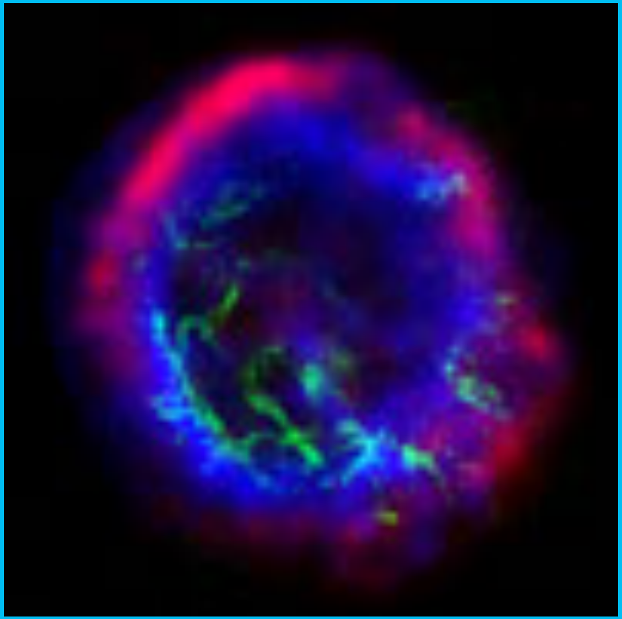
The Facility for Antiproton and Ion Research



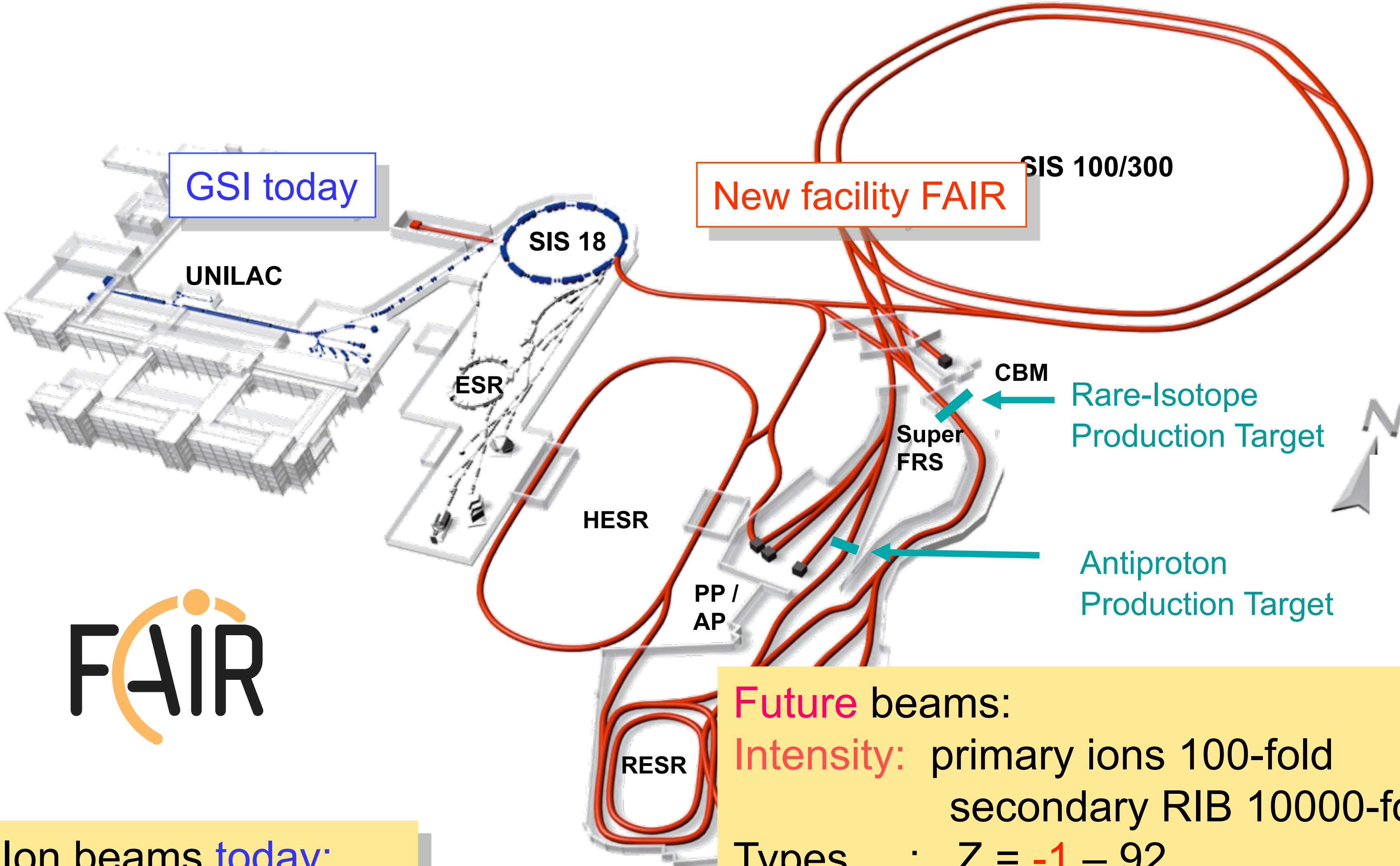
Karlheinz Langanke
GSI Helmholtzzentrum Darmstadt
TU Darmstadt

HELMHOLTZ | ASSOCIATION

GSI

INPC, Adelaide, September 15, 2016

Google Earth: FAIR in 2022

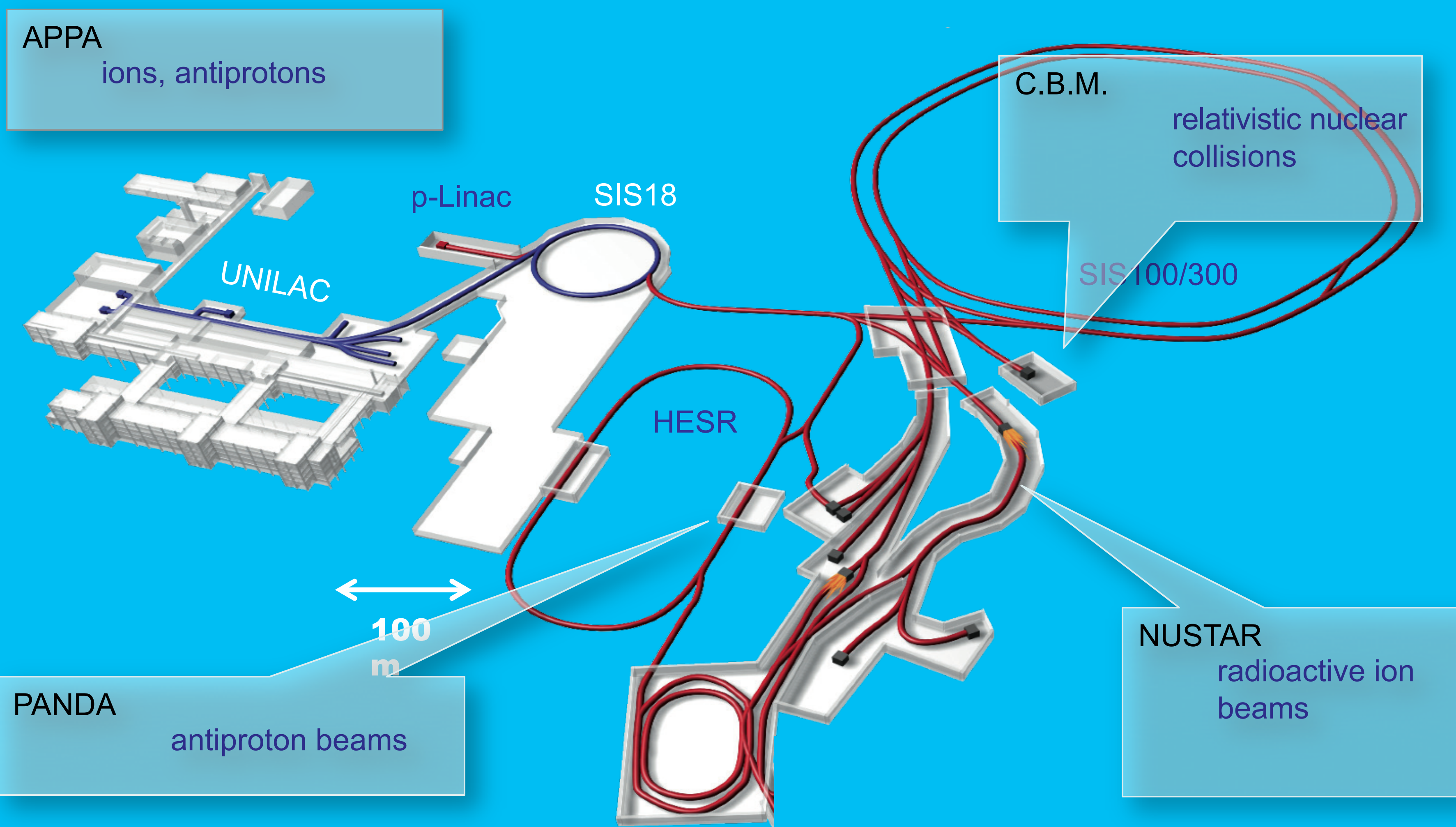


FAIR

Ion beams today:
Z = 1 – 92
(Protons til uranium)
Up to 2 GeV/nucleon

Future beams:
Intensity: primary ions 100-fold
secondary RIB 10000-fold
Types : Z = -1 – 92
(Antiprotons til uranium)
Energies: ions up to 35 - 45 GeV/u
antiprotons 0 -15 GeV/c

