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Performance and Aging of the BaBar Drift Chamber*

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Abstract

The BaBar Drift Chamber has been operating since May 1999 at the PEP-II B-Factory, integrating a total of 140 fb^{-1} luminosity in e^+e^- collisions at $\sqrt{s} \sim$ 10.6 GeV. The chamber has accumulated a dose of approximately 10.6 mC/cm. The performance of the drift chamber with respect to aging (efficiency, gain, resolution) will be presented, along with projections over its expected lifetime.

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1 Introduction

The BaBar experiment [1] is a general-purpose particle detector operating at the PEP-II B-Factory at SLAC [2]. Since May 1999, PEP-II has collided beams of electrons and positrons with center-of-mass energy at or near the $\Upsilon(4S)$ resonance ($\sqrt{s} \sim 10.58$ GeV). The collisions are asymmetric, with beam energies $E_{e^-} = 9$ GeV and $E_{e^+} = 3.1$ GeV. PEP-II was designed to deliver a instantaneous luminosity of $3 \times 10^{33}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$; in June 2003, the peak luminosity had reached $6.58 \times 10^{33}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. PEP-II has delivered some 140 fb^{-1} of integrated luminosity (9% of which below the $\Upsilon(4S)$ mass), corresponding to over 100 million $B - \overline{B}$ meson pairs recorded by BaBar.

A primary physics goal of the BaBar experiment was the observation and precision measurement of CP violation in the B-meson system, through time-resolved asymmetries in decay rates to CP eigenstates such as $J/\psi K^0_S$ [3]. Additional physics goals include observation of rare decays of B mesons with precise branching fraction determinations, charm and tau physics, etc. This program is expected to continue through 2009.

To meet these physics goals, the BaBar drift chamber was designed [4] to achieve a transverse momentum resolution of $\sigma(p_T)/p_T \sim 0.21\% + 0.14\% \times p_T(\mathrm{GeV}/c)$, and a hit position resolution of 140 μm. In data taken from 1999–2003, we have measured $\sigma(p_T)/p_T \sim 0.45\% + 0.13\% \times p_T$, and hit residuals of $100 \sim 125$ μm. Early commissioning data showed that the drift chamber as built could achieve $\sigma(\mathrm{d}E/\mathrm{d}x) < 7\%$ for relativistic electrons. We currently observe $\sigma(\mathrm{d}E/\mathrm{d}x) \sim 7.5\%$, with systematic biases of $\pm(0.5 - 0.7)\%$.

2 Drift Chamber Design and Operation

The BaBar drift chamber (Figure 1) is a 2.8 m-long cylindrical chamber surrounding the PEP-II beam pipe and BaBar SVT. The inner cylinder ($r = 2.3$ cm) is aluminum, with a 1 mm beryllium central section. The outer cylinder is a carbon-fiber/Nomex sandwich. The two end plates are aluminum: the rear end plate is 2.5 cm thick, the forward has a 2.5 cm-thick inner section and 1.2 cm-thick outer section. The DCH uses a small hexagonal-cell design with a single 2 kV sense wire (20 μm gold-plated tungsten-rhenium) in each cell surrounded by six grounded field-shaping wires (120 μm gold-plated aluminum). There are forty cell layers in the chamber, organized into ten superlayers alternating between axial and left- or right-stereo orientations, with a total of 7,104 cells. The stereo superlayers provide z-coordinate resolution of about 700 μm.

The active gas is a mixture of 80% helium, 20% isobutane, and 3500 ppm water vapor, with < 100 ppm of oxygen impurity present. The original design called for the sense wires to be operated at 1960V. From May through July 1999, the chamber was operated at 1960V, with a palladium filter removing all of the oxygen and water vapor from the recirculating gas mixture. On 28 July 1999, experienced frequent, high-current discharges in one region of the chamber (Fig. 2). The affected HV supply was turned off, and the gas distribution system was modified to include a water bubbler with a flow restrictor, to achieve the current operating mix.

The chamber's HV distribution system was modified in October 1999 to permit a small region around the affected wires to be turned off (Fig. 3), and the operating voltage was

