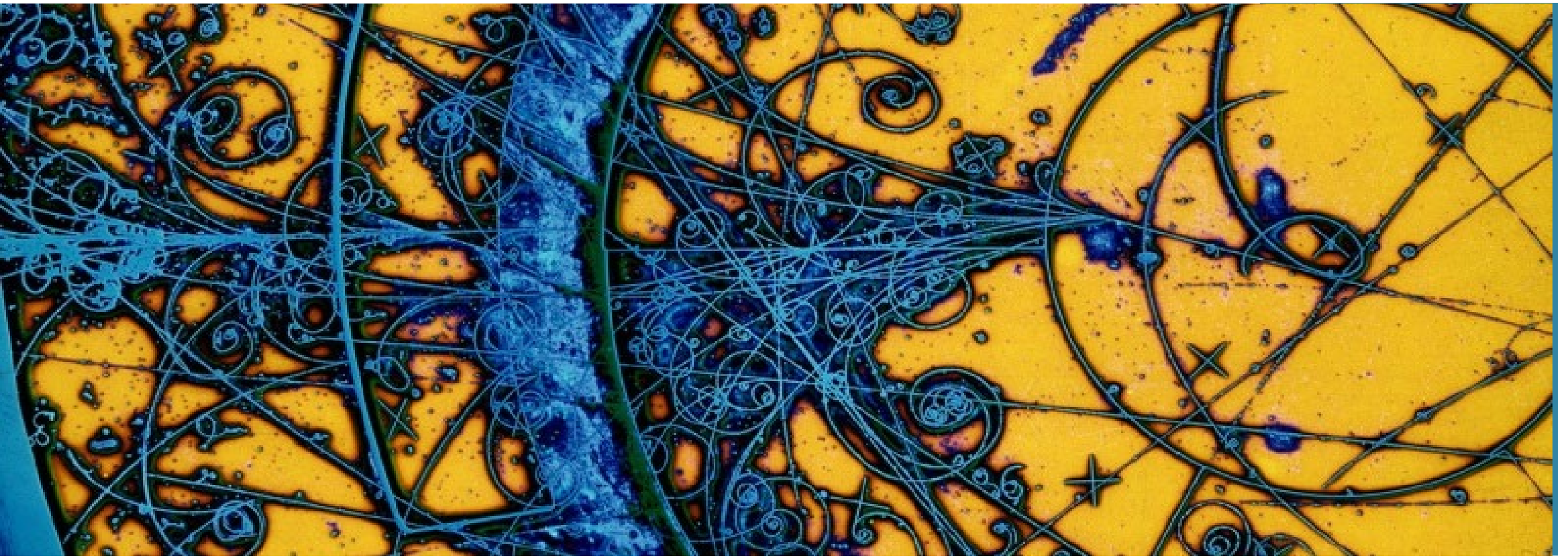
INFN research activities: facilities and experiments

10 July, 2024



Mauro Mezzetto (INFN PD)

Kick-off event of the TFPA PhD course

Groups from the Universities of Rome, Padua, Turin, and Milan founded the INFN on 8th August 1951 to uphold and develop the scientific tradition established during the 1930s by Enrico Fermi and his school, with their theoretical and experimental research in nuclear physics.

The National Institute for Nuclear Physics (INFN) is the Italian research agency dedicated to the study of the fundamental constituents of matter and the laws that govern them, under the supervision of the Ministry of Universities and Research (MUR).

The **mission**

- INFN promotes, coordinates and conducts theoretical and experimental research in the fields of subnuclear, nuclear and astroparticle physics
- All of the INFN's research activities are undertaken within a framework of international competition, in close collaboration with Italian universities on the basis of solid academic partnerships spanning decades

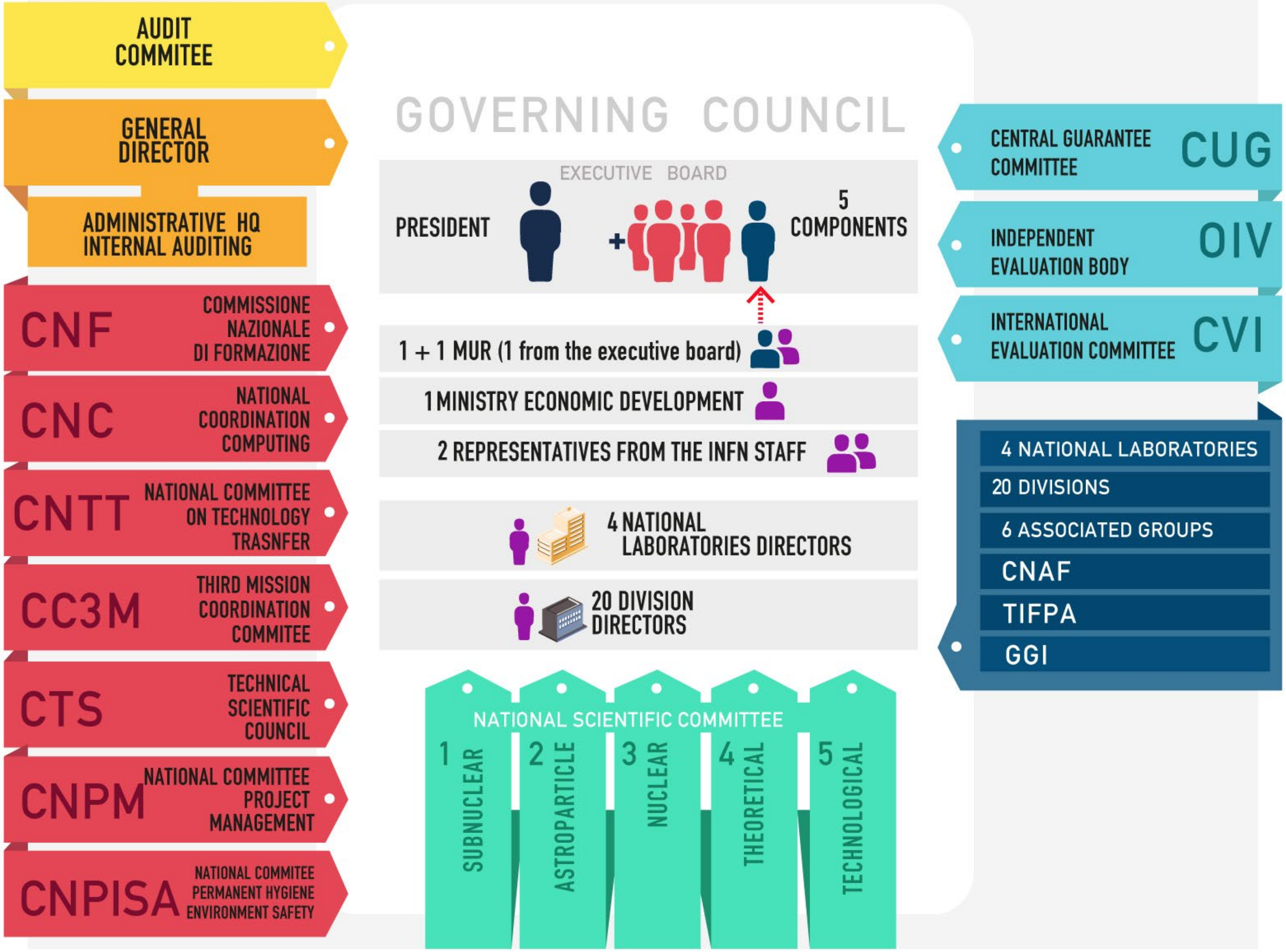
Pushing the frontiers of knowledge.

