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ASFAE
ASTROFÍSICA Y FÍSICA DE ALTAS ENERGÍAS

R&D instrumentation for future detectors

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

IFIC INSTITUT DE FÍSICA CORPUSCULAR

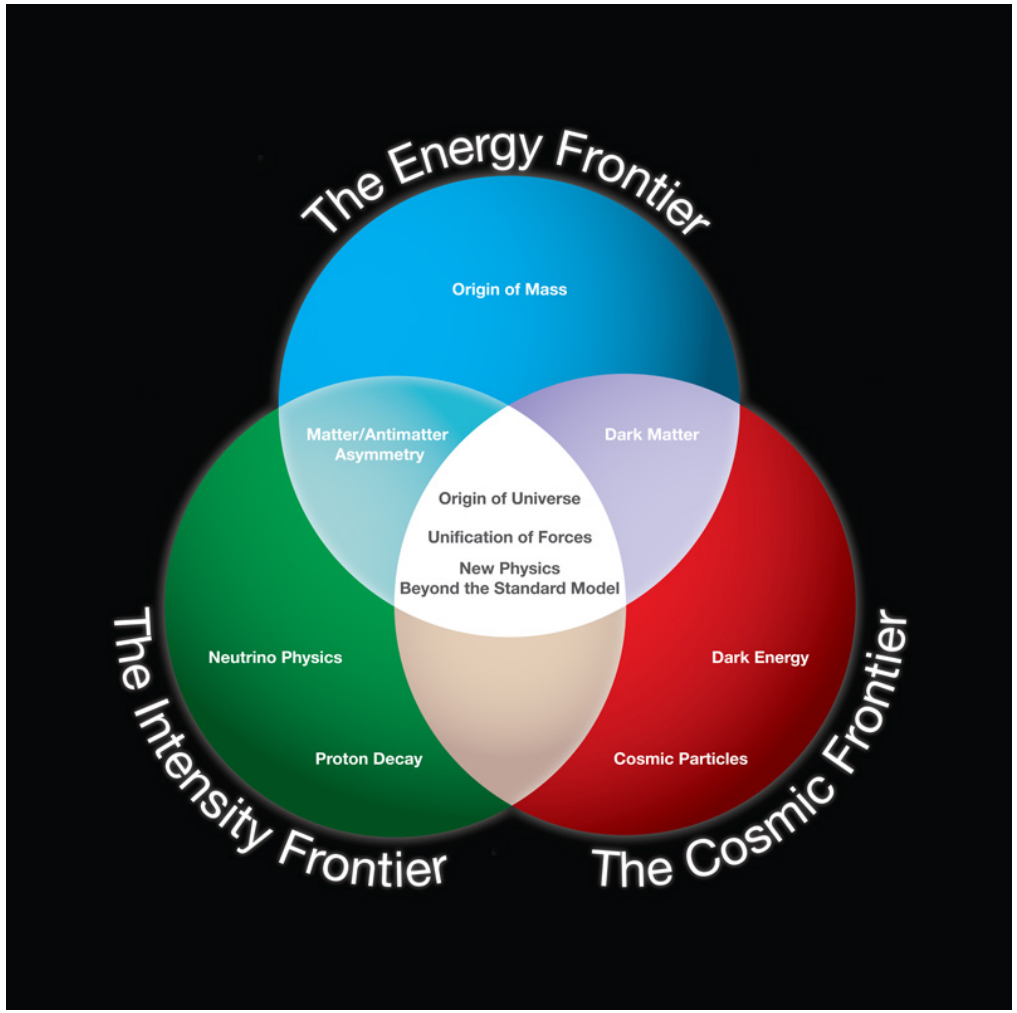
Laura Molina Bueno[1]

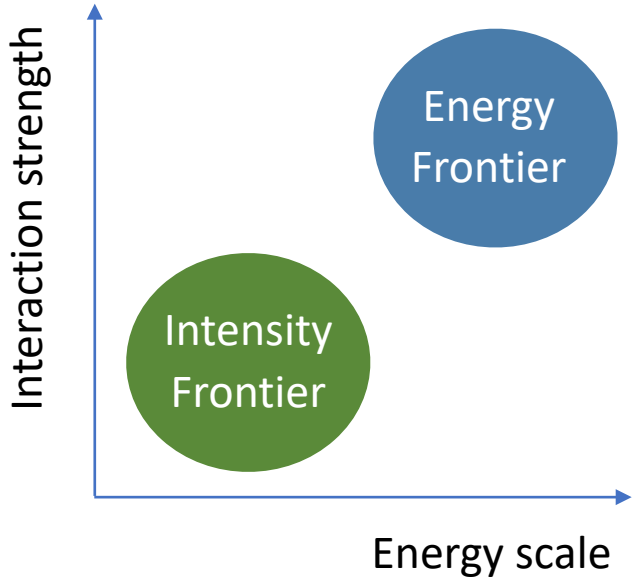
[1]Instituto de Física Corpuscular (CSIC/UV)

ASFAE Workshop, 4-6 Marzo 2024, Alicante

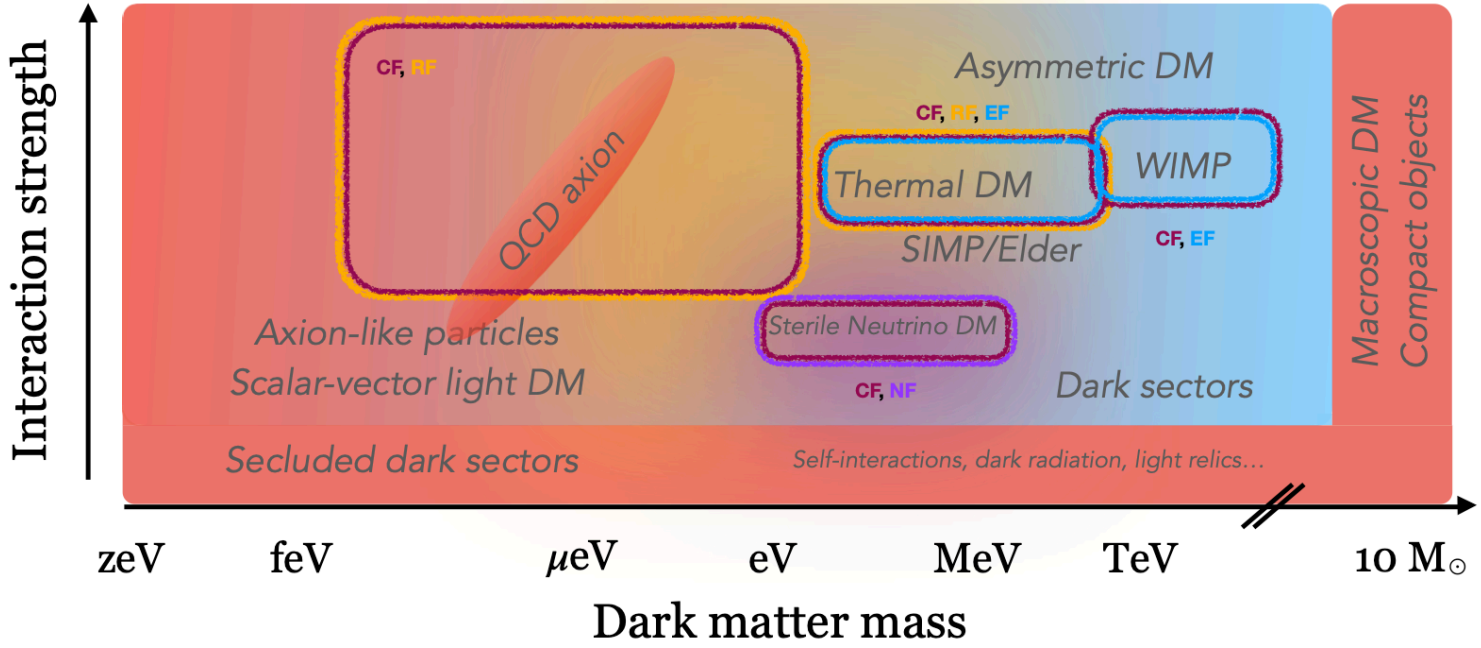
Universitat de València · Universitat Politècnica de València · Universitas Miguel Hernández · Universitat d'Alacant Universidad de Alicante · CSIC Consejo Superior de Investigaciones Científicas

Motivation





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



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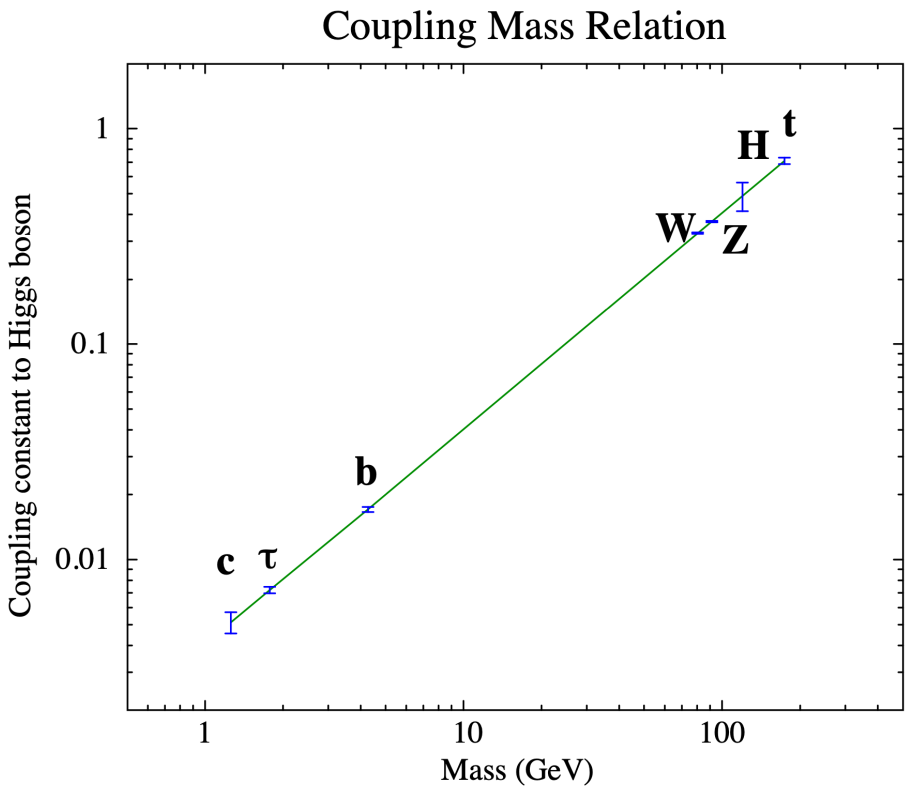
Motivation



