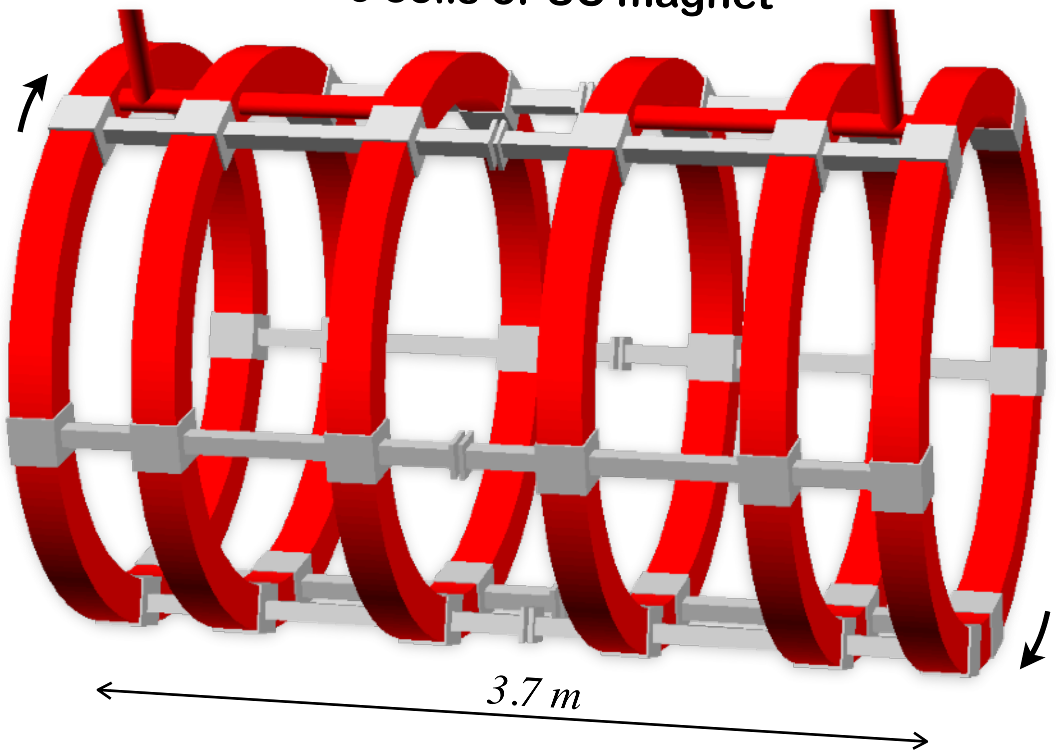


Size of the detector is limited by its weight <1200 ton

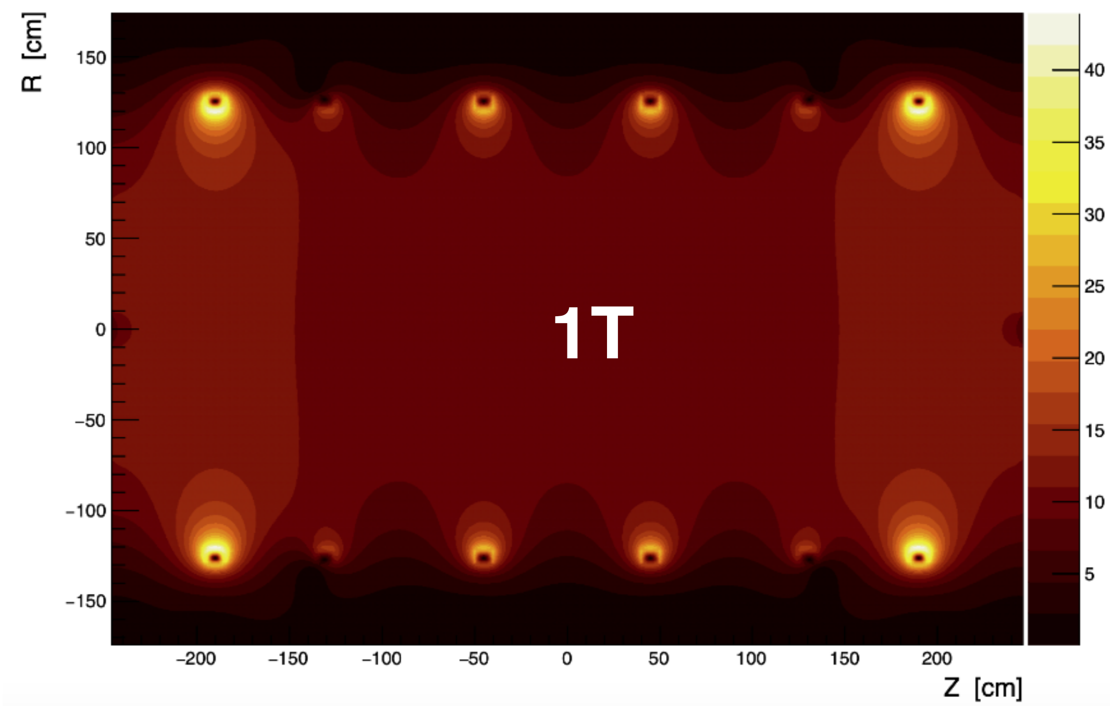
CDR of SPD, arXiv:2102.00442

Superconductive magnetic system of SPD

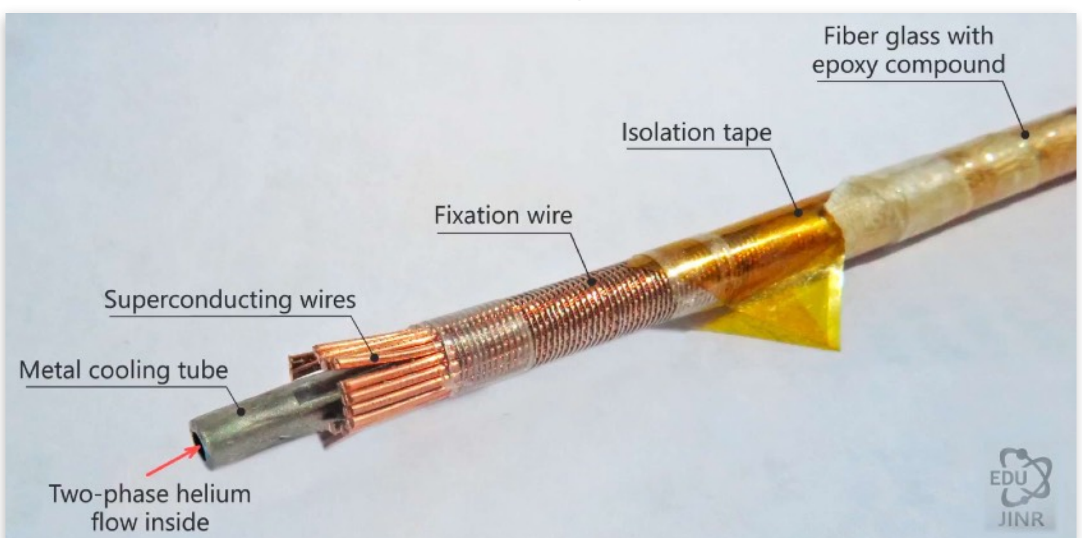
6 coils of SC magnet



Magnetic field [kG]



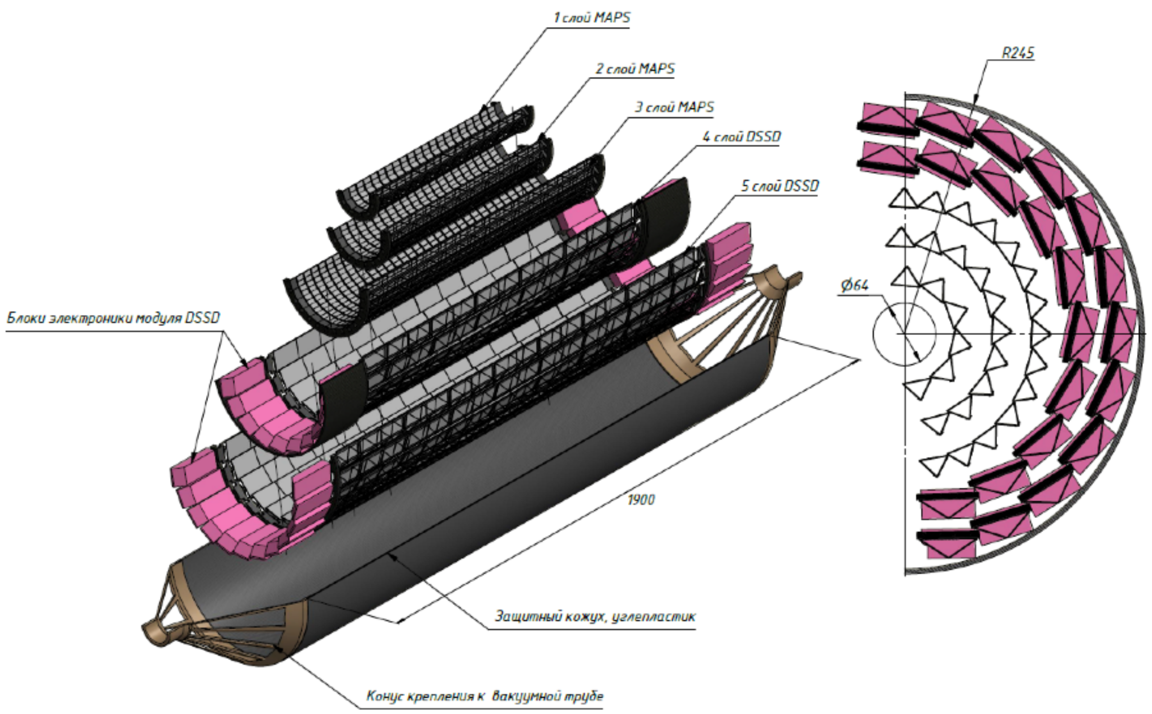
SC cable used for magnets of Nuclotron



- 6 isolated superconductive coils
  - Minimization of total amount of material
- Every coil consists of 60 turns of NbTiCu cable with the 10 kA current
  - Total current: 60×10 kA = 600 kA · turn
- The same cable as used in Nuclotron magnets: hollow superconductor with the two-phase helium flows inside (~4.5 K)
- Similar cryogenic system as the one of Nuclotron

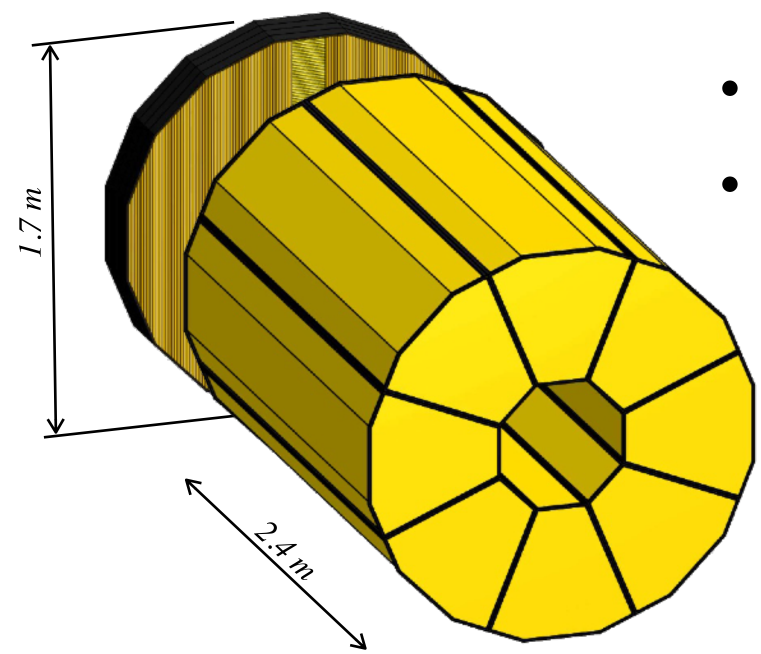
Tracking system of SPD

Vertex Detector (VD)

