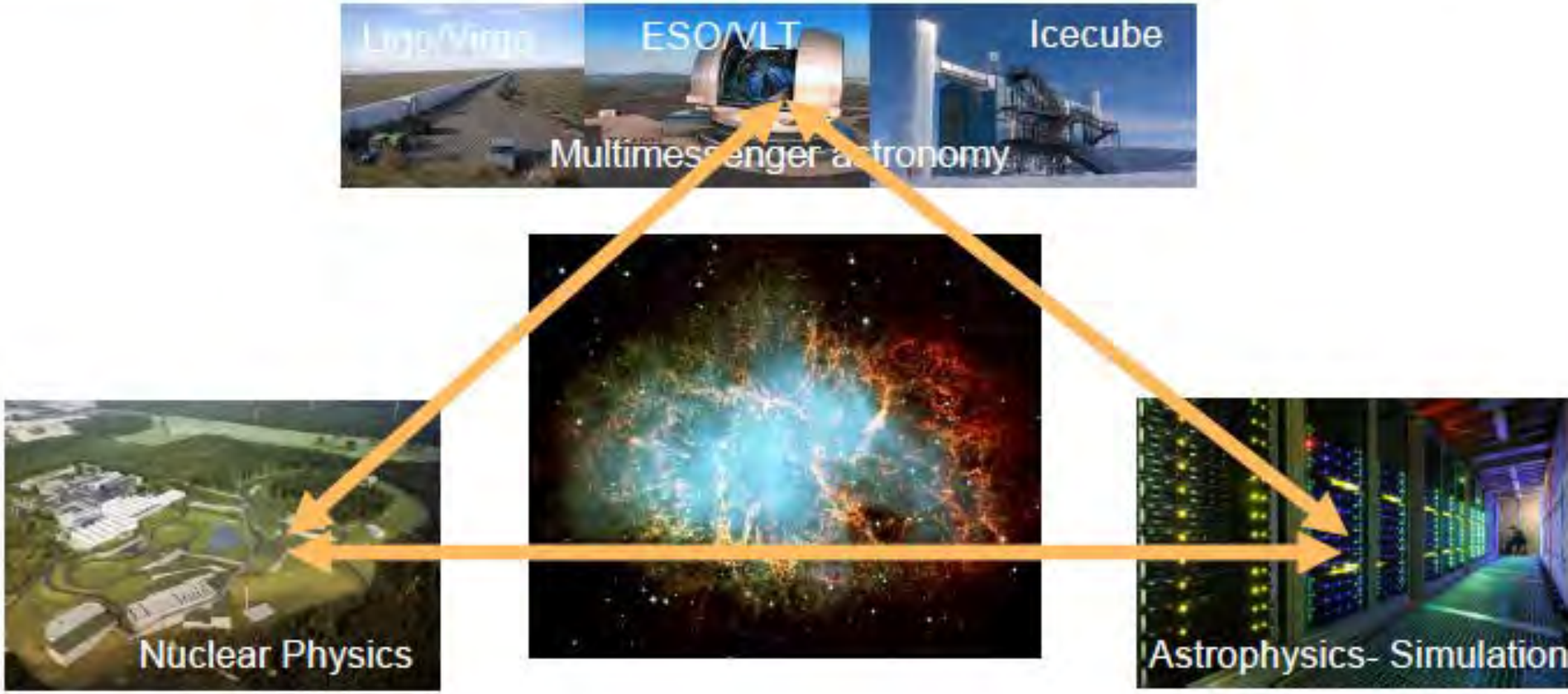
The Universe in the Lab: current and future science at GSI/FAIR

Paolo Giubellino

Tsukuba, Tomonaga Center for the history of the Universe

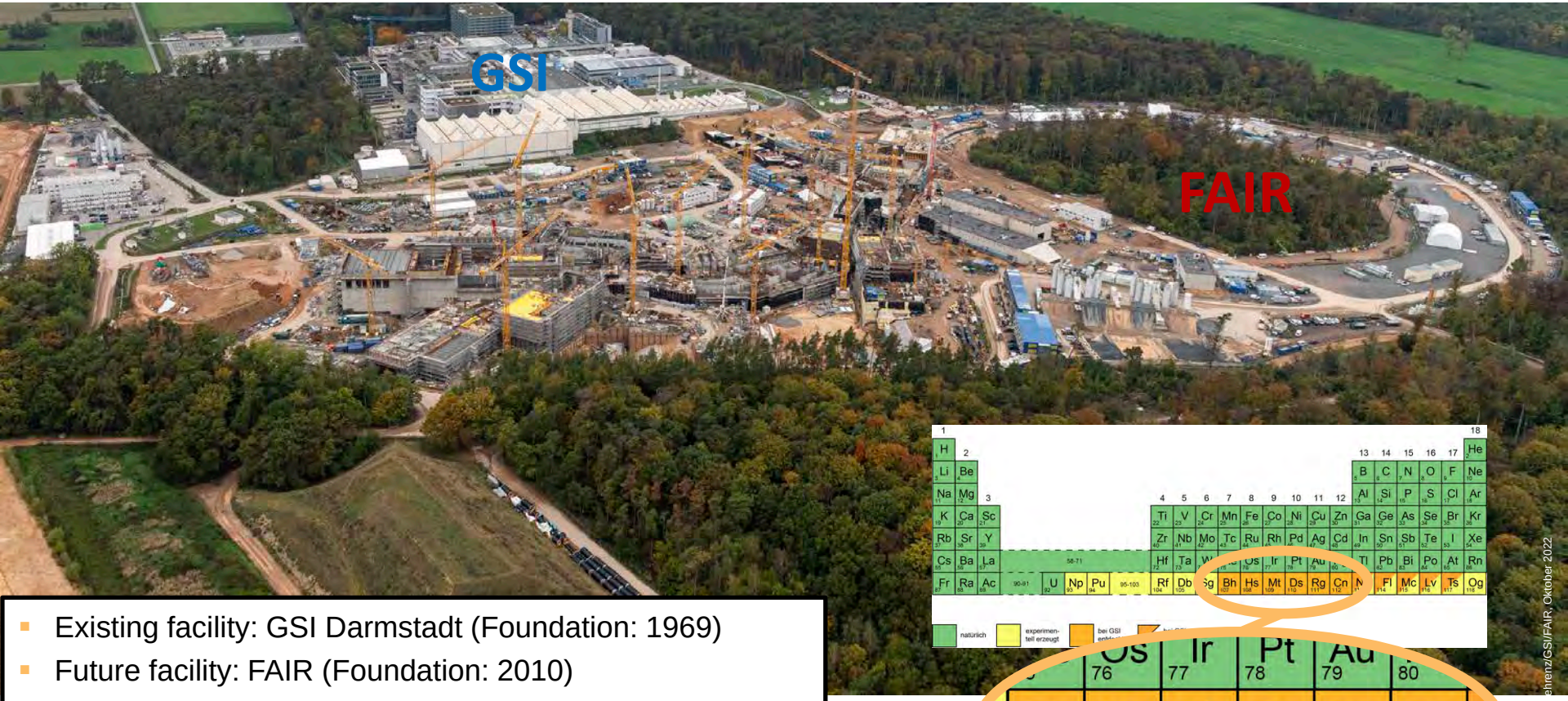
September 28th 2023

A special moment for Nuclear Physics

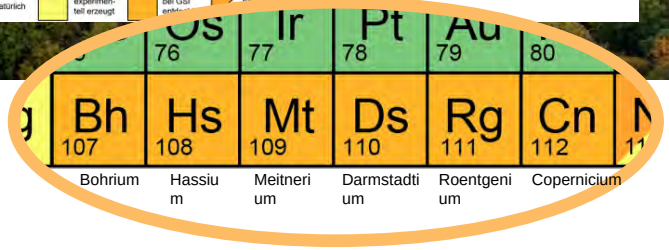


- **But also "Nuclear Physics in Everyday Life"… space, energy, medicine…**
- **https://www.nupecc.org/pub/np_life_web.pdf**

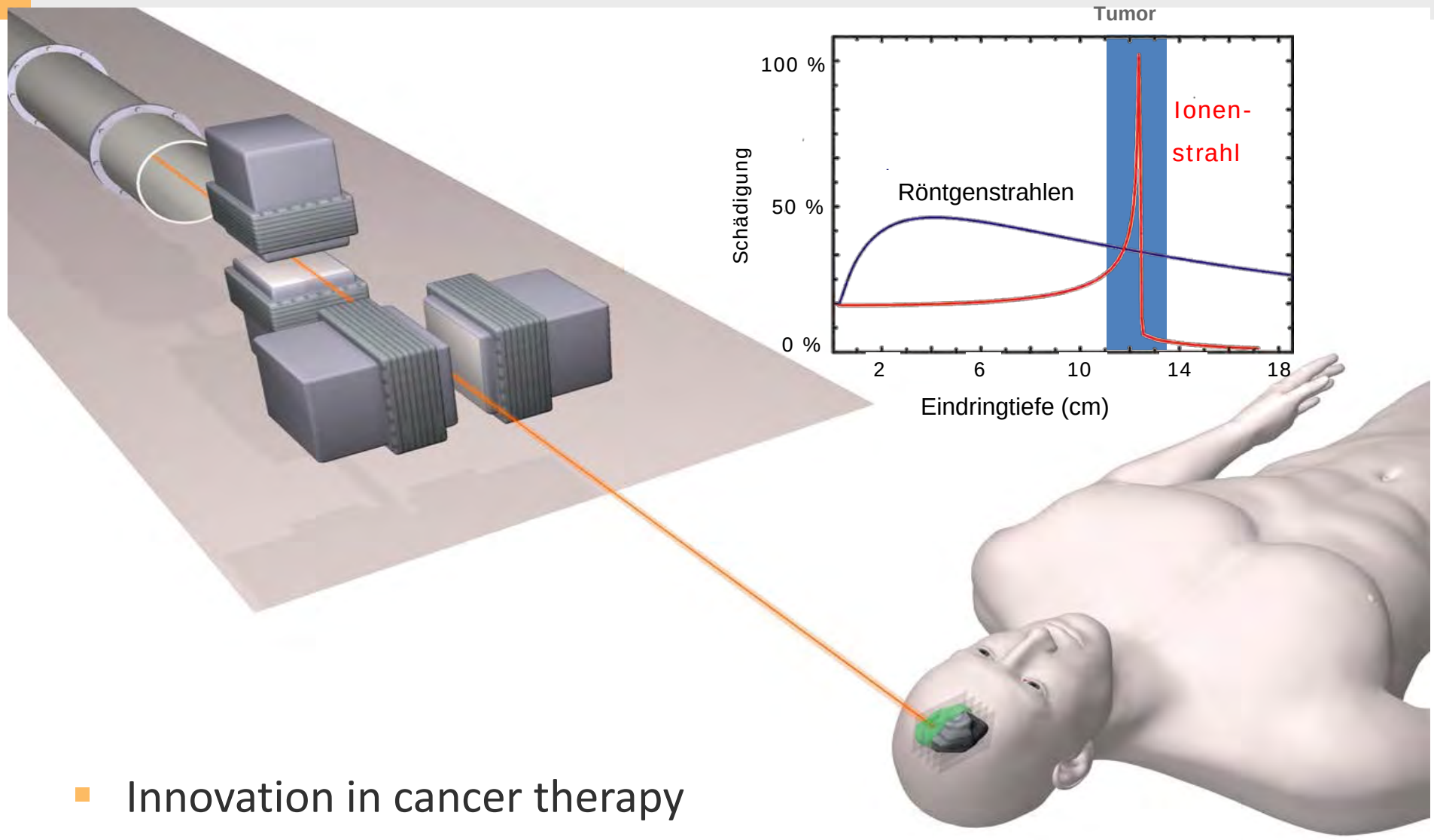
GSI GmbH – Helmholtzzentrum für Schwerionenforschung
FAIR GmbH – Facility for Antiproton and Ion Research



- Existing facility: GSI Darmstadt (Foundation: 1969)
- Future facility: FAIR (Foundation: 2010)
- Landmark in the European research roadmap (ESFRI
- Employees on location: approx.1580



GSI: Ion Beam Therapy



- Innovation in cancer therapy

Forefront Technologies

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

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 training and education of young scientists and engineers

Creating extreme conditions existing in the universe with heavy ion accelerators

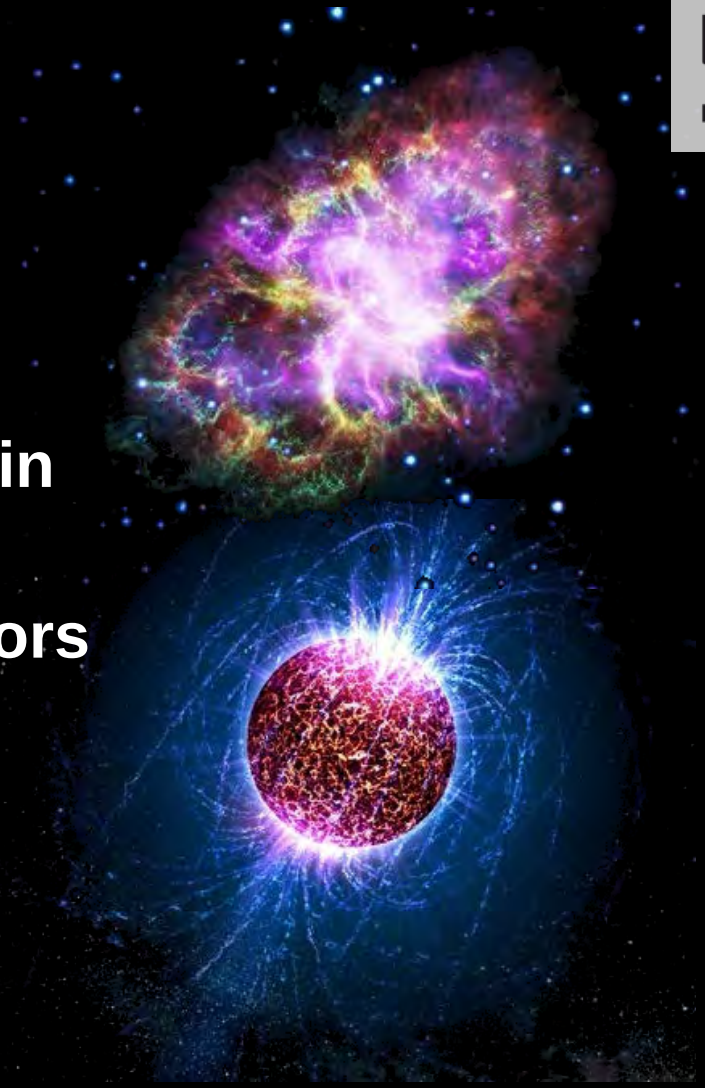


Foto: NASA, ESA, G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; A. Loll et al.; T. Temim et al.; F. Seward et al.; VLA/NRAO/AUI/NSF; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; and Hubble/STScI (oben), Penn State University (unten)

To find answers to fundamental questions about the Universe : The Universe in the lab ...

Where are heavy elements created?

NUSTAR

What is in the interior of a neutron star?

CBM

PANDA

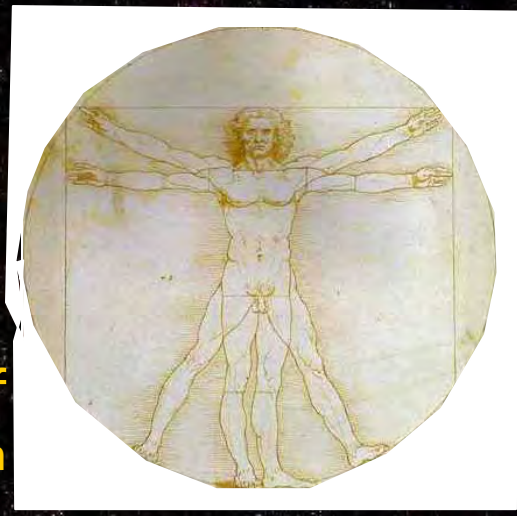
Glueballs:
What are protons and neutrons made of?
What is the structure of hadrons?

APPA

How do materials behave under high pressure?

Fotos: Uranus, Jupiter, Erde Quelle: http://de.wikipedia.org

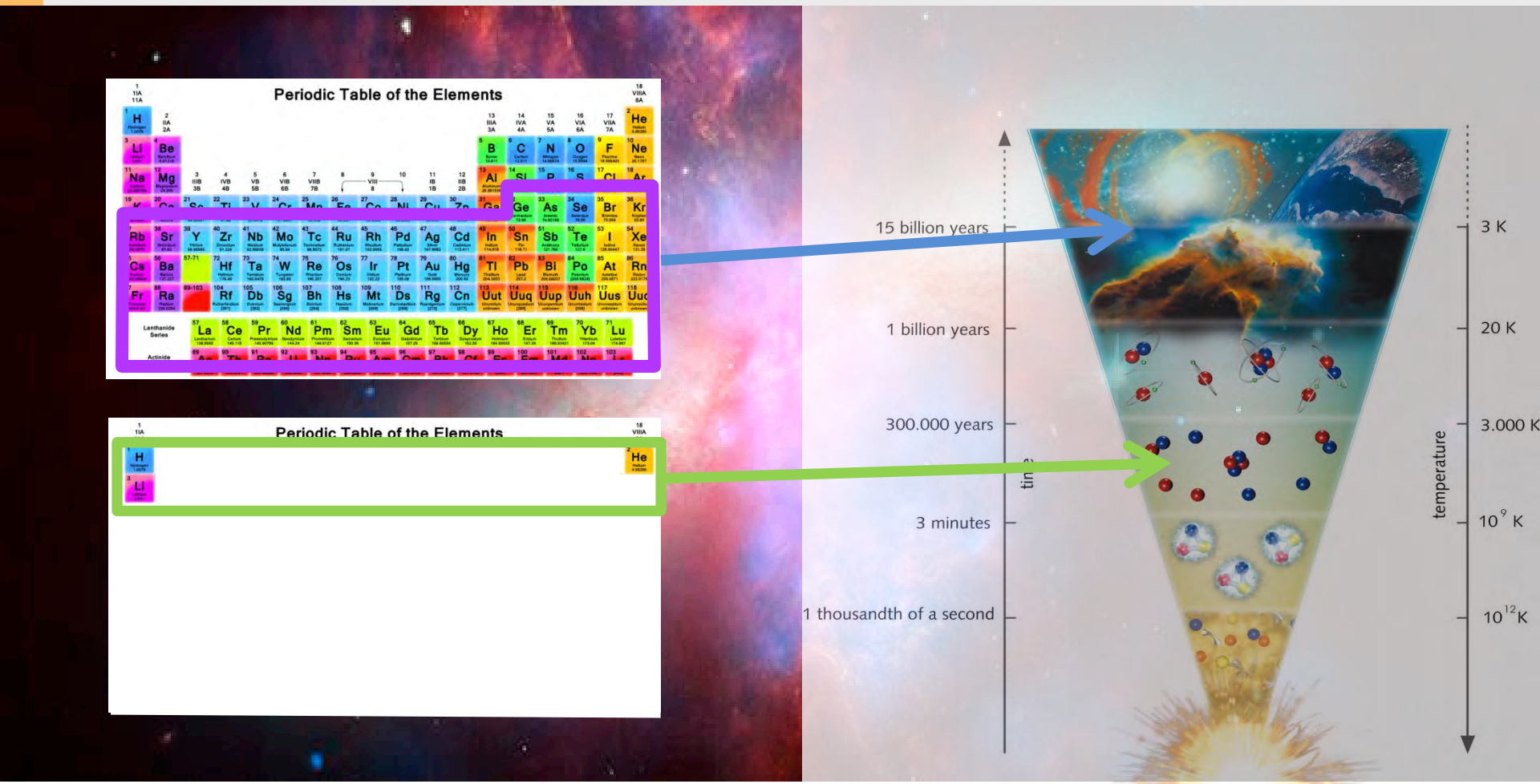
Each heavy atom in our body was build and processed through many star generations since the initial Big Bang event!



