Simulation of FwdSi, GEM and CSC tracking detectors for heavy ion setup

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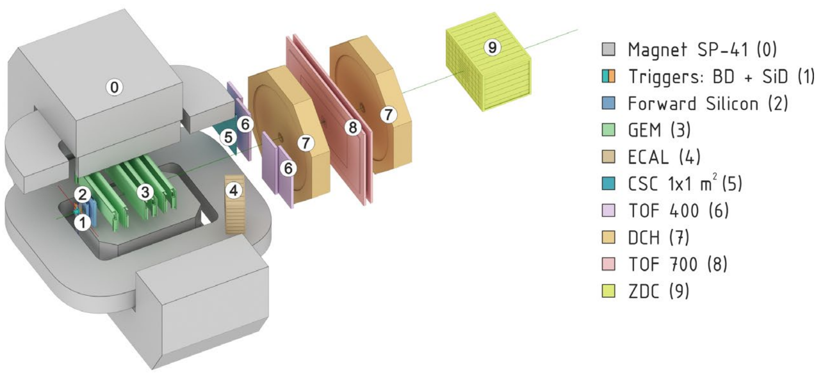
Introduction

Talk topics:

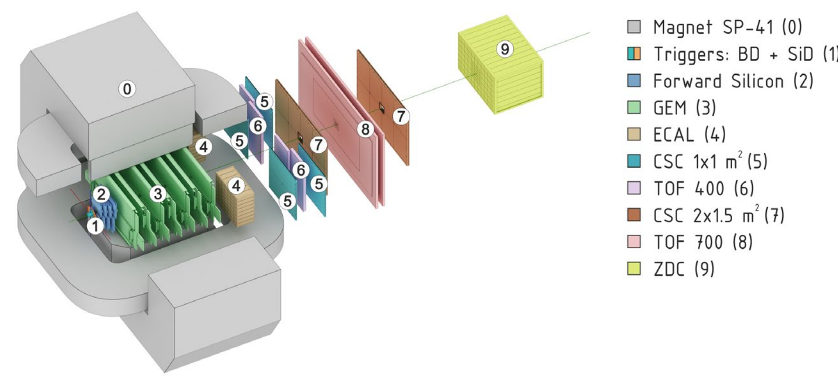
- ❑ BM@N setup for RUN-7 and RUN-8
- ❑ Tracking detectors of the BM@N setup for RUN-8:
  - Forward Silicon
  - GEM
  - CSC
- ❑ Tracking detectors: steps of simulation
- ❑ Description of tracking detectors: ROOT geometry
- ❑ Material budget calculation

BM@N setup: configurations

BM@N (**B**aryonic **M**atter at **N**uclotron) is a fixed target experiment aimed to study dense baryonic matter on heavy-ion collisions.



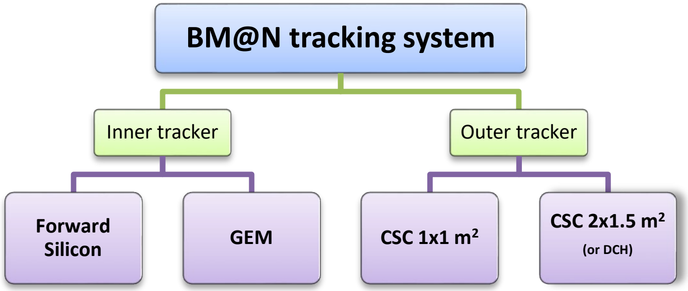
Previous configuration of the BM@N setup in the spring of 2018 (RUN-7)

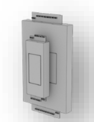
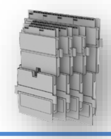
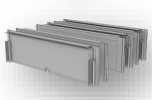
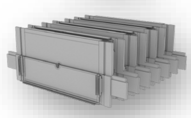
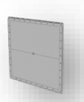
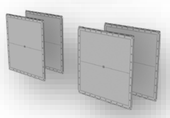
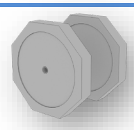
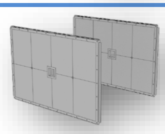


Future full configuration of the BM@N setup planned to be carried out in the spring of 2022 (RUN-8)

BM@N tracking system

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

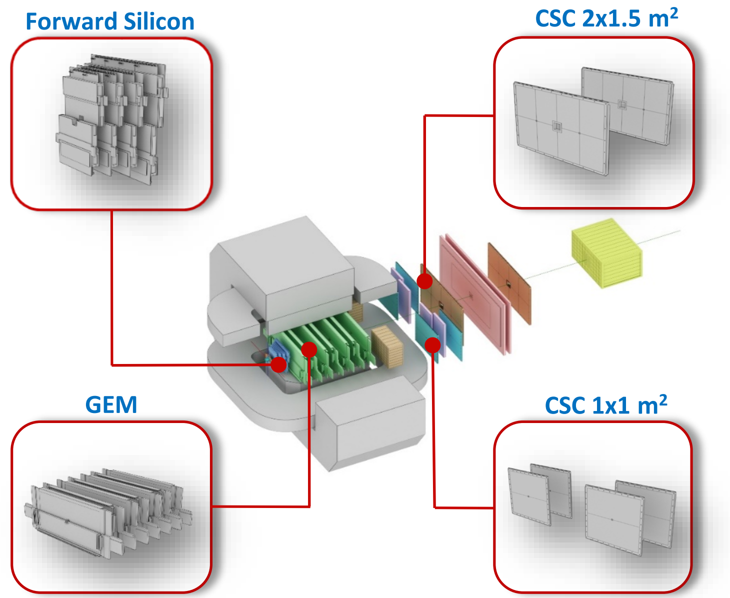


Detector	RUN-7	RUN-8	Features
Fwd Si			**RUN-7**: 2 stations (14 Si-modules) **RUN-8**: 4 station (64 Si-modules)
GEM			**RUN-7**: 6 stations (6 half-planes) **RUN-8**: 7 stations (14 half-planes)
CSC			**RUN-7**: 1 station (1x1 m^2) **RUN-8**: 4 stations (1x1 m^2)
DCH->CSC			**RUN-7**: 2 DCH chambers **RUN-8**: 2 CSC stations (2x1.5 m^2)

