Belle Silicon Vertex Detector for the Super B Factory
M. Friedl (HEPHY Vienna) for the Belle SVD Group

Outline

- Introduction
- The Past: SVD1
- The Present: SVD2
- The Future
- Near Future: SVD2.5
- Distant Future: SVD3
- Summary
Outline

Introduction
- The Past: SVD1
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Summary
Introduction – Location

KEK
Located in Tsukuba Science City, ~60km NE of Tokyo, Japan

KEK-B
8GeV e⁺ ↔ 3.5GeV e⁻ collider, >10^{34} cm² s⁻¹ luminosity, 509 MHz RF

Belle
Single experiment located in “Tsukuba area”
**Introduction – Belle Detector**

Belle is a typical medium-sized experiment with dimensions (L=7.3m, $\varnothing=7.2$m, W=1500t).

**Subsystems**
- Silicon Vertex Detector
- Central Drift Chamber
- Aerogel Cherenkov
- Time of Flight
- EM Calorimeter
- Superconducting Magnet
- H Calorimeter

**Magnetic field**
- $B=1.5$T
Outline

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Distant Future: SVD3

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The Past: SVD1 – Overview

Layout: 3 layers (8/10/14 ladders), r=3.0...6.1 cm

Coverage: 23°...139° polar angle

Silicon: 102 double sided silicon detectors (DSSDs), 0.2m² overall active area

Readout: VA1 chip (1.2µm/0.8µm, radiation tolerance ≤1MRad)

81920 channels in total
The Past: SVD1 – Main Problems

**Gain loss**

Due to radiation → performance degradation

**AC Coupling**

Voltage level translation implemented on sensor AC capacitance

Pinhole implies to decrease bias voltage to keep readout operational

5 ladders essentially lost due to this problem
## The Present: SVD2 – Overview

<table>
<thead>
<tr>
<th>Layout</th>
<th>SVD2: 4 layers (6/12/18/18 ladders), r=2.0…8.8cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>17°…150° polar angle (matching with Central Drift Chamber)</td>
</tr>
<tr>
<td>Silicon</td>
<td>246 DSSDs, 0.5m² overall active area</td>
</tr>
<tr>
<td>Readout</td>
<td>VA1TA chip (0.35µm, radiation tolerance 20MRad; with internal trigger)</td>
</tr>
<tr>
<td></td>
<td>110592 channels in total</td>
</tr>
</tbody>
</table>
The Present: SVD2 – Solved SVD1 Problems

- Stable gain
- Floating power readout scheme
- Gain
  - Radiation tolerant chip → stable gain and performance
- AC Coupling
  - Voltage level translation implemented by optocouplers
  - No more pinhole problems
The Present: SVD2 – Comparison to SVD1

SVD1 – SVD2 geometries

Layout changes

Smaller z strip pitch (84→75µm) and smaller beam pipe

Hence

Significant improvements of impact parameter resolutions
The Present: SVD2 – Main Problems

Occamay in layers 1 to 4

Hit finding efficiency in layer 1

Occupancy | Layer 1 $\sim$10% (mainly off-time background events)
Deteriorates hit finding efficiency and (moderately) resolution

Dead Time | Event readout takes $128 / 5MHz = 25.6\mu s$
$\sim$3% dead time @ 450Hz trigger rate ($L=1.5\times10^{34}\text{cm}^{-2}\text{s}^{-1}$)
The Present: SVD2 – Reinforcement

Proposed options for short term improvements

**Occupancy**
- Shortening of VA1TA shaping curve
  - Currently: $T_p \sim 800$ns, total $\sim 2\mu$s
  - Slight reduction potential (max. 30%) at the cost of S/N

**Dead Time**
- Increasing readout clock
  - Currently: 5MHz
  - 10MHz possible at the cost of slight crosstalk

**Conclusions**
- Investigations done
- Might be adopted once necessary, currently not (yet)

**Baseline**
- Not too much can be gained with present system
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The Future: Luminosity Projection

Projection of KEKB Luminosity

1 /ab comes on the horizon!

Integrate Luminosity (fb)


Year

24 /fb/mo.

“official” goal

We are here

18 /fb/mo.

