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ISIS1 beam test using the EUDET telescope

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On behalf of the LCFI collaboration

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Abstract

In summer 2008 a beam test of the ISIS prototype sensors was performed using the EUDEt telescope. The status and first results are presented here.

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1 Scientific Background

1.1 Introduction

The ISIS1, Imaging Sensor with In-situ Storage, device has been developed as part of the Linear Collider Flavour Identification (LCFI) project [1, 2]. It is a proof-of-principle device intended to show that such a detector is suitable for use at an International Linear Collider. Beam-tests in test-beam 22 at DESY in October/November 2007 have demonstrated that the device operates well to track charged particles. Since the DESY beam test also a second variant of the ISIS1 has become available, the p-type ISIS1. This was also tested in the CERN beam test.

The ISIS1 pixel size is $40 \times 160 \mu m^2$. Especially in the large pitch direction, there is hardly any charge sharing. Therefore, the resolution in this direction is only binary. This makes the study of pixel position dependent properties like efficiency and charge sharing very difficult. Therefore we repeated our beam test at CERN using the EUDET telescope. The EUDET telescope is used for precise tracking over the entire ISIS1 area. The EUDET telescope yields very precise space points for the tracks on the sensors. This allows to study the ISIS1 behavior in great detail yielding important results required for further ISIS development.

1.2 Requirements for ILC Vertex Detector

In order to reach the full potential of an International Linear Collider a vertex detector should have the following properties:

- Excellent point resolution ($3.5 \mu m$), pixel size = $20 \mu m$, close to IP
- Low material budget ($<0.1\% \ X_0$ per layer), which also implies low power dissipation.
- The readout should avoid excessive event overlap, which implies an occupancy $\ll 1\%$.
- Inner layer should be read out at $50 \mu s$ intervals during the $1 ms$ pulse train (20 readouts). Information may leave the sensor or be stored in pixel.
- Outer layers read out at $250 \mu s$ intervals.
- Moderate radiation hardness ($\sim$20 $krad/year$).
- Tolerates the Electro-Magnetic Interference (EMI) produced by the beams.

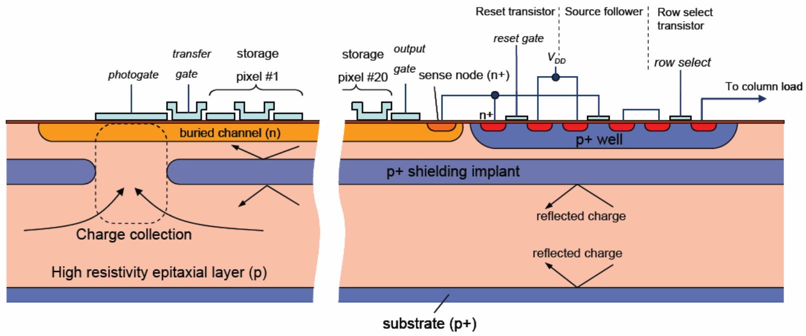

Figure 1: *Schematic drawing of an ISIS pixel.*

2 About LCFI

The Linear Collider Flavour Identification Collaboration consists of particle physicists from five British academic institutions. The collaboration is pursuing an ambitious research and development programme to develop a pixel-based vertex detector for heavy flavour identification at the International Linear Collider. The main areas of research are:

- Developing and testing new sensor technology suitable for the International Linear Collider.
- Designing readout electronics for the new sensors.
- Investigating mechanical options for ultra-thin detector elements.

The beam structure of the ILC requires to read out the detector 20 times per bunch train. The bunch train is followed by a long pause ($\sim$200ms). To minimize the power consumption, a sensor that stores the 20 frames on the sensor and reads out the detector in the low pause would be ideal. The LCFI collaboration is developing Imaging Sensors with In-situ Storage (ISIS). These sensors have memory cells in each pixel.

3 Imaging Sensors with In-situ Storage (ISIS) Device

The ISIS device consists of pixels, each with a short CCD register. Charge is collected under a photo-gate. For an ILC device charge is transferred to 20-cell storage CCD in each pixel, 20 times during the 1ms-long train. Conversion of the charge to a voltage and readout happens during the 200ms-long quiet period after the train. A 1MHz column-parallel readout during the gap between bunch trains is sufficient.

