Electronics Contributions to the Belle Silicon Vertex Detector by HEPHY Vienna

BELLE

HEPHYVIENNA

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M. Friedl*, C. Irmler, M. Pernicka, C. Schwanda

HEPHY, Institute of High Energy Physics, Austrian Academy of Sciences, Vienna (Austria)

ABSTRACT

The Belle experiment at KEK (Tsukuba, Japan) studies CP violation in B meson decays by measuring the sides and angles of the unitarity triangle. Some of these measurements require the reconstruction of the vertices of the two decaying B mesons in an Y(4S) event, making the Silicon Vertex Detector (SVD) a critical device for the experiment. The initial SVD1 was in operation from 1999 until 2003, suffering from radiation levels beyond expectation. The current SVD2, installed in 2003, introduced several improvements, like radiation tolerance and a higher accuracy due to an additional fourth layer. Over the years, the occupancy levels grew along with luminosity especially in the innermost layer (~10%), compromising tracking precision and data acquisition throughput. This leads to another upgrade called SVD2.5, where the two inner layers will be equipped with faster and dead-time-free front-end amplifiers.

The Electronics-2 group at HEPHY Vienna designed and built the SVD2 FADC VME modules which digitize the analog data from the front-end, extract the first-level trigger using combinatorics between layers and present binary hit data to the L1.5 trigger electronics. Due to our experience from CMS, we suggested the APV25 front-end chip for the SVD2.5 upgrade and built several prototype systems including various front-end modules, repeaters, VME controllers and FADCs with hardware data processors performing pedestal subtraction, common mode correction and zero suppression within FPGAs. Moreover, multiple samples along the shaping curve of the APV25 can be used to reconstruct the particle timing with a precision of a few nanoseconds, which will also be implemented in FPGA firmware using look-up tables, in order to reject off-time hits and thus eliminate the occupancy problem. Finally, we try to optimize the signal-to-noise ratio of the front-end detector module, using SVD2.5 sensors and the APV25 front-end chip.
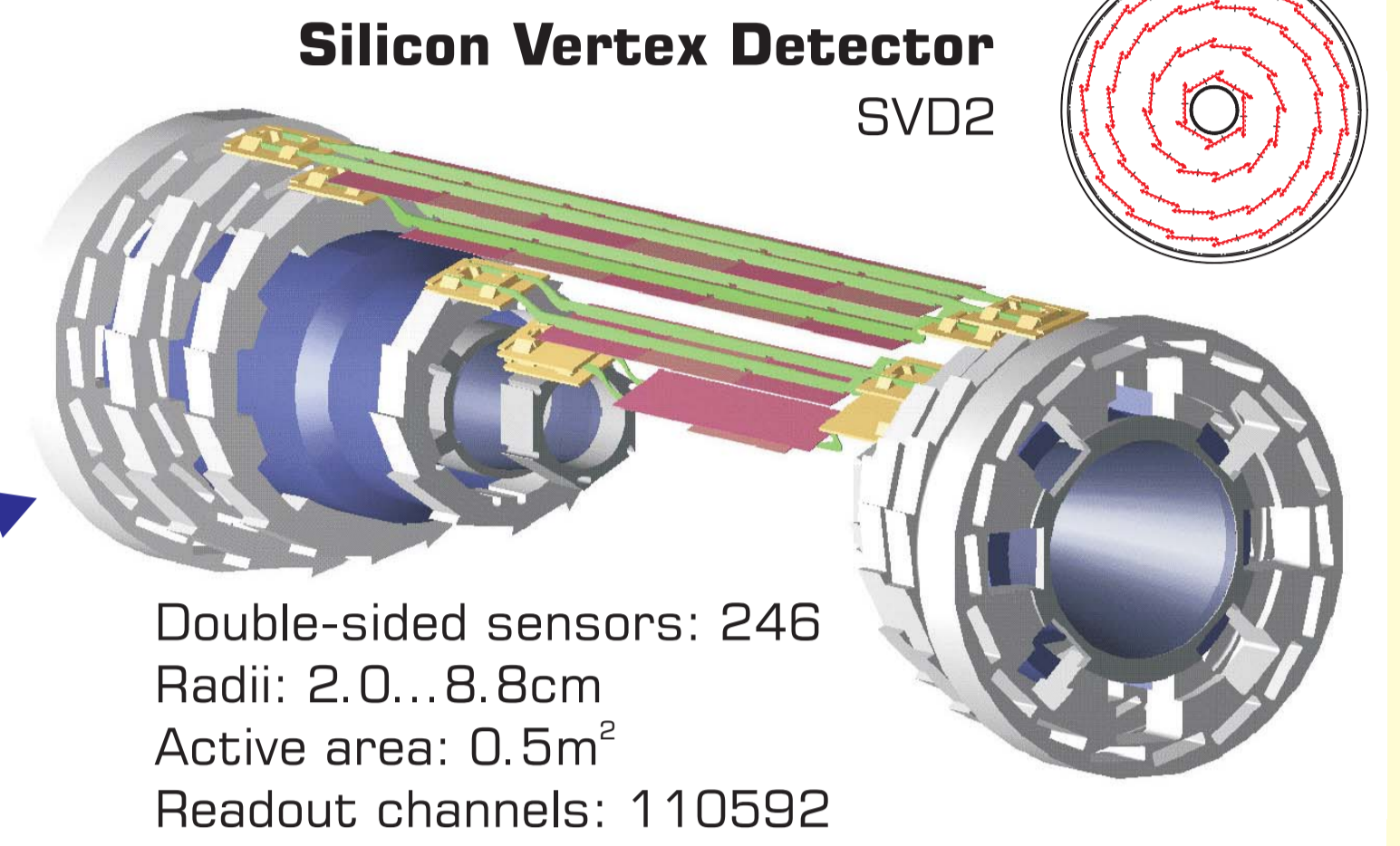
KEKB/BELLE OVERVIEW
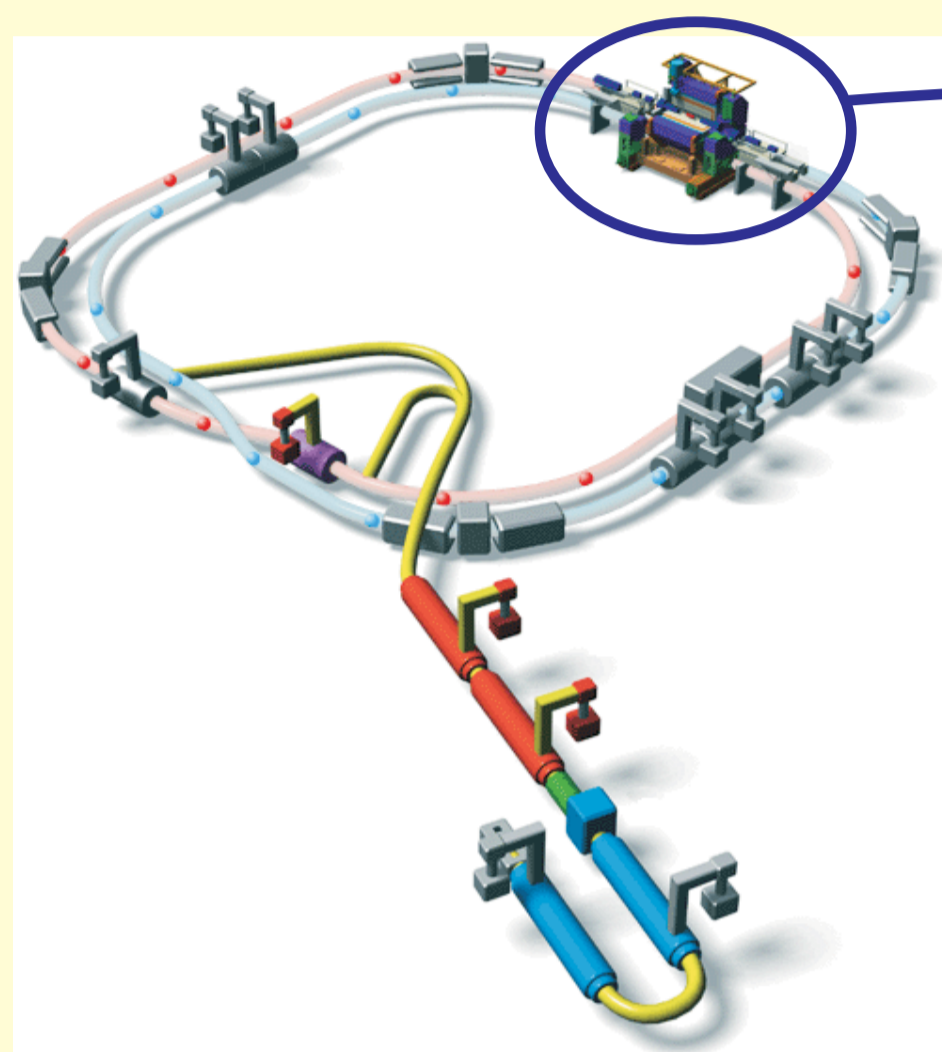
KEKB Ring

