Radiation Amplitude Zeros for Processes with More Than One Photon

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ABSTRACT

We show how one can generalize the phnomenon of Radiation Amplitude Zeros (RAZ) to processes with more than one photon. The zero conditions are

$$\frac{k_j \cdot P_i}{Q_i} = \frac{k_j \cdot P}{Q}, \; j = 1, \ldots m \text{ and } i = 1, \ldots n$$

where the process $Q \to Q_1 + Q_2 + \ldots Q_n + \gamma(k_1) + \gamma(k_2) + \ldots + \gamma(k_m)$ has m photons and n + 1 charged particles. The amplitude vanishes for each zero condition j = 1, 2, . . . m.

It is now 13 years since Radiation Amplitude Zeros (RAZ) were first discovered[1] in the process $d\bar{u} \to W^-\gamma$. Subsequently, it was shown[2,3] that these RAZ are due to the complete destructive interference of the radiation patterns and occur wherever the process contains one real photon, only like–sign charges, and $g = 2$ for all particles with spin.

For the decay process

$$Q \to Q_1 + \ldots Q_n + \gamma \tag{1}$$

the zero conditions are

$$\frac{k \cdot P}{Q} = \frac{k \cdot P_1}{Q_1} = \frac{k \cdot P_2}{Q_2} = \ldots = \frac{k \cdot P_n}{Q_n} \tag{2}$$

All of these conditions must be satisfied for the RAZ to occur. The notation used is the same as in ref 3: Q and Q_i denote the charges of the particles in eq (1) with the four momentum of Q, Q_i and γ chosen to be P, P_i and k respectively. Although the process chosen here is the radiative decay, one can easily also describe direct photon production and photoproduction.

In this letter we wish to generalize RAZ to processes with an arbitrary number of photons. To be specific we will consider radiative decay, but one can easily also describe direct photon production and photoproduction.

First let us consider the case $m = 2$. The process we consider is

$$Q \to Q_1 + \ldots Q_n + \gamma(k_1) + \gamma(k_2) \tag{3}$$

The diagrams for this process are obtained by attaching first $\gamma(k_1)$ in all possible ways to the external lines. Then $\gamma(k_2)$ is attached in all possible ways to each of these diagrams. Note that when this is done there are some diagrams that have photons attached to

internal lines. This generalization is possible because the RAZ is <u>not spoiled</u> by photons attached to <u>internal lines</u>. We now show that this is true.

Consider the process

$$Q \to Q_1 + (Q_{int} \to Q_2 + Q_3 + \ldots Q_n) + \gamma(k) \tag{4}$$

where Q_{int} represents a virtual particle of mass m and, of course,

$$Q_{int} = Q - Q_1 \tag{5}$$

Otherwise the notation is the same as before. The total amplitude for this process, obtained by attaching the photon in all possible ways to the external lines and <u>also the internal line</u>, is

$$A_{TOT} = -i\epsilon \cdot \left\{ \left[\frac{QP}{k \cdot P} - \frac{Q_1 \; P_1}{k \cdot P_1} - \frac{Q_{int} \; (P - P_1)}{k. \; (P - P_1)} \right] \Big/ \left[(P - P_1 - k)^2 - m^2 \right] - \left[\sum_{i=2}^{n} \frac{Q_i \; P_i}{k \cdot P_i} - \frac{Q_{int} \; (P - P_1)}{k \cdot (P - P_1)} \right] \Big/ \left[(P - P_1)^2 - m^2 \right] \right\} \tag{6}$$

It can easily be verified that under the previous zero condition (Eq (2)), the quantity in each square bracket of eq (6) vanishes and, hence, $A_{TOT} = 0$. Thus, amazingly, <u>the zeros persist at the same location in phase space, independent of the mass of the internal particle</u>.

We now return to the process in eq (3). Because the RAZ are not spoiled by radiation from internal lines the RAZ occur if <u>either</u> of the following two conditions are satisfied:

$$\frac{k_1 \cdot P}{Q} = \frac{k_1 \cdot P_1}{Q_1} = \frac{k_1 \cdot P_2}{Q_2} = \ldots = \frac{k_1 \cdot P_n}{Q_n} \tag{7}$$

or

$$\frac{k_2 \cdot P}{Q} = \frac{k_2 \cdot P_1}{Q_2} = \frac{k_2 \cdot P_2}{Q_2} = \ldots = \frac{k_2 \cdot P_n}{Q_n} \tag{8}$$

The generalization to the process

$$Q \to Q_1 + Q_2 + \ldots Q_n + \gamma(k_1) + \gamma(k_2) + \ldots + \gamma(k_m) \tag{9}$$

is now clear. The zero conditions are

$$\frac{k_j \cdot P_i}{Q_i} = \frac{k_j \cdot P}{Q} \text{ for all } i = 1, \ldots n \tag{10}$$

The RAZ occurs if eq (10) is satisfied <u>for any $j = 1, \ldots m$</u>.

In conclusion we have shown how RAZ can be generalized to an arbitrary number of photons. RAZ have yet to be observed experimentally although they may soon be observed in $p\bar{p} \to W\gamma X$ or $pp \to W\gamma X$. As was first suggested in ref (1) these RAZ may provide a sensitive test of the magnetic moment of the W boson.

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References

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