DE LA RECHERCHE À L'INDUSTRIE

cea

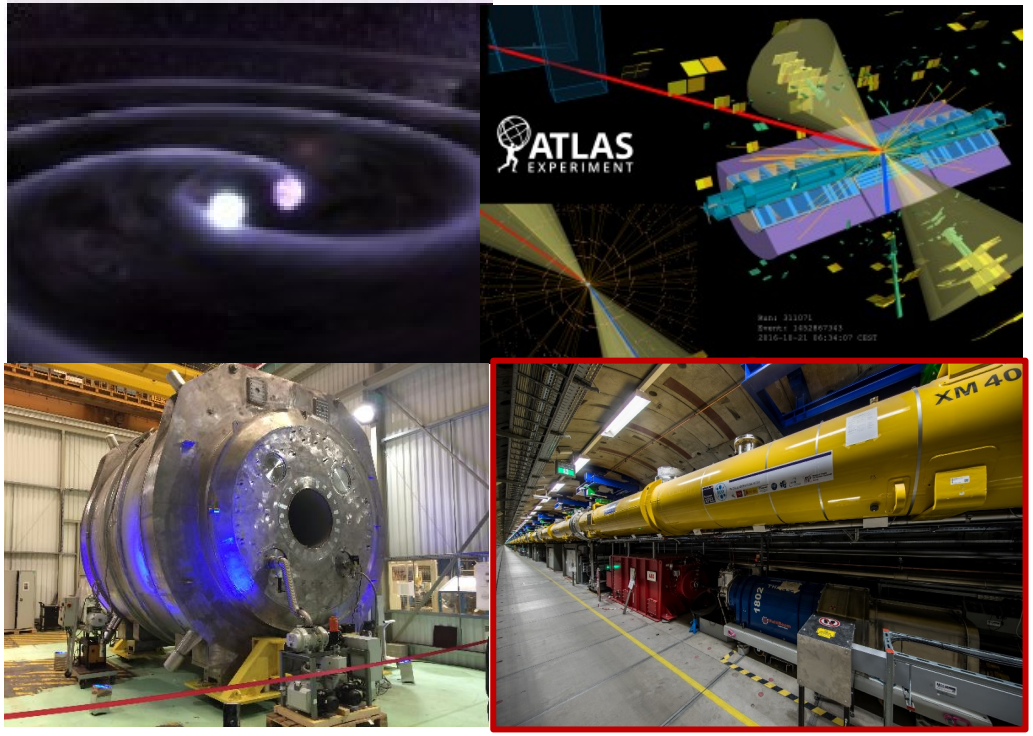
www.cea.fr

IRFU - GENERAL OVERVIEW

MARC BESANCON

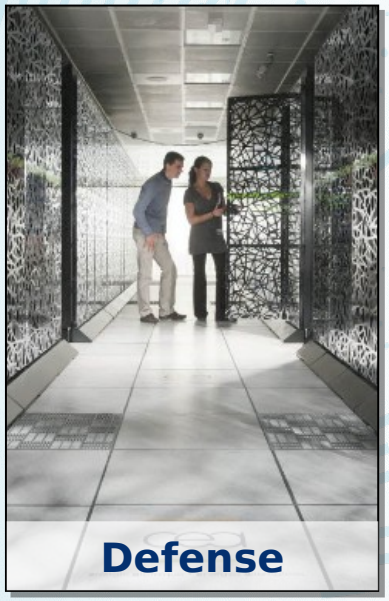
BASED ON SLIDES FROM

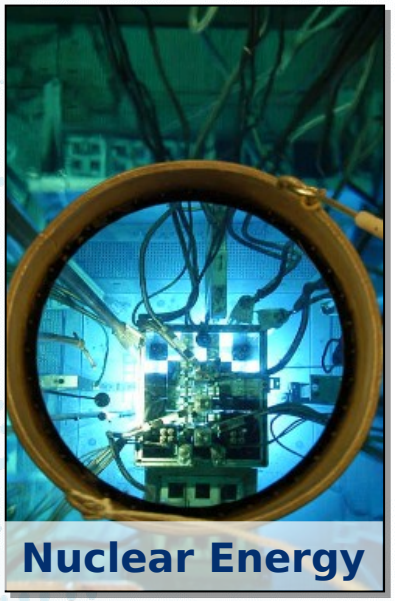
ANNE-ISABELLE ETIENVRE (HEAD OF IRFU)



JEJU – MAY 2019

IRFU WITHIN CEA





16 000
Technicians, engineers, researchers and staff

4 400
Million euros budget

10
Research centers in France

FUNDAMENTAL RESEARCH

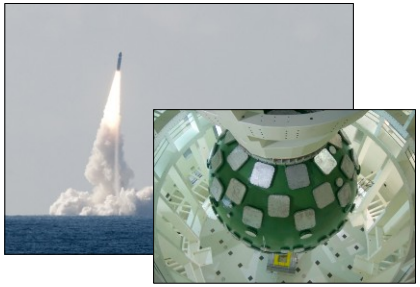
Institute of Research into the Fundamental Laws of the Universe (IRFU)

CEA MISSIONS: APPLICATIONS & TECHNOLOGIES

Defense and security

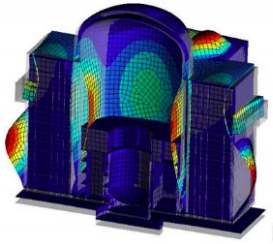
security

- Design, manufacturing, operational maintenance, dismantling of nuclear weapons warheads
- Nuclear propulsion
- Global security
- Control of nuclear treaties



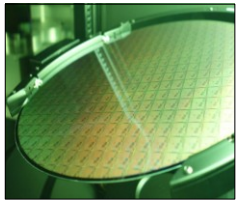
Nuclear energy

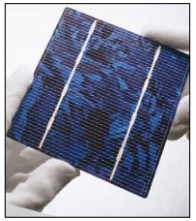
- Support for nuclear power stations in operation
- Theory, simulations, technologies, processes and data for nuclear operations
- Systems for the future (Gen-IV reactors)
- Waste management and dismantling of obsolete installations



Transfer to the industry

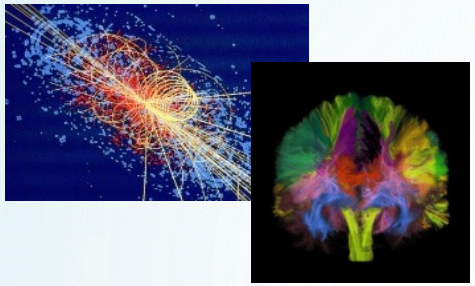
- Micro & nanotechnologies
- Software and information system technologies
- Technologies for health and biotechnologies
- Renewable energies
- Instruments





FUNDAMENTAL RESEARCH ACTIVITIES

PUSHING THE LIMITS OF TECHNOLOGY … TO ACHIEVE CUTTING EDGE SCIENCE



From basic research to applications

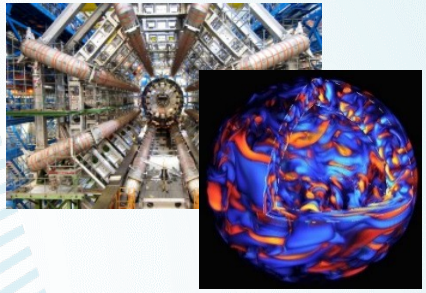
- Physics

  (Nuclear physics, high energy physics, astrophysics, fusion, quantum engineering)
- Material sciences, chemistry
- Biology and biotechnologies, health
- Climate & environmental studies

KNOWLEDGE

CEA Fundamental Research Division

KNOW-HOW



Infrastructures and instrumentation

- Cryotechnologies, accelerators, magnets, lasers, detectors
- Radioisotopic tagging, radiochemistry
- Genomics, proteomics, radiobiology, bio-imaging
- High performance computing
- Micro and Nanotechnologies, material processes

IRFU : GENERAL STRATEGY

- **Answer to the main questions** concerning the four fundamental interactions, at different scales, from the very smallest (building blocks of matter, nuclear matter) to the largest (energy content and structure of the Universe)

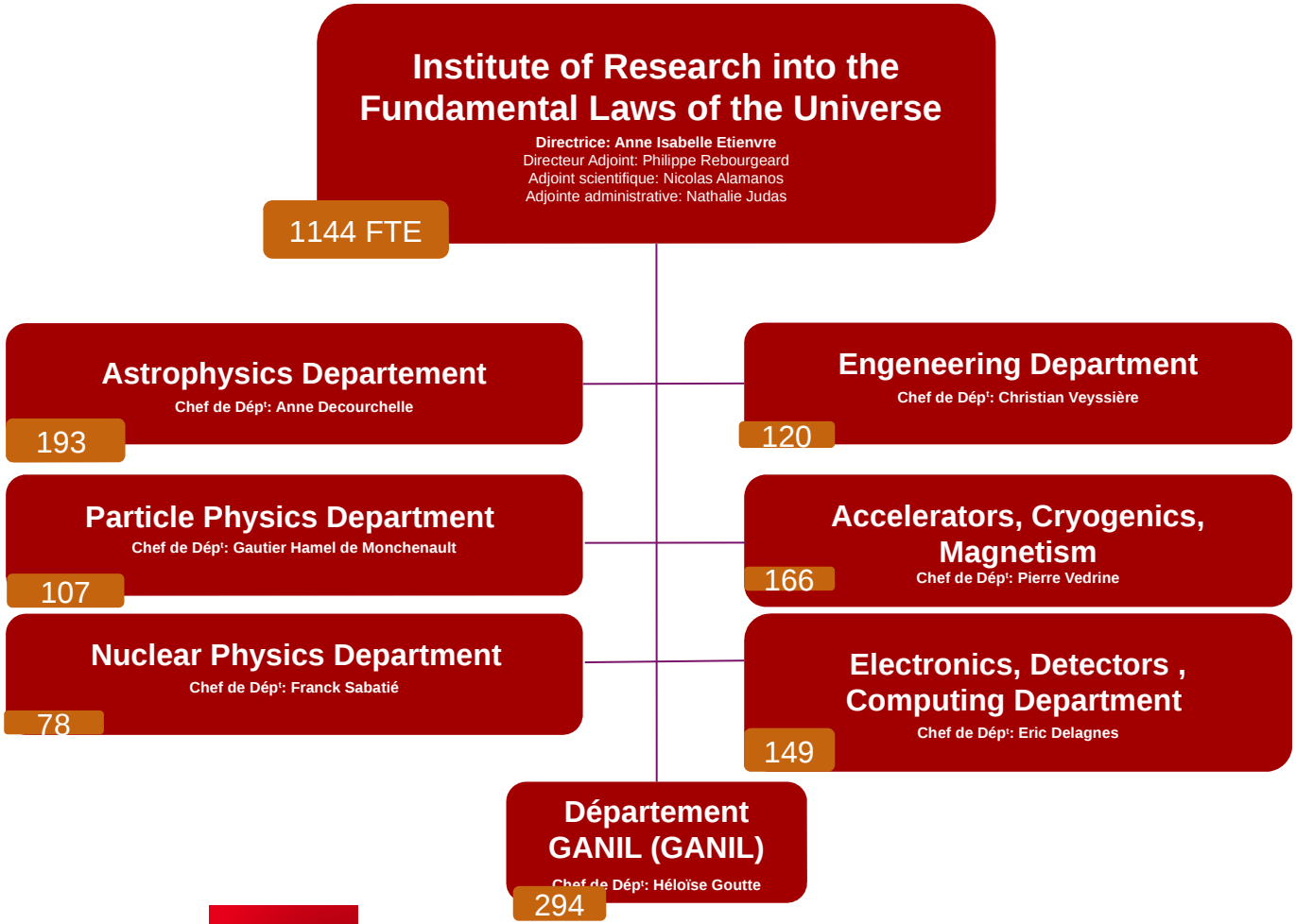
- **Design, construction, operation of high technology instruments**
  - for these research topics
  - …and beyond

- **Key actor within major international collaborations**

- **Core fundamental research actor of CEA strategy, in interaction with other divisions**

- **Teaching, training**

IRFU ORGANIZATION



EXPLORING THE FUNDAMENTAL LAWS OF UNIVERSE

What are the ultimate constituents of matter ?

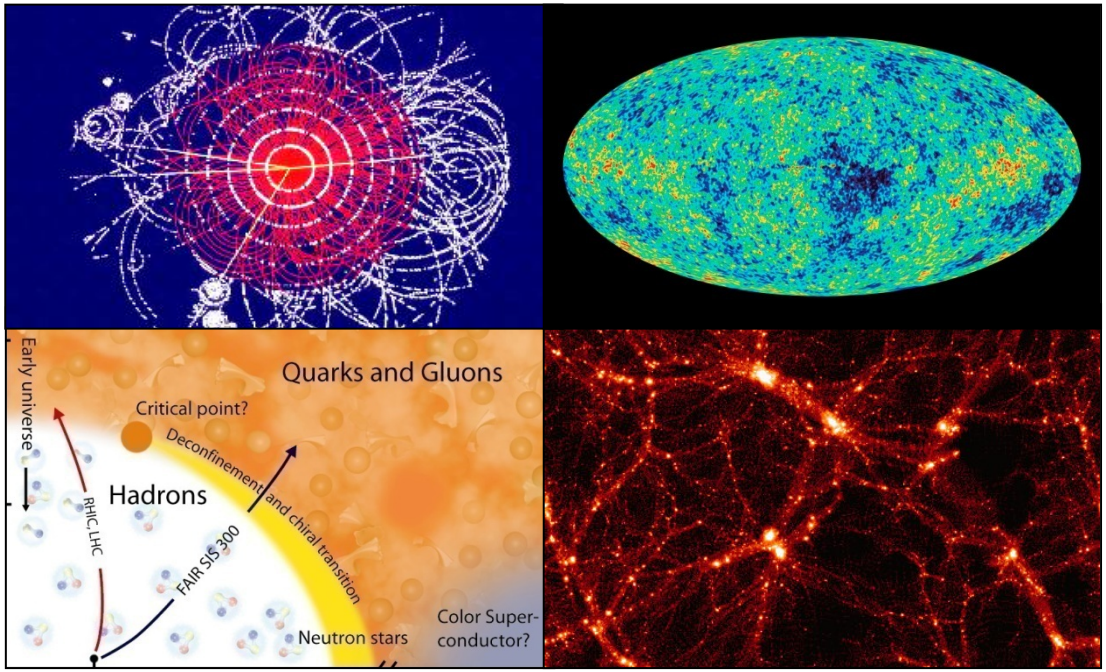
- *LHC*
- *Neutrinos*

What is the energy content of the Universe ?