Developing
new frontier technologies

Train
the next generation of scientists and engineers

Working together
with young researchers and with researchers coming from all over the world

INFN structure

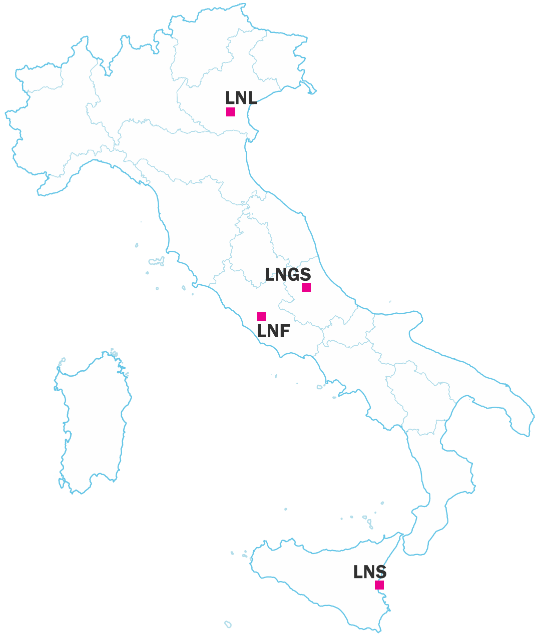


The only case in Italy where the top management of a public institution is appointed by the institution itself and the board includes representatives from all divisions and laboratories.

INFN facilities

INFN facilities

4 National Laboratories



INFN

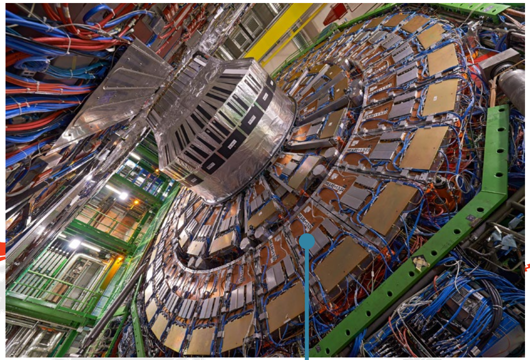
INFN facilities

3 National Centres

INFN facilities

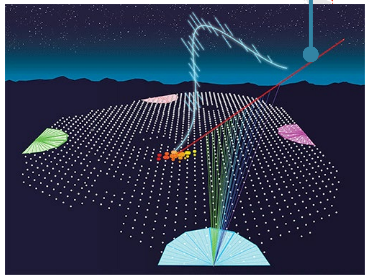
1 International Consortium

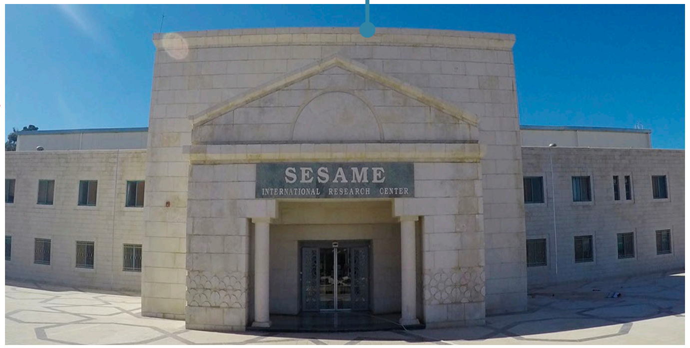
EGO-VIRGO
European Gravitational Observatory

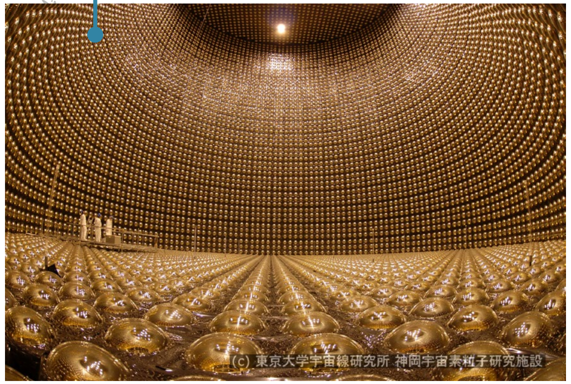


An

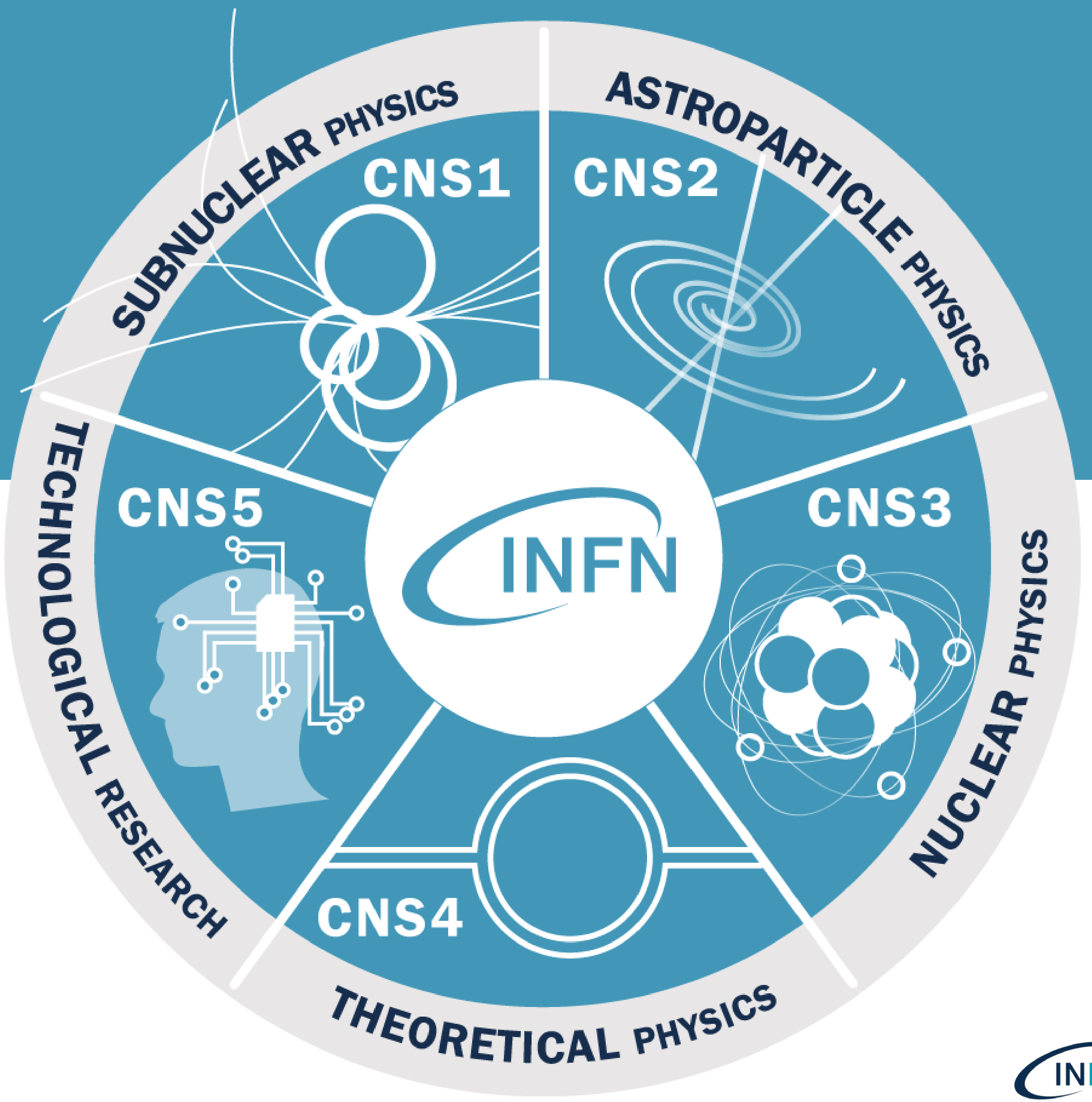
international DNA







The **5 research lines** and the National Scientific Committees



A unique scientific organization in the world:

- Each Scientific Committee is composed by representatives of all the INFN facilities, chosen by local elections.
- The representatives (coordinators) vote their president.
- Scientific Committees approve new experiments and evaluate and referee the running ones based on peer review.

