Application for CBM/HADES detector tests in beam at COSY in Q2 and Q3/4 2020

- *Highlights from recent tests at COSY (11/2019)*
- *Beamtime application at COSY for Q2 and Q3/4 2020*

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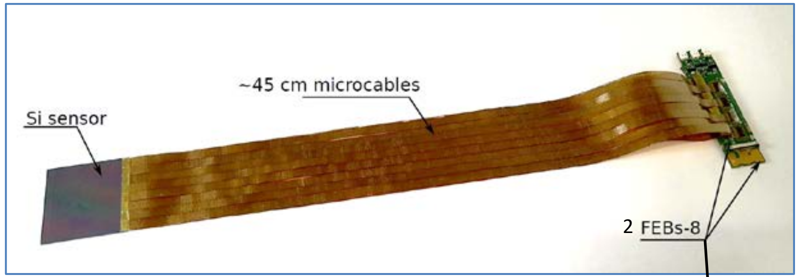
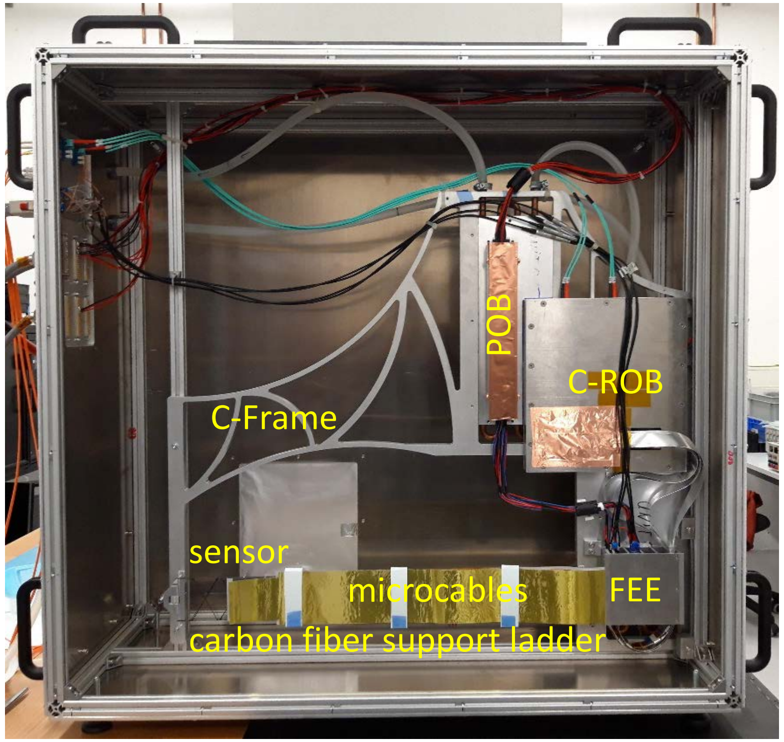
for CBM and HADES

11th COSY Beamtime Advisory Committee Meeting,
IKP FZ Jülich, 3+4 February 2020

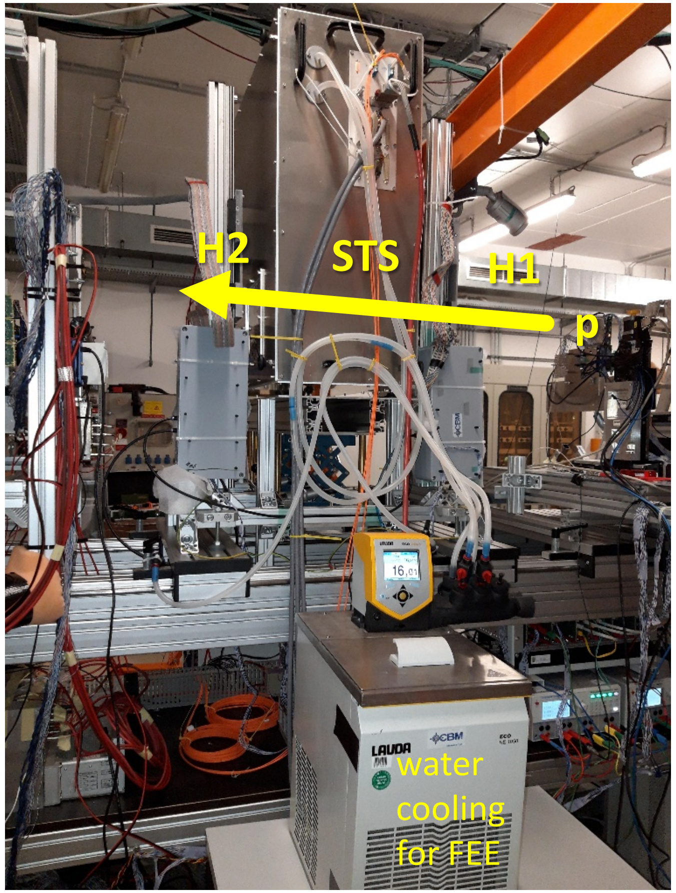
Highlight 1: Test of full CBM-STS module, 11/2019



- **STS module:**
  - final prototype silicon microstrip sensor
  - microcables, longest variant
- **FEB-8 with near-final ASIC:** STS-XYTER v2.1
- **Issues to test:**
  - ASIC performance, for final v2.2
    → Engineering Design Review 12/2019
  - connectivity and read-out integrity after full module assembly procedure, full sensor area read-out
    → Production Readiness Retreat 2/2020



STS test system
+ LV/HV powering
+ free-streaming DAQ



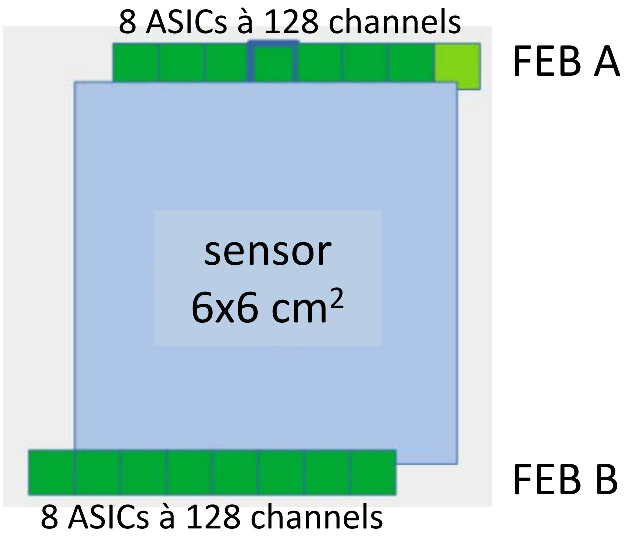
set up on beam table in JESSICA cave

Results:

