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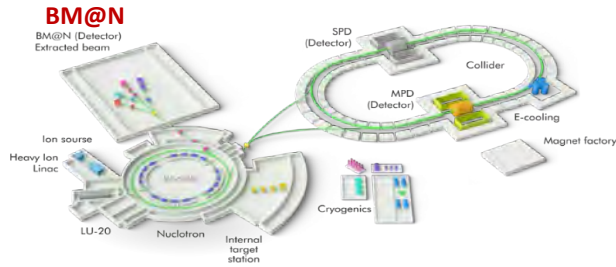
## Software development for tracking detectors of the BM@N experiment for the first experimental run in 2022

Baranov Dmitry

*for the BM@N collaboration*

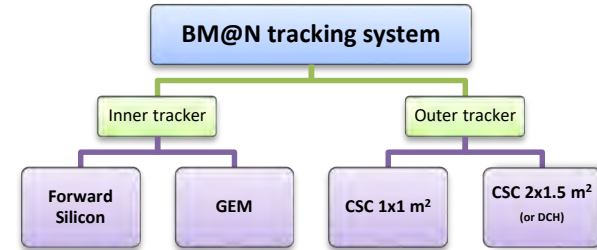
# BM@N experimental setup

**BM@N** (Baryonic Matter at Nuclotron) is a fixed target experiment at the **NICA accelerator complex** aimed to study dense baryonic matter on heavy-ion collisions



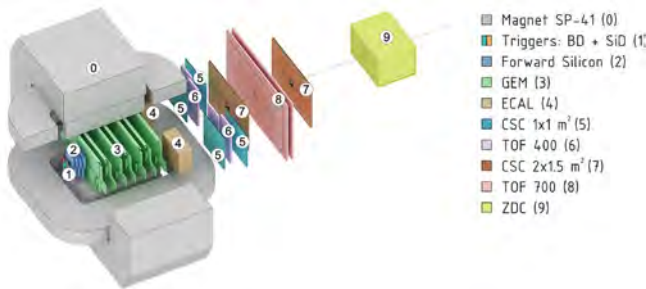
**NICA** (Nuclotron-based Ion Collider fAcility) is a collider complex being constructed by the Joint Institute for Nuclear Research in Dubna

The complete **tracking system** of the BM@N setup is divided into **inner** and **outer** trackers:



**BM@N experimental setup** includes:

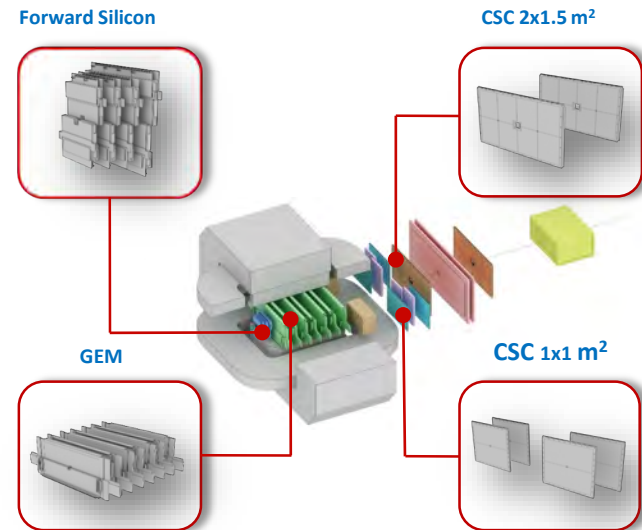
1. **Tracking system :**
  - Forward Silicon (Semiconductor Silicon Modules)
  - GEM (Gas Electron Multipliers)
  - CSC (Cathode Strip Chambers)
  - DCH (Drift Chambers)
2. **Particle identification system:**
  - TOF-400 (First Time-of-Flight detector)
  - TOF-700 (Second Time-of-Flight detector)
3. **ECAL and trigger systems:**
  - Trigger detectors
  - ECAL (Electromagnetic Calorimeter)
  - ZDC (Zero Degree Calorimeter)