We are made of star stuff

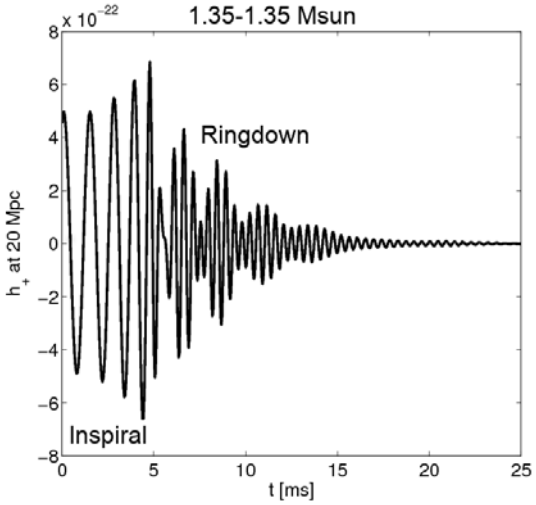
Carl Sagan

Why FAIR? (... just SOME of the questions)

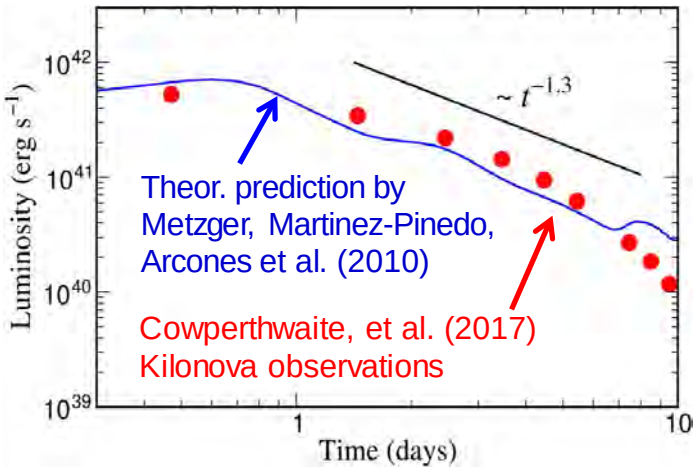


- Where and how were the heavy elements made in the universe? ← ***One of the top unanswered questions in Physics***

Neutron star mergers and their role for the production of heavy elements ….



Gravitational wave signal



Elektromagnetic “Kilonova”-Signal

Electromagnetic afterglow - "Kilonova-lightcurve" - reveals that heavy elements, e.g. Au and Pt, were produced (r-process), as predicted by GSI theorists.

Neutron Stars and Mergers vs HI collisions

Neutron stars

Temperature
$T < 10$ MeV

Density
$\rho < 10\ \rho_0$

Lifetime
$T \sim$ infinity

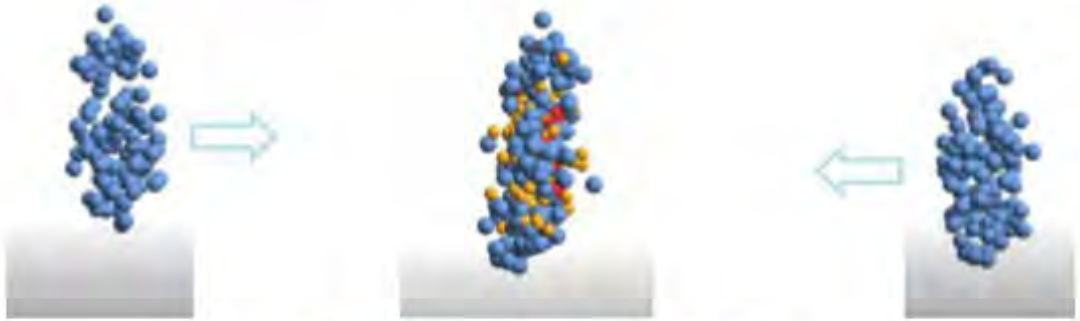
Neutron star merger

Temperature
$T < 50$ MeV

Density
$\rho < 2 - 6\ \rho_0$

Reaction time
(GW170817)
$T \sim 10$ ms

Heavy ion collisions at SIS100



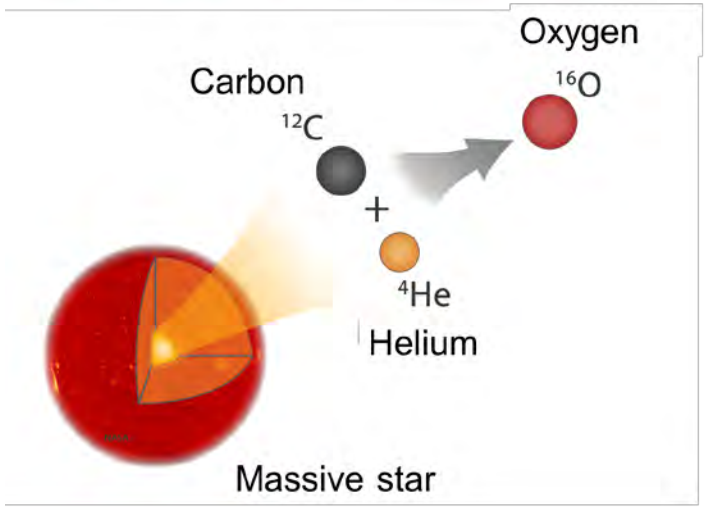
Temperature
$T < 120$ MeV

Density
$\rho < 8\rho_0$

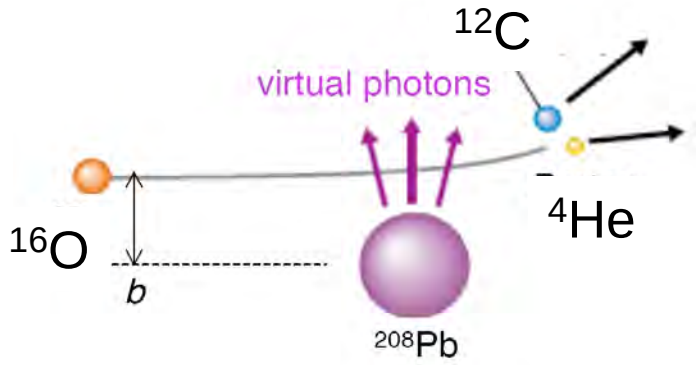
Reaction time
$t \sim 10^{-23}$ s

Compressed Baryonic Matter

How Nature makes the building blocks of life



rate insufficiently known at astrophysically energies

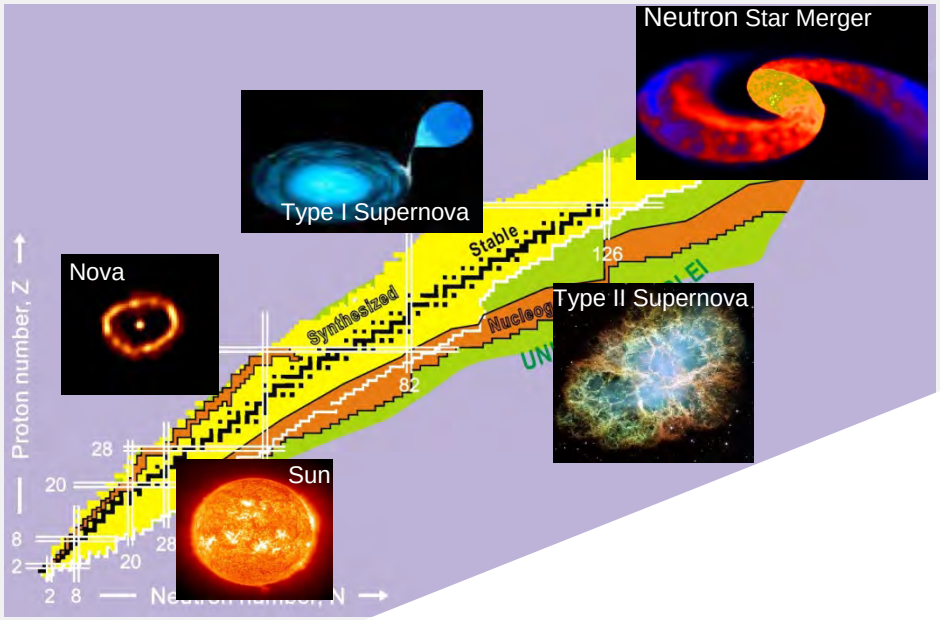


Alpha fusion on 12C is the stellar reaction of paramount importance,

W.A. Fowler, Nobel lecture 1983

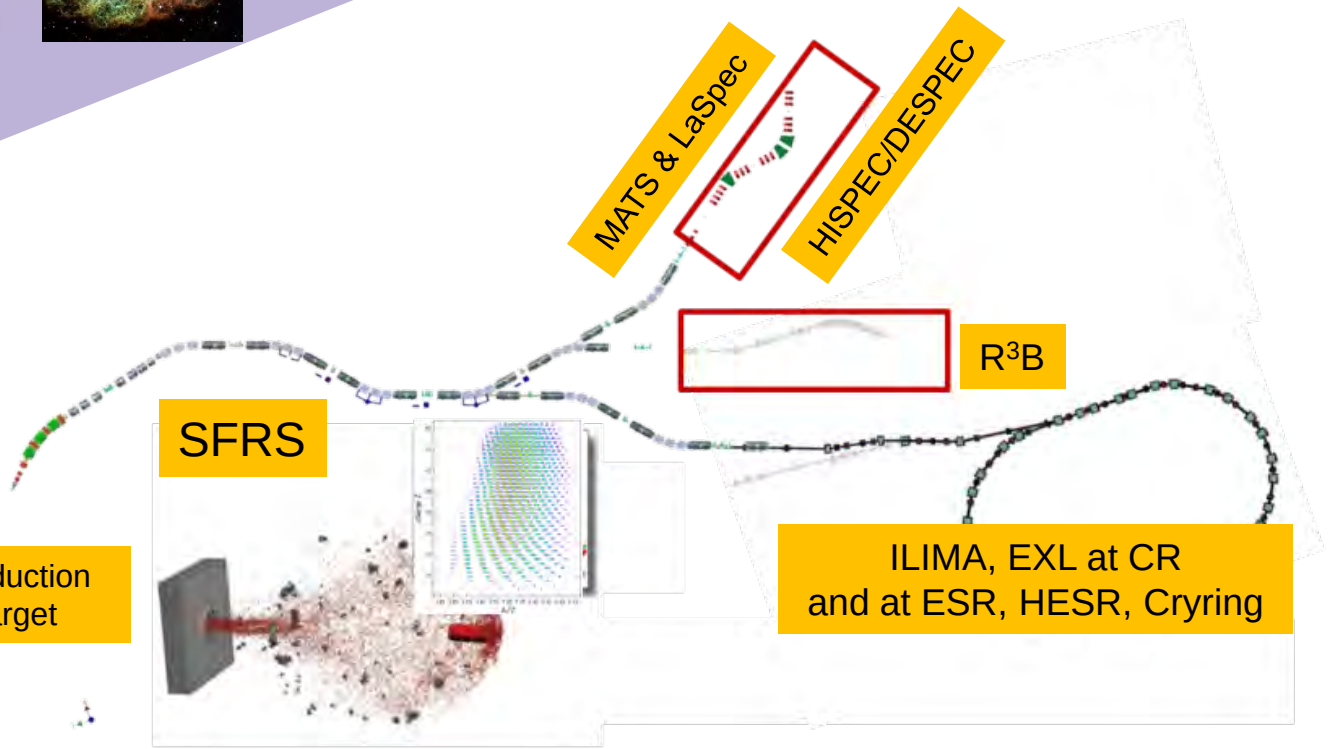
Experiment in inverse kinematics (Coulomb dissociation) requires high energies -> GSI/FAIR

NUSTAR
- Origin of Elements in the Universe



„Nucleosynthesis sites“ in the universe

„Nucleosynthesis sites” at FAIR

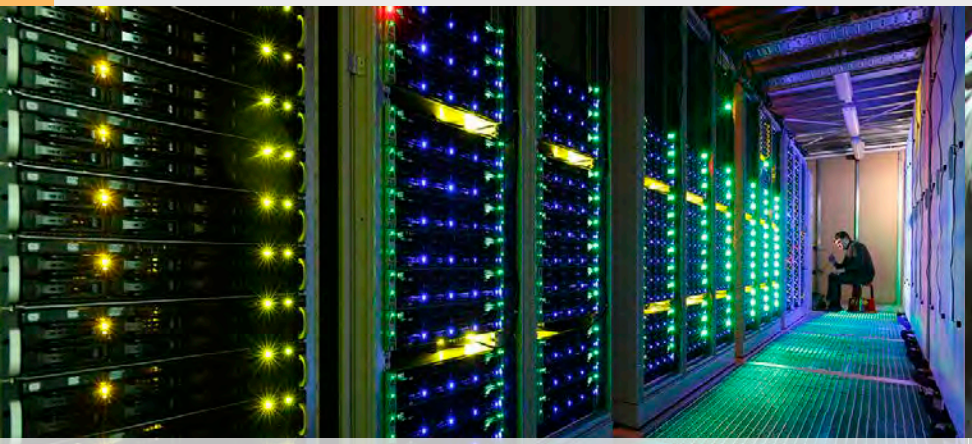


Primary intensities vs. GSI: x 100

SIS 100

production target

… with direct applications

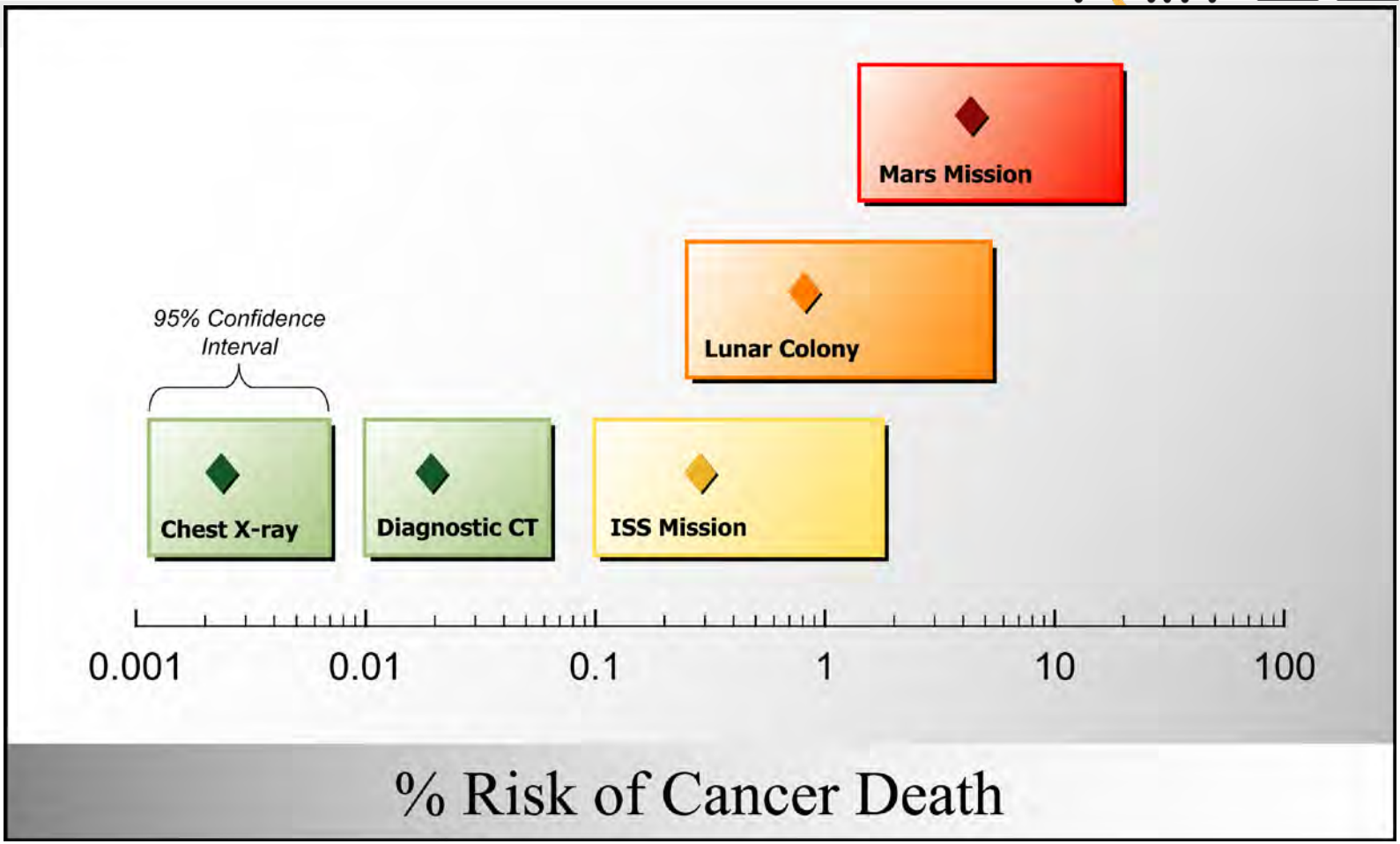


High-performance and scientific computing, big data, green IT

Space radiation protection, unique facility for simulation, collaboration with ESA

Development of nuclear clock: Promising candidate thorium-229

Novel applications for tumor and non-tumor diseases

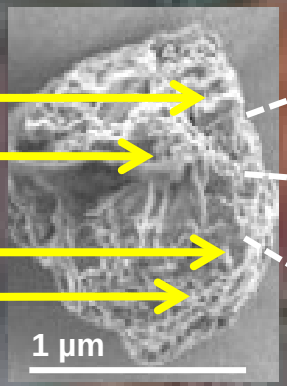


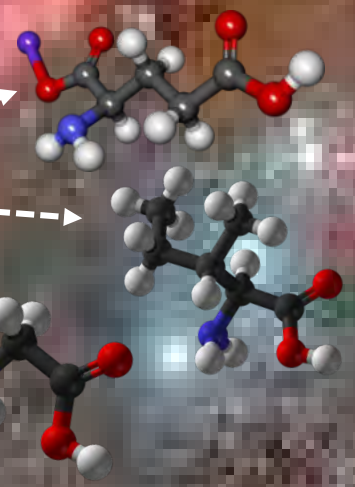
Durante & Cucinotta, *Nature Rev. Cancer* (2008)

Studying cosmic radiation induced processes

astrophysical ice grains (H_2O, CH_4, CO_2, NH_3, SO_2...)

