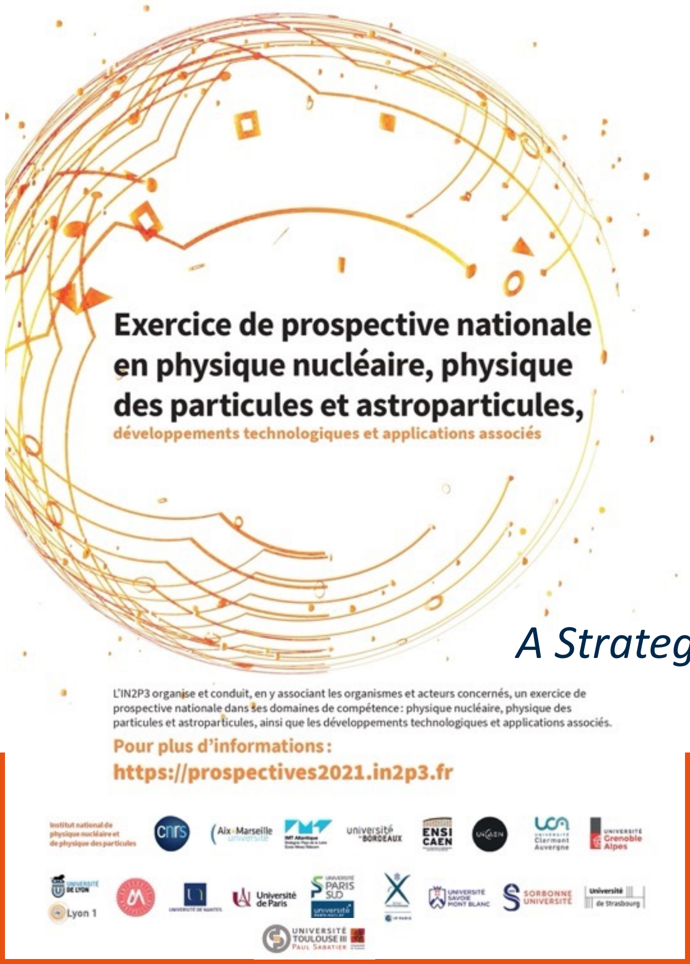
Institut national de physique nucléaire et de physique des particules

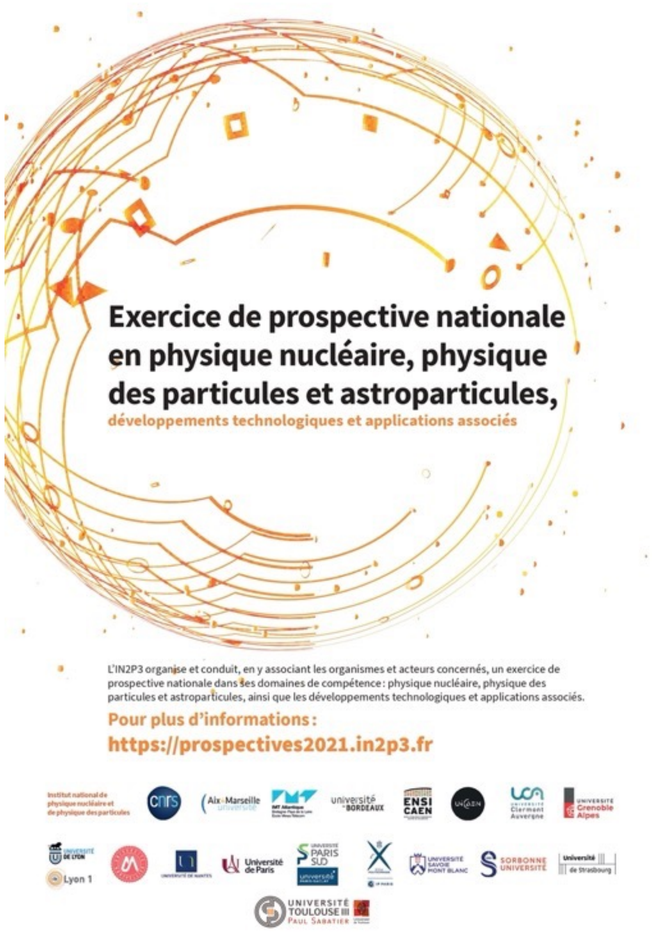


Reaching for the infinities

A Strategic Plan for French Nuclear, Particle and Astroparticle Physics in the 2030 horizon

Conseil Scientifique de l'IN2P3 – Paris

Patrice Verdier – patrice.verdier@in2p3.fr – Oct. 27th, 2022



One of the missions of IN2P3 is to organize and conduct national prospective exercises by involving the organizations and actors concerned.

https://prospectives2021.in2p3.fr/

Prospective exercise

1. European Level / International Context

- Nuclear & Hadronic Physics → NuPECC LRP published end of 2017
- Astroparticle Physics & Cosmology → ApPEC Roadmap published end of 2017
- Particle Physics → ESPP update approved in June 2020

2. National level - IN2P3 mission

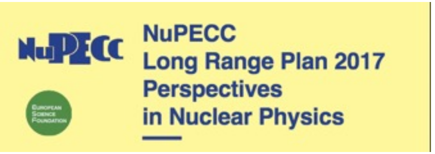
Goals : rolling out European priorities + other national projects at national level

With whom ? Universities + partner organizations

- Fundamental Physics: Nuclear, Particles and Astroparticles
- Associated technological developments in: Accelerators (of particles), Detectors (of particles), Computation and Data (for NPA physics)
- Associated applications in: Health, Energy, Environment, etc.

3. IN2P3 Level

- Associated human resources: number, expertise, skills
- Organization (partnerships) and funding (local/regional, national, European, etc.)



