BaBar Drift Chamber performance

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Super B Factory Workshop in Hawaii
April 20-22, 2005
Outline

1. BaBar Drift Chamber performance
2. Backgrounds
3. Electronics upgrade
4. Higher luminosities
5. Additional material for discussion
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Drift Chamber design and operation

- Main tracking device in BaBar surrounding SVT
- 2.8m length, 1.6m diameter, 7104 sense wires
- 40 axial and stereo layers of 1-2cm hex cells
- Gas: 80:20 He:C₄H₁₀, 4000 ppm H₂O vapor
- Operating voltage: 1930V
Reconstruction

- Single hit resolution 125 $\mu$m
- Momentum resolution, $p_T : 0.45\% + 0.15\% \frac{p_T}{(\text{GeV}/c)}$
- Tracking efficiency : $>95\%$ matching with SVT tracks
- $dE/dx$ resolution $\approx 7.5\%$
Particle identification

- Good $K/\pi$ separation up to $\approx 700$ MeV/c
- Provides confirmation of DIRC information
- Additional coverage outside DIRC acceptance
**Tracking**

Mass difference as a function of reconstructed distance from IP

\[
K^0_s \to \pi^+ \pi^- \quad \quad \quad \quad \Lambda \to p\pi^-
\]

Fits with DCH only are comparable to full tracking

“Jumps” are due to material scattering uncertainty
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Background characterization – Motivation

- PEP-II plans to increase luminosity to $2 \times 10^{34}$ by 2007

- Increasing luminosity means
  - aging
  - increased read-out time and deadtime
  - larger occupancy potentially affecting tracking

- A set of background characterization runs were taken to study BaBar behavior as a function of beam currents and luminosity

- Used to extrapolate to future luminosities
Background characterization – Method

- 49 short runs were recorded during 16 hours in January 2004 with varying beam currents and configurations.
- Quantities of interest (Drift Chamber current, occupancy and read-out time) are parametrized with a functional form

\[ Bkg = A + B \, I_{LER} + C \, I_{LER}^2 + D \, I_{HER} + E \, I_{HER}^2 + F \, \mathcal{L} \]

where \([I_{LER}] = [I_{HER}] = A\) and \([\mathcal{L}] = 10^{33}\)

- no LER*HER term as no 2-beam, non-collision data taken
- beam-beam interaction and trickle injection is added linearly in the extrapolations
- fitting is performed in a 3-step approach
  - fit pedestal runs and extract A
  - fit single-beam runs after pedestal subtraction (→ B-E)
  - fit luminosity runs after single-beam subtraction (→ F)
- 1-step - simultaneous fit to all parameters as cross-check
# Background characterization – Result

<table>
<thead>
<tr>
<th>FCN</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>No beam pedestal</td>
<td>56</td>
<td>0.606 ± 0.033</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.0</td>
</tr>
<tr>
<td>Single beam LER</td>
<td>227</td>
<td>-0.606</td>
<td>0.21 ± 0.07</td>
<td>-0.03 ± 0.05</td>
<td>-0.0</td>
<td>-0.0</td>
</tr>
<tr>
<td>Single beam HER</td>
<td>117</td>
<td>-0.606</td>
<td>-0.0</td>
<td>-0.0</td>
<td>4.76 ± 0.21</td>
<td>-0.96 ± 0.25</td>
</tr>
</tbody>
</table>

**No quadratic terms**

| Single beam LER  | 227 | -0.606 | 0.166 ± 0.018 | -0.0 | -0.0 | -0.0 | -0.0 |
| Single beam HER  | 131 | -0.606 | -0.0 | -0.0 | 3.97 ± 0.06 | -0.03 ± 0.05 | -0.0 |
| Lumi HER 2/3, LER scan | 36 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.460 ± 0.015 |
| Lumi HER max, LER scan | 47 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.372 ± 0.012 |
| Lumi HER 2/3, HER scan | 139 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.393 ± 0.015 |
| Lumi LER max, HER scan | 116 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.525 ± 0.011 |
| Lumi trickle, HER scan | 118 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.555 ± 0.015 |
| All good Lumi points | 348 | -0.606 | -0.166 | -0.00 | -3.966 | -0.00 | 0.420 ± 0.007 |

**Preferred result**

\[
\text{Occupancy(\%)} = 0.61 + 0.17 I_{LER} + 3.97 I_{HER} + 0.42 \mathcal{L} + 0.21 I_{LER} (\text{beam} - \text{beam}) + 0.03 \mathcal{L} (\text{trickle inj.})
\]
Goal is to understand differences and commonalities in background patterns.

For DCH and CDC similar currents but different occupancies are observed.