200 MeV Ca ions

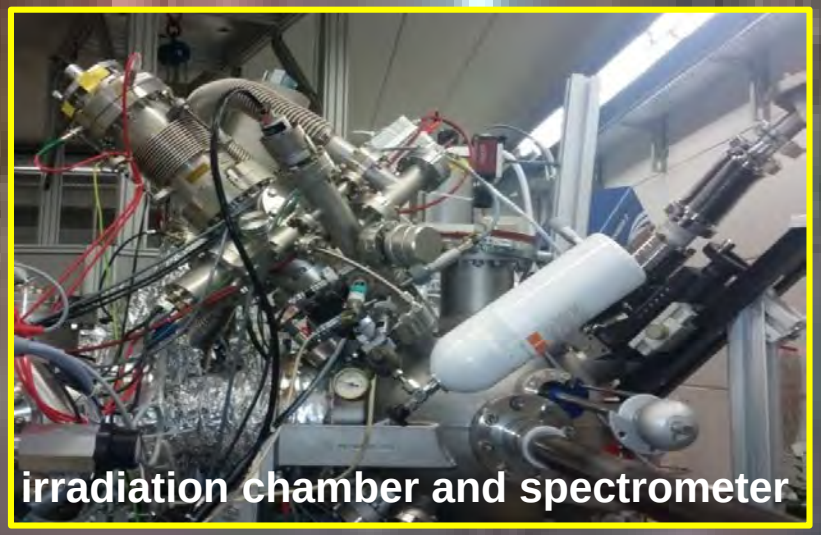




C_nH_m polyaromatic hydrocarbons

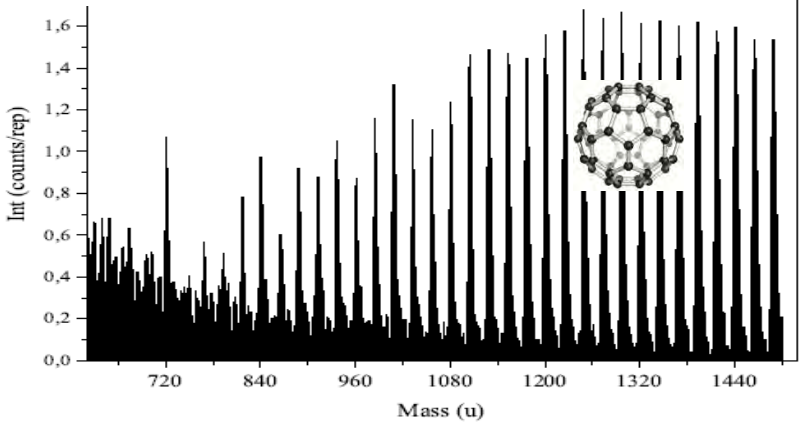
$C_6H_{13}NO_2$ amino acids

C_{60}, C_{70} fullerenes

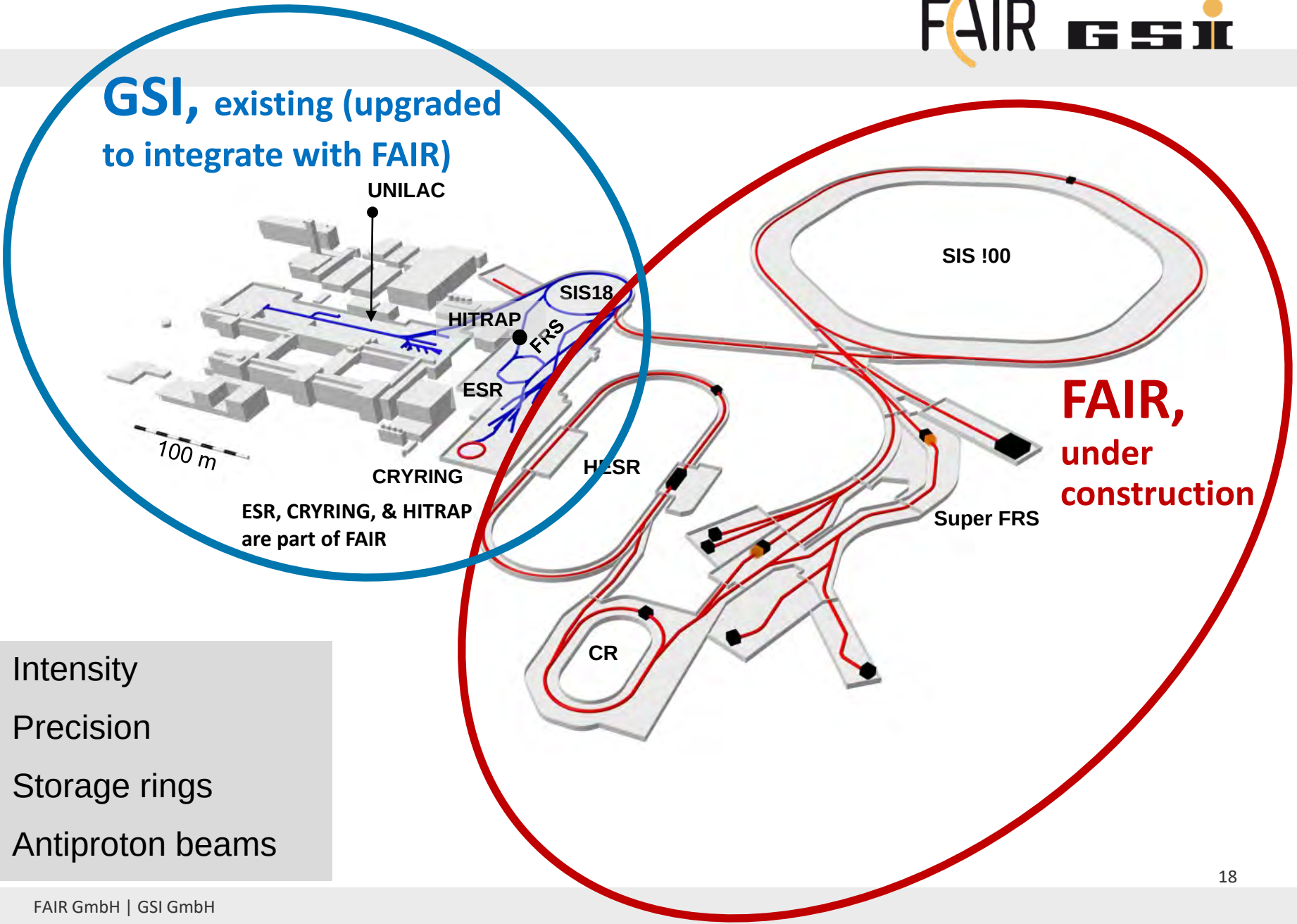


irradiation chamber and spectrometer

spectrum of large desorbed molecules

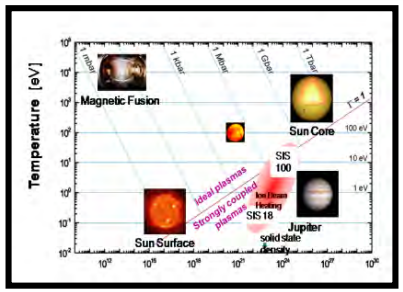


GSI and FAIR – The Facility



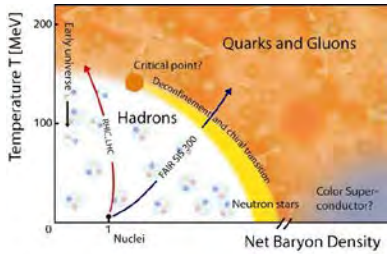
- Intensity
- Precision
- Storage rings
- Antiproton beams

The FAIR science: four pillars



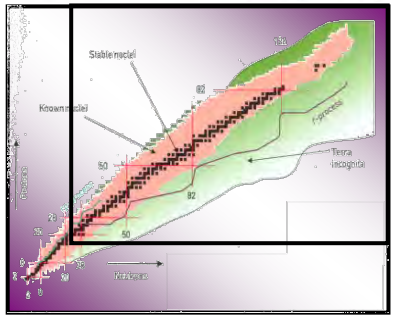
atomic physics, biophysics,
plasma physics, material research

APPA



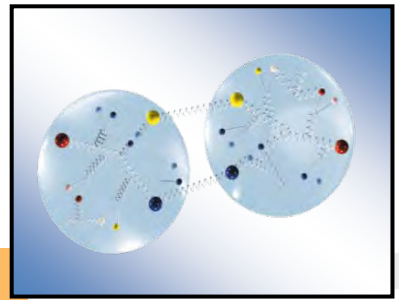
nuclear- and quark-matter

CBM



nuclear structure and
nuclear astrophysics

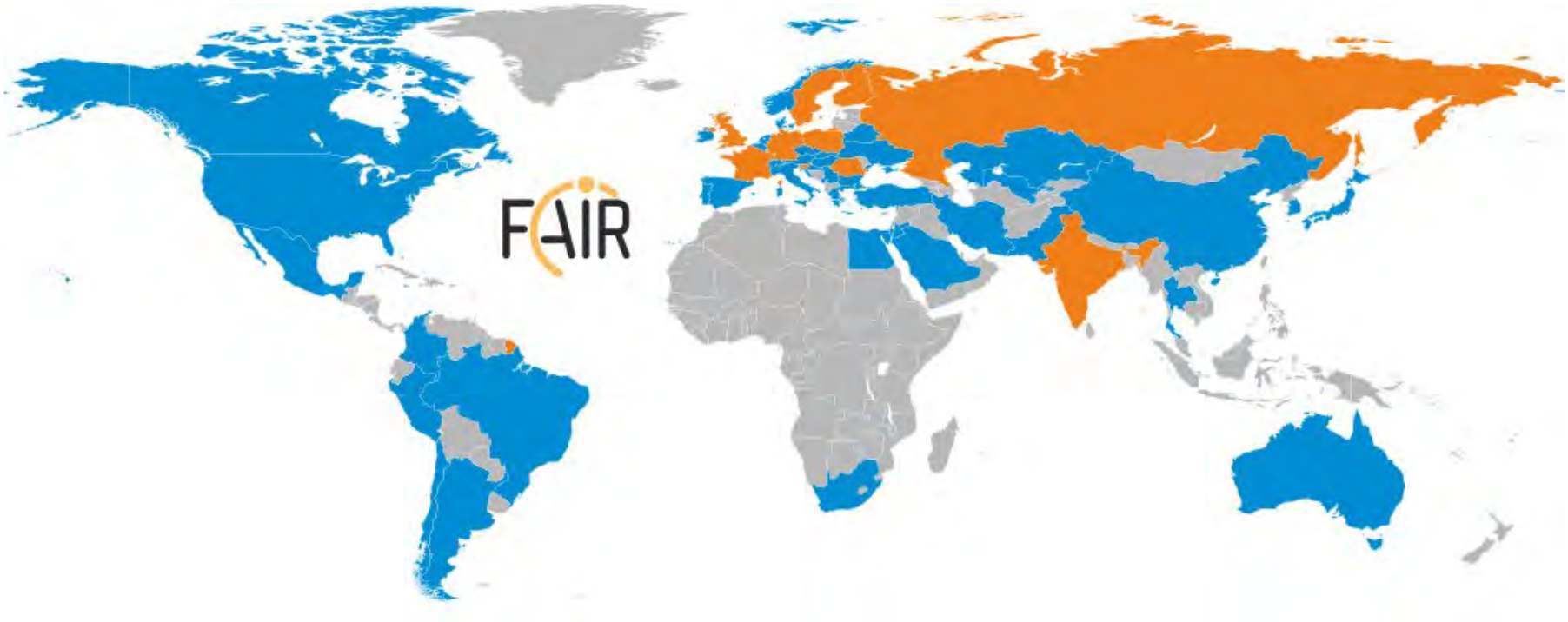
NuSTAR



hadron structure and dynamics

PANDA

Poland @ FAIR



- FAIR governed by international convention
  - 9 shareholders:
  - + 1 associated partner:
  - + 1 aspirant partner:
  - Over 3000 Scientists and Engineers from all over the world
- Scientists from More than 200 institutions from 53 countries (orange + blue)

Construction volumes

2 million m^3

of earth

to be moved

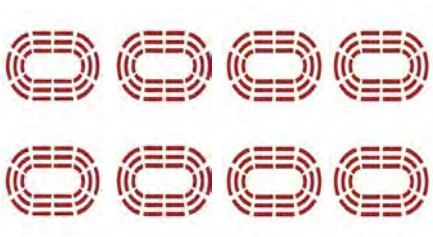
As much as for 5,000 single-family homes

600,000 m^3

of concrete

to be used

As much as eight Frankfurt soccer stadiums

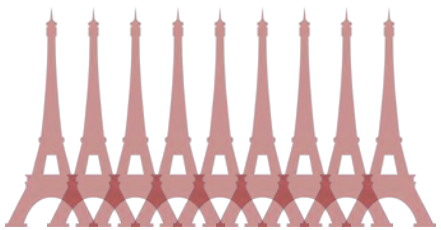


65,000 tons

of steel

to be utilized

As much as nine Eiffel Towers



Civil Construction

Movie on
https://edms.cern.ch/file/2893949/LATEST/FAIR*.mp4

FAIR SIS100 accelerator tunnel

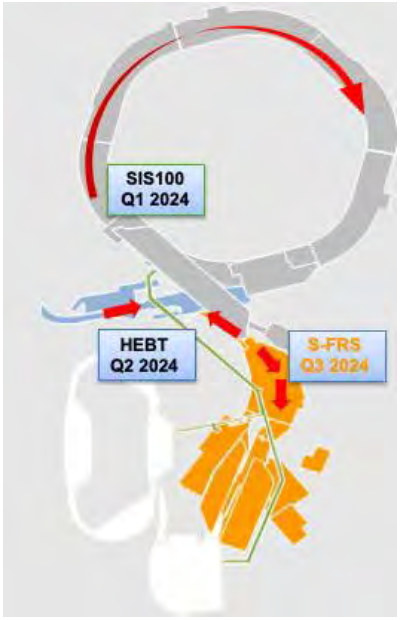
FAIR Area South

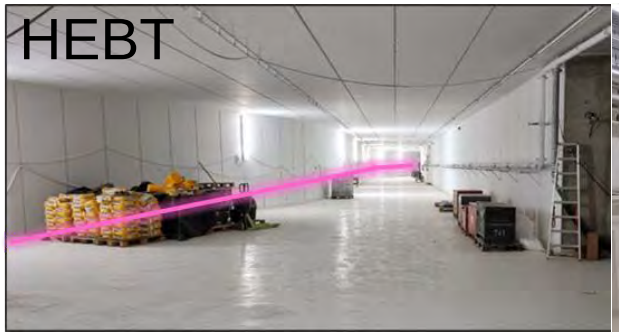
FAIR CBM Cave

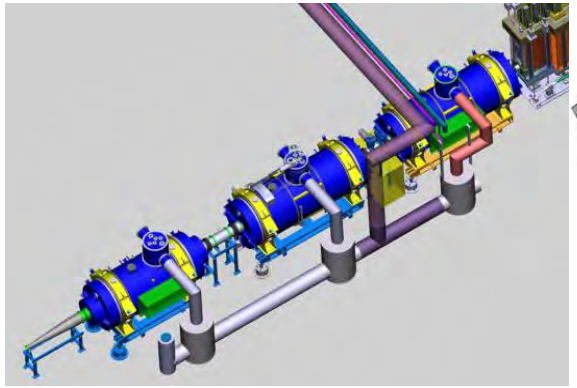
Accelerators: delivery of components continues steadily

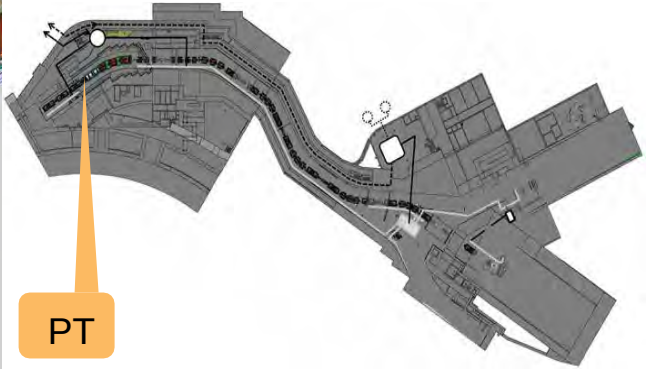
- Storage area: approx. 9.900 m²
- 4.195 objects (Components, assemblies, boxes, etc.)
- 50% of SIS100 components stored
- 90% of HESR components stored

