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Measurement of rare probes with the silicon tracking system of the CBM experiment at FAIR

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Abstract

The *Compressed Baryonic Matter* (CBM) experiment at FAIR will explore the phase diagram of strongly interacting matter at highest net baryon densities and moderate temperatures. The CBM physics program will be started with beams delivered by the SIS 100 synchrotron, providing energies from 2 to 14 GeV/nucleon for heavy nuclei, up to 14 GeV/nucleon for light nuclei, and 29 GeV for protons. The highest net baryon densities will be explored with ion beams up to 45 GeV/nucleon energy delivered by SIS 300 in the next stage of FAIR. Collision rates up to 10^7 per second are required to produce very rare probes with unprecedented statistics in this energy range. Their signatures are complex. These conditions call for detector systems designed to meet the extreme requirements in terms of rate capability, momentum and spatial resolution, and a novel DAQ and trigger concept which is not limited by latency but by throughput. In this paper we outline the concepts of CBM's central detector, the Silicon Tracking System, and of the First-Level Event Selector, a dedicated computing farm to reduce on-line the raw data volume by up to three orders of magnitude to a recordable rate. Progress with the development of detector and software algorithms are discussed and examples of performance studies on the reconstruction of rare probes at SIS 100 and SIS 300 energies given.

Keywords: Compressed baryonic matter; CBM; FAIR; QCD phase diagram; Silicon tracking; Rare probes

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[1] A list of members of the CBM Collaboration and acknowledgements can be found at the end of this issue.

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1. Introduction

The study of nuclear matter at highest net baryon densities ("Compressed Baryonic Matter") is considered as a tool to the understanding of the formation of matter from its constituents, i.e. quarks and gluons confined in nucleons. In nature, deconfined matter is predicted to exist in the cores of neutron stars. In the laboratory, several past and current experimental programs carried out at CERN's SPS and at BNL's RHIC accelerators aimed at realizing such extreme conditions by colliding different nuclear systems at various energies, pushing the nucleons into each others or even breaking them up, yielding a temporal deconfined system of quarks and gluons. Highest net-baryon densities are predicted to be created at collision energies around 30 GeV per nucleon. At the SPS, this regime was studied with projectile beams steered onto stationary targets. More recently, during the beam-energy scan at RHIC, Au + Au collisions in this density regime have been realized with circulating beams at $\sqrt{s_{NN}} = 7.7$ GeV. Since collision rates were limited either due to the non-optimal accelerator performance at those energies, or by the capabilities of detectors and data acquisition systems themselves, the experiments were essentially bound to abundantly produced particles (pions, protons, kaons and hyperons, as well as their anti-particles). Less often produced probes, as light vector mesons and mesons with open (D) and hidden (J/ψ) charm content, could not been accessed. The reconstruction of the dense environment from the detected reaction products, though, can only be completed with those so-called "rare" probes included, which are produced in the dense medium and thus are particularly sensitive to the conditions there which they transport to the observer through their decays into lepton pairs or hadrons. New experiments at dedicated accelerators are therefore being prepared. This includes MPD at NICA, BM@N at Nuclotron, and in particular the Compressed Baryonic Matter (CBM) experiment at FAIR. The accelerators optimize in particular on the beam intensities around the energies of interest. The experiments are conceived to detect a large set of probes with diverse signatures and will enable the detection of rare probes through innovative concepts of fast detectors and high-rate capable data acquisition and event reconstruction.

2. The CBM experiment at FAIR

Beams for the compressed baryonic matter studies will be provided by FAIR's sychrotrons SIS 100 (delivering projectile energies between 2 and 14 GeV/nucleon for nuclei, up to 29 GeV for protons) and SIS 300 (up to 45 GeV/nucleon for nuclei, up to 90 GeV for protons) to the CBM experimental hall. With intensities of up to 10^9 ions per second they are steered onto a target of typically 1% nuclear interaction length. The CBM detector systems will allow the diagnostics of 10^5 to 10^7 collisions per second. For a description of the CBM experiment with its silicon tracking and vertex detectors in the super-conducting dipole magnet, the muon and electron detection systems, hadron identification with a time-of-flight system, and calorimetry for photon identification and event characterization, see [1]. All sub-systems are laid out to meet in radiation tolerance, rate capability and precision the physics program with rare probes. Their read-out is realized through streaming time-stamped detector signals to a high speed data acquisition system. The data is then reconstructed on-line in a powerful computing farm, where event building and the assignment of triggers take place before selected data is stored.