Circumference: 3km
Energies:
e^- 8GeV, e^+ 3.5GeV
Peak Beam Currents:
e^- 1.4A, e^+ 1.8 A
Peak Luminosity:
$1.7 \cdot 10^{34} cm^{-2} s^{-1}$
Bunch Spacing: 2ns max.
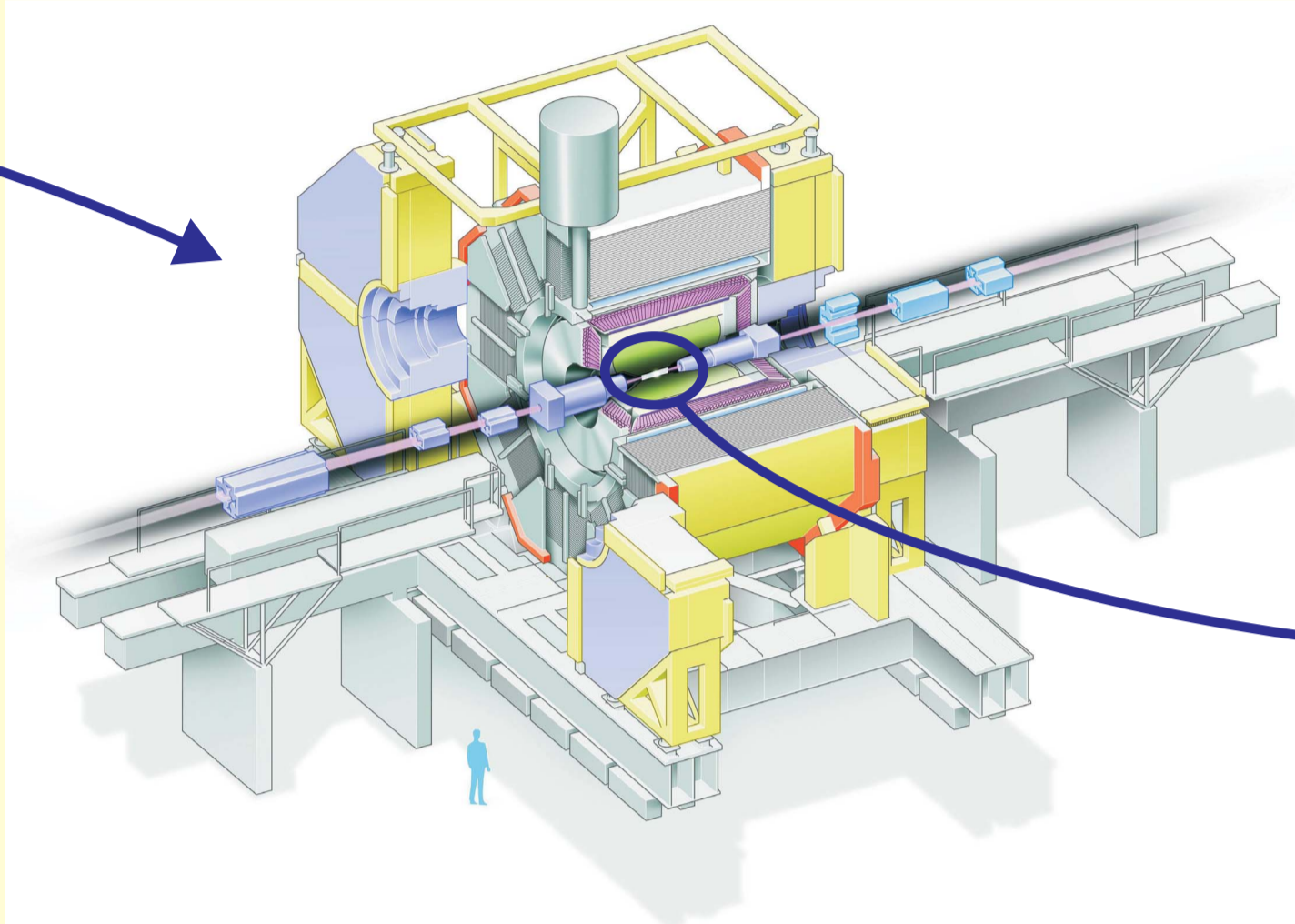
Belle Experiment

