Low Mass Mechanics and Cooling for Belle II Pixel Vertex Detector (PXD)

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Max-Planck-Institut für Physik
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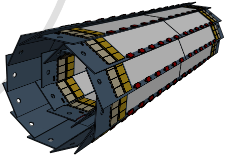
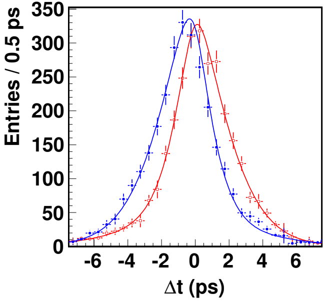
DEPFET
Active Pixel Detector



Measurement of CP Violation

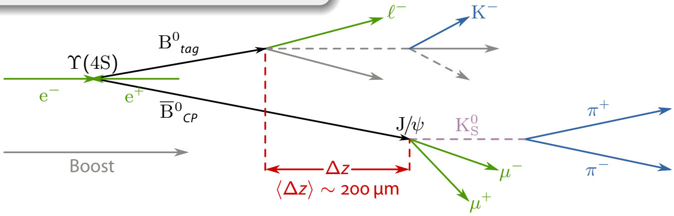
Measure time dependent decay asymmetry of B and $\overline{\mathrm{B}}$ going to the same final state

- lifetime of B mesons is 1.5 ps
- flavour of B meson has to be known

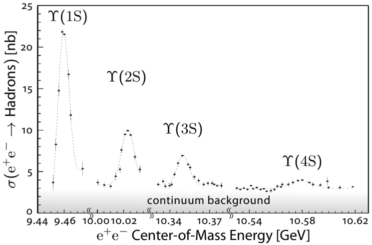


Solution

- $\Upsilon(4\mathrm{S})$: coherent B-meson pair production
- one B to determine flavour (tag side), other B for CP measurement (CP side)
- boost system using asymmetric beam energies $t \to \Delta t = \frac{\Delta z}{\langle\beta\gamma\rangle c}$



Experimental requirements



Best place to produce $B\overline{B}$ in a clean environment is at the $\Upsilon(4S)$:

- lowest energy with free B mesons
- 1/3 of all hadronic events are $B\overline{B}$
- possibility to "turn off" B production by lowering center of mass energy by 50 MeV

Differences to LHC Experiments

Energy is factor $\mathcal{O}(1000)$ smaller than at the LHC

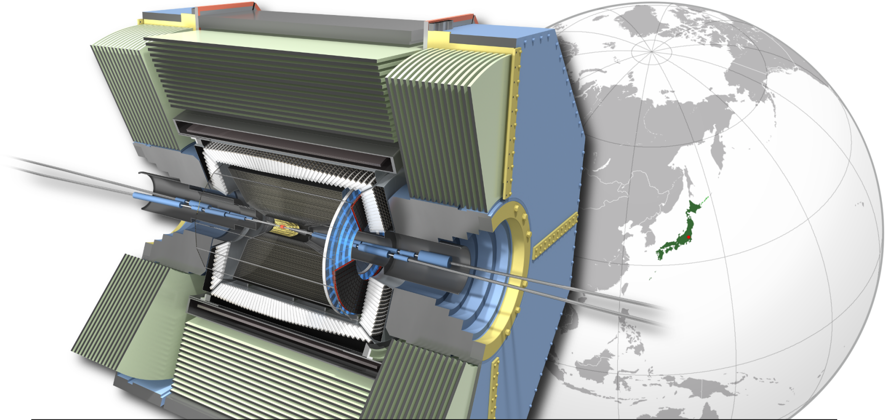
- mean momentum of charged particles is around 500 MeV
- tracking charged particles down to $p_t \approx 50$ MeV

Electron Collider:

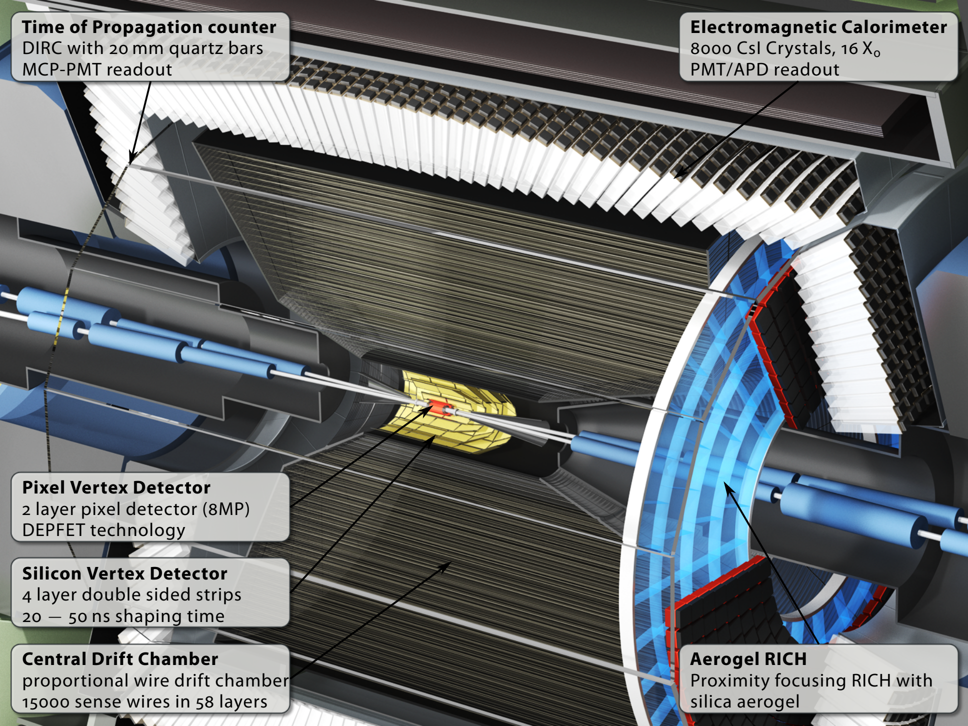
- full knowledge about the center of mass frame
- no underlying events
- but: lower cross section (more than factor 100)

Belle/Belle II Experiment

Asymmetric e^+e^- experiment mainly at the $\Upsilon(4S)$ resonance (10.58 GeV)



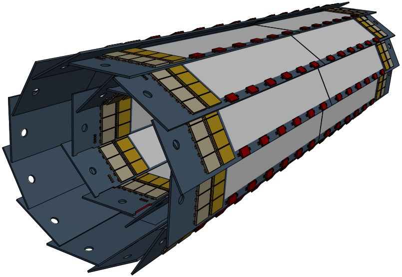
	KEKB/Belle	SuperKEKB/Belle II
operation	1999 – 2010	2018 –
peak luminosity	$2.11 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
integrated luminosity	$1023\,\mathrm{fb}^{-1}$ (772 million $\mathrm{B\overline{B}}$ pairs)	$50\,\mathrm{ab}^{-1}$

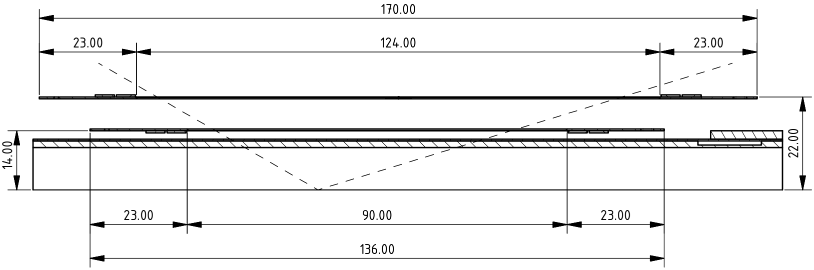


Time of Propagation counter
DIRC with 20 mm quartz bars
MCP-PMT readout
Electromagnetic Calorimeter
8000 CsI Crystals, 16 X_0
PMT/APD readout
Pixel Vertex Detector
2 layer pixel detector (8MP)
DEPFET technology
Silicon Vertex Detector
4 layer double sided strips
20 — 50 ns shaping time
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers
Aerogel RICH
Proximity focusing RICH with
silica aerogel

