Plans for AC-LGAD ePIC Barrel ToF

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for the EIC Japan group

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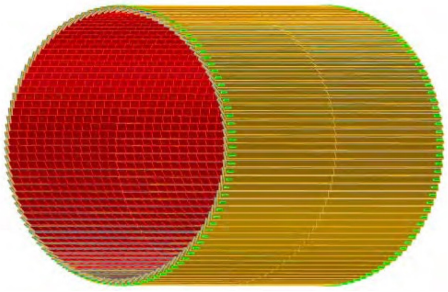
Presentation Outline

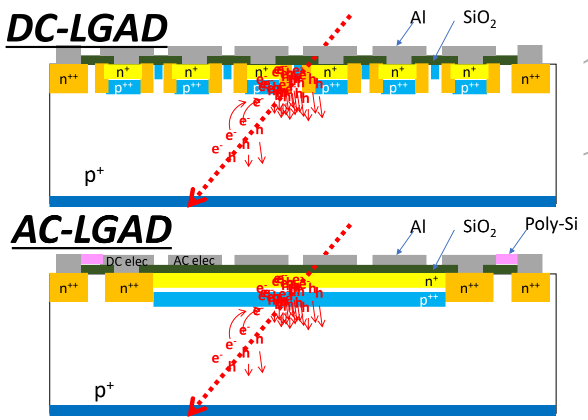
- ePIC barrel timing detector
- AC Low Gain Avalanche Diode
  - R&D elements
  - ongoing R&D for ePIC and HL ATLAS
  - BNL/KEK/Tsukuba/Hamamatsu achievements
- EIC-Japan on barrel ToF
  - R&D start up status and plan
  - team Japan experience and capability
  - new “WPI” institute at Hiroshima
- summary and concluding remarks

ePIC Barrel Timing Detector

- ePIC designed compactly with SC solenoid
- requirements for barrel ToF at ~ 80 cm radius:
  - ~ 30 ps time resolution
    - short path length, wide transverse momentum range
  - loose position resolution requirement
    - low multiplicity and spatial density
  - 10^{10} n_{eq} cm^{-2} radiation torrerance
    - integrated at top luminosity L ~ 10^{34} $cm^{-2}s^{-1}$
    - *cf.* HL LHC 10^{15-16} n_{eq} cm^{-2} at L ~ 10^{35} $cm^{-2}s^{-1}$
  - ~ 11 m^2 area
  - insensitivity to magnetic field preferred
  - *nb.* AC-LGAD chosen for ePIC endcap ToF



Low Gain Avalanche Diode (LGAD)

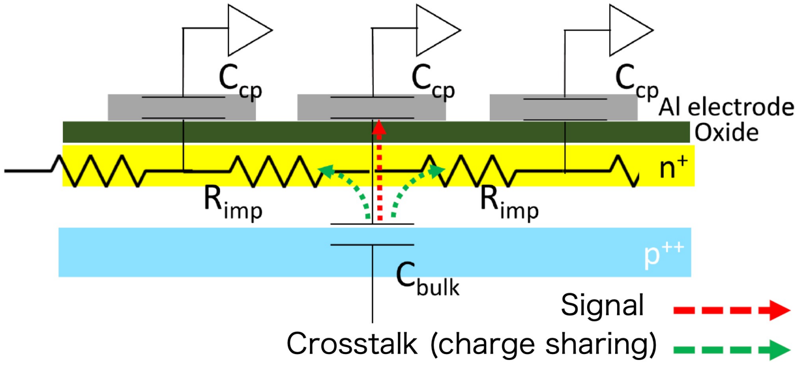


K. Nakamura *et al.*,
JPS Conf. Proc. 34, 010016 (2021)

- DC (*i.e.* standard) -LGAD
  - individual p^{+} gain layer per electrode
    - inactive gaps between granules
  - n^{++}-in-p type sensor w/ p^{+} gain layer
    - high dope for high signal conductivity
- AC-LGAD
  - spanning p^{+} gain layer w/ multiple electrodes
    - ~ 100% fill factor w/ fine pitch
    - AC coupling w/ oxide layer between n^{+} layer and electrodes
  - n^{+}- in-p type sensor w/ p^{+} gain layer
    - low dope for low sideward conductivity
- AC-LGAD better suited for single layer barrel ToF

