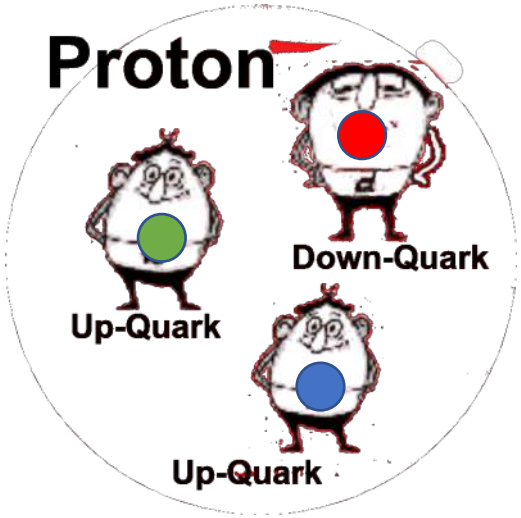
FAIR Facility for Antiproton and Ion Research
Status & Highlights

Sao Paolo, Feb 25, 2019

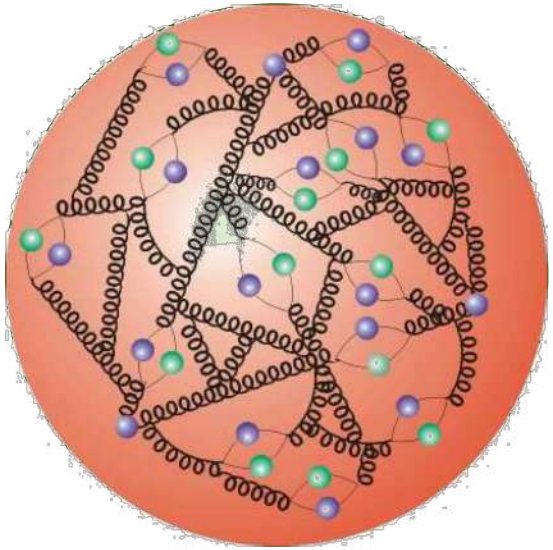
Klaus Peters GSI/U Frankfurt

The Proton – and its properties

the usual picture is, that the **Proton** consists of a **few Quarks**



if you look **more closely**, things appear to be more **complicated**

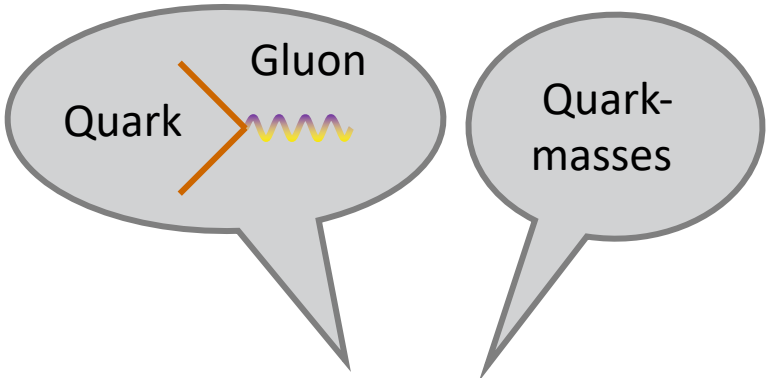


a **Proton** is one configuration
In general they are called **Hadron**
(from old-gr. ***ἀδρός hadrós*** ‚thick' ‚strong')

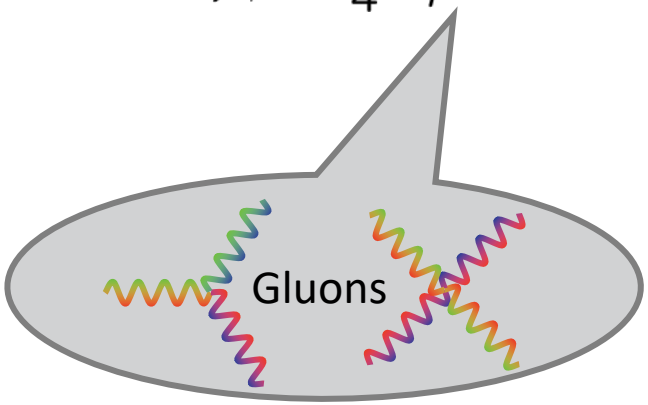
In addition there is glue → **Gluons**

QCD – Quantum Chromo Dynamics

Fritzsch, Gell-Mann, Leutwyler 1973



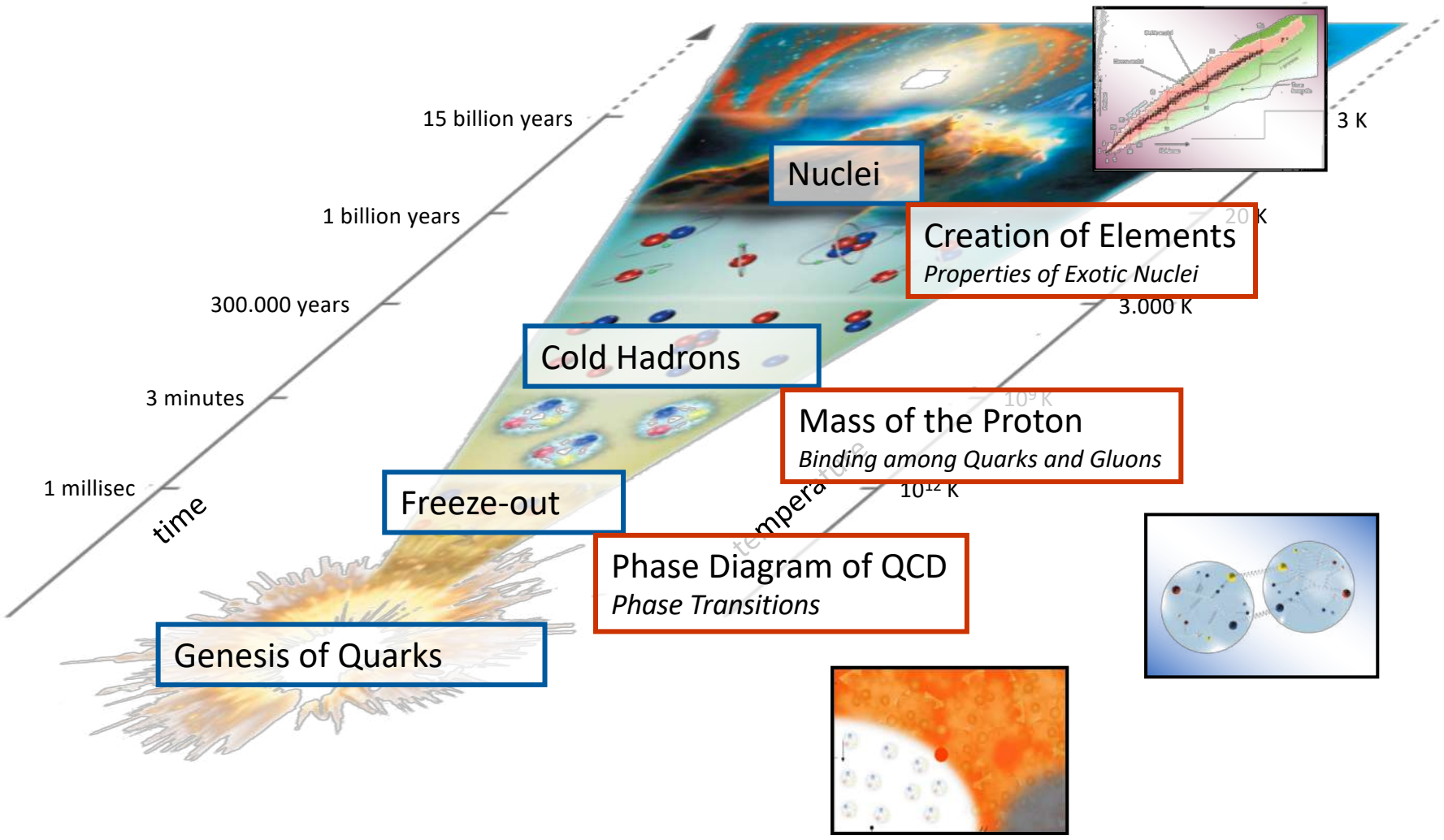
$$L_{QCD} = \bar{\psi}(i\gamma_\mu D^\mu - m)\psi - \frac{1}{4}G_{\mu\nu}G^{\mu\nu}$$



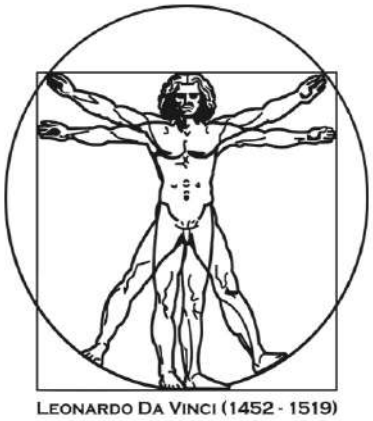
Quarks		spin=½	
Flavor		Approx. Mass GeV/c²	Charge
u	up	0.003	2/3
d	down	0.006	-1/3
c	charm	1.3	2/3
s	strange	0.1	-1/3
t	top	175	2/3
b	bottom	4.3	-1/3

Gauge Boson		spin=1	
Name		Mass GeV/c²	Charge
g	gluon	0	0

Cosmic Matter in the Laboratory

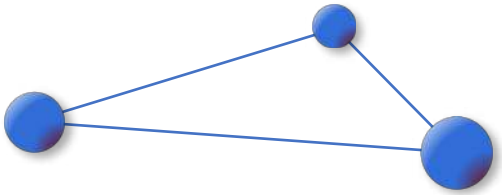


Frontiers



Complexity Frontier

Intensity Frontier



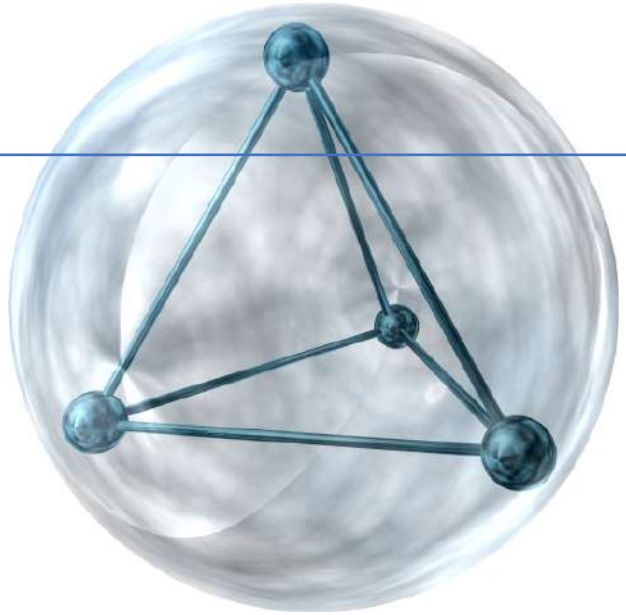
Energy Frontier

Precision Frontier

Complexity

Complexity Frontier

REALITY



Intensity Frontier

SIMPLICITY

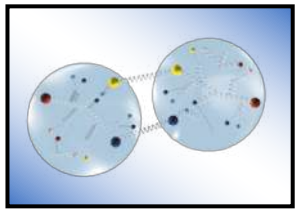
Energy Frontier

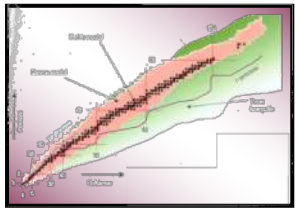
Precision Frontier

sub nuclear material research….

