Summay Talk
Vertex2022

Kazuhiko Hara

Past Vertex workshops

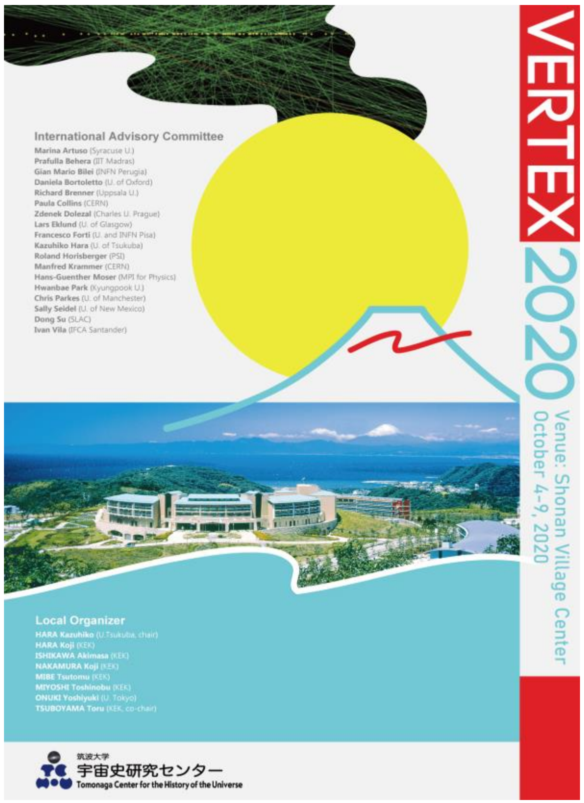
- 2021 virtual, Oxford/UK
- 2020 virtual, Tsukuba/Japan
- 2019 Lopud Island, Croatia
- 2018 Chennai, India
- 2017 Asturias, Spain
- 2016 Isola d'Elba, Italy
- 2015 Santa Fe, New Mexico, USA
- 2014 Mácha Lake, Doksy, Czech Republic
- 2013 Lake Starnberg, Germany
- 2012 Jeju, Korea
- 2011 Rust, Austria
- 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

Keywords: Water, Isolated
room and full board
invited talks

LEP experiments 1989
RD19 1992

VERTEX2020 & VERTEX2022

Start organizing w/o any idea of the venue



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

Decided to be on-site July 1

Finally vertex2020 logo is realized on real objects

designer: michiko hara

Running detectors

Giulia
Kerstin
Ivan Ravasenga
Arthur

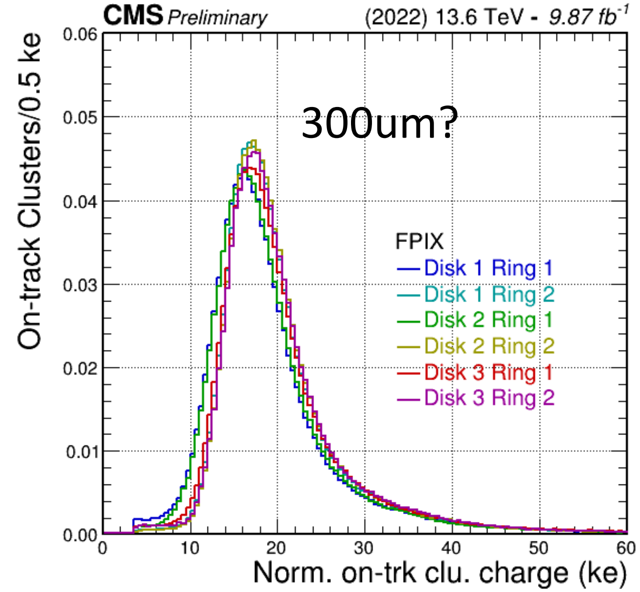
Kookhyun
Valeriia
Dimitra

Suvankar
Hanna
Benedikt
Shinji

Giulia Negro

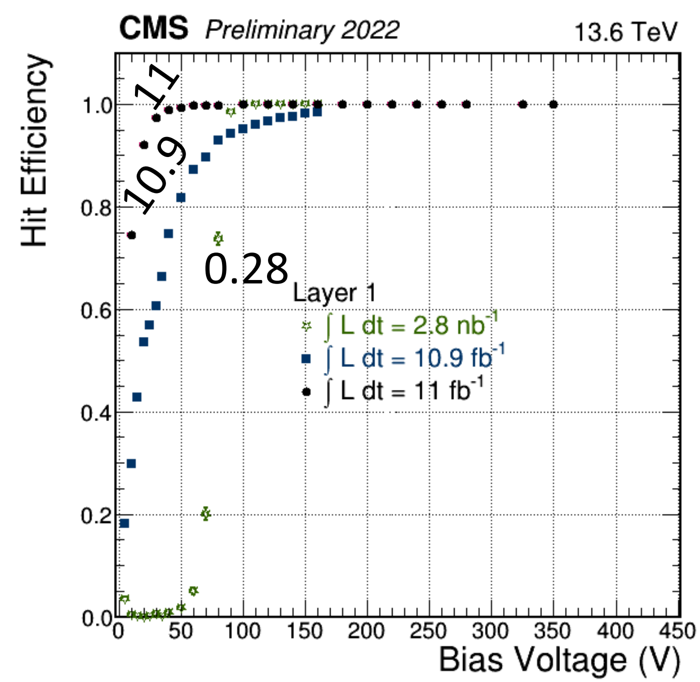
Highlights of CMS Inner Tracker

- 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

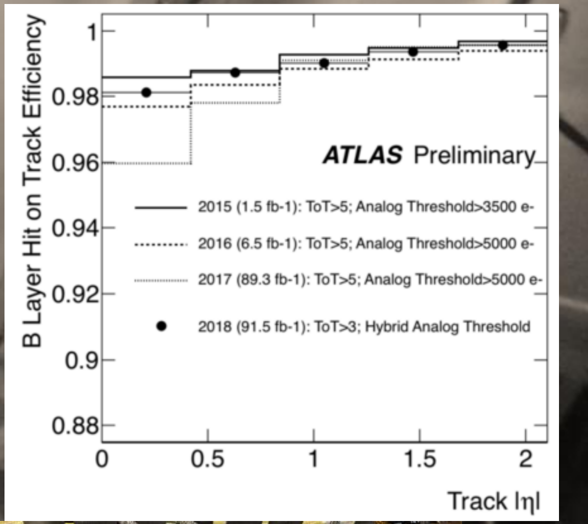
- First Run 3 performance are good!
  - bias scans to monitor evolution of radiation damage
    - large charge efficiency loss in Layer 1 within first 10 fb^{-1}
    - recovered by raising bias voltage and with positive annealing in period without beam
  - timing scans to find optimal delay settings
    - 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

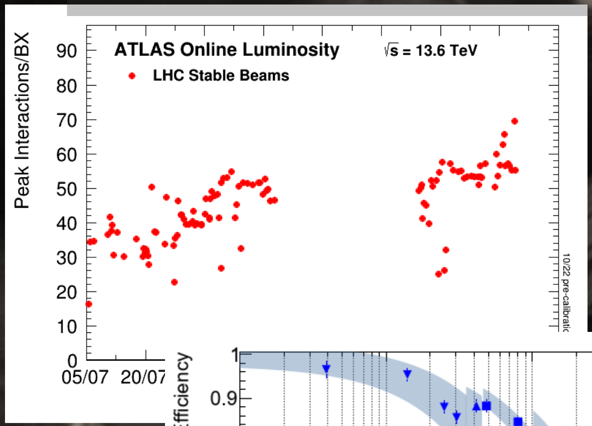


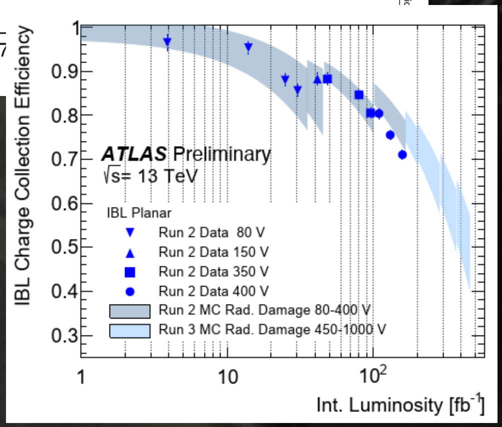
ATLAS Pixel

Kerstin Lantzsch

- Excellent performance in Run 2, thanks to optimization of operational parameters and recovery routines.
- Replacement of on-detector electro-optical transceivers (optoboards) and sealing against humidity during Long Shutdown 2 → No new failures!







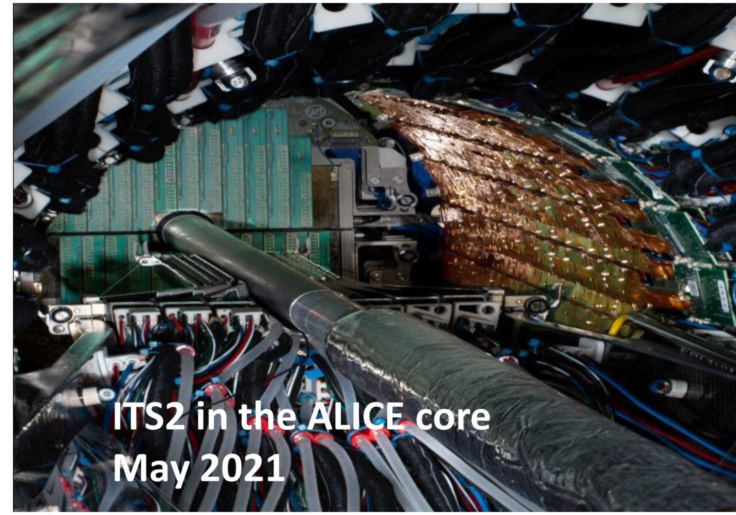
- Start of Run 3: recover performance of Run 2 with ~similar but more challenging conditions.
- Main focus for Run 3 will be the Radiation Damage.
  - Optimize parameters (threshold, HV, temperature)
  - Describe and predict effects to take them into account in data reconstruction (new "radiation damage digitizer" standard now for Monte Carlo).

Commissioning and performance in Run 3 of ALICE ITS2

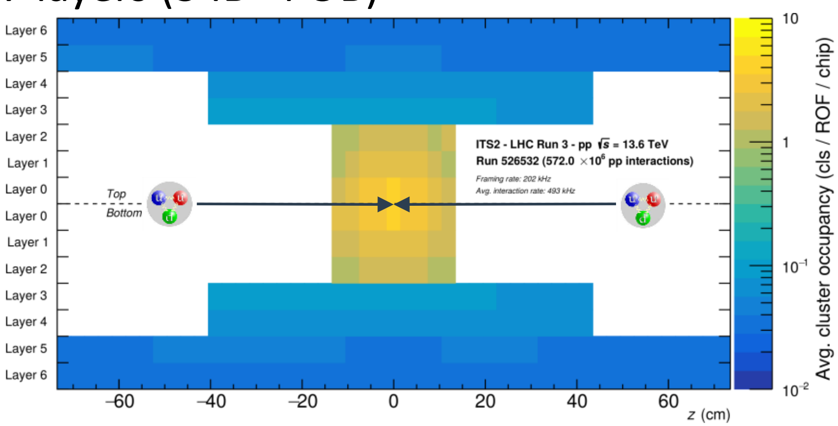
→ *Highlights*

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

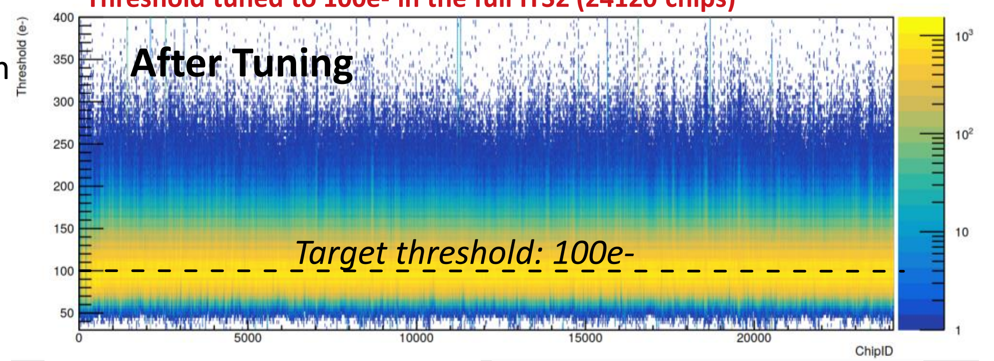


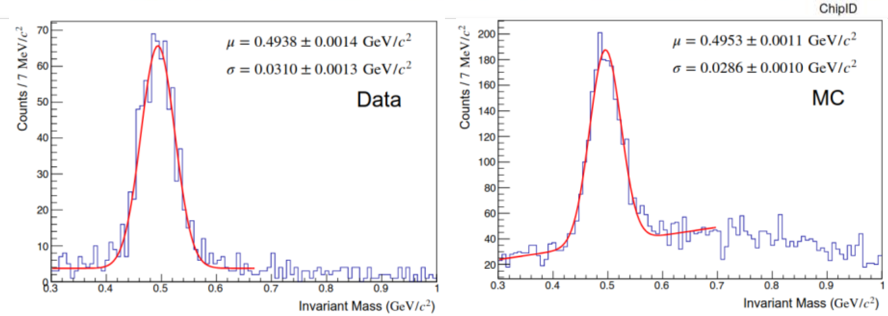
7 layers (3 IB+4 OB)



Average #clusters / chip / ReadOutFrame in the full detector

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





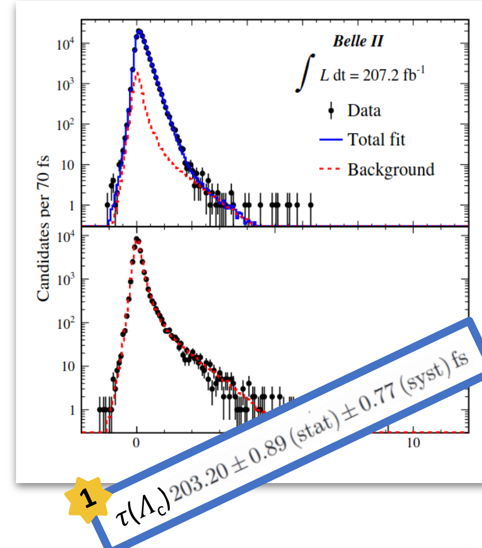
K^0_S invariant mass: ITS stand-alone tracking (δmean=a few/mile)

Belle II PXD Status 2022

Arthur Bolz

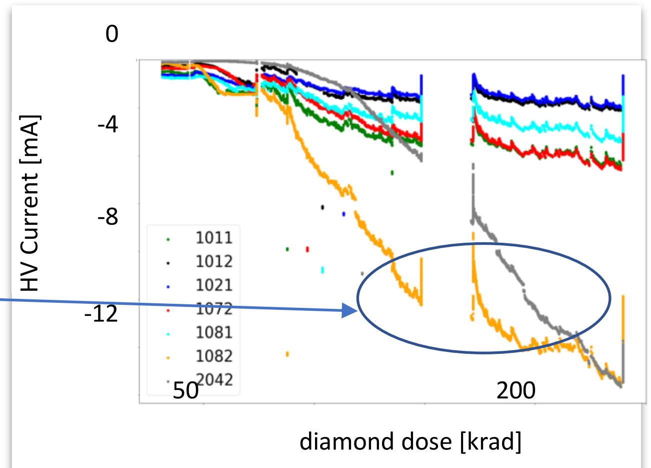
The exciting

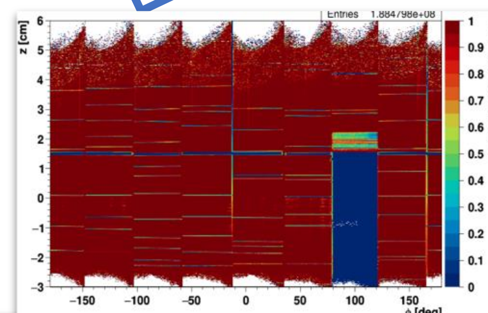
- PXD has been performing very well and stably 2019-2022
- good performance increasingly ending up in physics publications
- eg charmed meson lifetime measurements with world-leading precision



The interesting

- irradiation and detector aging studied in greater detail
- mystery of rising hv currents finally understood: unexpected shorts in guard ring structures



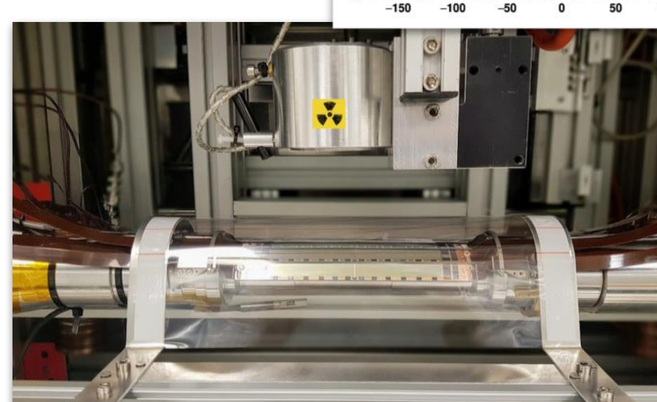


The worrying

- great improvements to SuperKEKB operation and beam monitoring, as well as measures to protect PXD
- nonetheless uncontrolled beam losses have damaged PXD and remain a great risk

The outlook

- complete PXD2 has been produced
- installation foreseen for spring 2023 (some challenges in ongoing pre-commissioning still to be overcome)

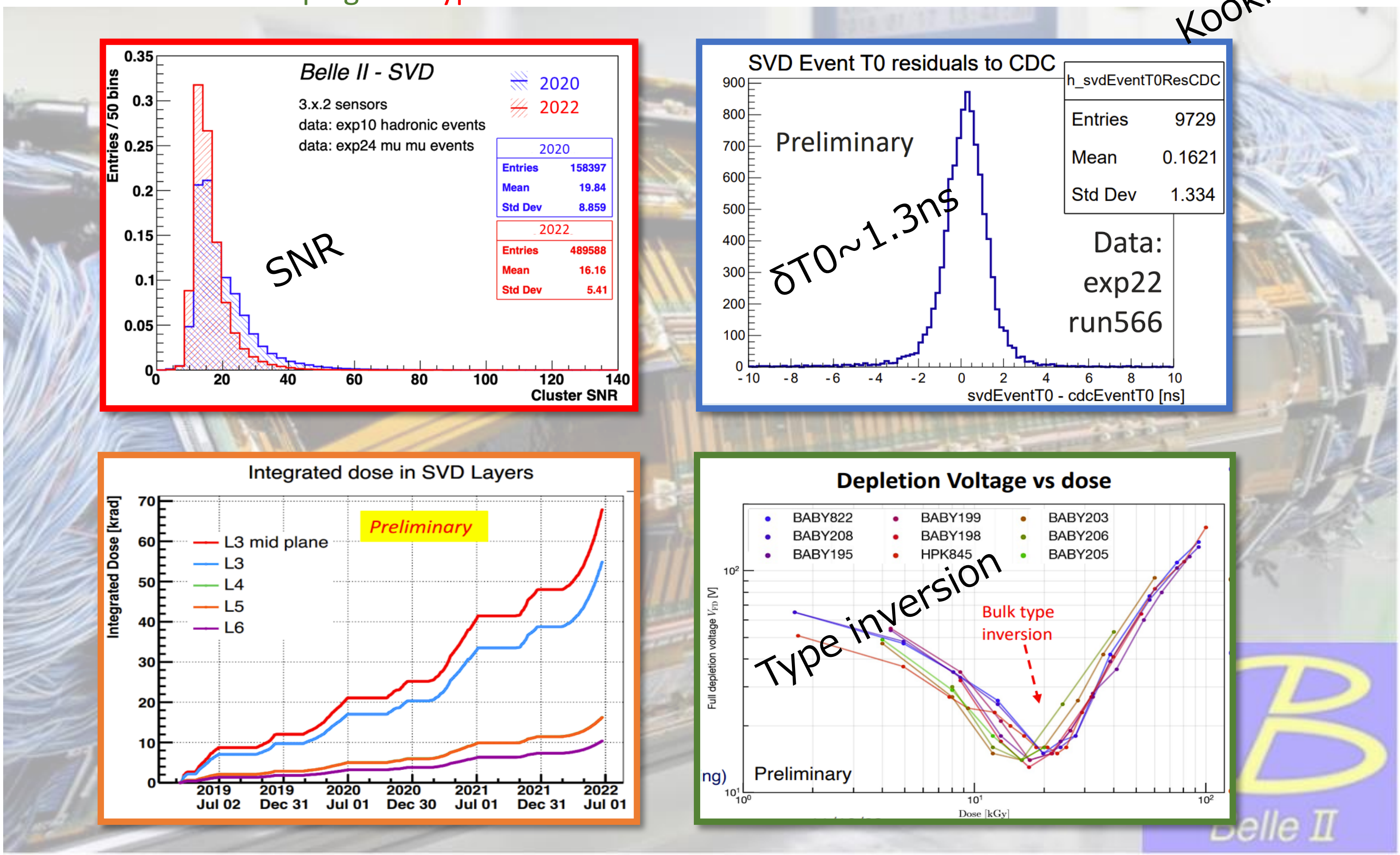


The **Silicon Vertex Detector(SVD) of the Belle II Experiment**

has been in operation providing high quality data since March 2019

- SVD operated smoothly and reliably with an excellent performance w.r.t SNR, - efficiency, position resolution, hit time resolution, and event T0 resolution
- Observed first effects of radiation damage (~70 krad for L3), not affecting performance
- Irradiation campaign → Type inversion confirmed between 1.5 – 2 Mrad

