DRAFT 31.03.98

MODIFICATION OF THE H1 LUMINOSITY SYSTEM FOR THE HERA UPGRADE 2000

(PROPOSAL)

LPI Group, DESY, March 1998

Abstract

The new system of small angle detectors are proposed for the measurements of ep collision luminosity and for the study tagged photoproduction events at the H1 experiment after HERA upgrade 2000.

1 Introduction

The foreseen in 2000-2001 HERA collider upgrade has a goal to increase provided for high energy physics experiments the ep-collision luminosity L from presently achieved value $1.4 \cdot 10^{31} cm^{-2} s^{-1}$ to $\approx 7.4 \cdot 10^{31} cm^{-2} s^{-1}$ [1, 2]. For the H1 luminosity system this will lead to the rise of counting rates, to pronounced manifestation of bunch-to-bunch and in-bunch pile up effects, to enlarging the irradiation of detectors since they are placed near the beam pipe of the accelerator.

The luminosity is an essential ingredient of physics studies to obtain absolute values of cross sections. It is measured by counting small angle bremsstrahlung events

$$e + p \rightarrow e' + \gamma + p \tag{1}$$

by detection of final state photons either on or without coincidence with the recoil electron. The coincidence data are also used for an energy calibration of both photon and electron detectors since for reaction (1) $E_\gamma + E_{e'} = E_e$. The H1 luminosity system [3] consists of photon detector (PD) and electron tagger (ET33) which are 5x5 and 7x7 matrix made of Cherenkov crystals (KRS 15) with photo-multiplier (PM) readout. They are placed in the HERA tunnel at distances $\approx 102m$ and $\approx 33m$ respectively from the interaction point (IP) downstream the e beam. These detectors [4, 5] reliably recorded luminosities for collision of $27.5 GeV$ electrons (or positrons) with protons of energy $820 GeV$ with presently achieved accuracy 1.3% [6]. The cross check performed on the level of the integrated luminosity measurement in the large angle quasi-real compton scattering confirms [7] the obtained results.

The photon detector is also used to trigger radiative corrections in deep inelastic electron-proton scattering thus improving the proton structure function determination.

The electron detector allows to tag photoproduction events in the process

$$e + p \rightarrow e' + X \tag{2}$$

since for low angle electron scattering the photon exchanged in the process (2) is almost real. The set of taggers placed at distances 7, 8, 33 and 44m from IP provides the realization of the study program of soft and hard photon induced reactions

$$\gamma + p \rightarrow X \tag{3}$$

in the wide c.m.s. energy ($W_{\gamma p}$) range from 80GeV to 280GeV which is not accessible at the other accelerators.

The luminosity system is essential for the tuning of HERA machine once the beams are brought into collision and for the on-line monitoring of its performance.

The requirements to the system after HERA upgrade are the following:

- the energy resolution $\leq 15\%/\sqrt{E(GeV)}$,
- the linearity in the energy response up to $100GeV$,
- hitting point resolution of $\approx 1mm$,
- stable operation of photodetectors and analogue electronics at rates up to $10MHz$,
- capability to control the pile up effects,
- luminosity measurement for each colliding bunch,
- sufficiently high radiation resistance.

The present system [3] meets already most of these requirements. The linearity is fulfilled at the level of $1-2\%$ at γ and e energies $E = 80GeV$, entry point resolution is about $1mm$, in-bunch pile up effects are measured in γ and e arms of the detector, single bunch luminosities have been measuring since 1991, photomultipliers operates stable at rates up to $3MHz$. The last parameter can be easily improved by the renovation of the devices installed several years ago.

After of 6 years operation and gathering $\approx 60pb^{-1}$ integrated luminosity the KRS crystals have got irradiation dose of $\approx 10^5Gy$ and show the evidence of radiation damage, i.e. of reduction of light transmission; as a result the detector energy resolution aggravated down from the required value.

After the upgrade the radiation load will increase and will lead to the necessity to exchange Cherenkov crystals built in the electromagnetic calorimeters for more radiation resistant materials and to extend or modify the existing active filter to absorb enlarged irradiation flux without losing in the energy resolution. Since the HERA magnet layout near the IP will be completely rearranged leading to the change of tagger positions and to the requirement on their compactness the ET7, ET8 and ET33 should be rebuilt.

Below the method of the luminosity measurement is displayed, the new construction of γ and e detectors is proposed, the necessary improvements in the electronics and DAQ are given.

2 The method of luminosity measurement

The luminosity will be determined from the rate of the Bethe-Heitler (BH) events (1) by single photon method. [1] The main source of background is bremsstrahlung from the residual gas in the beam pipe, $eA \to eA\gamma$. This background is measured experimentally using electron pilot bunches.

The luminosity is calculated as

$$L = \frac{R_{tot} - (I_{tot}/I_0)R_0}{\sigma_{vis}} \tag{4}$$

where R_{tot} is sum of the bunch rates of the bremsstrahlung events over all electron bunches, R_0 is sum of the bunch rates over electron pilot bunches, I_{tot}, I_0 are the corresponding electron beam currents and σ_{vis} is visible part of $ep \to ep\gamma$ cross section. Luminosity per bunch is calculated with the same formula with R_{bunch} and I_{bunch} instead of R_{tot} and I_{tot}. The single photon method counts the rates R_{tot}, R_0, R_{bunch} with photon energy above a certain threshold. Since every event is counted this procedure can be considered as dead time free,and has in addition very small statistical error. However the disadvantage in this method is the variation of the threshold with luminosity changing . Therefore the trigger efficiency function (threshold) has to be very carefully monitored and measured.

The major contributions to the systematic error in the luminosity measurement come from the determination of the visible cross section σ_{vis} and are:

1.Absolute energy calibration and resolution in the photon arm.

2.Accuracy of determination of photon detector acceptance.

3.Effect of multiple photons (pile-up in one bunch crossing).

4.Trigger efficiency (threshold).

[1] The coincidence method will be used for calibration of the photon detector and for cross check of luminosity measurements.

In the current online measurements the changes of photomultypliers (PM) responses with rates cause the changes of threshold in photon detector. Currently these changes are controlled by measuring mean value of energy in photon arm. The influence of multiple photons on the mean value of energy depends on the luminosity value and is taken into account by empirical formula. Correction of photon acceptance is done by Monte Carlo (MC) simulation of mapping of photon detector acceptance.

In offline correction the results of offline calibration are used. The effect of multiple photons and energy resolution are taken into account by fitting experimental photon spectra with Bethe-Heitler spectrum, detector resolution function and Poisson distribution for multiple photons. The threshold in photon arm is determined using random trigger or some other independent trigger.

There is one more method for luminosity measurement in high rates and multiphoton environment-this is measurement of the total energy per bunch crossing rather than the single photon energy [8]. The measurement of the luminosity is based on the relation

$$E_{meas} - E_{bkg} = AL \int_0^{E_{beam}} \epsilon(k) k \frac{d\sigma}{dk} dk \tag{5}$$

where k is the photon energy,L - the integrated luminosity, E_{meas} - the total measured energy in the bunch crossing, E_{bkg} - the background measured energy that is beam gas photons and is measured in electron pilot bunches, E_{beam} - the beam energy,A - the photon acceptance, $\epsilon(k)$ - the energy detection efficiency and threshold function,and $\frac{d\sigma}{dk}$ - the differential single bremsstrahlung cross section. The main sources of systematic errors for this method are the following:

1) Evaluation of the acceptance A of photon detector

2) Knowledge of the value of cross section σ.

The procedure of the determination of A will be the same as it is for ”rate” method [6] where the achieved accuracy is $\sim 0.5\%$. Uncertainty in the σ has two components.The first one is the theoretical one due to the unknown high order corrections. The second one is due to uncertainty in the energy threshold. Assuming each of these contributions of the order 1% we come to $\Delta\sigma/\sigma \sim 1.4\%$. The statistical error can be reduced to the level $\leq 2\%$ by collection of events in 1 s,assuming energy resolution $\sim 10\%/\sqrt{E}$. The main contribution to this error will be estimation of E_{bkg}. This method will be used in addition to the one mentioned above for cross check or even became the main one. We plan to involve the data from this method into main CDAQ data stream during 98-99 running period to perform offline analysis afterwards.

