MiniSPD test bench for testing of SPD detectors prototypes

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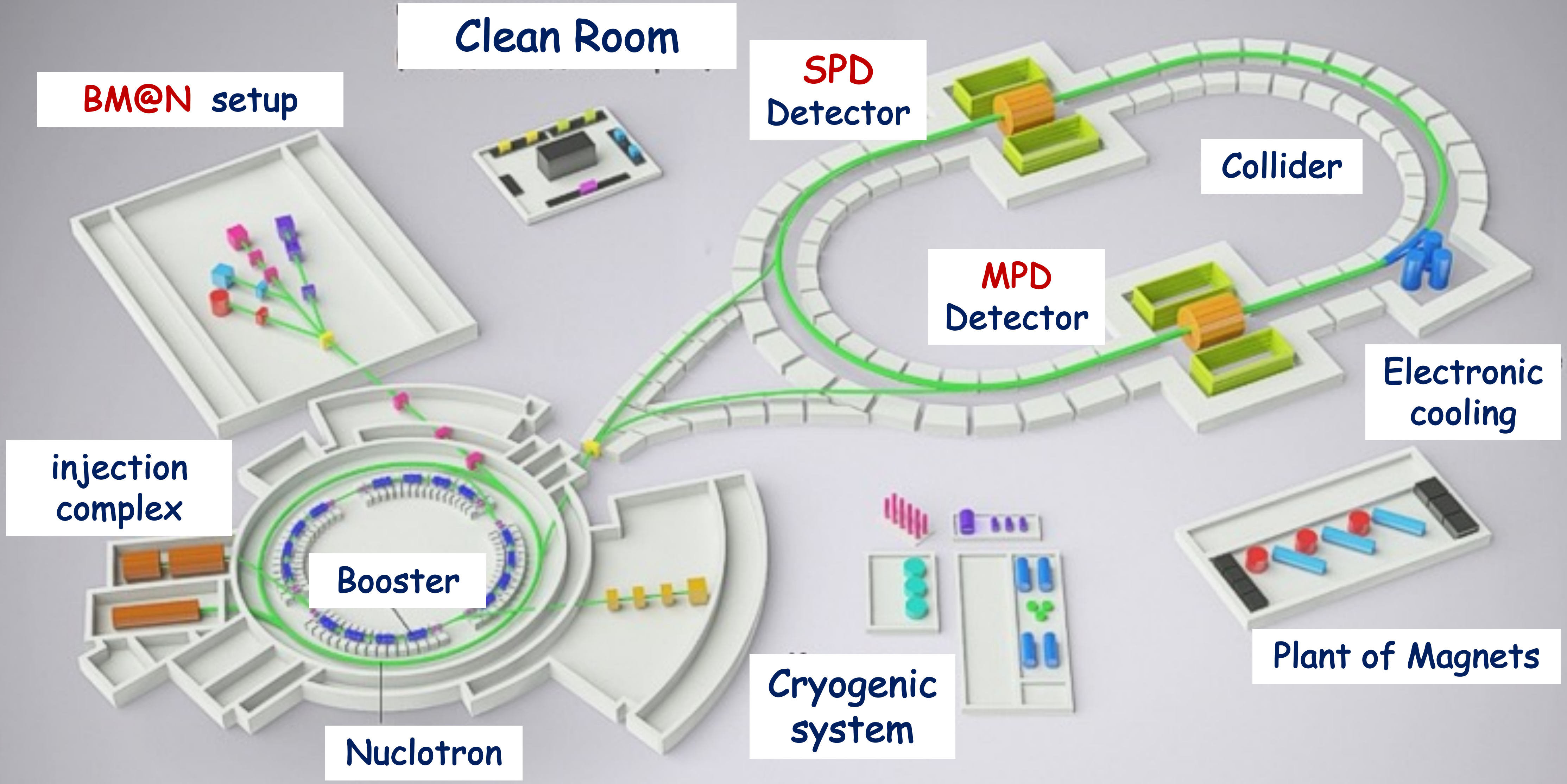
NICA (Nuclotron based Ion Collider fAcility)

Start of construction: 2013.

Our accelerator complex is being created
at the JINR, LHEP (Dubna, RF).
The main aims are the study of:

1) the properties of dense baryonic matter, a special state of matter in the first moments after the Big Bang, formation of quark-gluon plasma (MPD);
2) spin structure of proton (deuteron) (SPD).

NICA aerial view, April 2022


Clean Room
BM@N setup
SPD Detector
Collider
MPD Detector
Electronic cooling
injection complex
Booster
Nuclotron
Cryogenic system
Plant of Magnets

NICA scheme

The main tasks of SPD project

Spin is one of the fundamental properties of elementary particles. It cannot be explained by a static view of the proton:

total spin = s(q) + s(g) + angular momentum = 1/2.

It's not just the number 1/2. It is the result of interaction between quarks and gluons, more probably gluons.

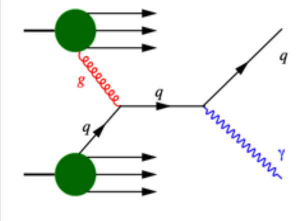
The origin of spin is a fundamental problem of physics. Our SPD (Spin Physics Detector) project is aimed at study spin properties of nucleons and light nuclei.

How are quarks and gluons, their spins distributed in space and on momentum inside the nucleon?

2102.00442[hep-ex]Conceptual design of the Spin Physics Detector (A. Guskov)

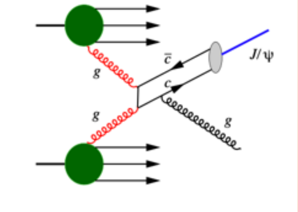
The main tasks of SPD project

- Direct photons

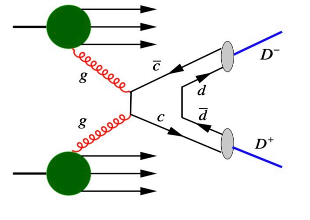


[SPD Collab. Phys.Part.Nucl. 52 (2021) 6]

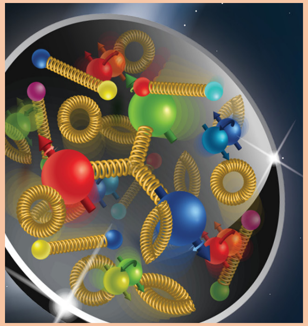
- Nucleon PDFs by J/ψ production



- Open charm production: D^0, $\bar{D}^0$, $D^{+/-}$, Λ_c, ...



- Spin-dependent effects in elastic pp, pd and dd scattering
- Spin effects in exclusive hadron production
- Spin effects in production of hadrons with high p_T



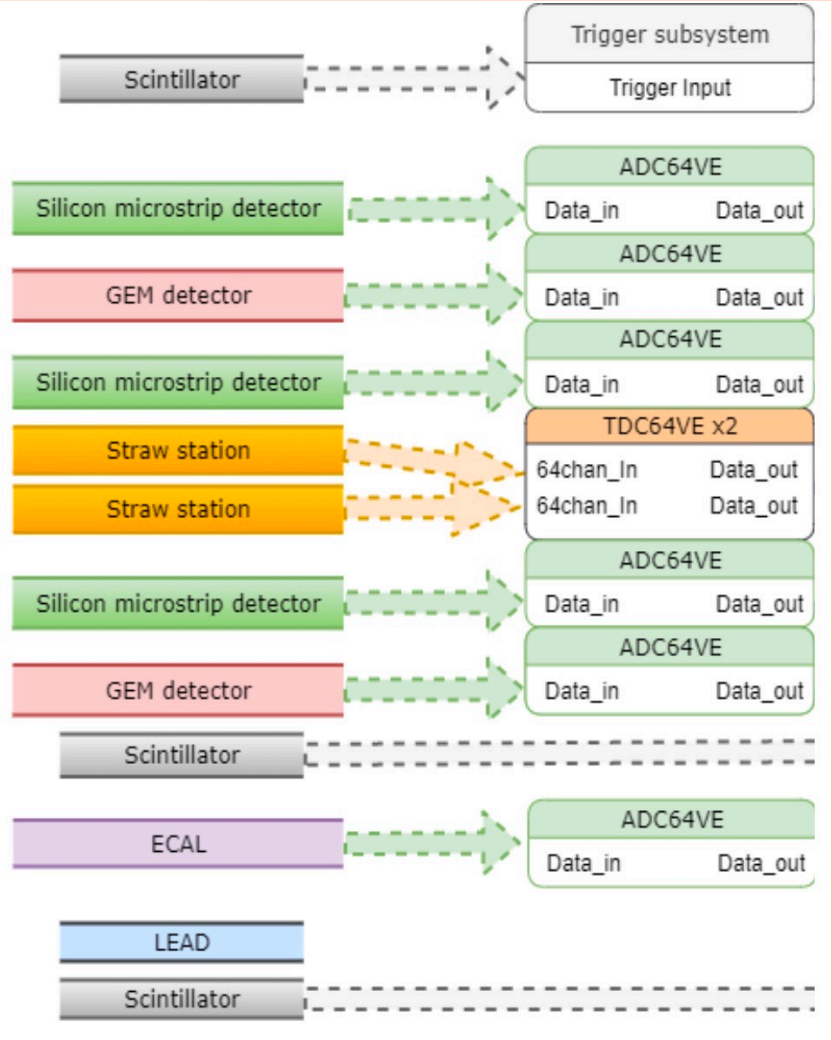
pp, dd, pd polarized beams with energy $\sqrt{s_{NN}}$ = 3.4 – 10 GeV

luminosity pp (dd) is estimated up to 10^{32} (10^{31}) $cm^{-2}s^{-1}$

Why do we need MiniSPD?

- ✓ MiniSPD is a setup for testing SPD detector prototypes with cosmic muons
- ✓ MiniSPD is used to test the Data Acquisition System (DAQ) of SPD
- ✓ MiniSPD is used to test the Detector Control System (DCS) of SPD
- ✓ MiniSPD is used to teach students how to work with real detectors

MiniSPD stand for testing SPD's elements



Top scintillator

Si

Si

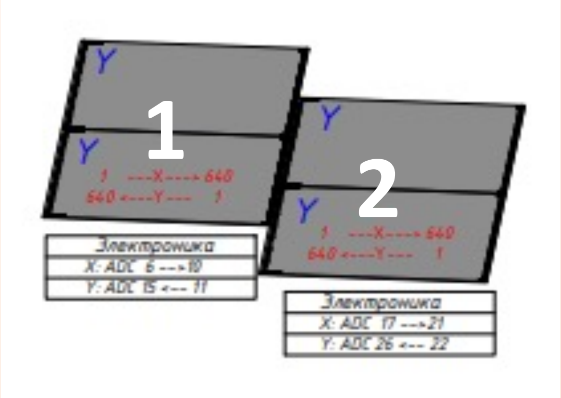
Si

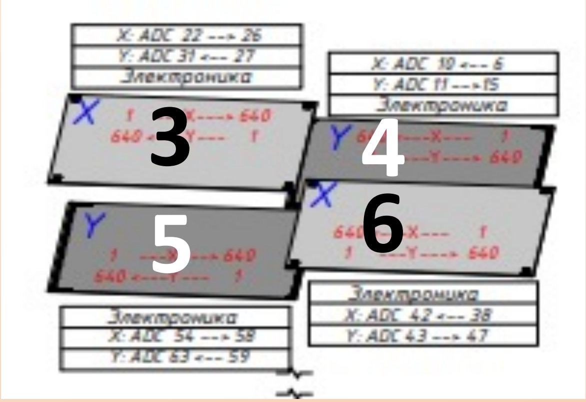
Trigger subsystem consists of 2 scintillators. Top: ScintPos[1] = 3 mm. Bottom: ScintPos[2] = 931,5 mm.

