STAR Note 434

A Description of the MWC slow simulator

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Abstract

MWC is a trigger detector in STAR. We explain the design of this detector and describe a simulation package that was developed for the MWC. Using the simulation, we study the properties of the MWC signal for various thresholds. Finally, we present the calculated average number of hits produced by a minimum ionizing particle in the MWC, which is equal to 0.78 at 60mV threshold ($\sim 1/3$ minimum ionizing particle).

1 Introduction

The STAR MultiWire Proportional Chambers system is designed to count charged particle multiplicity in the region $1 <| \eta |< 2$ on a beam crossing by beam crossing basis, for use in the STAR trigger. The MWCs are located on both endcaps on STAR time projection chamber (Fig. 1). There are 12 TPC sectors on each endcap. Each sector has 3 planes of wires - gating grid, ground plane and anode wire plane (Fig. 2). The volume between the gating grid and the TPC pad plane is the active volume of the MWCs. The anode wires perform a dual role - they help form the signal on the TPC pads, and they serve as an independent trigger detector. Each time a particle passes thru the active volume of the MWC a signal is generated on the anode wires. The system is set up to read out the signal from the anode wires once per RHIC crossing and determine the charged multiplicity in the MWC in that particular crossing.

2 MWC Hardware

Each TPC sector has 338 anode wires, only 320 of which are used for triggering. The active volume around one anode wire is called an MWC cell. Each anode wire is held at a high voltage, which creates the electric field configuration in the MWC cells as shown in Fig. 2, left cell [1]. When a charged particle goes thru the MWC cell, it deposits ionization along its track. This ionization then drifts to the anode wire, following the lines of the **E**-field. On approaching the anode, the drifting electrons cause avalanches, and the number of electrons reaching the anode wire is approximately equal to the original number of deposited ionization clusters times the gas gain. For example, consider a muon coming from the interaction point with the energy of 500MeV, almost a minimum ionizing particle (MIP). Details of the signal generated by such muon are provided in the table below:

MWC Subsector	Inner	Outer
Chamber size (r, z) [a]	4mm x 10mm	4mm x 14mm
Gas Gain (V_{inner} = 1152V, V_{outer} = 1403V)	2503	1315
Maximal # of Primary Electrons	63	85
Signal (electrons)	157,689	112,627

Table 1: Important Parameters in the MWC. A MIP deposits ionization every 0.17mm on the average, 63 primary electrons correspond to a maximal path of 10.77mm, and 85 to 14.56mm. The average ionization is much lower than maximal because a typical track divides its ionization between more than one cell.

[a] For the chamber size, r refers to the radial size (from the beampipe), and z is along the TPC drift direction.

