RPC Readout Topologies to Minimize the Accidental Trigger Rate

Changguo Lu and Kirk T. McDonald
Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544
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Abstract

Appropriate grouping of readout strips for purposes of triggering can make the accidental trigger rate acceptable even for 9-m-long strips.

1 Introduction

The Daya Bay Reactor Neutrino Experiment resistive plate chamber (RPC) system [1] has a baseline design consisting of 4 layers (gaps), with 2 layers readout viz x strips and 2 layers read out via y strips. The strip width and length is still to be determined, but the width is to be approximately 25 cm. Considerations of the strip length vary between 2 and 9 m, and are a major topic of this note.

The muon trigger based on the RPC signals is to be a coincidence of "hits" in 3 or more layers (out of 4 total). We denote this trigger requirement as "3/4" in the rest of this note. The coincidence is taken to be any nonzero overlap of signals whose width is nominally $T = 100$ ns.

The nominal area of the RPC system is $A = 18 \times 18$ m^2 for the Far Hall, and 12×18 m^2 for the Near Halls. In this note we will only consider trigger rates for the Far Hall.

The RPCs have a random (or "accidental") hit rate of $k \approx 2000$ Hz/m^2 not associated with particles such as muons, or electrons from low-energy γ's and neutrons. This estimate is based on Daya Bay note 556 [2] in which RPCs of area $A \approx 0.25$ m^2 showed singles rates of ≈ 500 Hz in the Aberdeen Tunnel.[1]

If all the accidental hits in layers of area A are used directly in the 3/4 trigger, the rate R of accidental triggers is,

$$R = \frac{1}{T}\sum_{i=3}^{4} iC_i^4 (kAT)^i e^{-2(4-i)kAT} = 12k^3A^3T^2\left(e^{-2kAT} + \frac{1}{3}kAT\right) \approx 12k^3A^3T^2, \qquad (1)$$

where $C_m^n = n!/m!(n-m)!$ is a binomial coefficient. This expression has been used in Daya Bay notes 1066 and 1032 [3, 4], but the factor i is omitted in notes 1003 and 293 [5, 6]. See also Daya Bay note 485 [7]. The factor i arises because in an overlap coincidence of i signals each of width T the time offsets can be larger than T. We will use only the approximate form of eq. (1) in the rest of this note, which assumes that $kAT \ll 1$. However, this approximation is not actually good for an area of 18×18 m^2, since $kAT = 2000 \times 18^2 \times 10^{-7} = 0.64$. For the smaller "module" areas considered later the approximation is, however, valid.

For $k = 2,000$ Hz, $A = 324$ m^2 and $T = 100$ ns, the accidental rate (1) is,

$$R_0 \approx 12k^3A^3T^2 \approx 32 \text{ kHz}. \qquad (2)$$

[1]Daya Bay notes 1066 and 1032 [3, 4] assume that $k = 1000$ Hz/m^2. Hence, the accidental trigger rates calculated there are a factor of 8 lower than those given here.

This rate is too large, so we explore more complex trigger topologies with the goal of reducing the accidental trigger rate (as well as possible simplification is aspects of the readout scheme).

How low should the accidental trigger rate be? We note that besides the accidental triggers, the system is also subject to triggers from electrons from γ's and neutrons from radioactive decays in the granite walls of the caverns. This rate is presently estimated to be about 15 Hz [3], so a reasonable goal would be to reduce the accidental trigger rate to 10 Hz. Here we also explore options to reduce the accidental rate to 1 Hz.

2 Trigger Topologies

2.1 Option 1: Trigger Based on Modules

One option is to subdivide the readout of each RPC layer into "modules" of area $l \times w$, form the 3/4 trigger for each readout module, and then OR these module triggers into the master trigger. This option has been considered in Daya Bay Notes 1066, 1032, 1003 and 293 [3, 4, 5, 6].

Here we consider only square modules ($l = w$). The number of modules is denoted by m where $m = A/A_m = 324/l^2$, since the area of a module is $A_m = l^2$. The accidental 3/4 trigger rate for a single module is $R_m \approx 12k^3 A_m^3 T3$, and the combined accidental trigger rate is,

$$R_1 \approx m12k^3 A_m^3 T^2 = 12k^3 A A_m^2 T^2 = \frac{A_m^2}{A^2} 12k^3 A^3 T^2 = \frac{R_0}{m^2} \approx \frac{32,000}{m^2}\,. \tag{3}$$

For example if the readout module size is the same as the physical RPC module size, then $l = 2$ m, the number of 2×2 m^2 modules is $m = 81$, and the accidental trigger rate is $R_1 \approx 5$ Hz.

However, if we adopt readout modules based on strips of length $l = 9$ m, then the readout module count is $m = 4$ and the accidental trigger rate is $R_1 \approx 2$ kHz.

2.2 Option 2: Trigger Based on Groups of Strips

Option 1 took no notice of the fact that the readout of each module will actually be subdivided into strips of width $w \approx 25$ cm. All strips within one layer of each module are ORed together before being sent to the 3/4 trigger in Option 1.

