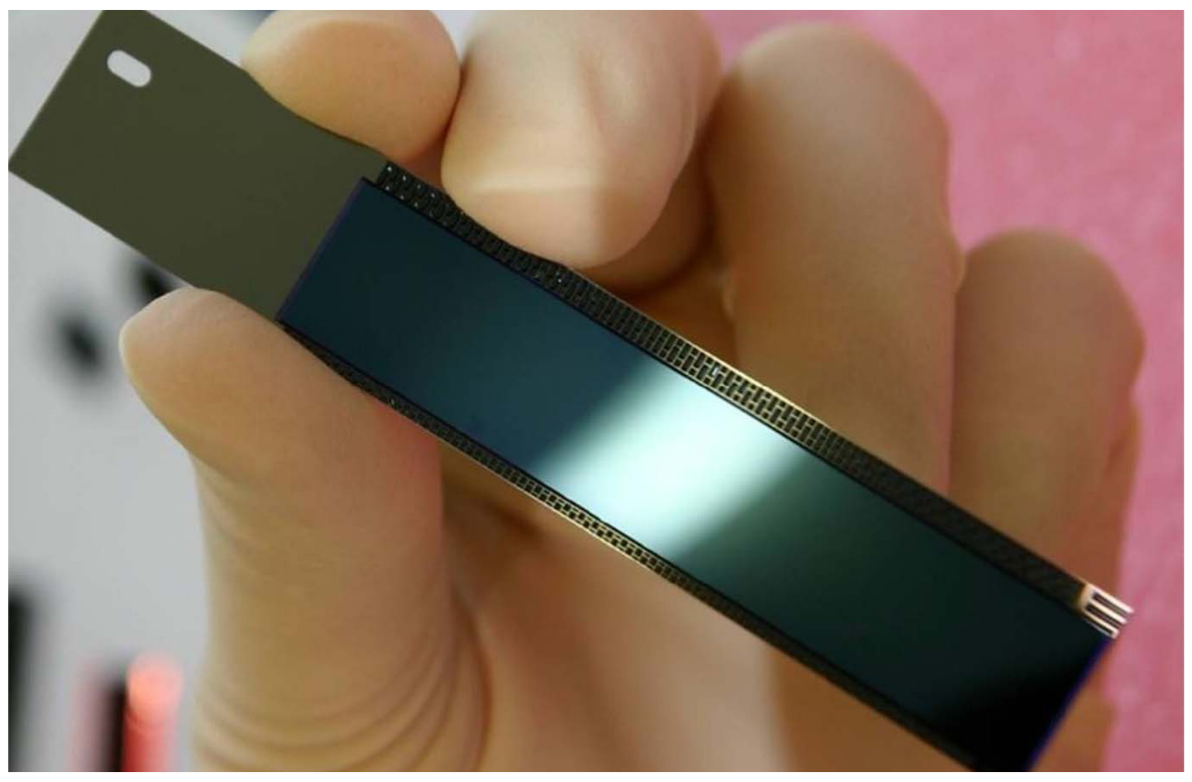
Ultra-thin fully depleted DEPFET active pixel sensors for future e+/e- collider

C. Koffmane on behalf of DEPFET collaboration

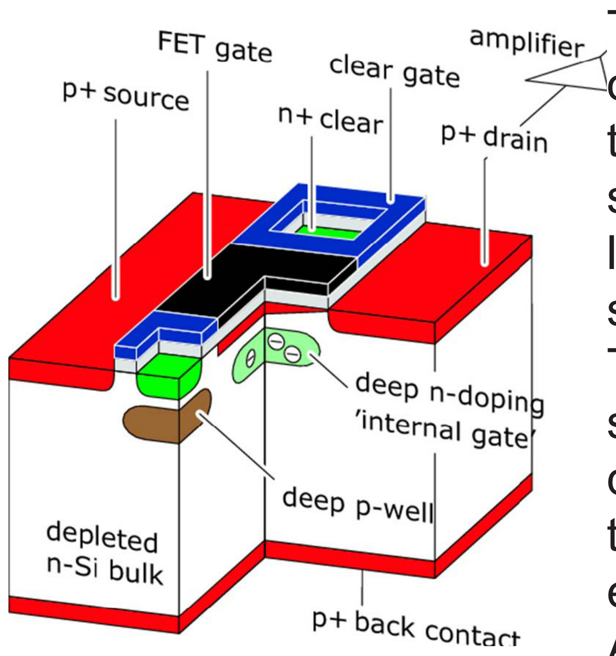
Max-Planck-Institut für Physik, München, Germany
MPI Halbleiterlabor, München, Germany
TU Berlin, Berlin, Germany

