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A Free-Streaming Readout for the CBM Time of Flight wall

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The Compressed Baryonic Matter (CBM) experiment will be built at the new Facility for Antiproton and Ions Research (FAIR) in Darmstadt, Germany. This fixed target experiment will investigate Heavy Ion collision up to 35 AGeV for Au beams and 89 GeV for protons beams, with high interactions rates: up to 10MHz in Au+Au collision at 25 AGeV. To avoid the limitations of triggered systems at such rates, most CBM detectors will operate a free-streaming readout. Charged hadron identification, especially a Kaon-Pion separation up to momenta of 3.5 GeV/c, is provided in CBM by a Time of Flight (ToF) wall placed 10m behind the target. This requires a time resolution for the full ToF system in the order of 80ps combined with a high efficiency. To achieve these performances, the wall is made of MRPC detectors with electrodes resistive material and channel layout both adapted to the particle flux found in the 2.5°to 25°polar angle range. This design induces hit rates up to 250 kHz/channel in some of the detectors and a total channel count between 70k and 120k. Because of those characteristics, the electronics needs a time resolution of 30 to 40ps, Time over Threshold capability and free-streaming readout. This free-streaming mode also requires a special care in the synchronization of the system and in the data analysis. A first prototype of the complete high resolution, free-streaming chain was built in Heidelberg, from differential detector to dedicated software, and later tested at COSY in Jülich. It will be described in this contribution as well as its first in-beam performance.

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1. The CBM experiment and its Time of Flight wall

The Compressed Baryonic Matter (CBM) experiment is an heavy-ion spectrometer which will be installed at the new Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. Its goal is to investigate the properties of strongly interacting matter in extreme conditions, more specifically the high baryionic densities obtained in heavy-ion collisions at energies between 4 to 45 AGeV. For this it will measure with high precision and high statistics rare probes, using high interactions rates: up to 10MHz in Au+Au collision at 25 AGeV[1].

It will be composed of a central Silicon Tracking System (STS) based on micro-strip silicon detectors, placed close to the target in the field of a supra-conducting magnet. Several other detectors will be placed outside of the magnet in forward direction: first a Ring Imaging Cherenkov detector (RICH) and Transition Radiation Detector (TRD) stations for electrons identification, then the Time of Flight (ToF) wall for hadrons identification and finally an Electro-magnetic Calorimeter (ECAL). An alternative setup comprises an active muon absorber (MUCH) instead of RICH.

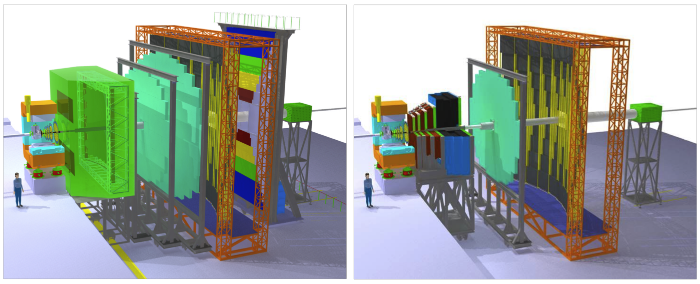

Figure 1: CBM setup: left is electron version, right us muon version. From left to right in each picture: STS, RICH/MUCH, TRD, ToF, ECAL

The ToF wall will be based on Multi-gap Resistive Plate Chambers (MRPCs), mostly Multi-strips MRPCs (MMRPCs), covering polar angles between $2.5^\circ$to 25°, at a distance from the target of 10m. The particle flux in this area ranges from a maximum of 25 kHz/cm^2 to 1 kHz/cm^2. The chambers will be assembled in 81 Super-Modules (SM), with MRPCs resistive materials and channel layout adapted in each SM to its maximal particle flux. To achieve the goal of separating kaons, protons and pions up to momenta of 3.5GeV/c, a full system time resolution of better than 80ps is needed, which translate in a contribution of the electronics lower than 40ps. The expected particle flux translate in hits rates up to 250 kHz/electronic channel for the current channel design, where a total channel count between 70k and 120k channels is reached.

