

Test Beam Results from sPHENIX prototype Time Projection Chamber

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Abstract. The sequential melting of Upsilon states gives us information about the Debye Screening length of Quark Gluon Plasma (QGP). To observe this sequential melting at RHIC energies of 200GeV, a Time Projection Chamber, as part of the sPHENIX detector assembly, with ability to resolve the Upsilon states is proposed. This paper details the construction of the prototype TPC, the method of analysis of test beam data and its results.

1. Introduction

sPHENIX is part of the second generation for physics program at RHIC [1]. One of the priorities of this program is to understand the density dependence of color screening in Quantum Chromodynamics (QCD). The sequential melting of different states of the Upsilon in the QGP is a tool to measure its debye screening length which when combined with the results from the LHC [2] will constrain various models and help us better understand QCD and the properties of QGP.

The Time Projection Chamber (TPC) is designed to achieve the resolution required to reconstruct the Upsilon states.

The three Upsilon states are separated by an invariant mass difference of about 500MeV/c², and simulation suggests that this necessitates the TPC to have a momentum resolution of 100MeV/c

2. Detector requirement and purpose of Test Beam

The required momentum resolution of 100MeV/c can be achieved if the position resolution of the TPC is better than 200μm. The total position resolution is given by

$$\sigma_{tot}^2 = \sigma_{int}^2 + \frac{D^2_{TL}}{N_{eff}} + \sigma_{sc}^2$$

where

a) σ_{int} is the intrinsic resolution (at zero drift) estimated to be ~70μm.

b) σ_{sc} is the resolution due to space charge term and detailed simulations place its value at ~ 50 μm. (in test beam, this is negligible)



The purpose of the test beam is to study σ_{tot}^2 as a function of transverse drift length (L) and obtain the slope helps in obtaining the effective number of electrons (N_{eff}).

3. Details of the prototype TPC

The sequence of layers of the prototype field cage (from inner to outer), has a layer of circuit card to provide the required electric field lines, Kapton to provide insulation and sandwiched layer of FR4, Honeycomb and FR4 to provide the field cage structural rigidity.

An aluminium ring (end ring) is embedded in the layers of the field cage at the edge. This is attached to an aluminium plate on both sides. One plate carries a stainless steel mesh which is held at -20kV and other side carries a module for the avalanche of primary electrons using Gas Electron Multipliers (GEMs) and discretized pad plane for readout.

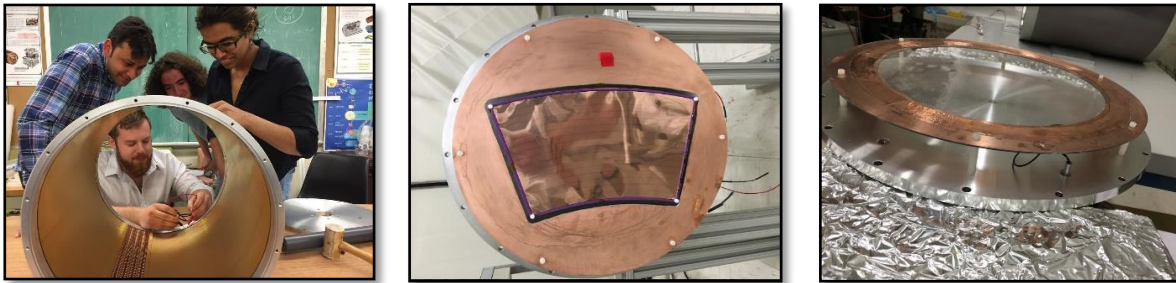


Figure 1: Left – The field cage of the prototype TPC. Middle – Module carrier which has stack of GEM and pad plane. Right – Cathode mesh which will be held at 20kV.

The TPC was placed on an assembly which gave it three degrees of freedom to move. These were - linear direction which changed the drift length of the electrons, rotation to mimic larger eta tracks and phi inclination. In this test beam, only the linear stage was used to scan the drift length.

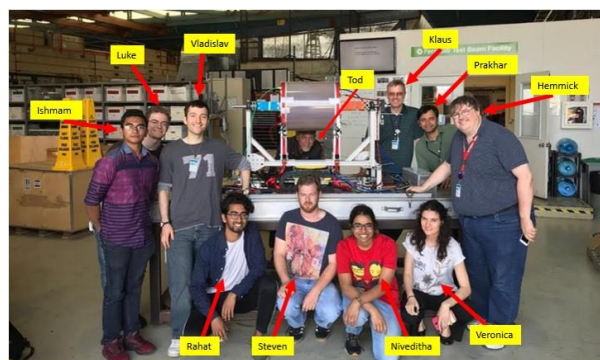


Figure 2: A picture of the TPC with the entire crew at Fermilab test beam facility.