Length: 7.3m
Diameter: 7.2m
Weight: 1500tons
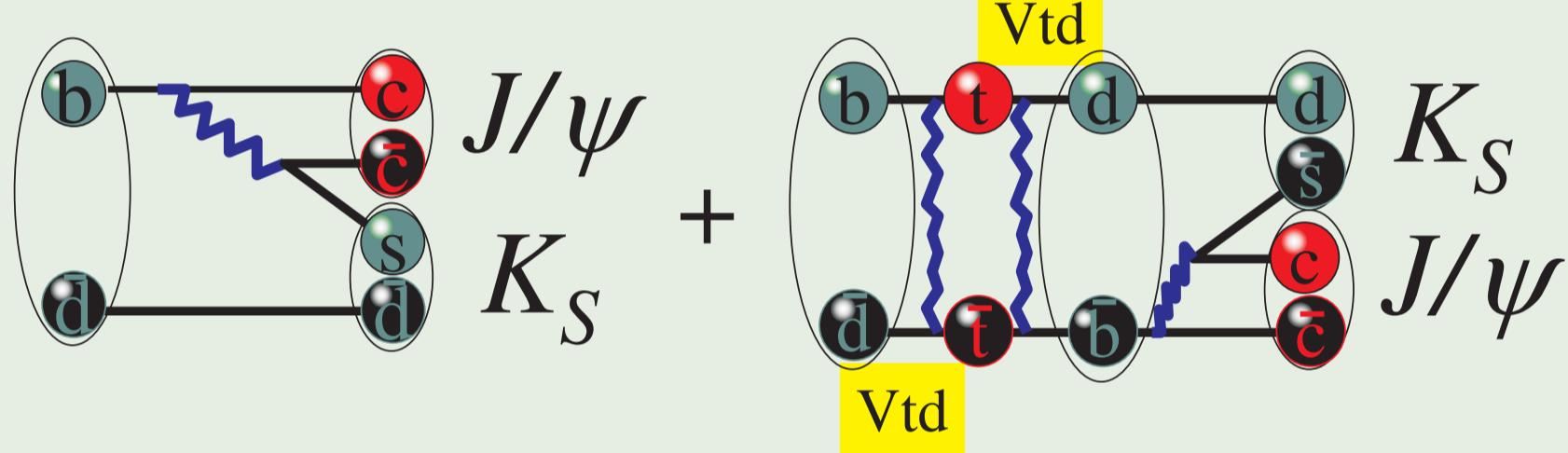Magnetic Field: 1.5T

Silicon Vertex Detector
SVD2

Double-sided sensors: 246
Radii: 2.0...8.8cm
Active area: 0.5m²
Readout channels: 110592

PHYSICS MOTIVATION

CP violation in $B^0 \to J/\psi\ K^0_s$ arises from the interference of these two diagrams

tree diagram

box diagram + tree diagram

J/ψ
K_S
+
K_S
J/ψ

Vtd
Vtd

Time-dependent CP asymmetry

Decay time difference between the two Bs in the event
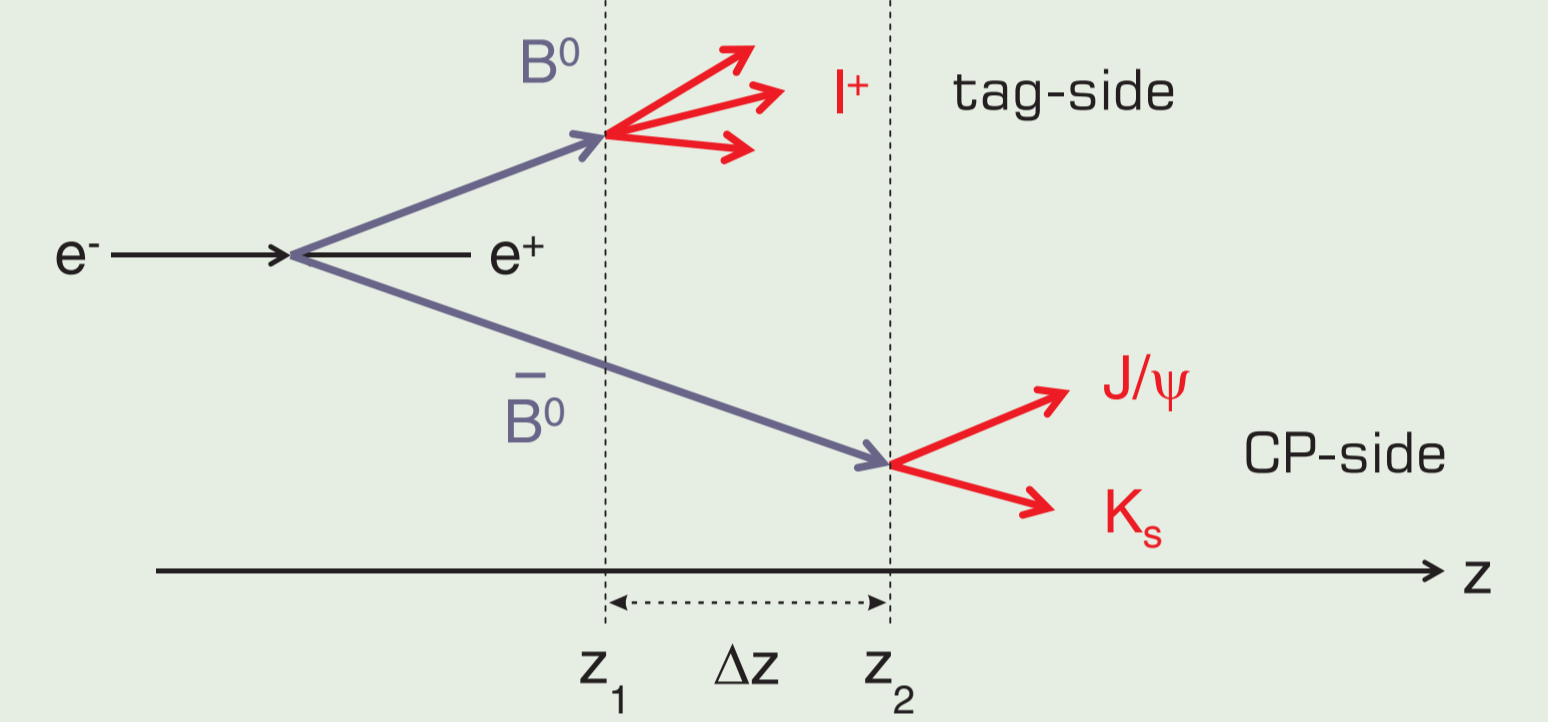
Decay time flavor of the other (non-signal) B

$$A_{CP}(\Delta t)$$
$$\equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)}$$
$$= \mathcal{S}\sin\Delta m\Delta t + \mathcal{A}\cos\Delta m\Delta t$$

