Associating the correct tracks to the trigger event in STAR for high luminosity proton on proton running

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Introduction

A recurring question to the STAR collaboration is how one can do tracking in pp running where one has a high event rate with a relatively slow detector. The purpose of this note is to document how this will be done.

Basic Parameters

The baseline luminosity for pp running at RHIC is ~1 x 10^{31} $cm^{-2}{\cdot}s^{-1}$. The baseline bunch crossing frequency is about every 220 ns. For the purposes of this study I'll use a pp luminosity of 2 x 10^{32} $cm^{-2}{\cdot}s^{-1}$.and a bunch crossing frequency of every 110 ns. I'll assume throughout this document that the gas in the TPC is 90% Ar and 10% CH4 (P-10) with a drift velocity in STAR of 5 cm/μs. The STAR cylindrical TPC (axis along z) has a cathode plane in the middle (z = 0) so that the electron clouds drift 200 cm to each endcap, for a total drift time of 40 μs. I'll use 40 mb for the pp cross section. The diamond size for pp running has an rms length of 10 cm.

Basic Calculations

Using the luminosity and pp cross section above, the average interaction rate is:

$$\text{rate} = L * \sigma = 2 \times 10^{32}\ cm^{-2}{\cdot}s^{-1} * 40 \times 10^{-27}\ cm^{2} = 8.0 \times 10^{6}\ s^{-1}$$

The average number of interactions per bunch crossing is:

$$8.0 \times 10^{6}\ s^{-1} * 110\ ns = 0.88 \text{ interactions/bunch crossing}$$

A minimum bias pp event at $\sqrt{S}$ = 200 GeV, on average, has ~2.5 charged tracks per unit η. These tracks have a mean pt of ~ 440 MeV/c.

Shown in Fig. 1 are the rates per second to get bunch crossings with 0, 1, 2, or 4 pp interactions in a single bunch crossing plotted versus multiples of the baseline pp luminosity. The rates are calculated using Poisson statistics. The luminosity which will be considered in this note corresponds to twenty times the nominal baseline luminosity for pp running at RHIC.

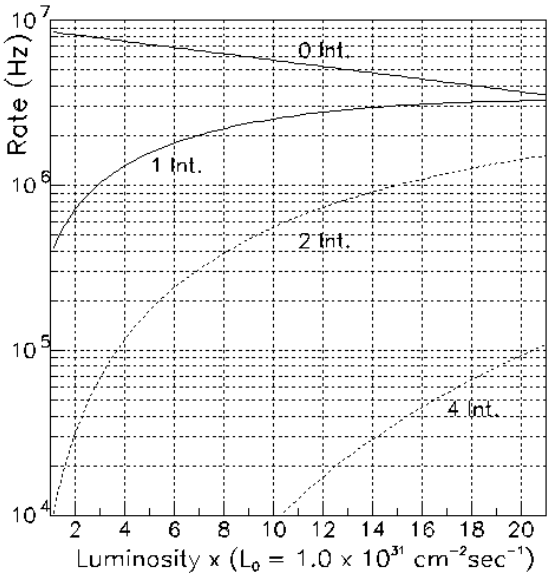

Fig. 1 Rates per second to get bunch crossings with 0, 1, 2, and 4 pp interactions versus multiples of the baseline luminosity. Bunch crossing time of 110 ns used in calculation.

Event Pileup in the TPC

As given earlier, the total drift time in the TPC is ~ 40 μs for P-10 gas. The tracks which pileup in the TPC can come from events which happen in the 40 μs before and the 40 μs after the trigger event. The tracks from events which occur

much earlier (> 2 μs) then the triggered event will appear in the reconstructed event as tracks which are either vertical, or point toward the closest pad plane, and they will intersect the Z (beam) axis somewhere between the center of STAR and the cathode which they point toward. Tracks from events which occur much later than the triggered event will appear to terminate on the central Cathode plane. This is illustrated in Fig. 2.

