GT03 – Physique hadronique

https://prospectives2020.in2p3.fr

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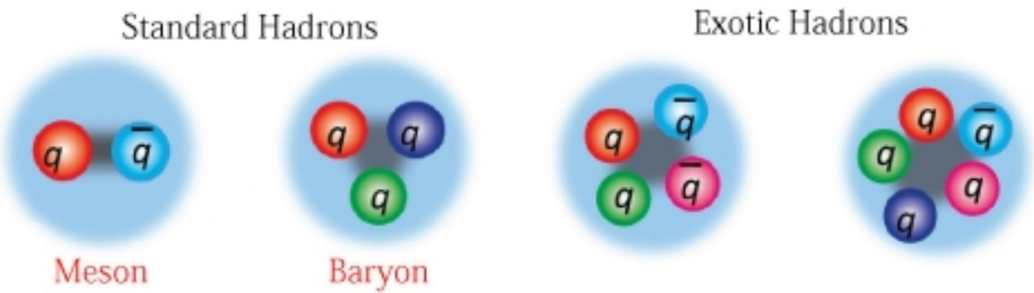
- La structure du nucléon
- Les propriétés fondamentales de la matière en interaction forte



Science Drivers

- **SD1: Understanding the origin of the proton mass**
  How quantum fluctuations of quark-antiquark pairs, gluons, and the dynamics of their interactions eventually generate most of the mass of the nucleon ?
- **SD2: Mapping the structure of nucleons and nuclei**
  (a) Quark content: how do the different flavours of quarks distribute in space and momentum inside hadrons ?
  (b) Gluon content: how do the nucleon and nuclei look like at high energy, where gluons are dominant ?
  (c) Saturation: how could gluon recombination lead to a saturation of the number of gluons inside nucleons and nuclei, creating a regime of high parton density, but small coupling ?
- **SD3: Understanding the deconfined state of quarks and gluons**
  (a) Nature of QGP: what are the precise transport properties of the medium? how does color screening apply?
  (b) Collectivity: are collective-like effects observed in small systems of the same nature as in large systems ? what are the conditions of collectivity ?
  (c) Chiral symmetry restoration: can signals be observed and is the restoration of this fundamental symmetry of QCD simultaneous to the deconfinement transition at finite baryon densities ?
- **SD4: Establishing the equation of state of strong interactions**
  (a) Phase transition: what are the thermodynamic parameters and the order of the transition ?
  (b) Critical point: where is it located in the phase space diagram ?
  (c) Hadronic matter: what is its microscopic structure (baryon resonances, strangeness,...) and how are hadrons modified in dense and hot hadronic matter ?

Recommendations

NUST: Science Drivers SD1 & SD2

1. **Support the theory groups to maintain the French leadership over the next decade on the outstanding problems of hadron and nuclear structure** in terms of TMDs and GPDs, as well as cold nuclear matter effects of interest at the EIC and in p+A collisions at the LHC. Phenomenological studies in close connection with the French experimental program in the field should be encouraged.
2. **Capitalize on the investments on the Jefferson Lab experimental program** and take full advantage of the recent CEBAF energy upgrade to complete a three- dimensional exploration of the structure of nucleon and nuclei in the valence quark region. The program, centered around the determination of the GPDs, is well-defined till 2025-2030, with the experiments relying on the CND, NPS and ALERT detectors.
3. **Consolidate the French community interested in a participation to the Electron-Ion Collider project** which is emerging as a flagship project for hadronic physics, for at least two decades starting around 2030. A stronger involvement in early studies and design phase, gathering the many experimental and theoretical expertises, should be supported as the framework for shaping the French scientific project. A contribution to the detector construction should be focussed and commensurate with the size of the interested community.