3.1. Module – Gas Electron Multiplier (GEM) and pad plane

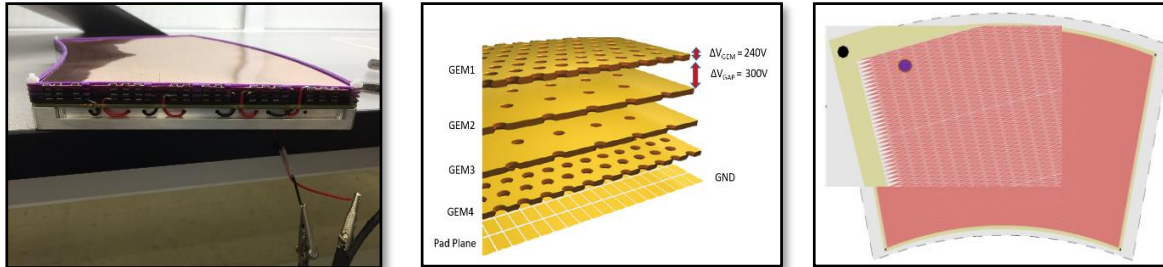


Figure 3: Left – stack of GEM that was installed in the prototype. Middle – Depiction of the four GEM stack with different hole spacing (large pitch of 260μm and small pitch of 140μm). Right – Depiction of Zigzag pad plane.

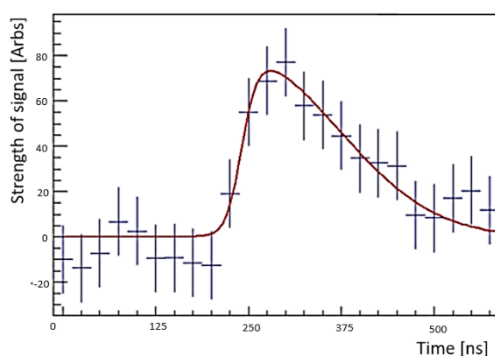
The drifted electrons from the primary ionization are too weak to produce any signal that can be measured. To produce a measurable signal, it needs to be amplified. The gas electron multiplier (GEM) does this by guiding the electrons through a region of high electric field which avalanches the electrons. The prototype had four GEMs stacked on top of each other to provide serial amplification. Each GEM was voltage separated by ΔV_{GAP} and the top and bottom of the GEM is voltage separated by ΔV_{GEM} . An external High Voltage divider card supplies HV to each of these GEMS via traces on top and the bottom of each GEM.

The cloud of avalanched electrons falls on a pad which are discretized in the shape of zig-zags for better resolution. Studies have shown that these provide better resolution than rectangular pads for the same acceptance. The signal from the pads is sent to the data acquisition system via a series of steps which routes the signal and sends a waveform via HDMI cable.

4. Analysis of the data from Test beam

The data from the test beam was analysed in the following steps.

4.1. Data selection



The pulse from the flash digitizer, with a sampling fraction of 40MHz, is a parameterized function that well represents the amplifier response as a function of time. Any pulse outside the digitization window is rejected.

Figure 4: Pulse from the flash digitizer.

4.2. Forming clusters with ZigZags

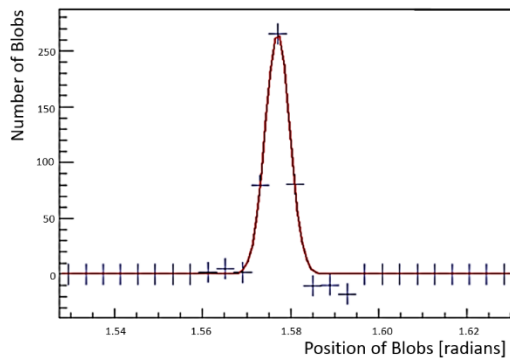


Figure 5: – Charge collection from three pads

A Blob is a collection of neighboring zigzags (ZZs) which have all been hit and the centre of the blob is the average of the position of the ZZs which are hit weighted by their charge.

As a way of analysing the data quickly, the noise threshold was set high. This way most of the noise is eliminated. To each zigzag that crossed the threshold, one or two ZZs were added to each side of it and their charge included in the analysis. Blobs were now obtained from these collections of ZZs.

The above method cannot be done in real data as it is zero suppressed before being recorded.

