Analysis of the operation of coordinate systems based on Si-detectors, information on radiation damage

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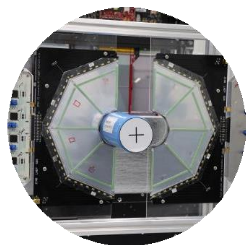
10th Collaboration Meeting of the BM@N,
15 ÷ 19 May 2023

Beam Silicon detectors, Multiplicity trigger and Forward Silicon Tracker on Xe - run

Forward Silicon Tracker

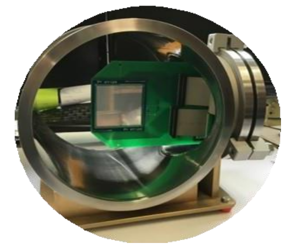
(four XY planes)



Multiplicity trigger

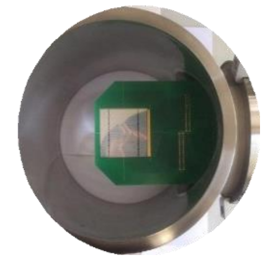
(64-radial strips plane)

Target



Beam tracker

(three station)



Beam profilometer

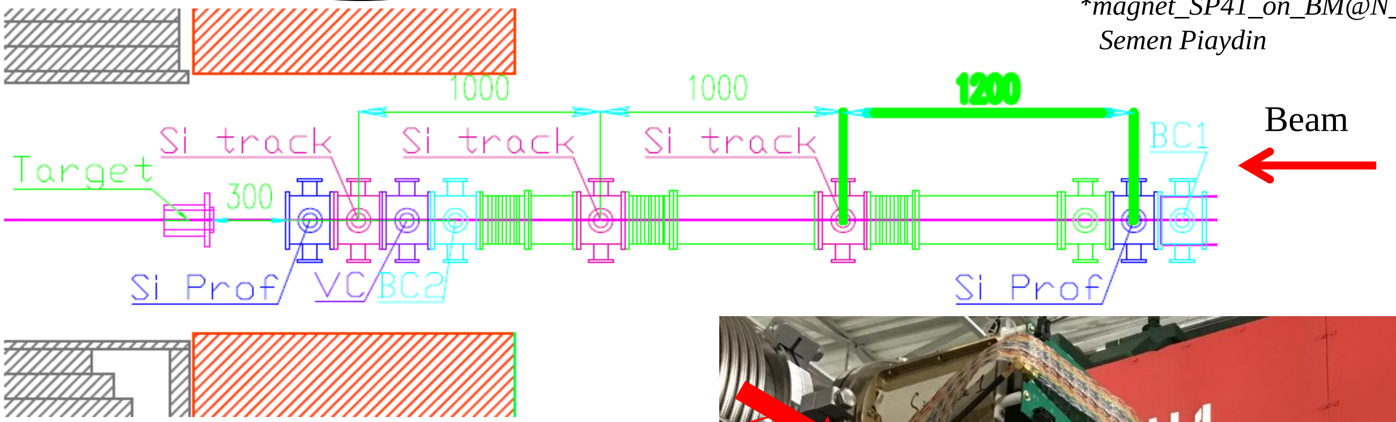
(two station)

Direction of Ion Beam

Position of beam Si-detectors inside of beam pipe before target

SP-41

magnet_SP41_on_BM@N_22_10_18 Model
Semen Piaydin



Beam

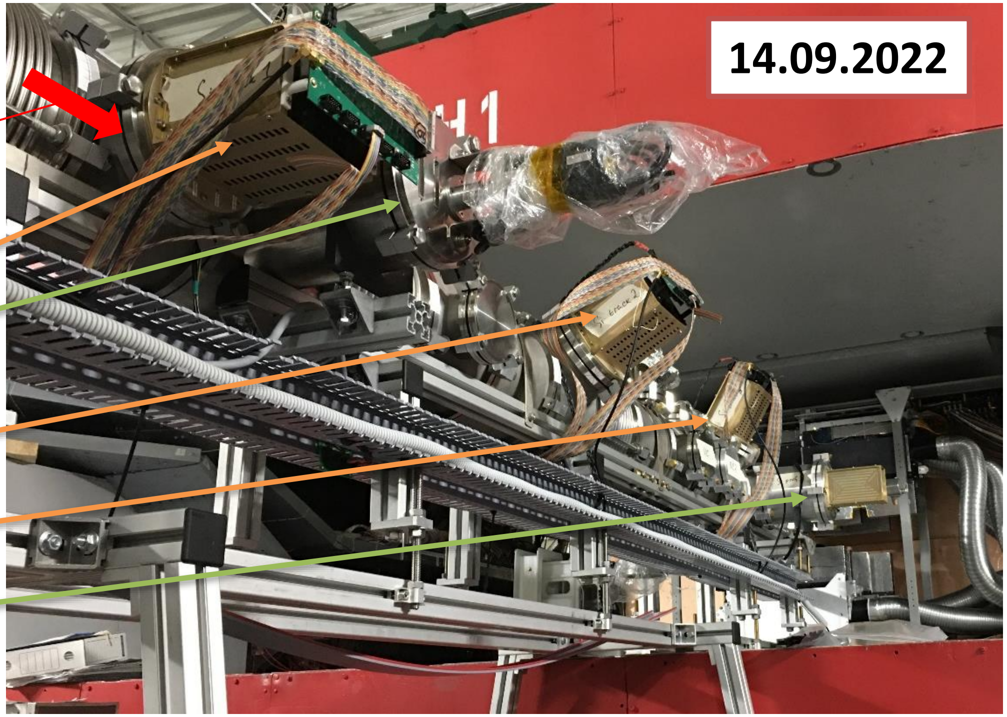
Beam tracker #1 (0^0)

Profilometer #1

Beam tracker #2 (30^0)

Beam tracker #3 (60^0)

