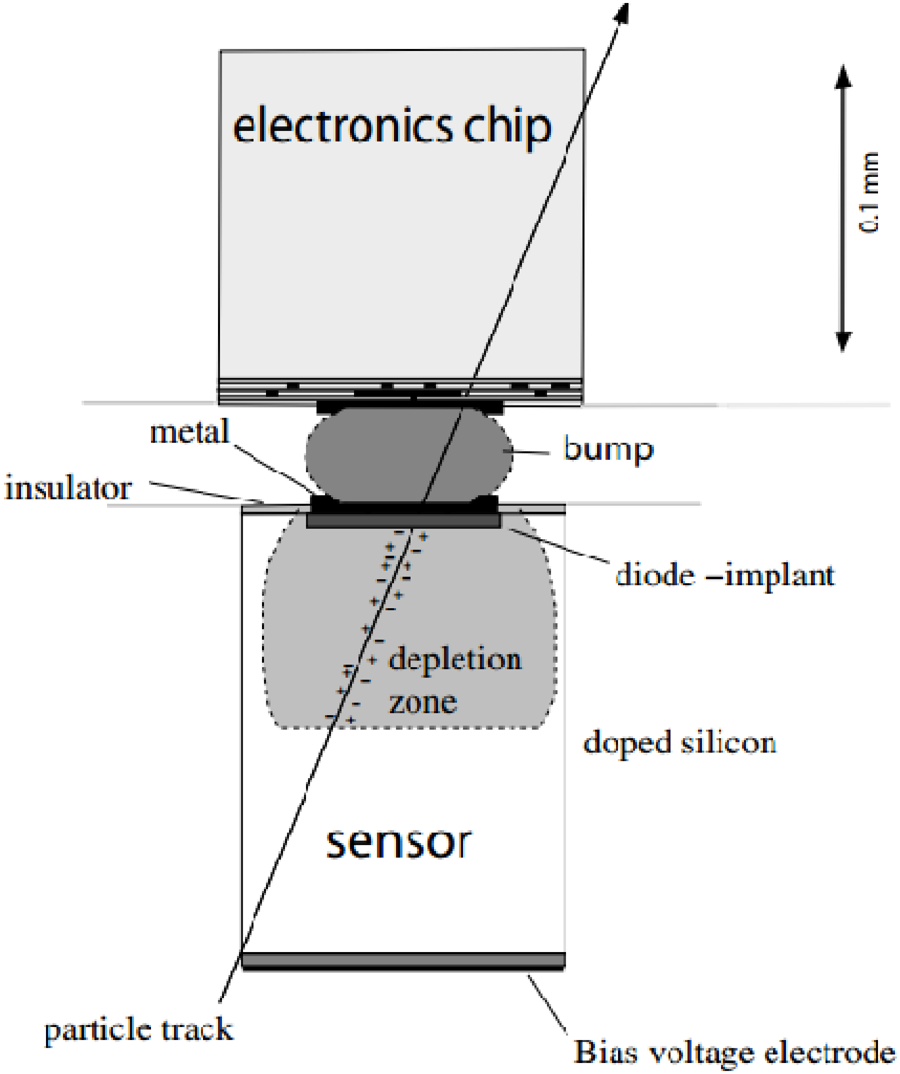
Pixel detector

1.1 Generalities on Pixel Detectors

1) The notion of pixel (short for “picture element”) has been introduced in image processing to describe the smallest discernable element in a given process or device. A pixel detector is therefore a device able to detect an image and the size of the pixel corresponds to the granularity of the image.
2) In particular, detectors are discussed where the image is generated in a semiconductor and is processed electronically and where data are readout in parallel.
3) Planar integration technology allows one to put together several thousands of those building blocks in a matrix covering few square centimeters.
4) Particle physics applications demand high speed, good time resolution, and the ability to select hit patterns, while applications in other fields emphasize more high sensitivity and stability.

- This is the so-called hybrid pixel detector (hybrid because electronics and sensors are fabricated separately and then mated)
- The ionizing particle crosses the sensor and generates charges that, moving in the depletion region under the action of an electric field, produce signals.