Start of installation at four locations in



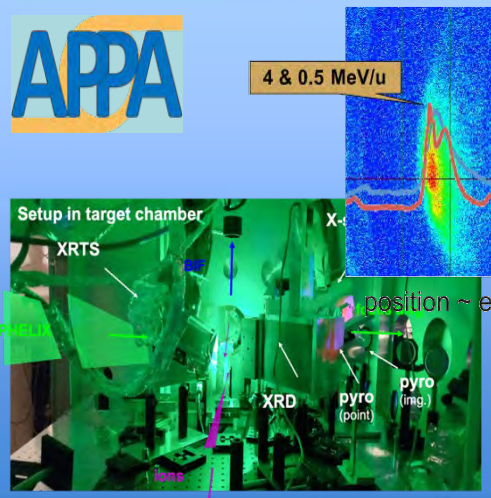


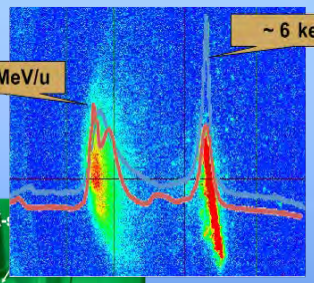




Experiment Construction

APPA

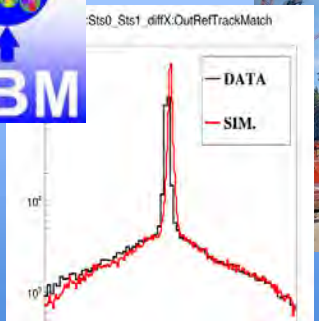




HITRAP commissioning

HED@FAIR diagnostics

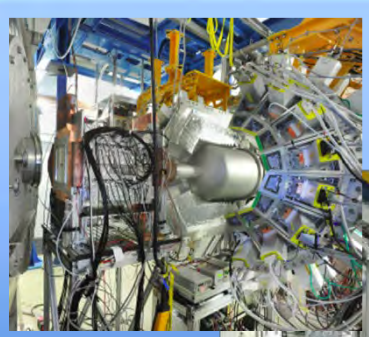
CBM



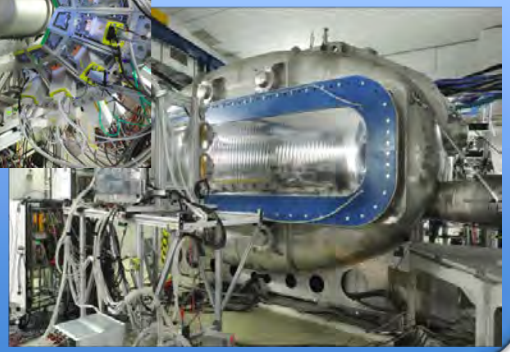
mCBM performance

Available detectors are used in Phase-0

NUSTAR

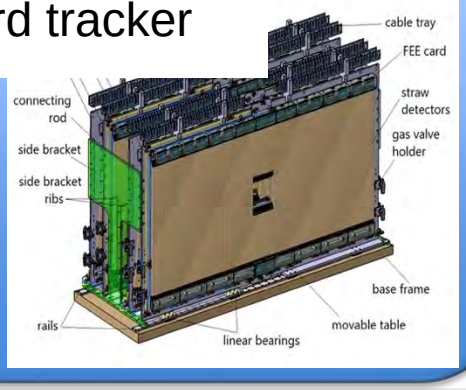


R3B: LH2 target, CALIFA, GLAD

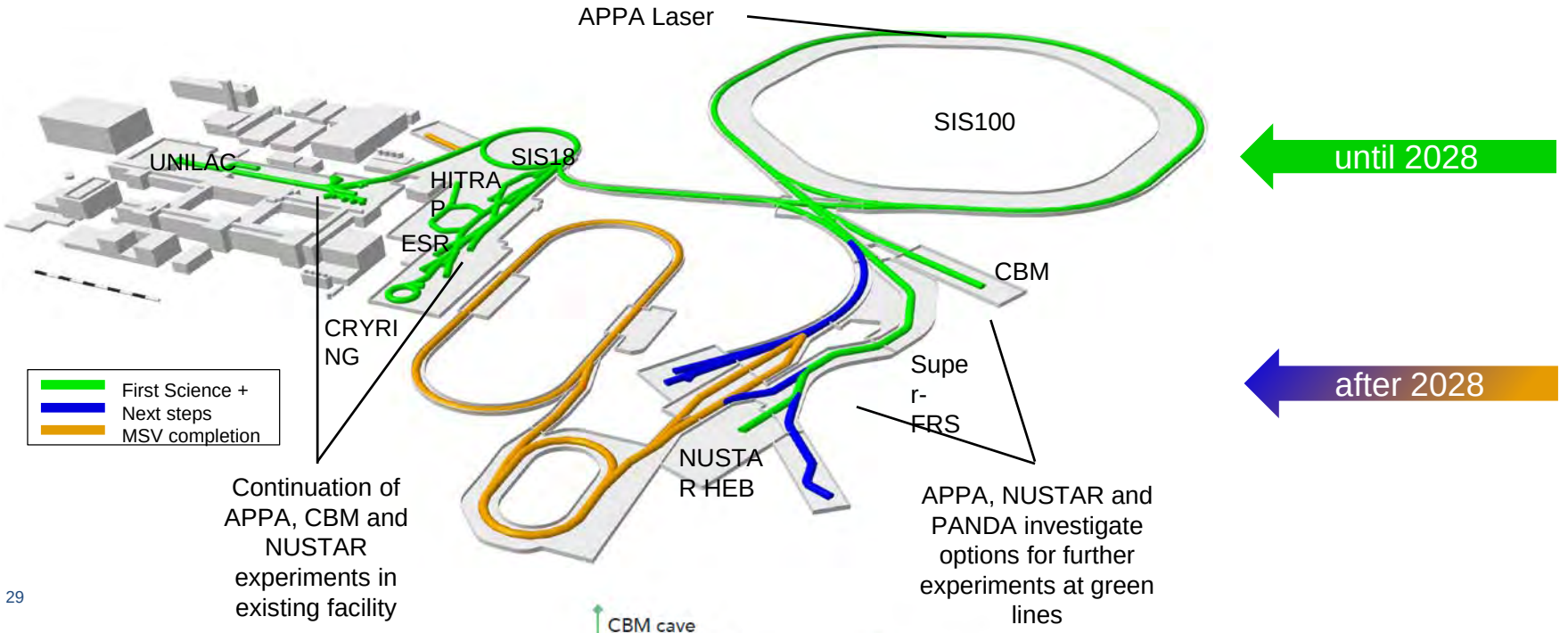


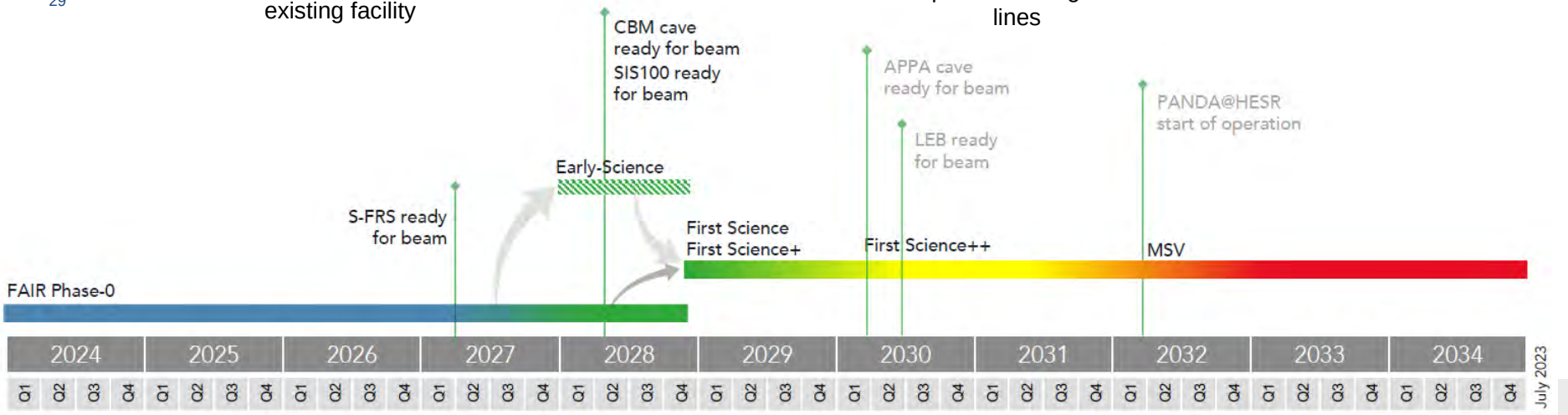
PANDA

Forward tracker



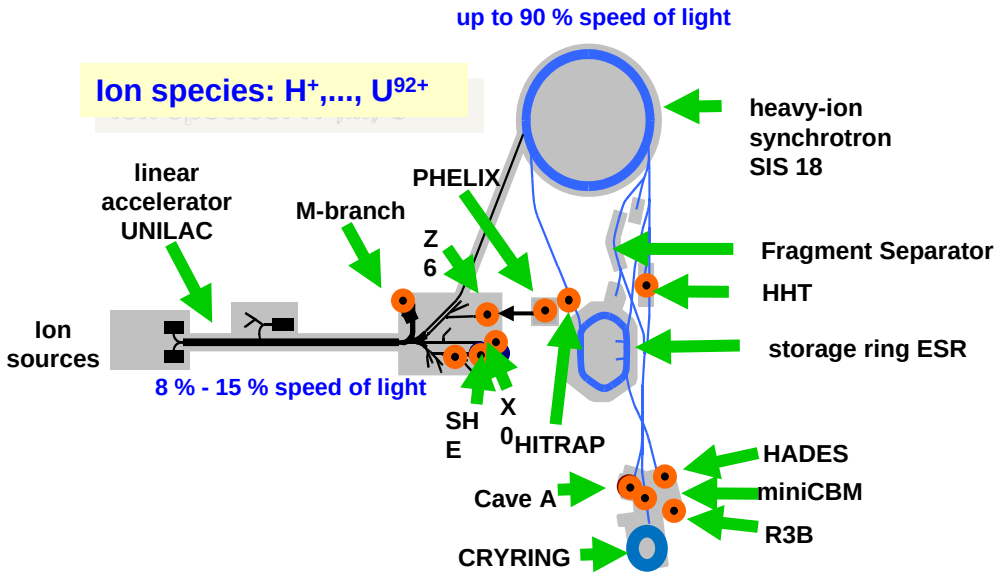
Current prospects and timeline

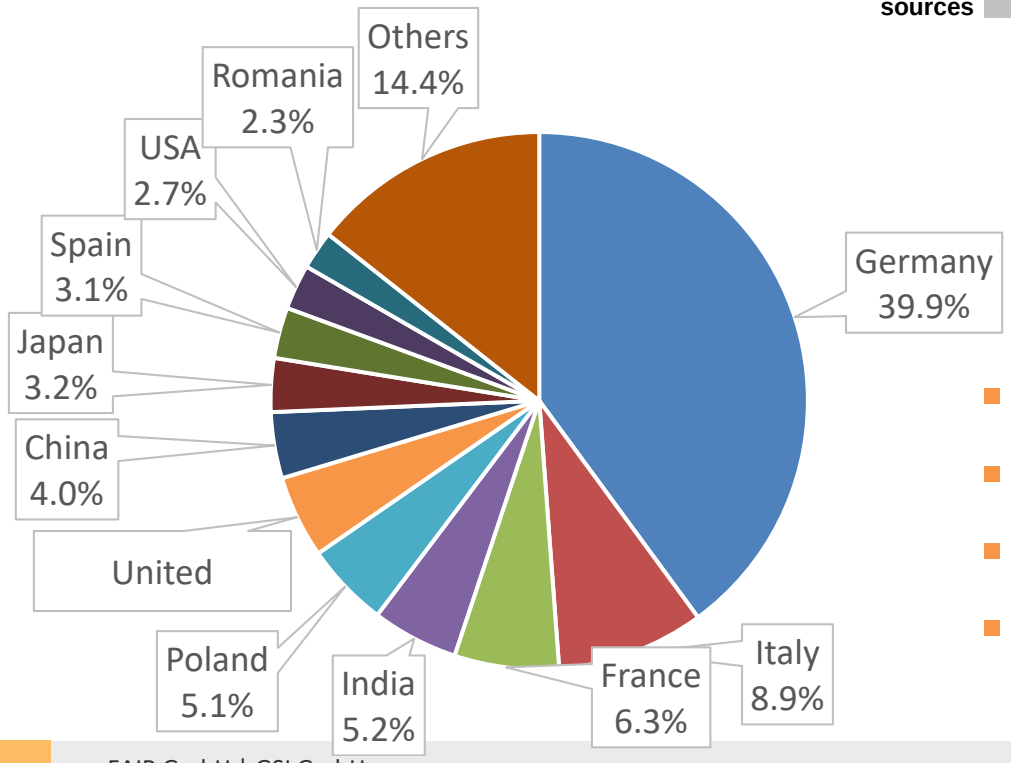




Ongoing: Early science program FAIR Phase-0

- Started in 2019, annual runs of ~110 days until FAIR operation





- Science while commissioning FAIR
- latest call: 124 proposals submitted
- 1729 participants of proposals
- From institutes in 45 countries

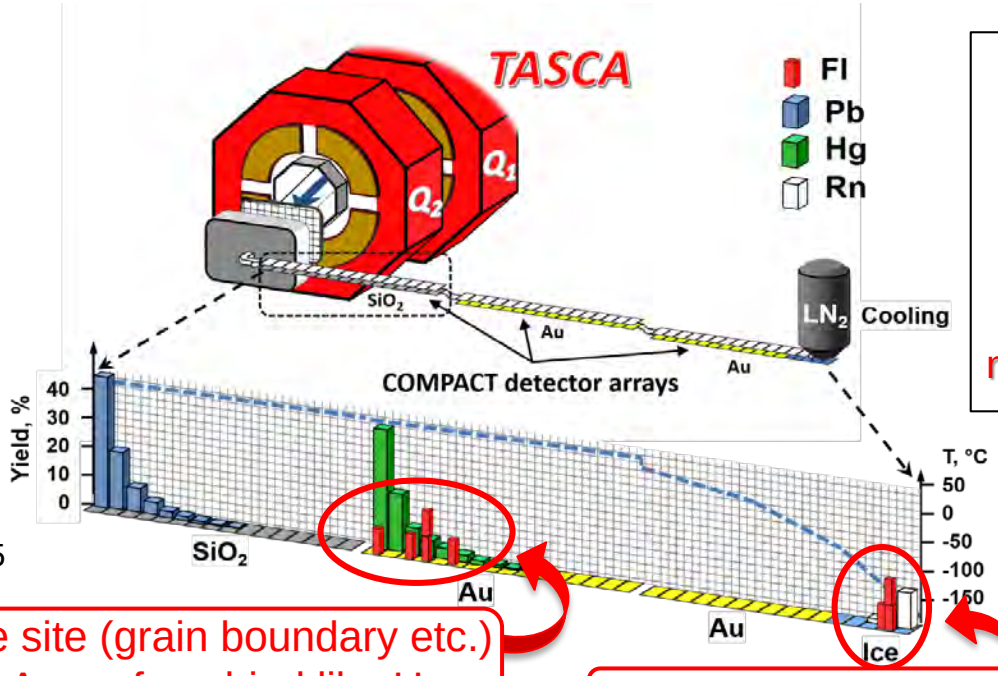
Chemical properties of element 114, Flerovium

- Flerovium: heaviest element with experimentally studied chemical properties
- Eight registered atoms in three beamtimes of total 2.5 months duration

Production:
^{244}Pu(^{48}Ca,3-4n)
^{288}Fl: $t_{1/2}$ ~0.7 s
^{289}Fl: $t_{1/2}$ ~2.0 s

Isolation in **TASCA**;
Chemical study and detection: COMPACT

A. Yakushev *et al.*,
Front. Chem. 10 (2022) 976635



Volatility:
Rn > **Fl** > Hg >> Pb

Reactivity:
Rn < **Fl** < Hg << Pb

Fl is the most volatile metal in the periodic table

Atoms hitting a reactive site (grain boundary etc.) on the inhomogeneous Au surface bind like Hg

Other atoms reach location of Rn adsorption

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

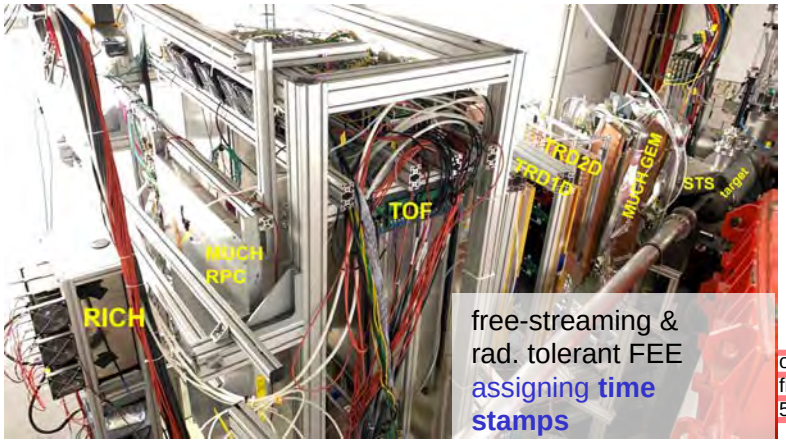
Research highlight
FLASH radiotherapy

- FLASH Radiotherapy, is a novel approach of RT using ultra-high dose rate aiming to get **unchanged tumor control protection (TCP)** and **decreased normal tissue complication probability (NTCP).**

- GSI has demonstrated for the first time that the FLASH effect can be obtained with accelerated carbon ions (18 Gy in one spill of 150 ms) paving the way to clinical translation in particle therapy

- The paper made the cover of the prestiogious *Nature Reviews Clinical Oncology*

With mCBM@SIS18 towards CBM



free-streaming & rad. tolerant FEE assigning **time stamps** to hit messages

optical fibers 50m

FLES entry nodes
CRI FPGA
µSlice building
(DAQ container)

optical fibers 300 m

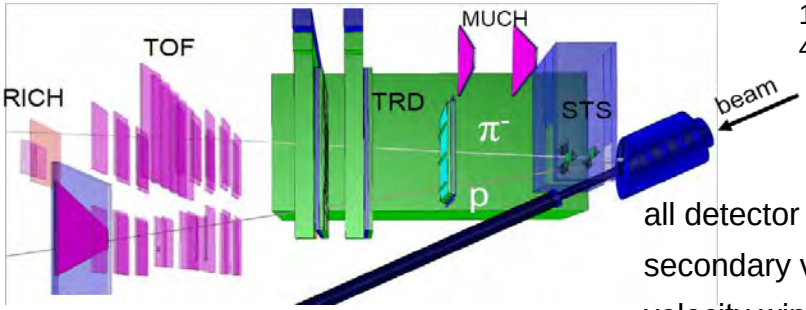
FLES processing nodes
time slice building
event reconstruction & selection
archiving

Free-streaming CBM data transport

Pre-series productions of all CBM detector systems

High-rate studies up to 10 MHz coll. rate in nucleus-nucleus coll.

