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AGENCIA ESTATAL DE INVESTIGACIÓN
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

IFIC's Interests in DRD3

C. Marinas
IFIC – Valencia

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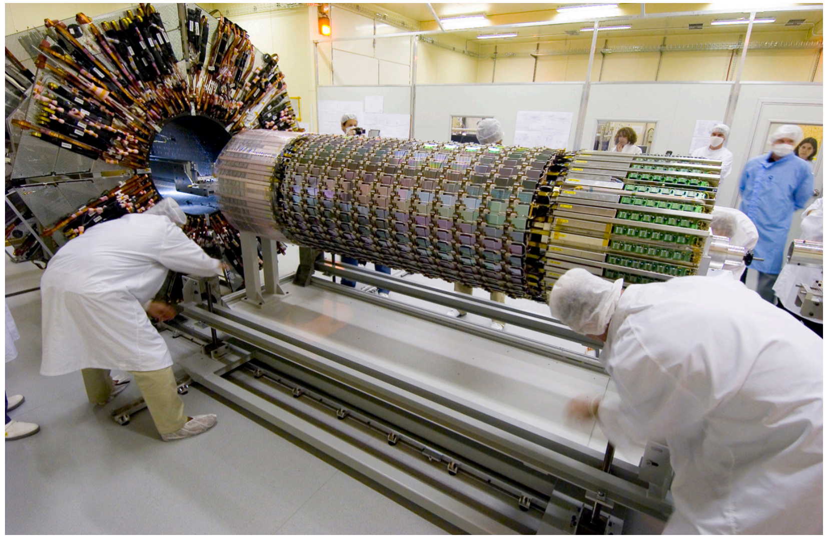
Silicon Detector Developments at IFIC

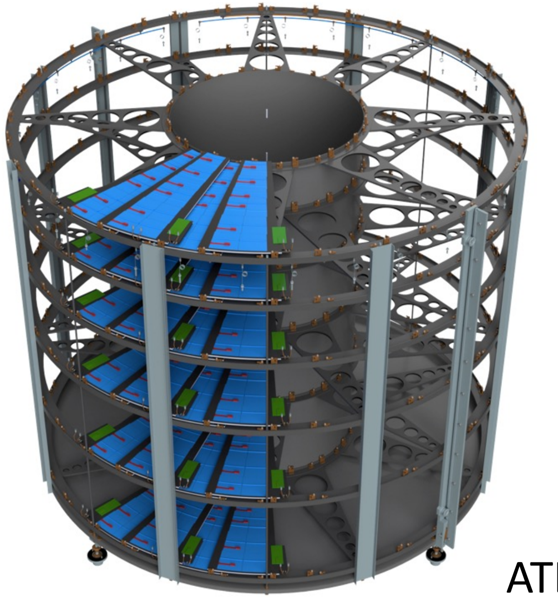
Long-standing expertise in large silicon detector systems.

Different flavors of pixel and strip technologies.

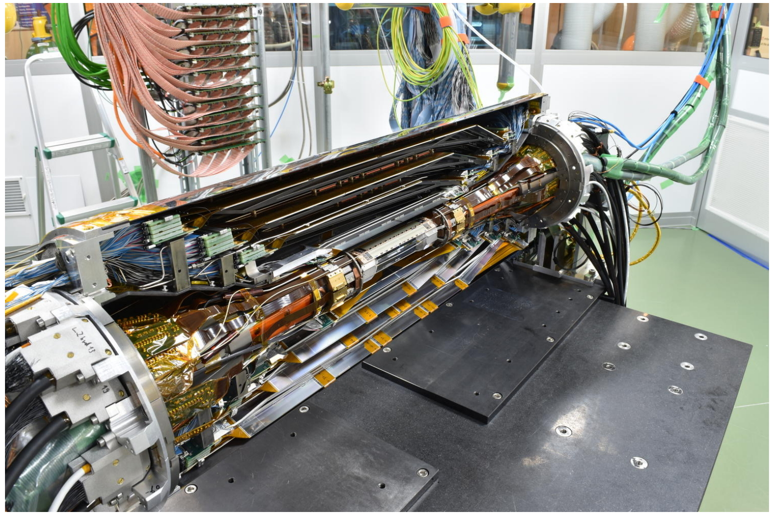
→ We can offer a full development package: *'From chips to Higgs'.*