2. Event-driven readout concept

In most physic cases where the high rate is needed, no easy/fast trigger signature is available, requiring the reconstruction of a big part of the event before online selection. The data size, processing power and time needed to build such a trigger and propagate it backward to the front-end are not compatible with the high rate. For this reason the CBM experiment will be operated in data-driven (also called event-driven) mode. In this readout concept, all data generated at detector level are transmitted as fast as possible toward event building, and with the minimal amount of backward propagating signals as possible.

At detector level, this is realized by having only self-triggering front-end electronics (FEE), where all hits passing the threshold and matching local conditions like signal presence on both ends of a strip are accepted, digitized and time-stamped. The time-stamp has to be against either the main CBM clock or a coupled clock to allow hit matching and event building in later stages.

The readout and transport chain has then to be free-streaming between the FEE and the event builder located in a building a few hundreds meter away. This means that each layer transmits continuously the data in its buffers toward the upper level. Therefore there is no event separation in these data, only hits, which arrive asynchronuously at the aggregating layers from the different parts of the detectors/experiment. The data are assembled in times slices using their time-stamps at latest in the layer before the First Level Event Selector, where event are detected, built and selected.

The synchronization of all time-stamping components in the experiment with a common clock with a precision on the ns level is of course mandatory is such a system to allow the event reconstruction. One other property of such system is the sensibility to noise which as to be minimized, as a single channel could saturate the transport links.

We develop in Heidelberg a prototype for the ToF wall electronic chain, specifically adapted for RPCs and fully event-driven, with self-triggering front-end and free-streaming readout.

3. The readout chain prototype

The prototype is based on components designed at GSI Darmstadt and in Heidelberg.

Our front-end is composed of the four channel preamplifier and discriminator ASIC PADI-3[2], and the first prototype of the four channel event-driven TDC ASIC GET4[3]. Those chips were developped in parallel for maximal compability. The PADI is specifically developped for reading out RPC detectors with minimal noise and reflections, trough an adaptable input impedance and a fully differential design. It also provide Time-Over-Threshold (TOT) measurement. The GET4 provide a self-triggered timing measurement with two timing units per channel, one for each edge, allowing the TOT measurement of short signals with a resolution $\sigma < 25ps$ in chip tests. It also includes a token ring between its 4 channels, continuously readout via a serial link, which compose the first stage of the free-streaming readout. They are mounted by pairs on matching front-end boards called FEET-PADI and FEET-GET4, each having thus 8 channels.

The readout is done by a ReadOut Controller (ROC) based on the FPGA board SYSCORE v2[4]. This ROC can readout up to 7 FEET boards in its current version and also allows their control, chip masking and eventually some pre-processing. It is on the other side connected to a computer hosting the data acquisition system (DAQ) either through Ethernet or through optical fiber. All front-end boards are continuously readout and their data transfered as fast as possible to the DAQ, forming so the second part of the free streaming readout. In the optic readout case, the computer has to host an optical transmission and buffer board, the ABB, which is based on a commercial FPGA development board[5]. This allows noise reduction by decoupling grounds.

This kind of system requires precise and stable clocks, both for the timing measurement and the synchronization of the data in the different parts. For this a very precise clock-generator, the CLOSY2[6], was developed, which provides the two frequencies used in our system. A first 250MHz clock is used for the ROC and planned to later be derived from the general CBM clock. A second phase coupled 156.25MHz clock is needed by the TDC, thus being specific of the ToF wall. Additionally a third signal is send out by the CLOSY2 for synchronization of the two provided clocks and to create epoch markers. It is generated at every fifth coincidence between the two clocks, which makes a $26.2144\mu s$ period between two possible re-synchronization. A clock distribution is needed to spread out these three signals in a tree-kind to all components with lowest jitter. This is realized by one or two levels of 1:10 splitters for each CLOSY2 signal.

The data acquisition and analysis are performed using dedicated software developped at GSI Darmstadt. The DABC DAQ[7] can combine data from the MBS triggered system and data from the new free-streaming systems. The GO4 framework[9] adds to the ROOT[8] framework new tools needed for the analysis of free-streaming data. Its User Interface gives the possibility to build online monitoring close to the final analysis.