criteria of stability can be derived from extreme (exotic) structures

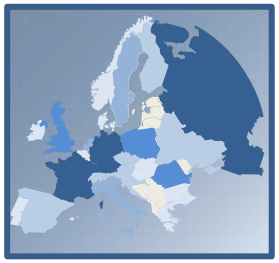
→ properties of the binding





4 Scientific Core Activities

About 3’000 Scientists
hundreds of institutions



50+ countries Worldwide
about 30 countries in Europe

Physics of Hadrons and Nuclei

Our Mission: Study strongly interacting matter on all scales

The **strong force** is responsible for forming
the pion, the proton, all nuclei,
thus it is the basis of our existence

The **strong force** is the least understood (not calculable),
when it comes down to
relations to the real life …

The combination of the large coupling and the non-abelian structure
of the interaction are the scientific reasons for the difficulties

It requires theoretical and experimental progress on
strongly interacting systems on all relevant scales

Common Features

High reaction rate → Frequent events

Speed is an issue (few 10^7)

High incident flux → Luminosity and high doses

Radiation hardness is an issue (up to 100 krad)

Price scales with volume →

Compactness of the detector (up to 1000 t)

Compact volumes →

High fields are an issue (2 T), Heat is an issue

High Precision →

Systematics is an issue

Rare signals →

Dead-time is an issue

} Full coverage is an issue

Additional Features (not common to all)

High dynamic range →

Hadron physics (e.g. calorimeters 10 MeV-10 GeV)

High occupancy →

Relativistic heavy ion coll. (e.g. tracking, >1000 tracks)

Complex topologies →

Challenging hardware & software (e.g. FPGA, GPU,..)

Factory mode →

Rare access → durability

Large assemblies →

Many electronics channels → high integration

Long delivery and assembly lines/times

FAIR: International Cooperation

Realisation and operation of FAIR in **international cooperation**

Nine international FAIR shareholders plus Associate Partners and Aspirants

Participation of **3.000 scientists from all continents**

FAIR @ Darmstadt

Nuclear Structure & Astrophysics
(rare isotope beams)

Hadron Physics
(stored and cooled
15 GeV/c anti-protons)

QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

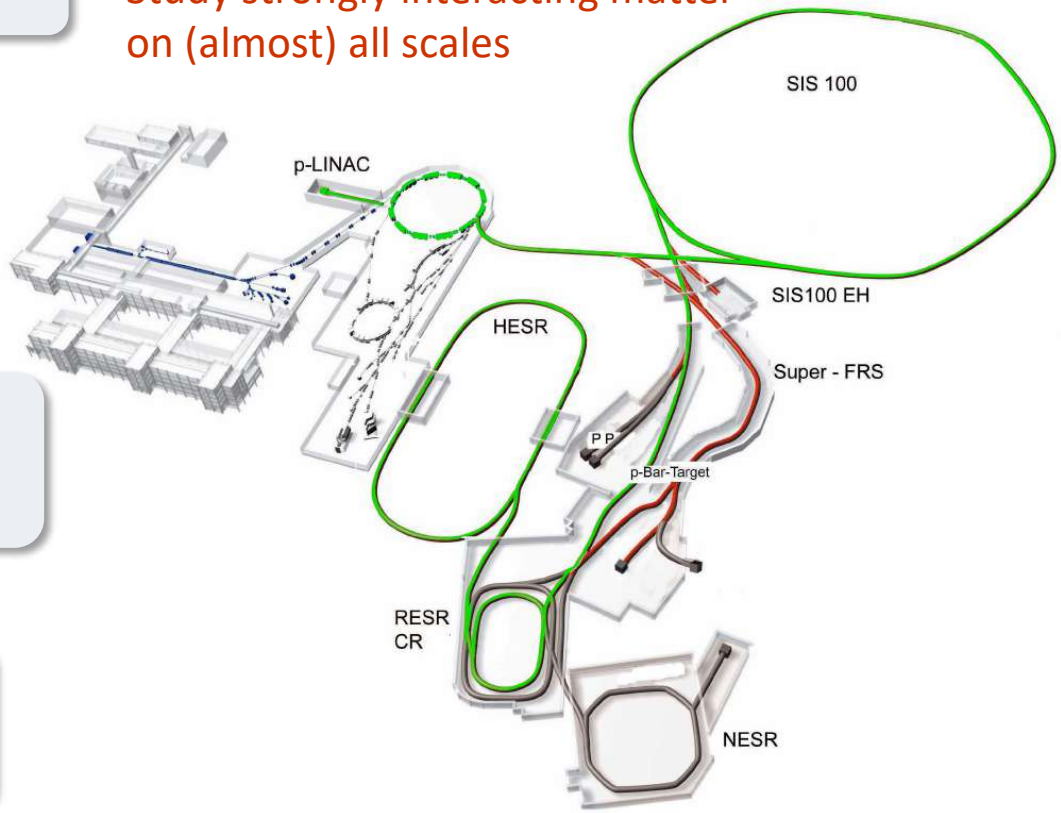
Fundamental Symmetries
& Ultra-High EM Fields
(anti-protons & highly stripped ions)

Dense Bulk Plasmas
(ion beam bunch compression
& petawatt-laser)

Materials Science & Radiation Biology
(ion & anti-proton beams)

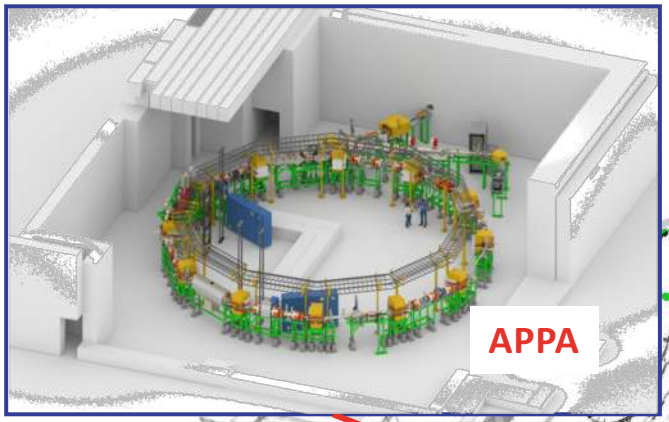
Our Mission

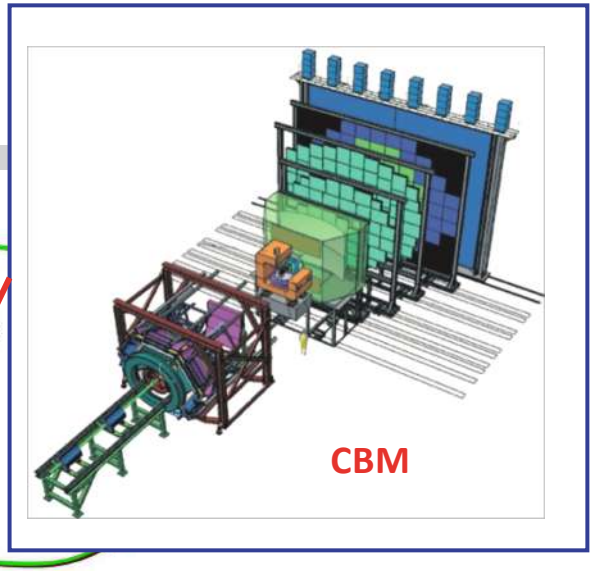
Study strongly interacting matter
on (almost) all scales

