Construction of the Belle II Pixel-Vertex Detector

Martin Ritter, Christian Kiesling, Karlheinz Ackermann

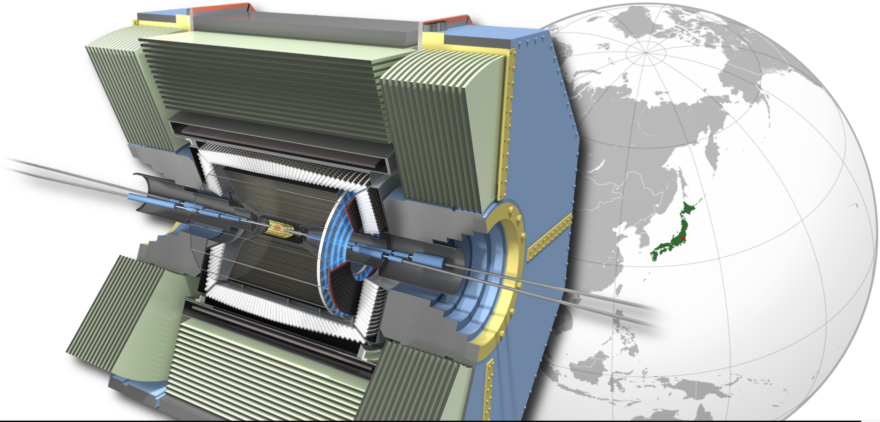
DPG Frühjahrstagung 2011, Karlsruhe
27 März 2011

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

DEPFET
Active Pixel Detector

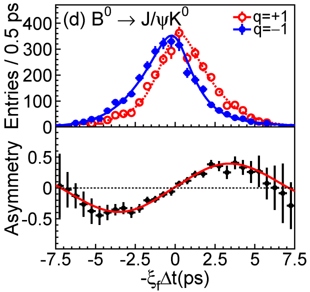
Belle/Belle II Experiment

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



	KEKB/Belle	SuperKEKB/Belle II
operation	1999 – 2010	2014 –
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 $B\bar{B}$ pairs)	$50\,\mathrm{ab}^{-1}$

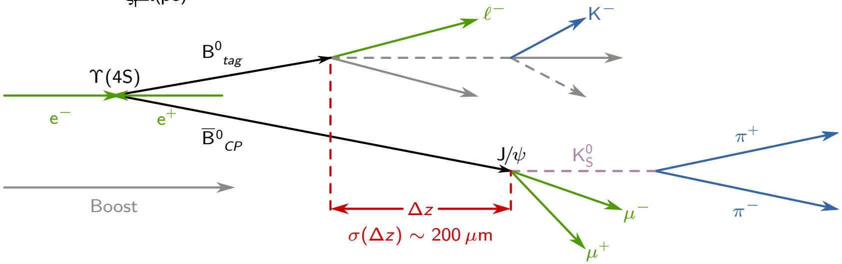
Vertex finding



Vertex finding is the Key to CP-Violation measurement:

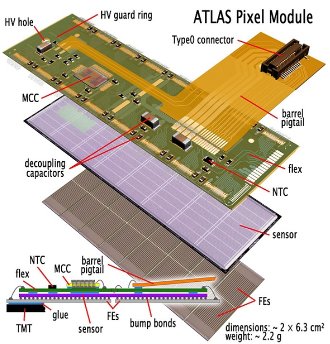
- CP violation is time dependent ($\sigma(\Delta t) \sim 1$ ps)
- boost translates lifetime difference into vertex distance ($\sigma(\Delta z) \sim 200\,\mu$m)

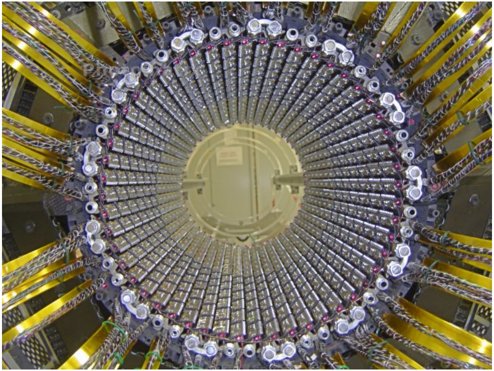
➡ precise silicon vertex detector needed



