Performance and Aging of the BaBar Drift Chamber

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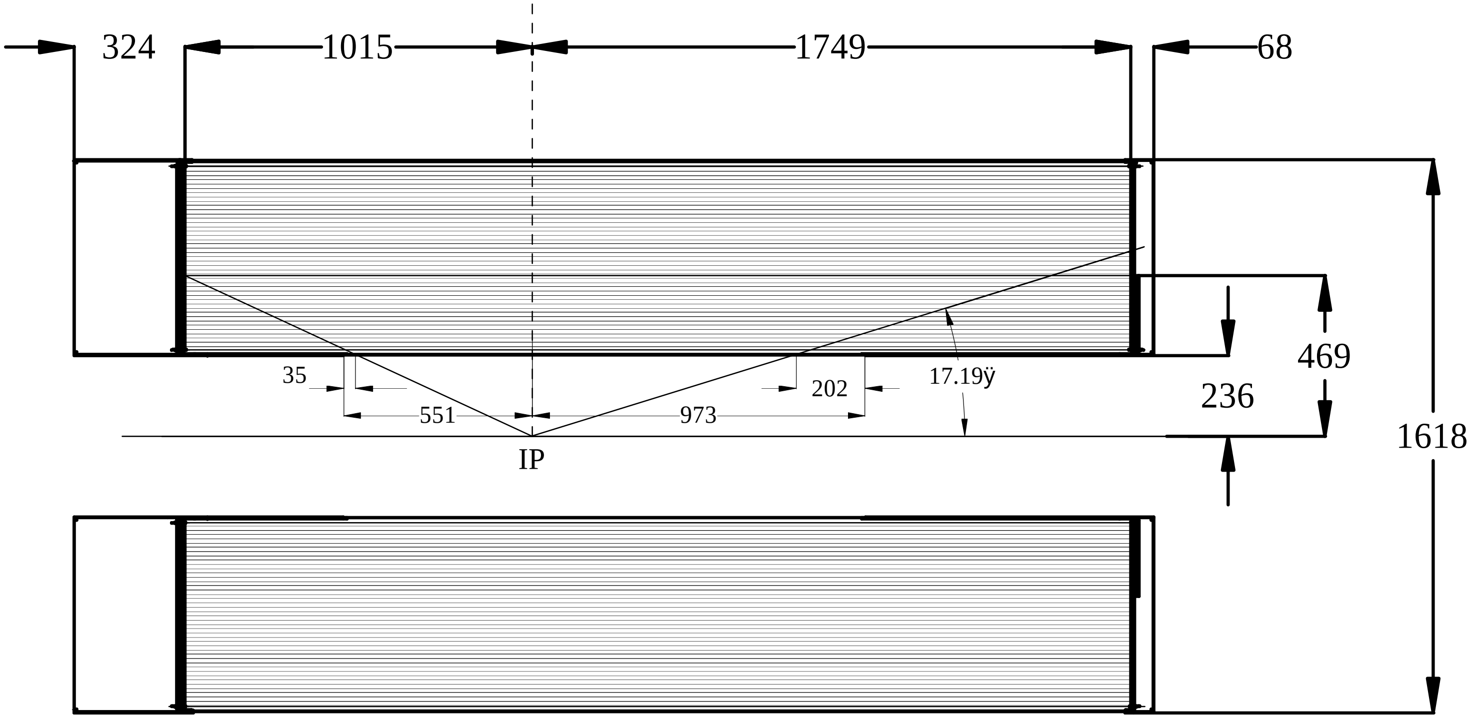
Outline

- Drift Chamber Design and Operation
- Aging and Wire Damage
- Tracking, dE/dx, and Physics
- Data Acquisition Upgrade
- Summary

BaBar Drift Chamber



Dimensions in mm

24 cm inner radius

81 cm outer radius

2.8 m length

IP 37 cm behind center

Be & Al inner cylinder

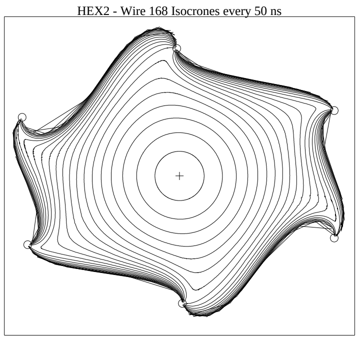
Carbon fiber/Nomex outer

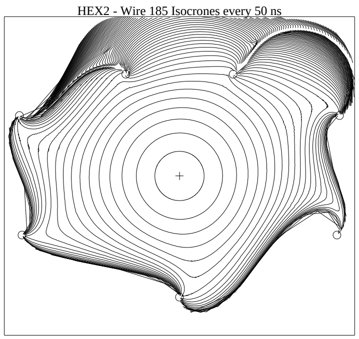
2.5 (1.2) cm Al end plates

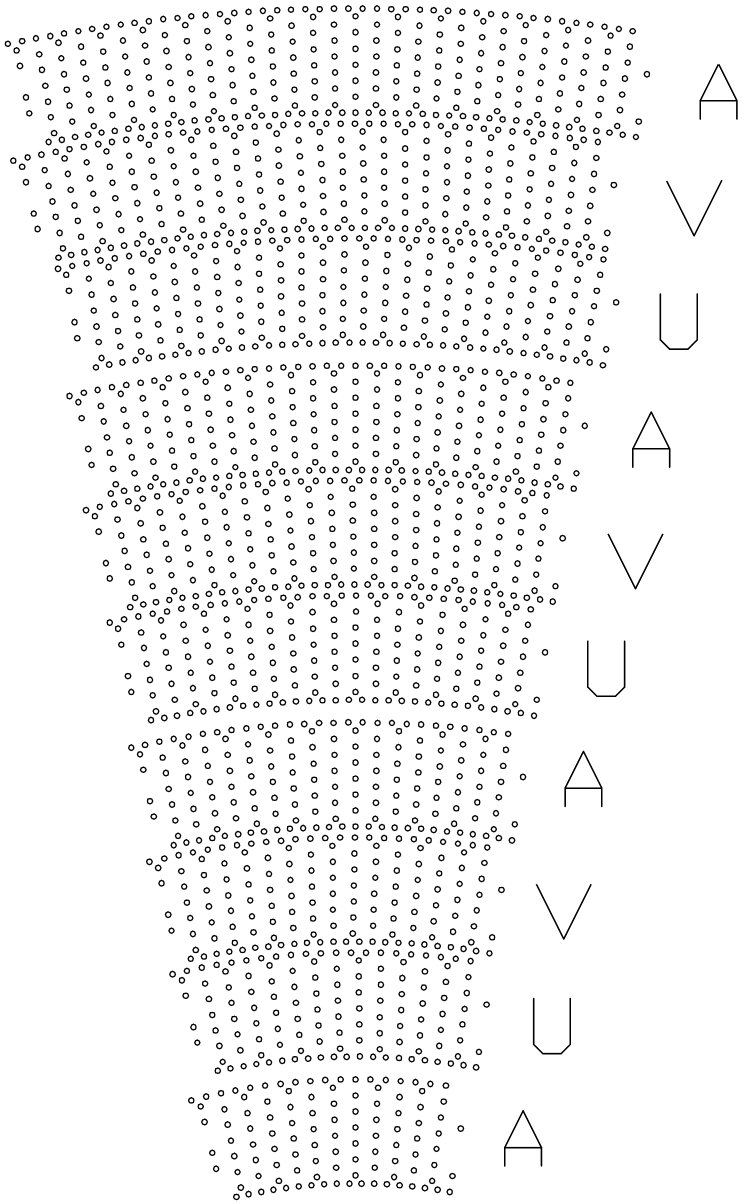
All electronics on rear

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)

Construction

High-bay Class 1000 clean room at TRIUMF

- Chamber volume enclosed in Class 100 clean tent
- Measured at 10-20 particles/m^3
- No contact with wire in chamber or inner surfaces

Automated wire stringing

- Operators attached wire from spool to steel rod
- Pulled by robot (magnet grip) to opposite endplate
- Feedthroughs, crimping outside clean tent

