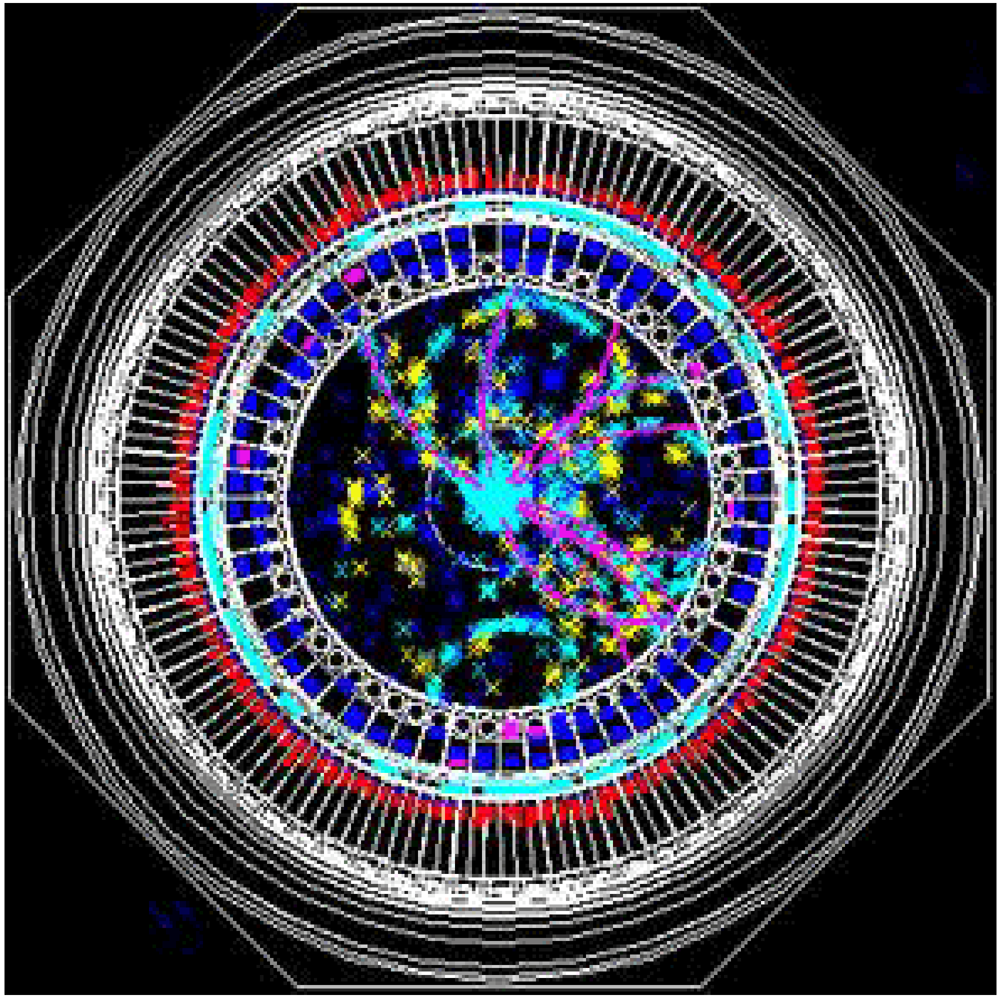
Nikko
8 Nov 2005

Belle Silicon Vertex Detector for the Super B Factory

M.Friedl (HEPHY Vienna) for the Belle SVD Group

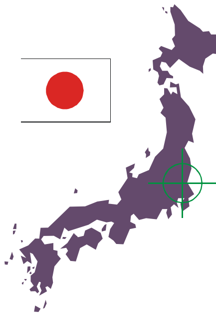


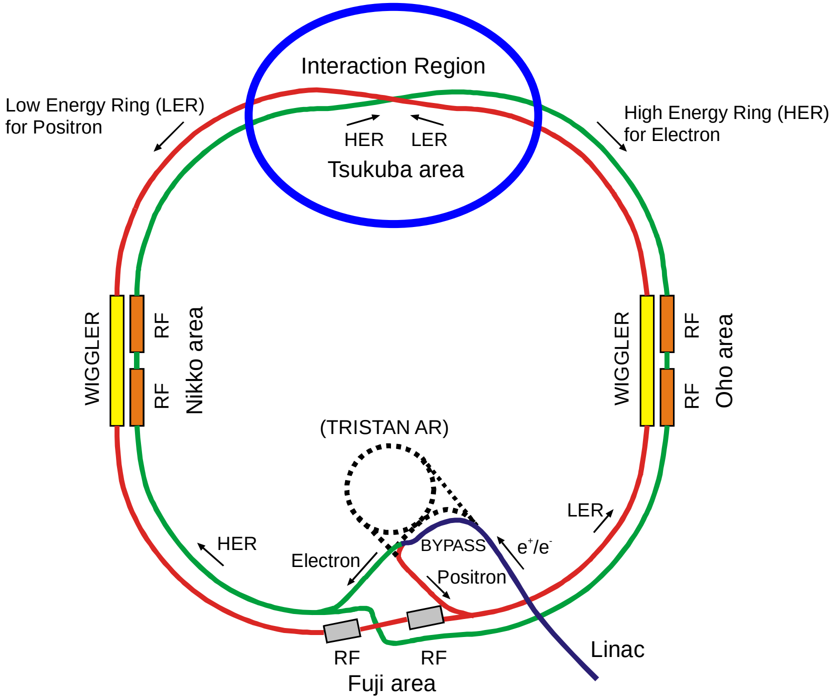
Outline

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

Outline

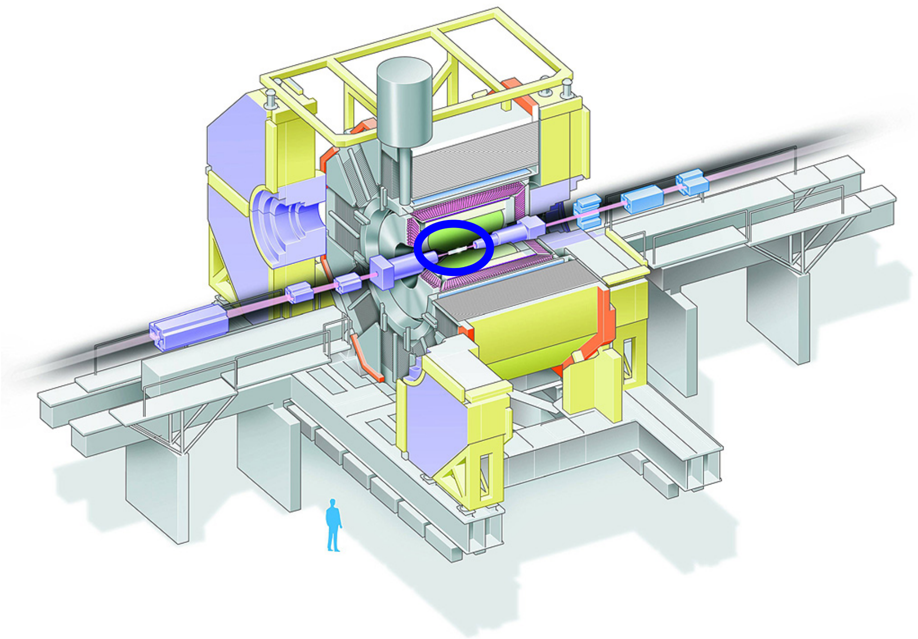
Introduction – Location

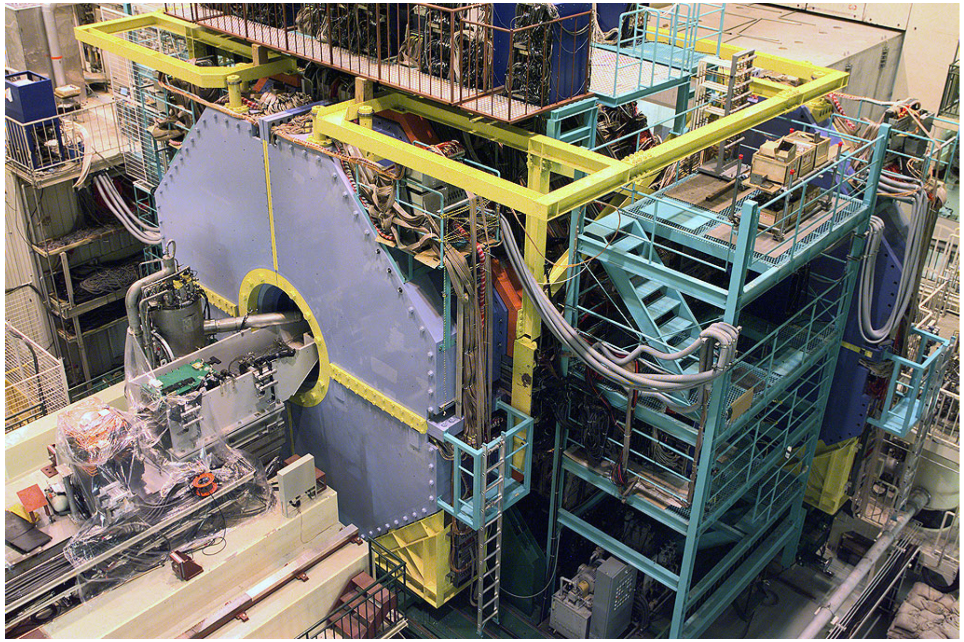




KEK	Located in Tsukuba Science City, ~60km NE of Tokyo, Japan
KEK-B	8GeV $e^+ \leftrightarrow$ 3.5GeV e^- collider, $>10^{34}$ cm^{2} s^{-1} luminosity, 509 MHz RF
Belle	Single experiment located in “Tsukuba area”

Introduction – Belle Detector