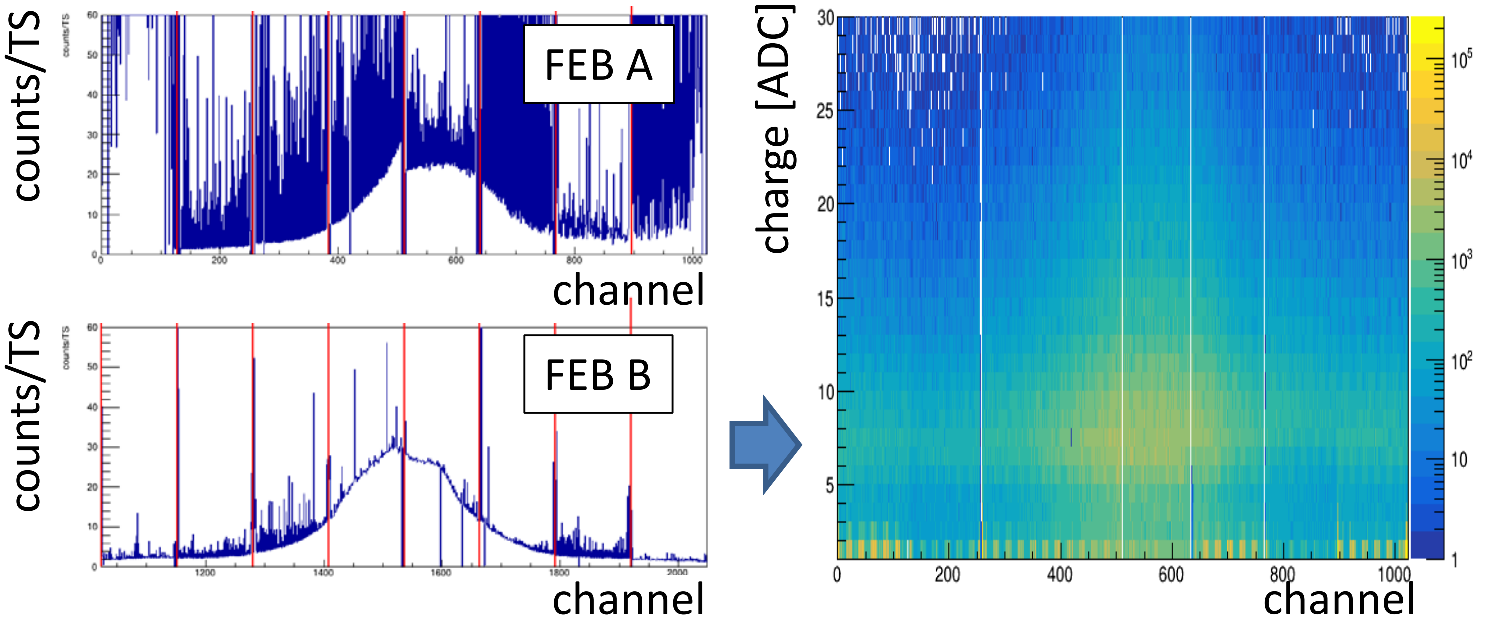
Proton Beam (p = 2.7 GeV/c) directly on sensor:

- X-Y scan of sensor position wrt. beam
- beam intensity scan
- various electronics settings

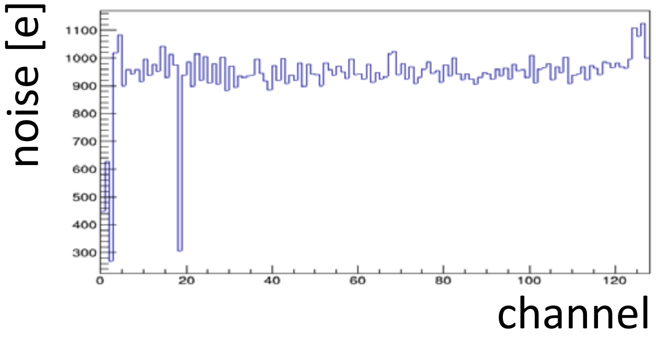
(1) First operation of a fully functional and noise-optimized module in beam



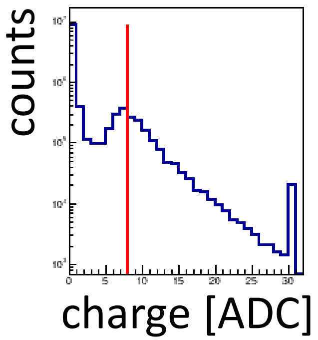
(2) Beam profile in rate and charge measurements across full sensor



(3) Low noise ~ 1000 e^-



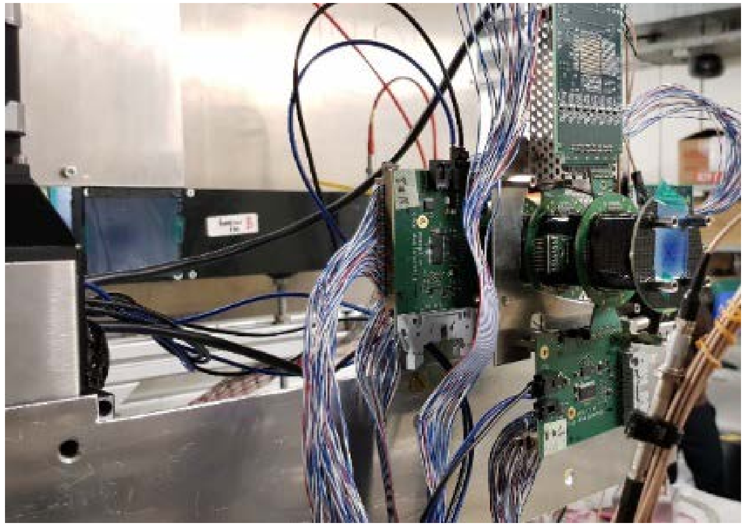
(4) Signal in one ASIC



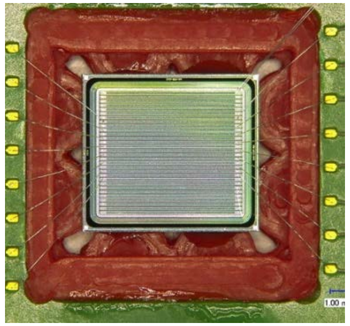
Detailed analysis in progress:

