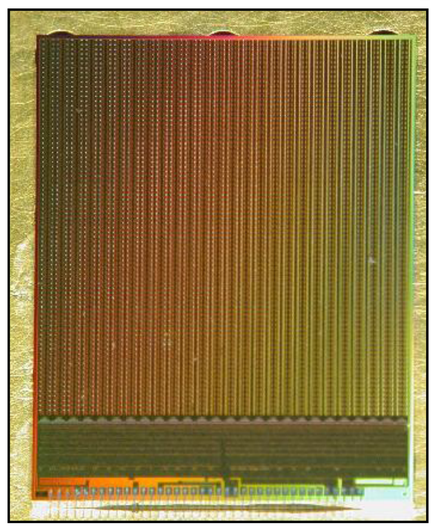
University of Tennessee, Rutgers University, HEPHY-Vienna, Vanderbilt University, Princeton University, CERN

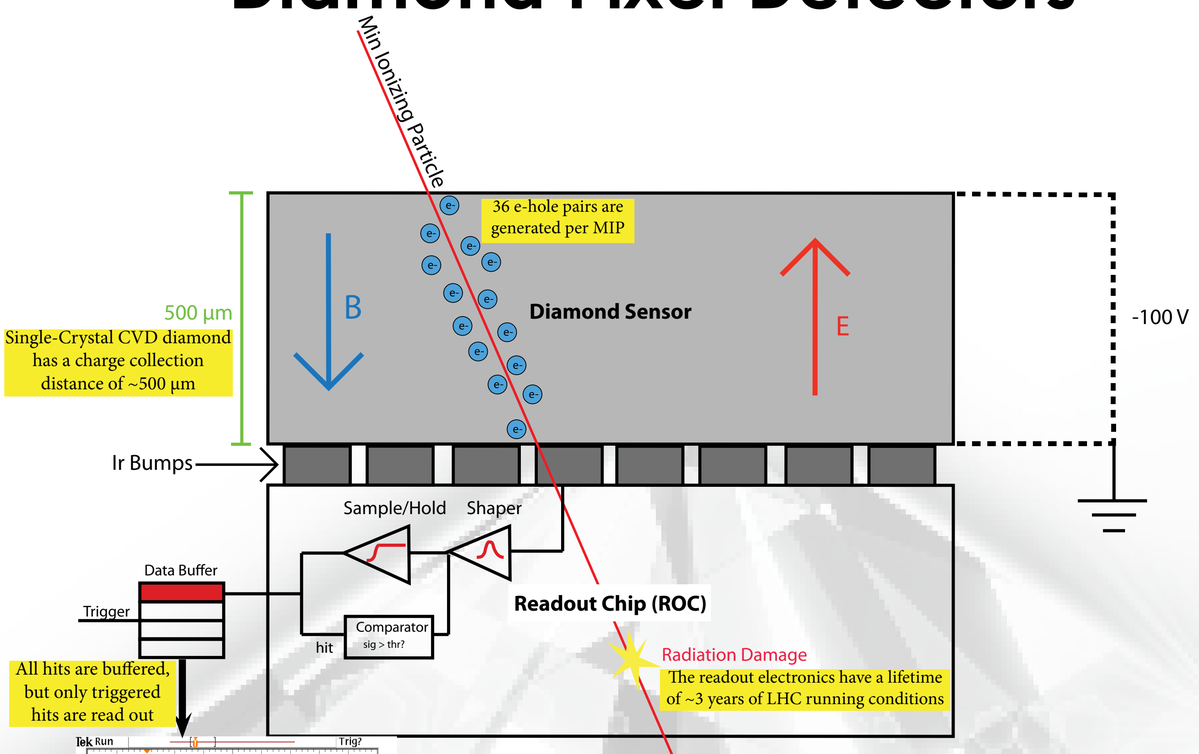
Resolution Studies of Single-Crystal Diamond Pixel Detectors

Diamond Pixel Detectors

PSI46 Pixel Readout Chip

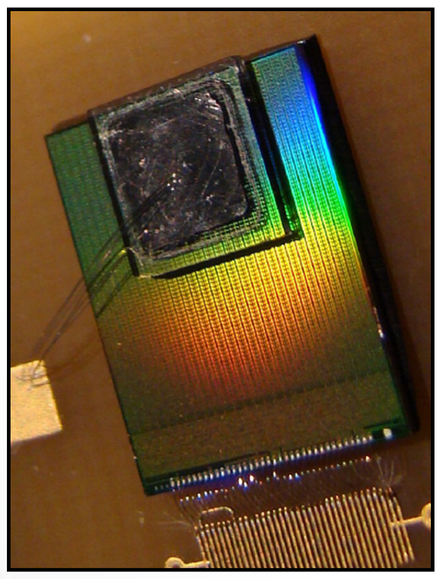


The PSI46 chip consists of an array of 52 x 80 pixels with a pitch of 150 µm x 100 µm. Each pixel features individual pixel threshold/mask settings, full analog readout of the pixel hit address and charge deposit, as well as a column-multiplicity signal (known as the Fast-OR), which indicates the number of double columns that had pixels over threshold in each bunch crossing. Fast-OR signals are read at the full bunch-crossing rate of 40 MHz clock, while the full pixel information, consisting of the row and column addresses and the pulse heights of all pixels over threshold, is read out at a lower rate of a few kHz.



