Tracking Detectors for Belle II

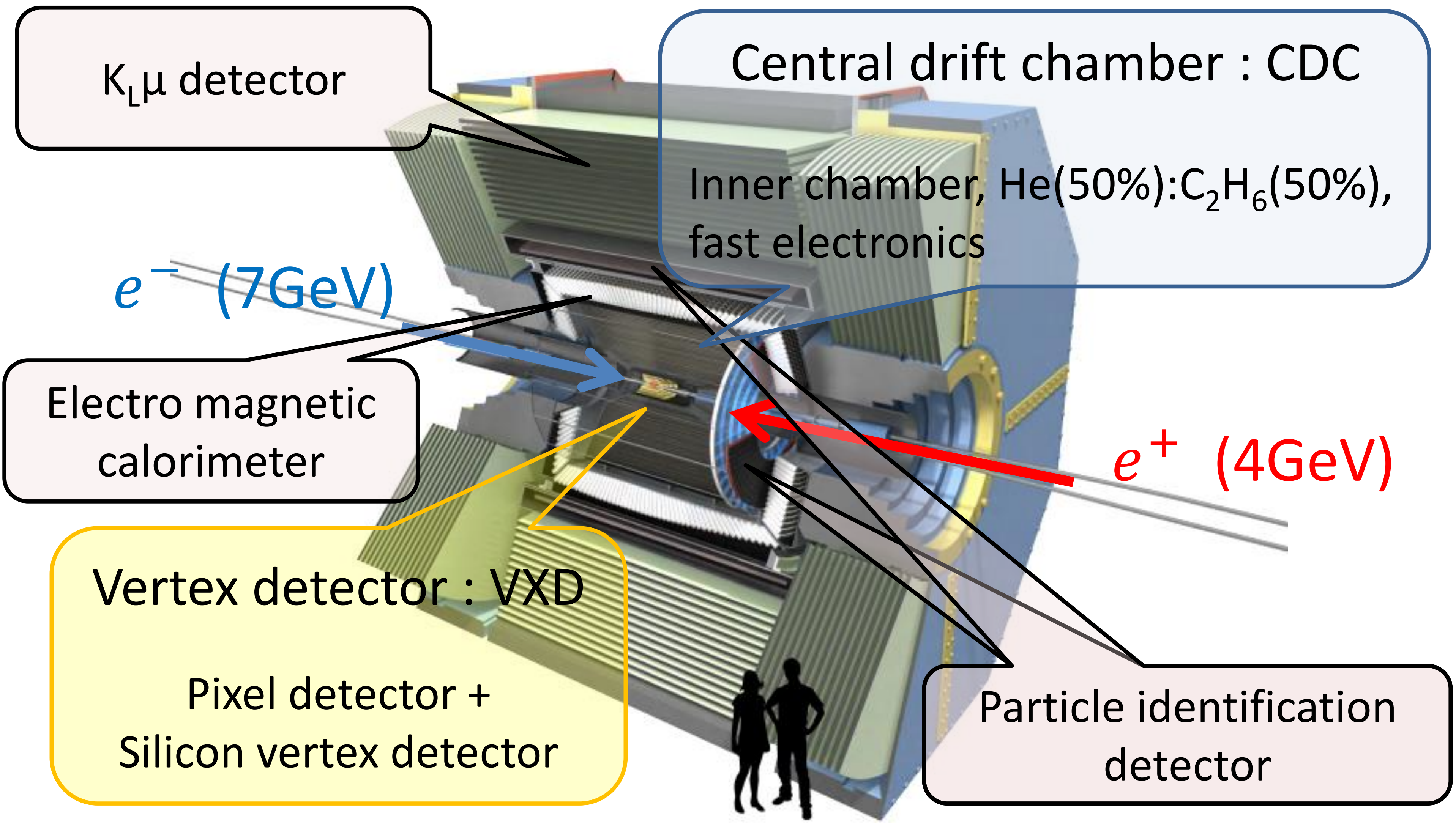
Tomoko Iwashita(Kavli IPMU (WPI))

Beauty 2014

Introduction

- Belle II experiment is upgrade from Belle
  - Target luminosity : 8×10^{35} cm^{-2} s^{-1}
  - Target physics : New physics search
- The charged particle tracking in Belle II
  - In order to achieve the high background immunity and high rate capability, the detector system Belle II must introduce the available best solutions.

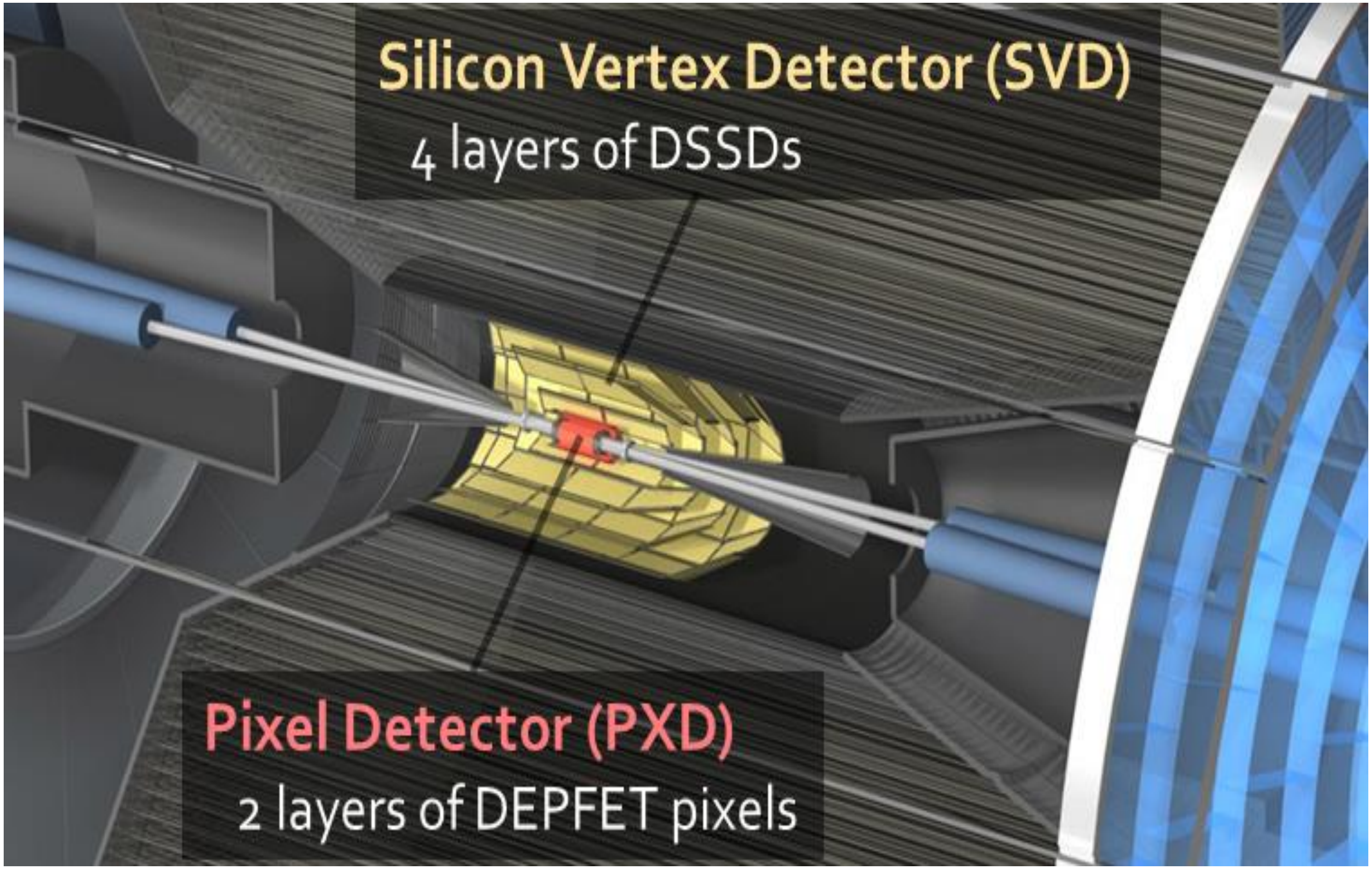
Belle II detector



Improvements in the vertex detector system (VXD)

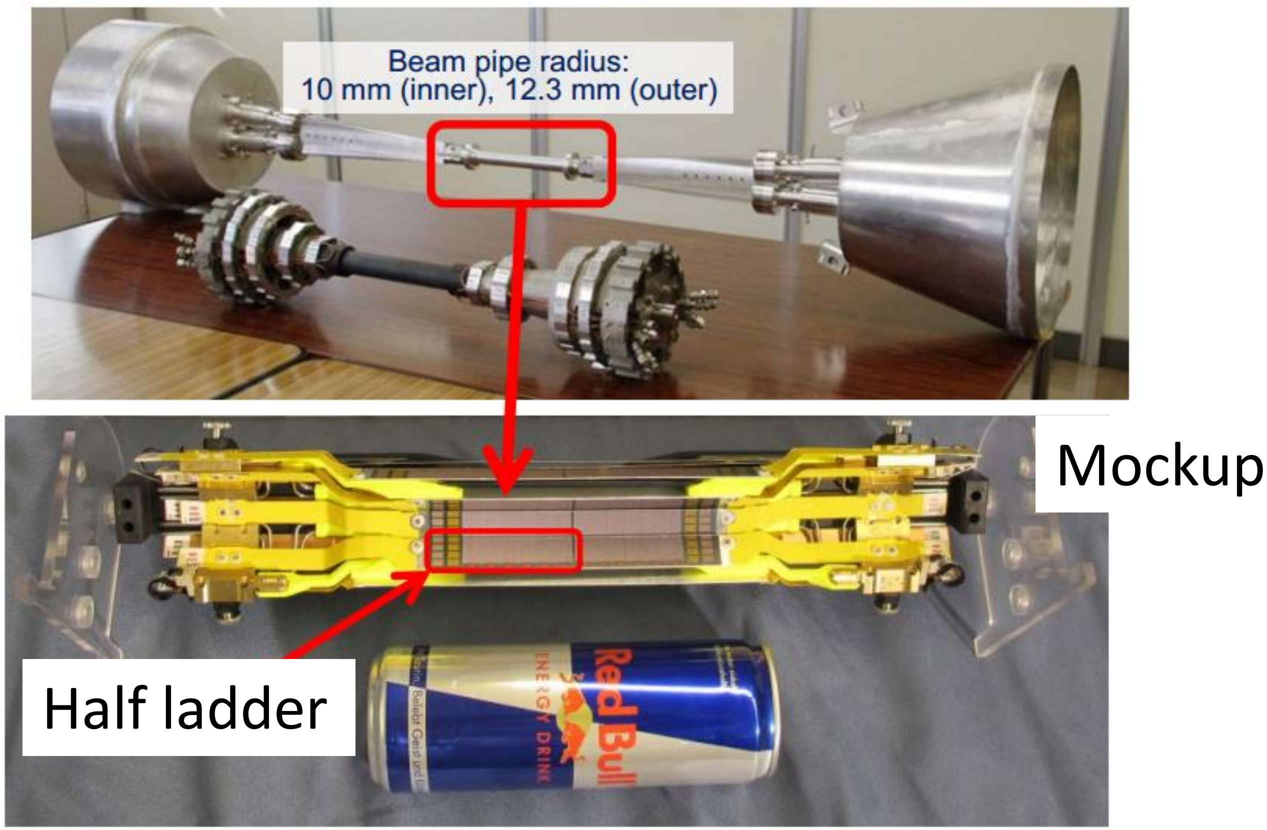
1. Introduce 2-layers DEPFET pixel sensors
   - Placed close to the IP (at r=14mm and 22mm)
   - Thin sensor (75μm thick) to reduce multiple scattering
     ➔Good for time dependent CP measurement
2. Silicon strip detectors cover larger volume
   - From layer 3 (r=38mm) up to layer 6 (r=135mm)
   - Acceptable occupancy
   - Improved reconstruction efficiency for B vertex reconstruction with
     $K_S \to \pi^+\pi^-$
     i.e. $B^0 \to K_S K_S$, $B^0 \to K_S K_S K_S$, $B^0 \to K_S$ pi^0, etc.