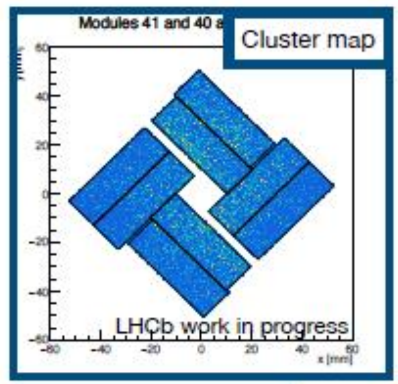
Kookhyun Kang

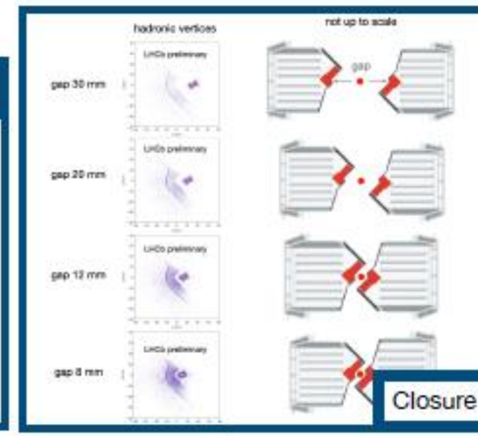


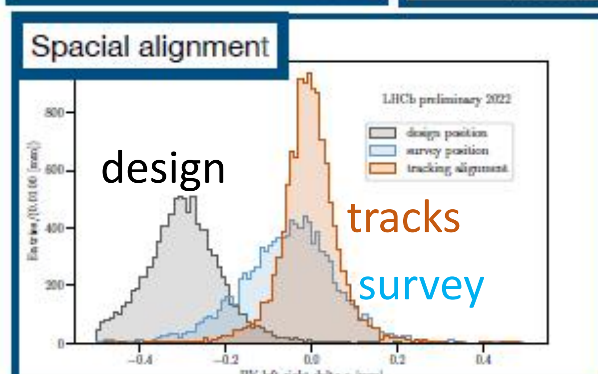
The LHCb Vertex Locator in Upgrade I

- **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



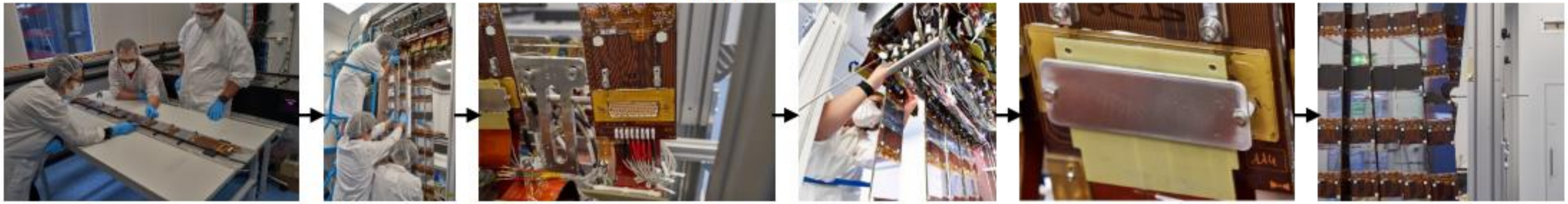




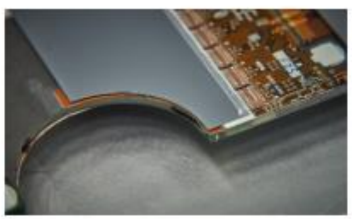
LHCb Upstream Tracker

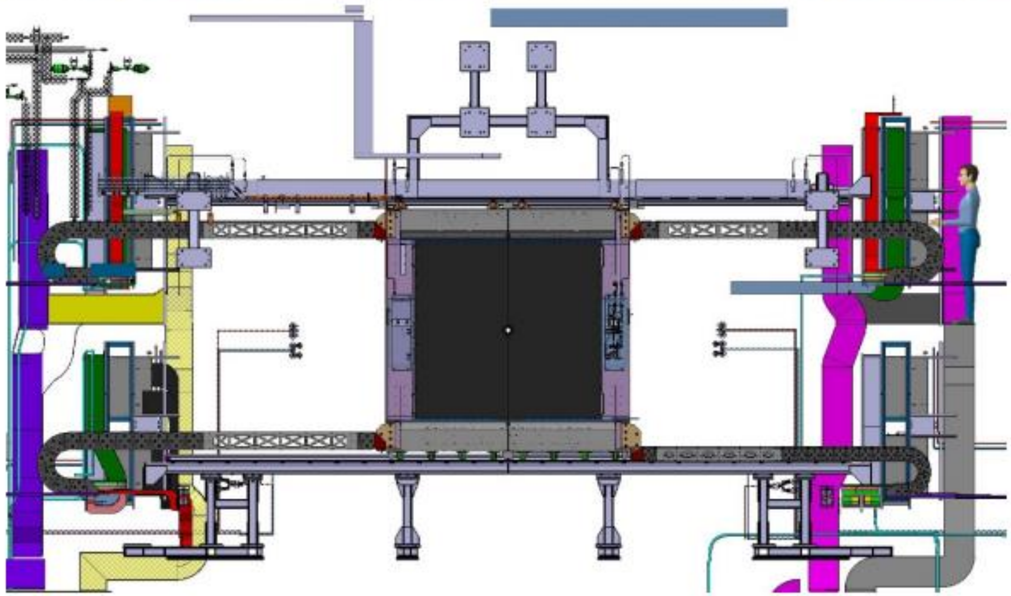
Upstream Tracker Upgrade
D. Andreou

Stave installation



Modules

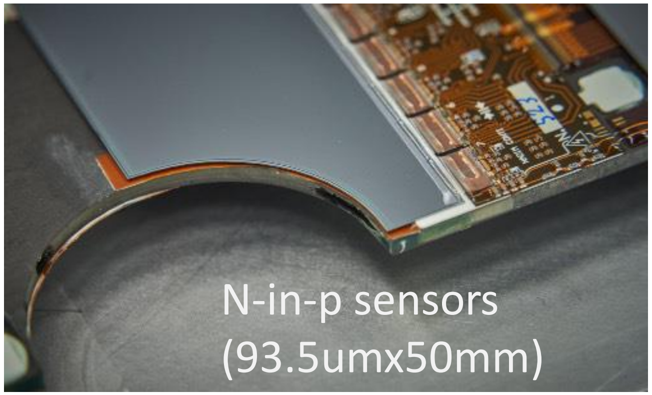


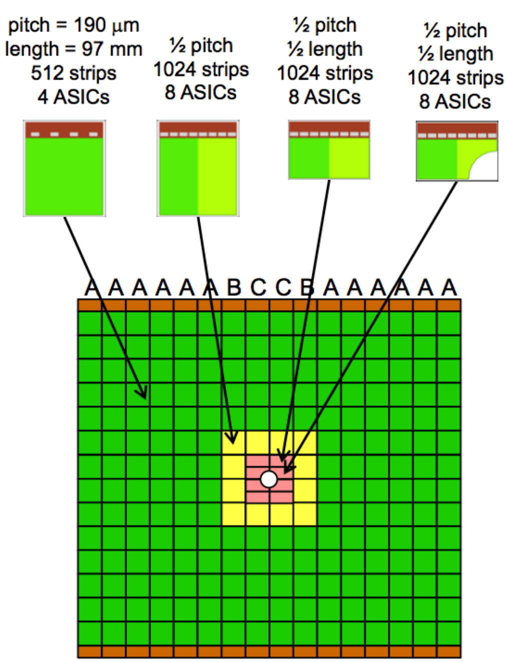


C-side

Integration

LHCb New Upstream Tracker dimitra

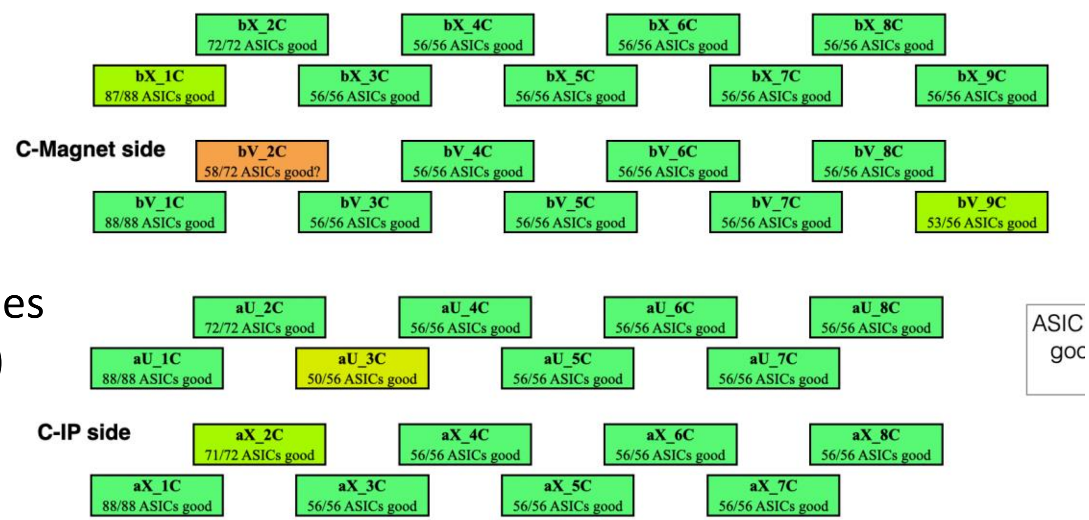




X 4 planes
(X,Y,U,V)

assembly challenges!

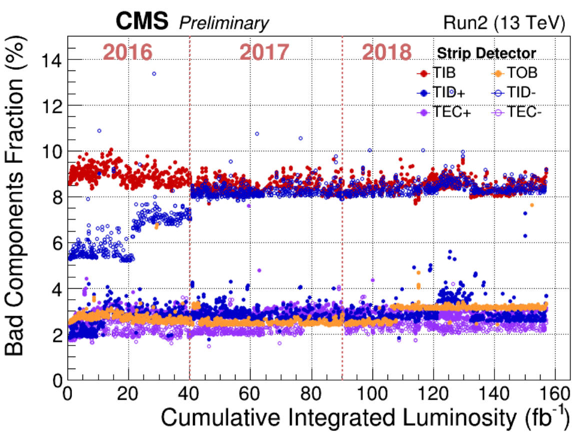
C-side stave installation completed

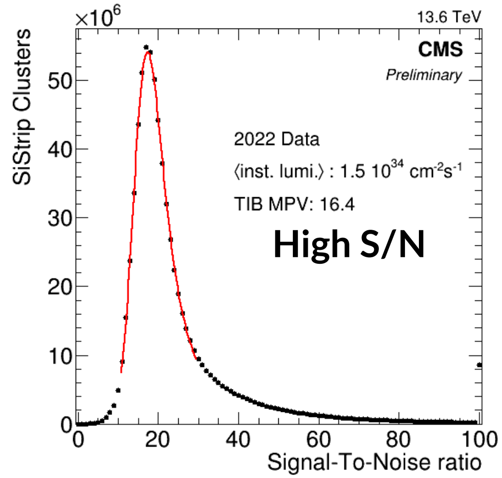


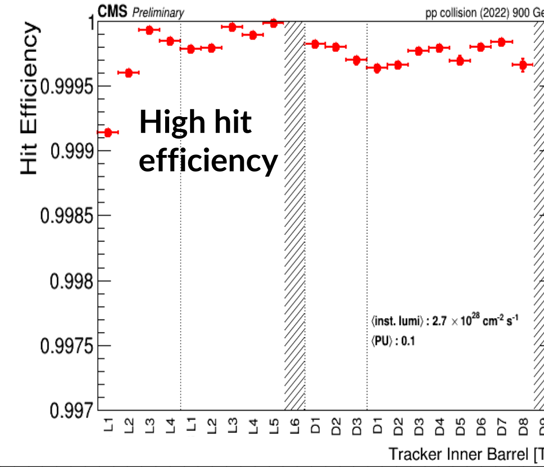
A-side stave installation (in progress)

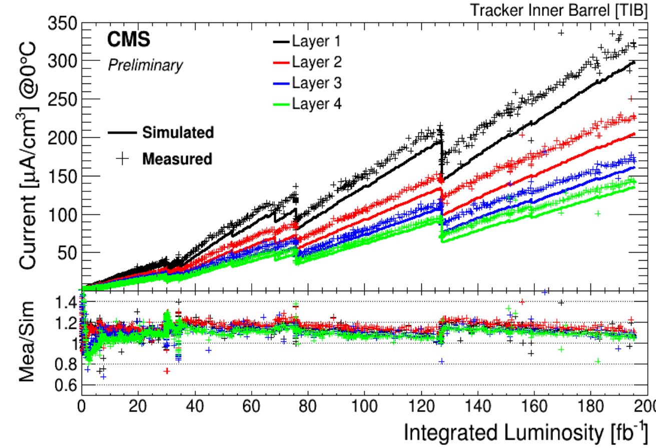
Suvankar

Status of the CMS Silicon Strip Tracker









- The CMS Silicon Strip Tracker operational and performing well after ~ 12 years of operation.
- Performance at Run 3 startup is satisfactory.
- Fraction of active channels ~ 96 %
- High S/N, stable on track cluster charge, excellent single hit efficiency and resolution even in high PU
- Excellent tracking efficiency in Run 2 and also during Run 3 startup.
- Effect of radiation visible.
  - Leakage current, Depletion voltages are monitored.
  - Simulation in place to model the behaviour of the detector with increased radiation.

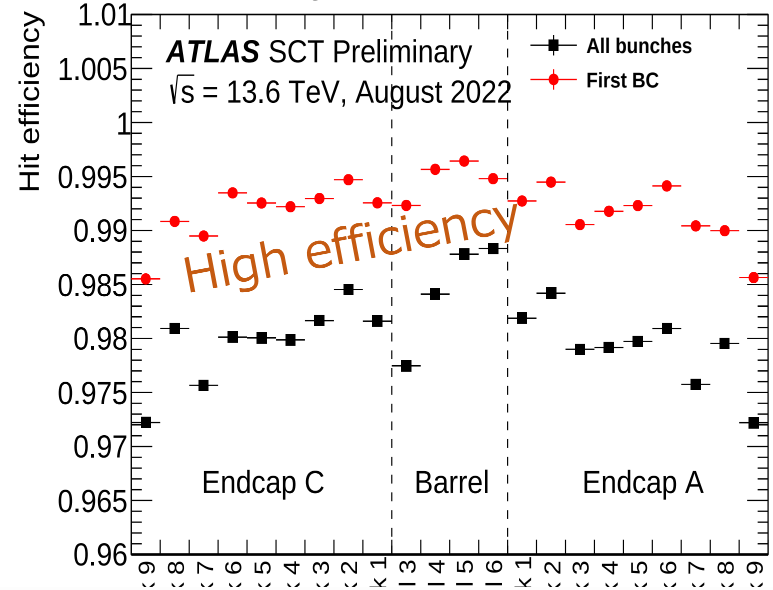
14

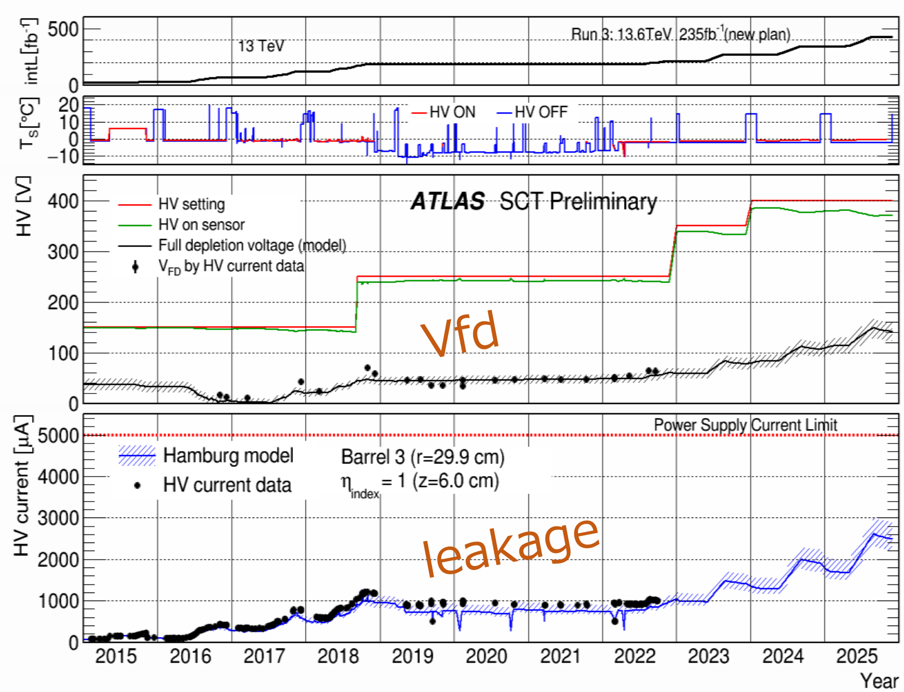
Leakage agree with sim <10%

ATLAS SCT detector in Run 2, LS2 and early Run 3

Hanna Maria Borecka-Bielska

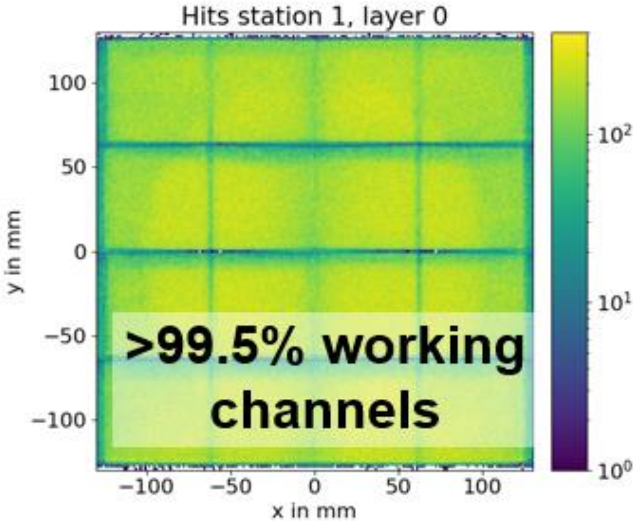
- SCT detector is in a very good shape after almost 13 years of operations with **98.3%** of strips still active
- We had an excellent start of Run 3 and we continue to take data with a very high efficiency (mostly **above 0.99**)
- We ensure high data taking efficiency and monitoring of radiation damage by performing regular routine calibrations and special scans
- Measured values of the leakage current and full depletion voltage in SCT sensors agree well with model predictions and we are confident **SCT will run stably until the end of Run 3**

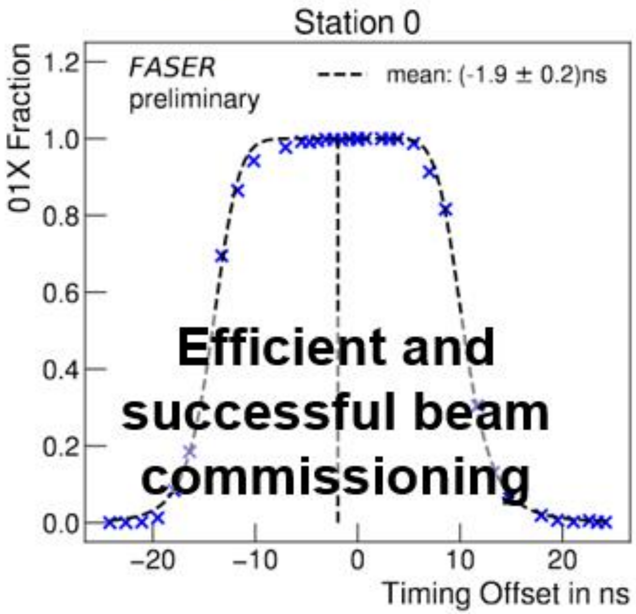


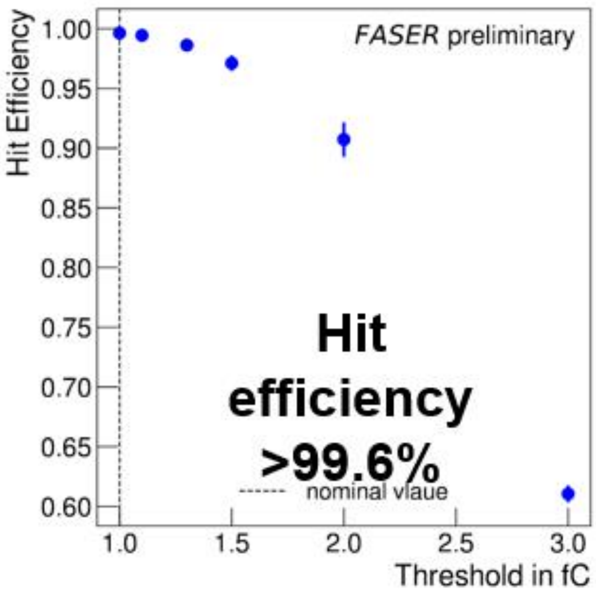


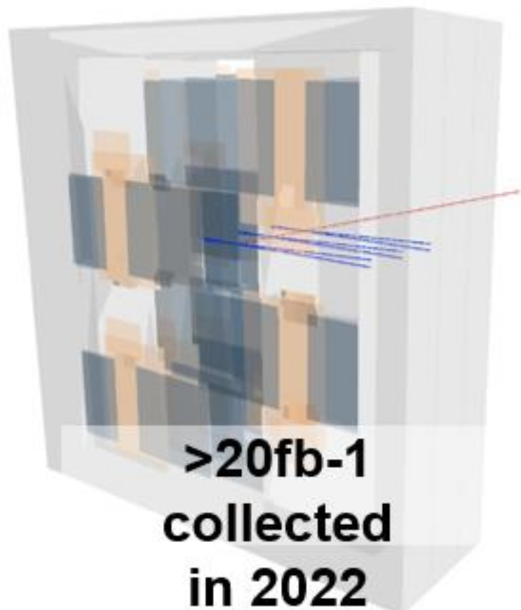
FASER Tracker Highlight VERTEX 2022

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





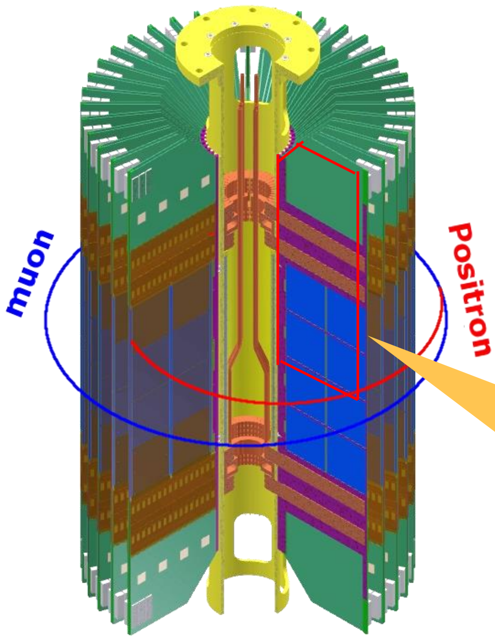




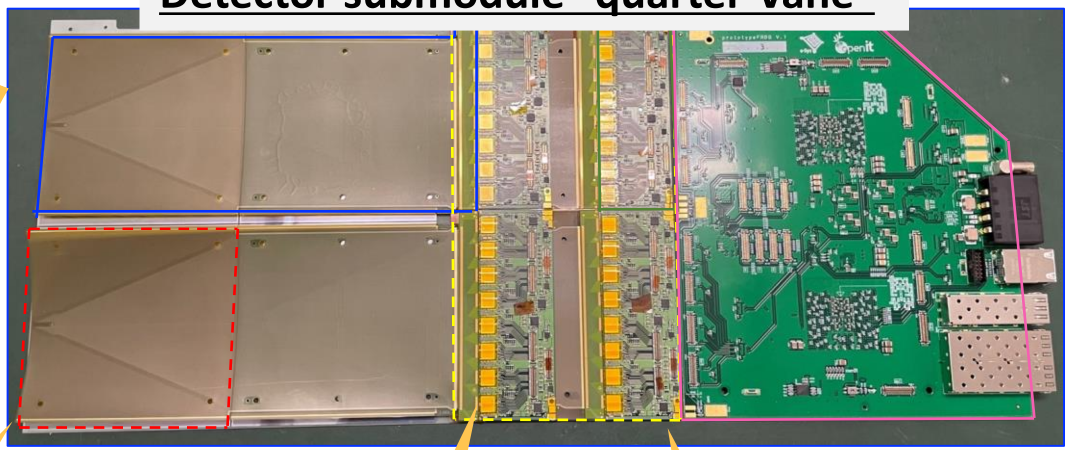
Silicon strip positron detector for J-PARC muon g-2/EDM experiment

Prototyping of submodule is ongoing towards detector assembly from JFY 2024.

Shinji Ogawa



Detector submodule "quarter-vane"



Silicon sensor
Precise sensor alignment for EDM measurement. **Precision of 2 um** is already achieved.

Frontend ASIC
Mass production completed. **Quality assurance** has started.

Cooling system
Assembly procedure to **control adhesive thickness** has been established.

Sorry for wrong category – K.H.
…but not an upgrade, R&D?, future?

Upgrade

Giacomo
Fabio
Mei
Mauro
Toru
Zihan

Helen
Benedikt
Stefania
Christoph
Shigeki

Francesca
Lukas
Ryu

The CMS Pixel Detector for the High Luminosity LHC

[Giacomo Sguazzoni]

CMS Inner Tracker for HL-LHC

~4.9m^2 Pixel Silicon Sensors

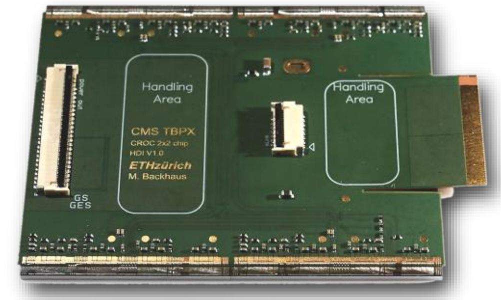
~2B 25x100μm^2 pixels

~4'000 Modules

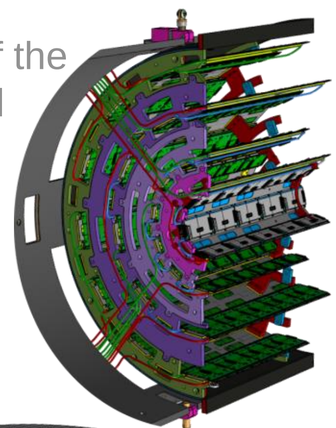
750kHz readout rate (on L1 accept)

~50kW power budget

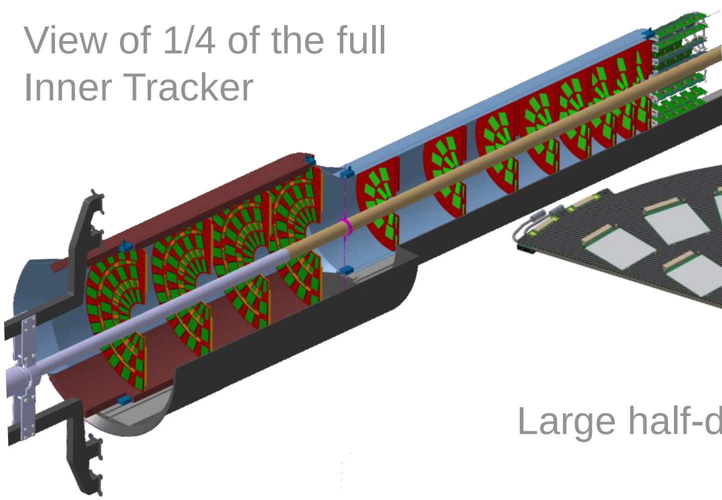
Small half-disk



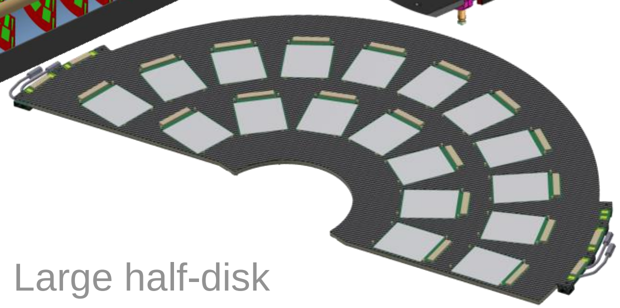
Final-size module prototype



1/4 of the barrel



View of 1/4 of the full Inner Tracker

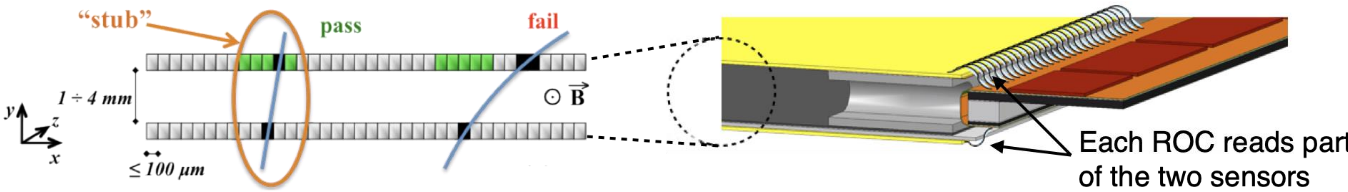


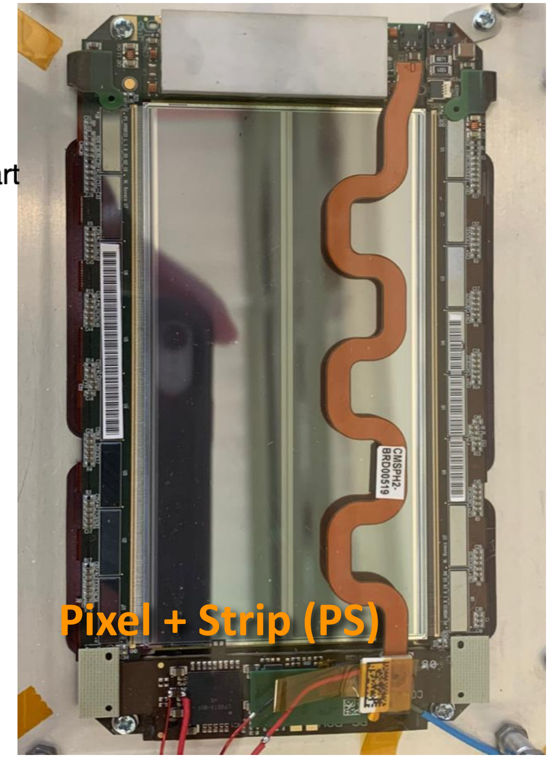
Large half-disk

- Key features
  - compliant w/ HL-LHC running conditions (high rate, granular, radiation hard)
  - fully maintainable
  - reduced material budget
  - contributes to luminosity measurements
- Key frontier technologies
  - Planar & 3D rad-hard pixel sensors
  - 65nm high-rate ROC (C-ROC)
  - Serial Powering & CO2 cooling

