Fluence and Absorbed Dose Calculations for the Biological Samples Irradiated with Heavy Ion Beams at the Long-Term modes

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❖ A class of unique scientific installations in the Russian national project "Science": large-scale and very expensive international research complexes that are technologically ahead of all existing analogues in the world --> the main idea is the acquisition of new fundamental knowledge, the applied use is desirable, but secondary:

- ✓ NICA in Dubna – study of heavy ion collisions in the region of maximum baryon densities
- ✓ PIK reactor in Gatchina - a powerful source of neutrons
- ✓ Tokamak in Troitsk
- ✓ Fourth-generation synchrotron radiation source in Protvino
- ✓ Center for research of extreme light fields in Nizhny Novgorod
- ✓ Accelerator complex with colliding electron-positron beams in Novosibirsk
- ✓ Ring photon source in Siberian
- ✓ Synchrotron on Russky Island

Nuclotron-based Ion Collider fAcility

- Beams: from *p, d*[1] to *Au*
- Luminosity: $10^{27}(Au)$, $10^{32}(p)$
- Collision energy *4 – 12.6 GeV*
- 2 interaction points: *MPD*(2025), *SPD*(2028)
- Fixed target experiment *BM@N*
- applied research: *ARIADNA* experiments

ARIADNA COLLABORATION TODAY

ARIADNA-LS Collaboration	ARIADNA-MSTE Collaboration	ARIADNA-NPT Collaboration
The Collaboration is being established in order to perform experiments in the field of life sciences at the NICA Complex with the ARIADNA beamlines	The Collaboration is being established in order to perform activities and experiments in radiation materials science and radiation testing of electronics at the NICA Complex with the ARIADNA beamlines	The Collaboration is being established in order to facilitate study of accelerator driven subcritical reactor systems with the use of ARIADNA beamlines

Collaborating organizations

1. Joint Institute for Nuclear Research (Dubna, Int.)
2. Institute of Biomedical Problems, RAS (Moscow, Russia)
3. Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency (Moscow, Russia)
4. Skobeltsyn Research Institute of Nuclear Physics, Moscow State University (Dubna, Russia)
5. Saint Petersburg State University (Saint Petersburg, Russia)
6. Tsyb Medical Radiological Research Centre (Obninsk, Russia)
7. Semenov Research Center of Chemical Physics, RAS (Moscow, Russia)
8. Institute of Theoretical and Experimental Biophysics, RAS (Moscow, Russia)
9. Moscow Institute of Physics and Technology (Dolgoprudny, Russia)
10. Kurnakov Institute of General and Inorganic Chemistry, RAS (Moscow, Russia)
11. National Research Nuclear University MEPhI (Moscow, Russia)
12. Joint Institute of High Temperatures, RAS (Moscow, Russia)
13. North Ossetian State University (Vladikavkaz, Russia)
14. Institute of Nuclear Problems of the Belarusian State University (Minsk, Belarus)
15. CANDLE SRI, Yerevan, Armenia
16. Yerevan State University, Yerevan, Armenia
17. A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute), Yerevan, Armenia
18. Omsk State University,Omsk, Russia
19. LLC Research and production company “Kvant-R” (Moscow, Russia)
20. LLC “S-Innovations” (Moscow, Russia)
21. LLC “SOL-Instruments” (Minsk, Belarus)