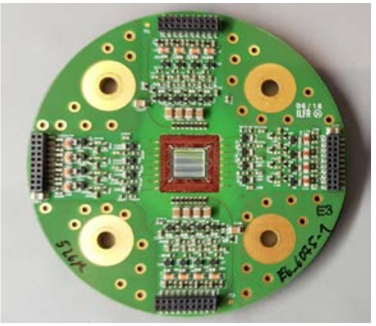
- *signal calibration*
- *signal-to-noise*
- *detection efficiency*

Highlight 2: Test of HADES UFSD, 11/2019

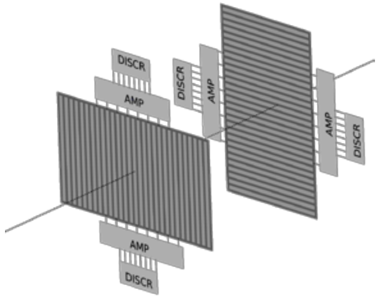


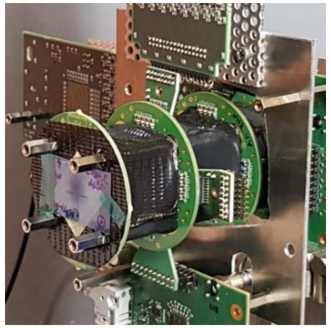
Test setup in JESSICA cave





Ultra-fast silicon detectors





UFSD HADES team

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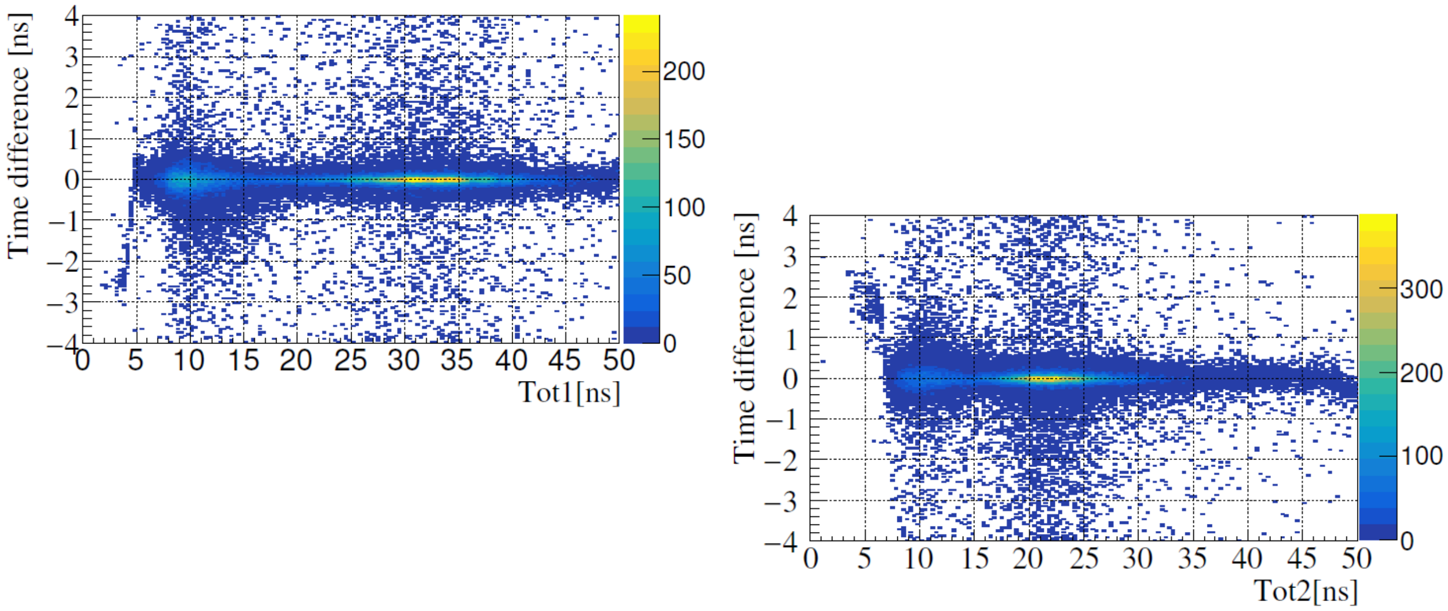
Goals and achievements :

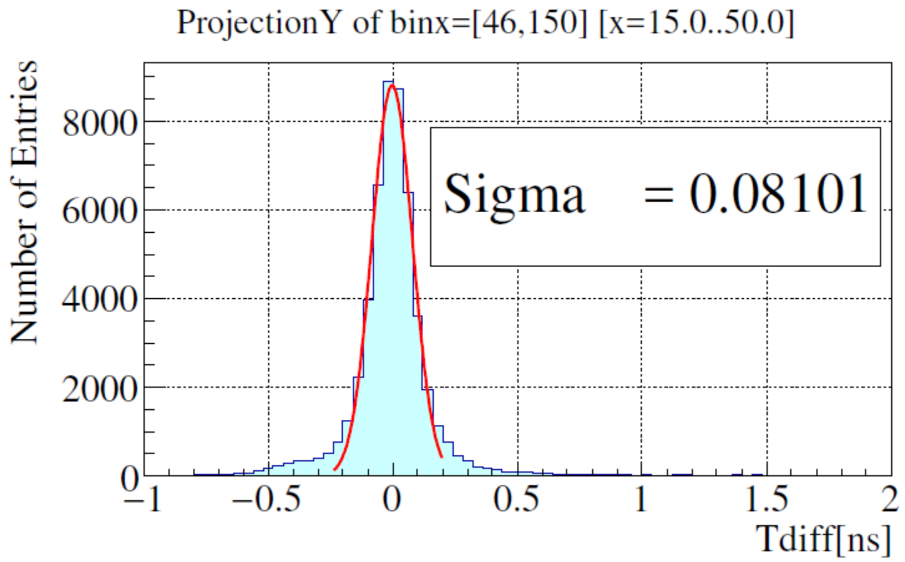
Goals:
- Time precision determination
- Long term stability test

System based on a leading edge readout concept → Walk correction is essential
- Time-of-Arrival, Time-over-Threshold measurements available for Walk