1.1.1 Motivations for Pixel Detectors in Particle Physics

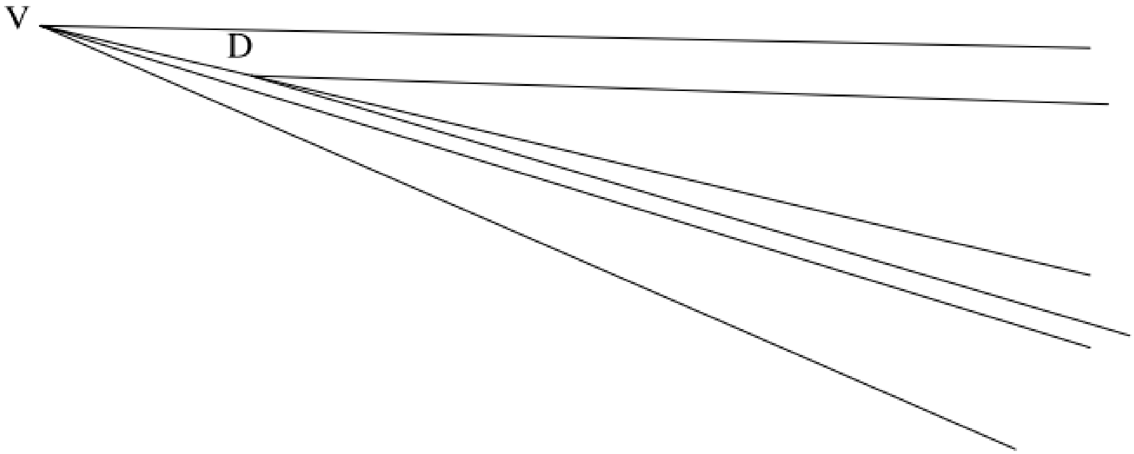
The development of pixel detectors in particle physics has been primarily triggered by two specific requirements :

① The possibility of studying short-lived particles

② The capability of coping with the increasing interaction rates and energies (and therefore the number of particles produced per collision) of modern particle accelerators

High-energy accelerators generate elementary particle collisions at a rate of 10–100 MHz, with 10–100 particles emerging from every collision. Some rare, but interesting, particles live about 1 ps (10−12 s) and then decay into a few daughter particles.

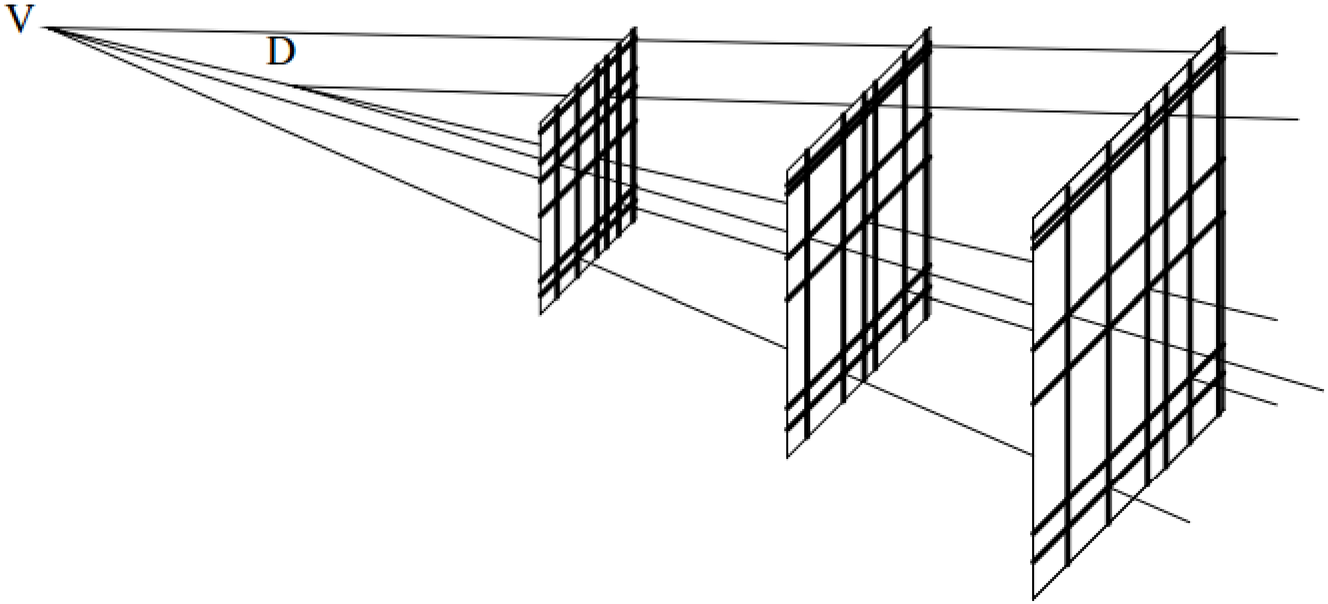
Topology of a short-lived particle decay, with ordinary particles emerging from the same collision. The collision vertex (V) and the decay vertex (D) are indicated.



