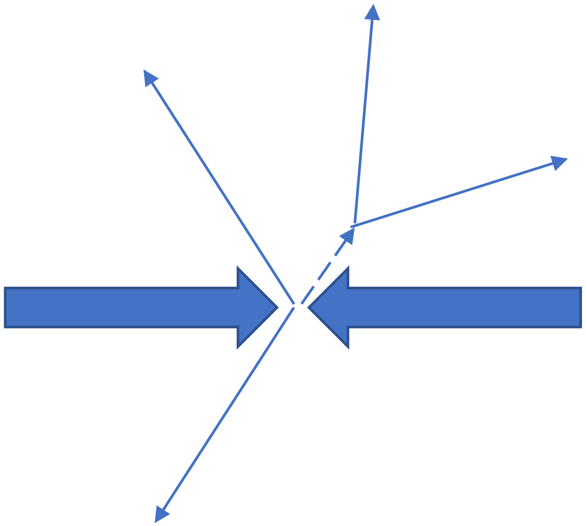
31th International Workshop on
Vertex Detectors (VERTEX2022)

Vertex2022 organized

Kazuhiko Hara



粒子生成や多くの崩壊は衝突点（原子核内）
Bハドロンなどは数mm飛んでから崩壊

粒子軌跡を精密に測定する
⇒どんな反応が起きたかを知る重要情報

VERTEX Detector（or Tracker）
Mainly, silicon semiconductor trackers

Past Vertex workshops

- •2021 virtual, Oxford/UK
- •2020 virtual, Tsukuba/Japan
- •2019 Lopud Island, Croatia
- •2018 Chennai, India
- •2017 Asturias, Spain
- •2016 Isola d'Elba, Italy
- •2015 Santa Fe, New Mexico, USA
- •2014 Mácha Lake, Doksy, Czech Republic
- •2013 Lake Starnberg, Germany
- •2012 Jeju, Korea
- •2011 Rust, Austria
- •2010 Loch Lomond, Scotland, UK
- •2009 Mooi Veluwe, Putten, The Netherlands
- •2008 Uto Island, Sweden
- •2007 Lake Placid, New York, USA
- •2006 Perugia, Italy
- •2005 Chuzenji Lake, Nikko, Japan
- •2004 Menaggio Como, Italy
- •2003 Low Wood, Lake Windermere, Cumbria, UK
- •2002 Kailua-Kona Hawaii, USA
- •2001 Brunnen, Switzland
- •2000 Sleeping Bear Dunes, Lake Michigan, USA
- •1999 Texel, The Netherlands
- •1998 Santorini, Greece
- •1997 Mangaratiba, Rio de Janeiro, Brazil
- •1996 Chia, Sardignia, Italy
- •1995 Ein Gedi, Dead Sea, Israel
- •1994 Lake Monroe, Indiana, USA
- •1993 Lake Bohinj, Slovenia
- •1992 Basto Island, Finland

KH: International Advisory Committee member since 2010

Style keywords: Water, Isolated
full board
invited talks

LEP experiments 1989
RD19 1992 (pixel sensors)

VERTEX2022: 36 invited (30') talks + 17 short (15') talks

VERTEX2020 & VERTEX2022

Start organizing in Feb.
w/o any idea of the venue

Decide to be virtual
April 1, 2020 as for Tokyo
Olympics is postponed

Decided to be on-site July 1
Visa requirement set void
since 11 October ….

Running detectors

Giulia (CMS Inner Tracker)
Kerstin (ATLAS pixel)
Ivan Ravasenga (Alice ITS3)
Arthur (Belle II PXD)

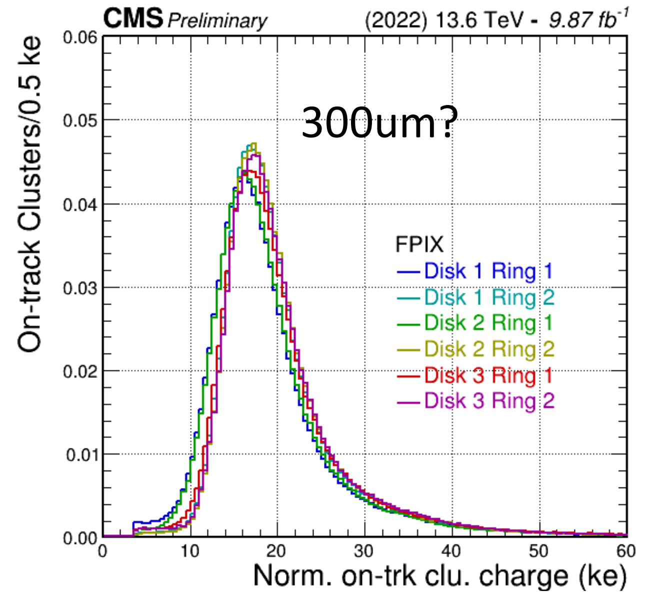
Kookhyun (Belle II SVD)
Valeriia (LHCb VELO)
Dimitra (LHCb UT)

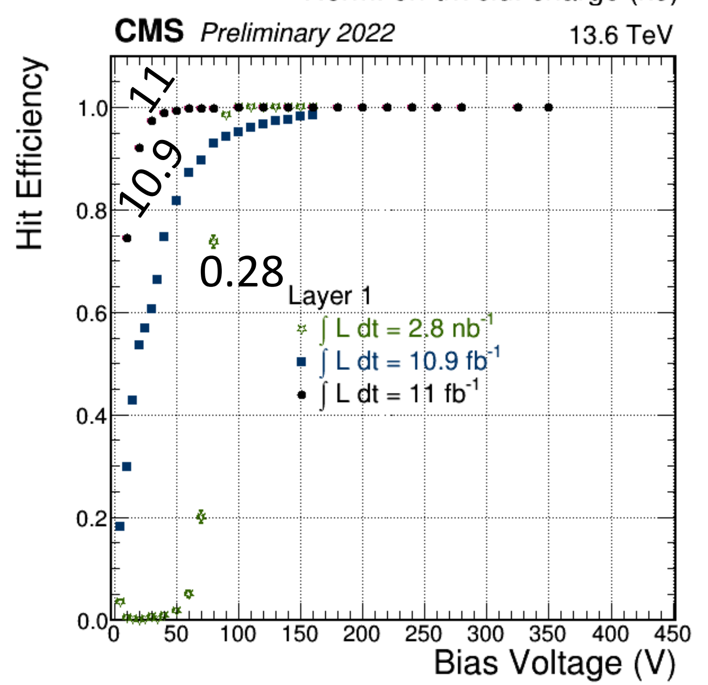
Suvankar (CMS silicon tracker)
Hanna (ATLAS SCT)
Benedikt (FASER)
Shinji (J-PARC g-2/EDM)

Giulia
Negro

Highlights of CMS Inner Tracker

- Detector refurbishment during Long Shutdown 2
  - **new Layer 1 modules**
    - **new readout chip (PROC600v4)** to fix dynamic inefficiency issue and reduce crosstalk noise
    - **new Token-Bit-Manager (TBM10d)** with delay and power reset option
    - **new HDI design** to eliminate HV issues
  - **new DCDC converters** to fix failure mechanism in disabled state
  - …
- Smooth installation and commissioning in 2021
- First Run 3 performance are good!
  - bias scans to monitor evolution of radiation damage
    - large charge efficiency loss in Layer 1 within first 10 fb^{-1}
    - recovered by raising bias voltage and with positive annealing in period without beam
  - timing scans to find optimal delay settings
    - now also for Layer 1 w.r.t. Layer 2 thanks to new TBM feature
  - excellent position resolution in full detector
    - comparable to Run 2





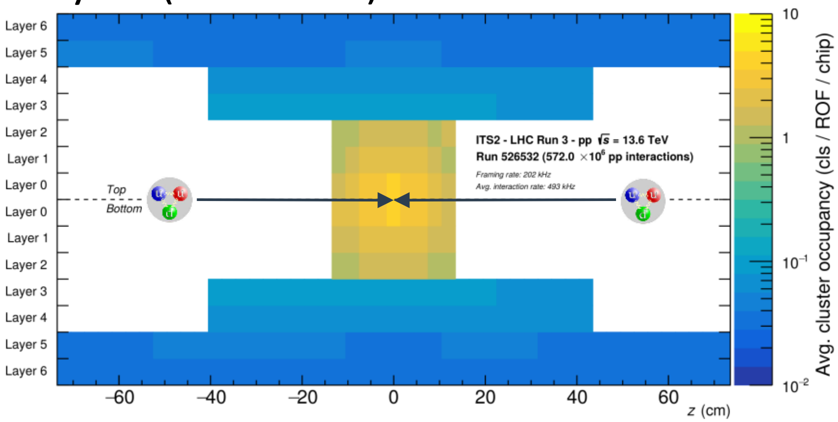
Commissioning and performance in Run 3 of ALICE ITS2

→ *Highlights*

Ivan Ravasenga (CERN) – ALICE Collaboration

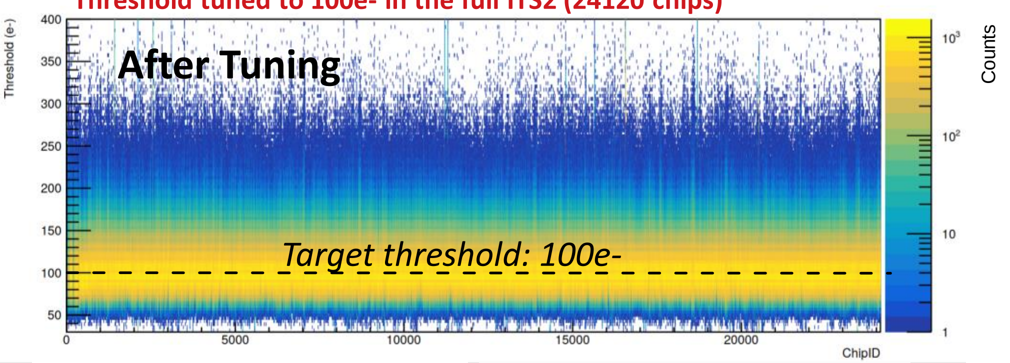
- **ITS2**: upgraded ALICE Inner tracking system based on MAPS → 10m^2 active area, low material budget (~0.36% X_0 in IB)
- **Installation in ALICE cavern**: May 2021
- **Commissioning in the cavern**: June 2022
- **Taking data in Run 3**: pp collisions √s = 13.6 TeV, nominal 500 kHz interaction rate, nominal 202 kHz framing rate
- **Calibration is challenging** for 24120 chips: 1% of pixels pulsed – 40 processing nodes + parallel processing
  - Masking 0.15‰ of total pixels and tuning the discrimination thresholds to 100 e-
  - **Benchmarking the pre-alignment with K^0_S**: ~80um with pre-alignment

