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H1 1994 Integrated Luminosity Measurement Using bremsstrahlung Overlapping Events and quasi-real QED Compton Events

L. Favart[1], R. Maraček[2]

[1] Laboratoire de L'Accélérateur Linéaire, IN2P3-CNRS et Université de Paris-Sud, Orsay, France

[2] Institute of Experimental Physics Slovak Academy of Sciences, Košice, Slovak Republic

Abstract

The experimental study of the integrated luminosity delivered to the H1 detector during 1994 data taking period is presented. Two different methods are used. The first is based on bremsstrahlung interactions overlapping randomly triggered events while the second on the detection of QED Compton events detected in the backward electromagnetic calorimeter (BEMC). The obtained integrated luminosities are compared to the value provided by H1 luminosity system.

1 Introduction

For a direct luminosity measurement one has to choose a process with a well calculable cross section and a clear experimental signature. This is the case for the elastic bremsstrahlung process:

$$ep \rightarrow ep\,\gamma \quad , \tag{1}$$

and of the elastic QED Compton process [1]:

$$ep \rightarrow eX\,\gamma \quad . \tag{2}$$

The bremsstrahlung process (1) consists in the radiation at $0°$ (corresponding to $180°$ in H1 frame) of a photon by the electron in the electromagnetic field of a proton. The scattered electron as well as the proton remain in the beam pipe and escape detection in the central detector. However, depending on its energy, the electron 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 [2], using the number of events with a photon detected in the photon detector. The pilot bunches are used to correct the measurement for the contamination due to interactions of electrons on the residual gas.

It has been shown in [3] that the integrated luminosity can also be measured, at H1, using events containing a bremsstrahlung process (1) accidentally overlapping with an independently triggered event.

The quasi-real QED Compton process (2) can be seen as a $Q^2 \sim 0$ GeV ^{2} interaction involving a large four-momentum transfered Compton process ($e\gamma \rightarrow e\gamma$). The leptonic final state consists of a coplanar $e-\gamma$ system, both observable in the central H1 detector.

This note presents the 1994 H1 luminosity measurements based on the random bremsstrahlung overlapped method and based on quasi-real QED Compton sample with both $e-\gamma$ detected in the backward electromagnetic calorimeter (BEMC) [4]. The comparison of the two methods to the on-line measurement is shown.

2 1994 data

The data used in the present note consists events collected in 1994 (77325 < run number < 90419). In order to follow the different configuration of HERA and H1 experiment, i.e. switching electron to positron beam mode, moving the z coordinate of the nominal interaction point to the shifted position, including the four most inner BEMC stacks into the trigger, and repairing of CJC chambers, the whole data sample is divided into five run periods.

1. Electron data[2]

   $77325 <$ run number ≤ 82005

2. first positron data[2]

   $82961 \leq$ run number ≤ 87556

[2]the four most inner stacks in BEMC (triangular ones) were **not** included into the trigger

3. positron data after readout repair of CJC[2]

   $87586 \leq$ run number ≤ 89412

4. a) positron data after readout repair of CJC[3]

   $89413 \leq$ run number ≤ 89912

   b) positron data after shifted z-vertex[3]

   $90101 \leq$ run number ≤ 90419

5. positron data - shifted z-vertex data[3]

   $89929 \leq$ run number ≤ 90025

3 Bremsstrahlung overlapping Events method

The integrated luminosity can be determined from events containing a bremsstrahlung process (1) accidentally overlapping with an independently triggered event. From a random selection of bremsstrahlung events, one can deduce the total number of bremsstrahlung events produced in a given run period, and hence the integrated luminosity, knowing the bremsstrahlung cross section computed in the Beth-Heitler approximation.

The method used here has been presented in details in [3]. The integrated luminosity obtained by this method is independent of the trigger elements, of L4 filter efficiencies, and of the DAQ dead time.