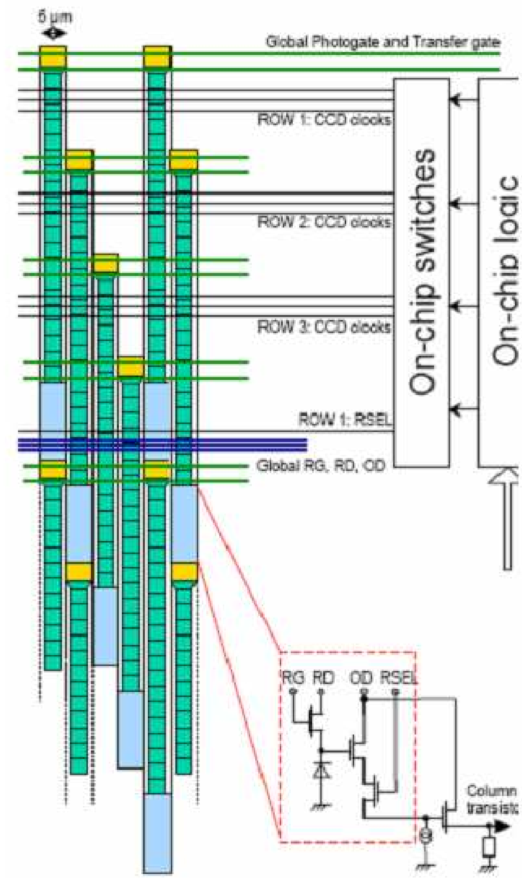

Figure 2: *Schematic overview of the ISIS sensor.*

The use of the CCD register means that charge is shifted from cell to cell during the beam-train, rather than being converted to a to a voltage and then sampled. This gives ISIS a higher degree of immunity to EMI than designs where a voltage is sampled during the bunch-train. In addition, since far fewer charge transfers are needed than for a traditional CCD the ISIS is approximately 100 times more radiation hard than a CCD. Figure 1 shows a schematic drawing of an ISIS pixel. In figure 2 a schematic overview of the ISIS sensor is shown. The use of edge logic together with CCD storage cells allows for a highly integrated system, but requires a fabrication process capable of producing both CCD and CMOS features.

The ISIS1 sensor is a "proof of principle" device, with 16×16 ISIS cells with a five-pixel buried channel CCD storage register in each. The pixels are $40\mu m \times 160\mu m$ and there is no edge logic, allowing fabrication using a pure CCD process. Figure 3 shows ISIS1. For this beam-test devices have been packaged in a ceramic pin-grid array with a $3mm$ hole drilled to allow passage of the beam.

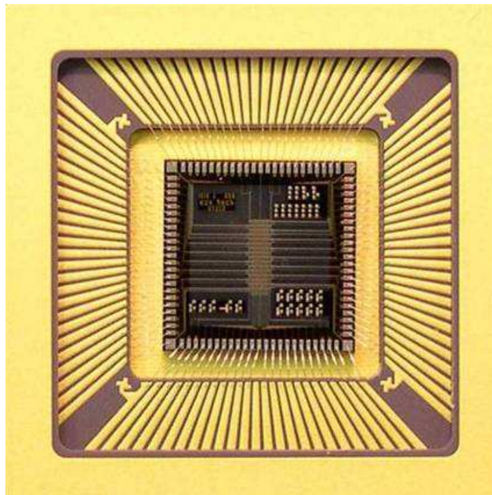

Figure 3: *Photo of the ISIS1 sensor.*

4 First results

At DESY the tests were performed using a self-contained ISIS1 telescope consisting of 5 modules. A particle traversing all 5 ISIS1 sensors should yield a hit in all 5 ISIS1 sensors. Each ISIS1 will be slightly misplaced, but when one plots the X-coordinate of the hits in one ISIS sensor against the X-coordinate of hits from the same tracks in another ISIS sensor, clear correlations should be visible. In figure 4 this is shown for the Y-coordinates of all 5 sensors . The correlation plots shows that the first four ISIS1 are very well aligned with respect the each other. Unfortunately, the 5^{th} is off. More importantly, it proves that the ISIS1 sensors are detecting the same particles and hence that the set up and the software is working well.
In figure 5 the residual position distributions are shown. The resolution still contains a tracking error of 6.6±0.1 μm. In the X-direction the situation is much more complicated. The pixel pitch is so large that there is hardly any charge sharing. Hence the position is reconstructed as the middle of the seed pixel. Since the telescope consists fully of ISIS sensors, all 4 sensors yield the same position (after alignment). This results in a position resolution of 0.