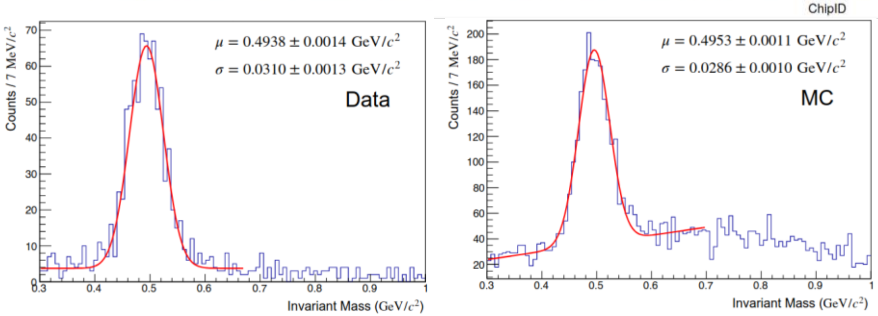
7 layers (3 IB+4 OB)



Average #clusters / chip / ReadOutFrame in the full detector

Threshold tuned to 100e- in the full ITS2 (24120 chips)

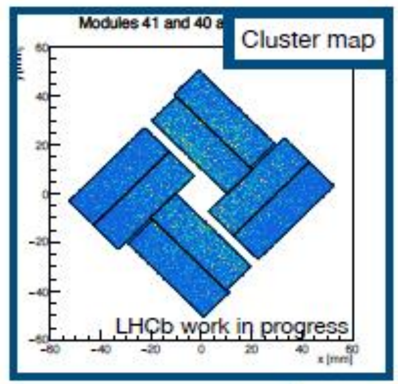




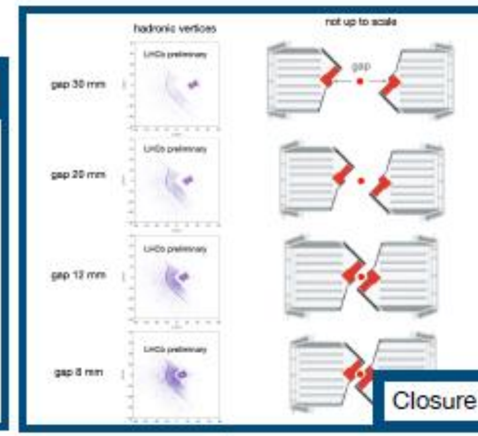
K^0_S invariant mass: ITS stand-alone tracking (δmean=a few/mile)

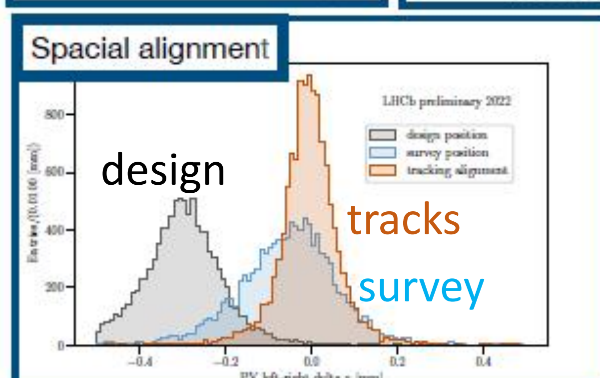
The LHCb Vertex Locator in Upgrade I

- **New silicon pixel** tracking detector for the heart of LHCb
- 52 modules with 4 sensors and 3 ASICs (VeloPix, based on TimePix3) per sensor. Pitch: 55x55 μm. Readout: 900MHits/s.
- Both detector **halves** (each 26 modules) successfully **installed in March and May** this year!
- **Huge amount of work by many people to make sure everything is of the highest quality and on time.**
- **First data is there!**
  And halves were closed for the first time!
- Working on configuring the detector and repeating calibrations for the installed detector



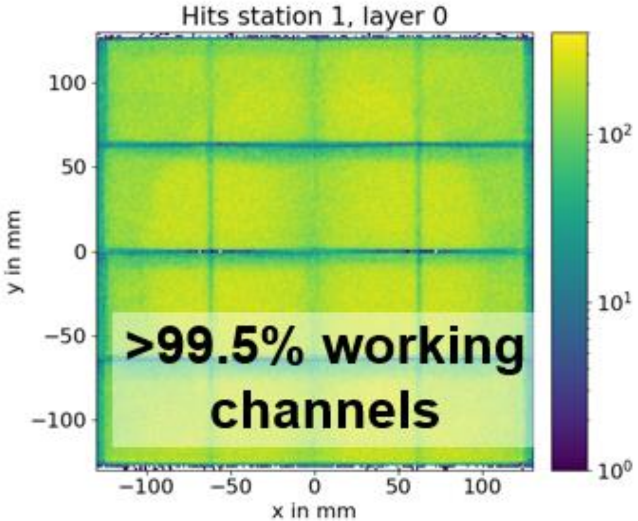
Hadronic events

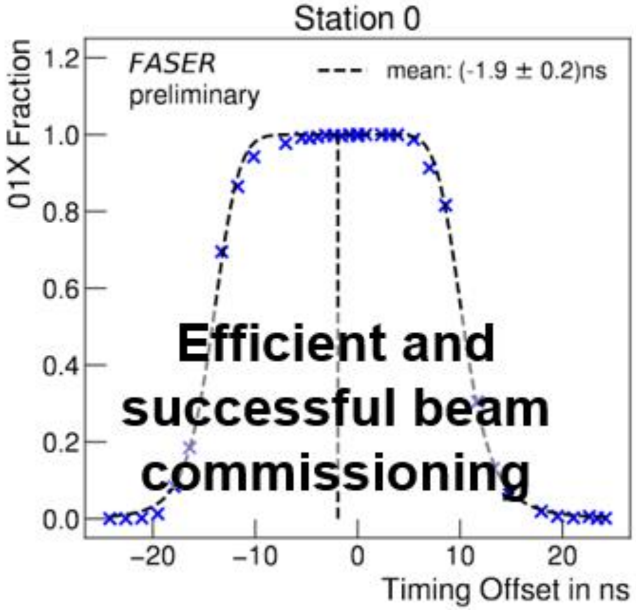


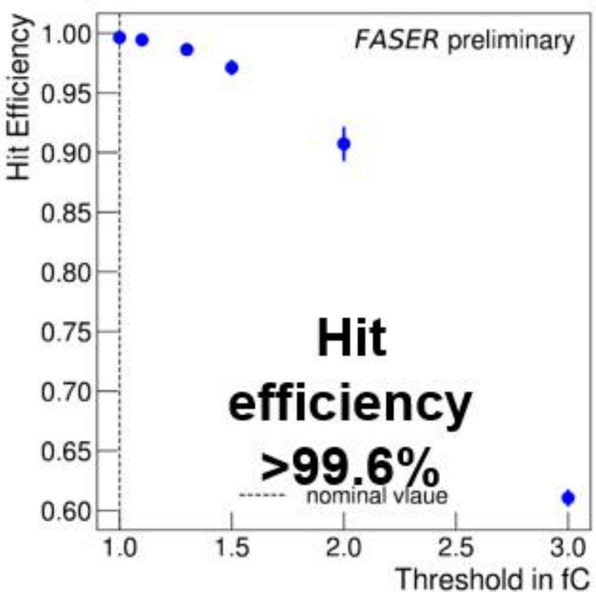


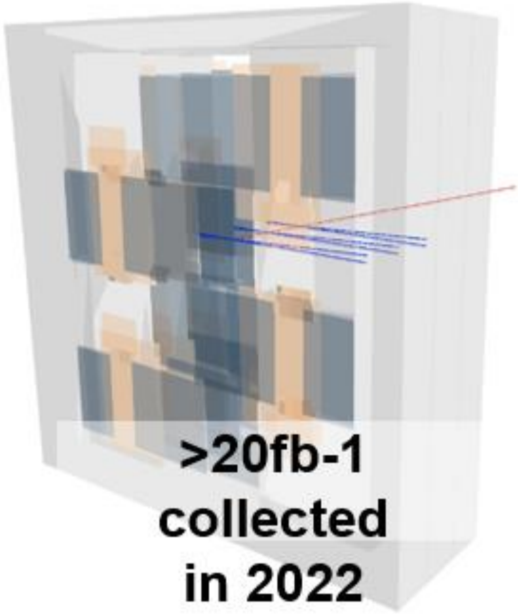
FASER Tracker Highlight VERTEX 2022

FASER tracker made of 12 layers with silicon strip modules
(ATLAS SCT modules)









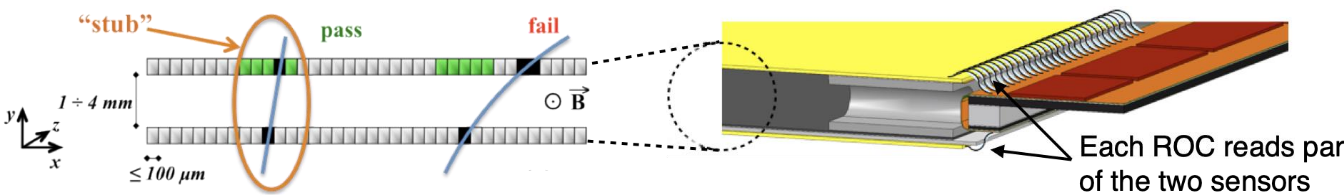
Upgrade

Giacomo (CMS pixel HL-LHC)
Fabio (CMS Outer Tracker)
Mei (CMS L1 tracker finder)
Mauro (CMS 3D)
Toru (Belle II upgrade)
Zihan (Belle II thin-fine pitch SVD)