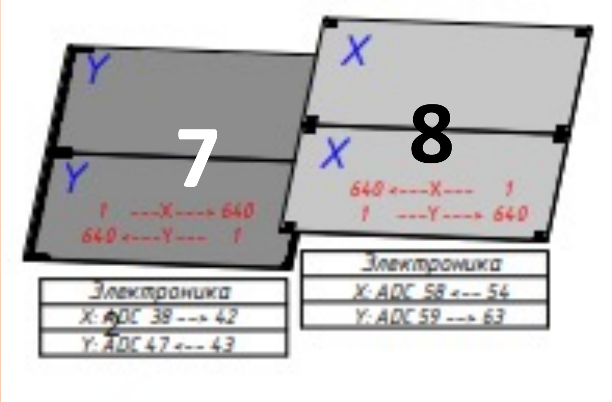
Bottom scintillator

Description of Si-modules

Coordinates (top/bottom): X – light, U – dark.







1 - U/X, 2 – U/X

3 – X/U, 4 – Y/U
5 – U/X, 6 – X/U

7 - U/X, 8 – X/U
U-coordinate, ±2.5°

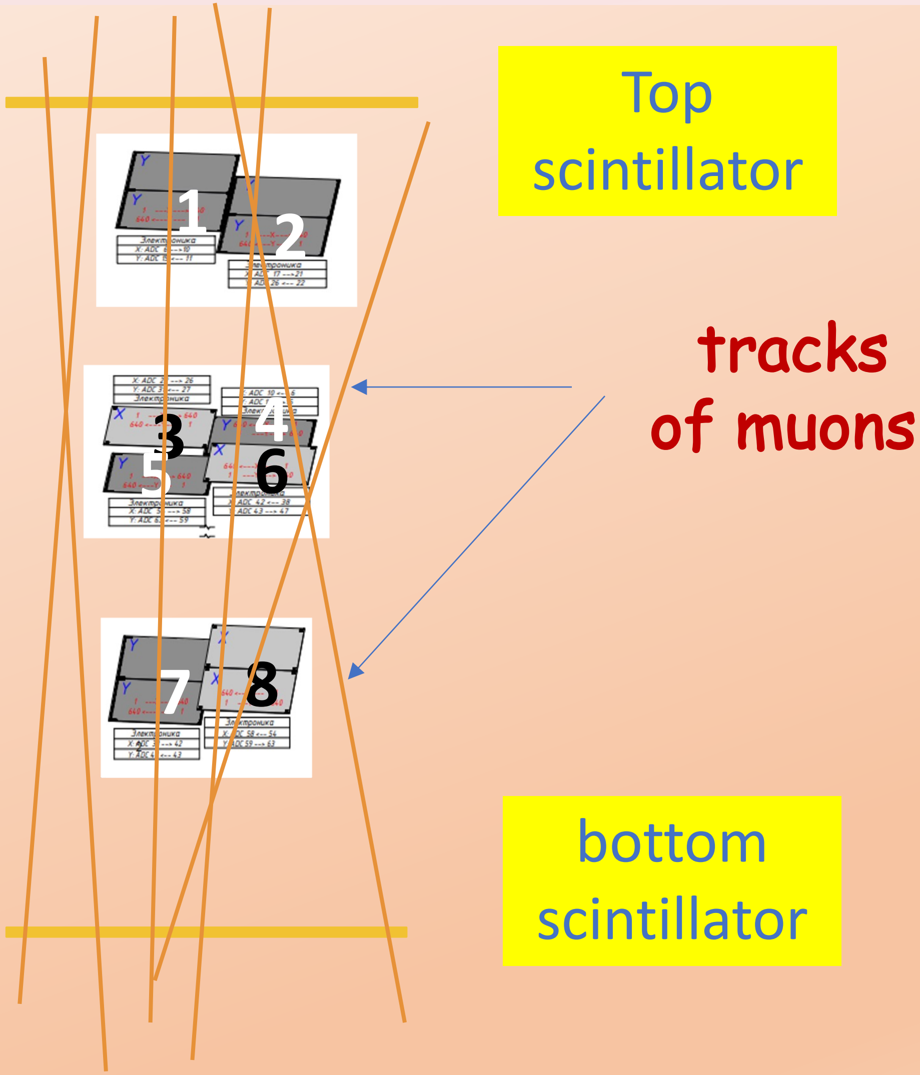
Numeration of strips
left -> right: X1, X2, X4, X5, X7, U1, U2, U3, U4, U5, U7;
right -> left: X3, X6, X8, U6, U8.

Thickness – 0.3 mm
Number of strips – 640
Pitch – 0,095 mm

MiniSPD stand for testing Si-detectors

We select events when top and bottom scintillators trigger. One, two or three Si-plates can trigger.

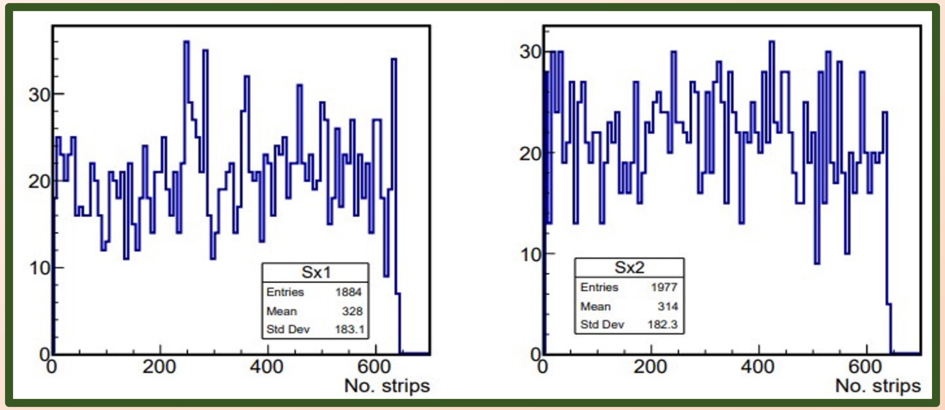
The simulation shows that the scintillator response efficiency is close to 99.99 %.

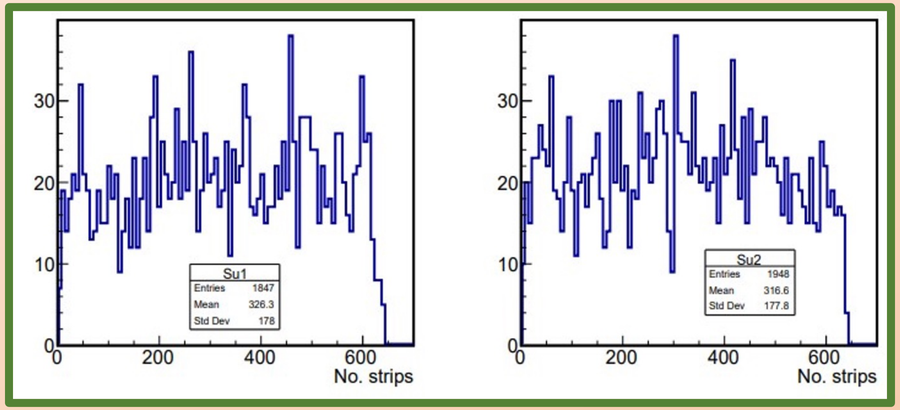


MiniSPD stand for testing Si-detectors

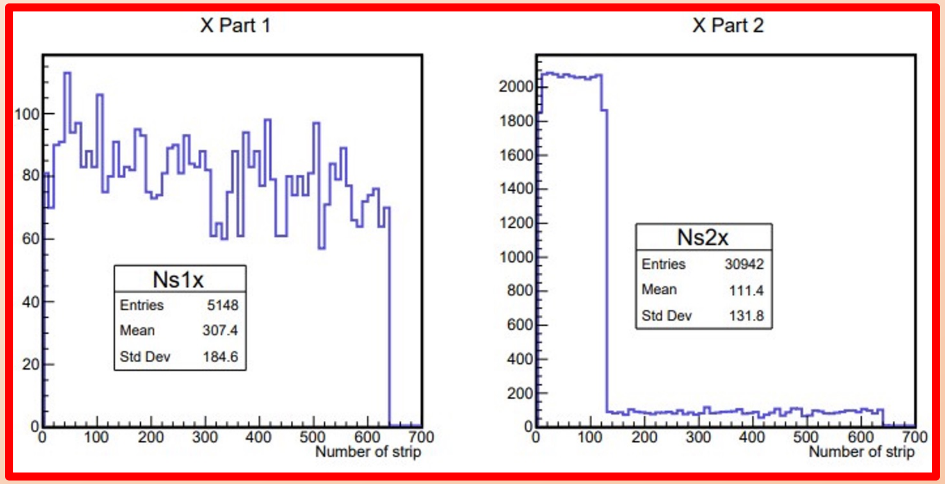
We compare our MC simulation of 50 000 muon tracks with experimental data (~ the same number) obtained from the operation of two scintillator triggers and Si-plates at the MiniSPD stand.

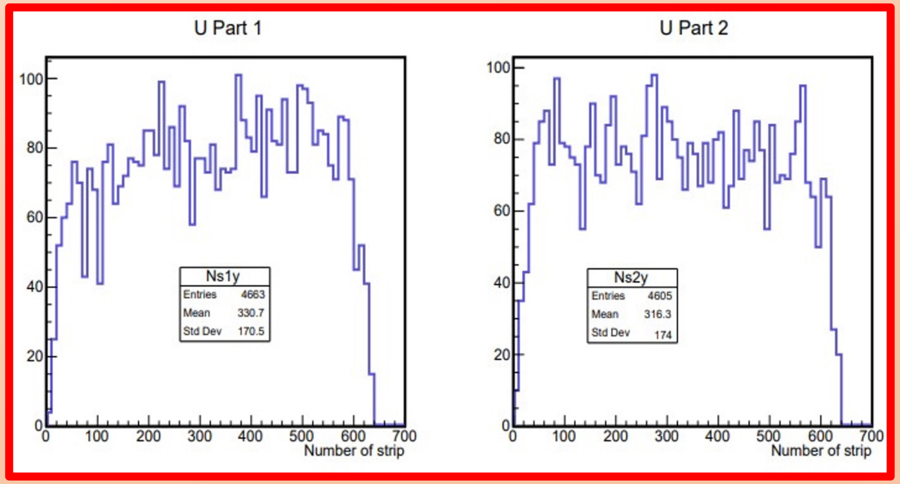
Strip number distributions for X1, X2, U1, U2 plates