Accelerator complex

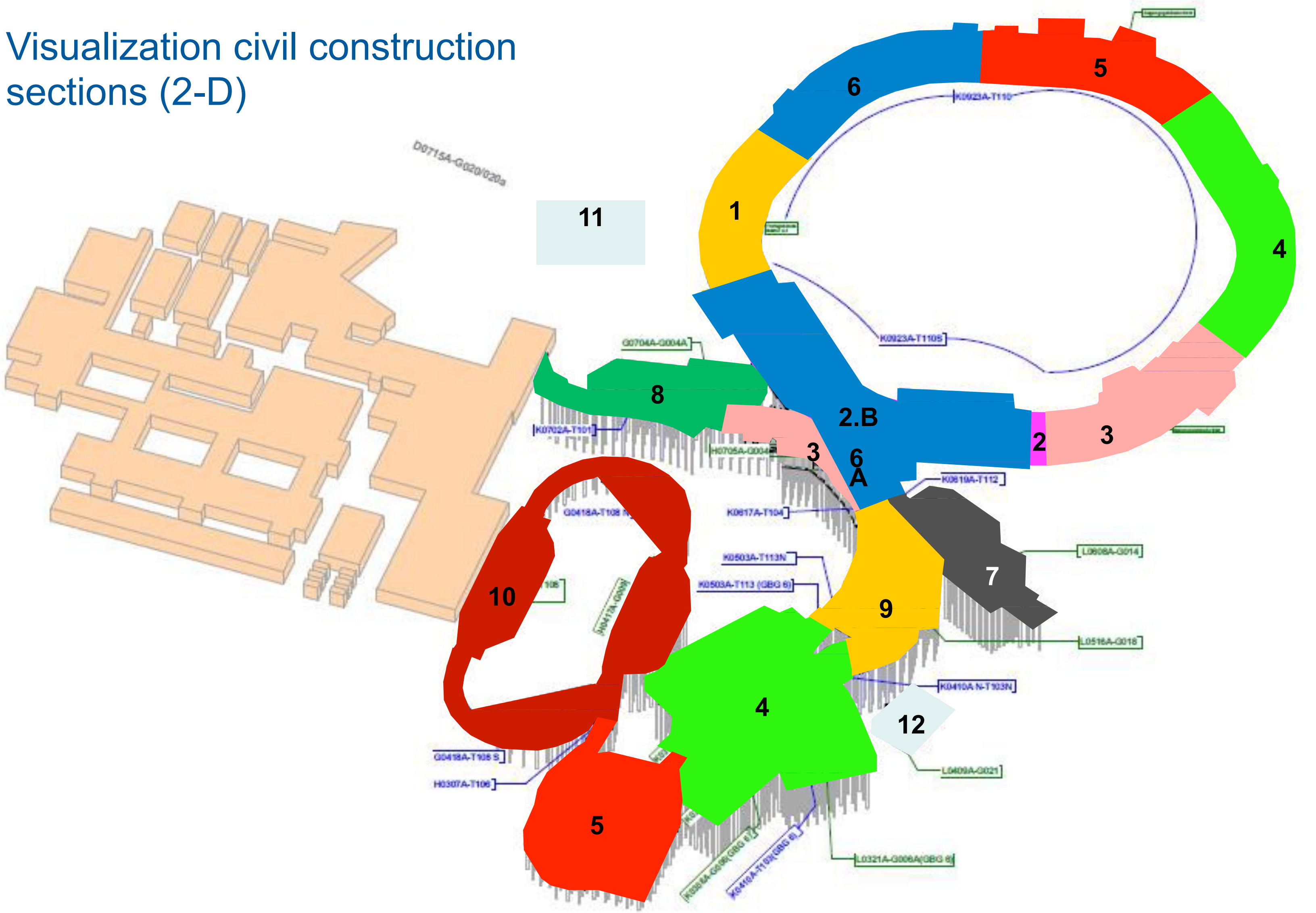


International Participation in FAIR

- FAIR governed by international convention
  - 9 shareholders + 1 assoc. partner (orange)
- Scientists from all over the world are engaged
  - More than 200 institutions from 53 countries are involved with their scientists (orange + blue)

Civil construction execution plan

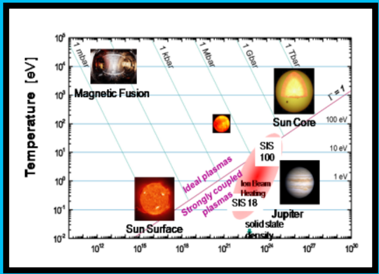
Visualization civil construction sections (2-D)



The GSI/FAIR Joint Management

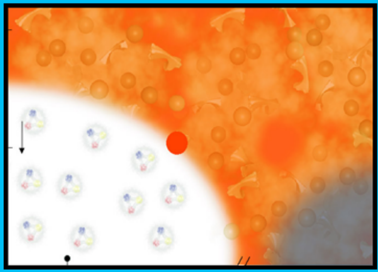
Paolo Giubellino   Ursula Weyrich   Jörg Blaurock

Experimental Collaborations



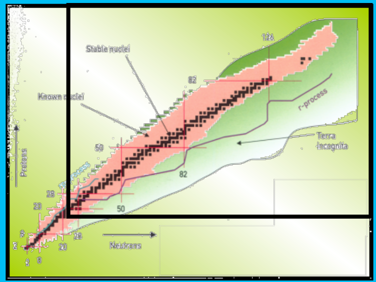
atom-, bio-,plasma physics, material research

APPA



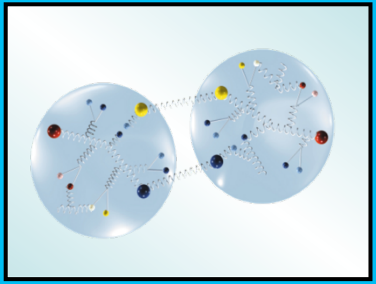
nuclear- and quark-matter

CBM



exotic nuclei and
nuclear astrophysics

NuSTAR



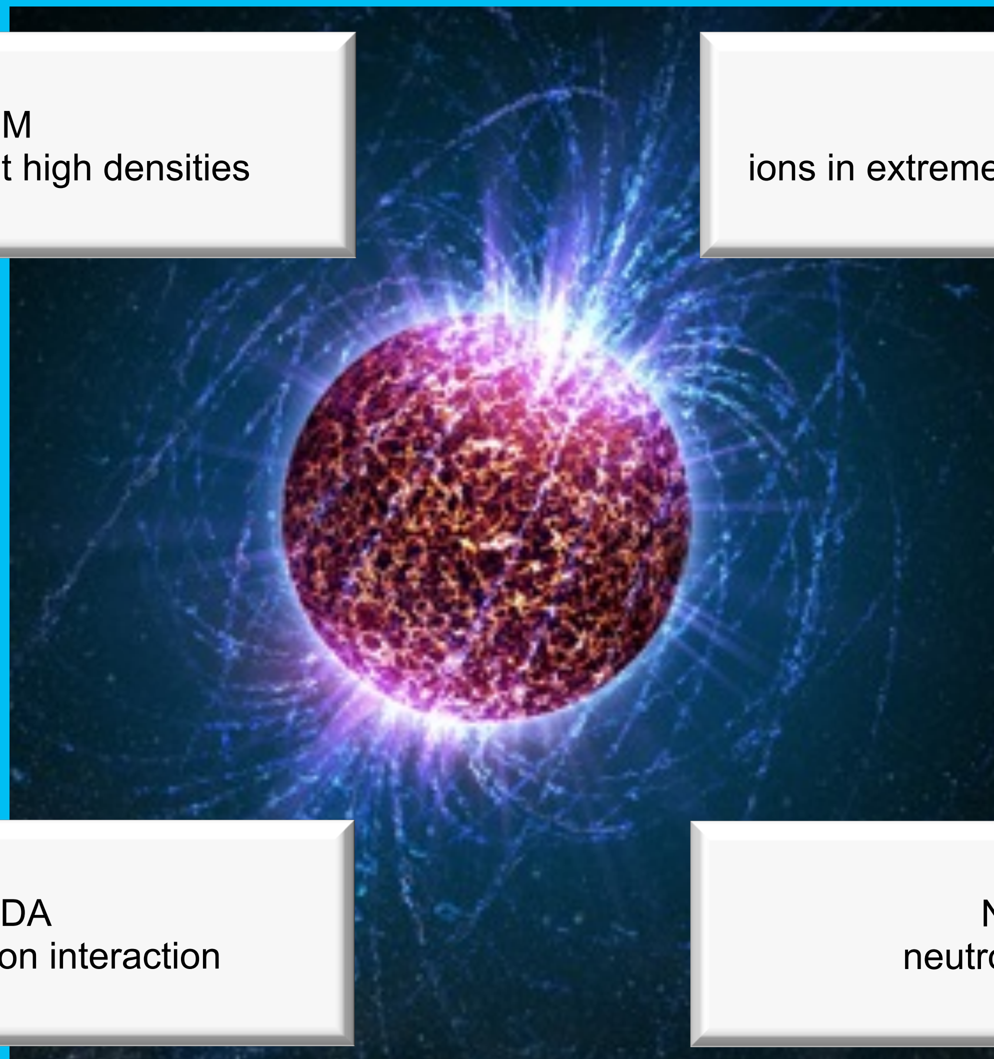
hadron structure and dynamics

PANDA

FAIR

FAIR - Universe in the laboratory

Neutron stars – Universe's lab of exotic matter



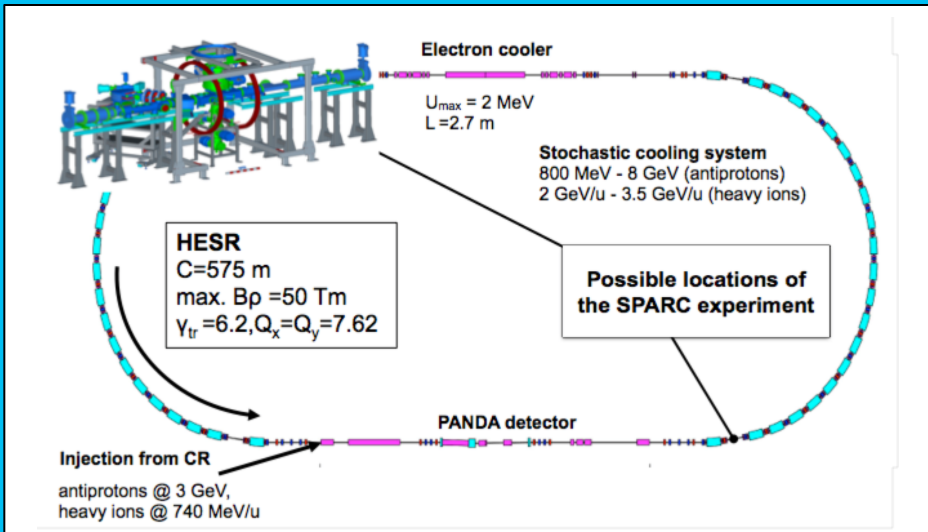
CBM
nuclear matter at high densities

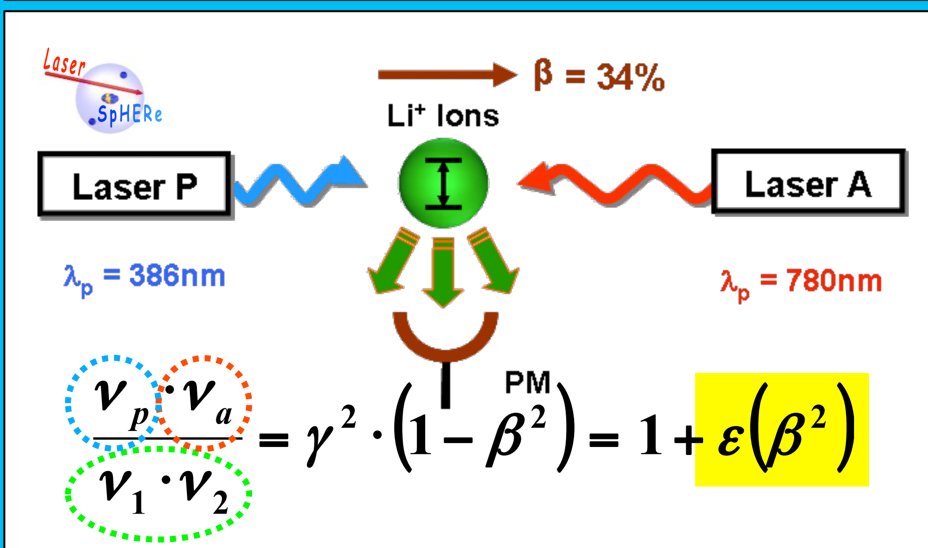
APPA
ions in extreme electro-magnetic fields