Upgrade of the BM@N tracking system in transition from RUN-7 to RUN-8

BM@N tracker consists of the following components:

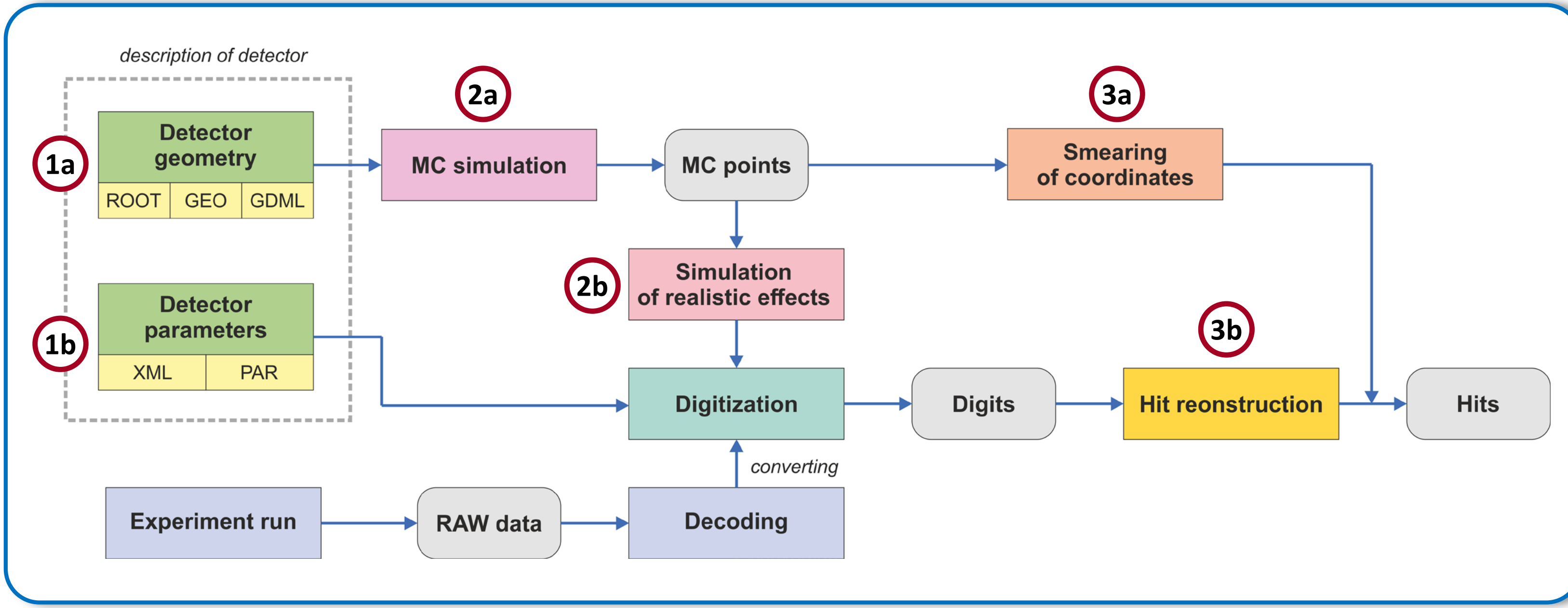
- ❑ **Forward Silicon** detector (8 half-planes)
- ❑ **GEM** detector (14 half-planes)
- ❑ **CSC** detector (4 planes of 1x1 m^2)
- ❑ **CSC** detector (2 planes of 2x1.5 m^2) *as a replacement for DCH*



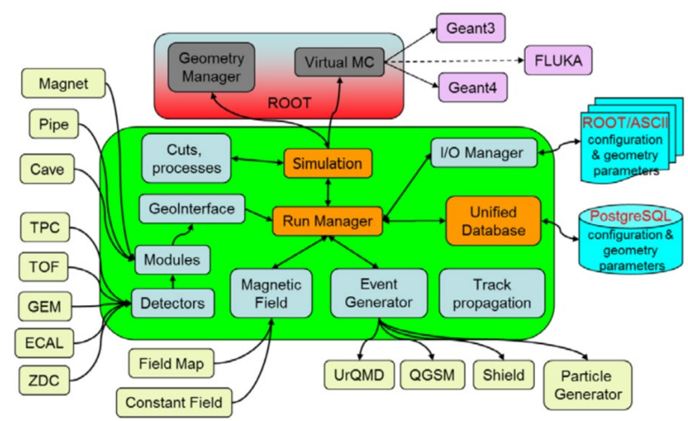
Tracking detectors of the BM@N setup in the future configuration (RUN-8)

Tracking detectors: steps of simulation

Scheme of the main steps of simulation for tracking detectors in the BmnRoot



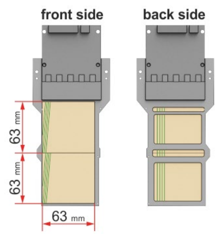
1. **Complete description of a detector**:
   a) Description of detector geometry (ROOT files)
   b) Description of detector parameters (XML files)
2. **Simulation**:
   a) Monte-Carlo simulation
   b) Simulation of realistic effects
3. **Procedures of getting "hits"**:
   a) Smearing Monte-Carlo points (hit producing)
   b) Hit reconstruction from "digits":
      - Realistic simulation + digitization
      - RAW experimental data + digitization



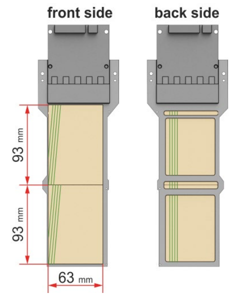
Structure of the BmnRoot framework

Forward Silicon detector

Forward Si is a silicon based semi-conductor detector consisting of Si-modules. There are two types of these modules: standard with sensor sizes of **63x126** mm^2 and long with sensor sizes of **63x186** mm^2