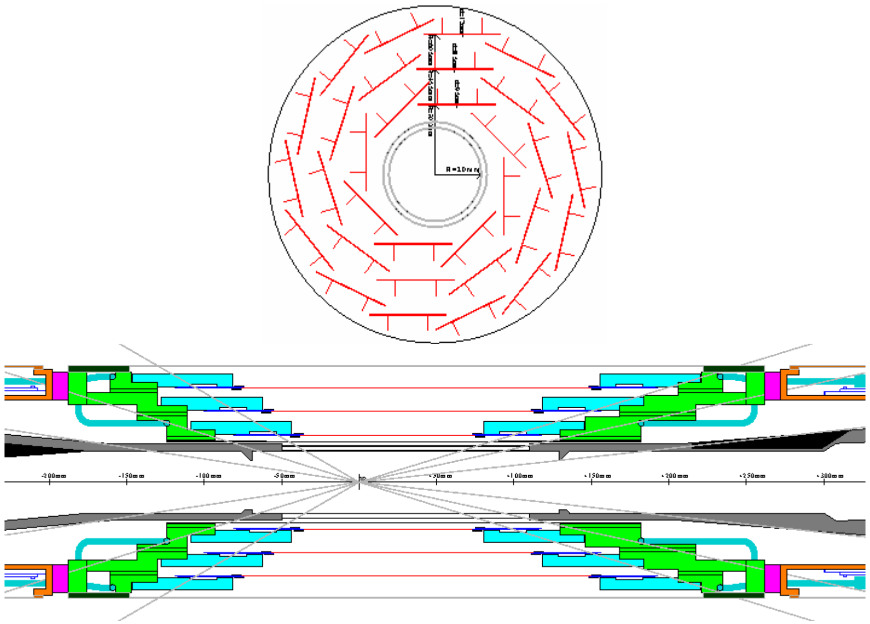


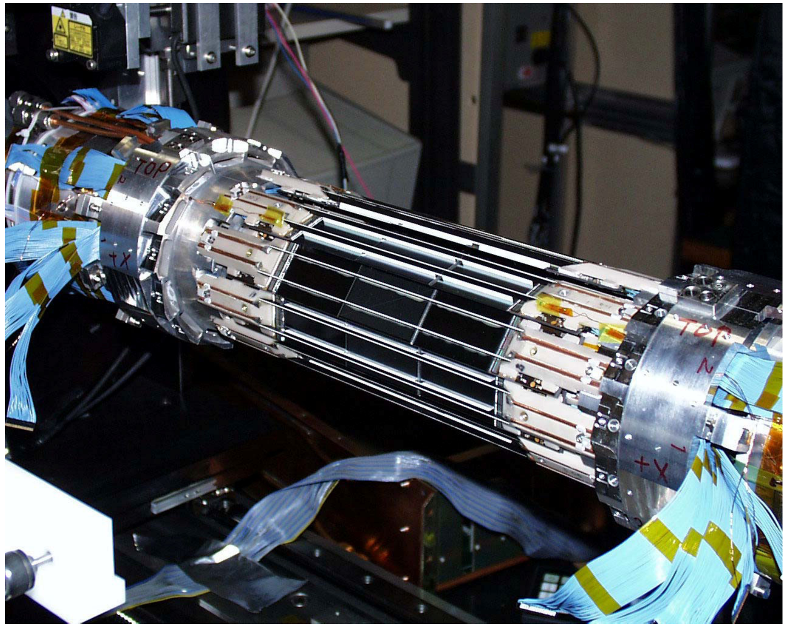


Belle	Typical medium-sized experiment (L=7.3m, ∅=7.2m, W=1500t)
Subsystems	Silicon Vertex Detector, Central Drift Chamber, Aerogel Cherenkov, Time of Flight, EM Calorimeter, Superconducting Magnet, H Calorimeter
Magnetic field	B=1.5T

Outline

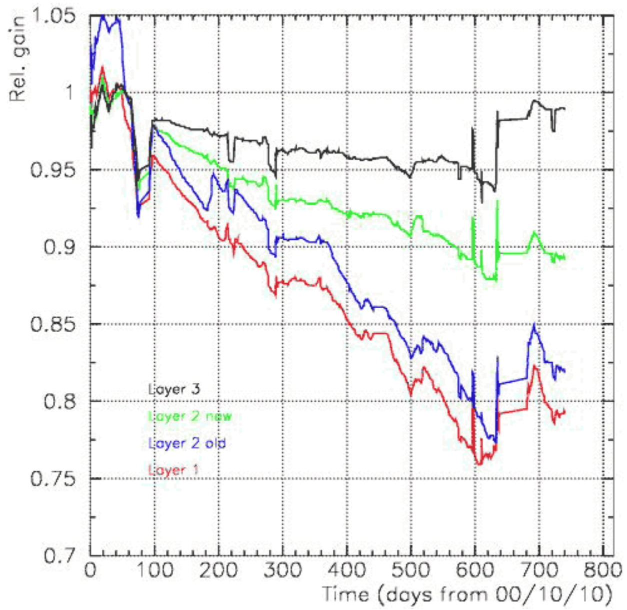
The Past: SVD1 – Overview



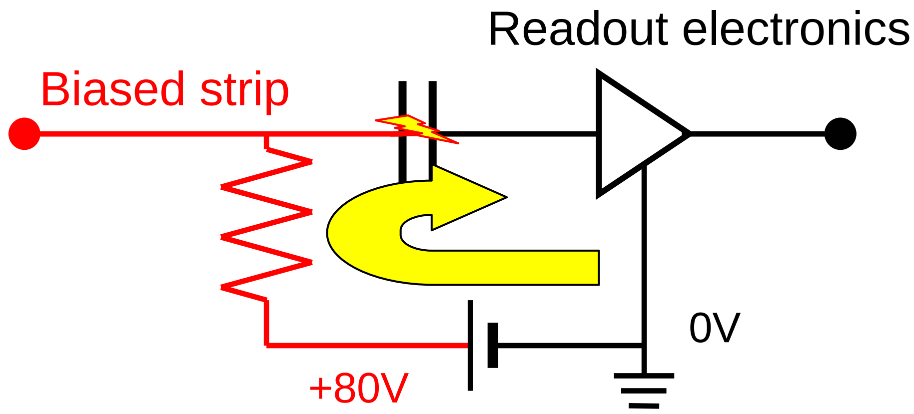


Layout	3 layers (8/10/14 ladders), r=3.0...6.1cm
Coverage	23°...139° polar angle
Silicon	102 double sided silicon detectors (DSSDs), 0.2m^2 overall active area
Readout	VA1 chip (1.2μm/0.8μm, radiation tolerance $\leq$1MRad)
	81920 channels in total

