Interest in AC-LGAD development of the EIC-Japan

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APCTP Workshop on the Physics of Electron-Ion Collider
Howard Johnson Incheon Airport Hotel, Korea
1st - 4th Nov., 2022

Timing detector in the EPIC collaboration

- The EPIC detector is designed compactly with ~1.7 T magnetic field
  - Time-of-Flight (ToF) measurement is the main technique for particle identification (PID)
  - Excellent timing resolution is necessary for PID over a wide p_T and rapidity region

- Barrel (hadron end-cap) ToF requires a spatial resolution of 30 um (30 um) and a timing resolution of 30 ps (25 ps), which covers 10.9 m^2 (2.22 m^2)
  - Very high spatial resolution is not necessary for EIC due to not high multiplicity environment @ R ~80 cm

- Expected radiation is 10^{10} n_{eq}/cm^2 at top luminosity ~10^{34} $cm^{-2}s^{-1}$
  - This is very small compared to HL-LHC environment with $10^{15\sim16}$ n_{eq}/cm^2 @ luminosity ~10^{35} $cm^{-2}s^{-1}$

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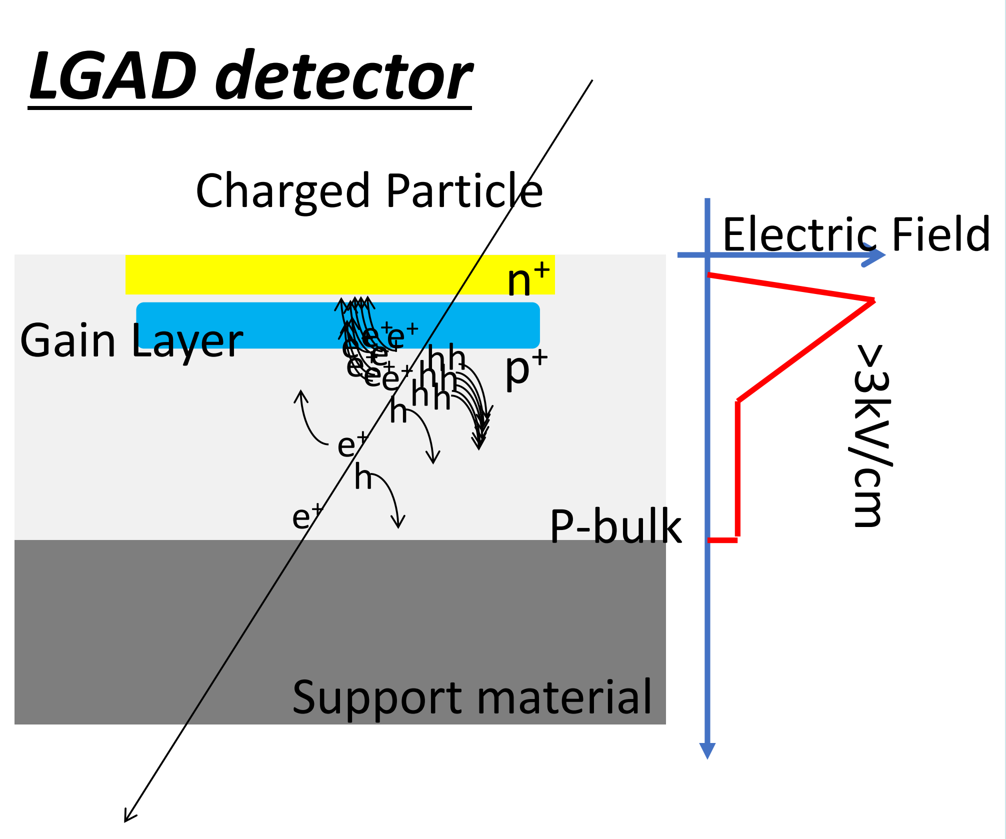
LGAD technology is the first candidate to fulfill the requirements

Low Gain Avalanche Diode (LGAD)

- DC-LGAD (standard LGAD)
  - n^{++}-in-p type sensor with p^+ gain layer under n^{++}
  - 30 ps timing resolution
  - Individual gain layer for each electrode → nonnegligible inactive area with not achieving O(10) ps time resolution



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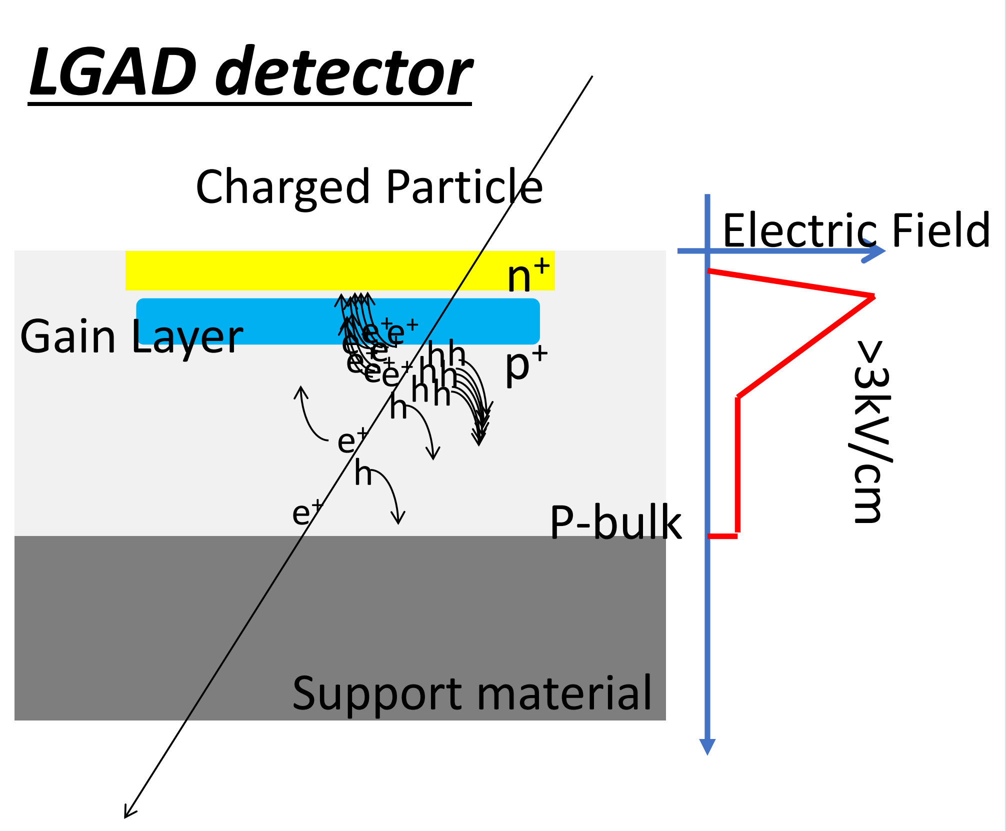

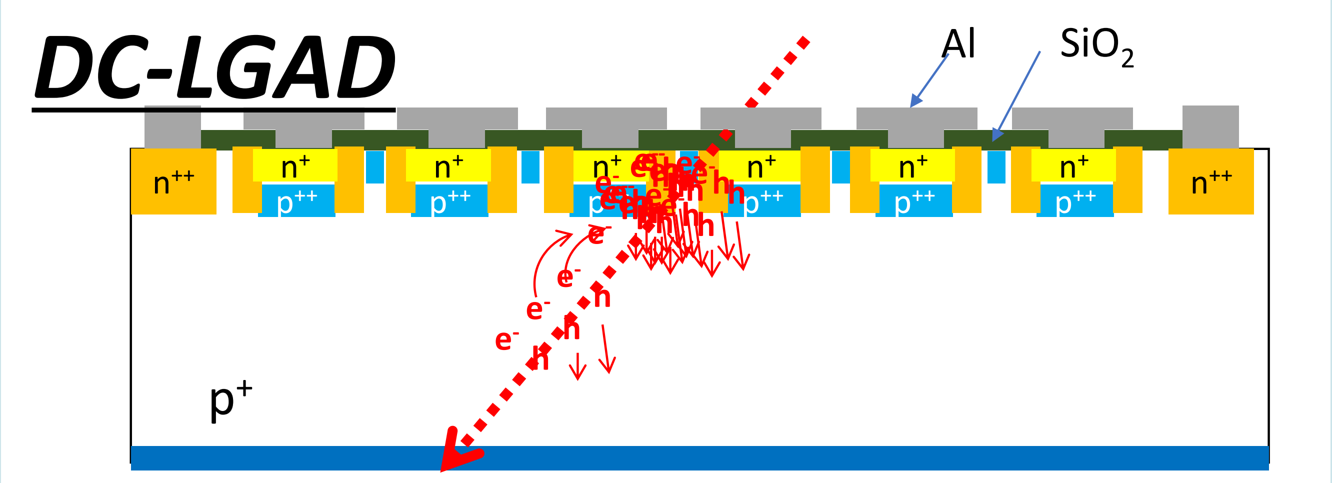

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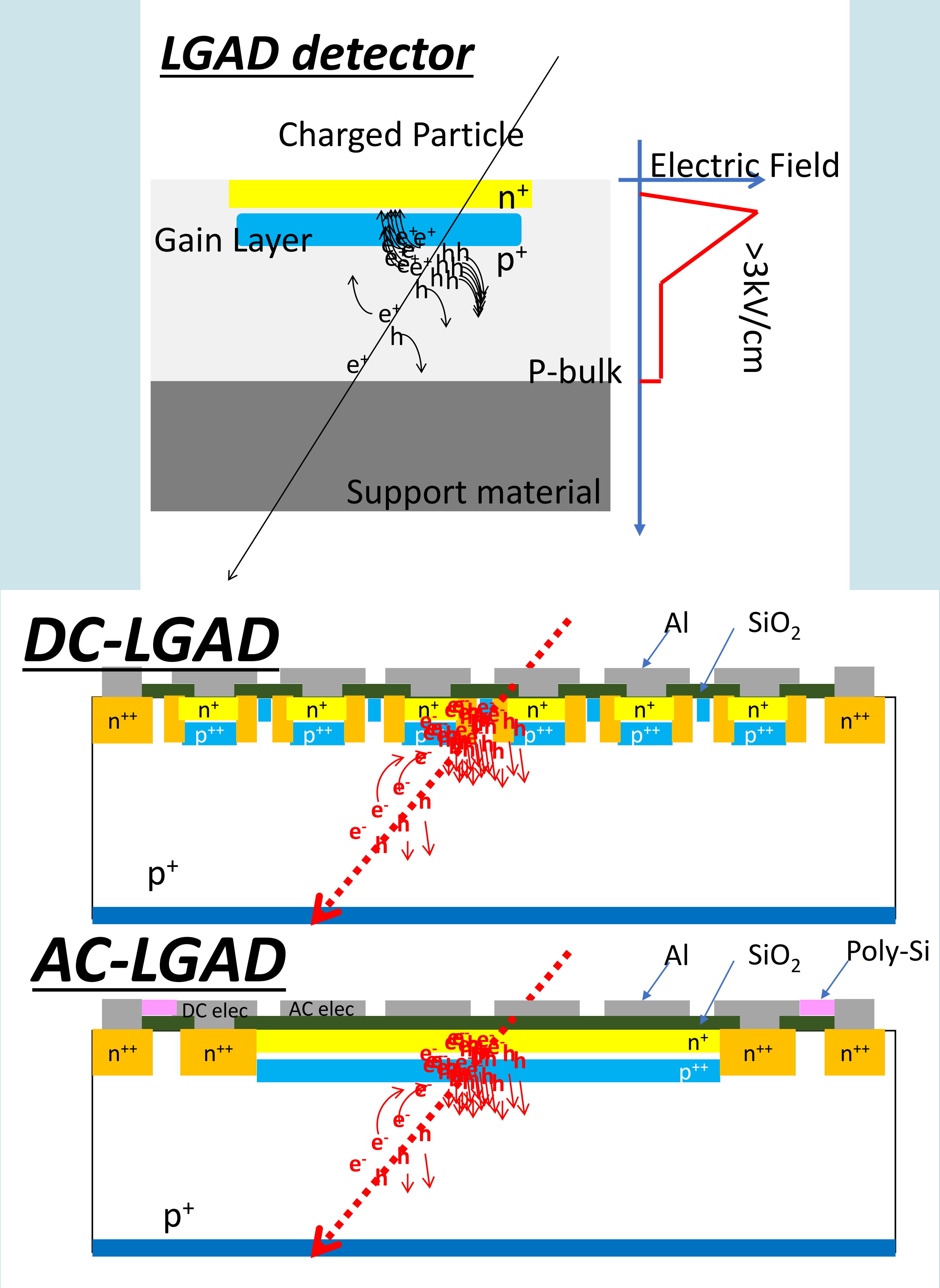
- AC-LGAD
  - n^+-in-p type sensor with p^+ gain layer under n^+ (lower doped n layer)
  - Oxide layer between n^+ layer and electrode (AC-coupling)
  - 30 ps timing resolution
  - One large gain layer for electrodes → 100% of fill factor