Organization

Period considered 2020-2030, 5-year update

Procedure: we invited the VP Research of the universities and the DRF of the CEA to appoint representatives to form a steering committee. The universities responded positively, Irfu did not wish to have a representative on this steering committee

Oversight Committee :

IN2P3 direction + one representative per university (VP Research or representative) :

Organization :

- 12 scientific themes steered by the DAS
- 10 "Town hall meeting/Open symposium"
- 1 restitution colloquium
- A roadmap document sent to the superving authorities + Ministry

Directeur de l'IN2P3: Reynald Pain
Directeur adjoint de l'IN2P3: Patrice Verdier
Aix Marseille Université : José Busto
Ecole Polytechnique / Institut Polytechnique de Paris : Benoit Deveaud
Sorbonne Université : Marco Cirelli
Université de Bordeaux : Philippe Moretto
Université Caen Normandie : Francesca Gulminelli
ENSI Caen : Marco Daturi
Université Claude Bernard Lyon 1 / Université de Lyon: Aldo Deandrea
Université Clermont-Auvergne : Philippe Rosnet
Université Grenoble Alpes : Laurent Derome
Université de Montpellier : Jacques Mercier
Nantes Université: Gines Martinez
IMT Atlantique : Pol-Bernard Gossiaux
Université Paris-Diderot / Université de Paris : Matteo Cacciari
Université Paris-Sud / Université Paris-Saclay : Tiina Suomijarvi
Université Savoie-Mont Blanc : Roman Kossakowski
Université de Strasbourg : Christelle Roy

The 13 Working Groups

Institut national de physique nucléaire et de physique des particules

CNRS

GT01 – Physique des particules ***L. Vacavant***

Dirk Zerwas (IRN Terascale, IJCLab), Francesco Polci (GDR InF, LPNHE), Christopher Smith (CSI, LPSC), Marie-Hélène Genest (LPSC), Christophe Ochando (LLR)

GT02 – Physique et astrophysique nucléaire ***F. Farget***

Jérôme Margueron (GDR RESANET, IP2I), Giuseppe Verde (CSI, L2IT), Stéphane Grévy (CENBG), Iulian Stéphan (IJCLab)

GT03 – Physique hadronique ***L. Vacavant***

Frédéric Fleuret (GDR QCD, LLR), Béatrice Ramstein (CSI, IJCLab), Klaus Werner (SUBATECH), Carlos Munoz (IJCLab)

GT04 – Physique des astroparticules ***B. Giebels***

Chiara Caprini (GDR OG, APC), Frédérique Marion (CSI, LAPP), Régis Terrier(APC), Francesca Calore (LAPTH)

GT05 – Physique de l'inflation et énergie noire ***B. Giebels***

Sophie Henrot (CSI, IJCLab) Emmanuel Gangler (LPC), Mathieu Tristram (IJCLab), Andrea Catalano (LPSC), Ken Ganga (APC)

GT06 – Physique des neutrinos et matière noire ***B. Giebels***

Dominique Duchesneau (GDR neutrino, LAPP), Anselmo Meregaglia (GDR neutrino, CENBG), Corinne Augier (GDR Underground physics), Frédéric Yermia (CSI, SUBATECH), Laurent Vacavant (IN2P3), Fanny Farget (IN2P3)

GT07 – Accélérateurs et instrumentation associée ***J.-L. Biarrotte***

Rodolphe Cledassou (IN2P3), Brigitte Cros (GdR Appel, CSI, LPGP), Angeles Faus-Golfe (IJCLab), Luc Perrot (IJCLab)

GT08 – Détecteurs et instrumentation associée ***J.-L. Biarrotte***

Rodolphe Cledassou (IN2P3), Didier Laporte (LPNHE, CSI), Julien Pancin (GANIL), Laurent Serin (IJCLab), Véronique Puill (IJCLab), Giulia Hull (IJCLab), Mariangela Settimo (SUBATECH)

GT09 – Calcul, algorithmes et données ***V. Beckmann / S. Crépé-Renaudin***

Rodolphe Cledassou (IN2P3), Nadine Neyroud (CSI, LAPP), Pierre-Etienne Macchi (CCIN2P3), Catherine Biscarat (L2IT), David Rousseau (IJCLab)

GT10 – Sciences nucléaires et vivant ***S. Incerti***

Fanny Farget (IN2P3), Sylvain David (IN2P3), Marc Rousseau (CSI, IPHC), Denis Dauvergne (GDR MI2B, LPSC), Lydia Maigne (LPC), Hervé Seznec (CENBG), Christian Morel (CPPM)

GT11 – Energie nucléaire et environnement ***S. Incerti***

Fanny Farget (IN2P3), Sylvain David (IN2P3), Annick Billebaud (GDR SCINEE, LPSC), Rémi Maurice (CSI, SUBATECH), Gilles Montavon (SUBATECH), Maelle Kerveno (IPHC), Nathalie Moncoffre (IP2I)

GT12 – Géosciences, système solaire et milieu interstellaire ***S. Incerti***

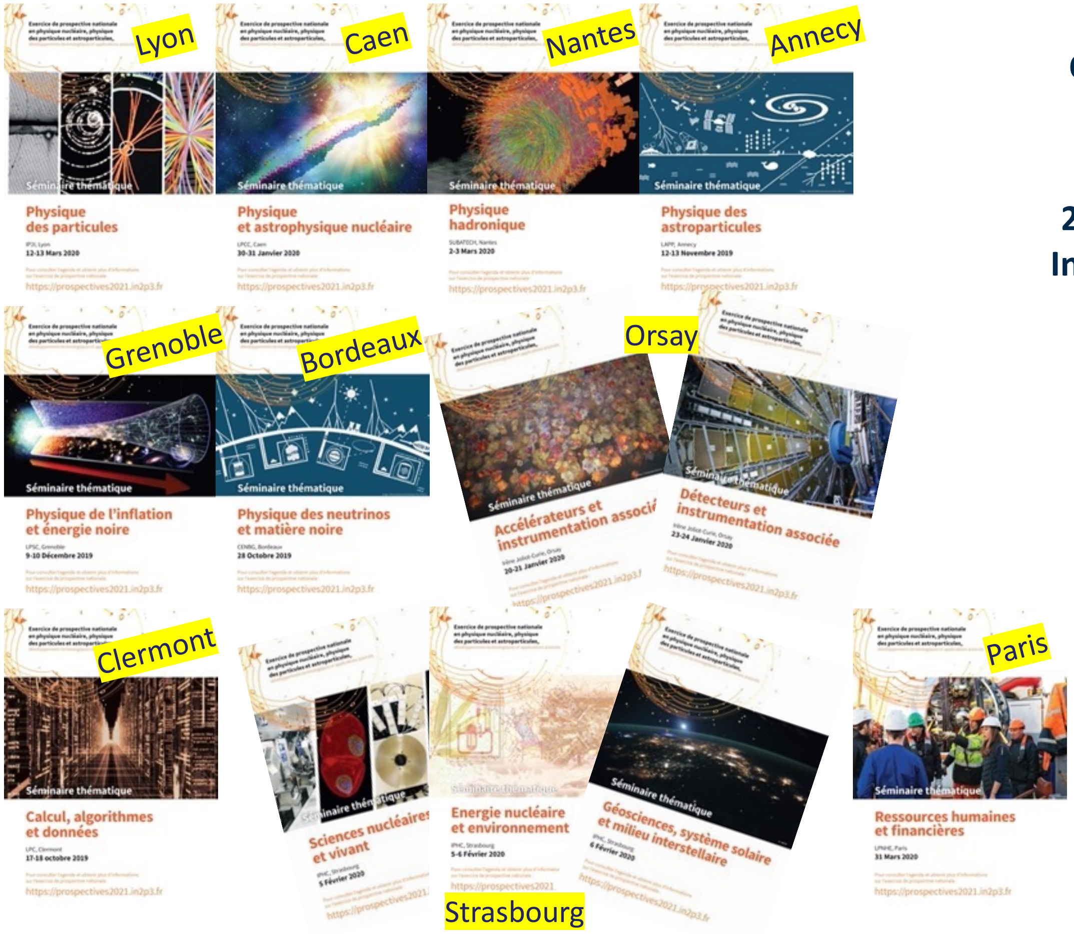
Berrie Giebels (IN2P3), Olivier Drapier (CSI; LLR), Marin Chabot (IPNO), Jean Duprat (CSNSM), Véronique Van Elewyck (APC)

