Performance and Aging of the BaBar Drift Chamber

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Super B Factory Workshop in Hawaii

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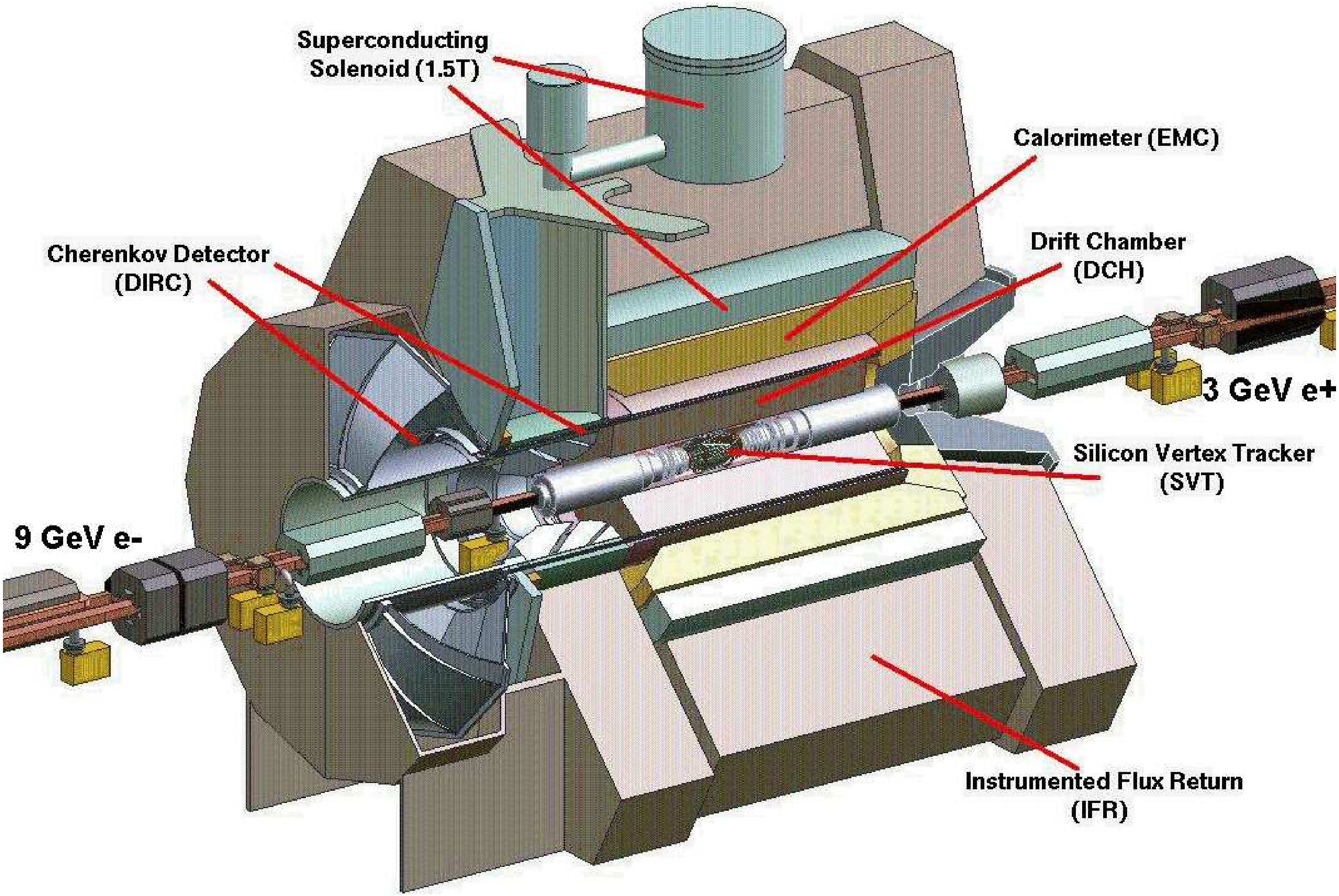
Outline

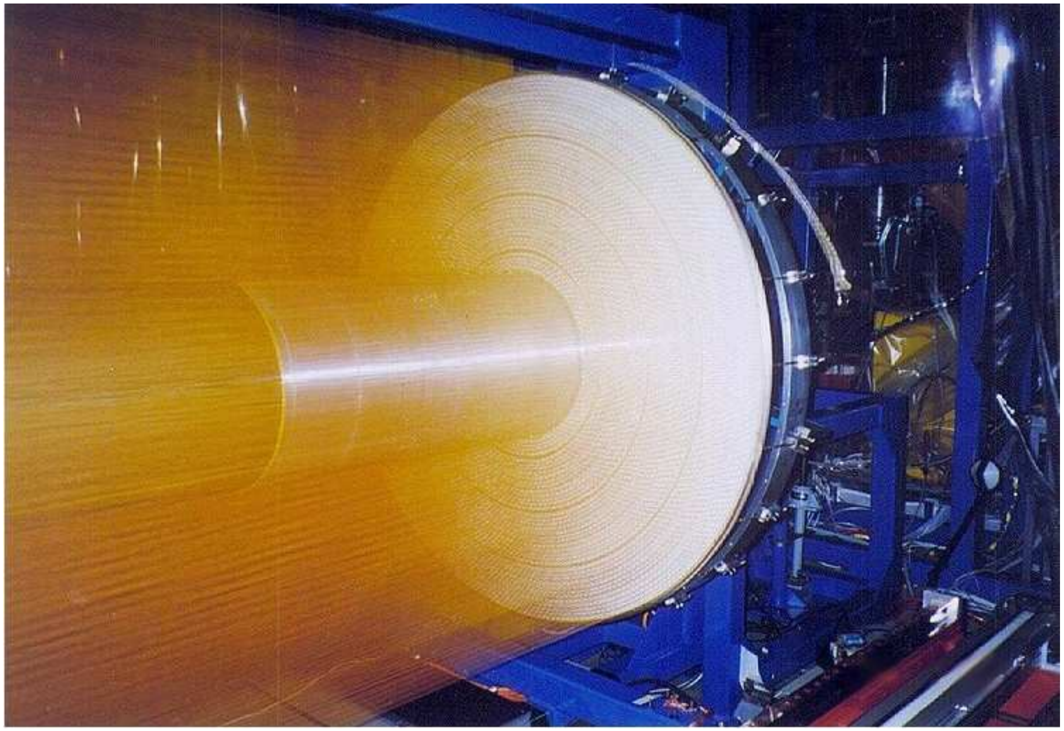
- Drift Chamber Design and Operation
- Tracking, dE/dx, and Physics
- Aging, Damage and Remediation
- Future Operations, Performance
- Summary and Outlook

BaBar Detector



BaBar Drift Chamber

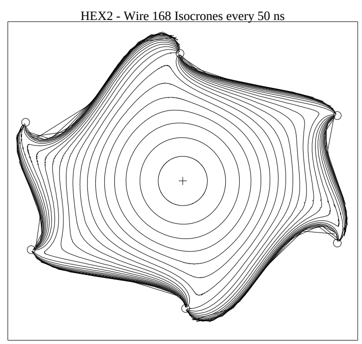
Main tracking detector in BaBar

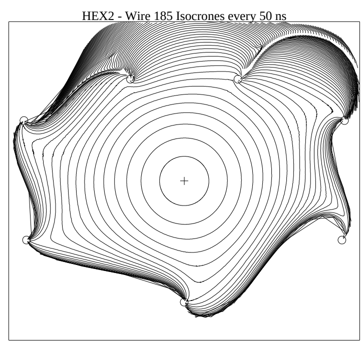


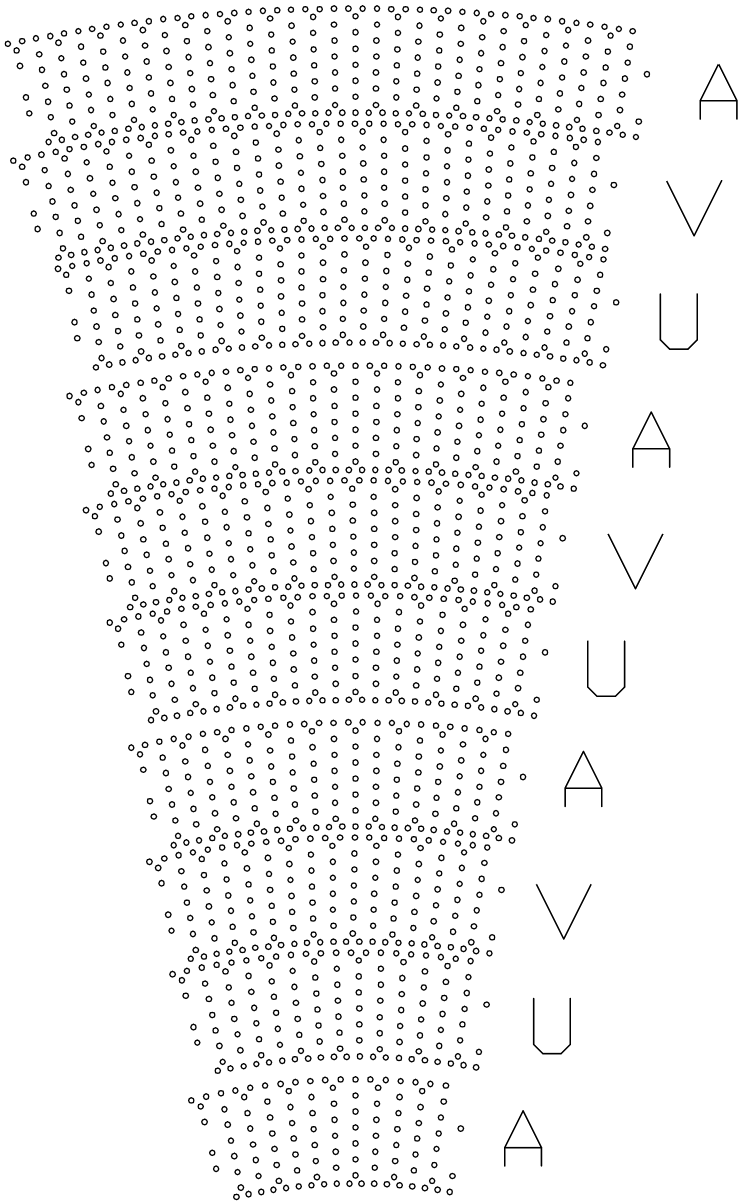
Surrounds beam pipe, final focus magnets, and silicon vertex tracker

BaBar Drift Chamber

Small hex cells (1∼2 cm)







10 superlayers of 4 layers each

Axial and stereo ($\sim 4^\circ$)

96–256 cells/superlayer

Sense wires 20 μm W-Rh (Au)

Field wires 120 μm Al (Au)

Guard wires 80 μm Al (Au)

DCH Operation

Gas mixture 80% helium, 20% isobutane, 3500–4000 ppm water vapor, $\sim$ 80 ppm O_2