- *Dark matter & energy*
- *Antimatter*

Infinitely small → *Infinitely large*

Elementary ↓ *Complex*



What are the origins of particles and nuclei ?

- *Exotic nuclei*
- *QGP*
- *Structure*

What are the origin and structure of the Universe ?

- *Star and galaxies*
- *Planets*
- *Violent phenomena*

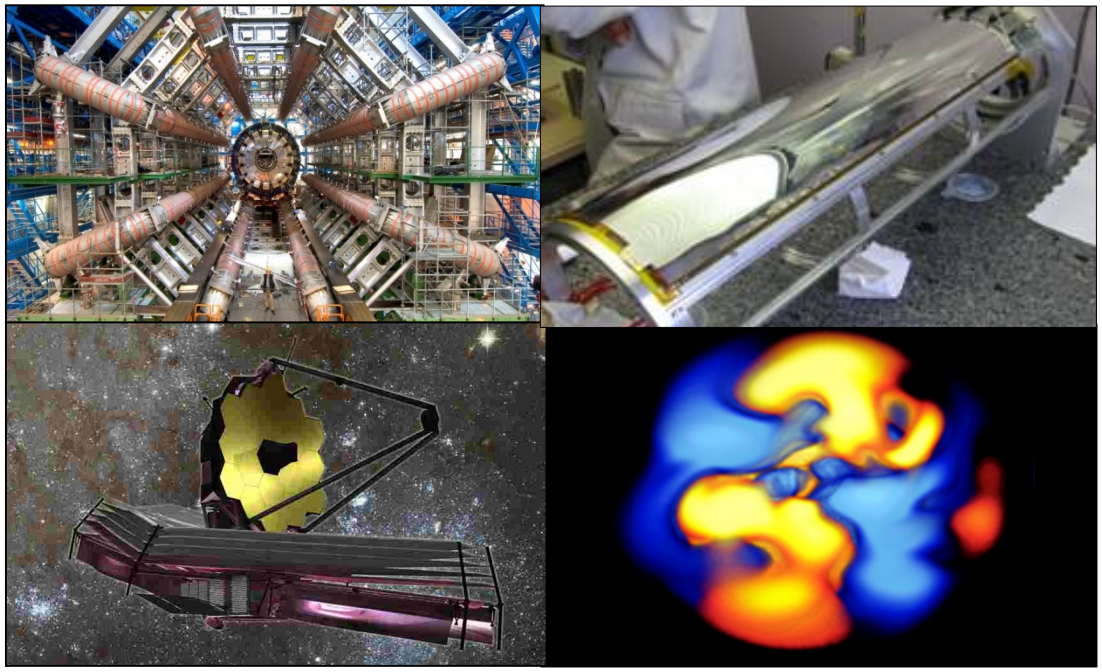
INVENTING AND CONSTRUCTING NEW DEVICES

Accelerator and superconducting magnets

- ***Intense ion sources, RFQ, Cryomodules***
- ***Beam dynamics***
- ***Superconducting magnets for accelerators and detectors***
- ***MRI***

Detecting

- ***Gaseous detectors (Micromegas)***
- ***Solid detectors (bolometers)***
- ***Electronics (ASICS)***



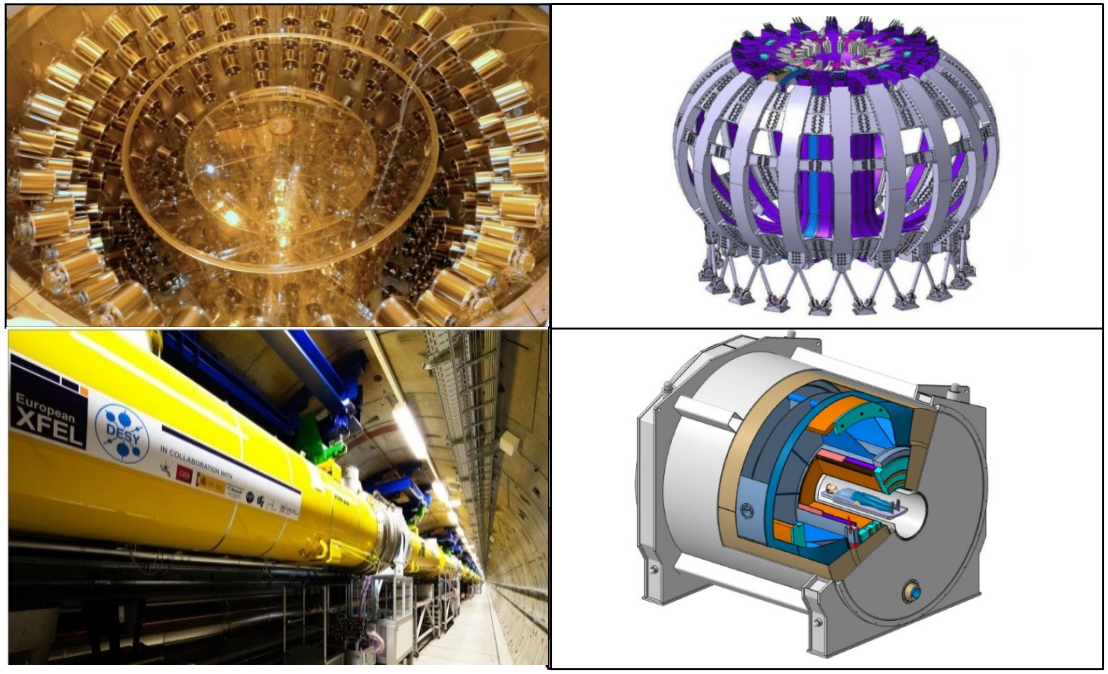
Observing : space devices

- ***Camera, spectroimaging***
- ***cryomecanisms***

Simulating

- ***HPC***
- ***Grid***

Knowledge and know-how for other communities

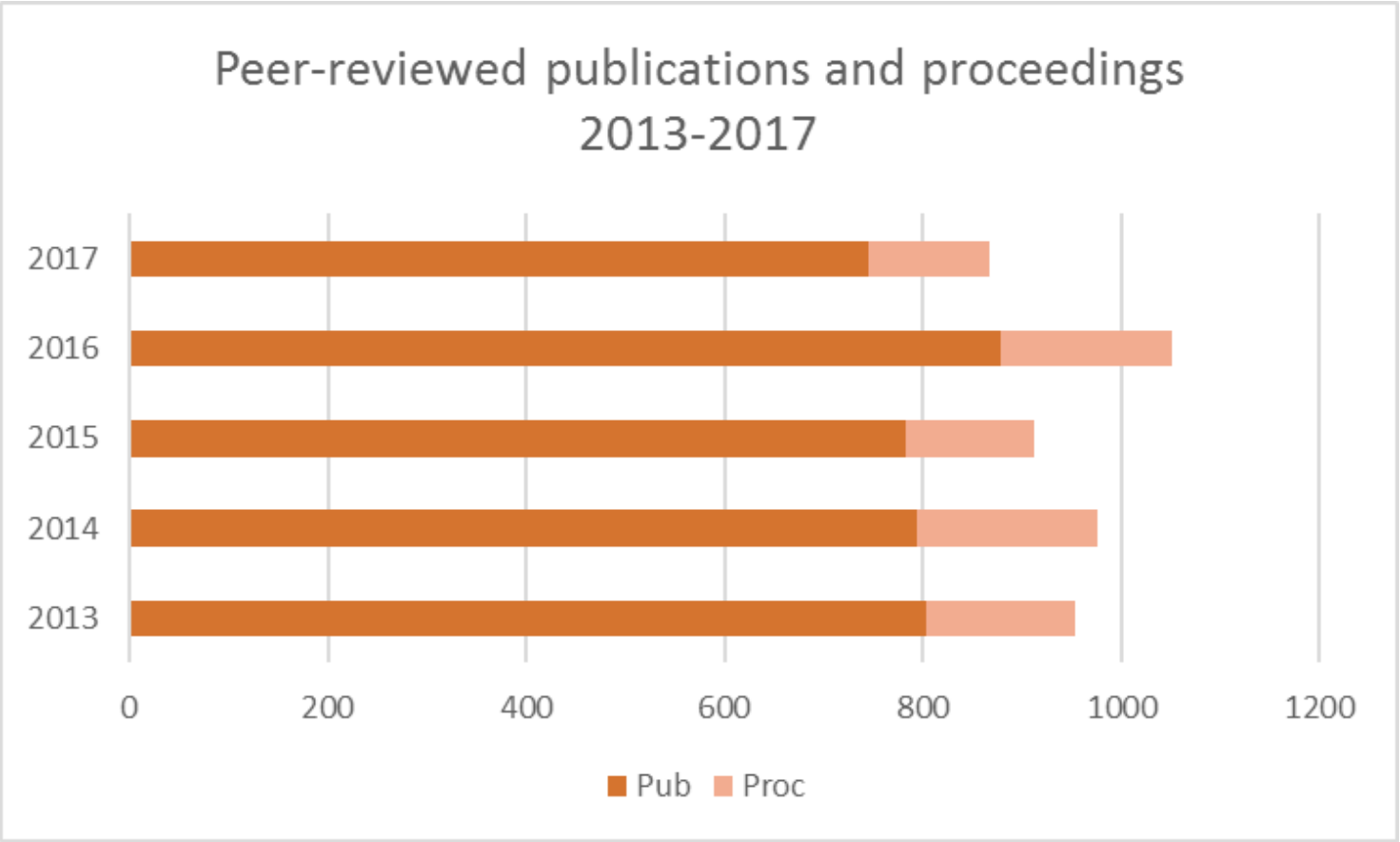


- *Fusion (broader approach: IFMIF, JT60-SA, ITER)*
- *Light sources (major contribution to E-XFEL)*
- *Health: MRI (11.7 T Magnet Iseult), detectors*

STRONG INTERNATIONAL COLLABORATIONS

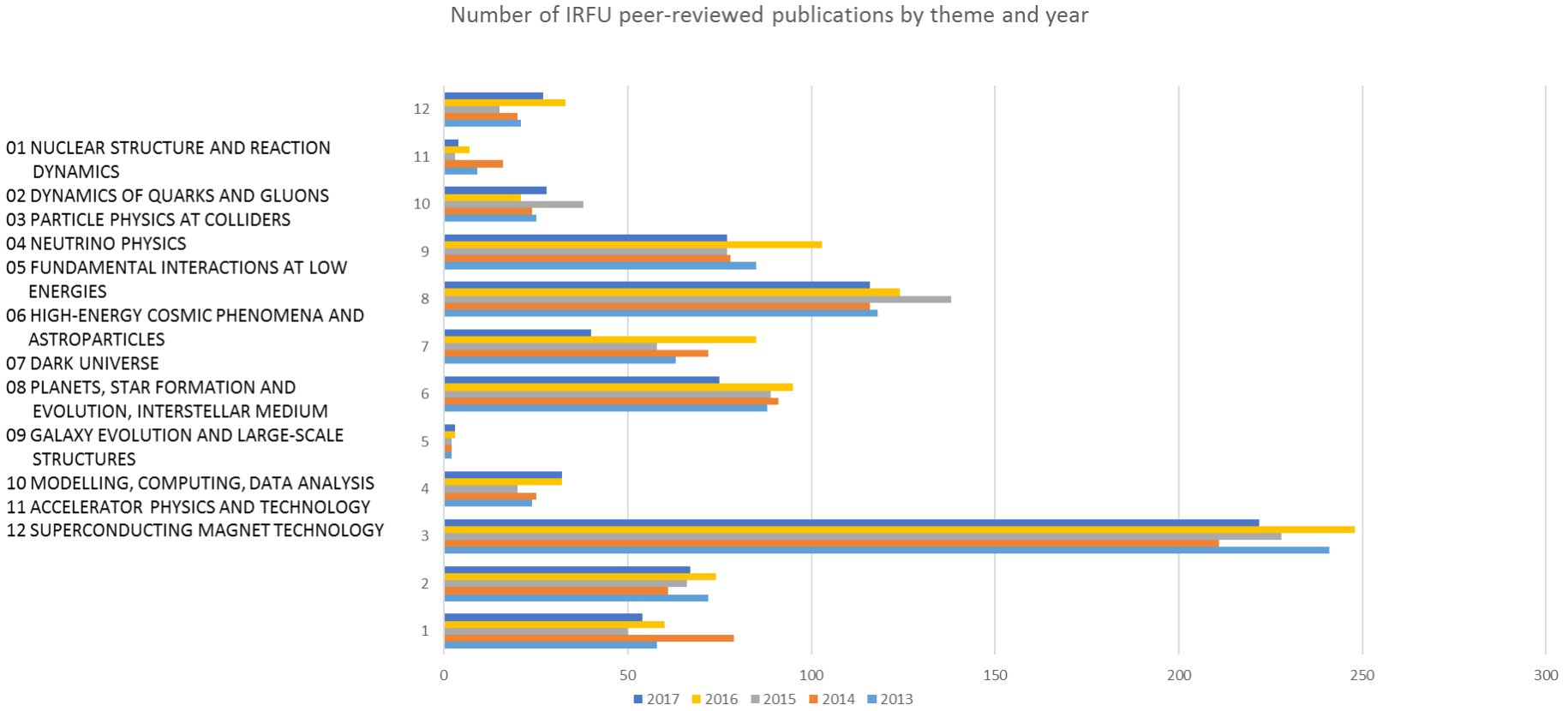
PUBLICATIONS

More than 900 publications and proceeedings/year



PUBLICATIONS

Distribution % theme, year



PUBLICATIONS

Highly cited publications

Performances of true citations from 2013 to 2017						
	Publication year					
IRFU	2013	2014	3015	2016	2017	Total
Number of papers	805	794	784	879	745	4,007
Sum of real quotes (on March 22, 2018)	29,215	36,977	15,963	14,077	2,239	98,471
Word average of quotes (ESI Physics)	10.7	8.6	6.1	3.3	0.7	
Word average of quotes (ESI Space Science)	17.8	13.6	9.3	5	1.2	
Average number od quotes per paper (on March 22, 2018)	36.3	46.6	20.4	16.3	24.6	
Number of non-quoted paper (on March 22, 2018)	11	22	32	77	277	419