Prototype DEPFET active pixel sensors designed for the vertex detector at the Belle-II experiment at KEK, Japan, and for experiments at a future linear collider have been produced on thin silicon-on-insulator (SOI) material. The DEPFET (DEpleted P-channel FET) is a field effect transistor with an additional implantation beneath the transistor channel integrated on a fully depleted substrate. The inherent property of combined signal detection and signal amplification of the DEPFET allows the production of very thin sensors with an excellent signal-to-noise ratio for minimum ionizing particles. Combining a highly specialized MOS process which includes two poly-silicon and three metal layers on a fully depleted bulk with MEMS technology makes it possible to build thin wafer-scale (150 mm wafers) DEPFET active pixel sensors on a self-supporting all-silicon module.



The DEPFET Pixel

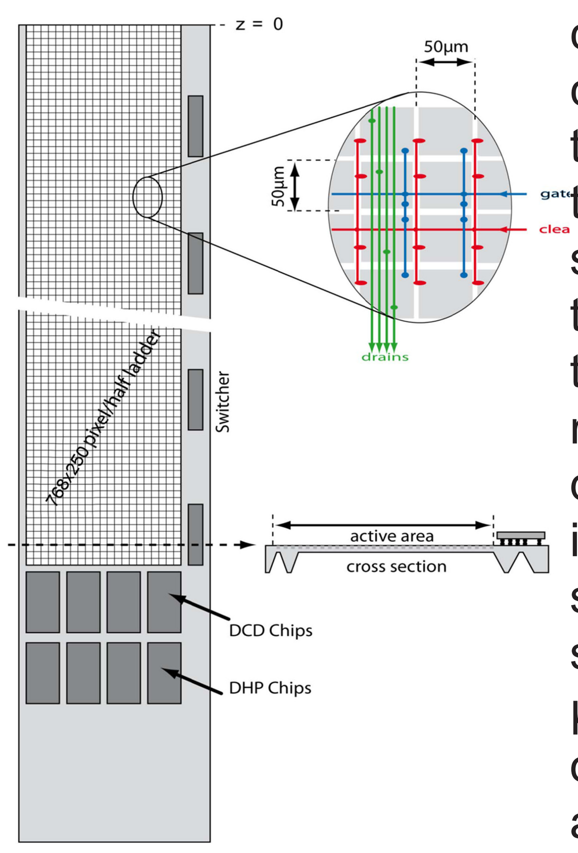
The DEPFET is the basis element of the PXD. It implements a MOS field effect transistor on a sidewards depleted silicon bulk. The transistor is located on top of a low-doped n-type semiconductor substrate which becomes fully depleted by applying a sufficiently high voltage. The depleted bulk is the sensitive volume of the detector in which electron-hole pairs are created by incident radiation. A particular doping forms a potential minimum below the transistor channel. While holes drift to the negatively biased backplane the electrons are collected in the potential minimum. The accumulated charge changes the potential and thus modulates the FET current. After the signal is read-out, the charge is removed via a clear contact. The advantages of this technology are a low power consumption, fast charge collection, large signal, and low noise.



