Report from IRFU

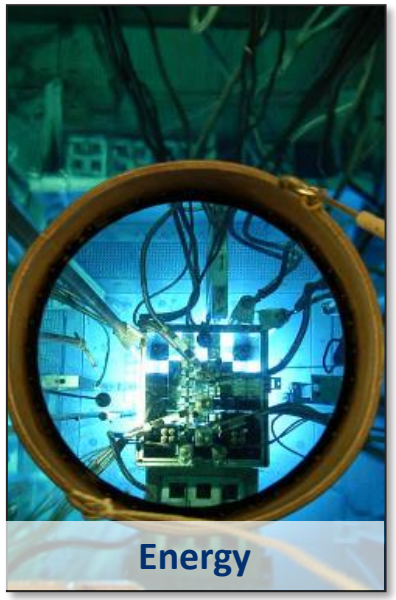
Institute for Research into the Fundamental laws of the Universe

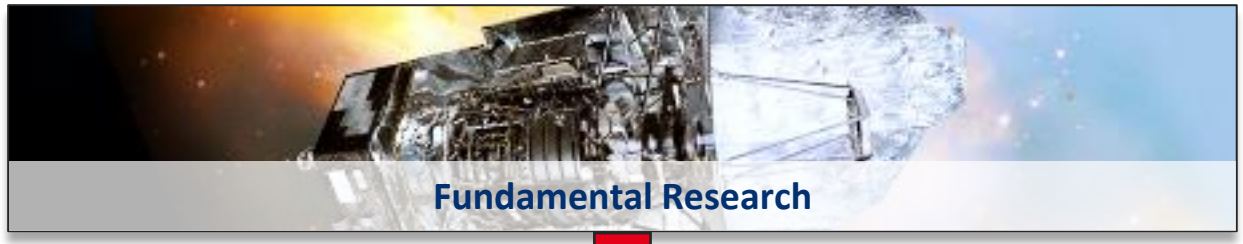
3rd International Summit on the Future of Double Beta Decay – Heidelberg

Nathalie Besson – head of Particle physics department

On behalf of IRFU director Franck Sabatié

CEA





cea irfu Institute for Research into the Fundamental Laws of the Universe

21000 employees

5.8 billion euros

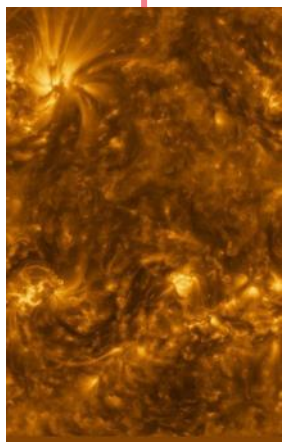
> 5000 publications

> 450 European projets

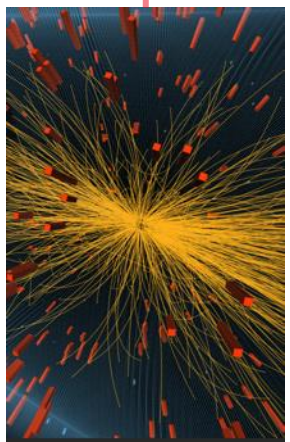
Staff on 2024, December

irfu — Institute for Research into the Fundamental laws of the Universe

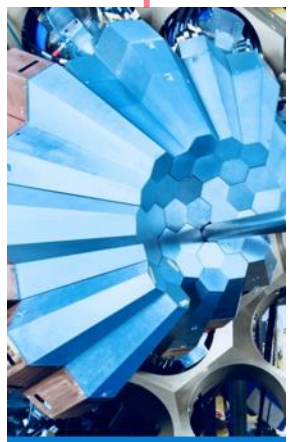
Management Office



DAP
Astrophysics



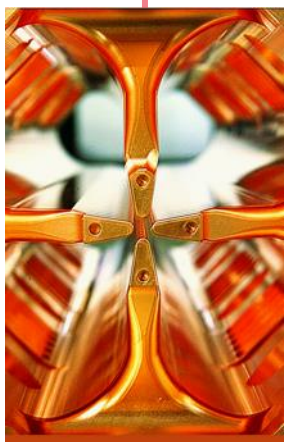
DPHP
Particle Physics



DPHN
Nuclear Physics

GANIL
Heavy Ion National Accelerator

DEDIP
Detectors
Electronics
Computing



DACM
Accelerators
Cryogenic
Magnets

DIS
System Engineering

- **679 permanents contracts**
- **398 fixed term contracts** (inc. 117 PhD students and 90 postdoctoral fellows)