3 Photon detector

Due to the severe radiation conditions after HERA upgrade 2000 photon detector should be built out of radiation resistant material.

The sketch view of proposed photon arm is given on Fig.1.

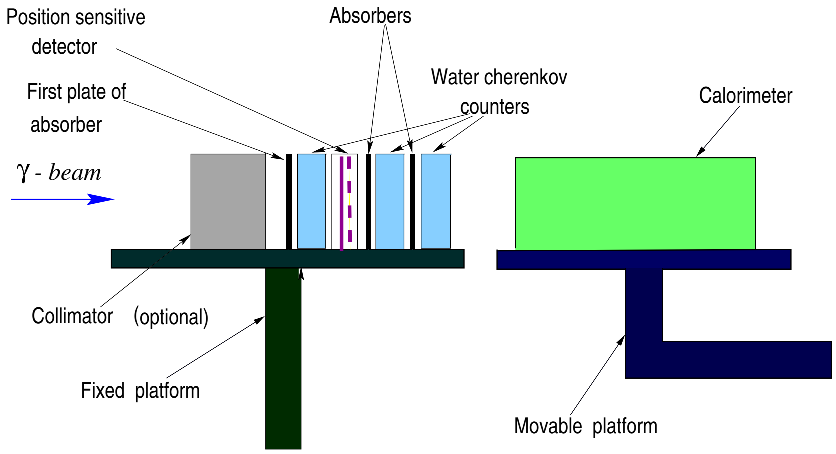

Figure 1: Schematic view of photon arm.

3.1 *Radiation environment*

There are several sources which contribute to the irradiation of the photon detector : bremsstrahlung photons, synchrotron radiation and proton beam halo. In order to diminish radiation from the latter one the iron wall of 2m length is situated behind photon detector along the proton beam.

Bremsstrahlung

Assuming electron beam energy $E_e = 27.5GeV$, annual integrated luminosity 150 pb^{-1} after HERA upgrade and taking into account that for photons with energies above 10 Mev the total bremsstrahlung cross section is equal to 0.46 b and photon mean energy is 2.5 GeV one can get the annual energy deposit in photon arm of 28 kJ per year. Since 68% of photons enter the photon detector in the area restricted by $\sigma_x \sigma_y$ of the photon beam and then taking into account that lateral distribution of the shower is not uniform but has the relatively narrow core ($\sigma \sim 0.3cm$ for KRS) we obtain the annual dose of about $1.2 \cdot 10^5 Gy$. Here it was also assumed that the photon energy was absorbed in the 5 X_0 of the crystal.

Applying this calculation to the years 94-97 when integrated luminosity is $66pb{-}1$ we get energy deposited in the photon detector over these 4 years of 12 kJ and radiation dose of $\sim 9 \cdot 10^4 Gy$. For cross check radiation dose in glass dosimeter is calculated. Glass dosimeter is the rod with diameter 0.8 mm and length 6 mm [9]. Assuming dE/dx in glass equal 1.7 $MeV/g \cdot cm^2$ we arrive at the dose absorbed in glass dosimeter due to bremsstrahlung of $1.7 \cdot 10^4 Gy$. The glass dosimeters are equal sensitive both to bremsstrahlung and to synchrotron radiation. The ratio of number of bremsstrahlung photons to synchrotron radiation ones on photon detector after filter is $\sim 1/10$ [10]. Taking into account an average beam gas bremsstrahlung photons of $\sim 10\%$ we obtain the estimation of dose on glass dosimeter over 4 year $1.9 \cdot 10^5 Gy$. The experimental measured value is $1.7 \cdot 10^5 Gy$.

Synchrotron radiation

Synchrotron radiation critical energy and flux will also increase in year 2000. The critical energy will be about 140 keV for electron energy 27.5 GeV instead of 35 keV in 97. Assuming that 80% of synchrotron radiation with the mean energy of $200keV$ is absorbed in the first $2mm$ of the crystal we obtain the radiation dose from synchrotron radiation for 94-97 years of $\sim 5{\cdot}10^4 Gy$ for the very first thin layer of crystal. In the year 2000 the total power of synchrotron radiation in the photon arm before filter will be $\sim 2kW$ for electron beam energy $27.5GeV$ and beam current 58 mA. In the 1997 this value is $\sim 0.2kW$ assuming mean value of e current of 30 mA. The synchrotron radiation spectrum for $E_e = 27.55GeV$ and $I_e = 58mA$ is shown in Fig.2. Here is shown as well the spectrum of photons after $1X_0$ of carbon and plus $1 - 3X_0$ of water.

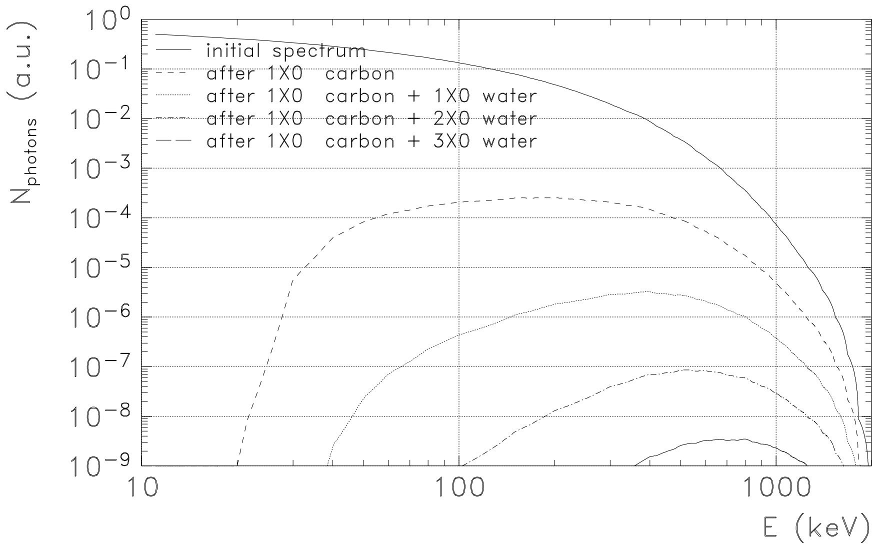

Figure 2: Synchrotron radiation spectrum.

As one can see from Fig.3 where the energy attenuation is plotted as a function of absorber depth in X_0 the energy absorption of photons depends on the material.

Assuming that energy attenuation for combined filter ($1X_0$ of carbon and $3X_0$ of water) is $\sim 1 \cdot 10^{-6}$ we obtain the radiation dose per sec of $0.05Gy/sec$ that yield $0.5MGy$ per year provided 10^7 sec annual HERA operation after upgrade.

Simple increasing of passive filter thickness in front of photon detector from X_0 to $2X_0$ would deteriorate energy resolution of detector and increase the threshold in photon arm. Therefore it is reasonable to install an active synchrotron radiation filter in front of photon detector.