The Past: SVD1 – Main Problems



Gain loss

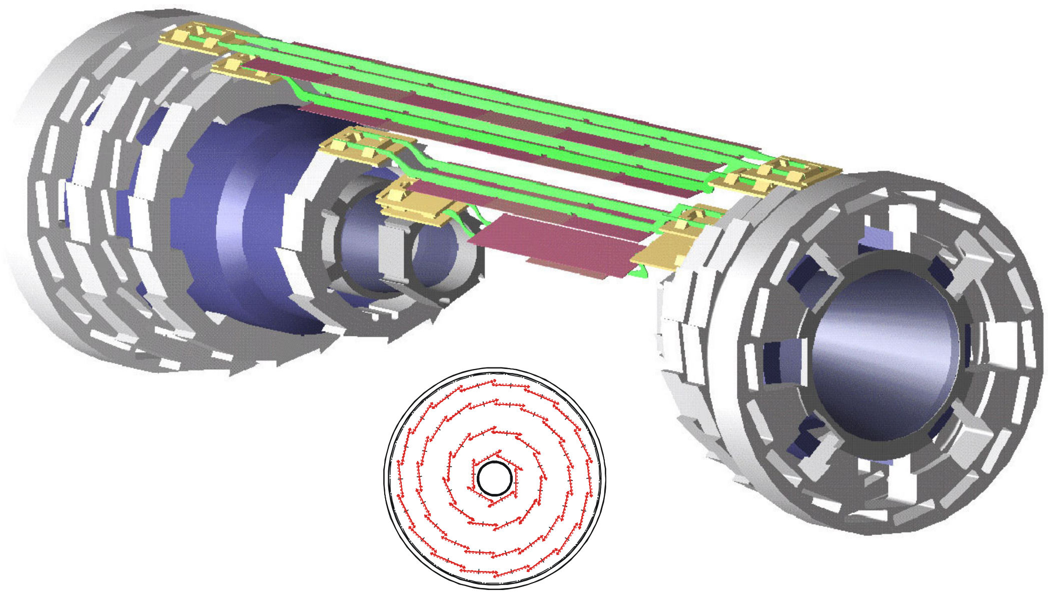


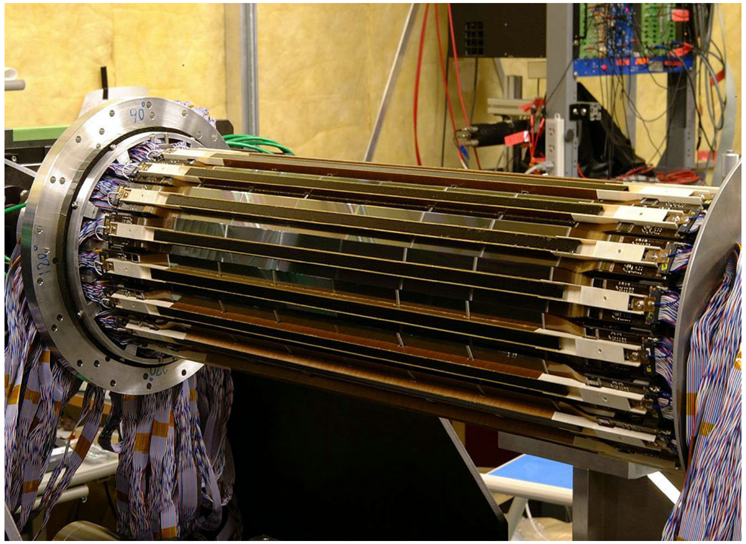
Level separation through sensor AC coupling

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

Outline

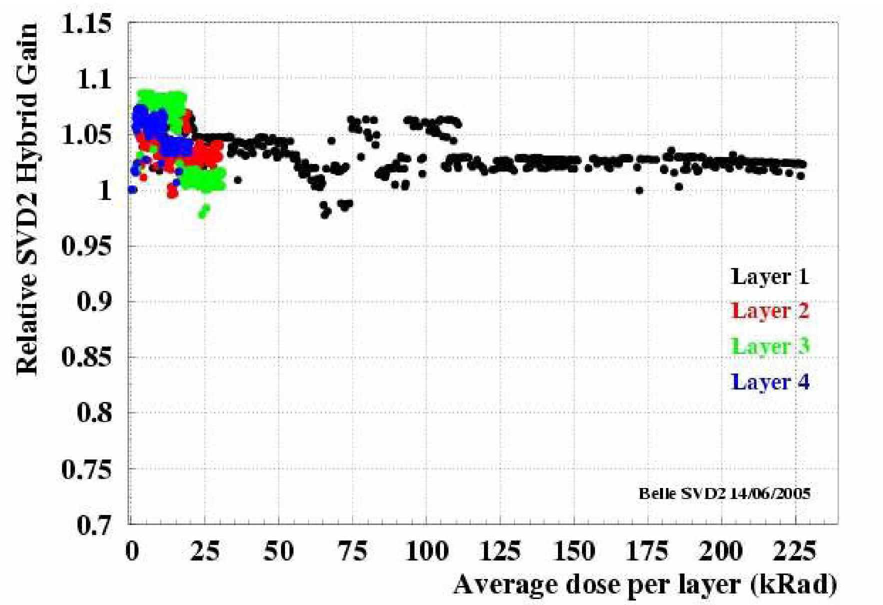
The Present: SVD2 – Overview



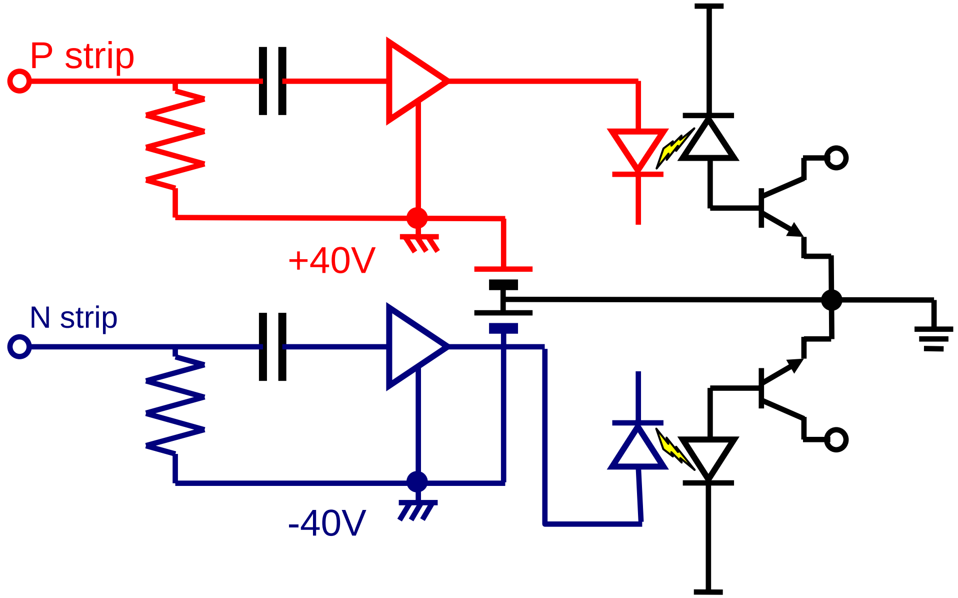


Layout	SVD2: 4 layers (6/12/18/18 ladders), r=2.0...8.8cm
Coverage	17°...150° polar angle (matching with Central Drift Chamber)
Silicon	246 DSSDs, 0.5m^2 overall active area
Readout	VA1TA chip (0.35μm, radiation tolerance 20MRad; with internal trigger)
	110592 channels in total