Crab Cavity Beam Test

Super-KEK-B accelerator upgrade

Integrated Luminosity

Luminosity Increases constantly

Accelerator Crab cavities will boost luminosity in 2006

Future Plan Major upgrade of accelerator and detector in 2009/2010
### The Future: SVD Upgrade Roadmap

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity ($10^{34}$)</td>
<td>2.0</td>
<td>3.0</td>
<td>5.0</td>
<td>5.0</td>
<td>0</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>SVD2.0 reinforcement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVD2.0→SVD2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replace L1 &amp; L2 ladders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVD2.5→SVD3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full upgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **SVD2.5** Inner ladders will be equipped with APV25 readout
- **SVD3** Completely new detector, pixel option
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# SVD2.5 – Objectives & Strategies

## Objectives
- Reduce occupancy
- Reduce/avoid dead time

## Dead Time
- Front-end chip with pipeline

## Occupancy
- Two possibilities:
  - Geometry: Reduce sensitive area of each strip
  - Time: Shorten shaping time

More advanced method and details will be presented on Wednesday by Manfred Pernicka: "**Occupancy Reduction by APV25**"

## Solution
- APV25 front-end chip (developed for CMS)
- 192-cell pipeline
- 50ns shaping time
SVD2.5 – Occupancy Reduction – Geometry Approach

Conventional DSSD

- Strips 71 / 8.5mm
- All strips 12mm long

Pros
- Smaller active area covered by each strip
- Better S/N

Cons
- Larger number of channels
- Rotated geometry

Gain
- ~6 times smaller acceptance (for long strips)

UV-Striplet DSSD
SVD2.5 – Occupancy Reduction – Time Approach

VA1TA
Tp~800ns

APV25
Tp~50ns

Time over threshold ~ 2000ns (measured)

Time over threshold ~ 160ns (measured)

Pulse shape processing
RMS(tmax)~3ns

Sensitive time window ~ 20ns

Gain ~12.5

Gain ~8

Total gain ~100

Details Manfred Pernicka: “Occupancy Reduction by APV25” (Wednesday)
### SVD2.5 – Design

| Scope           | SVD layers 1 & 2 will be replaced  
|                 | (Layers 3 & 4 will remain as they are) |
| Sensor          | Conventional x-y (very similar to SVD2)  
|                 | Mixed xy/uv layout would make tracking quite complicated |
| Readout         | APV25 |
| Processing      | ~20ns sensitive time window |
| Comparison      | Innermost layer SVD2 ~10% occupancy (L=1.5x10^{34}cm^{-2}s^{-1})  
|                 | With SVD2.5 ~0.1% occupancy |
|                 | Assuming that occupancy scales with luminosity, this solution potentially works up to L~10^{36}cm^{-2}s^{-1} |
**SVD2.5 – Comparison VA1TA, APV25**

<table>
<thead>
<tr>
<th>Property</th>
<th>SVD2</th>
<th>SVD2.5</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIC</td>
<td>VA1TA</td>
<td>APV25</td>
<td></td>
</tr>
<tr>
<td>CMOS Process</td>
<td>0.35</td>
<td>0.25</td>
<td>µm</td>
</tr>
<tr>
<td>Radiation Tolerance</td>
<td>20</td>
<td>&gt;100</td>
<td>MRad</td>
</tr>
<tr>
<td>Peaking Time</td>
<td>800</td>
<td>50</td>
<td>ns</td>
</tr>
<tr>
<td>Clock</td>
<td>5</td>
<td>40</td>
<td>MHz</td>
</tr>
<tr>
<td>Readout dead time</td>
<td>25.6</td>
<td>0.075 (pipeline)</td>
<td>µs</td>
</tr>
<tr>
<td>Trigger input</td>
<td>async hold</td>
<td>sync trigger</td>
<td></td>
</tr>
<tr>
<td>Trigger output</td>
<td>fast-or</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

**APV25**
- Features “deconvolution” option to narrow shaper output pulse
- Designed for bunched (=CLK-synchronous) LHC beam
- Does not work @ Belle because of 509MHz beam (~continuous)

**APV25 Details**
- Manfred Pernicka: **“Occupancy Reduction by APV25”** (Wednesday)
**SVD2.5 – DAQ**

SVD2.5 implies DAQ upgrade
- Parallel paths of old and new readout chain
- SVD2: Zero-suppression is done by software in PC farm
- SVD2.5: Zero-suppression and pulse shape processing is done in FPGAs inside FADC units

