DuTiP Vertex Detector for Belle II Upgrade and ILC

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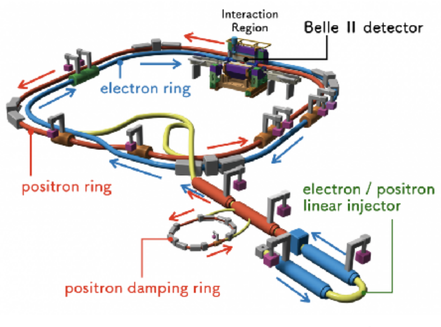
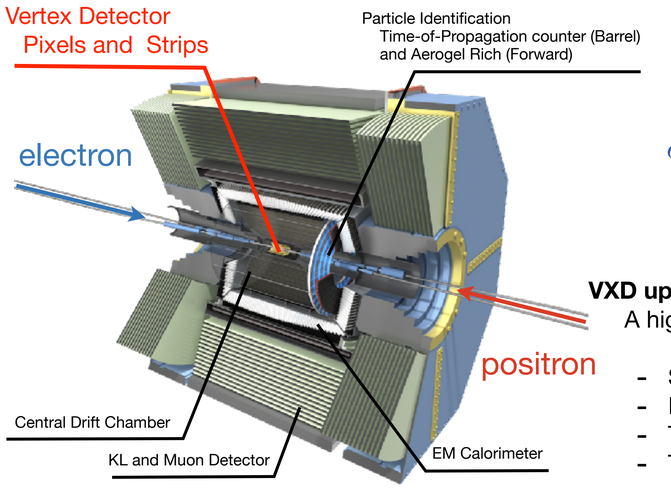
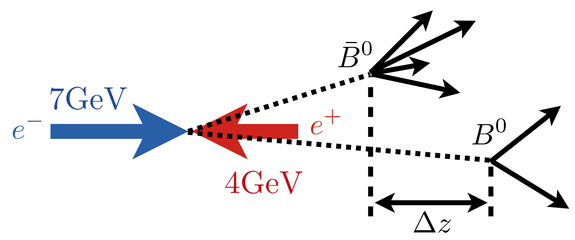
Introduction

Physics Program at SuperKEKB
Based on the accumulation of 50 ab^{-1} of e^+e^-
Instantaneous luminosity: 6×10^{35} cm^{-2}s^{-1}
→ Getting more physics with increasing background

Belle II Vertex Detector (VXD)
Located R = 1.4 cm from the collision point
Suffer from huge beam background
→ **High hit rate: 113 MHz/cm²**





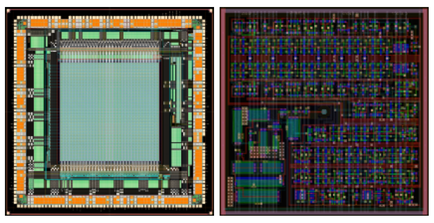


VXD upgrade will be done in the Long Shutdown 2
A higher space-time granularity pixel detector is required

- Spatial Resolution: < 10-15 μm
- Material Budget: 0.1 % X_0/layer (~50 μm thick Si sensor)
- Time Precision: < 100 ns (hit occupancy < 0.1 %)
- Trigger rate and latency: 30 kHz and 5-10 μs

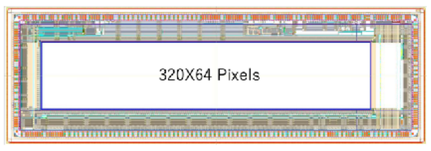
DuTiP Series

DuTiP1 **Pixel**



6 × 6 mm² 45 × 45 μm²

DuTiP2



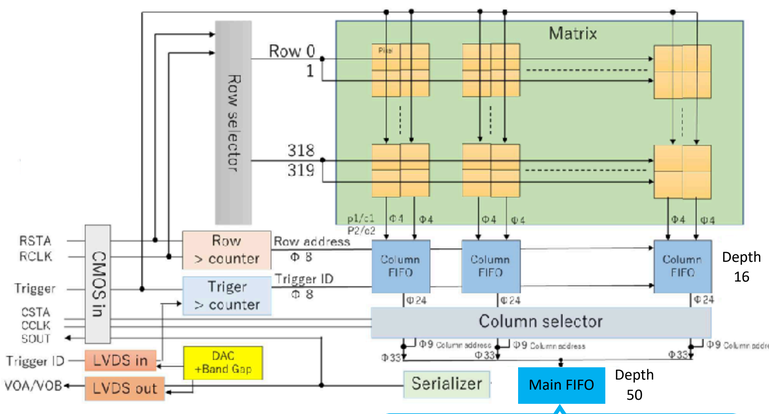
Pixel
- 45 μm × 45 μm,
- 320 pixels for Row (Full Size)
- same as DuTiP1

