TOF (AC-LGAD) study at Hiroshima

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Hiroshima University

EIC Asian Workshop
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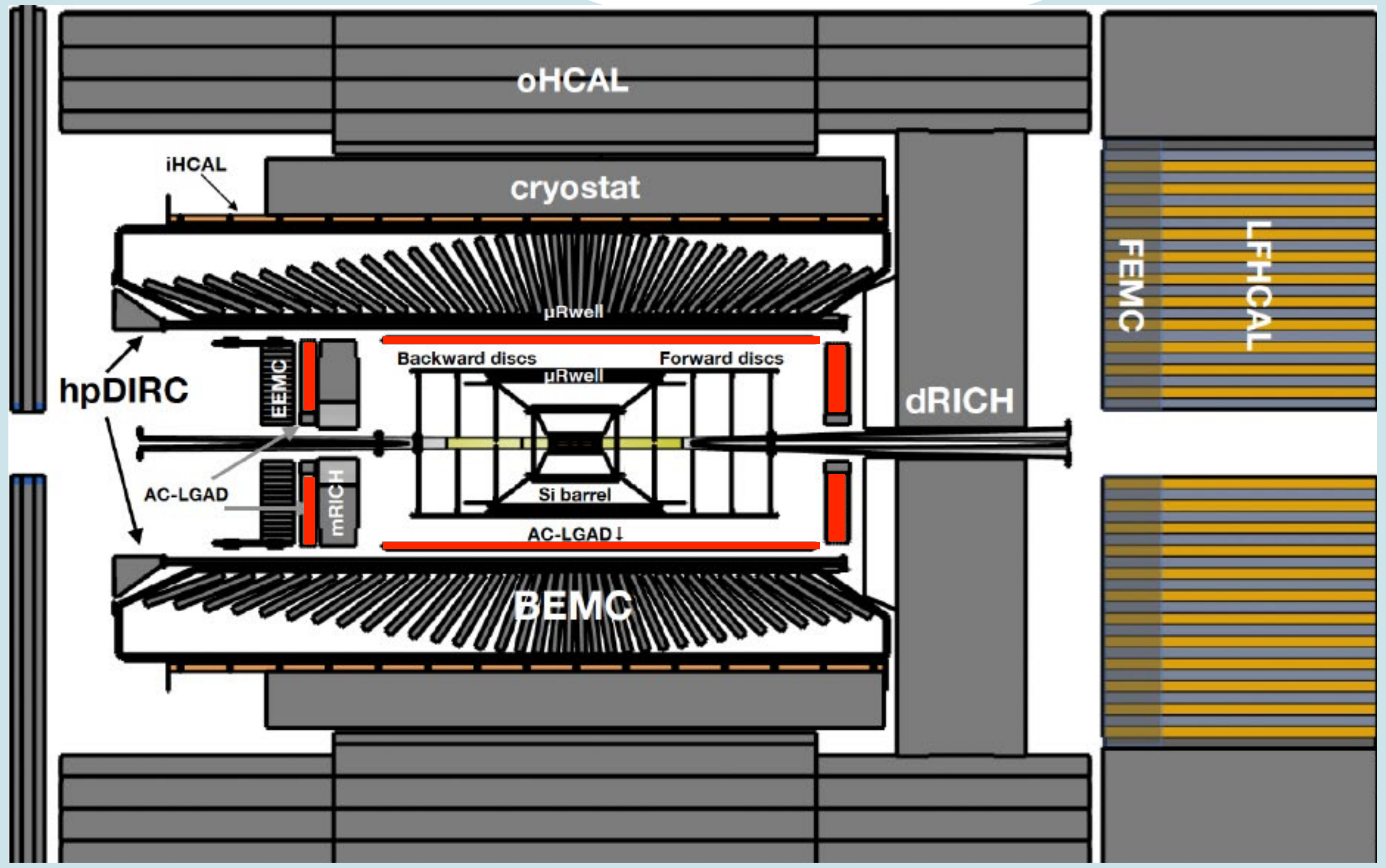
Time-of-Flight (TOF) in the ePIC collaboration

- Main identification detector at low- to middle-p_T region
  - Requiring an excellent timing resolution due to the compact design detector at $|\eta|<1.4$ (Barrel) and $1.8<|\eta|<\sim4.0$ (Endcap)



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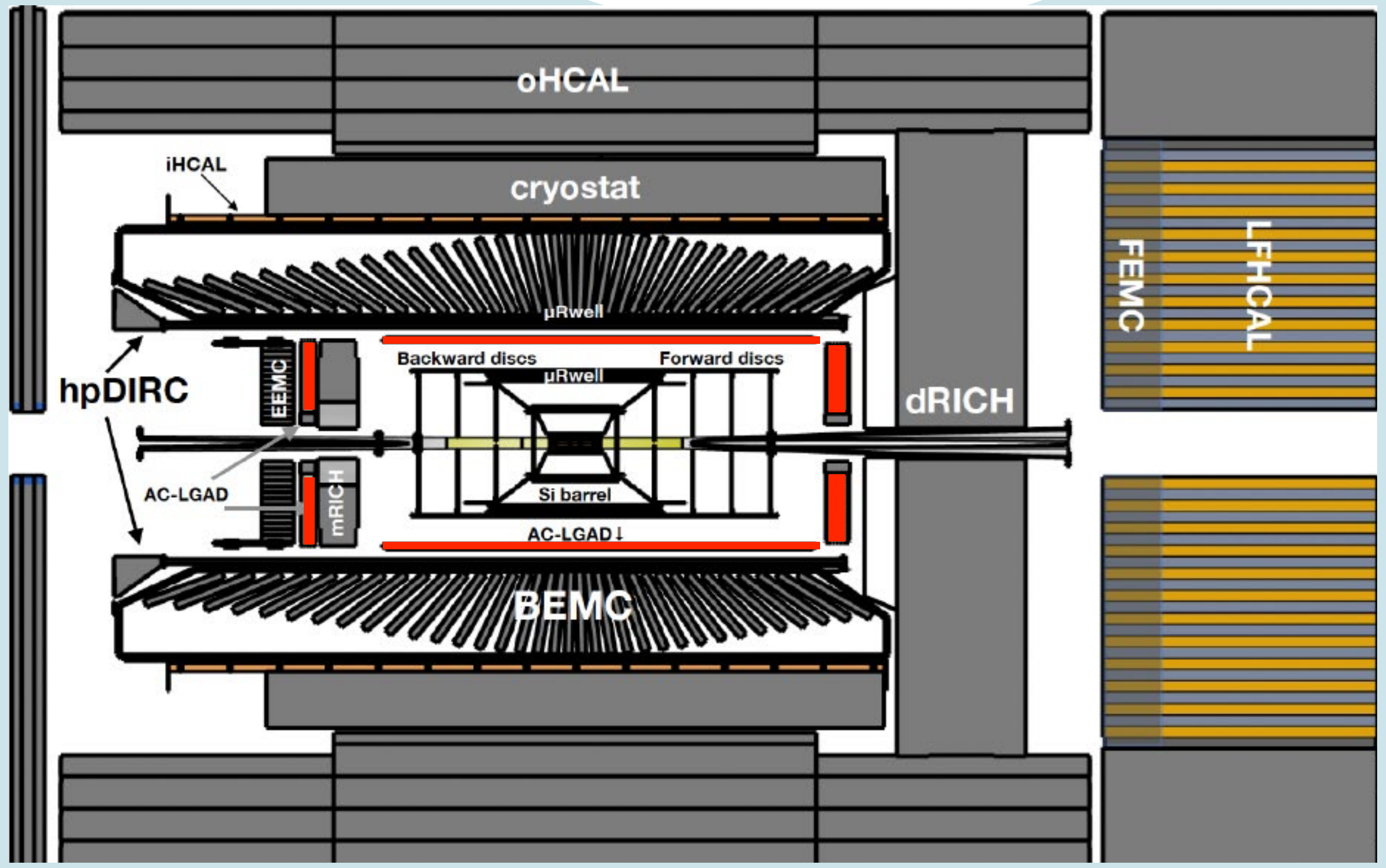
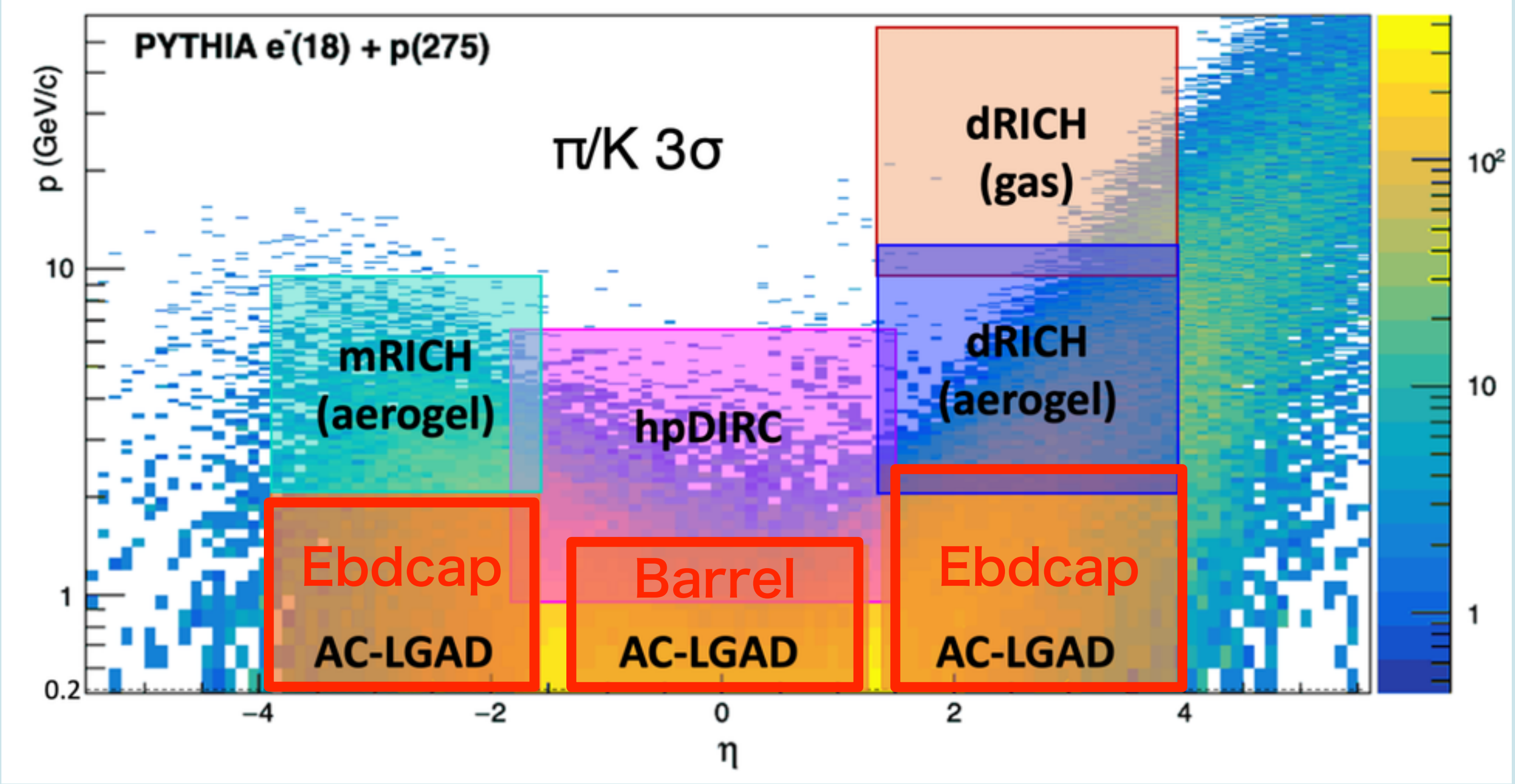
  - Particle identification e/π/K/p separation 0.15 < p < 2 GeV/c (0.15 < p < 2.5 GeV/c)





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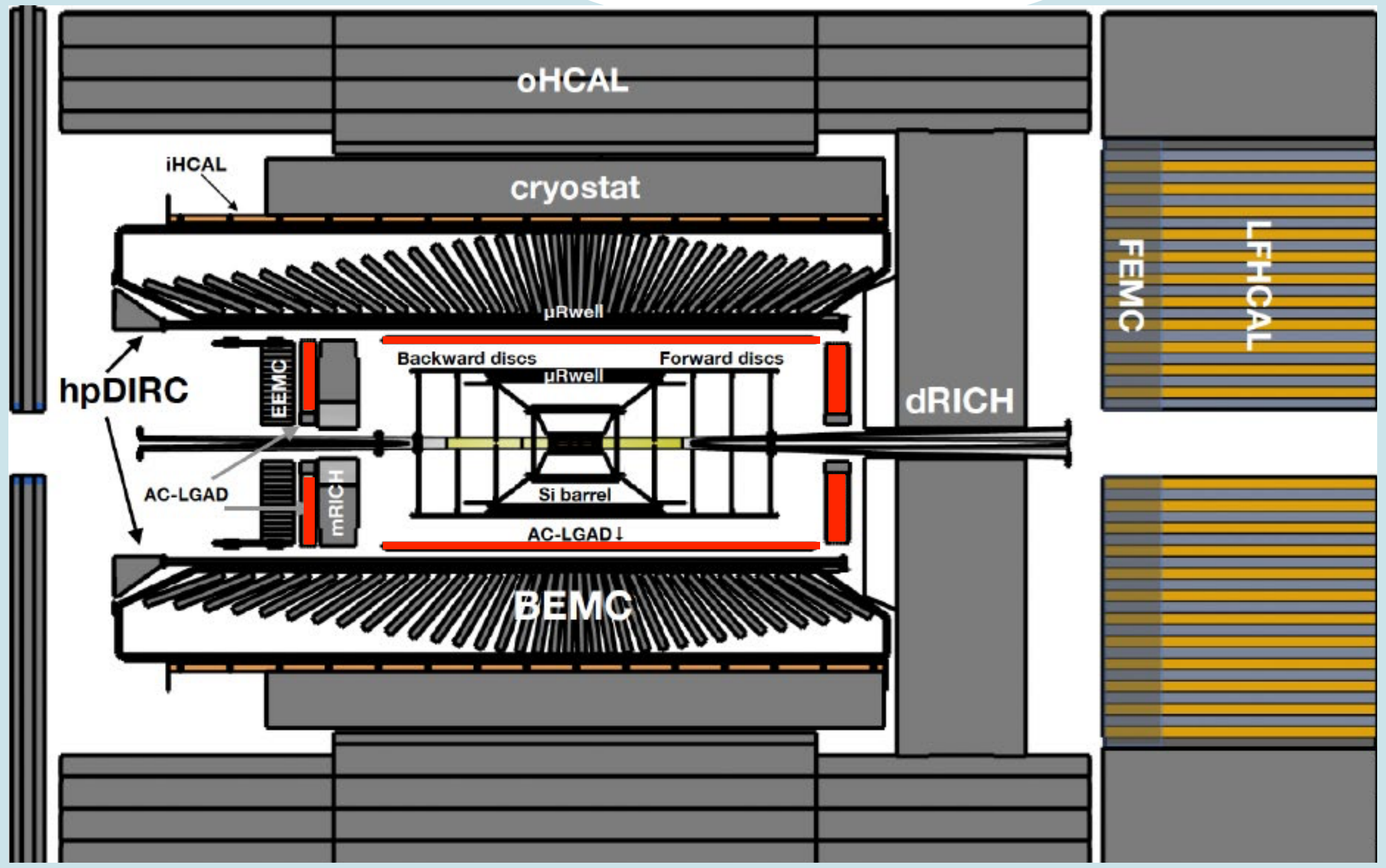