Profilometer #2



1. Si-beam tracker (3 station):

- three two-coordinates station based on DSSD (128x128) orthogonal strips, silicon thickness 175 µm (0.0019 X_0), fast FEE (t_p=50;100;150;300ns);

- three coordinate stations, each rotated by angle of 30° relative to the previous one;

- all stations worked in the run normally, as planed;

Problems in the session: **we did not fully check the ASICs modes before the run;**

- the goal is to minimize the effect pile-up at a beam intensity of 10^6 ions/spill (the signal duration on the base is no more than 600 ns)

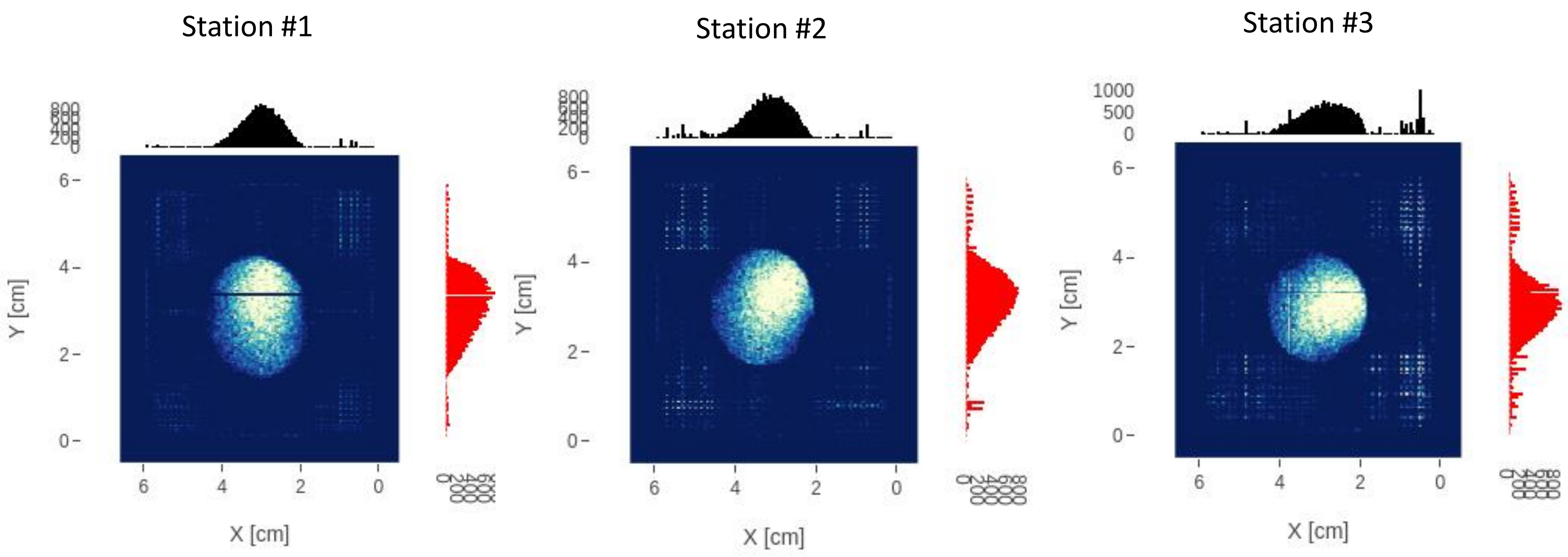
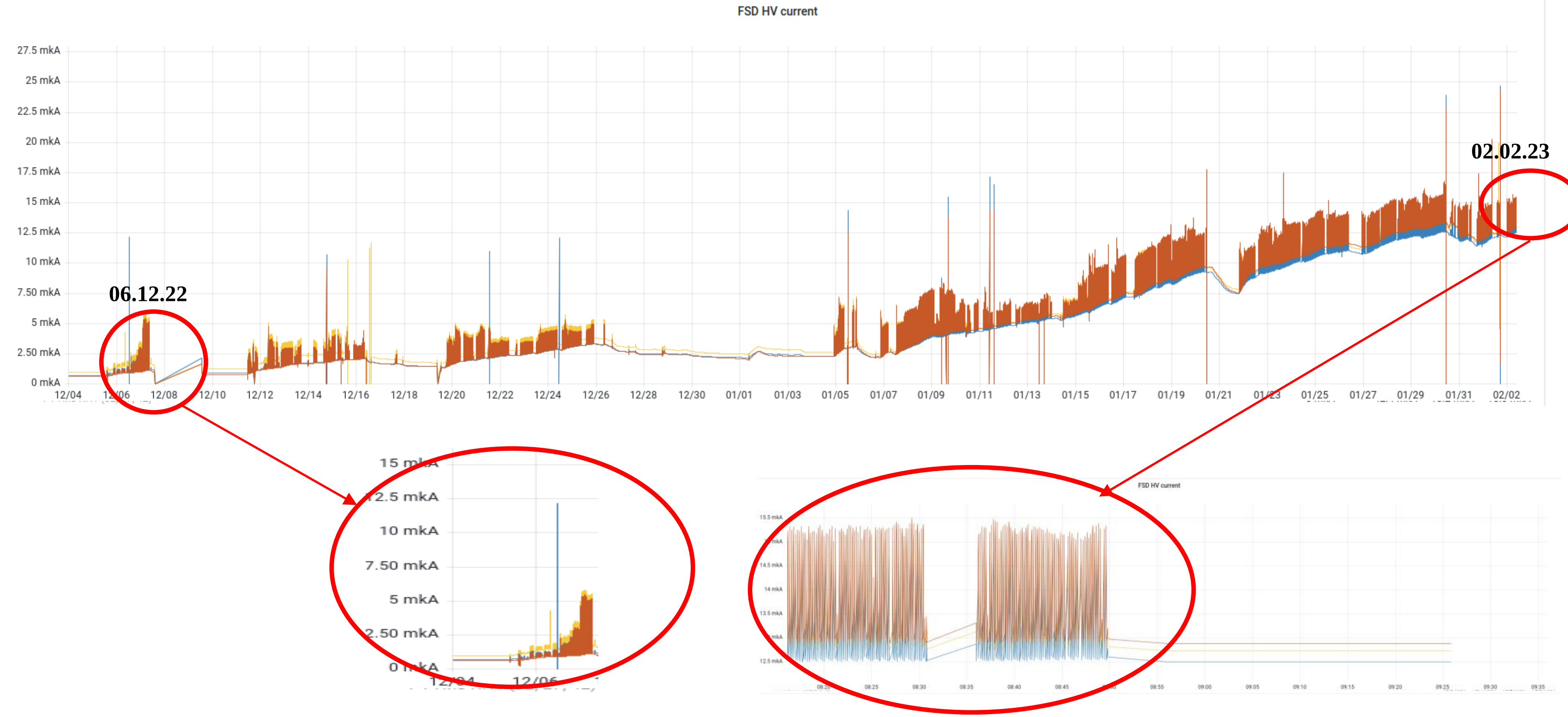