3.2 *Active filter*

We propose for active filter a sectioned cherenkov water counter which serves as an active synchrotron radiation filter and a photon counter giving spectrometric information. The advantages of having such an active filter are the following:

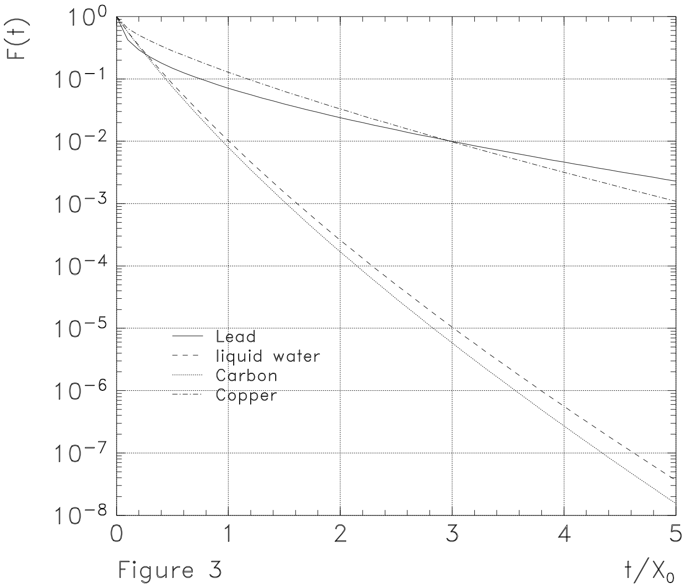

Figure 3: Non absorbed energy fraction vs absorber thickness.

1.Shielding the photon detector against synchrotron radiation.

2.Improving energy resolution of photon detector by summing signals from active filter and photon detector.

3.Lowering the threshold in photon arm due to decreasing of dead material thickness from $2X_0$ to $1X_0$.

4.Moreover the water filter has no limitation from point of view of radiation hardness.

As an passive filter it is reasonable to choose carbon (graphite) of $1X_0(18.8cm)$ thickness since it absorb better the hard part of synchrotron radiation. The sectioned graphite absorber of $1X_0$ thickness in total and 3-4 stacks of cherenkov water counter (3-4 X_0 in total) as active filter of $1X_0$ thickness each will be installed on the fixed platform at the distance $\approx 99m$ from the IP downstream the electron beam. Each stack will consists of cherenkov water counter and absorber in front of it. The final ratio of the absorber and sampling material has been investigated to achieve the best energy resolution ($\sim$ $(15\% - 20\%)/\sqrt{E}$). The present active filter setup gives $18\%/\sqrt{E}(GeV)$ for energy deposited in the filter.

Cooling problem for water counters might be solved by natural thermal convection or forced flow of water into large enough external reservoir with cold water. The first inactive X_0 of filter will consist of carbon sectioned in several pieces to make easier cooling. The cooling could be done by air funs or water.

As an option the liquid scintillator can be used in the last stage of the filter. The liquid scintillators have the potential of offering maximal radiation tolerance (over plastics). For instance, 1-phenylnaphtalene (1PN) has been tested as a more radiation-resistant base for a synthesized fluor MOPOM [11].Even after 100 kGy irradiation the light output dropped by only a few percent over X_0. One can foresee circulating the fluid so as to replace the damaged material in the worst case scenario. The light output will be measured by PM.

It is supposed to place a grid made of radiation hard scintillator strips [12] behind the first water filter with 2.5 mm space resolution. This is the two planes of perpendicular to each other scintillator strips with low cost photodetectors since precise signal amplitude determination is not needed. The prime aim of this position sensitive detector is to measure the photon beam position and profile for acceptance correction. The second is a providing an additional information to distinguish several separated electromagnetic showers that is seems to be problematic due to the lateral photon beam dimensions ($\sigma_x = 1.9cm, \sigma_y = 1.3cm$). The partial radiation damage of the scintillators during some period of running also is not essential due to bitwise (not amplitude) information from the detector. A special construction of the frame of this position sensitive detector should be foreseen to allow fast (during $\sim 30min$) changing of the scintillators in one of the scheduled tunnel accesses.

3.3 *The main calorimeter*

The main photon detector will be built out of double sodium bismuth tungstate crystals: $NaBi(WO_4)_2$ (NBW), which have a factor 2-3 more radiation resistance than KRS. Properties of these crystals are shown in the Table 1.

Table 1. Properties of KRS, NBW and PWO crystals [3, 13, 14].

Properties	KRS-15	NBW	PWO
Chemical composition	$TlCl(78\%)TlBr(22\%)$	$NaBi(WO_4)_2$	$PbWO_4$
Crystal type	Cherenkov	Cherenkov	Scintillator
Density $\rho(g/cm^3)$	7.65	7.57	8.3
Refractive index	2.2	2.15	2.2
Radiation length $X_0(cm)$	0.92	1.03	0.9
Moliere radius $R_m(cm)$	2.08	2.38	2.0
Melting point (^oC)	420	920	1123
Optical transparency $(nm) \geq$	410	380	350
Peak emission (nm)	-	-	480
Radiation hardness $(Gy) \leq$	$5 \cdot 10^5$	10^6	$5 \cdot 10^5$
Critical energy $E_c(MeV)$	8.95	9.75	-
Decay time $\tau(ns)$	-	-	2.1, 7.5, 26

The cell structure of 5x7 matrix i.e. 35 channels of $20 * 20 * 200mm^3$ NBW crystals will be placed on the movable table to lower down the detector from the plane of e beam orbit during electron and proton injection and ramping to minimize its irradiation. The total length of photon arm of $\approx 24X_0$ provides the reliable energy measurement and the detector covers the 3σ lateral size of photon beam providing almost 100% acceptance. The detectors based on NBW crystals have good energy resolution $\sim 8\%/\sqrt{E}$ and spatial resolution $\sim 1mm$. The only concern is that after 2 years of performance the crystals can become damaged by radiation that would degrade the energy resolution. Since NBW crystals have relatively low price comparing to KRS it is possible to renovate NBW crystals every two years and thus keeping energy resolution on acceptable level.

More precise energy measurement can be achieved by using scintillating crystals $PbWO_4$ (PWO) [15] as active elements of photon detector. They have small X_0 and R_m (see Table 1.) and will provide energy resolution of photon detector $\approx 4\%/\sqrt{E}(GeV)$ [16]. The on line monitoring of the performance of these crystals can help in overcoming the problems of their sensitivity to small irradiation doses.

The options of using PWO crystals in photon detector as well as radiation hard scintillating liquids or water Cherenkov counters having unlimited radiation resistance are under elaboration.

4 e-taggers

Since the luminosity increase is achieved by earlier e and p beams separation in the HERA with help of moving magnet elements into H1 detector the tagger positions should be adjusted again. The determination of optimal positions for taggers and the study of their acceptances have been performed using the fast Monte Carlo (MC) simulation H1LUMI package [17] upgraded to take into account the future beam optics.

The new magnet layout near the IP is given in the Fig.4. Electron tracing made according to this layout shows (Fig.5) that it is reasonable to place taggers between end of cold magnet BG and horizontal focusing quadrupole QI2. The requirement of compactness is very essential for these taggers.

MC simulation predicts very good acceptance to photoproduction events for ET3 with the size 40*40*100 mm^3 placed between magnets BG and QI1 at the distance $3.8m$ from IP (see Fig.6b). The correlation energy-distance plot (Fig.6a) shows that for big distances of ET3 from beam axis ($8cm$) the recoil electron energy is determined by the geometry.