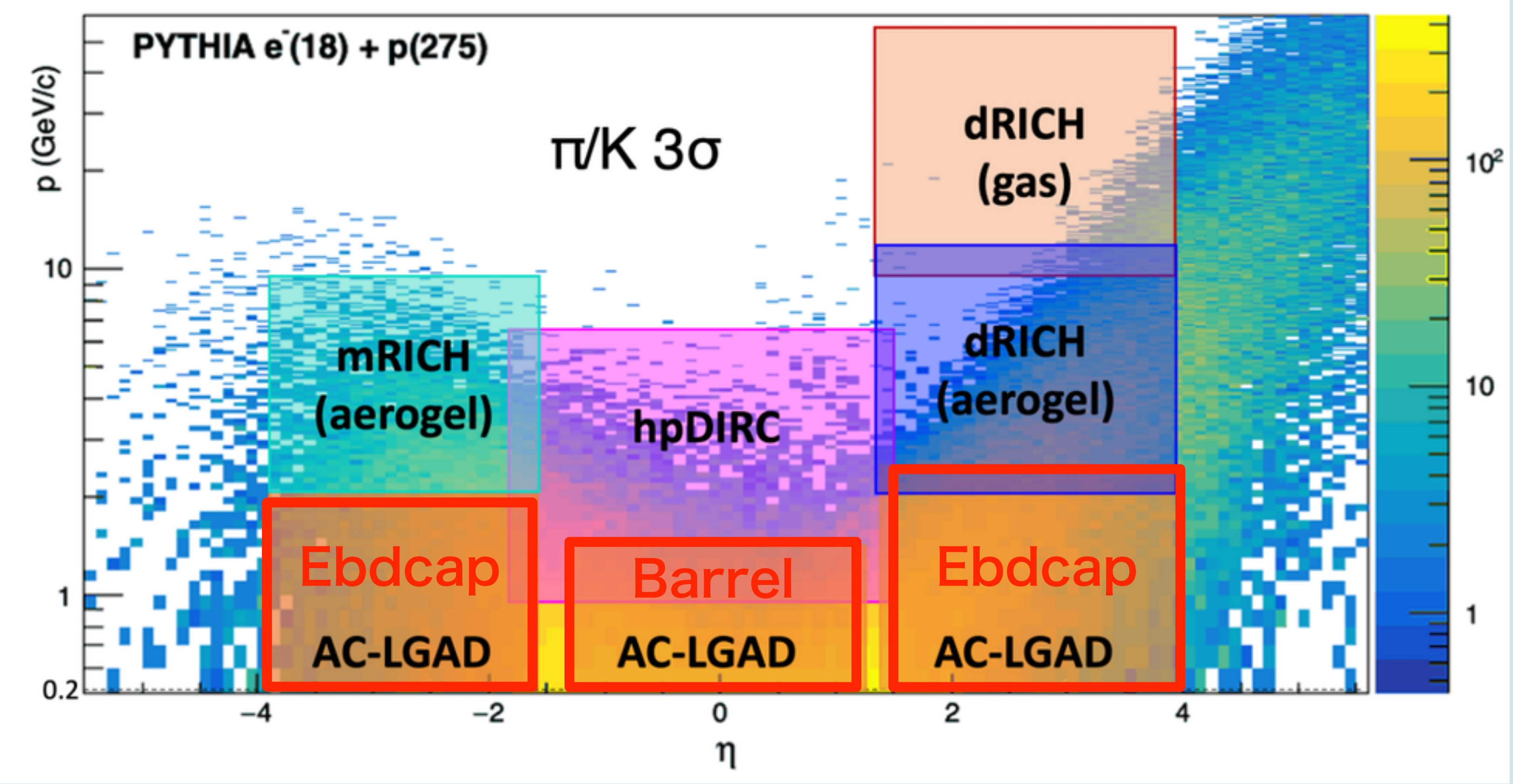

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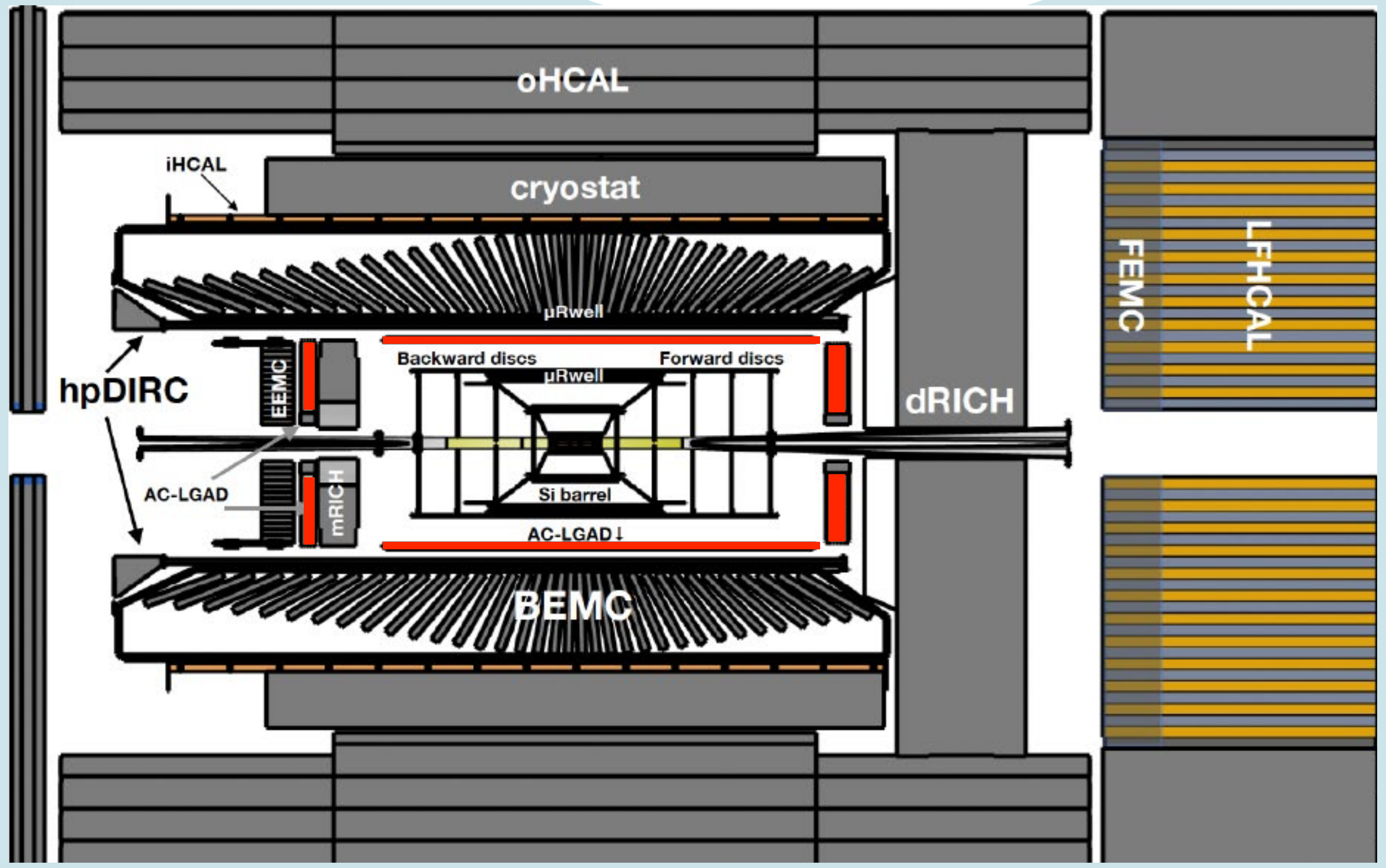
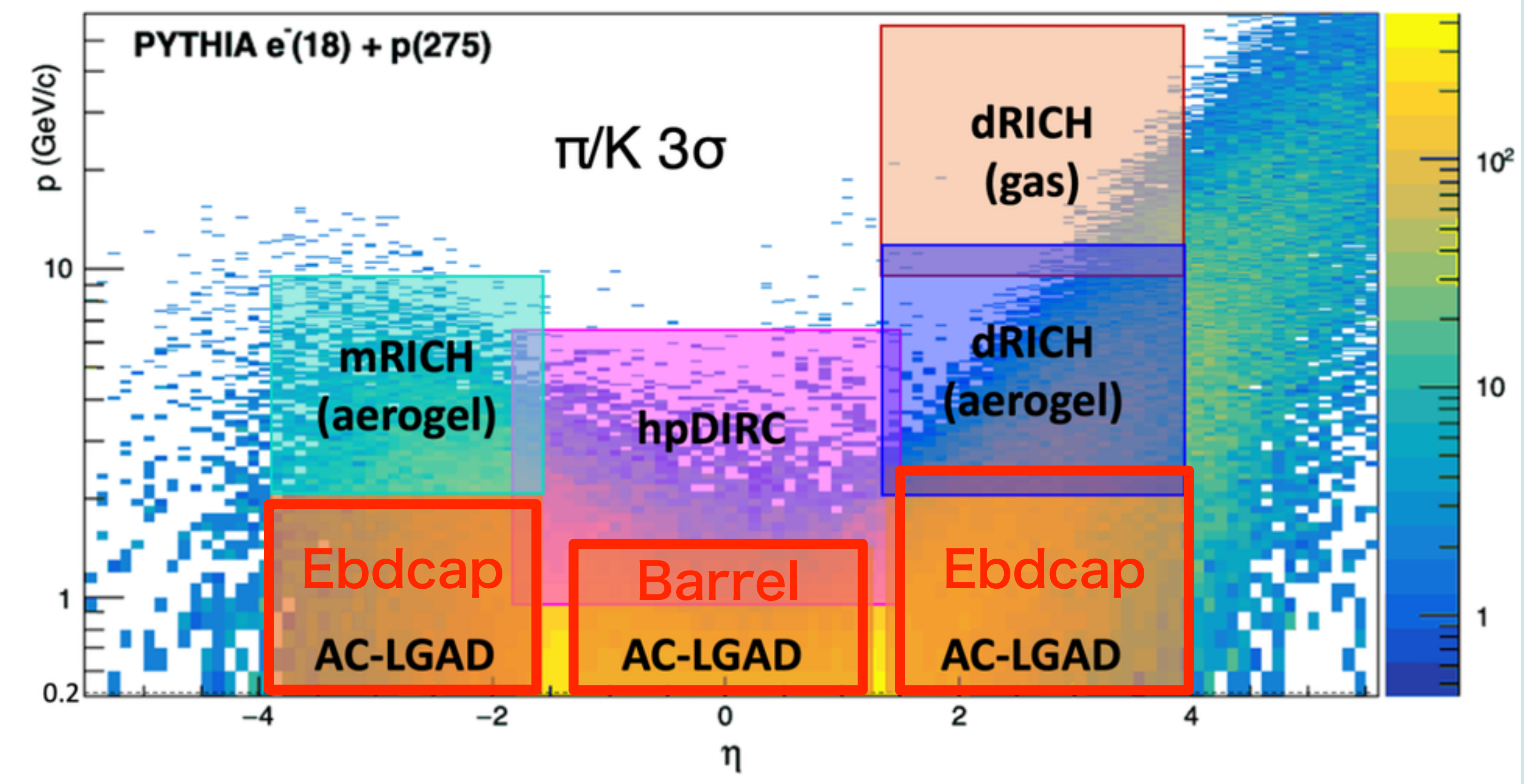


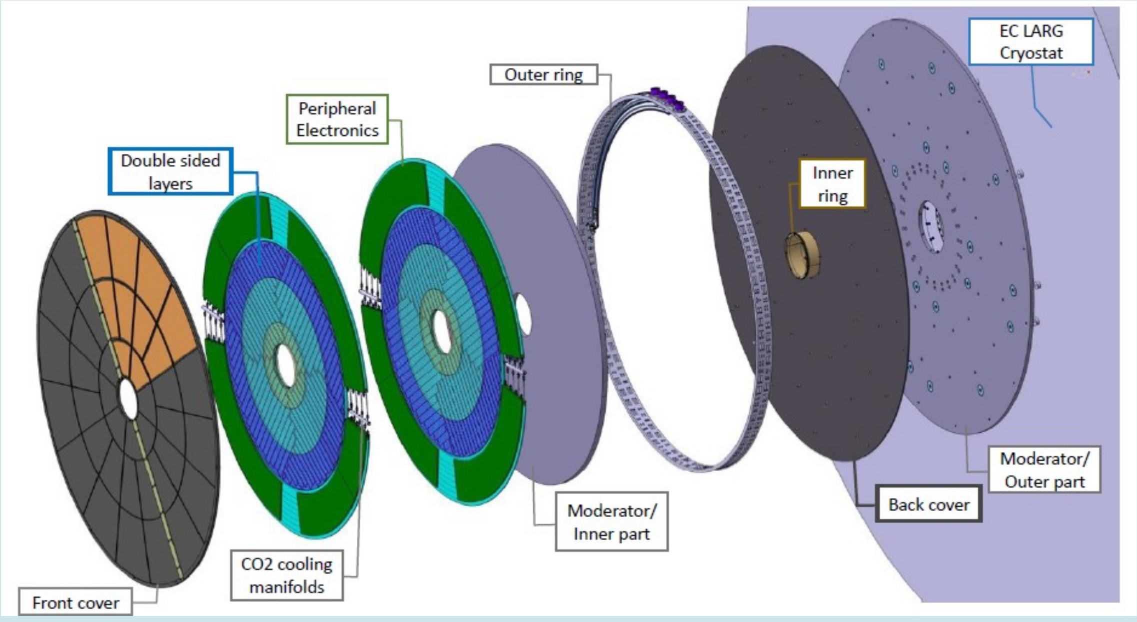


LGAD technology is the primary candidate to fulfill the requirements

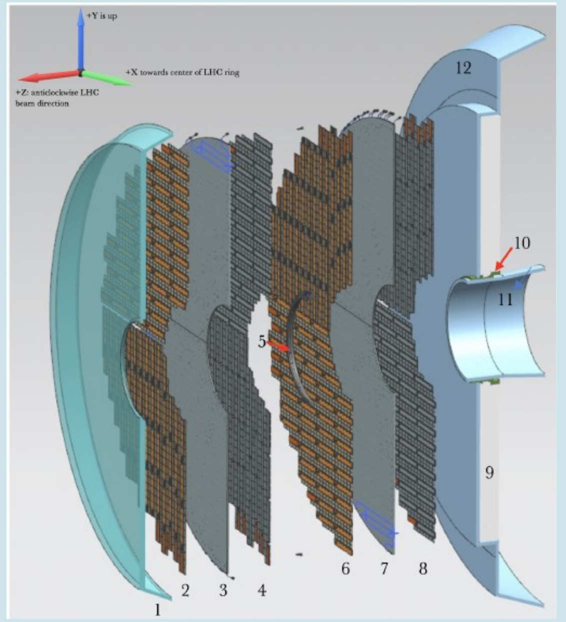
Low Gain Avalanche Diode (LGAD)

- DC-LGAD (standard LGAD)
  - Being built by ATLAS and CMS (LHC Run 4)
  - 30 ps timing resolution
  - Non-negligible inactive area due to individual readout
  - Not good spatial resolution (Pad: 1.3x1.3 mm^2 for ATLAS/CMS)

ATLAS



CMS



K. Nakamura et al.,
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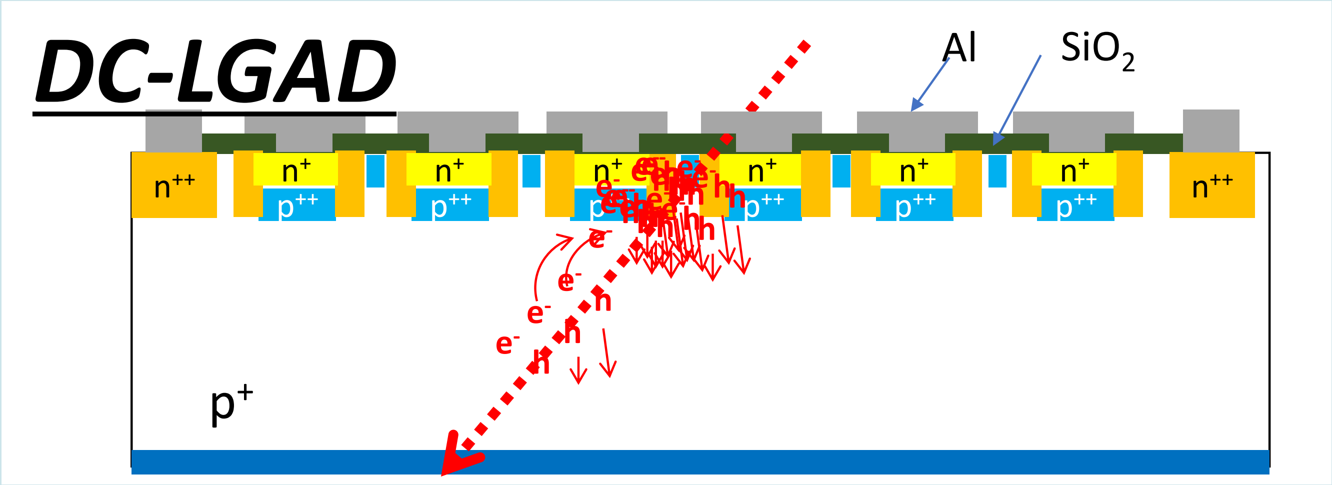

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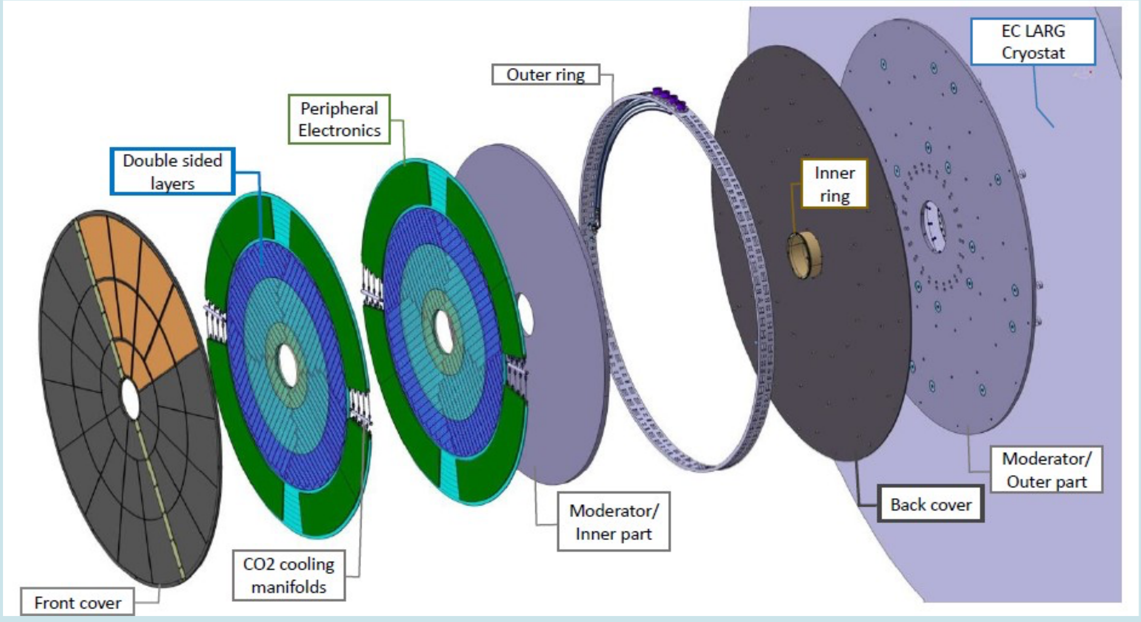
- AC-LGAD
  - Additional oxide layer for AC-coupling readout
  - 30 ps timing resolution
  - One large gain layer for electrodes → 100% of fill factor
  - Good spatial resolution thanks to charge sharing

ATLAS



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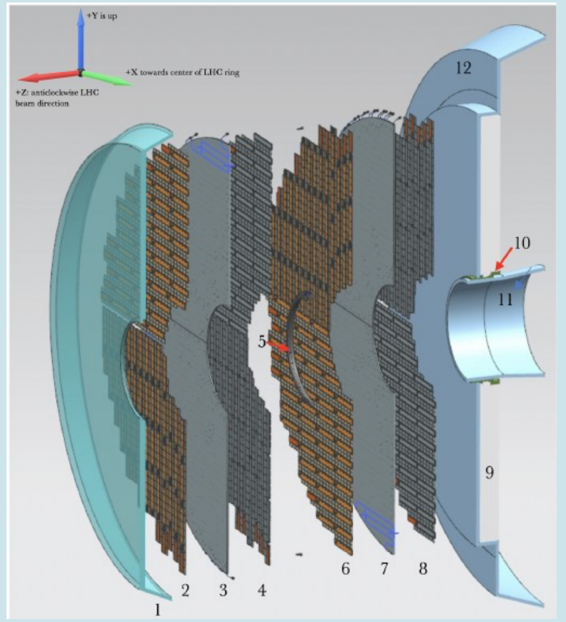

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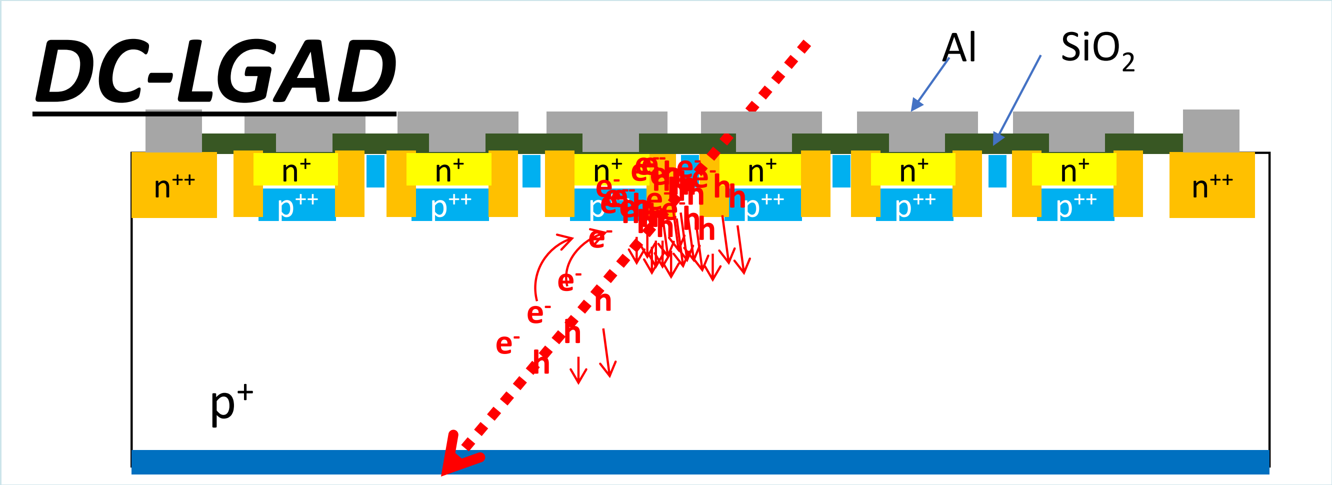

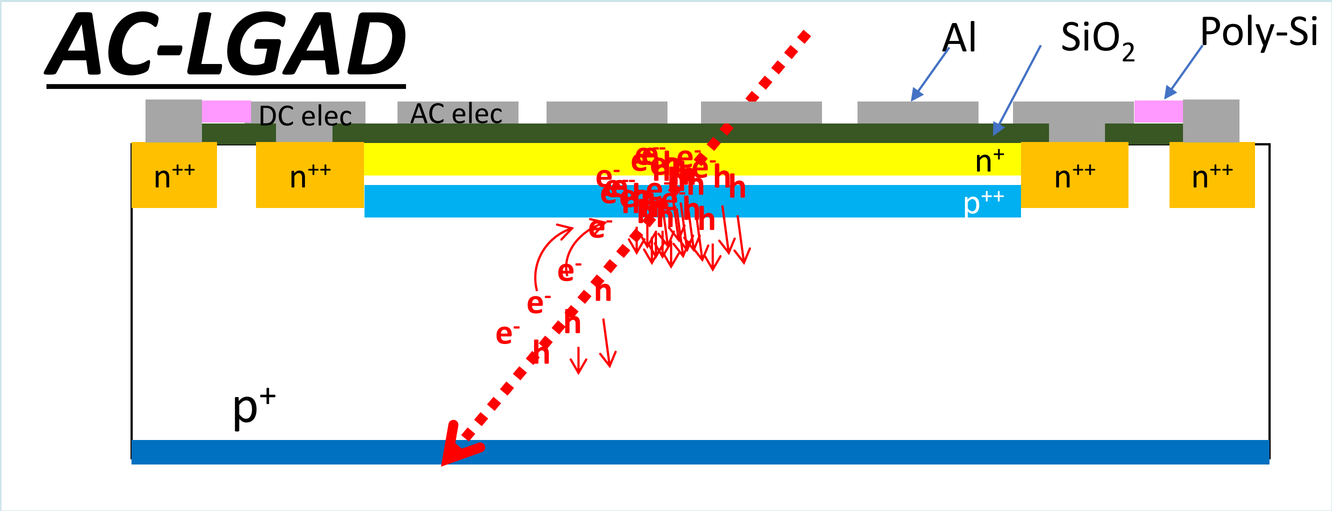

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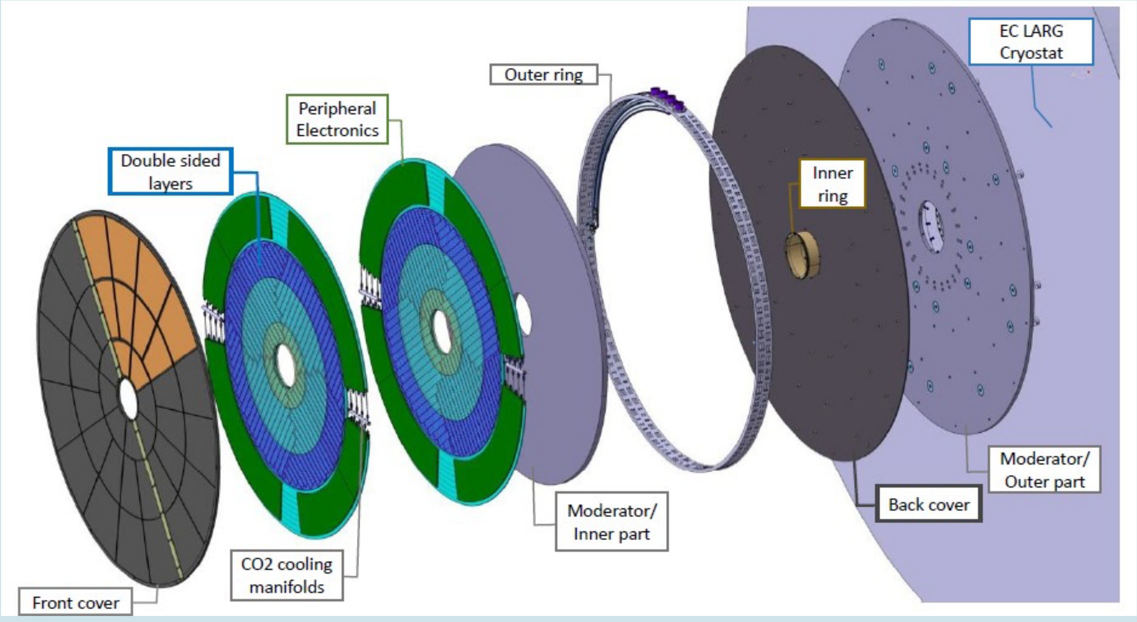

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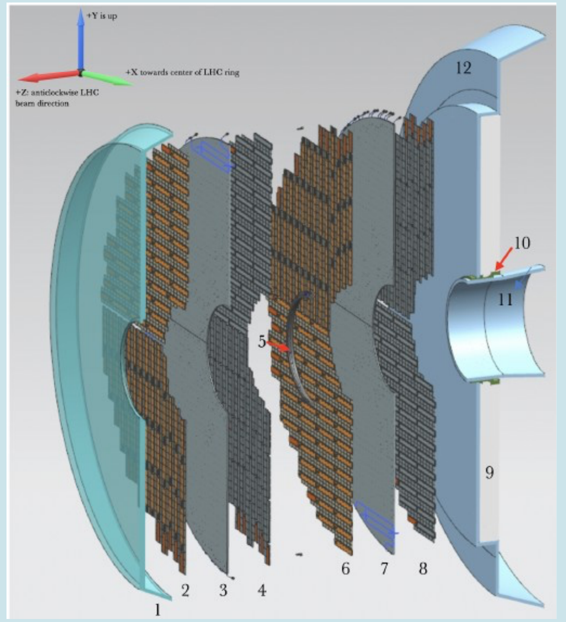