SCIENTIFIC RECOGNITION

Many scientific recognitions awarded to Irfu scientists

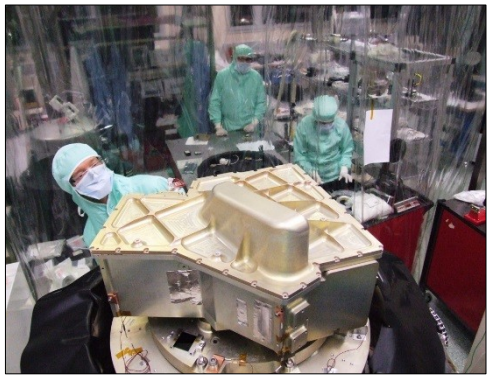
- **2017: 3 prices awarded by the «Académie des Sciences »**

LARGE PLATFORMS @ SACLAY (50 000 M²)

DETECTORS

rge migromegas detectors integration and tests (LHC UPGRADES)

Clean room - 130m²



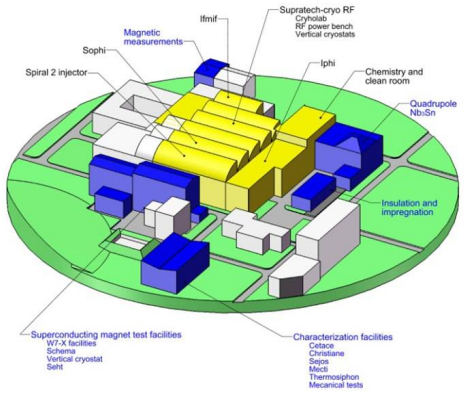
SPACE

Clean rooms for space instruments integration and tests

Magnets and accelerators

Synergium - 25 000m²

Integration halls, clean rooms cryostats



Computing

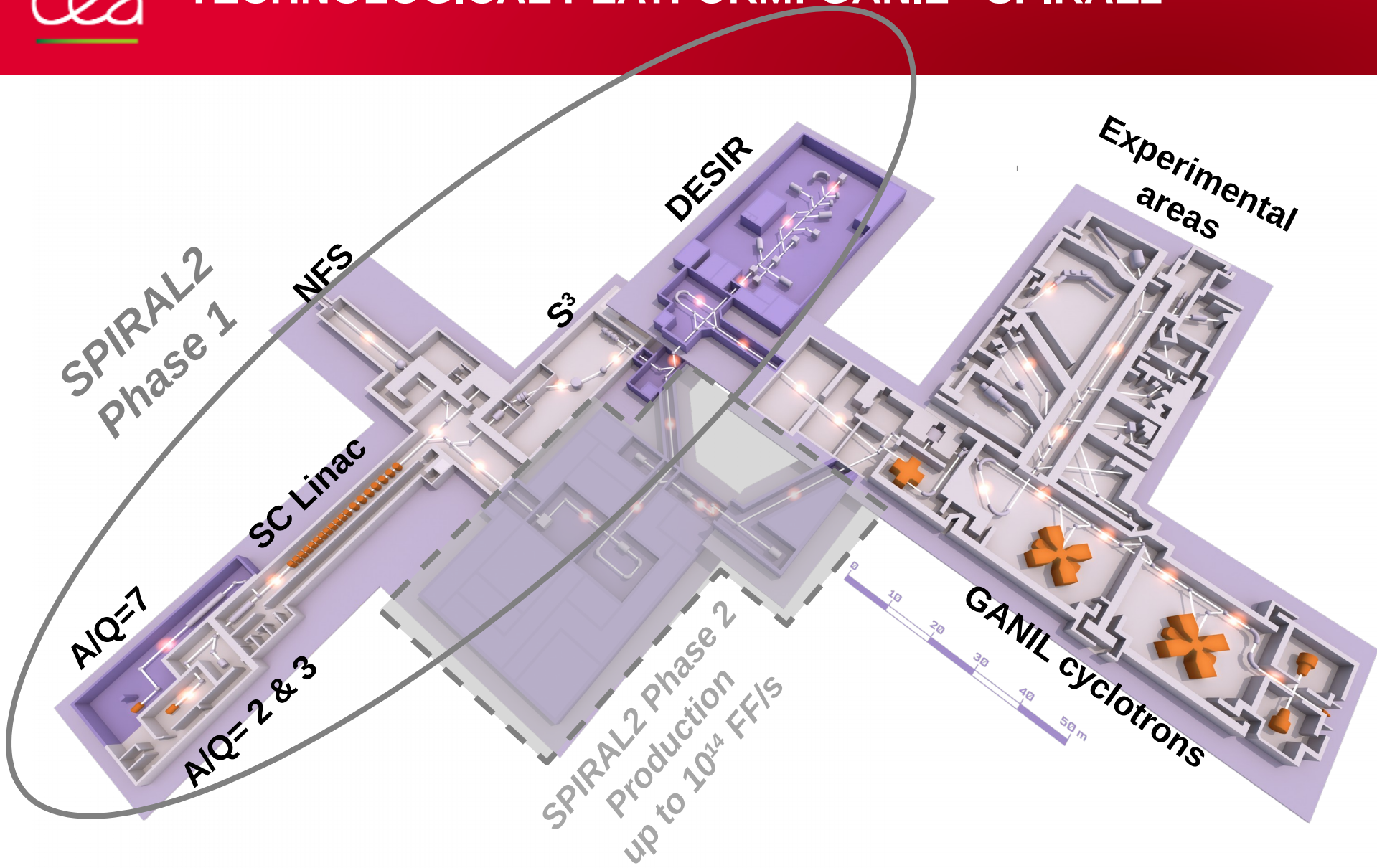
HPC cluster

Node of Grid@LHC

CEA-CNRS Large infrastructure in CAEN

Le 3 novembre 2016 le Président de la République Francois Hollande a inauguré l'accélérateur de particules Spiral2 au Ganil.

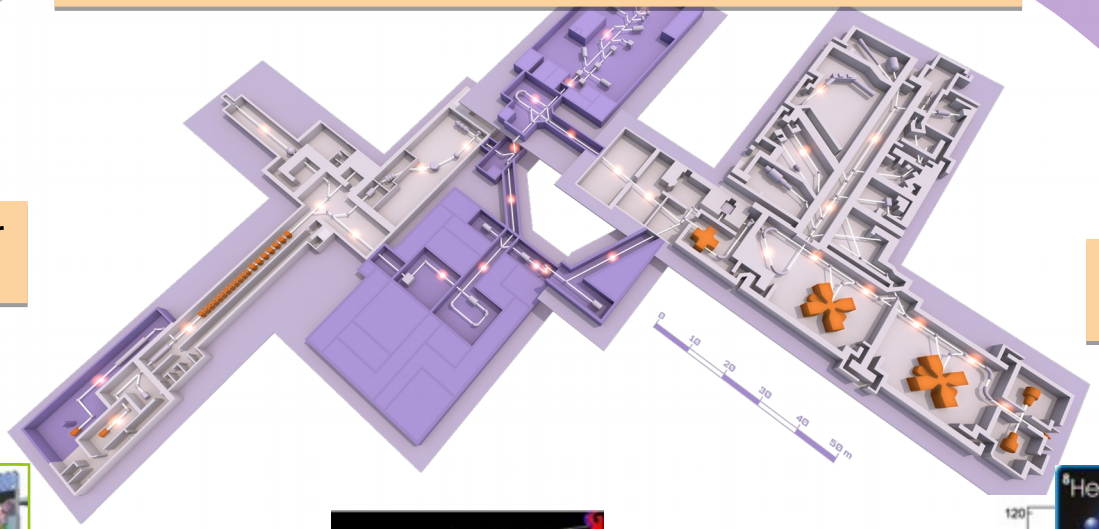
TECHNOLOGICAL PLATFORM: GANIL - SPIRAL2

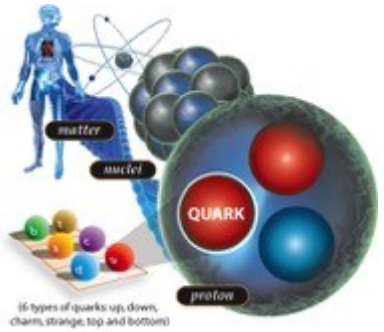


GANIL STRATEGY, MISSION

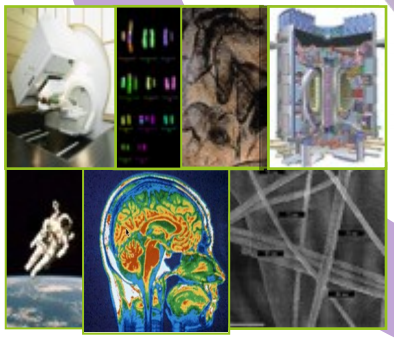
- With and at the service of the international scientific community
- Contribute to the growth of scientific and technical knowledge

Detector & accelerator science & technology



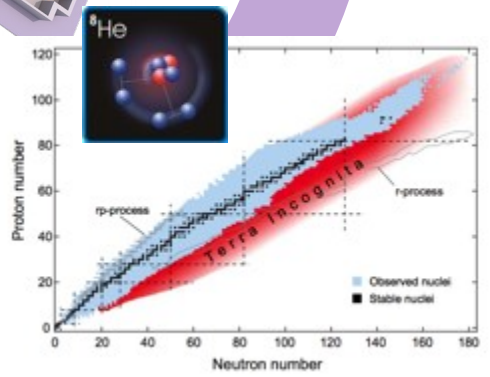


Fundamental interactions



Multidisciplinary research and applications

Nuclear astrophysics



Nuclear structure and reaction

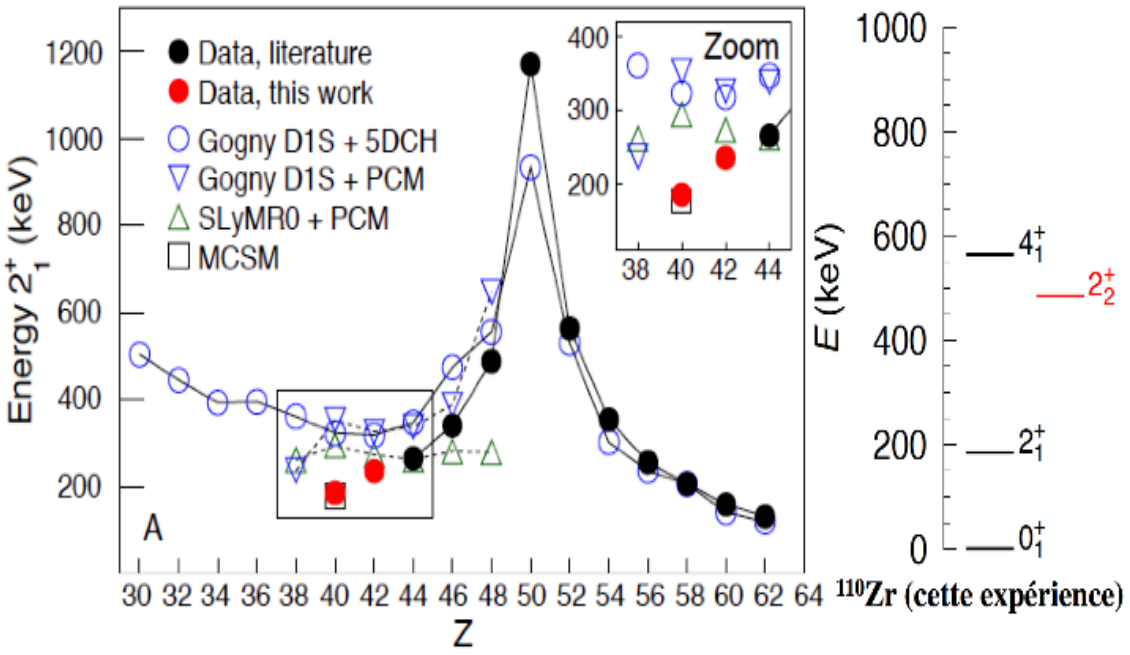
SOME RECENT HIGHLIGHTS

MINOS @ RIKEN

Construction of the overall setup in Saclay

(hydrogen target, TPC detector, electronics and acquisition system)

