GSI/FAIR

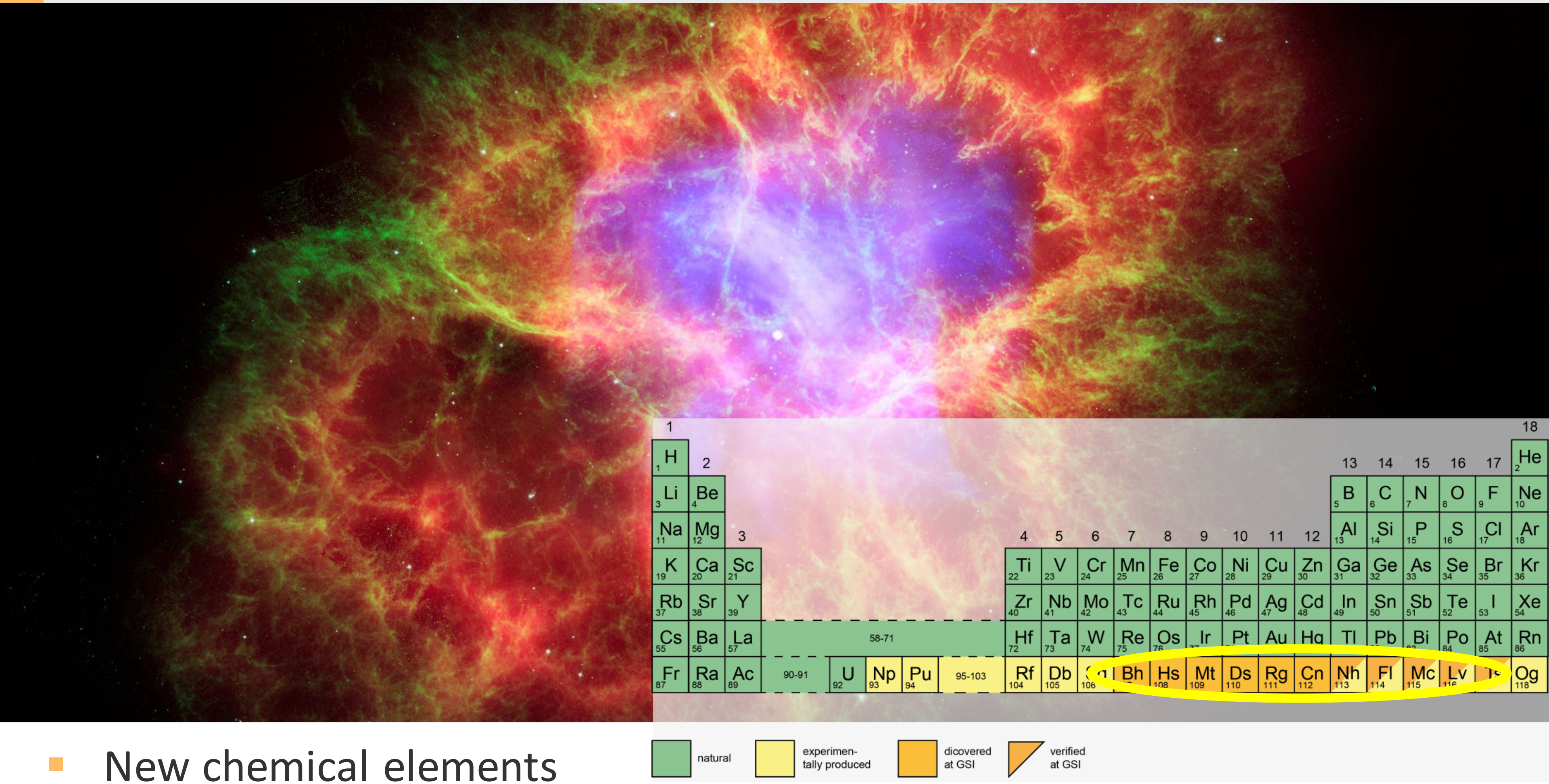
- FAIR Physics and Perspectives

Paolo Giubellino

GSI – More Than 40 Years of Scientific and Technical Expertise

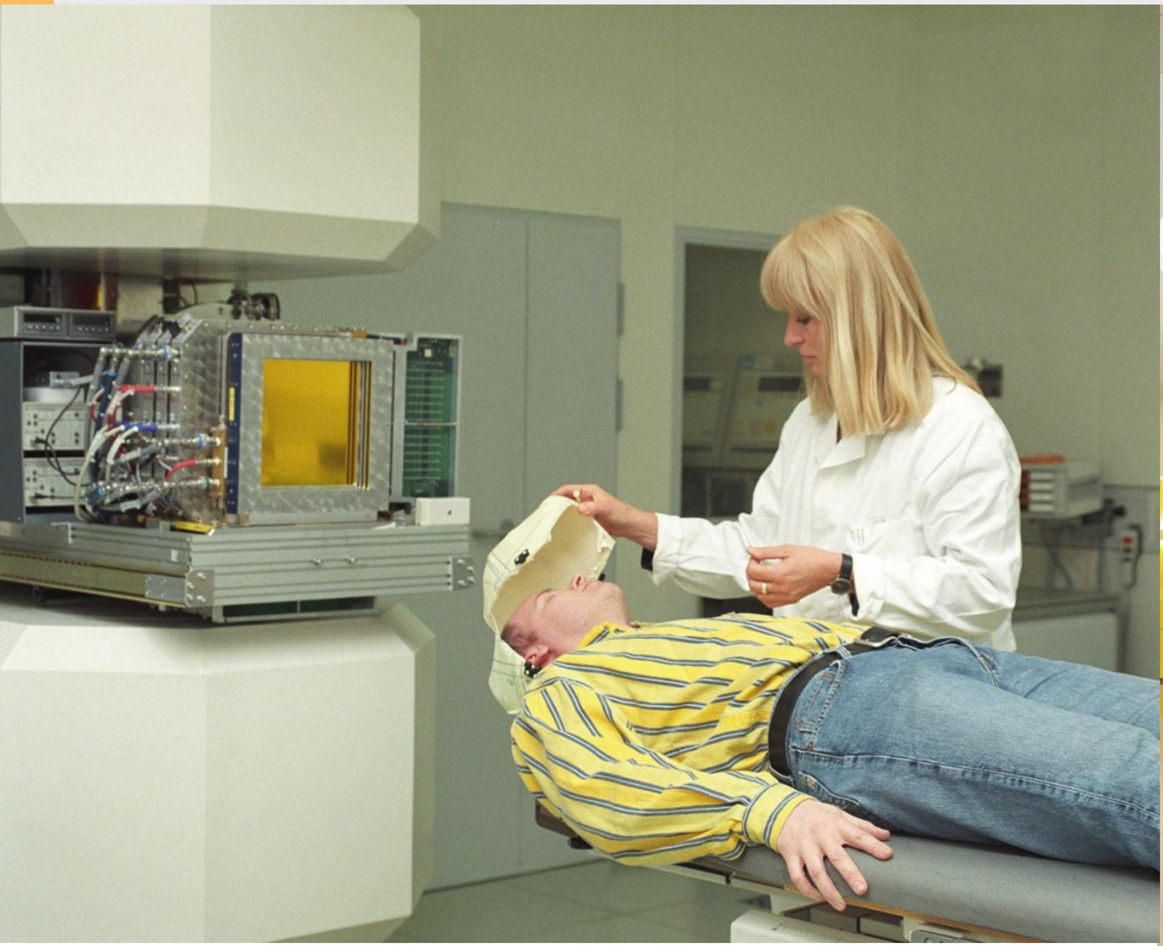
- Reference laboratory for nuclear physics in Europe, one of the top laboratories in the world

Major GSI Discoveries



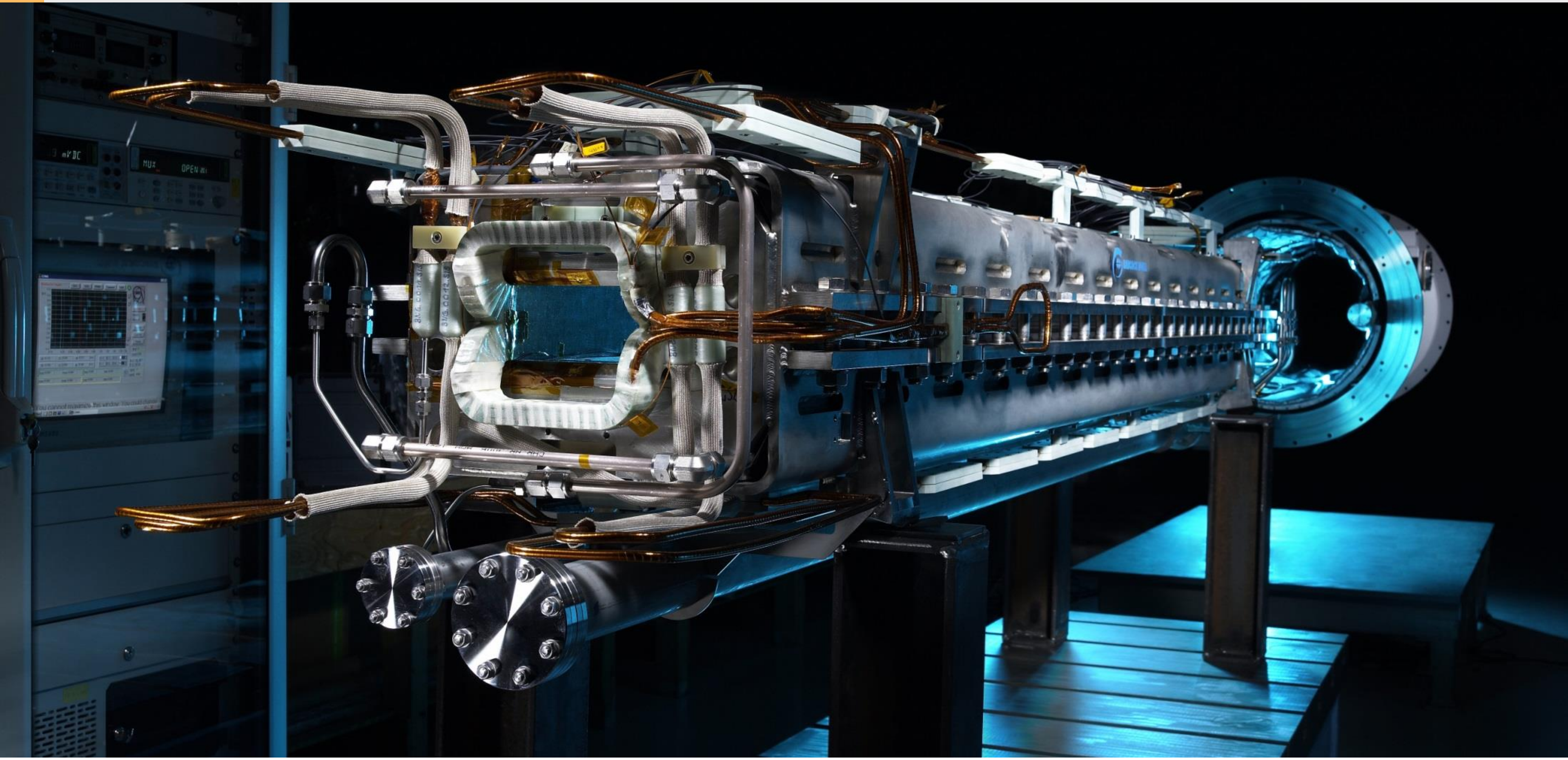
- New chemical elements
- Hundreds of new isotopes
- New decay modes

Major GSI Discoveries



- Innovation in cancer therapy

Forefront Technologies



- Applications in accelerator science, detector instrumentation, materials research, radiation biology, therapy

Forefront Technologies

- Technological advancements in high-performance & scientific computing, Big Data, Green IT

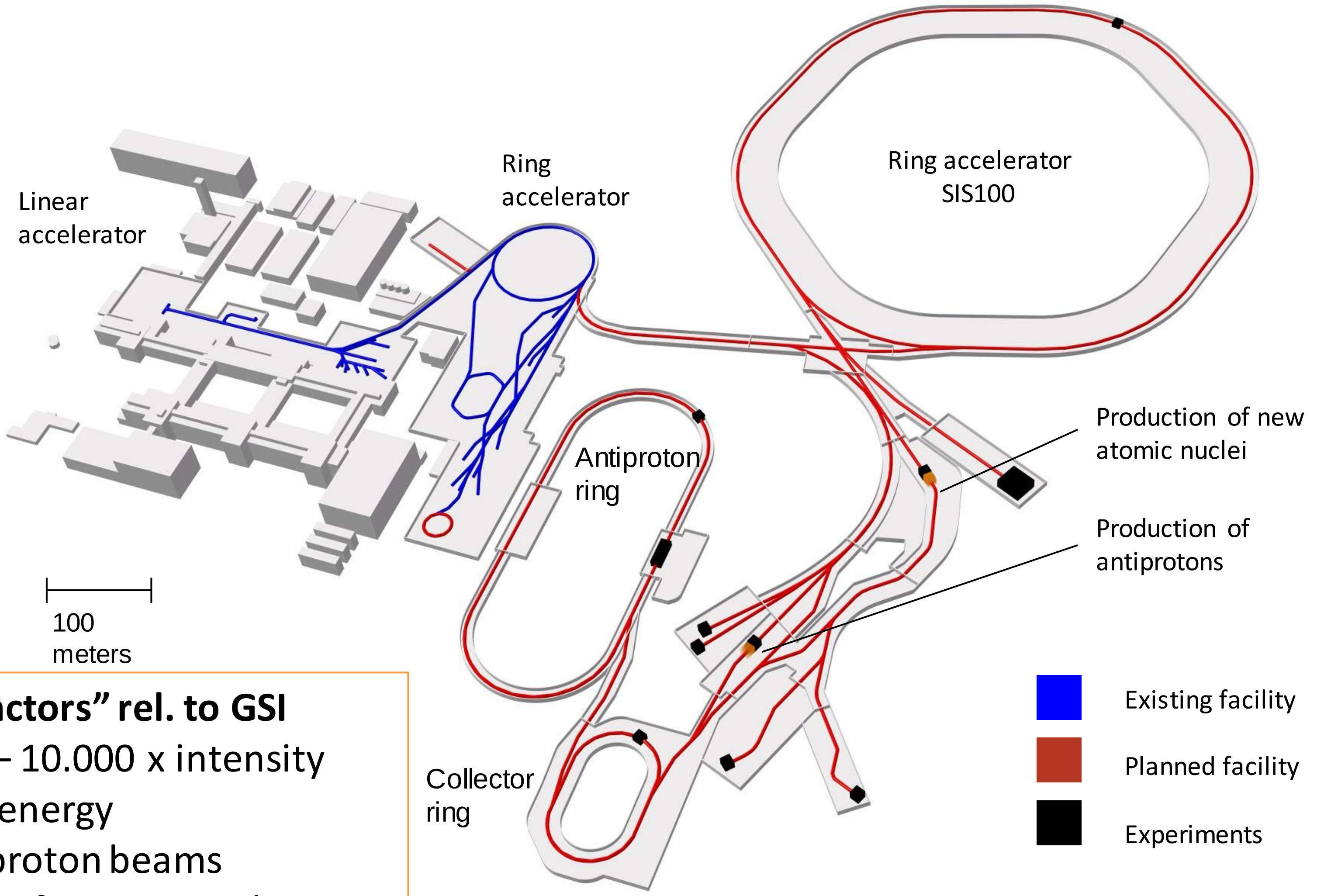
FAIR – World-Wide Unique Accelerator Facility

- ESFRI Landmark
- Top priority for European Nuclear Physics Community

A Talent Factory

- A unique capability to attract and create talent and know-how.
- Training and education of the next generation of scientists, engineers and computing experts from all over the world:
  - Graduate Schools with currently more than 300 doctoral students from all over the world
  - International Postdoc Programs
  - Multiple training programs for students
  - Bilateral Agreements with several countries for exchange of scientists and education of young researchers and engineers, e.g. French German Cooperation Agreement DSM-CEA/IN2P3 – GSI/FAIR

FAIR – The Facility



"Gain factors" rel. to GSI

- 100 – 10.000 x intensity
- 10 x energy
- antiproton beams
- suite of storage cooler rings

