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7 H1 Luminosity System and Electron Tagger

The H1 luminosity system is designed as a multipurpose device. Its main task is a fast relative luminosity measurement with a statistical precision of $\sim 2\%\ \mathrm{s}^{-1}$ at nominal conditions. In addition it provides electron beam monitoring for the HERA machine, absolute luminosity measurement in the H1 interaction region with an accuracy of $\sim 5\%$, tagging of the photoproduction events and energy measurement for small angle scattered electrons and radiative photons from initial state radiation.

7.1 System Overview

The luminosity is determined from the rate of the Bethe-Heitler events $ep \rightarrow ep\gamma$ having a large and precisely calculable cross section [1]. The main source of background is bremsstrahlung from the residual gas in the beam pipe, $eA \rightarrow eA\gamma$, with even a larger cross section and the same experimental signature. The rate of these events at design luminosity for the pressure in our beam pipe is expected to be at the level of 10 % of the $ep \rightarrow ep\gamma$ rate. This background is measured experimentally using electron pilot bunches. Then the luminosity is calculated as

$$L \;=\; \frac{R_{tot} - (I_{tot}/I_0)R_0}{\sigma_{vis}}$$

where R_{tot} is the total rate of the bremsstrahlung events, R_0 is the rate in the electron pilot bunches, I_{tot}, I_0 are the corresponding electron beam currents and σ_{vis} is a visible part of the $ep \rightarrow ep\gamma$ cross section, taking into account the acceptance and the trigger efficiency of the whole system.

The H1 luminosity monitor detects scattered electrons and outgoing photons in coincidence. It contains therefore two arms: the electron tagger (ET) and the photon detector (PD). Since the angular distributions for both the electrons and photons are strongly peaked in the direction of the primary e-beam – at 30 GeV polar angles are of the order of $\theta \simeq O(m/E) \simeq 17\ \mu$rad – the detectors should be placed close to the beamline and very far from the interaction region in order to cover these small angles.

The general view of the luminosity system is shown in Fig. 7.1. Scattered electrons are deflected by a set of warm low-beta quadrupoles and a bending magnet located in the region $5.8\ \mathrm{m} < -z < 23.8\ \mathrm{m}$, pass exit window at $-z = 27.3$ m and hit ET at $-z = 33.4$ m. The bremsstrahlung photons leave the proton beam pipe through the photon exit window at $-z = 92.3$ m, where the proton beampipe bends upward, and hit PD at $-z = 102.9$ m. A $2X_0$ Pb filter followed by a $1X_0$ water Čerenkov counter, located in front of PD, protects the detector from the high synchrotron flux. From the p-beam side PD is shielded by an iron wall of 2m length against the proton halo. The water counter can be used as a veto (VC) to select only clean events where the bremsstrahlung photons pass through the filter without interacting. Both ET and PD are installed on remotely controlled movable platforms, and can be moved down from the working positions in the median plane of the e-beam during the beam injection. The time needed to return from the parking to the working position is $1-2$ min, the accuracy of the platform position measurement is ~ 10 μm.

The acceptance of the luminosity system for nominal electron beam conditions ($E_e = 30$ GeV, zero tilt) and the expected rates at the design luminosity of 1.5×10^{31} cm^{-2}s^{-1} are given in the Table 7.1. One of the main contributions to the systematic error in the absolute luminosity comes from the dependence of the system acceptance on possible variations of the electron beam angle in the interaction region. This tilt (θ_x, θ_y), typically of the order of 100 μrad, is controlled by the position of the beam profile at PD with high precision, of the order of 10 μrad. The corresponding corrections $C(\theta_x, \theta_y)$ to the σ_{vis} are taken into account already online: $\sigma_{vis}(\theta_x, \theta_y) = \sigma_{vis}(0,0)C(\theta_x, \theta_y)$, and can be further improved during the offline analysis.

	unit	ET	PD
Energy interval, $E_\gamma/E_e = 1 - E_{e'}/E_e$		$0.2-0.8$	$0.004-1.0$
Polar angle acceptance interval	mrad	$0-5$	$0-0.45$
Average acceptance for luminosity events	%	48	98
Average acceptance for photoproduction	%	36	–
Visible $ep \to ep\gamma$ cross section	mb	28	174
Luminosity rate for $E > E_{thr} = 4$ GeV	MHz	0.4	1.3
Photoproduction event rate	Hz	$20-30$	–

Table 7.1: Acceptance parameters of the luminosity system.