ATLAS SCT



ATLAS ITk



Belle II PXD

DRD3 Participants

IFIC PixLab Pixel Laboratory

J. Bernabeu

C. Garcia

C. Lacasta

R. Marco

C. Marinas

S. Marti

F. Martinez

J. Mazorra

L. Molina

C. Solaz

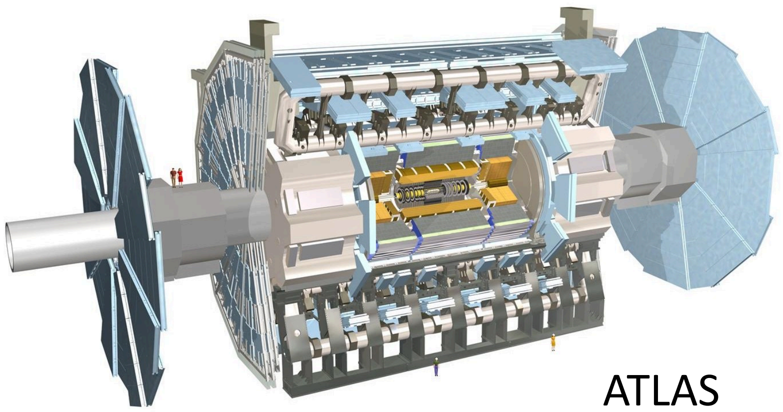
U. Soldevila

M. Vos

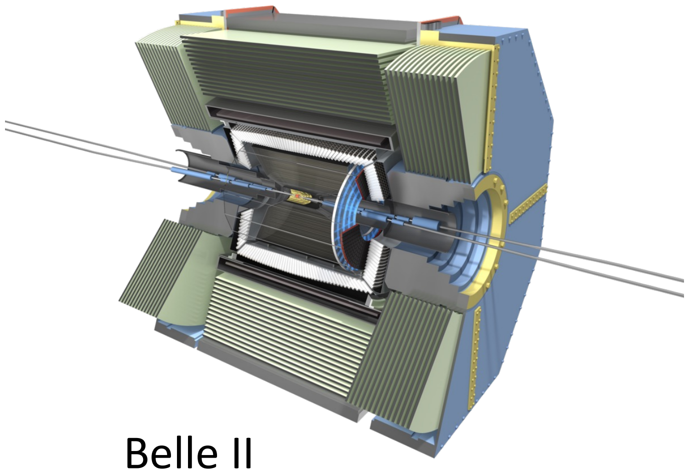
DRD3 Interests and Expertise

- Sensor design: Digital periphery, verification, …
- Detector characterization: Laboratory (static, laser and radioactive sources) and beam tests
- Development of thermomechanical solutions: FEM simulations, vibration, TFM, …
- Qualification radiation hardness: TID and NIEL, annealing, …
- Development of DAQ systems: Hardware, firmware and software
- Detector integration: Wafer level postprocessing, selective thinning, stitching, RDL, …

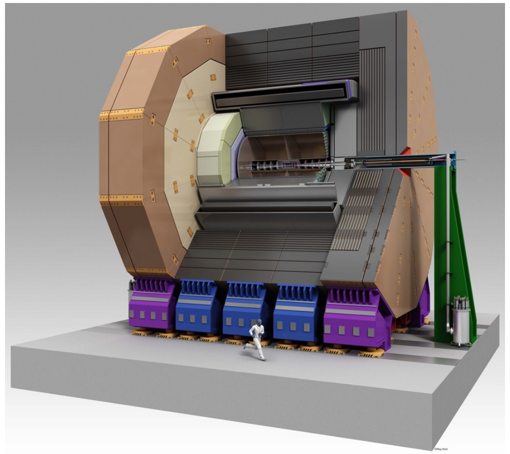
Experiments and R&D Collab. at IFIC



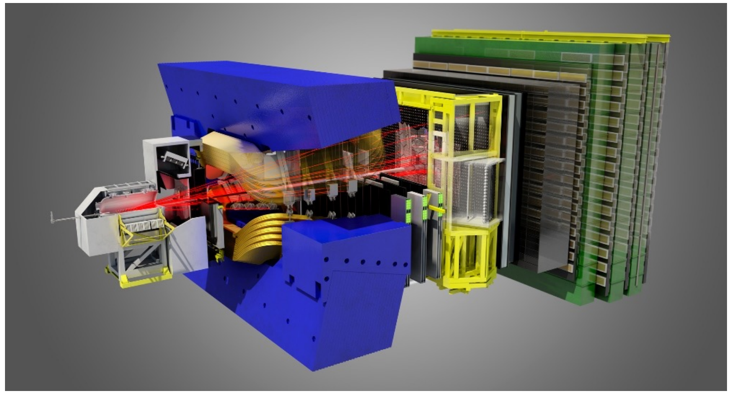
ATLAS



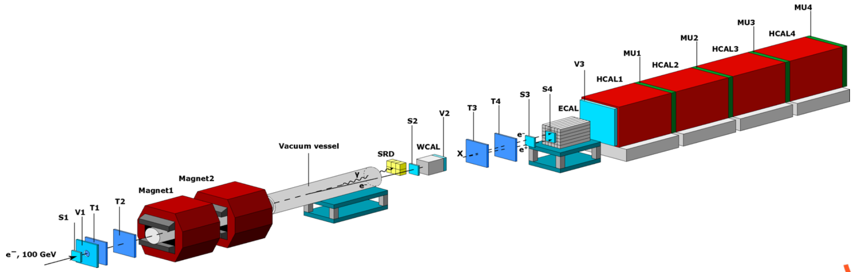
Belle II



Higgs Factories



LHCb



NA-64

There are some common needs among them…

ECFA Detector R&D Roadmap

Solid state

DRDT 3.1 Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors

DRDT 3.2 Develop solid state sensors with 4D-capabilities for tracking and calorimetry

DRDT 3.3 Extend capabilities of solid state sensors to operate at extreme fluences

DRDT 3.4 Develop full 3D-interconnection technologies for solid state devices in particle physics

- 🔴 **Must happen or main physics goals cannot be met**
- 🟠 **Important to meet several physics goals**
- 🟡 **Desirable to enhance physics reach**
- 🟢 **R&D needs being met**

