PIXEL 2014

1-5 September 2014, Niagara Falls(Canada)

The DEPFET pixel detector for the Belle II experiment at SuperKEKB

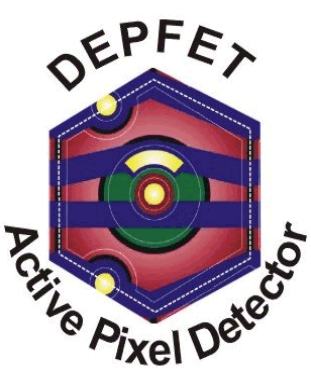
Peter Kodyš, *On behalf of the DEPFET Collaboration*

Charles University Prague

15:00 - 15:25, Laci ANDRICEK *(MPG Semiconductor Lab):*
DEPFET Based Ultra-light All-silicon Modules for Vertexing at a Future Linear Collider

16:20 - 16:45, Luigi LI GIOI *(Max-Planck-Institut fuer Physik):*
Physics Benchmarks for the Belle II Pixel Detector

The DEPFET Collaboration



Charles University
Prague

List is not complete

Belle II

Belle II - a particle physics experiment at the site of the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan.

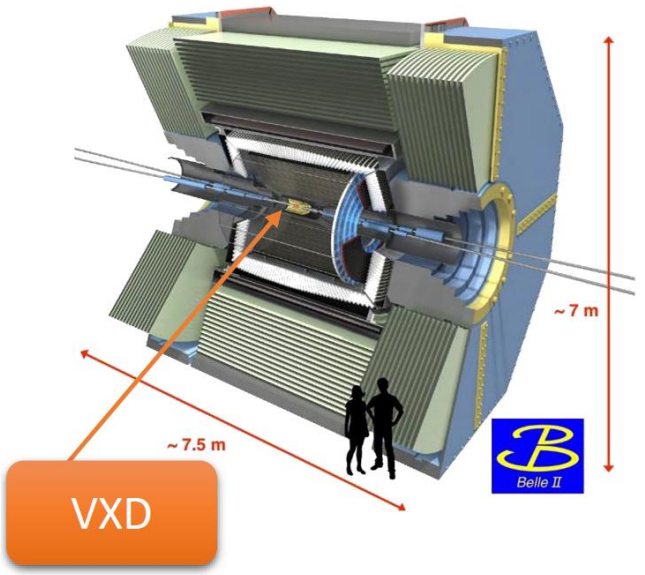
Expected to take its first physics data in 2016.

Luminosity 8 x 10^{35} cm^2s^{-1} of the SuperKEKB accelerator, an asymmetric (4 GeV, 7 GeV) e^+e^- collider .

The radiation dose expected in the inner region of the detector is around 2 Mrad/yr.

The experiment requires excellent vertexing performance.

Highly granular pixel detectors are needed in the innermost layers, featuring fast readout and minimum material budget to reduce the impact of multiple Coulomb scattering on measurement.