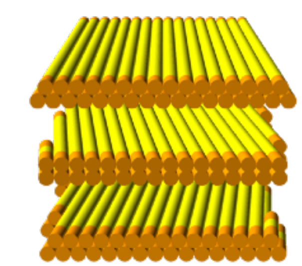


- Purpose: reconstruction of D meson decay vertices
- 5 layers = 2 DSSD + 3 MAPS
  - Double Side Silicone Strip (DSSD), 300 μm thickness, strip pitch 95 μm - 281 μm
  - Monolithic Active Pixel Sensors (MAPS) designed for ALICE, pixel size 29 μm × 27 μm
- Low material budget
- Vertex spatial resolution < 100 μm
- Use of MAPS improves the signal-to-background ratio of D meson peak by a factor of 3

Straw Tracker (ST)



- Barrel: 8 modules with up to 30 double-layers, *ZUV*
- Endcap: 12 double-layers, *XYUV* orientation



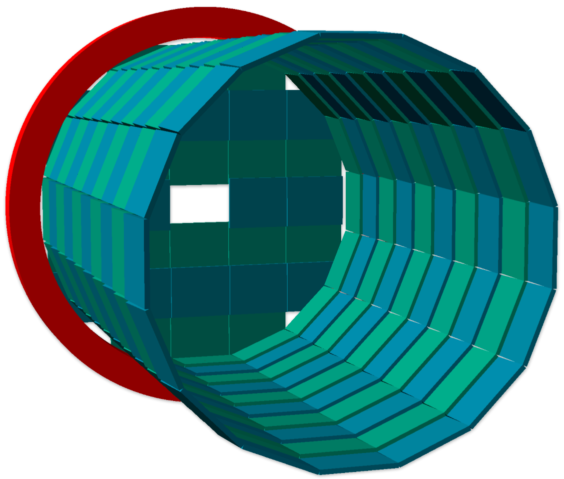
- Main tracker system of SPD
- Maximum drift time of 120 ns for ∅=10mm straw
- Spatial resolution of 150 μm
- Expected DAQ rate up to half MHz (electronics is limiting factor)
- Number of readout channels ~50k
- Can be used for PID if energy deposition if detected
- Extensive experience in straw production in JINR for various experiments (NA58, NA62, NA64…)

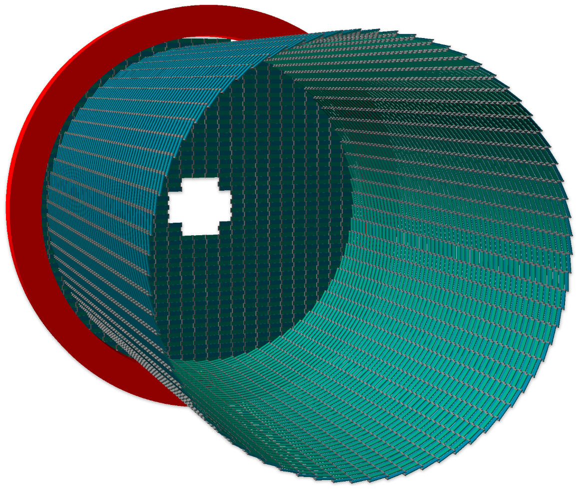
Particle Identification (PID) system

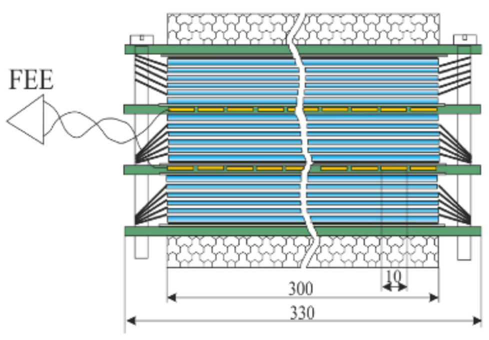
Time-of-Flight (TOF)

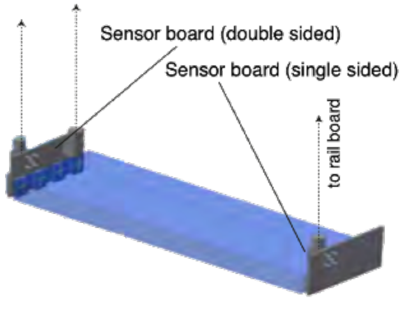
MRPC option

Scintillator Tile (SciTil)



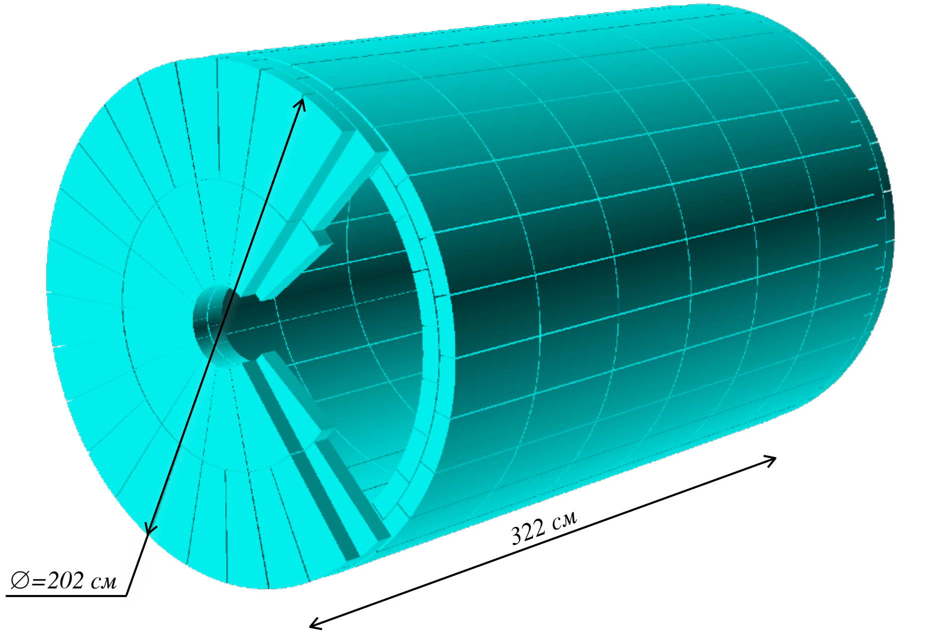






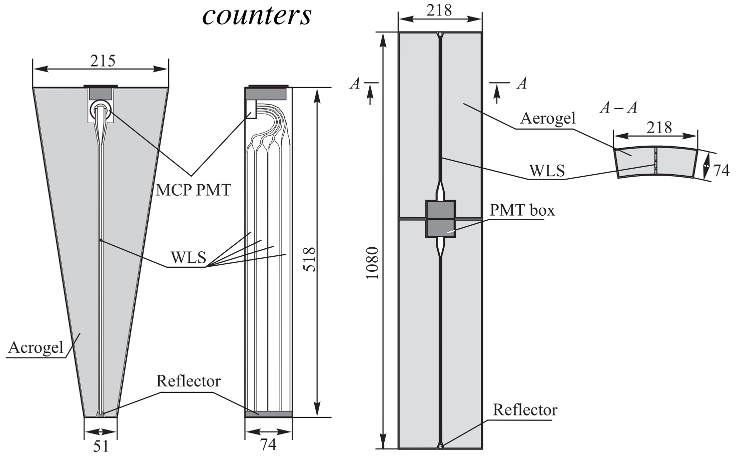
- Two options with similar performance are considered
  - MRPC: used in two other experiments of NICA (BM@N, MPD)
  - SciTil: design can be similar to the one of PANDA, easier to assemble and maintain w.r.t. MRPC
- Minimum flight distance 1m
- Time resolution in both cases is ~60ps
- No interaction time $\Rightarrow$ multiple tracks with particle flavor hypothesis for identification

Aerogel

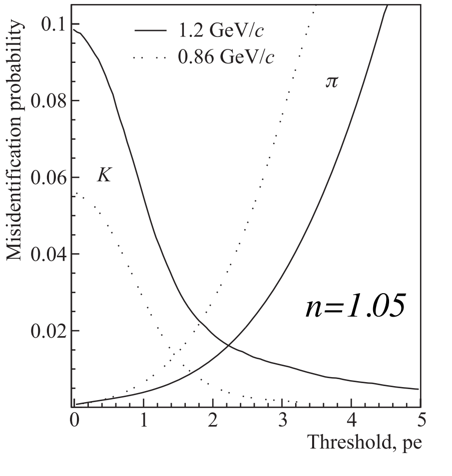


- Identification based on Cherenkov light radiation
- Range of π/K separation is a function of refractive index n
- The design follow closely the one of KEDR (Novosibirsk)
- Low light yield ~6 p.e.