PANDA
hyperon-hyperon interaction

NUSTAR
neutron-rich nuclei

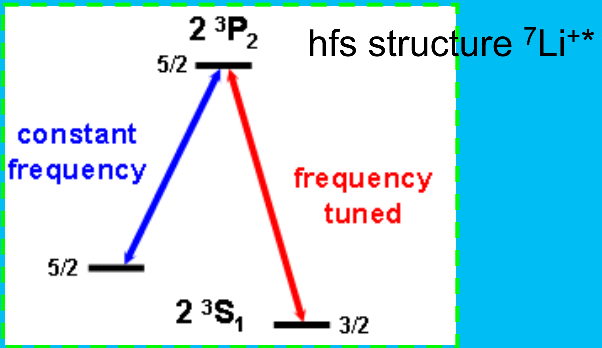
APPA – Atomic Physics (SPARC)



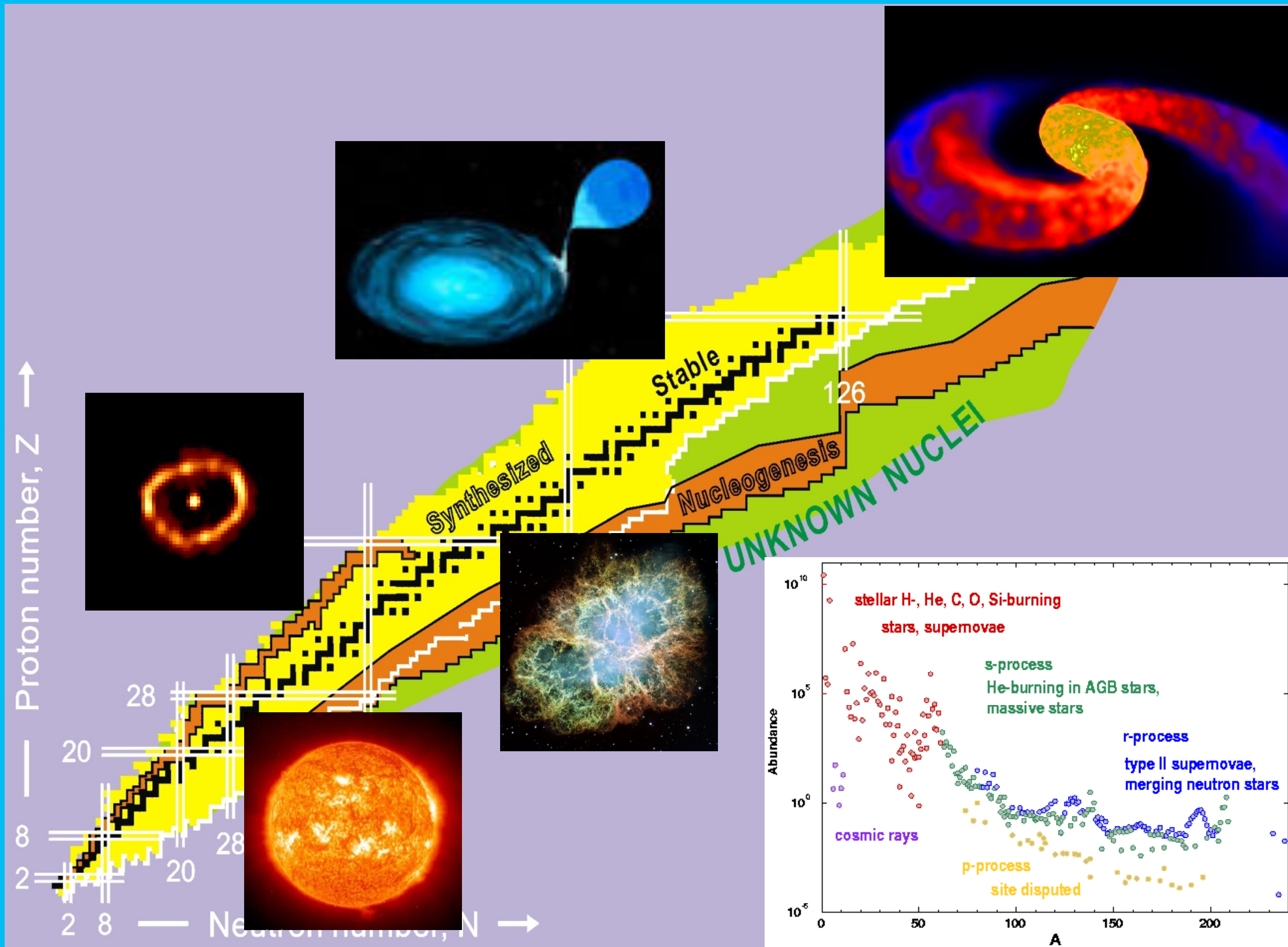


Exploiting storage rings for

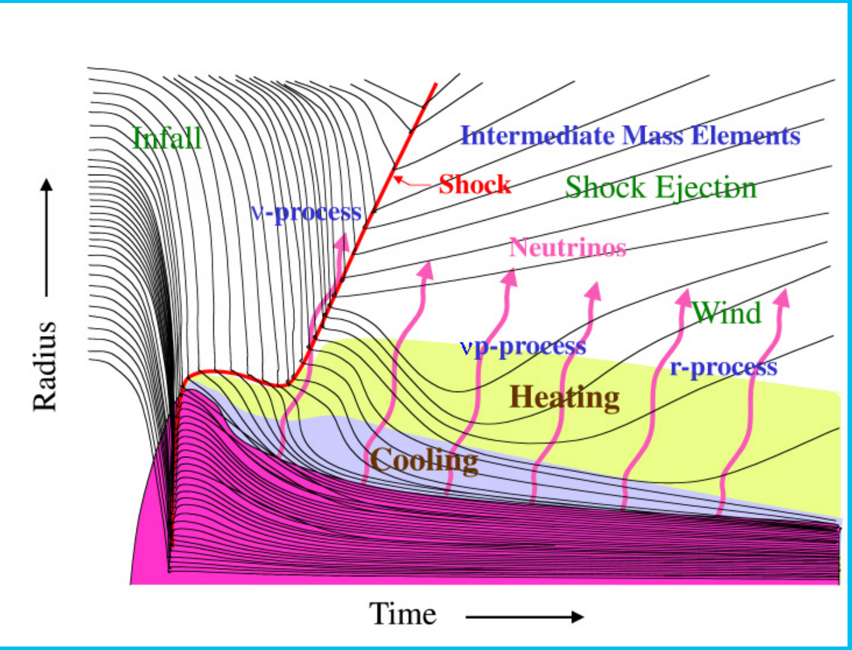
- electron spectrum of highly charged ions
- correlated multi-body dynamics for atoms and ions
- test of fundamental symmetries
- QED in non-perturbative regime