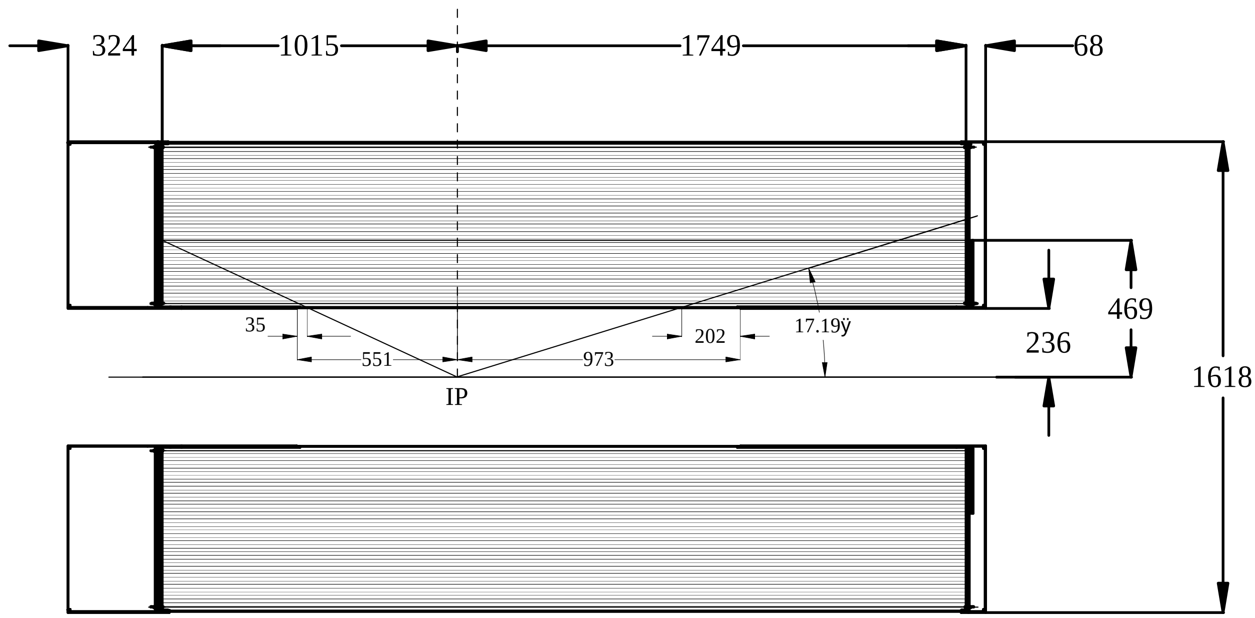


Figure 1: Side view of BaBar drift chamber; the rear of the chamber is to the left. Linear dimensions are mm, angles are degrees.

reduced to 1900V.

After evaluation of the discharge behavior and consultation with drift chamber experts outside BaBar, the voltage was returned to 1960V in July 2000. We chose a permanent operating point of 1930V in January 2001. No additional discharges have been observed since 1999.

The BaBar drift chamber accumulated a specific charge of 10.6 mC/cm on its sense wires (Fig. 4). The original design [4] projected 25 mC/cm after five years of operation.

3 Calibrating and Measuring Gain

To determine the gain of the chamber, the average $\mathrm{d}E/\mathrm{d}x$ of Bhabha-scattered electrons ($e^+e^- \rightarrow e^+e^-(\gamma)$) are normalized to a value of 665 units. The normalization (gain) scale, G, is measured every one to two hours during colliding-beam operation.

Figure 5 summarizes the hourly gain measurements over the lifetime of the chamber. The large steps correspond to changes in the operating voltage (Sec. 2); smaller systematic shifts appear following extended shutdowns. During each continuous running period, the main systematic effect on the gain scale is seasonal (and daily) variation in the gas density driven by atmospheric pressure and ambient temperature. This variation (represented by the error bars in Fig. 5) can be reduced by fitting G vs. P/T over few-week blocks of data throughout the operation of the detector.

Aging in gaseous detectors is generally expressed as a fractional reduction in gain for a given specific charge accumulation. We fit the data of Fig. 5, corrected for density, to a single exponential with a coefficient that includes step-functions for each known systematic