Pixel Hits, Row, Column, Charge deposit

Fully Assembled Detector Plane



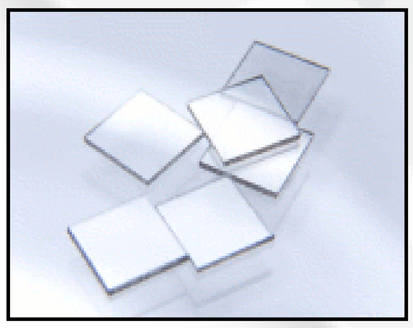
Deposition of the pixel electrode pattern on the diamonds and the bump-bonding of the diamond sensors to the pixel readout chips were performed at the Princeton Institute of Science and Technology Materials (PRISM) micro-fabrication laboratory. Following surface preparation, electrodes were sputtered onto the diamond surface using a Ti/W alloy target as an under bump metalization (UBM). A 4 mm x 4 mm electrode was deposited on one side of the diamond using a shadow mask. On the other side, a pixel pattern was deposited using a standard lift-off photolithographic process.

Single-Crystal CVD Diamond

Advantages

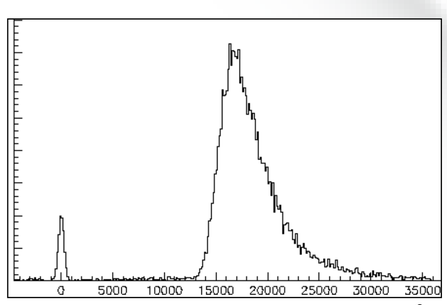
- ✓ No need for cooling
- ✓ High radiation tolerance
- ✓ High charge mobility
- ✓ Capable of surviving up to 2 x 10^{15} protons/cm^2
- ✓ Full charge collection at < 0.2 V/um

Diamond sensors are ideal for detectors which are exposed to high radiation environments, such as those found in modern high energy physics experiments.

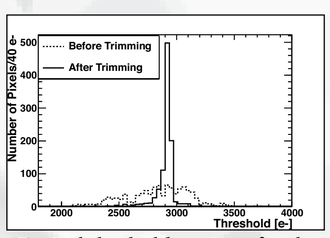


Single-Crystal CVD Diamond

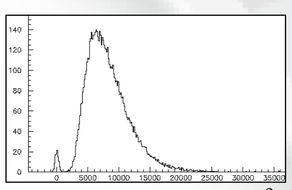
Single-crystal diamond is the preferred sensor material rather than polycrystalline diamond since the pulse height distribution of single crystal diamond is large and well separated from zero, ensuring that any efficiency changes due to threshold drifts will be small.



Single-Crystal CVD diamond charge deposit from a ^{90}Sr source (~minimum ionizing)



Typical threhold settings for the PSI46 readout chip. The threshold of 3000 e- is well separated from the Single-Crystal MPV of ~18000 e-.



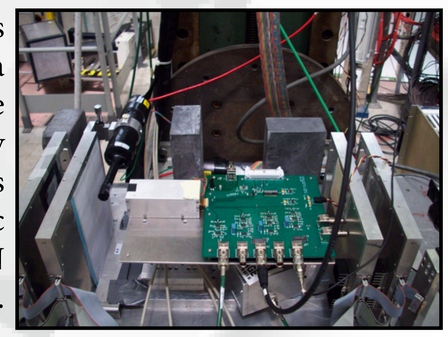
Charge deposit from ^{90}Sr for Poly-Crystal CVD Diamond