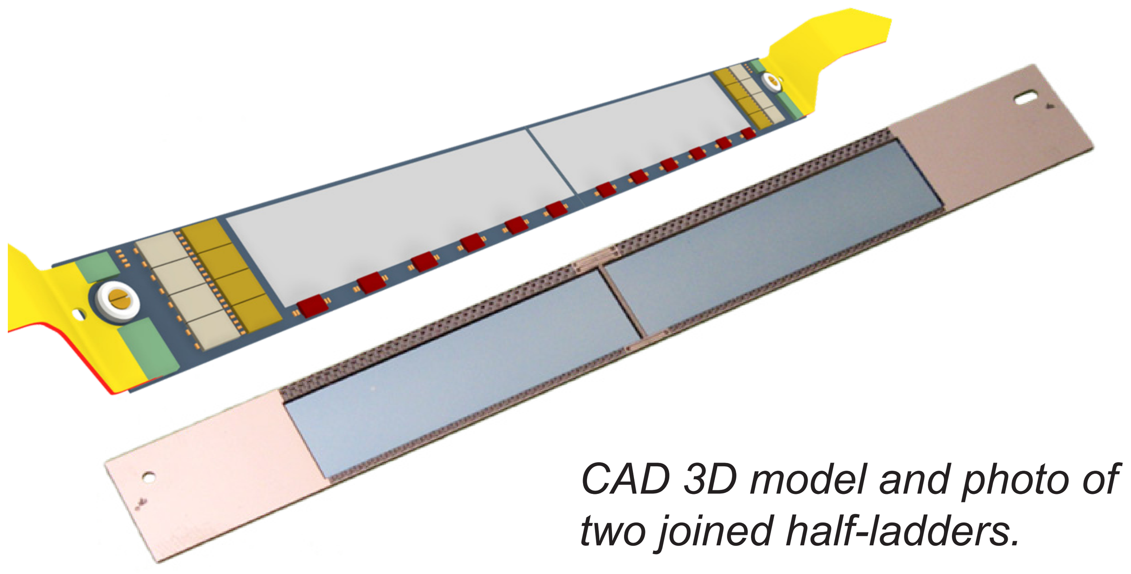
Schematic view of the DEPFET pixel.

All Silicon Module

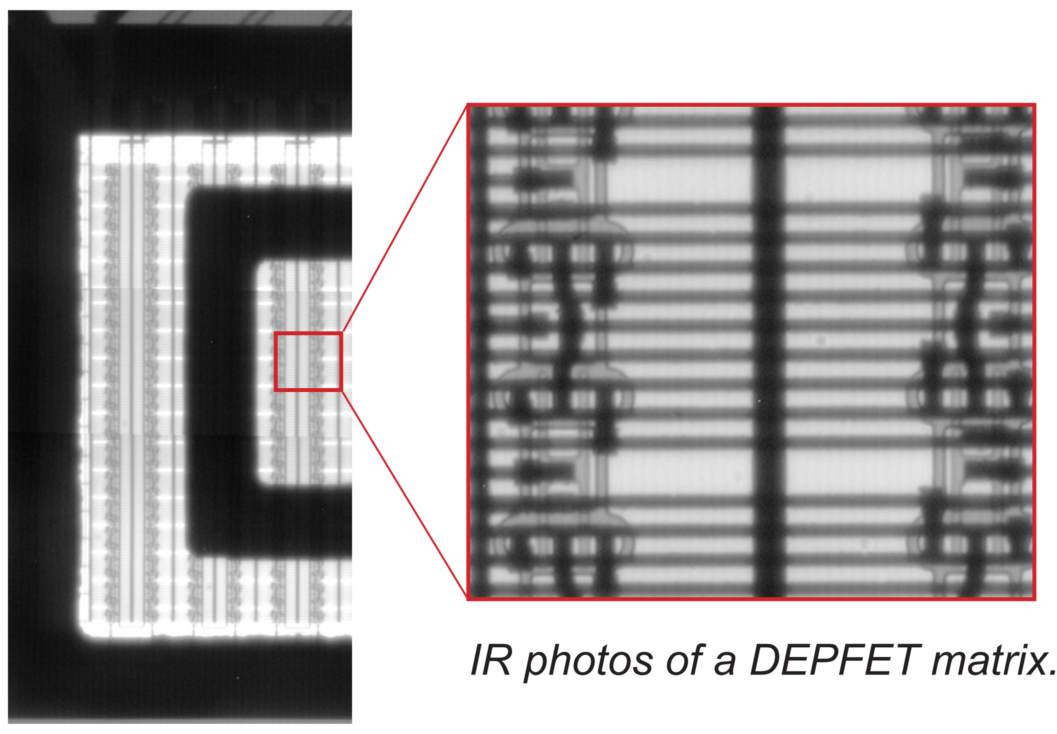
The DEPFET pixels are arranged in arrays of 768 x 250 pixels called half-ladders. The sensitive area is about 5 cm by 1.25 cm. The excellent signal to noise ratio allows for very thin detectors, reducing multiple scattering for low momentum particles. A thinning technology, based on direct wafer bonding and deep anisotropic etching, is used to produce self-supporting sensors with a sensitive layer of only 75 µm thickness. By thinning only the sensitive area an integrated support frame is created which allows safe handling and serves as substrate for the auxiliary control and read-out ASICs. As shown in the above figure two half-ladders are joined together to a full ladder by gluing ceramic inserts into small grooves etched in the support frame.