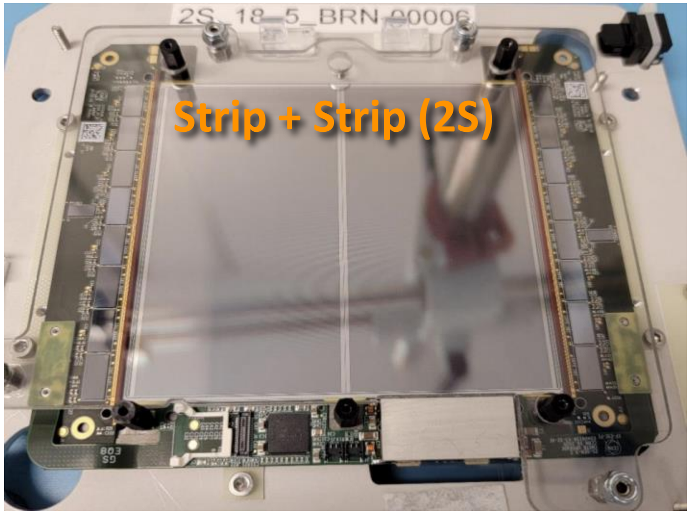
The design is finalized or close to finalization in all the main areas (modules, electronics, mechanics, cooling) •Production and detector integration is ahead of us

The CMS Outer Tracker for the High Luminosity LHC





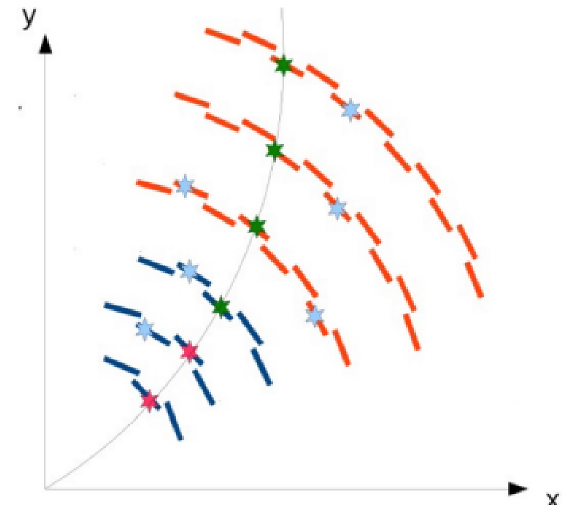
- The new Outer Tracker will be equipped with the pT-modules
  - Will allow running the particle flow at 40 MHz
  - Two types of pT-modules: 2S and PS
- Module production centers are getting ready
  - Assembly and QA procedures are being finalized
  - Several prototypes successfully assembled and qualified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



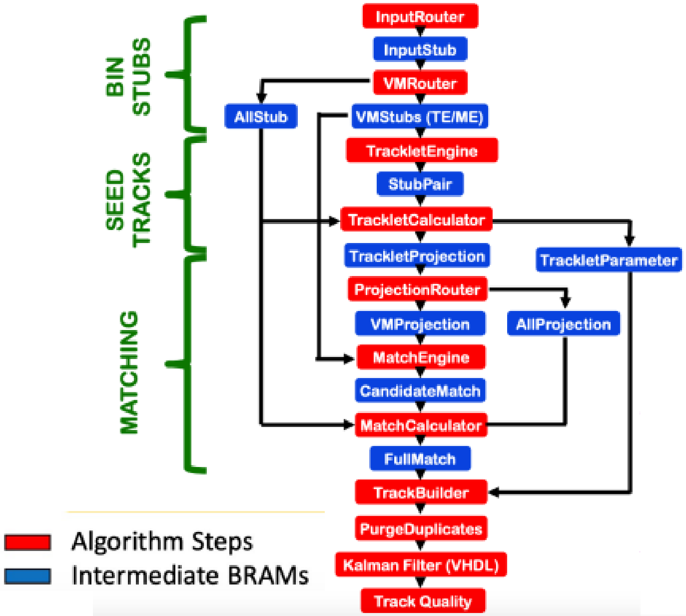
MEI-LI HOLMBERG

LEVEL-1 TRACK FINDER

for the CMS HL-LHC upgrade



- L1 Track Finding at CMS is necessary to reduce the L1 trigger rate to an acceptable level at HL-LHC
  - Reconstruct tracks with $p_T > 2$ GeV at 40 MHz
  - Performed in under 4 μs
  - Data from Outer Tracker
- Track Finder is implemented on FPGAs
  - Algorithm is split into multiple modules
  - All modules have been implemented in firmware
- Partial algorithm chains have been implemented
  - Small "skinny" chain runs on hardware
  - Larger "barrel-only" chain is ongoing work
- Scale up to the full project in the future



Characterisation of 3D pixel sensors for the CMS upgrade at the High Luminosity LHC

Silcon 3D pixels made by ***FBK*** (Italy) and ***CNM*** (Spain)

Column diameter ~5 µm

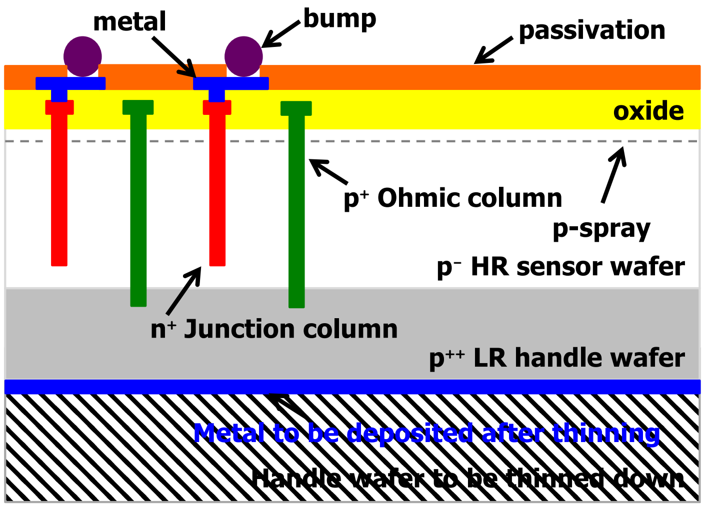
High Resistivity layer

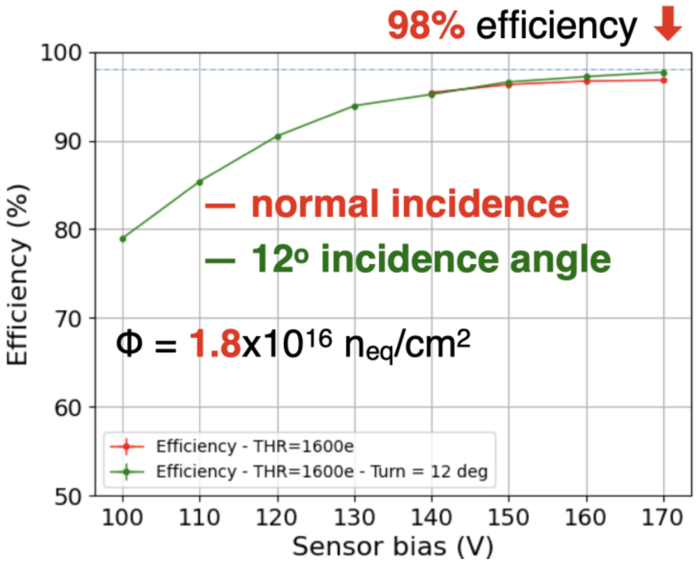
- Active layer thickness ~150 µm
- Resistivity > 3 kOhm•cm

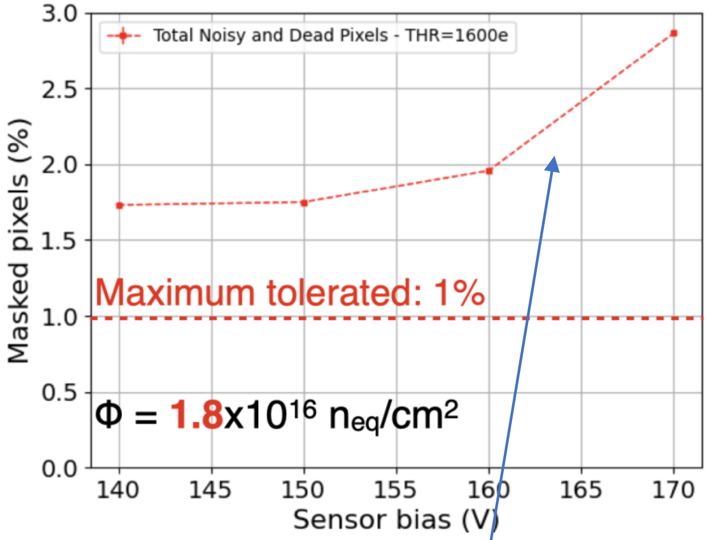
Low Resistivity layer

- Resistivity 0.1-1 Ohm•cm
- Residual wafer thickness after thinning 50-100 µm

Mauro Dinardo



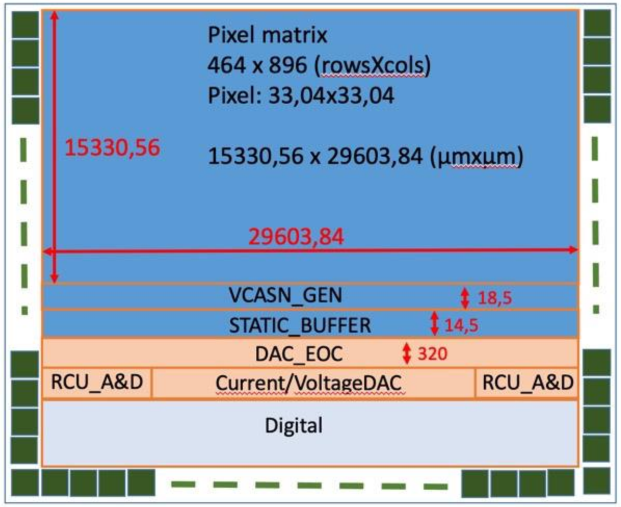




- 3D pixels baseline choice for barrel layer 1
- CMS baseline: replace pixel layer closer to beamline at integrated fluence ~1.9×10^{16} n_{eq}/cm^2
- Tested at different fluencies
- Overall performances extremely encouraging
- Large increase of noisy pixels vs bias at fluences >1.5×10^{16} n_{eq}/cm^2 under investigation

Belle-2 Upgrade scheduled 2027-2028

Toru Tsuboyama

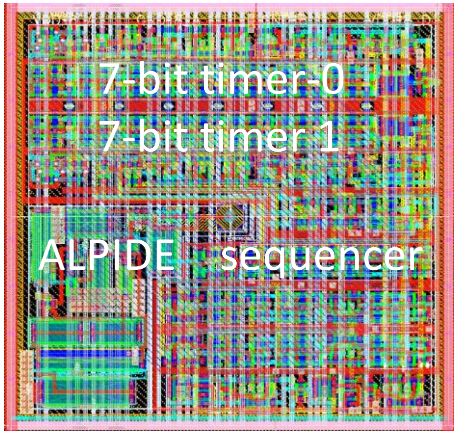


DMAPS OBELIX: Optimized BELle II pIXel sensor

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

SOI DuTip: Dual Timer Pixel

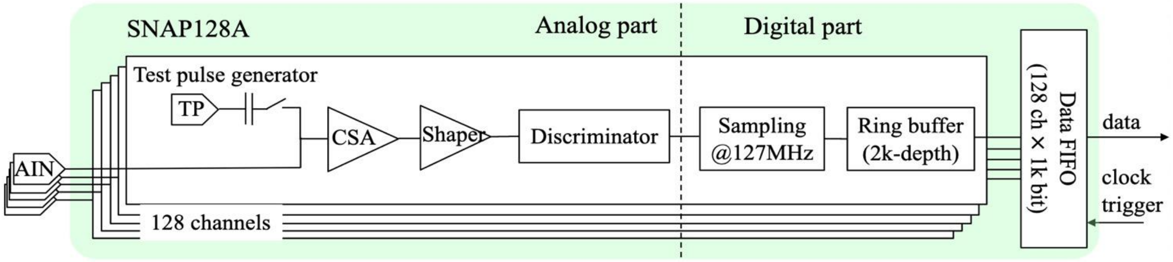
- ALPIDE type frontend (modified for faster response)
- Lapis 200nm
- Seemless readout
- Innermost layer



45x45 µm pixel

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

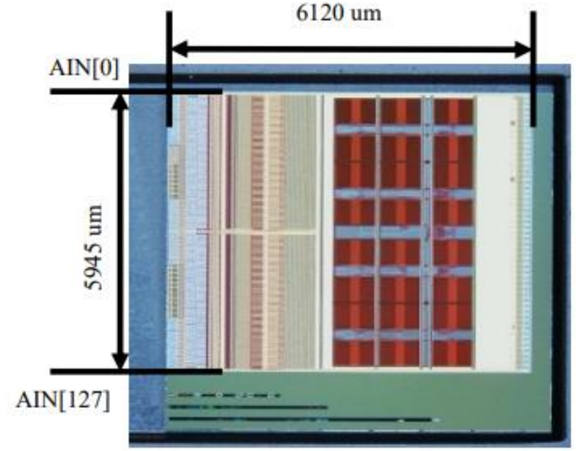
- 150 um thick DSSD (prototype@Micron)
- Binary readout SNAP128A (pipeline~8us)



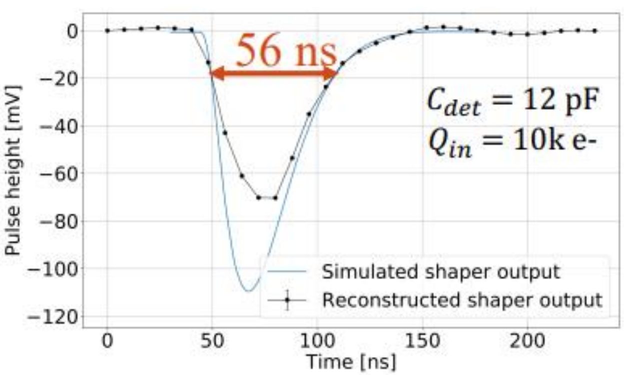
TFP-SVD project for Belle II VXD upgrade

thin and fine pitch silicon strip vertex detector

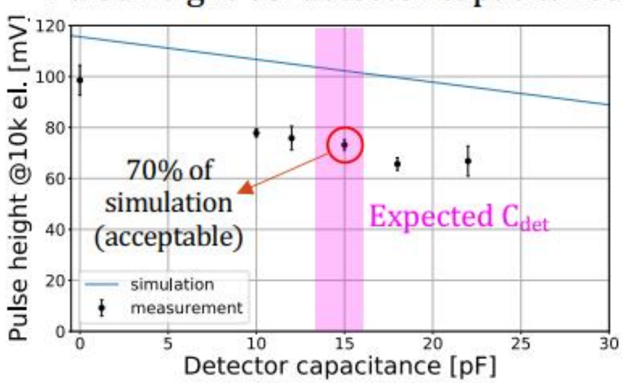
- Prototype ASIC (SNAP128A) tested
- Pulse width meets design requirement
- Next prototype will be submitted in December
  - Hoping to solve the large noise and positive signal saturation problems



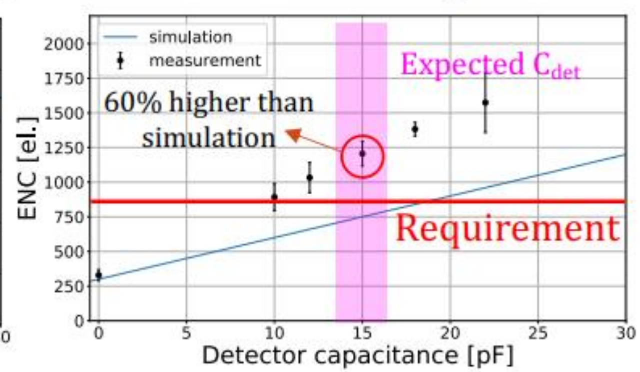
Prototype front-end ASIC (SNAP128A)



Pulse height VS. detector capacitance



Noise VS. detector capacitance



ITk Pixel Detector

Helen

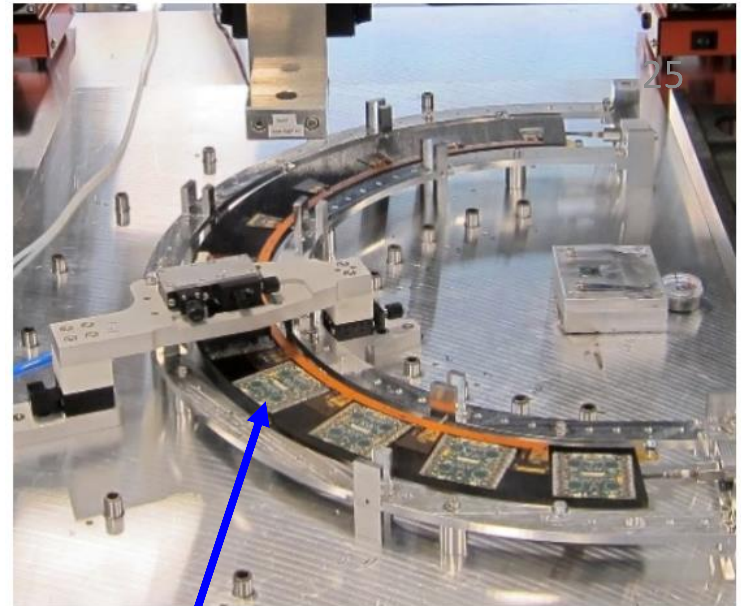
163 RD53A Quads have been assembled and QC/tested in 20 assembly sites.

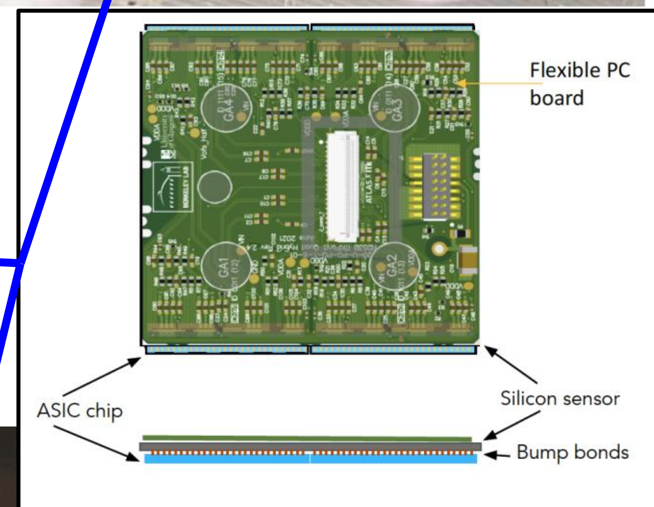
3 prototype loaded-local supports

- Serial powering tests ongoing

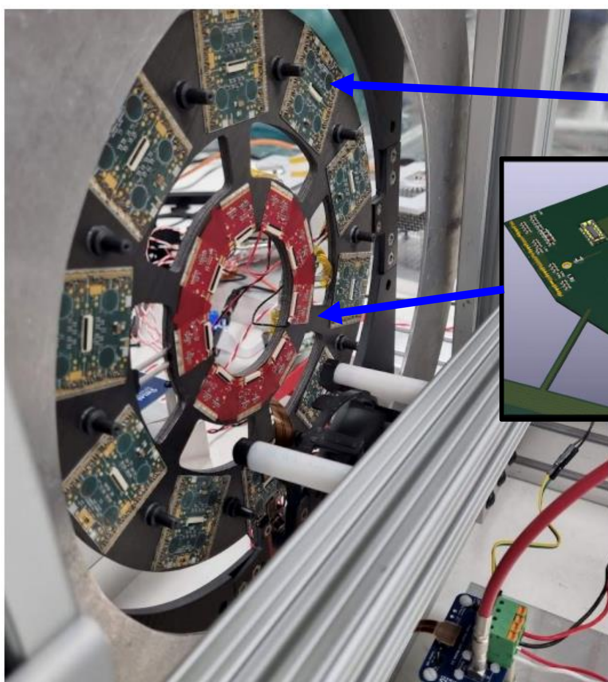
Vital prototyping step to evaluate loading, electrical and mechanical functionality and robustness

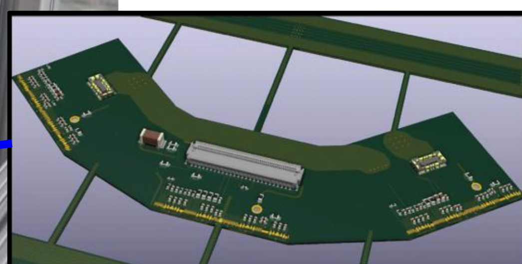
irradiated RD53A module has 99% hit efficiency at 600 V



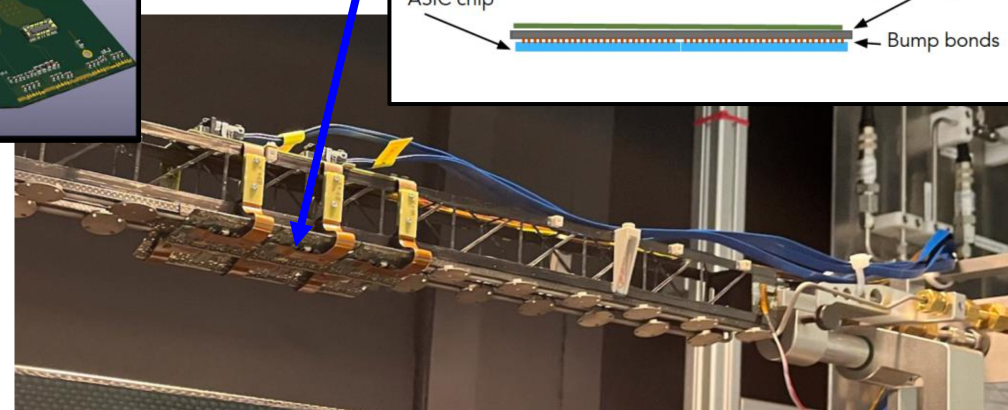


Planar quad module



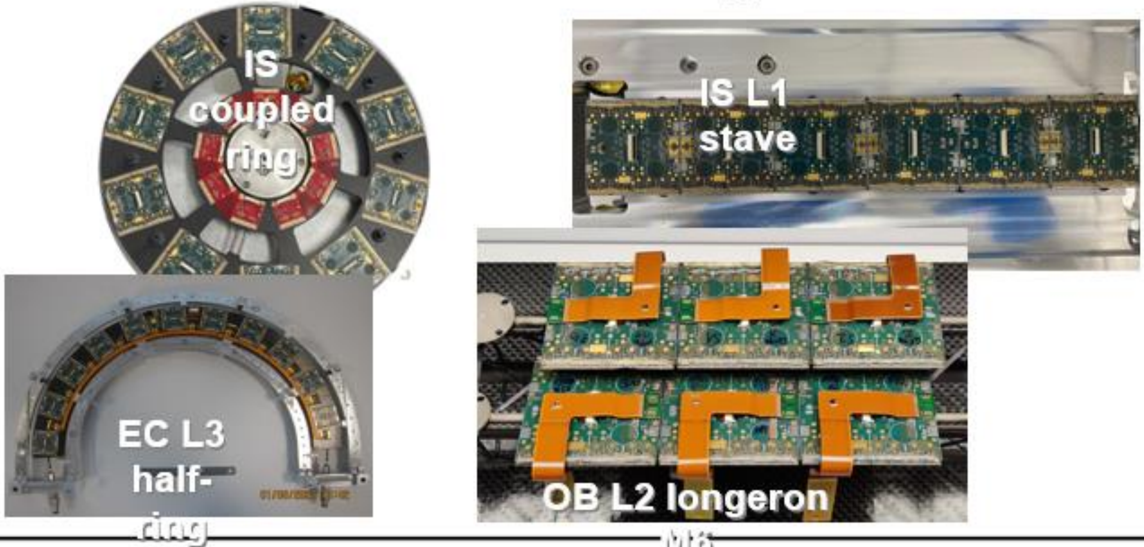


Triplet of 3D modules

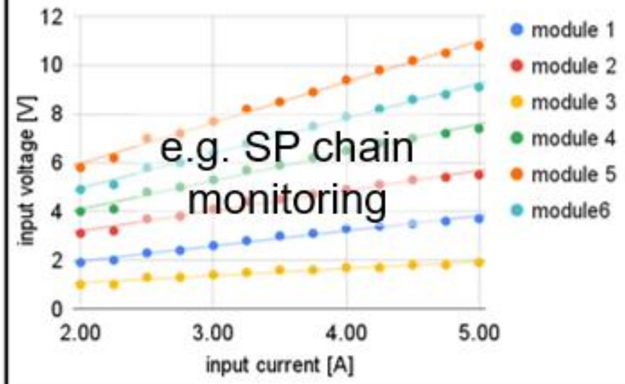


ITk Pixel LLS Highlight VERTEX 2022

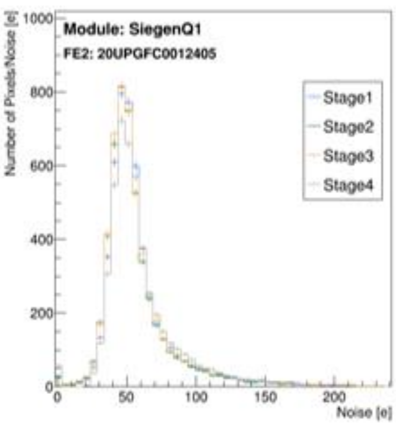
Different flavors of loaded local support demonstrators