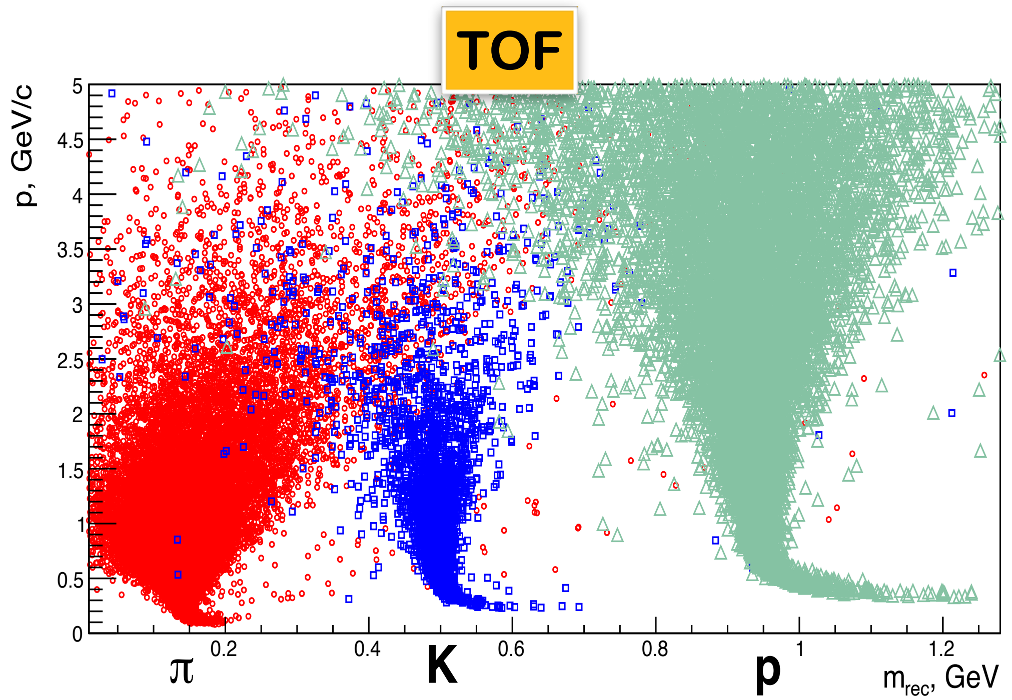
Endcap and barrel counters

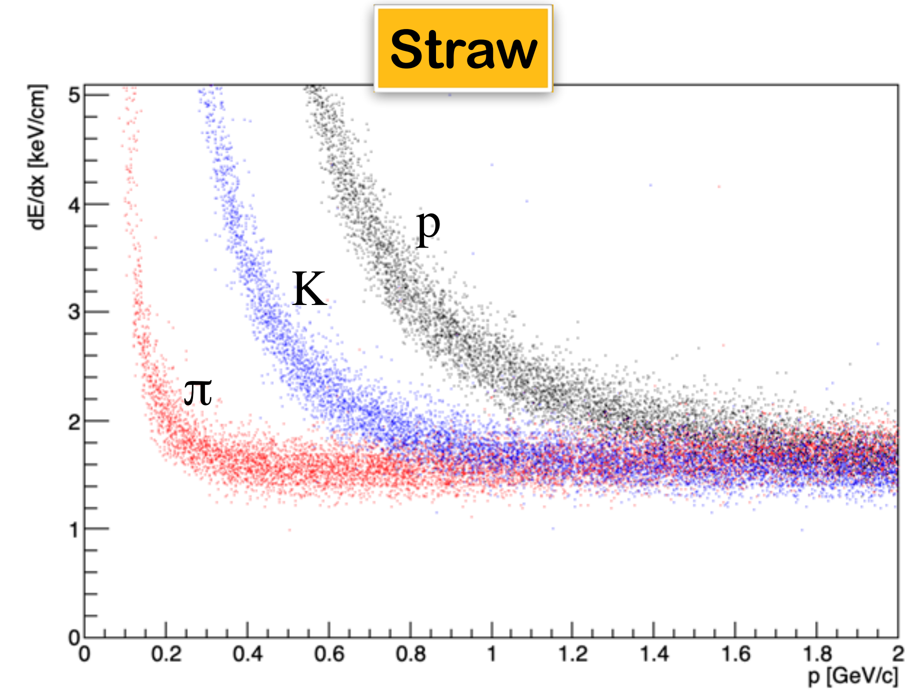


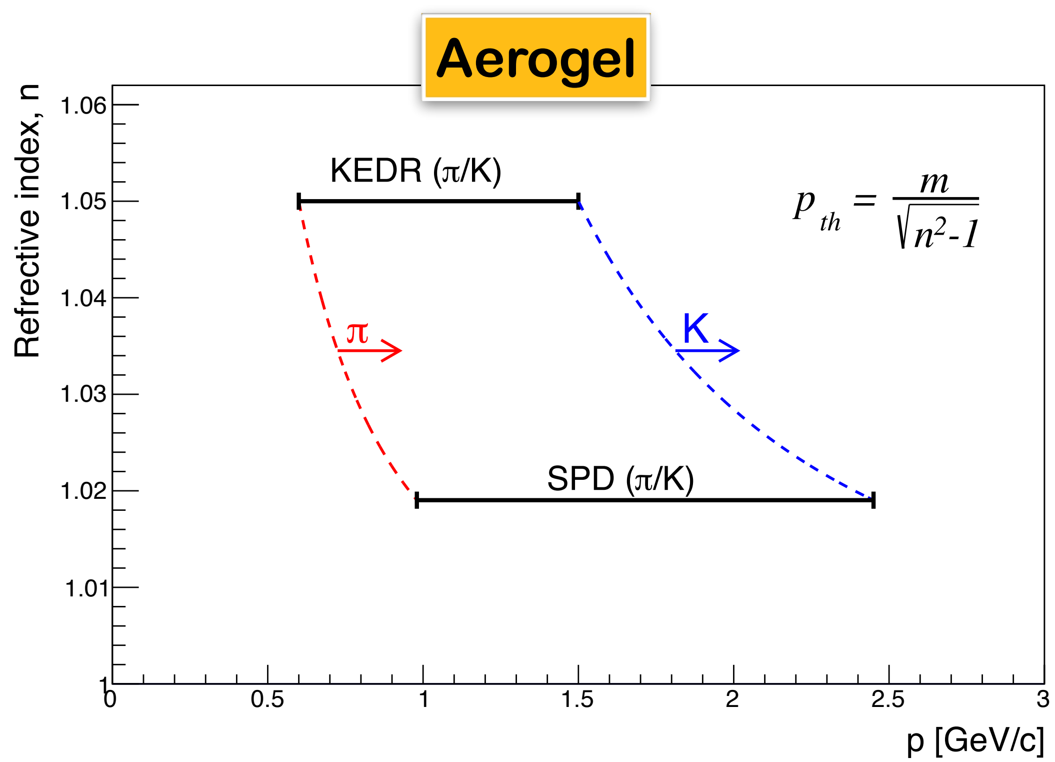
Probability of wrong identification, KEDR



PID analysis in SPD (π, K, p)





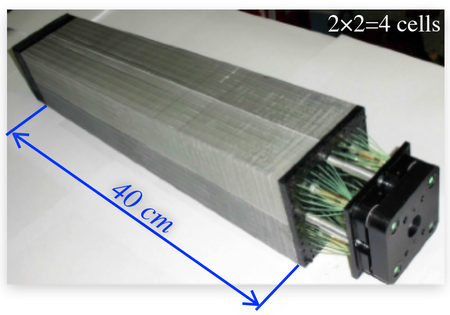


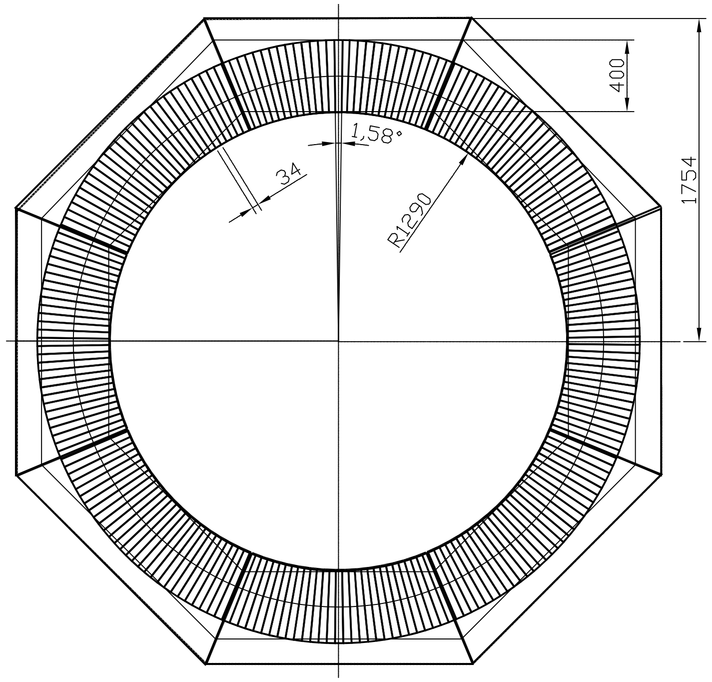
π/K separation

- Short tracks (R<1m) to be identified by straw up to 0.7 GeV/c
- Long tracks (R>1m) to be identified by straw+TOF up to 1.5 GeV/c
- tracks with p>1.5 GeV/c to be identified by aerogel

Electromagnetic Calorimeter (ECal)

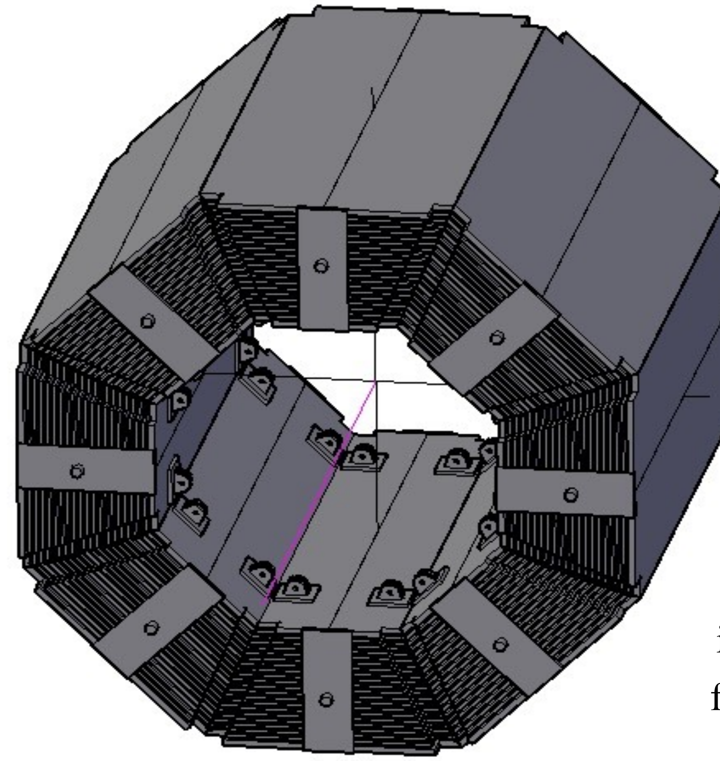
- 200 layers of lead (0.5 mm) and scintillator (1.5mm)
- 36 fibers of one cell transmit light to 6×6 mm² SiPM
- Moliere radius is ~2.4 cm

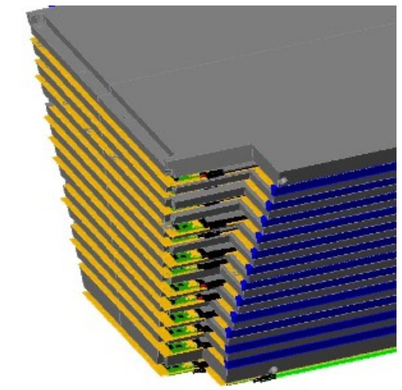




- Purpose: detection of prompt photons and photons from π^0, η and χ_c decays
- Identification of electrons and positrons
- Number of radiation lengths $18.6X_0$
- Total weight is 40t (barrel) + 28t (endcap) = 68t
- Total number of channels is ~30k
- Energy resolution is ~5% / √E
- Low energy threshold is ~50 MeV
- Time resolution is ~0.5 ns

Range System (RS)