FAIR – The Facility

FAIR

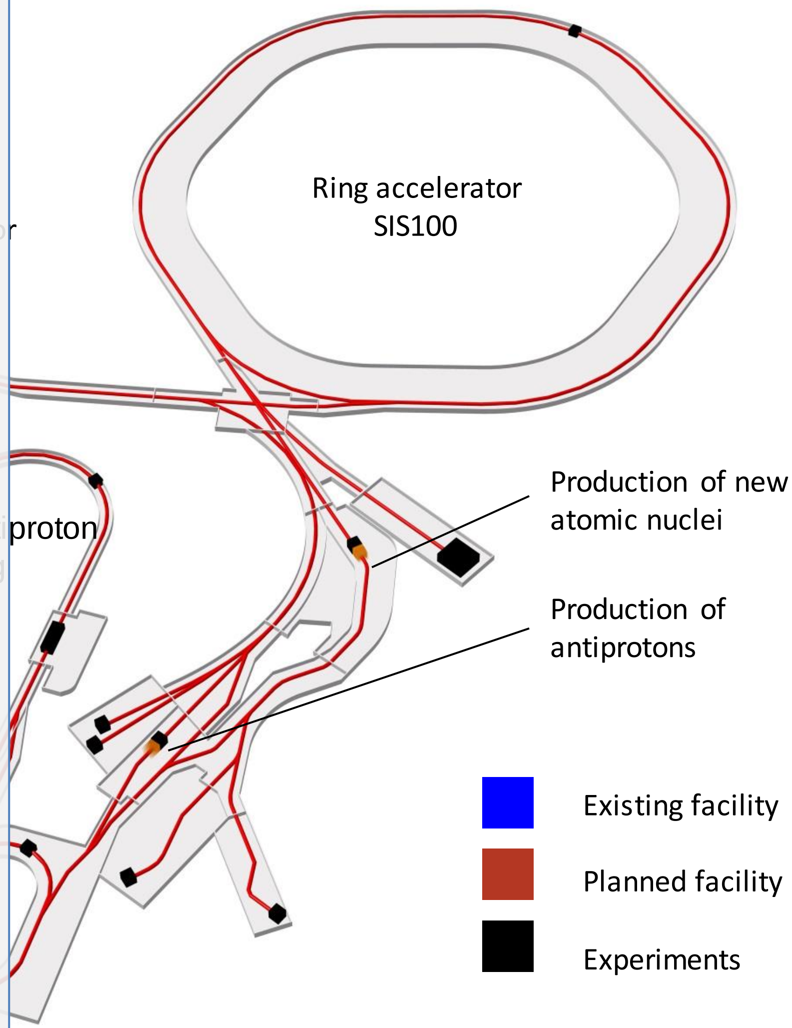
... accelerates particle beams from (anti)protons up to uranium ions with

- very high intensities
  - up to a factor of ~100 increase for primary Uranium beams (~ 5 x 10^{11} U^{28+} ions /s),
  - up to a factor of ~10.000 increase for secondary rare isotope beams
- high pulse power (up to ~ 50 kJ / 50 ns)
- suite of storage cooler rings equipped with stochastic and electron cooling for brilliant beam quality

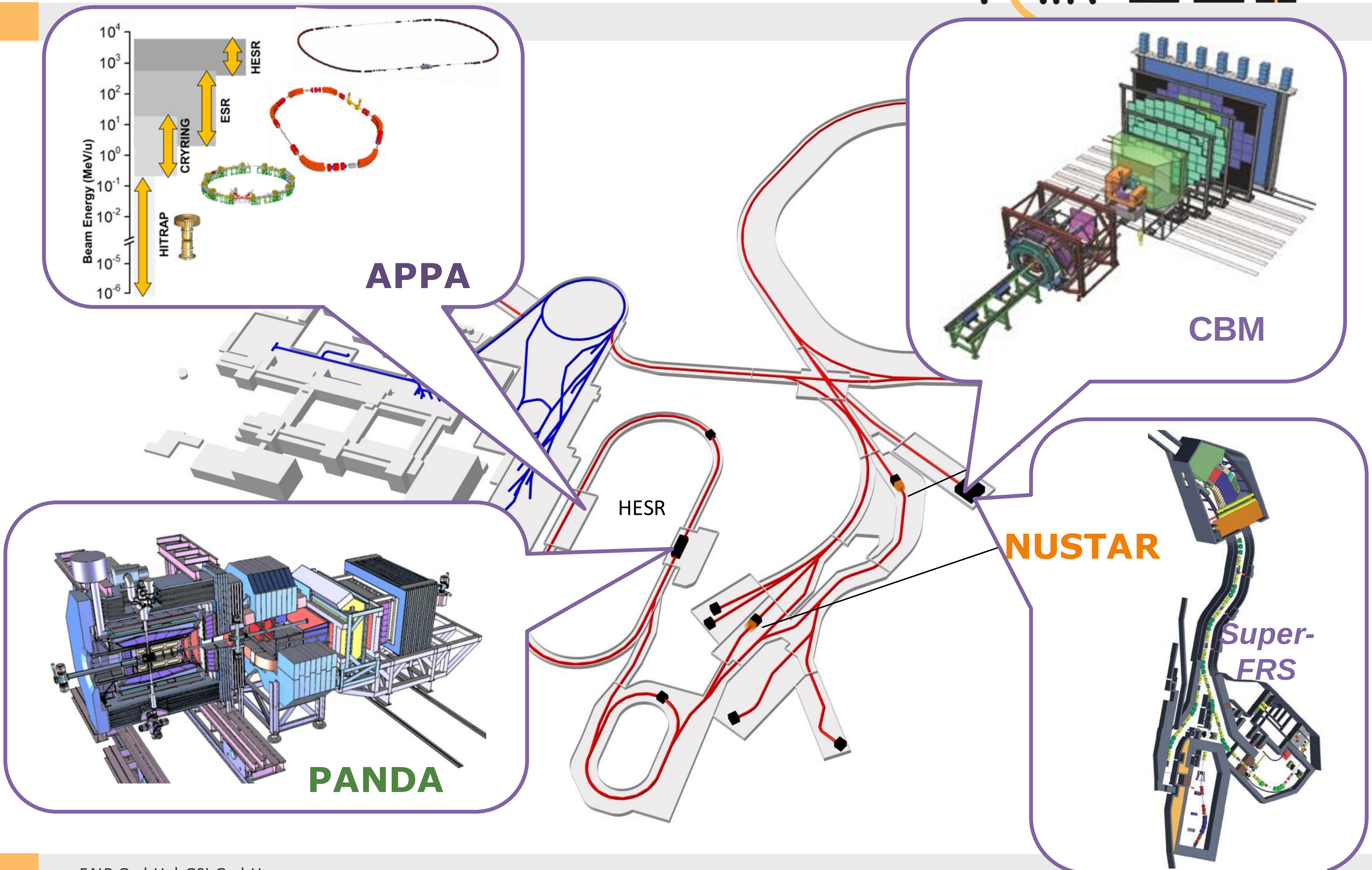
... develops and exploits innovative particle separation and detection methods, as well as novel computing techniques

... to perform forefront experiments towards the production and investigation of

New Extreme States of Matter.



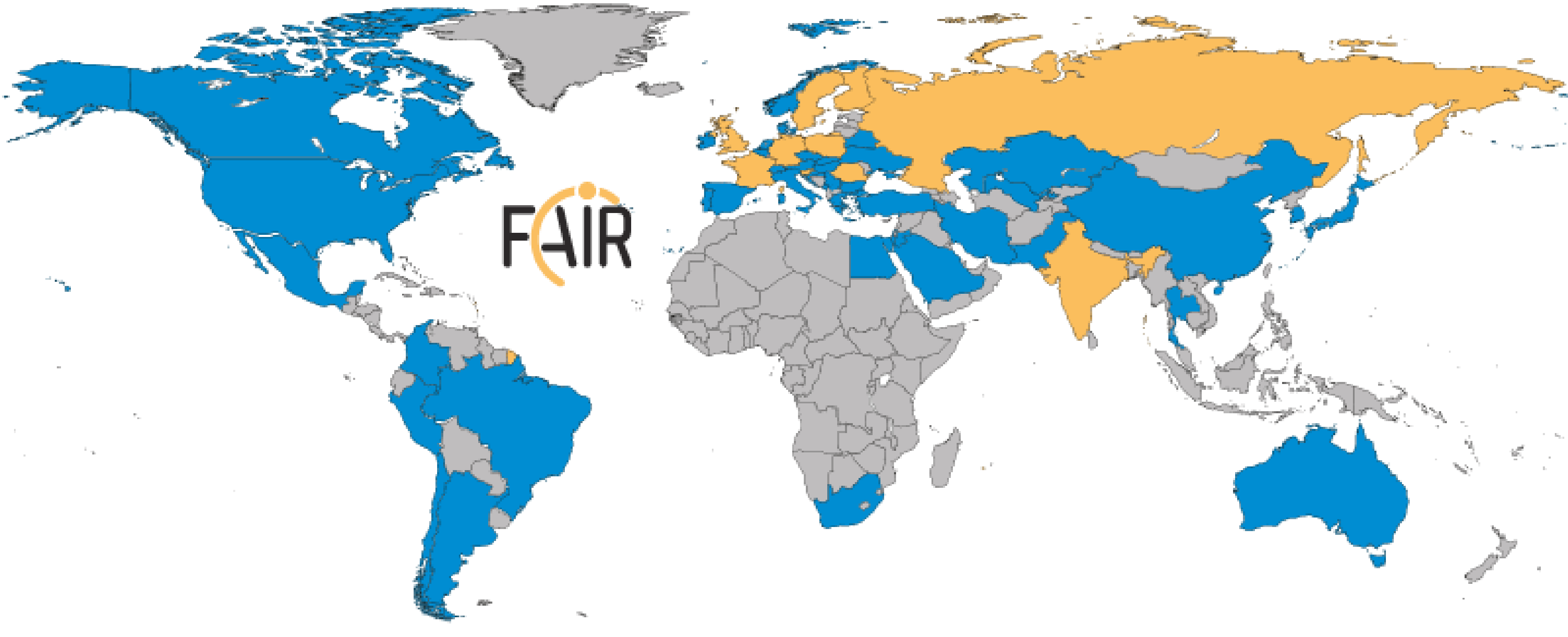
FAIR – four research pillars



Four Scientific Collaborations

APPA	Atomic Physics and Fundamental Symmetries, Plasma Physics, Materials Research, Radiation Biology, Cancer Therapy with Ion Beams / Space Res.
CBM	Dense and Hot Nuclear Matter
NUSTAR	Nuclear Structure far off stability, Physics of Explosive Nucleosynthesis (r process)
PANDA	Hadron Structure & Dynamics with cooled antiproton beams

FAIR: International Cooperation

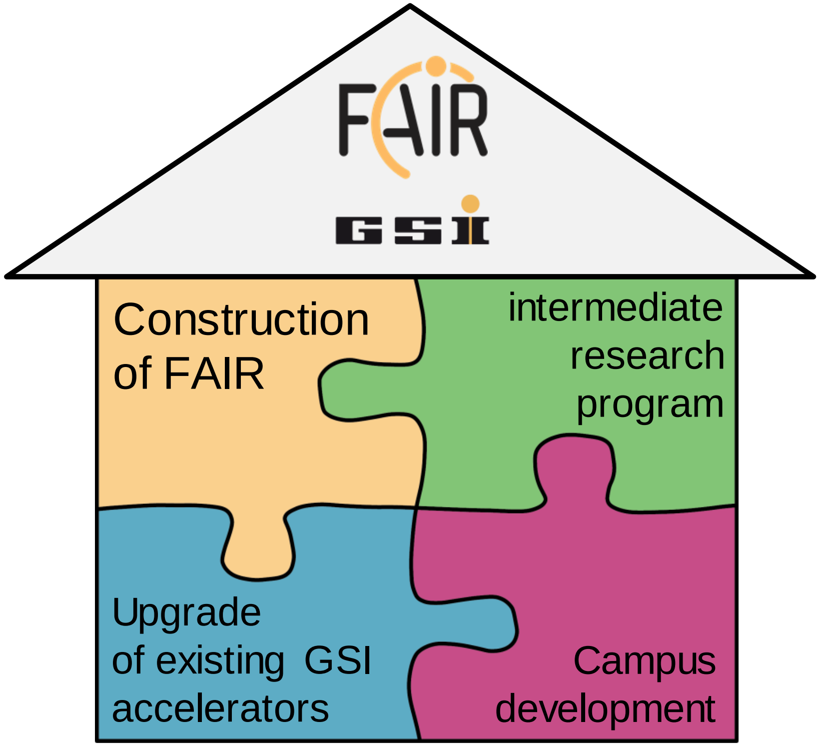


- Realization and operation in international cooperation
- Nine international shareholders
- Participation of 3.000 scientists from all continents

Challenges and Priorities in the Forthcoming Years

- Build FAIR and develop GSI for FAIR - in time and to budget

- Making FAIR a success requires:
  - a strong host laboratory with world-class facilities and a leading role in the international scientific arena
  - a vibrant scientific community, in particular young researchers, performing a first-class intermediate research program
  - a modern campus with appropriate infrastructure for the employees and the international users



Important Achievements in 2015/2016

- After critical project review successful restart in 2015 and 2016

- Comprehensive civil construction plan:
  ➔ completion of all buildings by 2022

- Full integrated planning for construction and commissioning of the entire project:
  ➔ completion and commissioning of the full FAIR facility by 2025.

- ***Work is going on:***
  <u>Groundbreaking for Synchrotron tunnel on 4 July 2017 !</u>

Integrated Project Time Schedule – Level 1: FAIR Buildings, Accelerators & Experiments