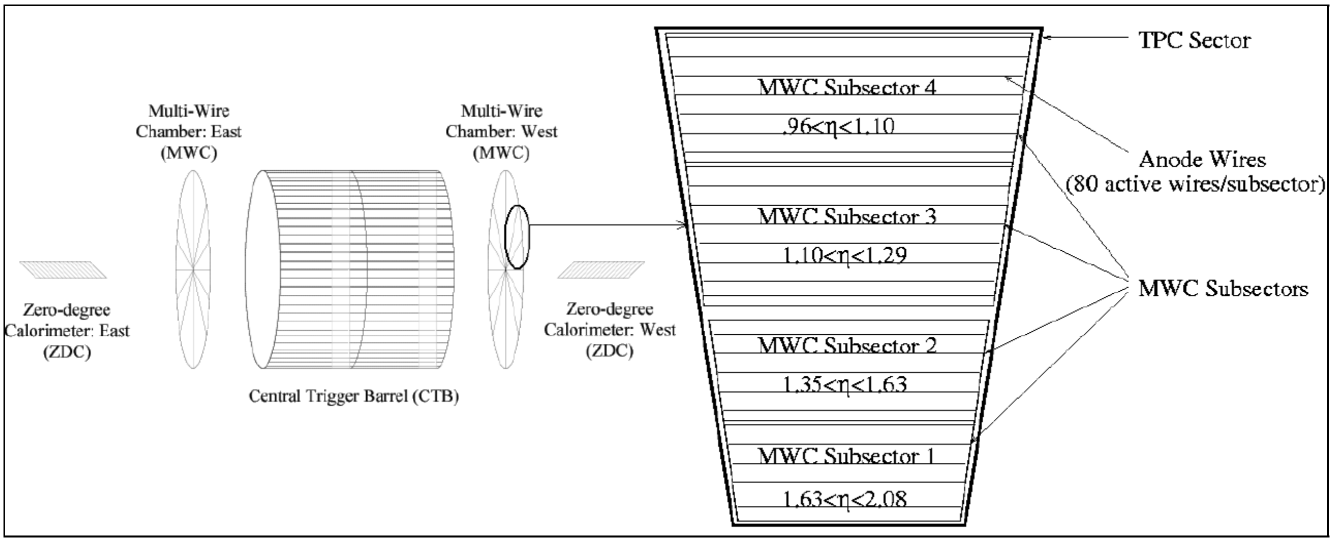

Figure 1: Star Trigger Detectors, with enlarged view of MWCs

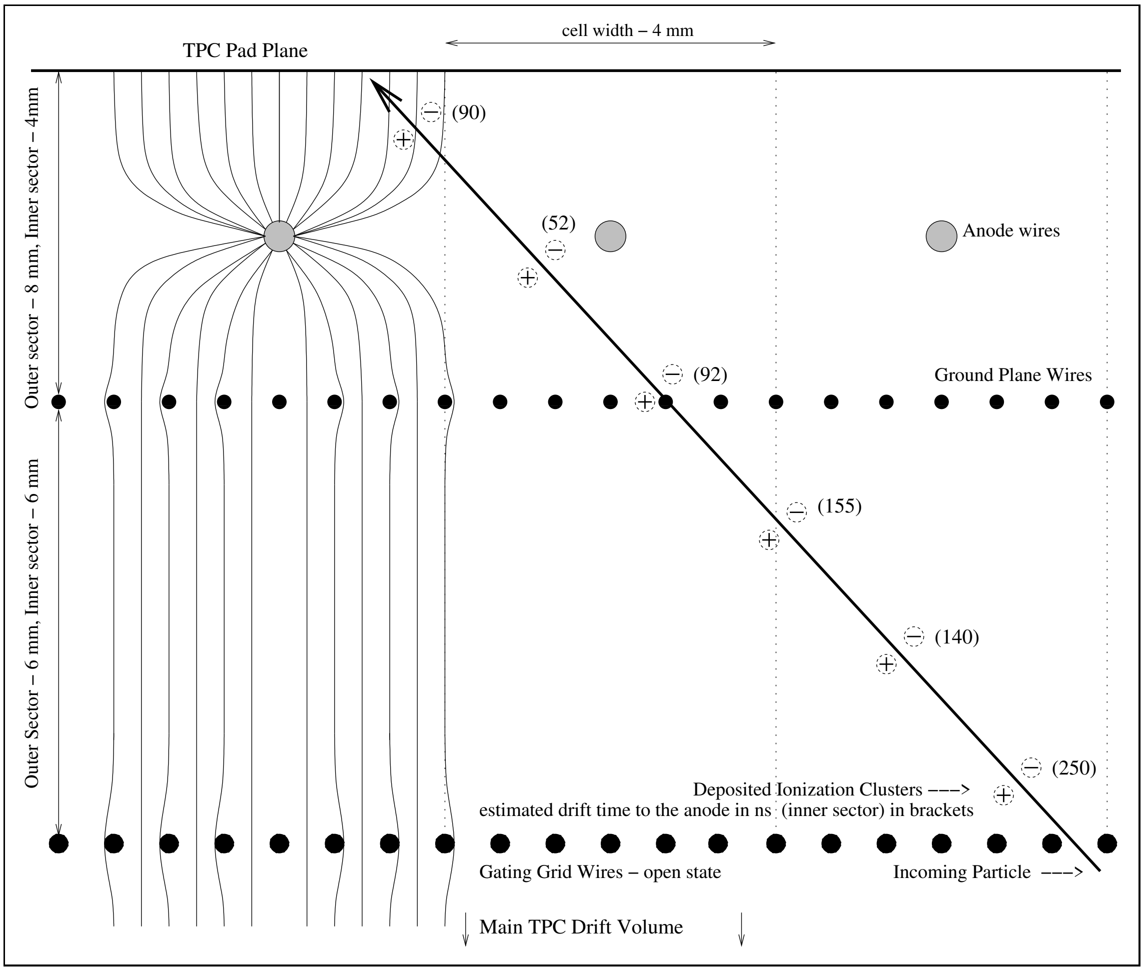

Figure 2: The active volume of the MWCs

Signals from the MWC anode wires are received by the readout electronics: front end electronics cards (FEE), sector controller boards (SCB), and sector readout boards (SRB). Each FEE card contains a low-noise preamplifier-shaper and discriminator for 20 wires [2]. Once per RHIC crossing, FEE cards transmit a 20-bit word to the SCB, representing a hit or no hit in each of the 20 wires feeding into that FEE. There is one SCB board per TPC sector. FEE cards and SCB boards are mounted on the endcaps of the STAR detector. Each SCB receives signals from 16 FEE cards (320 channels). The signals from each FEE card are counted, producing a 5-bit word containing the number of hit wires. Then, the 16 5-bit words are transmitted serially to the SRB over a G-link based fiber optic system to the SRB on the platform. The SRB board receives these signals, and sums groups of 4 5-bit words into one 8-bit sum representing a rapidity slice of $\Delta\eta = 0.25$ (80 MWC cells), which is called an MWC subsector (actual rapidity values vary for different sectors, see Fig. 1). This is the signal granularity available to the trigger. The identity of each wire in the MWC subsector is lost at the trigger level. 96 8-bit MWC sums are differentially transmitted to DSM boards in the trigger. The DSMs perform the final conversion from the number of hit MWC cells to the charged multiplicity in the MWC and use this information for triggering. The trigger system checks the MWC output on every RHIC crossing, and makes an accept or reject decision for each crossing, using the information from the MWC and other trigger detectors (Fig. 1) Once a particular RHIC crossing triggers, slow STAR detectors start readout and the Data Acquisition system records an event. DAQ system will also write on tape MWC signal from up to 5 crossings before and after the triggered crossing.

3 MWC Electronics