3.1 Data selection and random overlap probability

The data used consist of events (excluding the runs with a DAQ dead time larger than 30 %) containing a cluster of at least 25 GeV in the BEMC:

$$E_{\mathrm{BEMC}} > 25 \text{ GeV}. \tag{3}$$

In this sample, the overlapping events are selected by the requirement of a minimal reconstructed energy in the photon arm:

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

The energy requirement in the BEMC, one can be ensures that the photon is not due to initial state radiation from a deep inelastic scattering event, but is well due to a bremsstrahlung process.

The measured probability for a randomly triggered event to have an overlapped bremsstrahlung event with a photon energy larger than $E_\gamma^0 = 5$ GeV is given in the table 1 for the different run periods. As illustrated in Fig.1, knowing the bremsstrahlung cross section, the random overlap probability can be extrapolated down to smaller E_γ^0 limit. Following this extrapolation, the random overlap probability derived for $E_\gamma > E_\gamma^0 = 150$ MeV is also given in table 1.

[3]the four inner triangular stacks in BEMC were included into the trigger

run period	$E_\gamma^0 = 5$ GeV	$E_\gamma^0 = 150$ MeV
1	1.06 ± 0.04	4.41 ± 0.17
2	1.37 ± 0.02	5.69 ± 0.08
3	1.70 ± 0.03	7.07 ± 0.12
4	1.41 ± 0.04	5.86 ± 0.17
5	1.34 ± 0.07	5.57 ± 0.29
all	1.43 ± 0.02	5.94 ± 0.07

Table 1: Random overlap probability (in %) of a bremsstrahlung event with a photon energy larger than E_γ^0

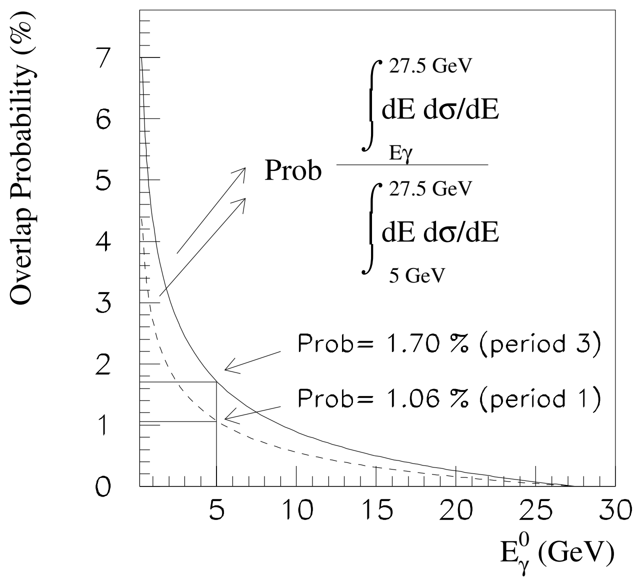

Figure 1: Random overlap probability in function of E_γ^0 for the run periods 1 and 3

3.2 Integrated luminosity measurement

The total luminosity (for a given run period), $\mathcal{L}^{Tot}$, is related to the total number of bremsstrahlung events produced on the proton beam (during this period), N^{Tot}_{BH}, and to the bremsstrahlung cross section by:

$$\mathcal{L}^{Tot} = \frac{N^{Tot}_{BH}}{\sigma_{BH}} \tag{5}$$

and

$$N^{Tot}_{BH} = \sum_{i=1}^{N^{Tot}_{bc}} P^i_{BH}, \tag{6}$$

where, N^{Tot}_{bc} is the total number of bunch crossings for the considered run period, and P^i_{BH} is the probability for detecting a bremsstrahlung (produced on the proton beam) in the bunch crossing i.

This probability, P^i_{BH}, is computed as the ratio $N^{overlap}/N^{peak}$ in a sample of events produced with the same luminosity as bunch i, after subtracting the gas contamination and correcting for pile-up effect.

$$P^i_{BH} = \frac{N^{overlap}_i}{N^{peak}_i}(1 - R^{gas}_i)(1 - R^{Pile-up}_i) \tag{7}$$

The fraction R^{gas} of events produced on the gas is estimated from the fraction of events produced by pilot bunches in monitoring events. The gas rate estimate is shown in Fig. 2 in function of the run number.