GT13 – Ressources humaines et financières ***R. Pain/P. Verdier***

Rodolphe Clédassou (IN2P3), Olivier Drapier (CSI, LLR), Anne Ealet (IP2I), Eric Kajfasz (CPPM), Arnaud Lucotte (LPSC), Laurence Mathy-Montalescot (IN2P3), Steve Pannetier (IN2P3), Christelle Roy (IPHC)

Town Hall Meetings & Workshops

Institut national de physique nucléaire
et de physique des particules



The 12 Town Hall Meetings took place between October 2019 and march 2020 + GT13 by video in juin 2020

2 workshops en 2021 : Theoretical physics of the 2 Infinities and Quantum technologies for the physics of the 2 Infinities

Strong mobilization and strong participation:

273 « White papers » received

750 participants to the THM

« White papers » & presentations are available on the web site of the GTs

https://prospectives2021.in2p3.fr/?page_id=18

The reports of the GTs are available on:

https://prospectives2021.in2p3.fr

Restitution colloquium in Giens

Institut national de physique nucléaire
et de physique des particules

https://indico.in2p3.fr/event/22028

- **Restitution and discussion exercise on the work carried out by each WG**
  - ~1000 participants: 350 on site, 650 online
  - The Giens symposium: synthesis, discussion and debates on the work of the WGs

- **Presentation and discussion of the "Science Drivers" and recommendations of each WG**

  Methodology in the WG reports:
  - Each GT has formulated "Science Drivers" (SD)
  - SDs are formulated as an action
  - Each WG then formulates recommendations that address one or more SD

- **At the end of this restitution exercise, the IN2P3 direction draws up the national roadmap based on the recommendations of the WGs, the discussions that took place in Giens, by integrating elements of human and financial resources, timetables, European roadmaps, scenarios**

=> Document in English, about 30 pages, with an executive summary

Goals of the roadmap

- **This roadmap covers the next 10 years**

- Goal: nationally set out European and international strategic priorities in the three domains, **Nuclear, Particle and Astroparticle physics, to define objectives and priorities for national activities and projects**

- Provide **a comprehensive view of activities and projects** in these scientific fields, as well as an **analysis of the strategic positioning** of French teams and laboratories and of **their impact in the international landscape**

- The broad vision presented in this roadmap provides **near-term (5-10 years) prioritization of the scientific projects**, but also **anticipates the developments needed for the long-term future** in order to keep the excellence of the French teams in these fields and thus be major players in **preparing for future discoveries**

Methodology

- **Budget scenario:**
  - Assume that CNRS project funding (AP and IR) will remain constant
  - that more projects funding will be obtained through ANR, whose budget is scheduled to double in the next years, and that European funding will continue to increase as well as funding through joint collaborative project with industry.
  - Funding through the IR* scheme or PIA is by construction subject to large fluctuations and cannot be easily anticipated. Nevertheless, large projects that will require IR* funding and projects of intermediate size that could benefit from PIA funding are being proposed and we have assumed new funding through these schemes will remain possible.

- The projects and actions considered require **large scale resource investments** and are expected to have **a strong impact**

- Important aspects are their **relevance on the Science Drivers**, their **alignment with Program Wide Priorities**, as well as **considerations on the timeliness, feasibility, existing commitments, and the size of the French collective of scientists involved : those aspects are essential to address the great ambitions of a research field and to define the corresponding project priorities**

- It is also essential that new ideas and developments, possibly leading to new opportunities, are supported at a level which this research program can provide

Reaching for the infinities

A Strategic Plan for French Nuclear, Particle and Astroparticle Physics in the 2030 horizon

The 12 Science Drivers

Institut national de physique nucléaire
et de physique des particules

Science Driver definition:

Within the scientific domains where IN2P3 coordinates research, SD have been defined for the next decade as actionable lines of inquiry derived from those identified in the reports from GT01 to GT06.

The synthesis of the SD from GT01-06: from 45 to 12

Enhance knowledge of the Higgs sector	Higgs
Study of matter-antimatter asymmetry and flavor transitions	Flavor
Pursue searches for unknown particles and interactions	New Phenomena
Understand the structure and the origin of the properties of hadrons	Hadrons
Pursue the exploration of nuclear matter phase diagram	Nuclear Matter
Explore the limits of stability of nuclear systems	Nuclear Structure
Understand how nuclear processes shape the Universe	Nuclear Processes
Use gravitational waves as a tool to explore the Universe and its fundamental laws	Gravitational Waves
Study the physics of high energy messengers and probe extreme astrophysical phenomena	High Energy Gamma and Cosmic Rays
Understand the physics behind inflation and dark energy	Inflation and Dark Energy
Explore further the physics associated with the properties of neutrinos	Neutrinos
Identify the nature of dark matter	Dark Matter

(In the document, each SD is described in a paragraph of 20-25 lines)

5 Program Wide Priorities

Institut national de physique nucléaire
et de physique des particules

cnrs

Program Wide Priorities:

Enable optimal research programs which address the Science Drivers

Complete French commitments to large national and international projects and secure the expected science return

Pave the way to sustainable programs which will enable to support small scale projects which could result in a leading role when opportunities arise

