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WP2.5: Development of FSD for the CBM experiment at FAIR

1. Technical design of new projectile spectator detector for CBM

The detection of projectile spectators is required for the characterization of the heavy-ion collision. The physics aim of the new Forward Spectator Detector of the CBM experiment is very much the same as it was for the previous (now canceled) PSD forward calorimeter. The detector is designed to measure the centrality and orientation of the collision plane for individual nuclear collisions. For many physical processes, accurately measuring these fundamental observables for each collision is essential. In nuclear collisions, centrality, essentially the geometric overlap of colliding nuclei, can be determined by detecting (ideally measuring the energy of) so-called "spectators" – nucleons that do not participate in the collision and continue in their original flight direction even after the collision. To be able to detect the spectators such a detector must be positioned in a very forward direction in the close vicinity of the beam pipe. For the schematic picture of the CBM detector position of the forward detector see section on performance studies.

The very forward location of the detector, the ultra-high frequency of collisions at the future SIS100 accelerator, and the detection of highly ionizing nuclear fragments create specific requirements on the detector driving the selection of the used technologies. Typically high-speed radiation tolerant hadronic calorimeters are used. This was also the case for the previously considered PSD detector. However, the PSD project was canceled in 2022 due to the war and the new detector must be available at the beginning of the first data collection planned for CBM in 2027. Hence the schedule does not allow for a design of a new calorimeter, therefore different approach has to be chosen. The new Forward Spectator Detector (FSD) is conceived as a scintillation hodoscope somewhat similar in function to the HADES Forward Wall. The aim is to design a detector which will be sufficiently radiation hard with fast response capable of free streaming readout required by CBM. Considering the planned schedule for the construction of FAIR, the goal is to leverage as much knowledge gained from the previous PSD project as possible and rely on proven technologies and solutions from FAIR-GSI. This mainly imprints on the chosen electronics and the readout system of the detector as it will be described below. At this point, the concept and prototypes of readout electronics, scintillation modules, and mechanical parts of the detector are available.

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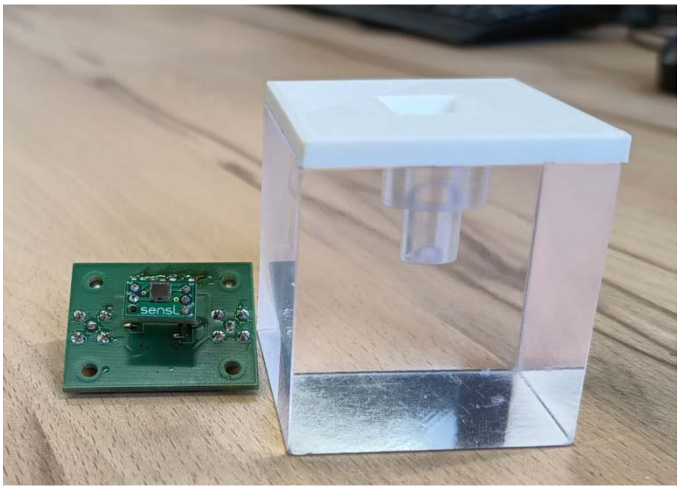
1. The design of FSD modules

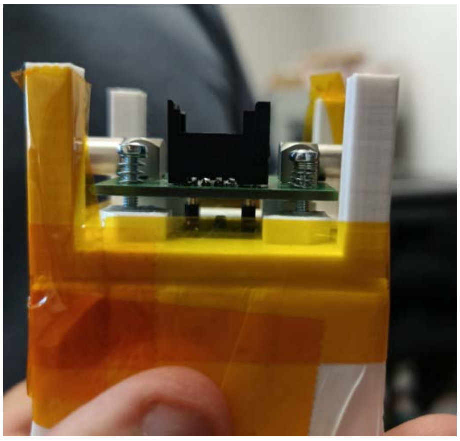
Since the design of the hardware goes in parallel with physics performance simulation, the final detector and scintillator pad geometries were not initially fixed. However, based on the experience of HADES experiment and previous PSD design it is expected that the detector will be approximately 1.6x1.3 m2 and the smallest modules could be around 5x5 cm^2 in the transverse direction.