The Present: SVD2 – Solved SVD1 Problems



Stable gain



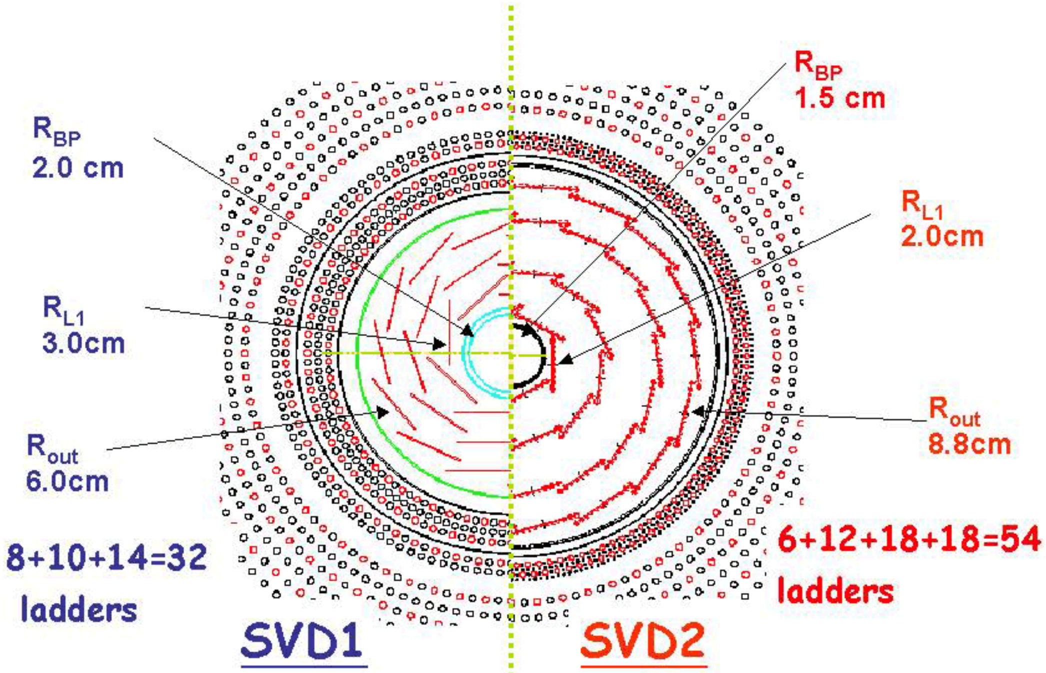
Floating power readout scheme

Gain — Radiation tolerant chip → stable gain and performance

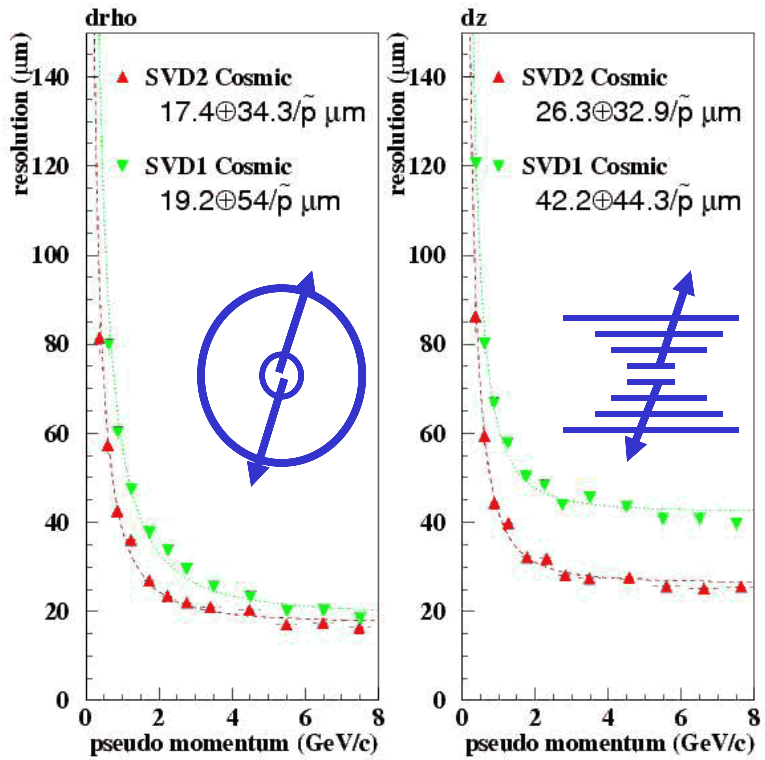
AC Coupling — Voltage level translation implemented by optocouplers

No more pinhole problems

The Present: SVD2 – Comparison to SVD1



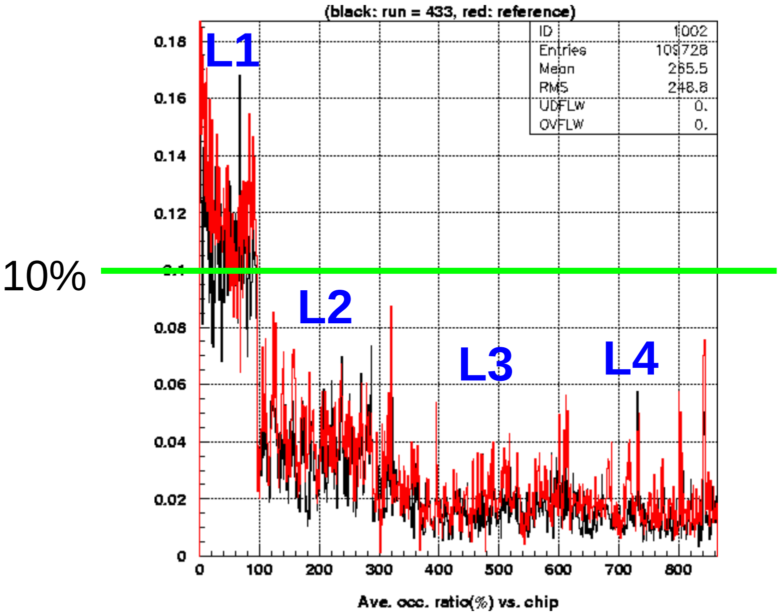
SVD1 – SVD2 geometries



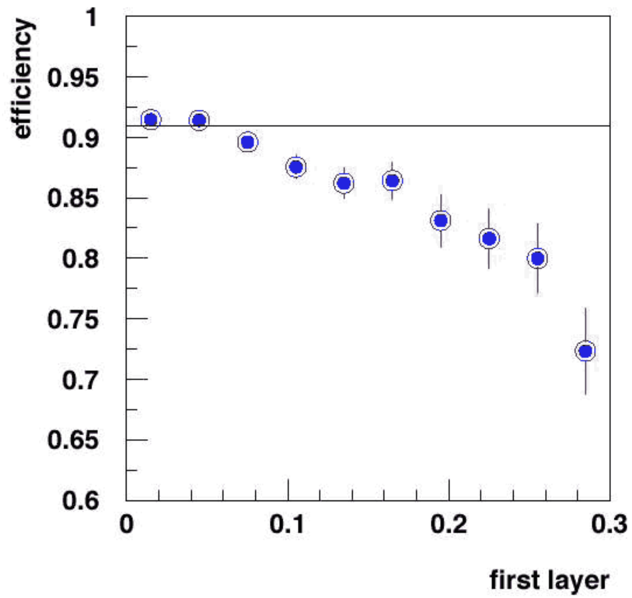
rφ and z IP resolutions

Layout changes	Smaller z strip pitch (84→75μm) and smaller beam pipe
Hence	Significant improvements of impact parameter resolutions

The Present: SVD2 – Main Problems



Occupancy in layers 1 to 4



Hit finding efficiency in layer 1

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

Dead Time
- Event readout takes 128 / 5MHz = 25.6μs
- ~3% dead time @ 450Hz trigger rate (L=1.5x10^{34}cm^{-2}s^{-1})

The Present: SVD2 – Reinforcement

Proposed options for short term improvements

Occupancy
- Shortening of VA1TA shaping curve
- Currently: T_p~800ns, total~2μs
- Slight reduction potential (max. 30%) at the cost of S/N

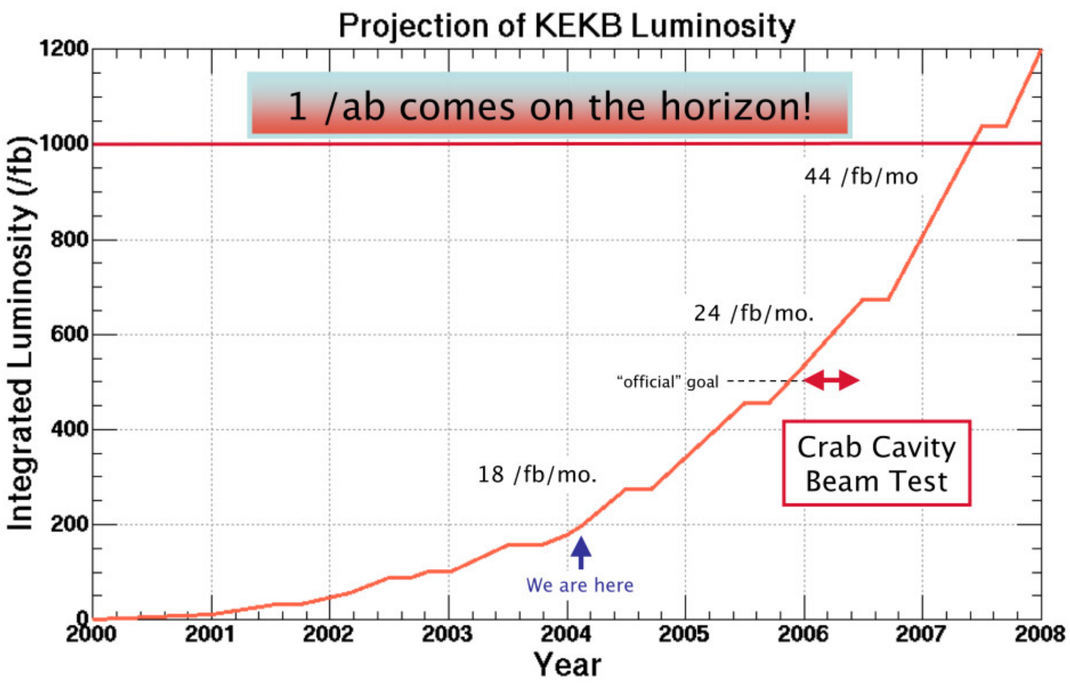
Dead Time
- Increasing readout clock
- Currently: 5MHz
- 10MHz possible at the cost of slight crosstalk