3. The CBM silicon detector systems

The central detector of the CBM experiment is the Silicon Tracking System. Installed in the super-conducting dipole magnet, its task is to track the hundreds of charged particles created in

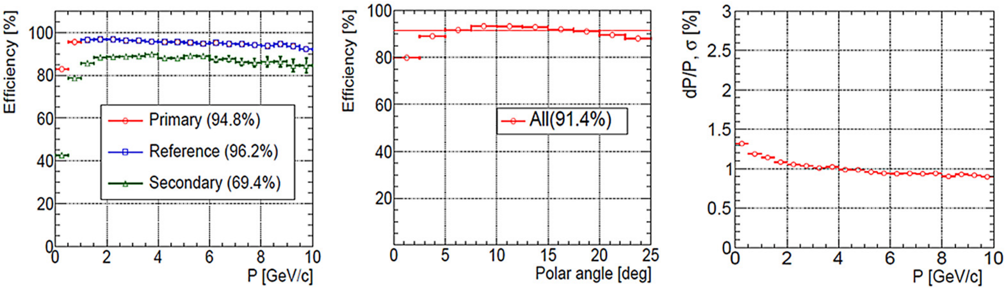

Fig. 1. Track reconstruction performance of the Silicon Tracking System.

every beam–target interaction, and to determine the momenta of the particles. This requires a large aperture, covering rapidities from close to center-of mass to beam rapidity, translating to polar angles between 2.5 and 25 degrees. Eight tracking stations between 30 and 100 cm downstream of the target will allow for redundant track point measurement along particle trajectories, and the identification of in-detector decays. The four upstream stations are horizontally enlarged to 35 degree aperture to enhance the detection of low-momentum tracks. The space-point resolution of about 25 μm in the bending plane and the detector system's low material budget will be achieved with radiation-tolerant double-sided silicon microstrip sensors that are read out through ultra-thin read-out cables with fast electronics allocated outside the physics aperture at the periphery of the detector. The detector modules are arranged on low-mass carbon-fibre ladder structures which build up the tracking stations. The track reconstruction performance studied with a detailed realistic detector model, carried out with the simulation framework CbmRoot, is shown in Fig. 1.

For the detection of short-lived decays, the trajectories are extrapolated to the Micro Vertex Detector. This detector system will be installed upstream of the Silicon Tracking System in the target vacuum chamber. Its four stations are based on thinned monolithic active pixel sensors yielding a spatial hit resolution of 3.5 μm. The sensors are mounted onto thin actively or passively cooled support structures based on carbon or diamond. The aim of on-going developments is to achieve a material budget of less than 0.3% X_0 per station. The Micro Vertex Detector will be able to operate with moderate event pile-up up to few times 10^5 collisions per second.

More information on the CBM silicon detector systems can be found in Refs. [2] and [3].

4. Data acquisition and on-line event selection

Data streaming off the detectors and on-line event reconstruction are required since no simple trigger signatures can be defined in the CBM environment. For instance, J/ψ decaying into electron–positron pairs, or D, Ω mesons decaying into charged hadrons must first be identified from the respective tracks and the reconstructed invariant masses. Such complex trigger signatures are difficult to implement in hardware. Furthermore, the extreme event rates set strong limits to trigger latency. Thus, the CBM DAQ concept foresees self-triggering read-out electronics, which ship data, furnished with time stamps, as they come asynchronously and may overlap in time. The classical data acquisition task of "event building" becomes a "time-slice building". Physical events are defined later in software. The data reduction is shifted entirely to software, which gives maximum flexibility w.r.t. physics. The data acquisition is limited only by its throughput capacity and by the rejection power of the on-line computing farm.

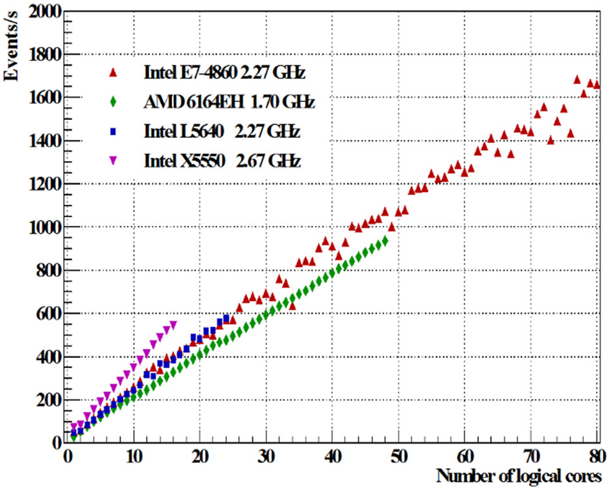

Fig. 2. Scaling of event processing with the number of logical cores on different computing architectures.