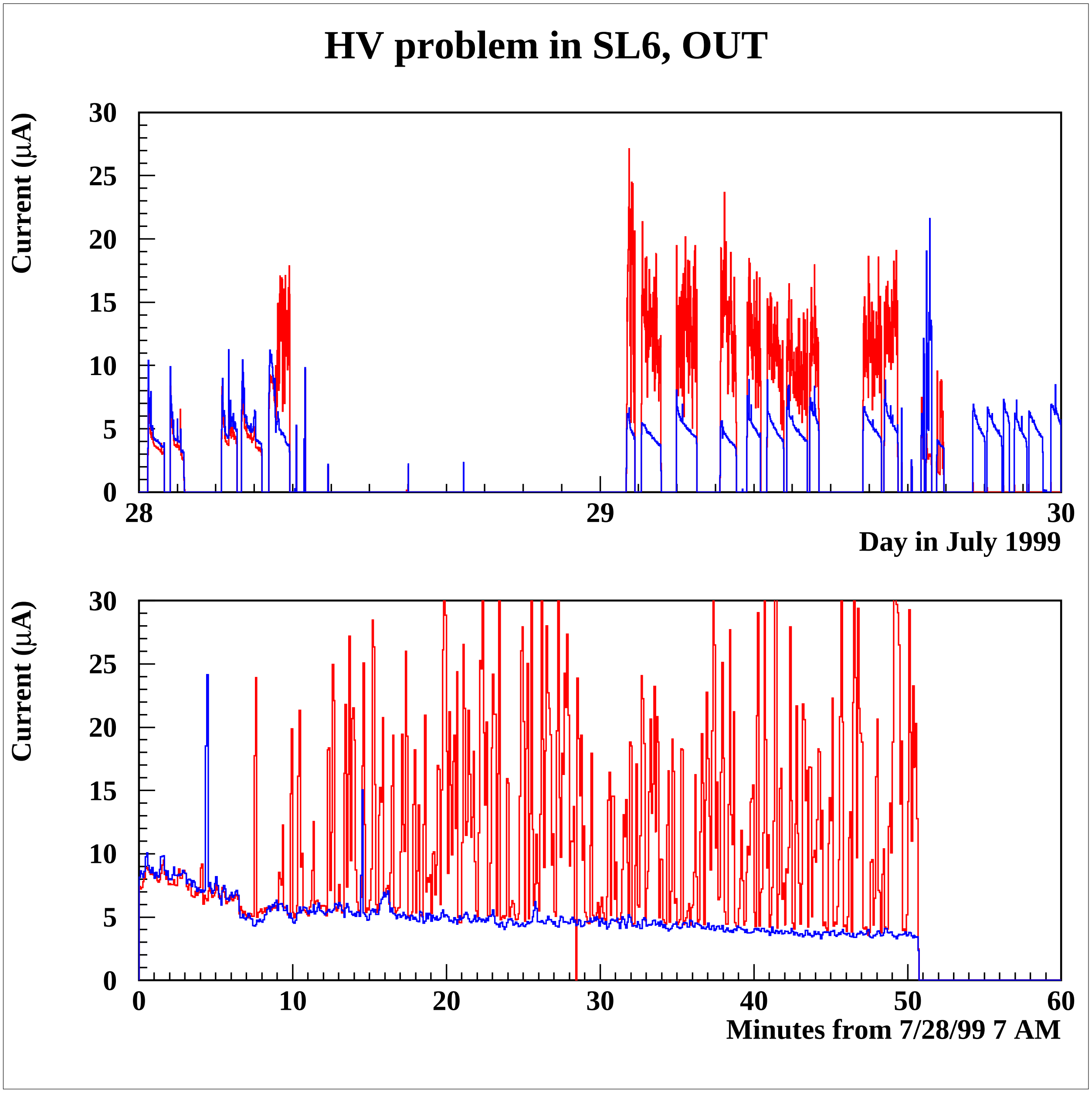


Figure 2: Discharge sequence observed in BaBar drift chamber, 28 July 1999. Blue trace shows current draw on normal HV power supply over several runs; red trace shows discharges leading to unstable behavior. *Top:* 28-29 July 1999 *Bottom:* 7:00–8:00 am (PDT) 28 July 1999

