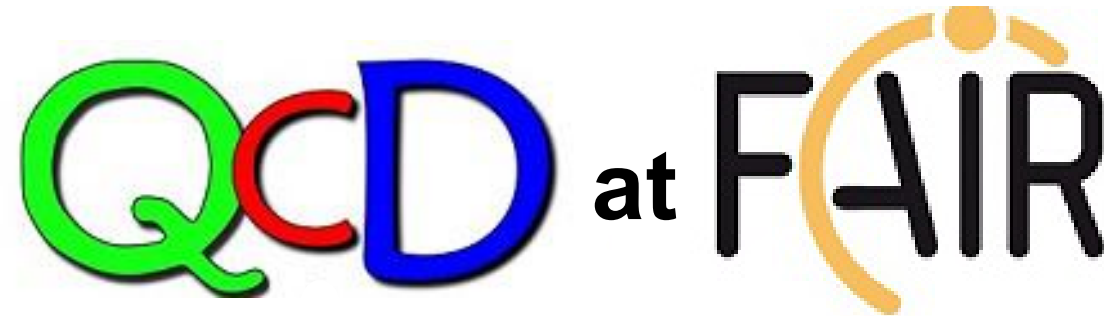


“QCD at FAIR” Symposium 2025 – Opening & brief introduction

EMMI Collaboration Meeting: „QCD at FAIR“ Workshop – Physics perspectives
with hadron beams for the next decade (“First Science”+)

Frank Nerling, and
HFHF, GU Frankfurt & GSI Darmstadt
Johan Messchendorp
FFN, GSI Darmstadt



On behalf of the Organisation Committees:

J. Messchendorp, F. Nerling, J. Ritman

A. Pilloni, I. Vidana, and B. Hadzimehmedovic

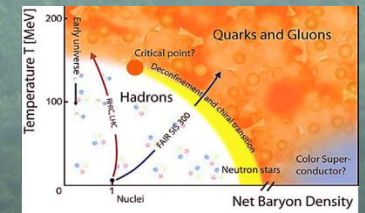
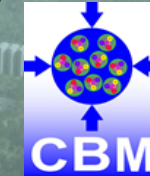
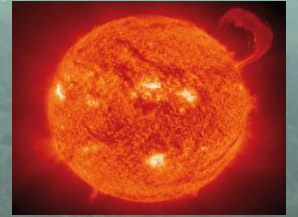




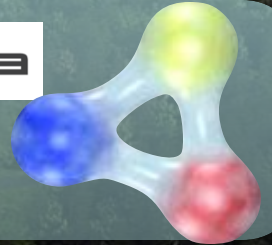
FAIR – The Facility to study QCD



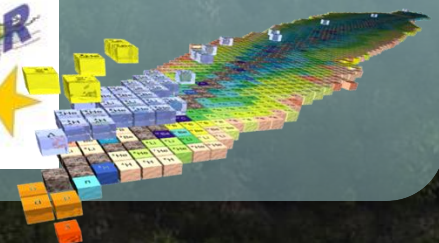
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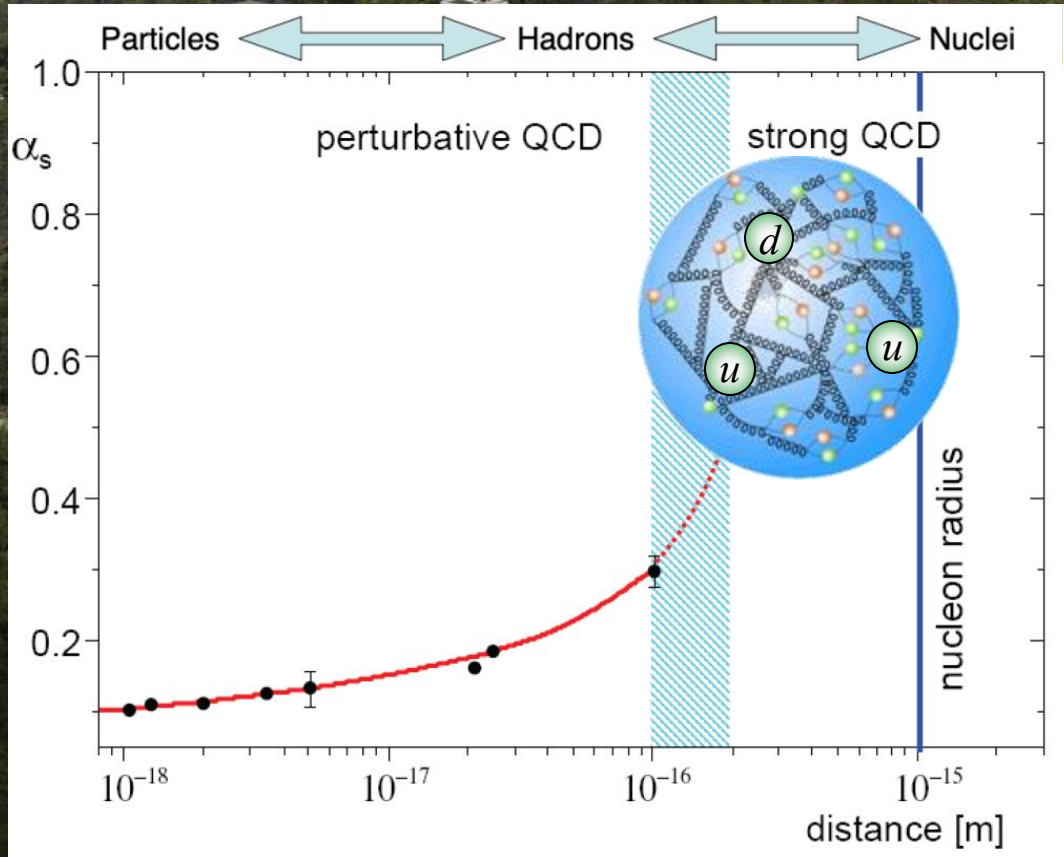
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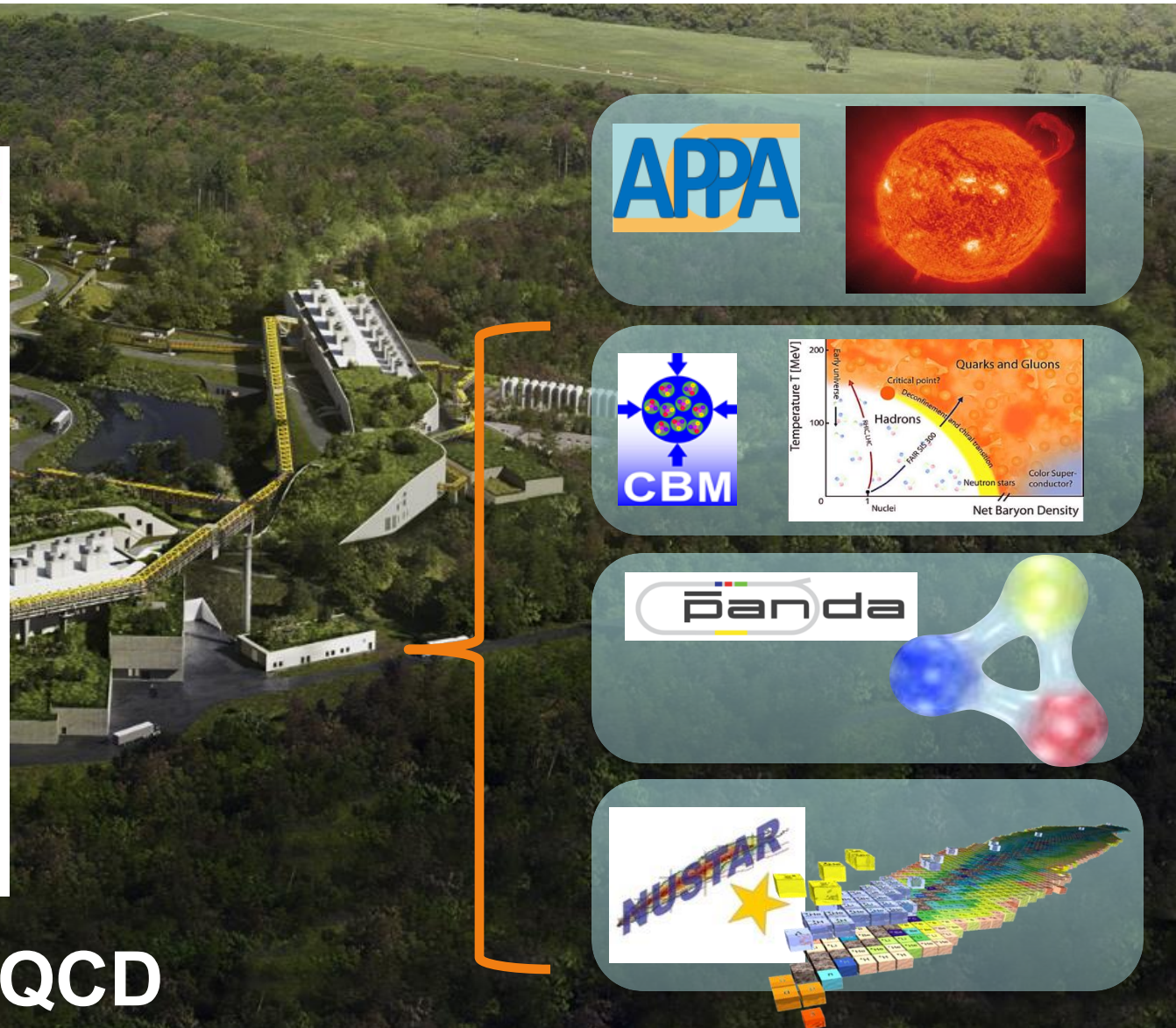
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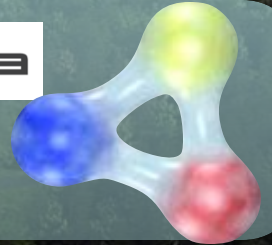
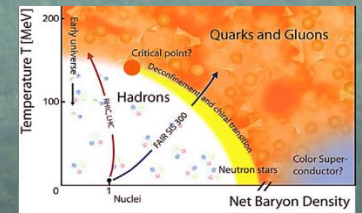
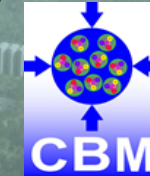
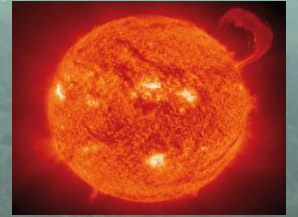
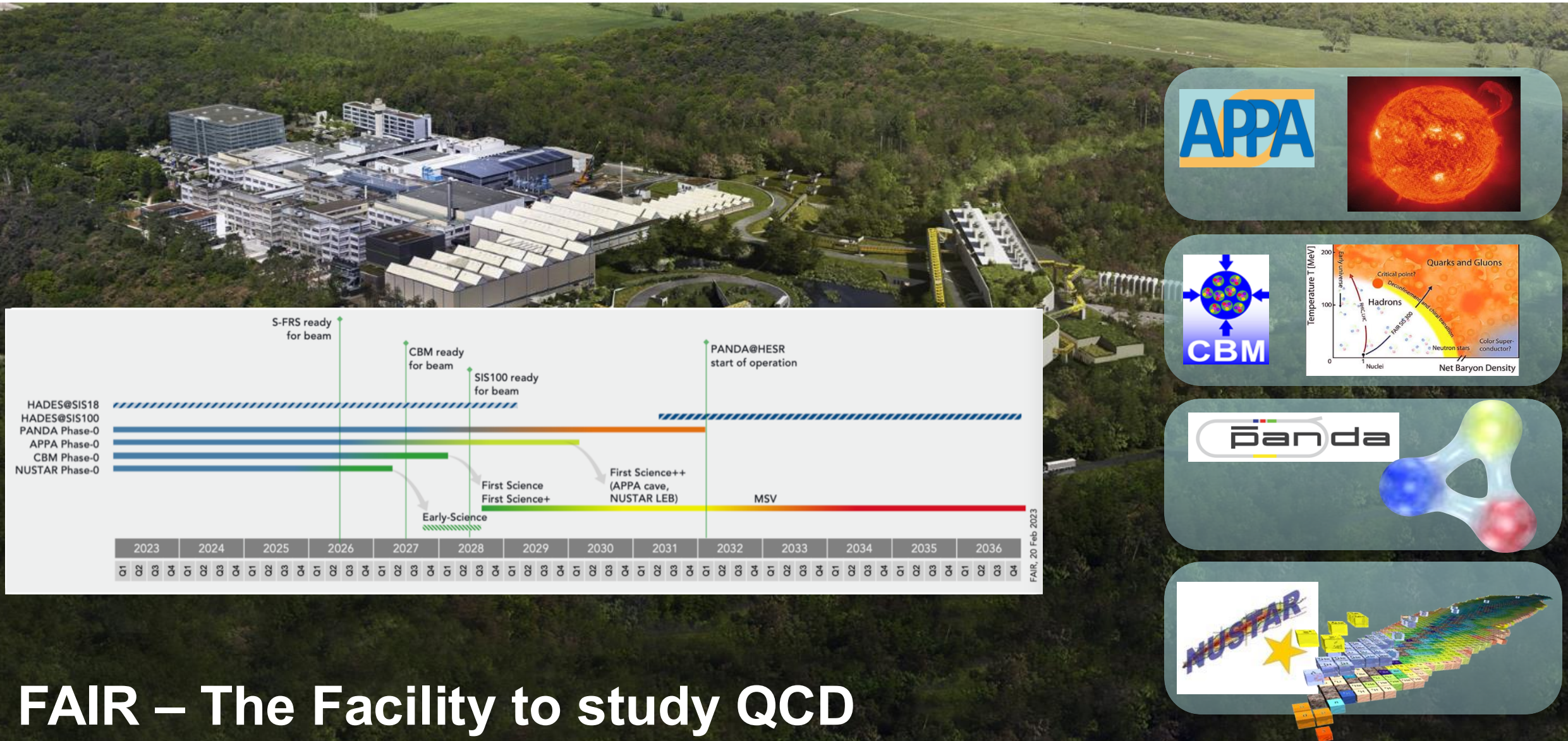


