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ASFAE ASTROFÍSICA Y FÍSICA DE ALTAS ENERGÍAS

R&D instrumentation for experiments beyond HL-LHC

ASFAE/2022/013
D. Esperante
N. Fuster

ASFAE/2022/015
A. Irles
M. Vos

ASFAE/2022/016
C. Mariñas
L. Molina Bueno

ASFAE/2022/019
G. Llosa
I. Torres

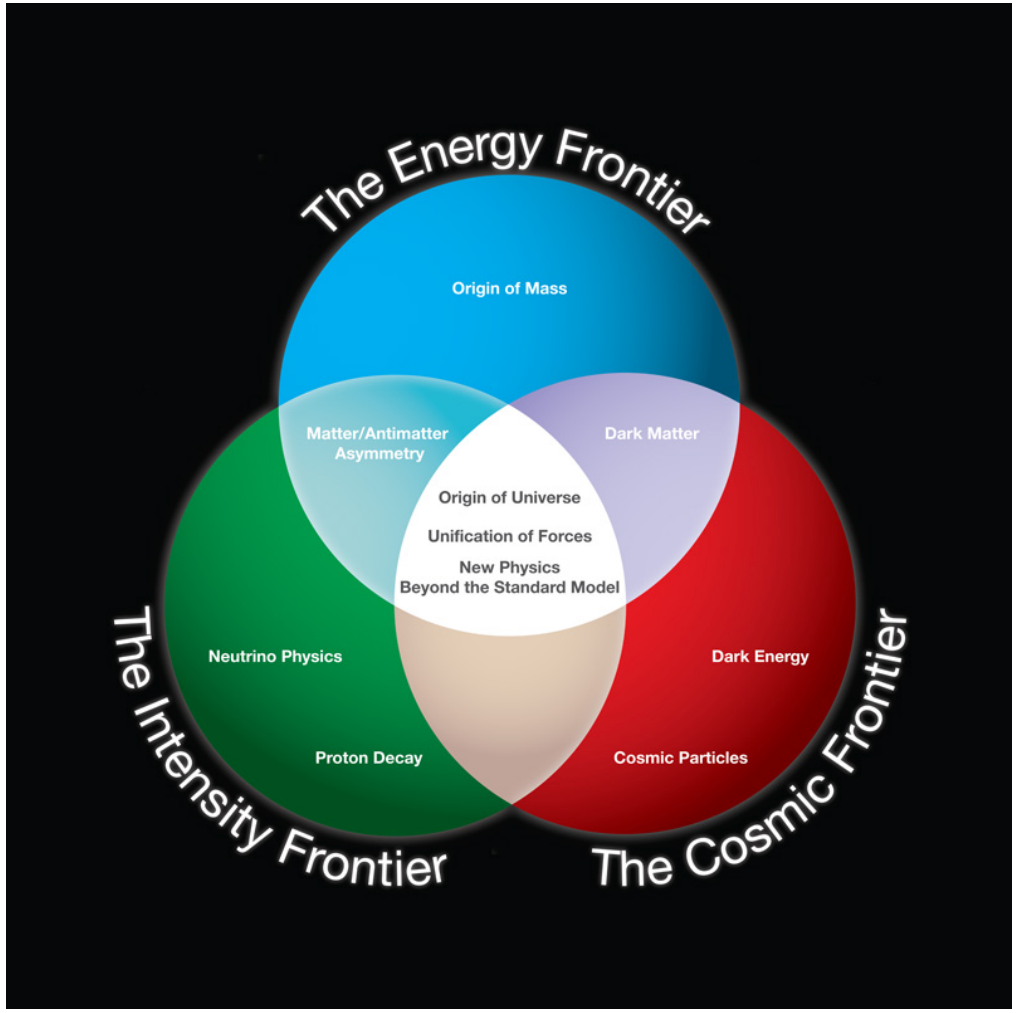
Laura Molina Bueno[1]

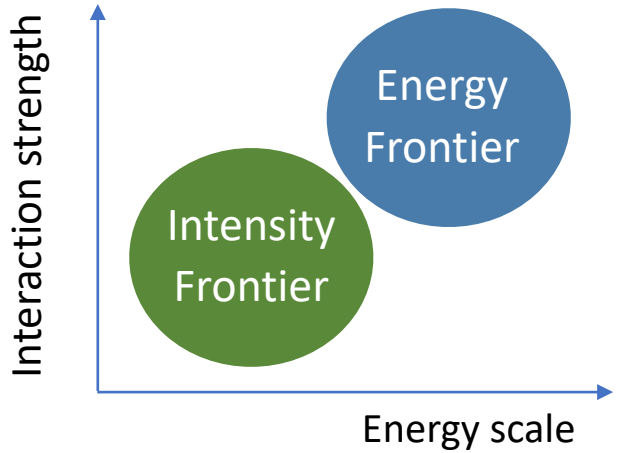
[1]Instituto de Física Corpuscular (CSIC/UV)

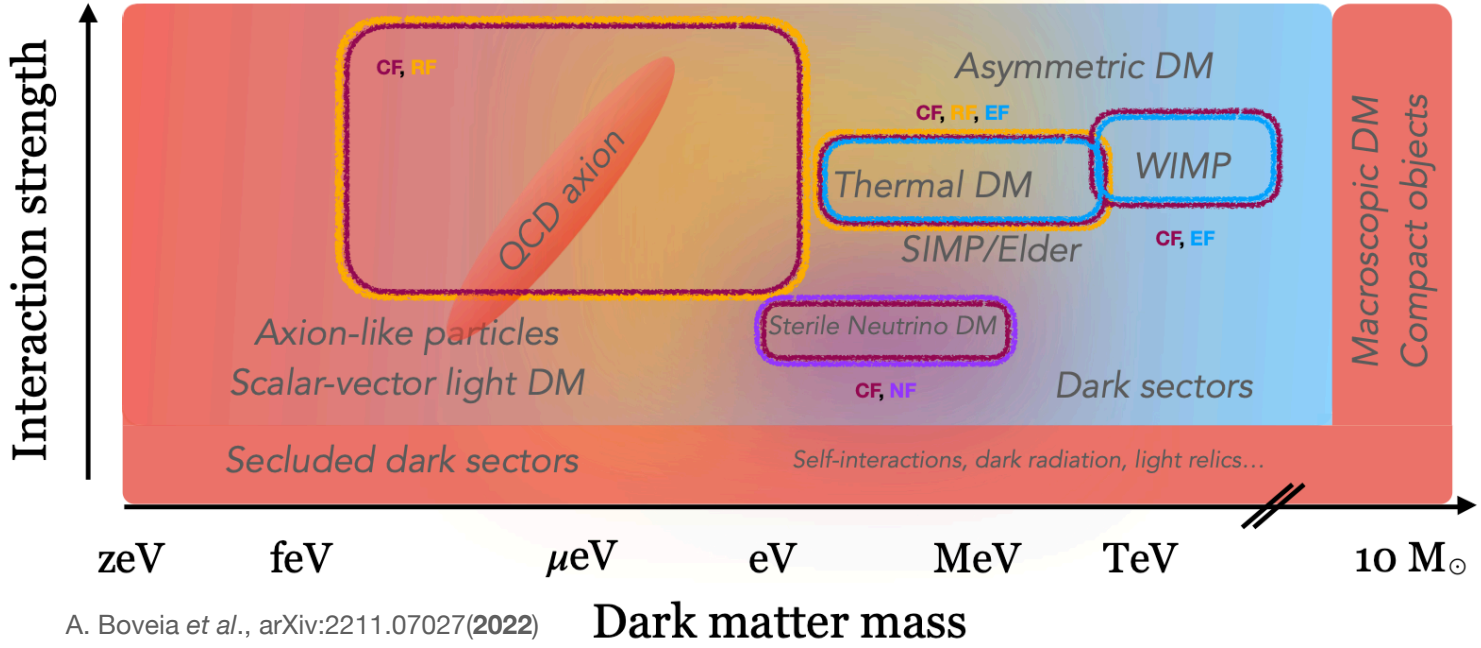
ASTROHEP-PPCC24, 5-7 Junio 2024, Zaragoza

IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
VNIVERSITAT DE VALÈNCIA

Motivation







A. Boveia *et al*., arXiv:2211.07027(**2022**)

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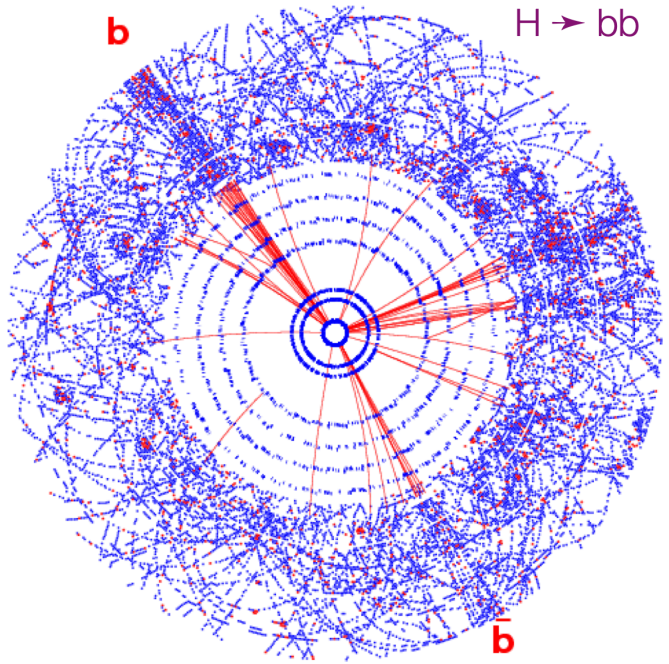
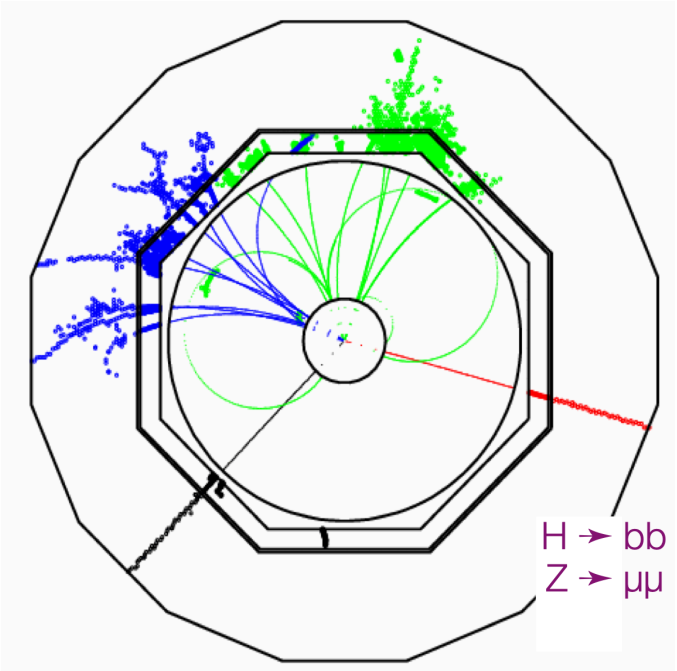
Motivation



pp ➔ H + X



ee ➔ H + Z

From H.C. Schultz-Coulon, 6th Linear collider school 2016

Requirements: *excellent energy reconstruction, particle identification, track and vertex resolution, timing,…*
Challenges: *high rates, high radiation levels, high occupancy,…*

Future Accelerator Roadmap

<2030	SPS fixed target (CERN) Belle II (SuperKEKB) Other fixed target, FAIR (hep) PIP-II/LBNF/DUNE/Hyper-K ALICE LS3
2030-2035	ALICE 3 LHCb (>LS4) EIC LHeC
2035-2040	ILC
2040-2045	FCC-ee CLIC
>2045	FCC-hh FCC-eh Muon collider

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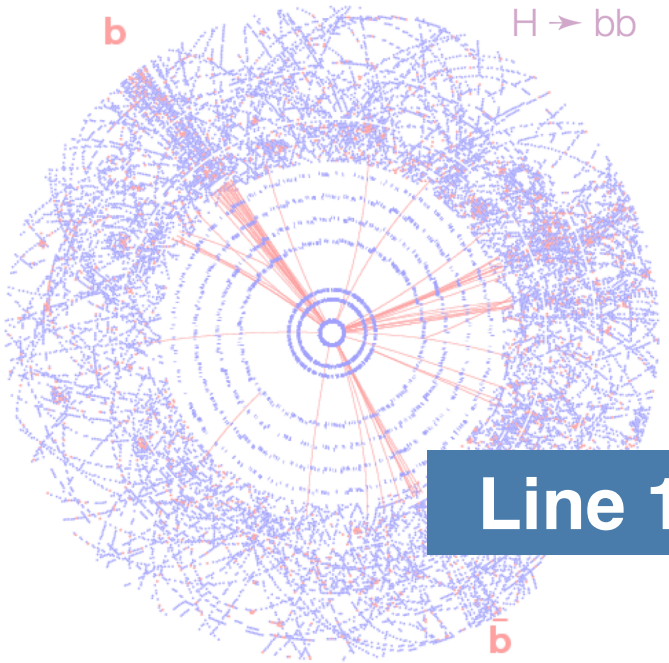
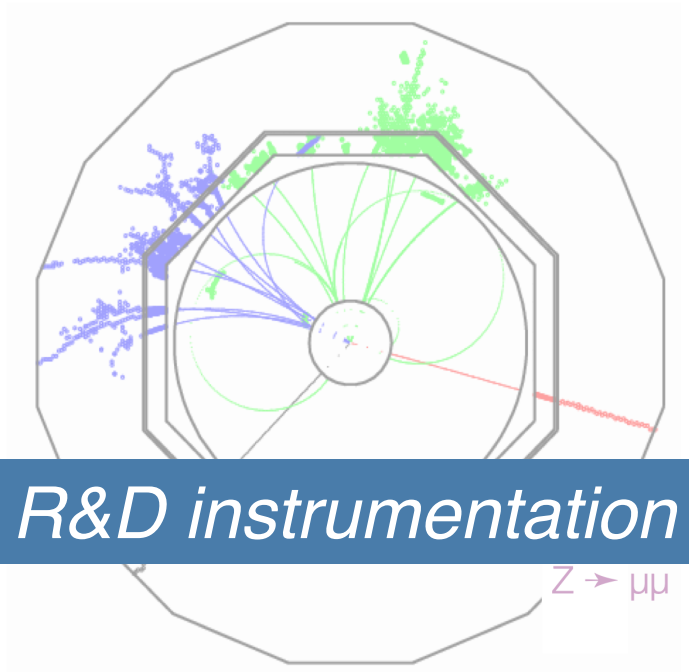
Motivation





$pp \rightarrow H + X$ $ee \rightarrow H + Z$

From H.C. Schultz-Coulon, 6th Linear collider school 2016

Line 1: ***R&D instrumentation for future detectors***

Requirements: *excellent energy reconstruction, particle identification, track and vertex resolution, timing,…*
Challenges: *high rates, high radiation levels, high occupancy,…*

Future Accelerator Roadmap

<2030	SPS fixed target (CERN) Belle II (SuperKEKB) Other fixed target, FAIR (hep) PIP-II/LBNF/DUNE/Hyper-K ALICE LS3
2030-2035	ALICE 3 LHCb (>LS4) EIC LHeC
2035-2	ILC
2040-2045	FCC-ee CLIC
>2045	FCC-hh FCC-eh Muon collider