900/y

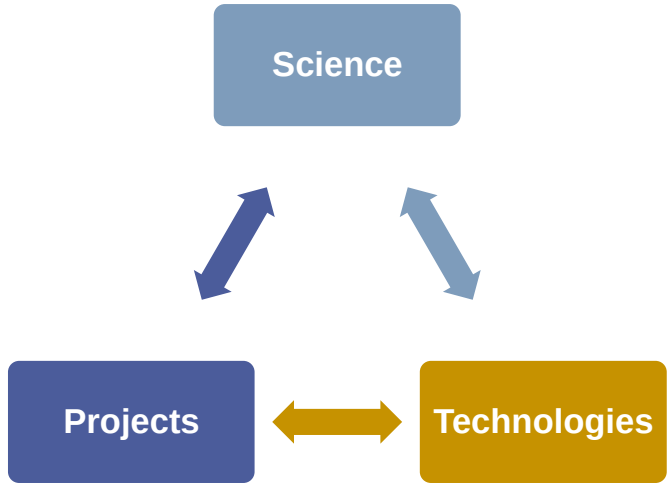
24 ERC
(8 ongoing)

Missions of IRFU

- **Carry out technological and fundamental research** within the framework of CEA's missions, in order to explore the fundamental laws of the Universe, from the smallest scales (elementary constituents, nuclear matter) to the largest (energy content and structure of the Universe)
- **Apply our technological innovations** to major national or international projects: MRI or fusion magnets, accelerators and neutron sources, medical imaging, etc.

With two specificities due to IRFU's size and the strong integration of its departments:

- **Ability to cover the entire research chain**
  - Theory, experiment proposal, simulation, design, construction, operation, data analysis, phenomenology and communication
- **Ability to manage large, innovative and complex projects**
  - Accelerators, magnets, detectors



IRFU research themes

Structure of the Universe

5 Energy content of the Universe

6 Formation and evolution of structures, galaxies, stars

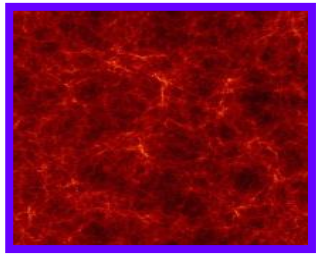
7 Stars and planetary systems

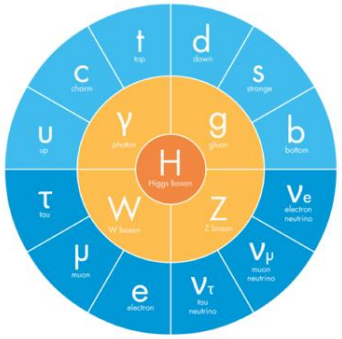
8 Exploration of the transient Universe

Detection Systems
all themes

Infrastructures & Platforms

Simulation and Big data analysis 11



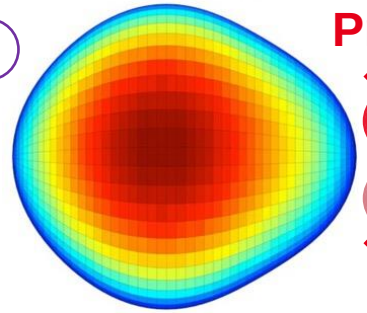


Elementary constituents, Fundamental symmetries

1 Consistency tests of the standard model

2 Structural tests of the standard model

Accelerator systems and High field magnets 9 10



Property of Nuclear matter

4 Nuclear structure and dynamics

3 Dynamics of quarks and gluons

Platforms

COMPUTING	SPACE
3 HPC clusters 13000 cores, 2500 Mh HS06/y **LHC Grid** (tier 2) 9000 cores, 500 Mh HS06/y	**Clean rooms** iso5-8 Instrumentation **Integration** and test halls