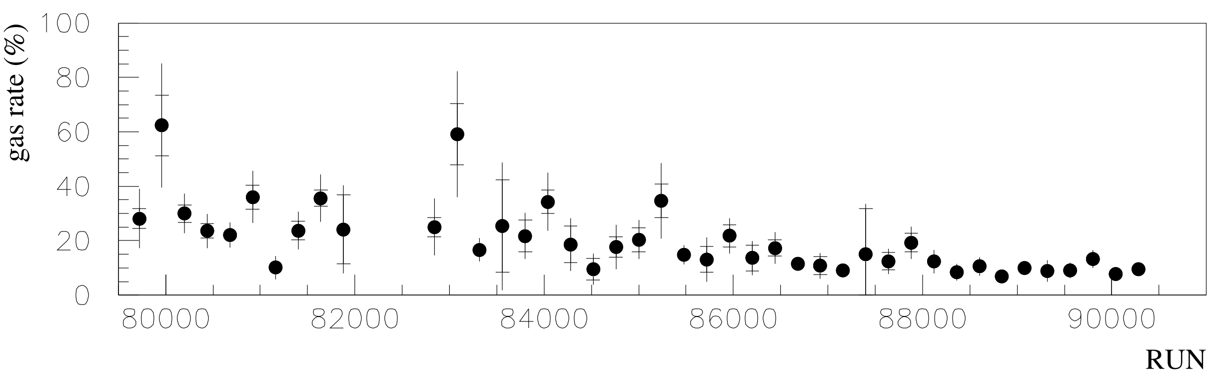

Figure 2: Gas rate estimate. The first part of the error bar represents the standard deviation inside one bin of run numbers, the total error bar includes the statistical error.

The number of selected overlapping events is itself affected by a pile-up effect. The possible presence of several overlapping events affects the E_γ spectrum and increases the number of selected events. The pile-up correction factor $R^{Pile-up}$, estimated by Monte Carlo, is given for the different run periods in the table 2.

Run period	$R^{Pile-up}$ (%)
1	1.3 ± 0.2
2	1.6 ± 0.2
3	2.0 ± 0.2
4	1.7 ± 0.2
5	1.6 ± 0.2
all	1.7 ± 0.2

Table 2: Pile-up correction factor.

So far the instantaneous luminosity was considered to be constant inside a run period. In practice, to reduce the effect of this assumption, the events are classified in groups of similar instantaneous luminosities inside one run period. The variation of the luminosity measurement according to the number of luminosity groups is shown in Fig. 3. This effect varies between 5 and 8% for the different run periods. The statistical error of the integrated luminosity measurement increases with the number of luminosity groups. In order to limit this error, it is required that each group contains at least 50 events. If not, the groups with a few events are gathered with the neighboring groups. The variation of the number of events in each groups explains the fluctuation in the error bars shown in Fig. 3. In this analysis the number of luminosity groups has been chosen to be 5, since no effect is observable for larger number of groups.

