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Study of time resolution of low-gain avalanche detectors

University Of Tsukuba K. Onaru, K. Hara, D. Harada, S. Wada, KEK K. Nakamura, Y. Unno

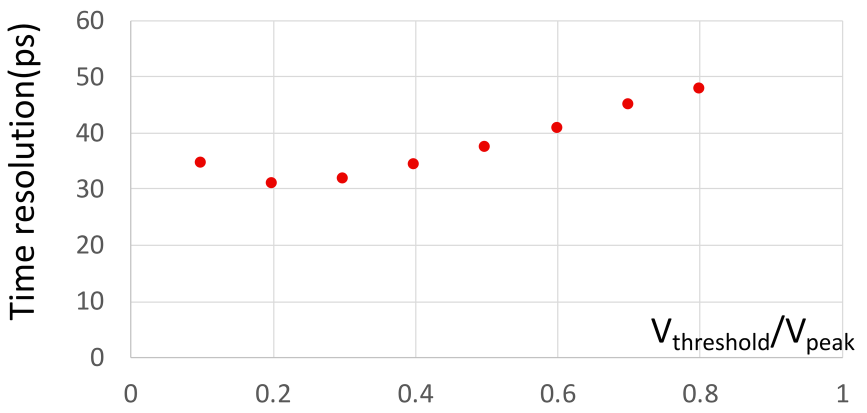
Low Gain Avalanche Detector

- N^+ in P type silicon detector
  - P^+ layer under N^+ readout implant
    -> High Electric Field at P^+ - N^{++} junction
    -> Avalanche

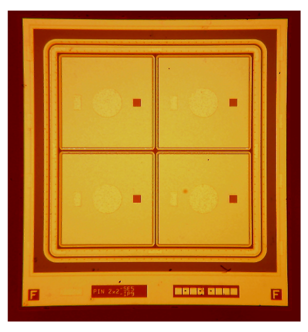
➢ Fast signal + High S/N ratio @gain~10
= high time resolution

✓ Time resolution ~30ps @FNAL Test beam

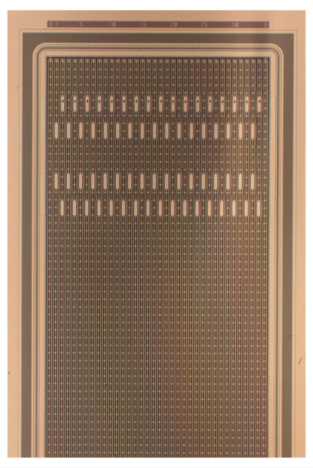
LGAD structure



Pad-type(ATLAS/HPK)

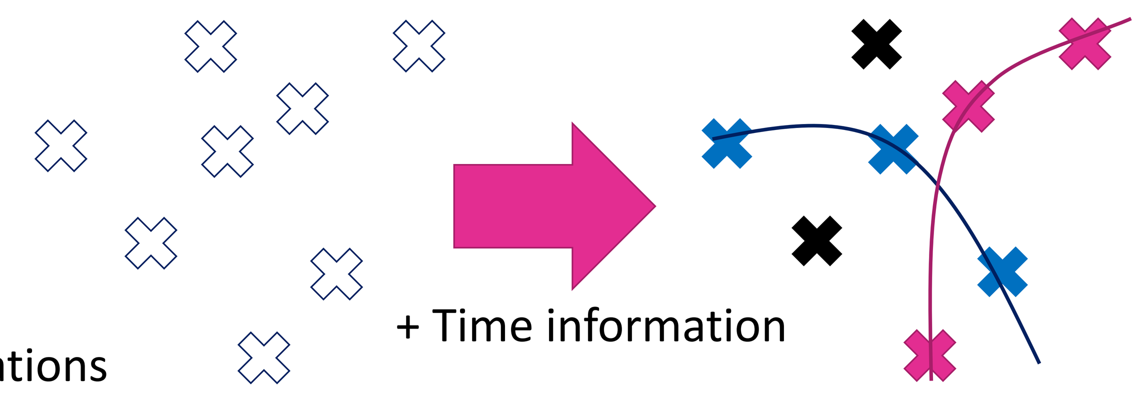


Strip-type(KEK/HPK)