Vertex detector



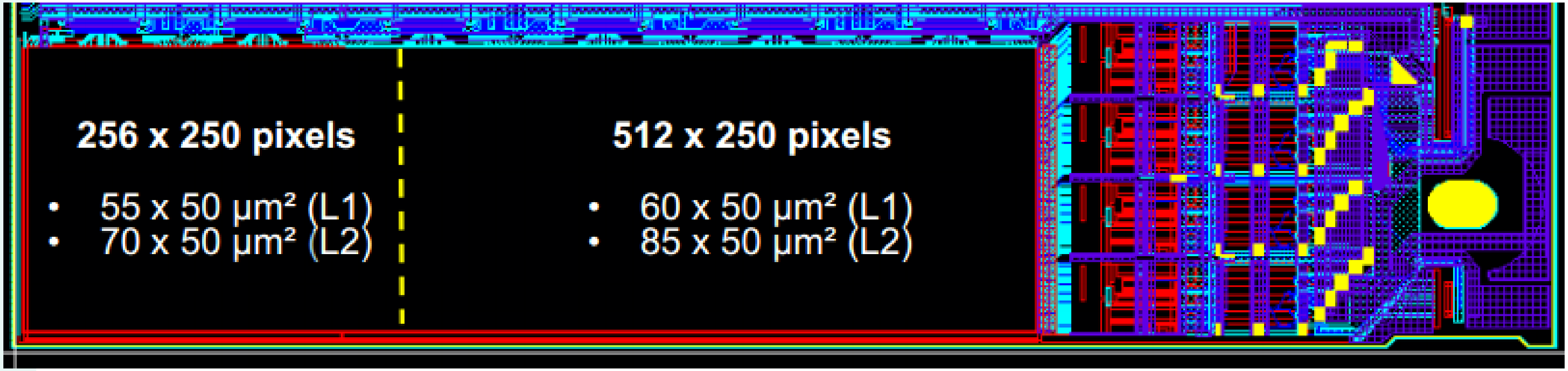
PXD configuration

- Two layers of DEPFET pixels
- Inner radius = 1.4 cm, outer radius = 2.2 cm



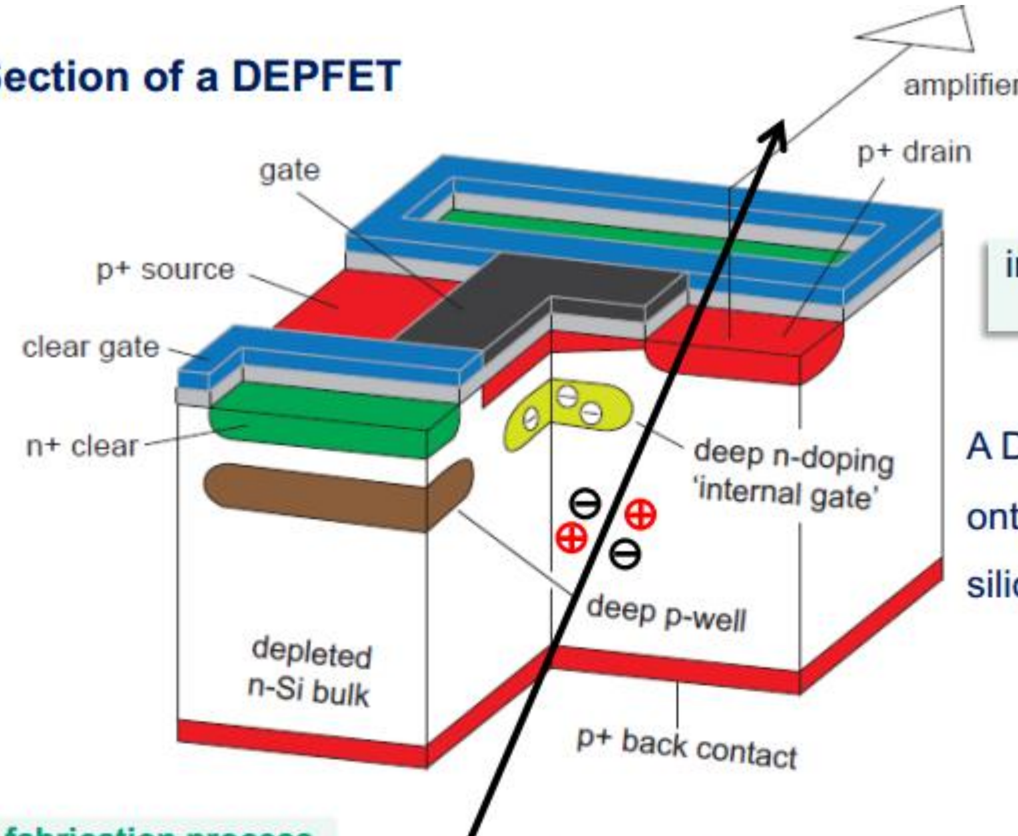
Half ladder of DEPFET PXD

	Inner layer (L1)	Outer layer (L2)
# modules	8	12
Distance from IP (cm)	1.4	2.2
Thickness (μm)	75	75
Total # pixels	3.072×10^6	4.608×10^6
Pixel size (μm²)	55, 60 x 50	70, 85 x 50
Sensitive area (mm²)	44.8 x 12.5	61.44 x 12.5
Sensor length (mm)	90	123
Frame/Row rate	50 kHz / 10 MHz	50 kHz / 10 MHz



DEPFET
(Depleted p-channel field effective transistor)

Cross Section of a DEPFET



internal amplification:
$g_q \approx 0.5$ nA/e$^-$

A DEPFET is a MOSFET

onto a fully depleted

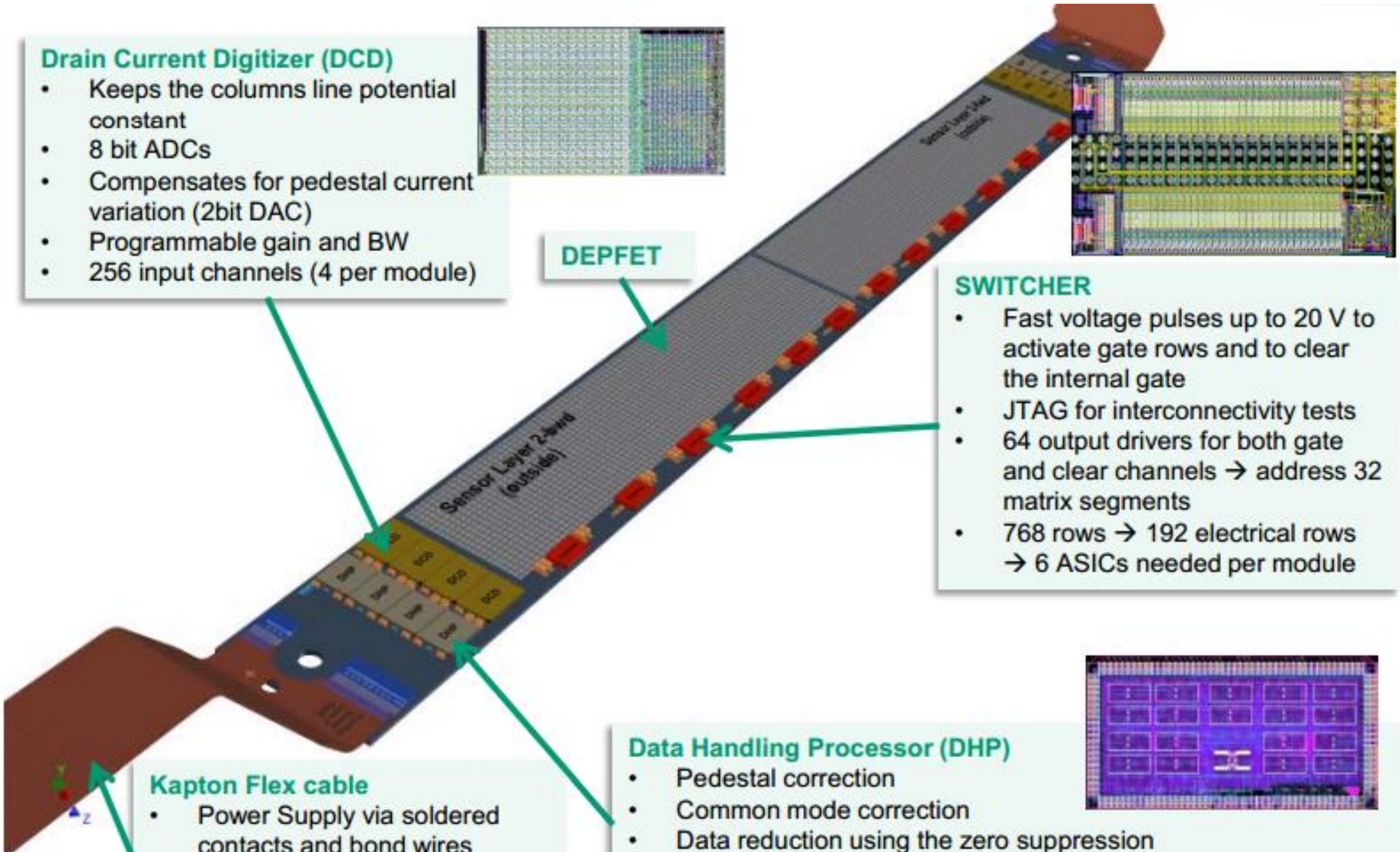
silicon bulk

90 steps fabrication process

- 9 implantations
- 19 lithographies
- 2 Poly-layers
- 2 Aluminum layers
- 1 Copper layer
- Back side processing