The most promising place for an electron calorimeter is a gap between magnets QI1 and QI2. As it is seen in the Fig.7 the accelerator beam pipe inside the quadrupole QI1 may be widened to make exit window with lateral length $8cm$ for recoil electrons at the downstream edge of QI1 ($5.7m$ from IP). We plan to install behind the window the ET6: Compact Tungsten Calorimeter (CTC) - to determine the energy and entry point of electrons emitted in the processes (1) and (2). CTC is a SPACAL type calorimeter. It contains scintillating fibers of $0.5mm$ diameter

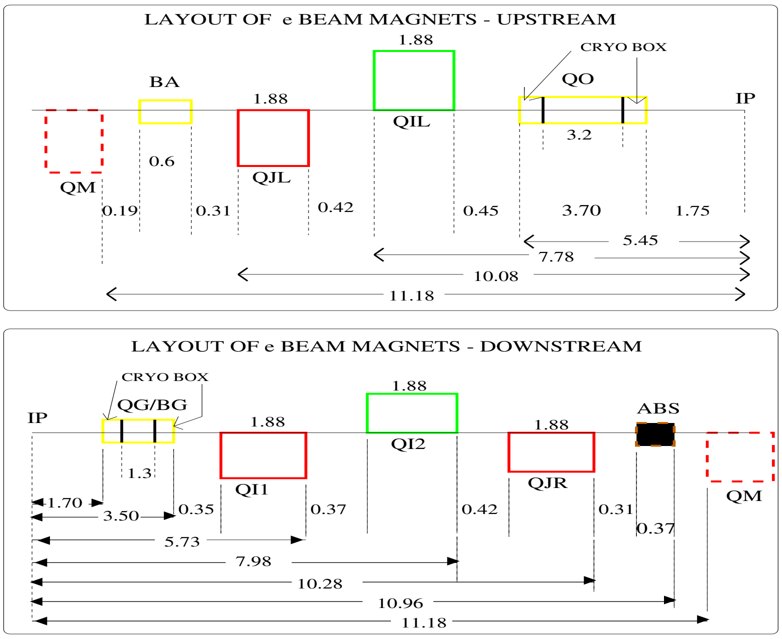

Figure 4: Upgrade HERA magnet layout near the IP (distances are in m).

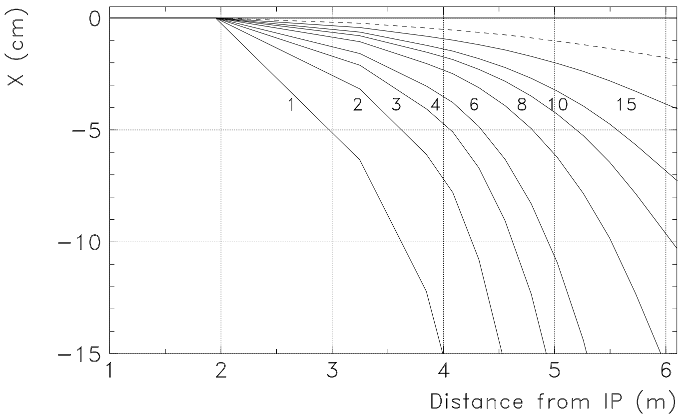

Figure 5: The trajectories of electrons with energies from $1GeV$ to $27.5GeV$ downstream the IP (dashed curve corresponds to 27.5 GeV).

placed at the distance $1.5mm$ from each other along the tungsten block. Such a system has the filling coefficient of $\approx 25\%$ and is characterized by $R_m = 1cm$ and $X_0 = 0.7cm$. The length choice of $15cm(\approx 20 \cdot X_0)$ for the calorimeter will provide the energy resolution better than $7\%/\sqrt{E}(GeV)$.

MC simulation shows (Fig.8a) that recoil electrons stay within the vertical size of $Y_{e'} = \pm 1.5cm$ from the e beam axis for ET6 position near the beam pipe of $4cm$ radius. This gives the recommended thickness of $4cm$ for CTC. Its optimal lateral length is determined by the $x_{e'}/E_{e'}$ correlation plot (Fig.8b) as $8cm$. The plot illustrates that the precise coordinate measurement is necessary for good energy reconstruction for events with a hit point near detector boundary

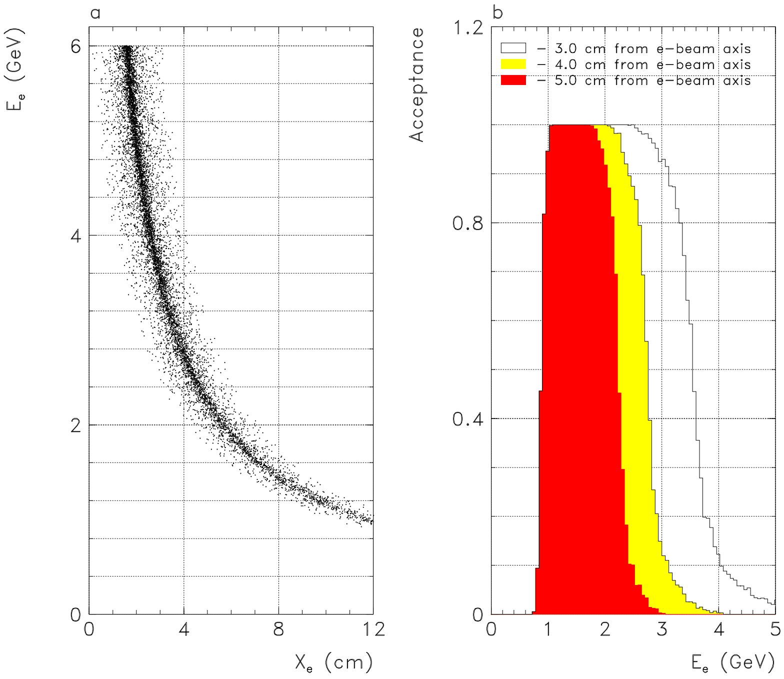

Figure 6: The correlation plot (a) and the result of acceptance simulation (b) for different positions of ET3 relative to the e-beam axis.

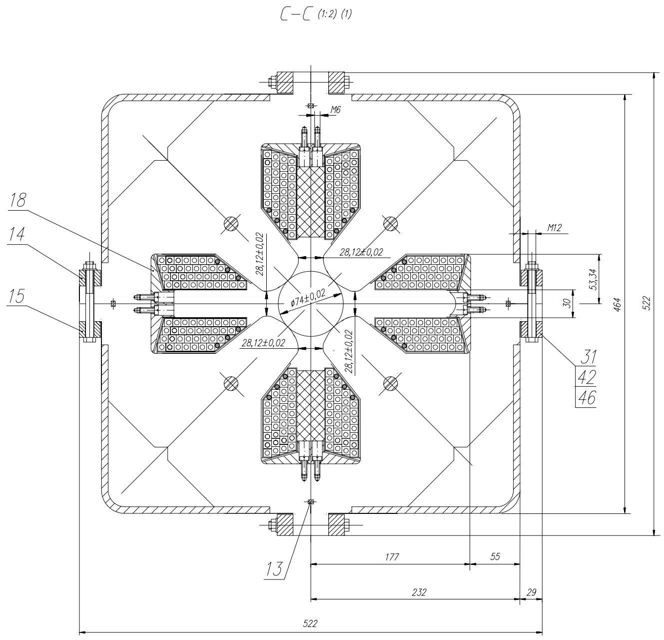

Figure 7: Cross section of QI1 quadrupole with horizontal gap for beam pipe.

when the noticeable leakage of electromagnetic shower happens.

So ET6 with the size 4x8x15cm^3 will cover the whole available space and provide maximum possible acceptance for photoproduction events. The good space resolution allowing to determine the electron entry point with the precision ($\approx 1mm$) can be achieved by energy readout from different parts of the detector. As an option the preshower made of PWO tiles or CTC