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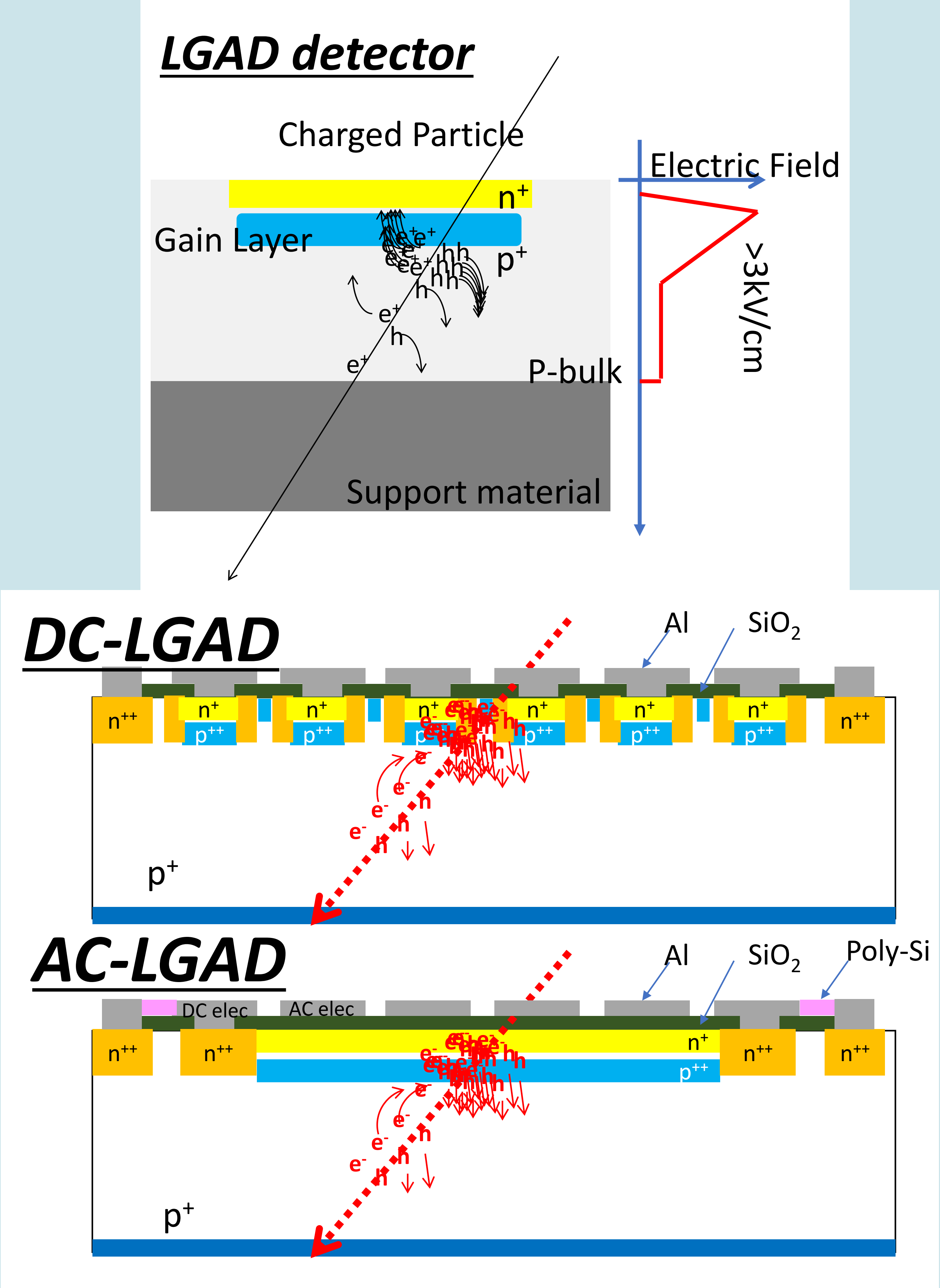

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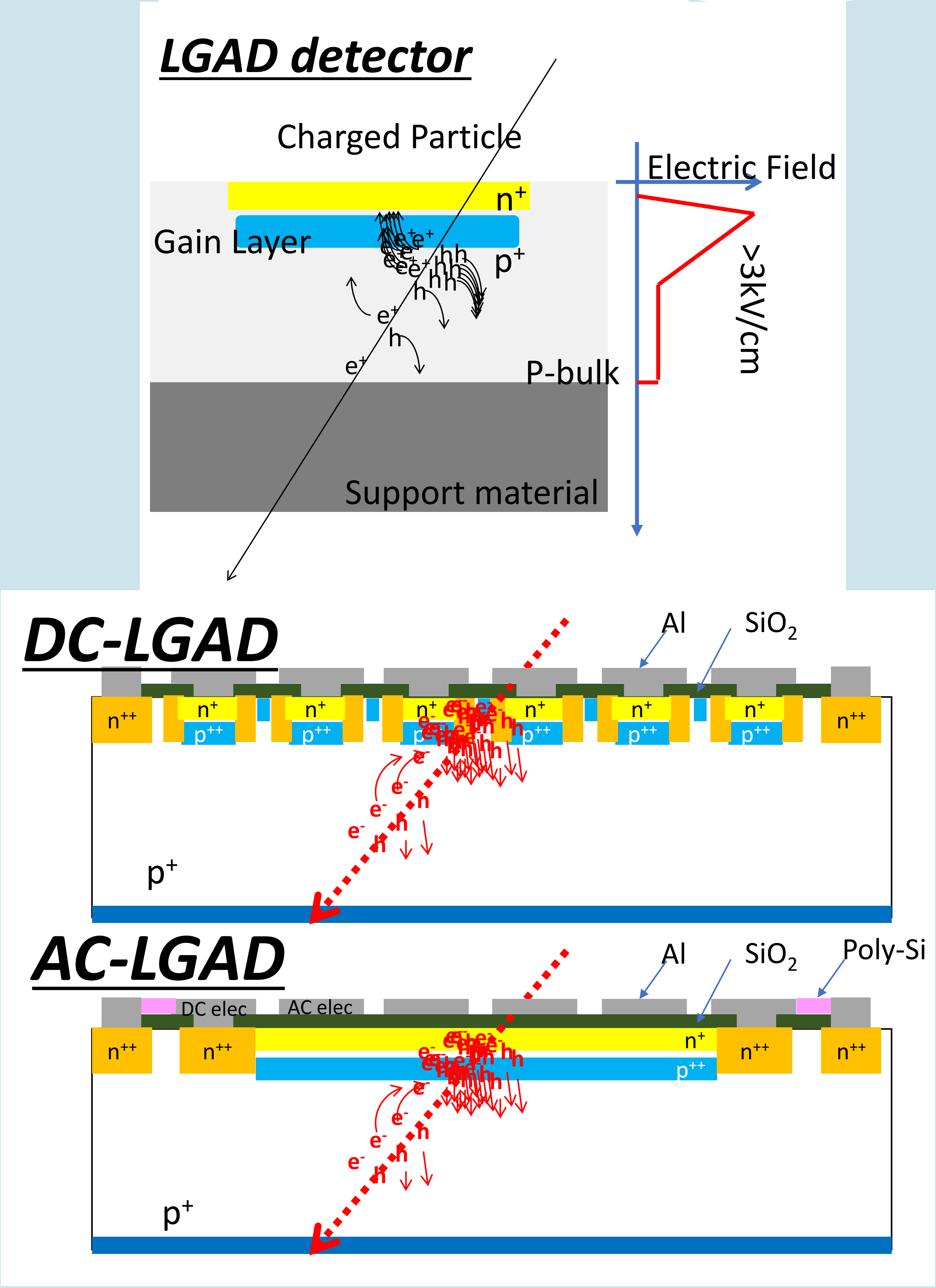

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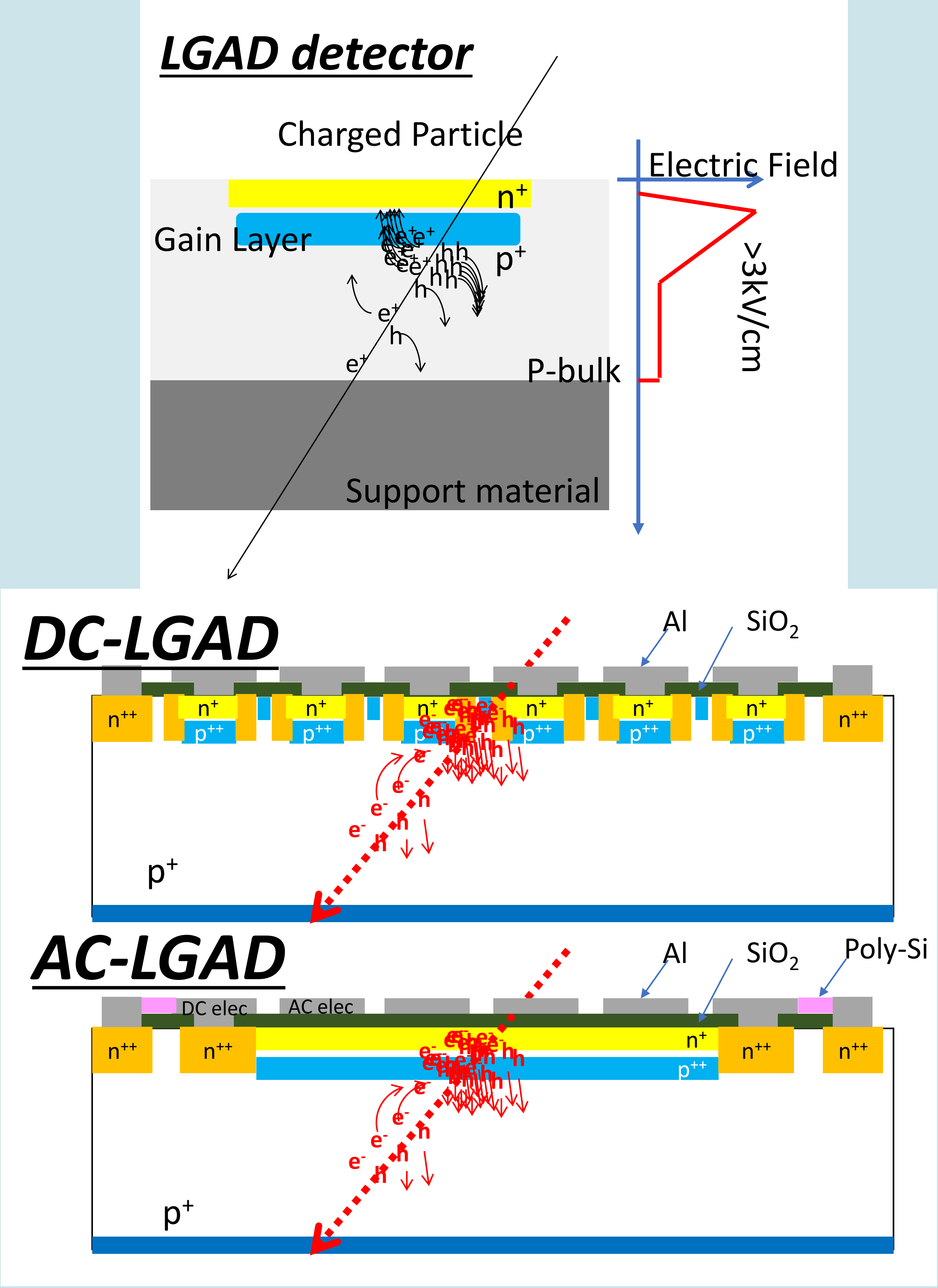

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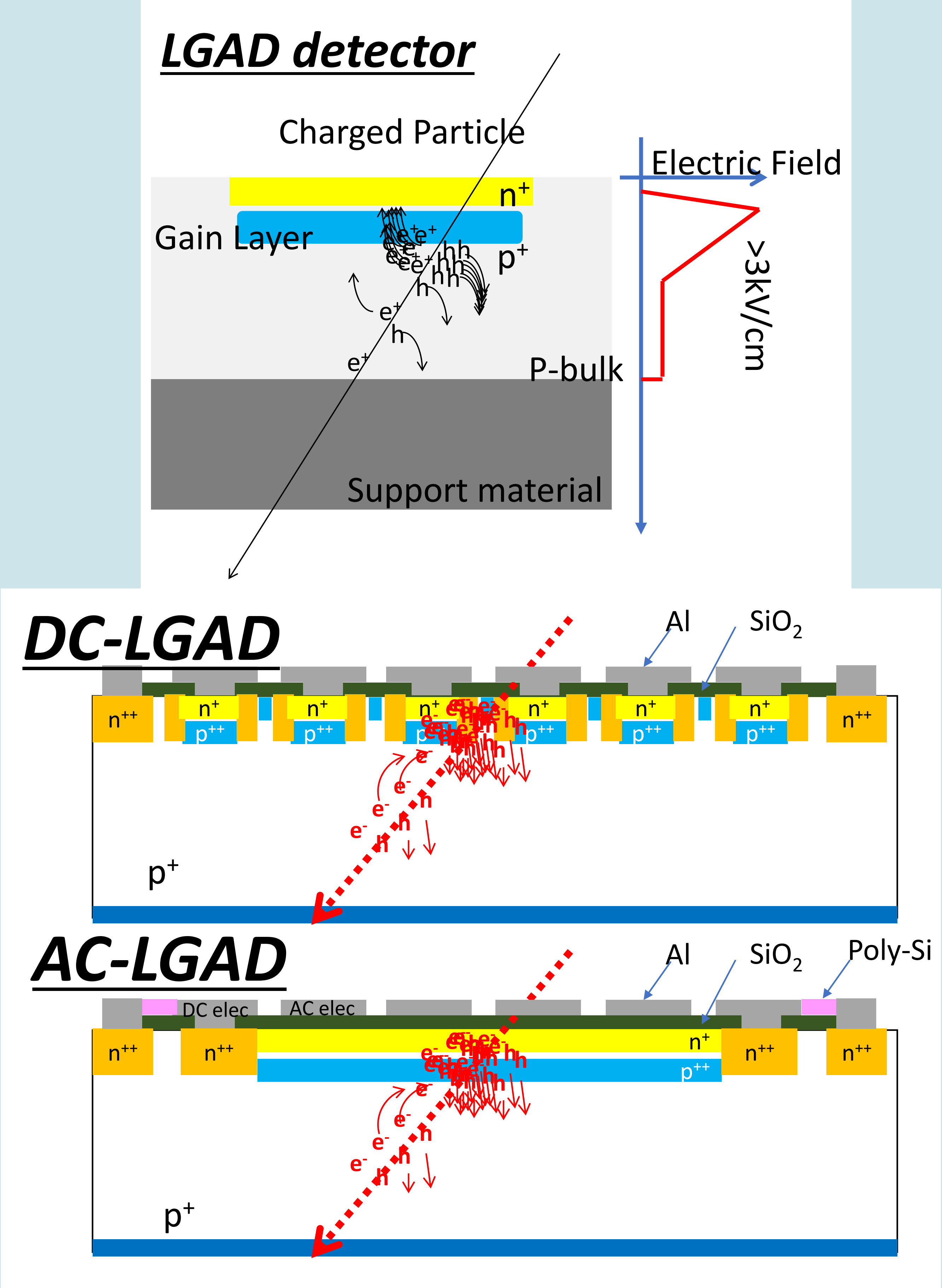

