Spin Physics Detector at NICA

Alexey Zhemchugov
(JINR Dubna)
on behalf of SPD Collaboration

06 December 2022

Sixth Biennial “Workshop on Discovery Physics at the LHC” (Kruger2022)

The NICA project

Timeline

2009 – first proposal

2016 — construction started

2023 — first collision

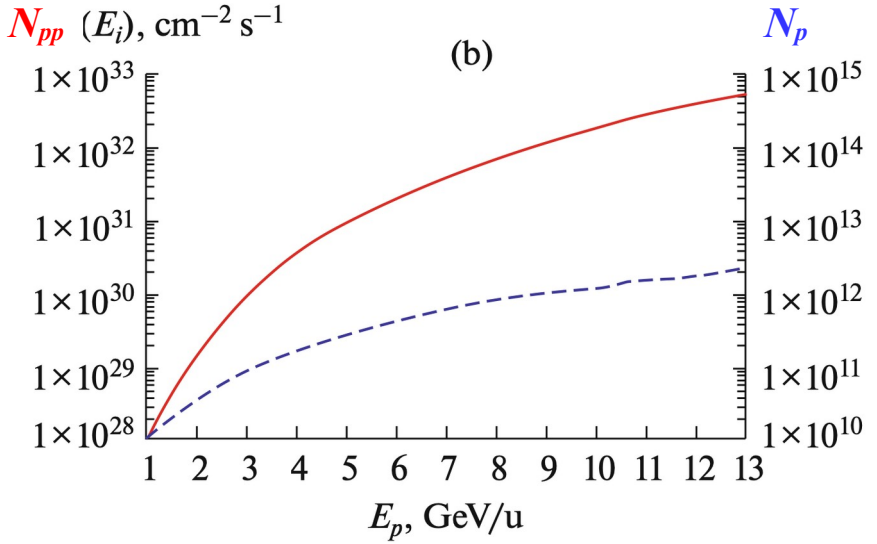
2024 — MPD starts operation

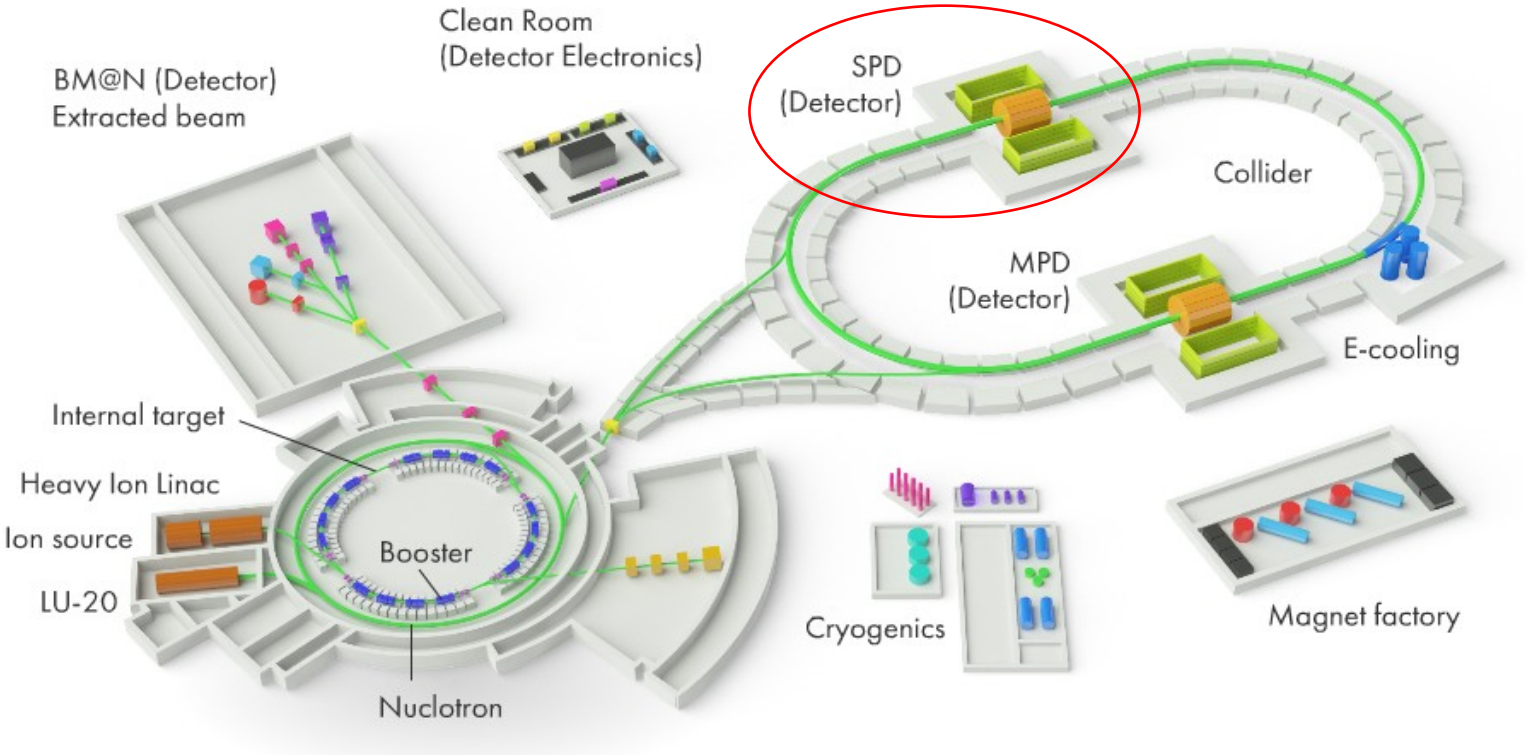
2028 – SPD starts operation

SPD at NICA

p ↑ p ↑ : $\sqrt{s} \leq 27$ GeV
d ↑d ↑ : $\sqrt{s} \leq 13.5$ GeV
d ↑p ↑ : $\sqrt{s} \leq 19$ GeV