This system was tested in the laboratory with a pulser signal fed in parallel to all channels of 4 FEET, in a standalone and purely free-streaming setup. It reached then a resolution of $\sigma = 40ps$ between channels on different boards.

4. Beam test

The free-streaming data were acquired in November 2011 at COSY, Jülich, with a 2GeV/c momentum proton beam.

The self-triggered chain hardware described in previous part was used to readout a fully differential RPC built in Heidelberg[10]. In total 16 channels were equipped, reading out 8 strips on both ends. The signals used as time reference in this test are produced by 3 plastic scintillators, 2 in front of the setup and 1 in the back, equipped on both ends with Photomultipliers (PMT). We readout these signals in a triggered v1290A CAEN VME TDC board based on the CERN HPTDC. This allows to run a triggered detector test in parallel to the readout system test. For this reason we need an hybrid system allowing to combine times measured in the two systems. The trigger was built from coincidences of one of the front and the back scintillator signal. The trigger rate was kept to a few hundred Hz because of instabilities in the free-streaming part.

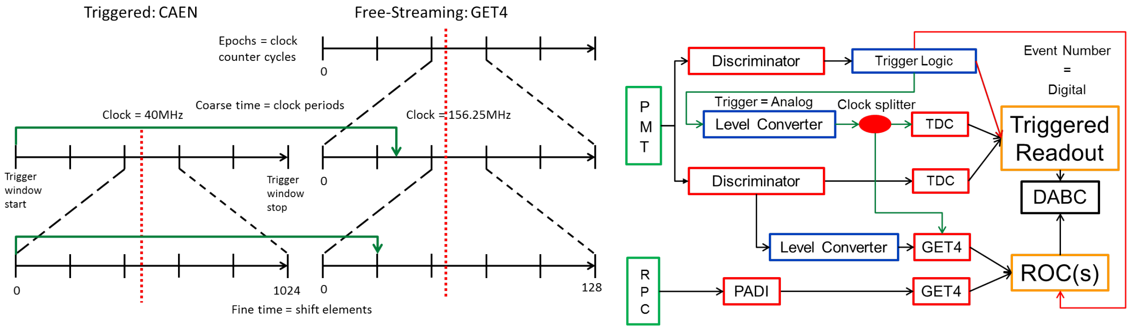

Figure 2: Concept and implementation of the synchronization in the hybrid system, Green lines are time synchronization signals and red ones are event synchronization. Red dotted lines in the concept diagram indicate an interesting hit in each system.

The synchronization between the two systems proceeds with two levels of accuracy, as shown in Fig.2 left: first at the event level, using already existing possibilities of the DABC DAQ and our trigger board, then at the timing resolution level, using signals measured in both systems. The first one is needed because the triggered time frame is event relative, giving times measured from the beginning of the trigger window, while the free-streaming time frame is absolute, giving times measured from the start of the acquisition. This synchronization allows to match free-streaming hits with a defined triggered event. It is done by injecting in both the MBS event and all ROC data streams an event number generated by the trigger board. This number is timestamped against the 250MHz clock by each ROC on reception. The second level is achieved by generating a common point for each event in both the free streaming time frame and the triggered TDC time frame at their full resolution. This is needed to compare the reference time to the detector time and evaluate the system performance, as they run on different clocks. This synchronization is realised by converting the NIM trigger signal from the triggered system to a LVDS signal accepted by both systems, splitting it with a low jitter clock splitter and re-injecting it in the input of the GET4 TDC and the CAEN TDC, see Fig.2 right. One PMT signal (PMT 6) signal is also measured in the GET4 system, allowing for an independent cross check of the time offset.

