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Cross section measurement in heavy ion collisions at ALICE

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1 Introduction

Measurement of cross-sections from first principles entails a knowledge of beam fluxes, which are not at present available to ALICE. The alternatives involve relating the cross sections one wishes to measure to a 'known' cross section, either that for a known process (as was done with Bhabha scattering in the case of the LEP detectors), or to the total cross section.

There are two physical processes in heavy ion collisions which are considered to be used for luminosity measurement: the production of charged particles (the total inelastic cross section) and electromagnetic dissociation. The total cross section is expected to change very slowly and be governed essentially by geometrical factors. It therefore provides the best candidate for cross section normalization. Here the complication comes from the fact that what can be measured is not the total cross section, but a 'minimum bias' cross section, which loses an indeterminate fraction of the peripheral events. Fortunately, techniques such as Glauber theory allow extrapolation to the full cross section to be performed in a reasonably straightforward and reliable way [1]. Electromagnetic dissociation is proposed as another candidate for luminosity measurement [2]. The uncertainty in theoretical calculation of the electromagnetic dissociation cross section is of order 5% [3].

In this note two possible ways of arranging the scalers required to determine the cross sections are compared, each of which would enable the simultaneous measurement of the cross section. In the following section the implementation of these methods is discussed. In the last section conclusion is made and the list of proposed trigger scalers is given in the appendix.

2 Trigger Counting

Two options will be discussed: the first counts the *trigger class* triggers; the second counts the *detector cluster* triggers. Both methods use the following way of the luminosity measurement. The number of events N of the type I produced during time t is

$$N = L\sigma_I t, \tag{1}$$

where L is the luminosity of the collider and σ_I is the cross section for production of the event of type I in collision. A direct way of measuring the luminosity L is not possible, but there is an indirect way of measuring L and therefore the cross section. If there is a process for which the cross section is known, σ_0, then the unknown cross section can be calculated as

$$\sigma_I = \frac{N_I}{N_0}\sigma_0, \tag{2}$$

where N_I is the number of events of type I and N_0 is the number of events of the known process.

2.1 Class triggers counting

As already mentioned, the first option counts class triggers. Both past-future protection and rare trigger vetos are automatically taken into account. In the User Requirement Documents, Section 3.1.19, six counters for each trigger class are proposed:

- L0 triggers before any vetos (L0CB),
- L0 triggers after all vetos (L0CA),
- L1 triggers before past-future protection (L1CB),
- L1 triggers after past-future protection (L1CA),
- L2 triggers before past-future protection (L2CB),
- L2 triggers after past-future protection (L2CA),

From the physics point of view the number of triggers counted by counters can be viewed as in Fig.1. The boxes represent counters associated with different trigger levels before and after the trigger vetos. The first counter – L0CB – counts during a time T the number of events $N_1 = L\sigma_0 T$, where cross section σ_0 is the cross section corresponding to the L0 trigger inputs for corresponding trigger class without any vetos. In the counter L0CA only the triggers which pass vetos – dead time and past-future protection at L0 – are counted.

The counter L1CB counts events with the cross section corresponding to the physics of L1 trigger inputs for a given class without any L1 vetos. Therefore, the ratio of counts of counters L1CB to L0CA, (N_3/N_2) is the ratio of corresponding cross sections and

$$\sigma_1 = \frac{N_3}{N_2}\sigma_0. \tag{3}$$

The same situation holds for the counters L2CB and L1CA.

$$\sigma_2 = \frac{N_5}{N_4}\sigma_1. \tag{4}$$

In this way, the cross section σ_2 can be expressed in terms of the cross section σ_0:

$$\sigma_2 = \frac{N_5}{N_4}\frac{N_3}{N_2}\sigma_0. \tag{5}$$

The cross section σ_0 depends on the L0 trigger inputs and their corresponding physics process. The two situations may occur:

- the case where the cross section σ_0 is known and the cross section σ_2 is calculated directly from (5);

- the case where the cross section σ_0 is not known and it can be estimated from the known cross section of some other class (e.g. minimum bias).

Rare events should present no problem; they are just one of the vetos at the L1 level.

