Background at HERA: Perspective of the Experiments

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Abstract

Machine induced background of various kinds has played an important role in the four experiments at the ep collider HERA which has been in operation from 1992 to 2007 at DESY in Hamburg. The largest impact on the operation was seen during the initial phase of HERA II after the HERA luminosity upgrade in 2000-2001 when backgrounds were found to be intolerably high in the colliding beam experiments H1 and ZEUS and machine currents had to be limited for some time in order to avoid damage to the sensitive detector components. In this article the main sources of this background and the measures taken to mitigate them are described. More specific background issues like those related to the operation of Roman pot devices or the wire target of the HERA-b experiment are not discussed here. The background related HERA machine aspects are desribed elsewhere in these proceedings [1].

INTRODUCTION

The most sensitive components of the colliding beam experiments H1 and ZEUS are the tracking devices. They consist of silicon strip detectors with their associated readout electronics which are mounted close to the beam pipe and of conventional gas detectors. Already before the luminosity upgrade of HERA (1992-2000, HERA I) some radiation damage was observed in the H1 silicon detector after periods of machine studies [2] and in the gas detectors which are only operated during luminosity runs [3]. While over the years the readout electronics for the vertex detectors was replaced with more radiation tolerant versions the basic operational parameters of the gas detectors could not be altered. As a consequence rather stringent background limits had to be respected for safe operation of both detector systems. Bad background conditions after the luminosity upgrade unexpectedly enforced to set limits on the maximum beam currents for several months in order to avoid damage. Many experiments and simulations very carried out to study the different background sources in detail and to devise counter measures. External expertise from other laboratories was involved within the framework of an international workshop and two external reviews between July 2002 and January 2003. The results of the studies are documented in several reports [4, 5] and most of the measures were implemented in a shutdown in the year 2003. Although several different background mechanisms contributed to the problem the interaction of the proton beam with residual rest gas atoms in the vacuum system was identified as the major source of background. This type of background is particularly severe at the ep collider HERA because of the unique combination of vacuum degradation in the beam pipe close to the experiments caused by photo desorption resulting from the intense synchrotron radiation and the large hadronic cross section for the interaction of protons with the released rest gas atoms.

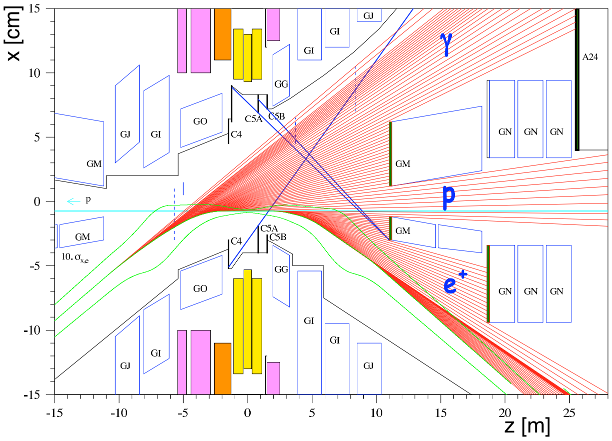

Figure 1: Schematic view of the H1 interaction region after the luminosity upgrade. Note the different scales in x and z. The shaded boxes indicate the position of the detector elements close to the beam pipe. Starting from absorber 4 at a distance of 11 m from the IP the common beam pipe splits into three separate beam pipes for electrons, protons and for the synchrotron radiation fan.