Each 20-channel FEE card contains 2 SAS16B preamplifier/shaper chips and 5 4-bit discriminators. The SAS16B 10-channel chips are very similar to the SAS16F chips used in the TPC front end electronics. The main difference is that the MWC chip has a continuously reset integrator, so the input is always active. The price is a slightly higher noise - about 1200 electrons for this system. Also, the SAS16B has a gain of 24 mV/fC, which is higher than the gain in SAS16F chips. The shaper is set to have a full-width-half-maximum of 200 ns, as with TPC FEE. The main goal of the shaper is to cut off the long signal tail, and give a more narrow shape to the resulting signal. For example, Fig. 3 (bottom, right) gives amplifier/shaper response to a 1-electron input. Note the maximum height of the curve is $3.7\mu V$. Output of the SAS chip channel is sent into the discriminator.

The output of the discriminators is latched up once per RHIC crossing by a one shot mechanism, which means that if we latch up a 1 from a discriminator in some RHIC crossing, then the next RHIC crossing we will necessarily latch up a zero from the discriminator no matter what was the output of the discriminator, then in the following RHIC crossings we will latch up a 1 only if a discriminator output goes below zero at least in one RHIC crossing.

The next important aspect of MWC electronics is the delay in the MWC signal, which comes from several sources. Table 2 presents a summary of all such delays. As the result of delays in different parts of the MWC system, the MWC signal arrives at the DSM several RHIC crossings later than signals from other STAR trigger detectors, and this latency needs to be considered when correlating MWC readout with the data from other trigger detectors.

Latency Source	Delay due to source
Flight time from the interaction point [b]	10 ns
Drift + Shaping	100 - 200 ns
Latch up [c]	50 ns
Summing up in the SCB	20 ns
Fiber link transmission + multi/demultiplexer	360 ns
Summing in SRB	50 ns
Total :	580 ns $\simeq$ 5 RHIC ticks

Table 2: Time delays in various MWC system components

4 MWC Slow Simulatior description

4.1 Requirements for the MWC simulations

The software package must simulate for each event the signal in 96 MWC subsectors in 11 successive RHIC crossings, starting from the moment when the interaction happens. This package should be able to:

1) Account for the flight time from the interaction point to the MWC,
2) Simulate the deposition of the ionization in the active volume of the MWC,
3) Ionization drift to the anode wires,
4) Convolute the charge signal on the anode with the amplifier/shaper response,
5) Simulate electronic noise,
6) Simulate the discriminator and the one-shot mechanism,
7) Simulate other signal delays in the hardware.