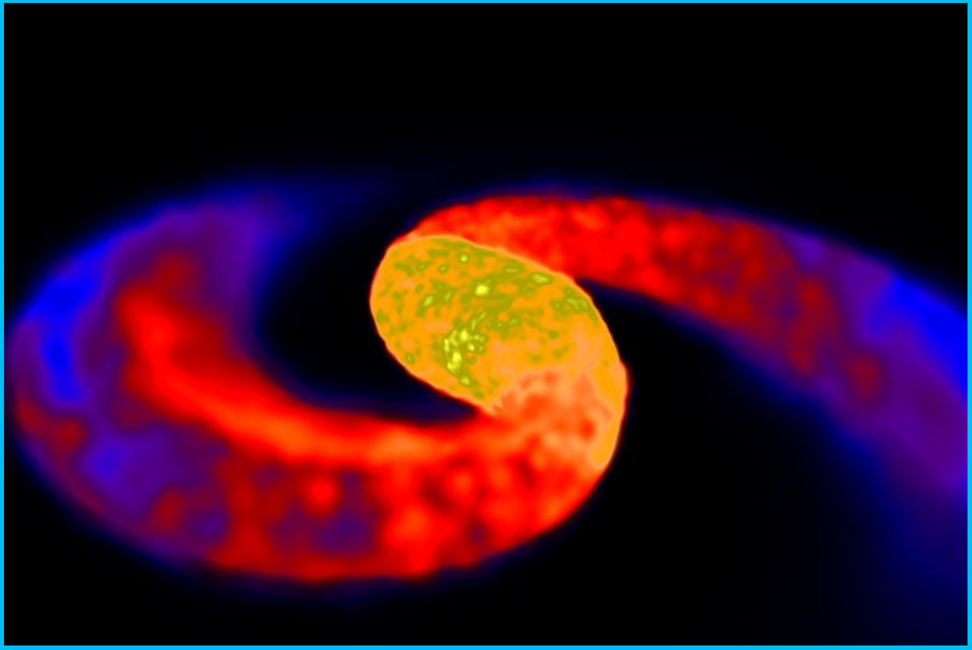


NUSTAR - Origin of elements in the universe



Potential r-process sites





Neutrino-driven wind from a nascent neutron star in a supernova explosion

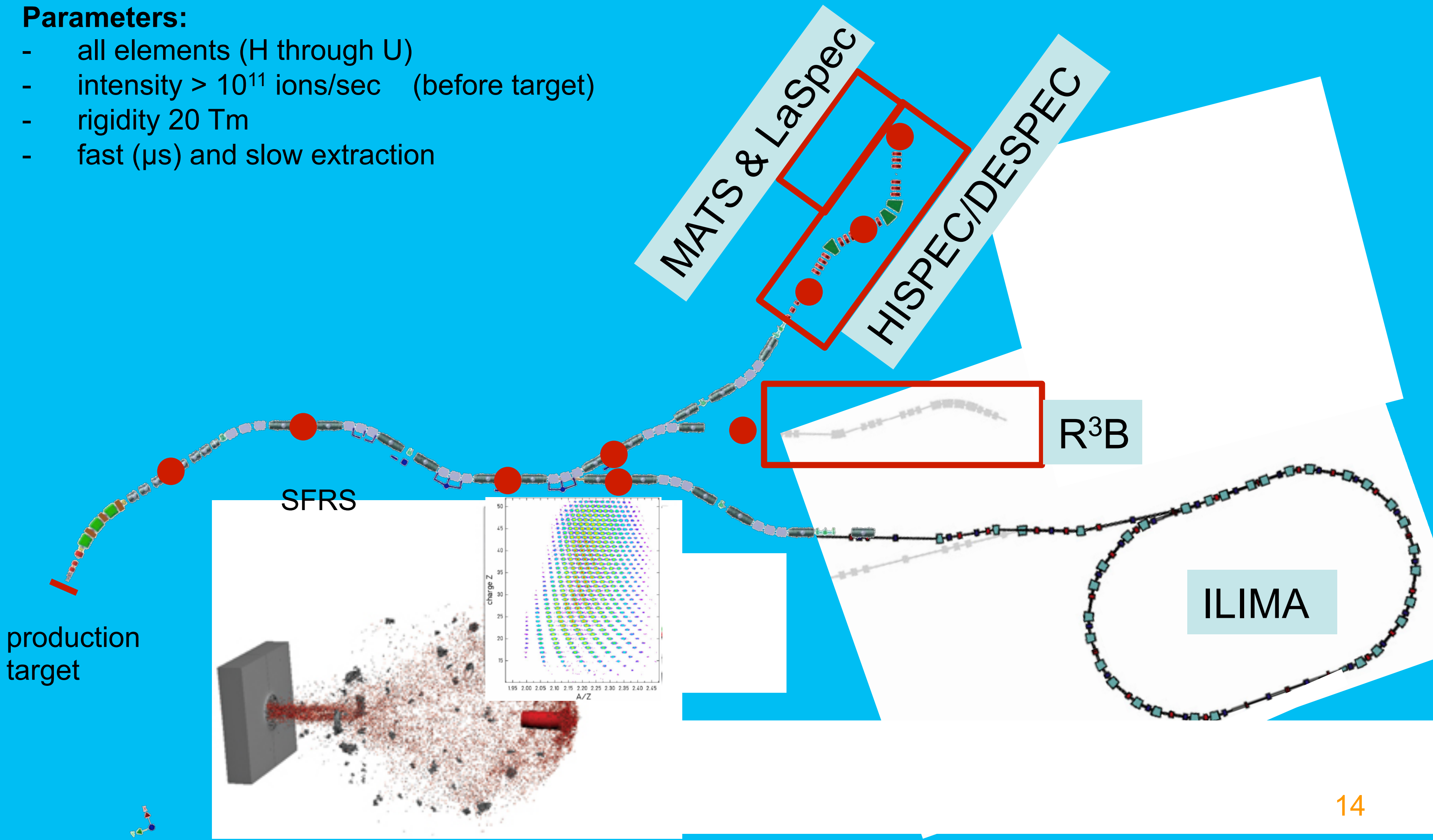
Woosley et al.

Neutron star mergers

Rosswog, Thielemann et al.,

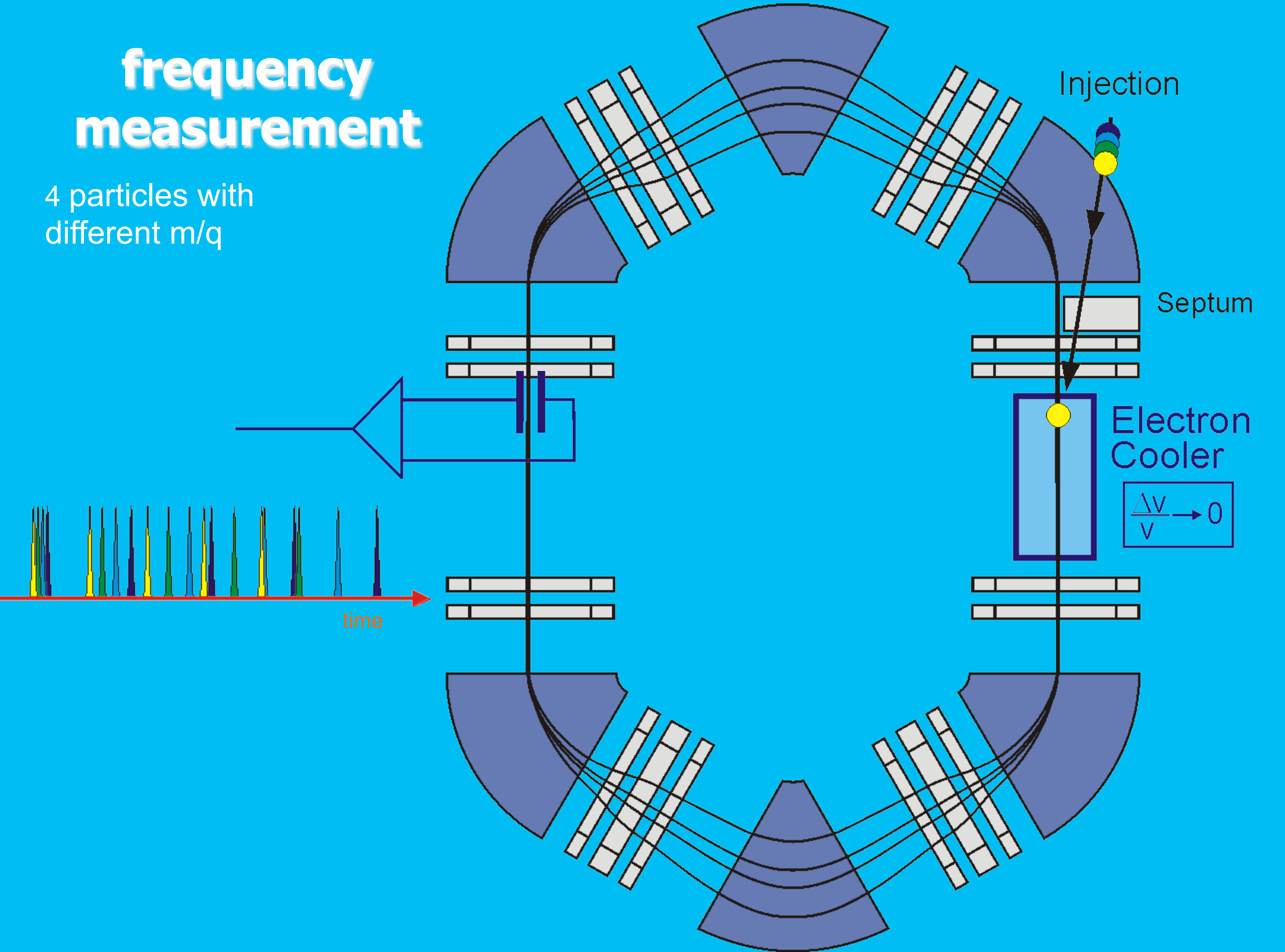
FAIR asset – rings and instrumentation

Parameters:
- all elements (H through U)
- intensity > 10^{11} ions/sec (before target)
- rigidity 20 Tm
- fast (μs) and slow extraction

