A precise digitization of Si detectors

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March 21, 2017

Introduction

- overview of the Si detector and digitization
- key issues in digitization

the 1st version code

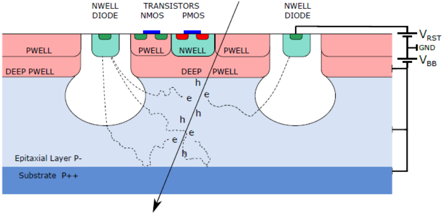
- condition
- implement

result

- resolution simulation

principle of Si detector

- pixel detector
  - CMOS
  - SOI
  - hybrid
  - DEPFET
- micro strip detector

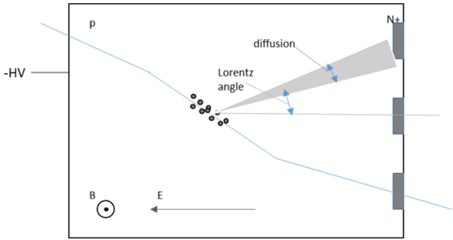


process of digitization[1]

- *SimTrackHits → TrackerPluser → TrackerHits → Clustering*
  - SimTrackerHits: the hits in Mokka(center point of each step)
  - TrackerPluser: the charge collected in the diode(transport of electrons and holes)
  - TrackerHits: a cluster of hitting pixels(electric noise ENC)
  - Clustering: the final poisition(special algorithm)

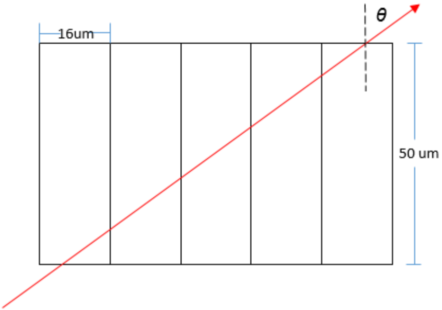
transport of electron and hole

- Drift and Diffusion
  - Drift: main power of charge collection
  - Diffusion: main reason for a cluster in small incidence angle
- Lorentz angle
  - $tan(\theta) = \mu_H \times B$



readout and algorithm

- analog readout
  - COG algorithm: when the cluster size $\leqslant 2$
  - η algorithm: when the energy deposited is nonlinear and cluster size $\leqslant 2$
  - head-tail algorithm: when the cluster size > 2
- digital readout
  - don't find algorithms specially for digital readout
  - may be deduced from analog algorithm



condition

- detector model: P-N junction
- Lorentz angle: 10 degree
- noise and threshold are considered
  - threshold = 5×noise
- algorithm
  - analog: COG and head-tail
  - digital: head-tail
- very primary!

SimTrackHits $\rightarrow$ *TrackerPluser*

- get hit track from VXDCollection
- calculate the number of electrons ionizing from the track(Poisson sampling)
  - $N_{electron} = \frac{EDep}{3.65eV}$
- For every electron calculate the final position when it reaches the surface of sensitive layer
- Map all the electrons to pixel array, calculate pixel center and electron numbers it collects.

TrackerPluser $\rightarrow$ *TrackerHits*

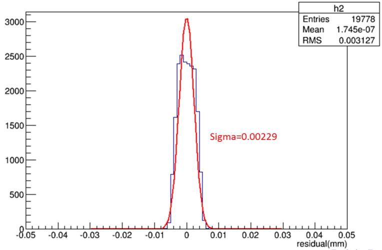
- get the cluster of hitting pixels
- smear electron numbers with ENC(noise in e^-)
- compare with the threshold(e^-),if $>$ threshold, the number will be set to 1, else to 0

TrackerHits $\rightarrow$ Clustering

- use head-tail algorithm to calculate the final position
  - $x_{hit} = \frac{x_{min}+x_{max}}{2}$ (x_{min}, x_{max}) present the leftmost and rightmost pixels
  - $y_{hit} = \frac{y_{min}+y_{max}}{2}$ (y_{min}, y_{max}) present the leftmost and rightmost pixels