SIMP: Science Drivers SD2, SD3 & SD4

1. **Fully exploit the physics potential of LHC Run 3 and Run 4** with the upgraded ALICE, CMS and LHCb (+SMOG2 with its fixed-target program) experiments to pursue the study of the matter at high temperature. The three experiments exhibit very rich and interesting complementarities, which should be promoted by combining their measurements.
2. **Strengthen efforts involving theorists and experimentalists towards a global interpretation of data**, taking advantage of the forth coming various and precise data from all experiments at different energies and correlating them. A forum like the GDR QCD should be fully exploited to this end. Moreover, the establishment of a centralized platform, providing various model predictions in a complete manner, as already done in particle and cosmic ray physics, would be highly valuable.
3. **Organize the strategic choices to be made for QGP studies after LHC Run 3**. Given the size of the French community, and the beginning of the EIC program in the US, strategic orientations should be based on long-term perspectives, well-identified French collaborations and comprehensive studies of the ALICE, CMS and LHCb upgrade-related physics gain. For instance, a comprehensive comparison between the physics gain of the already upgraded CMS experiment (including low-field configuration) and the ANGHIE project should be performed. Key-decision points for these strategic choices should be planned on timescales compatible with LHC pre-Run 4 and pre-Run 5 installations.
4. **Support the scientific production at GSI/FAIR in the baryon-rich sector, and develop prospective activities along new connections to astrophysics**, in light of the world-wide development of new projects and the recent detection of gravitational waves. In addition to the participation to the HADES/CBM project at SIS100, interests for Na60+/CERN and J-PARC-HI have been expressed, which demonstrate, together with the developing theoretical activity in France in the field, that a new dynamics is growing in this sector. The objective in the next years should be to gather a critical mass of physicists and to elaborate a common project, taking into account investments already made. A research program should be developed in close connection with the astrophysics community interested in the equation of state of the dense hadronic matter.
5. **Strongly support theoretical activities on QGP which are are closely related to the experimental programs in France**, in particular covering open and hidden heavy flavor, effective theories of the QCD phases, the hydrodynamic evolution of quark matter, and their implementation in Monte Carlo event generators.

SIMP: Science Drivers SD2, SD3 & SD4

ALICE ITS3

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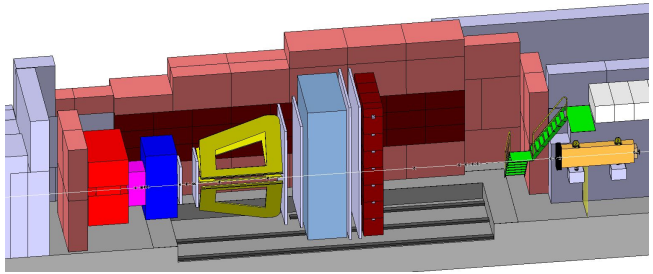
ALICE 3

NA60+



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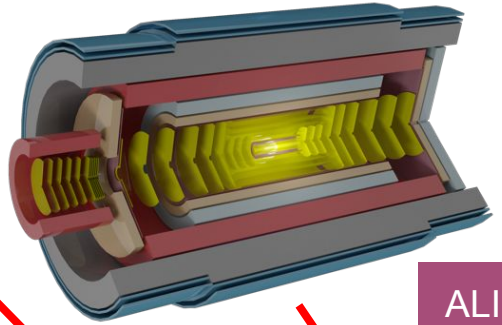

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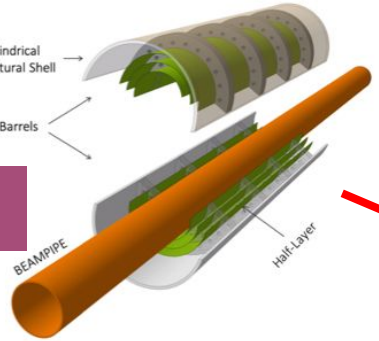
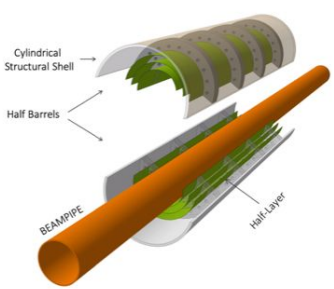
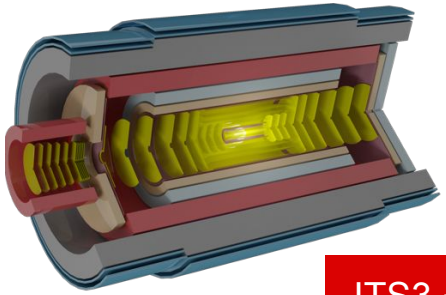