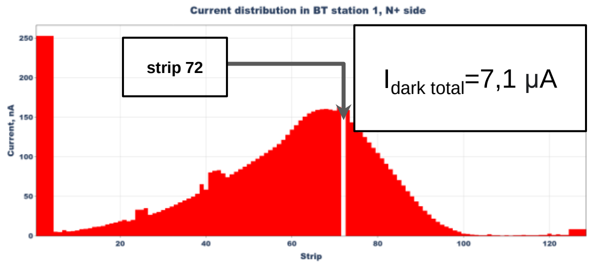
Fig.3. X, У – profiles of Xe-beam upstream the target.
Session BM@N 2022 г. – 2023 г., RUN 6705 (13.12.2022), t = 30°

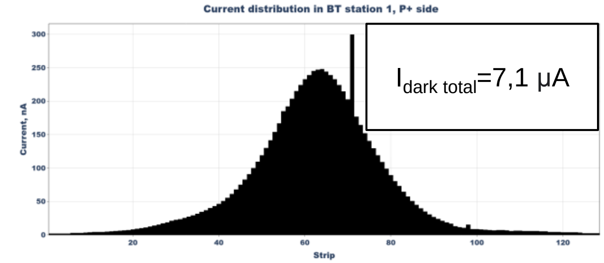
Increasing the dark current of beam trackers during Xe run

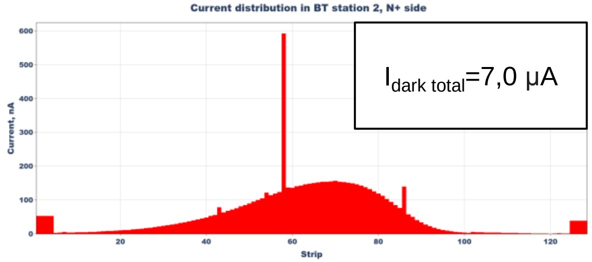


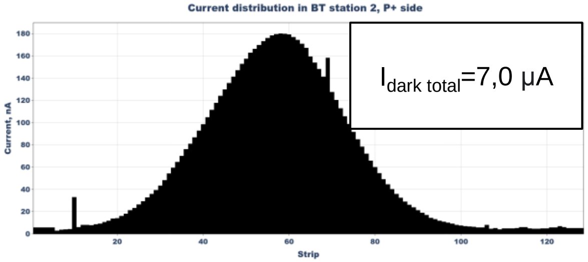
run start, $< I >= 0.761 \mu A;\ t = +22.5^{\circ}C$ run stop, $< I >= 12.7 \mu A;\ t = +26.8^{\circ}C$

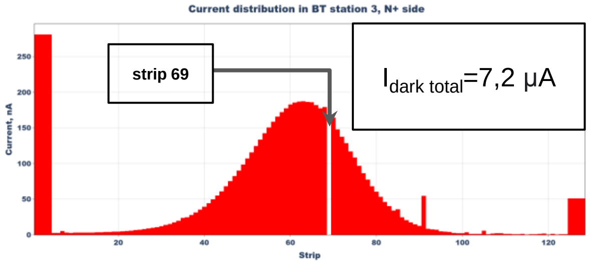
Dark current per strip after Xe run

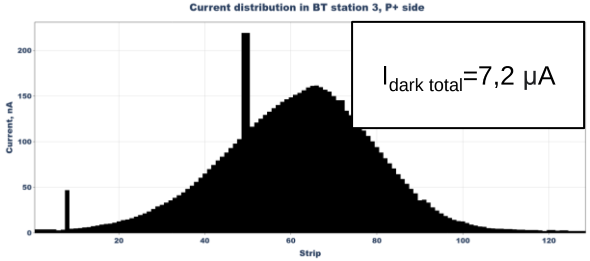












S_{det} = 37,2cm^2, (d=175mkm)
t = +22°

Method of measuring the fluence using silicon detectors

	I_{d0}, μA/+20 V/+22.5°C 04.12.2022 (run start)	$I_{d(s)}$, μA/+20 V/+26.8°C 2.02.2023 (run stop)	$\Delta I = I_{d(s)} - I_{d0}$, μA **(at +20 °C)**
BT1	0.965	12.7	6.3
BT2	0.692	12.5	6.4
BT3	0.626	12.9	6.7
Mean	0.761	12.7	6.44

Fluence can be estimated by the empirical formula:

$$\Delta I = \alpha \cdot \Phi_n \cdot V_{det} \ , \alpha = 3 \cdot 10^{-17} \ A \cdot cm^{-1}, V_{det} = 61 \cdot 61 \cdot 0.175 \ mm^3$$