Operating Parameters

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

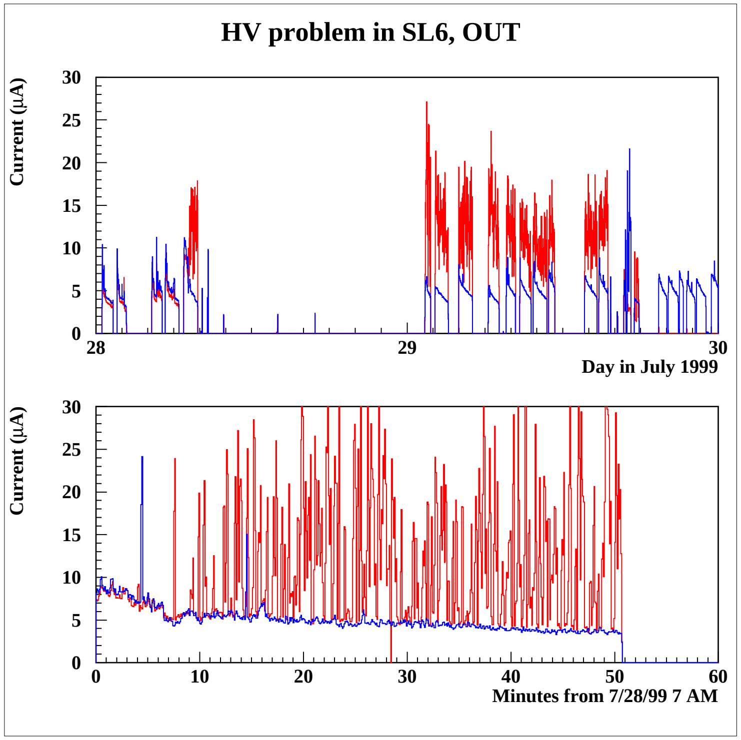
Designed to operate at 1960V

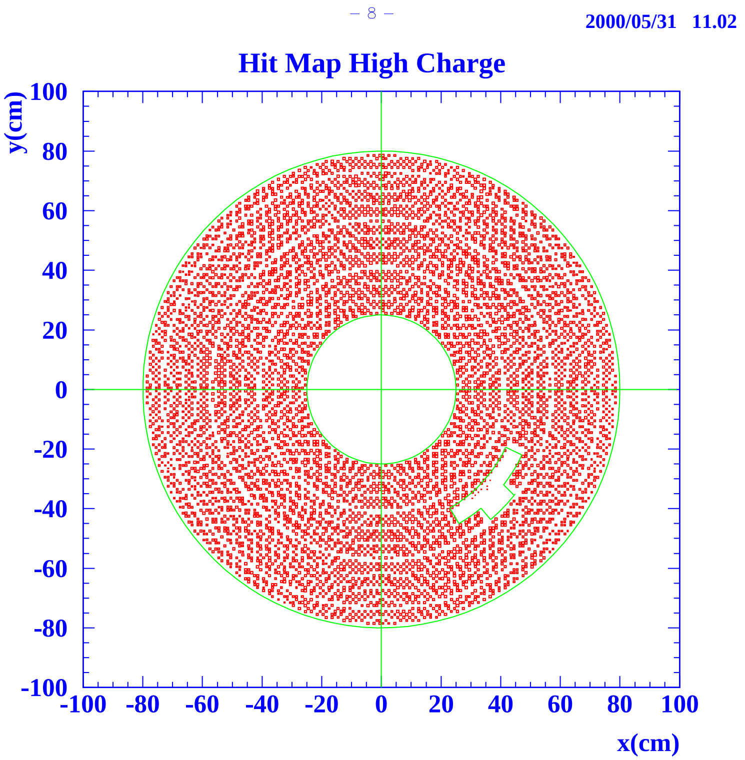
- Initially operated without water vapor
- Discharges observed in small region of chamber
- Reduced to 1900V (October 1999–July 2000)
- 1930V January 2001–December 2006
- 1945V since January 2007

Initial Damage

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

28 July 1999: Large spikes in HV current



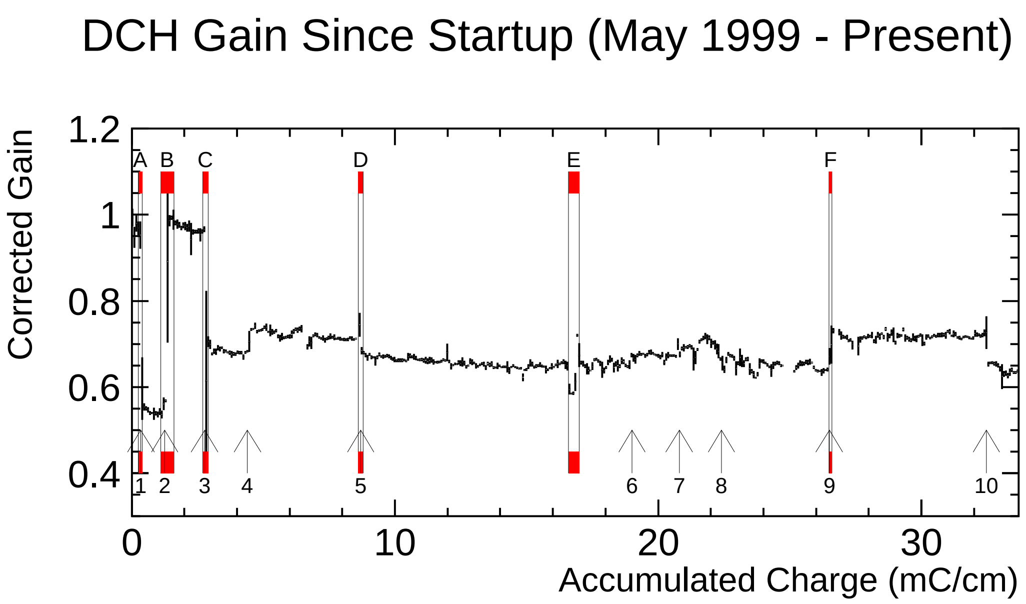


October 1999: Turned off affected region, added water

$\Longrightarrow$ No discharges observed in chamber since

Gain vs. Time

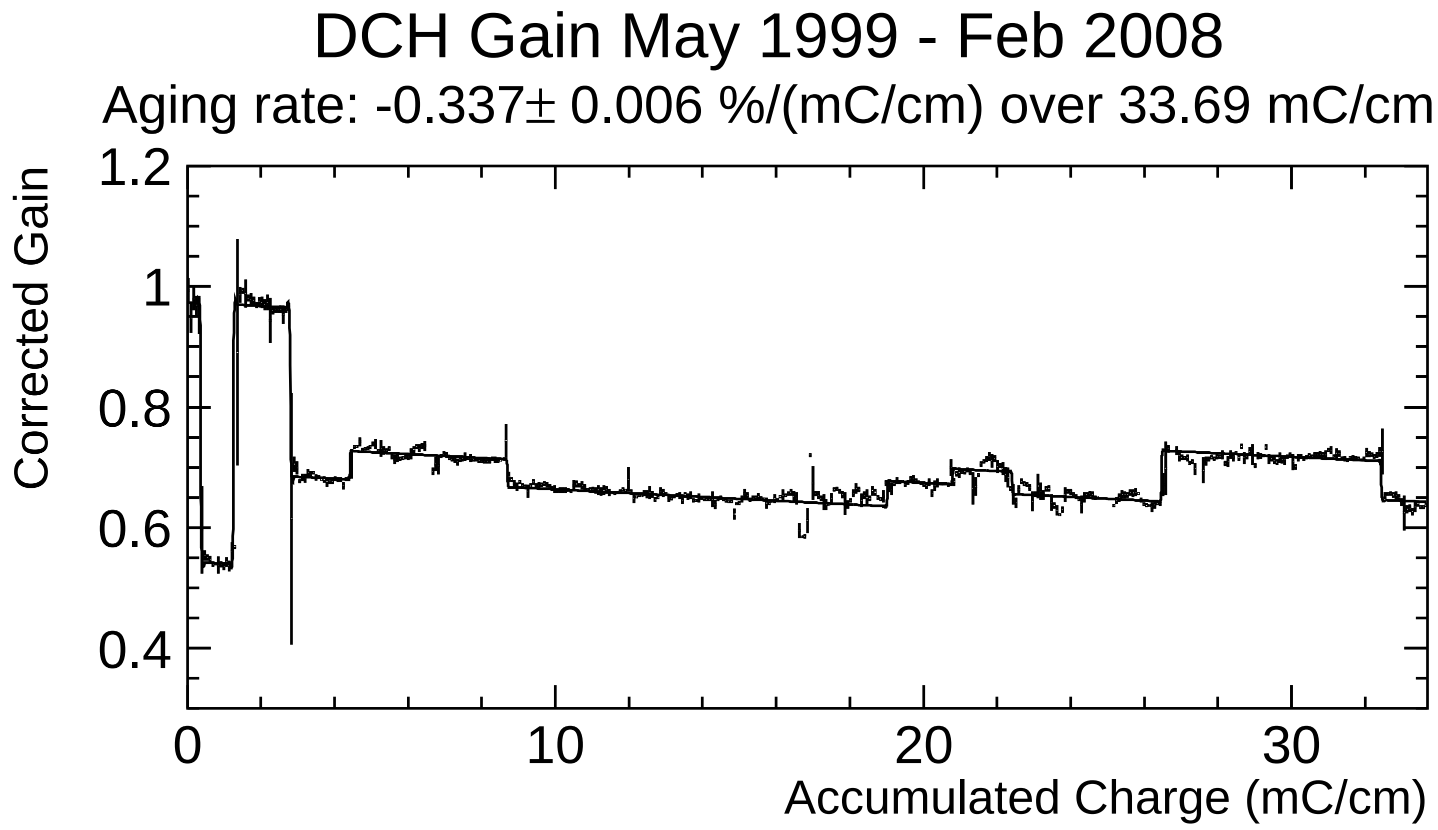
Expect continuous decrease $G = G_0 \exp(-AQ)$ due to aging (charge accumulation)