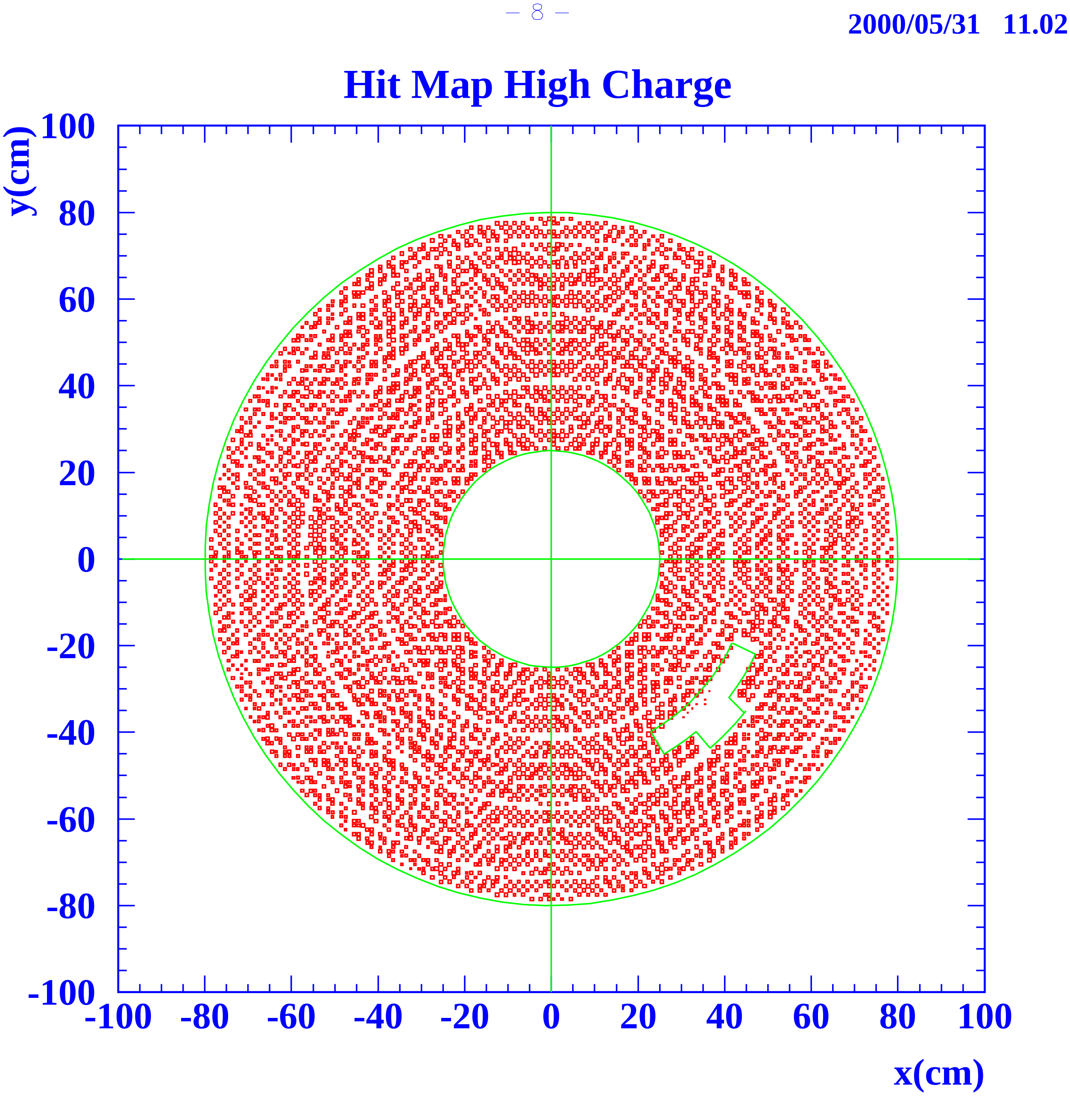


Figure 3: Occupancy map of drift chamber used for online data quality monitoring, showing region with HV turned off following discharges.

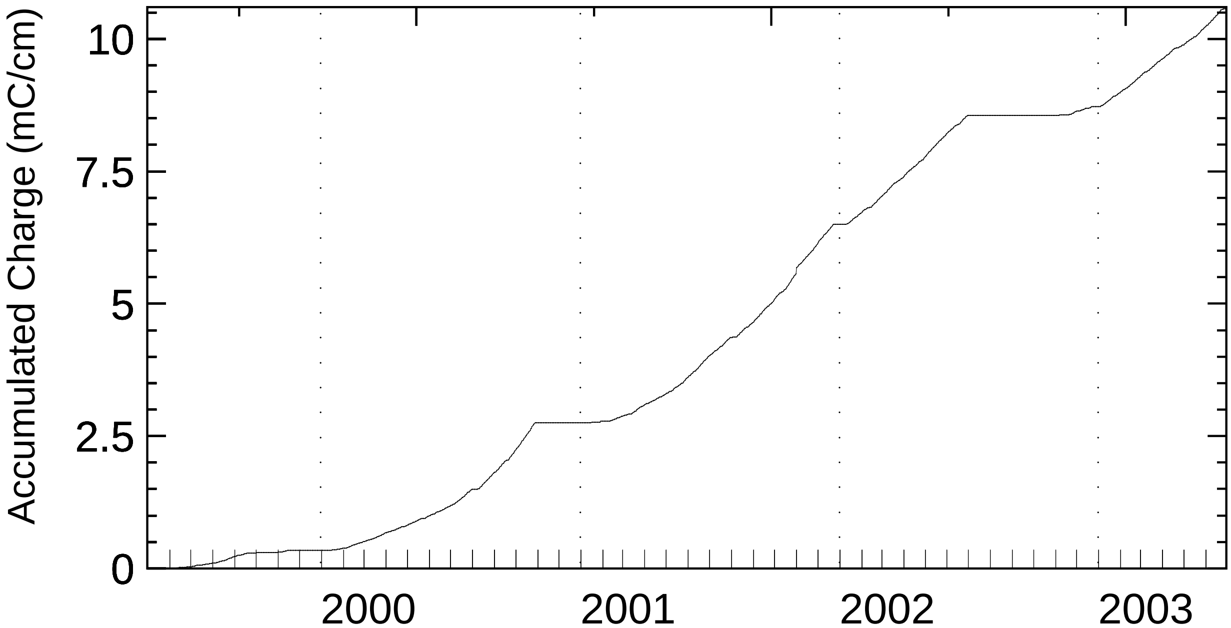


Figure 4: Specific charge [mC/cm] accumulated since start of running, May 1999 through June 2003.

shift,

$$G(Q) = \{G_0 + \sum_{i=1}^{5} \Delta G_i|_{Q>Q_i}\} \exp(-AQ) \tag{1}$$

where Q is the accumulated specific charge [mC/cm]; A is the aging parameter, $\delta G/G$ per mC/cm; and the five ΔG_i are systematic steps at specific times (see Fig. 6). The result, $A = (0.651 \pm 0.023)\%$/mC/cm, is shown in Figure 6. This compares well with other large experiments (Table 1), which generally demonstrate aging of a few percent per mC/cm.

4 Performance Extrapolations

The loss of gain measured so far in the BaBar drift chamber, 6.7% in four years, is small enough not to have affected either tracking or particle ID resolutions, or trigger efficiency. Over the lifetime of the experiment, however, this rate of aging may become significant. The PEP-II accelerator group is developing a program for increasing the luminosity delivered to BaBar up to 3.3×10^{34} cm^{-2} s^{-1} by 2007 [9] (Table 2).