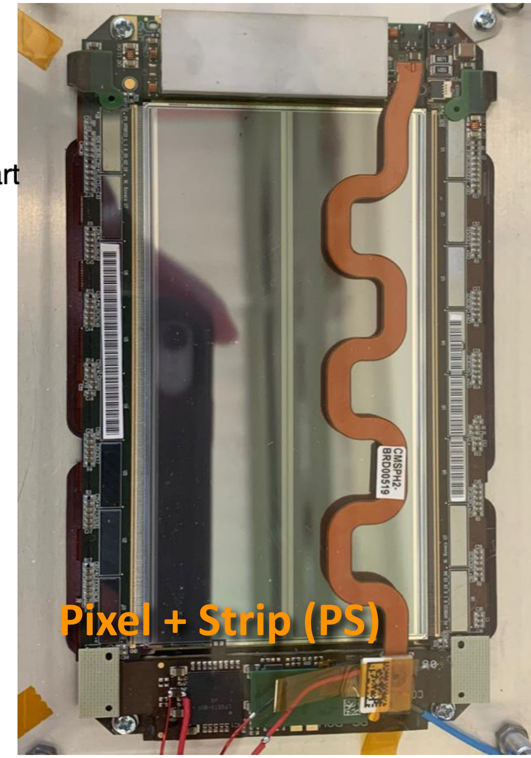
Helen (ATLAS Itk pixel)
Benedikt (ATLAS Itk strip)
Stefania (ATLAS pixel Loaded Local Support Demonstrstor)
Christoph (ATLAS strip QC)
Shigeki (ATLAS strip QA)

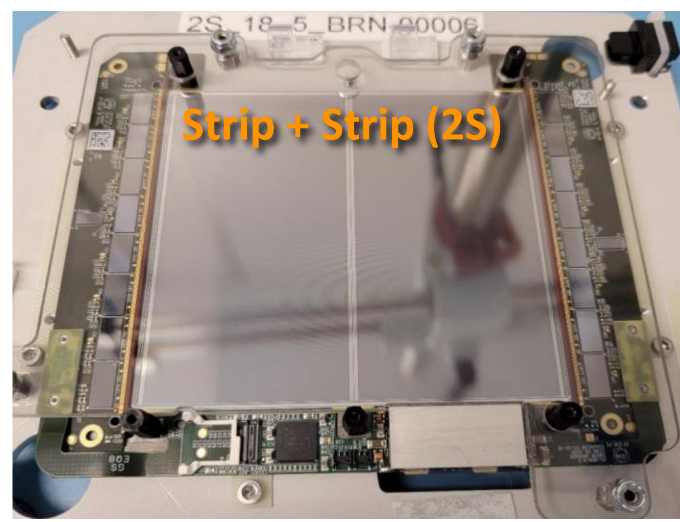
Francesca (ALICE ITS for Run4)
Lukas (ALICE ITS beam test)
Ryu (LHCb Mighty Tracker w/ HV-CMOS)

The CMS Outer Tracker for the High Luminosity LHC



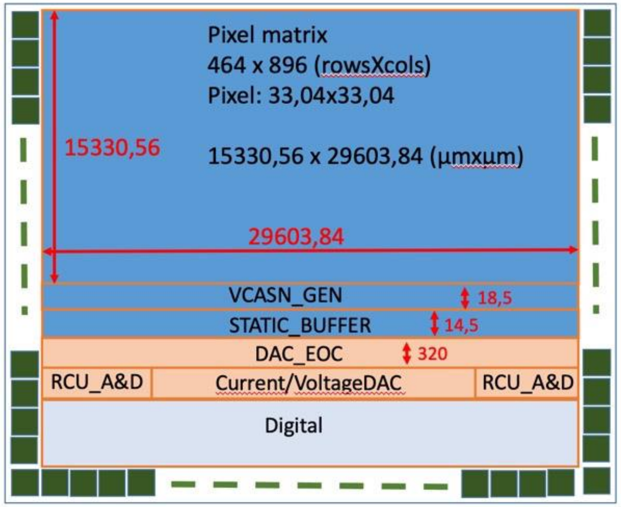
- The new Outer Tracker will be equipped with the pT-modules
  - Will allow running the particle flow at 40 MHz
  - Two types of pT-modules: 2S and PS
- Module production centers are getting ready
  - Assembly and QA procedures are being finalized
  - Several prototypes successfully assembled and qualified
- Improvement in detector geometry, better materials and cooling, more clever power distribution
  - Low material budget





Belle-2 Upgrade scheduled 2027-2028

Toru Tsuboyama

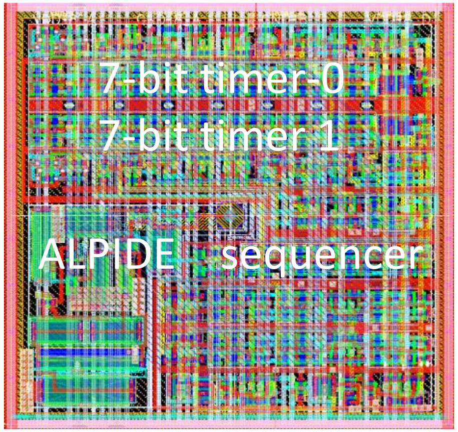


DMAPS OBELIX: Optimized BELle II pIXel sensor

- Monopix2: 33 µm pitch, 25 ns integration
- Tower Jazz 180nm
- Cover entire volume

SOI DuTip: Dual Timer Pixel

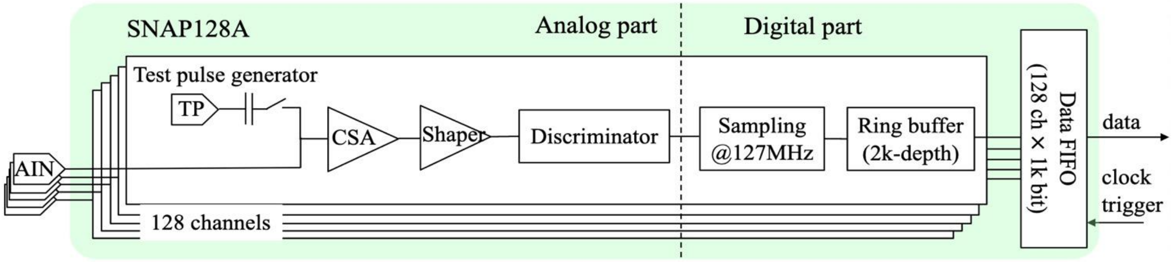
- ALPIDE type frontend (modified for faster response)
- Lapis 200nm
- Seemless readout
- Innermost layer



45x45 µm pixel

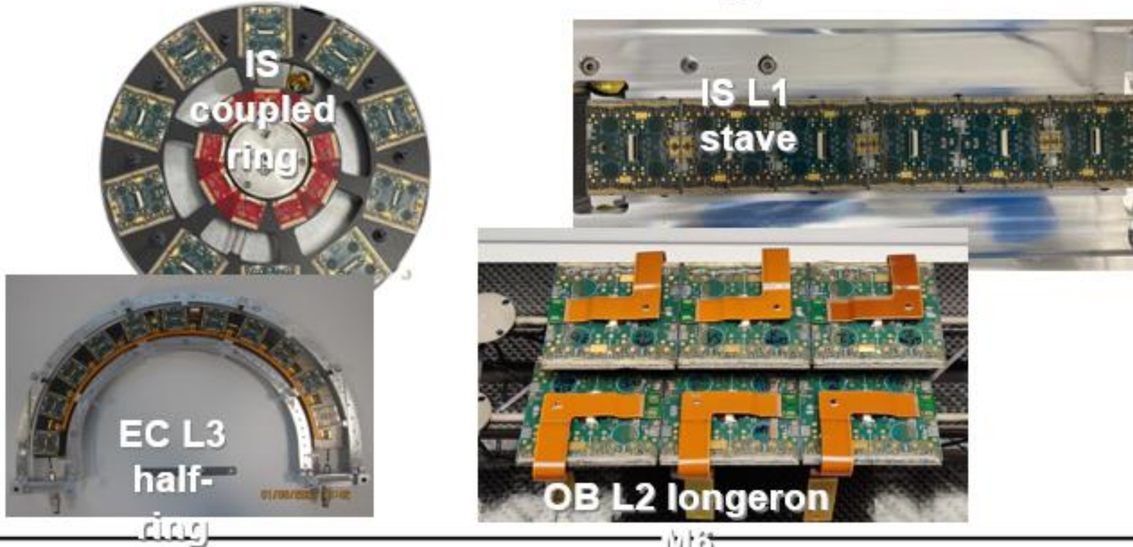
Si TFP: Thin fine-pitch DSSD to cover outer volume

- 150 um thick DSSD (prototype@Micron)
- Binary readout SNAP128A (pipeline~8us)

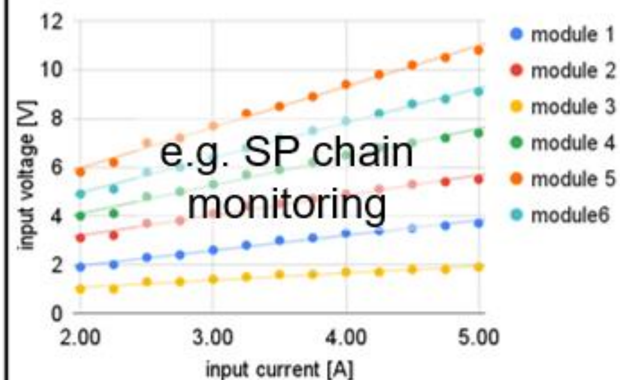


ITk Pixel LLS Highlight VERTEX 2022

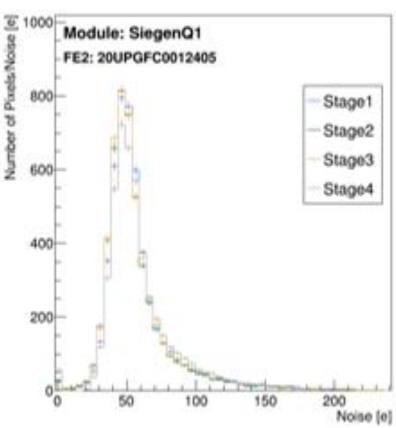
Different flavors of loaded local support demonstrators

