Development of a ToF-BEMC Map for the Quarkonia Level-2 Trigger

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Abstract

The study of quarkonia production is an integral part of the STAR physics program. The collection of sufficiently large samples of J/ψ and Υ mesons requires the deployment of higher level triggers. Up to now these triggers are based on signals from the barrel electromagnetic calorimeter (BEMC). In run 10, STAR will be able to include the recently completed Time-of-Flight (ToF) barrel detector into the trigger algorithms. This will allow us to substantially increase the background rejection power of the existing triggers by requiring that all candidate decay electrons have a signal in the ToF *and* the BEMC tower. Coincident signals in the BEMC tower and the matching ToF-cell will eliminate a large fraction of the background from photons that cannot be rejected based on the BEMC alone. In this note we outline how the ToF-cell – BEMC-tower map is set up and discuss the increase of rejection power achieved.

1 Introduction

The study of the various quarkonium states is an excellent tool to probe the properties of the Quark-Gluon-Plasma produced in A+A collisions at RHIC. This subject has been originally motivated by theoretical prediction made by Matsui and Satz [1, 2], which describe the dissociation of bound charmonium (bottomonium) in the quark-gluon plasma due to color screening. In a deconfinement state the potential that binds the charm (bottom) partons is weakened allowing the quarks to dissolve. As a consequence the yield of onium states in reaction where a plasma is formed is reduced.

The quarkonium measurements in STAR are based on the electromagnetic decay $Q\bar{Q} \rightarrow e^+e^-$. Electrons are identified using the TPC and the BEMC. In some analysis the SMD is used as well to further enhance the electron purity. Due to the small production cross-sections of the various quarkonia states at RHIC energies an efficient trigger scheme is needed to record sufficiently large samples. During the past years, the heavy flavor working group had developed a set of triggers that make these measurements possible.

The STAR quarkonia triggers are divided into two levels: Level-0 (L0) and level-2 (L2). Until now, both triggers are based solely on the BEMC information. The L0 trigger for the J/ψ is based on the coincidence of two BEMC towers above a given threshold with constraints on the topology of the towers ("opening angle"). The one for the Υ is based on a single high BEMC tower. The L2 trigger for both J/ψ and Υ is implemented in the form of a software trigger deploying a sophisticated fast algorithm that identifies pairs of electrons and determines their approximate invariant mass.

Starting with run 10 (2010) the L2 will be able to use the ToF information as well. This STAR note will describe how this is done and discusses the benefits of this approach.

2 Detectors Used in the Trigger

The STAR detector components important for an upgraded quarkonium trigger are the barrel electromagnetic calorimeter (BEMC) *and* the time-of-flight (ToF).

The BEMC [3] is located at r=220 cm from the beam axis. It covers $|\eta| < 1$ and $|\phi| < \pi$. It is divided into two halves, East and West. Each half has 60 trays giving us a total of 120 trays. A tray has 40 towers each with equal dimensions in $\phi - \eta$ space: $\Delta\phi = 0.05 \times \Delta\eta = 0.05$. In total there are 4,800 towers.

The Time-of-Flight detector is based on Multi-gap Resistive Plate Chamber (MRPC) technology [4, 5]. It consists of 23,040 individually read out cells. The full ToF barrel covers $|\eta| < 1$ and 2π in azimuth. The ToF consist of 120 trays, each tray has 32 module and each module has 6 cells.

The main goal of the ToF is to extend the particle identification beyond what is possible with dE/dx measurements in the TPC. However, the ToF detector will also provide information that can be used in the STAR trigger system on various levels. At Level-1 it provided overall multiplicity information based on the number of hit cells. This input was historically provided by the CTB which was removed in order to allow the installation of the ToF. The binary single cell information (hit or not hit) will be available for the Level-2 trigger, *i.e.*, it will be shipped to the L2 computer together with the BEMC ADCs and the DSM boards output.

The exact format is still a little in flux, but the content is already well defined. There will be a total of four sets of data words, corresponding to the four fibers connecting the ToF system to the L2 system. Each set of data words from one fiber will carry a bit map of the hits from 30 trays, 5760 bits on each (30 times 192 channels per tray). Each bit corresponds to a hit in one of the channels, a 1 means there was a hit, a 0 means no hit. The trays are grouped as follows: (1) 21-50, (2) 51-60, 1-20, (3) 96-120, 61-65, and (4) 66-95. Trays 1 - 60 are on the West, while 61 - 120 are on the East of the detector.