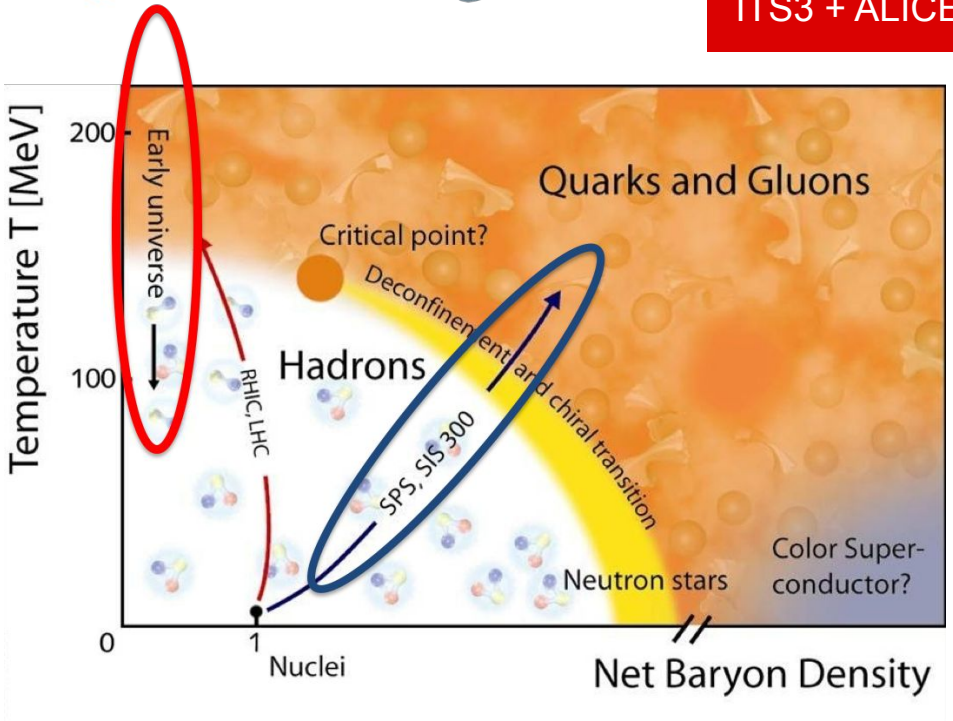
ALICE ITS3





ITS3 + ALICE 3

The high-energy frontier: large and long-living QGP, large cross-sections for hard probes. Vanishing net baryon density: Early Universe conditions



The low-energy frontier: focus on the energy scan, search of the critical point and characterization of the phase transition

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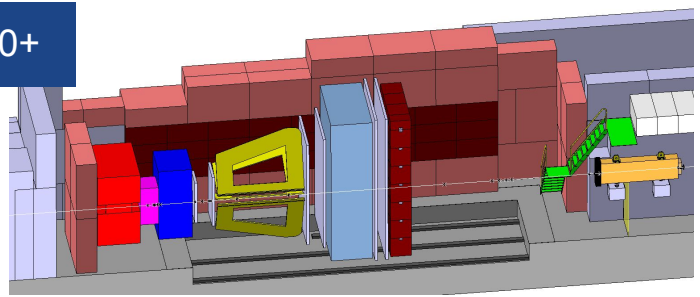