FAIR – The Facility to study QCD

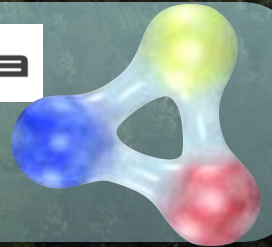
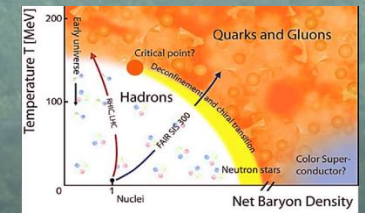
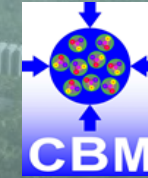
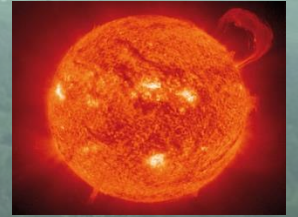


FAIR – The Facility to study QCD





FAIR – The Facility to study QCD

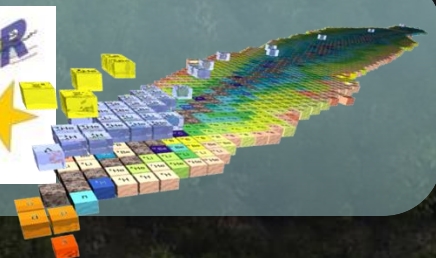
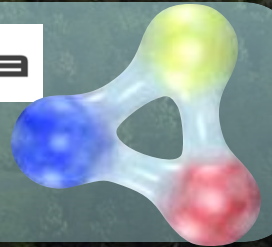
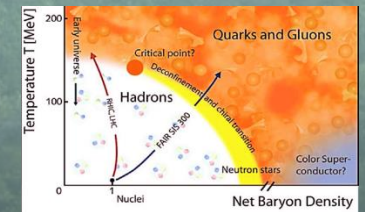
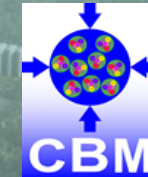
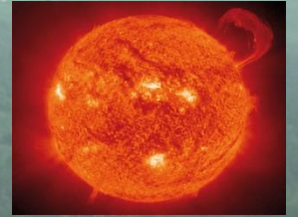


Hadron Physics Facilities at FAIR



Overcome and bridge delay:

→ *Cross-community strong QCD- driven
Hadron Physics program at GSI/FAIR*



Hadron Physics Facilities at FAIR

Heavy-ion physics:

