The SPD (Spin Physics Detector) experiment at NICA

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on behalf of the SPD Collaboration

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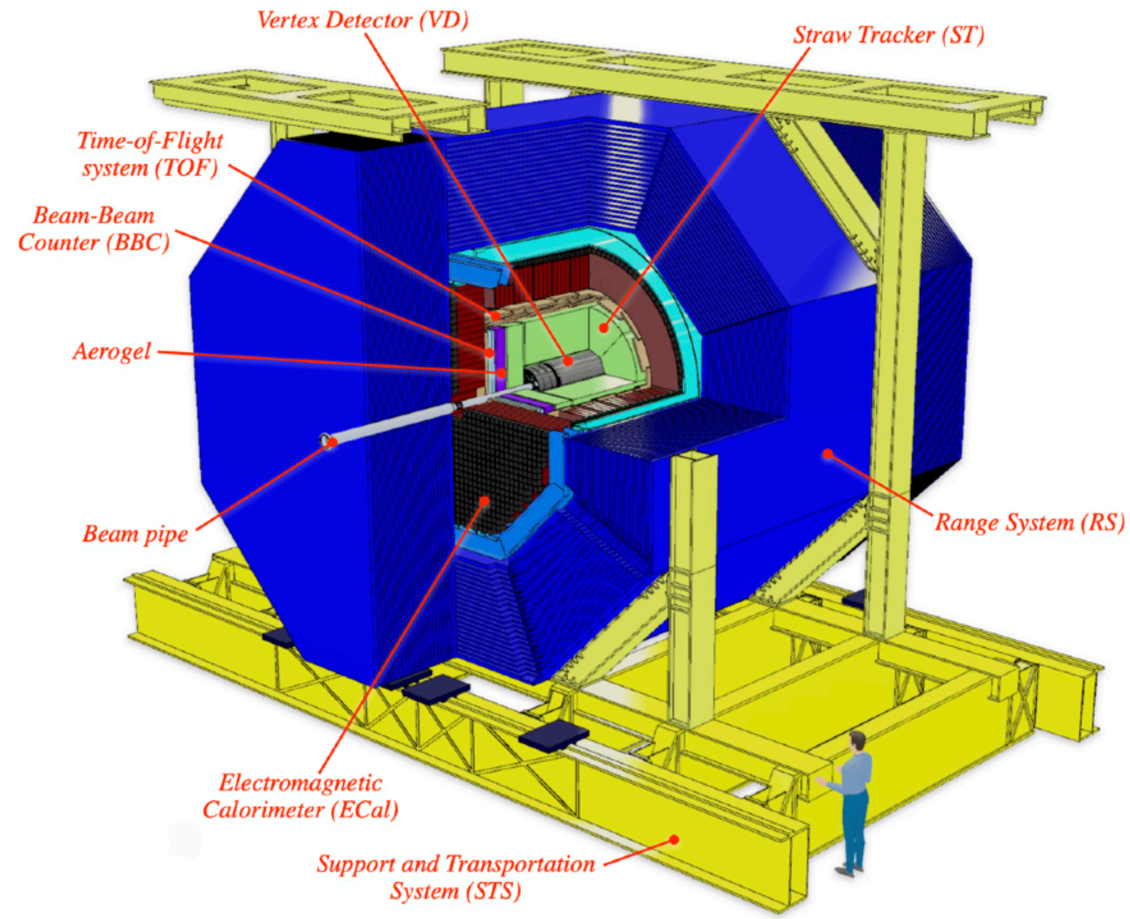
September 4-8, 2023

SPD project at NICA (JINR, Dubna)

~300 participants from 32 institutes from 15 countries

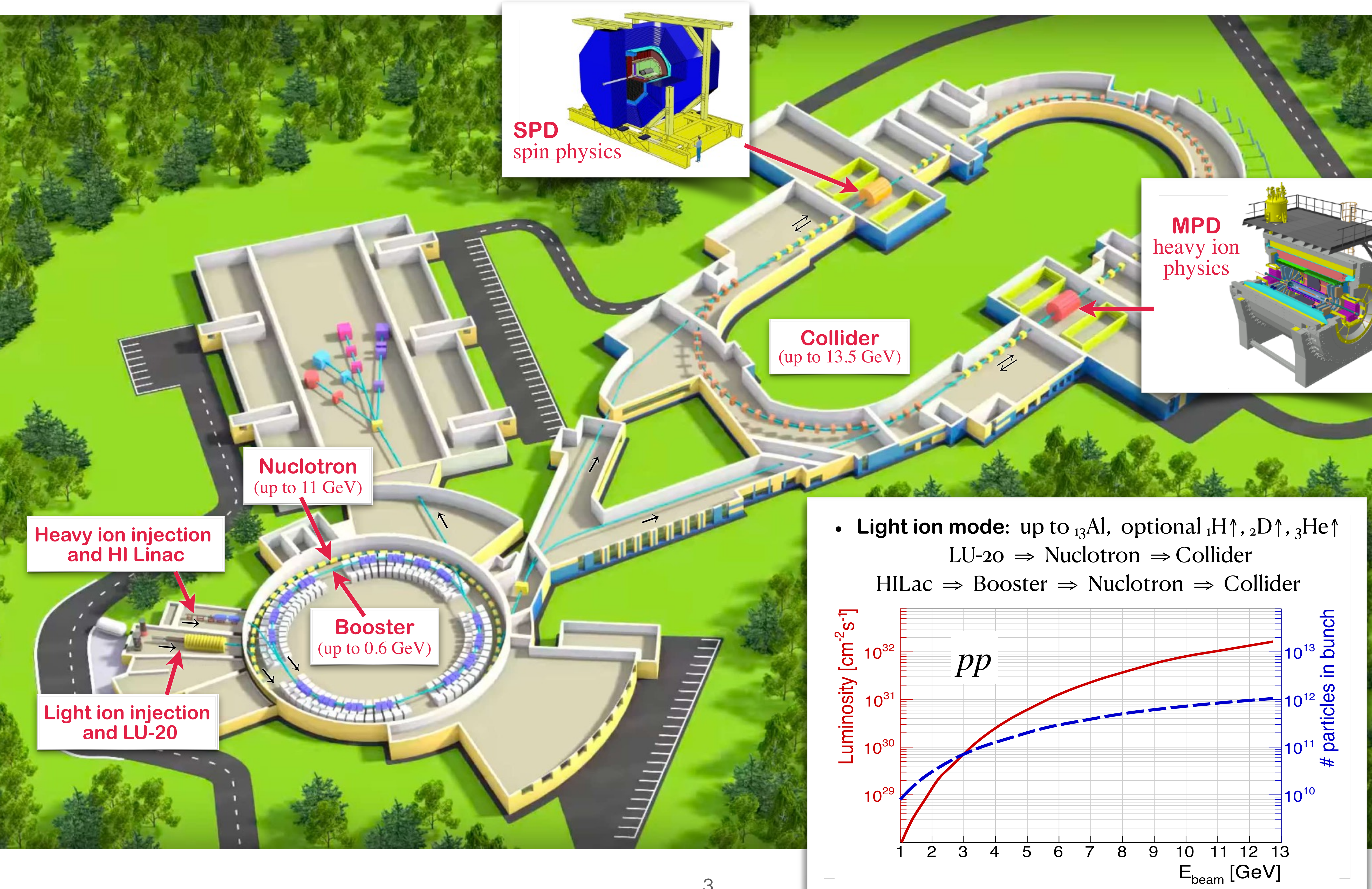
- SPD (Spin Physics Detector) is a universal facility with the primary goal to study *unpolarized and polarized gluon content of proton and deuteron*
- SPD project was approved by PAC JINR and had its first proto-collaboration meeting in June 2019
- Conceptual Design Report (CDR) was released in January 2021, [arXiv:2102.00442]
- Official birthday of the SPD collaboration in June 2021
- Technical Design Report (TDR) v1 of SPD was released in January 2023
- Beginning of datataking (1-st stage, partial setup) in 2028



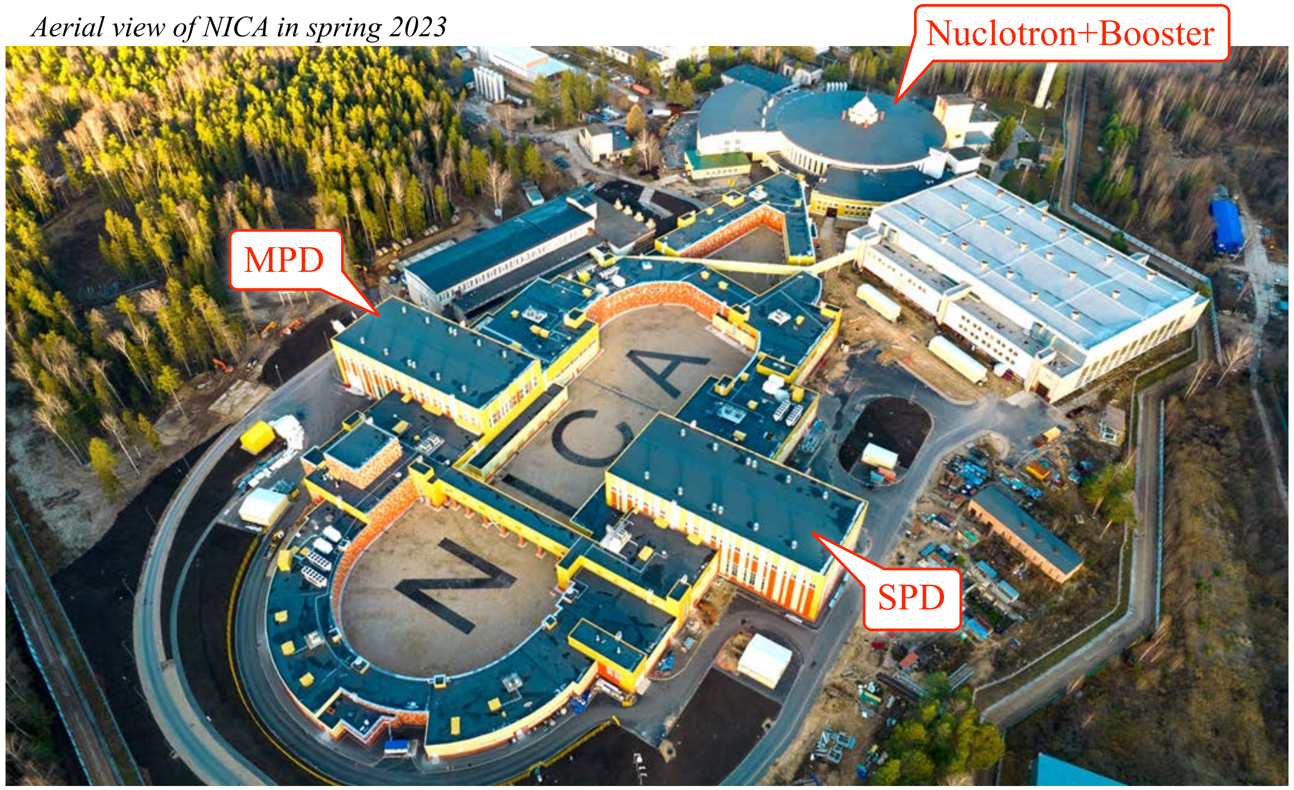
Physics program of SPD

- A.Arbuzov et al, *On the physics potential to study the gluon content of proton and deuteron at NICA SPD*, Prog.Part.Nucl.Phys. 119 (2021) 103858 [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*, Phys.Part.Nucl. 52 (2021) 6 [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, …

Accelerator complex NICA in JINR



Aerial view of NICA in spring 2023

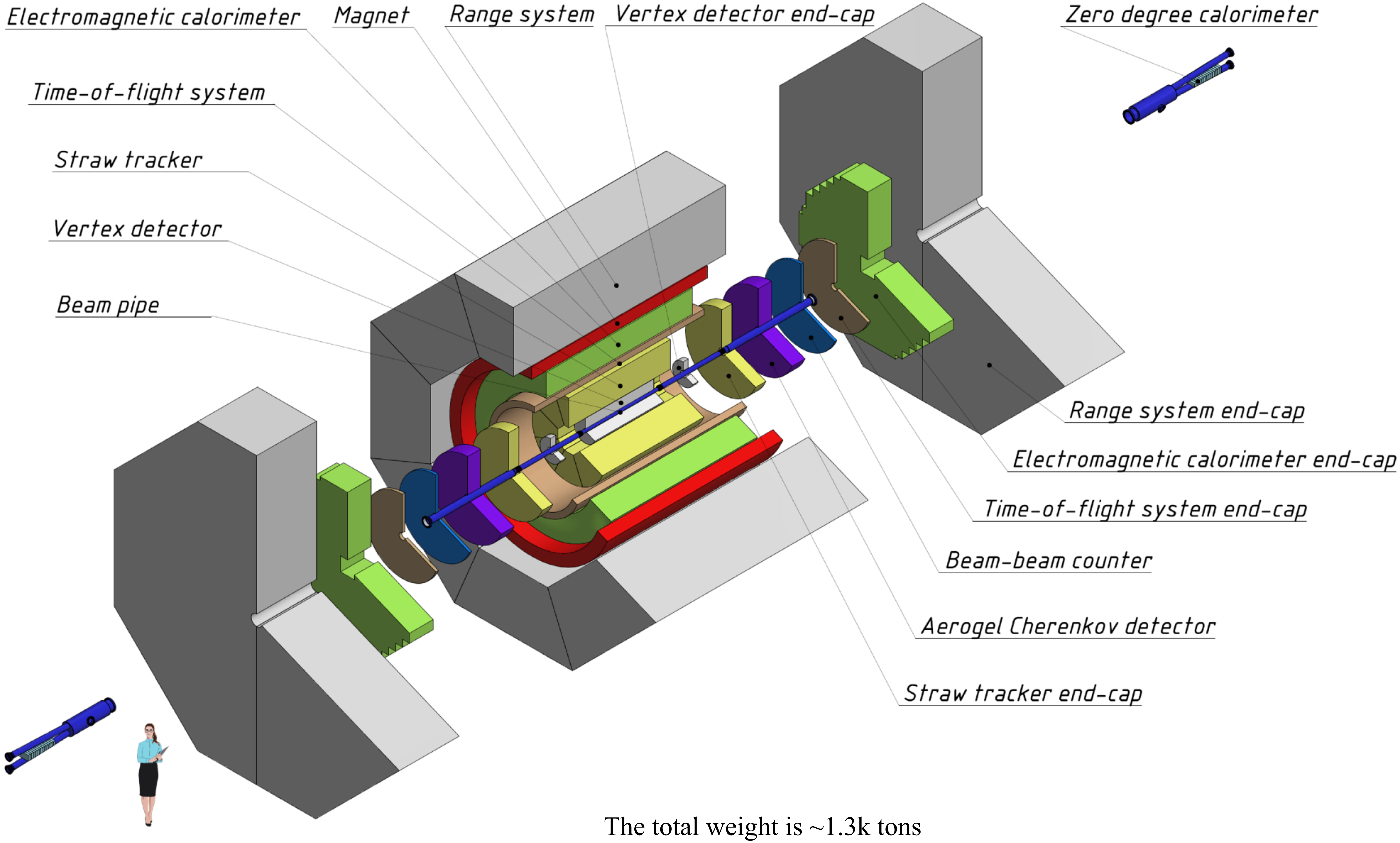


- Construction work is mostly completed
- Injectors, Nuclotron & Booster are operational
- Assembly of the Nuclotron-Collider beam transfer line, “cold” and vacuum tests in 2024
- First heavy-ion run for MPD in early 2025
- Still significant upgrade is required for the polarized proton beam (Siberian snakes, spin navigators and flippers, polarimeters)

- The SPD hall is currently used for storing concrete blocks of biological protection and collider elements.
- The detector rail system will be installed at the end of this year.
- Biological protection will be installed earlier next year (extension of accelerator tunnel) and will remain until the construction of the SPD detector is completed.