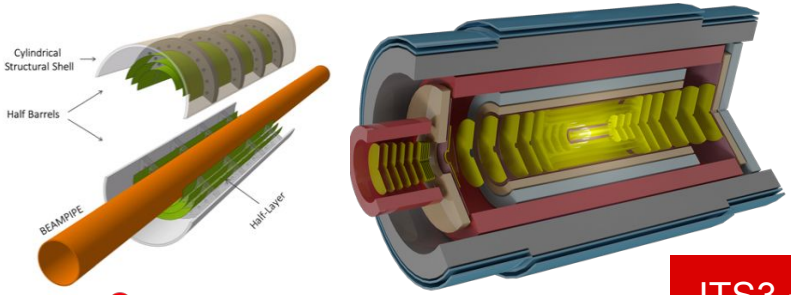

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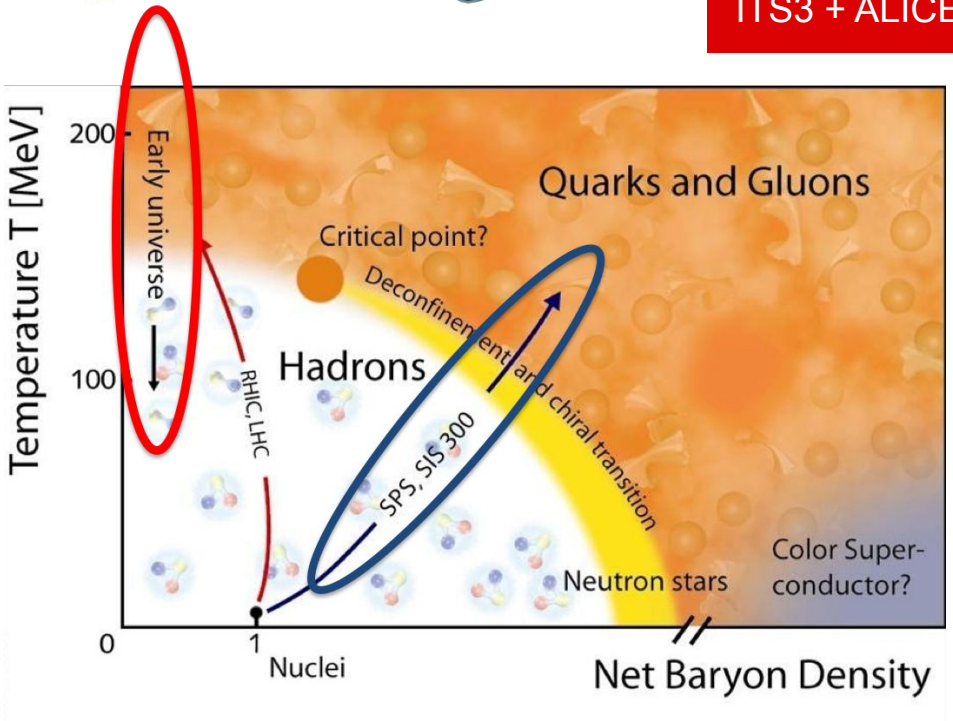


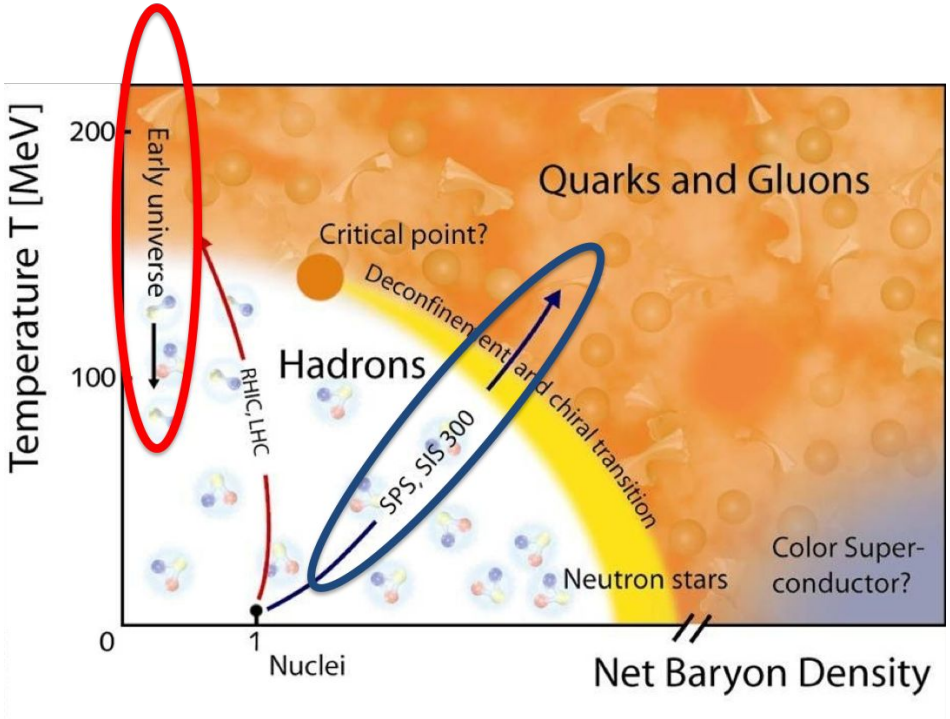
The high-energy frontier: large and long-living QGP, large cross-sections for hard probes. Vanishing net baryon density: Early Universe conditions