Readout/Peripheral
- Column FIFO
- DAC, LVDS in/out

Pixel
- 45 μm × 45 μm, 64 × 64 pixels
- Pre. Amplifier (*ALPIDE* type)
- Shaper
- Comparator
- Dual Down Time Counters (7bits)
- Timing Memory (Previous/Current)

Readout/Peripheral
- Full Frame
- CMOS in/out

Sensor
- FZ *p*-type, 4 kΩ·cm
- 300 μm/50 μm



Hit: Previous/Current
Position: Row/Column Address
Timing: Belle II Trigger ID

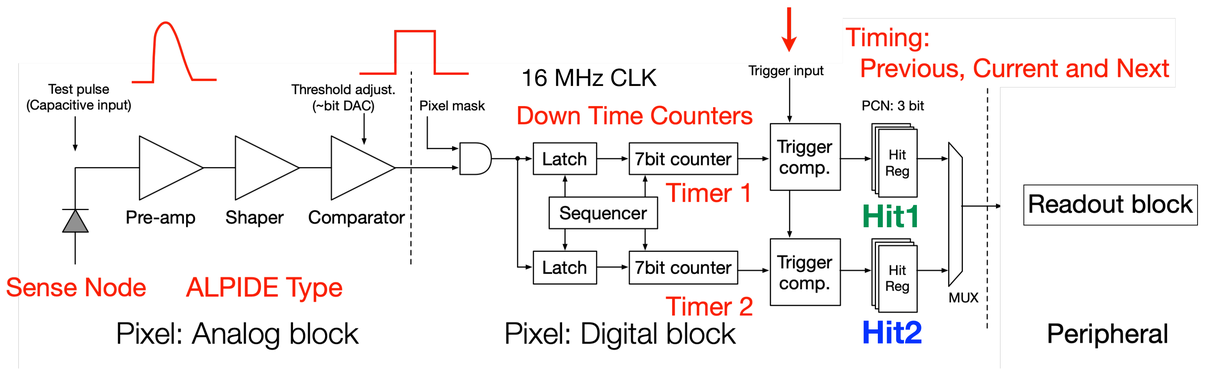
DuTiP Architecture

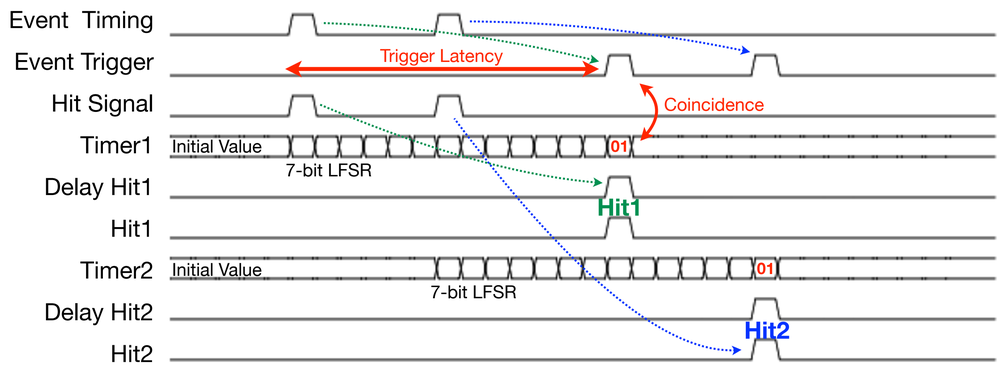
DuTiP (Dual-Timer-Pixel) for Belle II Upgrade

At upgrade SuperKEKB, the background level is 113 MHz/cm², and the Belle II trigger rate is 30 kHz. If the Region of Interests are not provided from the strip detector (SVD) due to higher occupancy, the hit information of the pixel detector (PXD) is lost.

The new pixel detector concept DuTiP has two down time counters in a pixel to store hits and wait for a trigger signal from the Belle II DAQ system. The length of the time of the down time count corresponds to the trigger latency < 10 μs so that the hits associated with the e^+e^- collision are recorded. The hits that did not coincide with the trigger are not recorded in order to suppress the huge background that occurred outside the collision time.