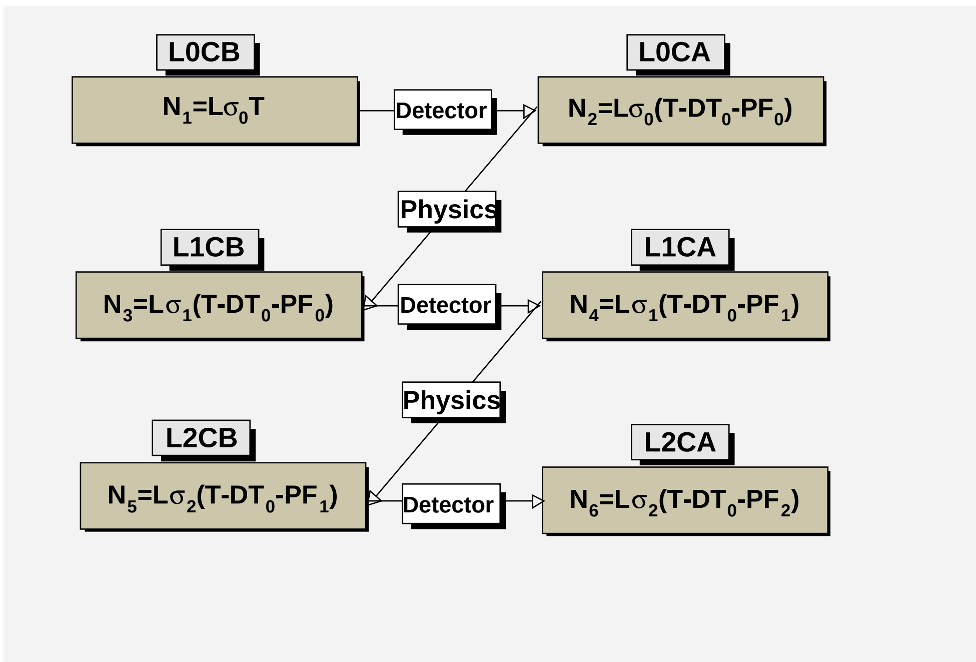

Figure 1: Counters for trigger class. First row corresponds to level L0, second to L1, third to L2.

2.2 Detector Cluster counting

The second option counts detector cluster triggers. In addition to trigger class counters proposed in previous section four other counters per detector cluster are needed and they are shown in Fig.2. The cross section σ_0 corresponds to the known cross section for the process chosen for luminosity measurement, e.g. the total inelastic cross section. The unknown cross section σ_2 is calculated from the ratio of the counter L2CA to the counter L2C2Cl:

$$\sigma_2 = \frac{N_6}{M_6}\sigma_0. \tag{6}$$

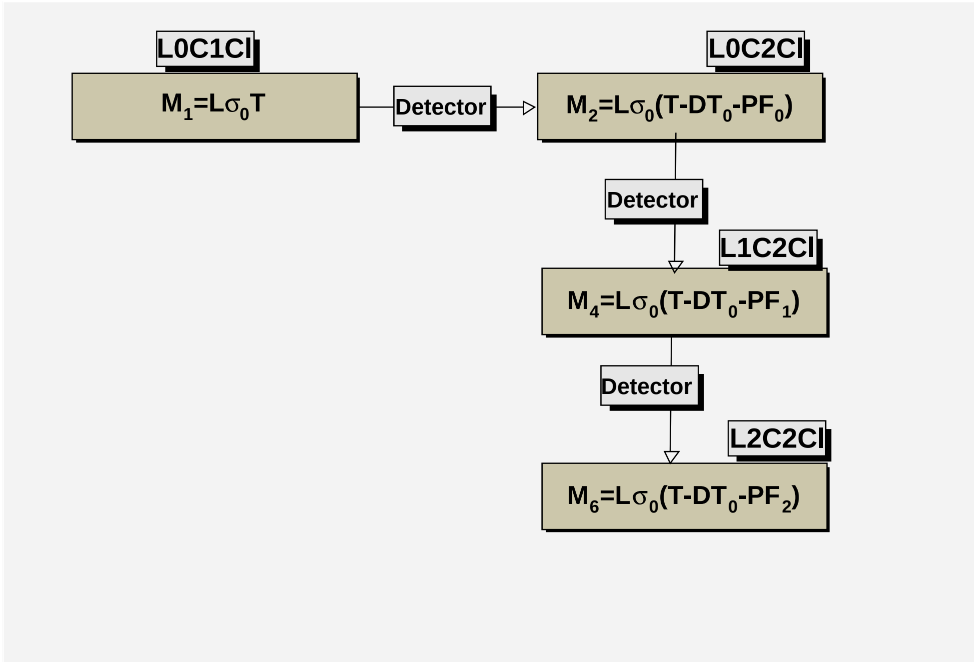

Figure 2: Counters for detector cluster. First two boxes correspond to counting at L0 level, third to L1, fourth to L2.

