Pair Monitor for Linear Collider

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Abstract. Progress is reported on research and development into the technologies and techniques for the construction of a beam profile monitor for a linear collider interaction region. Based upon measuring in detail the copious production of electron-positron pairs through beam-beam interaction, such a pair monitor has been proposed previously. Studies and simulation results are based on the JLC parameter set, but it is believed that this method can be exploited for other linear colliders.

PAIR MONITOR DESIGN CONCEPT

At linear colliders it is expected that a large number of e^+e^- pairs are created by the QED process $\gamma\gamma \rightarrow e^+e^-$ where γ may be off-shell or near-on-shell [1]. These pairs are predominantly created along the beamline and acquire p_t kick by the elctromagnetic field of the on-coming bunch. As long as the pair is relativistic and the direction is the same as the co-moving bunch, the net force due to the co-moving bunch cancels out: one then only needs to consider the effect of the on-coming beam (Fig. 1). If the charge of the created particle and the on-coming bunch are opposite sign, the particle would undergo a number of oscillations around the beam plane and the net p_t acquired will be small. On the other end, if the particle and the on-coming bunch have the same sign, the p_t kick will be larger and, due to the laminar shape of the beam, mostly in the vertical direction. It was shown [2] that distributions of p_t and azimuthal angle of this latter large deflection can be used to study σ_x and σ_y of the on-coming bunch. It should be noted that this technique allows to measure independently the size of the two beams because the created particles are deflected asymmetrically in the forward and backward angular regions if the two beams have different parameters.

The proposed beam profiles monitor for JLC are located at ± 176 cm from the IP: Fig. 1 shows the azimuthal trajectory of a particle created with a p_t kick perpendicular to the beam plane. The parameters r and ϕ are uniquely determined by p_t and p_z and, given the JLC parameter set, it was found that the maximum p_t is about 20 Mev/c which gives curvature $r = 3.3$ cm in a 2 Tesla field, which in turn translates to the maximum distance ρ from the beamline of 6.6 cm.

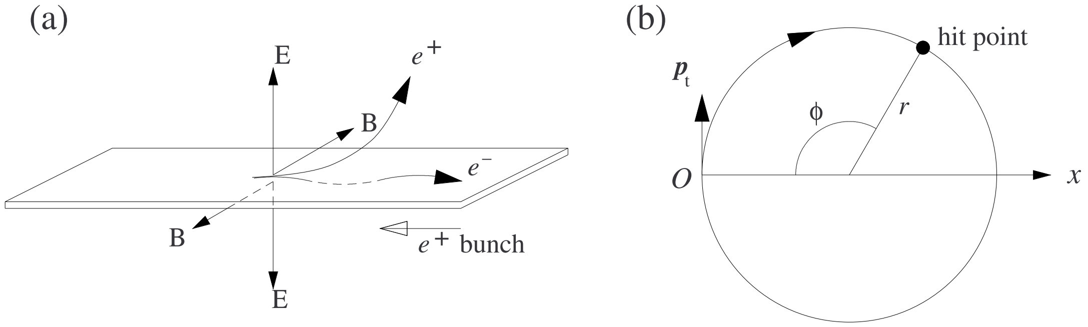

FIGURE 1. a) effect of the electromagnetic field of the on-coming bunch on pairs in the lab. frame and, b), azimuthal view of a particle created at the IP: the point O is the location of IP.

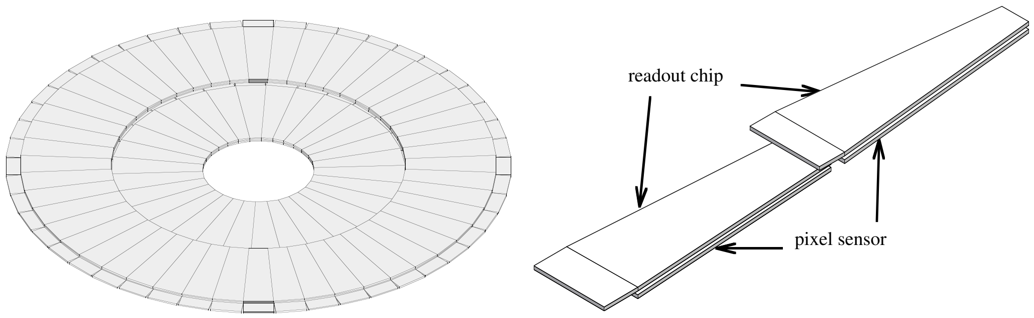

FIGURE 2. A wheel is composed by trapezoids of silicon sensor/readout electronics pairs.