AC-LGAD R&D Elements

- issues compared to DC-LGAD
  - weaker signal due to AC coupling
  - crosstalk due to charge sharing in spanning n^+ layer
  - uniformity
- factors for signal strength
  - R_{imp} (higher preferred)
    - low n^+ dope $\rightarrow$ high R_{imp}
  - C_{cp} (higher preferred)
    - high segmentation $\rightarrow$ low C_{cp}
    - thin oxide layer $\rightarrow$ high C_{cp}
- hurdles for good time and position resolutions



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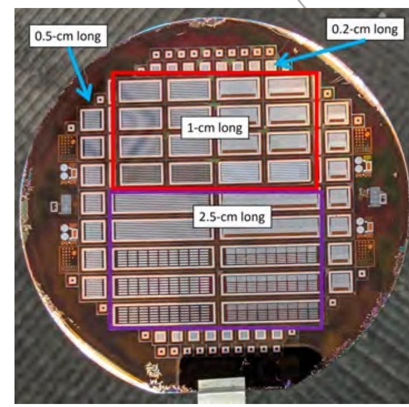
Ongoing AC-LGAD R&D

- BNL, U.S.A.
  - inhouse chip manufacture (not for mass production)
  - ATLAS Japan bridging ePIC/BNL and Hamamatsu
- KEK and U. Tsukuba, Japan
  - led by Koji Nakamura (KEK)
  - close connection w/ Hamamatsu HAMAMATSU PHOTON IS OUR BUSINESS
  - pad/strip/pixel; electrode shape/size; oxide properties
  - future ATLAS vertex detector at HL LHC from 2028
- HL LHC more demanding than EIC case
  - 30 ps time resolution, *o*(10) μm position resolution
  - $o(10^{15})\ n_{eq}\ cm^{-2}$ radiation tolerance

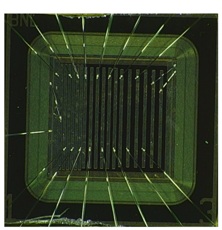
BNL/Hamamatsu Made Sensors

- *ref.* R.Heller *et al.*, JINST 17 P05001 (2022)
- strip type by BNL
  - *e.g.* electrode size effects
- pad type by Hamamatsu
  - *e.g.* n^+ dope concentration effects
- good performance achieved w/ small sensors

BNL 4” wafer

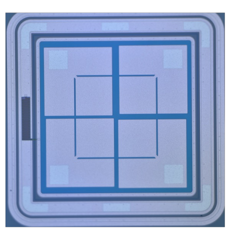


Strip type by BNL



3x3 mm² Sensor size

Pad type by HPK



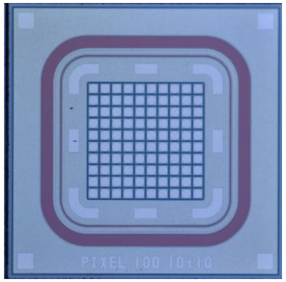
3x3 mm² Sensor size

Name Unit	Pitch μm	Primary signal amp. mV	Position res. μm	Time res. ps
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

R. Heller *et al.*, JINST 17 P05001 (2022)

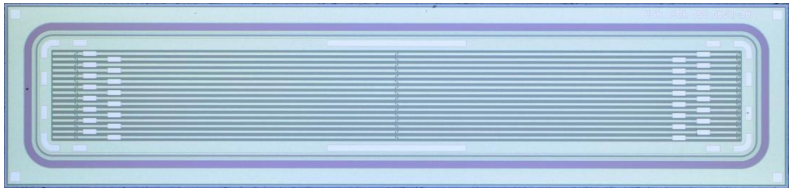
R&D News from KEK/Tsukuba/HPK

- *ref.* S.Kita *et al.*, VERTEX 2022
  - 24–27 October 2022, Tateyama, Japan
- pixel and strip types prototyped



sensor size: 1 × 1 mm^2
sensor pitch: 50, 100, 150, 200 μm
electrode size: 40, 90, 140, 190 μm