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

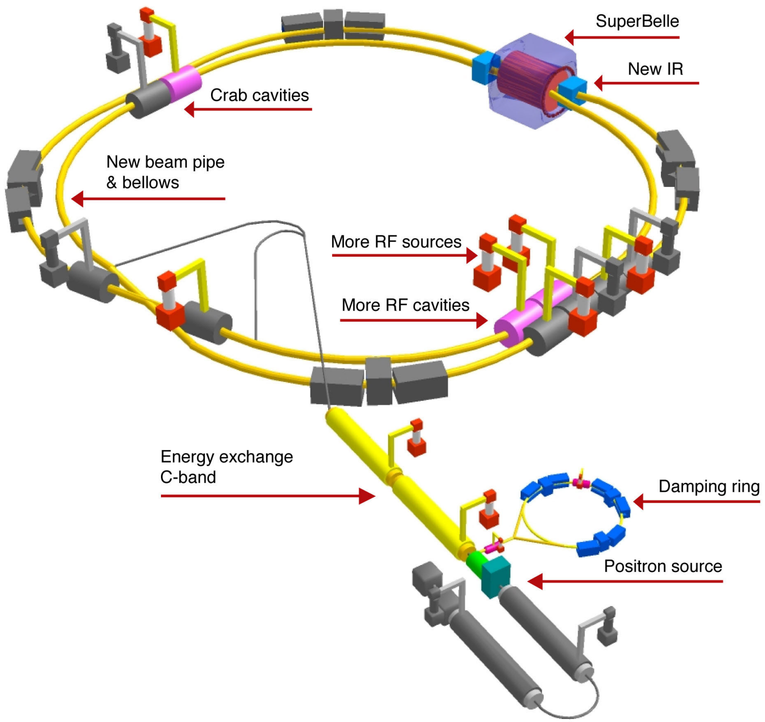
Baseline
- Not too much can be gained with present system

Outline

The Future: Luminosity Projection



Integrated Luminosity



Super-KEK-B accelerator upgrade

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

	2005	2006	2007	2008	2009	2010	2011
Luminosity (10^{34})	2.0	3.0	5.0	5.0	0	0	25
SVD2.0 reinforcement							
SVD2.0→SVD2.5 Replace L1 & L2 ladders	R&D	R&D Prod.	Test				
SVD2.5→SVD3 Full upgrade	R&D	R&D	R&D Prod.	Prod.	Test	Install.	

SVD2.5 | Inner ladders will be equipped with APV25 readout

SVD3 | Completely new detector, pixel option

Outline

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”**

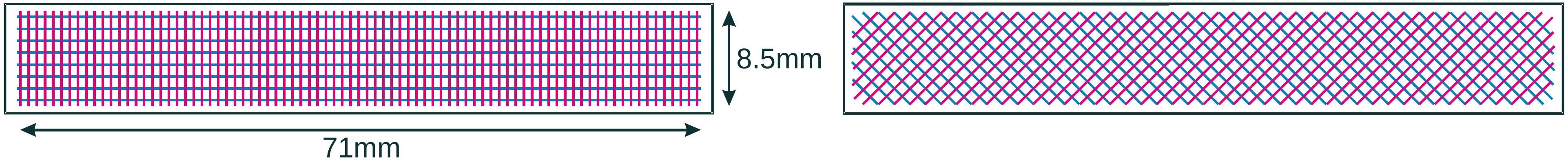
Solution

APV25 front-end chip (developed for CMS)

192-cell pipeline

50ns shaping time

SVD2.5 – Occupancy Reduction – Geometry Approach

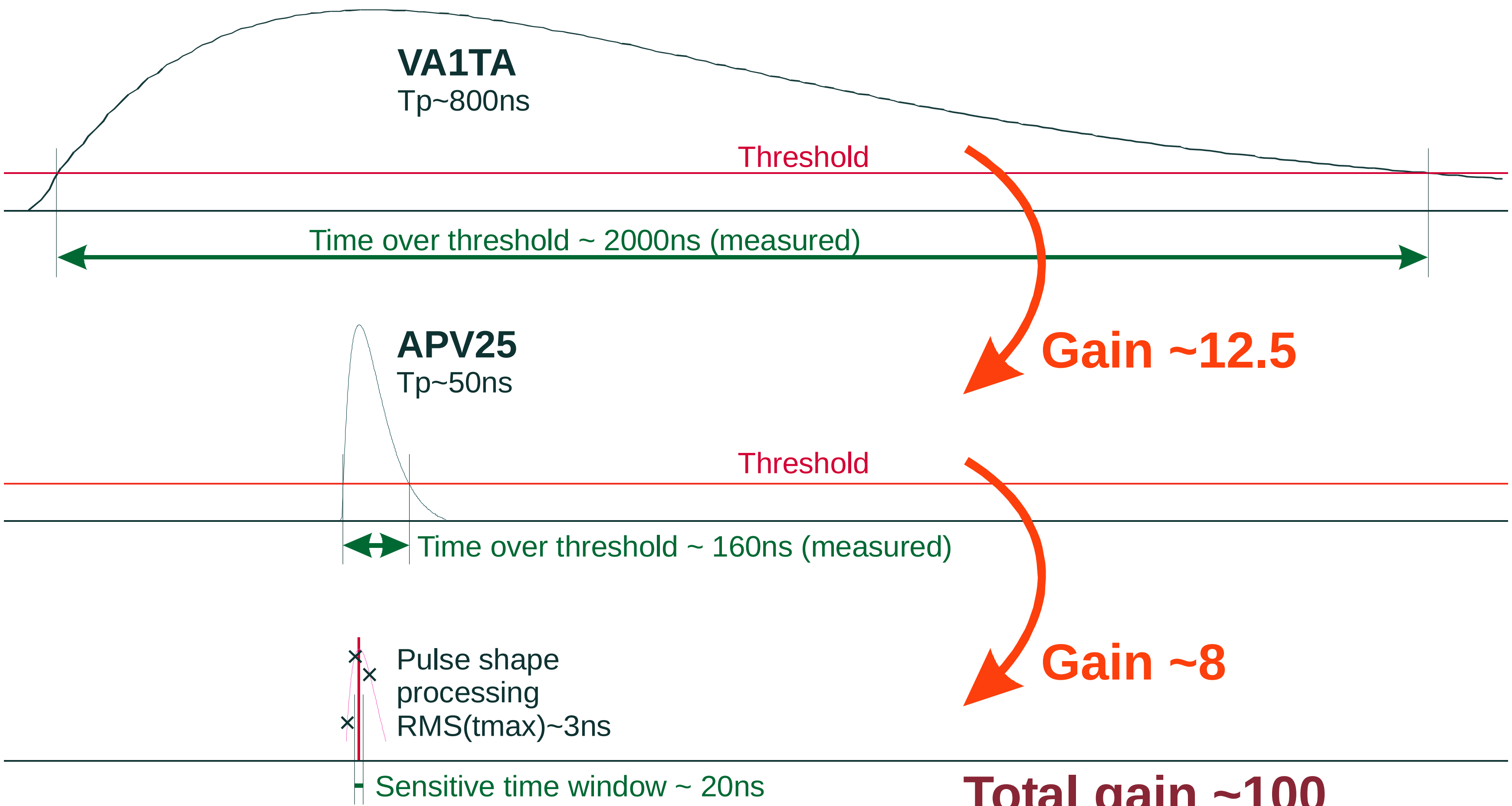


Conventional DSSD

UV-Striplet DSSD

Conventional	Strips 71 / 8.5mm
Striplet	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)

SVD2.5 – Occupancy Reduction – Time Approach



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 $L \sim 10^{36}cm^{-2}s^{-1}$