ALPIDE, the MAPS for the ALICE ITS Upgrade
https://doi.org/10.1016/j.nima.2015.09.057





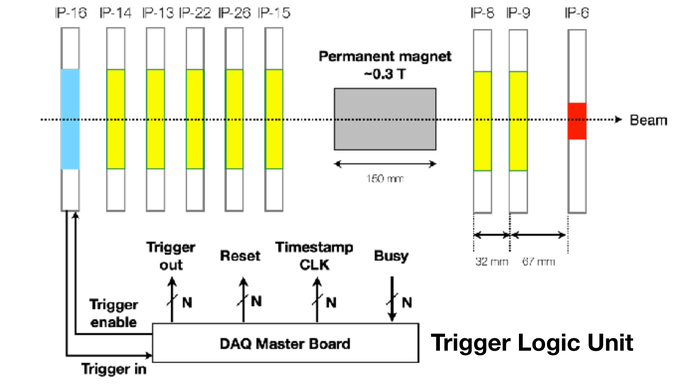
A. Ishikawa *et. al.*, "*New pixel detector concept DuTiP for Belle II upgrade and the ILC with an SOI technology*", NIMA, Volume 978, 164404, 2020

Beam Test

INTPIX4NA SOI Pixel Sensor and Telescope System

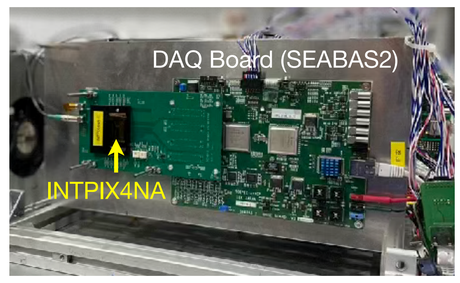
The precision beam tracking system optimizing for GeV order electron beams at the KEK AR Test Beamline.

Sensor for the tracker: INTPIX4NA (SOIPIX) with Region of Interest. **Readout**: Full Frame/Zero Suppression.
Trigger: Scintillator/XRPIX5 (SOIPIX) with Region of Interest.
Permanent Magnet (0.3 T): for Micro Spectrometer. Demountable.



Trigger Logic Unit

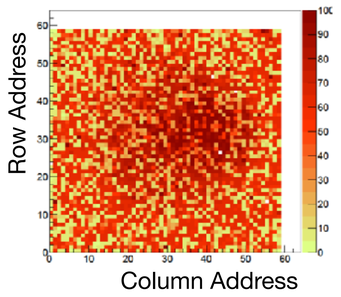
INTXPI4NA Sensor Specification	
Chip Size	15.4 mm × 10.2 mm
Active Area	14.1 mm × 8.7 mm
Pixel Size	17 μm × 17 μm
Pixel Array	512 (row) × 832 (column)
Readout	Analog (on board 12-bit ADC)
Sensor	FZ n-type, 11 kΩ·cm 300 μm thick
INTPIX4NA Position Resolution	1.56 μm (120 GeV proton beam @ FTBF)
SOIPIX Telescope Track Pointing Resolution	3.02 ± 0.04 (5 GeV/*c e*- beam @ KEK AR-TB)



H. Suzuki, *et al.*, PTEP, Volume 2022, Issue 10, 103C01, 2022.
https://doi.org/10.1093/ptep/ptac124

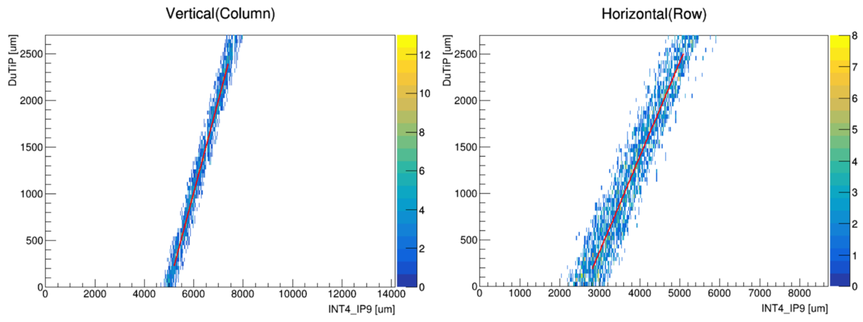
^{90}Sr β-ray Image

Trigger:
Scintillator: 1 cm (W) × 1 cm (L) × 5 mm (H)
Lead collimator (ϕ=1.5 mm)