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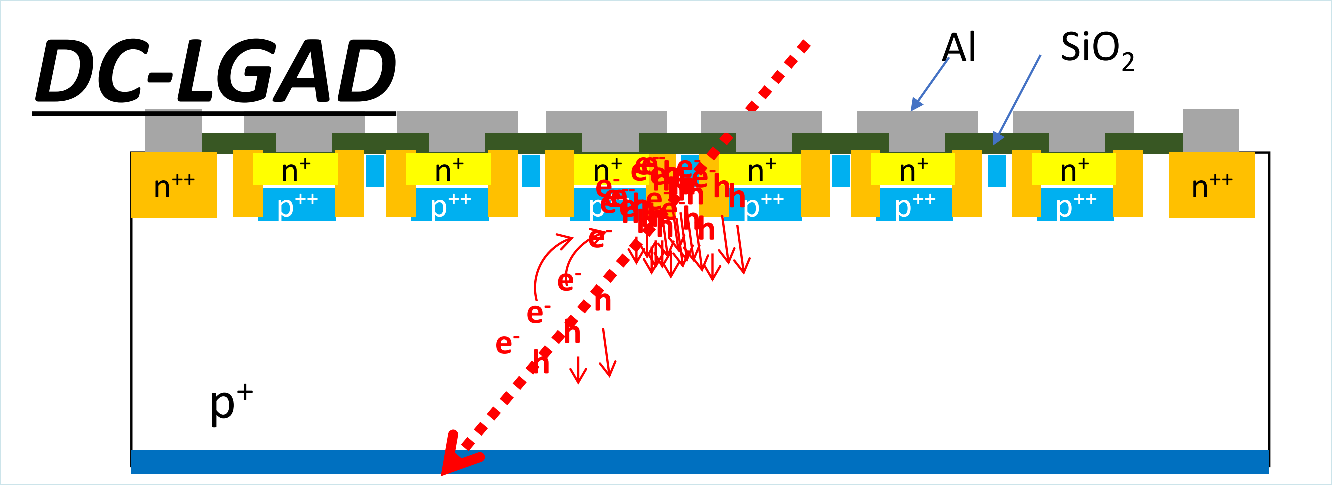
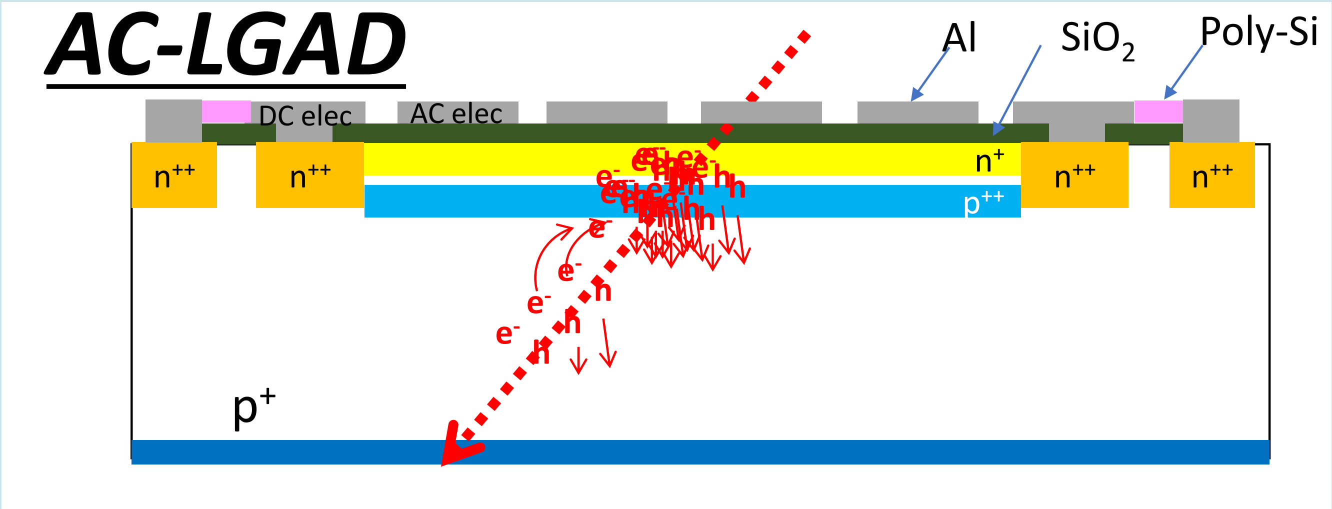


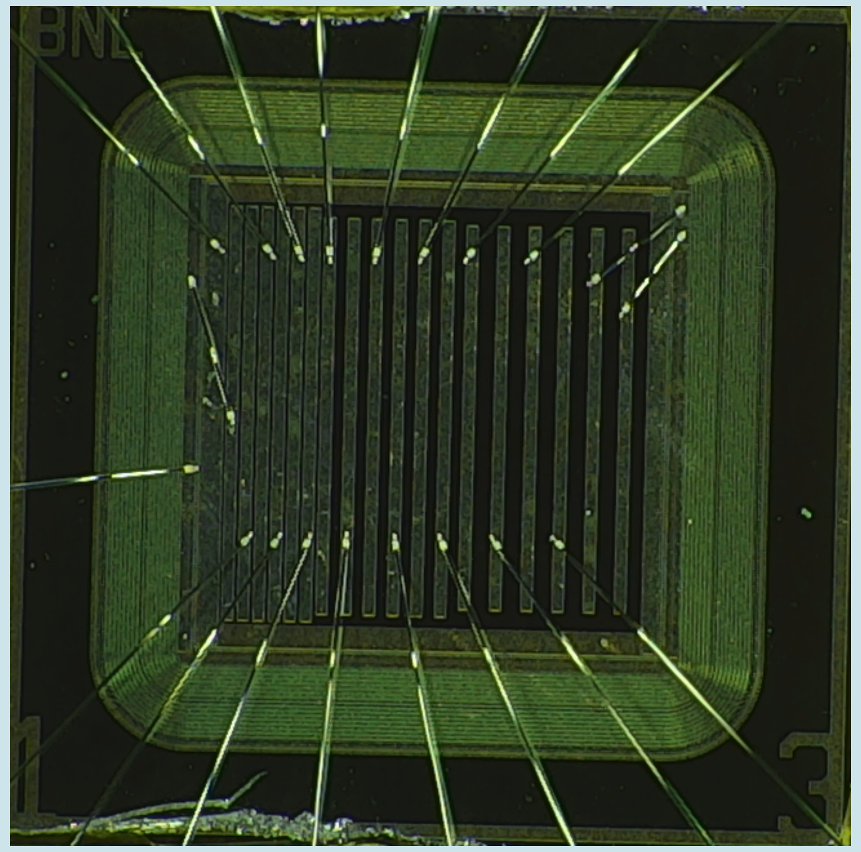


EIC-Japan has high hopes for AC-LGAD technology

Situation of AC-LGAD development

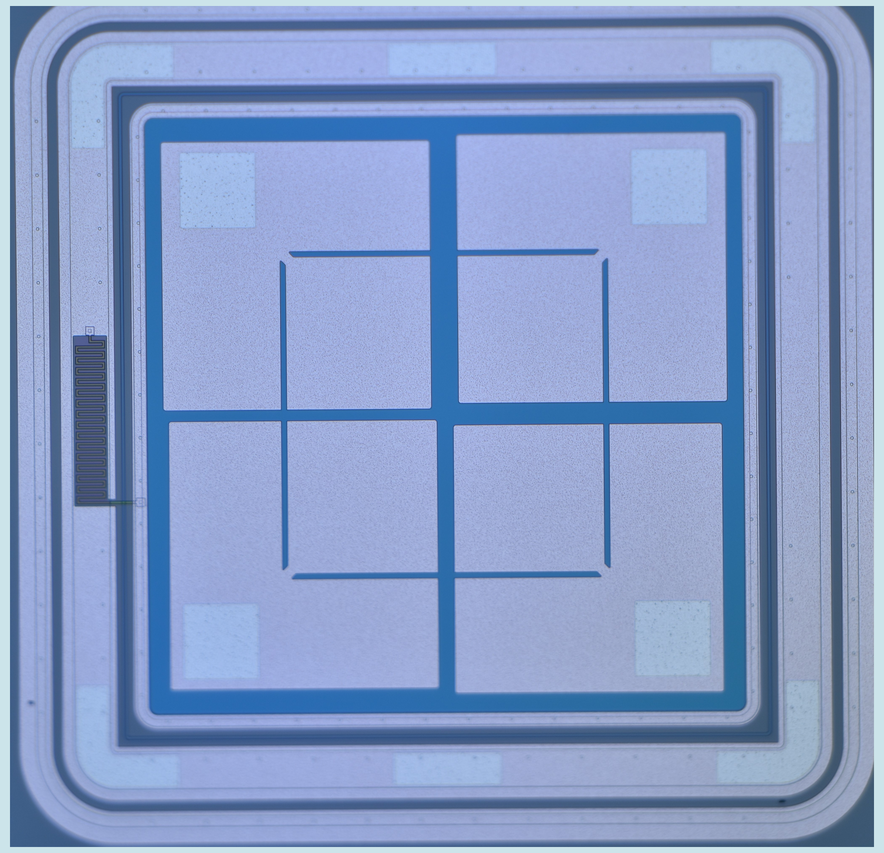
- Development of AC-LGAD for use in HL-LHC environment
  - R. Heller et al., JINST 17 P05001, 2022
  - Fabricated by BNL and KEK/Tsukuba (Hamamatsu Photonics : HPK)
  - Strip type and pad type (small sensor 3x3 mm^2)

Strip type by BNL



3x3 mm^2
Sensor size

Pad type by HPK



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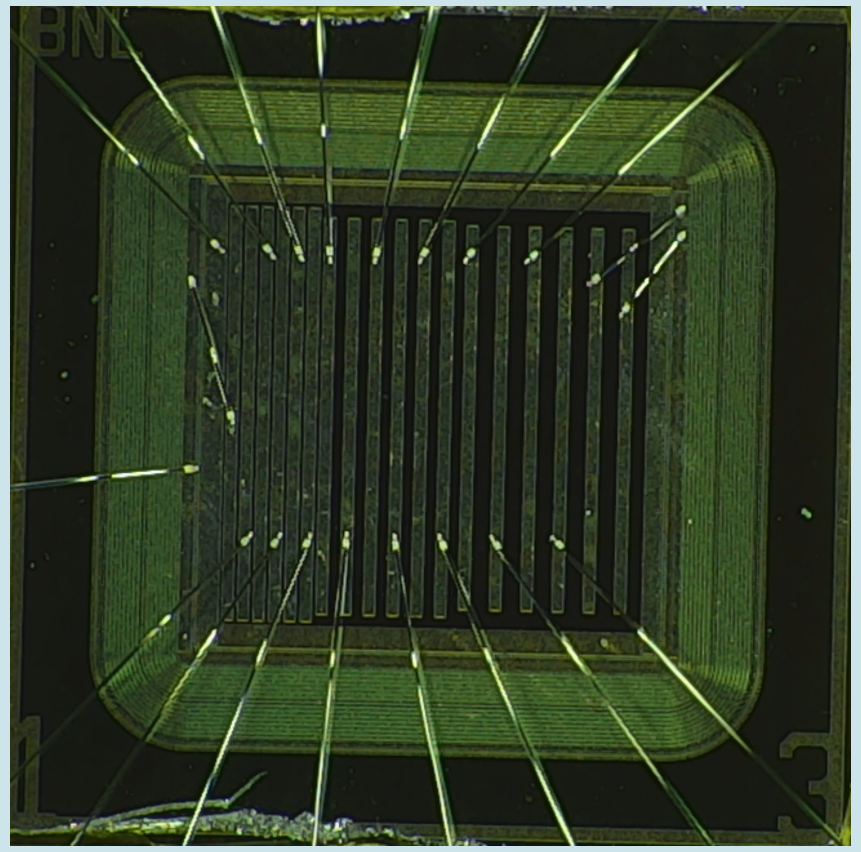

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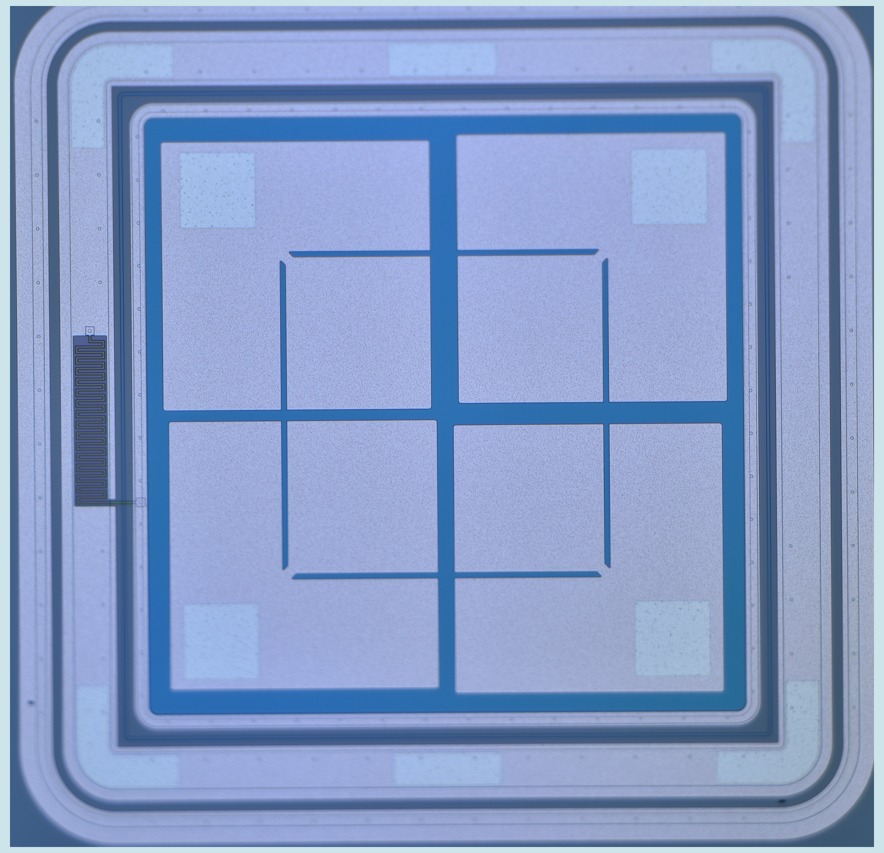

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Name	Pitch	Primary signal amp.	Position res.	Time res.
Unit	µm	mV	µm	ps
BNL 2020	100	101 ± 10	≤6	29 ± 1
BNL 2021 Narrow	100	104 ± 10	≤9	32 ± 1
BNL 2021 Medium	150	136 ± 13	≤11	30 ± 1
BNL 2021 Wide	200	144 ± 14	≤9	33 ± 1
HPK C–2	500	128 ± 12	22 ± 1	30 ± 1
HPK B–2	500	95 ± 10	24 ± 1	27 ± 1

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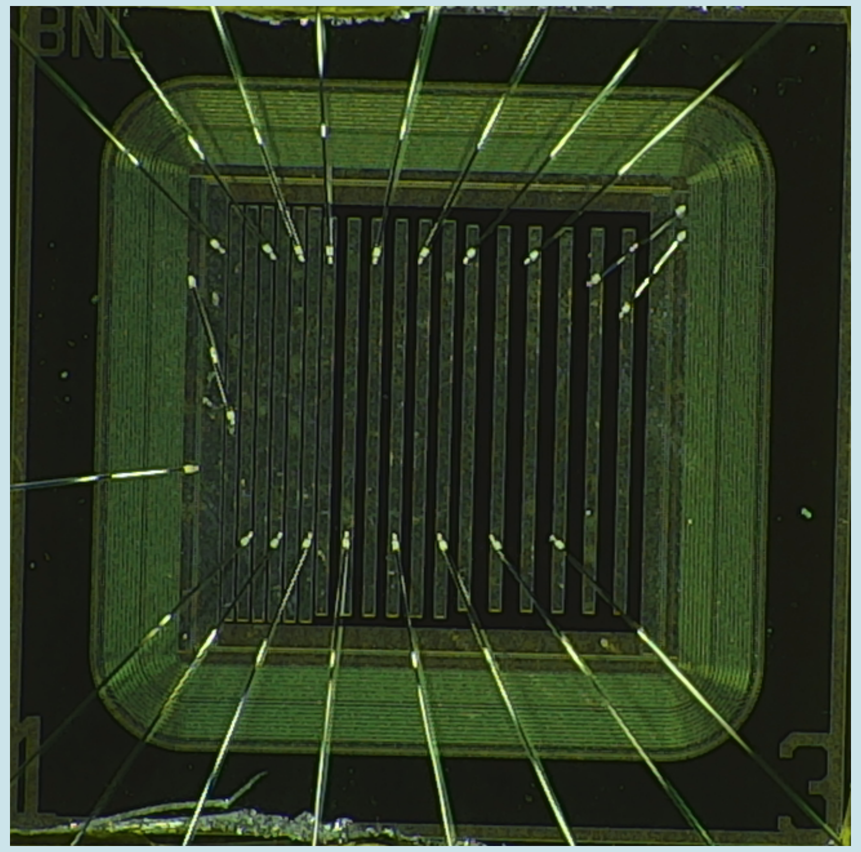

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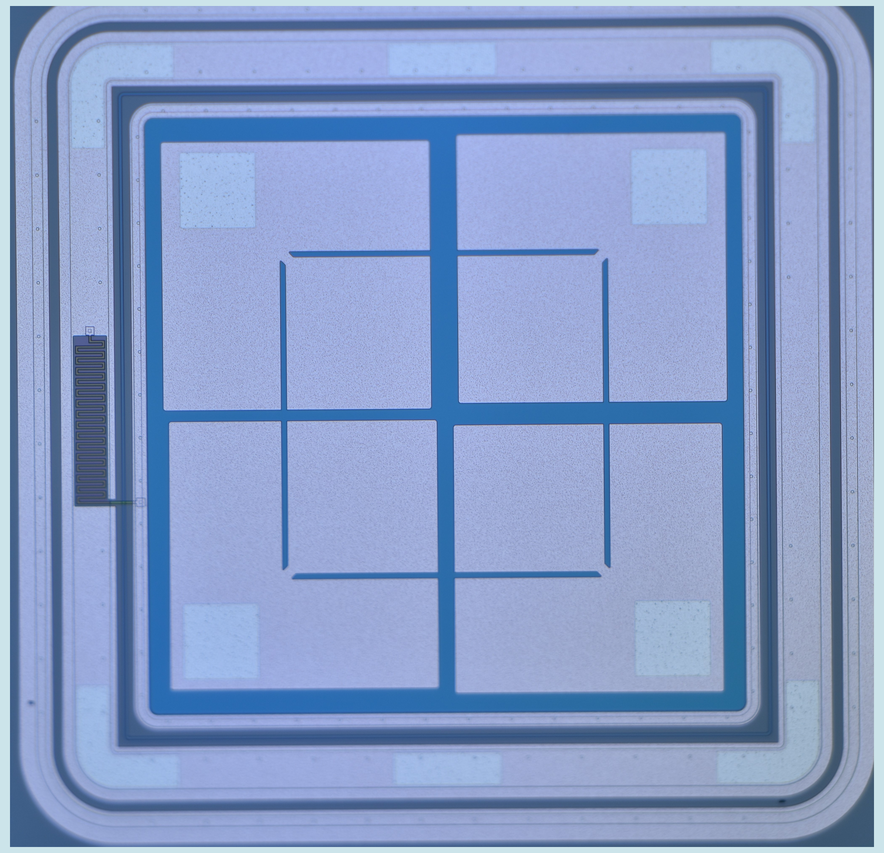

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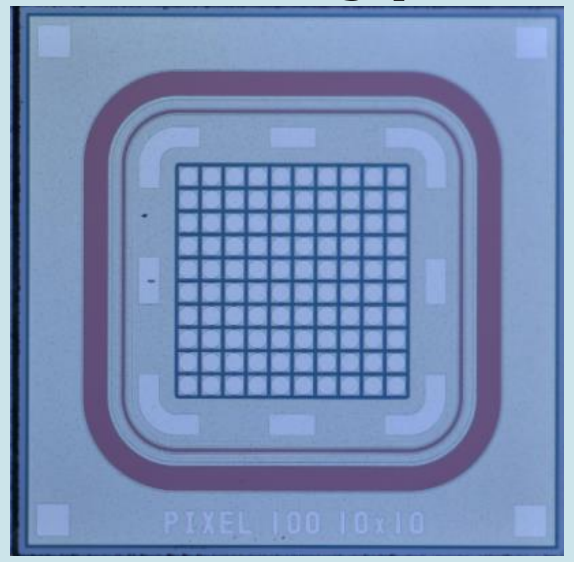
~30 ps time and < 30 um spatial resolution

Development trend
S. Kita et al., at VERTEX 2022

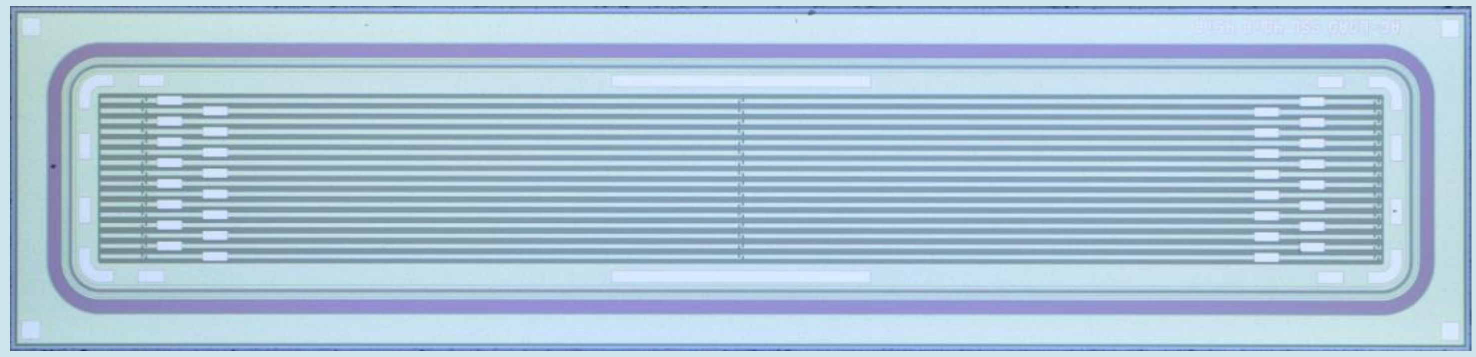
- The latest development at VERTEX2022 (for HL-LHC)
  - Larger strip and smaller pixel sensors

Pixel-type



1x1 mm^2 : Sensor size:
50, 100, 150, 200 um
Electrode shape
40, 90, 140, 190 um

Strip-type



Sensor size: 3x10 mm^2
Electrode width: 40, 45 um

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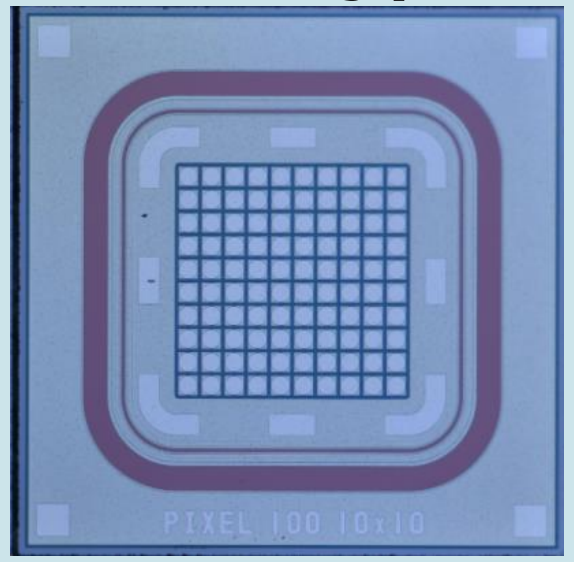
  - Smaller signal than pixel type
  - Due to inter-electrode capacitance