- The tracks emerging from this decay must be measured as close as possible to the interaction point, with an accuracy of ≈0.1 $c\tau$ (where τ is the particle proper lifetime and c is the speed of light). This gives a required measurement accuracy of 0.03 mm for a lifetime in the order of a picosecond.

- Tracks emerging from the decay of a relativistic particle, once extrapolated back to the primary interaction vertex, miss this vertex on average by a distance $c\tau$. This distance is known as impact parameter. In order to discriminate the tracks coming from the rare heavy quark decays from other tracks emerging directly from the interaction, the impact parameter must be measured with an accuracy sensibly smaller than $c\tau$: 10% $c\tau$ is commonly assumed.

The tracks are measured by three double-sided microstrip detectors with 100-μm strip pitch. The hit strips (i.e. the pattern “seen” by the detectors) are highlighted.



- The same space resolution is obtained using two planes of microstrip detectors rotated by 90◦, but, together with the N true strip coincidences due to the N tracks, one must also take into account (N^2 − N) ghosts strip coincidences which can severely hamper the track reconstruction capability. (strip 交叉的部分會導致信號被多算了一次，因此要 (N^2-N) 減去多算的信號)

Requirement of pixel detector

1) A detector with a high granularity able to detect multiple tracks with good space and time resolution.

Pixel detectors with cell sizes in the order of 100 × 100 μm2 can cover areas as large as a few square meters with 108 pixels.

2) Electronics of pixel detector should be capable of selecting the interesting patterns.