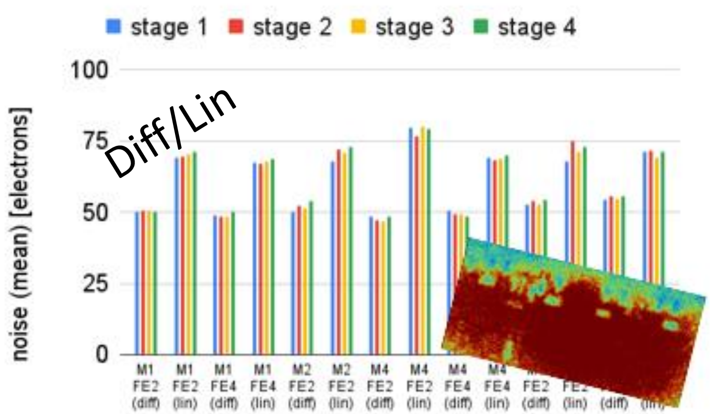


Validation of system level concepts

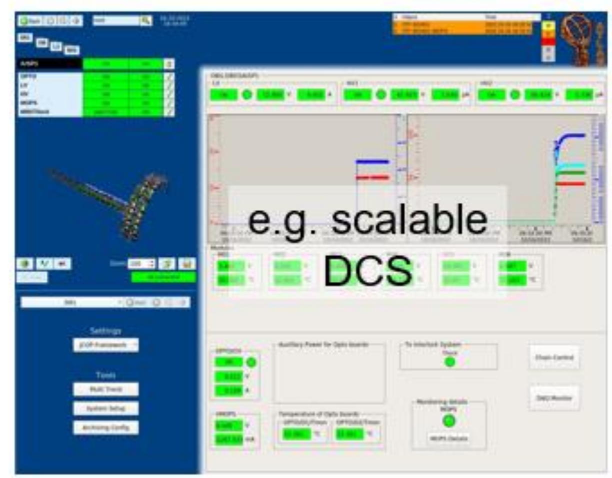


Validation of electrical performance after loading

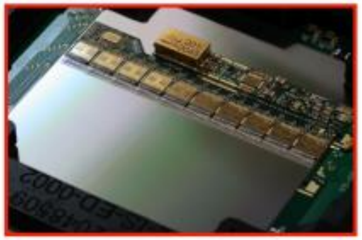




Development towards detector operation

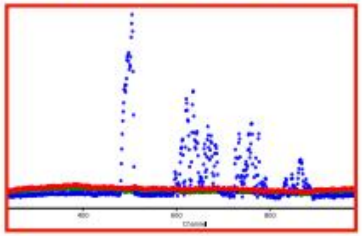


ATLAS Itk Strip



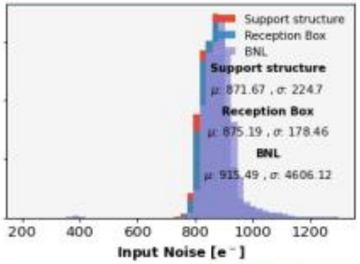
ITk Strip project deep into preproduction and starting production in some areas

Assembly and testing of pre-production staves and petals in progress

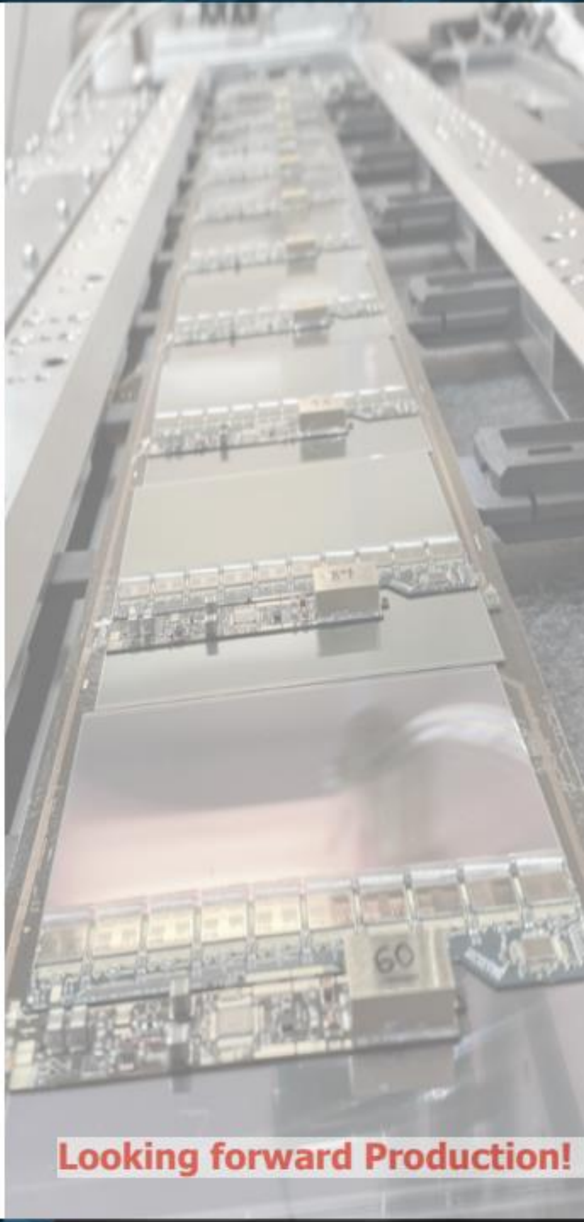


Unexpected 'cold noise' effect found during module testing. Experts are working to understand the source while mitigations are under study

Extensive test campaign over first pre-productions staves



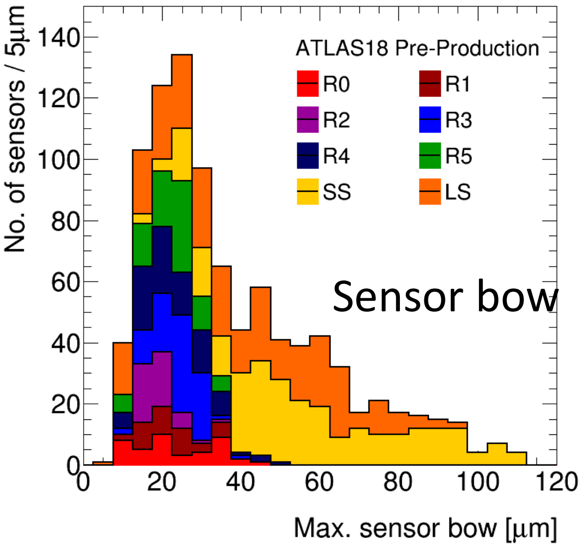
System tests and completing module pre-production are high priority

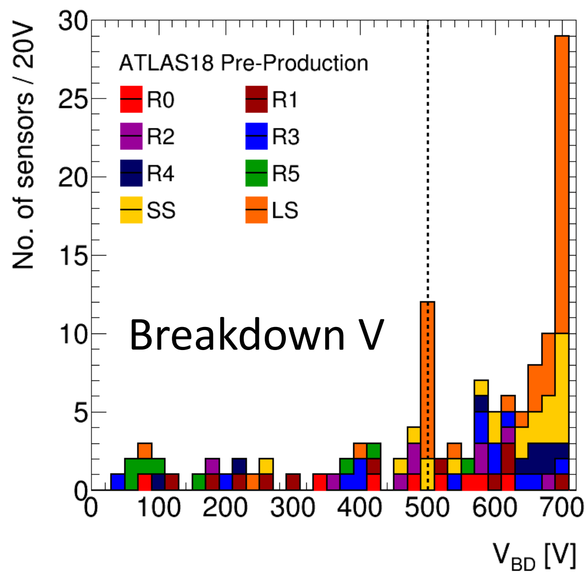


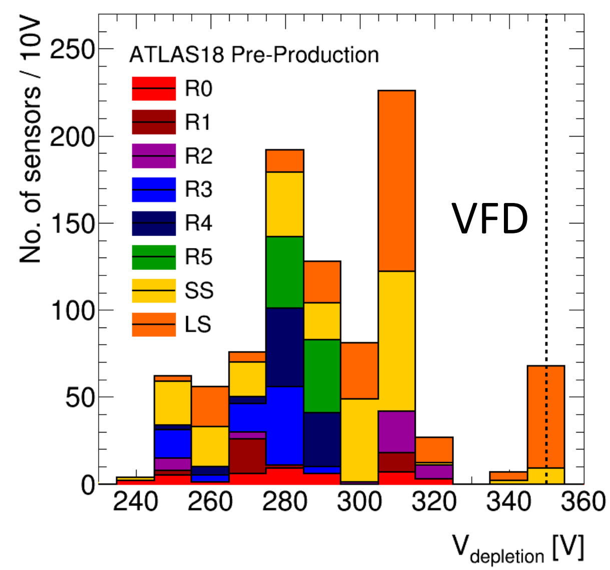
ATLAS Itk strip sensor QC

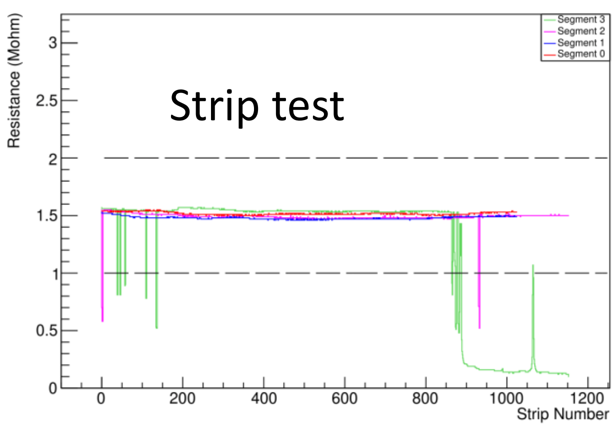
christoph

Order type	Sensor type	Contractor	No. sensors		
Pre-production	all 8 types	HPK	1,041	9.2 m2	completed
Production	all 8 types	HPK	20,800	190.3 m2	ongoing