Standard Silicon Detector

for example ATLAS





- multiple sensitive modules are glued on support ribs which provide mechanical stability
- support, cooling and cables inside acceptance region (between 5% and 30% X_0)
- too much material for Belle II (10 GeV CM energy)

Belle II Vertex Detector

Vertex resolution is the key to CP-Violation

⇨ low material budget required to minimize energy loss and multiple scattering, leading to a different design compared with existing Silicon detectors

- silicon sensors self supporting
- sensitive area will be thinned down to 75 μm
- almost no additional material inside of the acceptance

Silicon has good mechanical properties (high tensile strength, no plastic deformation, good elasticity)

But:

Silicon is very brittle: Once there is a small crack, this crack can grow very easily

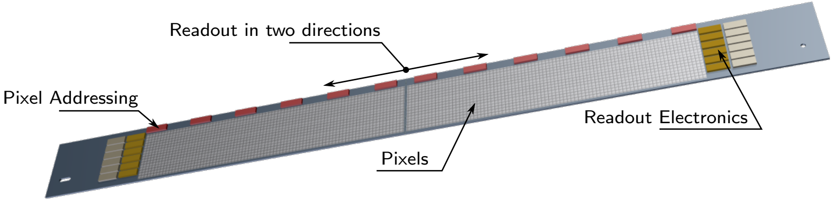
No prior experience with this design

⇨ additional tests required to make sure nothing breaks

Sensor Module

Each sensor module consists of two front-faced silicon wafers of DEPFET Pixels

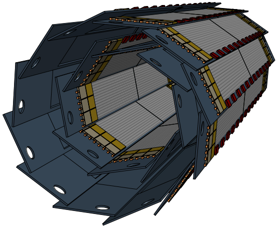
- 1536×250 pixels per module
- row wise readout on both sides
- each pixel readout with 8bit ADC



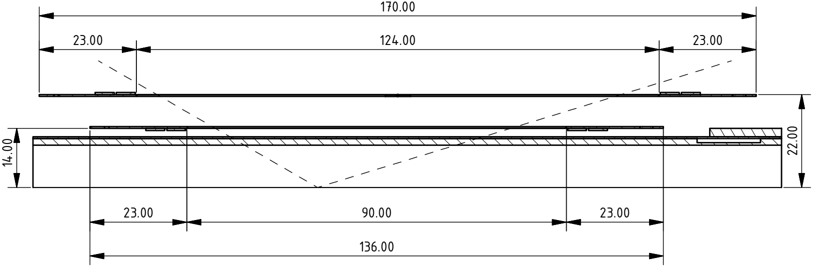
Sensor has to be cooled

- active area produces 0.5 W of heat
- addressing chips produce 0.5 W of heat
- readout electronics produce 8 W of heat per side