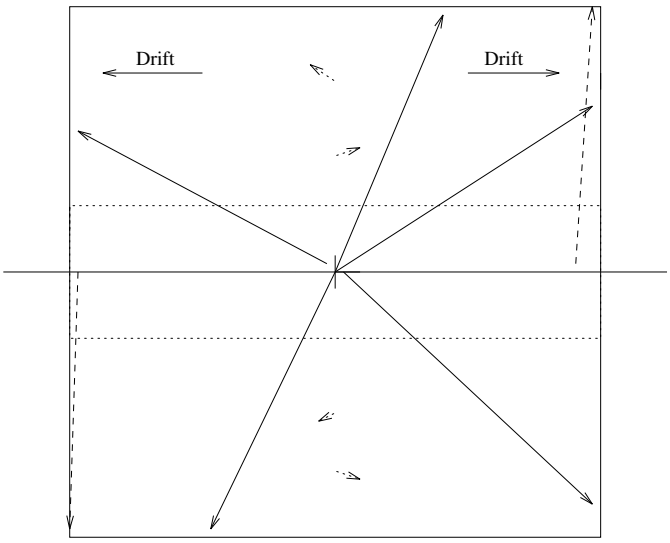

Figure 1. Pileup of tracks in the STAR TPC. Solid lines represent tracks from trigger event. Dashed arrows represent tracks from an event ~ 40 μs before the trigger event, and dotted arrows represent tracks from an event ~ 40 μs after the trigger event.

The total number of partial to full events which pileup in the TPC is thus:

$$\#\ \text{of Evts} = \sigma * L * 80\ \mu s$$
$$= 40\ \text{mb} * 2 \times 10^{32} * 80\ \mu s$$
$$= 640$$

Each out of time event in the TPC will give rise to two "apparent" vertices along the z axis. This is a result of the fact that the tracks in the STAR TPC drift from the center outward toward the ends. Thus there are 640 of these apparent vertices along each half of STAR. This gives a mean separation of 640 vertices/200 cm or ~ 3 apparent vertices per cm. Each of these apparent vertices has, on average, ~ 2.5 charged tracks associated with it (~2.5 charged trks/unit η * 2 units of η, split between two apparent vertices).

Analysis

The number of tracks in the TPC volume due to the 640 piled up partial to full minimum bias pp events is about the same as that due to one central Au on Au event, thus finding all the tracks should not be a problem. An advantage in the pp case is that the tracks are spread out along the z axis, as opposed to Au on Au events where they all originate at the center of STAR. This decreases the number of merged clusters in the inner pad rows of the TPC.

The effect of the piled up pp events depends on the type of analysis one is pursuing. In this note I'll deal with the cases where one is interested in studying min. bias pp events, cases where one requires high single EMC tower thresholds in the trigger, and jets.

First the minimum bias case. To collect a sample of min. bias events STAR will not run at 20 times baseline luminosity. One would run at baseline luminosity, or perhaps even lower. Referring to Fig. 1, at the baseline luminosity the interaction rate is a bit less than 0.5 MHz. This will give an average of 2 μs between interactions which corresponds to a distance of 10 cm between the vertices along the z axis. The tracking resolution of the TPC will easily associate the correct tracks to the trigger event. The trigger condition for

this data set will probably be one or more hits in any of the STAR trigger counters, in coincidence with the RHIC crossing clock.

Next, consider an analysis where one is interested in events which have very high single tower energies in the Electromagnetic Calorimeter. An example of this could be events with 40 GeV towers due to electrons from W decays. There are two questions which must be addressed:

1.) How well can STAR associate the correct tracks with the trigger event?

2.) What is the effect of including tracks from other than the trigger event?

In addressing these questions in the discussion which follows I'll begin with the crudest analysis and work toward the more sophisticated.

We begin by seeing how many tracks we have to choose from. The diamond length at RHIC for pp running has an rms length of 10 cm. Recalling the earlier discussion, and utilizing no other knowledge to localize the trigger event vertex, this gives us ~ 30 apparent vertices (~3/cm) with ~2.5 tracks associated with each one (2 apparent vertices for each pp event) for a total of 75 tracks. A feature of STAR which helps in analyzing these events is that all of the trigger counters and the EMC towers are digitized and stored for every bunch crossing. One thus knows which slats in the Central Trigger Barrel (CTB) and which towers in the EMC must be struck by the correct tracks. Let's assume that the trigger event is ~ twice as violent as a min bias event and that there are thus ~ 10 CTB slats hit.. The correct tracks must point to these locations.

The probability for any one of the 75 incorrect tracks to point to one of the 10 struck (out of 120) CTB slats is ~10/120 x 100% = 8.3%. Thus if one selects all tracks which point to a struck CTB slat, and have a vertex within the 10 cm diamond, one will get the 10 correct tracks and about 6 incorrect tracks (75 trks * 8.3%/trk = 6.2 trks). Looking at the intersection of these 16 tracks with the z axis one will find that 10 of them form a cluster with an rms width along z of ~ 8 mm and that the other six are uniformly distributed over the 10 cm diamond length. Putting a cut on this vertex cluster at the FWHM (~2 cm) will leave one with 6 - 8 of the correct tracks and ~ 1 of the incorrect tracks (~ 1 incorrect track/2 cm along z). The correct tracks which are excluded will usually be those with the lowest momentum and hence the greatest Multiple Coulomb Scattering (MCS). This is not too bad but STAR can do much better.