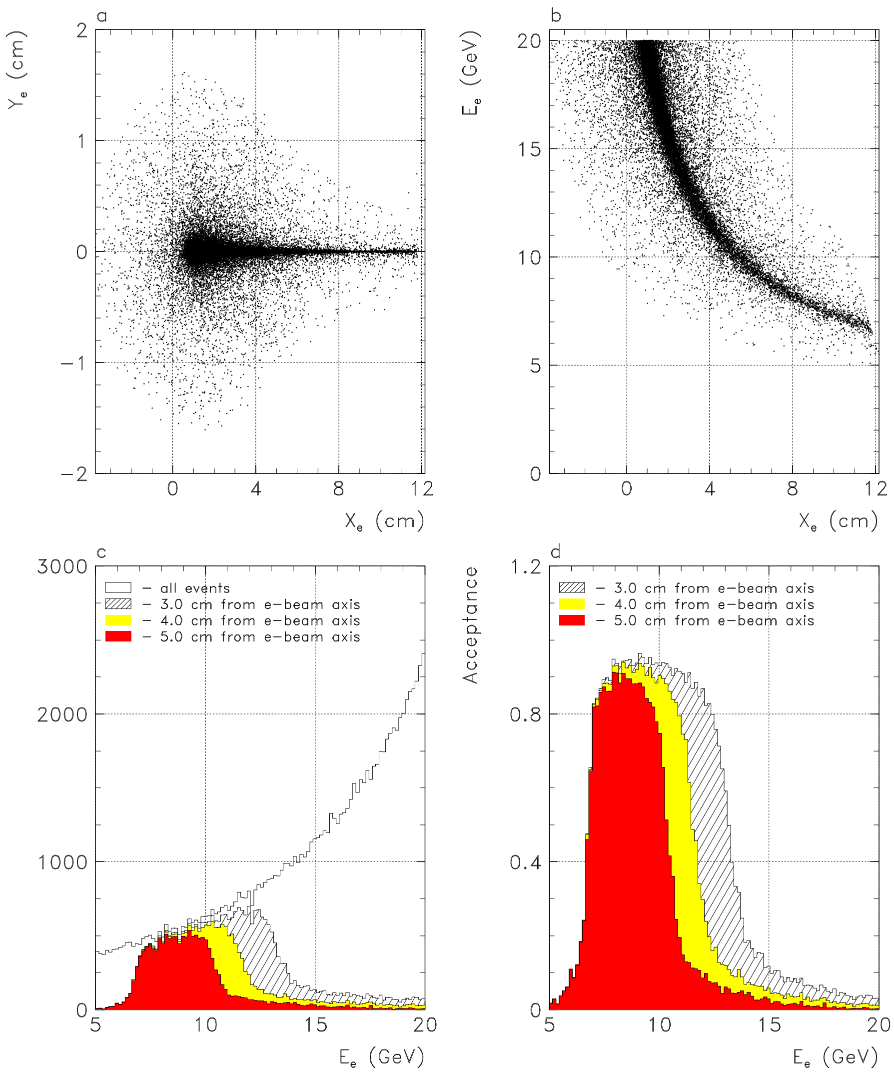

Figure 8: Scatter plot (a), correlation plot (b), events vs energy distribution of electrons (c) and acceptance (d) for ET6 .

elements with vertical fibers alignment are also considered to improve the space resolution. The readout will be performed by 16 pixel PM or by APD.

The energy distribution of accepted by CTC electrons which is given on Fig.8c corresponds to the process of particle production by quasireal photons with $Q^2 < 0.01GeV$. The distribution and expected acceptance (Fig.8d) cover the energy range of electrons from $6GeV$ to $11-14GeV$ depending on the minimal distance of the CTC edge from the e beam axis. The corresponding energies of quasireal photon will lie in the interval $11-20GeV$ allowing to study processes (3) at $< W_{\gamma p} >\approx 220GeV$. Thus ET6 will provide after HERA upgrade approximately the same conditions as the present ET33.

The chosen appropriate lateral size of the beam pipe at distances $3.85-5.7m$ from IP allows to extend the tagging system by placing small electron detectors inside the QI1 magnet in the free space between the boundary of the gap in the magnet (Fig.7) and the edge of widened beam pipe. The detectors will be made of single PWO crystals with the size $20*20*200mm^3$. They will serve as a tracking device (to determine the recoil electron hit point) and a calorimeter with a partially developed electromagnetic shower.

MC simulation made for eight such crystals placed in the magnet at the distance $12cm$ from the electron beam axis shows a clear correlation between energy and electron hit point (Fig.9left) and predicts good acceptance for photoproduction events (Fig.9right). The use of

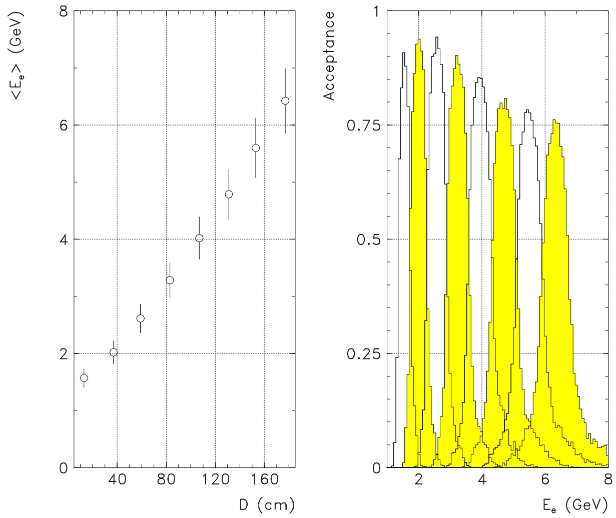

Figure 9: The acceptance of electron PWO detectors placed near widened beam pipe in the QI1 quadrupole.

scintillating crystals calorimetry will help to tell the recoil electrons from minimum ionization particles and to improve the signal - background ratio. The temperature of PWO crystals and readout (APD or others) can be stabilized on the level $\pm 1^0 C$ by cool air flow through the gap in QI11 magnet and thermoinsulation. These detectors can be attached to nonmagnetic bar to slice into the QI1 gap.

Since future HERA magnet system at distances $> 30m$ from IP stays almost unchanged the tagger ET44 can be effectively used after the HERA upgrade. The KRS crystals used in it are exchanged to NBW crystals and it will serve in 1998-99 as a prototype of Cherenkov calorimeter for new photon detector. The use of scintillating PWO crystals (Table 1.) in ET44 to have better energy resolution (this is important for more precise acceptance determination) is under discussion. MC simulation performed for the new magnet lattice predicts approximately the same ET44 acceptance (Fig.10) as for the present HERA layout [18].

Table 2 presents visible by considered above taggers cross sections of photoproduction processes.

After the HERA upgrade even such rare photoprocesses as production of high p_t jets as well as heavy quark photoproduction will be characterized by high event rates.

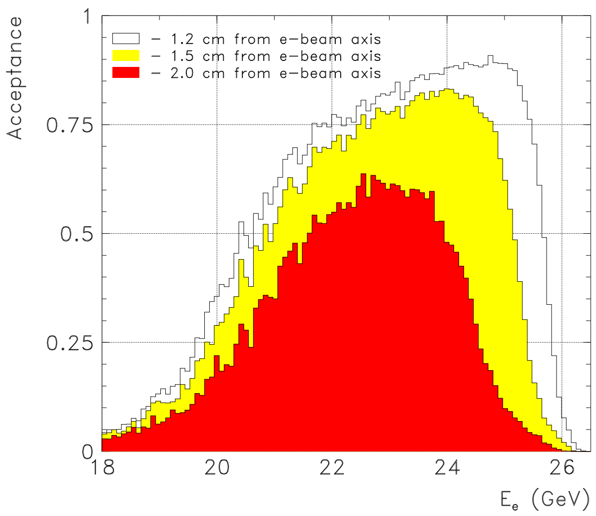

Figure 10: The results of acceptance simulation for ET44 for different positions of taggers relative to the e-beam axis.

Table 2. Visible photoproduction cross sections for electron taggers placed at different distances (d) from the electron beam axis.

d(cm)	ET3	ET6	d(cm)	ET44
3.0	$0.140\mu b$	$0.898\mu b$	1.2	$5.17\mu b$
4.0	$0.090\mu b$	$0.615\mu b$	1.5	$3.90\mu b$
5.0	$0.061\mu b$	$0.420\mu b$	2.0	$2.19\mu b$

5 Photodetectors

In the very high rates environment PM used now for readout would have higher degree of nonlinearity provided they will operate under the same regime as now. This problem can be solved by:

1.Selection of special regime for PM to get good linearity up to 10 MHz. Possible remedies are connecting one or more last dynodes to anode, lowering the gain of PMT,designing of special bias etc. Needs investigations.