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R&D

Fundamental Physics

Standard Model

Dark Matter

Higgs Boson

Axions

Flavour

Gravitational waves

Applications

Medical Physics

Industry

Accelerator developments

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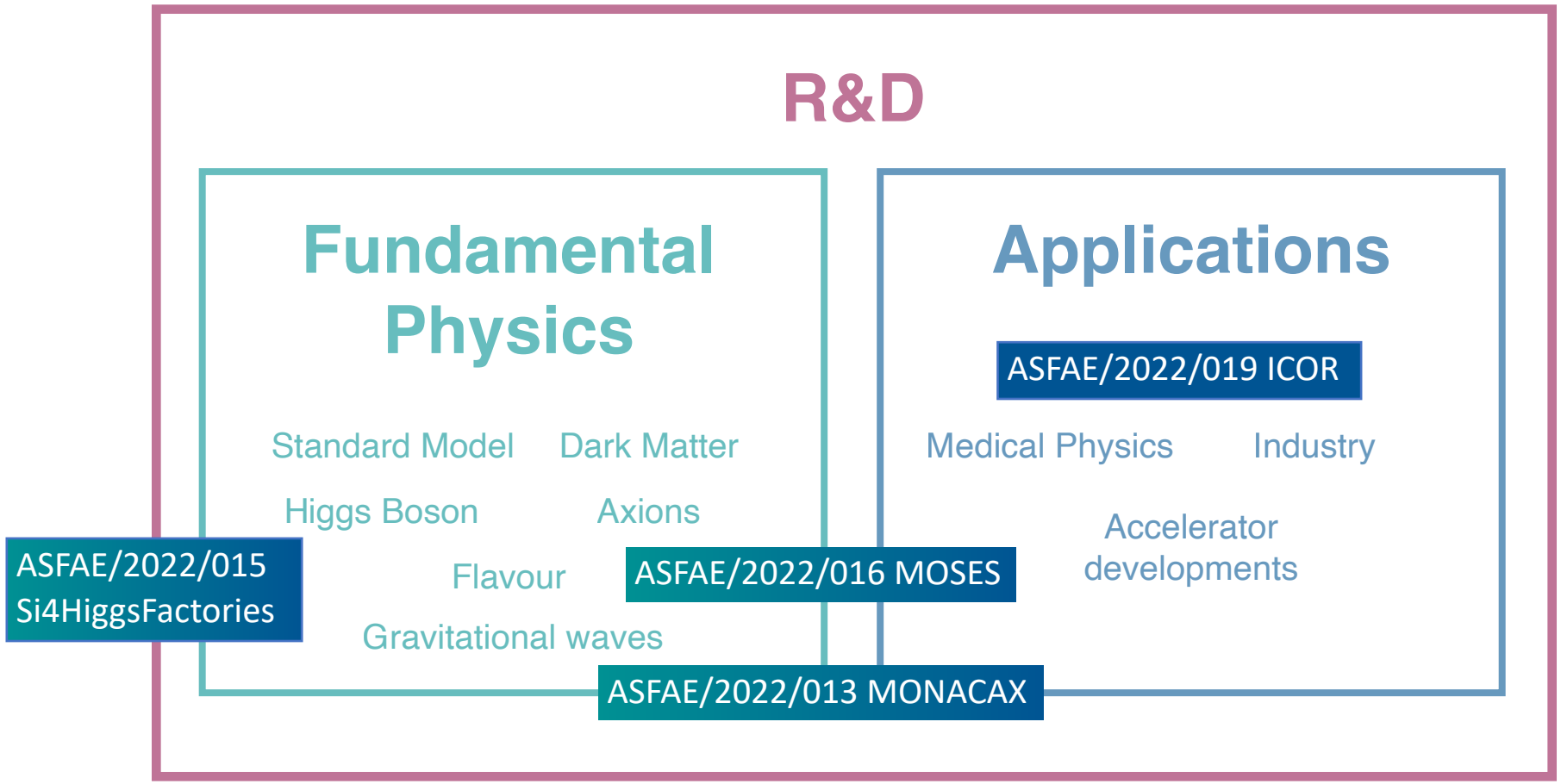

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R&D

Fundamental Physics

Standard Model — Dark Matter

Higgs Boson — Axions

Flavour

Gravitational waves

Applications

Medical Physics — Industry

Accelerator developments

ASFAE/2022/016 MOSES *C. Mariñas, L. Molina*

To develop a demonstrator of a pixel monolithic sensor based on CMOS technology to be used in vertex (VTX) and tracking detectors in Belle II (SuperKEKB, KEK, Japan) and NA64 (SPS, CERN, Switzerland).

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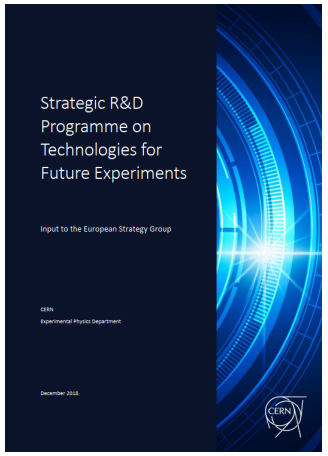
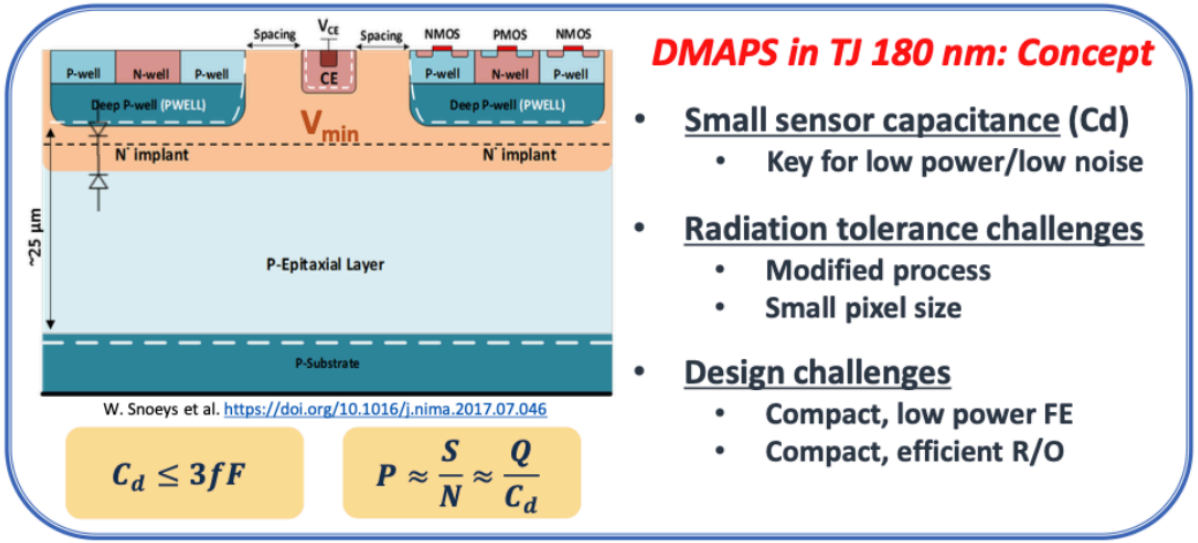
Monolithic sensors for New Physics

CERN R&D new technological program

Detector research and developments themes (DRDTs) (DRD6, WG1)



Depleted Monolithic Active Pixel Sensors (DMAPS)



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**

Requirements

- very high spatial resolution;
- Good timing performances;
- high data rate;
- high radiation tolerance;
- keeping an affordable cost;
- low mass;
- covering large areas;
- reducing power;

➡ **and ultimately combining these requirements in one single sensor device.**

From https://indico.cern.ch/event/1356910/contributions/5712986/attachments/2812248/4909140/DRD3.pdf