Throughout the project three versions of the detector scintillator pads were designed and tested. All three version used polystyrene-based plastic scintillator from local Czech company (Nuvia). This allowed fast turnaround of assembly and testing. It should be noted that based on the simulations of expected radiation doses these scintillators should be able to withstand one period of two moths long data taking.

2. Read out via WLS+SiPM

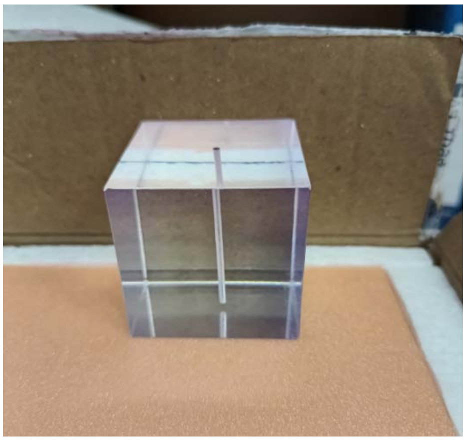
First two prototypes used readout of the scintillator by Silicon Photomultipliers (SiPM). They differed in the way the light was transported to the SiPMs. The first method involves placing SiPMs and preamplifiers directly on the face of the scintillator to achieve high light collection efficiency and fast readout. Since the area of the face of the scintillator is much larger that the active area of the SiPM (3x3mm^2) there would be a significant in homogeneity in the collected light yield depending on where the particle entered the scintillator. Based on the GEANT simulation it was decided to remove part of the scintillating material in front of the SiPM. This significantly improved the homogeneity of the light collection. The prototype with SiPM and preamplifier were directly connected to scintillator (two version with slightly different reflector):

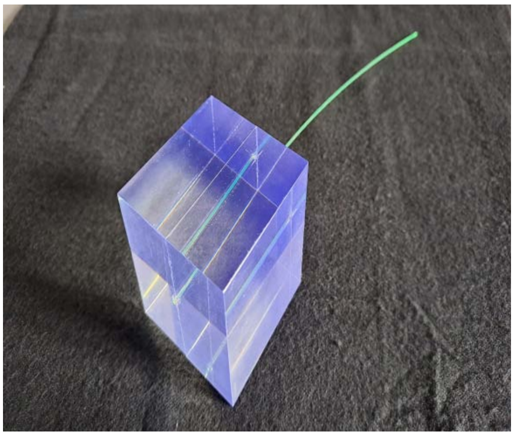




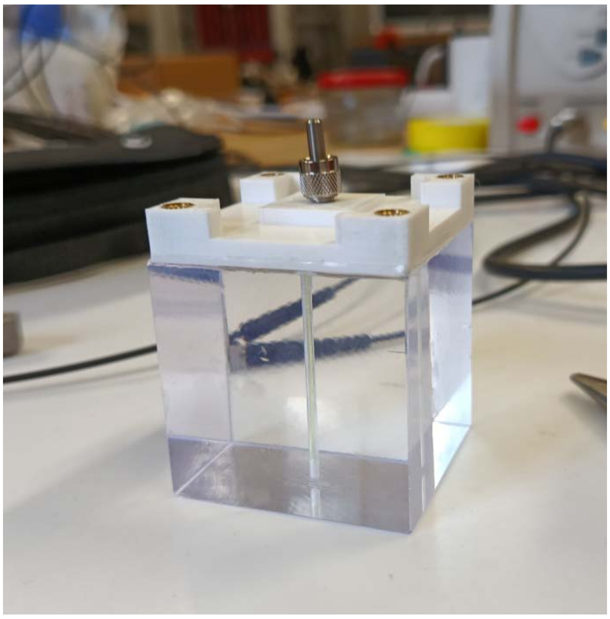
A white 3D printed reflector from PETG was used to hold the SiPM and preamplifier and connect it to the scintillator. The PETG is suitable for this tasks as similar solution has been previously used by other experiments. The prototype was tested using cosmics and showed good performance. At the same time as the results from simulations started to provide information about neutron flux in the region of the detector it was realized that the damage of the SiPM would likely be too high in the region close to the beam pipe unless the SiPM would be cooled which would be too complicated solution.