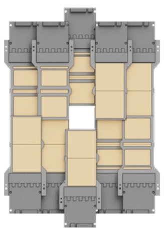


*Standard Si-module with sensor **63x126** mm^2*

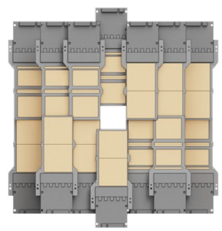


*Long Si-module with sensor **63x186** mm^2*

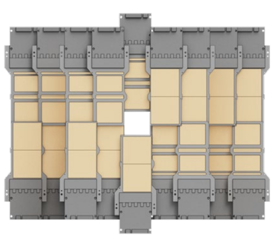
Si-modules are combined into **4 stations** of 10, 14, 18 and 22 modules (64 modules in total)



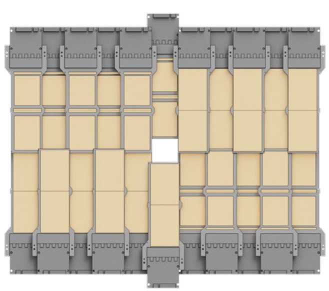
Station 1:
10 Si-modules of 63x126 mm^2



Station 2:
14 Si-modules of 63x126 mm^2

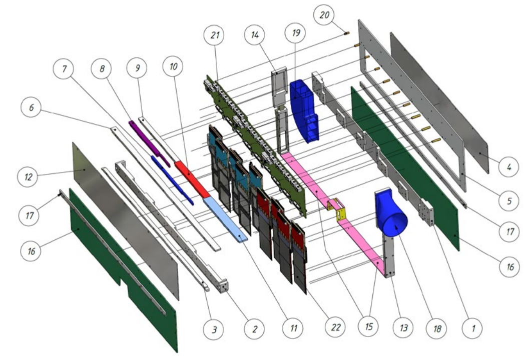


Station 3:
18 Si-modules of 63x126 mm^2



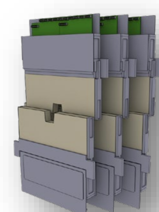
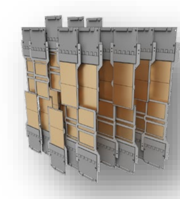
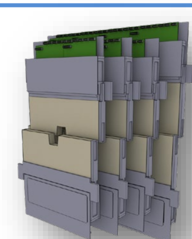
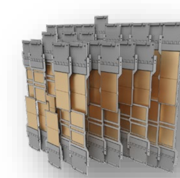
Station 4:
22 Si-modules of 63x126 mm^2

Then the Si-modules combined together are put into an air-cooled housing which comprises different components of various materials



Scheme of one half-plane (a half station) of the forward Silicon detector

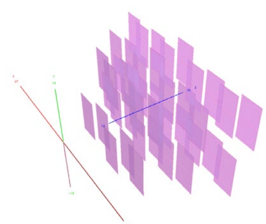
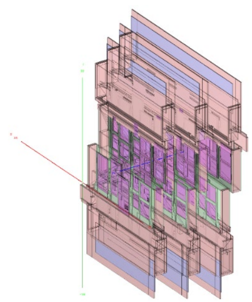
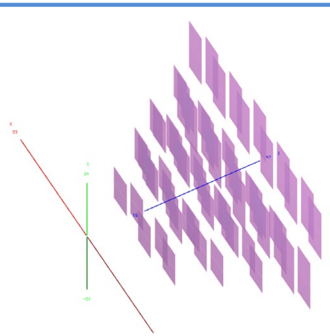
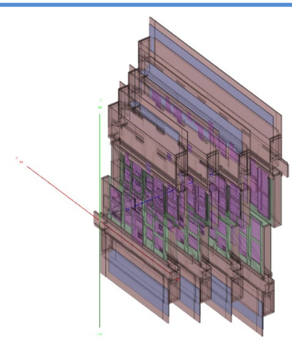
At this moment there are two versions of the configuration for the Forward Silicon detector for the future RUN-8

1st configuration (realistic)	 *3 stations (or 6 half-planes)*	 *42 Si-modules in the configuration*
2nd configuration (optimistic)	 *4 stations (or 8 half-planes)*	 *64 Si-modules in the configuration*

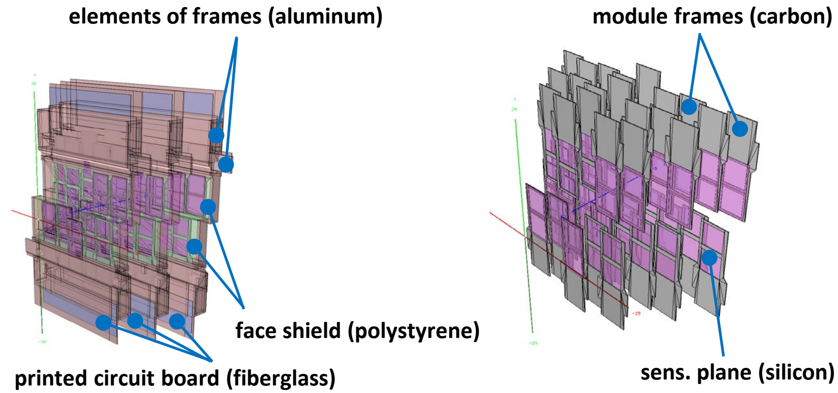
Forward Silicon detector: ROOT geometry

There are two versions of ROOT geometry for each configuration of the Forward Silicon detector: **simplified** and **detailed**.

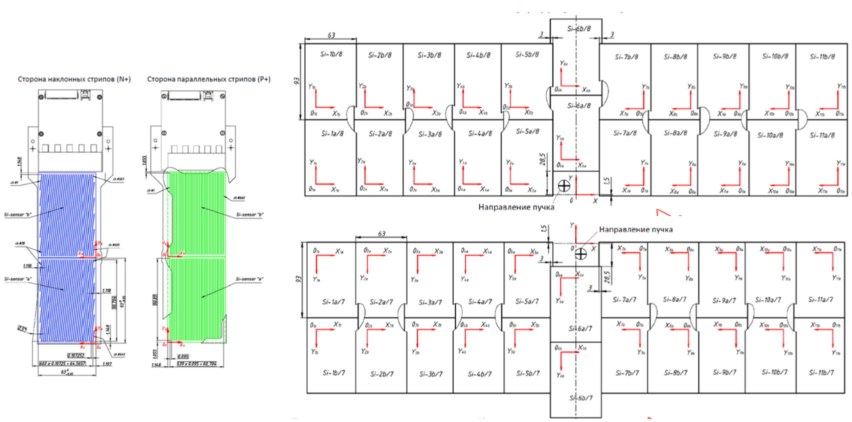
- **Basic ROOT geometry** consists of only sensor elements without any passive materials.
- **Detailed ROOT geometry** completely describes the detector including passive elements such as electronics, housing and supporting components.

