Requirements for STAR Level-0 Trigger Timing Measurement System Run-16 and Onward

Hank Crawford, Jack Engelage, Eleanor Judd, Chris Perkins

September 5, 2014

The STAR detector at RHIC uses two different detectors to determine the vertex location of an interaction at the initial trigger level; the Beam-Beam Counters (BBC) and the Vertex Position Detectors (VPD). There are two sets of each detector type, one on the East side of the intersection diamond (BBCE and VPDE) and one on the West side (BBCW and VPDW). The vertex location is determined by measuring the time difference between when particles from an interaction hit detectors on the East and West sides. This note describes the requirements for the electronics system which measures when particles hit the detectors.

1) Requirement: Dynamic Range
   Measure the time difference between the leading edge of detector signals and the rising edge of the RHIC clock (~ 10 MHz) over a range from 0 to 70ns.
   Justification: The acceptance of the main STAR tracking detector is +/- 2m centered on the interaction diamond. The Beam-Energy Scan program is planning to run in a fixed-target mode, where the target will be situated right on the edge of the 2m acceptance region. Additional background sources exist up to 10m away and STAR needs to be able to trigger on interactions generated in those sources in order to understand them. Particles from an interaction that is 10m from the center must travel 20m to reach the detectors on the other side. Travelling at the speed of light it takes ~70ns to travel 20m.

2) Requirement: Jitter
   The jitter introduced by the electronics system in each channel must be no more than 20 ps.
   Justification: In STAR the ultimate aim is to be able to locate the primary vertex with a resolution of 1cm. For particles travelling at approximately the speed of light it takes ~30ps to travel 1cm. This means the timing electronics needs to be able to measure the difference between two times with accuracy better than 30ps. In order for the accuracy of the difference to be 30ps the accuracy of the individual measurements must be $\sqrt{(30^2/2)} = 20$ps.

3) Requirement: Timing Digitization
   The time measurements must be digitized with a range and granularity that at least matches the range and jitter requirements of the measurements, i.e. a range covering at least 0ns to 70ns with a step size no more than 20 ps.
   Justification: This will enable STAR to meet its goals of detecting primary vertices up to 10m from the center of the diamond with a resolution of 1cm.

4) Requirement: Gain Linearity

   The gain function for each channel must be simple enough, preferably linear, that any other corrections (e.g. slewing corrections) can be performed in a look-up table.

   Justification: In order to locate the primary vertex it is necessary to identify the fastest particle on each side of STAR, and then calculate the difference in their flight times. The fastest particles have the largest fully-corrected digitized time measurement. The process of correcting the raw time measurements, and then selecting the largest, needs to be done in real-time on an event-by-event basis. The correction must therefore be simple enough that it can be implemented independently for each channel in a single step (e.g. a look-up table).
   NOTE: The degree of linearity is still TBD.

5) Requirement: Gain Adjustment

   It must be possible to adjust the gain on each channel remotely so that different channels on different boards produce the same digital value for the same time measurement.

   Justification: Gain matching is necessary to ensure that the time difference values, which are used to locate the interaction vertex, are valid. Some gain variations can be corrected in downstream look-up tables, but this is easiest to do if the variations have already been minimized in the hardware. Since STAR is not physically accessible when there is beam in RHIC it will sometimes be necessary to adjust the gain remotely.
   NOTE: The accuracy of the gain adjustment is still TBD.

6) Requirement: Gain Stability

   Once the gain has been set it must be stable enough that there is no need to re-calibrate the system for at least six months.

   Justification: Currently it takes many weeks to full calibrate all TAC channels in the STAR trigger. This includes time with access to STAR to calibrate the hardware using test pulses, and then beam time to set up the slew corrections in the look-up tables. We do not want to have to go through this process more than once during each six-month RHIC run.

7) Requirement: Latency

   The latency of the timing system must match the latency of the existing charge-measuring system.

   Justification: The trigger decision is made by combining charge and time measurements to discriminate hits associated with good beam interactions from background sources. If the latency of the time measurement is more than the latency of the charge measurement then the trigger decision would have to be delayed, which would result in a loss of data in several STAR detectors.
   Status: The timing through the existing system is very flexible. All times are measured with respect to the end of the ADC gate, which is itself variable. There is 150ns between the end of the gate and when the ADC data is latched into a

parallel register in the FPGA. It is ~21ns more before that data has been synchronized with the FPGA clock.

8) Requirement: Hit Outputs

   The system must provide an output logic signal for each channel indicating whether or not that channel was hit once or more than once during this RHIC clock tick.

   Justification: These signals are needed as inputs to the Scaler Systems.
   Status: We need to sort out with the users exactly what form factor and time profile they need for these signals. We also need to decide how far apart in time signals must be in order to register as separate hits.
   NOTE: See email thread titled "BBC/ZDC/VPD sum out signal" from November 2013 which summarizes our thinking on this issue.

9) Requirement: Output "OR" Signal

   The system must provide a logic signal indicating whether or not there was at least one hit during that RHIC crossing. The circuitry that drives this signal should have a stable, known behavior when the system itself is not fully configured.

   Justification: This signal is currently used by both the RICH and RHIC scaler systems for monitoring real-time collision rates, background rates and luminosity, and also in TPC space-charge calculations. In addition it is very useful when testing individual boards. The existing circuit is known to behave oddly and can produce random outputs when the system is re-powered or re-booted but has not yet been configured. This causes communication problems between STAR and the RHIC Main Control Room (MCR), which is monitoring the RHIC scalers.
   NOTE: The existing circuit actually provides a sum of the number of hits. However for many years the users have discriminated this sum to just look for "at least one hit". They have no plans to ever need use the sum again.

10) Requirement: Monitor Output

    The system must provide a copy of at least one input channel and its control signals (gate, start/stop…) on connectors that are easily accessible when all the hardware is installed and fully cabled.

    Justification: This will make it possible to check that the control signals are properly timed in with respect to the arrival time of the input signals.

11) Requirement: Calibration

    The system must include a built-in sub-system that makes it possible to perform a channel-by-channel calibration under remote control.

    Justification: To achieve the required resolution and gain matching it is necessary to calibrate each channel individually. The calibration must be checked at regular and frequent intervals throughout a RHIC run, and STAR is not physically accessible when there is beam in RHIC.