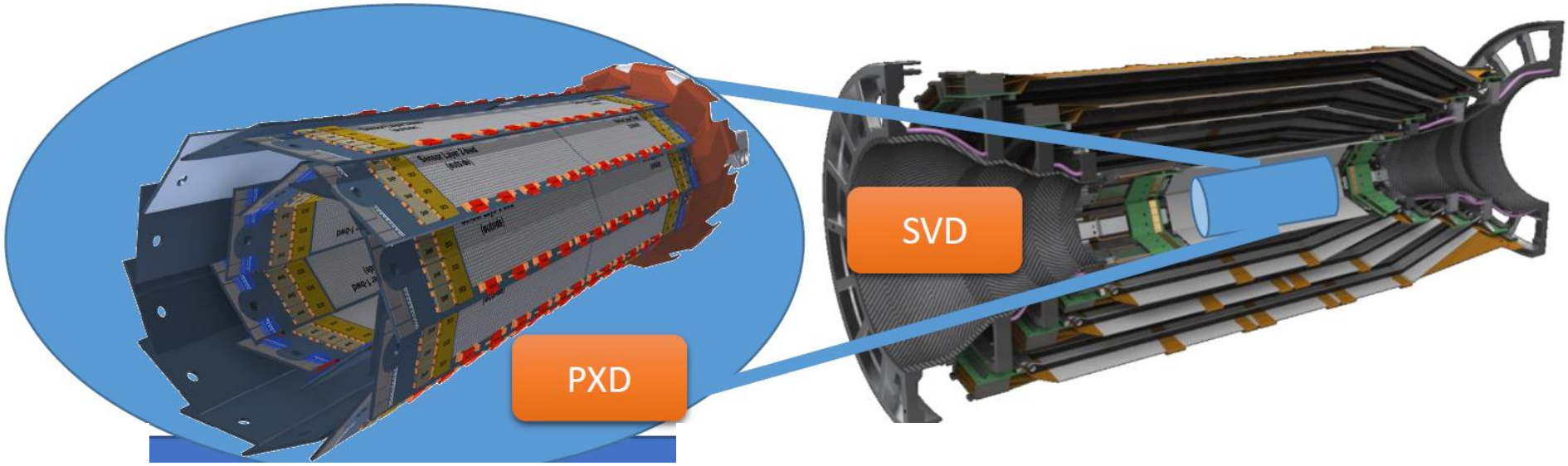


More details about physics goals:
16:20 - 16:45, Luigi LI GIOI

DEPFET sensors at Belle II

The DEPFET technology of active pixel sensors is among the frontier detector concepts for high energy physics at high luminosities.

It has been chosen for the innermost 2 layers (PXD) of the Belle II vertex (VXD) detector, together with four layers of strip detectors (SVD).



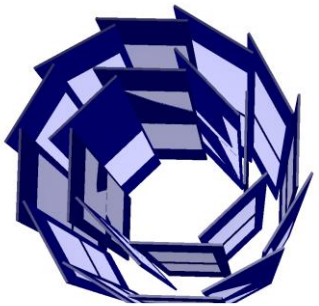
More details about DEPFET technology:
15:00 - 15:25, Laci ANDRICEK

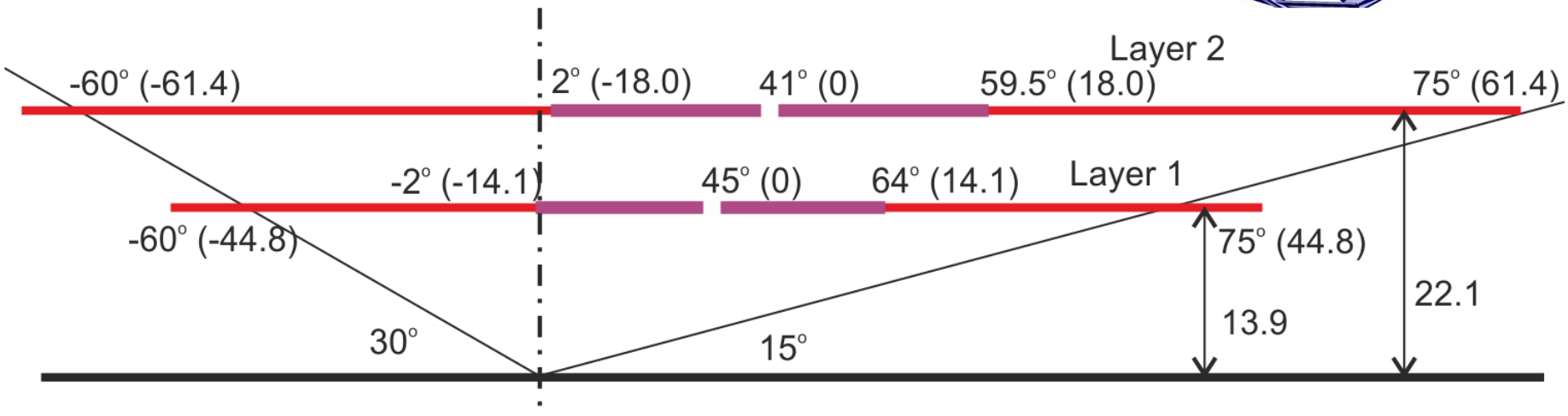
DEPFET sensors at Belle II

The in-pixel amplification of the DEPFET technology allows for 75 micron thin low-noise sensors which do not require additional support or cooling structures in the active region of the detector. Low material budget up to a maximum of ~0.2 % X_0 per layer.