Steps due to operating changes (voltage), transitions between runs (gas mix), etc.

Gain vs. Time

$$G(Q) = \{G_0 + \sum \Delta G_i|_{Q>Q_i}\} \exp(-AQ)$$



Long-term Effects

Sudden damage always a concern, not observed

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

Long-term studies of aging 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 lifetime dose

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

Reconstruction Performance

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

Target: 140 μm in middle region of cell

Momentum $\sigma(p_T)/p_T = 0.45\% + 0.13\%\, p_T$ (GeV/c)

Target: 0.21% + 0.14% p_T

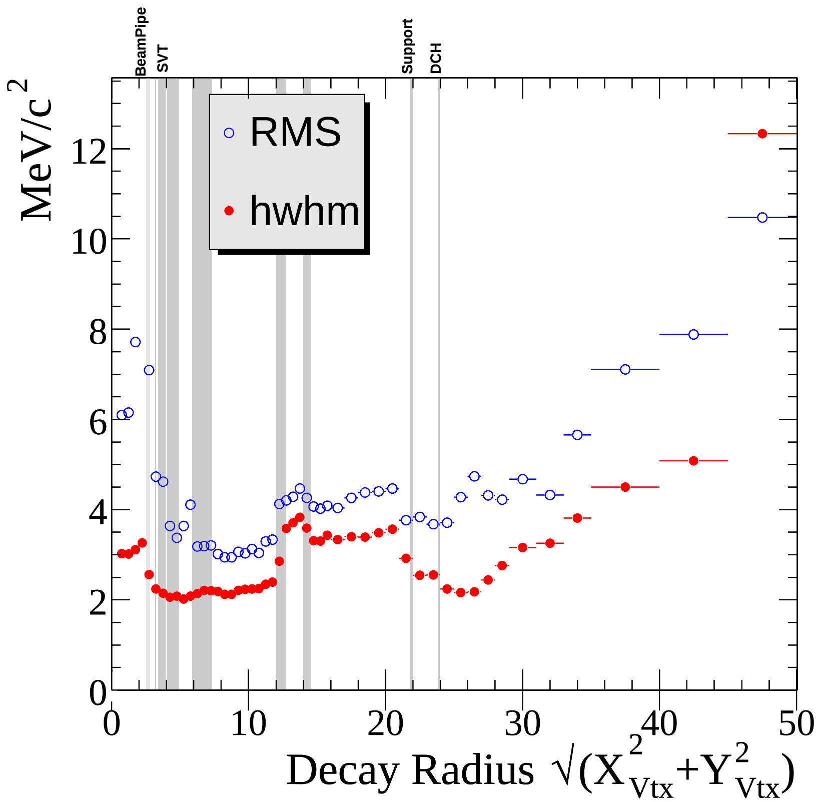
Tracking $>$ 95% matching with SVT

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

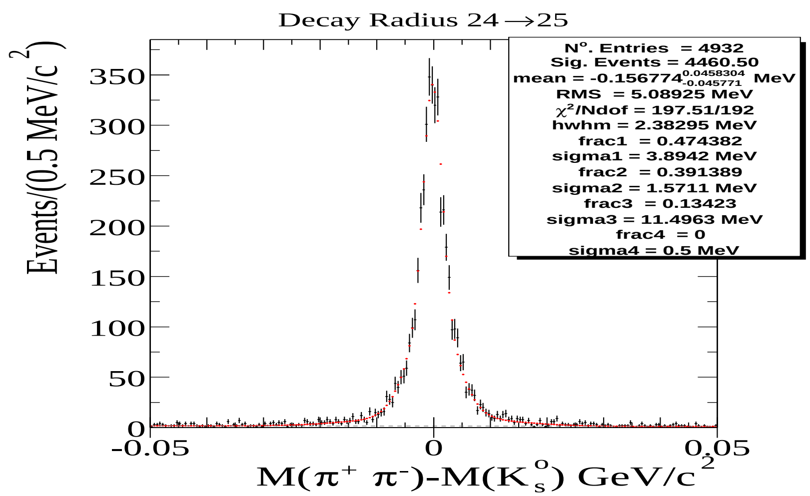
Early test results: 7.0%

Physics Performance

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



Fits in DCH comparable to DCH+SVT

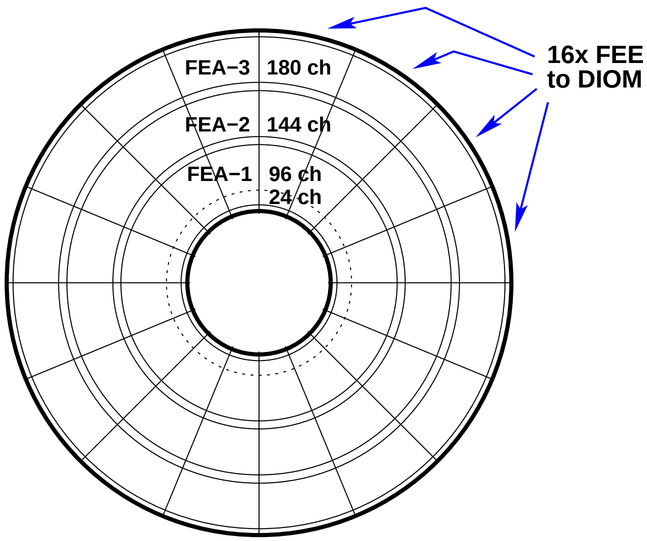


"Jumps" due to material scattering uncertainty and fewer hits per track fit

High Rate Data Acquisition

Modular, parallel electronics
4-buffer pipeline per channel
16 elements per quadrant
via 1 GHz fiber to processor

Original 1995 design



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 wires (32 bytes) each

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

High Rate Data Acquisition

Replace multiplexer with modern FPGA

Implement feature extraction in firmware

- Charge (waveform) integration
- Leading edge (hit time) finding
- Pedestal subtraction
- Calibration constants in FPGA memory

Data volume reduced 32 $\rightarrow$ 6 bytes/channel

Identical data format used for reconstruction

Essentially no deadtime up to 10 kHz trigger rate

Front-end Upgrade

New boards installed during Run 5 (Oct 2005)

Improved diagnostics, programmability vs. original

Firmware downloadable through FPGA to EPROM via normal DAQ path

"Pass-through" firmware (emulates original front-end) software selectable through DAQ command

Summary

BaBar Drift Chamber operated for nine years

- Tracking performance up to design
- dE/dx performance good
- Excellent operational efficiency
- No substatial problems after startup