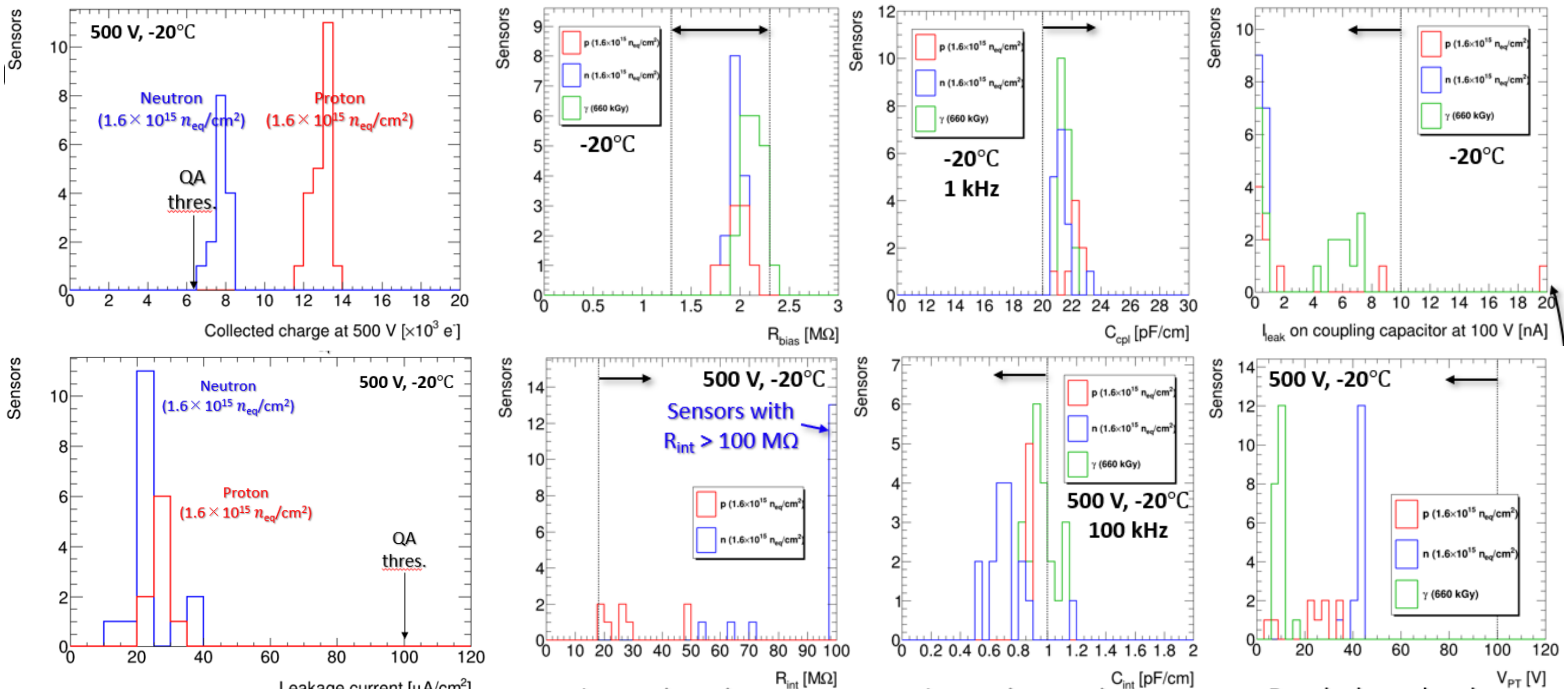
Strip test: each by HPK and samplings by Institutes

- Fully established QC site testing procedures with finalised setups and hardware
- use of ITk Production Database

  records of all tests by HPK + ATLAS sites

  shipments

ATLAS ITk Strip sensor pre-pro.



- ITk strip sensor pre-production was carried out in 2020
- With >100 QA pieces, very good performance was confirmed
  - Various good lessons to improve our QA procedure for main production!
- Based on the outcomes from pre-production, ATLAS18 sensor main production was started in July 2021

Upgrade of the ALICE Inner Tracking System for LHC Run 4

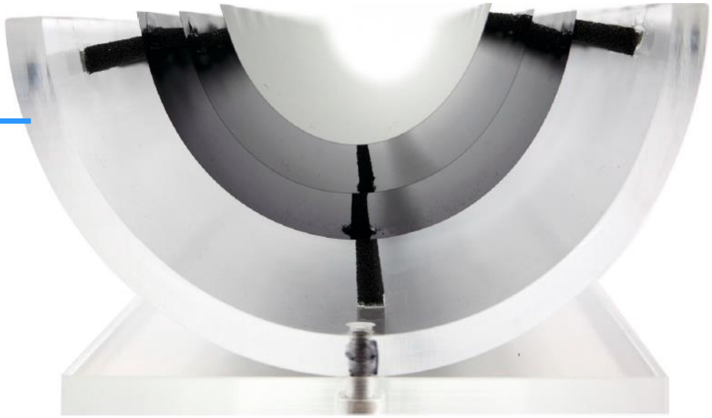
Francesca Carnesecchi

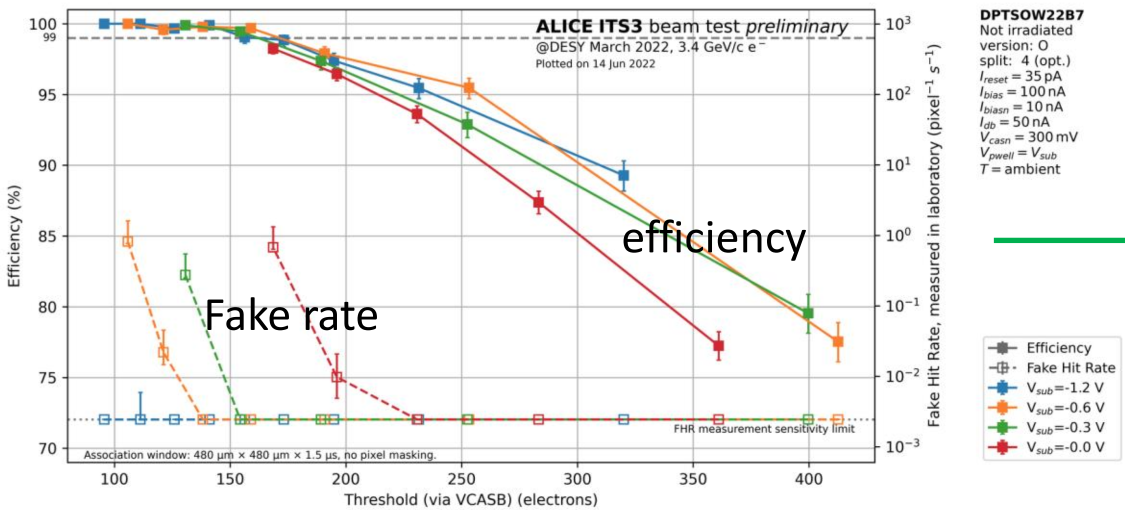
From 432 sensors to 6 truly cylindrical wafer-scale MAPS sensors

Ultimate vertex detector

Silicon flexibility and bending proved

Full mock-up of the final ITS3 done, uniform performances among different radii



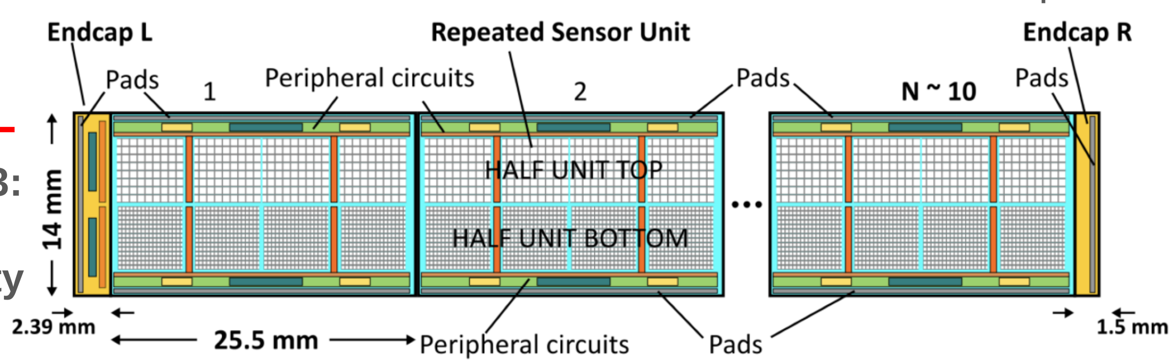


Sensor design validated

Improved charge collection efficiency with new design, 100% detection efficiency reached and radiation hardness higher than one needed from ALICE (10^{13} n_{eq}/cm^2)