4.2 Details of the MWC simulator algorithm

The main part of the simulation of the passage of the particles thru the active volume and ionization deposition is done by GEANT. GEANT provides us the position of the hit in the MWC, flight time, length of the track in the cell, momentum of the track and the amount of energy lost by the particle in the MWC cell. Here are the steps of the simulation algorithm:

1) Merge all hits which come from different tracks if they happen in the same cell. Proper account is taken for possibly different flight times for all of these particles from the interaction point to the MWC.

2) Simulate each track hitting the MWC cell as a straight line. Since each MWC cell is very small this approximation is adequate. In the simulated event pool of 5000 events, only 15 events show a twist of more than 4 degrees within an MWC cell (this includes secondary tracks)

[b] This is the time from the moment the primary interaction occurs to the instant when the ionization is deposited in the MWC cell. For secondary particles this may be significant. The flight time from the diamond to the outer region of the MWC is 10 ns at $\beta = 0.75$.

[c] Since the discriminator output is latched up only once per RHIC crossing, there may be some delay between the instant the discriminator gives a 1 and the time when this signal is latched up and sent further.

3) Deposit ionization evenly along the line of the track. We assume that each ionization cluster takes about 30 eV to form, and the number of ionization clusters deposited in a cell is proportional to the energy lost by a particle in a cell. In our sample pool, only 108 tracks caused a secondary particle to be produced within active MWC volume, so again, this assumption is reasonable.

4) Simulate the drift of the deposited ionization to the anode wire[d]. The electrons in deposited ionization clusters have little initial kinetic energy, so they follow the electric field lines. The number of electrons collected on the anode wire is the number of primary electrons times the gas gain (which depends on the anode voltage).

5) Convolute the signal on the anode wire with the amplifier/shaper response and add electronic noise. Fig. 3 shows a sample response from 3 different minimum ionizing particles going thru the MWC cell (in the outer subsector), without the noise.

6) Add voltage outputs for the different tracks going thru the same MWC cell. We assume here that shaper/amplifier are linear.

7) Shift the voltage curve by the amount of delay that MWC signal has compared to the rest of STAR trigger detectors.

8) Slice the voltage curve into 11 RHIC crossings, find a maximum voltage in each slice and compare it to the voltage threshold.

9) Simulate the one-shot mechanism.

10) Group MWC cell signals in the groups of 80 cells, compute a total number of hit cells in each group (one MWC subsector)

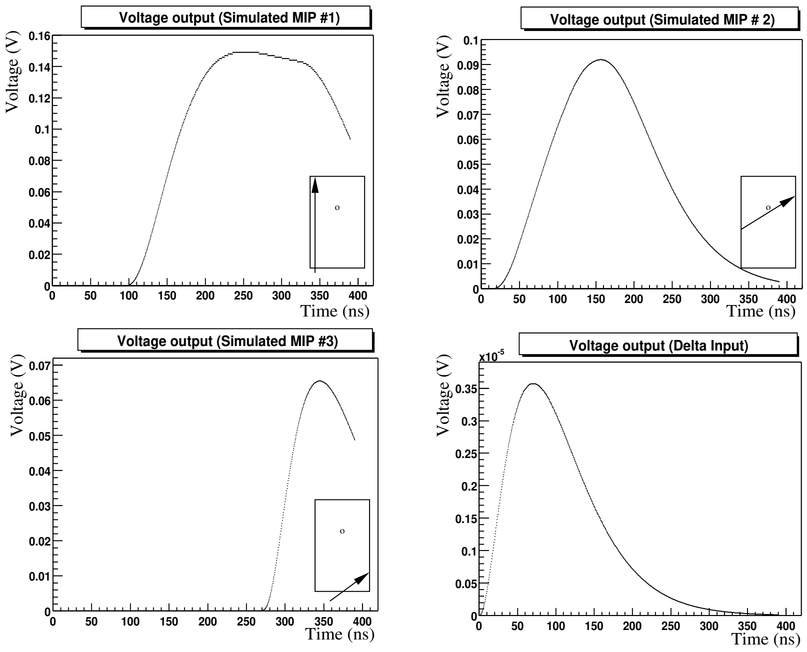

Figure 3: Top and bottom left: SAS chip voltage for simulated MIPs. Drawings to the right of each graph show how the MIP went thru the MWC cell. MIPs cross the cell at t=0. Bottom right: voltage output for a single electron input at t =0

[d]A crude parameterization of the **E**-field in the MWC cells is hard-wired into the code, with two input parameters that can be adjusted - drift field value in the main TPC volume and the voltage on the anodes.