Pixel-type



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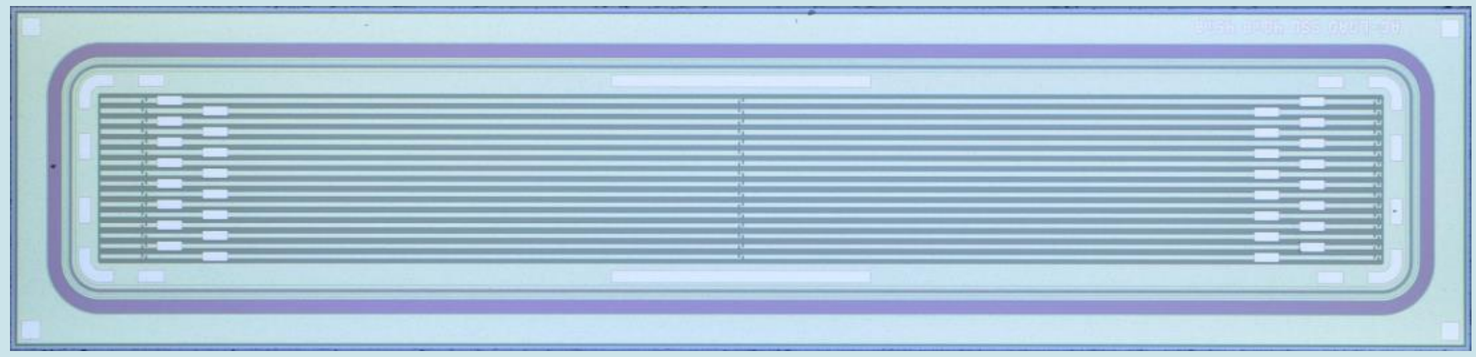

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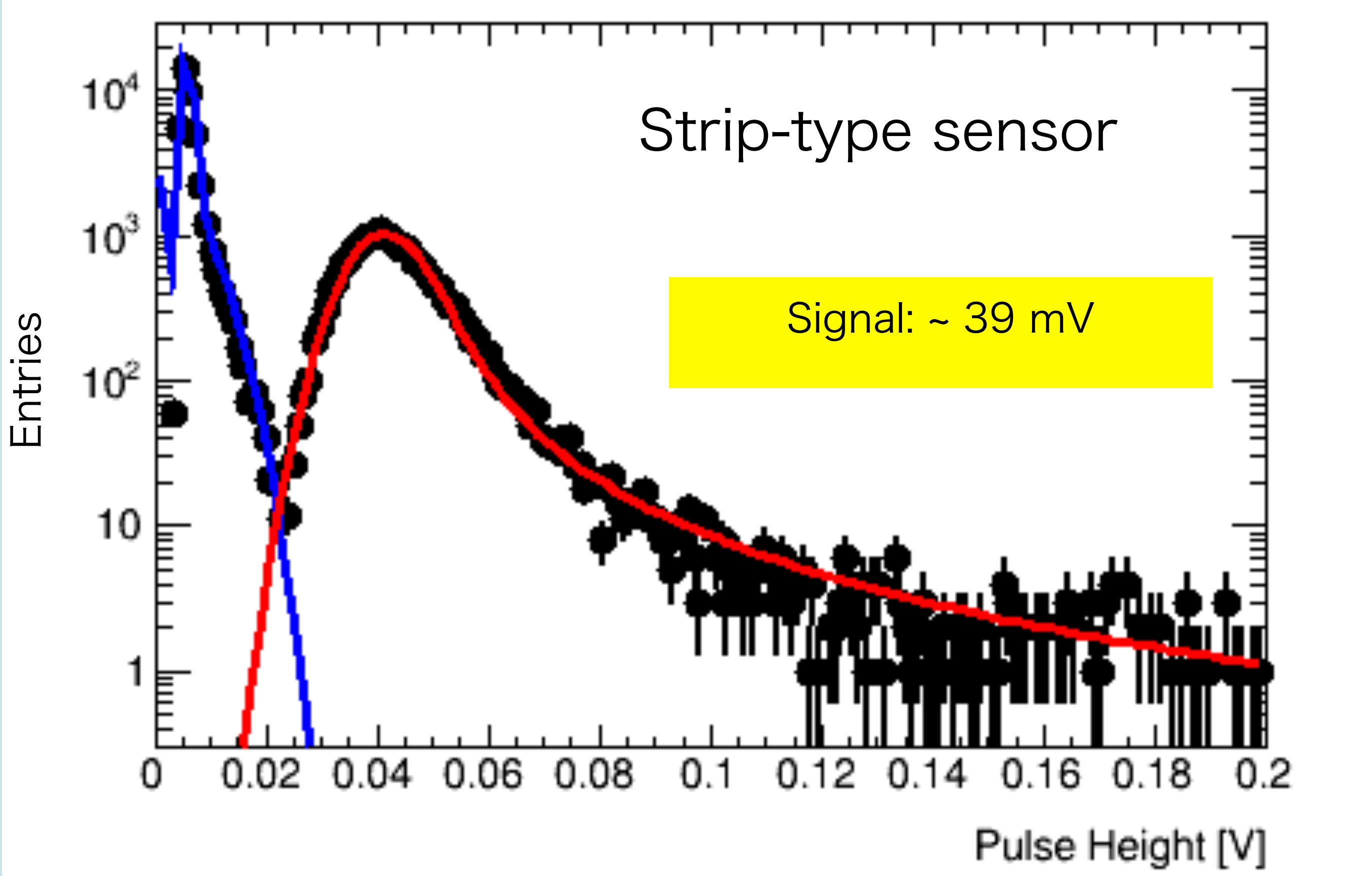
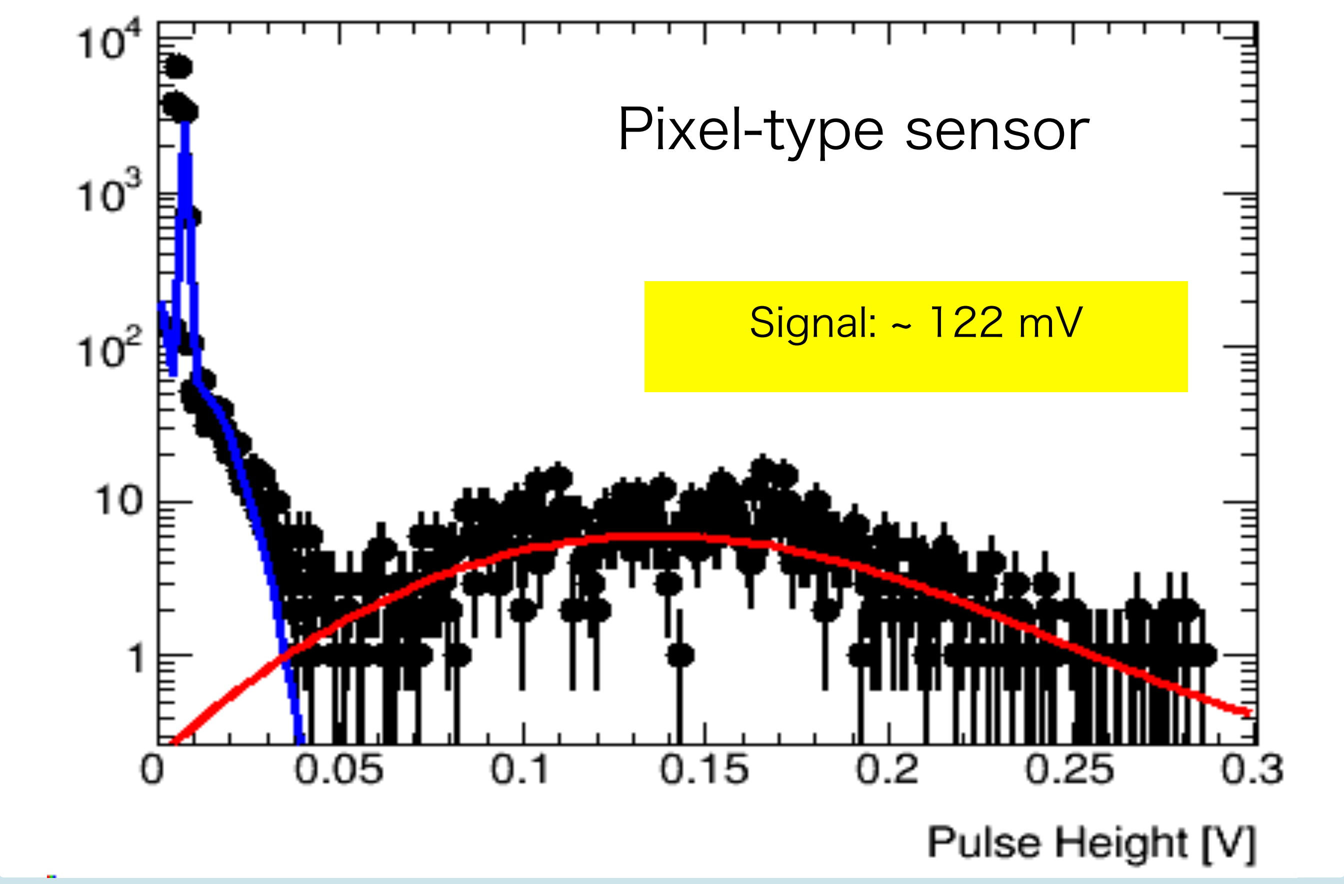
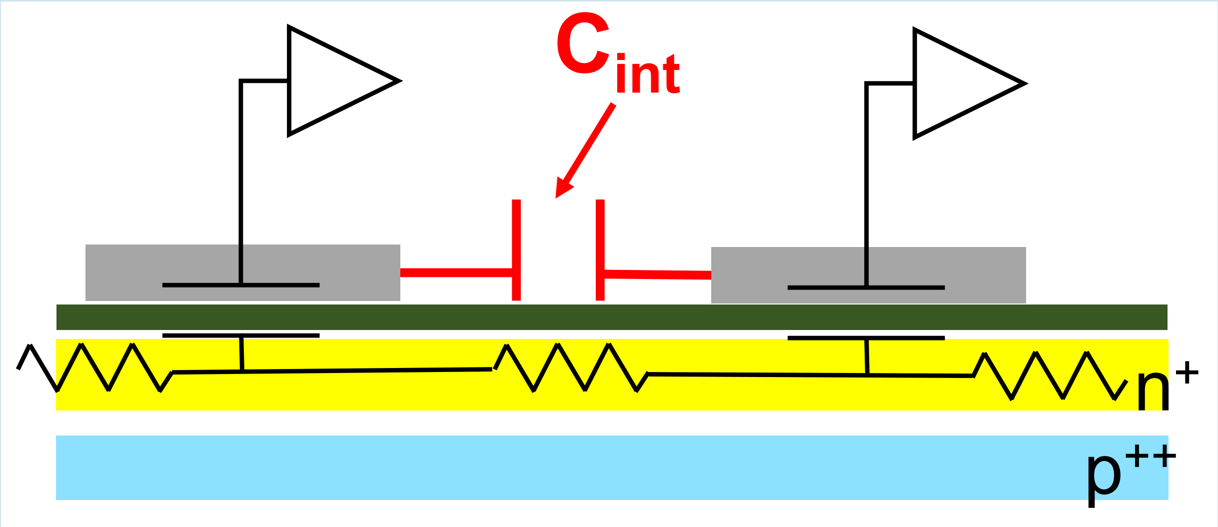
Signal size of strip-type 9880x45 um² electrode



Signal size of pixel-type 100x100 um²



Inter electrode capacitance



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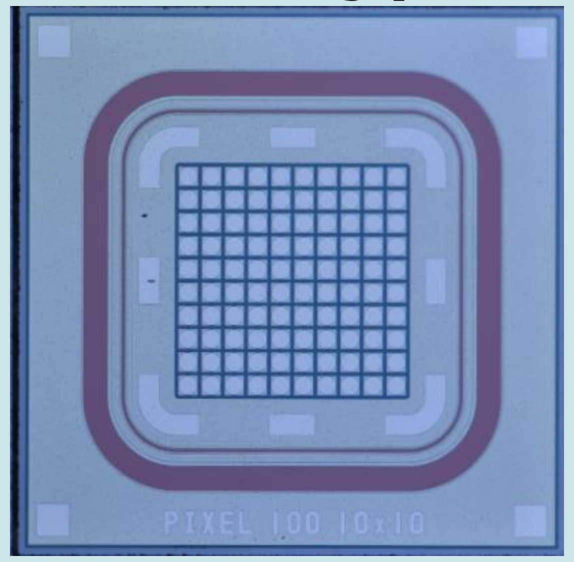

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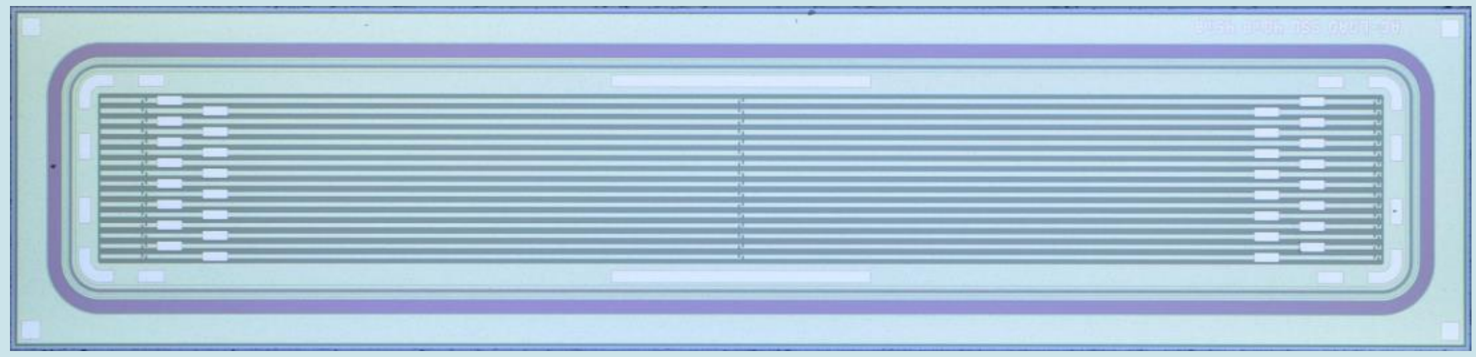

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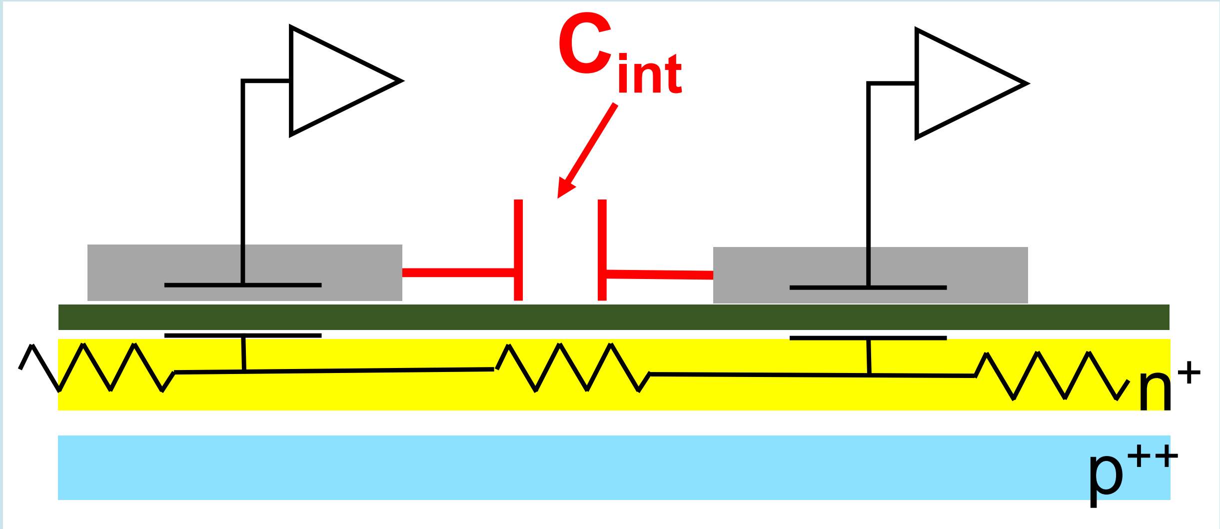

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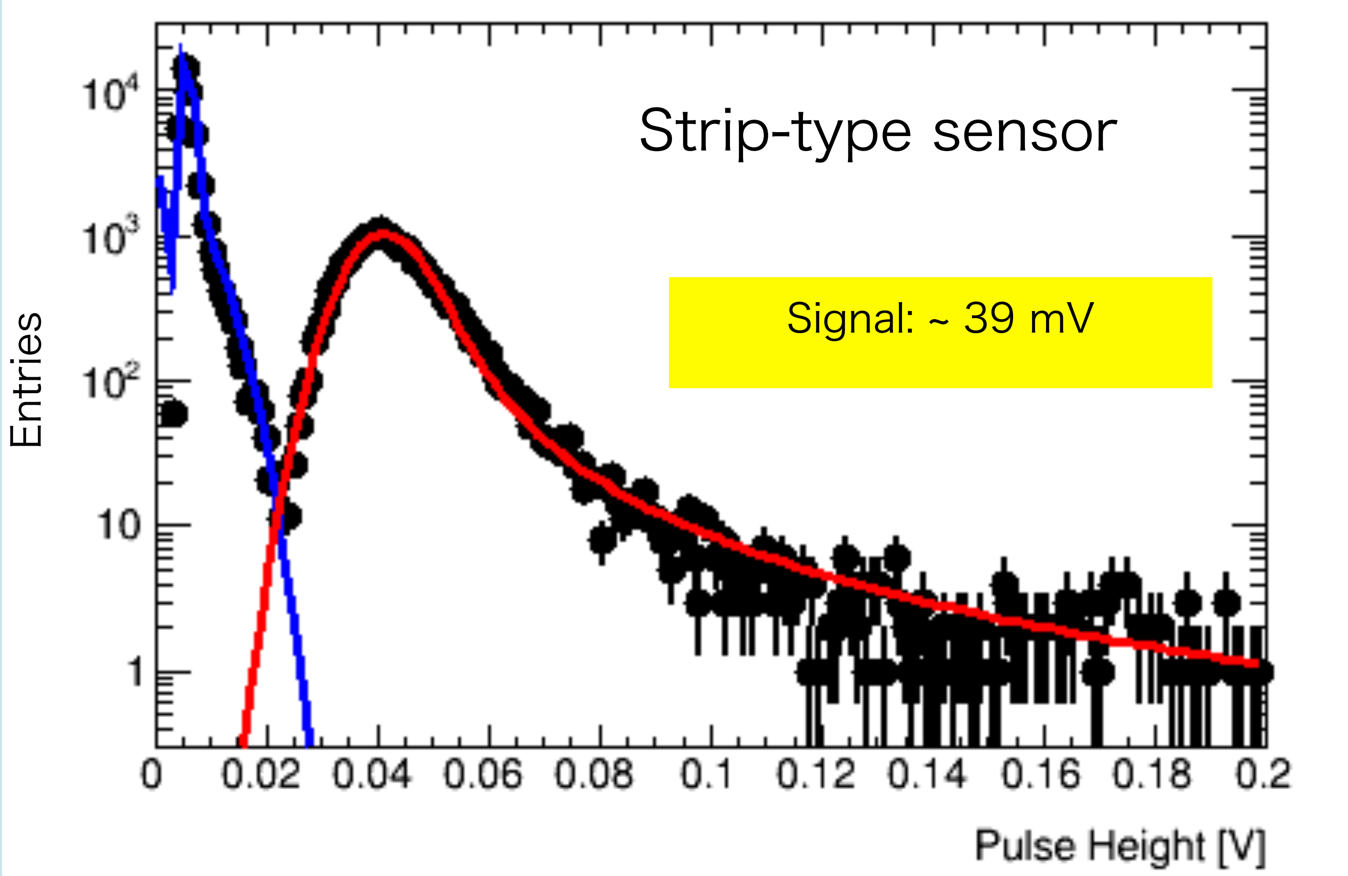
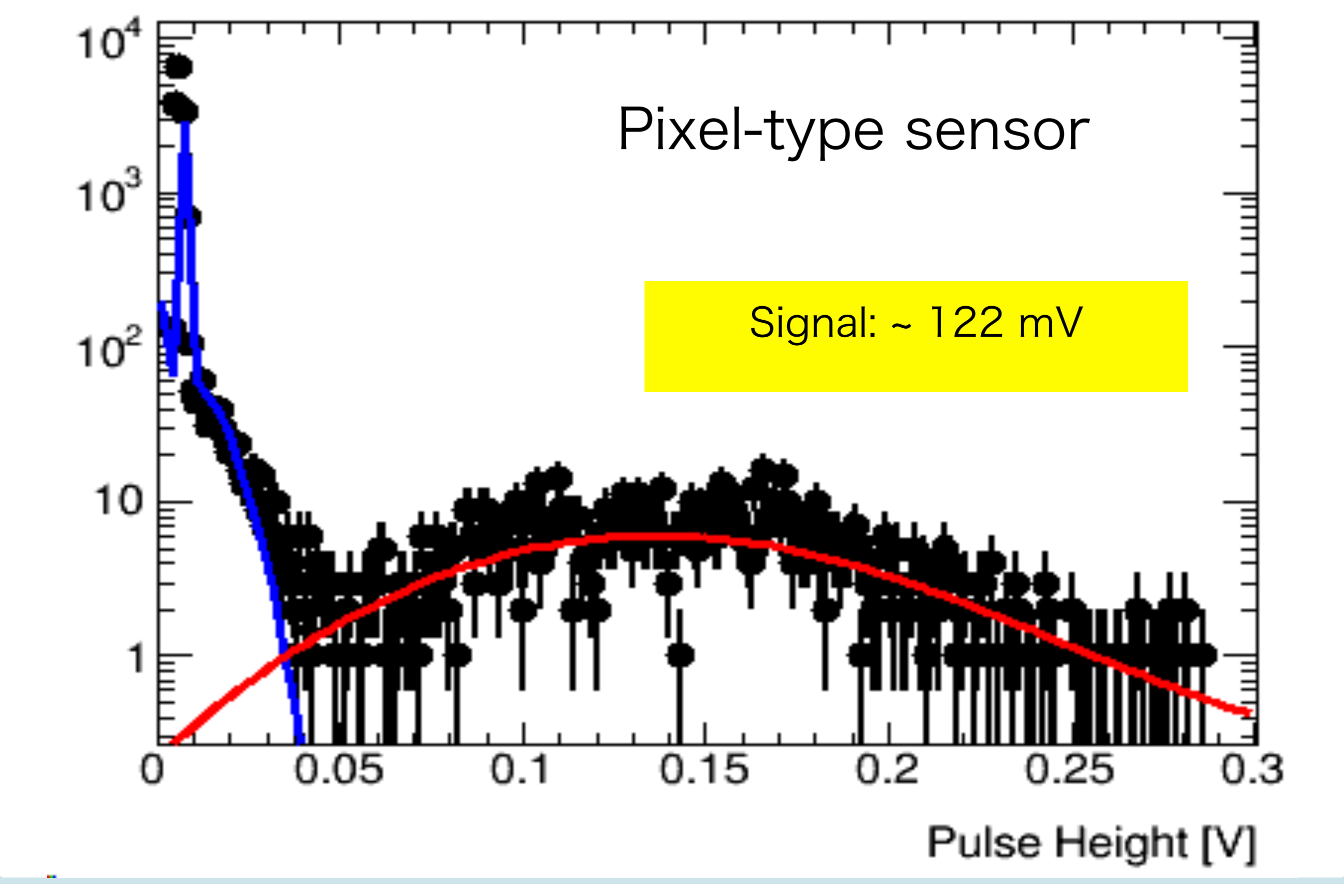