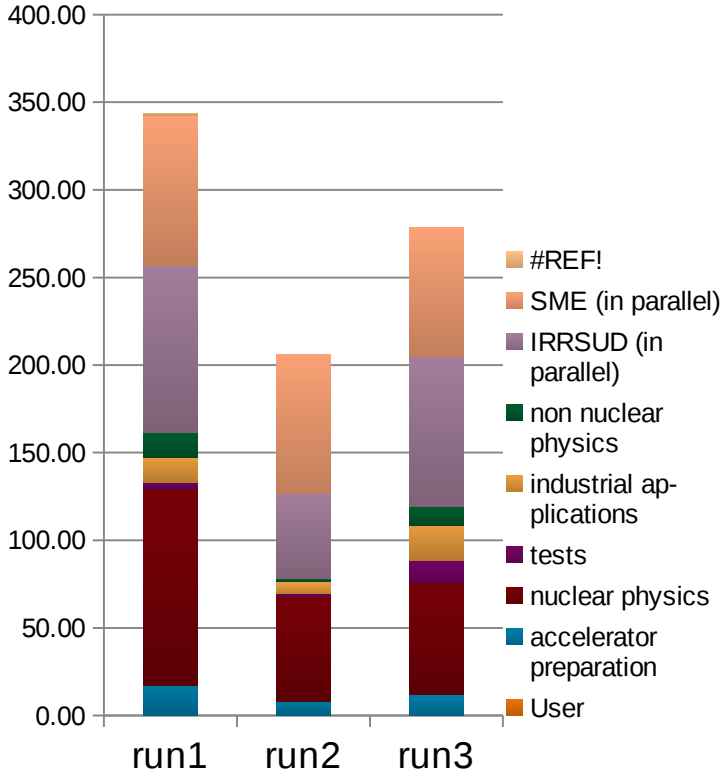
ERC Grant

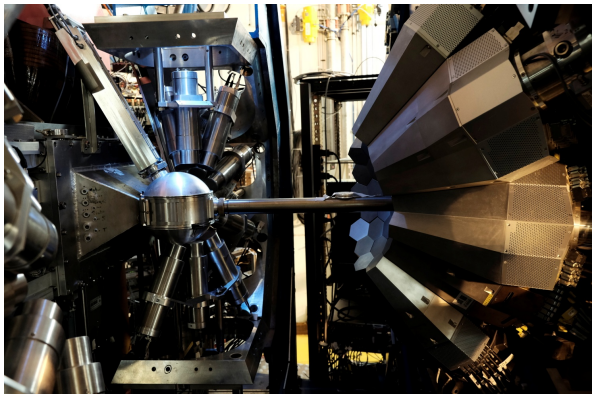


Energies of the first 2^+ excited states of the N=70 isotones (solid dots, the results of this experiment are given in red) and predictions using various “beyond mean field” (5DCH, PCM) and shell model (MCSM) calculations.

2017 run (4 months)

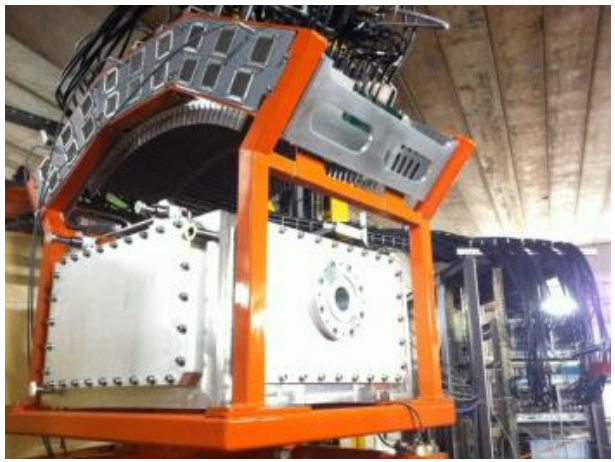
- **Excellent beam availability:**
  - 5000 h
  - 1900 h for nuclear physics experiments
  - Beam lines in parallel
- **7 experiments using several set-ups**

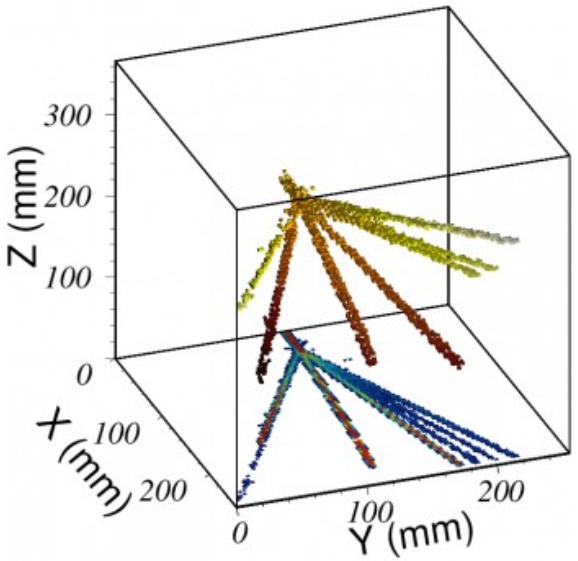




ACTAR(**ACtive TARget Time Projection Chamber)**

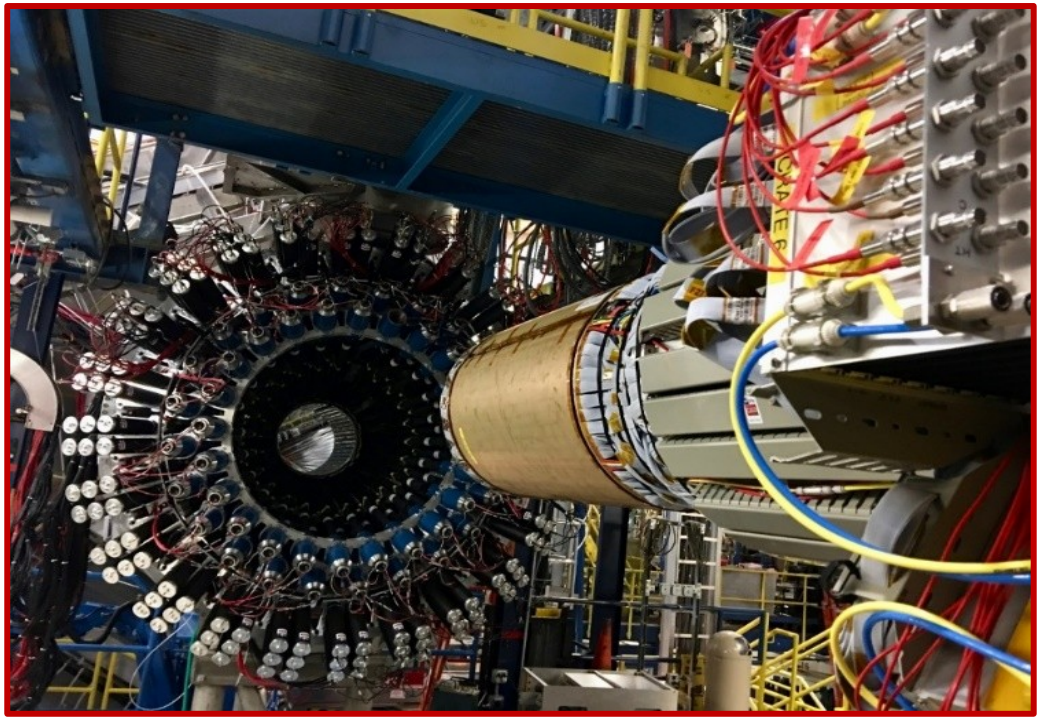
- **Nuclear interaction ions beam/target = detector gas nuclei**
- **3D precise reconstruction of particle tracks**
- **First test: oxygen beam , detector gas = isobutane**





Installation of the CLAS12 Micromegas tracker at Jefferson Lab and initial data taking

The Micromegas Vertex Tracker and the associated electronics are the fruit of more than 10 years of R&D at IRFU, which led to significant scientific and technical spin-offs.



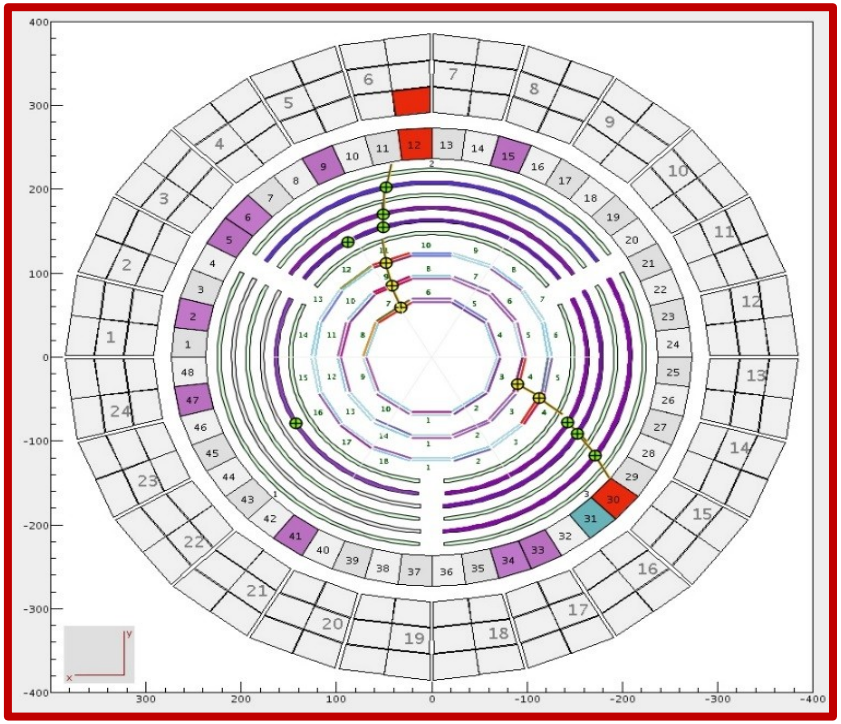
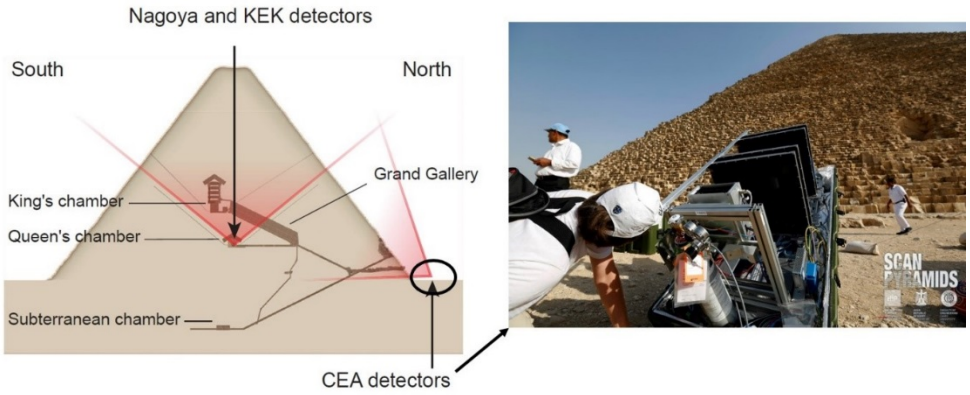
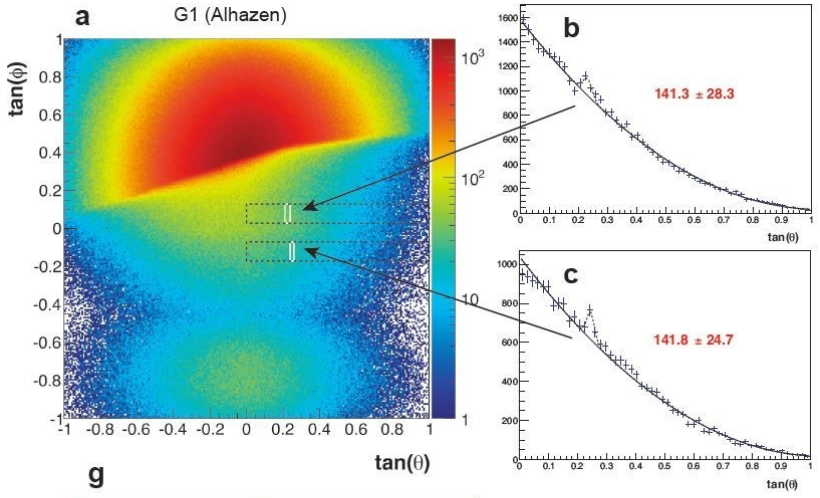


Photo of the Micromegas tracker being inserted in the CLAS12 barrel detector. Event detected in the CLAS12 barrel detector during its commissioning, showing two tracks jointly detected in the Micromegas tracker and the Silicon vertex tracker.