Next step: stitching

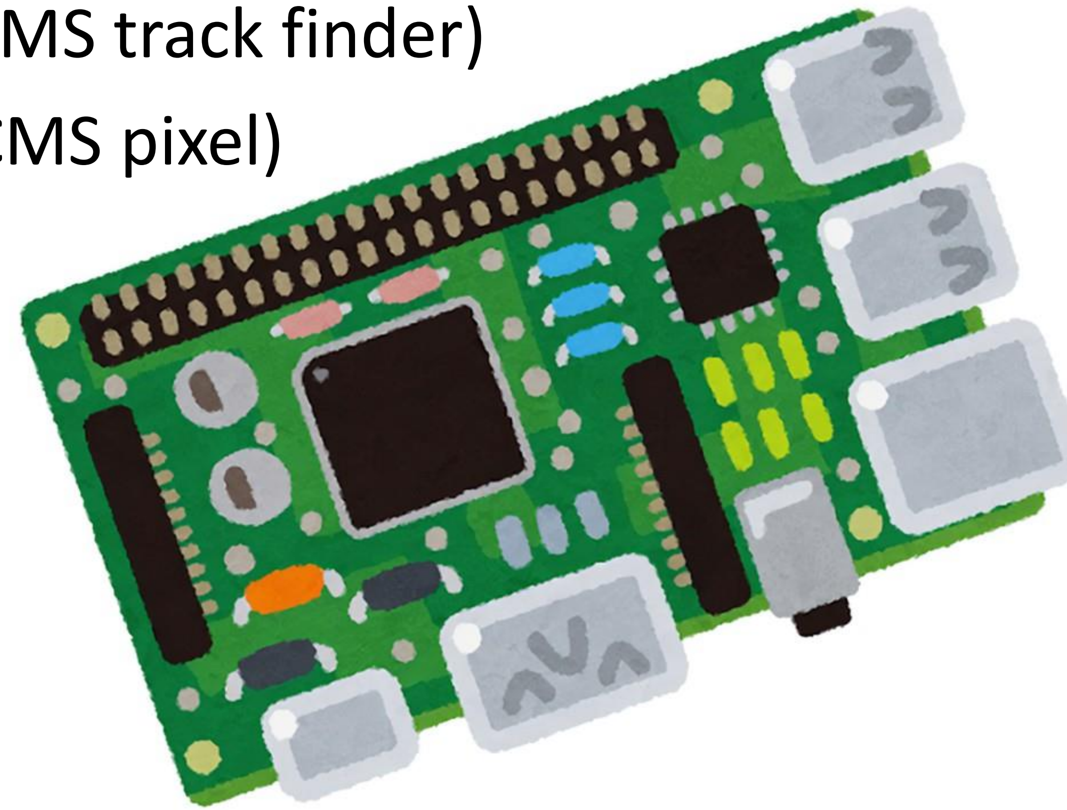
First prototype to be received in 2023: fundamental for understanding the rules of stitching, yield and uniformity



ASIC

AlessandroCaratelli (CMS track finder)

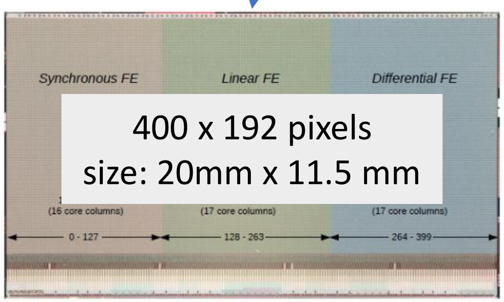
John (RD53 – ATLAS/CMS pixel)



RD53 Pixel chips for ATLAS and CMS Phase II upgrades

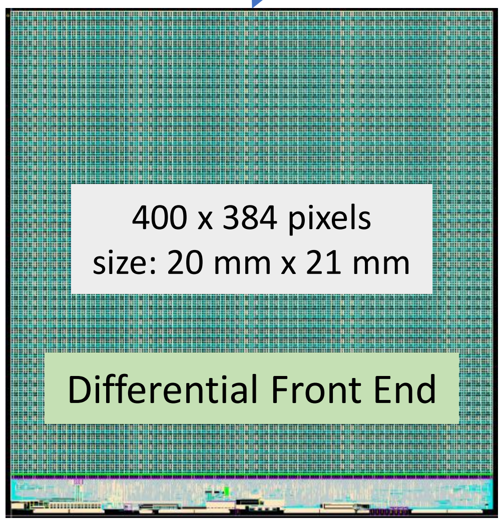
2013–2017	2018–2020	2020–2021	2021–2022	2022–2023
Designing blocks and test chips, testing radiation hardness, designing RD53A, verification	Protecting against single event effects, adding features, verification	Adding features, fixing bugs, verification	Fixing bugs, verification	Fixing bugs, verification

2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023



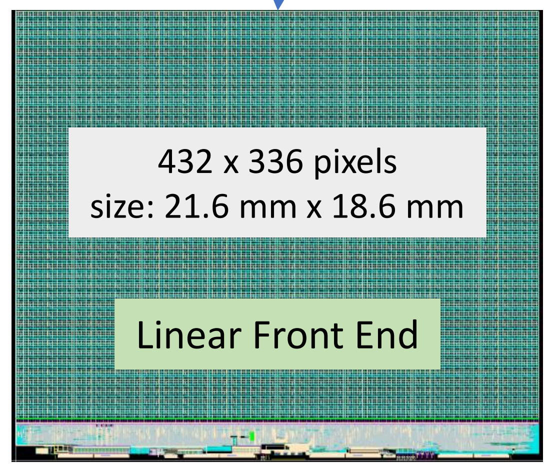
RD53A

- **Half-size demonstrator for:**
  - **evaluating alternatives:**
    - 3 analogue front ends
    - 2 readout architectures
  - **prototyping Pixel modules**
- submitted in August 2017



RD53B-ATLAS (ITkPix-V1)

- **ATLAS pre-production**
- Submitted in March 2020
- In October 2020, a mask respin was submitted to patch a serious bug in the pixels' Time over Threshold latches



RD53B-CMS (CROC-v1)

- **CMS pre-production**
- Submitted in June 2021

RD53C-ATLAS:
Q4 2022
ATLAS production
(ITkPix-V2)

RD53C-CMS:
Q1 2023
CMS production
(CROC-v2)

RD53:

Pixel chip collaboration of 24 ATLAS and CMS institutes for 9 years and counting

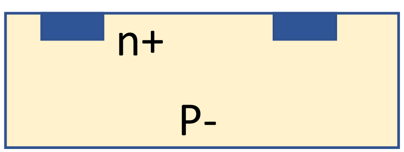
RD53

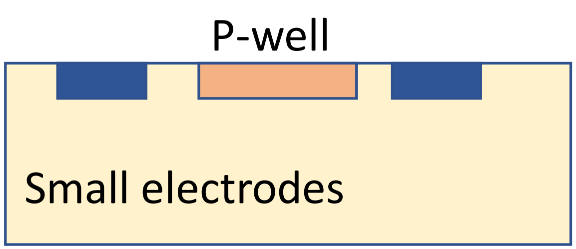
UNIVERSITY OF OXFORD

Monolithic

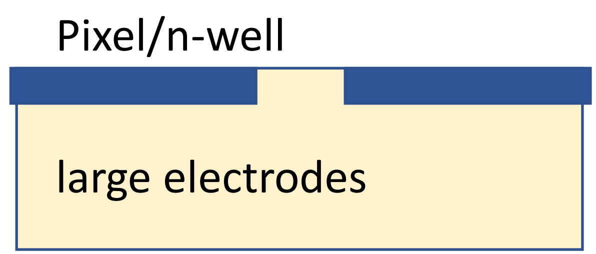
Luigi (MuPix for Mu3e)
Ivan Dario (DMAPS)
Jory (TPA)
Lingxin(HVCMOS test beam)
Pascal (digital MAPS)

Akimasa (SOI)
Didier (FASER preshower)
Heinz (small pixel: MALTA)

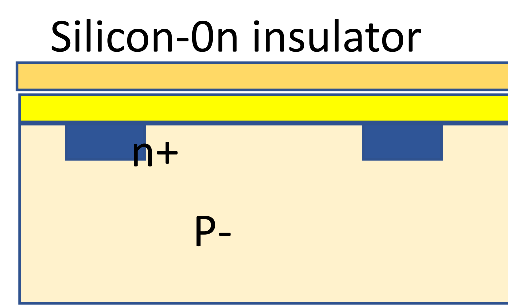




MALTA



DMAPS/HVCMOS



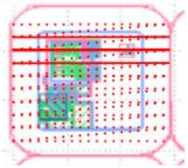
SOI

Jory Sonneveld

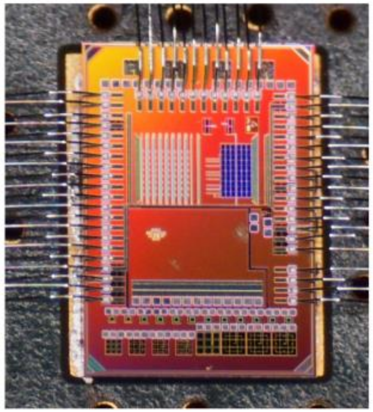
TPA (two photon absorption) laser to image * TPA occurs at focal point

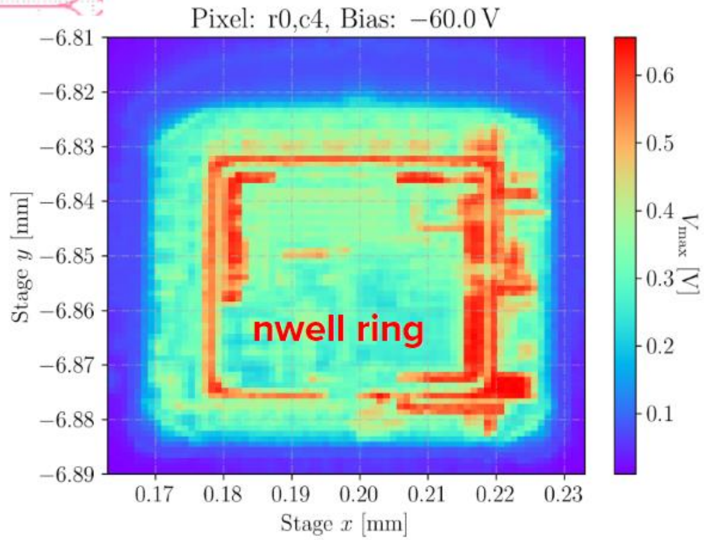
3D image of an RD50 HV CMOS pixel

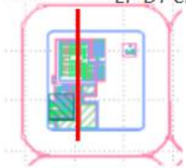
Francisco Rogelio Palomo Pinto[a], Sebastian Pape[b,c], Michael Moll[b], J.María Hinojo Montero[a]
[a] Electronic Engineering Department of School for Engineering in University of Seville, Spain
[b] EP-DT CERN, [c] TU Dortmund University