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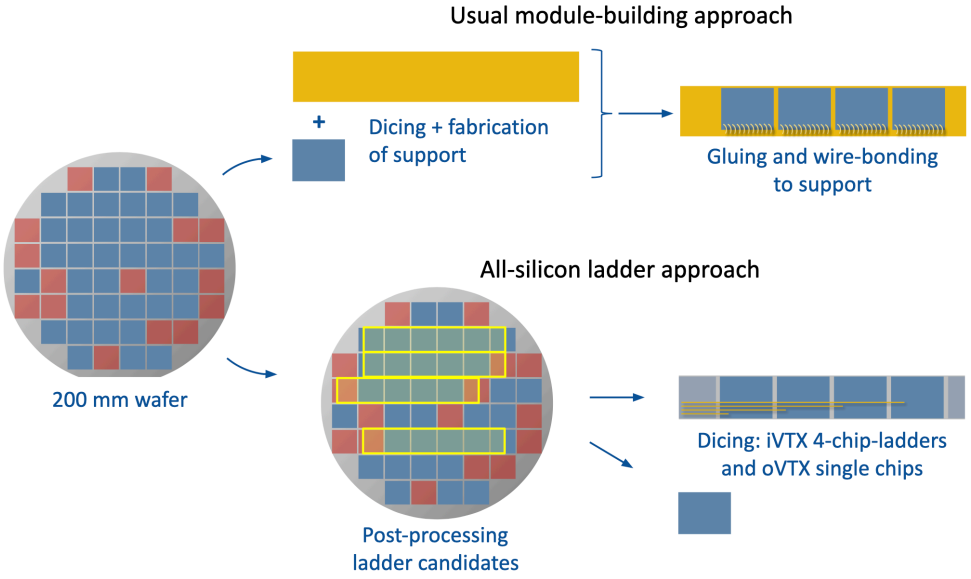
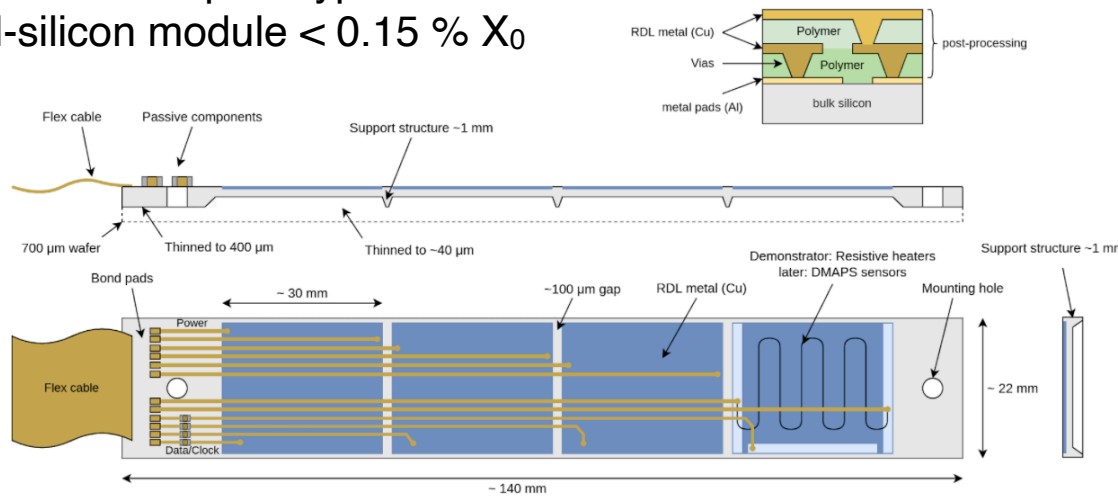
Monolithic sensors for New Physics



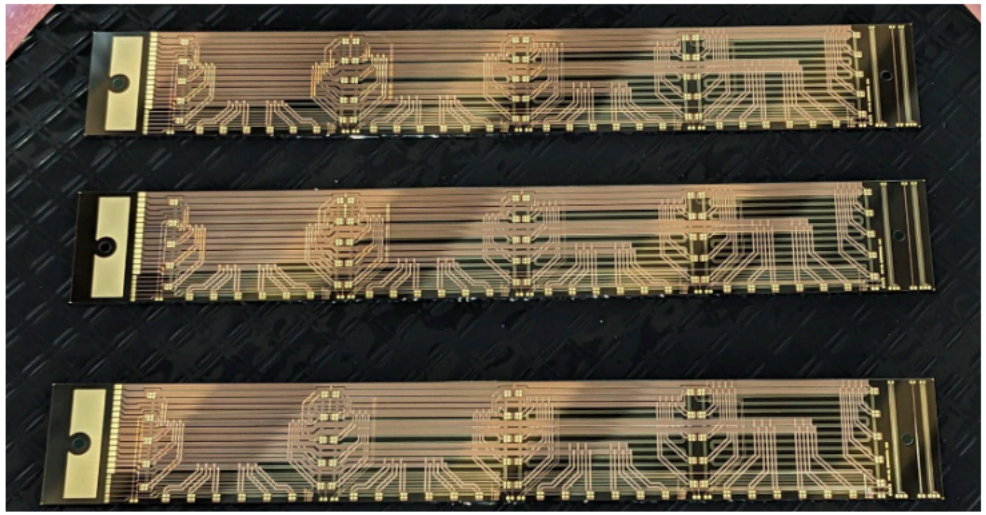
iVTX Ladder prototype
All-silicon module < 0.15 % X_0



Project goals and current status

- Characterisation of CMOS sensors TJ-Monopix2 irradiated in the laboratory and at test beams at KEK and CERN.
- Development of CMOS monolithic ladders: ***First demonstrator produced under electrical, mechanical and thermal tests.***
- Evaluation of the impact in physics results: ***First vertex detector performance evaluation suggesting robustness in background level and improvements in resolution and tracking efficiency.***

- First RDL demonstrators: 8 Wafers (725 μm, 400 μm, 300 μm)



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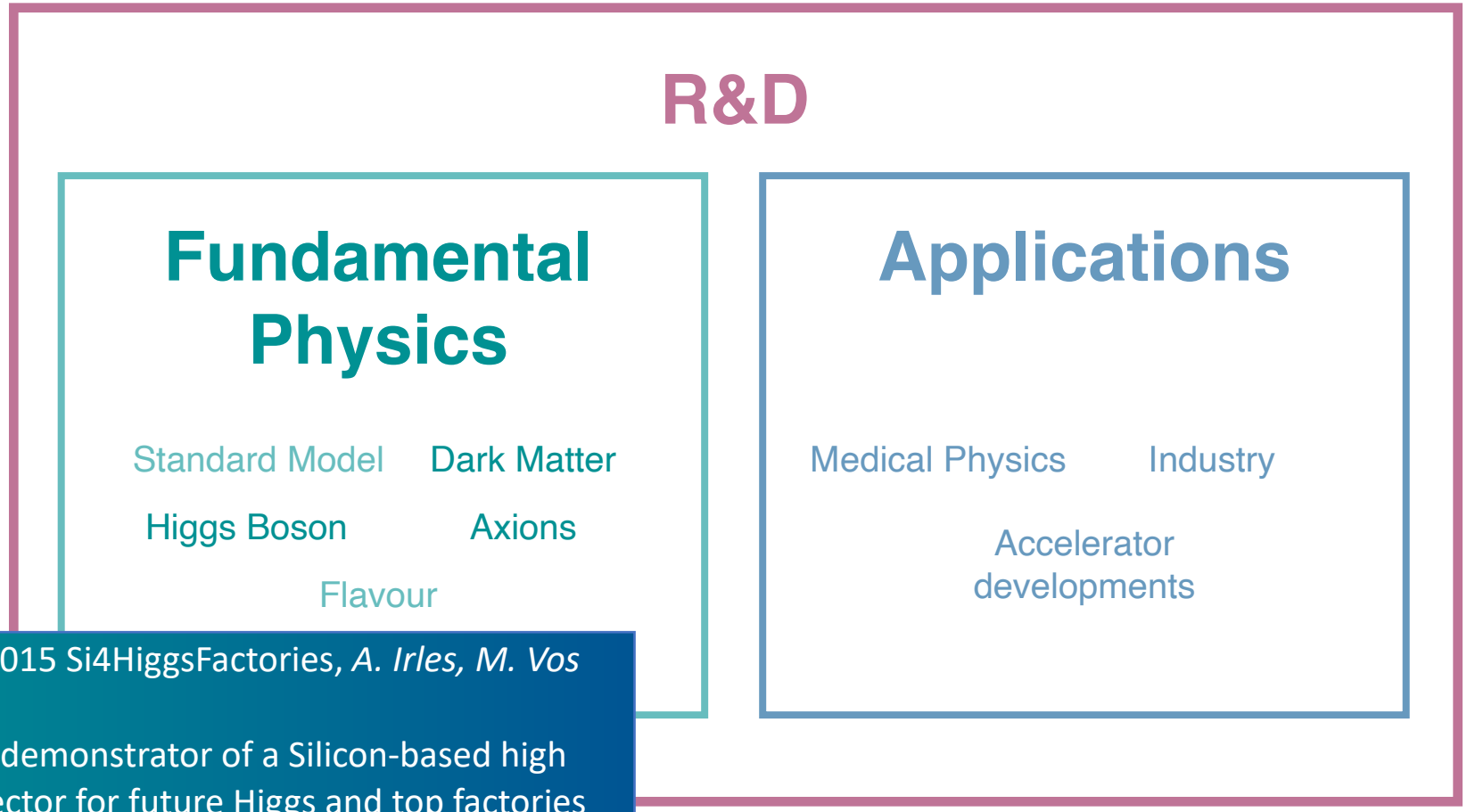