Enable the definition of French contributions supporting emerging or evolving projects

Maintain a world-class theoretical and computational physics research program, and support developments aligned with the Science Drivers

- Enable world-leading research to be undertaken in the fields of NPA physics
- Require optimal research environments, collaborations and infrastructures
- Foster international partnerships in the framework of a national organization

- Complete existing commitments to research programs from previous prioritizations, in particular those issued in the associated European roadmaps

- Require a balance between large-and-mid scale international projects and small-scale projects, together with strong support from theoretical inputs
- Require dedicated programs of Research & Technological Development to push available or emerging technologies beyond their current limits
- Set up an innovative and renewed R&D program, drawing on existing expertise, technological platforms and industrial partnerships

- Keep the potential for discovery and innovation at the highest level
- Require mechanisms to exploit new opportunities, either completely new projects or upgrades of existing ones

- Support in theoretical and computational activities in NPA physics should be further enhanced in order to enable new discoveries and progress in these fields

Priorities in Quark & Lepton Physics

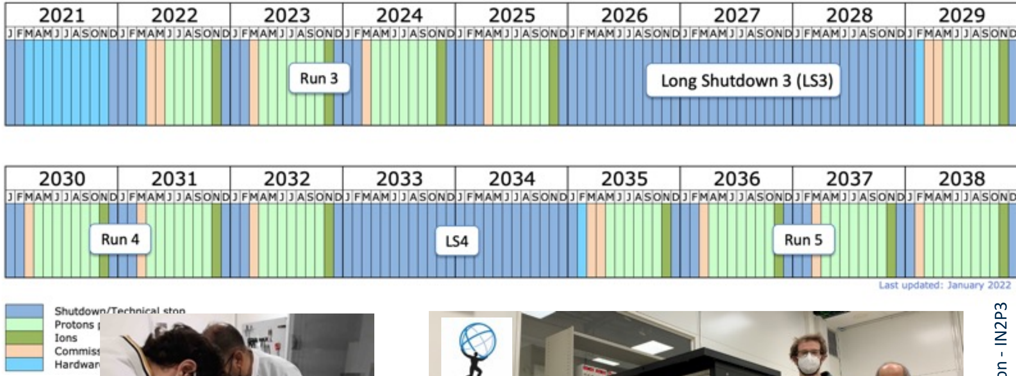
Institut national de physique nucléaire
et de physique des particules

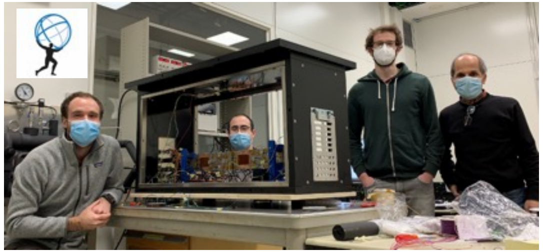
Pursue the exploration of the energy frontier at high energy collider

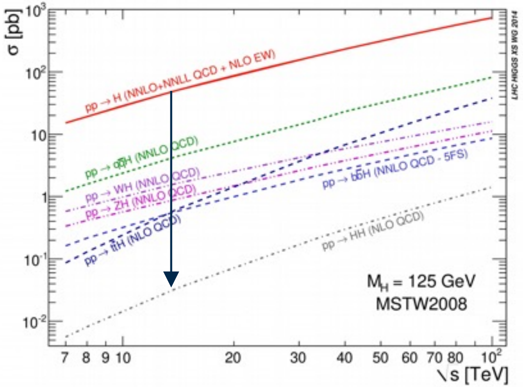
(I) Pursue a full and optimal exploitation of LHC general-purpose experiments ATLAS and CMS.

(II) Complete the ATLAS and CMS phase-2 upgrades on schedule and prepare their exploitation at the HL-LHC.

(III) French laboratories should contribute to the European effort to investigate the feasibility of the FCC at CERN, and engage in the R&D programs to develop technologies for particle detection and acceleration.







Images : Laurent Serin, Nicolas Chanon - IN2P3

Pursue flavor physics at the intensity frontier

(I) Fully exploit on-going LHCb physics program. Maintain an appropriate participation in other experiments addressing the Science Drivers.

(II) Prepare a sustainable experimental flavor physics program beyond 2030.

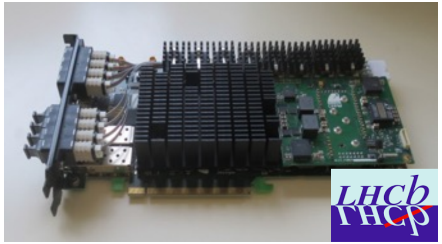
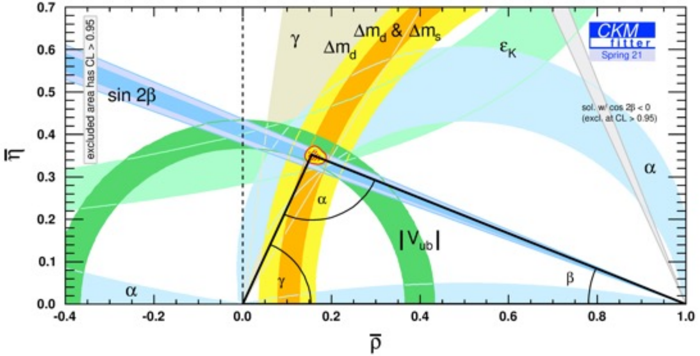
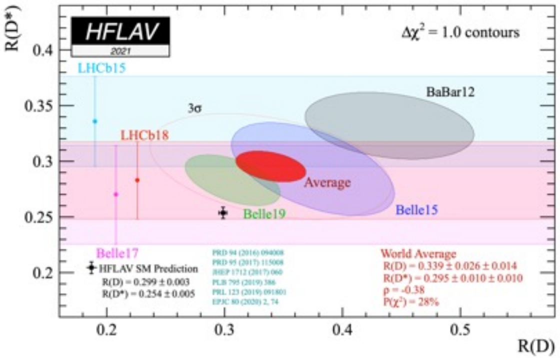