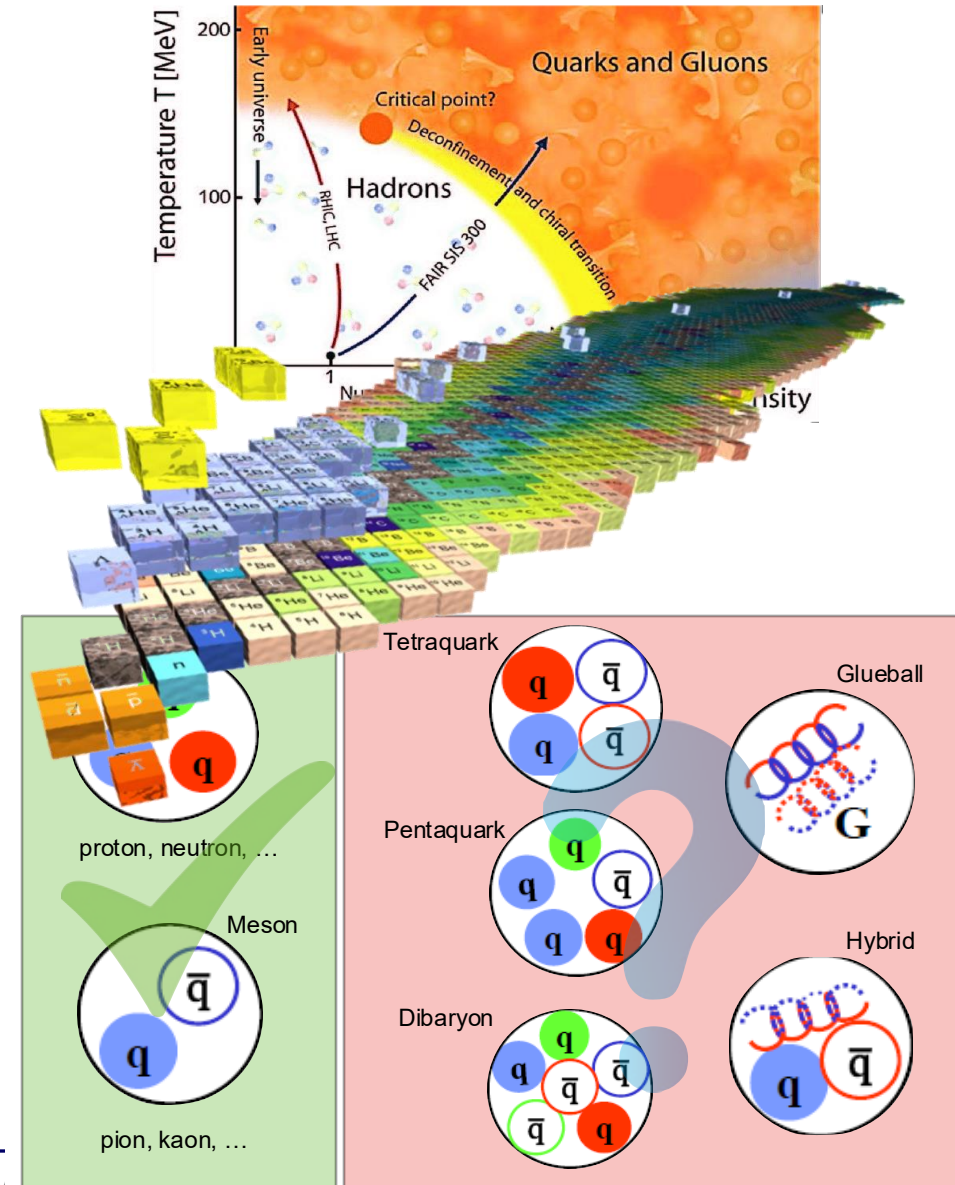
- Exploring **dense QCD** matter
- Probe strongly-interacting **many-body** systems
- Hadrons as **probes** of the **medium**
- Properties of **hadrons** in a **dense environment**

Nuclear physics:

- Map out the **nuclear spectrum** in **isospin** and **strangeness**
- Properties of **nuclei** at the **edge of stability**, e.g. *neutron-rich*
- Probe **baryon/meson** degrees-of-freedom in **many-body** systems

Hadron physics:

- Map out the **hadron spectrum**
- Search for “**exotic**” forms of **hadrons**
- “Microscopic” study of **hadron-hadron** interactions



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Hadron interactions:
Reference for understanding medium effects

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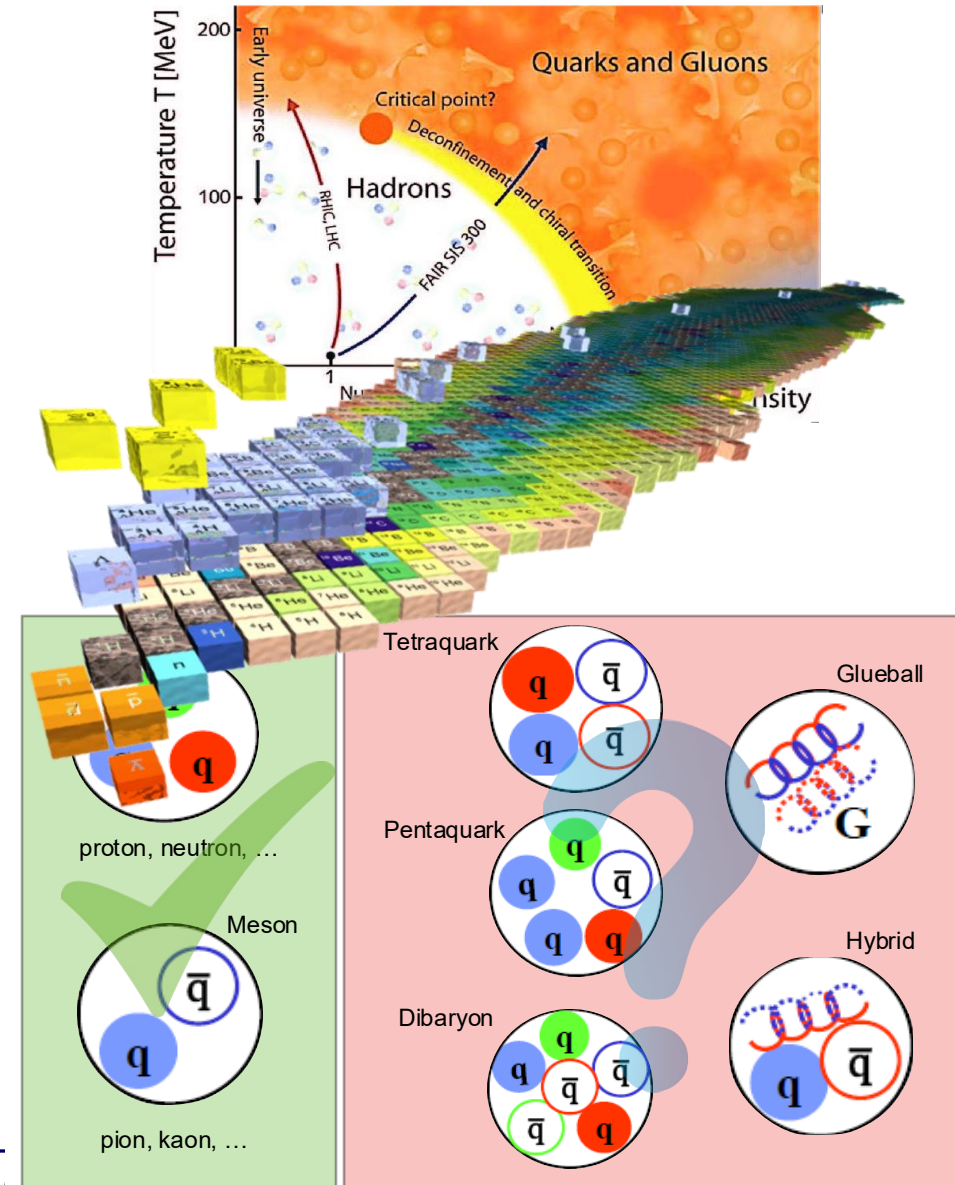
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Provide baryon-baryon data in flavour SU(3)

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Enable spectroscopy of (new) hadronic matter



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Nuclear physics:

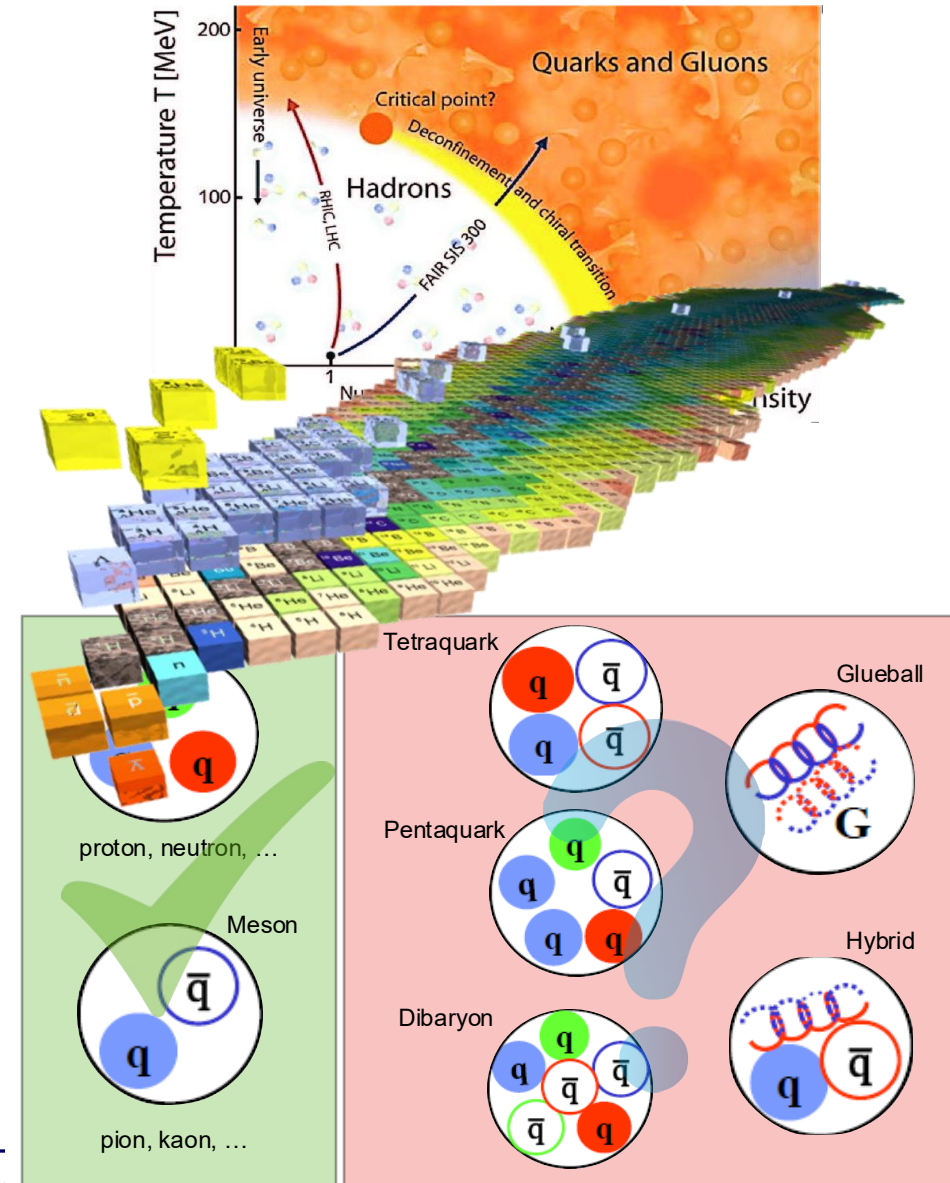
- Map out the **nuclear landscape** in **isospin** and **strangeness**
- ... including interdisciplinary connections to astrophysics
- "The Universe in the Lab"