The time resolution for the reference system is obtained from the width of the time difference distribution of the front scintillators:

$$\Delta t_{ref} = \frac{t_{f1} + t_{f2}}{2} - \frac{t_{f3} + t_{f4}}{2}$$

It amounts to $\sigma_{\Delta t_{ref}} = 45ps$. The contribution of the time synchronization part of the setup can be estimated by calculating the time difference between the PMT6 signal in the triggered system and its signal in the free-streaming system, re-aligned using the offset obtained with the trigger signal:

$$\Delta t_{PM6} = t_{PM6,CAEN} - t_{PM6,GET4} - Offset \text{ with } Offset = t_{trigger,CAEN} - t_{trigger,GET4}$$

The contribution is given by the width of the difference between those two quantities (Fig. 3, left), which gives $\sigma_{\Delta t_{PM6}} = 83ps$.

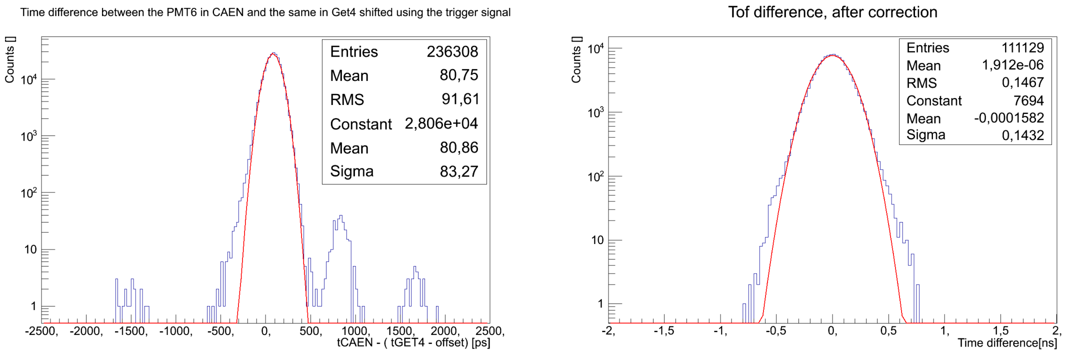

Figure 3: Left: Difference between the time of PMT6 measured in the triggered system and the same recorded in the free-streaming system corrected using the trigger signal. Right: Difference between the mean time of the 2 front references cintillators measured in the triggered system and the mean time of the triggered RPC strip recorded in the free-streaming system, corrected using the trigger signal

The resolution of the full system is obtained by looking at the time difference between the 4 front scintillators and the studied RPC strip (Fig. 3, right):

$$\Delta t_{syst} = \frac{t_{f1,CAEN} + t_{f2,CAEN} + t_{f3,CAEN} + t_{f4,CAEN}}{4} - \left(\frac{t_{RPC\,left,GET4} + t_{RPC\,right,GET4}}{2} - Offset\right)$$

The width of this distribution, after both walk and non linearities corrections, gives a resolution of $\sigma_{\Delta t_{syst}} = 143ps$ for the main strip. By quadratically subtracting the contributions of the reference and of time synchronization, as well as the one of the RPC detector itself, which using the fully triggered test done during the same beam time is estimated at $\sigma_{RPC} \sim 70ps$, we obtain an estimation of the electronics contribution:

$$\sigma_{elec} = \sqrt{\sigma^2_{\Delta t_{syst}} - \sigma^2_{\Delta t_{ref}} - \sigma^2_{\Delta t_{PM6}} - \sigma^2_{RPC}} = 82ps$$

The efficiency, defined as the number of events where hits passing the timing cuts on both ends for at least one strip where found divided by the number of events with all 4 reference signals valid and the synchronization offset present, is then 82%.

5. Conclusion

A prototype for the free-streaming readout of the CBM Time of Flight wall as been built in Heidelberg and tested in beam with a differential MMRPC. The setup used was an hybrid between triggered and free-streaming systems. The time synchronization between those two parts was at $\sigma_{\Delta t_{PM6}} = 83ps$ not as accurate as could be expected from the simple combination of used components jitter. Further tests in the lab are under way to identify the source of this additional jitter and look for improvements in the perspective of further beam times. The contribution of the electronics to the system resolution was extracted at $\sigma_{elec} = 82ps$ for an efficiency of 82%. These values are worse than was expected from laboratory tests. A more detailled analysis is under way to understand the eventual contribution of problems at the TDC level in the free-streaming part of the setup.

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