MC





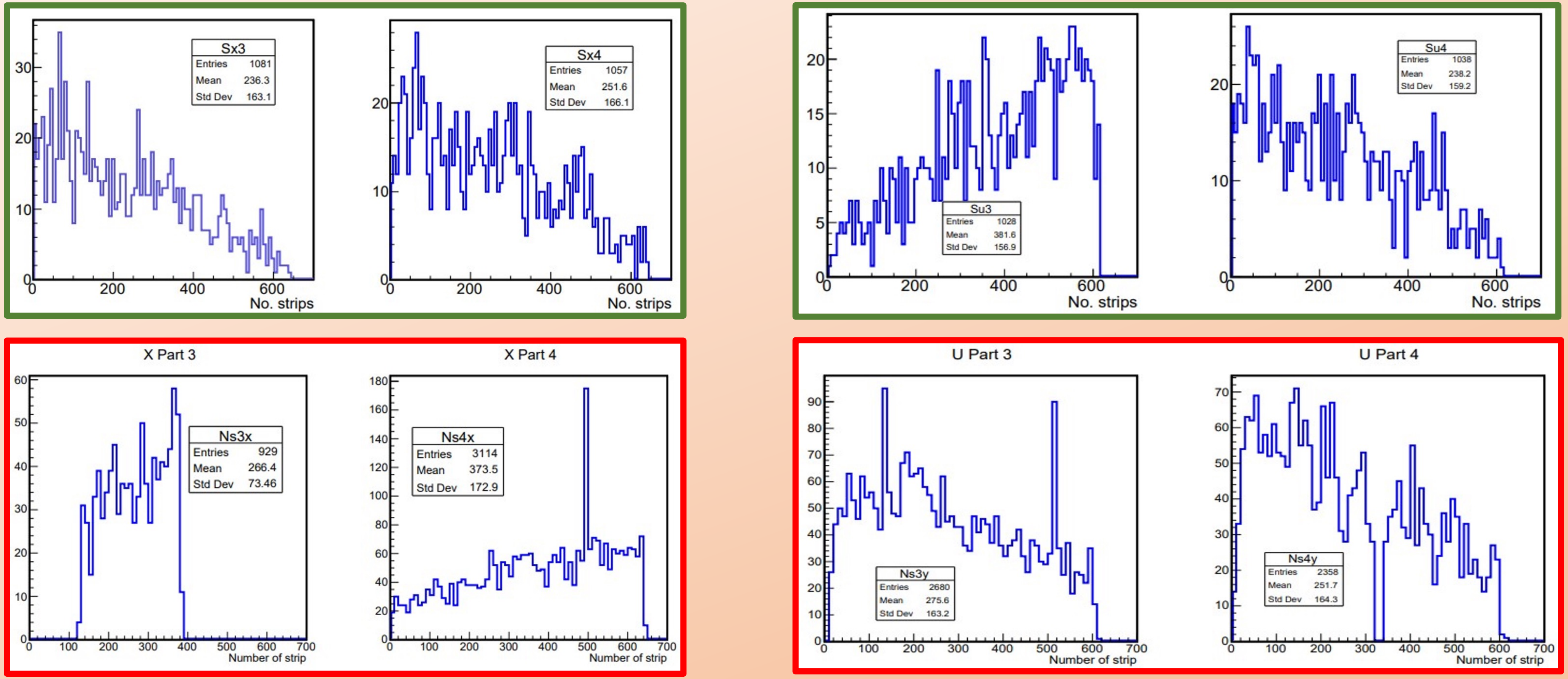
DATA

X1 - good work

X2 ~ 100 channels make enhanced noise

good work

Strip number distributions for X3, X4, U3, U4 plates



MC

DATA

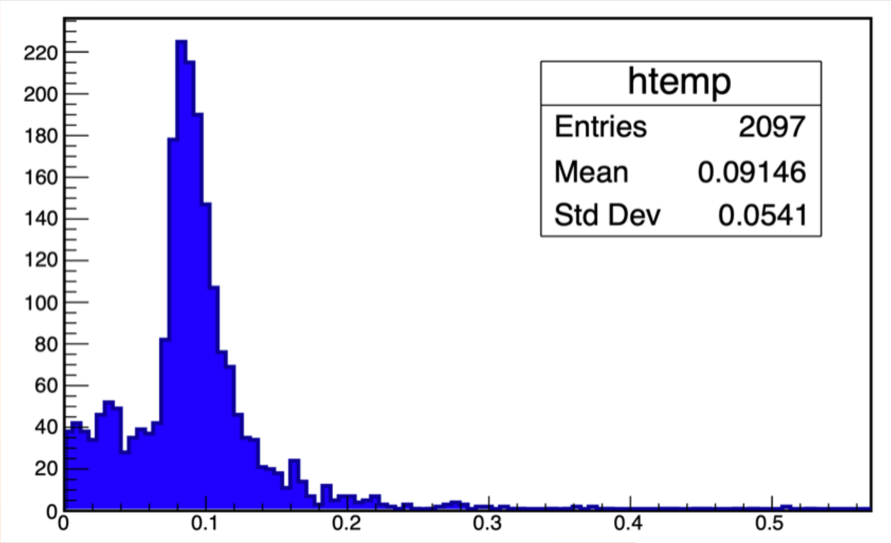
X3 ~ ½ of strips don't work

X4 – there are noise channels

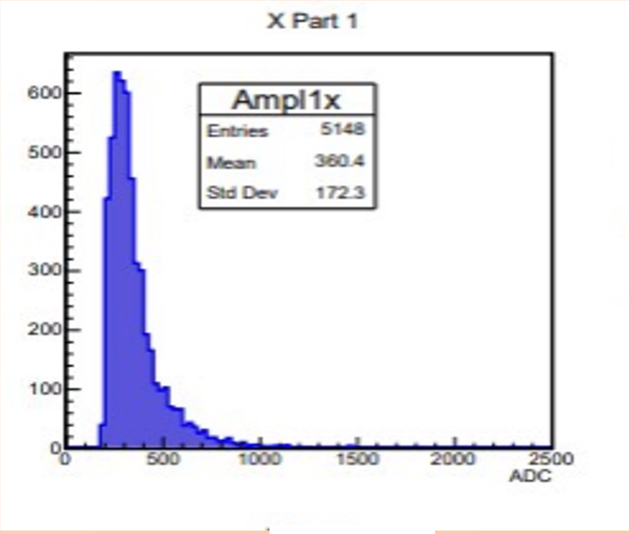
U3 - noise channels

U4 - dead channels

Lower registration threshold on energy



Ed, MeV

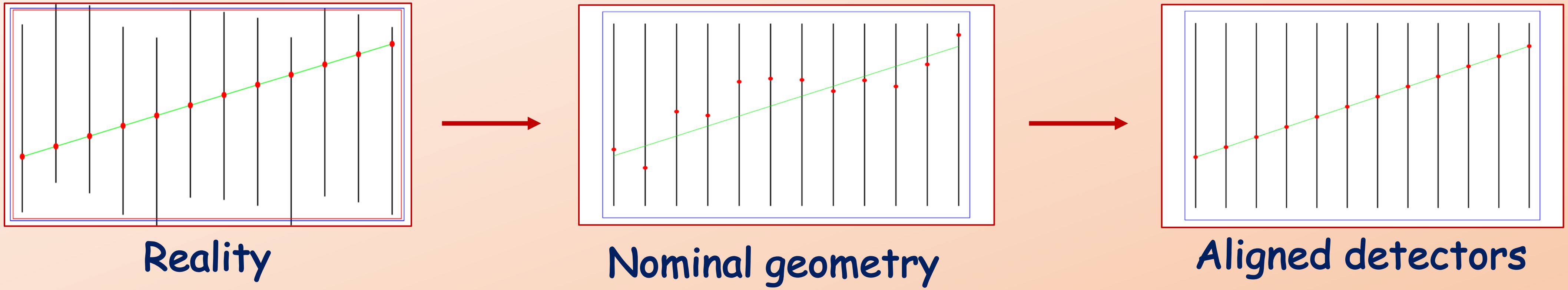


ADC

<ADC> ~ <Edep> (energy deposition in a single strip), the lower threshold of ADC ~ the lower threshold registration of energy deposition (E_cut). Using good planes (X1, X6, U2, U8) we get

30 keV < E_cut < 60 keV and its average value is equal ~ 55 keV.

Alignment from minimization of residuals of F



- $F = \sum_{events} \sum_{tracks} \sum_{hits} \left(\frac{d_i^2}{\sigma_{d_i}^2} \right)$, $d_i = u_{fit} - u_{mes}$

Large number of parameters: track parameters (4 * number of tracks) and shifts(numbers of detectors), number of hits >> parameters.

$$u_{fit} \rightarrow u_j(z_i) = (x_0 + t_x z_i)\cos(\alpha_i) + \left(y_0 + t_y z_i\right)\sin(\alpha_i) + \Delta u_i$$

Millipede procedure improves $\chi 2 - distr.$

χ^2 distributions

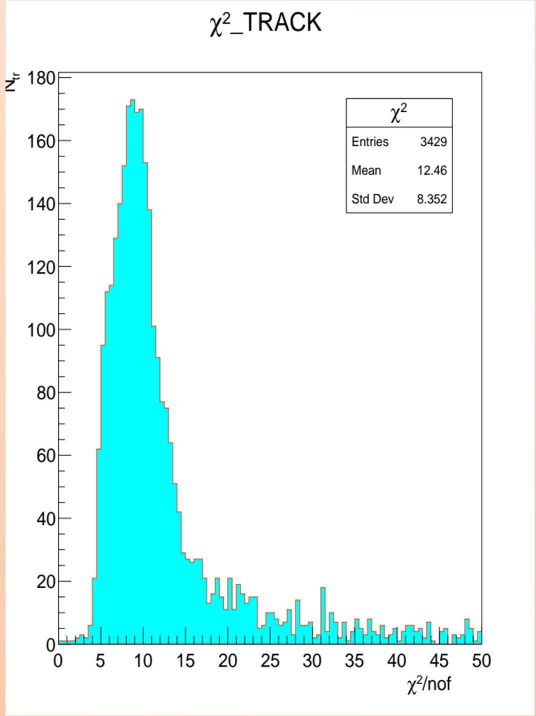
Shifts for part 5 (mm)

Result of fit for global parameters
================

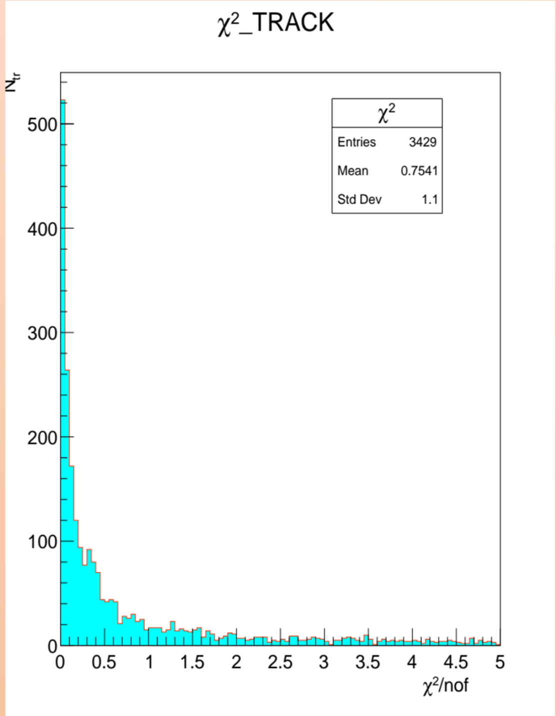
I	initial	final	
1	0.00000	0.00000	
2	0.00000	0.00000	
3	**0.02798**	**0.02841**	**- x-side**
4	**0.97531**	**0.97572**	**- u-side**
5	0.00000	0.00000	
6	0.00000	0.00000	

Total 3428 local fits,
1335 rejected.

