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Integrated Luminosity Measurement using Bethe-Heitler Overlapping Events

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Abstract

Bethe-Heitler interactions overlapping over randomly triggered events are used to measure the integrated luminosity delivered by HERA to H1.

1 Bethe-Heitler Process

1.1 Cross Section

The Bethe-Heitler process:

$$e^- p \to e^- p\, \gamma \quad , \tag{1}$$

consists in the bremsstrahlung emission of a photon by the electron in the electromagnetic field of a proton. In the ultra-relativistic limit and the small angle approximation, the cross section reads [1]:

$$\frac{d\sigma_{BH}}{dy} = \frac{4\alpha r_e^2}{y}\left[1 + (1-y)^2 - \frac{2}{3}(1-y)\right]\left[\ln\frac{s(1-y)}{M_p m_e y} - \frac{1}{2}\right] \quad , \tag{2}$$

where $y = E_e/E_e^0$, E_e^0 and E_e being, respectively, the energies of the incident and scattered electrons, s the total energy squared in the center of mass system, M_p and m_e the proton and electron masses, respectively, and r_e the classical electron radius.

1.2 On-Line Luminosity Measurement

At H1, in the case of a Bethe-Heitler interaction, the scattered electron remains in the beam pipe and escapes detection in the main detector. However, depending on its energy and transverse momentum, it may be detected in the electron tagger. The radiated photon is detected in the photon arm.

This process is used on-line to measure the luminosity [3], using the number of events with an electron detected in the electron tagger, in coincidence with a photon detected in the photon detector. The pilot bunches are used to correct the measurement for the presence of residual gas.

1.3 Luminosity Measurement using Bethe-Heitler Overlapping Events

The goal of the work presented here is to use events containing a Bethe-Heitler process (1) accidentally overlapping with an independently triggered event, in order to estimate the integrated luminosity.

Indeed, from this random selection of Bethe-Heitler events, one can deduce the total number of Bethe-Heitler events produced in a given run period, and hence the integrated luminosity, knowing the Bethe-Heitler cross section (2).

The selected random sample of Bethe-Heitler events consists of all events containing both a photon with an energy larger than 5 GeV in the photon arm and a high energy cluster ($E_{bemc} > 25\ GeV$) in the BEMC (see section 2). Due to the energy requirement in the BEMC, one can be sure that the photon is not due to initial state radiation from a deep inelastic scattering event, but is well due to a Bethe-Heitler process.

To compute the total number of Bethe-Heitler events, one takes into account the bunch to bunch luminosity variation. This correction is applied using the on-line luminosity measurement. However, it should be emphasized that the results are independent of the absolute calibration of the on-line luminosity measurement (see section 3).

The integrated luminosity obtained this way is thus independent of the trigger elements and L4 filter efficiencies, and of the DAQ dead time.

2 Probability for Random Overlap of Bethe-Heitler Events

The data used in the present analysis consist of $N^{peak} = 19848$ events of DST4 (excluding the runs with a DAQ dead time larger than 30 %), after the no magnetic field period ($62575 \leq RUN \leq 66607$), containing a cluster of at least 25 GeV in the BEMC:

$$E_{bemc} > 25\ GeV. \tag{3}$$

Only events corresponding to luminosity bunches are considered.

These N^{peak} events are thus DIS events from the kinematic peak region, and events due to the proton beam halo or to cosmic muons (the sample contains $10 \pm 2\%$ of events triggered by cosmic muon). We call them, hereafter, "peak events". These events are triggered independently of any signal in the photon arm [2].

In this sample, $N^{over} = 170$ overlapping events are selected by the requirement of a minimal reconstructed energy in the photon arm:

$$E_{\gamma} > 5\ GeV. \tag{4}$$

The selected Bethe-Heitler events are produced either on the proton beam or on the residual gas. When a peak event has triggered the detector, the probability P for a Bethe-Heitler event to be produced (on the proton beam) in the same bunch crossing is thus given (supposing a constant luminosity) by:

$$P(\mathcal{L}) = \frac{N^{over}}{N^{peak}}\,(1 - R^{gas}) \tag{5}$$

where R^{gas} is the fraction of events produced on the gas. The latter is estimated for each group of runs (corresponding to about 10 nb^{-1}) using monitoring events triggered by the subtrigger element WATVET (energy in the Veto Counter of the photon arm [3]), with a reconstructed energy in the photon arm larger than 4 GeV. Using this unbiased sample, R^{gas} can be computed as:

$$R^{gas} = \frac{n^{e-pilot}}{n^{lumi-bunch}}\,\frac{84}{10}\,\frac{I^{lumi-bunch}}{I^{e-pilot}} \tag{6}$$

where $n^{e-pilot}$ is the total number of events (in the group of runs) observed in the electron pilot bunches (10 electron pilot bunches per cycle), $n^{lumi-bunch}$ is the total number of events (in the group of runs) observed in the luminosity bunches (84 per cycle), $I^{e-pilot}$ (resp. $I^{lumi-bunch}$) is the average current for the electron pilot bunches (resp. luminosity bunches).

The average fraction of Bethe-Heitler interaction on the gas is $< R^{gas} >= (23.6 \pm 0.6)\%$.

After thi correction, the average probability for detecting a Bethe-Heitler event with energy in the photon arm larger than 5 GeV is $(0.66 \pm 0.06)\%$.

In practice, this probability has to be computed taking into account run-to-run luminosity variations. This is done in section 3.

3 Integrated Luminosity Measurement

The total luminosity (for a given run period), $\mathcal{L}^{Tot}$, is related to the total number of Bethe-Heitler events (in this period), N_{BH}^{Tot}, and to the Bethe-Heitler cross section by:

$$\mathcal{L}^{Tot} = \frac{N_{BH}^{Tot}}{\sigma_{BH}} \tag{7}$$

and

$$N_{BH}^{Tot} = \sum_{i=1}^{N_{bc}^{Tot}} P_{BH}^{i}(\mathcal{L}), \tag{8}$$

where, N_{bc}^{Tot} is the total number of bunch crossings for the considered run period, and $P_{BH}^{i}(\mathcal{L})$ is the (luminosity dependent) probability for detecting a Bethe-Heitler process in the bunch crossing i.

This probability, $P_{BH}^{i}(\mathcal{L})$, is computed as the ratio N^{over}/N^{peak} in a sample of events produced with the same luminosity as close as bunch i. In practice, the events are classified in $N_{[L]}$ groups of similar luminosities.

The integrated luminosity is taken as the sum of the luminosity groups:

$$\mathcal{L}^{Tot} = \sum_{g=1}^{N_{[L]}} \mathcal{L}^{g} = \frac{1}{\sigma_{BH}} \sum_{g=1}^{N_{[L]}} N_{bc}^{g} P_{BH}^{g} \tag{9}$$

where N_{bc}^g is the total number of bunches in the luminosity group g, and P_{BH}^g the probability to observe a Bethe-Heitler event at the luminosity of group g.

The total number of bunch crossings is computed from the total running time divided by the time delay between two bunch crossings (96 ns). The cross section is computed from the integration of eq. (2) for photon energies between 5 and 26.7 GeV ($0.81 < y < 0$):

$$\sigma_{BH}(E_\gamma > 5GeV) = \int_0^{0.81} \frac{d\sigma}{dy}\, dy = 70.20\ nb \tag{10}$$

In each group, the probability P_{BH}^g is estimated as:

$$P_{BH}^g = \frac{\sum_{i=1}^{N^{peak}} W^i \delta^i}{\sum_{j=1}^{N^{peak}} 1} \tag{11}$$

where

$$\delta^i = \begin{cases} 1 & \text{if an overlapping Bethe-Heitler event is observed in} \\ & \quad \text{the bunch crossing containing the peak event i} \\ 0 & \text{if there is no overlapping event,} \end{cases} \tag{12}$$

and

$$W^i = 1 - R_i^{gas}, \tag{13}$$

N^{peak} beeing the number of peak events in the group g.

Note that eq. (11) is the same as eq. (5), for in the luminosity group g.

The luminosity computed for 7 groups of similar luminosity is shown in Fig. 1 and compared to the QED Compton [5]-[6]-[7] method and to the on-line measurement.