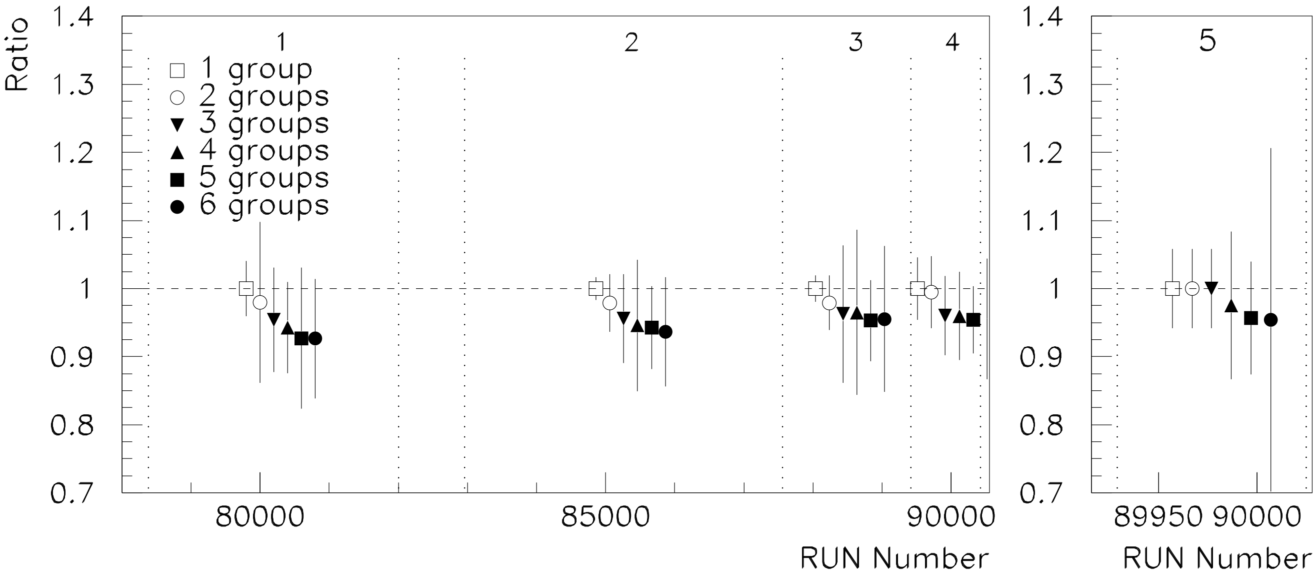

Figure 3: Ratio of the luminosity estimate for different number of constant luminosity groups over the luminosity estimate for 1 group.

3.3 Error Estimate

The main error on this measurement is the statistical one. Actually, the need of splitting the sample into constant luminosity groups increases the statistical error on the total luminosity value.

The main systematic errors are due to the Photon Detector calibration, which is estimated by Monte Carlo increasing the energy scale by 1.5%, and due to the error on the gas rate estimate. The systematic estimate is given in table 3.

Run period	R^{gas} (%)	calibration (%)
1	1.7	1.1
2	1.0	
3	0.7	
4	0.5	
5	2.3	

Table 3: Systematic errors estimate.

4 QED Compton event method

As it was shown [6, 7], the absolute value of the integrated luminosity can be measured using the sample of quasi-real QED Compton events detected in the central H1 detector. In the following only the QED Compton events with both scattered particles in the BEMC are considered.

In order to determine the integrated luminosity from the measured sample of the QED Compton events $\mathcal{L}_{\rm QEDC}$ we used the following formula:

$$\mathcal{L}_{\rm QEDC} = \frac{N_{\rm QEDC} - N_{bg}}{\epsilon_{eff} N_{\rm MC}} \mathcal{L}_{\rm MC}$$

where $N_{\rm QEDC}$ is the number of selected QED Compton events, N_{bg} is the number of background events remaining in the selected sample (see below), ϵ_{eff} is the efficiency of the QED Compton event sub-trigger, $N_{\rm MC}$ is the number of Monte Carlo QED Compton events which were selected by the same selection procedure as the data sample and $\mathcal{L}_{\rm MC}$ is the integrated luminosity corresponding to the generated MC QED Compton event sample.