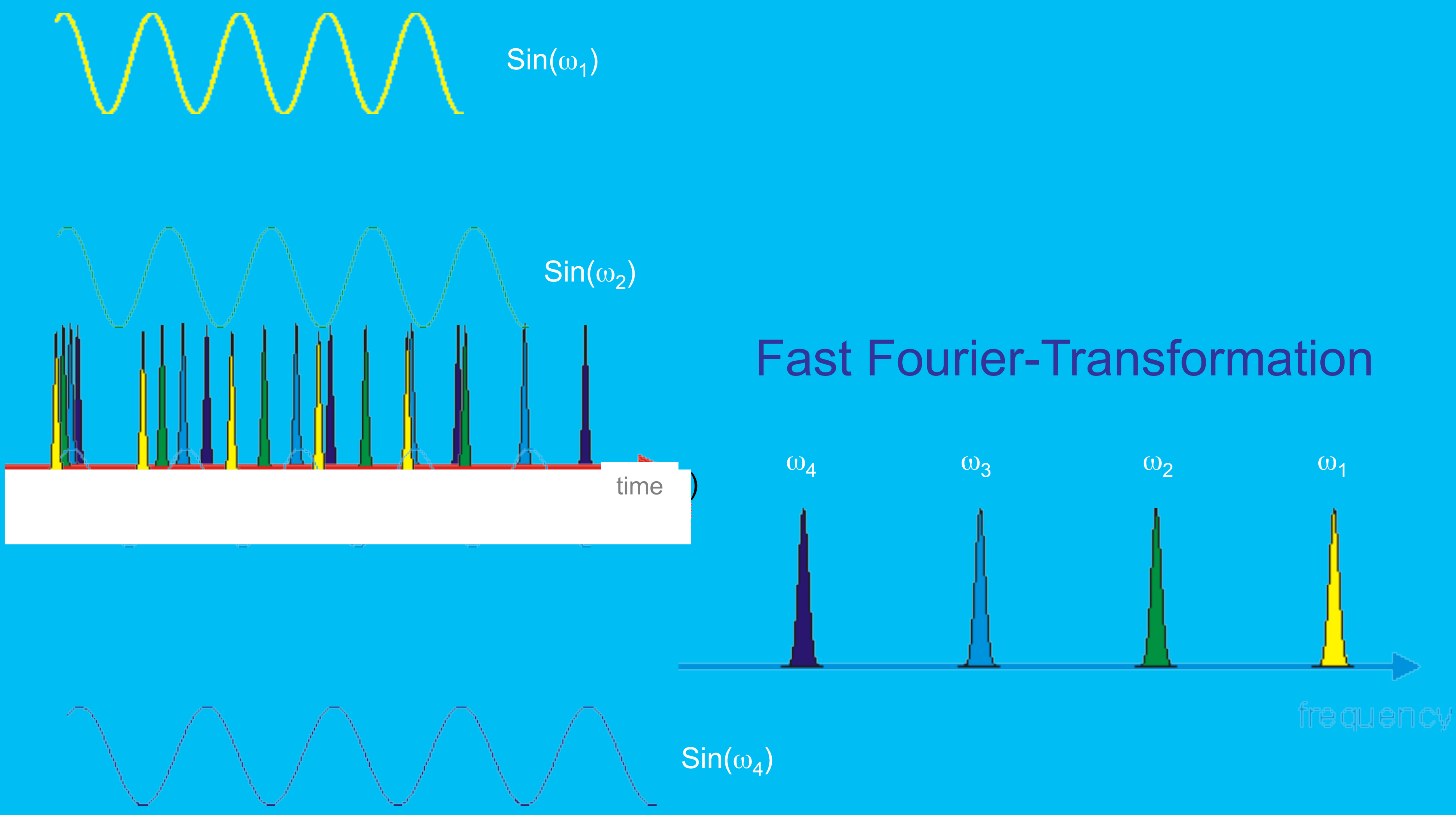


frequency measurement

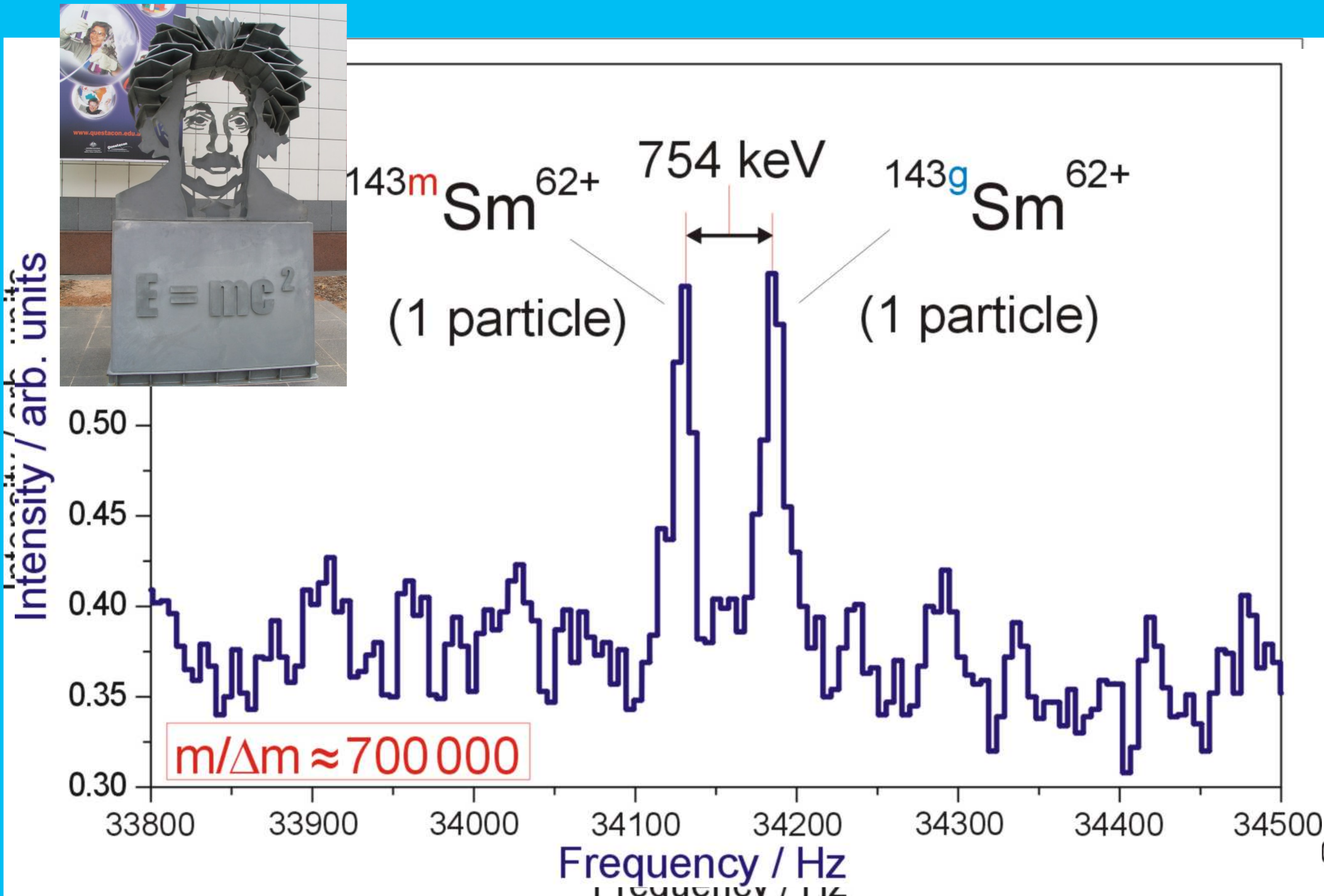
4 particles with different m/q



Frequency measurement

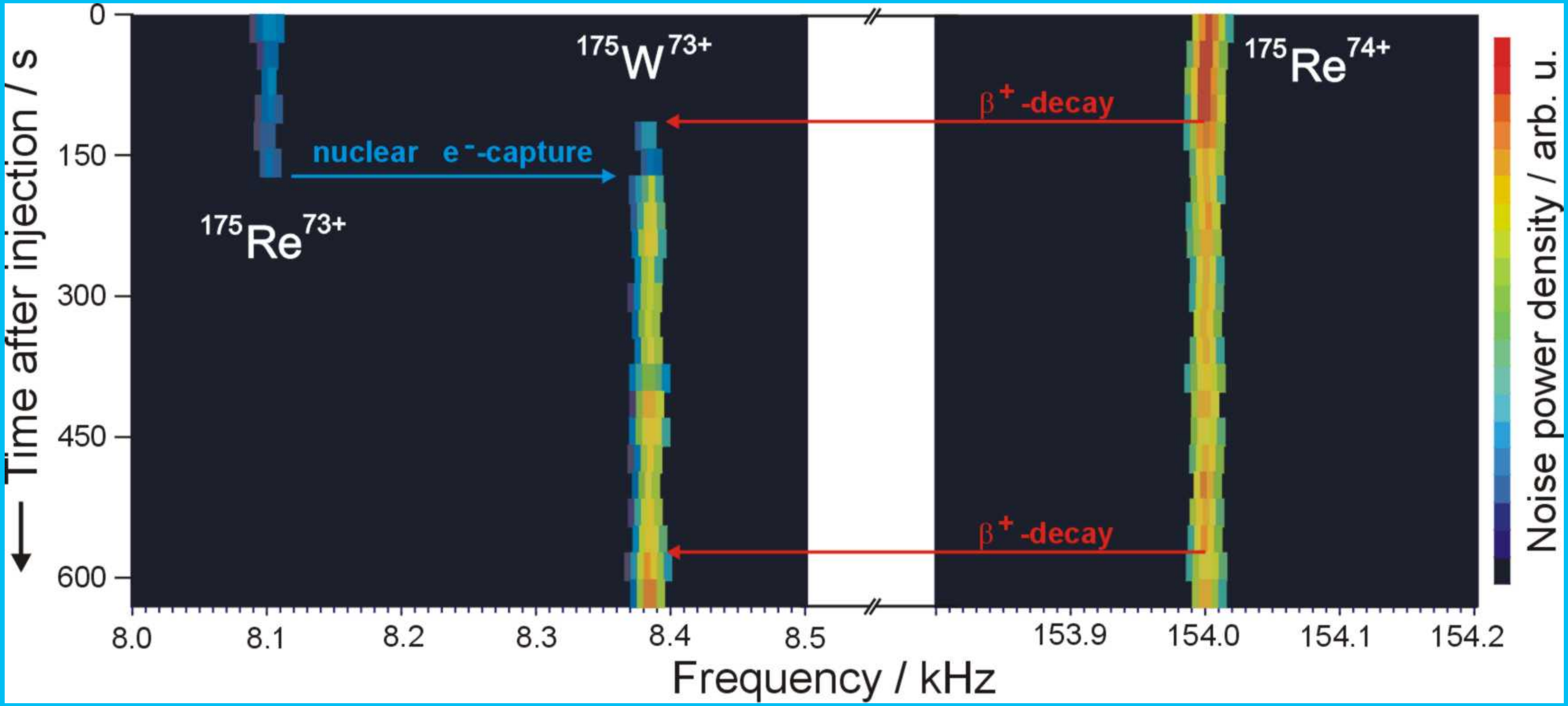


Measured mass spectrum

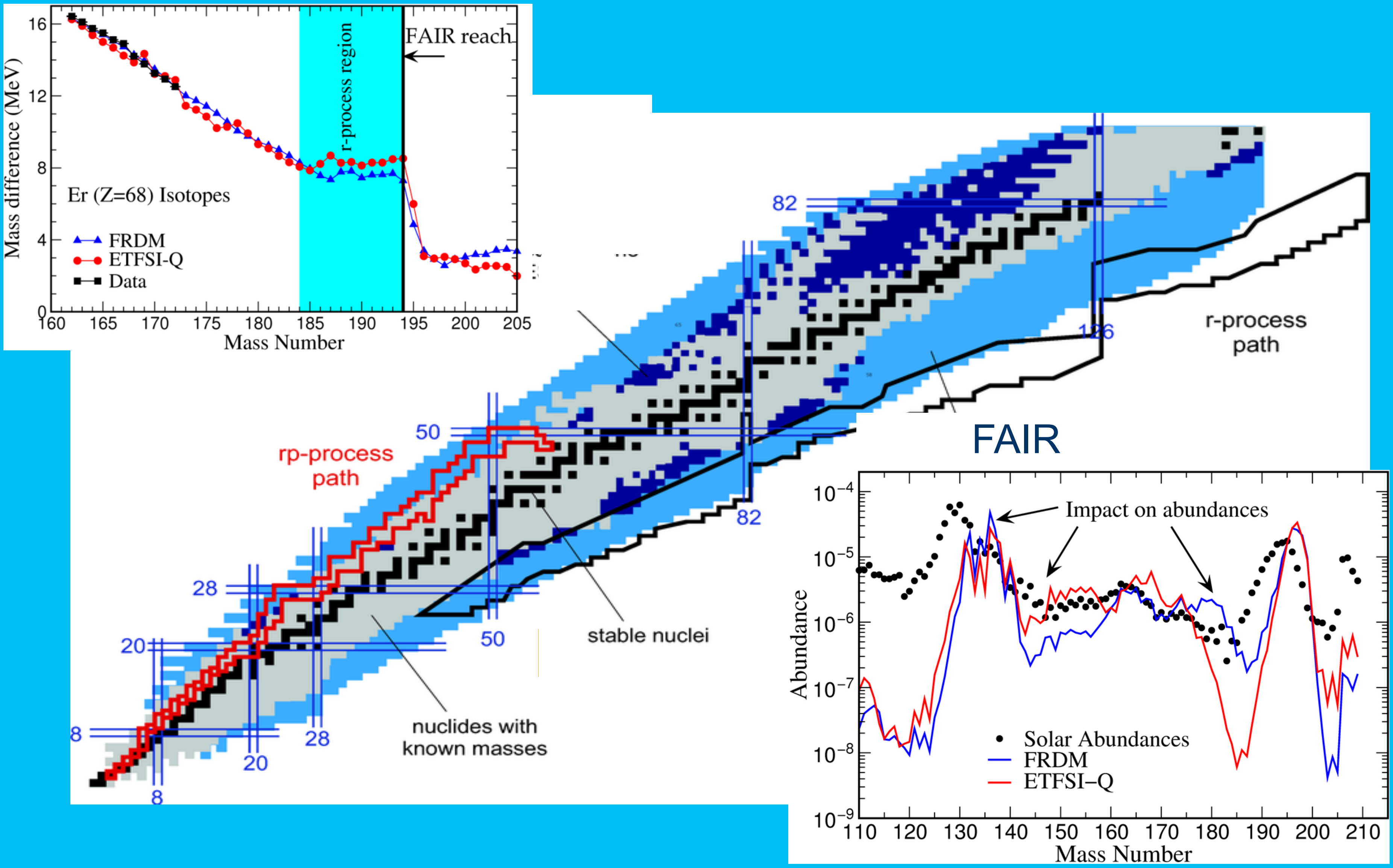


Nuclear decays in storage rings

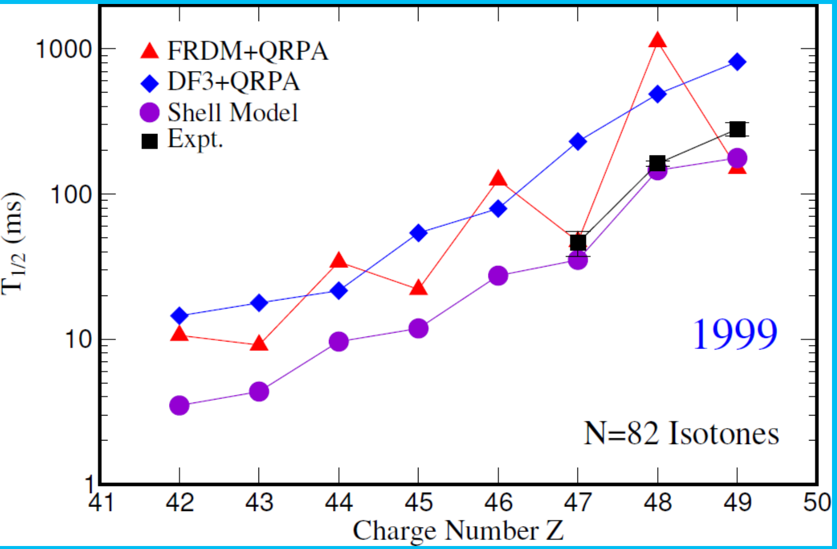
Time-resolved Schottky mass spectrometry is perfect tool to study nuclear decays in the storage ring

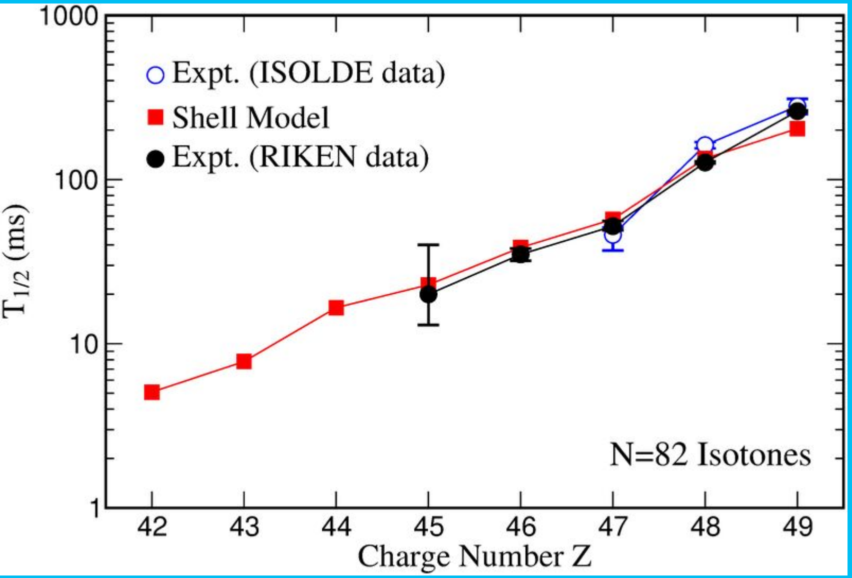


FAIR contribution: masses

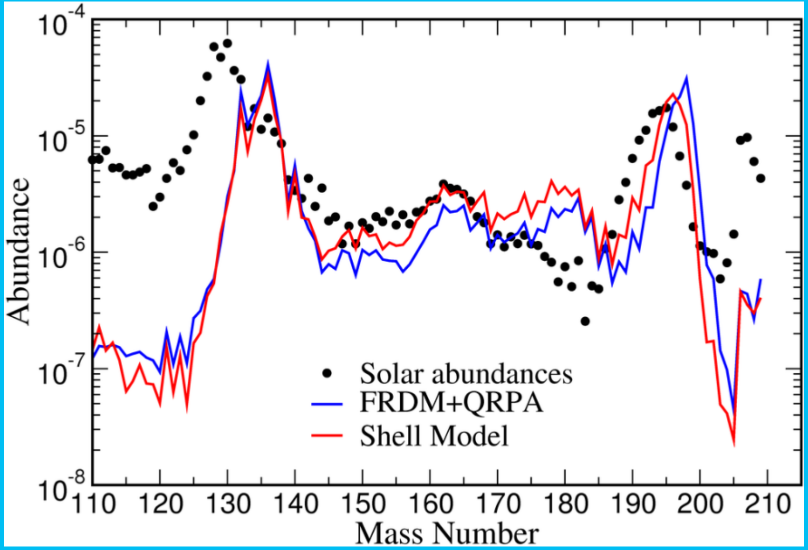


Impact of nuclear half-lives





