

# Application of micro-pattern gas detectors in the present and future experiments in Budker INP

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**Abstract.** Micro-pattern gas technology is planned for the upgrade of the tracking system of the CMD-3 detector at the VEPP-2000 electron-positron collider in Budker INP. The upgrade includes a new cylinder tracking and trigger detector that consists of two tracking layers at a radius of 32 to 33 cm with coordinate resolution close to 0.1 mm in Z (along the beam axis) and trigger segments of about 1 cm in phi. Another new coordinate subsystem includes two end-cap discs with active area between radius of 50 mm and 250 mm, that provides spatial resolution in R and in phi close to 1 mm as well as trigger signal from the phi segments. For these two subsystems we plan to use micro-RWELL technology because it allows much simpler assembling of large cylindrical detector and large discs due to more rigid glass-fiber support as compared to the triple GEM technology. The new cylindrical detector and end-cap discs of the CMD-3 are considered as a prototypes of the Inner Tracker of the detector for the future Super C-Tau Factory (SCTF) at Budker INP. The SCTF is an electron-positron collider for the energy range of 3-7 GeV in the center of mass system that will provide luminosity of  $10^{35} \text{ cm}^{-2}\text{s}^{-1}$ . Coordinate system of the detector for the SCTF will include among other systems, the Inner Tracker and the end-cap discs. The Inner Tracker will be 60 cm long and occupy radius up to 20 cm, while the end-cap discs will have radius up to 180 cm and will have to provide trigger signal. For the end-cap discs the MPGD option is considered based either on the triple-GEM or on the micro-RWELL, while for the Inner Tracker three main options are competing: compact Time Projection Chamber, silicon micro-strip tracker and cylindrical MPGD tracker. The first results of simulations with all these options are presented with preliminary discussion about the choice of the option.

## 1. Introduction

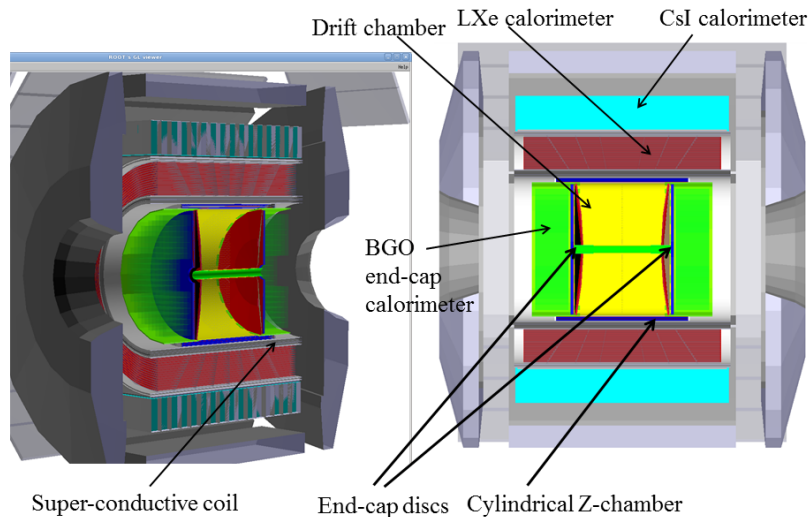
Cryogenic Magnetic Detector [1] is a general-purpose detector at the VEPP-2000 collider [2, 3] intended to measure parameters of the light vector mesons and their excited states with accuracy better than 1% and to study the dynamics of the multihadron production (Fig. 1). The CMD-3 detector, as a part of tracking and trigger systems, contains a thin cylindrical detector, Z-chamber (ZC). The present Z-chamber is the double-layer cylindrical MWPC that consists of three cylinders with cathode and anode readout. The inner and outer diameters of Z-chamber are 612 mm and 647 mm.

The Z-chamber operated practically ten years at VEPP-2M collider with CMD-2 detector [4, 5] and six years at VEPP-2000 with CMD-3. Hence, some of its parameters degraded with



time. In particular, the energy resolution significantly degraded and discharge threshold was reduced that resulted in considerable reduction of efficiency plateau.

After careful consideration the MPGD technology was chosen as the best technique for construction of the new Z-chamber [6, 7, 8]. This choice was based on success of the KLOE-2 inner tracker project where cylindrical GEM technology was exploited [9, 10].