Mixing-induced CPV   Direct CPV

For $B \to J/\psi\ K^0_s$, S=sin 2φ, and A=0 (no direct CP violation)

Principle of the measurement

B^0 l^+ tag-side
e^- e^+
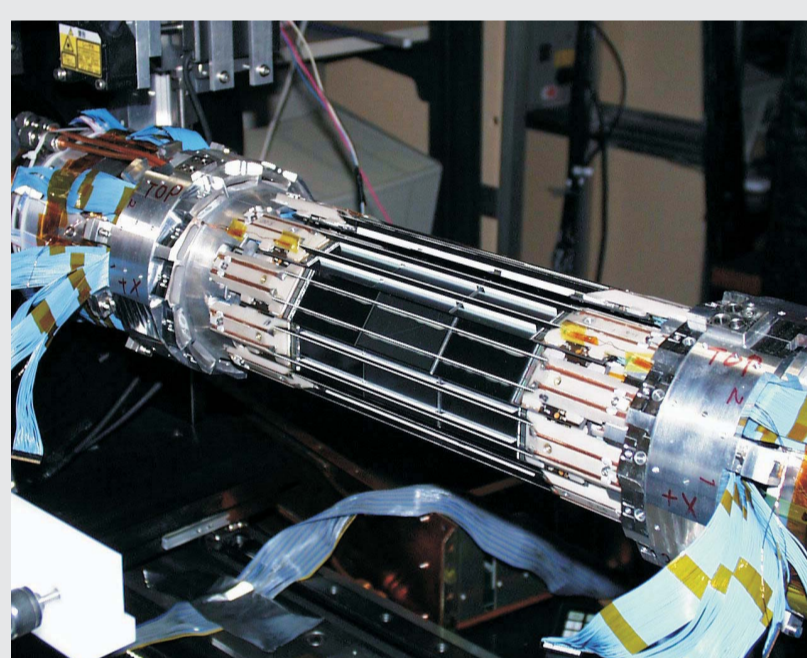B^0 J/ψ CP-side
K_S z
z_1 Δz z_2

$\Delta t = \Delta z/\beta\gamma c$, $\beta\gamma = 0.425$ at KEKB

THE PAST: SVD1
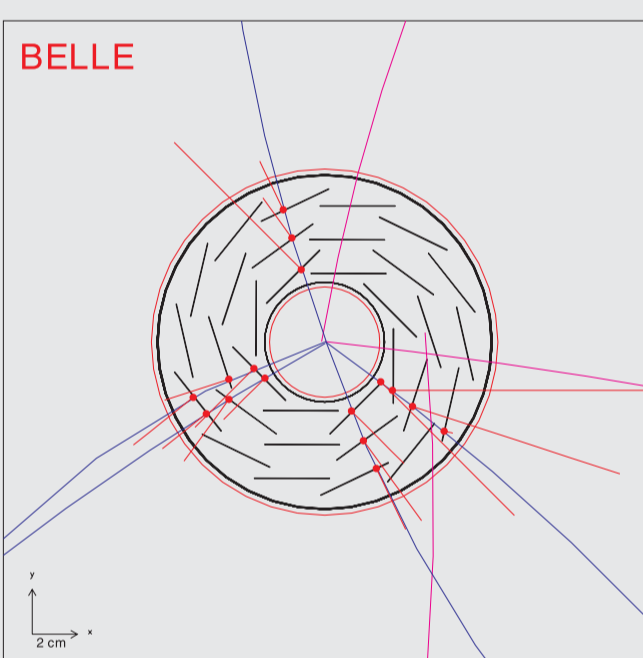
Reconstructed event

Fully mounted SVD 1

The first version of the Silicon Vertex Detector (SVD1) was in operation from 1999 until 2003 and performed well, delivering excellent physics results.

Unfortunately, radiation levels were higher than expected, so SVD1 suffered from radiation damage and had to be repaired/improved several times before it was finally upgraded to SVD2.