Configuration	Basic ROOT geometry	Detailed ROOT geometry
1st configuration	 *42 Si-modules*	 *3 stations (or 6 half-planes)*
2nd configuration	 *64 Si-modules*	 *4 stations (or 8 half-planes)*

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.



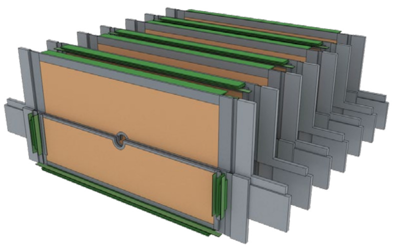
Materials of some elements of the Forward Silicon detector



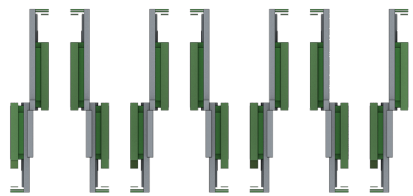
The present geometry was prepared in according to the drawings and schemes provided by E. Zubarev and other members of the detector group

GEM detector

GEM (**G**as **E**lectron **M**ultiplier) is a gaseous detector with micro-strip readout. Its configuration for RUN-8 comprises seven stations located inside the magnet along the beam axis.

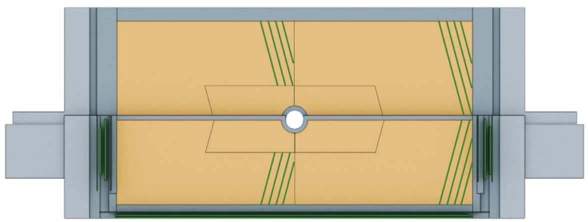


GEMs for RUN-8

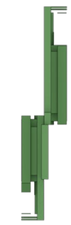


GEMs for RUN-8 (side view)

Each station in the configuration RUN-8 is combined from two half-planes: upper and lower. These half-planes are joined together to form an XY plane.



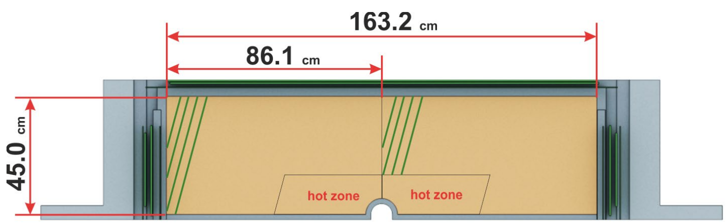
1st GEM station



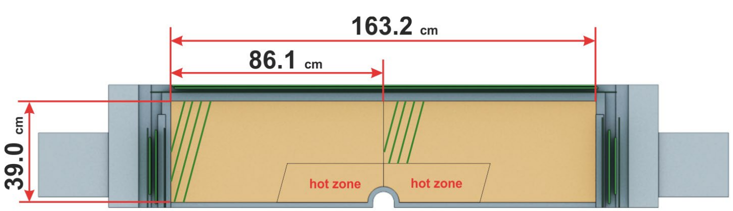
1st GEM station (side view)

Upper and lower half-planes have different sizes of their sensitive areas:

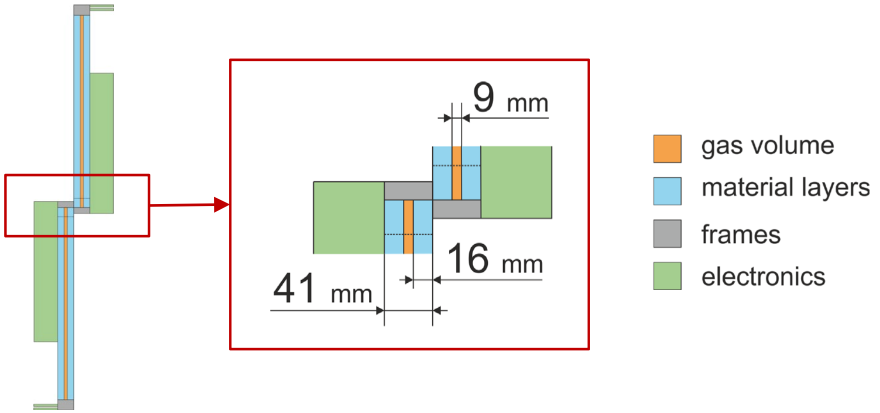
- Upper half-plane sensor: **163x45** cm
- Lower half-plane sensor: **163x39** cm



Upper half-plane



Lower half-plane

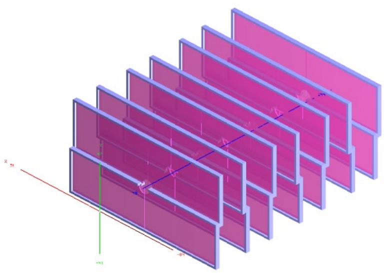


Scheme of joining two half-planes together in a station (side view)

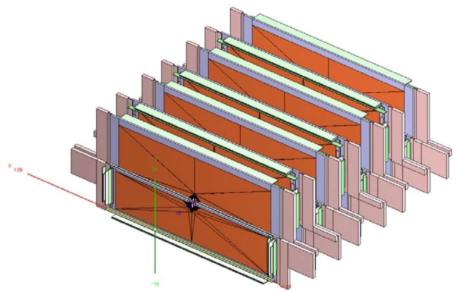
GEM detector: ROOT geometry

Two versions of ROOT geometry of the GEM detector have been prepared for the next RUN-8 configuration:

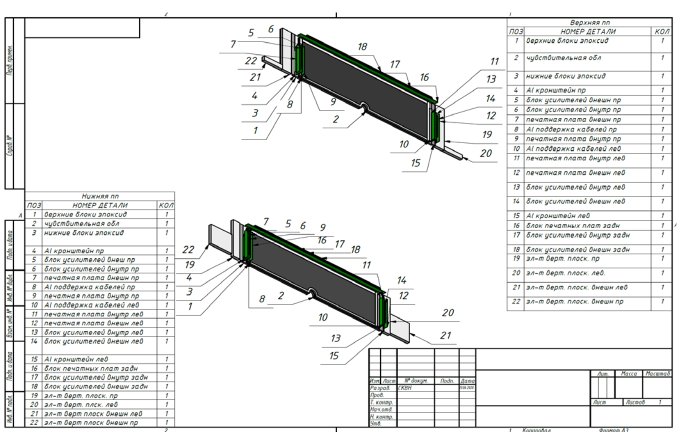
- **Basic ROOT geometry** comprises 14 sensitive volumes with simplified frames around each one.
- **Detailed ROOT geometry** completely describes the detector including passive elements such as electronics, housing and supporting components.



Basic ROOT geometry of the GEM detector



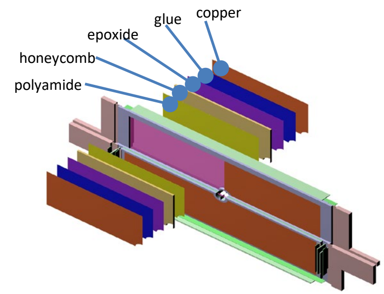
Detailed ROOT geometry of the GEM detector



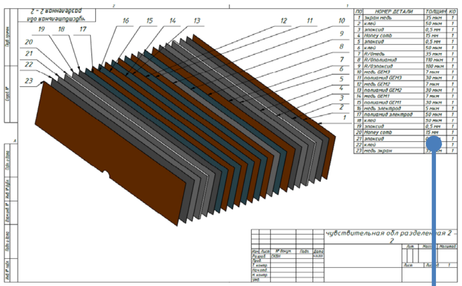
Geometry of the GEM detector was created in accordance with detailed drawings prepared by the GEM group

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 process.



Multi-layer structure of a GEM chamber (ROOT-geometry)



Scheme of layers in a half-plane (prepared by the GEM group)

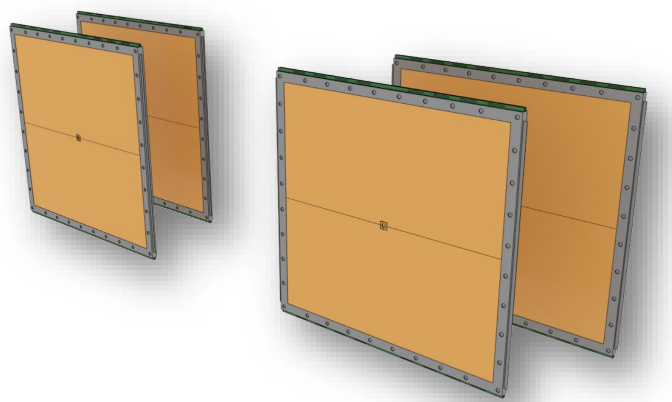
copper: 35µm + 35µm + 7µm + 7µm + 7µm + 5µm + 35µm = **131µm**
glue: 50µm + 50µm +50µm + 50µm = **200µm**
epoxide: 0.5mm + 0.5mm + 100µm + 0.5mm + 0.5mm = **2.1mm**
honeycomb: 15mm + 15mm = **30mm**
polyamide: 110µm + 30µm + 30µm + 30µm + 50µm = **250µm**

layer	material	density [g/cm-3]	thickness (X) [cm]	X0 [cm]	X/X0 [%]
gas	ArC_4H_{10} (80/20)	0.002	0.9	12343	0.0073
copper	copper	8.96	0.0131	1.435	0.9129
glue	acrylic glue	1.25	0.02	32.1603	0.0622
epoxide	polyurethane	1.8	0.21	22.5351	0.9319
honeycomb	nomex aramid honeycomb	0.048	2.86	755.397	0.3786
polyamide	polyamide	1.14	0.025	36.4052	0.0687

Properties of layers

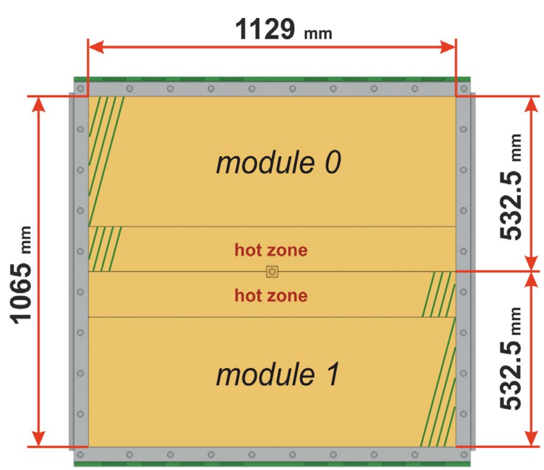
CSC detector

CSC (**C**athode **S**trip **C**hamber) is a gaseous detector with micro-strip 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 stations located behind the magnet.