The steps of event reconstruction involve [4]: (1) Time-slice sorting of detector hits as a first step in "pre-event" definition. This task is done on data processing boards still in the vicinity of the detectors; (2) Track finding is performed on the computing farm, e.g. with cellular automaton algorithms. The hits in the detector layers are associated to their respective tracks. This large combinatorial problem is well to be parallelized and applied to many-core CPU/GPU systems. (3) The track parameters are then optimized through a Kalman Filter, a recursive and fast method. (4) Based on the tracks, an event determination can then be performed, establishing which tracks belong to the same interaction. (5) The final step is the particle finding, the identification of decay topologies and other signatures of the event.

In order to match the high data rates, several levels of parallelization are applied to event reconstruction. On "event" level, reconstruction is distributed to independent processes on many-core computing systems with multi-threading, involving one thread per logical core and enabling the treatment of 1000 event per core. The CBM computing center "FLES" will comprise about 60 000 cores. Further parallelization is applied at the level of "tasks", i.e. digitizers, finders, fitters, and analyses. This procedure has been performed on many-core CPUs and prototype computing centers employing different computing techniques and architectures (see Fig. 2). A technical document is currently being prepared [5].

5. Measurement of rare probes

The sensitivity of CBM to rare probes like D mesons was studied through a realistic simulation of the detector system and reconstruction of the simulated data as described above. Fig. 3 shows exemplarily results for D reconstruction, with the input yields being adjusted to model predictions. The obtained results clearly show the feasibility of the open charm measurement, both in p + A and in A + A collisions.

6. Conclusions

The CBM experiment focuses on rare probes to investigate "Compressed Baryonic Matter" in a dedicated experimental facility. The experimental concept builds on a consequent application

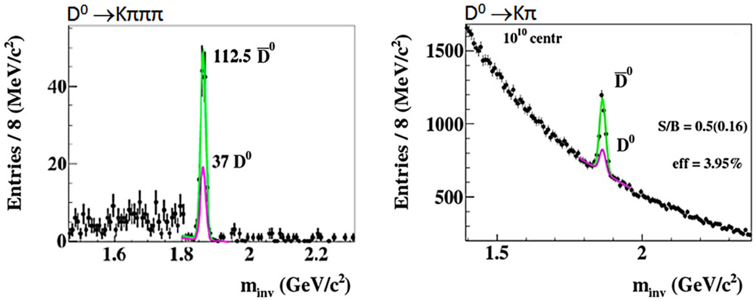

Fig. 3. Open charm in 10^{12} p + C collisions at 30 GeV proton beam (left panel), and in 10^{10} central Au + Au collisions at 25 A GeV (right panel).

of new paradigms for detectors, read-out, on-line event determination and analysis to meet the requirements on rate capability and precision. The development status of the components and systems is advanced [6]. Among those are the Silicon Tracking System as the main tracking device whose technical design report has been approved by FAIR. The technical design report for the on-line computing is being prepared for submission in 2014. Tests of prototype components in the laboratory and simulation studies of the complete CBM detectors demonstrate the expected performance of the technical and computing systems. The construction of CBM components has started. The commissioning of the detector systems in the CBM cave is expected in 2019, as soon as access to the installations will be possible.

References

[1] J. Heuser, et al., Nucl. Phys. A 904–905 (2013) 941c–944c, http://www.sciencedirect.com/science/article/pii/S0375947413002960.

[2] CBM Collaboration, Technical design report for the CBM silicon tracking system, GSI Report 2013-4, October 2013, http://repository.gsi.de/record/54798.

[3] M. Deveaux, J. Heuser, The silicon detector systems of the compressed baryonic matter (CBM) experiment at FAIR, PoS Vertex2013 (2013) 009, http://pos.sissa.it/archive/conferences/198/009/Vertex2013_009.pdf.

[4] V. Friese, Lect. Notes Comput. Sci. 7125 (2012) 17, http://link.springer.com/chapter/10.1007%2F978-3-642-28212-6_2.

[5] CBM Collaboration, Technical design report for the CBM on-line computing system, in preparation.

[6] CBM Collaboration, CBM progress report 2013, https://www-alt.gsi.de/documents/DOC-2014-Mar-16-1.pdf.