→ Low noise
→ Low power
→ High signal/noise-ratio
→ Non-destructive readout

Control and readout electronics



Drain Current Digitizer (DCD)

- Keeps the columns line potential constant
- 8 bit ADCs
- Compensates for pedestal current variation (2bit DAC)
- Programmable gain and BW
- 256 input channels (4 per module)

DEPFET

SWITCHER

- Fast voltage pulses up to 20 V to activate gate rows and to clear the internal gate
- JTAG for interconnectivity tests
- 64 output drivers for both gate and clear channels → address 32 matrix segments
- 768 rows → 192 electrical rows → 6 ASICs needed per module

Kapton Flex cable

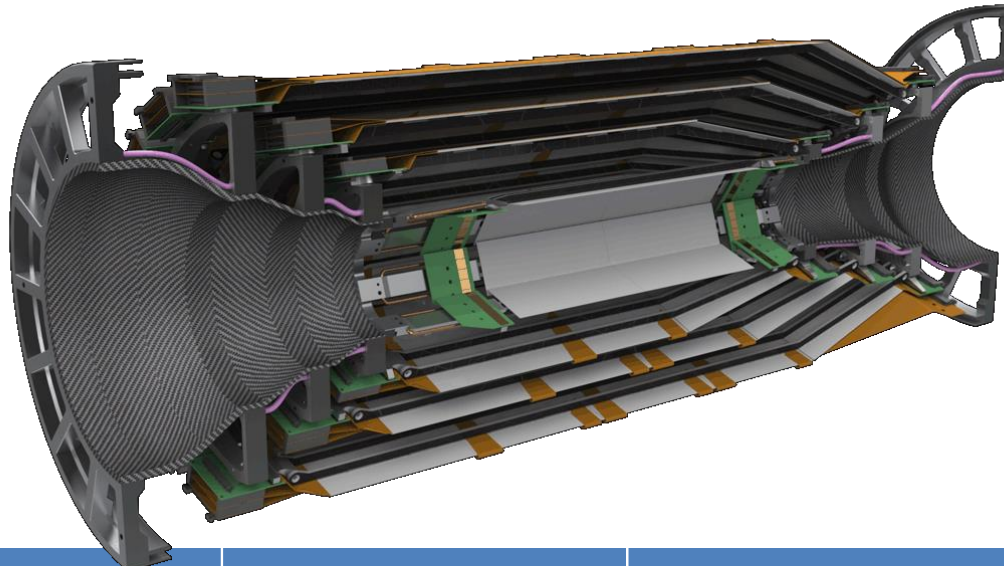
- Power Supply via soldered contacts and bond wires
- Data transmission via bond wires
- 4 layers, 48 cm

Data Handling Processor (DHP)

- Pedestal correction
- Common mode correction
- Data reduction using the zero suppression
- Triggered readout scheme introduces further data reduction
- Controls the Switcher sequence

SVD configuration

- 4 cylindrical layers

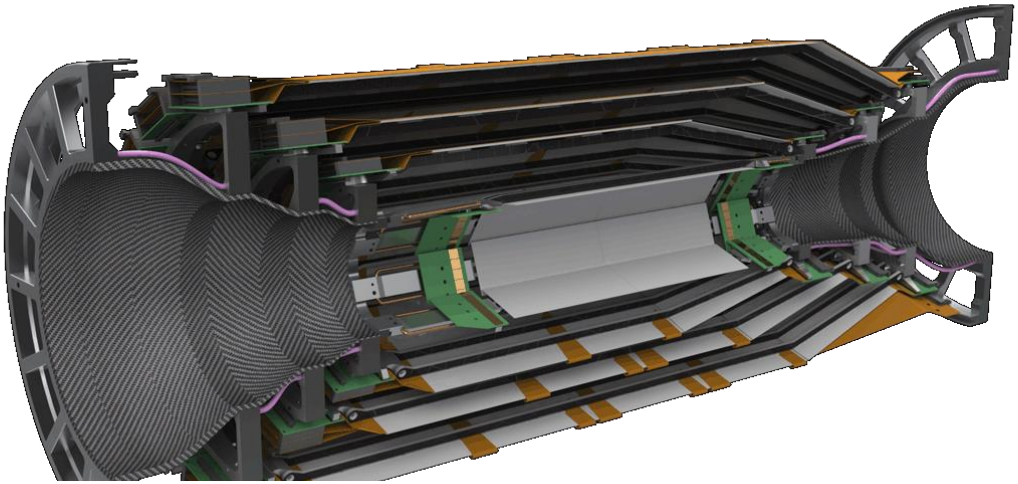


Layer	# of ladders	Sensors/ladder	Radius [mm]	Length [mm]
6	16	5	135	701
5	12	4	104	579
4	10	3	80	456
3	7	2	38	404

*Length shows between FW and BW mount point

SVD configuration

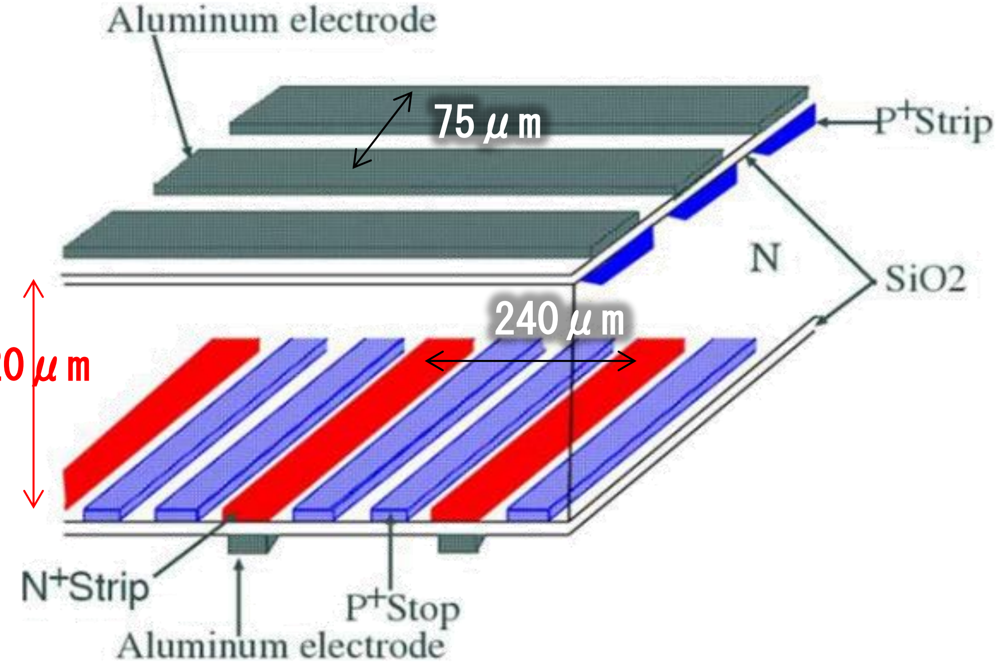
- 4 cylindrical layers



Layer	Assembly site
6	IPMU
5	HEPHY
4	TIFR at IPMU
3	Melbourne
	Forward and backward module : Pisa

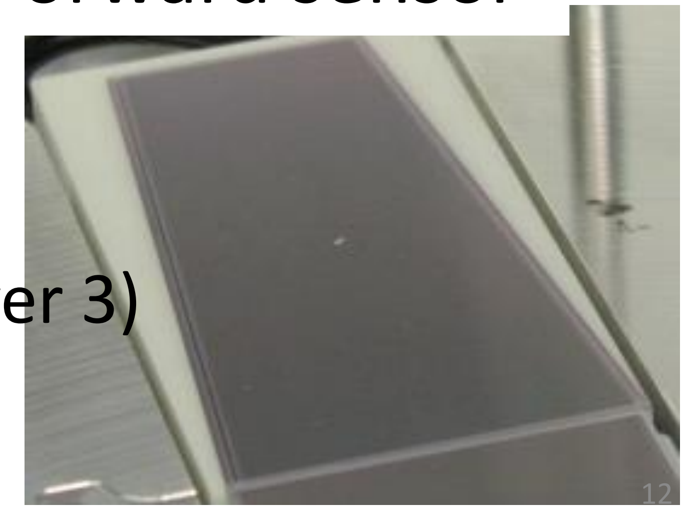
Double sided Si detector : DSSD

Large rectangular DSSD



Barrel sensor

Forward sensor



Kinds of sensors

- Slim rectangular for barrel (For layer 3)
- Large rectangular for barrel
- Trapezoidal for forward

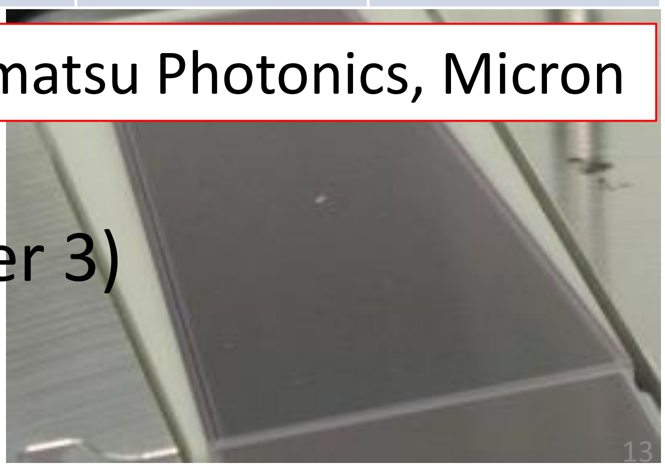
Double sided Si detector : DSSD

Large rectangular DSSD

Barrel sensor

Sensor type	# of strips (P)	# of strips (N)	Pitches z [μm]	Pitches rϕ [μm]	Thickness [μm]
Slim rectangular	768	768	160	50	320
Large rectangular	768	512	240	75	320
Trapezoidal	768	512	240	50-75	300