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

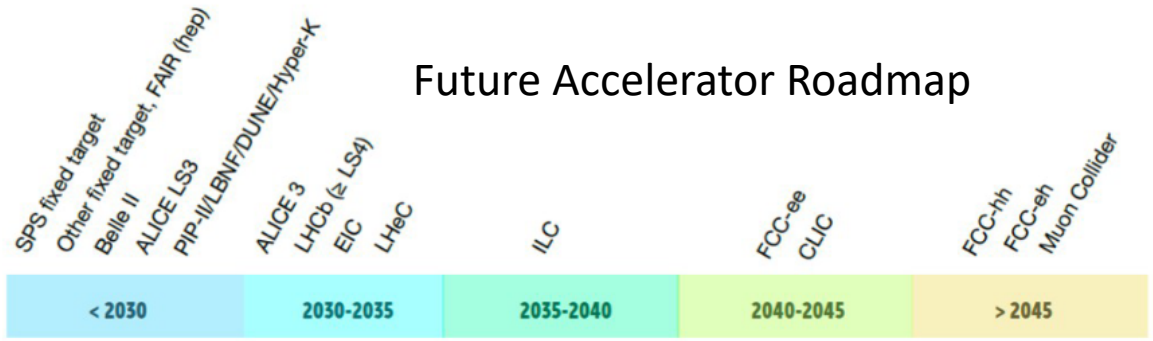
H ➔ HH
H ➔ WW
H ➔ ZZ

Requires excellent energy resolution

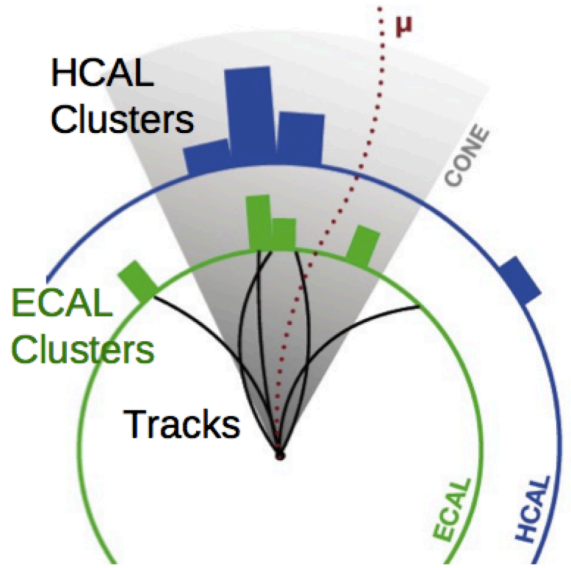
H ➔ bb

H ➔ cc

Requires excellent flavour tagging



Detector Level



Challenge: *Reconstruct and identify each particle*

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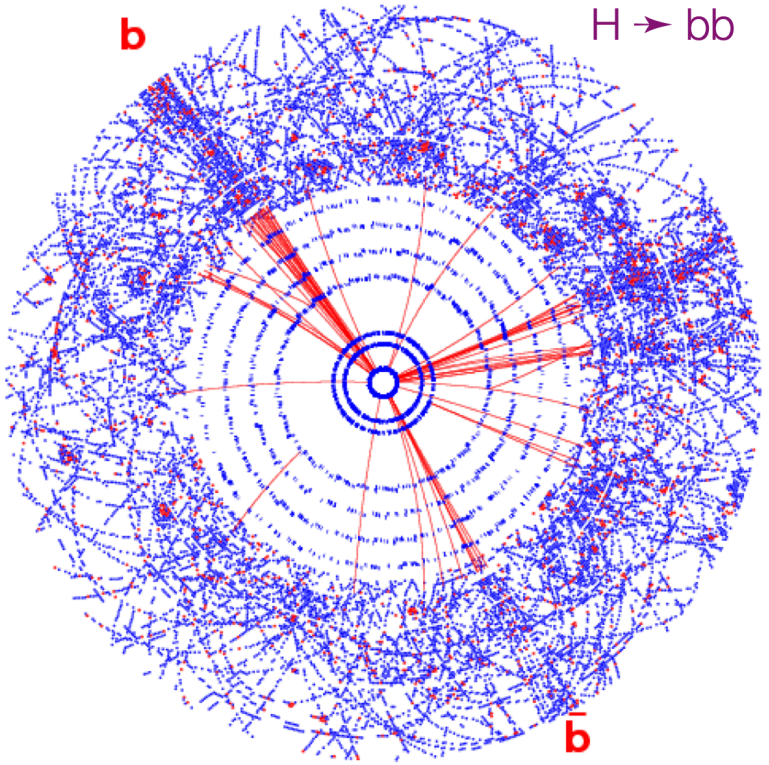
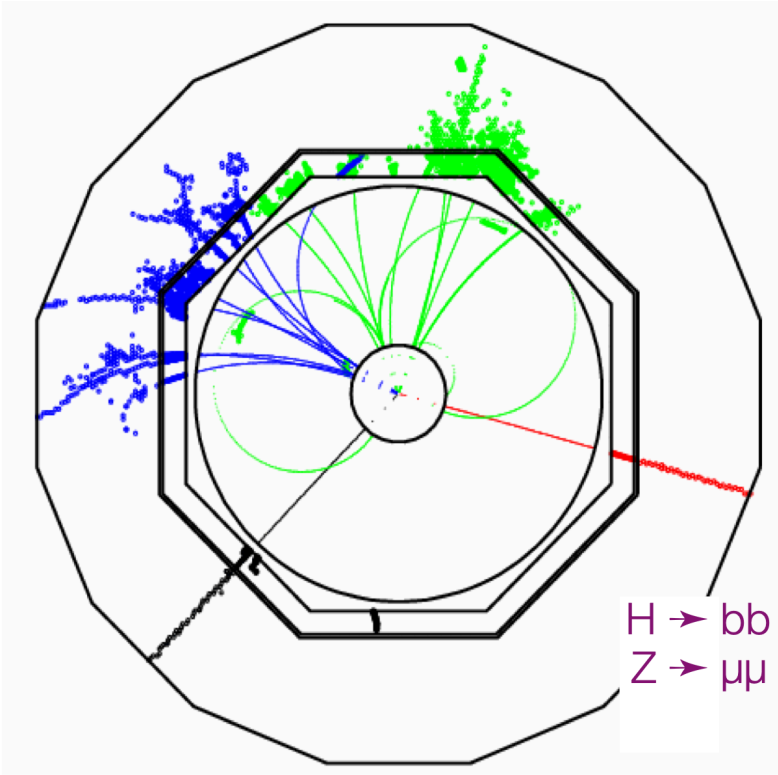


pp ➔ H + X



ee ➔ H + Z

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

We need excellent energy reconstruction, track and vertex resolution, timing,…
Deal with high rates, high radiation levels, high occupancy,…

Line 1: R&D instrumentation for future detectors

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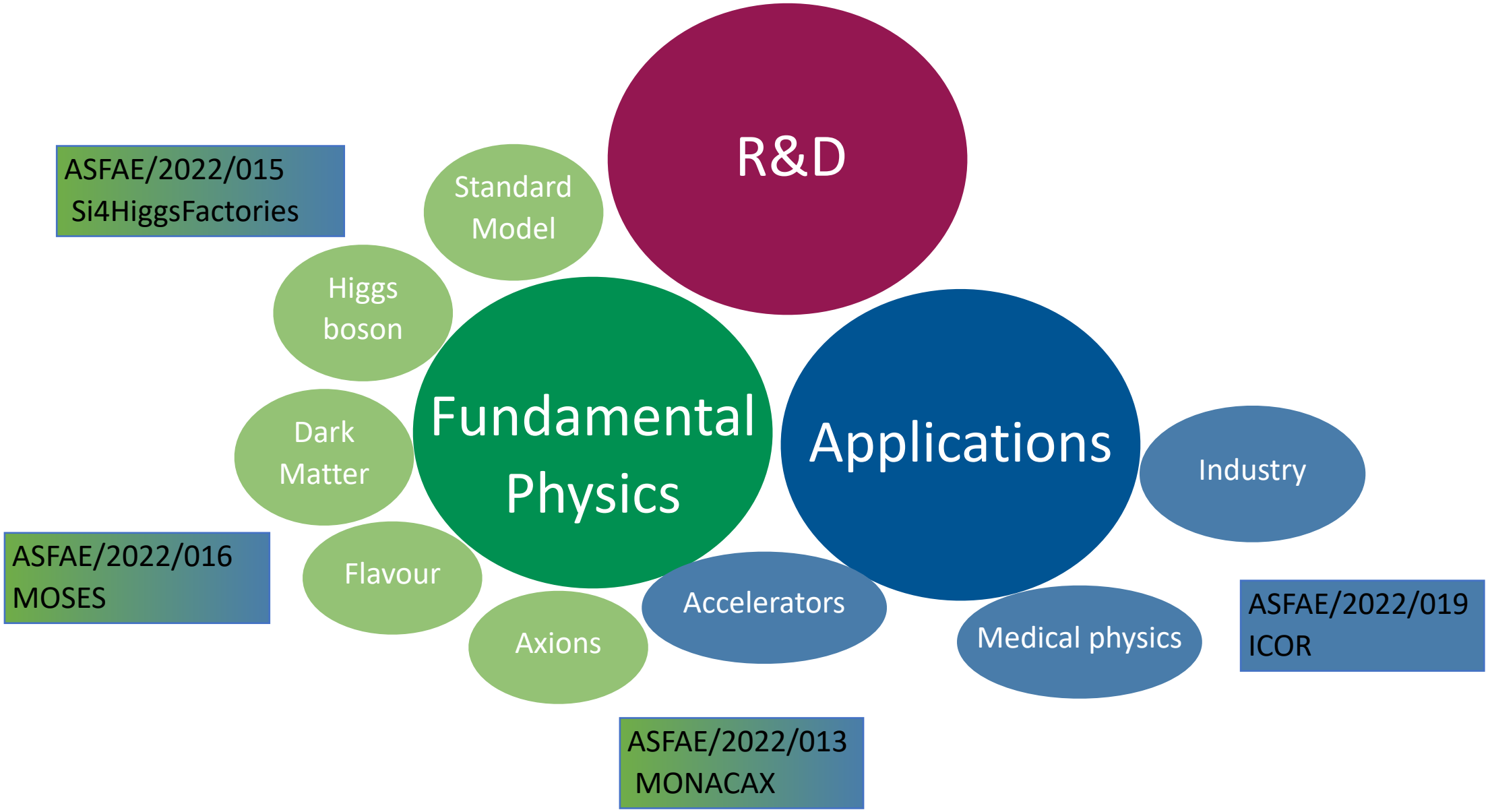
Motivation



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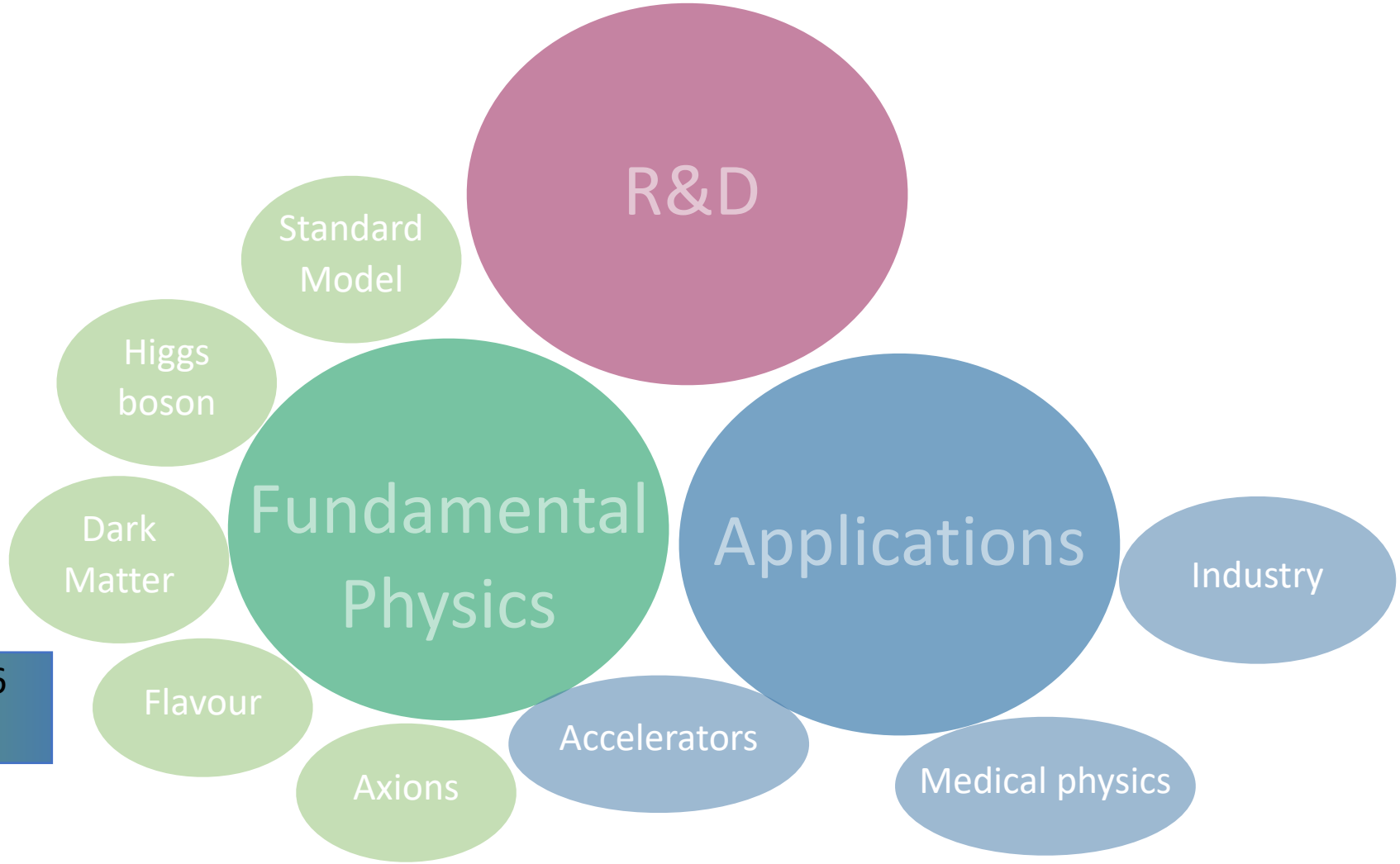