HERA LUMINOSITY UPGRADE

In the year 2000 HERA regularly surpassed its design luminosity of $\mathcal{L} = 1.5 \times 10^{31}$ cm^{-2}s^{-1} at the beginning of a luminosity fill and a major upgrade of the machine was needed to substantially increase luminosity for the experiments further. In order to reach a reduction of the beam cross sections in the transverse plane by roughly a factor of 3 a more compact design of the magnet lattice for bending and focussing of the two beams close to the interaction points was required [6]. As a result the interactions regions of the colliding beam experiments H1 and ZEUS were completely rebuilt in the years 2000-2001. One of the challenges of the new machine layout was the handling of the intense synchrotron radiation generated by the newly designed superconducting separation magnets inside the detectors (GO and GG in Fig. 1). A total synchrotron radiation power of 15-20 kW with critical energy in the range 100-150 keV had to be transported through the ex-

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periments. At a distance of 11 m from the IP a septum absorber (absorber 4) is installed which separates the electron[1] and proton vacuum systems and which has to absorb a power of 4-6 kW. The major part of the radiation is absorbed further downstream at a distance of 25 m from the IP. In order to leave space for the synchrotron radiation fan the shape of the beam pipe inside the experiments is elliptical. Integrated tungsten collimators (C4, C5 in Fig. 1) shield the inner detector elements and the beam pipe from radiation which is backscattered from the absorbers.

BACKGROUND SOURCES

The following types of background mechanisms were observed in the experiments: (i) synchrotron radiation, (ii) electron-gas, (iii) proton-gas and (iv) proton beam-halo losses. Under normal conditions the last type of background (iv) did not represent a major problem for the experiments. Exceptions were periods when malfunctioning machine components like faulty magnet power supplies or noisy RF-systems caused background spikes or led to a to buildup of coasting beam. The contribution of the sources (i)-(iii) to the total current observed in the central track detector (CTD) can be parametrized as follows:

$$I_{CTD} = I_0 + \alpha_{SR} I_e + \alpha_e I_e^2 + (\alpha_p I_e + \alpha_{p0}) \cdot I_p \qquad (1)$$

This parameterization reflects the fact that the direct and backscattered synchrotron radiation, which is proportional to the electron beam current not only directly contributes to the chamber current $\propto I_e$, but in addition causes a dynamic pressure increase on top of the base pressure p_0 around the experiments by photo desorption.

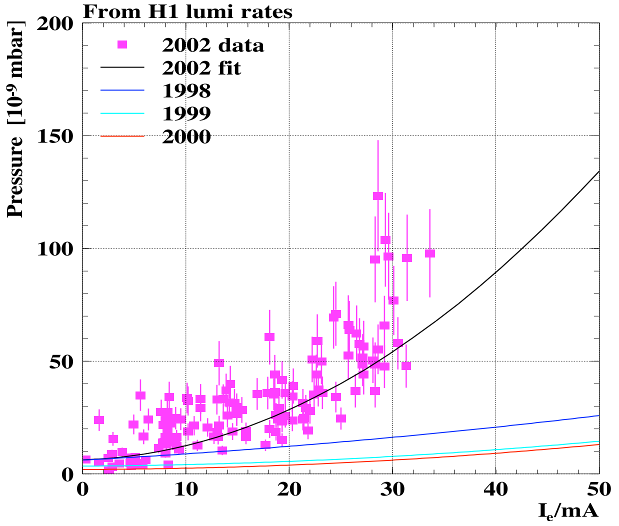

Figure 2: Pressure in the H1 interaction region as deduced from the observed rate in the luminosity system as a function of the electron beam current. The 2002 data are compared to parameterizations obtained at HERA I.

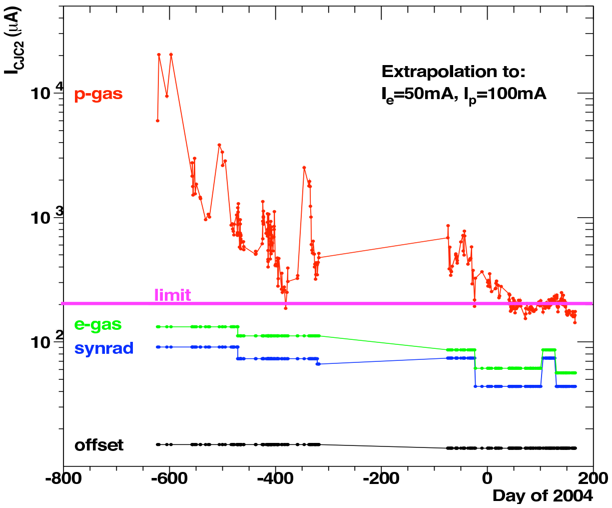

Figure 3: Evolution of the sum of the different contributions to the chamber current in the H1 central tracker from 2002-2004. The data are extrapolated to the design beam currents using the parameterization given in Eq. 1. The limit for safe operation of the chamber at 200 μA is indicated.

