SLAC-PUB-10344

April 2004

Performance and Aging of the BABAR Drift Chamber

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Presented at Tenth Vienna Conference on Instrumentation, 2/16/2004—2/21/2004,
Vienna, Austria

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Work supported by Department of Energy contract DE–AC03–76SF00515.

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Abstract

The BaBar Drift Chamber is a cylindrical, small-cell drift chamber installed at the PEP-II B-Factory. It has been operating since May 1999, integrating nearly 175 fb^{-1} luminosity in e^+e^- collisions at $\sqrt{s} \sim 10.6$ GeV. The chamber has accumulated a dose of 12.8 mC/cm, resulting in a drop in gain of approximately 6.4%. The drift chamber has met most of its design goals (position, momentum, and dE/dx resolution) while maintaining extremely high efficiency for charged track reconstruction. The chamber's operational history and performance will be presented, along with a discussion of the effects of aging and extrapolations for future performance, through 2008.

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 3×10^{33} cm^{-2} s^{-1}; by Feburary 2004, the peak luminosity has reached 8×10^{33} cm^{-2} s^{-1}. PEP-II has delivered some 175 fb^{-1} of integrated luminosity (9% of which below the $\Upsilon(4S)$ mass), corresponding to over 130 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-

[1] Work supported by U.S. Department of Energy contract DE-AC03-76SF00515

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, with the peak luminosity increasing to several 10^{34} cm^{-2} s^{-1} and a total dataset approaching 1000 fb^{-1}.

2 Design and Operation

The BaBar drift chamber (Fig. 1) is a 2.8 m-long cylindrical chamber surrounding the PEP-II beam pipe and BaBar SVT. A portion of the inner cylinder surrounding the interaction point is 1 mm beryllium; the remainder, and the two endplates, are aluminum; the outer cylinder is a carbon fiber/Nomex sandwich. The DCH uses a hexagonal small cell design with individual 2 kV sense wires surrounded by ground wires. The 7,104 cells are arranged in ten superlayers alternating between axial and left- or right-stereo orientations, which 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 present. The chamber is operated with the sense wires at a voltage of 1930V, corresponding to an avalanche gain of $\sim 4 \times 10^4$. The BaBar drift chamber has accumulated a specific charge of 12.8 mC/cm on its sense wires (Fig. 2). The original design [4] projected 25 mC/cm after five years of operation.

Single-hit resolution is measured directly from reconstructed tracks, by comparing the fitted trajectory of a given track with and without each hit included as a constraint (Fig. 3). The average resolution across the entire cell is 125 μm, compared with the design goal [4] of 140 μm just in the central region (about ± 2 to 7 mm). Momentum resolution has been measured using cosmic ray muons. The reconstruction software assumes that particles originate from the interaction point at the center of the detector, so that cosmic ray particles appear as two tracks. Transverse momentum resolution can be measured directly with cosmic rays, as the difference in momentum of the two track "halves" (Fig. 4), $\sigma(p_T)/p_T \sim 0.45\% + 0.13\% \times p_T$ (GeV/c), where the design goal was $0.21\% + 0.14\% \times p_T$.

The drift chamber is not the primary instrument for particle identification (PID) in BaBar. Nevertheless, it does contribute to the experiment's overall PID performance through measurement of dE/dx (Fig. 5). With a resolution of $\sim$ 7% (for high momentum electrons, consistent with early commissioning measurements), the drift chamber provides 2σ π/K separation up to about 700 MeV/c (Fig. 6).

3 Future Performance

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 [5]. As the luminosity increases, both the event rate and the per-event occupancy (due to backgrounds) will increase (Fig. 7). This combination will put extreme pressure on the data acquisition system, since the time required to readout each event will increase while the mean time between events will decrease. Figure 8 shows the result of extrapolations of drift chamber DAQ deadtime through 2007. The projected 50% deadtime has large but unquantifiable uncertanties, since the machine operation will be significantly different (magnet optics, bunch patterns, etc.) than it is today.