SVD1 Layer 2 Ladder
SVD1 Layer 2 Ladder
SVD1 Layer 2 Ladder
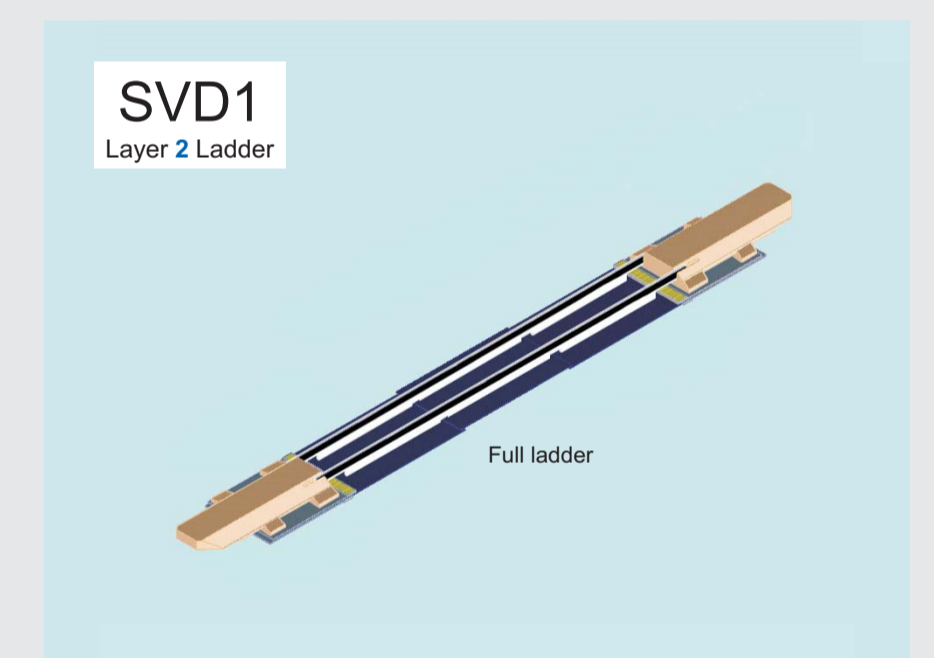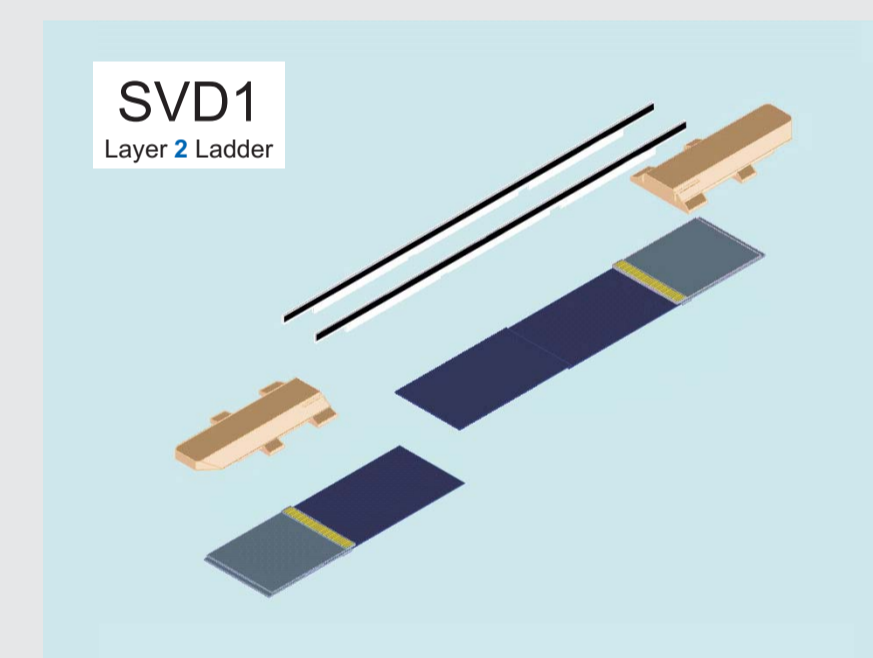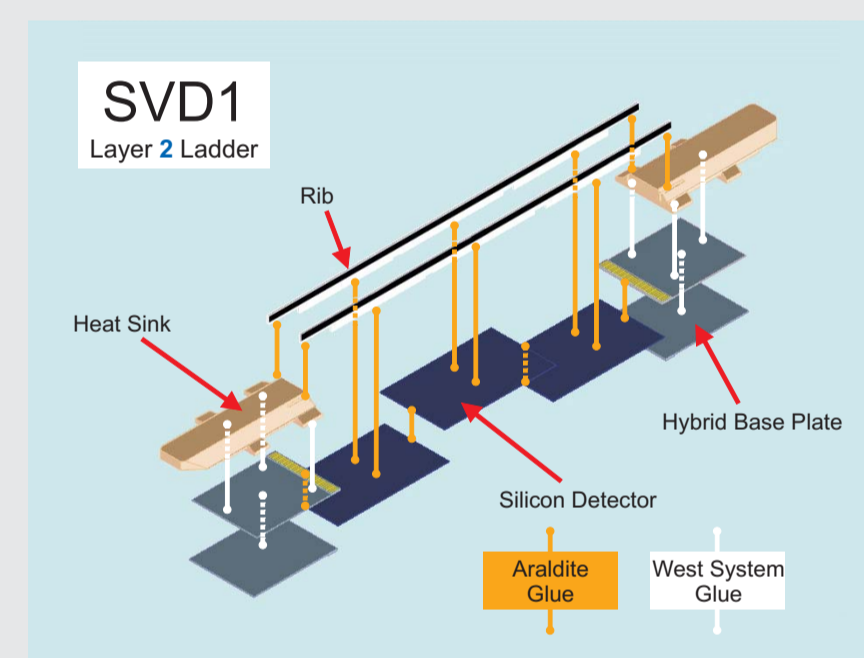
Steps of SVD1 ladder assembly performed at KEK and in Melbourne

Presented to the Electronics-2 group at HEPHY Vienna by J. Haba, then leader of the Belle SVD group.

The original poster contains a real SVD1 ladder here. Yes, it is a 3D poster :-) Unfortunately, this cannot be shown in a PDF...

One of the first layer ladders of SVD1 which actually measured the CP asymmetry of B-meson system for the first time in the human history.
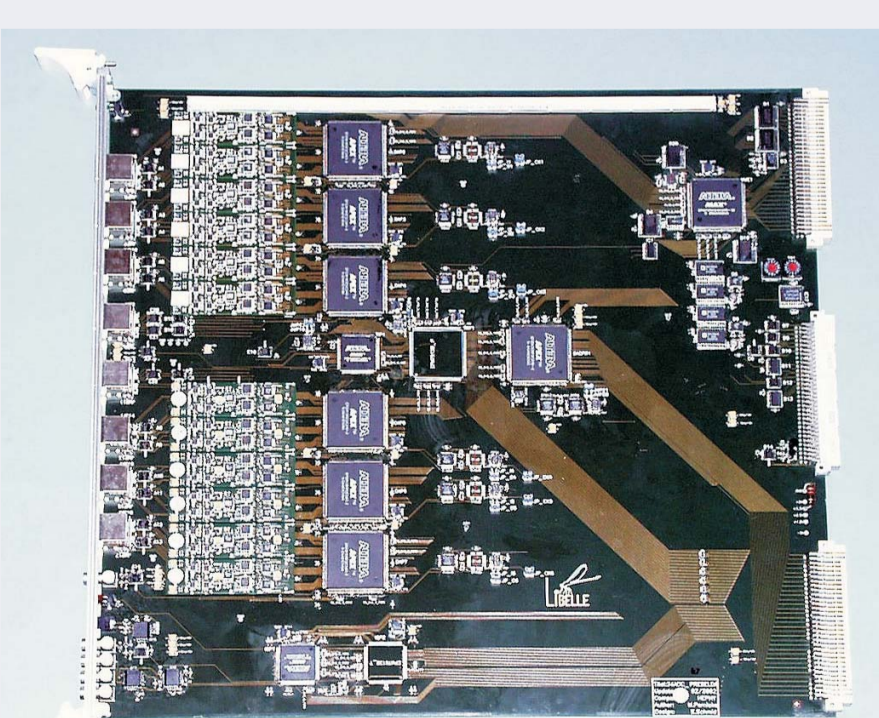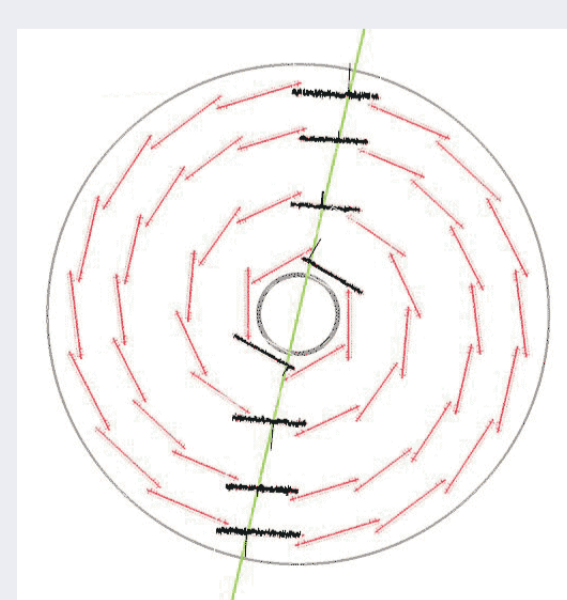
THE PRESENT: SVD2
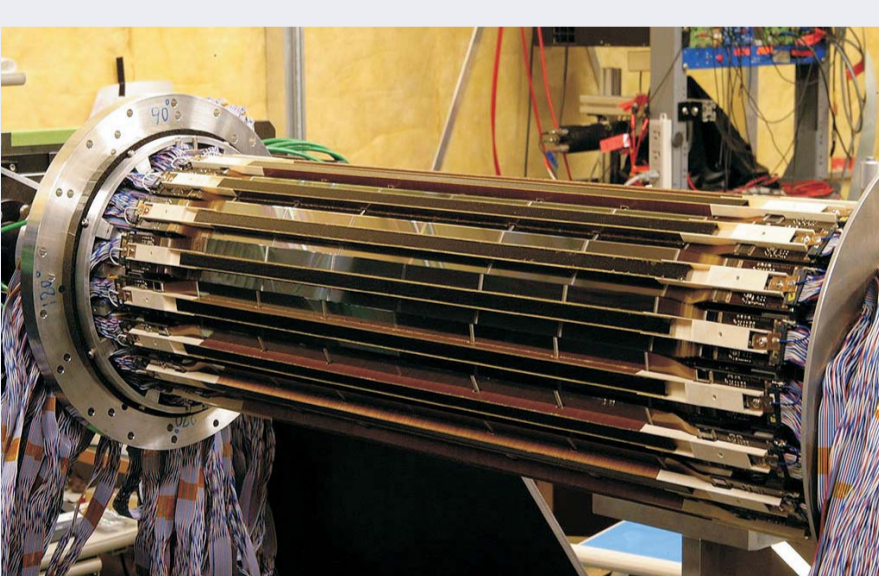
Completed SVD2 structure

