Development of AC-LGAD detectors with finer pitch electrodes suitable for future hadron collider experiments

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US-Japan Hawaii Symposium 22-24 May, 2023

Present research has been carried out in the framework of the US-Japan Collaboration with US collaboration institutes are:

Fermilab, Brookhaven National Laboratory, University of California Santa Cruz

Motivation

Low-**G**ain **A**valanche **D**iode (**LGAD**) detector

Detector with precision timing resolution!!!

In future higher luminosity hadron colliders, tracking will be difficult due to high particle density environment. An LGAD sensor with good time resolution will be one of candidate technologies to solve this.

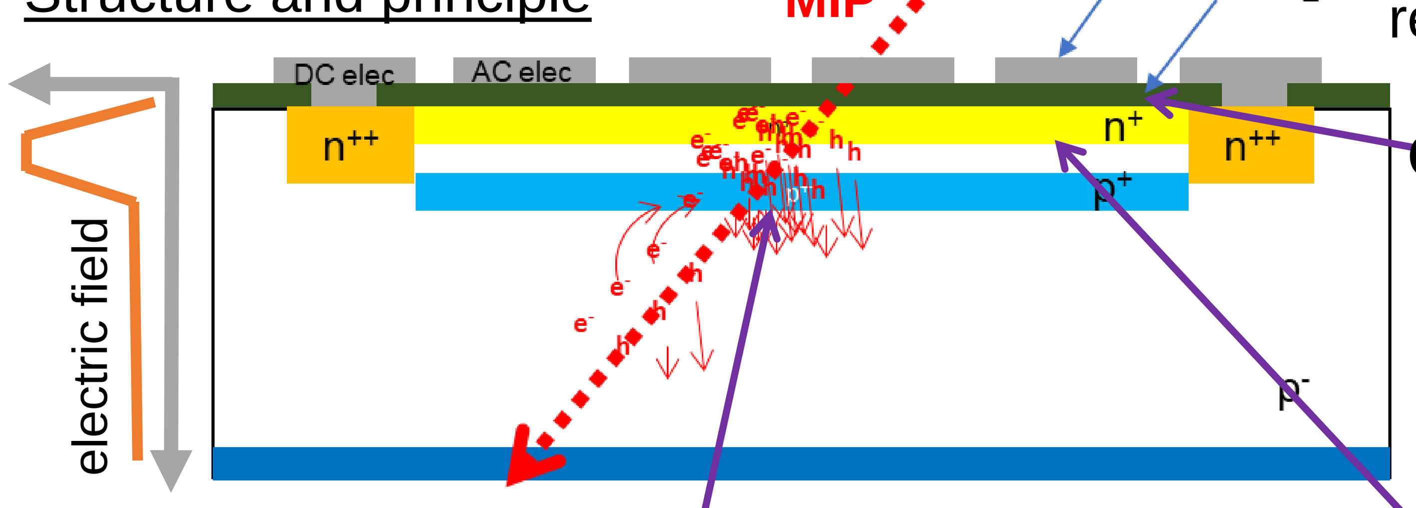
Tracker requirements in **future hadron collider**

1. High spatial resolution : o(10um)
2. High timing resolution : ~30ps
3. High radiation tolerance : ~1x10[16] n_{eq}/cm^2

Strong candidate

AC-LGAD is capable of satisfying all requirements.

Structure and principle



Oxide layer signal is read out by AC coupled electrodes

Conventional LGAD idea

Gain layer
High electric field : induce electrode avalanche

High timing resolution

NEW LGAD idea

Uniform gain layer
No dead region : enable to make electrode pitch finer

High spatial resolution

AC-LGAD samples were fabricated by HPK and we examined the performance concerning the three requirements: spatial resolution, timing resolution and radiation tolerance. The results are shown about spatial resolution, timing resolution and radiation tolerance.