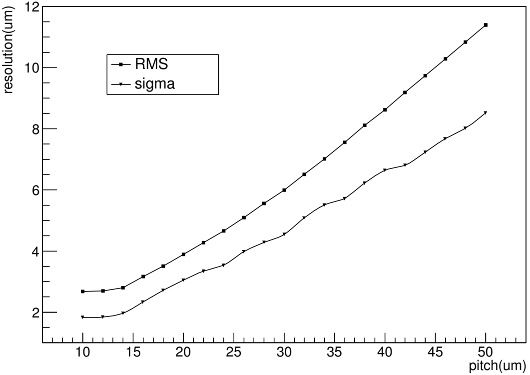
resolution

- condition
  - 50000 10GeV μ^-, normal incidence, pitch=16um, T=300K, ENC=20e^-, Threshold=100e^-,digital readout
  - cut: $-0.05mm < residual < 0.05mm$
- result in local coordinate
  - Residual = detector measured position − actual position



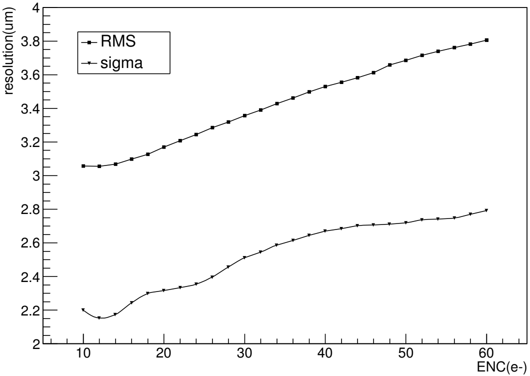
resolution

- change along with pixel pitch



resolution

- change along with ENC



formula of electron's transportation

$$\mu(x) = \frac{\mu_0}{(1+(\frac{E(x)}{E_c})^{\beta})^{\frac{1}{\beta}}}$$

$$\upsilon(x) = \mu(x)E(x)$$

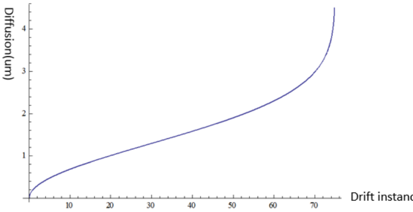
$$t = \int \frac{1}{\upsilon(x)}dx$$

$$\sigma = \sqrt{2Dt} \quad \text{while } D = \frac{kT}{q}\mu\bar{(}x)$$

- E(x): the electric field
- μ: electron mobility
- t: drift time
- D: diffusion coefficient
- σ: cluster size

transportation equation for P-N junction model

- P-N junction electric field $E_{pn}(x)$
  - $E_{pn}(x) = \frac{qN}{\varepsilon}(x - W)$
  - $\mu(x) = \mu_0$
- $t = \int_{x_0}^{0} \frac{dy}{\mu_0 E(x)} = \frac{\varepsilon}{qN\mu} ln(\frac{W}{W - x_0})$
- $\sigma = \sqrt{\frac{2\varepsilon kT}{q^2 N} ln(\frac{W}{W - x_0})}$



algorithm[2]

- COG algorithm
  - $x_{COG} = \frac{\sum_{cluster} x_i q_i}{\sum_{cluster} q_i}$
- η algorithm
  - $x_\eta = x_{left} + pitch \frac{\int_0^{\eta_0} \frac{dN}{d\eta} d\eta}{\int_0^1 \frac{dN}{d\eta} d\eta}$ while $\eta = \frac{q_R}{q_R + q_L}$
- head-tail algorithm
  - $x_{headtail} = \frac{x_R + x_L}{2} + \frac{q_R - q_L}{2\bar{q_{ln}}} pitch$

silicon detector parameters[3, 4, 5, 6, 7, 8, 9, 10]

type	name	pitch	thickness	efficiency	power	cluster	resolution	fake hit	frequency
HV-CMOS	-	21um	50um	98%	3.05uW/pixel	6pixels	3um	-	20KHz
CMOS	ALPIDE	30um	50um	99%	40mW/cm^2	2-3pixels	5um	$< 10^{-6}$	100KHz
CMOS	MIMOSA	21um	50um	99.5%	150mW/cm^2	5×5pixels	4um	$< 10^{-4}$	5KHz
DEPFET	-	50um	50um	100%	5W	1-2pixels	9um	-	50KHz
SOI	CPV	16um	75um	100%	-	-	-	-	-

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