ASFAE/2022/015 Si4HiggsFactories, *A. Irles, M. Vos*

To develop a demonstrator of a Silicon-based high granular detector for future Higgs and top factories

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Silicon-based high granular detectors

Electromagnetic calorimeters for several experiments:

- *HL-LHC Upgrade of existing detectors*
- *Higgs factories*
- *Strong field QED experiments as LUXE*
- *Dark Photon and ALPs experiments as EBES (KEK) and Lohengrin (Uni Bonn), LUXE-NPOD*

Requirements:

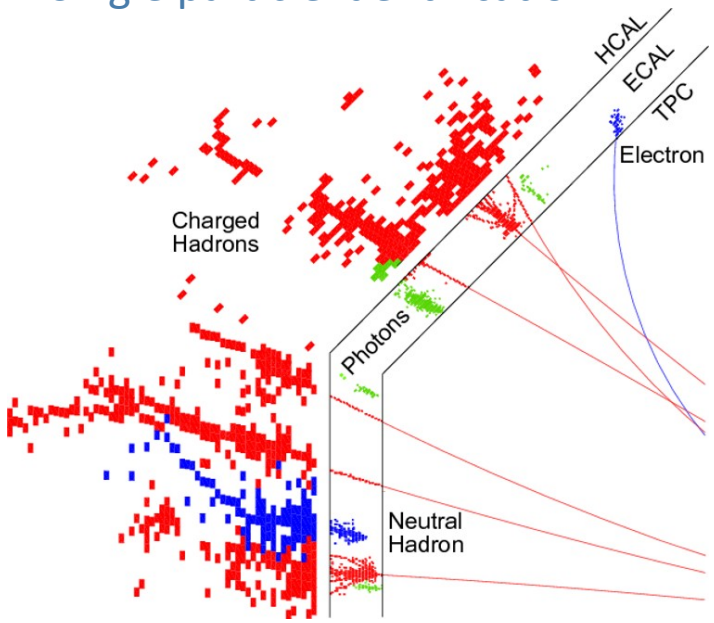
- high granular and compact sandwich calorimeters (i.e. silicon + tungsten)
- Fully embedded electronics and minimal molière radius

Two approaches:

- Fully embedded electronics (CALICE-type)
- Ultra compact design (FCAL-type) to ensure minimal Molière Radius (RM) of about ~10 mm (nearly the tungsten RM) → 1 mm between tungsten planes

Particle Flow detectors

- Separation of charged and neutral signals in the calorimeters
- Precise tracking measurement
- Single particle identification



$$E = E_{ECAL} + E_{HCAL} \xrightarrow{\text{Particle Flow}} E_{Charged} + E\gamma + E_{h0}$$

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Silicon-based high granular detectors

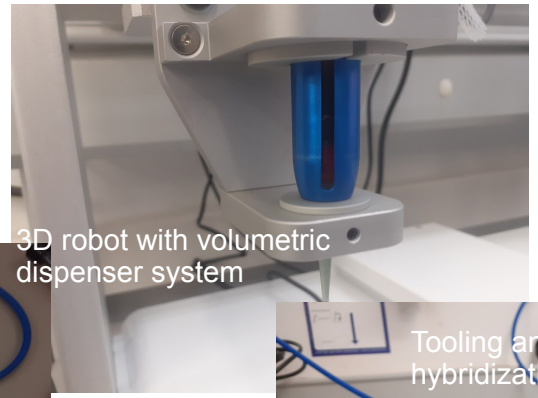
Project goals:

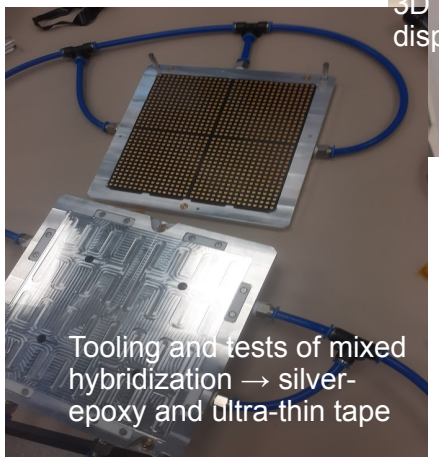
- Contribution to CALICE, FCAL. *Aligned with ECFA – R&D roadmap, the goals of DRD6 and ASFAE 1.2.*
- R&D on different techniques for sensor – electronics hybridization. I*n collaboration with: Tel Aviv, Krakow, Warsaw, Orsay institutes*
- Optimisation studies for future Higgs and Top factories

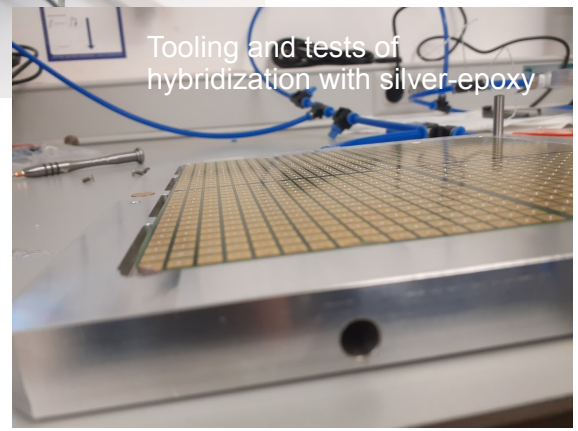
Current status:

- ***IFIC:*** center for module assembly and validation, for beam test coordination and for building the demonstrator
  - R&D on hybridization and small prototype production
  - Demonstrator (full modules assembled and tested in beam facilities): 2024-2025


Dry cabinet, curing oven


3D robot with volumetric dispenser system


Tooling and tests of mixed hybridization → silver-epoxy and ultra-thin tape


Tooling and tests of hybridization with silver-epoxy


New installation at IFIC (to be finished in March/Abril 2024)

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Applications

Medical Physics

Industry

Accelerator developments

ASFAE/2022/013 MONACAX, *D. Esperante, N. Fuster*

Radio Frequency technologies for beam position monitors in accelerators and detection of dark matter axions

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Radio Frequency technology developments

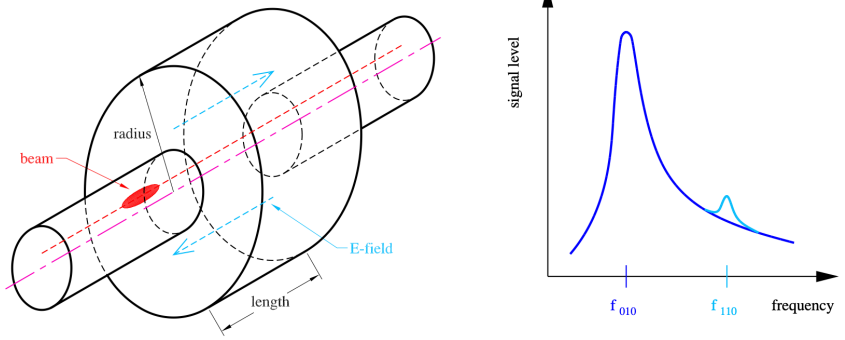
1. Development of a Beam Position Monitor (BPM) to determine the transversal position of a beam