THE DETECTOR

In Fig. 2 is a graphic depiction of the physical implementation of a beam monitor wheel: the beam will be going through its central hole and the wheel will be located in front of the final focusing quadrupoles. It consists of an array of trapezoidal wedges, each composed by a sensor and a readout chip. There will be a large amount of X-ray hits from nearby devices (quadrupoles, luminosity monitor...) that need to be removed either by requiring a coincidence between two adjacent wheels or by being able to set a clean 70 Kev threshold per hit [3], thus reducing by 50% the overall number of nedeed channels. Most of the created pairs will hit the central part of the monitor while X-rays are almost uniformly distributed generating a background that needs to be removed in the external region where the monitor should withstand an occupancy up to 30% of created pairs per train crossing.

Beam instabilities are often caused by preceding bunches in a train: it is thus desirable to measure the beam profile monitor for individual bunch or at least as a function of the time from the beginning of train. It is also highly desirable that such information be available real time for machine tuning. The high occupancy suggests

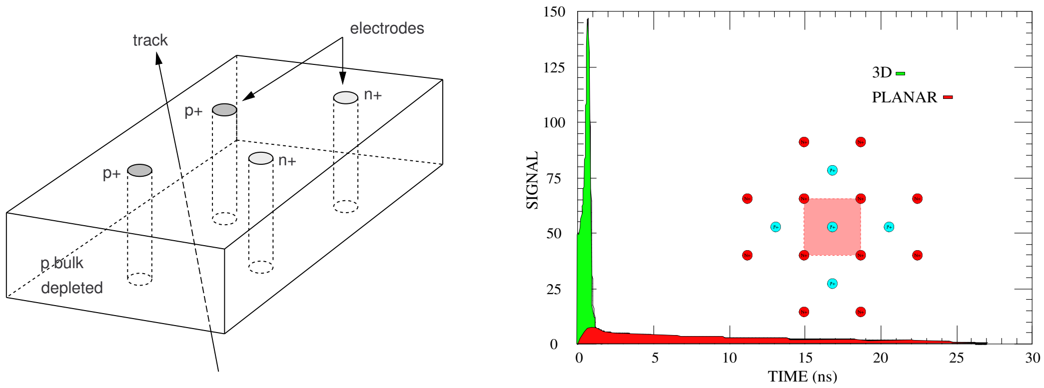

FIGURE 3. 3D pixel architecture: the charge collection time is one order of magnitude faster than planar devices.

that silicon strip detectors are not suited for this application. A CCD sensor would be a good candidate in terms of occupancy; since the integrated charge deposit in each pixel is read out at the end of each train, hower, the information on the location in a train is lost unless some external gating is applied. On the other hand, active pixel sensors can handle high occupancies just as CCDs and timing of hit can be digitized on each pixel. The 3D pixel design shown in Fig. 3 is particulary suited for this application for the following reasons:

-it is fast: the charge collection time is about 10 times faster than typical pixel devices as shown in Fig. 3 for a $50 \mu m$ pitch 3D cell where the ionizing track is midway between the central p and corner n electrode, perpendicular to the surfice of the silicon crystal.

-it is radiation hard:the depletion voltage is of the order of 5 V and has a large margin for increase by radiation.