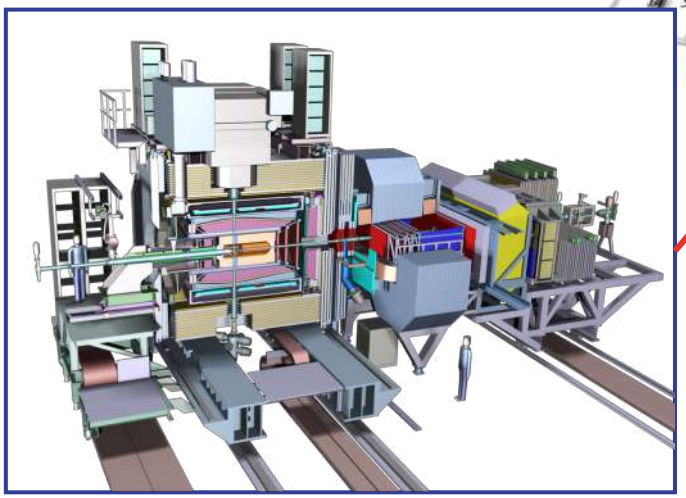


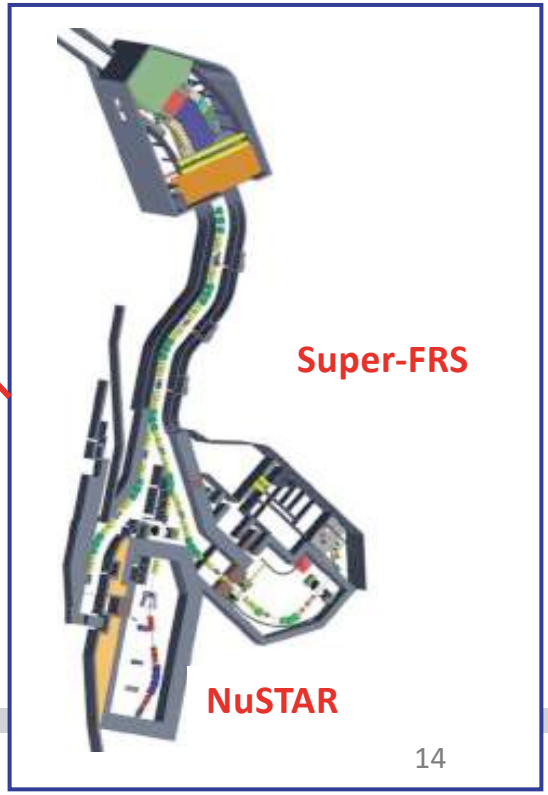
Accelerator Physics

FAIR Experiments

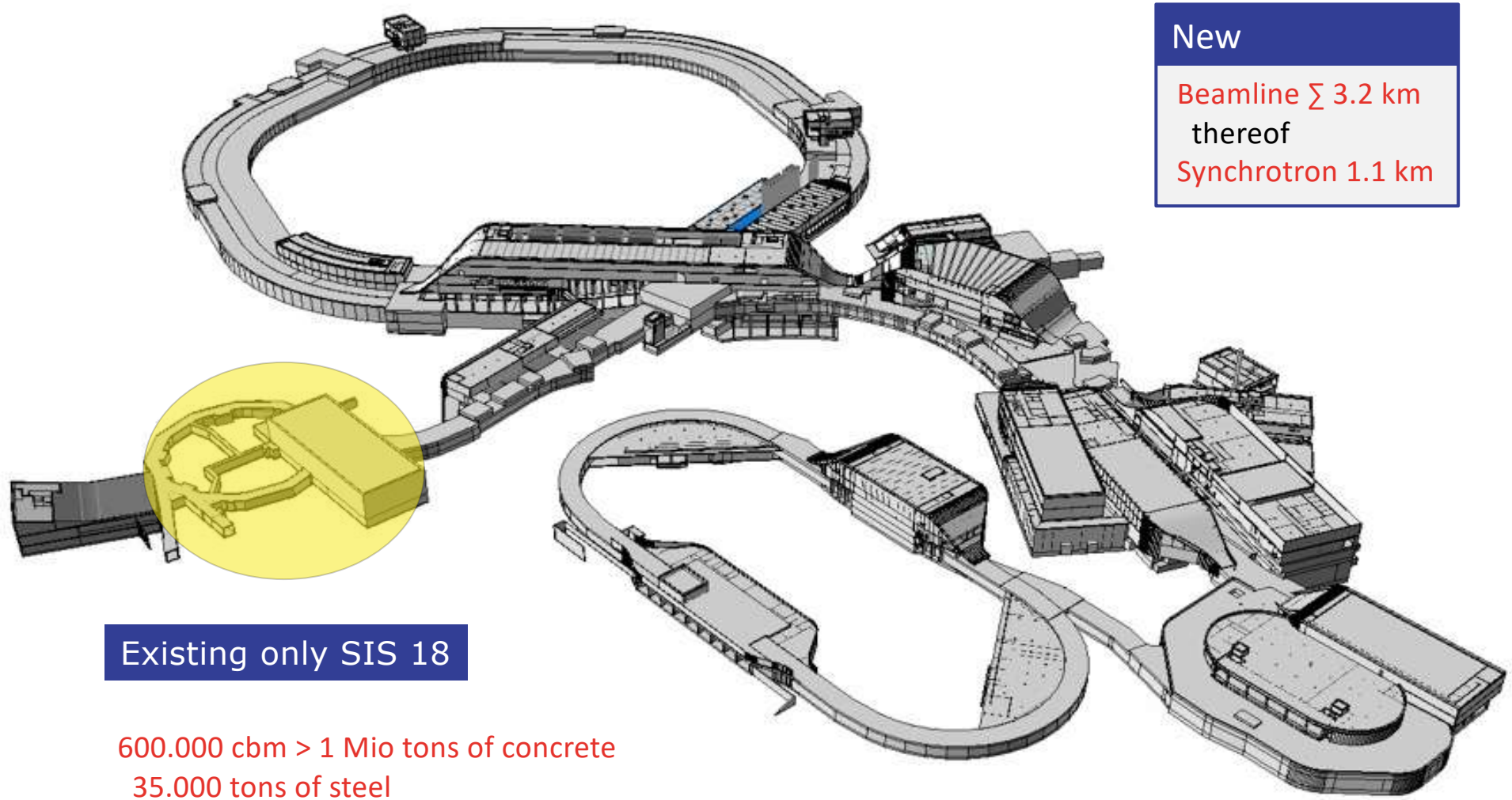








Civil Engineering



New

Beamline ∑ 3.2 km
thereof
Synchrotron 1.1 km

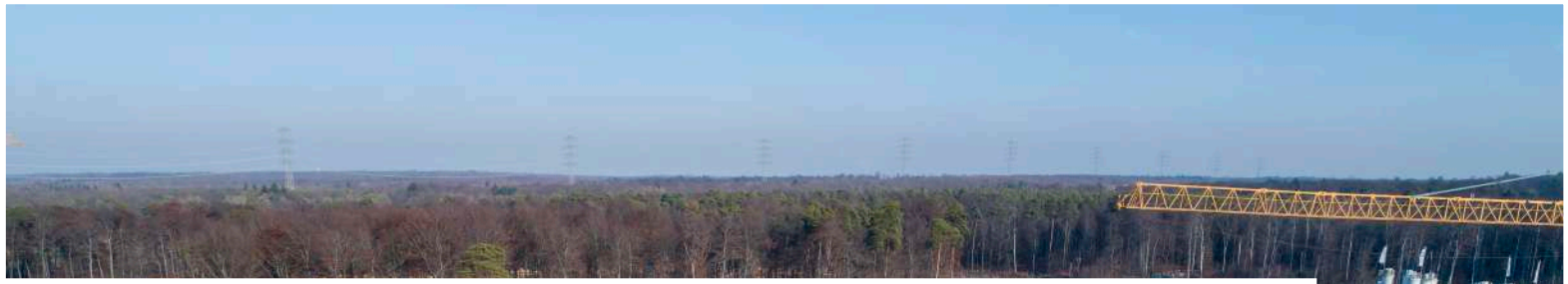
Existing only SIS 18

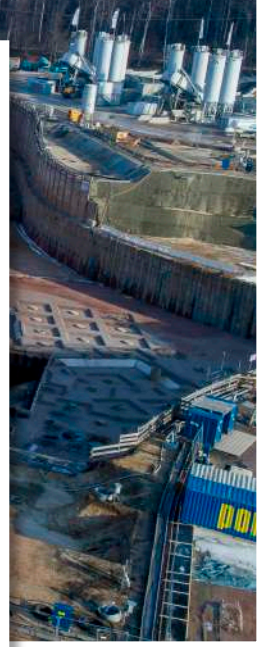
600.000 cbm > 1 Mio tons of concrete
35.000 tons of steel