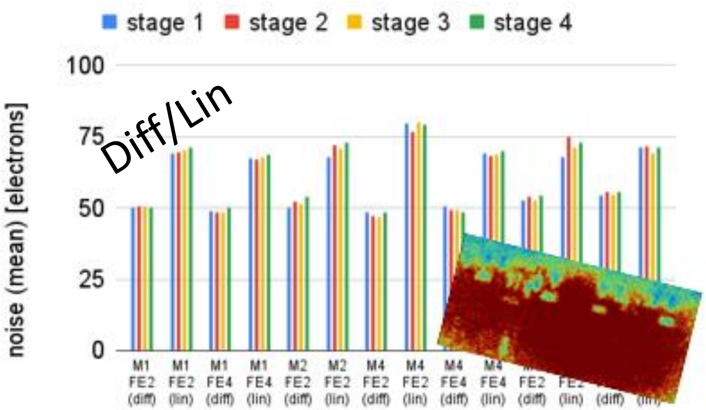


Validation of system level concepts



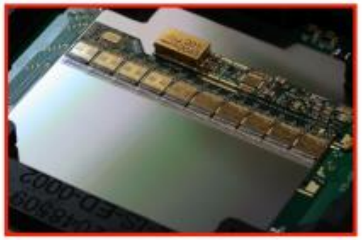
Validation of electrical performance after loading





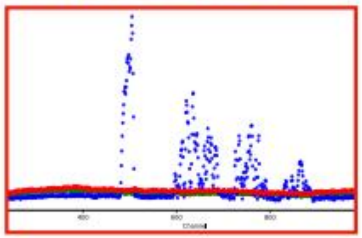
Development towards detector operation

Highlight



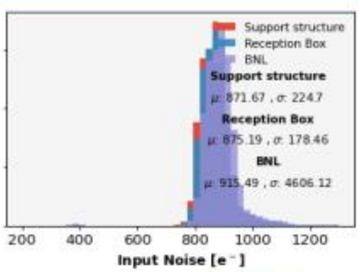
ITk Strip project deep into preproduction and starting production in some areas

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

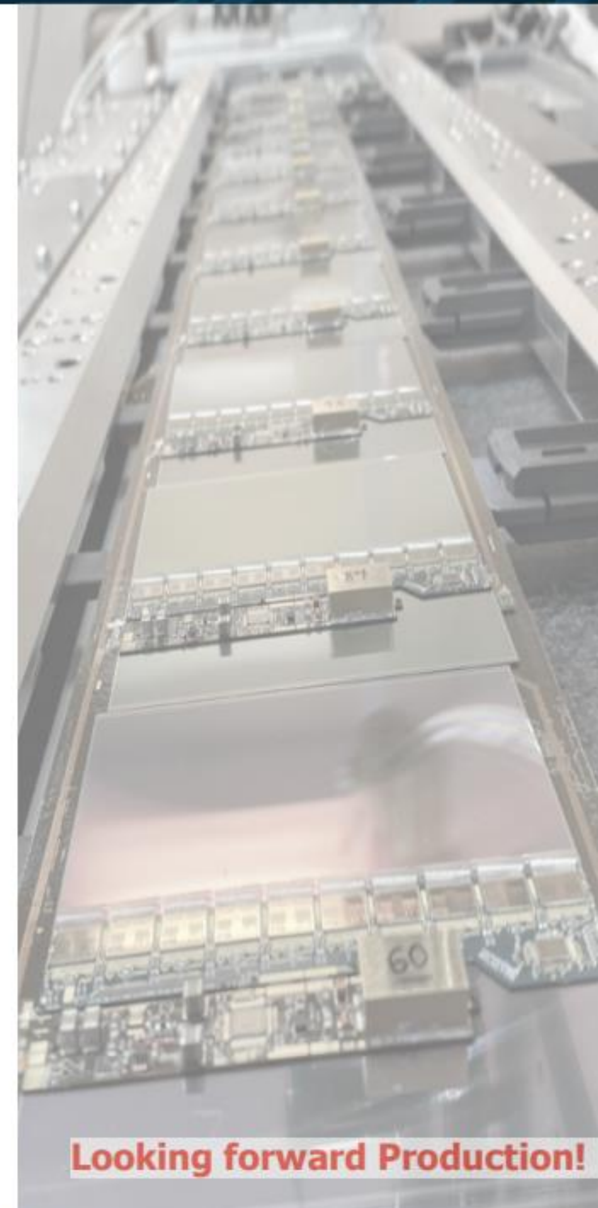


Unexpected 'cold noise' effect found during module testing. Experts are working to understand the source while mitigations are under study

Extensive test campaign over first pre-productions staves



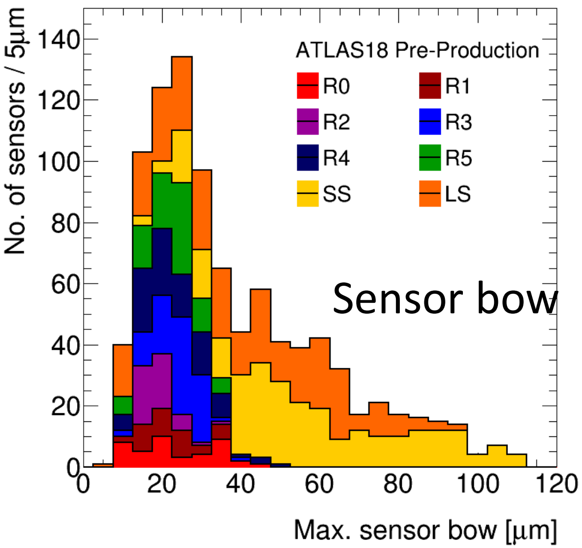
System tests and completing module pre-production are high priority

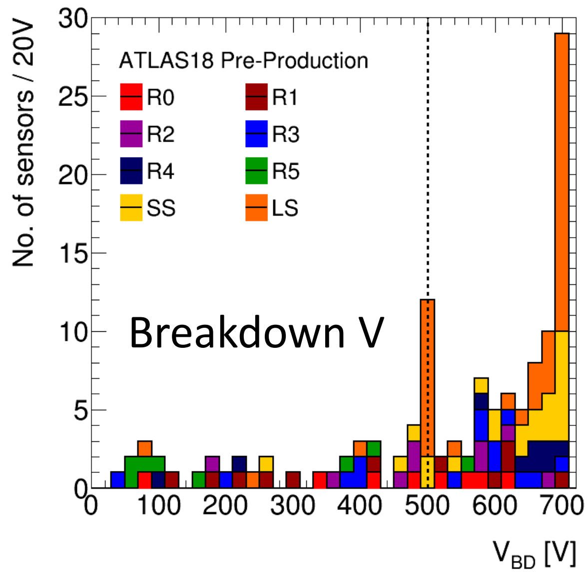


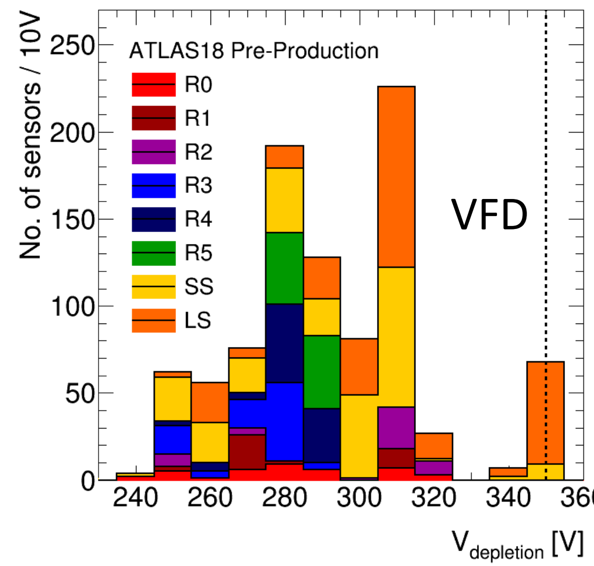
ATLAS Itk strip sensor QC

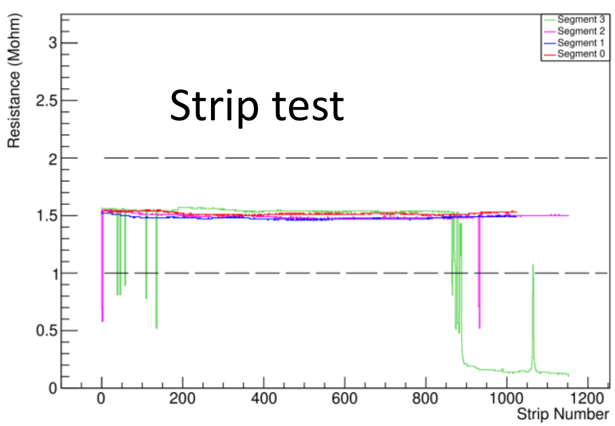
christoph

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





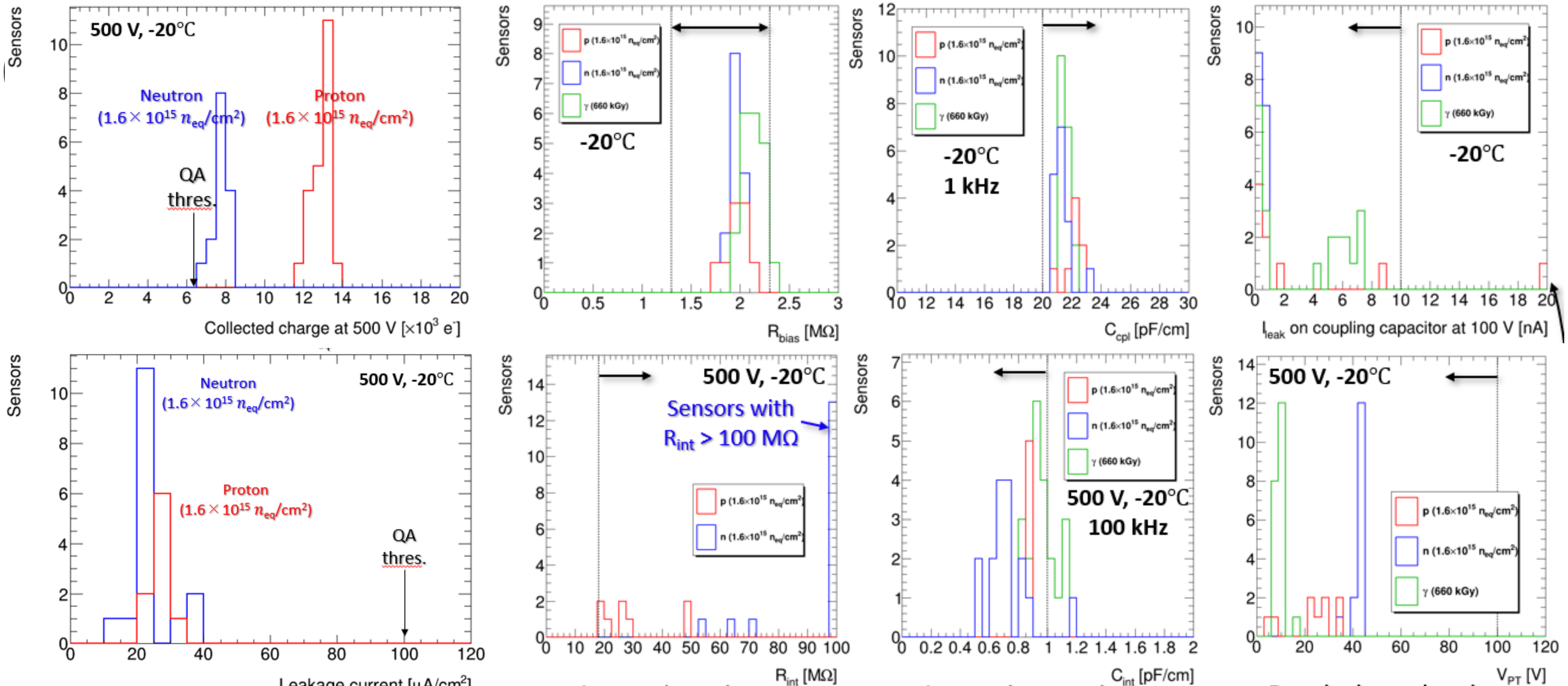




Strip test: each by HPK and samplings by Institutes

- 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

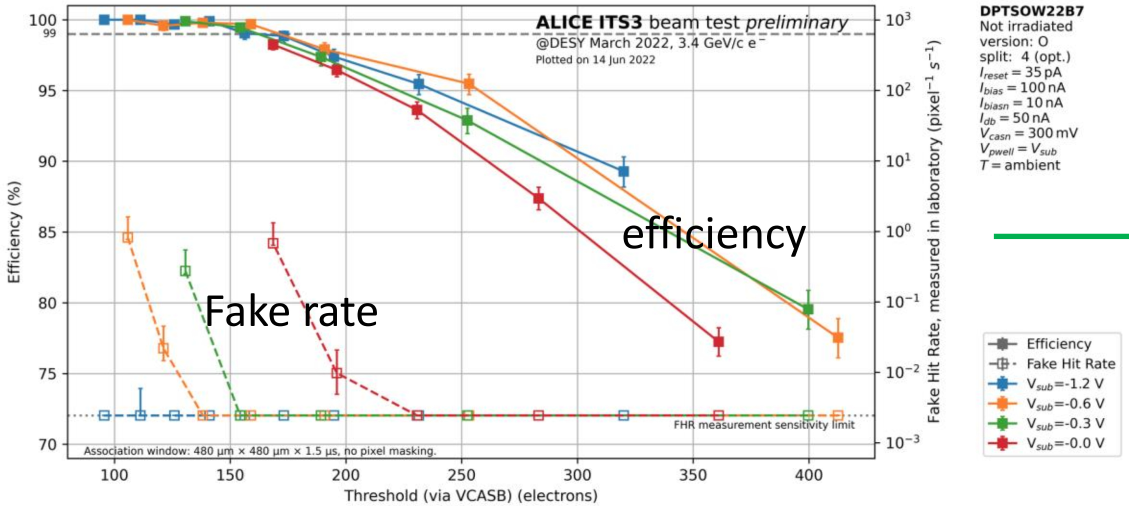
Francesca Carnesecchi

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

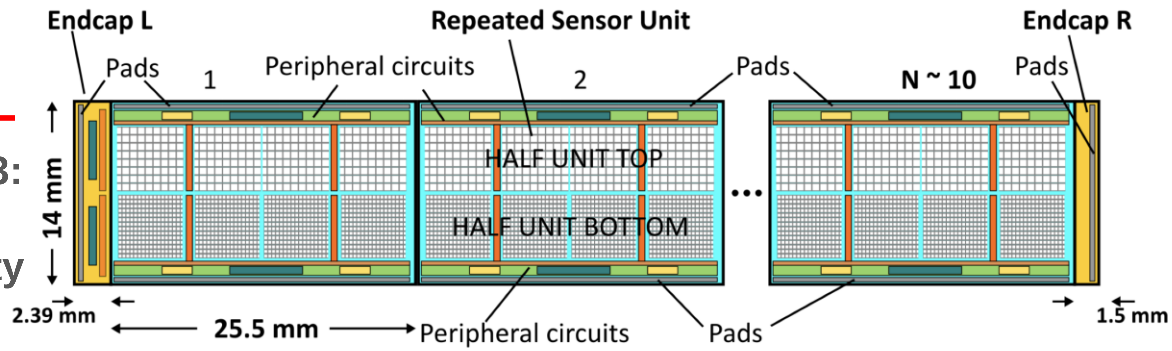


Sensor design validated

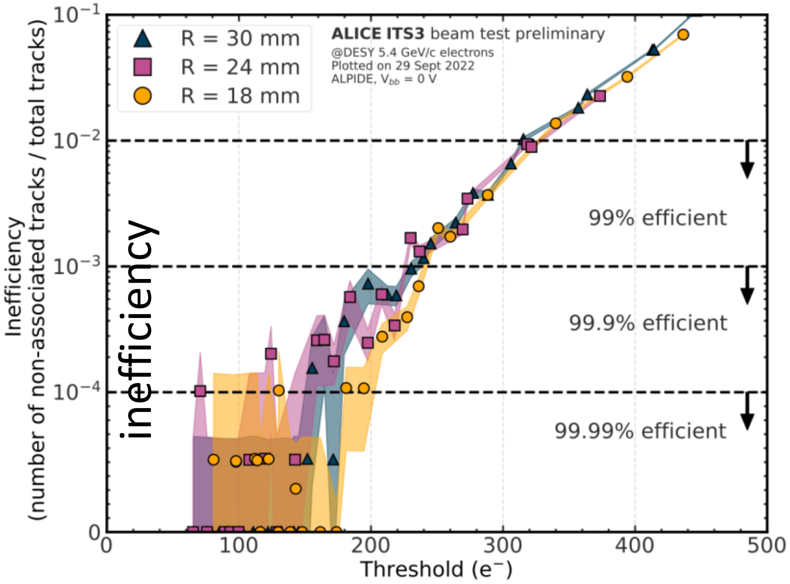
Improved charge collection efficiency with new design, 100% detection efficiency reached and radiation hardness higher than one needed from ALICE (10^{13} n_{eq}/cm^2)

Next step: stitching

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

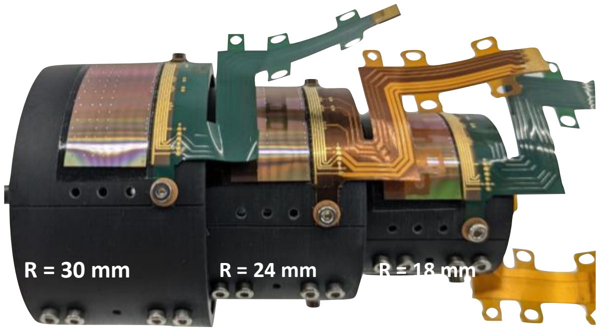


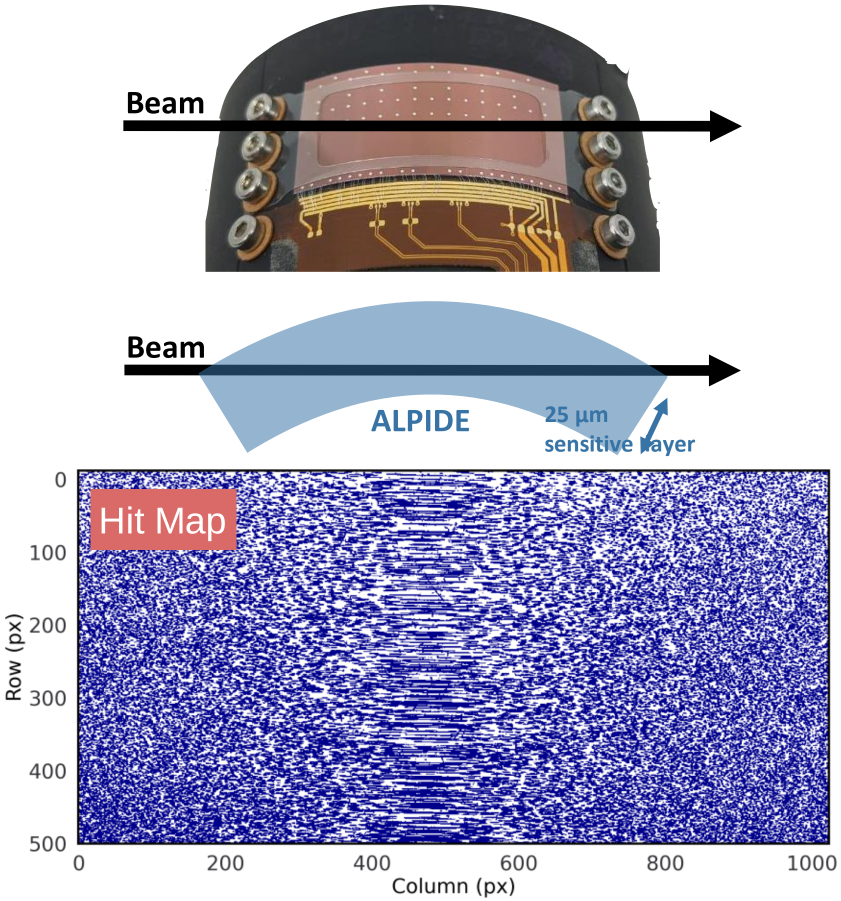
Beam test studies of bent MAPS for ALICE ITS3



Beam test studies of bent ALPIDE

- Spatial resolution and efficiency **independent** of bending radius
- Performance consistent with flat ALPIDEs





Long, continuous in-sensor tracks

- Grazing beam geometry
- Single particle tracks **>3 mm** in sensor

Lukas Lautner

LHCb MT HV-MAPS (MightyPix) R&D activities

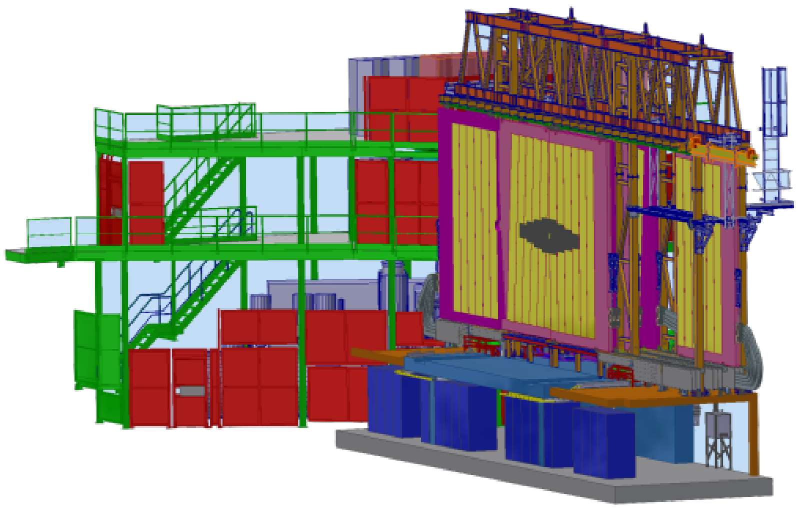
- DESY Testbeam results with ATLASPix3.1 show
  - a high total efficiency ($> 99\%$) for the lowest thresholds.
  - a time resolution down to ≈ 5 ns (lowest thresholds).
  - Noise estimate below ≈ 1.25 Hz after ≈ 130 DAC ($< 10^{14}\ \mathrm{n_{eq}cm^{-2}}$).
  - We hope for a timing performance closer to our target requirements with the MightyPix1.
  - The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

3ns goal

<5Hz 6E14 goal

Active area=3m^2/layer

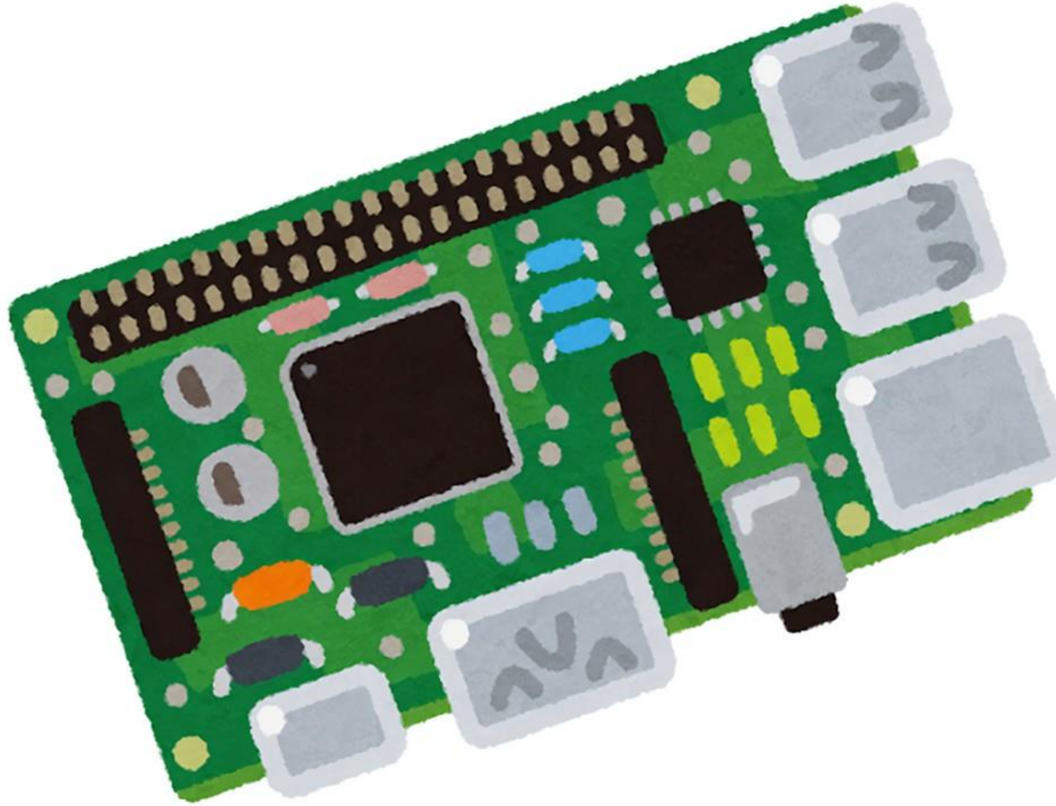
- Much experience gained along the way, in testbeam, lab setups, and analysis.
- MightyPix1 submitted and on the way, with more testbeams planned.