MAGNETS ACCELERATORS	DETECTORS
Synergium 25000 m^2 Clean rooms iso4-5 Integration halls and test cryostats	**Clean rooms** incl. Ciclad iso7 130m^2 and iso5 50m^2 **Integration** and test halls

The GANIL infrastructure in Caen (Normandy)

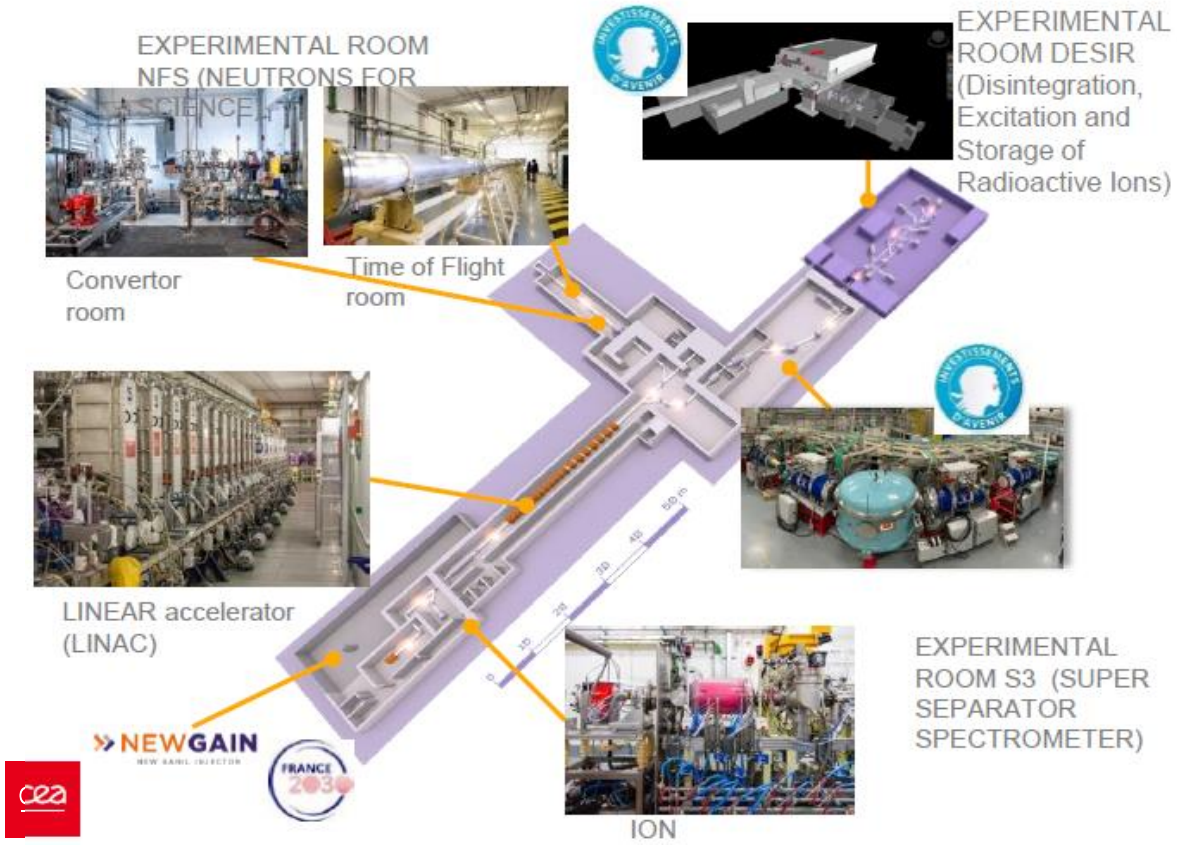
Included in the ESFRI landmark since 2016