SPD hall in 2022

Schematic view of the SPD setup



The total weight is ~1.3k tons

Superconductive solenoid magnet

Control Dewar
The volume of the Dewar tank is enough to cool the magnet offline for about a day without an influx of helium from the outside

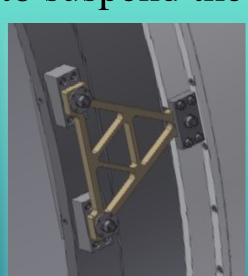
Steel cryostat
Outer diameter 4.01 m
Inner diameter 3.47 m
Thickness 27 cm
Length 4.2 m
Weight 22 tons

Cooling He pipe welded to the support cylinder

Thermal shield cooled by gaseous He

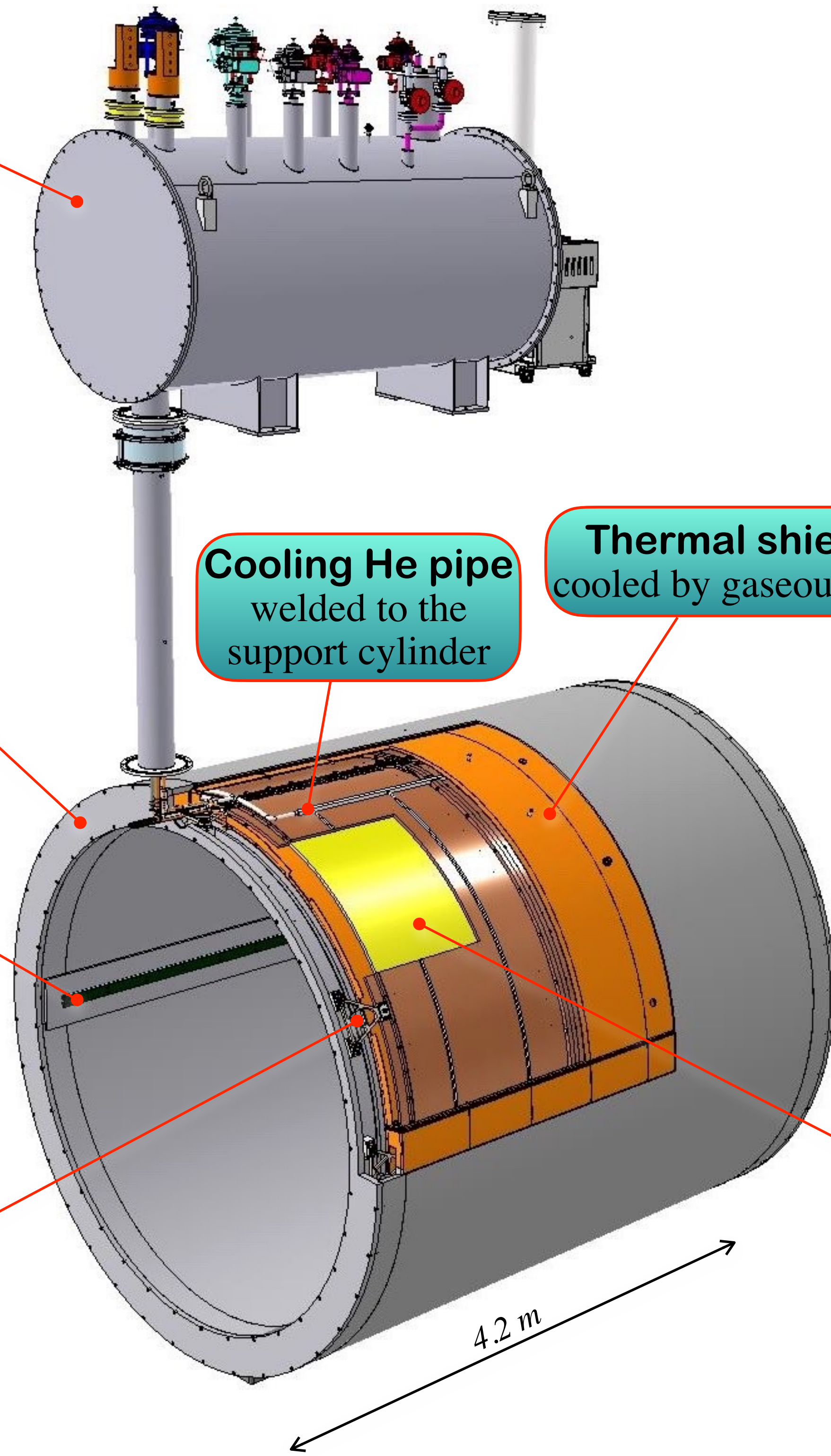
Linear guides used for positioning an electro-magnetic calorimeter

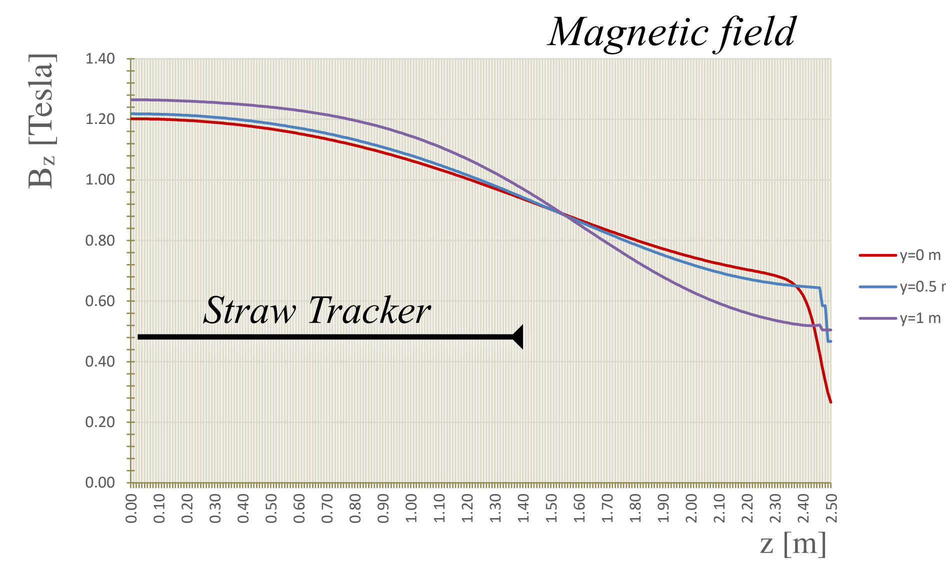
Triangular **supports** are used to suspend the "cold mass".



12 pieces on each side.

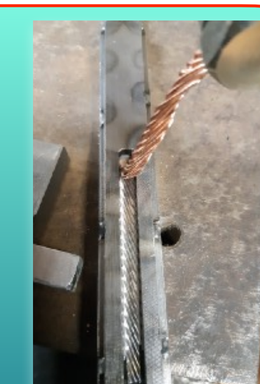
Made of fiberglass.





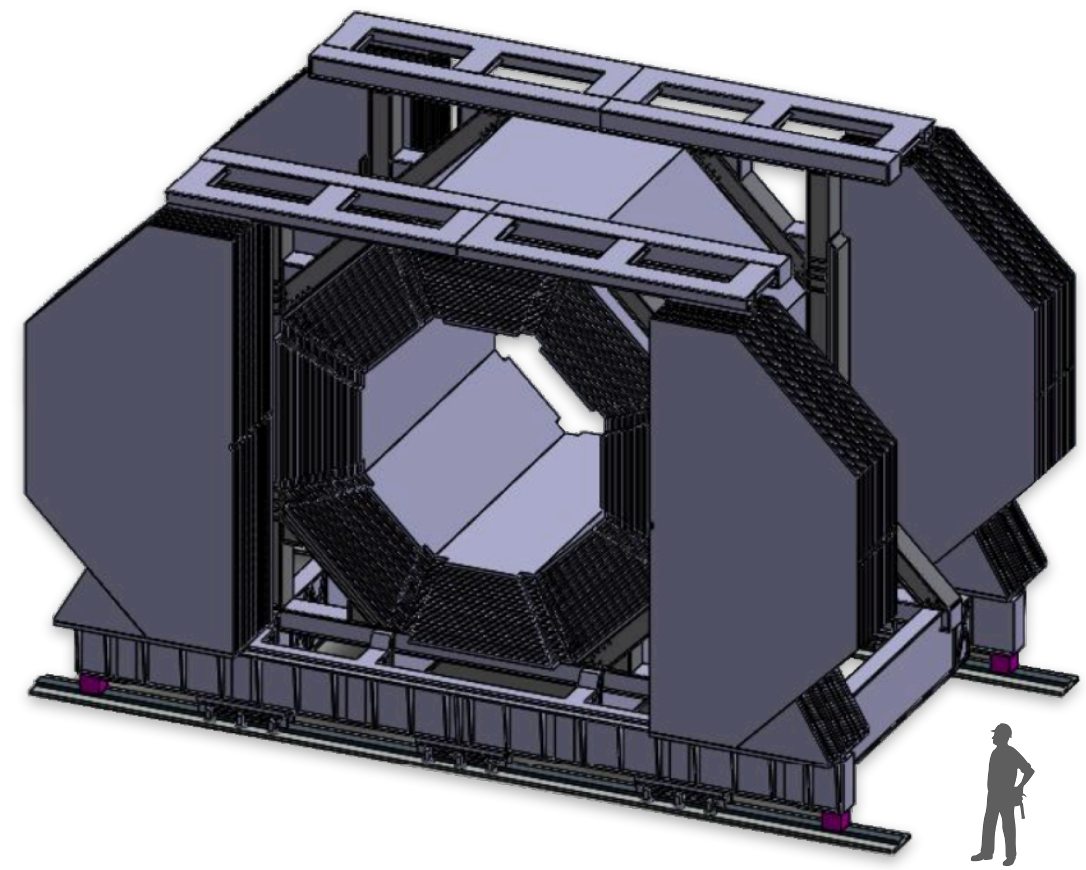
- 1.1 Tesla field with ±9% uniformity within ±1.4 m distance from center (tracking det.)
- Solenoid consists of 3 coils with 750 turns in total (two layer edge-wise winding)
  - central coil with 2×75=150 turns
  - 2 side coils with 2×150=300 turns
- The use of the *thermosyphon method* for cooling the superconducting coils (natural convection of two-phase helium at 4.5K)
- It will be constructed in BINP Novosibirsk

Rutherford-type cable made of 8-strands NbTi/Cu superconductor. The cable will be encased in an aluminum stabilizer using a co-extrusion process that provides a good bond between aluminum and superconductor in order to ensure quench protection during operation.

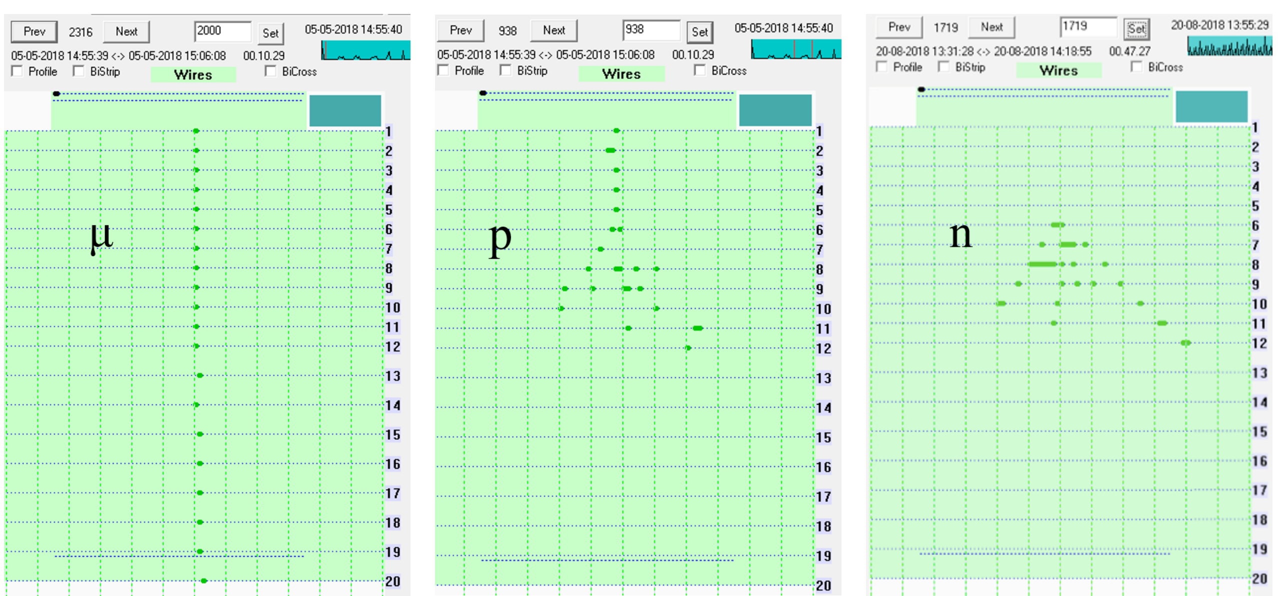


Range System (RS)