Rare signal reconstructed: $\Lambda \rightarrow p\ \pi^-$

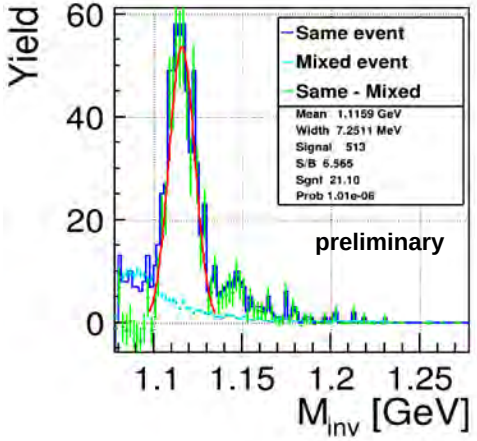


Ni+Ni 1.93 AGeV
run 2391 (May '22):
10^9 collisions, 1:57h
400 kHz av. coll. rate

all detector systems involved

secondary vertex

velocity windows for p and π^- candidate



Campaign 2024:

high-rate studies

online reconstruction & selection

Λ baryons in Ni+Ni at 1.0 - 1.93 AGeV

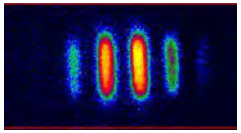
Japan @ GSI/FAIR

- GSI/FAIR has a long-standing cooperation with many prominent Japanese research centers and Universities.
- In particular, MOUs and cooperation agreements exist with
  - Japan Atomic Energy Agency (JAEA),
  - Riken Nishina Center and
  - Gunma University Heavy Ion Medical Center.
  - National Inst. for Quantum and Rad. Sc. Tech (QST)
  - High Energy Accelerator Research Organization (KEK)
- Since the early 1990s, there has always been continuous collaboration with Japanese scientists on-site and participation in many pioneering experiments with radioactive beams. Collaboration over decades has helped in the training and education of young scientists.
- Especially in the field of Accelerator development, experiments and related instrumentation.
- For many years, scientists from Japan have served as members of the Scientific Supervisory bodies of GSI and FAIR, and Scientists from GSI have served as members of the Japanese ones.

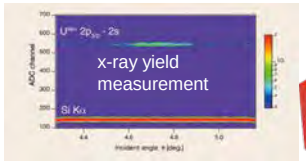
More than 50 scientists involved from 17 different Institutes in Japan

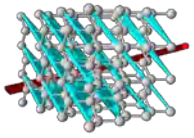
Japan and APPA (Atomic Physics)

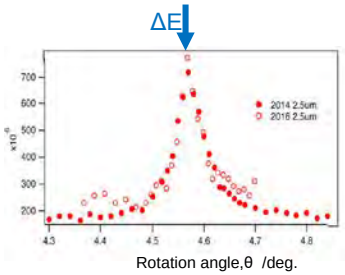
QED effects on the structure of relativistic highly charged ions using the resonant coherent excitation of ions in the virtual photon field of a Si crystal (proof of principle)



Resonance conditions identification







ΔE= 4460.9 ± 0.1(stat) ± 2.2(sys) eV

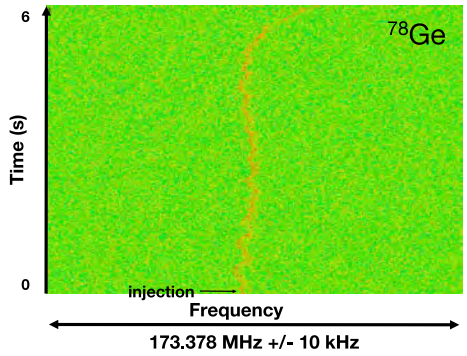
Demonstrator Experiment for SIS100 beams at APPA-Cave

Development of position-sensitive Schottky detector

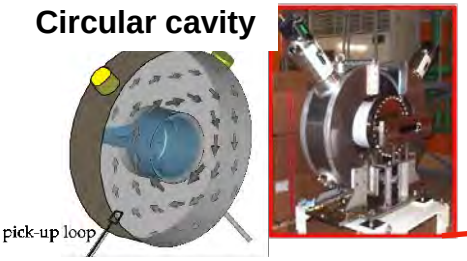
Schottky detector is useful in storage ring.

At GSI/FAIR developments for ESR and CRYRING

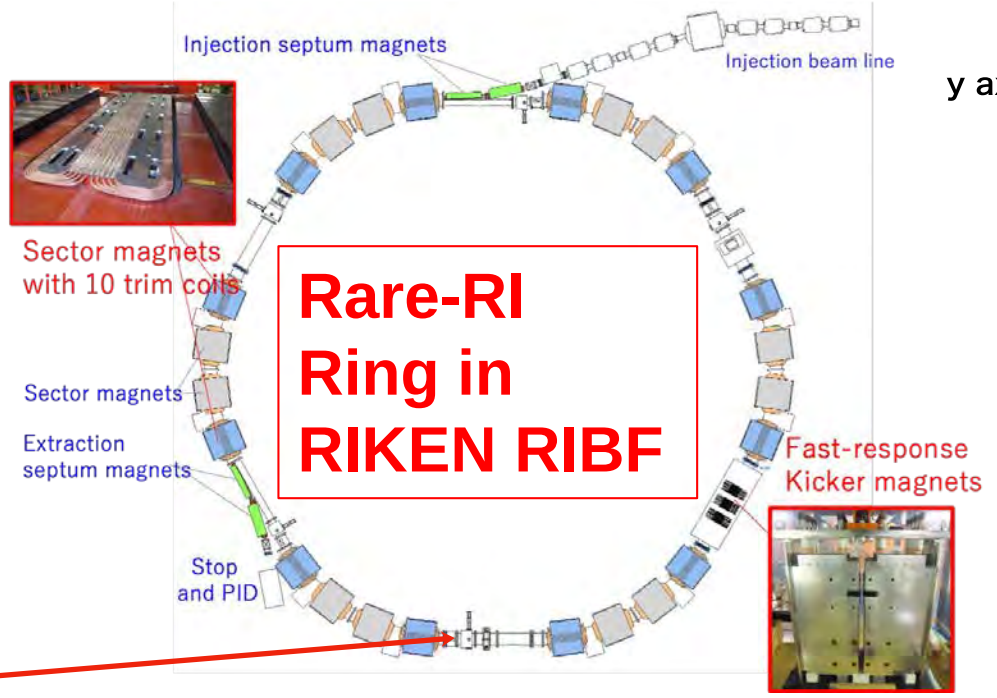
Collaboration Tsukuba - GSI



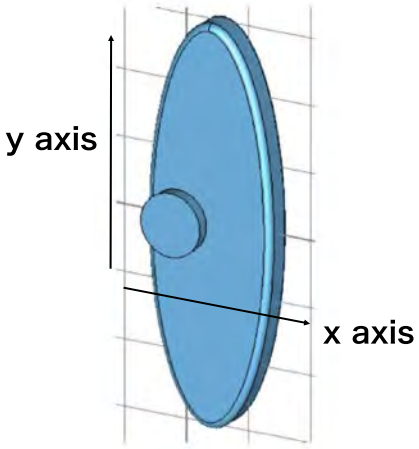
Circular cavity



Resonant Schottky



Elliptical cavity



Signal amplitude proportional to x-position.

Position sensitive.

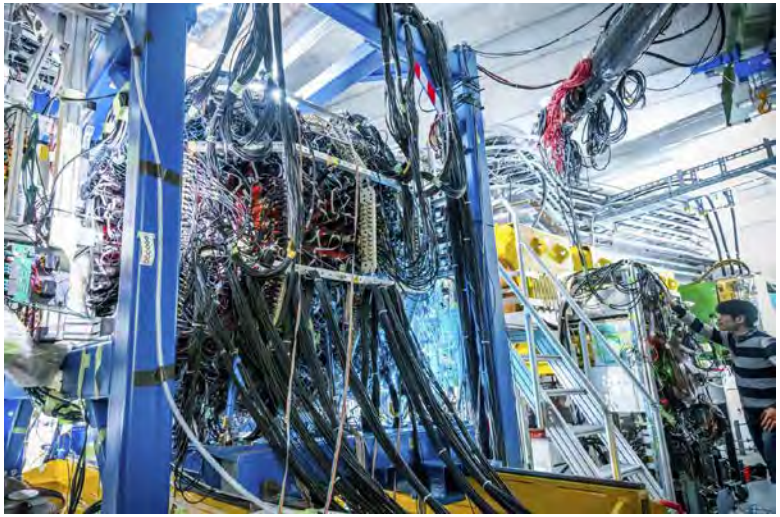
Akira OZAWA

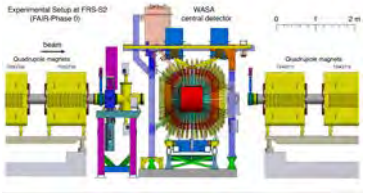
Experiments with Japanese Project lead at WASA@FRS 2022 (GSI): pilot experiments for Super-FRS

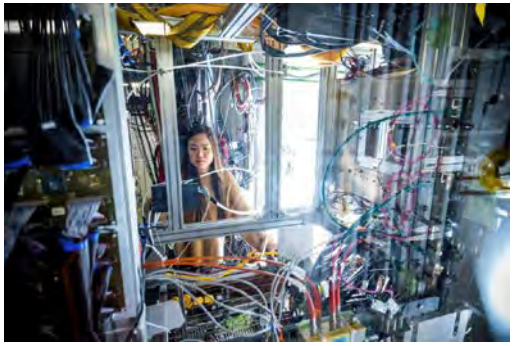
- Novel spectroscopic techniques are explored to study exotic nuclei and exotic atoms
- For the first time a calorimeter is coupled to a high-resolution spectrometer for relativistic beams
- The present experiments are among the 3 top priorities of the NUSTAR Collaboration and serve as pilot experiments for Super-FRS at FAIR
- **Spokesperson for granted experiments:**

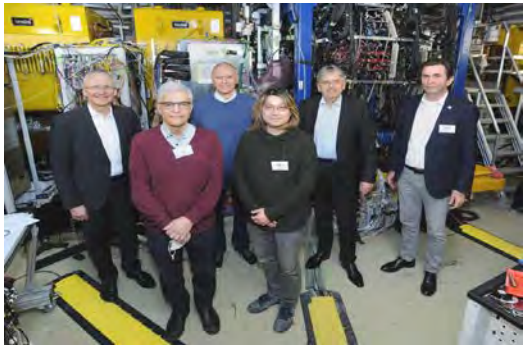
  T. Saito (RIKEN and GSI, Japanese)

  K. Itahashi (RIKEN, Japanese))





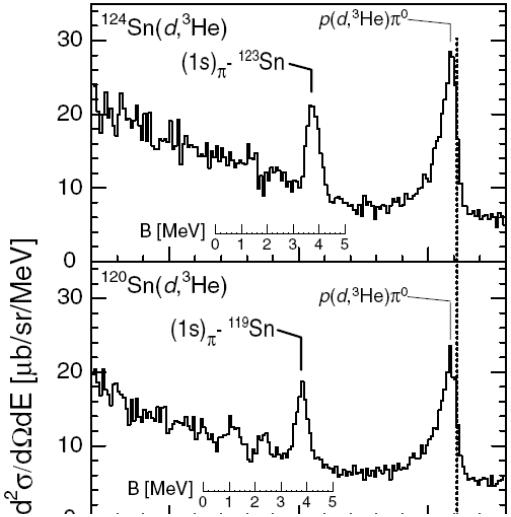




Project leader: Take Saito (RIKEN and GSI, Japanese)

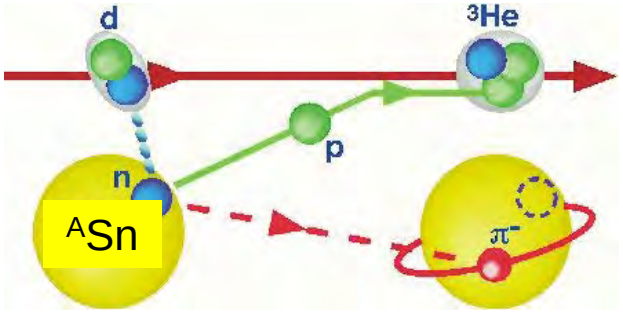
Japan in NUSTAR

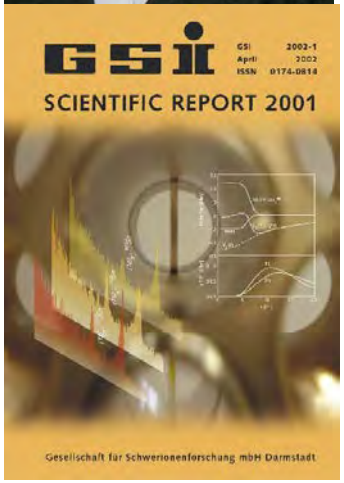
Discovery of Deeply-bound Pionic States in Heavy Ions



H. Geissel et al., Phys. Rev. Lett. 88 (2002) 122301
K. Suzuki et al., Phys. Rev. Lett. 92 (2004) 072302

R. Hayano, K. Itahashi, T. Yamzaki, P. Kienle





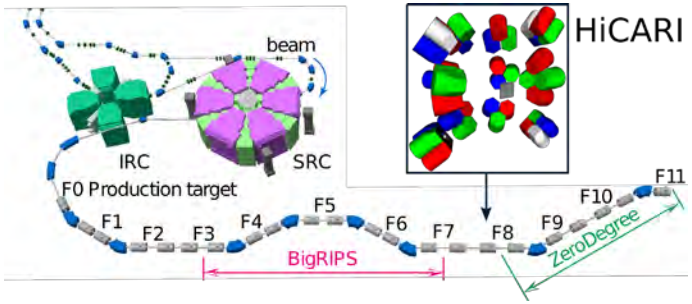
GSI lead experiments in Japan:

HiCARI: High-resolution Cluster Array at the Rare Ion Beam Facility (RIBF)

international hybrid HPGe array with contributions from GSI:

- located at BigRIPS separator of RIKEN Nishina Center
- in-beam gamma-ray spectroscopy of very exotic nuclei
- high-resolution energy measurements to study
  - single-particle and
  - collective excitations

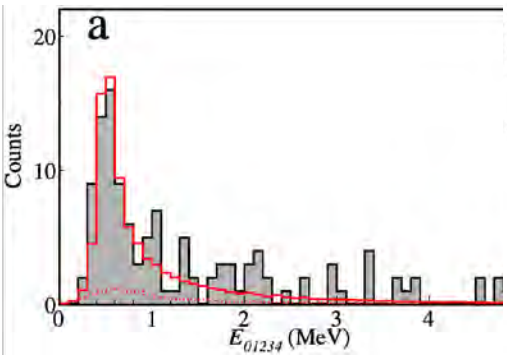
  in exotic nuclei
- **7 experiments performed in 2020/21 (2 lead by GSI scientists)**

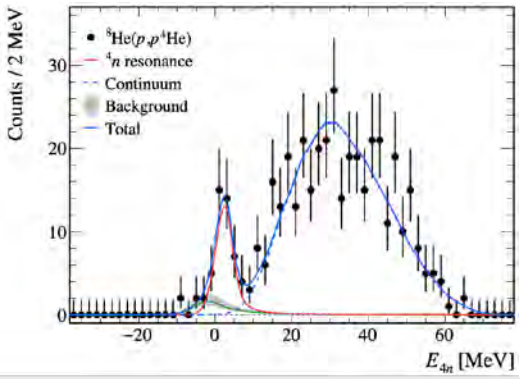


Detectors from GSI/FAIR at the Rare Ion Beam Facility in Japan

R3B Neuland integrated in the SAMURAI experiment at RIKEN 2015-2017 as **key detector for neutron detection** in many experiments.

- Discovery of ^{28}O located 4 neutrons beyond drip line
- **First observation of a strong 4-neutron correlation in the continuum at around 1 MeV (publication in NATURE)**
  => one of the 10 Breakthroughs in Physics in 2022!!
- First fully exclusive invariant-mass measurement with four neutrons detected in coincidence (B(E1) of ^{8}He, ^{28}O ground state)



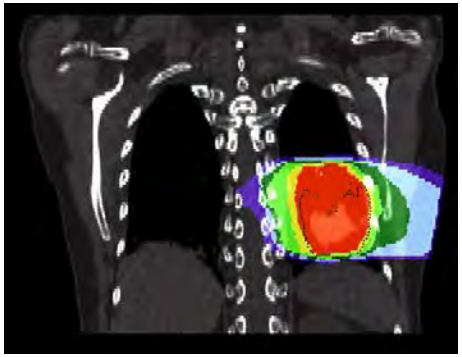


NeuLAND@RIKEN project leaders:
T. Aumann, H. Simon from GSI,
T. Uesaka (Japanese) from RIKEN
12 experiments in 71 days of beamtime
3 experiments with GSI leadership
(T. Aumann, C. Caesar, D. Rossi)

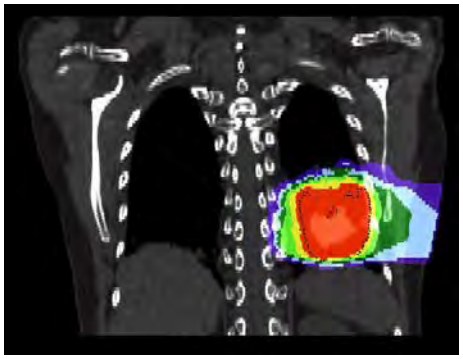
FAIR/GSI BIOPHYSICS and Japan

PRE-CINICAL RESEARCH IN PARTICLE THERAPY

- Over 20 years co-operation with NIRS/QST in Chiba
- GSI led an International Open Laboratory (IOL) at NIRS in Chiba (2-12.2016)
- Strong collaboration with Gunma Heavy Ion Center (the Biophysics Department Head is Adjunct Professor at Gunma University)
- “Hot” collaboration topics: medical physics, combination of heavy ions with immunotherapy (several common papers in the past few years)