-it has a flexible geometry and it can be easily made in a trapezoidal shape as shown in Fig. 4 and, finally, the sensor can be active very close to the edge [4]

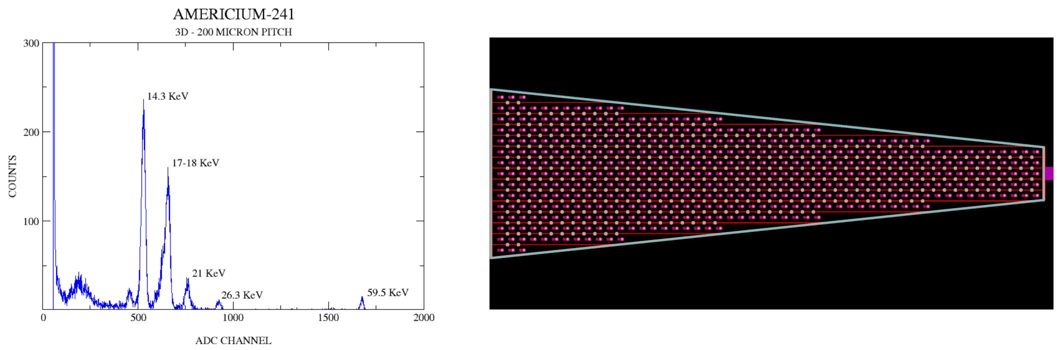

FIGURE 4. Americium-241 spectroscopy from 14 p-type 3D electrodes tied together connected to a slow shaping time charge sensitive amplifier. At right the layout of a trapezoidal prototype with 100 μm pitch currently in fabrication.

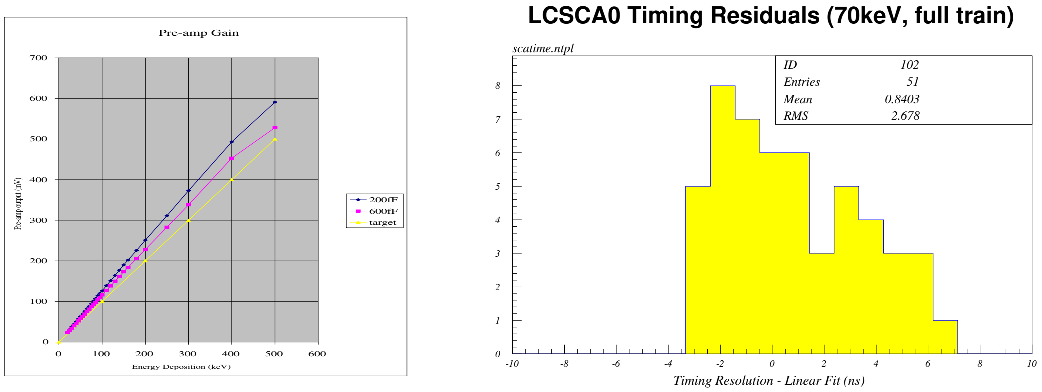

FIGURE 5. Pre-amplifier gain and time resolution for the multi hit TDC electronics design.

Each pixel sensor is bump-bonded to a readout chip which collects the charge, discriminates and time-digitizes it. The proposed pixel size for the beam monitor is $100x100\mu m$, thus its readout electronics has to fit in such a footprint and, given the JLC bunch crossing rate, the readout time target for the whole system has to be of the order of few ms.

The sensor thickness is a parameter that could be optimized in order to reduce the number of X-ray hits: for that purpose a study has been done showing that the proposed electronics can cope with a 100 μm thickness sensor still matching the needed preamplifier gain target as shown in Fig. 5.

The time separation between buch crossings is of the order of 3 ns: the electronics under study is showing a hit time resolution of about 1 ns, thus allowing a clean separation between adjacent bunches. Given the high occupancy expected even in the external region of the beam monitor, it could be needed either to apply an external gate to the electronics, thus reading only a window of the train adjustable with respect to the beginning of the train itself, or to have a waveform digitizer on each pixel: simulations show that such a design could fit in the footprint, having a time resolution of about 3 ns, as shown in Fig. 5.

REFERENCES

1. T.Tauchi, K.Yokoya and P.Chen, Particle Accelerators 41 (1993) 29.
2. T.Tauchi and K.Yokoya, Phys. Rev. E51 (1995) 6119.
3. T.Tauchi, talk given at the second ACFA workshop on Linear Collider, 1999, Seoul, Korea.
4. For more details about 3D pixels, see "Pixel detector R&D at UH", G.Alimonti, LCWS2000 proc. and its references.