In Fig. 2 the pressure in the H1 interaction region as determined from the rate of electron-gas events in the H1 luminosity system is shown as a function of the electron beam current. The observed dynamic pressure increase has contributions from outgassing due to higher order mode (HOM) heating at injection energy (12 GeV) and of photo desorption due to synchrotron radiation. Comparing the dynamic pressure increase in the early period of 2002 with the situation before the luminosity upgrade shows that the conditions in HERA II were worse by about a factor of 5.

Off-momentum electrons resulting from upstream electron-gas interactions are deflected into the detector by the bending magnets inside the experiments leading to a term $\propto I_e^2$ in Eq. 1. Similarly proton interactions with the rest gas inside and proton upstream of the detectors result in secondary scatters at aperture limitations in the vicinity of the sensitive detector components (e.g. synchrotron radiation masks) and thus to a contribution $\propto I_e I_p$. The coefficients α_{SR}, α_e, α_p and α_{p0} have been determined using special runs and were used to extrapolate the expected chamber currents to the design currents of the machine of $I_e = 50$ mA and $I_p = 100$ mA. Fig. 3 shows the development of the sum of the three background contributions to the chamber current in the central drift chamber of H1. All components are seen to go down with time. Since the coefficients for electron gas and synchrotron background could only be determined in dedicated runs the corresponding background contribution exhibit a rather coarse time dependence in the plot. The structures visible in the proton gas contribution however result from various vacuum incidents followed by reconditioning of the vacuum (see below). In spring 2004 the machine currents for the first time were no longer limited by background in the chamber.

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[1] HERA was operated with electrons or positrons. For simplicity the term electrons is used for both particle types throughout this text.

A very similar improvement of the chamber current with time was seen in the ZEUS central tracker. Fig. 4 shows the chamber current as a function of the electron beam current for various runs in the period from October 2003 to July 2004.

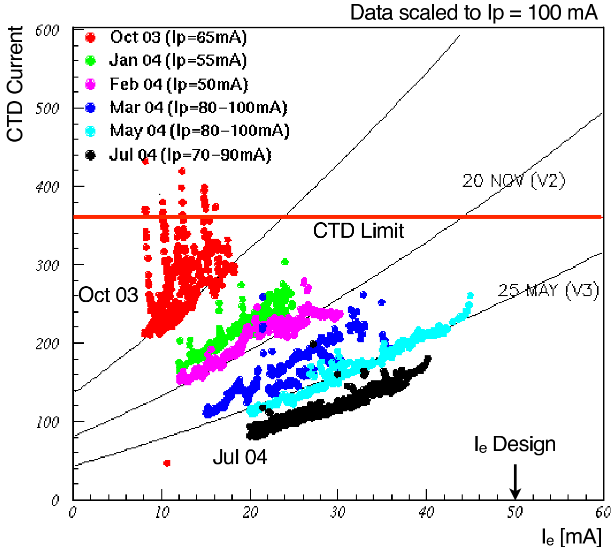

Figure 4: Dependence of the chamber current in the ZEUS CTD as a function of the electron beam current for different runs from October 2003 to July 2004. For comparison the data have been scaled to $I_p = 100$ mA using the parameterization given in Eq. 1. Around March 2004 the chamber currents for the first time did not limit the machine currents.