Now consider the same arguments as used for the struck CTB slats but for the struck EMC towers. For our assumed trigger pp event with 10 charged tracks we can expect ~ twenty struck towers (10 charged πs, ~ 5 π^0s $\rightarrow$ 10 γs) out of 1200. The probability for any one of our 75 tracks from the pp diamond to point to any of the struck towers is 20/1200 = 1.7%. Thus if we select all tracks which point to a struck tower and come from the pp diamond we'll end up with the ten correct tracks and only ~ a 30% probability to have one incorrect track. Looking at the distribution along the z axis we can reduce the probability of associating this incorrect track with the trigger event by a factor of five (2 cm FWHM/10 cm diamond), down to ~ 6%. Thus, using this analysis scheme one expects to incorrectly associate one incorrect track with the trigger event ~ once every 16 events. Not bad at all, but STAR can still do better.

The next tool we can bring to bare is the STAR Silicon Vertex Tracker (SVT). The SVT helps us in two ways. Once one has matched the TPC and SVT tracks the rms for the trigger event vertex will drop from ~ 8 mm to ~ 1 mm. This allows us to open up

the vertex cut used for the CTB analysis above to, say ± 3σ (± 3 mm) so that we get essentially all of the correct tracks, while reducing the probability of including an incorrect track from ~ 100% down to ~ 36%. In the analysis above where we use the EMC tower information the inclusion of the vertexing capability of the SVT drops the probability of including an incorrect track from ~ 6% down to ~ 1.8%.

The second way the SVT can help us is in discriminating between the correct and the incorrect tracks via tracking. The maximum drift time in the SVT is 6 μs, thus when running at a pp luminosity of 2 x 10^{32} $cm^{-2}{\cdot}s^{-1}$ there will be ~ 100 pp events piled up in the SVT as opposed to the ~640 in the TPC. The number of full or partial tracks in the SVT will be ~ 500, which is about 25% as many tracks as it sees in a central Au on Au event, thus the density of hits should not be a problem. Now, whereas in the TPC all of the tracks on each side of the central cathode drift in the same direction, and hence tracks from early or late (relative to trigger event) are merely translated along z, this is not true for the SVT. The SVT is constructed of many individual Silicon Drift Detectors (SDD) arranged on ladders. The ladders are joined to form cylinders, and the SVT is composed of three concentric cylinders separated radially by a few cm. Each of the SDD has a center cathode and drifts the electron clouds to either end of the wafer. The tracks from the trigger event will have hits in the SVT which line up as tracks. A track from an earlier or later event will have only a 25% probability that its three hits in the SVT line up (50% prob. that hit in cyl. 2 drifts in same direction as hit in cyl. 1, 50% prob. hit in cyl. 3 in same dir. as hit in cyl.2 → .5*.5 = .25). Thus requiring a track in the SVT should decrease the probabilities of associating an incorrect track with the trigger event by a factor of four.

These probabilities are summarized in Table 1.

Table 1

Detectors used	Probability to include an incorrect track	Comment
CTB	100%	~ one inc. trk / event
CTB,SVT	36%	Using SVT vertex res.
CTB,SVT	9%	SVT vertex res. and tracking requirement
CTB, EMC	6%	
CTB,EMC,SVT	1.8%	Using SVT vertex res..
CTB,EMC,SVT	0.5%	SVT vertex res. and tracking requirement

Multiple Interactions in trigger bunch crossing

The primary purpose of this note was to describe and quantify how the relatively long read out time of the STAR TPC affects STAR's ability to analyze pp events at very high luminosities. *There is an additional problem which must be addressed for which the speed of the detector is not a factor.* This is the problem of multiple pp interactions in the same bunch crossing. Referring to Fig. 1 we see that at a luminosity of 2 x 10^{32} $cm^{-2}{\cdot}s^{-1}$ about 30% of the time the bunch crossing on which one has triggered will have two or more pp interactions. All of the tracks from these additional pp interactions will be in time and register correctly on the trigger counters, and thus can not be discriminated against as