The acceptance of the detector must cover the range 17°-155° in azimuth angle. The detector will be read continuously with a frame time of 20 µs keeping the occupancy below 3%.

	Inner Layer	Outer Layer
Modules	8	12
Thickness	75 microns	75 microns
Length	90 mm	123 mm
Sensitive	44.8 x 12.5 mm^2	61.44 x 12.5 mm^2
Pixel Size	55,60 x 50 μm^2	70,85 x 50 μm^2
Pixels	3.072 x 106	4.608 x 106
Frame Rate	50 kHz	50 kHz



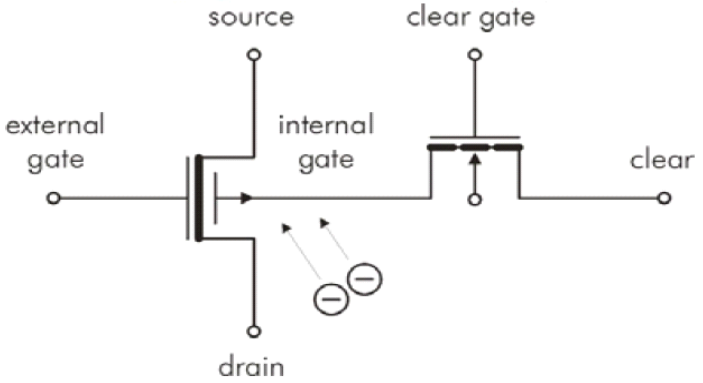


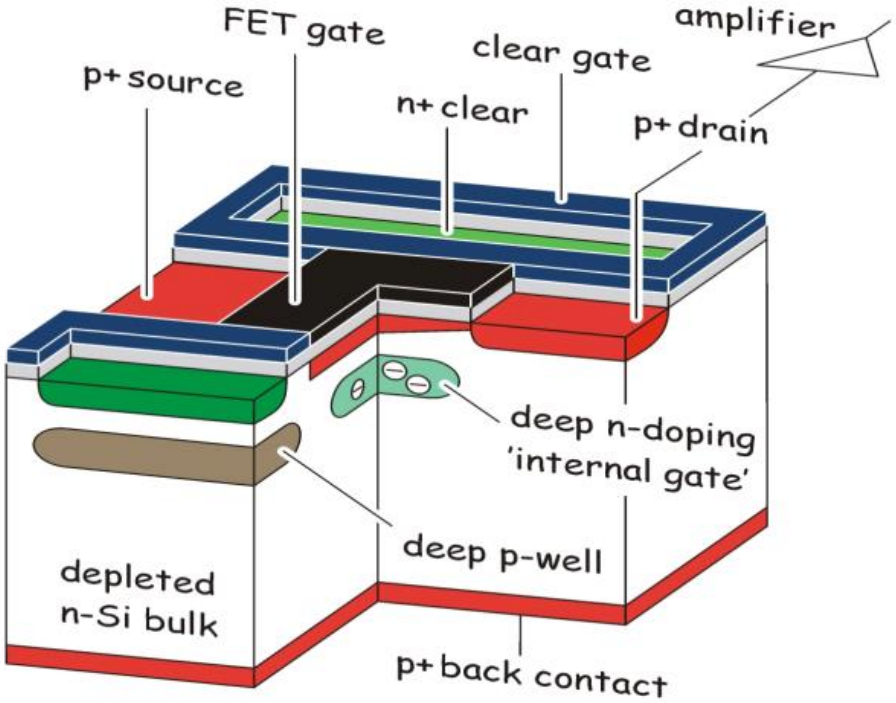
DEPFET sensors at Belle II

Spatial point resolutions below 10 μm are expected.