Construction Site

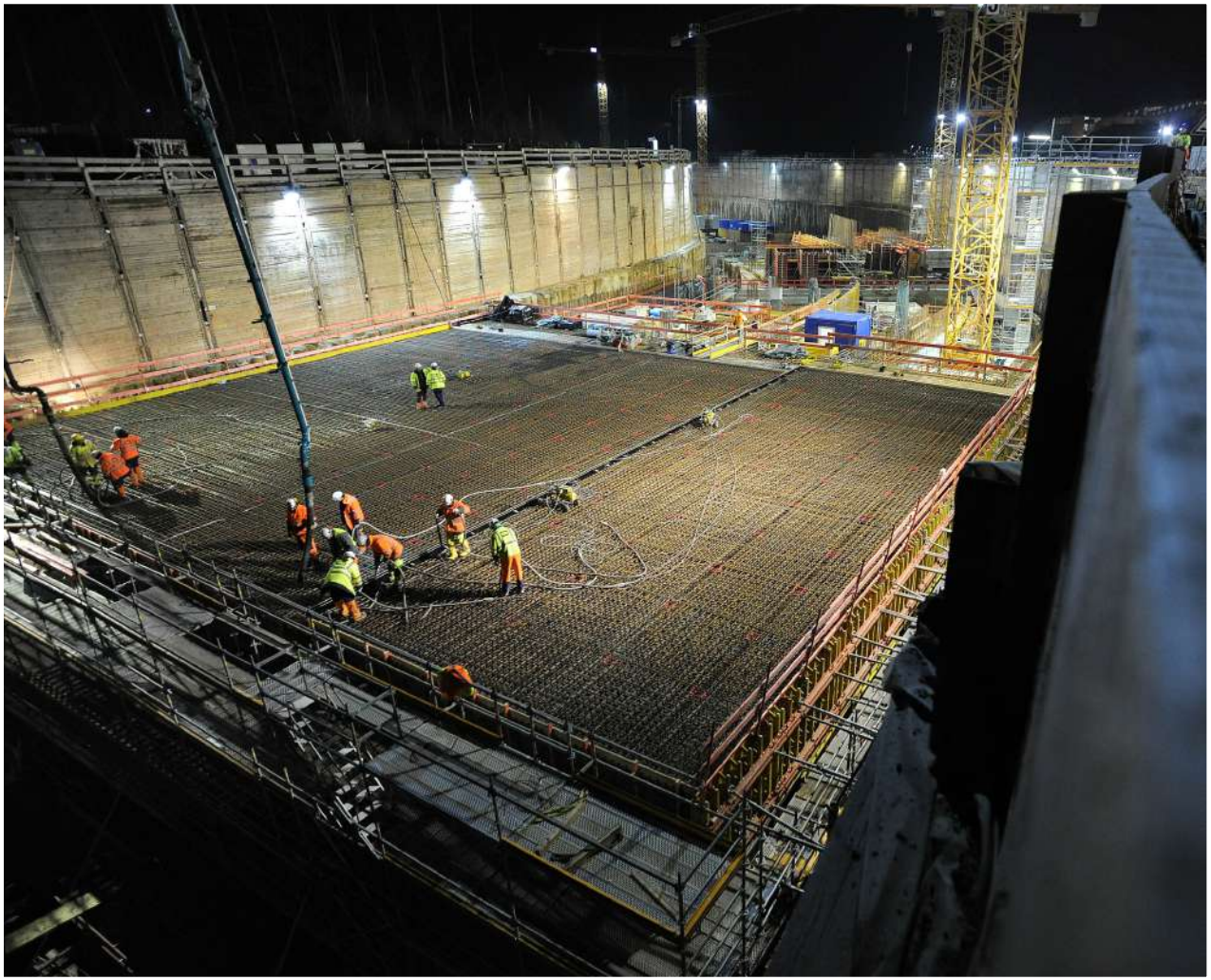
Construction Site

Construction Site





Construction Site



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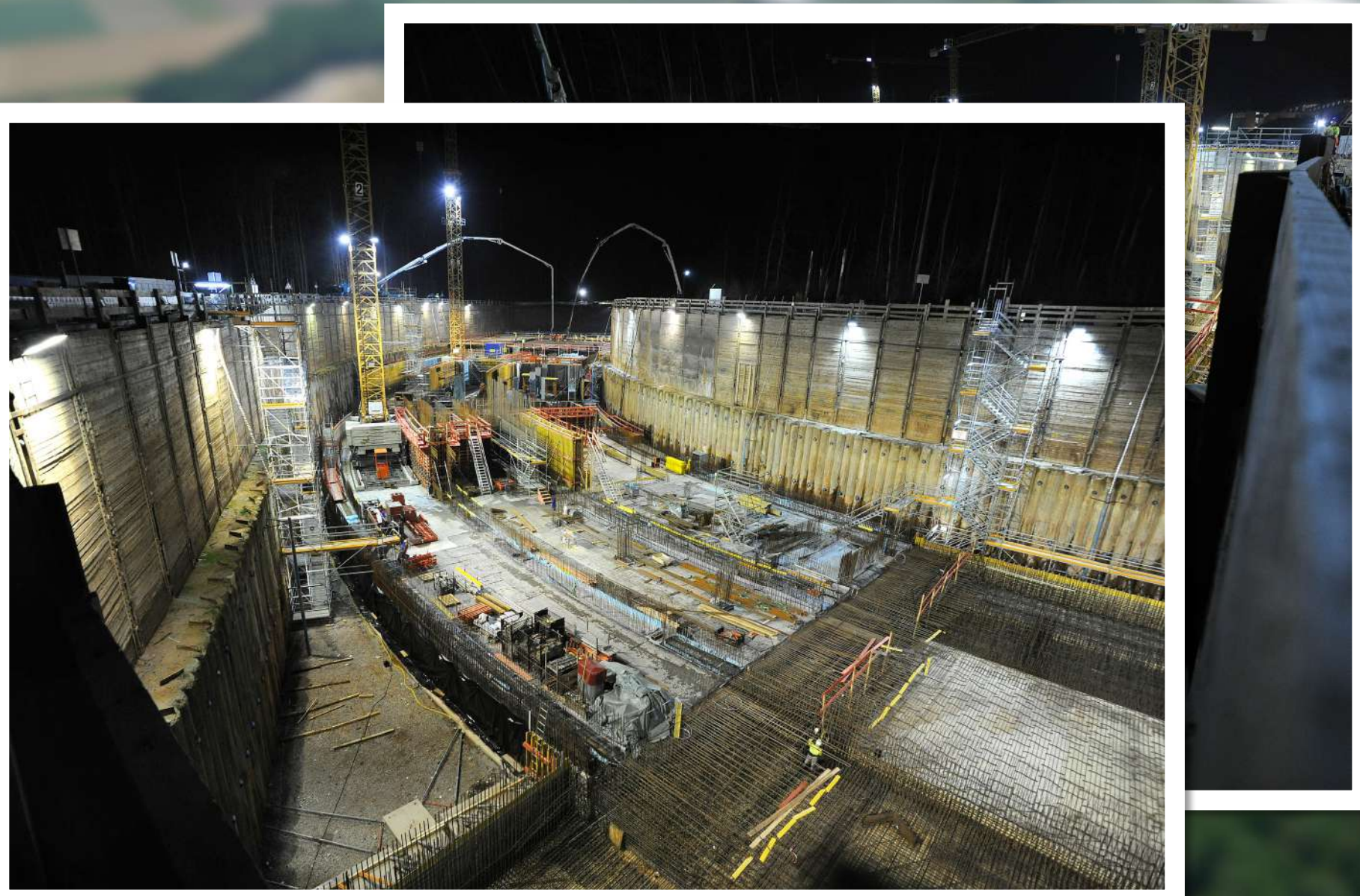


Construction Site

Overall Project – Recent Highlights

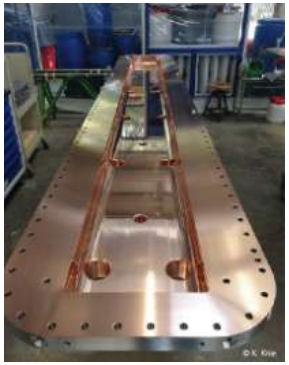
Testing facility for magnets of the FAIR SuperFRS is now ready for use at CERN

Six quadrupole power converters for HEBT were delivered from india in November 2018

Dipole magnets with integrated vacuum chambers for high energy beam transfer are prepared for storage

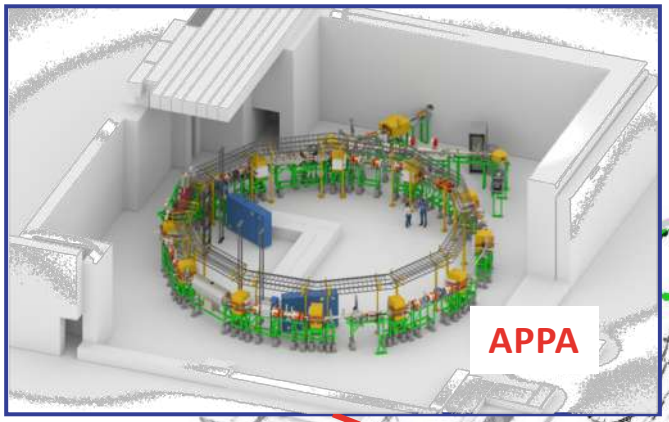
Overall Project – Recent Highlights

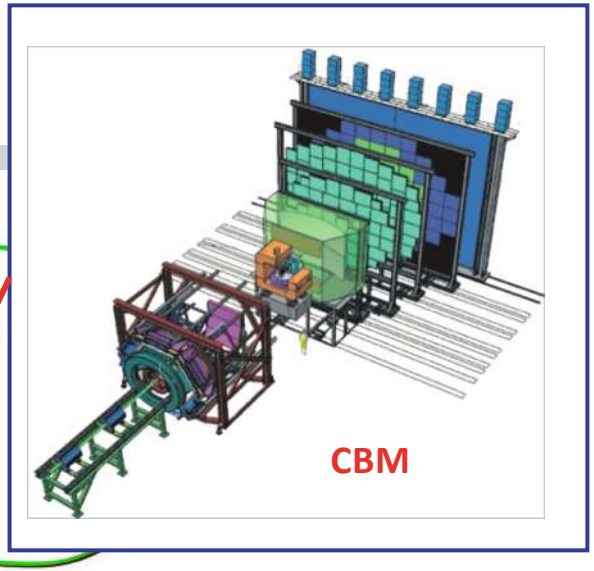
Contract for Testing of SIS100 Quadrupole Units signed with JINR on 26th October 2018

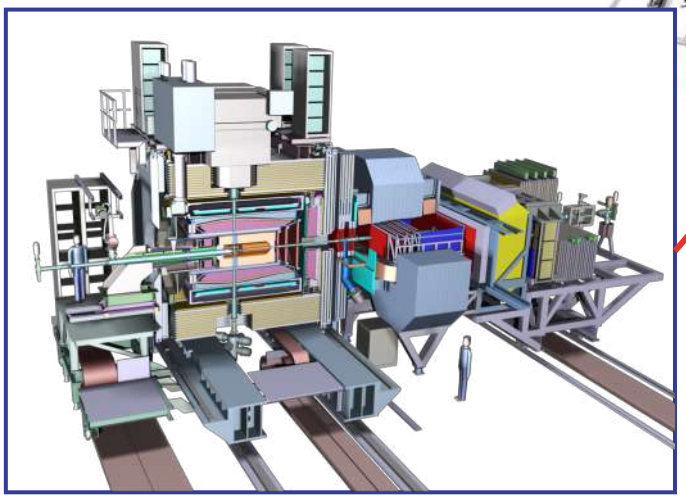


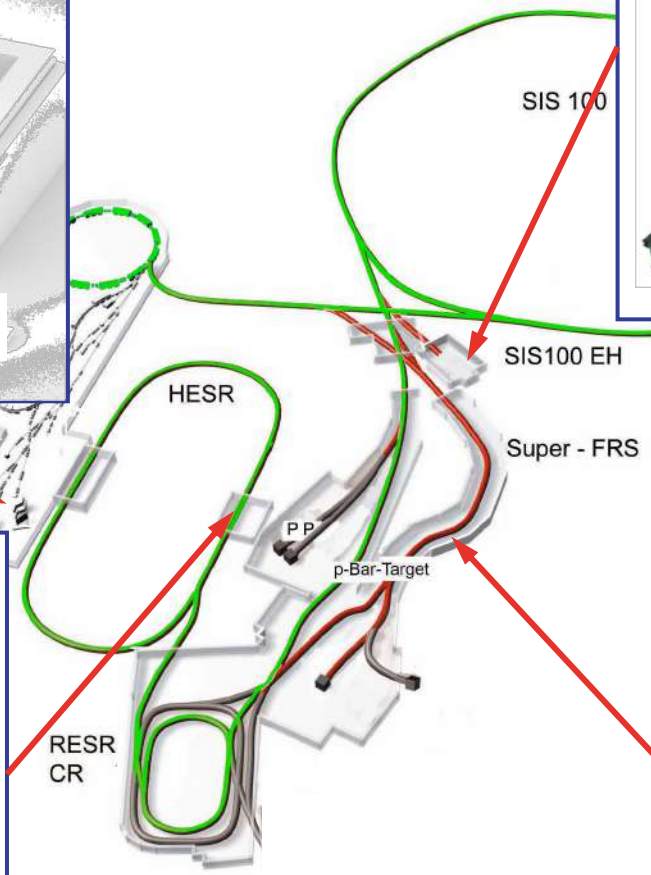
Copper plating and first tests of the RFQ accelerator cavity for the p-Linac have been completed and match specification