11) Write out 96x11 numbers, representing 11 RHIC crossings of MWC signal information [e] .

4.3 MWC Response

If we applied the total deposited ionization in a cell to an anode instantaneously, the maximal voltage generated by a MIP would be $24mV/fC \cdot 59,175\ e = 548mV$ in the outer sector, and $767mV$ in the inner sector. However, a particle traversing the MWC cells deposits ionization which is spread along the MIP's track. The maximum voltage that can be produced by a MIP in the MWC is about 180mV in both the inner and outer sectors.

4.4 Sample Event Pool

We use the GEANT Mickey-Mouse generator to generate 5000 events, each containing 1 muon coming from the origin with $P_\perp = 1$ GeV and $0.90 < \eta < 2.10$. Particles are distributed evenly over the (ϕ, η) space. All the simulated results described here, except Fig. 6, were produced with this event pool.

To check how the simulator works, we consider MWC hits generated by the muons in our sample event pool in all time bins. Fig. 4 presents probability for such muons to leave 0, 1, 2 or > 2 hits in the MWC for different subsectors and different voltage thresholds in the discriminator. For comparison, the rightmost column gives the pure geometric probability for 0, 1, 2 and > 2 hits. Note that in the geometric probability column events with no hits in the MWC come from the particles striking the dead regions of the MWC. The dead regions are 24 gaps in η between subsectors 2 and 3, and 24 gaps in ϕ. However, in all other columns, we filter out events which have no hits in the active volume of the MWC, so the small fraction of events with no hits in the MWC comes from the tracks which do not leave enough ionization in the MWC cell for the anode wire to fire.

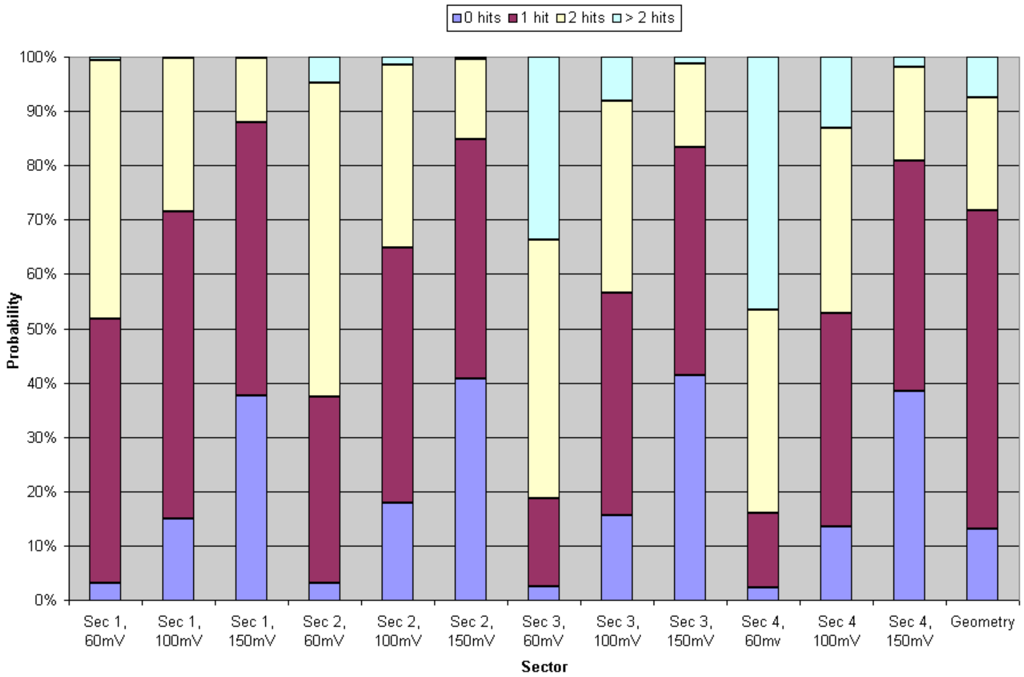

Figure 4: Probability to fire for different sectors and thresholds, all time bins included.

[e] With this setup the simulated data format is slightly different from the real data format - real data contains 5 pre-trigger crossings, 1 trigger crossing and 5 post-trigger crossings, with the trigger crossing being determined by the data from all trigger detectors. Since the final MWC timing has not been set yet, the simulator writes out the very first time bin after the event occurred and 10 RHIC crossings after that.