Configuration of the BM@N setup for the first experimental run in 2022

**BM@N tracker** consists of the following components:

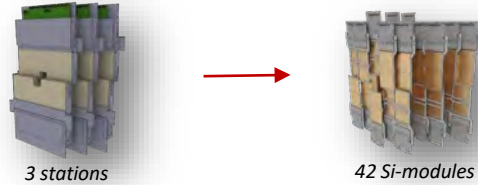
- Forward Silicon** detector (4 planes)
- GEM** detector (7 planes)
- CSC** detector (4 planes of 1x1 m<sup>2</sup>)
- CSC** detector (2 planes of 2x1.5 m<sup>2</sup>) as the replacement of DCH



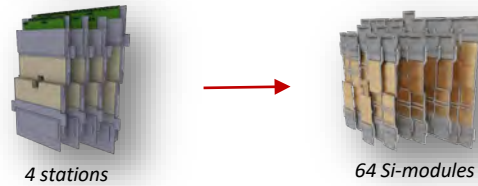
# Tracking detectors: configuration

**Forward Si** is a silicon based semiconductor detector consisting of Si-modules. There are two types of these modules: standard with a sensor size of **63x126 mm<sup>2</sup>** and long with a sensor size of **63x186 mm<sup>2</sup>**

**1<sup>st</sup> configuration (minimal)**

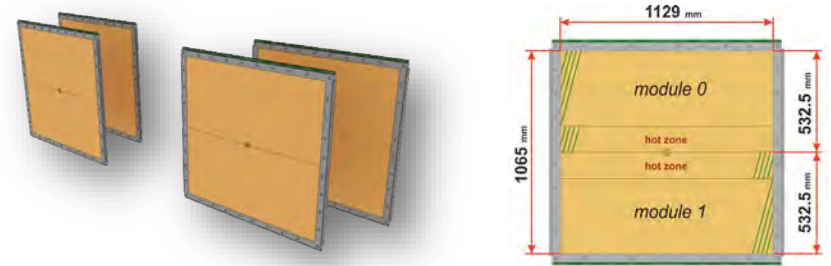


**2<sup>nd</sup> configuration (maximal)**



At this moment there are two versions of the configuration for the Forward Silicon detector for the future BM@N run

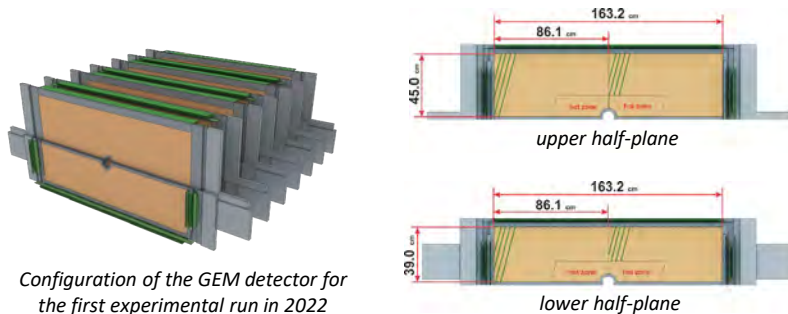
**CSC (Cathode Strip Chamber)** is a gaseous detector with microstrip readout. It is comprised in the outer tracking system of the BM@N setup. The configuration of this detector for RUN-8 consists of four planes located behind the magnet



Configuration of the CSC detector for RUN-8

Each plane has sensitive area with a size of **1129x1065 mm<sup>2</sup>**

**GEM (Gas Electron Multiplier)** is a gaseous detector with microstrip readout. Its configuration for RUN-8 comprises seven stations located inside the magnet along the beam axis

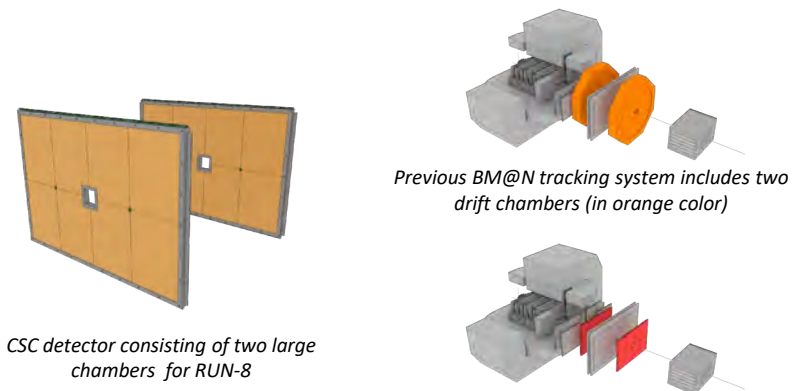


Configuration of the GEM detector for the first experimental run in 2022

Each station in the configuration is combined from two half-planes: upper and lower. They have different sizes of their sensitive areas:

- Upper half-plane sensor: **163x45 cm**
- Lower half-plane sensor: **163x39 cm**

**CSC detector** consisting of two large chambers with a sensor area size of **2190x1453 mm<sup>2</sup>** was also developed for the next RUN. As a part of the upgraded BM@N tracking system, this detector will replace the current DCH (drift chambers) detector with itself

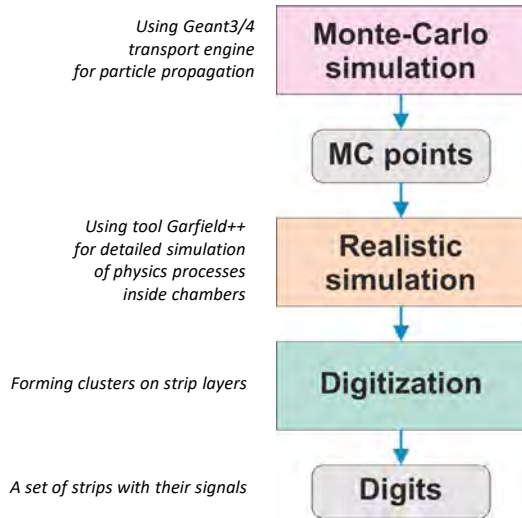


CSC detector consisting of two large chambers for RUN-8

Upgraded BM@N tracker has two cathode strip chambers (in red color) instead of drift chambers

# Tracking detectors: simulation

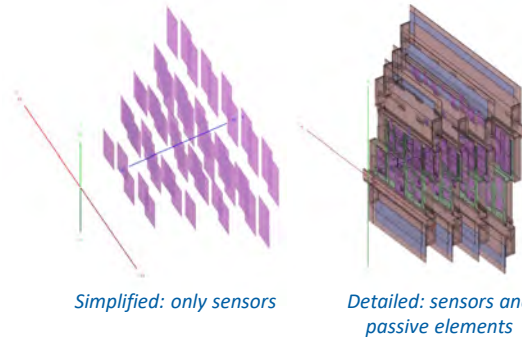
## Stages of simulation for tracking detectors in BM@N



## Monte-Carlo simulation

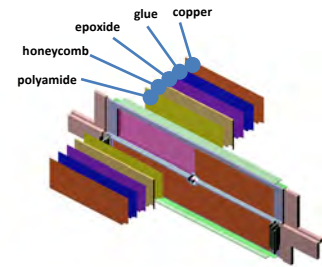
To perform Monte-Carlo simulation we must prepare **ROOT geometry**, which describes the constructive features of detectors. Then, this geometry is used by a transport engine, such as Geant3 or Geant4, **to simulate the propagation of particles** through matter. The result of the procedure is a set of **Monte-Carlo points** (spatial coordinates), that describe particle trajectories.

There are two versions of ROOT geometry designed for each tracking detector: simplified and detailed



Example of ROOT geometry for the Forward Silicon detector

Detailed geometry completely describes the detector structure, which is needed to take into account the material budget of detector in MC-simulation

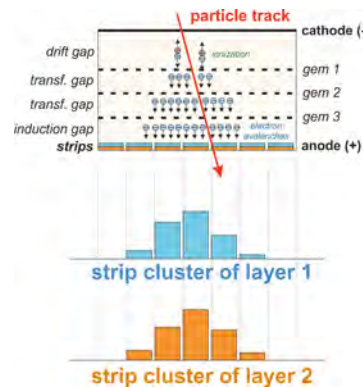


Example: structure of the detailed ROOT geometry for the GEM detector

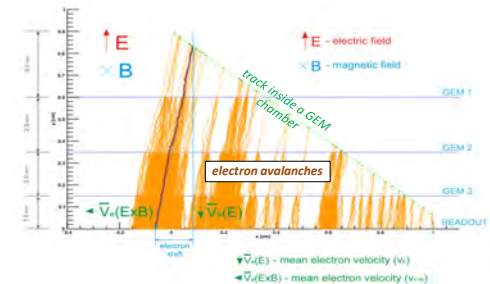
## Realistic simulation

In addition to Monte-Carlo simulation, to achieve maximum conformity between simulated and experimental data we use **realistic simulation**, that takes into account the features of signal formation in our detectors.

