Optimisation of Beam-Pipe Shielding for MUCH detector of CBM experiment

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The Compressed Baryonic Matter (CBM) experiment is one of the major scientific pillars of FAIR. The main goal of the experiment is to explore the Quantum ChromoDynamics (QCD) phase diagram in the regions of high baryonic densities and moderate temperatures in the beam energy range of 10-45 AGeV. This includes also the search for the critical point, the first order deconfinement phase transition from the hadronic matter to the partonic matter and the study of equation-of-state of dense baryonic matter. The CBM research program comprises a comprehensive scan of observables, beam energies and collision systems. The observables includes low-mass dilepton pairs, charmonia and open charm, but also collective flow of rare and bulk particles, correlations and fluctuations. Some of the particles under study have low cross sections (like charm) or small branching ratios (like low-mass vector mesons). Therefore, in order to compensate for the low yield the measurements have to be performed at very high reaction rates of up to about 10 MHz. These conditions demand for fast and radiation hard detectors and associated fast electronics, readout and online event reconstruction. Low material budget is required with in the detector acceptance to avoid multiple scattering which would limit high-precision measurements [1].

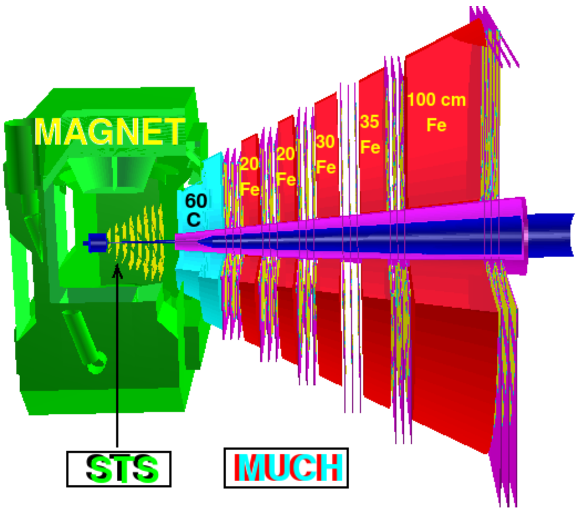


Figure 1: Muon Chamber set-up in CBM experiment for 25 AGeV collision energy

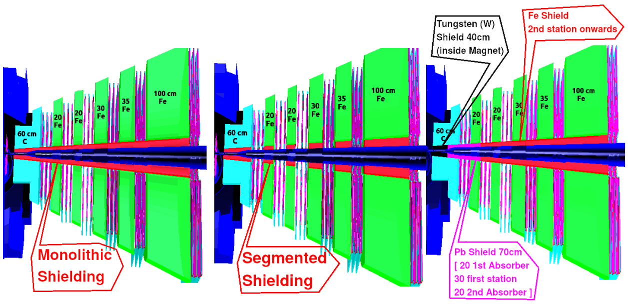
For muon measurements, identification of high and low momentum muons simultaneously i.e. to cover both the regions of low-mass vector mesons(ρ, ω, ϕ) and high mass regions of charmonia (J/ψ) is the challenge for the detector. The novel feature of the proposed muon chambers (MUCH) is that the total absorber is sliced and detector chambers are placed in between absorbers to facilitate momentum dependent track identification. This improves the detection efficiecny of low momentum muons, which would have been otherwise stopped by a single thick absorber. The full design of the muon detector system consists of 6 hadron absorber layers, first made of carbon of thickness 60 cm and rest five iron absorbers of thickness 20, 20, 30, 35, 100 cm respectively as shown in Fig. 1. The 18 gaseous tracking chambers are located in triplets behind each hadron absorber. The track parameters are reconstructed by a system of silicon tracking stations (STS) placed inside the dipole magnet and then propagated through the absorbers in MUCH.

The layout of the MUCH system, i.e. the number, thickness and material of the absorber slices, the number and granularity of the tracking detectors among others has been optimized by simulating the response of the Au+Au collisions at 25 A GeV beam energy using input particles from the UrQMD event generator [3] for background generation. Signal particles like low-mass vector mesons or charmonium are generated using PLUTO event generator [4]. Events from PLUTO and UrQMD are then embedded and transported using the GEANT [2] through the CBM setup. Primary track finding and reconstruction is carried at STS using cellular automaton method and MUCH detector propagates these tracks through the detector in which track and vertex fitting makes use of a Kalman filter [7, 8].

Since CBM experiment is required to operate at moderate energies and even higher luminosities. The high collision rates (up 10 MHz) will also result in high levels of radiation backgrounds. Therefore, in addition to physics requirements, the various detector subsystems must also be designed to operate in high radiation environments. One can emphasize two main targets for radiation influence: (a) effects of radiation on electronics and optical devices; (b) irradiation of personnel. Predicting particle fluences and doses at future high energy physics experiments is important for estimating the following:

- Detector counting rates or occupancies. Determined by convolving the predicted particle energy spectra with detector sensitivity functions.
- Radiation damage to detectors and electronics.
- Activation and consequences for detector access and maintenance scenarios.