Hadron interactions:
Provide baryon-baryon data in flavour SU(3)

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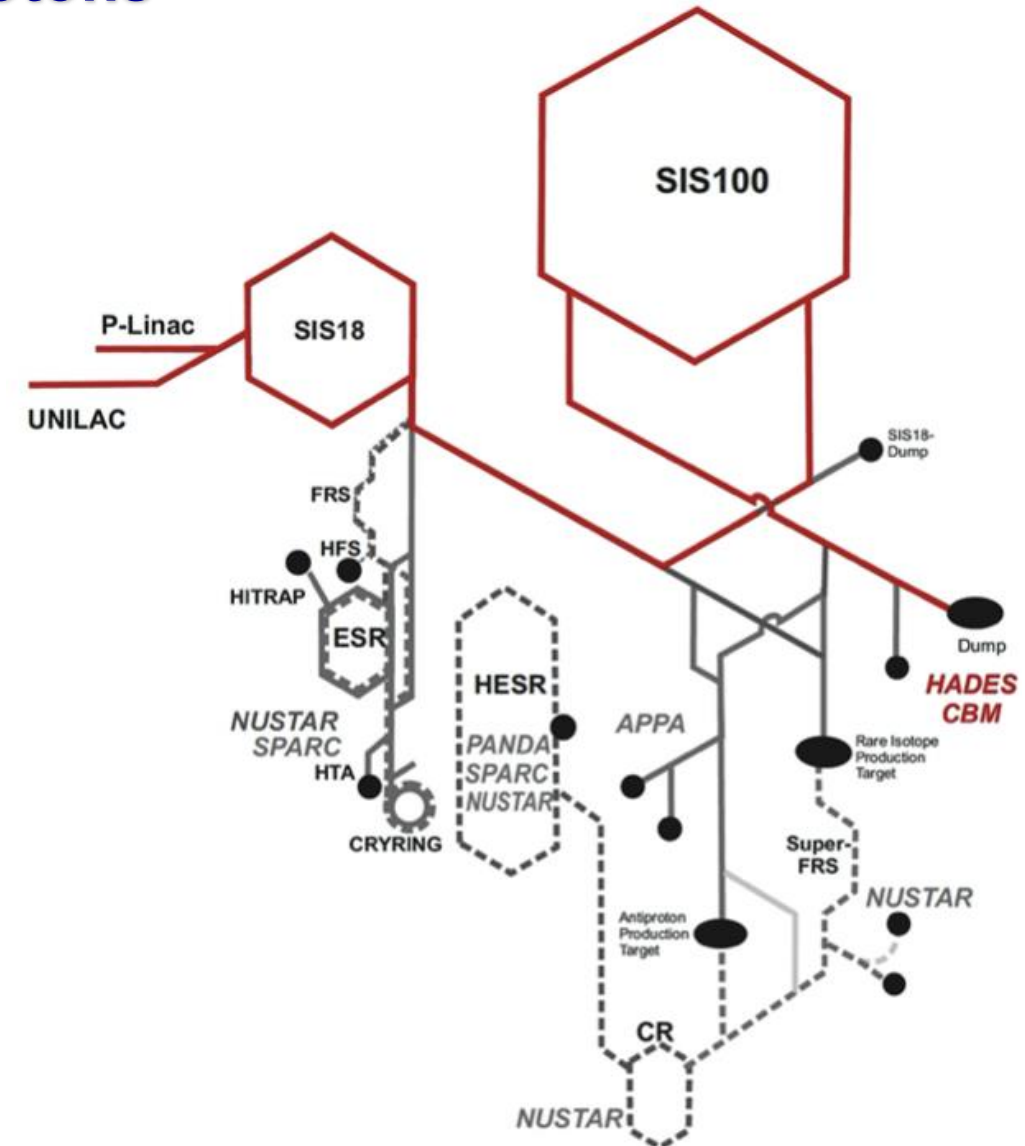
From SIS18 to SIS100 – Hadron physics with pions and protons

Energy upgrade:

- From max 4.7 GeV (SIS18) to 29 GeV (SIS100)
proton energy: $\sqrt{s_{NN}} \approx 3.5 \text{ GeV} \rightarrow 7.6 \text{ GeV}$
- Opening new realm: double & triple strangeness and even charm baryons and mesons!
- Significant increase in production yield of hyperons

Intensity upgrade:

- From max protons/cycle of 10^{12} (SIS18) to 2×10^{13} (SIS100)
- Even during “commissioning” (10^{10} protons/cycle) and 5 cm LH2 target: $\sim 10 \text{ pb}^{-1} \text{ day}^{-1}$



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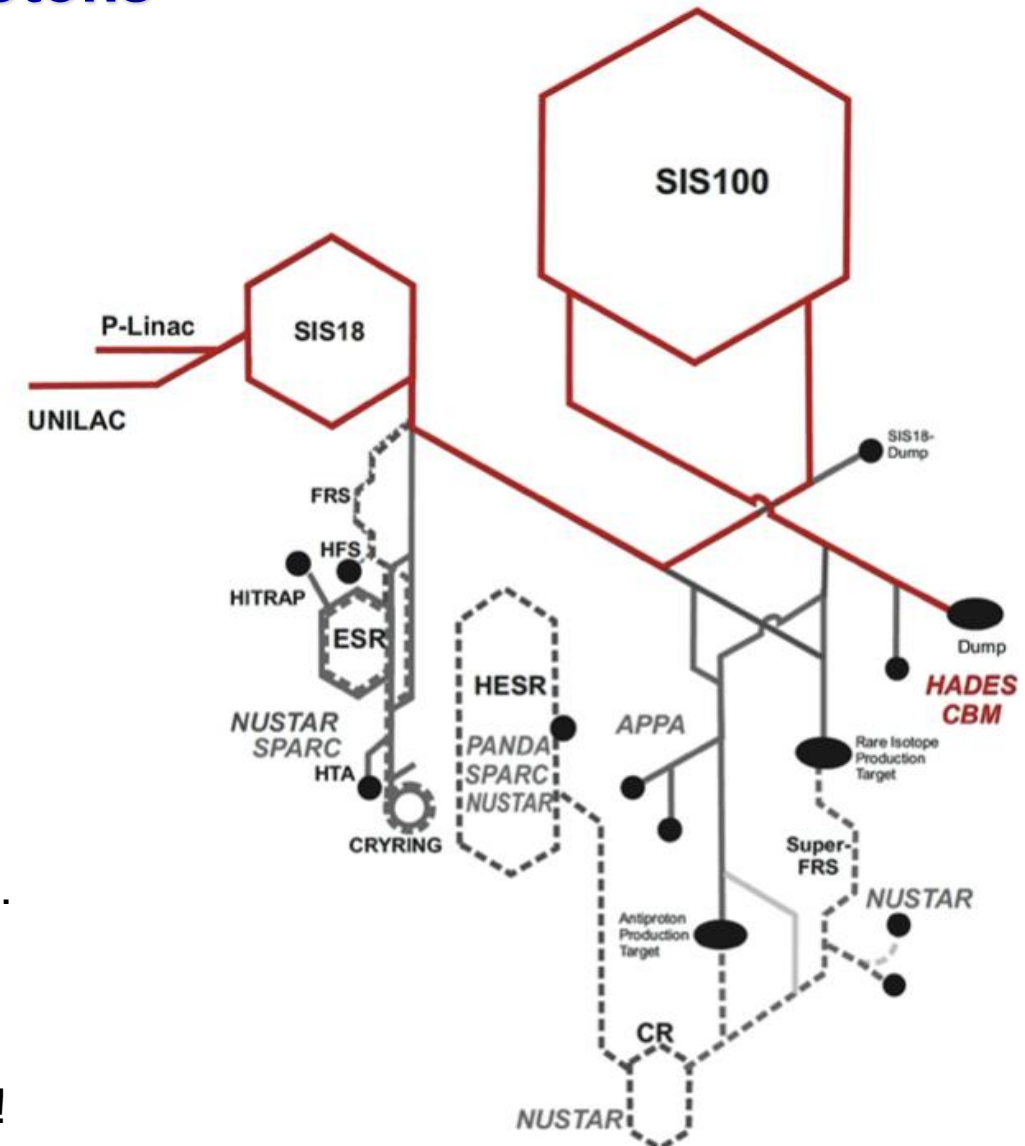
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Detector enrichment:

- Towards **high-rate capabilities** and free-streaming DAQ's etc.

Theory enrichment:

- Terra **incognita**: intellectual challenges in this energy regime!