, α - bulk radiation damage constant, Φ_n is the equivalent fluence of 1 MeV neutrons, related to the fluence of xenon by the relation:

$$\Phi_n = k \cdot \Phi_{Xe}$$

K =276 - hardness factor of 4 A*GeV Xe

Using the calculated hardness factor and experimentally obtained increases of currents we obtain:

	Fluence of 1 MeV neutrons, cm^{-2}	Fluence ^{128}Xe, cm^{-2}	Number of xenon nuclei
BT1	$3.21 \cdot 10^{11}$	$1.16 \cdot 10^{9}$	$4.33 \cdot 10^{10}$
BT2	$3.27 \cdot 10^{11}$	$1.18 \cdot 10^{9}$	$4.41 \cdot 10^{10}$
BT3	$3.41 \cdot 10^{11}$	$1.23 \cdot 10^{9}$	$4.60 \cdot 10^{10}$
Mean	$3.30 \cdot 10^{11}$	$1.19 \cdot 10^{9}$	$4.44 \cdot 10^{10}$

Based on the obtained fluence, we can estimate the number of xenon nuclei that passed through the detectors during the run:

$$N_{Xe} = \Phi_{Xe} \cdot S_{det}$$

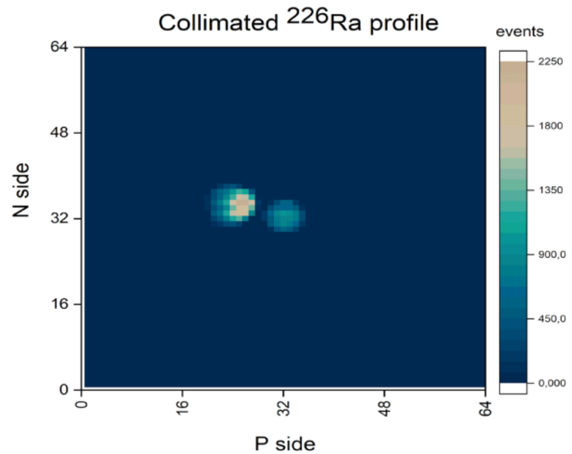
S_{det}=37,2cm^2

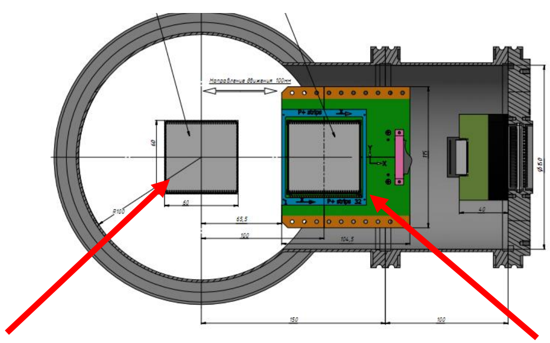
2. Beam profilometer *(two station):*

- We expected beam profiles for Xe to be approximately the same shape as profiles in the tests with alpha-source ^{226}Ra, but it did not happen due to signals overlap with usage "slow" electronics (VA163) and with large area of strips (pitch = 1.87 mm);

- both profilometers were put in the "park" position and were not used in the session;

- our plans and actions: we are making a new development based on DSSD with 128x128 strips (pitch = 450 µm) and turn it to 64x64 strips (pitch=900 mkm) + new FEE based on fast chip VAHDR64





working position

parking position

- **detector:** DSSD, ($32p^{+}\times 32n^{+}$), strips pitch = 1.8 mm, thickness (Si) -175 µm, active area (60 × 60) mm^2;
- **mechanical design:** the plane of the profilometer is automatically removed from the beam zone to the parking position;
- **FEE:** for light ($_{6}$C ÷ $_{18}$Ar) ions based on **VA163 + TA32cg2 (32 ch, dynamic range (DR): -750fC ÷ +750fC)** **desing in progress**;
- **current status:**

  - two vacuum stations with flanges and cable connectors are ready, Silicon Detectors assembled on PCBs and tested with alpha-source (5.5 MeV), autonomus (ADC+DAQ) subsystem ready;

  - for heavy (Kr ÷ Au) ions will be developed another version of the FEE with DR = ± 20 pC.

3. Two planes of Si-multiplicity trigger, 64 strips ϕ, pitch=5.63, detector thickness – 525 μm ($0.0056X_0$):

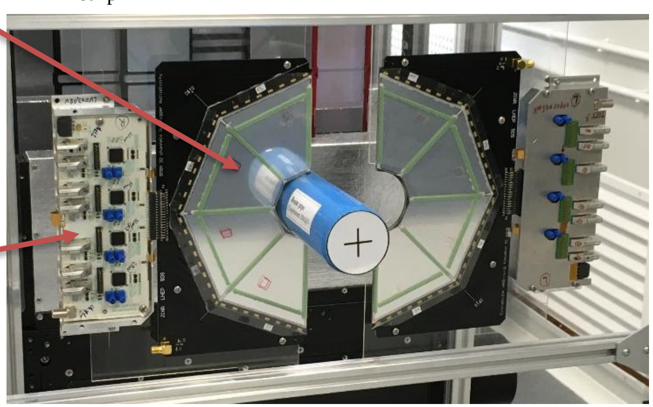
- Almost did not work in session, 16.12.2023 planes were moved away from beam pipe and were outside the beam zone;
- In the last two days of session, the detector was installed in the working position and data was recorded (did not participate in the trigger) with a beam Xe=3.0 A*GeV;
- To make a decision on further application, an analysis of the recorded data is required (there are two data streams: - a monitor with a display of noise counting and multiplicity (the indicator of equipment operation is OK!); – branching to TDC with recording measurements in DAQ, these data are in doubt