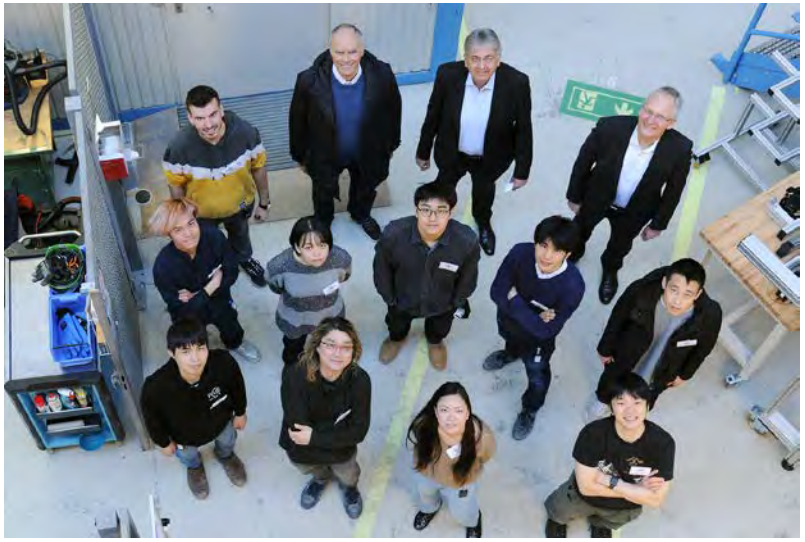


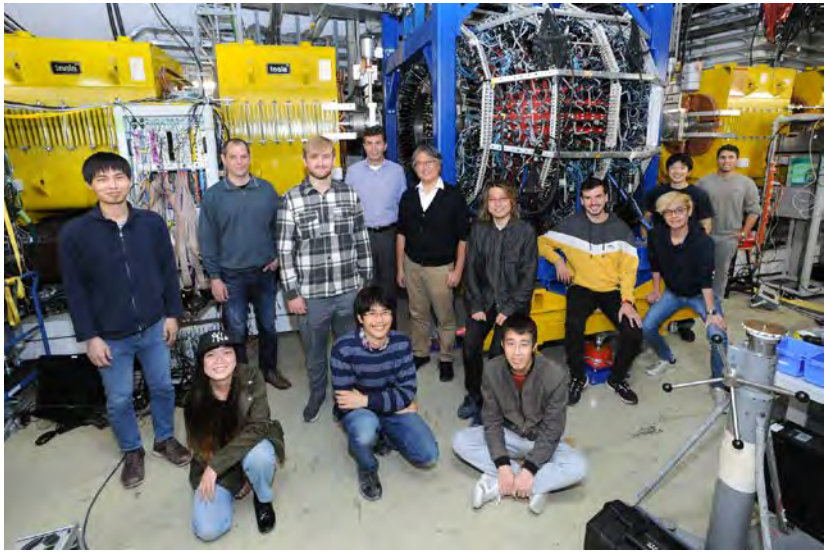
Internal Target Volume (ITV)



synchronized delivery

Impressions from FAIR Phase0 experiments

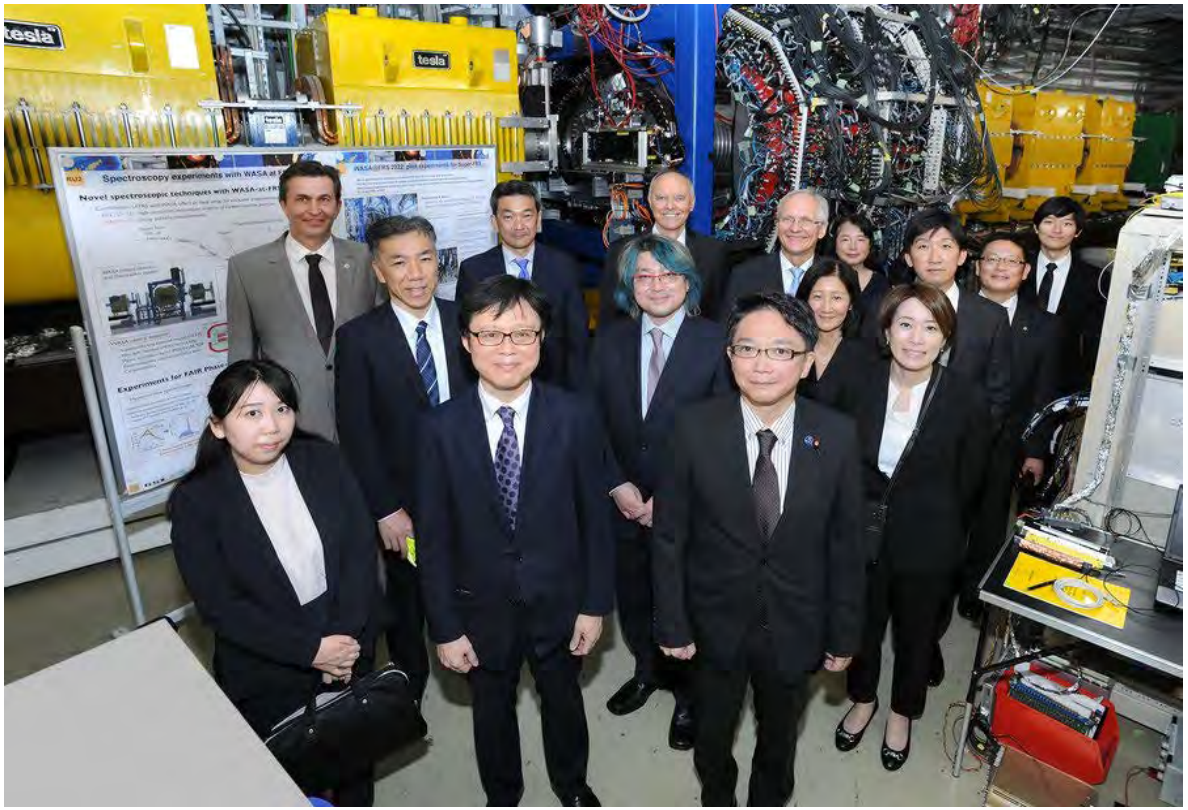




Several researchers from Japanese institutes participate in FAIR Phase 0 experiments at GSI.

RIKEN RCNP RIKKYO UNIVERSITY 首都大学東京 KYOTO UNIVERSITY FOUNDED 1897 岐阜大学 GIFU UNIVERSITY 東京大学 THE UNIVERSITY OF TOKYO

June 12, 2022: Visit to GSI/FAIR of Dr. Keitaro Ohno, Minister of State for Cabinet Affairs

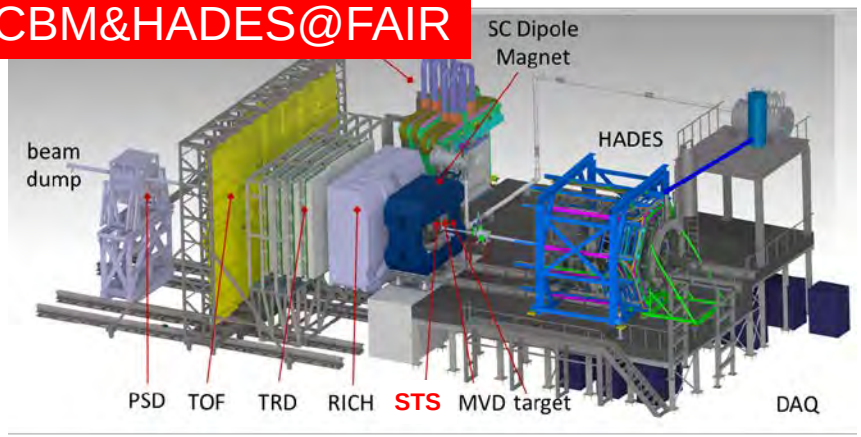


- On this occasion, MoU Between GSI/FAIR and RIKEN was signed

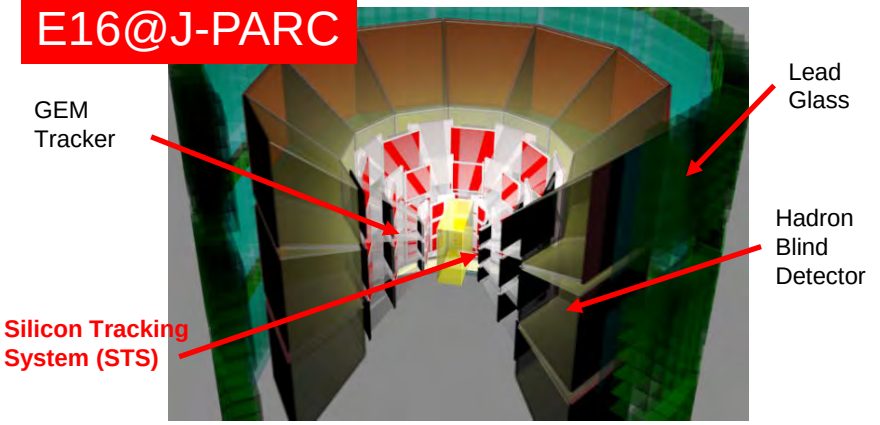
Japan and CBM@FAIR

“QCD Laboratory” in Germany and Japan

CBM&HADES@FAIR



E16@J-PARC



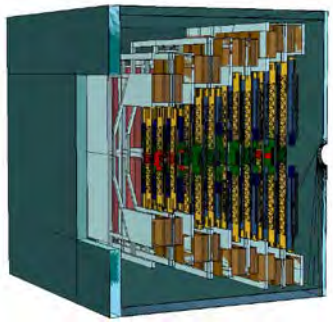
High density QCD matter w Heavy Ion collisions
High Intensity Heavy ion beam

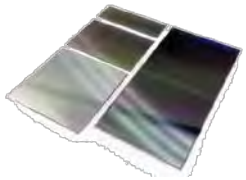
Nuclear Matter w Proton-Nucleus collisions Hadron Physics w secondary particles
High Intensity Proton beam

Complementary Physics Program
Collaboration for detector developments with high intensity beam

CBM Silicon Tracking System developments

CBM-STS





Silicon Sensors (Hamamatsu)

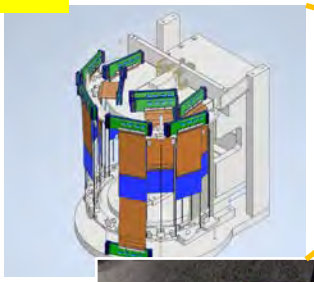
Sensor, cables, and Front-end electronics

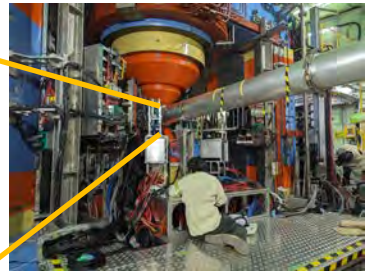
- CBM-STS is in the construction phase
- Construction and operation methods will be improved by feedbacks from Japan
  - Knowledge of constructions and operations and performance of total system are useful
  - Experienced PD and student from KEK will join the CBM-STS construction

Sent to Japan for performance check

Feedback

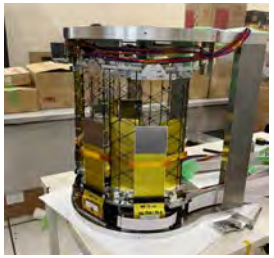
E16-STS





Spectrometer

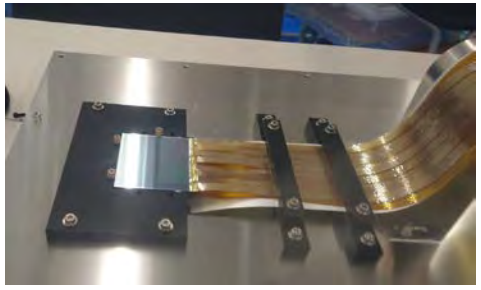
Sensor, ladder, cable

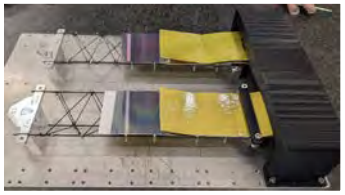


E16-STS

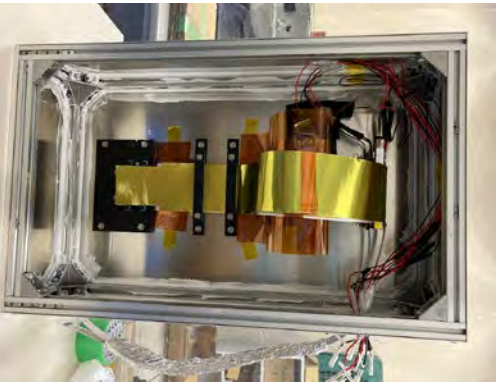
- E16-STS is installed and will be tested in the next year
- Performance will be evaluated in high-rate counting situation
  - 10MHz interaction rate

Photos of E16-STS

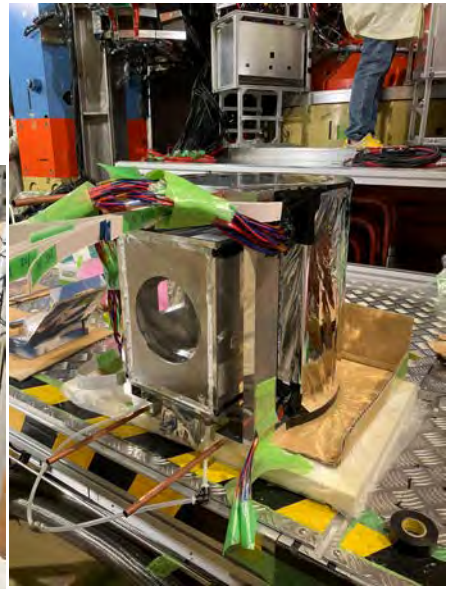




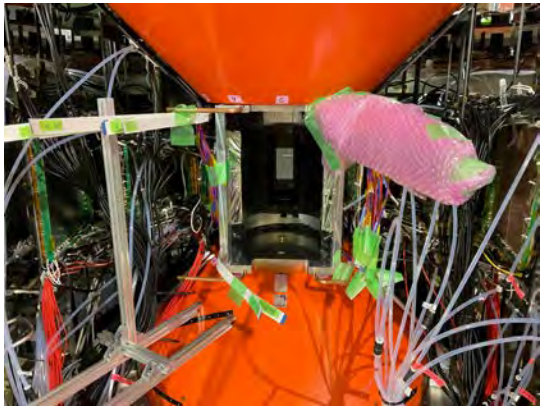
Sensor, ladder, cable



Test Chamber

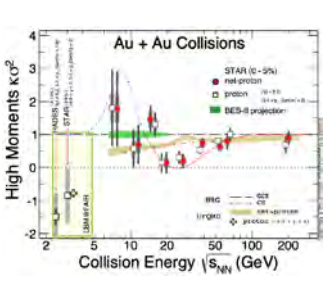


E16 STS

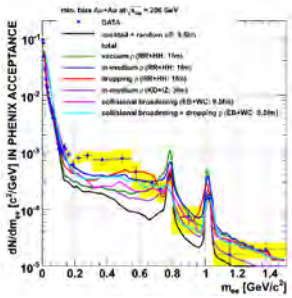


Further Interests in CBM from Japan

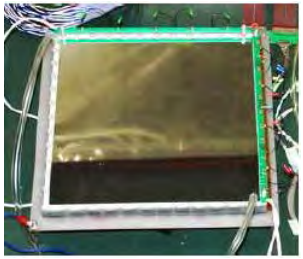
- Growth of CBM collaboration in Japan
  - University of Tsukuba and KEK are Associated members
  - Hiroshima University applies for Associate member in Sep. 2023
  - RIKEN and NIAS are interested in joining CBM
- Further collaboration both in Physics and Detectors
  - Many experts of heavy ion physics analysis in Japan
    - Correlations, fluctuations (Tsukuba)
    - Di-leptons (Hiroshima, KEK)
  - Interests and experiences on Hadron Physics
    - Hyper nucleus in heavy ion collisions (RIKEN)
    - Particle correlations and hadron interactions (Hiroshima, KEK)
  - Common interests for detector developments
    - Silicon Tracking System (Hiroshima, KEK)
    - Micro Vertex Detector and MAPS technology (Hiroshima, NIAS, KEK)
    - Gas Electron Multiplier technology (KEK)
    - Streaming readout and DAQ (NIAS)
- Complementary physics program at FAIR and J-PARC
  - Further discussions should be developed to maximize activities in both sides



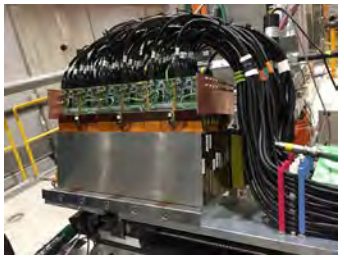
Fluctuation @ STAR (Tsukuba)



Di-electrons @ PHENIX (Hiroshima, KEK)



GEM Tracker @ J-PARC (KEK)



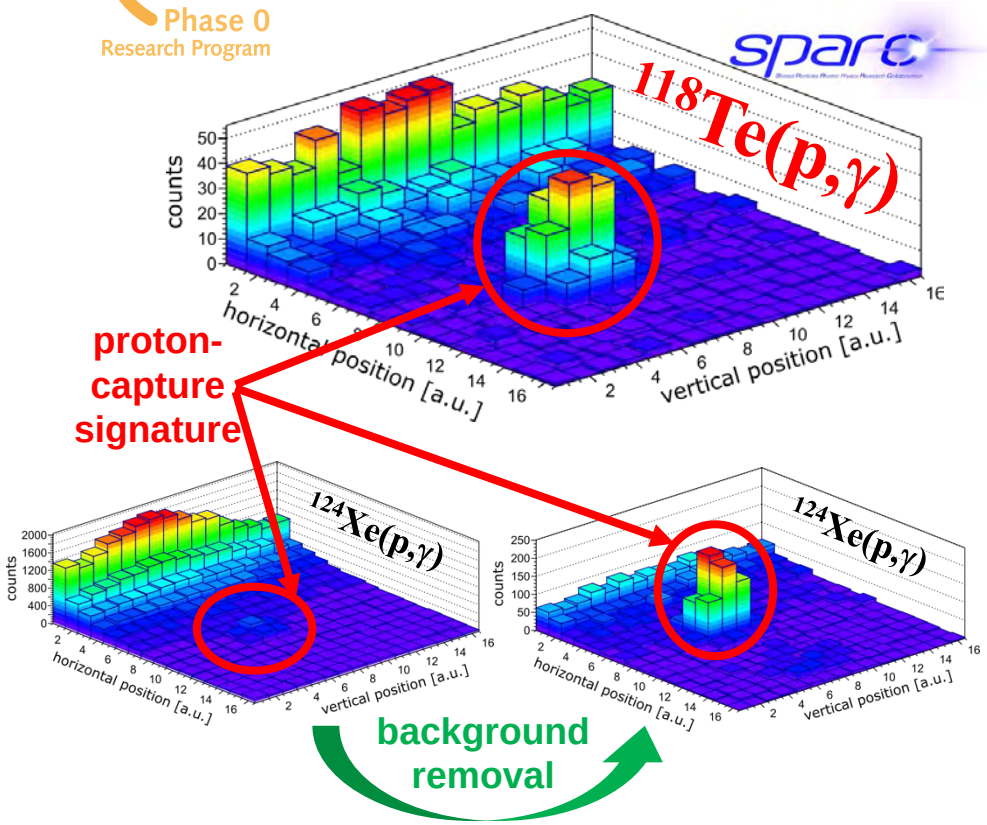
ALICE FOCAL Readout (NIAS)

FAIR: Unique Opportunities . . . & Challenges

Backup

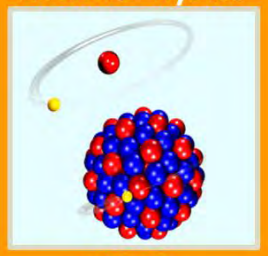
Ground-breaking experiment opening way for nuclear astrophysics experiments at FAIR with ESR

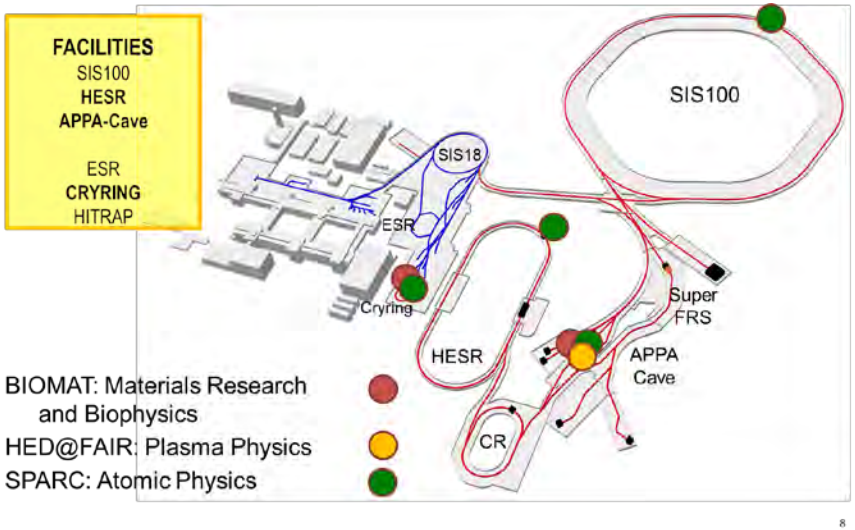
- E127: Proton-capture rates for nuclear astrophysics:
  First reaction study on stored radio-beam at low energies
- Study of radioactive ^{118}Te (6 days half-life)
  - production, storage, accumulation and deceleration in FRS-ESR
  - proton-capture measurements realized at 7 MeV/u and 6 MeV/u
- New background-free detection method demonstrated



Jan Glorius et al.