Time difference in the two coordinates:



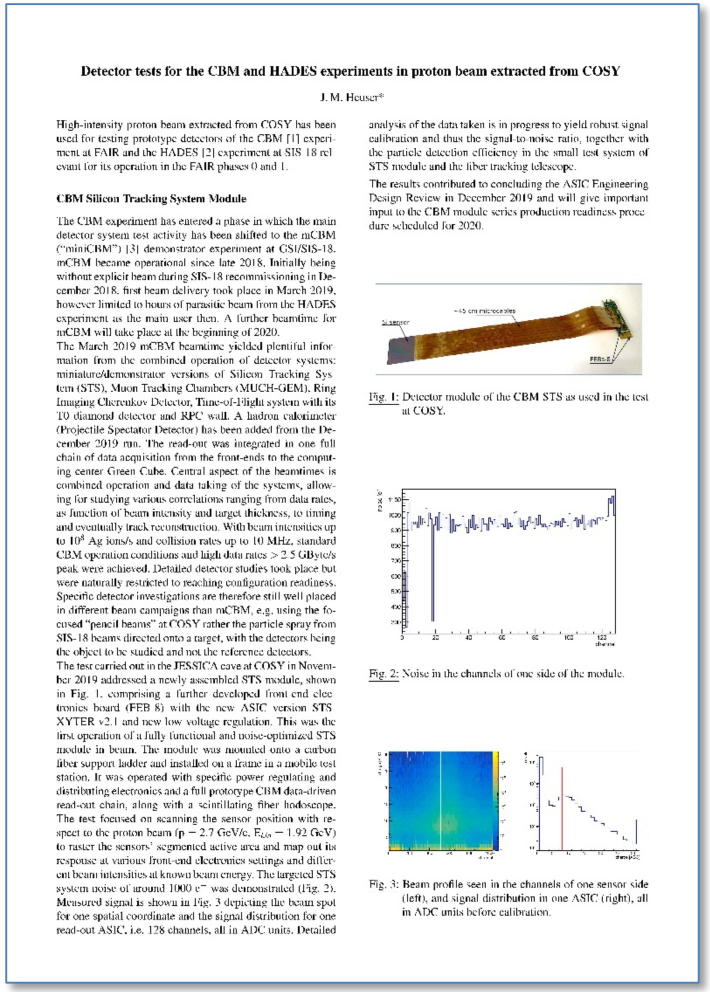
Results:



Time precision, 81 ps/1.4 = 58 ps

This is the performance at room temperature without cooling !

Write-up for the IKP Annual Report



Detector tests for the CBM and HADES experiments in proton beam extracted from COSY

J. M. Heuser*

High-intensity proton beam extracted from COSY has been used for testing prototype detectors of the CBM [1] experiment at FAIR and the HADES [2] experiment at SIS 18 relevant for its operation in the FAIR phases 0 and 1.

CBM Silicon Tracking System Module

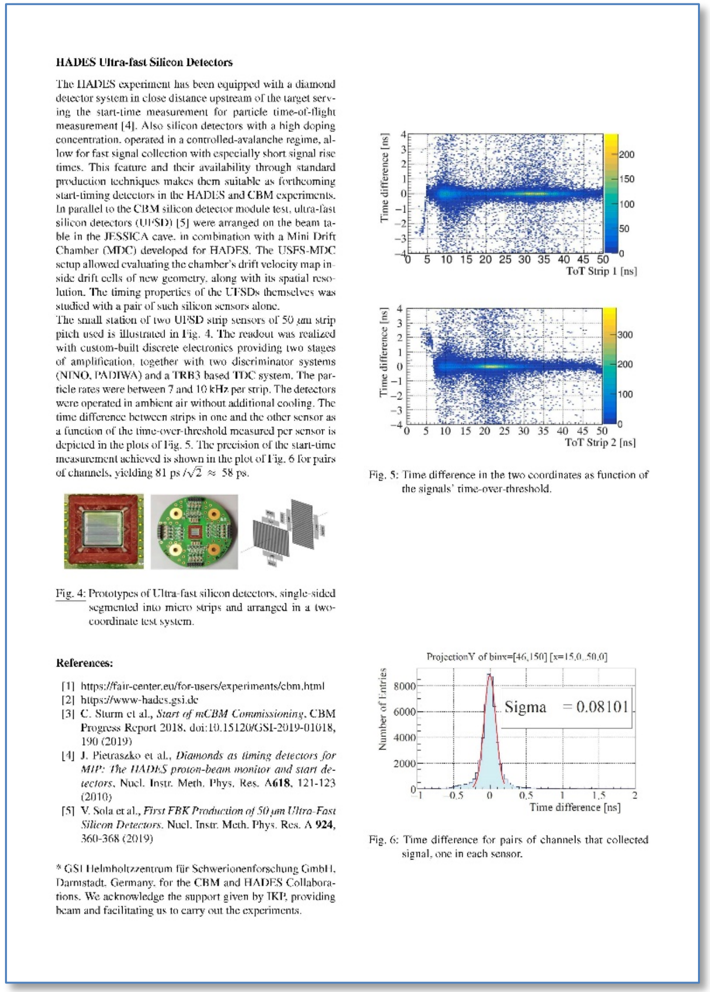
The CBM experiment has entered a phase in which the main detector system test activity has been shifted to the mCBM ("miniCBM") [3] demonstrator experiment at GSI/SIS-18. mCBM became operational since late 2018. Initially being without explicit beam during SIS-18 recommissioning in December 2018, first beam delivery took place in March 2019, however limited to hours of parasitic beam from the HADES experiment as the main user then. A further beamtime for mCBM will take place at the beginning of 2020.
The March 2019 mCBM beamtime yielded plentiful information from the combined operation of detector systems: miniature/demonstrator versions of Silicon Tracking System (STS), Muon Tracking Chambers (MUCH-GEM), Ring Imaging Cherenkov Detector, Time-of-Flight system with its T0 diamond detector and RPC wall. A hadron calorimeter (Projectile Spectator Detector) has been added from the December 2019 run. The read-out was integrated in one full chain of data acquisition from the front-ends to the computing center Green Cube. Central aspect of the beamtimes is combined operation and data taking of the systems, allowing for studying various correlations ranging from data rates, as function of beam intensity and target thickness, to timing and eventually track reconstruction. With beam intensities up to 10^8 Ag ions/s and collision rates up to 10 MHz, standard CBM operation conditions and high data rates > 2.5 GByte/s peak were achieved. Detailed detector studies took place but were naturally restricted to reaching configuration readiness. Specific detector investigations are therefore still well placed in different beam campaigns than mCBM, e.g. using the focused "pencil beams" at COSY rather the particle spray from SIS-18 beams directed onto a target, with the detectors being the object to be studied and not the reference detectors.
The test carried out in the JESSICA cave at COSY in November 2019 addressed a newly assembled STS module, shown in Fig. 1, comprising a further developed front-end electronics board (FEB 8) with the new ASIC version STS XYTER v2.1 and new low voltage regulation. This was the first operation of a fully functional and noise-optimized STS module in beam. The module was mounted onto a carbon fiber support ladder and installed on a frame in a mobile test station. It was operated with specific power regulating and distributing electronics and a full prototype CBM data-driven read-out chain, along with a scintillating fiber hodoscope. The test focused on scanning the sensor position with respect to the proton beam (p = 2.7 GeV/c, E_{kin} = 1.92 GeV) to raster the sensors' segmented active area and map out its response at various front-end electronics settings and different beam intensities at known beam energy. The targeted STS system noise of around 1000 e^- was demonstrated (Fig. 2). Measured signal is shown in Fig. 3 depicting the beam spot for one spatial coordinate and the signal distribution for one read-out ASIC, i.e. 128 channels, all in ADC units. Detailed analysis of the data taken is in progress to yield robust signal calibration and thus the signal-to-noise ratio, together with the particle detection efficiency in the small test system of STS module and the fiber tracking telescope.