Result1 : Timing resolution

Three contributions in timing resolution

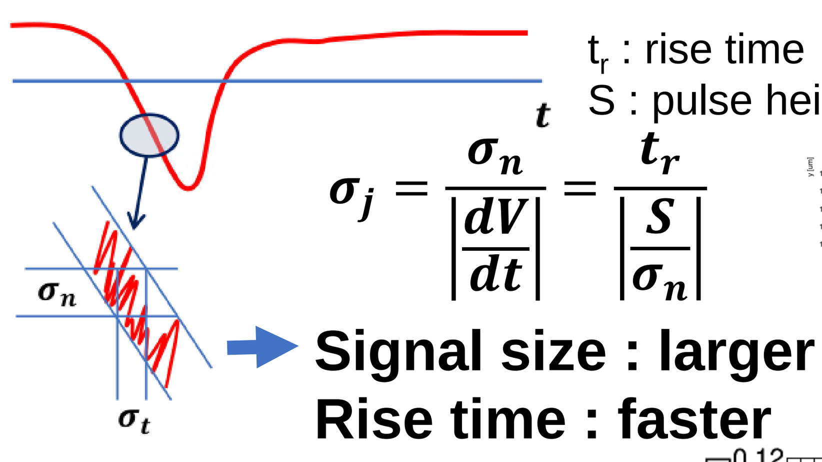
$$\sigma_t^2 = \sigma_{tw}^2 + \sigma_j^2 + \sigma_L^2$$

1. Time walk σ_{tw}

The effect of in arrival time of signals with different heights for pre-fixed threshold. → **Using a constant fraction threshold**

2. Jitter σ_j

The effect of electronics noise



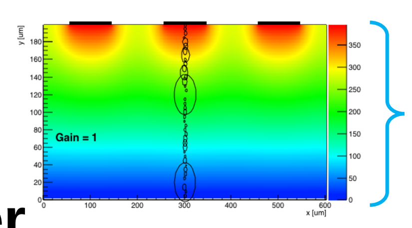
t_r : rise time
S : pulse height

$$\sigma_j = \frac{\sigma_n}{\left|\frac{dV}{dt}\right|} = \frac{t_r}{\left|\frac{S}{\sigma_n}\right|}$$

→ **Signal size : larger**
Rise time : faster

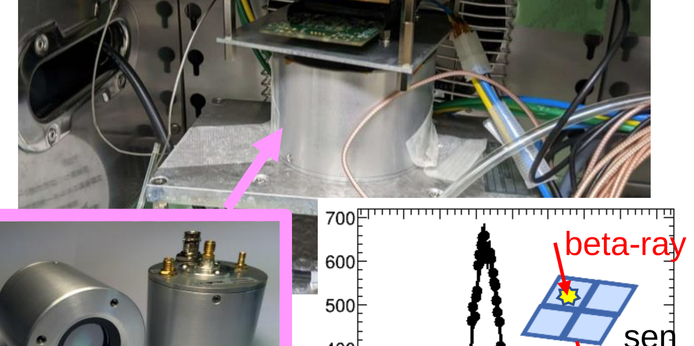
3. Landau noise σ_L

Due to non-uniform charge deposit in depth of MIP particle → **better in thinner sensor**

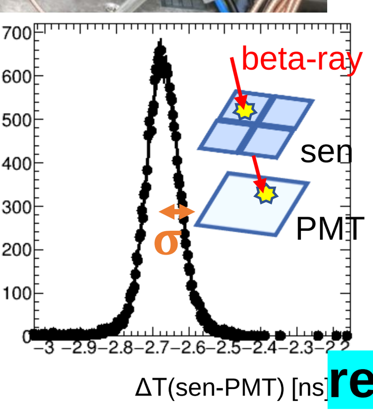


Various thick sensors (20um/ 30um/50um) were produced.