In Option 2, we suppose that only j strips are ORed together within each layer of a module before being sent to the 3/4 trigger. In particular, j could be 1, in which case the 3/4 trigger is based on single strips.

Each strip has area $l \times w$, so the area of the group of strips used in each 3/4 coincidence is $A_g = jlw$. The number of such groups in a module (of area l^2) is $n = l/jw$. The accidental coincidence rate in each group is $R_g = 12k^3 A_g^2 T^2$.

Because each 3/4 coincidence involves both x and y strips, the area of overlap of the strips in the various layers is only $j^2 w^2$. The total number of 3/4 coincidences needed to cover the entire area A is $g = A/j^2 w^2 = n^2 m^2$, recalling that the number of modules is $m = A/l^2$. After ORing all of these coincidences together to form the master trigger, the accidental rate is,

$$R_2 \approx g12k^3A_g^3T^2 = 12k^3Ajl^3wT^2 = \frac{jl^3w}{A^2}12k^3A^3T^2 = \frac{R_0}{nm^2} \approx \frac{32,000}{nm^2}\,. \tag{4}$$

For example, if we use long-strip modules with $l = 9$ m and $w = 25$ cm, then $m = 4$ and $n = 36/j$. The accidental rate is $R_2 \approx 32,000j/36 \cdot 4^2 = 56j$ Hz.

Note that the signal from each group of j strips in a layer must be input into n different 3/4 coincidences. That is, we must add n-fold fanouts to the trigger circuitry.

2.3 Option 3: Trigger Based on x Strips Only

If the readout of each RPC layer included x strips (as well as y strips on 2 of the 4 layers), the implementation of Option 2 would be more efficient. Namely, the area of overlap of a stack of 4 groups would be the same as the area of a group, $A_g = jlw$. Hence, the total number of 3/4 coincidences would be only A/A_g, and the accidental trigger rate would be,

$$R_3 \approx \frac{A}{A_g}12k^3A_g^3T^2 = 12k^3Aj^2l^2w^2T^2 = \frac{j^2l^2w^2}{A^2}12k^3A^3T^2 = \frac{R_0}{n^2m^2} \approx \frac{32,000}{n^2m^2}\,. \tag{5}$$

For example, if we use long-strip modules with $l = 9$ m and $w = 25$ cm, then $m = 4$ and $n = 36/j$. The accidental rate is $R_3 \approx 32,000j^2/36^2 \cdot 4^2 = 1.5j^2$ Hz.

3 Summary

Table 1: Summary of RPC trigger options for an array of total area $A = 18 \times 18$ m^2 with readout strips of width $w = 25$ cm. For Option 3, the number of readout strips is 3/2 the number of readout channels, *i.e.*, 864. The accidental trigger rates are based on the assumption of an accidental hit rate of $k = 2$ kHz/m^2 for an individual RPC layer.

Option	Module Length l (m)	No. of Modules $m = A/l^2$	Strips in Group j	Groups in Mod. $n = l/jw$	No. of 3/4 Coinc.	No. of Readout Ch.	Acc. Trig. Rate	Trig. Rate (Hz)
0	18	1	72	1	1	288	R_0	32,000
1	2	81	8	1	81	2835	R_0/m^2	5
1	9	4	36	1	4	576	R_0/m^2	2,000
2	9	4	1	36	5184	576	R_0/nm^2	56
3	9	4	1	36	144	576	R_0/n^2m^2	1.5
3	9	4	2	18	72	576	R_0/n^2m^2	6

Appropriate grouping of readout strips for purposes of triggering can make the accidental trigger rate acceptable even for 9-m-long strips. The most conservative trigger using long strips would be based on the OR of 3/4 coincidences of 9×0.25 m^2 x strips, for which an accidental coincidence rate of only 1.5 Hz is predicted.

We remark that no 3/4 trigger, except Option 0, will be 100% efficient for muons, in that muons whose trajectory crosses a boundary between trigger modules/strips will not satisfy the trigger. The inefficiency is proportional to the length of the boundary between trigger modules/strips, and so would be 2.25 times larger for Option 3 with $m = 4$ and $j = 2$ compared to Option 1 with $m = 81$, which cases have comparable accidental trigger rates.

A Appendix: Accidental Count Rate in Existing RPC Systems

The BESSIII experiment reports an average count rate [8], including that due to cosmic rays, of about 0.09 Hz/cm^2, as shown in Fig. 1. Since the cosmic-ray rate at the Earth's surface is about 0.016 Hz/cm^2, we infer that the accidental counting rate in the BESS3 RPCs is about 0.07 Hz/cm^2, or 700 Hz/m^2.