U, L, T
|P|>70%





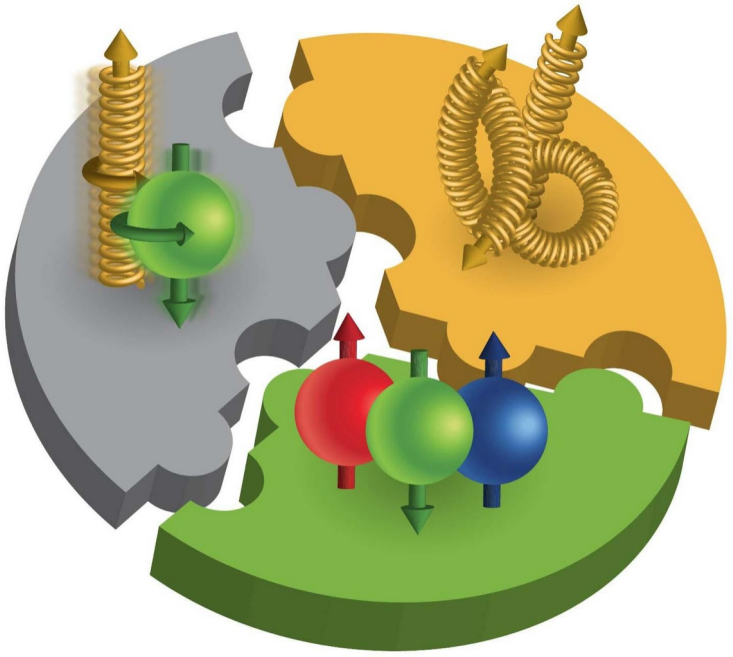
SPD Collaboration

32 institutes from 14 countries, ~300 members

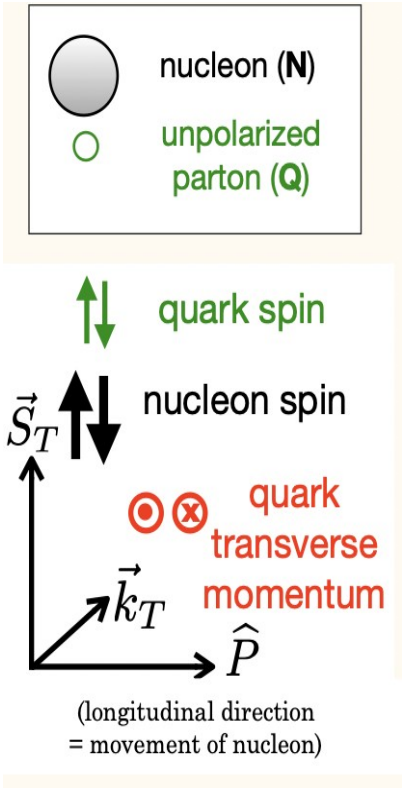
Physics program

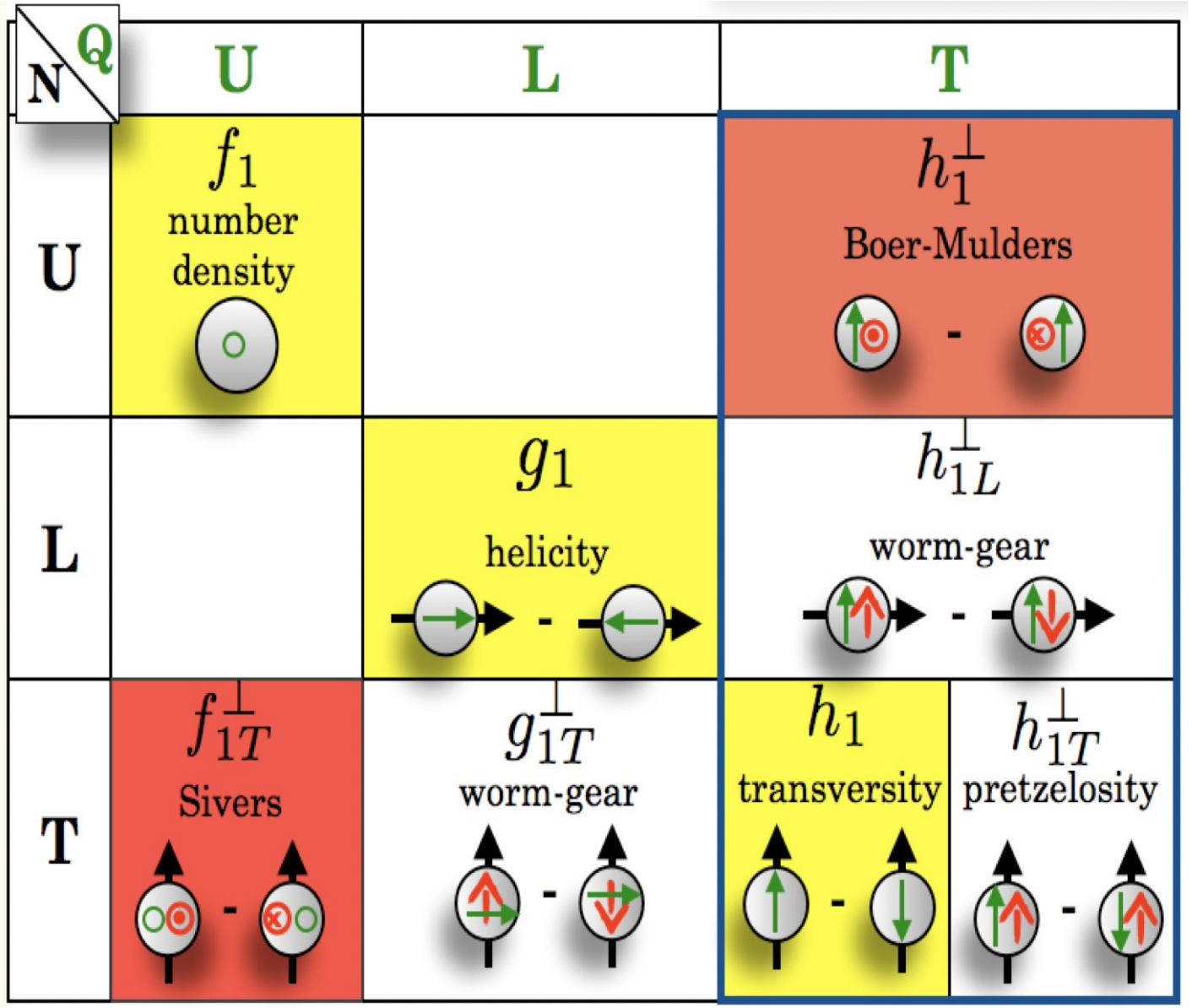
- SPD - a universal facility for comprehensive study of gluon content in proton and deuteron at large x
  - Prompt photons
  - Charmonia
  - Open charm
- Other spin-related phenomena
- Other physics

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



TMD PDFs


nucleon (N)
unpolarized parton (Q)
quark spin
nucleon spin
$\vec{S}_T$
quark transverse momentum
$\vec{k}_T$
$\hat{P}$
(longitudinal direction = movement of 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 PDFs

Unpolarized gluons at high x in proton and deuteron

Gluon helicity

Gluon Boer-Mulders function

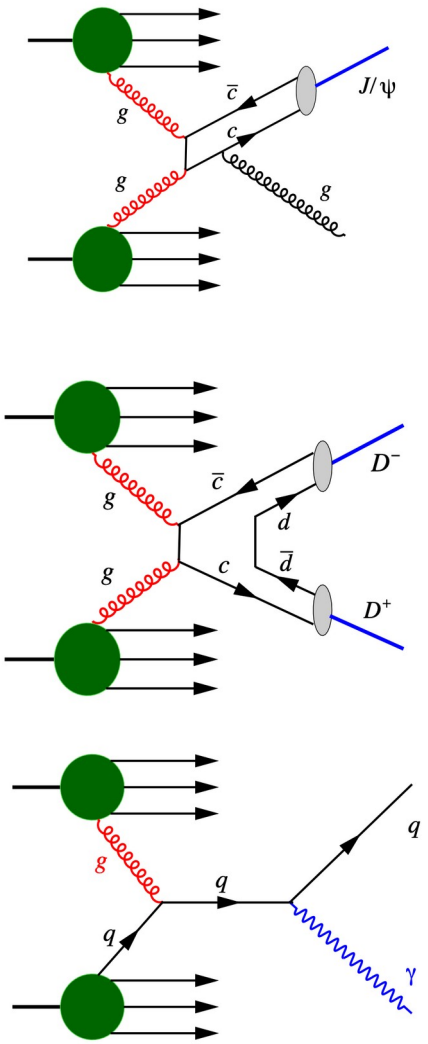
GLUONS	*unpolarized*	*circular*	*linear*
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	$h_{1T}^g, h_{1T}^{\perp g}$

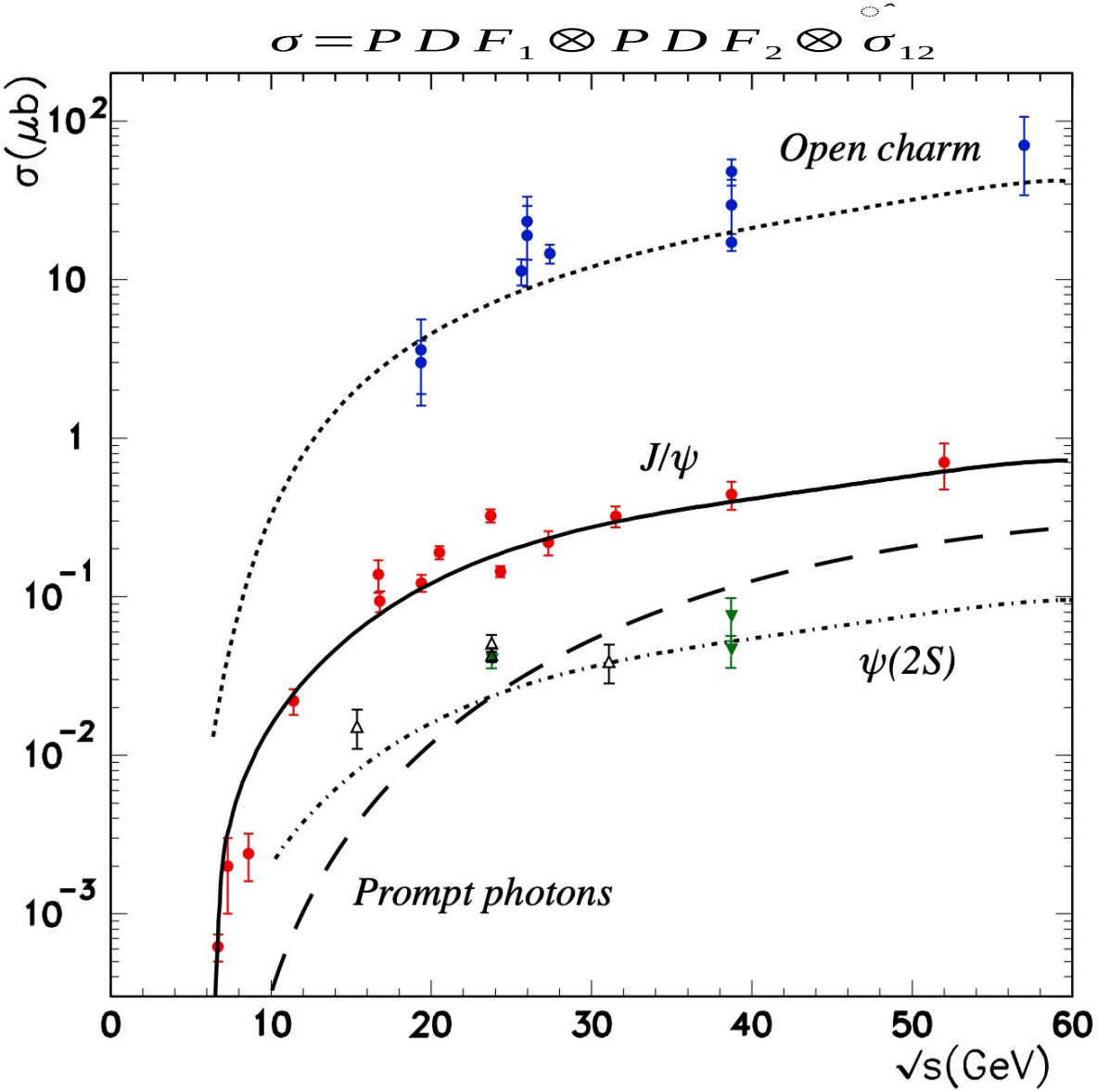
Gluon Sivers function

Gluon transversity in deuteron

Gluon probes at SPD

not only J/ψ!