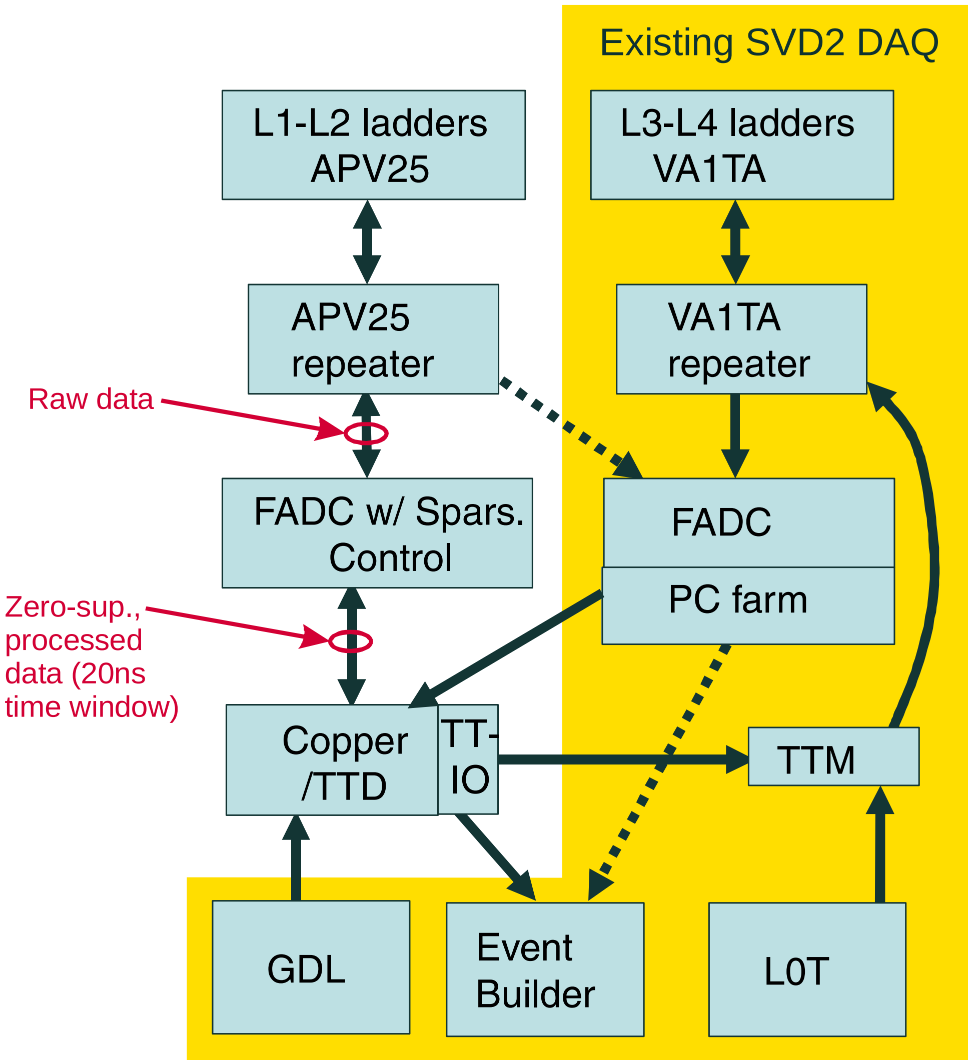
SVD2.5 – Comparison VA1TA, APV25

Property	SVD2	SVD2.5	Unit
ASIC	**VA1TA**	**APV25**	
CMOS Process	0.35	0.25	μm
Radiation Tolerance	20	>100	MRad
Peaking Time	800	50	ns
Clock	5	40	MHz
Readout dead time	25.6	0.075 (pipeline)	μs
Trigger input	async hold	sync trigger	
Trigger output	fast-or	–	

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)

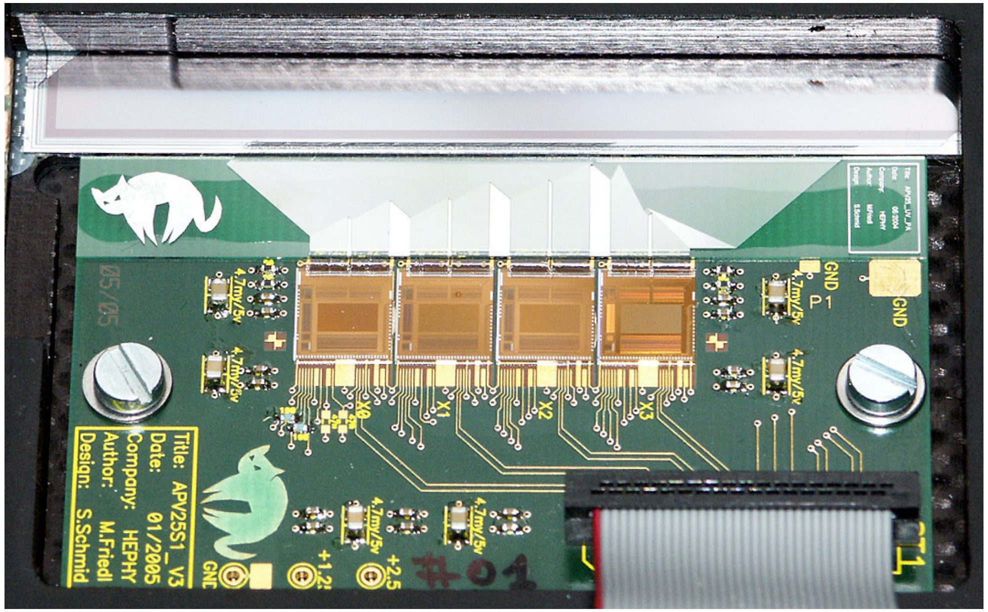
SVD2.5 – DAQ



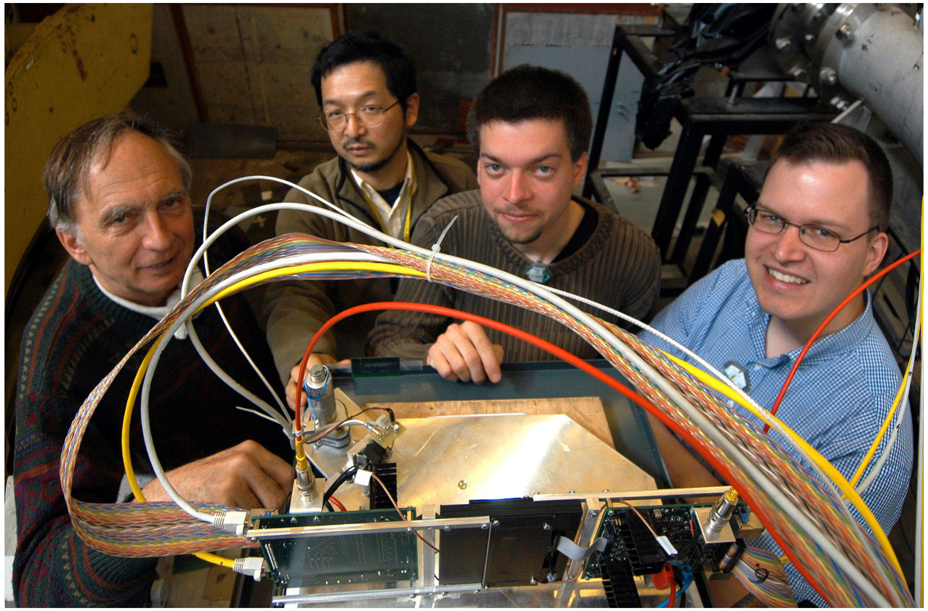
- SVD2.5 implies DAQ upgrade
- Parallel paths of old and new readout chain
- SVD2: Zero-suppression is done by software in PC farm
- SVD2.5: Zero-suppression and pulse shape processing is done in FPGAs inside FADC units