FAIR GSI

	Name	Duration	Start	Finish
0	**Level 1 - FAIR Integrated Master Schedule**	**226,22 mons**	**08.08.2008**	**11.12.2025**
1	**FAIR Buildings**	**72,1 mons**	**08.06.2017**	**16.12.2022**
2	T110 SIS100	68,75 mons	08.06.2017	16.12.2022
11	G004 Transfer Building/T104N Transfer SIS100/T112N Trar	62,55 mons	29.11.2017	16.12.2022
20	G017A Cryo Compressor Building	43,25 mons	27.06.2019	16.12.2022
29	G017.1 Main Supply Building North	45,6 mons	23.04.2019	16.12.2022
36	G014 CBM/T112S Transfertunnel SIS100-CBM	48,75 mons	24.01.2019	16.12.2022
45	G004A Transfer Supply/T101 Transfer Line SIS18	30,4 mons	08.07.2020	16.12.2022
54	G018 SFRS/T103N Transfer SFRS-Experimente/T113N Tran	39 mons	24.10.2019	16.12.2022
64	G020 p-linac	26,5 mons	26.10.2020	16.12.2022
73	G017.2 Main Supply Building South/G006 SFRS HE-Cave/G	49,55 mons	17.12.2018	16.12.2022
88	G007 CR/T106 Transfer CR-HESR	47,55 mons	27.02.2019	16.12.2022
97	G009 HESR PANDA/T108 HESR	34,4 mons	18.03.2020	16.12.2022
107	G021 Storage	21,65 mons	01.04.2021	16.12.2022
114	G120 Supply Line	32,6 mons	07.05.2020	16.12.2022
120	**SIS100**	**174,17 mons**	**17.10.2011**	**20.02.2025**
121	SIS 100 procurement phase	128,25 mons	17.10.2011	13.08.2021
126	SIS 100 installation into tunnel, commissioning without beam phase	45,6 mons	31.12.2020	28.06.2024
132	SIS100 commissioning with beam	8,42 mons	28.06.2024	20.02.2025
135	**SuperFRS**	**143,92 mons**	**02.06.2014**	**12.06.2025**
136	SuperFRS procurement phase	114,45 mons	02.06.2014	09.03.2023
141	SuperFRS installation into tunnel, commissioning without beam	30,4 mons	06.10.2021	02.02.2024
148	SuperFRS commissioning with beam	17,67 mons	02.02.2024	12.06.2025
151	**pLINAC**	**192,43 mons**	**06.01.2011**	**08.10.2025**
152	pLinac procurement phase	138,2 mons	06.01.2011	11.08.2021
157	pLinac installation + commissioning with beam	15 mons	25.10.2021	16.12.2022
161	pLinac installation after HBO, commissioning with beam	36,63 mons	19.12.2022	08.10.2025
162	**p-bar separator**	**150,5 mons**	**05.09.2013**	**20.03.2025**
163	p-bar procurement phase	103,93 mons	05.09.2013	24.08.2021
168	p-bar installation into tunnel, commissioning without beam phase	34,34 mons	24.08.2021	10.04.2024
174	p-bar commissioning with beam	12,28 mons	10.04.2024	20.03.2025
177	**Collector Ring**	**183,57 mons**	**24.08.2011**	**18.09.2025**
178	CR procurement phase	134,85 mons	24.08.2011	24.12.2021
183	CR installation into tunnel, commissioning without beam	28,05 mons	16.06.2021	09.08.2023
188	CR commissioning with beam	27,51 mons	09.08.2023	18.09.2025
191	**HESR**	**218,02 mons**	**26.03.2009**	**11.12.2025**
192	HESR procurement phase	113,8 mons	26.03.2009	15.12.2017
197	HESR installation into tunnel, commissioning without beam	20,1 mons	18.11.2021	02.06.2023
203	HESR commissioning with beam	32,92 mons	02.06.2023	11.12.2025
206	**HEBT**	**138,77 mons**	**02.01.2014**	**22.08.2024**
207	HEBTprocurement phase	92,8 mons	02.01.2014	11.02.2021
224	HEBT installation and commissioning without beam	45,52 mons	25.02.2021	22.08.2024
240	**CBM**	**152,67 mons**	**08.07.2013**	**20.03.2025**
241	CBM procurement phase	130,25 mons	08.07.2013	30.06.2023
245	CBM installation and commissioning without beam	33,55 mons	01.12.2021	26.06.2024
250	CBM commissioning with beam	9,52 mons	26.06.2024	20.03.2025
253	**APPA**	**199,07 mons**	**16.12.2009**	**20.03.2025**
254	APPA procurement phase	172,65 mons	16.12.2009	10.03.2023
259	APPA installation into tunnel, commissioning without beam	36,6 mons	31.12.2020	20.10.2023
271	APPA commissioning with beam	18,42 mons	20.10.2023	20.03.2025
274	**NUSTAR**	**141,17 mons**	**15.09.2014**	**10.07.2025**
275	NUSTAR procurement phase	120 mons	15.09.2014	27.11.2023
278	NUSTAR installation into cave or tunnel phase	38,85 mons	17.06.2021	07.06.2024
288	NUSTAR commissioning with beam	14,17 mons	07.06.2024	10.07.2025
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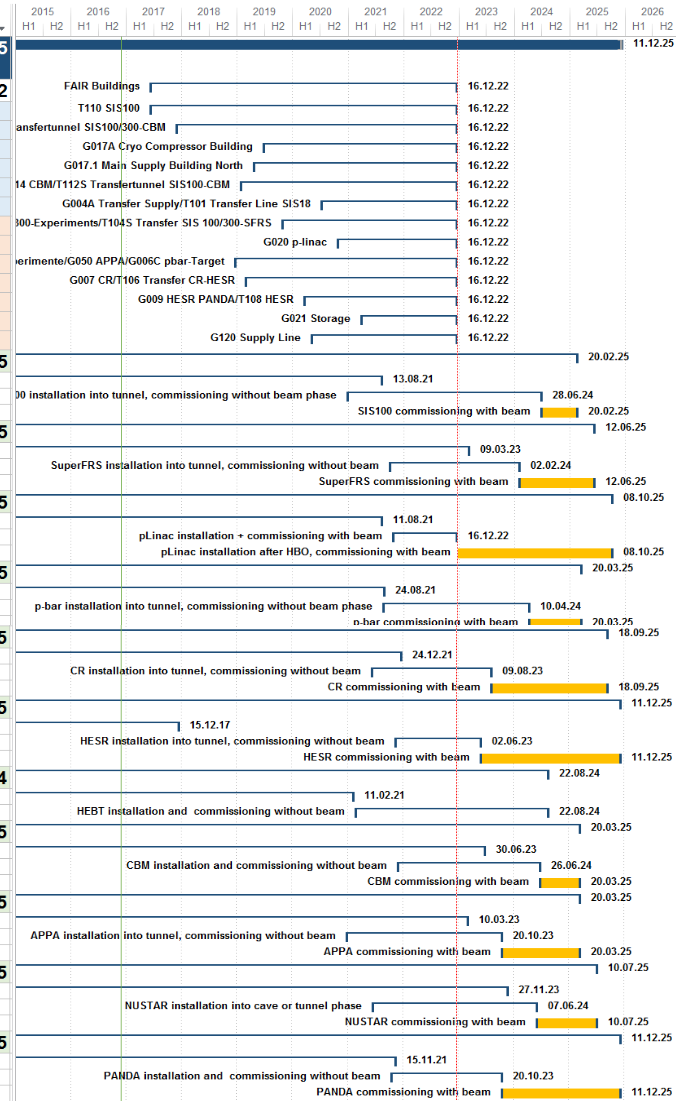

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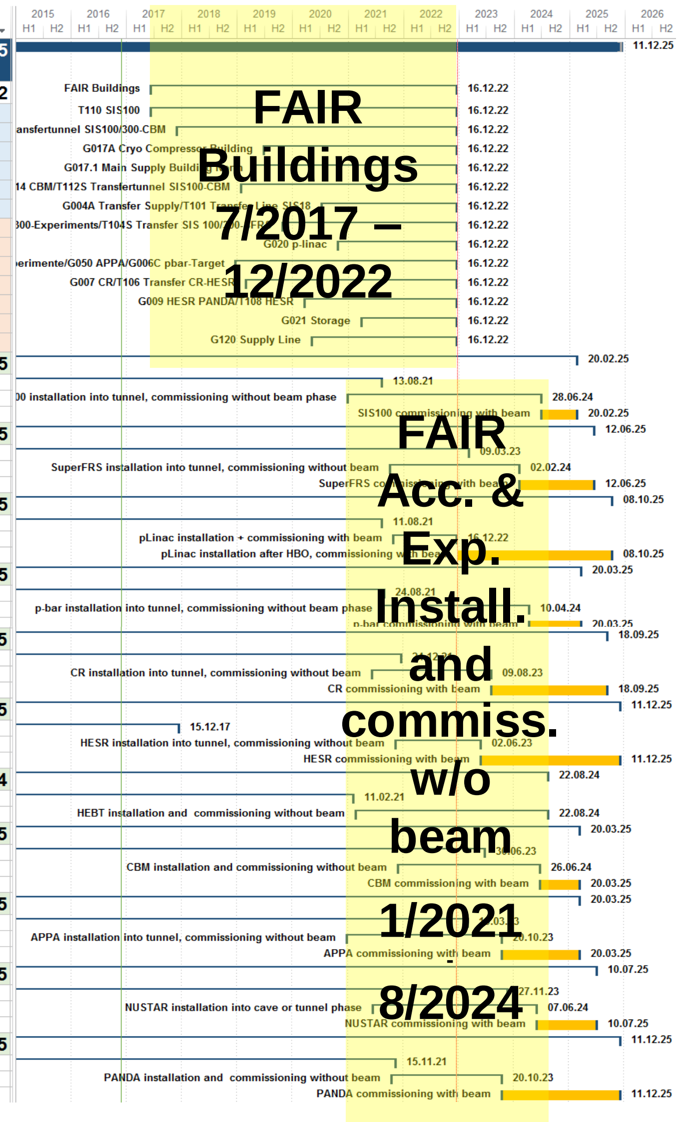
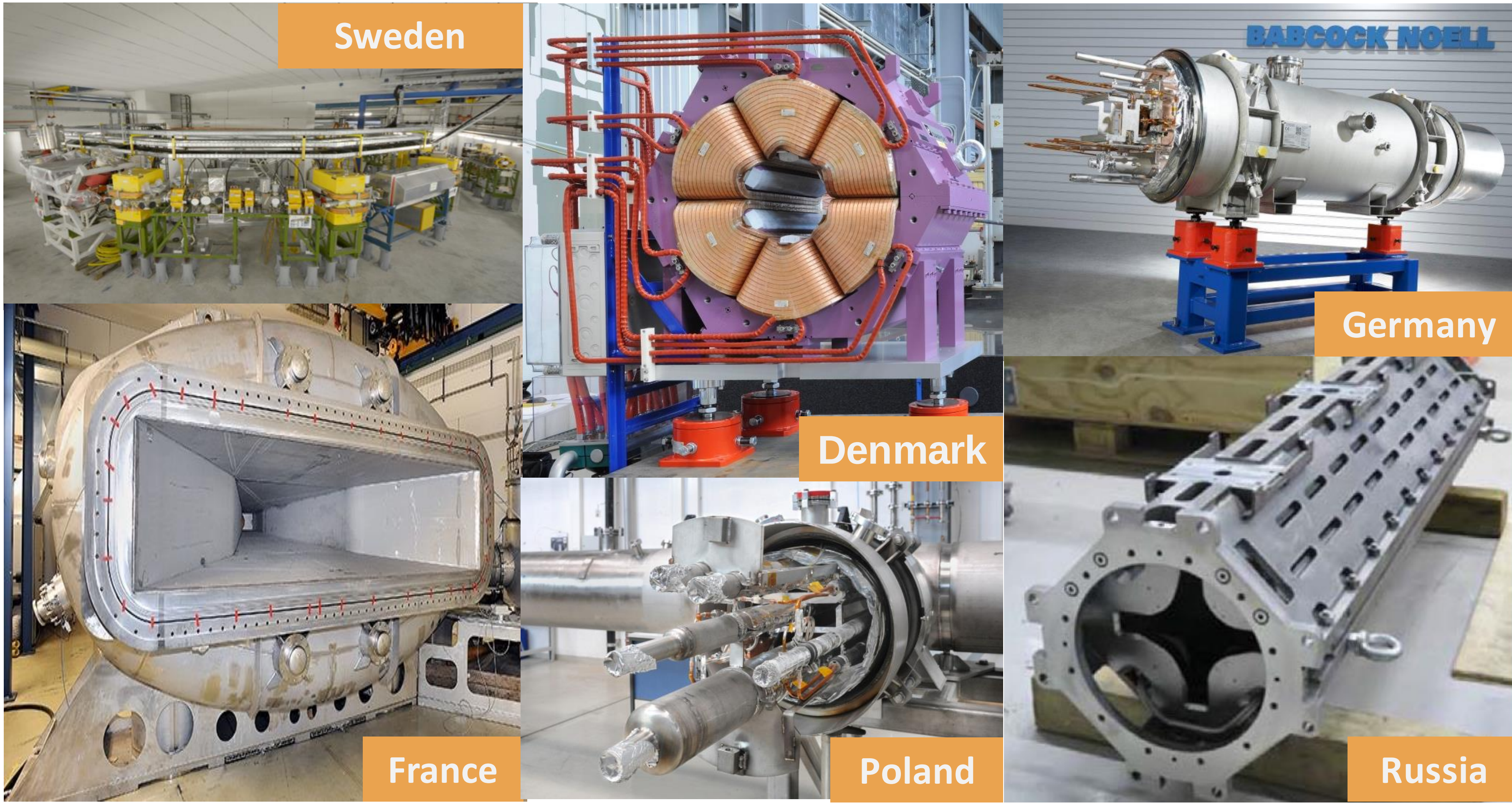
LEVEL_1

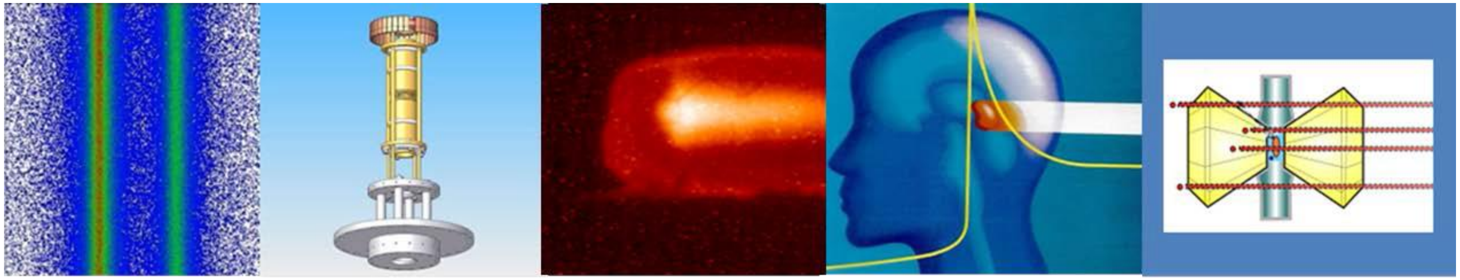


Procurement of FAIR components is in full swing ...



- Accelerator and detector contributions from many different partner institutions

The experiments advance!



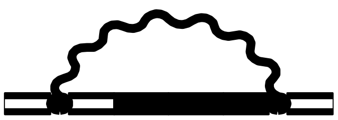
From fundamental to applied research – Atomic physics, Plasma Physics, Application

APPA

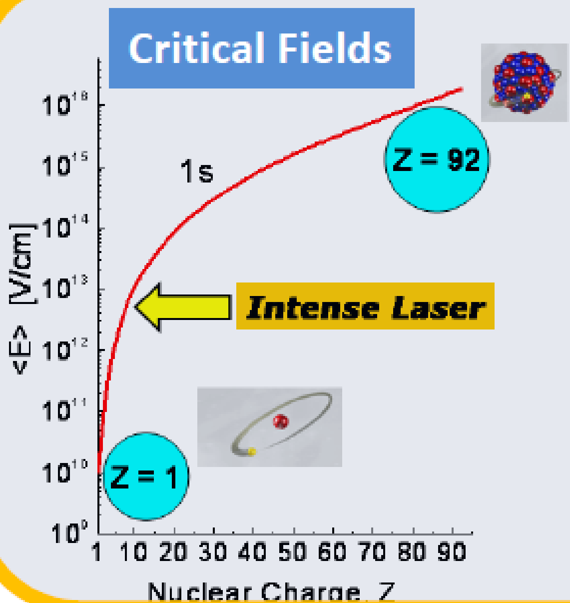
Atomic & Fundamental Physics

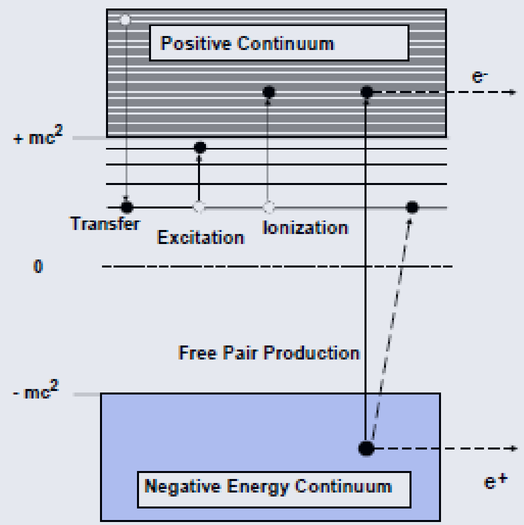
Interplay between Relativity, Correlation, and QED in the Non-Perturbative Regime

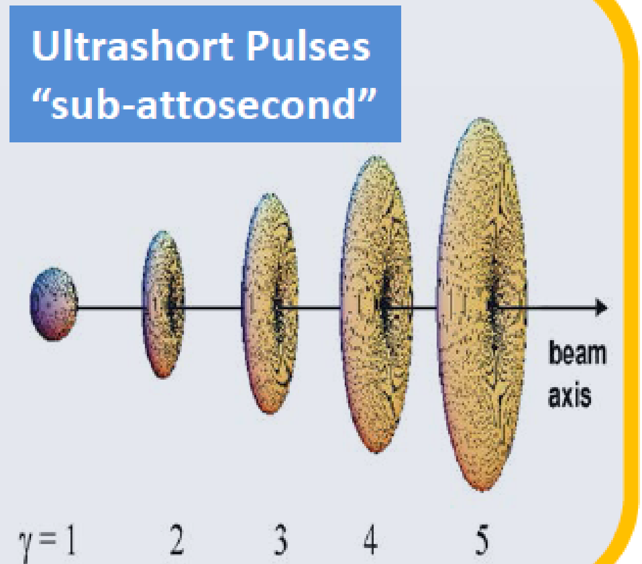
$$\alpha Z \approx 1$$



- **Radiative corrections in the non-perturbative regime**
- **Correlated multi-body dynamics for atoms and ions**
- **Precision determination of fundamental constants**
- **Influence of atomic structure on nuclear decay properties**