Synchrotron Radiation Background

The design of the new interaction region was made such that synchrotron radiation should only reach the beam pipe inside the experiments after at least two scatters and therefore should not lead to a significant background contribution in the detectors. However, first attempts to switch on the electron machine at HERA II immediately showed that this was not the case. By a combination of detailed Monte Carlo simulations and dedicated measurements it was found that initial misalignment of beam elements beyond the tolerances of 0.3 mm, oversight of an additional source of synchrotron radiation at a distance of -90 m far electron upstream of the IP and wrongly designed internal synchrotron radiation masks inside one of the experiments could explain the observed problems.

To disentangle the different background contributions dedicated electron-only runs with isolated bunches were taken. Observing the dependence of the chamber current as a function of the electron beam current allowed the separation of synchrotron radiation contribution ($\propto I_e$) from electron gas contribution ($\propto I_e^2$). By measuring the leading edge of the drift time distribution of hits from the isolated bunch in the drift chambers (see Fig. 5) the absorber 4 at 11 m was confirmed as the main source of backscattered radiation. By installation of an additional movable collimator 65 m electron upstream of the experiments and after a redesign of the internal synchrotron masks in ZEUS which was implemented during the 2003 shutdown to avoid sneak-through of back scattered photons the synchrotron radiation background was brought to an acceptable level for both experiments.

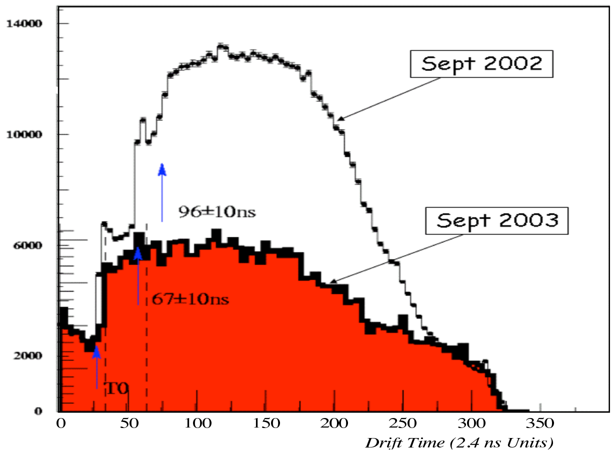

Figure 5: Drift time distribution of hits from an isolated electron bunch in the ZEUS CTD before and after the modification of the synchrotron radiation masks. The delayed component which is compatible with backscattering from the synchrotron radiation absorbers was successfully suppressed after the shutdown in 2003.

To improve the overall alignment of the machine the method of beam based alignment [7] was found to be very useful especially for the superconducting combined function magnets GO and GG inside the experiments. Furthermore time-dependent orbit fluctuations, partially arising from magnet movements due to changing magnetic forces, were reduced using an automatic orbit stabilizer [8]. Despite these efforts some residual misalignment of the machine elements and the experimental beam pipe in the H1 interaction region could not be fully resolved. Possibly as a consequence two major vacuum incidents occurred in 2004 and 2006 when the common stainless beam pipe around $6 - 8$ m proton upstream was hit by direct synchrotron radiation for several minutes, probably during electron injection or during a period of dedicated HOM-heating at 12 GeV (see below). The large temperatures following from the incident radiation led to gas outburst which then resulted in huge background from proton-gas interactions. Moreover the beam pipe was locally deformed by several millimeters which further restricted the available aperture also for luminosity operation thus constraining the available parameter space for the machine considerably. As a consequence this section of the beam pipe had to be replaced. In the subsequent period machine currents had to be limited again until the original vacuum conditions were restored. In order to prevent further damage a multitude of temperature sensors mounted on beam pipe and absorbers and vacuum pressure monitors were added as input to the electron beam-dump trigger system which otherwise was based on several independent radiation monitor systems.