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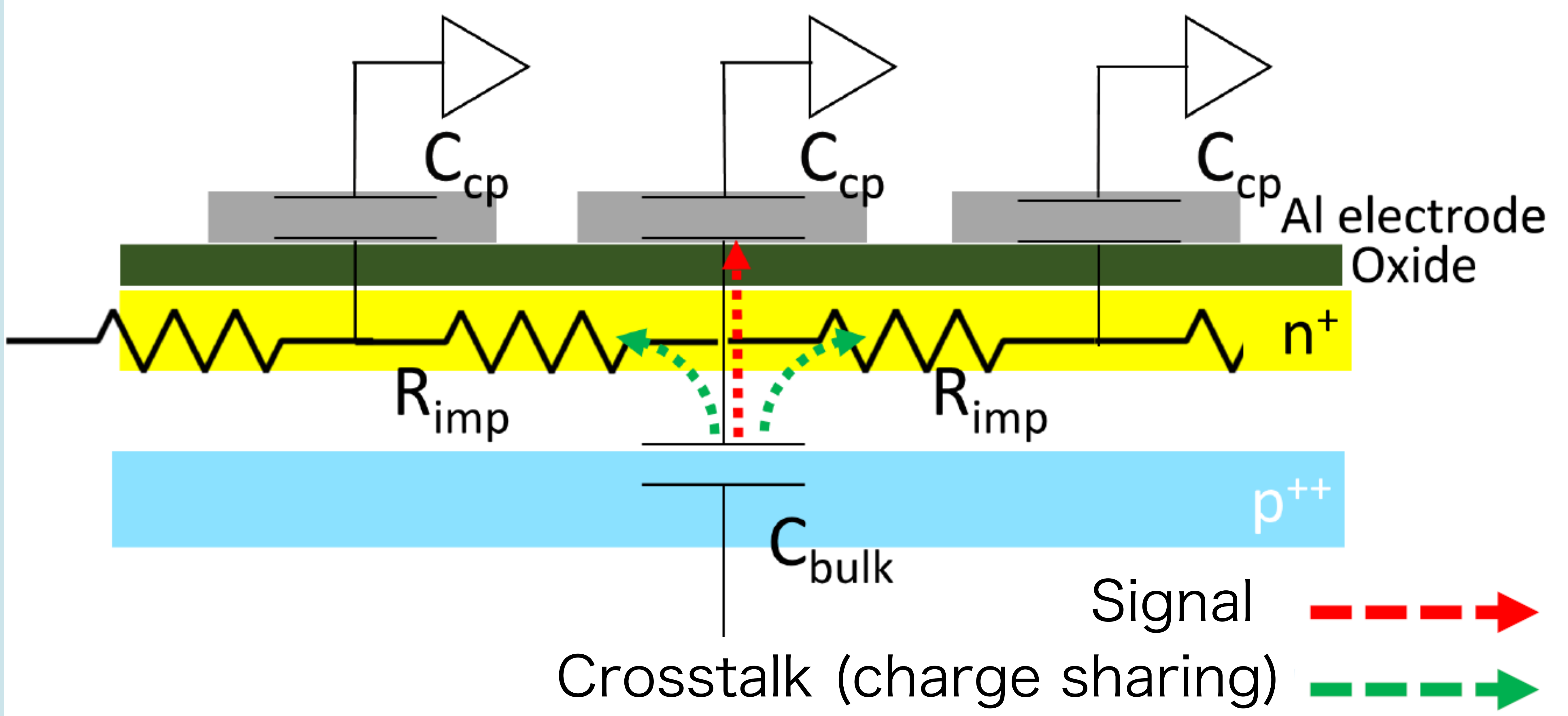
EIC-Japan has high hopes for AC-LGAD

R&D elements for AC-LGAD

- Issues of AC-LGAD
  - Crosstalk in n^+ layer
  - Small signal due to AC-coupling
- Signal size Q

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

- Two important parameters
  - R_{imp} → larger is better
    - n^+ doping concentration
  - C_{cp} → larger is better
    - Smaller electrode size → smaller C_{cp}
    - Thinner oxide → larger C_{cp}



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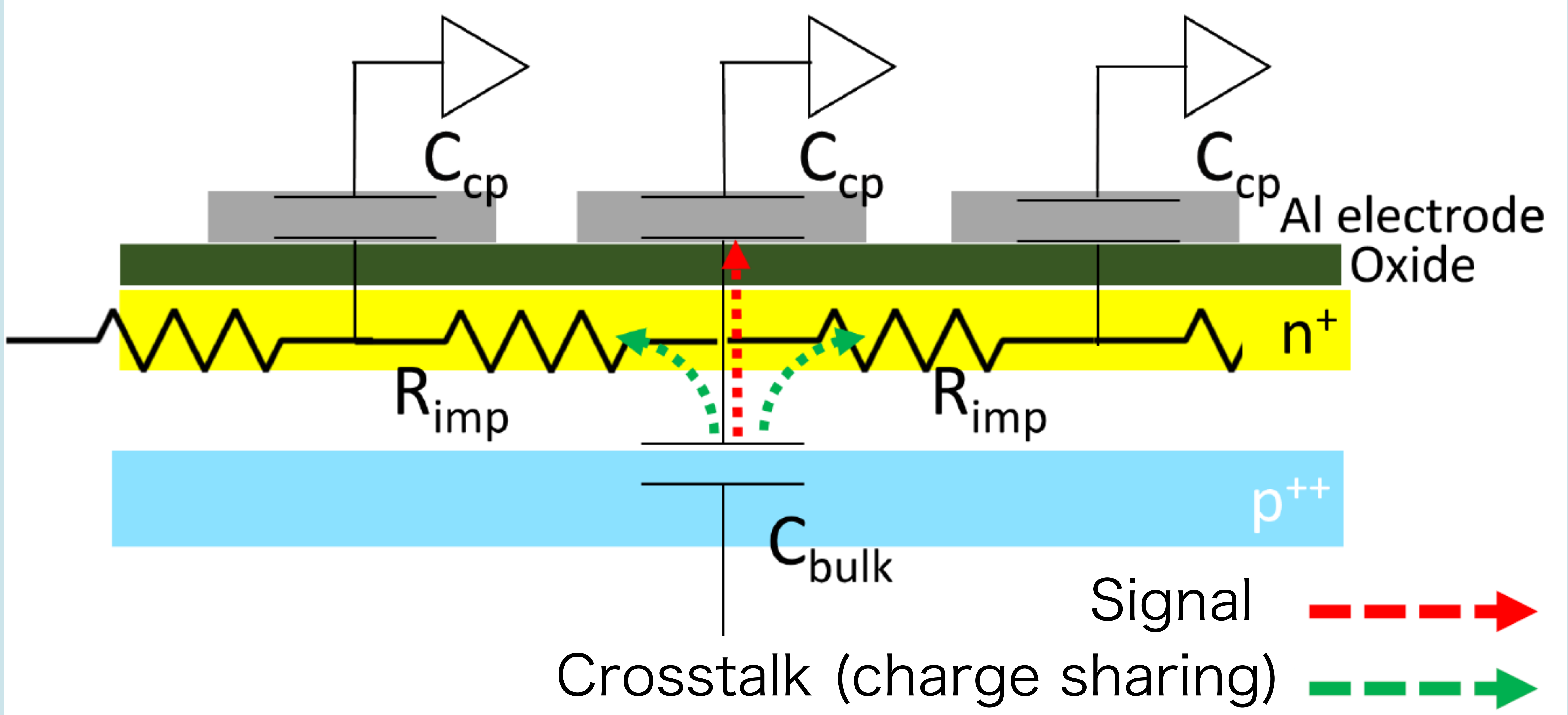

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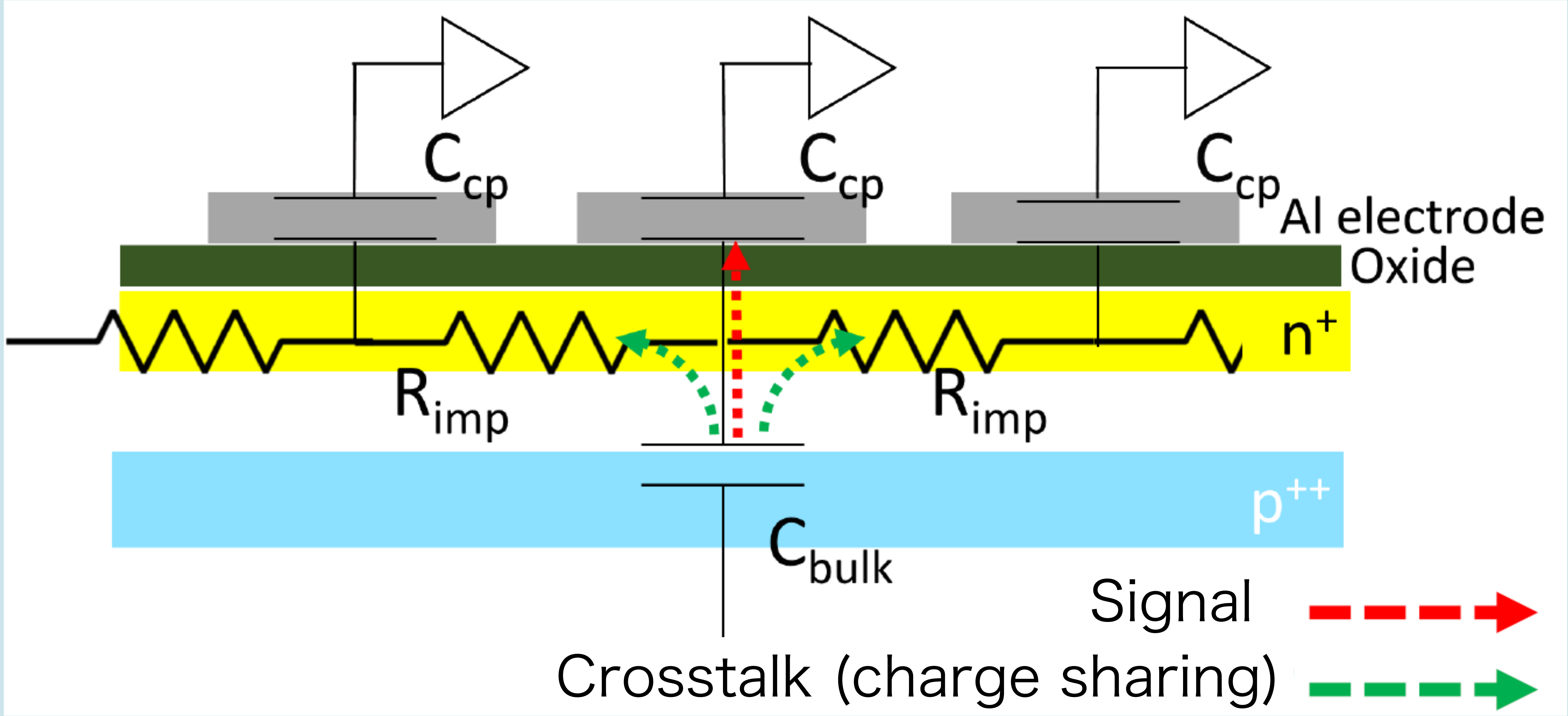

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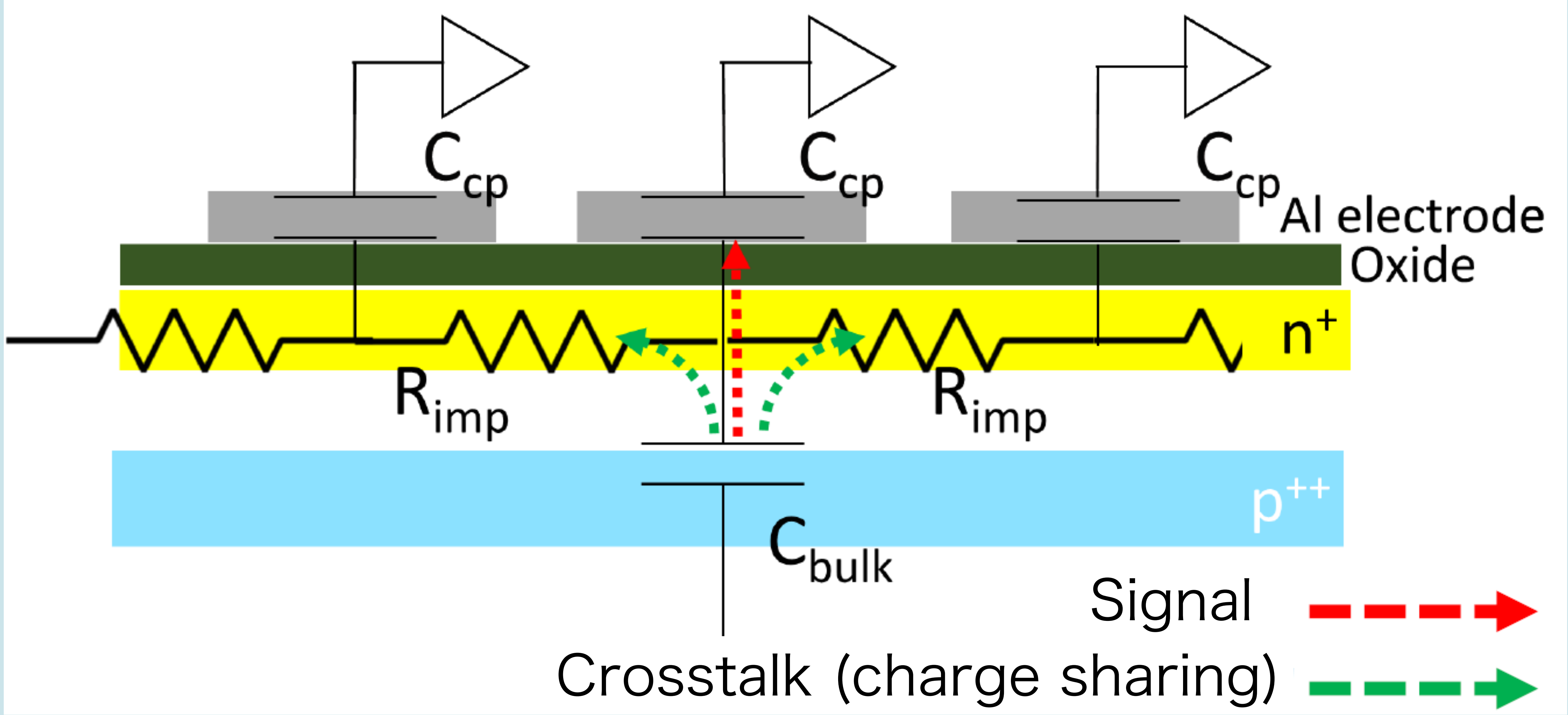