Geographical background distributions.
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During poor background conditions the dead time is driven by DCH

**Cause:**

- Serialization and shipping of data from the front-end to the ROM
- Increased luminosity $\mathcal{L} \sim 9 \times 10^{33}$
- Increased L1 rate $\sim 2$ kHz

**Problem:**

- Dead time was noticeable in Run 4
- Would have been significant in Run 5 with no intervention
Predictions for future PEP beam configurations

Extrapolations

- Dead time would soon become a serious issue e.g. 30% at 5 kHz in 2007

PEP parameters

<table>
<thead>
<tr>
<th>year</th>
<th>$I_{LER}$</th>
<th>$I_{HER}$</th>
<th>$L(10^{34})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>2.45A</td>
<td>1.55A</td>
<td>0.9</td>
</tr>
<tr>
<td>2005</td>
<td>3.1A</td>
<td>1.7A</td>
<td>1.1</td>
</tr>
<tr>
<td>2006</td>
<td>3.6A</td>
<td>1.8A</td>
<td>1.3</td>
</tr>
<tr>
<td>2007</td>
<td>4.0A</td>
<td>2.0A</td>
<td>2.0</td>
</tr>
<tr>
<td>2008</td>
<td>4.5A</td>
<td>2.2A</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Short-term solution:
ship less raw data!
Implementation: Waveform decimation

- 32 samples of FADC values with bilinear packing; time information of TDC hits override ADC value
- Algorithm: out of a pair keep the TDC hit or ship the second sample
- This preserves all TDC hits and reduces waveform to 16 bytes
- Expand decimated waveform to original size interpolating in the ROM after the bottleneck
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Hardware implementation

**Firmware**
- Only a firmware change in PROM which drives the slave FPGA

**Status**
- Burnt and validated before shutdown
- Fully implemented with uploadable software
- Validated with Run4 data and cosmics

*Read-out interface board of a DCH front end assembly*
Emulation with data

- We have the ability to ship raw waveforms together with data
- End of March 2004 ~ 30 runs were taken in this mode
- Applied decimation algorithm to 14 of these runs

Evaluate the effect of waveform decimation at the level of

- Single digis
- Track-by-track comparison (1 run)
- $dE/dx$ distributions
- Physics from online monitoring (3.5 runs)
Example physics check

Simple Analysis not available in standard monitoring

Look at \( m(D^*) - m(D^0) \) in \( D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+ \)

Channel interesting for tracking (slow \( \pi \)) and PID (K/\( \pi \) separation)

Yields and S/B ratio are unchanged within statistical errors
Performance comparison on cosmics runs

Looked at actual data (cosmics)

- Compare before (black) and after (red) electronics change
- Global gain difference due to testing of different gas composition
- After calibration (green) no difference in $dE/dx$

The present fix buys us some precious time at a low cost and solves the dead time problem on the short time.
Redesign the front-end board to perform feature extraction directly

- Installed a “Phase II” board on the detector in December 2004
  - Can switch between “old” and “new” configuration, uploading software into the FPGA
  - Waiting for beams to ensure radiation tolerance
- Pre-production board testing is being finalized
- New boards will be installed during short accesses to the IR

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Mix Monte Carlo $B \rightarrow D(\ast)D(\ast)$ with real random-trigger data

Multiple triggers overlaid to match luminosity extrapolations

Evaluate physics quality relative to current performance

<table>
<thead>
<tr>
<th>Compared to design $3 \times 10^{33}$ $\mathcal{L}$</th>
<th>$2 \times 10^{34}$ (3× bkg)</th>
<th>$4 \times 10^{34}$ (5× bkg)</th>
<th>$4 \times 10^{34}$ (10× bkg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking eff. (%)</td>
<td>$98.6 \pm 0.1 \pm 0.7$</td>
<td>$97.4 \pm 0.1 \pm 1.0$</td>
<td></td>
</tr>
<tr>
<td>Momentum $\sigma(p)/p = 4.7 \times 10^{-3}$</td>
<td>$+4.2 \times 10^{-5}$</td>
<td>$+5.5 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$D^0 \rightarrow K^+\pi^-$ (%)</td>
<td>$96.0 \pm 0.5$</td>
<td>$95.5 \pm 0.5$</td>
<td>$80 \pm 3$</td>
</tr>
<tr>
<td>$D^0$ Mass $\sigma = 6.5 \pm 0.2$ MeV/$c^2$</td>
<td>$6.5 \pm 0.2$</td>
<td>$6.4 \pm 0.2$</td>
<td>$7.0 \pm 0.3$</td>
</tr>
<tr>
<td>$D^* \rightarrow D^0\pi$ (%)</td>
<td>$84.4 \pm 1.1$</td>
<td>$75.0 \pm 1.3$</td>
<td>$25 \pm 2$</td>
</tr>
<tr>
<td>$D^*$ Mass $\sigma = 0.80 \pm 0.03$ MeV/$c^2$</td>
<td>$0.97 \pm 0.04$</td>
<td>$1.50 \pm 0.08$</td>
<td>$3.2 \pm 0.8$</td>
</tr>
</tbody>
</table>
Extrapolation to much higher luminosity

How would the Drift Chamber perform in an $10^{36}$ environment?