Image : Patrick Dumas/CNRS / Photothèque IN2P3





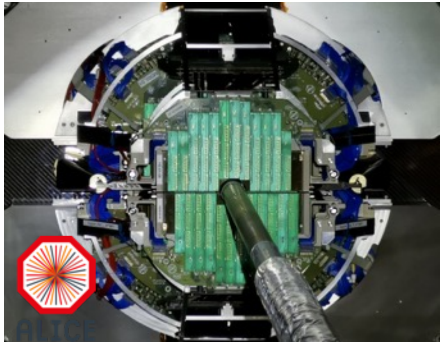
Priorities in Hadron Physics

Institut national de physique nucléaire
et de physique des particules

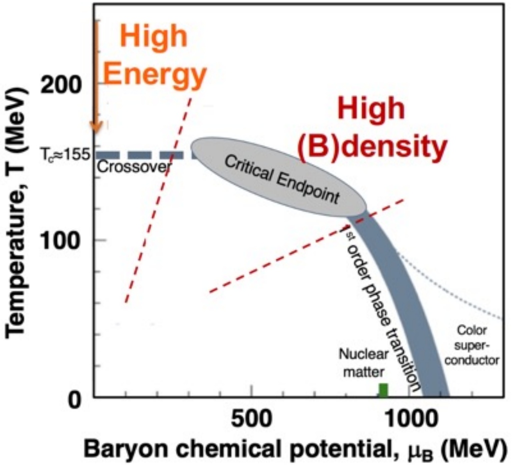
Pursue studies of strongly interacting matter at high energy and of nucleon structure

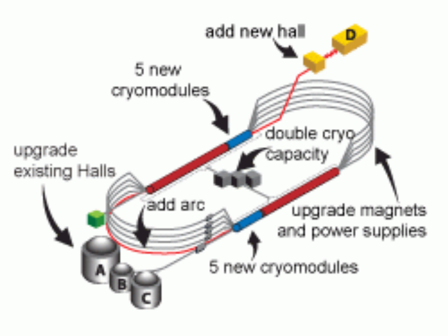
(I) Achieve a successful physics program on the study of QCD matter at the highest energies during Run 3 and 4 of the LHC.

(II) Pave the way for a strategic decision to be taken around 2025 concerning potential involvement in hadronic and hadron physics programs beyond 2030.



Images : CERN





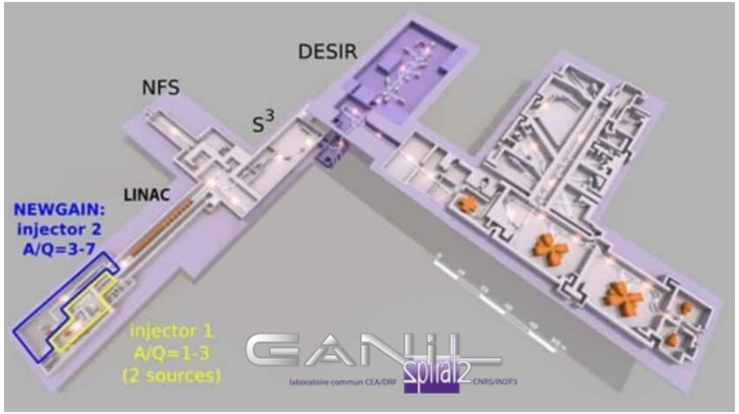
Nuclear structure and nuclear astrophysics

(I) Complete the construction of the experimental installations S3, DESIR and NEWGAIN at GANIL as planned.

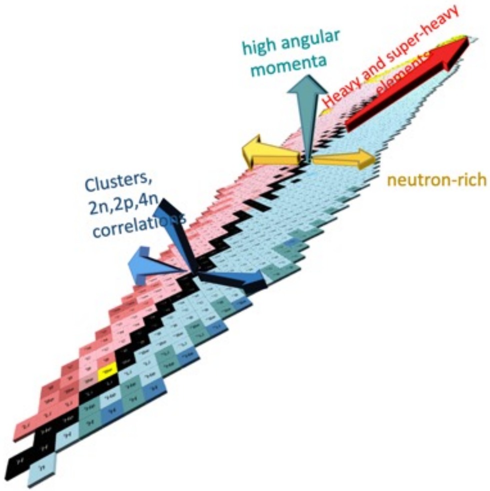
(II) Secure the French participation to the phase 2 construction of the AGATA detector.

(III) Consolidate the existing expertise in the nuclear computing physics program for the next decade. Enable the emergence of new techniques and innovative ideas, especially those arising with quantum computing and parallel computing.

(IV) Decisions and design studies should proceed diligently toward submitting a proposal for GANIL upgrade beyond SPIRAL2 phase 1.



Images : Photothèque IN2P3

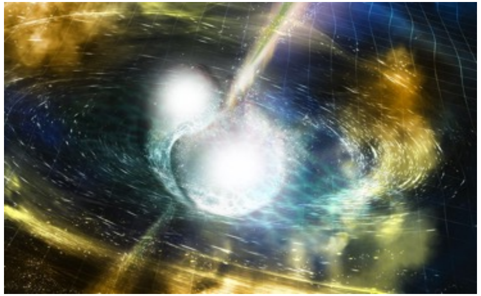


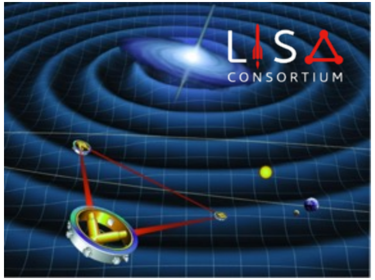
Maintain French international leadership in Gravitational Wave physics

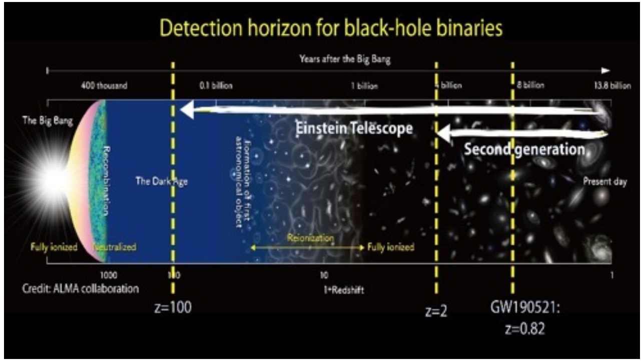
(I) Maintain continuous and adequate support to keep a competitive and successful GW antenna at EGO.

(II) Participate in the 3G GW interferometer development guided by the leveraging of French Virgo expertise and facilities.

(III) Develop the French contribution to LISA with the critical CNES support.