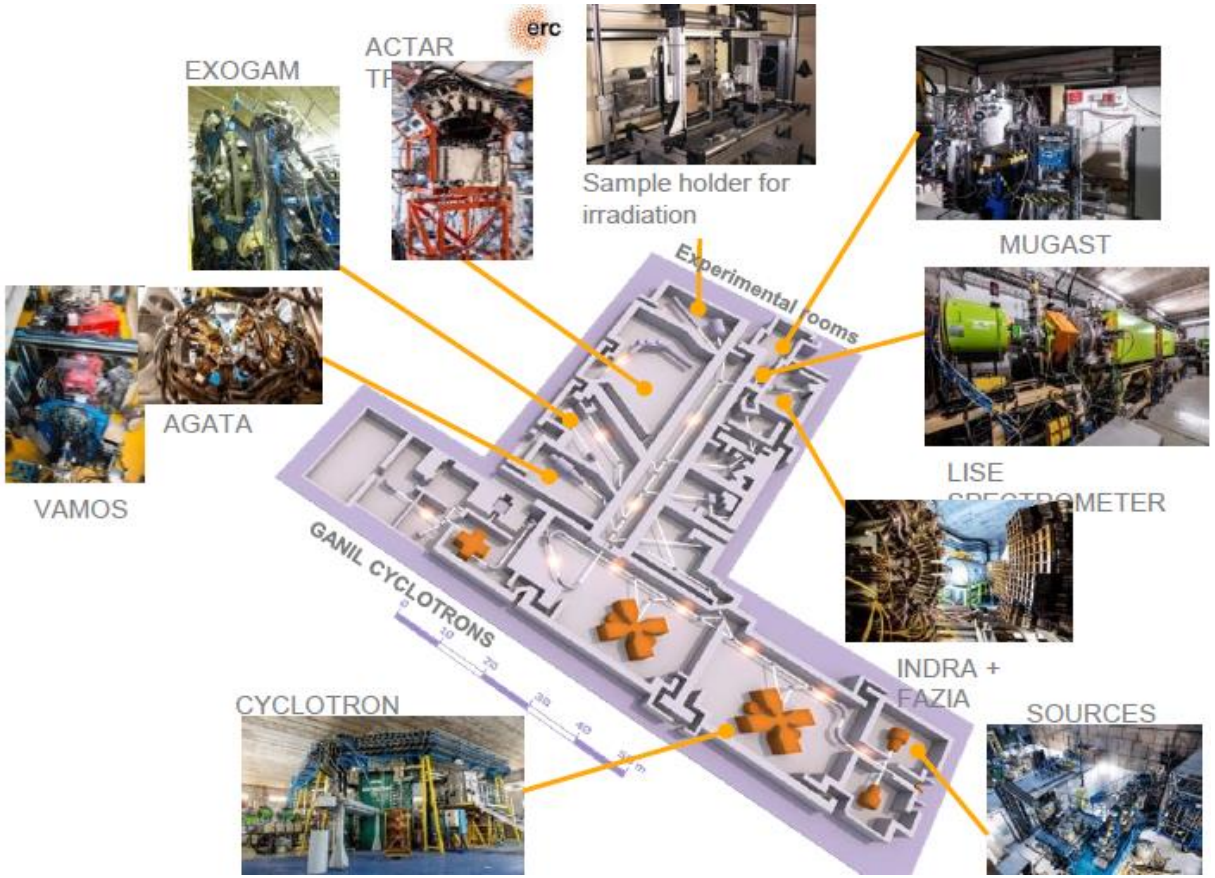
Multidisciplinary research: nuclear physics, material irradiation, radiobiology, industrial applications, accelerators and detectors.