After a series of workshops ...

One-day satellite workshop prior to the MESON2023 conference in Cracow, June 21th, 2023.

Physics opportunities with proton beams at SIS100

Wednesday Jun 21, 2023, 9:00 AM → 11:00 PM Europe/Berlin



Four-days workshop in Wuppertal, Feb 6-9th, 2024

Physics opportunities with proton beams at SIS100

6-9 February 2024
Wuppertal University
Europe/Berlin timezone

<https://indico.gsi.de/event/18475>

Overview

Timetable

Registration

Participant List

Venue details

Accommodation

Workshop fee

Payment details

Purpose of this workshop is to bring together experts working in the field of proton induced interactions, and to explore possibilities for exciting physics at the SIS100 accelerator at FAIR.

This workshop is a follow-up of a kick-off event that was held in June 2023 connected to the MESON2023 conference. For further details including an executive summary and slides that were presented, we refer to <https://indico.gsi.de/event/17693>.



CBM / HADES cave 2023



Frank Nerling
James Ritman
Johan Messchendorp
Karl-Heinz Kampert
Piotr Salabura
Tetyana Galatyuk



Physics opportunities with proton beams at SIS100

6-9 February 2024
Wuppertal University
Europe/Berlin timezone



Physics opportunities with ~~proton~~ beams at ~~SIS100~~ p, d, π GSI/FAIR

6-9 February 2024
Wuppertal University
Europe/Berlin timezone



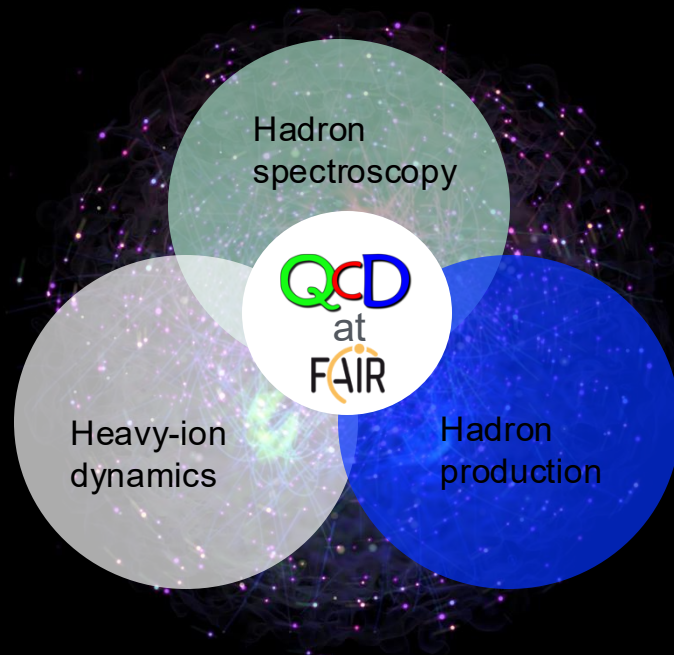


QCD at FAIR Workshop 2024

Nov 11 – 14, 2024

GSI Helmholtzzentrum für Schwerionenforschung GmbH

Europe's Future Accelerator



White Paper

Purpose:

- Involve hadron, nuclear and heavy-ion (QCD) communities
- Develop hadron physics program for next decade at GSI/FAIR

Preparatory workshops

- Cracow, June 21, 2023
- Wuppertal, February 6-9, 2024
- GSI, November 11-14, 2024
- Italy, June, one week, 2025

Eds.: Johan Messchendorp & Frank Nerling



White Paper:

- Paper under production
- ~100 contributors
- Including leading theorists & experimentalist from strong-QCD communities
- ~130 pages
- Publication ~ autumn 2025

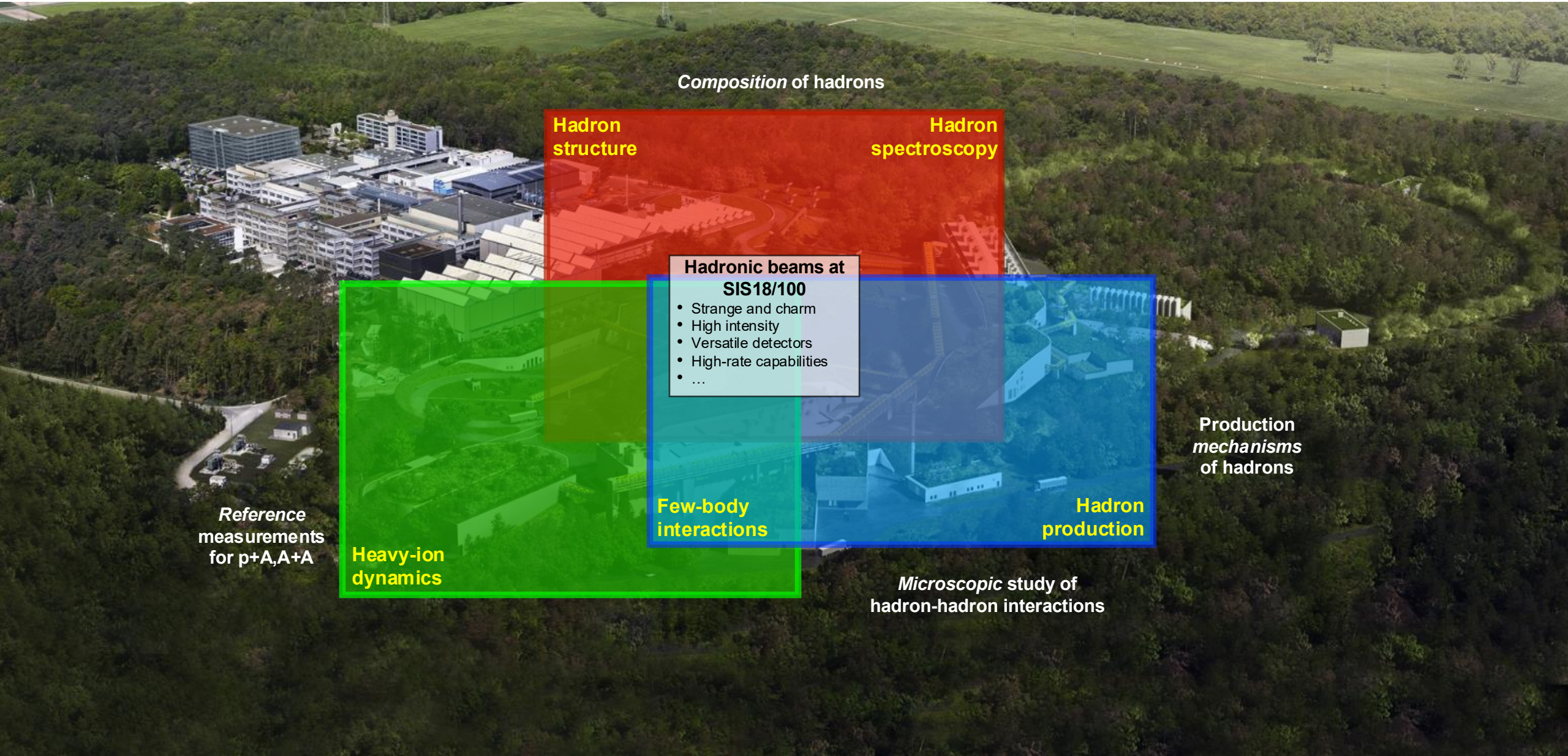
Hadron Physics at GSI/FAIR:
=> Prospects for next decade

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Composition of hadrons

**Hadron
structure**

**Hadron
spectroscopy**

**Hadronic beams at
SIS18/100**

- Strange and charm
- High intensity
- Versatile detectors
- High-rate capabilities
- ...