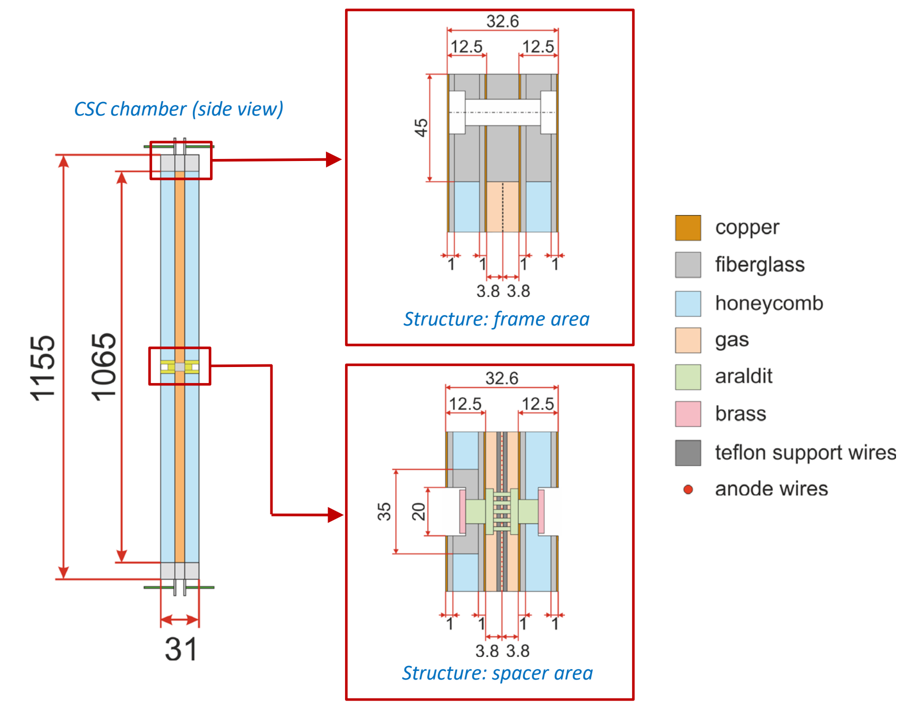


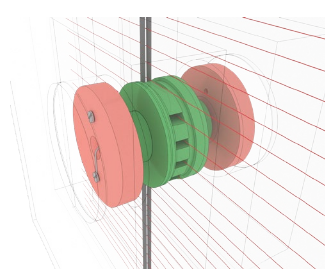
CSC chambers for RUN-8

Each chamber has sensitive area with sizes of **1129x1065** mm^{2}.

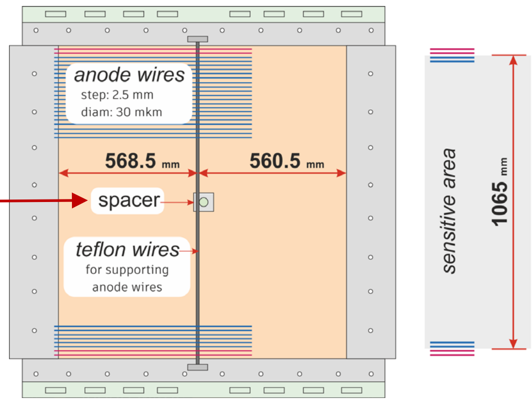


Structure of a CSC chamber :





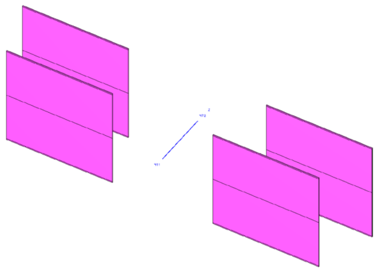
Spacer for supporting a fixed distance between two cathode plates



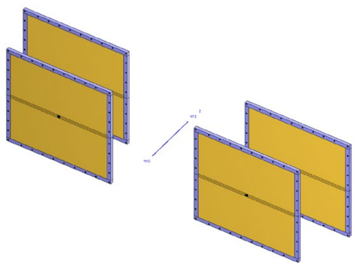
CSC detector: ROOT geometry

As well as for others tracking detector there are two versions of ROOT geometry of the CSC detector which have been prepared for the forthcoming RUN-8:

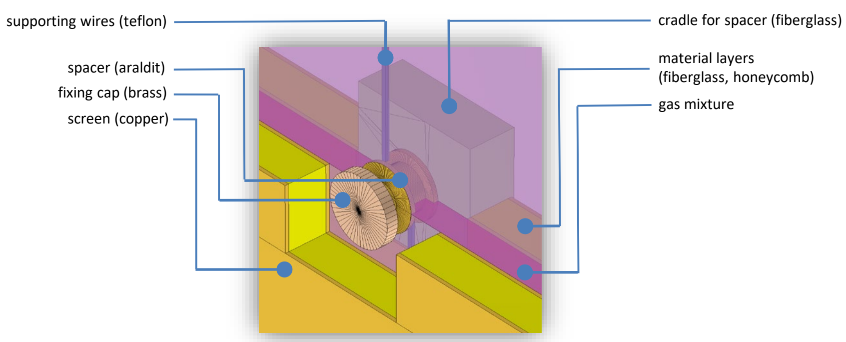
- **Basic ROOT geometry** is four sensitive volumes filled with an active gas mixture (without any frames)
- **Detailed ROOT geometry** includes, in addition to gas volumes, passive elements, such as frames, material layers and other constructive components



Basic ROOT geometry of the CSC detector



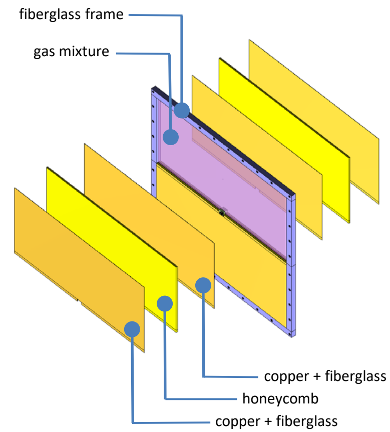
Detailed ROOT geometry of the CSC detector



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

Sensitive area of a CSC 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 process.