IFIC's Main R&D Development Lines

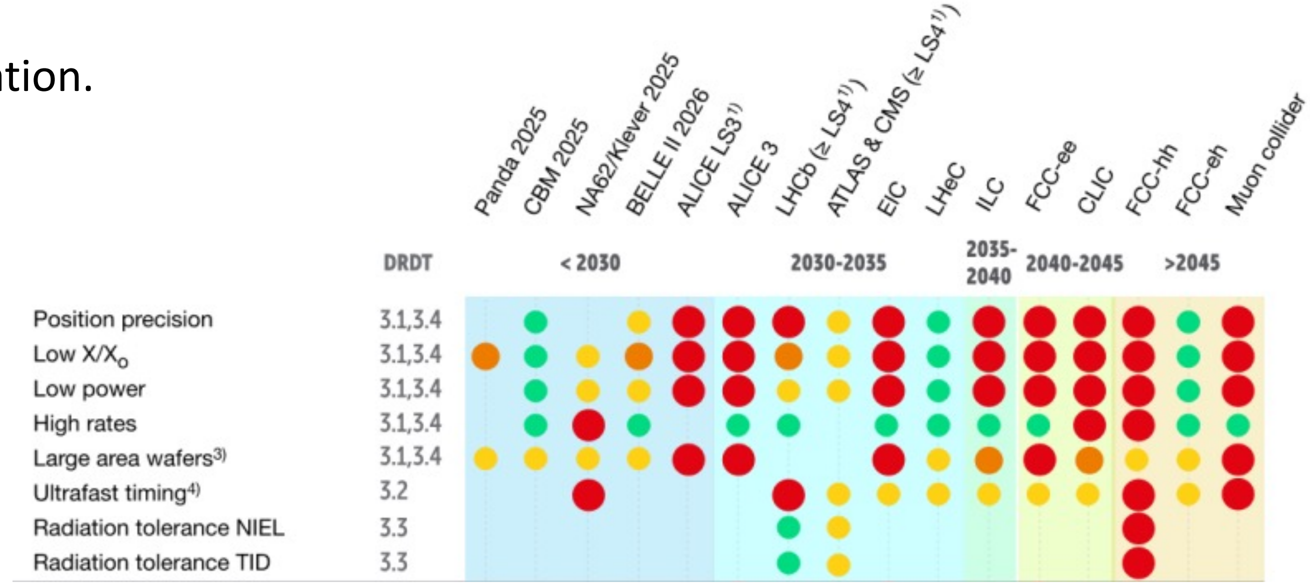
Driven by the physics experiments we are committed to:

→ Large area, ultrathin and highly granular detector systems with emphasis in timing

1) Development of high granularity DMAPS sensors.
   Mid-size technology nodes (150/180 nm). Evolving to 65 nm whenever affordable.
   $O(10)$ µm² pixel pitch, $O(10)$ ns time precision

2) Timing layers. Silicon sensors with internal amplification.
   iLGADs, SiEM, …
   $O(100)$ µm² pixel pitch, $O(10)$ ps time precision

3) Large area sensors. Wafer scale postprocessing.
   RDL, stitching, selective thinning, MCC.
   $O(10)$ cm all-silicon CMOS ladder, $O(0.1)$ % X/X_0



Must happen or main physics goals cannot be met | Important to meet several physics goals | Desirable to enhance physics reach | R&D needs being met

Summary

- Long-standing expertise in developing large vertex and trackers for particle physics experiments
- DRD3 provides the framework to develop next generation silicon detector systems
- Our interests in enabling technologies for current upgrades and future collider experiments:

  - Highly granular CMOS sensors
  - Timing layers
  - Large area ultra-transparent detectors

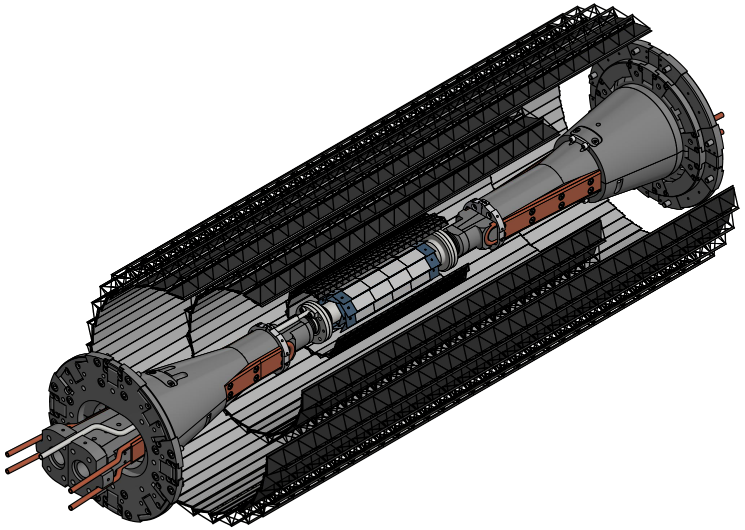
  → Well aligned with the European Strategy and being developed within a large instrumentation community

- Experimental opportunity: Leading Belle II vertex detector upgrade with CMOS sensors
  Intermediate step in technology deployment → Precision + timing

Belle II Upgrade: VTX - DMAPS

SuperKEKB and Belle II LS2 Upgrade (2028)

- 5 straight layers barrel, using CMOS pixel sensors (~1 m^2)
- Low material : 0.1% X_0 (L1+L2) - 0.4% (L3) - 0.8% X_0 (L4+L5)
- Moderate pixel pitch ~ 40 μm^2
- Fast integration time 25-100 ns
- iVTX: innermost 2 layers, self-supported, air cooled
- oVTX: 3 outer layers, CF structure, water cooled
- Overall service reduction and operation simplification



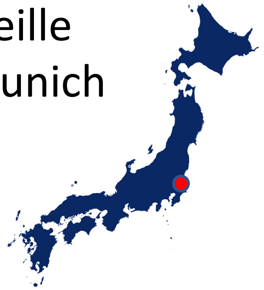
Belle II VTX Upgrade - Organization

Belle II VTX collaboration

- 6 countries
- 12 institutions
- 73 members

- France: Paris, Strasbourg, Marseille
- Germany: Bonn, Goettingen, Munich
- Austria: Vienna
- Italy: Pisa, Bergamo, Pavia
- Japan: KEK

