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Photon Flux Normalisation for CLAS

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Abstract

The first part of this note describes in a general way the problem of the normalisation of a photon experiment. Then, a standard procedure will be described, together with some results that show that it can be used, and deal properly with the prescale scheme used in g1, and with E-T coincidence been turned ON or OFF. Further electronical problems that happended during g1 and g6 are discussed in the third part, that the standard procedure could hardly account for. We then propose an alternate solution.

1 General aspect of the normalisation

The aim of the normalisation is to obtain the number $N_\gamma(E_j)$ of tagged photons at an energy E_γ, i.e per channel E_j of the tagger and thus allow to extract a cross-section in a photon experiment.

The procedure with an intermediate normalisation run using the TAC (Total Absorption Counter) and the PS (Pair Spectrometer) has already been described (Ref :CLAS-note 92-14). Here, we make the assumption that all electronic devices taking part in the normalisation are stable between a normalisation run and a production run. We will see that these conditions were not filled all the time and that a special treatment is required in that case.

The quantity that is directly accessible during any run (normalisation or production run) is the number of detected electrons in the tagger hodoscope N_{e^-}. This quantity is contaminated by Moller scattered electrons and by some background which may depend on the beam setting and the status of the E-T coincidence module (level 2 or level 3). Nothing garanties that the proportionnality factor between this number of electrons detected in the hodoscope and the number of corresponding photons that reached the experiment target is constant during time and with the beam setting. This factor is the tagging efficiency:

$$\epsilon = \frac{N_{\gamma(target)}}{N_{detected\ e^-}} \tag{1}$$

The tagging efficiency has to be monitored throughout the experiment in order to correctly normalise cross-sections.

1.1 Normalisation run

Three informations are extracted from a **normalisation run**:

- The tagging efficiency:

$$\epsilon_{T_i}^{norm} = \frac{a_i \times [T_i * TAC]}{[T_i^{raw}]_{norm}} \tag{2}$$

  where $[T_i^{raw}]_{norm}$ counts the number of coincidences $T_{left} * T_{right}$ (2-fold) or $T_{left} * T_{right} * E$ (3-fold) triggers during a normalisation run (i.e. electrons hits in the tagger hodoscope), and $[T_i * TAC]$ is the number of those hits which are detected in coincidence with the TAC (i.e which are actual photons that made it to the TAC).[1]

  a_i's are coefficients, that can possibly depend on the T counter id, that account for photon beam flux absorption between the target and the TAC. This coefficients will have to be determined by Monte-Carlo.

- The efficiency of the PS **versus** the TAC. (the TAC is supposed to be 100% efficient.)

$$\epsilon_{PS} = \frac{[T_i * PS]}{[T_i * TAC]} \tag{3}$$

  where $[T_i * PS]$ is the number of tagger hits (2-fold left-right coincidence (E.T coincidence module off) or 3-fold Left-rigth-E (E.T coincidence module on)) which are detected in coincidence with the PS. (For g6, as tagging was restricted to the high energy part of the bremstrahlung spectrum, only the last $PS_{left} * PS_{right}$ were turned on in order to reduce the contribution of accidentals $T_i * PS$).

- The number of photons $N_\gamma(E_j)_{norm}$ [2] evaluated at the target level, given by the number of tagger hits in channel E_j in coincidence with a detected hit in the TAC, as reconstructed from the TDCs (TAGR BOS bank, output of RECSIS). This quantity has to be corrected by the trigger prescale, and by the photon beam transmission coefficients between the target and the TAC, a_i.

[1] notation [...] refers to the number of counts in a scaler channel

[2] Since the E counters overlapp, the index j can be either 1-384 or the rebinned index taking into account this overlapp 1-767. The choice, which can be guided by statistical consideration, does not change the formula.

1.2 Production run

If the tagging efficiency is constant, the number of photons reaching the target would be proportionnal to the number of detected electrons in the tagger hodoscope, thus giving[3] :

$$N_\gamma(E_j)_{prod} = N_\gamma(E_j)_{norm} \times \frac{[T_i^{raw}]_{prod}}{[T_i^{raw}]_{norm}}$$

Yet we have to take into account the variations in the tagging efficiency, and therefore:

$$N_\gamma(E_j)_{prod} = N_\gamma(E_j)_{norm} \times \frac{[T_i^{raw}]_{prod}}{[T_i^{raw}]_{norm}} \times \frac{\epsilon_{T_i}^{prod}}{\epsilon_{T_i}^{norm}} \tag{4}$$

The tagging efficiency is measured during a production run using the Pair Spectrometer (One can also use the pair counter at intermediate rates). To do so, the coincidences $[T_i * PS]$ "in time" and accidentals are recorded in scalers. Accidentals can then be substracted to the "in time" counts to obtain the number of True coincidences. An additionnal term α_i must be used to take into account the measured difference of the width of coincidence windows for $[T_i * PS]_{in\ time}$ over $[T_i * PS]_{acc}$. This leads to substract the accidentals using this correction : $[T_i * PS]_{in\ time} - \alpha_i * [T_i * PS]_{acc}$