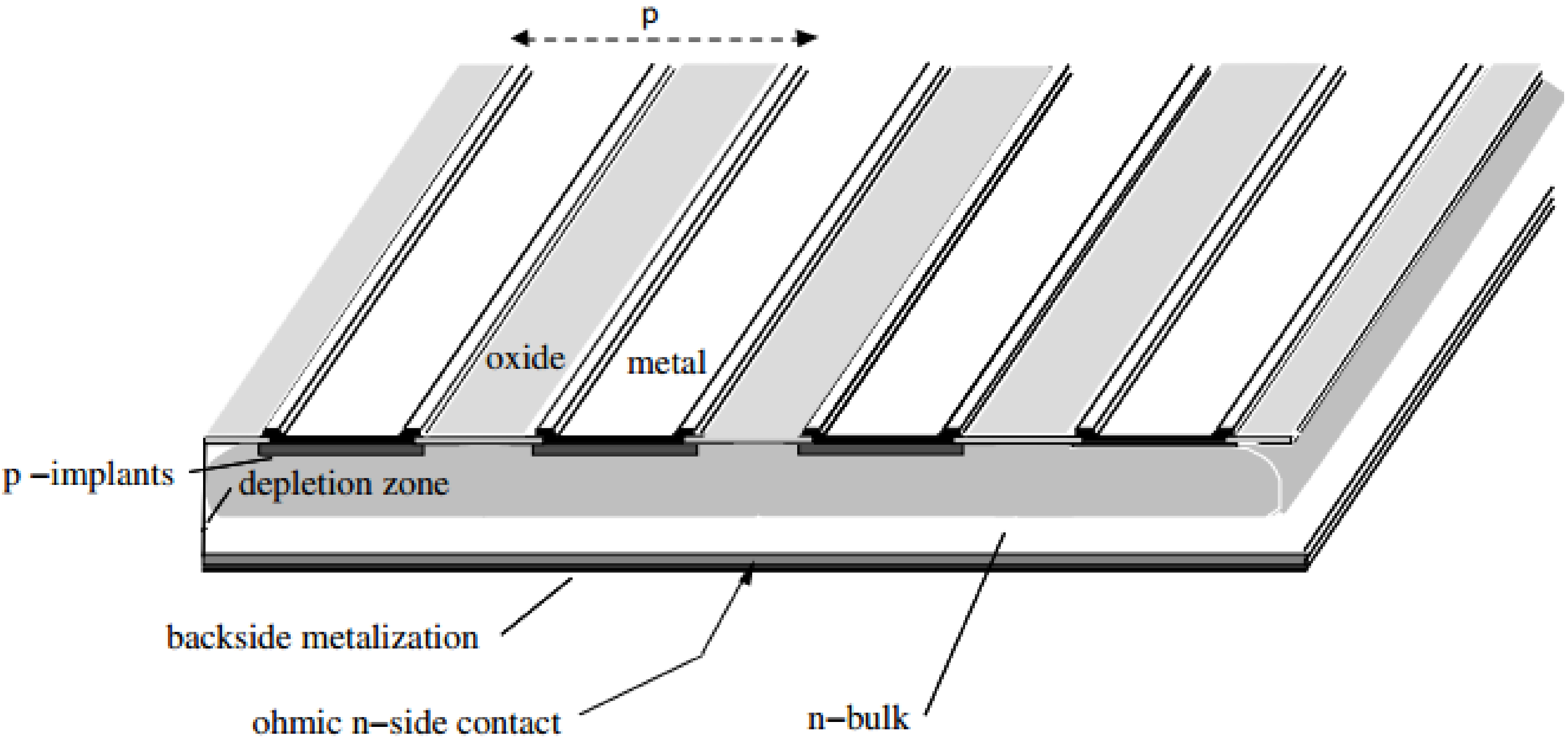
The readout electronics should be designed to temporarily store the hit pattern belonging to an individual event which is judged possibly interesting on the basis of its topological or dynamical variables.

3) The typical particle physics application requires that one hit pattern (image) is one event.

- Other applications (like X-ray radiography) require instead that one image is made of many events (the individual X-ray conversions in the detecting medium). The readout electronics should therefore not select events, but accumulate them for a preset period of time under known and stable conditions.