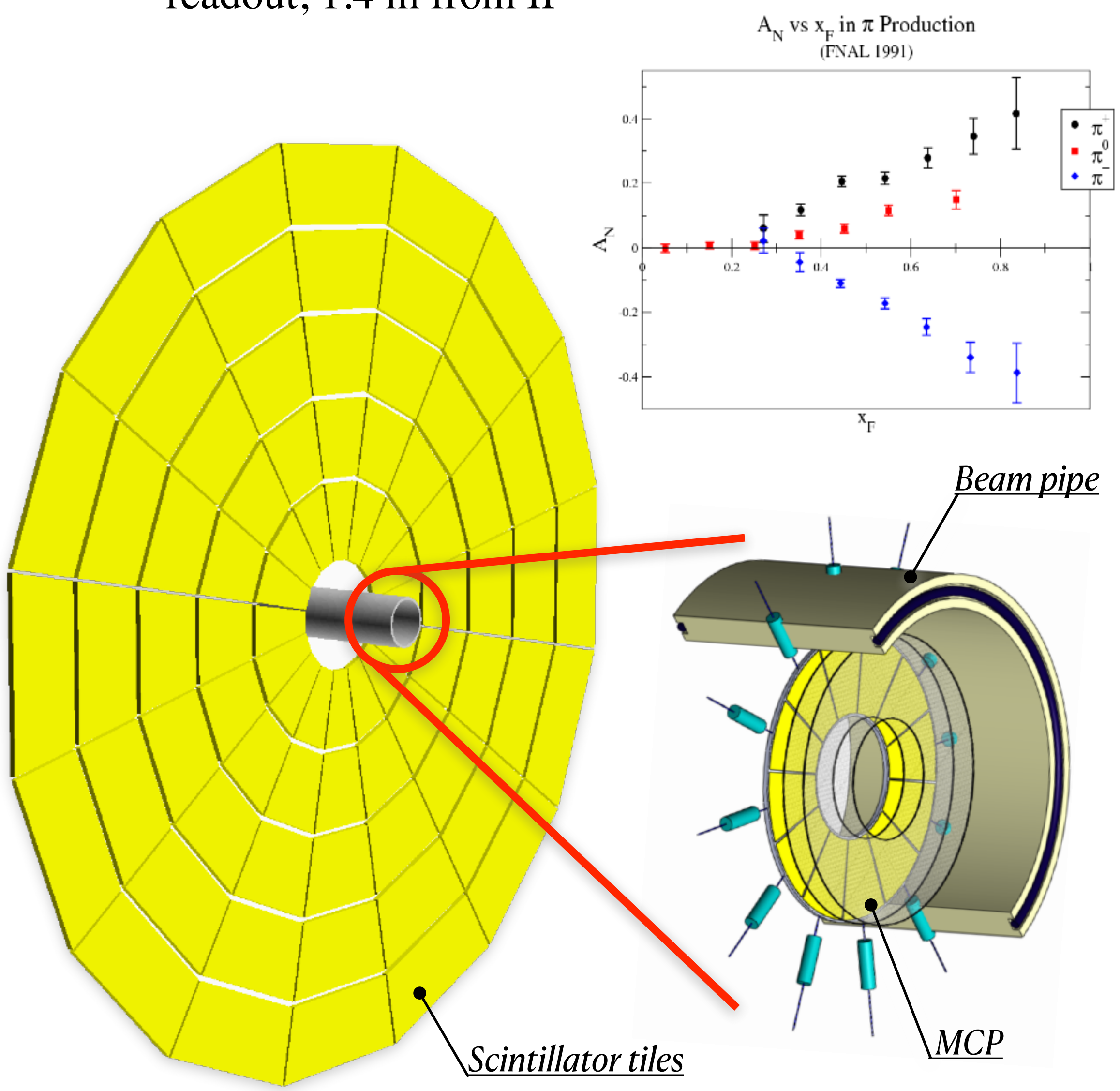
17 layers of Fe (3-6 cm) interleaved with 3.5 cm gaps for Mini Drift Tube detectors

- Purposes: μ identification, rough hadron calorimetry
- Used as a yoke for the return field
- Total mass ~800 t, at least $4\lambda_I$
- The design follow closely the one of PANDA
- MDT provide 2 coordinate readout (~100 kch)
  - Al extruded comb-like 8-cell profile with anode wires + external electrodes (strips) perpendicular to the wires

Local polarimetry and luminosity control

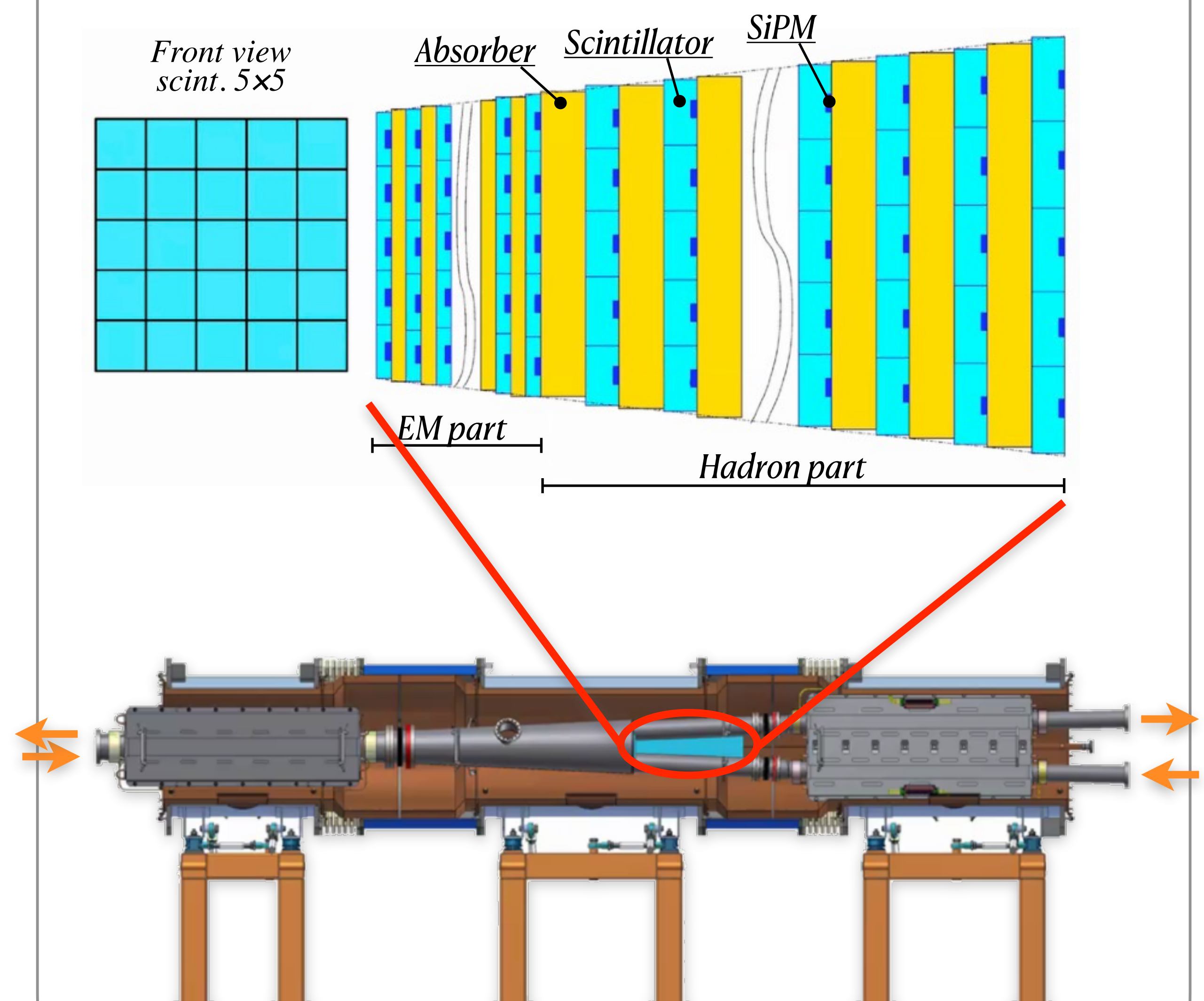
Beam Beam Counter (BBC)

- BBC consists of inner and outer parts
  - Inner part: Micro-Channel Plates (MCP) located in the vacuum of the beam pipe, 1.4 m from IP
  - Outer part: plastic scintillator tiles with SiPM readout, 1.4 m from IP

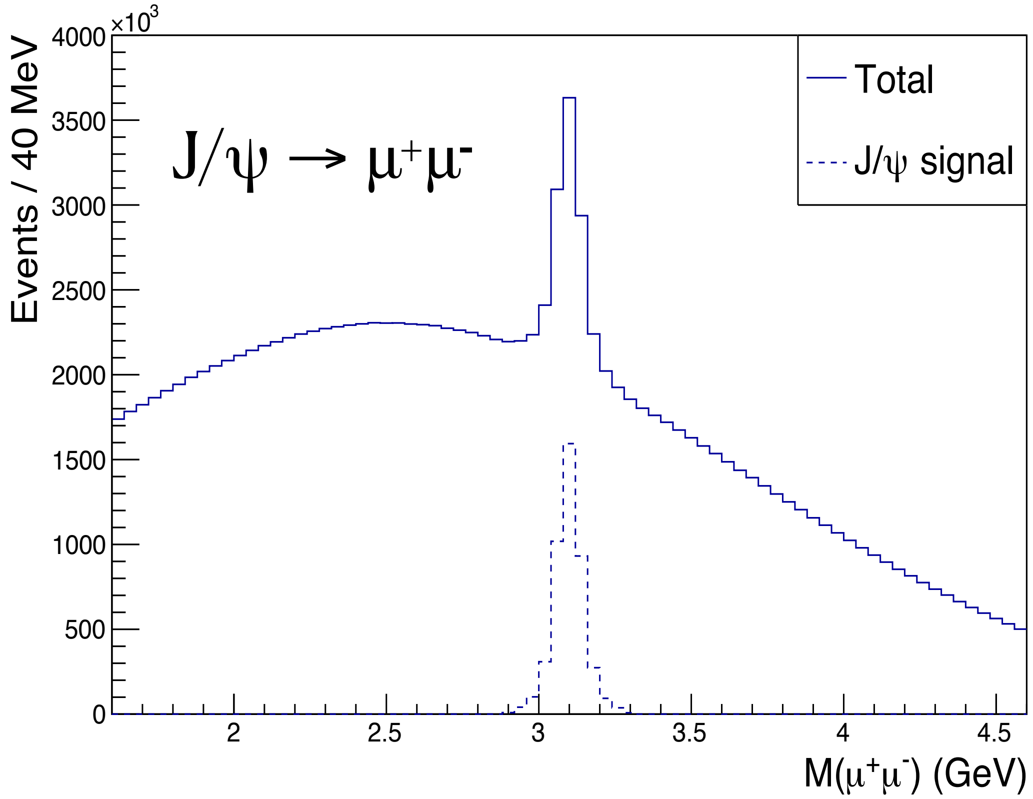


Zero Degree Calorimeter (ZDC)

- ZDC will be integrated in the cryostat placed between two vertically deflecting magnets, 14m from IP
- Sampling calorimeter with fine segmentation, 5x5 matrix
- SiPM light readout, about 1000 channels
- Readout based on electronics designed for the DANSS neutrino experiment at Kaliniskaya NPP