Cyclotrons: ion beams from ^{12}C to ^{238}U at different energies

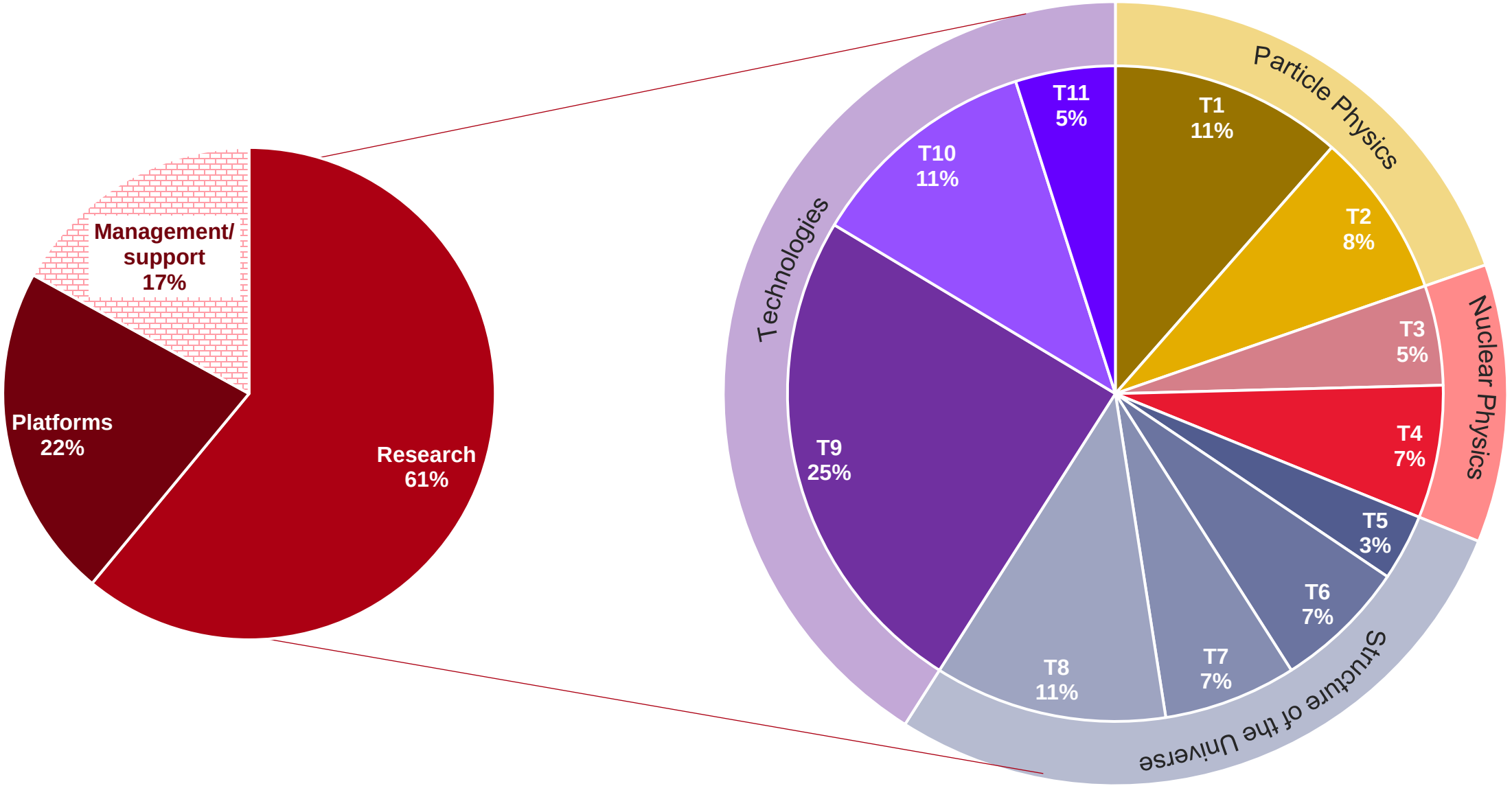
SPIRAL2: high intensity beams including light ones

230 permanent staffs (50% CEA-IRFU) – 1000 users





Repartition of Irfu's collaborators per activity and theme



Elementary constituents
Fundamental symmetries

Consistency tests of the Standard Model

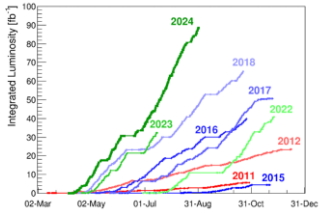
Search for deviations from the Standard Model by studying bosons and quarks

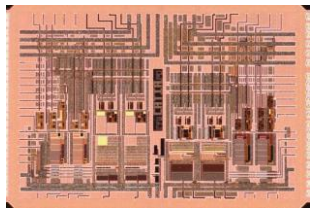
Structural tests of the Standard Model

Mass hierarchy, nature and properties of neutrinos

Current LHC Experiments
ATLAS & CMS Upgrades

T2K
HyperK
DUNE
NUCLEUS
CUPID - BINGO - TINY
GBAR





Highlight LHC

Run 3 at the record energy of 13.6 TeV & already high $\mathcal{L}$!