**Figure 1.** The CMD-3 detector.

As the diameter of Z-chamber is larger than that of the KLOE-2 inner tracker, in order to facilitate the technology, we propose to make the new detector with microresistive WELL ( $\mu$ -RWELL) structure, rather than triple GEM ([11, 12]). As  $\mu$ -RWELL is a rigid structure that can be easily handled, rolled in a cylinder and attached to the end-caps, this technology facilitate much construction of Z-chamber as compared to triple GEM. Indeed, as GEM is a flexible foil, special care has to be taken to insert three GEM cylinders at a distance 1-2 mm from each other. In case of micro-RWELL cylinders are made of 0.5-1.0 mm thick glass-fiber and the distance between them is 3-6 mm. For two cylindrical triple-GEM detectors we would need nine precise molds, while in case of micro-RWELL the number of molds is three. Another advantage of  $\mu$ -RWELL solution is that the detector becomes very compact with a 3 mm gas gap and thin  $\mu$ -RWELL (0.5 - 1.0 mm).

In order to increase the acceptance for the trigger for charged particles and improve the precision of track polar angle measurements, the end-cap discs based on  $\mu$ -RWELL structures are proposed for the upgrade. The end-cap discs can provide the following improvements:

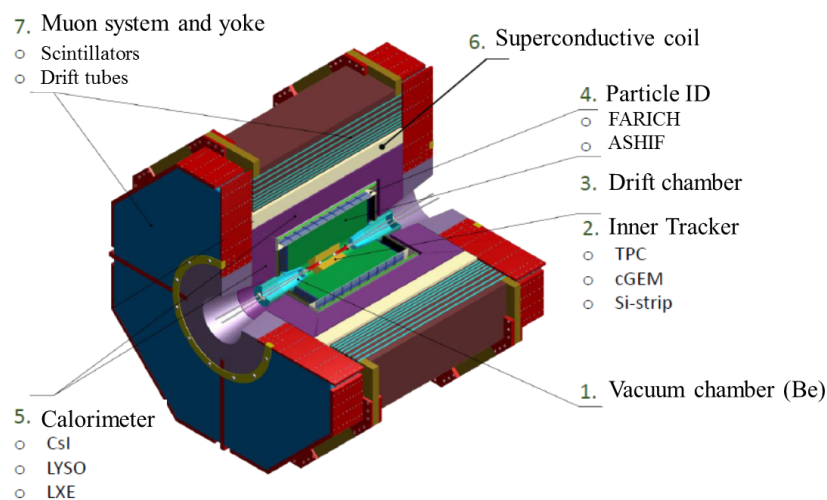
- Detection efficiency for multihadron events will not be very sensitive to the theoretical model (for exact influence of models on systematic error see, for example, [13, 14]).
- Charge asymmetry for the process  $e^+e^- \rightarrow \mu^+\mu^-$  can be studied.
- The cross section of the process with neutral pion production in the two-photon channel with detection of double-tag electrons or single-tag electrons, with the decay  $\pi^0 \rightarrow e^+e^-\gamma$ .
- Detection of small angle Bhabha events for luminosity measurements and for the extraction of the contribution of hadronic polarization of vacuum into the cross section that amounts several percent.

The end-cap discs and new Z-chamber based on  $\mu$ -RWELL structures are considered as a prototypes for the tracking system of the Super Charm-Tau Factory Detector (SCTD). Super C- $\tau$  factory is electron-positron collider with "Crab-Waist" collision scheme, that will operate in the energy range of 1.5 - 3.5 GeV per beam, provide luminosity up to  $10^{35}$  cm $^{-2}$ s $^{-1}$  and longitudinal polarization of electrons in the interaction point [15].

The physics program of experiments at the Super c- $\tau$  factory is dedicated to studies of rare decays of D mesons,  $\tau$  lepton,  $D_0\bar{D}_0$  oscillations and searches for so-far unobserved lepton-flavor-violating  $\tau$  decays, in particular  $\tau \rightarrow \mu\gamma$  decay. The proposed program requires construction of a general purpose magnetic detector with a field of about 1.5 T. The detector should provide the following features:

- Energy resolution not worse than 2% at 1 GeV and momentum resolution better than 0.5% for 1 GeV/c particles
- High efficiency for soft hadrons
- $\pi/K$  separation better than  $3\sigma$  for energies up to 2.5 GeV and  $\pi/\mu$  separation better than  $3\sigma$  up to 1.2 GeV
- Maximum output event rate up to 300 kHz
- Minimum CP-asymmetry of the detector

Detector for Super c- $\tau$  factory (SCTD) consists of the Inner Tracker (IT) with end-cap discs, the Drift chamber (DC), the Particle identification system (PID), the Calorimeter, the Superconductive coil and the iron yoke with the Muon system. Conceptual design of the SCTD is shown in Fig. 2.