21

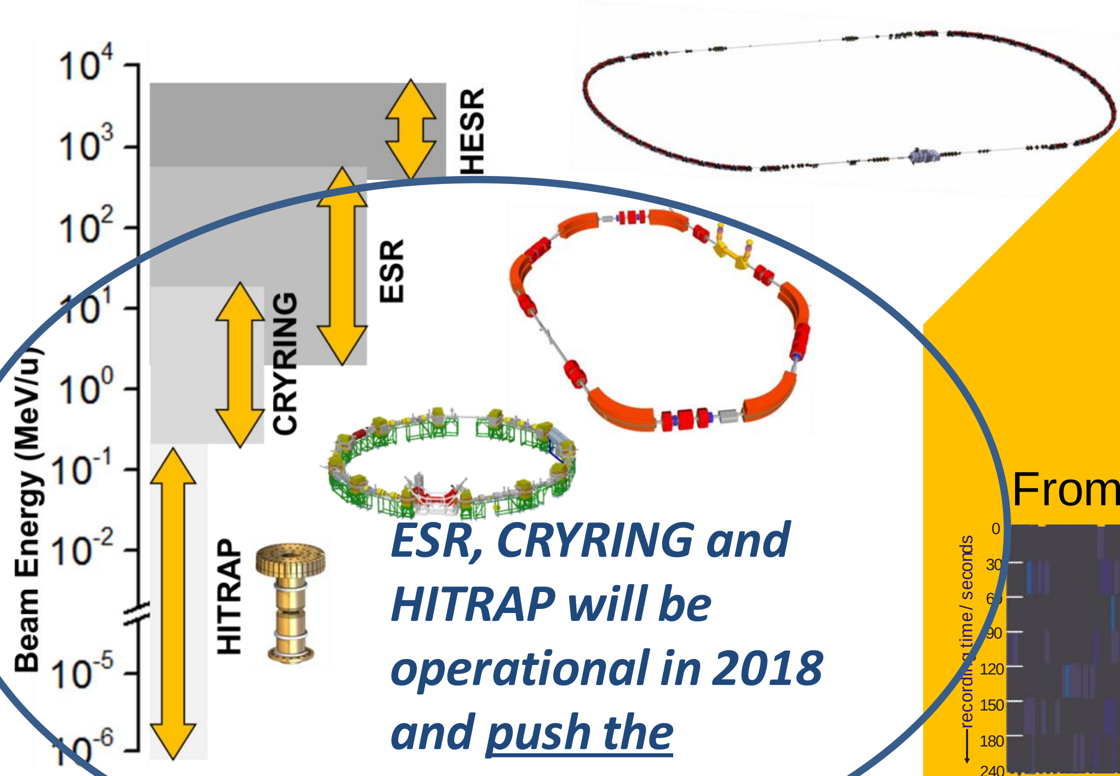
Ion Beam Facilities / Trapping & Storage

Worldwide Unique

Stored and Cooled

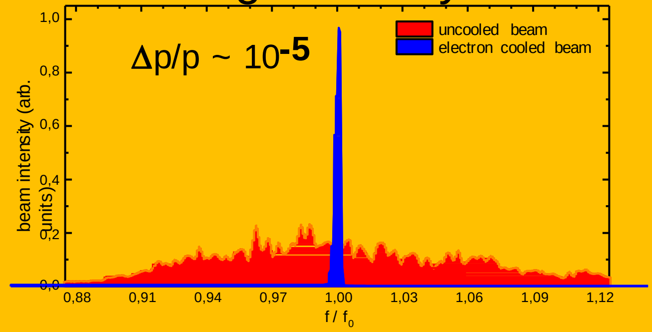
Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei

From Rest to Relativistic Energies (up to 4.9 GeV/u)

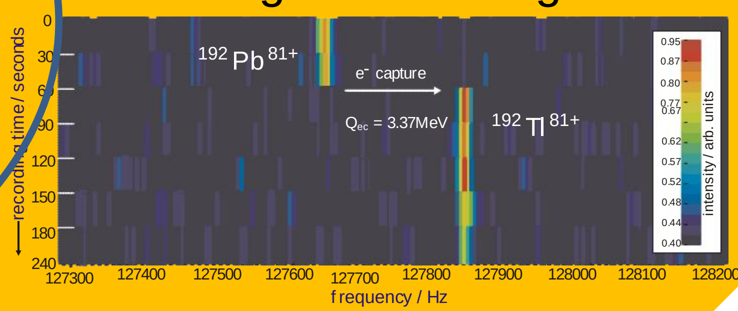


ESR, CRYRING and HITRAP will be operational in 2018 and push the "precision" frontier!

Cooling: The Key for Precision



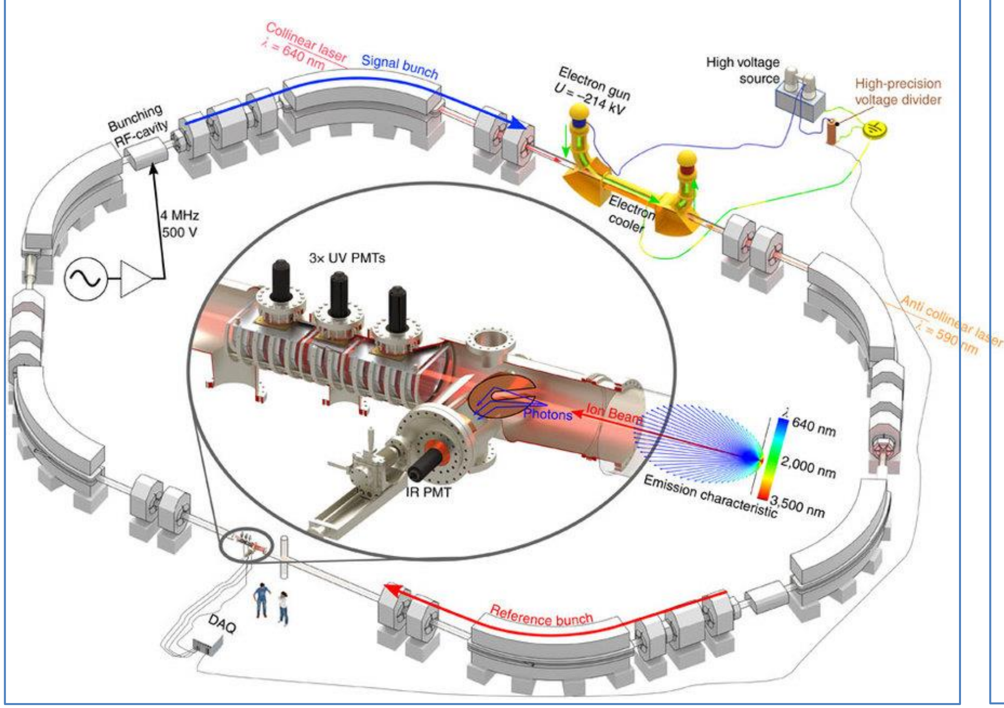
From Single Ions to Highest Intensities



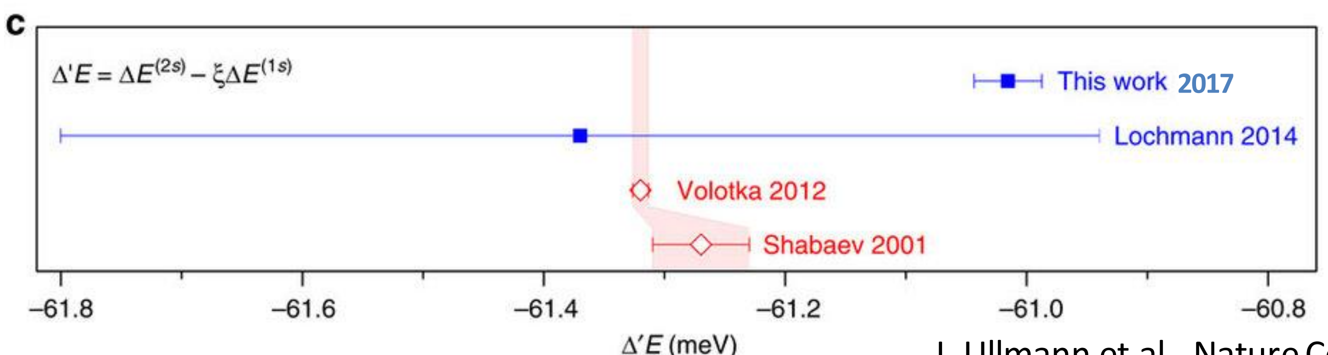
22

Recent "precision highlight" from SPARC@ESR: Precision determination of HFS in H- and Li-like Bismuth ions

ESR storage cooler ring - part of FAIR facility



- Measurement of hyperfine splittings in hydrogen-like <u>and</u> lithium-like bismuth $^{209}Bi^{82+,80+}$ allows to disentangle QED and nuclear effects.
- New ESR measurement has improved the precision by more than one order of magnitude.
- **New experimental result (blue)** shows a 7-σ discrepancy compared to the **theoretical QED prediction (red).**

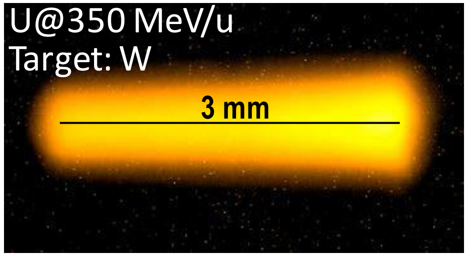


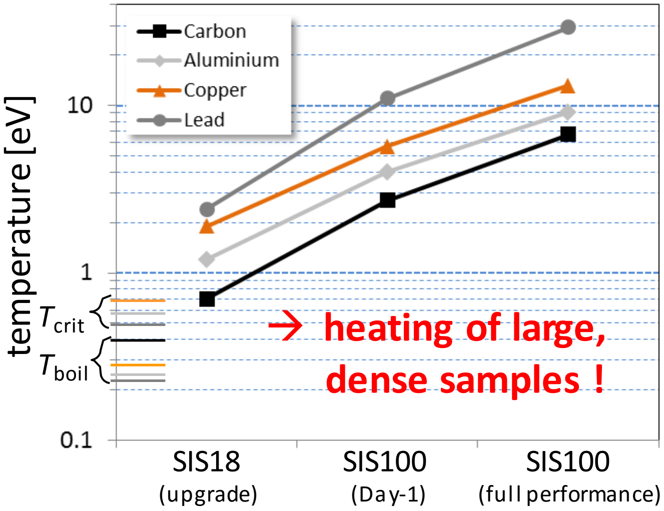
J. Ullmann et al., Nature Communications 8, 15484 (2017).

FAIR will offer exciting new possibilities for research in High-Energy Density Science

Unique properties of heavy-ion driven plasmas

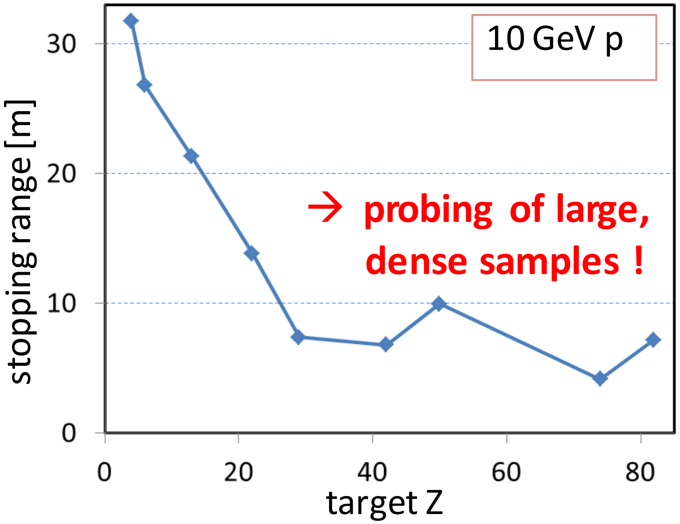
- large volumes (mm³)
- uniform conditions
- -> thermal equilibrium
- any target material
- rep. rate, reproducibility





Protons as dense matter probe

- Long range (~m) of relativistic protons
- High-resolution imaging of small angle deflection →accurate density meas.
- Ultra-intense proton pulses allow for short (~10ns) time exposure

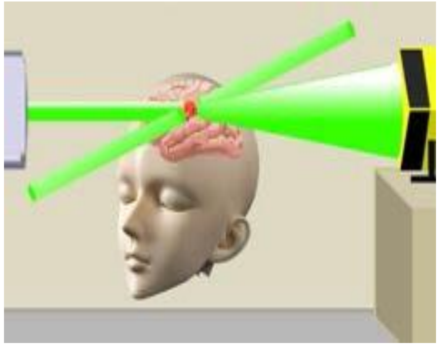


- **FAIR will produce the worlds largest volumes of uniform HED matter** (x100 increase in specific energy deposition over GSI)
- **FAIR will host the worlds highest resolution proton microscope**

BIO*MAT

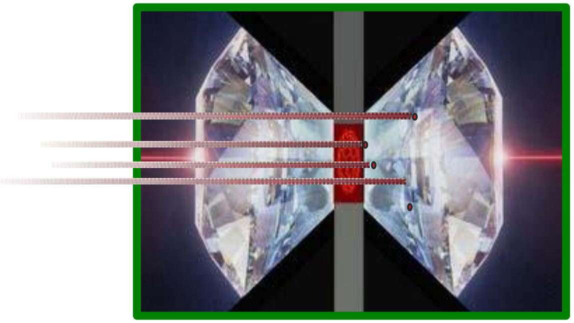
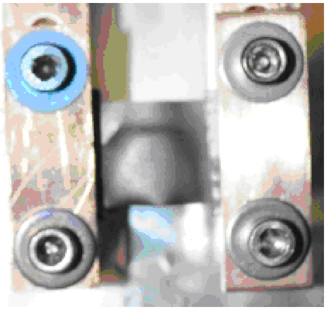
Research topics at FAIR

Biophysics



- **Space radiation biophysics**
- **Biological effects of very high energetic ions**
- **Shielding measures: new materials**
- **Particle therapy: "theranostics"**
  (use of high energetic proton beams for simultaneous diagnostics and therapy)

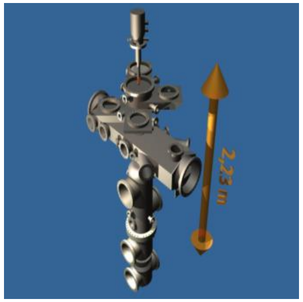
Materials Research

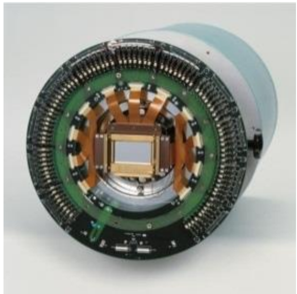
- **Ion-matter interaction at highest energies and highest charge states**
- **Materials behavior under extreme conditions (high flux irradiations)**
- **Irradiations under multiple extremes (high pressure, temperature, dose)**
- **Radiation hardness of accelerator and spacecraft components**