Schematic view of the a half-ladder.



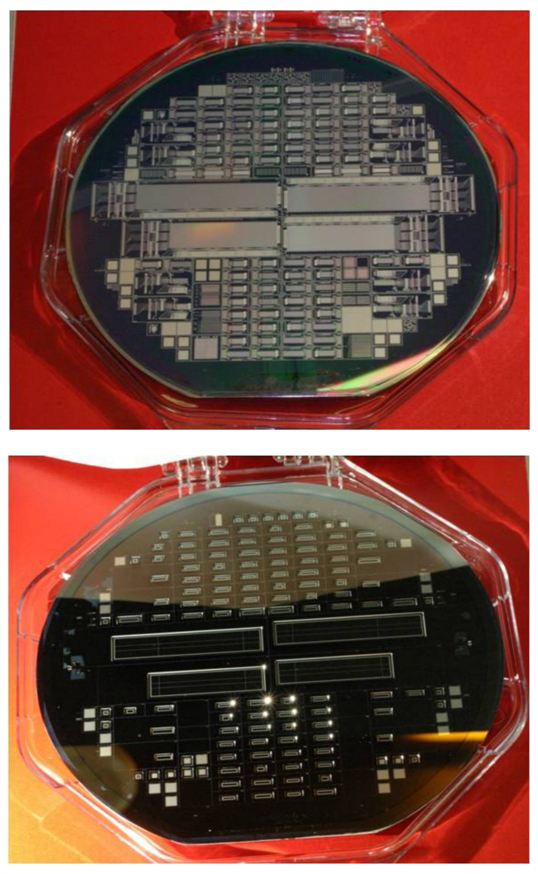
CAD 3D model and photo of two joined half-ladders.



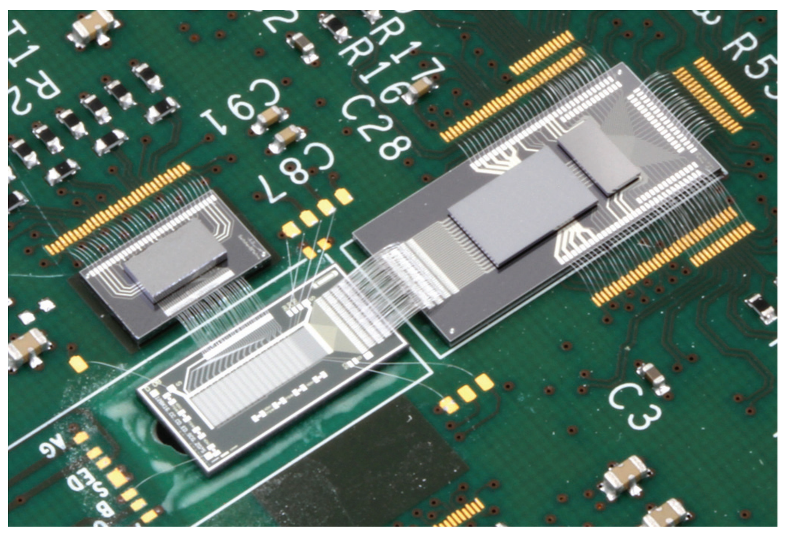
IR photos of a DEPFET matrix.