was done for the tracks from different bunch crossings. The only method that can be used is the projected vertex distributions along the z axis. Using the vertex resolution of the SVT each of the pp vertex distributions should have an rms of ~ 1mm. If we take $\pm 3\sigma$ ($\pm$ 3 mm) for each vertex, the trigger vertex will occupy 6 mm out of the 10 cm crossing diamond. The probability to include one or more of the tracks from the other pp vertex can be estimated as the probability that part of the two distributions overlap. If the center of the second vertex distribution is anywhere within ~ 6 mm on either side of the trigger vertex distribution then there will be some overlap. This gives roughly 1.2 cm/10 cm = 12% probability to include one or more incorrect tracks in the trigger event. Multiplying this 12% probability of including an incorrect track when one has 2 or more interactions in the same bunch crossing by the 30% probability to get the multiple interactions, one find that the total probability of including an incorrect track due to multiple interactions in a bunch crossing is ~ 3.6%. If one wished to reduce this probability further a $\chi 2$ cut could be placed on the fit of the vertex distribution to something like a guassian. This would give a fair amount of discriminating power to recognize partially overlapping pp interaction vertices. However, when one looks at the effect of these incorrect tracks on the physics analysis, one finds that it is negligible. A point which I'd like to emphasize is that this probability of including an incorrect track due to multiple interactions in a bunch crossing, *which has nothing to do with the speed of the TPC*, is two to four times higher than the probability of including an incorrect track because of effects associated with the speed of the TPC.

Effect of inclusion of incorrect tracks in Physics analysis

In this section I'll give a few examples on how these incorrect tracks affect various physics analyses. The highest probability to associate an incorrect track with a trigger event is the ~3.6% due to the multiple interactions, so in what follows I'll use ~ 4% for the probability to include an incorrect track in the analysis

First, suppose that one is doing an analysis in which single tower energies are important. Some examples would be looking for multiple tens of GeV $e^{\pm}$ from W decays, high energy γs from γ - jet events, or inclusive high energy π^0s, etc. The trigger one would use to collect these events would be to require a high energy deposition in a single EMC tower module. Now, the probability that one associates an incorrect track with the event, and that the incorrect points to a given EMC tower is ~ 4% (prob. for inc. trk) * 0.08% (1/1200 = prob. to point to given tower) $\approx$ 0.0033%, i.e. one out of every 30k events! This is not a problem. In the one of 30k events where this happens one would incorrectly subtract the energy deposited in the tower by an ~ 440 MeV/c hadron (440 MeV/c = mean pt for min bias pp). Depending on the threshold used in the trigger, and incorporating the fact that very little of a hadrons energy is deposited in the plastic layers of the EMC (relative an $e^{\pm}$ or γ), one sees that the effect is less than the intrinsic energy resolution expected for the STAR EMC, ~ $16\%/\sqrt{E}$. I conclude that the effects on single tower type analyses is negligible.

Now, suppose one is interested in the energy in a number of towers and due to a number of charged tracks in the TPC, i.e. a jet analysis. The typical jet has a radius of $\sqrt{\Delta\varphi^2 + \Delta\eta^2} \leq .7$. The ratio of a jet to the total area of the STAR EMC barrel is thus ~ π *$(.7)^2$ / 2.0*6.28 = 0.12 or 12%. Starting with the 75 incorrect tracks in the pp crossing

diamond, we can eliminate 88% of them which don't lie in the area of the jet using the trigger detectors bunch crossing time stamp. This gets us down to ~ 9 tracks which hit the CTB and EMC in the same area as the tracks from the jet. I'll assume that due to the large particle density in the jet I can't use the trigger counters to discriminate against these 9 tracks. If I now project all of the remaining tracks back to the z axis, and use the added vertex resolution of the SVT, the correct tracks will form a distribution with an rms of ~1 mm, while the 9 incorrect will be randomly distributed along the 10 cm of the diamond. If I include all tracks within $\pm 3\sigma$ ($\pm$ 3 mm) of the correct vertex the probability to associate one of the 9 incorrect tracks is ~ 54% ((.6 cm/10 cm)* 9). Therefore on average I'll associate an incorrect track with the jet about every other event. Recall that the mean pt for a track from pp min. bias interaction is ~ 440 MeV/c. The energy resolution we expect to achieve using the tracking information and the EMC is ~ 32% rms for a jet of 20 GeV and 25% rms for a jet of 40 GeV. The incorrect track will contribute ~ 2% to the energy of a 20 GeV jet. Therefore the effect of associating one, or even a few, incorrect tracks with a jet is much less than STAR's expected jet energy resolution. I thus conclude that the association of incorrect tracks has a negligible effect on STAR's ability to do jet analyses.

Summary

In this note it has been shown that with the complement of detectors which comprise the STAR detector system we can take and analyze pp data up to pp luminosities of 2 x 10^{32} $cm^{-2} \cdot s^{-1}$. The probability to associate incorrect tracks with a trigger interaction due to effects associated with the speed of the TPC is 2 to 4 times less than the probability due to multiply pp interactions is a single bunch crossing. The problems due to these multiple interactions in a single bunch crossing are common to any detector system running at these luminosities at RHIC. Finally, for the types of analyses which one wishes to do with this high luminosity pp data, the results are unaffected (effects << resolution) by the incorrectly associated tracks.