Context: the Main Linac (ML) of the International Linear Collider Project (ILC)

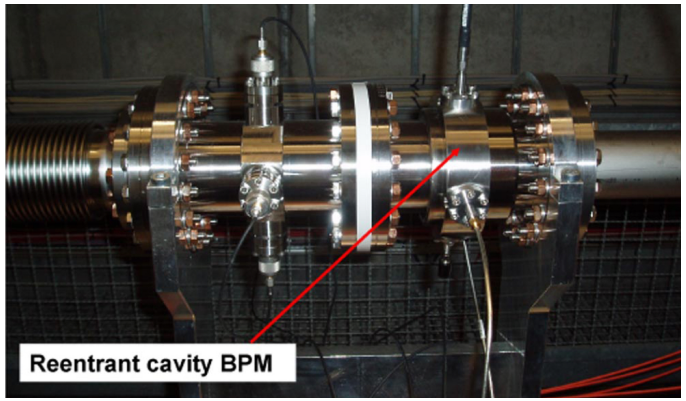
Requirements:

- spacial resolution < 1 μm and temporal resolution < 396 ns (6ns) ILC (STF)
- cryogenic and UV conditions
- mechanical attachment to a Super Conducting quadrupole in the ML (cryogenic environment)

From here



Cavity BPMs work under the principle of detection of special field configurations on a resonant geometry crossing the beam pipe



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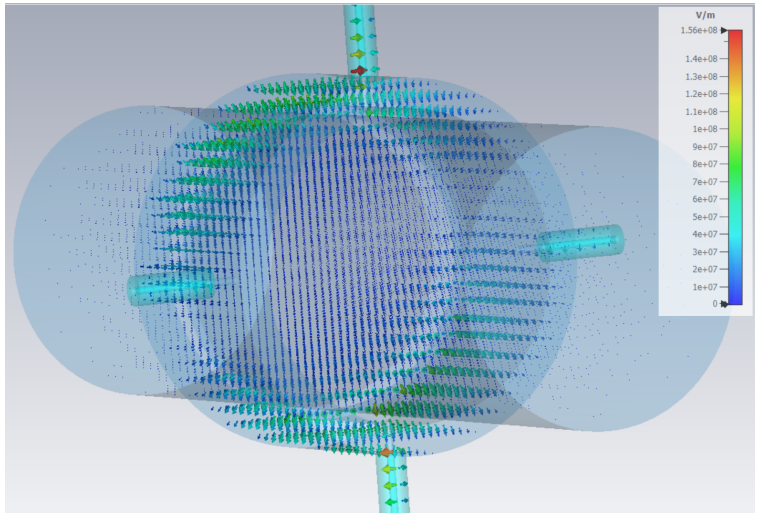
Radio Frequency technology developments

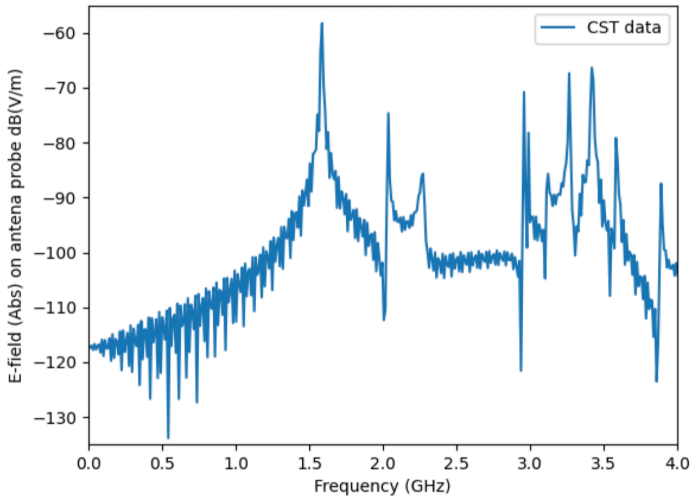
Project goals:

1) Electromagnetic (EM) design studies, data acquisition system development and BPM manufacturing
2) Test of the BPM without beam at the RF laboratory at IFIC
3) Test of the BPM + electronics with beam at ATF (KEK, Japan)
4) Final tests at STF (KEK, Japan) with beam and cryogenic conditions



Current status:

- Performance and EM design studies with simulations: *parametric studies to evaluate the influence of the geometry on the performance of the BPM*
- Data acquisition and electronics design



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Radio Frequency technology developments

Project goals:

Development of microwave and milimeter-wave of haloscopes and cavities for detection of dark matter axions and high-frequency gravitational waves.

See more details in D. Ibañez's talk on Thursday!

Work developed for several experiments:

-RADES (X-band 8 – 12 GHz , m_a ~10 – 100 μeV)

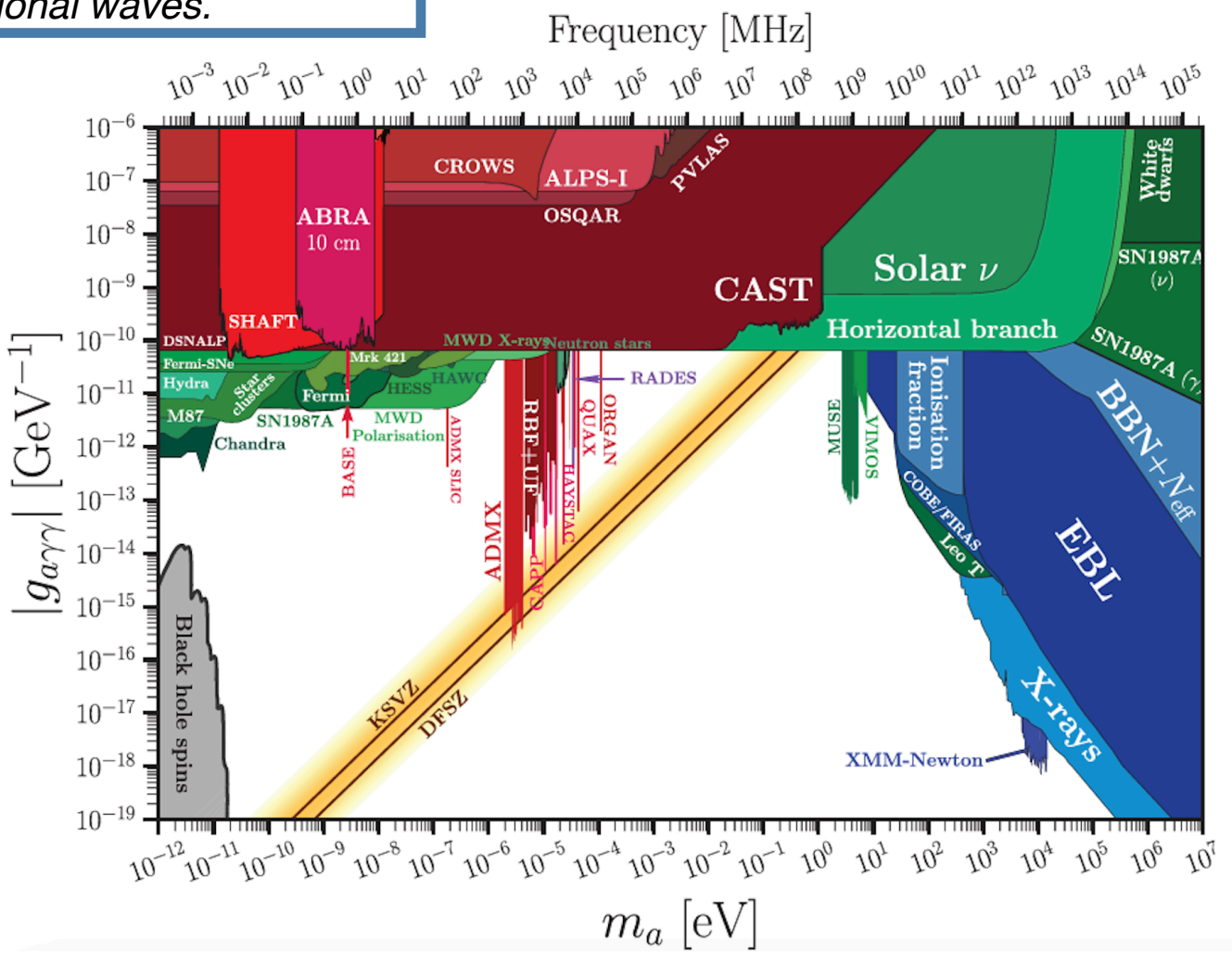
-CADEX (W-band 90 – 110 GHz, m_a ~330 – 460 μeV)