→ One additional country currently applying



Steering Group

Project Leader
C. Marinas (Valencia)

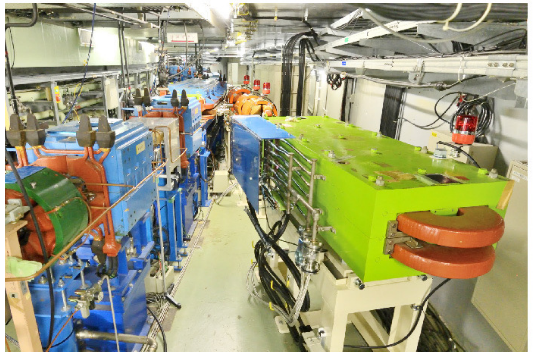
WG1: Software, performance, benchmarking
B. Schwenker (Goettingen)

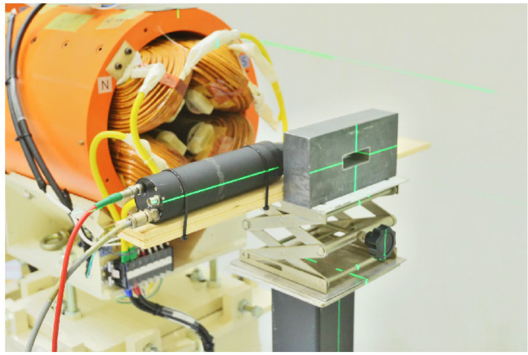
WG2: Chip design, testing
J. Baudot (Strasbourg)

WG3: System integration, services
S. Bettarini (Pisa)

Beam Line (KEK) Detector Development

IFIC PixLab Pixel Laboratory





Plans to develop within DRD3 a beam telescope system

- 6 DMAPS planes
- 2 timing layers

→ Technology demonstrator Belle II VTX upgrade

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THANK YOU

Leadership

J. Bernabeu

C. Lacasta

C. Marinas

L. Molina

C. Solaz

M. Vos

- J. Bernabeu:
  ATLAS ITk-Strips Service Coordinator
- C. Lacasta:
  ATLAS ITk-Strips Local Supports Coordinator
- C. Marinas:
  Belle II Technical Coordinator, Inner Detector Upgrade coordinator, Belle II CMOS leader
- L. Molina:
  NA-64 Deputy Technical Coordinator
- C. Solaz:
  ATLAS ITk-Strips Deputy Production Manager
- M. Vos:
  AIDAInnova WP10 coordinator. ECFA Detector Roadmap TF8 Panel member.

Current Funding Related to DRD3

- Outlining sensors for future experiments in large radiation environments and the ITk strip upgrade of ATLAS

C. Lacasta, C. Marinas. PID2021-126327OB-C21. Proyectos Generación de Conocimiento 2021. Agencia Estatal de Investigación.

- Sensores monolíticos para búsqueda de nueva física

C. Marinas, L. Molina. ASFAE/2022/016. Programa I+D+I de tecnologías avanzadas para la exploración del universo y sus componentes 2022. GVA.

- Ultralight pixel detectors for new physics searches in the flavor sector at the Belle II experiment

C. Marinas. RYC2020-029875-I. Ayudas Ramón y Cajal 2020. Agencia Estatal de Investigación.

- Ultrathin CMOS pixel modules for precision tracking in high rate e+e- environment

C. Marinas. AIDAinnova. Advancement and Innovation for Detectors at Accelerators. H2020. EU.

- R&D for particle physics detectors and silicon sensors

M. Vos. AIDAinnova. Advancement and Innovation for Detectors at Accelerators. H2020. EU.

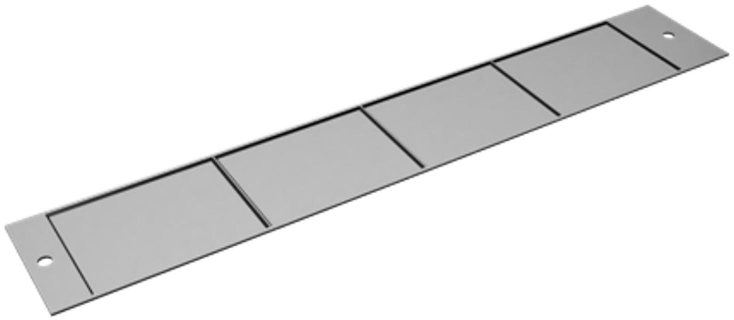
CMOS R&D Structure in Europe

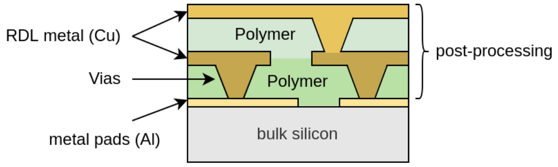
- CERN
  - Driving activities with TPSCO 65 nm process
- RD50 – CMOS group
  - IFIC R&D with process LF-150 nm
- AIDAInnova - WP5 DMAPS
  - IFIC High granularity DMAPS (Belle II and Higgs factories)
  - Radiation hard DMAPS (LHC upgrades, future hadron colliders)
- Experiments-project / process
  - IFIC TowerJazz 180 nm: Belle II, NA-64, FLC, LHCb
  - HVCMOS-TSI 180 nm: Mu3e, CEPC, LHCb, PANDA
  - LF-150 nm: ARCADIA-project
  - TPSCo 65 nm: ALICE, EIC