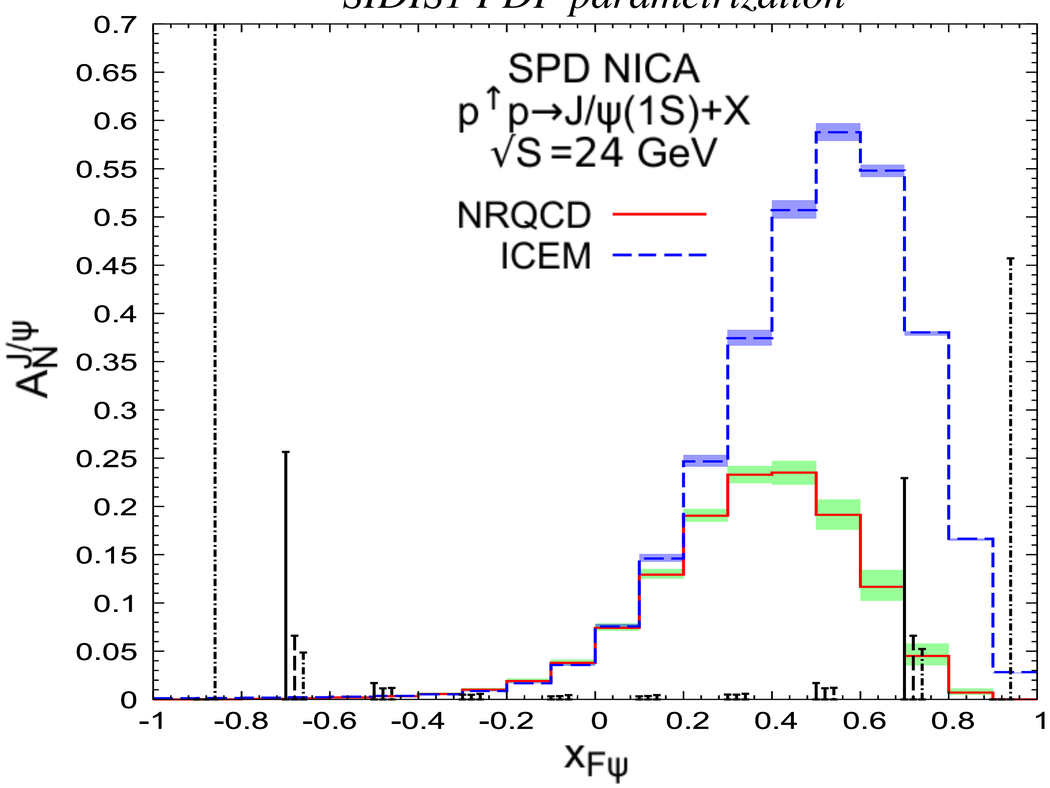


MC study: charmonia production

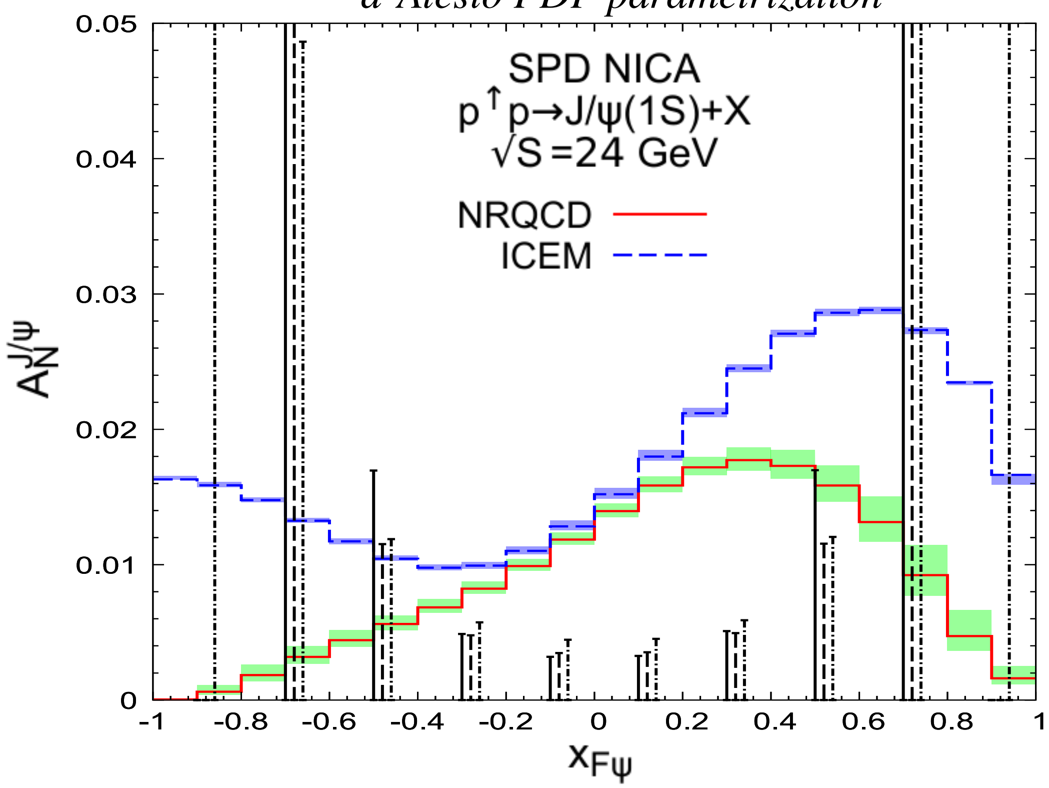


- 200 nb cross-section at $\sqrt{s}$=27 GeV, taking data for 10^7 s ⇒ 12 · 10^6 decays $J/\psi \to \mu^+\mu^-$ in the detector
  - ~4 · 10^6 after all cuts
- TSSA probes the **Sivers function** in J/ψ production
- Two approaches describing hadronization stage
  - Non-Relativistic QCD factorization (NRQCD)
  - Improved Color-Evaporation Model (ICEM)
- GPM model prediction, A.Karpishkov, V.Saleev, M.Nefedov, arXiv:2008.07232