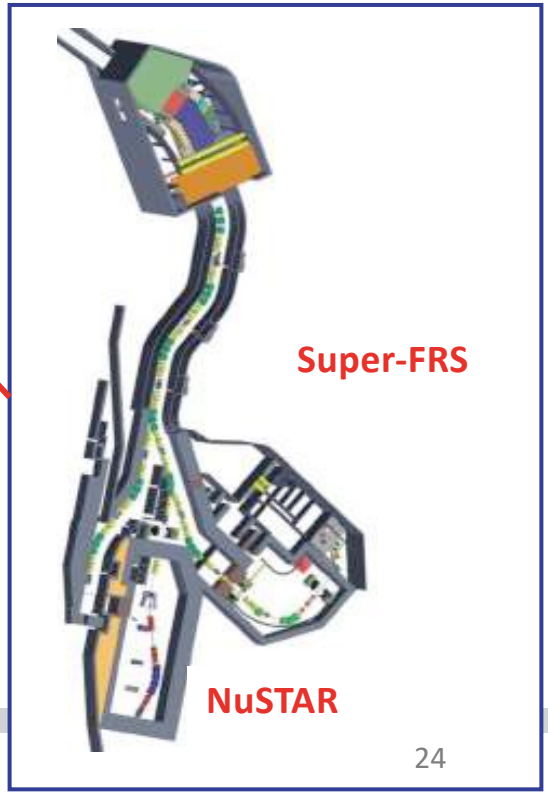
FAIR Experiments











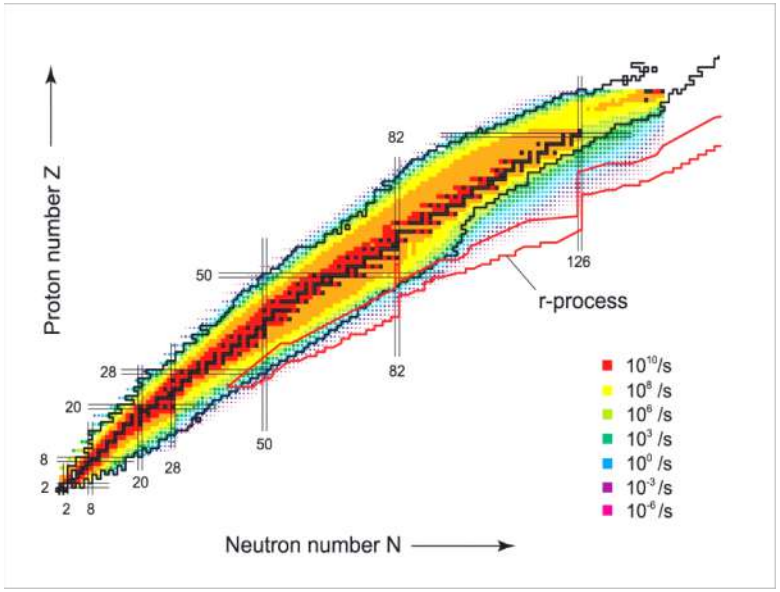
NUSTAR @ FAIR: physics of the nuclei

How Are Elements Made ?

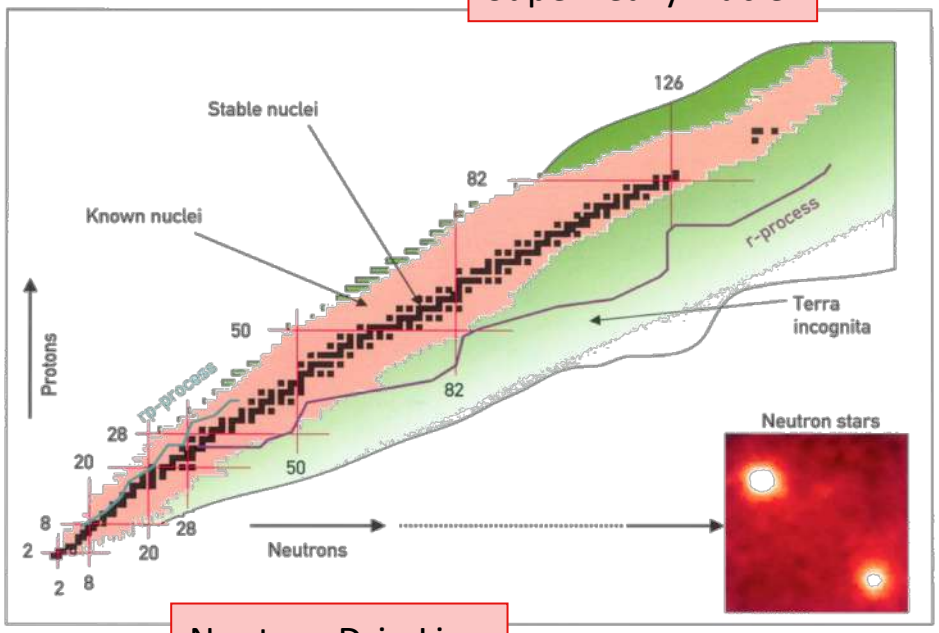
Structure of exotic nuclei far off stability ?

Nuclear synthesis in stars
and star explosions

Fundamental interactions
and symmetries



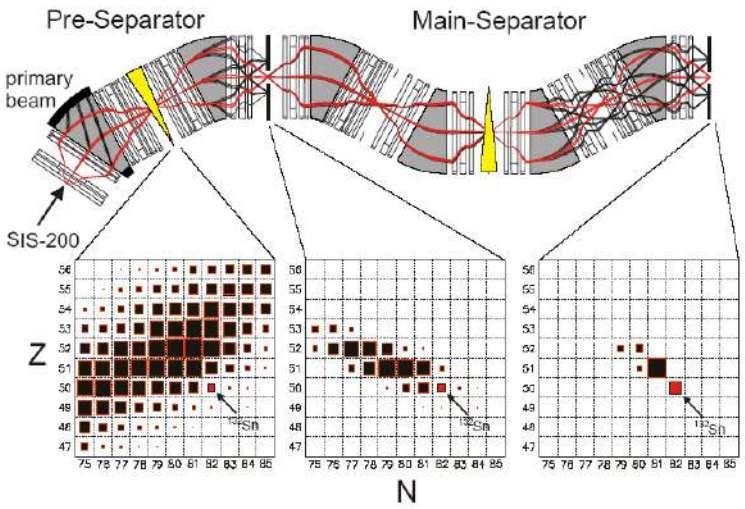
Superheavy Nuclei



Neutron Drip Line

NUSTAR @ FAIR: Installations

Superconducting **FR**agment **S**eparator
High-Energy Reaction Setup
Multi-Storage Rings (CR, NESR, eA)
Energy-Bunched Stopped Beams



MATS & LaSpec

HISPEC/DESPEC

R³B

Super-FRS

ILIMA

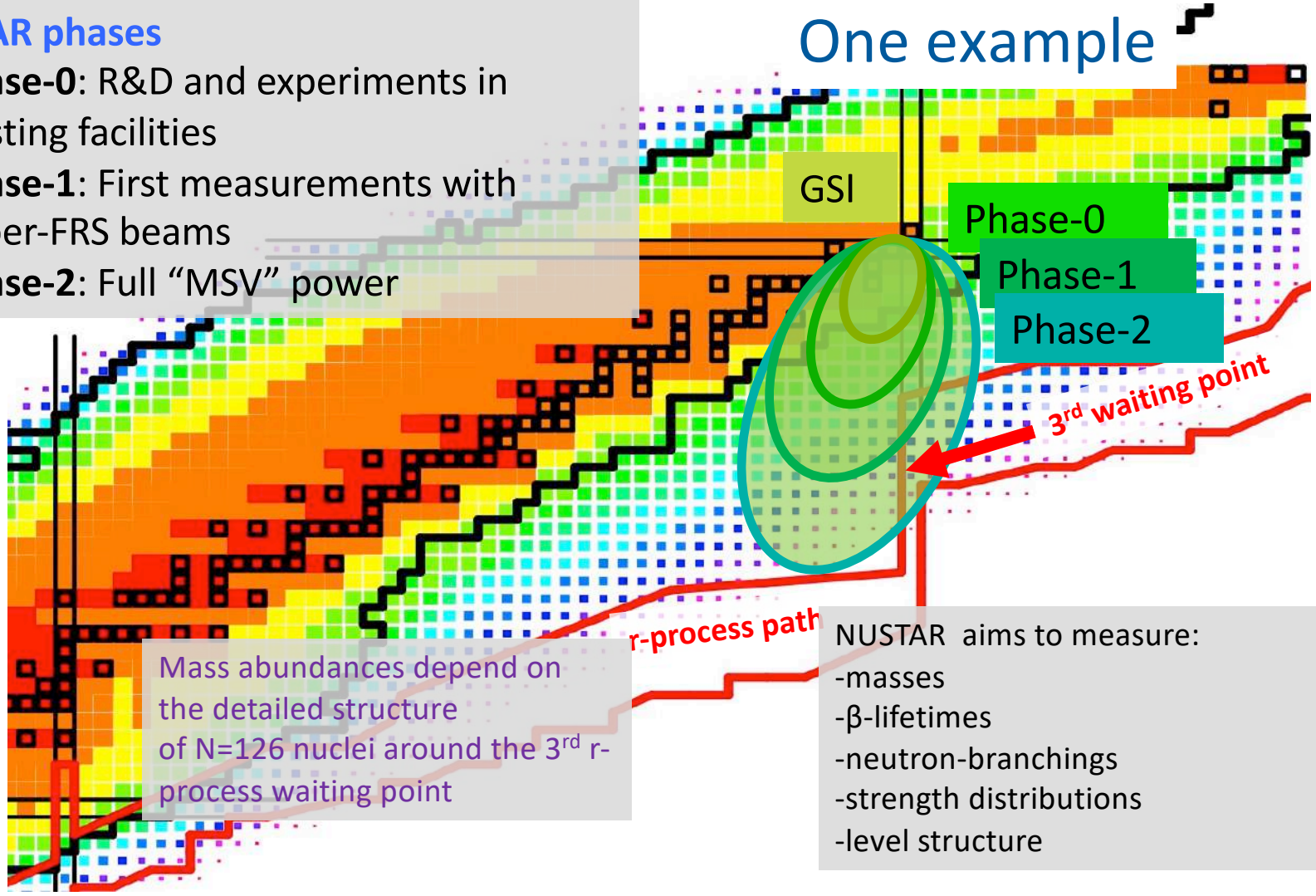
production target

Key characteristics :
- *all elements, H to U*
- *intensity > 10^{12} ions/sec.*
- *high and low energies*
- *pulsed and CW beams*