A unique gated data acquisition mode allows to suspend data readout for time periods with high noise occupancy; over this period, acquired charge is frozen and kept for later readout.

The front end electronics and the data acquisition schemes supporting the integration into Belle II are finalized and the two-layer pixel vertex detector (PXD) will be ready for data acquisition from its 7.6 million pixels in 2015.

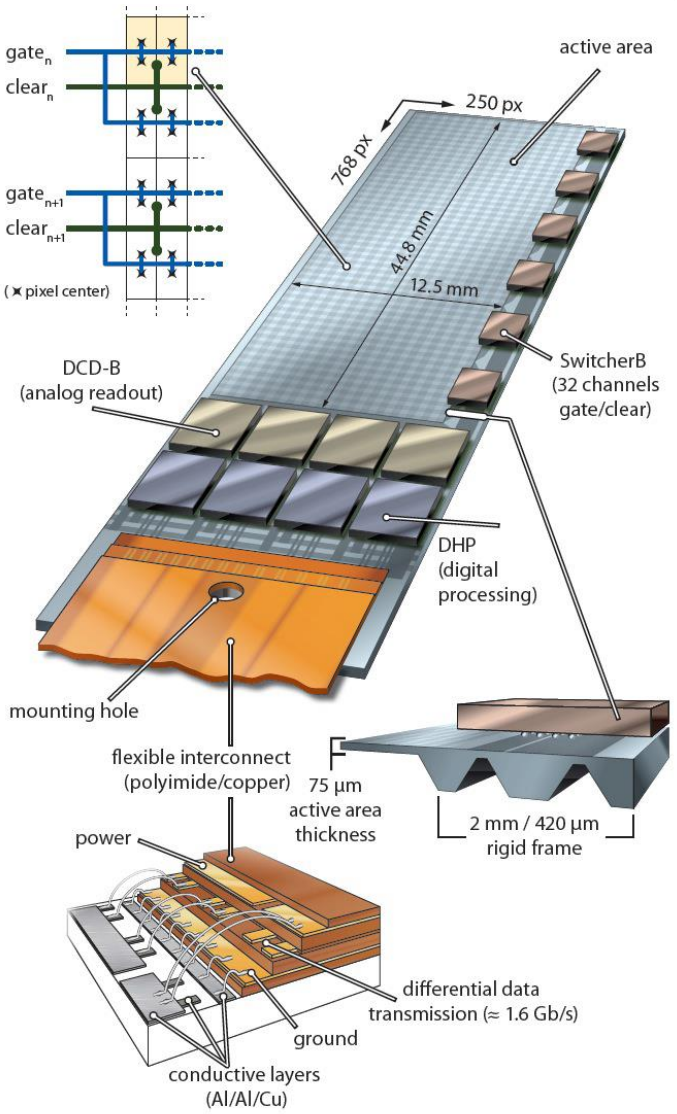




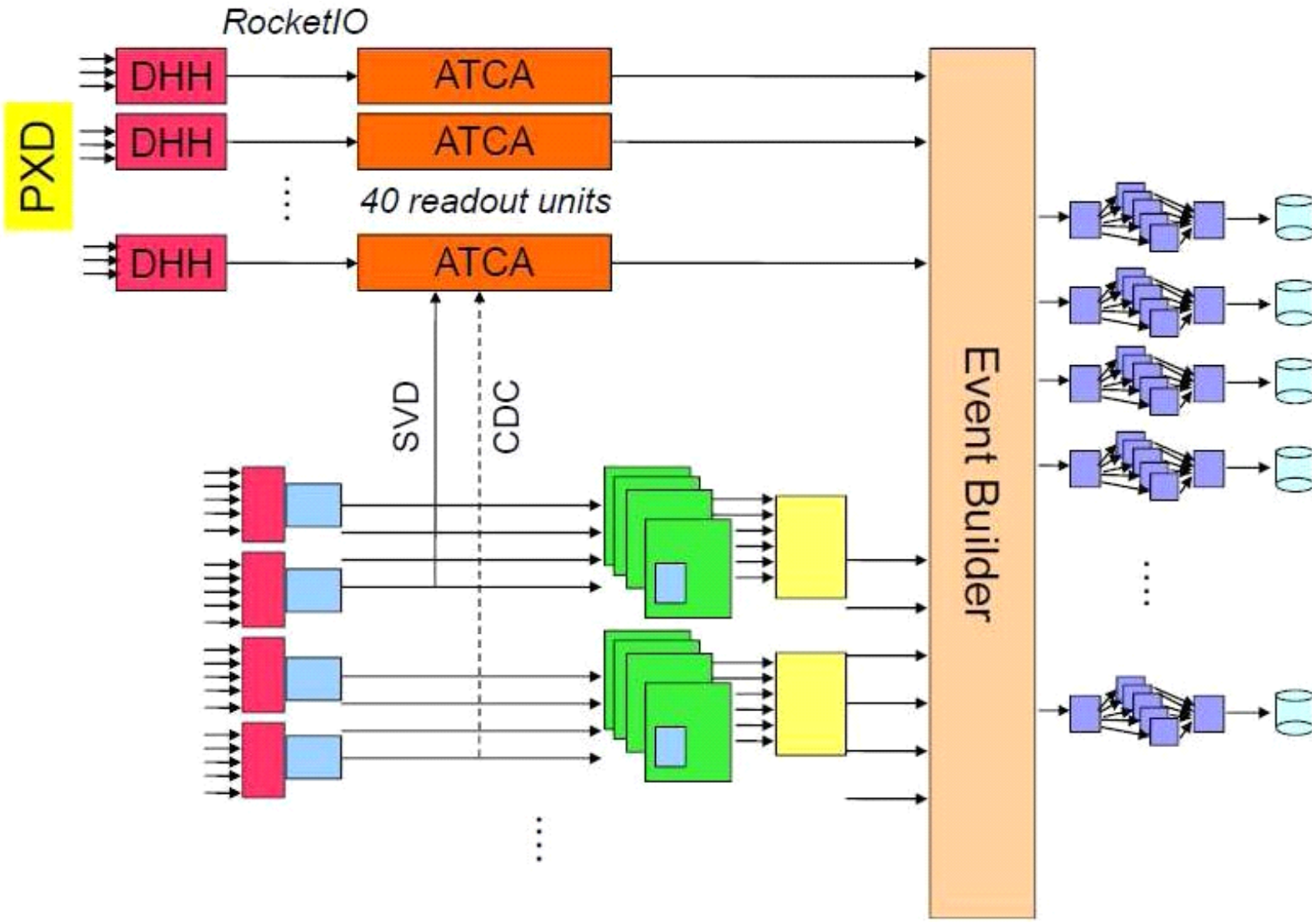
DEPFET data acquisition

Belle II PXD produces 180 GB/s of raw data:
40 PXD half ladders with 250 x 768 pixels each and 8 x 10^6 pixels in total, expected occupancy up to 3 %, trigger rate of 30 kHz.
Data volume reduced by a factor of 10.

PXD module readout: Gate and Clear Switchers organize the readout sequence, DCD (Drain Current Digitizer) are readout chips and A/D converters, DHP (Digital Handling Processor) chips provide first-stage pre-processing and data reduction (pedestals, CMN correction, zero suppression, compression algorithm). From DHP to DHH (Data Handling Hybrid) 15 m line: kapton converted to twisted-pair in a passive patch panel, DHHs via optical links to ATCA Compute Nodes, ATCA CNs reduce data based on triggers, ATCA CNs compute fast tracking using SVD data to quickly identify regions of interest in the PXD.