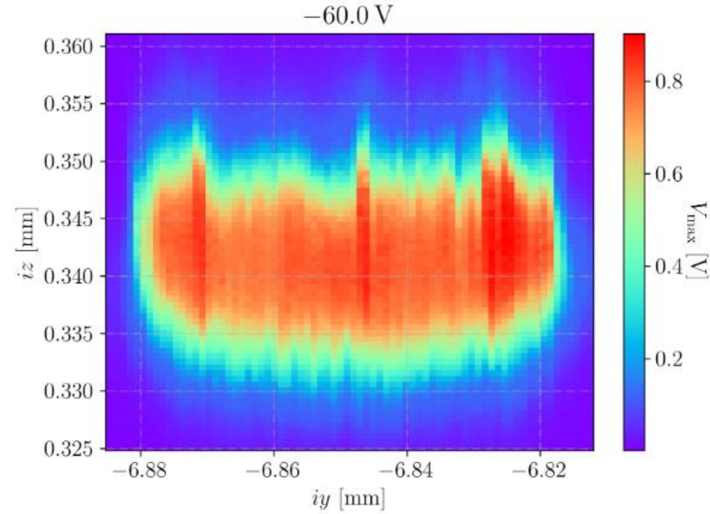
XY-Scan middle depth focus







YZ-Scan across the electronics



- Chip electronics no obstacle to mapping
- N-well ring clearly visible in image made with TPA laser
- Active region is clearly visible

From RD50 CMOS meeting
https://indico.cern.ch/event/1184355/contributions/4976091/

1

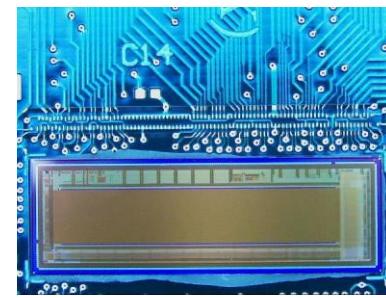
SOI

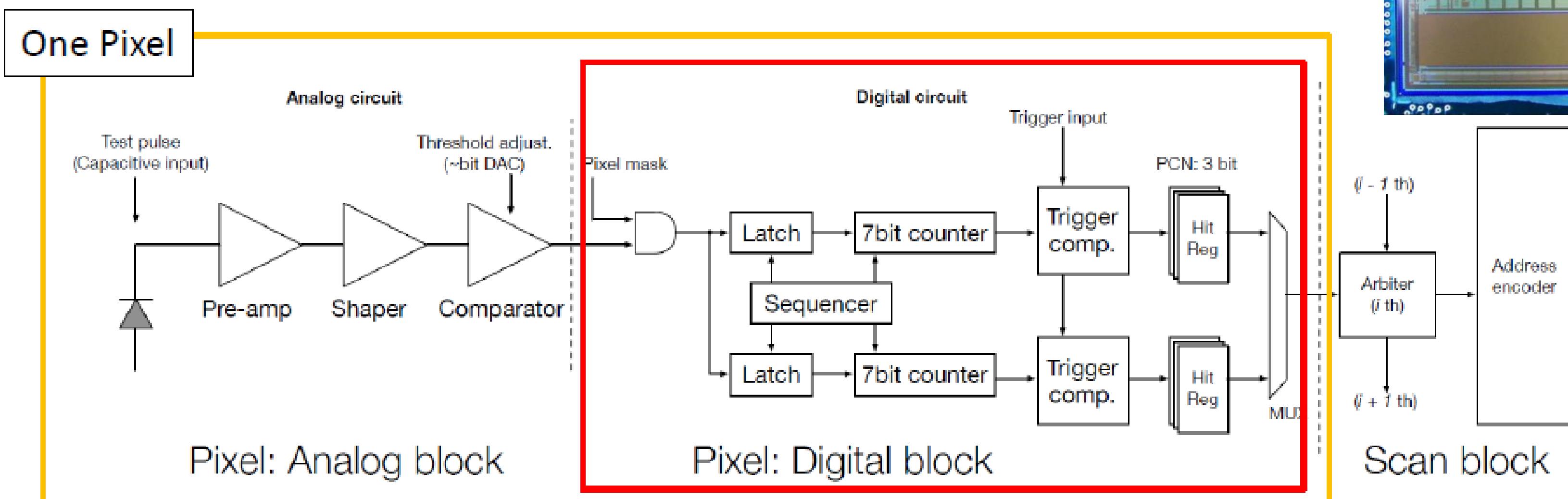
Akimasa ishikawa

Since 2005, Japanese group is developing the SOI pixel detector with Lapis semiconductor (200nm FD-SOI)

- DuTiP concept for Belle II and ILC
  - First prototype DuTiP1 was tested
  - DuTip2 (full functionality) was delivered

Tested with 90Sr and 50MHz CLK (20ns) - good enough for 63ns bucket





7bitx 2

ALPIDE analog circuit
Modified for faster response

15.9MHz(62.9ns) CLK (SuperKEKB509MHz/32(1.97ns*32))Trigger latency of at most 8us (4.4us requirement)

R&D New Detector/Material

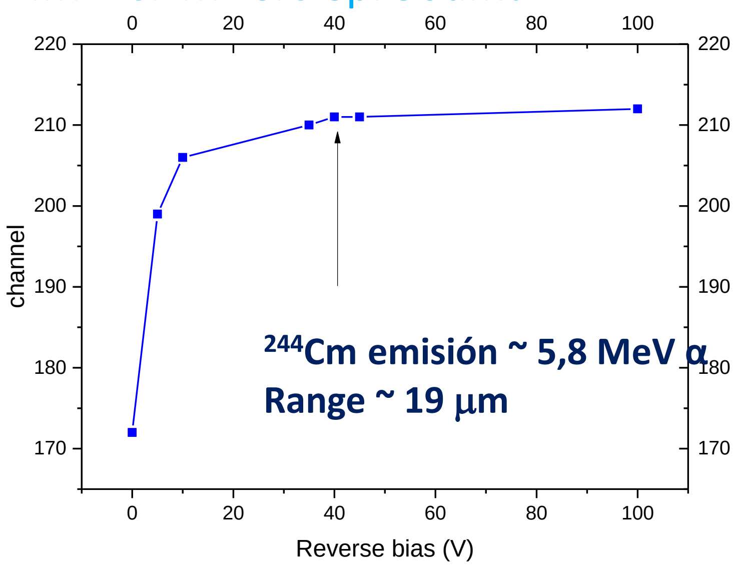
Christopher (RD50 activity)
Giulio (SiC)
Harris (Diamond)

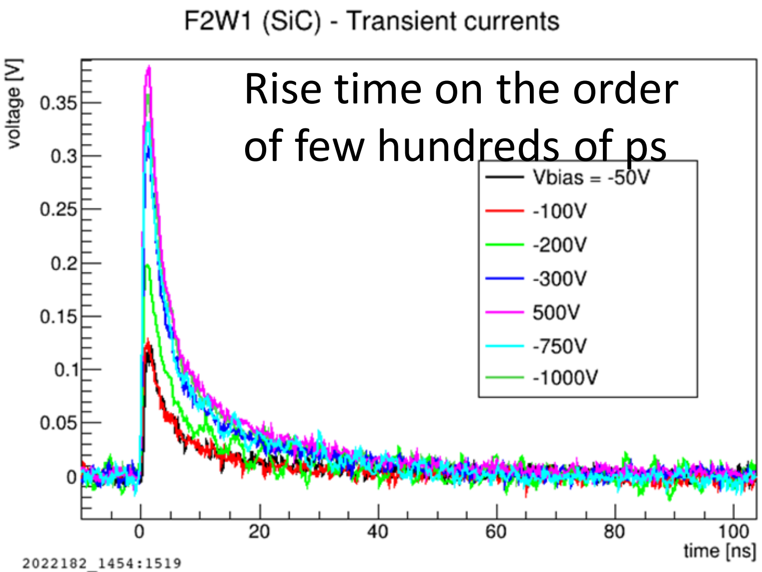
SiC

High quality, low defect density SiC is available up to 200 mm wafers

- Wide bandgap
  - reduces the leakage current, maintaining ***low noise*** levels ***at high temperatures***.
  - Insensitive to visible light.
- High atomic displacement threshold (~20 eV for C, and ~40 eV for Si), ***which should make the material more radiation resistant***;
- ***Fast saturated electron drift velocity*** ($2x10^7$ cm/s at RT), twice faster than silicon;
- ***High thermal conductivity*** (490 $Wm^{-1}K^{-1}$), which is three times higher than that of Si

IMB-CNM SiC epi 50umt





3D in prep.

LGAD idea (57eh/um, 50umt) Gain layer by epi

Timing

Mengqing (ATLAS HGTD)
Valentina (HGTD rad-hardness)
Vagelis (LHCb Velo2 – 4D)
Kevin (TimePix monolithic 440ps)
Wilhelm (HADES beam monitor-LGAD)
Francesco (Resistive RO – LGAD, 20ps/15um)

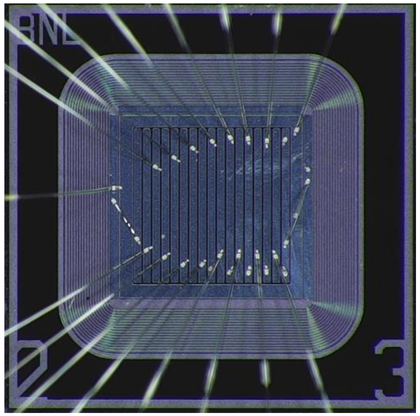
Alessandro Tricoli (AC-LGAD 28ps/6um)
Sayuka (AC-LGAD)
Francesco (TCAD simulation)
Adriano (TimeSPOT: 10ps⇒50ps w/ ASIC)
Giuseppe (picoAD: monolithic 17.3ps)