Knowing the Pair Spectrometer efficiency from the normalisation run, we can deduce:

$$\epsilon_{T_i}^{prod} = a_i \times (\frac{([T_i * PS]_{in\ time} - \alpha_i * [T_i * PS]_{acc})}{\epsilon_{PS}}) * \frac{1}{[T_i^{raw}]_{prod}}$$

Using this later expression, the expression (4) can be re-written:

$$N_\gamma(E_j)_{prod} = N_\gamma(E_j)_{norm} \times \eta \tag{5}$$

where :

$$\eta =< \frac{[T_i * PS]_{in\ time} - \alpha_i * [T_i * PS]_{acc}}{[T_i * PS]_{norm}} >$$

During g1 and g6 in 1998, the scalers were not gated by live time, whereas the TDC informations coming from the trigger are. The above factor should thus be corrected by the ratio $\frac{(life\ time)_{prod}}{(life\ time)_{norm}}$.

η should be independant of T_i if there is no electronical variation for T counters between the normalisation run and the production run. Furthermore, one has to take the mean value since there are some fluctuation

[3]Here, T_i is chosen as the T counter which matches best with the E counter E_j.

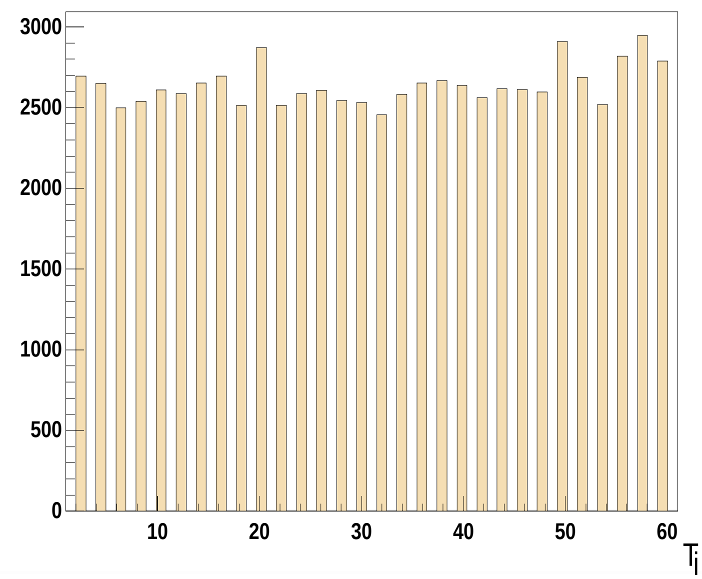

Figure 1: η for run 11881 with normalisation run 11875

due sometime to the low statistics on $[T_i * PS]_{norm}$ for some runs (this was particularly the case during g1).

η takes into account the possible variation of the tagging efficiency relative to the normalisation run. It supposes that the efficiency of the PS does not vary, this is why they have to be checked every day by a normalisation run. This simple and general procedure to normalize an experiment requires good statistics for the normalisation run. If one wants 1% accuracy per E_j channel, given that there are 767 E bins, it means that, roughly, a total of 10^7 triggers are needed for each normalisation run.

We will explain in the next section the tolerance of this procedure to some of the electronical problems encountered in g1 and g6.

2 Applications to g1 and g6 98

2.1 Extracting $N_\gamma(E_j)$ for the normalisation run

The trigger type used for the normalisation run changes the way these quantities are measured. We detail the two configurations and how to analyse them separately.

2.1.1 g6 experiment

Normalisation runs were taken with a "special" trigger which was the logical OR of three coincidences : (PS*MOR)+(PC*MOR)+(TAC*MOR/50). The coincidence TAC*MOR was divided by 50 in order to have roughly the same statistics on all terms. Because of the division on the TAC, when we count $N_\gamma(E_j)_{norm}$, we have to know which one gave the trigger. The TDC spectrum of the TAC (fig. 2) shows three well separated peaks. Each corresponds to different trigger combinations, because the start time given by each coincidence is then different:

- the first one corresponds to a trigger PC*MOR when the trigger signal TAC*MOR has not fired due to the division by 50 (As the pair counter is located in front of the TAC, an e^+e^- pair detected in the PC always gives a signal in the TAC). We call this peak the PC$_{peak}$.
- the second peak corresponds to either TAC*MOR (with nothing in the PC) or TAC*MOR+PC*MOR when the TAC trigger (divided) fired (Indeed, for this trigger, the TAC TDC appears at this position because the TAC trigger signal arrives **before** the PC one). We call this one the TAC$_{peak}$
- the third one, very weak, corresponds to a trigger PS*MOR. The TAC TDC appears in a different peak, because, in that case, the TAC trigger signal arrives **after** the PS one (The corresponding signal in the TAC is probably due to the production of some e.m. background in the PS). We neglect the PS$_{peak}$.