The results contributed to concluding the ASIC Engineering Design Review in December 2019 and will give important input to the CBM module series production readiness procedure scheduled for 2020.

Fig. 1: Detector module of the CBM STS as used in the test at COSY.

Fig. 2: Noise in the channels of one side of the module.

Fig. 3: Beam profile seen in the channels of one sensor side (left), and signal distribution in one ASIC (right), all in ADC units before calibration.



HADES Ultra-fast Silicon Detectors

The HADES experiment has been equipped with a diamond detector system in close distance upstream of the target serving the start-time measurement for particle time-of-flight measurement [4]. Also silicon detectors with a high doping concentration, operated in a controlled-avalanche regime, allow for fast signal collection with especially short signal rise times. This feature and their availability through standard production techniques makes them suitable as forthcoming start-timing detectors in the HADES and CBM experiments. In parallel to the CBM silicon detector module test, ultra-fast silicon detectors (UFSD) [5] were arranged on the beam table in the JESSICA cave, in combination with a Mini Drift Chamber (MDC) developed for HADES. The USFS-MDC setup allowed evaluating the chamber's drift velocity map inside drift cells of new geometry, along with its spatial resolution. The timing properties of the UFSDs themselves was studied with a pair of such silicon sensors alone.
The small station of two UFSD strip sensors of 50 μm strip pitch used is illustrated in Fig. 4. The readout was realized with custom-built discrete electronics providing two stages of amplification, together with two discriminator systems (NINO, PADIWA) and a TRB3 based TDC system. The particle rates were between 7 and 10 kHz per strip. The detectors were operated in ambient air without additional cooling. The time difference between strips in one and the other sensor as a function of the time-over-threshold measured per sensor is depicted in the plots of Fig. 5. The precision of the start-time measurement achieved is shown in the plot of Fig. 6 for pairs of channels, yielding 81 ps $/\sqrt{2} \approx$ 58 ps.

Fig. 4: Prototypes of Ultra-fast silicon detectors, single-sided segmented into micro strips and arranged in a two-coordinate test system.

Fig. 5: Time difference in the two coordinates as function of the signals' time-over-threshold.

Fig. 6: Time difference for pairs of channels that collected signal, one in each sensor.

References:

[1] https://fair-center.eu/for-users/experiments/cbm.html
[2] https://www-hades.gsi.de
[3] C. Sturm et al., *Start of mCBM Commissioning*, CBM Progress Report 2018, doi:10.15120/GSI-2019-01018, 190 (2019)
[4] J. Pietraszko et al., *Diamonds as timing detectors for MIP: The HADES proton-beam monitor and start detectors*, Nucl. Instr. Meth. Phys. Res. A**618**, 121-123 (2010)
[5] V. Sola et al., *First FBK Production of 50 μm Ultra-Fast Silicon Detectors*, Nucl. Instr. Meth. Phys. Res. A **924**, 360-368 (2019)

* GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany, for the CBM and HADES Collaborations.

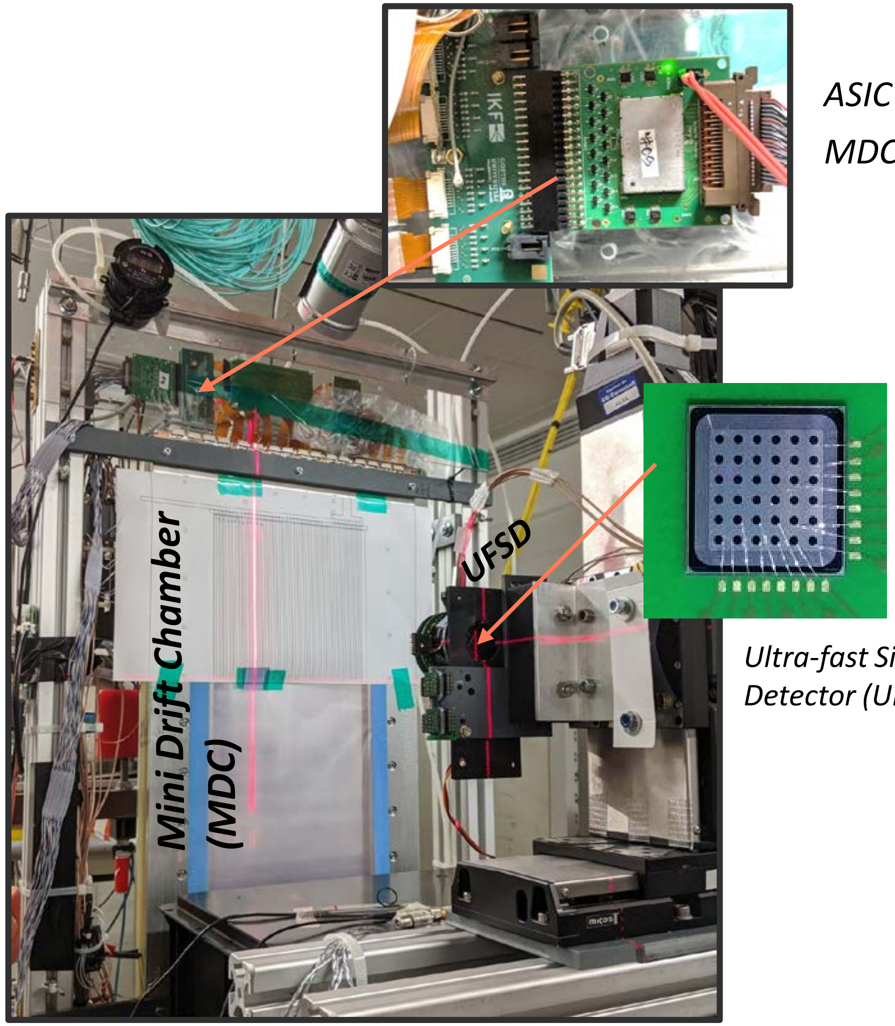
We acknowledge the support given by IKP, providing beam and facilitating us to carry out the experiments.