- Radiation-exposure to personnel working in nearby caverns during beam operation.



(a) monolithic (b) segemented (c) W+Pb+Fe

Figure 2: Muon Chamber with (a) Monolithic, (b) Segmented, and (c) New Optimised Combination [W(40cm) + Pb(70cm) + Fe(335cm)] beam-pipe shielding set-up for 25A GeV central Au+Au collisions

Typically, the interaction probability of the primary beam with the target is about 1%. Therefore, nearly 100% of the beam has to be propagated through beam-pipe and stopped in a dump located behind the experimental setup. Beam can interact with the beam-pipe to generate large radiation background effecting the detectors. One needs to put the beam-pipe shielding in such a way that it should reduce this background to its minimal value and at the same time it should not effect the overall detection process.

In this work, we study the overall performance of MUCH and individual detector occupancy for different shielding materials. We analysed shielding in two ways: one with complete monolithic set-up and one with segemented sheilding with no shield beneath the stations as shown in Fig. 2. We also tried a combination of different materials as shown in Fig. 2c in which first 40cm of shielding is made of tungstun then 70cm of lead and rest made or iron. At present we have been using segemented shielding with lead 60cm beneath the first absorber and iron beneath the rest of absorbers whereas there is no shielding below the detector stations. We tried to analyse shielding materials for the best performance in terms of detector occupancy as well as overall S/B (signal to background ratio).

Work has been done using GEANT3 simulation with heavy ion collision events given by the UrQMD event generator for radiation background. We used signal input for ω at 25 AGeV Au+Au collisions from the PLUTO event generator with multiplicity taken from HSD [6] and branching ratios from Particle Data Group(PDG) database [5].

First we analyse the effects on the detector in terms of point density. Fig. 3 shows the point density at the first and the fifth detector station of the MUCH. From this it can be seen that tungstun material looks to have the lowest possible point density and thus the best for the detector. Where as our proposed combination seems to be the next best material giving 10% less hit density than the present shielding at first station. On fifth station it can be seen that tungstun and our new combination gives the same results of lowest possible hit density which is 2 times less than the present shielding set-up. From fifth station results one can also note that the monolithic shielding is performing better than the segemented shiedling.

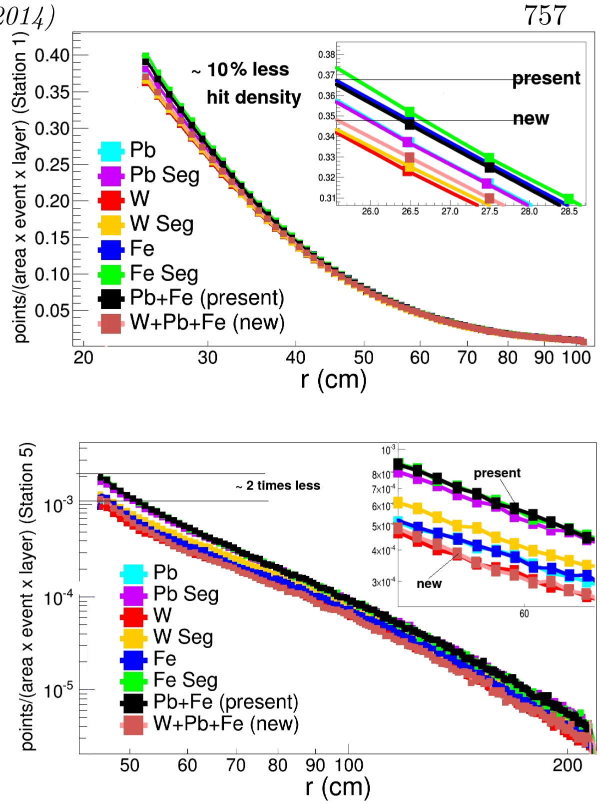


Figure 3: Point/Hit density at: Detector Station first (upper pannel) and Detector Station fifth (lower pannel) of MUCH for different beam-pipe shielding materials at 25A GeV central Au+Au collisions

Same thing can be seen from the Occupancy plots as shown in Fig. 4. Its obvious from the results that detector occupancy can be improved if shielding material is tungstun or our new proposed combination.

Next we analysed the overall detector performance interms of reconstruction effeciency and background reduction for effecient muon detection which can be quantified interms of a quantity like S/B (signal to bacground ratio). Invariant mass spectra has been calculated from the reconstructed signal muons after embedding them event by event into the UrQMD events.

To calculate detector effeciencies for signal particles, STS reconstructed tracks and STS+MUCH reconstructed tracks have been used at STS and MUCH respectively. In order to reduce the background, conditions on the quality of the number of hits in STS and MUCH, on the quality of the primary vertex, and on the quality of the tracks in the MUCH were required in the analysis. The MUCH optimised cut values (sts hits ≥ 6, much hits ≥ 14, chi^2 vertex