Rates for main probes

Probe	$\sigma_{27\,\mathrm{GeV}}$, nb (×BF)	$\sigma_{13.5\,\mathrm{GeV}}$, nb (×BF)	$N_{27\,\mathrm{GeV}}$, 10^6	$N_{13.5\,\mathrm{GeV}}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
J/ψ	200	60		
$\to \mu^+\mu^-$	12	3.6	12	0.36
$\psi(2S)$	25	5		
$\to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\to \mu^+\mu^-$	0.2	0.04	0.2	0.004
$\chi_{c1} + \chi_{c2}$	200			
$\to \gamma J/\psi \to \gamma\mu^+\mu^-$	2.4		2.4	
η_c	400			
$\to p\bar{p}$	0.6		0.6	
Open charm: $D\overline{D}$ pairs	14000	1300		
Single D-mesons				
$D^+ \to K^-2\pi^+$ ($D^- \to K^+2\pi^-$)	520	48	520	4.8
$D^0 \to K^-\pi^+$ ($\overline{D}^0 \to K^+\pi^-$)	360	33	360	3.3

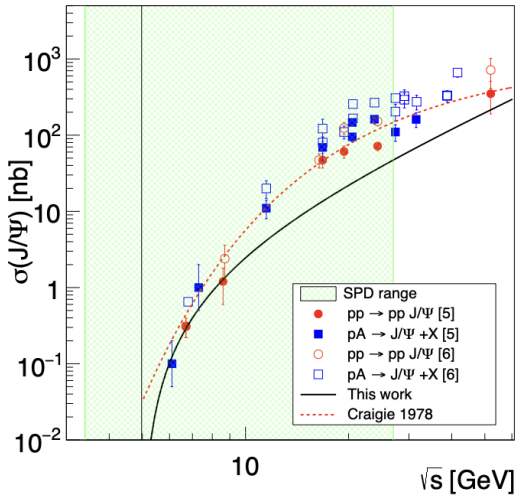
per 1 year of data taking

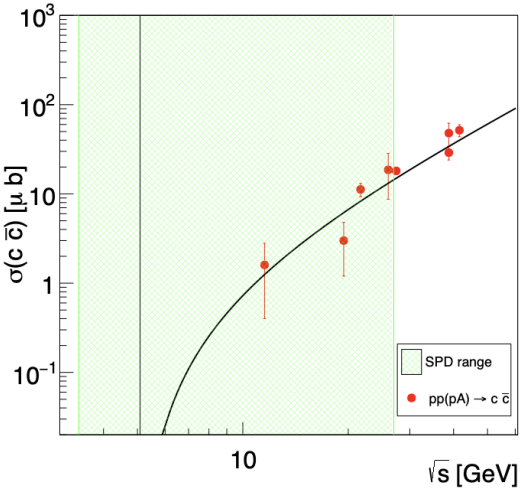
Phase-I

A dedicated physics program for the NICA starup, when polarized beams of high energy are not available:

- Spin effects in p-p, p-d and 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
- Light hypernucei $dd \to K^+\,K^+\,{}^{4}_{\Lambda\Lambda}\mathrm{n},$
- Open charm and charmonia near threshold
- Auxillary measurements for astrophysics

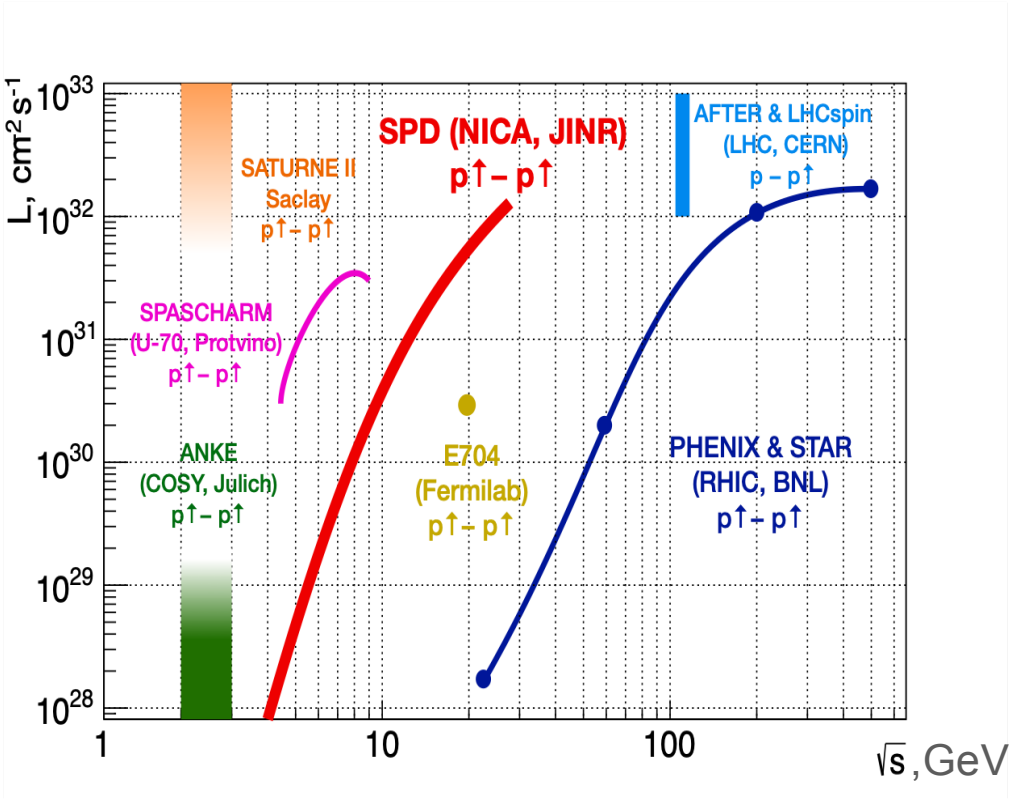
More details:
Phys.Part.Nucl. 52 (2021) 6, 1044-1119
arXiv:2102.08477





SPD vs others

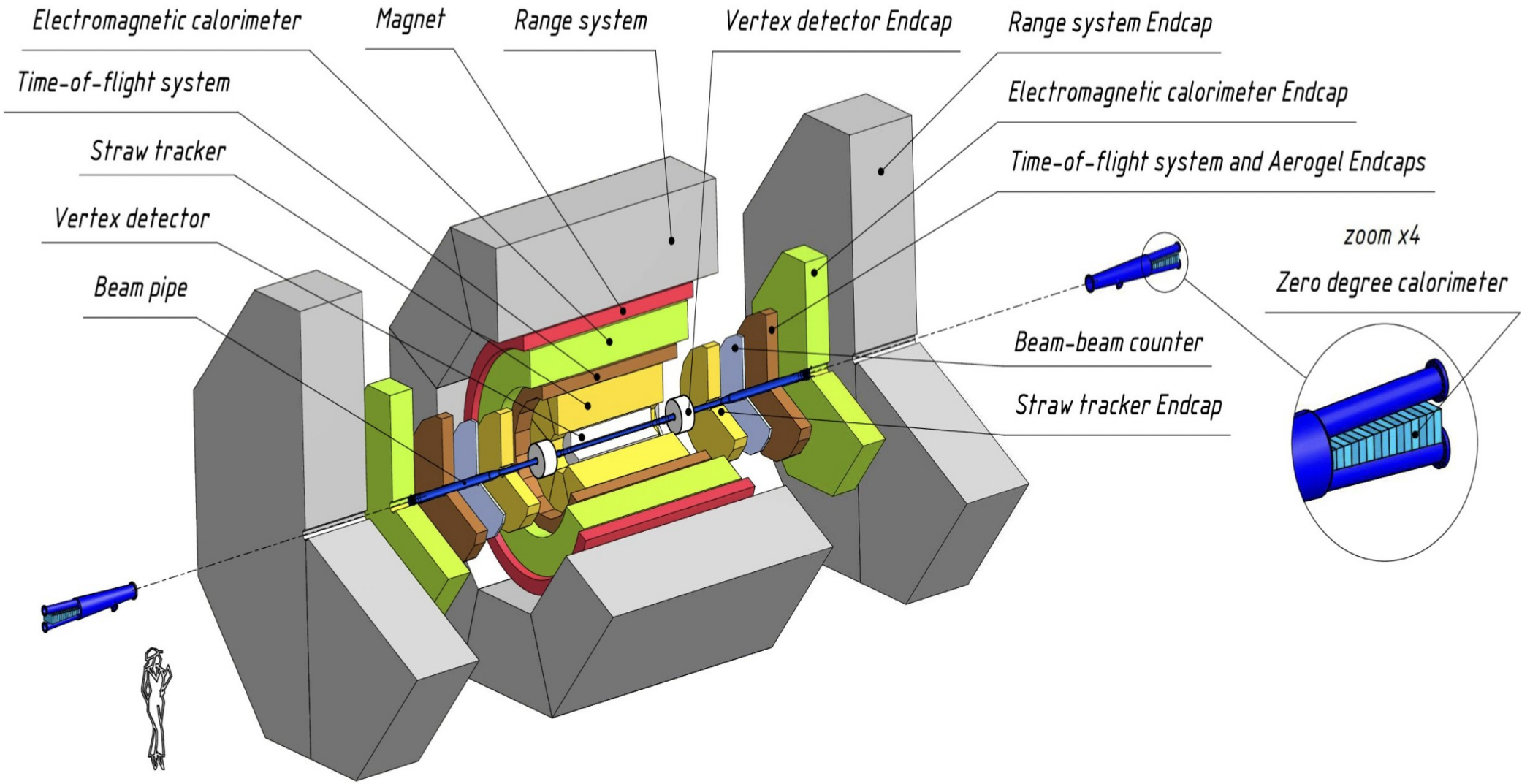
In the p↑p↑ mode:



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-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, $^3He^{\uparrow}$	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

In the d↑d↑ mode we are unique

Detector overview



Central detector

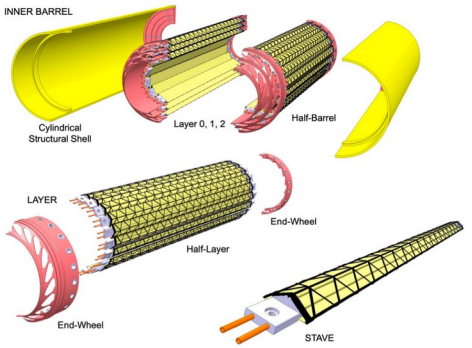
Goals:

- *Reconstruction of secondary vertices for D-mesons decay*
- *Participation in track reconstruction and momentum measurement*

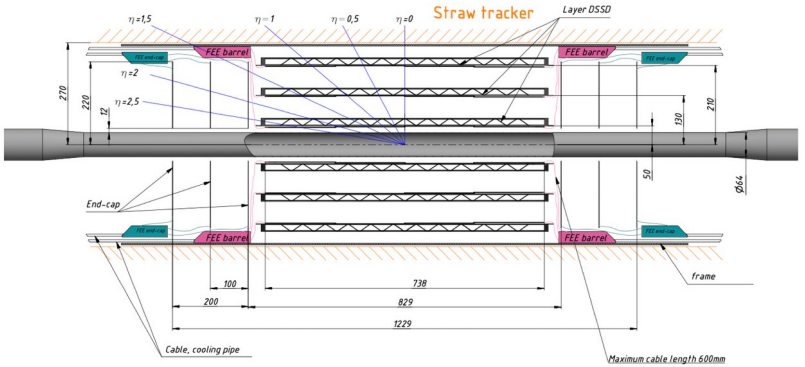
Requirements:

- *Spatial resolution <100 μm*
- *Low material budget*
- *Has to be installed as close as possible to the* IP

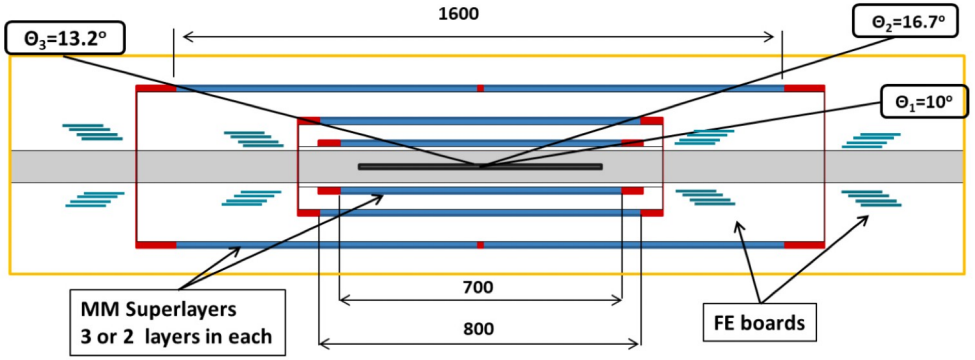
MAPS option

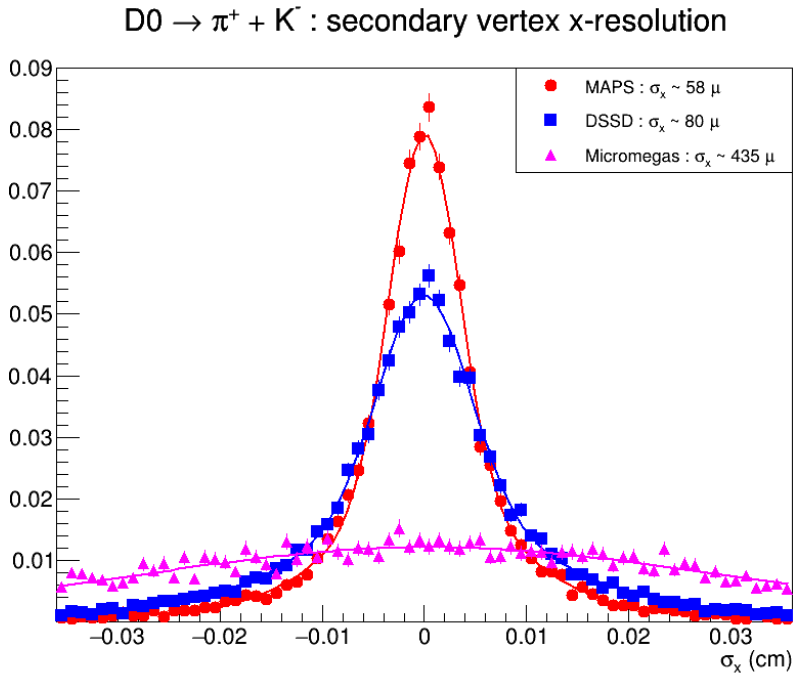


DSSD option



Micromegas-based central tracker for Phase-I





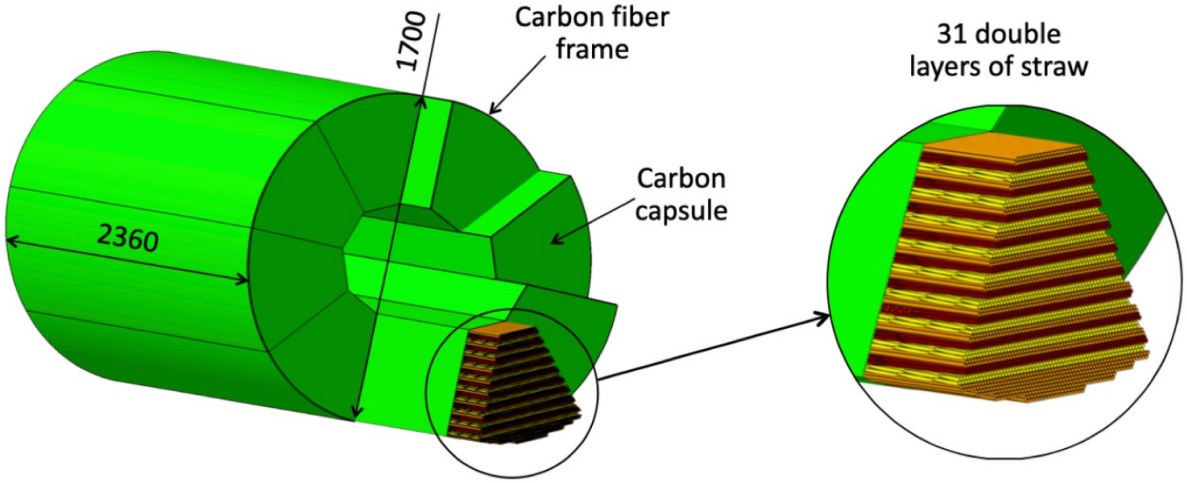
Straw tracker

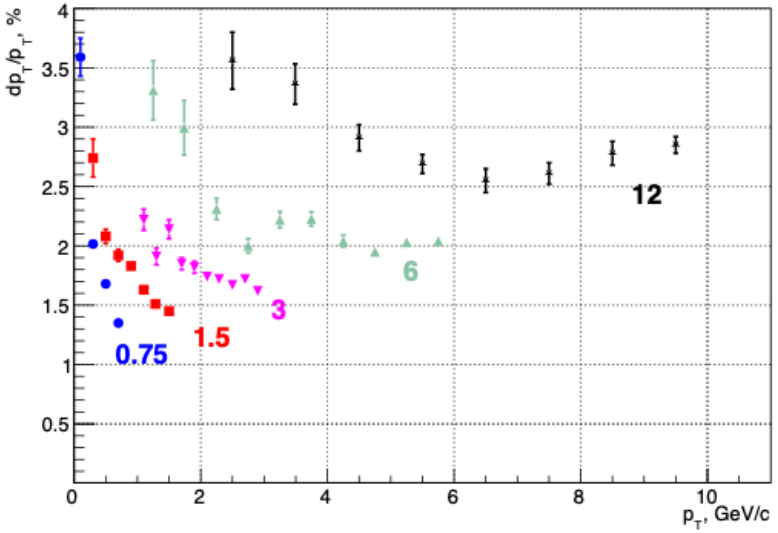
Goals:

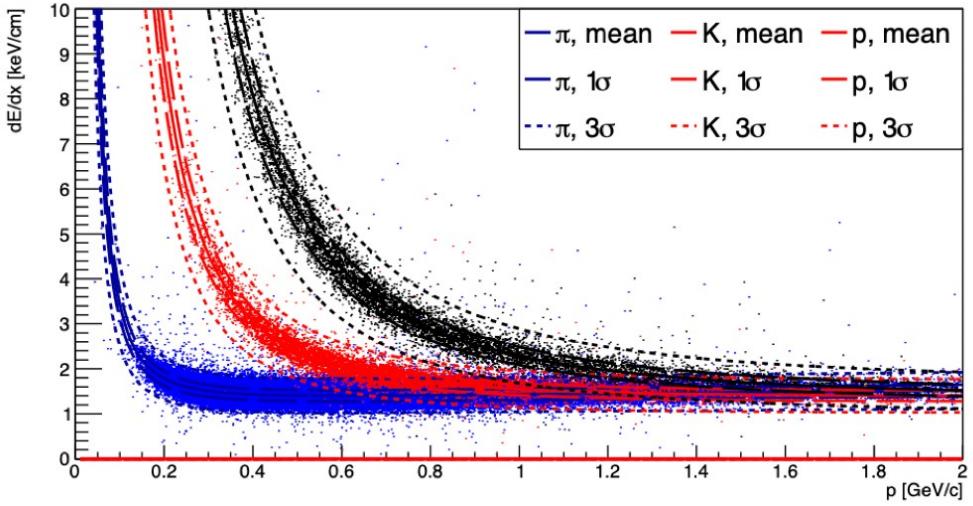
- *Track reconstruction and momentum measurement*
- *Participation in PID via dE/dx measurement*

Requirements:

- *Spatial resolution ~150 μm*
- *Low material budget*
- *Operation in magnetic field of about 1 T*

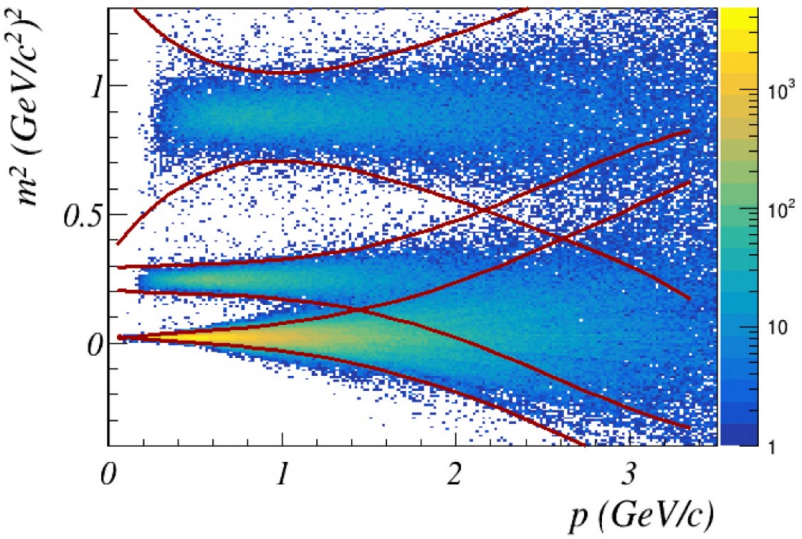


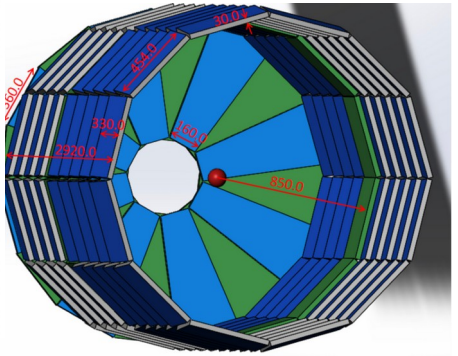




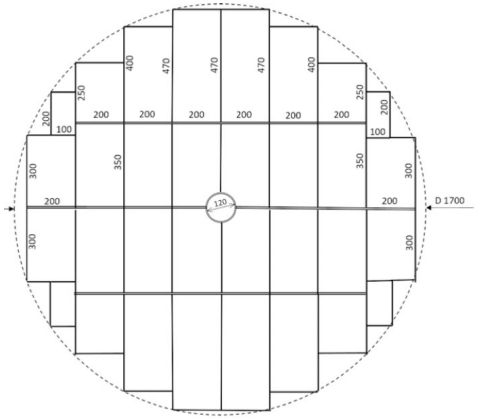
Particle identification system

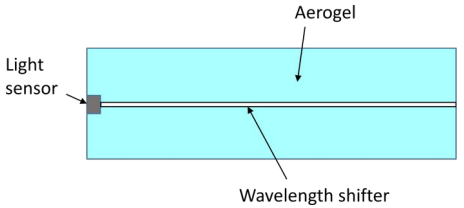
MRPC-based TOF system





Aerogel counters in endcaps





Goals:

- *π/K separation up to ~1.5 GeV*
- *K/p separation*
- *t_0 determination*

Requirements:

- *Time resolution ~60 ps*

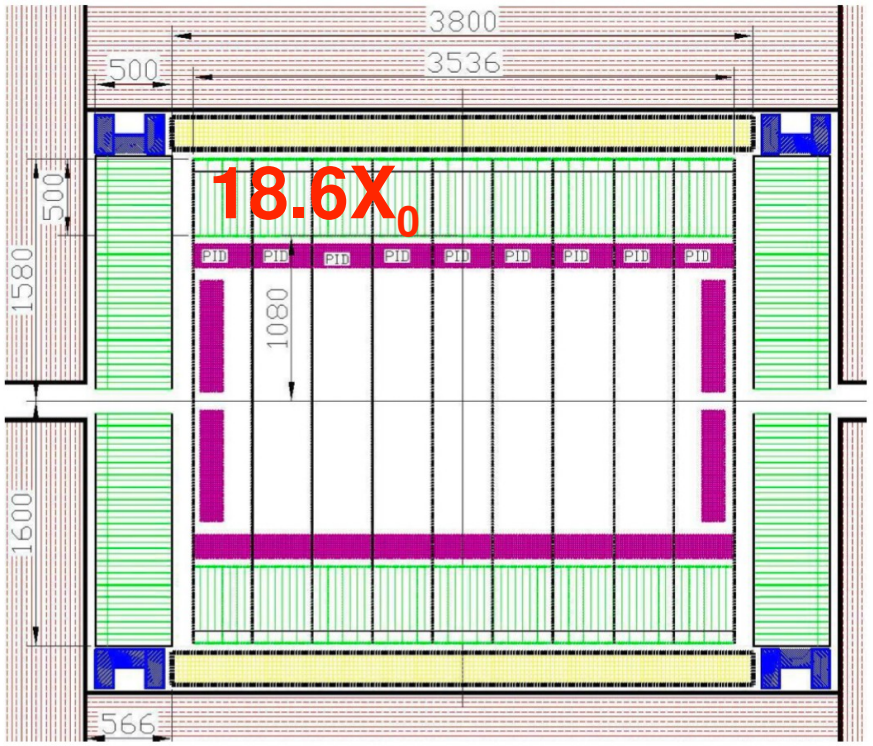
Goals:

- *π/K separation up to 2.5 GeV range*

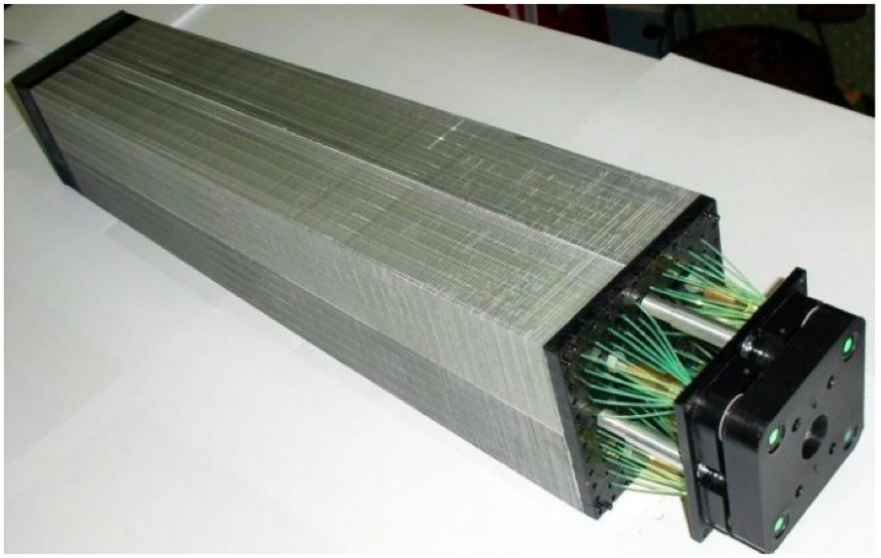
Requirements:

- *We should have enough light!*

Electromagnetic calorimeter



190 layers Sc/Pb =1.5/0.5 mm



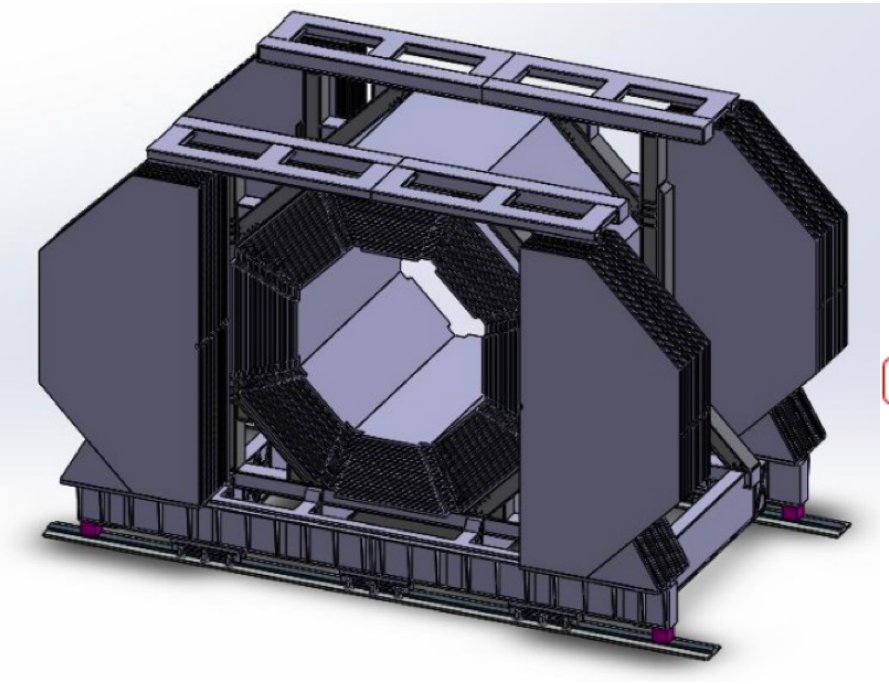
Goals:

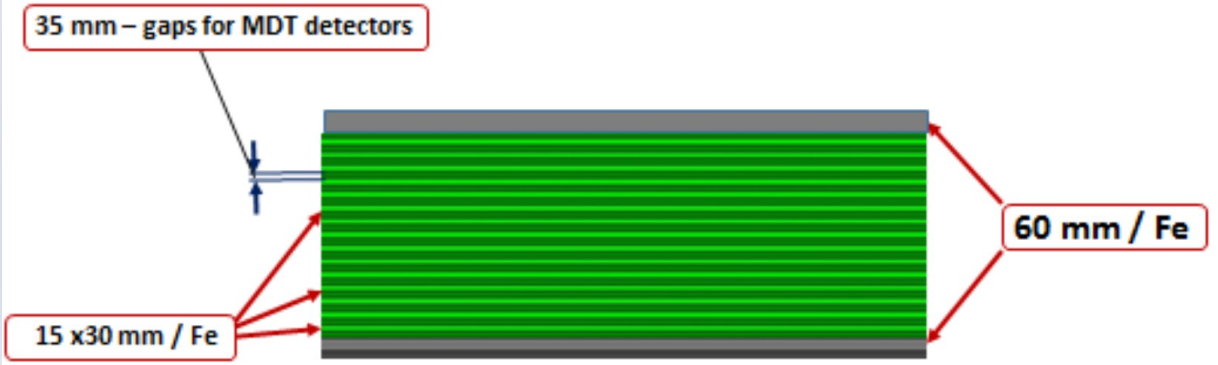
- *Detection of prompt photons, photons from π^0, η and χ_c decays*
- *Identification of electrons and positrons, participation in muon identification*

Requirements:

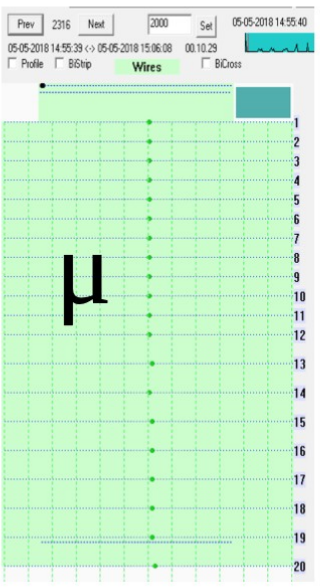
- *Granularity ~4 cm*
- *Low energy threshold (~50 MeV)*
- *Energy resolution*

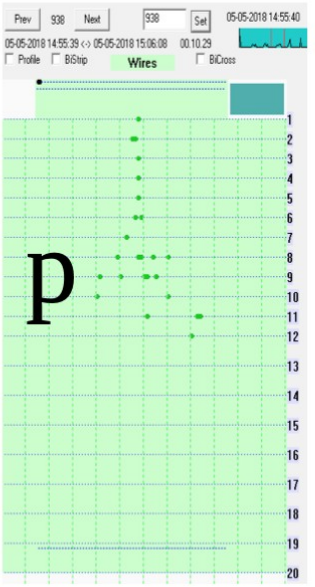
Range (muon) system

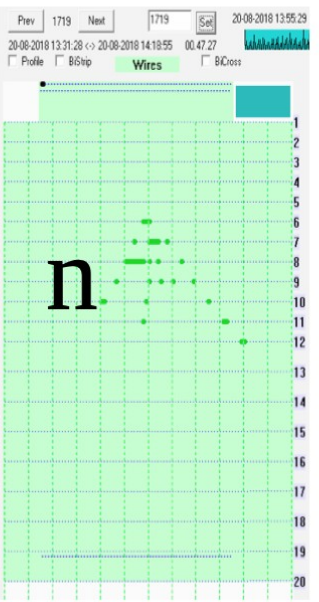




Event examples at 5 GeV/c







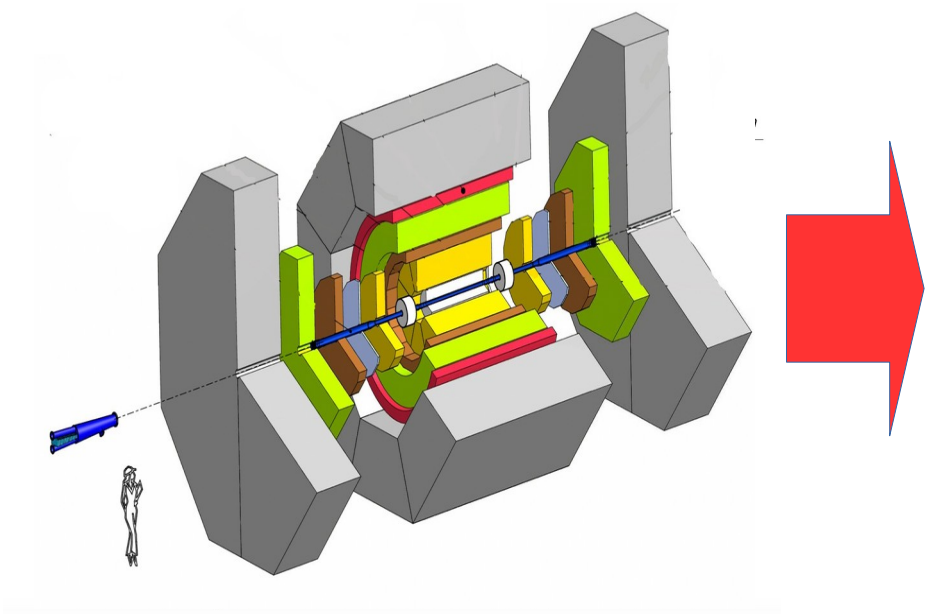
Goals:

- *Muon identification*
- *Rough hadron calorimetry*
- *Magnet yoke*

Requirements:

- *should have at least 4λ$_I$*

SPD as a data source

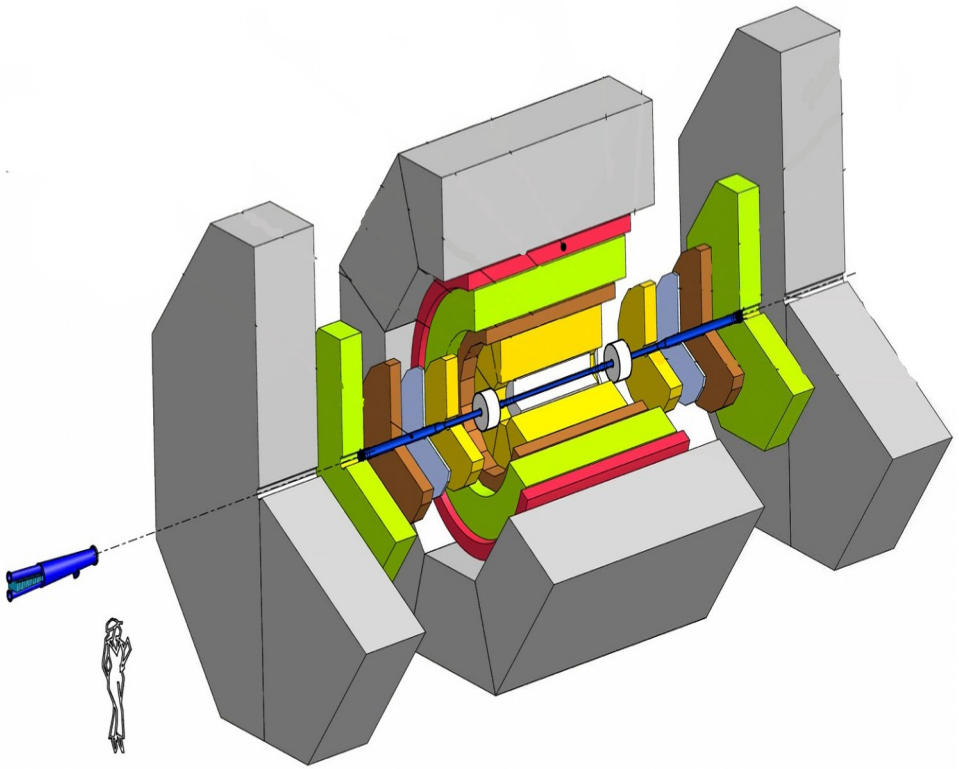


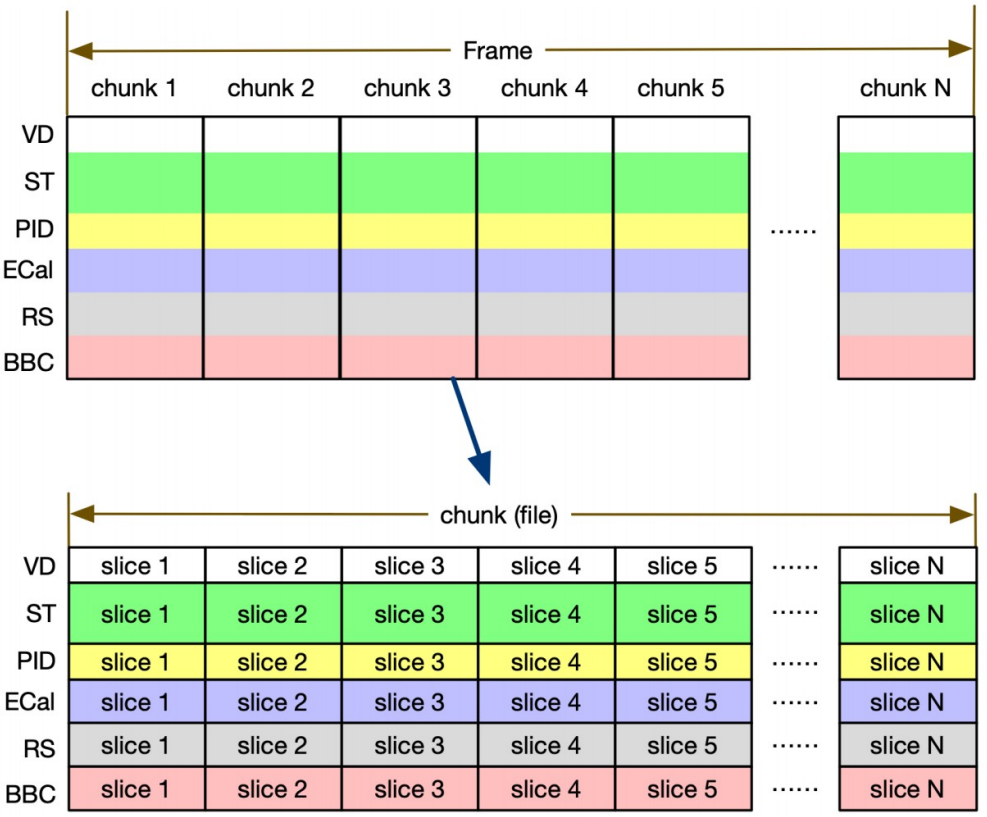
- Bunch crossing every 76.3 ns = crossing rate 13 MHz
- ~ 3 MHz event rate (at 10^{32} $cm^{-2}s^{-1}$ design luminosity)
- 20 GB/s (or 200 PB/year (raw data), $3*10^{13}$ events/year)
- Selection of physics signal requires momentum and vertex reconstruction → no simple trigger is possible

The SPD detector is a medium scale setup in size, but a large scale one in data rate!

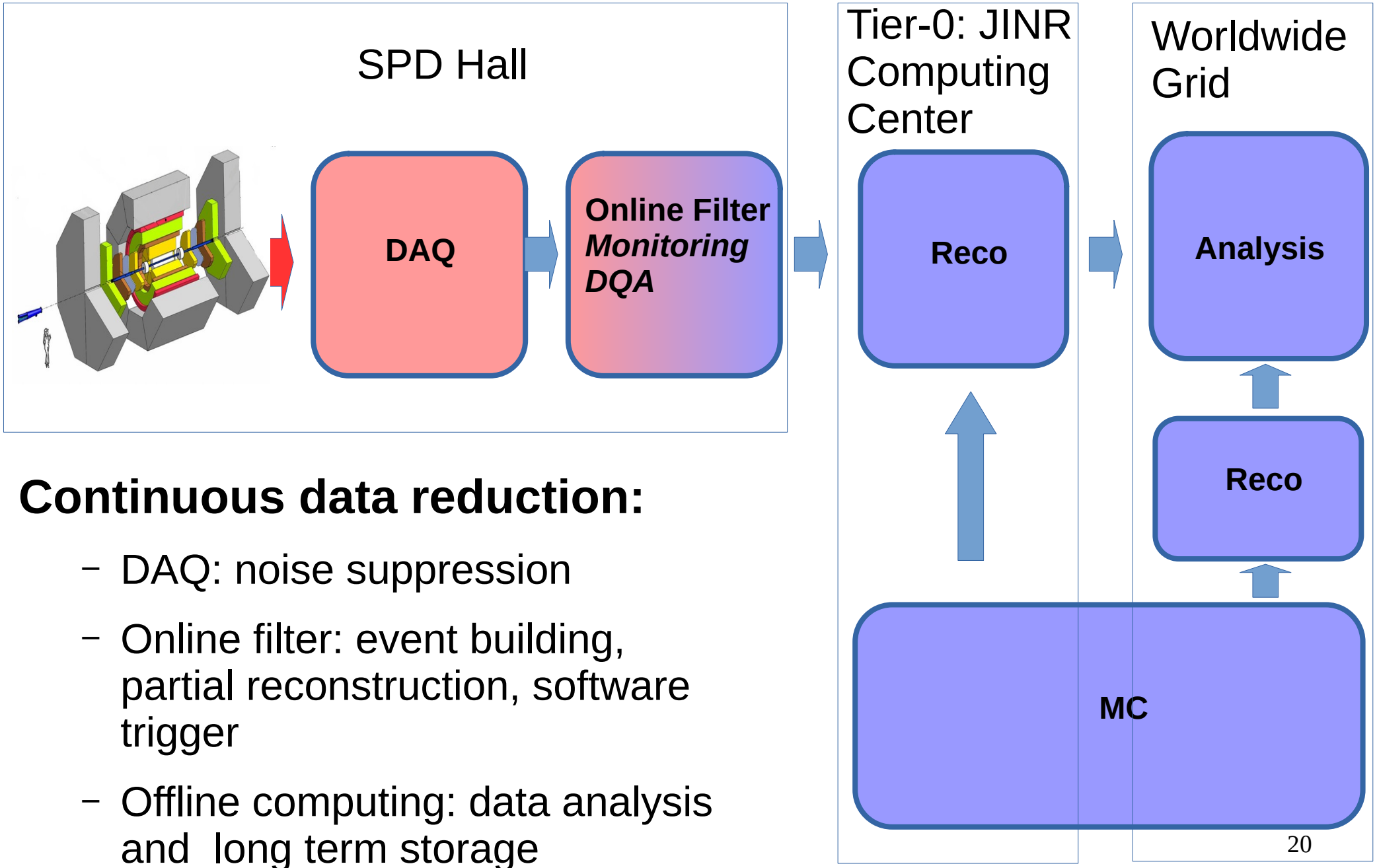
Free running DAQ

No trigger = No classical events anymore





Data workflow



Continuous data reduction:

- DAQ: noise suppression
- Online filter: event building, partial reconstruction, software trigger
- Offline computing: data analysis and long term storage

Online Data Filter

High-performance heterogeneous computing cluster

- Partial reconstruction
  - Fast tracking and vertex reconstruction
  - Fast ECAL clustering
- Event unscrambling
- Software trigger
  - several data streams