NUSTAR @ FAIR: Day-1

NUSTAR phases

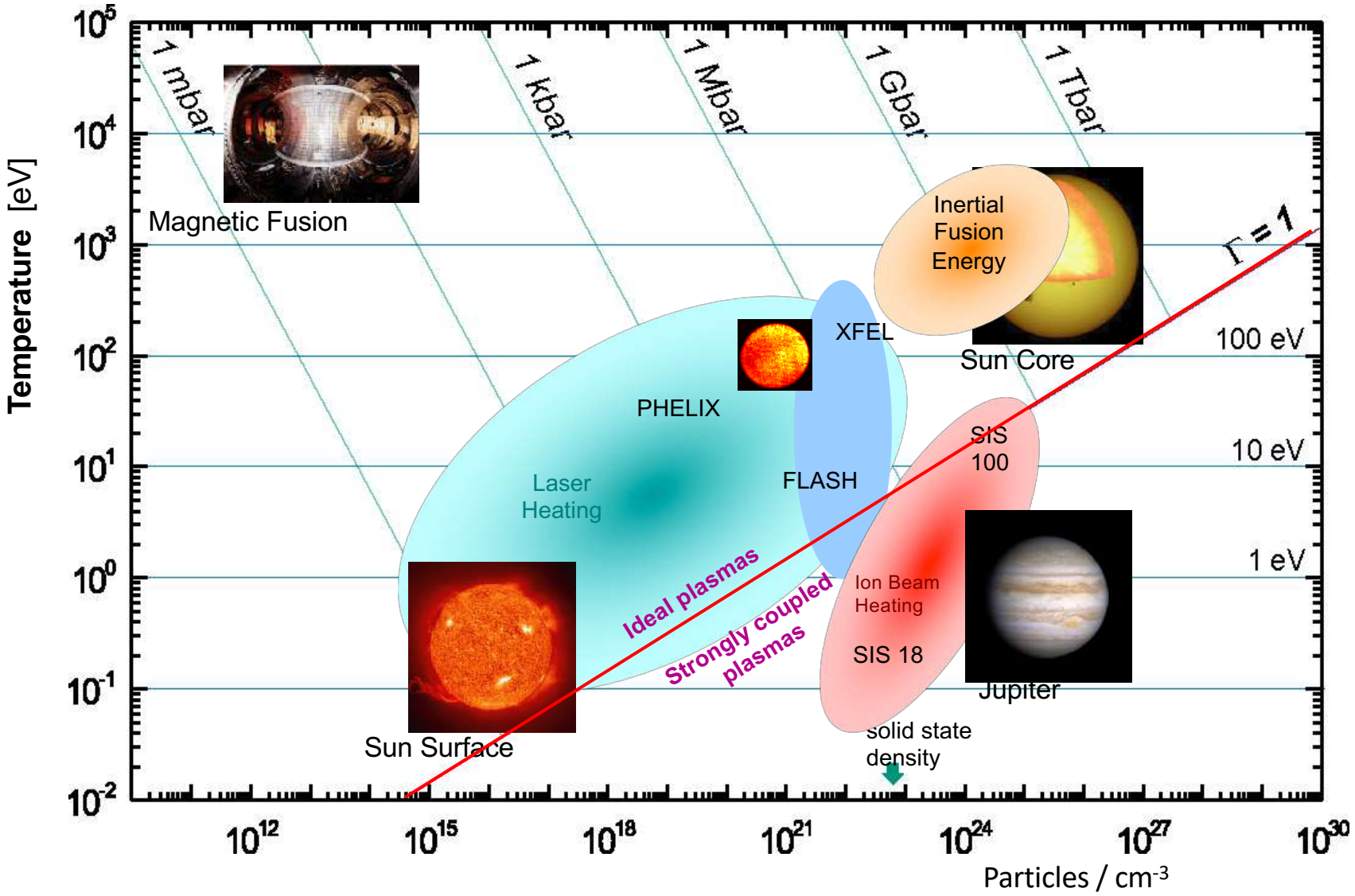
- **Phase-0**: R&D and experiments in existing facilities
- **Phase-1**: First measurements with Super-FRS beams
- **Phase-2**: Full "MSV" power



Mass abundances depend on the detailed structure of N=126 nuclei around the 3rd r-process waiting point

NUSTAR aims to measure:
-masses
-β-lifetimes
-neutron-branchings
-strength distributions
-level structure

APPA - Plasmas



APPA– Day 1 (Examples)

BIOMAT *(Biophysics and Materials Research)*
- Materials under extreme conditions (pressure, heat, irradiation)
- Radiation shielding of cosmic radiation

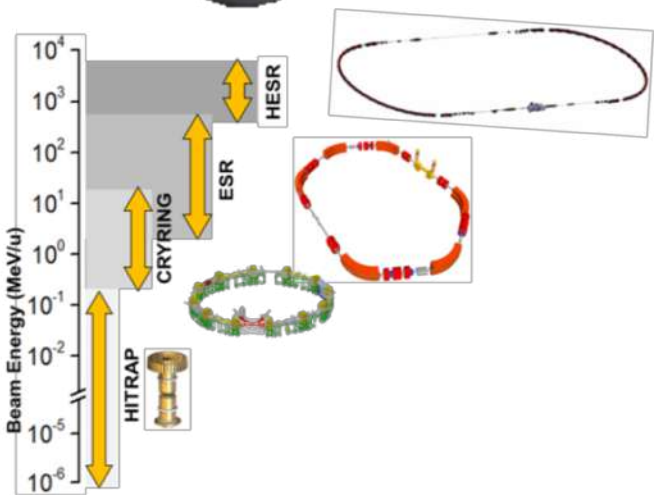
Day-1 experiments @ APPA cave
- Sample irradiation using high pressure cells
- Irradiation of biological samples

HEDgeHOB/WDM *(Plasma Physics)*
- Phase transitions shocked/compressed matter
- Opacity measurements of Warm Dense Matter

Day-1 experiments @ APPA cave
- Proton microscopy of shocked/compressed materials
- Opacity changes from Cold- to Warm Dense-Matter

SPARC *(Atomic Physics)*
- Precision test of QED in the strong field domain (αZ≈1)
- Model independent determination of nuclear parameter

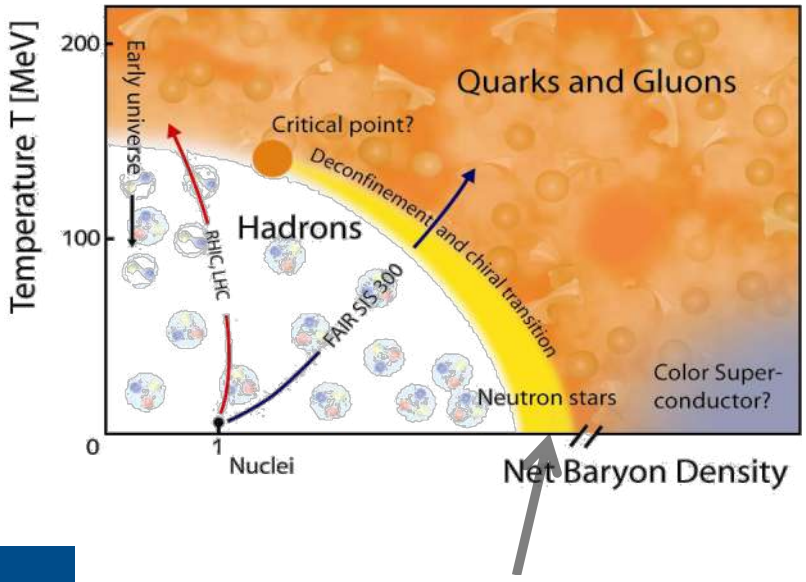
Day-1 experiments @ Storage Rings
- Ion channeling at APPA cave
- Laser spectroscopy at HESR (fine-structure) and at CRYRING (hyperfine)



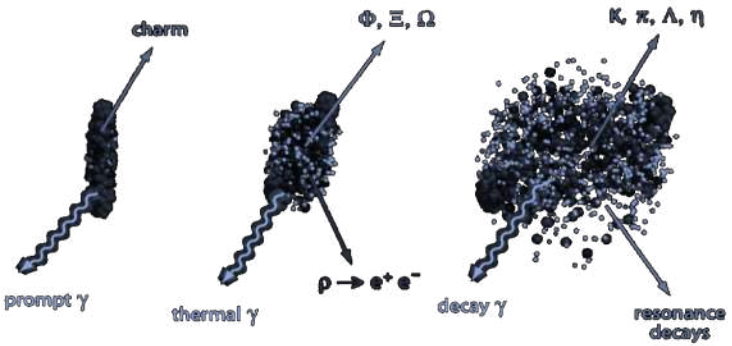
CBM: Exploring the phases of nuclear matter

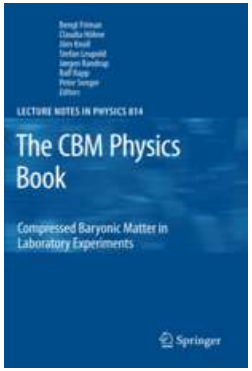
Nuclear Equation-of-state at high density

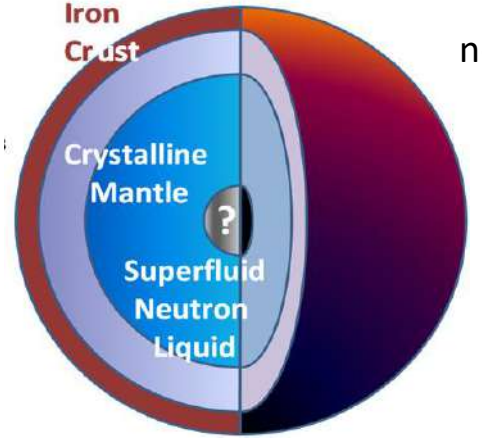
Search for phase transitions
Search for the QCD critical endpoint
Study chiral symmetry restoration and
the origin of the hadron mass