3 Quarkonia Trigger

The architecture of the STAR quarkonia trigger is based on a two-stage system comprising a Level-0 (L0) hardware component [7] (decision time ~ 1 μs) and a Level-2 (L2) software component (decision time ~ 100 μs in p+p, ~ 400 μs in Au+Au). Here, these two components will be described in more detail.

3.1 Level-0 Trigger

The level 0 trigger for the J/ψ is a fast topology trigger using EMC high-tower data. A trigger is issued if two towers exceed a given threshold (typically $E_T > 1.2$ GeV) and are topologically separated by ~ 60 degrees. This topological separation is achieved by dividing the EMC into 6+6 "patches" on DSM level (6 East, 6 West). For details see [7].

This scheme is illustrated by Figure 1. For example a high-tower is found in the 12 o'clock patch, the algorithm ignores the adjacent patches, 2 and 10 o'clock, and looks for another high-tower at patches 4, 6 and 8 o'clock. This topological back-to-back trigger improves the rejection considerably compared to a single high tower trigger.

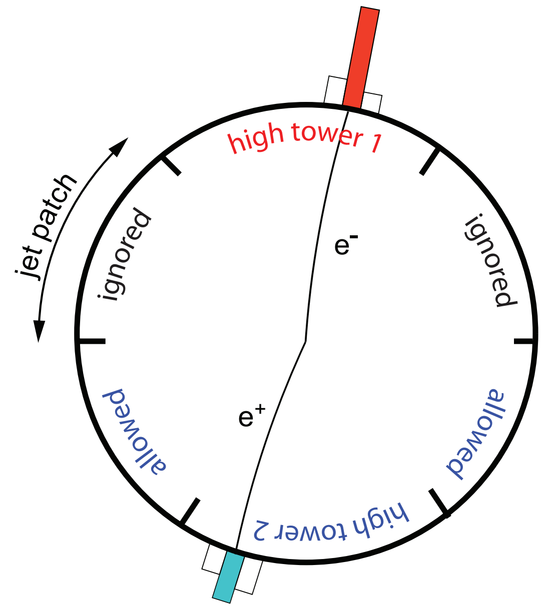


Figure 1: *Schematics of the quarkonia Level-0 trigger.*

Because of the large mass of the Υ and consequently higher momenta of the decay electrons, the bottomonium trigger is based on a single high-tower trigger only. It provides very high efficiency at a sufficiently high rejection rate. All quarkonia L0 trigger, independent of their flavor, are passed to the higher level, L2, trigger.

3.2 Level-2 Trigger

The level 2 is a software trigger consisting of algorithms written in C++. The L2 starts after an event was accepted by L0. The identified high-towers that triggered the L0 are used as *seeds* in the L2 algorithm. The Υ and the J/ψ L2 code are very similar, the only difference being the applied cut values.

The algorithm first creates EMC clusters based on the identified seeds. The cluster size, measured in towers, is an input parameter but is typically set to 3. In this case a cluster is defined as the high-energy (seed) tower plus the two highest neighbors. This improves the energy resolution for it minimizes effects of energy leaking into the neighboring towers. The second step is to combine the clusters into pairs and calculate the invariant mass of the pair using:

$$m = \sqrt{2E_1E_2(1 - cos\theta)}. \tag{1}$$

Here, E_i is the energy of the cluster i and θ is the opening angle of the cluster pair. Due to the lack of tracking and vertex information the topology of the decay is reconstructed assuming a vertex at $x = y = z = 0$ and zero curvature of the tracks.

	Threshold Energy (GeV)
L0 seed	> 4.0
L2 seed	> 1.2
L0 cluster	> 4.5
L2 cluster	> 3.0
$cos\theta$	< 0
Invariant mass	$5 < m < 20$

Table 1: Υ *threshold values used in run 9.*

	Threshold Energy (GeV)
L0 seed	> 1.2
L0 HTs	> 2
$cos\theta$	< 0.5
Invariant mass	$2.2 < m < 5.0$
CTB adc	≥ 3

Table 2: J/ψ *thresholds used in run 6 [8].*

If the event has a pair candidate with an invariant mass that falls into the desired mass window, the event is accepted and a trigger is issued. If not the trigger systems aborts the current event.

