Software for the hybrid tracking system of the next BM@N run

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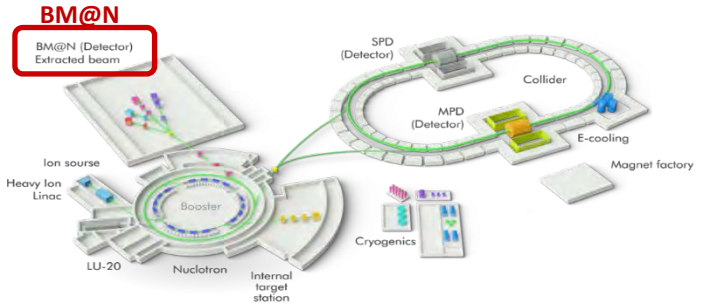
BM@N experiment

BM@N (**B**aryonic **M**atter at **N**uclotron) is the first stage experiment at the accelerator complex of NICA

This is a fixed target experiment aimed to study interactions of relativistic heavy ion beams with a fixed target



NICA *(Nuclotron-based Ion Collider fAcility) accelerator complex located at Joint Institute for Nuclear Research in Dubna*

At this moment, **eight BM@N RUNs** have already been carried out since 2015:

RUN 1-2-3-4 (2015)
beam: deuteron; target: C, Cu

RUN 5 (2016)
beam: deuteron; target: CH2, C, Cu, Pb

RUN 6 (2017)
beam: deuteron, C; target: CH2, C, Al, Cu, Pb

RUN 7 (2018)
beam: Ar, Kr; target: C, Al, Cu, Pb

RUN 8 (2023)
beam: Ar, Xe; target: CsI

Next RUN

The detector setup of BM@N

Tracking system

- **SiBT** (*Silicon Beam Tracker*)
- **VSP** (*Vertex Silicon Plane*) *or STS*
- **FSD** (*Forward Silicon Detector*)
- **GEM** (*Gas Electron Multipliers*)
- **CSC** (*Cathode Strip Chambers*)
- ~~**DCH** (*Drift Chambers*)~~ **removed**

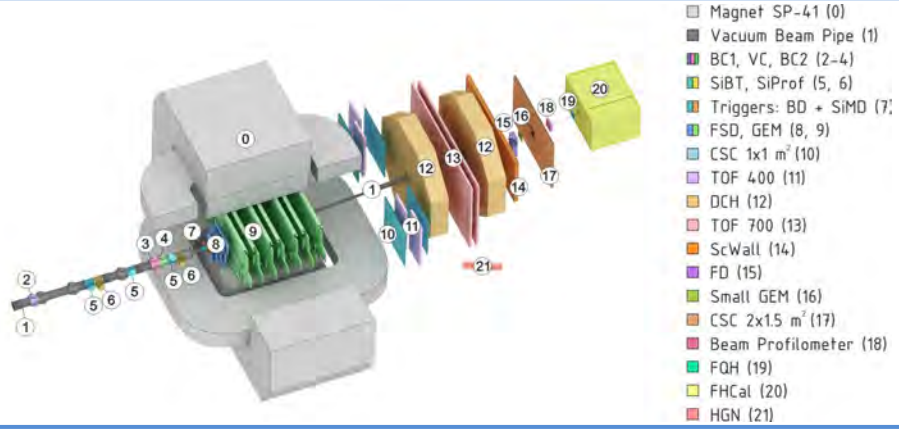
Particle identification system

- **TOF400** (*1st Time-of-Flight detector*)
- **TOF700** (*2nd Time-of-Flight detector*)

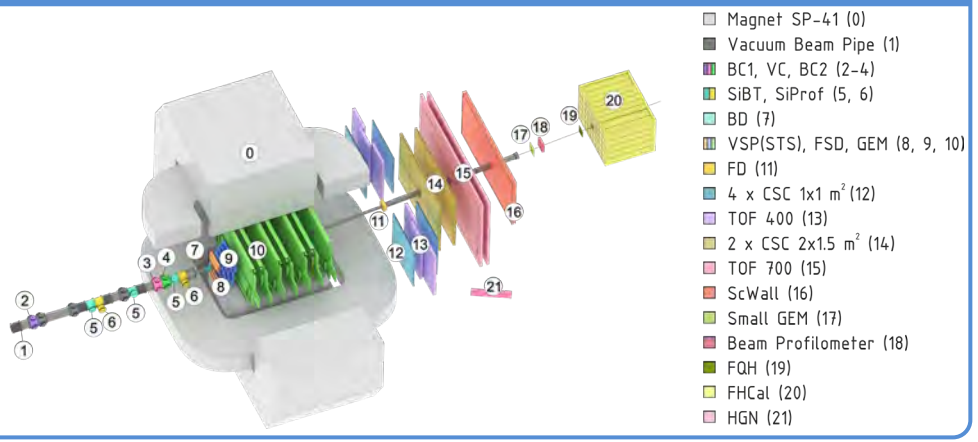
Other detector systems

- **Triggers system**
- **FQH** (*Forward Quartz Hodoscope*)
- **ScWall** (*Scintillator Wall*)
- **FHCall** (*Fwd. Hadron Calorimeter*)
- **HGN** (*High Granularity Neutron*)