Now we can look at how the MWC signal develops in 11 successive RHIC time bins. Fig. 5 shows such distribution for our event pool. The MWC hits from 1 particle start in time bin 6, the number of hits reaches a maximum in time bin 7, and then falls off. From this we can conclude that if MWC signal needs to be timed with the signal from other trigger detectors, 7 RHIC crossing after the event is the best time to use, since it will provide the largest signal[f].

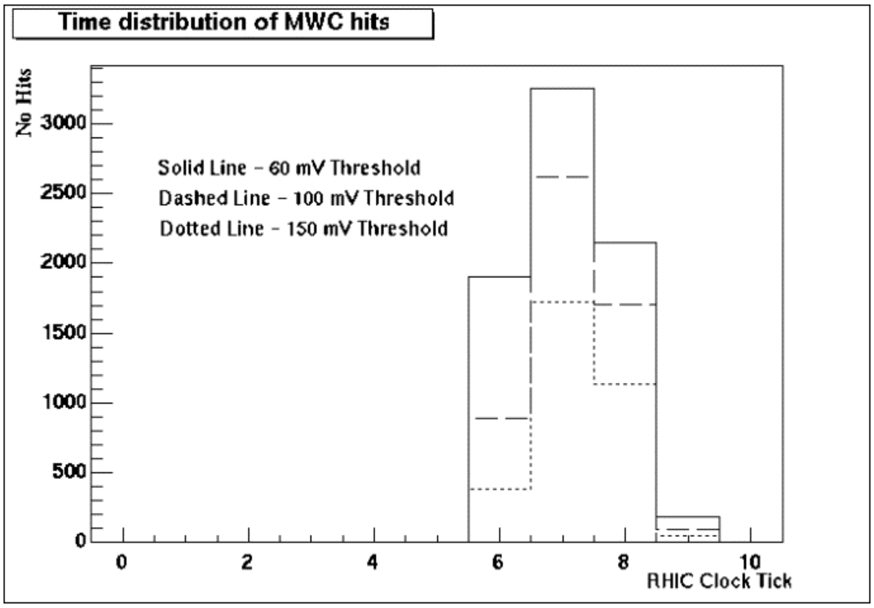

Figure 5: Sum of signals in 11 successive RHIC crossing from 4316 tracks going thru the active region of the MWC.

The total number of events in this histogram is 4316 - 684 out of 5000 tracks (14%) in our sample pool go thru the dead area of the MWC. Using this plot we can also estimate how many hits 1 particle leaves on the average in the trigger time bin. This ratio is $3300/4316 \simeq 0.764$ - less than one hit per particle[g].

This average number of hits from one MIP must not be confused with the MWC efficiency - about 30% of the data in the timebin 7 comes from double hits by one particle, and about 0.5% comes from triple hits from one particle[g]. The ratio $\frac{\#\ detected\ particles}{\#\ particles\ in\ MWC} \sim 59\%$ is our detection efficiency in the MWC. Timebuckets 6, 8 and 9 display almost no multiple hits from one particle (0.2% double hits in timebucket 6, 3% double hits in timebucket 8, and 0% double hits in timebucket 9)[g]. Modifying the MWC electronics to produce longer pulses (i.e. making one MWC signal 2 RHIC crossings long) should increase the efficiency, since one signal would then contain information from 2 RHIC crossings.

One final check on the simulation, is to look at multiple particles in the MWC. Fig. 6 compares charged multiplicity in the MWC with the number of hits in the trigger time bin of the MWC. We used 1230 events, each containing 20-60 1GeV muons, for this study.

[f] The timing can be continuously adjusted to latch the discriminators at any point within 109 nsec RHIC cycle. This allows us to obtain maximal signals from the MWC.

[g] at 60 mV threshold, which is about 1/3 of the maximal signal from a MIP.