4.1 QED Compton event sample selection

The data used in the presented analysis were collected in 1994 (77325 < run number < 90419). We used the sample of QED Compton event candidates preselected by the event classification (`FPACK class 12`). The part of classification routine which is devoted to recognizing the topology of the QED Compton events with both scattered particles detected in BEMC, the so-called BEMC-BEMC QED Compton events, imposes the following conditions:

- The energy requirements on the first three most energetic clusters in BEMC (`BCLR bank`) are respectively $E_{\rm cl1} > 8$ GeV, $E_{\rm cl2} > 4$ GeV, $E_{\rm cl3} < 2$ GeV, and the cut on the sum of the energy of the first two BEMC cluster is $18 \text{ GeV} < \rm E_{cl1} + E_{cl2} < 32$ GeV

- The absolute value of the difference of the azimuthal angles corresponding to the first and second cluster in BEMC (accoplanarity restriction) $135^\circ < |\phi_{\rm cl1} - \phi_{\rm cl2}| < 225^\circ$

- The number of central tracks[4] is less than 4.
- In case of a reconstructed vertex the absolute value of its z coordinate is demanded to be less than 100 cm

The final QED Compton event sample used for luminosity measurement was obtained by requiring:

- Only good and medium runs (according the h1ep-classification)
- Well defined H1 detector status (requiring the HV bit of all relevant components to be on)
- The sub-trigger 0 is active with a pre-scale factor less then 5.
- The energy requirements on the first three most energetic clusters in BEMC (`BCLR bank`) are respectively $E_{\rm cl1} > 8$ GeV, $E_{\rm cl2} > 4$ GeV, $E_{\rm cl3} < 2$ GeV, and the cut on the sum of the energy of the fist two BEMC cluster is 20 GeV $< \mathrm{E_{cl1}+E_{cl2}} <$ 32 GeV
- The total LAr energy in forward region defined by the conus covering 45° area from the nominal interaction point had to be less than 2 GeV
- The sum of all BEMC cluster energies minus energy of both leading and second most energetic cluster had to be less than 1.20 GeV, which is approximately three times the noise of a BEMC cluster
- No single diode events
- Accoplanarity restriction, $160^\circ < |\phi_{\rm cl1} - \phi_{\rm cl2}| < 200^\circ$
- The lateral spread of the cluster had to be less than 5 cm (cluster radius)
- No forward track contained in any planar segment was demanded
- All good tracks should point to the shower center of gravity in the BEMC in the conus of 10°
- In the case there was a hit in BPC, its coordinates had to match the shower center of gravity in the BEMC to within 8 cm in radius
- For the data sample corresponding to the run ranges when the four most inner stacks in BEMC (triangular ones) were not included into the trigger (periods 1,2,3) we required:
  - The right ToF ep-collision timing for both first and second most energetic cluster (i.e. $t_{\rm Tof} > -5$ns),
  - in order to cut out regions where the BSET cluster trigger CL2 is not 100 % efficient the leading cluster energy in BEMC had to be greater than 10 GeV and the hottest stack of the leading cluster had to be outside of the triangular region.

[4]CJC tracks, which have to fulfill the following requirements: The number of CJC hits is great or equal to 10, the absolute value of the distance of closest approach (DCA) is less than 2 cm, the absolute value of the z coordinate at DCA is less than 50 cm, the radius at track start is less than 30 cm.

The total number of selected QED Compton events for run periods 1, 2, 3, 4 and 5 in the selected sample was 201, 650, 360, 224, and 50 respectively.

In order to evaluate the possible contributions of background processes to the selected sample a Monte-Carlo study was performed. The contribution of deep inelastic scattering (DIS), photoproduction and diffractive production of vector mesons (VM) processes to the sample of quasi-real QED Compton events was estimated using the Monte-Carlo samples generated by DJANGO, PHOJET and RAYVDM respectively. Events which satisfy all described above selection criteria spoil the selected sample. The fraction of these background events is given in the Table 4.

Process	Background contribution
DIS	negligible
photoproduction	2.6 ± 0.6 %
VM production	1.6 ± 0.5 %

Table 4: The obtained Monte-Carlo estimates of background contribution due to deep inelastic, photoproduction and vector mesons production processes in the QED Compton sample.