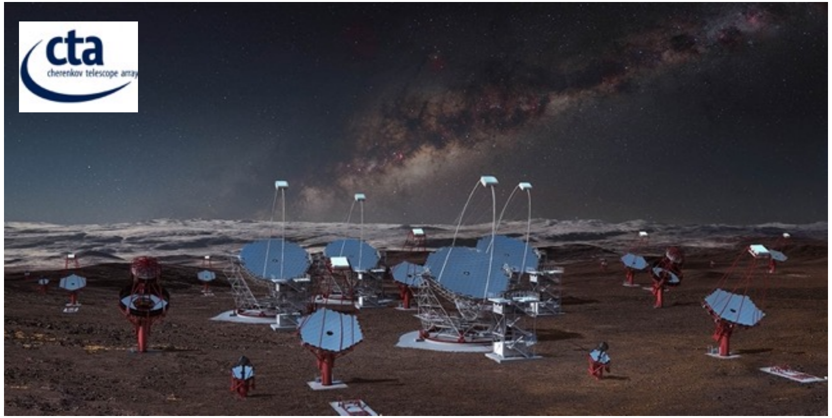




Fully exploit the High Energy Messengers

(I) Complete the French contributions to the CTA-North site as planned. Deliver and promote the science return on telescope and computing investment through strong engagement in Key Science Projects aligned with the Science Drivers.

(II) Support the high-energy multi-messengers approach to understand the High Energy Universe.



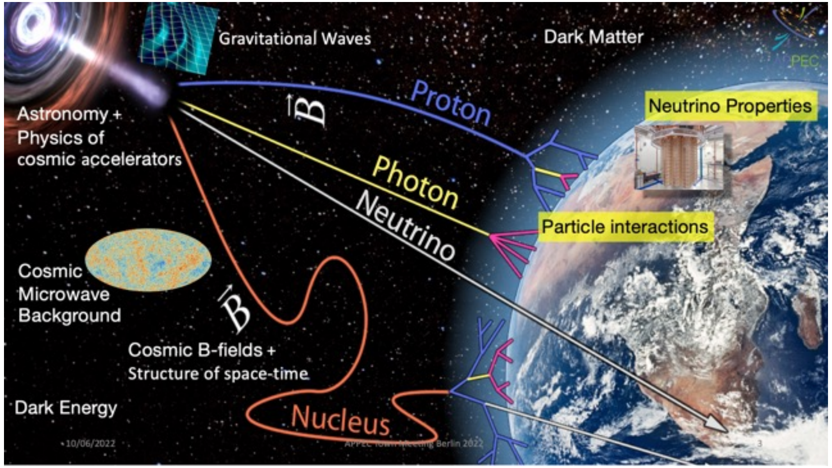


Image: Sijbrand de Jong APPEC

Priorities in Inflation & Dark Energy Physics

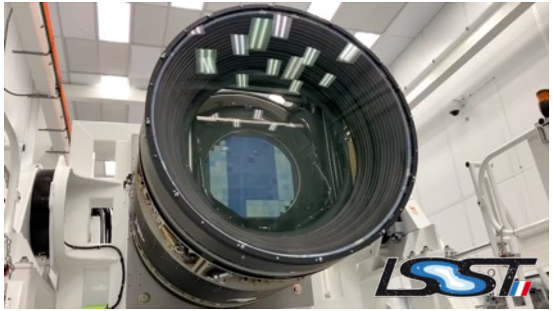
Institut national de physique nucléaire
et de physique des particules

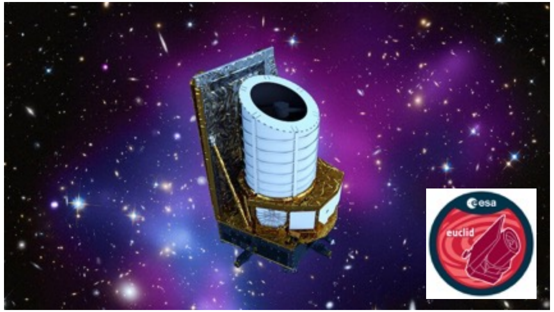
Investigate further Inflation and Dark Energy

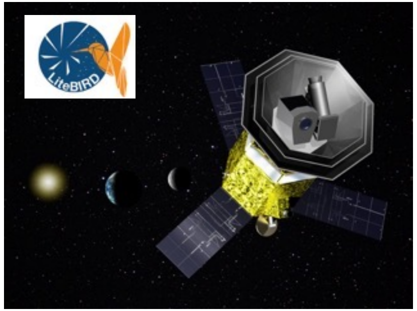
(I) Reap the science rewards of the ongoing and upcoming large optical surveys, in particular those carried out in the LSST and EUCLID. Maximize science return on cameras and computing investment by effecting research with impact on the Science Drivers.

(II) Develop the French contribution to LiteBird with the critical CNES support.

Images : Rubin Observatory





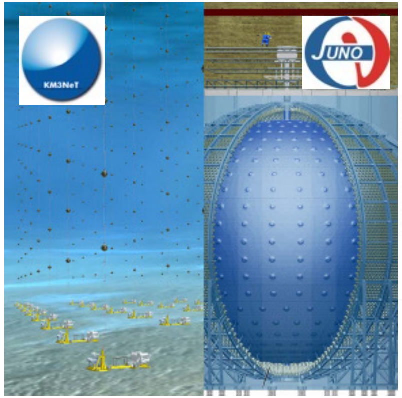


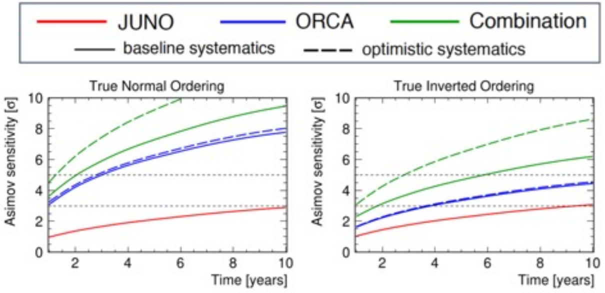
Build the future of Neutrinos oscillation physics

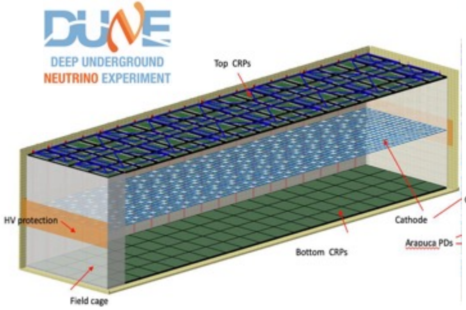
(I) Complete the KM3NeT/ORCA and JUNO experiments to prepare neutrino mass hierarchy determination.