-Baby-IAXO (250 – 450 MHz, m_a ~1 – 2 μeV)

Main focus in:

- Analysis of the electromagnetic decay of dark matter axions by means of full-wave modal techniques
- Impact of directional sensitivity on the axion detection
- Application of interferometric techniques well-known in radioastronomy for the increase of signal-to-noise ratio

➡ Development of the cavity haloscopes



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ASFAE/2022/019 ICOR
G. Llosa, I. Torres

Medical Physics

Industry

Accelerator developments

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Compton imaging for Radionuclide therapy

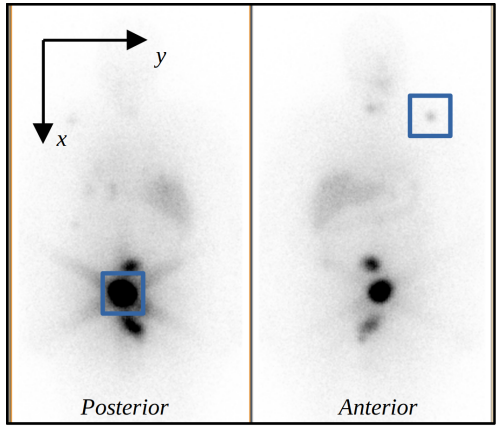
Development, improvement and tests of Compton camera performance with scintillators and a silicon scatterer.

- Radionuclide therapy is expanding due to its good results.
- Imaging can be used to visualize their distribution in the body and carry out dosimetry employing secondary gamma radiation.
- ***Challenge:*** *photon energies and activities are not optimized for gamma cameras*. Particularly complicated for alpha emitting radionuclides due to low activities and high photon energies.

➡ **New approach:** *To use Compton cameras, initially developed for astroparticles physics, to overcome these difficulties.*

See more details in G. Losa's talk on Thursday!

Collaboration between the IRIS group (IFIC) and Hospital La Fe (Valencia).



Gamma camera images of a patient treated with ^{131}I-NaI for treatment assessment and dosimetry.

http://ific.uv.es/iris

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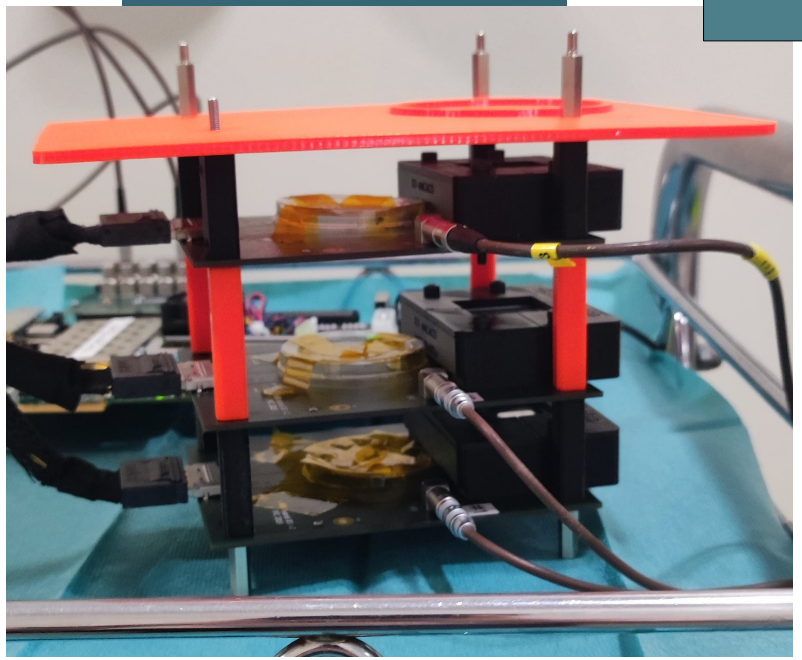
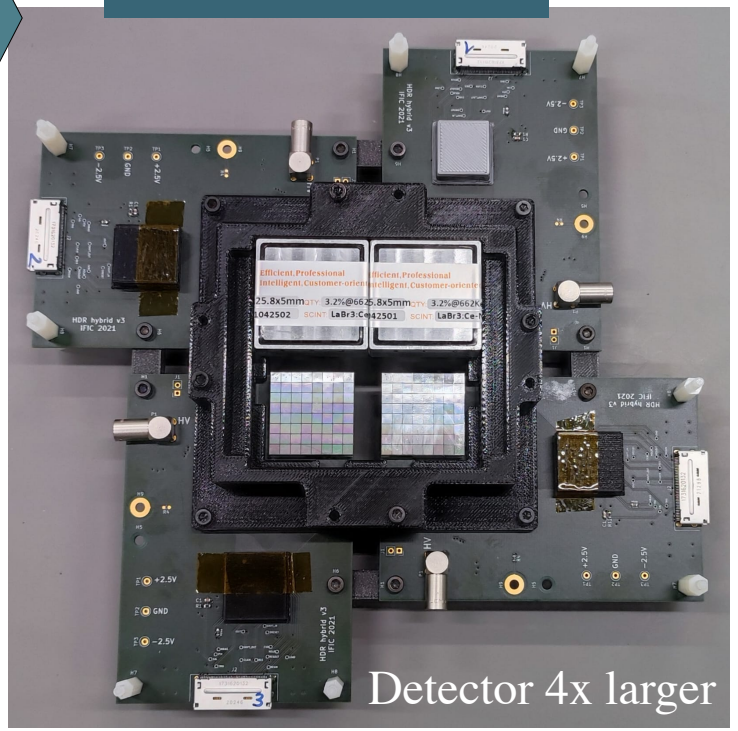
Compton imaging for Radionuclide therapy