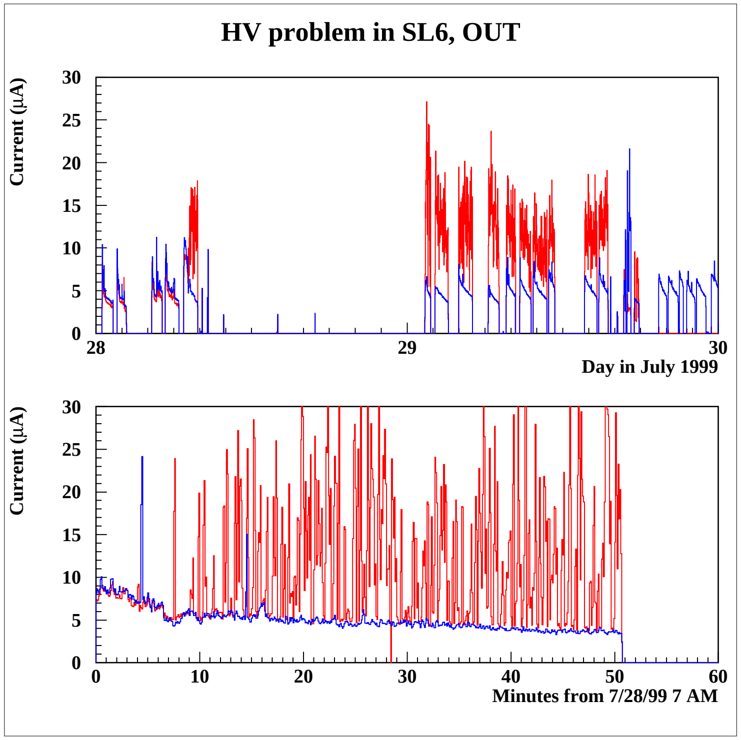
Designed to operate at 1960V

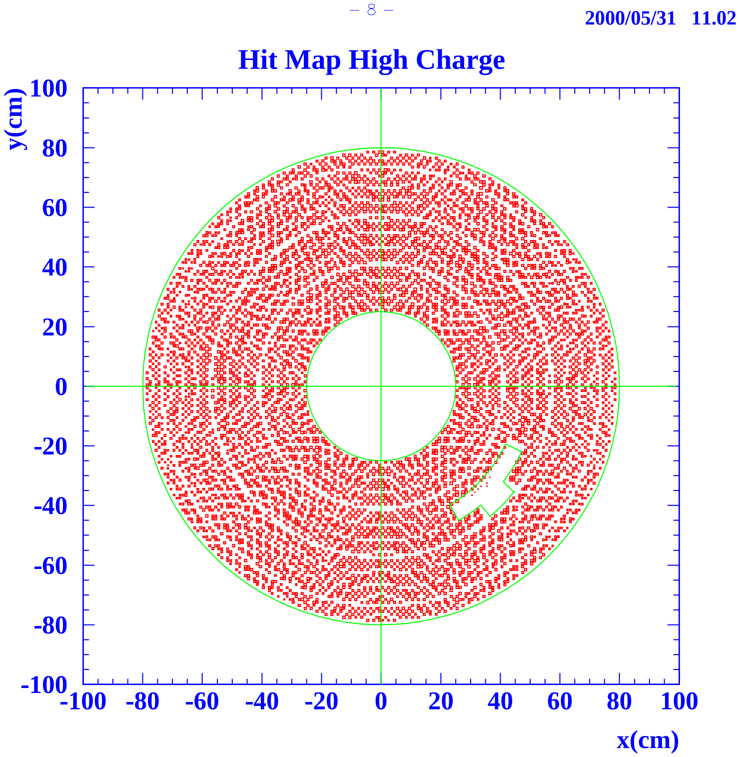
- Initially operated without water vapor
- Discharges observed in small region of chamber
- Reduced to 1900V (October 1999–July 2000)
- Since January 2001 (85% of total data) at 1930V

Premature Aging

May 1999: 80:20, $O_2 < 10$ ppm, $H_2O \lesssim 100$ ppm

28 July 1999: Large spikes in HV current





October 1999: Turned off affected region, added water

$\Longrightarrow$ No discharges observed in chamber since

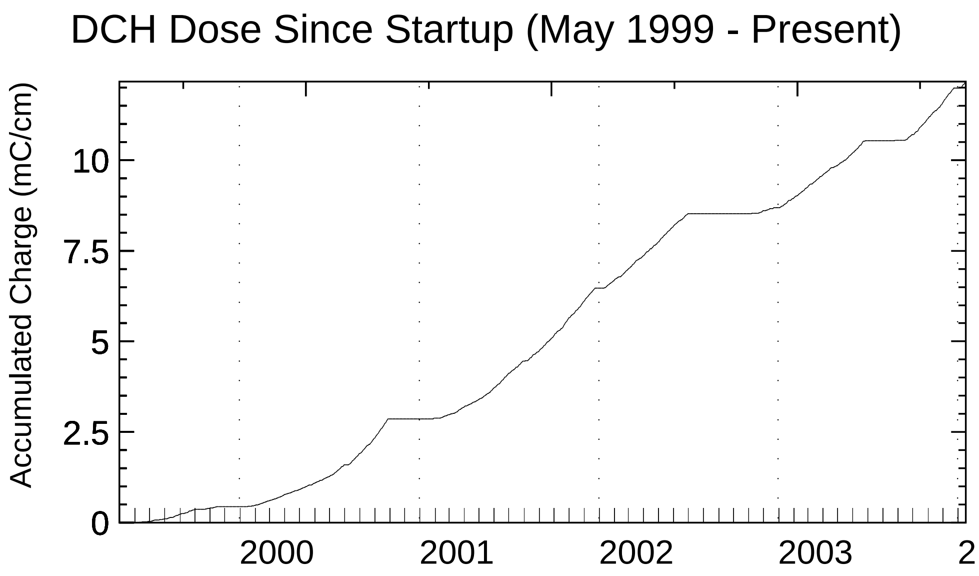
Accumulated Charge

Measure aging vs. accumulated charge per unit wire length

276.4 cm $\times$ 7104 cells
$=$ 19.6 km sense wire

400–600 μA w/beams
(0.25 nA/cm)

Recorded every second



Total charge 12.2 mC/cm in nearly five years

Reconstruction Performance

Hit resolution $\langle\sigma(\text{resid})\rangle \sim 125\ \mu$m

Target: 140 μm in middle region of cell

Momentum $\sigma(p_T)/p_T = 0.45\% + 0.15\%\, p_T$ (GeV/c)

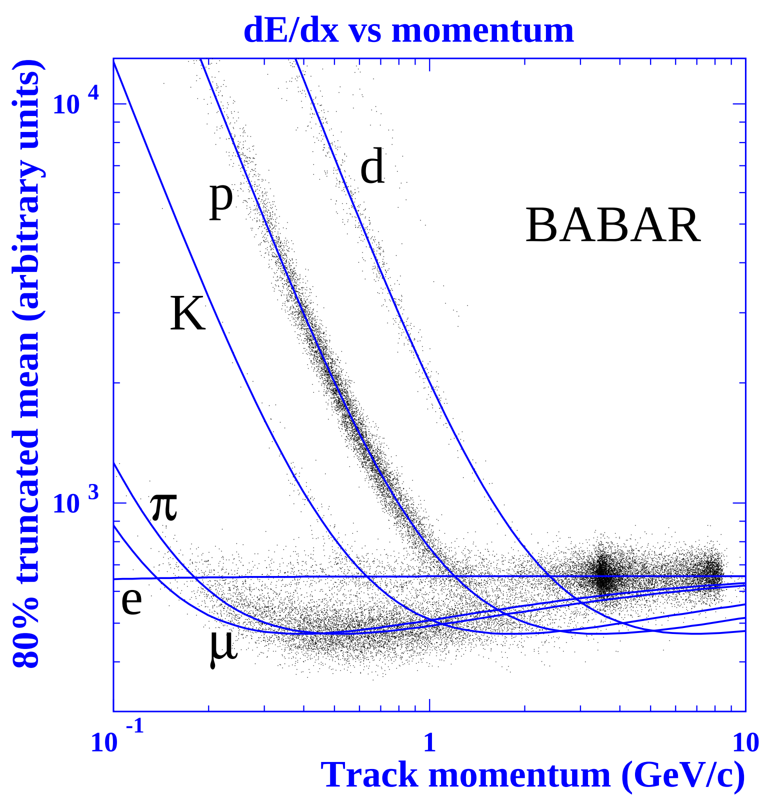
Target: 0.21% + 0.14% p_T

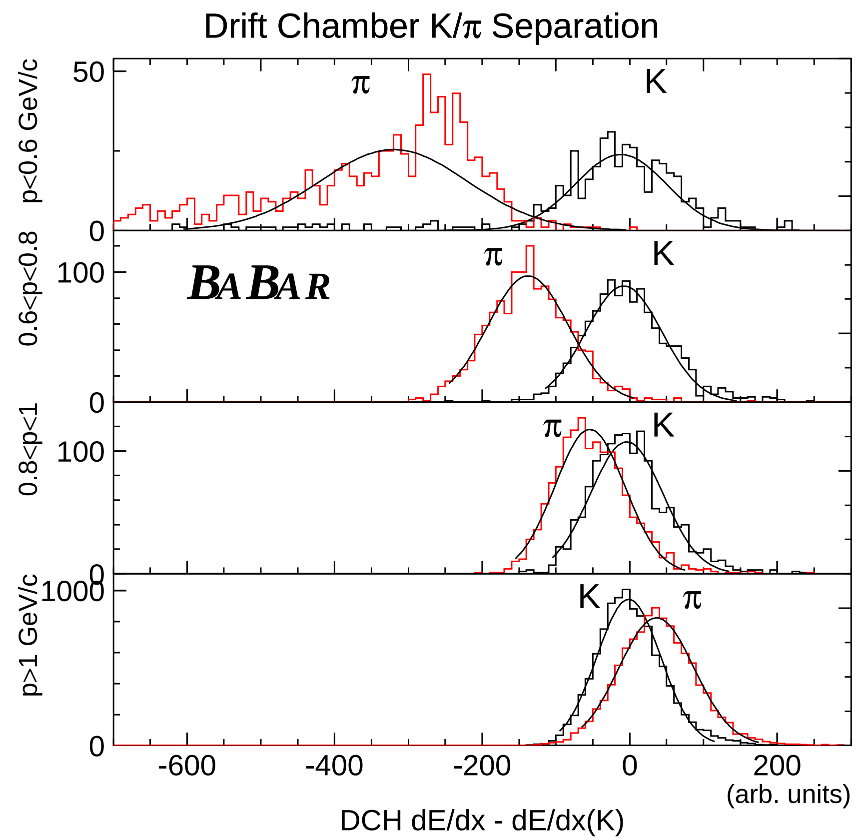
Tracking $>$ 95% matching with SVT tracks