*Production
mechanisms
of hadrons*

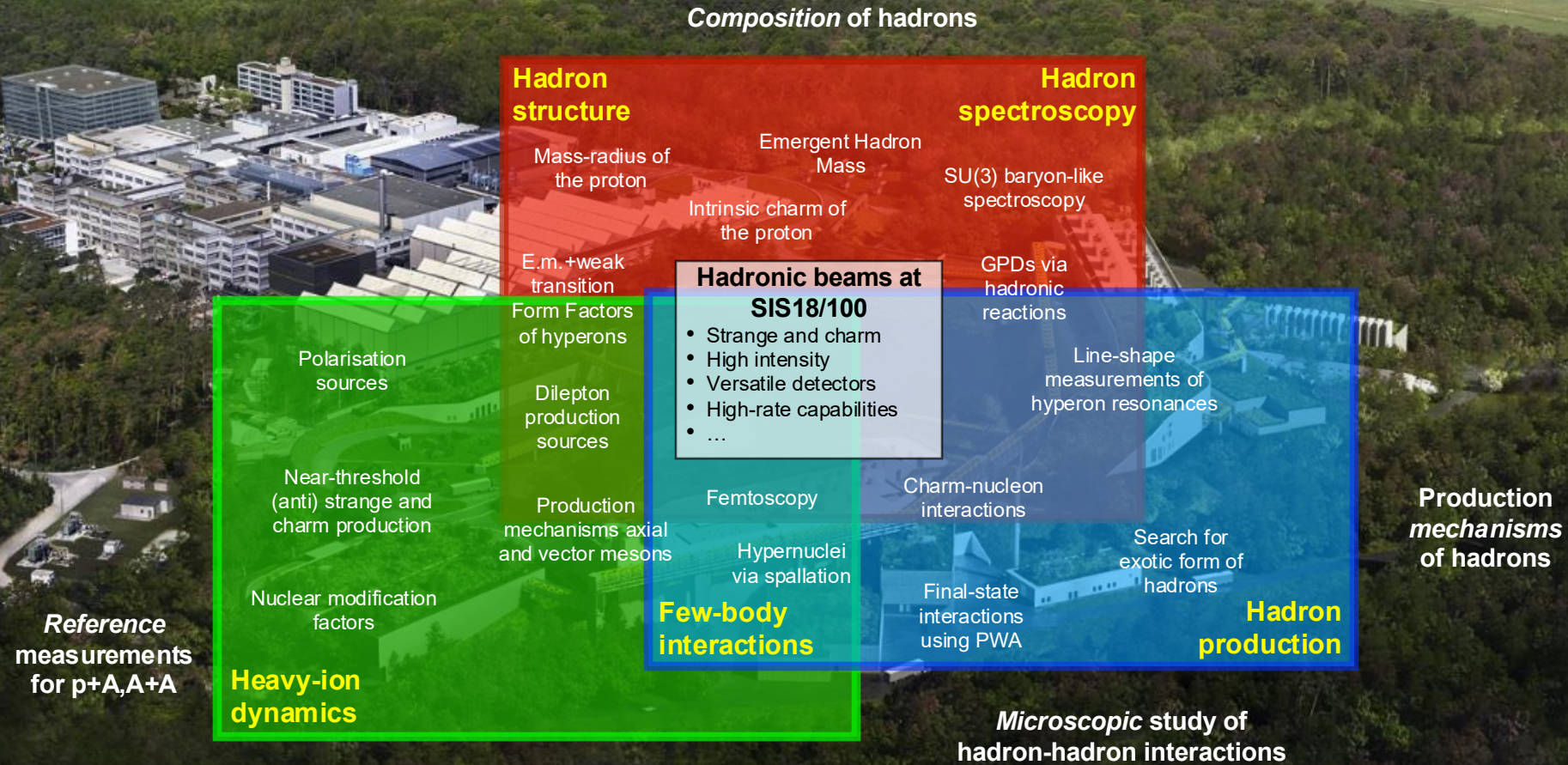
*Reference
measurements
for p+A,A+A*

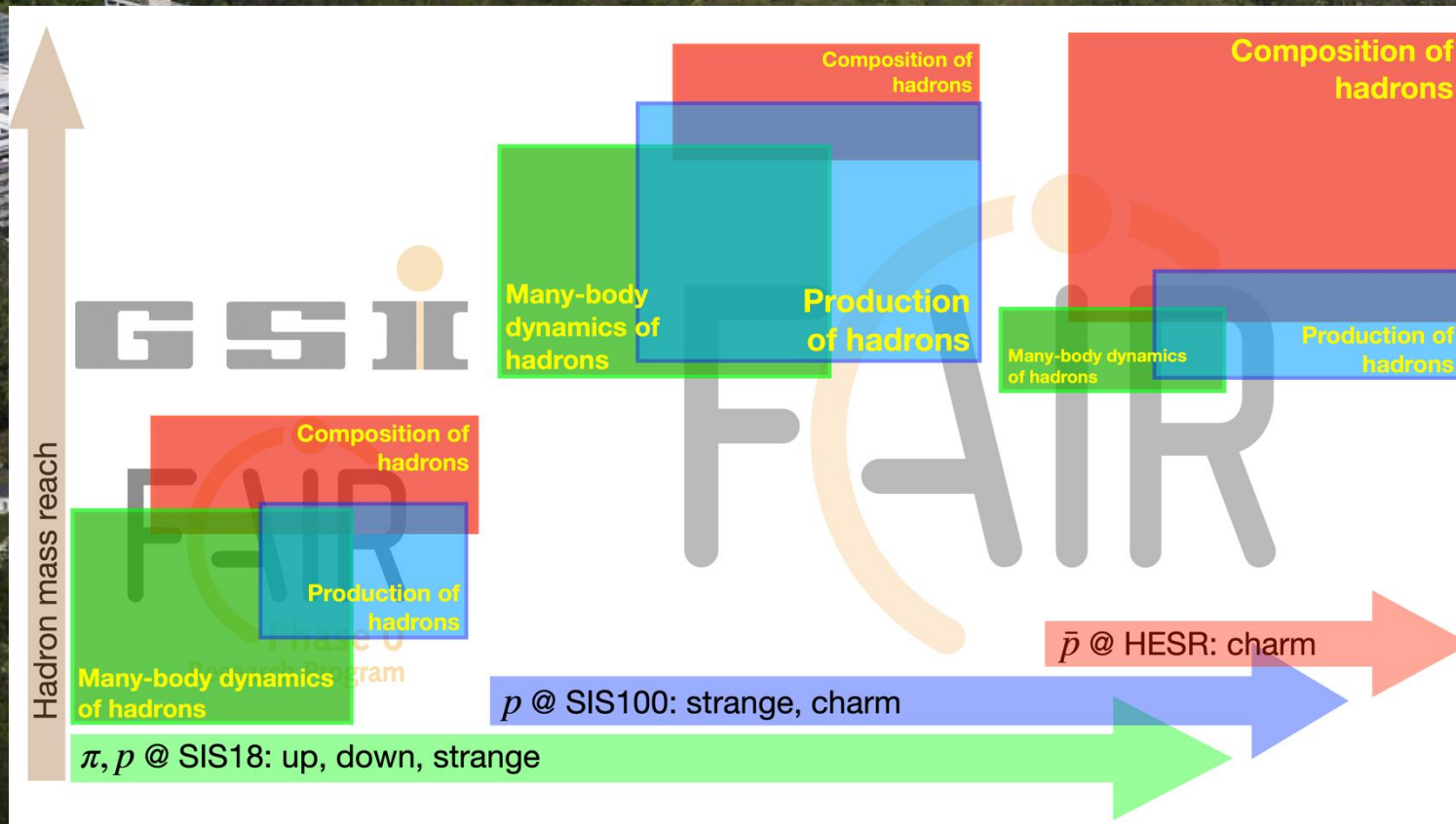
**Heavy-ion
dynamics**

**Few-body
interactions**

**Hadron
production**

*Microscopic study of
hadron-hadron interactions*





Nuclear Physics News

Volume 35/No. 1



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facilities and methods

A Cross-Community-Driven Hadron Physics Program at GSI/FAIR

Strong-Quantum Chromodynamics (QCD) Research at the Facility for Antiproton and Ion Research (FAIR): "QCD at FAIR"

The strong interactions in the Standard Model of particle physics are described by QCD, a gauge theory based on the non-Abelian symmetry group known as color-SU(3). Among the remarkable phenomena arising from QCD are color confinement and the generation of hadronic mass, both linked to the self-interaction of gluons, the carriers of the strong force. Experimental approaches aim to deepen our understanding of QCD, focusing on uncovering the fundamental degrees of freedom that determine the formation and properties of matter across different conditions and scales.

A key focus of research at the Helmholtzzentrum für Schwerionenforschung GSI and FAIR accelerator complex in Darmstadt, Germany, is exploring QCD phenomena through the study of matter under extreme

conditions. The Compressed Baryonic Matter (CBM) will examine fundamental properties of dense, baryon-rich systems that play an important role in understanding the physics of the interior of neutron stars and their mergers [1]. Complementarily, the nuclear physics community investigates nuclei at the limits of stability, focusing on extreme isospins and the inclusion of strangeness, such as in hypernuclei [2]. The hadron physics community maps the meson and baryon spectrum, searches for exotic hadronic states, and studies the processes behind matter formation [3]. At GSI/FAIR, the aim is to integrate these approaches to deepen our understanding of nonperturbative QCD ("strong QCD"), as shown in Figure 1.

The Facilities

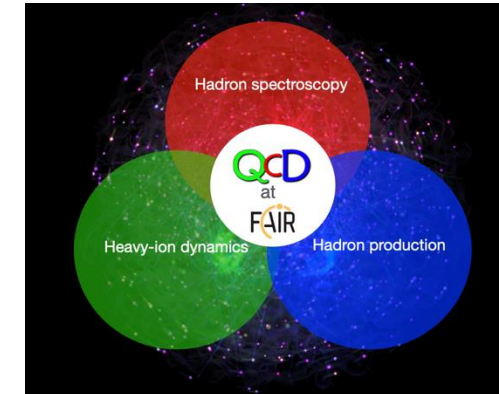
The goal of "QCD at FAIR" is to exploit synergies between the hadron, nuclear, and heavy-ion physics

communities at GSI/FAIR to address key QCD questions using advanced detectors and beams. The facility enables studies of matter from the light-quark (up, down, strange) sector, accessible at GSI, to charm-quark matter with the future SIS100 accelerator. With unprecedented beam intensities, high-acceptance detectors, and free-streaming data processing, FAIR will enable precision studies in strong QCD.

The existing SIS18 accelerator at GSI provides proton and heavy-ion beams with center-of-mass energies of up to about $\sqrt{s} = 3.5$ GeV in the NN system. Moreover, pion beams are available reaching $\sqrt{s} = 2$ GeV in the πN system with reasonable intensities. The High Acceptance Dilepton Spectrometer (HADES) [4] has been in operation at SIS18 for more than 20 years, addressing a rich heavy-ion related physics program and also dedicated open questions and topics in hadron physics, especially employing the available pion beam (see, e.g., Ref. [5]).