4.2 Stability of the QED Compton event method

In order to study the stability of the luminosity measurement using the sample of QED Compton events each run period was divided into intervals with comparable values of integrated luminosity, $L_{\mathrm{on-line}}$, determined by luminosity system. The distribution of the ratio of number of QED Compton events N_{QEDC} to $L_{\mathrm{on-line}}$ calculated for each subinterval according to run numbers is depicted in Fig. 4.

It shows that the presented method is stable within the interval of statistical errors for periods with closed (periods 1, 2, 3) and opened BEMC triangles (period 4).

Including the four innermost triangular stacks into the trigger increases acceptance of the BEMC closer to the beam pipe and thus to the higher values of the polar angle of the scattered particles $\theta_{e'}, \theta_\gamma$. Since the cross section of quasi-real QED Compton process increases with the $\theta_{e'}, \theta_\gamma$ it is natural that the value of the ratio $N_{\mathrm{QEDC}}/L_{\mathrm{on-line}}$ is higher in run periods with open BEMC triangular stacks (period 4) and with shifted z-position of the nominal vertex (period 5).

4.3 Quasi-real QED Compton event Monte Carlo

The Monte-Carlo sample was obtained by generating events using the generator program COMPTON 2.00 [8], with the following parameters:

- The incident electron energy ($E_e = 27.5$ GeV)
- The incident proton energy ($E_p = 820.0$ GeV)
- The interval of polar acceptance ($3.6^\circ < \theta_{e'},\ \theta_\gamma < 177.5^\circ$)
- The outgoing particles energy restrictions ($E_{e'},\ E_\gamma\ > 2$ GeV, $E_{e'} + E_\gamma\ > 18$ GeV)

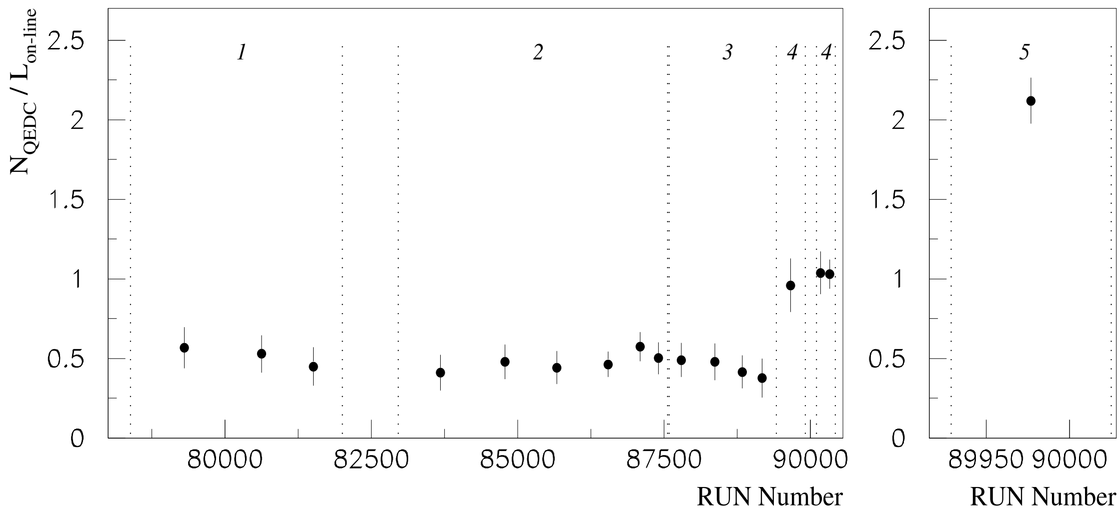

Figure 4: The stability of number of QEDC events per integrated luminosity determined by the luminosity system of H1 detector for different run period. The error bars stand only for statistical errors. The dotted lines define the intervals of run periods. The ratio $N_{\rm QEDC}/L_{\rm on-line}$ is higher in run periods with open BEMC triangular stacks (period 4) due to enlarging the BEMC geometrical acceptance closer to the beam pipe and hence to the higher value of polar angles of scattered particles. Similarly, running with open BEMC triangular stacks and with shifted z-position of the nominal vertex to the forward direction (period 5) increases the ratio $N_{\rm QEDC}/L_{\rm on-line}$ even more.