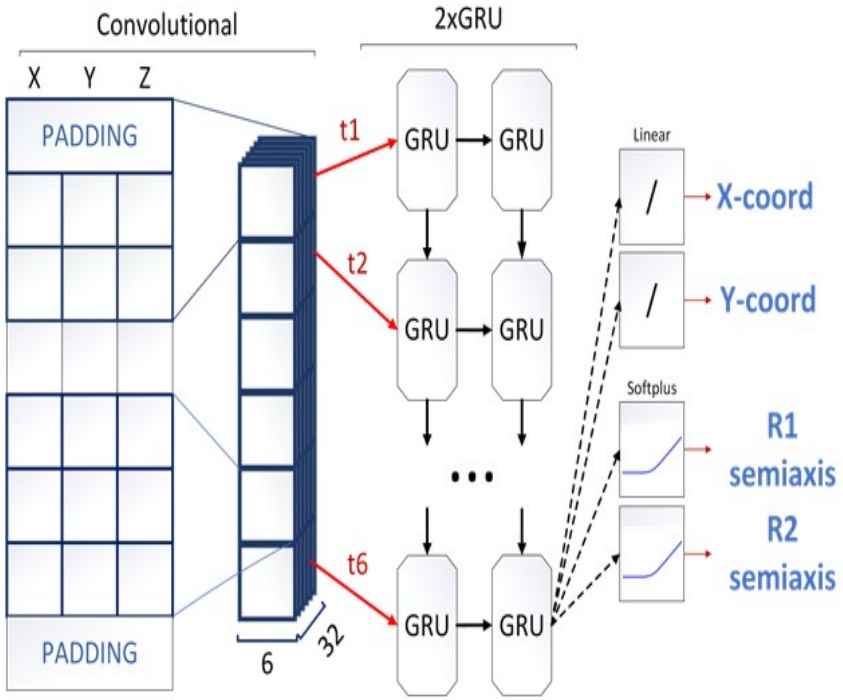
Machine learning is a key technology

Control of systematics?

- Monitoring and Data quality assessment
- Local polarimetry

Example: TrackNETv3 for track recognition

https://arxiv.org/abs/2210.00599

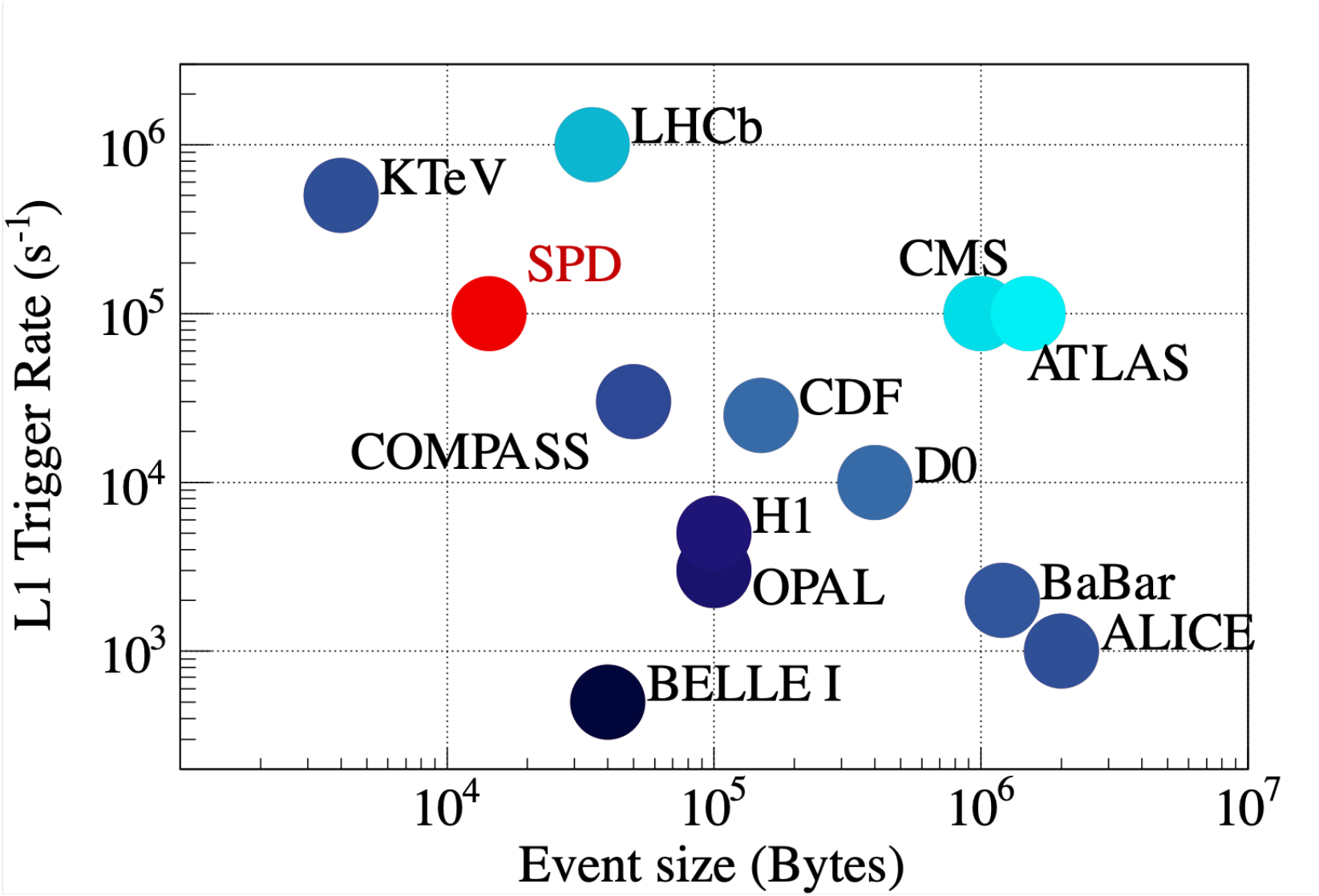


- Network predicts an area at the next detector layer where to search for the track continuation
- If continuation is found the hit is added to the track candidate and the procedure repeats again
- Essentially reproduces the idea of the Kalman filter: track parameters are predicted by synaptic weights determined by network training
- Generalization? Stability? Missing hits?

	Single events	Time slices of 40 events
Track efficiency (recall) (%)	99,62	96,78
Track purity (precision) (%)	99,52	88,02
Time slices / sec	48,70	43,52 (*40 = 1741,19)

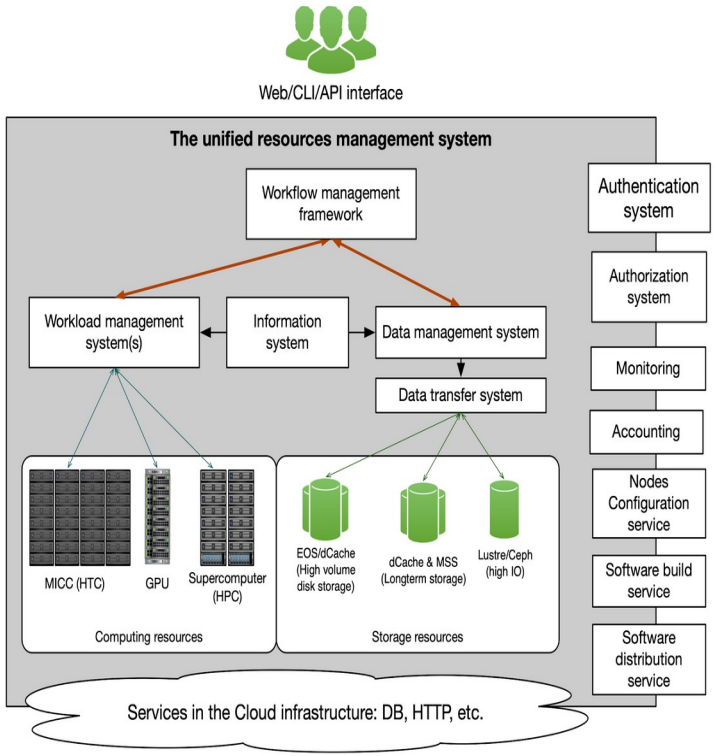
PRELIMINARY

After the online filter



Distributed computing system

By 2030:
- up to 30 PB of storage
- up to 1.5 Pflops of computing power



All basic components are already available from LHC experiments:

- *Workload management: likely PANDA*
- *Data management: RUCIO and FTS*
- *Software distribution: CVMFS*

Adaptation to operate with the SPD event model and offline software is needed

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 $\sqrt{s} < 27$ 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 moderate and high-x in proton and deuteron;
  - gluon transversity in deuteron.
- Dedicated physics program for Phase-I with reduced luminosity and beam energy.
- The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC, AFTER, EIC) and mesons (AMBER, EIC).
- SPD CDR is available as *arXiv:2102.00442* for more details.
- SPD TDR is about to be completed.
- More information could be found at *http://spd.jinr.ru*

This work is supported by the Russian Science Foundation under contract No. 22-12-00109, https://rscf.ru/project/22-12-00109.