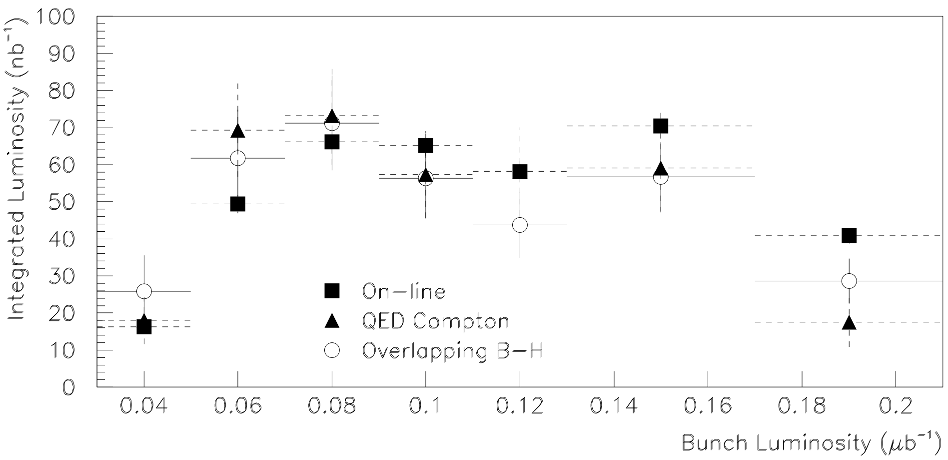

Figure 1: *Integrated luminosity measurements, in function of the bunch luminosity, using the overlapping event method, the QED Compton method and the on-line measurement.*

The overall correction introduced by the clasification in groups of similar luminosites is of the order of 5%.

So far, the variation of the luminosity from bunch to bunch has not been considered into each group of similar luminosity. The probabilities of producing a Bethe Heitler process at different luminosities, $\mathcal{L}_1$ and $\mathcal{L}_2$, are related by:

$$P_{BH}(\mathcal{L}_1) = P_{BH}(\mathcal{L}_2)\frac{\mathcal{L}_2}{\mathcal{L}_1} \tag{14}$$

In each group, the luminosity measurement can be corrected for the variation relatively to the average luminosity, $\overline{\mathcal{L}}^g$, using:

$$P_{BH}^g = \frac{\sum_{i=1}^{N^{peak}} W^i \delta^i \overline{\mathcal{L}}^g}{\sum_{j=1}^{N^{peak}} \mathcal{L}^j} \tag{15}$$

where $\mathcal{L}^j$ is the bunch j luminosity.

The effect of this second order correction on the integrated luminosity measurement, shown in Fig. 2, is a decrease of 0.4%.

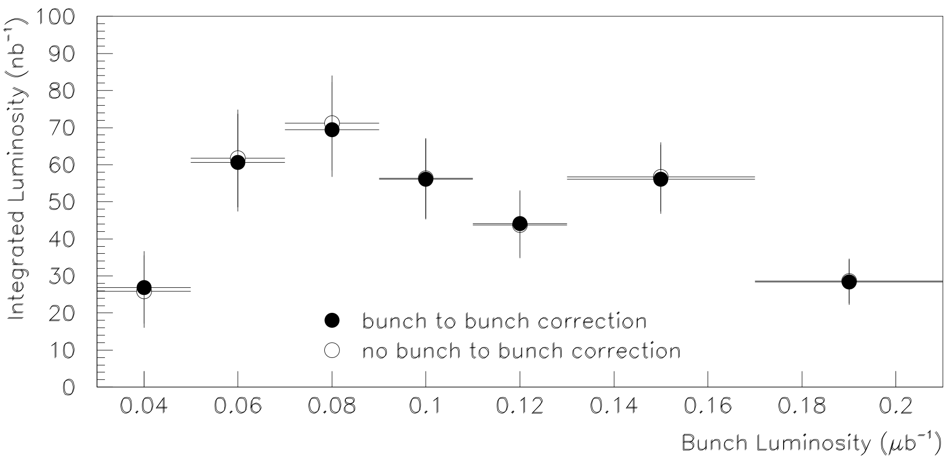

Figure 2: *Integrated luminosity measurement, in fuction of the bunch luminosity, with and without bunch to bunch luminosity corrections*

The integrated luminosity has been computed for several running periods. The result is shown on Fig. 3 and compared with the QED Compton and on-line measurements. Due to the limited statistics for each running period, the luminosity classification has been done using only in 4 groups of similar luminosites (the effect of this restriction in the number of groups is estimated to be smaller than 1%).