Use of Micromegas detector to scan Kheops pyramids

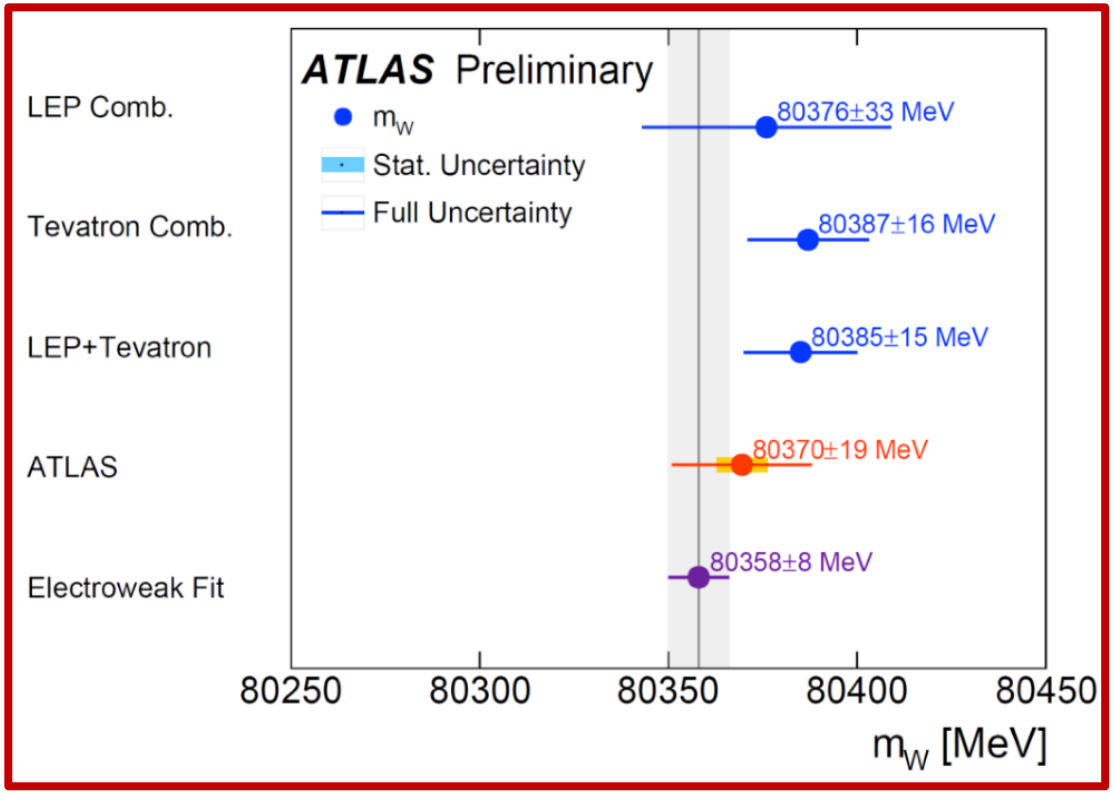
- **New cavity identified within the pyramid**





Measurement of the W boson mass at the LHC

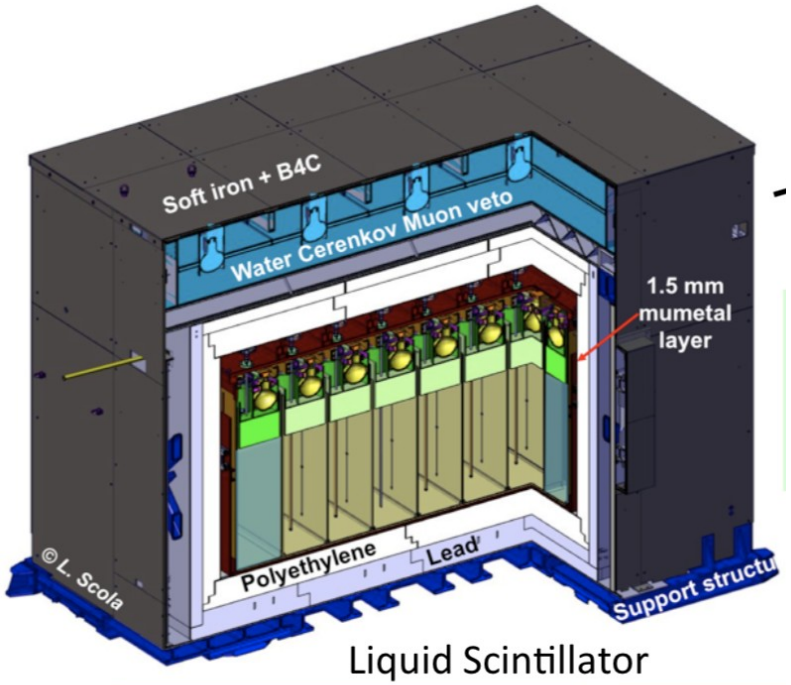
The first high-precision measurement of the mass of the W boson obtained by ATLAS relies on an original method developed by the Saclay team

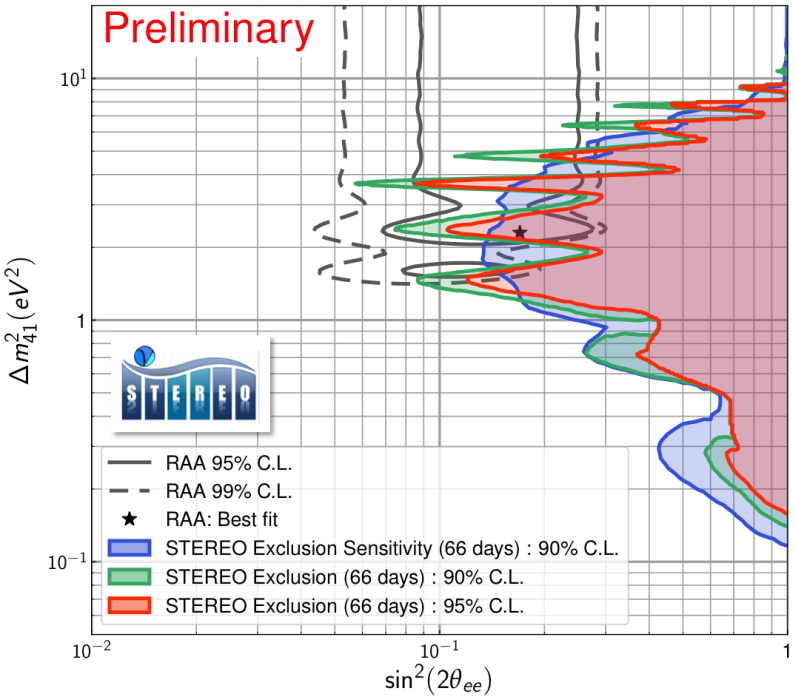


Measurement of the mass of the W boson by ATLAS (in red) compared with the Standard Model prediction (in purple) and the values obtained at LEP or at Tevatron (in blue)

Sterile neutrinos search: first results

- 66 days of data taking @ ILL
- First constrain on the existence of a sterile neutrinos
- More statistics in 2018

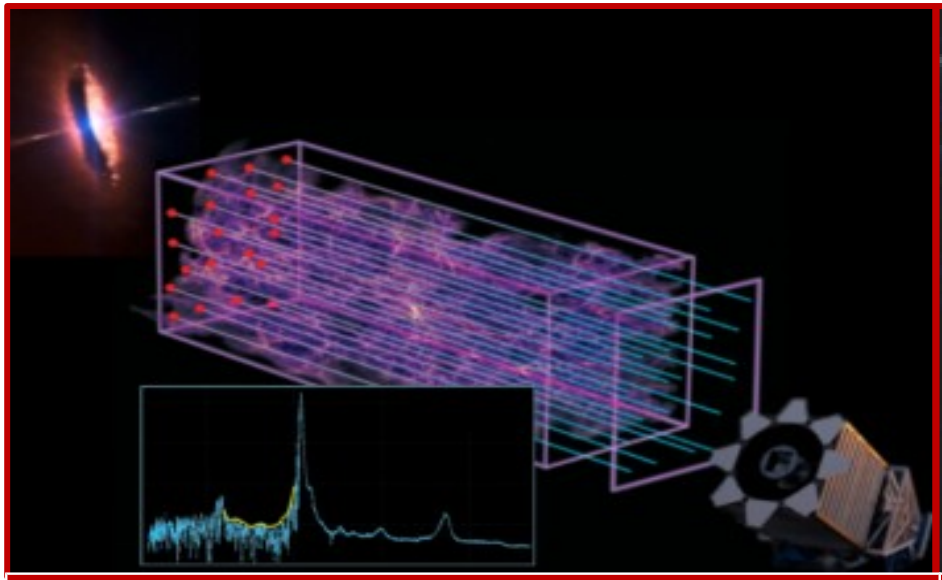




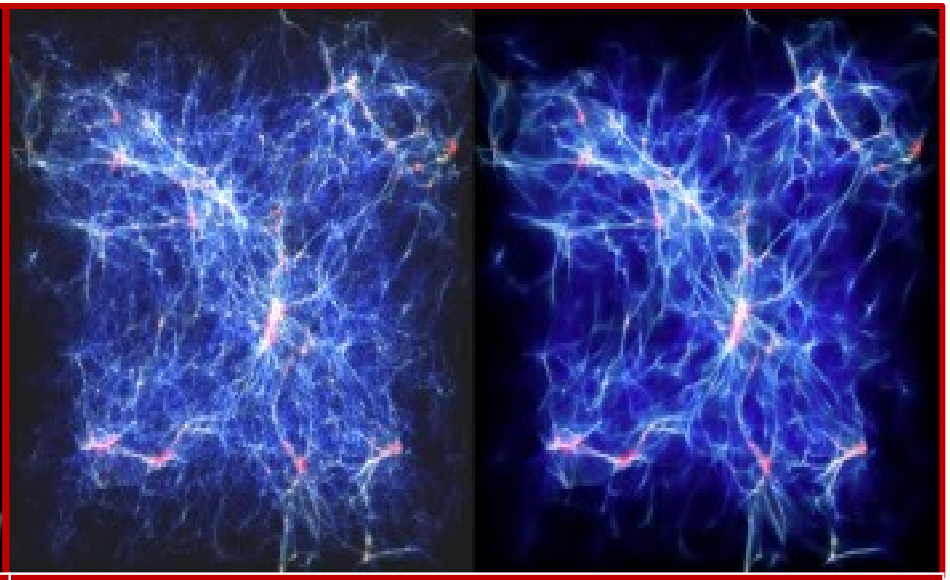
Dark matter probed by quasar light – particle mass limits

Use of the Lyman-α quasar forest to test several dark matter models.

The IRFU team has been involved in the BOSS, e-BOSS and DESI large-scale surveys since 2009 and it has more specifically developed a broad set of simulations of the formation of large-scale structures which make it possible to interpret these data.



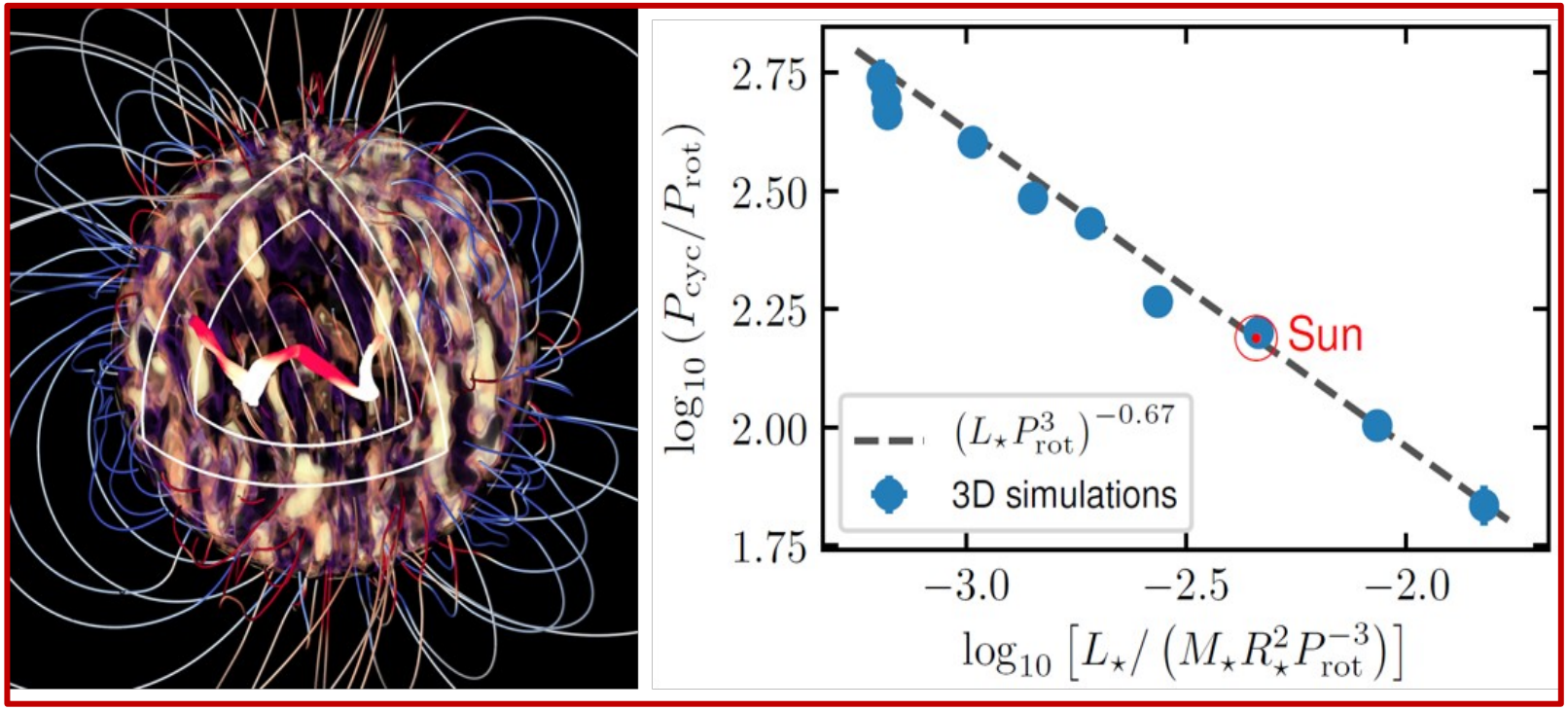
The light from distant quasars is partially absorbed as it passes through intergalactic hydrogen clouds (centre). This phenomenon creates a “forest” of absorption lines, which can be interpreted to produce an intergalactic gas map.