dE/dx resolution $\sim$ 7.5%, $\pm$ (0.5-0.7)% bias

Early test results: 7.0%

dE/dx, Particle ID



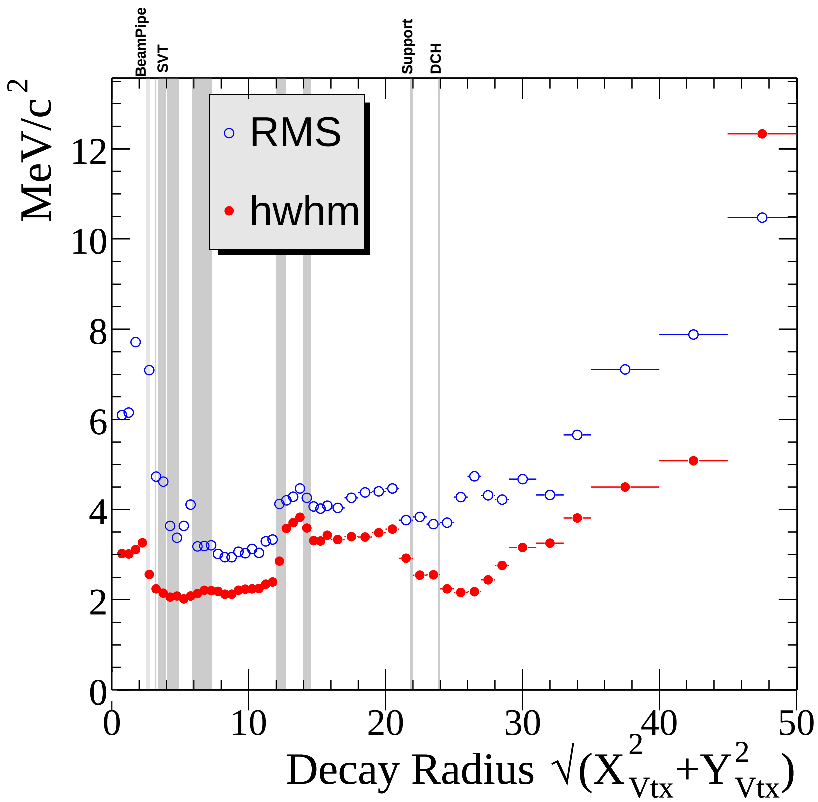


Good π/K separation up to $\sim$ 700 MeV/c.

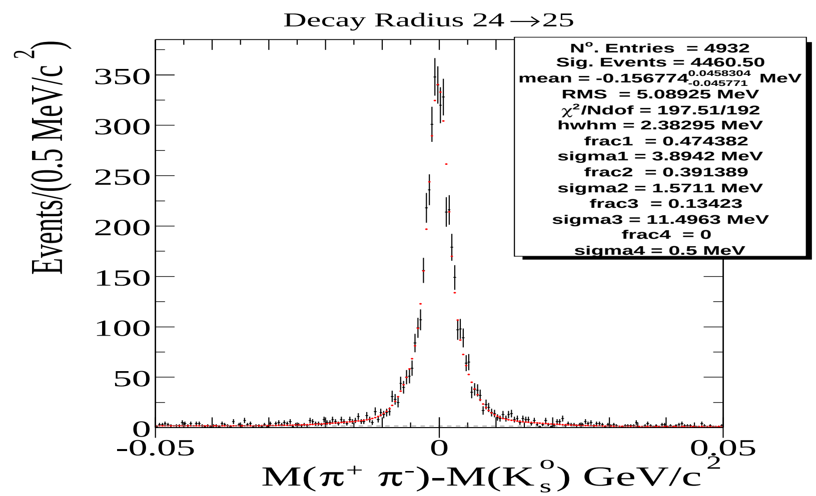
Provides confirmation of DIRC, and coverage outside of DIRC acceptance.

Physics Performance

Reconstruction of $K_S^0 \to \pi^+\pi^-$ at large radii



Fits in DCH comparable to DCH+SVT



"Jumps" due to material scattering uncertainty and fewer hits per track fit

Physics Performance (II)

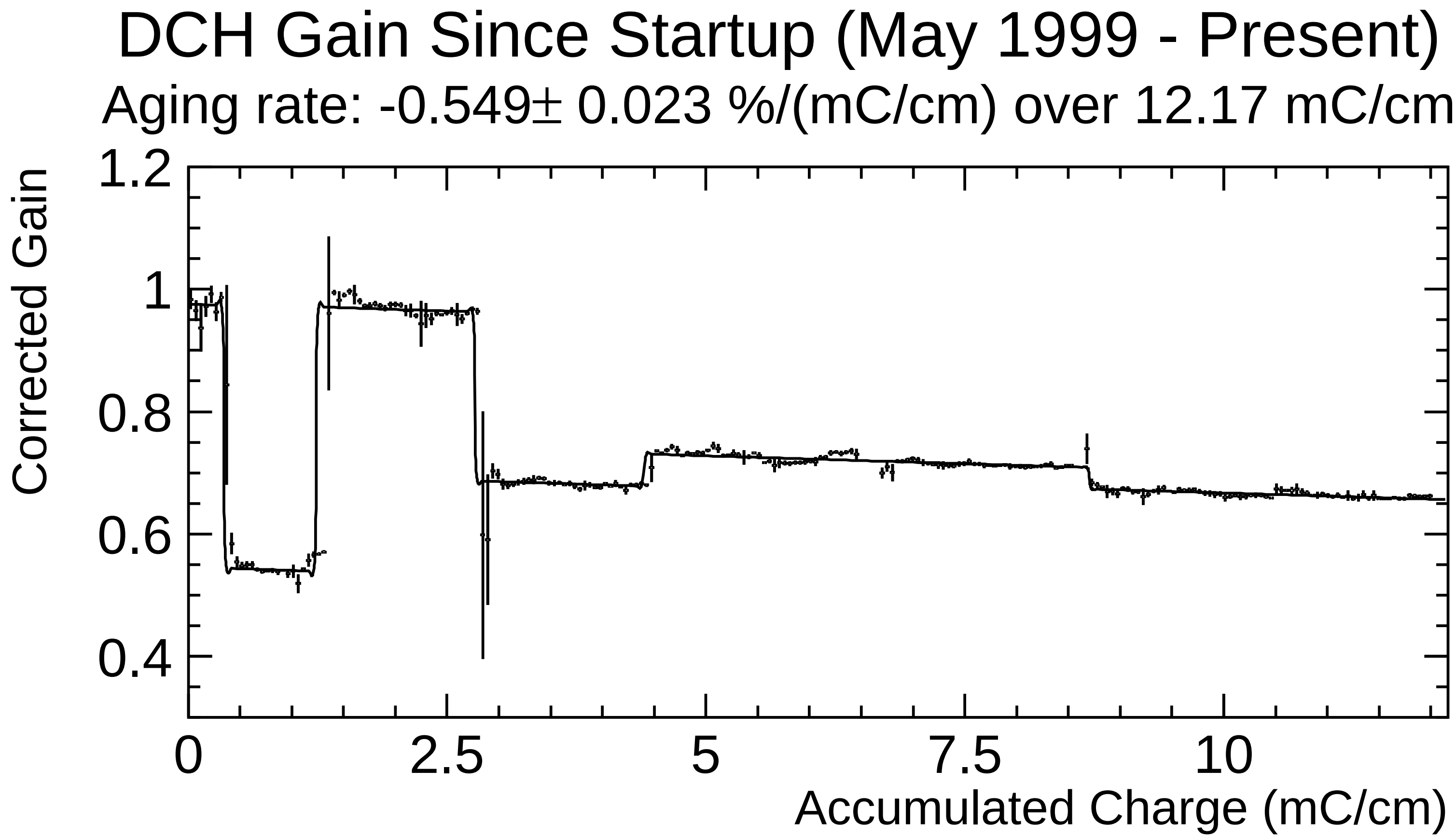
$$B \to D^{(*)} D^{(*)}, D^{*+} \to \pi^+ D^0, D^0 \to K^- \pi^+$$

(Monte Carlo generated events)

Momentum $\sigma(p)/p$	4.7×10^{-3}	
$D^0 \to K^- \pi^+$ σ(mass)	6.5 ± 0.2	MeV/c^2
$D^* \to \pi^+ D^0$ σ(mass)	0.80 ± 0.03	MeV/c^2

Gain vs. Time

$$G(Q) = \{G_0 + \Delta G_1|_{Q>Q_1} + \Delta G_2|_{Q>Q_2} + \ldots\} \exp(-AQ)$$



Long-term Damage

Besides aging, “sudden damage” always possible

- Transient discharges, voltage trips
- Buildup of deposits on wires
- Self-sustaining discharge (Malter effect)

Long-term studies of aging and remediation

- Lu Changguo (Princeton)
  - *Pisa Frontier Detectors Meeting* (2003)
- Adam Boyarski (SLAC)
  - *DESY Aging Workshop* (2001)
  - *IEEE NSS/MIC* (2003)
- Other groups (Colorado, Montreal, Novosibirsk, ...)

Accumulated several times BaBar lifetime charge

Suppressing Damage

Running chamber without water vapor allows polymer (dielectric) buildup, increases likelihood of discharges

- Presumed mechanism for damage seen in July 1999

Princeton test chamber run dry up to 130 mC/cm, saw discharges, high singles rate, 10% drop in gain

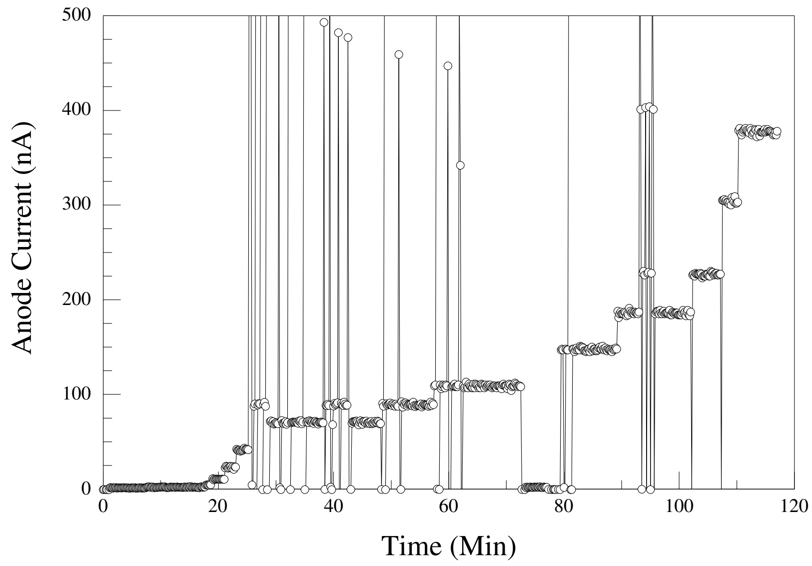
- Adding 1500–4000 ppm H_2O eliminated discharges
- Gain stabilized at 0.9 of initial value, up to 300 mC/cm