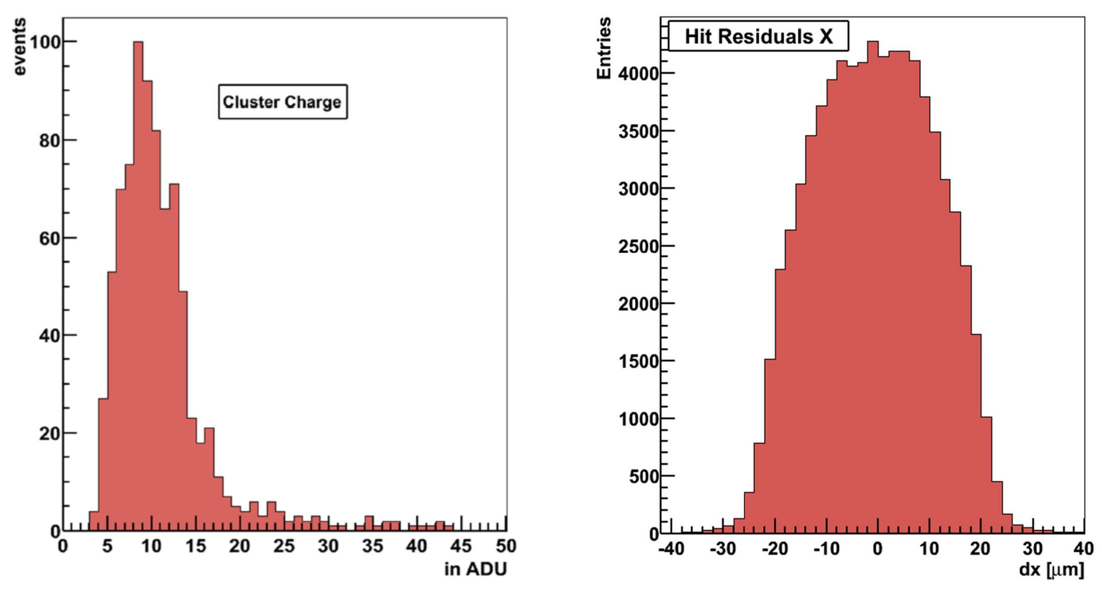
Tests of DEPFET sensors

Prototypes of 50 µm thin DEPFET sensors have been produced on 150 mm wafers and are tested to verify that the pixels perform as expected. Laser scans and radioactive source measurements are used to determine the operation point of the DEPFET pixel and beam tests at CERN and DESY have been performed to investigate its resolution. Due to charge sharing between several pixels, the hit resolution is better than expected from the actual pixel size alone. The observed signal to noise ratio is ~40 and confirms the prediction from detailed simulations. The DEPFET pixels are read out by a series of specially designed ASIC chips. The ASICs (SwitcherB and DCDB) switch on the matrix row by row and digitize the drain currents.



150mm wafer - top and bottom side - with prototypes for Belle II and ILC.





Left: Photograph of DEPFET matrix, control and read-out ASIC. Down: Preliminary beam test results: left plot signal distribution and right plot hit resolution.

Expected Physics Performance of the PXD at Belle II

The Belle II collaboration will search for new CP violating effects by studying the behavior of particles and antiparticles as a function of their decay position with very high statistics. The purpose of the PXD is to precisely measure the decay vertices of the B-mesons recorded by the Belle II experiment. Due to the PXD, the expected vertex resolution will improve by roughly a factor of two compared to Belle, as shown in the figure below.