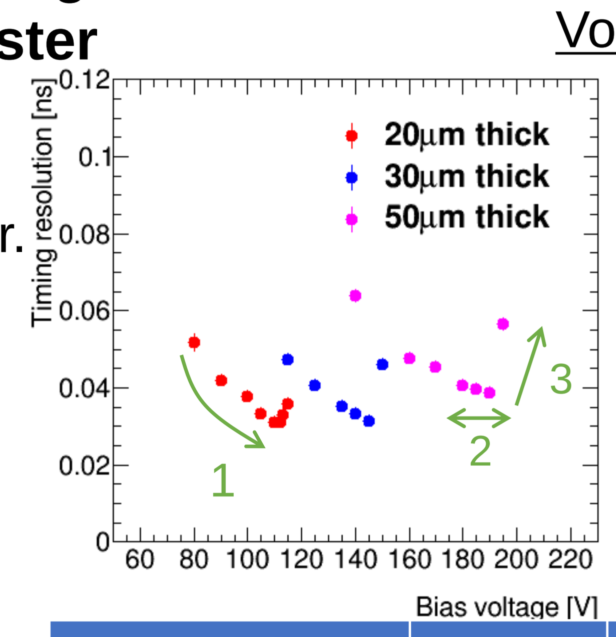
Timing resolution is calculated from time difference of PMT and sensor.



MCP-PMT240
~ 8ps timing resolution



Voltage dependence



1. Getting better with increasing gain
2. Saturated : drift velocity is saturated
3. Getting worse : noise effect

Thick	50um	30um	20um
Time resolution	38.8 ps	31.5 ps	31.2 ps
jitter	9.8 ps	11.8 ps	15.9 ps
Landau noise	37.5 ps	29.2 ps	26.8 ps

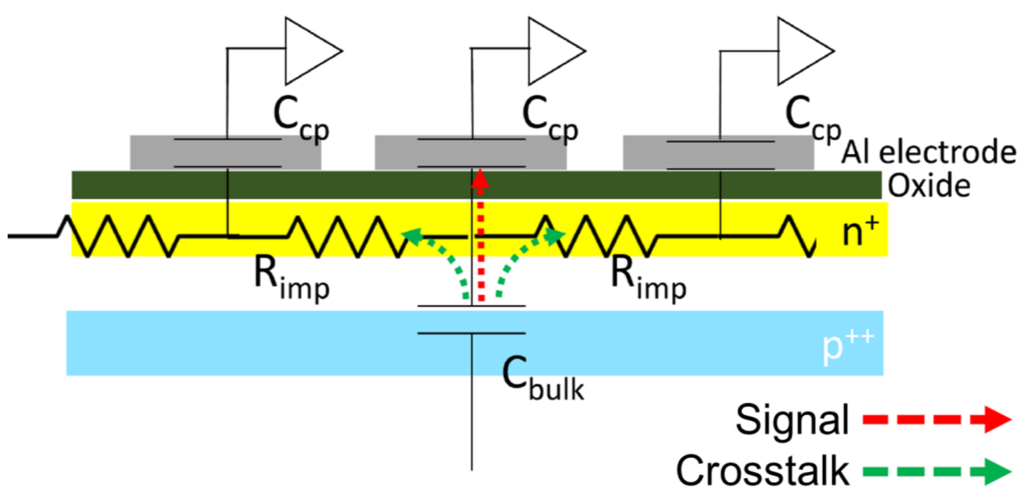
Thinner sensor has higher timing resolution thanks to smaller landau noise !

Result2 : Spatial resolution

Two approaches for high spatial resolution

1. **Finer pitch** : In high particle density environment, need to suppress charge sharing (our approach)
2. **Using charge sharing** : effective in low occupancy environment, better resolution achievable even with coarse electrodes.