Beamtime application: for the period Q2 and Q3/4 2020

Aim: We apply for two weeks of beamtime at COSY/JESSICA cave to enable CBM and HADES groups to test detector systems under beam particle load.

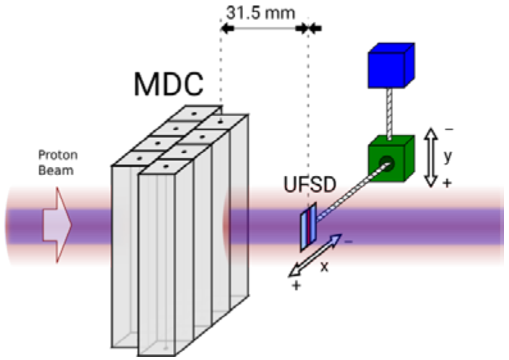
- The *proposals P1* (HADES MDC) and *P2* (HADES UFSD) are refined tests of modern high-rate detectors equipped with upgraded electronics (in particular for MDC, in two packaging variants), important to HADES operation in FAIR phases 0 and 1.
- The test *proposal P3* (CBM MAPS) is to be carried out for the first time in the high-intensity proton beam at COSY, focussing on high particle densities at close to minimum ionizing energies similar to the CBM collision environment, important to future CBM MVD/Silicon Tracker development. Foreseen in parallel to *proposal P2*.

Proposal P1: HADES MDC



ASIC test board for MDC FEE upgrade

Ultra-fast Silicon Detector (UFSD)



Setup:

- compact, 1m along beam axis
- Mini Drift Chamber (MDC), already used at COSY twice
  - 50x20 cm^2 active area
  - 2 drift cell layers, each 80 cells
  - drift gas Ar/CO2 (70/30)
- reference / tracking by Silicon strip detector (UFSD):
  - 36 strips, active area: 4.5 x 4.5 mm^2
  - time precision < 100 ps
  - movable (µm step precision)

The result of both tests are decisive for the MDC FEE upgrade project, which is mandatory to run HADES at even higher beam intensities at FAIR phase 0 and phase 1.

Subject:
Validating the new HADES MDC FEE based on the PASTTREC chip:

1) PASTTREC glued and bonded to PANDA Analog board, generic in-beam studies on S/N, time precision and efficiency: **done 2019**

2) PASTTREC packaged and integrated in modified PANDA analog board: **Q2 2020**

3) PASTTREC packaged and integrated to new HADES-MDC frontend board: **Q3/4 2020**

→ 2 beamtime campaigns in 2020, of 1 week each

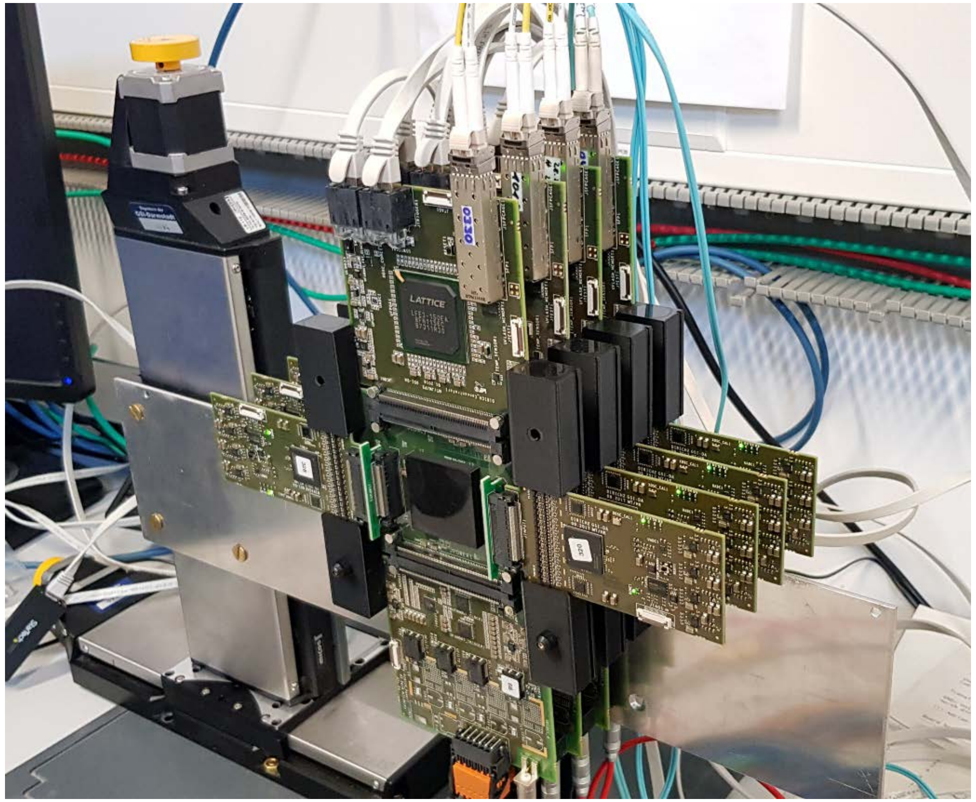
Proposal P2: HADES UFSD

Novelty:
- New sensor generations available, inactive space between stripes significantly reduced → almost to 0% !
  - Sensors available now – setup in preparation
- Next version of the readout electronics in preparation,
  - High channel granularity - discrete
  - FAST ASIC, Ampl. + Discriminator (20 channels) 1.6 mm x 5 mm, available, ready for usage in February 2020