Electron Gas Background

Off-momentum electrons which have lost part of their energy by Bremsstrahlung in an interaction with the residual gas atoms upstream of the experiment are deflected by the superconducting dipoles and quadrupoles and hit the beam pipe inside the detectors. This kind of background events can be distinguished from proton-gas events by the lower track multiplicity and the non-uniform spatial distribution of the showers the off-momentum electrons produce in the detectors. According to detailed simulations the sensitivity of the experiments to this type of background extended beyond -60 m electron upstream. In contrast to the rest of the straight section of the machine a 5 m long section of beam pipe inside one of the focusing quadrupoles (GA) for the proton beam originally was not equipped with NEG pumps because of limited space in the transverse direction and therefore was suspected to produce a pressure bump within the sensitive region. By piecewise modification of the iron yoke of this magnet it was possible to connect this section of the beam pipe to ion getter pumps during the shutdown 2003. After this modification and due to further vacuum conditioning the contribution of electron gas background was brought to an acceptable level.

Proton Gas Background

As explained in the previous sections the proton-gas background was the dominant contribution to the background problem for H1 and ZEUS after the initial problems with the synchrotron radiation had been solved. It became clear that the dynamic pressure increase had to be drastically reduced in order to be able to stand design machine currents. A particular challenge was to disentangle the impact of higher order mode (HOM) losses, which are strongest during electron injection at 12 GeV, of photo desorption due to direct or reflected synchrotron radiation and of the vicinity of the cold inner surfaces (T$\sim$55K) of the superconducting magnets on the proton-gas background. In order to gain a better understanding of the vacuum behavior around the IPs and its contribution to the detector background many experiments and simulations were carried out. This included the simulation of the vacuum profile under different boundary conditions (an example is shown in Fig. 6), operating the superconducting magnets at elevated temperatures, trying to thermally bake out the interaction region by operating the electron ring for about a week at injection energy (HOM heating), the creation of artificial pressure bumps by heating individual pumps and comparing with simulation (see Fig. 7), laboratory experiments with NEG-pumps, Titanium sublimation pumps (TSP) and installation of a dedicated residual gas analyzer to monitor the gas decomposition close to the IP.

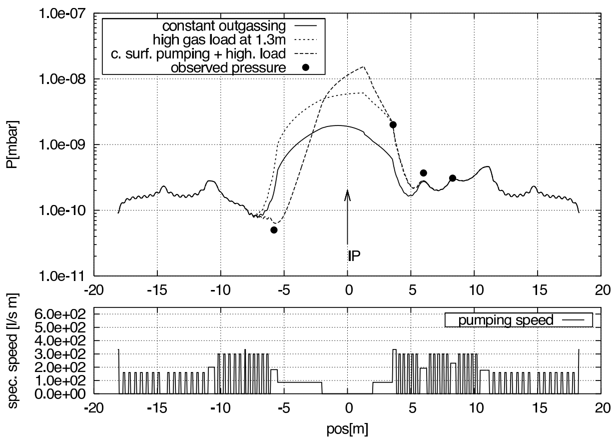

Figure 6: Pressure profile simulations for the inner interaction region at H1, for different outgassing and pumping scenarios in comparison with observed pressure readings.

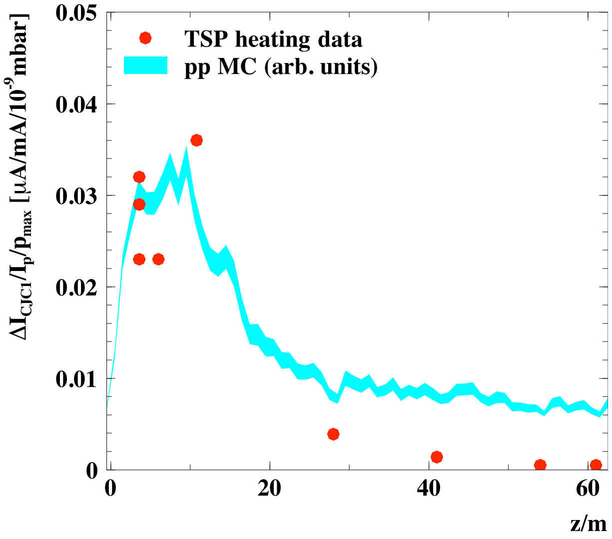

Figure 7: Comparison of observed and simulated increase of chamber current in the H1 central track detector normalized to the proton current and to the magnitude of the pressure bump after TSP heating as a function of the distance to the pump.