Two major upgrade projects are underway to alleviate this data acquisition bottleneck. First, a new Level 1 trigger system [6] is being commissioned. This new trigger produces full three-dimensional track fits (6 μs fit time, $\sigma_z \sim 4$ cm), to select events with tracks that originate from the interaction point. This should reduce the background rate by some 40%. A second upgrade involves making the DCH readout architecture highly parallel, reading out groups of 24 channels simultaneously. This should (Fig. 8) reduce the deadtime to just a few percent at 3×10^{34}cm^{-2} s^{-1}.

4 Aging and Damage

Aging in gaseous detectors is generally expressed as a fractional reduction in gain for a given specific charge accumulation. Figure 9 shows the gain, corrected for density, fit to a single exponential with a coefficient that includes step-functions for each known systematic shift,

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

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. 9). The result, $A = 0.517 \pm 0.023$ %/(mC/cm), compares well with other large experiments, which generally demonstrate aging of a few percent per mC/cm [7–10].

Integrating over the lifetime of the experiment implies a total charge accumulation of 50 to 80 mC/cm, with a concommittant reduction of about 25% in gain from current performance. Making small adjustments in the operating voltage ($\Delta V = 10\text{V} \Rightarrow \Delta G \sim 9\%$) as suggested by Fig. 10, could smooth out the performance over the lifetime of the experiment.

In addition to "classical" aging—the gradual loss of efficiency described above—drift chambers are subject to more dramatic and damaging effects. In July 1999, the chamber, which had been operated with a gas mix lacking water vapor, experienced frequent high-current discharges in a limited area. Turning off the affected region and adding a water bubbler to the gas system alleviated this situation. No additional discharges have been observed since 1999.

Several BaBar collaborating institutions have conducted studies of aging in chambers with the BaBar cell design, using strong ^{55}Fe sources. Since 2001, Adam Boyarski of SLAC has used such a chamber to investigate the underlying mechanisms of discharge [11], and various means of remediating the damage caused by them. As reported at the 2001 DESY Workshop on Aging [12], he has found that some additives (notably 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 12.8 mC/cm with a 6.4% reduction of gain since 1999. 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 likely 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. Major upgrade projects are underway to meet the challenges of accelerator performance an order of magnitude beyond the original design.

Acknowledgments

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support BaBar. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l'Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

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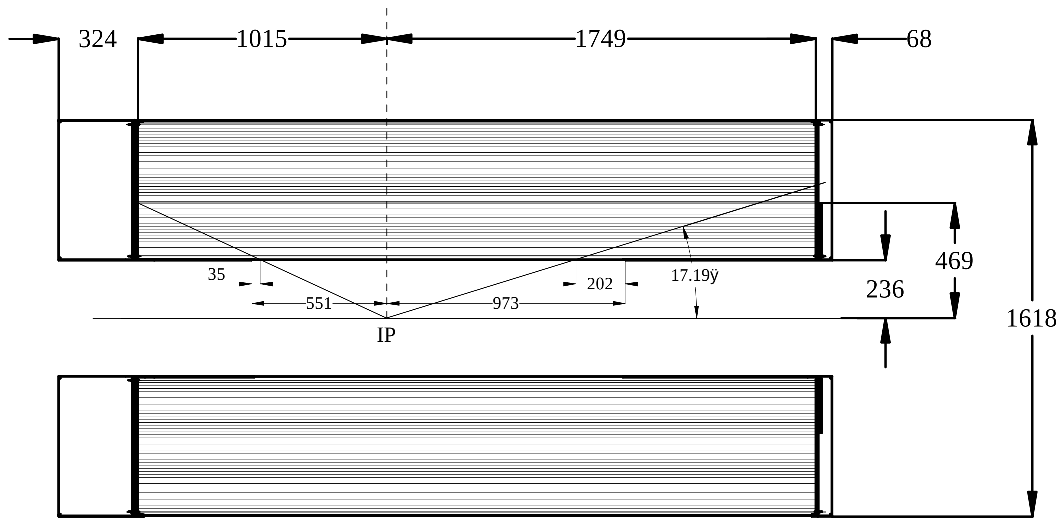

Fig. 1. Side view of BaBar drift chamber; the rear of the chamber is to the left. Linear dimensions are mm, angles are degrees.