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Development goal

Keep a larger signal and smaller crosstalk with a good time and spatial resolution

AC-LGAD development in Japan

- KEK and the University of Tsukuba have been developing AC-LGAD sensors in collaboration with Hamamatsu Photonics (HPK) for use in the future ATLAS experiment
  - Several pads, pixels, and strips types with changing electrode shape sizes and oxide properties
- BNL also has been developing AC-LGADs with collaborating with the ATLAS
  - ATLAS Japan has played an important role as a bridge between HPK and BNL
- Performance requirements from HL-LHC are more demanding than EIC
  - Time resolution 30ps, spatial resolution O(10)um, and radiation tolerance $O(10^{15}) n_{eq}/cm^2$

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Japan has one of the state-of-art technology of AC-LGAD

Performance of AC-LGAD at BNL/HPK

- Performance of AC-LGAD at BNL and HPK has been published (link)
  - R. Heller et al., JINST 17 P05001, 2022
- Strip types and pad types have been fabricated by BNL and HPK, respectively
  - Electrode gap and size effects have been tested with BNL products

    n^+ doping concentration (resistivity) effects have been tested with HPK product

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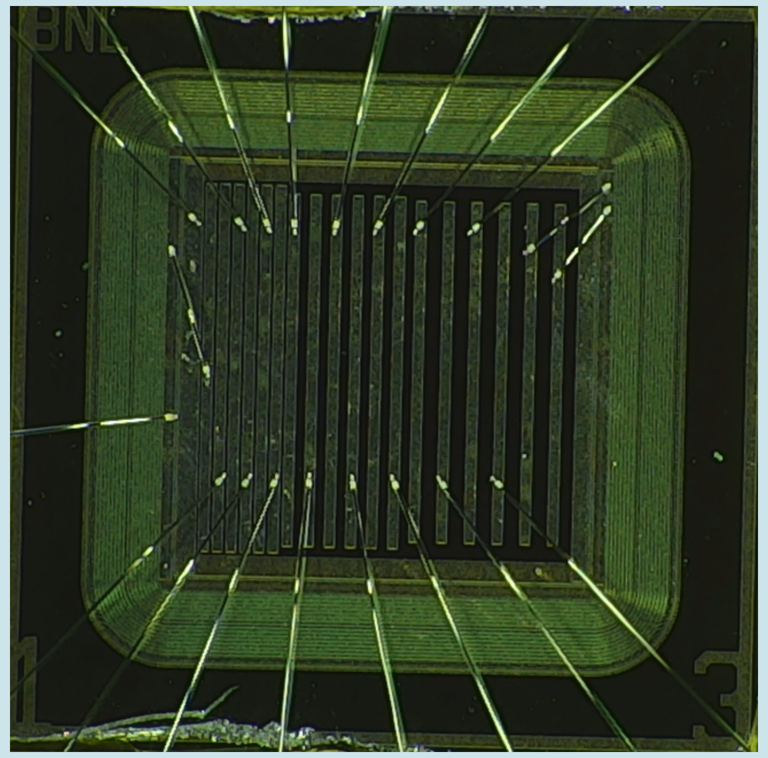
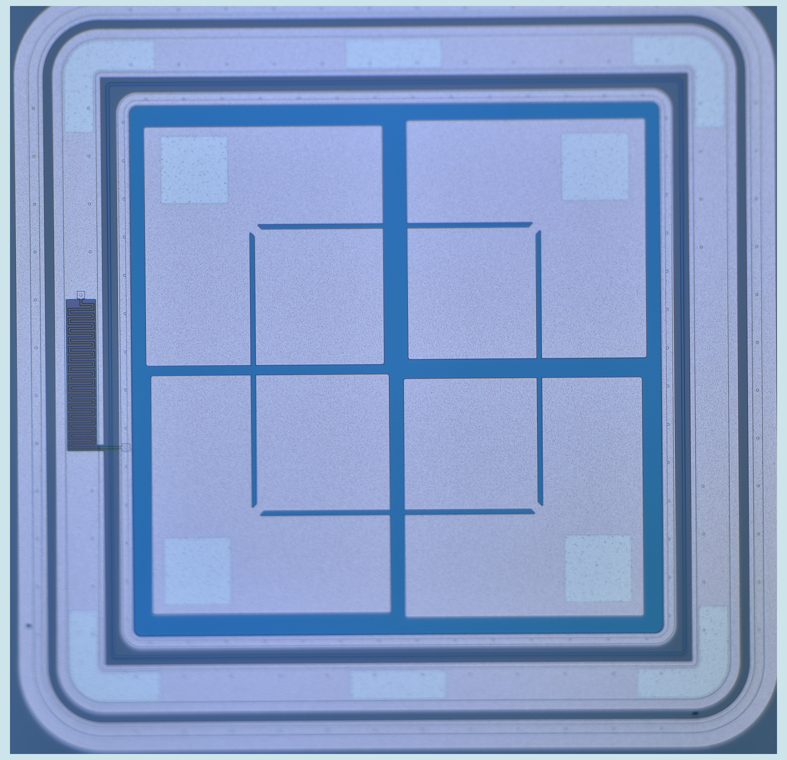
Strip type by BNL



3x3 mm^2

Sensor size

Pad type by HPK



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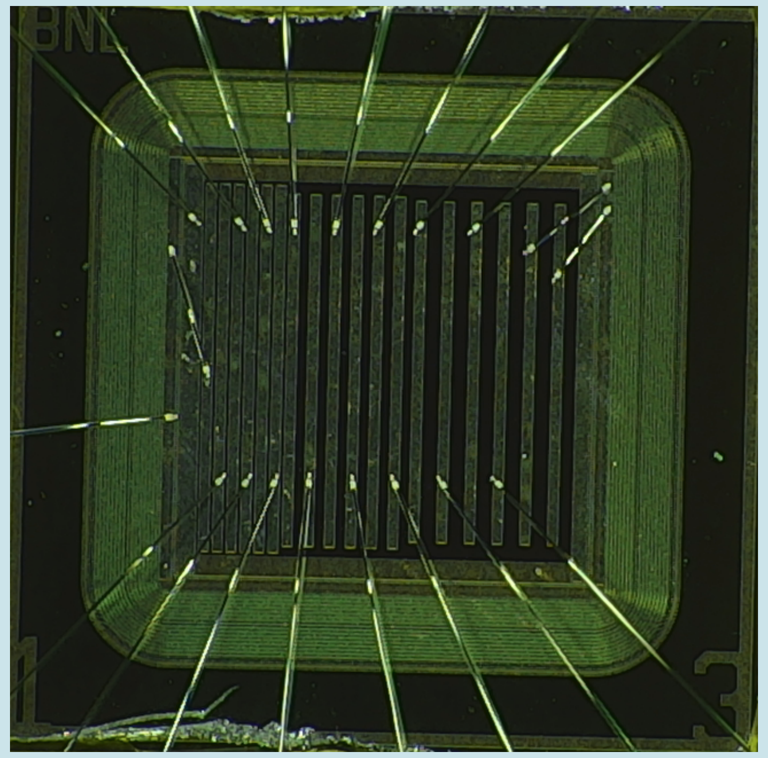

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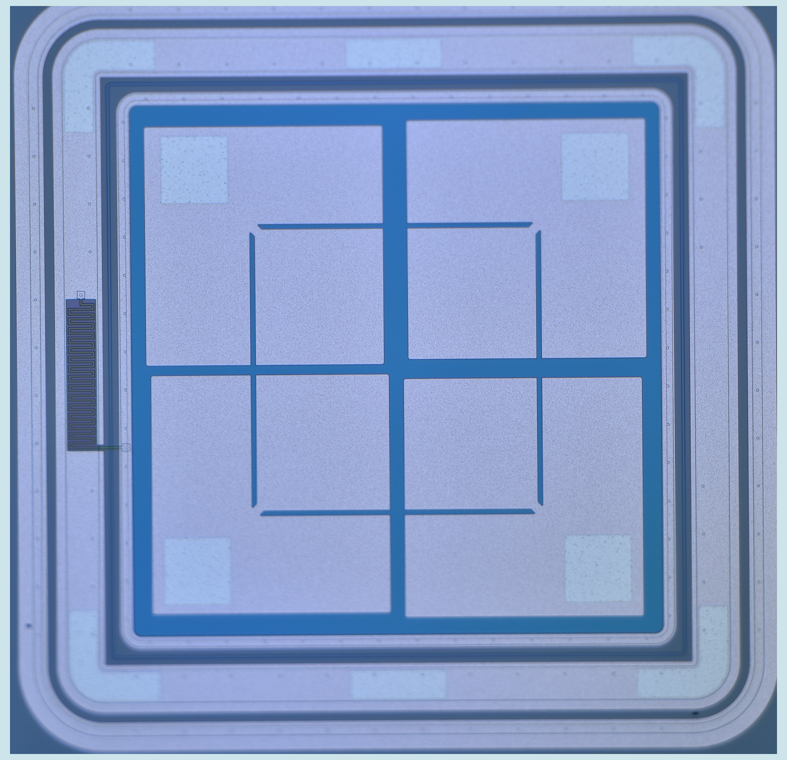

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BNL 2020	100	101 ± 10	≤6	29 ± 1
BNL 2021 Narrow	100	104 ± 10	≤9	32 ± 1
BNL 2021 Medium	150	136 ± 13	≤11	30 ± 1
BNL 2021 Wide	200	144 ± 14	≤9	33 ± 1
HPK C–2	500	128 ± 12	22 ± 1	30 ± 1
HPK B–2	500	95 ± 10	24 ± 1	27 ± 1

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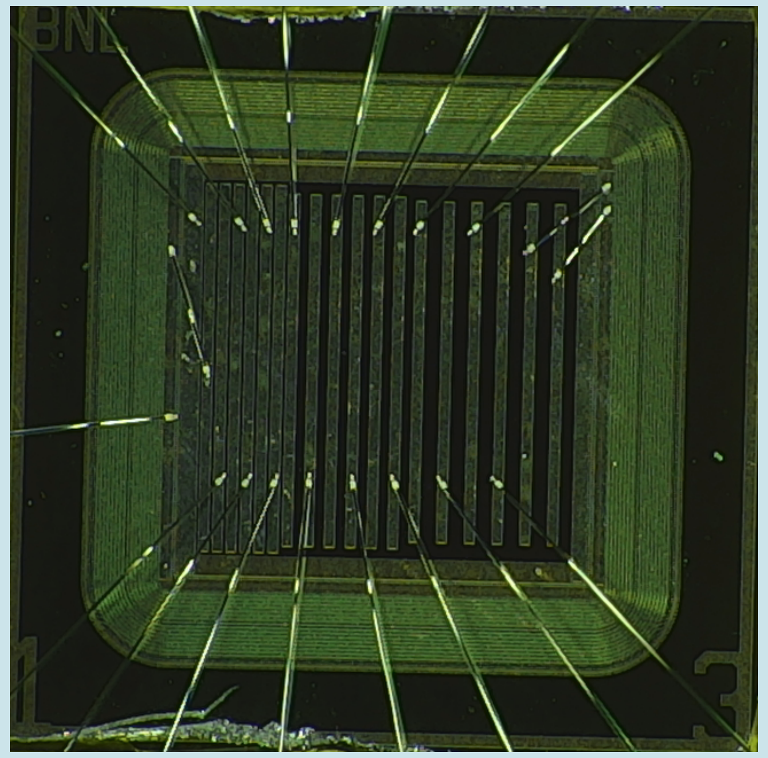

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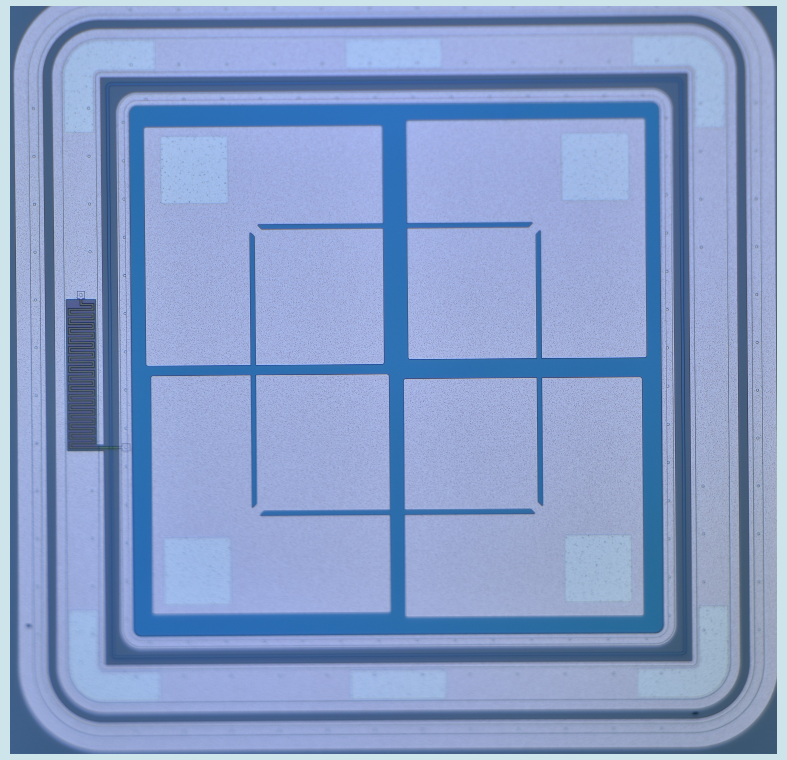

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~30 ps time and <30 um spatial resolution have been achieved!