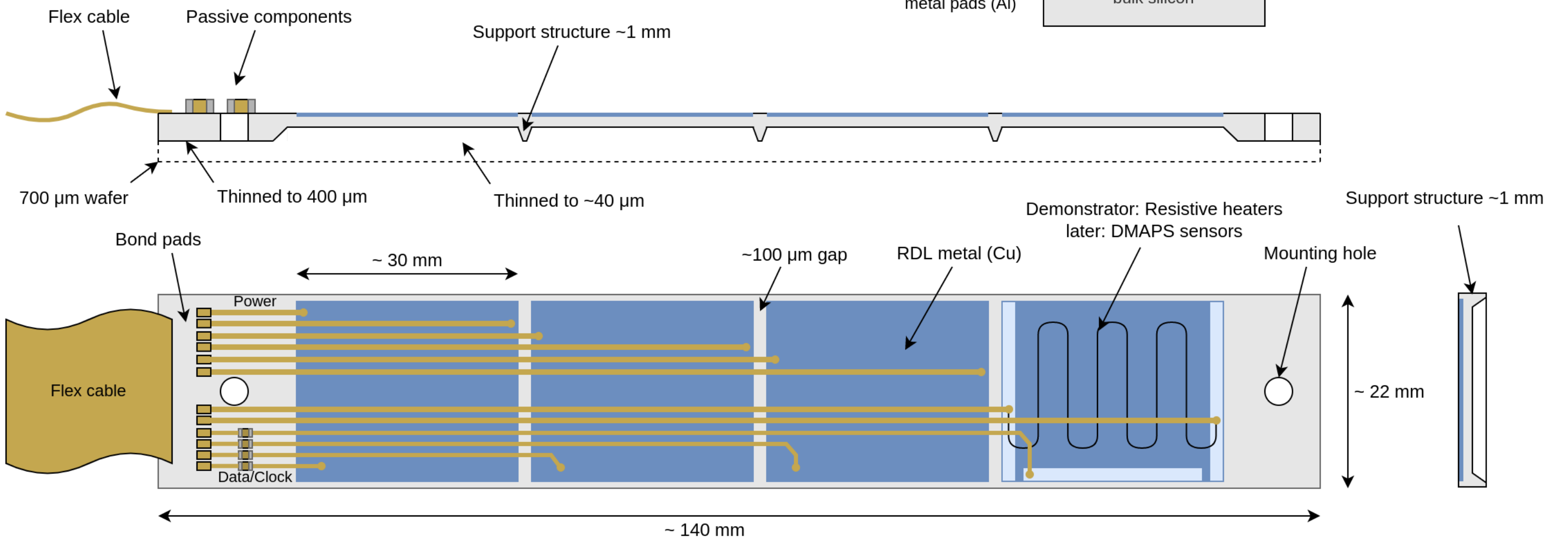
IFIC: CMOS developments as enabling technology for upgrades and future collider experiments

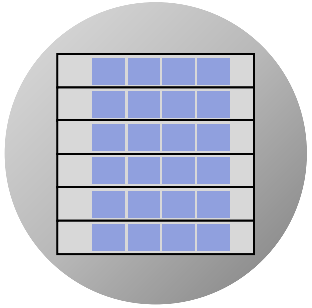
iVTX Ladder Demonstrator

- Multi-reticle all-silicon CMOS ladder
- Demonstrator designed and reviewed together with IZM
    - Process evaluation (RDL, thinning)
    - Thermal studies, mechanical stability
    - Signal quality, power delivery, component assembly

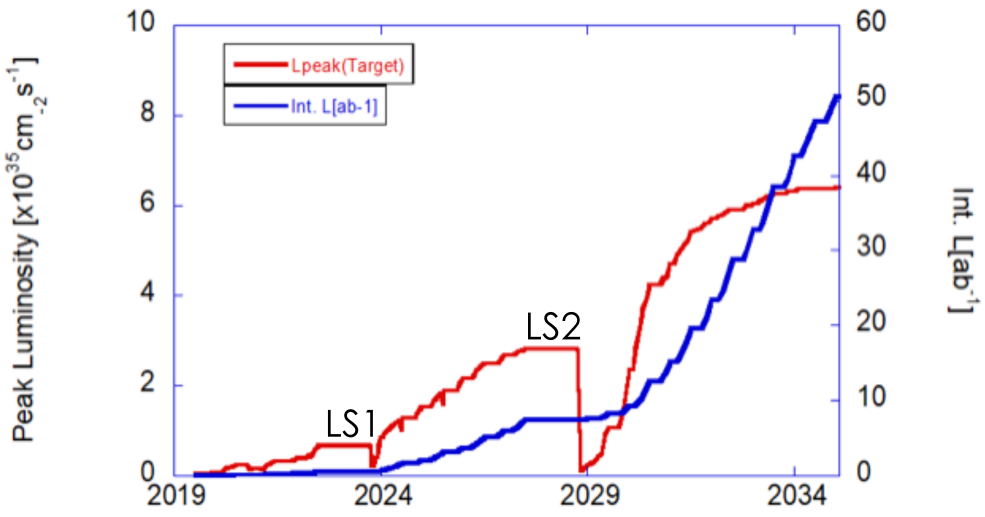








Belle II Upgrade Program



LS1: Detector consolidation
LS2: IR and detector upgrades

→ Currently: CDR preparation

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Snowmass Whitepaper:
The Belle II Detector Upgrade Program

Belle II Collaboration

March 23, 2022

Abstract

We describe the planned near-term and potential longer-term upgrades of the Belle II detector at the SuperKEKB electron-positron collider in Tsukuba, Japan. These upgrades will allow increasingly sensitive searches for possible new physics beyond the Standard Model in flavor, tau, electroweak and dark sector physics that are both complementary to and competitive with the LHC and other experiments. We encourage the instrumentation-frontier community to contribute and study upgrade ideas as part of the Snowmass process.