Poor performance returned when water removed

Remediating Damage

Excess current can trigger self-sustaining discharges

Maximum safe current significantly reduced over time



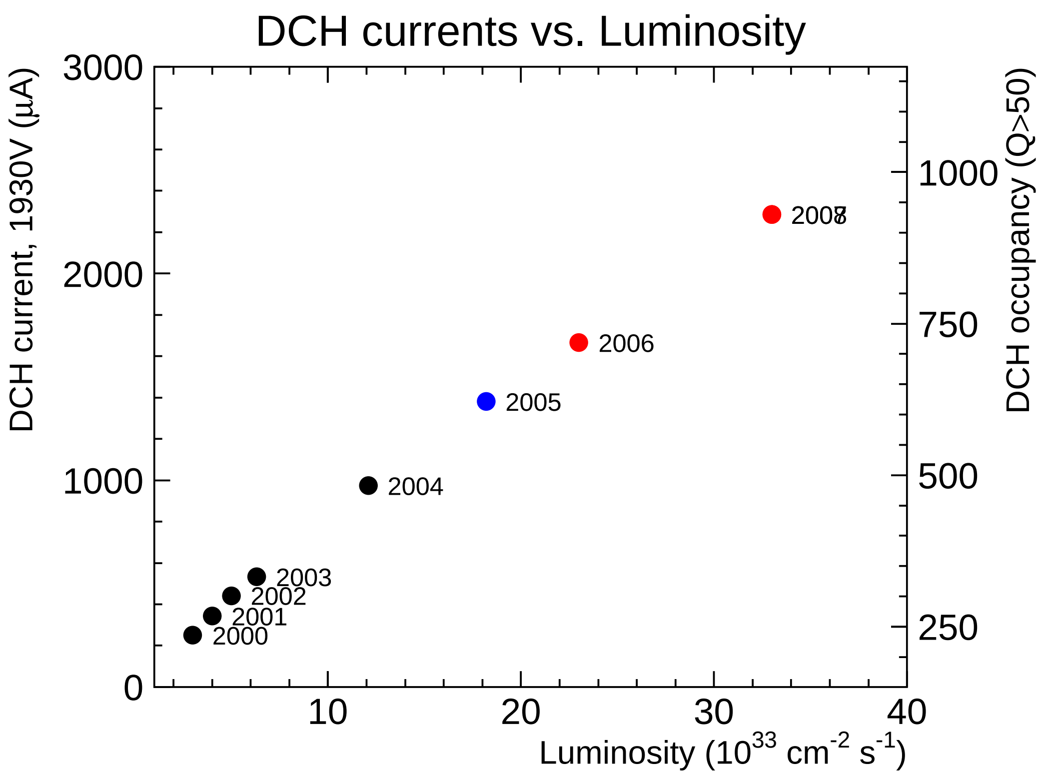
Adam Boyarski, SLAC

"Training" with oxygen (500 ppm) gradually raises current limit to original construction. Maintained after O_2 removed.

Further study underway to confirm long-term performance

Future Performance

Can we operate at ten times design luminosity?



High occupancy?

High currents?

High rates?

Aging problems?

DCH performance computed from beam currents and luminosity

By 2008, average occupancy, current, trigger rates will be tripled from current (2003) conditions.

Tracking at High Luminosity

Mix Monte Carlo $B \to D^{(*)}D^{(*)}$ with real random-trigger data

Multiple triggers overlaid to match luminosity extrapolations

Evaluate physics quality relative to current performance

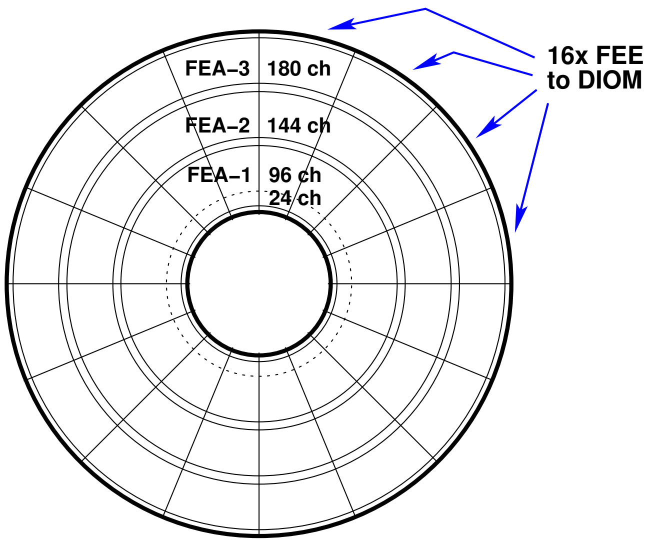
Compared to design 3×10^{33} cm^{-2} s^{-1}	2×10^{34} ($3\times$ bkg)	4×10^{34} ($5\times$ bkg)	4×10^{34} ($10\times$ bkg)
Tracking eff. (%)	$98.6 \pm 0.1 \pm 0.7$	$97.4 \pm 0.1 \pm 1.0$	
Momentum $\sigma(p)/p = 4.7\times10^{-3}$	$+4.2 \times 10^{-5}$	$+5.5 \times 10^{-5}$	
$D^0 \to K^+\pi^-$ (%)	96.0 ± 0.5	95.5 ± 0.5	80 ± 3
D^0 Mass, σ 6.5 ± 0.2 MeV/c^2	6.5 ± 0.2	6.4 ± 0.2	7.0 ± 0.3
$D^* \to D^0\pi$ (%)	84.4 ± 1.1	75.0 ± 1.3	25 ± 2
D^* Mass, σ 0.80 ± 0.03 MeV/c^2	0.97 ± 0.04	1.50 ± 0.08	3.2 ± 0.8

High Rate Data Acquisition

Modular, parallel electronics

4-buffer pipeline per channel

16 elements per quadrant
via 1 GHz fiber to processor



Readout time set by single element's occupancy

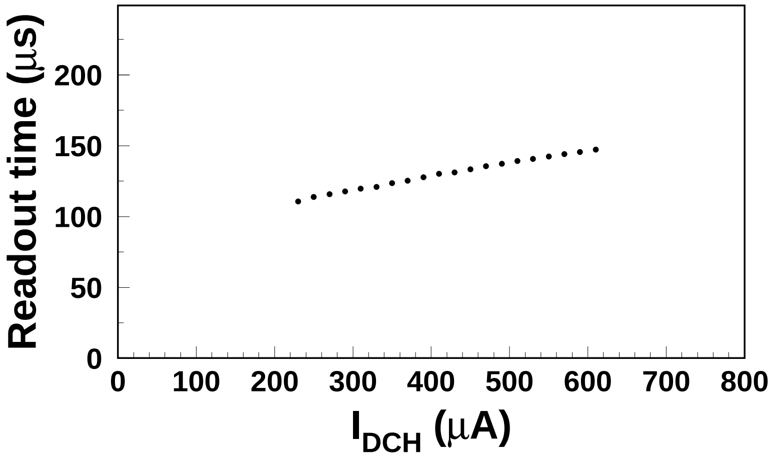
$$T_{DAQ} = 8\left\{8 + \sum^{N}(32m_i + 4)\right\} \times 16.7 + 33 \text{ ns}$$

N non-empty chips, $m_i = 1$–8 hits each

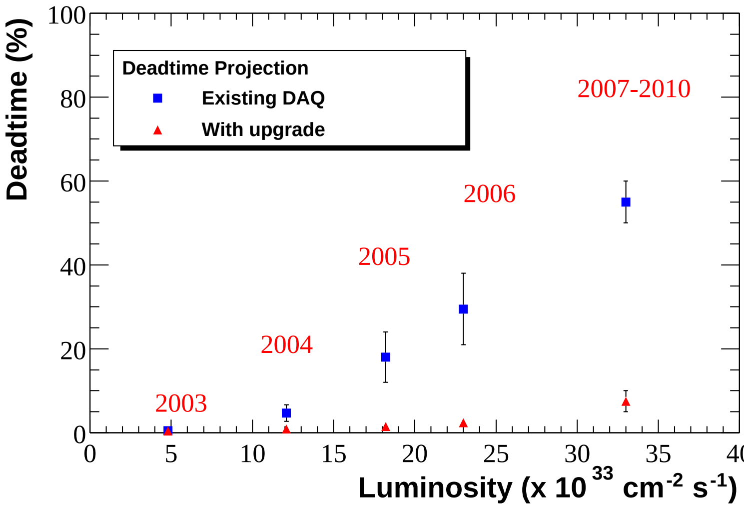
$\Longrightarrow$ 45 hits requires 200 μs (5 kHz)

High Rate Data Acquisition

Readout time scales with HV current, luminosity (uniform occupancy)



M. Cristinziani



C. Jessop

Deadtime when readout ~ trigger rate

Expect 30–40% d.t. by 2006, 50+% by 2007

High Rate Data Acquisition

Redesign front-end with extreme parallelism

- Three chips per logical "element"
- $\leq$ 24 channel serial readout
- $<$ 105–140 μs readout time, 7 kHz rate

Essentially no deadtime for normal running, through lifetime of Babar.

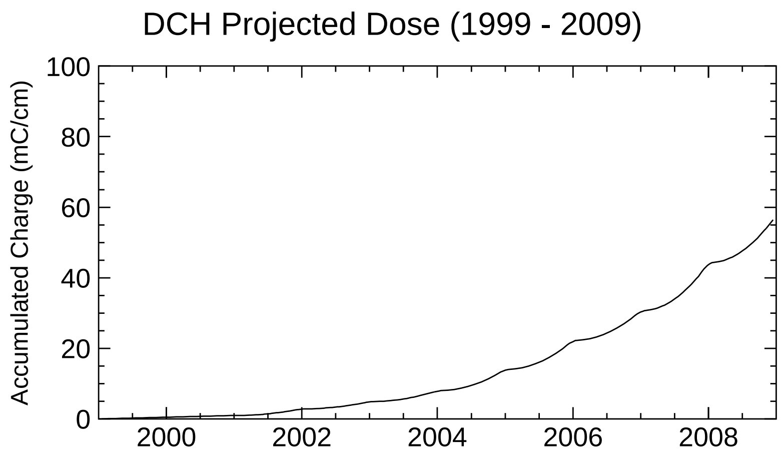
Requires 20 fiber readout processors

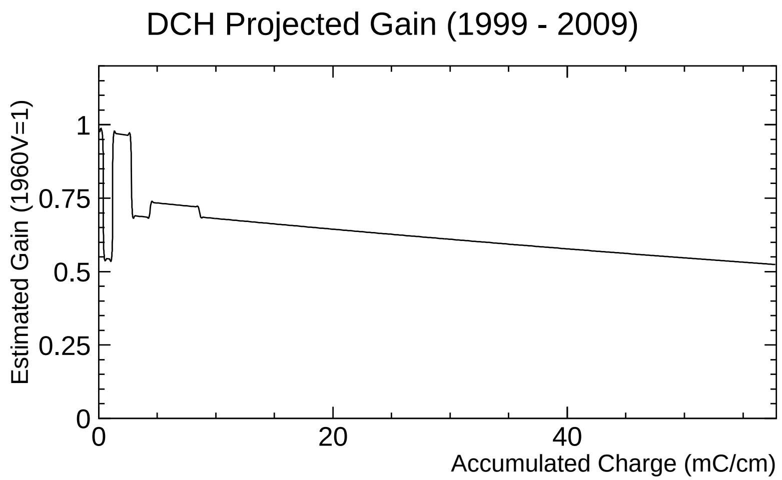
Targeting installation in mid-2005

Effect of Aging on Gain

Integrate current to estimate accumulated charge

- Include expected running year by year
- Linear lumi improvement within years





Use fitted aging function to extrapolate gain

- Assume 1930V operation, no gas changes

Compensating for Aging

By 2007, gain at 1930V could be $\gtrsim$ 25% below current performance

- Significant impact on trigger, track finding
- Non-uniform acceptance, efficiency

