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Fast Micro-Channel Plate Detector *

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We present results of development of the fast Forward Multiplicity Detector (FMD) for ALICE at the future LHC. The UHV compatible UHF sector type detector prototype based on the application of the micro-channel plates (MCP) was designed and produced.

The double MCP setup (gain 10^8) gives a strong signal for the UHF readout which includes also a multichannel passive summator which separates the fast and slow components of the signal providing the combination of individual pads charge readout, precise timing and analog multiplicity information.

The status of the isochronous MCP disk development and the experimental tests are also discussed, including :

- model simulations of the FMD detector performance in heavy ion collisions at the LHC;
- tests of variuos FMD-MCP structures (small area prototypes and sector multipad prototype).

1. INTRODUCTION

The purpose of the Forward Multiplicity Detector (FMD) for ALICE is to measure charged particle multiplicity distributions outside the central acceptance and to provide fast signal for the trigger system [1]. The FMD is composed of seven disks, situated around the beam line on both sides of the interaction region . FMD covers the pseudorapidity range from 1.6 to 4.7 . Disks are segmented into sectors and individual pads in order to study the multiplicity over rapidity distributions. In high multiplicity events during Pb-Pb collisions the multiplicity of charged particles is supposed to be determined by unfolding the total charge collected from each FMD pad [2]. The integral of the multiplicity over the FMD disk is supposed to be used for the fast centrality Trigger decision [1,3,4] provided by the Fast Multiplicity Discriminator. The leading edge of the FMD signal is also bearing the precise timing information which helps the fast determination of the primary vertex location (Z-coordinate) and the beam-gas interaction suppression.

In order to study these multiplicity and timing distributions we have to know, at the stage of experiment planning, the nature of the possible signal and background effects and to prepare and test the prototypes of the novel detector.

This work is a continuation of the study of the fast readout systems[5] of the MCP-based detectors. We describe here both the simulations of FMD performance, the resulting requirements to the detectors and front-end electronics, technology developments and prototype tests.

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2. SIMULATION OF THE FMD RESPONSE FOR CENTRAL PB-PB COLLISIONS AT LHC

For the evaluation of the FMD response in the future experiment it is necessary to estimate the density of all charged and neutral particles passing the FMD sensitive plane in one Pb-Pb collision. It means the generation of events, propagation of all particles to the detector and simulations of the detector response to the primary and bacground particles with the account of the real geometry and detector materials.

On the muon arm side the FMD disks are placed not far from the front absorber of the muon spectrometer; the nearest one is at about 20 cm distance. The backscattering particle flux from the muon absorber into FMD region may have the significant influence on the FMD multiplicity information. Hence, it is very important to calculate the backsplash particle density as well as the time structure of backsplash to estimate a distortion of electric signal from the FMD.

For the simulation of the central Pb-Pb interaction at the LHC energies the HIJING event generator was used. The GEANT code is applied for the tracking of the primary particles from the generated Pb-Pb collision through the detector system including the beam-pipe, TPC, FMD and the muon spectrometer.The total cross-section of the hadronic processes was computed at CERN using FLUKA routines.

The description of the geometry and realistic materials is included in two options (coarse and detailed) into GALICE code. For the simulation of the backscattering from the muon absorber and the beam shield we use the geometrical code with detailed geometry, described in [6].

We present the results obtained for one selected central Pb-Pb collision, in which the total number of generated particles is 78285. In order to score the backsplash particles from the muon absorber into FMD we made tracking of all primary particles with pseudorapidity corresponding the muon absorber acceptance. All demonstrated distributions concern the third disk of FMD disposed at distance of 20 cm from muon absorber.

In Fig.1 we show the arrival time distribution of particles passing the third disk of FMD. The first peak corresponds to primary particles reaching the FMD disk from the interaction point, and the second large peak includes all particles backscattered from the beam shield and muon absorber. We see, that leading edge rise time of the first peak is less than 50 ps, and its amplitude is not distorted by backsplash.

The total number of particles passing the FMD disk in a given event is shown in Table 1. We see that the contribution from backsplash particles to the total particle number is very sizable (67%) : although the part of charged particles leaking out of the absorber is small (5%), the neutral particles (photons and neutrons) make up the main part (95%) of the backsplash. Therefore, for the evaluation of the backsplash influence on the FMD signal, the following information is needed : (i) time structure of particles passing the FMD; (ii) FMD efficiency and response function for neutral and charged particles.