How an INFN Division is organized: the case of Padova

127 Employes
323 Associates from University
25 Postdoc and other grants

ORGANIGRAMMA DELLA SEZIONE INFN DI PADOVA

Direttore
Prof. Roberto Carlin
1 feb 2022 – 31 gen 2026

Esperto Qualificato
Marta Dalla Vecchia

Medico Competente
Maddalena Mazzi

Rappr. Lavoratori per la Sicurezza
Luca Taffarello

Formazione Interna
Alessandra Betto

Referente TT
Luca Taffarello

Mobility Manager
Sandro Ventura

ATTIVITA' TECNOLOGICHE E AMMINISTRATIVE

Amministrazione
STEFANIA PASQUATO
Alessandra Betto
Giulia Coltri
Federico Dessì
A.E. Lombardo
Giorgia Salvato
Daniela Sofia TD
Marco Storti TD
Riccardo Zanardi
Marisol Zuin

STG e Elettronica
MARINO NICOLETTO
Marco Bettini
Fulvio Calaon
Lorenzo Castellani
Federico Fabris
Stefano Marchini
Gabriele Rampazzo
Paolo Sarcheletti
Mario Tessaro
Pier Giuseppe Zatti

Officina Meccanica
LORIS RAMINA
David Agguiaro
Andrea Benato
(Leonardo Garizzo)
Michele Giarin
Daniele Mazzaro
Roberto Peghin
Alberto Pitacco
Massimo Rebeschini
Fabio Veronese

Direzione
GIOVANNI MOSCHIN
Marina Andreazzo
Laura Dal Fabbro
Natalia Miletti
Elena Pavan
Giuseppina Salente
Maristella Zuin
più 3 Borsiste

Progettazione Elettronica
MARCO BELLATO
Antonio Bergnoli
Daniele Corti
Alessandro Griggio
Roberto Isocrate
Luciano Modenese
Marco Toffano

Calcolo e Reti
MICHELE MICHELOTTO
Fabio Bredo
Alberto Crescente
Massimo Gravino
Rita Lenzo TD
Daniele Piccoli
Ivo Saccarola
Massimo Sgaravatto

Fondi Esterni
SABINE E. HEMMER
Judilka I. Bermudez
Alessandra F. Casotto
Anna Dalla Vecchia

Progettazione Meccanica
MASSIMO BENETTONI
Nicola Bez
Mirco Rampazzo
Marco Romanato
Matteo Turcato
Mario Zago

Tecnologie Avanzate
ADRIANO PEPATO
Rubens Raffagnato
Enrico Berto TD

Prevenzione e Protezione
NICOLA CRESPAN

Rossana Chiaratti
Andrea Colombo

ATTIVITA' SPERIMENTALI

Esperimenti CSN I
Fisica delle Particelle
Coord. Stefano Lacaprara

Esperimenti CSN II
Fisica Astroparticellare
Coord. Andrea Longhin

Esperimenti CSN III
Fisica Nucleare
Coord. Daniele Mengoni

Esperimenti CSN IV
Fisica Teorica
Coord. Dmitri Sorokin

Esperimenti CSN V
Ricerca Tecnologica
Coord. Gabriele Simi

Terza Missione C3M
Coord. Sabine Hemmer

ILO
Coord. Mauro Morandin

Commissione Calcolo e Reti (CCR)
Coord. Michele Michelotto

Progetti su Fondi Europei

Progetti Speciali

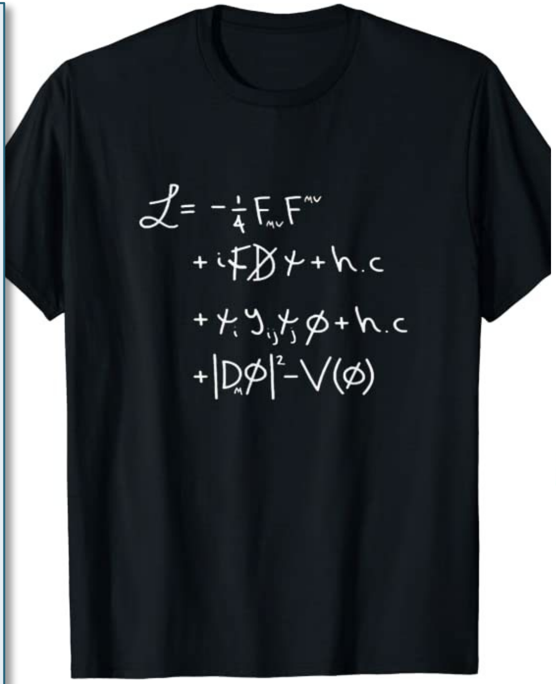
CSN1: the Standard Model

The Standard Model describes with great success the elementary particles and their interactions.
It's last prediction, the Higgs boson, has been discovered at CERN in 2012.

Is it enough?

NO. It doesn't:

- include gravitation
- explain Dark Energy, Dark Matter, Matter-Antimatter asymmetry in the Universe.
- explain the origin of neutrino masses.
- It miserably fails (by about 62 orders of magnitude) to compute the Vacuum Energy Density.