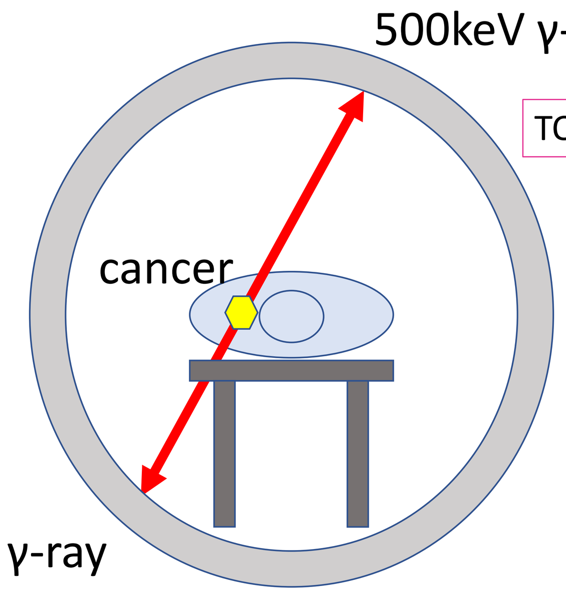


Applications of LGAD

- Timing Detector for future colliders
  - Additional time information to
    hits->reduce wrong track combinations
    tracks-> Identify the vertex position
    (30ps time resolution = 1cm)
  - ➢ 4D detector



- TOF-PET
  - Cancer diagnostic equipment
  - Measure annihilation position from difference of flight times of annihilation gamma rays
  - Time resolution = position resolution of annihilation point



Time resolution measurement using β-rays

- We measured time resolution in FNAL beam test ~ 30ps
  - Is it possible to measure time resolution more easily using a beta source?
  - A measurement system was developed using FlashADC CAEN DT5742
    5GHz 10bit time sampling(200ns FS)
    0.25mV 12bit ADC($1V_{pp}$)
- Time resolution measurement
  - Stack 2 pad-type sensors (lower->Trigger&signal, upper->signal)

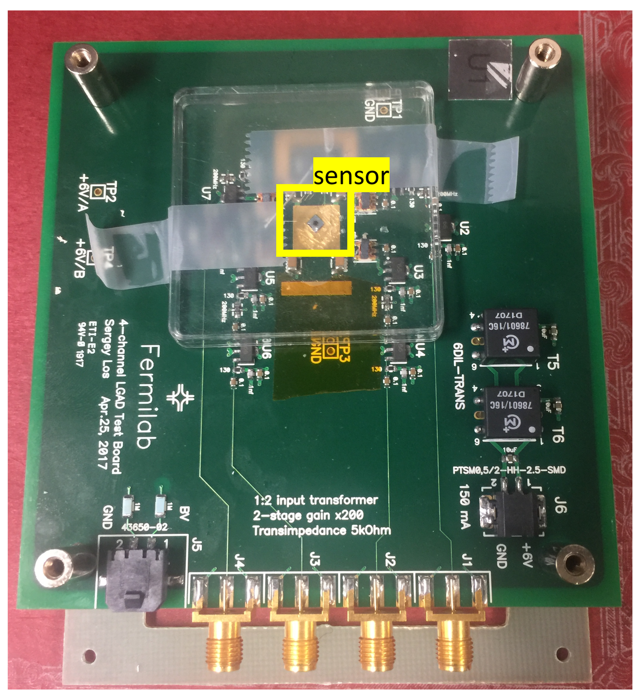
①Noise cut (Max ADC value > 450ADC ~ 100mV , time difference of Max ADCs < 3ns)
②Find time exceeding $V_{threshold}$ = factor × V_{peak}
③Evaluate the time difference of two overlapping sensors
④Evaluate the time resolution of each sensor

$$\sigma(T_1 - T_2) = \sqrt{\sigma(T_1)^2 + \sigma(T_2)^2}, \qquad \sigma(T_1) \approx \sigma(T_2)$$