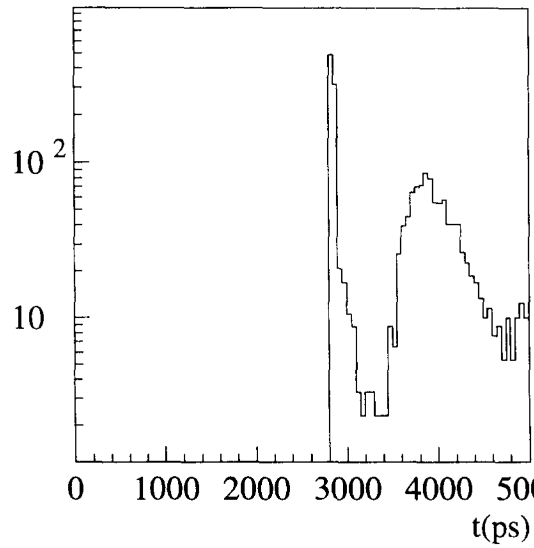

Figure 1. Simulated arrival time distribution for particles passing disk-3 FMD in one central Pb-Pb collision.

Table 1
Number of particles passing the 3-rd FMD disk in one central Pb-Pb collision.

Third FMD disk	Primary particles	Backsplash particles
Charged particles	463	97
Neutral particles	482	1867
All particles	955	1964

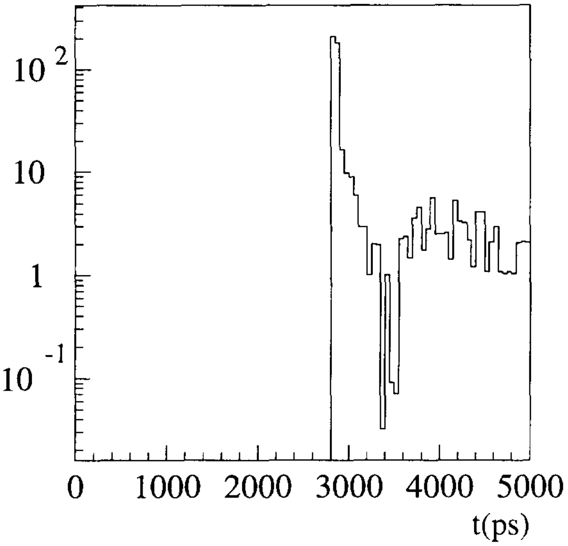

Figure 2. Disk-3 FMD response function for one central Pb-Pb collision

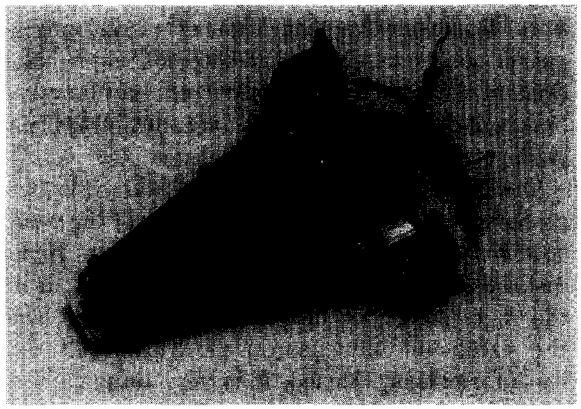

Figure 3. Photo of the FMD-MCP sector prototype showing the back plane of the detector containing the UHF multichannel passive summator

These results shown on the Fig.1 are in the agreement with the first model simulations of multiplicity distributions expected in Pb-Pb collisions and time of flight (TOF) spectra of charged particles reaching the FMD surface from the collision point which were done [7] using standard event generator based on the Quark-Gluon String Model. They showed that in high multiplicity events expected in Pb-Pb collisions the rise time of the TOF spectrum could be less than 50-100 ps, which indicates to the possible application of high timing resolution detectors. Hence, if an integration time of FMD is expected to be less than 50-100 ps, the FMD will provide the precise trigger system signal at the earliest possible moment after Pb-Pb collision.

Folding the components of the simulated arrival time distribution of particles for the given event (see Fig.1) with the different efficiencies for charged and neutral particle registartion (we assumed in these calculations that MCP efficiency for charged and neutral particles makes up 98% and 1% respectively), one can get the result shown in Fig.2.

The electric signal coming from the MCP-based detector corresponding to a single registered particle has the triangle form and its rise time is about 0.5 ns. The response signal of the FMD to the particle flux generated in Pb-Pb interaction can be easily calculated by the additional folding of the results of Fig.2 with the relevant single particles response functions and the shape of electric signal mentioned above.

We see, that the electric signal from the third disk of FMD has a 'tail' being conditioned by the backsplash particles. Thus, for the correct multiplicity reconstruction it is needed to account the backsplash contribution, the part of which for given Pb-Pb interaction makes up 17% for the Disk-3.