**Figure 2.** Conceptual design of the Super C- $\tau$  factory detector.

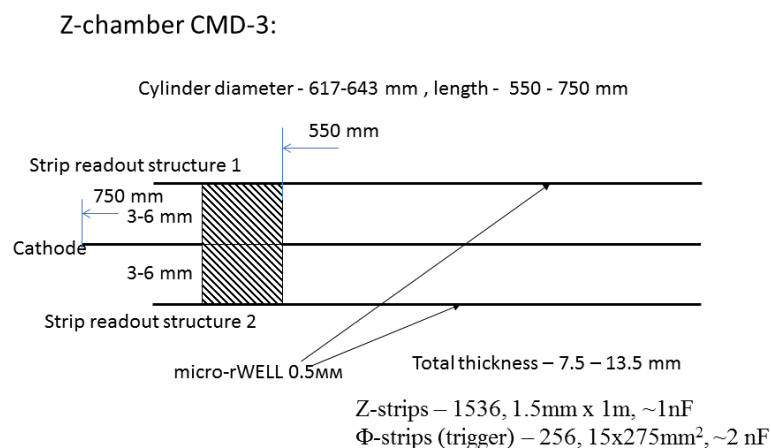
Most of SCTD subsystems have several options. In particular the IT has three main options: compact time projection chamber (TPC) with MPGD-based read-out, cylindrical Gas Electron Multiplier tracker (CGEM) and silicon microstrip tracker (Si-strip). As the IT is the closest subsystem to the interaction point, the particle flux is an important factor affecting the choice of IT technology.

This paper describes the proposed design of the Z-chamber and end-cap discs for CMD-3 upgrade as well as the results of the first measurements with  $\mu$ -RWELL prototypes. The results

of simulations of background particle fluxes in the region of IT of the SCTD are discussed and the outcome of these data for the TPC option is analyzed. The first results of ion back flow (IBF) measurements with  $\mu$ -RWELL-GEM detector are demonstrated.

## 2. Upgrade of CMD-3 with micro-RWELL detectors

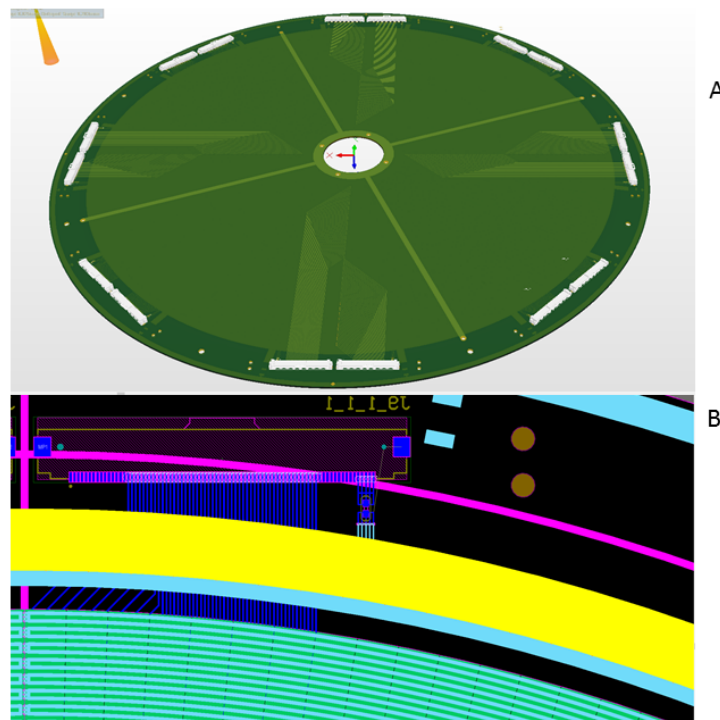
Z-chamber of CMD-3 detector is a triple cylinder with central cathode 630 mm in diameter and 750 mm long. The inner cylinder has diameter either 617 mm or 623 mm, depending on 3 mm or 6 mm gas gap that will be chosen after final tests of the prototypes. The outer cylinder will be either 636 mm or 643 mm in diameter. The inner side of the outer cylinder and outer side of the inner cylinder are covered with  $\mu$ -RWELL on top of the double-layer strip readout structure. Strips that measure Z-coordinate follow with a pitch of 1.5 mm and trigger pads are oriented along Z-coordinate and have pitch of 15 mm. Schematic structure of Z-chamber is shown in Fig. 3. The first measurements with  $10 \times 10 \text{ cm}^2$  prototypes ([16]) showed that specific capacitance of the  $\mu$ -RWELL is about  $40 \text{ pF/cm}^2$  and thus the readout electrodes of Z-chamber will have capacitance of the order of 1 nF. For the readout from electrodes with such high capacitance we plan to use electronics based on VMM ASIC, developed in BNL for ATLAS muon system upgrade [17], that demonstrate equivalent noise charge (ENC) of about 10000 electrons with input capacitance of 1 nF.