Signal readout model



Signal size

$$Q = \frac{Z_{R_{imp}}}{Z_{R_{imp}} + Z_{C_{cp}}} Q_0$$

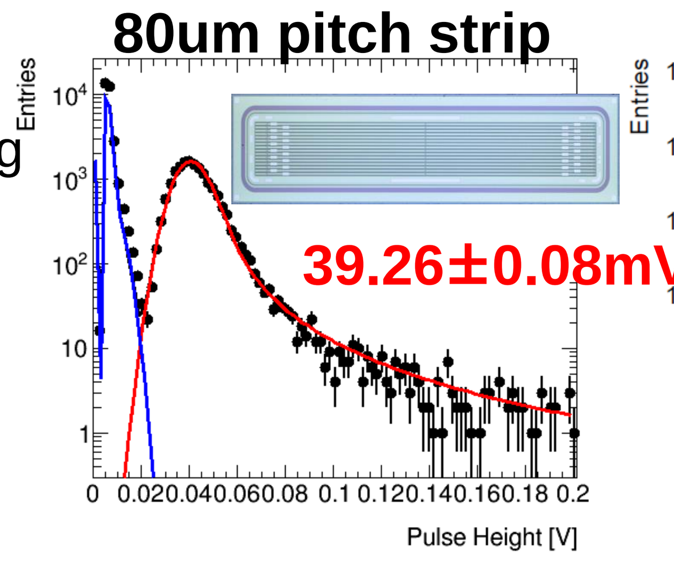
- R_{imp} : n^+ doping concentration
- C_{cp} : electrode size and oxide thickness

To make signal large and to separate from noise… **Larger R_{imp} and C_{cp}**

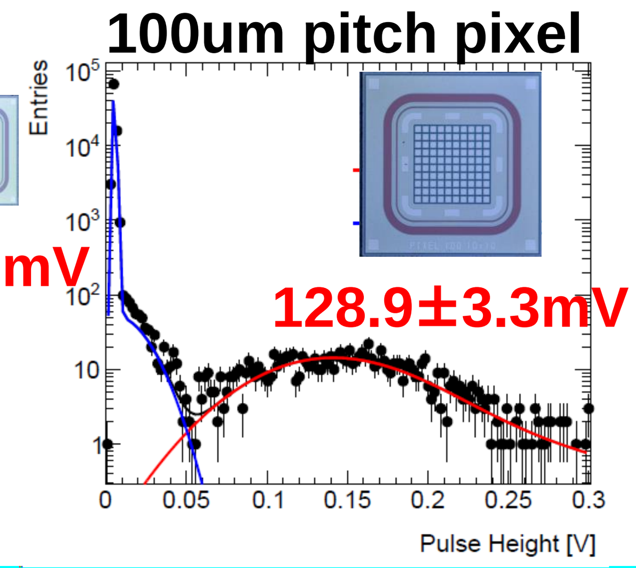
Signal size

x40 R_{imp} by reducing n^+ doping concentration and x5 of C_{cp} by making oxide thinner signal height measured using beta-ray (90Sr).

80um pitch strip



100um pitch pixel



80um pitch strip and 100um pitch pixel are realized !