In run 9, only the Υ L2 trigger was used, since the low-p_T J/ψ trigger could not provide sufficient rejection to justify its deployment. The threshold values are in Table 1. The last time the J/ψ L2 code was used was in the p+p run in 2006 (run 6). The thresholds and parameters used are listed in Table 2.

The threshold values for J/ψ trigger had to be considerable lower than that of the Υ. To trigger on low-p_T quarkonia the threshold values typically chosen are in the order of $M_V/2$. This makes the J/ψ trigger more sensitive to background coincidences. To resolve this, we propose to use the ToF information which helps to remove the photon background substantially.

Earlier attempts (run 6) used the CTB (Central Trigger Barrel) [6], which consists of 240 scintillator slats arranged in four cylindrical bands each covering 0.5 unit of pseudorapidity. The low granularity of this setup yielded mixed results and was applicable only in p+p collision.

4 Map Between ToF and BEMC

4.1 Motivation

Our motivation in this work is developed a trigger that makes full use of the information provided by the ToF for the L2-trigger. The coincidence between a hit in a ToF cell and the referring EMC tower vetoes against photons, our main background source. The high granularity of the ToF might even allow a deployment of the updates J/ψ trigger in A+A collisions.

For this purposes a geometric mapping of ToF cells with BEMC towers was needed. These maps were generated using two different methods: (i) a simple geometric map based on known detector dimensions and (ii) a map generated through simulations incorporating a realistic vertex distribution and track curvature. Both were tested using a small sample from the Υ express stream from the run 09, where the resulting improvements in the trigger rejection power could be evaluated.

4.2 Approach

The geometric map is a plain geometric projection and can give us only a first impression since effects of event vertex smearing distribution of track curvature are neglected. The final map is created using Monte-Carlo simulations. Here we used three different primary vertex Z distribution, with widths of 10, 30 and 60 cm. This allows to use an optimized map for different vertex triggers (VPD, BBC). A plain geometric map would bias the data sample towards events with vertex at $z = 0$, an effect that is hard to correct afterwards.

4.2.1 Geometric Map

For the geometric map we used the values from the STAR data base accessed through the STAR detector geometry implemented in GSTAR. For each BEMC tower, the distance between the center tower with all the ToF cells is calculated using:

$$D = \sqrt{(\eta_{BEMC} - \eta_{ToF})^2 + (\phi_{BEMC} - \phi_{ToF})^2}. \qquad (2)$$

If the distance D is less than $\sqrt{2} \cdot 0.05/2 = 0.035$ (half the tower diagonal), the referring BEMC tower and the ToF cell were considered to match. This threshold value reflects the radii that cover all the area of a single tower.

In this map, two assumptions were made: (i) All tracks are straight lines and (ii) all tracks origin from an event vertex at (0,0,0). The first assumption is not a real problem, since tracks with p_T above 1 GeV/c have almost straight trajectories. However, effects of vertex smearing are significant as we will illustrate below.