The main results of the DESY beam test [3] were a signal-to-noise ratio of 36.8±0.2 for hits occurring around the photogate, an intrinsic spatial resolution of 9.4±0.2 μm in the small pitch direction and an efficiency of 59.3%. The considerable inefficiency is due to the large and asymmetric pitch of these proof-of-principle devices. To map in in-pixel efficiency variations, we performed a beam test at CERN using the EUDET telescope.

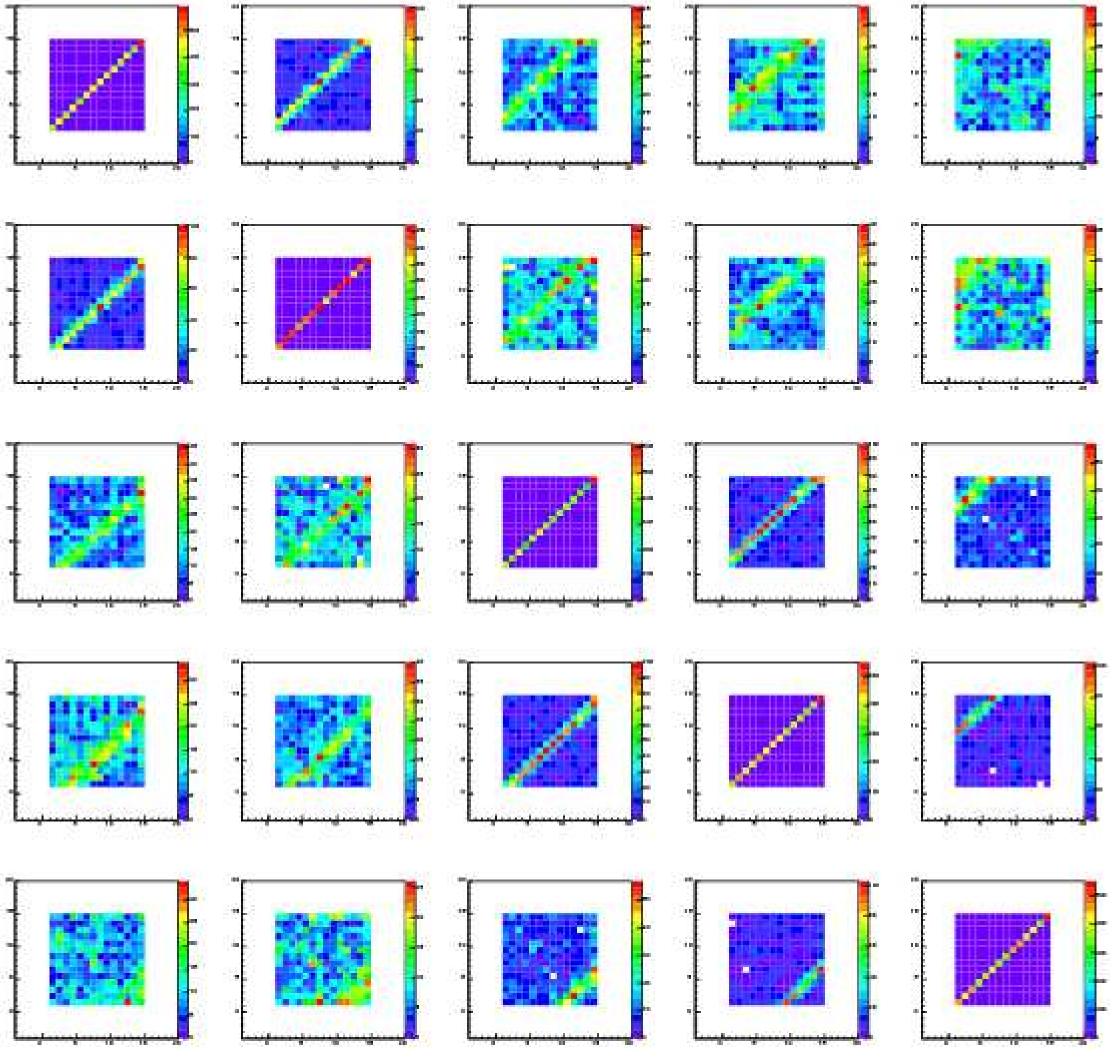

Figure 4: *Hit correlations in the 5 ISIS sensors in the short pixel direction. In every row the on X-axis the Y-coordinate of the hit in the ISIS with the same row number is plotted versus the Y-hit accoring to the ISIS with the same column number. Correlations indicate tracks.*