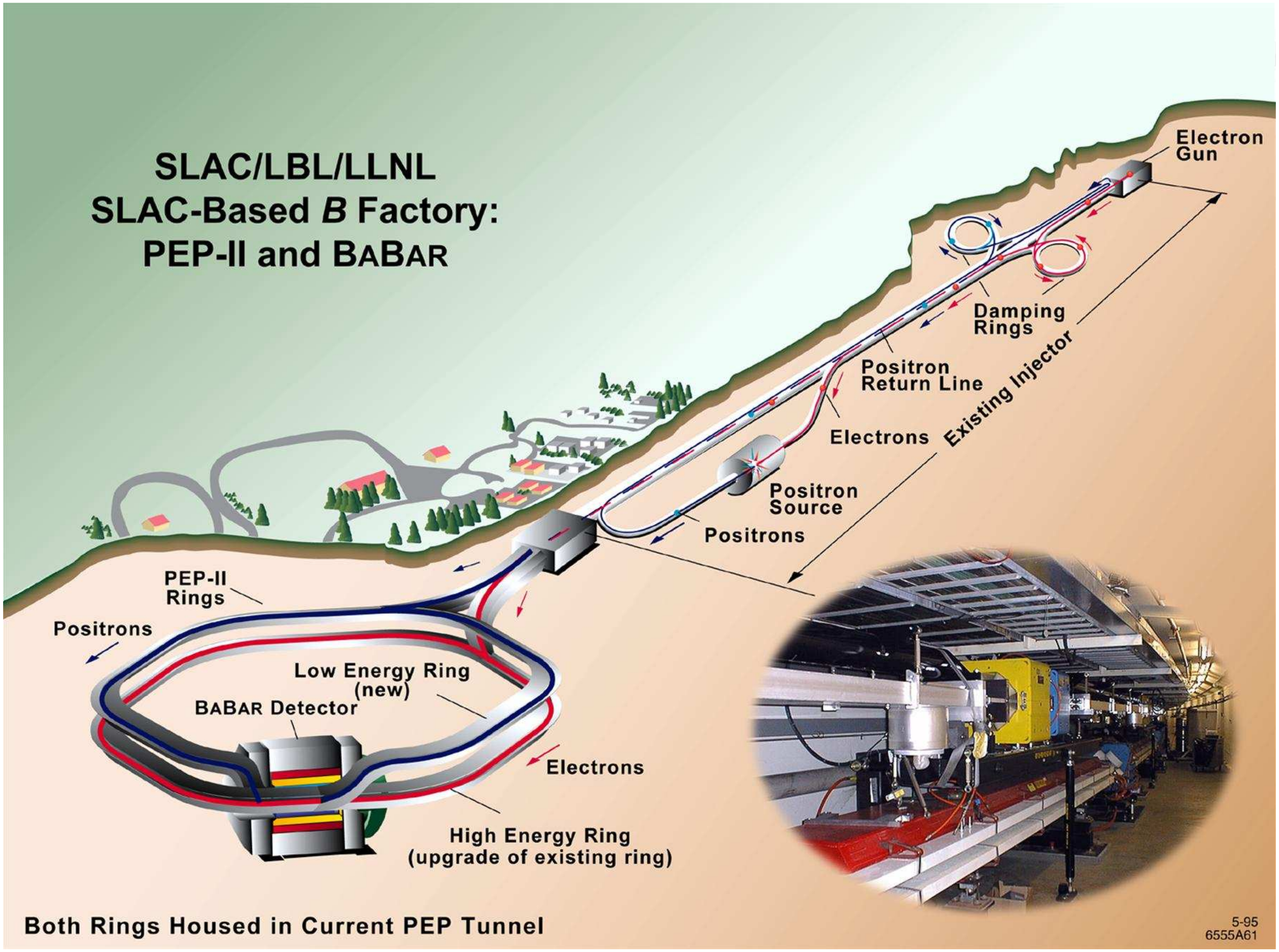
Excellent aging rate 0.3% / (mC/cm)

Clean-room construction, comprehensive QA/QC procedures

Real-time monitoring of environment and data quality

Electronics upgraded to support luminosity

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: $\Upsilon(4S) \to B^+B^-, B^0\overline{B}^0$

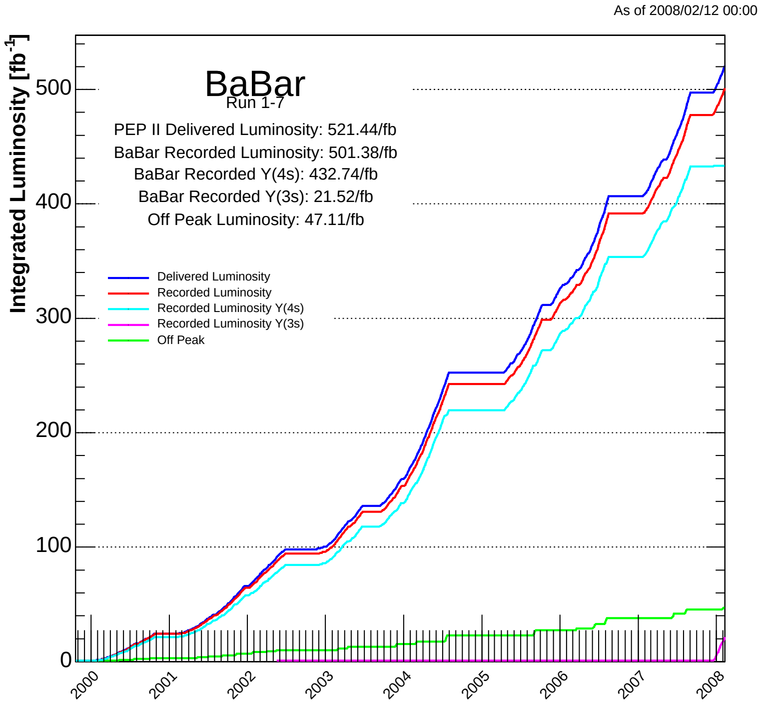
B decay length increased from $\sim 30\ \mu$m (CMS) to $\sim 250\ \mu$m (lab), allowing precision time-dependent measurements

PEP-II delivers $\mathcal{L} > 10^{34}$ cm^{-2}s^{-1} (3$\times$ design)

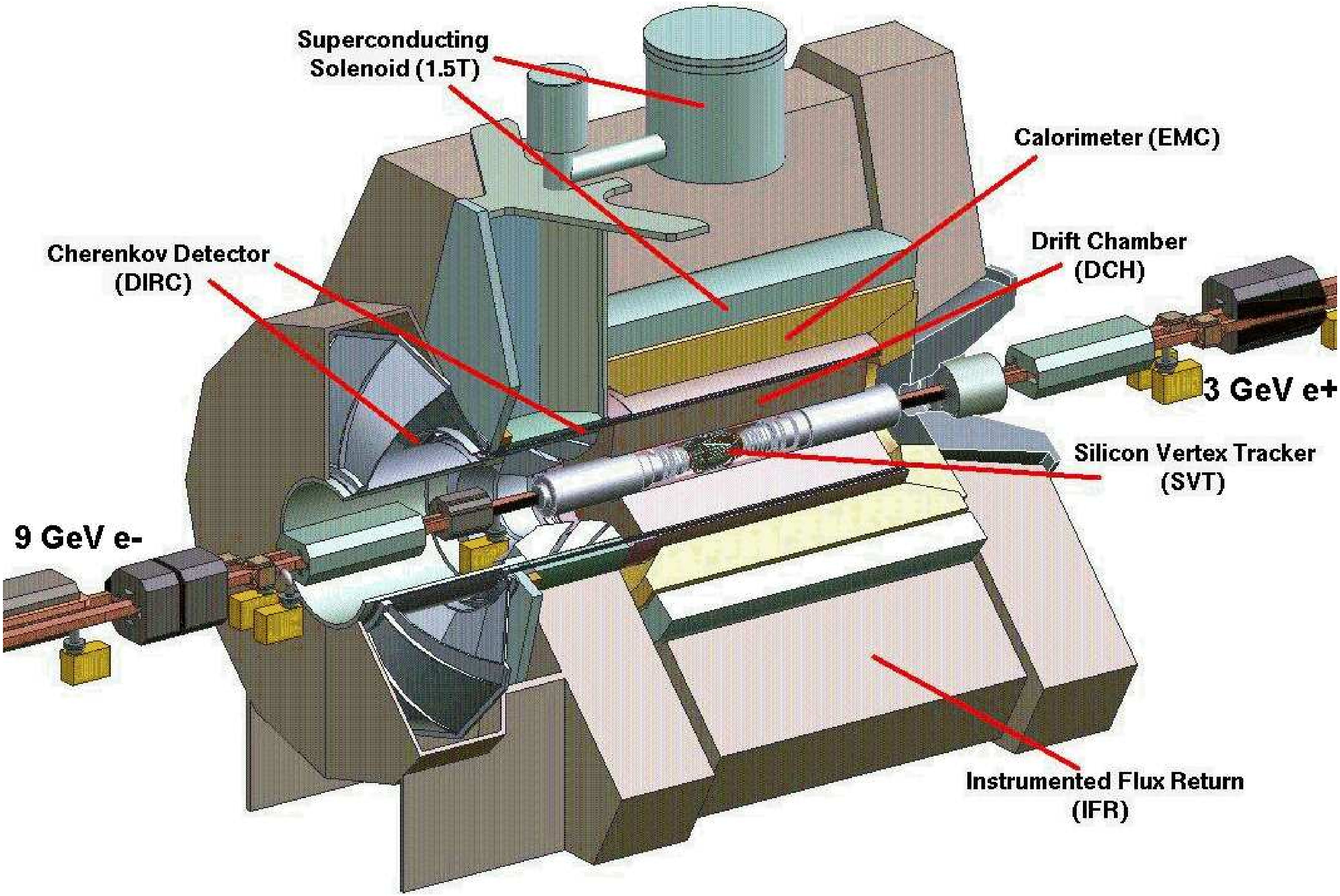
433 fb^{-1} at $\Upsilon(4S)$, $\sim$ 9% off-peak