BM@N setup for the previous configuration (RUN-8)



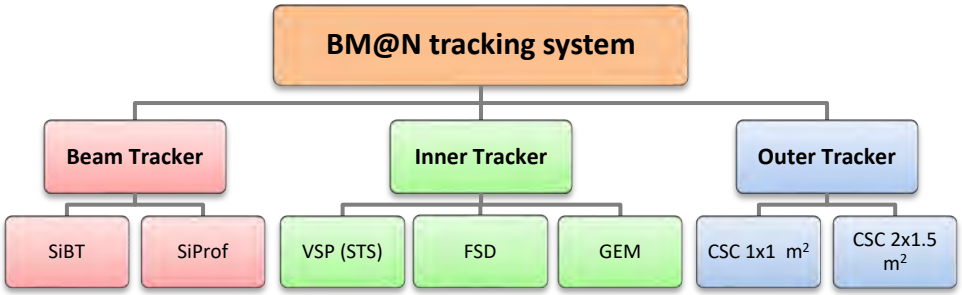
Preliminary BM@N setup for the next configuration

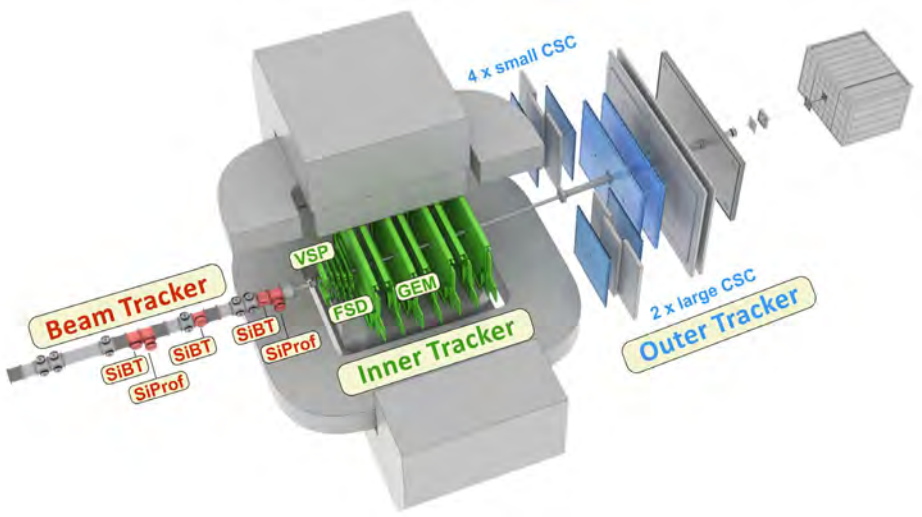


Hybrid tracking system

The hybrid tracking system of the BM@N experiment consists of high-precision coordinate detectors for charged particle track registration.

The tracking system is subdivided into three parts: **beam tracker**, **inner tracker** and **outer tracker**. The beam tracker includes detectors located inside the vacuum pipe to monitor the beam. The inner tracker comprises detectors located inside the magnet, the outer – outside





BM@N tracking system for the next RUN consisting of microstrip detectors (highlighted with different colors)

BM@N tracking detectors for the next RUN:

Beam tracker:

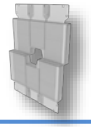
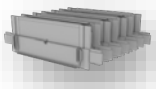
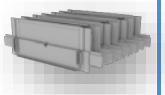
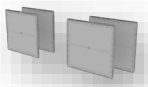
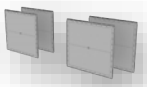
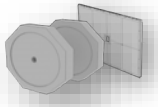
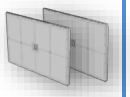
- **SiBT (Silicon Beam Tracker)** : 3 planes of 63x63 mm²
- **SiProf (Silicon Profilometers)** : 2 planes of 63x63 mm²

Inner tracker:

- **VSP (Vertex Silicon Plane)** ***or STS*** : 1 plane of 6 modules
- **FSD (Forward Silicon Detector)** : 8 half-planes
- **GEM (Gas Electron Multipliers)** : 14 half-planes

Outer tracker:

- **small CSC (Cathode Strip Chamber)** : 4 planes of 1x1 m²
- **large CSC (Cathode Strip Chamber)** : 1 plane of 2x1.5 m²

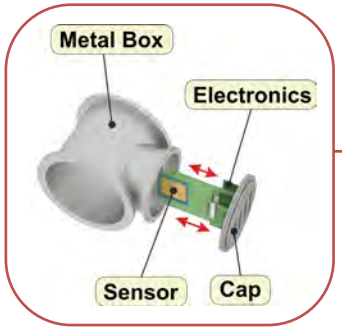
Detector	RUN-8	RUN-9	Features
VSP (STS)	—		New coordinate detector in the next RUN
FSD			—
GEM			—
small CSC			—
large CSC			Two DCH were replaced by two large CSC

Beam tracker detectors

SiBT (*Silicon Beam Tracker*) and SiProf (*Silicon Beam Profilometer*) detectors are designed to monitor and track the ion beam.

They are located before the target inside metal boxes integrated into the first section of the vacuum pipe.

Software for simulation and reconstruction, including detailed geometric models of these detectors, was implemented in the BMNROOT framework.