It turned out that the most critical area concerning bad vacuum was the region 2-11 m proton upstream. As a result of these studies [4, 5] the following modifications to the vacuum system [9] and to the region of the experimental beam pipes were introduced in the shutdown 2003:

- doubling the pumping speed of the ion getter pumps between 3.6 and 11 m
- improving conductance of pumping ports by increasing width of pumping slits
- reducing the thickness of over-designed synchrotron radiation mask C5B by a factor of 4 in order to reduce the interaction probability for secondaries from proton-gas events

- reducing HOM losses in the interaction region at injection energy by tapering the C5B synchrotron mask and by improving its cooling

- installing a new integrated ion getter pump inside the H1 experiment at 1.5 m from the IP

Fig. 8 shows the long term evolution of the proton gas background contribution in the H1 interaction region as derived from the normalized track trigger rate. The normalization is chosen such, that at values of 1 the chamber current due to proton background at design beam currents is roughly equal to the limit of 200 μA. The long-term trend of vacuum improvement has a time constant of approximately 600 days. As can be seen this overall trend was repeatedly interrupted by vacuum leaks which in most cases occurred in the region close to absorber 4. This region turned out to be the weak point in the design of the area around the IP after the luminosity upgrade where three vacuum flanges share a very crowded space. Slight misalignments of machine components in this constrained area in combination with the large heat load of absorber 4 caused large mechanical and thermal stresses on the flanges. In several occasions one of the flanges opened at H1 or ZEUS due to the fast temperature change which followed an electron beam loss at high intensity. The average time constant for restoring the previous vacuum conditions after such incidents was observed to be in the range $20-30$ days.

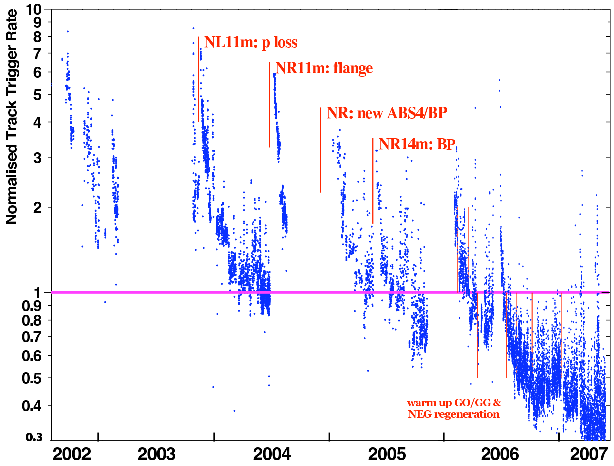

Figure 8: Long term history of normalized track trigger rate in H1, which is proportional to the proton gas background contribution to the chamber current.

After many tests the most effective strategy for long term improvements of the vacuum was found to be a combination of vacuum conditioning during luminosity operation interleaved with regularly warming up of the superconducting magnets in order to release the gas which had accumulated on the cold surfaces and subsequent activation of Ti- and NEG pumps.

SUMMARY

Machine induced background severely affected the start-up after the luminosity upgrade of HERA. Until spring of 2004 machine currents had to be limited in order to prevent damage to sensitive detector components thus reducing the available luminosity for the experiments. Several background mechanisms were identified to contribute to the overall problem but a background component specific to the ep collider HERA and resulting from dynamic pressure increase due to synchrotron radiation in combination with the large hadronic cross section for the interaction of protons with the rest gas upstream of the experiments was found to be the dominating source. In a very fruitful collaboration between experiments and the machine group very detailed experiments and simulations were carried out to study possible counter measures. Besides the effect of several such improvements that were implemented in the area around the IPs in the shutdown 2003 the conditioning of the vacuum system by regular luminosity operation in combination with regular warming up of the superconducting magnets and subsequent pump activation was found to be most effective for long-term improvements.

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