APPA - Atomic Physics, Plasma Physics, and Applied Sciences

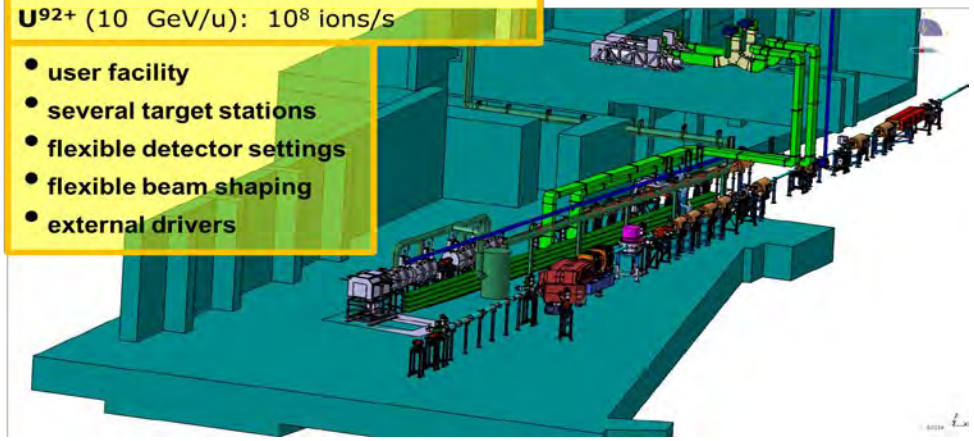
Atomic Physics	Plasma	Materials	Bio
			
SPARC	HED@FAIR	MAT/BIOMAT	BIO/BIOMAT
strong field research ... probing of fundamental laws of physics	**warm dense matter** ... states of matter common in astrophysical objects	**radiation hardness** ... mechanical and electrical degradation of materials	**space travel** ... cosmic radiation risk and shielding



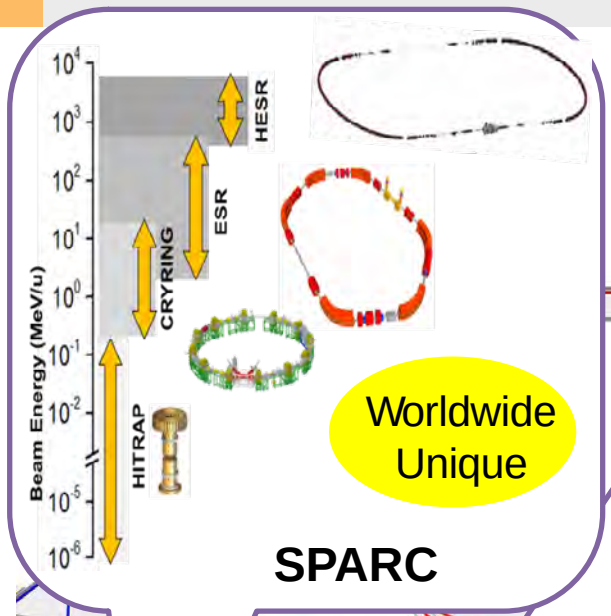
protons (10 GeV): 2 x 10^{13} p/bunch
U^{28+} (2 GeV/u): 5 x 10^{11} ions/bunch
U^{92+} (10 GeV/u): 10^{8} ions/s

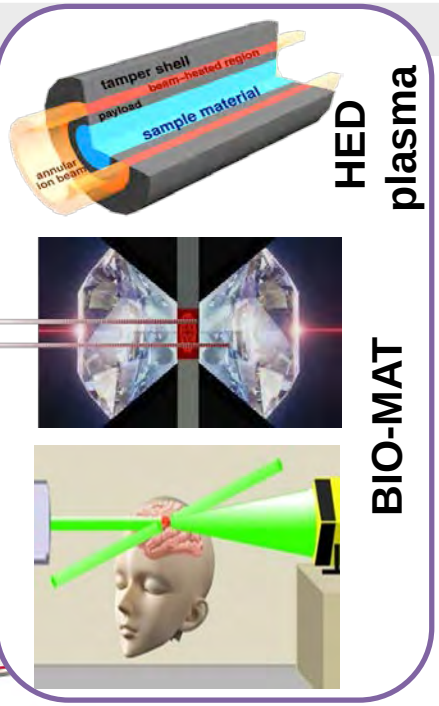
- user facility
- several target stations
- flexible detector settings
- flexible beam shaping
- external drivers

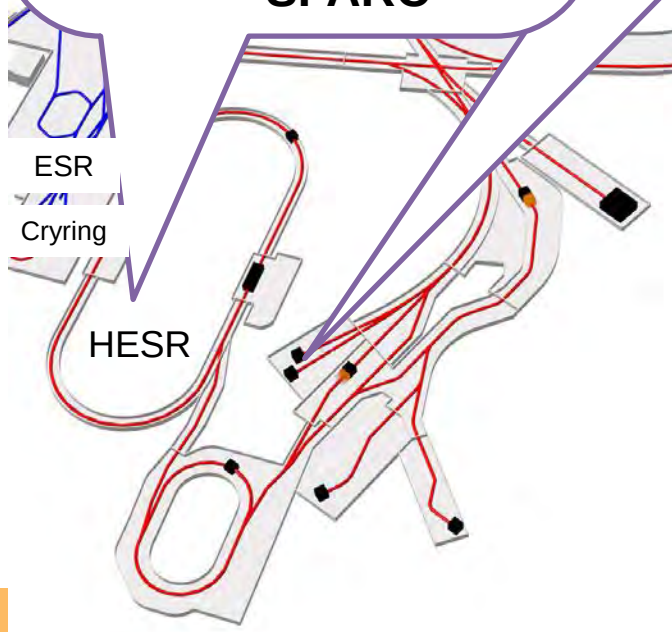
APPA Cave



APPA







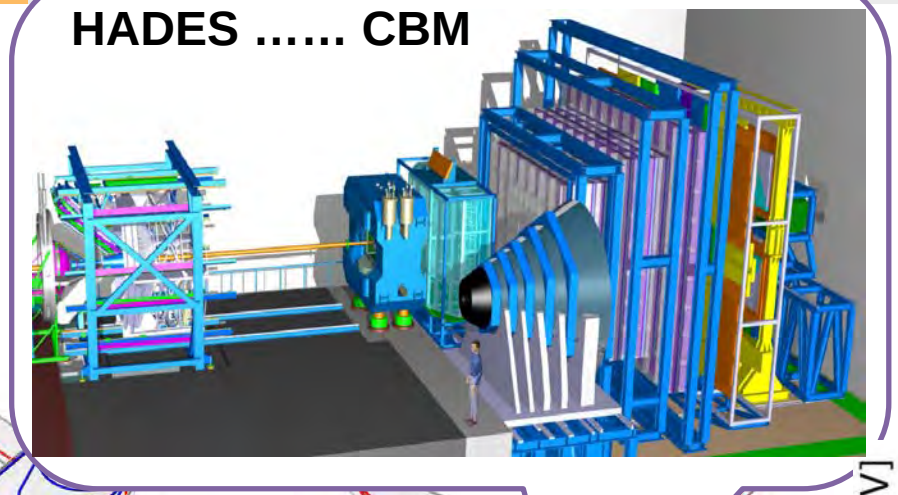
- Atomic, Plasma Physics and Applications
  - About 800 members
  - Wide field of science
    - basic research into material, biological and medical applications and space research

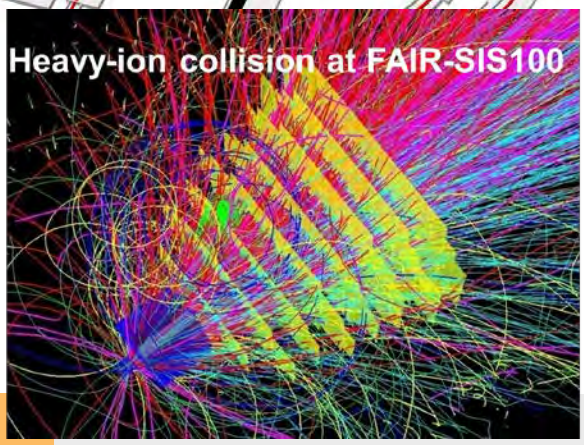
Atomic Physics
SPARC: ~400 members from 26 countries

Plasma Physics
HED: ~300 members from 16 countries

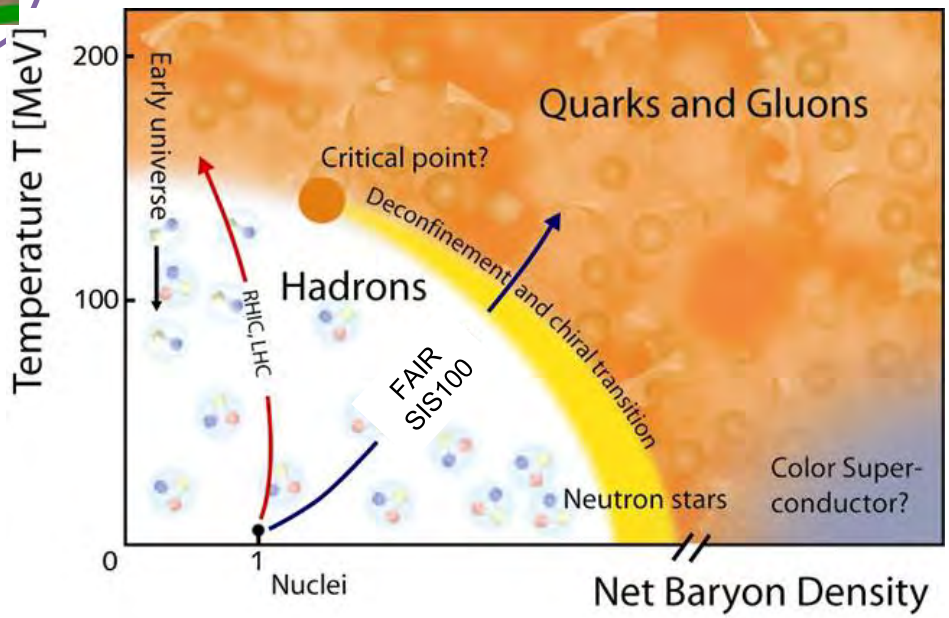
Materials Research and Biophysics
BIOMAT: ~100 members from 12 countries

C.B.M.





- Compressed Baryonic Matter Experiments
  - About 400 members

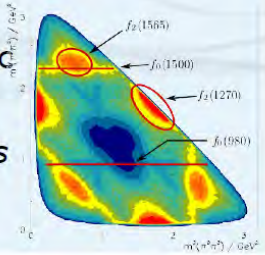


PANDA - AntiProton Annihilation at Darmstadt

Bound States of Strong Interaction

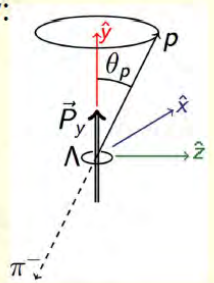
Spectroscopy

- New narrow XYZ: *Search for partner states*
- Production of exotic *QCD states: Glueballs & hybrids*



Strangeness

- Hyperon spectroscopy: *excited states largely unknown*
- Hyperon polarisation: *accessible by weak, parity violating decay*

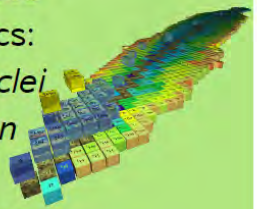


Nucleon Structure

- Generalized parton distributions: *Orbital angular momentum*
- Drell Yan: *Transverse structure, valence anti-quarks*
- Time-like form factors: *Low and high E, e and μ pairs*

Nuclear Hadron Physics

- Hypernuclear physics:
  - *Double Λ hypernuclei*
  - *Hyperon interaction*
- Hadrons in nuclei: *Charm and strangeness in the medium*

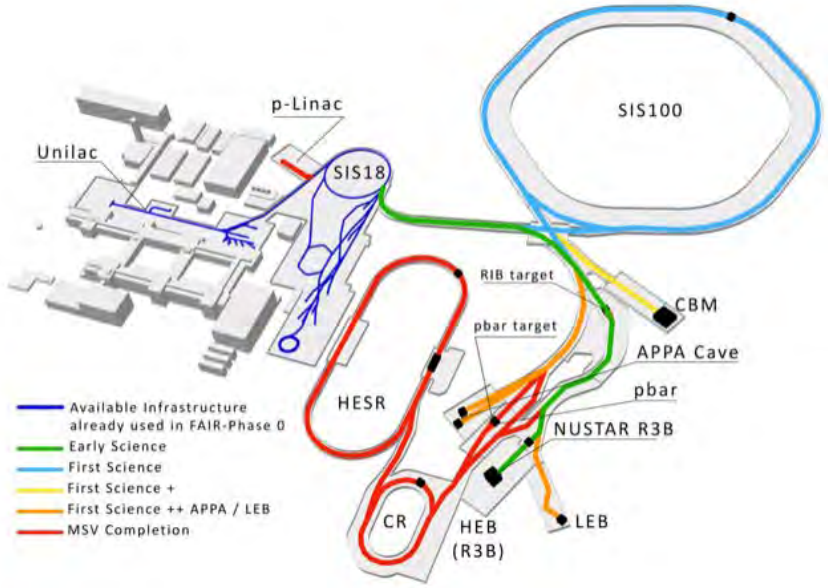


NUPECC Long Range Plan

The combination of PANDA's discovery potential for new states, coupled with the ability to perform high-precision systematic measurements is not realised at any other facility or experiment in the world.