148-file



Before alignment



After alignment

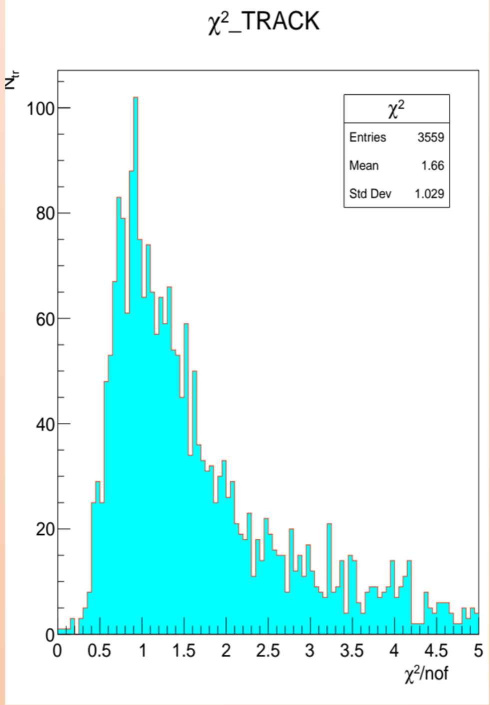
Millipede procedure improves $\chi 2$ – distribution

Shifts for part 4 (mm)

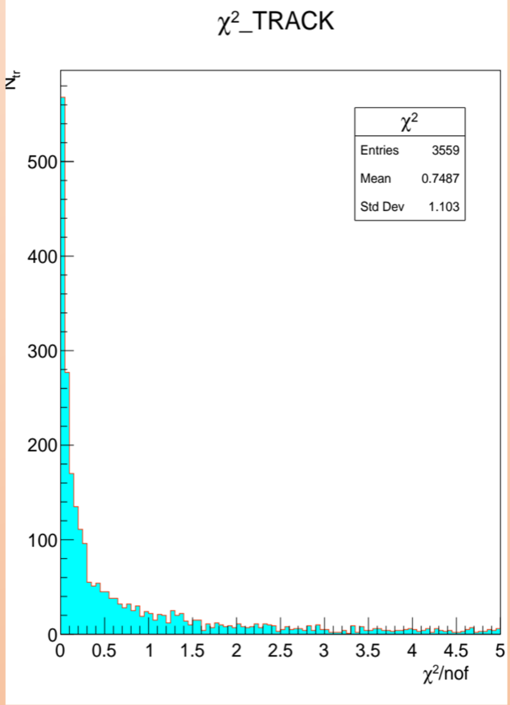
Result of fit for global parameters

I	initial	final	
1	0.00000	0.00000	
2	0.00000	0.00000	
3	-0.00378	-0.00365	- x-side
4	0.34720	0.34735	- u-side
5	0.00000	0.00000	
6	0.00000	0.00000	

Total 3558 local fits,
1409 rejected.



Before alignment



After alignment

Results

1. Monte Carlo simulation of double-sided silicon plates of miniSPD stand is carried out for two cases: with and without taking into account operation of the scintillator triggers.
2. Comparison of Monte Carlo simulation with experimental data allows to estimate the lower threshold on energy for a single strip operation.
3. Work of all parts (1-8) and their X and U sides of Si-detectors was analyzed and compared with MC simulation.
4. **Noisy and dead channels are seen directly from the distributions according to the numbers of the triggered strips.**
5. **Alignment task is solved for the middle (II) module. The distributions on residuals of its parts and $\chi 2$ on tracks are obtained.**

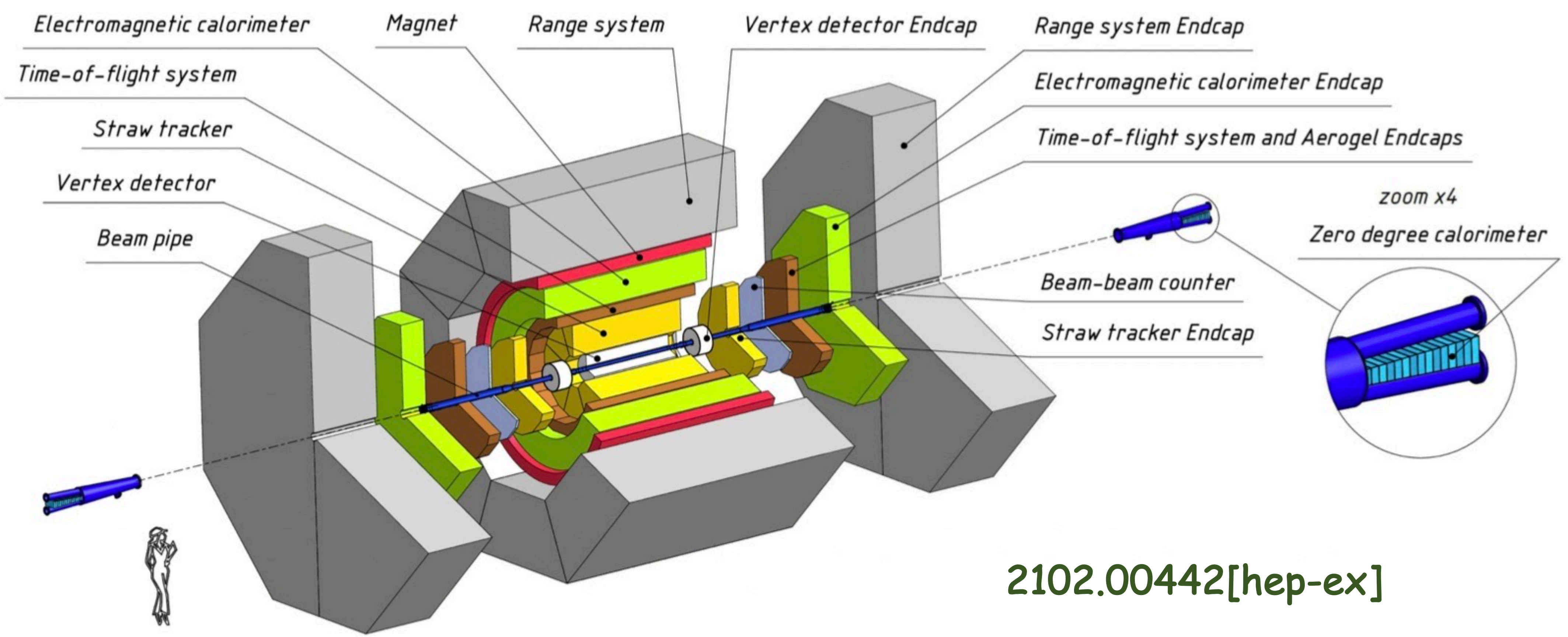
Outlook

1. We continue carrying out MC simulation of straw (drift) tubes to compare its with experimental data obtained at MiniSPD stand.
2. We also plan carrying out Monte Carlo simulation of the electromagnetic calorimeter work (8 modules).
3. It will allows us to start solving our basic task, studying (direct) soft photon yield and the pionic condensate formation (restoration of π^0) in pp (pd, dd) interactions at high multiplicity.

https://www.youtube.com/watch?v=wCqX_rNi-60&feature=emb_imp_woyt

Backup

General layout of SPD setup



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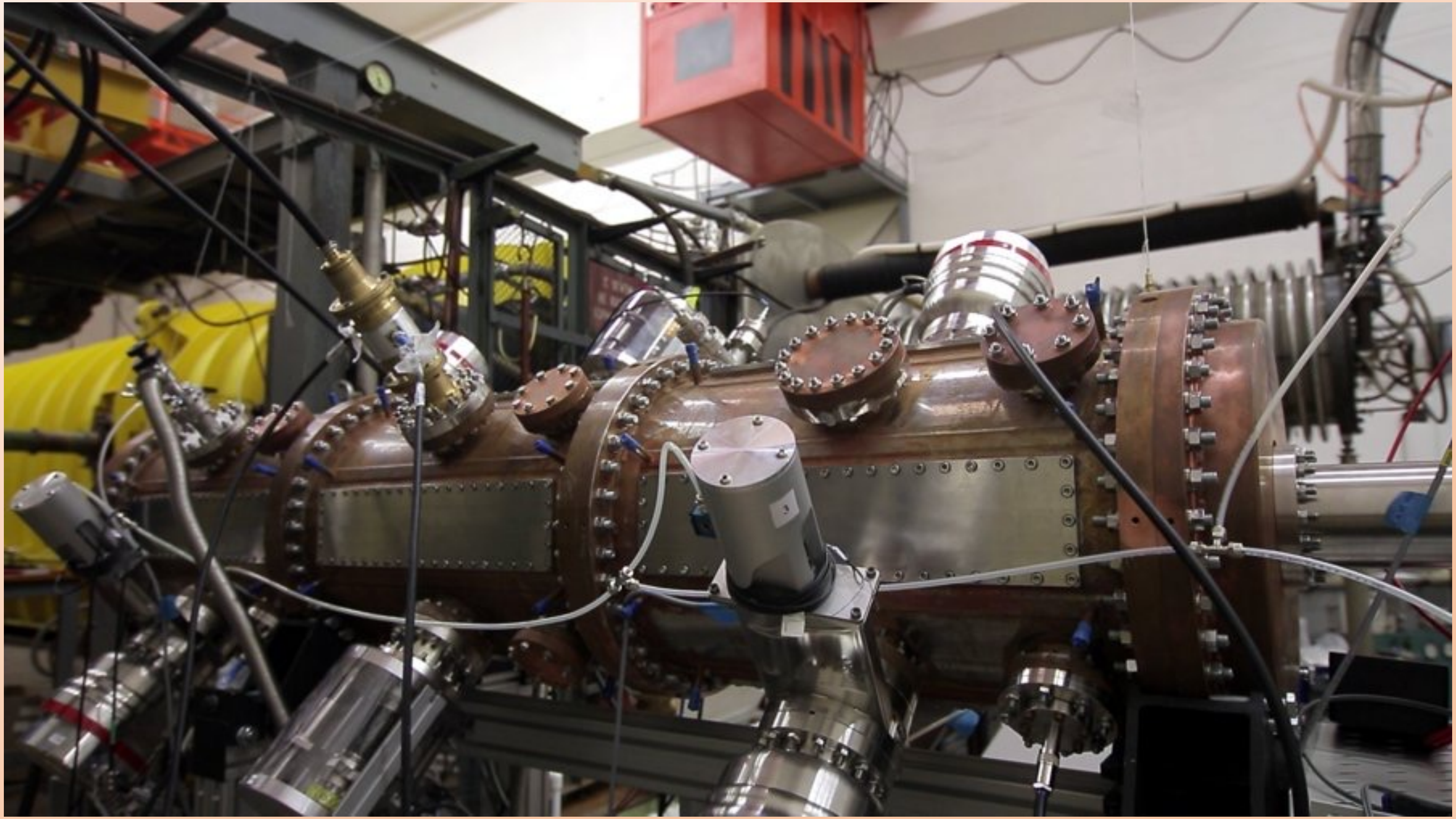
Light Ion Linear Accelerator (LU-20)



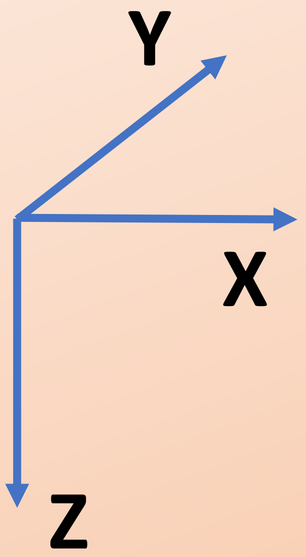
Nuclotron – superconducting heavy ion accelerator