Besides the luminosity measurement, the system is used to tag quasi-real photoproduction events with $Q^2 < 0.01$ GeV^2 in the energy interval $0.2 < E_{e'}/E_e < 0.8$. In this case the trigger requires only the energy in ET, while PD and VC act as a veto. The use of such eTAG trigger in coincidence with one of the main H1 detector trigger elements allows to suppress proton induced background by a factor of ~ 200 and thus to enrich the photoproduction physics sample in ~ 20 times [2]. This is especially important during the first stage of the data taking when the background conditions are usually very hard.

7.2 Detectors

In order to perform all their functions at HERA the luminosity detectors should possess high radiation resistance, provide good energy, coordinate and time resolution and be rather compact. This has been achieved using total absorption Čerenkov calorimeters, made of KRS-15 crystals, with a hodoscopic structure. The properties of these calorimeters are summarized in the Table 7.2. The values given for the resolution have been reached at HERA.

Each cell of the calorimeters is read out by a separate photomultiplier FEU-147 [3] with a 20 mm diameter cathode coupled to the crystal over the gap with an optical contact.

The veto counter is viewed by two phototubes operating in different regimes. The PM running in a standard mode is included in a common spectrometric branch of the photon arm. The second PM is operating with increased voltage and reacts with an efficiency of 100% to the charged particles with total range in VC exceeding 35 cm. Taking into account the material in front of VC, this corresponds to the 100% efficiency for the e.m. showers initiated by the photons with $E_\gamma > 1.5$ GeV. The veto signal used in the trigger branch is created as "OR" of the two VC channels.

The absolute calibration is an important problem for the luminosity detectors. They should be able to operate at extremely high rates, up to few MHz at design luminosity. In addition, these rates may

Parameter	unit	ET	PD
Aperture $x \times y$	mm^2	154×154	100×100
Lateral granularity		7×7	5×5
Chemical composition		$TlCl(78\%) + TlBr(22\%)$	
Radiation length, X_0	cm	0.93	
Moliere radius, R_m	cm	2.10	
Crystal length	cm	20	
Radiation hardness	Rad	$> 6 \cdot 10^7$	
Energy resolution, σ_E/E	%	$1 + 10/\sqrt{E}$, (E in GeV)	
Position resolution, $\sigma_x = \sigma_y$	mm	0.3 – 1.2	
Time resolution, σ_τ	ns	< 3	

Table 7.2: Properties of the H1 luminosity detectors.

vary within one beam filling by a factor of 3 to 10. Both calorimeters are being permanently calibrated during data taking, using the energy constraint for the luminosity events selected: $E_{ET} + E_{PD} = E_{e-beam}$. Although the calibration coefficients themselves are not stable enough and may change within 5 – 20% due to the changing conditions, this method allows to achieve high precision of the absolute calibration, better than 1%. Figure 7.2 illustrates the energy correlation between the e and γ arms for the luminosity events selected by the trigger: ET$*$PD$*\overline{\text{VC}}$.

7.3 Trigger and Data Acquisition

The system must allow to measure total and H1 gated luminosity without dead time, to trigger the photoproduction candidates and to provide information for the ep events triggered by the main detector. Consequently, this implies a special trigger concept, based on the two completely independent trigger and data acquisition branches.

The output signals from the photomultipliers of PD, VC and ET are read out into differential preamplifiers mounted close to the detectors and then driven via fast coaxial cable pairs, 170 m and 100 m long respectively, to a second set of preamplifiers, installed in a trigger electronics crate. This solution provides the relevant noise reduction and compensates the signal attenuation in the long cables. The second set of the preamplifiers, having a double fanout structure, is connected to two asynchronously running groups of FADC (2×80 channels).