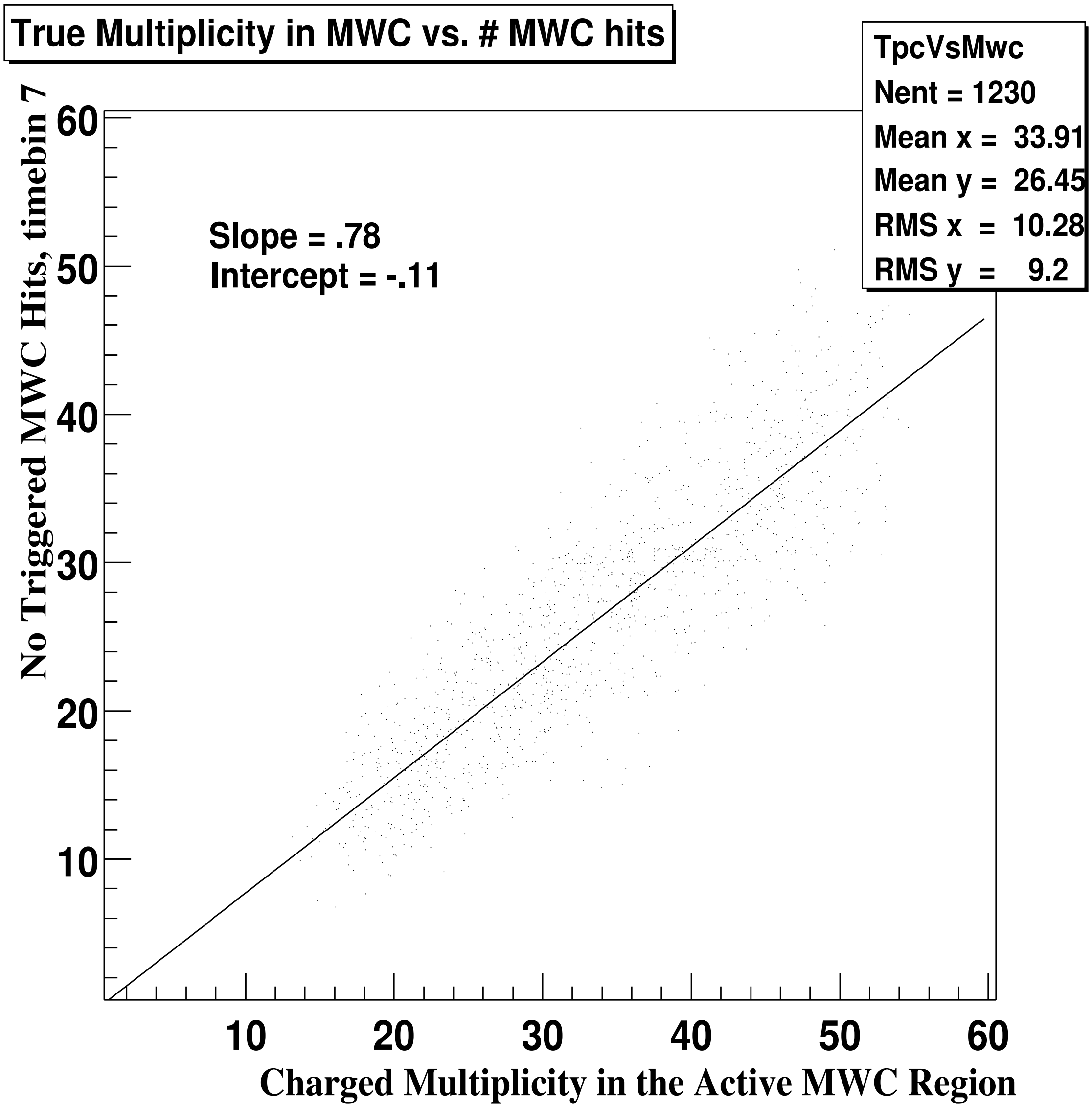

Figure 6: True MWC multiplicity vs. detected multiplicity.

The data shows a high degree of linear correlation ($corr(x, y) = 0.88$) The slope of this line can be used as a conversion coefficient MWC hits $\rightarrow$ charged multiplicity in the trigger DSMs. The least squares fit gives a slope value of 0.78 ± 0.02. This is very close to the estimated average number of hits per MIP from Fig. 5. As Table 3 shows, the correlations are similar at two other thresholds, 30 mV and 100 mV. At 100 mV threshold, the slope begins to drop, indicating that the efficiency is dropping. The slopes at 30 and 60 mV are similar, indicating that a plateau has been reached. The slope never reaches 1 (which would correspond to an average 1 wire/MIP), so a correction will always be needed.

Threshold	30 mV	60 mV	100 mV
Slope	0.81 ± 0.02	0.78 ± 0.02	0.64 ± 0.02
$corr(x, y)$	0.89	0.88	0.87

Table 3: Detected multiplicity in MWC vs. true multiplicity at different thresholds.