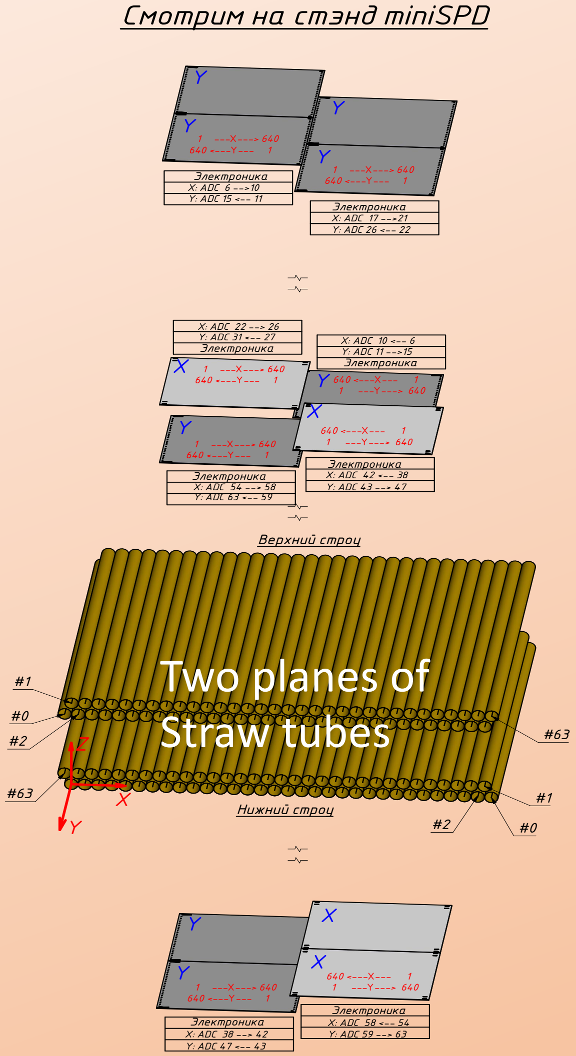
First magnet in collider's tunnel

On 28 December last year, the first superconducting magnet was installed in the tunnel of the NICA accelerator complex. Moreover, a testing system of the MPD solenoid was launched. The magnet factory produces superconducting magnets not only for the NICA project but also for the German project FAIR. The next purchasers of Dubna magnets will be China and CERN.

Layout of silicon plates at MiniSPD stand

Our coordinate system



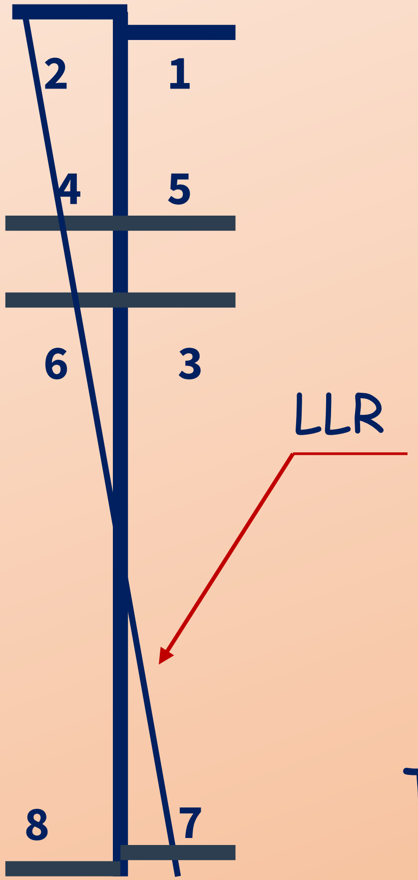


Modules of two-sided Si-plates: dark color indicates oblique (U, 2.5°) strips, light - vertical (X) strips

I. The top (I) module consists of two parts: left (1) and right (2) plates
II. The middle (II) module consists of 4 parts. We numerate them 3, 4, 5 and 6 parts from left to right.
III. The bottom (III) module is similar to I with numeration of left and right: 7 and 8.

Combinations of Si-modules for passing tracks

		N file	Comb.	N tracks
Vertical tracks	I	268	*LLL*	5602
		157	*RRR*	4378
		248	*LLL*	3558
		137	*RRR*	2187
Oblique tracks	II	158	*RLL*	3428
		267	*LLR*	2396
		247	*LLR*	2105
		138	*RRL*	378
	III	257	*LRR*	2392
		148	*RLL*	1550
		168	*RLL*	1037
		237	*LRR*	3
Low level of noise	IV	258	*LRL*	88
		147	*RLR*	3
		167	*RLR*	0
		238	*LRL*	0

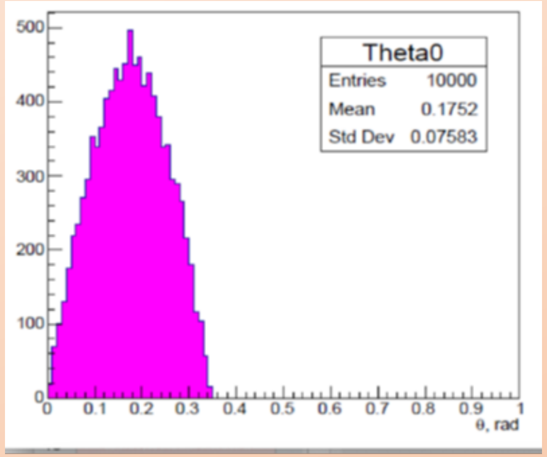


part, N	angle, deg
1	+2.5
2	+2.5
3	-2.5
4	+2.5
5	+2.5
6	-2.5
7	-2.5
8	+2.5

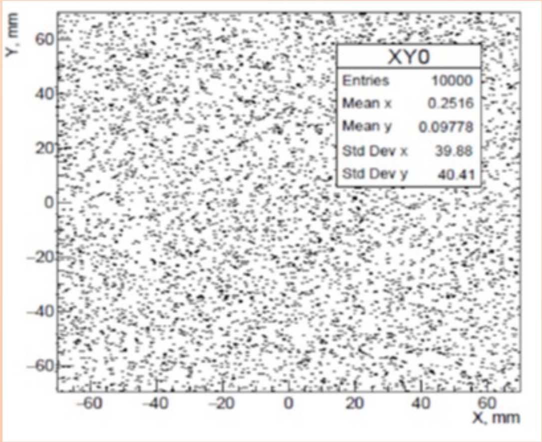
The same orientation for U-coord. is only for 148, 158, 248 combin.

Simulation of cosmic muons (170 MeV)

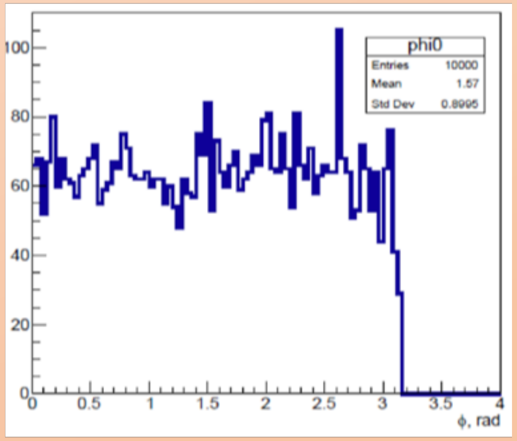
- Polar angle (θ) distribution by cosine
- Azimuthal angle (φ) - uniform distribution
- $\rho = \sqrt{x^2 + y^2} < R = 10$ cm - uniform distribution



$-10 < \theta < 10$



$\rho < 10$ cm



$0 < \varphi < 2\pi$

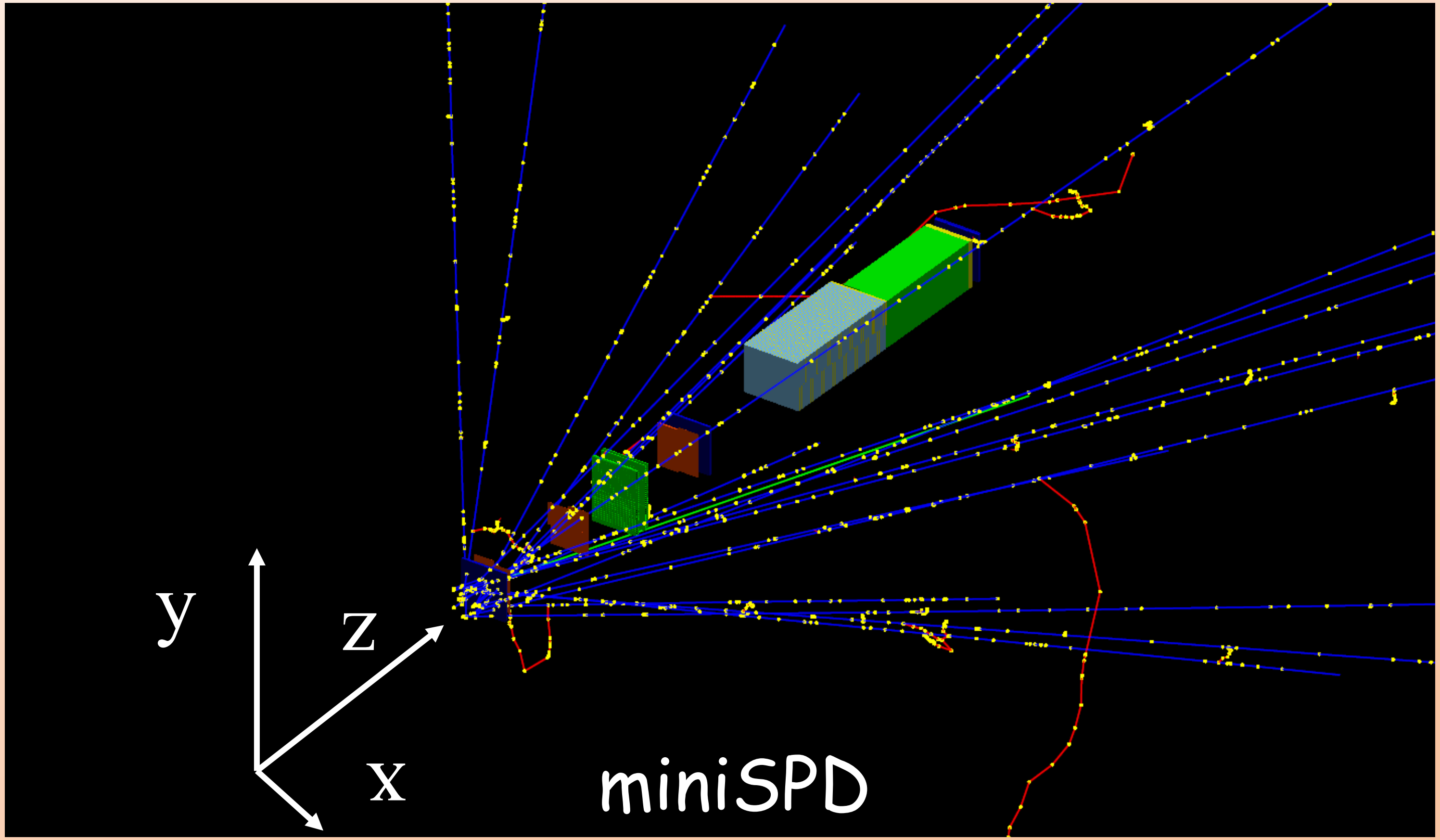
Simulation of triggered strips

Adding of StripStepping.cc to SteppingAction.cc

We use GEANT4 for simulation. In StripStepping for every module and its parts:

1. Connect the triggered strip number with X-coordinate, define U-coordinate for the same plane, the strip number on U-plate and its E_dep (energy deposition).
2. Sorting of the triggered strip numbers in ascending order for elimination of repeating numbers (for X & U).
3. Accounting for crossing the border of the triggered strip when making a stepping.