4.2.2 Simulation Map

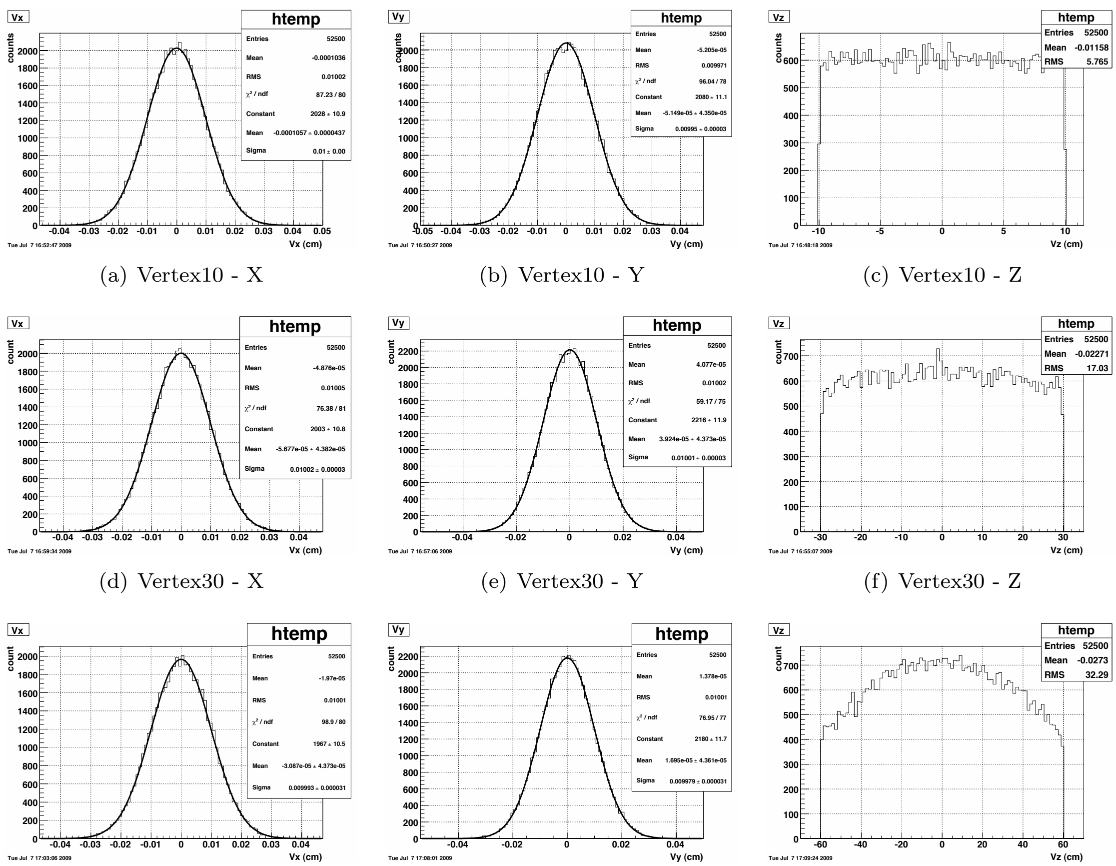
For the simulation map, three different setups were used. They only difference between them is in the vertex-z distribution. Values used are listed in Table 3. Only electrons were simulated and we generated 10 tracks per event.

	Vertex10	Vertex30	Vertex60
Pt (GeV)	$2 < p_T < 100$	$2 < p_T < 100$	$2 < p_T < 100$
ϕ	$0 < \phi < 2\pi$	$0 < \phi < 2\pi$	$0 < \phi < 2\pi$
η	$-1.1 < \eta < 1.1$	$-1.1 < \eta < 1.1$	$-1.1 < \eta < 1.1$
Vertex z (cm)	$-10 < z < 10$	$-30 < z < 30$	$-60 < z < 60$

Table 3: *Parameters used in simulations.*

The generated GEANT `fzd` files were used as input to the `BFC` macro. The primary vertex distribution used are depicted in Fig. 2. While the z position was smeared in all cases, we assumed $x = y = 0$ for all event vertices. The vertex z distribution was limited in different regions for each setup.

In order to find a pair we followed a simple approach. For each track, the ToF and BEMC hits were determined (the trigger hit in a tower is the hit with the max. energy deposited), and the BEMC tower and ToF cell that contain those hits were considered a pair.



(a) Vertex10 - X (b) Vertex10 - Y (c) Vertex10 - Z

(d) Vertex30 - X (e) Vertex30 - Y (f) Vertex30 - Z

(g) Vertex60 - X (h) Vertex60 - Y (i) Vertex60 - Z

Figure 2: *Primary vertex distribution from simulations.*

For each configuration, 52.5k events were generated resulting in around a half million tracks, sufficient to build the map. All theses tracks were classified in three kinds: Good tracks, Different match, Same match. Good tracks are the tracks that effectively return a BEMC and ToF hit, since there are some tracks with η bigger than 1 and don't give us a pair of ToF cell and BEMC tower. Different match is the number of tracks from Good tracks that have a different pair, if a track give us a pair that is already seen it counted as Same match. Details are shown in Table 4.