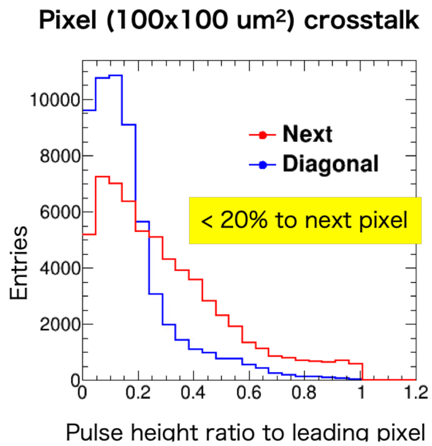
sensor size: 3 × ~ 10 mm^2
pitch: 80 μm
electrode width: 40, 45 μm

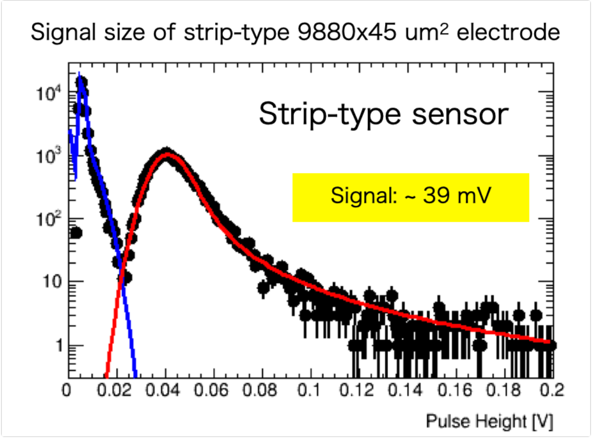


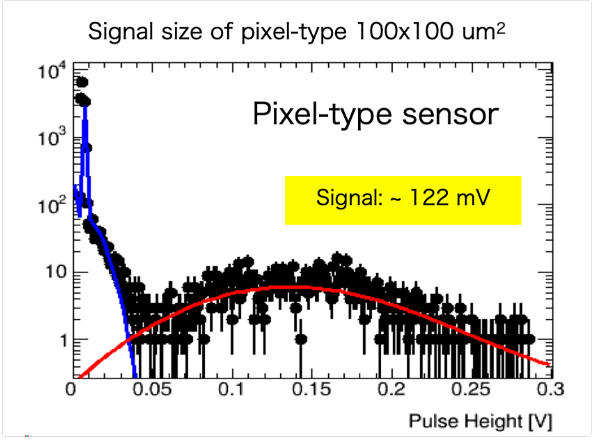
- resistivity/capacitance parameter optimization

KEK/Tsukuba/HPK Latest Results

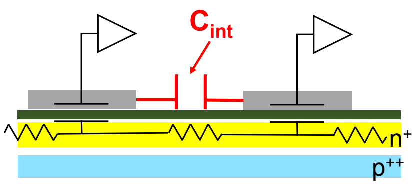
- good performance w/ 100 μm pixel and larger
  - next: larger sensor (~ 20 × 20 mm²) w/ ASIC readout







- problem w/ long (e.g. ~ 10 mm) strip
  - unexpectedly weaker signal than pixel
  - inter-electrode capacitance newly noticed
  - further R&D for future ATLAS inner tracker