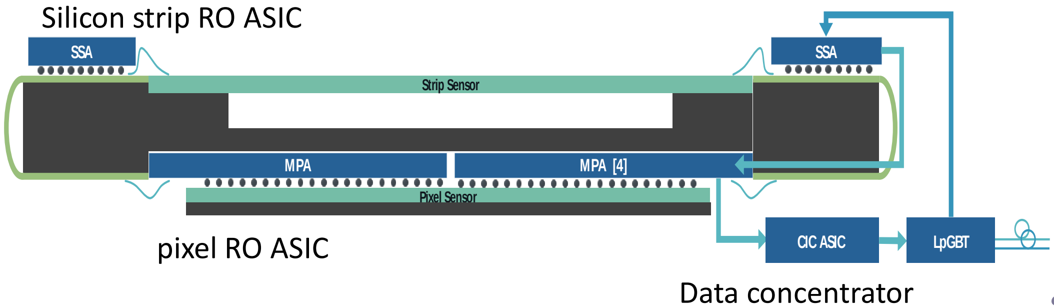
ASIC

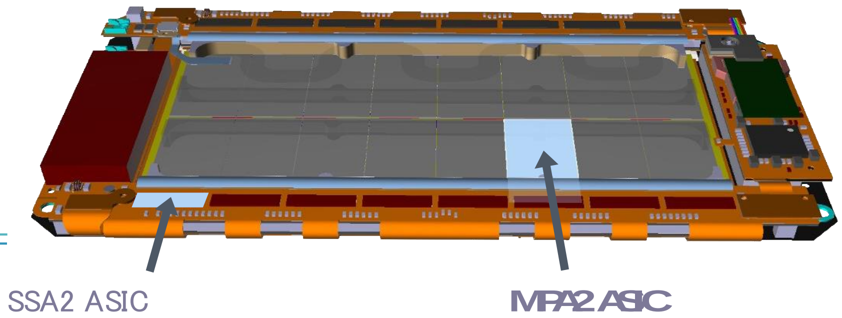
AlessandroCaratelli

John



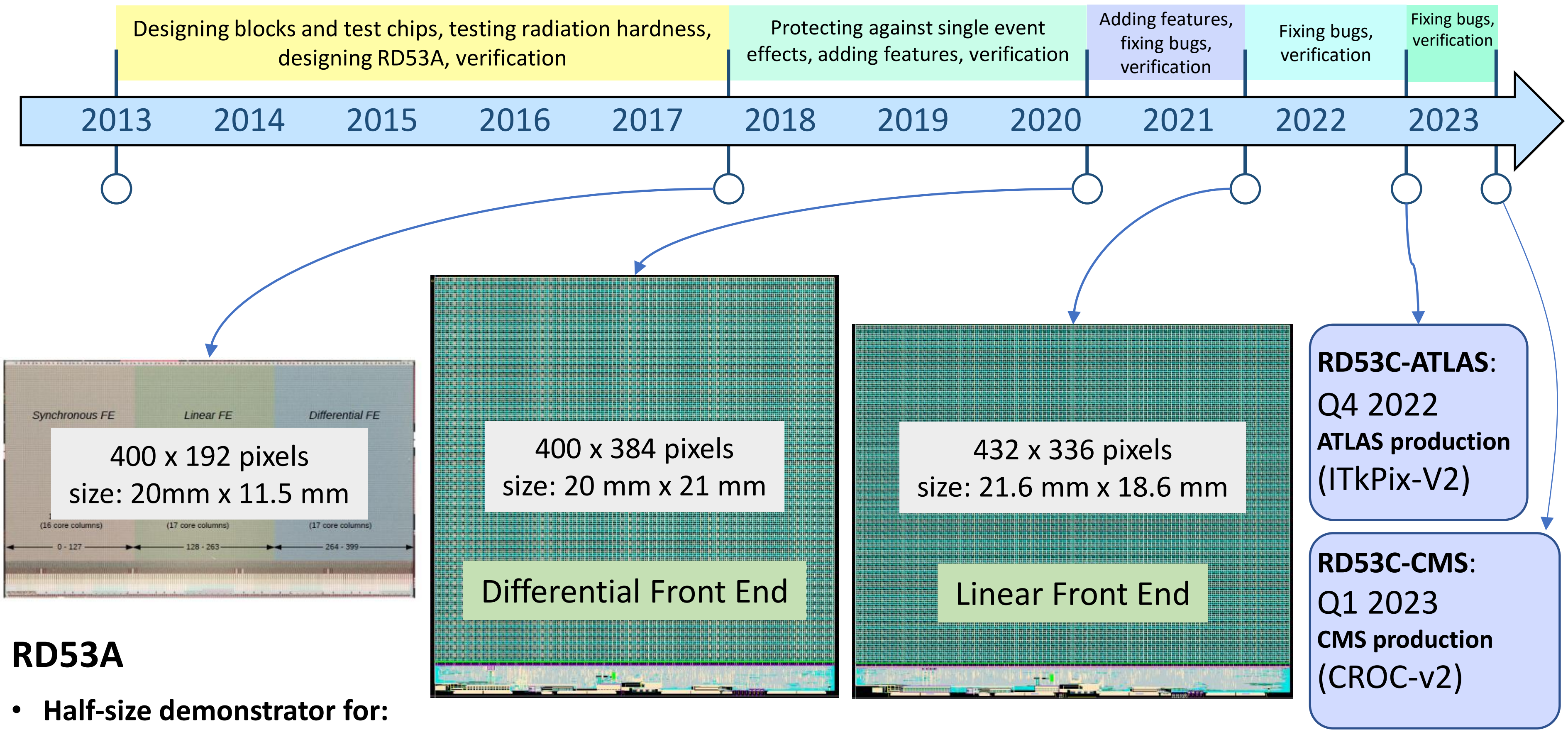
- In order to participate to the L1 trigger decision, the CMS OT ASICs have to transmit self-selected information for every event requiring the front-end readout ASICs to locally perform an efficient data reduction.
- The MPA, SSA and CIC ASICs are design in advanced CMOS technologies to provide pixel and strip sensor readout, data reduction and on-chip continuous discrimination based on the particle transverse momentum





- System-level studies allowed to define the architecture of the CMS OT PS-Module ASICs
- The tests on the final version of the chips show results in agreement with the simulations:
  - Front-end performances fulfil specifications
  - X-Ray TID test confirms radiation harness up to 200 Mrad
  - Heavy Ion test confirms the tolerance to Single Event Effects
  - Climatic chamber tests shows a parameter variation within the calibration range
- Wafer-level testing show a high yield,
- The production of about 200 wafers will start in 2023

RD53 Pixel chips for ATLAS and CMS Phase II upgrades



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

RD53:

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

Monolithic

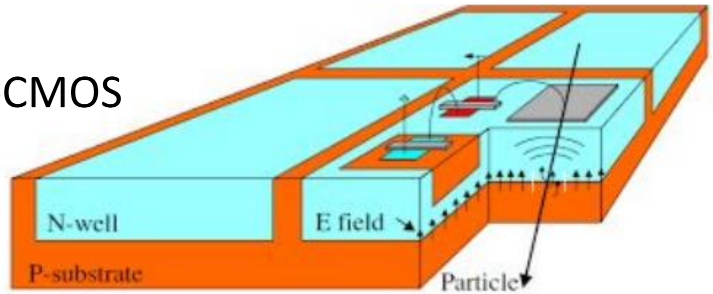
Luigi
Ivan Dario
Jory
Lingxin
Pascal

Akimasa
Didier
Heinz

Mupix: Monolithic sensors for the Mu3e experiment

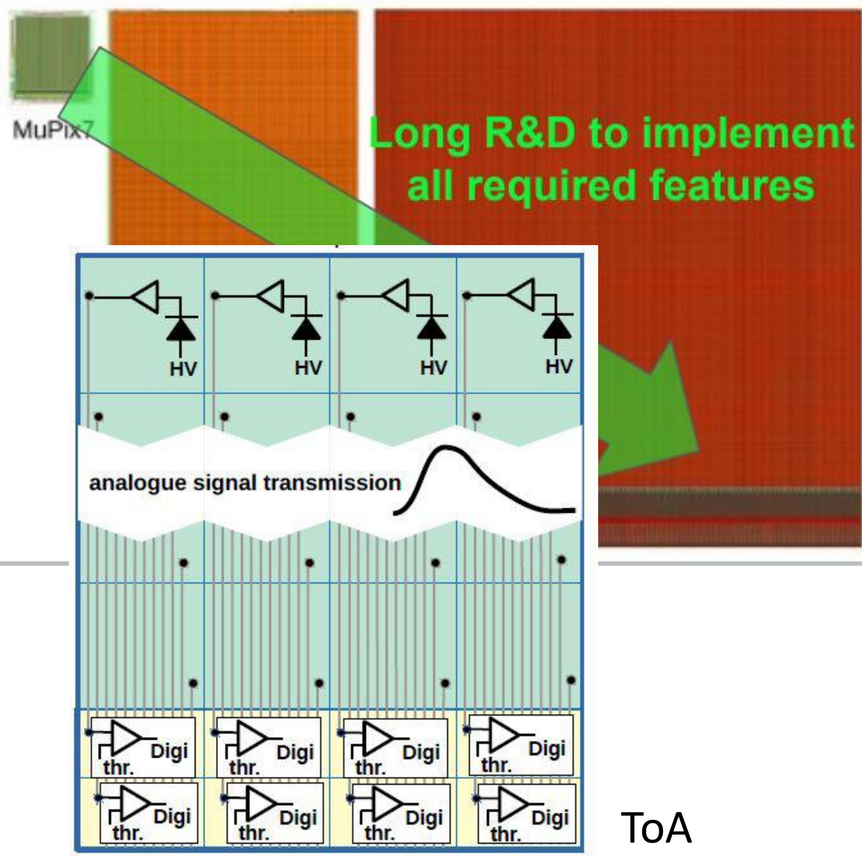
Luigi Vigani
University of Heidelberg

HV-CMOS

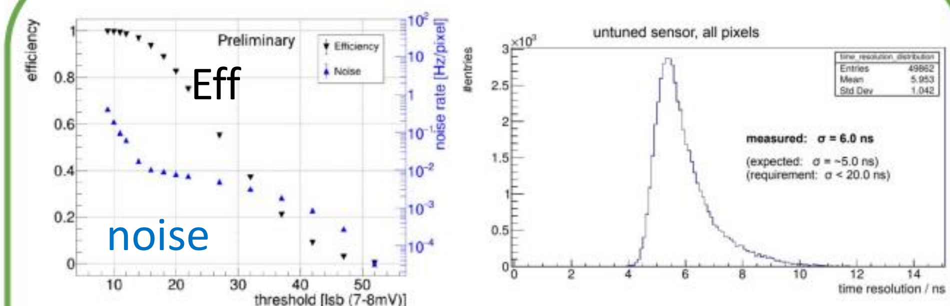


Mupix sensors: HV-MAPS developed for Mu3e:

- Low material budget (thinned to 50 μm)
- Good performance (space and time resolution,...)
- Very challenging experimental conditions



ToA



Vth

σtime~6ns
(20ns req.)

Several testing campaigns to verify the requirements are met!

D=depleted

Design and performance of the Monopix2 reticle-scale DMAPS

- **DMAPS** in large and small electrode designs (LF, TJ)
- **Fully functional column-drain** read-out architecture at a reticle-size scale
- All signal processing and R/O **electronics placed within the pixel volume**
- **Radiation-hard** up to the requirements of current HEP experiments (NIEL: 10^{15} n_{eq}/cm^2, TID: 100Mrad)

UNIVERSITÄT BONN

SI LAB Silizium Labor Bonn

Iván Caicedo

	ITk Outer Layer	Belle II VTX
Occupancy	1 MHz/mm²	1.5 MHz/mm²
Time Res.	25 ns	O(100) ns
NIEL	10^{15} n_{eq}/cm^2	5×10^{14} n_{eq}/cm^2
TID	80 Mrad	100 Mrad
Area	O(10m²)	O(3m²)

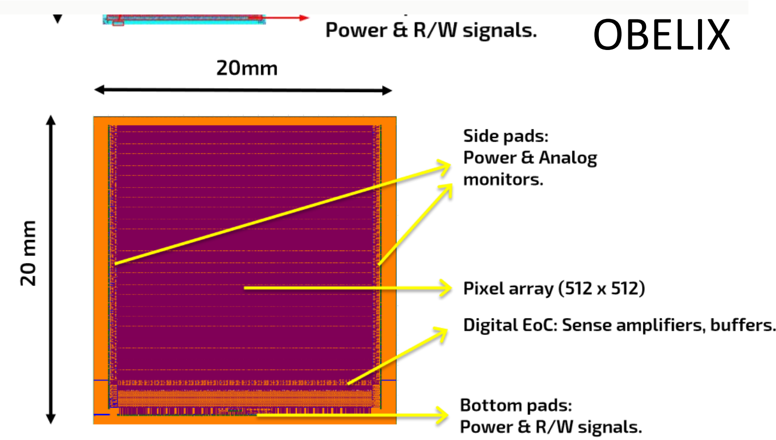
LF-Monopix2

Large electrode DMAPS in LFoundry 150 nm CMOS

TJ-Monopix2

Small electrode DMAPS in Tower 180 nm CMOS

OBELIX

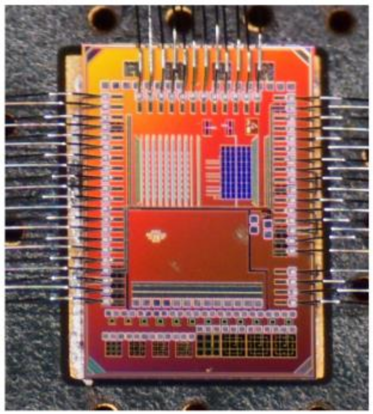


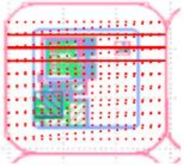
Jory Sonneveld

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

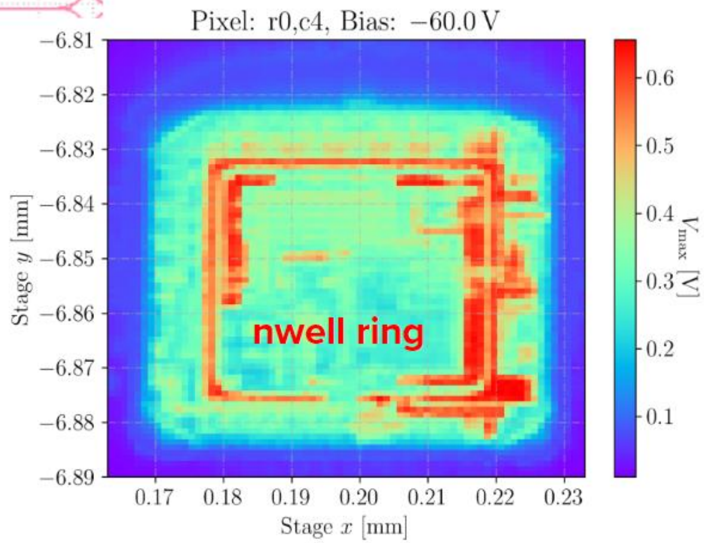
3D image of an RD50 HV CMOS pixel

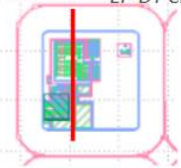
Francisco Rogelio Palomo Pinto[a], Sebastian Pape[b,c], Michael Moll[b], J.María Hinojo Montero[a]
[a] Electronic Engineering Department of School for Engineering in University of Seville, Spain
[b] EP-DT CERN, [c] TU Dortmund University



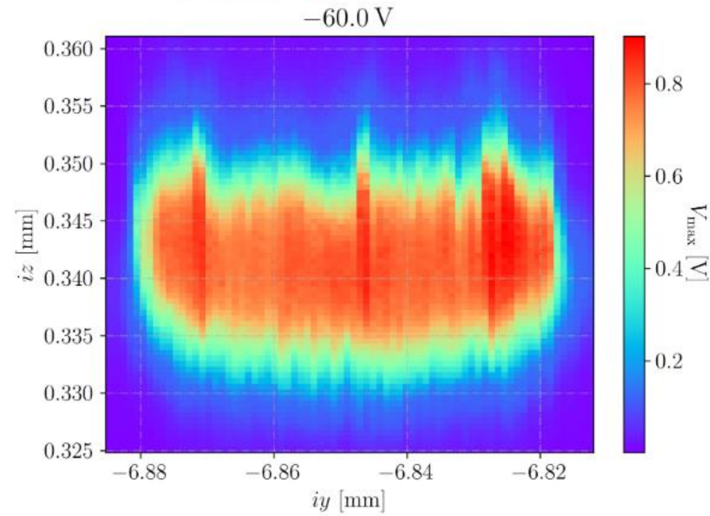


XY-Scan middle depth focus



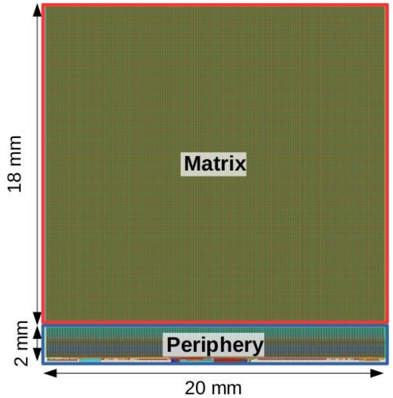


YZ-Scan across the electronics

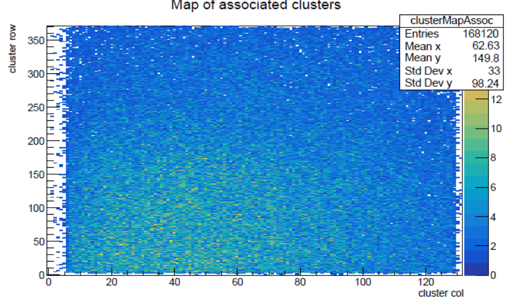


- Chip electronics no obstacle to mapping
- N-well ring clearly visible in image made with TPA laser
- Active region is clearly visible

From [RD50 CMOS meeting](https://indico.cern.ch/event/1184355/contributions/4976091/)
https://indico.cern.ch/event/1184355/contributions/4976091/

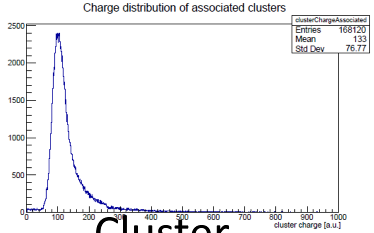


HVCMOS
=>2x2
(ATLASPix3.1)



Clusters associated to tracks. Beamspot seen on DUT.

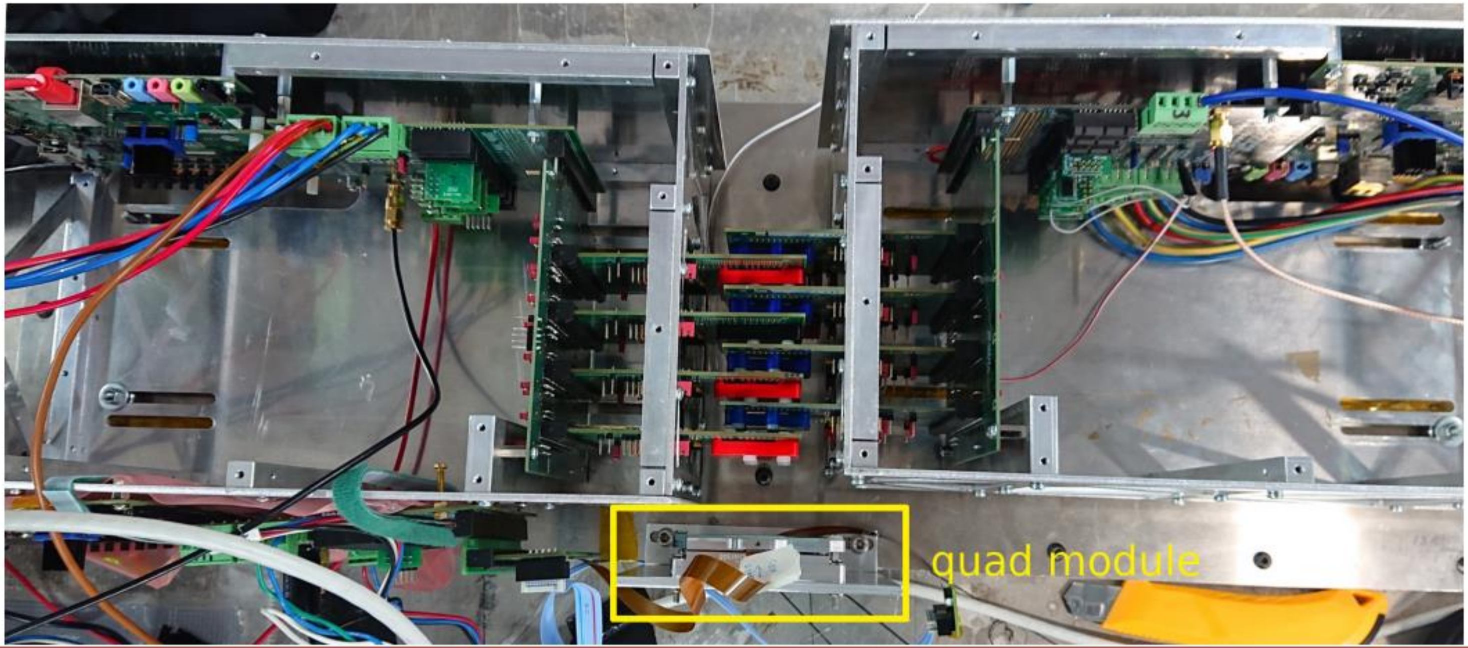
Testbeam at DESY



Cluster
hit map &
charge

Lingxin Meng
Lancaster University

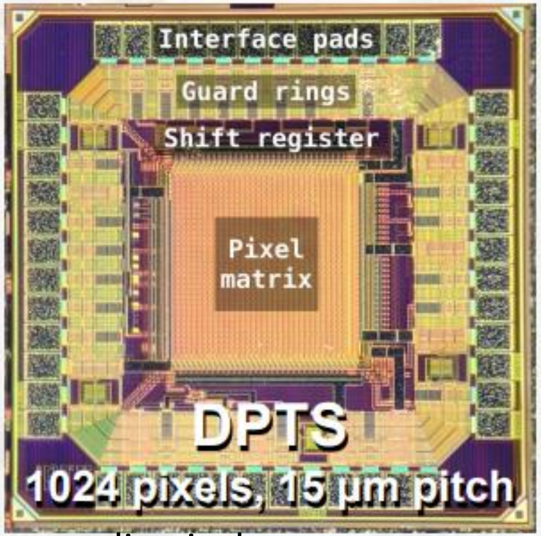
- Testbeam at DESY in April using 6 GeV electron beam
- 2 arms in 2 standalone systems, biased at ~ 50 V
- Synchronisation provided by the primary system sending sync signal to the secondary
- Using hit-driven readout
- Interleaved arms with 1.27 cm distance between planes
- Quad module in the beam (bottom, in the pixel module carrier)



In-beam characterisation of irradiated, digital MAPS prototypes produced in 65 nm CMOS process

Pascal Becht

- 65 nm CMOS technology node qualified for application in MAPS
- Excellent detection efficiency and operational margin already in first submission (MLR1)
- Spatial resolution as expected
  - Dominated by small cluster size (binary resolution)
- Promising performance after irradiation



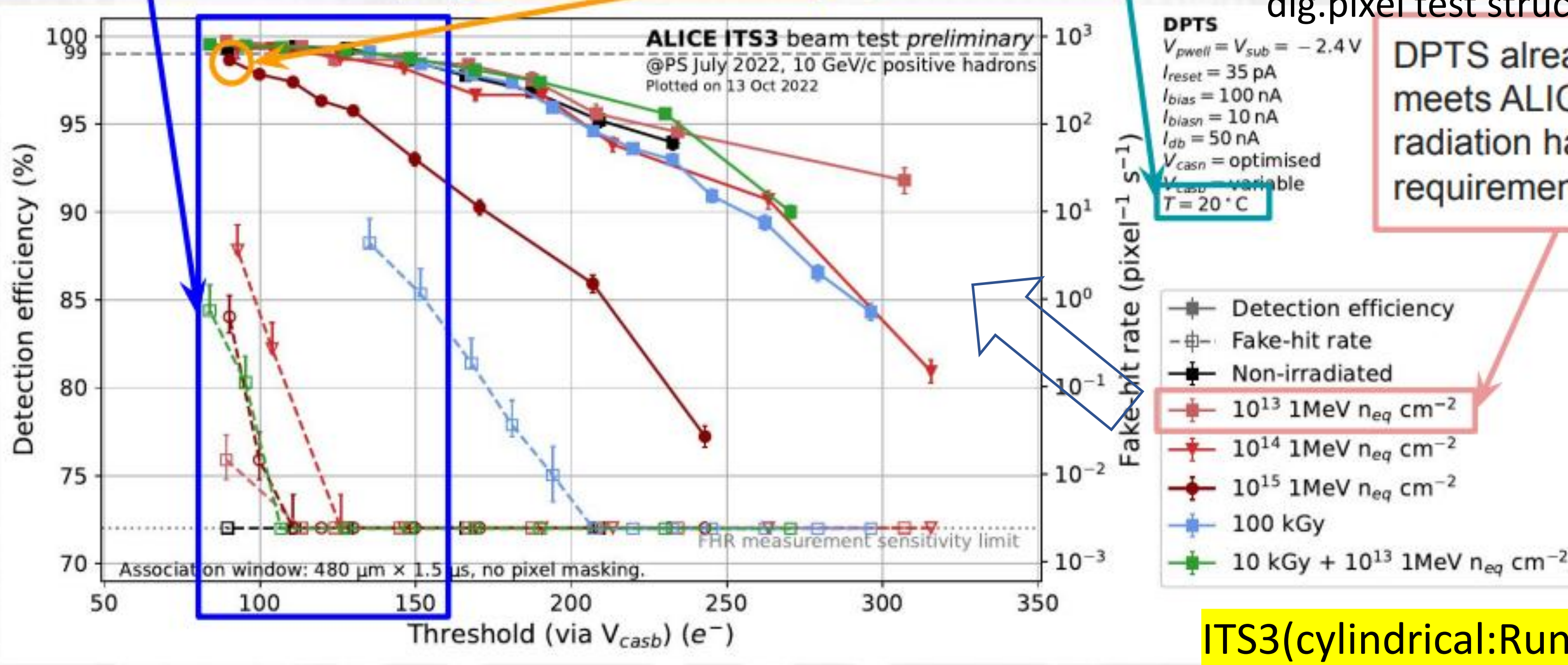
dig.pixel test struct.

Efficiency exceeds 99% for wide range of operating points

99% efficiency in reach even for 10^{15} NIEL

Room temperature!