Current status following FAIR Council decisions in March 2023

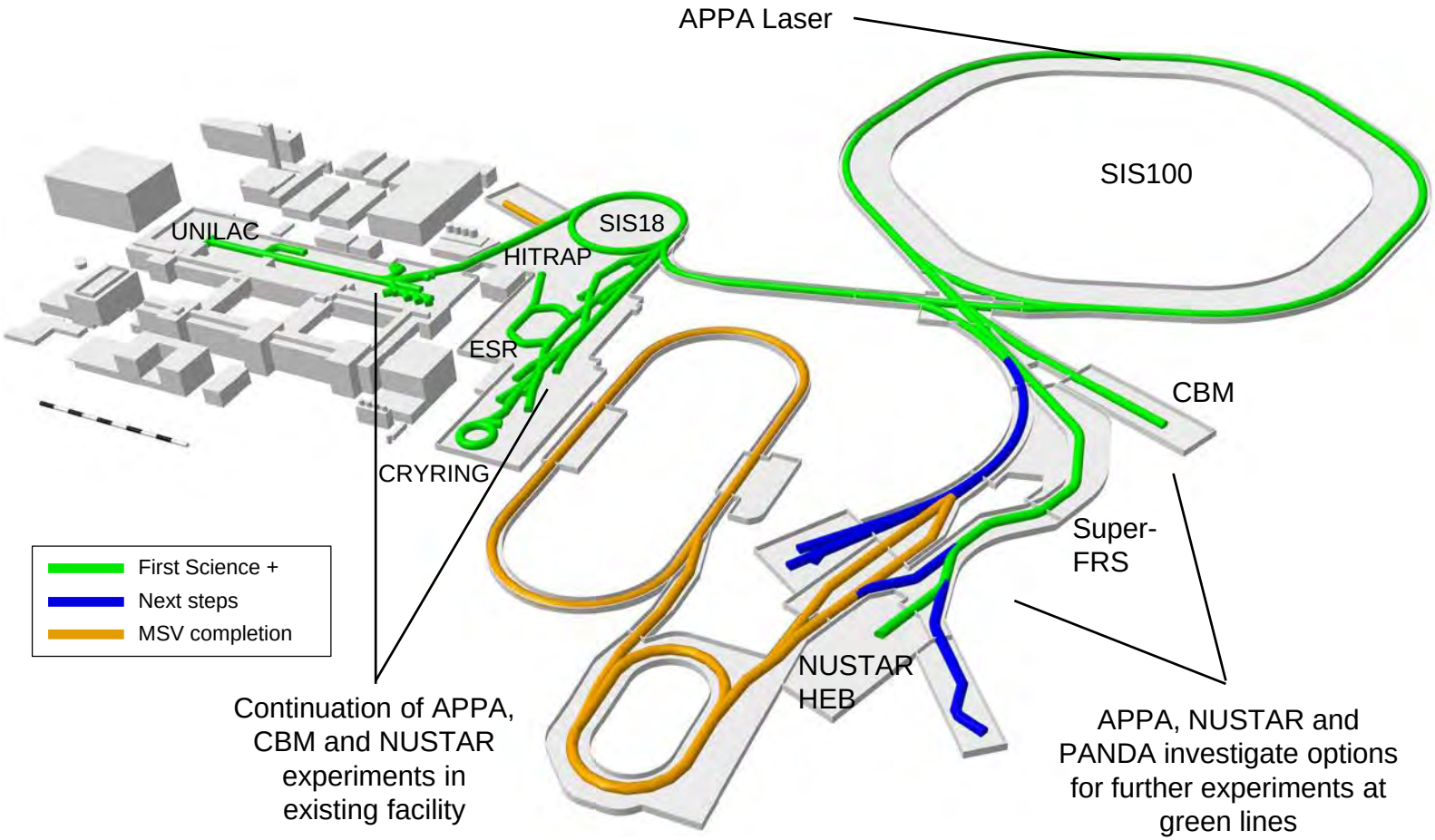
- Due to budget constraints a Scientific Review panel was tasked by the FAIR Council in 2022 to perform a “First Science and Staging Review of the FAIR Project”.
- The Scientific Review panel recommended in October 2022 that the scenario FS+ (SIS100, Super-FRS-HEB and CBM) would be the most appropriate starting scenario to achieve world leading science.
- FAIR Council decided on 9th & 10th March 2023 to use the additional funds provided by Germany to proceed with FS and to make further decisions on FS+ based on the contributions by other shareholders in future meetings, possibly already in July 2023. Council stated that “*the realisation of the MSV… …remains the aim of the FAIR-Project*”



until 2028 (ES,FS,FS+)

after 2028

FAIR 2028


APPA Laser
SIS100
UNILAC
SIS18
HITRAP
ESR
CBM
CRYRING
Super-
FRS
NUSTAR
HEB
First Science +
Next steps
MSV completion
Continuation of APPA, CBM and NUSTAR experiments in existing facility
APPA, NUSTAR and PANDA investigate options for further experiments at green lines

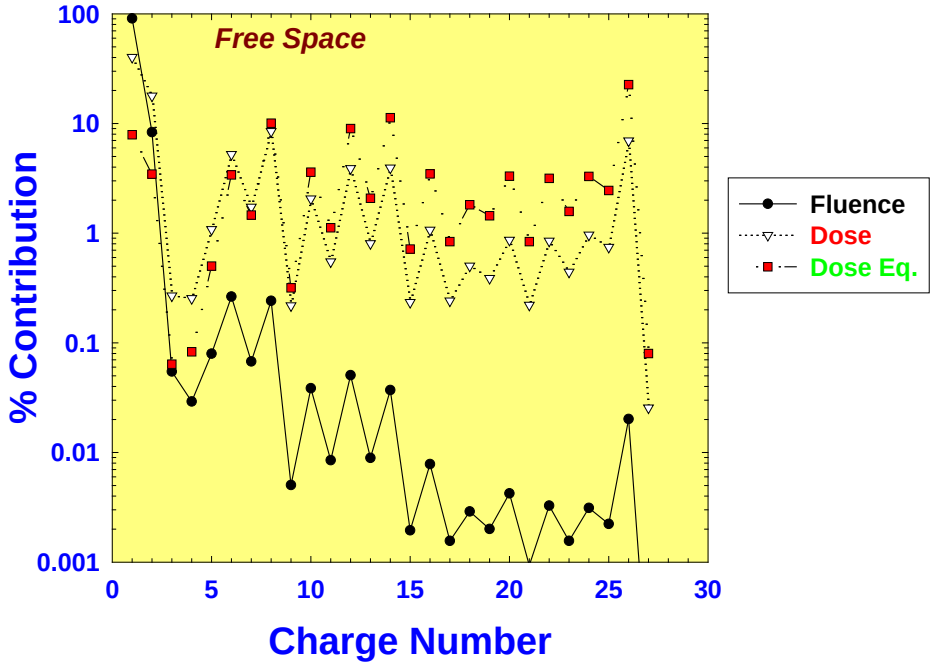
Evolution towards FAIR 2028

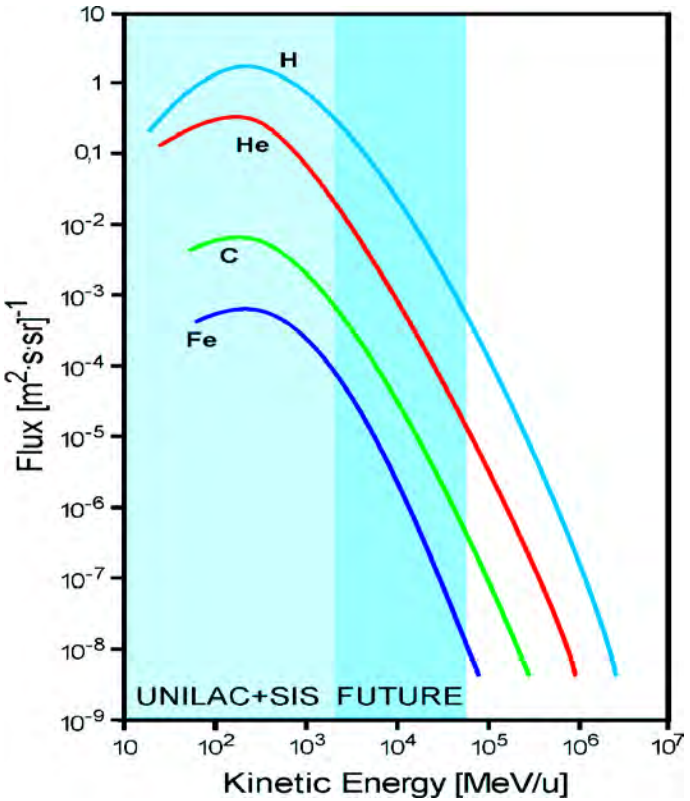
- Up to 2025 we continue with FAIR the annual block of continuous beamtime for Phase-0, from 2026 onwards we enter the mixed-mode of Phase-0 with the commissioning of the new beamlines.
- Annual beamtime for science will increase progressively, to reach full year operation from 2028 onwards.
- Some experiments at the Super-FRS will start already in 2027 using SIS18 beams („Early Science“)
- We will try to keep a broad research programme on campus, which will also serve the long-term goals of FAIR.

- The construction of further components towards the completion of the MSV will require additional funding. If provided by ~ 2026, the MSV could be completed by 2031-2032. The timetable is dictated by the availability of funds

Galactic Cosmic Radiation

GCR Charge Contributions





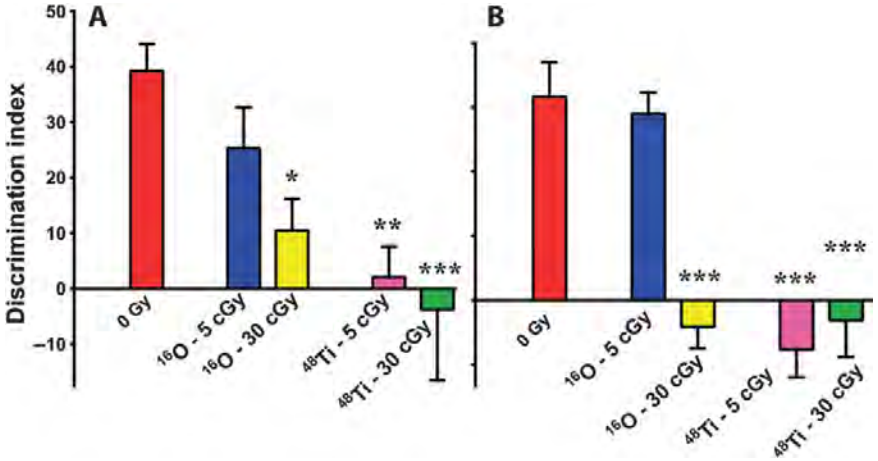
Durante and Cucinotta, *Rev. Mod. Phys*. 2011

RESEARCH ARTICLE Parihar *et al.* Sci. Adv. 2015;1:e1400256 1 May 2015

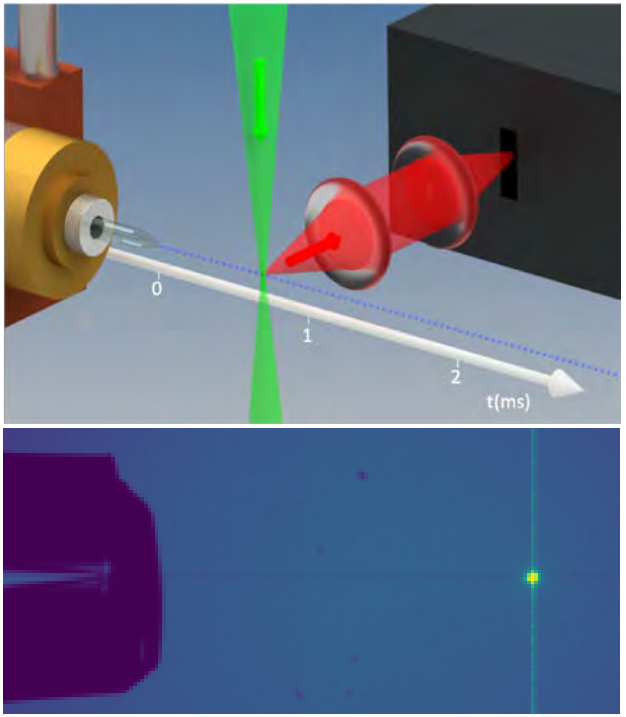
COGNITIVE NEUROSCIENCE

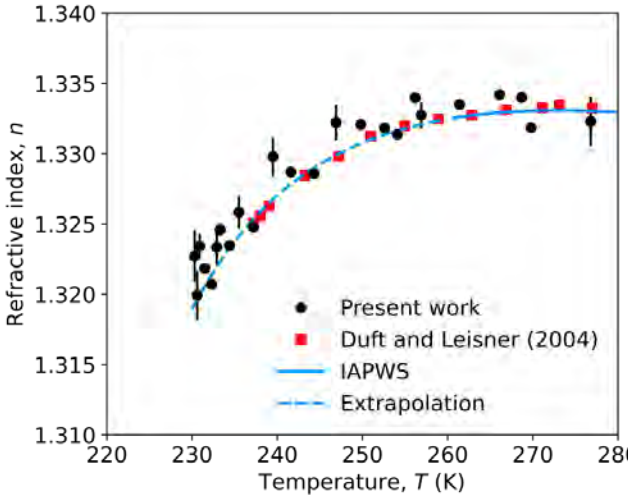
What happens to your brain on the way to Mars

Vipan K. Parihar,[1] Barrett Allen,[1] Katherine K. Tran,[1] Trisha G. Macaraeg,[1] Esther M. Chu,[1] Stephanie F. Kwok,[1] Nicole N. Chmielewski,[1] Brianna M. Craver,[1] Janet E. Baulch,[1] Munjal M. Acharya,[1] Francis A. Cucinotta,[2] Charles L. Limoli[1]*



Refractive index of supercooled water down to 230 K (- 43,15° C)





- Knowledge of the refractive index *n* of supercooled water is crucial for improving climate models.
- Water microjets in vacuum probed by Raman scattering allowed the determination of refractive index n for visible light down to 230 K.

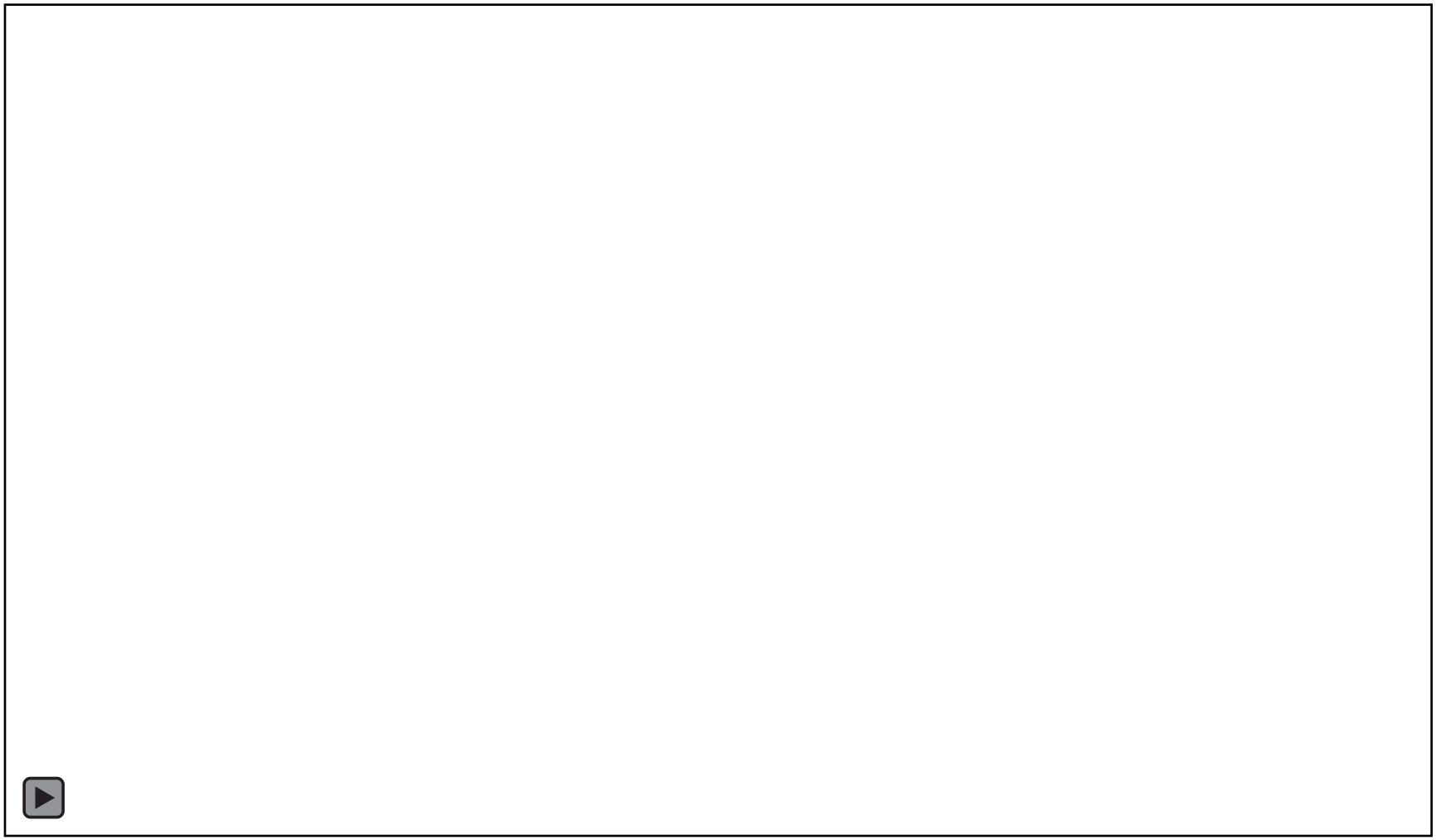
Goy *et* al., J. Phys. Chem. Lett. **13**, 11872 (2022)

FAIR SIS 100 supply tunnel

April 2023

The theory:

where the elements come from ...



FAIR - The Universe in the Laboratory

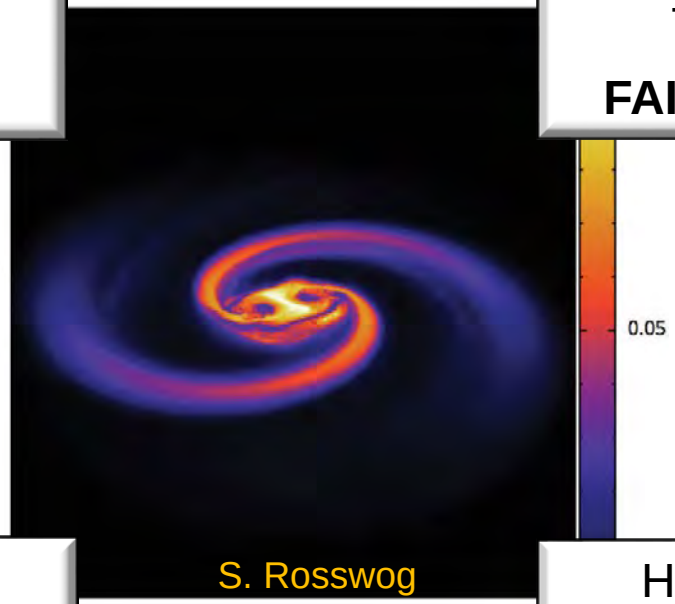
From Neutron Star Mergers to Platinum and Gold

How Matter behaves at extreme electromagnetic Field Strengths

FAIR/ APPA

How Matter behaves at extreme Densities and Temperatures

FAIR/ CBM-HADES



How the chemical elements evolve from Neutron-Star Matter

FAIR/ NUSTAR

How the Protons and Neutrons are formed

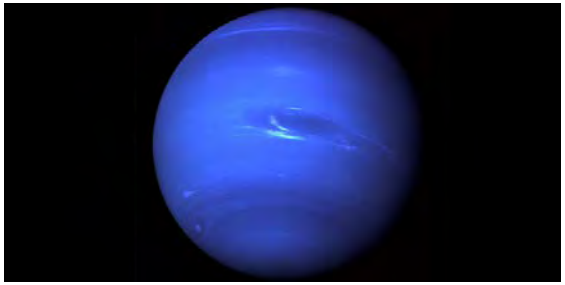
FAIR/ PANDA

Questions about the Universe

Matter in the interior of the Earth and of large planets

- The interior of our Earth is most likely composed of liquid iron. What is exactly the melting curve for iron?

- Does hydrogen form a metallic state under the extreme conditions of pressure and temperature on and in Jupiter? How does hydrogene separate from He?



- Are there diamond layers in Uranus and Neptune? What role does the high-density metallic state of water play for the magnetic field in Uranus and Neptune?