Pixel Vertex Detector (PXD)

- innermost part of the detector
- covers acceptance of $17^\circ < \theta < 150^\circ$
- 2 layer pixel detector with 40 DEPFET sensors (7.68 million pixels)
- readout time of 20 µs
- data rate of $240\,\mathrm{Gb/s} = 30\,\mathrm{GB/s}$
- pixel size from 50×55 µm to 50×85 µm
- total material budget of $0.28\,\%X_0$

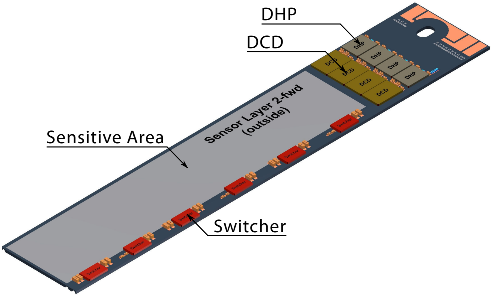




Sensors and Power Consumption

DEPFET pixel sensors (details by Ladislav Andriček)

- 250 × 768 pixels
- sensitive area size:
  12.50 mm × 44.80 mm (layer 1)
  12.50 mm × 61.44 mm (layer 2)



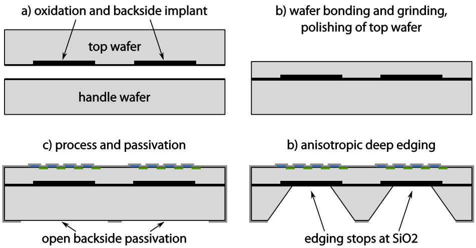
Three different ASICs on the sensors:

Name	Purpose	Position	Power consumption
DCD	Signal digitization	end of sensor	4 W
DHP	Digital signal processing	end of sensor	4 W
Switcher	Row addressing	along sensor	0.5 W

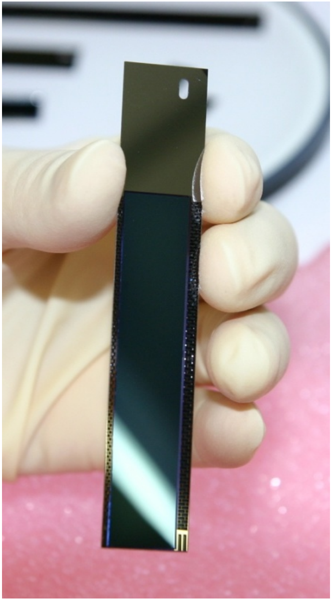
- sensitive area has power consumption of 0.5 W
- power consumption dominated by end of sensor (8 W)
- no need for extensive cooling inside acceptance

Sensor Thinning

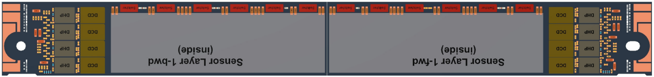
- sensitive area will be thinned down to 75 µm
- integrated support frame to keep stability



- additional mass reduction by edging brick structure into frame



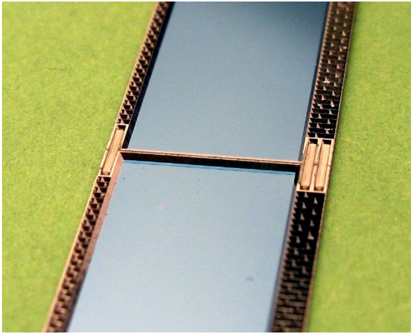
Ladder Design



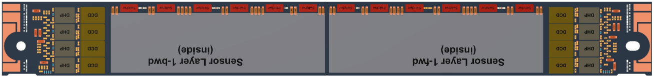
Ladder formed from 2 sensors

- ladders are self supporting
- butt-face joint glueing
- reinforced with ceramic inserts
- almost no additional material
- only 850 µm dead area