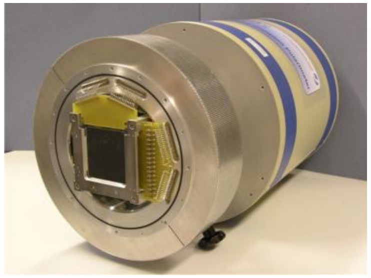
25

APPA – Detector Development

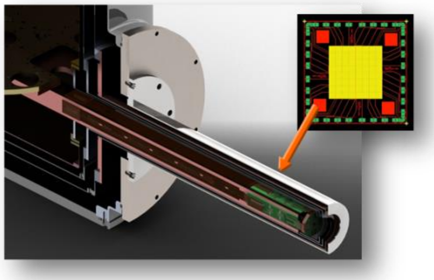


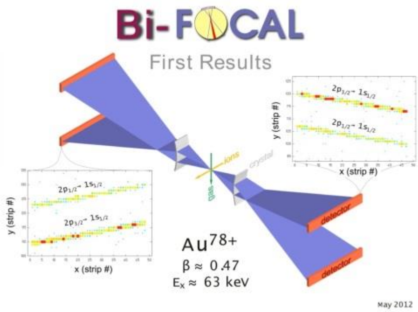
Targets



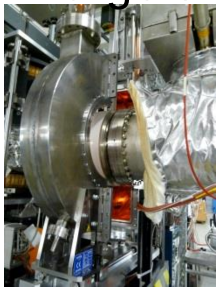


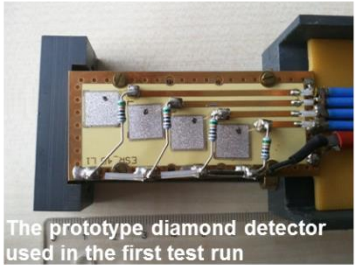
3D solid-state detectors



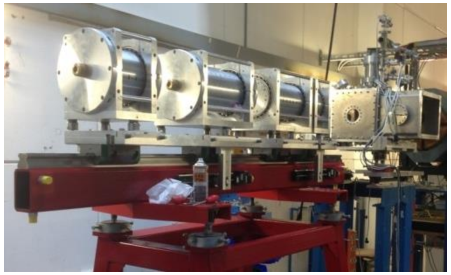


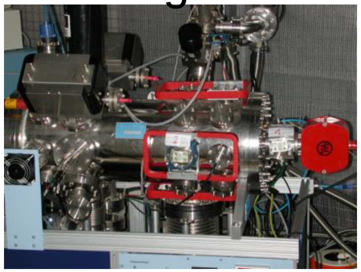
High-resolution spectrometers





Particle detectors

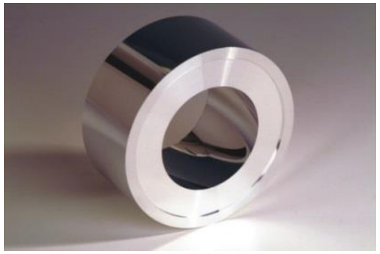


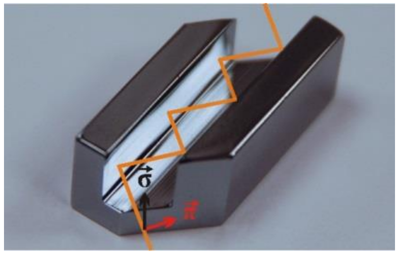


Particle spectrometers

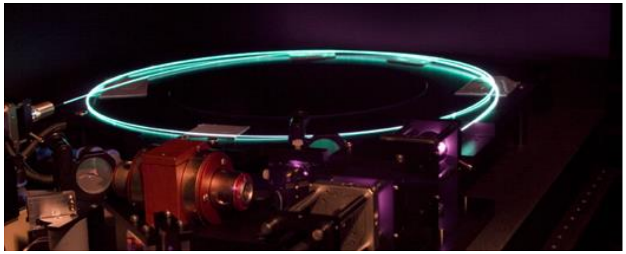
High pressure cell

Traps





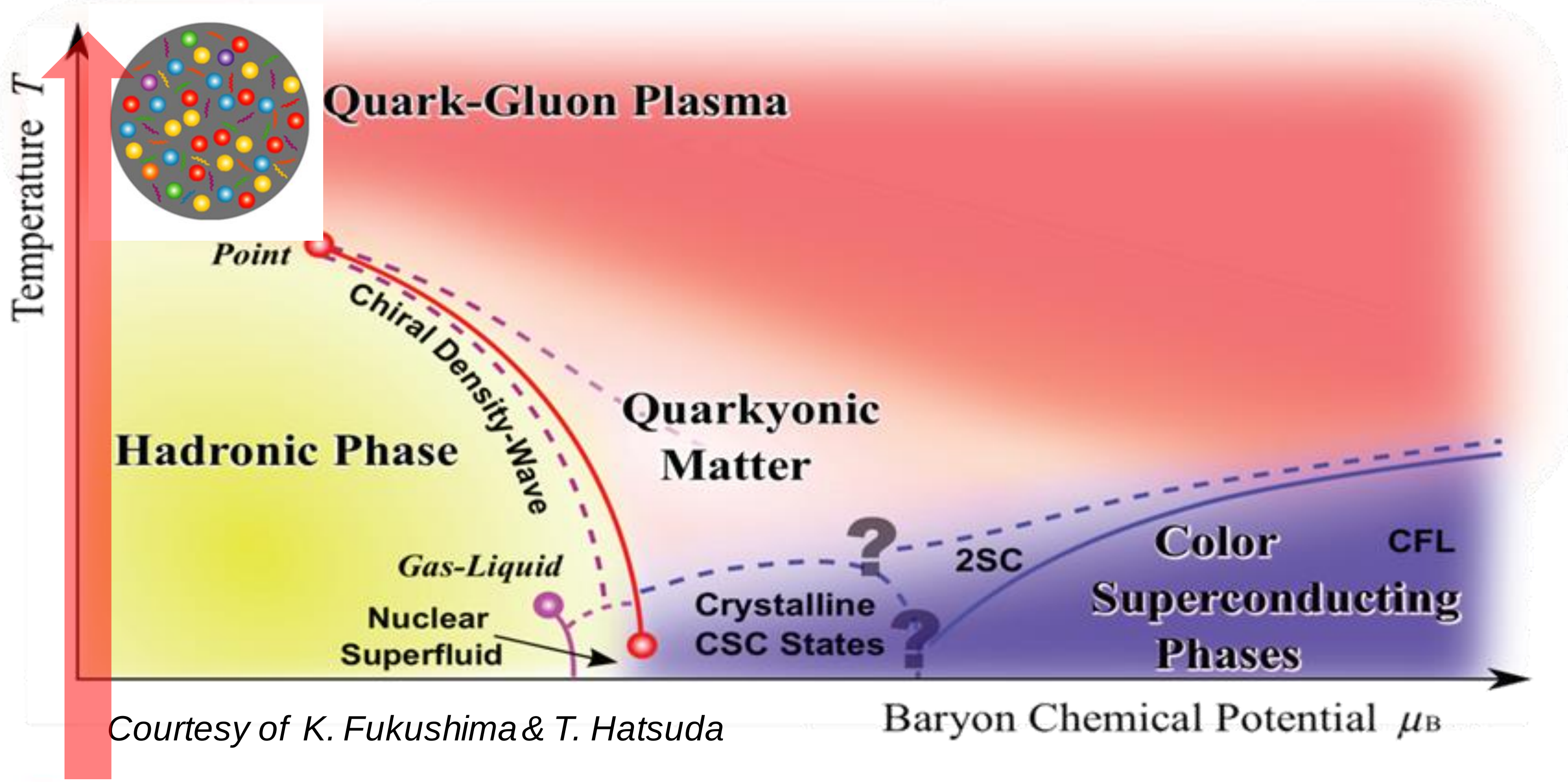
X-ray optics, channel-cut crystals



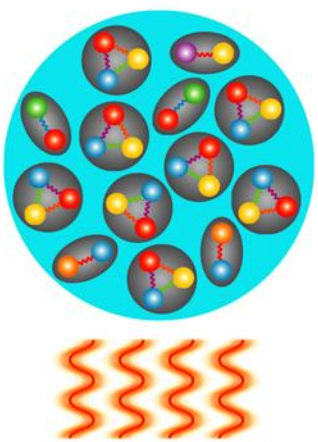
Laser systems

Compressed Baryonic Matter

Exploring the phase diagram of „nuclear“ matter



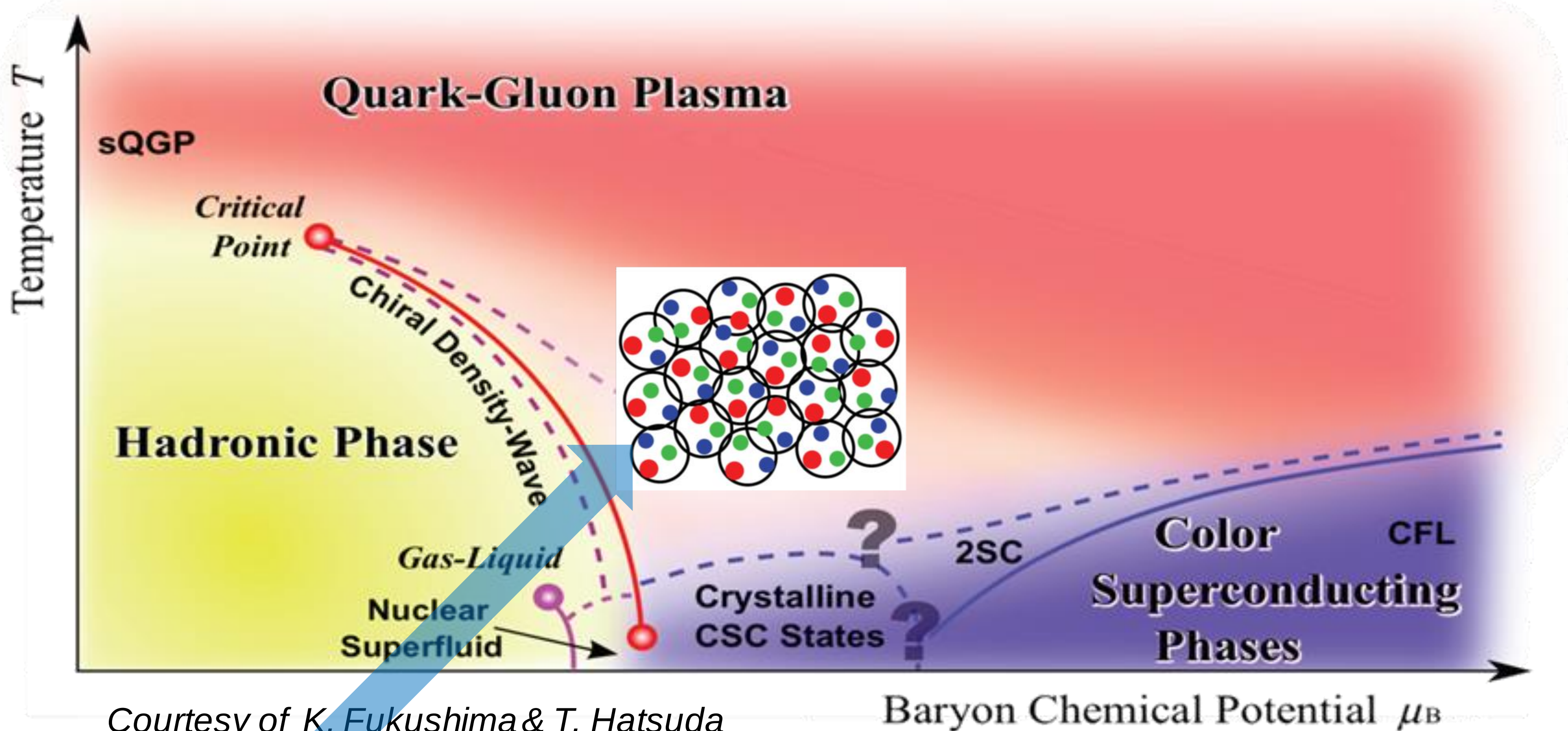
Courtesy of K. Fukushima & T. Hatsuda



<u>At very high temperature:</u>

- N of baryons ≈ N of antibaryons
  Situation similar to early universe
- L-QCD finds crossover transition between
  hadronic matter and Quark-Gluon Plasma
- ALICE, ATLAS, CMS at LHC
  STAR, PHENIX at RHIC

Exploring the phase diagram of „nuclear“ matter



Courtesy of K. Fukushima & T. Hatsuda

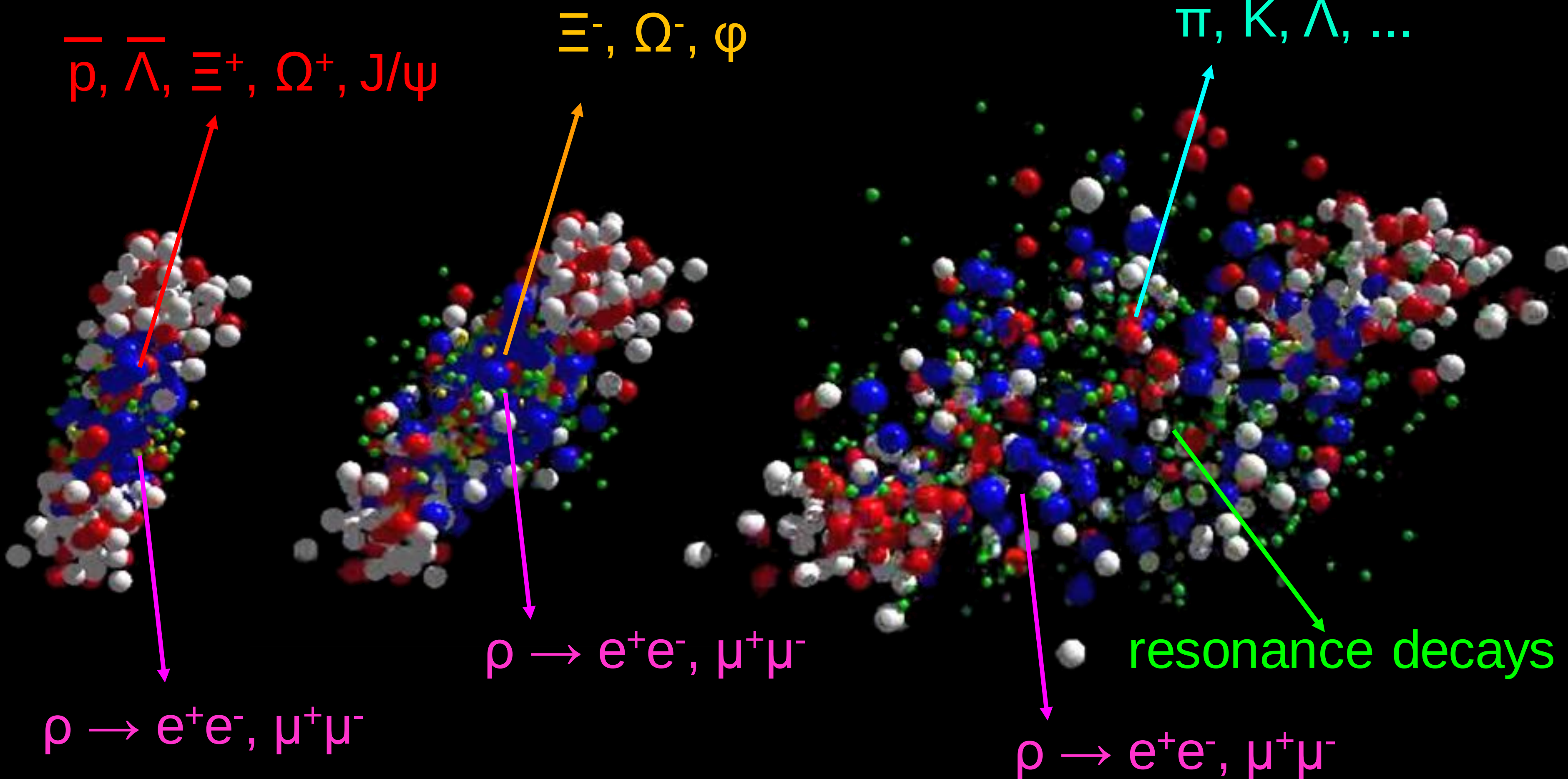
CBM

<u>At high baryon density:</u>

- N of baryons >> N of antibaryons
  Densities like in neutron star cores
- L-QCD not (yet) applicable
- Models predict first order phase transition with mixed or exotic phases
- Competing Experiments: BES at RHIC, NA61 at CERN SPS, NICA at JINR