Multi-layer structurer of a CSC chamber

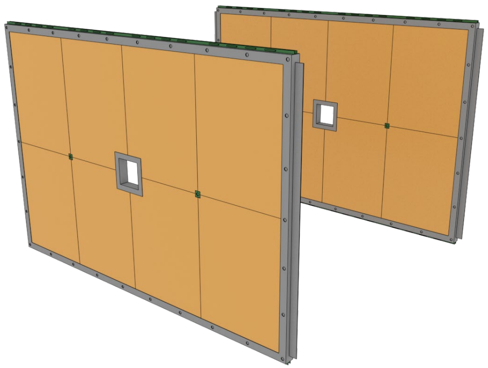
gas mixture: 3 mm + 3 mm = **6 mm**
copper: 35 μm + 35 μm + 35 μm + 35 μm = **140 μm**
fiberglass: 0.965 mm + 0.965 mm + 0.965 mm + 0.965 mm = **3.86 mm**
honeycomb: 10.5 mm + 10.5 mm = **21 mm**

layer	material	density [g/cm-3]	thickness (X) [cm]	X0 [cm]	X/X0 [%]
gas mixture	ArC_4H_{10} (75/25)	0.002	0.76	11579.9	0.0066
copper	copper	8.96	0.014	1.435	0.9896
fiberglass	fiberglass	1.9	0.386	18.411	2.0977
honeycomb	nomex aramid honeycomb	0.048	2.1	755.397	0.2780

Properties of layers

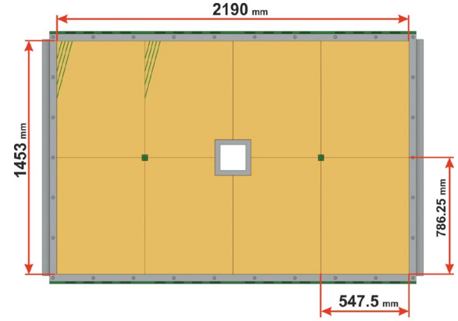
CSC detector: large chambers 2x1.5 m^2

For the next RUNs of the BM@N experiment was developed the micro-strip **CSC detector** consisting of two large chambers with sensor area sizes of **2190x1453** mm^2. As a part of the upgraded BM@N tracking system, this detector will replace the present DCH (drift chambers) detector with itself.

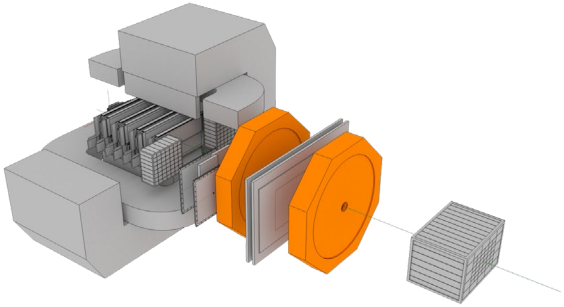


CSC detector consisting of two chambers for RUN-8

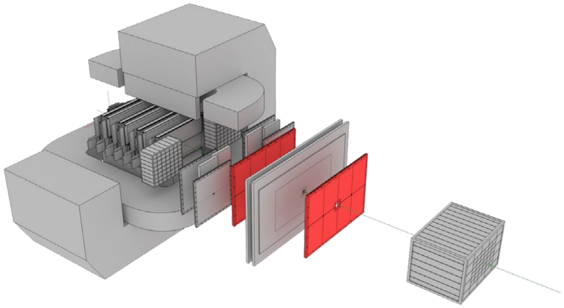
The sensitive area of a large CSC chamber has two cathode planes inside (one on each side of a gas volume). A cathode plane comprises 8 PCB plates, each of them is divided into “hot” and “cold” zones.



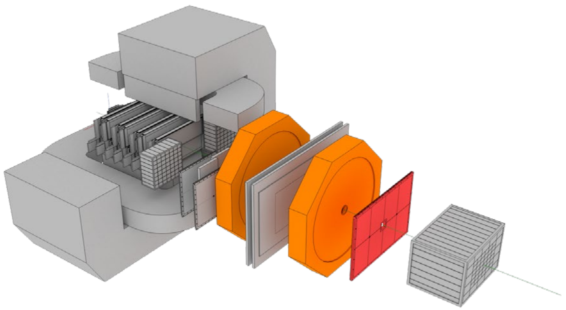
Big cathode strip chamber (front view)



The present BM@N tracking system includes two DCHs (in orange color in the picture)



The upgraded BM@N tracker has two Cathode Strip Chambers (in red color) instead of the DCH detector



It is planned to make and use at least one of the CSC station in the future RUN-8. It is expected this station will be placed behind the DCH detector

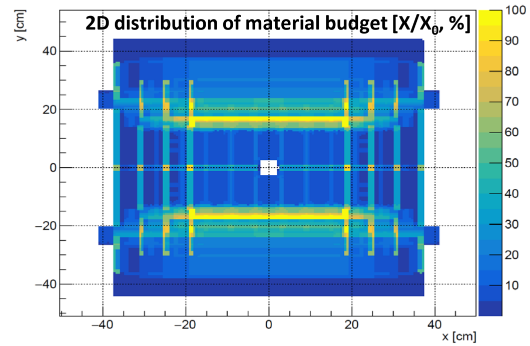
Tracking detectors: material budget

Based on the detailed geometry of the detectors, described in the previous slides, we have calculated **material budget** for the RUN-8 configuration.

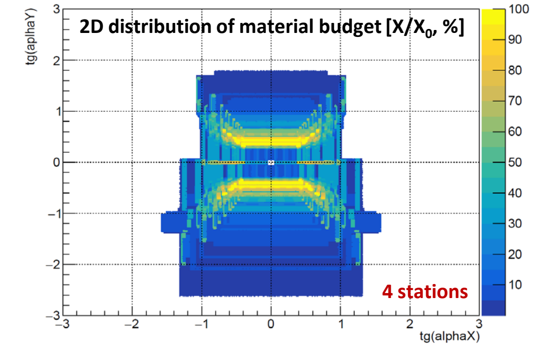
$$\textit{Material budget} = \frac{X}{X_0} \cdot 100\%$$

The material budget is a ratio of a total thickness (X) of some compound material to its radiation length (X_0), that is expressed in percentage terms (X/X_0, %).

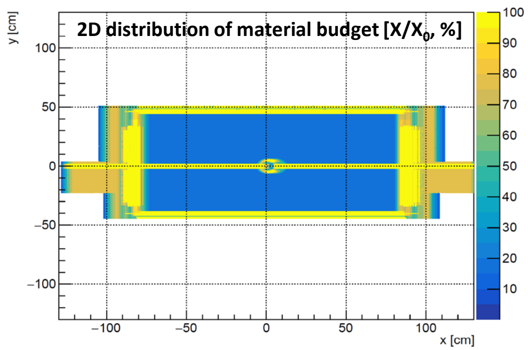
The **radiation length** (X_0) is the mean path which an electron passes in a certain material to reduce its energy by the factor 1/e.