The naive expectation for the simulated trigger efficiency is close to 100%. Indeed, every track in the active region of the MWC fires 1 or more wires with a total probability of $\sim 97\%$ at 60mV threshold (Fig. 4). But due to the long drift times and shaping, the signal develops over several RHIC crossing. Therefore different particles can trigger in different RHIC crossings, and there will be no one specific RHIC crossing when all particles cause a signal in the MWC.

5 Conclusions

We present a slow simulation algorithm for the MultiWire Proportional Chamber. This algorithm has been tested on several sample event pools, and produced correct results. We find that the average number of hits per minimum ionizing particle in the MWC is 0.78 ± 0.02 MWC signals from one event are spread over several RHIC crossings, and as a result, a trigger decision on any single RHIC crossing will miss a fraction of MWC hits, reducing efficiency. The best efficiency is achieved 7 RHIC crossings after the event. The simulation code is available from the STAR CVS repository, and is included as a part of STAR Simulations production chain. Appendix 1 gives information on how to run the code, and how to adjust the parameters of the simulation.

References

1. R. Bossingham, Field Details in the Anode Plane Region (1997). `www.star.bnl.gov/STAR/html/tpc_l/tpc.html`
2. E. Beuville *et. al.*, "Front End Electronics for the STAR TPC", *IEEE Trans.Nucl.Sci.* **43**, 1768 (1996).
3. V. Morozov, `http://sseos.lbl.gov/~vlmrz/mwc/MWC.ps`

Appendix 1

The current version in stardev is dated May 25, 2001 and contains all the functionality described above. Here are a few tips on how to use the simulator:

- If you wish to get a private copy of the code, check out into your private directory the following: $\$STAR/pams/mwc$ and $\$STAR/StRoot/St\_mwc\_Maker$
- Once you've copied the code compile by typing: $'cons\ +'$
- In $bfc.C$ chain you *must* indicate the option "mwc", and optionally, "trg"
- A sample chain might be: $'.x\ bfc.C(No\_events, "fzin\ Cy2a\ mwc\ trg", "your\_fz\_file.fz")'$
- As the chain runs it will print out a bit of useful info about MWC hits
- After $bfc.C$ finished running, you can open a TBrowser, find the bfc tree, and goto $bfc \rightarrow .make \rightarrow$ (if present, $L0chain \rightarrow$) $mwc \rightarrow .data$ or $mwc \rightarrow .hist$
- In the *.hist* directory you will find a bunch of histograms that show properties of MWC signal
- In *.data* you can find mwc output tables - table "raw" is the most relevant one - it provides signal values in each of the 96 MWC sectors for 11 consecutive RHIC crossings (crossing # 6 - trigger crossing)
- Remember that sector numbering scheme in the MWC simulator is *very* different from the STAR convention. The map in ref. 3 presents such a scheme.
- If you have run trigger maker, MWC sectors in there will be numbered by a set of two indices - (sector number (0-23); subsector number (0-3)) - sector number is the same as TPC sector number -1, subsector number represents different position in pseudorapidity: 0 - innermost subsector, 1 - next innermost subsector, etc.
- After the trigger maker you can put MWC information into StEvent, which makes this information easy to access.
- If you find that the slow simulator is too slow for your purposes, you can easily go back to the fast simulator. You will have to check out the MWC maker into your private directory, change the call to the slow simu to the call to the fast simu and recompile the code. Here are the steps:
  klog
  stardev
  $cvs\ co\ StRoot/St\_mwc\_Maker$
  edit $StRoot/St\_mwc\_Maker/St\_mwc\_Maker.cxx$
  find the line where I call "mws" - see the commented instructions on how to call "mwf"
  save this file
  $cons\ +StRoot/St\_mwc\_Maker$
  You may now run *root4star*
- There are a number of parameters that you might want to change in the MWC simulation (see idl files for mwc_mpar and mwc_pars). If you wish to change any parameters, check out St_mwc_Maker, open it for editing, find where in the code these parameters are defined (all parameters come from the database, but I give examples in the code how to use your own values instead of the database), compile and use the code (see instructions above for help with checking out and compilation)
- If you ever have to mess with the simulation code, you'll need to check out $pams/mwc$, change the file $pams/mwc/mws/mws.F$ and then recompile. One thing to remember is that you have to compile in this order:
  $cons\ +pams/mwc$
  $cons\ +/mwc/$