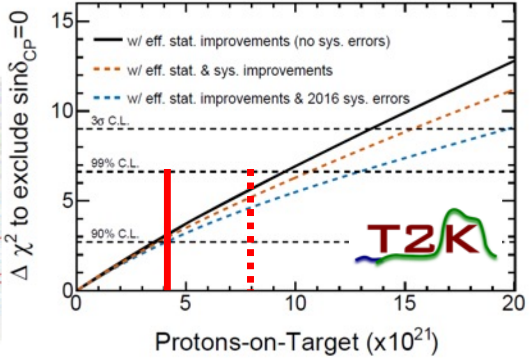
(II) Fully exploit neutrino data from T2K and SK.

(III) Participate in the next generation neutrino oscillation experiments, DUNE and Hyper-Kamiokande, including the completion of major instrumental commitments to the DUNE far-site detector and to the PIP-II accelerator at Fermilab.









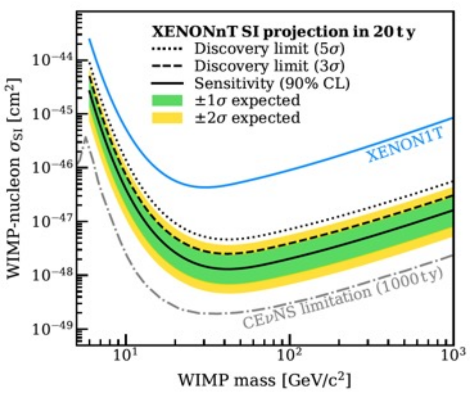
Define a future of neutrinoless double-beta decay and dark matter searches

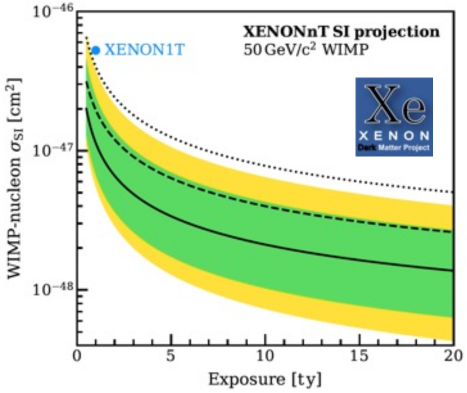
(I) Fully exploit DM physics and the NDBD potential of XENONnT.

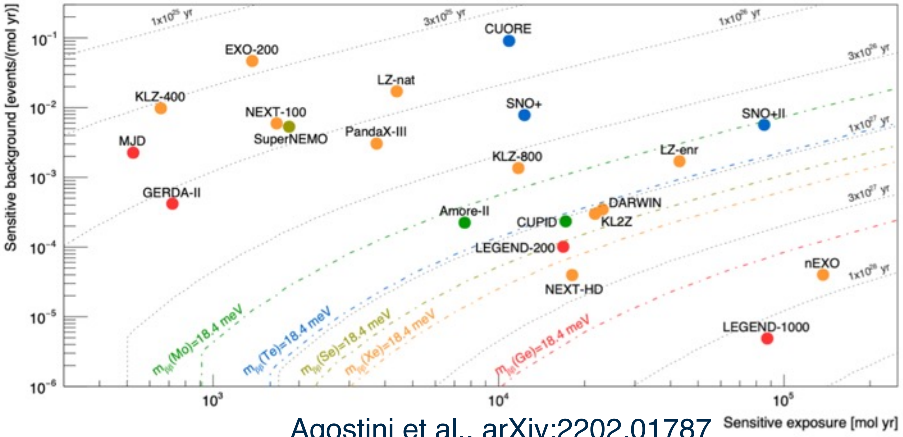
(II) A strategy for opportunities of a French participation in a next generation NDBD discovery experiment should be developed.