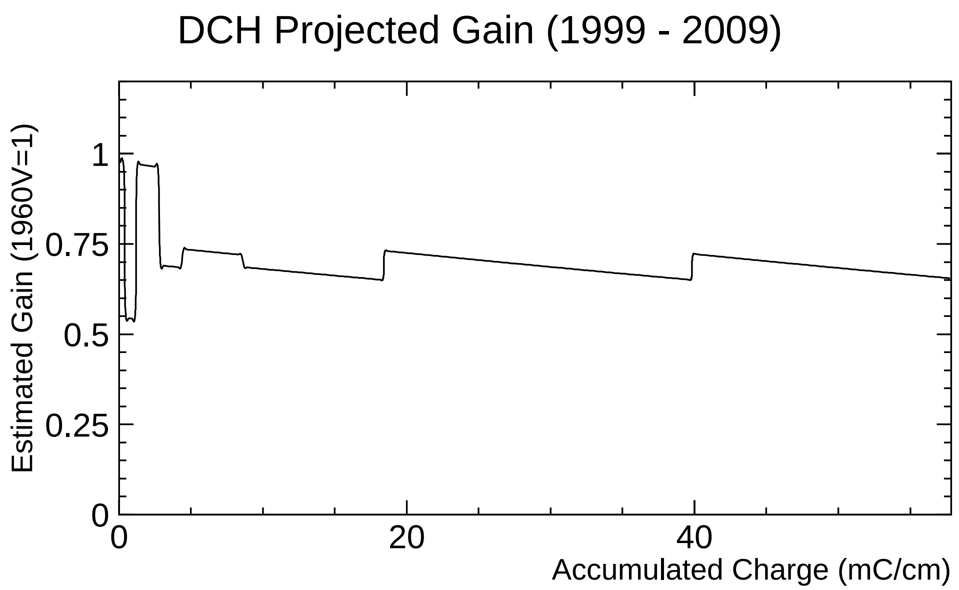
Compensate for gain loss by increasing voltage

- Lower gain, same HV current as now

$+10\text{V} \Rightarrow \Delta G \sim +0.09$

Raise when $G \lesssim 0.65$

E.g. 2006, 2008



Summary and Outlook

BaBar Drift Chamber has been operating smoothly since October 1999

- Tracking performance up to design
- dE/dx performance good, improvable
- Excellent operational efficiency

Reasonable aging rate observed so far

- Accumulated 12.2 mC/cm after five years
- Gain fits well for simple aging 0.55%/(mC/cm)
- Overall reduction 15% since startup

Comparable to other large experiments

Summary and Outlook

Expect reliable performance over 10-year lifetime

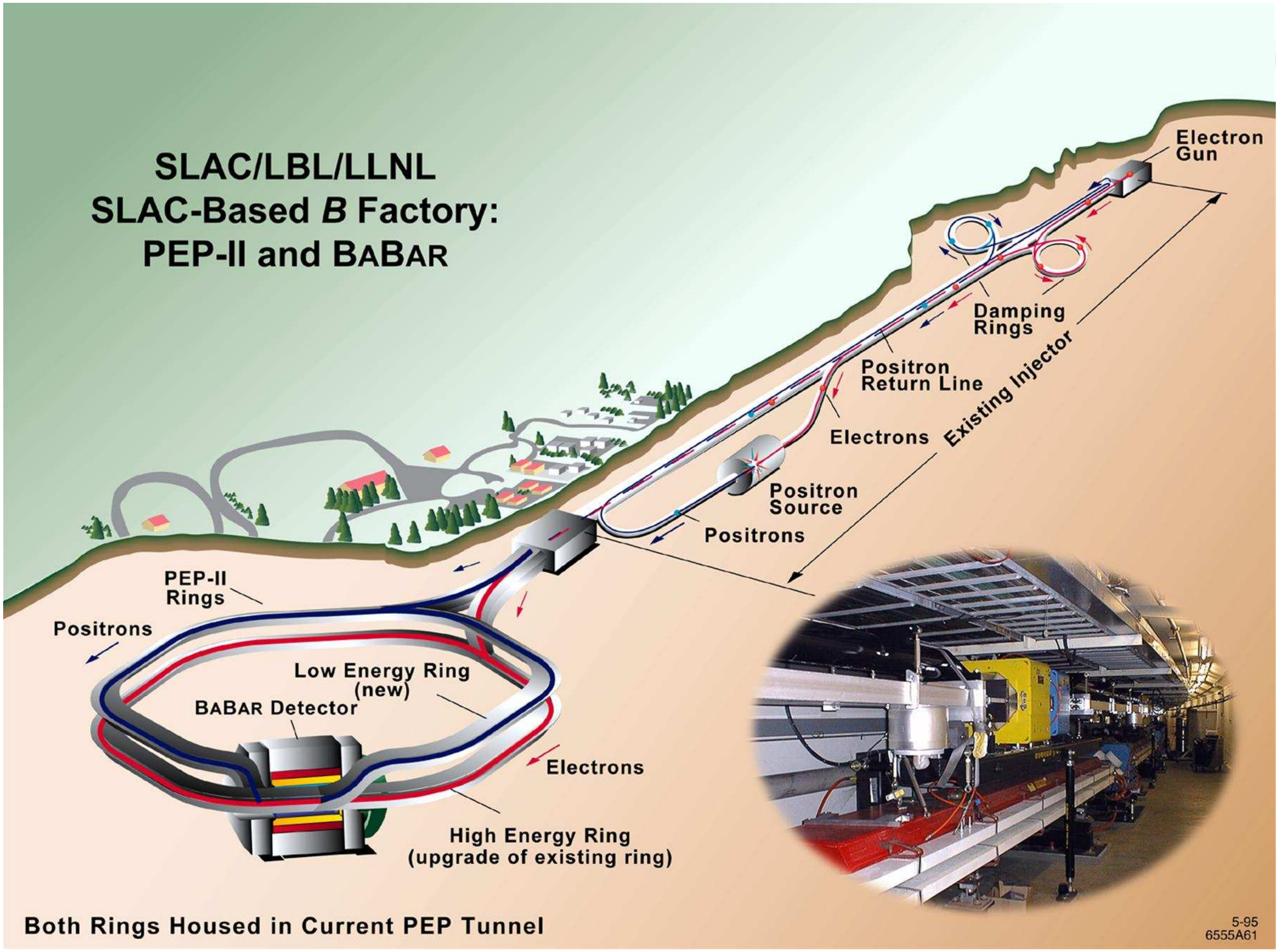
- 50–80 mC/cm total charge, 25% loss of gain
- ⇒ Well below limits found in test chambers
- Minimal degradation of physics performance

Increasing data rate will require significant electronics upgrade

Damage and aging may be remediated with additives

- 3500 ppm H_2O should prevent discharges
- Aging may be compensated by adjusting voltage

Supplemental Information


SLAC/LBL/LLNL
SLAC-Based B Factory:
PEP-II and BABAR
Electron Gun
Damping Rings
Positron Return Line
Existing Injector
Electrons
Positron Source
Positrons
PEP-II Rings
Positrons
Low Energy Ring (new)
BABAR Detector
Electrons
High Energy Ring (upgrade of existing ring)
Both Rings Housed in Current PEP Tunnel
5-95
6555A61

The PEP-II B Factory

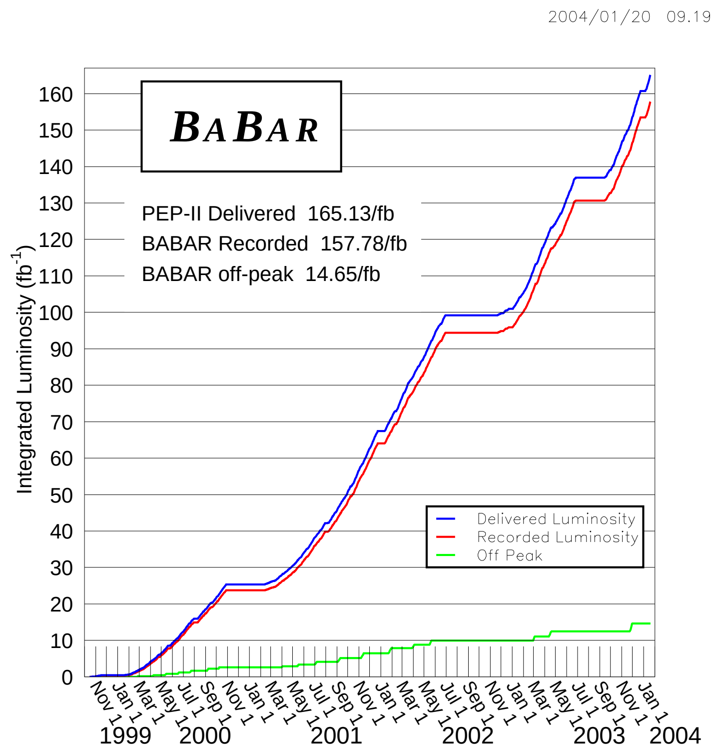
Asymmetric e^+e^- collider: $E(e^+) = 3.1$ GeV, $E(e^-) = 9$ GeV
$\Rightarrow$ 10.58 GeV CMS: $\Upsilon(4S) \to B^+B^-, B^0\overline{B}^0$

B decay length increased from $\sim 30\ \mu$m (CMS) to $\sim 250\ \mu$m (lab), allowing precision time-dependent measurements