DPTS already meets ALICE ITS3 radiation hardness requirement



ITS3(cylindrical:Run4)

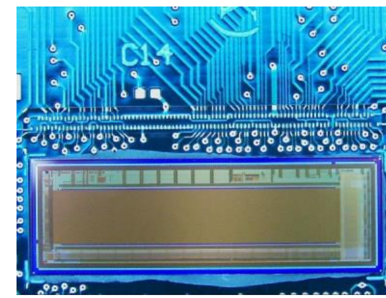
SOI

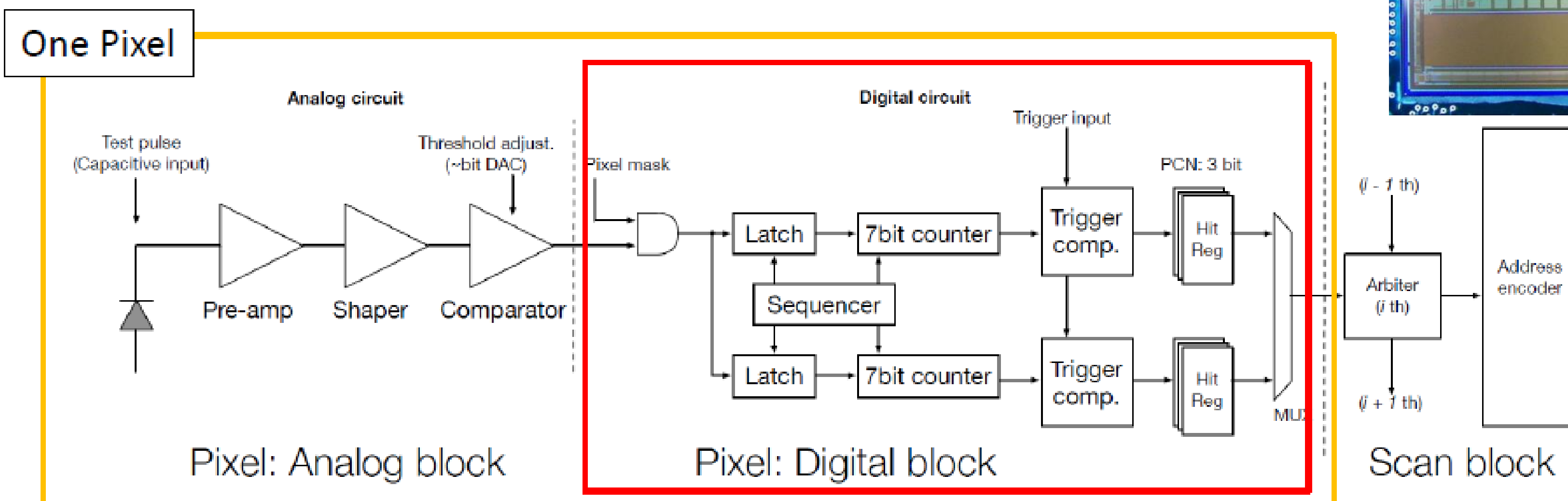
Akimasa ishikawa

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 ^{90}Sr and 50MHz CLK (20ns) - good enough for 63ns bucket





7bitx 2

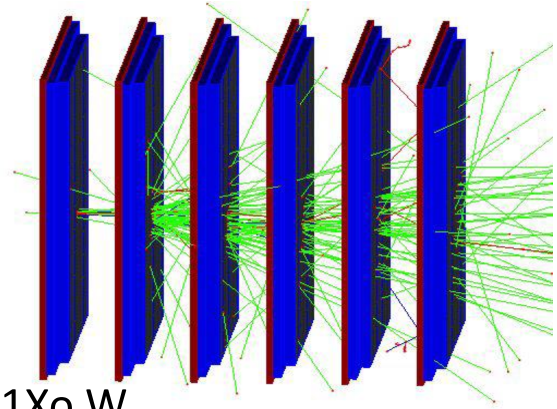
ALPIDE analog circuit
Modified for faster response

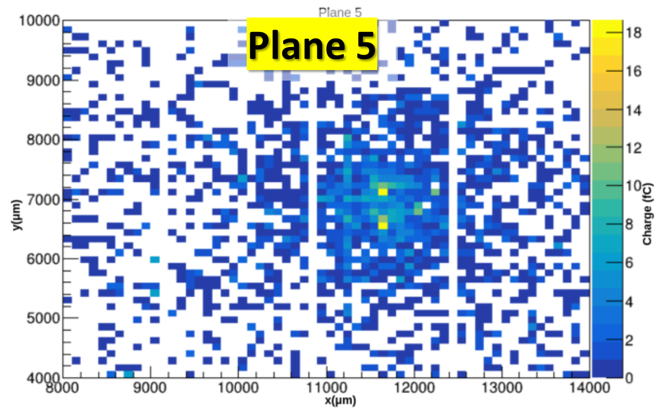
15.9MHz(62.9ns) CLK (SuperKEKB509MHz/32(1.97ns*32))Trigger latency of at most 8us (4.4us requirement)

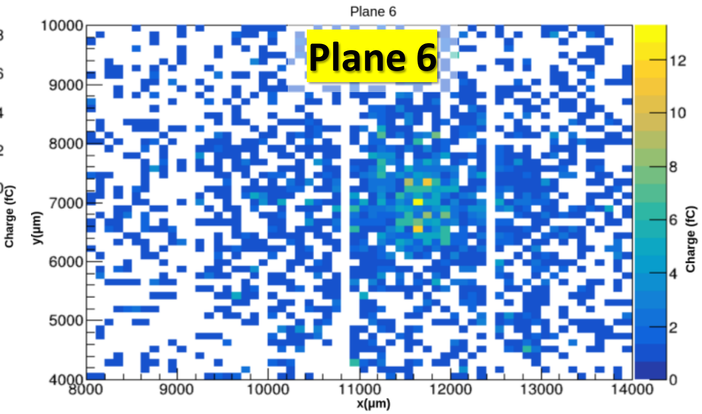
D. Ferrere
Univ- of Geneva

MAPS for FASER Preshower Upgrade

Goal: Axion Like Particles (ALP) detection with final state π0 in two closely spaced photons







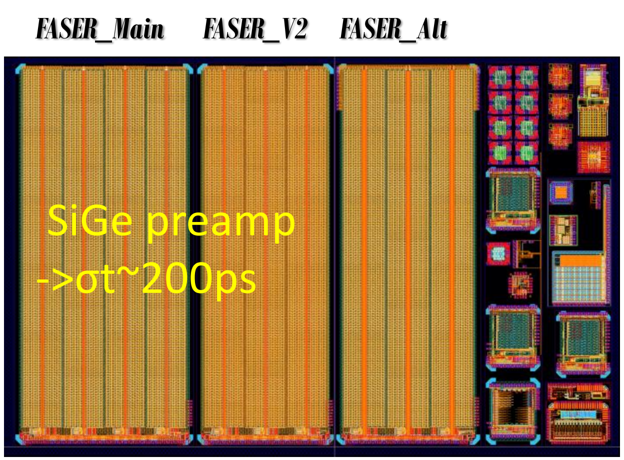
MC Simulations with realistic detector 100 μm pitch and 2 photons of 1 TeV separted by 500 μm → 99% efficiency

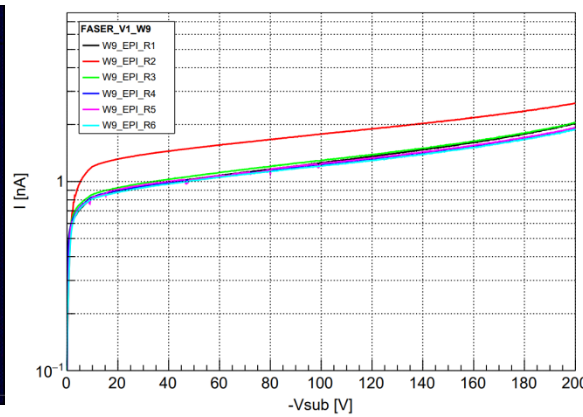
→**Preproduction wafers** delivered in June

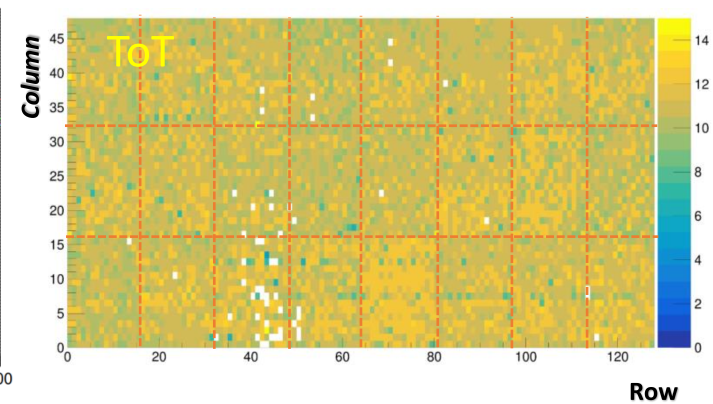
→ **Production to be submitted early in 2023**

Excellent performance measured so far

- IV can exceed 200V while 120V is optimal
- Pixel response of v2 chip with > 6000 pixels → fine
- TOT with Laser injected pulse measured and ok
- Preliminary results in TB are confirmed with MC simulations







Radiation hard MALTA CMOS pixel sensors for tracking applications

Heinz Pernegger / CERN EP Department
Heinz.pernegger@cern.ch

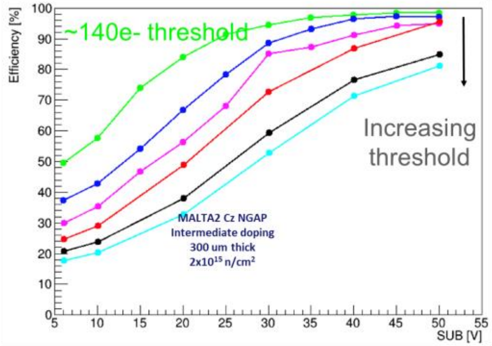
On behalf of H. Pernegger, P. Allport, I. Asensi Tortajada, D.V. Berlea, D. Bortoletto, C. Buttar, F. Dachs, V. Dao, H. Denizli, D. Dobrijevic, L. Flores Sanz de Acedo, A. Gabrielli, L. Gonella, V. Gonzalez, G. Gustavino, M. LeBlanc, K. Oyulmaz, F. Piro, P. Riedler, H. Sandaker, C. Solans, W. Snoeys, T. Suligoj, M. van Rijnbach, A. Sharma, M. Vazque Nunez, J. Weick, S. Worm, A. Zoubir

MALTA = Radiation hard small pixel CMOS sensor for tracking

MALTA sensor parameters and performance

- Pixel Pitch pixel size 36.4x36.4μm^2
- Matrix size 512 x 512 pixel (MALTA1) and 512 x 224 pixel (MALTA2)
- Asynchronous readout architecture to stream all hit data to output (trigger-less operation)
- Sensors data daisy-chain for sensors-to-sensor data transmission
- sensor thickness optimised to application 50μm to 300μm on Cz-substrate
- full efficiency (>98%) 2 x$10^{15}n_{eq}/cm^2$
- TID radiation hardness tested OK to 100Mrad
- time-resolution <2ns
- threshold after irradiation 120 e-

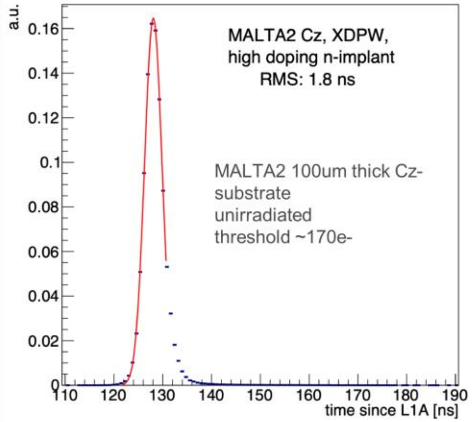
MALTA2 efficiency >98% after 2 x$10^{15}n_{eq}/cm^2$ irradiation



- Good performance of Cz samples at 2x10^{15} n/cm^2
- Expected uniformity at lowest threshold setting
- Cluster size increases with substrate voltage
  - Maximum at ~1.9 at 50 V at 120 e-
- Efficiency better than 98% at 50 V bias at 120 e-

MALTA2 time resolution in beam tests ~2ns

- Time of arrival of leading hit in the cluster w.r.t. scintillator reference
  - Included scintillator jitter : 0.5 ns
  - Signal latching at FPGA: 3.125/sqrt(12) = 0.9 ns
- Timing distribution integrated on full chip after correction in X and Y direction:
  - Y correction due to time propagation across the column (linear behaviour)
  - X correction compensates for non-uniformities in chip response



CERN · University of Oxford · University of Birmingham · University of Glasgow · Abant İzzet Baysal University · UiO University of Oslo · DESY · CSIC · University of Zagreb

MALTA3 with on-sensor time-tagging and data serialisation to enable system integration for asynchronous matrix readout (1.28GHz Tclk, 5-bit) in future experiments (2023 subm.)

R&D New Detector/Material

Christopher
Giulio
Harris

Summary

christopher

- RD50 investigates radiation-hard semiconductors for high-luminosity colliders
- Comprises 66 institutes, 430 members
- Four research lines: Defect/Material characterization, Detector characterization, New structures, Full detector systems
- RD50 has contributed significantly to the LHC and LHC upgrade detectors
  - p-type silicon
  - MCZ and oxygenated silicon
  - 3D detector technology
  - LGAD (Low Gain Avalanche Detectors)
  - 4D tracking
  - planar devices are a feasible option for LHC upgrade
  - damage models & New characterization techniques
- Current collaboration finishes at the end of 2023
  $\rightarrow$ Replaced by DRD3 collaboration

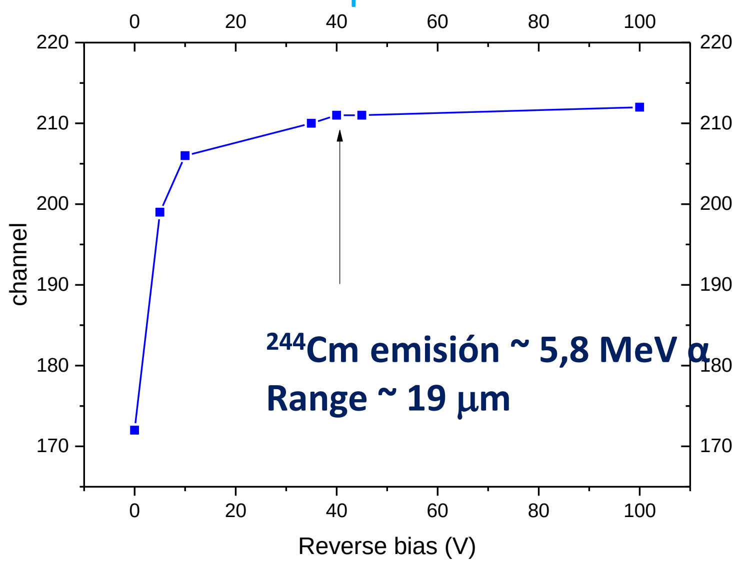
giulio

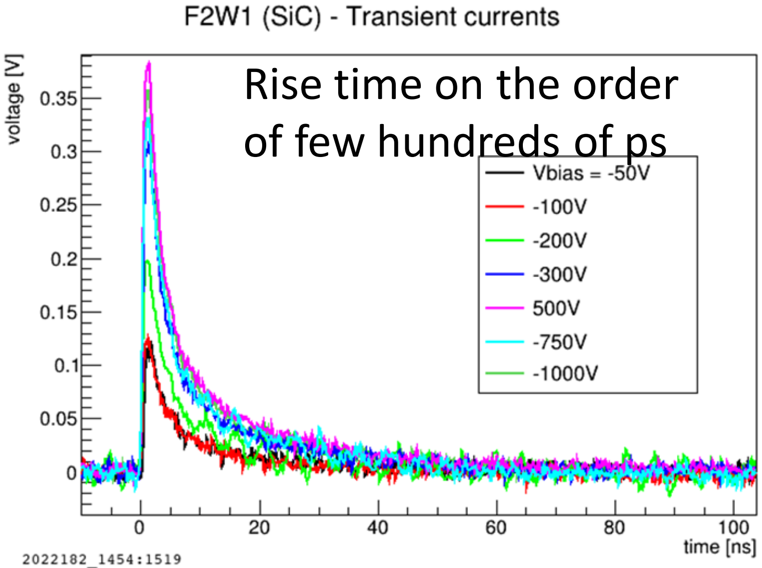
SiC

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*** (2×10^7 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





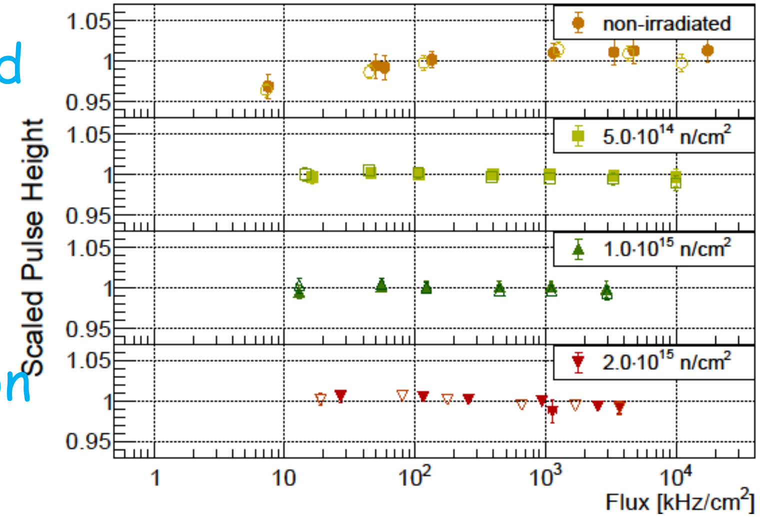
3D in prep.

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

Diamond RD42

Harris

M.ReichmannThesis2022



▪Quantified understanding of radiation and rate effects

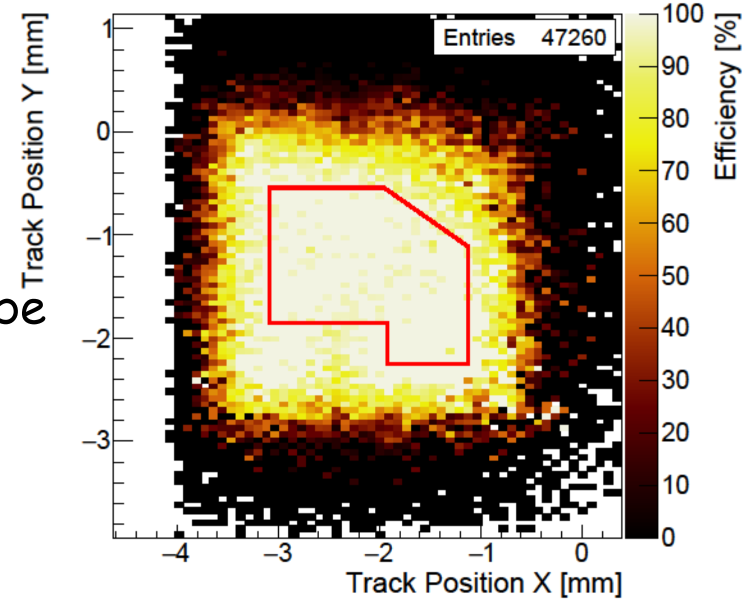
- pCVD shows no rate effect up to 10MHz/cm2,8x10^{15}n/cm2@1000V
- Irradiate devices to 2-4x10^{16} this year;

▪3D detector prototypes for 10^{17} operation

- 3D works in pCVD diamond
- Smaller cells (50µm x 50µm) worked; test smaller cells (25µm)
- Thinner columns (2.6µmD) worked; try 2.0µm

▪3D diamond pixel devices being produced

- tested 50µm cells irrad@3.5x10^{15}n p/cm2
- Visible improvements with each step
- Efficiencies look good(>99.3%), still a bit to be understood w/charge(>85%)



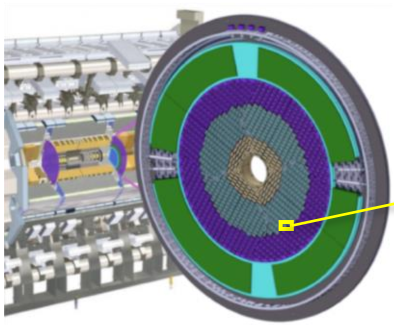
▪ATLAS BCM' design underway –nearly complete

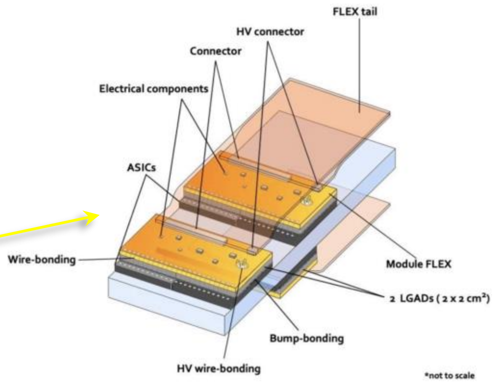
Timing

Mengqing
Valentina
Vagelis
Kevin
Wilhelm
Francesco

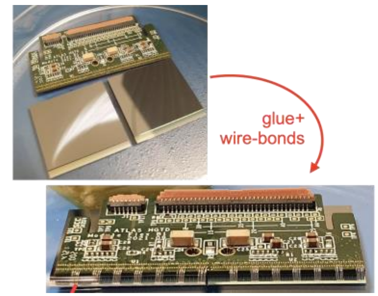
Alessandro Tricoli
Sayuka
Francesco
Adriano
Giuseppe

A High Granularity Timing Detector for the ATLAS Phase-II upgrade



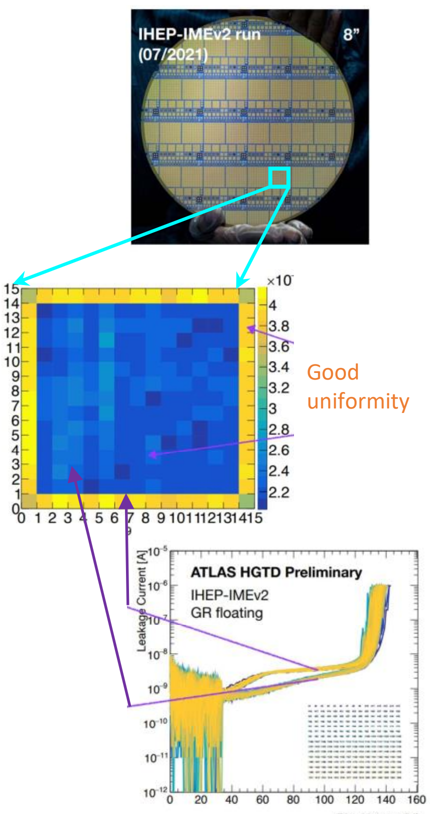


15x15 pads full size sensor



First modules assembled for tests

Module tests in DAQ demonstrator

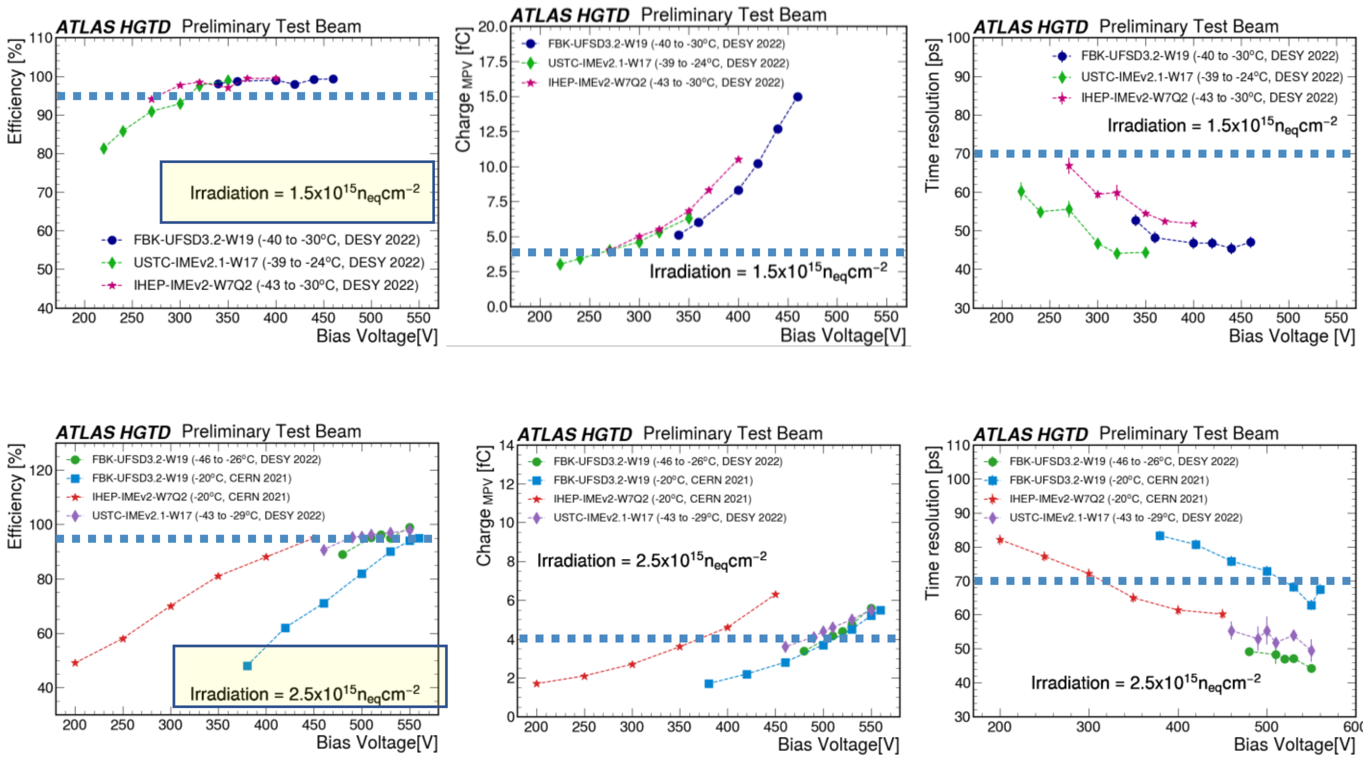


- The HGTD will yield track time measurements with a time resolution of 30-50 ps in the forward region 2.4<|η|<4
  - Expect important benefits from suppression of pile-up tracks and forward jets, and more potential in object identification
- Great progress has been made in developing the LGAD sensors and the ALTIROC readout ASICs
- Good progress in LGAD design fulfilling the radiation hardness requirements
- Carbon enriched LGADs fulfil the radiation hardness requirements up to 2.5e15 neq/cm2
- ALTIROC2 (first full size prototype) tested, so far all blocks functional and performed as expected
- ALTIROC3 submission expected in November
- Next milestones: many critical elements move to pre-productions in 2023, modules and detector units pre-production starts in 2024, both end-cap vessels integration in 2025-2026.