3. FMD-MCP SECTOR PROTOTYPE

The following design considerations for the sector prototype of the FMD-MCP were used [1,10]:

- compactness of the detector setup;
- UHF requirements to the fast MCP signal transfer lines;
- minimization of the mass of the whole material used in the design;
- compatibility of materials to the ultra high-vacuum application requirements;
- integration of the independent vacuum getter micro pump;
- minimisation of a technological dead-areas for the sensitive detector surface.

The technology aimed at the UHV compatible production of the multipad fast MCP-based detector was developed and described in more details in [10]. The first two sector portypes were produced. Photo of one of these prototypes of the Forward Multiplicity Detector for the ALICE experiment can be found on the Fig.3.

We used sector type single MCP setup and chevron (two MCPs) during these first tests.

Sector MCPs are mounted on a 200μ ceramics board with the multipad readout integrated with a passive summator done in microelectronics design (summator is occupying the back plane of the sector MCP setup, see Fig.3).

This microelectronics UHF device provides isochronous analogue summation of the fast 1 ns signal components from 8 pads along with the individual readout of charges. The separation of the fast and slow components allows us to use this detector as the zero level trigger, in pile up and beam-gas interaction diagnostics and for the determination of the collision vertex position along the beam axis.

As it goes from the results of simulations of the detector response function one has to provide the minimum distorsions in shaping and transfer of 1 ns pulses from the fast MCP detector to the front-end electronics. The signal rise time and the amplitude are not affected by the backsplash if the relevant fast detector and the front-end electronics are provided capable to handle 1-2 ns short pulses.

The first tests of this device are described below. They were aimed at the performance studies of microelectronics UHF design of the setup and the front-end components including the multipad readout, passive summator, fast low-noise preamplifier (50-700MHz frequency range, 500ps rise time) and the timing discriminators.

4. COUNTING RATE CAPABILITIES TESTS

These tests are needed in order to prove the linear response of the detector signal under the load of high multiplicity events expected (10^6 1/s is considered presently as a benchmark for the charged particle flux on the detector per 1 cm^2). Preliminary results of tests obtained at the low energy beams of protons and α -particles of St.Petersburg university cyclotron were reported [10].

Here the new results of the recent studies, which were obtained using the chevron MCPs setup with 100 MOhms resistance, are presented.

The needed controllable intensity per 1 cm^2 (up to $6.7*10^7$) of the particles coming to the detector was achieved by the variable scattering angle. The intensity could also be easily changed by a factor of 100 by using another (thinner) Au target inside the chamber.

Tests have shown that the UHF performance of the FMD-MCP setups is achieved: the signal duration for the given FMD-MCP test structure was obtained to be about 2 ns and the signal rise time is better 500-700 ps. Proton spectra were