2.Using another type of photodetectors,for instance APD or HPD. The main disadvantage of APD and HPD is low comparing with PMT low gain 50 for APD and 1000 HPD. One more drawback is temperature dependence of gain $2-3\%$ per degree.For HPD also high voltage $\sim 10KV$ is needed. These photodetectors are not radiation resistant $\sim 1MRad$.

We see now that using of PM with special regime is more preferable solution, but the best solution needs investigations.

6 On-line processing tasks

The basic online processing tasks for the luminosity system are:

- Real time luminosity calculation.

- Central and local DAQ running providing relevant data set for H1 physics and monitoring events, luminosity related data stream to be offline cross-checked and recorded into H1 NDB. This is described in the section ”The data acquisition”.

- Calibration is described in the section 9.

- Luminosity and beam related parameters presentation (section ”Networking ”)

- Monitoring and control the validity of the luminosity measurement, slow control of the system.

Real time luminosity calculation

The current online procedure has to be modified after the year 2000 luminosity measurement due to the increasing of in-bunch pile-up effect. The increased BH events rate will lead to some saturation of the events registration rate due to one or more photons with energy more than 1GeV will hit the detector in each collided bunch. Under this conditions any real events rate changing will not cause an adequate changing of trigger rate or corresponding number of histogram entries. Of course suitable threshold selection should help to the problem. An ideal online BH events counting procedure would be when the front end readout and a complete events processing will be performed for each bunch crossing i.e. with rate 10 MHz. For suggested number of detector channels and existing event reconstruction algorithms it seems rougher complicated to build out so fast processing system and leaving in the frame of a reasonable cost. From the other hand using much more powerful processor, which is proposed in the following section ”Electronics”, allows considerably speed up of the events processing rate to have a complete lumi corrections set in every few minutes. Once not every bunch crossing can be processed it is a natural way to use a triggering to have an optimal statistics for all types of monitoring and calibration events. For instantaneous luminosity monitoring it is supposed to use as a basic the current ”rate” method, but with much improved pile-up and threshold correction procedure. The improvements are based on:

- The fast monitoring events processing (factor 30 faster) that will give an accurate the pile-up and threshold correction functions just with few minutes delay.

- The using of presently running in the background the total energy flux method of the luminosity measurement.

To provide a correction for integrated luminosity it is proposed to use a method similar to the current offline procedure [6], but for every single bunch using relevant trigger mix (Random OR PD OR PilotBunch OR ...). An appropriate readout dead time determining facility will be foreseen in this case. The basic online calculated correction parameters are : photon arm acceptance, in-bunch pile-up (function of the events rate), trigger efficiency (function of threshold, channel gains and electronics inefficiency), absolute photon energy scale. For absolute photon energy scale determining the shape of the single BH spectrum can be measured using electron pilot bunches where the edge of spectrum will be much more prominent.But one has to keep in mind that for beam gas bremsstrahlung there is no beam-size correction that contribute mainly in the low part of spectrum.

7 Electronics

Because of essential dependence of the luminosity measurement systematic error on photon energy resolution a careful requirements should be applied not only for Photon Detector but for the readout electronics too. Sufficient ADC dynamic range and linearity of analog electronics are the basic requirements for the front end readout to not make worse the total energy resolution.

The present system electronics (Fig.11, 12) is able to operate at the event rate of 10MHz(above 20 GeV threshold) providing sufficient linearity and dynamic range. The only thing could be upgraded for 2000Y running conditions is an encreasing of air cooling for the front end preamplifiers after switching them to more high rate operation mode. Another possible occasion of the upgrade is changing of these preamplifiers and design new would happen if the new photodetectors will require much higher amplification gain(say two orders more). The currently using FADCs and trigger electronics have no any limits up to 100 MHz signal processing rate and hence there is no any principle reason to upgrade them. In terms of 2000Y new functional requirements, like lumi measurement per bunch(polarization study), the present electronics has all needed for that functions which well running since 1991 and also sufficient redundancy to implement some new measurement methods(total energy flux meter).

Therefore any the present ”lumi electronics” upgrade should be considered as a not ability running after year 2000, but doing the system with some improved parameters. In this way several possible improvings could be applied:

-Increasing of the processing power. It is supposed to implement a more powerful general purpose low cost VME platform processor RIO2 8062 (product of the ”CES” firm). This is 300MHz PowerPC based VME board has a complete set of functions for optimal performance in the present ”lumi” system making much faster it's readout and computing. An on-board CES VME interface provides autonomous fully hardware-driven chained block transfers that allow doing a 50 Mbytes/sec data transfer without consuming of the processor time for the VME readout. The RIO2 8062 also provides a huge speed improvement with an optimised CPU Memory arbitration and a massive 1Mbyte L2 cache delivering a 400 Mbytes/sec. This will lead to speed up of the event processing rate by factor 20-30 compared to the present. A developed by CES and stored in the Flash EPROMs monitor software (PPCMon) allows to execute the

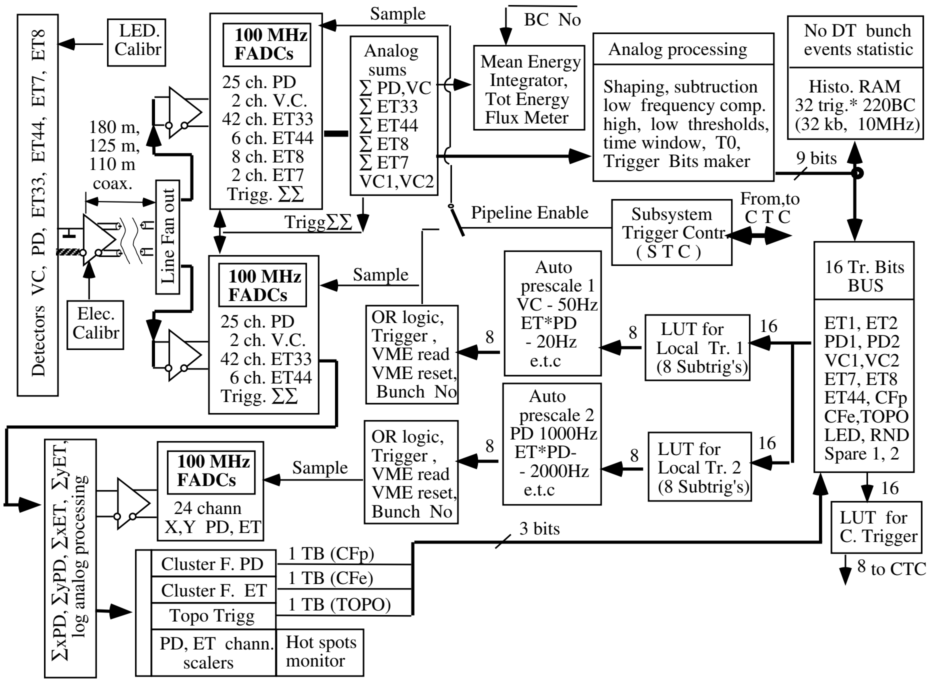

Figure 11: H1Lumi system readout and trigger block diagram.

stand-alone C and FORTRAN programs directly from a PowerMac environment. Taking into account a wast using in H1 a Macintosh based software environment this will be an optimal modification with minimum software efforts and maximum benefit. Using the VME hardware-driven chained block transfers for reading the FADC's data and hence negligible computer power will be needed for readout we foresee 20 kHz monitoring events processing rate and 2-3 kHz for fully reconstructed events.

- Reliability improving. Since some electronics was designed and integrated in the system as far as new tasks have being coming during 93-97 running, therefore a kind of not optimal cabling and modules functionality take place. Designing of several new VME boards with an optimal integration of it's functions will provide a considerable decreasing number of module-to-module connections and add more flexibility in the system.