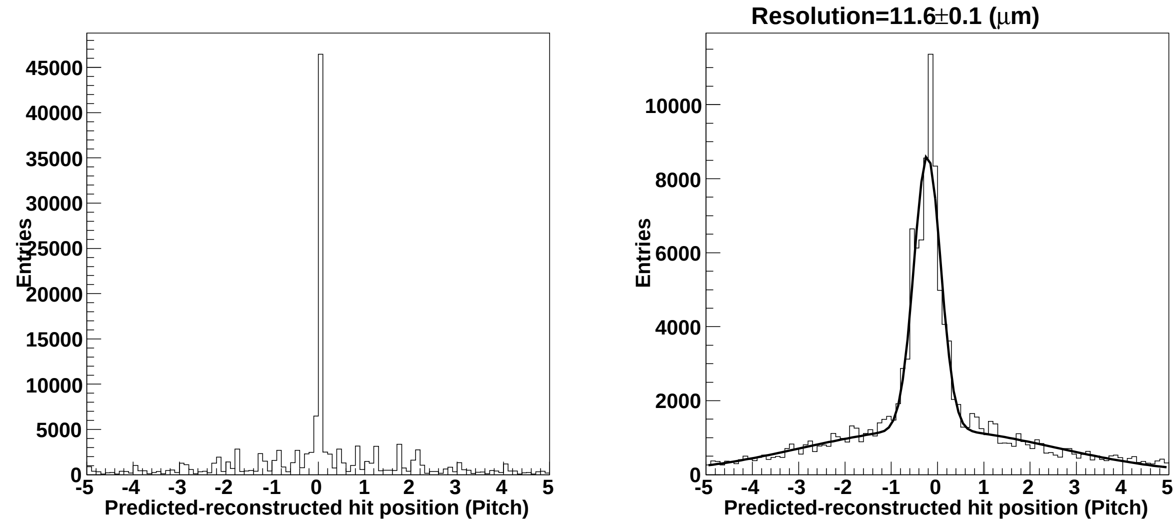

Figure 5: *Distribution of the difference between the predicted and reconstructed hit positions in the X-direction* (left) *and Y-direction* (right) *for ISIS 2 using 3 other ISIS sensors to predict the track. The quoted position resolution still includes the uncertainty on the predicted position and a multiple scattering error.*

5 EUDET beam test

Last summer we performed a beam test using the EUDET telescope. Since our DAQ was written using LabVIEW, we used a "poor-man" integration of the two DAQ systems. We only accepted triggers for ISIS when the ISIS was sampling and we stored the accompanying EUDET trigger number. The disadvantage of this system is that we had to start and stop the EUDET DAQ and ISIS DAQ by hand.

5.1 EUDET performance

The EUDET telescope performed fine. In figure 6 the cluster signal distribution and a hitmap on EUDET plane 2 can be found. The most probable signals are around 125 ADC counts while the noise is typically between 2 and 4 ADC counts. The hit map clearly displays the 3.5×4 mm^2 trigger scintillator. Also teh tracking and alignment work fine. In figure 7 the track occupancy and the position resolutions for EUDET plane 2 are shown. In figure 8 the position resolutions are plotted as a function of the plane number. These plots clearly demonstrate that the alignment and tracking work fine.