Deep Underground Physics

https://gdrduphy.in2p3.fr



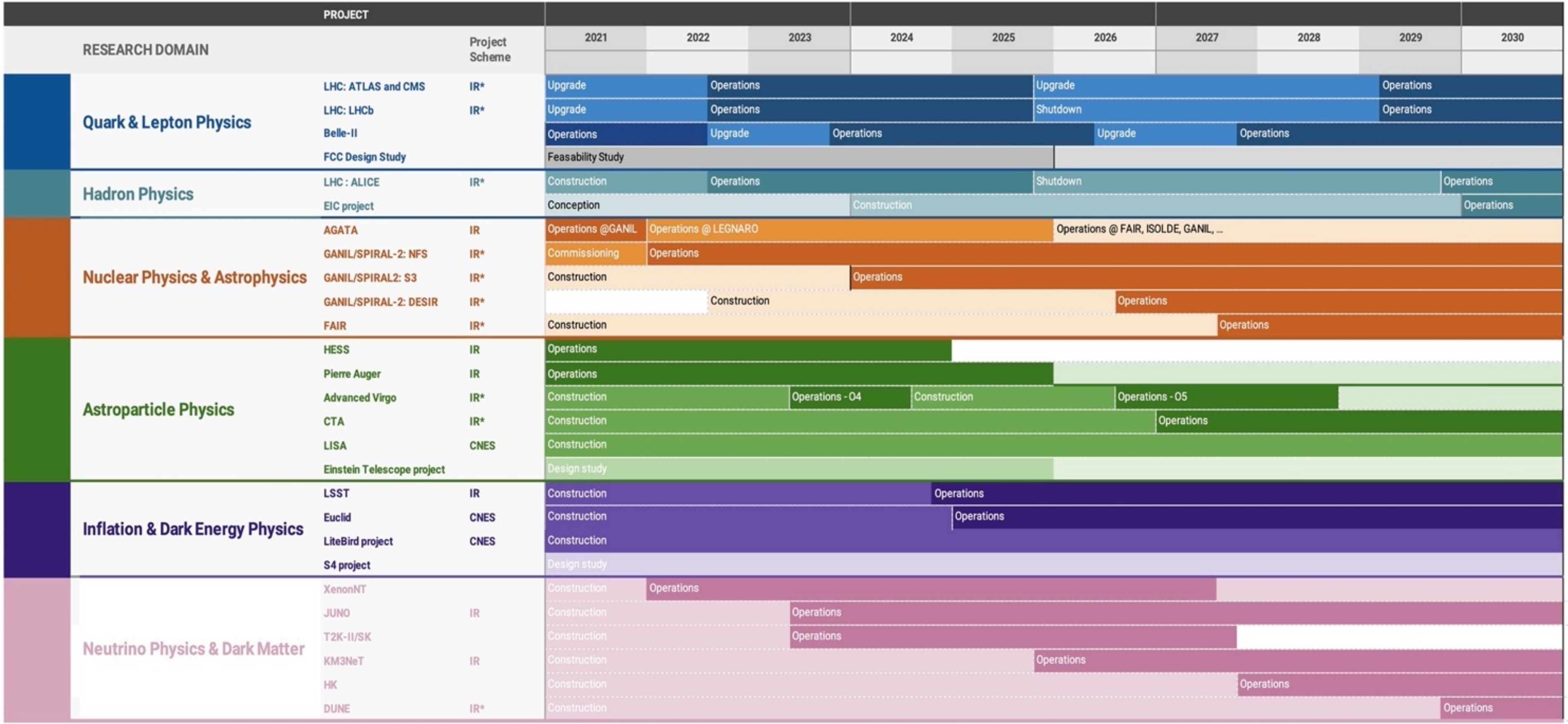




Agostini et al., arXiv:2202.01787

Timeline of major projects in Nuclear, Particle and Astroparticle physics

Institut national de physique nucléaire et de physique des particules



Science Drivers addressed by each major project in Nuclear, Particle and Astroparticle physics

Institut national de physique nucléaire et de physique des particules

SCIENTIFIC DOMAIN	PROJECT	SD1 - Higgs	SD2 - Flavor	SD3 - New Phenomena	SD4 - Hadrons	SD5 - Nuclear Matter	SD6 - Nuclear Structure	SD7 - Nuclear Processes	SD8 - Gravitational Waves	SD9 - High Energy Gamma & Cosmic Rays	SD10 - Inflation & Dark Energy	SD11 - Neutrinos	SD12 - Dark Matter
Quark & Lepton Physics	LHC: ATLAS and CMS	✗		✗		✗							✗
	LHC: LHCb		✗	✗	✗	✗							
	Belle-II		✗	✗	✗								
	FCC	✗	✗	✗	✗	✗							✗
Hadron Physics	LHC: ALICE				✗	✗							
	EIC				✗	✗							
Nuclear Physics & Astrophysics	AGATA						✗	✗					
	GANIL/SPIRAL-2: NFS						✗	✗					
	GANIL/SPIRAL-2: S3						✗	✗					
	GANIL/SPIRAL-2: DESIR			✗			✗	✗					
	FAIR					✗	✗	✗					
Astroparticle Physics	HESS									✗			✗
	Pierre Auger									✗		✗	
	Advanced Virgo							✗	✗	✗	✗		✗
	CTA									✗			✗
	LISA								✗	✗	✗		✗
	Einstein Telescope							✗	✗	✗	✗		✗
Inflation & Dark Energy Physics	LSST									✗	✗	✗	✗
	Euclid										✗		✗
	LiteBird										✗	✗	✗
	S4										✗	✗	✗
Neutrino Physics & Dark Matter	XenonNT											✗	✗
	JUNO									✗		✗	
	T2K-II/SK									✗		✗	
	KM3NeT									✗		✗	
	HK									✗		✗	
	DUNE									✗		✗	

Breaking the technological frontier

Institut national de physique nucléaire et de physique des particules

Push detector development towards

- enhanced sensitivity and lower background
- better energy, time and space resolutions
- higher efficiency, lower greenhouse emissions, and increased reliability and lifetime
- high-rate and high-speed read-out with efficient data acquisition

GDR DI2I:

Détecteurs et Instrumentation pour les 2 Infinis

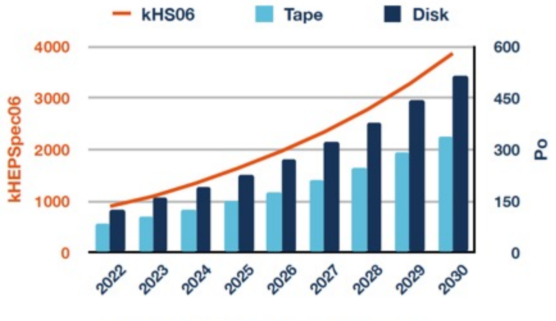
Mai 2022 : IJCLab reçoit la première cavité prototype pour le projet PIP-II.

Push accelerator development towards

- higher beam energies ⇒ next generation high-energy colliders
- enhanced beam intensities & luminosities for nuclear physics, high-precision frontier colliders or for neutrino physics
- higher beam quality, efficiency & reliability, to increase the general performance of accelerator-based research infrastructures

Push computing and data handling development towards

- More powerful and efficient IT solutions to worldwide nuclear, particle and astroparticle scientific collaborations
- Consolidate the organization of national computing resources
- Strengthen further the links between CC-IN2P3 and the laboratories
- Strengthen collaborations with Machine learning Computer Scientists
- More use of *Real Time Analysis* to enhance the scientific throughput of experiments
- Engage further in evolving and emerging technologies, including quantum computing.



IN2P3 resource evolution projection

Broader impacts

- Research activities and technological developments carried out within the framework of NPA physics scientific programs, contribute to the emergence of new fundamental research activities through interactions with other fields : Ex. multi-disciplinary projects involved in major societal challenges

- **Long-term relations** exist between research in the domains of the **physics of the Universe, and fundamental research in other basic sciences**, which has provided tremendous benefits to the partners within their own specific programs

- Developments in nuclear and high energy physics have direct applications within society especially in the sectors of **health, energy, space and the environment**
  - Research efforts on nuclear energy production, from the modeling of innovative nuclear reactors to the study of nuclear materials, nuclear waste and the impact of radionuclides on the environment
  - Development of new medical-imaging techniques and new approaches in radiotherapy

- This section of the document also contains a short summary of the general impact on:
  - Communication and outreach
  - Open Science

Conclusion

- **A document in English, ~30 pages, with an executive summary, intended for :**
  - Tutelles and parnters: CNRS, Universities, CEA, MESR,..
  - Foreign partners (NUPECC, APPEC, ECFA, CERN, INFN, DOE …)
  - Laboratories and scientists in the fields

- **Transmitted to the DAS and 4 DU’s to ask questions and clarify issues on the text : done**

⇒ The quasi-final version of the document is ready

- **IN2P3 communication team is working on the document design and illustrations**

- **Publication in November 2022**