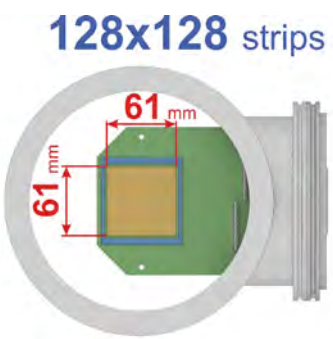


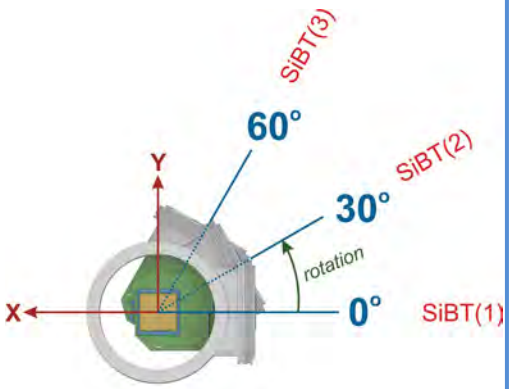
SiBT detector

Metal box, as a part of the vacuum tube, contains one detector inside

The first section of the vacuum pipe containing different detectors

Silicon Beam Tracker

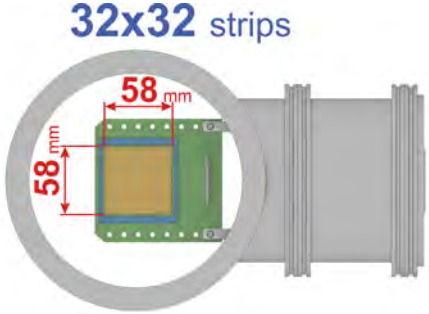




sensor: **61x61 mm²**
sensor thickness: **175 µm**
strip pitch: **0.475 mm**
stereo angle between strips: **90°**

Three SiBT detectors are arranged along the beam axis and each one is rotated by a certain angle around this axis

Silicon Beam Profilometers

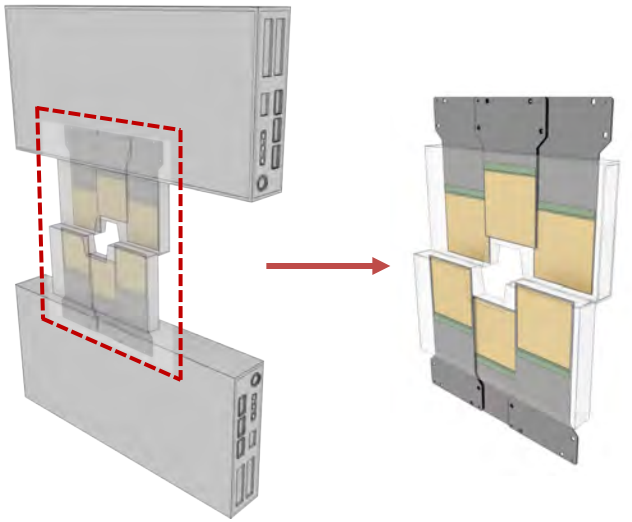


sensor: **61x61 mm²**
sensor thickness: **175 µm**
strip pitch: **0.475 mm**
stereo angle between strips: **90°**

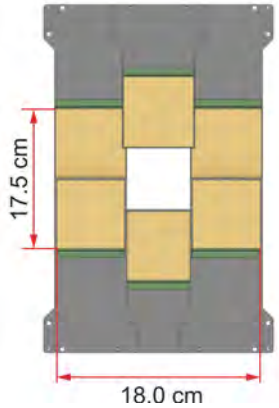
Each silicon profilometer can have two positions: "sensor on the beam" (1) and "sensor removed" (2)

Vertex Silicon Plane (VSP) or STS

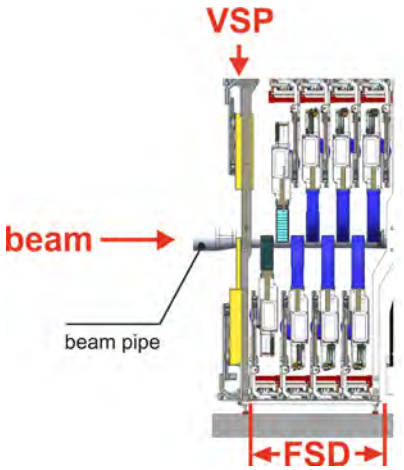
Vertex Silicon Plane (VSP) or STS is a high-precision microstrip coordinate detector of the inner tracking system of the BM@N setup. In next run it is represented by one plane.