Result3 : Radiation torrelance

Serious for LGAD

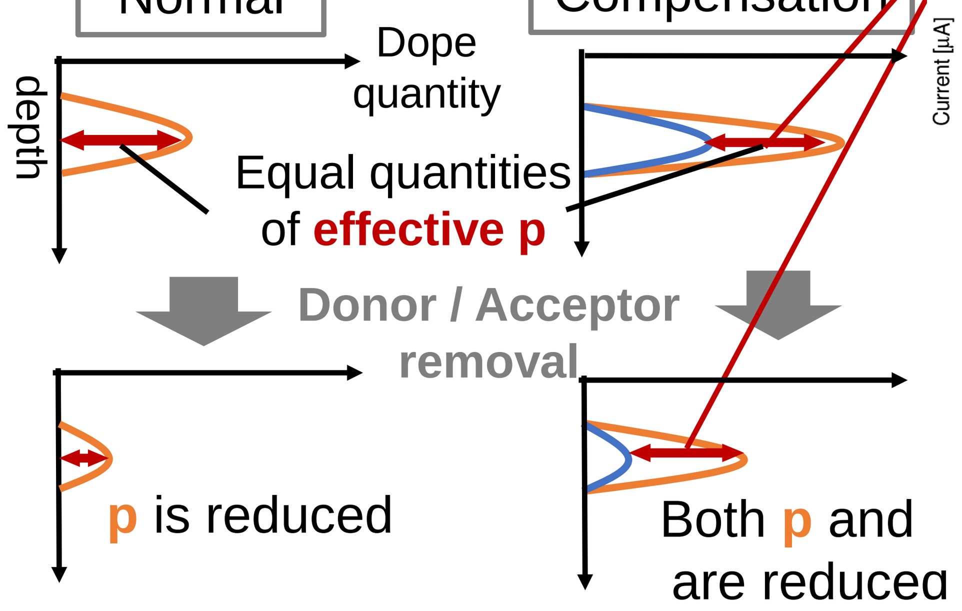
Radiation damage → NIEL (bulk) , TID (oxide) , **acceptor removal**

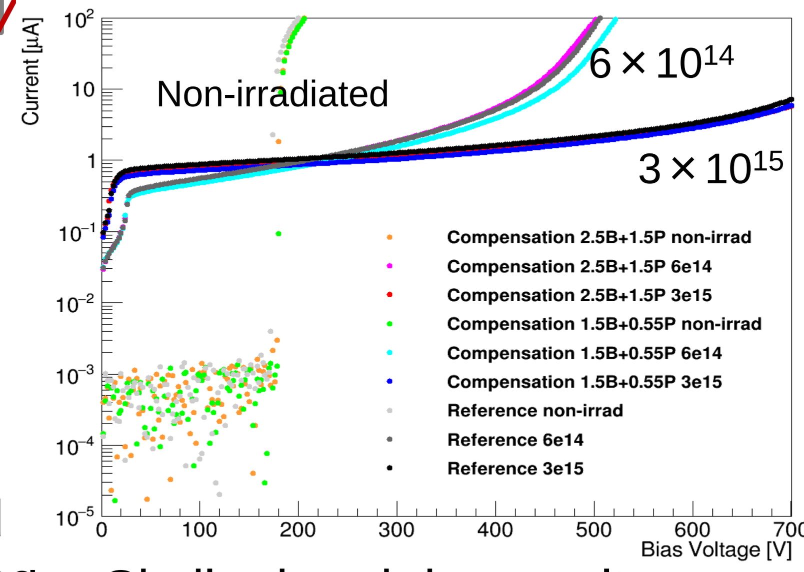
Because p^+ in gain layer reduced by acceptor removal, higher voltage is required for gain, and exceeds the limit of the device. Current limit is 1-2 x 10[15] n_{eq}/cm^2.

→ **two new ideas**

Idea1 : Compensation method

Add Boron + Phosphorus in p^+ layer → **The quantities of effective p remains the same**