Key questions:

- How do heavy quarks propagate, lose energy and hadronize in the QGP?
- What are the limits of the applicability of hydrodynamics to the evolution of a QGP volume?
- How collective effects in small collisions systems should be interpreted?

Key questions:

- Which are the conditions for the onset of a QGP phase?
- Is there a critical point in the region of the QCD phase diagram beyond the crossover characterizing the transition at vanishing net baryonic density?



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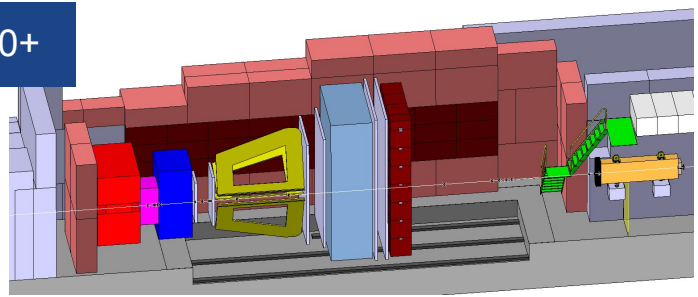
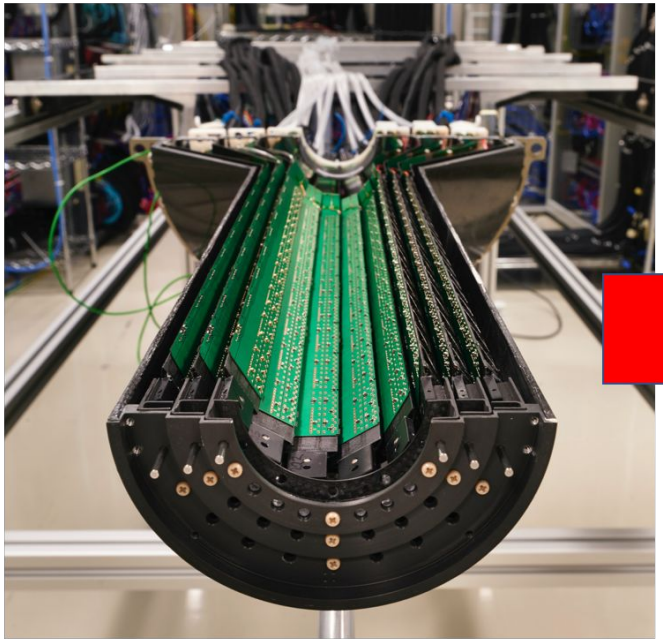