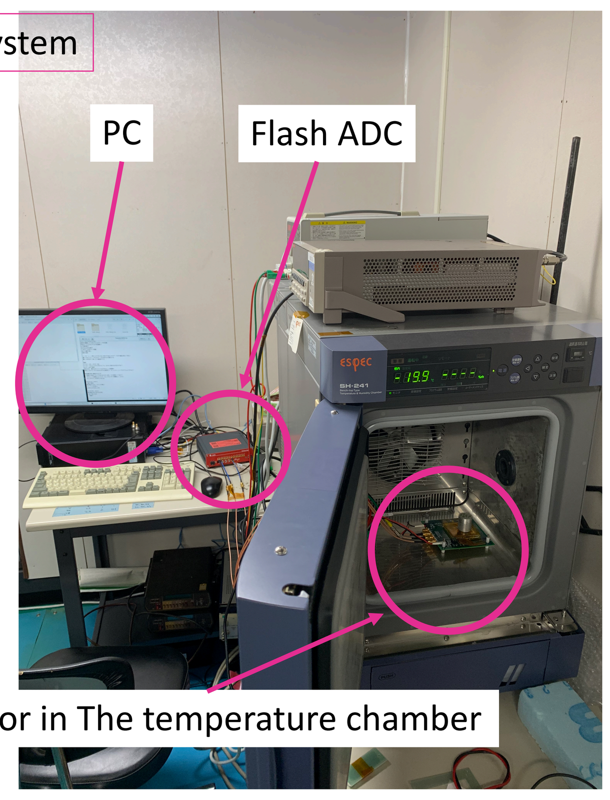
✓ Time resolution using beta-rays ~ 36ps