Only a rough guess can be made with these assumptions:

- Backgrounds scale according to January parameterization
- Finer segmentation, e.g. cell size down to $1/8^{th}$
- Luminosity term might be reduced by a factor of 5
BaBar Drift Chamber is stable and performing as designed – since 5 years

After initial problems, aging is well understood and under control

Deadtime bottleneck solved with electronics upgrade in two phases

With the full upgrade the chamber is well suited for data taking until the end of the BaBar lifetime

In the present configuration occupancy will soon become prohibitive with increasing luminosities
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Performance degradation in Run4

- We observe $\sim 5\%$ less reconstructed $B$ per $fb^{-1}$
- Significant changes in running mode (injection → trickle)
- Average background level is higher
- Key point is that this effect is modeled correctly in Monte Carlo
- The effect goes inversely with purity of the signal

DCH pseudo-efficiency plot for Run4 data

Efficiency for Drift Chamber, normalized to SVT tracks
Aging and gain variation

Continuously monitoring accumulated charge per unit wire length

Total charge 16.9 mC/cm in five years

After "accident" (cured adding water vapor), smooth decrease with time

Long-term studies of aging and remediation accumulated several times BaBar lifetime charge
### Babar-Belle Backgrounds Task Force

#### Performance

<table>
<thead>
<tr>
<th>CDC-DCH</th>
<th>Belle $10^{34}$</th>
<th>BABAR same Lumi</th>
<th>BABAR same beams</th>
</tr>
</thead>
<tbody>
<tr>
<td>total current ($\mu A$)</td>
<td>1000</td>
<td>1050</td>
<td>620</td>
</tr>
<tr>
<td>fraction due to const</td>
<td>8</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>fraction due to LER</td>
<td>65%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>fraction due to HER</td>
<td>27%</td>
<td>37%</td>
<td>45%</td>
</tr>
<tr>
<td>fraction due to lumi</td>
<td>0%</td>
<td>57%</td>
<td>49%</td>
</tr>
<tr>
<td>occupancy</td>
<td>1%</td>
<td>9%</td>
<td>6%</td>
</tr>
</tbody>
</table>

#### Currents

Comparison is approximate since absolute gain measurement is uncertain

- 40000 in 1998 for BaBar
- 20000 in 1994 for Belle ($\times 2-3$)

#### Occupancy

- **Belle** measures hit rate (discriminator+scaler)
- **BaBar** uses random triggers, multi-hit electronics, a waveform quality cut and integrates over $2\mu$sec

**Exp 27 Run 206**

- HER 1.1A
- LER 1.5A
- $L=9.6\times10^{33} \text{cm}^{-1}\text{s}^{-1}$

**Hit rate/wire (kHz)**

- Cathode
- Inner
- Main

**Layer**

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Effect on digis

Comparison at the single DCH digi level

- Charge resolution degradation for single digis is $\sim 6\%$
- A charge and TDC dependent correction is applied but is nearly irrelevant
- 0.6% originally “good” digis do not pass the $Q > 50$ cut

Expected new dE/dx resolution (for Bhabha’s)

$$(9 \oplus 6/\sqrt{35})\% = 9.05\%$$
**Track-by-track comparison**

**Method:**
- Try $n^2$ combinations and sort track pairs by $\Delta \phi$
- Match and remove pairs if $\Delta \phi < 0.01$
- Similarly for # of same hits > 5 on remaining track pairs
- Statistics on one run: 2.125 Mtracks

Out of 1000 tracks:
- 713 tracks are identical
- 281 are matched by $\phi$ and hits
- 6 are lost, 7 new are found with compatible distributions
- Lost tracks: low hit multiplicities, high background, ghosts, loopers, ...

![Graph showing track match distribution](image-url)
Effect on dE/dx

- Reconstructed 3.5 runs comparing old and new algorithm
- Yields and distributions of electron and protons are unaffected
- Carefully scanned tens of monitoring plots

Resolution is marginally degraded, as expected from single digits.
Effect on physics

Example of monitoring plots available in standard production

**All tracks**

- Original
- Modified WF

**Kaon selection**

- Original
- Modified WF

---

**Performance**

**Background**

**Upgrade**

**HiLumi**

**Extra**
Performance comparison on cosmics runs

- **dE/dx**
  - Counts
  - dE/dx July Cosmics Run 50437
  - dE/dx December Cosmics Run 51966

- **dE/dx December - dE/dx July (normalized) Vs P**
- **dE/dx December - dE/dx July (normalized) Vs Dip**
- **dE/dx December - dE/dx July (normalized) Vs phi**
Fit vs. Lumi after single beam subtraction

Lumi HER 2/3, LER scan

Lumi HER max, LER scan

Lumi HER 2/3, HER scan

Lumi LER 2/3, HER scan

Lumi LER max, HER scan

Lumi trickle, HER scan

All good Lumi points

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BaBar Drift Chamber performance – Extra material