Requirements for VXD Upgrade

Upgrade motivation:

- Cope with larger background activity
- Improve momentum and impact parameter resolution in low p_T region
- Simplify tracking chain with all layers involved
- Operation without special modes nor data reduction

Key sensor specifications:

- Pixel pitch 30-40 µm
- Integration time $\lesssim$100 ns
- Power dissipation $\lesssim 200\ \mathrm{mW/cm^2}$

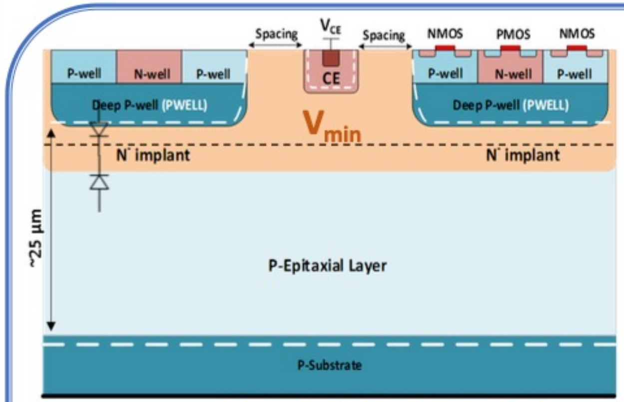
Improve physics reach per ab^{-1}

Radius range	14 – 135 mm

Tracking & Vertexing performance	
Single point resolution	< 15 µm
Material budget	0.2% X_0 / 0.7% X_0 inner- / outer- layer

Robustness against high radiation environment (innermost layer)	
Hit rate	~ 120 MHz/cm²
Total ionizing dose	~ 10 Mrad/year
NIEL fluence	~ 5e13 n_{eq}/cm²/year

TJ-Monopix Family



W. Snoeys et al. https://doi.org/10.1016/j.nima.2017.07.046

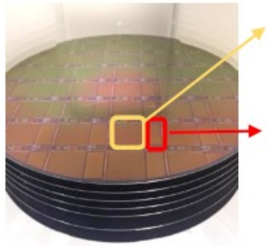
$C_d \leq 3fF$

$P \approx \frac{S}{N} \approx \frac{Q}{C_d}$

DMAPS in TJ 180 nm: Concept

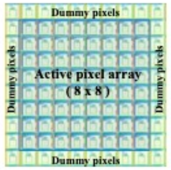
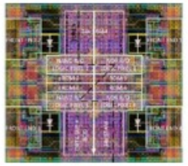
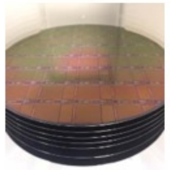
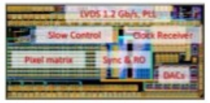
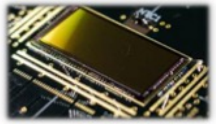
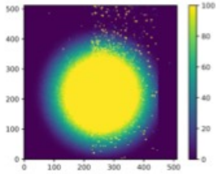
- Small sensor capacitance (Cd)
  - Key for low power/low noise
- Radiation tolerance challenges
  - Modified process
  - Small pixel size
- Design challenges
  - Compact, low power FE
  - Compact, efficient R/O

Large scale demonstrator chip development



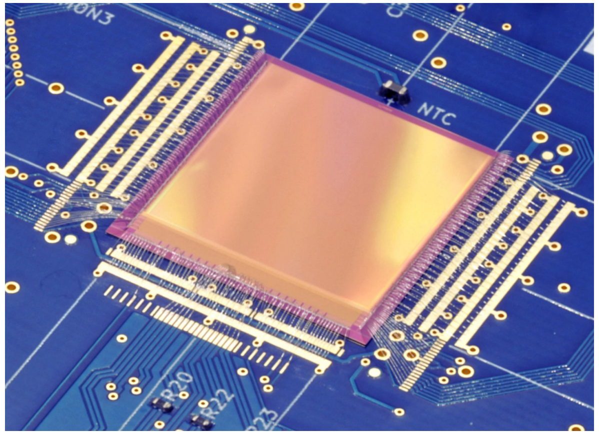
- MALTA
  - Asynchronous readout
- TJ-Monopix1
  - Synchronous column-drain R/O

- Process modification enhancements, Cz substrate ⟹ improved efficiency
- TJ-Monopix2: Improved full-scale DMAPS

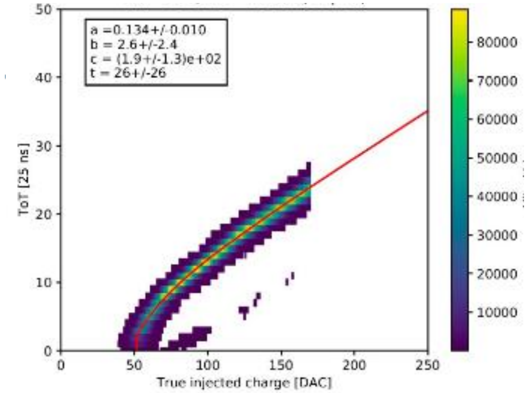
TJ-Investigator characterization	*TJ-Monopix1* & MALTA Design	*TJ-Monopix1* & MALTA Submission	Mini-MALTA sub. with process fixes	*TJ-Monopix1* resub. process fixes & Cz	*TJ-Monopix2* & *MALTA2* Design	*TJ-Monopix2* & MALTA2 Submission	*TJ-Monopix2* Characterization	*"OBELIX"* Design
								Full scale System-ready: LDO, CDR, memory etc.
Q2 2016	Q4/2016	Q3/2017	Q3/2018	Q2/2019	Q2/2019	Q3/2020	Present	Future plans