The drift chamber's performance has been measured as a function of PEP-II beam currents and luminosity.† We can use these measurements to extrapolate the accumulated

†Using single- and colliding-beam runs, we fit $I(DCH) = -1.52 + 0.046\mathcal{L} + 0.145 I(e^-) + 0.0496 I(e^+)$, with $I(DCH)[\mu\text{A}]$, $\mathcal{L}[10^{30}\text{cm}^{-2}\,\text{s}^{-1}]$, and $I(e^\pm)[mA]$.

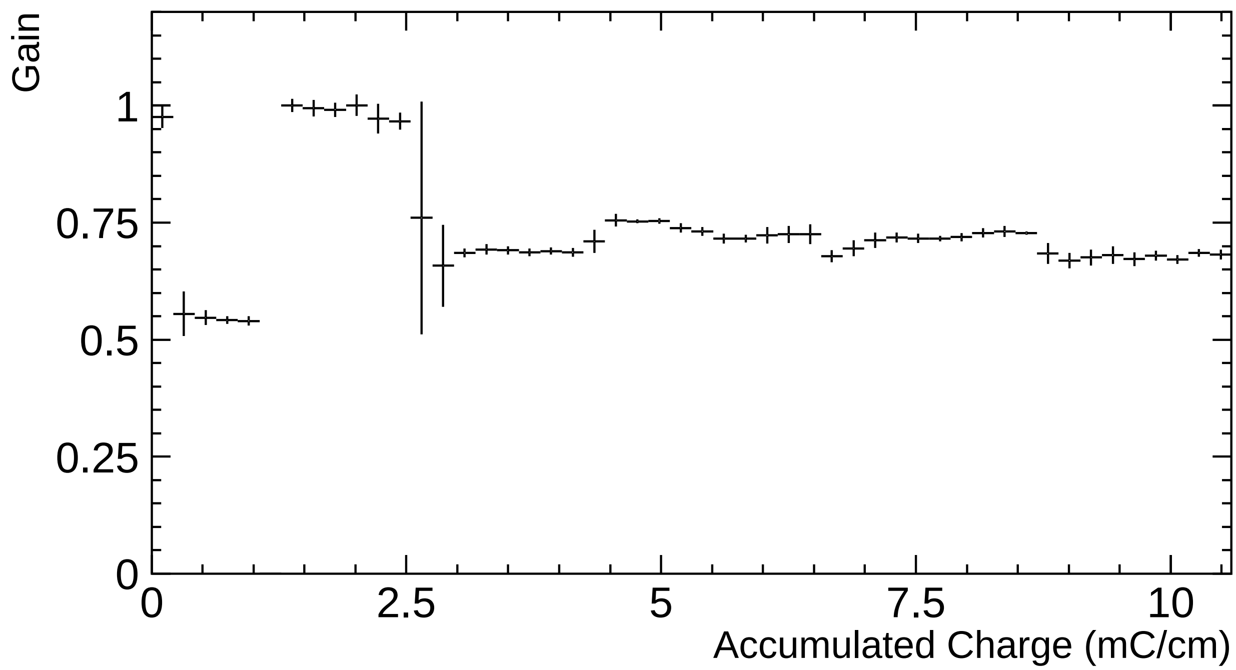
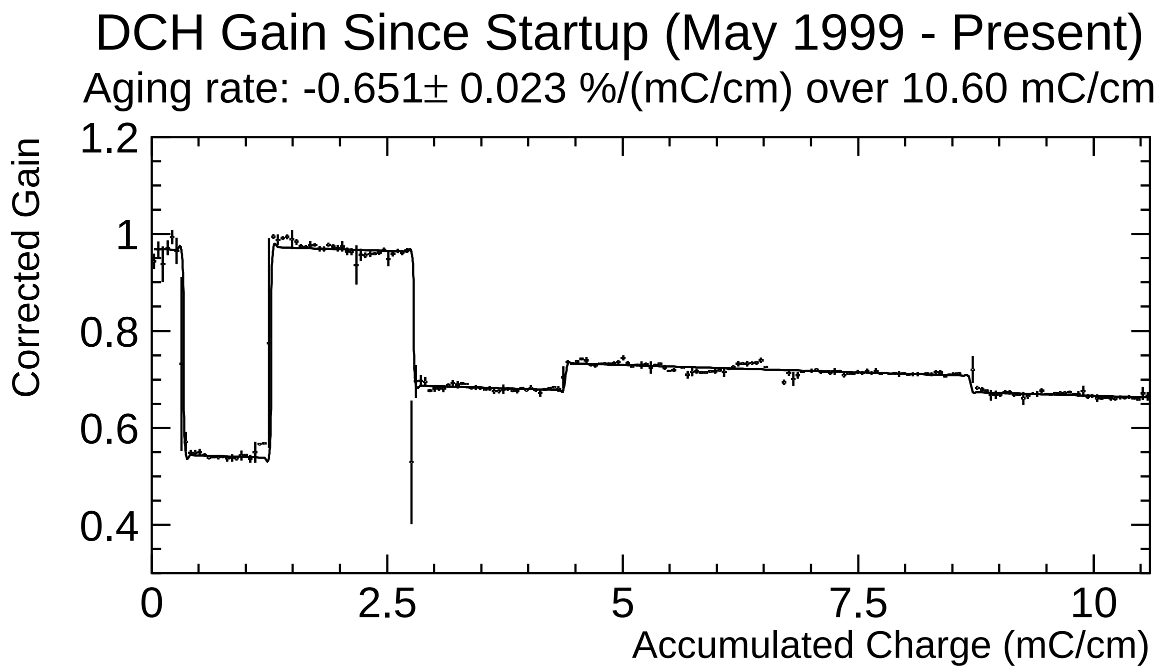


Figure 5: Hourly determination of gain G vs. accumulated charge [mC/cm]. Error bars indicate spread (RMS) of gain measurements contributing to each bin.