**Figure 3.** Schematic structure of CMD-3 Z-chamber with main parameters.

The CMD-3 end-cap discs have 50 cm diameter sensitive area with 10 cm diameter hole in the middle for the vacuum pipe. In Fig. 4a the 3D view of the disc from the back side is shown with 8 pairs of connectors at the perimeter for VMM front-end hybrids. In Fig. 4b a fragment of the readout structure is shown with sectors in phi and quarter-rings in R. The sectors are divided in two groups: the area between  $R=5 \text{ cm}$  and  $R=15 \text{ cm}$  is divided into 144 sectors and the region from  $R=15 \text{ cm}$  to  $r=25 \text{ cm}$  has 244 sectors. The quarter-rings have 2 mm pitch in radius. Total number of readout electrodes is 832. Contacts to all electrodes are routed through inner layers of the readout PCB to the connectors at the disc edge.

First tests of  $10 \times 10 \text{ cm}^2$   $\mu$ -RWELL prototypes with different gas mixtures demonstrated the ability of this single-stage detector to provide gas amplification up to 20000 - 30000 (fig. 5). Due



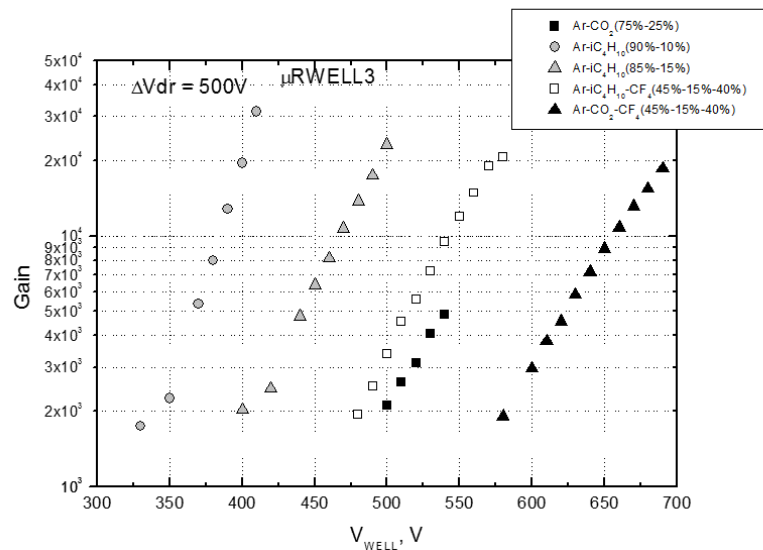
**Figure 4.** a - 3D view of the back-side of the disc with 8 pairs of connectors for front-end hybrids; b - fragment of the readout structure design with quarter-rings and phi-sectors.

to high capacitance of the readout electrodes of Z-chamber the electronic noise will be about 10000 electrons and the gain, necessary to reach full efficiency for minimum ionizing particles with sensitive gas gap of 3 mm, should be higher than  $\sim 14000$  including safety factor of 2 [16]. Therefore to provide safe operation we either have to increase gas gap or to add the second amplification stage.