- The p_t-balance ($\vec{p_t}^{e'} + \vec{p_t}^{\gamma} < 20$ GeV)
- The accoplanarity cut ($\pi - |\phi_{e'} - \phi_\gamma| < 45°$)

The total cross section of the QEDC process for the mentioned above conditions is $\sigma_{tot} = 5395.78$ pb, and the MC sample of 100 000 events was equivalent to an integrated luminosity of 18.53 pb^{-1} .

The simulation and reconstruction of MC event sample was done by `H1SIM 3.06/41` and `H1REC 6.04/01` respectively.

4.4 Estimation of Systematic Errors

For the luminosity determination via the QED Compton method there are four main sources of the systematic errors:

- Systematic effects of the apparatus, mainly the backward electromagnetic calorimeter. Its energy and space resolution, the cluster radius determination, and its electronic noise are the crucial issues in minimizing the systematics.
- The uncertainty of the control on the inelastic QED Compton contribution to the sample of selected events. It was estimated from the observed tail of the accoplanarity distribution to be of 2.4% [9].
- According to [10] the theoretical uncertainties in the Monte Carlo, related to the uncertainty in the elastic proton form factor.

- The uncertainty of the estimation of different background processes contribution.

The obtained estimates of different sources of systematic errors together with the total value of systematic error of the QED Compton method are presented in the Table 5.

Source	Variation	syst. error closed tr.[%]	syst. error open tr. [%]
BEMC energy scale	$\pm$ 1%	0.8	1.0
BEMC cluster radius	$\pm$ 5 mm	2.0	3.6
BEMC noise cut	$\pm$ 350 MeV	2.3	2.3
accoplanarity restriction	$\pm 2.5°$	2.0	2.0
distance to closest BPC hit	$\pm$ 7 mm	0.9	0.5
t_{ToF}	$\pm$ 1 ns	2.6	not used
LAr energy deposition	$\pm$ 300 MeV	0.4	0.4
inelastic QED Compton		2.4	2.4
MC uncertainties		1.0	1.0
DIS		negl.	negl.
photoproduction		0.7	0.7
VM production		0.6	0.6
Total systematic error		5.4	5.6

Table 5: The obtained estimates of systematic errors for different cuts.

Comparing the closed and open triangular data periods one can see that the total systematic error for open triangular data is a little bit higher mainly because of the worse cluster radius determination in the inner triangular stacks. The smaller contribution of the BPC hit position cut to the total systematic error is due to the reduced geometrical acceptance in the beam pipe region, i.e. that it does not cover all the active surface of the BEMC.

5 Results

The integrated luminosity measurements, for the different methods, are presented in Fig. 5, both absolute values and ratio to the on-line measurement are shown.

Both random overlap and on-line luminosity measurement methods do not include the data acquisition dead time[5] in contrary to the QED Compton method. In order to compare the luminosities as gated by the H1 detector, the dead time value has been introduced, for each run, in the two dead time independent methods.

The values given for the so called on-line method correspond to the off-line corrected values given in the database. For the QED Compton measurement, corrections for HV inefficiencies have been introduced in the comparison. Note that both methods presented in this note include the contribution of satellite bunches to the luminosity. No such corrections have been introduced neither on the analyzed samples of overlapped bremsstrahlung and QED Compton events, nor on the on-line luminosity values used for comparison.

[5]For the random overlap luminosity measurement, the dead time dependence cancels in the ratio of eq. 7, while it affects the statistical error on this measurement.