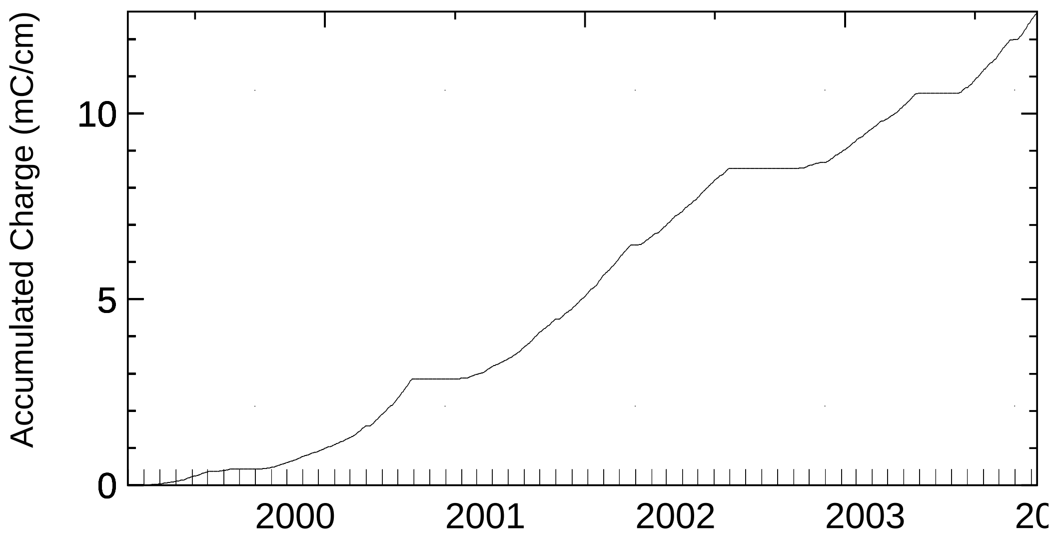

Fig. 2. Specific charge [mC/cm] accumulated since start of running, May 1999 through June 2003.

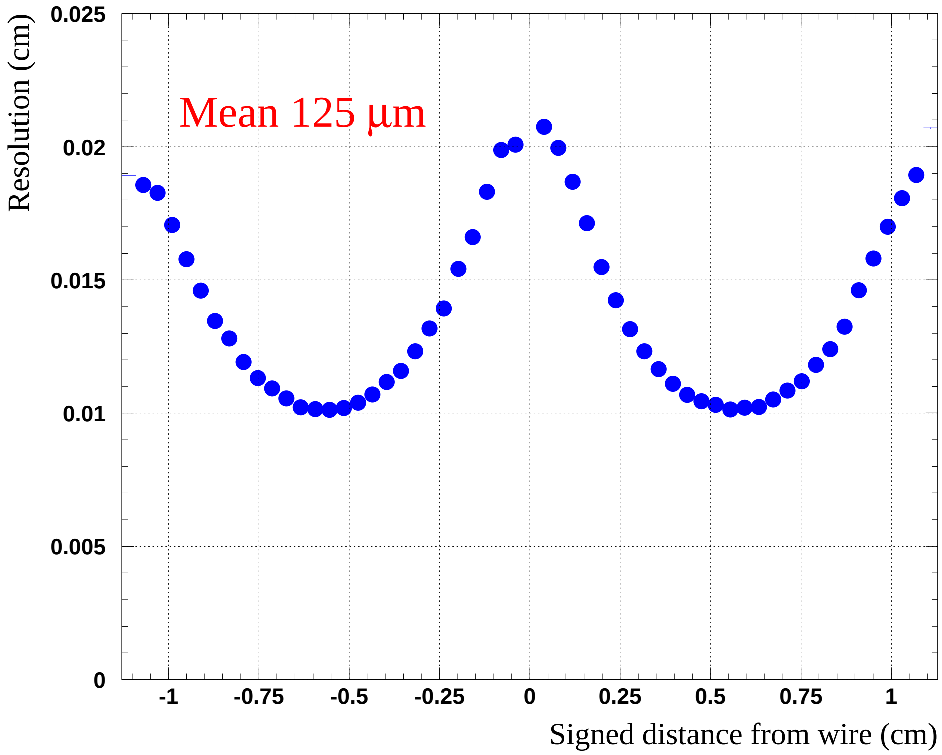

Fig. 3. Mean residuals of hits to fitted tracks *vs.* distance of track from sense wire.