„Rare" Messengers from the dense fireball: CBM at FAIR

Yield:
1 particle in 1 million collisions

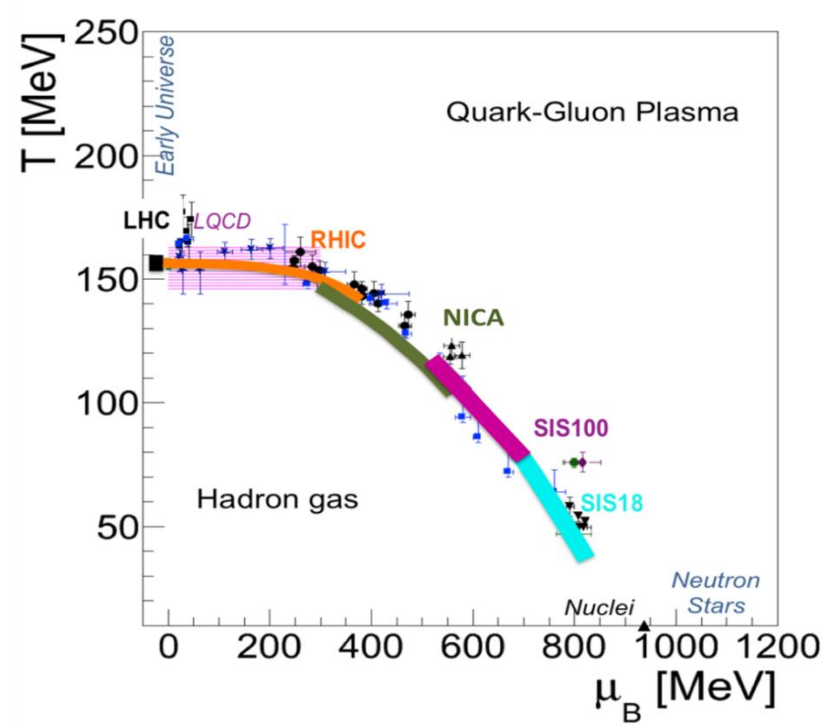


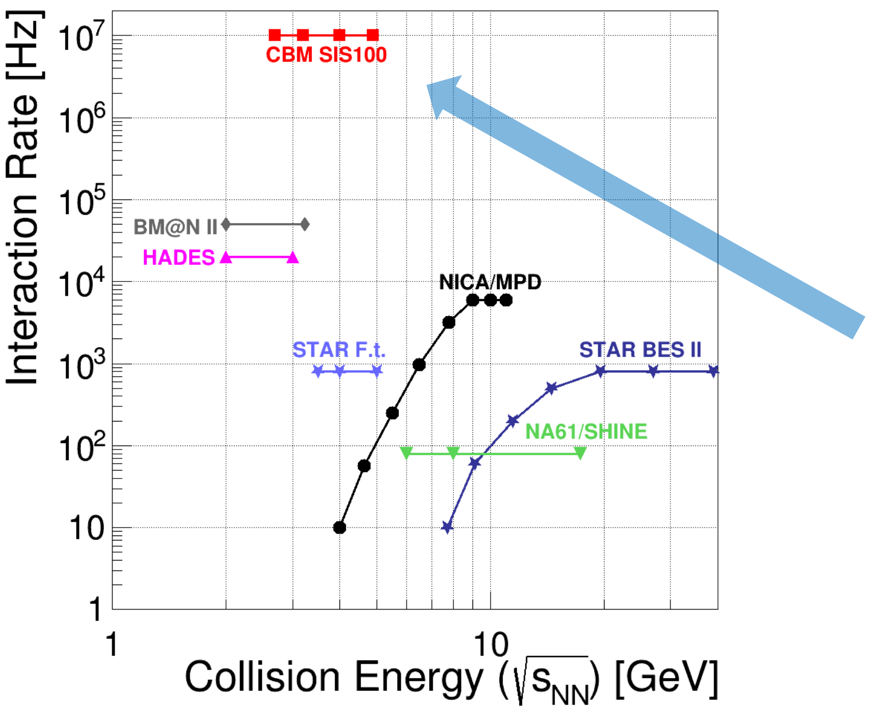
UrQMD transport calculation Au+Au 10.7 A GeV

CBM: Focus on SIS100 beam energies

Physics program: Exploring QCD matter at neutron star core densities (> 5 ρ_0)

- nuclear matter equation of state
- search for phase transition, phase coexistence, exotic phases
- onset of Chiral symmetry restoration
- hypernuclei, strange matter

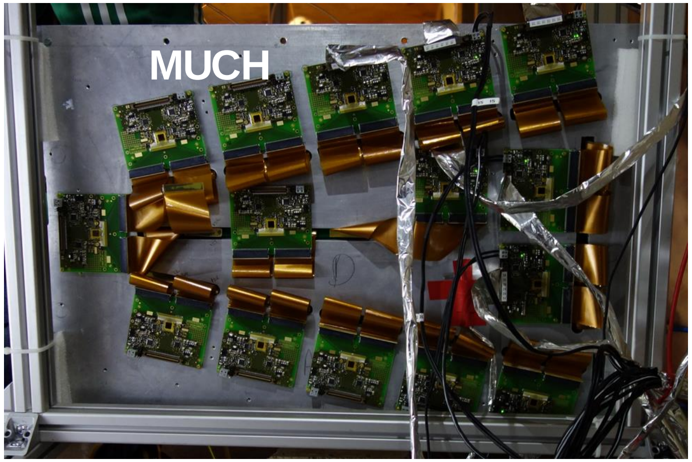


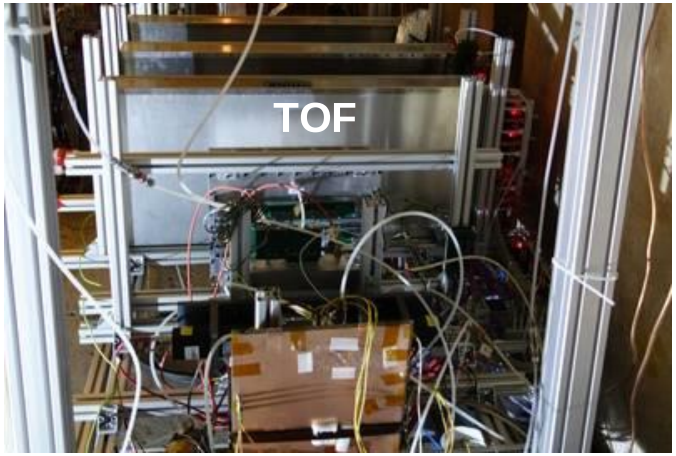


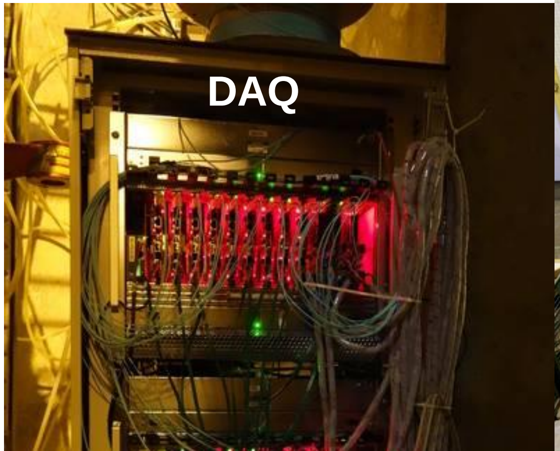
- New physics insights by "pushing" interactions rates up to 10 MHz
- optimized for precision measurements of rare probes (hyperons, hypernuclei, dileptons, charm)

CBM detector and DAQ tests at CERN SPS

- Successfull operation of detectors and of the DAQ system
- Events successfully reconstructed from free-streaming data
- Data quality allows for investigation of detector performance



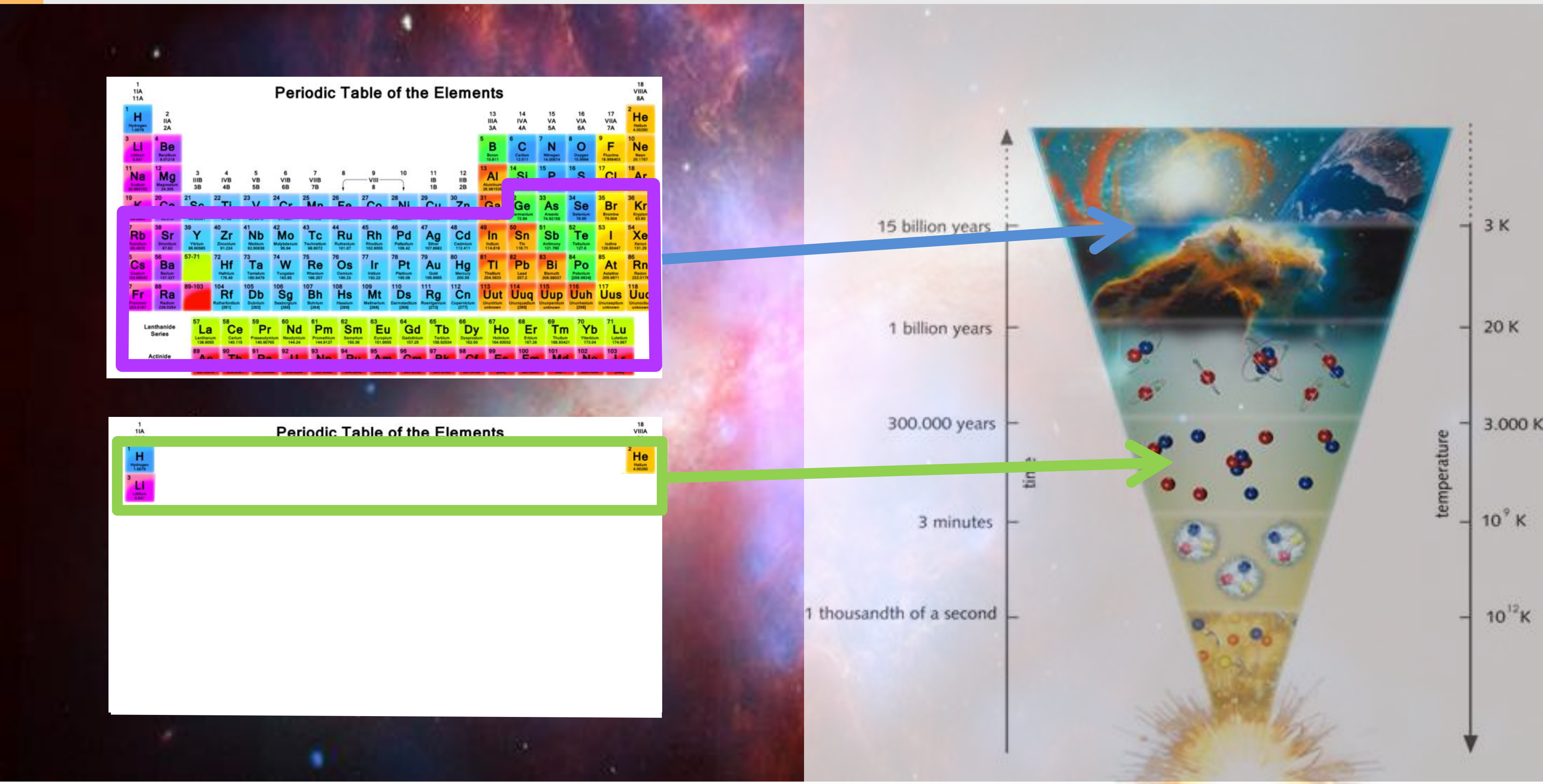




NUSTAR

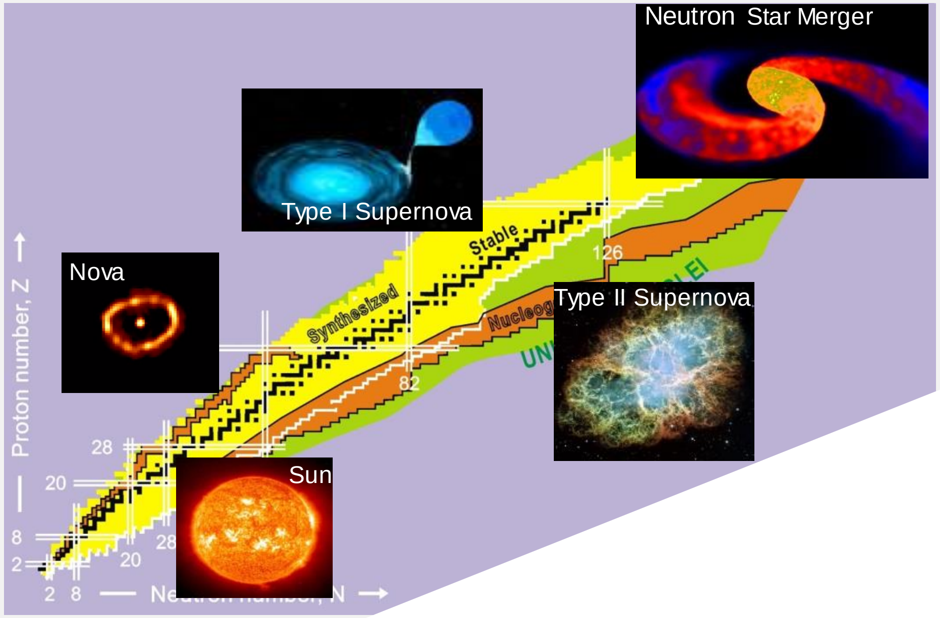
Synthesis of the chemical elements

Synthesis of the chemical elements



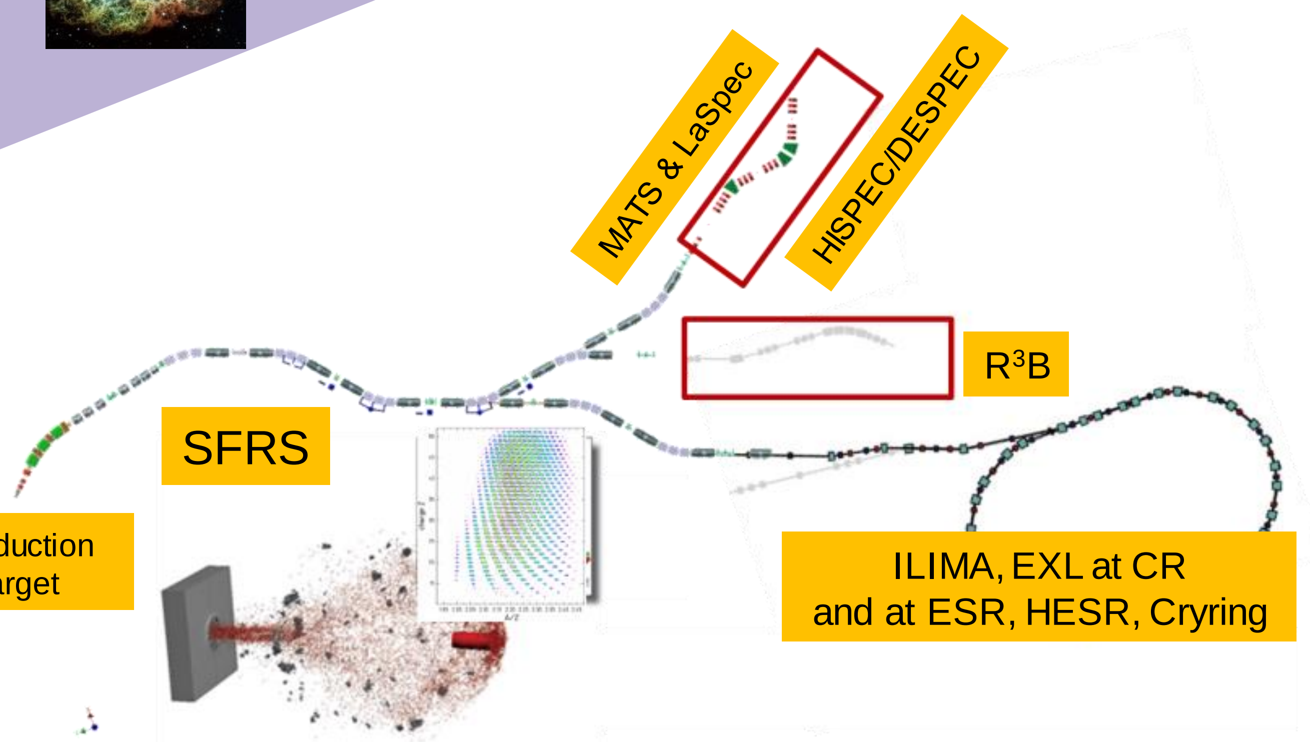
- „Pushing“ our understanding of the origin of the chemical elements: Where and how were the heavy elements made in the universe?