Signal size of pixel-type 100x100 um^2

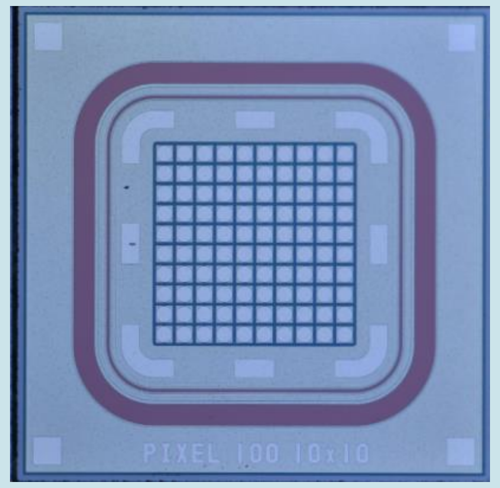


Higher spatial resolution and more radiation tolerant for HL-LHC

Strategy of AC-LGAD (TOF) R&D in EIC
(My own perspective)

- Maximize the timing resolution and stable readout
  - PID performance
- Realize larger size sensor with reasonable segmentation
  - Simplify construction & operation, and cost reduction

Pixel-type



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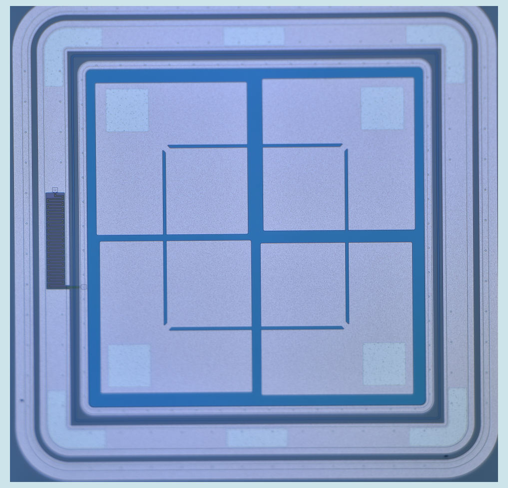

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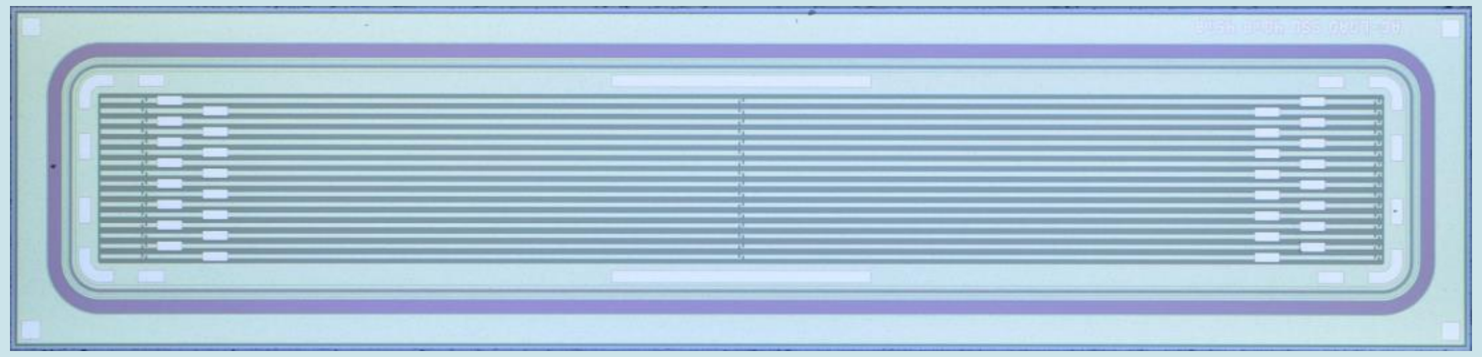

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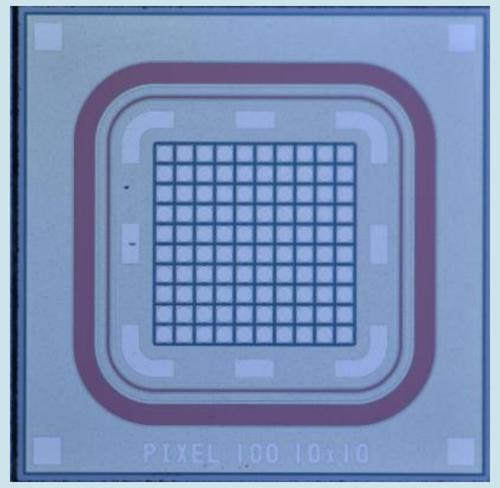

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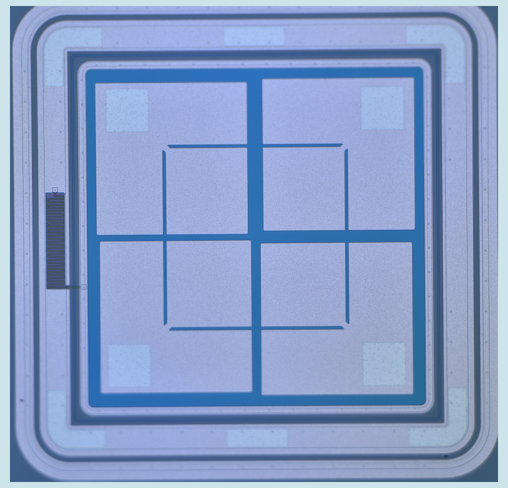

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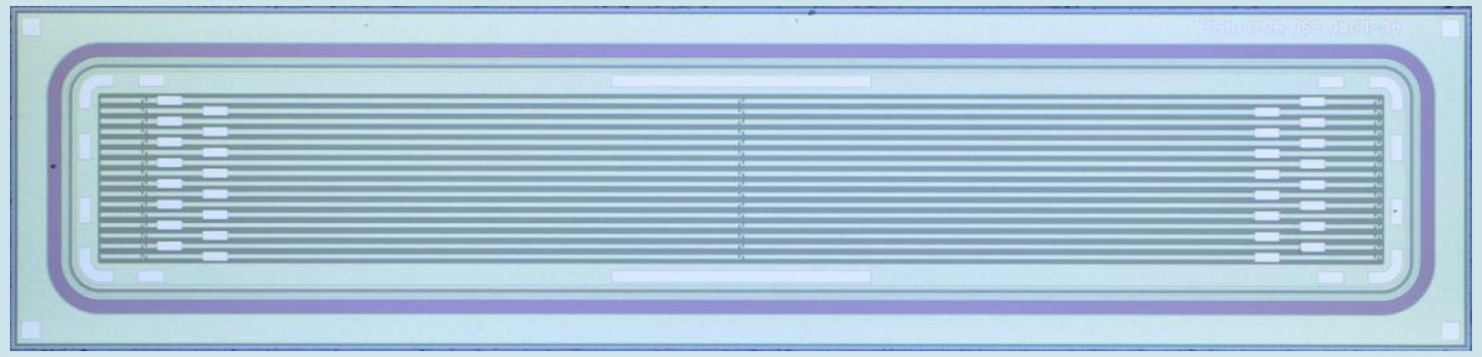

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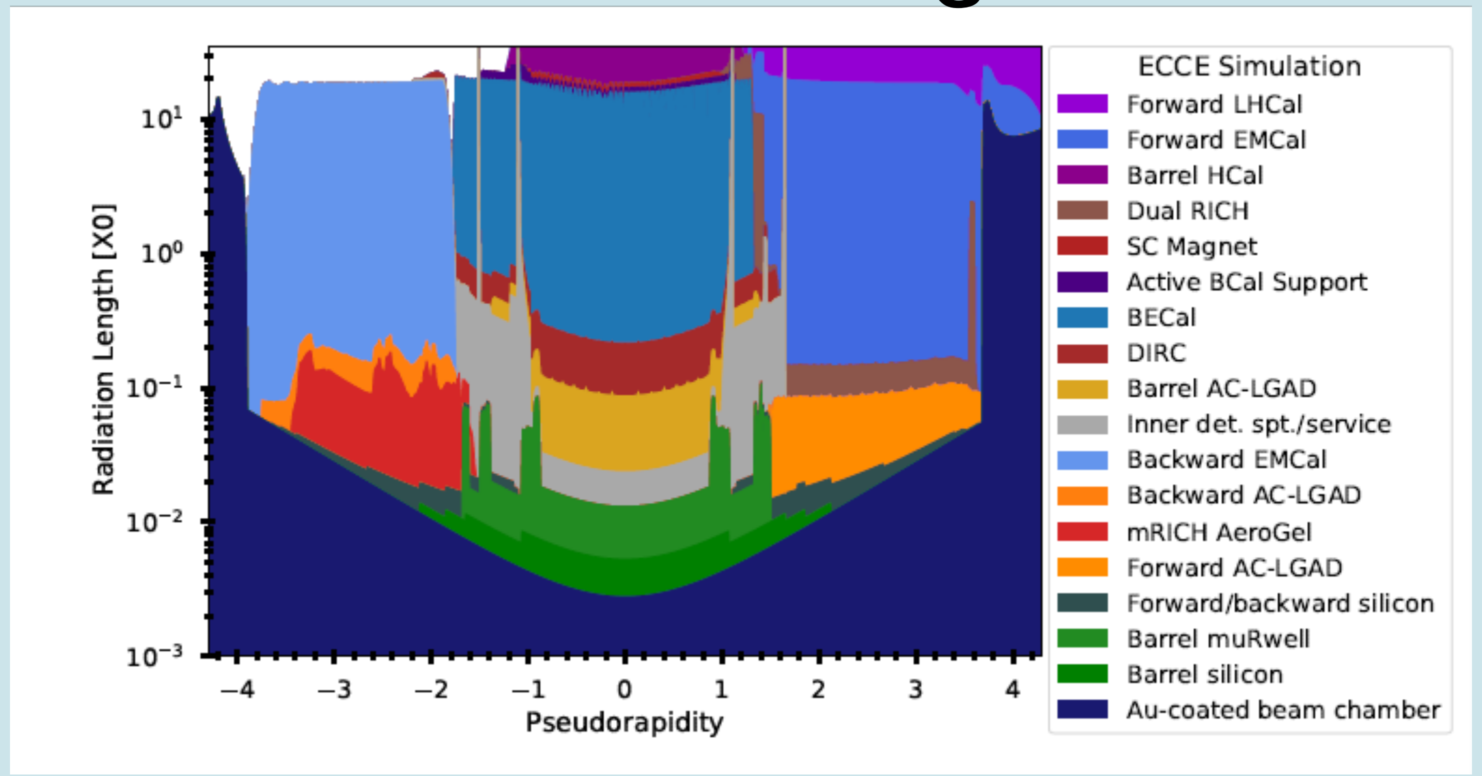

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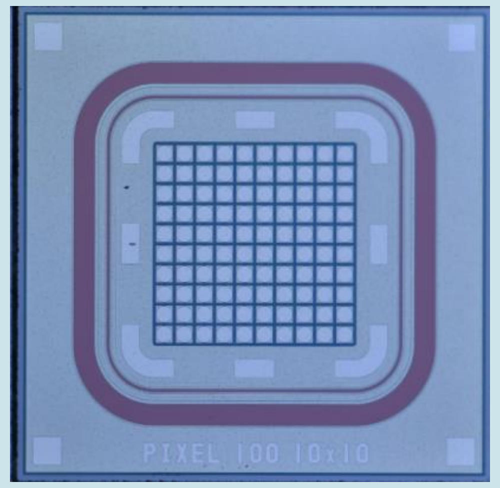
- Radiation tolerance
  - 10^{10} n_{eq}/cm^2 at top luminosity ~10^{34} $cm^{-2}s^{-1}$ in EIC ($10^{15\sim16}$ n_{eq}/cm^2 in HL-LHC)

Pixel-type



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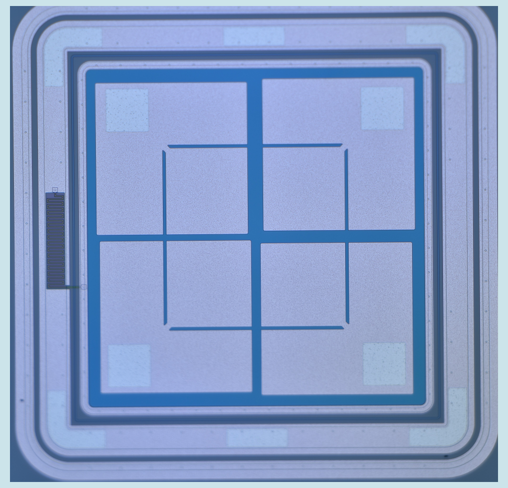

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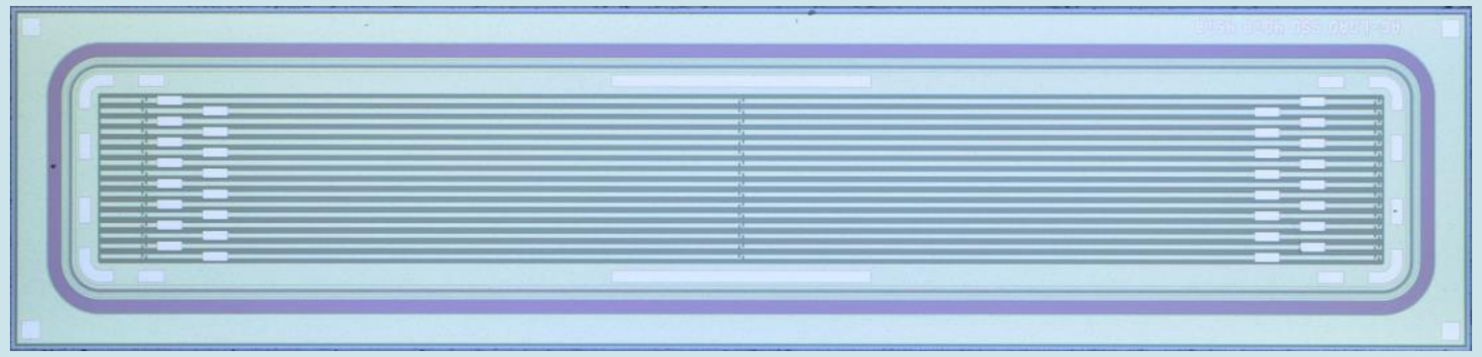

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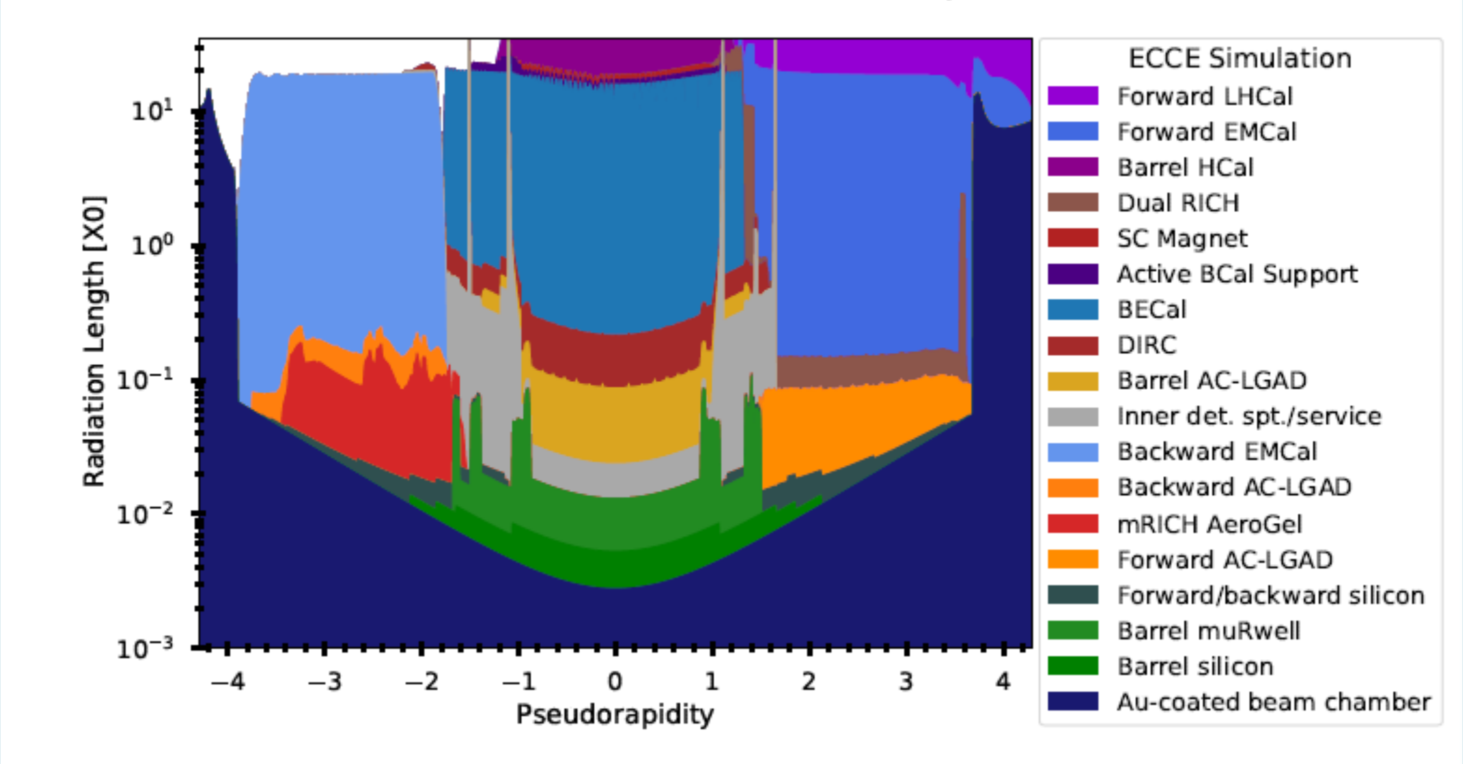

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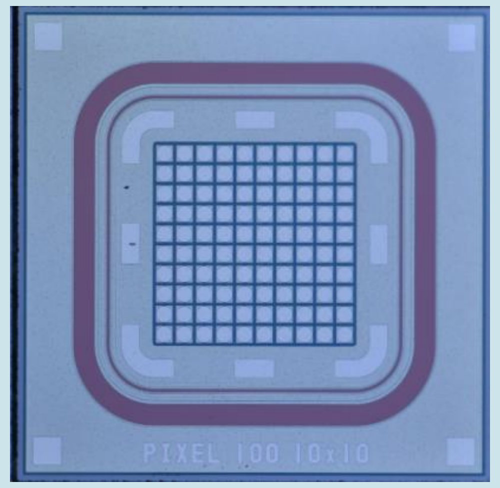

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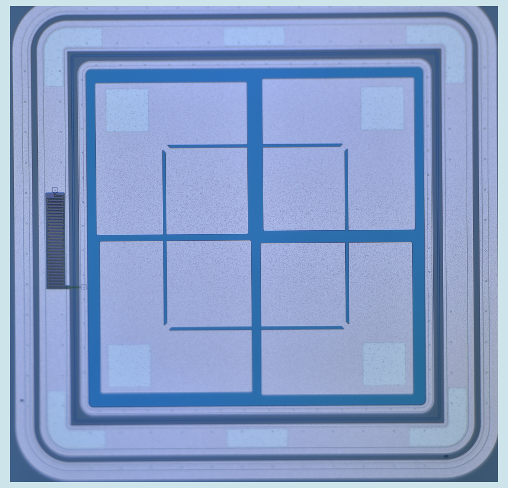

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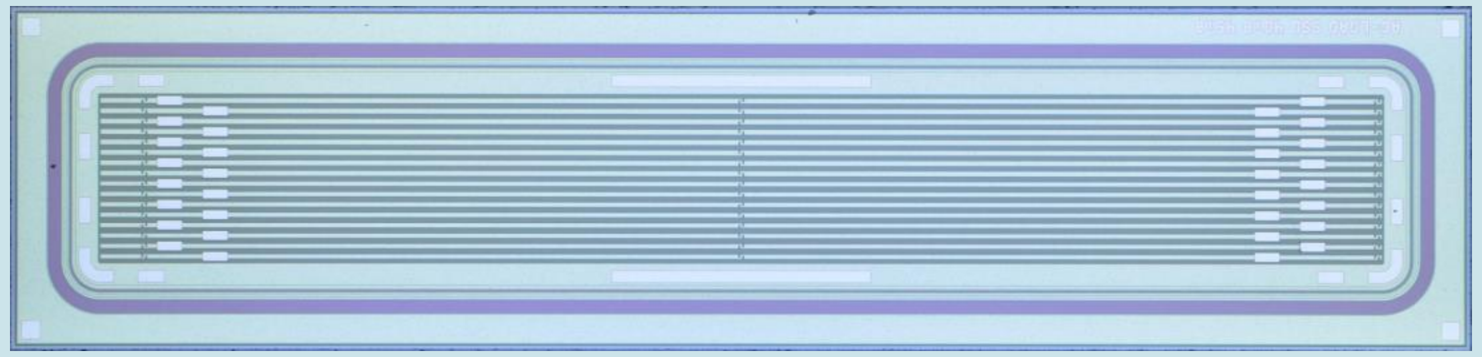
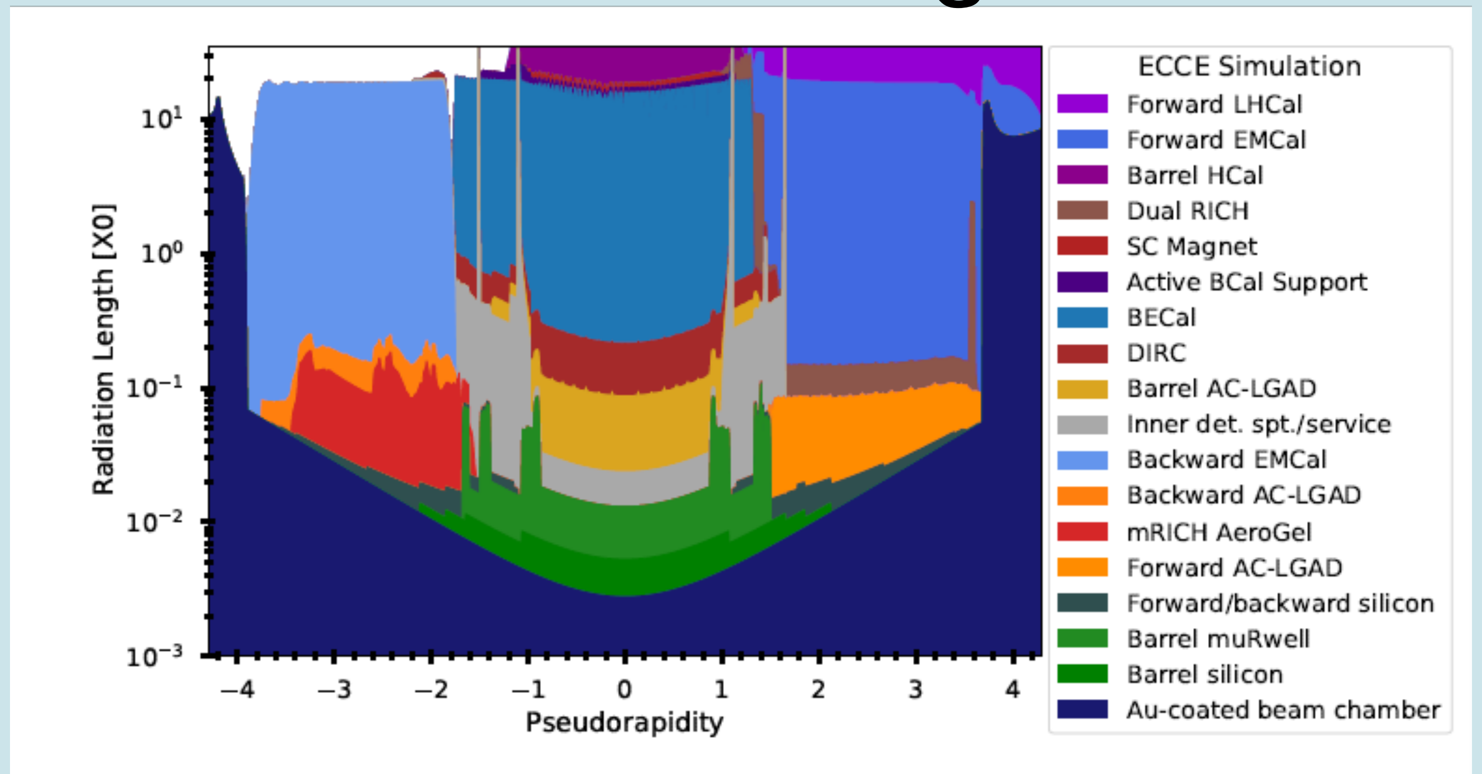