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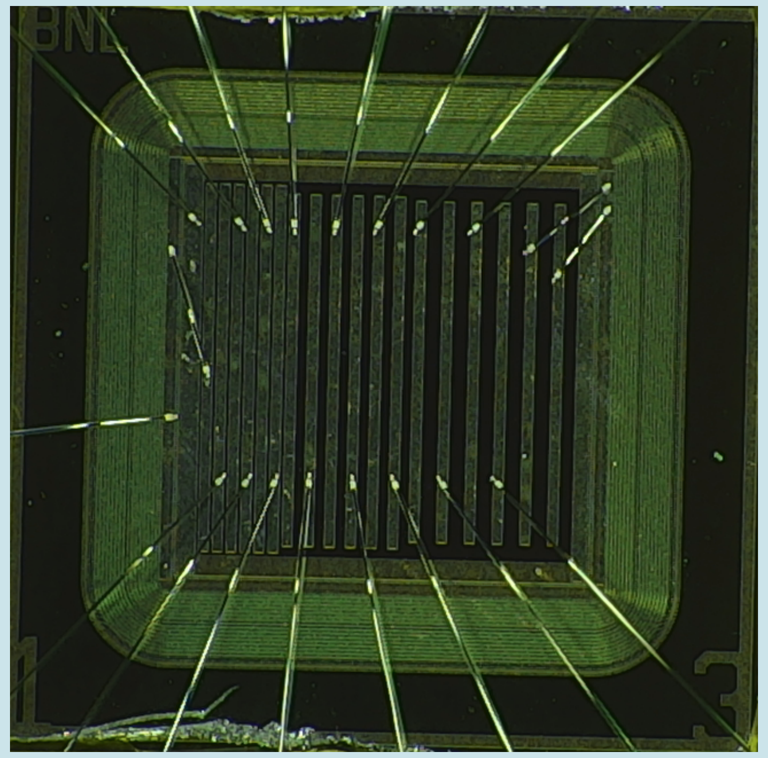

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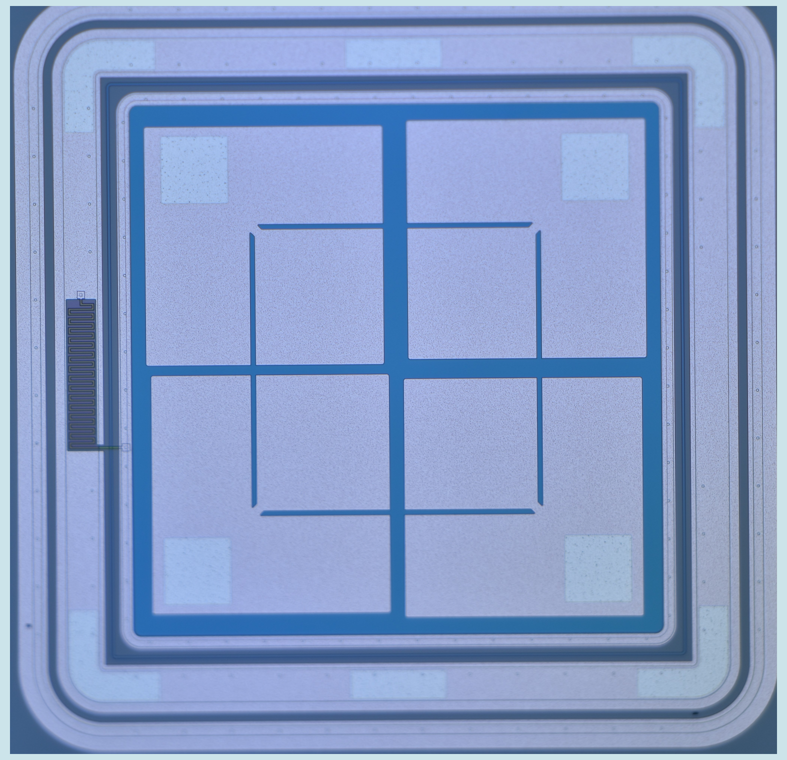

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S. Kita et al., at VERTEX 2022

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  - S. Kita et al., presentation link → here
- New Pixel-type and larger strip-type products were shown
- 100um pitch pixel sensor has good performance on crosstalk
  - Next step: 2x2 cm^2 sensor size
- New characteristic is found in the large stripe-type sensors
  - Unexpected smaller signal height is found than pixel type
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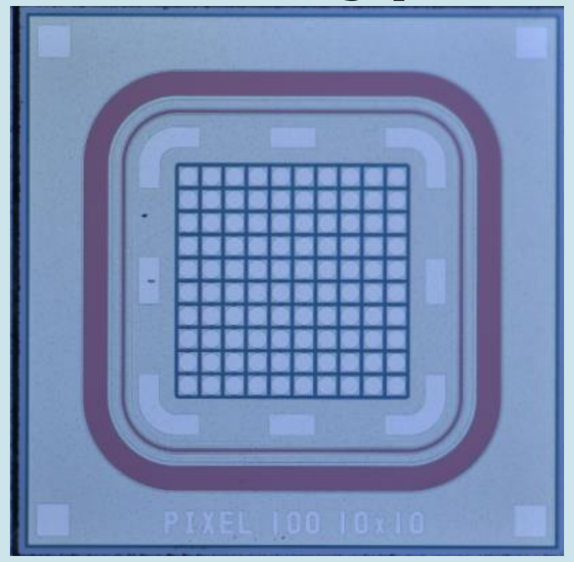


1 x 1 mm^2

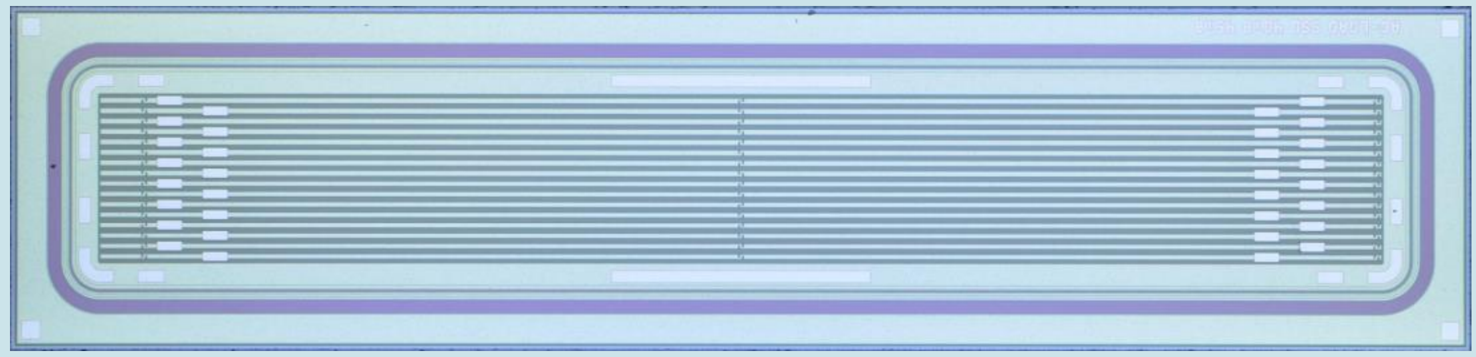
Sensor size:

50, 100, 150, 200 um

Electrode shape

40, 90, 140, 190 um

Strip-type



Sensor size: 3 x ~10 mm^2

Electrode width: 40, 45 um

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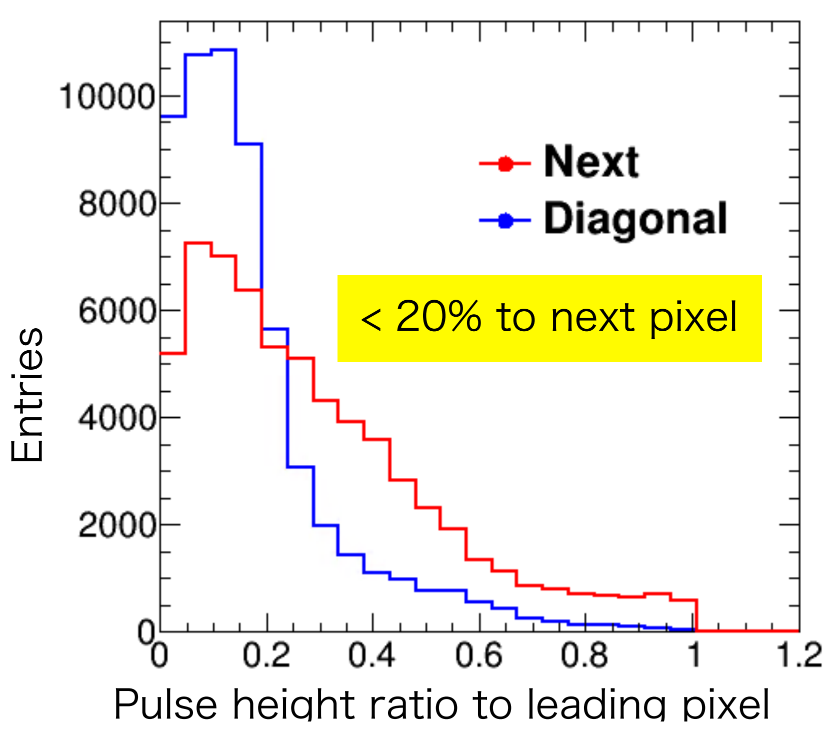
Pixel (100x100 um^2) crosstalk



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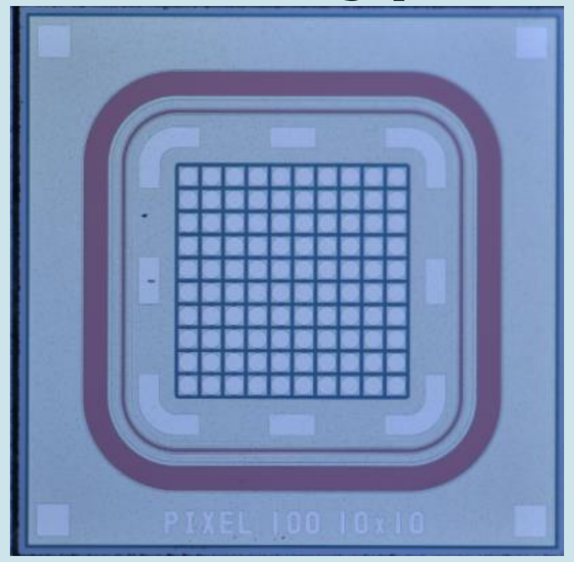

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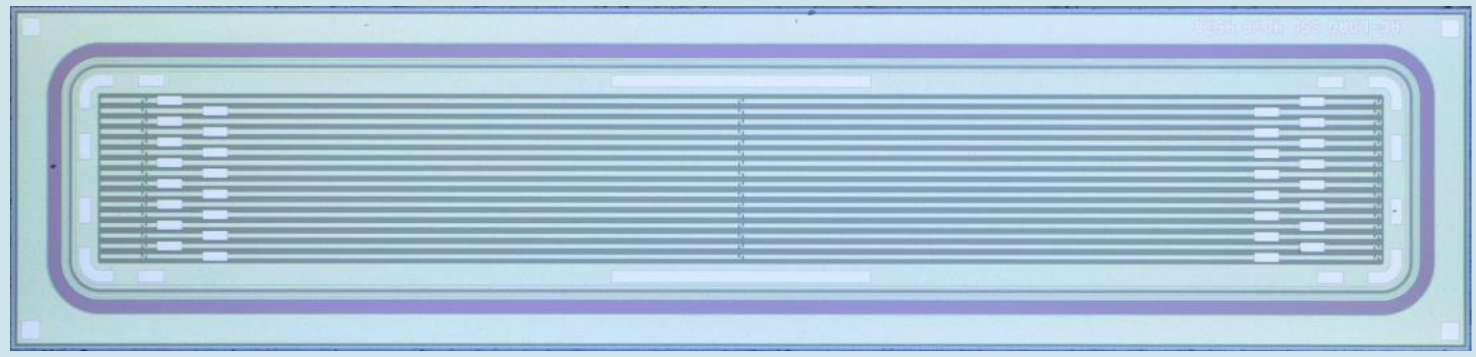