ASFAE/2022/016
MOSES

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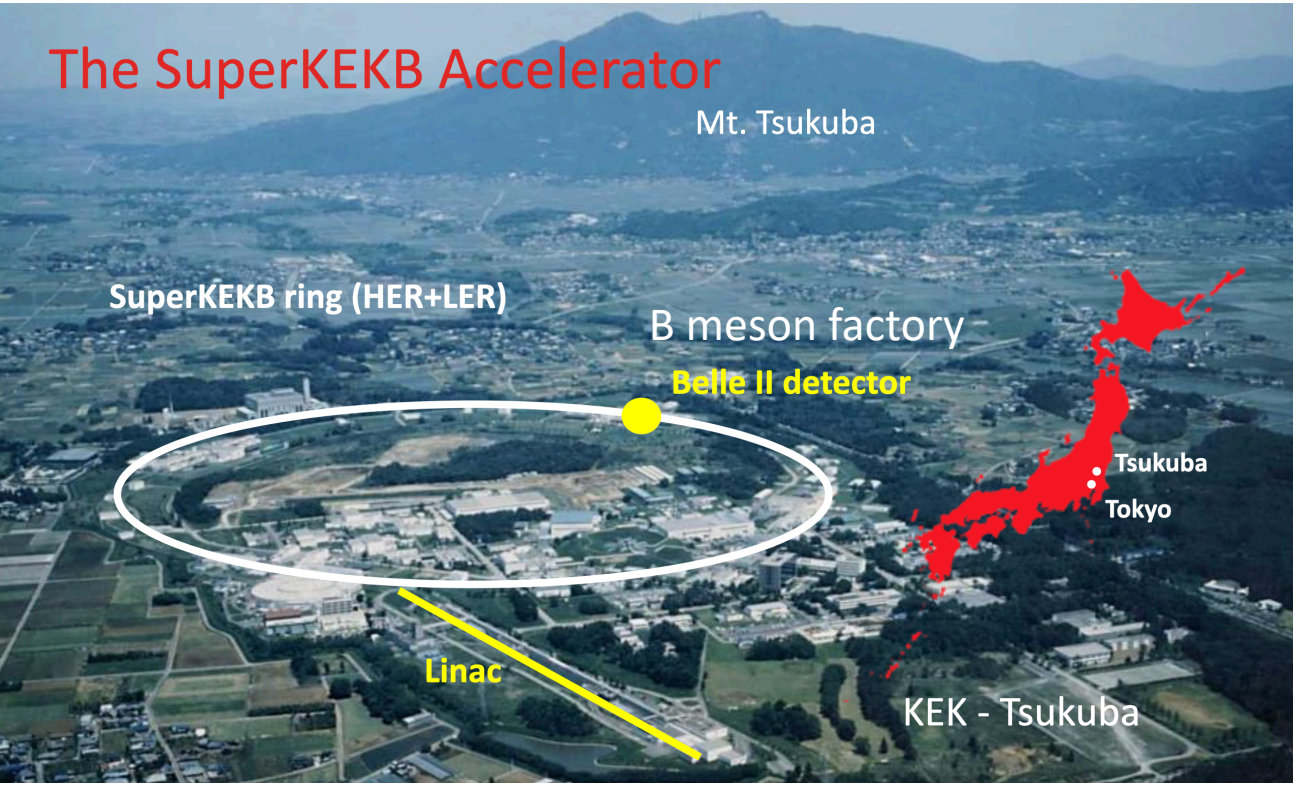
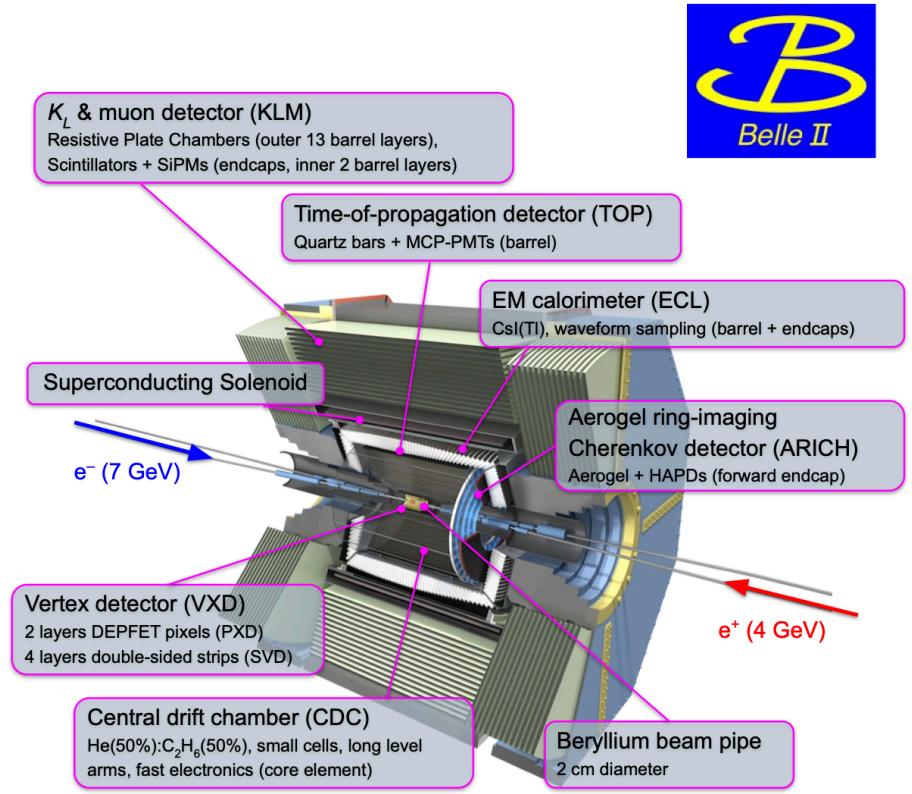
MOSES: *Monolithic sensors for New Physics*

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

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





A. Natochii *et al.* Nucl.Instrum.Meth.A 1055 (2023) 168550

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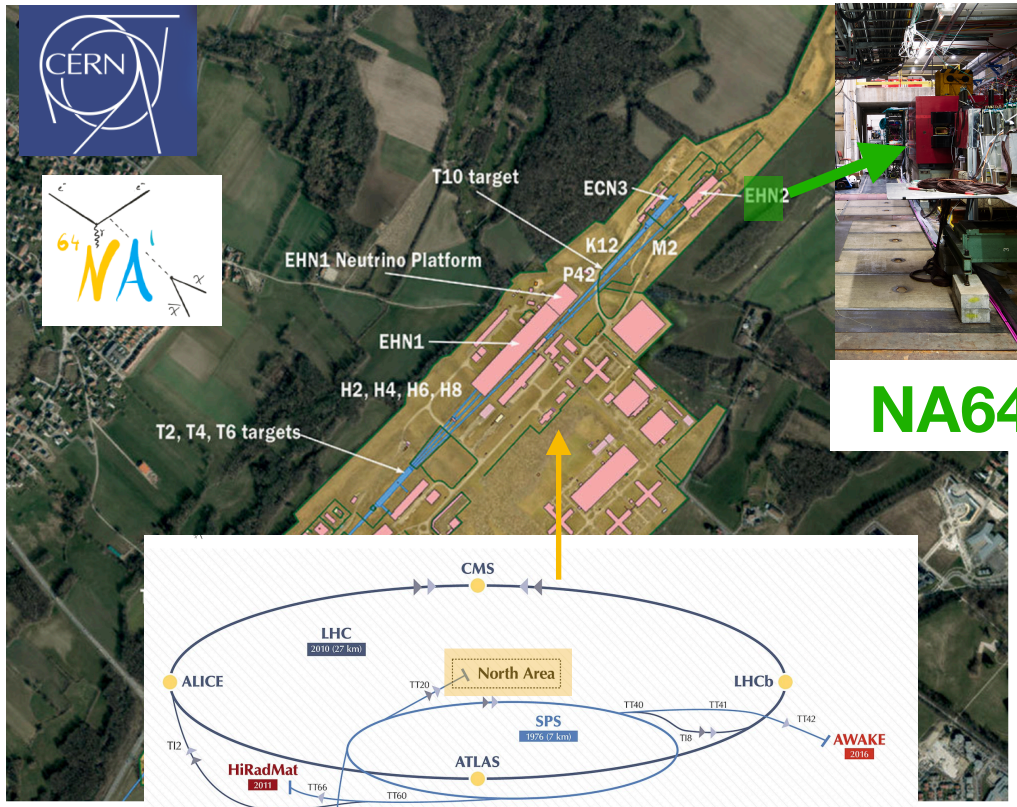
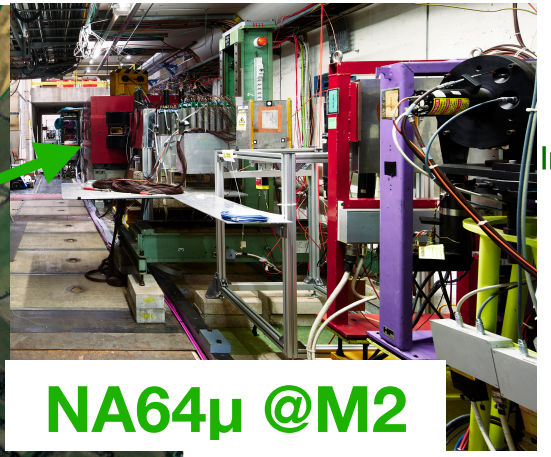
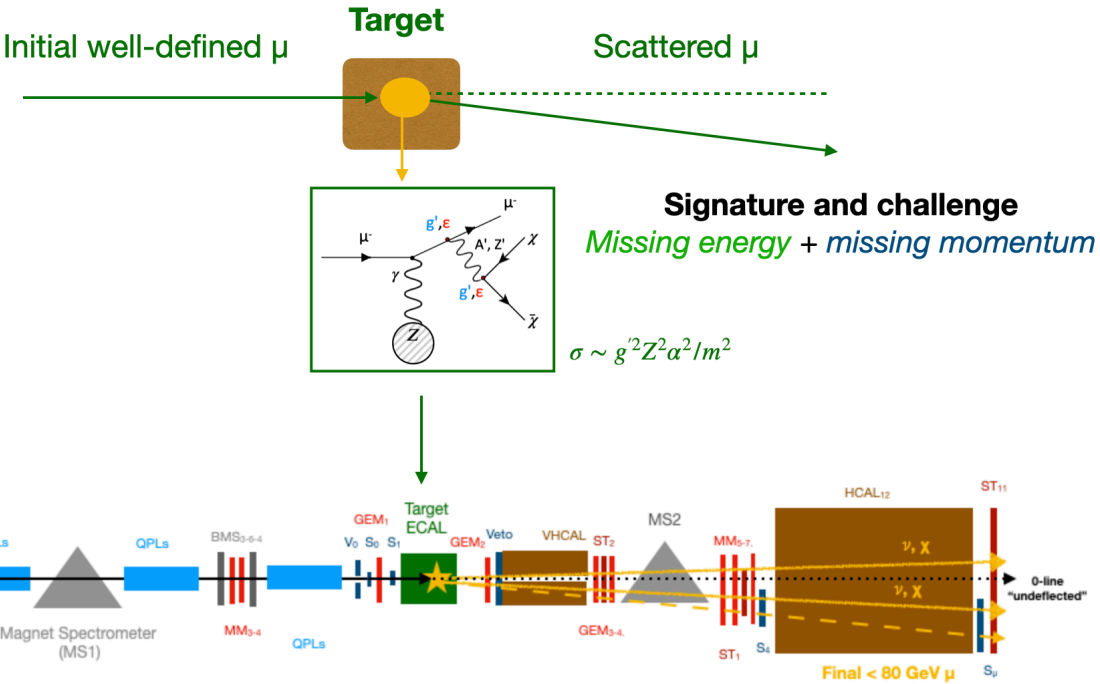