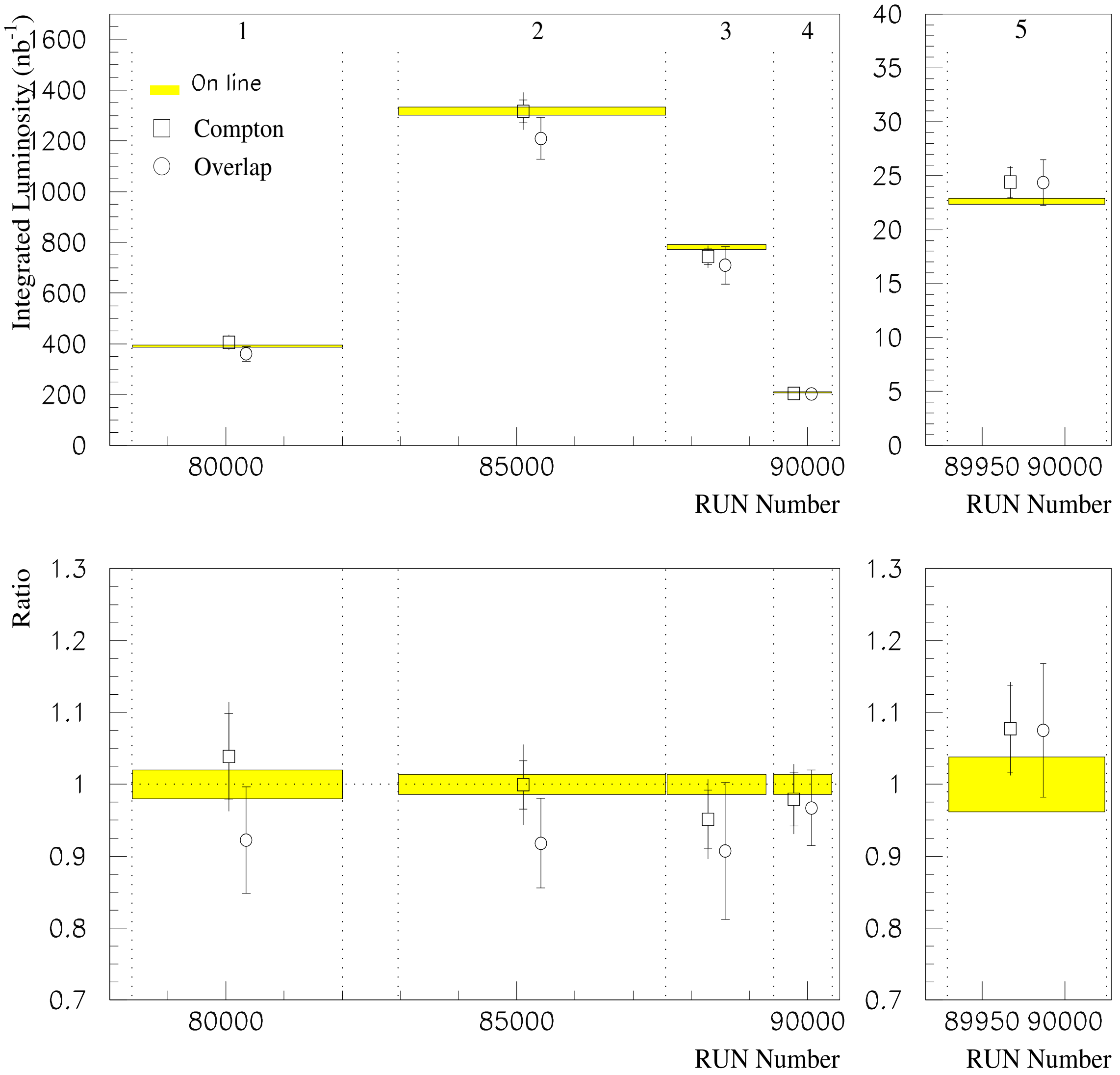

Figure 5: Luminosity measurements comparison integrated over each of the five run periods defined in section 2, for the different methods.

6 Conclusion

The integrated luminosities using random overlapped bremsstrahlung and quasi-real QED Compton event samples are in agreement within one sigma statistical error. The presented results confirm the on-line luminosity measurement.

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