Since we can clearly identify the trigger type in this spectrum, $N_\gamma(E_j)$ can be calculated (using the TDC information in TAGR bank) for each E_j as :

$$N_\gamma(E_j)_{norm} = a_i \times (50 \times \int TAC_{peak} + \int PC_{peak}) \tag{6}$$

Where we compensate for the division rate of 50 on the TAC and counts the additional events where the PC produced a e^+e^- pair (detected in the TAC) but where the PC*MOR trigger fired and not the TAC*MOR. a_i accounts for the loss of photon flux between the target and the TAC.

2.1.2 g1 experiment

Normalisation runs were taken with a MOR trigger, prescaled by 16 at the trigger supervisor level. We therefore define $N_{e^-}(E_j)$ as the number of counts of reconstructed hits in the tagger[4] on the jth channel with the

[4] This will be defined in a future CLAS-note and can be already found on the web at http://www.jlab.org/~anciant

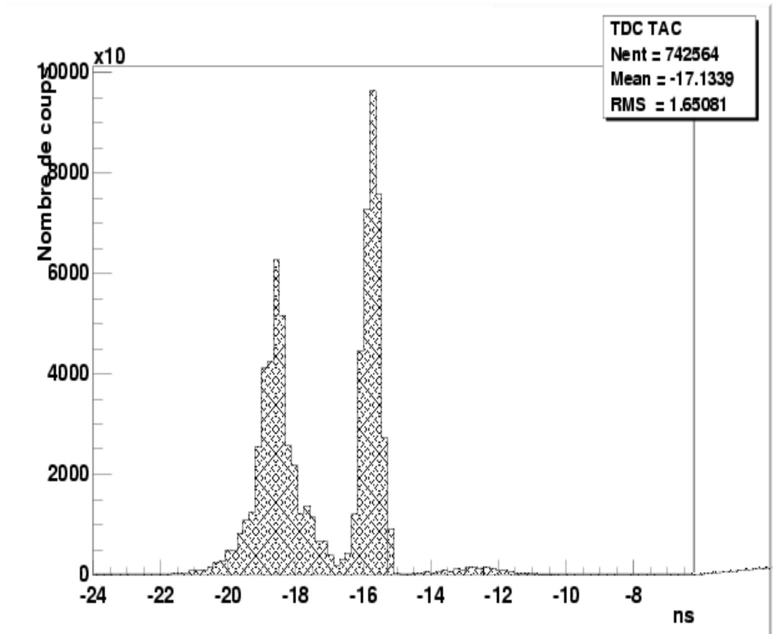

Figure 2: *The TAC TDC spectrum, showing the 3 triggers peaks.*

requirement to find a corresponding signal in the TAC. This quantity is mulptiplied by the prescale factor and the a_i coefficient. For some runs, the above g6 trigger was used.

2.2 Consistency check of DSD's efficiency

The main purpose of the special trigger is to enable us to measure the PC and the PS efficiency using the TDCs, with a reasonable statistics on each term. The scaler coincidence rates were measured on each T (1-61) for the TAC, and on half of them for the PS and the PC. The rules to count the number of hits for TAC, PS and PC[5] are:

- N_{TAC} is equal to $50 \times \int TAC_{peak} + \int PC_{peak}$.
- N_{PS} is the number of counts in the PS TDC channel.
- N_{PC} is the number of counts in the PC TDC channel.

With these definitions, the efficiencies $\epsilon_{PS} = \frac{N_{PS}}{N_{TAC}}$ and $\epsilon_{PC} = \frac{N_{PC}}{N_{TAC}}$ are the same, either measured with the TDCs or with the scalers (see fig : 3).

[5]To compare with the scalers, we use a 1-61 T binning.

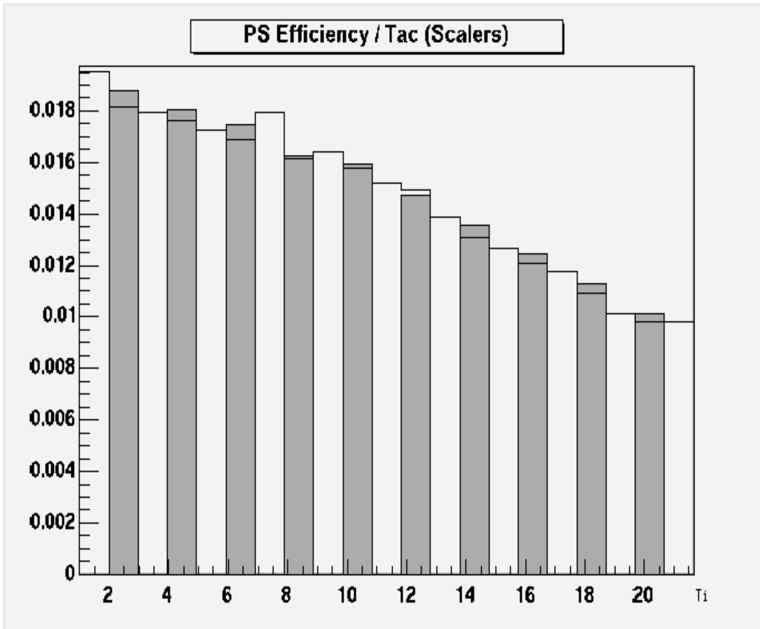

Figure 3: *Comparison of efficiencies as measured by the TDCs (continuous line) and the scalers (gray bars) for a typical run in g6.*