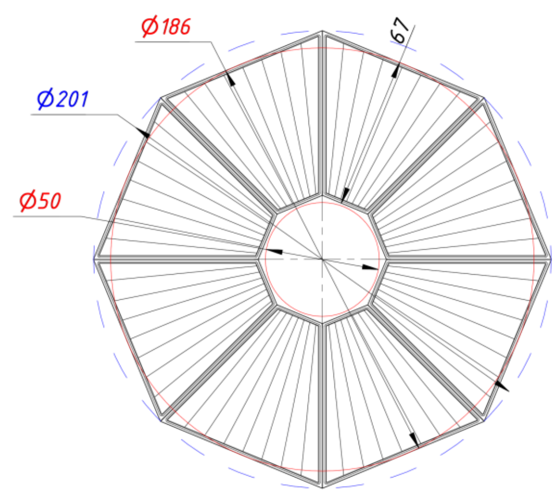
The detecting plane of the silicon trigger is assembled from 8 trapezoidal one-sided detectors:

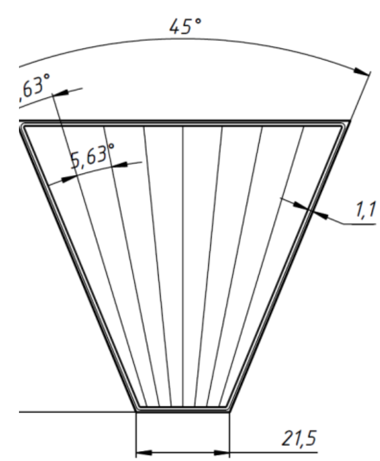
- Total 64 radial strips with 5.630 angle
- Diameter of inner hole for ion guide Ø50 mm (dead zone Ø55 mm)
- External diameter of the sensitive zone 186mm
- Max diameter 201mm
- Detector thickness 500 μm
- S_{strip} – 3.55 cm^2

Half plane 32 channels,

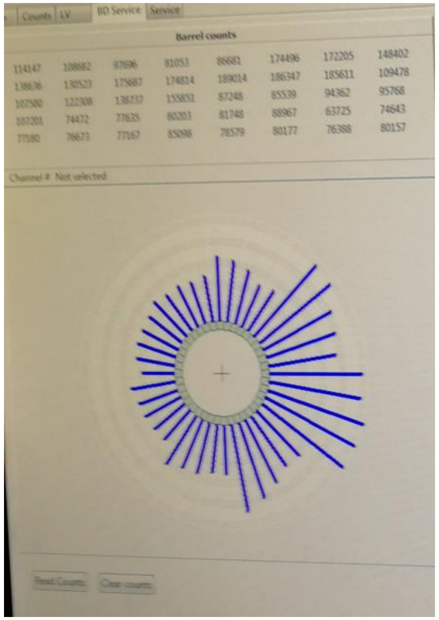
FEE



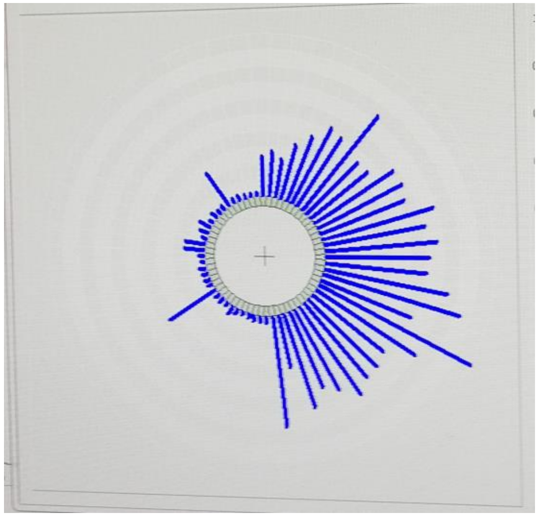




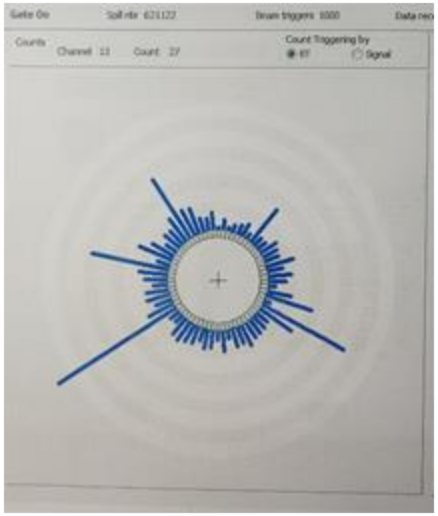
Trigger data with beam of Xe (3.0 A*GeV),



Trigger barrel detector (BD) counting distribution



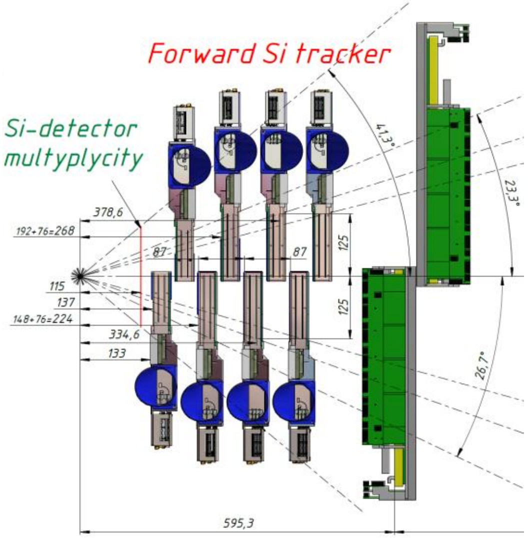
Forward part of Si-MD counting distribution