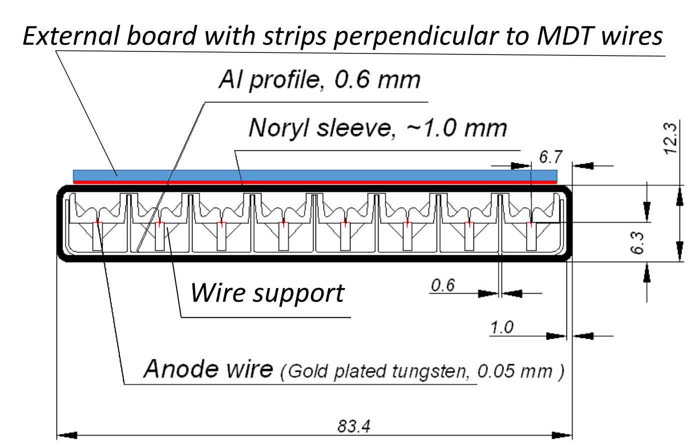
- Purposes: μ identification, rough hadron calorimetry, iron return yoke of the magnet, mechanical support structure of the overall detector
- 20 layers of Fe (3-6 cm) interleaved with gaps for Mini Drift Tube (MDT) detectors
- The endcaps must withstand the ~100 tonne magnetic force
- Total mass ~10^3 tons, at least $4\lambda_I$
- The design will 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

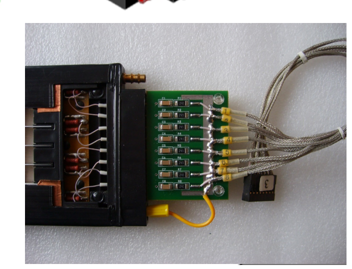


Results of beam tests of RS prototype (10 ton, 4k ch)

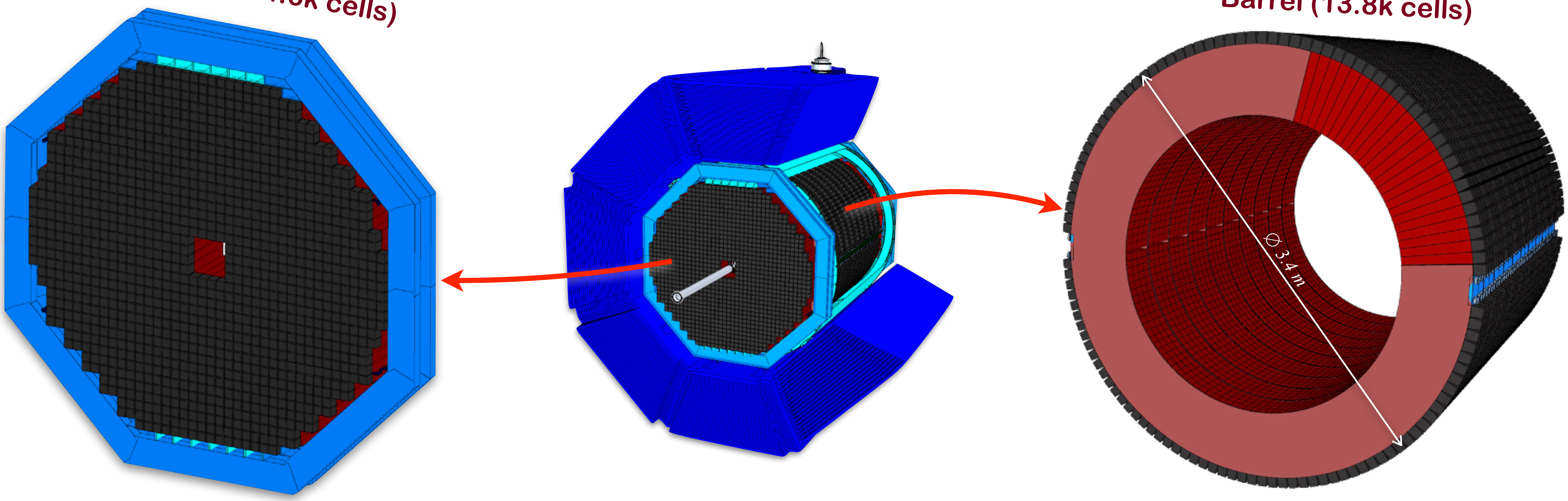


Mini Drift Tubes (MTD)

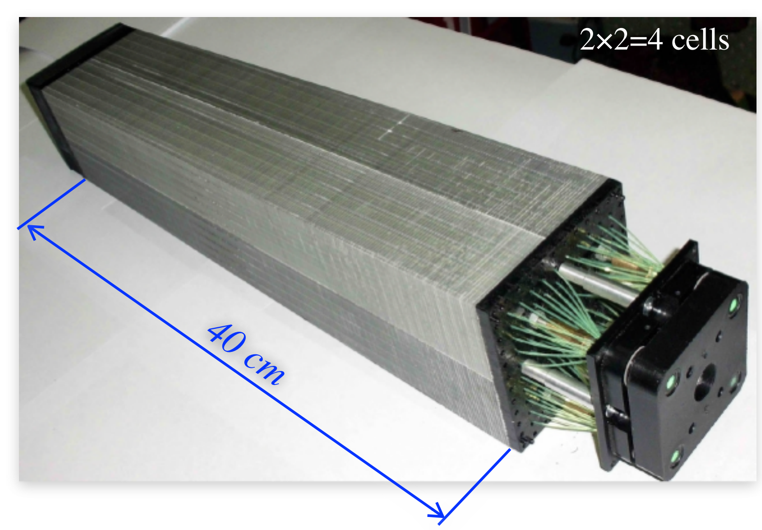




Electromagnetic Calorimeter (ECal)



- 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 ~23k
- Energy resolution is ~5% / $\sqrt{E}$
- Low energy threshold is ~50 MeV
- Time resolution is ~0.5 ns

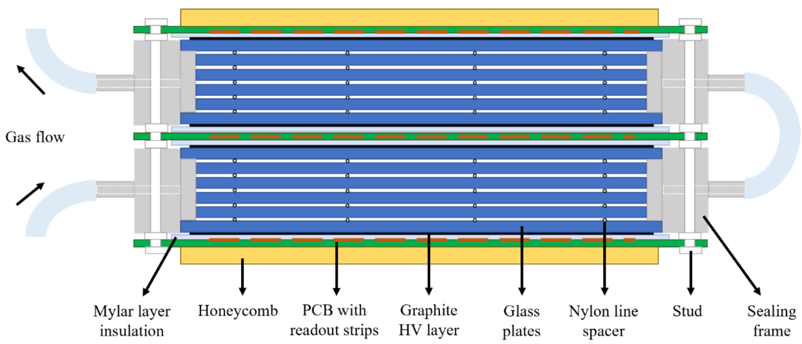


- 200 layers of lead (0.5 mm) and scintillator (1.5mm)
- 36 fibers of one cell transmit light to 6×6 mm² SiPM
- Moliere radius is ~2.4 cm

Time-of-flight (TOF) detector

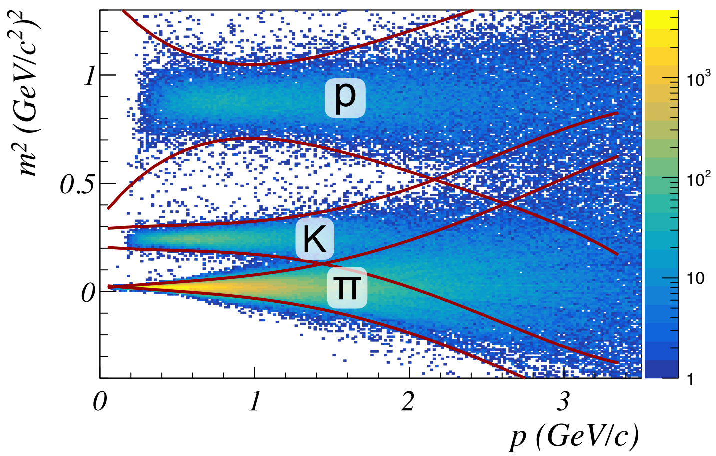
Schematic view of self-sealed MRPC

(B.Wang et al, JINST 15 (2020) 08, C08022)



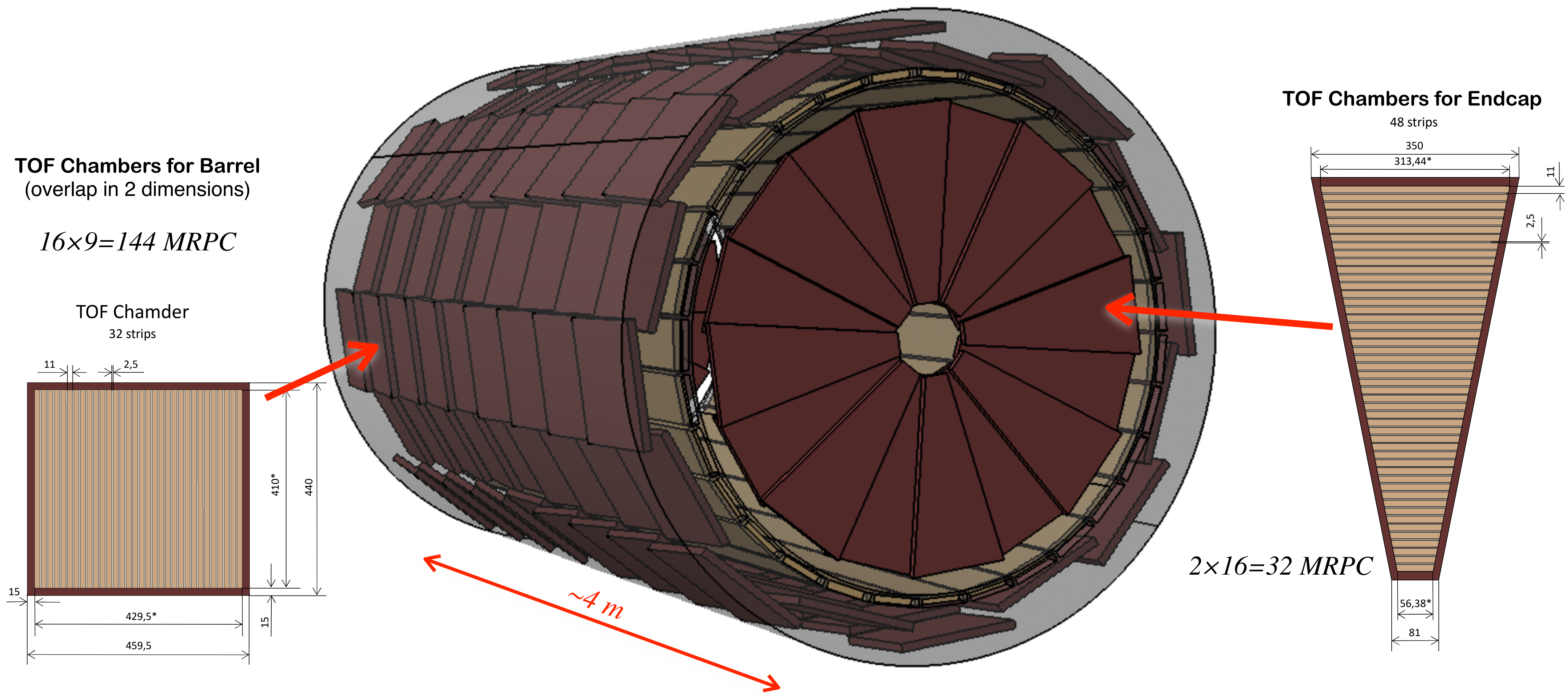
- Purpose: π/K/p discrimination for momenta ≤2 GeV, determination of t_0.
- Time resolution requirement <60 ps.
- Self-sealed Multigap Resistive Plate Chambers (MRPC) are the base option.
- Eco-friendly gas is under discussion HFO-1234ze ($C_3H_2F_4$) 4-th generation.
- Number of readout channels is ~12.2k

Reconstruction for pp at √s=27 GeV



TOF Chambers for Barrel
(overlap in 2 dimensions)