Setup:
- Telescope consists of two UFSD sensors
- Two stages of amplification (custom design, W.Koenig, HADES)
- NINO based discriminator system
- TRB3 based TDC system

Running conditions:
- Operation in air, without the need for cooling!
- Beam: p@1.92 GeV kinetic energy from COSY

2 beamtime campaigns in 2020 of 1 week each together with *P1* – HADES MDC test

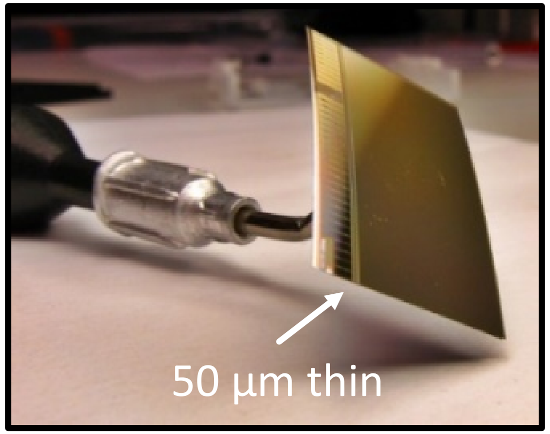


New UFSD test system under preparation at GSI Detector lab

Proposal P3: CBM MAPS System Test (I)

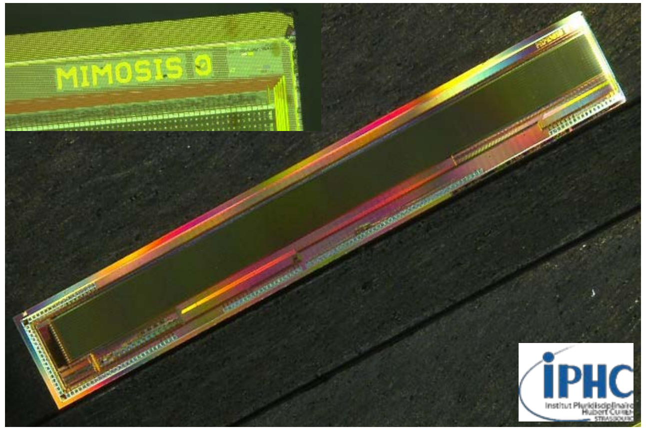
CBM-MVD pixel sensor, in close cooperation with

2010 – MIMOSA-26



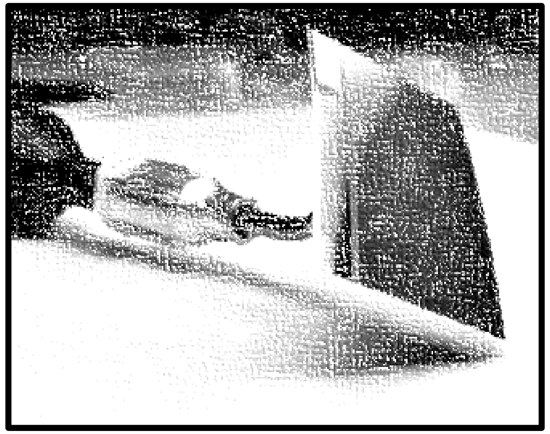
8k frames/s, pixels 18.4 × 18.4 µm²

2019 – MIMOSIS-0



200k frames/s – demonstrator

Q2 – 2020 MIMOSIS-1



200k frames/s – first full-size sensor for the future MVD

CMOS Monolithic Active Pixel Sensors:

- Invented for digital cameras (2D imagers)
- Modified for charged particle tracking since 1999 (thin!)
- CBM-MVD design goal: 200k frames/s, 10 MHz/cm² hit rate
- Presumably reached with MIMOSIS-1 (2020)
- Calls for systematic sensor and system tests

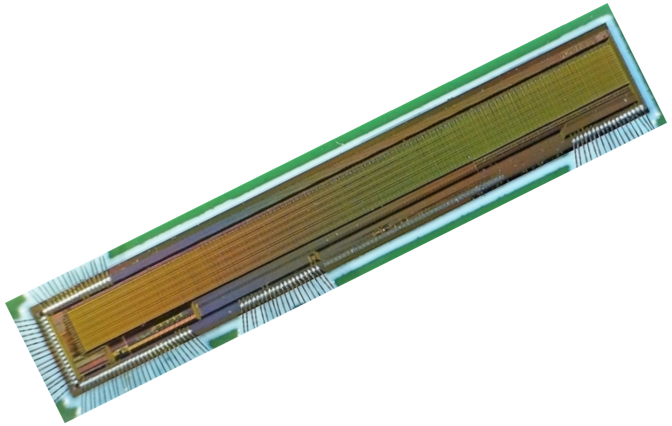
$\Rightarrow$ High-flux MIP beam required for test

Beam extracted from COSY is well suited:

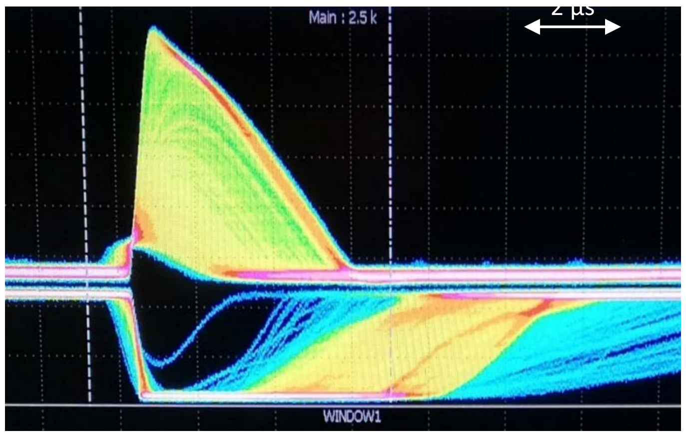
- Protons around MIP energies
- Particle hit rates 1-10 MHz/cm²

Proposal P3: CBM MAPS System Test (II)