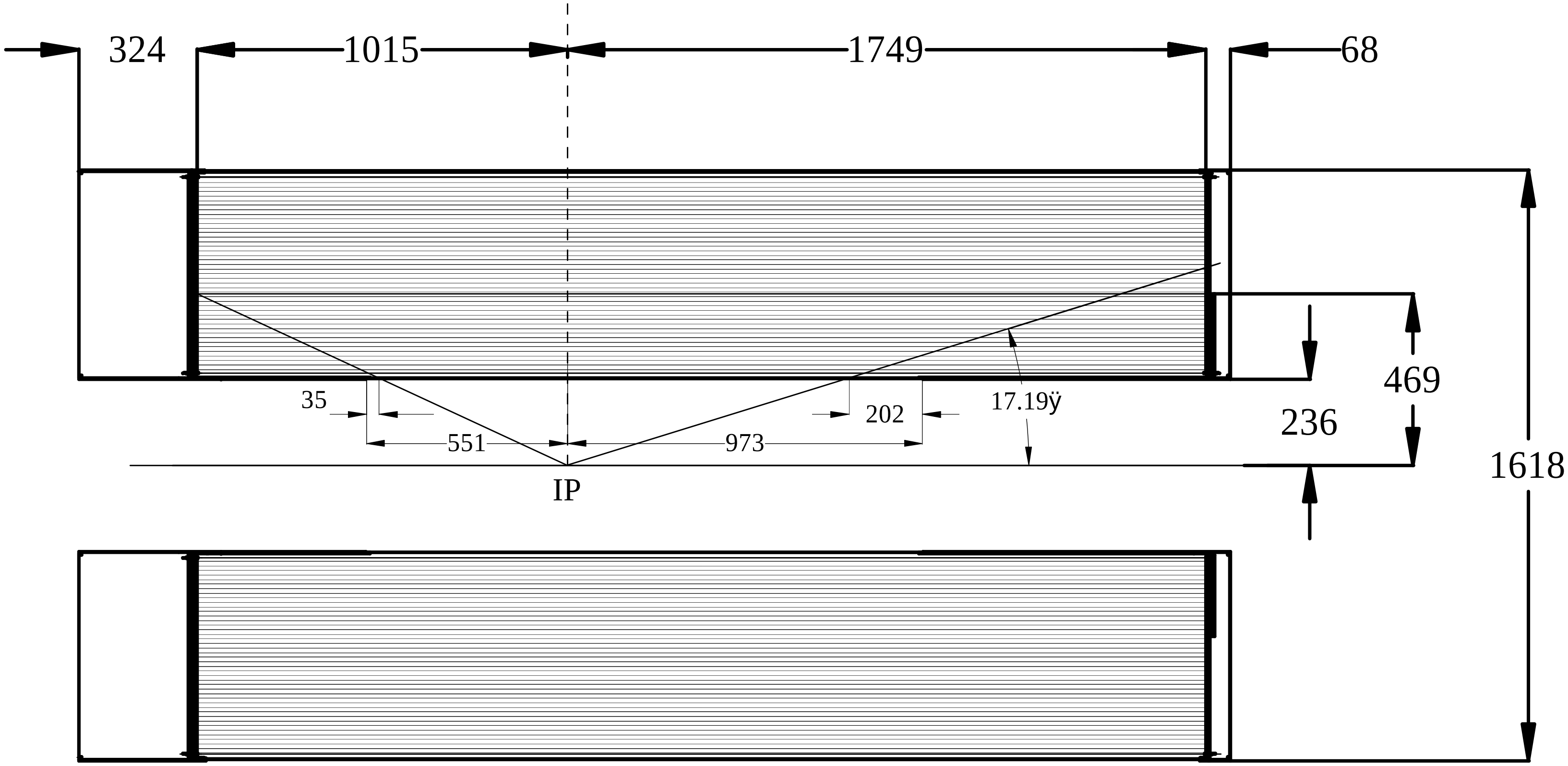
PEP-II delivers luminosity in excess of $6\times\ 10^{33}$ cm^{-2} s^{-1}

Over 165 fb^{-1} delivered to BaBar ($\sim$ 9% off resonance)

BaBar runs $>$ 95% efficiency: nearly 120 million $B\overline{B}$ pairs



BaBar Drift Chamber

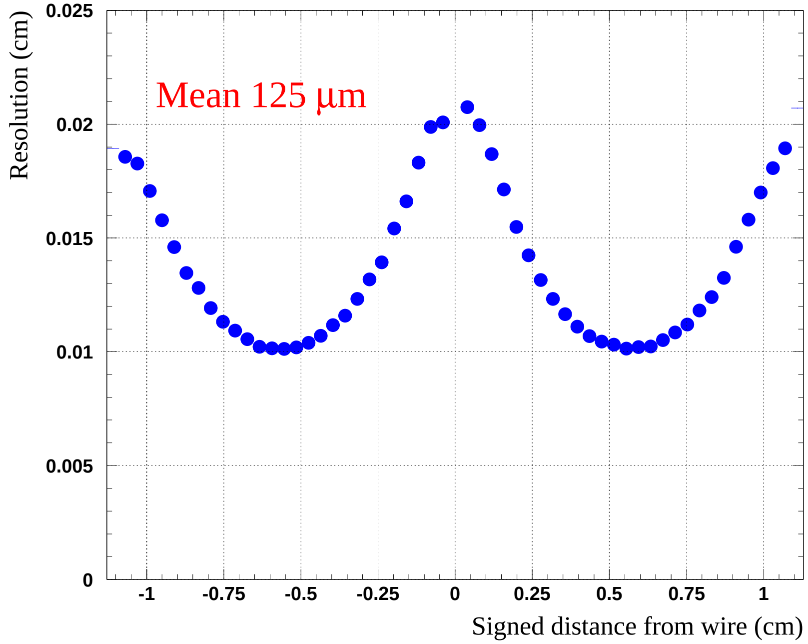


Dimensions in mm

24 cm inner radius	Be & Al inner cylinder
81 cm outer radius	Carbon fiber/Nomex outer
2.8 m length	2.5 (1.2) cm Al end plates
IP 37 cm behind center	All electronics on rear

Track Fitting

Residuals of hits vs. distance from sense wire



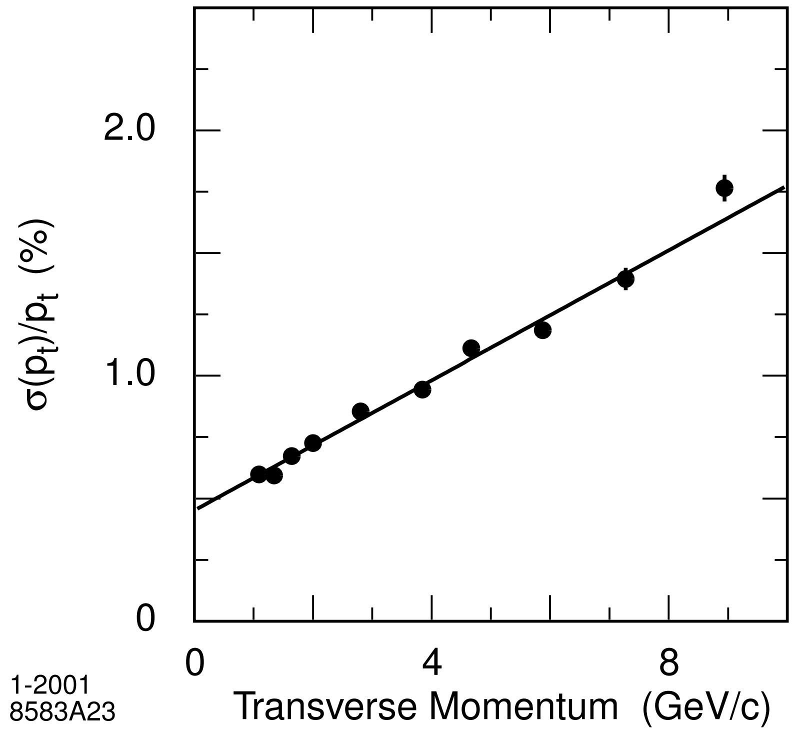
$$\langle\sigma(\text{resid})\rangle \sim 125\ \mu\text{m}$$

Design target: 140 μm in middle region of cell

$d(t)$: pair of 7th order Chebyshev functions, each side of cell. Adjusted for angle through cell.

Track Fitting

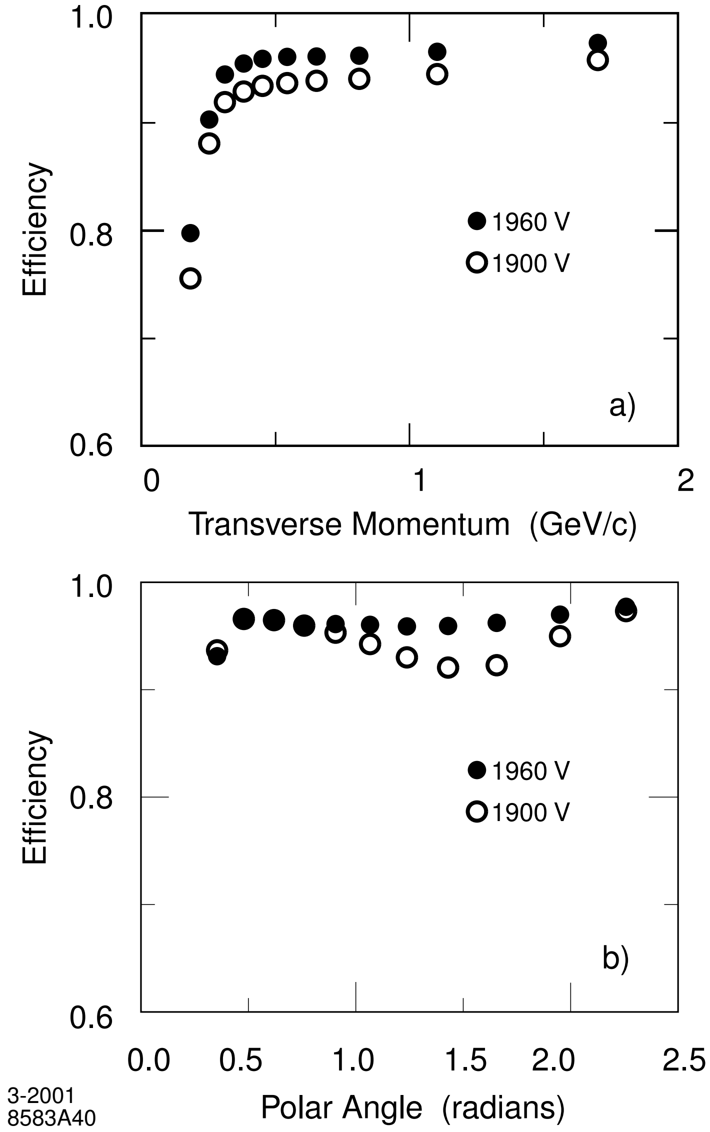
Momentum resolution from cosmic rays



$$\sigma(p_T)/p_T = 0.45\% + 0.15\%\ p_T\ (\mathrm{GeV}/c)$$

Design target: $0.21\% + 0.14\%\ p_T$

Tracking Efficiency



"Pseudo-efficiency"

Count DCH+SVT tracks vs. total SVT tracks

Measure acceptance in

- momentum or p_T
- polar angle
- azimuth (not shown)

DCH and SVT not independent

Physics Performance (III)