Map of the large-scale structures of the Universe obtained using simulation calculations. The cubes represented are about 300 million light years wide. Left: “standard “cold dark matter” scenario. Right: WDM scenario with a mass m = 0.5 keV.

The sun's magnetic field reverses every 11 years

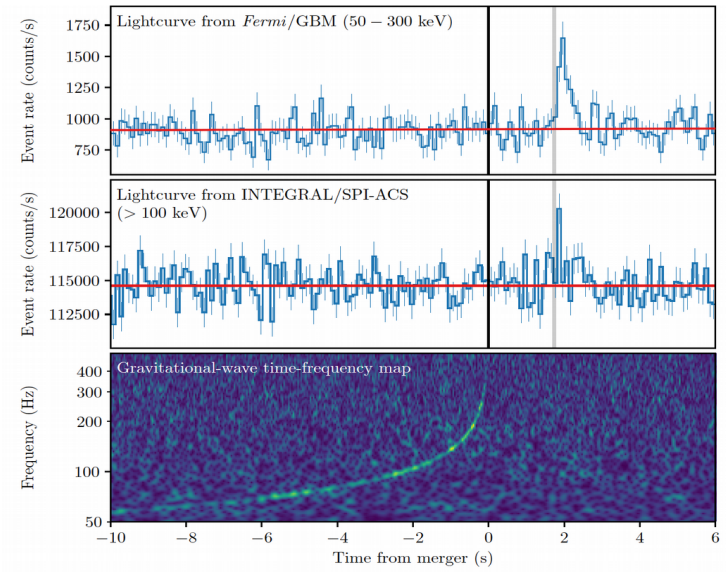
Thanks to new numerical simulations, an international scientific team has managed to explain why the Sun's magnetic field reverses every 11 years. IRFU researchers produced a 3D simulation of the interior of stars to explain their magnetic cycle. These results were obtained using supercomputers (GENCI, PRACE and Compute Canada).

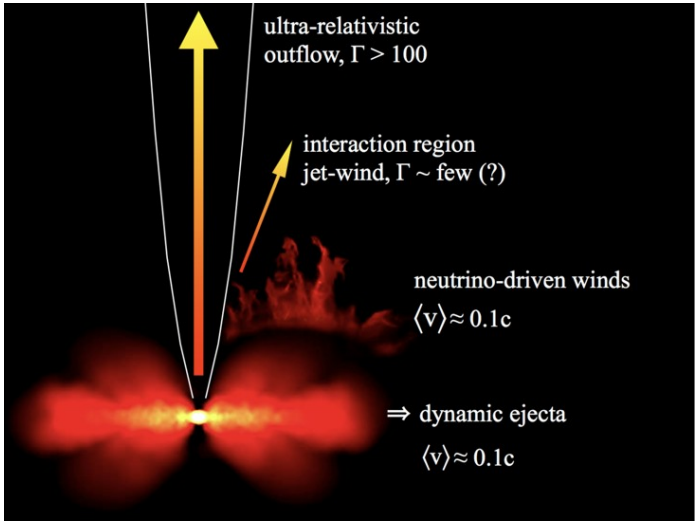


On the left, a snapshot of a 3D non-linear dynamo simulation with a regular magnetic cycle. On the right, the scaling law (grey dashed line) obtained by numerical simulations for the cycle period.

GW170817

First electromagnetic counterparts to a GW observed
Multi-messengers astronomy involvement from several Irfu teams

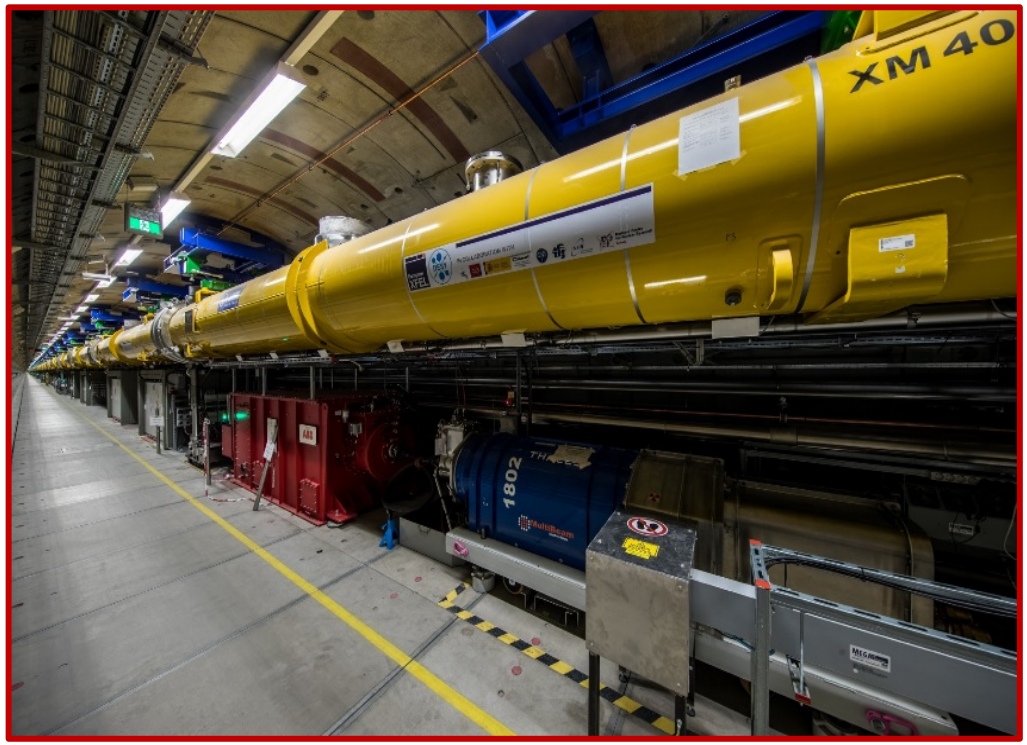




Short gamma ray burst observed
Kilonova observation and analysis (IR, vis.)

European XFEL

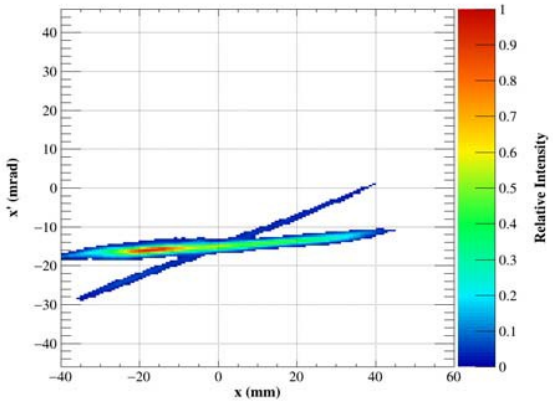
Eleven countries took part in building this research infrastructure, with a total budget of 1.2 G€. In France, IRFU played a leading role in the design and construction of the linear electron accelerator. IRFU carried out industrial transfer of its expertise to the Alsyom company and set up a dedicated infrastructure at Saclay, enabling assembly rates to be increased to one cryomodule every four days



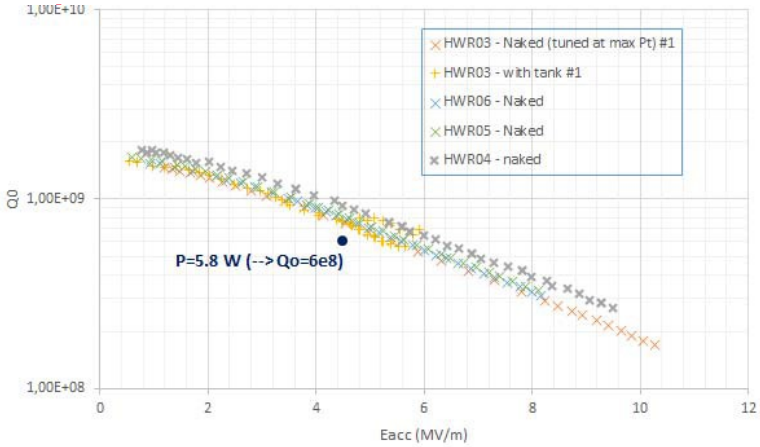
Cryomodules of the European-Xfel superconducting linear accelerator (in yellow) installed in the tunnel.

IFMIF (JAPAN)

Injector commissioning achieved

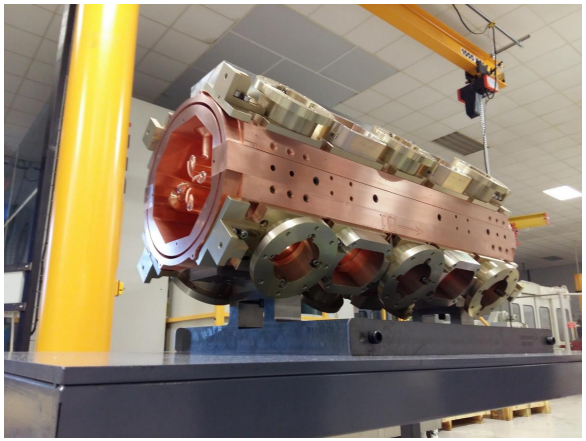


SRF-Linac : cavities production ong

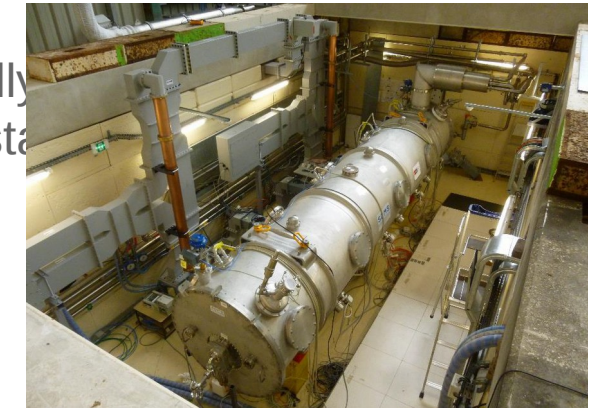


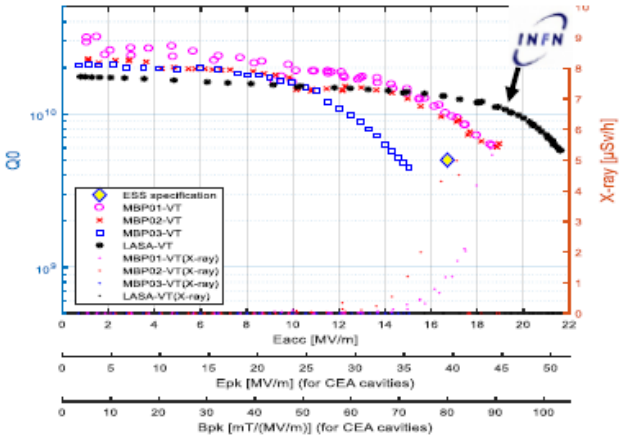
Major in-kind contributions from France

- **RFQ**
  - First part delivered soon in Saclay



- **Cryomodules**
  - Prototype fully
  - Production sta

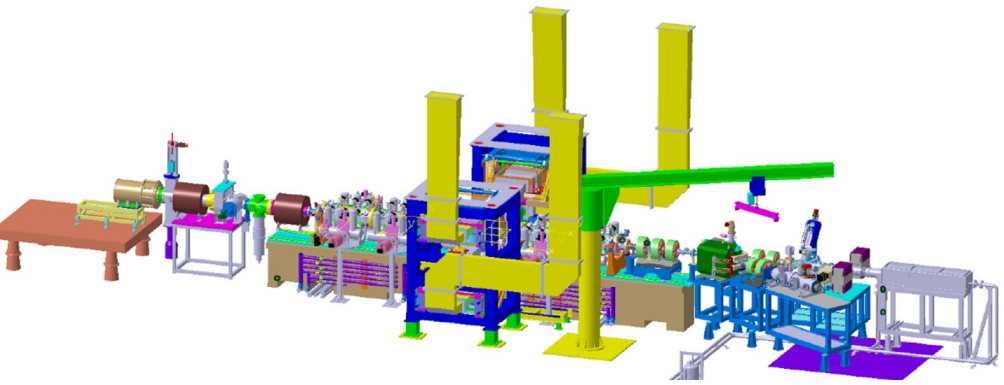


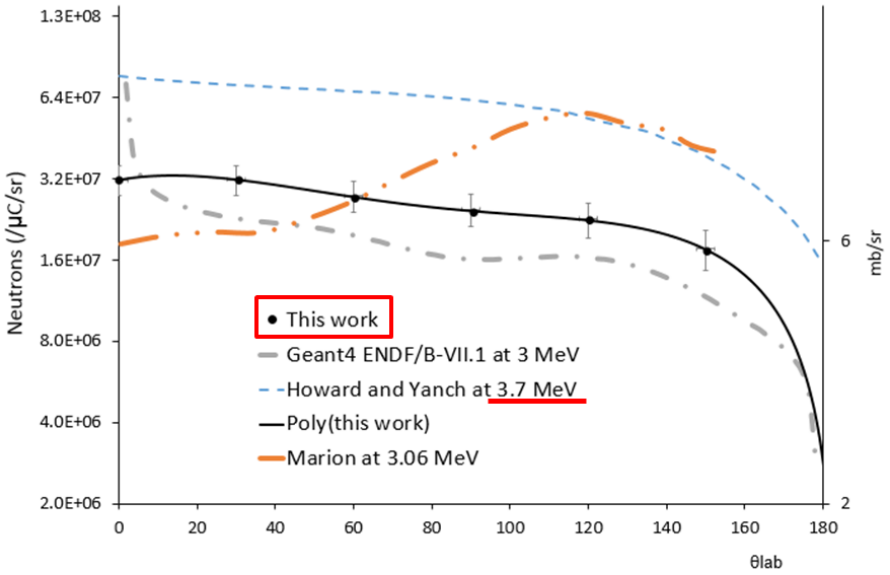


PRODUCTION OF NEUTRONS WITH IPHI

- IPHI beam (p, 3 MeV, 80 mA) □ Be, low duty cycle: first neutrons produced at low power (15 W)