The first FADC group operates in a standard mode, similar to all other subdetector trigger systems, and is integrated into the common H1 trigger scheme, as described in the next chapter. The trigger electronics discriminates the analog energy sums against the individually set thresholds, producing a dead time free trigger bit stream, sampled by the HERA beam crossing frequency. The trigger elements, which can be used in a central trigger logic, are any combination built of the three basic trigger bits: ET – electron arm signal ($E_{ET} > E_{ET}^{thr}$), PD – photon arm signal ($E_{PD+VC} > E_{PD+VC}^{thr}$), VC – veto counter signal ("OR" of the two VC channels). An additional set of more complicated ET and PD topological trigger elements is also formed. The main physical trigger element, used so far, was eTAG = ET$*\overline{\text{PD}}*\overline{\text{VC}}$, giving an e-tagged event sample for γp physics. The front end readout and the data transfer to the central data acquisition are done by a program running on the master processor FIC8230 [4].

The second FADC group is controlled by the local trigger controller of the luminosity branch and is completely decoupled from the H1 trigger system. Two basic triggers are used for the luminosity calculation: ET$*$PD and ET$*$PD$*\overline{\text{VC}}$. The latter is used as well for the online detector calibration. All combinations of any 5 trigger elements, chosen by the operator, are being permanently stored without dead time for each of the 220 bunches in a special fast histogramming memory of 32×220 channels. The content of this memory gives a complete information for all bunch related trigger statistics. This allows, for example, to monitor the level of the accidental coincidences, which is essential for the high rates expected at design luminosity. The online luminosity event processing, including the fast reconstruction, calibration, trigger verification and calculation of the current luminosity value, is performed by the second FIC8230 processor.

7.4 Performance in 1992

The luminosity subdetector is equipped with a set of special sensors and switches and is integrated to the central slow control system, which allows to monitor all critical parameters essential for a safe and reliable operation. The luminosity information is transmitted via the normal event stream to the central IBM, where it is stored in the H1 database. In addition, it is distributed to other users (H1 control room, HERA control room, TV screens). A typical example of the information provided by the luminosity system during ep collisions is shown in Fig. 7.3.

The system works successfully since April 1992. For safety reasons, the measurements at HERA in 1991 [5] in a stand alone $e-$beam mode and then during the first $ep-$collisions have been done using the alternative lead-scintillator calorimeters as ET and PD. In the early phase, when HERA operated at 1% of the design luminosity, the detectors have been permanently used even during the injection and ramping of the electron beam, which allowed machine crew to understand better the details of the beam dynamics and to achieve the collisions quickly.

The total integrated luminosity for the 1992, as measured by H1, is shown in Fig. 7.4. The present understanding of the systematic error is summarized in the Table 7.3. Due to the redundancy in the trigger, the systematic error can be further reduced in future by combining the present method with other possible triggers (e.g. with the total photon flux measurements [6] etc.).

The eTAG sample taken with the help of this system was so far the main source for the clean γp physics [7, 8].

Contibution	Design	Achieved
Corrections to σ Bethe-Heitler [9]	0.1	0.3
Acceptance calculation	3.5	5.5
Background subtraction	0.1-0.5	2.0
Trigger efficiency and purity	1.0	2.5
Absolute calibration	0.5	2.0
Total	≤ 4	≤ 7

Table 7.3: Systematic error for the absolute luminosity measurement (in %).