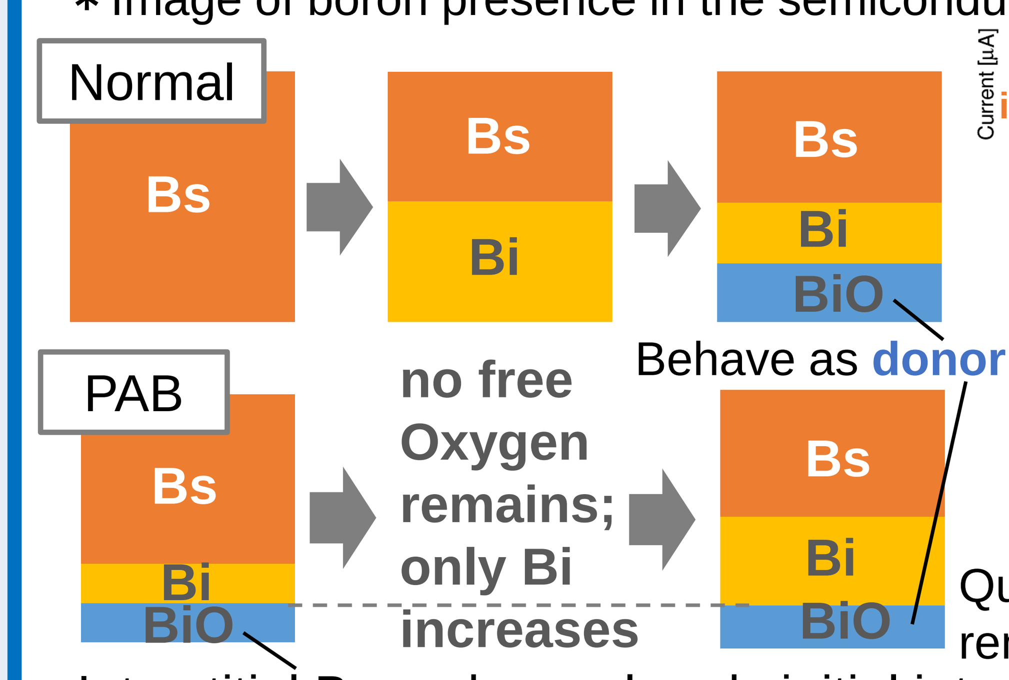


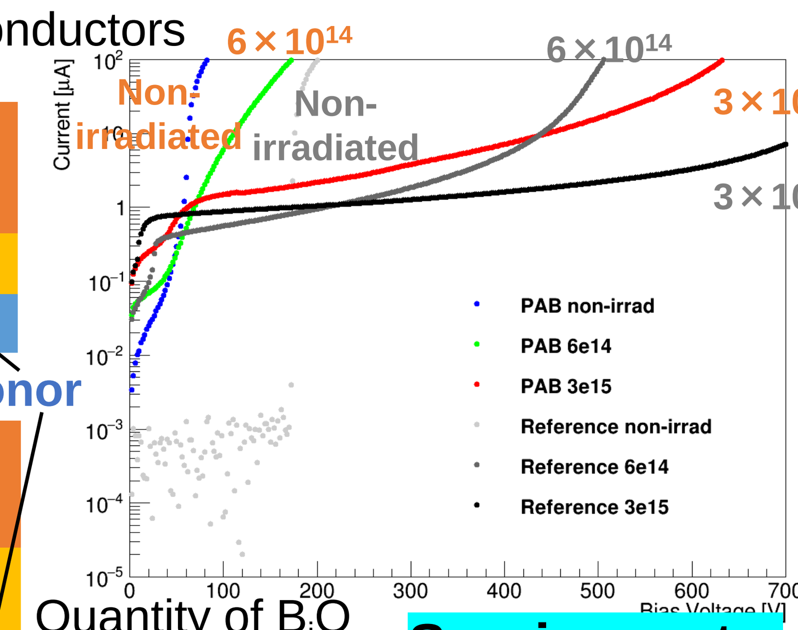
Similar breakdown voltage → need to investigate removal coefficients.

Idea2 : Partially activated boron (PAB)

Large number of B_i at the beginning to clean O_i

∗ Image of boron presence in the semiconductors





Quantity of B_iO remains the same

Interstitial Boron have already initial interstitial boron and oxygen are already combined with Oxygen

Survive up to 3x10[15]
Very promising !

Conclusion

For inner tracker in future hadron colliders, we are developing AC-LGAD.

Timing resolution
~31ps (beta-ray)
Thinner sensor is better

Spatial resolution
100um pitch pixel
80um pitch strip

Radiation torrelance
2 new idea
PAB survived up to 3e15 irradiated

AC-LGAD works well ☺

Next subject
→ **ASIC for multiple channel readout**
→ **Radiation hardness AC-LGAD**