CAEN DT5742 FlashADC

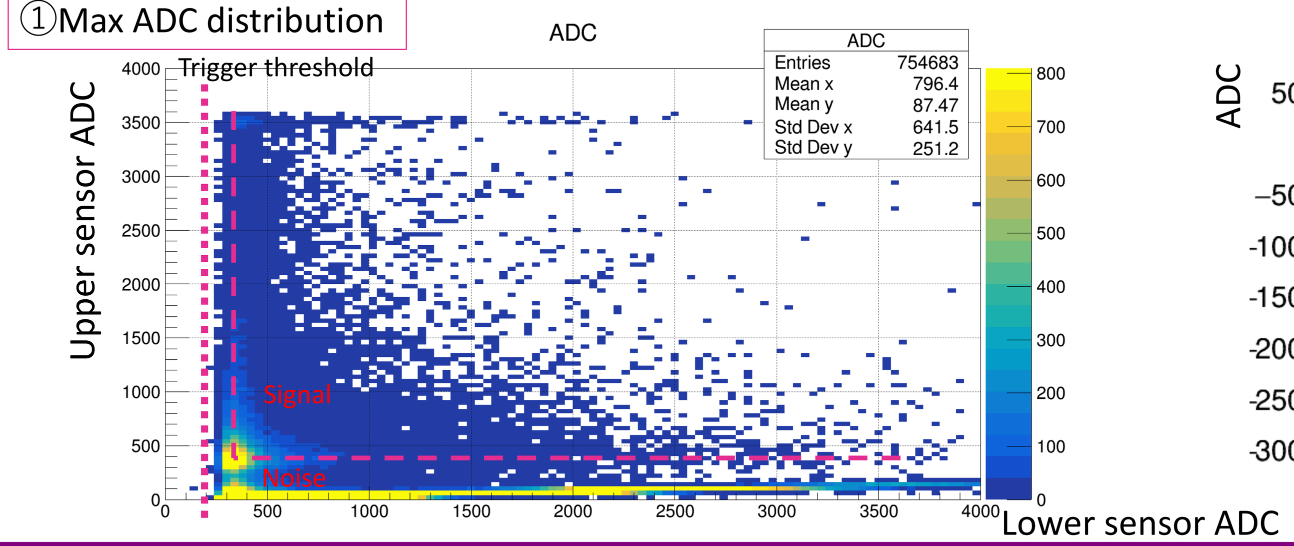
Amp + pad sensor



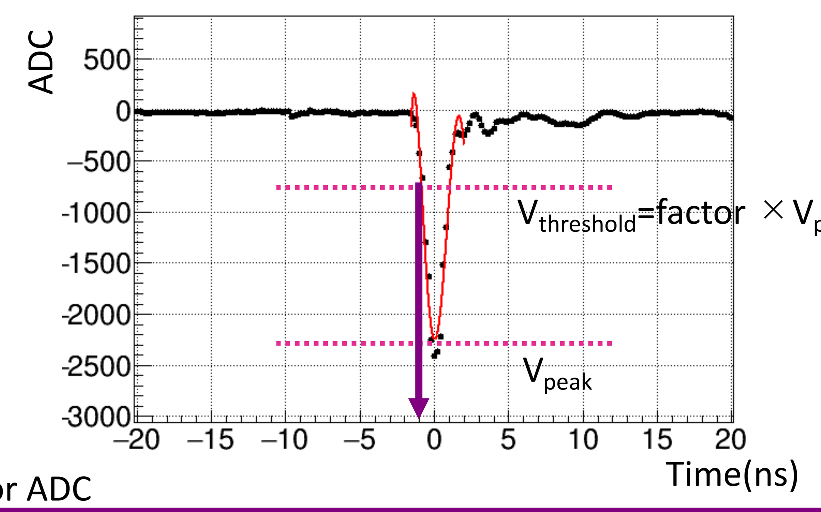
Measurement system



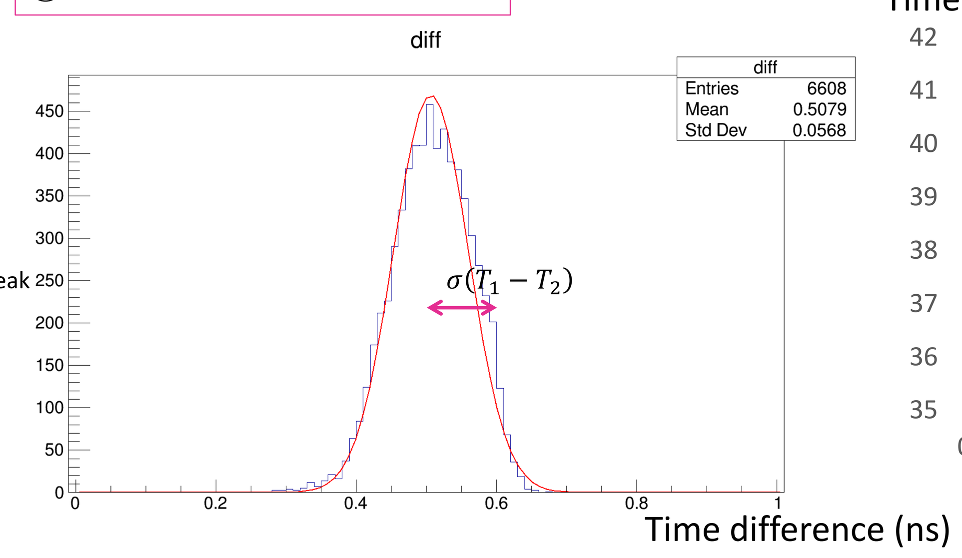
①Max ADC distribution



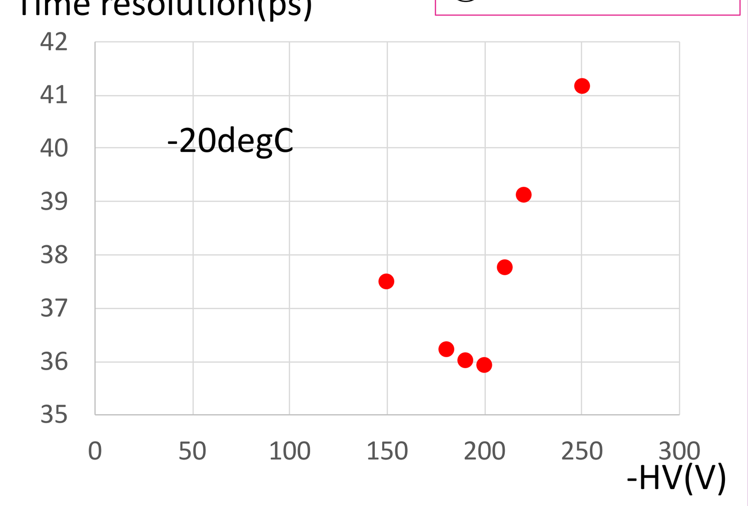
②Signal & fit



③time difference distribution



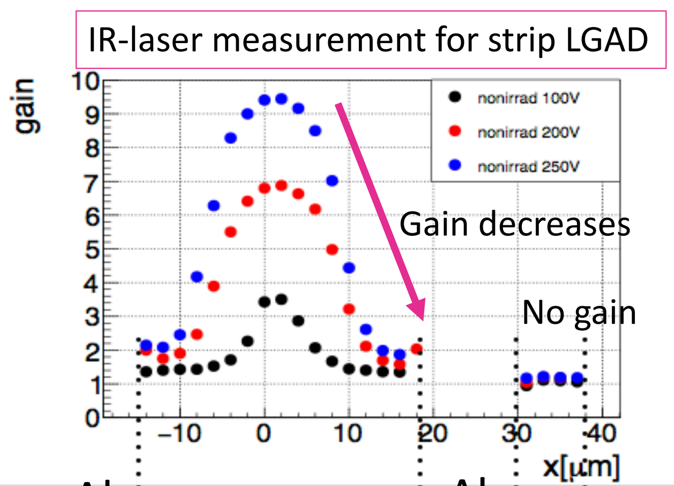
④Time resolution



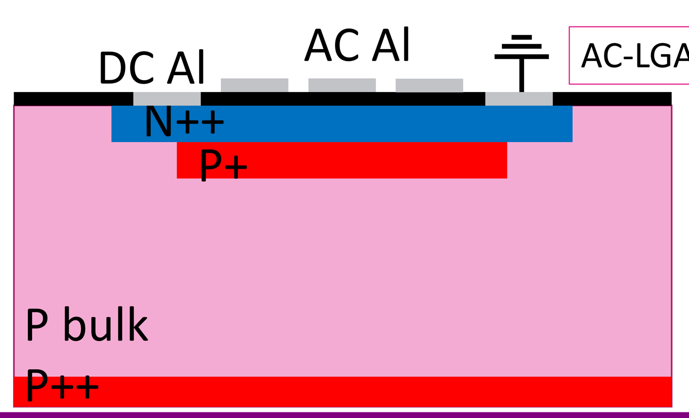
AC–LGAD TCAD Simulation

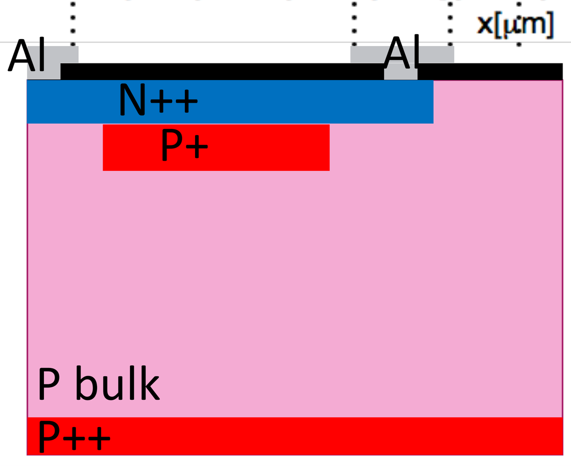
- Evaluated gain uniformity for strip type LGAD
  - Focused IR-laser was incident, and the position dependence of gain was evaluated from the amount of charge collected at each position
  - ✓ The gain decreases toward the edge of the P^+ amplification layer
  - ✓ No gain at the position where there is no P^+ amplification layer
- AC-LGAD is considered as a structure to solve these problems
  - Dope N^{++} in entire sensitive area
  - P^+ is doped similarly -> uniform amplification
  - Read signals from AC coupled Al electrodes
- designed an AC-LGAD using TCAD simulation
- Concerns
  - Enough gain?
  - Signal separation?
- Search for parameters to satisfy both