FADCTF module (VME 9U)

Cosmic event

FADCTFs in operation in Belle

The SVD2 has many improvements compared to its predecessor and was installed in 2003.

All weaknesses of the SVD1 were successfully cured and an additional (fourth) layer was added, thus improving the impact parameter resolution.
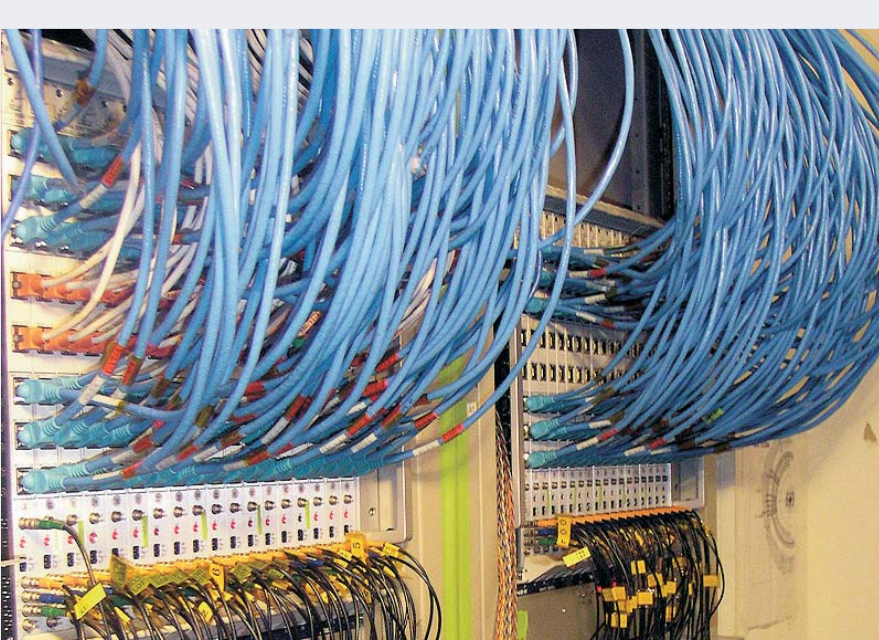
The FADCTF modules digitize the analog data from the front-end, extract the first-level trigger information using combinatorics between layers in both rz and rφ projections and present binary hit data to the L1.5 trigger.