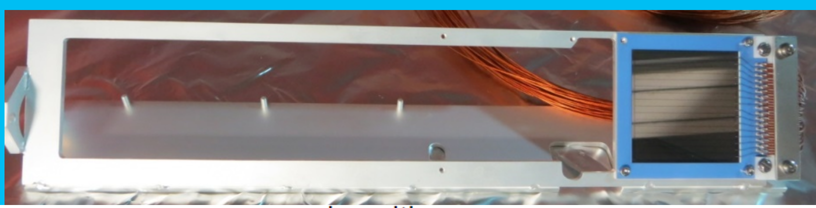
Impact of nuclear half-lives on r-process abundances

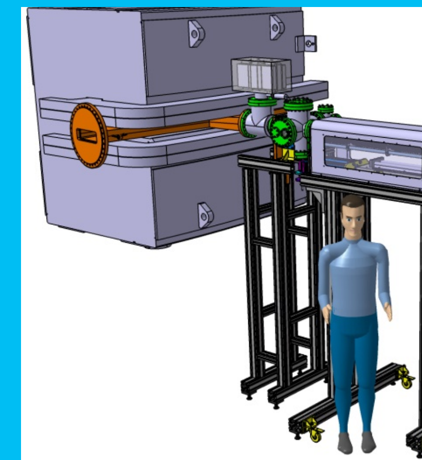


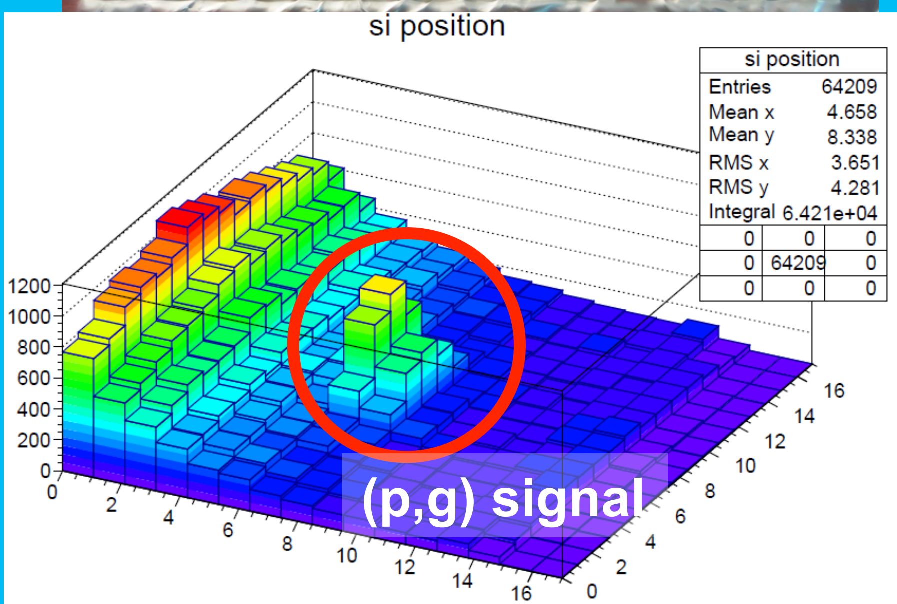
Knowing the half-lives we will constrain the dynamics of the supernova explosion

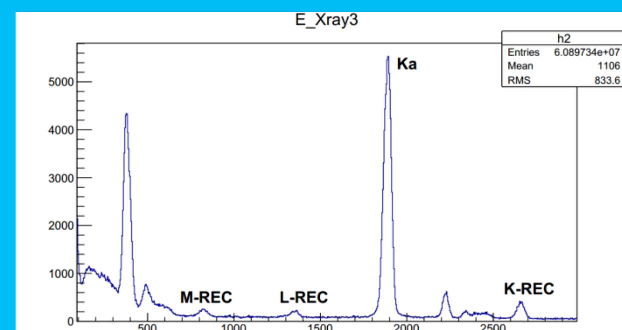
Pioneering experiment to prove nucleosynthesis studies in storage rings

- New UHV grade silicon detector (GUF)
- New detector manipulator (Uni Giessen)
- 5-7 MeV/u $^{124}Xe^{54+}$ ions stored in ESR
- Stable, dense H_2 target
- Successful proof-of-concept (also for CRYRING)