In order to include the rare trigger class cross section calculation the number of counters needs to be doubled. The provision of different past-future protection option for trigger classes associated with the same detector cluster (included in the current past-future protection proposal) requires that the number of counters be doubled again.

2.3 Statistical error analysis

Error analysis for these cases depends on the particular circumstances. If all the counters are independent, then the error on the cross section estimate in equation (5) is

$$\delta\sigma_2 = \frac{N_5 N_3}{N_4 N_2} \left\{ \delta^2\sigma_0 + \left(\frac{1}{N_2} + \frac{1}{N_3} + \frac{1}{N_4} + \frac{1}{N_5} \right) \right\}^{\frac{1}{2}} . \quad (7)$$

The values of N_3 and N_4 will be similar, since the only difference is the application of the L1 past-future protection, which does not remove many events. However, in many cases this formula will overestimate the error, as the counters are *not* independent. For example, for those trigger classes where little or no reduction occurs at L1, we can drop N_4 and N_5 from equation (7) to obtain

$$\delta\sigma_2 = \frac{N_5 N_3}{N_4 N_2}\left\{\delta^2\sigma_0 + \left(\frac{1}{N_2} + \frac{1}{N_3}\right)\right\}^{\frac{1}{2}}. \tag{8}$$

For detector clusters triggers counting, the corresponding error is

$$\delta\sigma_2 = \frac{N_6}{M_6}\left\{\delta^2\sigma_0 + \frac{1}{N_6} + \frac{1}{M_6}\right\}^{\frac{1}{2}}. \tag{9}$$

Since N_6 and N_5 are of similar magnitude (and indeed N_6 and N_3 are of similar magnitude if the conditions described for equation (8) apply) then we see that the error will usually be dominated by the statistics for the final stage. Although equation (9) in principle gives smaller errors than equations (7) and (8), in practice this will only be significant if the conditions of validity for equation (8) do not apply and at least one of the terms $1/N_2 \ldots 1/N_4$ is not small with respect to $1/N_5$. An example of such a case would be for a moderate L1 reduction factor, say $N_5/N_4 \sim 1/3$. Then equation (7) applies and both the terms in N_4 and N_5 have a significant effect on the overall error. Otherwise, either the error on the final step N_5 dominates the errors or at least the one of the quotients will have correlated and similar numerator and denominator, and so equation (7) does not apply. (All the trigger classes currently include a second pass centrality cut using the ZDC, so all the trigger classes will have some L1 reduction, but probably not much if there are no other conditions applied.)

2.4 Simulation

A simulation of the trigger system for both scenarios has been performed. The simulated system contains four detectors (for details see [4]): two detectors are assumed to produce the L0 trigger inputs (e.g. V0 and muon detector (DM)), one detector produces the L1 trigger input (e.g. TRD) and one detector produces no trigger inputs (e.g. TPC). The detector dead time is set to $5.5\mu s$ for V0, $5.5\mu s$ for DM, $5.5\mu s$ for TRD, and depends linearly on the event size with minimum $100\mu s$ for the TPC. Detectors are divided into three clusters:

Cluster 1 (V0, TRD, TPC);

Cluster 2 (V0, TPC);

Cluster 3 (V0, DM).

The three trigger classes are defined:

Class 1, with the V0 input and associated with the **Cluster 2**;

Class 2, with the V0 and the DM inputs and associated with the **Cluster 3**;

Class 3, with the V0 and the TRD inputs and associated with the **Cluster 1**.

Table 1: Results of the simulation. The trigger classes are Minimum Bias (the V0 input), Dimuon (the V0 and the DM inputs) and Electron (the V0 and the TRD inputs). First row corresponds to counting of the class triggers – formulae (3) and (4). The second row corresponds to counting of the detector cluster triggers – formula (6) The generated input values of the cross sections are in the last row.