These 9U VME modules were designed and built by HEPHY Vienna. 36 units are in operation in the Belle experiment at KEK.
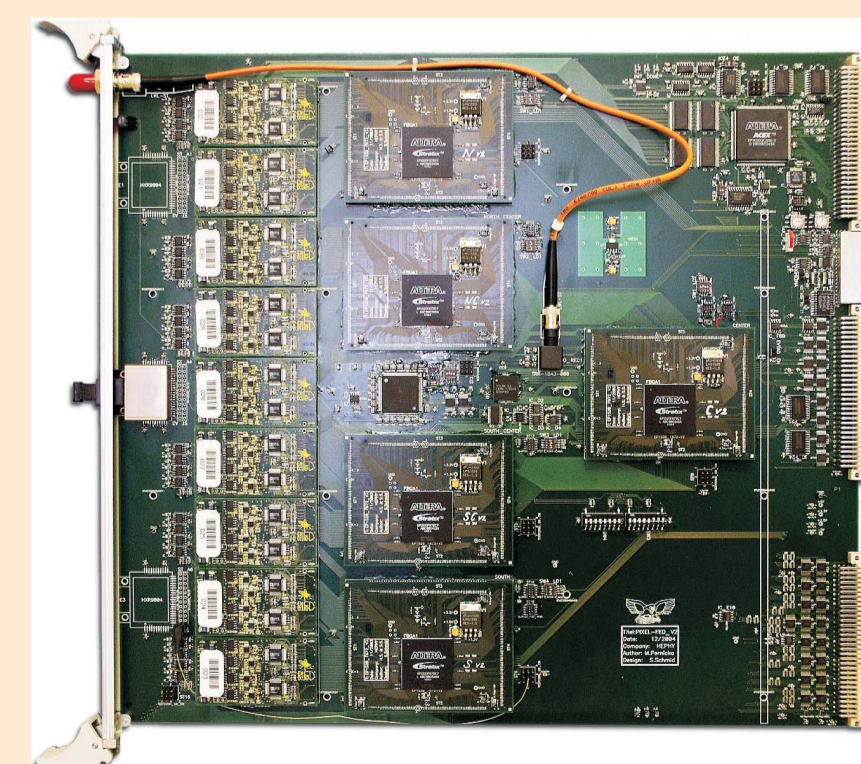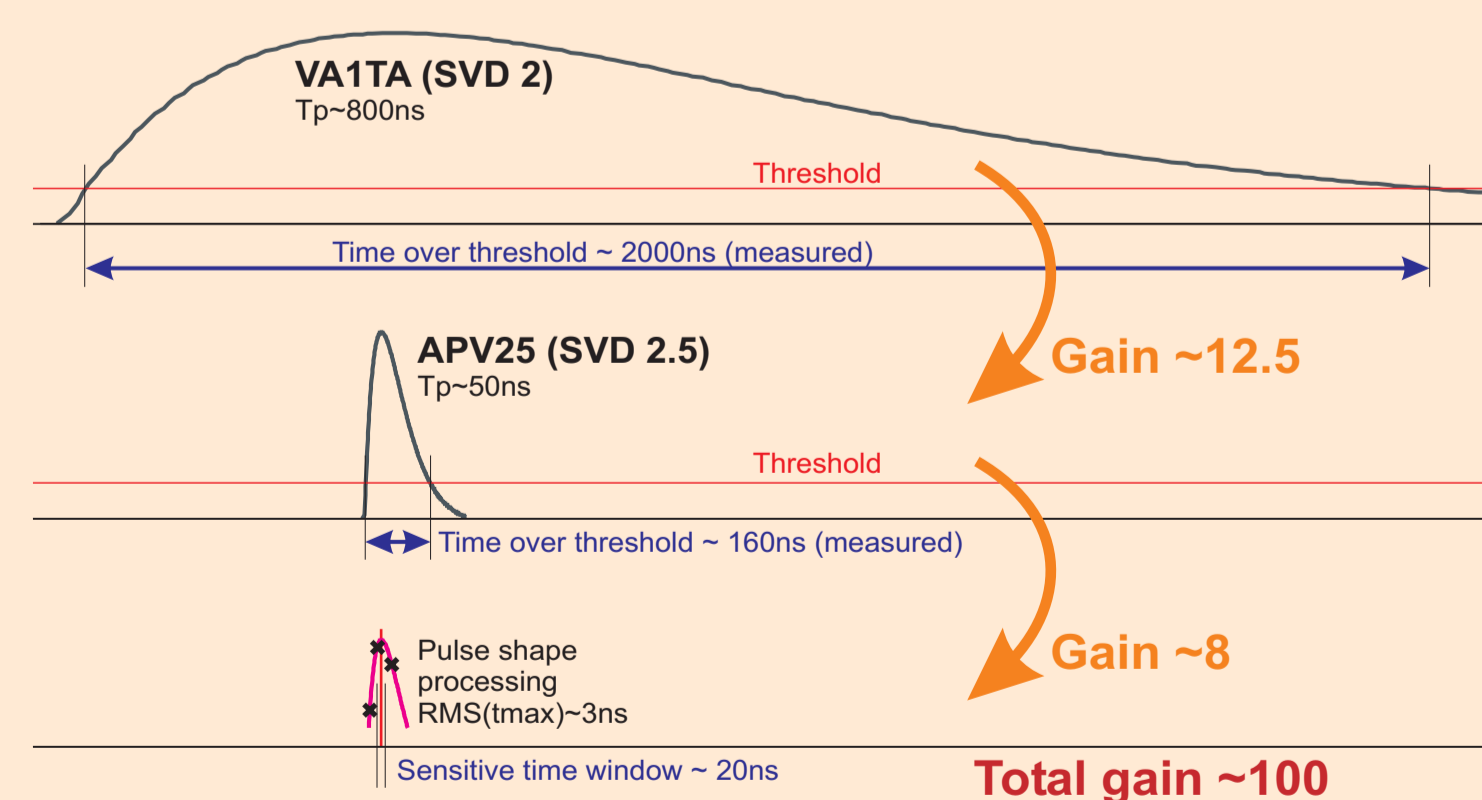
THE FUTURE: SVD 2.5

Currently, the innermost layer of the SVD2 has about 10% occupancy, which will increase together with luminosity, deteriorating the tracking accuracy. Moreover, the fraction of dead-time will grow as well.

These issues will be solved by replacing the front-end readout chip (SVD2: VA1TA) with the fast, pipelined APV25 (originally designed for CMS at LHC) and by real-time data processing using FPGAs.

VA1TA (SVD 2)
Tp~800ns
Threshold
Time over threshold ~ 2000ns (measured)

APV25 (SVD 2.5)
Tp~50ns
Threshold
Time over threshold ~ 160ns (measured)
Gain ~12.5

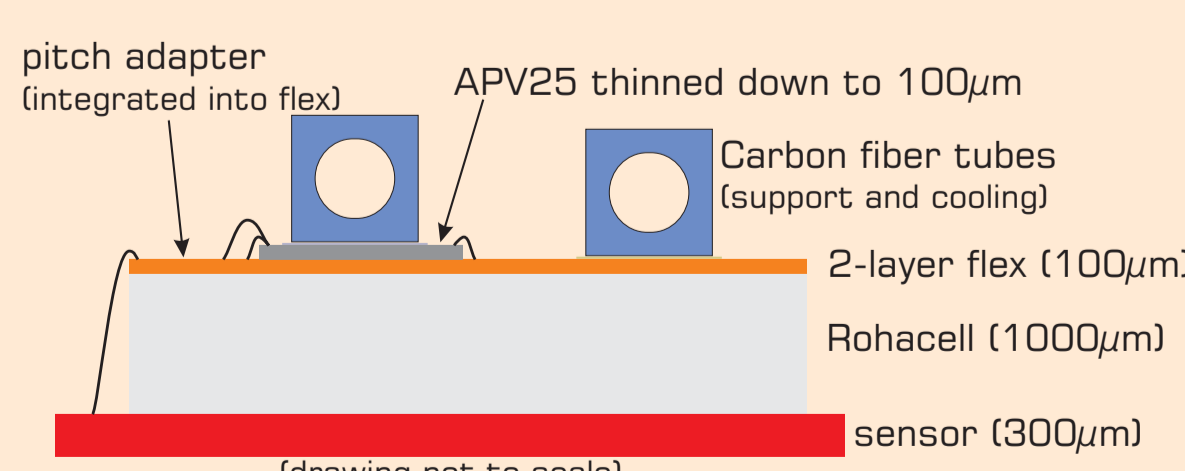Pulse shape processing RMS(tmax)~3ns
Sensitive time window ~ 20ns
Gain ~8