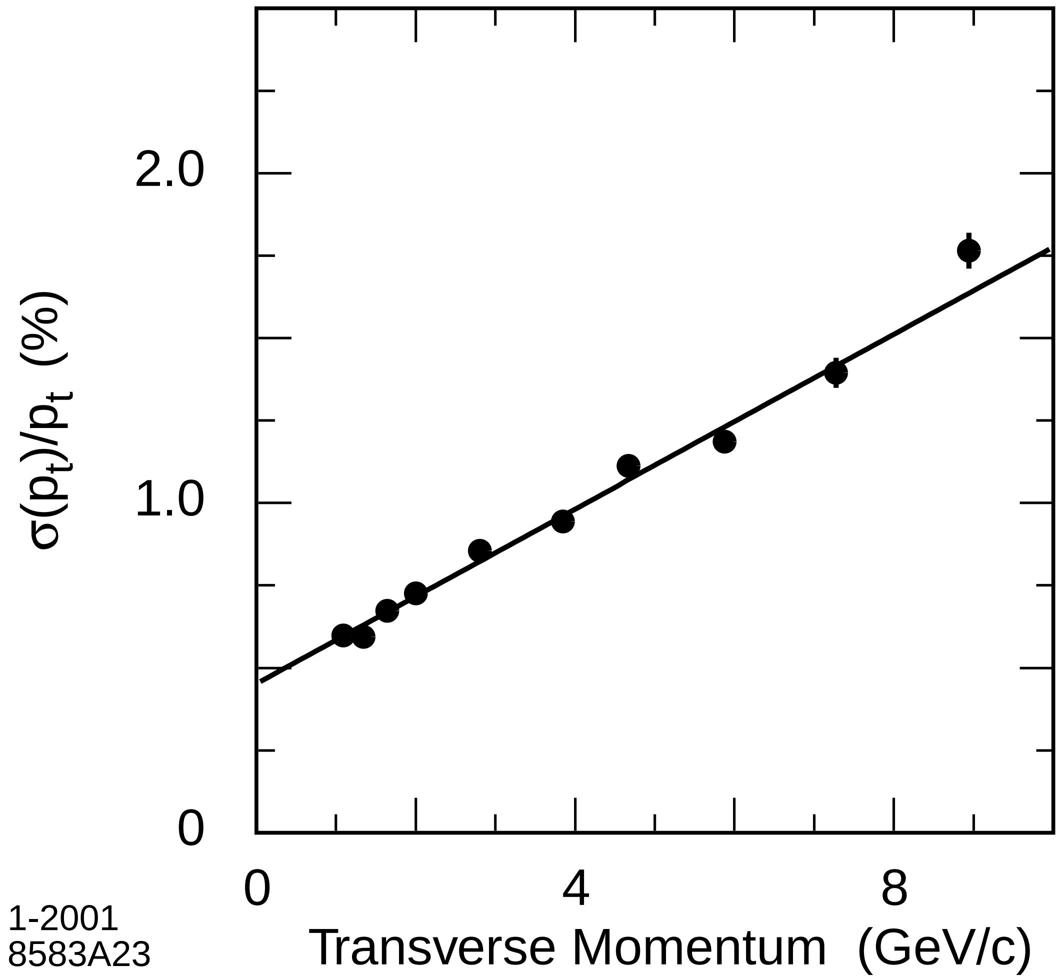

Fig. 4. Transverse momentum resolution for reconstructed cosmic ray tracks.