- Next step : higher power (few kW)

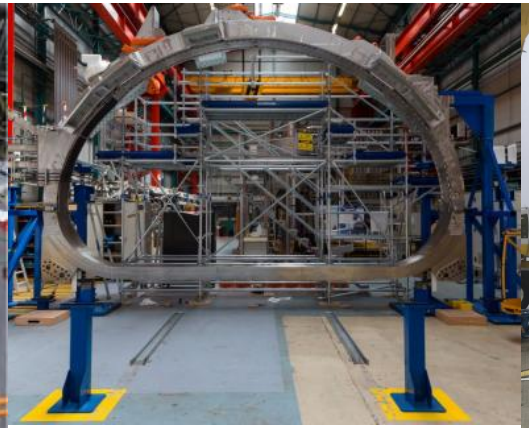




JT60 coils

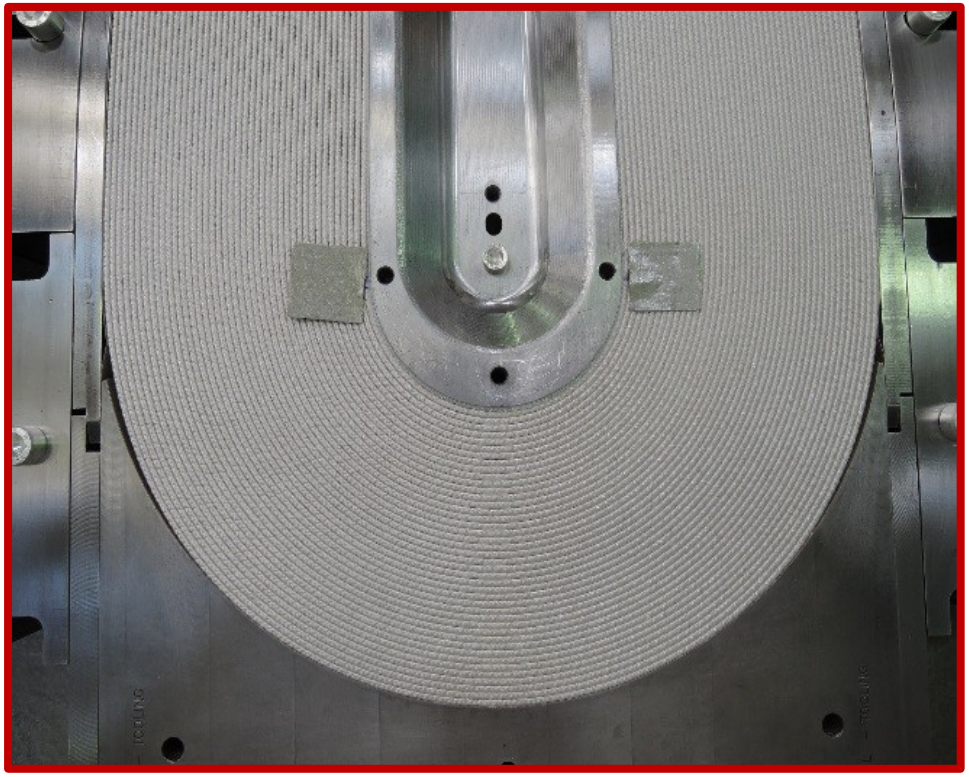
Delivery of 18 magnets for the JT60 – SA tokamak (Nara, Japan), under CEA supervision. Extensive tests performed in Saclay.

All coils have been delivered to Japan.



Fresca2

At the beginning of August 2017 the FRESCA2 dipole, jointly designed and built by IRFU and CERN, achieved a field of 13.3 T at the centre of its 100 mm aperture during testing at CERN’s HFM test station and remained stable for 4 consecutive hours. This is a new world record, with a stored energy of 3 MJ/m and mechanical forces never yet achieved in this type of magnet.



Partial view of the windings of a FRESCA2 layer

11.7 T MRI magnet @ Saclay

- **Whole body magnet designed by Irfu**
- **Some key numbers :**
  - **B0 / Aperture 11.75 T / 900 mm**
  - Stability 0.05 ppm/h
  - Homogeneity < 0.5 ppm
  - NbTi @ 1.8 K (He superfluide)

Energie stockée	338 MJ
Inductance	308 H
Courant	1483 A
Longueur	5.2 m
Diamètre	5 m
Poids	132 t

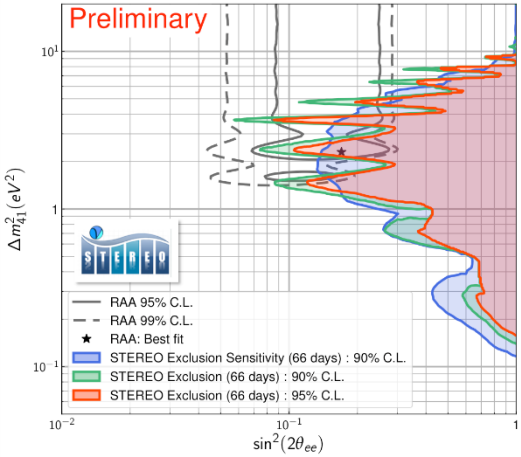
PROJECT FOR THE FORTHCOMING YEARS

LHC and beyond

- **Scientific exploitation of RUN2, RUN3 ATLAS and CMS data**

- **Detector upgrades (phase 1, phase 2)**
  - Important funding obtained in 2017

Neutrino physics

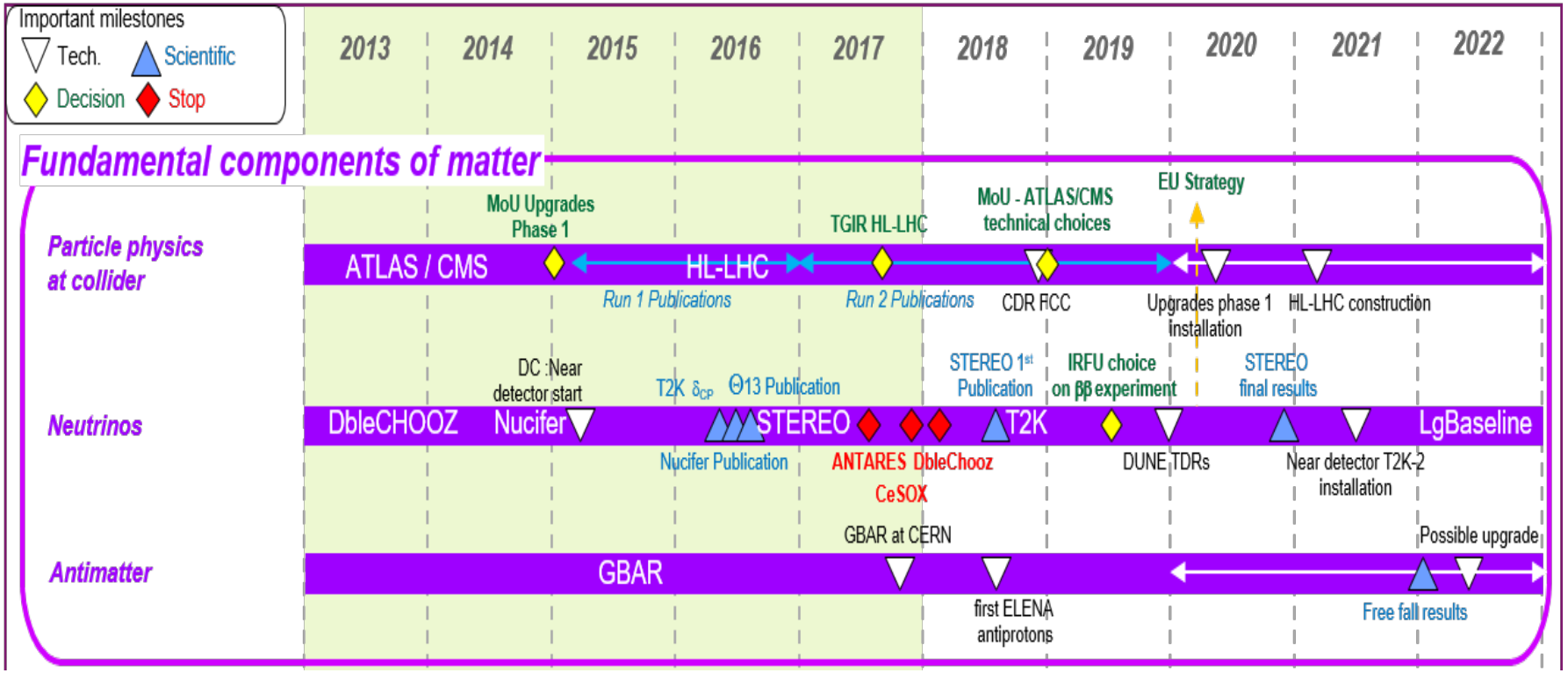


- Ac**celerator based neutrino:**
  - T2K upgrade
  - Involvement in the next generation of long baseline experiments
  - $\beta\beta0\nu$: choice between several R&D ongoing

GBAR experiment

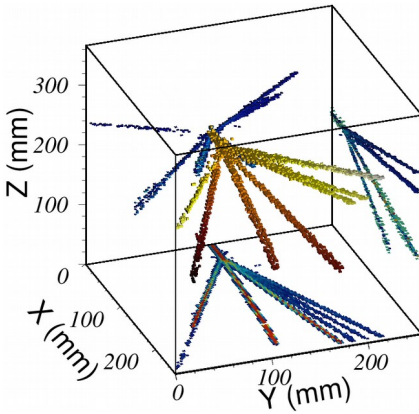
- **First antiprotons from Elena in 2018**

Roadmap


Important milestones
Tech.
Scientific
Decision
Stop
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Fundamental components of matter
Particle physics at collider
Neutrinos
Antimatter
MoU Upgrades Phase 1
TGIR HL-LHC
MoU - ATLAS/CMS technical choices
EU Strategy
ATLAS / CMS
HL-LHC
Run 1 Publications
Run 2 Publications
CDR FCC
Upgrades phase 1 installation
HL-LHC construction
DC : Near detector start
T2K δCP
Θ13 Publication
STEREO 1st Publication
IRFU choice on ββ experiment
STEREO final results
DbleCHOOZ
Nucifer
STEREO
T2K
LgBaseline
Nucifer Publication
ANTARES DbleChooz
CeSOX
DUNE TDRs
Near detector T2K-2 installation
GBAR at CERN
Possible upgrade
GBAR
first ELENA antiprotons
Free fall results

Nuclear structure

- **Ganil**
  - New generation of detectors (VAMOS-GF, ACTAR,..)
  - Spiral2 phase1: NFS, S3 experiments; injector A/Q = 7
  - Post - phase 1 program to be consolidated



- **Riken (Minos), GSI**

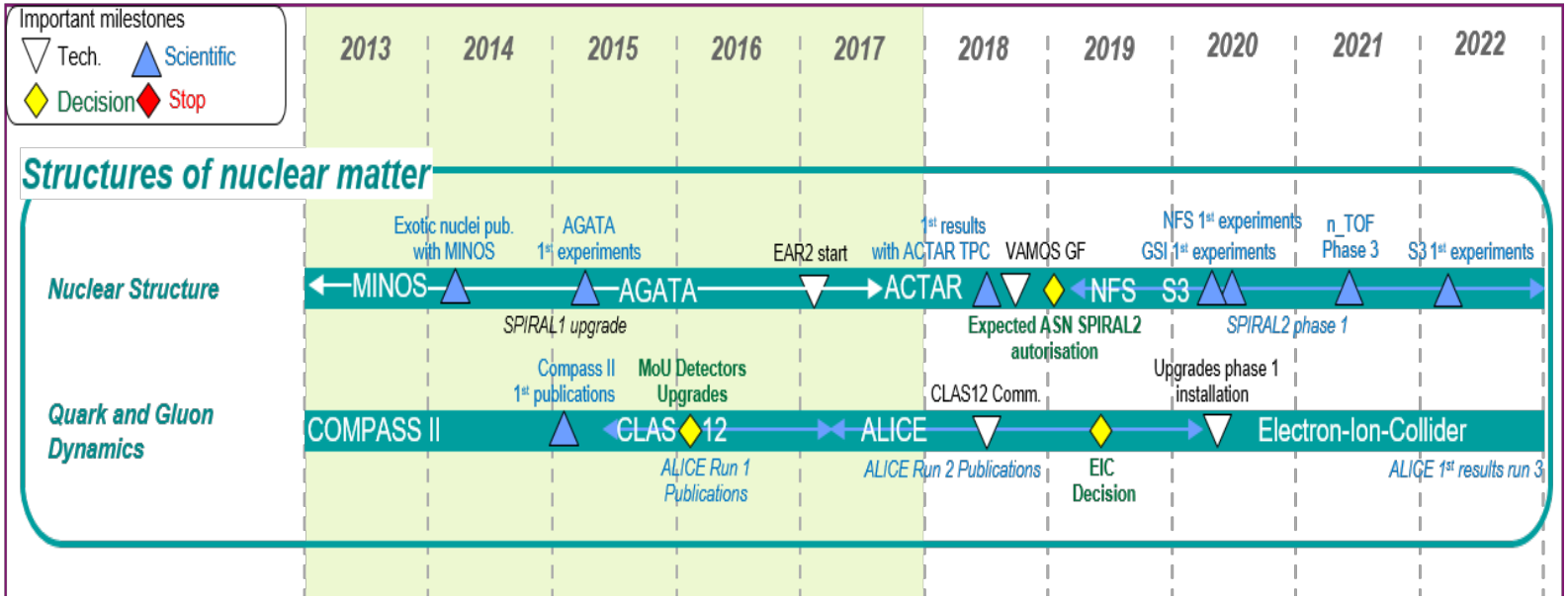
- **Fission actinides studies @ ILL, CERN**

Quark and gluons dynamics

- **QGP : Alice**
  - Full exploitation of RUN2, RUN 3 data
  - Upgrade
  - Possible contribution to sPhenix

- **Structure of the nucleon**
  - CLAS12, Partons, EIC?