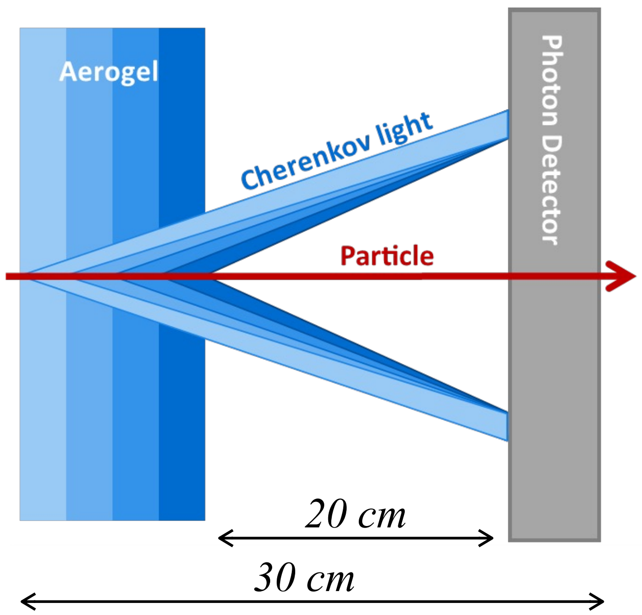
16×9=144 MRPC



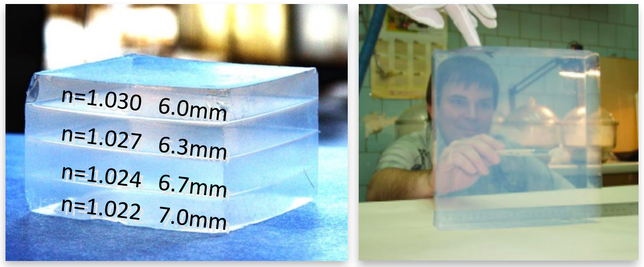
2×16=32 MRPC

Focusing Aerogel RICH (FARICH) detector

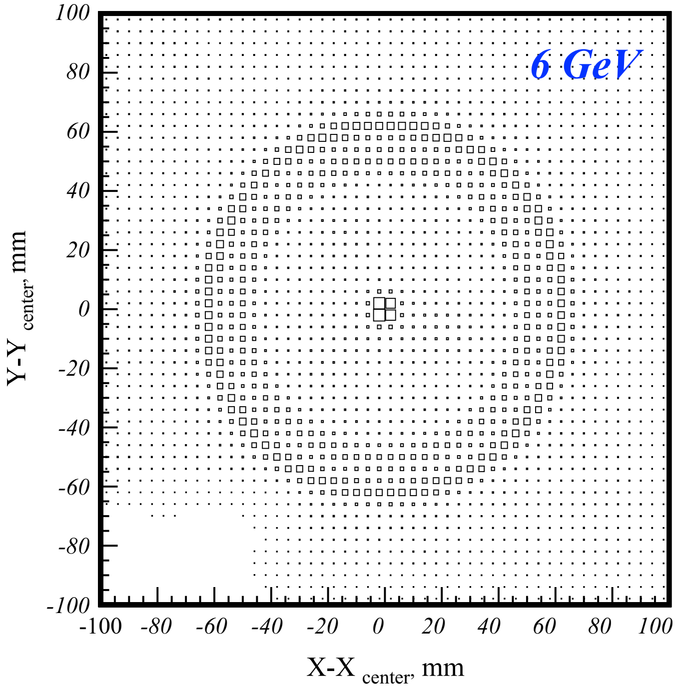
Principle of detector operation



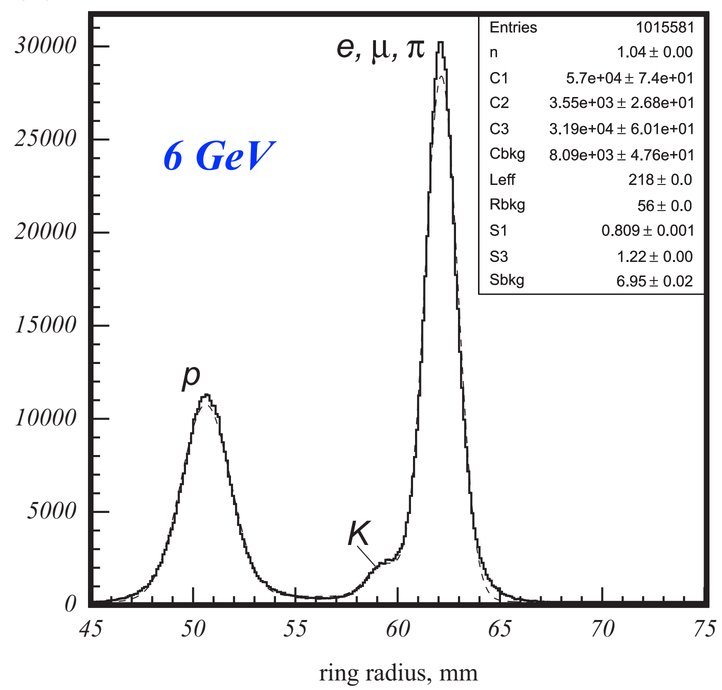
- Purpose: identification of high momentum particles ($p \gtrsim 1.5$ GeV) which cannot be discriminated by TOF
- Requirement: π/K separation at 6 GeV/c up to 3.5σ
- Disk-shaped detector in endcap with an area of 2 m^2
- Multilayer focusing aerogel radiator produced in BINP
- Development of Multi-anode MCP-PMT is ongoing in Russia (so far PMT of Hamamatsu, Photonis, Photek)
- The FARICH concept was published in 2005
- It was realized as a detector in Belle-II (KEK) in 2017



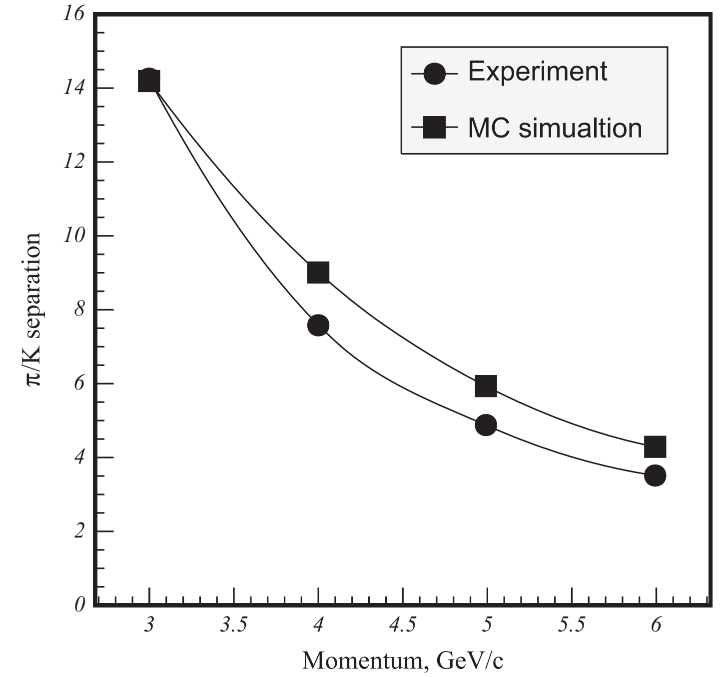
Accumulated *xy* distribution of hits



Ring radius distribution of γ

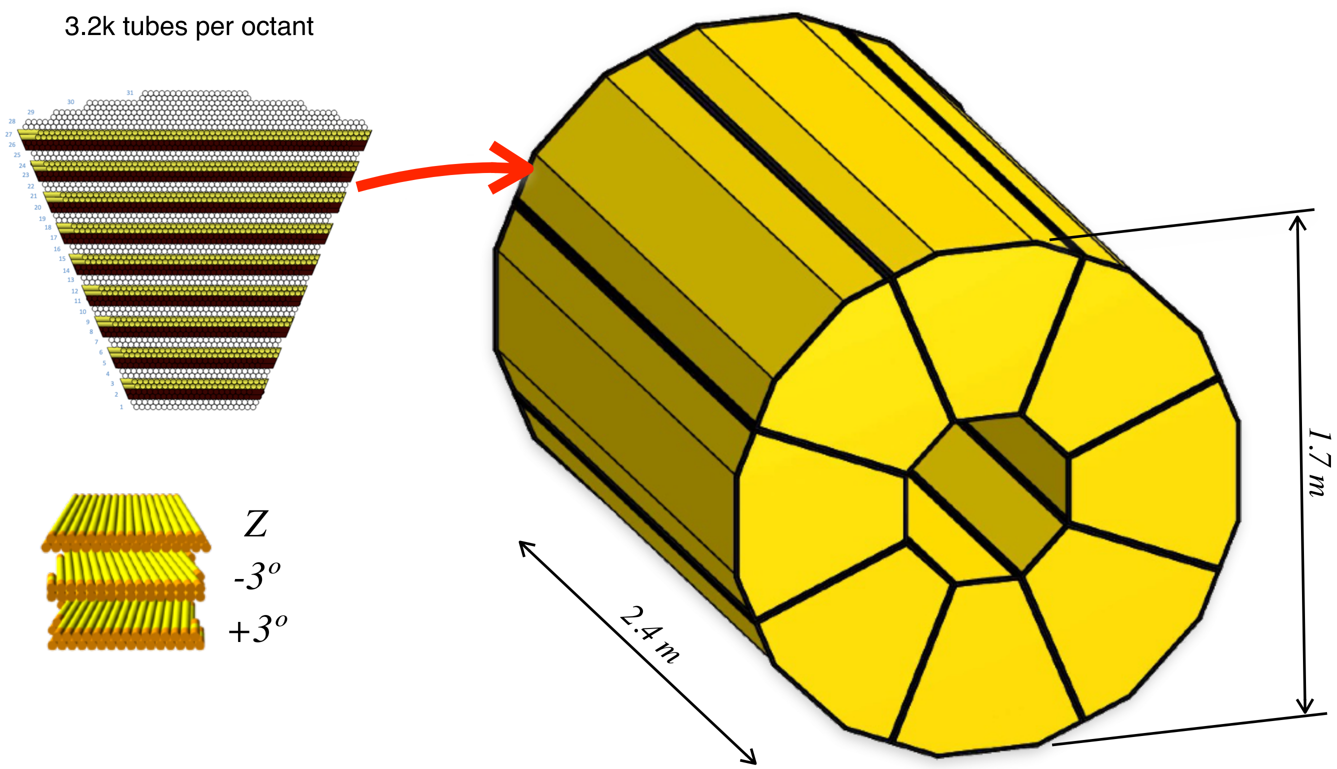


Ability to distinguish between π and K



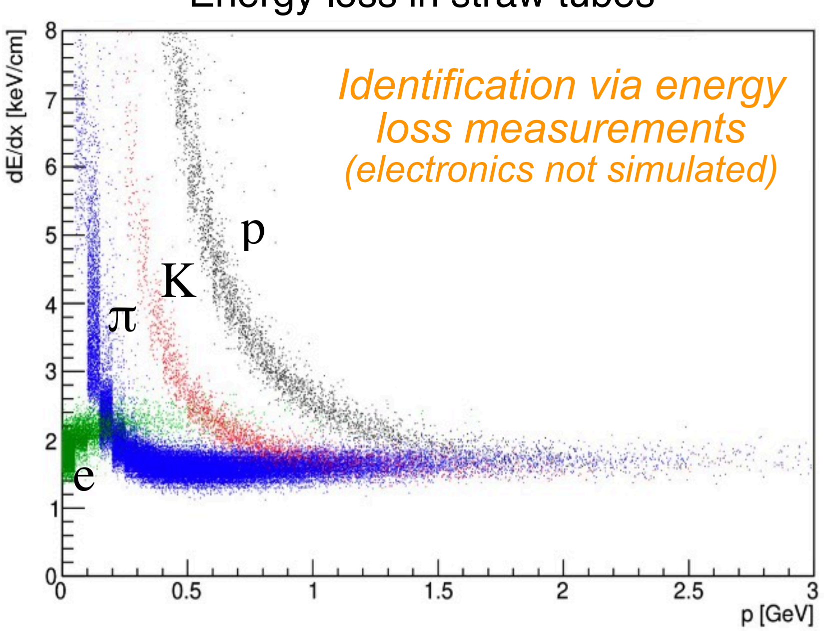
A.Barnyakov et al, NIMA732(2013)352

Barrel of Straw Tracker (ST)

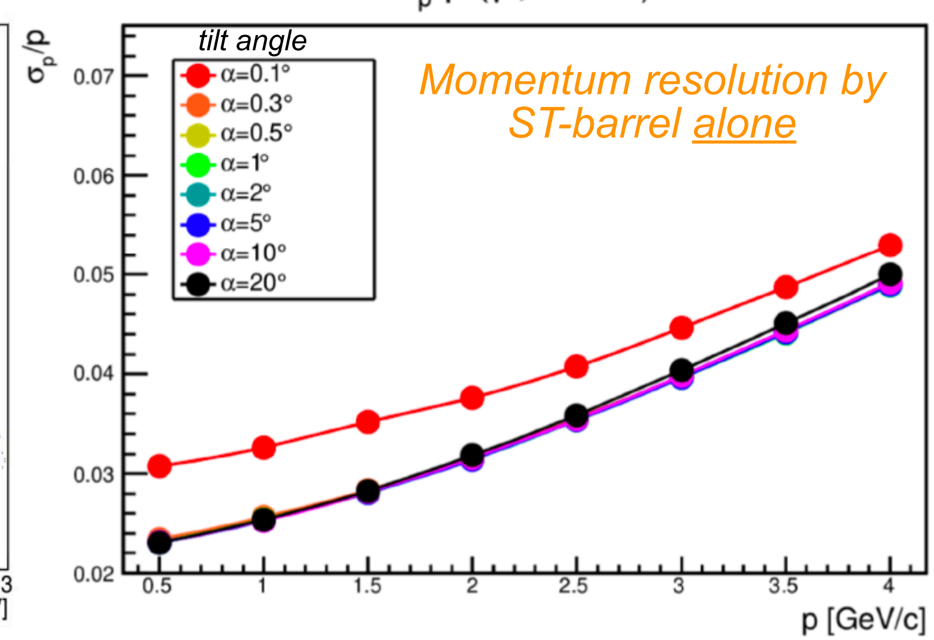


- Main tracker system of SPD
- Barrel is made of 8 modules with 30 double-layers oriented as *z,+3°,-3°*
- Maximum drift time of 120 ns for ∅=10mm straw
- Straw tubes are made of a PET foil that is ultrasonic welded to form a tube
- Spatial resolution of 150 μm
- Expected DAQ rate up to several hundred MHz/tube (electronics is limiting factor)
- Number of readout channels ~26k
- Extensive experience in straw production in JINR for several experiments: ATLAS, NA58, NA62, NA64; prototypes for: COZY-TOF, CREAM, SHiP, COMET, DUNE.