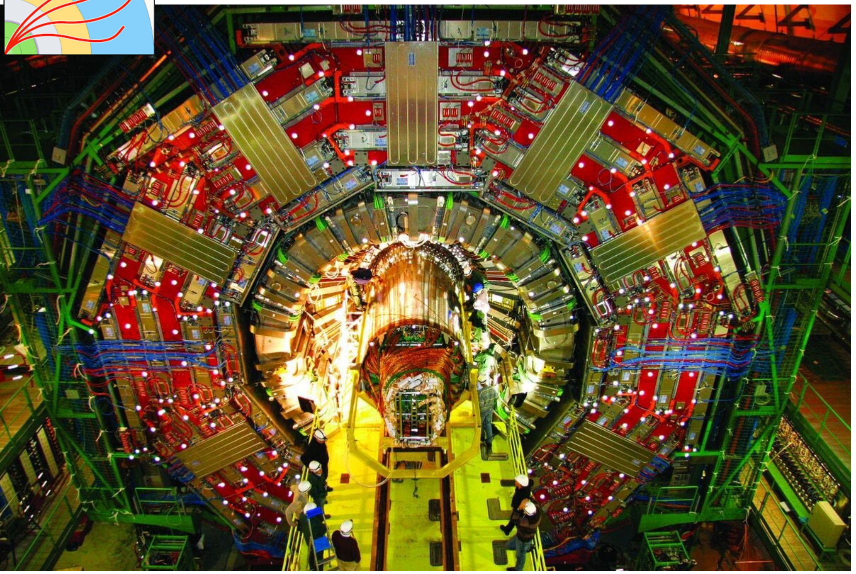
For sale at the CERN store

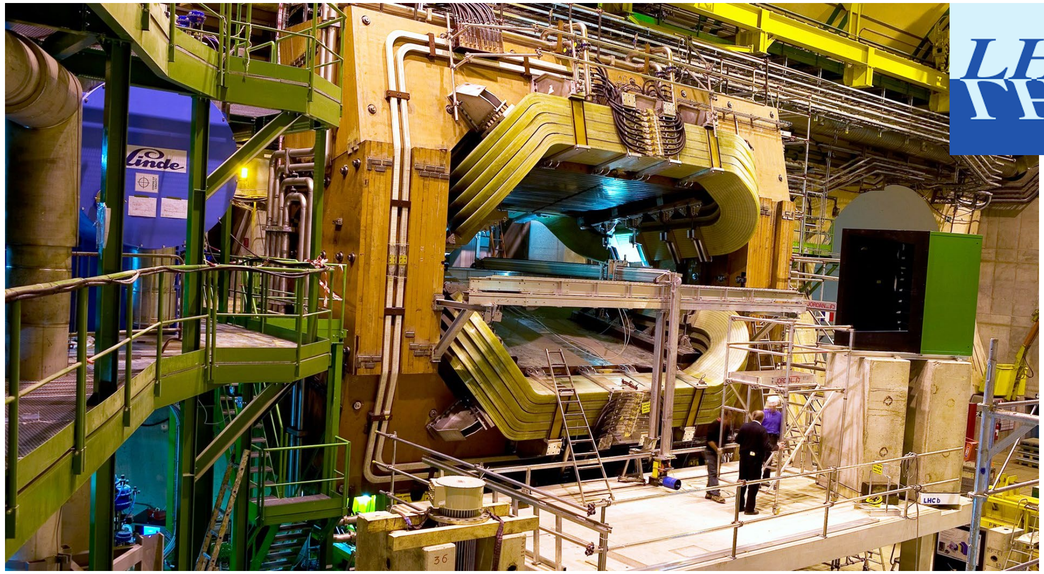
$$\begin{gathered}
\mathcal{L}_{SM} = -\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g^2_s f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c^2_w}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - \\
igs_w(\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - \\
W^-_\nu \partial_\nu W^+_\mu)) - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c^2_w(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - \\
Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s^2_w(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w(A_\mu Z^0_\nu(W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \frac{1}{2}\partial_\mu H \partial_\mu H - 2M^2\alpha_h H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \\
\beta_h\left(\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right) + \frac{2M^4}{g^2}\alpha_h - \\
g\alpha_h M\left(H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-\right) - \\
\frac{1}{8}g^2\alpha_h\left(H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2\right) - \\
gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c^2_w}Z^0_\mu Z^0_\mu H - \\
\frac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
\frac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
M\left(\frac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+\right) - ig\frac{s^2_w}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - \\
W^-_\mu\phi^+) - ig\frac{1-2c^2_w}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
\frac{1}{4}g^2 W^+_\mu W^-_\mu\left(H^2 + (\phi^0)^2 + 2\phi^+\phi^-\right) - \frac{1}{8}g^2\frac{1}{c^2_w}Z^0_\mu Z^0_\mu\left(H^2 + (\phi^0)^2 + 2(2s^2_w - 1)^2\phi^+\phi^-\right) - \\
\frac{1}{2}g^2\frac{s^2_w}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s^2_w}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c^2_w - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
g^2 s^2_w A_\mu A_\mu\phi^+\phi^- + \frac{1}{2}ig_s\lambda^a_{ij}(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + \\
m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_w A_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
\frac{ig}{4c_w}Z^0_\mu\{(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s^2_w - 1 - \gamma^5)e^\lambda) + (\bar{d}^\lambda_j\gamma^\mu(\frac{4}{3}s^2_w - 1 - \gamma^5)d^\lambda_j) + \\
(\bar{u}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s^2_w + \gamma^5)u^\lambda_j)\} + \frac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)U^{lep}{}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
\frac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}{}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \\
\frac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_e(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m^\lambda_\nu(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1+\gamma^5)e^\kappa\right) + \\
\frac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_e(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa\right) - \frac{g}{2}\frac{m^\lambda_\nu}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \\
\frac{g}{2}\frac{m^\lambda_e}{M}H(\bar{e}^\lambda e^\lambda) + \frac{ig}{2}\frac{m^\lambda_\nu}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \frac{ig}{2}\frac{m^\lambda_e}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \frac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa - \\
\frac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa + \frac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j\right) + \\
\frac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j\right) - \frac{g}{2}\frac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
\frac{g}{2}\frac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \\
\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c^2_w})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \\
\partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \\
\partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \\
\partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \\
\partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM\left(\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c^2_w}\bar{X}^0 X^0 H\right) + \frac{1-2c^2_w}{2c_w}igM\left(\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-\right) + \\
\frac{1}{2c_w}igM\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + igMs_w\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + \\
\frac{1}{2}igM\left(\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0\right).
\end{gathered}$$

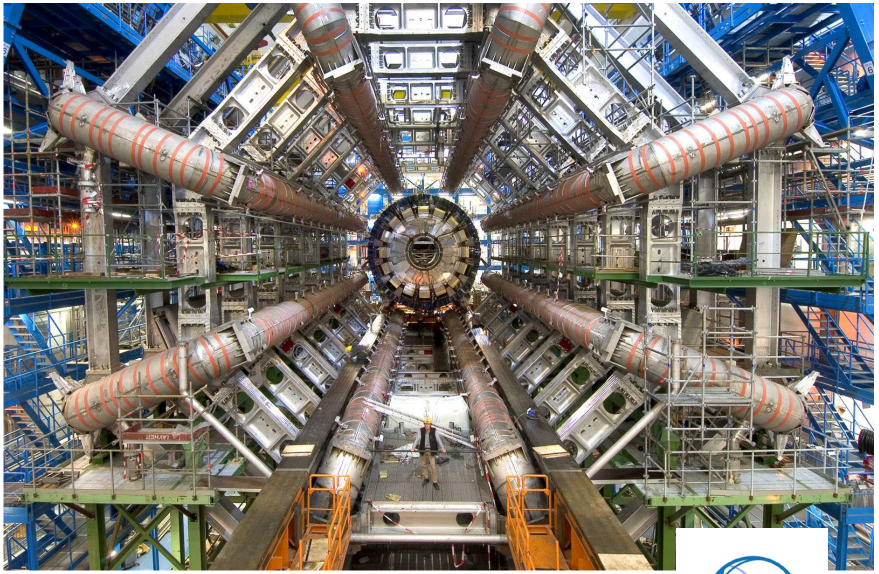
We don't know where the **physics beyond the standard model** is

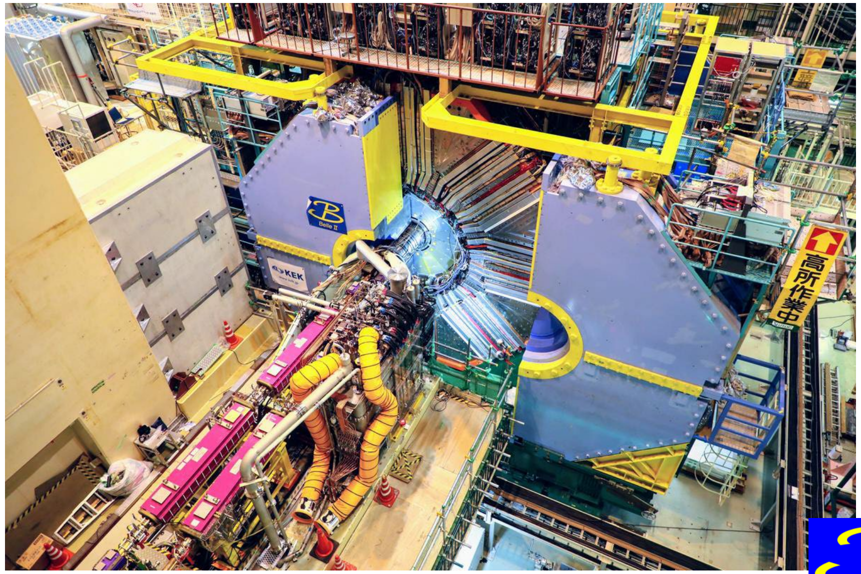
Experimentally: assess with precision all the properties of the Standard Model and look for failures

CSN1: the big experiments at accelerators







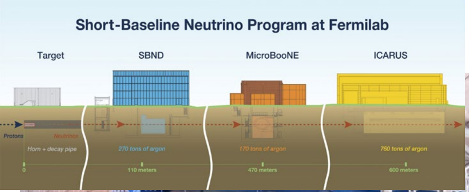


… as well as smaller experiments specialized in looking for failures of the Standard Model:

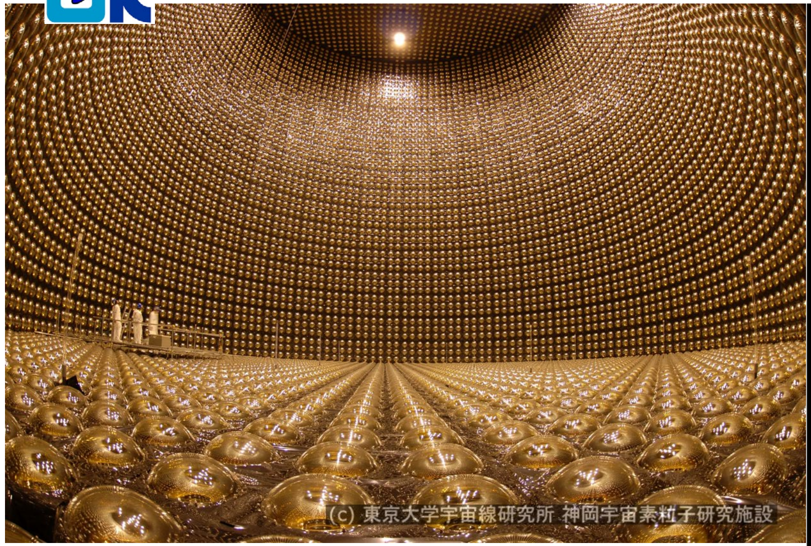
- Gminus2 @ Fermilab
- MEG @PSI (Zurich)
- PADME @ LNF
- Pmu2e @ Fermilab