NA64μ @M2



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MOSES: *Monolithic sensors for New Physics*

European Committee for Future Accelerators (ECFA)

Develop a roadmap in strategic R&D technologies: *Focus on high precision advanced technologies*

To appropriately test our current level of understanding requires ***very high accuracy instrumentation****.*

DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs) & DETECTOR COMMUNITY THEMES (DCTs)

		< 2030	2030-2035	2035-2040	2040-2045	> 2045
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					

Requirements

		DRDT	Panda 2025	CBM 2025	NA62/Kiever 2025	BELLE II 2026	ALICE LS3[1]	ALICE 3	LHCb (≥ LS4[1])	ATLAS & CMS (≥ LS4[1])	EIC	LHeC	ILC	FCC-ee	CLIC	FCC-hh	FCC-eh	Muon collider
			< 2030					2030-2035					2035-2040	2040-2045		>2045		
Vertex detector[2]	Position precision	3.1,3.4																
	Low X/X_0	3.1,3.4																
	Low power	3.1,3.4																
	High rates	3.1,3.4																
	Large area wafers[3]	3.1,3.4																
	Ultrafast timing[4]	3.2																
	Radiation tolerance NIEL	3.3																
	Radiation tolerance TID	3.3																

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

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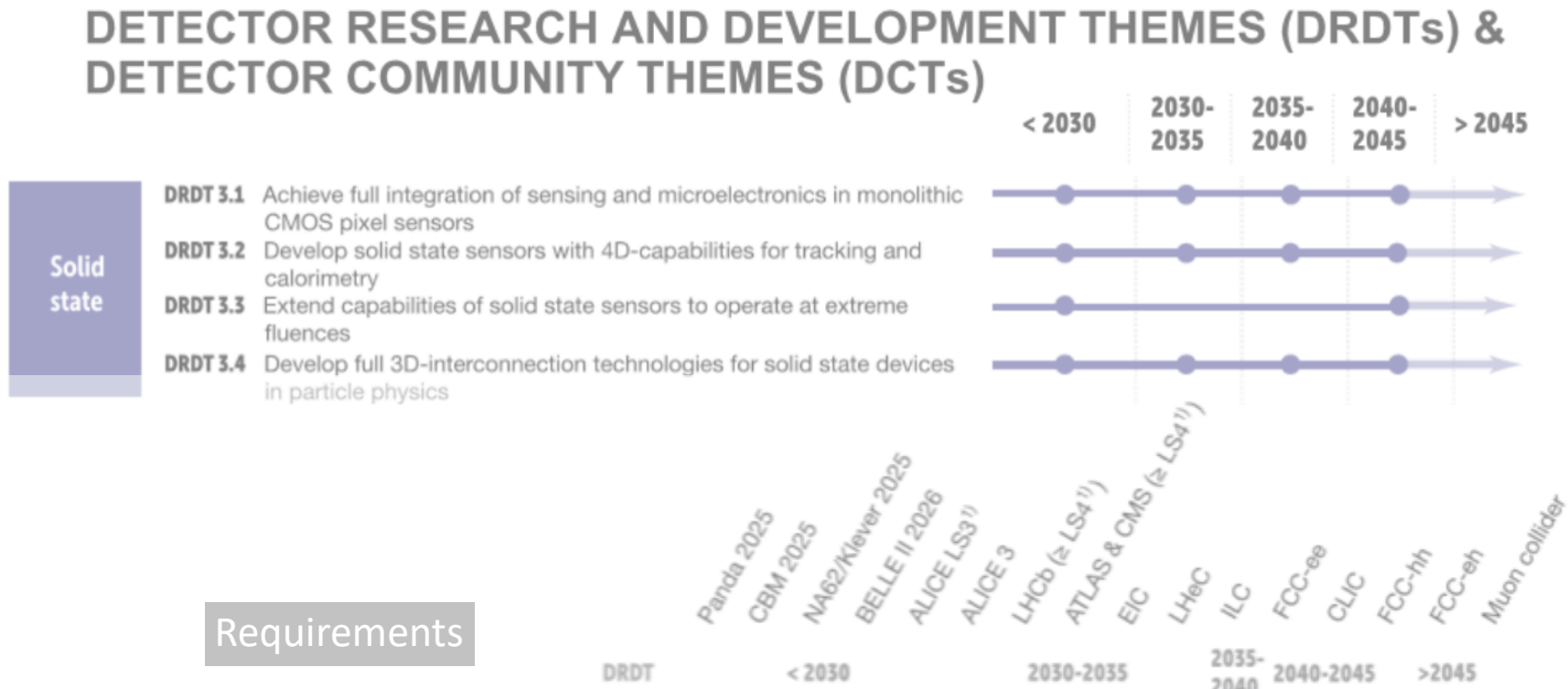
MOSES: *Monolithic sensors for New Physics*

European Committee for Future Accelerators (ECFA)



Requirements

The 2020 European Strategy for Particle Physics update approved by CERN Council on 19 June 2020 recommended to support searches for Dark Sectors at the high intensity frontier (fixed target experiments as NA64, Belle II) and recommends participation in Flavour experiments outside Europe as Belle II.

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instrumentation.

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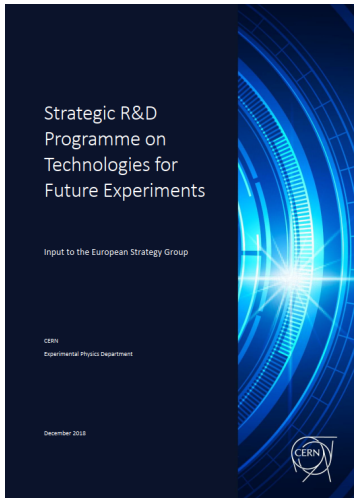
MOSES: *Monolithic sensors for New Physics*

CERN R&D new technological program



WP1: Silicon Sensors

Module development

Novel hybrid pixel detectors

Ultimate time/space accuracy and rad hardness

Monolithic pixel detectors

Cost effective depleted CMOS for ee and hh

Simulation and characterization

Focus on Pixel Detectors

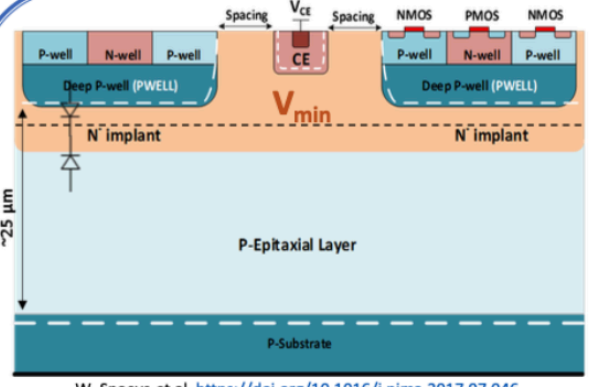
WP4: Mechanics

Low mass structures
- Vertex detectors
- Cryostats for calorimetry + magnets

Cooling techno-logies
- Methods (gas/liquid)
- Coolants (GWP)
- Piping and instrumentation

Interfaces and service architectures for automated installation and maintenance, in future high radiation environments

Monolithic detector:
Combine sensor and readout on the same wafer



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

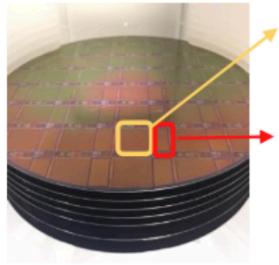
$C_d \leq 3fF$

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

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

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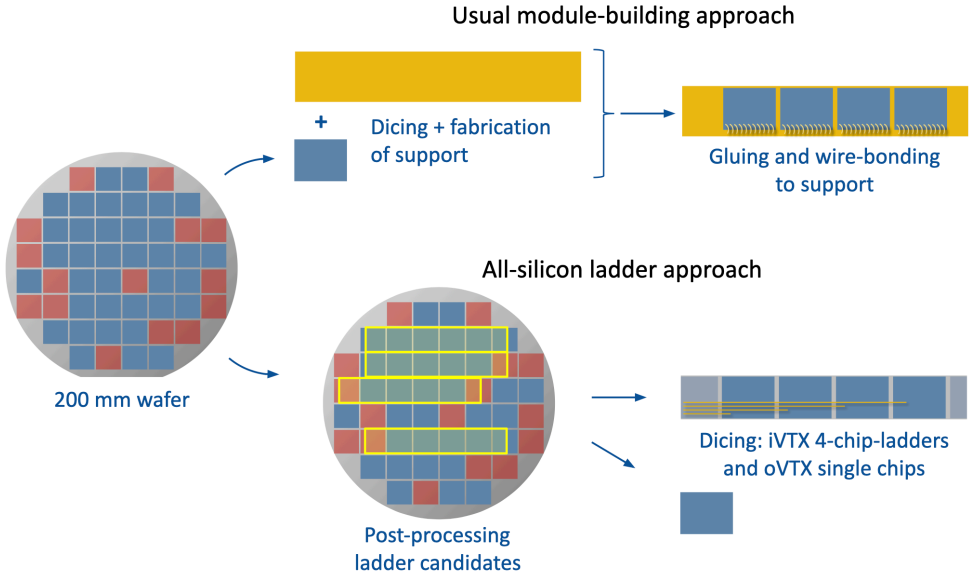
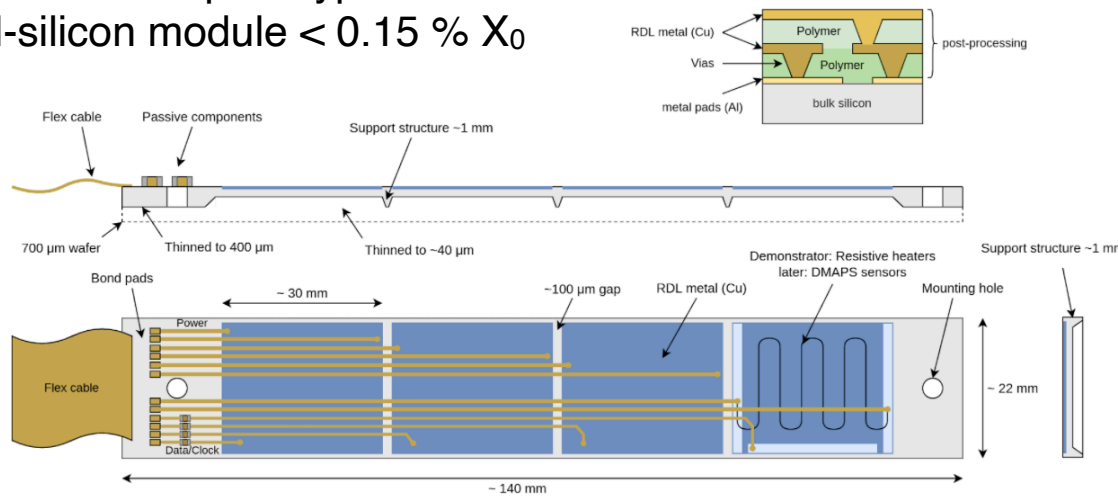