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

SVD2.5 – Beam Tests



UV striplet with double-sided APV25 readout

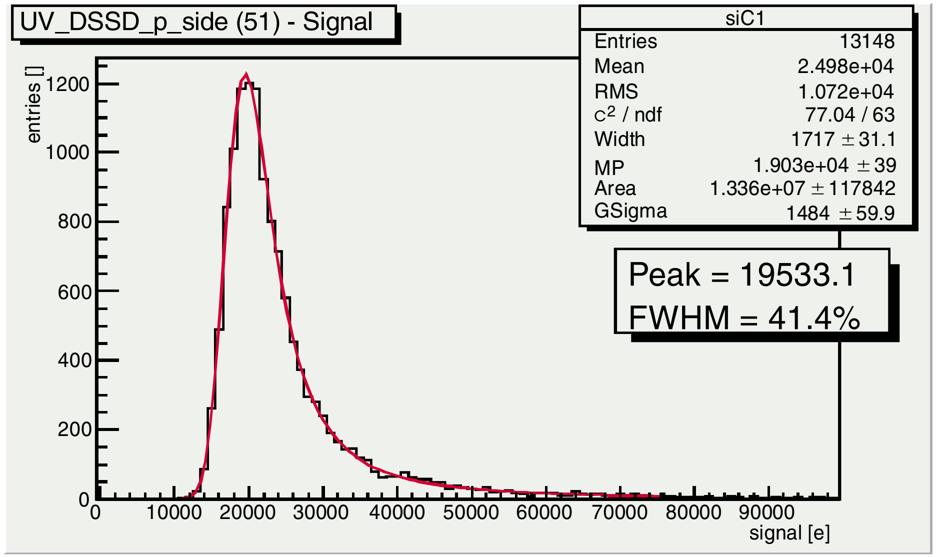


April 2005 beam test @ KEK

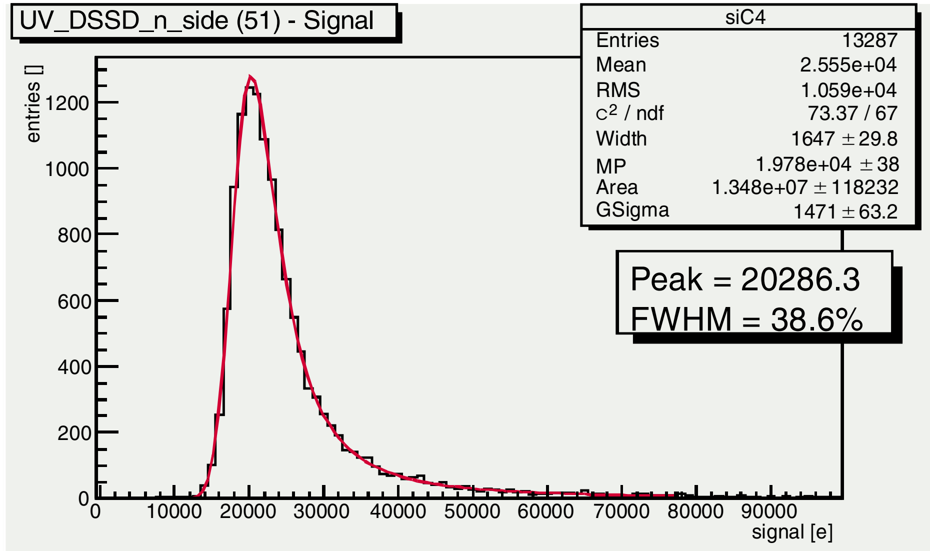
Beam Tests

- 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



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)

Outline

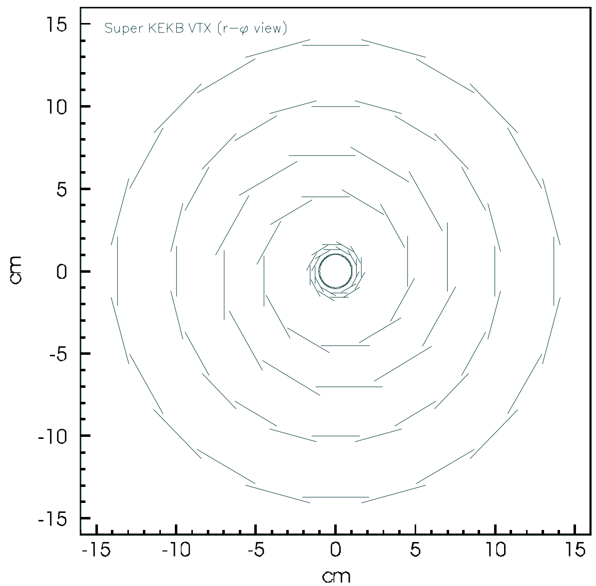
SVD3 – Overview

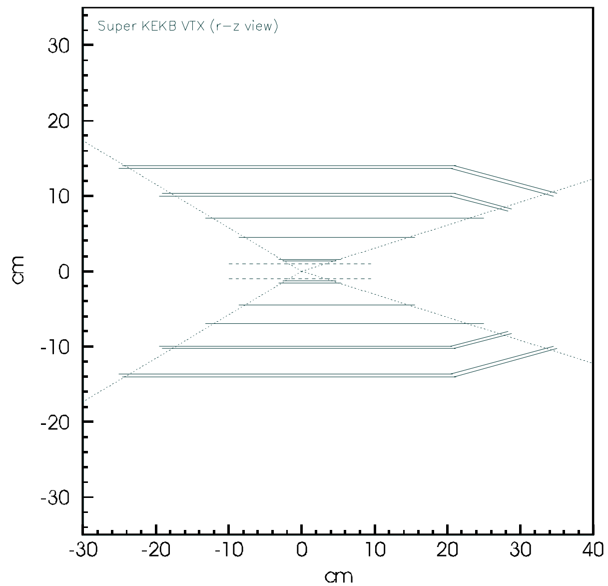
LoI
- "Letter of Intent for KEK Super B Factory"
- Published 18 Feb 2004
- Contains conceptual design

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

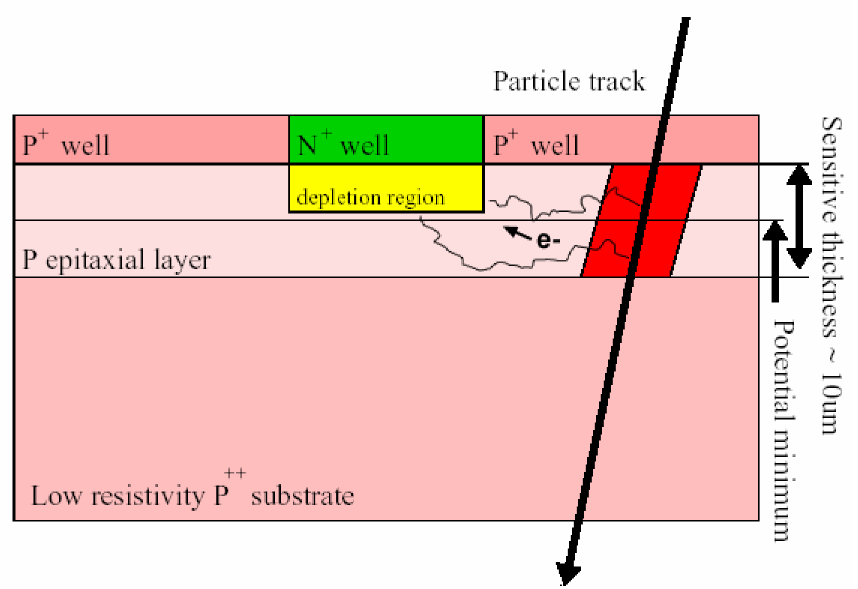
Coverage 17°…150° polar angle (same as SVD2, matching with CDC)

Layers 1 & 2 Options:

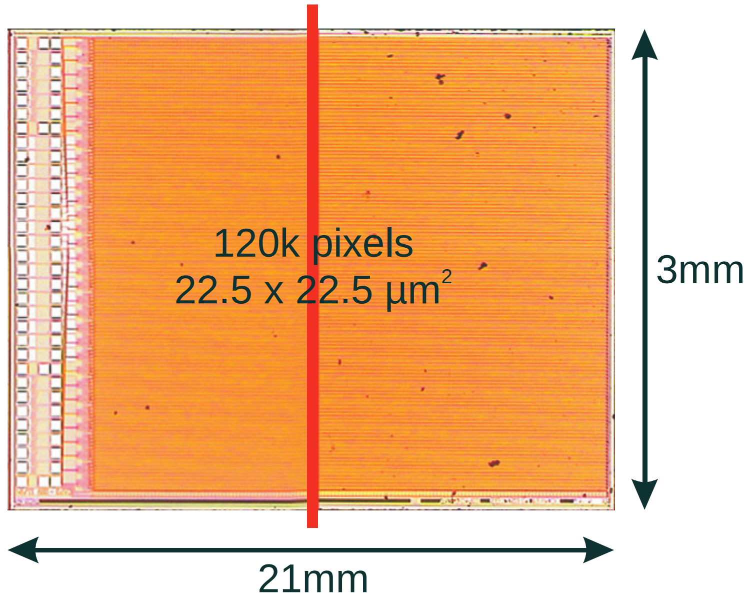
- APV25 with DSSD striplet → "test case" SVD2.5
- Pixel