Table 1: Comparison of Drift Chamber Aging Results

Experiment	Gas Mix	[mC/cm] Charge	[%/(mC/cm)] Aging
CDF (Run 2)	Ar:Eth:Alc 50:50:1	130	$<1 \sim 20$ [5]
ZEUS	Ar:Eth:CO_2 83:5:12	100	$\lesssim 0.1$ [6]
H1	Ar:Eth:H_2O 50:50:0.1	< 10	$\gtrsim 1$ [7]
HERA-B (test)	Ar:CF_4:CO_2 65:30:5	2300	$\sim$ none [8]
BaBar	**He:iBu:H_2O 80:20:0.4**	**10.6**	**0.65**



$$\begin{aligned}
\chi^2/\text{dof} &= 344.12\ /\ 188 \\
-A(\%) &= -0.651 \pm 0.023 \\
G_0 &= 0.969 \pm 0.002 \\
\Delta G_1 &= -0.423 \pm 0.002 \quad (Q_1 = 0.3) \\
\Delta G_2 &= 0.434 \pm 0.001 \quad (Q_2 = 1.2) \\
\Delta G_3 &= -0.276 \pm 0.001 \quad (Q_3 = 2.8) \\
\Delta G_4 &= 0.056 \pm 0.001 \quad (Q_4 = 4.4) \\
\Delta G_5 &= -0.033 \pm 0.001 \quad (Q_5 = 8.7)
\end{aligned}$$

Figure 6: Gain corrected for density vs. accumulated charge, fit to aging rate (1). Best fit values and errors of all parameters, along with the χ^2, are tabulated.

Table 2: PEP-II Expected Luminosity, 2003–2008

	$[10^{33}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	[mA]	[mA]
Year	$\mathcal{L}$	$I(e^-)$	$I(e^+)$
2003	6.3	1140	1450
2004	12.1	1600	2700
2005	18.2	1800	3600
2006	23.0	2000	3600
2007	33.0	2200	4500
2008	33.0	2200	4500

charge expected until 2009, as shown in Fig. 7. Different parameterizations range from 50 to 80 mC/cm.

Equation (1) and Fig. 7 can be used to estimate the loss in gain over the lifetime of the experiment (Fig. 8). The result implies that by 2009 the gain will have dropped nearly 25% from current performance.

A way to compensate for loss of gain in the future is to increase the operating voltage of the chamber. The first three steps in (1) correspond to changes of voltage from 1960 to 1900V (ΔG_1), back to 1960V (ΔG_2), and finally to 1930V (ΔG_3). From the gain steps, a change of 10V in the operating voltage corresponds to approximately 9% change in gain. We could change the DCH operating point to 1940V at 18 mC/cm (2006) and to 1950V at 30 mC/cm (2008), resulting in the somewhat constant performance shown in Fig. 9.

In addition to "classical" aging—the gradual loss of efficiency described above—drift chambers are subject to more dramatic and damaging effects. Imperfections on wires or other surfaces inside the chamber can become high-field regions, leading to emission of electrons and excess current draw. The high-voltage, high-radiation environment can cause hydrocarbon gas components to polymerize and deposit on wire surfaces, producing dielectric regions that accumulate charge until the break down. Localized electron emission (especially when running without a magnetic field) can develop into a self-sustaining, runaway avalanche.

Several BaBar collaborating institutions have conducted small-scale studies of aging in chambers with the BaBar cell design, using strong ^{55}Fe sources. Two in particular are worth mentioning here. Lu Changguo of Princeton has conducted long-term studies, accumulating 300 mC/cm in a single-cell chamber [10]. He confirmed that adding a few parts per thousand of water vapor to the BaBar DCH gas mixture could inhibit catastrophic discharges indefinitely; his results also imply that the water vapor additive inhibits gradual aging (10% reduction after 130 mC/cm charge).