Silicon plane

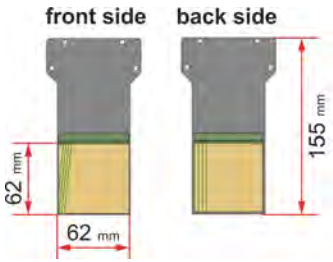


Vertex Silicon Plane consists of 6 modules which are assembled to form a hole of about 50 mm for passing the beam pipe

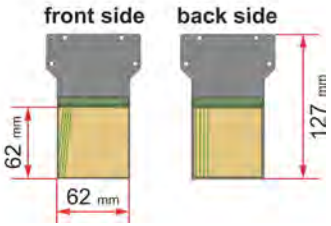


VSP detector is placed near the target before the other tracking detectors

Silicon module types



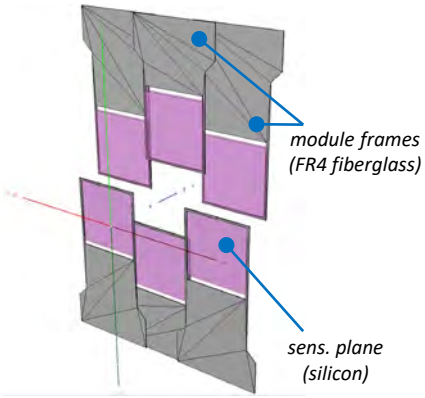
Si-module with one double-sided strip sensor of ***62x62*** *mm² mounted on* ***a long frame***



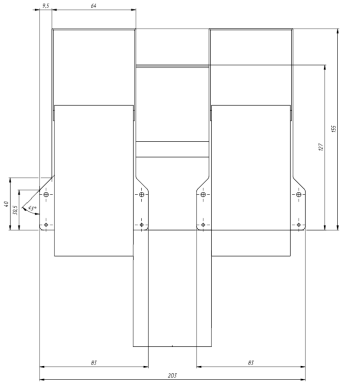
Si-module with one double-sided strip sensor of ***62x62*** *mm² mounted on* ***a short frame***

sensor thickness: **300 µm**
strip pitch: ≈ **58 µm**
stereo angle between strips: **7.5°**

ROOT geometry



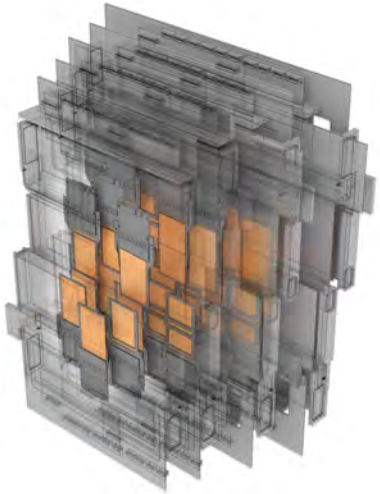
ROOT geometry of the VSP detector



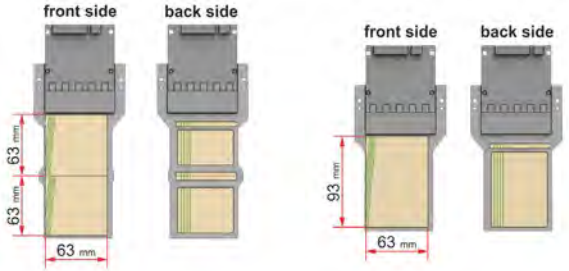
Geometry was prepared in accordance with the drawings provided by the detector group

Forward Silicon Detector (FSD)

Forward Silicon Detector (FSD) is a high-precision coordinate detector of the inner tracking system of the BM@N setup. It consists of a set of silicon modules which are assembled into 4 stations.



Silicon module types

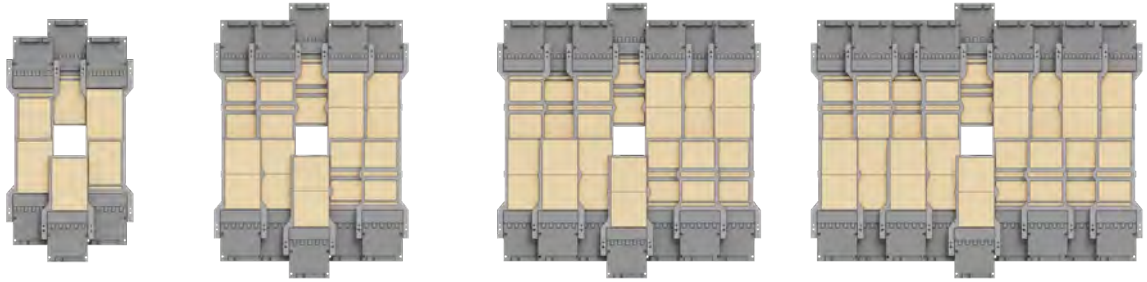


*Si-module with two double-sided strip sensors of **63x63** mm² each*

*Si-module with one double-sided strip sensor of **63x93** mm²*

sensor thickness: **300 µm**
strip pitch: **≈ 100 µm**
stereo angle between strips: **2.5°**