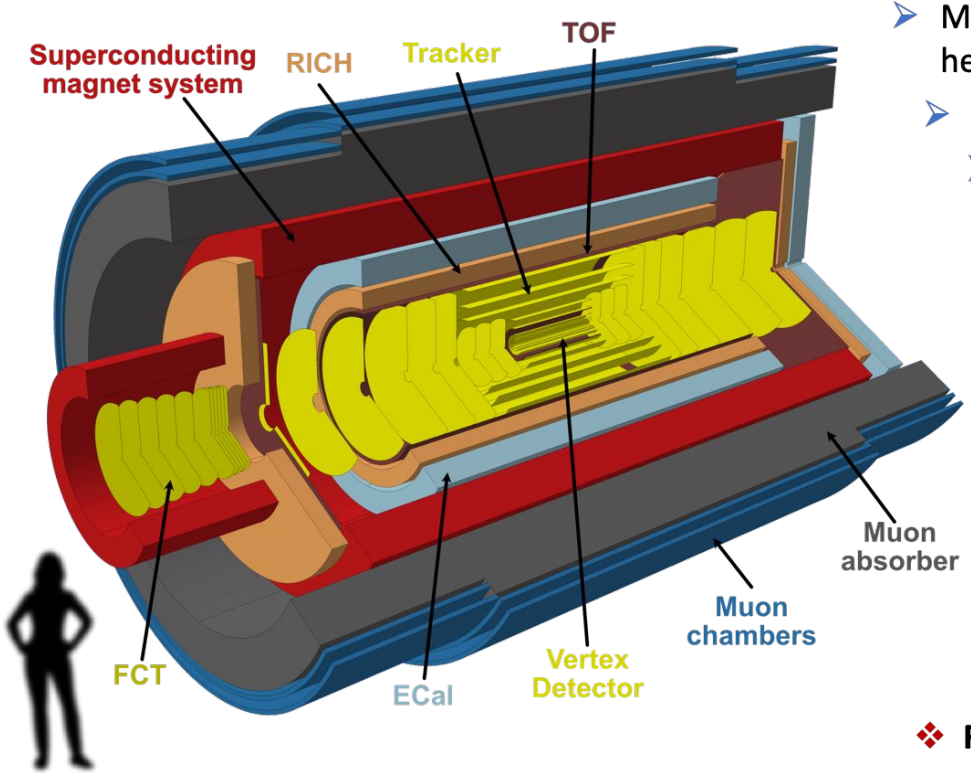
Bridging ALICE 2 to ALICE 3: the ITS3 Project

ITS3: replacing the 3 innermost layers of the Inner Tracking System with a next-generation vertex detector based on truly cylindrical layers (bent, wafer-scale CMOS sensors)



TDR planned for mid 2023

ALICE 3: a new experiment for Run 5 and beyond

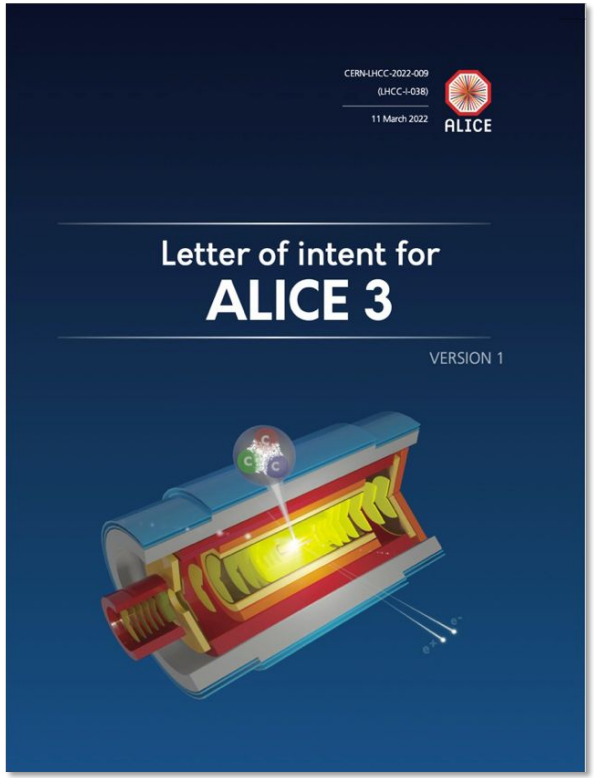


Selected physics case (CERN-LHCC-2022-009):