DEPFET data acquisition



Data acquisition scheme of pixel detectors at Belle II

DEPFET hit position reconstruction

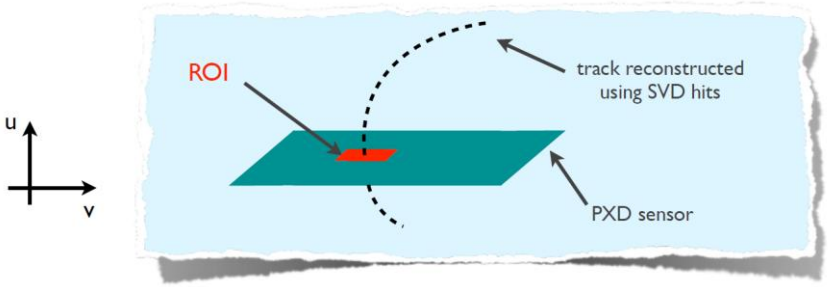
The point where a particle track crosses a sensor is reconstructed using pixel charges in a cluster, RMS pixel noises and clustering thresholds. These data are used to estimate hit position and its uncertainty. Tracking can provide a further improvement in accuracy and precision: when a hypothesis about a track in the sensor is available, information on incidence angle, particle type, etc. can be used to improve the estimates. Several methods are available to improve hit position reconstruction in the Belle II vertex detector:

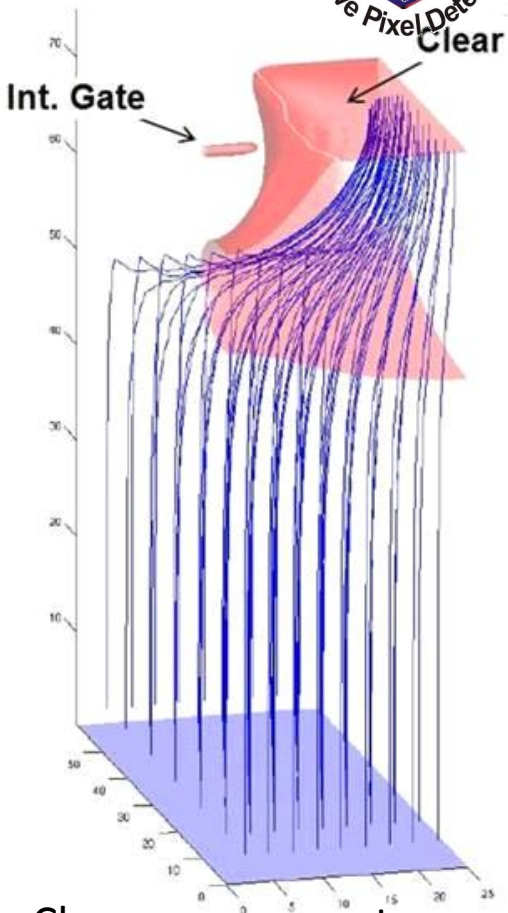
1) Sensor design provide efficient charge transport from full bulk to internal gate of DEPFET.

2) Ladders are tilted to increase charge sharing between pixels in R-phi coordinate.

3) Data reduction based on regions of interest (ROIs) based on online track extrapolation from four strip layers to suppress electronic noise and beam background.

4) Correction of position bias of reconstructed cluster position for non-symmetric small clusters.