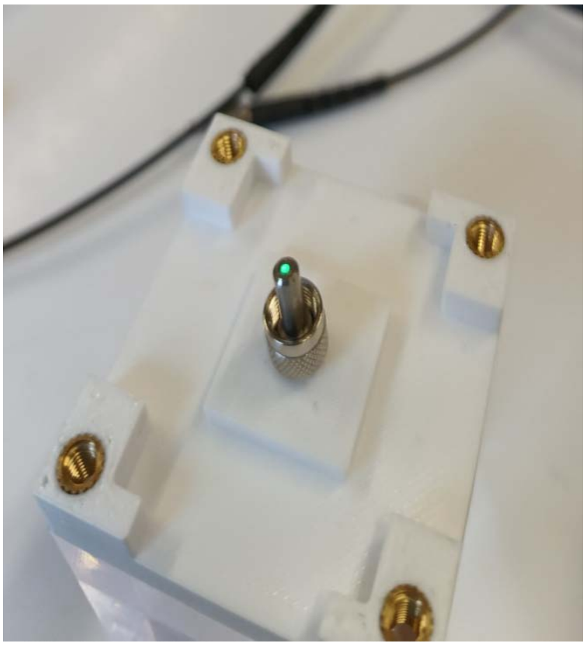
Second way how to readout the scintillators using SiPMs and at the same time protect them from the radiation damage is to readout the scintillator by wavelenght shifting fiber (WLS) then transfer the light into clear fiber and transport the light out of the radiation zone. Prototype with such a readout was developed and tested as well. Throughout the development various ways of embedding of the WLS into the scintillator were tried such as making a groove, embedding into a drilled hole or gluing into a drilled hole. Example of such prepared scintillator modules are here:





A common known problem of such a designs is the fragility of the WLS fiber which can easily be damaged at the point of insertion and the necessity to make a connection to the clear fiber. It was conceived that from construction point of view it would be advantageous to use standard commercially produced clear fibers with connectors. For this reason a prototype with WLS „pig tail“ with standard SMA connector was developed and tested which allows for direct connection to 1mm clear fiber patch cables (Thorlabs fibers were used for testing).





The SMA connector is embedded into the top PETG reflector which also serves as a mouting point for the module using thread inserts as can be seen from the top view. The clear fiber then carries signal to a readout/interface board on which SiPM are mounted under standard Amphenol SMA mounting receptacle. Hence no custom made connectors are necessary. The function of the readout/interface board will be explained later.

These prototypes were used for multiple test. We have tested a difference between light yield and mainly between its homogeneity using the setup below with movable platforms with electron source. These tests were carried out in a cooperation with the provider of the scintillator material