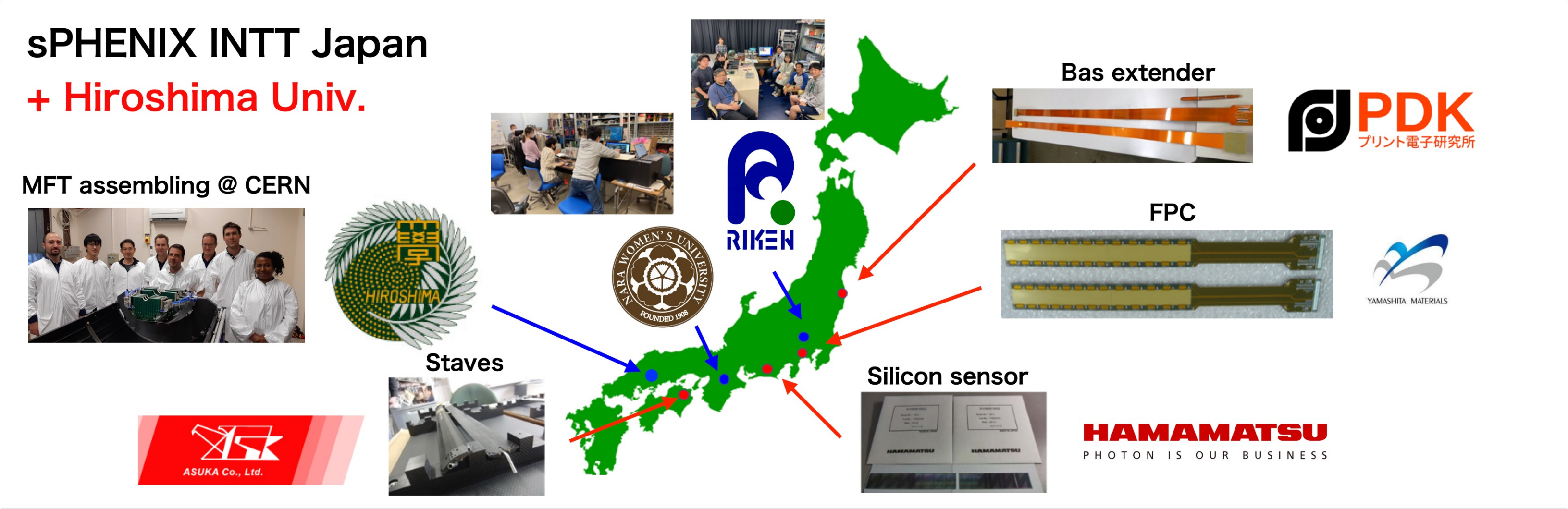


EIC-Japan Barrel ToF Plans

- eager to lead ePIC barrel ToF
  - responsibly like for sPHENIX INTT detector
  - capable to manufacture all components in Japan
- sensor strategy
  - AC-LGAD already (almost) satisfying ePIC barel needs
    - remaining major issue to increase sensor size
  - joining AC-LGAD R&D to finalize sensor design
  - preparing to test ePIC/BNL prototypes first
  - to bridge R&D team (eRD112) and Hamamatsu
- also to take care of other components
  - *e.g.* FPC, cables, support structures