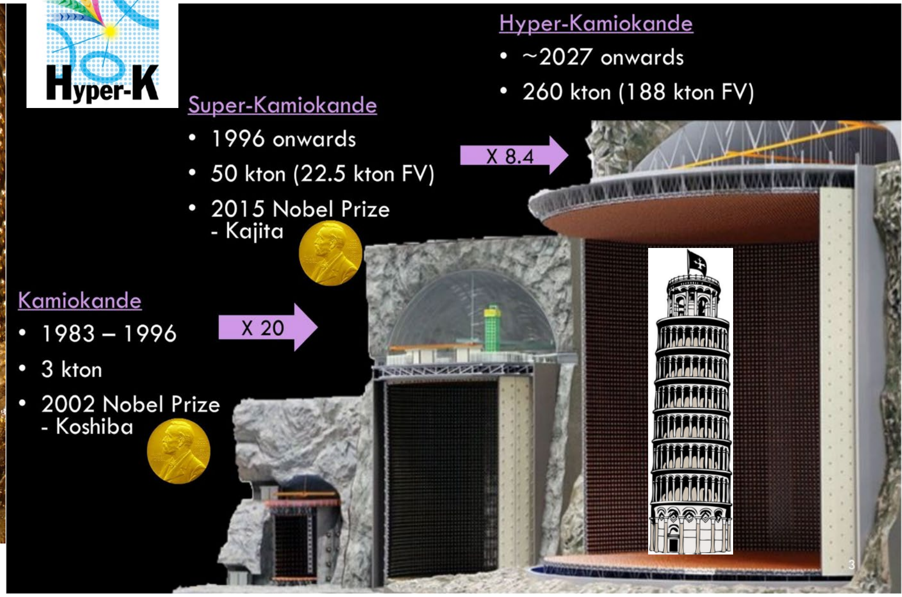
CSN1: Neutrino Oscillations at Accelerators

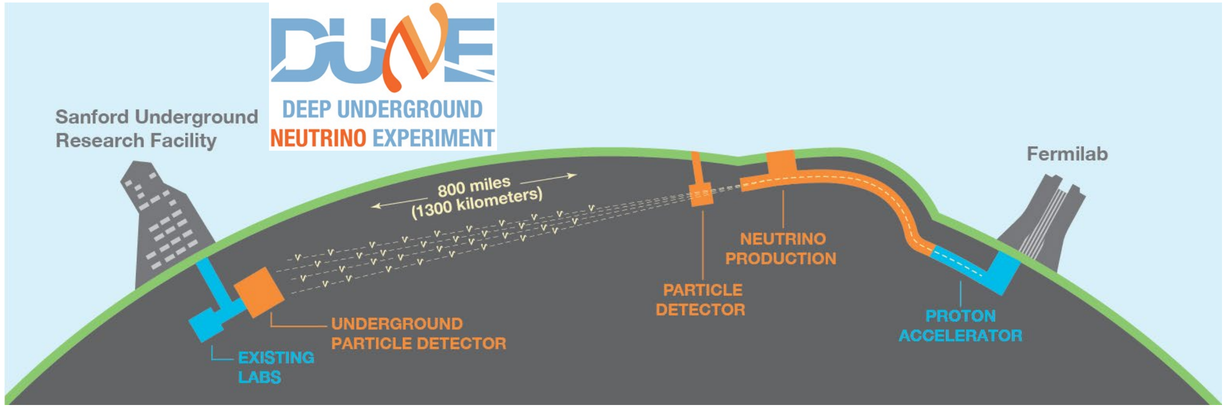
- Informations about the values of neutrino masses
- Informations about the matter-antimatter asimmetry in the Universe
- Sterile neutrinos
- Stability of the matter (proton decay)
- Indirect searches for Dark Matter
- Neutrinos from the atmosphere, the sun, the cosmo

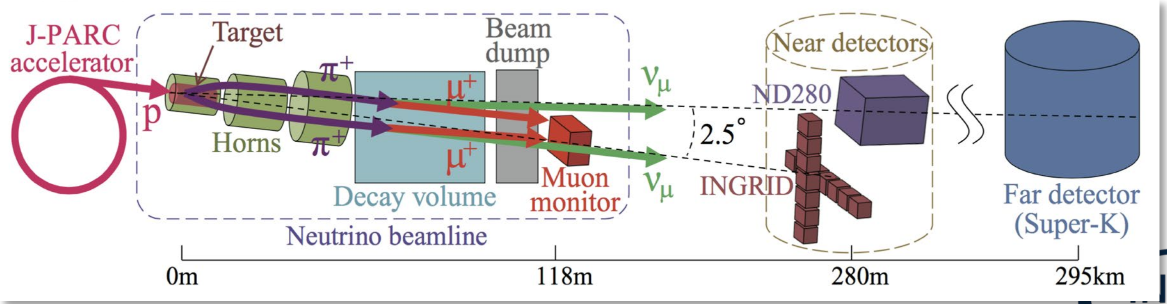


ICARUS





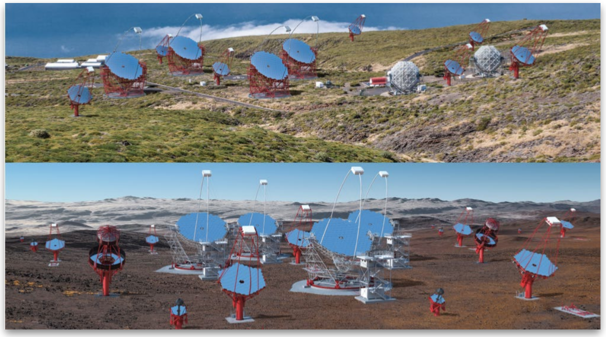




CSN2: "Un altro modo di guardare il cielo"

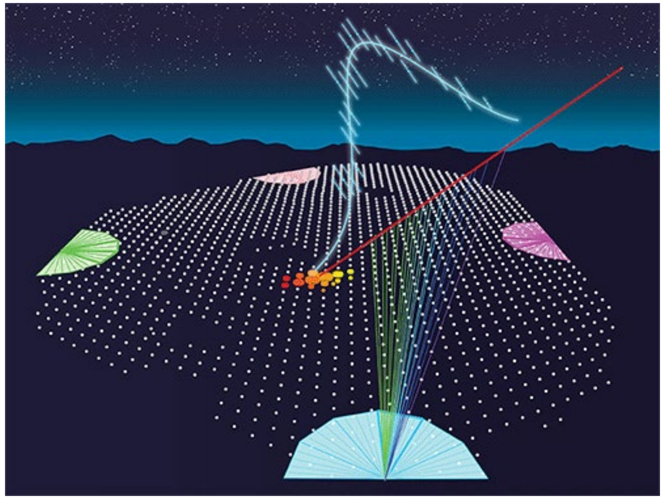
Visible light extends like an octave in a piano keyboard ⟶ difficult to recognize and appreciate a symphony if you can only listen to that octave ⟶ better if you can extend the keyboard and add other instruments ...