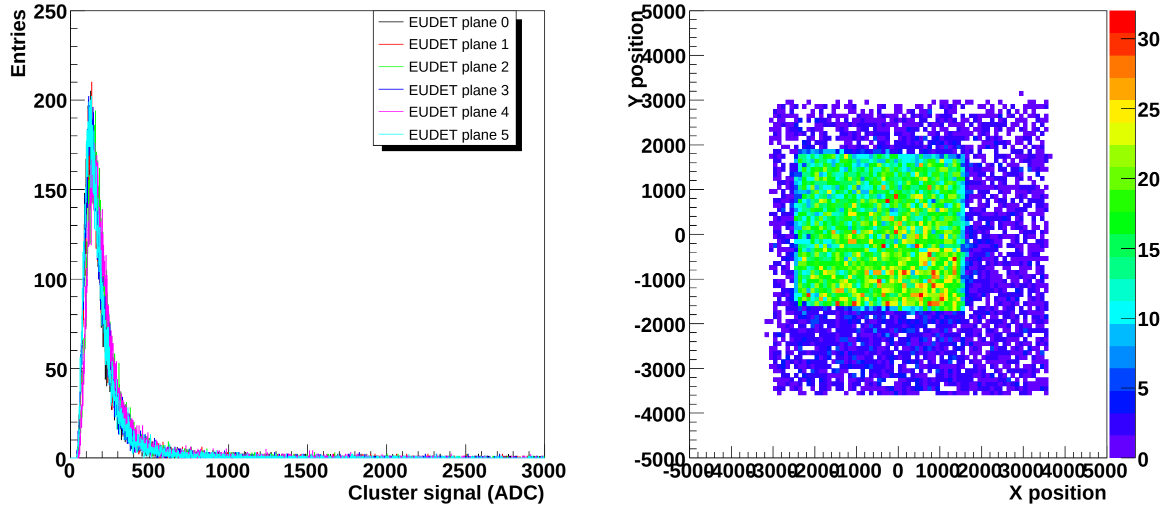

Figure 6: *Cluster signal distribution for the EUDET planes* (left) *and hitmap on EUDET plane 2* (right).

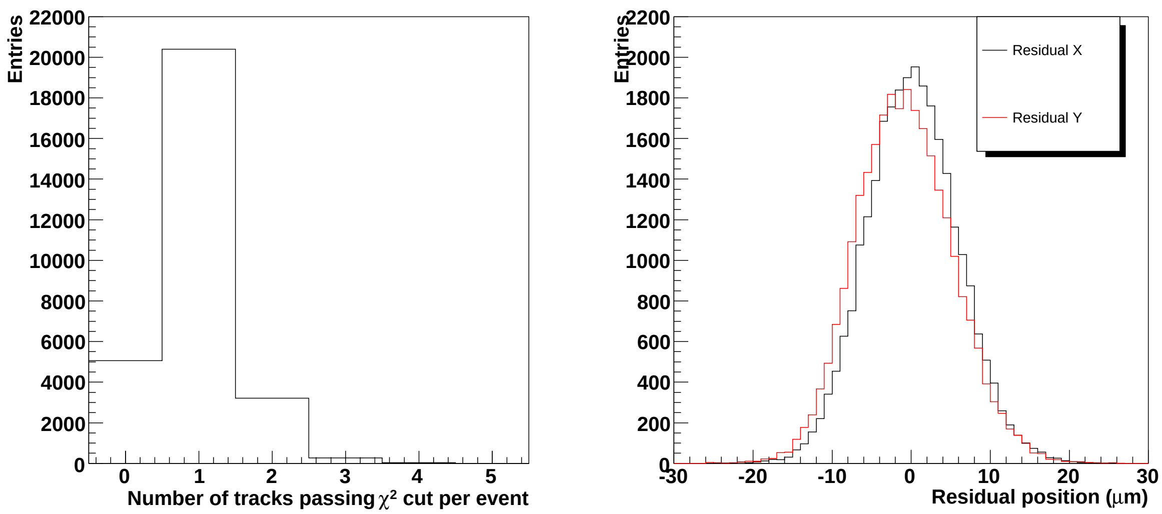

Figure 7: *Track occupancy* (left) *and position resolution for EUDET plane 2* (right).