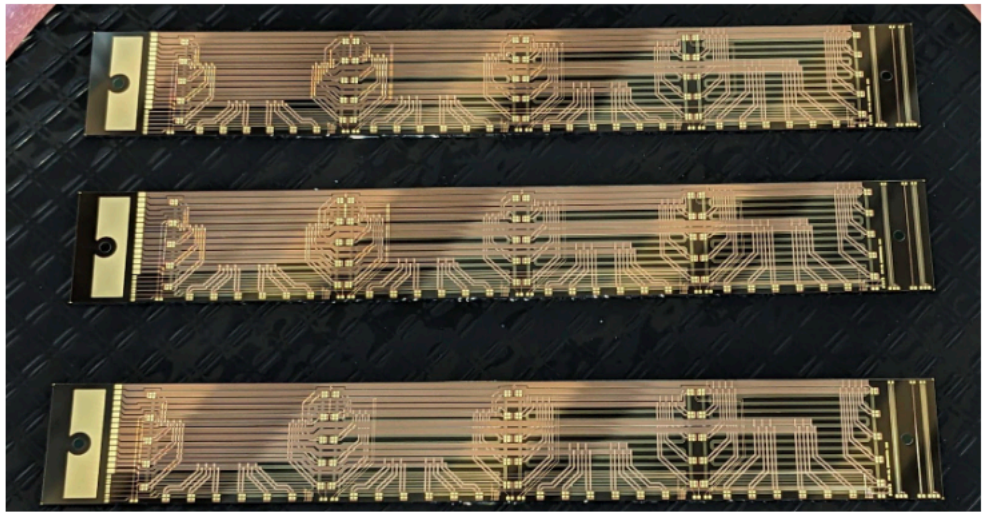
iVTX Ladder prototype
All-silicon module < 0.15 % X_0



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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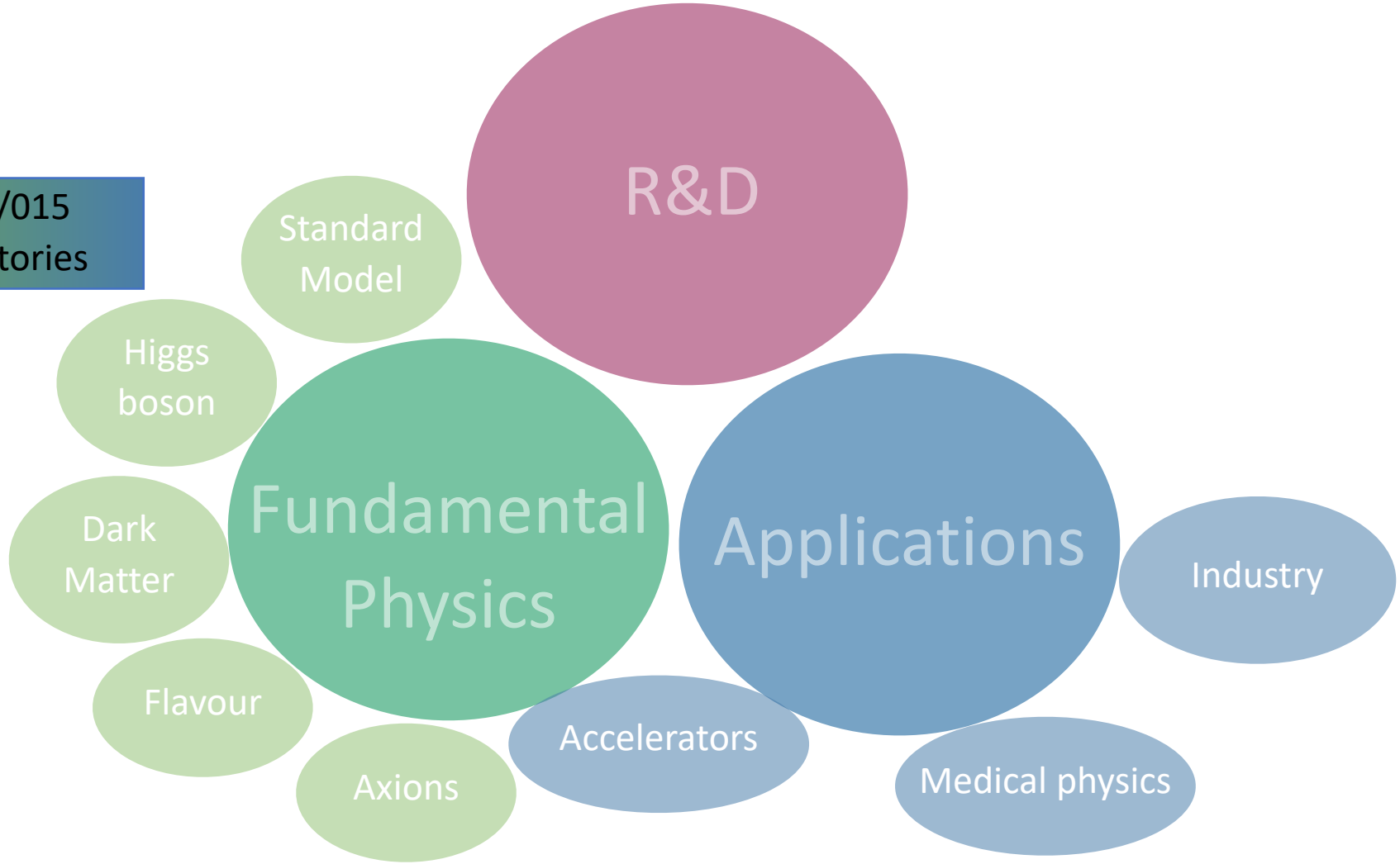
ASFAE/2022/015
Si4HiggsFactories



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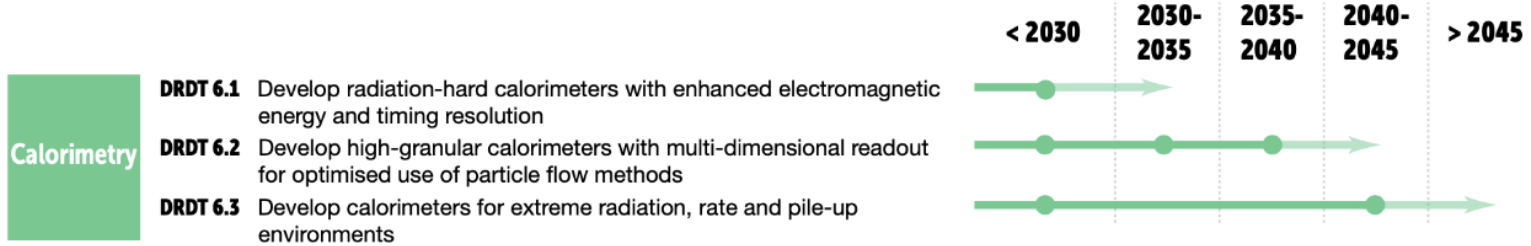
Si4HiggsFactories

ASFAE/2022/015
A. Irles
M. Vos

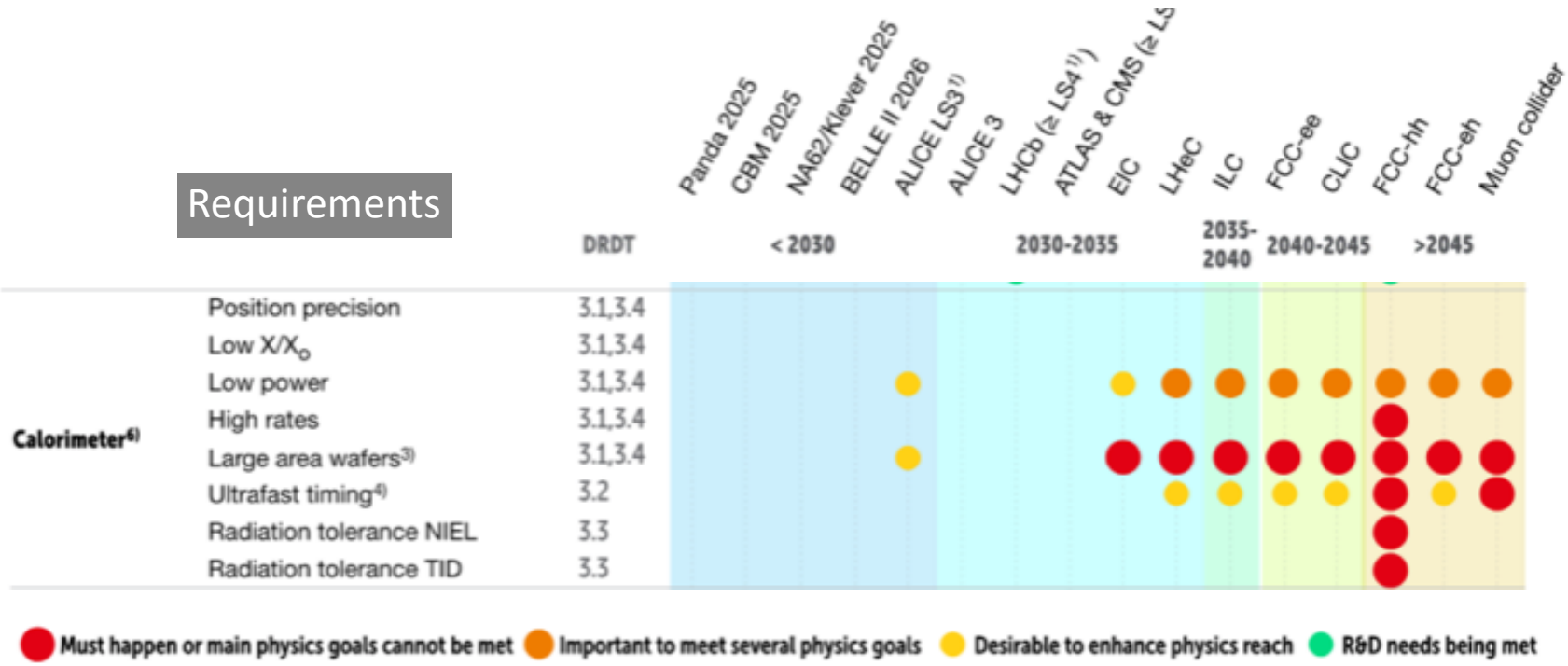
To develop a demonstrator of a Silicon-based high granular detector for future Higgs and top factories

Development of high granular detectors for variety of experiments

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



Requirements



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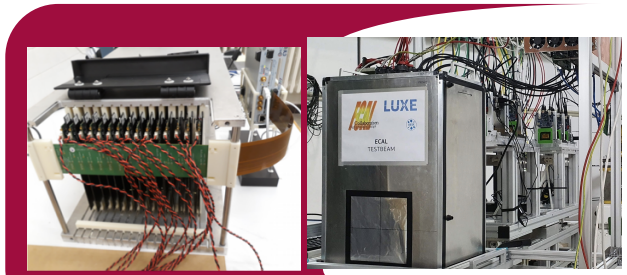
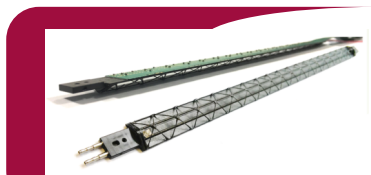
Si4HiggsFactories