Since 2001, Adam Boyarski of SLAC has conducted a series of aging studies with a single-cell chamber [11]. He has investigated the underlying mechanisms of discharge, and various means of remediating the damage caused by them. As reported at both the 2001 DESY Workshop on Aging and this Satellite Workshop, he has found that some additives (notably

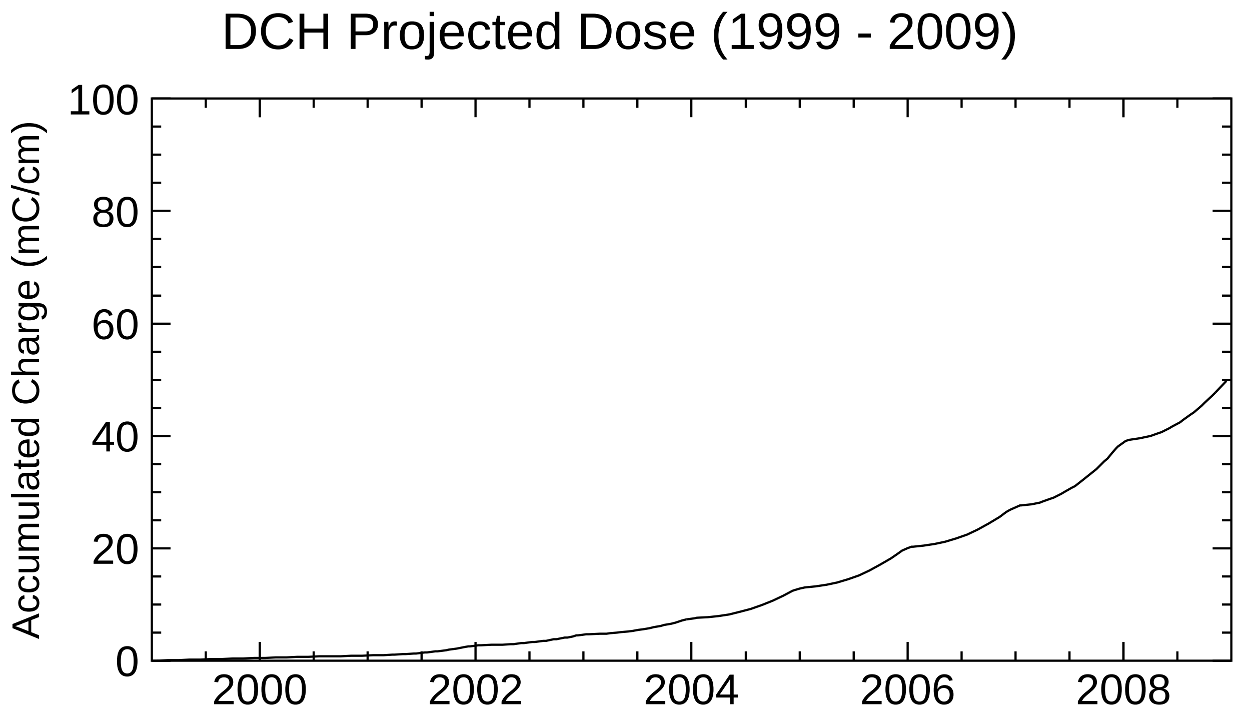


Figure 7: Accumulated charge [mC/cm] expected in BaBar drift chamber through 2008.