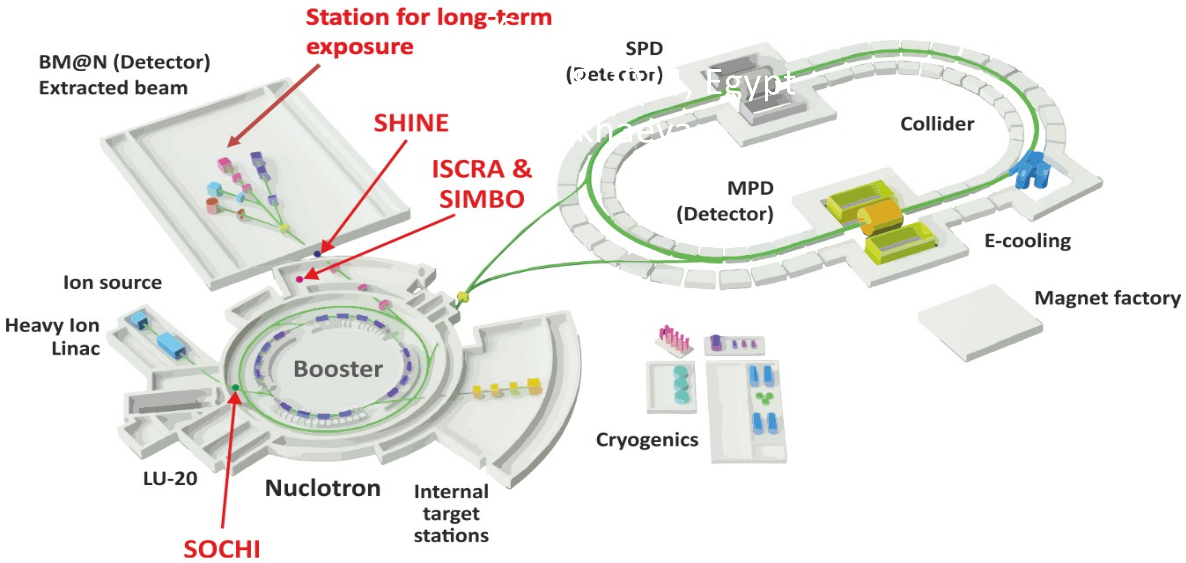
162 participants

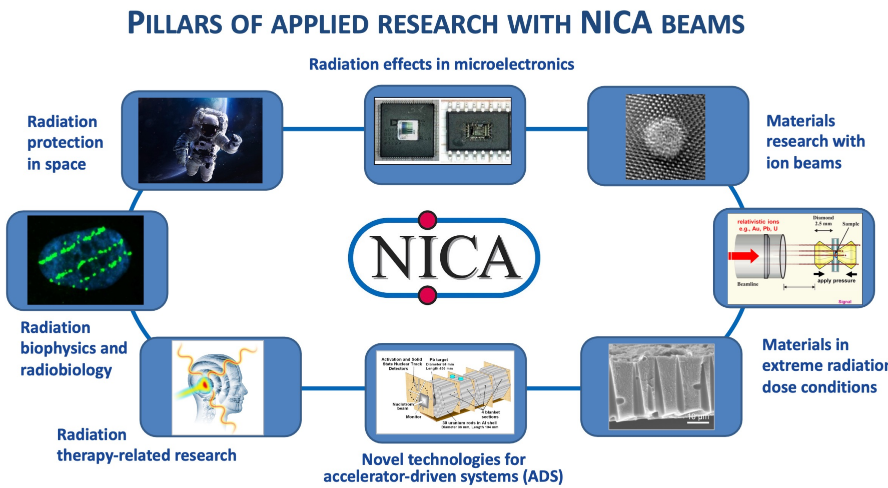
Stations for applied research at NICA complex

- ***LTI –*** *Long-Term Irradiation Station*
- ***SOCHi*** *- Station Of Chip Irradiation, for irradiating decapsulated microchips*
- ***ISCRA-*** ***I****rradiation* ***S****tation of* ***C****omponents of* ***R****adioelectronic* ***A****pparatus, to determine radiation resistance of electronic components and works on radiation materials science.*
- ***SIMBO-*** ***S****tation of* ***I****nvestigation of* ***M****edico-****B****iological* ***O****bjects, will works on life sciences underway with the use of accelerated ions at the energies of 500-1,000 MeV/nucleon*
- ***SHINE-*** ***S****tation of* ***H****igh Energy* ***I****nvestigation in* ***N****uclear* ***E****nergetic, for solve the topical issues of nuclear technologies related to the production of energy and nuclear waste disposal.*

The Applied Research Infrastructure for Advanced Development at NICA fAcility

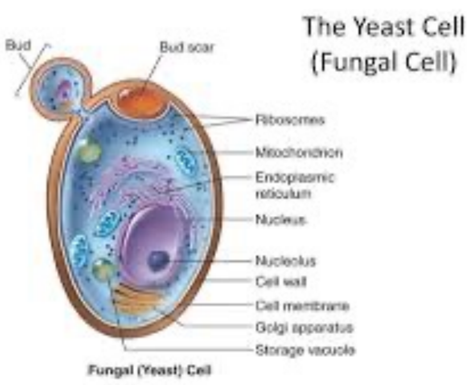
- ***ARIADNA* – *collaborations* formed around the created research infrastructure**
- ***ARIADNA-LS*** – *life science*
- ***ARIADNA-MSTE*** – *radiation materials science and radiation testing of electronics*
- ***ARIADNA-ADSR*** – *study of accelerator driven subcritical reactors*





Analyzed data

- Fluence and absorbed dose values are calculated for the experiment with exposure of yeast cells to heavy ions in order to select mutants with increased accumulation of squalene
- Squalene is an important polyunsaturated triterpene with wide applications in the food, pharmaceutical and other biotechnology industries
- The main methods for squalene production are extraction from oil-producing plants, microbial fermentation with Saccharomyces cerevisiae, but the scale economic viability are limited.
- Radiation-induced mutagenesis is one of the alternative ways to obtain mutant strains with improved squalene production. In this regard, the use of heavy ions as a mutagen is of great interest because of their high biological effectiveness
- To calculate the fluence and absorbed dose values, we assume that Petri dishes with yeast cultures on solid media are placed perpendicular to ion beam and that Petri dishes are stacked to a pack of 1-8 pieces.