Synergies and complementarities between different experiments: LHC, ILC, LUXE

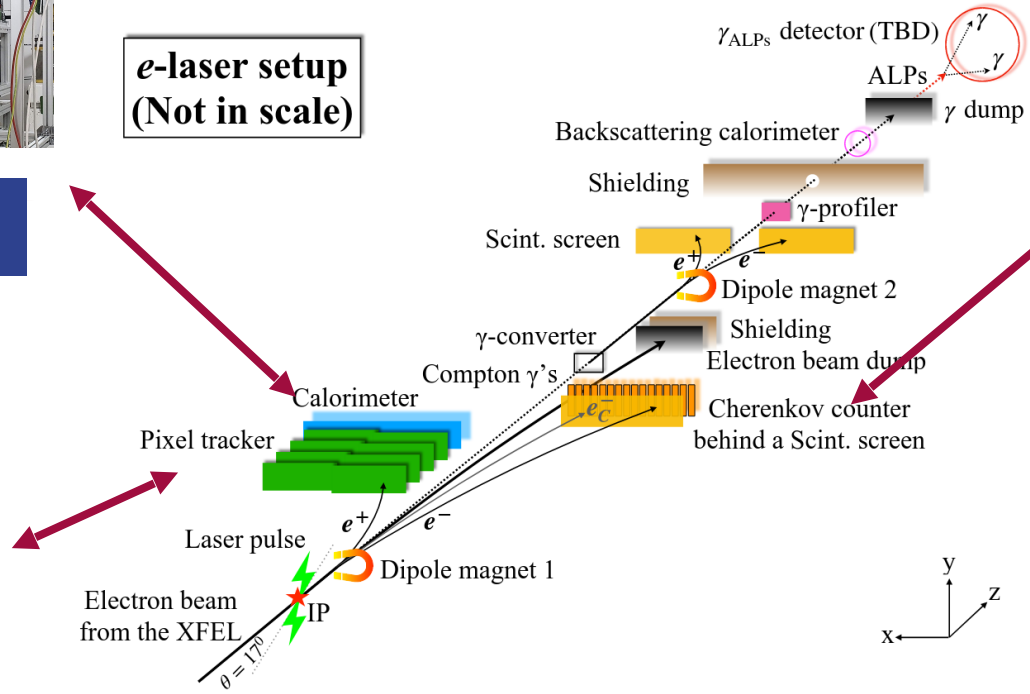


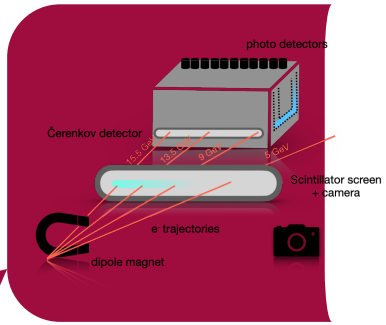
CALICE -type calorimeter

FCAL-type calorimeter



ALPIDE sensors (ALICE)





ILC polarimeter

Requirements:

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

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Si4HiggsFactories

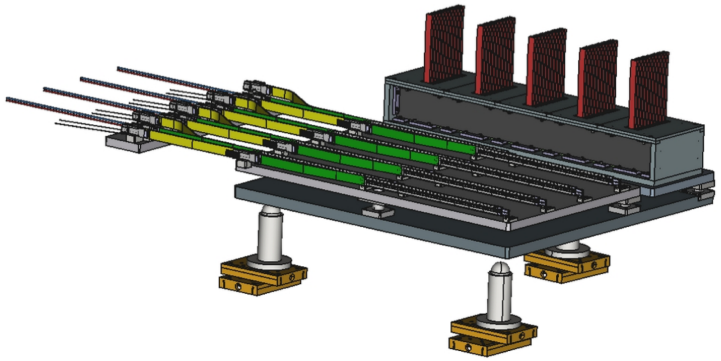
Development of electromagnetic calorimeters for LUXE and Higgs factories

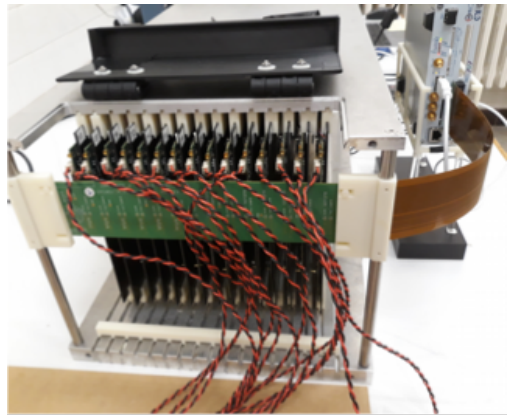
- ***Multilayer high granular calorimeters based on linear collider prototypes (FCAL and SiW-ECAL-CALICE)***
  - 20X0, 5.5x5.5 mm2 sensors (silicon and GaAs under study)
- ***Two approaches:***
  - Fully embedded electronics (CALICE)
  - Ultra compact design (FCAL) to ensure minimal Molière Radius (RM) of about ~10 mm (nearly the tungsten RM) → 1 mm between tungsten planes

➡ Both approaches put very strong constraints on the hybridization process → not possible a wire bonding solution (as used in the CMS-HGCAL)

Goals:

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





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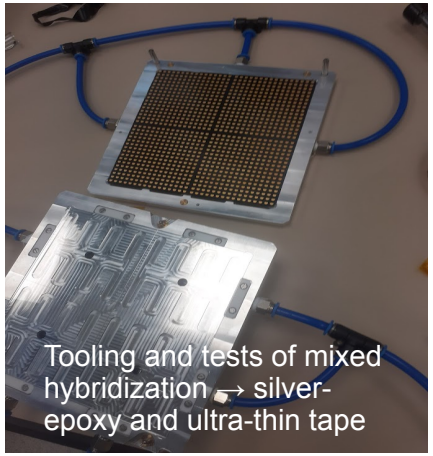
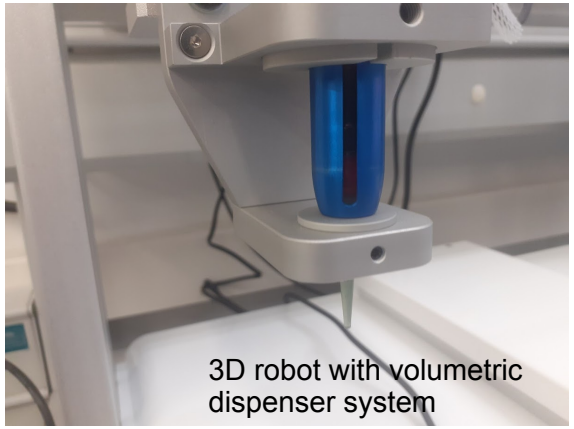
Si4HiggsFactories

- ***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





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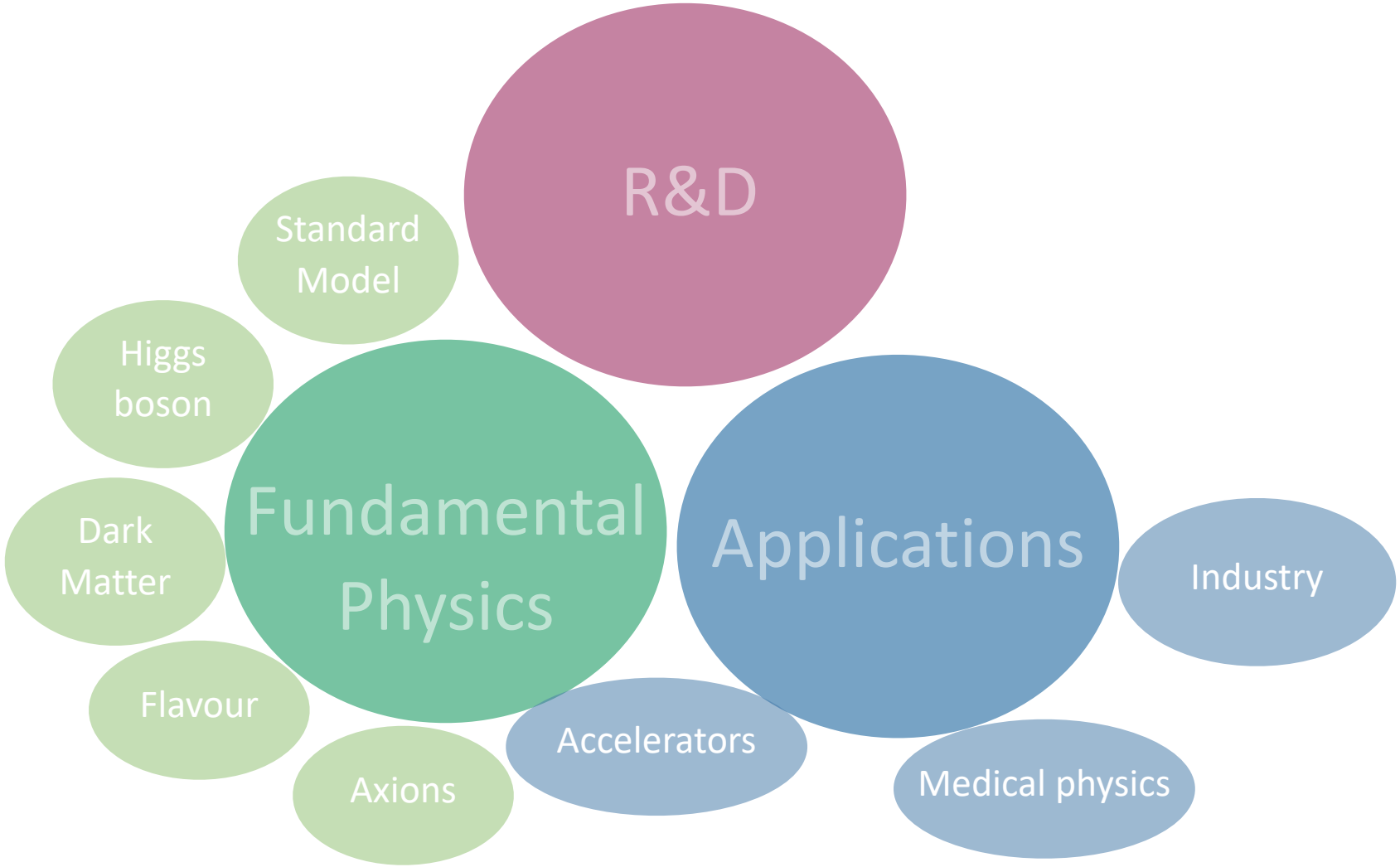
Motivation



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ASFAE/2022/013
D. Esperante
N. Fuster

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

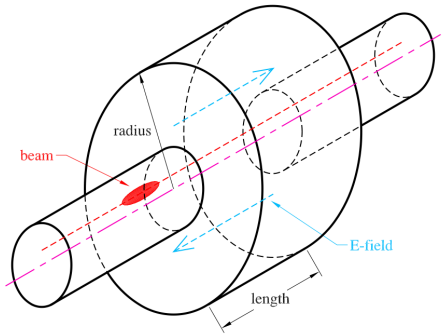
AITANA

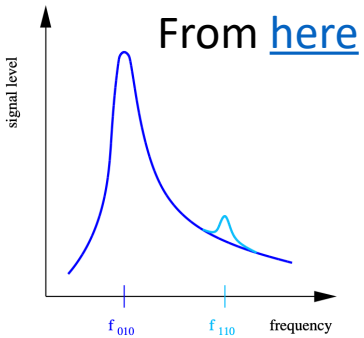
1. Development of a Beam Position Monitor (BPM) to determine the transversal position of a beam

<u>Context:</u> the Main Linac (ML) of the International Linear Collider Project (ILC)

<u>Requirements:</u>

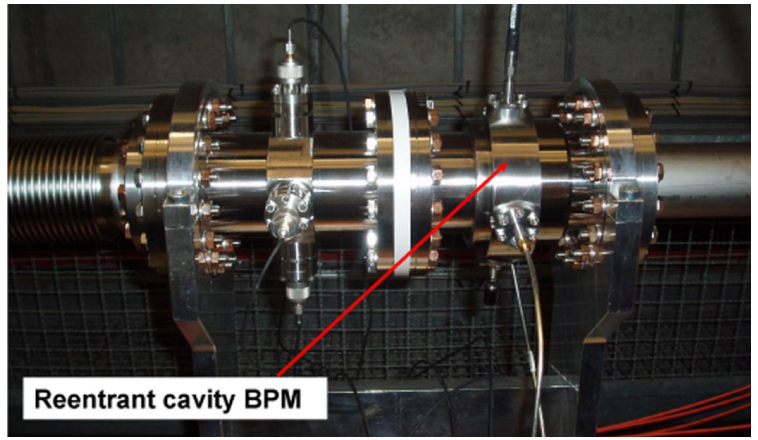
- spacial resolution < 1 μm and temporal resolution < 396 ns (6ns) ILC (STF)
- cryogenic and UV conditions
- mechanical attachment to a Super Conducting quadrupole in the ML (cryogenic environment)