LGAD performance studies highlights

Presented results have been essential to validate various LGADs designs to be used for HGTD::

1. Efficiency of all presented sensors is > 98% at $1.5\text{x}10^{15} n_{eq} / \text{cm}^2$ and is > 95% at $2.5\text{x}10^{15} n_{eq} / \text{cm}^2$ going up to ~99% for some sensors (95% is the project requirement)
2. Charge of all presented sensors is > 5 fC at $1.5\text{x}10^{15} n_{eq} / \text{cm}^2$ and $2.5\text{x}10^{15} n_{eq} / \text{cm}^2$ (min. 4fC is the project requirement)
3. Time resolution is lower than 60 ps for all the tested sensors at $1.5\text{x}10^{15} n_{eq} / \text{cm}^2$ and $2.5\text{x}10^{15} n_{eq} / \text{cm}^2$ and can get < 50 ps for some sensors (max. 75ps is the project requirement)



Corresponds to the project requirement

Depends on vendor, temper.

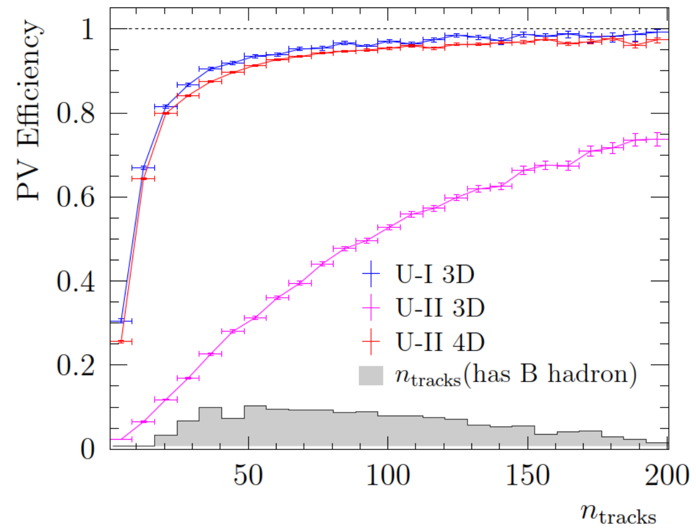
- Single Event Burnout resolved at voltages required to meet HGTD specifications
- Qualified performance of latest generation of Carbon diffused LGADs at the highest irradiation

Oscilloscope-> Test Beam campaigns studying the combined performance of LGAD + ALTIROC have started this summer

• LHCb Velo Upgrade 2

Vagelis

4D Tracker for 2030s

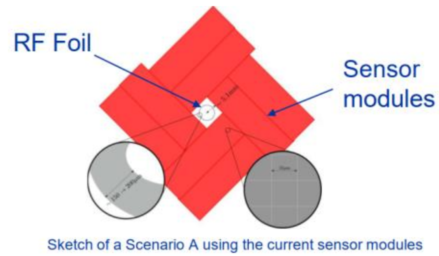


Full 4D Velo Tracker

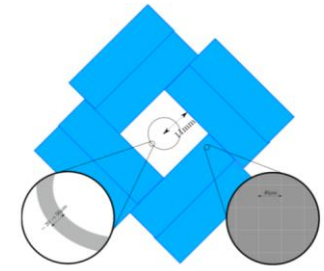
- 20 ps per track timing to recover Run 3 efficiency
- Timing plane options rejected due to more complicated construction

Two Scenarios considered as a starting point

- S_A: High data rate and radiation tolerance at > 6 × 10^{16} n_{eq}/cm^2
- S_B: Higher hit resolution and reduction of material budget



Scenario A (S_A)



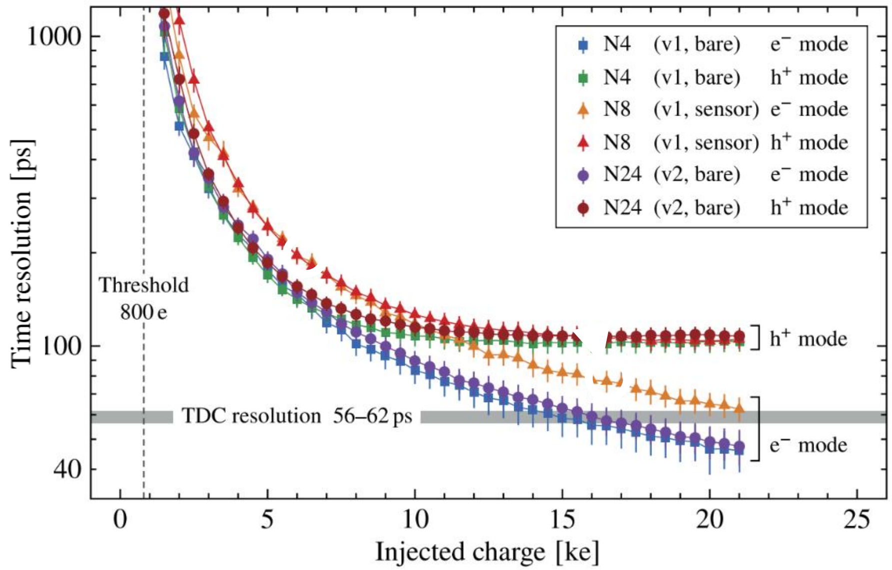
Scenario B (S_B)

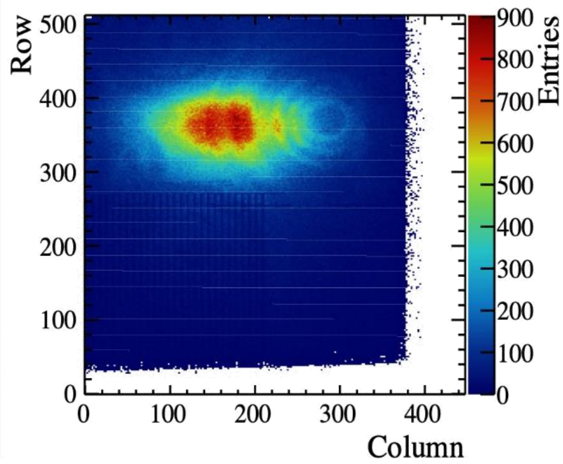
R & D Paths

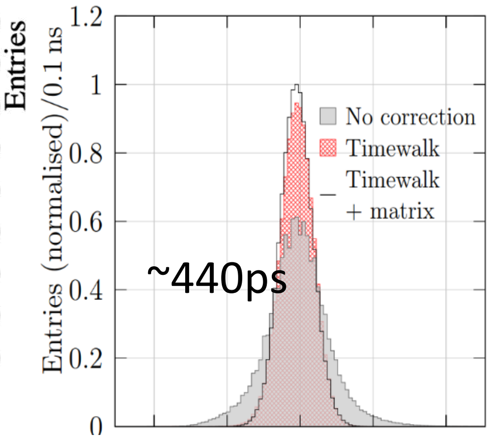
- Next 2 years crucial to develop necessary technologies:
  - Fast and radiation hard sensors and ASIC
  - Reduced material budget RF shield option
  - New cooling solution
  - Vacuum tank that satisfies the requirements

- Timepix4: Expected time resolution and first testbeam results

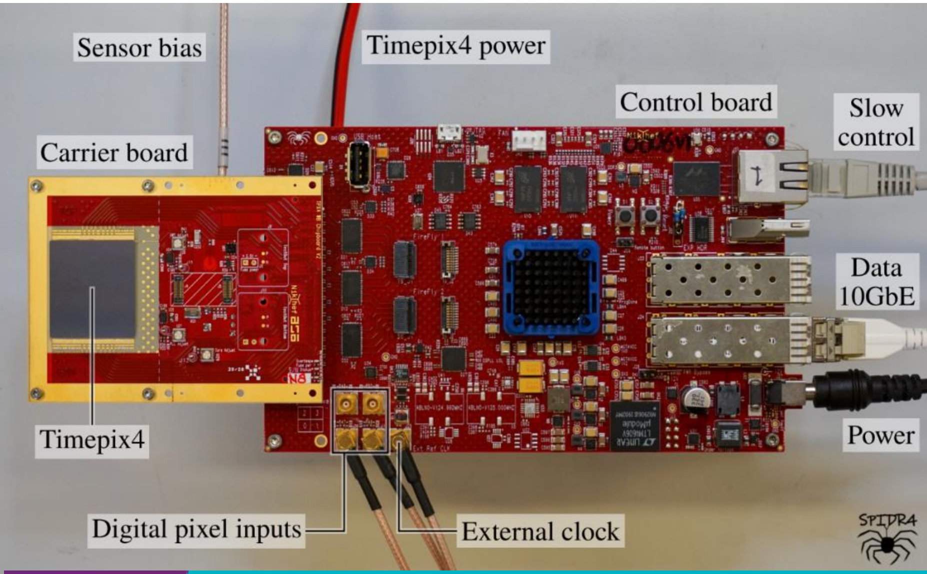
Kevin

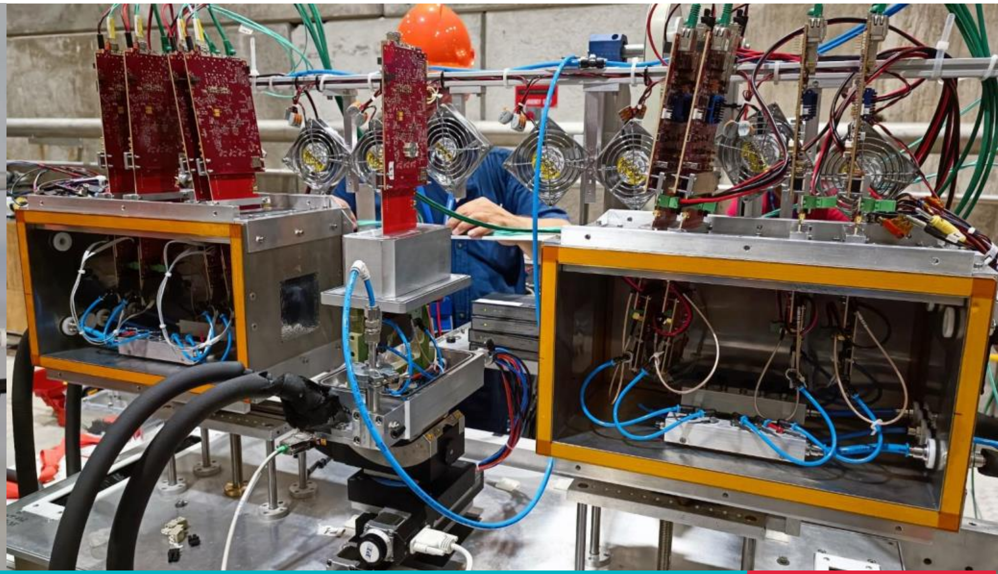






Time residual [ns]

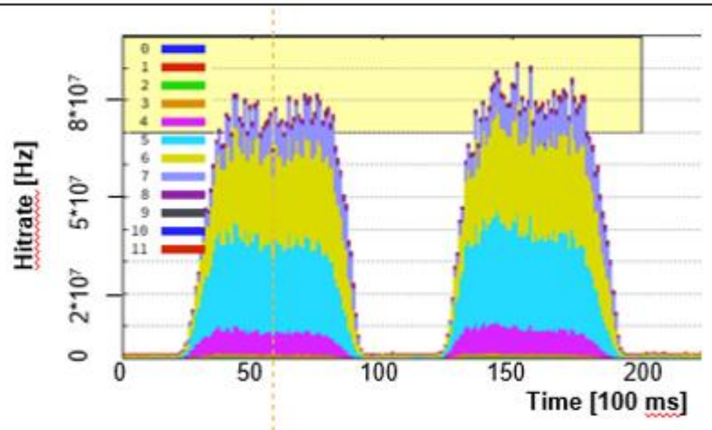




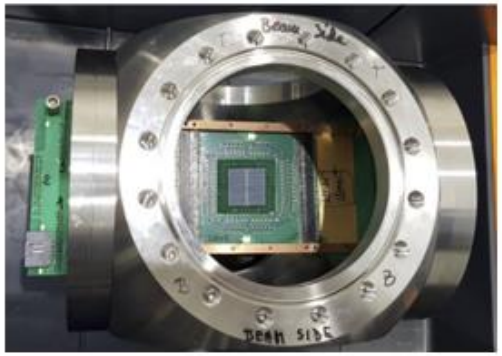
Performance of the LGAD-based in-beam detector at HADES

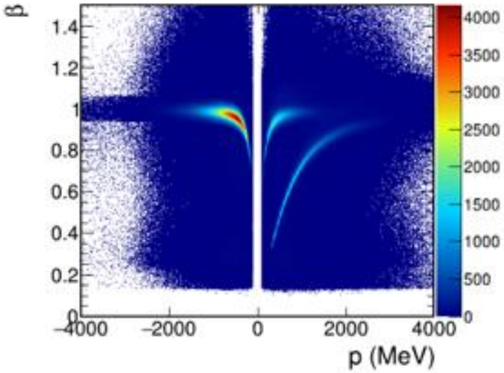
LGAD-based in beam detector used by HADES in 4.5 GeV pp run in February 22

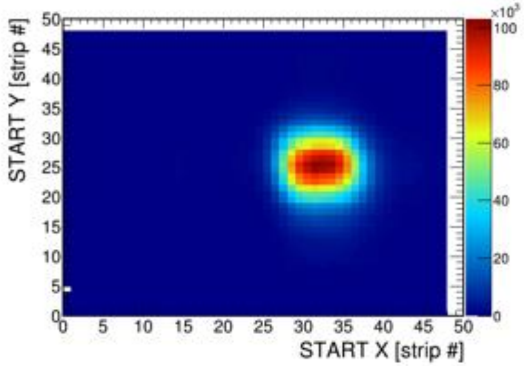
- 10^8 protons/s
- Used for beam monitoring
    - Macro- and micro-spill structure
    - Beam position
- Part of PID via ToF measurements



W. Krüger et al., Nucl. Instrum. Meth. A 1039 (2022), p. 167046, https://doi.org/10.1016/j.nima.2022.167046





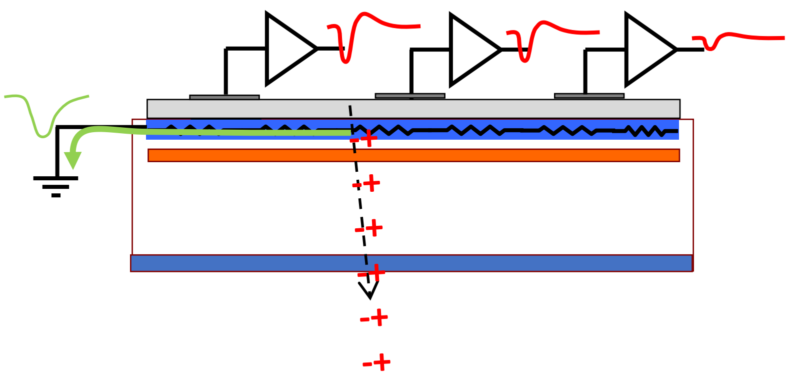


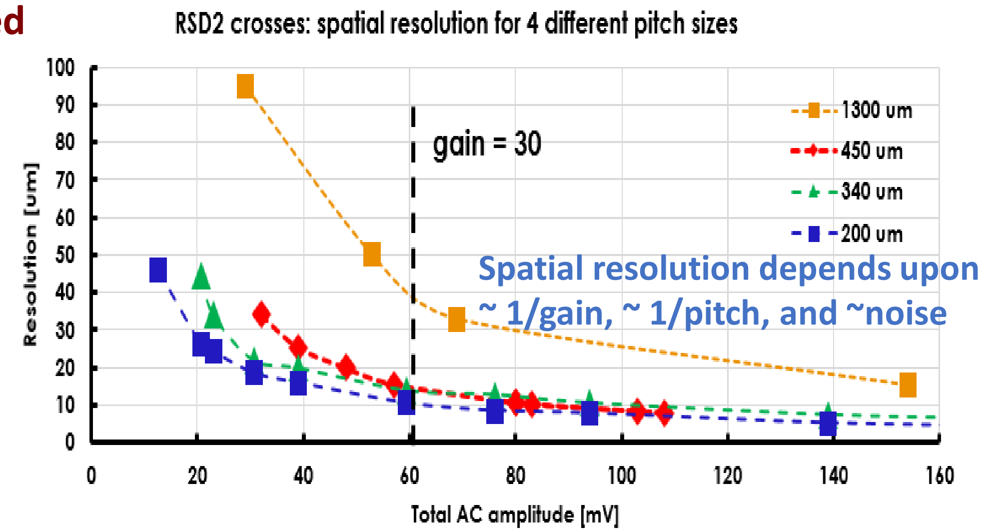
The power of resistive read-out in silicon sensor

Francesco Moscatelli and Nicolò Cartiglia
On behalf of Italian PRIN "4DInSiDe" research project.

The results on FBK – RSD2 production are presented

In resistive readout the signal is naturally shared among pads
Thanks to the internal gain, full efficiency even with sharing

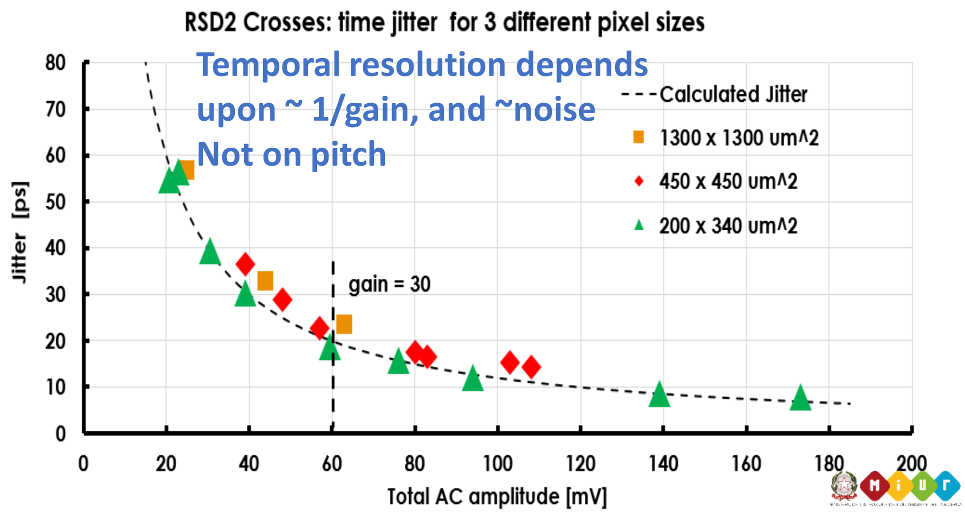




RSDs at gain = 30 achieve a spatial resolution of about 3% of the pitch size:

RSD:

- **1300 x 1300 μm²: σ_x ~ 40 μm**
- **450 x 450 μ m²: σ_x ~ 15 μm**

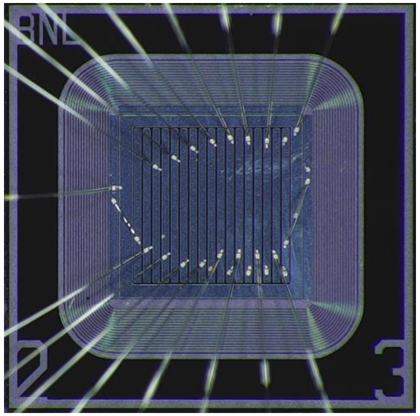


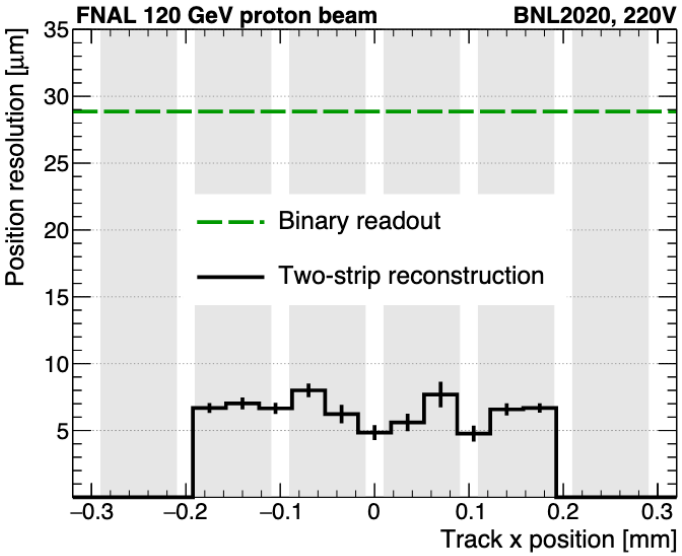
Rise of 4D Detector

Alessandro Tricoli

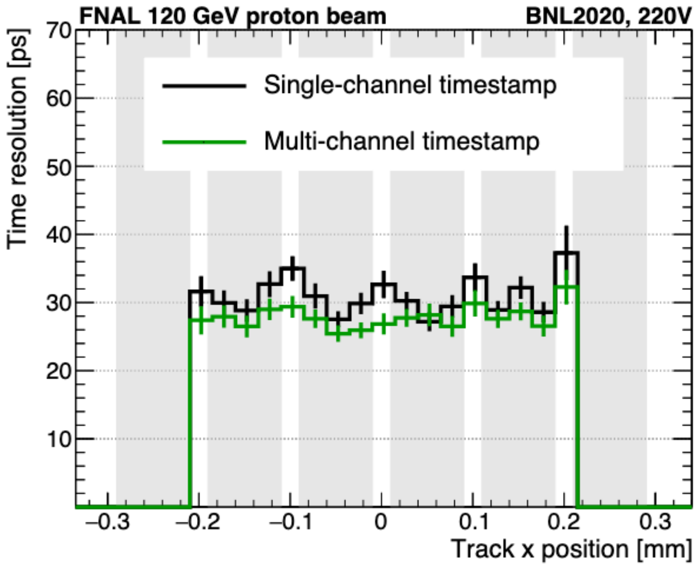
LGADs are a stepping stone to develop **4D detectors**, and **AC-LGAD** is the most mature technology

- 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)



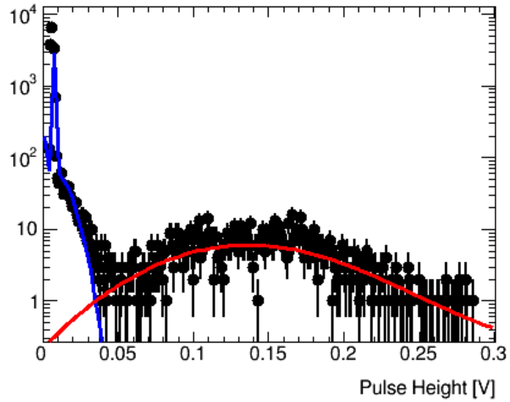
Time Resolution ~28 ps:

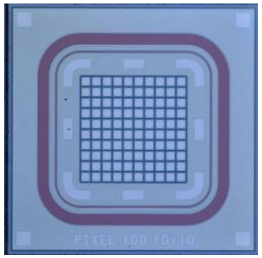
AC-LGAD for hadron collider

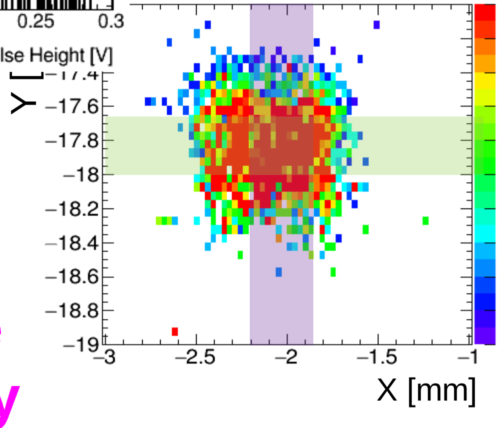
Sayuka Kita

finer pitch AC-LGAD sensors (strip&pixel) are prototyped with HPK – process parameters are optimized

Pixel (100um pitch)

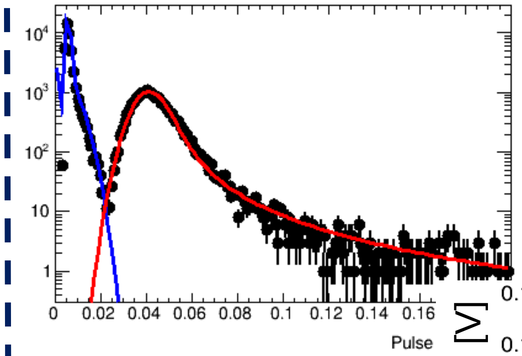


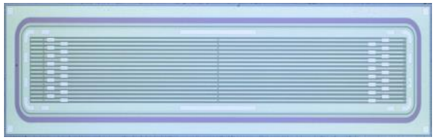


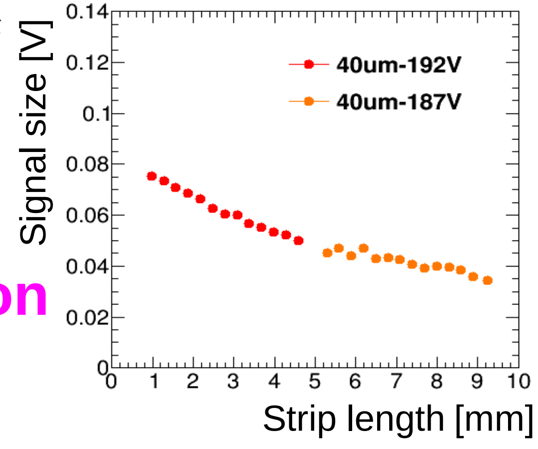


large signal & good performance e.g. efficiency

Strip (80um pitch)







large signal but signal reduction by C_{int}

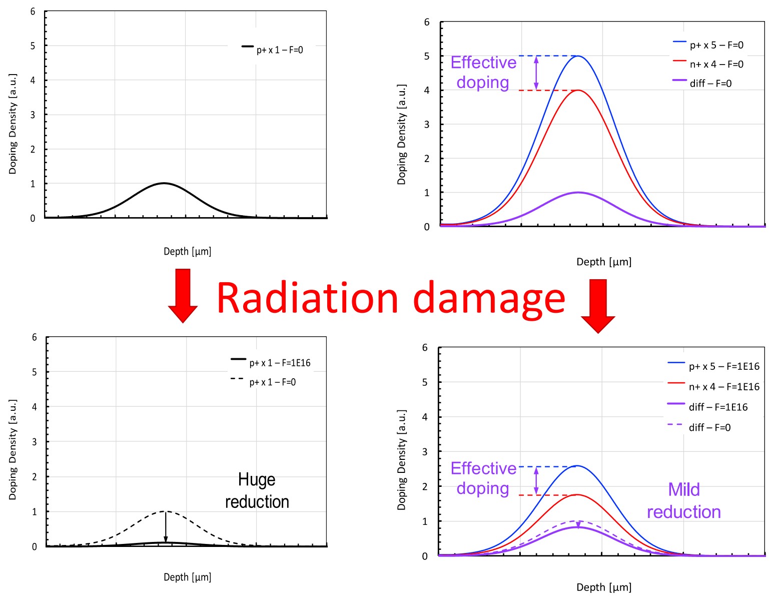
TCAD simulations of innovative Low-Gain Avalanche Diodes for particle detector design and optimization

Francesco Moscatelli

on behalf of CNR-IOM, INFN and University of Perugia (Italy) and INFN and University of Torino (Italy) groups

Developing innovative radiation-hard silicon detectors for 4D particle tracking in the future HEP experiments

A compensated design of the LGAD gain layer

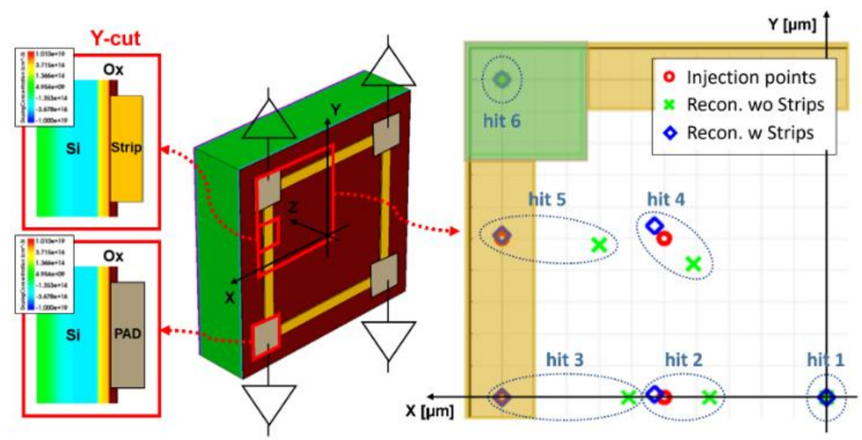


Standard LGAD design

Compensated LGAD

- New strategy to overcome the present limit of radiation tolerance for the gain implant, i.e. 1-2×10^{15} n_{eq}/cm^2.
- Use the interplay between radiation induced acceptor and donor removal to keep a constant gain layer active doping density after irradiation.