The results of the gain measurements with GEM on top of the  $\mu$ -RWELL are shown in Fig. 6 for different gas mixtures and selected voltage across GEM that provides GEM effective gain about 10. We can see that maximum gain is increased by a factor of  $\sim 10$  that allows to provide safe operation of Z-chamber. The final selection of the approach between wider gas gap (6mm) or additional GEM will be done on the basis of tests of two prototypes of end-cap discs partly equipped with VMM-based electronics.

### 3. Inner Tracker of the Super charm-tau factory detector.

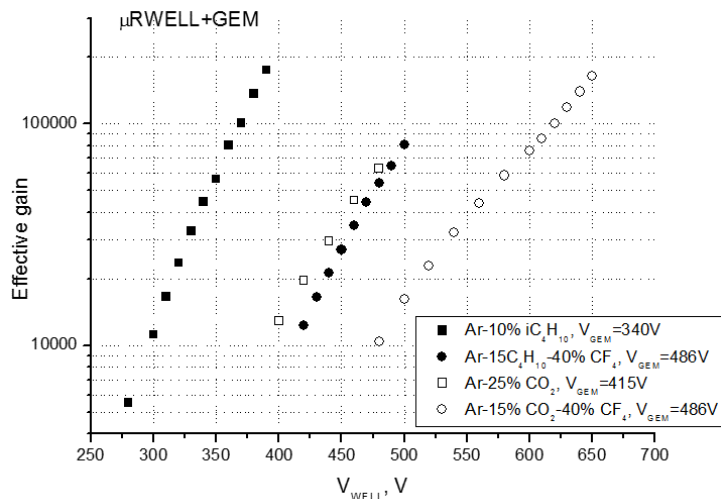
Inner Tracker of Novosibirsk Super Charm-Tau Factory Detector has to measure momenta of soft hadrons, which do not reach the drift chamber; complement the drift chamber in measuring the momenta; detect secondary vertices of short-lived particles. Thus, proper choice of the option for the Inner Tracker is of significant interest. The simulation of charged pions propagation in the perpendicular direction to the beam axis was carried out with DD4HEP program based on GEANT4 [18]. Three options were considered: 4-layered Silicon microstrip detector, 4-layered cylindrical Gas Electron Multiplier (GEM) detector and Time Projection Chamber (TPC). The simulation results demonstrate that pions with initial momenta less than 50 MeV/c do not pass through the beampipe (two 1.5 mm thick Be walls with 0.5 mm paraffin layer in between).



**Figure 5.** Gain as a function of voltage on top electrode of  $\mu$ -RWELL for different gas mixtures. Voltage across the drift gap is 500 V.

Pions with momenta above 65 MeV/c provide energy depositions in all 4 layers of the Inner Tracker based on Silicon microstrip detectors, hence their trajectories can be reconstructed. Cylindrical GEM detector provides reconstruction possibility (hits in 4 layers) for pions with momenta greater than 60 MeV/c. TPC with thin inner wall (50  $\mu$ m kapton with 5  $\mu$ m copper electrodes) provides reconstruction of pions with momenta higher than 55 MeV/c.

The TPC option of the IT with thin inner wall is the most attractive one, because of the lowest threshold for low momentum hadrons and the possibility to use energy deposition along a track to distinguish between low momentum hadrons and background electrons and positrons. However, the TPC operation depends crucially on positive ion back flow from the readout end-caps to the main field cage, that is determined by the background particle flux in the region of the IT. The results of the first simulations of the background created by electron-positron collisions in the SCTD are reported in [19]. Flux of charged particles in the region of the IT consists mainly of electrons and positrons that are produced in two-photon interactions of primary beams, by radiative Bhabha scattering, by electrons, positrons and photons back scattered from the material near the vacuum pipe. Flux of charged particles at the inner radius of the IT (5 cm) is about  $10^5$  particles/cm<sup>2</sup>s, and it drops down to  $10^3$  particles/cm<sup>2</sup>s at the outer radius of the IT. These particles produce ionization in the sensitive gas of the TPC that drifts towards end-caps where gas amplification occurs. Part of ions produced at the end-caps drift back into the TPC volume and build up a space charge, that distorts drift paths of primary ionization. Assuming that the TPC operation parameters are close to those of upgraded ALICE TPC [20], i.e. 1% ion back flow, gas amplification at the end-caps is 2000 and field strength in the main volume is 500 V/cm (400 V/cm in ALICE TPC) we can estimate field distortion due to ion space charge. For charge particles flux of  $10^5$  particles/cm<sup>2</sup>s, 50 e/cm of primary ionization per track, and ion drift time of 16 ms per 30 cm we can get additional z-component of