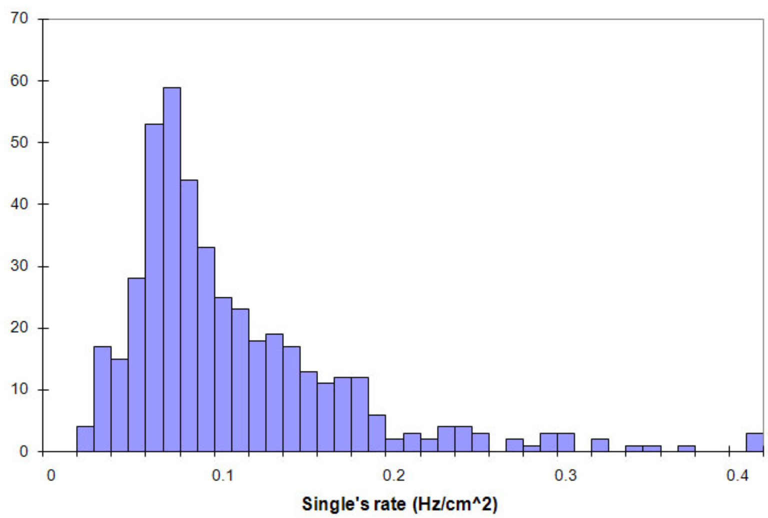

Figure 1: Distribution of singles rates, including that due to cosmic rays, in the BESSIII RPC system [8].

Studies in the Aberdeen Tunnel using BESSIII RPCs report accidental counting rates of about 2 kH/m^2 [2], where the cosmic-ray contribution to this rate is negligible. We have no immediate explanation as to why these rates are a factor of 3 higher than those seen in the BESSIII studies.

The BELLE experiment reports a singles rate, after subtraction of the cosmic-ray rate, of 300 Hz/m^2 for their glass RPCs [9].

The OPERA experiment reports a singles rate, including the cosmic-ray rate, of 300 Hz/m^2 in surface tests, and claims the rate drops to 30 Hz/m^2 in the Gran Sasso underground site [10]. Studies of $\approx$ 1500 RPCs indicate that those chambers which have higher than average count rates tend to have localized "hot spots" along the edges of the chambers [11].

B Appendix: Derivation of Eq. (1)

We deduce the rate of accidental coincidences of exactly i detectors out of a total of j, supposing each detector has an individual accidental counting rate of kA, and that the coincidence is satisfied by any overlap of signals each with a width T in time.

The accidental coincidence rate $R(j,i)$is the product of the binomial coefficient C_i^j and the rate for a specific pattern of hits in i detectors (and no hits in $j-i$ detectors). That is,

$$R(j,i) = C_i^j \times ... \tag{6}$$

We begin by considering a particular detector, for which the accidental rate is kA. Including this factor in the expression for the accidental coincidence rate, we have,

$$R(j,i) = C_i^j(kA) \times ... = \frac{1}{T}C_i^j(kAT) \times ... \tag{7}$$

We next focus on a single hit in that detector, say at time t.

For another detector to have no time overlap with this hit, given that the signals all have time width T, there must be no signal occurring in the other detector during the interval $[t-T, t+T]$ whose width is $2T$. The probability of this is $e^{-2kAT} \approx 1 - 2kAT$, where the approximation hold only if $2kAT \ll 1$. Hence, the probability that $j-i$ of the other detectors do not overlap with the hit in the first detector is $(e^{-2kAT})^{j-i}$. Thus,

$$R(j,i) = \frac{1}{T}C_i^j(kAT)e^{-2(j-i)kAT} \times ... \tag{8}$$

We next consider the probability that a hit in the second detector overlaps the hit in the first detector. As noted above, if the second detector has a hit during the interval $[t-T, t+T]$ it will overlap with the first hit as desired. The probability of this is $2kAT$. Hence, if $i=2$, our calculation is complete, and the coincidence rate is,

$$R(j,i=2) = \frac{1}{T}C_i^j(kAT)(2kAT)e^{-2(j-i)kAT} \times ... = \frac{1}{T}iC_i^j(kAT)^i e^{-2(j-i)kAT} \times ... \tag{9}$$

Next, we consider that case that $i=3$, for which a hit in the 3$^{\rm rd}$ detector must overlap with the coincidence of hits in the first two detectors. Now, the length of the time overlap of the hits in the first two detectors is not T, but rather is a width T_2 whose probability distribution is uniform between $T_2 = 0$ and T, *i.e.*, the probability distribution is dT_2/T. The probability that a hit in the 3$^{\rm rd}$ detector overlaps with a time interval T_2 is $kA(T+T_2)$. Hence, the total probability that a hit in the 3rd detector overlaps with a coincidence of hits in the first two detectors is,

$$\int_0^T kA(T+T_2)\,\frac{dT_2}{T} = \frac{3}{2}kAT. \tag{10}$$

Then, the rate for an accidental coincidence of exactly 3 hits is,

$$R(j,i=3) = \frac{1}{T}C_i^j(kAT)(2kAT)\left(\frac{3kAT}{2}\right)e^{-2(j-i)kAT} \times ... = \frac{1}{T}iC_i^j(kAT)^i e^{-2(j-i)kAT} \times ... \tag{11}$$

Next, we consider that case that $i = 4$, for which a hit in the 4^{th} detector must overlap with the coincidence of hits in the first three detectors. Now, the length of the time overlap T_3 of the hits in the first three detectors varies between 0 and T, but the probability distribution of T_3 is not flat. *This means that the previous argument cannot be applied to $i = 4$ and higher, so we lack a full mathematical proof of eq. (1) for these cases.*

References

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