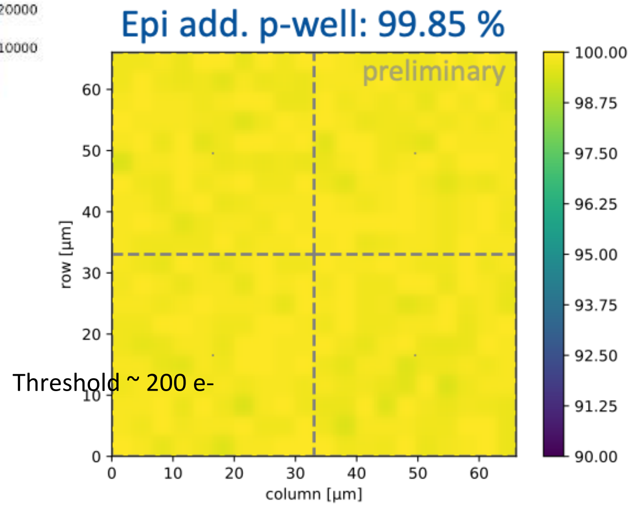
TJ-Monopix2 Characterization

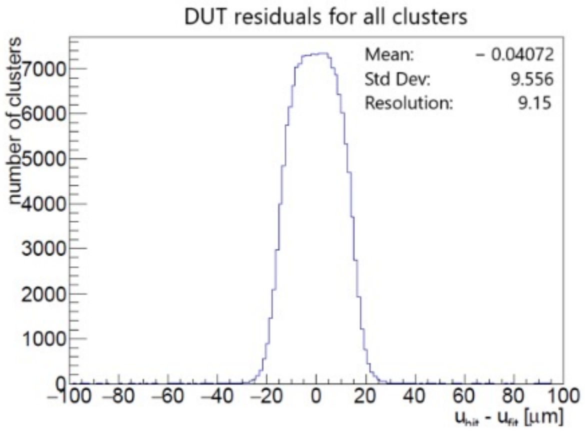
- TJ-Monopix2 as forerunner of OBELIX
    - 33x33 µm^2 pitch, 25 ns integration, 2x2 cm^2 matrix
    - 7 bit ToT information, 3 bit in-pixel threshold tuning
    - Various sensing volume thickness (CZ-bulk, epi-30 µm)



- Characterisation on-going
    - In-laboratory
        - Threshold / noise
        - ToT calibration
    - In-beam (DESY, 5 GeV electrons)
        - Efficiency ~99%
        - Position resolution ~9 µm

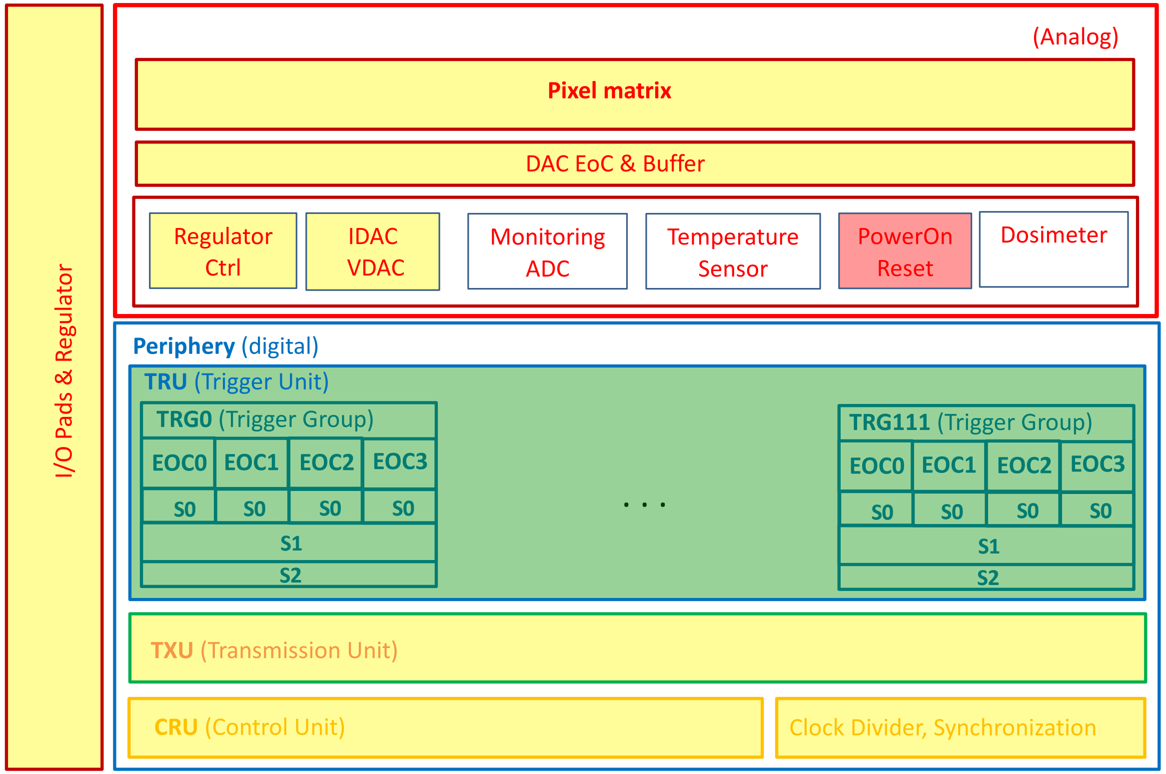






OBELIX

- Pixel matrix
  - Inherited from TJ-Monopix2
    - Radiation tolerance granted
  - Pitch possibly increased from 33 to <40 µm
    - For robustness & power dissipation
  - Frequency ~10-30 MHz
    - Time-stamp precision 100 or 30 ns
- Power pads
  - Power regulators
    - Simplified system integration
  - But area limited to <150 um
- Periphery
  - New end-of-column adapted to Belle II trigger
    - Timestamped hits stored in memories
    - Readout when timestamp matched with trigger
  - Single output at 320 MHz
    - Average bandwidth/sensor 140 Mbits/s
  - Biasing generation and monitoring