18 fb^{-1} at $\Upsilon(3S) \Longrightarrow$ 30 fb^{-1} plan

BaBar operates at $>$ 95% efficiency

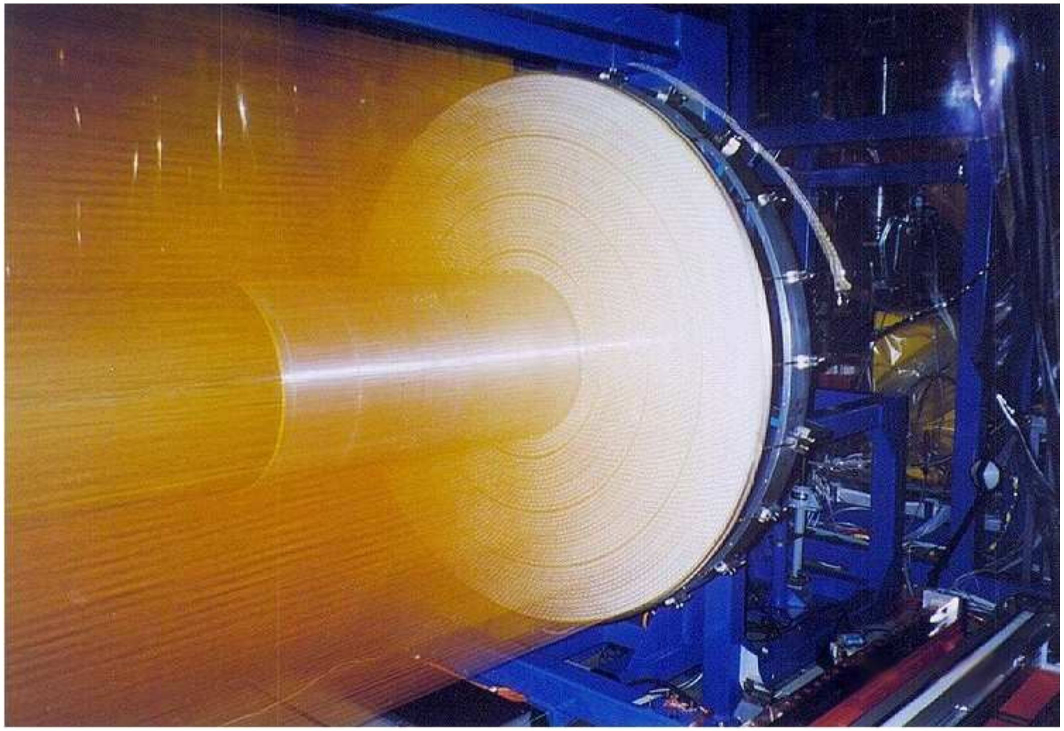


BaBar Detector



BaBar Drift Chamber

Main tracking detector in BaBar



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

Construction QA/QC

Continuous QA/QC monitoring

- Tension measured during stringing
- Before and after crimping
- Daily evaluation of wires and feedthroughs
- Replacement done during subsequent shift

Stringing completed in 3 months (Aug–Nov 1997)

Just 19 of 28,768 wires outside specification

- Tension, crimps, continuity
- Assembly fixture repositioned vertically
- Wires removed and restrung *in situ*

Commissioning

Tested at voltage with operating gas

- Mixed in radioisotope (^{133}Xe)
- Pulses, singles rates measured for all 7,104 cells

Shipped fully operational, ready for comissioning

Commissioned at SLAC with production DAQ system before installation in IR-2

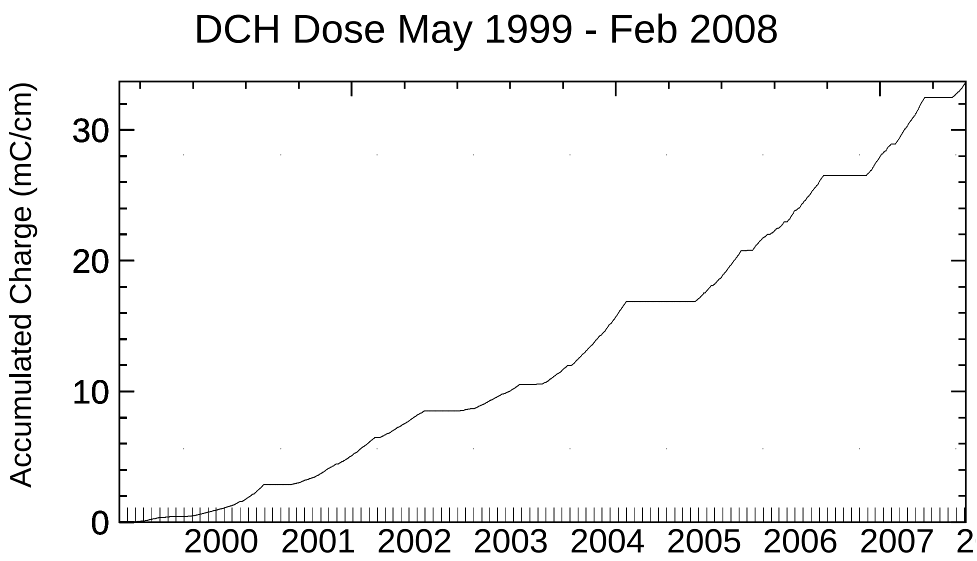
Accumulated Charge

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 33.7 mC/cm in nine years

Quantifying Gain

Normalize to absorb environmental effects

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

Compute dE/dx for tracks from Bhabha-scattering events [$e^+e^- \rightarrow e^+e^-(\gamma)$]