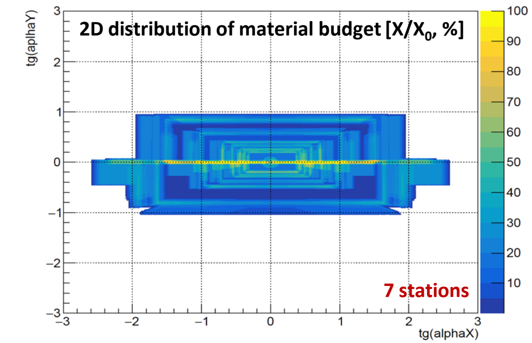
*Material budget for the **Forward Silicon** detector.*
XY distribution plot



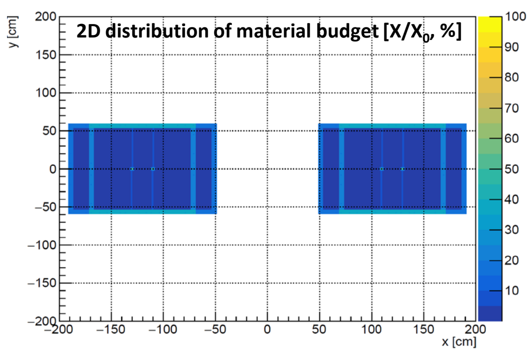
*Material budget for the **Forward Silicon** Detector.*
Angular distribution ($tg(a_x)/tg(a_y)$)



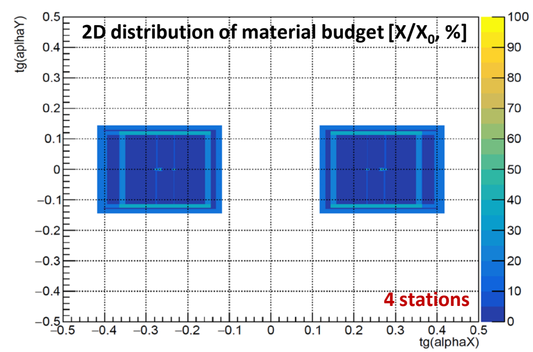
*Material budget for the **GEM** detector.*
XY distribution plot



*Material budget for the **GEM** detector.*
Angular distribution ($tg(a_x)/tg(a_y)$)



*Material budget for the **CSC** detector.*
XY distribution plot



*Material budget for the **CSC** detector.*
Angular distribution ($tg(a_x)/tg(a_y)$)

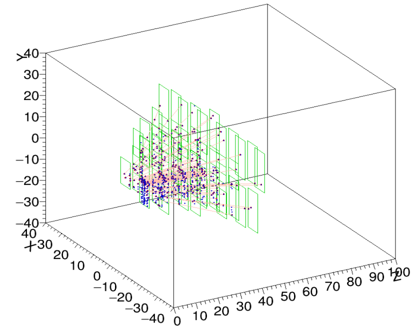
Conclusion: what has been done

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

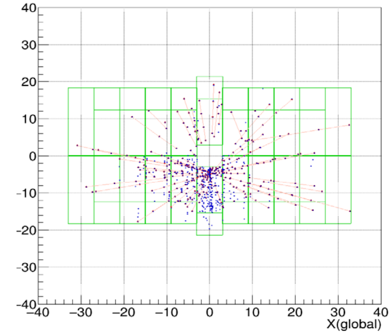
- ✓ Full geometry description (basic and detailed versions for each detector)
- ✓ Algorithm for realistic Monte-Carlo simulations
- ✓ Algorithm for the reconstruction of spatial coordinates from micro-strip readout planes (hit reconstruction)

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

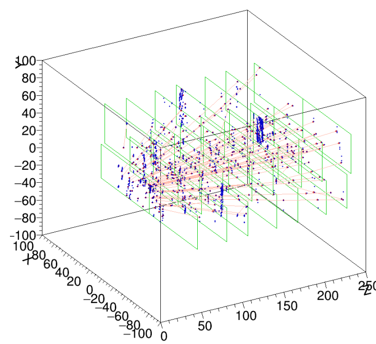
Example of a single event as a results of Monte-Carlo simulation and hit reconstruction for the three tracking detectors



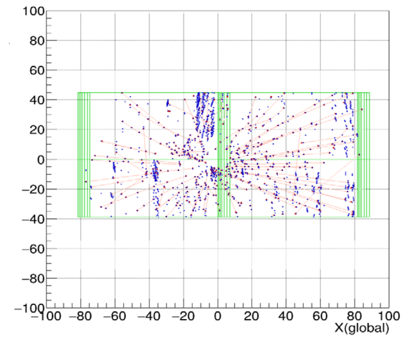
***Forward Silicon** detector (3D view)*



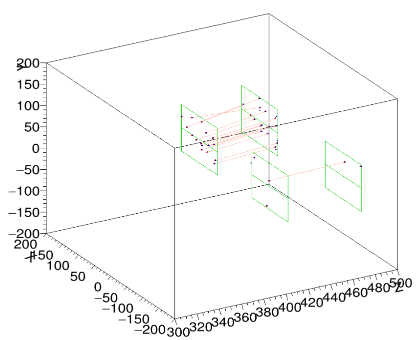
***Forward Silicon** detector (XY view)*



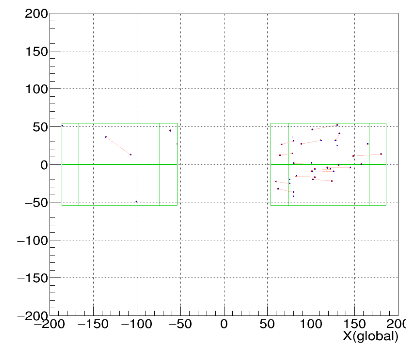
***GEM** detector (3D view)*



***GEM** detector (XY view)*



***CSC** detector (3D view)*



***CSC** detector (XY view)*

Thank you for your attention…