Manufacturer: Hamamatsu Photonics, Micron

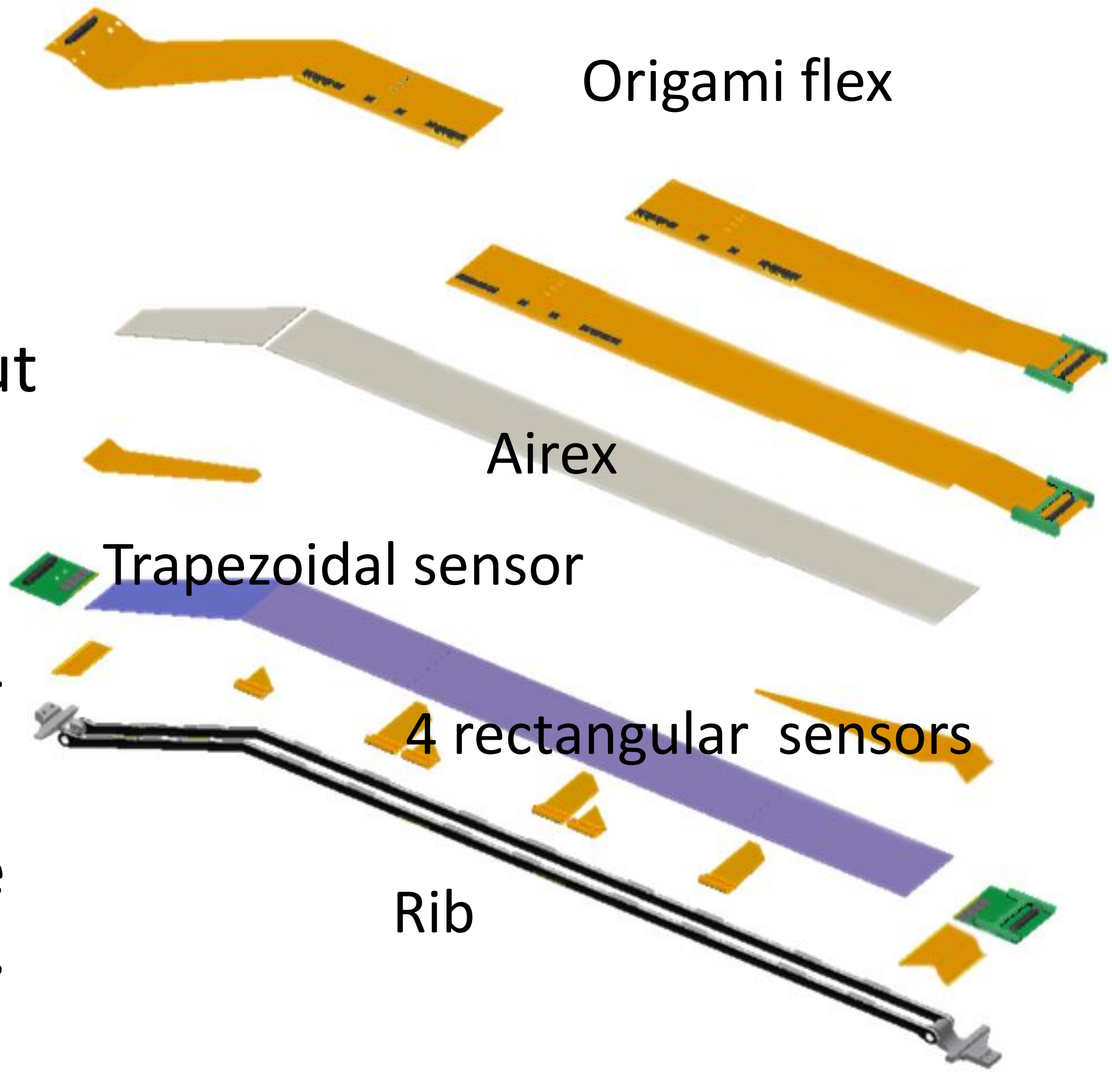


Kinds of sensors

- Slim rectangular for barrel (For layer 3)
- Large rectangular for barrel
- Trapezoidal for forward

Ladder structure (Layer 6)

- Precise alignment of the sensor modules
- Each DSSD is read out with individual readout hybrid
- Thanks to the slant structure, the polar angular acceptance of Belle, ranging from 17° to 150°, can be covered with 5 DSSDs.



Ladder structure (Layer 6)

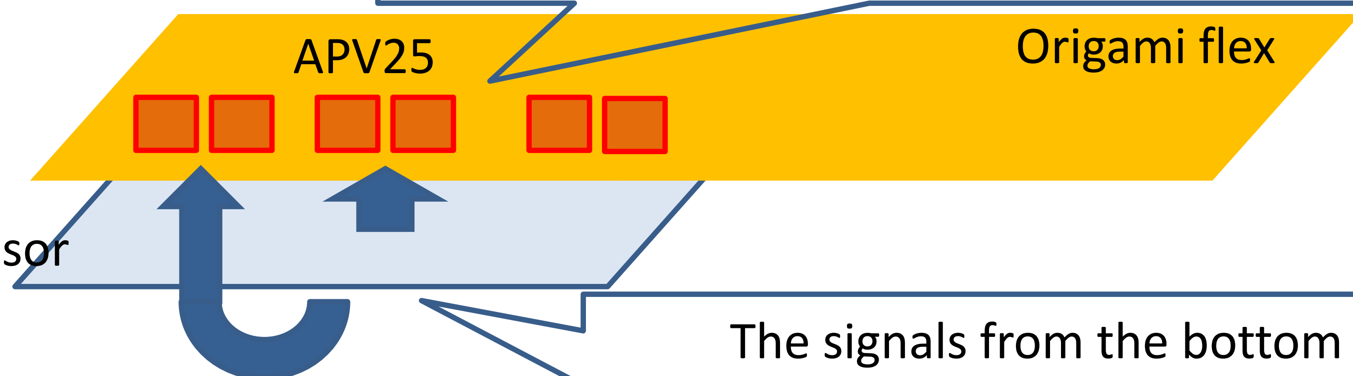
- Precise alignment of the se[...]
- Each [...] with i[...] hybri[...]
- Thank[...] struct[...] angul[...] Belle, [...] 17° [...] cover[...]

The chip on sensor scheme

APV25
- High radiation hardness
- Short shaping time and long pipeline
- Low noise

- APV25 is adopted for the readout
  - ➢ If electrical wiring is long, capacitive noise become big
  - ➢ APV25 should be located to right above on DSSD

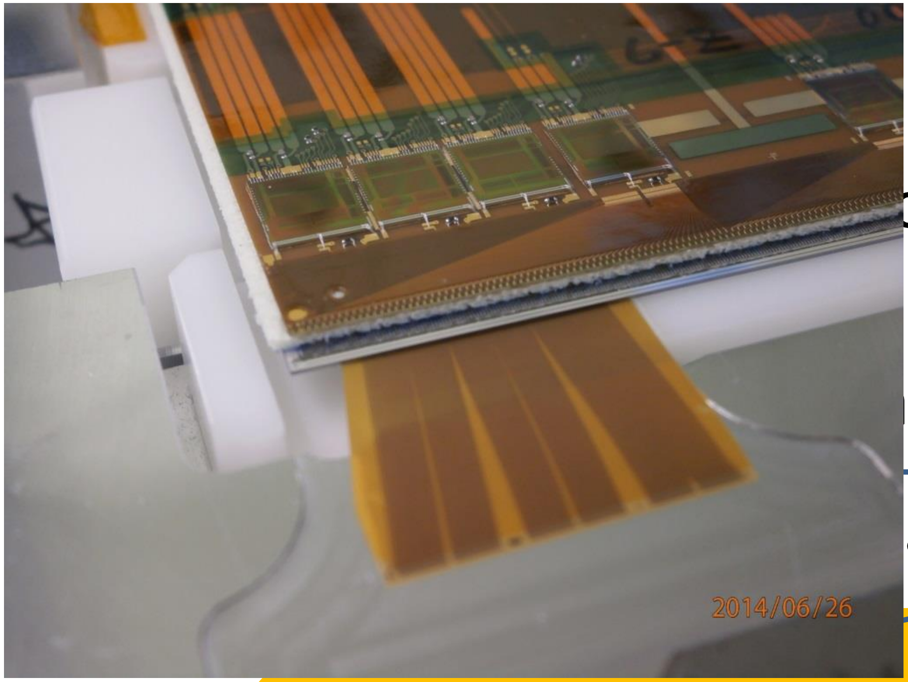
The APV25 flex circuit is located on the top (n-side) of the DSSD