A central part of the future FAIR presently under construction at the GSI site will be the SIS100 accelerator providing proton and heavy ion beams to access center-of-mass energies of up to about $\sqrt{s} = 7.6$ GeV in the NN system. The versatile multipurpose CBM detector presently under construction will receive beams accelerated by SIS100.

Both experiments, HADES at SIS18 and CBM at SIS100, as well as, for example, the wide-angle shower apparatus at the Fragment Separator [6], allow addressing a wide range of hadron physics questions already before the



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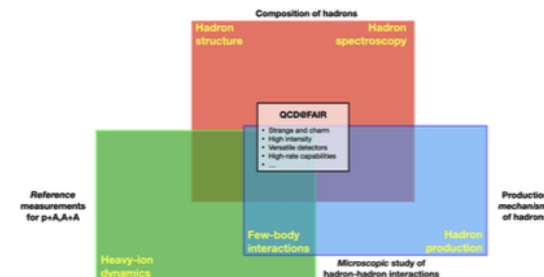


Figure 1. A schematic overview of the QCD-driven research themes to be explored using the proton beams at FAIR, with a particular emphasis on the cross-disciplinary connections between hadron, nuclear, and heavy-ion physics.



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Plus: Conference contributions
→ Presentations and posters at workshops and conferences

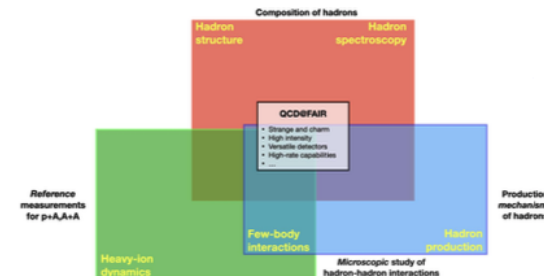


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Toward a White Paper and a Cross-Community-Driven Program

A group of researchers [14] from diverse communities at GSI/FAIR organized several workshops [15–17] to

14. T. Galatyuk, N. Hermann, C. Höhne, K.H. Kampert, J.G. Messchendorp, F. Nerling, J. Ritman, P. Salabura, K. Schönning and J. Stroth.



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Sunday, June 22nd – Friday June 27th



In Summary:

- 45 Participants
- 15 Symposium Talks (open)
- 6 Plenary Sessions (closed)
- 6 Breakout Sessions

Social Events:

- **Come-together** (Sun, evening)
- **Reception** (Mon, evening)
- **Conference Dinner** (Wed, evening)
- **Excursion** (Thu, afternoon)

(all free of charge)





Monday June 23rd

14:00	Opening	Rash Nisim et al.
	Welcome by INFN	Alessia Triossi
	Welcome by INFN	Santo Gamito
	Welcome by INFN	Stefano Romano
	Welcome by UNiMe	Marina Thoma
	Welcome FAIR	Thomas Alkaseh
15:00	Astro(particle) physics	Karl-Heinz Kampert
	Grand Hotel Faraglioni, Sicily /Italy	14:45 - 15:15
	Femtoscopy	Hanna Zarusky
	Grand Hotel Faraglioni, Sicily /Italy	15:15 - 15:45
16:00	"EoS and Compact Stars"	Fiorina Burgio
	Grand Hotel Faraglioni, Sicily /Italy	15:45 - 16:15
17:00	Coffee Break	
	Grand Hotel Faraglioni, Sicily /Italy	16:15 - 16:45
	Hadron spectroscopy at B factories	Alessandro Bocchi
	Grand Hotel Faraglioni, Sicily /Italy	16:45 - 17:15
18:00	"Highlights and recent results from BESIII"	Wolfgang Grad
	Grand Hotel Faraglioni, Sicily /Italy	17:15 - 17:45
	Hyperon structure	Andrei Kupac
	Grand Hotel Faraglioni, Sicily /Italy	17:45 - 18:15
	Tridige	Maxim Ma
	Grand Hotel Faraglioni, Sicily /Italy	18:15 - 18:45
19:00	Reception & Dinner	

Tuesday June 24th

	Hypernuclei	Benjamin Dörmann
	Grand Hotel Faraglioni, Sicily /Italy	08:30 - 09:00
09:00	Meson-nuclei dynamics	Kenta Nakashima
	Grand Hotel Faraglioni, Sicily /Italy	09:00 - 09:30
	Hadron physics at JPARC	Kazuya Aoki
	Grand Hotel Faraglioni, Sicily /Italy	09:30 - 10:00
10:00	Hadronisation studies at CERN	Victor Fouillard
	Grand Hotel Faraglioni, Sicily /Italy	10:00 - 10:30
	Coffee Break	
	Grand Hotel Faraglioni, Sicily /Italy	10:30 - 11:00
11:00	Physics with Kaon Beams	Sean Dobbs
	Grand Hotel Faraglioni, Sicily /Italy	11:00 - 11:30
	JPARC	Daniel Winney
	Grand Hotel Faraglioni, Sicily /Italy	11:30 - 12:00
12:00	"AMBER: A QCD Facility at CERN"	Stefan Diehl
	Grand Hotel Faraglioni, Sicily /Italy	12:00 - 12:30
	"Nucleon structure from Generalized Parton Distributions"	Mutsaers Toshiaki
	Grand Hotel Faraglioni, Sicily /Italy	12:30 - 13:00
13:00	Lunch	
	Grand Hotel Faraglioni, Sicily /Italy	13:00 - 14:00

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- 15 Symposium Talks (open)

This series of workshops is organised for:

- Hadron-driven “QCD” physics at FAIR – a win-win-win situation!
- Heavy-ion physics perspectives:
 - Crucial reference to heavy-ion reactions
 - Detailed information on baryons and meson-baryon couplings
- Nuclear physics perspectives:
 - (Ab-initio) baryon-baryon data in flavour SU(3)
- Hadron physics perspectives:
 - Controllable tool for hadron spectroscopy & structure studies in u,d,s,c sectors
 - Intermediate physics program with pions & protons towards antiprotons

=> Summarising White Paper will be concluded this week

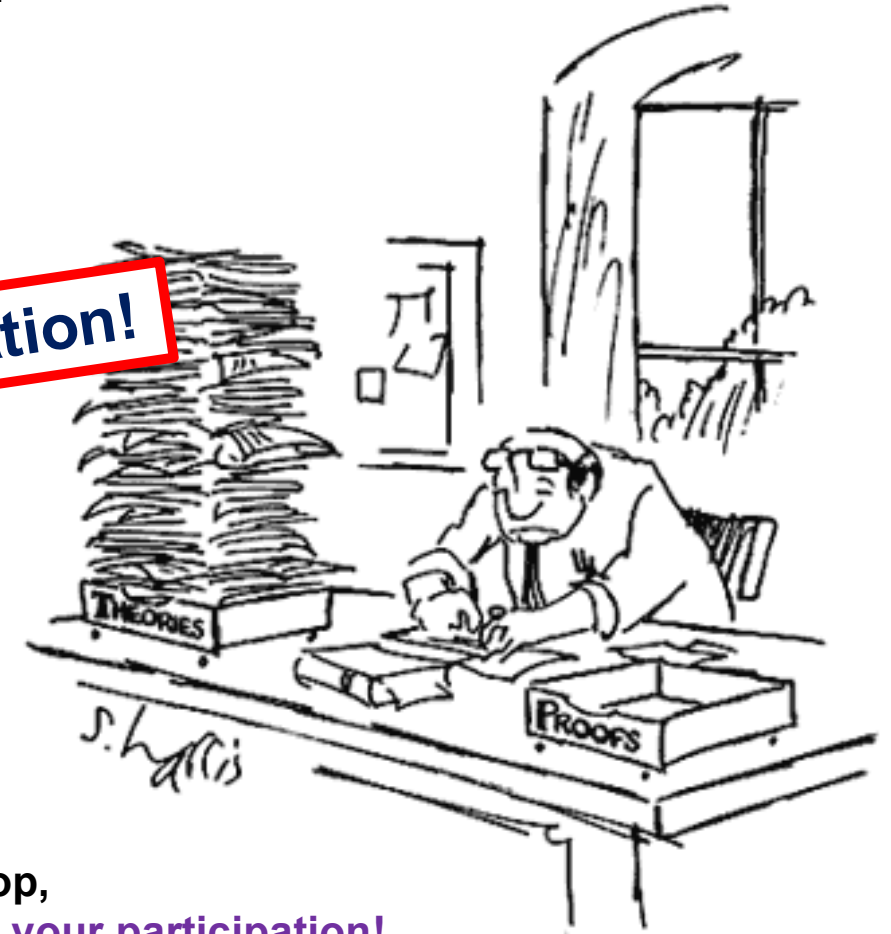
Let me wish us a very interesting symposium to introduce our workshop, with constructive discussions and progress – thank you very much for your participation!