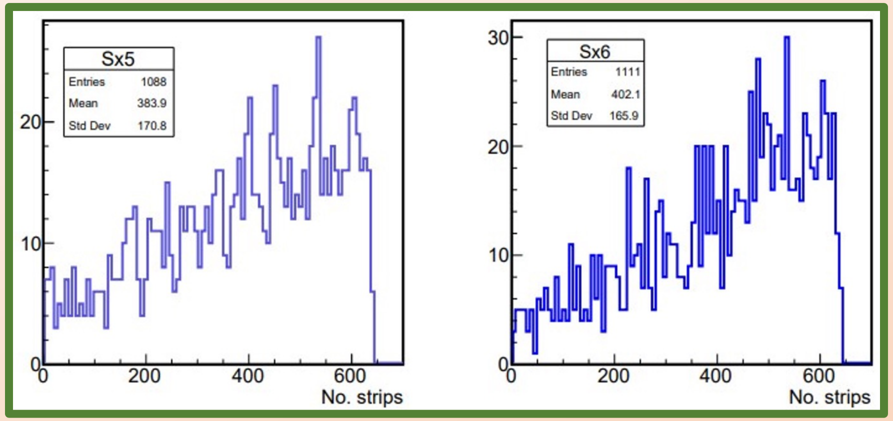
Simulation of cosmic rays by Geant4 at theta = 50 deg.

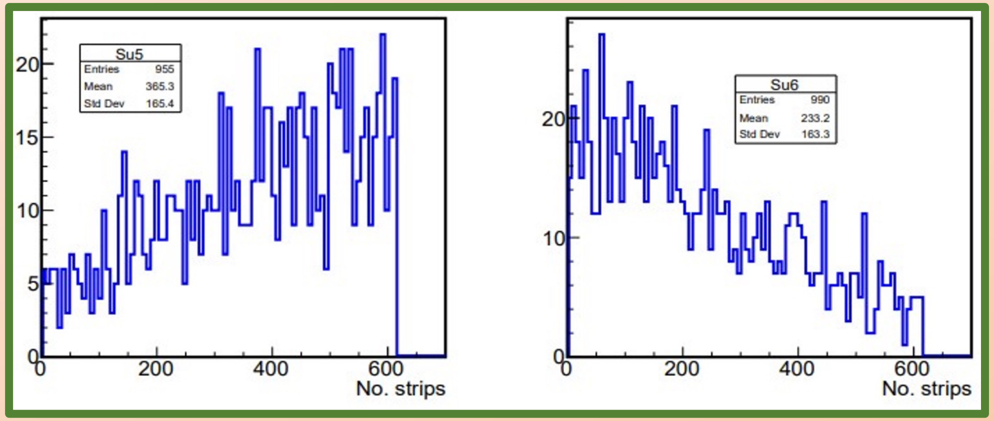


Positioning of Si-plates

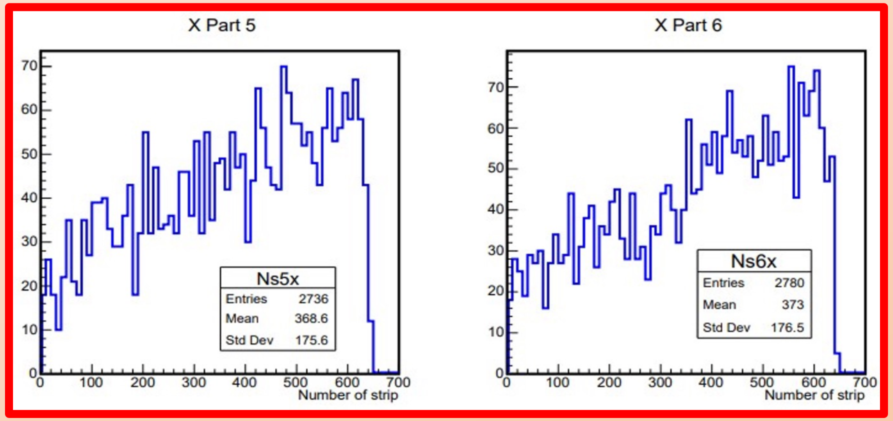
Plane	X, mm	Y, mm	Z, mm	Size, mm
X1, U1	-28,55	0	35,0	63 x 126
X2, U2	31,55	0	50,3	63 x 126
X3, U3	-32,55	-27,55	387,8	63 x 63
X4, U4	27,55	-32.55	395,1	63 x 63
X5, U5	-27,55	32,55	395,1	63 x 63
X6, U6	32,55	27,55	387,8	63 x 63
X7, U7	-28,55	0	893,5	63 x 126
X8, U8	31,55	0	886,2	63 x 126

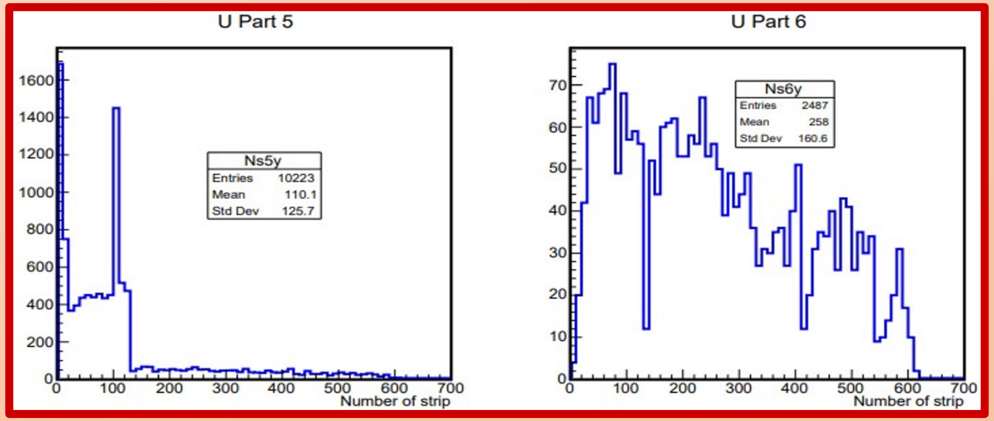
Strip number distributions for X5, X6, U5, U6 plates





MC





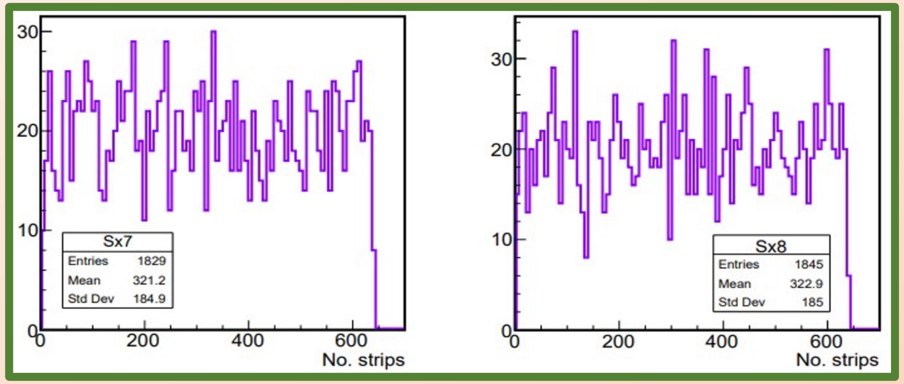
DATA

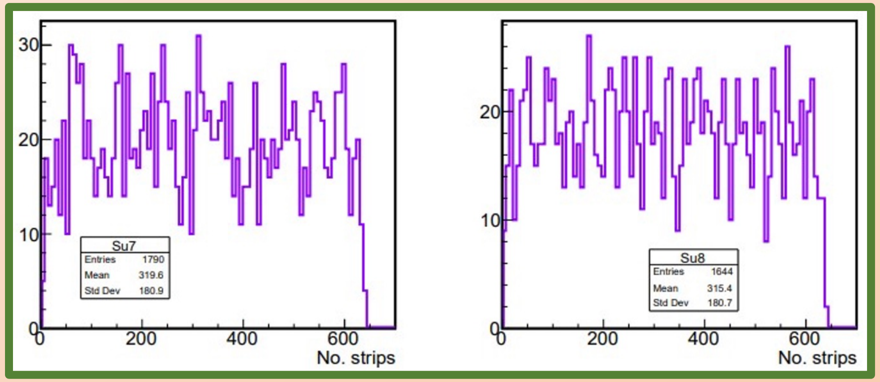
X5 and X6 - good work

U5 ~1/4 channels make noise

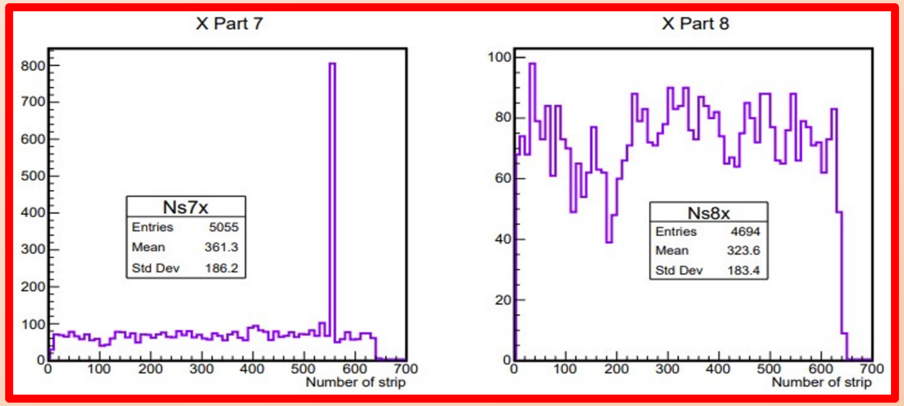
U6 - almost good work

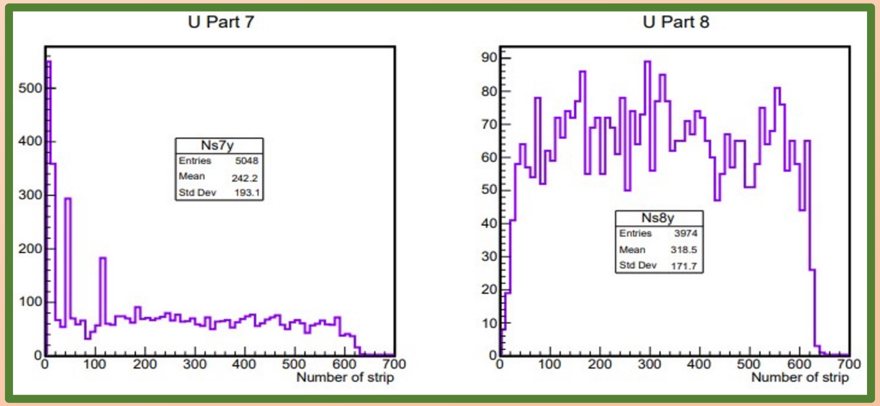
Strip number distributions for X7, X8, U7, U8 plates