Petri dishe

Method of Analyzed data

Fluence: $\Phi = d(N)/dA$	(1)	ϕ represents the fluence value, N is the number of particles (nucleons) that arriving on the area, A is the surface area (in cm^2)
Energy: $E = \phi\, (dT/(\rho dx))\, \rho t$	(2)	The energy lost in collision interactions by a fluence ϕ (charged particles/cm^2)

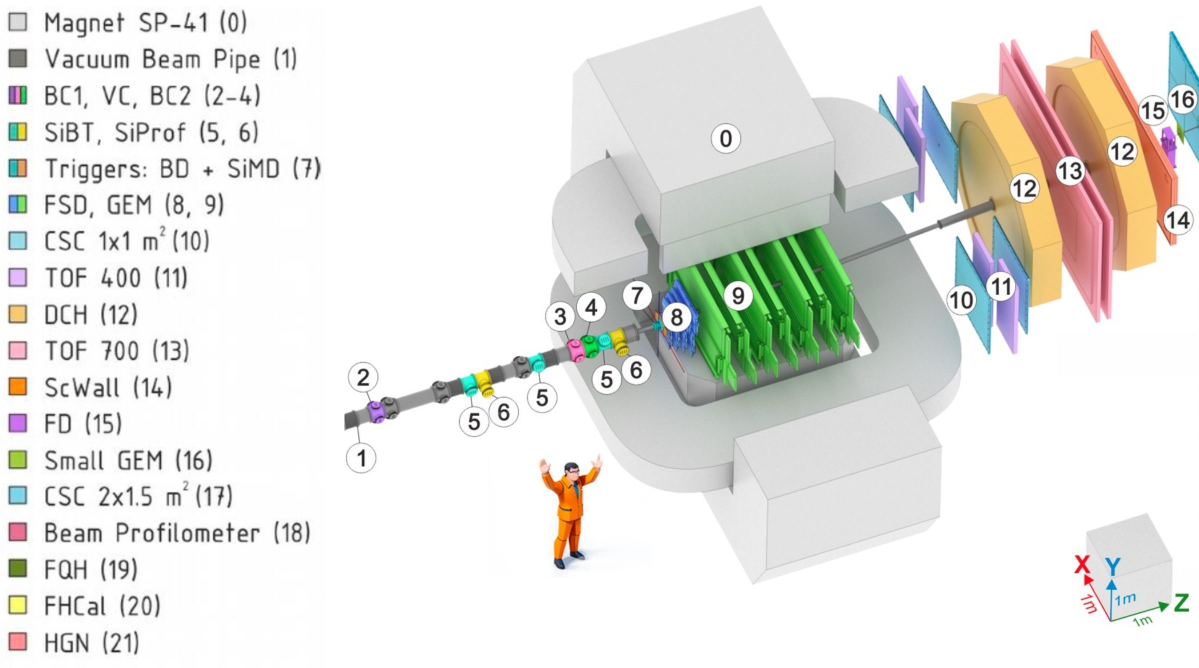
Where dT/(ρdx) is the mass collision stopping power of the foil medium, and ρt is the particlepath length through the foil.

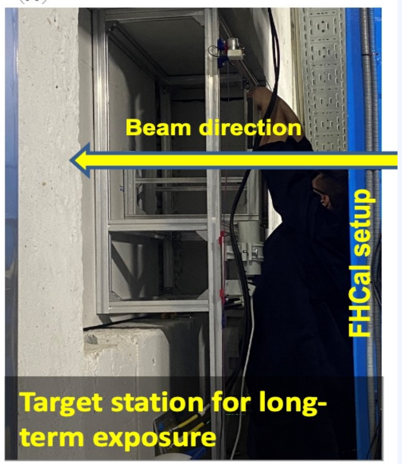
Dose: $D = d\varepsilon/dm$	(3)	ε is the expectation value of the energy imparted in the finite volume V during some time interval, and dm is the mass in dv.
$D = \phi\, (dT/(\rho dx))$	**(4)**	**Dose as simply the product of fluence and mass collision stopping power.**

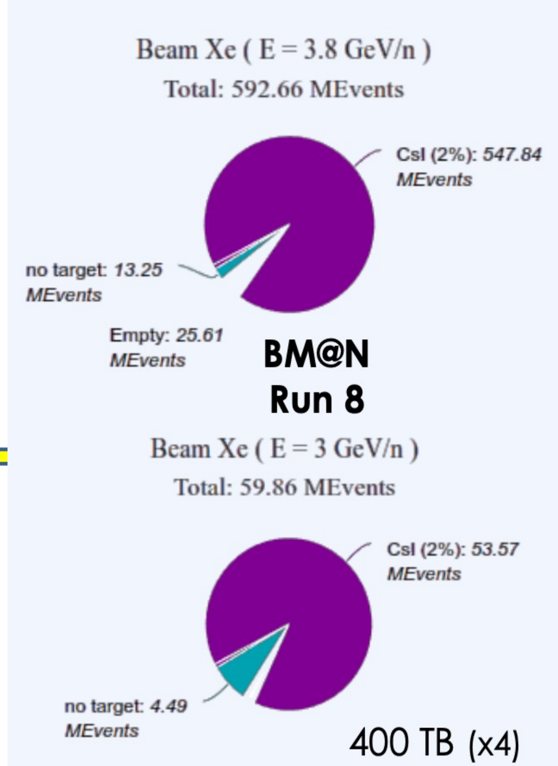
Method of Analyzed data

BM@N with Station

- First BM@N Physics Run
- Interaction rate: 10 kHz
- Dec 12 – Feb 02 2023
- Beam: Xe 3.8, 3.0 GeV
- Target: Csi or empty
- Detectors: FSD, GEM, ToF400, ToF700, FHCal, …