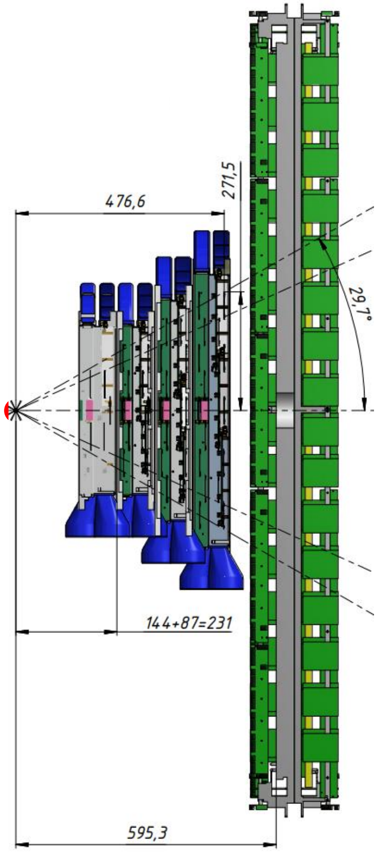
Noise distribution of Si-MD (without beam)

4. FSD-tracker (4 stations)

Si-tracker plane (9 modules)



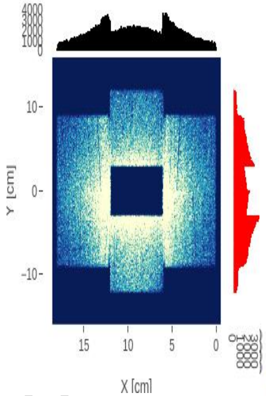
Location of FSD planes in session 2023 (YZ-view)



Location of FSD planes in session 2023 (XZ-view)

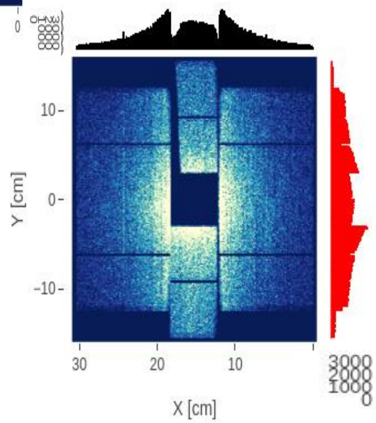
Planes	#0	#1	#2	#3	Total
Modules	6	10	14	18	48
Channels	7680	12800	17920	23040	53760
Area, m^2	0,035	0,073	0,102	0,132	0,307

Occupancy of 4-planes FSD in Xe session, RUN 7529 (11.01.2023), target №2 CsI (2%)



8.9 μA / 8.2 μA
(start / stop)

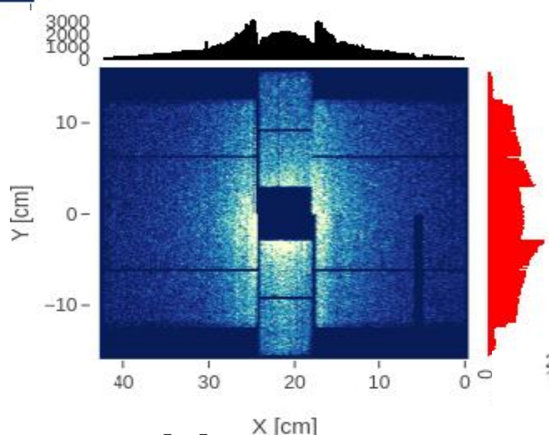
6 modules



27.6 μA / 28.5 μA
(start / stop)

10 modules

Values of bulk dark current per each Si-plane are not change during the Xe-run, we can conclude that Si-detectors are not damaged by irradiation

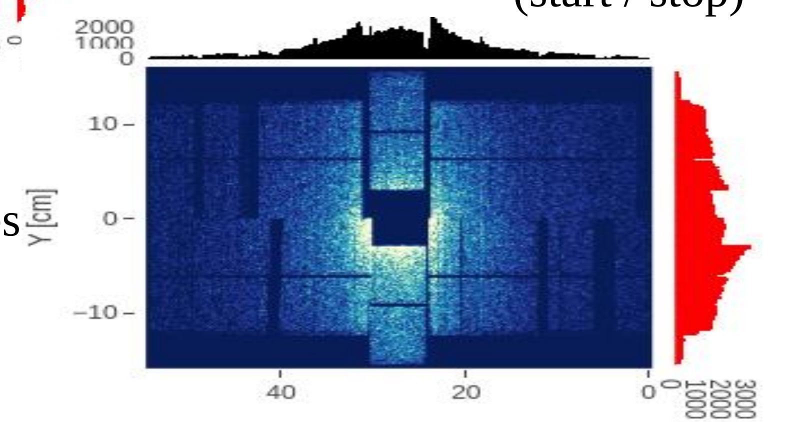


40 μA / 48 μA
(start / stop)

14 modules

69 μA / 73.8 μA
(start / stop)