2.3 Absolute comparison between the scalers and TDC's informations

2.3.1 Results

We can also extract the ratio scaler/tdc for the coincidence T*TAC by correcting the scalers (which are not gated by a busy signal) by the life-time measured by the ratio $\frac{\text{recorded events}}{\text{total events}}$. We use the N_{TAC} defined ealier for a special trigger normalisation run or, simply the number of counts per T with a hit in the TAC when no special trigger was used (Eventually corrected by the trigger supervisor prescale factor, if any). The ratio between $[T_i * TAC]_{scaler}$ and $(T_i * TAC)_{tdc}$ are depicted on fig. 4 and 5.

2.3.2 Discussion

This ratio is not equal to 1 everywhere!

For g1 (fig. 4) in the prescaled region, the scalers count systematically less than the TDCs. The cabling of the tagger is such that scaler signals were taken **from the output** of E*T coincidence and E*T match[6] whereas the TDCs signals are collected **before** E*T coincidence. The prescale in g1

[6]here, coincidence refers to the time coincidence done between $T_{left} \times T_{right} \times E$ done within a window of 20 ns. E*T matching refers to a geometric match between E & T channels done with another module.

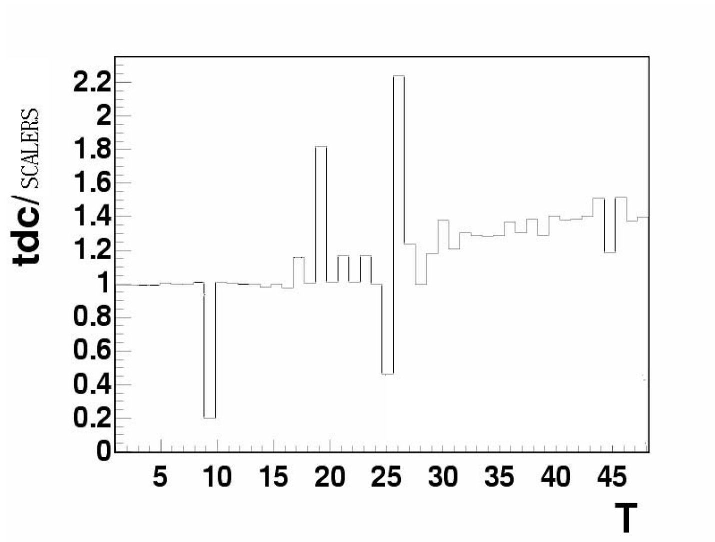

Figure 4: *Ratio for g1 between scalers and TDCs using TAC TDC spectrum (T_9 had a bad trigger cable giving more counts in the scaler, T_{25} & T_{26} are swapped, explaining the strange pattern).*