**Figure 6.** Gain as a function of voltage on top electrode of  $\mu$ -RWELL for different gas mixtures. Voltages on GEM are indicated in the figure. Transfer gap and drift gap are 3 mm. Voltages across the drift and the transfer gap are 500 V.

the field close to 75 V/cm and R-component about 2.5 V/cm. This calculation was performed for a 30 cm long section of infinite uniformly charged cylinder. It is clear that Z-component of the additional field is too high compared to the external field of 500 V/cm and, thus, the ion back flow has to be further reduced down to 0.1%.

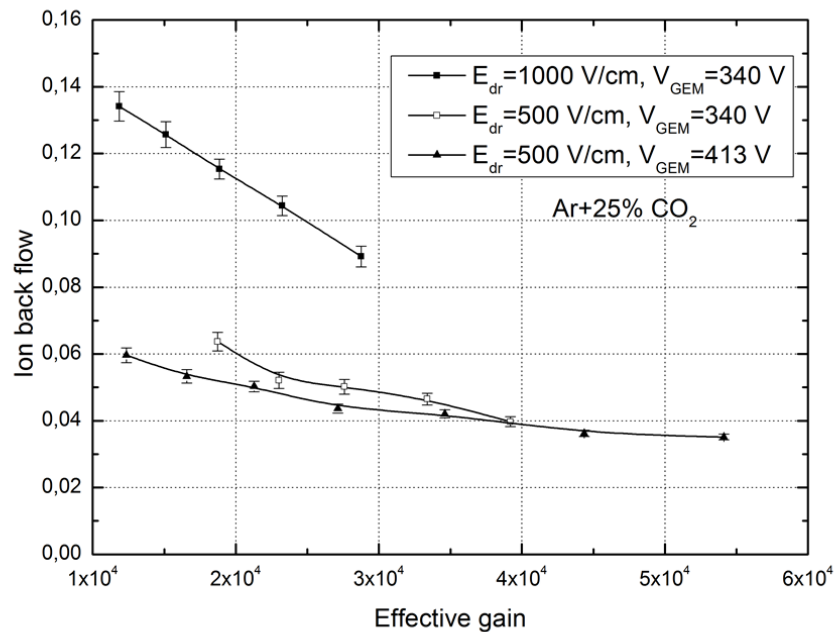
Studies of ion back flow with micromegas demonstrated the ability of this detector to absorb ions produced in the amplification gap. With single stage micromegas a value of 1% ion back flow can be easily achieved [21, 22]. The field structure in  $\mu$ -RWELL is very close to that of bulk micromegas [21] therefore we expected to get low ion back flow in  $\mu$ -RWELL-GEM combination. The results of the first measurements of IBF in such detector are shown in Fig. 7. IBF is determined as a ratio between the current to drift electrode and the anode current.

As we can see from the figure with the indicated parameters the IBF is not lower than 4% at a gain of 40000. This is quite high value and this study will be continued.

#### 4. Summary and conclusions

$\mu$ -RWELL structures are used for the upgrade of the CMD-3 tracking system. Maximum gain that can be achieved with single-stage  $\mu$ -RWELL detector with 3 mm gas gap looks not enough for safe operation of the device with available electronics. Final choice between thicker gas gap or combined  $\mu$ -RWELL - GEM detector will be made on the basis of tests of two prototypes of the end-cap discs that are now in production.

MPGD technologies are considered for two options of the Inner Tracker of future Super Charm-Tau factory Detector, the Cylindrical triple-GEM tracker or the TPC with MPGD-based readout. The TPC is most attractive option, but background particle rates are so high that ion back flow must be reduced down to 0.1%. Studies of ion back flow for combined  $\mu$ -



**Figure 7.** Ion back flow as a function of effective gain in  $\mu$ -RWELL - GEM detector. GEM voltages and drift fields are indicated in the figure. Drift and transfer gas are 3 mm. Transfer field is varying between 3500 V/cm and 4200 V/cm.

RWELL - GEM detector does not show advantage as compared to multiple GEMs combination and this work will be continued.

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