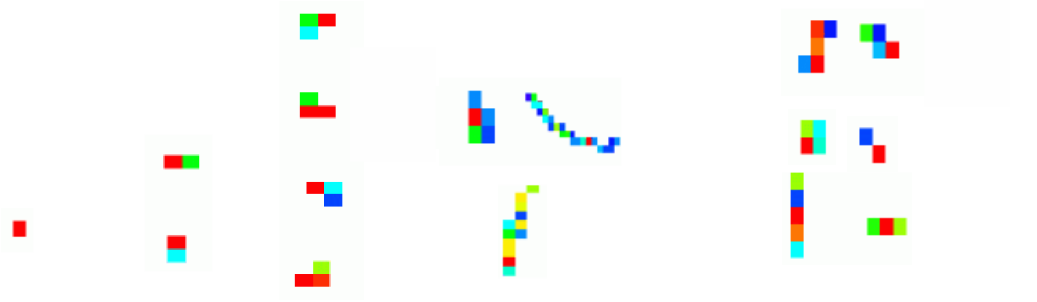




Charge movement simulation in DEPFET pixel design, situation for “gated mode” regime (Richter, MPI)

Using cluster shape to improve of hit position

- Full Geant4 simulation in the basf2 (software framework for the Belle II)
- There are five basic types of clusters for four different pitch in v direction: single, double and triple pixel clusters, rest of symmetrical and nonsymmetrical clusters.
- In Belle II geometry for particles shot of 0.05 – 3.0 GeV electrons and positrons in uniformly distributed directions from the interaction point and in range phi 17 – 150 deg
- In Belle II: 25 % form single-pixel clusters, 15 % form 2-pixel clusters along the R-phi coordinate, and 26 % along the z-coordinate. 12 % form non-symmetric "L"-shaped three-pixel clusters, 16 % form larger non-symmetrical clusters, and rest 6 % form symmetrical clusters (like 2x2 clusters).



1-pixel 2-pixels 3-pixels non-symmetrical symmetrical

Categorization of cluster shapes

Using cluster shape to improve of hit position

- For single-pixel clusters, the obvious hit position estimate is the center of the pixel.

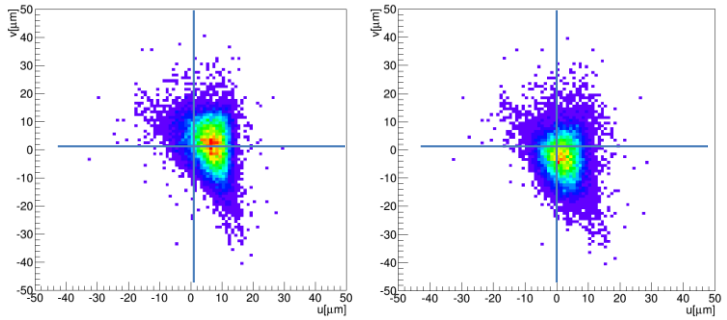
- For larger clusters, hit position is estimated separately for the u- and v-coordinates, using center-of-gravity estimates for clusters size 2 and the analog head-tail method for size 3 and more. Generally, the average resolution is best for small clusters of size 2 and 3.

- For single-pixel clusters, hit position uncertainty is given by the area where a given energy deposition is mostly contained within the single pixel - it therefore depends on pixel charge and clustering threshold.

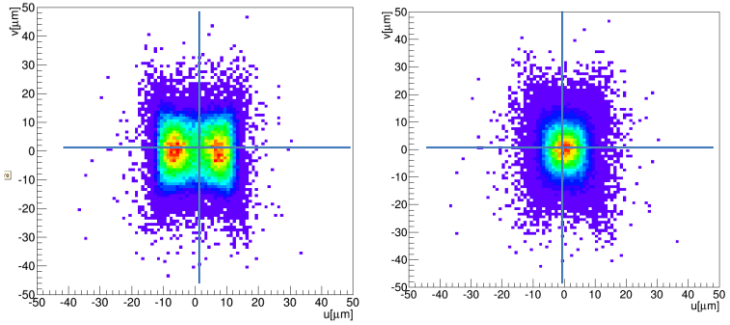
- With particles arriving at different (and unknown) directions, the standard eta-correction algorithms are not usable. Therefore, simple bias-correcting methods for center-of-gravity and head-tail estimates are desirable, that would only use measurable quantities to correct for bias.