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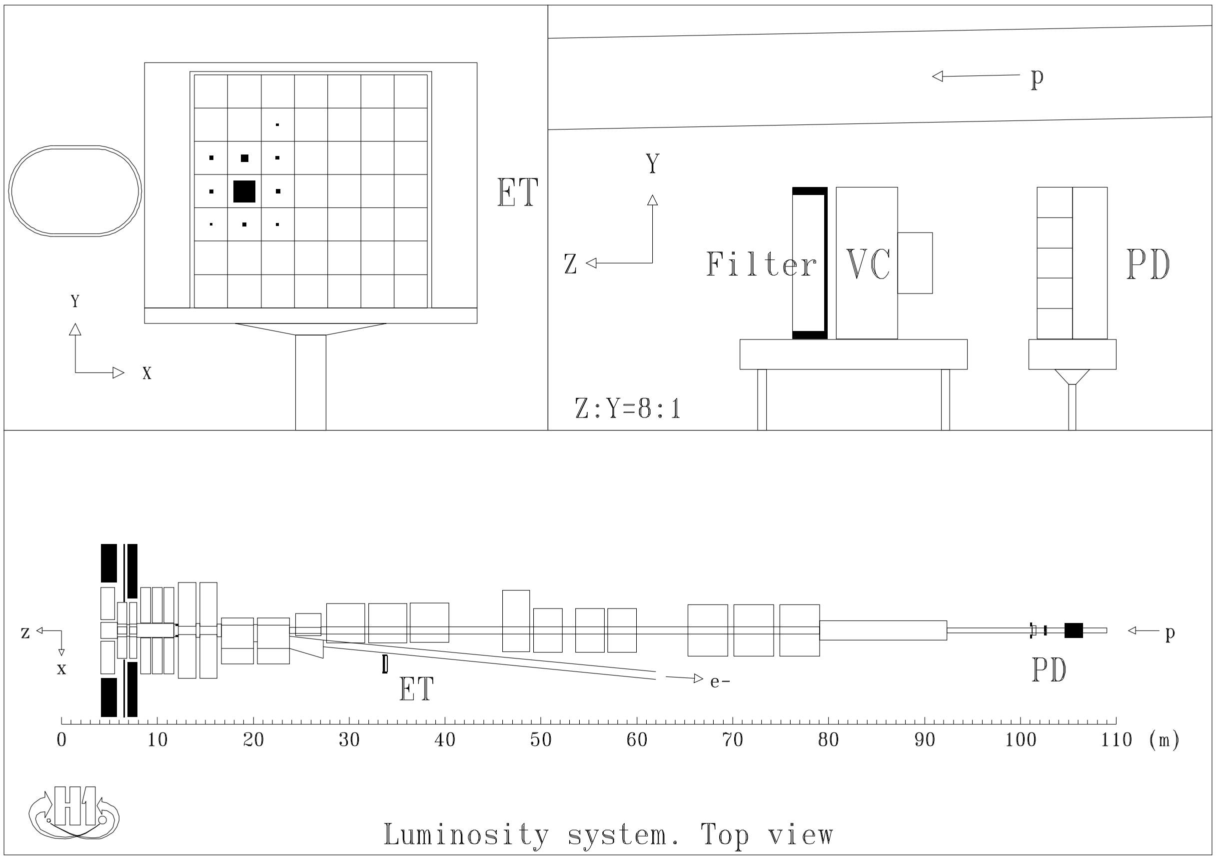

Figure 7.1: The layout of the luminosity system.