Current status (October 2005):
- FPGA programming in progress
- Zero-suppression (including pedestal subtraction and CMC) works
- Clustering, processing to be done

- L1-L2 ladders APV25
- L3-L4 ladders VA1TA
- Existing SVD2 DAQ
- Raw data
- Zero-sup., processed data (20ns time window)

- FADC w/ Spars. Control
- VA1TA repeater
- Copper /TTD
- TT-IO
- GDL
- Event Builder
- L0T
- TTM
- PC farm
SVD2.5 – Beam Tests

UV striplet with double-sided APV25 readout

April 2005 beam test @ KEK

Beam Tests

August 2004 @ CERN: UV striplet with single sided APV25 readout

April 2005 @ KEK: UV striplet with double sided APV25 readout

August 2005 @ PSI: same at high intensity and statistics
**SVD2.5 – Beam Test Results – Signal**

**UV_DSSD_p_side (51) - Signal**
- Entries: 13148
- Mean: 2.498e+04
- RMS: 1.073e+04
- $\chi^2$/ndf: 77.04/63
- Width: 1717 ± 31.1
- MP: 1.903e+04 ± 39
- Area: 1.336e+07 ± 117842
- GSigma: 1484 ± 59.9

**Peak = 19533.1**
**FWHM = 41.4%**

**UV_DSSD_n_side (51) - Signal**
- Entries: 13287
- Mean: 2.555e+04
- RMS: 1.059e+04
- $\chi^2$/ndf: 73.37/67
- Width: 1647 ± 29.8
- MP: 1.978e+04 ± 38
- Area: 1.348e+07 ± 118232
- GSigma: 1471 ± 63.2

**Peak = 20286.3**
**FWHM = 38.6%**

**p side signal distribution**

**n side signal distribution**

**Signal**
- Nice signal distributions for both p and n sides
- Perfectly fit with Landau*Gauss
- Cluster S/N~27

**More Results**
- Manfred Pernicka: “**Occupancy Reduction by APV25**” (Wednesday)
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SVD3 – Overview

**LoI**
“Letter of Intent for KEK Super B Factory”
Published 18 Feb 2004
Contains conceptual design

**Trigger**
SVD trigger desirable
Could be used to reduce beam background triggers (~80%) and enhance physics → significant load reduction in DAQ system
Will be difficult... (SVD2 triggers were not very successful)
Obviously there are still many question marks
R&D ongoing
SVD3 – Sensor Configuration

**Layout**
SVD3: 6 layers (12/12/12/12/24/24 ladders), r=1.3…15.0cm

**Coverage**
17°…150° polar angle (same as SVD2, matching with CDC)

**Layers 1 & 2**
Options:
- APV25 with DSSD striplet → “test case” SVD2.5
- Pixel
**SVD3 – Pixel option**

Hybrid pixel  Conventional option hardly improves resolution (pixel size and $X_0$ too big) → need thinner device with smaller pixels

Possible solution: CAP (Continuous Acquisition Pixel)
Monolithic pixel  Thermal charge collection in thin (~10µm) epitaxial layer

Cross section

![CAP3 (December 2004)](image)
**SVD3 – Monolithic Active Pixel Sensor: CAP**

**CAP3 Pixel cell with mini-pipeline**

**Double correlated sampling**

<table>
<thead>
<tr>
<th>DSC</th>
<th>Double correlated sampling with reset in abort gaps (500ns every 10µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration Time</td>
<td>10µs, sub-divided by 2x5 cells mini-pipeline → 1µs</td>
</tr>
<tr>
<td>CAP1</td>
<td>Signal<del>300e, Noise</del>16e → S/N~19</td>
</tr>
<tr>
<td>Readout</td>
<td>1.6 GS/s optical links</td>
</tr>
<tr>
<td>Critical R&amp;D</td>
<td>Readout speed, radiation hardness (20MRad), thinning to 50...100µm</td>
</tr>
</tbody>
</table>
**SVD3 – Comparison APV25, CAP**