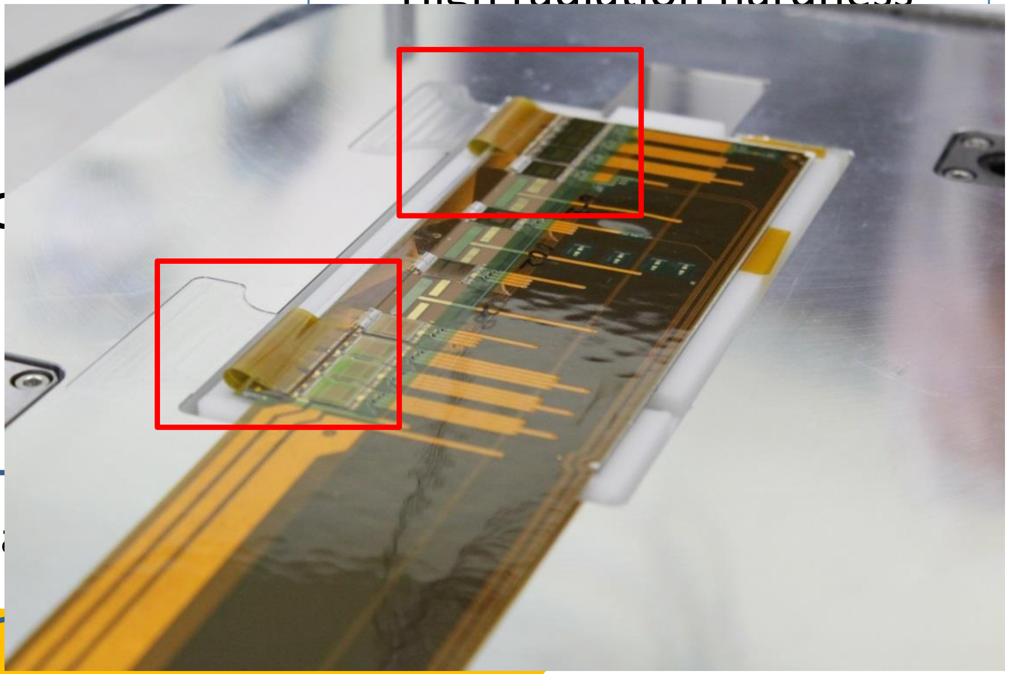


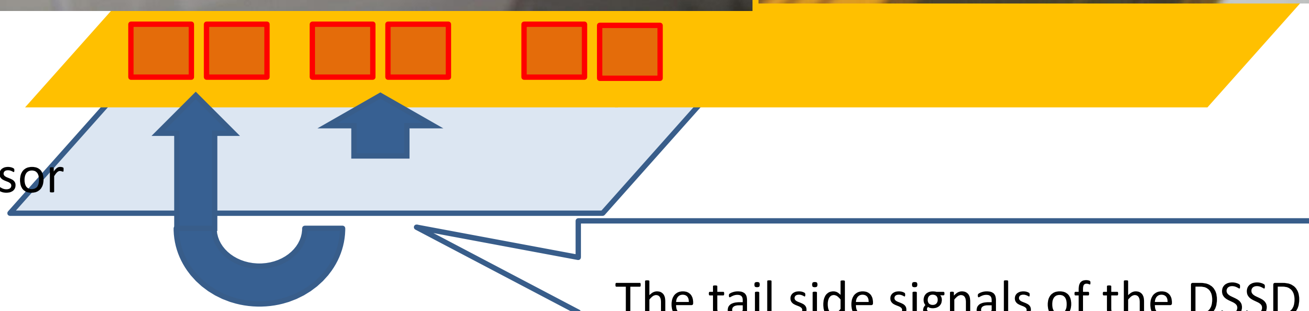
The signals from the bottom (p-side) are transferred to the APV25s via wrapped flex circuits.

The chip on sensor scheme

APV25
- High radiation hardness



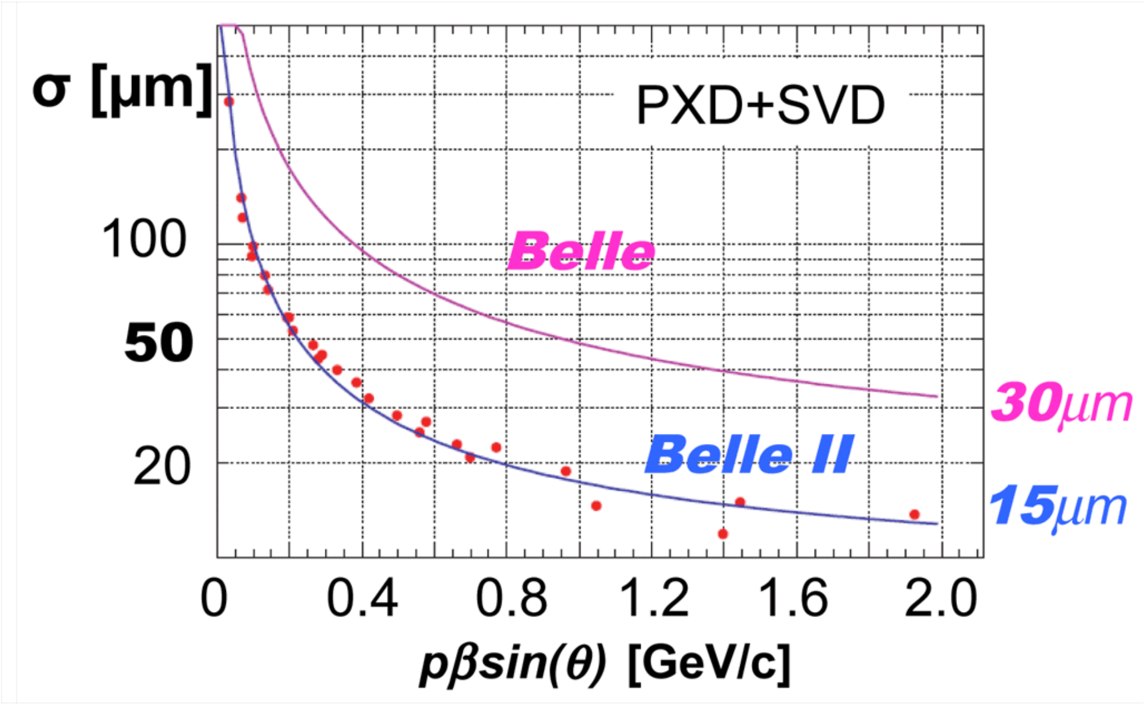


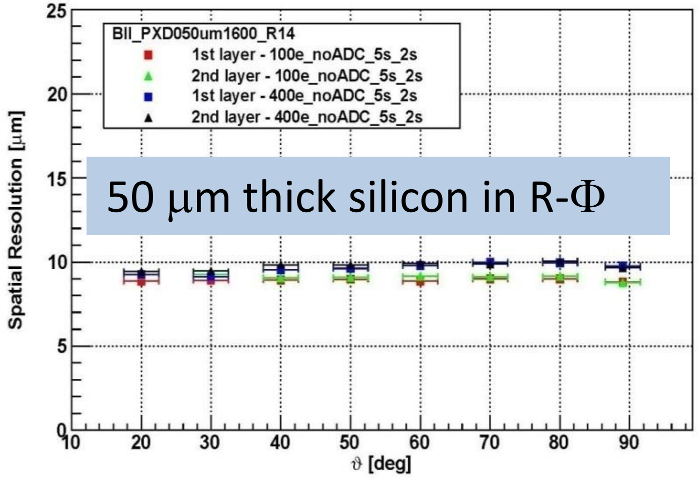


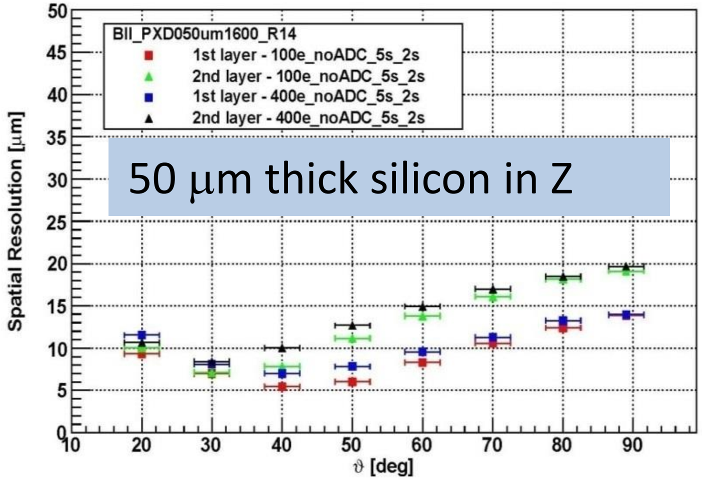
The tail side signals of the DSSD are transmitted to the APV25s via wrapped flex circuit.

Spatial Resolution of the Belle II detector

MC simulation for 50 and 75 μm thick silicon: intrinsic resolution in R-Φ and Z



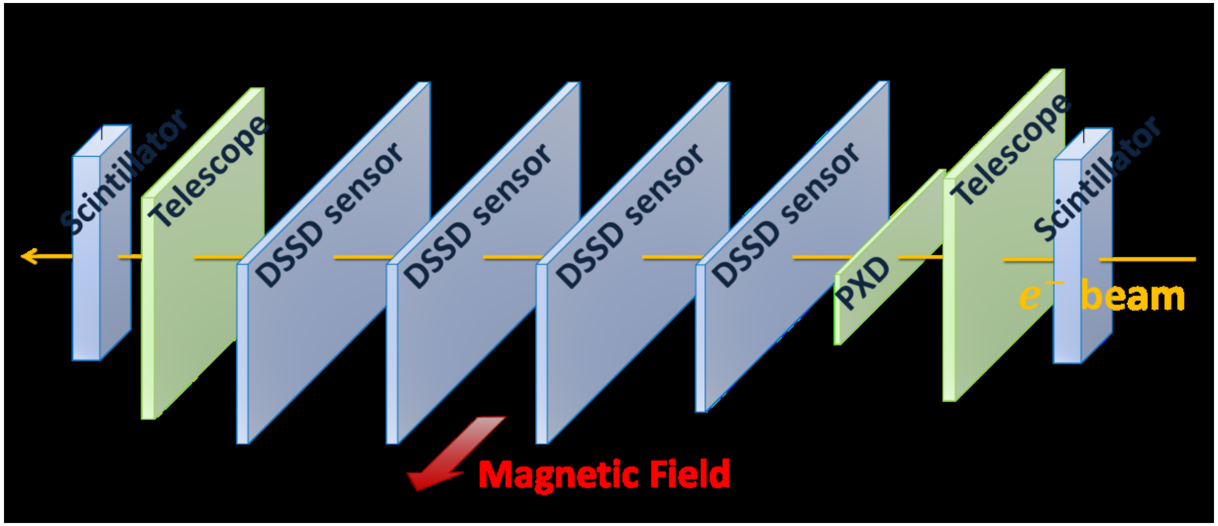




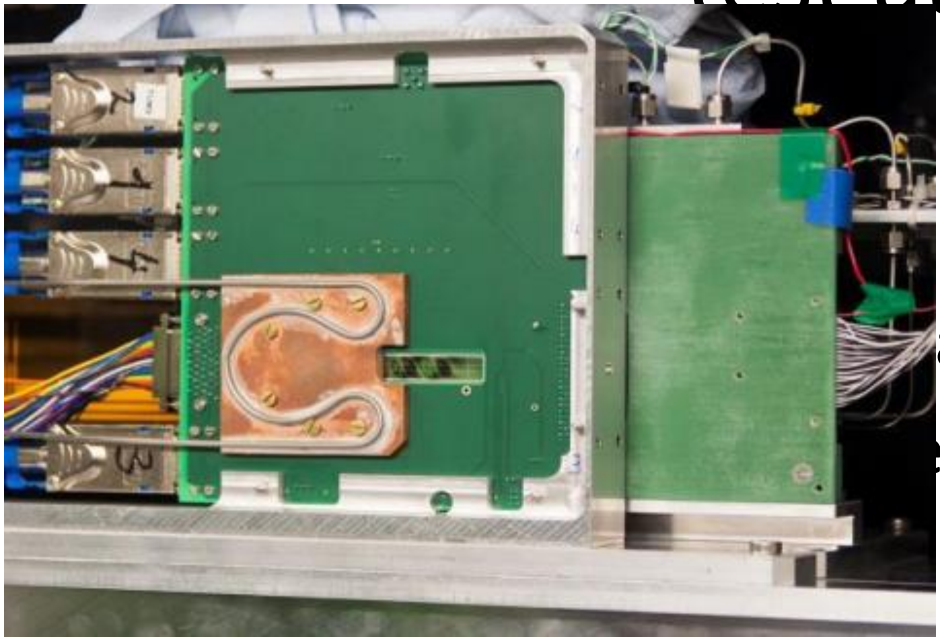
From TIPP2014 June 6 Nakamura-san's slide