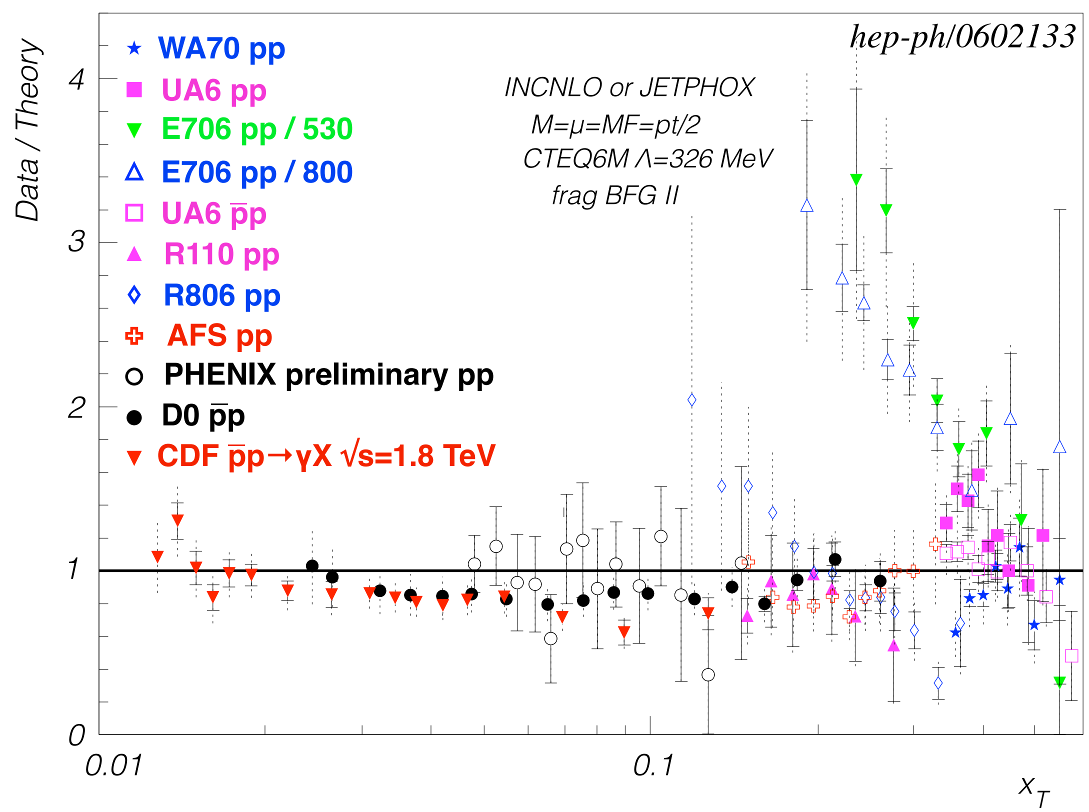
SIDIS1 PDF parametrization



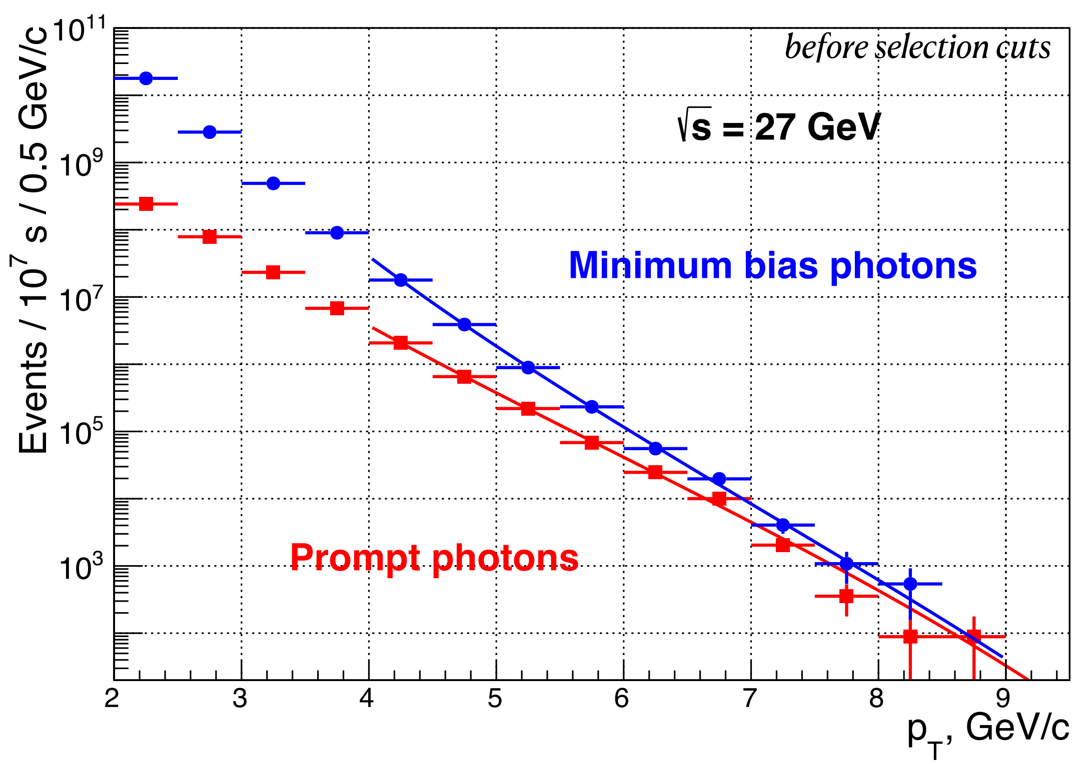
d'Alesio PDF parametrization

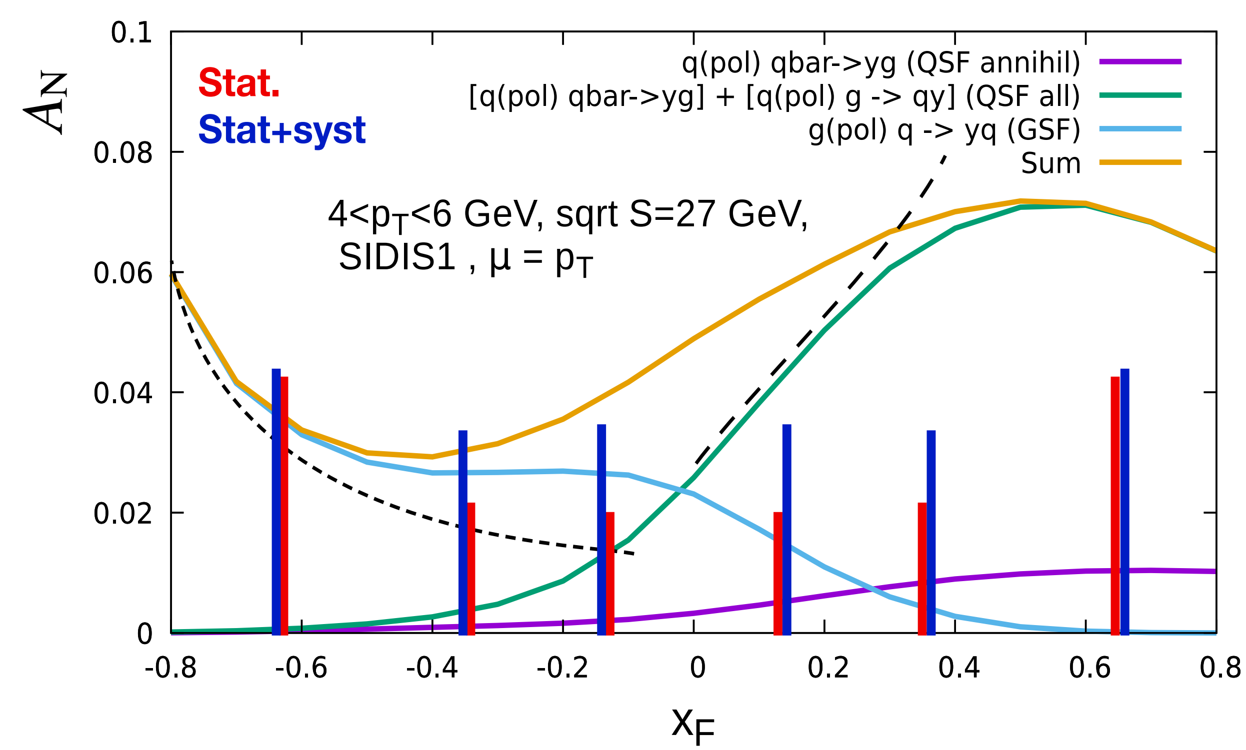


MC study: prompt photon production

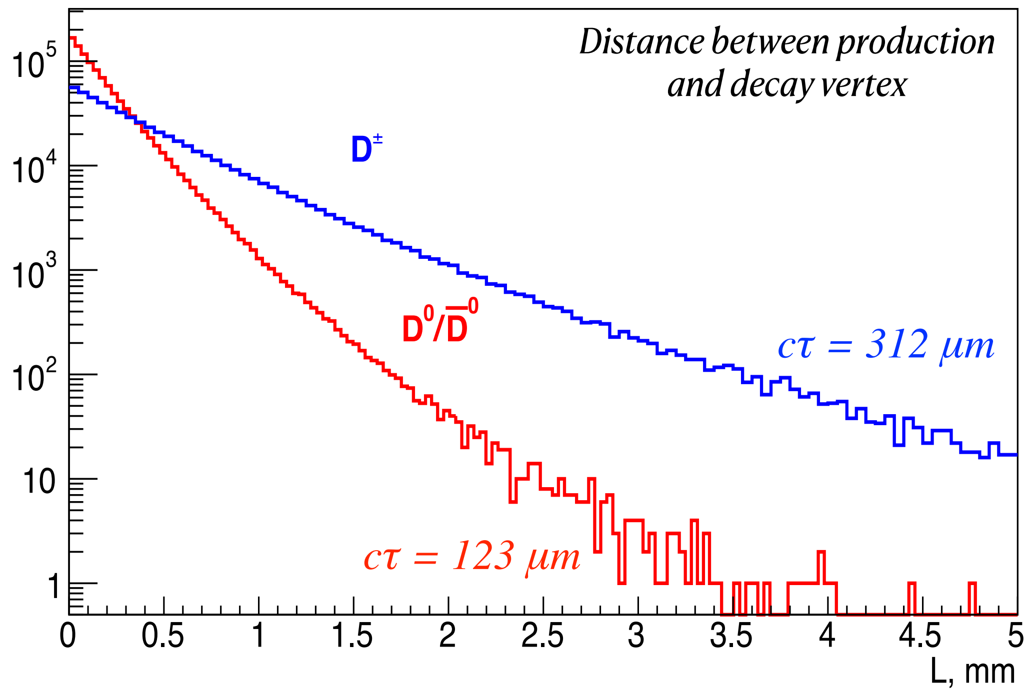


- Clean probe to study the Sivers DF and twist-3 correlation functions
- Proceeds without fragmentation ⇒ is exempt from the Collins effect
- Disagreement of theory and data at high x_T
- Main source of background: photons from decays of secondary π^0 and η. The rest of the decays contributes on the level of 3%
- Quark and gluon SF contributions were estimated separately within GPM

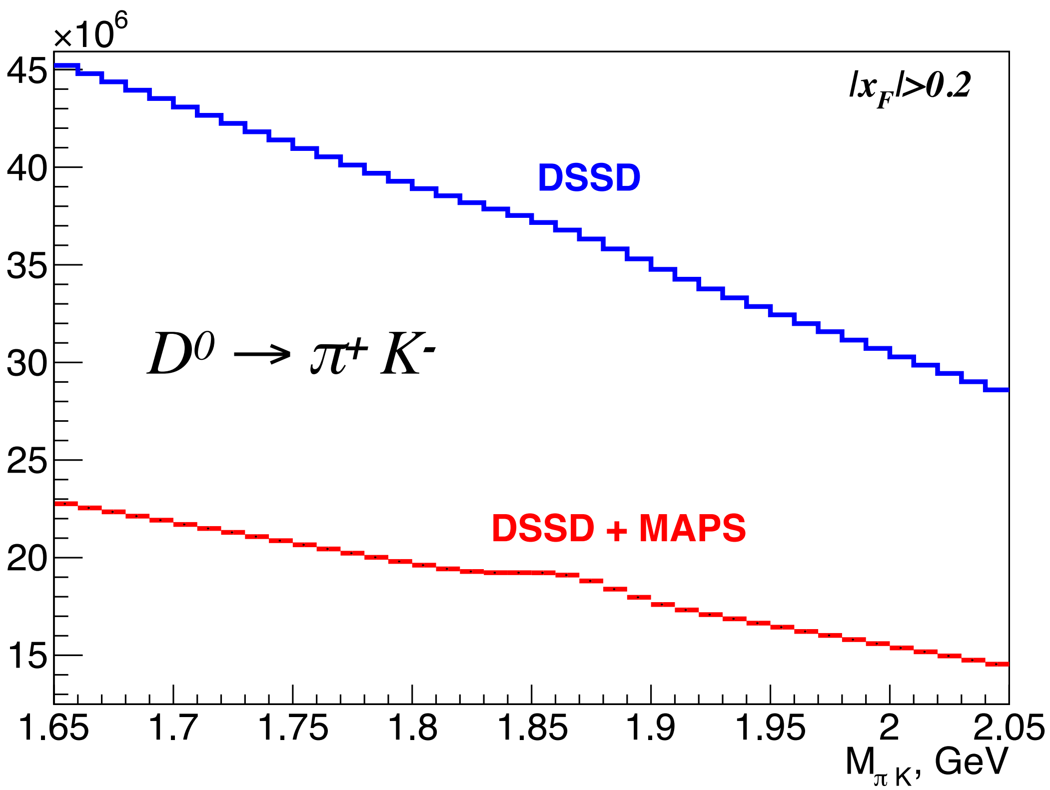


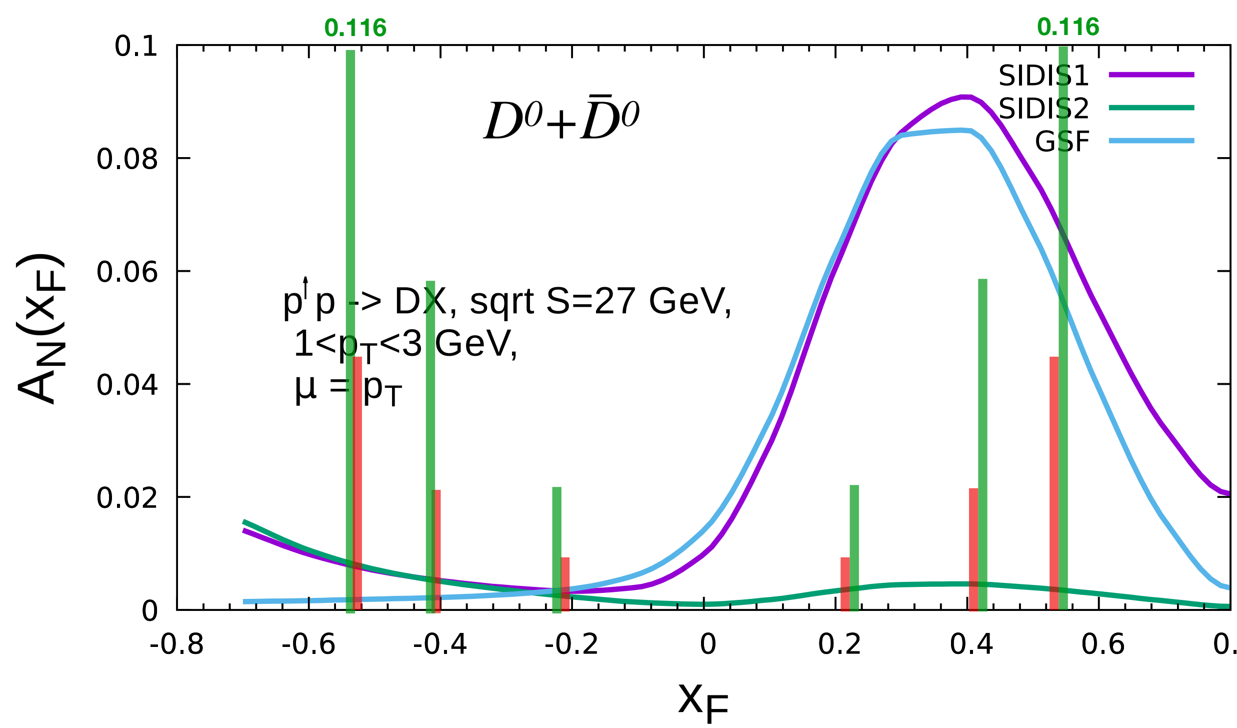


MC study: open charm production



- "Golden" decay channels
  - $D^0 \to \pi^+ K^-$ and $D^+ \to \pi^+ K^- \pi^+$
- Typical momentum of D mesons is 2 GeV/c
- Selection criteria: χ^2, distance, angle
- Signal-to-background ratio for D^0
  - 1.3% for the DSSD-only option of VD
  - 3.9% for the DSSD+MAPS option of VD
- The expected Sivers contribution to SSA was estimated within GPM