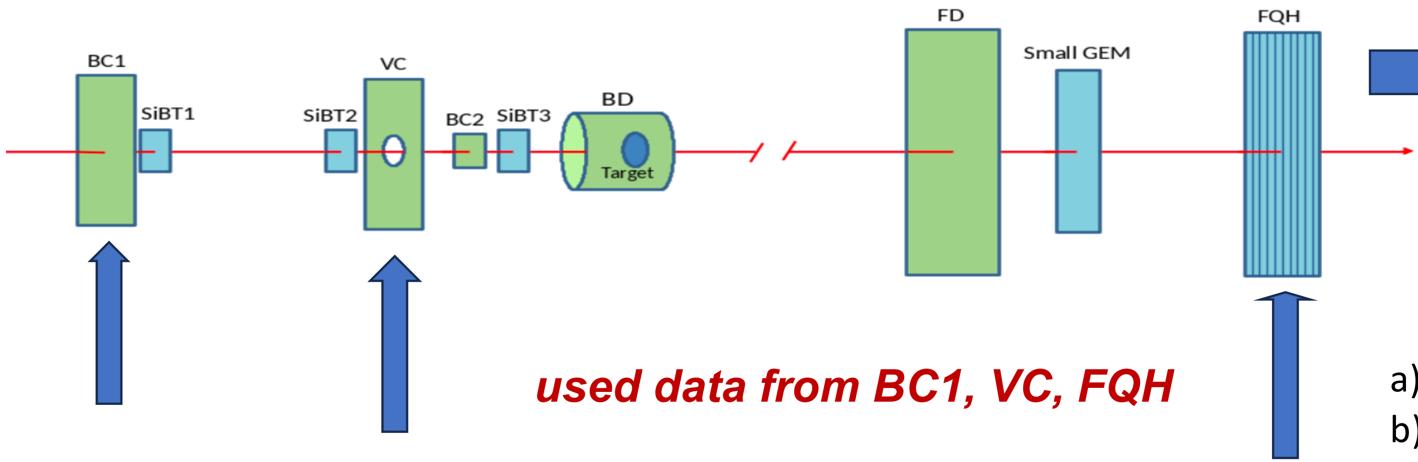




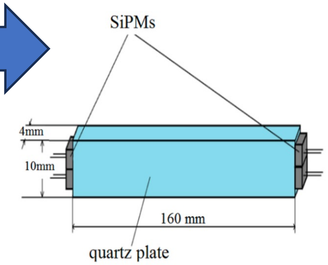


Method of Analyzed data

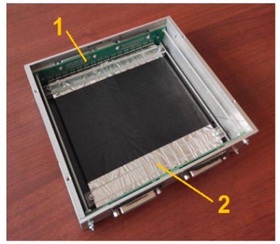
from BC1, VC, FHQ



used data from BC1, VC, FQH



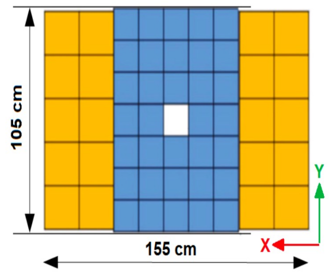
a)

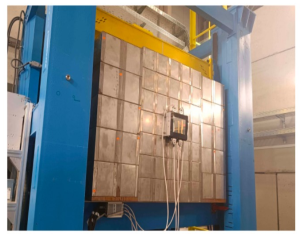


b)

a) An FQH strip with SiPM photodetectors
b) b) The Forward Quartz Hodoscope

Detector	Z position, cm	Active area, $mm \times mm$	Material	Thickness, mm
BC1	-422	100×100	Scint. BC400B	0.25
SiBT1	-283	61×61	Silicon	0.175
SiBT2	-183	61×61	Silicon	0.175
VC	-124	113×113 (hole ⌀25)	Plastic Scint.	4
BC2	-104	34×34	Scint. BC400B	0.15
SiBT3	-84	61×61	Silicon	0.175
FD	+784	150×150	Scint. BC408	0.5
Small GEM	+793	100×100		
FQH	+970	160×160	Quartz	4