Energy loss in straw tubes

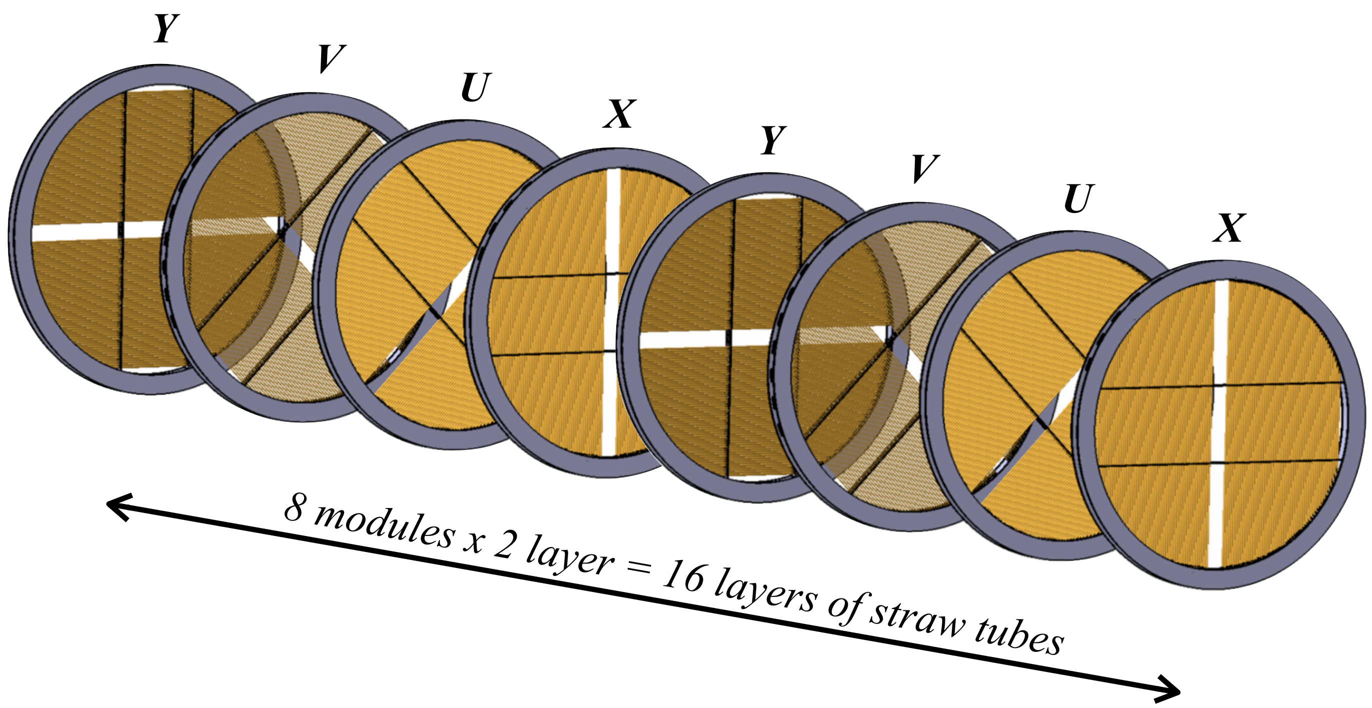


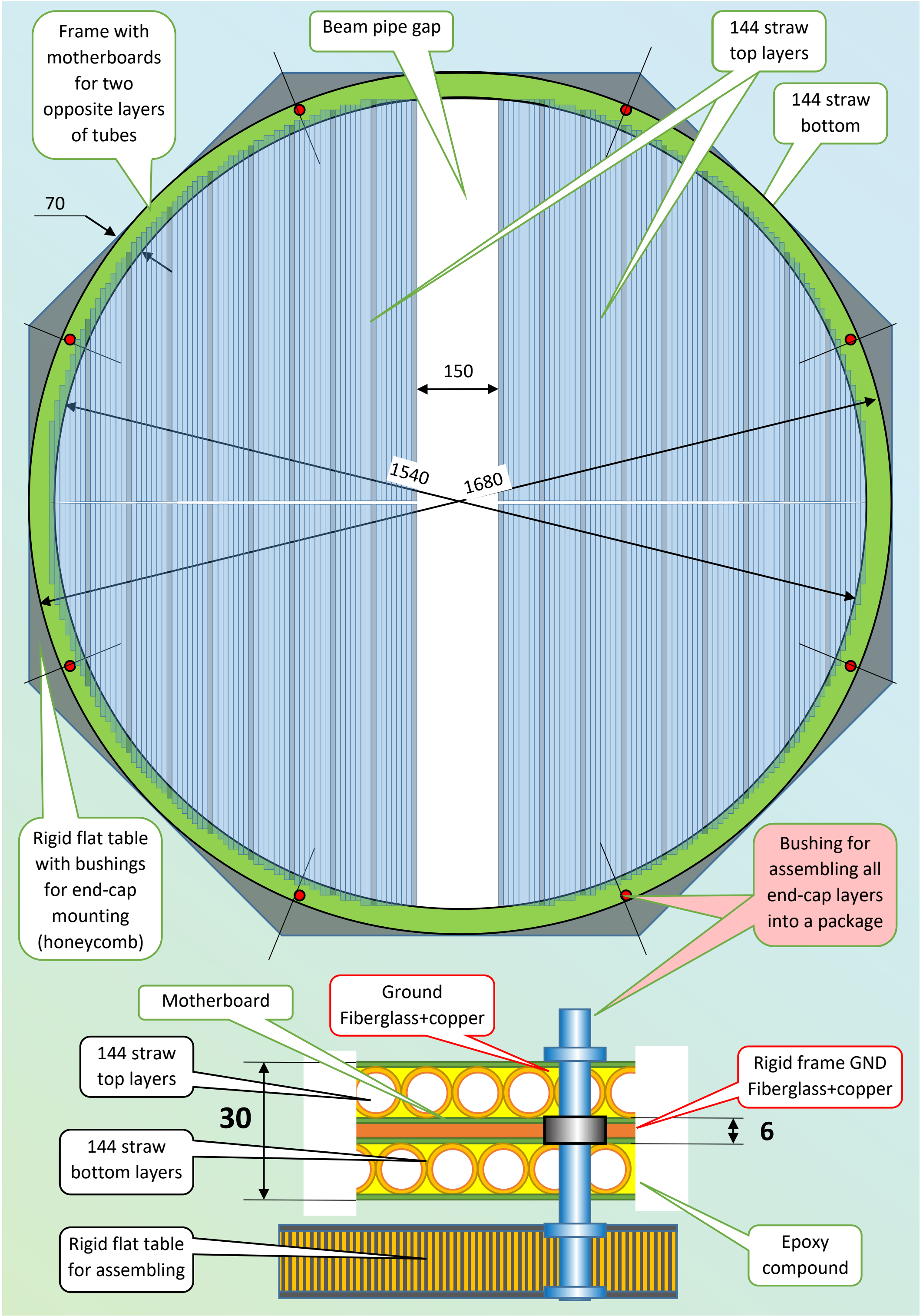
σ_p/p (μ, θ=90°)



straw production for NA62 (~2010)

Endcap of Straw Tracker (ST)

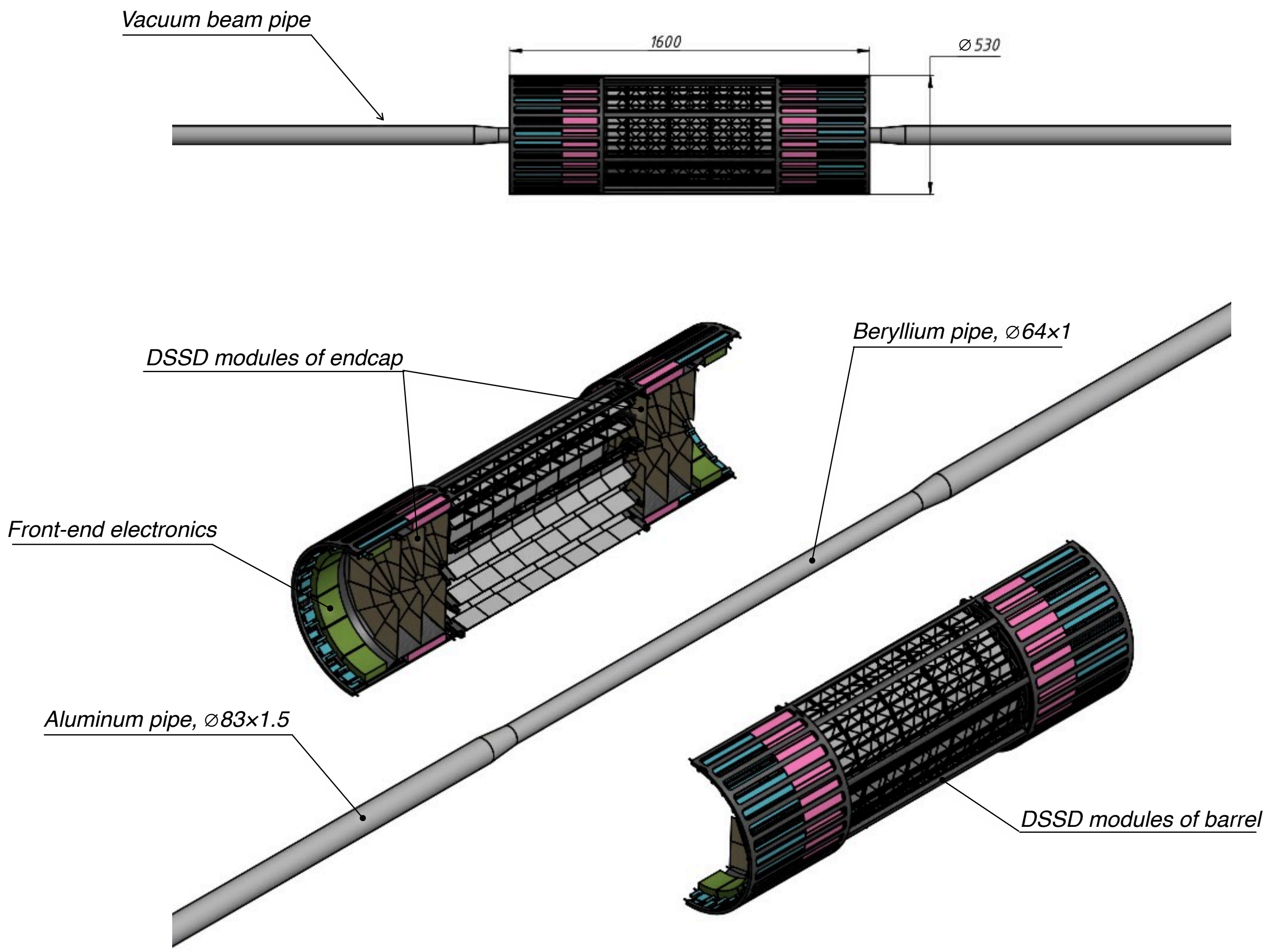




- One ST endcap contains 8 modules: *X*, *+45°*, *-45°*, *Y*
- One module contains 288 tubes in total, which are arranged in two layers shifted by half a tube
- Total number of tubes in two endcaps is

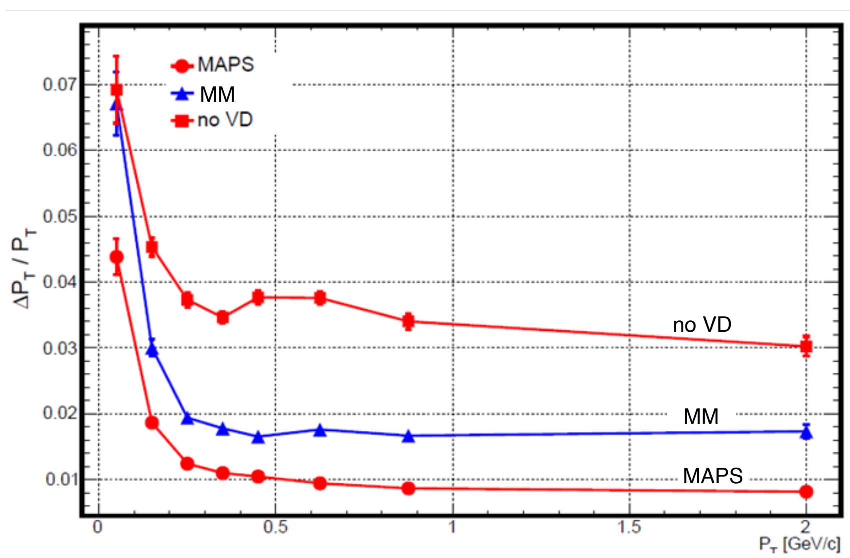
  288 tubes × 16 modules × 2 endcaps = 9216 tubes
- The thickness of one module is 30 mm
- Eight coordinate planes are mounted together on a rigid flat table to form a 240 mm thick rigid block
- One straw is made by winding two "kapton" tapes forming a tube with ∅ = 9.56 mm

Silicon Vertex Detector (SVD)

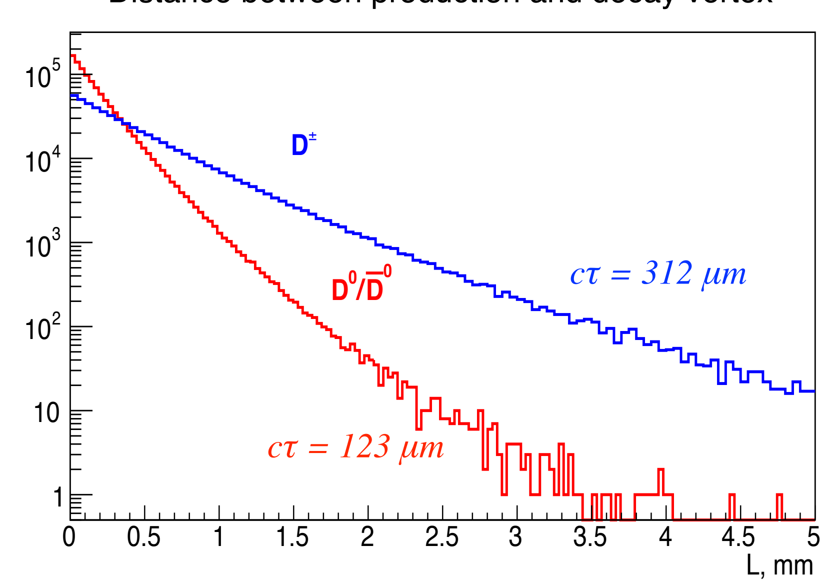


- Silicon Vertex Detector (SVD) by 2035
  - Double-Sided Silicon Detector (DSSD), strip readout, σ=28 μm
  - Monolithic Active Pixel Sensors (MAPS), pixel readout, σ=5 μm
- MicroMegas (MM) detector by 2028
  - Temporary solution while waiting for SVD
  - Strip readout, σ=150 μm
- Detector will be divided into halves, which will be assembled separately
- Once VD is closed it will form a single module with the beam pipe. The detector will not touch the pipe to avoid heat transfer

