A review of advances in pixel detectors for experiments with high rate and radiation

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Section 2th

[Space-time point resolution]

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In general, the tasks of pixel detectors in HEP experiments can be listed as follows:

1. Pattern recognition and identification of particle tracks at large background and pile-up levels
2. Measurement of primary and secondary vertices;
3. Multi-track separation and vertex identification in the core of (boosted) jets;
4. Momentum measurement of particles (together with other detectors, like strip detectors);
5. Measurement of specific ionization.

- **Space point and direction measurements**

The precision of a space-point measurement enters the momentum resolution in a track measurement with N detector layers as given by the Gluckstern formula:

$$\frac{\sigma_{p_T}}{p_T} = \left(\frac{p_T}{0.3|z|} \frac{\sigma_{\text{point}}}{L^2 B} \sqrt{\frac{720}{N+4}} \right) \oplus \left(\frac{\sigma_{p_T}}{p_T} \right)_{\text{MS}}$$

Important for a precise momentum measurement is the point resolution, but also (quadratically) the total length L of the tracker and the bending field B. **The multiple scattering (MS) contribution** for a number of detector layers N can be written as

$$\left(\frac{\sigma_{p_T}}{p_T} \right)_{\text{MS}} = \frac{0.0136}{0.3\,\beta\,BL} \sqrt{\frac{(N-1)\,x/\sin\theta}{X_0}} \sqrt{C_N}\,, \qquad [L] = \text{m},\ [B] = \text{T}$$

More details about Gluckstern formula:

1. Generalization of the Gluckstern formulas I: Higher orders, alternatives and exact results 10.1016/j.nima.2008.02.016
2. Generalization of the Gluckstern formulas II: Multiple scattering and non-zero dip angles 10.1016/j.nima.2009.05.024

• Space-point reconstruction methods

Resolutions achievable with classical space point reconstruction methods can be classified as follows:

1. **For single hit clusters** — independent of having binary (yes/no) or analog origin—resolution is given by the well-known **pitch/$\sqrt{12}$** RMS resolution assuming a flat prior distribution of track position within the pixel (most conservative assumption).
2. **For analog hit cluster** — The reconstructed hit position x_{rec} can be obtained e.g. by the centre of gravity method:

$$x_{\text{rec}} = \frac{\sum (S_i + n_i)\, x_i}{\sum (S_i + n_i)}$$

3. **If two hit clusters is the most common case for pixel detectors the η-reconstruction method is optimal for space reconstruction of Gaussian charge clouds**, since detector effects are automatically included. For two adjacent left and right electrodes the function

$$\eta = \frac{S_L}{S_L + S_R}$$

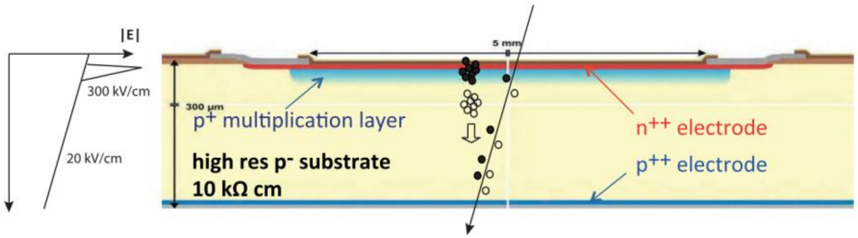
• Time measurement

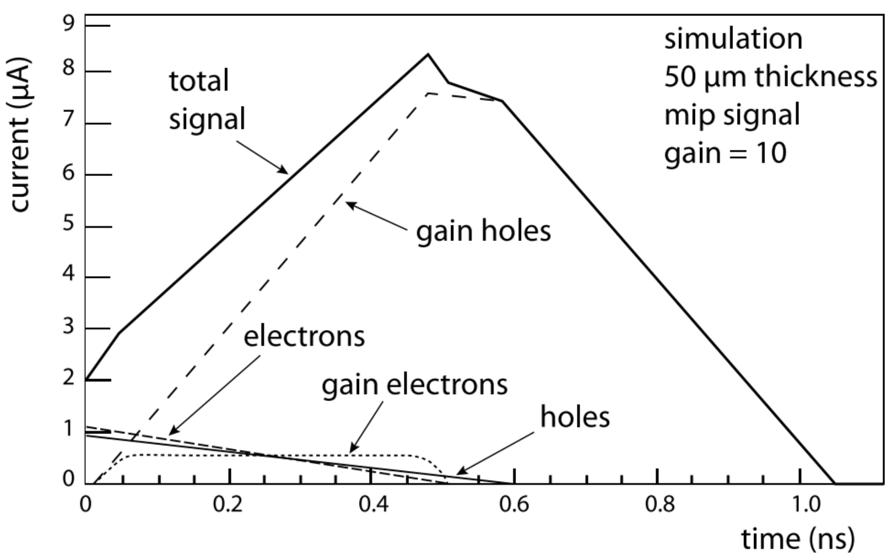
The charge collection time, i.e. the time until the arrival of the last electron at the pixel electrode, typically is in the order of 3–10 ns, depending on sensor thickness and E-field.

slew rate

$$\frac{\mathrm{d}V}{\mathrm{d}t} \approx \frac{\text{signal height}}{t_{\text{rise}}}$$

LGADs (low gain avalanche diodes):





The signal induced on the electrodes:

- The individual e/h parts of this contribution are small before amplification takes place and end when the last carriers have arrived at their respective electrodes.
- Amplification electrons created in the multiplication layer reach the top electrode almost instantaneously and their contribution to the induced signal current according to Shockley–Ramo theorem

Question from Ryuta :
Except this radiation hardness, what would be not superior (or technical difficulties), compared with the other normal silicon pixel detectors ?

It seems that all current developing for pixel detector is focusing on radiation hardness. But in my opinion, some superiors are included in 'radiation hardness' which is not really to change radiation hardness. Some improvements are to **weaken influence of radiation damage** (but there are sufficient damages in matter), common method to implant high resistance layer (high electric field), most papers also mention it. Another one is really to **improve radiation hardness** (I mean to modify materials in atomic level , strengthening crystal lattice… May be high resistance layer has firm crystal lattice in some respects, but I think they are different, at least in original intentions). Most of superiors aim radiation hardness, though by different methods.

There are many superiors which I don't know, if I mistake any concepts, please let me know. Thanks!