e^+ e^- Collider Detector R&D

Status Report to US Japan Committee
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June 1, 2000
Outline

• Resistive Plate Chamber R&D
  – KEK, Princeton, Tohoku, Va Tech

• Vertex Detector R&D
  – Hawaii, KEK, Princeton, Tokyo
A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally \((r \approx 0.1 \text{ cm}^2)\) available charge is consumed.

The discharged area recharges slowly through the high-resistivity glass plates.
Efficiency

A simple test of system performance comes from looking for missing hits along muon tracks.

The three-muon event to the left shows that the RPC system is working well.

\[ B^+ \rightarrow J / \Psi K^+ \] candidate

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A Major Problem Develops

The first signs of trouble showed up shortly after installation and looked something like the plot to the right. The current from a chamber would “suddenly” show a dramatic increase.

Given that there is a “pedestal” current resulting from the spacers, the true dark-current increase was in fact substantial.
A Major Problem Develops . . .

High dark currents induce a significant IR voltage drop across the glass plates, which lowers the voltage across the gap, causing the chamber to slide off the efficiency plateau.

Increasing the applied voltage doesn’t help since it merely results in increased dark current.

The is what I like to call the classic “RPC Death Spiral”.
A Major Problem Develops . . .

The correlation between dark current and efficiency loss is readily apparent.
A Solution Emerges . . .

We replaced the long runs of polyethylene with copper (~5 km in all!) and flowed gas at the highest possible rate (~one volume change per shift).

Slowly, but surely, the RPCs began to dry out.
Where Does All That Water Come From?

- If one integrates the amount of water extracted from the chambers, it corresponds to several tens of molecular layers on the glass surfaces.
- A naive estimate is that the surfaces could hold only of order three molecular monolayers.
- But that is true only for a smooth surface.
- As we will see, the surfaces of chambers quickly become any but smooth.
STM Picture of a Virgin Glass Surface

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Surface of “Good” Anode

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We believe that the surfaces were etched by HF acid formed from the water and the Freon (R134A) in the gas. The trapped water probably affects the surfaces conductivity of the glass.
A Solution Emerges . . .

We were greatly relieved to see an accompanying drop in the dark currents after a prolonged dryout.
A Bullet Dodged . . . but

- We should understand this better.
- This could be important to future experiments (LHC etc.)
- Open questions:
  – Is the solution stable? (If we keep the RPCs dry, will they continue to work?)
  – What do the surfaces of “bad” RPCs that have been dried out look like?
  – Does this problem bear any relation to the problem that has affected the BaBar RPCs?
... Moving Inward to the SVD

\[ B^+ \rightarrow J/\Psi K^+ \] candidate
The SVD Readout Chip: the VA1

- 128 channels
- Descendent of Viking (O. Toker et al., NIM A340 (1994) 572.)
- AMS 1.2 um CMOS
- Noise:

\[ \text{ENC} = 165 e^- + 6.1 e^- / \text{pF} \]

@ 2 \( \mu \text{s} \) shaping time
SVD Performance

Bhabha miss distance

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Physics Results: Charm Lifetimes

$M_{K^+\pi^-}$ (GeV/c$^2$)

$D^0$ candidate proper time (fs)
B Mixing

Though not radiation hard, the current SVD has allowed us to do some physics.
Now the Bad News . . .

We see a drop in gain over time, which is consistent with what we expect from the measured dose. The 1.2-micron VA1s are projected to die after about 10 fb\(^{-1}\) (c.f. initial goal of 100 fb\(^{-1}\)).
In June of 1999 we noticed a sudden decrease in gain of the inner layer VA chips. The problem was ultimately found to be a large flux of low-energy x-rays.
Although we could easily solve the x-ray problem, it’s hard to anticipate every possible problem. Greatly improved radiation-hardness is clearly needed.
Something even a physicist can understand . . .

Reducing the oxide thickness by half is equivalent to cutting the dose by four.

\( \vec{E} \propto \rho \vec{x} \)

\[ \Delta V_{th} = \int_{0}^{t_{ox}} \vec{E} \cdot d\vec{x} \]

\[ \propto \rho \int_{0}^{t_{ox}} \vec{x} \cdot d\vec{x} \]

\[ \propto \rho t_{ox}^2 \]
AMS Process Comparison

<table>
<thead>
<tr>
<th>Feature Size</th>
<th>$t_{\text{oxide}}$</th>
<th>Projected Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 m</td>
<td>250 Å</td>
<td>200 kRad</td>
</tr>
<tr>
<td>0.8 m</td>
<td>160 Å</td>
<td>≡ 500 kRad</td>
</tr>
<tr>
<td>0.6 m</td>
<td>125 Å</td>
<td>800 kRad</td>
</tr>
<tr>
<td>0.35 m</td>
<td>75 Å</td>
<td>2200 kRad</td>
</tr>
</tbody>
</table>

One in fact expects to do considerably better than $t_{\text{oxide}}^{-2}$ scaling since tunneling plays an important role in deep submicron processes.
Original VA1 Test Results

AMS 1.2 um CMOS
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AMS 0.8 um CMOS
Process Comparison

In the range of interest to BELLE, the noise performance dramatically improves with decreasing feature size, as expected.
Indeed, the 0.35-um process exhibits phenomenal radiation hardness.
Conclusions and Plans

• In terms of cumulative radiation dose, the 0.35 um VA1 is much harder than what we require: > 20 MRad (cf. DMILL, which guarantees 10 MRad and Honeywell, which guarantees 1 MRad).

• Outstanding issues include:
  – single-event upset (not a major issue for the VA1, which can be reset every event)
  – single-event latchup (more studies are needed)