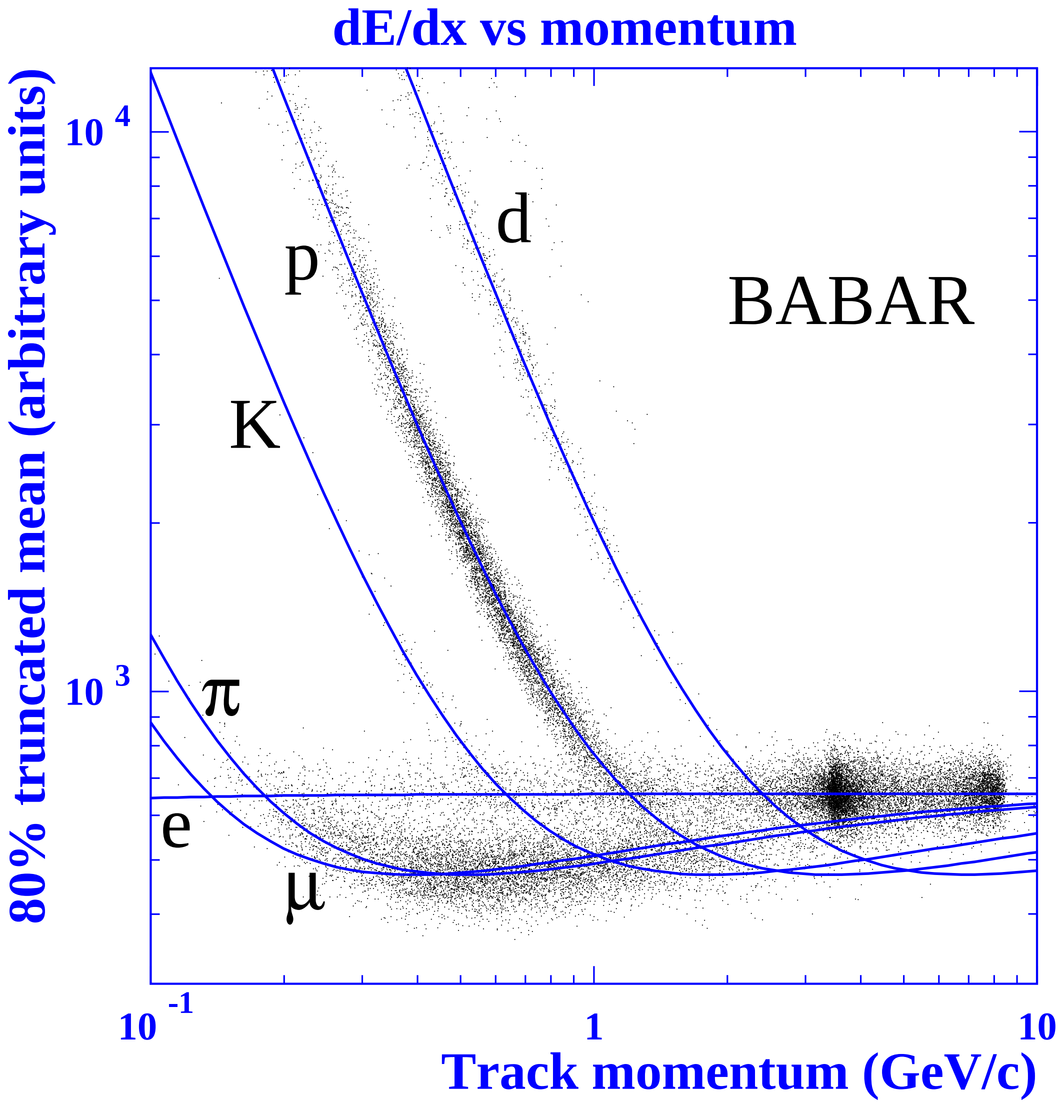

Fig. 5. dE/dx *vs.* momentum for inclusive sample of tracks.