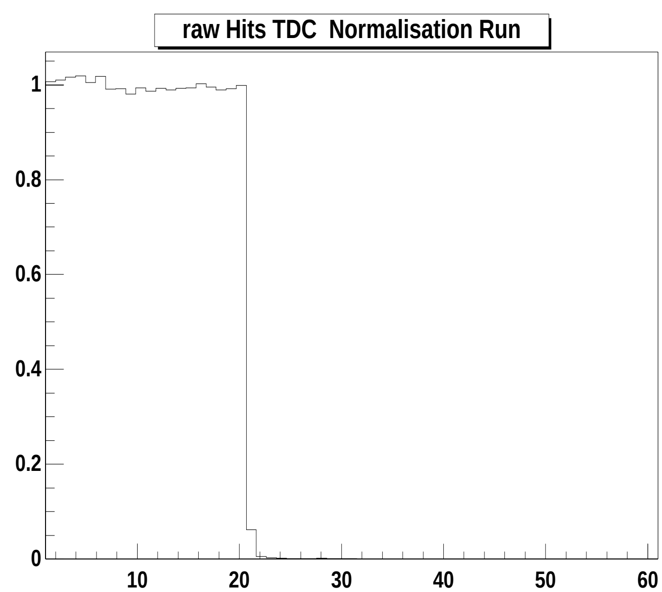

Figure 5: *Ratio for g6 between scalers and TDCs using TAC TDC spectrum.*

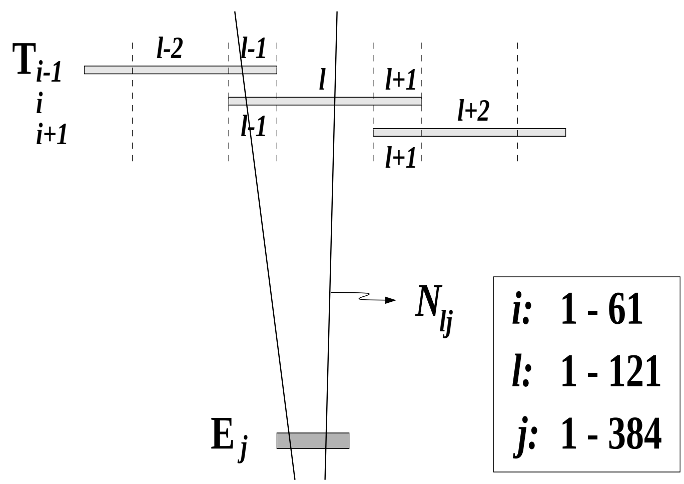

Figure 6: *Geometrical matching between E and T counters for run 12271.*

was applied at the E*T coincidence level therefore affecting the scalers, but not the TDC information.

For prescaled T, because the T counters overlap (see fig. 6), when an electron crosses 2 contiguous T, the trigger can be recorded thanks to one of them (its corresponding scaler is then incremented) but the other T being masked off after E*T coincidence (for the prescale) does not increment its scaler. Because we have no way to know when a given T is active or not, our TDC procedure increments both of them giving an excess on one of them, thus giving a biased ratio.

This effect doesn't affect the DSD's efficiency comparison between scaler and TDC, because the efficiency is an intrinsic property of the DSD. (It is measured via the ratio of two counting rates and the prescale factor vanishes.)

For g6, the comparison is good at the beginning of the experiment (run 12271 to run 12403), but show drastic changes for the rest of the period (run 12404 to end of exp.). Starting run 12404, the ratio deviates from 1 for some T counters.

This problem has been tracked down to E*T coincidence module flaws that will be discussed in the next section concerning unstable electronic.

2.4 Conclusion

Fig. (8) shows the normalised distribution of $p\,\pi^+\,\pi^-$ events, obtained using this procedure. It is very satisfying when compared to the $N_\gamma(E_i)$ distribution (fig. (7)) which is quite irregular.

This procedure works when no major electronic problem occurs.