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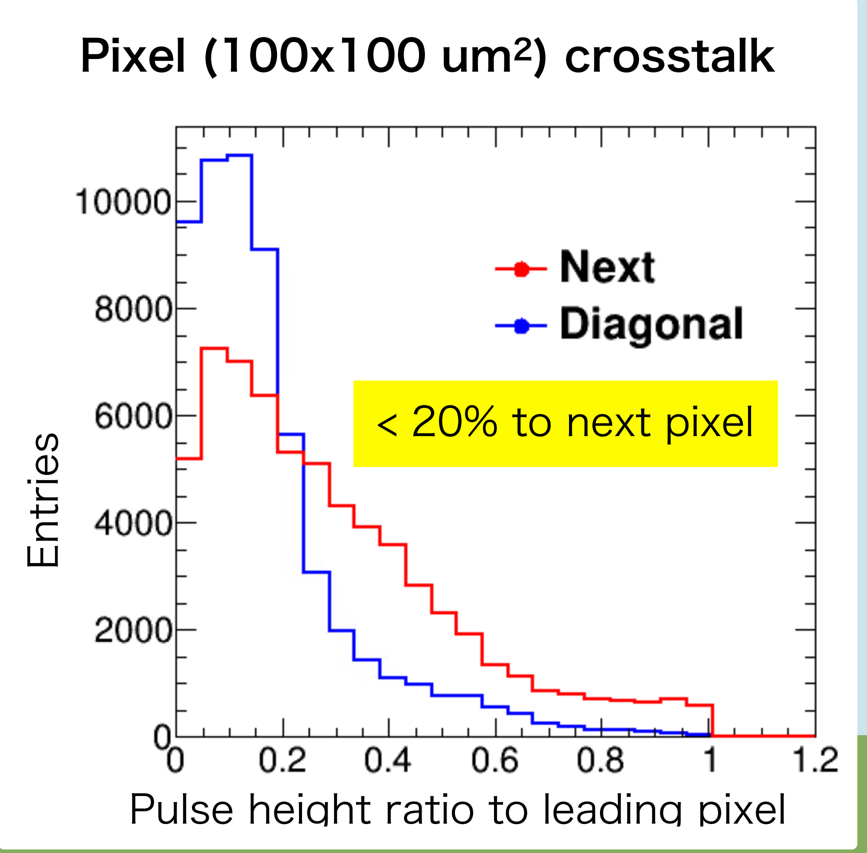
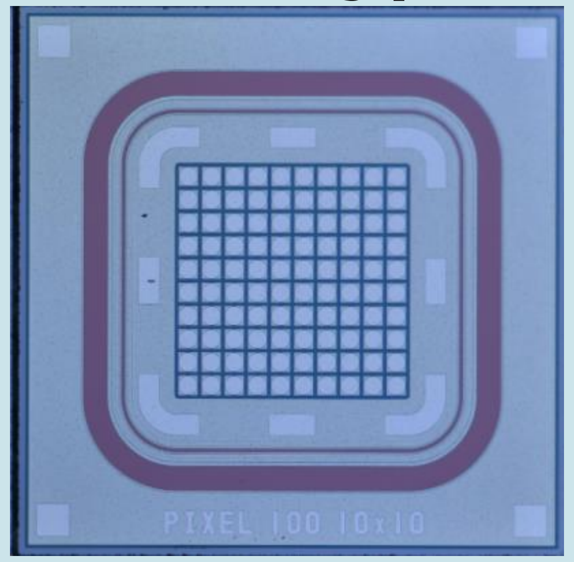
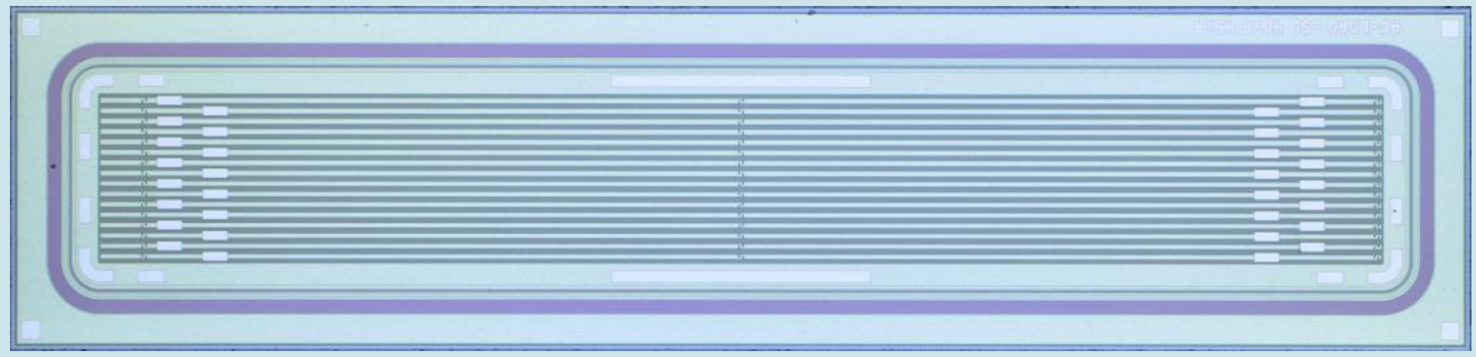


Pixel-type



1 x 1 mm^2
Sensor size:
50, 100, 150, 200 um
Electrode shape
40, 90, 140, 190 um

Strip-type



Sensor size: 3 x ~10 mm^2
Electrode width: 40, 45 um

S. Kita et al., at VERTEX 2022

- The latest results were presented at the VERTEX2022
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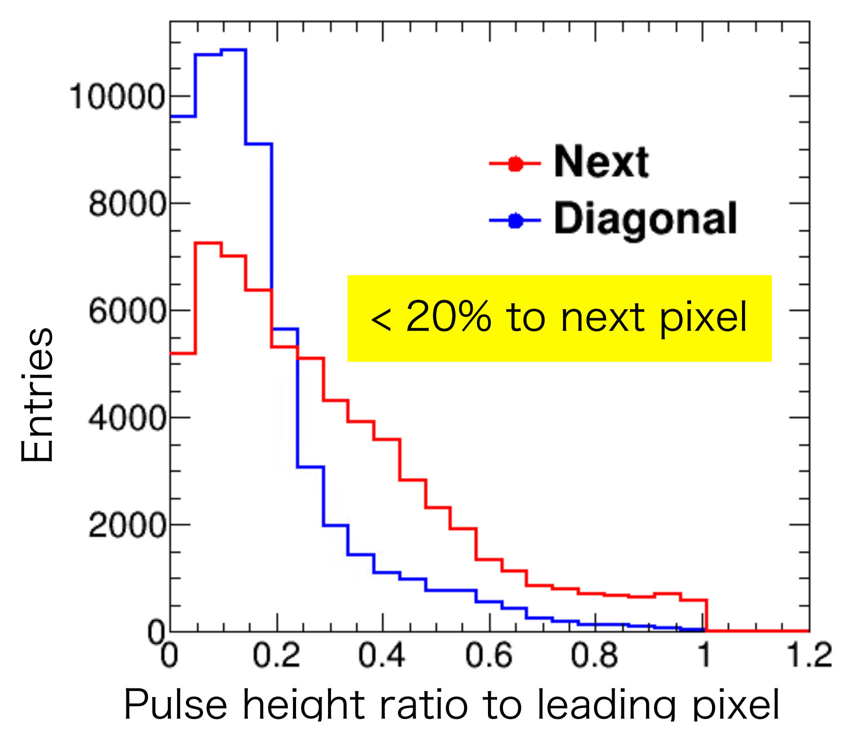
Pixel (100x100 um^2) crosstalk



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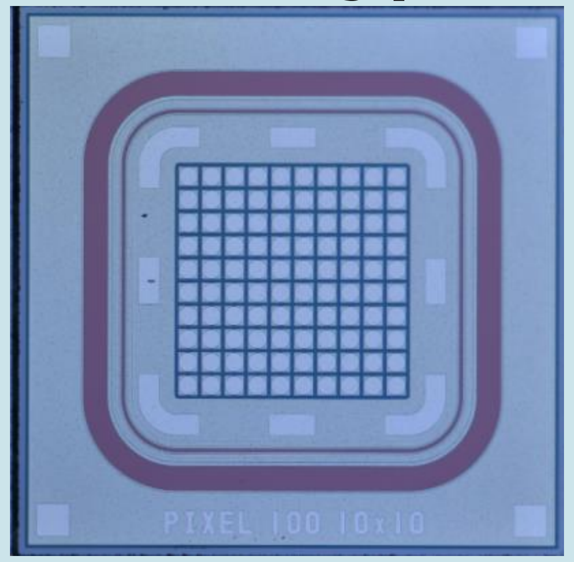

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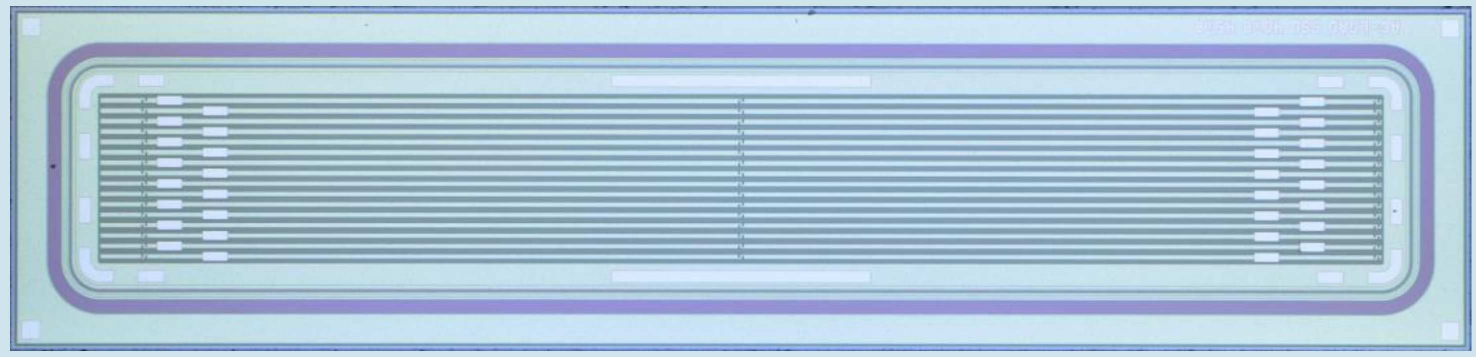

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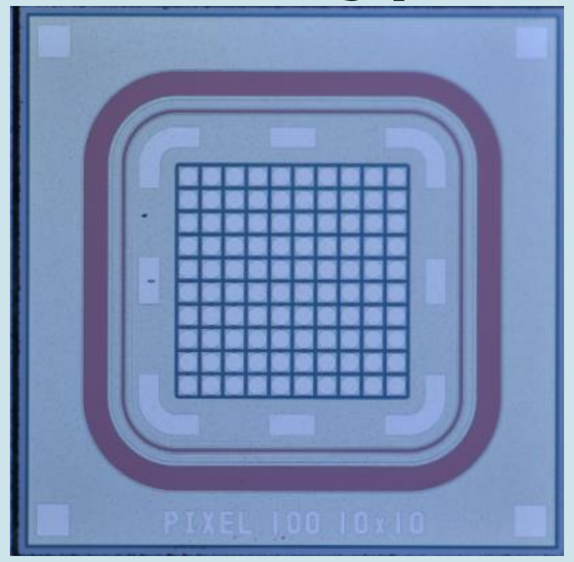

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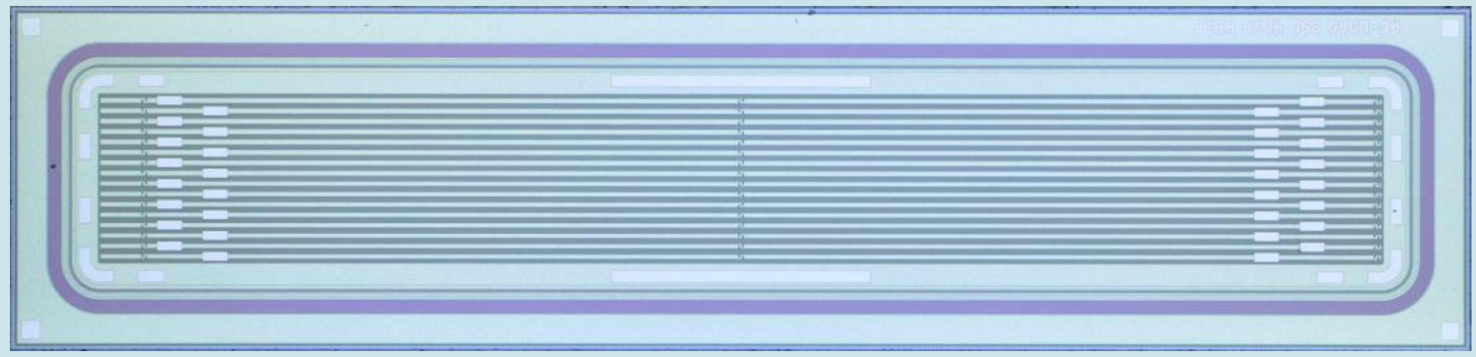

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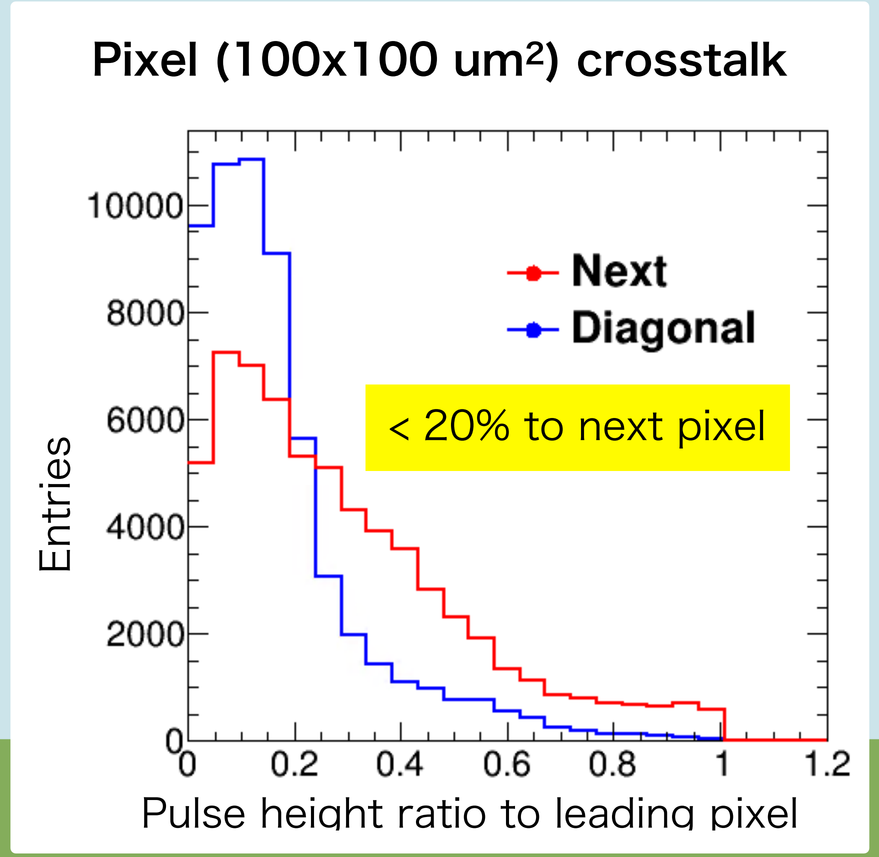