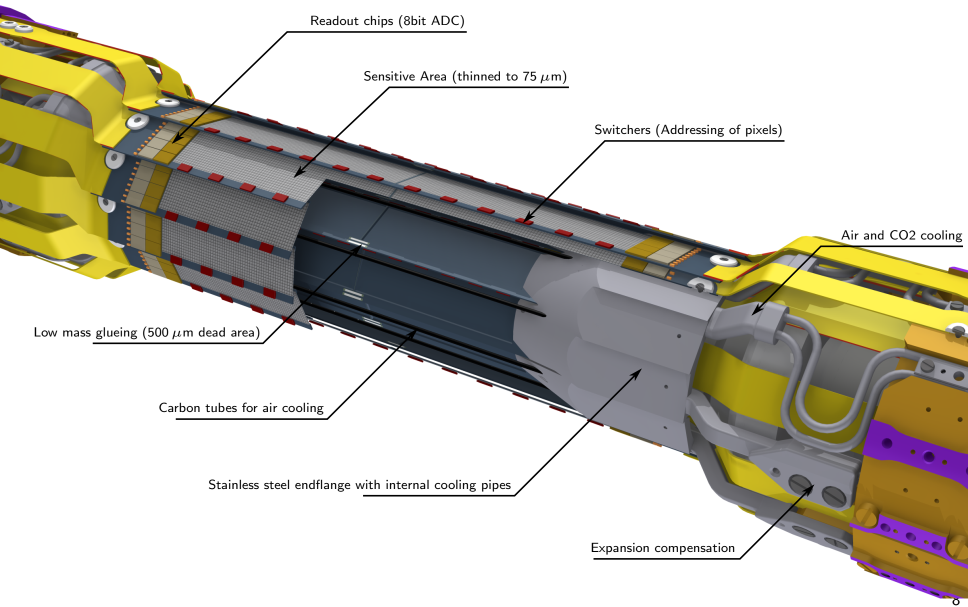
Layout of the PXD



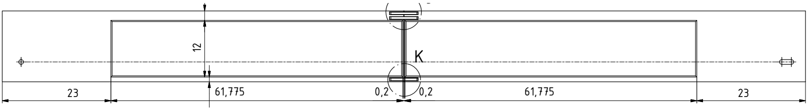
- PXD consists of 20 Modules in 2 layers
- pixel size of $50 \times 50\,\mu$m for the inner layer and $75 \times 50\,\mu$m in the outer layer
- total readout time of $20\,\mu$s
- inner layer at 1.4 cm radius
- outer layer at 2.2 cm radius



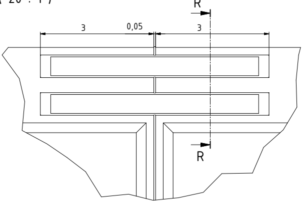
PXD Overview



Module Glueing



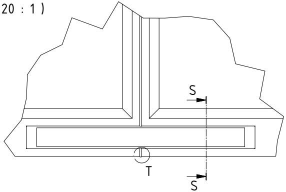
J (20 : 1)

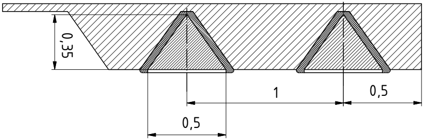


Reinforced front face glueing

- reinforced using ceramic “prisms”
- almost no additional material
- only $\sim 500\,\mu$m of dead area

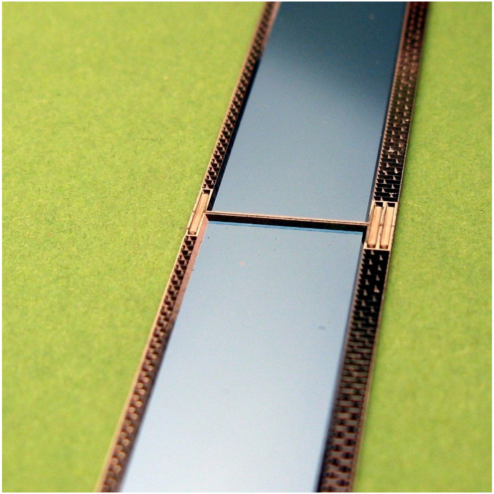
K (20 : 1)



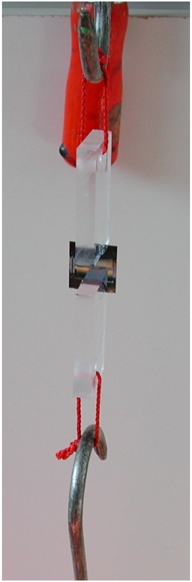


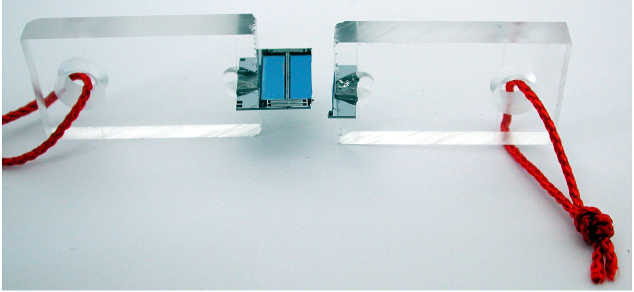
Test Glueing

Test glueing of mechanical dummies thinned to 50 μm to verify design



Tensile Strength Test





Tensile strength test carried out:

- ends of the module fixated
- increasing force applied to pull the pieces apart
- solid 450 μm silicon tested to 7 kg
- unthinned front face glueing achieved $\sim$ 6 kg

Long time test (unthinned, 3 kg) still ongoing: 6 weeks already achieved

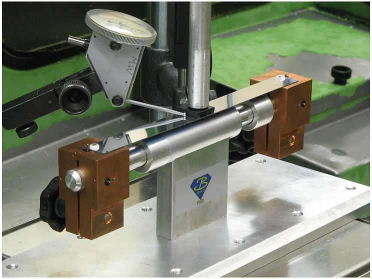
Strengh Test Results

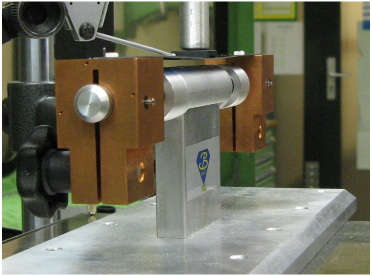
- module broke just above 5 kg
- glue more or less still intact
- silicon seems to be weaker then glue (for 50 μm)
- long time test with 3 kg broke after few hours: silicon again the weak part

Bowing Strength Test

Additional test to study deformation perpendicular to module axis

- module screwed to endplate on both sides
- one endplate fixed, one free to slide along module axis
- applying pressure to module center (0.025 mm every 15 seconds) up to 1 mm deformation

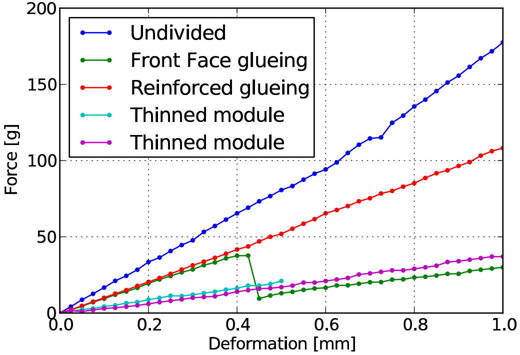




Bowing Test Results

- undivided, inner layer dummy broke at deformation of 1.445 mm (equivalent to a force of 315 g)
- front face glued outer layer module:
  - glueing broke at 0.4 mm deformation (37.7 g)
  - half modules remained in good order, tested to 1 mm deformation ($\sim$ 30 g)
- reinforced glueing successfully tested up to 1 mm deformation (110 g)

- thinned down outer layer dummy tested up to 1 mm deformation (35 g)
- cracks in thinned area: no growing visible



Conclusions

Belle II will be major upgrade to Belle

- Vertex finding is paramount for CP Violation measurements
- low material budget for vertex detector required due to low momenta

PXD Mechanical Design

- challenging spacial and material constraints: Sandwiched between beampipe and SVD
- small size allows to keep support out of acceptance
- silicon as “self supporting structure”
- tests needed to verify feasibility
- so far very promising results
- low material PXD design well underway

Thank you
for your attention

CP Violation

- CP violated in weak interactions
- represented by non-vanishing complex phase in the weak mixing matrix (CKM model, Nobel Prize 2008 for Kobayashi & Maskawa)

$$\begin{pmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\mathbf{C}_{CKM}} \begin{pmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{pmatrix}$$