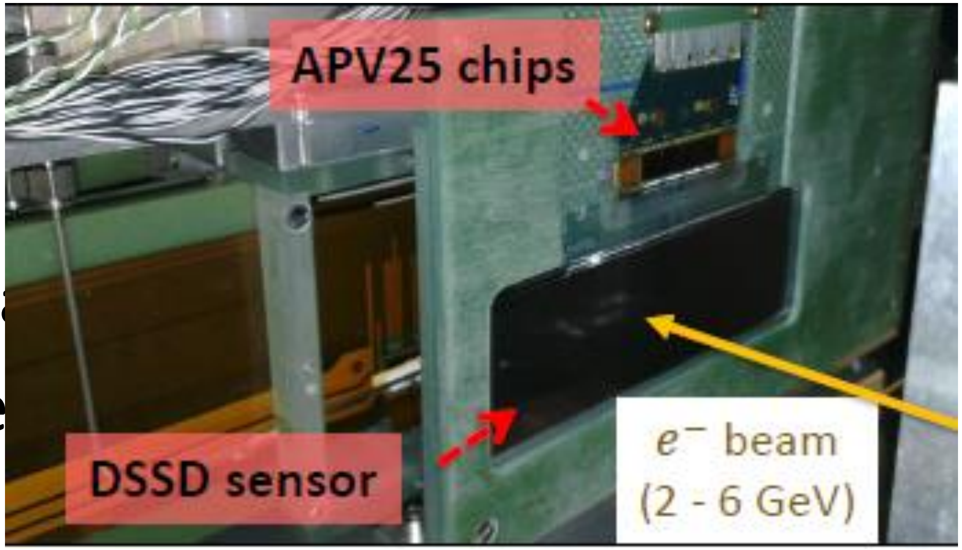
2014 Jan. PXD + SVD combined beam test at DESY

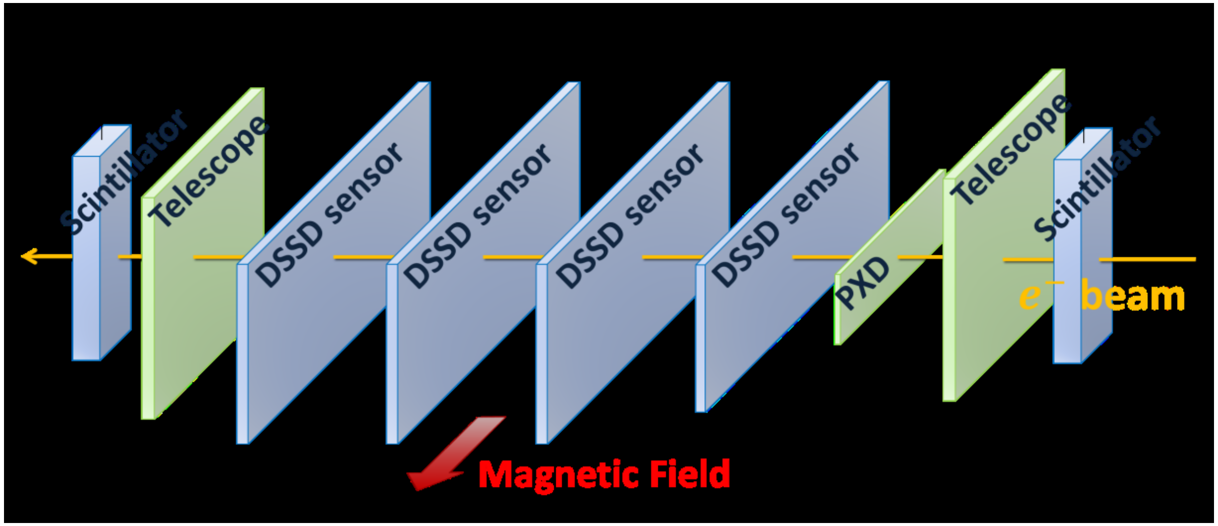
- Full Belle II readout chain of SVD + PXD
- Trigger rate: ~ 400 Hz
- Confirmation of correct data processing
- Stable operation of the readout during the beam test (about 3 weeks)



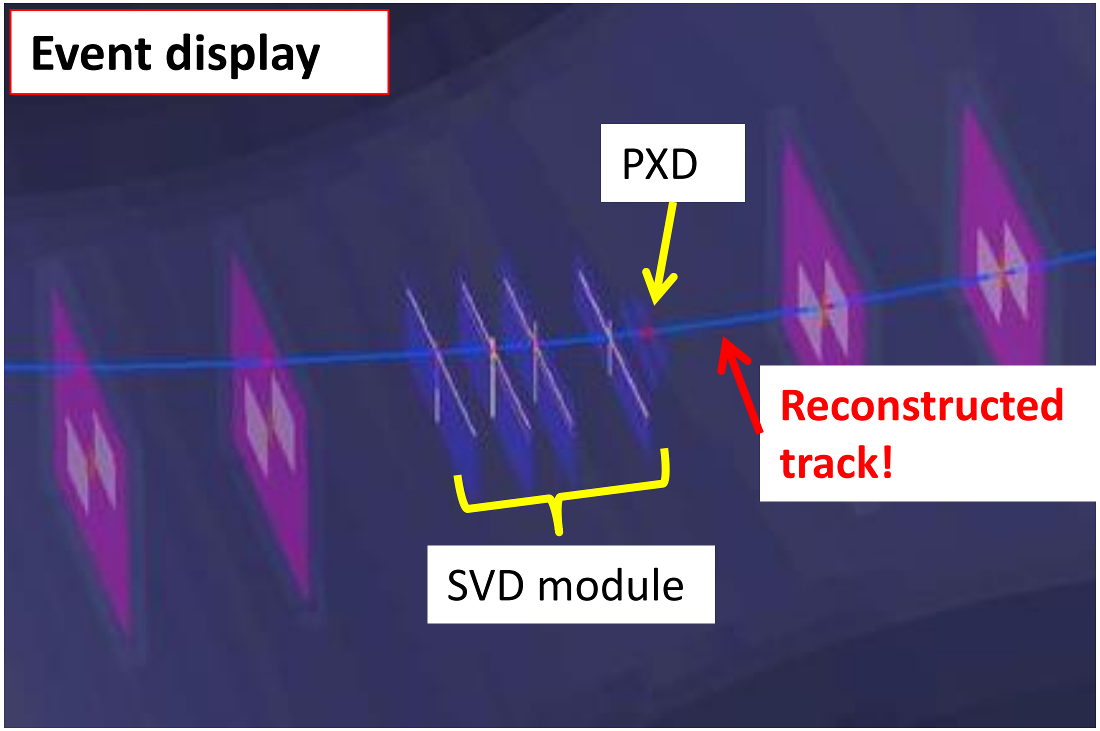
2014 Jan. PXD + SVD combined beam test at DESY



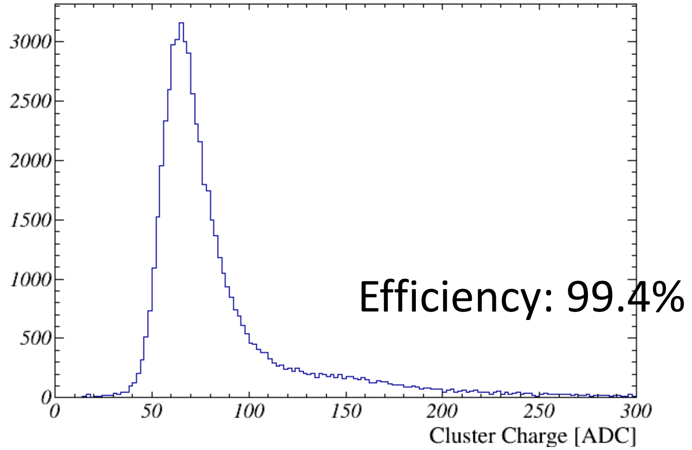




Analysis result of beam test



Cluster charge distribution of SVD



- Belle II SVD + PXD readout system has been verified
- Stable operation of the SVD readout system during the beam test
- Confirmed the PXD readout scheme with ROI (region of interest)
- SVD+PXD alignment and track reconstruction have been performed with beam data

Belle II central drift chamber : CDC

The Belle I experiment proved that the He:C_2H_6=50:50 gas and aluminum alloy field wires is an excellent solution realizing a low-material drift chamber

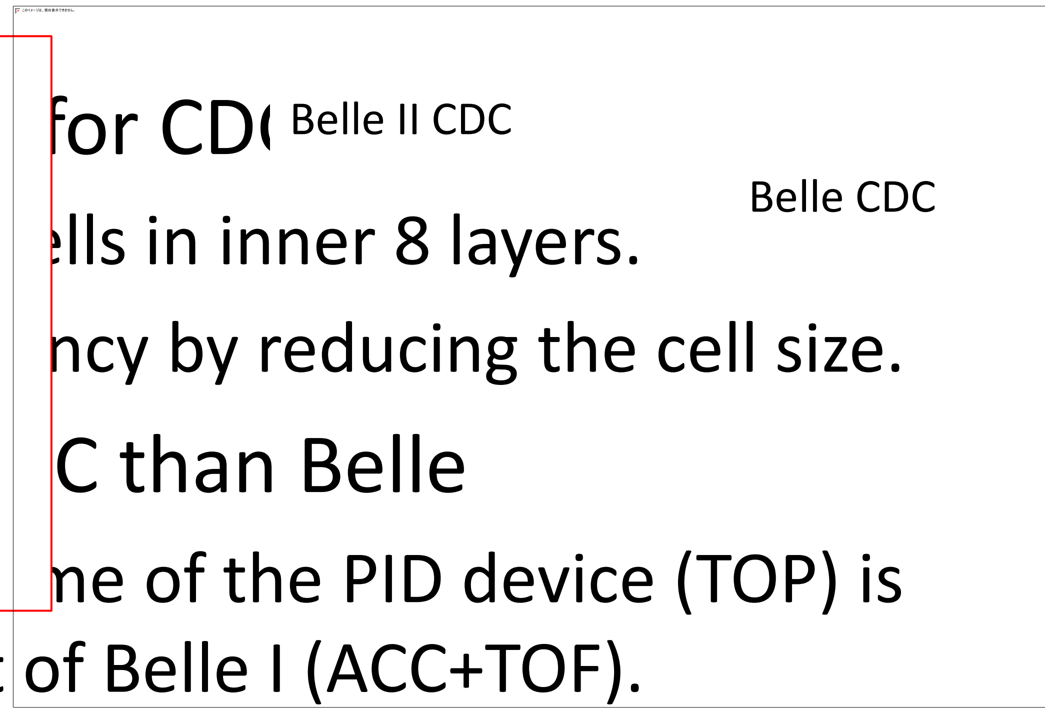
1. Set the small-cells for CDC
   – Adopts the small cells in inner 8 layers.
   – Reduce the occupancy by reducing the cell size.
2. Larger radius of CDC than Belle
   – In Belle II, the volume of the PID device (TOP) is smaller than Belle's (ACC+TOF).