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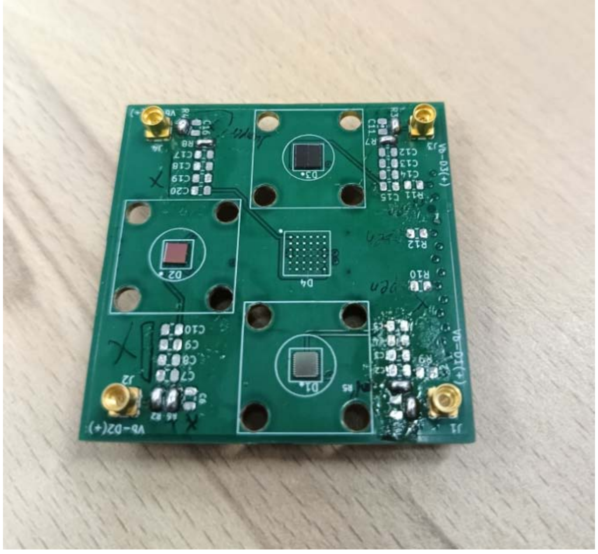
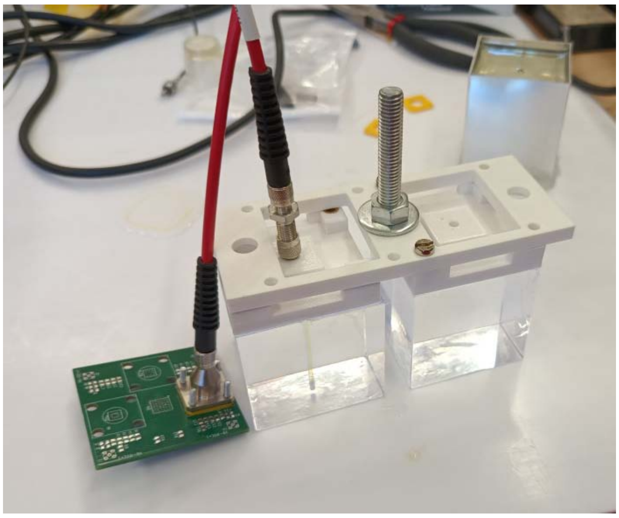
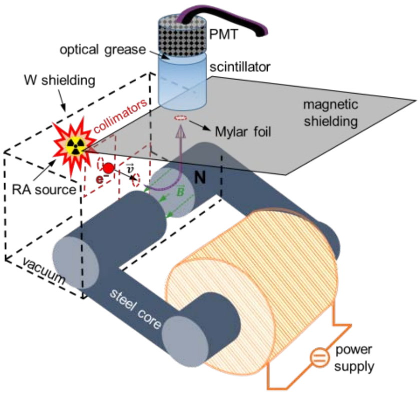
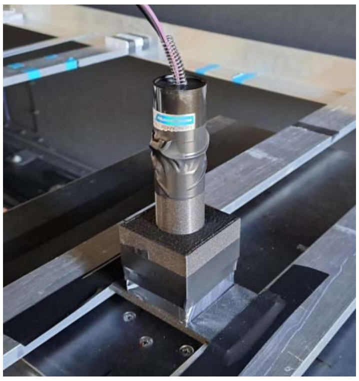