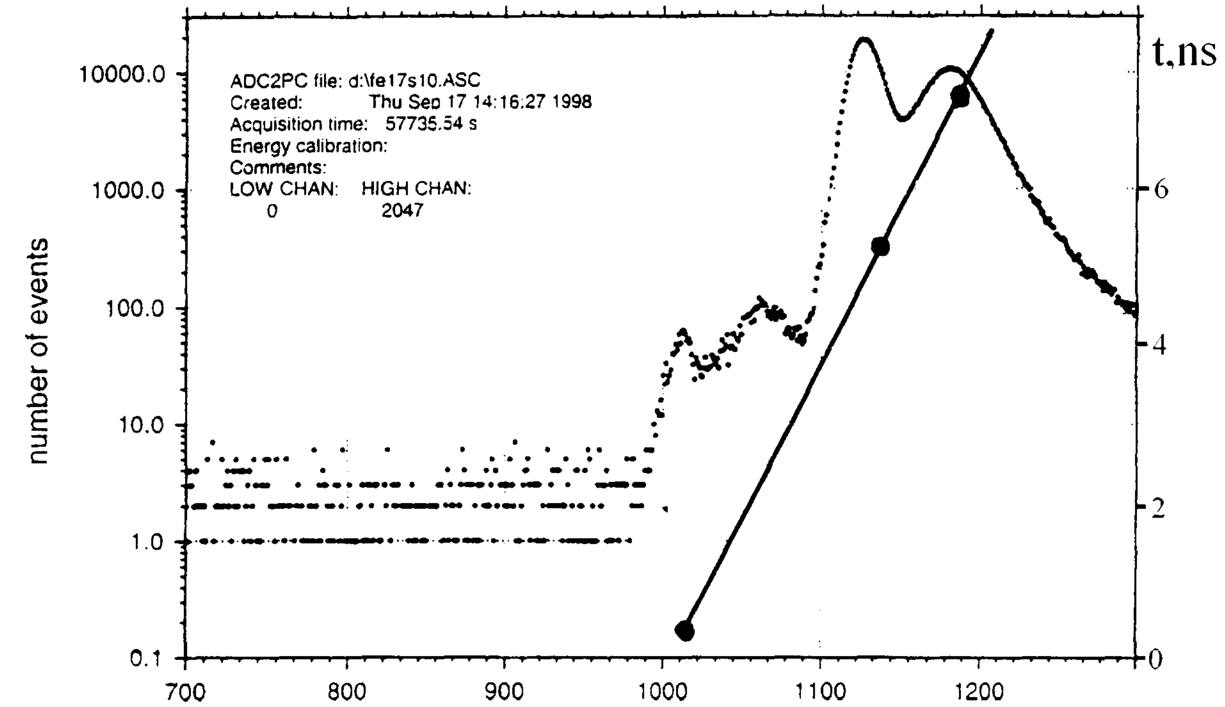

Figure 4. Time of flight spectrum of some of ^{252}Cf fission products including prompt photons and nuclei fragments measured by the sector prototype of the FMD-MCP detector

normalised to the charged particles beam integrator counts used for measurements of the intensity of the primary proton beam.

The studies of the gain stability vs. protons counting rate showed that for the given type of MCPs used (100 MOhms) one can get $1*10^6$ counts/s for 1 cm^2 FMD-MCP pad anode (at 64% gain decrease).

Further in-beam tests are also planned for the sector FMD-MCP prototypes aimed at the multiplicity and the time resolution measurements using the available beams.

5. SECTOR PROTOTYPE DETECTOR TESTS IN TOF MEASUREMENTS

We did the first tests for this sector prototype using the ^{252}Cf source, positioned between two detectors at the distance of 5 mm from one of the them ("start") and 70mm (sector prototype , "stop" detector) inside the vacuum chamber.

^{252}Cf decays predominantly into two fragments of the mean mass A=108.9 and 143.1 [8] and relevant velocities of 1.369 and 1.035 cm/ns [9].

Other ^{252}Cf fission products coming from the vertex are the following : prompt photons (up to 50 MeV), betas and neutrons. They could be also detected in coincidence with charged fragments. Thus the performance of the FMD prototype can be studied in the conditions which rouhgly simulate those expected at future central relativistic ion collisions.

We tested the FMD-MCP sector prototype containing one and two MCPs. The sample of the TOF spectrum of particles coming from the

^{252}Cf decay, which was measured using single stage MCP setup, is represented on the Fig.4. The first peak corresponds to the prompt photons, the second one to electrons (E about 0.53 Mev), two large peaks are for the fragments TOF distribution. The resulting peak widths in the TOF spectrum relevant to the prompt photons is totally derived by the 5 mm distance from Cf252 to the start detector. (Timing resolution of the detector and the front-end electronics used in the present experiment setup was much better, i.e. about 100ps.)

The data obtained with single and chevron MCP applications are very useful for the tuning of MCP detector vs. front-end electronics gain. Data analisys was also performed on the event-by-event base. It has shown the different TOF spectra shapes for prompt photons, electrons and fragments. This information is to be used for the future analysis of the FMd-MCP setup performance.

6. CONCLUSIONS

1) Results of simulations of the FMD response with the account of realistic TOF background estimates confirmed that the goals of ALICE requirements to the Forward Multiplicity Detector could be met in case of application of fast detector and the adequte front-end electronics:

- The rise-time of the TOF spectrum of charged particles originated in Pb-Pb central collisions and reaching the FMD sensitive plane is better than 100ps for all FMD disks
- Simulation show a strong dominanace of neutral particles for the FMD disk 3 - the main contribution to the backsplash from the muon absorber.
- The multiplicity and timing information contained in the FMD signal can be preserved in case of the integration time of the detector applied is less than 50 ps.

2) UHF-UHV technology developments were completed for the production of sector type FMD-MCP prototypes with isohronous multipad read-out.

3) Experimental studies of the counting rate capabilities of the FMD-MCP prototype detector were succesful up to 10^6 1/s rates for the lower resistance (100MOhm) MCPs used. Stability of MCP output signal amplitude spectra vs. counting load was achieved, which is important for the applications of the FMD-MCP at high multiplicity events.

4) TOF measurements of the ^{252}Cf fission products were done with single stage and two-staged MCPs (chevron) setups.

5) Further experiments are planed for tests of the large-area isohronous FMD-MCP prototypes in accordance with the functional designation of FMD-MCP in ALICE experiment: efficiency for MIPs, multiplicity and timing resolution.

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