   ➔Better momentum resolution than Belle

Belle II central drift chamber : CDC

The Belle I experiment proved that the He:C_2H_6=50:50 gas and aluminum alloy field wires is an excellent solution realizing a low-material drift chamber

- CDC cylinder size
  - Inner 77mm→160mm
  - Outer 880mm→1130mm
- Increase sense wires
  - 8400→14330



for CD(

ells in inner 8 layers.

ncy by reducing the cell size.

C than Belle

ne of the PID device (TOP) is smaller than that of Belle I (ACC+TOF).

➔Better momentum resolution than Belle

Inner chamber

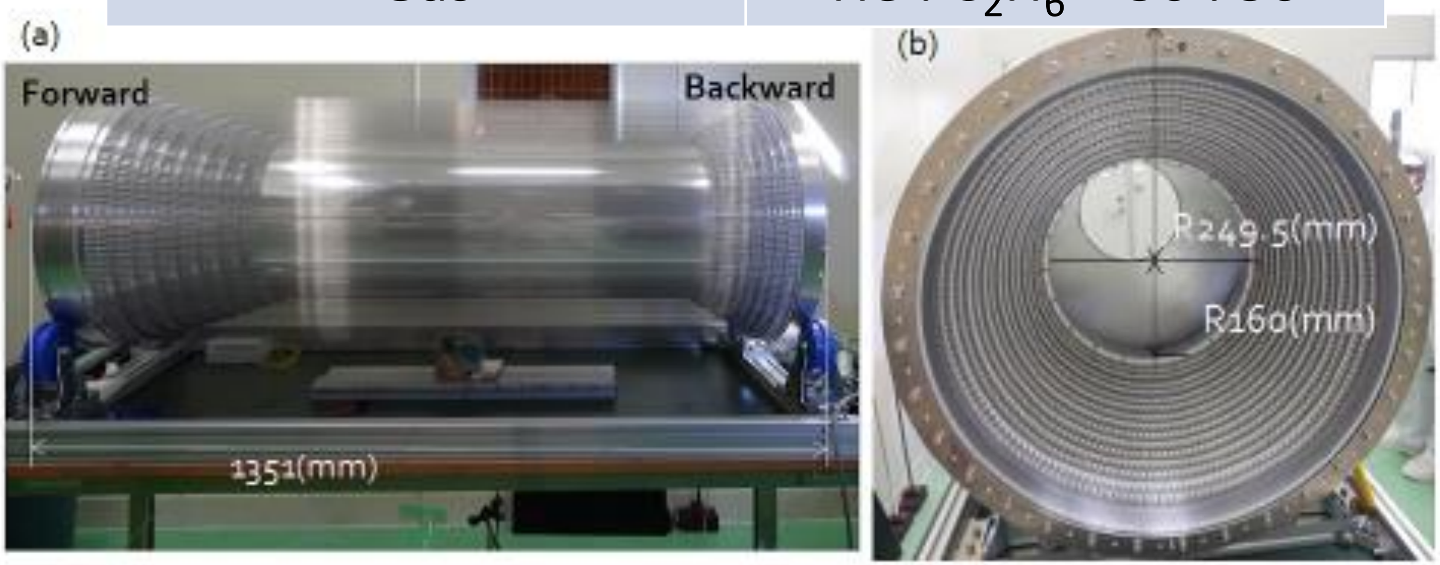
- CDC is consisted from two parts
  - Inner chamber and main chamber
- Inner chamber (small-cell chamber) is in order for high background immunity

Small-cell chamber

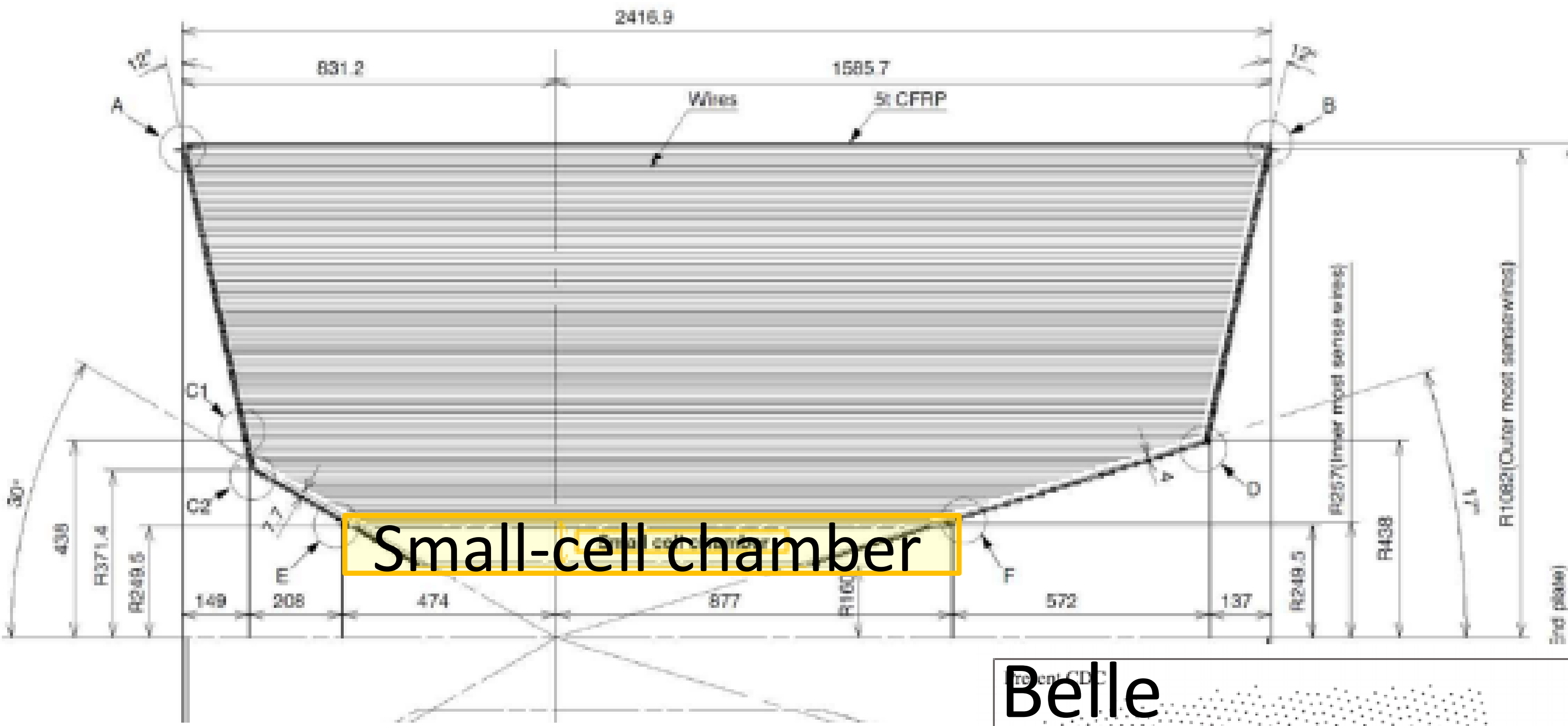
Inner chamber

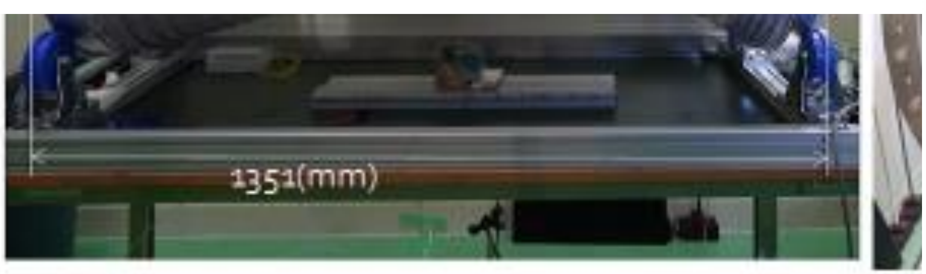
- CDC
  - In
- Inne
  cou

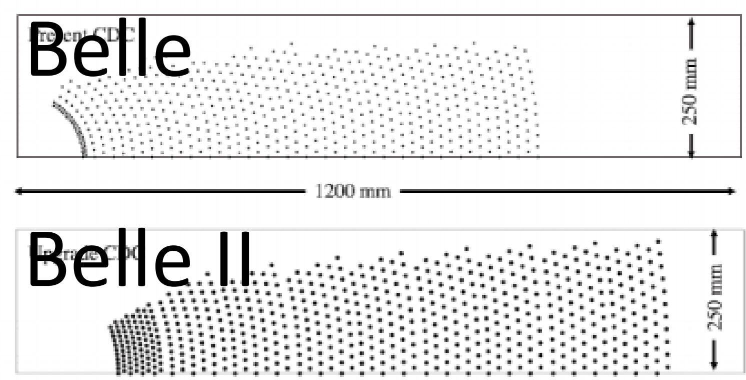
Contents	
Inner layer radius	168 [mm]
Outer layer radius	238 [mm]
# of layers	8
# of sense wires	1280
Gas	He : C_2H_6 = 50 : 50