Silicon stations



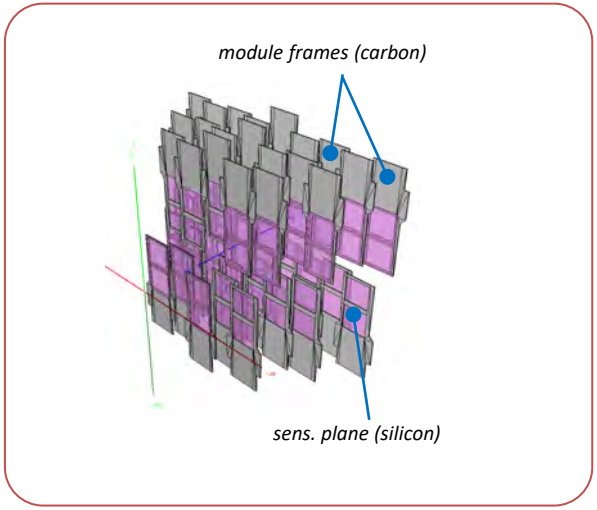
Station 1: *6 modules of 63x93 mm²*

Station 2: *10 modules of 63x126 mm²*

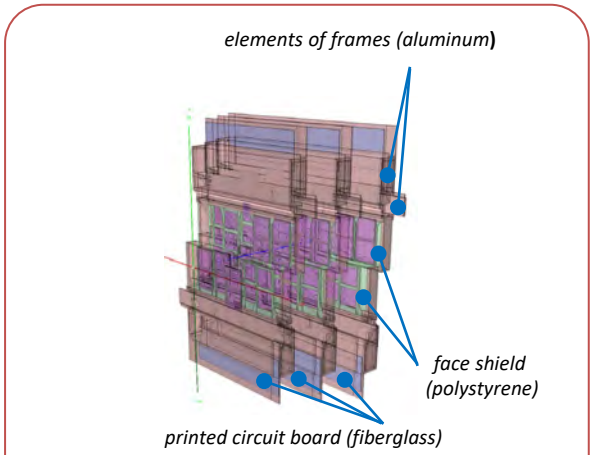
Station 3: *14 modules of 63x126 mm²*

Station 4: *14 modules of 63x126 mm²*

ROOT geometry



Basic ROOT geometry of the FSD detector



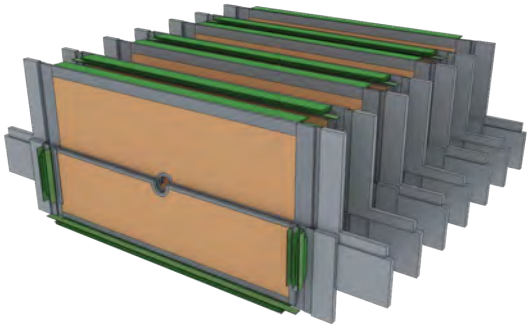
Detailed ROOT geometry of the FSD detector

Adding passive elements to the geometry allows us to take into account detector materials which affect the passage of particles trough matter. This, in turn, improves the accuracy of the Monte-Carlo simulation.

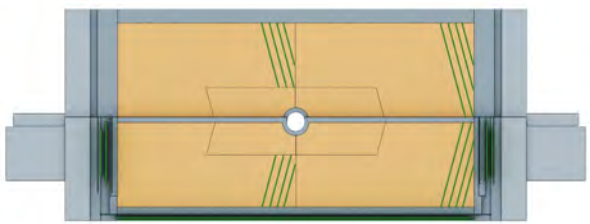
GEM detector

GEM (Gas Electron Multipliers) is a microstrip coordinate detector of the central tracker in the BM@N setup. It consists of gaseous chambers with electron multiplier system inside.

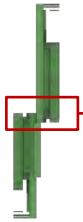
The configuration of this detectors for RUN-9 comprises **seven stations** located inside the magnet along the beam axis.



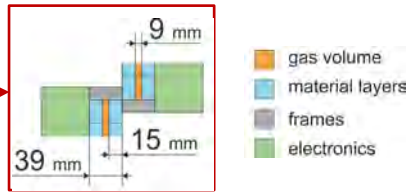
GEM station assembly



1st GEM station (front view)



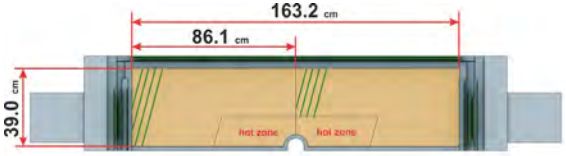
1st GEM station (side view)



Scheme of joining two half-planes together into a station (side view)