Using cluster shape to improve of hit position

- The 3-pixel “L”-shaped clusters are the simplest and most common case where such a bias correction would be desirable.
- For these clusters, the center-of-gravity estimate is biased by about 10% of pixel size, comparable to the typical RMS error of the position estimate. Therefore, correction of the bias highly desirable.
- We show that adding a fixed (pixel noise dependent) charge to the pixel with zero signal in the 2x2 matrix can significantly improve the center-of-gravity estimate of hit position for such clusters. Adding the fourth pixel with the signal of 1.3 x ENC improved position RMS error from 7.4 microns to 4.7 microns in R-phi, and reduced position from 5 to 2 microns.

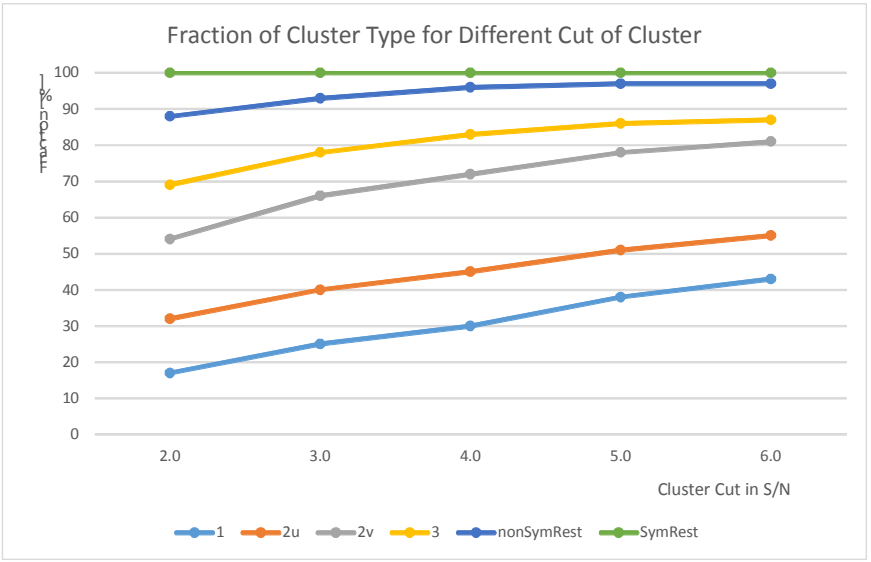


Residual plot of “L” shape in one orientation before (left) and after (right) correction



Residual plot of “L” shape in all orientation before (left) and after (right) correction

Using cluster shape to improve of hit position



Fractions of cluster shape types for different clustering cuts.

Table for hit position bias reconstructed from "L"-shaped clusters before and after correction for different clustering cuts

Cluster cut [ENC]	2	3	4	5	6
No correction R-phi	5.8	5.7	5.6	5.6	5.5
No correction Z	4.0	3.4	3.1	2.9	3.0
Correction R-phi	1.9	2.0	2.0	1.8	
Correction Z	-0.6	-1.3	-1.4	-1.9	

clustering cuts 3xENC (default)

Cluster cut [ENC]	2	3	4	5	6
No correction R-phi	7.6	7.4	7.4	7.4	7.5
No correction Z	7.3	7.6	8.0	9.2	10.1
Correction R-phi	4.9	4.7	4.7	4.7	
Correction Z	6.6	7.4	8.0	9.6	

Table for RMS error reconstructed from "L"-shaped clusters before and after correction for different clustering cuts

Conclusion

- The exciting Belle II experiment is under construction at KEK.
- The goal of the first physics run in 2016 seems realistic and the pixel detector will be ready with all specifications met.
- Improvement of hit position reconstruction is important for vertexing performance and new physics searches.
- Realistic estimates of hit position uncertainties and correction of reconstruction bias is equally important.
- We have shown that the most important reconstruction biases in small “L”-shaped clusters can be easily corrected by adding a constant charge in the missing pixel.
- This efficiently corrects for center-of-gravity bias and improves the distribution of residuals.
- Impact on physics analyses is under study.

Thank you for attention