- Main focus on Higgs, EW and top physics

Phase 2 upgrades in production phase

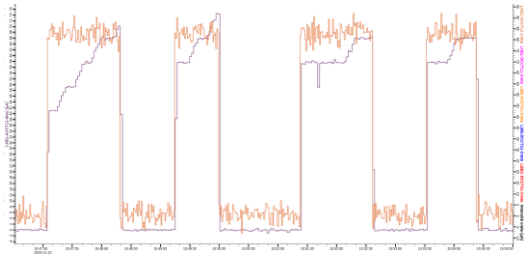
- ATLAS (Itk, LAr, HGTD, MUONS) & CMS (BCAL, HGCAL, MTD)

National contribution to ESPPU

Property of Nuclear matter

Nuclear structure and dynamics	Binding limits of nuclei, nature of the nuclear interaction, influence of the nuclei structure on nuclear reactions
Dynamics of quarks and gluons	Quark and gluon plasma, 3D structure of the nucleon

GANIL
Spiral2 (NFS, S3, DESIR)
AGATA
FAIR
n_TOF
Nuclear Theory
ALICE
LHCb upgrade
sPHENIX
Jefferson Lab
EIC
Hadronic Theory



Highlight GANIL

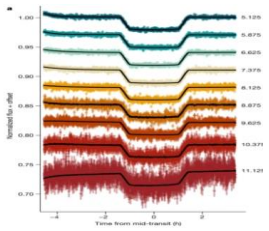
Commissioning of the S^3 spectrometer

- Late in November, a high-intensity Argon40 beam with an energy of 5 MeV/A is sent to
- Synchronization of target rotation with LINAC beam structure

Structure of the Universe

Energy content of the Universe	Constraints on dark energy and dark matter
Formation and evolution of structures, galaxies, stars	Structure of the universe from the cosmic microwave background to the stars and the galaxies
Stars and planetary systems	Characterization of exoplanets and their host stars, study of the star-planet interaction
Exploration of the transient Universe	Multi-messenger observations (photons, GW) of transient phenomena in the Universe

HESS	ARIEL
DESI	PLATO
EUCLID	SVOM
LITEBIRD	CTA
James Webb	THESEUS
ATHENA	SKA
	LISA



Highlight JWST

MIRI measures sulfur dioxide abundance on a hot Saturn (WASP-39b)

- Using the transit technique, the JWST detected for the 1st time SO_2 clouds in the atmosphere of a gaseous exoplanet
- It is a compound which is produced by photochemistry: a phenomenon never before observed in an exoplanet!

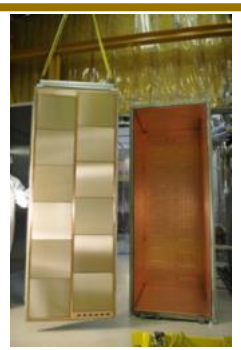
Detection systems, sample of projects

in operation

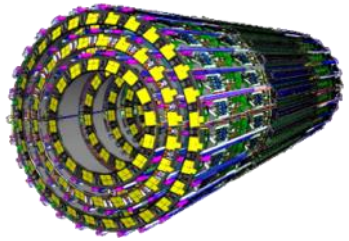
in development

Elementary constituents, Fundamental symmetries

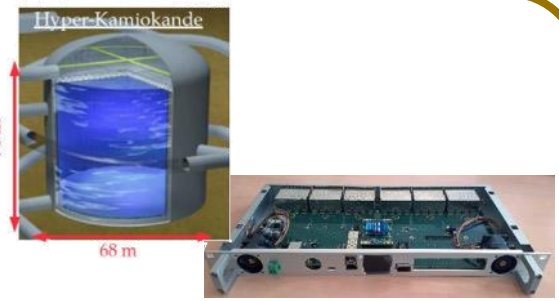
ATLAS New Small Wheels
400m^2 of Micromegas detectors



T2K Micromegas Time projection chambers system Tokai Lab (Japon)