$D^0 \to K^- \pi^+$ reconstruction efficiency vs. ϕ

ask David Williams for plot

Quantifying Gain

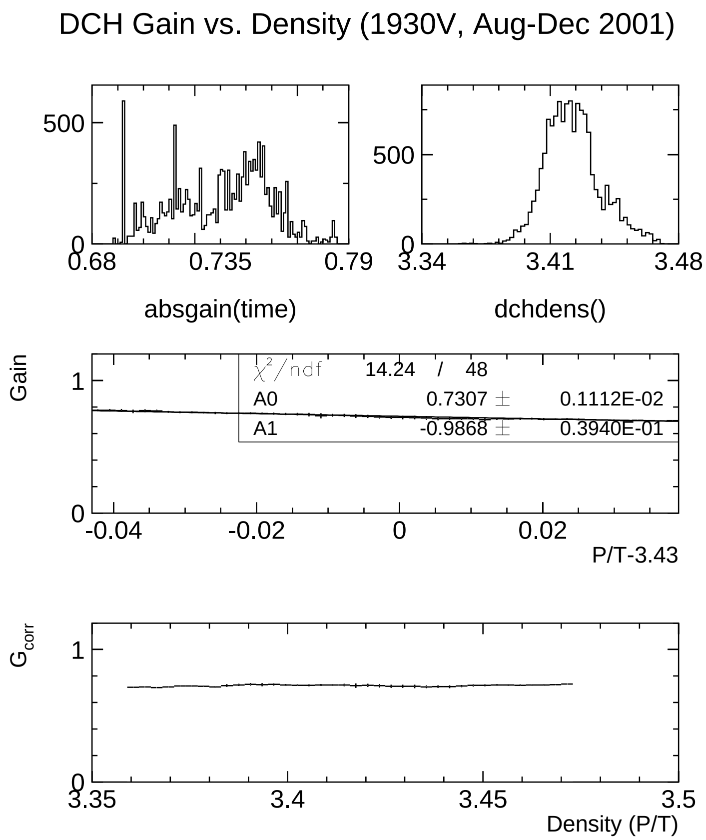
Normalize gain to absorb environmental effects

- Pressure and temperature $\Rightarrow$ density
- Detailed gas mixture (He:i-C_4H_{10}, H_2O, O_2)
- Precise operating voltage

Scale dE/dx from Bhabha-scattering events [$e^+e^- \to e^+e^-(\gamma)$]; normalization done $\sim$ hourly

Normalizing Gain

Most significant correlation with gas density



$$nR/V = P_{abs}/T_{abs}$$

Several short time intervals

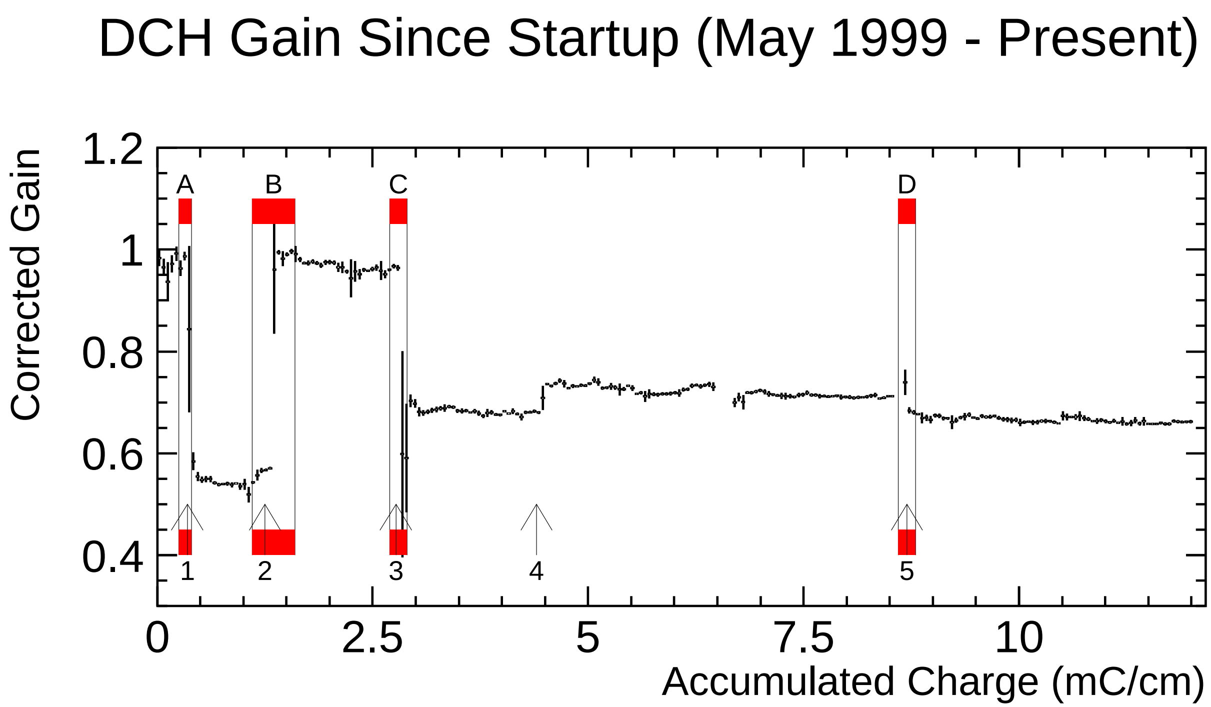
Jan–Jul 2000 (1900V)
Jul–Dec 2000 (1960V)
Mar–Jul 2001 (1930V)
Aug–Dec 2001
Feb–Jun 2002
Feb–Jun 2003

Correct gain using slope of fit

Applying offset could obscure aging effects

Gain vs. Time

Continuous decrease $G = G_0 \exp(-AQ)$ due to aging



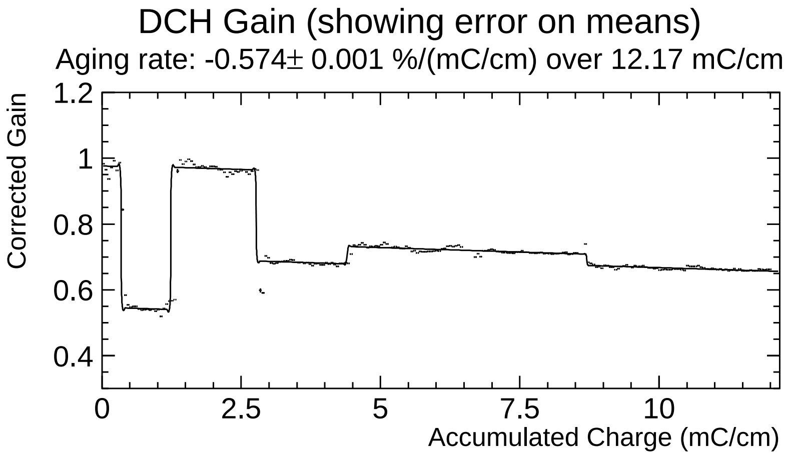
Steps due to operating changes (e.g., voltage)

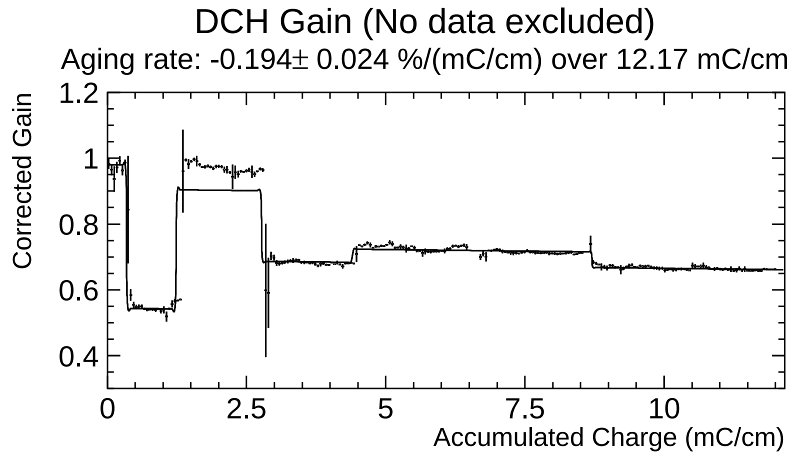
Gain vs. Time Fit Details

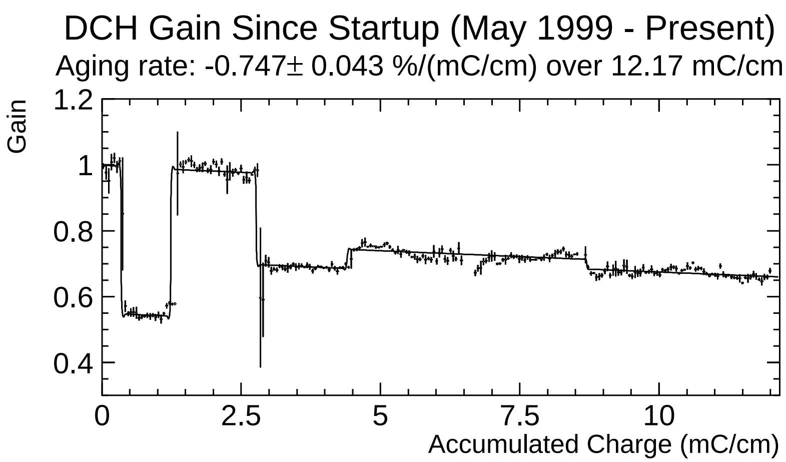
$$G(Q) = \{G_0 + \Delta G_1|_{Q>Q_1} + \Delta G_2|_{Q>Q_2} + \ldots\}\exp(-AQ)$$

$$\begin{aligned}
\chi^2/\text{dof} &= 668.33\ /\ 214 \\
-A(\%) &= -0.549 \pm 0.023 \\
G_0 &= 0.975 \pm 0.009 \\
\Delta G_1 &= -0.429 \pm 0.009 \quad (Q_1 = 0.3) \\
\Delta G_2 &= 0.432 \pm 0.001 \quad (Q_2 = 1.2) \\
\Delta G_3 &= -0.276 \pm 0.001 \quad (Q_3 = 2.8) \\
\Delta G_4 &= 0.053 \pm 0.001 \quad (Q_4 = 4.4) \\
\Delta G_5 &= -0.035 \pm 0.001 \quad (Q_5 = 8.7)
\end{aligned}$$

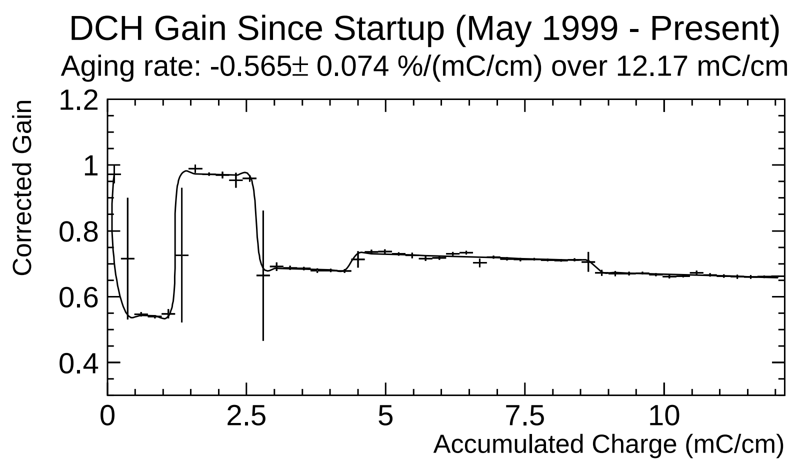
Systematic Checks







No density correction



Coarser binning (50 vs. 200 bins)