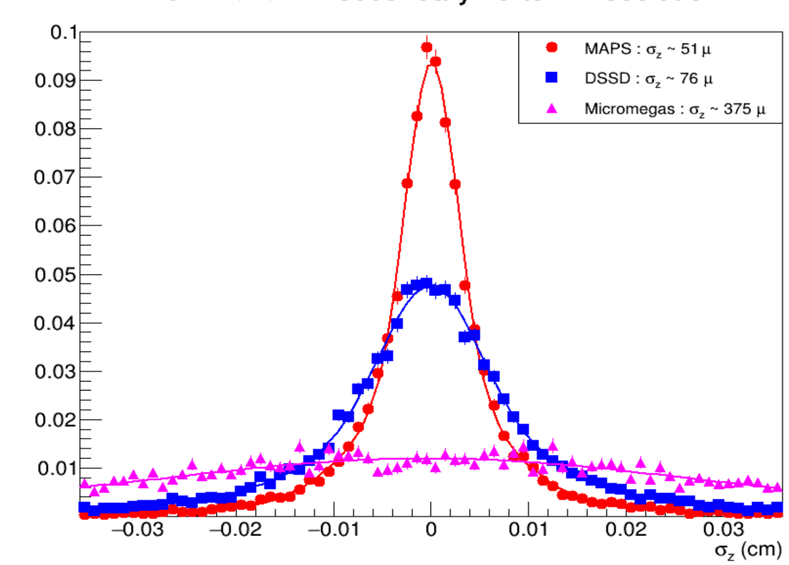
Transverse momentum resolution



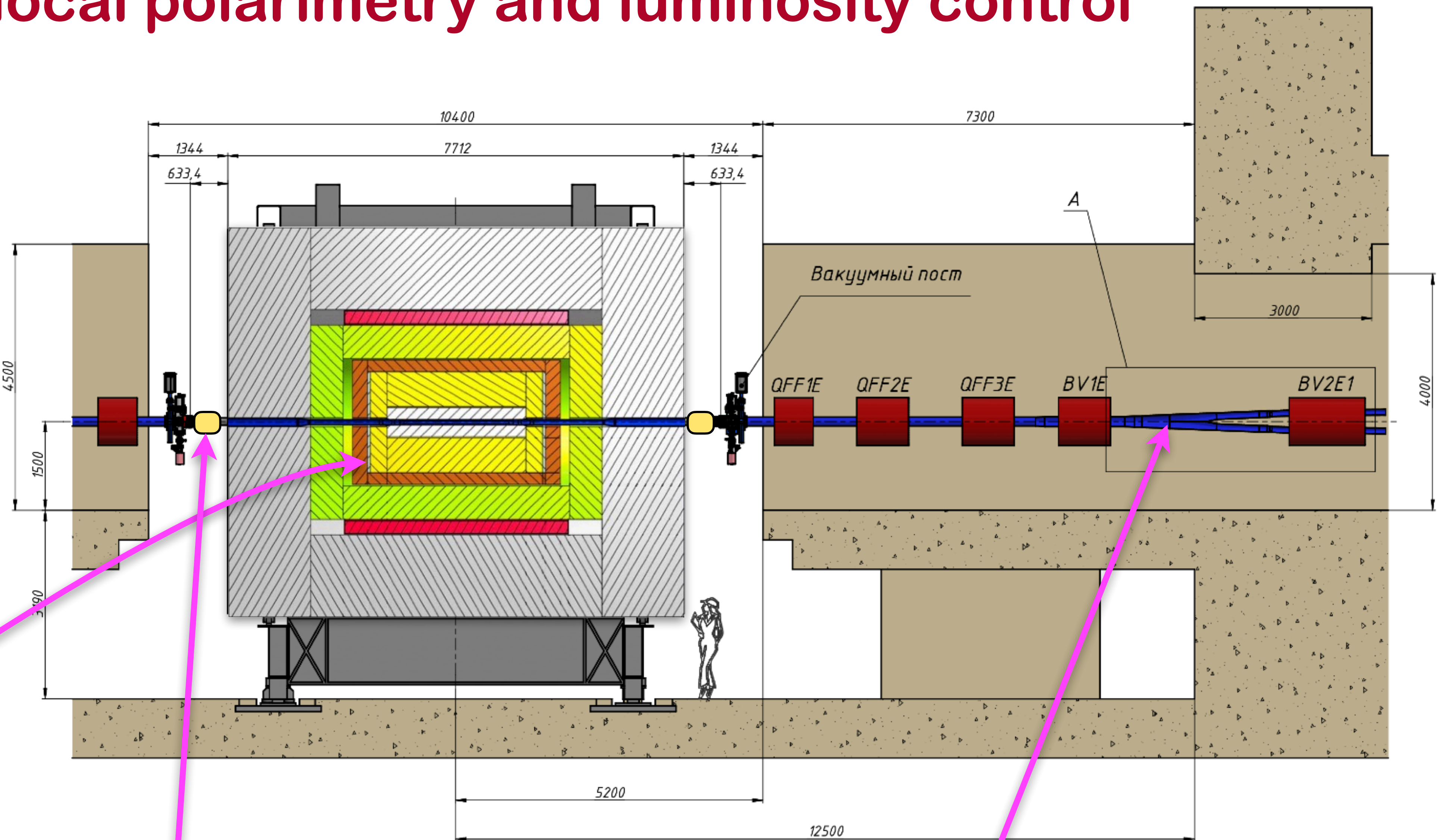
Distance between production and decay vertex



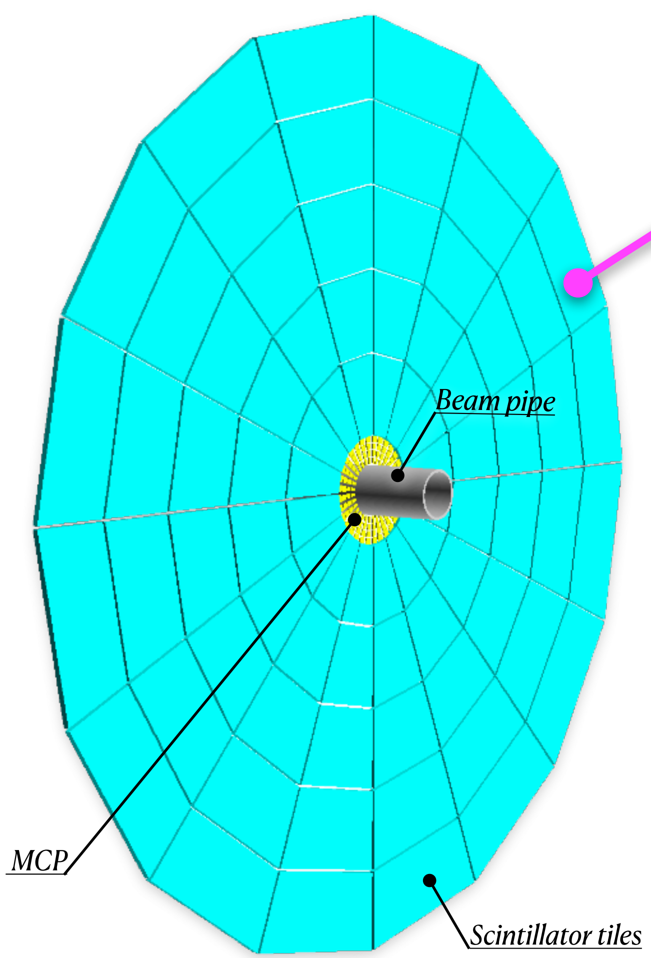
D0 → π⁺ + K⁻ : secondary vertex z-resolution

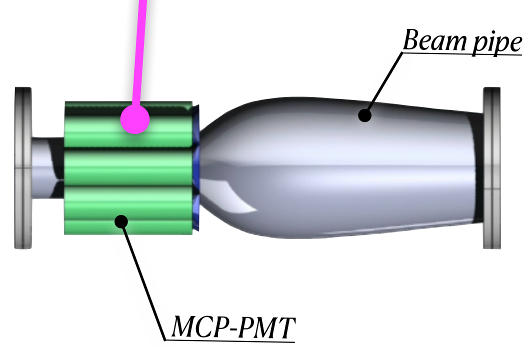


Detectors for local polarimetry and luminosity control

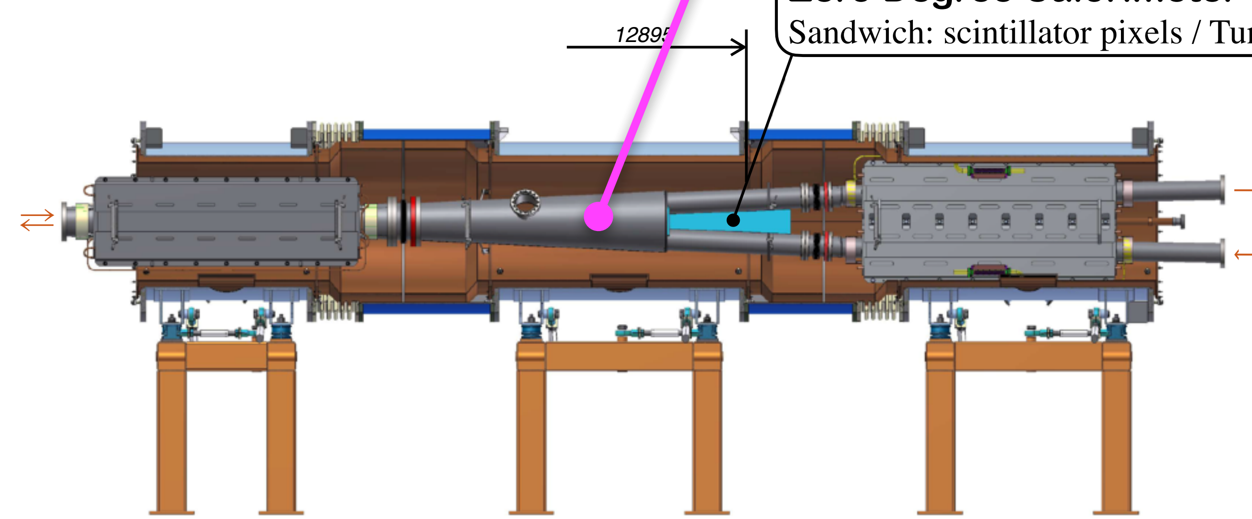


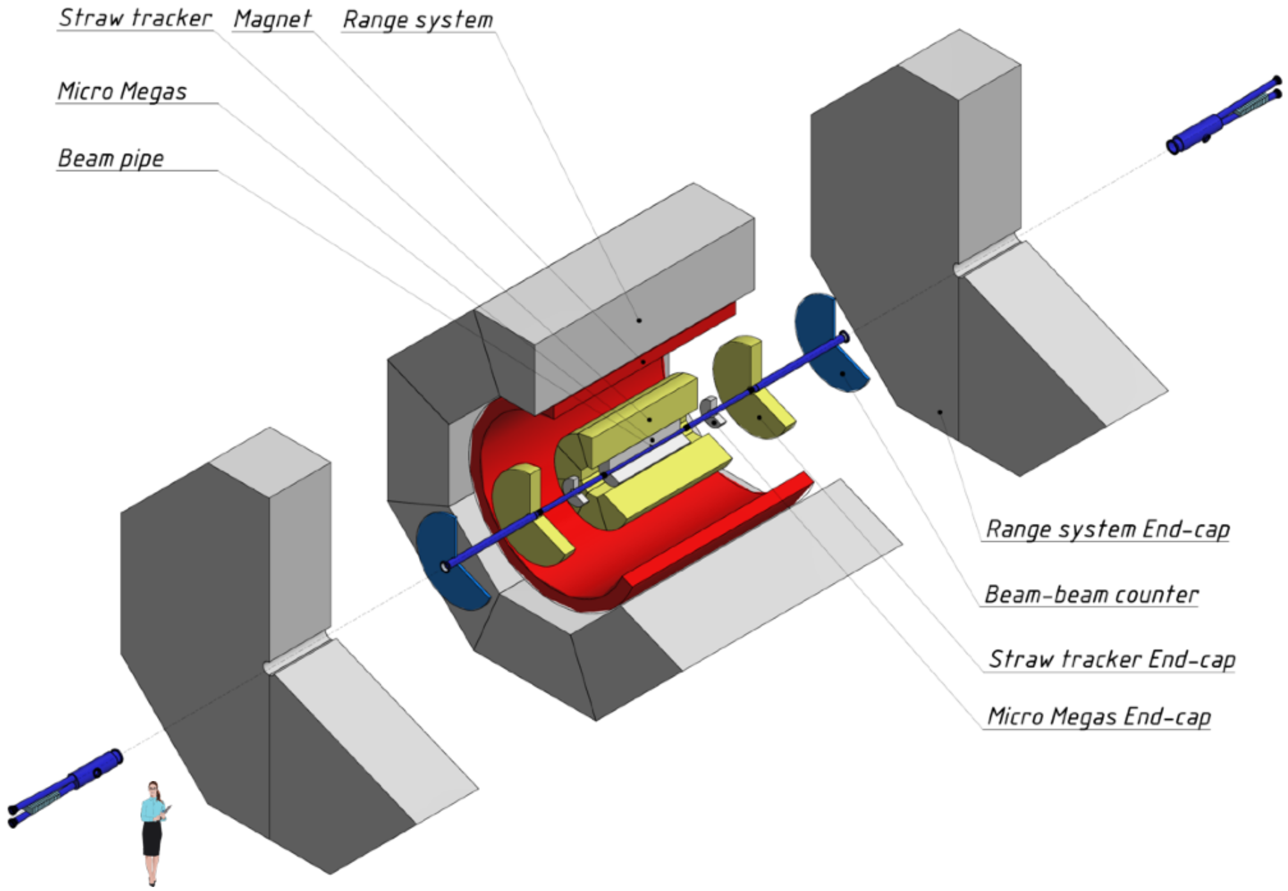
Beam-Beam Counter (BBC)
Plastic scintillator tiles
z = ±1.4m