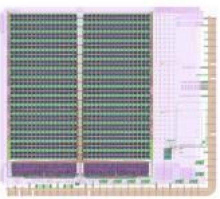
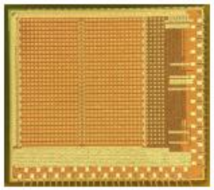
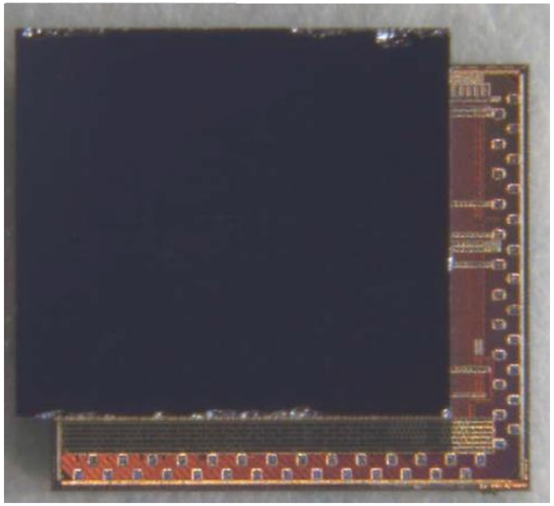
DC-coupled Resistive Silicon Detectors (DC-RSD)



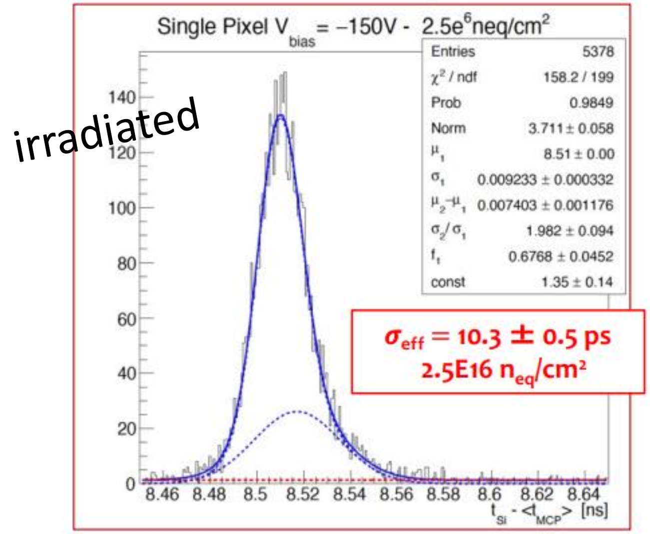
- DC-RSD with low resistivity strip between collecting pads, as an evolution of the RSD paradigm [1].
- Addressing few known issues (e.g. baseline fluctuation, long tail-bipolar signals) and maintaining the advantages (e.g. signal spreading over ~mm distances, 100% fill factor).

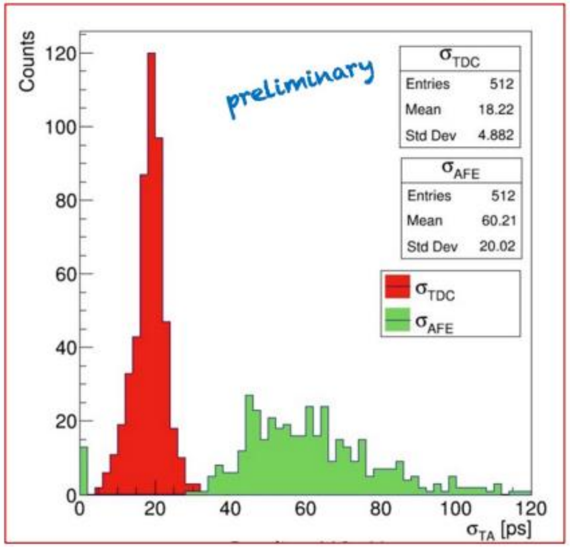
Summary on TimeSPOT results

- Most of the **very challenging requirements,** which appeared almost an absurdity when we started this RnD, have been **matched at the prototype level:**
  - ≈ 10 ps at the sensor level at 99% efficiency and > 2.5 10^{16} n_{eq}/cm^2
  - 55 μm pitch on sensor and electronics
  - < 50 ps on full chain at the ASIC level within power budget
  - high hit rate ≈ O(1) MHz per pixel
- **The next step** is to reproduce comparable results on a larger system:
  - ✓ Better production yield on larger area sensors
  - ✓ Better uniformity in time resolution on larger area ASIC
  - ✓ Clock and power distribution is critical
  - ✓ Increase the readout BW capability
  - ✓ Design protection against radiation
  - ✓ …

Timespot1 ASIC
28-nm CMOS





AFE: Analog FE

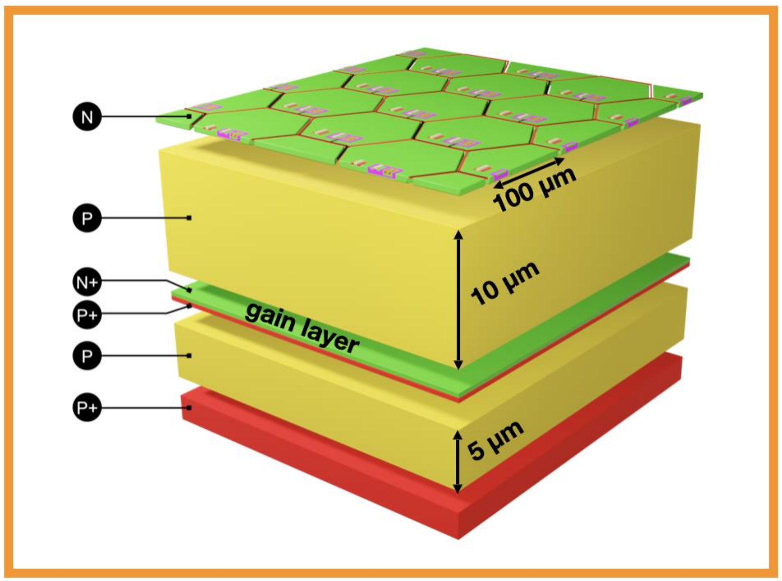
The MONOLITH ERC Project

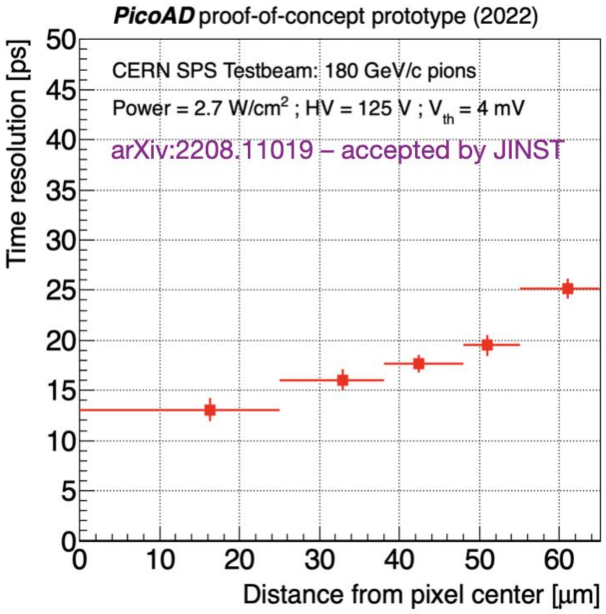
G. Iacobucci

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
Xuan
Nazar
Haken

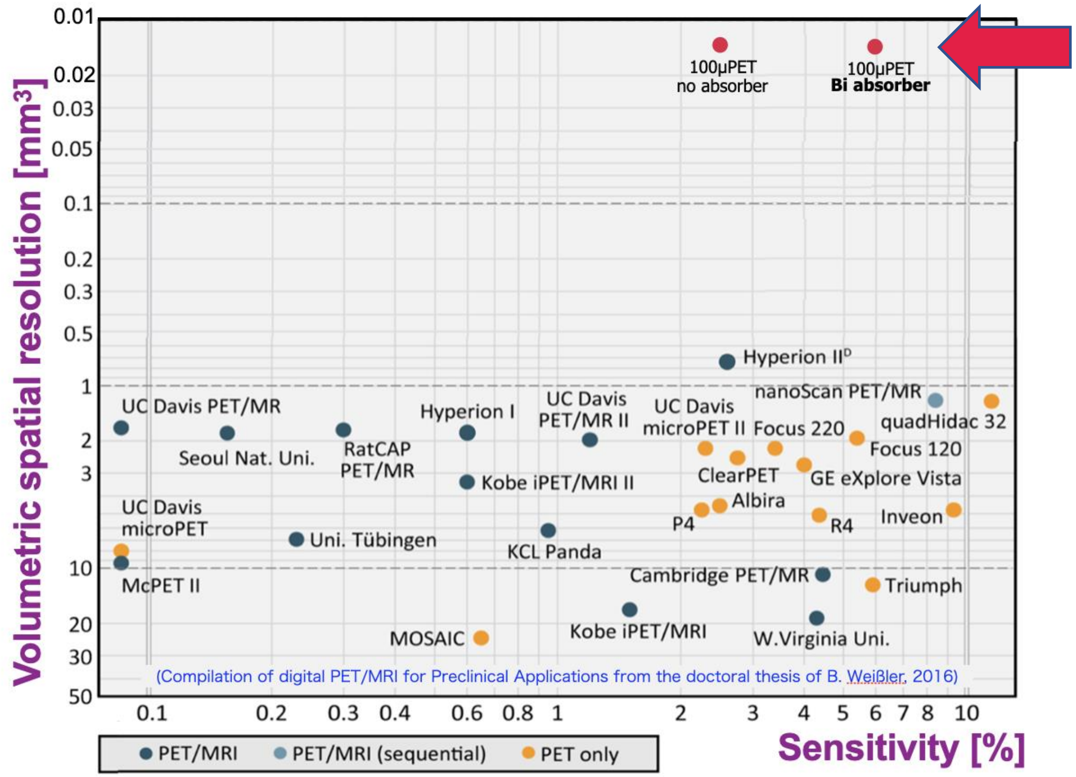
G. Iacobucci

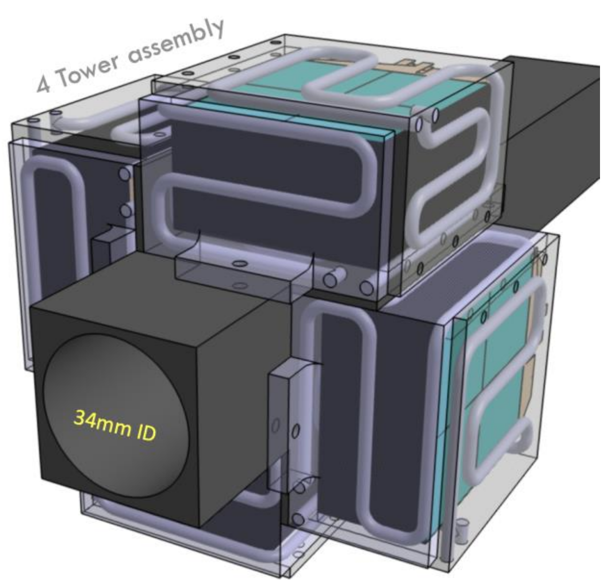
100μPET ULTRA-HIGH RESOLUTION MOLECULAR IMAGING

pioneering ultra-high resolution molecular imaging

Use stack of 60 monolithic Si pixel planes with 100μm pitch (SiGe BiCMOS 130nm by IHP).

To build a small-animal PET scanner with outstanding resolution.



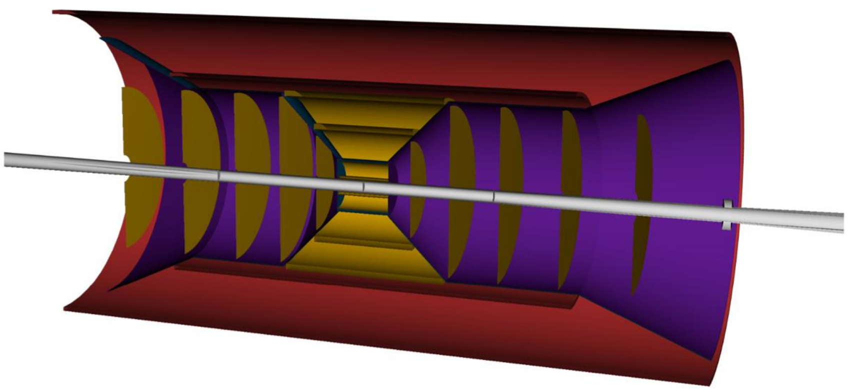


ACF being considered for ASIC glueing on flex.

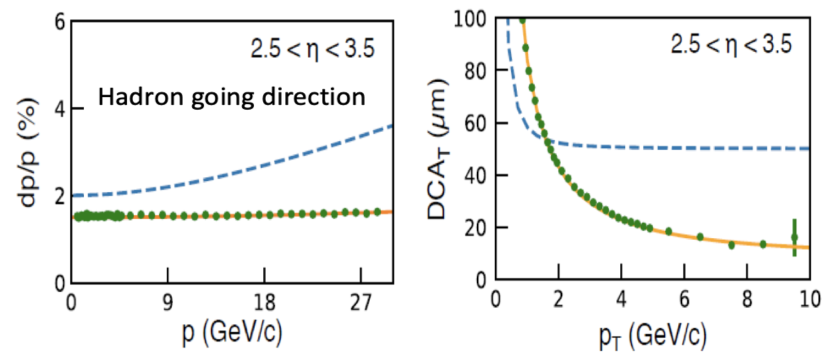
EIC vertex/tracking detector development

- The BNL Electron-Ion Collider (EIC) vertex/tracking detector ($|\eta|<3$) is under development by the EPIC collaboration.
- Current vertex/tracking detector design can meet the EIC physics requirements, and a series of detector geometry optimization and detector R&D is ongoing.
- **We welcome new collaborators to contribute to the EIC detector design and R&D towards the EIC detector construction scheduled to start in 2025!**

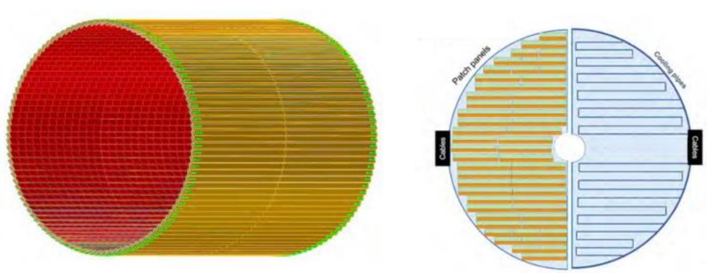
EPIC MAPS vertex/tracking detector design



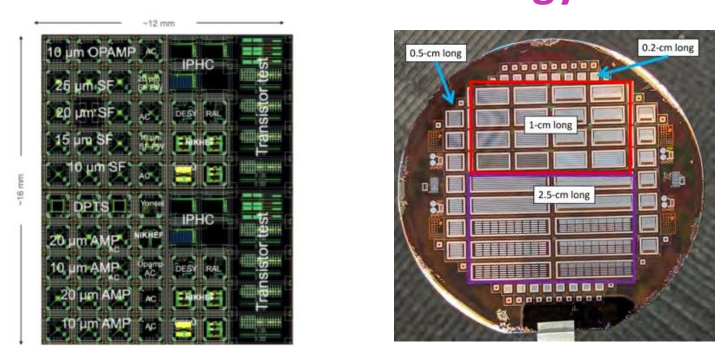
EPIC vertex/tracking performance



EPIC AC-LGAD outer tracker detector design



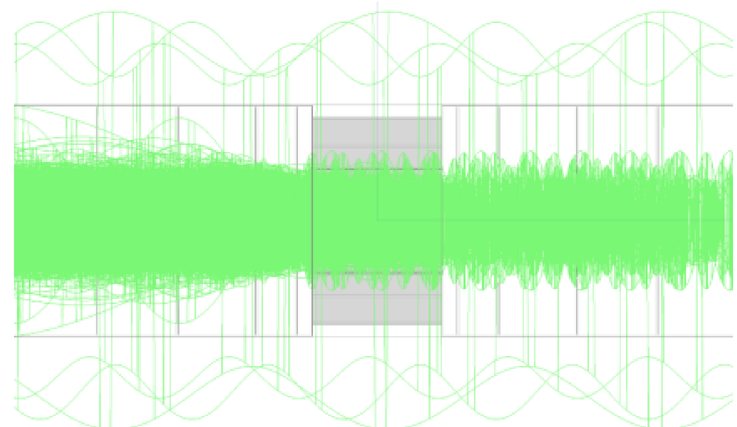
EPIC silicon detector technology candidate



Nazar bartosik

Muon Collider combines the best features of the two classes of machines:
high precision of e^+e^- colliders + **high energy reach** of *pp* colliders

↳ **the most energy-efficient machine starting from $\sqrt{s}$ = 3 TeV**

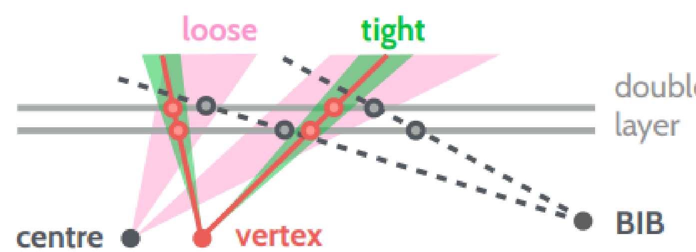


Beam Induced Background creating extreme occupancy
in the Vertex Detector up to 1K hits/cm^2
from very soft electrons $\langle p_T \rangle \sim 10$ MeV

High granularity (50×50 μm^2) **+ time resolution** (≤30 ps)
are required for effective BIB suppression after readout

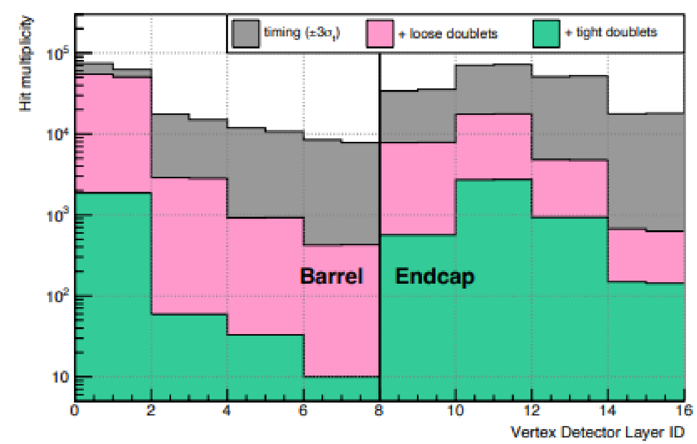
Angular information at the readout level is very important
due to BIB particles crossing at shallower angle

↳ **double-layer layout with stub readout allows to reduce occupancy by orders of magnitude**



Directions we are exploring for further optimisations:

- **single-hit BIB rejection based on cluster shapes**
- **increase of B-field for stub separation**
- **4D track reconstruction:** integrating single-hit time measurements into track seeding + fitting



Looking forward to the progress of detector R&D in this field

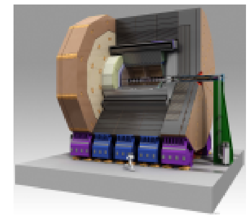
Vertexing and tracking semiconductor detectors for the ILC

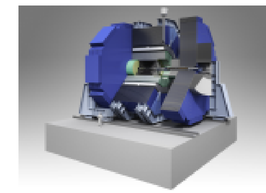
Håkan Wennlöf

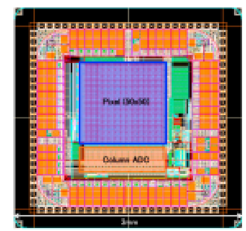
international linear collider

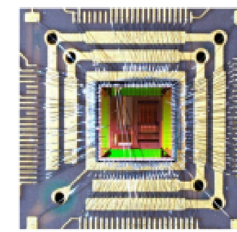
https://linearcollider.org/

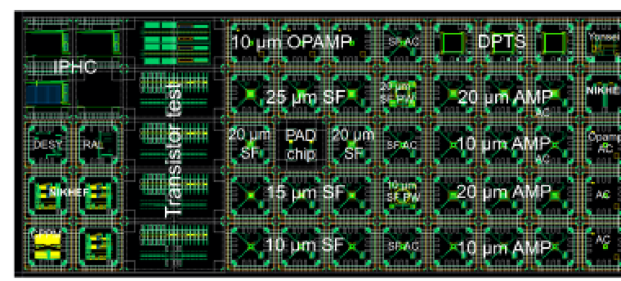
- ILC requires **low material budget** and **excellent resolution,** but **radiation is less of an issue**
- **Silicon sensors** are needed to fulfill tracking and vertexing requirements in **both proposed detector concepts**
- Many ongoing developments (too many to mention in the talk, only some select examples shown);
  - Hybrid sensors
  - SOI
  - MAPS (small and large collection electrode)
- Depleted MAPS in 180 nm and 65 nm show great promise for future capabilities
- ILC R&D has helped create useful tools, and is generic and useful for many e^+e^--collider experiments











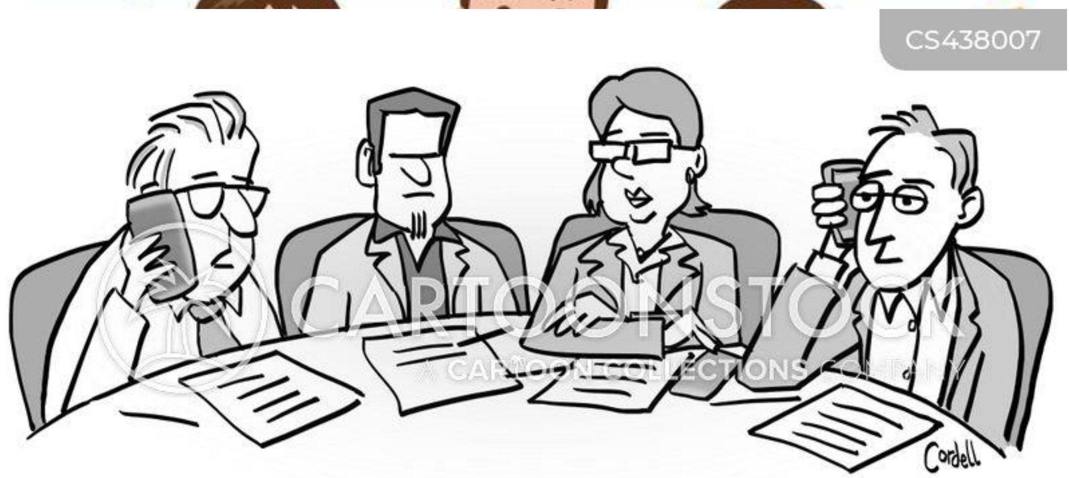
Face-to-face: good chance to know each other well, network less critical …pro

Need to fly Japan…pro/con?

My time is occupied by discussions…con

Remote is efficient and less time constraint…pro

Network mandatory…con



"Can't talk now David, I'm in a meeting – with you."

Cellars can be inhibited
Smart phones are ….
⇒ Need network

"We haven't talked for three years" by Harris & Adriano on Oct. 27, 2022 around 6 pm.

From Mainichi Shimbun

London
October 26, 2021

Tokyo
September 24, 2022

Getting back as we were …

VERTEX meetings continue





Thank you all for participating

I mean, not excursion but

Vertex2022