1.1.2 Working Principle and Operating Characteristics of Segmented Silicon Detectors

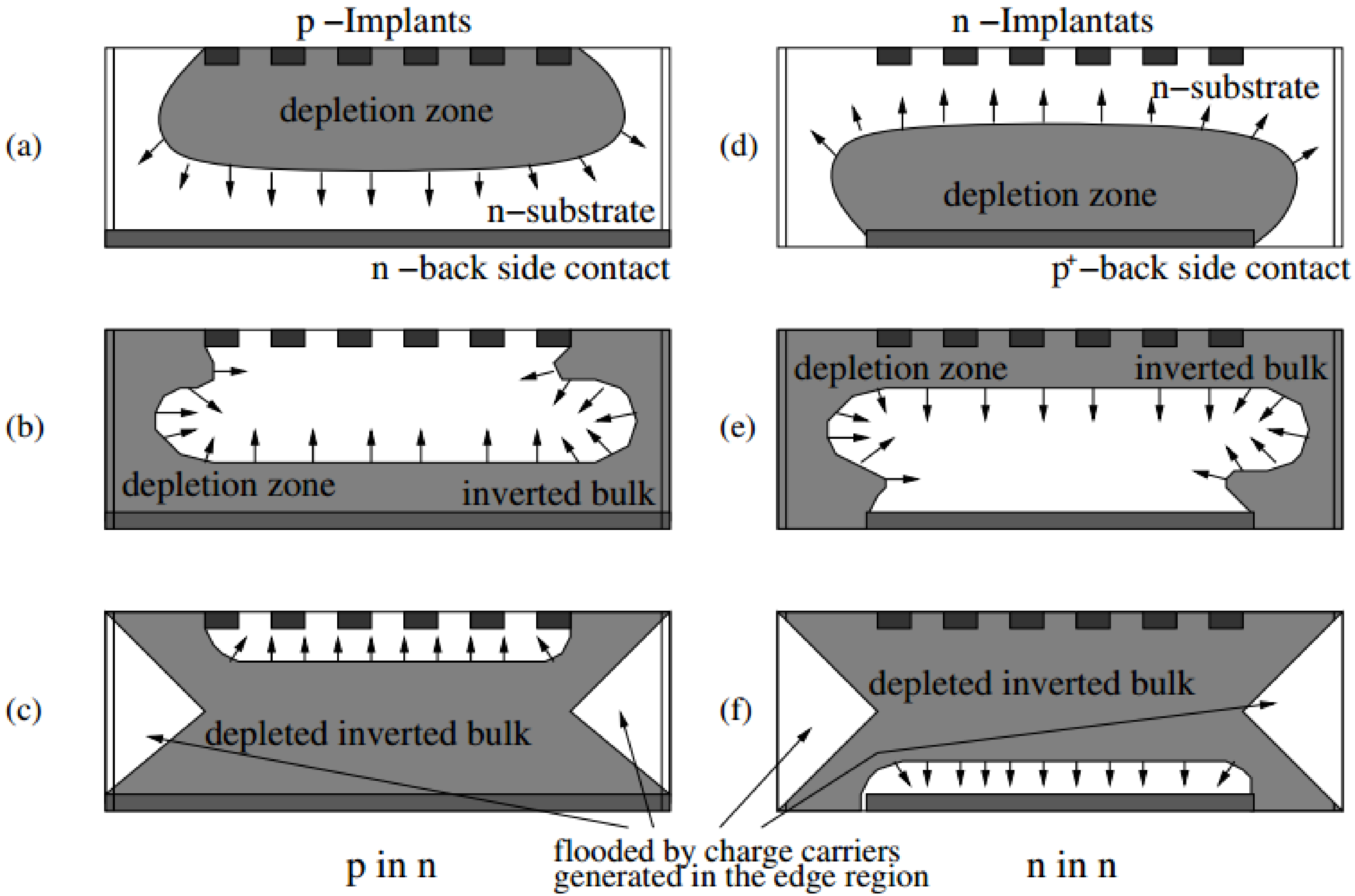
1) Single-sided microstrip detectors are a special case of semiconductor detectors in which one electrode is segmented in thin parallel strips.
2) Ion implantation and photolithographic techniques are used to selectively dope the surfaces of the semiconductor wafer of typically 300-μm thickness and to deposit the metallization patterns necessary to extract the signals.



- Sketch of a single-sided microstrip detector. In this example strips are p+ implants on n type silicon. They are repeated at a pitch p. In between the strips, metallizations are regions with a silicon dioxide layer. The detector is operated by applying a voltage between the backside metallization and the strips. In this example the detector is only partially depleted. Increasing the voltage would extend the depletion zones toward the backside and toward the neighboring strips.

- Resistivity : $\rho=1/eN\mu$,where e is the elementary charge, μ is the majority carrier mobility
- Depletion zone thickness : $W = \sqrt{2\varepsilon_0\varepsilon_{si}(V/eN)} = \sqrt{2\varepsilon_0\varepsilon_{si}(V\mu p)}$
- The depletion zone can be seen as a charged capacitor of value C per unit area : $C = \frac{\varepsilon_0\varepsilon_{si}}{W} = \sqrt{e\varepsilon_0\varepsilon_{si}N/2V}$

Increasing the reverse bias voltage V increases the thickness of the depletion zone and reduces the capacitance of the sensing element, and both these effects increase the signal-to-noise ratio (S/N).


p –Implants
n –Implantats
(a)
depletion zone
n–substrate
n –back side contact
(d)
n–substrate
depletion zone
p+–back side contact
(b)
depletion zone
inverted bulk
(e)
depletion zone
inverted bulk
(c)
depleted inverted bulk
(f)
depleted inverted bulk
p in n
flooded by charge carriers
generated in the edge region
n in n