	Min. Bias $[10^{-4}]$	Dimuon [%]	Electron [%]
Trig. class	1.997 ± 0.002	12.51 ± 0.03	3.90 ± 0.18
Det. cluster	1.997 ± 0.002	12.82 ± 0.03	3.90 ± 0.18
Input value	2.0	12.5	3.75

Table 2: Results of the simulation. The trigger classes are : Minimum Bias (the V0 input), Dimuon (the V0 and the DM inputs) and Dimuon+Dielctron (the V0, the DM and the TRD inputs). First row corresponds to counting of the class triggers – formulae (3) and (4). The second row corresponds to counting of the detector cluster triggers – formula (6) The generated input values of the cross sections are in the last row.

	Min. Bias $[10^{-4}]$	Dimuon [%]	Dimuon+Electron [%]
Trig. class	1.997 ± 0.002	12.51 ± 0.03	6.18 ± 0.30
Det. cluster	1.997 ± 0.002	12.82 ± 0.03	6.15 ± 0.23
Input value	2.0	12.5	6.25

The interaction rate is 8000 Hz, the dimuon rate 1000 Hz and the electron rate 300 Hz. Using the natural units – luminosity $L = 1$ and unit of time being beam crossing – the rates correspond to cross section $1/5000 = 2.10^{-4}$ for minimum bias interaction, with 12.5 % for dimuons and 3.75% for electrons. The measured cross sections after 100 seconds of simulated collisions are in Table 1, and are consistent with generated values.

In order to compare both methods, a situation where the trigger class has both L0 and L1 inputs has been simulated. The results are in Table 2.

3 Conclusion

Both methods give results that are consistent with the values from which they were generated, with very comparable errors on the channel cross sections after a run of about 100 seconds of simulated collisions. In most practical applications (as illustrated in the "dimuon" and "dielectron" cases given above) the trigger reduction occurs mainly at one level only, and so the errors are comparable even with small statistics. It is possible to create an example in which, after 100 seconds of running, there is an appreciable difference between the two methods (favouring the cluster triggers counting method) but if we aim to have large samples for each class the statistical error on the channel cross section will always be negligible compared to the other errors. This means that differences between the two methods will probably be negligible. The choice of method therefore depends on other factors, such as ease of use and implementation. As has been pointed out, rare-event-handling is straightforward for class triggers counting but not for detector cluster triggers counting, and therefore *class triggers counting should be chosen as the more flexible method.*

The proposed list of the trigger scalers for the User Requirement Document (URD) of the ALICE Central Trigger Processor (CTP) is given in the Appendix.

4 Appendix

Proposed description of scalers for the ALICE CTP URD

3.1.19 Scalers

1.19.1 The CTP shall include scalers that will count continuously during a run. The frequency of scaler reading will probably be every two minutes and the output will be sent to the local monitoring processor. The scalers shall count the following:

- all the trigger input signals (L0, L1 and L2),
- two interaction and one interaction test signals;

and for each trigger class:

- L0 triggers before vetos,
- L0 triggers after vetos (scaling, busy, past-future etc.),
- L1 triggers before past-future protection,
- L1 triggers after past-future protection,
- L2 trigger before past-future protection,
- L2 triggers after past-future protection.

1.19.2 The capacity of the scalers will be 32 bits.

1.19.3 The scalers shall reset at the beginning of a run and read out to the DAQ at the end of a run.

1.19.4 The CTP shall also include scalers to count the number of bunch crossings during which the following signals are asserted:

- all the sub-detector BUSY signals,
- CTP BUSY,
- DAQ BUSY.

1.19.5 The capacity of these scalers is to be decided.

1.19.6 The scalers shall be read in regular intervals by the local monitoring processor. Real-time analysis of the data shall be performed, and any potential problem shall be reported to the run-control system. The data shall be written to permanent storage in the run log and made available for use by the off-line analysis.

References

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[4] T.Antičić, P.Jovanović, R.Lietava, O. Villalobos-Baillie: *Trigger Simulation*; http://www.ep.ph.bham.ac.uk/user/lietava/alice.html