ATLAS Itk Module assembly and testing.
1/4 of the silicon internal Tracker



HyperK Neutrinos Oscillations
High precision clock distribution system

Property of Nuclear matter

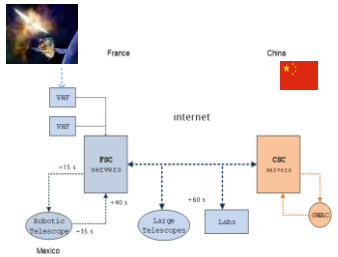
ALICE Muon Forward Tracker
based on MAPS technology

ALICE muon arm
Upgraded back-end electronics

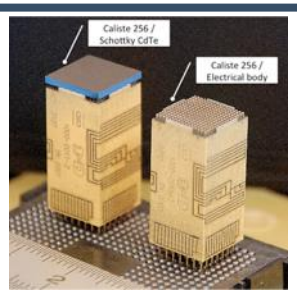
ESS Advanced beam diagnostics High Intensity profile monitors and low energy beam loss monitors

Sirius Silicon detectors used at GANIL/Spiral2-S3

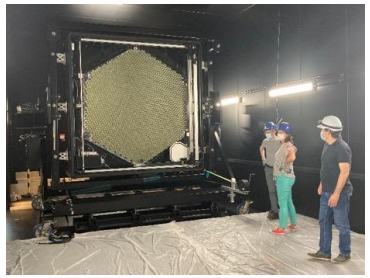
Structure of the Universe



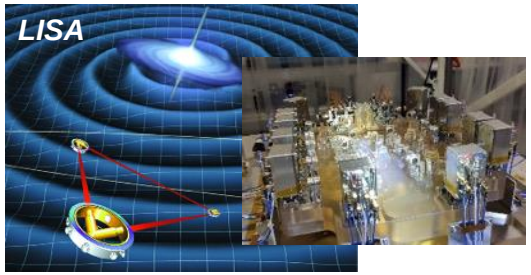
SVOM On-board computing
&Ground Segment



Solar Orbiter / Caliste: mini CdTe gamma camera



NectarCAM MDT telescopes of CTA
& Mirrors



LISA ground support equipment
Data analysis based on IA technologies

Accelerator systems and cryomagnetism

- **High-intensity/energy accelerators** — Developments of RF sources and injectors, studies on future colliders
- **Superconducting RF systems** — Cryomodules and superconducting cavities, studies on higher efficiency or gradients, and new cooling technologies
- **High-field superconducting magnets** — Simulation, design, manufacturing and operation of high-field / large / "special" / high homogeneity magnets

IFMIF
TITAN / ICONE
NEWGAIN
SARAF
ESS
PIP-II
ISEULT (MRI)
CERN HL-LHC
CERN HFM
EIC magnets
MADMAX
SUPRAFUSION (HTc)

Highlight ESS

ESS first assembled section (180 m) cooled down for the 1st time

- After 5 years of assembly at Saclay, the cryomodules installed in the European Spallation Source (ESS) tunnel were cooled for the first time to 4K at the end of November 2024
- First assembled section of the linac, capable of accelerating protons up to 876 MeV, including 14 cryomodules integrated at Irfu

Neutrino physics at IRFU

	Nν	Mixing param.	Mass ordering	Masses	Nature	ν properties
Oscillation exp.	✓	✓	✓			✓
β decay exp.	✓		✓	✓		
2β decay searches			✓	✓	✓	
Coherent scattering						✓
Cosmology	✓			✓		

Neutrinos raise many fundamental questions & there's a wealth of tools available:

IRFU capitalizes on three key strengths:

- An important historical involvement in neutrino oscillation experiments such asT2K, Double Chooz, STEREO, HK, DUNE
- Expertise in nuclear processes, neutrino fluxes measurements, neutrino interactions, neutrino production processes from for instance CEVNS with NUCLEUS or flux computations with NENUFAR
- Expertise in the development of low background detectors for neutrinoless double beta decay experiments

- Cosmology: BOSS, eBOSS, DESI

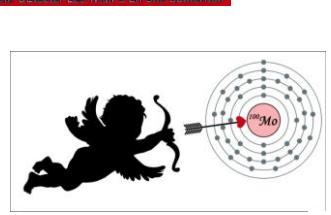
Comparison and combination of data from various experiments are crucial for precise neutrino measurements and a comprehensive understanding of their nature.