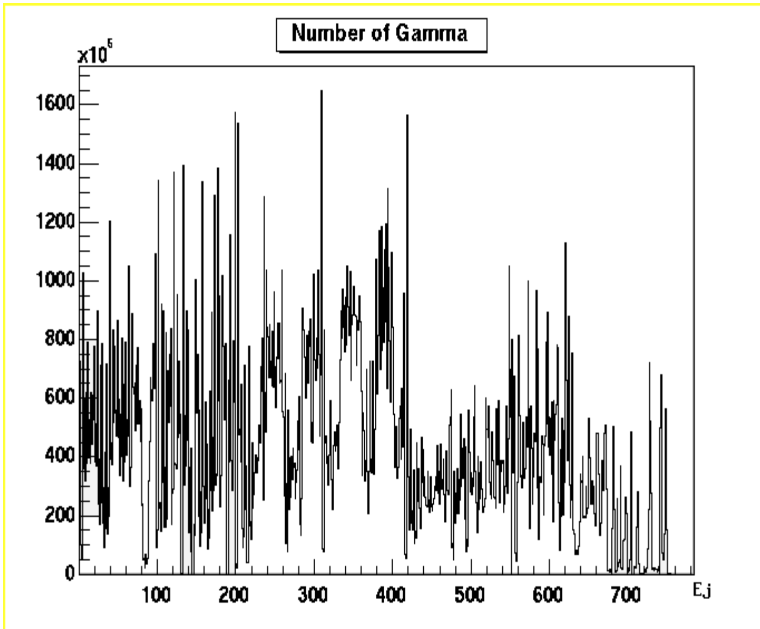

Figure 7: *Distribution $N_\gamma(E_j)$ for run 11881.*

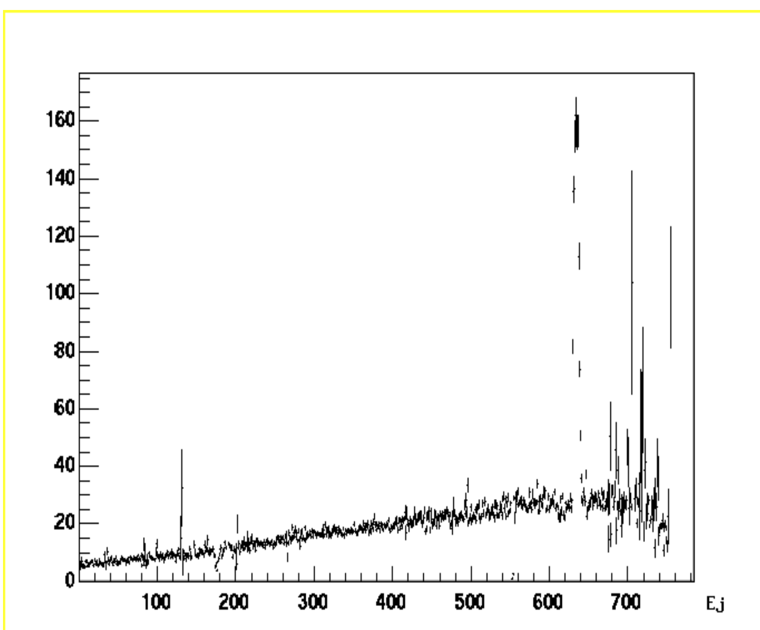

Figure 8: *Normalized number of $p\,\pi^+\,\pi^-$events using $N_\gamma(E_j)$ for run 11881 with the statistical errors (unit is μbarns). Spikes are due either to low stats. channel or well identified hardware problems.*

3 Unstable electronics

It happened during the course of g1 that the prescale stopped working. During g6, some channels of the E-T matching module died during production runs. When this happens, one can not use the $N_\gamma(E_j)_{norm}$ distribution obtained during the previous normalisation run.

We will describe how within the general procedure, one can hope to detect such changes.

General scheme If we take into account that electrons in the tagger can cross two adjacent T's, formula (5) has to be generalized. In this case, one can choose arbitrarily any of the two T counters to renormalise $N(E_j)$. One can make a distinction between electrons that go through one T, and electrons that go through two adjacent T's, by extracting from the normalisation run the quantity $N(E_j, T_l)$ of electrons that went through the E bin j AND the T bin l. l odd means the electron went through only one T. l even means the electron went through two adjacent T's.

The formula giving the number of photons in a production run becomes:

$$N_\gamma(E_j)_{prod} = \sum_l N_\gamma(E_j, T_l)_{norm} \times \eta_i \tag{7}$$

where for odd l values, $i = (l+1)/2$, while for even l values (overlapping channels), one has two choices $i = l/2$ or $i = l/2 + 1$, so one can pick arbitrarily one of them (refer to figure 6).

Here, we assume the η coefficients varies from one T to the other due to electronic changes (E.T flaw, prescale). (Whereas in the first section of this clas note we assumed that there was no electronic problem, and therefore T to T variations were only due to statistic fluctuation, so we were taking the mean value of η.)

3.1 Problems connected with the E-T matching module

- Fig. 9 shows the ratio of tagger hits $N_{e^-}(E_\text{j})$ spectrum for a production run, taken at the beginning of the g6 experiment over the same spectrum after a week with the E-T coincidence set to level 3.
- Fig. 10 shows the distribution of the E counters in coincidence with T_7 for 2 different runs with E*T ON or OFF obtained from TDC spectra.

One can clearly see that when E*T match was ON some $E_j * T_l$ coincidence channels were dead, whereas with a level 2 coincidence there is no loss. During the g6 period the coincidence level was changed several times from 3 to 2 and vice-versa, these defects being detected only after some time.

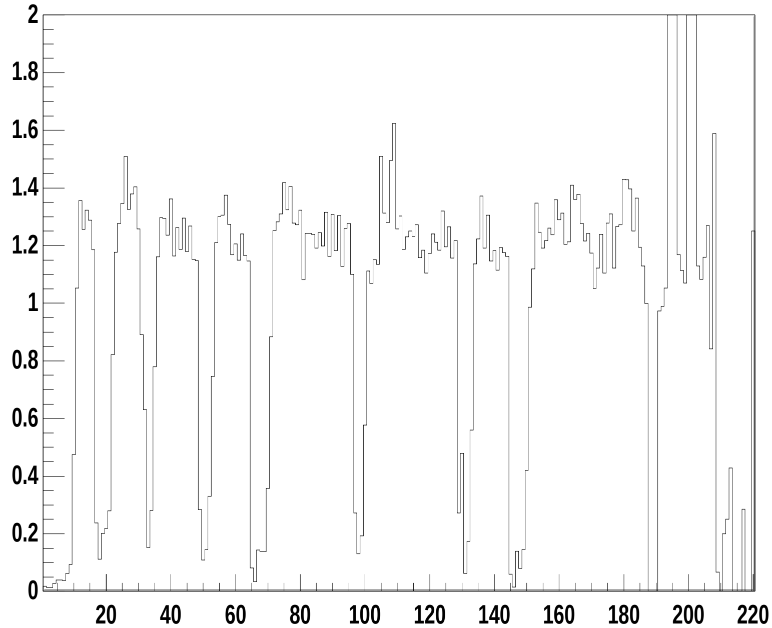

Figure 9: *Ratio of $N_{e-}(E_j)$ spectrum for 2 production runs E*T ON and E*T OFF.*