The quoted errors are statistical only for the overlapping method, since systematic errors due to the luminosity sytem are expected to essentially cancel and are neglected. For the QED Compton

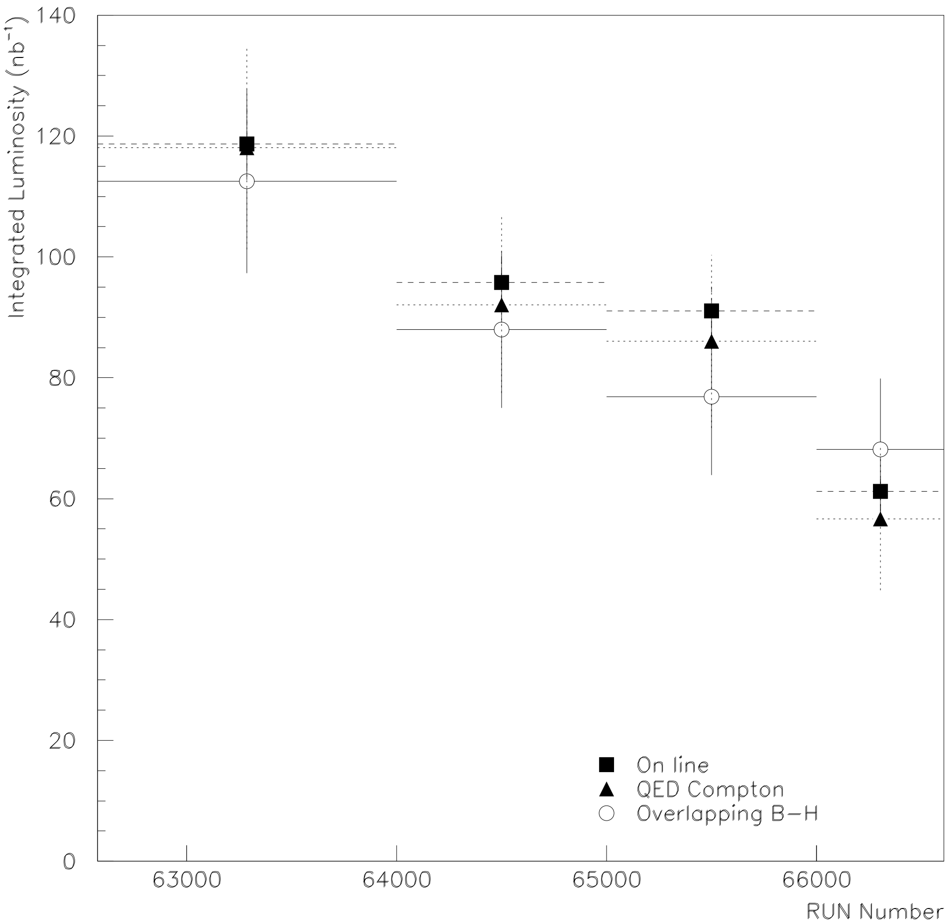

Figure 3: *Integrated luminosity measurements, for several running periods, using three different methods: overlapping Bethe-Heitler events, QED Compton events and on-line measurement*

method, both statistical and systematic errors are quoted. The errors on the on-line measurement are mainly systematic.

The total luminosity, integrated over the whole second half of 1993 running period is given in Table 3, together with the QED Compton and on-line measurements. Results are shown including or not the DAQ dead time factor. The three results are compatible within 1 sigma.

	$\mathcal{L}$ (nb^{-1}) dead time independant	$\mathcal{L}$ (nb^{-1}) dead time factor incl.
Overlap	344 ± 26	$296^{*} \pm 22$
Compton	$353^{*} \pm 29$	305 ± 25
On-Line	366 ± 18	315 ± 16

Table 1: *Comparaison of the Luminosity measurement for three different methods: the overlapping event and the QED Compton event methods and the on-line measurement.*
(*) scaled for dead time dependence

4 Conclusions

A new method for the measurement of the integrated luminosity, using Bethe-Heitler events overlapping on randomly triggered events, has been presented. This method is independent of trigger and L4 level rejection inefficiencies and of the DAQ dead time. For the 1993 run period, after magnetic field recovering, an integrated luminosity of (344 ± 26) nb^{-1} is found. For the 1993 data, the statistical error is 7 % and the systematic error are neglected. This measurement is compatible with the QED Compton and on-line measurements within one sigma.

Acknowledgements

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