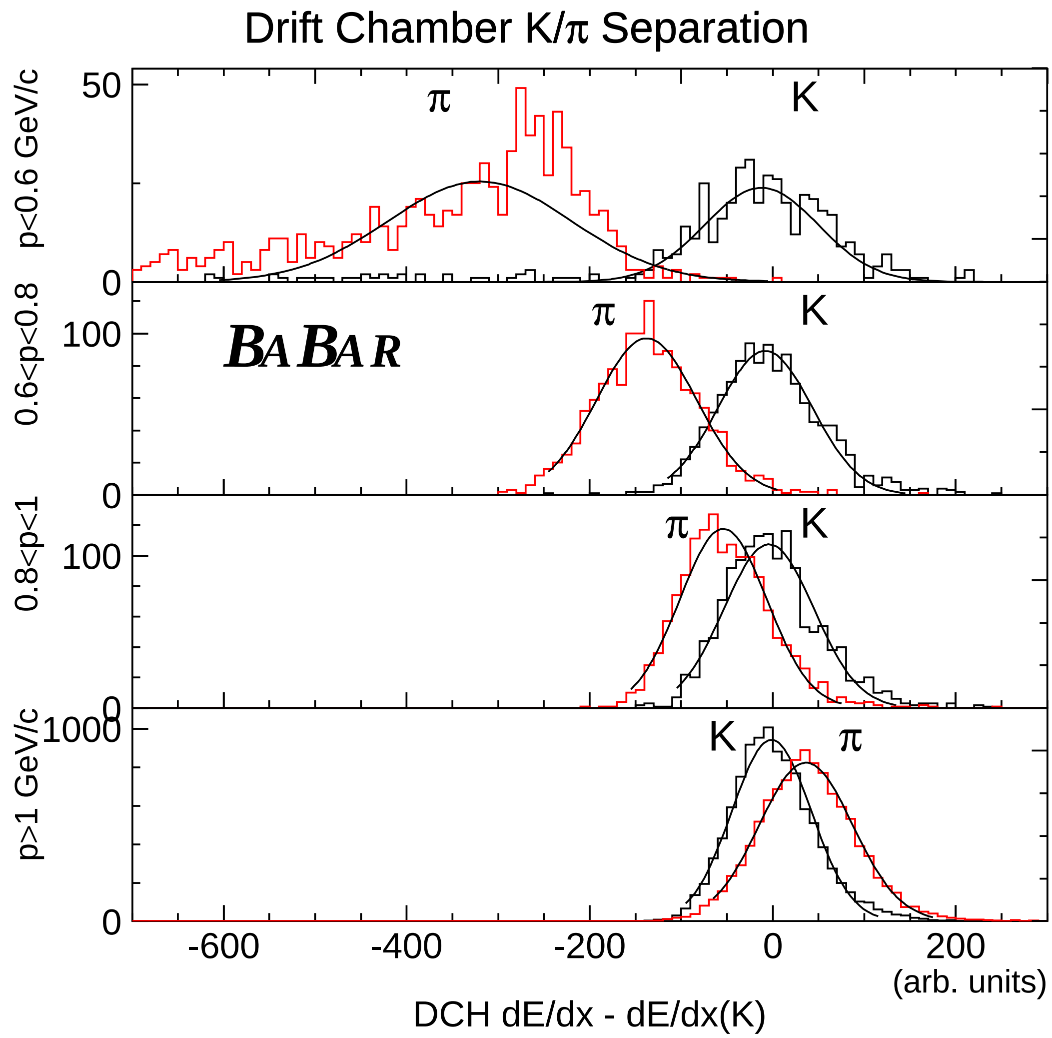

Fig. 6. Measured $\mathrm{d}E/\mathrm{d}x$ compared to that expected for kaons, in different momentum ranges indicated.