Relativistic plateau of Bethe-Bloch curve, fixed average value

Normalization done $\sim$ hourly

Gain vs. Time Fit Details

$$G(Q) = \{G_0 + \sum \Delta G_i|_{Q>Q_i}\} \exp(-AQ)$$

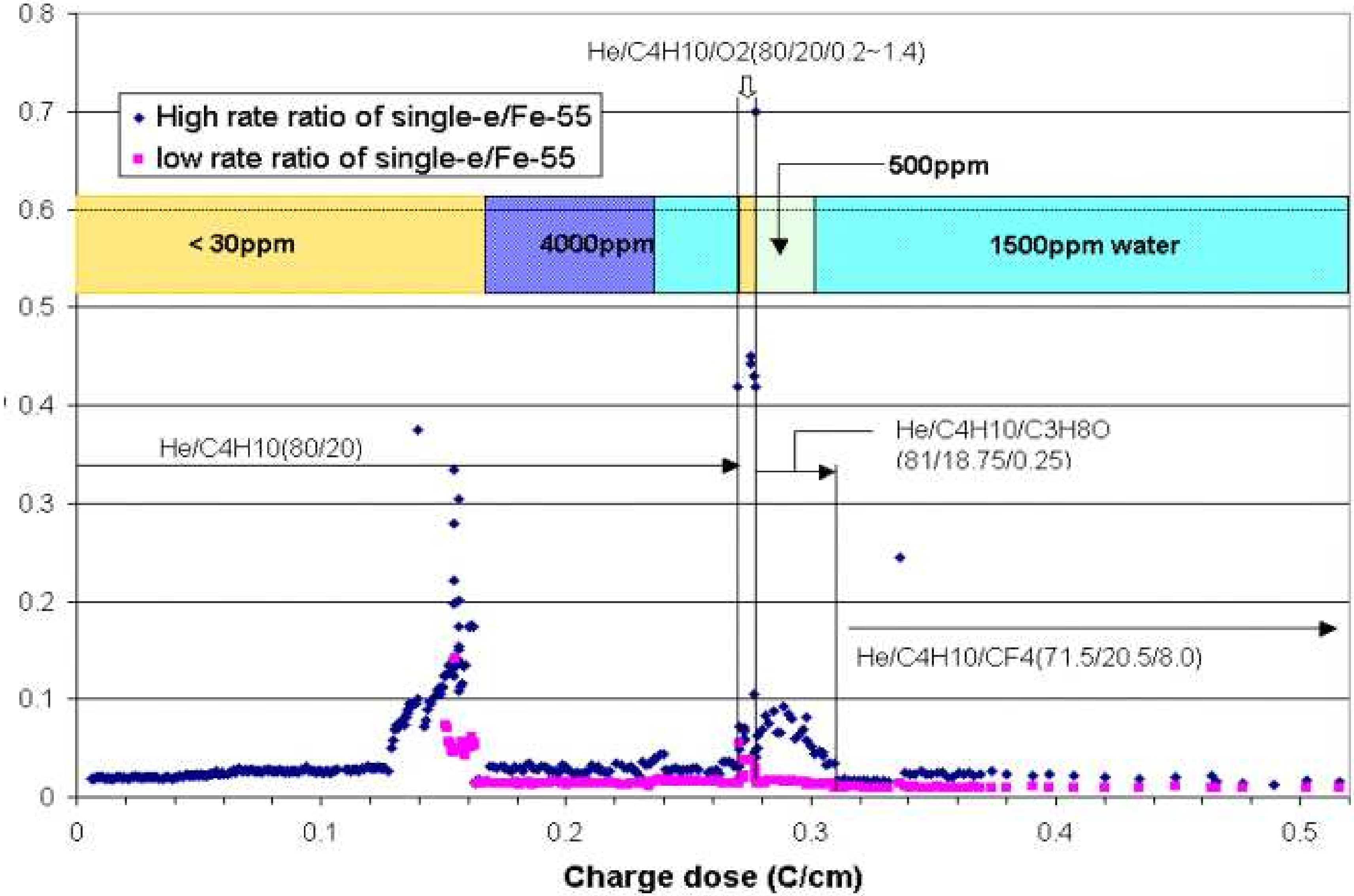
χ^2/dof	=	1789.58 / 418	
$-A(\%)$	=	-0.337 ± 0.006	
G_0	=	0.974 ± 0.001	
ΔG_1	=	-0.430 ± 0.001	($Q_1 = 0.3$)
ΔG_2	=	0.430 ± 0.001	($Q_2 = 1.2$)
ΔG_3	=	-0.280 ± 0.001	($Q_3 = 2.8$)
ΔG_4	=	0.047 ± 0.001	($Q_4 = 4.4$)
ΔG_5	=	-0.046 ± 0.001	($Q_5 = 8.7$)
ΔG_6	=	0.042 ± 0.001	($Q_6 = 19.0$)
ΔG_7	=	0.026 ± 0.001	($Q_7 = 20.8$)
ΔG_8	=	-0.037 ± 0.001	($Q_8 = 22.4$)
ΔG_9	=	0.084 ± 0.001	($Q_9 = 26.5$)
ΔG_{10}	=	-0.064 ± 0.001	($Q_{10} = 32.5$)