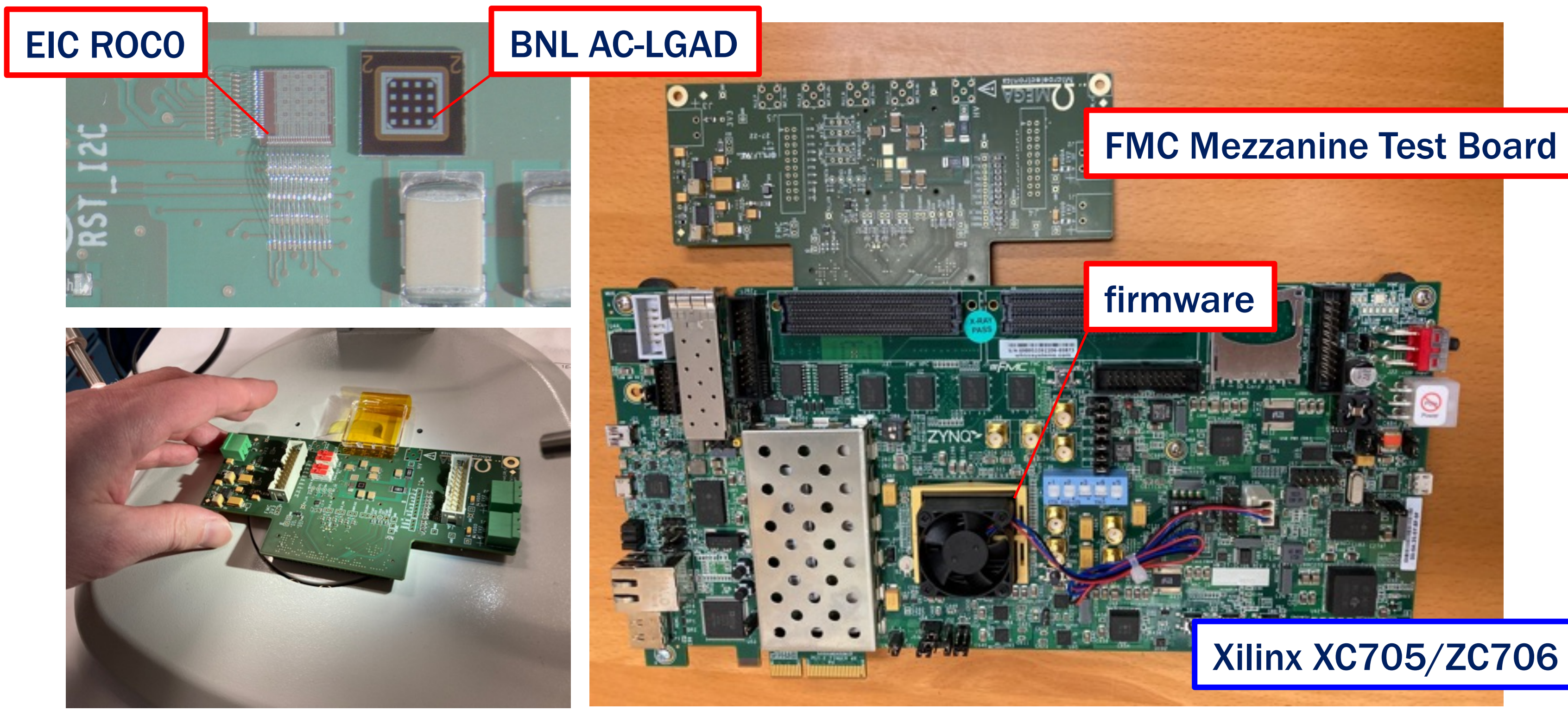
Team Japan Experiences

- Riken w/ sPHENIX INTT experience
  - w/ Japanese technologies
  - R&D, mass production, QA environments available
- Hiroshima w/ ALICE forward μ tracker experience



R&D Start Up Kit

- contact: Alessandro Tricoli (BNL)
- from ePIC: BNL sensor, EIC ROC, firmware, DAQ
- also: Xilinx board, PC, measuring instruments, ...



Brand-New “WPI” Institute at Hiroshima

- “world premier” center SKCM^2 just established
  - just funded last month by JSPS for 2022–2031
    - ~ 5 M USD per year × 10 years
  - 14 existing (e.g. Kavli IPMU) + 3 new institutes in Japan

wpi World Premier International Research Center Initiative

- K. Shigaki as PI on exp. nuclear/particle physics
  - to promote interdisciplinary science
  - ePIC declared as one of main projects
- HR, building/facilities, student supports, ...
  - new group/lab to complete in coming years

Summary and Concluding Remarks

- ePIC ToF requiring excellent timing resolution
- AC-LGAD: most promising technology choice
- EIC-Japan eager to lead barrel ToF efforts
  - in addition to forward calorimeter (*ref.* talk by Y. Goto)
- starting with ePIC/BNL sensor and ROC tests
  - components starting to arrive this month
    - Riken, Hiroshima, and NCU
- Hiroshima joined the team w/ new resources
- very glad to welcome Taiwan to collaborate!