Gamma rays: Magic and later CTA

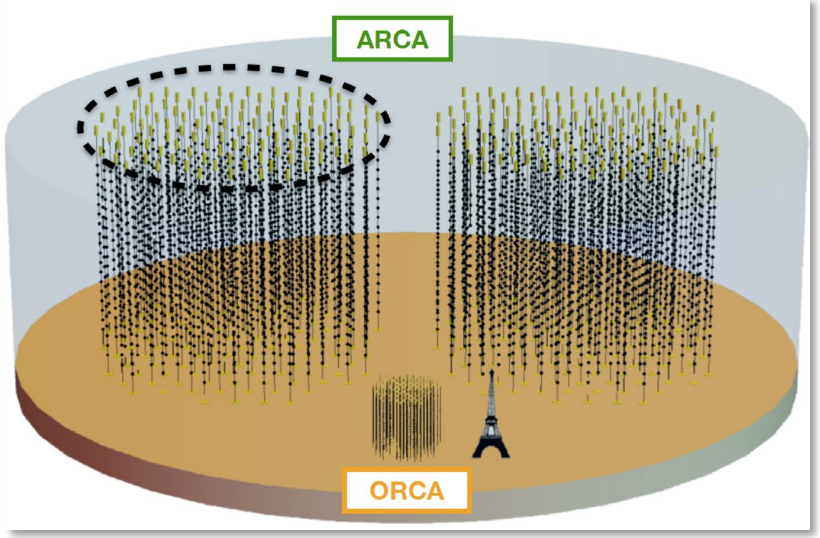


Gamma rays from satellite: FERMI-LAT

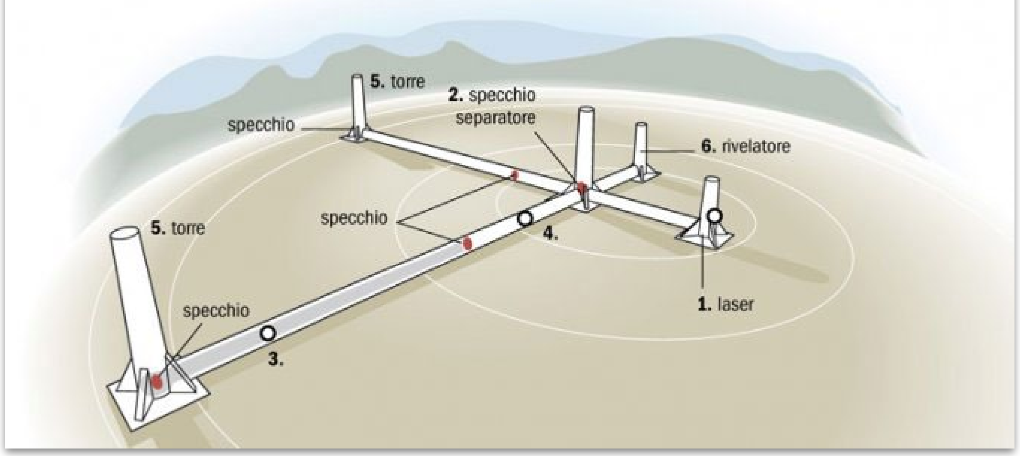
Charged cosmic rays: AUGER



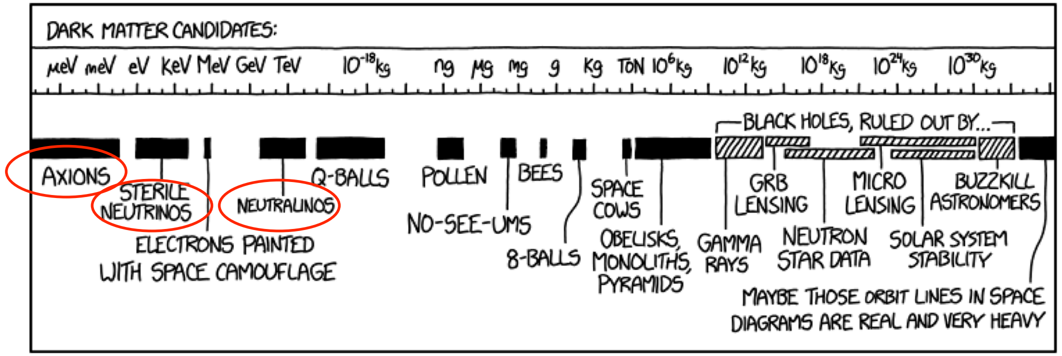
Neutrinos: KM3NeT

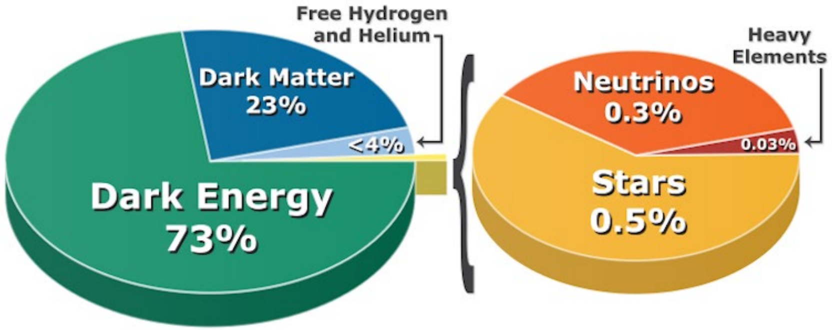


Gravitational Waves: VIRGO, waiting for the Einstein Telescope



CSN2: Dark matter and dark energy, where is the Universe?



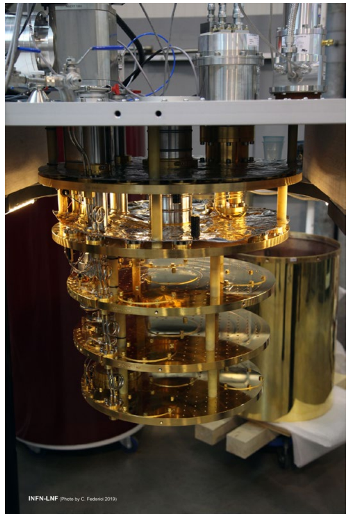


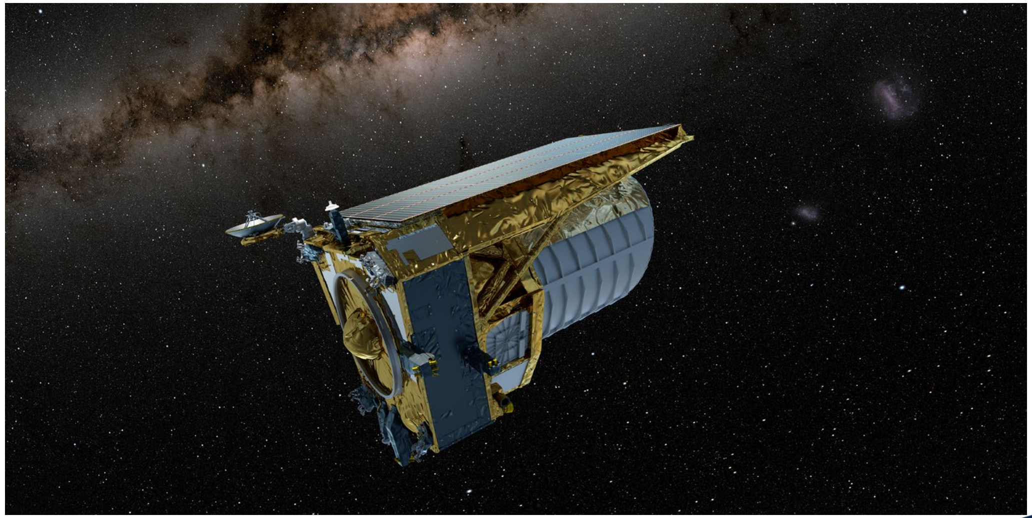
Several WIMP (Weakly Interactive Massive Particles) Dark Matter searches at Laboratori Nazionali del Gran Sasso

- Cosinus
- Cresst
- Dama
- DarkSide
- NEWSdm
- Xenon

Study the Dark Universe: EUCLID (where INFN joins another community for the first time)