-Signal processing improving. Under real lumi 2000 conditions practically every bunch crossing will produce one or more BH events. Due to big length(180m) of the signal cables which connected detectors and readout electronics there is a signal shaping-attenuation leading to bunch-to-bunch pile-up effect. An analog preprocessing could helps to suppress this effect in case of using a charge ADCs. But any additional analog processing due to possible fluctuations around adjusted frequency response function could be a source of an additional unlinearity. More preferable in this case to use the Flash ADCs with 100-400MHz bandwidth that allows to do any optimal signal processing to extract the correct amplitude value and hence it is not need to do any analog preprocessing. In assumption that total number of calorimeter channels will be less due to removing the Etagg33 detector(49 channels) the released FADC's channels could be used in parallel that gives an equivalent of 200-400MHz FADC mode running and extends the current dynamic range from 12bits to 13-14bits that allows more precise signal shape processing.

-Implementation 400MHz digital signal processing in the trigger. Current analog part of the trigger processor has a response function adjusted for the real signal to provide relevant filtering of the noise and bunch-to-bunch pile-up. This shape dependent response in case of big frequency-amplitude fluctuations can provide some additional uncertainty for the finale trigger solution. The effect usually is compensated after some delay by the real time calculation of the trigger efficiency function with sufficient accuracy. From the other hand using 400MHz ADC and applying digital signal processing with the 10MHz output rate it is possible to minimize this frequency-amplitude dependence due to much large bandwidth.

- Placing an alternative trigger electronics close to detector. This is an analog sum and discriminator based electronics with $\sim 1GHz$ bandwidth receives the signals directly from the preamplif ier outputs and therefore there is no any long cable signal distortion. The trigger signal are sent then through coaxial cable to the main electronics rack. This is a very low cost and simple electronics and can be considered as a part of the preamplifiers upgrade.

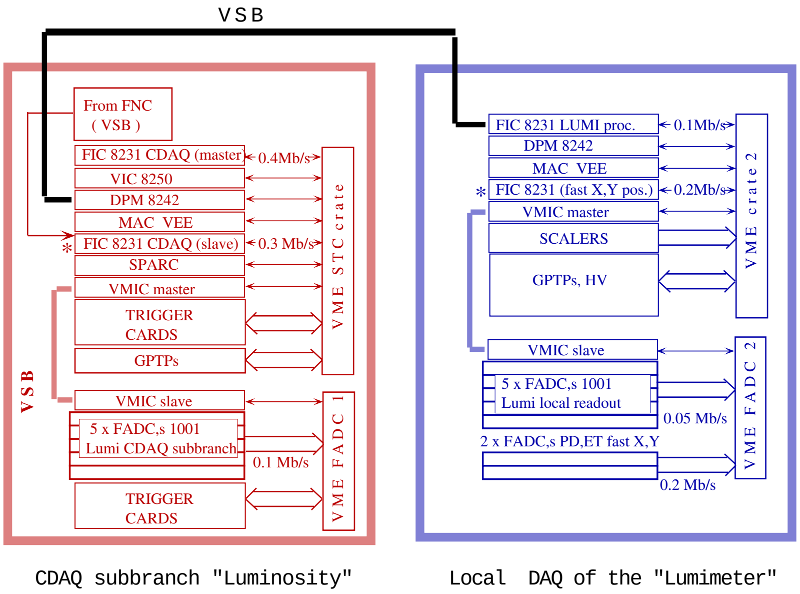

Figure 12: H1Lumi system central and local DAQ layout.

8 The data acquisition

Since H1 Central Data Acquisition (H1CDAQ) architecture stays after HERA upgrade the same (as concerning to Luminosity branch) the future scheme of this branch data handling will be similar to the present one.

Fig.13 displays the proposed schematic view of the lumi system data flow.

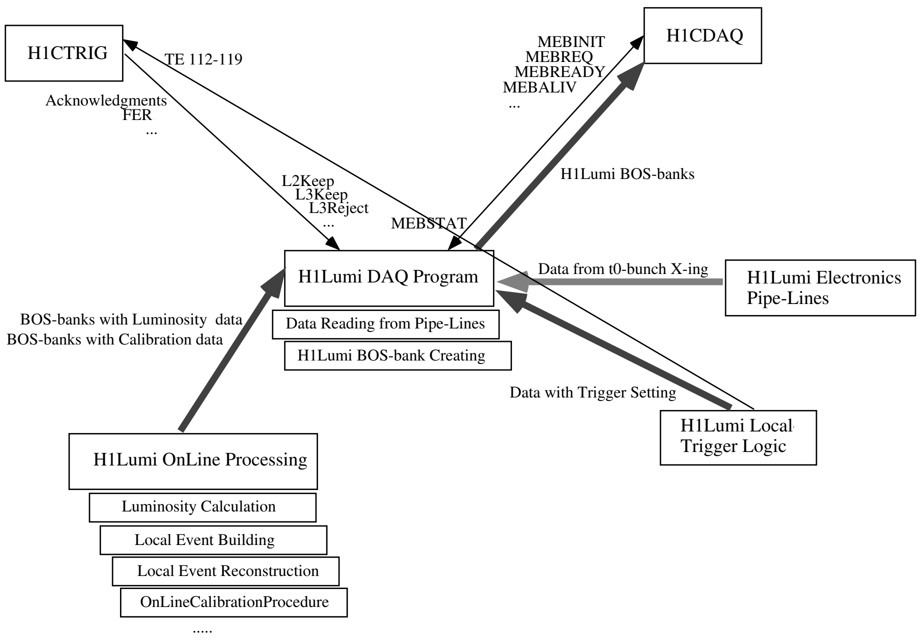

Figure 13: H1Lumi Data Acquisition Data Flows.

DAQ software will consist of one or more programs which will operate at FrontEndProcessor board. The programs running should be synchronized with H1CDAQ status and H1 Central Trigger (H1CTRIG) signals. Correct and adequate reaction of the programs on receiving of all needed signals from H1CTRIG (L2Keep, L3Keep, L3Reject, etc.) must be provided with acknowledgements and FrontEndReady (FER) signal sending. Correct interface with H1CDAQ must be supported in accordance with existing H1CDAQ standard (through MEB-family subroutines [19]).

DAQ program running will create for each event at H1 Detector (H1Event) the set of BOS-banks with data from detectors of H1 Luminosity System (H1Lumi) - photon arm detectors and electron taggers - and BOS-banks with data from another H1 subdetectors connected optionally to H1Lumi DAQ - VetoWall and FNC. All these data will be retranslated to H1 EventBuilder through special buffers at DualPortedMemory module and optic link.

We plan to renew BOS-structure of most H1Lumi BOS-banks in accordance with new set of H1Lumi detectors, numbers of their channels and new electronics for channel signal digitization.

For the case of FADCs usage in H1Lumi electronics it is planning to read more than one bunch crossing signal shapes from each amplitude channel pipe-line in order to determine correctly the current pedestal value for this channel.

It is reasonable to keep H1Lumi RawData at H1DataFlow for the implementation of different complicated algorithms of Raw Data processing at L4 and L5 levels and not remove them as it is made at present. As an option the implementation of some the most simple and fast algorithms of Raw Data processing at DAQ program level should be foreseen.

Online Luminosity values measured with single photon and γe coincidence methods will be presented at H1DataFlow for the cross-check. Instantaneous and integrated luminosity values and related data will be retranslated to H1DataFlow once per 10 s at special so-called KEEP-family BOS-banks. Bunch luminosities (instantaneous and integrated ones) will be added into H1DataFlow.

Some important of the system parameters - trigger setting for H1Lumi trigger elements (TE 112-119), movable detectors positions etc. - will be also retranslated to H1DataFlow through BOS-banks for StartRun and EndRun Records.

The results of OnLine Calibration procedure - calibration coefficients for all H1Lumi detectors energy channels - will be placed into H1DataFlow for each H1 event.

Programs must provide standard for H1 detector dead time (not more than $800\mu s$ on H1Lumi data reading from pipe-lines) and $\approx 200Hz$ H1 logging rate.