MC





DATA

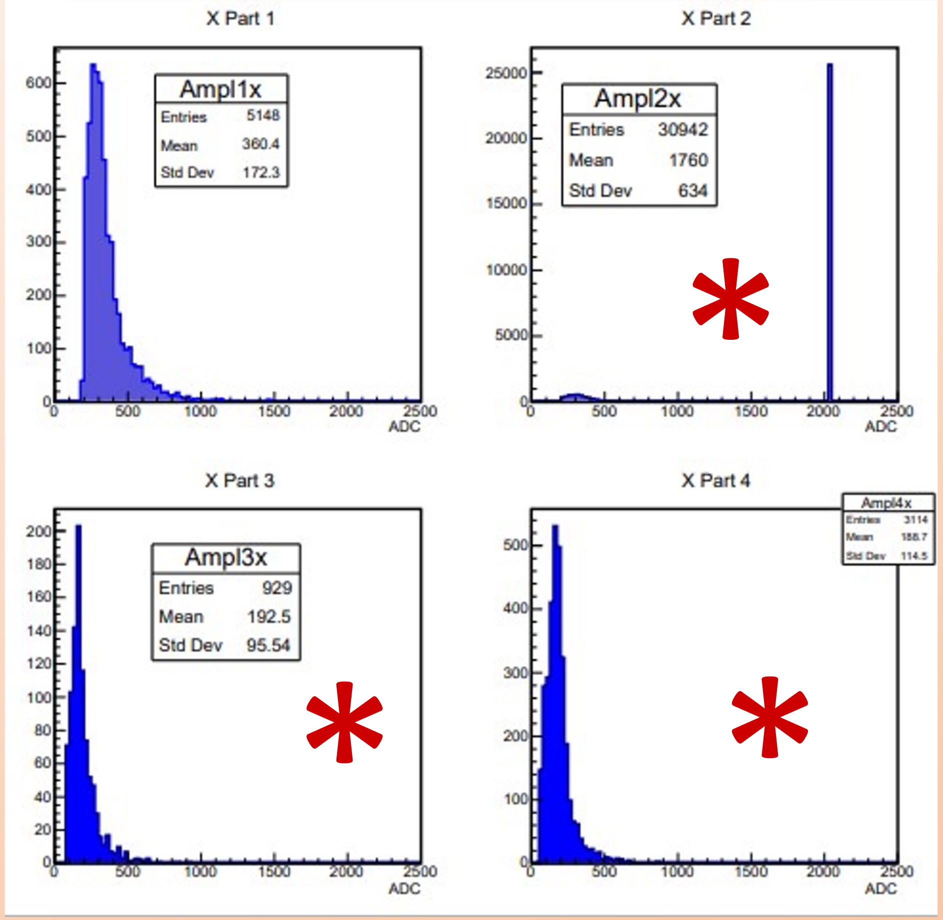
X7 – there are few noise channels

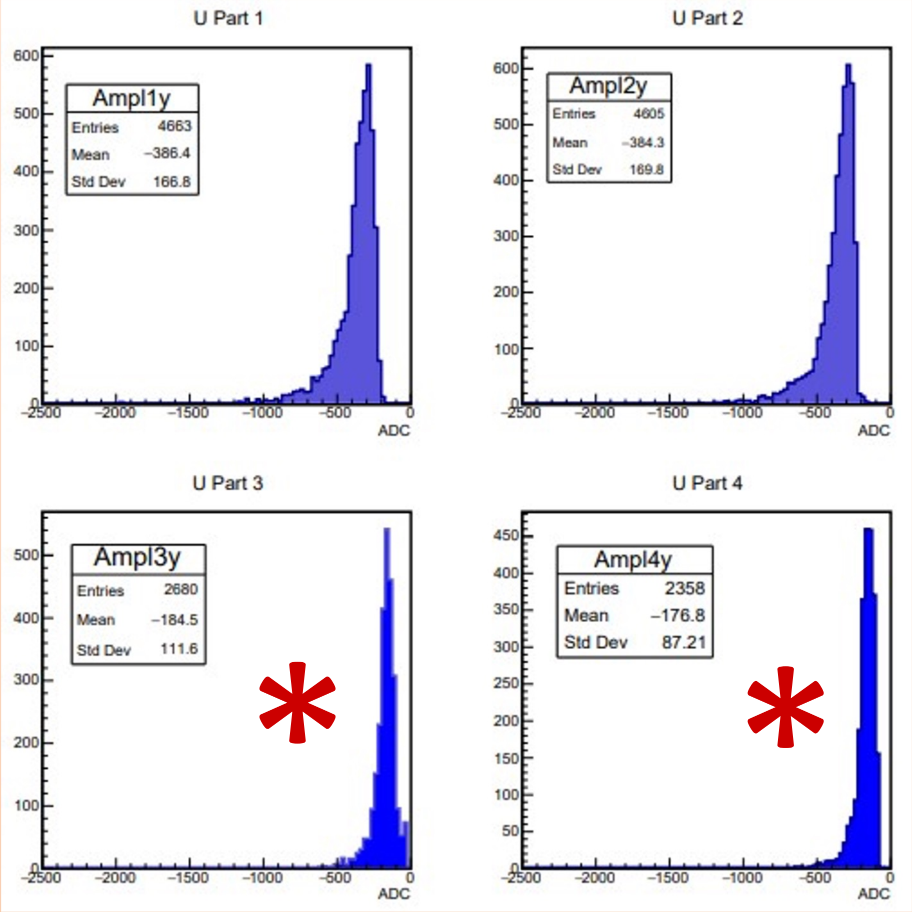
X8 – work almost well

U7 – there are some noise channels

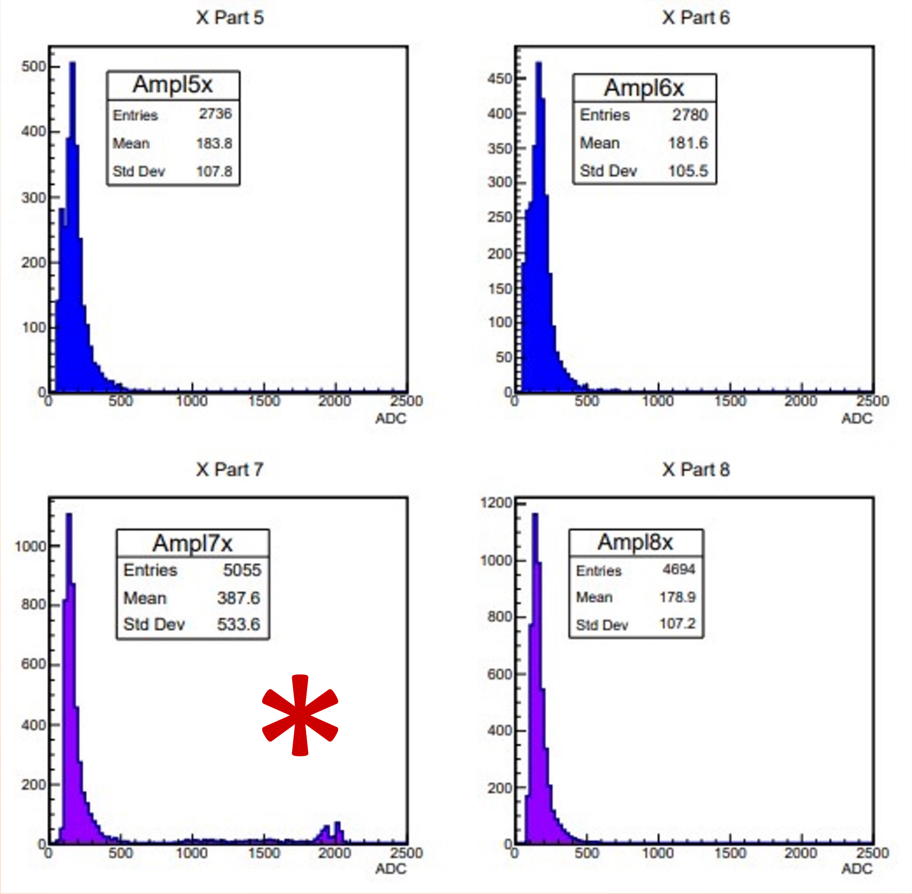
U8 works well

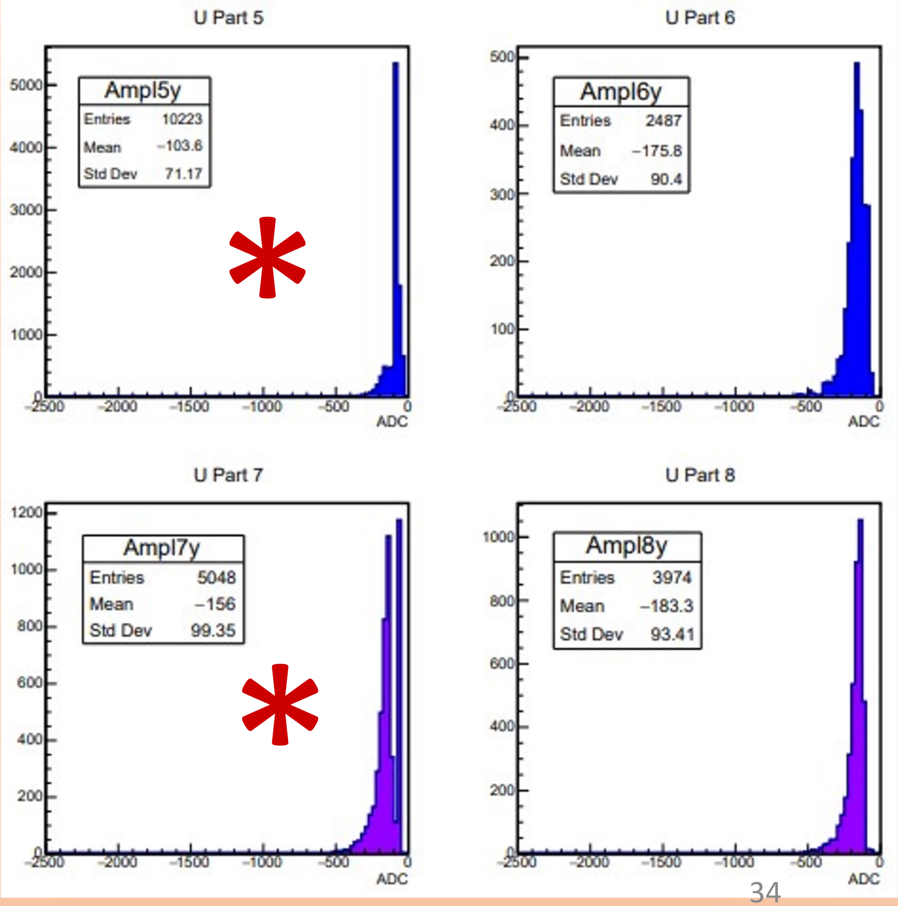
ADC for X & U plates (* - issues with electronics)





ADC for X & U plates (* - issues with electronics)