Dark Matter in the form of Axions: QUAX@Legnaro





CSN2: properties of the neutrinos

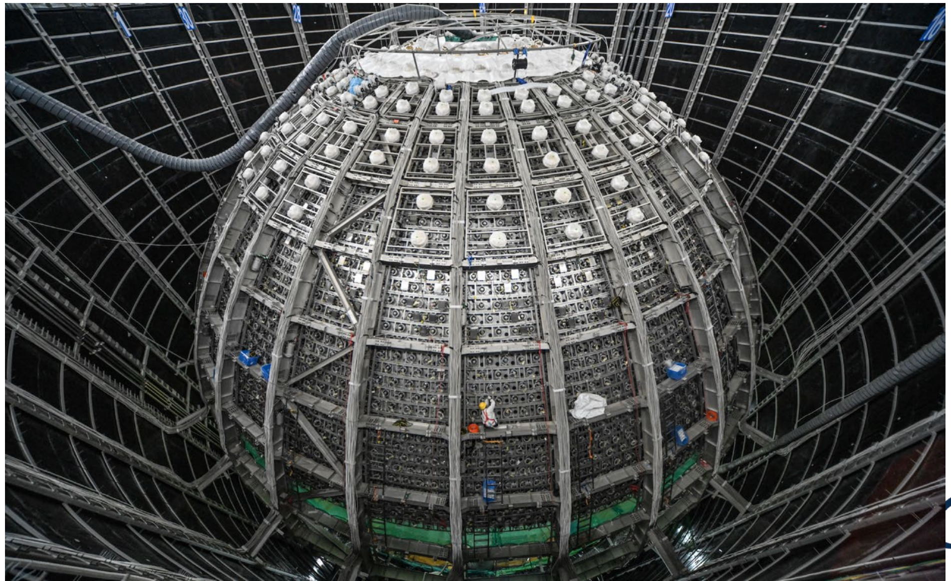
Neutrinoless Double Beta Decay experiments: is the neutrino its own antiparticle?

Gerda -> Legend at LNGS

Cuore -> Cupid at LNGS

Direct neutrino mass measurement: Katrin @ Karlsruhe

Neutrino oscillation parameters and neutrino astrophysics: JUNO with neutrino reactors, China

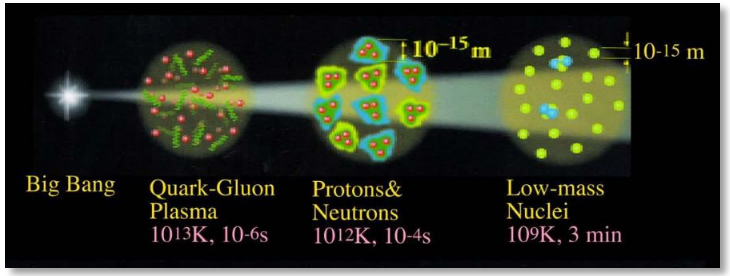


INFN

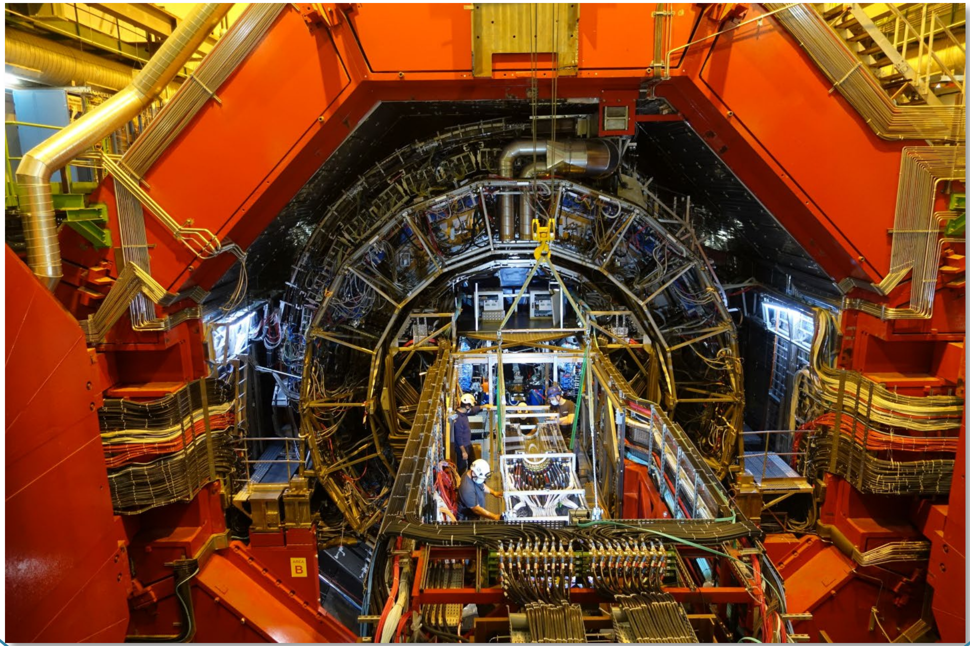
CSN3: structure and dynamics of nuclear matter

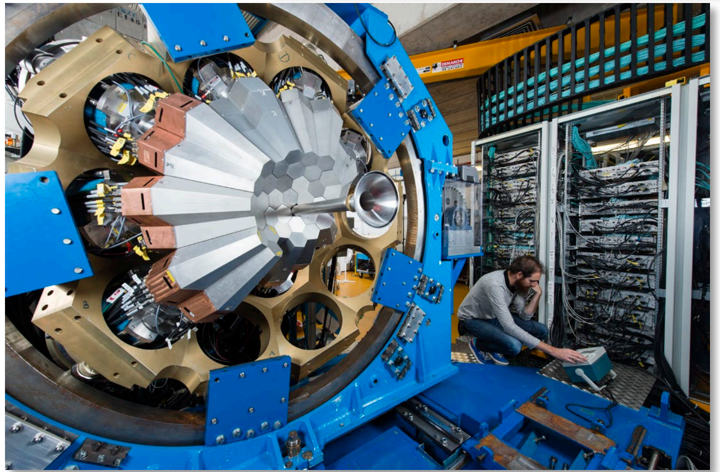
1. Quarks and Hadron Dynamics
2. Phase Transition in Hadronic Matter
3. Nuclear Structure and Reaction Mechanism
4. Nuclear Astrophysics
5. Fundamental Interactions
6. Applications and Societal Benefits

High Energy: Quark-Gluon Plasma



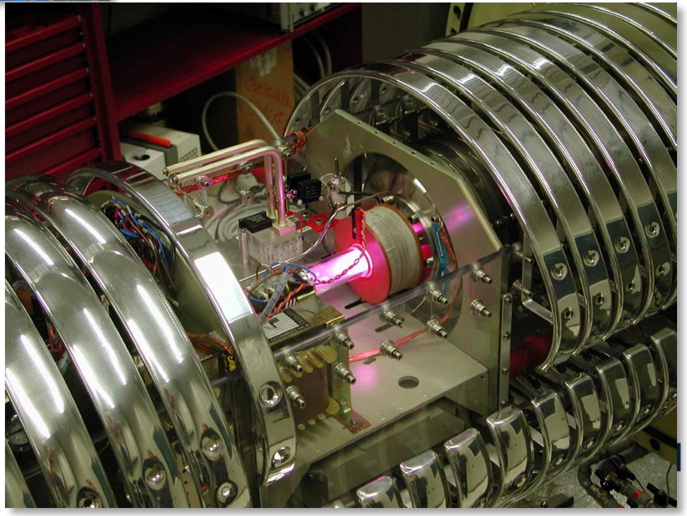
ALICE @ LHC, CERN





The Advanced GAmma Tracking Array (AGATA) is a gamma-ray spectrometer used for nuclear structure studies, at present at Laboratori Nazionali Legnaro