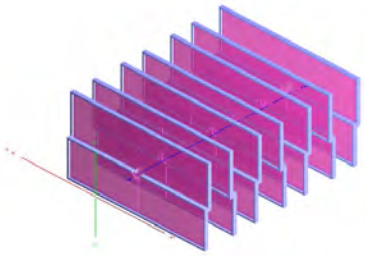
GEM chamber types

Upper half-plane

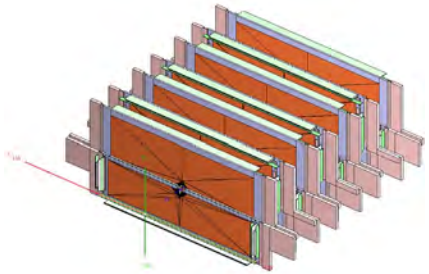


Lower half-plane

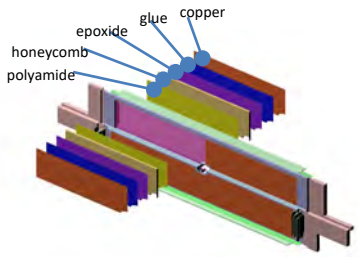
ROOT geometry



Basic ROOT geometry of the GEM detector



Detailed ROOT geometry of the GEM detector



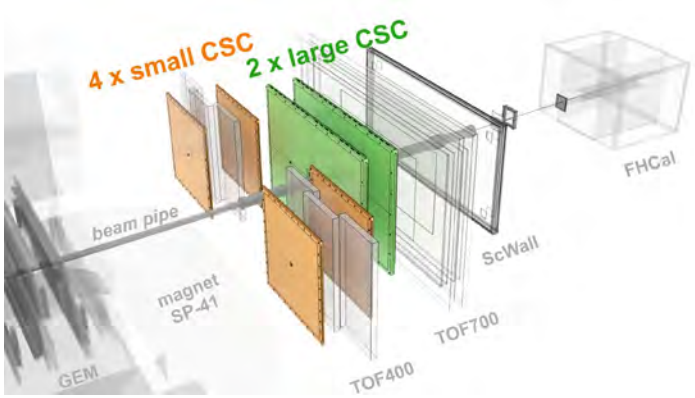
Sensitive area of a GEM chamber

Each active zone in a GEM chamber has a multi-layer structure. A layer has the following properties: thickness, material type and other characteristics which are taken into account in the Monte-Carlo simulation.

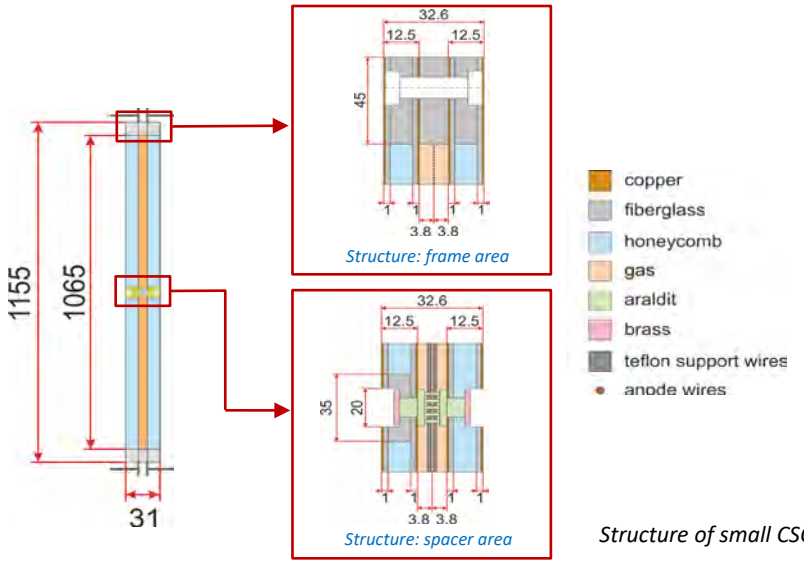
CSC detector

CSC (Cathode Strip Chamber) is a gaseous detector with microstrip readout. It belongs to the **outer tracking system** in the BM@N setup.

The configuration of this detector for the next run consists of **four small** and **two large** stations located behind the magnet.

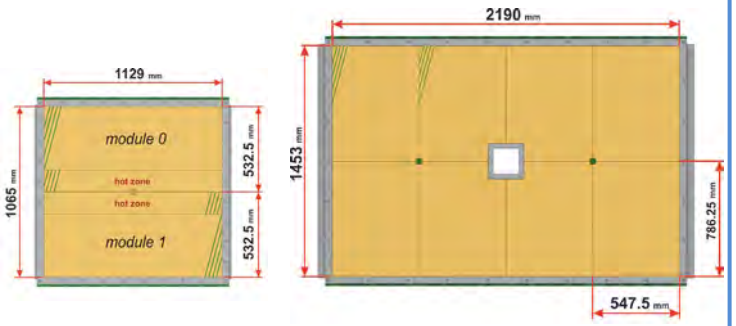


CSC chamber structure



Structure of small CSC chamber

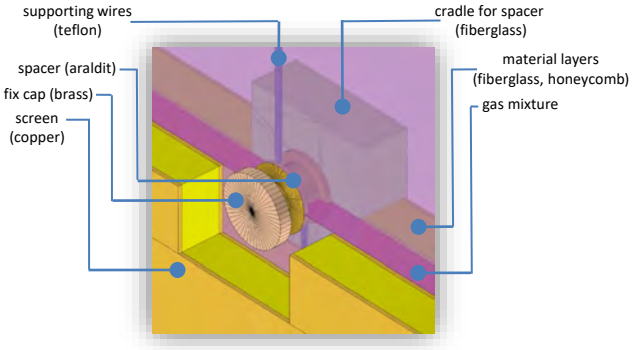
CSC chamber types



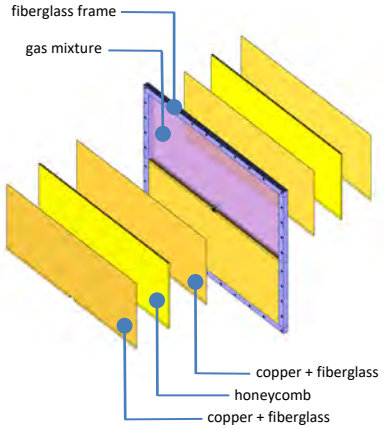
Small CSC *Large CSC*

gas volume thickness: **7.2 mm (small CSC) and 6 mm (large CSC)**
strip pitch: **≈ 2.5 mm**
stereo angle between strips: **15°**