➡ extensive stability studies
➡ 4 types of different sensors



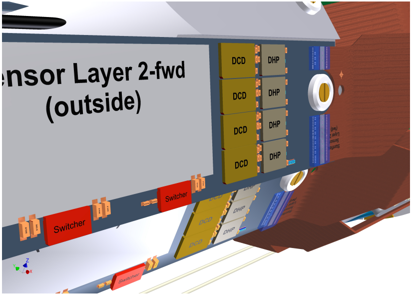
Ladder Assembly



Ladders screwed on support

- elongated hole on one side
- M1.2 screw with plastic washer
- o-ring to prevent contact between screw and silicon
- torque of 15 mNm

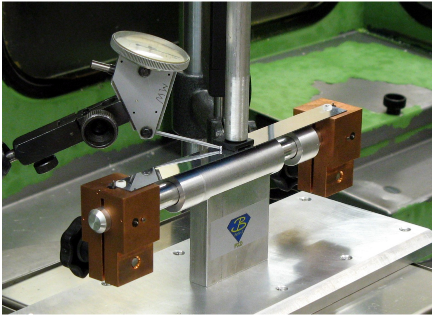
➡ torque allows for compensating of thermal expansions



Stability studies

tensile strength tests carried out

- single piece of silicon tested up to 7 kg
- gluing of unthinned silicon stable to 6 kg
- gluing of 50 µm thin silicon survived 5 kg



deformation tests

- single piece of silicon breaks at 1.4 mm
- no problems up to 1 mm deformation

Cooling Concept

Requirements

- total system power is 360 W (80 W in sensitive region)
- silicon temperature below 25 °C
- chip temperature below 50 °C

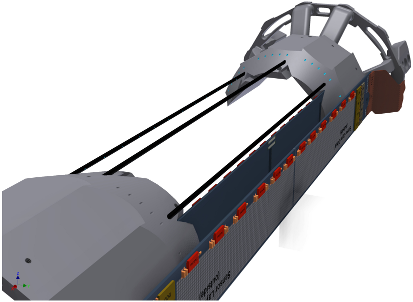
End of sensor:

- 2-phase CO_2 cooling system
- joint development with ATLAS IBL
- provide -20 °C below end of sensor to cool ASICs

Along the sensor:

- provide moderate airflow (1 m/s at -5 °C) to cool Switcher and sensitive area

Support

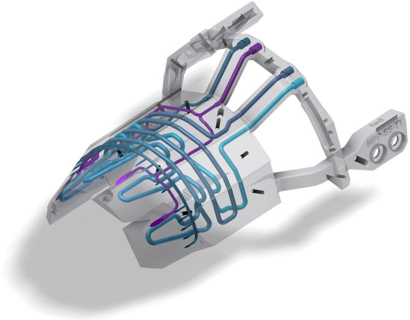


The PXD will be mounted directly on the beampipe

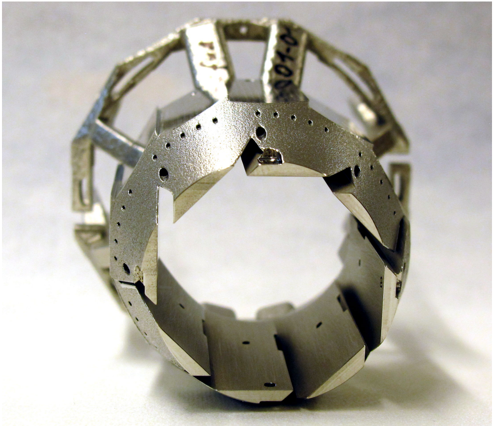
- assemble in two half shells
- one common support for both layers
- combined support and cooling blocks (SCB) per detector half
- connected by silver coated carbon fiber tubes for air cooling and grounding

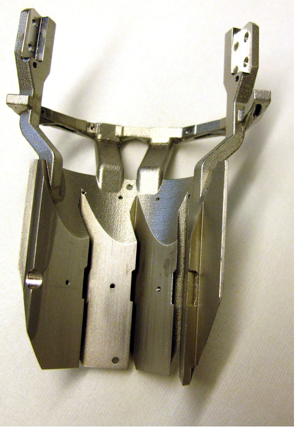
manufactured using 3D printing technology