The increase of the average of numbers of ToF cells per BEMC towers indicates the importance of vertex z distribution.

4.3 How to implement the Map in your macro

All maps were generated as a table in the format mapToFBemcName.h that has four vectors with size of 4801 units. The 4 vectors are:

- The number of ToF cells for a tower i;

	Vertex10	Vertex30	Vertex60
Good track	386798	383343	377816
Different match	38884	42619	49766
Same match	347914	340724	328050
Average	≈8.1	≈8.9	≈10.4

Table 4: *Statistics from simulations. "Good tracks" is the number of tracks that returned a ToF cell and a BEMC tower pair; "Different match" is the total number of pairs used to build the map; "Same match" is the total of repeated pairs; Average is given by "Different match"/4800.*

- The index of ToF tray;
- The index of ToF module;
- The index of ToF cell.

Example: The code below allows to retrieve the ToF cells in front of a given BEMC tower i, where the *trayId*, *moduleId* and *cellId* are the indices of one ToF cell in front of a BEMC tower with softId i.

Program 1 Example program showing how to include the map in your macro.

```
# include "mapToFBemcName.h"

for(Int_t cont = 0; cont < numberMatch[i]; cont++)
{
     trayId[cont] = trayMatch[i][cont];
     moduleId[cont] = moduleMatch[i][cont];
     cellId[cont] = cellMatch[i][cont];
}
```

4.4 Testing of the Map Using Data from Run 9

A small sample (26k events) of the Υ "Express-Stream" was produced for testing the new maps. Note that in this run only 75% of the barrel ToF were installed.

In order to test the validity and performance of the updated L2 algorithm using the new maps we used a offline implementation/mock-up of the L2 trigger. Only events were selected where two cluster fell into the actual ToF acceptance. The event had to pass all cuts used in the upsilon L2 trigger. A priori all events had to survive these cuts. Only in a few cases this was not the case due to slight differences in the online-offline calibration.

The events that fulfilled this requirement were used for further testing.

In those events we checked if in front of the two EMC clusters, a ToF hit could be found. If so, the event would be counted as accepted by the ToF filter.

It is important to evaluate how many events were falsely rejected. To do so, the rejected events were further evaluated by looking for TPC tracks that match with the given BEMC cluster. If in a rejected event one (or both) of the tracks had a referring BEMC hits but no ToF hit it would be counted as falsely rejected.

All these numbers together with an evaluation of the increase in rejection power using the ToF-BEMC map are listed in table 5.

	Good Events	ToF Filter Accepted	ToF Filter Not Accepted	Bad ToF rejection	Rejection power increase
Geometry	9279	1267 (14%)	8012 (86%)	407 (4%)	7.3
Vertex10	9279	1366 (15%)	7913 (85%)	385 (4%)	6.8
Vertex30	9279	1408 (15%)	7871 (85%)	381 (4%)	6.6
Vertex60	9279	1478 (16%)	7801 (86%)	372 (4%)	6.3

Table 5: *Statistics from tests using the upsilon express data stream from run 9.*

The rejection power was calculated by the ratio *Good Events/ToF Filter Accepted* and it represents the improvement in power rejection when the maps are used. To get the full power rejection it necessary to compute the L0-L2 rejection power of the real data used in this test.

5 Summary

In run 10 the STAR detector will run with the complete ToF detector. This will give us the opportunity to implement a significantly improved low-p_T J/ψ trigger that requires a valid ToF hit in front of the trigger EMC tower. For this purpose we must have an exact map between ToF cells and BEMC tower.

Two maps were developed, a geometric map and a more detailed map through simulations. The geometric map gave us a good rough idea how ToF cells are correlated with BEMC towers, while only the map generated through simulations allowed us to take the effect of the vertex primary distribution into account

Finally, we checked on real data how these maps perform. A small sample from the Υ express stream was produced and could be used to estimate the rejection power. The rejection powers of the trigger is found to increase by a factor of 7.3 for the geometric, and 6.3 for the more realistic map derived from simulations for a vertex cut of 60 cm.

References

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