Nuclear Astrophysics:
LUNA @ Laboratori Nazionali Gran Sasso



CSN4: theory

>1000 physicists in INFN
141 in Padova

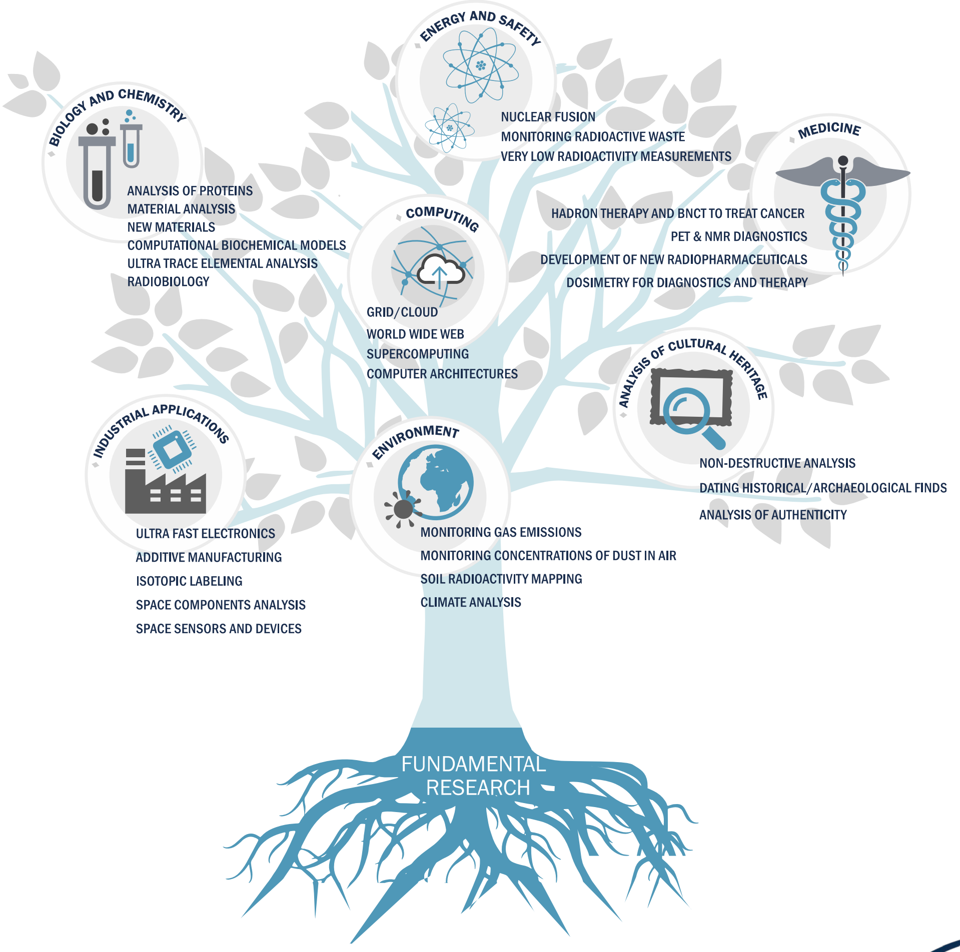
- Line 1 - FIELD AND STRING THEORY
- Line 2 - PHENOMENOLOGY OF ELEMENTARY PARTICLES
- Line 3 - NUCLEAR AND HADRONIC PHYSICS
- Line 4 – MATHEMATICAL METHODS
- Line 5 – ASTROPARTICLE PHYSICS
- Line 6 – STATISTICAL AND APPLIED FIELD THEORY

CSN5: Technological, inter- disciplinary and accelerators research

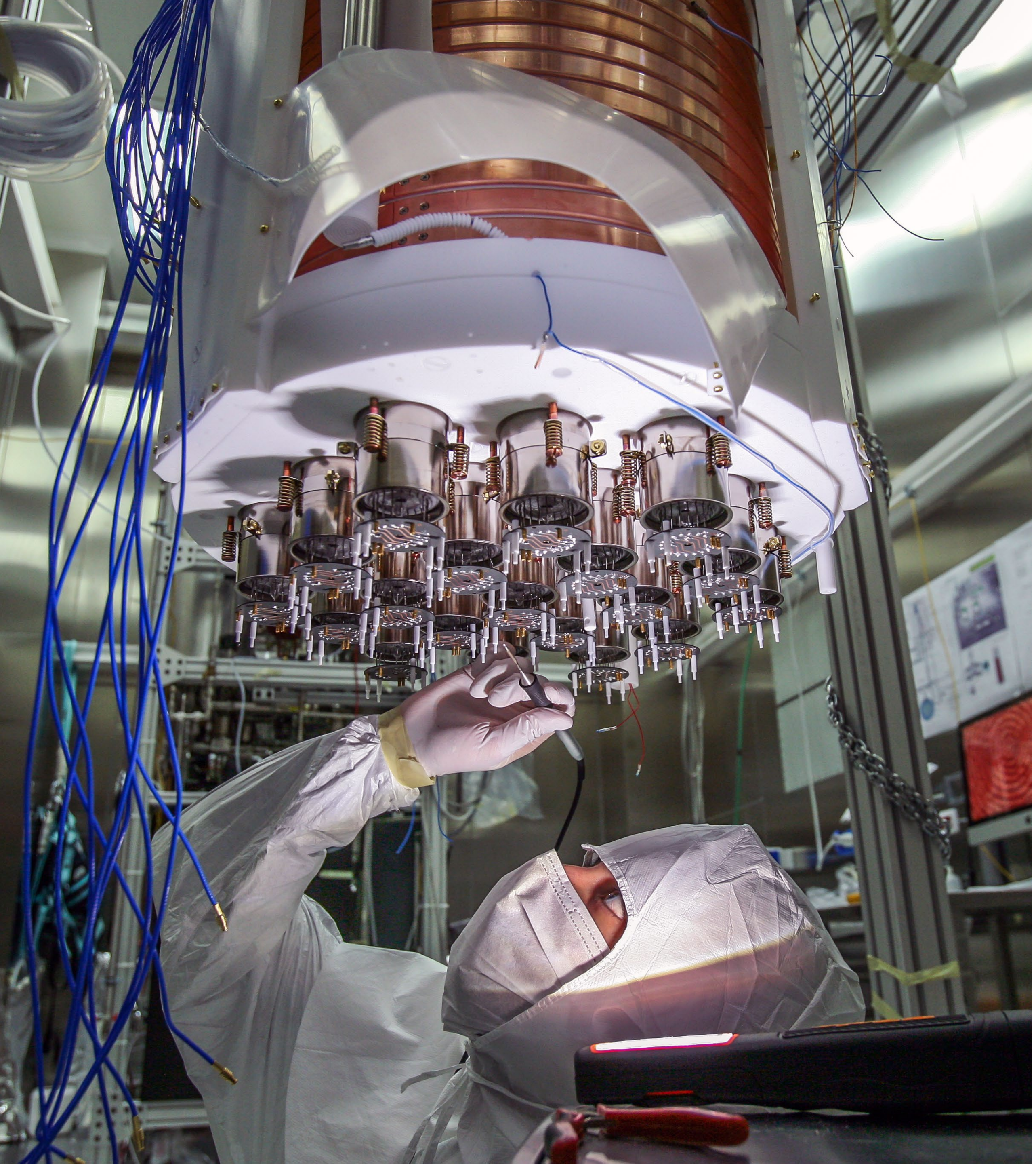
83 initiatives

CSN5 coordinates technological research and promotion of the use of fundamental physics instruments, methods and technologies in other sectors. Development of next-generation prototypes and the production of today's particle accelerators. These are used not only in fundamental physics research projects, but also in other areas of research and economic and social life.

- **Particle detectors**
- **Particle accelerators**
- **Electronics and software development**
- **Interdisciplinary applications of INFN cutting-edge techniques**
    - Medical applications
    - Energy
    - Environment
    - Cultural heritage



INFN



The INFN is ...

a community of over 6,000 people

~ **25%** of them have PhD grants, post-doc scholarships and research grants

People
... in training

	INFN	associates
Research grant	334	332
Post-doc scholarships	79	27
PhD students		1315

Up to 31/12/2023

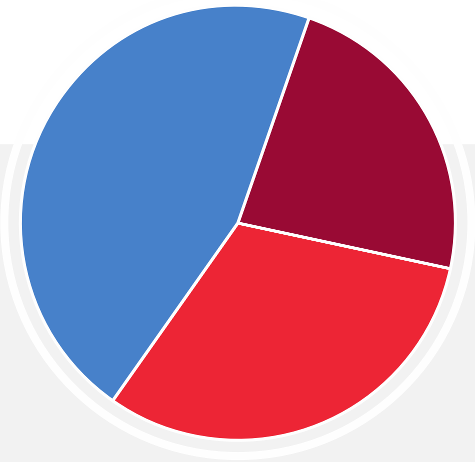
Budget 2023

652 mln di euro

Financial resources excluding funds allocated to specific projects

298

mln di euro



Funds allocated to specific projects (including PNRR)

150+204

mln di euro

Financial report 2024

Profile of expenditure for **research, personnel, operations and equipment**