Observables

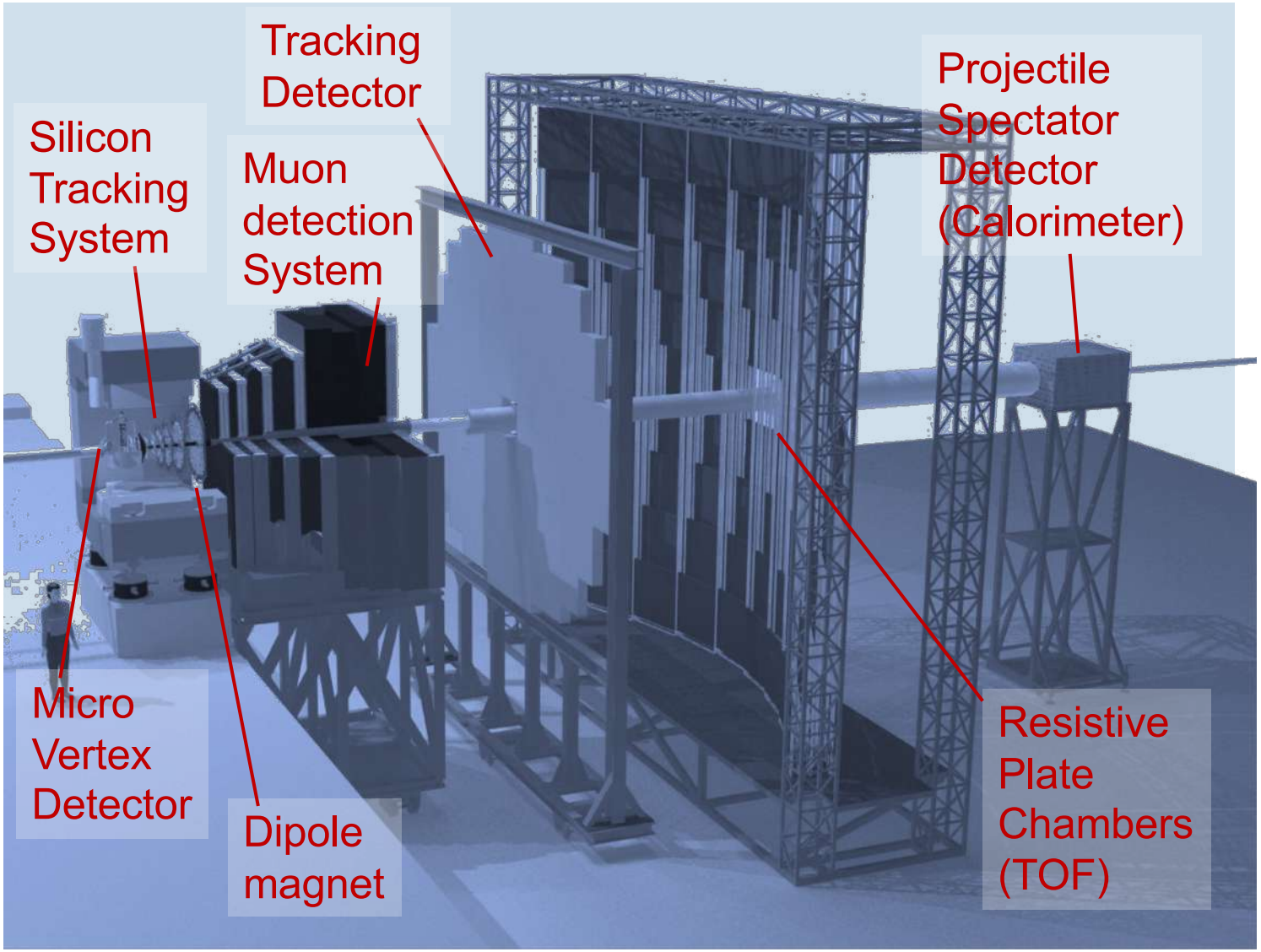






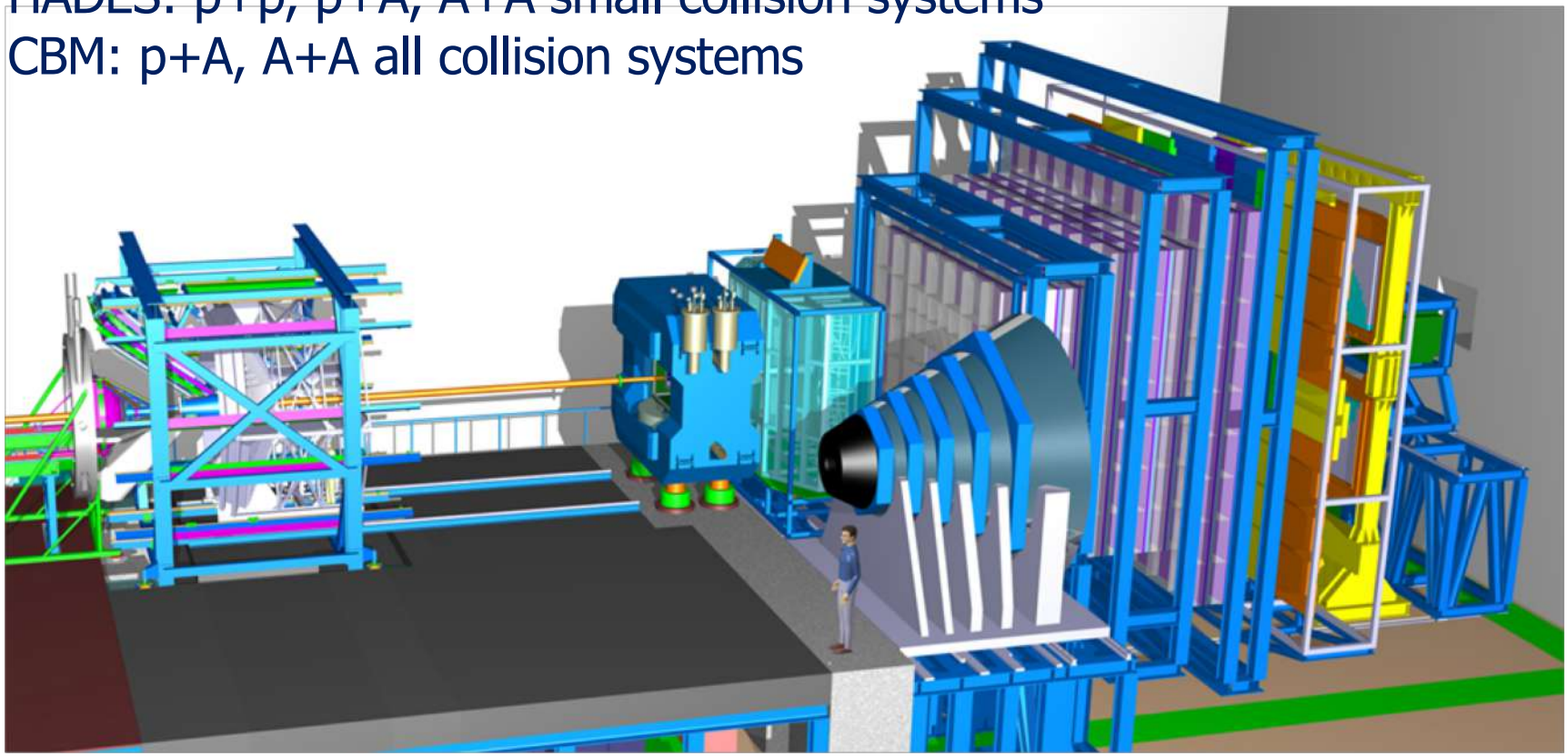
neutron star

CBM at FAIR: Detector



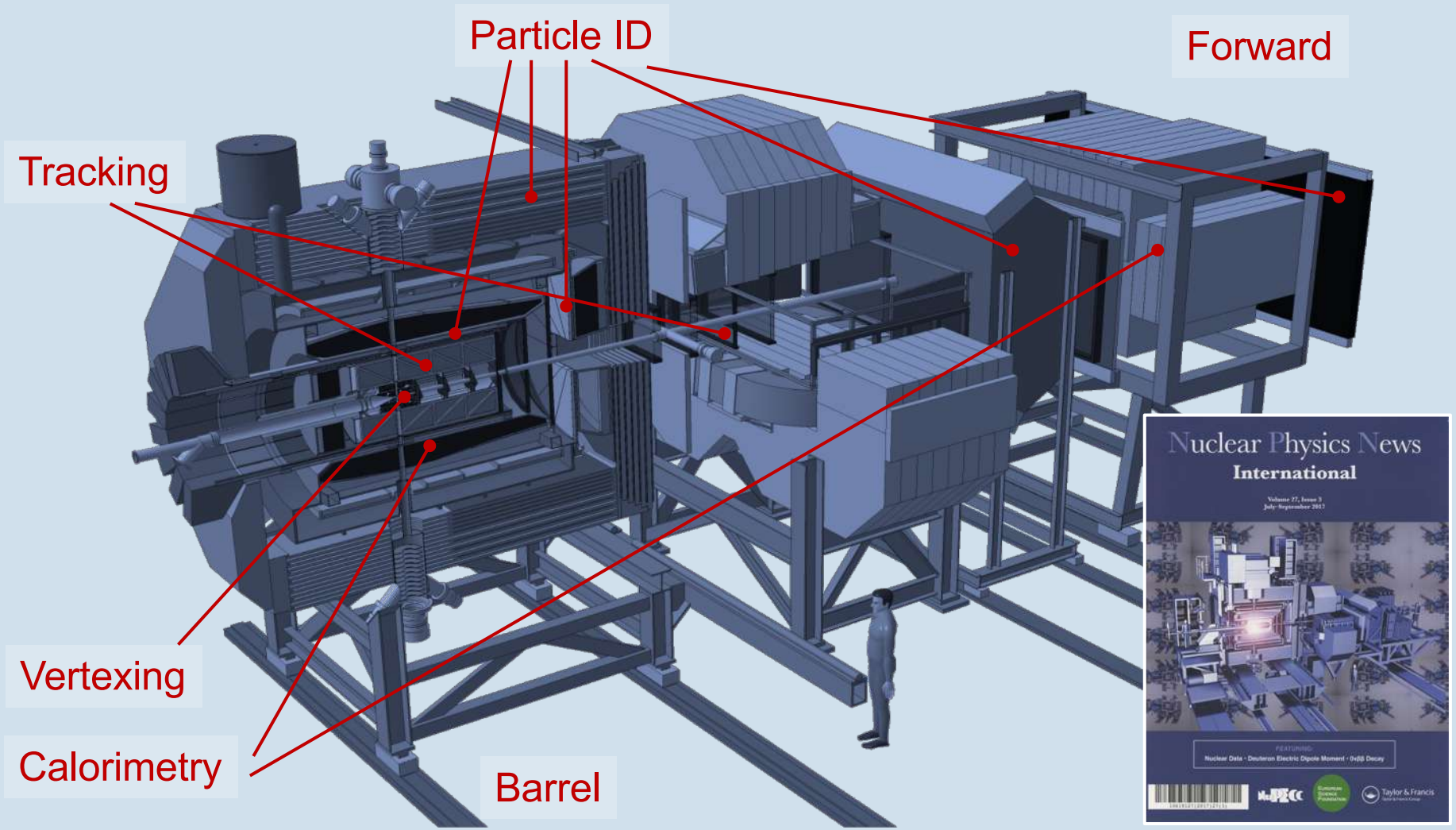
CBM at FAIR: Day-1 Equipment

HADES: p+p, p+A, A+A small collision systems
CBM: p+A, A+A all collision systems



Observables: Excitation function of yields and phase-space distributions of multi-strange hyperons and lepton pairs
→ Au+Au collisions from 2-11 A GeV (no data available in this energy range)

PANDA at FAIR: Detector



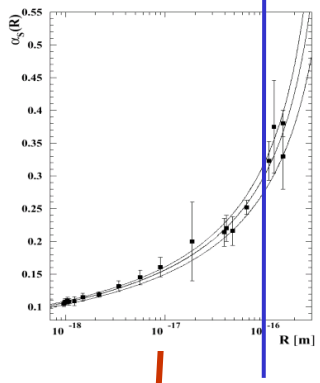
PANDA at FAIR: Hadron Physics with Antiprotons

The study of **QCD bound states** is of fundamental importance for a better, quantitative understanding of QCD. Particle spectra can be computed within the framework of non-relativistic potential models, effective field the-

tiquark and molecular states.