Hit Correlation between Telescope and DuTiP1

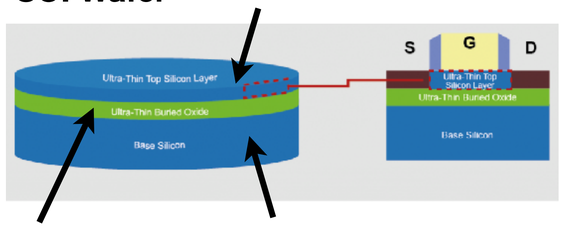
Beam test at KEK AR-TB in 2023
4 GeV/c electron beam, w/o permanent magnet



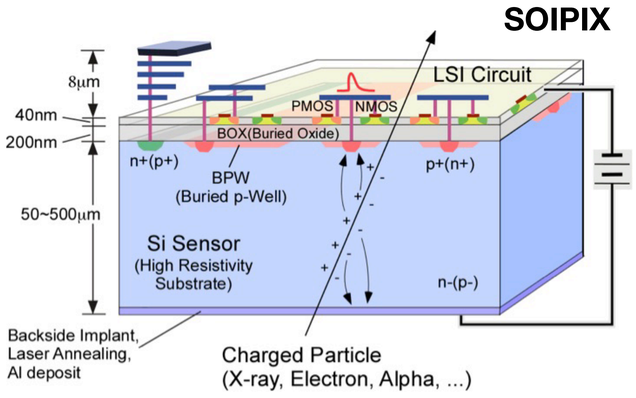
SOI Pixel Sensor

Monolithic Type Pixel Sensor with Silicon-on-Insulator Technology
Technology: 200 nm FD-SOI CMOS process by Lapis Semiconductor Co., Ltd.

SOI Wafer



SOIPIX



- LSI is processed on Buried Oxide layer (BOX)
- Smaller pixel size, complex circuit in pixel
- Low material budget
- Less single event effects (SEE) probability
- Sensor thickness: 50 - 500 μm
- Sensor Resistivity: > 1 kΩ·cm

Sensors

SOFIST for ILC ← Slides/Papers
Position Resolution: ~1.4 μm
Time Resolution: ~1.55 μs
3D Stacking Technology

XRPIX for X-ray astronomy
Event-Driven Readout
Energy Resolution: 230 eV @ 6.4 keV (FWHM) at 25 °C
Compton Camera

etc.

Summary

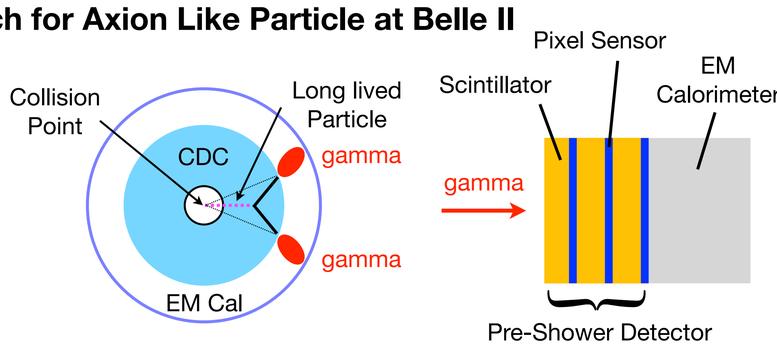
We are developing a new pixel sensor for the Belle II upgrade around 2030, which is called DuTiP (Dual Timer Pixel). Prototype sensor DuTiP1 has successfully obtained ^{90}Sr β-ray imaging and the hit correlation between the telescope at beam test.

We will perform a beam test at KEK AR-TB with a GeV order electron beam to evaluate hit detection efficiency and position resolution with our SOI telescope system in 2024.

DuTiP architecture with minor modifications can also be employed for layers 7 and 8 of the tracker detector for the ILC experiment.

Pre-Shower Detector for Search for Axion Like Particle at Belle II

To increase the sensitivity for ALP decay into gamma pairs, we propose to place the pre-shower detector just before the EM Cal to reconstruct the direction of the gamma. The DuTiP specification is suitable for the pixel sensor of the pre-shower detector. Pixel sensors are effective in identifying and reducing beam backgrounds.



Acknowledge

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SOIPIX Silicon-On-Insulator Pixel Detector Project