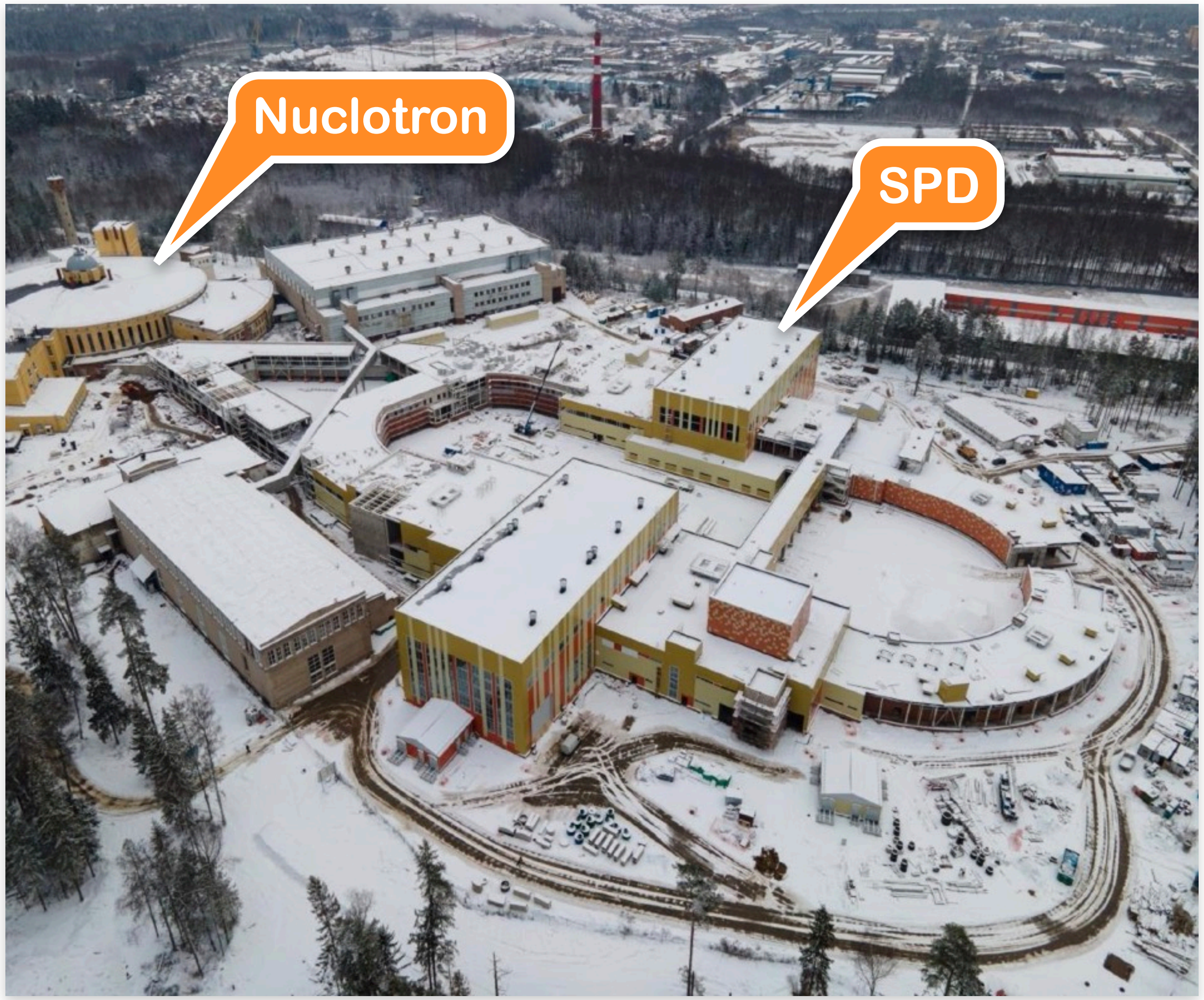


Conclusions

- NICA collider will start operation at JINR/Dubna in 2022
  - CM energy scan from few GeV to 27 GeV in *pp* mode
  - Measurements with *pp*, *pd* and *dd* beams
  - All configurations for the beam polarization: U, L, T
- SPD (Spin Physics Detector) is a universal facility with the primary goal to study unpolarized and polarized gluon content of *p* and *d*
  - Main probes: charmonia, open charm and prompt photons
  - 4π detector will be equipped with silicon detector, straw tracker, TOF (+aerogel) for PID, calorimetry and muon system
- Conceptual Design Report and physics program were released this winter
  - Proposed program cover at least 5 years of data taking
- Preparation of the Technical Design Report and detector prototyping in 2021-2022
- First data of SPD after 2025

spare slides

Aerial view to NICA



SPD experimental hall

- Infrastructure development is ongoing: modernization of power supply system, upgrade of plants for liquid helium and nitrogen production, construction of new buildings
- Plans for the SPD hall for this year: complete work on the interior, make crane in operation

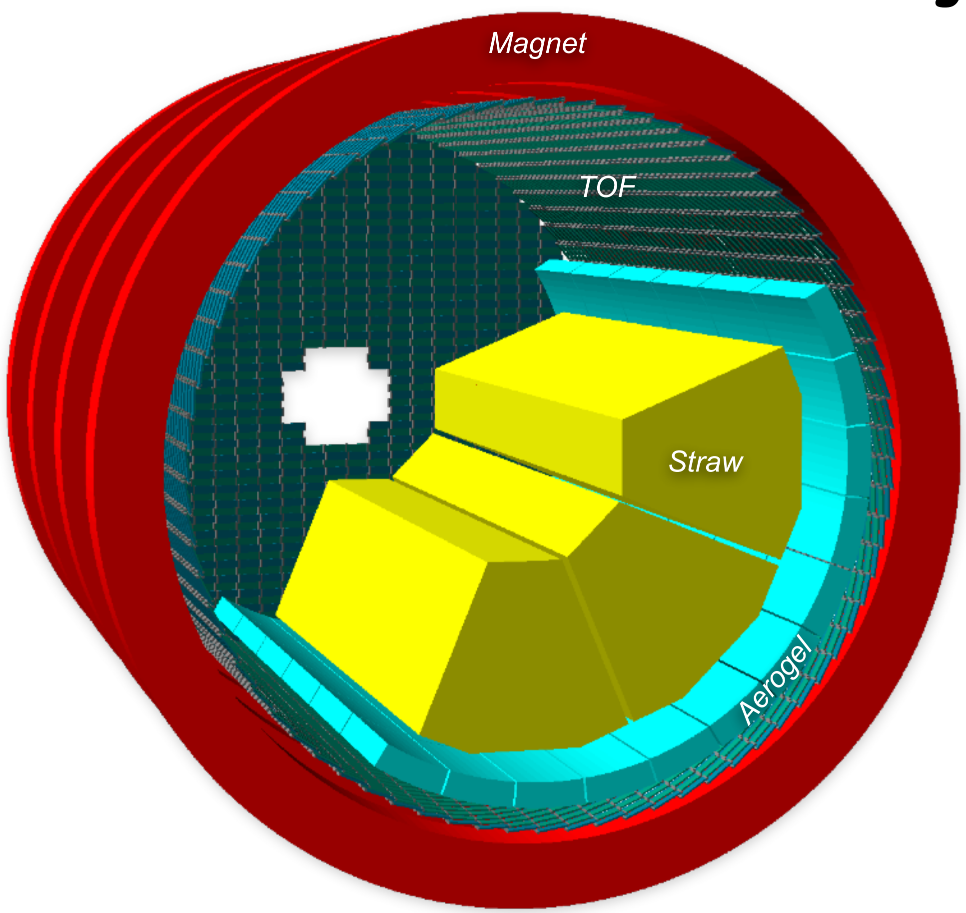
Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams, *arXiv:2102.08477*

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]

Table 12.1: Tentative running plan for the Spin Physics Detector.

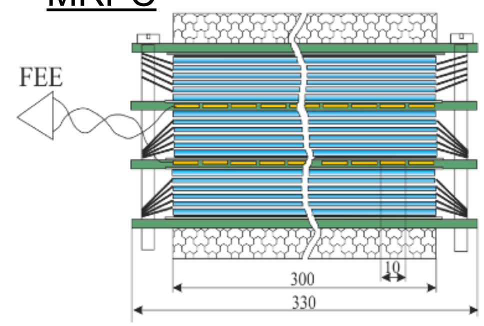
Physics goal	Required time	Experimental conditions	
	First stage		
Spin effects in p-p scattering dibaryon resonanses	0.3 year	$p_{L,T}$-$p_{L,T}$, $\sqrt{s}$ <7.5 GeV	3
Spin effects in p-d scattering, non-nucleonic structure of deuteron, $\bar{p}$ yield	0.3 year	d_{tensor}-p, $\sqrt{s}$ <7.5 GeV	4
Spin effects in d-d scattering hypernuclei	0.3 year	d_{tensor}-d_{tensor}, $\sqrt{s}$ <7.5 GeV	1
Hyperon polarization, SRC, ... multiquarks	together with MPD	ions up to Ca	2
	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	

PID system of SPD (possible options)



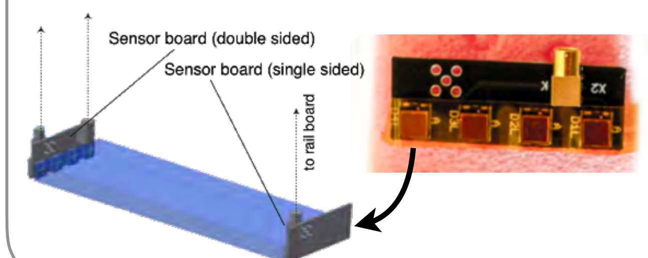
Time-of-Flight system (TOF)

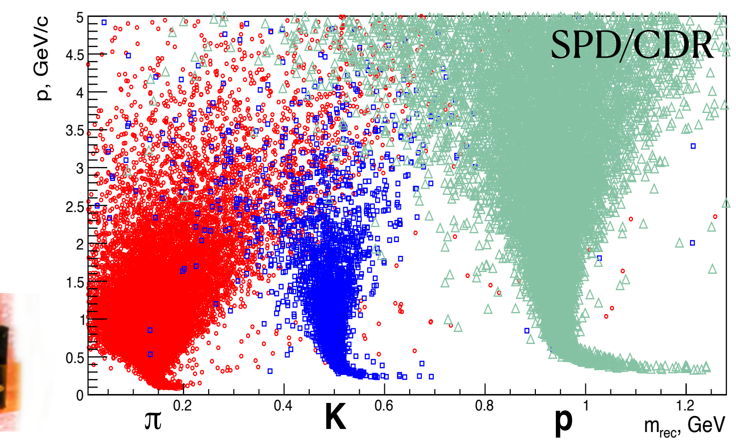
MRPC



For MRPC see TOF-TDR of MPD/NICA
For SciTil see TOF-TDR of PANDA

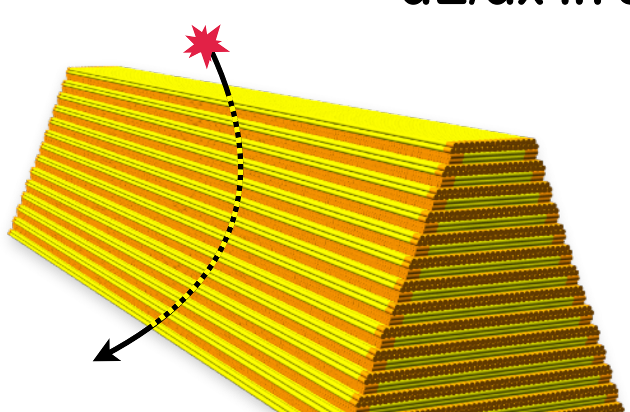
Scintillator Tile (SciTil)