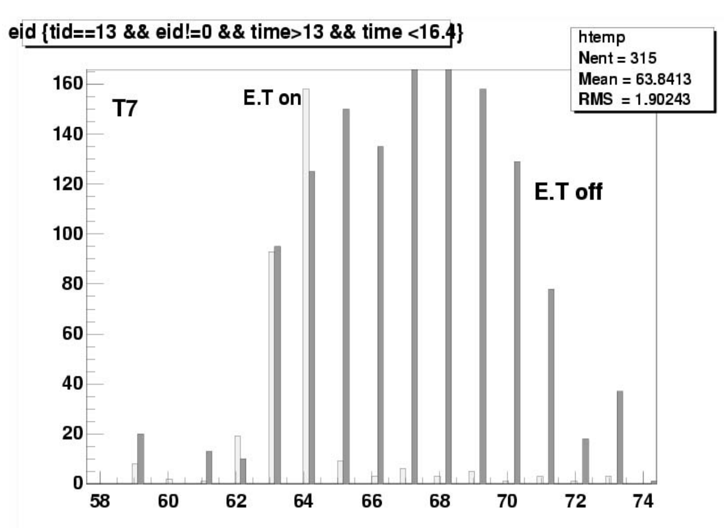

Figure 10: *Difference for T_7 between E*T match ON and OFF.*

How to detect when the E-T matching module fails As we just said in the previous paragraph, for a channel T_l, l even, corresponding to the overlap of T_i and T_{i+1}, there are two choices for rescaling the number of photons, either using the first T or the second T. The result should be the same, if not, that indicates that an electronical problem occured during the run.

3.2 Problems connected with the prescale used during g1 runs

Let's assume that two adjacent channels T_i and T_{i+1} have respectively a prescale factor A_i and A_{i+1}.

For a T_l channel (1 to 121) defined by only 1 T counter (l odd), the number of photons $N_\gamma(E_j, T_l)$ is correctly reduced by a factor A_i. But for a T channel corresponding to the overlap between T_i and T_{i+1} (even l channel), the number of triggers depends on the relative phase between the 2 gates used for the prescaling :

- If the 2 prescaling gates are in phase, the electron traversing T_i and T_{i+1} will increment both scalers $[T_i^{raw}]$ and $[T_{i+1}^{raw}]$.
- Otherwise, if the 2 prescaling gates are in opposite phase, only one of the 2 scalers will be incremented.

This means that the prescale scheme must be exactly the same during the normalisation run, when we determine $N_\gamma(E_j, T_l)$ and during the production when we estimating the scaling factor η_i. For exemple if an "opposite phase" prescale scheme is used, but stoping working during a production run, we suddenly switch from a the second case where one scaler is increased, to first one where two scalers are increased. One can hope that for odd T channels, i.e 1 T counter hit, using the $N_\gamma(E_j, T_l, odd\ l)$ determined during the normalisation run and rescaling it with η_i is a good aproximation. Yet, for even T channels corresponding to the overlap of two T's, rescaling $N_\gamma(E_j, T_l, odd\ l)$ with any of the two T's can be wrong by a 100%. Estimating the correction is almost impossible. Using the prescaled trigger coincidences between the tagger ands the start counter is biased by the hadronic cross section, and TDC are not prescaled, so one cannot use accidentals in the tagger to estimate the prescale coefficients for each T bin.

3.3 Conclusions

- Flaws in the E-T coincidence modules break the η rescaling scheme since it modifies the $N_\gamma(E_j)$ distribution shape between a production run and its corresponding normalisation run. The main justification for the use of the E.T modules was to reduce backgrounds in the tagger hodoscope and therefore reduce acquisition dead time. Due to the recent significant progress, this is no longer critical. It would therefore be judicious not to use this module in the future.

- Having the prescale affecting only scalers and not the TDC makes it very hard to normalise the TDC-based reconstructed events with the scaler-based measured number of tagged photons. An adequate solution would be to put the prescale on left (or right) side of the TDC discriminators and not on the E-T coincidence modules (As it might have been done already for the second part of g1). No correction would be needed anymore to rescale $N_\gamma(E_j, N_l)$ when prescale changes occurs.

4 General Alternate Solution proposed

The electronic problems are well identified. But it's not easy to find a way to recover the right number of tagged photons for all the channels E_j.

Since a spectrum like the normalized number of events of a given channel (the p $\pi^+\pi^-$ channel for exemple) is a constant quantity that doesn't change, we can use the data itself to renormalize directly the E_j channels with problems by using a reference spectrum obtained in a well understood run. The definition of the reference spectrum is flexible as one could use p $\pi^+\pi^-$ channel or any other experimental channel. The simplest one is the distribution of tagger hits in the trigger peak (so that it is coming from the ouput of the E*T coincidence module, and integrates prescaling and E*T modules electronic flaw) with a corresponding hit in the start counter, indicating that an hadronic event occured.