9 OnLine Calibration

The requirement to fulfill the relation

$$E_e = E_{e'} + E_\gamma \tag{6}$$

for detected small angle bremsstrahlung events and requirement to reproduce the form of photon arm BH spectrum provide the energy calibration of the H1Lumi detectors channels. It worth mentioning that in-bunch pile-up effects should be taken into account or suppressed. The main goal of Online calibration is to find the set of calibration coefficients in MeV/FADCcount units which can satisfy above mentioned requirements within present detectors energy resolution.

For all channels i in the Electron Tagger and j in the Photon Detector one requires that the following expression is fulfilled:

$$\sum_{events} \left\{ \left[F(\sum_i E_i(e)) + F(\sum_j E_j(\gamma)) - E_o \right]^2 \right\} = min \tag{7}$$

where E_o is electron beam energy and $F()$ is reconstruction energy.

Online calibration procedure will be not possible without H1Lumi Local Trigger. Powerful processor mentioned in section 7 is needed for local event building and event reconstruction of different H1Lumi detectors data flows used in the procedure. The influence of bunch-to-bunch pile-up effect on signal shape at $t0$ bunch crossing will be suppressed with local trigger selection events without hits at $t0 - 1$ bunch crossing for all trigger elements which are involved in building local H1Lumi subtriggers needed for the calibration. To suppress or remove in-bunch pile-up effects on photon arm energy spectrum the pilot-bunch triggered events and events with anti-Preshower $(!Preshower)$ PhotonArm trigger can be used.

Below examples of some H1Lumi local calibration subtriggers needed to suppress pile-up effects are given.
1. Subtrigger $ET\&PD\&!(Preshower)$ which is used at present release of H1Lumi for Electron Tagger and Photon Detector channels calibration can be extended by adding the coincidence on the absence of ET,PD and Preshower trigger elements hitting at $t0-1$ bunch crossing.
2. Subtrigger $PD\&!(Preshower)$ which was used for defining of Photon Detector Global Energy Shift can be extended with coincidence on absence of PD and Preshower trigger elements hitting at (t0-1) bunch crossing (optionally - on coincidence with pilot bunch)
3. Subtrigger $ET\&PD\&Preshower$ which was used for Preshower (Water Cherenkov Detector) channels calibration can be extended with coincidence on hitting absence of all involved trigger elements at $t0 - 1$ bunch crossing (bunch-in-bunch pileup suppression) and with coincidence with pilot bunch (in-bunch pile-up effect suppression).

So - for selection of the most pure events which can be used for OnLine calibration of H1Lumi energy channels a number of cuts at hardware level should be done. Additional software level cuts on hits coordinates in detectors and energy cuts should be done as well.

Each OnLine Processing branch connected with calibration starts data reading from pipelines after local subtrigger has stopped pipelines connected with local H1Lumi Trigger system. Data reading is enough fast now: up to 7-10 kHz.

The data are combined into H1Lumi local event which should be reconstructed with a similar manner as it is made by the reconstruction package for H1Lumi part of H1 event using current on-line produced calibration coefficients. It is important to mention that each local event renovates calibration coefficients which are retranslated into H1DataFlow with each H1Events. The OnLine reconstruction procedure is a main time consuming part of any calibration branch. The present H1LumiOnLine processing package can reconstruct local events with rates 7-20 Hz. The proposed new powerful board (PowerPC) will reconstruct events significantly fast.

Current calibration coefficients are used for online reconstruction of x- and y- coordinates for γ hit points at photon detector. This coordinates are necessary for calculation of Photon Detector Acceptance correction factor to obtain instantaneous luminosity and for the ep collision luminosity tuning by HERA machine.

10 Networking

Unix VME board will be used as network interface of Lumi subdetector. The purposes are :
to provide on-line data monitoring,
to provide remote subdetector control,

to provide slow data storage in the outside data bases.

Luminosity data monitoring has additional specific features:
fast monitoring with response time 0.5-1s,
reliable 24 hours/day service,
relatively big number simultaneously working clients (> 10).

The solution is based on popular client/server internet technology.

The lumi data monitoring proceeds in the following way. The lumi processor program prepares on-line lumi data extracting them from Lumi system through VME bus, processes them if necessary and puts to the shared memory.

The WWW browser on any client computer loads the Java applet from www server running on Unix VME board. The applet provides data monitoring connecting to correspondent server program on Unix VME board.

It is supposed to use Unix VME board on Intel processor running Linux with Apache www server (for example J Sparc VME board running Solaris with FastTrack 2.0 WWW server).

11 Conclusions.

11.1 Summary

11.2 Outlook

11.3 Funding

References

[1] W.Bartel, E.Gianfelice,N.Holtkamp et al, "HERA Luminosity Upgrade", Future Physics at HERA, Proceedings of the Workshop 1995/96, DESY, v.2, p.1095.

[2] L.Suszicki, R.Bandelmann, D.Barber et al., "HERA Luminosity Upgrade (Revised 2nd Draft 2.27.97)", http://www.desy.de:8888/parker/IR/Report970702/Report970702.html .

[3] I.Abt, T.Ahmed, S.Aid et al., "The H1 detector at HERA", NIM **A 386** (1997) 310.

[4] V.F.Andreev, P.S.Baranov, A.S.Belousov et al., "Electron and Photon Detectors of H1 Lumi System", LPI preprint 32, 1992, Moscow.

[5] V.F.Andreev, P.S.Baranov, A.S.Belousov et al., "Luminosity measurement of HERA Machine by H1 Lumi System", LPI preprint 28, 1993, Moscow.

[6] N.Gogitidze, S.Levonian, "An Offline Luminosity Determination for the 1995 H1 e^+p Data", H1 note, H1 - 02/96 - 471.

[7] L.Favart, R.Maracek, "H1 1994 Integrated Luminosity Measurement Using Bremsstrahlung Overlapping Events and Quasi-Real QED Compton Events", H1 note, H1 - 11/96 - 503.

[8] C.Bini et al., "Fast measurements of luminosity at LEP by detecting the single bremsstrahlung photons" NIM, **A 306** (1991) p468.

[9] H.Dinter, Private communication.

[10] S.Levonian et al, "Small Angle Electron Tagging for Luminosity Monitoring and Low Q^2 Physics" H1 note, **H1-TR 113** October 13,1987

[11] C.Kennedy et al., IEEE Trans.Nucl.Sc. **37** (1990) 144

[12] V.G Vasil' chenko, V.G.Lapshin, A.I.Peresypkin et al., "New Results on Radiation Damage Studies of Plastic Scintillators", NIM **A 369** (1996) 55.

[13] G.I.Britvich, I.I.Bushinskaya, M.Kobayashi et al., "Radiation resistant multicomponent inorganic materials for homogeneous e.m. calorimeters", NIM **A 321** (1992) 64.

[14] O.V.Buyanov, R.Chipaux, A.A.Fyodorov et al., "A first electromagnetic calorimeter prototype of $PbWO_4$ crystals", NIM **A 349** (1994) 62.

[15] V.G.Baryshevsky, V.A.Kachanov, B.I.Zadneprovsky et al., "Single crystals of tungsten compounds as promising materials for total absorption detectors of the e.m. calorimeters", NIM, **A 322** (1992) 231.

[16] G.Alexeev, E.Auffray, P.Baillon et al., "Studies of lead tungstate crystal matrices in high energy beams for CMS electromagnetic calorimeter at the LHC", NIM **A 385** (1997) 425.

[17] S.Levonian, "H1LUMI - A Fast Simulation Package for the H1 Luminosity system", H1 note, H1 - 04/93 - 287.

[18] V.Andreev, "Acceptance Determination of Electron Tagger (ET44) in 1995", H1 note, H1 - 10/96 - 493.

[19] W.J.Haynes, "VME-SSP.VMEtaxi System Software Package" H1 note, **h1-07/91-184**.