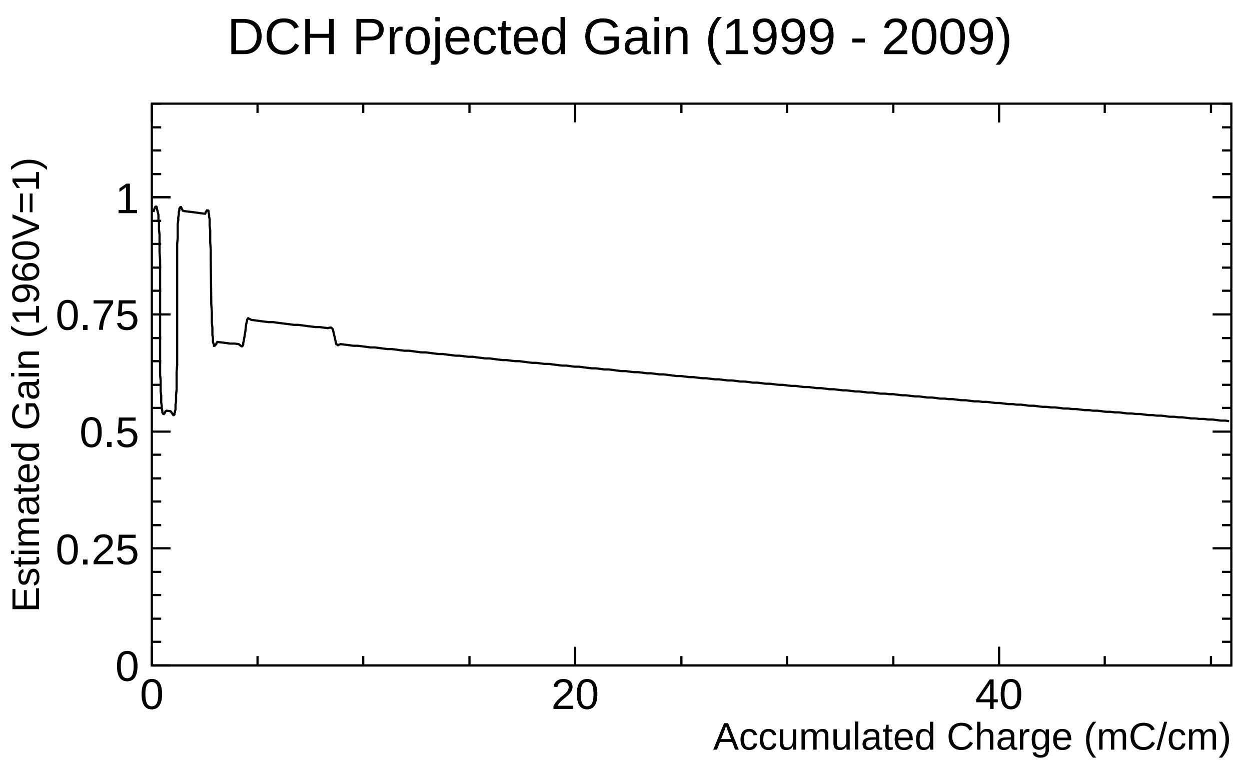


Figure 8: Average gain $G(Q)$ expected through 2008, based on PEP-II performance and DCH accumulated charge, using fitted results (1).

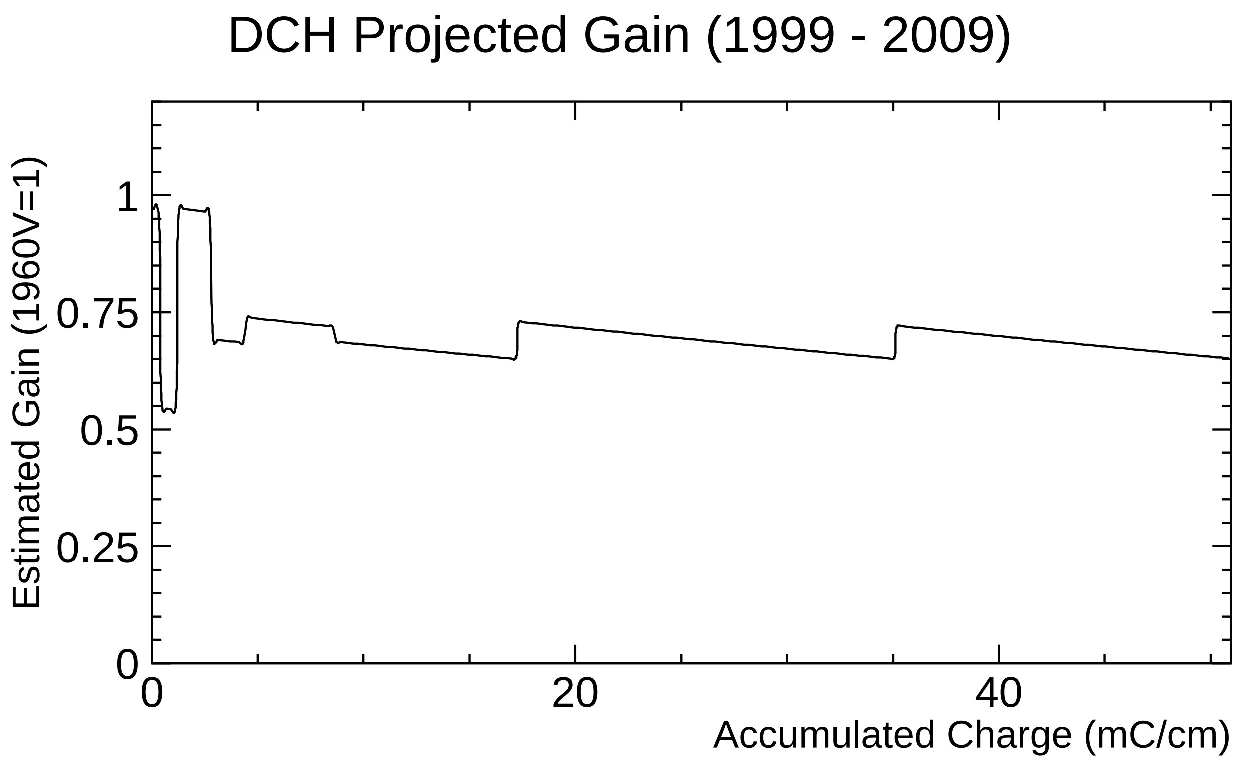


Figure 9: Average gain $G(Q)$ expected up to 2009, based on PEP-II performance and DCH accumulated charge, and adjusting the operating voltage periodically to compensate for aging.

500–1000 ppm O_2) may eliminate the sources of discharge, restoring the small chamber to performance comparable to its original construction. Whether this process can be applied to the full BaBar drift chamber requires additional study.

5 Conclusions

The BaBar drift chamber has operated for over four years with excellent results, meeting or approaching all of its design goals. It has accumulated 10.6 mC/cm of accumulated charge, with a reduction of 6.7% of gain, compared to its initial value. This loss of gain is consistent with results seen in other large experiments, and has not affected either tracking or particle identification, nor compromised any of the physics goals of the BaBar experiment.

We anticipate that the chamber will continue to operate with high efficiency through the lifetime of the experiment, at least until 2009, with an expected 25% reduction of gain. We have plans in place to compensate for this loss of performance, as well as for other effects, as the chamber ages.

Acknowledgment

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