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

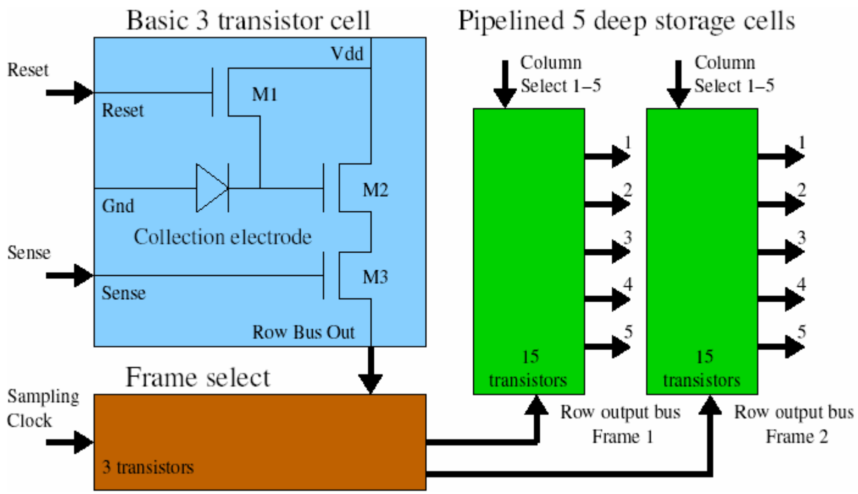


Cross section

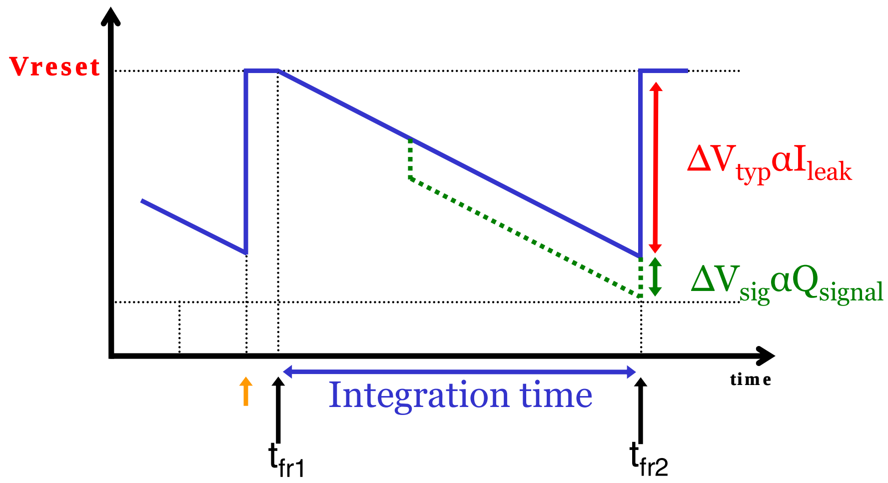


CAP3 (December 2004)

SVD3 – Monolithic Active Pixel Sensor: CAP



CAP3 Pixel cell with mini-pipeline



Double correlated sampling

DSC	Double correlated sampling with reset in abort gaps (500ns every 10μs)
Integration Time	10μs, sub-divided by 2x5 cells mini-pipeline $\rightarrow$ 1μs
CAP1	Signal$\sim$300e, Noise$\sim$16e $\rightarrow$ S/N$\sim$19
Readout	1.6 GS/s optical links
Critical R&D	Readout speed, radiation hardness (20MRad), thinning to 50...100μm

SVD3 – Comparison APV25, CAP

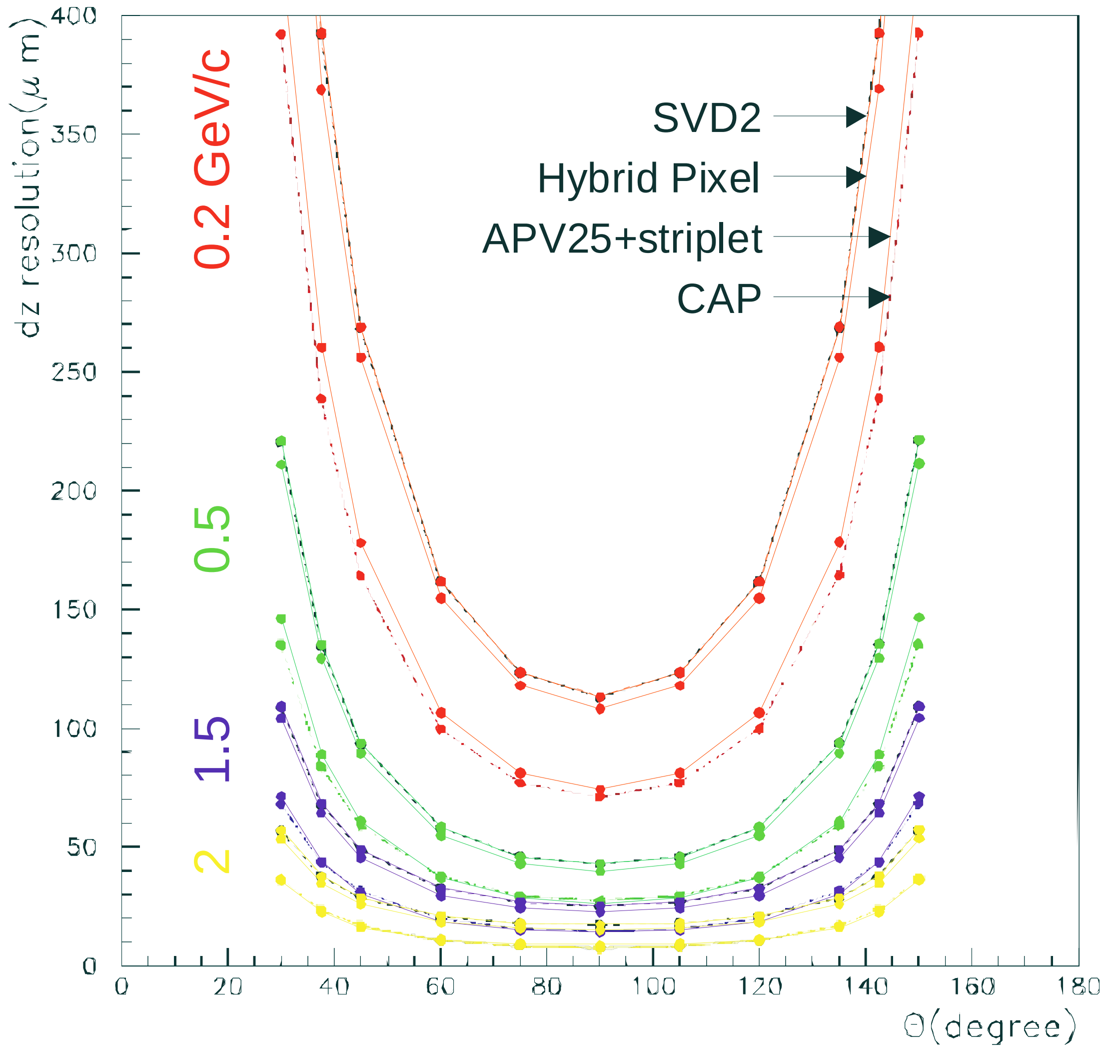
SVD2 — Current system is shown as reference

Property	SVD2	APV25+striplet	CAP	Unit
Channel area	3,840,000	601,800	506	μm^2
Sensitive time	2000	20	1000	ns
Ambiguity	space & time	space	time	
Chip channels	128	128	118,784	
Readout speed	5	42	1,600	MS/s
Readout/DAQ effort	low	low	high	
L1 radius	2.0	1.3	1.3	cm
L1 & L2 material (sensors)	600 (1.5%)	600 (1.5%)	200 (0.5%)	μm (X_0)
MC IP res. @ 2GeV/c, $\alpha=90°$	17	9	7.5	μm

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, 50x400μm^2)
- APV25+striplet
- CAP

Hybrid pixel offers very little improvement over SVD2

CAP slightly better than APV25+striplet

SVD3 – Occupancy Scaling

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

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)

Outline

Summary

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