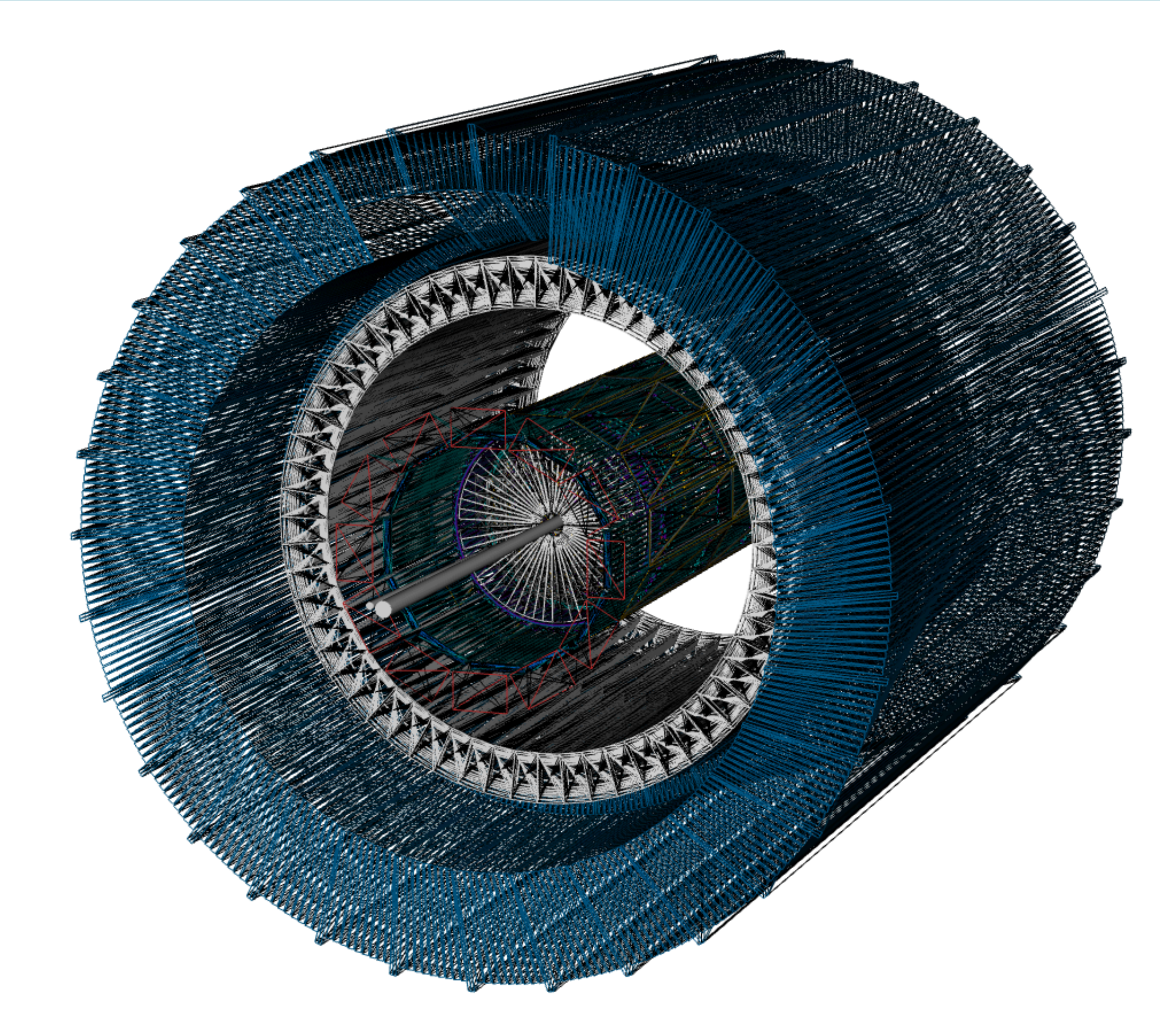
Material budget



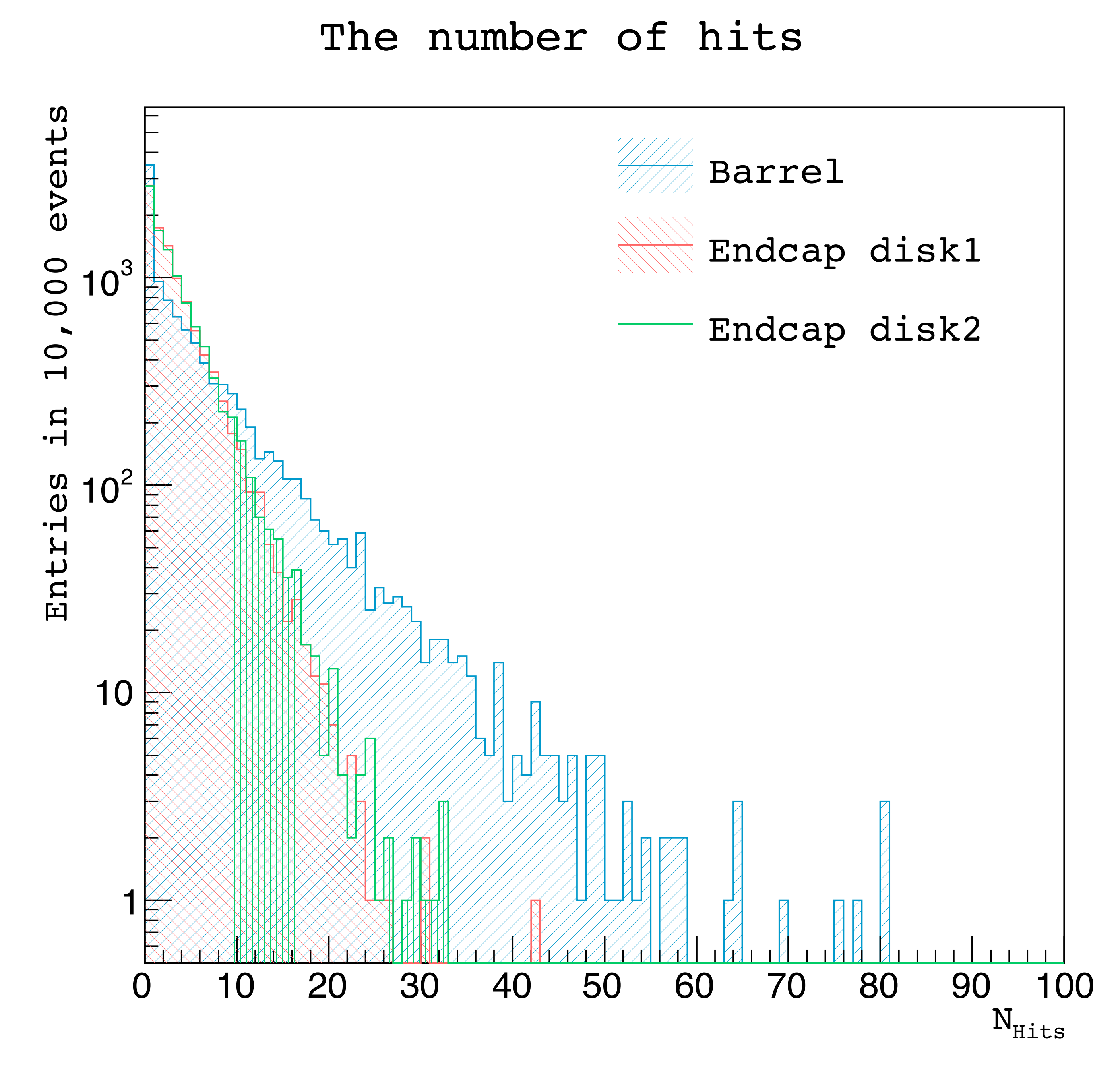
Simulation study

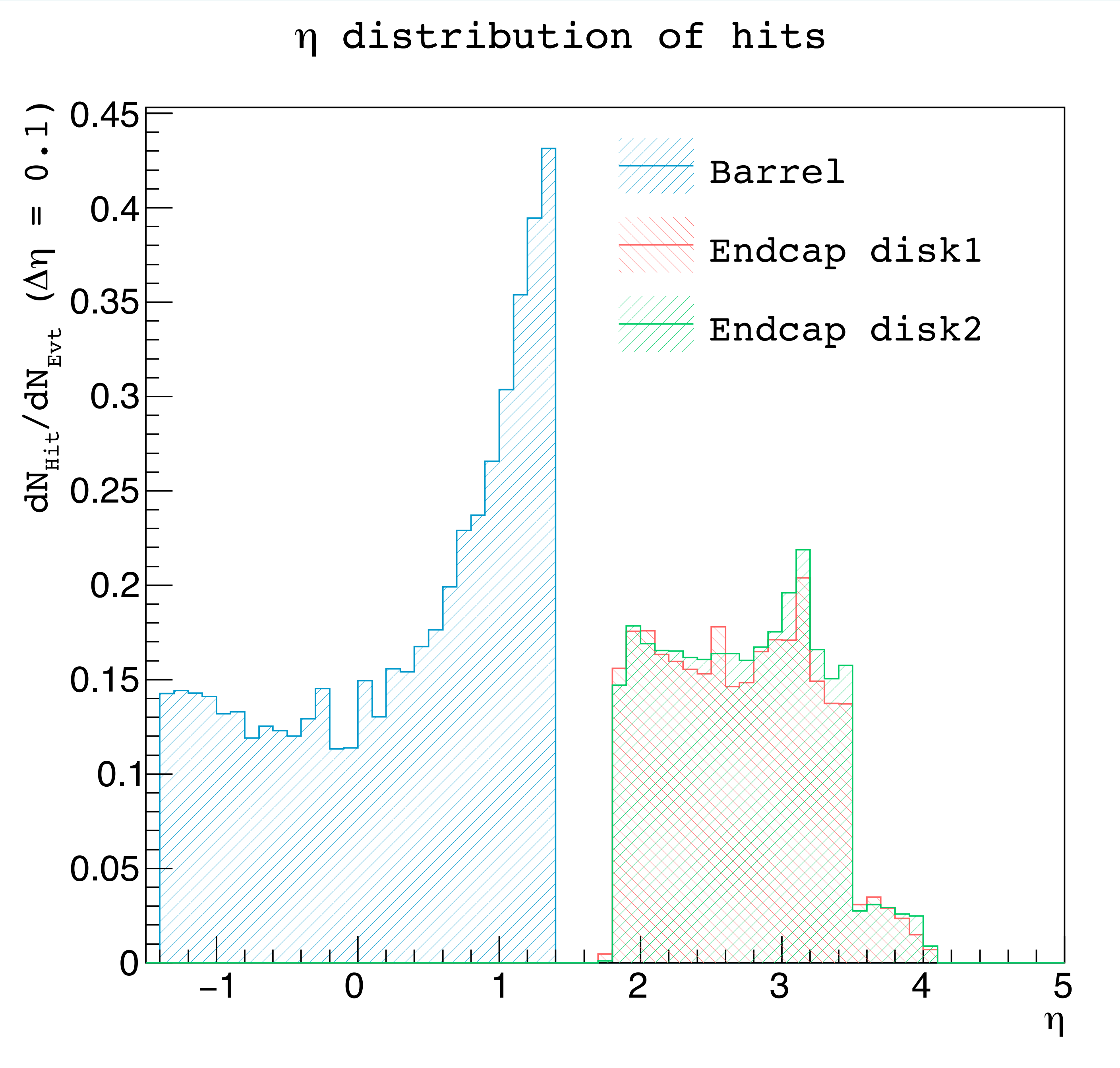
- Detector response and data reconstruction
  - ePIC detector (based on DD4Hep): https://github.com/eic/epic
  - EICRecon: https://github.com/eic/EICrecon
  - Pythia8 NC DIS Q2>1GeV2 in ep (18GeV electron + 275GeV proton beam) collisions (HepMC data archived in S3)
  - 10,000 events

- TOF detector in simulation
  - Sensor segment size of barrel-TOF: 100um x 1cm
  - Sensor segment size of endcap-TOF: 100um x 100um
  - Sensor thickness: 300um



The number of hits of TOF

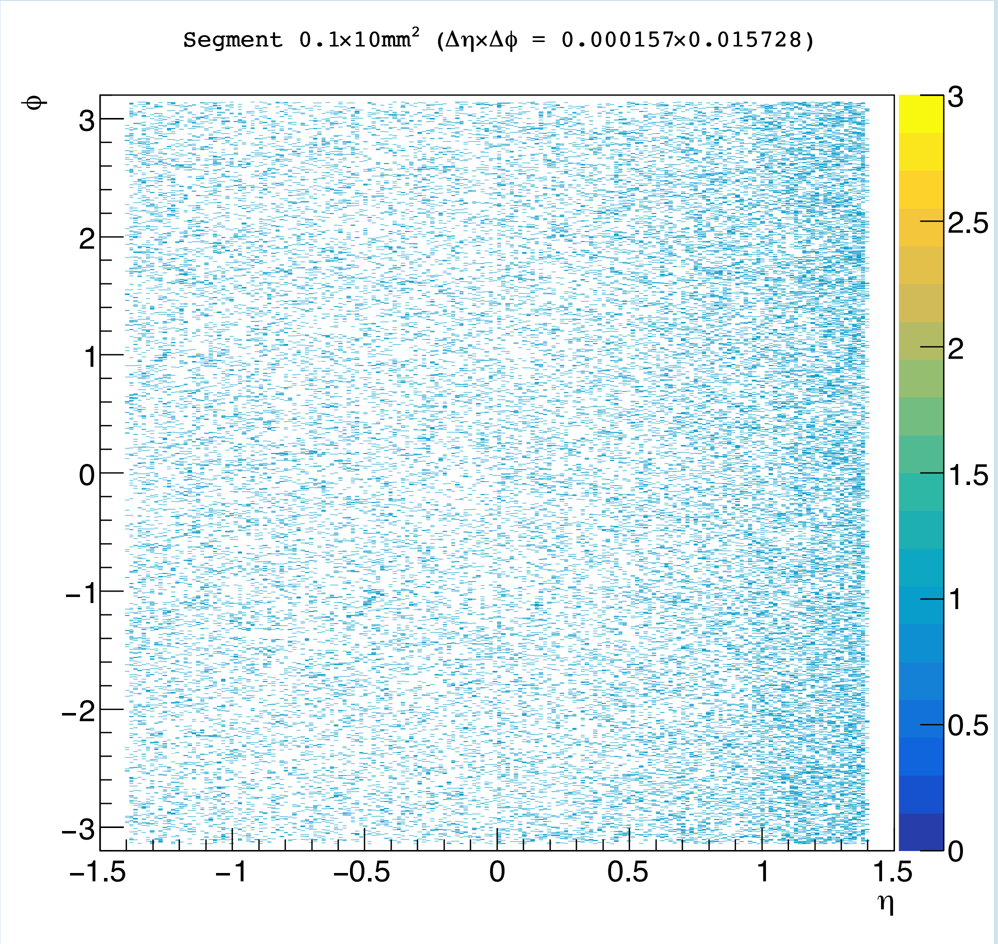




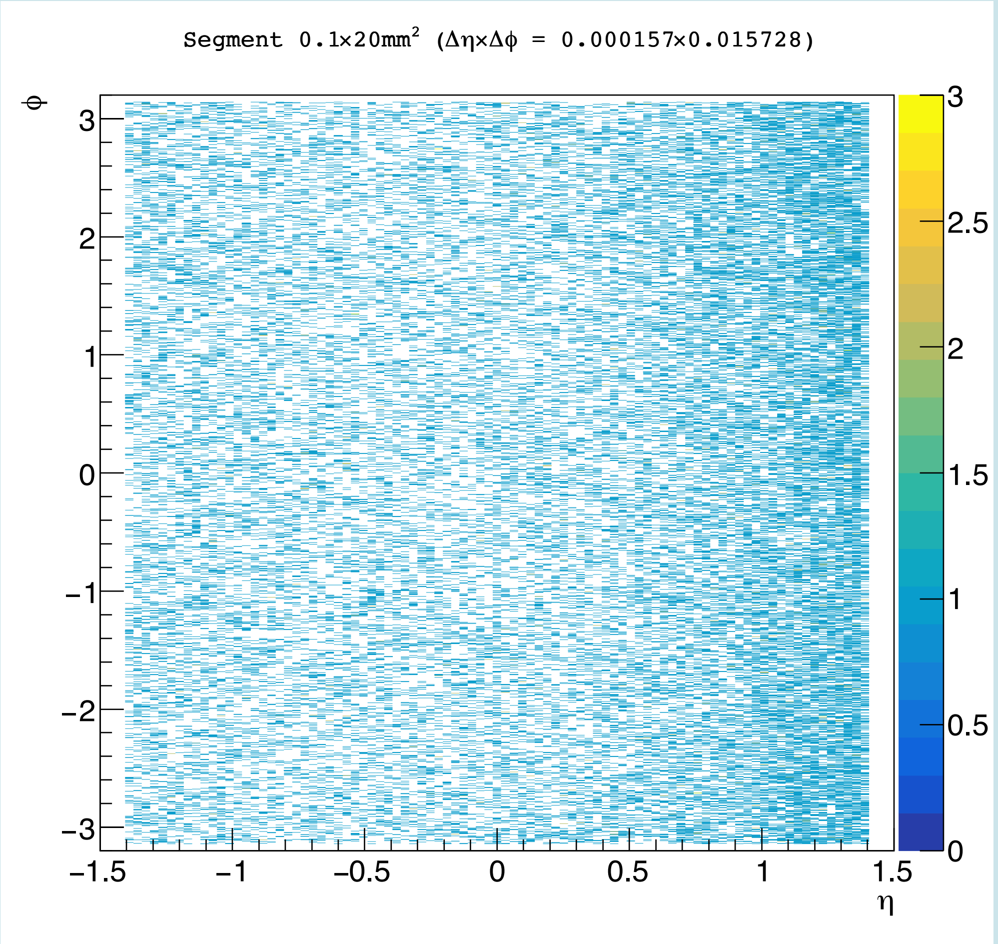
- The number of hits per event: 5.2 (Barrel), 2.8 (Endcap disk1), and 3.0 (Endcap disk2)
- 35% and 28% events without hits on Barrel and Endcap
- The maximum hit per event: ~80 (Barrel) and ~30 (Endcap)

Barrel TOF occupancy

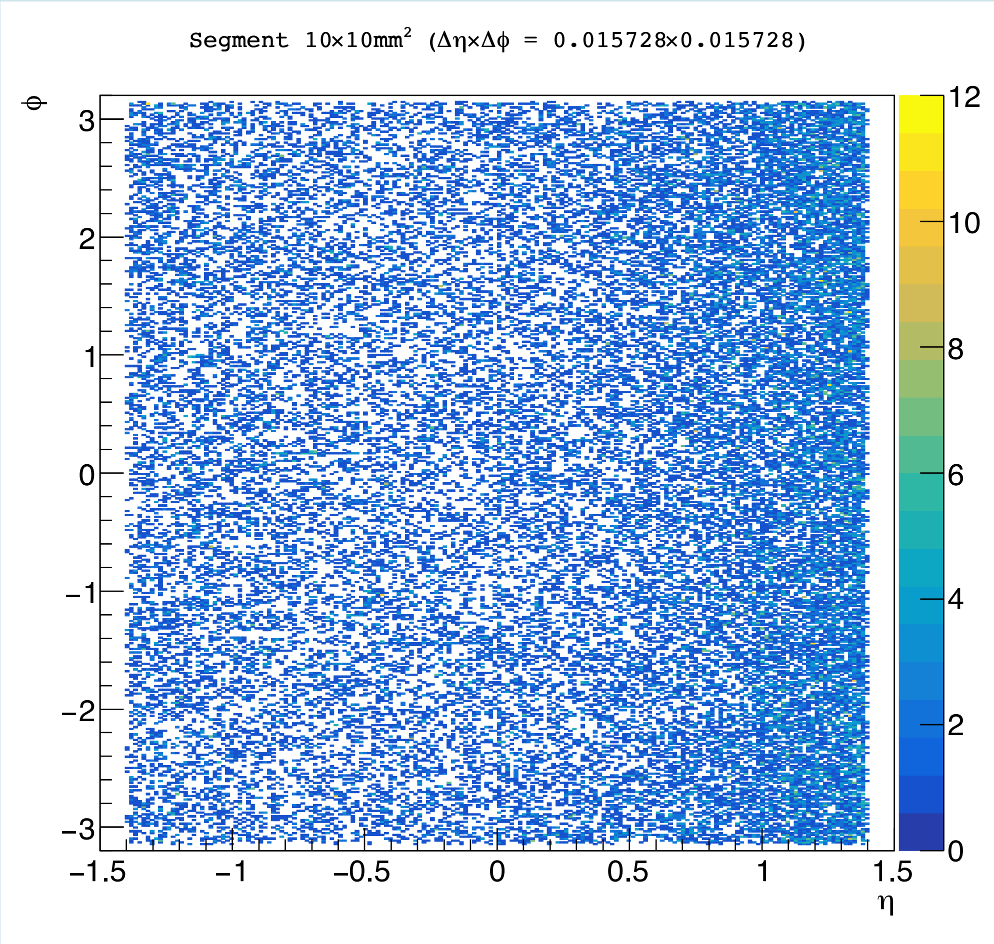
100um x 1cm (ϕxη)