Roadmap


Important milestones
Tech.
Scientific
Decision
Stop
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Structures of nuclear matter
Nuclear Structure
Exotic nuclei pub. with MINOS
AGATA 1st experiments
EAR2 start
1st results with ACTAR TPC
VAMOS GF
NFS 1st experiments
GSI 1st experiments
n_TOF Phase 3
S3 1st experiments
MINOS
AGATA
ACTAR
NFS
S3
SPIRAL1 upgrade
Expected ASN SPIRAL2 autorisation
SPIRAL2 phase 1
Quark and Gluon Dynamics
Compass II 1st publications
MoU Detectors Upgrades
CLAS12 Comm.
Upgrades phase 1 installation
COMPASS II
CLAS12
ALICE
Electron-Ion-Collider
ALICE Run 1 Publications
ALICE Run 2 Publications
EIC Decision
ALICE 1st results run 3

ASTROPHYSICS

Dark universe

- Full exploitation of eBOSS survey
- DESI and EUCLID instrumental achievements
- DESI and EUCLID scientific exploitation

High energy astronomy

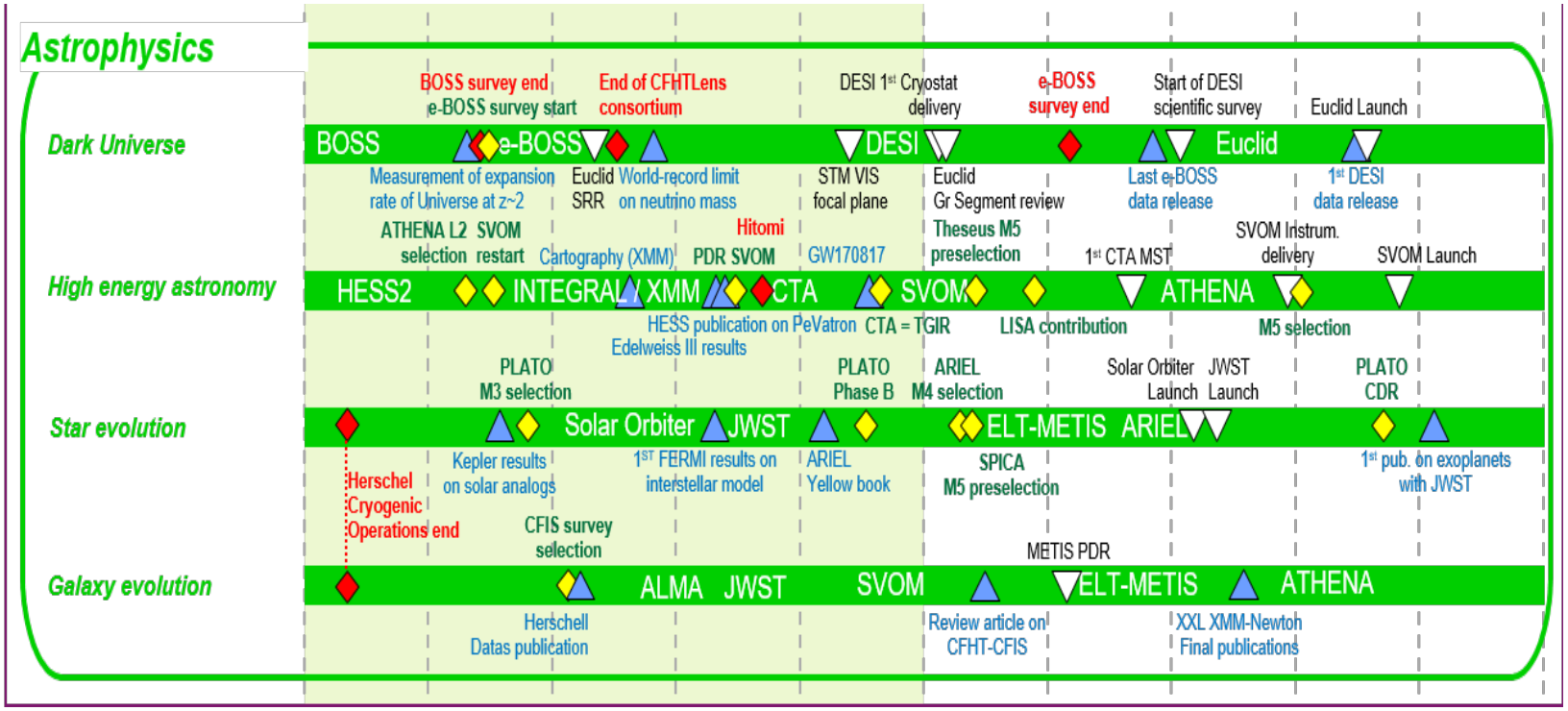
- End of Integral and XMM data analysis
- Hess 2 exploitation, CTA construction (TGIR funding)
- SVOM launch
- Athena construction

Star and galaxy evolution

- Alma, Artemis data exploitation
- Solar Orbiter, JWST launches
- ELT-Metis, Ariel : instrumental contributions

Gravitational waves

Roadmap


Astrophysics
Dark Universe
High energy astronomy
Star evolution
Galaxy evolution
BOSS survey end
e-BOSS survey start
End of CFHTLens
consortium
DESI 1st Cryostat
delivery
e-BOSS
survey end
Start of DESI
scientific survey
Euclid Launch
BOSS
e-BOSS
DESI
Euclid
Measurement of expansion
rate of Universe at z~2
Euclid
SRR
World-record limit
on neutrino mass
STM VIS
focal plane
Euclid
Gr Segment review
Last e-BOSS
data release
1st DESI
data release
ATHENA L2
selection
SVOM
restart
Cartography (XMM)
Hitomi
PDR SVOM
GW170817
Theseus M5
preselection
1st CTA MST
SVOM Instrum.
delivery
SVOM Launch
HESS2
INTEGRAL
XMM
CTA
SVOM
ATHENA
HESS publication on PeVatron
Edelweiss III results
CTA = TGIR
LISA contribution
M5 selection
PLATO
M3 selection
PLATO
Phase B
ARIEL
M4 selection
Solar Orbiter
Launch
JWST
Launch
PLATO
CDR
Solar Orbiter
JWST
ELT-METIS
ARIEL
Herschel
Cryogenic
Operations end
Kepler results
on solar analogs
1ST FERMI results on
interstellar model
ARIEL
Yellow book
SPICA
M5 preselection
1st pub. on exoplanets
with JWST
CFIS survey
selection
METIS PDR
ALMA
JWST
SVOM
ELT-METIS
ATHENA
Herschell
Datas publication
Review article on
CFHT-CFIS
XXL XMM-Newtoh
Final publications

ACCELERATOR AND MAGNETS

Injectors, SC linacs

- **Ifmif, Spiral2 commissioning**
- **ESS, SARAF construction**
- **Emerging projects:**
  - Compact neutron source
  - Spiral 2 injector Q/A=7
  - PIP-II
  - Post-IFMIF (DONES,..)

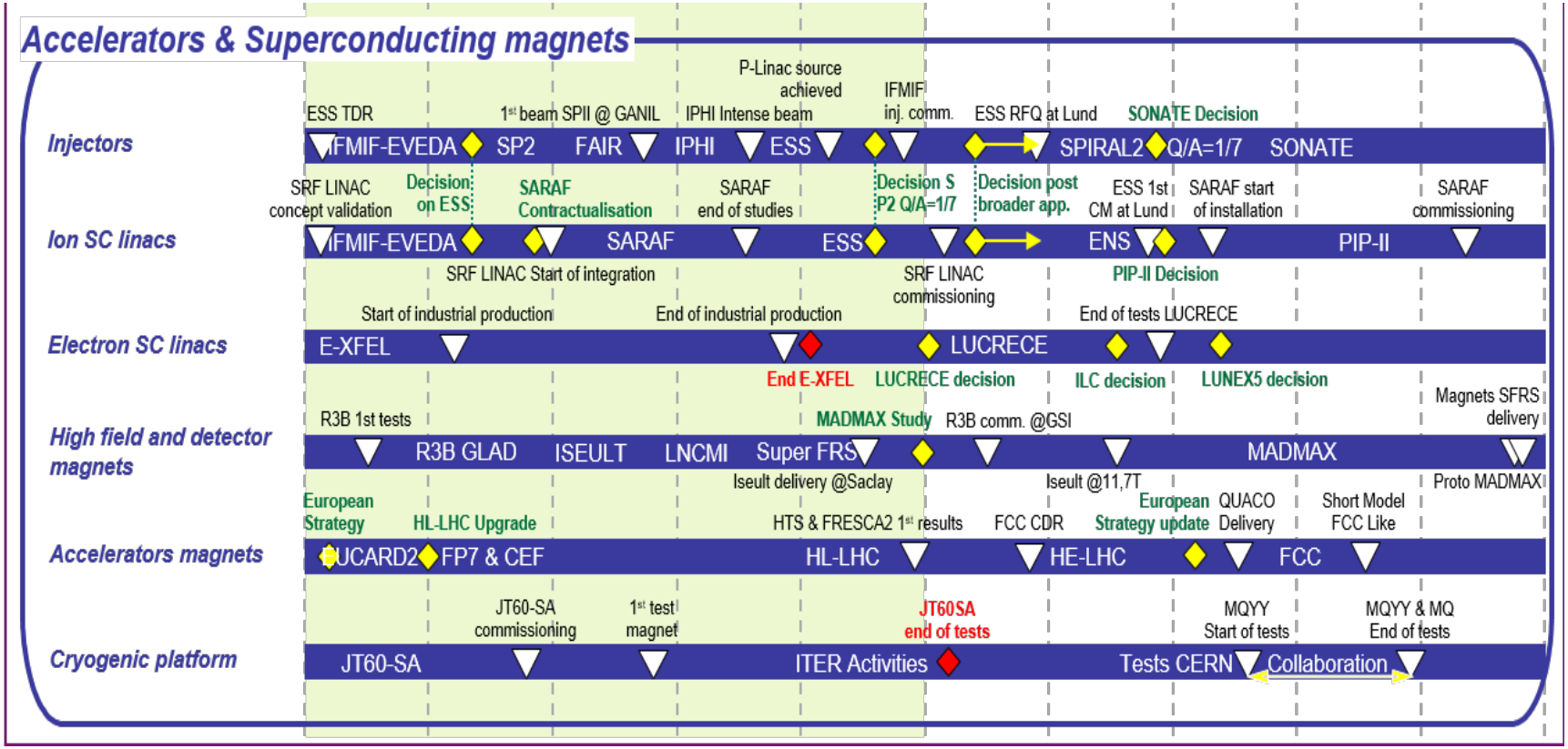
High field and detector magnets

- **R3B-GLAD , Iseult : commissioning**
- **LNCMI hybrid magnet, super-FRS dipoles: construction**
- **Emerging projects : MadMax, new MRI magnets?**

Accelerator magnets

- **Towards high energy (Fresca2, HTS,..)**

Roadmap


Accelerators & Superconducting magnets
Injectors
Ion SC linacs
Electron SC linacs
High field and detector magnets
Accelerators magnets
Cryogenic platform
ESS TDR
1st beam SPII @ GANIL
IPHI Intense beam
P-Linac source achieved
IFMIF inj. comm.
ESS RFQ at Lund
SONATE Decision
IFMIF-EVEDA
SP2
FAIR
IPHI
ESS
SPIRAL2
Q/A=1/7
SONATE
SRF LINAC concept validation
Decision on ESS
SARAF Contractualisation
SARAF end of studies
Decision S P2 Q/A=1/7
Decision post broader app.
ESS 1st CM at Lund
SARAF start of installation
SARAF commissioning
IFMIF-EVEDA
SARAF
ESS
ENS
PIP-II
SRF LINAC Start of integration
SRF LINAC commissioning
PIP-II Decision
Start of industrial production
End of industrial production
End of tests LUCRECE
E-XFEL
LUCRECE
End E-XFEL
LUCRECE decision
ILC decision
LUNEX5 decision
R3B 1st tests
MADMAX Study
R3B comm. @GSI
Magnets SFRS delivery
R3B GLAD
ISEULT
LNCMI
Super FRS
MADMAX
Iseult delivery @Saclay
Iseult @11,7T
Proto MADMAX
European Strategy
HL-LHC Upgrade
HTS & FRESCA2 1st results
FCC CDR
European Strategy update
QUACO Delivery
Short Model FCC Like
EUCARD2
FP7 & CEF
HL-LHC
HE-LHC
FCC
JT60-SA commissioning
1st test magnet
JT60SA end of tests
MQYY Start of tests
MQYY & MQ End of tests
JT60-SA
ITER Activities
Tests CERN
Collaboration

CONCLUSION

A large portfolio of topics in fundamental research

Participation to major large infrastructures around the world

Relies on our large technological platforms