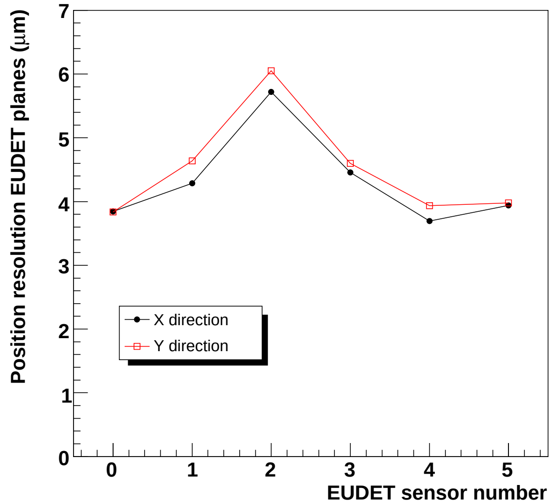

Figure 8: *Position resolution as a function of the EUDET plane number.*

5.2 ISIS performance

Unfortunately, the ISIS does not perform as nice as the EUDET telescope. In figure 9 the signal to noise ratio for each pixel in each event is shown. ISIS 0, 1 and 2 are of the new p-well type, while the other three are of the standard type. The plot shows that the three standard type ISIS are performing well. One of the p-well type does not see any signal and one has some problems. These problems are understood and can be fixed. The third p-well ISIS is performing fine.
Using a small fraction of the data, the ISIS position[1] can be projected onto EUDET plane 2 by plotting only the hit positions of tracks that occur when there is a hit found in ISIS. Due to the high occupancy, the limited statistics and the very small size of the ISIS, a background subtraction has been performed. The result can be found in figure 10. The ISIS shows up as the yelow/red area.

At the moment we are still working on a full analysis of the beam test. But given that we have hits in ISIS that correlate with tracks in the EUDET telescope, we are quite confident that we will be successful.

6 Summary

Last summer we have performed a beam test of the ISIS sensor. We are still working on the analysis. However, given that we have tracks in the EUDET telescope and we have hits in ISIS that correlate with these tracks, we are very confident that we will complete

[1]Here only ISIS 5 is shown.

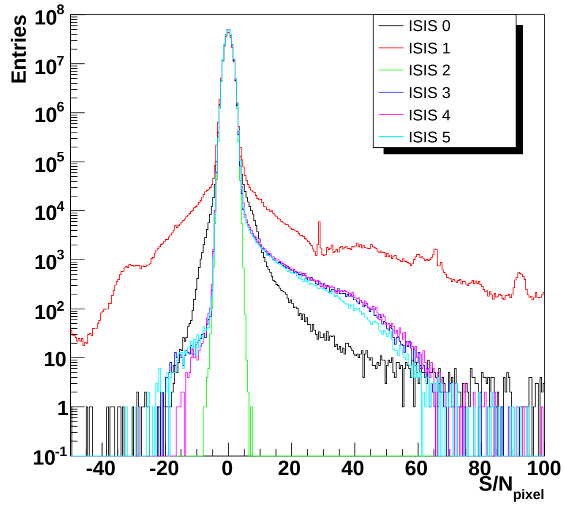

Figure 9: *Signal to noise ratio for each pixel in each event. ISIS 0, 1 and 2 are of the new p-well type, while the other three are of the standard type.*

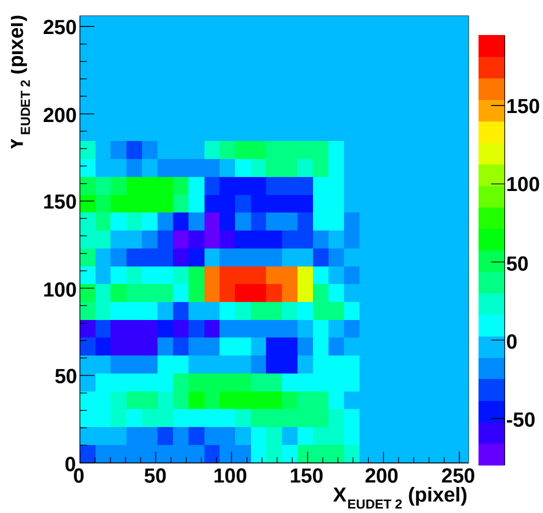

Figure 10: *ISIS 5 position projected onto EUDET 2.*

the beam test successfully.
We would like to express our thanks to the EUDET collaboration for our their help during the data taking.

References

[1] F.W. Kosonocky et al., *360×360-element very-high-frame-rate burst image sensor*, Digest of Technical Papers, 42nd ISSCC, pp.182-183, 1996.

[2] C.J.S. Damerell, *CCD-based vertex detectors*, Nucl. Inst. Meth.**A 541**, 178 (2005).

[3] J.J. Velthuis, D. Cussans, J. Goldstein, S. Mandry, K.D. Stefanov, Z. Zhang *et al*, *First results of the ISIS1 beam test*, accepted by Nucl. Inst. Meth.