ROOT geometry



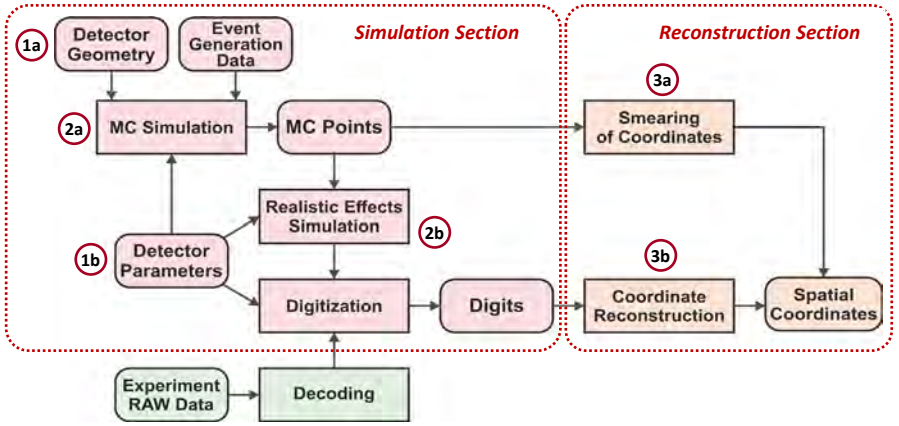
Spacer, as an example of a passive element, was implemented in the ROOT geometry of the CSC chamber



Multi-layer structure of CSC chamber was implemented in the ROOT geometry

Tracking detectors: software for data processing

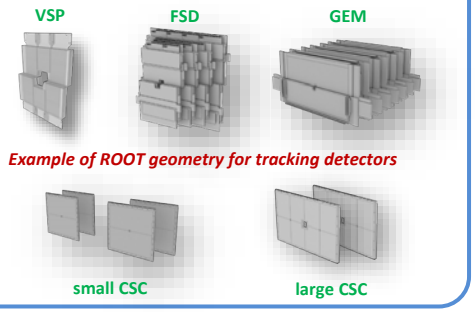
Stages of data processing



1. **Complete description of a detector:**
   a) Description of detector geometry (ROOT files)
   b) Description of detector parameters (XML files)
2. **Simulation**:
   a) Monte-Carlo simulation
   b) Simulation of realistic effects
3. **Hit-reconstruction (getting coordinates of spatial points)**:
   a) Smearing Monte-Carlo points (hit producing)
   b) Hit reconstruction from "digits":

1. Detector description

Detector geometry describes physical dimensions of a detector, its hierarchical structure, media and other parameters that are used of MC transport engine (Geant 4) to propagate charged particles through matter



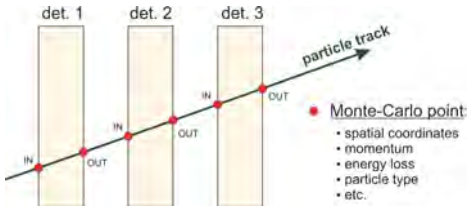
Example of ROOT geometry for tracking detectors

2. Simulation

Stage 1

Monte-Carlo simulation is used for imitation of charged particle passing through matter.

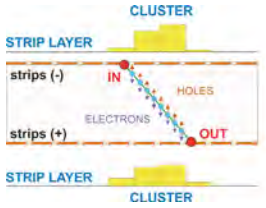
Result: A set of MC points, which charged particles left in detectors



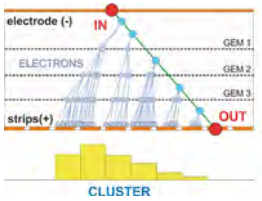
Stage 2

Realistic simulation is used to create signals on the strips (digits) taking into account the features of signal formation in a certain type of detectors.

Result: A set of digits (fired strips) as the real responses of detectors



Signal formation in silicon-based detectors

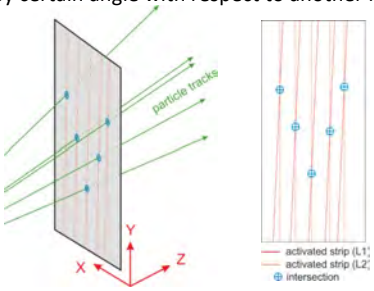


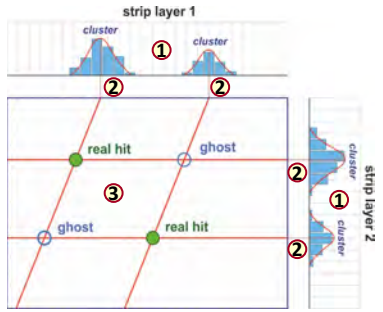
Signal formation in a GEM chamber

XY-readout plane

3. Hit-reconstruction

Tracking detectors have two-coordinate microstrip readout. In order to reconstruct XY-coordinates the strips of one layer are rotated by certain angle with respect to another layer





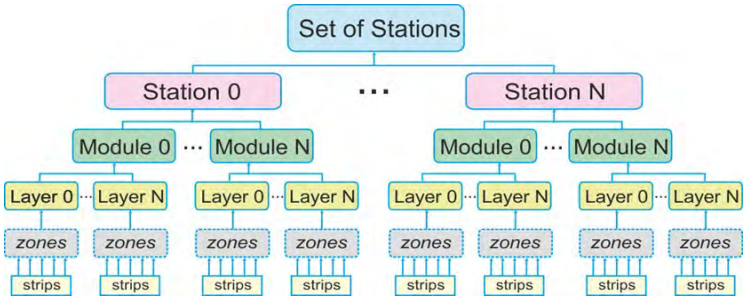
"**Hit**" is a reconstructed spatial point with coordinates (x, y, z) which a charged particle passed through.