Schematic view of the FHCal

Method of Analyzed data

study of profile

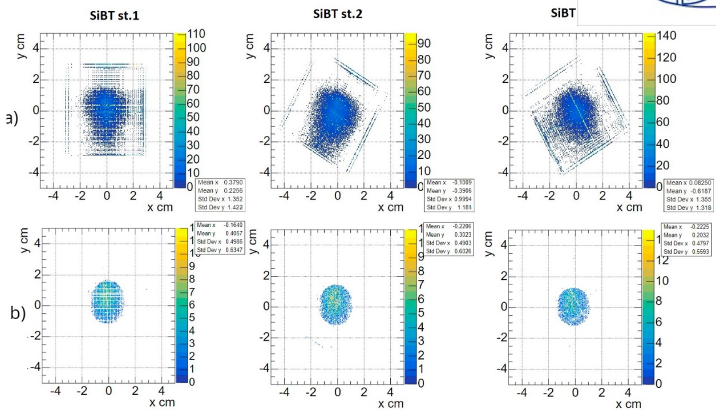
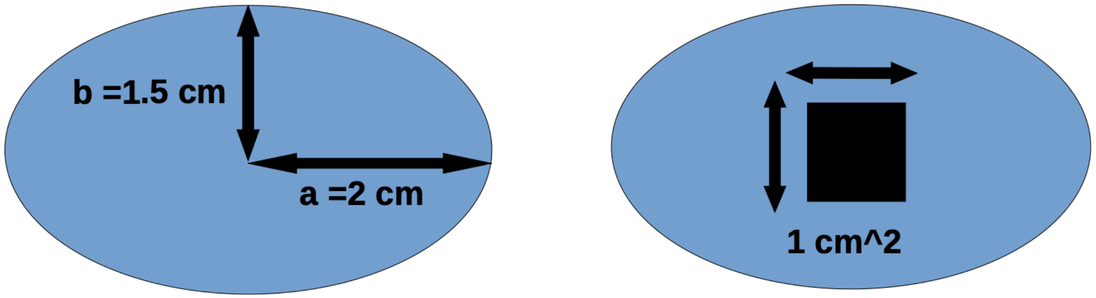
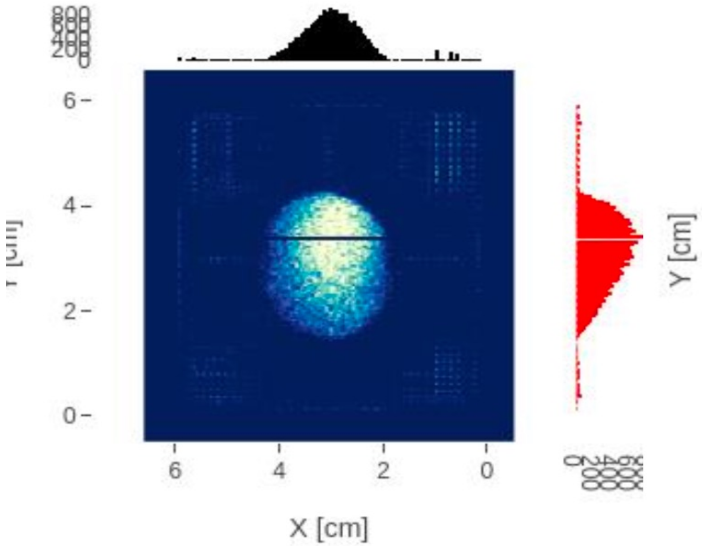


Figure 5: a-) Geometric representation of the ion beam, including the dimensions of the surface radius a and b. b-) Location of the sample with respect to the beam, the geometric representation and area value.



a-) **b-)**



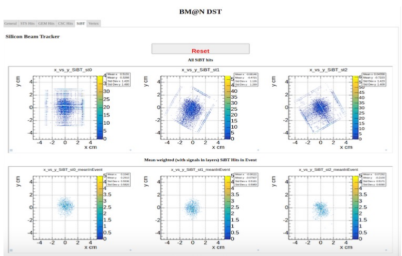
As can be seen, the shape of the beam has been approximated to an ellipse, whose radii a and b have values of 2 and 1.5 centimeters. The area of the ellipse that represents the surface of the beam was calculated as:

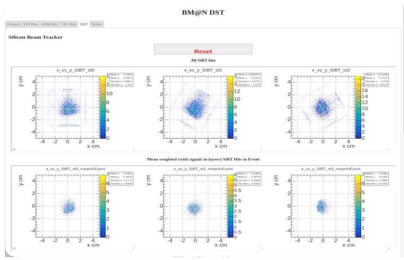
$$A = \pi \times (a \times b) \quad (5)$$

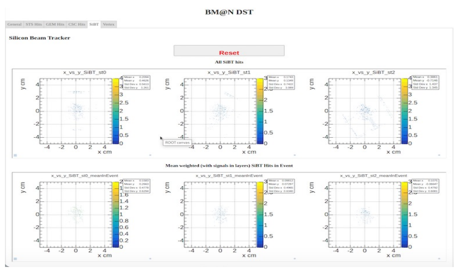
Method of Analyzed data

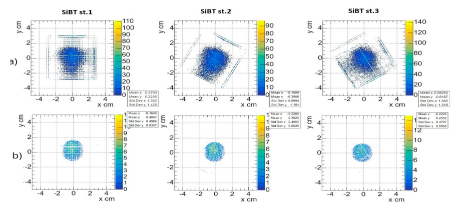
Measured intensity and profile per samples