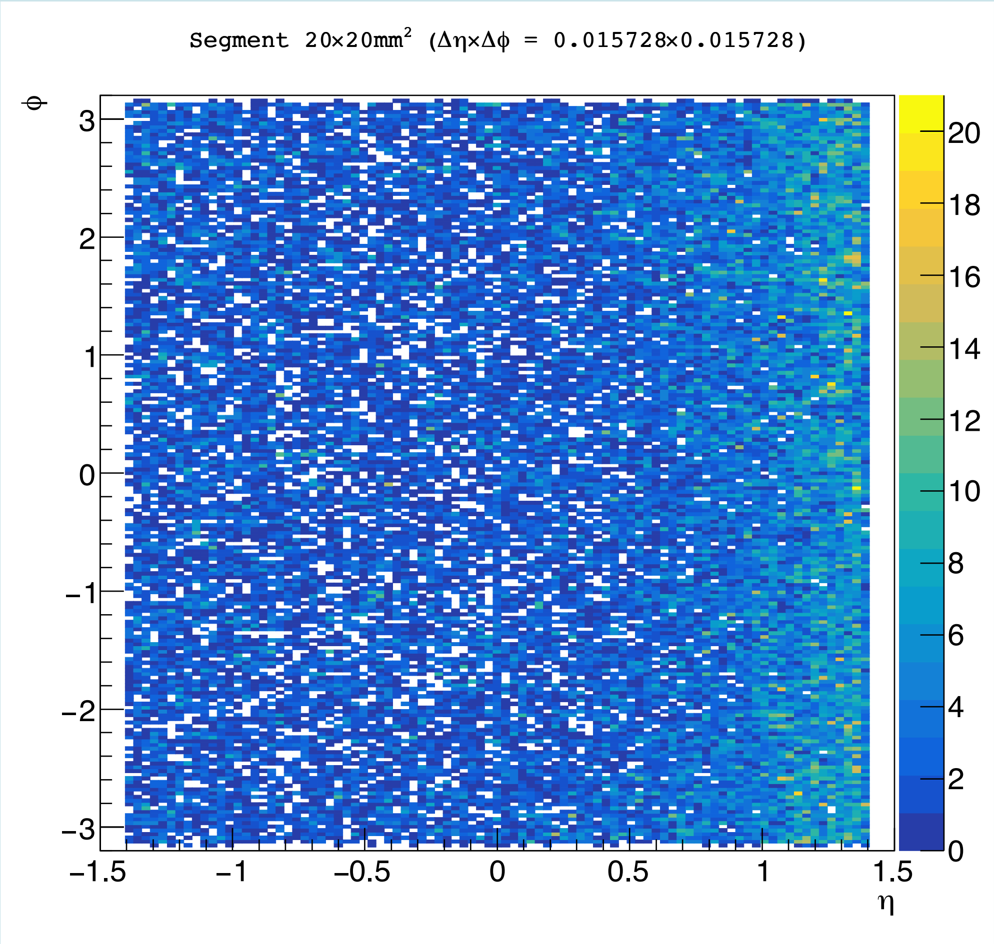
100um x 2cm (ϕxη)



1cm x 1cm (ϕxη)

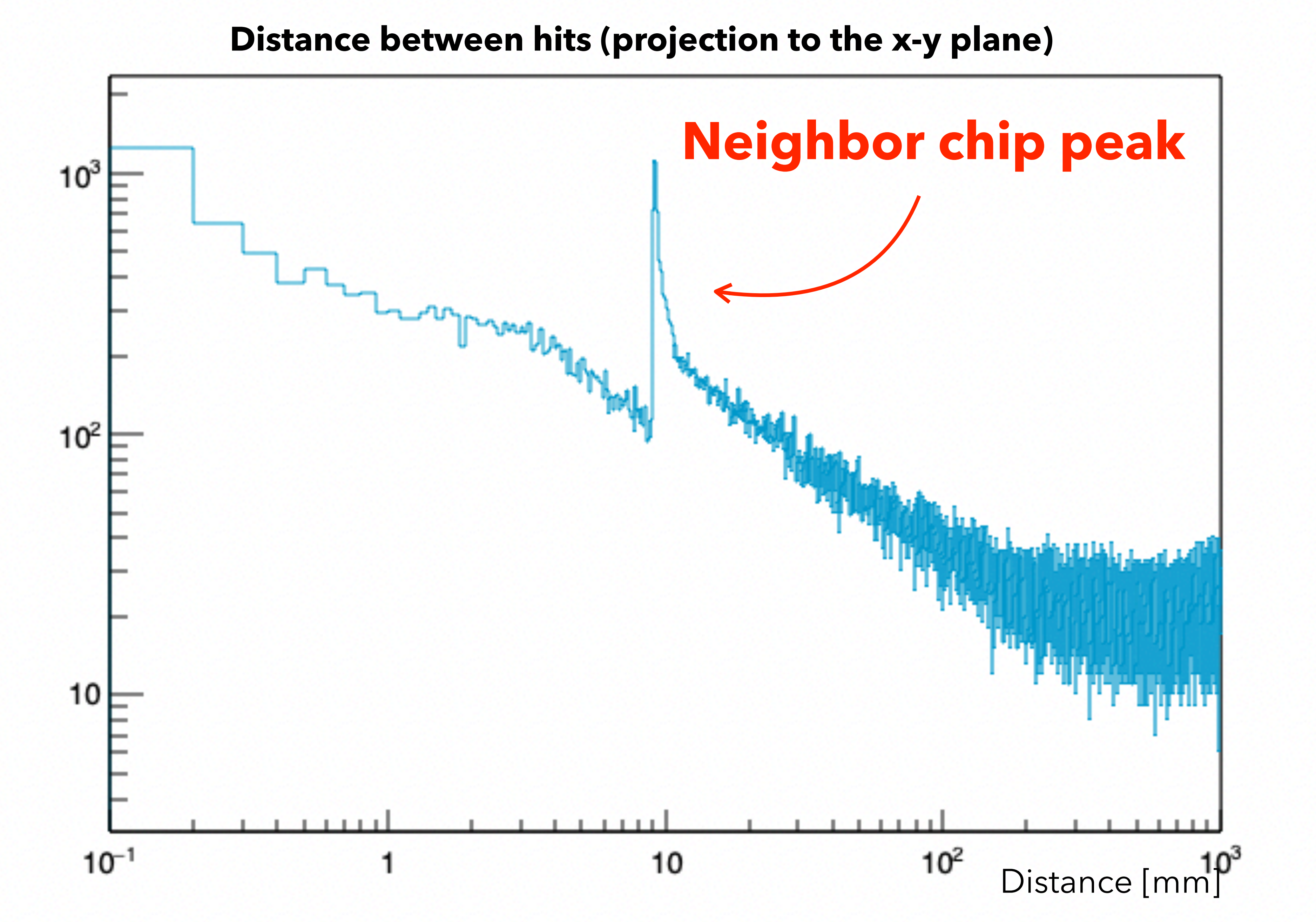


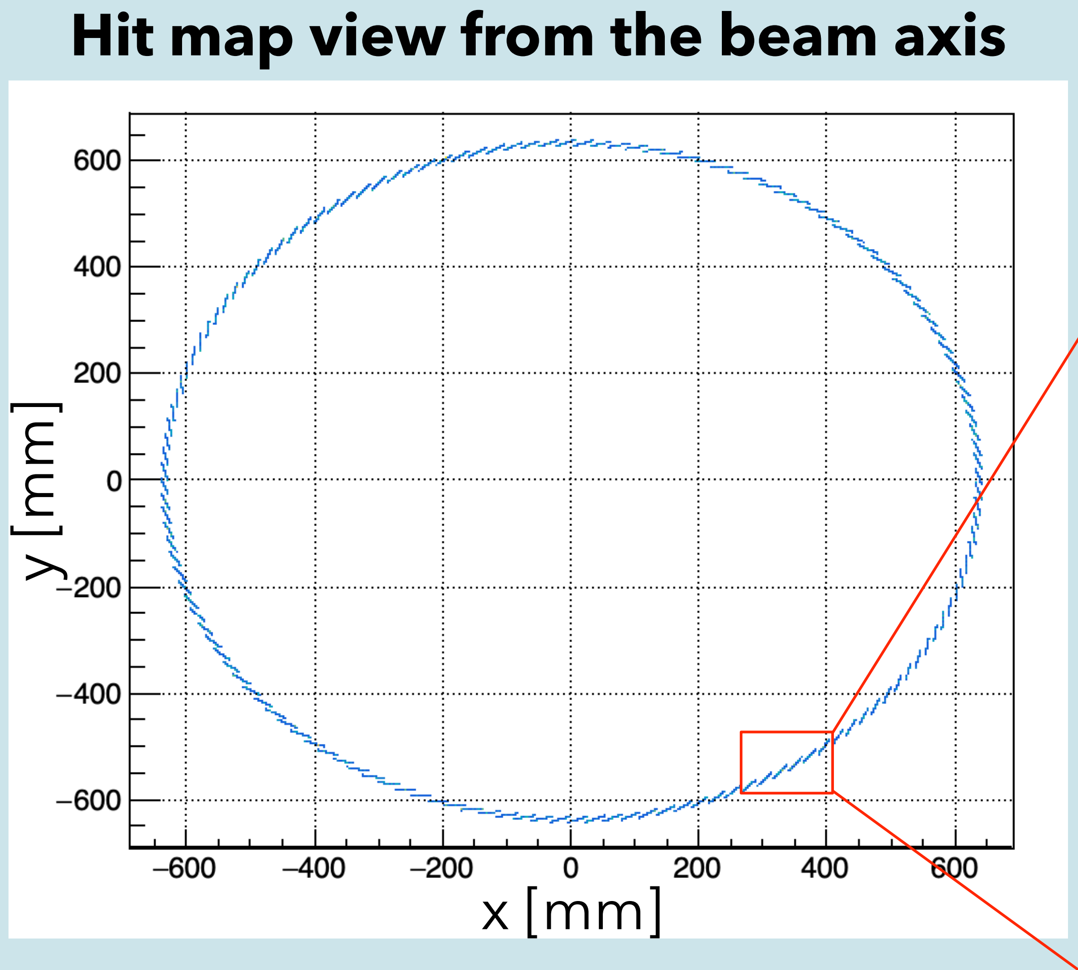
2cm x 2cm (ϕxη)

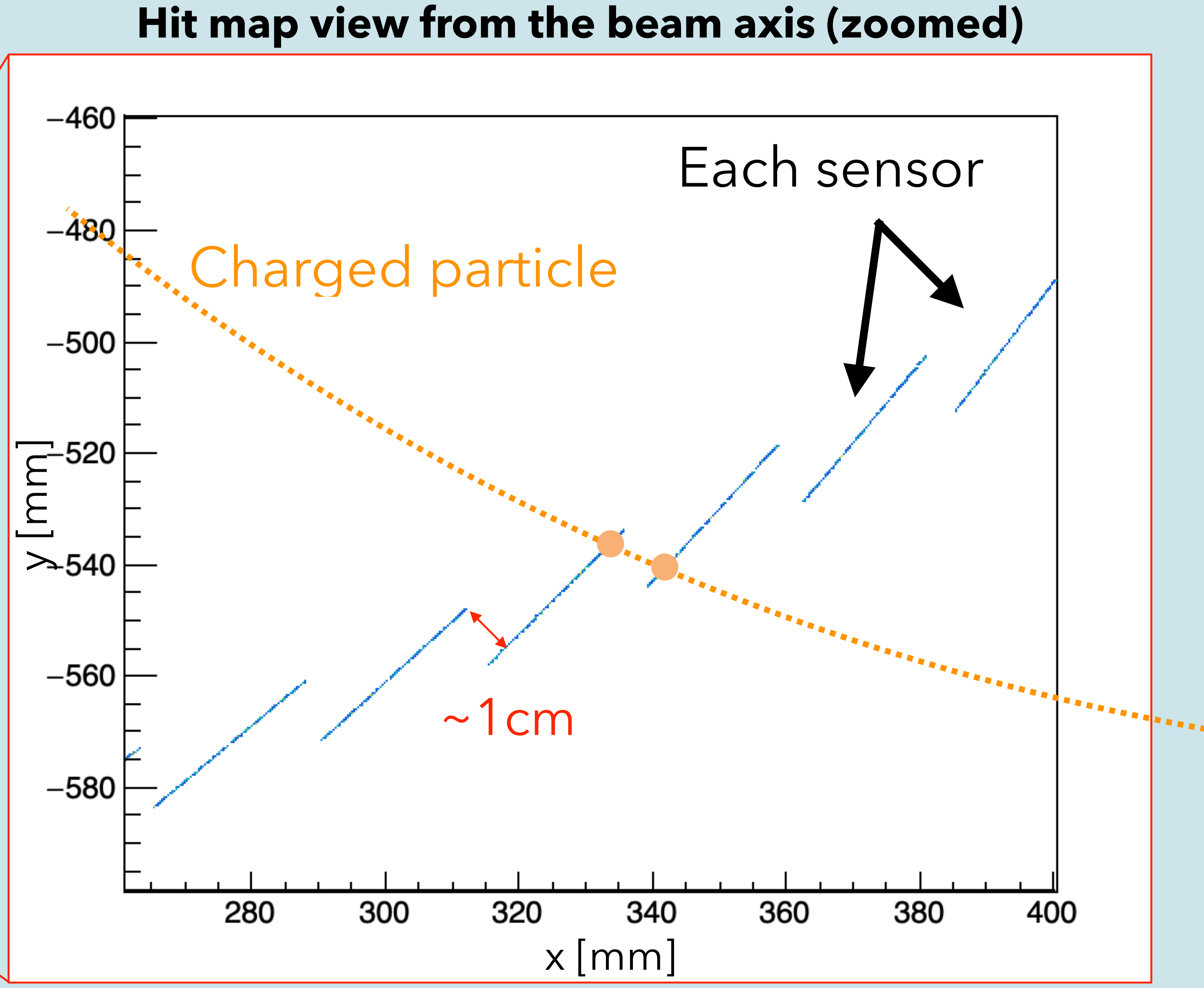


- The maximum multiple-hit segment
  - 100um x 1cm (strip-type) : 3×10^{-4}
  - 100um x 2cm (strip-type) : 3×10^{-4}
  - 1cm x 1cm (pad-type) : 12×10^{-4}
  - 2cm x 2cm (pad-type) : 20×10^{-4}
- Negligible overlapping effect per event even with O(1) cm size segment
- Not necessary the high granularity segment from the particle identification point of view
- Next step: effect on the tracking resolution

Barrel-TOF
Distance between hits





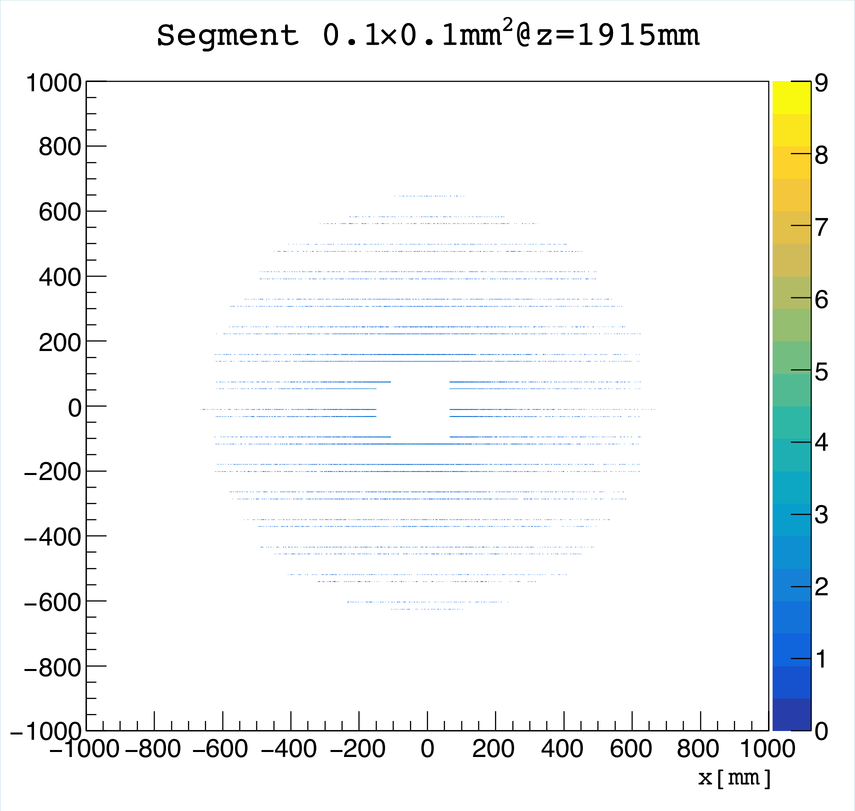


- Multiple hits on different chips by one charged particle
- Possibly improving tracking resolution by the effect?
- Starting point of the simulation study…