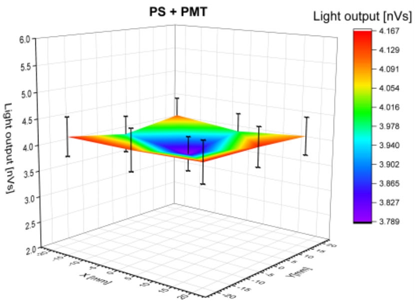


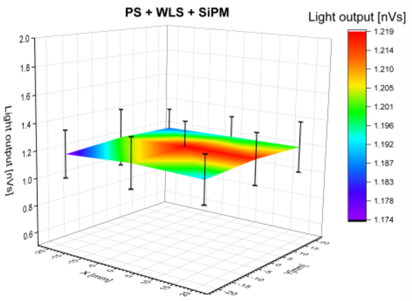


2.1. Read out via PMT’s

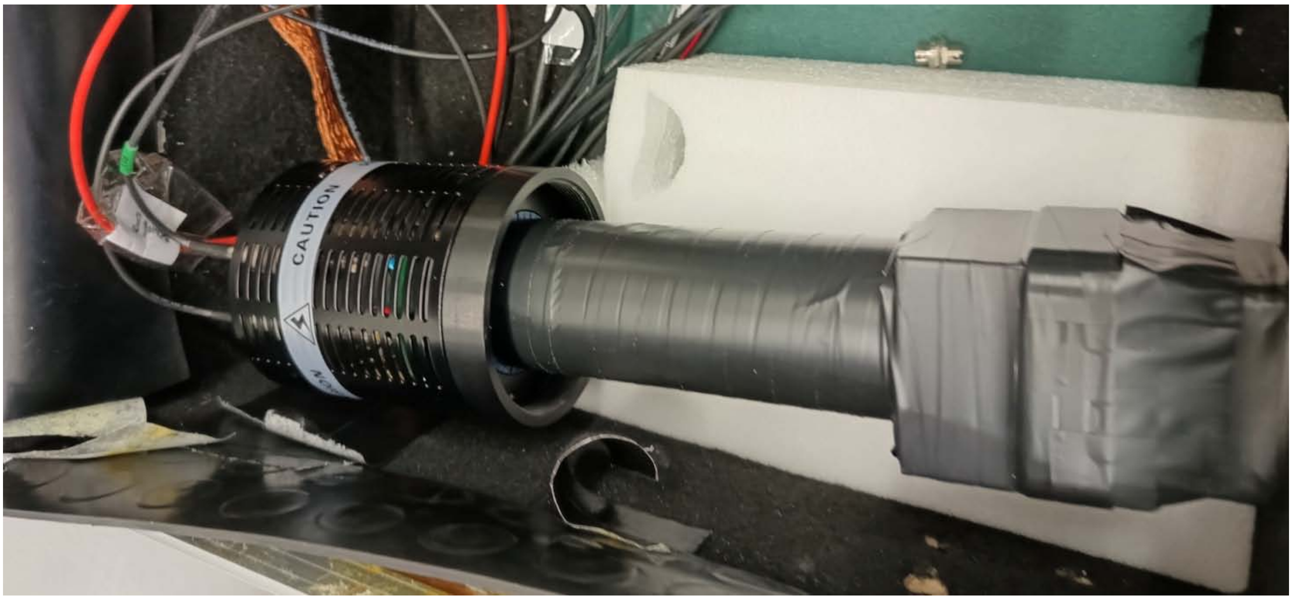
The results show a good homogeneity for both, sample with classical PMT and wavelentshifters+SiPM.

One should note that this is somewhat expected for the case when the scintillator and PMT are of comparable sizes. However, this procedure was tested and will be very important when studying the larger scintillator pads which are expected to be placed at the outer parts of the detector.





Additional test also included the testing of the effect of wrapping/coating the the scintillator with different reflective material. It was found out that (similarly as in literature), both teflon tape and paints based on titanium oxide work best and the difference between them is small.



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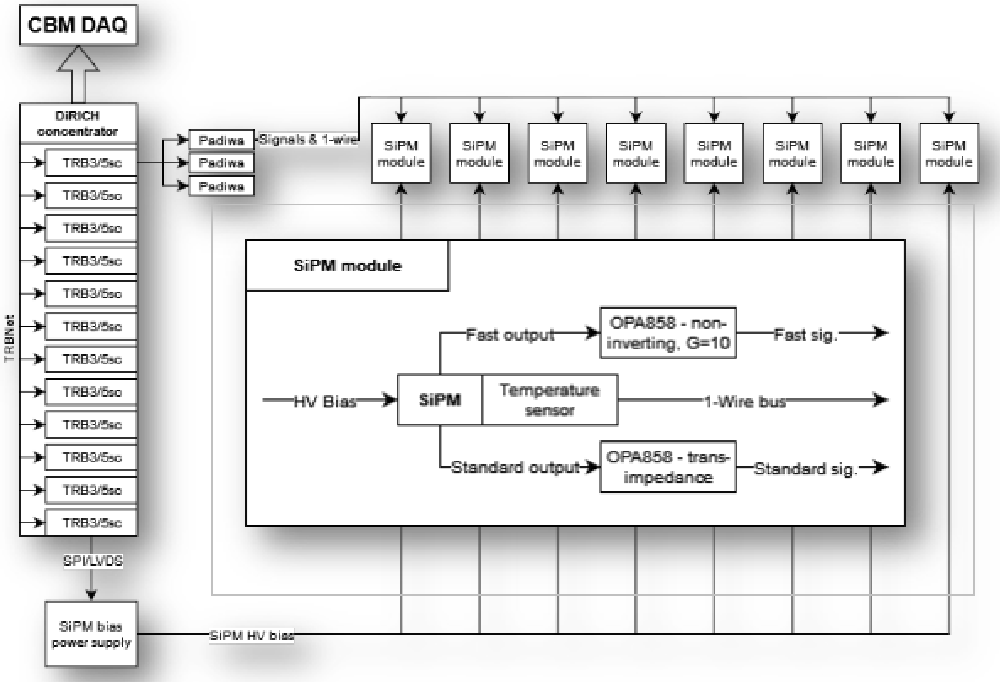
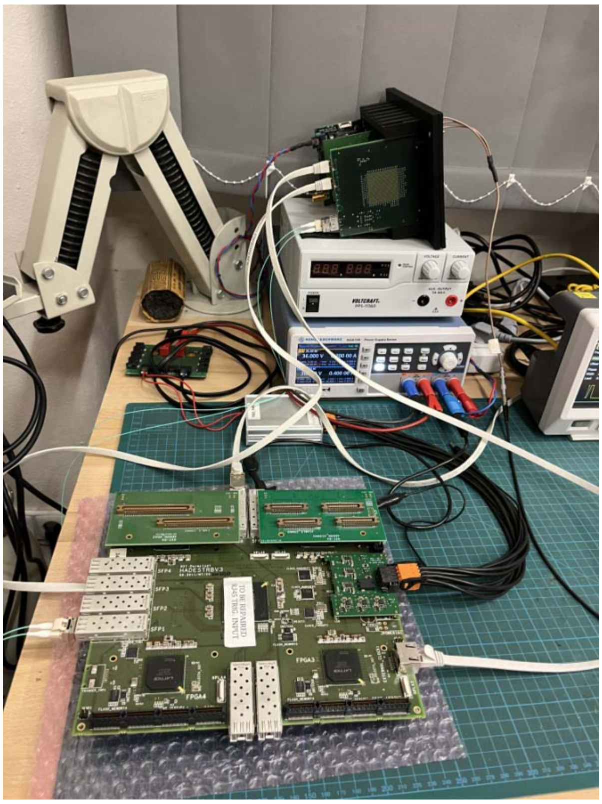
3. Read out electronics