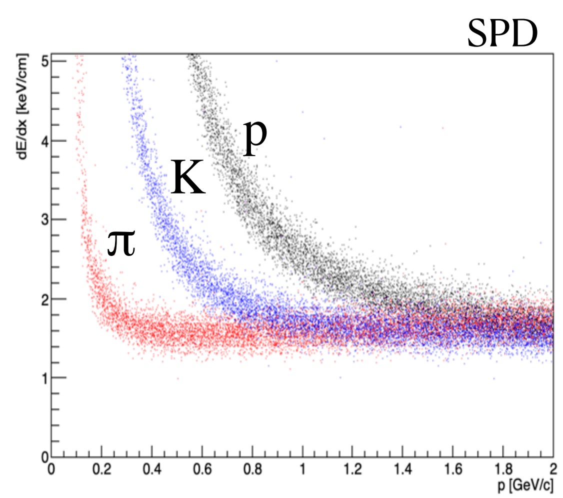


70ps resolution was assumed

dE/dx in straw tubes



$N_{tube}=8\times8.2k$



60 layers = 30 (Z), 30 (Tang). Radially: 86cm - 27cm = 59cm

Aerogel (threshold counter)

Детектор КЕДР, ФЭЧАЯ 2003 т.44 вып.4

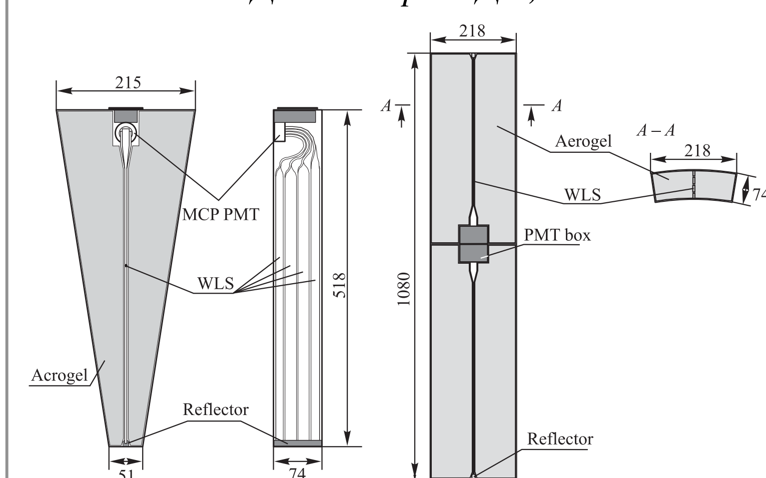


Рис. 16. Торцевой счетчик

Рис. 17. Два баррельных счетчика в одном корпусе

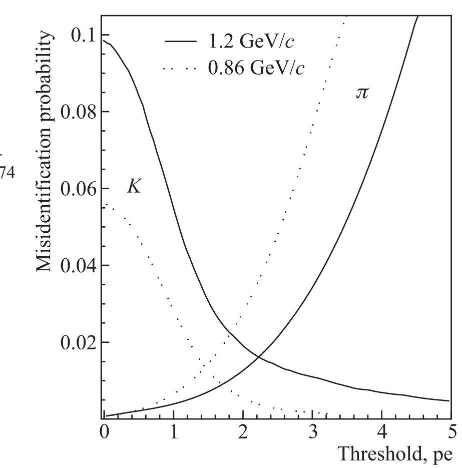
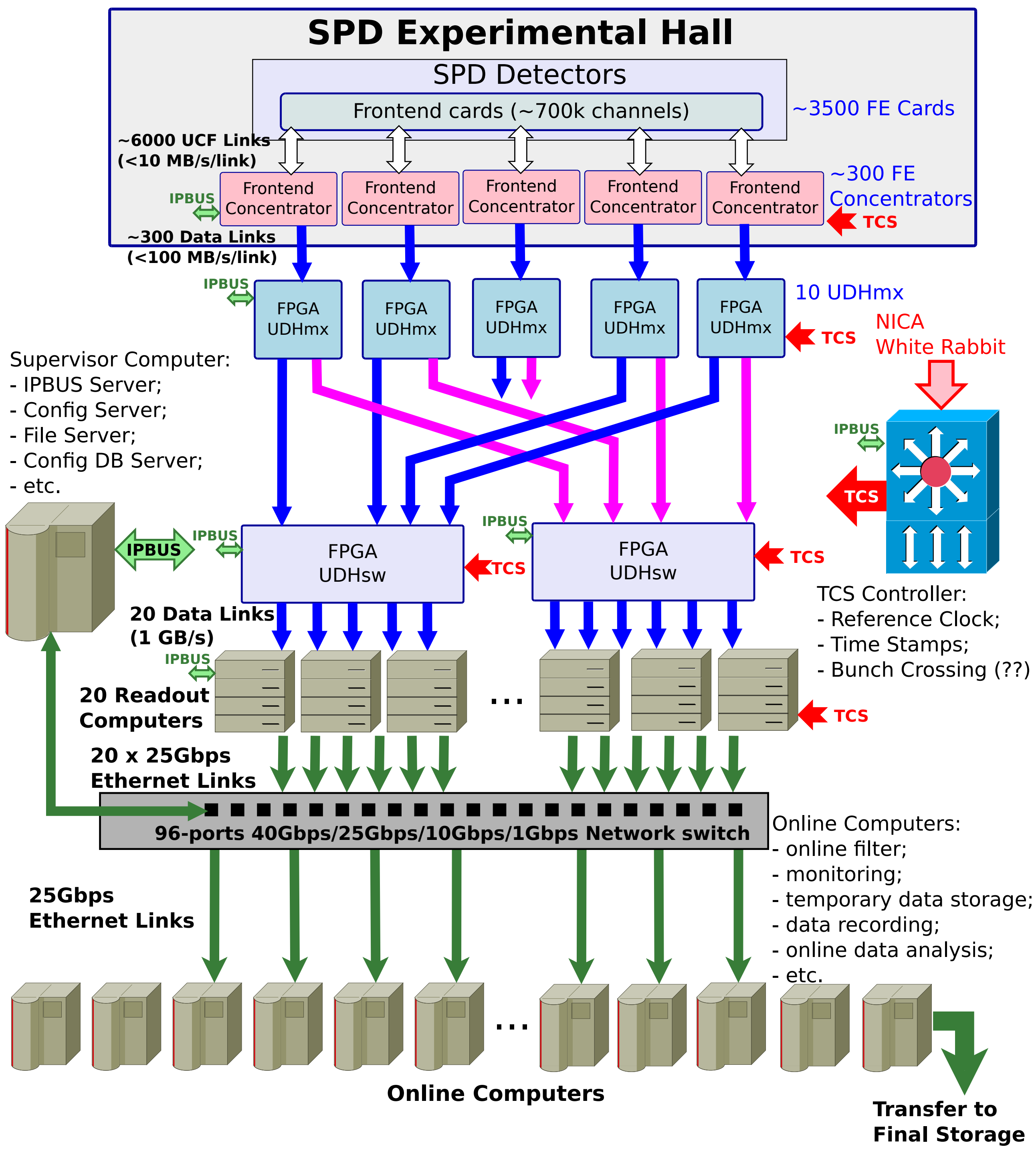


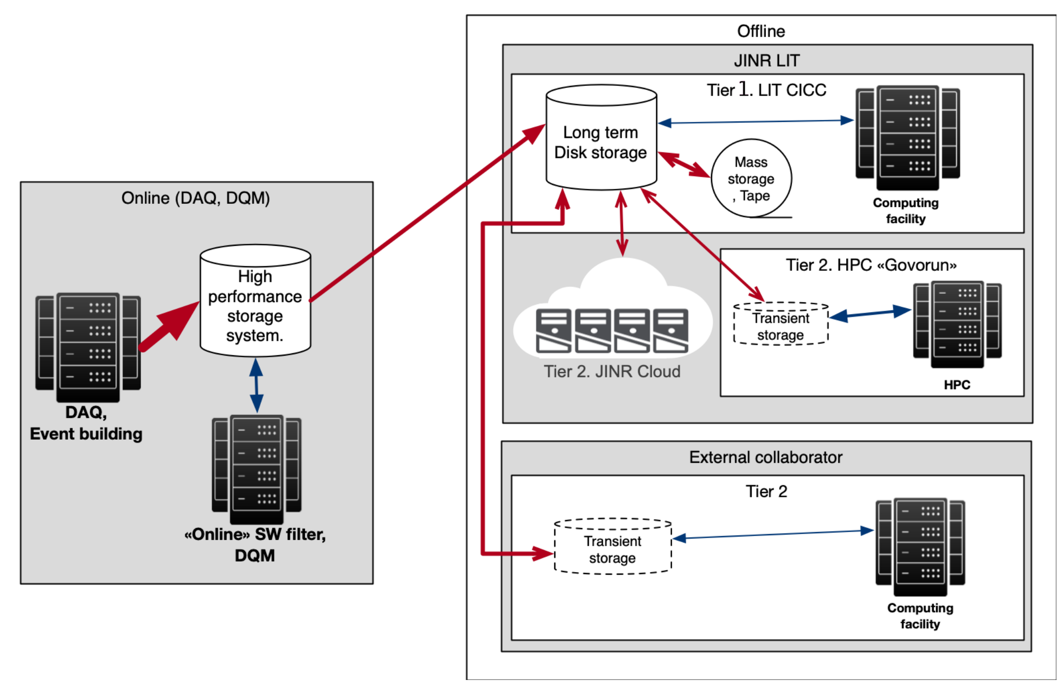
Рис. 20. Измеренная зависимость ложной идентификации пионов и каонов от амплитуды для импульсов $P = 0{,}86$ ГэВ/c и $P = 1{,}2$ ГэВ/c

6 p.e. per counter on average

Data Acquisition System (DAQ)



- Bunch crossing every 76 ns → crossing rate 12.5 MHz
- At maximum luminosity of 10^{32} $cm^{-2}s^{-1}$ the interaction rate is 3MHz
- No hardware trigger to avoid possible biases
- Raw data stream 20 GB/s or 200 PB/year
- Online filter to reduce data by oder of magnitude ~10 PB/year



	CPU [cores]	Disk [PB]	Tape [PB]
Online filter	6000	2	none
Offline computing	30000	5	9 per year