- Calibration — Intensity = 4.24668e+07 nucl. — Φ = 4.7e+06
- Sample I – seed — Intensity= 2.42622e+08 nucl. — Φ = 2.6e+07
- Sample II – seed — Intensity= 2.47850e+08 nucl. — Φ = 2.6e+07
- Sample III – seed — Intensity= 3.46815e+08 nucl — Φ = 3.7e+07
- Sample IV – seed — Intensity= 2.24907e+08 nucl — Φ = 2.4e+07
- Sample V – Sapphire +Films + Aluminum — Intensity= 5.79354e+09 nucl — Φ = 6.1e+08
- Sample VI – add composite ROC + VTSP(1) — Intensity= 4.86455e+09 nucl. — Φ = 5.2e+08
- Sample VII – add composite MCS + VTSP(2) — Intensity= 2.39928e+09 nucl. — Φ = 2.5e+08

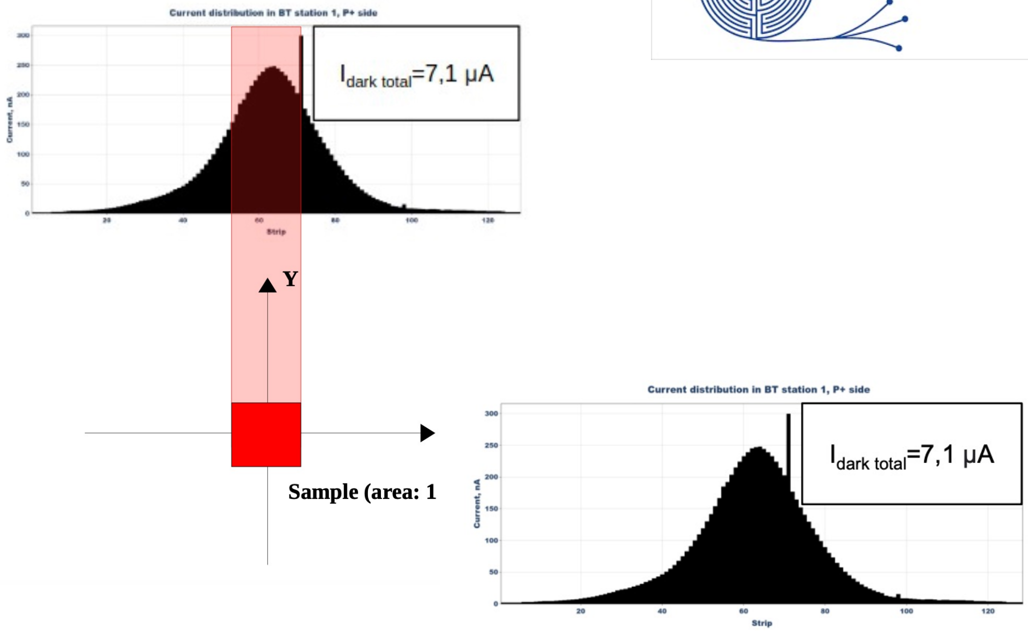








Analyzed data

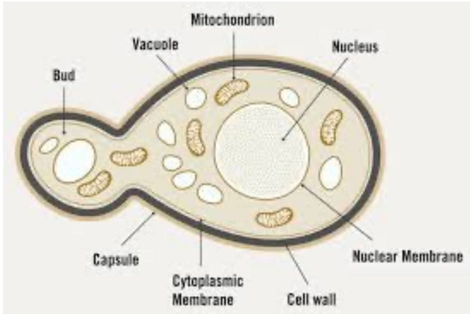


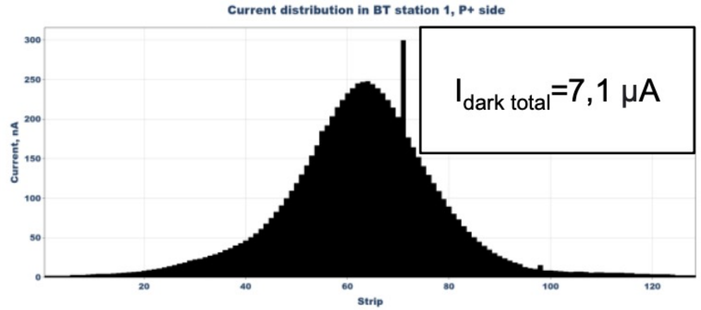
Dosimetry calculations were done for the set of absorbed doses expected to be most effective in terms of for producing mutant cells

Geometry of ion beam having a uniform central part and halo is taken into account in calculations.

Analyzed data

- The particle fluence and absorbed doses were calculated taking into account the intensity of the ion beams extracted from Nuclotron accelerator of the NICA complex.
- Very important that the dose in the foil is independent of its thickness as long as the particles travel straight through and do not lose enough energy to cause the stopping power to change significantly.