Zero Degree Calorimeter (ZDC)
Sandwich: scintillator pixels / Tungsthen



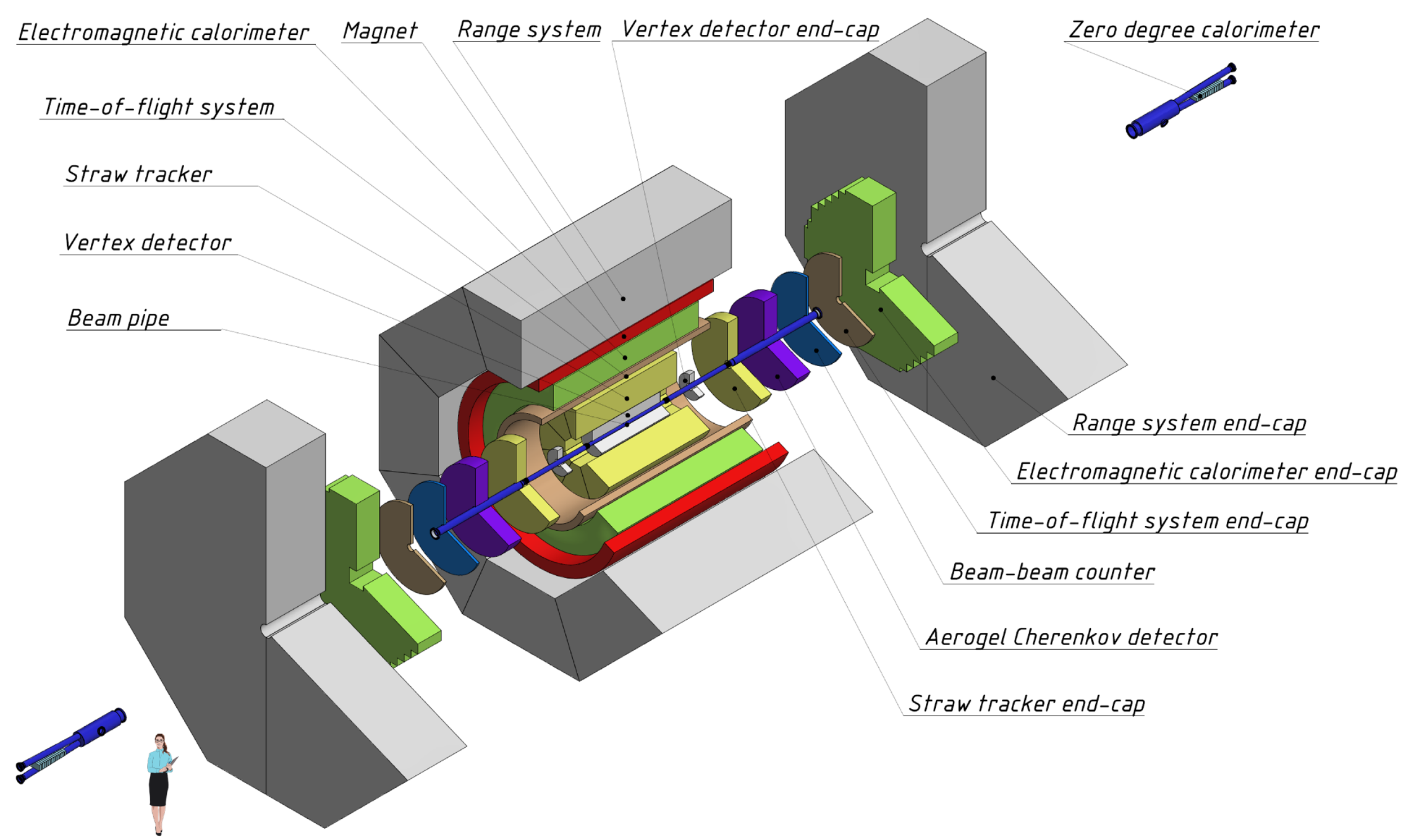


First stage of experiment by 2028

- Basic set of subsystems
  - RS, Straw, MM, and Magnet
  - BBC, MCP, ZDC
- No PID detector (TOF, FARICH), no ECal, no SVD
- p-beam: $\sqrt{s} \lesssim 15$ GeV, $\mathcal{L} \lesssim 10^{30}$ $s^{-1}cm^{-2}$

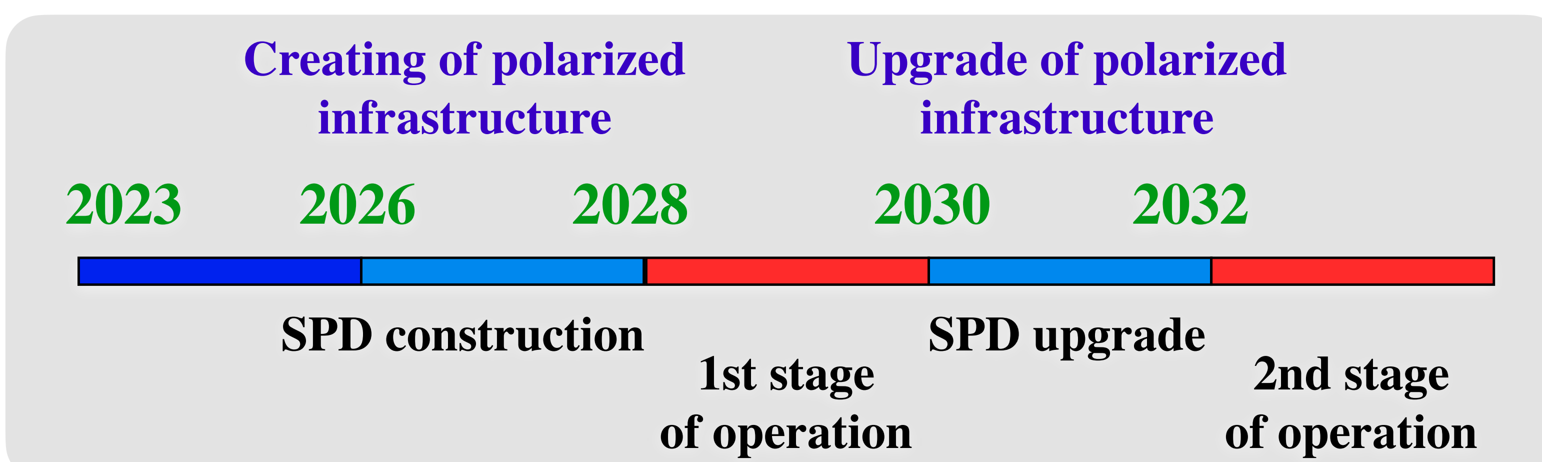
Fully assembled setup

- p-beam: $\sqrt{s}=27$ GeV, $\mathcal{L}=10^{32}$ $s^{-1}cm^{-2}$ with interaction rate of ~3 MHz
- No hardware trigger
- Raw data stream of 20 GB/s or 200 PB/year. It will be reduced by an order of magnitude using online filter



Conclusions

- NICA collider will start operation in heavy ion mode at JINR Dubna in early 2025
- First data with a proton beam are expected in 2028
  - Operation with *pp*, *pd* and *dd* beams. CM energy scan from few GeV to 27 GeV
  - 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*
  - 4π detector will be equipped with silicon detector, straw tracker, TOF and FARICH for PID, calorimetry, muon system and monitoring detectors
- SPD Technical Design Report was released at the beginning of this year
- More information could be found at http://spd.jinr.ru



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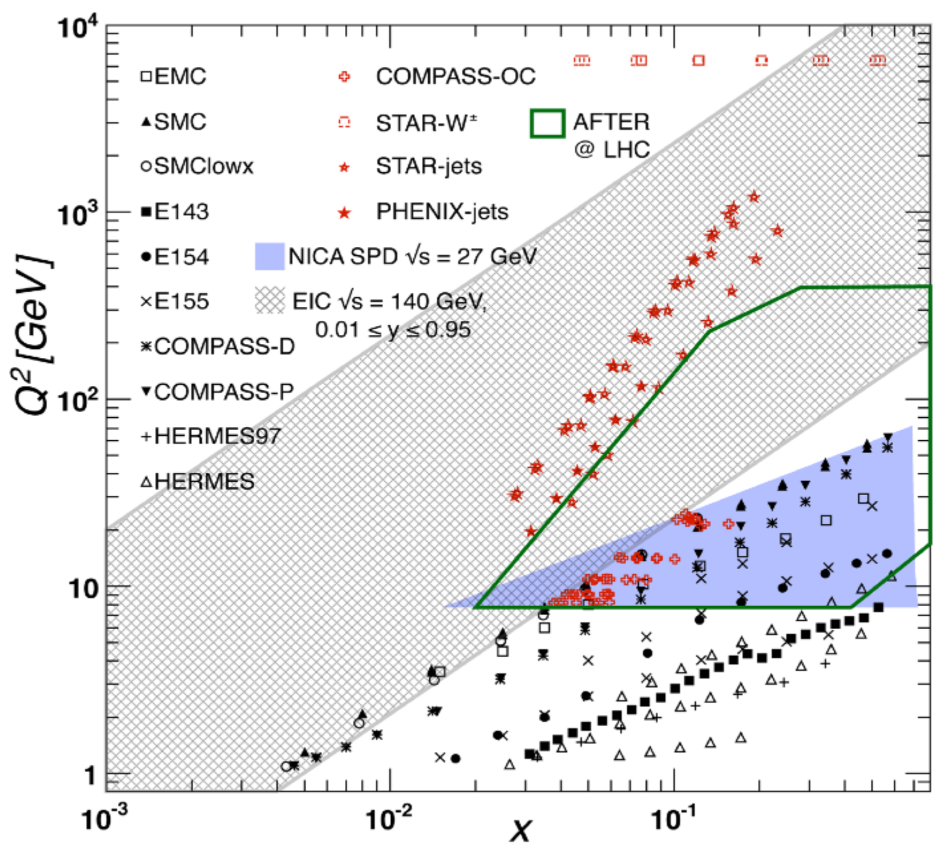
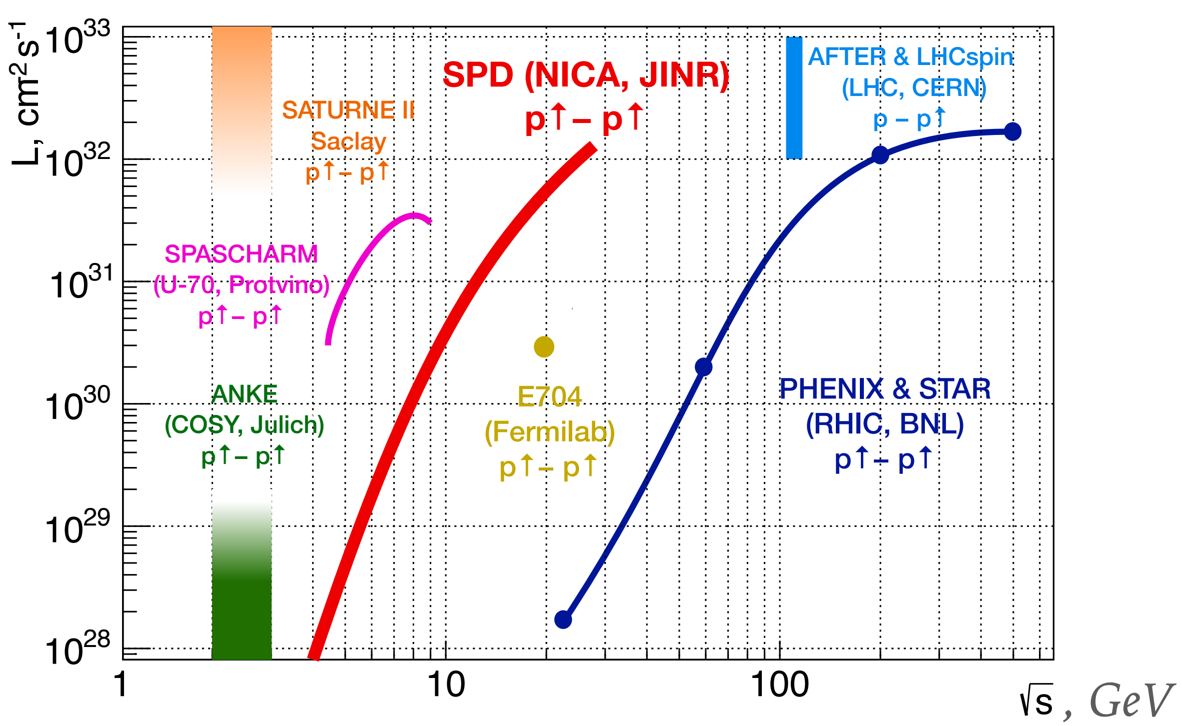
SPD compared to other spin experiments



Main present and future gluon-spin-physics experiments

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



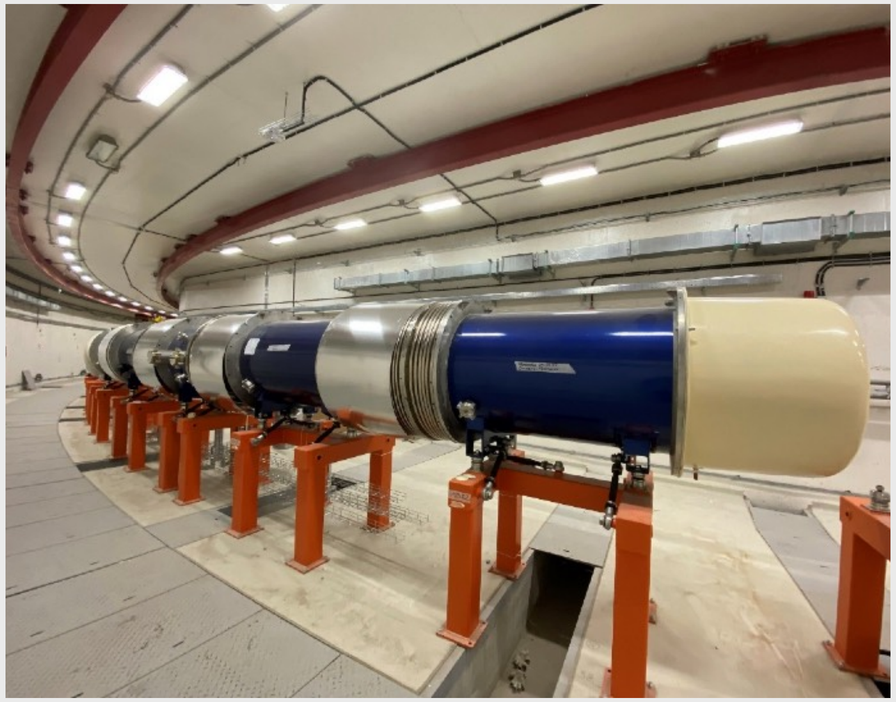
- Access to intermediate and high values of x
- Low energy but collider experiment (compared to fixed target). Nearly 4π coverage
- Two injector complexes available ⇒ mixed combinations p↑-d and p-d↑ are possible

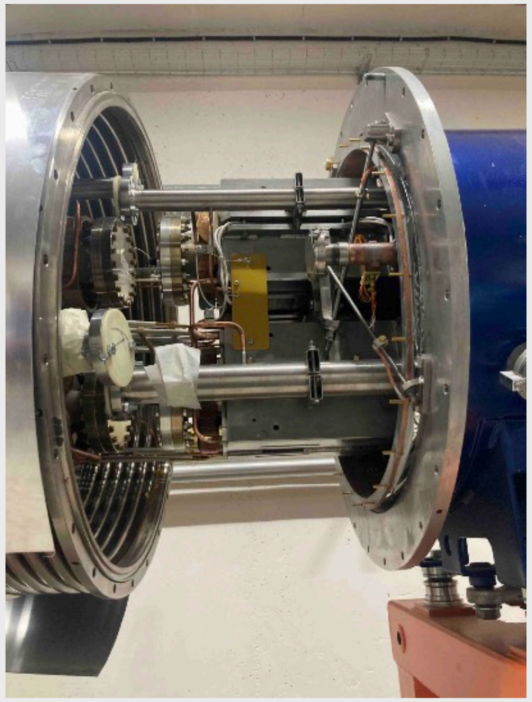
Nuclotron

It started operating ~30 years ago. First SC synchrotron in Europe. Hollow SC cable, cooled by circulating 2-phase helium. It is scheduled to be upgraded by 2030.

Booster

It was mainly introduced for the heavy ion mode (He, Xe, Fe, …, Au). The first run took place in December 2020. In pp mode, is only used to reduce the beam emittance.