NUSTAR - Origin of elements in the universe



„Nucleosynthesis sites“ in the universe

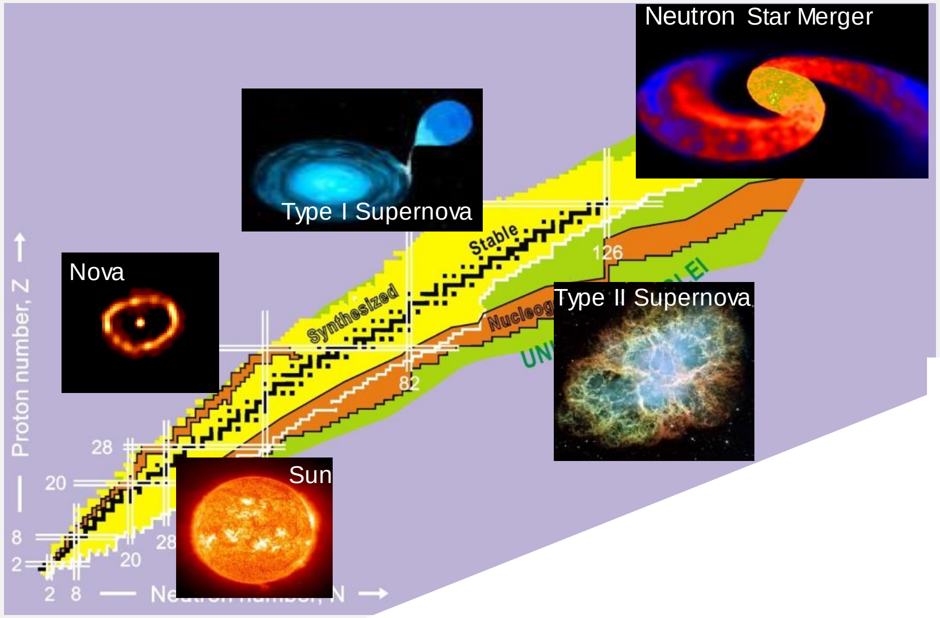
„Nucleosynthesis sites” at FAIR



SIS 100

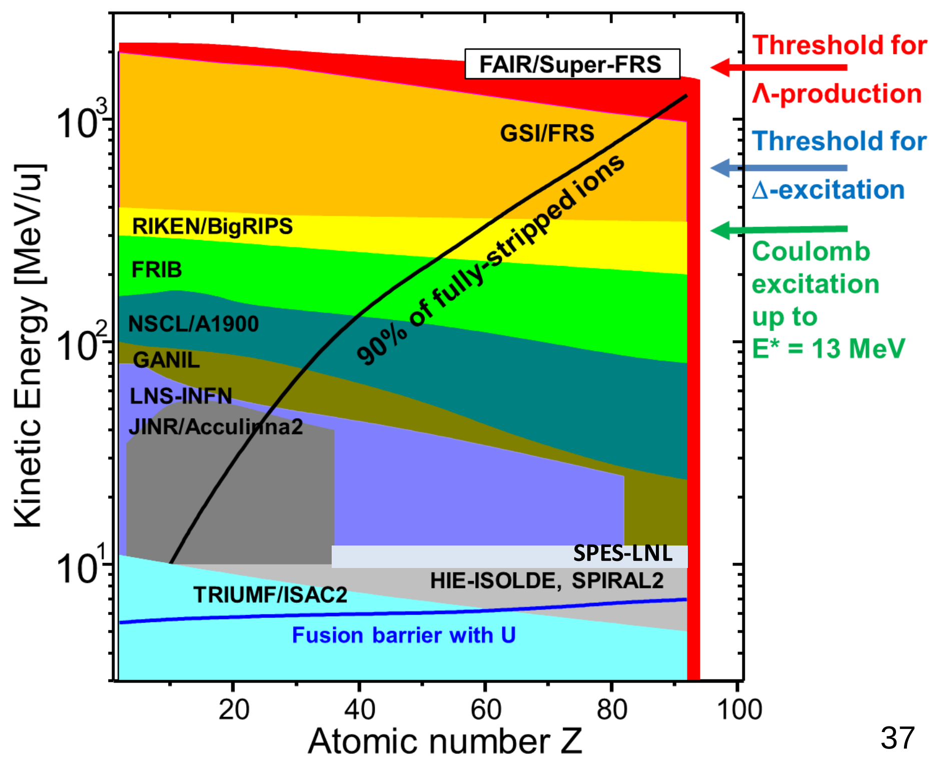
production target

NUSTAR - Origin of elements in the universe



„Nucleosynthesis sites“ in the universe

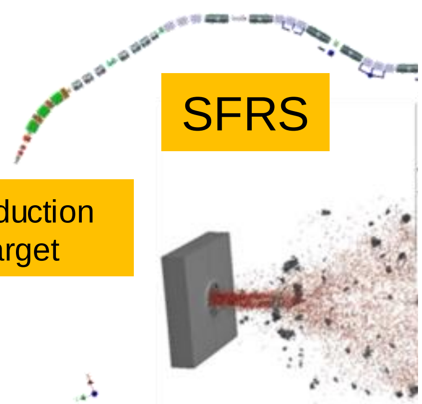
High SIS100 energies + SFRS: superior charge separation and beam quality



SIS 100

production target

SFRS

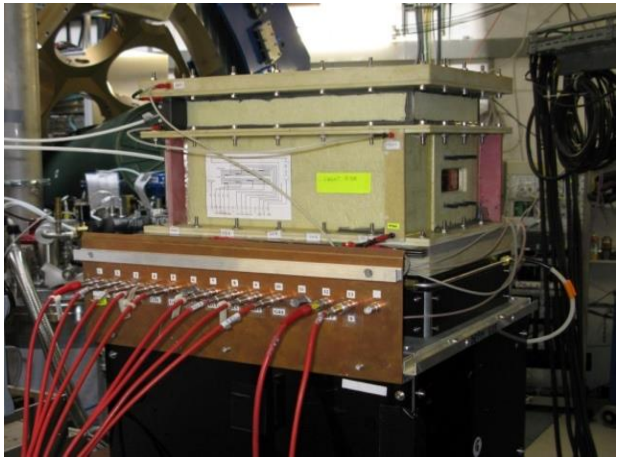


Physics goals / highlights of the NUSTAR program

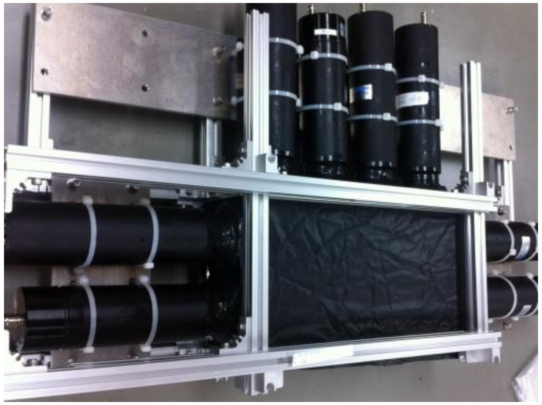
- Understanding the 3rd r-process peak by means of comprehensive measurements of masses, lifetimes, neutron branchings, dipole strength, and level structure along the N=126 isotones;
- Equation of State (EoS) of asymmetric matter by means of measuring the dipole polarizability and neutron-skin thicknesses of tin isotopes with N larger than 82 (in combination with the results of the first highlight);
- Exotic hypernuclei with very large N/Z asymmetry.

NUSTAR – Detectors Development

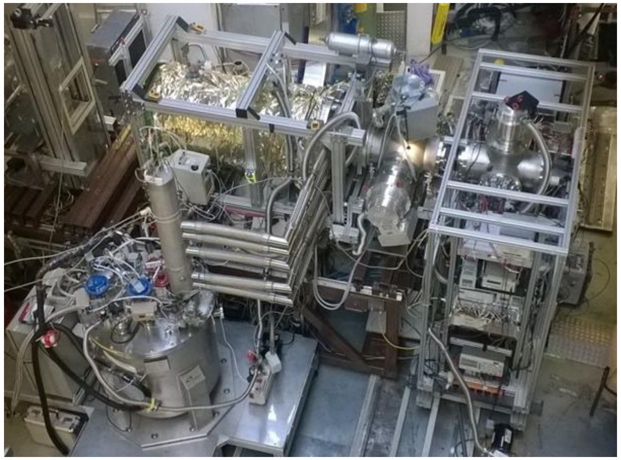
O-TPC



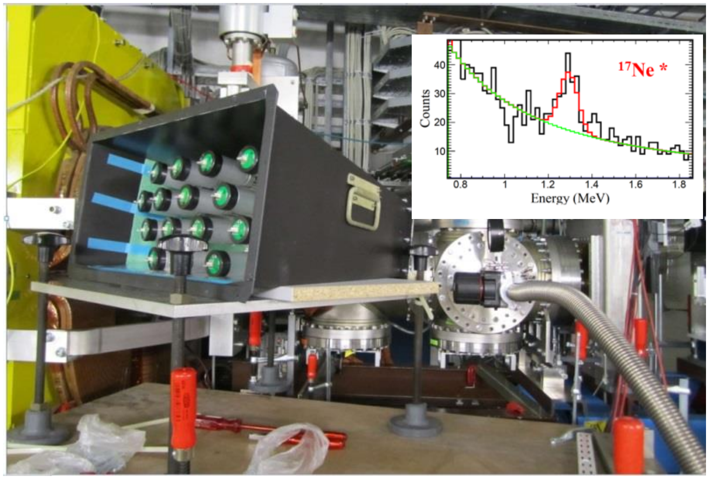
Backward-angle neutron detector



Ion Catcher → LEB-MATS/LASPEC



GADAST prototype measurements at S2



Full integrated S2 fiber tracker

Science Case

- PANDA physics program now focused on:
  - *Strangeness:* High statistics sample of unexplored territory hyperon ($\Lambda*$, $\Sigma*$, $\Xi*$, $\Omega*$) spectroscopy
  - *Charm(-like):*
    X,Y,Z-factory, high statistics allow new approach to lineshapes, transitions, nature of the states
    Heavy-light mesons unexplored high spin states, lineshape
  - *Nucleon Structure:*
    highest rates at lower q^2 for G_E, G_M, TDA, WACS, TMD
  - *Hypernuclei and nuclear targets:*
    Hyperon-potential in nuclei, excited states of $\Lambda\Lambda$-hypernuclei

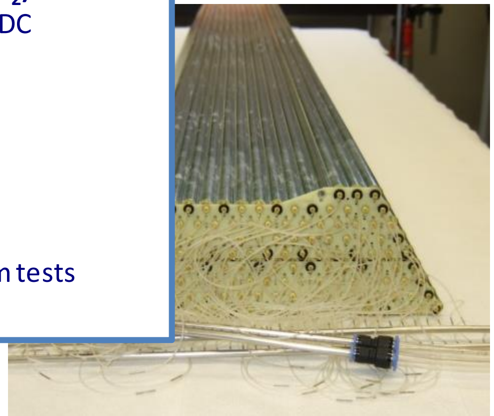
Strategy of PANDA

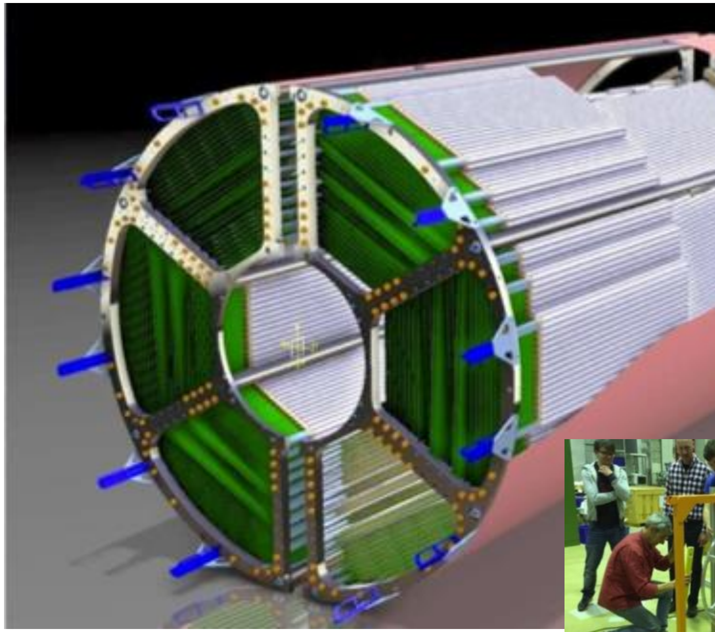
- After intense discussion with the scientific community, there is
  – a focusing of the *first key experiments*
  – a definition of the *start setup*
  – a proposal for *intermediate experiments/activities*

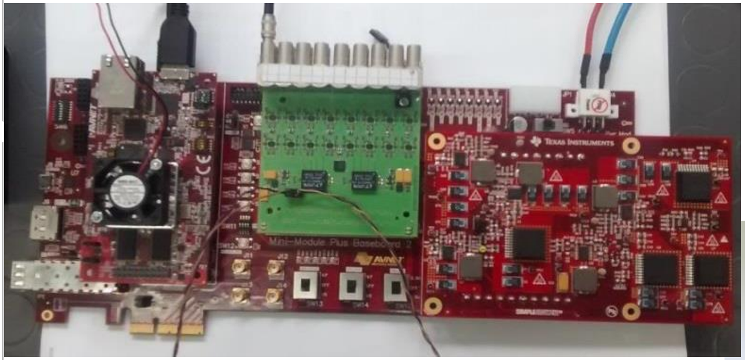
- And in addition:
  - Development of dedicated analysis methods at ELSA, MAMI, BESIII, Jlab, COMPASS to ensure a quick start of PANDA.
  - Application of modern PANDA technologies at present and future facilities, e.g. Trackers, Cherenkov (DIRC), EMC, Photon readout, Readout electronics

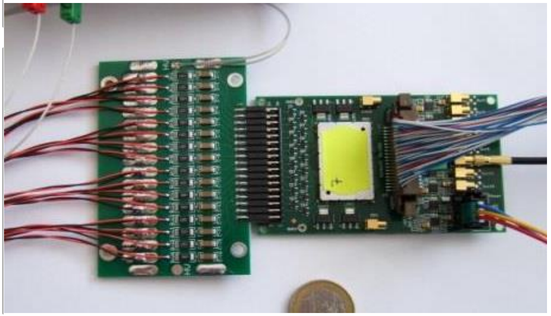
Straw Tube Tracker

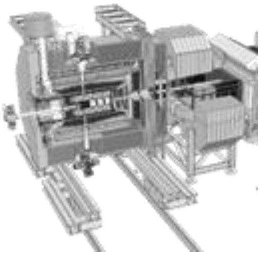
Detector Layout
4600 straws in 21-27 layers,
of which 8 layers skewed at ~3°
Tube made of 27 μm thin Al-mylar, Ø=1cm
R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
Self-supporting straw double layers
at ~1 bar overpressure (Ar/CO_2)
Readout with ASIC+TDC or FADC
Material Budget
Max. 26 layers,
0.05 % X/X_0 per layer
Total 1.3% X/X_0
Project Status
3000 Straws produced
Readout prototypes and beam tests
Ageing tests: up to 1.2 C/cm²











EM Calorimeter

Crystals

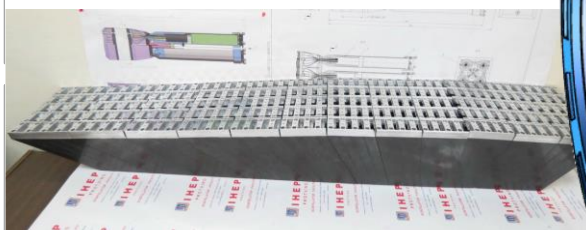
1st lot of crystals delivered
New producer Crytur
Test production in 2016 (~100pc)