If the fluence equal 6.1e+08
energy distribution on the surface 2.32e+09 (GeV/cm^2)

Thanks for your attention

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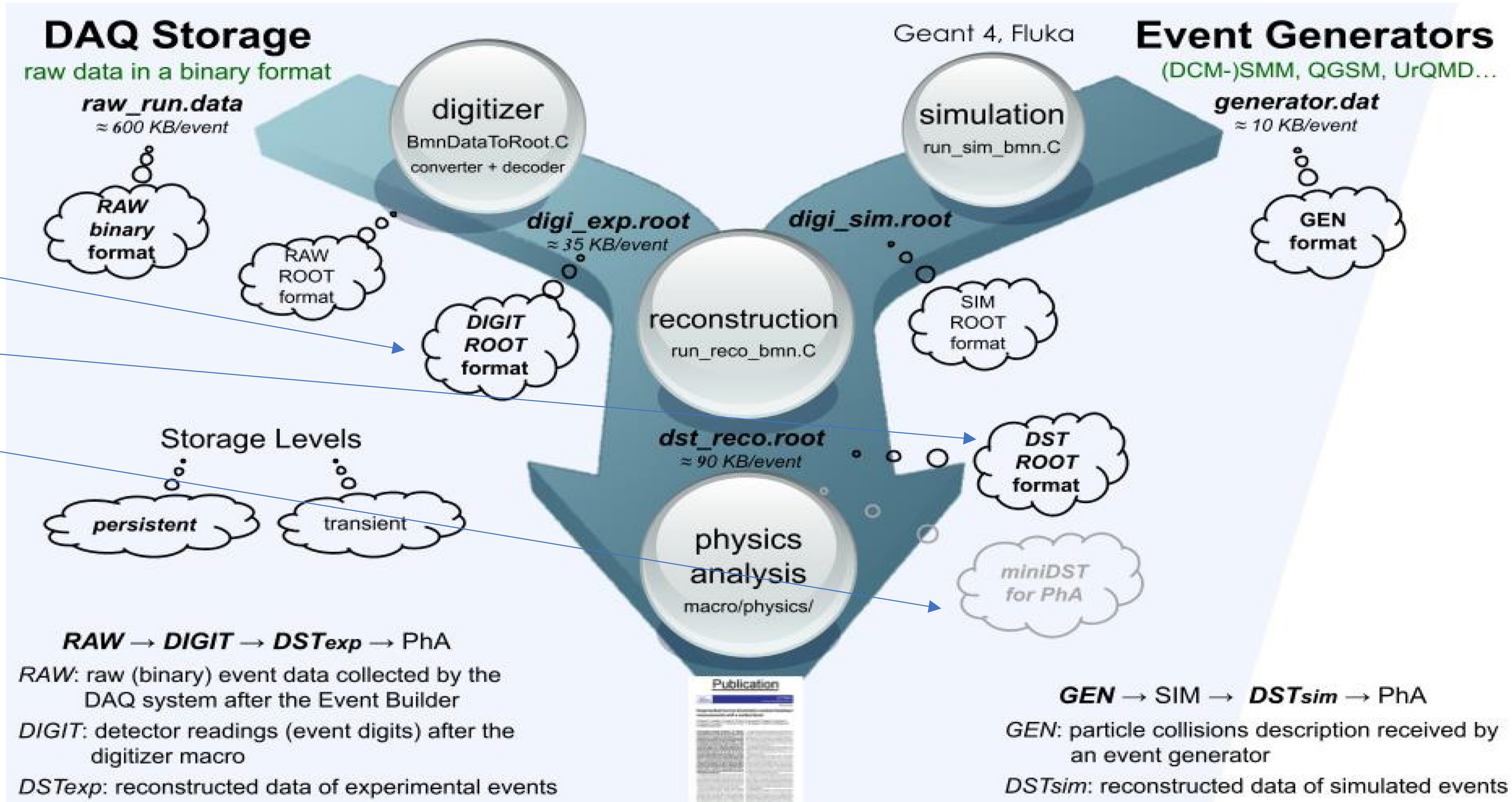
Analyzed data