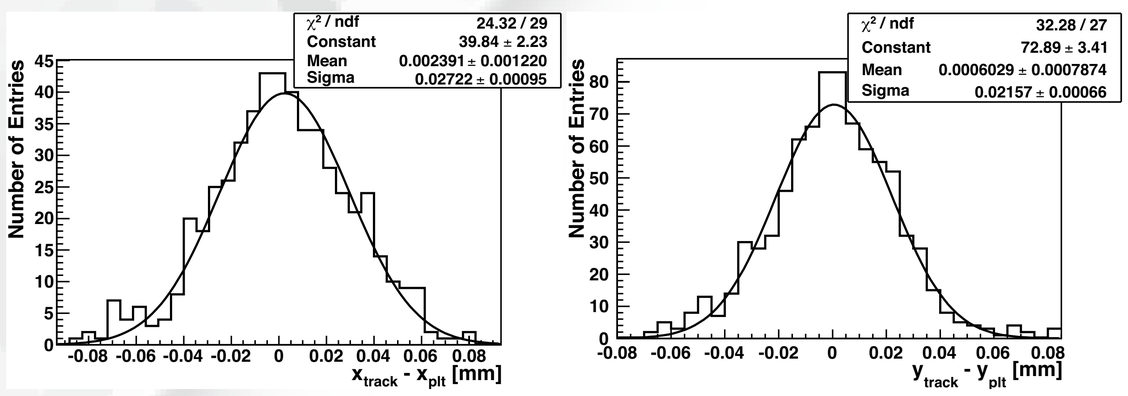
Spatial Resolution

Zurich Beam Telescope

- ✓ Silicon microstrip detector
- ✓ Intrinsic Resolution: 2 µm
- ✓ Resolution Achieved: 10 µm
- ✓ 4 independent X/Y planes

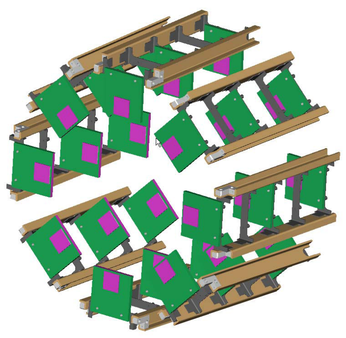
The spatial resolution was measured by utilizing a silicon microstrip telescope provided by the University of Zurich, which was inserted into a 10 GeV/c proton beam at the CERN PS .





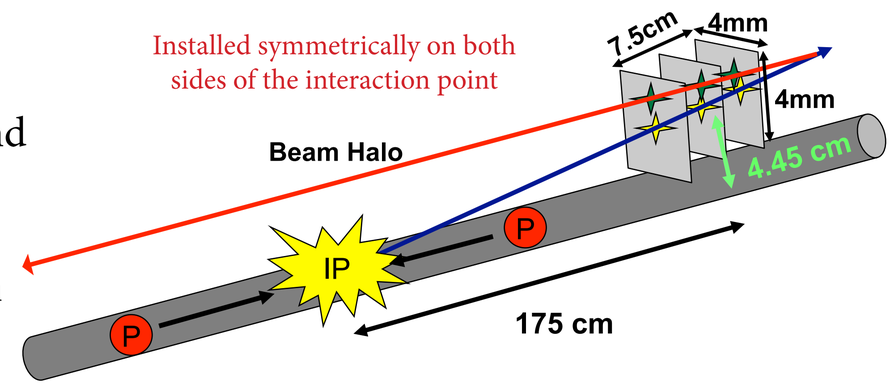
The x and y residuals for 2-hit clusters. Residuals for the PLT were defined as $\Delta X = x_{track} - x_{plt}$ where x_{track} is calculated as a linear fit through the silicon strip detector, and x_{plt} is given by the equation $x_{plt} = \frac{\Sigma\, x_i \cdot Q_i}{\Sigma\, Q_i}$ where Q_i is the charge in each pixel of the cluster in the PLT, x_i is the column address of the pixel, and the sum is over the number of hits in the corresponding cluster. The formula for y is analogous to these formulas. The measured resolution is significantly improved over the expected digital resolution of ΔX = 43 µm and ΔY = 29 µm.

CMS Pixel Luminosity Telescope (PLT)



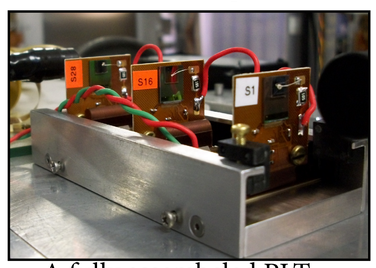
PLT Telescope Array

The PLT is a dedicated luminosity monitor for CMS based on single-crystal diamond pixel sensors. It consists of two arrays of eight small-angle telescopes situated one on each end of the CMS experiment at CERN.



Diamond Sensors -> stable operation over the lifetime of CMS

The PLT is designed to provide a high-precision measurement of the bunch-by-bunch relative luminosity at the CMS collision point on a time scale of a few seconds and a stable high-precision measurement of the integrated relative luminosity over the entire lifetime of the CMS experiment. The telescopes consist of three equally-spaced planes of diamond pixel sensors with a total telescope length of 7.5 cm. They are located 5 cm radially from the beam line at a distance of 1.8 m from the central collision point with a small angle pointing towards the collision point.



A fully assembeled PLT Telescope

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