Collider

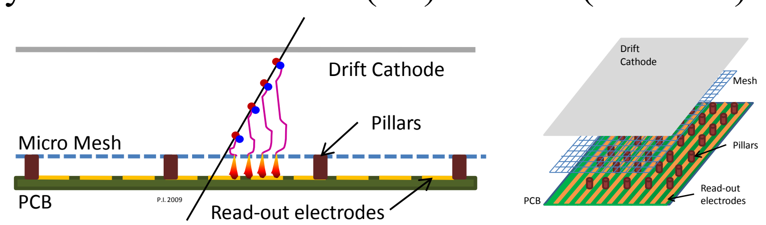
- In summer 2022, all the dipole magnets were installed in the collider arcs, mechanically adjusted and connected in pairs with each other.
- Installation of engineering infrastructure and straight sections (RF system) is ongoing in 2023.
- Assembly of the Nuclotron-Collider beam transfer line, “cold” and vacuum tests in 2024.

Inner Tracker System of SPD

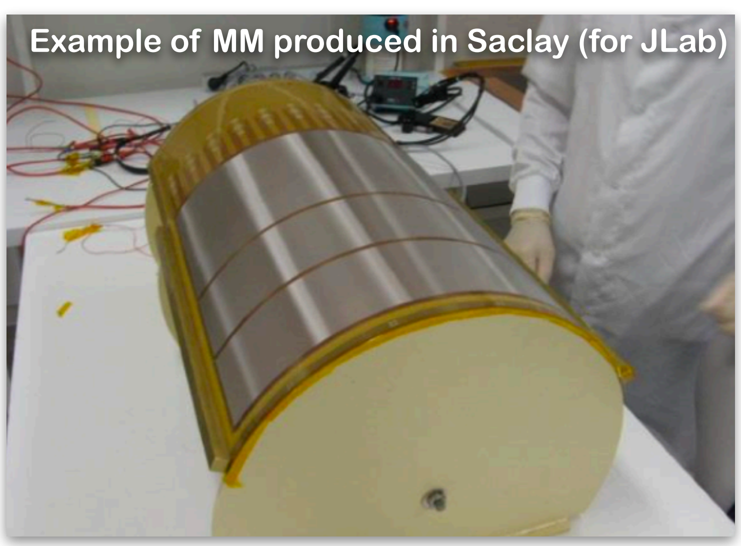
Micro pattern gaseous detector for the 1-st phase of SPD
(commissioning by 2028)

Cylindrical MicroMegas (MM)

Purpose: temporary replacement for SVD, it serves to improve momentum resolution of tracks by about 2 times 3.5% (ST) →1.7% (ST+MM).



Ionization gap 3 mm, amplification gap 120 μm, gas mixture Ar:C_4H_{10} = 90:10, gas gain 10^4, pitch size 450 μm, will be manufactured in LNP JINR, ***spatial resolution ~150 μm***.

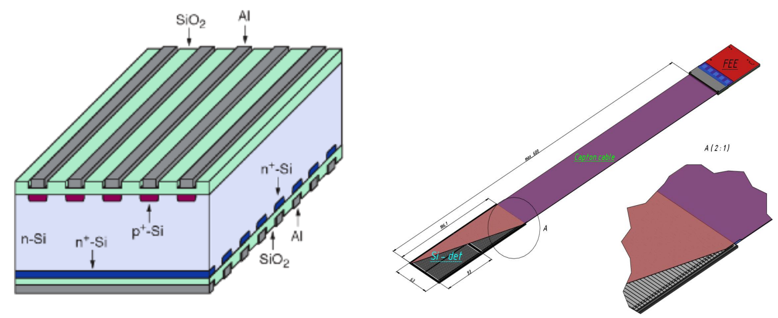

Example of MM produced in Saclay (for JLab)

Bulk technology, cylindrically bent, 3 super-layer (R = 5.5, 11.6, 18.4 cm) with strip tilt angles 0º, ±5º, length of the external layer is 160 cm, readout electronics at two ends, ~14k channels.

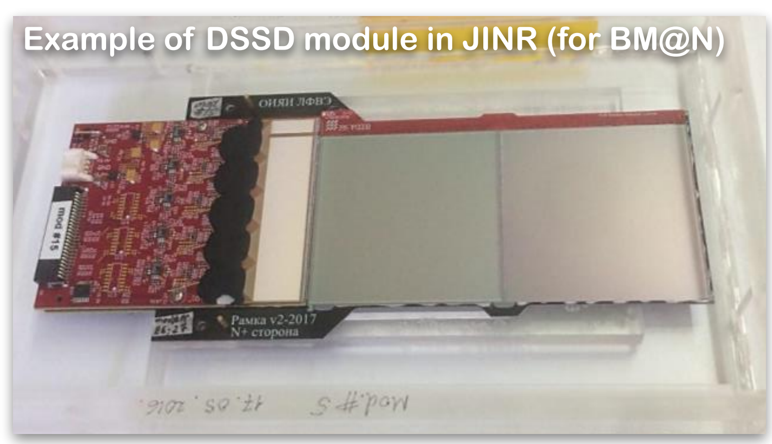
Silicon Vertex Detectors (SVD) for the 2-nd phase of SPD
(one of two options, commissioning by 2035)

Double-Sided Silicon Detector (DSSD)

Main purpose of the detector is to reconstruct the position of D-meson decay vertices (σ_z=76 μm).



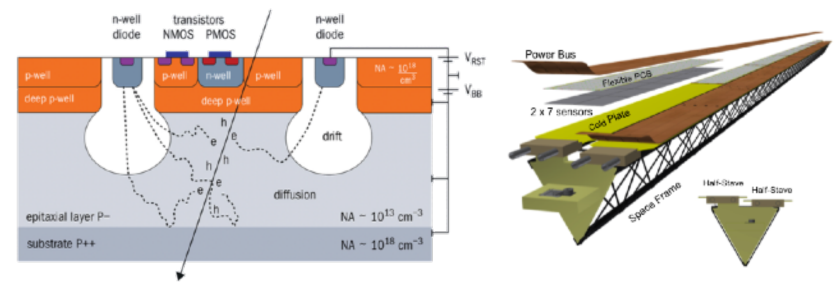
Silicon wafer size 63×93 mm², thickness 300 μm, orthogonal strips on p⁺ and n⁺ sides, p⁺ pitch 95 μm, n⁺ pitch 282 μm, produced by ZNTC Russia, ***spatial resolution 27 (81) μm*** for p⁺ (n⁺) side.


Example of DSSD module in JINR (for BM@N)

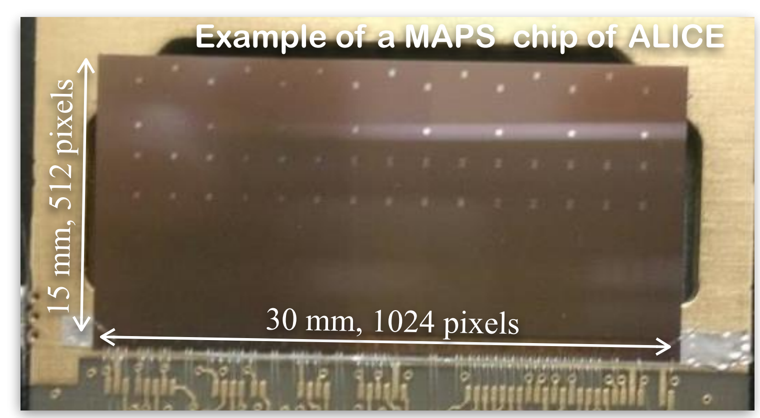
DSSD modules are assembled in ladders with carbon fiber support, 3 layers (R=5, 13, 21 cm) in barrel 74 cm long, 3 layers in each endcap, readout electronics at two ends, ~108k channels.

Monolithic Active Pixel Sensors (MAPS)

Main purpose of the detector is to reconstruct the position of D-meson decay vertices (σ_z=51 μm).



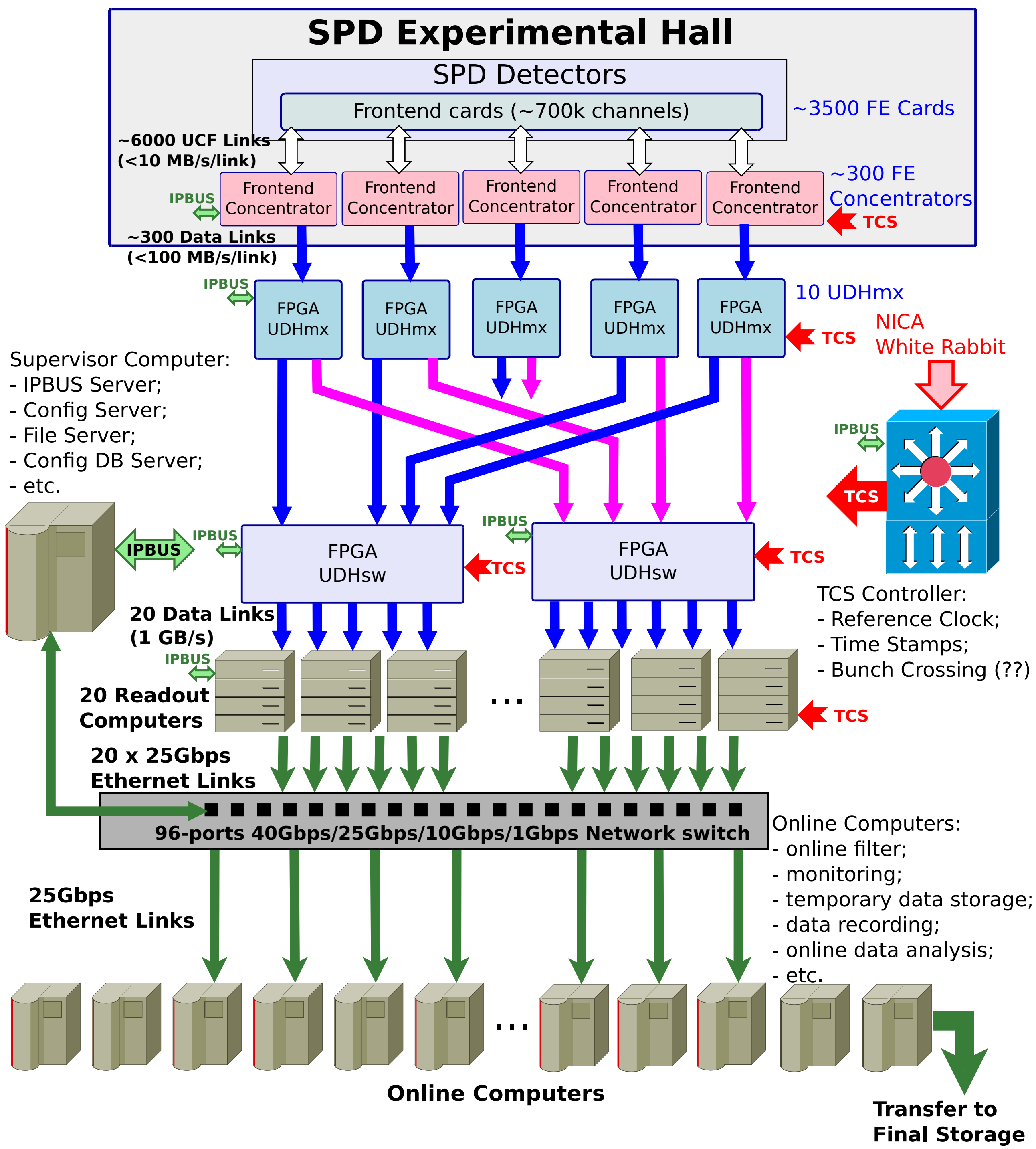
Silicon wafer size 30×15 mm², thickness 50 μm, pitch 28 μm, 512×1024 pixels, sensor and FEE sections are integrated in a single chip, so far is not produced in Russia, ***spatial resolution 5 μm***.



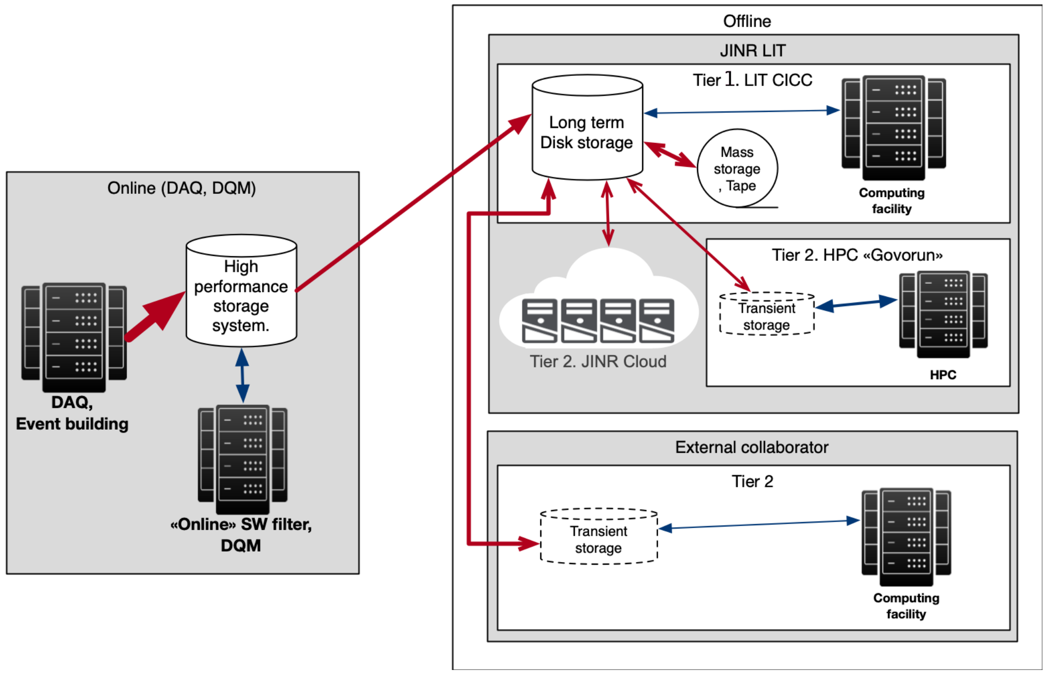
Example of a MAPS chip of ALICE

MAPS chips are assembled in staves with carbon fiber support, 4 layers (R=4, 10, 15, 21 cm) with the external layer 127 cm long, FE electronics is part of the chip, ~10^9 pixels for readout.

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 to ~10 PB/year



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