BM@N DATA Model

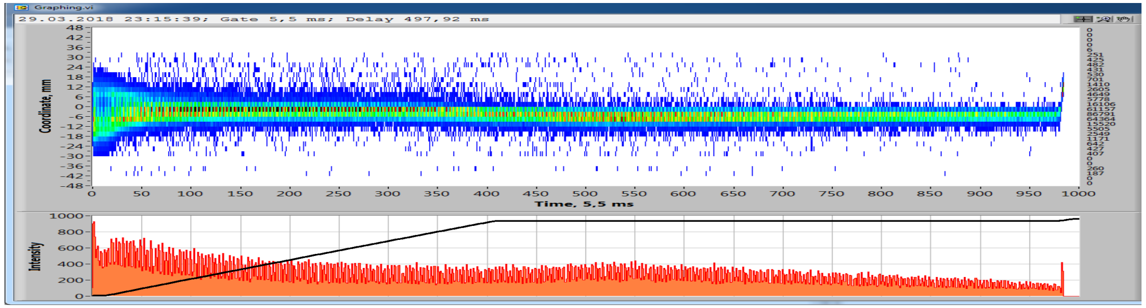
Used: DIGIT files

:DST_exp files

Create miniDST

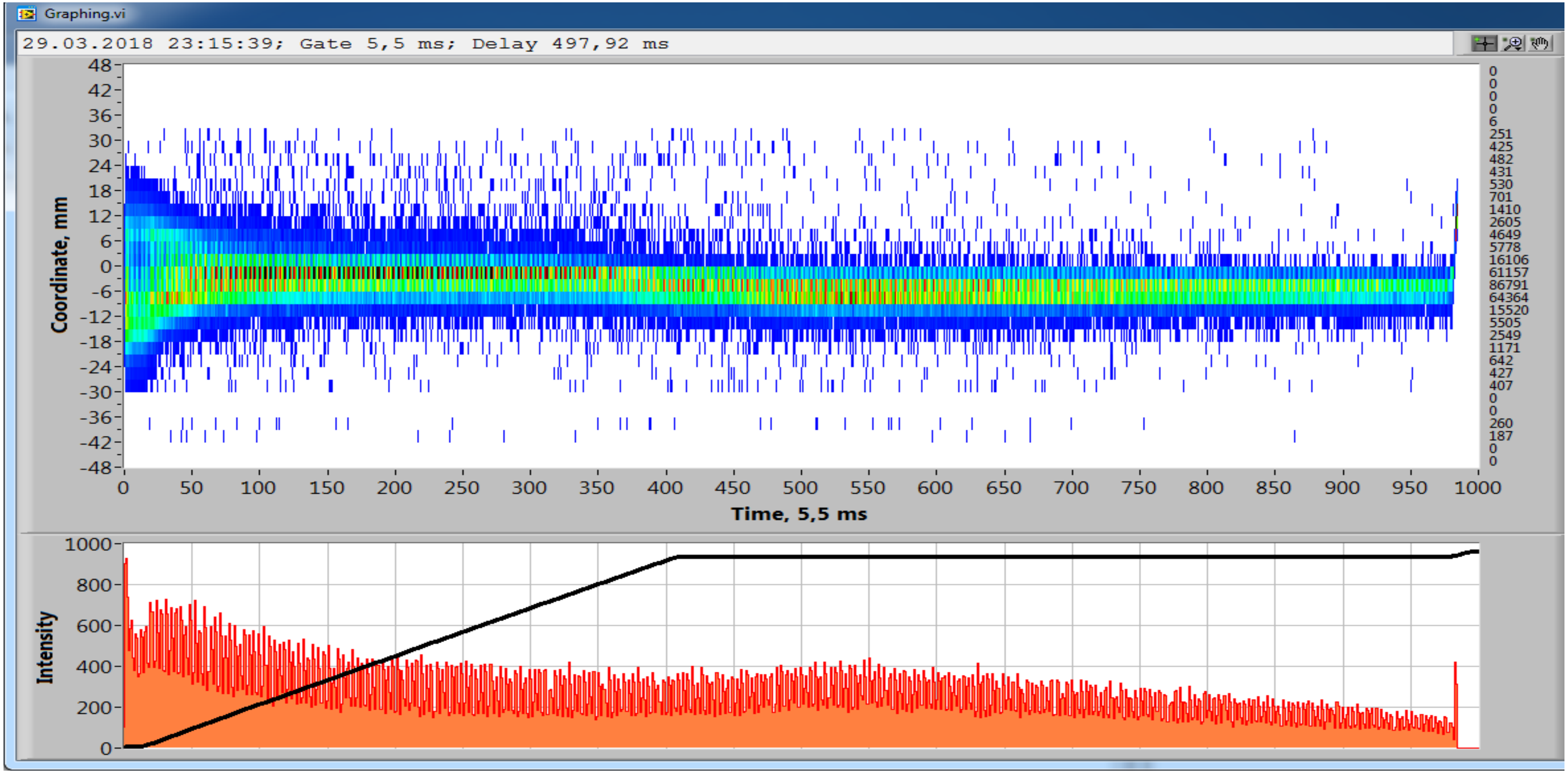


First results for study of irradiated samples from Nuclotron beam data at 3.8 AGeV



- Full data of Run8 ~ 550 mill events Analyzed
- Software was developed for investigation of intensity and profile of the beam
- Compered duration of each run with integral of intensity
- Investigated which fraction of beam could achieve till area of station
- Integral of intensity and profile of beam for each samples are measured
- The beam profile and intensity distributions together with overall intensity and duration of radiation exposure are analyzed for the set of samples of different geometry and chemical composition.
- Study under going, continue and ready for new data taking

300 × 225



Graphing.vi
29.03.2018 23:15:39; Gate 5,5 ms; Delay 497,92 ms
Coordinate, mm
Time, 5,5 ms
Intensity
0
0
0
0
6
251
425
482
431
530
701
1410
2605
4649
5778
16106
61157
86791
64364
15520
5505
2549
1171
642
427
407
0
0
260
187
0
0