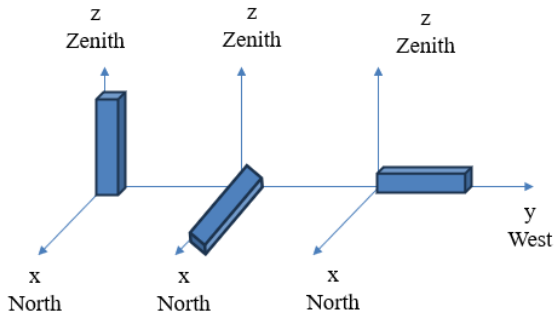


From here

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



2. Interferometry techniques for detection of dark matter axions using microwave and millimeter-wave cavities



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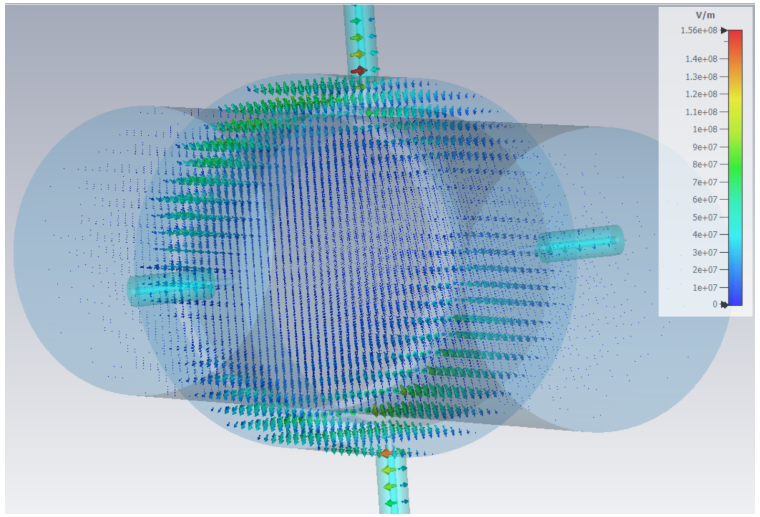
Cavity BPM for the Main Linac of the ILC project

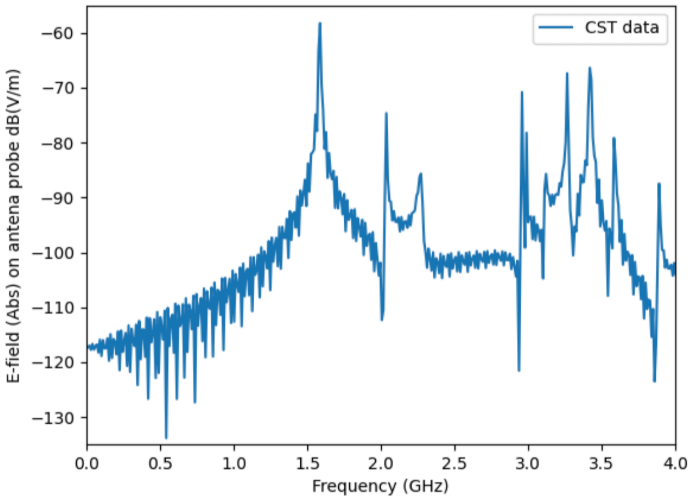
Project timeline:

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

Work in progress:

- Performance and EM design studies with CST-PS
  - Parametric studies to evaluate the influence of the geometry on the performance of the BPM
- Data acquisition and electronics design





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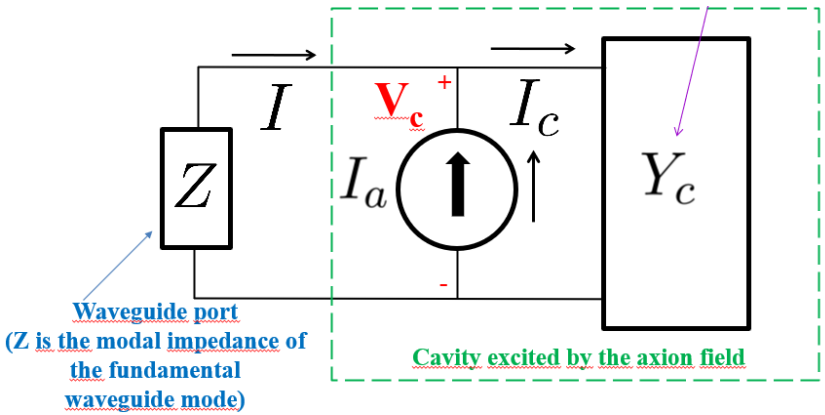
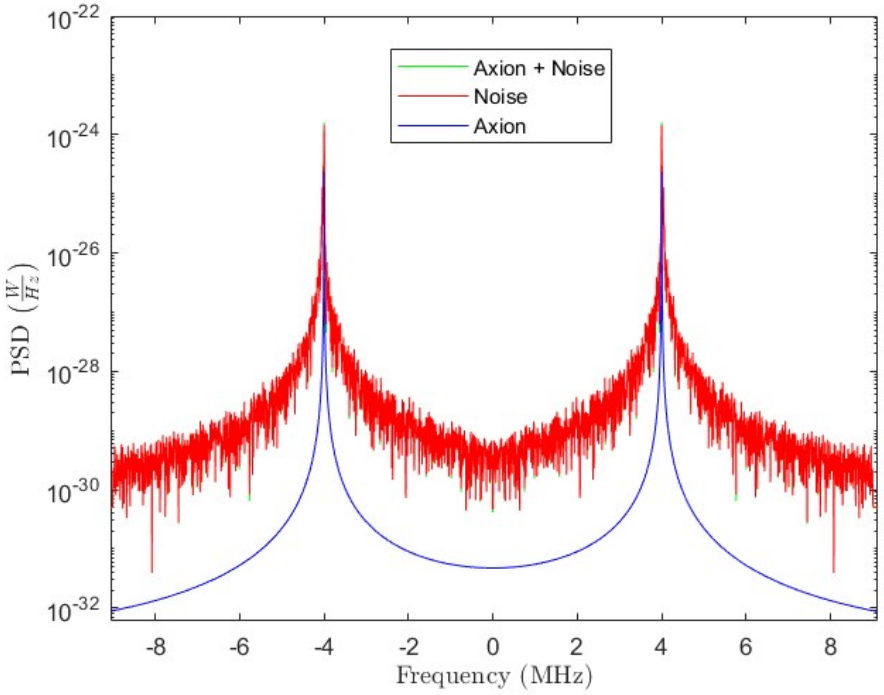
Interferometry techniques for detection of dark matter axions using microwave and millimetre-wave cavities

Work developed for the RADES and CADEX collaborations focused 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





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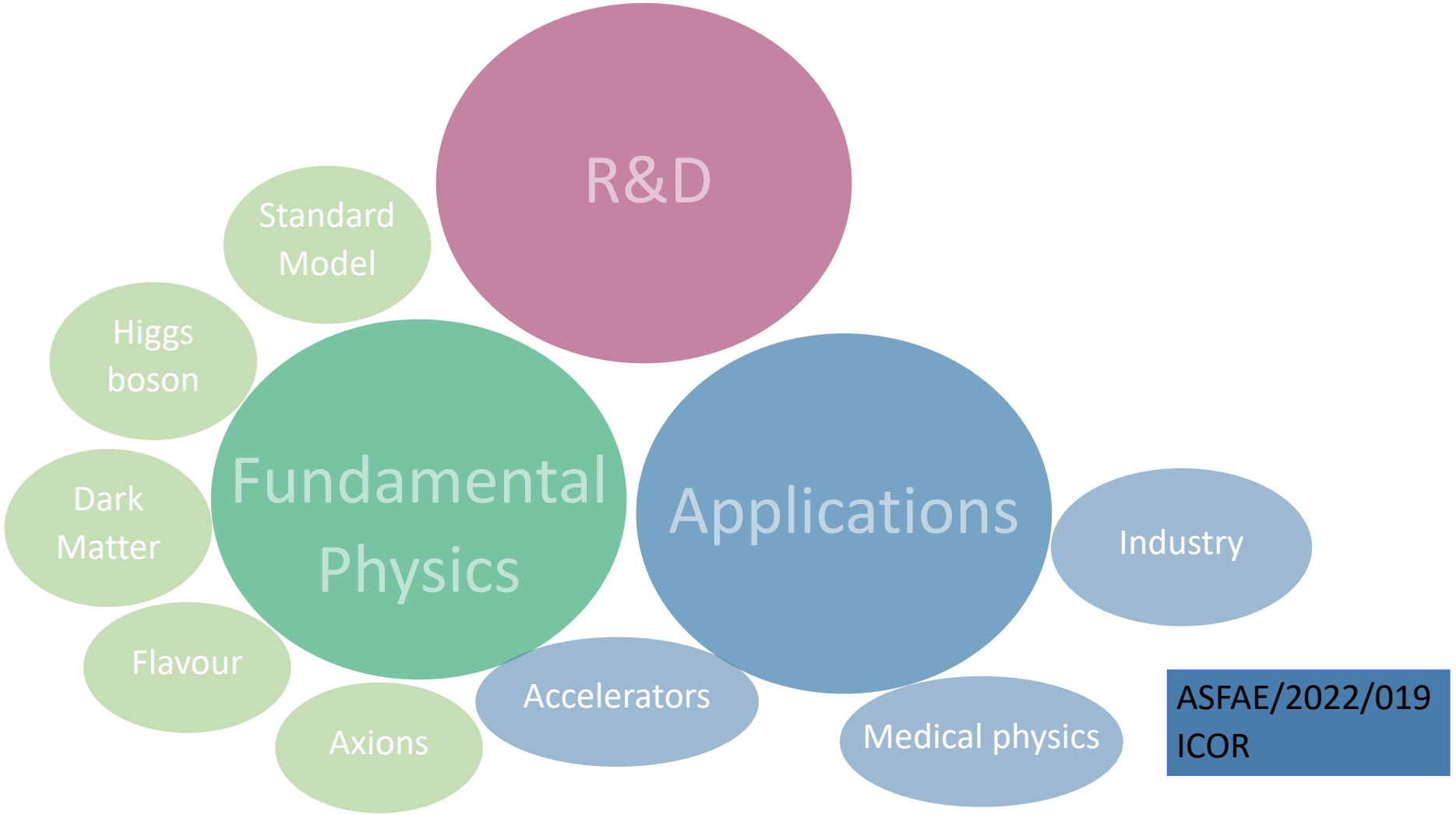
Motivation



ASFAE/2022/019
ICOR

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ICOR: *Compton imaging for Radionuclide therapy*