Other Chambers' Aging

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**	**33.6**	**0.3**

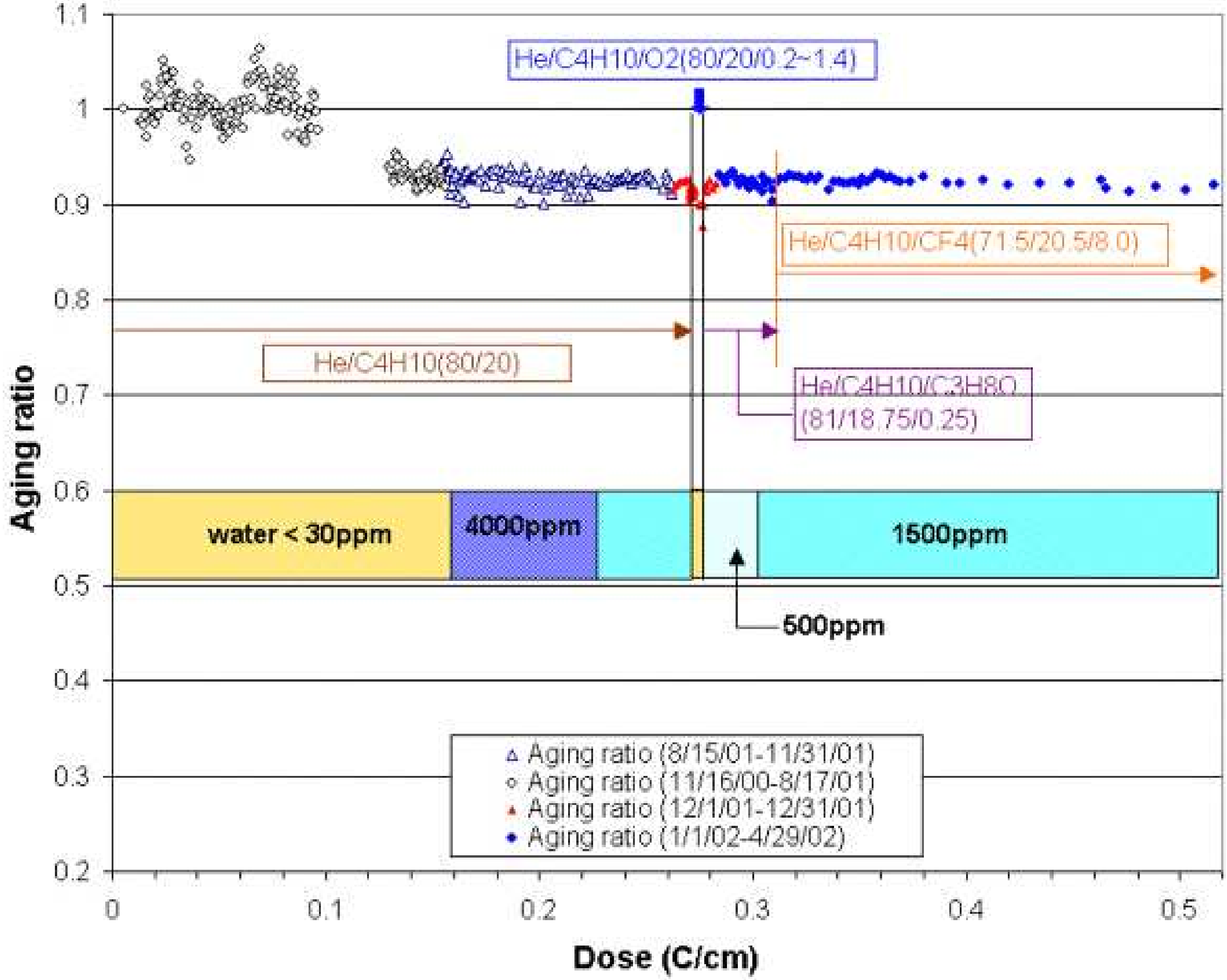
From 2001 DESY Workshop presentations

Suppressing Damage



Lu Changguo, Princeton

Suppressing Damage

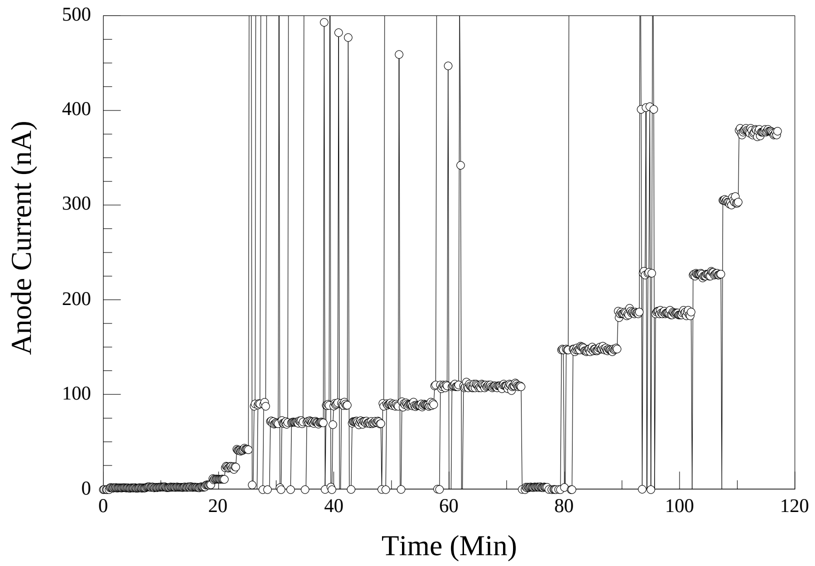


Lu Changguo, Princeton

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

Remediating Damage

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

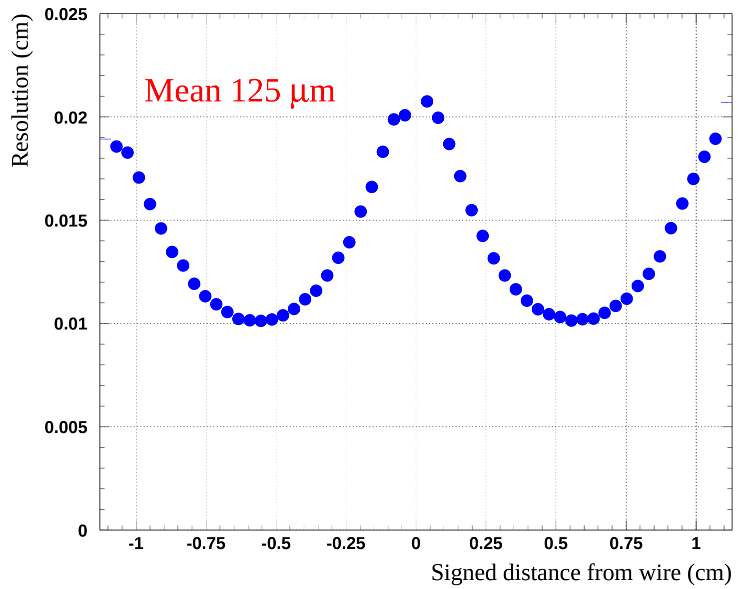
Additive	(%)	Before I_{max}	With Additive Time (hr)	With Additive I_{max}	After I_{max}	Cured?
Methylal	4	0.3	≈0	>8		No
	2			3	0.4	No
2-Propanol	1.0	≈0.5	≈0	>12		No
	0.5			>10		No
	0.25			>13	0.2	No
H_2O	0.35	0.4	≈0	>27		No
	0.18			>9	0.5	No
O_2	0.10	0.5	1.5	>32	>40	Yes
	0.05	0.4	2	>29	>16	Yes
	0.02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

Track Fitting

Residuals of hits vs. distance from wire



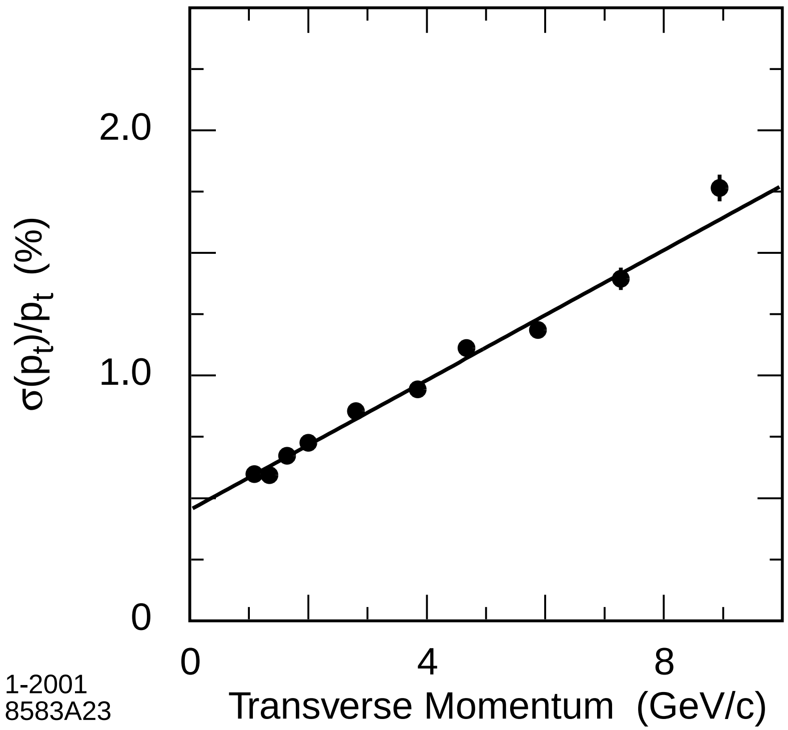
$\langle\sigma(\text{resid})\rangle \sim 125\ \mu\text{m}$

Design target: 140 μm in middle region of cell

$d(t)$: pair of 7th order Chebyshev functions, each side of cell, corrected for angle and position in cell.

Track Fitting

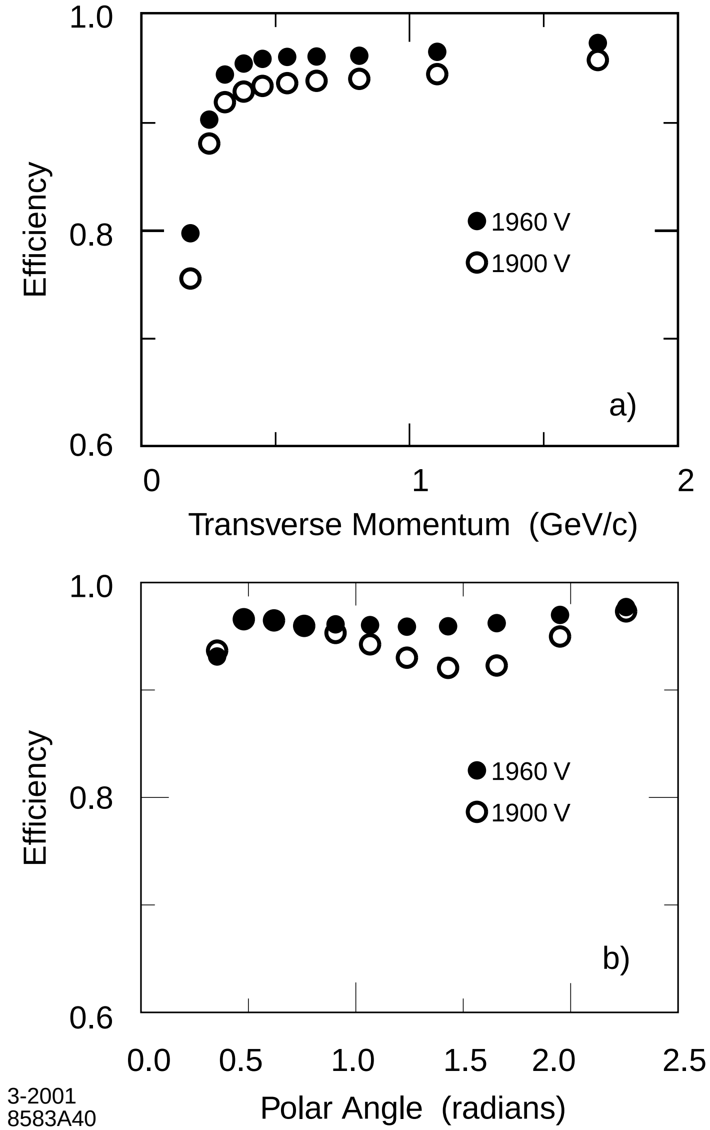
Momentum resolution from cosmic rays



$$\sigma(p_T)/p_T = 0.45\% + 0.13\%\ p_T\ (\text{GeV}/c)$$

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

Tracking Efficiency



"Pseudo-efficiency"