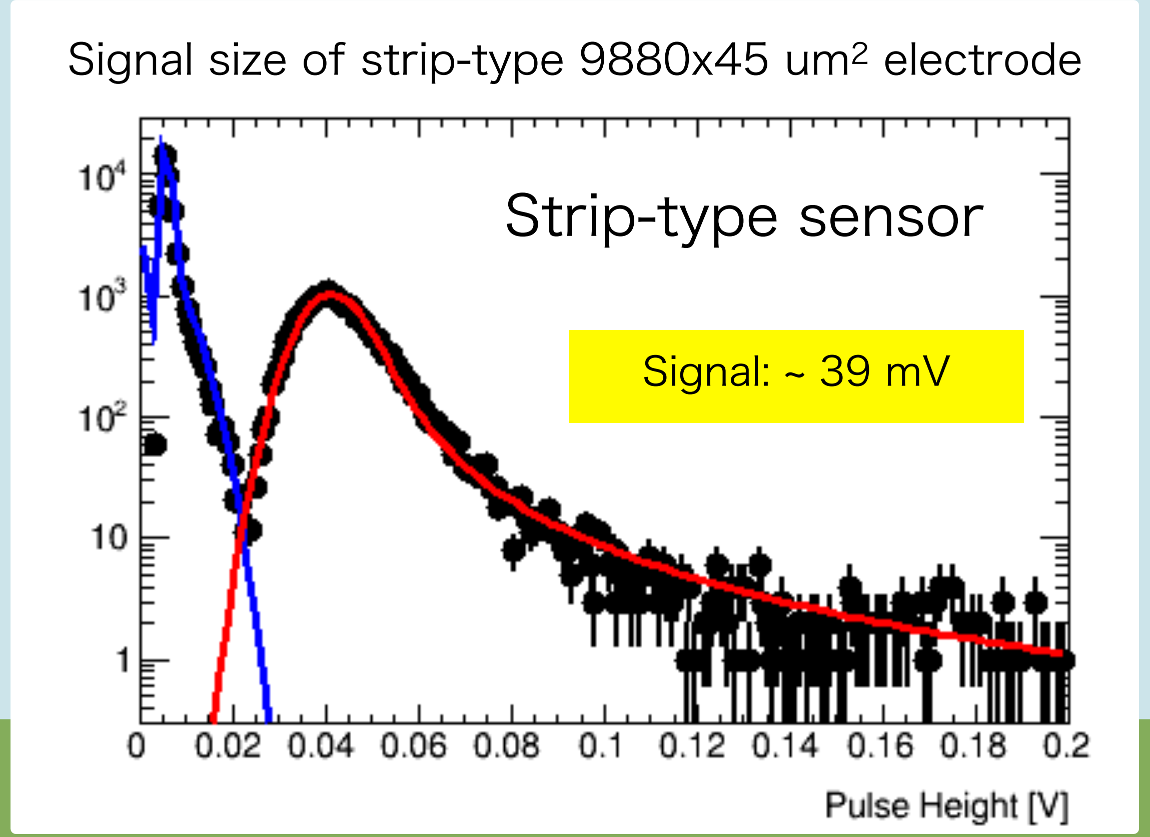

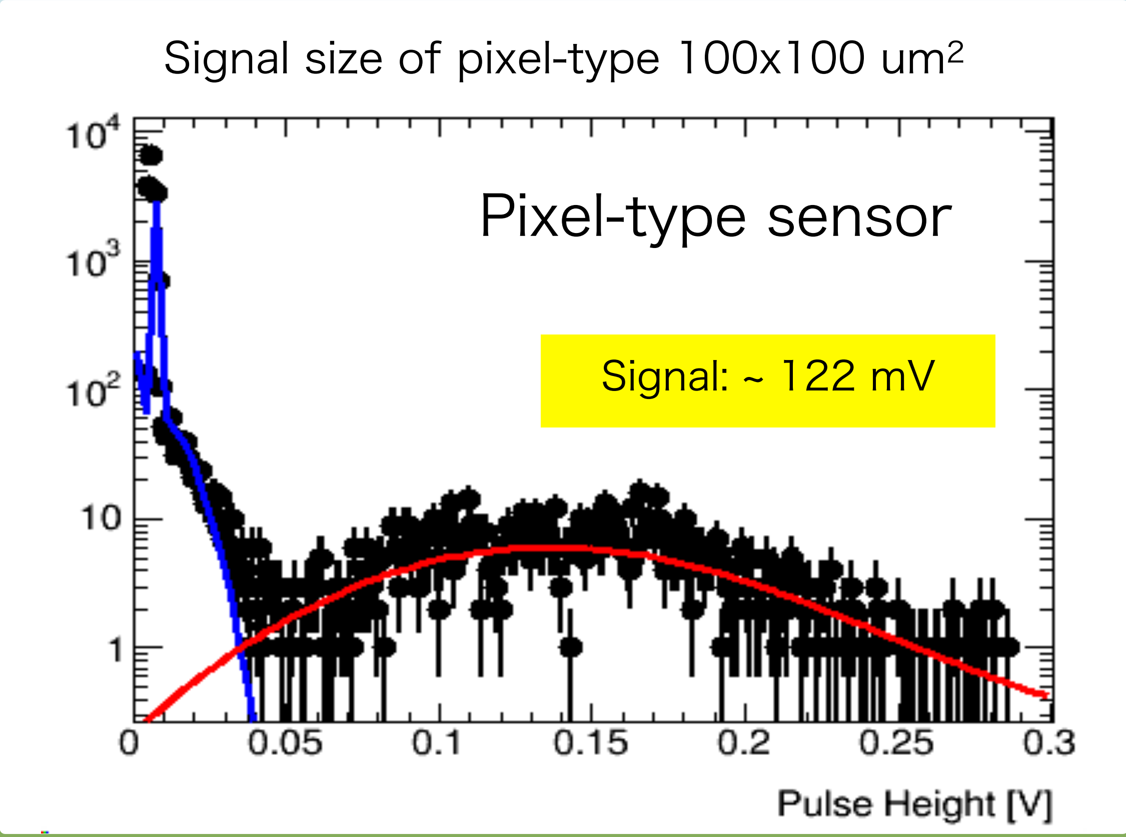

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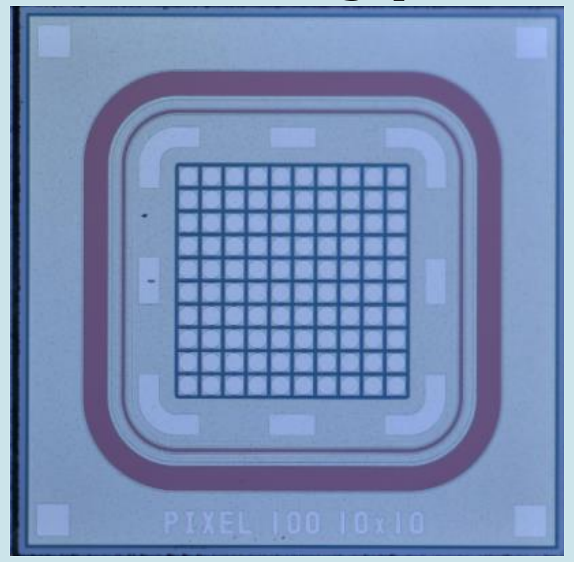

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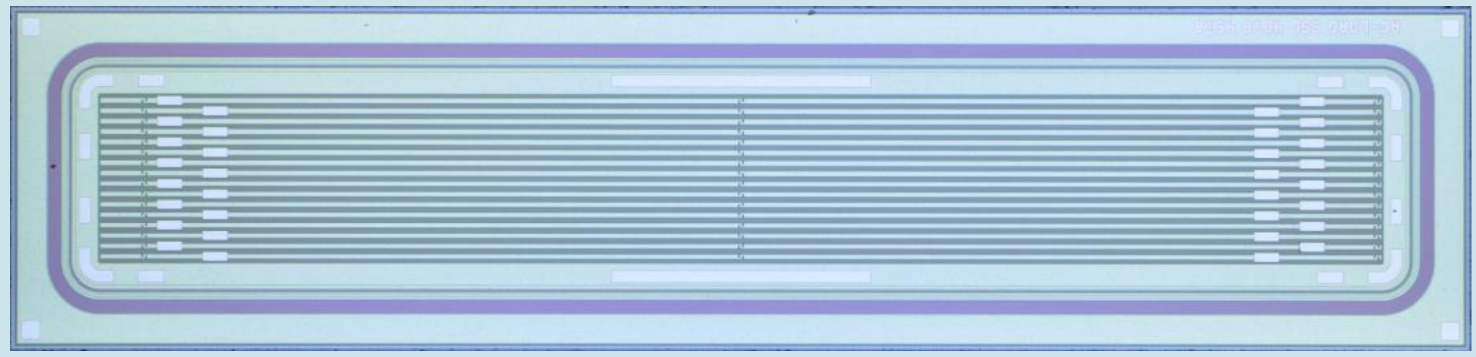