MACACO III

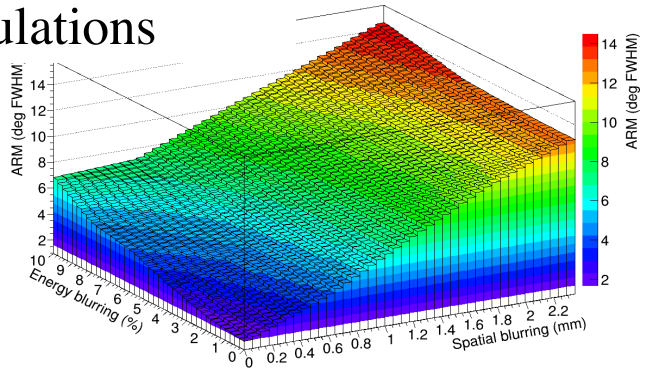


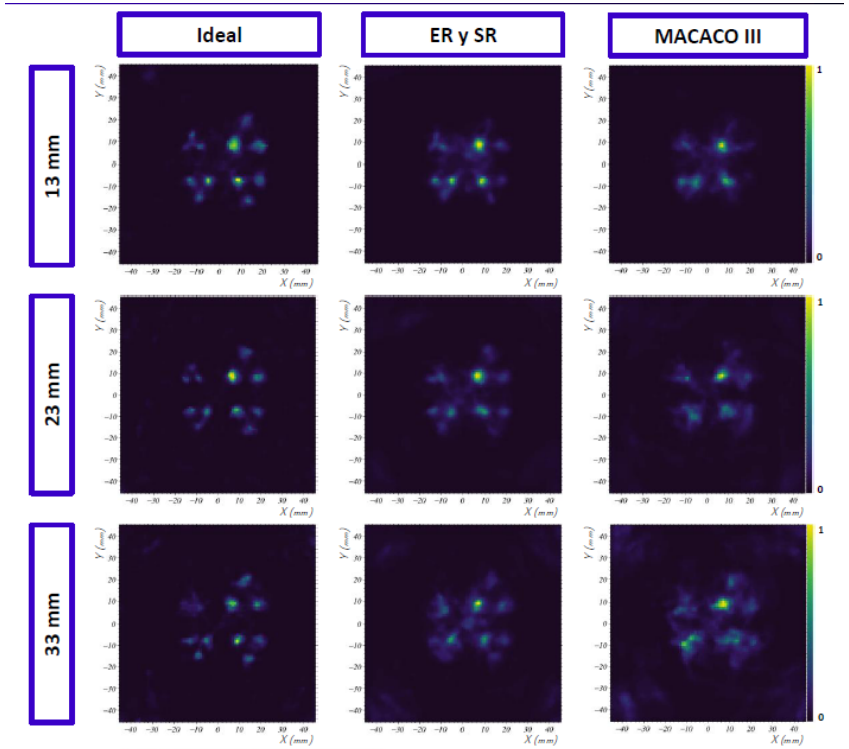
MACACO III+



Ac-225 simulations

Angular resolution @440 keV





- Detector performance improvement with scintillators.
- First tests with silicon pad detectors.
- *Simulations: detector performance under different conditions for different radionuclides.*

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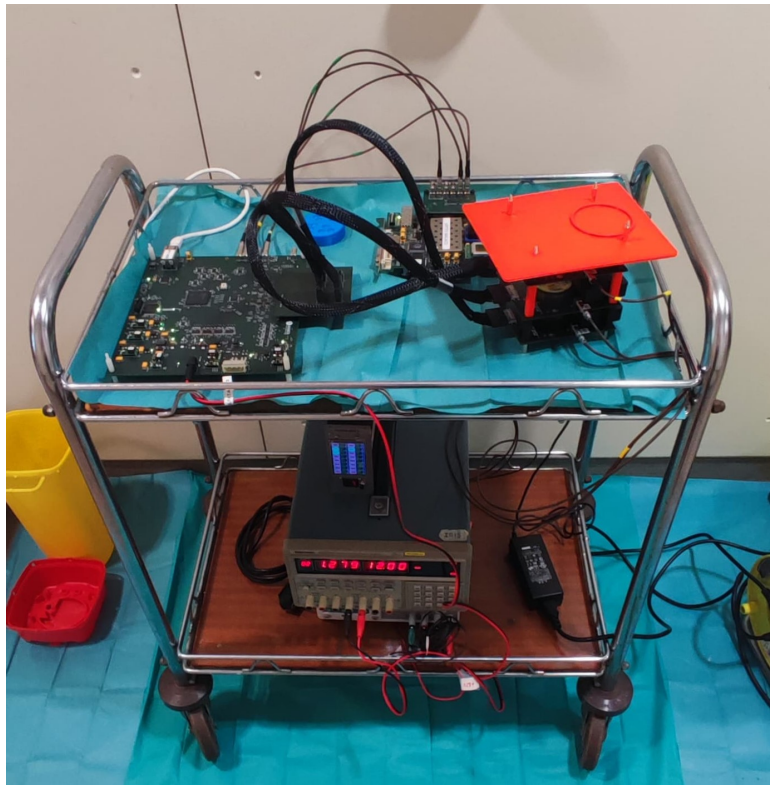
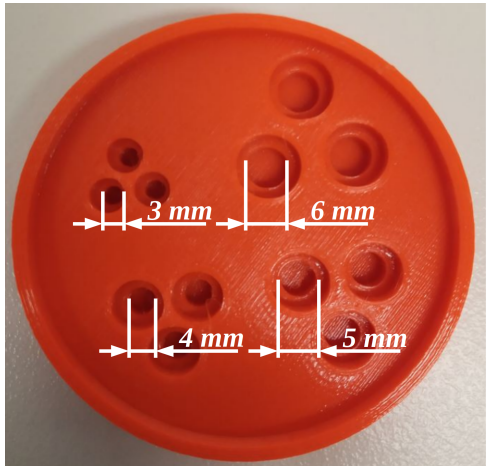
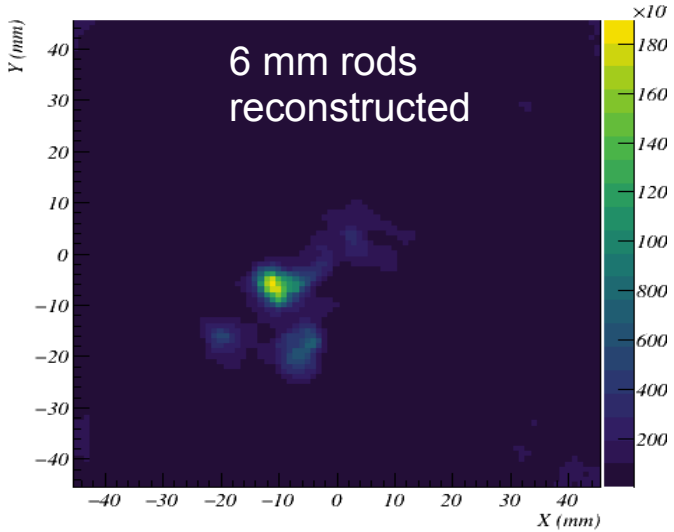
Compton imaging for Radionuclide therapy

Tests in hospitals

Tests with Ac-225 in a Derenzo-like phantom in the hospital Léon Bérard (Lyon)

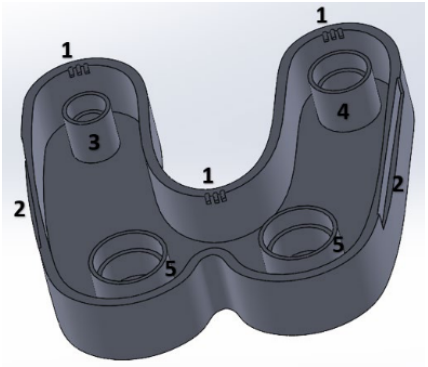




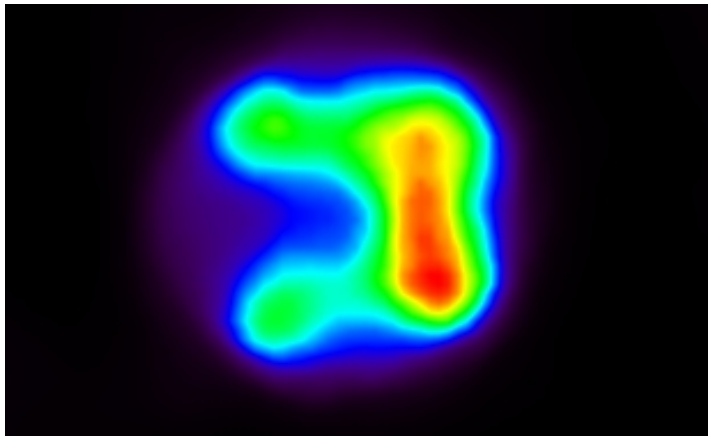


Further tests with I-131 in La Fe hospital (Valencia)

Ongoing tests with thyroid-shaped phantoms



Reconstructed image with MACACO III+



The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

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Plan de Recuperación, Transformación y Resiliencia
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GVANEXT

Summary

- **Instrumentation R&D is fundamental** for the development of future detectors to successfully accomplish the physics goals of the next decades.

  ➡*Many open and pressing questions requiring precision instrumentation.*

- These activities are developed inside **ASFAE line 1** with implications into *flavour physics, Dark Matter and other New Physics searches.*

- **These developments are at the fore-front of the experimental particle physics community** embedded into the European strategy for future accelerators and inside CERN detector research and developments themes.

- The ASFAE projects presented aim to improve present and future experiments as Belle II, NA64, LUXE and future Higgs and Top factories.

- Optimization and design studies are also in progress on the development of an RF cavity beam position monitor meeting the Higgs factory and the cryogenic test facility STF requirements.

- **R&D developments in fundamental physics have direct implications into medical physics** and inside these ASFAE actions is planned to improve imaging through Compton cameras.

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Thanks a lot for your attention!

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