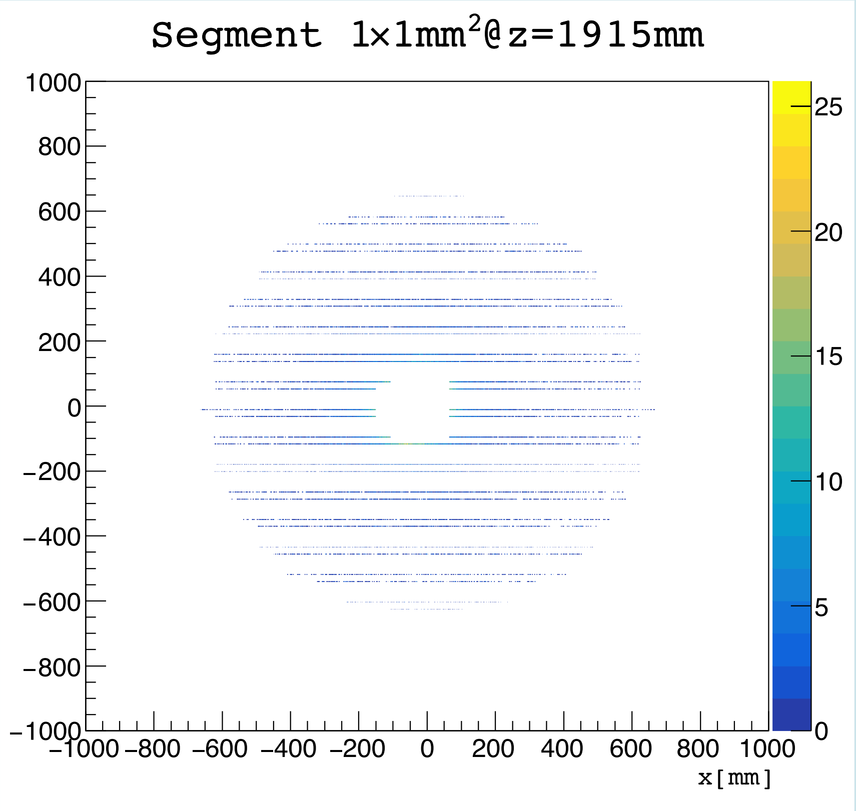
Endcap TOF occupancy

Occupancy of Disk1

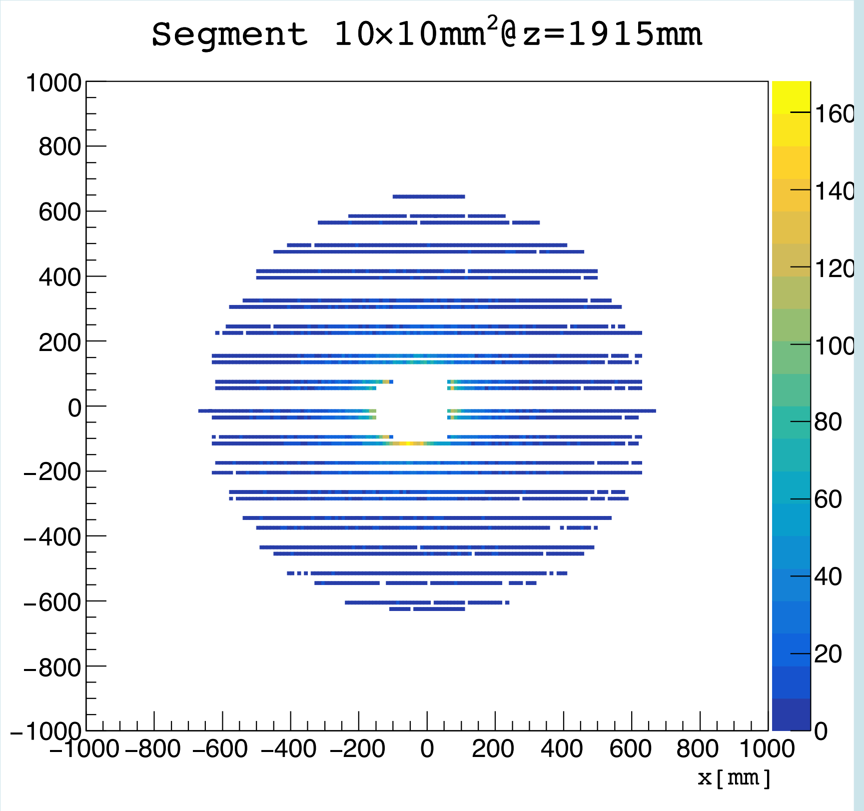
100um x 100um



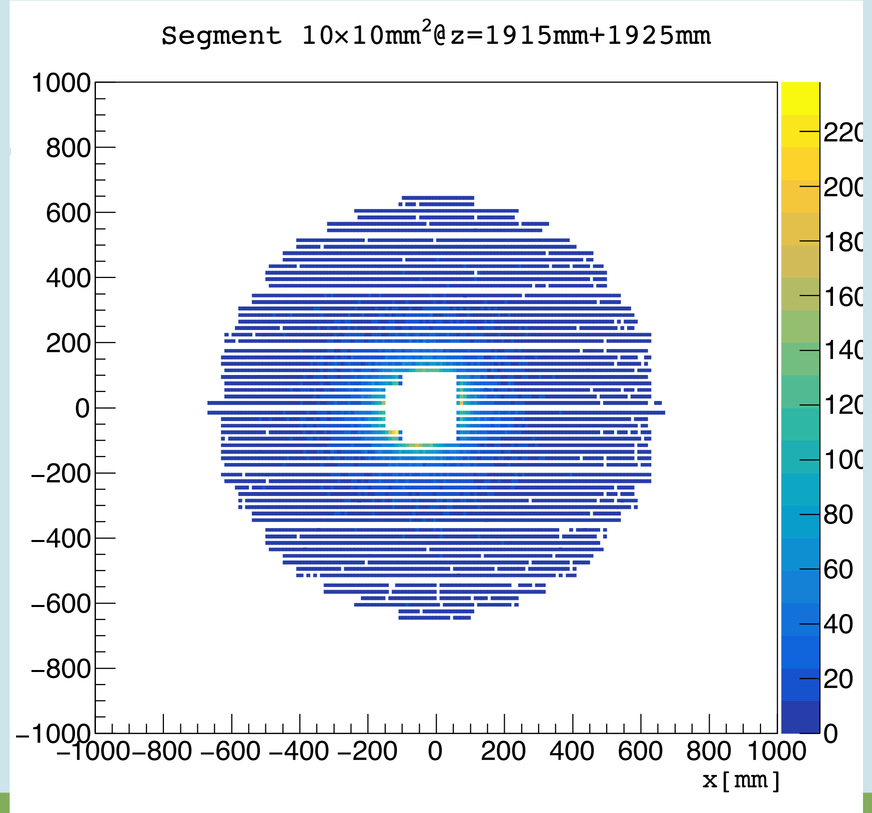
1mm x 1mm



1cm x 1cm



Occupancy of Disk1+ Disk2

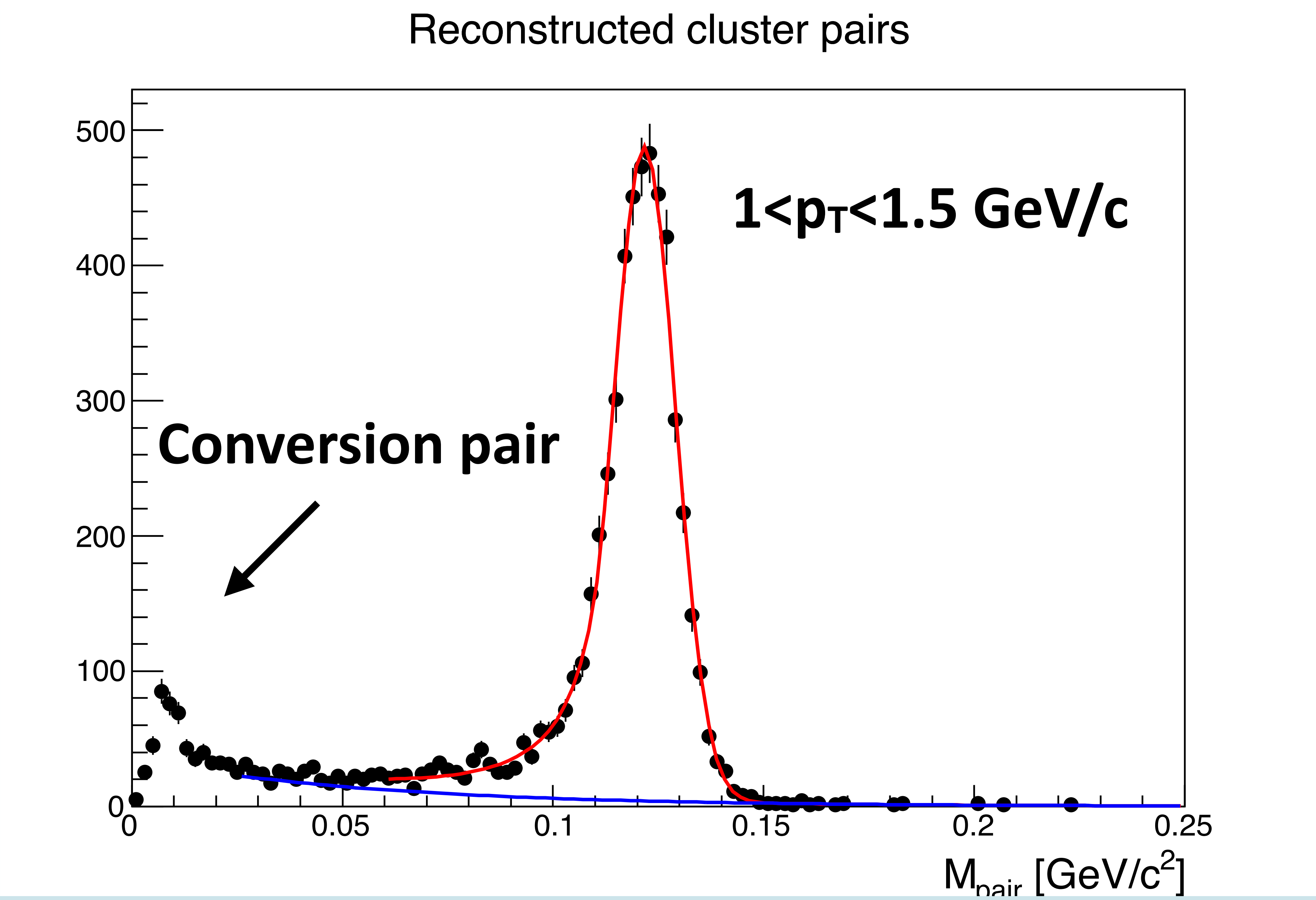


- The maximum multiple-hit segment
  - 100um x 100um (pad-type) : 9×10^{-4}
  - 1mm x 1mm (pad-type) : 2.5×10^{-3}
  - 1cm x 1cm (pad-type) : 1.7×10^{-2}
- Higher occupancy at innermost (forward rapidity)
  - Option: use multiple type chip
- Unexpected inactive area
  - Due to technical issue

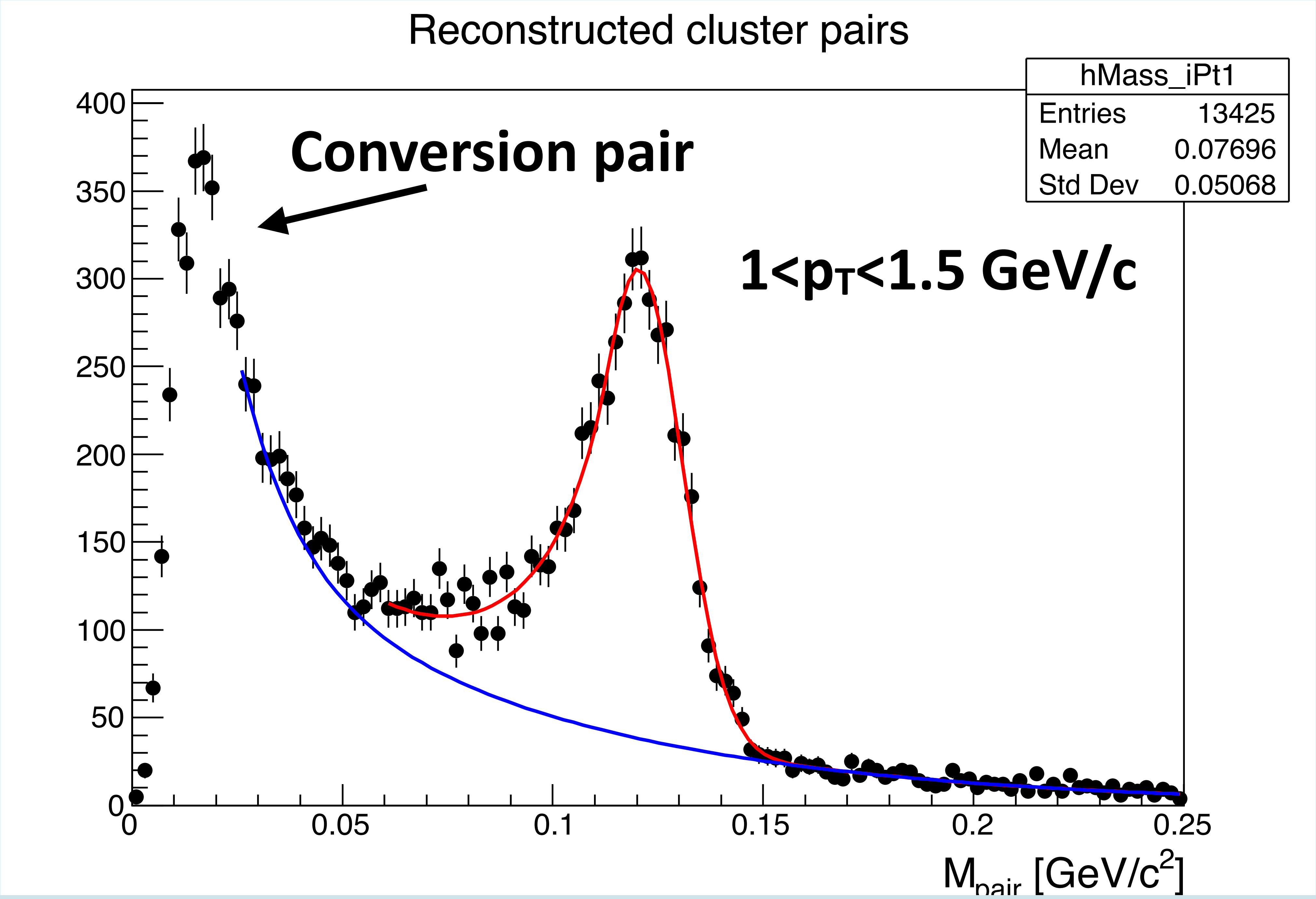
Very preliminary results
Material budget effect on EMC

- A study on the material budget effect on EMC (downstream of TOF)
- Inject single neutral pion

Only BEMC



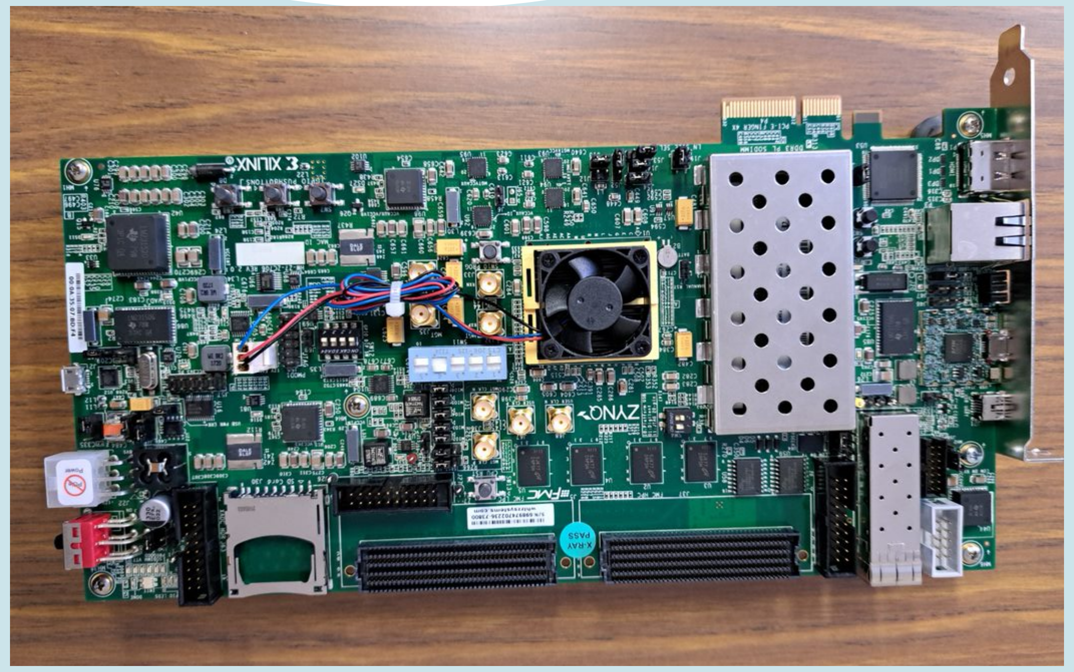
BEMC + inner detectors



- Enhance conversion due to interaction with the material

Test bench at Hiroshima

- Test of the AC-LGAD and EICROC (readout board for EIC)
  - Work closely with HPK for effective development

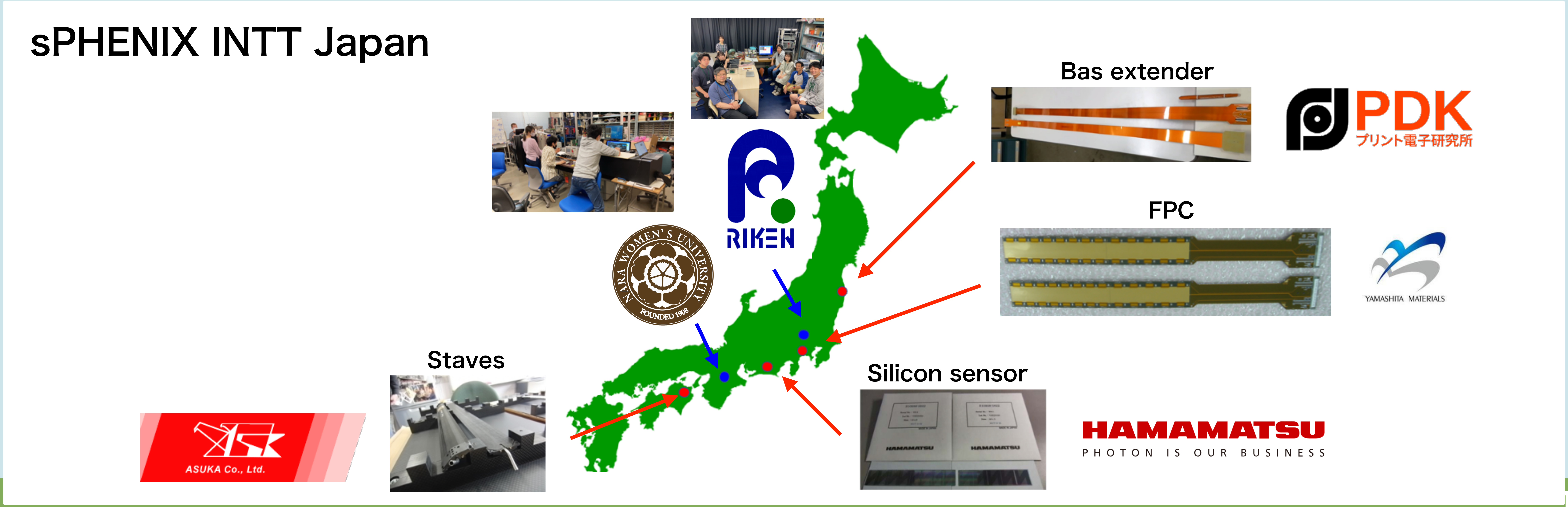


- Equipment based on the suggestion from BNL/KEK/Tsukuba teams
  - Focusing on timing resolution and cross-talk (charge sharing) measurement

- FPGA, digitizer (flash ADC), oscilloscope, and PMT
  - FPGA: ZC706
  - Oscilloscope: WaveRunner 8208HD (10GS/s, 8ch)
  - Digitizer: CAEN DT5742 (5GS/s, 16ch)
  - PMT: PHOTEK PMT240 (60 ps rising time)
  - Looking forward to receiving AC-LGAD and EICROC

Capability of the team Japan

- Experience to create the INTT detector in sPHENIX with (almost) only Japanese technology
- Same environments for R&D, mass production, and QA



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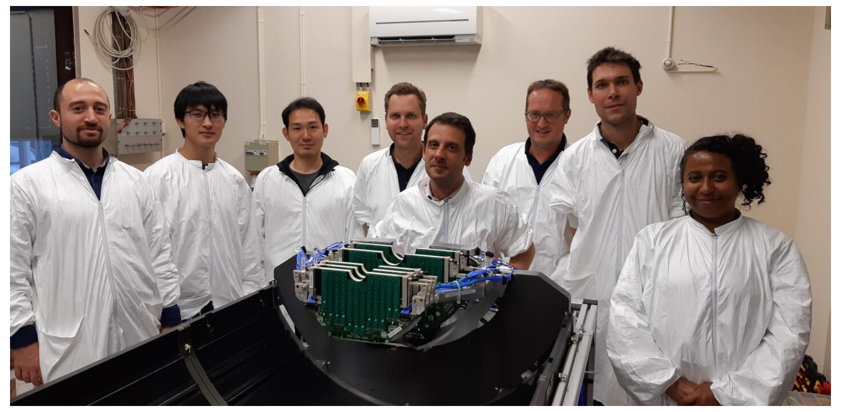
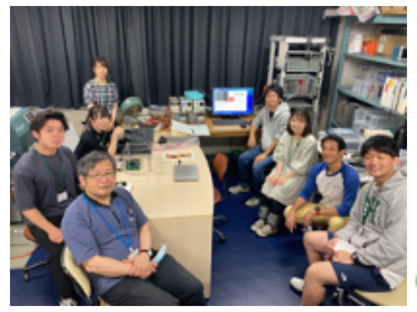
  + Hiroshima University with Si tracker development experience + SKCM^2 (WPI)

sPHENIX INTT Japan

+ Hiroshima Univ.

MFT assembling @ CERN





HIROSHIMA

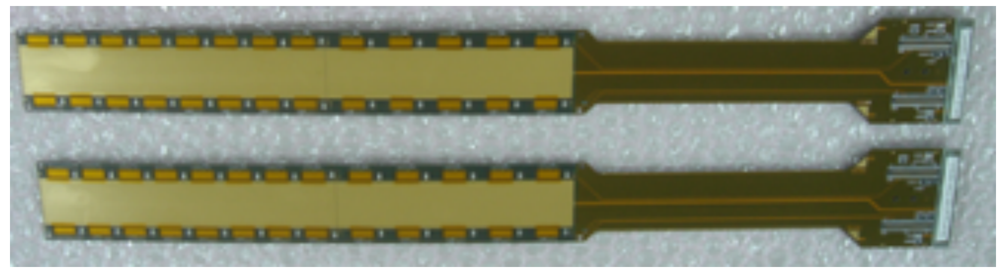
NARA WOMEN'S UNIVERSITY FOUNDED 1908

RIKEN

Bas extender

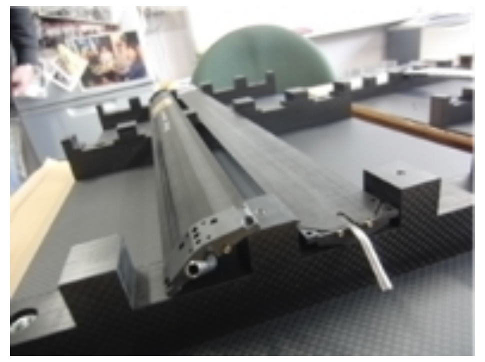
PDK プリント電子研究所

FPC



YAMASHITA MATERIALS

Staves



ASUKA Co., Ltd.

Silicon sensor

HAMAMATSU

PHOTON IS OUR BUSINESS

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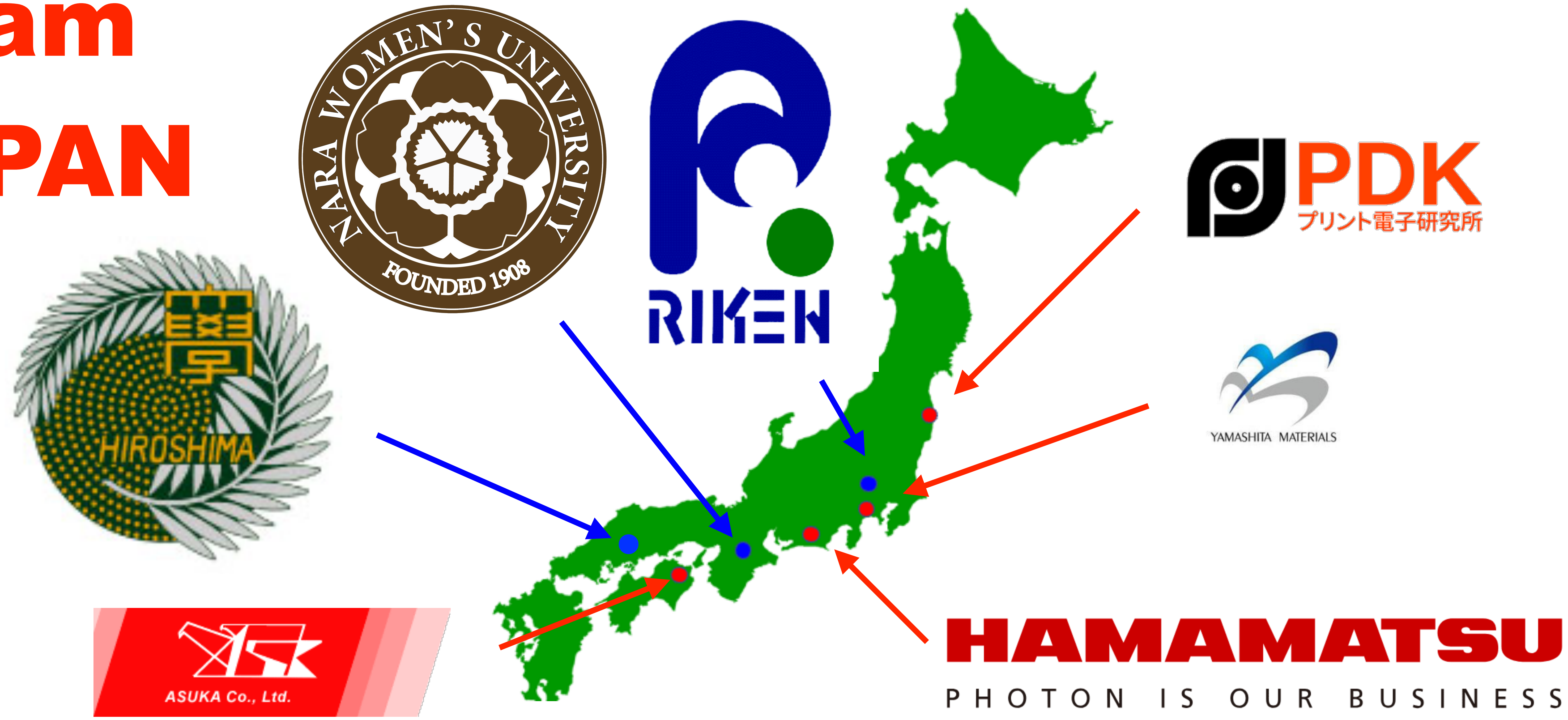
TOF team

EIC-JAPAN



Summary

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- AC-LGAD development elements suiting EIC are remaining, e.g. maximizing chip size, tuning segmentation and so on

- Hiroshima University (EIC-Japan) will play a key role in the development of TOF
  - The simulation study for the fine-tuning of segmentation and material budget has been started
  - The R&D lab is being constructed at Hiroshima University
    - Establishing a strong cooperative relationship with Hamamatsu Photonics