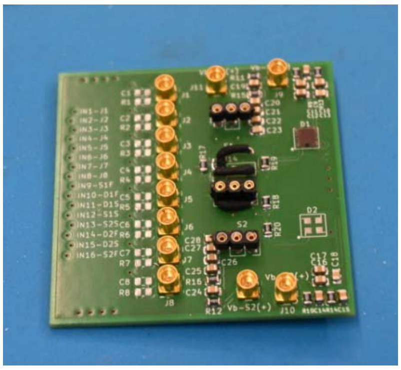
As it was stated the time schedule for the detector development and delivery is very tight. This means that a development of new custom readout electronics would not be feasible. For this reason we have instead decided to use an already existing solution based on combination of TRB and DiRCH(Padiwa) electronics which is a GSI in-house developed electronics which is readily available and is used for example in HADES experiment and also for CBM RICH detector. The scheme of the readout:

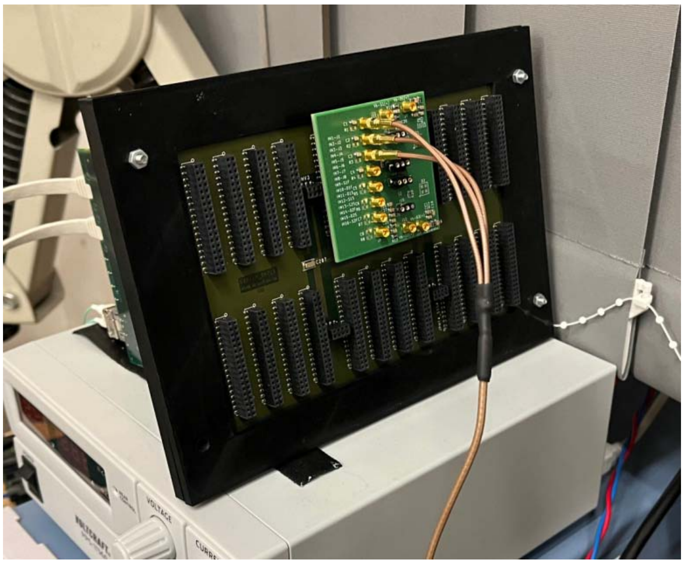


Compared to other detectors in the case of FSD the readout electronics has to be able to handle high hit rates up to couple of Mhz with signal of a very high dynamic range since it comes from ionizing particle from mip up to large nuclear fragments.