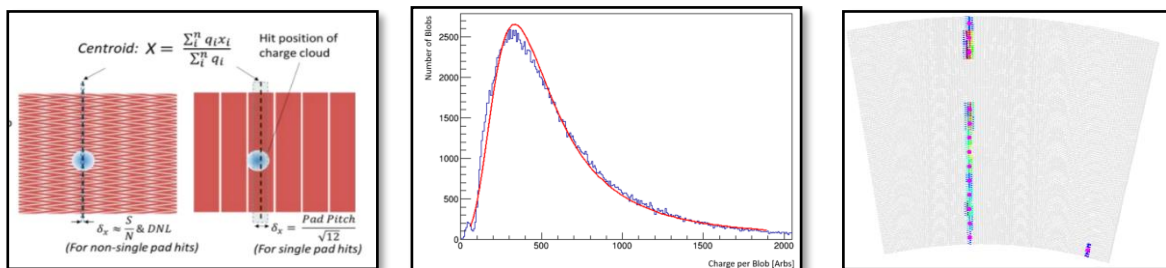


Figure 6: Left – Comparison of pad plane made of rectangular discretization and ZigZag discretization [3]. Middle – The charges in a blob fits a Landau distribution as it is expected for an ionizing detector. Right – PadPlane showing charge hits and blobs.

4.3. Hough Transformation for track determination

In the real analysis we will be implementing Hough transformation algorithm to isolate tracks from noisy background. In this algorithm, each pair of points will correspond to a specific point in the (slope, intercept) Hough space. In this case, there are 14 points and thus we will have 91(m,c) value. From the Hough space, it is easy to pick out true (m,c) value. The resolution will then be calculated by measuring the variance of distribution of the distance of the blobs from the straight line.

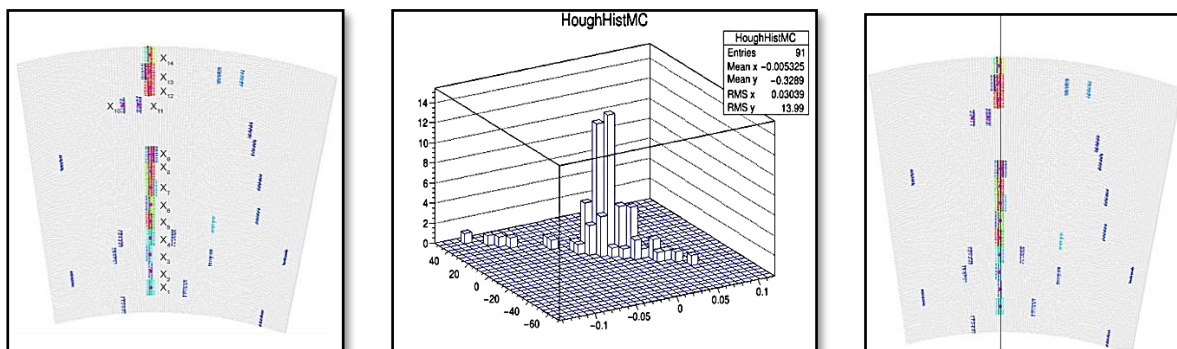


Figure 7: Left – display of an event which has noisy background apart from the hits from track. Middle

– Hough Space histogram of (slope (m), intercept ©) for all hits in the event. Right – a line predicting the correct (m,c) of the track.

4.4. Analysis

For resolution results, subset of data which has only one blob in row 3,4 and 5 (from inside to out) were chosen. The position of blob in row 3 and 5 was interpolated to find the position of blob in row 4 and compared with the actual blob position. The variance of the distribution was used to measure the distribution.

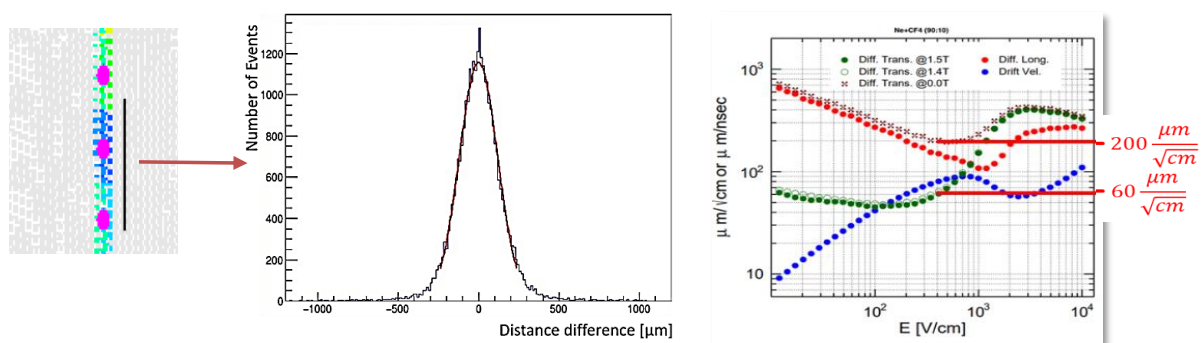


Figure 8: Left and Middle – The predicted position subtracted from the actual position of row 4. Right – Transverse and Longitudinal velocity of electrons in Ne:CF₄ (90:10) as a function of Electric field for various magnetic field configuration