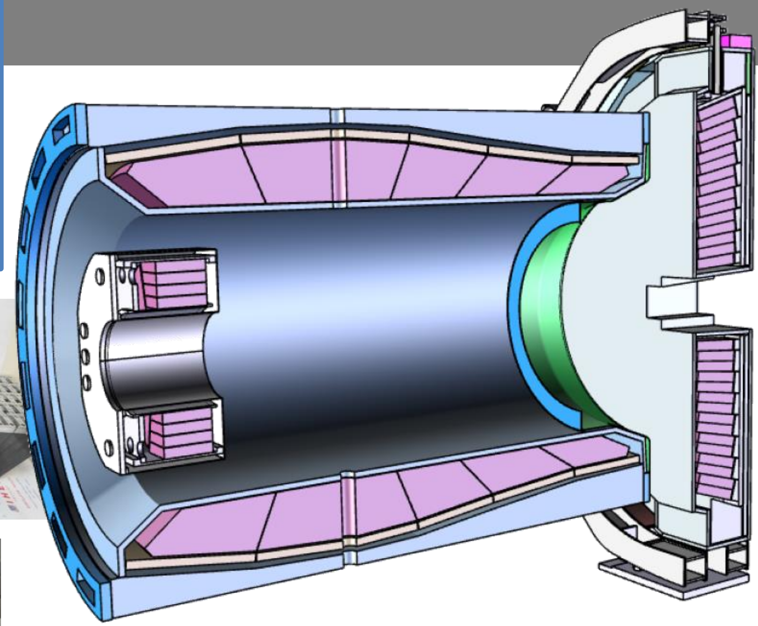
APD/Preamp/VPTT

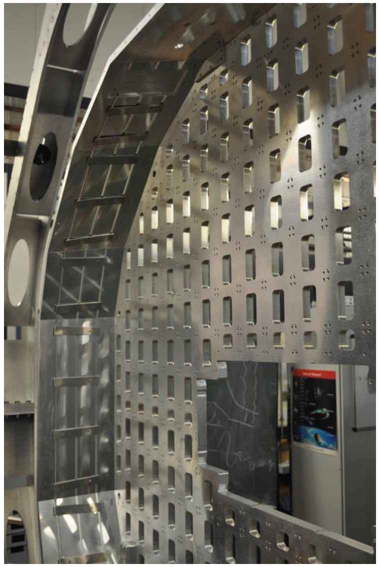
Screening of 30000 APDs ongoing
ASIC preamp design finalized
VPTT (Forward) characterized

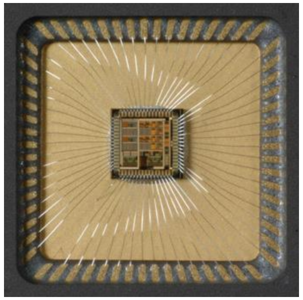
Assembly

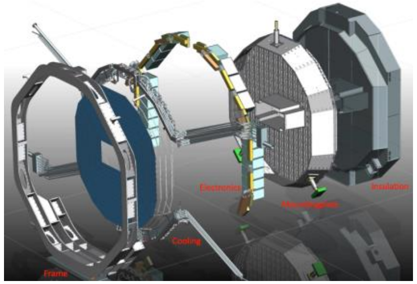
Forward-EMC full completion 'til 2018
Backward-EMC prototype-tests successful
Barrel-EMC: alveoles produced , 1st slice in construction

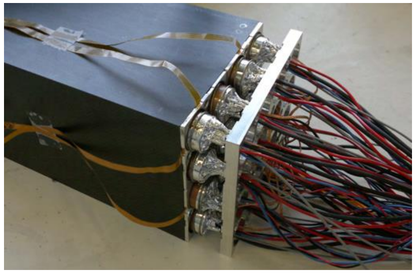


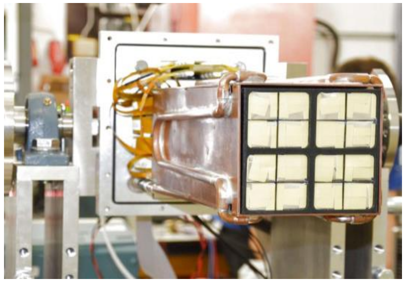


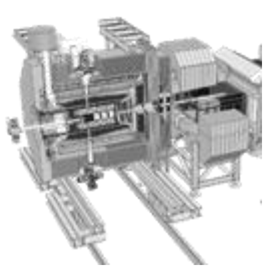






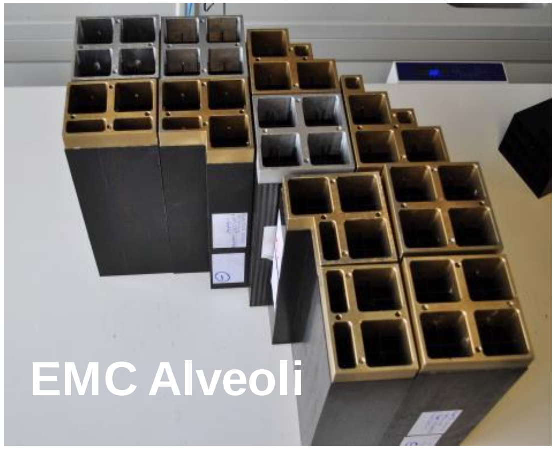


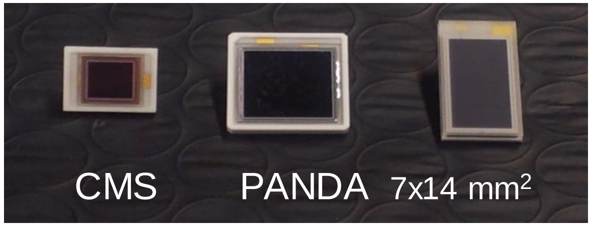


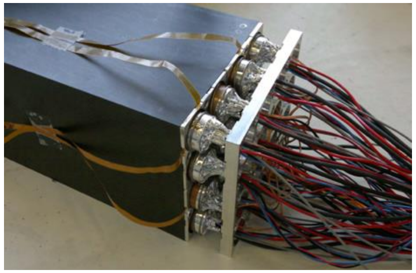


PANDA – Detector Progress

PANDA – Detector Development





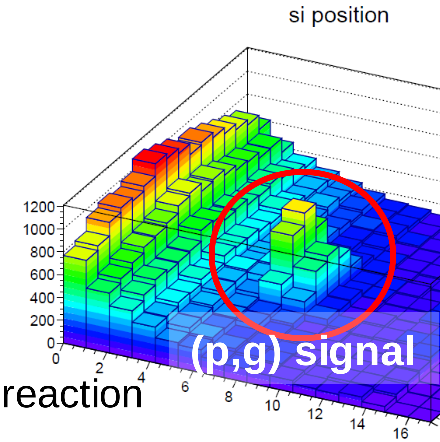


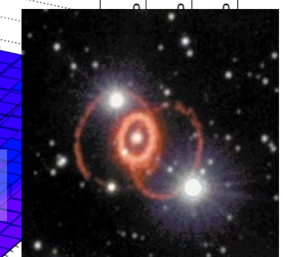
Research at GSI continues ...

- 2016: 3 months of beam time
- Technically induced shut-down in 2017
- 2018: restart of the intensity-upgraded UNILAC/SIS18 facility including storage ring ESR and the newly installed Cryring
- 2018 till start of commissioning of SIS100 synchroton about 3 months of beam time per year
  → FAIR Phase 0 program

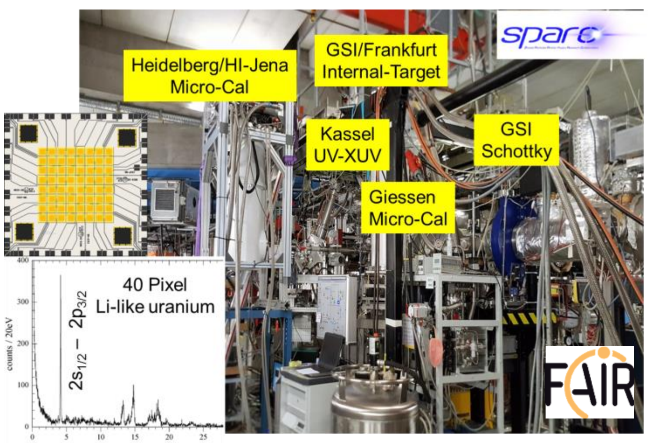
Highlights from 2016 Beam Time at GSI
- pushing experimental techniques and instrumentation

- Successful commissioning of the Cryring@ESR

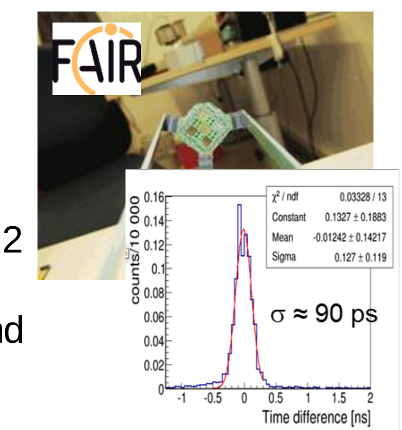




- Successful proof-of-concept of nuclear astrophysics studies in storage rings using the 124Xe (p,γ) nucleosynthesis reaction



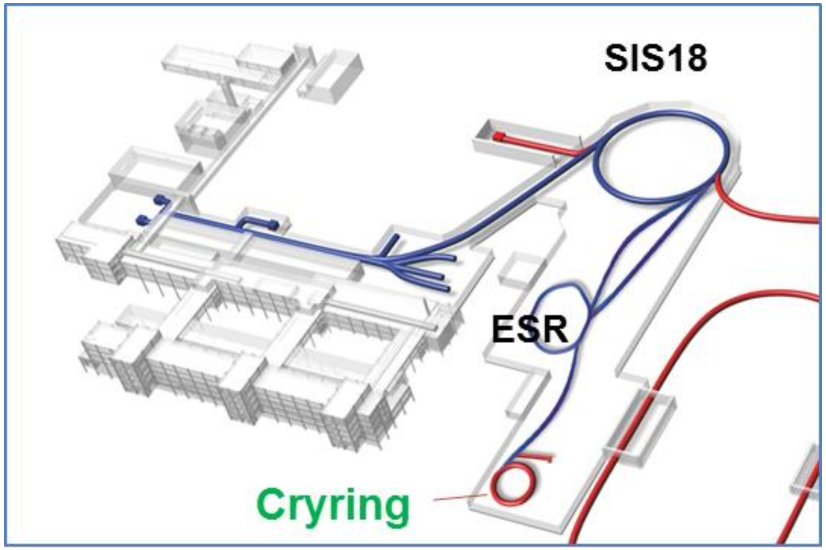
- Successful test of novel APPA / SPARC instrumentation



- Tests of CVD diamond detector
  - In vacuum operation without cooling
  - Rate capability up to 10^7 MIPs/s/mm2
  - Timing resolution (sigma) 90ps
  - Radiation hard material CVD diamond

Intermediate Research Program FAIR Phase 0

- Goals
  - Forefront research by employing and testing new FAIR detectors
  - Exploiting upgraded GSI accelerator facilities
    - ongoing upgrade of SIS18 completed by mid 2018
    - Make use of the Cryring
  - Education of young scientists
  - Maintain and extend skills and expertise
  - Serve national and international user community



FAIR Phase 0 – scientific opportunities

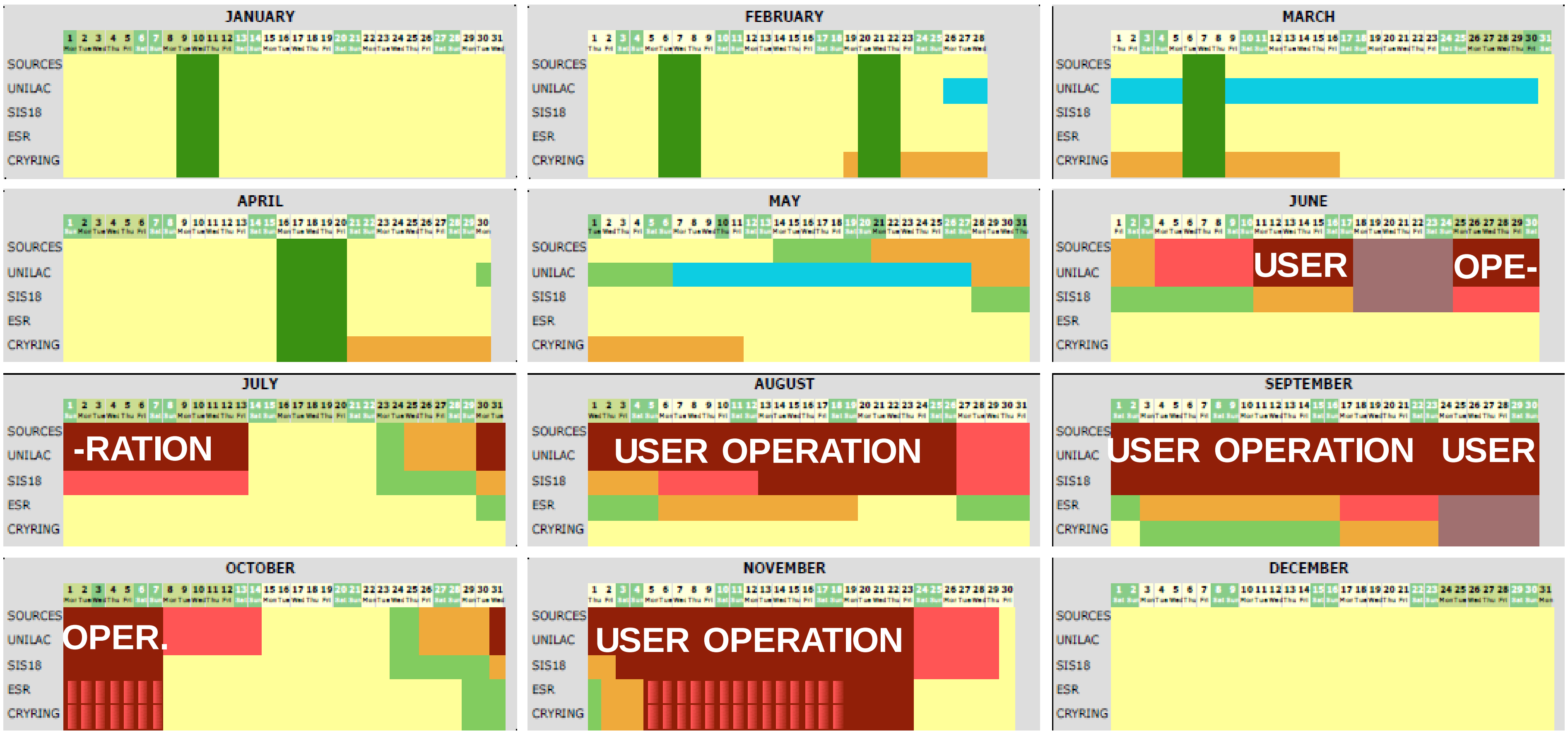
APPA	Facility	Research Activity
SPARC SPARC	ESR-HITRAP- CRYRING	Strong field QED, atomic collisions, fundamental symmetries, border to nuclear physics
BIOMAT	M Branch, Z0/ A	Biophysics, heavy ion therapy, Material Science
WDM/HEDgeHOB	HHT/PRIOR	Equation-of-state studies; phase transitions in matter
WDM/HEDgeHOB	PHELIX	Laser plasma interaction and acceleration
CBM		
CBM/HADES	HADES@SIS18	Di-lepton production in pion-induced and HI reactions
miniCBM	miniCBM@SIS18	Test of subsystem plus data acquisition of CBM
NUSTAR		
NUSTAR	FRS	Separator-/spectrometer expt.'s with exotic nuclei
NUSTAR	FRS-ESR	Nuclear physics with exotic beams in storage rings
NUSTAR	HISPEC/DESPEC	In-beam and stopped-beam spectroscopy experiments
NUSTAR	R3B@SIS18	Reactions with relativistic radioactive beams
NUSTAR	SHIP, TASCA	Physics and chemistry of SHE
PANDA		
PANDA	HADES	Hyperon Dalitz decays with HADES (use of PANDA F-TRK)

Preparatory steps taken

- Beam time plan for 2018 adopted by GSI Management Board; draft beam time plan for 2019 in preparation
- List of main possible beam parameters defined
- International Program Advisory Committee is established
  (Chair: Sydney Gales)
- 1st ‘Call for Proposals’ for beam time slot 2018/19

General Plan for Accelerator Operations 2018

In 2018, about three months of user beam time for experiments and tests exploiting novel instrumentation that has been developed for FAIR



Status Feb. 2017

1st Call for Proposals

- First 'Call for Proposals' has been announced in April 2017 for beam time in 2018 and 2019 (see G-PAC's webpage www.gsi.de/g-pac or https://www.gsi.de/fileadmin/GF-wiss/Call_for_Proposals_2018-19_deadline_prolonged.pdf)
- Deadline of submission of proposals: 19. June 2017

  → Incoming proposals overbook the "opportunities" by a factor of two to three.
- Meeting of G-PAC on 19.-21. September 2017
- Beam time in second half of 2018 and in 2019
- Next 'Call for Proposals' and G-PAC meeting planned in 2018 for beam time in 2019 – to allow for few up-to-date developments

FAIR Construction Field

FAIR 2025