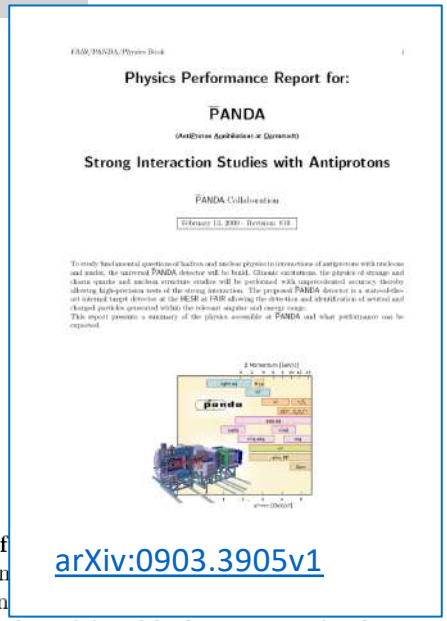
Electromagnetic Processes. In addition

timelike region over an extended q^2 region.



Hadrons in matter
Absorption
Modifications

QCD Bound States
Charmonium
Exotic States



arXiv:0903.3905v1

Study of
study of
bedded in
standing the origin of hadron masses in the context of spontaneous chiral symmetry break-
ing in QCD and its partial restoration in a
had
bee
hig
allo
sec
cha
are
gluon condensate.

Non-pert. QCD Dynamics
Strangeness and
Charm Production

eral reactions involving different quark flavours the OZI rule, and its possible violation, can be tested for different levels of disconnected quark-line diagrams separately.

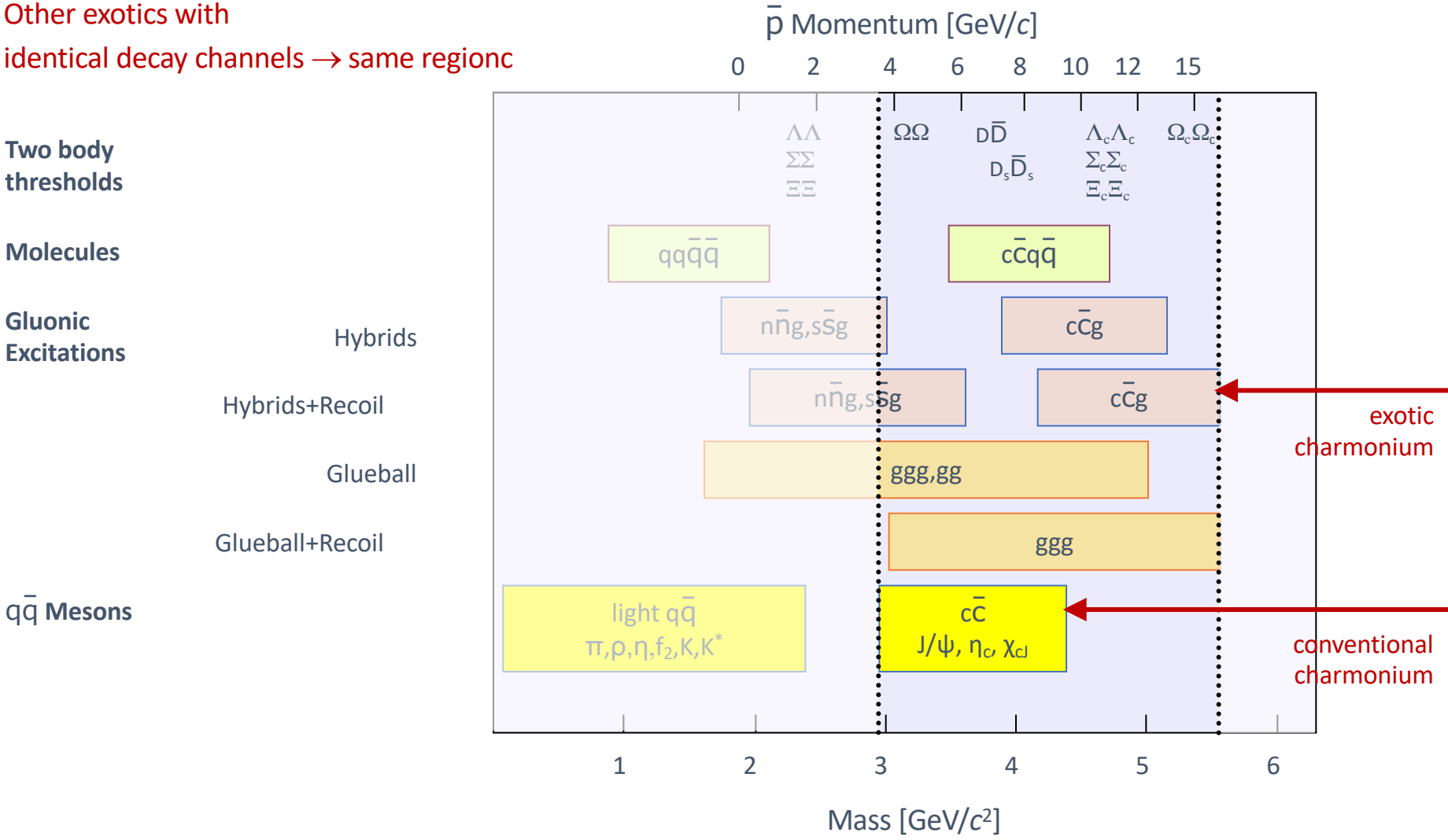
Hadron structure
DVCS
Formfaktors

ernuclear physics. Hypernuclei are sys-
in which up or down quarks are re-
d by strange quarks. In this way a new
um number, strangeness, is introduced
into the nucleus. Although single and double
Λ-hyp des
ago, o tly
known AIR
will al clei
with n king
PAND ted
faciliti for
nuclea dy-
ing the forces between hyperons and nucleons.

Hypernuclei
Molecules
Exotic nuclei

Accessible Charmed Hadrons at $\bar{P}$ANDA

Other exotics with
identical decay channels → same regionc

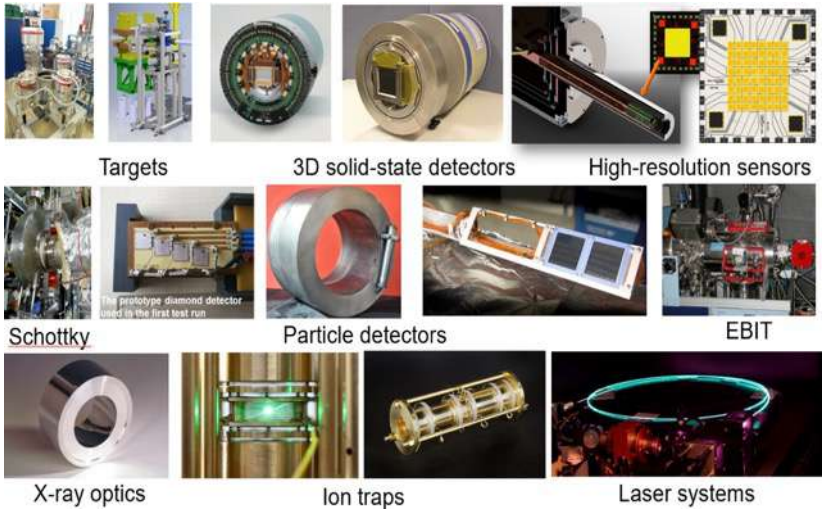


What we need

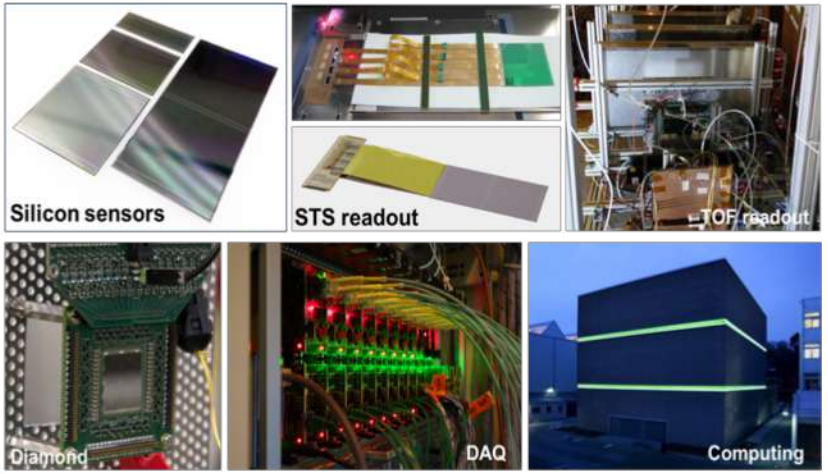
Status of FAIR: experiments

detector R&D and construction well on track …

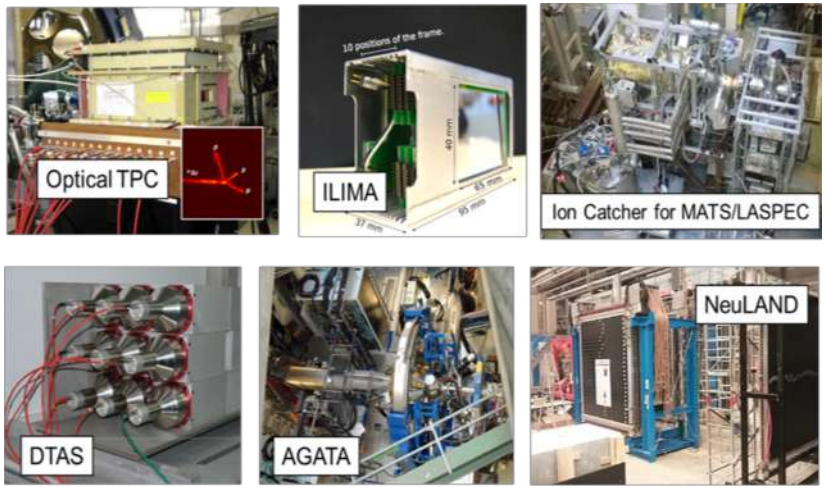
APPA



CBM



NUSTAR



PANDA

Summary/Outlook

- Despite of certain delays FAIR is progressing well.
- Rich scientific program and discovery potential already with completion of Modularized Start Version.
- FAIR will allow for unique measurements in many fields and remain competitive for decades.
- Versatile detector configurations for optimal performance are under construction.
- Day-one physics with start version for high interaction rates in preparation.
- Strong and experienced international collaborations are active, more scientists expected to join in the coming years.


Thank you