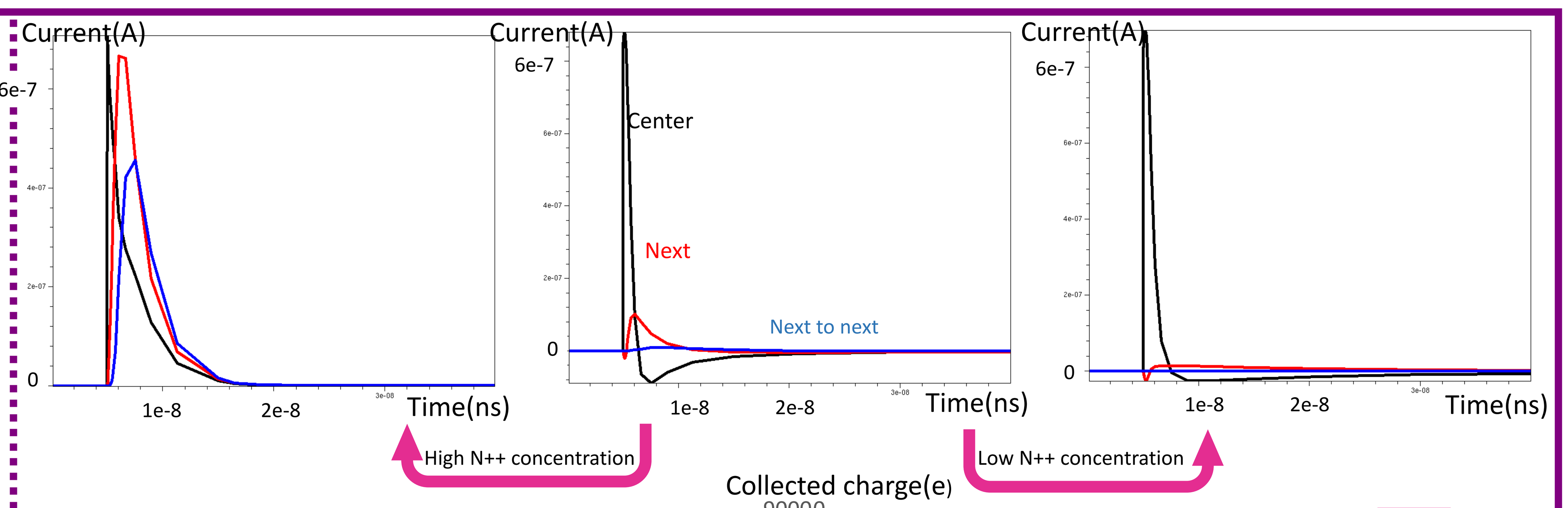
IR-laser measurement for strip LGAD



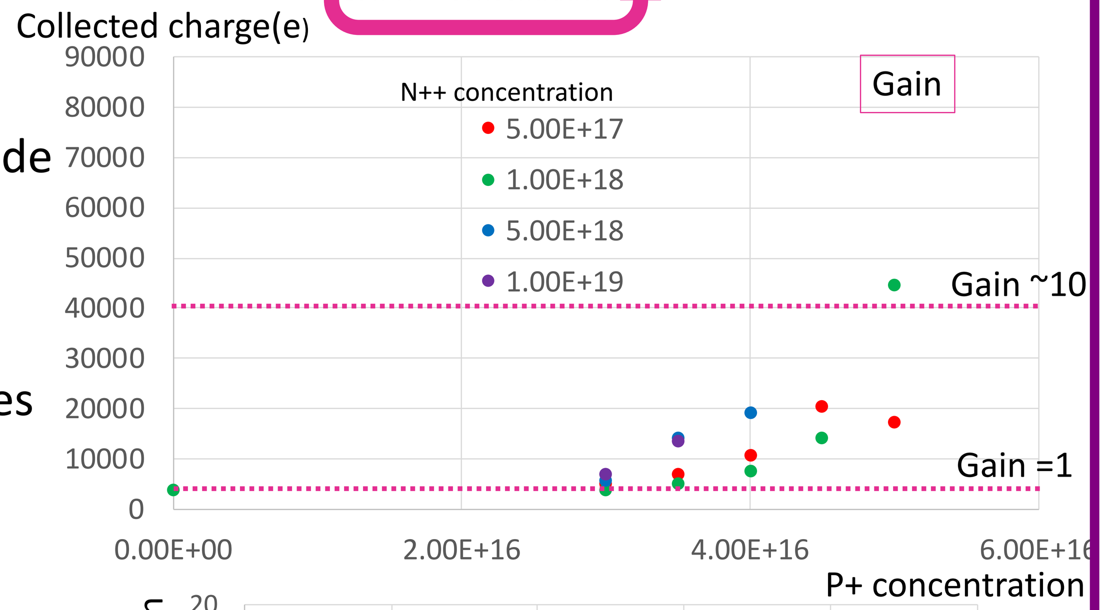
AC-LGAD structure



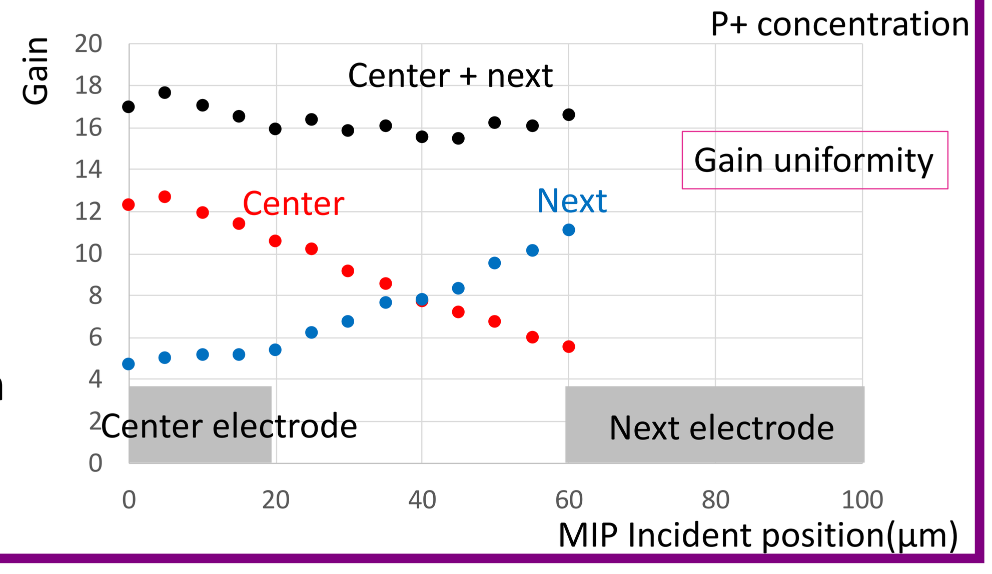




- MIP signal simulation
  - MIP is incident on the center electrode and measured charge collection
- N^{++} concentration
  - ✓ N^{++} high(low resistance)
    -> Charge flows to the next electrodes
  - ✓ N^{++} low(high resistance)
    -> No signal on the next electrode but charge collection is slow
- Gain
  - ✓ Enough gain
    Gain ~10 @N^{++}:1e18, P^+:5e16
- Gain uniformity
  - ✓ Uniform gain is obtainable in entire region



Gain uniformity



Summary

- We are developing LGAD for 4D detector
- Developed measurement system using Flash ADC and beta source. Can evaluate the time resolution to the same level as in the beam test
- TCAD Simulated AC-LGAD structure. AC-LGAD with enough and uniform gain can be designed

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