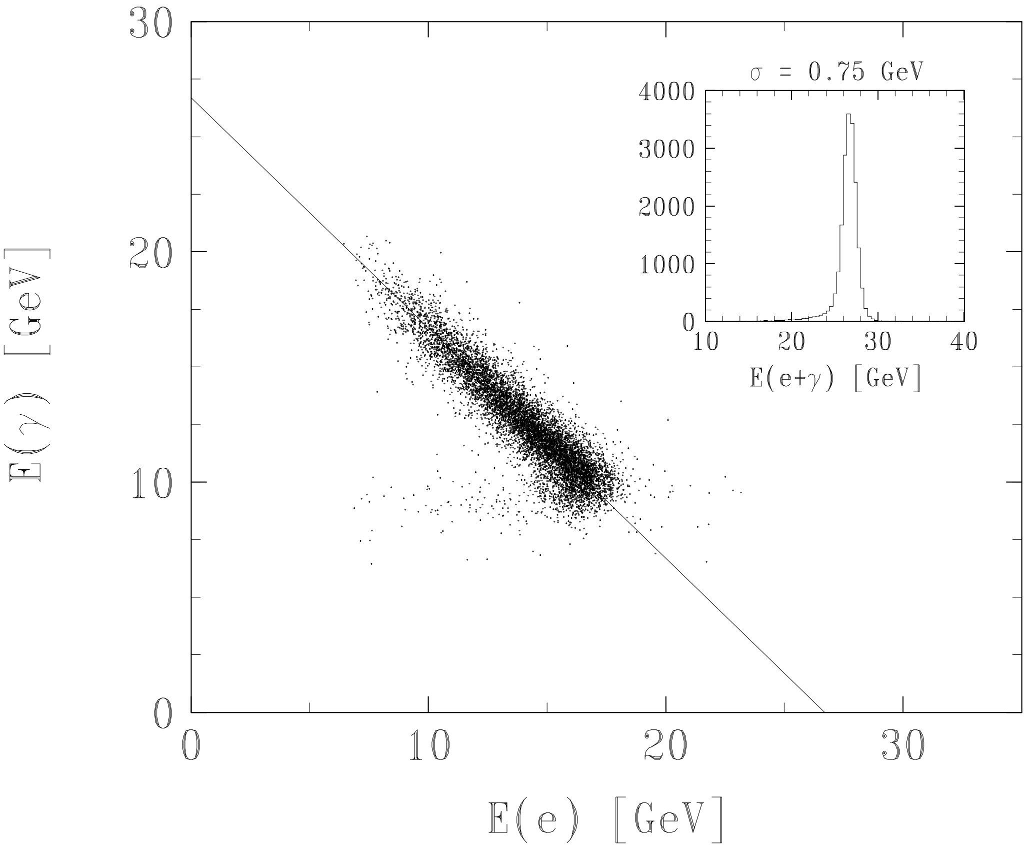

Figure 7.2: $e - \gamma$ energy correlation for bremsstrahlung events detected by the luminosity calorimeters. In the upper corner the total reconstructed energy is shown. Data from the summer 1992 HERA run at 26.7×820 GeV collision energy.