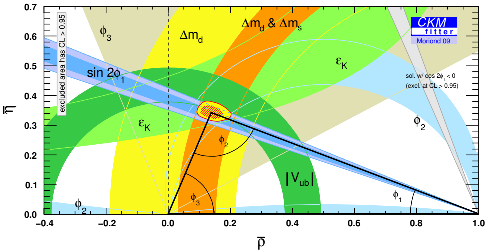
Precision Measurement of CP-Violation

- verification of the CKM model
- search for new sources of CP Violation ⇨ New Physics
- B mesons show large CP-Violation, well suited for CP measurements
- high statistics and precision needed to challenge SM

Unitarity Triangle

- unitarity of CKM matrix leads to column constraints $\sum_k V_{ik} V_{jk}^* = 0$
- triangles in complex space
- almost degenerate in Kaon system, large angles in B meson system

$$\underset{\mathcal{O}(\lambda^3)}{V_{ud} V_{ub}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{cd} V_{cb}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{td} V_{tb}^*} = 0$$



$$\overline{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \overline{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$

$$\phi_1 = \arg\left(-\frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*}\right) \qquad \phi_2 = \arg\left(-\frac{V_{td} V_{tb}^*}{V_{ud} V_{ub}^*}\right)$$

$$\phi_3 = \arg\left(-\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}\right)$$

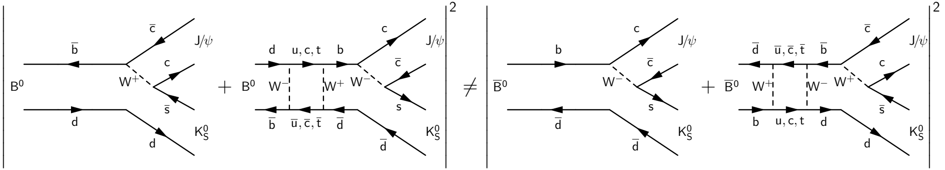
CP Observables

time dependent decay asymmetry

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

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

Measurement of CP-Violation

time dependent decay asymmetry

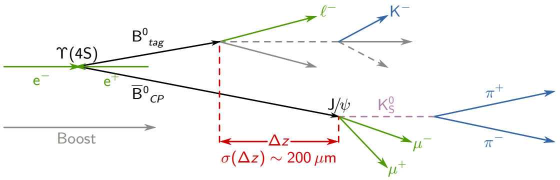
$$a_{CP}(t) = \frac{\Gamma\left(\overline{B}^0 \to f_{CP}; t\right) - \Gamma\left(B^0 \to f_{CP}; t\right)}{\Gamma\left(\overline{B}^0 \to f_{CP}; t\right) + \Gamma\left(B^0 \to f_{CP}; t\right)}$$

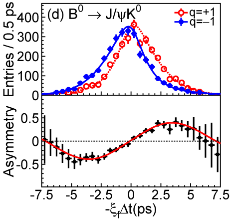
Experimental challenging

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

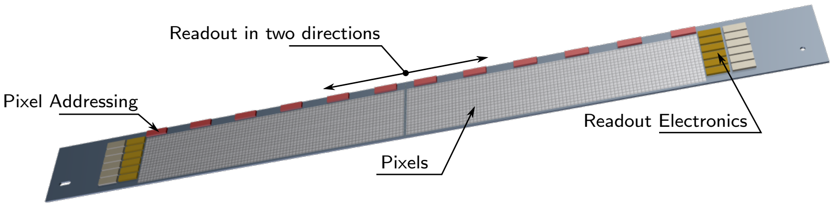
Solution

- $\Upsilon(4S)$: 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
  $t \to \Delta t = \frac{\Delta z}{\langle \beta\gamma \rangle c}$





Pixel Sensor



A sensor consists of many pixels in a 2D grid on a silicon module

- some additional electronics needed for addressing and readout of the pixels
- pixels are read out to both sides: one side per half

Sensor has to be cooled

- active area produces 0.5 W of heat
- addressing chips produce 0.5 W of heat
- readout electronics produce 8 W of heat per side

Ceramic Reinforcements

Initial batch of ceramic reinforcements received

- fitting very well into grooves
- manufactured within 42 μm to specification