A **digitization procedure** transforms Monte-Carlo points into “digits” (or “strips” in case of microstrip readout) by applying realistic simulation algorithms for a certain detector type.



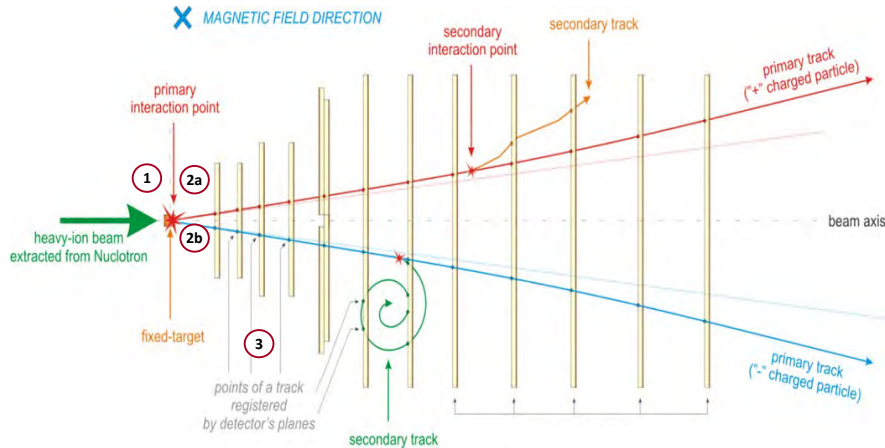
Example of signal formation in GEM chamber



Example of detailed simulation of one particle inside GEM chamber (calculated by using Garfield++)

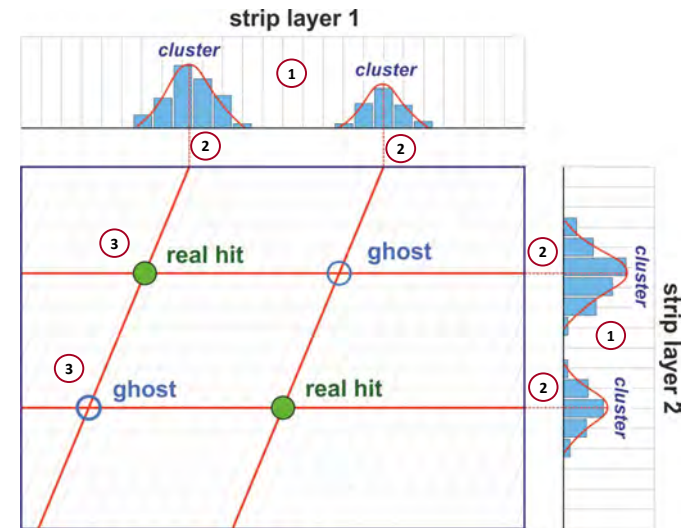
# Tracking detectors: hit-reconstruction

## Scheme of registering particle trajectories by tracking detectors



1. A heavy-ion beam, extracted from Nuclotron, collides with a fixed target
2. As a result of this primary interaction is various particles. Their flying directions depend on their charge and a magnetic field which the detector located in (due to the Lorentz force)
3. Passing through the detecting planes, a particle leaves a “trace” (signal) on each of them. Our purpose is to reconstruct a spatial point, called “hit”, which this particle passed through. A set of these hits from one particle defines its trajectory

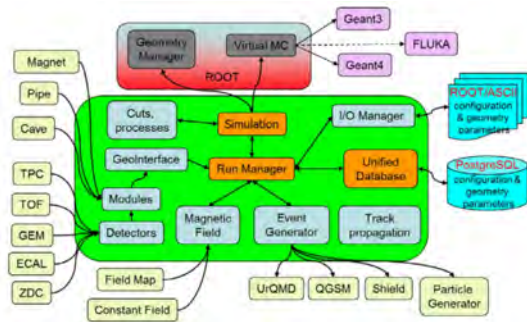
## Hit reconstruction procedure for microstrip readout