We therefore propose the following scheme :

1. Analyse a normalization run, taking care of the life time, trigger prescale, determining the tagging efficiency, the PS efficiency, and the $N_\gamma(E_j)_{norm}$
2. Analyse the first production run following the normalization run.
   - Determine the number of photons $N_\gamma(E_j)_{REF}$ according to (4) after corrections for life time and percentage of rejection of multiple T or E events in the tagger[7].
   - Check that a smooth cross section (for example the p $\pi^+\pi^-$ channel) is obtained.
   - Save the distribution H_{REF}, of tagger events in bin E_j that are in the trigger peak (fig. 11), requiring a corresponding hit in the start counter.

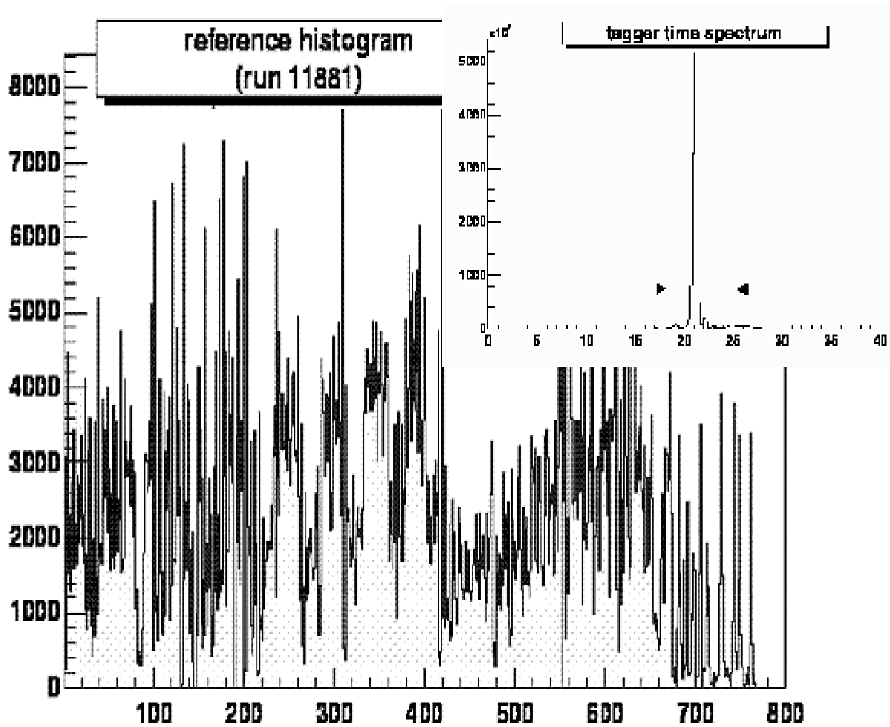

Figure 11: H_{REF}. *We select hits inside the window defined by the 2 lines.*

3. for any following run (with the same beam energy and torus field)

   - Determine the distribution H_{TOT} with the same conditions as H_{REF}.
   - Make the ratio of the two distributions: $R(E_j) = \frac{H_{TOT}}{H_{REF}}$ (fig. 12) .

If there is no problem with the electronic between the 2 runs, the ratio $R(E_j)$ is a constant over the bin j. If prescale or E-T matching module problem occurs, the $R(E_j)$ can be used to renormalized the channels which have problems, that is the number of photons $N_\gamma(E_j)$ is calculated using :

$$N_\gamma(E_j) = R(E_j) * N_\gamma(E_j)_{REF}$$

These $R(E_j)$ are defined from a spectrum which is roughly a total hadronic cross section. The statistics will be very large compared to any partial channel and this method will not add much additional errors.

[7] One has to check the status word of the TAGR BOS bank : a good hit has status equal to 7 or 15.

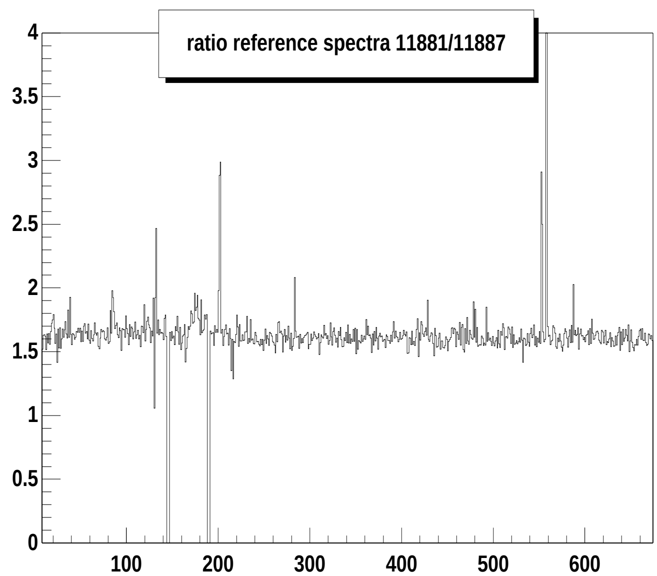

Figure 12: $R(E_j)$ *between run 11881 and run 11887.*