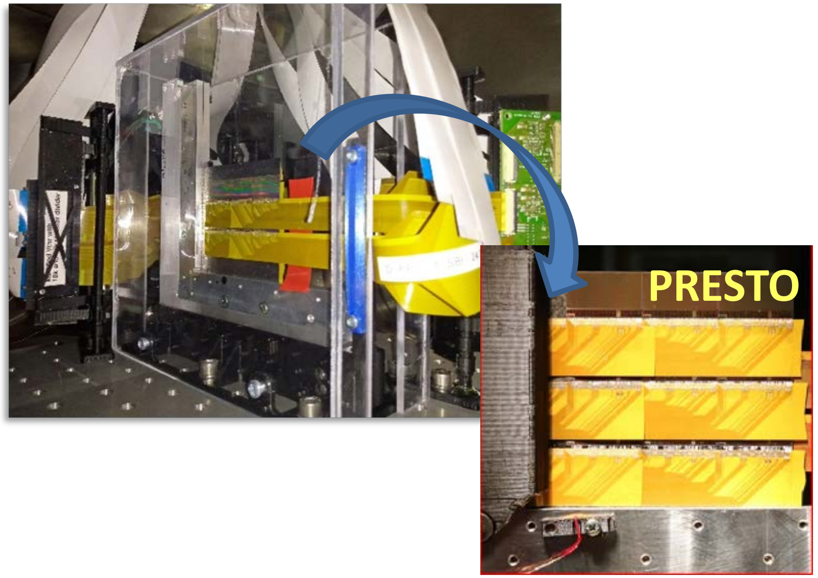
2019 – MIMOSIS-0



Response to ^{55}Fe (5.9 keV X-rays) verified in the laboratory



MIMOSIS-1 prototype station, based on the precursor station „PRESTO“, currently running 24/7



System test with MIMOSIS-1:

- First full-size sensor (5 cm²) based on the successful MIMOSIS-0 prototype, available in Q2 2020
- Immediate integration following the PRESTO concept
- Final goal: Compact telescope setup with minimum 2 stations

Beam tests at COSY:

- 2020, Q3/4: Sensor & test system **comissioning** (one station, parasitic to P2 – HADES-UFSD)
- 2021 – High-rate tests with a compact telescope setup

EU project CREMLINplus

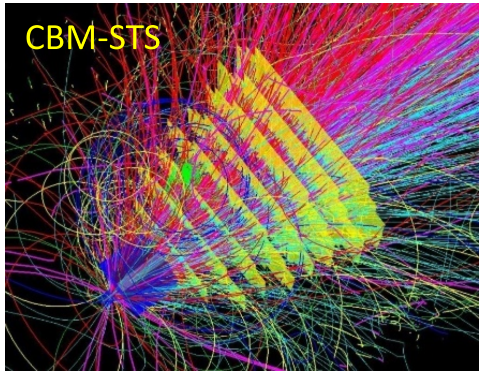
Cremlin Connecting Russian and European Measures for Large-scale Research Infrastructures

European Commission

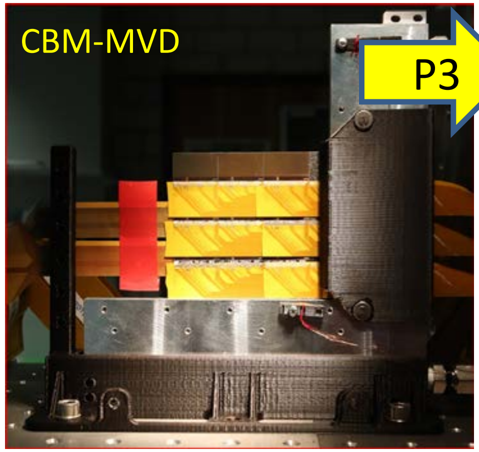
Science Cooperation between European Research Infrastructures and the Russian megascience projects (NICA, PIK, USSR, SCT and EXCELS)

Kick-Off: 19-20 Feb. 2020, DESY

Proposal approved: 4-year-project – starting 1.2.2020, **Total Budget: 25 M€**
Consortium: 35 participants from 12 countries - 25 European laboratories, 10 Russian laboratories
10 working packages (WPs), GSI/FAIR and JINR involvement in WP2 and WP7



WP2: Collaboration with NICA - Development of instrumentation for NICA and FAIR/CBM
(WP leader: J. Eschke)
Engineering and construction of fast detectors,
Development of high rate data acquisition chain and software packages for simulation and data analysis, PSD, beam pipe design
Budget 4.61 M€
Participants: JINR (9 FTE), FAIR (8.3 FTE), U Tübingen (1 FTE), WUT Warsaw (2 FTE), Wigner Budapest (2 FTE), MEPhI (4 FTE), INR Moscow (1 FTE), NPI Prague (2 FTE)



P3

WP7: Joint development of detector technologies
Develop a beyond state of the art CMOS pixel sensors (MAPS) for high-rate Silicon trackers for several particle physics and heavy-ion research communities in Europe and Russia for the potential upgrade of many experimental setups (WP leader: C.J. Schmidt)
Development of neutron detectors, detector school at BINP
Budget 1.8 M€ (~1.0 M€ for MAPS [CBM Institutes only])
Participants: JINR (0,75 FTE), FAIR (0,8 FTE), DESY (0,52 FTE), U Frankfurt (0,75 FTE), IPHC Strasbourg (1 FTE), KINR Kiev (0,75 FTE), ESS (0,75 FTE), PNPI (0,38 FTE), JINR (0,38 FTE), BINP

$\Rightarrow$ Beam tests @ COSY

Beamtime application at COSY for Q2 and Q3/2020

Total number of particles and type of beam (p,d,polarization)	Momentum range (MeV/c)	Intensity or internal reaction rate (particles per second) minimum needed	Intensity or internal reaction rate (particles per second) maximum useful
p	**p ~ 3000**	**~ $10^4 – 10^6$**	**up to 10^8**
Experimental area	Safety aspects (if any)	Earliest date of installation	Total beam time (No. of shifts)
JESSICA Cave	**None**	**one week in Q2, 2020 (MDC, UFSD)** + **one week in Q3/4, 2020 (MDC, UFSD, MAPS, [STS])**	**2 × 7 days** around the clock

- Experimental set-up:
  - JESSICA cave
  - test beam table installed
  - additional space in rack room close to the JESSICA door
  - “Wasaquarium” as control room
  - CO_2 gas bottle for MDC test
  - Ar gas bottle will be brought from GSI
- During the tests, access to the cave will be required in order to reconfigure the set-up, days and nights. The participating teams will be of moderate size in personnel.
- Delivery and installation of equipment during the week prior to the beam time could be helpful and efficient for the timely start of using the beam.