The resolution is calculated as a function of varying drift length (2cm, 18cm, 28cm, 37cm). The slope of the graph gives D^2_T/N_{eff} and the intercept gives σ^2_{int} . The gas characteristics were calculated using Garfield for $B=0T$ and $B=1.4T$ for Ne:CF₄ (90:10). Plugging D^2_T in the equation gives us a N_{eff} . Using the N_{eff} and the value of D for Ne:CF₄ at $B=1.4T$, we get the resolution of the TPC.

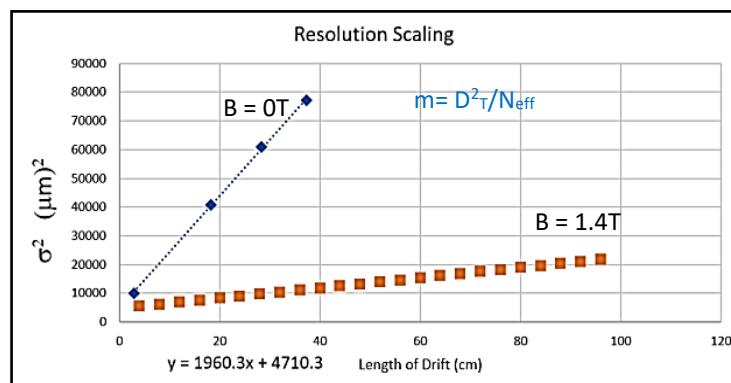


Figure 9: Resolution squared as a function drift length from data at $B = 0T$ and interpolated for $B = 1.4T$

5. Results

The results from simulation expected the resolution of the TPC to be at 138 μm . From the test beam result, we obtained an average resolution of 114 μm with $N_{\text{eff}} = 20.5$. under unrealistic noiseless condition, we obtained the limit of the resolution with the current choice of gas and drift field to be 106 μm .

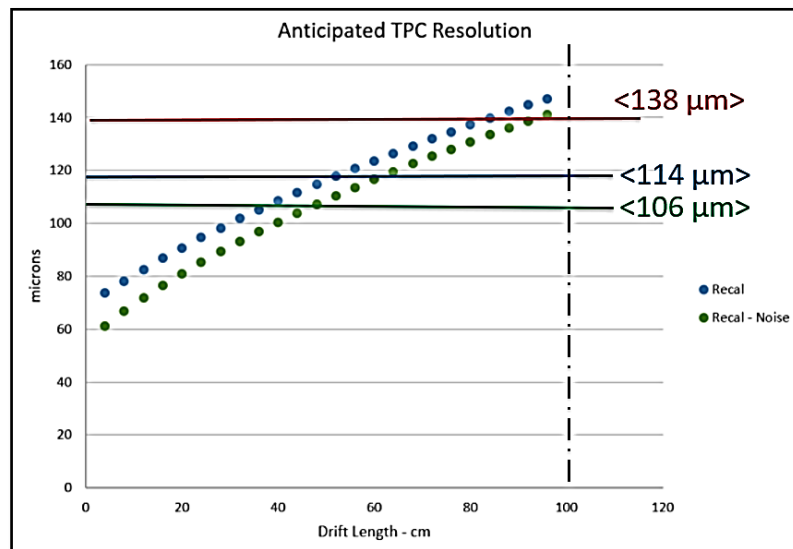


Figure 10: Plot of resolution as a function of drift length for present condition and under noiseless limit

References

- [1] – Reed, Rosi. “A New Detector at RHIC, SPHENIX Goals and Status.” *Journal of Physics: Conference Series*, vol. 779, 2017, p. 012019., doi:10.1088/1742-6596/779/1/012019.
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- [3] - Azmoun, B., et al. “Design Studies for a TPC Readout Plane Using Zigzag Patterns With Multistage GEM Detectors.” *IEEE Transactions on Nuclear Science*, vol. 65, no. 7, 2018, pp. 1416–1423., doi:10.1109/tns.2018.2846403.