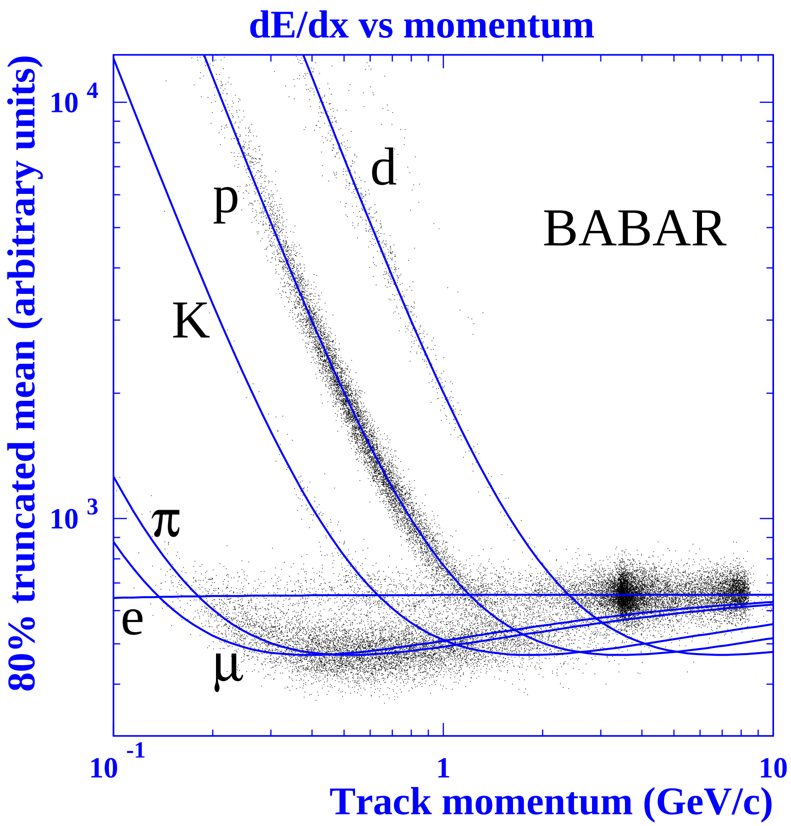
Count DCH+SVT tracks vs. total SVT tracks

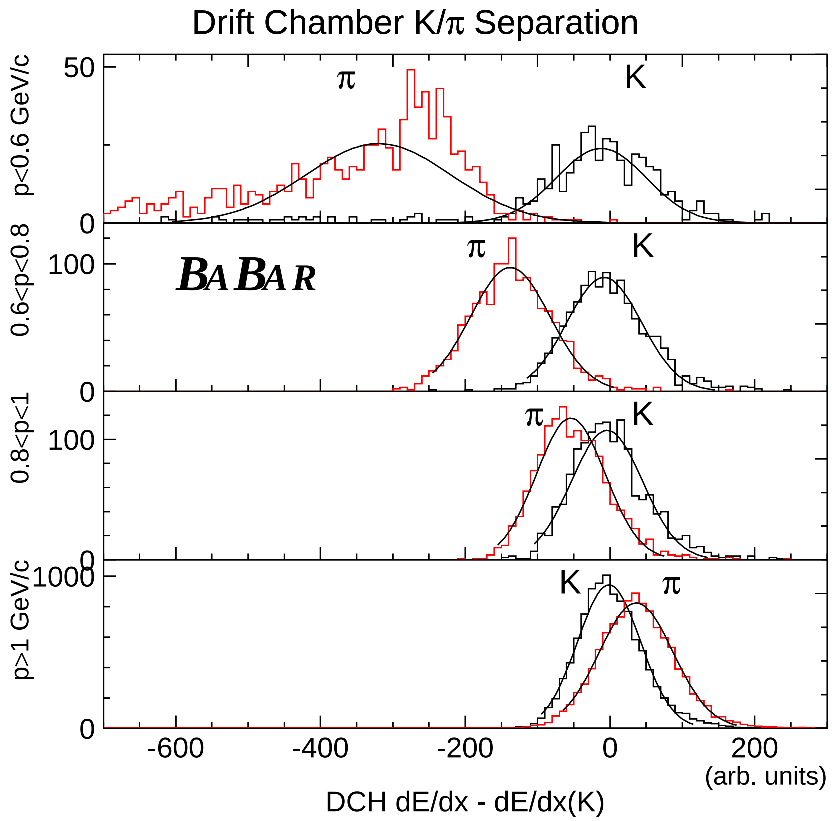
Measure acceptance in

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

DCH and SVT not independent

dE/dx, Particle ID





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

Confirms results in DIRC region, adds PID coverage outside DIRC acceptance

Physics Performance (II)

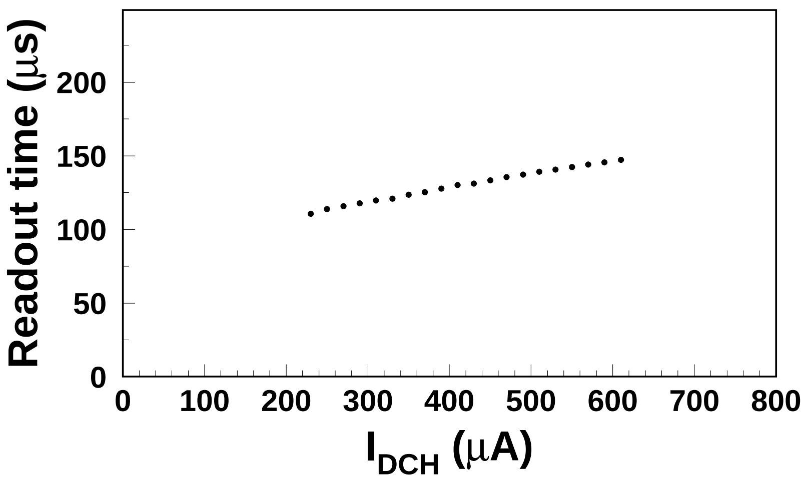
$$B \to D^{(*)}D^{(*)}, D^{*+} \to \pi^+ D^0, D^0 \to K^- \pi^+$$

(Monte Carlo generated events)

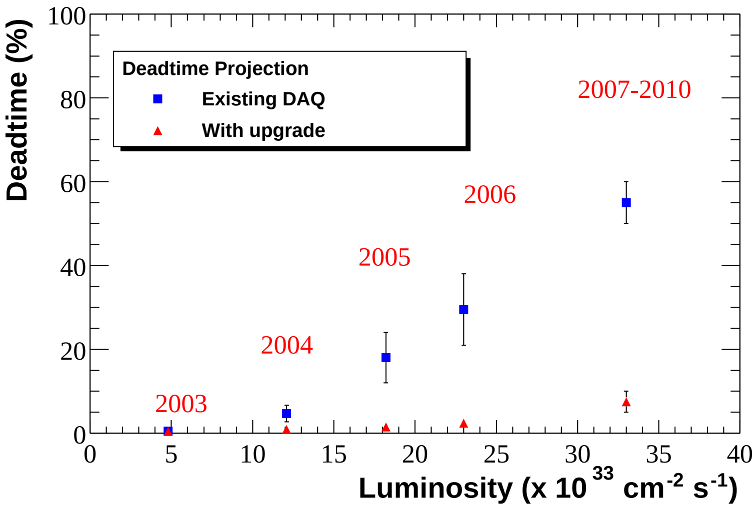
Momentum $\sigma(p)/p$	4.7×10^{-3}	
$D^0 \to K^-\pi^+$ σ(mass)	6.5 ± 0.2	MeV/c^2
$D^* \to \pi^+ D^0$ σ(mass)	0.80 ± 0.03	MeV/c^2

High Rate Data Acquisition

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



M. Cristinziani, 2004



C. Jessop, 2004

Readout $\sim$ trigger rate $\Longrightarrow$ **non-linear** deadtime