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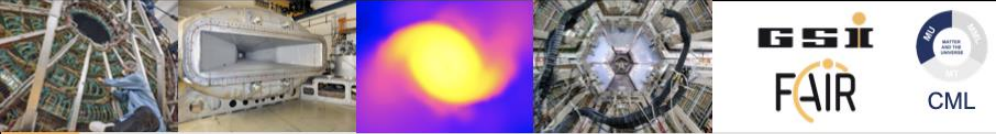
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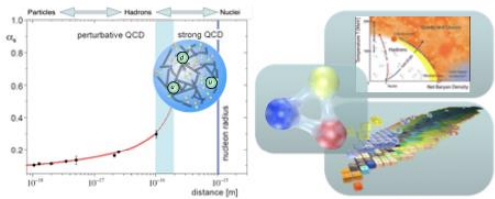
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A Hadron Physics Program – QCD at FAIR

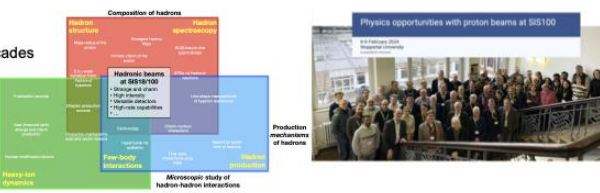
FAIR – The Facility to study QCD

- What is the origin of mass (only ~2% by Higgs)?
- How is QCD matter formed?
- What are the underlying symmetries?
- Degrees of freedom (quarks/gluons vs baryons/mesons)?
- Properties of strongly interacting (baryonic) matter?
- Composition and nature of (exotic) hadrons?
- FAIR: "QCD matter at extremes"



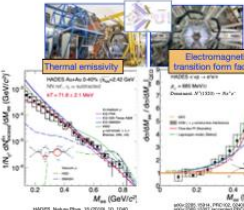
Towards a White Paper

- Develop hadron physics program for next decades
- Form a community involving all "QCD pillars"
- Theory and experiment
- Nearly a hundred people involved
- Series of workshops in 2023-2025:



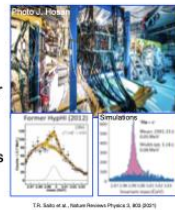
HADES at SIS18

- Diverse beams, incl. p, π
- Up to $\sqrt{s}_{pp} = 3.5 \text{ GeV}$, $\sqrt{s}_{pA} \approx 2 \text{ GeV}$
- E.m. structure of (light) baryons
- Baryon and meson production
- Strangeness formation
- Hyperon-baryon interactions
- SU(3) flavour dynamics!



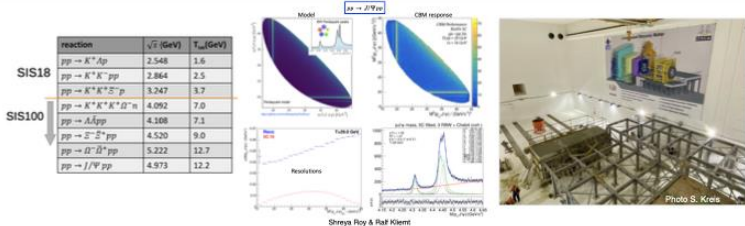
WASA at FRS

- Unique combination
- FRS: Precise forward spectr. & WASA: Large acceptance detector
- Physics topics (among others)
- Hypernuclei: heavy ion beams
- Mesic-nuclei & Baryon resonances
- Inv. mass spectroscopy, analyses with Machine Learning (ongoing)



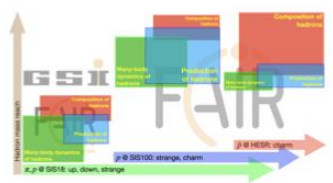
CBM at SIS100

- High-rate capabilities!
- Up to $\sqrt{s}_{pp} = 7.5 \text{ GeV}$
- Multi-strangeness and charm-rich matter!
- Multi-purpose detector
- Hadron & heavy-ion & nuclear physics



Summary & outlook

- Comprehensive hadron physics program identified
- Community from theory and experiment formed
- Synergies & complementary expertises
- ...



... a summarizing White Paper is underway.

Outside Visibility: GSI Centre Evaluation

GSI Helmholtzzentrum für Schwerionenforschung Research Field Matter Evaluation Report

Executive summary

Within the realm of strongly interacting systems, GSI's MU program has gained international recognition due to its exceptional user facilities, instruments, and research focus on multi-body systems. This program has been pivotal in achieving numerous significant research highlights through both internal endeavors and fruitful collaborations worldwide. Nuclear Structure groups study unique properties of exotic nuclei and the physics and chemistry of superheavy elements with very high impact results. A remarkable example of this impact is the nuclear astrophysics program which leverages GSI's unmatched ion and energy accessibility. The coherent combination of the high-rate capacities of HADES and future CBM at low/intermediate energies with ALICE at high energies will provide unprecedented insights into the hot and dense nuclear matter phase diagram. HADES has already mapped a crucial part of this diagram at lower energies, complementing RHIC and LHC data, and its low-energy role becomes even more vital with RHIC's anticipated closure. Due to funding constraints, the comprehensive FAIR project will proceed in stages, with the final phase, encompassing PANDA, currently postponed. Recognizing the significant investment in PANDA detector components, the GSI and HIM groups have made a wise decision to integrate these elements into the FAIR Phase-0 experiments. This strategic move maximizes scientific output from existing resources. The committee strongly supports developing a comprehensive hadronic physics program utilizing the funded FAIR experiments, seeing it as an insightful and promising direction for their developing program.

50 Years of Quantum Chromodynamics

arXiv:2212.11107 (2023)

Franz Gross^{a,1,2}, Eberhard Klempt^{b,3},

Stanley J. Brodsky^{c,4}, Andrzej J. Buras^{c,5}, Volker D. Burkert^{c,1}, Gudrun Heinrich^{c,6}, Karl Jakobs^{c,7}, Curtis A. Meyer^{c,8}, Kostas Orginos^{c,1,2}, Michael Strickland^{c,9}, Johanna Stachel^{c,10}, Giulia Zanderighi^{c,11,12},

Nora Brambilla^{5,12,13}, Peter Braun-Munzinger^{10,14}, Daniel Britzger¹¹, Simon Capstick¹⁵, Tom Cohen¹⁶, Volker Crede¹⁵, Martha Constantinou¹⁷, Christine Davies¹⁸, Luigi Del Debbio¹⁹, Achim Denig²⁰, Carleton DeTar²¹, Alexandre Deur¹, Yuri Dokshitzer^{22,23}, Hans Günter Dosch¹⁰, Jozef Dudek^{1,2}, Monica Dunford²⁴, Evgeny Epelbaum²⁵, Miguel A. Escobedo²⁶, Harald Fritzsch^{d,27}, Kenji Fukushima²⁸, Paolo Gambino^{11,29}, Dag Gillberg^{30,31}, Steven Gottlieb³², Per Grafstrom³³, Massimiliano Grazzini³⁴, Boris Grube¹, Alexey Guskov³⁵, Toru Iijima³⁶, Xiangdong Ji¹⁶, Frithjof Karsch³⁷, Stefan Kluth¹¹, John B. Kogut^{38,39}, Frank Krauss⁴⁰, Shunzo Kumano^{41,42}, Derek Leinweber⁴³, Heinrich Leutwyler⁴⁴, Hai-Bo Li⁴⁵, Yang Li⁴⁶, Bogdan Malaescu⁴⁷, Chiara Mariotti⁴⁸, Pieter Maris⁴⁹, Simone Marzani⁵⁰, Wally Melnitchouk¹, Johan Messchendorp⁵¹, Harvey Meyer²⁰, Ryan Edward Mitchell⁵², Chandan Mondal⁵³, Frank Nerling^{51,54,55}, Sebastian Neubert³, Marco Pappagallo⁵⁶, Saori Pastore⁵⁷, José R. Peláez⁵⁸, Andrew Puckett⁵⁹, Jianwei Qiu^{1,2}, Klaus Rabbertz⁶⁰, Alberto Ramos⁶¹, Patrizia Rossi^{1,62}, Anar Rustamov^{51,63}, Andreas Schäfer⁶⁴, Stefan Scherer⁶⁵, Matthias Schindler⁶⁶, Steven Schramm⁶⁷, Mikhail Shifman⁶⁸, Edward Shuryak⁶⁹, Torbjörn Sjöstrand⁷⁰, George Sterman⁷¹, Iain W. Stewart⁷², Joachim Stroth^{51,54,55}, Eric Swanson⁷³, Guy F. de Téramond⁷⁴, Ulrike Thoma³, Antonio Vairo⁷⁵, Danny van Dyk⁴⁰, James Vary⁴⁹, Javier Virto^{76,77}, Marcel Vos⁷⁸, Christian Weiss¹, Markus Wobisch⁷⁹, Sau Lan Wu⁸⁰, Christopher Young⁸¹, Feng Yuan⁸², Xingbo Zhao⁵³, Xiaorong Zhou⁴⁶

50th birthday of QCD

- About two years ago, important date
=> Comprehensive Review Article
- Chapter “The future”: QCD at FAIR

13.5 QCD and $(g - 2)$ of the muon	
14 The future	
14.1 JLab: the 12 GeV project and beyond	
14.2 The EIC program	
14.3 J-PARC hadron physics	
14.4 The NICA program	
14.5 QCD at FAIR	
14.6 BESIII	
14.7 BELLE II	
14.8 Heavy flavors at the HL-LHC	
14.9 High- p_T physics at HL-LHC	
Postscript	

FAIR – The Facility to study QCD