- Microscopic mechanisms of in-medium energy loss of heavy quarks
- HF hadronization mechanisms
- Non-conventional hadronic structures
- Dilepton production: temperature of the QGP and pre-equilibrium phase
- Ultra-soft photons, BSM searches, …

- **Compact and ultra-light all-silicon tracker with large acceptance and high-resolution vertex detector**
- **Superconducting magnet system**
- **Particle identification down to vanishing p_T over 8 units of pseudorapidity**
- **Fast readout and online processing**

ALICE 3: Costs and Planning



- **2023-25**: selection of technologies, small-scale proof of concept prototypes (≈ 25% of R&D funds)
- **2026-27**: large-scale engineered prototypes (≈ 75% of R&D funds) → Technical Design Reports
- **2028-31**: construction and testing
- **2032**: contingency
- **2033-34**: Preparation of the cavern and installation of ALICE 3

CERN-LHCC-2022-009

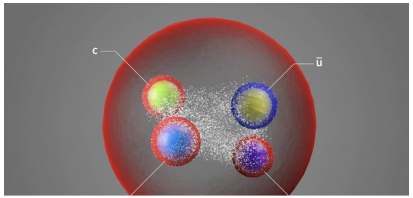
Physique-hadronique-théorie@IP2I.IN2P3.fr

Grande synergie théorie-expérience-observation

Compréhension du diagramme de phase QCD - transition de phase hadrons-QGP, liens avec expériences et astrophysique (étoiles à neutrons, ondes gravitationnelles)

Description de l'interaction forte entre les hadrons (brisure de la symétrie chirale, effet de la sous-structure en quarks pour la physique nucléaire, tétra-quarks, …)

Interaction neutrinos-hadrons et neutrinos-noyaux :
DUNE, neutrinos supernovae/kilonovae, …



LHCb découvre un tetraquark prédit il y a près de 40 ans par Jean-Marc Richard et ses collaborateurs

Project \ Science Driver	project scale	interest in FR	SD1	SD2			SD3			SD4		
			a) proton mass	a) quark content	b) gluon content	c) saturation	a) nature of QGP	b) collectivity	c) chiral symmetry	a) phase transition	b) critical point	c) hadronic matter
Structure of the nucleon												
JLAB	€€	★	***	***	*	-	-	-	-	-	-	-
EIC	€€	★★	**	*	***	***	-	*	-	-	-	-
Matter at high temperature												
ALICE	€€	★★★	-	-	**	**	***	***	*	*	-	*
FOCAL@ALICE	€	☆	-	-	**	**	-	-	-	*	-	*
FT@ALICE	<€	☆	-	**	**	-	**	**	**	**	*	*
ITS3@ALICE	€	★	-	-	-	**	***	***	*	*	-	*
ANGHIE	€€	★	-	-	**	**	***	***	*	*	-	*
†CMS	€€€	☆	-	-	**	**	***	***	*	*	-	*
†LHCb Ia+SMOG2	€€	☆	-	**	**	**	*	*	**	**	*	*
†LHCb Ib	€	★	-	**	**	**	**	**	**	**	*	*
†LHCb II	€€	★	-	**	**	**	***	***	**	**	*	*
Baryon-rich matter												
HADES@SIS18	€	☆	-	-	-	-	-	*	-	**	**	***
HADES/CBM	€	☆	-	-	-	-	*	**	**	***	***	***
NA60+	€	☆	-	-	-	-	**	*	***	***	***	***
J-PARC-HI	€	☆	-	-	-	-	*	**	**	***	***	***

Table 1: Summary of the projects discussed within GT03 and of their impact on the four main science drivers SD1 to SD4, declined along a few specific lines of interest (see text). The scale of the project is a rough indication of the construction cost (material only) of the whole experiment (but not the facility),. The interest (or participation for current projects) in France is indicated in the same manner. Projects tagged with a † have a wider physics scope than what is covered by GT03, the mentioned project scale refers to the whole project while the mentioned interest refers only to GT03 activities.