- stainless steel
- integrated cooling channels
- closed CO_2 channel to cool end of sensors
- nitrogen channels to provide airflow
- coated with 15 µm Parylen



SCB Prototypes





Final SCB Prototypes

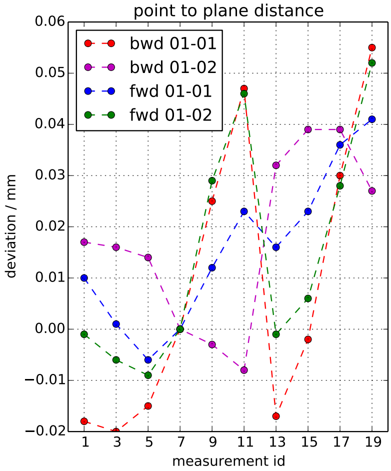
- precision machining of surfaces
- roughness R_a around 0.25 µm
- flatness better than 7 µm

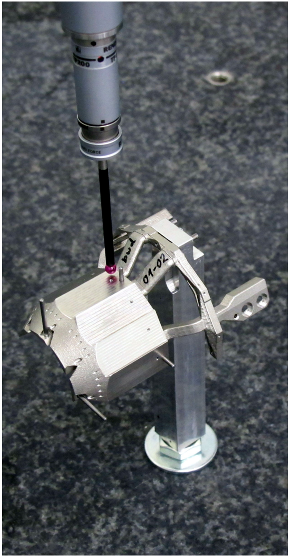
All cooling channels operational

- pressure tested with 186 bar for 1 h
- helium leakage smaller than 10^{-9} mbarl/s

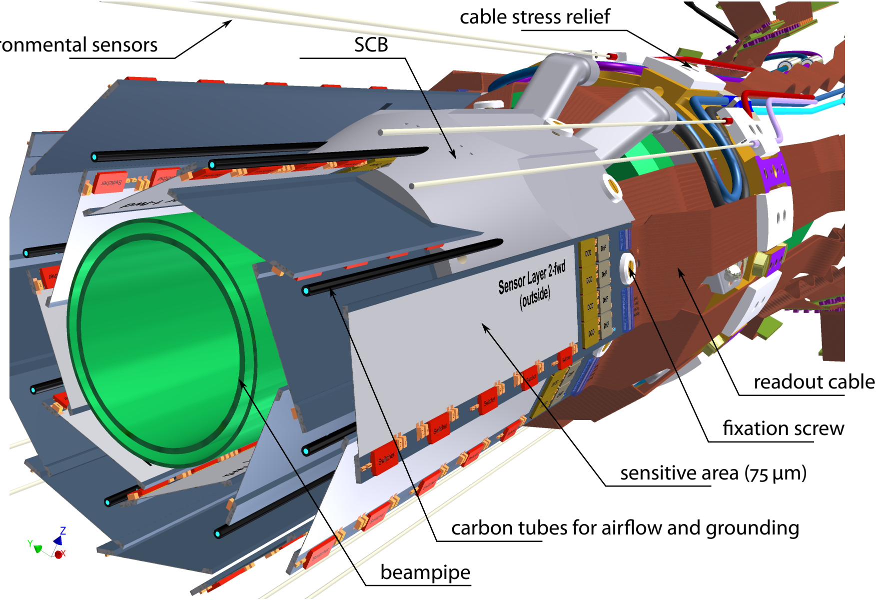
Measurement of SCB Prototypes

- measured relative distances between surfaces
- deviations from nominal mostly around 20 µm





Full System (Cut View)



Conclusions

Belle II Pixel Vertex Detector

- self supporting silicon detector
- sensitive area thinned to 75 µm
- power dissipation mostly outside of geometrical acceptance
- combined support and cooling blocks (stainless steel, 3D printed)
- total material budget of 0.28 $\%X_0$

Cooling

- 2-phase CO_2 cooling system to cool chips
- joint development with ATLAS IBL
- moderate airflow between sensors to cool sensitive area
- virtually no additional material from cooling inside acceptance