Total gain ~100

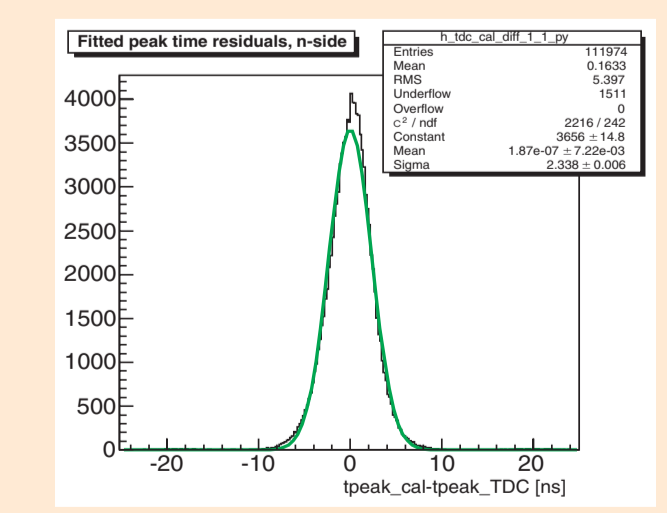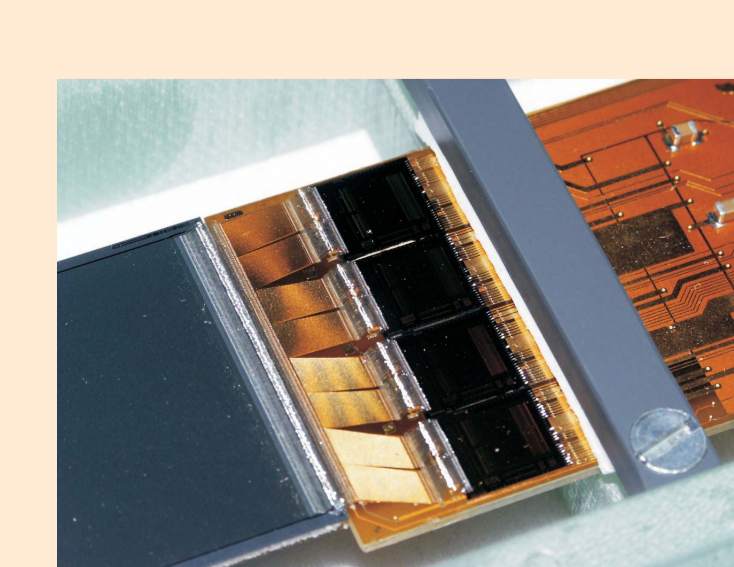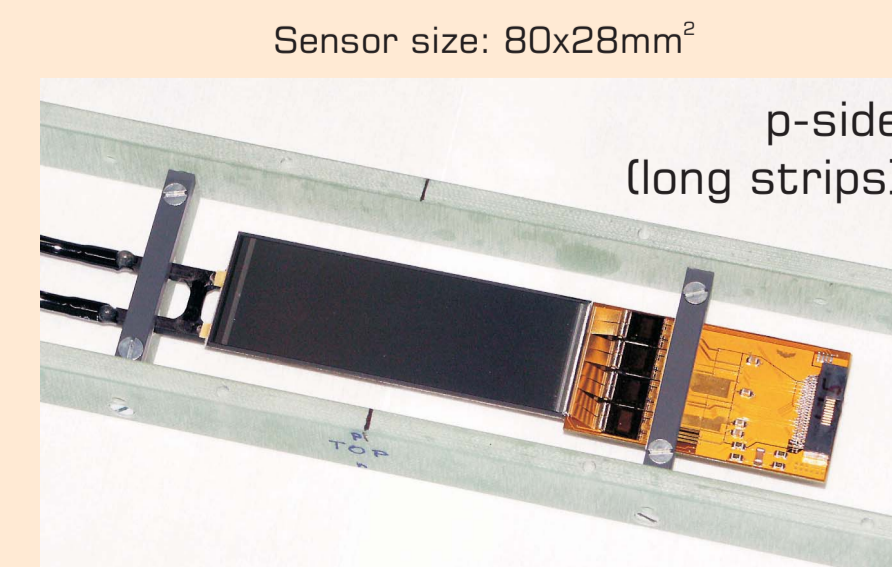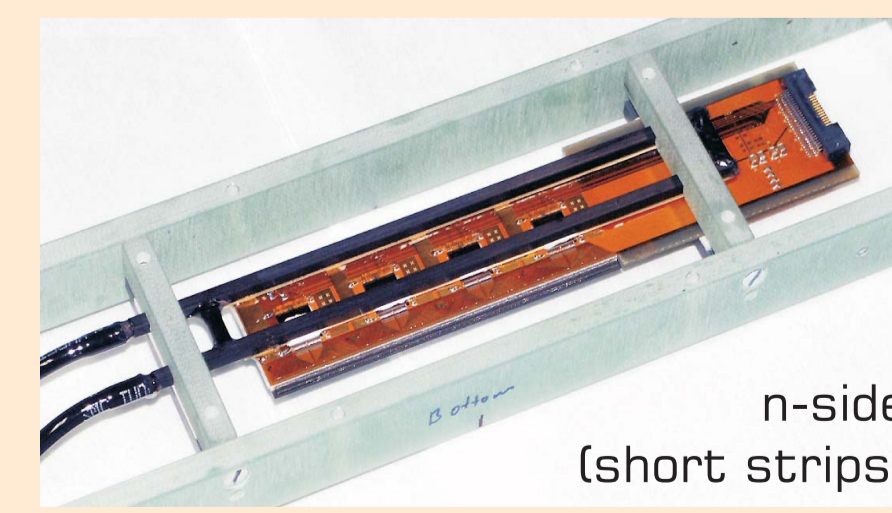Prototype of an FADC with FPGA data processors

The new SVD2.5 readout will be implemented in parallel to the existing one.

A time resolution of 2.3 and 4.0 ns was measured with the module shown below for n and p sides, respectively, at a cluster S/N of 14 and 19.

Thinned APV25s on top of sensor

pitch adapter (integrated into flex)
APV25 thinned down to 100µm
Carbon fiber tubes (support and cooling)
2-layer flex (100µm)
Rohacell (1000µm)
sensor (300µm)
(drawing not to scale)

In order to achieve good S/N (i.e. low capacitance) we mounted APV25 chips directly on the detector using a 2-layer flex "hybrid" circuit and Rohacell for insulation. The APV25 chips are thinned to 100µm to minimize the radiation length budget.

n-side (short strips)
Sensor size: 80x28mm²

p-side (long strips)

http://belle.hephy.at