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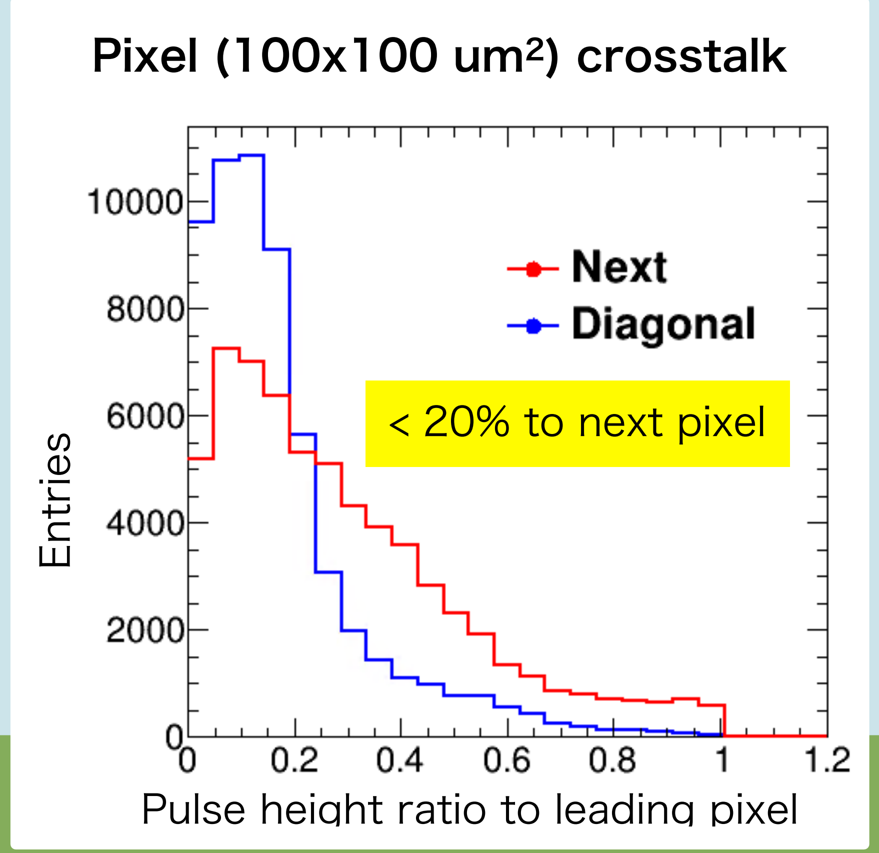
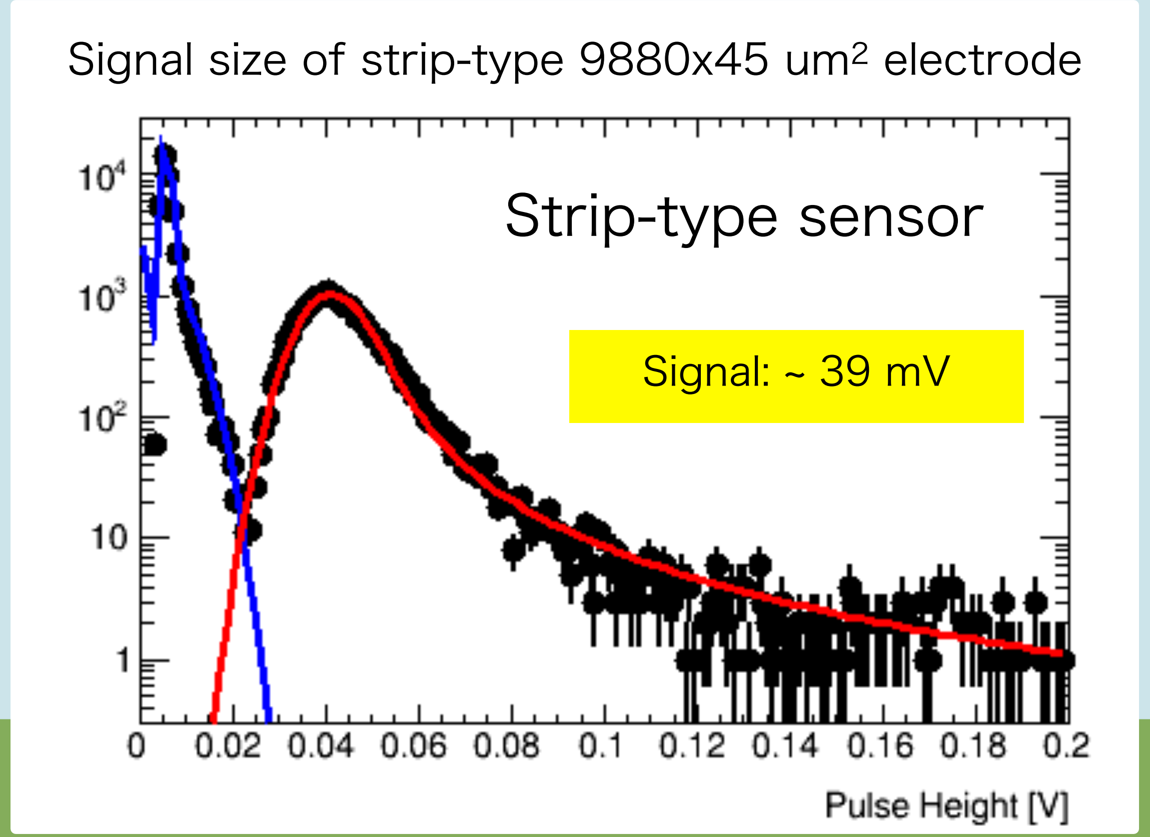
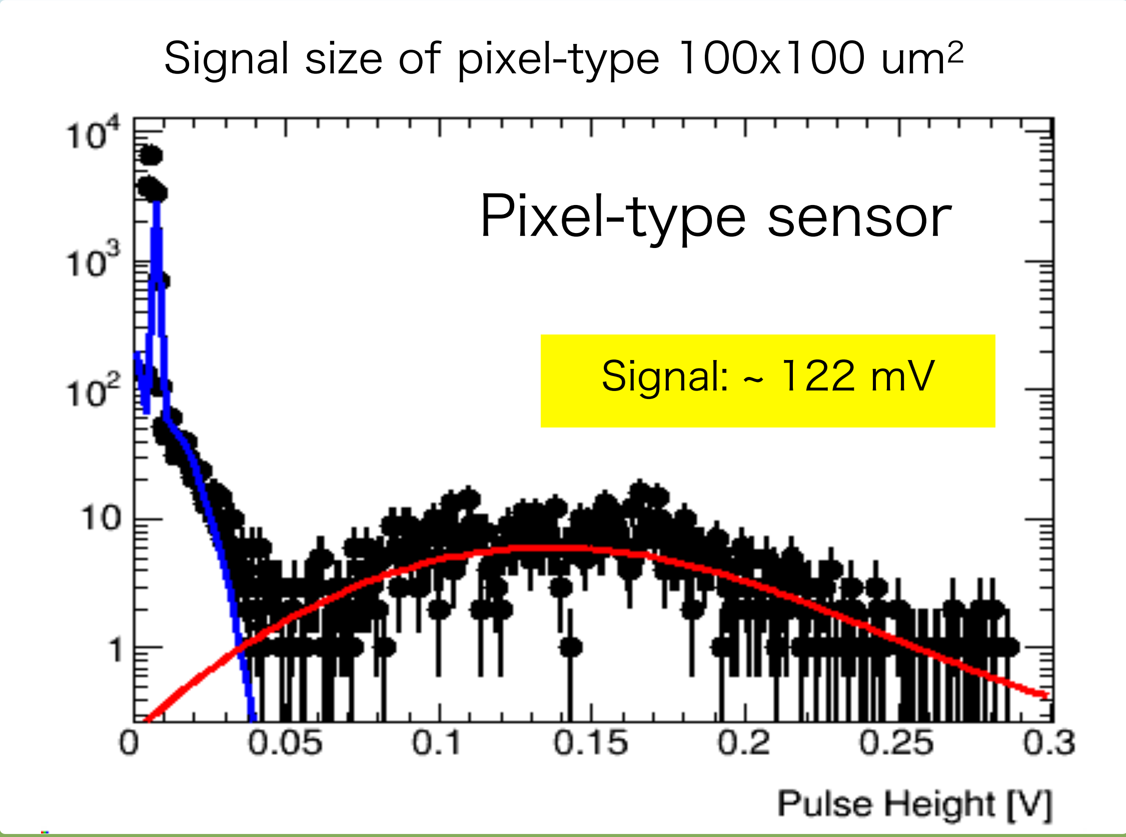
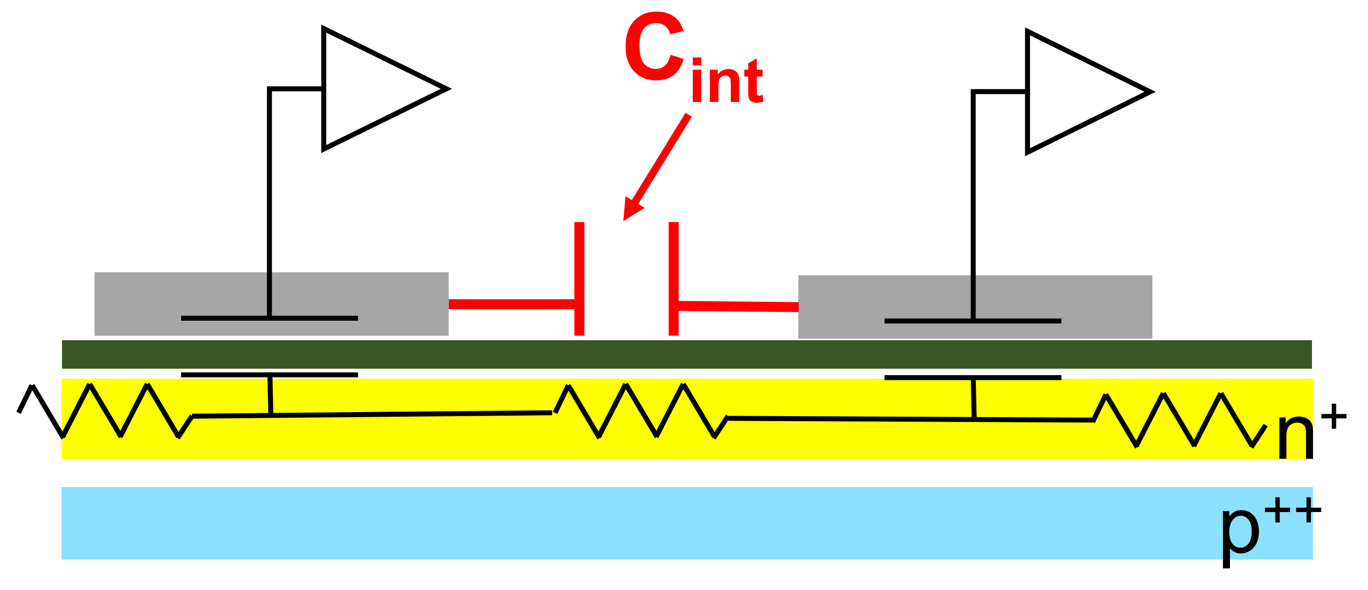






Inter electrode capacitance



Plan of the EIC-Japan for ToF detector

- EIC-Japan wants to lead the development of the ToF detector @ EPIC in a responsible position the same as INTT detector @ sPHEINX
  - All components of the detector will be manufactured in Japan

- We will join the R&D of AC-LGAD soon and finalize the sensor design for EIC
  - The first step is several tests with prototypes produced by BNL this winter
  - AC-LGAD has been designed for HL-LHC and already fulfilled our requirements in EIC
    - Main R&D will be increasing the sensor size
  - EIC-Japan will be a bridge between eRD112 and HPK

- EIC-Japan will take care of components other than sensor design
  - e.g. FPC, cables, support material, etc

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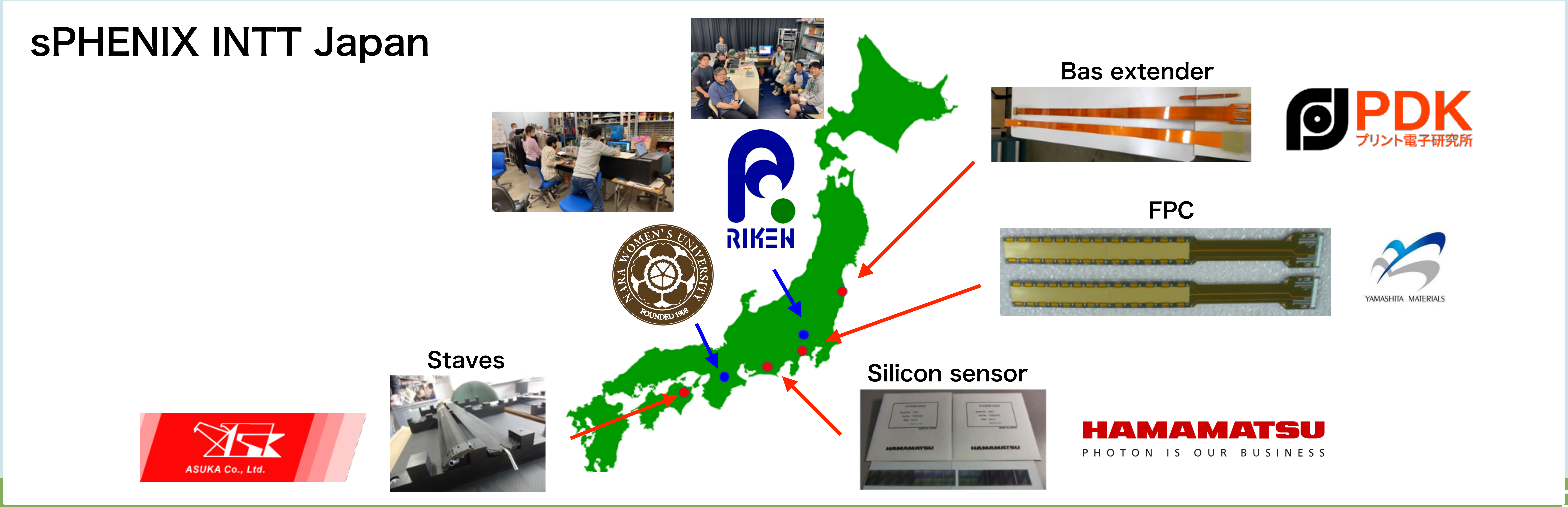

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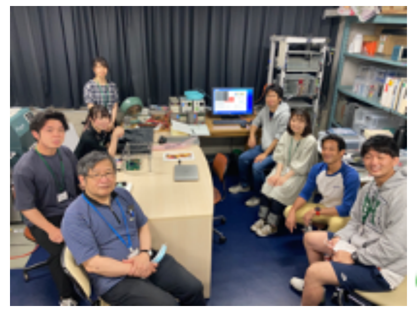
  + Hiroshima University (experienced ALICE forward silicon tracker development)

sPHENIX INTT Japan
+ Hiroshima Univ.

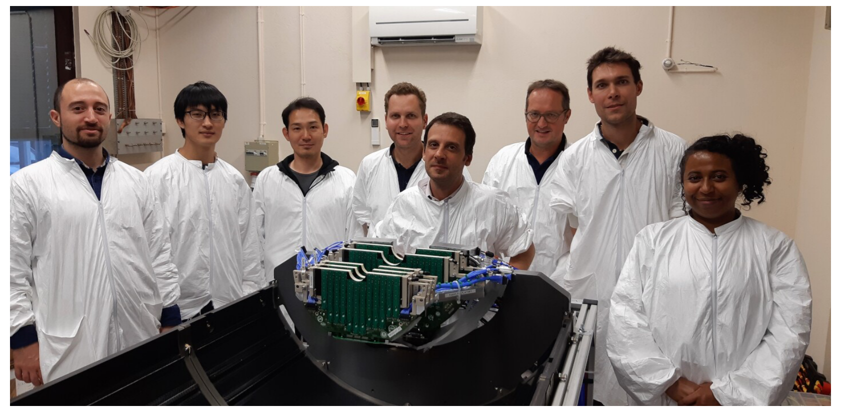


RIKEN

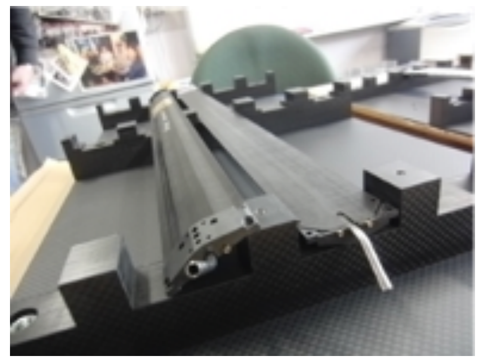
NARA WOMEN'S UNIVERSITY FOUNDED 1908

HIROSHIMA

MFT assembling @ CERN



Staves

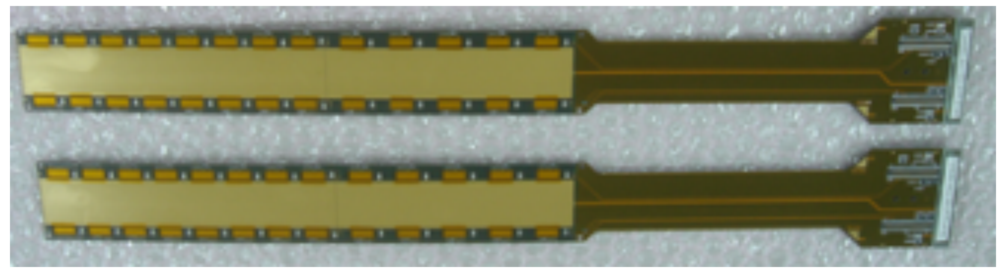


ASUKA Co., Ltd.

Bas extender

PDK プリント電子研究所

FPC



YAMASHITA MATERIALS

Silicon sensor

HAMAMATSU
PHOTON IS OUR BUSINESS

Summary

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