In order to test the functionality of the electronic design a local version of TRB+DiRICH setup was built by Czech group:







As can be seen in the top right picture an interface board was developed which can be connect to a distribution board which is used by HADES calorimeter, hence it is readily available. Multiple version of this interface boards were developed and tested. Some are only for connecting signal from classical photo multiplier. Other versions hold the SiPM photomultipliers as was shown above. In any case, no matter if the readout is done via classical photo-multipliers or SiPM the electronics setup is the same and the information about the deposited charge in the scintillator is read via time-over-treshold (ToT) measurement in the DiRICH module. It should be noted that such a readout has already been proven to work since it is very similar to the readout of HADES calorimeter. Hence there is a minimal need for significant development of new electronics. Since we expect large dynamic range of the output signal it is expected that the readout from single photomultiplier will have to be read out by two channels. This can be done by either splitting the output into two differently attenuated channels or in the case of classical PMT by reading out in addition to standard anode also last dynode. Test of a readout of PMT with the DiRICH via interface board to TRB was done by our collaborators in Wuppertal and the results show that such a readout setup will have a sufficiently good sensitivity to the charge

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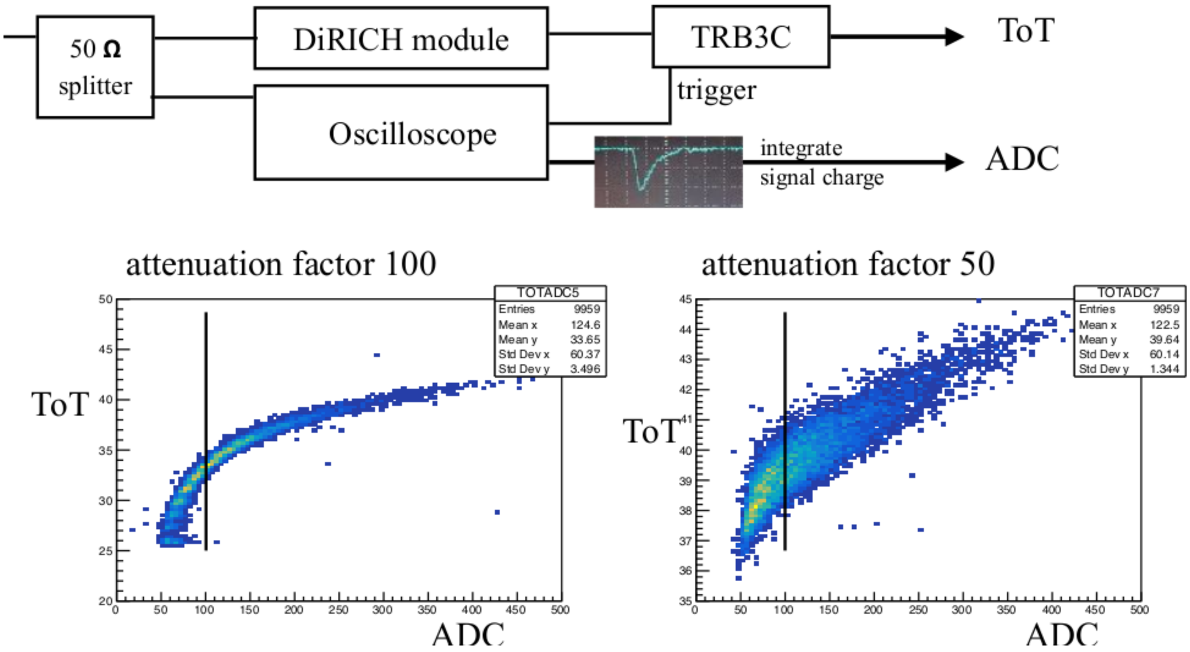
deposited in the scintillator. The test was done by comparing the ToT results from DiRICH to peak amplitude as measured by oscilloscope:



A similar setup with a laser generated pulses is now used by Czech group to study the perfomance and sensitivity of the whole setup to high frequency (up to MHz) pulses which simulat the expected event rate at the CBM.