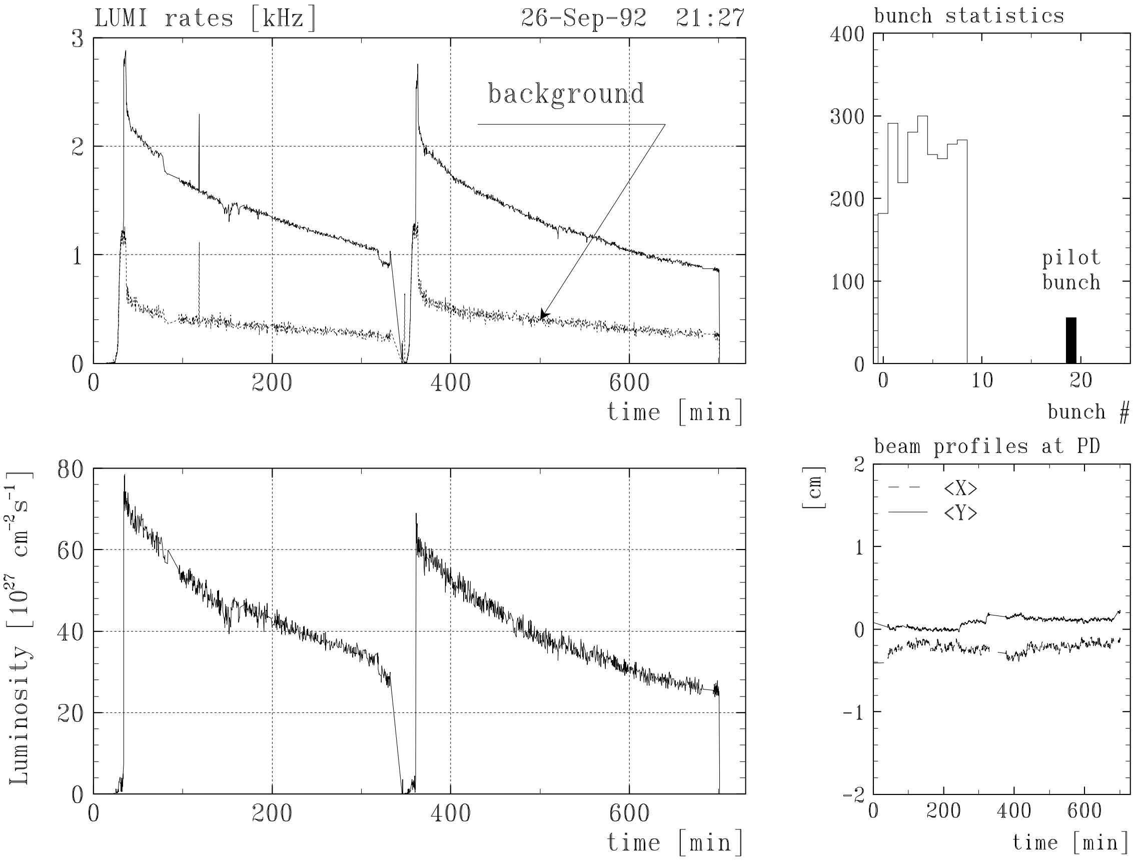

Figure 7.3: Data provided by the luminosity system during the *ep* collisions at HERA. Statistical fluctuations correspond to one measurement every 10 s.

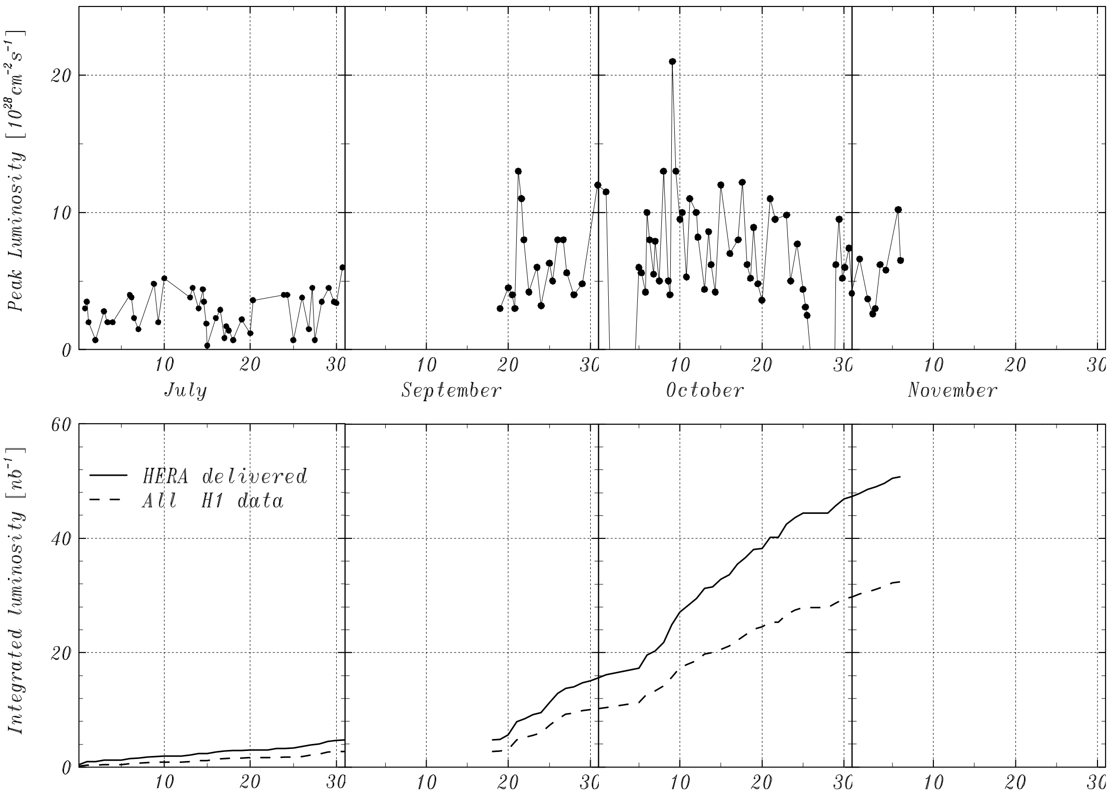

Figure 7.4: Luminosity as measured by the fast H1 Lumi Monitor during data taking at HERA in 1992.