**SVD2** Current system is shown as reference

<table>
<thead>
<tr>
<th>Property</th>
<th>SVD2</th>
<th>APV25+striplet</th>
<th>CAP</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel area</td>
<td>3,840,000</td>
<td>601,800</td>
<td>506</td>
<td>µm²</td>
</tr>
<tr>
<td>Sensitive time</td>
<td>2000</td>
<td>20</td>
<td>1000</td>
<td>ns</td>
</tr>
<tr>
<td>Ambiguity</td>
<td>space &amp; time</td>
<td>space</td>
<td>time</td>
<td></td>
</tr>
<tr>
<td>Chip channels</td>
<td>128</td>
<td>128</td>
<td>118,784</td>
<td></td>
</tr>
<tr>
<td>Readout speed</td>
<td>5</td>
<td>42</td>
<td>1,600</td>
<td>MS/s</td>
</tr>
<tr>
<td>Readout/DAQ effort</td>
<td>low</td>
<td>low</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>L1 radius</td>
<td>2.0</td>
<td>1.3</td>
<td>1.3</td>
<td>cm</td>
</tr>
<tr>
<td>L1 &amp; L2 material (sensors)</td>
<td>600 (1.5%)</td>
<td>600 (1.5%)</td>
<td>200 (0.5%)</td>
<td>µm (X₀)</td>
</tr>
<tr>
<td>MC IP res. @ 2GeV/c, α=90°</td>
<td>17</td>
<td>9</td>
<td>7.5</td>
<td>µm</td>
</tr>
</tbody>
</table>

**SVD3** APV25+striplet and CAP are quite contrary concepts

Maybe mixture of both, combining time & space sensitivities?
SVD3 – Impact Parameter Resolution

MC data shown for z direction and four scenarios here (L1 and L2 each):
- SVD2 (reference)
- Hybrid Pixel (ALICE type, 50x400µm²)
- APV25+striplet
- CAP

Hybrid pixel offers very little improvement over SVD2
CAP slightly better than APV25+striplet
## SVD3 – Occupancy Scaling

<table>
<thead>
<tr>
<th>Property</th>
<th>SVD2</th>
<th>APV25+striplet</th>
<th>CAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel area</td>
<td>1</td>
<td>1/6.4</td>
<td>1/7585</td>
</tr>
<tr>
<td>Sensitive time</td>
<td>1</td>
<td>1/100</td>
<td>1/2</td>
</tr>
<tr>
<td>1/(L1 radius)$^2$</td>
<td>1</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Occupancy @ L=$1.5\times10^{34}$</td>
<td>10%</td>
<td>0.038%</td>
<td>0.0016%</td>
</tr>
<tr>
<td>Occupancy @ L=$3\times10^{35}$</td>
<td>(200%)</td>
<td>0.75%</td>
<td>0.032%</td>
</tr>
<tr>
<td>Occupancy @ L=$10^{36}$</td>
<td>(667%)</td>
<td>2.5%</td>
<td>0.11%</td>
</tr>
<tr>
<td>Total # of L1 channels</td>
<td>12,288</td>
<td>24,576</td>
<td>~20M</td>
</tr>
<tr>
<td>Fired channels @ L=$10^{36}$</td>
<td>1,229 (now: L=$1.5\times10^{34}$)</td>
<td>614</td>
<td>~20,000</td>
</tr>
</tbody>
</table>

### Occupancy
No problem for APV25+striplet nor CAP

### DAQ / Tracking
APV25+striplet: effort similar to SVD2; CAP: much higher

### Conclusion
APV25+striplet more matured (with SVD2.5 as a test bench)
CAP slightly better for physics goals, but more difficult to build (→ R&D)
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## Summary

<table>
<thead>
<tr>
<th>SVD1</th>
<th>Radiation underestimated, pinhole problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVD2</td>
<td>Greatly improved detector, stable operation (4 layers, r=2.0...8.8cm)</td>
</tr>
<tr>
<td></td>
<td>L1 occupancy at limit (10%), significant dead time (25.6μs)</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Small improvements possible in the short term</td>
</tr>
<tr>
<td>SVD2.5</td>
<td>L1 and L2 replacement with APV25 (CMS)</td>
</tr>
<tr>
<td></td>
<td>Sensitive time window reduction from 2μs → 20ns: L1 occupancy 0.1%</td>
</tr>
<tr>
<td>~2010</td>
<td>Upgrade of accelerator and detector → Super-KEK-B and Super-Belle</td>
</tr>
<tr>
<td></td>
<td>Extended SVD3 proposed (6 layers, r=1.3...15cm)</td>
</tr>
<tr>
<td></td>
<td>L1 and L2: APV25+striplet (test bench SVD2.5) or pixel</td>
</tr>
</tbody>
</table>