Further testing of the modules is planned with the so called Mini-CBM (mCBM) experiment which is a precursor experiment at SIS18 where the main hardware and software components of the future CBM will be tested. The prototype FSD modules are expected to be placed close to the beam in order to test the readout under high frequency of hits. Mechanical holder was designed in order so that the modules could tested in the upcoming mini-CBM test run 2024. This will allow us to test the modules and mainly the readout under realistic condition which are otherwise hard to access.

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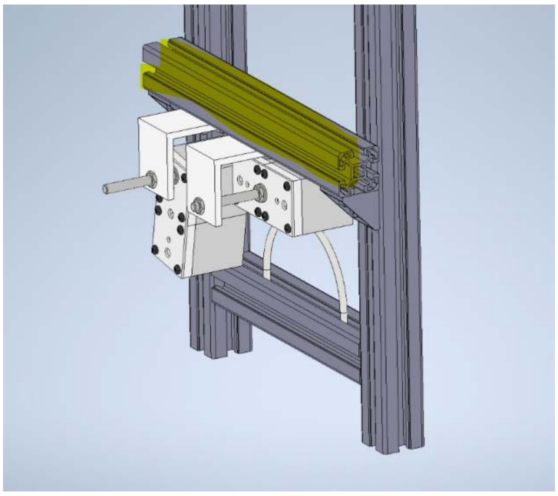
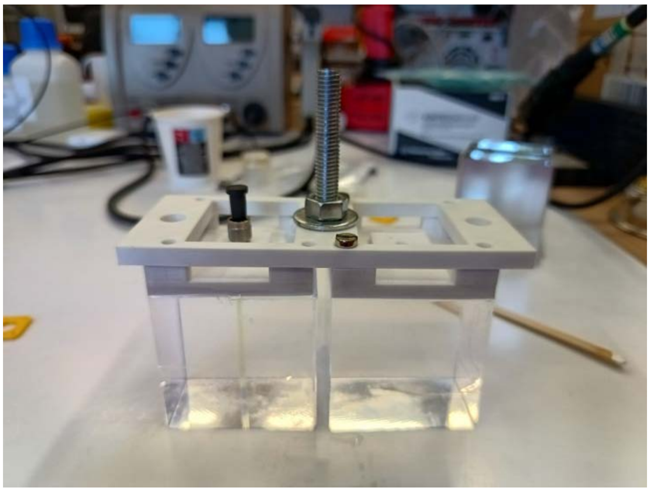
The mCBCM holder:





Summary and Outlook

Since February 2023 viable replacement for the PSD was developed by Czech group. This means we designed a detector which is able to measure collision centrality and event plane in harsh radiation conditions and with trigger-less readout. The Czech group decided to take this opportunity and propose to build low cost new scintillator-based forward detector with similar geometry as HADES FW, but with silicon photomultiplier (SiPM) readout, like STAR EPD detector. The properties of various scintillating materials were studied as well as their readout by embedded wavelength shifter with SiPM which was compared to direct readout by standart PMT. For this we cooperated with local developer of plastic scintillators NUVIATech (www.nuviatech-instruments.com). In the same time performance and radiation dose simulations were done assuming design shown on Fig.x.x. *Proposed plastic FSD for CBM consisting from three sizes of modules, Small: 4x4 cm2, Medium: 8x8 cm2 and Large: 16x16 cm2* Further these ideas and prototypes were tested on currently existing FW detector at HADES, which Czech group was preparing for forthcoming HADES experiment planned for spring of 2024.

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- CTU FNSPE Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering (Czech Republic)
- GSI-FAIR (Germany)
- Tuebingen University (Germany)
- Bochum University (Germany)

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[2] SENGER Peter, FRIESE Volfgang, CBM Collaboration: CBM Progress Report 2022 [online], 2. 5. 2023 cit[26. 01. 2023], page 140 – 141, GSI Darmstadt, doi: 10.15120/GSI-2023-00384, available on: https://repository.gsi.de/record/336786