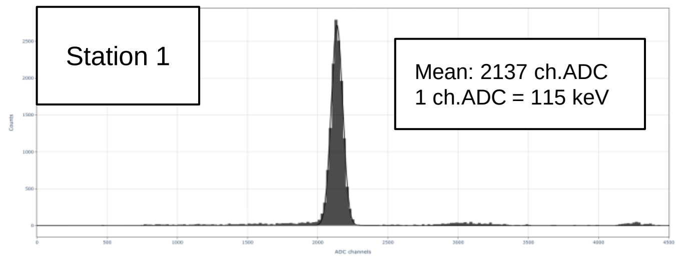
18 modules

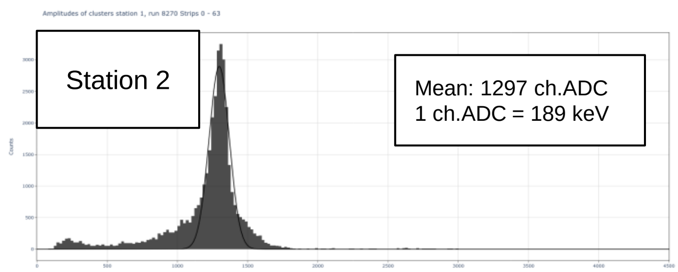


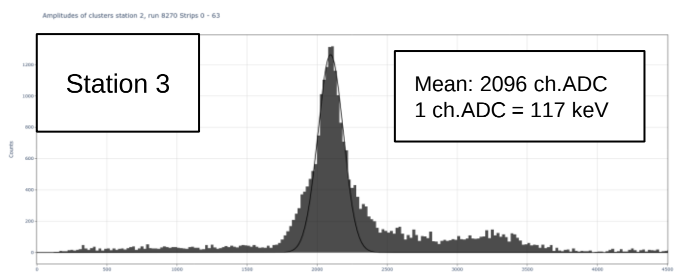
Backup

Energy deposition of Xe in 175 µm silicon

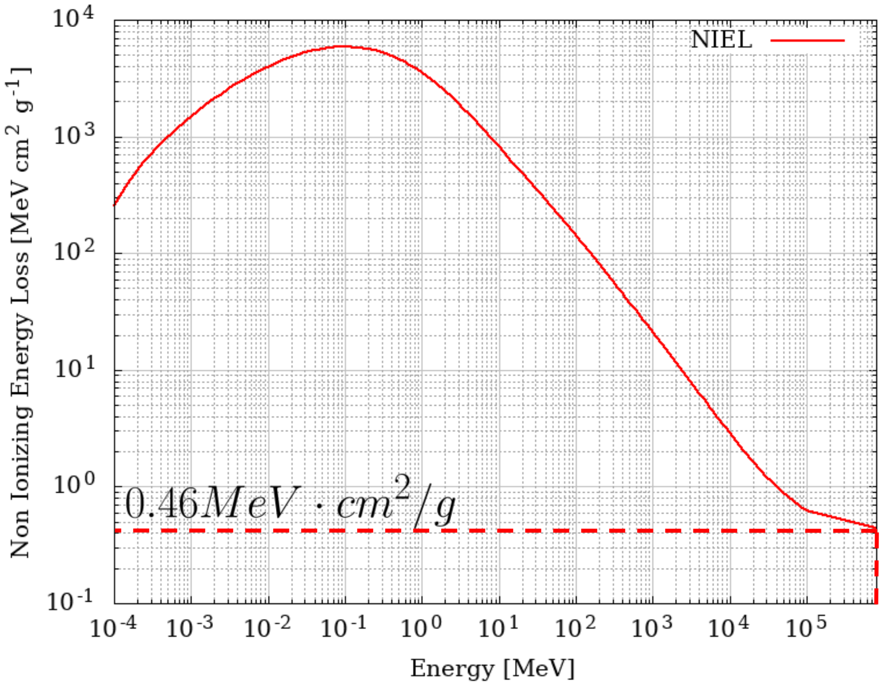
P+ side cluster amplitude distributions, run 8270







NIEL simulation of ^{124}Xe in 175 μm silicon



NIEL of Xe in 175 μm Si

BT Si detectors were installed in the most severe radiation conditions - in a direct beam of heavy xenon ions. Non-ionizing energy losses (NIEL) are used as a measure of the degree of radiation damage.
Using GEANT4 with the SR-NIEL library, NIEL of Xe in 175 μm Si values were obtained.

NIEL from 1 MeV neutron in Si (ASTM Standard E722-19):

$$NIEL_n = 0.0016 MeV \cdot cm^2/g$$

NIEL from 4 A*GeV Xe:

$$NIEL_{Xe} = 0.458 MeV \cdot cm^2/g$$

Hardness factor of 4A*GeV Xe:

$$\boxed{NIEL_{Xe}/NIEL_n \approx 276 \Rightarrow \Phi_n = \Phi_{Xe} \cdot 276}$$