Neutrino physics: 23 FTE + 9 postdoctoral fellows and PhD students. At DPhP +7 in the last 5 years including 4 new hiring

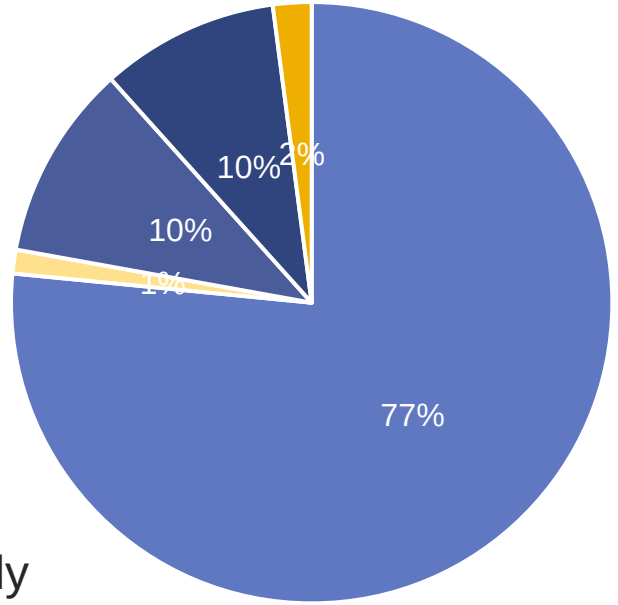
A focus on neutrinoless double beta decay

At IRFU, neutrinoless double beta searches follows the technology ligneage of rare event searches with bolometers, with expertise on:

- Conception and assembly of detectors
- Cryogenics and vacuum techniques
- Low radioactivity
- Underground Labs
- (Cold) Low noise electronics
- Data analysis
- Simulations



Funds: 2012-2025



Total of 6 M€
Hardware only

From 1 FTE and 1 PhD student in 2012-215
to 8,5 FTE, 2 PhD students and 2 postdoctoral fellows in 2025
3 PhD obtained

Neutrinoless double beta decay projects

01 LUMINEU

2012-2016
Selection of Li_2MoO_4 for a pilot experiment

02 CUPID-Mo

2017-2023
Selection of ^{100}Mo for CUPID

World limit on ^{100}Mo and technology chosen for CUPID

03 CUPID

2016 - …
Next generation experiment

04 BINGO

2020-2026
ERC grant
Open the way to normal hierarchy

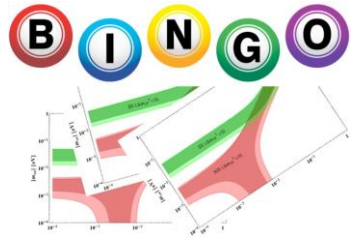
New low radioactivity cryo-platform at LSM

05 TINY

2023-2028
ERC grant
Two new isotopes under study

New cryo-platform at IRFU for above-ground test

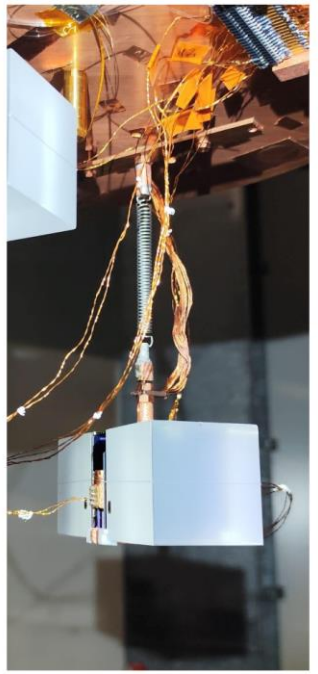
Beyond BINGO



The BINGO cryogenic infrastructure will be a low radioactivity platform available for several physics measurements.

New proposals are under evaluation to continue the BINGO physics at LSM:

- E-BINGO (ERC): for Enriched BINGO, to validate a French supply chain, for 100Mo isotope purchase and crystal growing
- MORELIGHT (ERC): to increase the Light Yield of scintillating crystals
- TOTEM (ANR): to develop fast sensors like TES and improve the energy resolution and pile-up discrimination
- Possibility to have a multi-isotope demonstrator (TINY)



Thank you for your attention