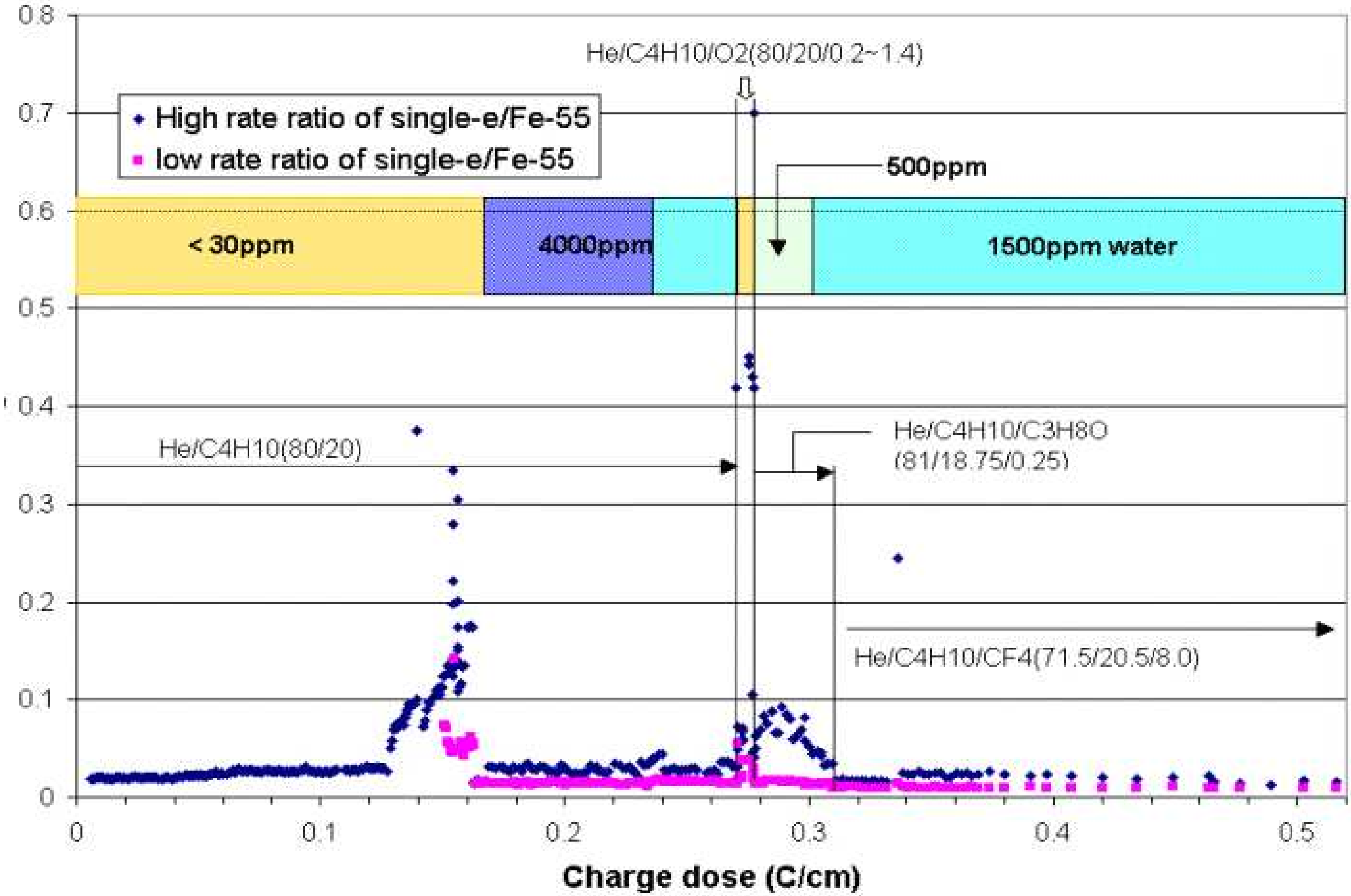
Comparative Aging

Aging measurements from other experiments

Experiment	Gas Mix	[mC/cm] Charge	[%/(mC/cm)] $\Delta G/G$ Aging
CDF (Run 2)	Ar:Eth:Alc 50:50:1	130	$<$1 $\sim$ 20
ZEUS	Ar:Eth:CO_2 83:5:12	100	$\lesssim$ 0.1
H1	Ar:Eth:H_2O 50:50:0.1	$<$ 10	$\gtrsim$ 1
HERA-B (test)	Ar:CF_4:CO_2 65:30:5	2300	$\sim$ none
BaBar	**He:i-C_4H_{10}:H_2O 80:20:0.4**	**12.2**	**0.6**

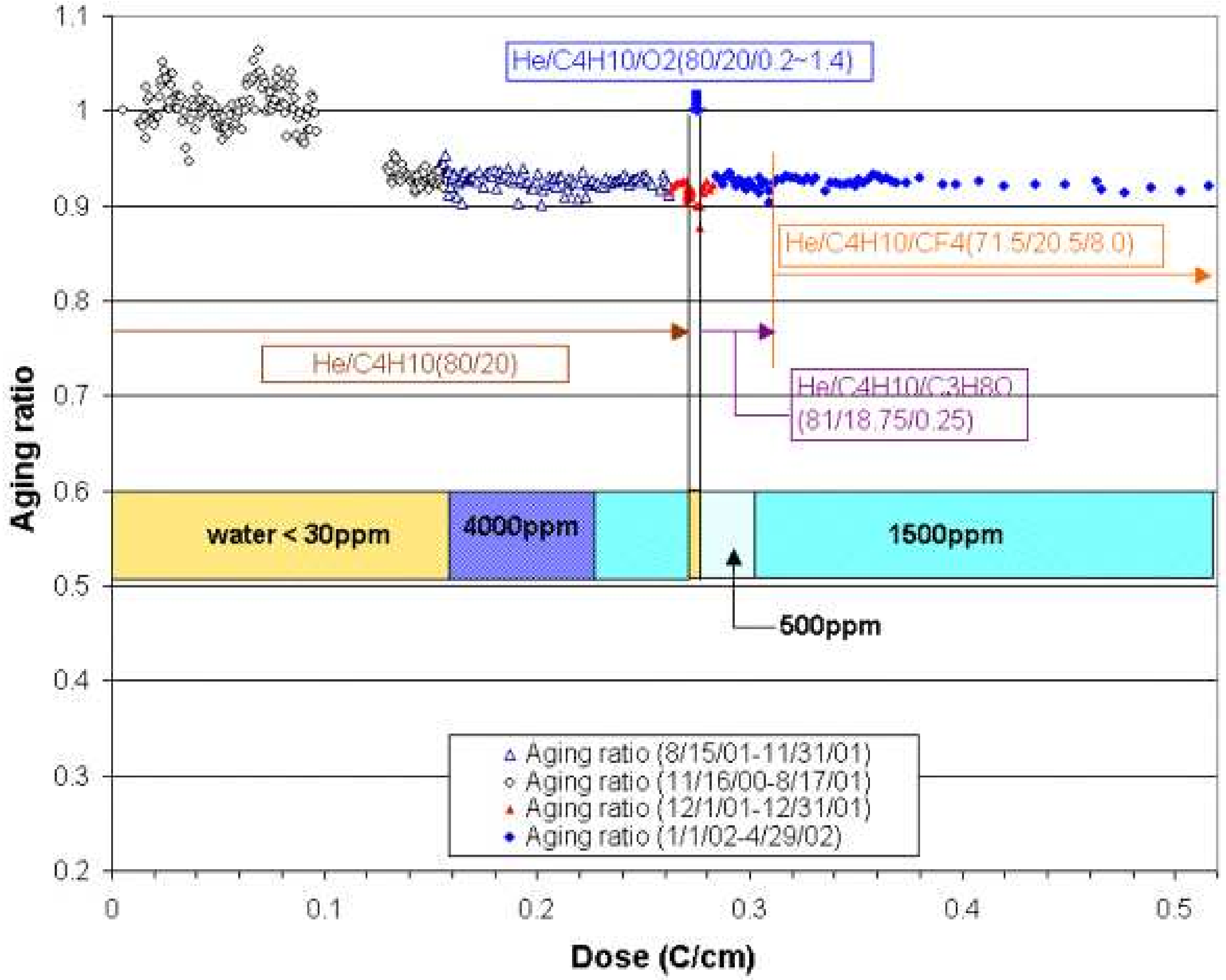
From 2001 DESY Workshop presentations

Suppressing Damage



Lu Changguo, Princeton

Suppressing Damage



Lu Changguo, Princeton

Remediating Damage

Additives (alcohol, water, oxygen) can suppress discharges, allow running at higher currents

Additive	(%)	Before I_{max}	With Additive Time (hr)	With Additive I_{max}	After I_{max}	Cured?
Methylal	4	0.3	≈0	>8		No
	2			3	0.4	No
2-Propanol	1.0	≈0.5	≈0	>12		No
	0.5			>10		No
	0.25			>13	0.2	No
H_2O	0.35	0.4	≈0	>27		No
	0.18			>9	0.5	No
O_2	0.10	0.5	1.5	>32	>40	Yes
	0.05	0.4	2	>29	>16	Yes
	0.02	0.9	10	>35	>14	Yes
CO_2	5	0.4	35	>40	>27	Yes
O_2+H_2O (0.05+0.35)		0.4	40	10	3	Partly

Adam Boyarski, SLAC

Temporary 500–1000 ppm O_2 running appears to "cure" discharge problem. Current limit restored to initial level.

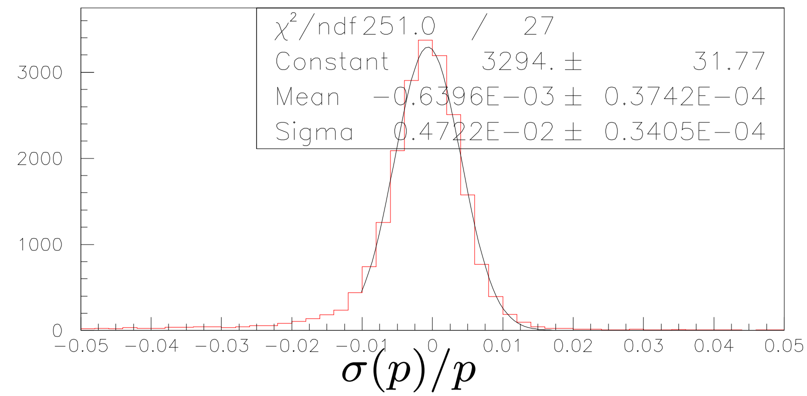
PEP-II Luminosity Upgrades

	$[10^{33}\text{cm}^{-2}\,\text{s}^{-1}]$	[mA]	[mA]	[μA]	[raw/rec]
Year	$\mathcal{L}$	$I(e^-)$	$I(e^+)$	DCH HV	Hits/ev
2003	6.3	1140	1450	532	456/ 332
2004	12.1	1600	2700	973	686/ 483
2005	18.2	1800	3600	1380	898/ 621
2006	23.0	2000	3600	1665	1046/ 719
2007	33.0	2200	4500	2284	1368/ 930
2008	33.0	2200	4500	2284	1368/ 930

J. Seeman/PEP-II, SLAC

Tracking at 4×10^{34}cm^{-2}s^{-1}

Momentum resolution



$D^* \to D^0\pi$ Mass