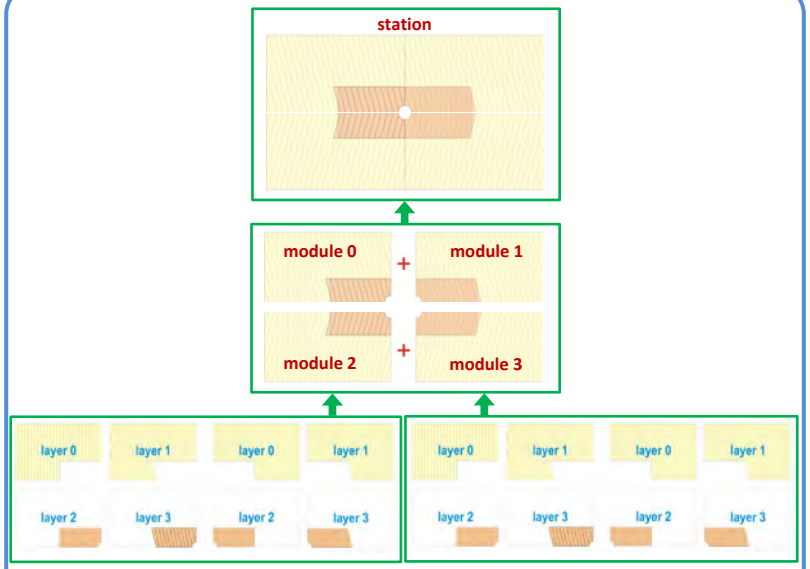
Tracking detectors: software structure

Structure of tracking detectors

All the tracking detectors have the same hierarchical structure, where:

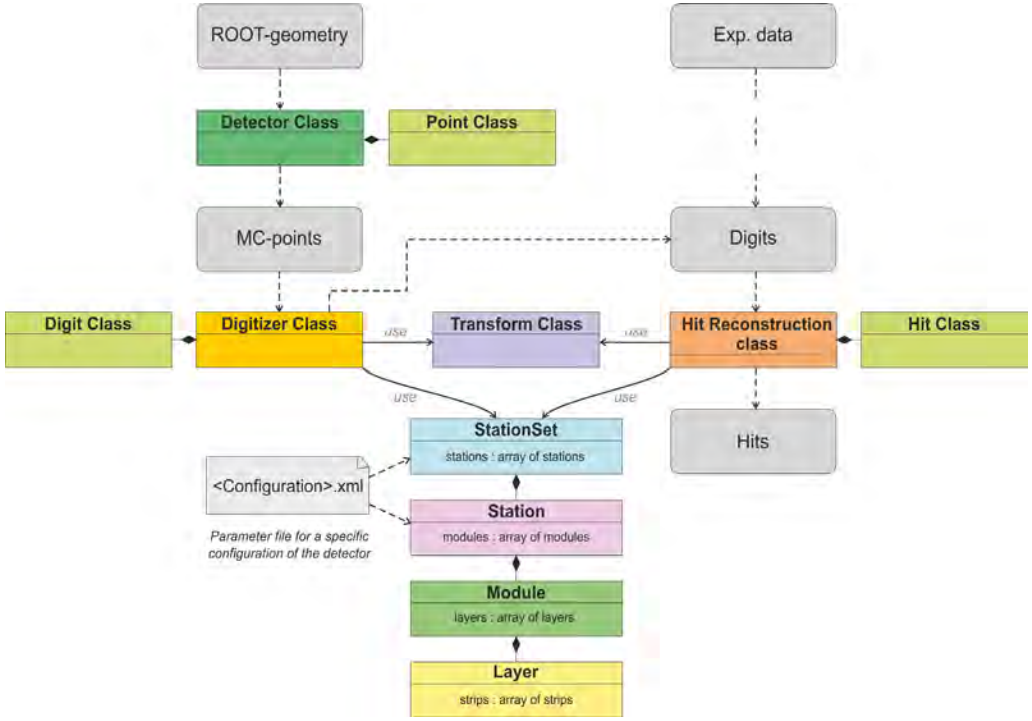
Strips are integrated into a layer,
Layers – into a module,
Modules – into a stations,
Stations – into a set of stations





Visual example of the structure of one GEM chamber

Software implementation



Software structure for the tracking detectors (as a class diagram)

Summary

What has been done:

- Software for realistic simulation and hit reconstruction for tracking detectors of the next BM@N run was prepared:
  - Silicon Beam Tracker (SiBT) and Silicon Profilometers (SiProf)
  - Vertex Silicon Plane (VSP) *or STS*
  - Forward Silicon (FSD) and GEM detectors
  - Small and large CSC detectors

Thank you for your attention…