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The Belle II Pixel Detector DAQ

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Overview

Belle II at SuperKEKB

- 2 Vertex detectors
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 - Belle II VXD DAQ
- Online Selection Nodes (ONSEN)
- Test beam setup at DESY
 - 7 First results from test beam

Belle II Experiment at SuperKEKB



Aerial view of KEK and SuperKEKB

Belle II experiment

- Upgrade of the Belle experiment at KEK in Tsukuba, Japan
- Asymmetric beam energies of 4 GeV (e^+) and 7 GeV (e^-), $\sqrt{s} = 10.58$ GeV
- Peak luminosity L = 8 · 10³⁵ cm⁻² s⁻¹ (40 times previous experiment)
- Average trigger rate of 30 kHz

Belle II Vertex Detectors (VXD)



Picture by HEPHY, Vienna

Pixel Detector (PXD)



- Innermost detector (r = 14 22 mm) around beam pipe (r = 12.5 mm outer radius)
- DEPFET (DEPleted Field Effect Transistor) technology
- Pixel size 50 × 55 60 μm² (inner layer) and 50 × 70 85 μm² (outer layer)
- Thickness only 75 μm
- 40 half ladder in two layers with 768 \times 250 pixels per half ladder; in total \sim 8 million

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Silicon Vertex Detector (SVD)



Picture by HEPHY, Vienna

- Second inner detector
- Double sided silicon strip detector
- 4 layers; outer 3 layers tilted at forward end
- Radius: r = 38 140 mm

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Concept for Region of Interests (ROI)



Inner and outer layer MC background data with Touschek effect

- Expected maximum occupancy of 3% dominated by background (synchrotron radiation, scattering of the beam on residual gas, Touschek scattering, radiative Bhabha scattering (e⁺e⁻ → e⁺e⁻γ), electron-positron pair production (e⁺e⁻ → e⁺e⁻e⁺e⁻))
- Total data rate >20 GB/s after zero suppression
- Data reduction needed for event builder and data storage

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Concept for Region of Interests (ROI)



Inner layer Touschek background data with one example hit and ROI

Idea:

- Calculating regions of interest (ROI) by extrapolating particle tracks from outer detectors
- Two independent tracking systems with different algorithms

Sources for ROIs





Illustrations by Michael Schnell (University of Bonn)

High Level Trigger (HLT)

- Uses SVD and outer detector data
- Based on cellular automaton on PC farm
- Event rejection with software trigger
- Calculation time up to 5 s

Data Concentrator (DatCon)

- Uses SVD data only
- Fast Hough transformation
- FPGA based hardware
- Calculation time up to 10 µs

Both systems extrapolate tracks to PXD layer and send ROIs to ONSEN

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Belle II VXD DAQ



Diagram of the Belle II VXD DAQ for setup at KEK

Compute Node (CN) rev. 3



AMC daughter board of CN rev. 3



Carrier board with 4 AMC daughter boards

Main hardware for ONSEN and DatCon

- Developed in cooperation between IHEP Beijing and University Gießen
- AMC daughter board of CN rev. 3
- Xilinx Virtex-5 FX70T
- Equipped with:
 - 2 × 2 GB RAM
 - 4 × 6.25 Gb/s optical links
 - GBit Ethernet
- An additional ATCA based carrier board with following features is under development:
 - Carries four AMC cards
 - Supplies direct highspeed interconnection between all four AMC
 - Connects all AMC cards to the full mesh ATCA backplane

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PXD - Readout



DHH at the test setup at DESY



Diagram of PXD-Readout with DHH and DHHC

- Data Hybrid Handler (DHH):
 - Slow control of FE-ASICs and DHH via IPBUS
 - Clock and trigger distribution
 - Readout out of PXD
 - Zero suppression
 - Clustering with pipelined neural network cluster processing algorithm
 - Data output via high speed optical link
- Data Hybrid Handler Controller (DHHC):
 - Slow control interface using IPBUS hub
 - Receiving data from 5 DHH
 - Mixed inner and outer layer
 - Load balancing
 - All data of one event combined together
 - Data output to 4 ONSEN
- Implemented on FPGA based hardware

ONSEN - ROI Merger Node



- Receive ROIs from DatCon via high speed serial link
- DatCon ROIs arrive after up to 10 µs and are stored in memory
- Receive ROIs unordered from HLT via GBit Ethernet (up to 5 s later)
- As soon as HLT ROIs arrive, corresponding DatCon ROIs of same event are read back from memory
- HLT and DatCon ROIs are merged
- Merged ROIs sent to Selection Node
- Implemented on a CN V.3

ONSEN - ROI Selector Node



- Receive pixel data from PXD readout system via high speed serial link
- Pixel data arrive first and are stored in memory
- Receive unordered ROIs from Merger Node with delay (up to 5 s)
- Corresponding pixels of same event are read back from memory
- Pixel data reduction by ROI selection: Discard pixel if not inside at least one ROI
- Untriggered data will be rejected
- Reduced data are sent out to event builder

ROI Selection Core



- Binary pixel data are decoded for further ROI selection.
- ROI selection is processed for all ROIs of one half ladder in parallel
- Implemented in FPGA logic

DESY Test Beam Setup



- Bremsstrahlung γ beam from synchrotron DESY II
- Metal plate converter
- Momentum and rate selection with dipole magnet and collimator

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Detector Setup for Test Beam at DESY



Illustration of the simplified detector setup for the test beam at DESY



front: beam telescope; behind: SVD

- Simplified setup for first test with full DAQ chain
 - PXD: one sensor
 - SVD: four sensors
- Additional beam telescope detectors (pixel detectors) provided by DESY for triggering and correllation studies

Pocket-ONSEN System



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Belle II VXD DAQ System at DESY



Diagram of the Belle II VXD DAQ at the test setup at DESY in January 2014

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Hitmap before ROI selection

- Full DAQ chain established
- More than 20 million events processed with full chain
- Full data stream recording for some runs to verify ROI selection
 - 4 GeV beam
 - 1.2 · 10⁶ events
 - Active area on PXD 480 × 128 pixel
 - 4.8 · 10⁸ hits
- Picture shows one example run with
 - 186 000 events excluding full matrix ROIs
 - Average occupancy before reduction ~ 0.80%

Data after ROI Selection



Hitmap after ROI selection

- Reduced data by ROI selection
- Real ROIs calculated by tracking algorithms on HLT and DatCon
- Additional full matrix ROIs for checking
- Picture shows same example run with
 - 186 000 events excluding full matrix ROIs
 - Average reduced occupancy ~ 0.12%
 - Average reduction rate ~ 6.9

Verification of ROI Selection



to illustrate ROI selection

- Stable runs checked with full data recording mode
- Total 1.2 · 10⁶ events with 4.8 · 10⁸ hits

	PXD hit	PXD hit
	inside ROI	outside ROI
Hit in	all selected	not observed
output data	\checkmark	\checkmark
Hit not in	not observed	all rejected
output data	\checkmark	\checkmark

NO ROI selection errors observed in 1.2 · 10⁶ events

- For the Belle II inner pixel detector a total data rate of >20 GB/s after zero suppression expected
- Data reduction with a region of interest selection
- Regions calculated by two separate systems using different tracking algorithms
- Region of interest selection in hardware on FPGA based Compute Nodes
- Selection algorithm parallelized in number of ROIs
- First beam test of combined VXD and full DAQ at DESY
 - More than 20 million events processed with full chain
 - 1.2 million events with 480 million hits processed with full recording mode to check ROI selection
 - No ROI selection errors observed in 1.2 million events

Thank you for your attention!