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High-accuracy 4D particle trackers with Resistive Silicon Detectors (AC-LGADs)

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Future particle trackers will have to measure concurrently position and time with unprecedented resolutions, approximately 5 microns and 10 ps respectively. A promising good candidate are the AC-LGADs, silicon sensors of novel design, with internal gain and an AC-coupled resistive read-out to achieve signal sharing among pads. This design leads to a drastic reduction of read-out channels, has an intrinsic 100% fill factor, and adapts easily to any read-out geometry. I will present the challenges in the design, the signal formation, recent test results, and the reconstruction techniques that exploit the distributed nature of the signal, including machine learning.

Summary (500 words)

Future accelerator designs call for trackers with extremely good (˜5 microns) position and time (˜10 ps) resolutions, very low material budget (less than 100 microns equivalent thickness per layer) and low power consumption. In this contribution, I will present the novel concept of silicon detectors with resistive readout, and outline how this design, coupled with the appropriate front-end, allows meeting such stringent requests.

The structure of a resistive silicon detector is sketched in Figure 1 (A) where the key features, (i) a gain implant, (ii) a resistive electrode, and (iii) AC-coupled read-out, are presented. The working principle of such a sensor is (see Figure 1 (B)): the signal, formed on the n+ electrode, spreads to the AC read-out pads that discharge with a time constant that depends on the read-out input resistance, the n+ sheet resistance, and the system capacitance. The pads surrounding the particle hit see a modified version of the original signal. During the propagation on the n+ resistive surface, the signal becomes smaller, wider, with slower leading and falling edges, and is delayed. Figure 1 (C) shows how the signal, generated by a laser beam, is shared among the read-out pads in a 50-micron thick AC-LGAD prototype. Each of the four pads surrounding the hit point sees a fast signal, with an amplitude that depends on its distance from the hit.

In the presentation, I will show how, exploiting the distributed nature of the signal in AC-LGADs, a spatial resolution of less that 5 micron can be achieved for 200 micron-pitch sensors, while also reaching a time resolution of less than 40 ps. These performances have been tested in prototypes, using a laser setup and beam tests with protons.

To exploit the wealth of information carried by the shared signals induced in the read-out pads, we envisage the use of front-end electronics able to sample the signals in multiple points (for example every 300-500 ps) so that many of its features - amplitude, area, width, the slope of rising and falling edges, time of arrival - can be determined. Two points on the leading and trailing edges should be enough to achieve the goal. The samples from each front-end are sent to a reconstruction code concentrator that combines them to estimate the position and time of the hit. This regression problem can be cast in terms of a multi-channel time-varying regression task that uses many inputs to determine two outputs (position and time).
One significant advantage of the AC-LGAD design with respect to every other silicon design is the amount of space available for the electronics. Given that very large pixels (150-300 micron pitch) are germane to the AC-LGAD design, this leads naturally into much more space available for the electronics and much less use of power.

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