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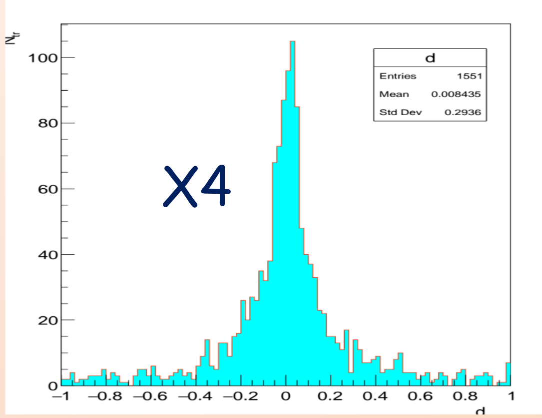
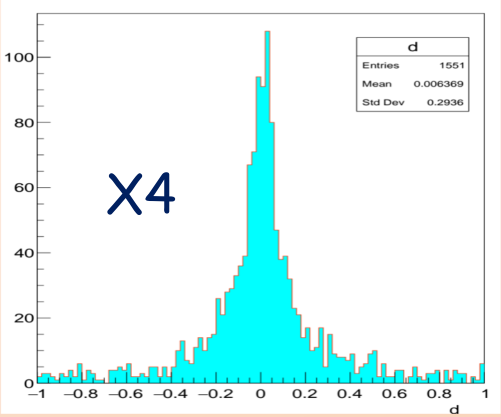
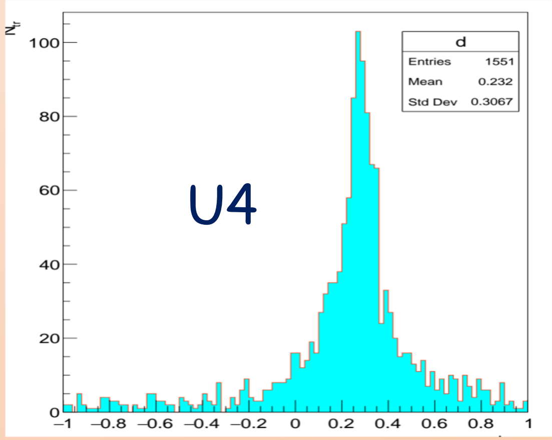
Residual distributions

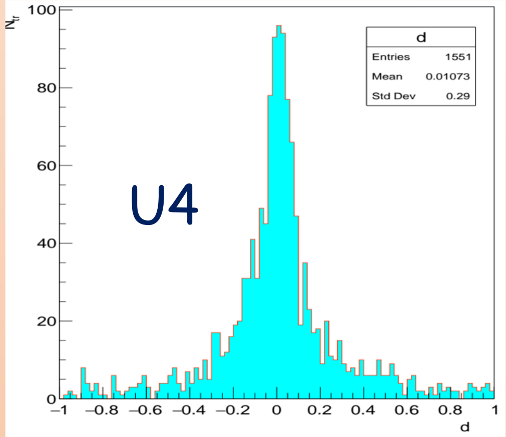
Before alignment

After alignment





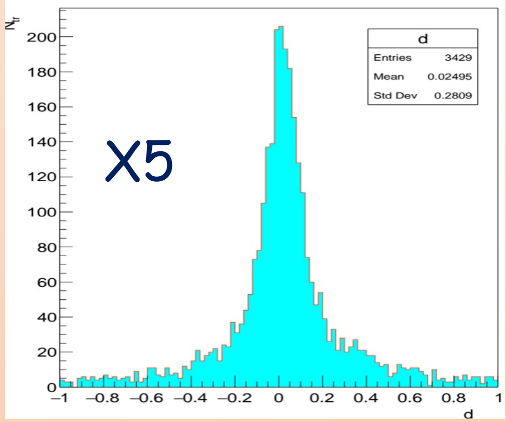


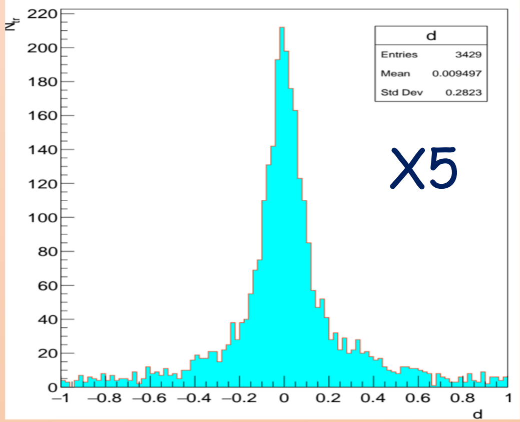


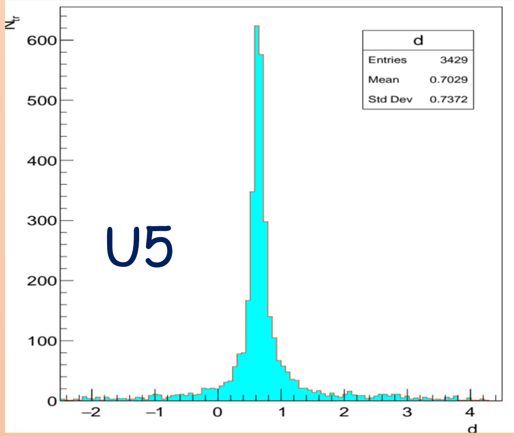
Parts 1,4,8

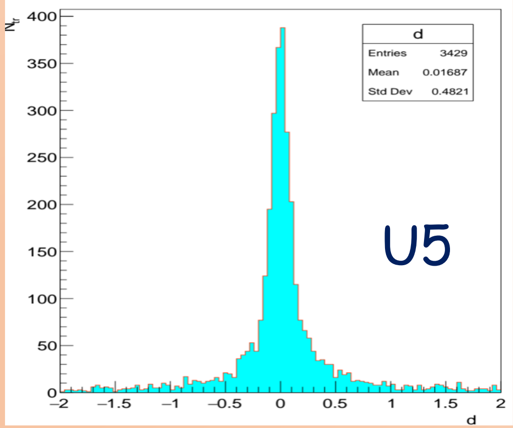
Before alignment

After alignment

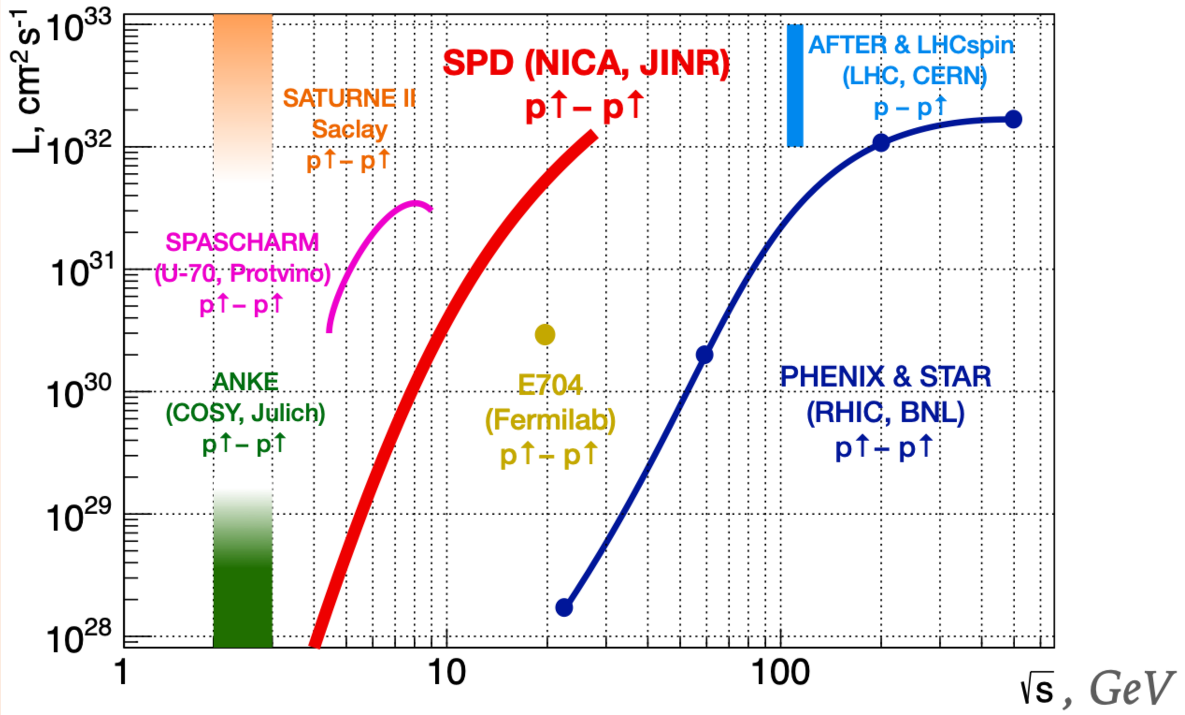






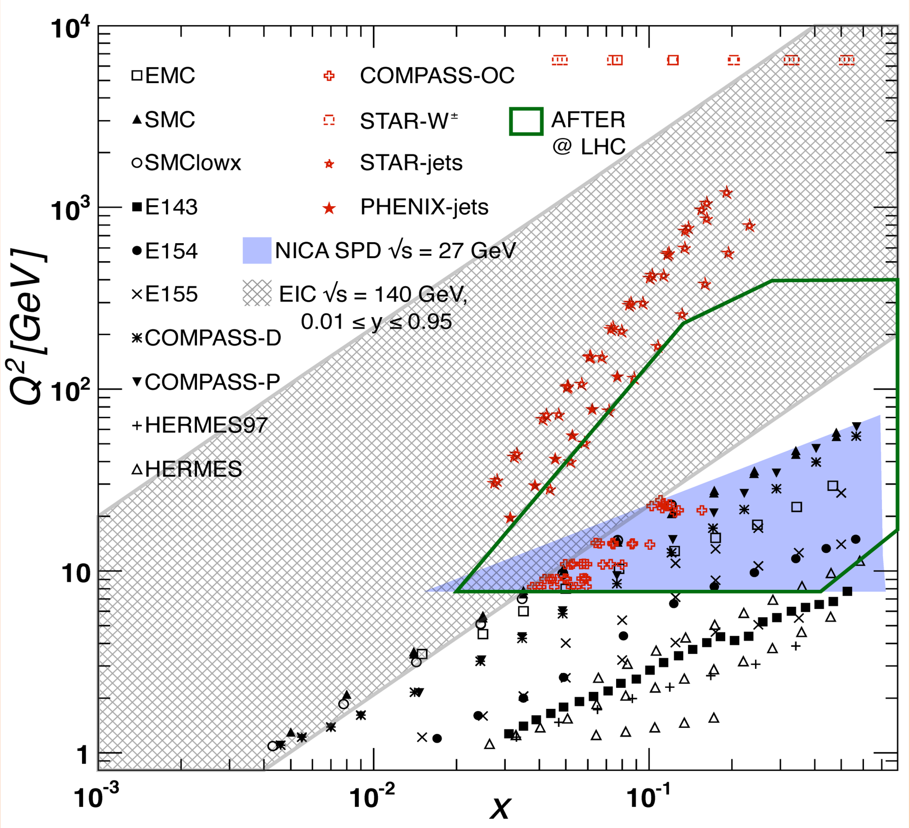


Parts 1,5,8



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

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

Tentative running plan for SPD (I stage)

Physics goal	Required time	Experimental conditions
Spin effects in *p-p* scattering dibaryon resonances	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_{tenzor} - p, $\sqrt{s}$ < 7.5 GeV
Spin effects in *d-d* scattering hypernuclei	0.3 year	d_{tenzor} - d_{tenzor}, $\sqrt{s}$ < 7.5 GeV
Hyperon polarization, SRC, ... multiquarks	together with MPD	d_{tenzor} - p, $\sqrt{s}$ < 7.5 GeV

Total cost ~ 100 M$

Tentative running plan for SPD (II stage)

Physics goal	Required time	Experimental conditions
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 deconfinement, p^{-}yield	1 year	d_{tenzor} - p, $7 < \sqrt{s} < 27$ GeV, (scan)
Gluon helicity, …	1 year	p_L - p_L, $\sqrt{s}$ < 27 GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor polarized" PDFs	1 year	d_{tenzor} - d_{tenzor}, $\sqrt{s_{NN}}$ = 13.5 GeV or/and d_{tenzor} - p_T, $\sqrt{s_{NN}}$ = 19 GeV