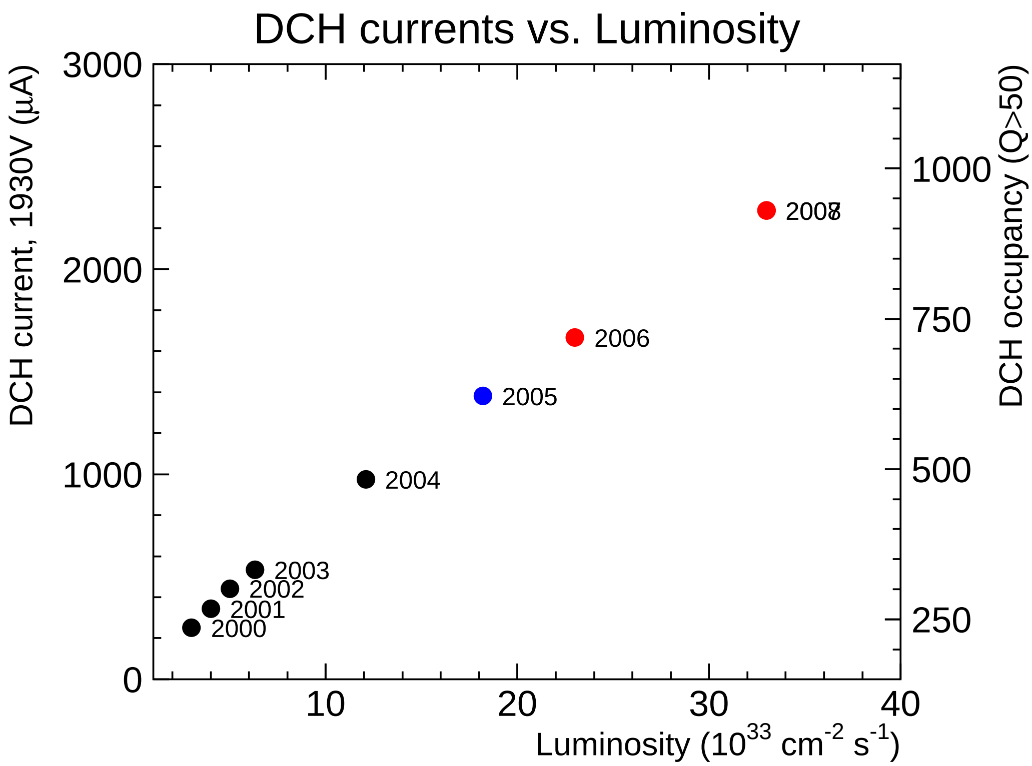

Fig. 7. Expected drift chamber HV current and readout occupancy, for projected PEP-II performance. Both current and occupancy are functions of luminosity and beam currents, as discussed in the text.

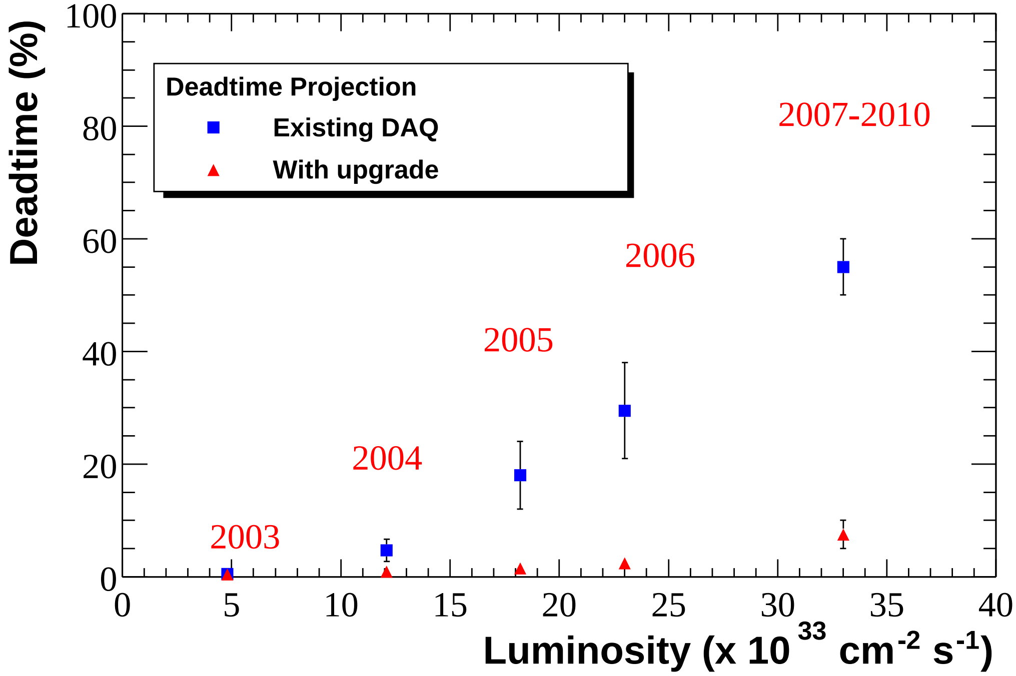

Fig. 8. Deadtime projections for drift chamber readout system as a function of delivered luminosity. Blue squares represent the current electronics; red triangles are for a major proposed upgrade.