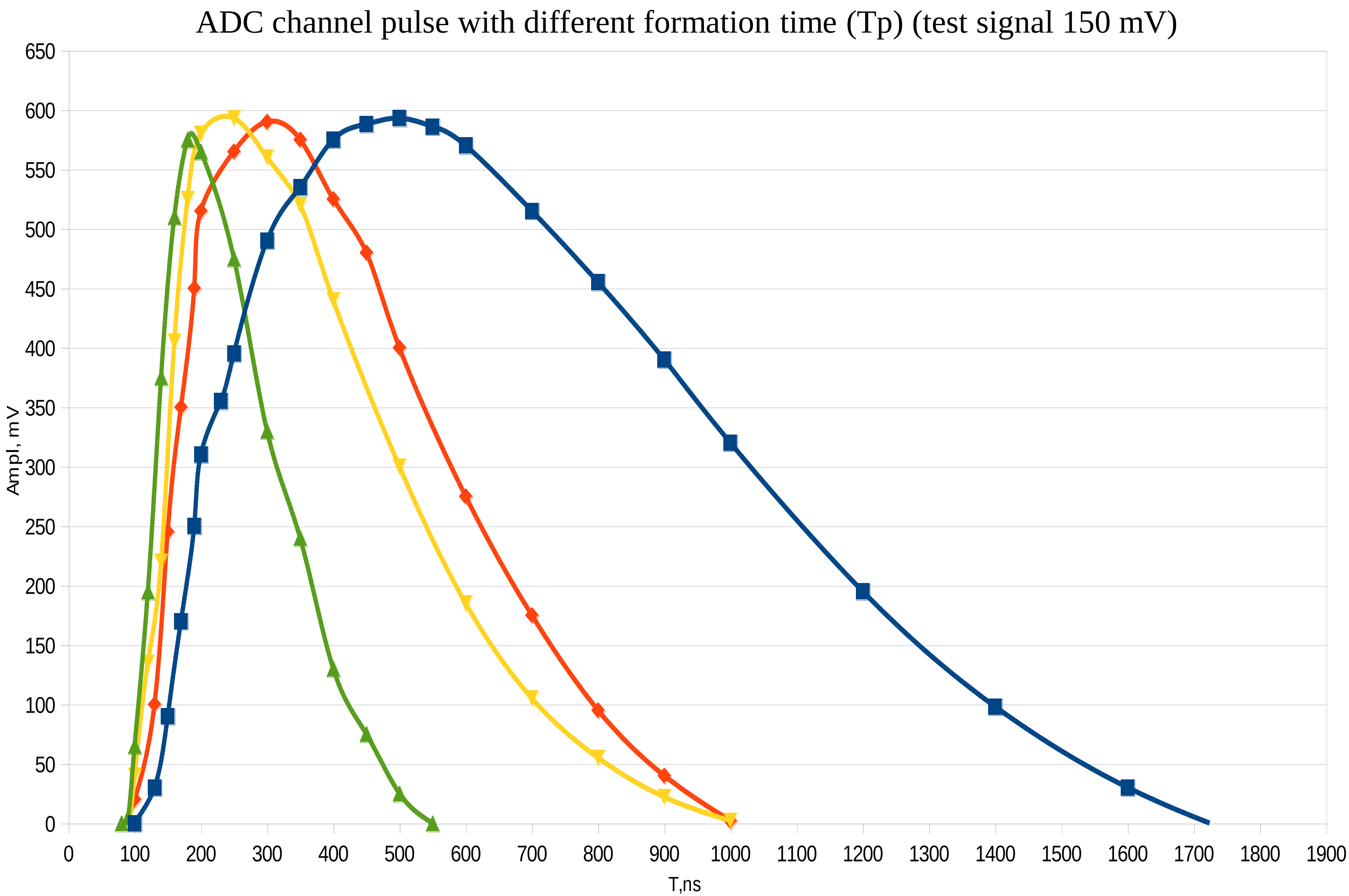
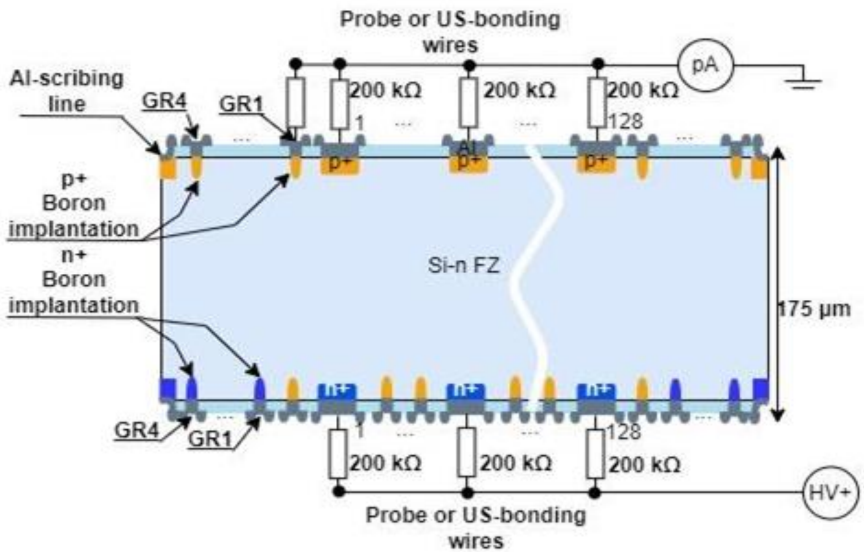
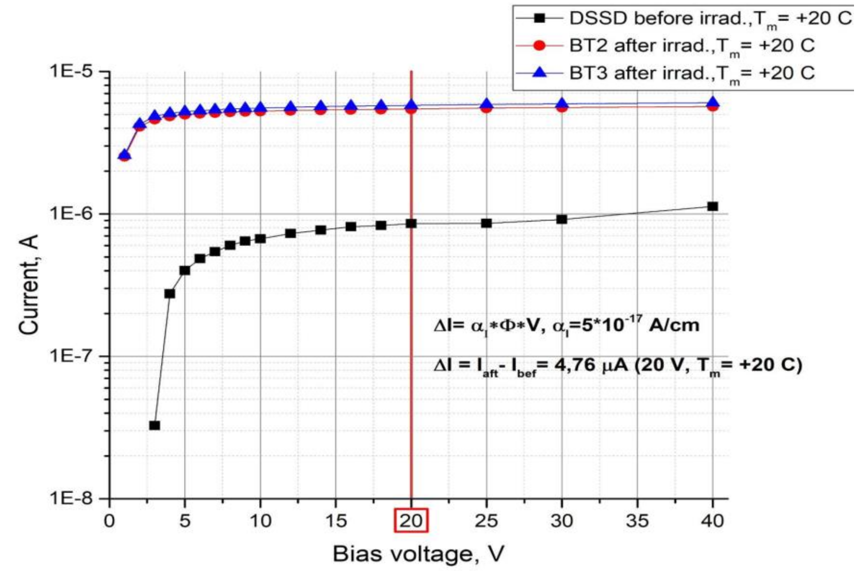


Fig.4. *Pulse shape of the test signal=1.8 pCl at different tp values, HDR 64 chip(VA)*



(a)



(б)

Рис.5. Схема измерений (а) темнового тока двухстороннего стрипового Si-детектора и ВАХ (б) до и после сеанса.

Формула определения эквивалентного 1МэВ флюенса нейтронов по повреждениям кремния $\Delta I = \alpha_1 \cdot \Phi \cdot V$

где: α_I – токовая константа повреждений кремния равняется 5×10^{-17} А/см, при +20˚С для нейтронов с энергией 1 МэВ и физически означает приращение тока в кремниевом детекторе объемом 1см^3 от прохождения одного нейтрона (1 МэВ), Ф,см$^{-2}$ – флюенс нейтронов, V, см$^{-3}$ – объем детектора.