Inner chamber

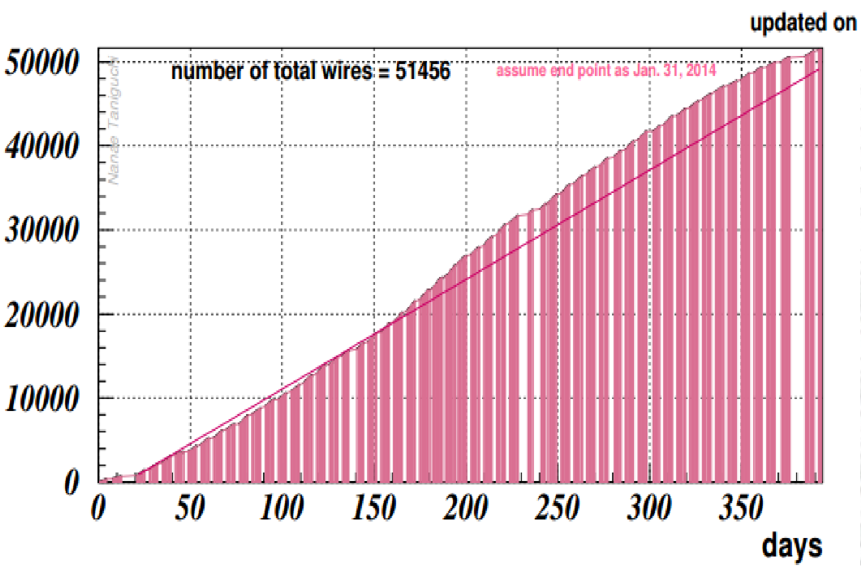


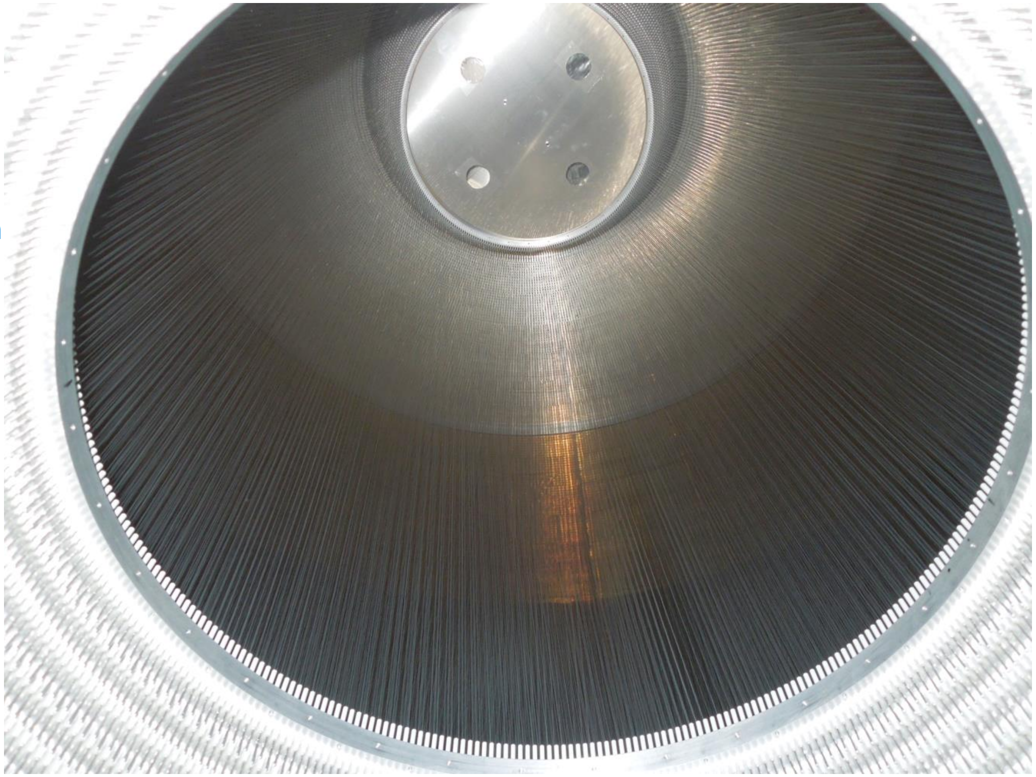




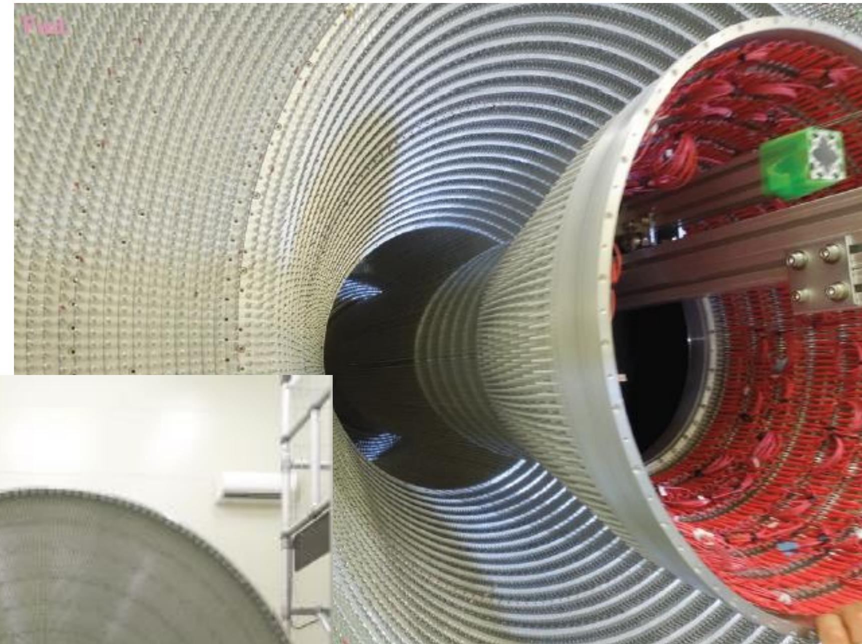
Completed wire work

- All wire (sense + field 51456 wires) work is completed in Jan. 2014





Installation of small-cell chamber



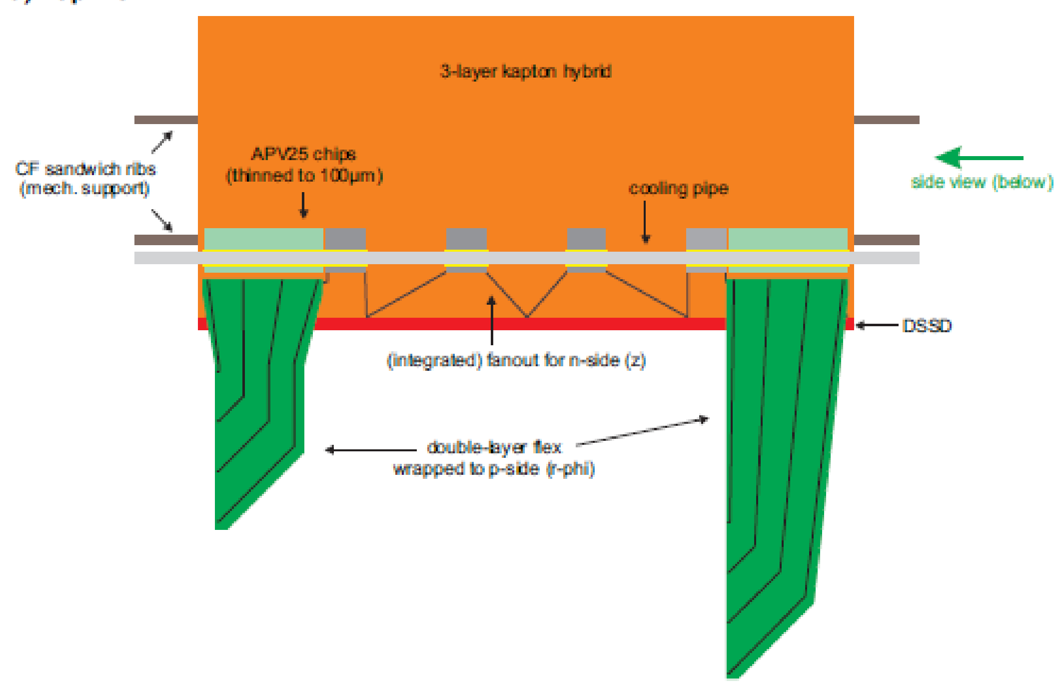
Summary

- Belle II luminosity is 40 times higher than Belle
- To improve or keep adequate performance, high rate capability and high background immunity are to be implemented

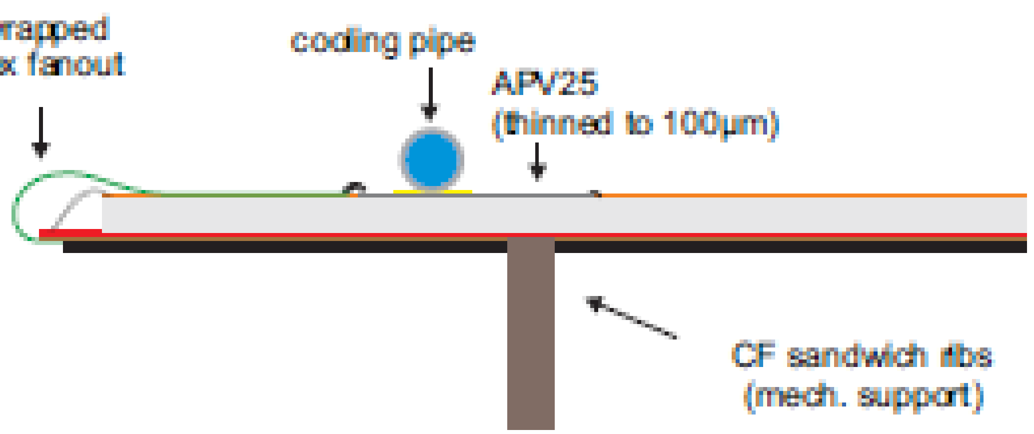
- PXD and SVD
  - Design and operation verification are finished
  - We are preparing mass production
- CDC
  - Completed wire stringing
  - Integration with the readout electronics is ongoing

BACKUP

The chip on sensor



b) Side view (cross section):



CDC performance from TDR

$$\sigma_{r\phi} = 100\ \mu\text{m},\ \sigma_z = 2\ \text{mm}$$
$$\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$$
$$\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}\ \text{(with SVD)}$$
$$\sigma_{dE/dx} = 5\%$$