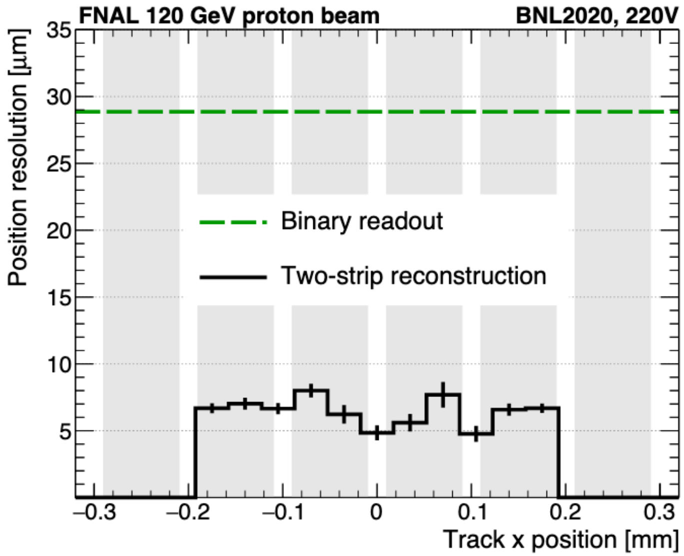
Rise of 4D Detector

Alessandro Tricoli

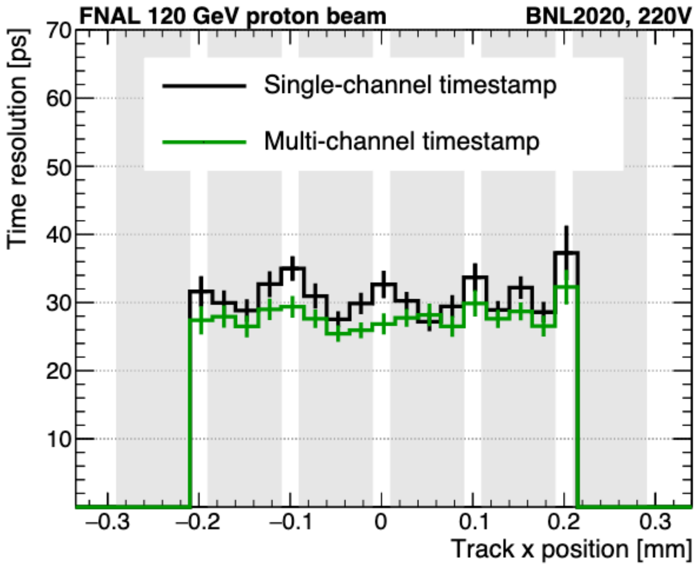
LGADs are a stepping stone to develop **4D detectors**, and **AC-LGAD** is the most mature technology

- Internal signal sharing combined with internal gain
- 100% fill factor
- Potential to reach <20 ps time resolution and ~1 μm space resolution → **4D detectors**
- Sparse electrode metalisation with similar space/time resolution → **Power saving in electronics**
- Available ASICs (ALTIROC) can be used for readout and dedicated ASICs (EICROC) that exploit signal sharing are being designed
- Potential to combine AC-LGADs with readout circuitry in a monolithic detector → **Low-mass detector**
- Longer term R&D is needed to optimize the **radiation hardness**





≲ 6 μm with 100 μm pitch
(limited by tracker resolution)



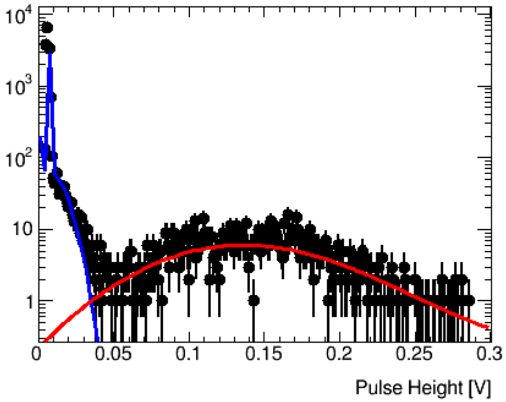
Time Resolution ~28 ps:

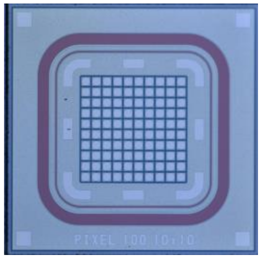
AC-LGAD for hadron collider

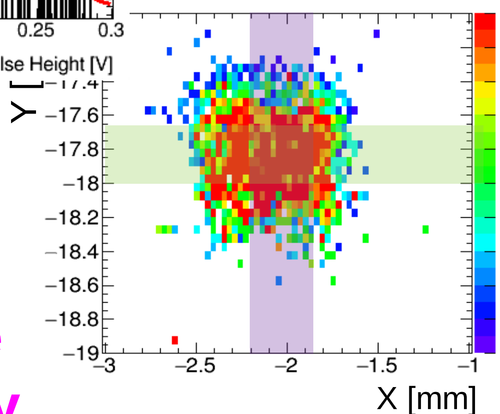
Sayuka Kita

<u>**finer pitch AC-LGAD sensors (strip&pixel)**</u> are prototyped with HPK – process parameters are optimized

Pixel (100um pitch)

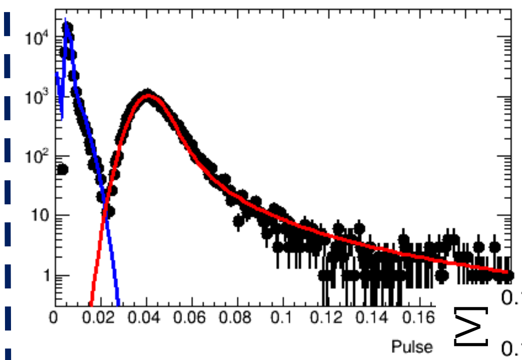


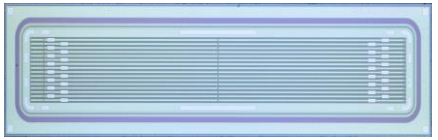


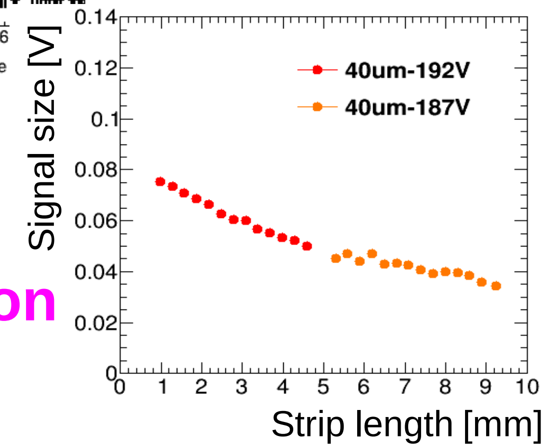


large signal
&
good
performance
e.g. efficiency

Strip (80um pitch)







large signal
but
signal reduction
by C_{int}

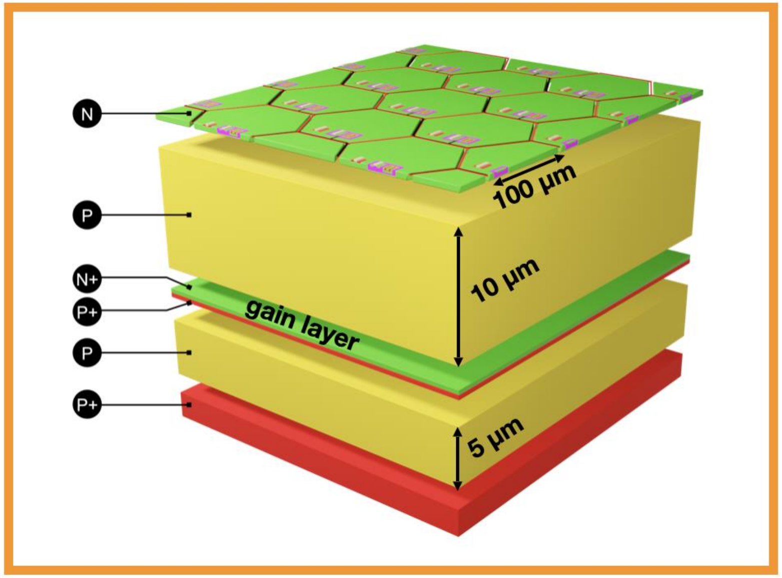
The MONOLITH ERC Project

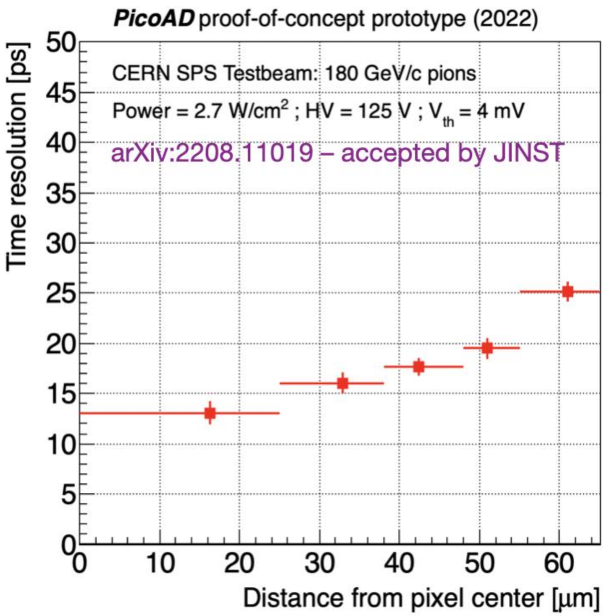
G. Iacobucci

Introduces the **PicoAD©** —Picosecond Avalanche Detector— a multi-PN junction sensor.

A **monolithic proof-of-concept prototype** was produced in SiGe BiCMOS 130nm IHP process. Continuous gain layer 10µm deep in sensor. Testbeam provided:

- **Efficiency = 99.9 %** including inter-pixel regions
- **Time resolution σ_t = (17.3 ± 0.4) ps** **13 ps** at center and **25 ps** at pixel edge (although sensor not yet optimized for timing)





Second monolithic prototype **WITHOUT GAIN** provides **21ps** time resolution.

Non HEP & Future experiments

Giuseppe (100µPET)
Xuan (EIC)
Nazar (muon collider)
Haken (ILC)

VERTEX2022

KEKのヘッドラインニュース

https://www2.kek.jp/ipns/ja/news/

- ✓ HEPNews　12月号に会議報告記事

VERTEX2022 国際会議を開催

2022年11月11日

トピックス

⇒VERTEX2023

IAC:　原から中村浩二（KEK）に交代

Vertex2023 will be hosted by Genova Group (Claudia Gemme)