Not yet planned

Not started

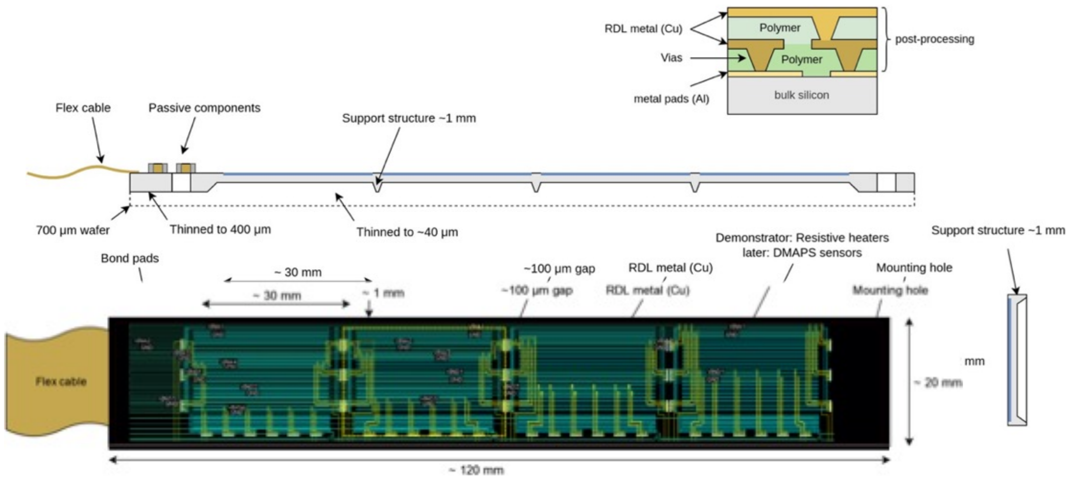
Started

Ready, waiting integration

→ OBELIX-1 design progressing well

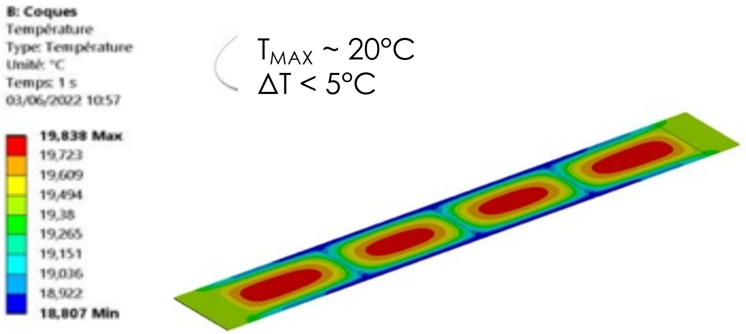
iVTX Inner Layer Concept

- All-silicon module < 0.15 % X_0
  - 4 contiguous sensors diced as a block from the wafer
  - Redistribution layer for interconnection
  - Heterogeneous thinning for thinness & stiffness



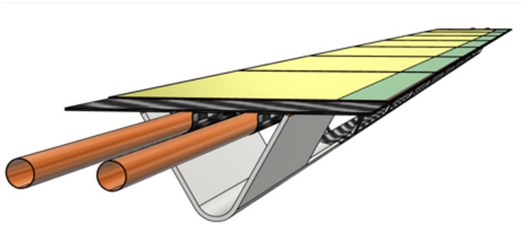
- Prototyping
  - With existing 10 cm^2 HV-CMOS ladder
    - Planarity demonstration
  - On-going at IZM-Berlin with dummy Si
    - True iVTX geometry → Spring 2023

- Simulation on cooling
  - Dry air cooling 15°C
  - Assume 200 mW/cm^2



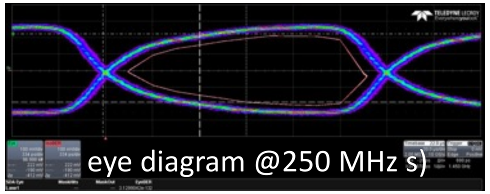
oVTX Outer Layer Concept

- Long ladders
  - Evolving from ALICE-ITS2
    - Carbon-fiber truss support frame
    - Cold-plate with water coolant
    - Long-flex for power & data



- L3-4, radius 4-9 cm, length < 50 cm
  - Single sensor row, ~0.5 % X_0
- L5, radius 14 cm, length 70 cm
  - Double sensor rows , ~0.8 % X_0

- Prototypes for L5 under test
  - Deformation & vibration
    - Max sagitta ~500 µm
    - First resonance f=250 Hz
  - Signal propagation
  - Cooling at T_{room} ~24°C
    - Leakless water flow at T_{in} = 10°C
    - Heaters dissipating 200 mW/cm²
    - 22°C < $T_{sensors}$ < 26°C


eye diagram @250 MHz s)

cmarinas@ific.uv.es