Outlook and schedule

- optimizing and refining ladder assembly/handling procedures
- start full ladder assembly beginning 2016
- ready for system tests and integration by March 2017

Thank you
for your attention

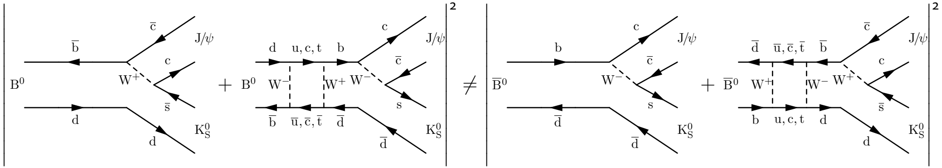
Measurement of CP Violation

Objective: Measure time dependent decay asymmetry of B and $\overline{\mathrm{B}}$ going to the same final state

$$a_{CP}(t) = \frac{\Gamma\left(\overline{\mathrm{B}}^0 \to f_{CP}; t\right) - \Gamma\left(\mathrm{B}^0 \to f_{CP}; t\right)}{\Gamma\left(\overline{\mathrm{B}}^0 \to f_{CP}; t\right) + \Gamma\left(\mathrm{B}^0 \to f_{CP}; t\right)}$$

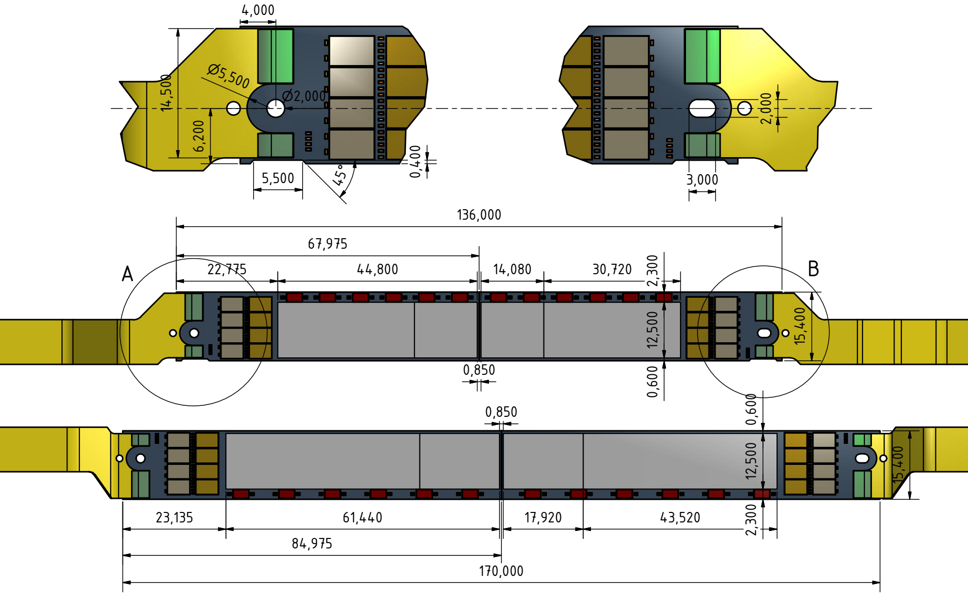
3 possible contributions

- CP violation in decay (direct)
- CP violation in mixing (indirect)
- CP violation by interference of mixing and decay (mixing induced)



- For B mesons, contributions from indirect CP violation are negligible
- For many decays, loop diagrams contribute to the amplitudes
  ➡ possibility to indirectly detect new physics

Ladder Dimensions



Particle Contamination of Cooling Channels

Cooling channels were cleaned after manufacturing

- blow N2 into cooling channels
- measure particle contamination at outlet
- probe volume 0.1 ft^3/min

particle size	contamination	N2 line
0.5 µm	9000–15000	8000
0.7 µm	4000–8000	3000
1.0 µm	2000–4000	1000
2.0 µm	300–1500	200
5.0 µm	20–80	30