1. There is a set of digits for one event (signals on strips for each layer). We find clusters of strips and estimate their parameters
2. We find weighted position of each cluster to collapse lighted strips into one average-weighted strip
3. Crossing these strips of one layer with another, we get intersections, where one part of them are hits from real particles and another – “ghosts”
4. The obtained hits are used in the subsequent track finding procedures which find tracks and eliminate ghost hits

# Tracking detectors: software implementation

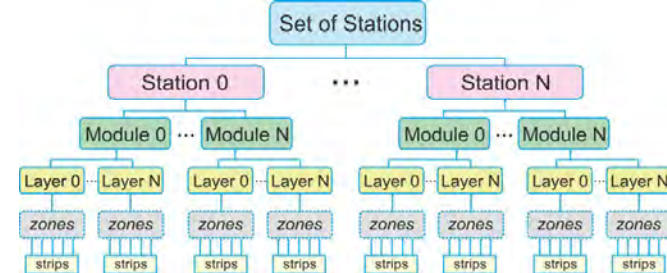
The official software used to support the BM@N experiment is based on the **BmnRoot** framework. It provides powerful tools for simulation, reconstruction and data analysis



Structure of the BmnRoot framework

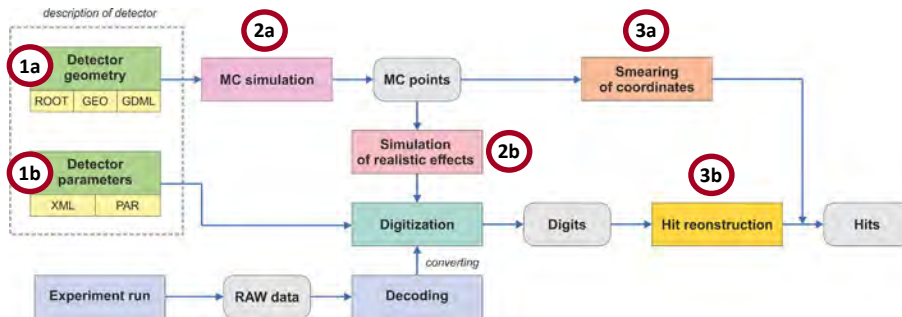
All the tracking detectors have the same hierarchical program structure:

Strips are integrated into a layer,  
Layers – into a module,  
Modules – into a stations,  
Stations – into a set of stations



Structure of tracking detector in BmnRoot

## Data processing cycle for tracking detectors in BmnRoot:



### 1. Complete description of a detector:

- Description of detector geometry (ROOT files)
- Description of detector parameters (XML files)

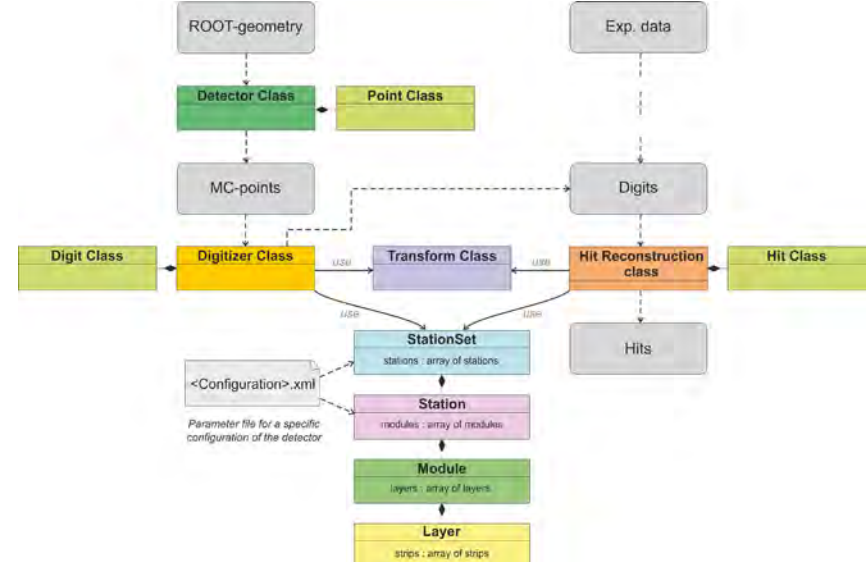
### 2. Simulation:

- Monte-Carlo simulation
- Simulation of realistic effects

### 3. Procedures of getting "hits":

- Smearing Monte-Carlo points (hit producing)
- Hit reconstruction from "digits":
  - Realistic simulation + digitization
  - RAW experimental data + digitization

Software for the tracking detectors of the BM@N setup, including Monte-Carlo and hit reconstruction procedures have been implemented in BmnRoot and are ready to be used



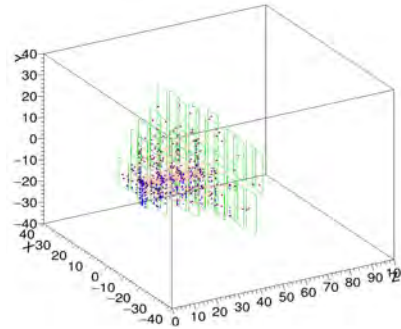
Software for the tracking detectors (class diagram)

# Conclusion: what has been done

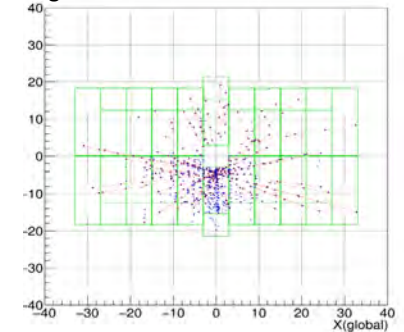
What we have done for the tracking detectors (RUN-8 configuration) at this moment:

- ✓ Complete geometry description (basic and detailed versions for each detector)
- ✓ Algorithm for realistic Monte-Carlo simulations
- ✓ Algorithm for the reconstruction of spatial coordinates from microstrip readout planes (hit reconstruction)

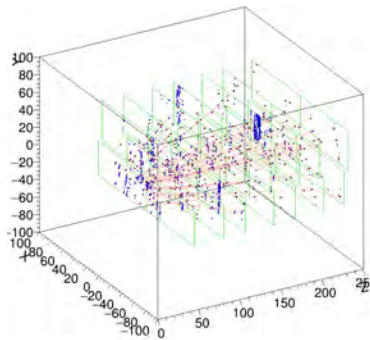
Example of a single event as a results of Monte-Carlo simulation and hit reconstruction for the three tracking detectors



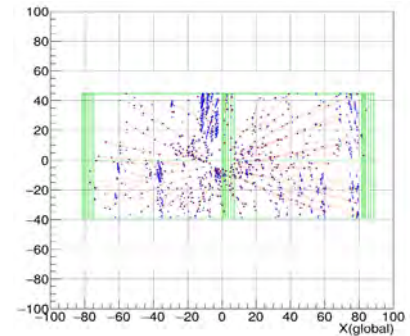
Forward Silicon detector (3D view)



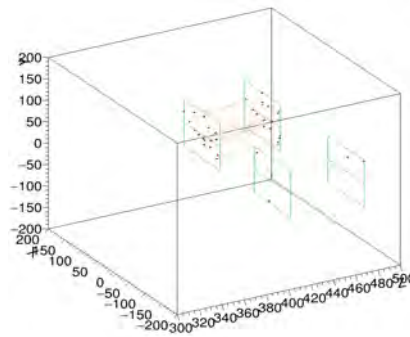
Forward Silicon detector (XY view)



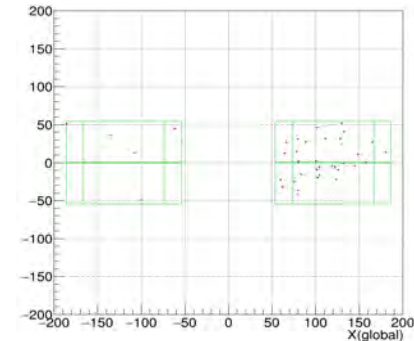
GEM detector (3D view)



GEM detector (XY view)



CSC detector (3D view)



CSC detector (XY view)

*In the pictures:*  
Red marks are MC- points;  
Blue marks are reconstructed hits;  
Green rectangles are borders of sens. areas

**Thank you for your attention...**