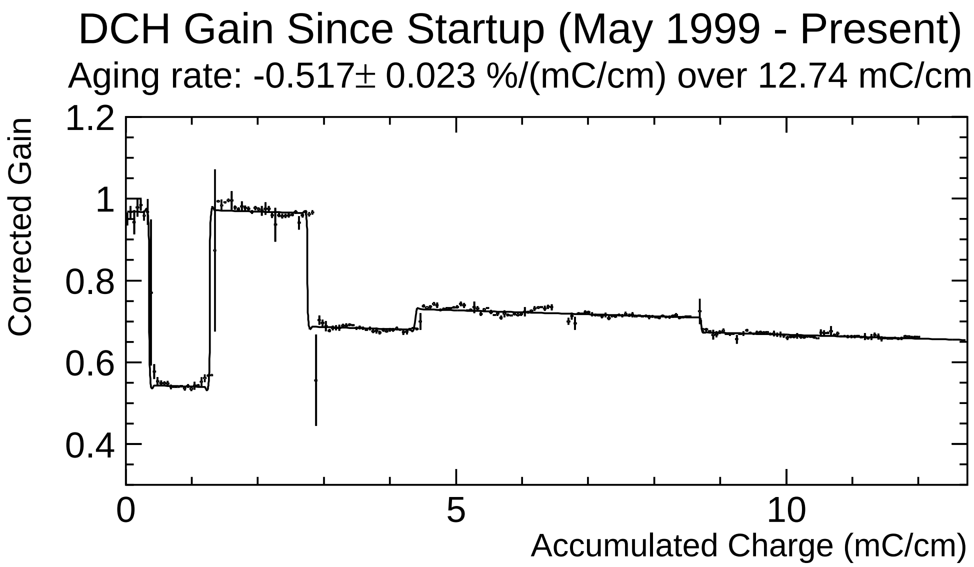

Fig. 9. Gain corrected for density *vs.* accumulated charge, fit to aging rate (1).

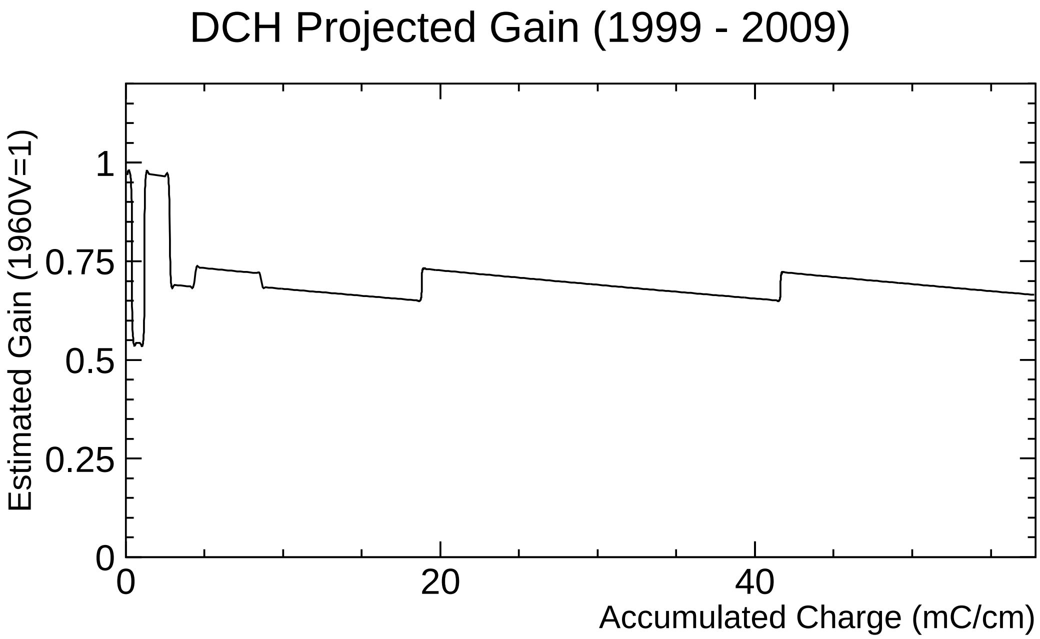

Fig. 10. Average gain $G(Q)$ expected up to 2009, based on PEP-II performance and DCH accumulated charge, and adjusting the operating voltage periodically to compensate for aging.