ASFAE/2022/019
G. Llosa
I. Torres

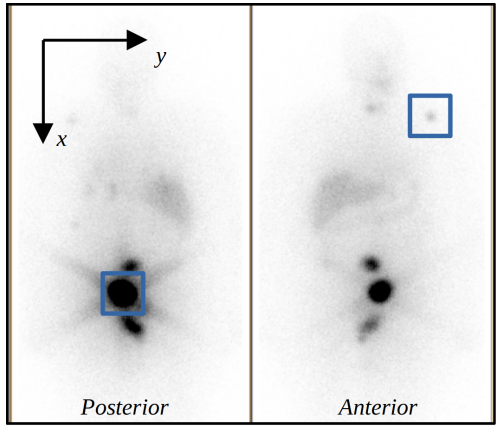
http://ific.uv.es/iris

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

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

- 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.*



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

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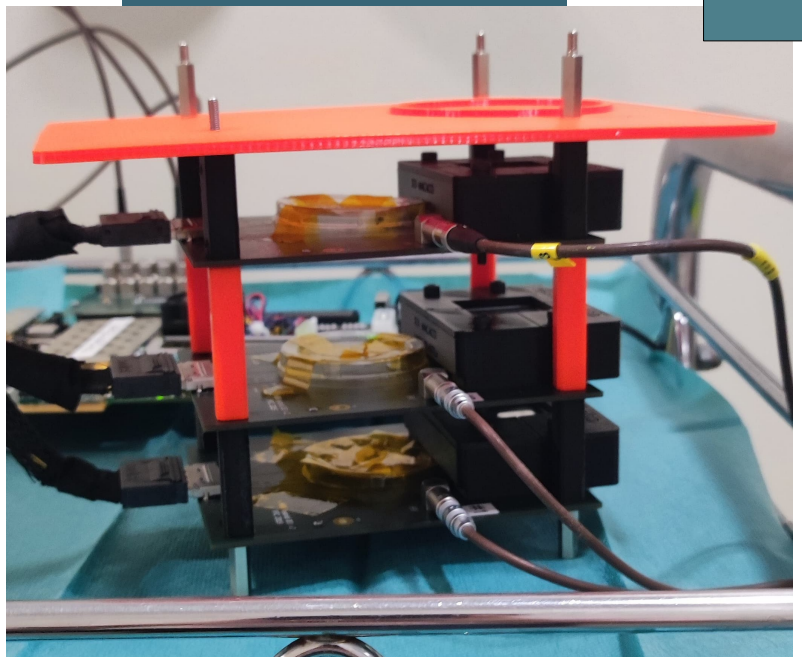
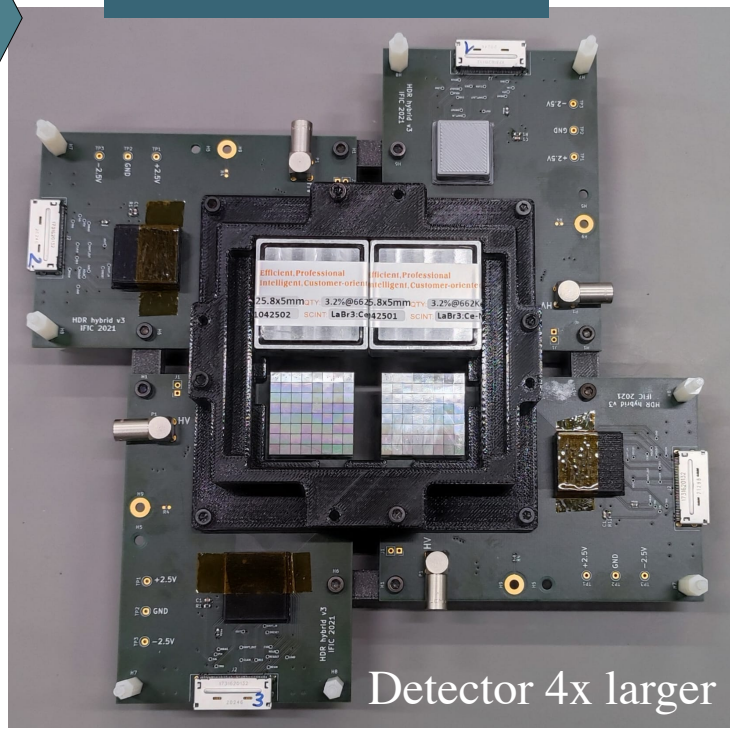
MACACO III

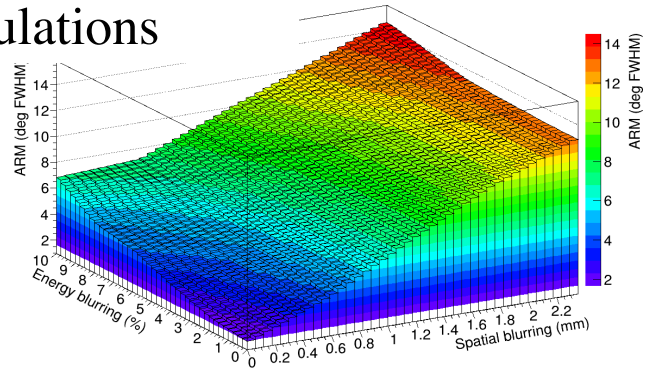


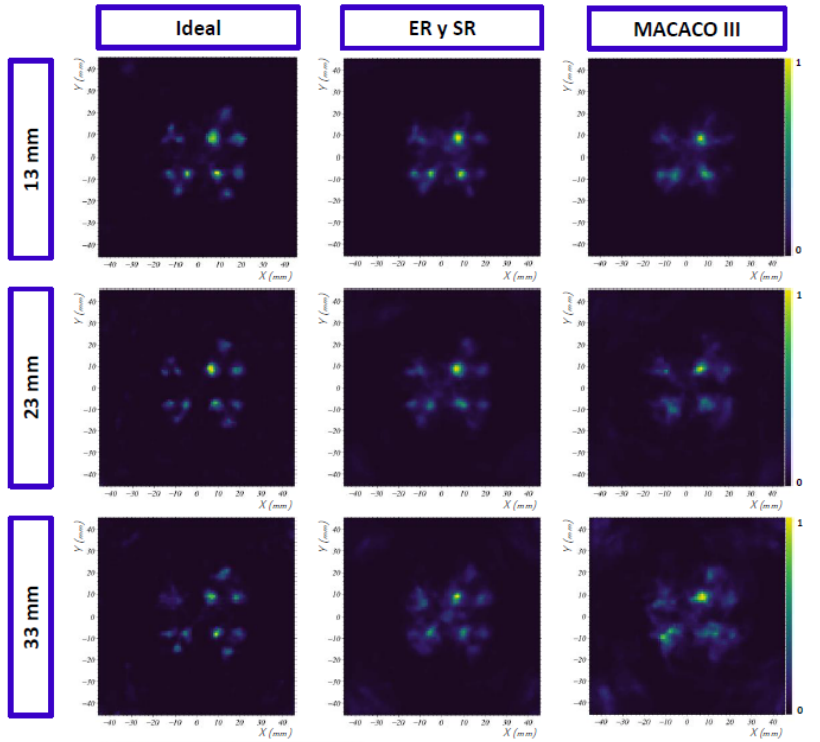
MACACO III+



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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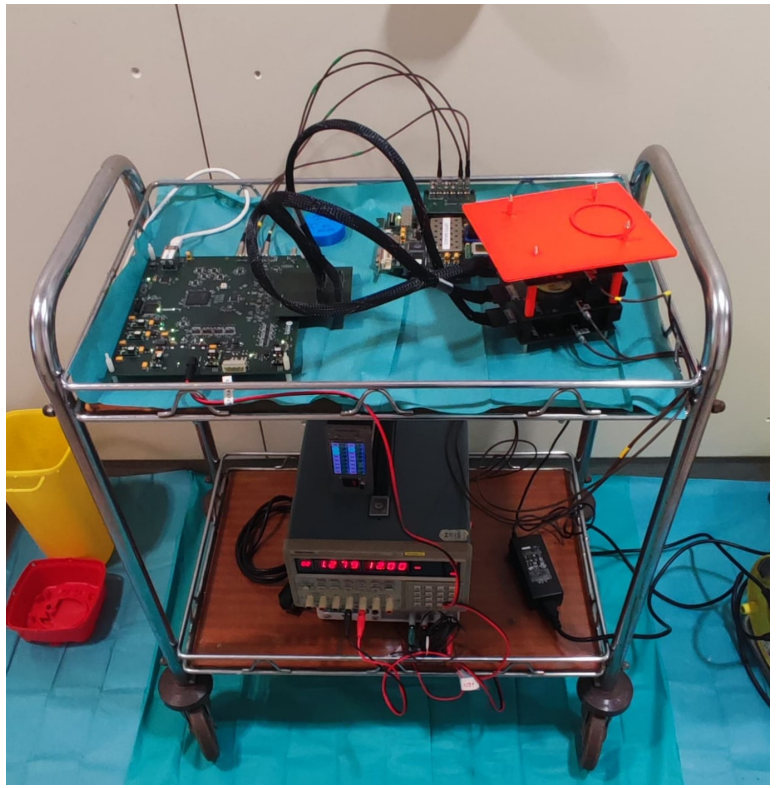
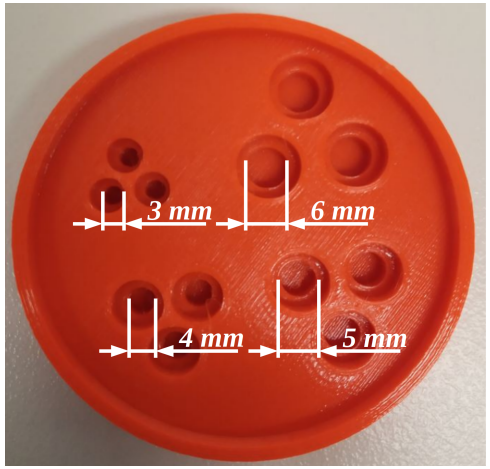
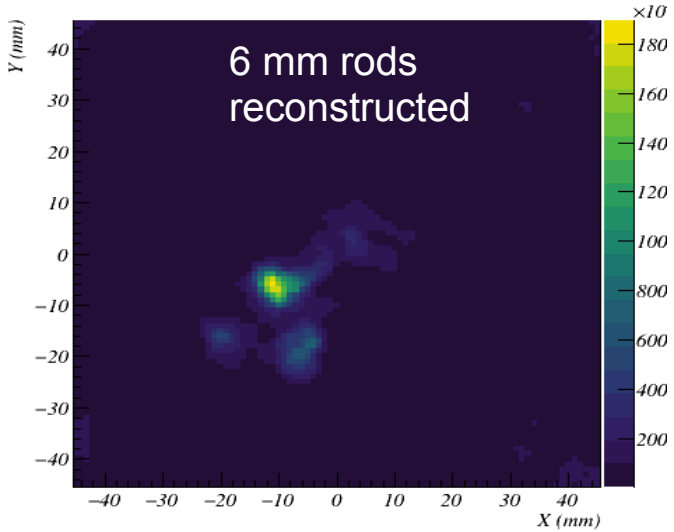
ICOR: *Compton imaging for Radionuclide therapy*

Tests in hospitals

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

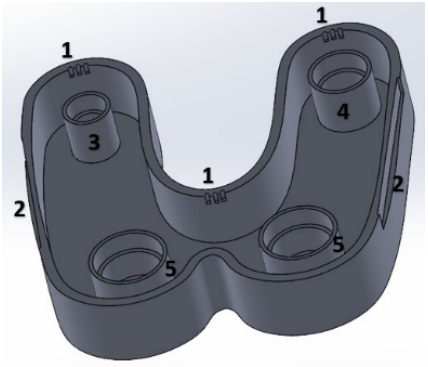




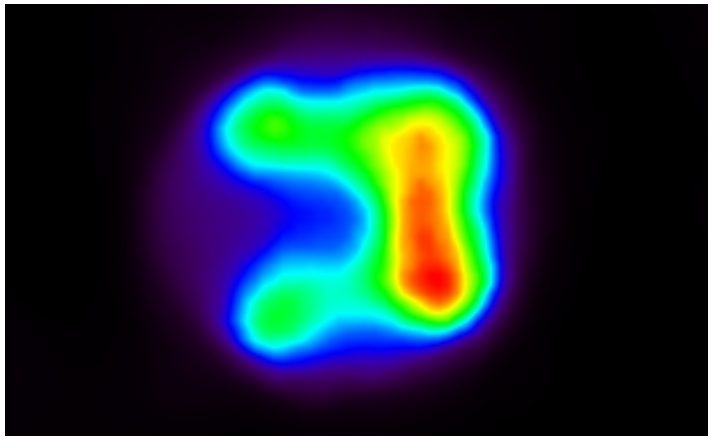


Further tests with I-131 in La Fe hospital (Valencia)

Ongoing tests with thyroid-shaped phantoms



Reconstructed image with MACACO III+



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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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N. Fuster

ASFAE/2022/015
A. Irles
M. Vos

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

ASFAE/2022/019
G. Llosa
I. Torres

Special thanks to C. Mariñas, A. Irles, N. Fuster and G. Llosa for the enormous help preparing this talk

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