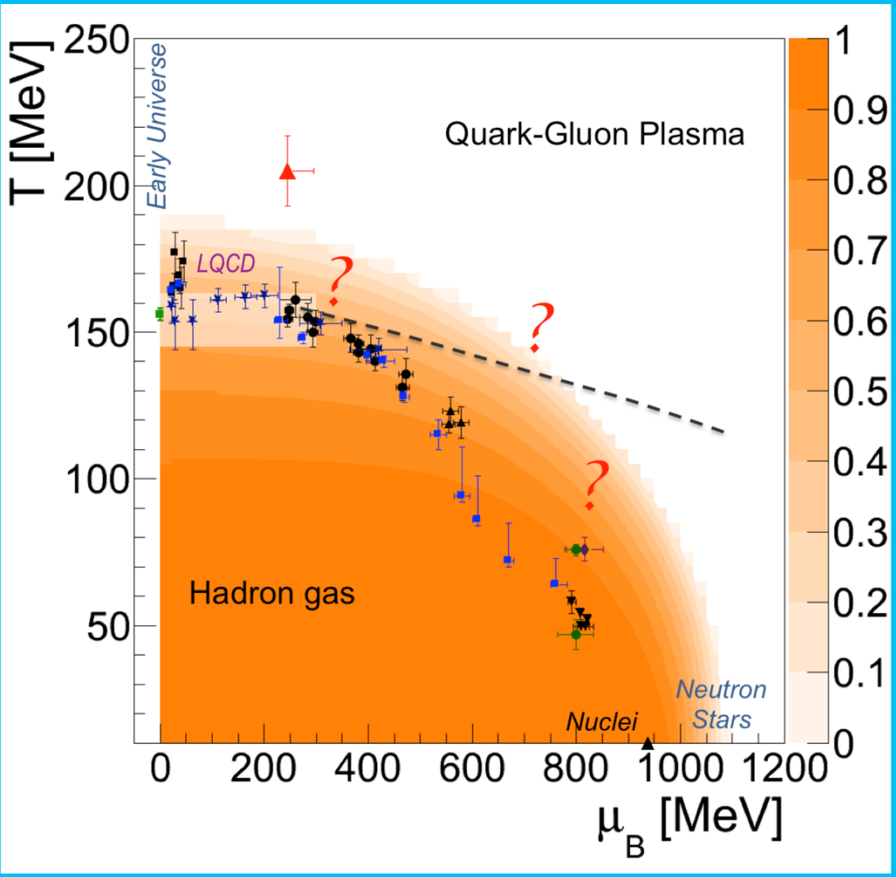






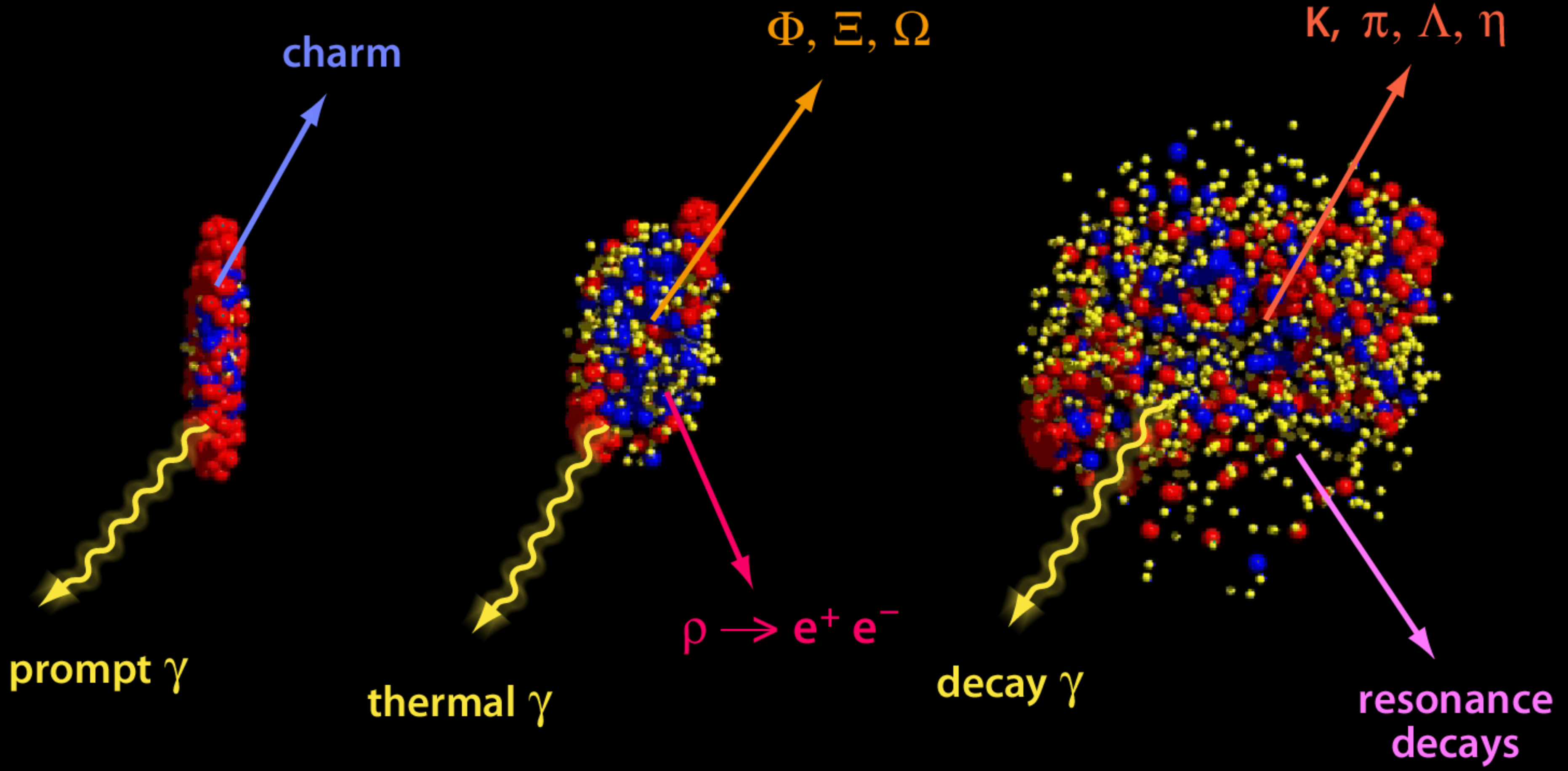


CBM – Searching for landmarks in the phase diagram of matter

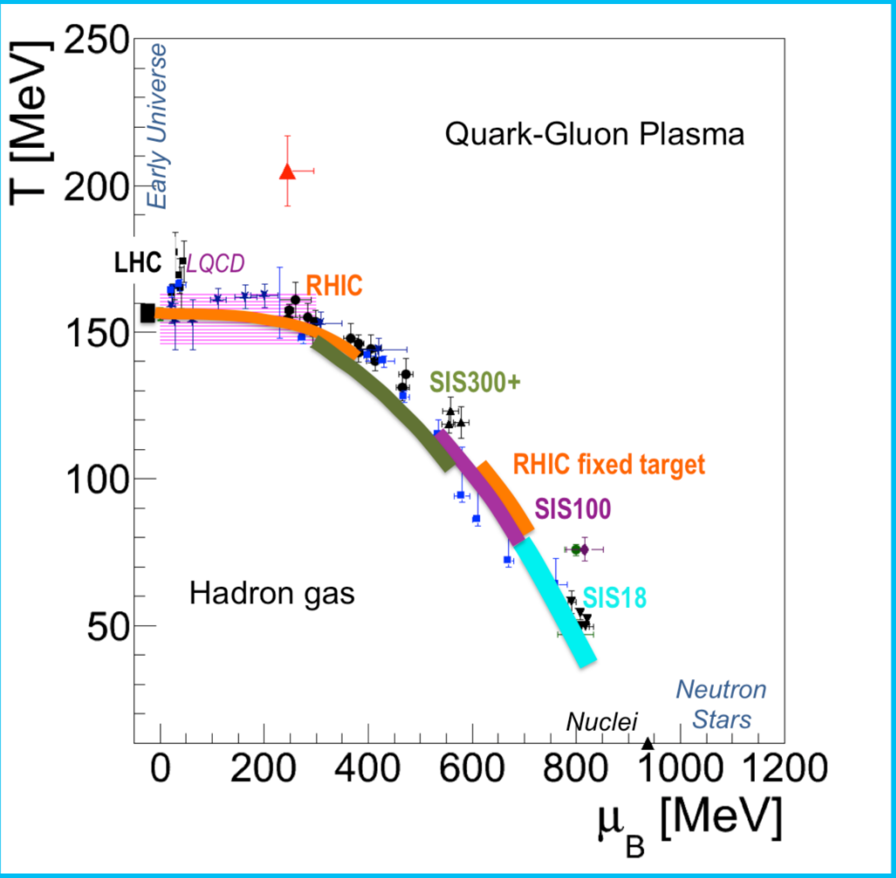


- What do we know?
  - Chemical „freeze-out“ from measured particle yields analyzed with Statistical Hadronization Model
  - LQCD: Crossover transition at small μ_B
- What is predicted?
  - Possible 1st order phase transition(s) and critical point? at large μ_B
  - Disappearance of the condensate at high T and high density → leading order parameter for χ symmetry restoration

Ultrarelativistic heavy-ion collisions



CBM: advantage over other experiments

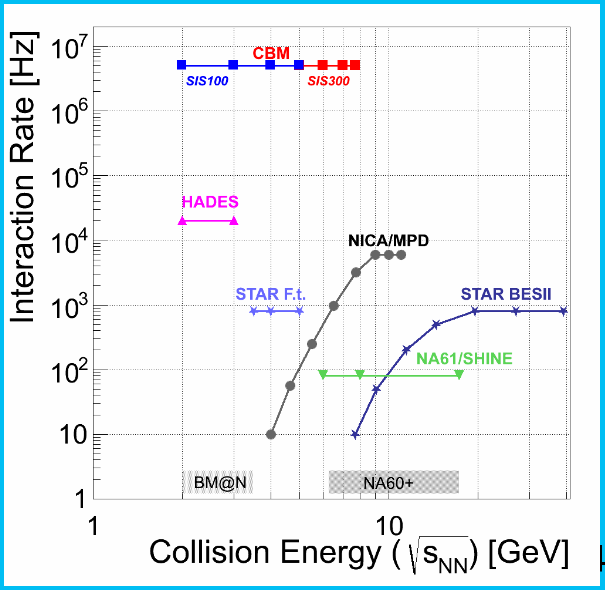


CBM physics program:

- search for phase boundaries and for new forms of QCD matter

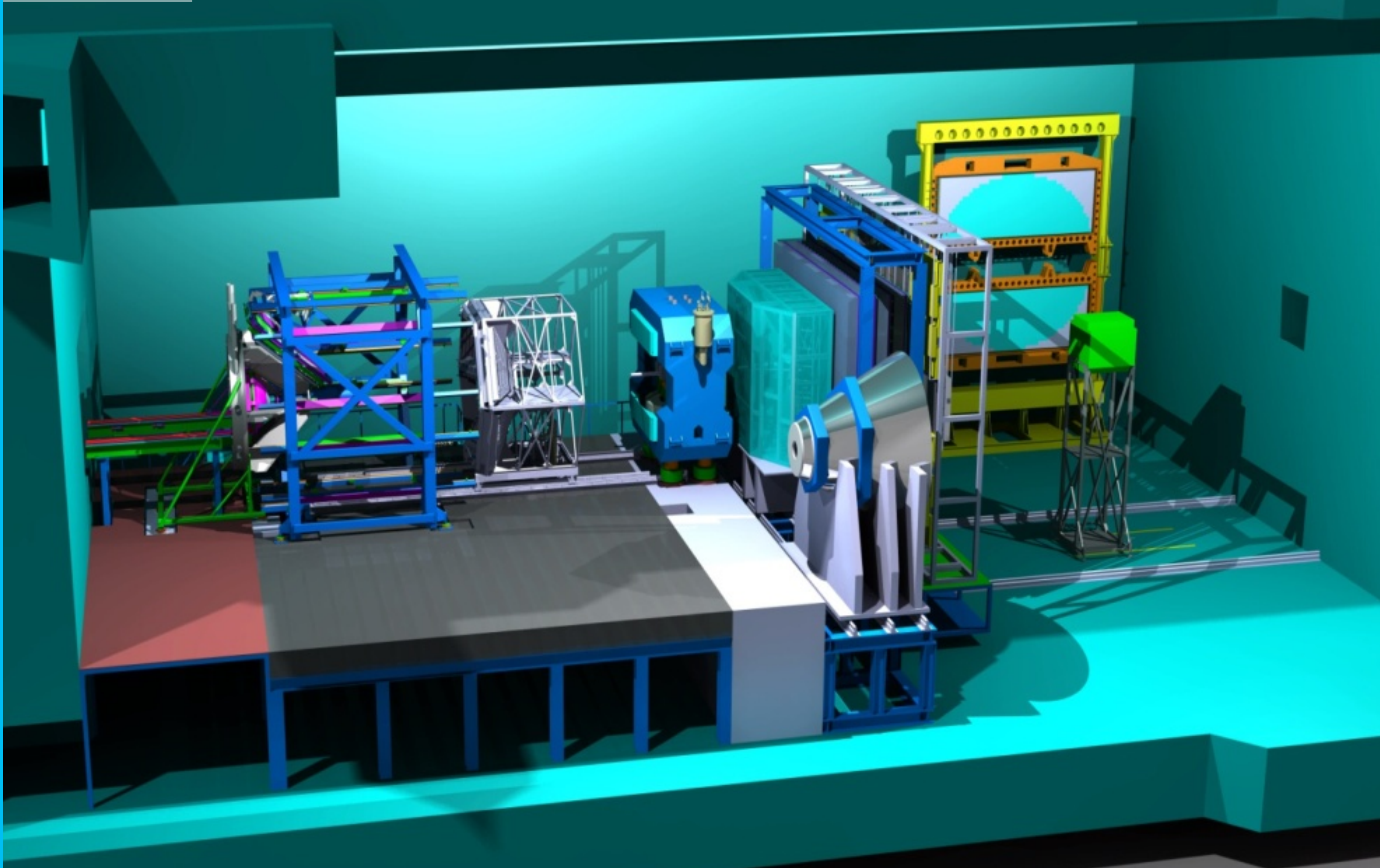
CBM observables looking deep into the fireball:

- dileptons and fluctuations
- charmonium production



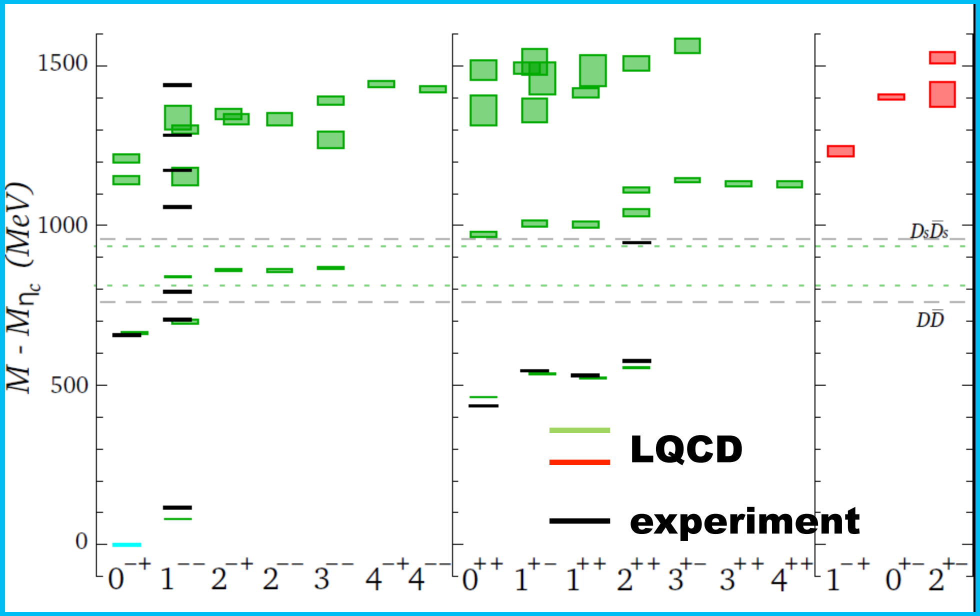
Key experimental requirement: operation at unprecedented high rates

Compressed baryonic matte



PANDA – Exploring QCD

LQCD (HSC collaboration, Lattice 2013) predictions for charmonium states



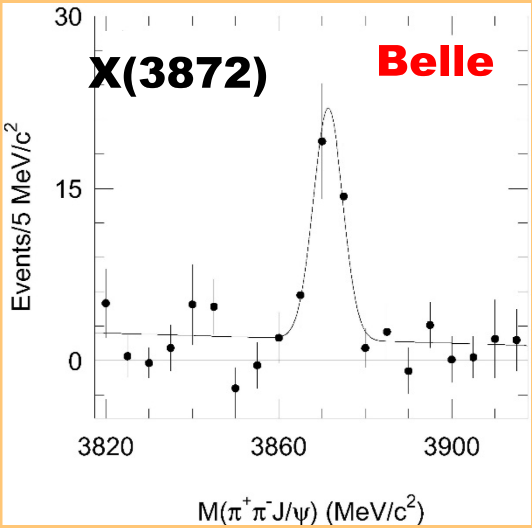
Approaches from theory:

- Lattice QCD
- Effective field theories

Experimental tools:

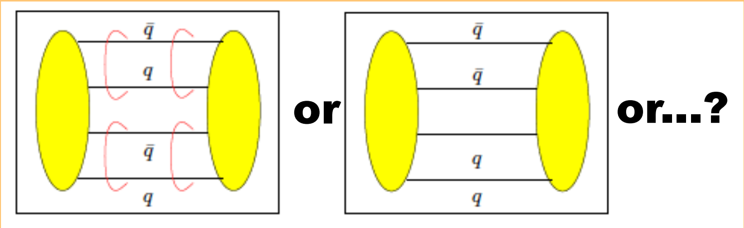
- e^+e^- (e.g. BELLE2, BESIII)
- μ/e/γ p,N (e.g. Compass, GlueX)
- pp (e.g. LHCb)
- pp_{bar} (e.g. PANDA)
  - hadron spectroscopy
  - hadron structure and Form factors
  - hyper nuclei

The PANDA contribution



Spin assignment:
$J^{PC}=1^{++}$ with LHCb in pp (B^+ decay)

Structure:

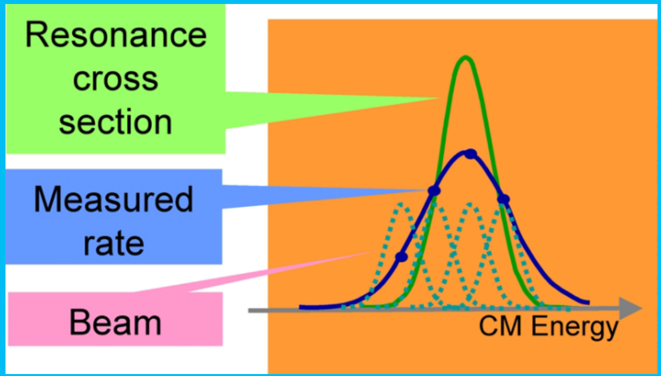


hadronic molecule **4quark state**

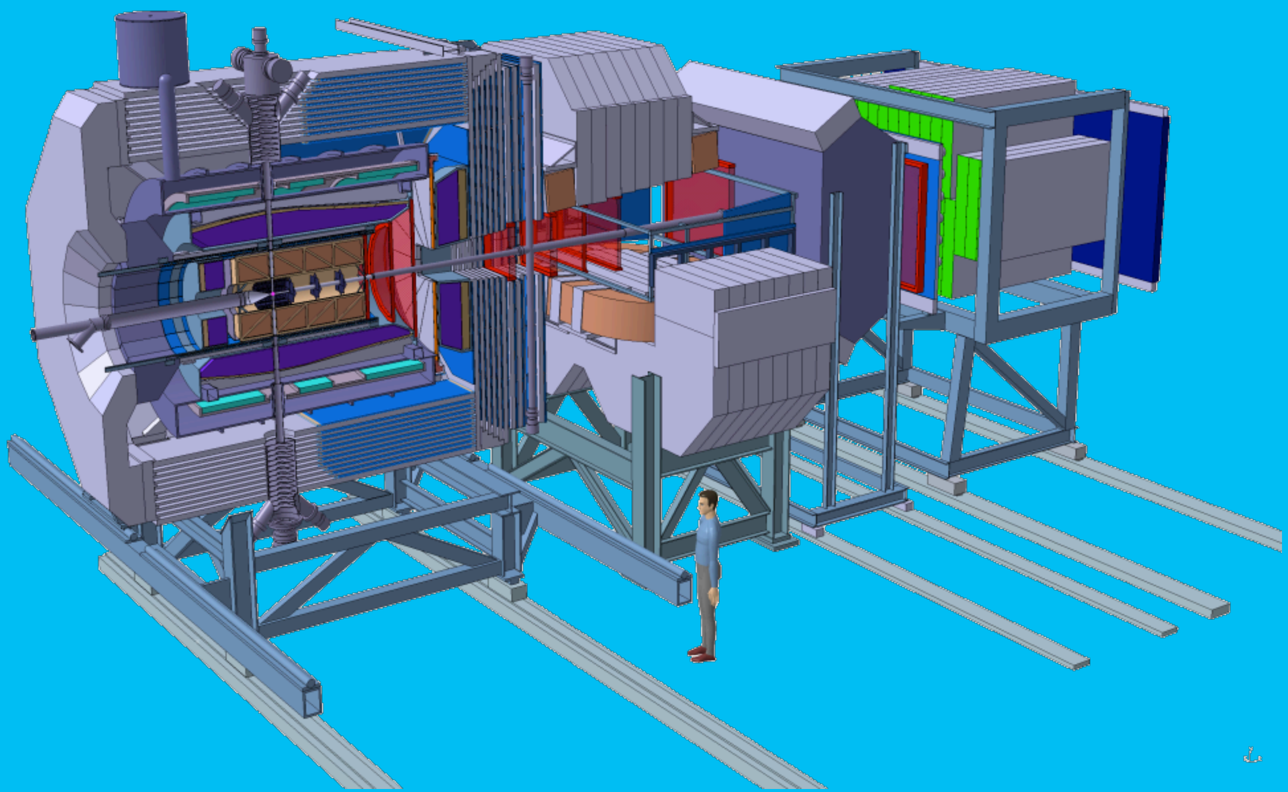
Understanding binding among quarks and gluons:

- Gluonic excitations
- Exotic hadrons
- Exotic quantum numbers

Low background
high precision and exclusive channels
All quantum numbers accessible
due to annihilation mechanism
States can be formed directly
high mass resolution
Line-shapes
pp_{bar} scans for excitation curves



The PANDA Detector



Midterm Research Program

- Goals
  - forefront research by employing and testing new FAIR detectors
  - exploiting upgraded GSI accelerator facilities
  - education of young scientists
  - maintain skills and expertise
  - serve national and international user community

➡ Start of “FAIR Phase 0”

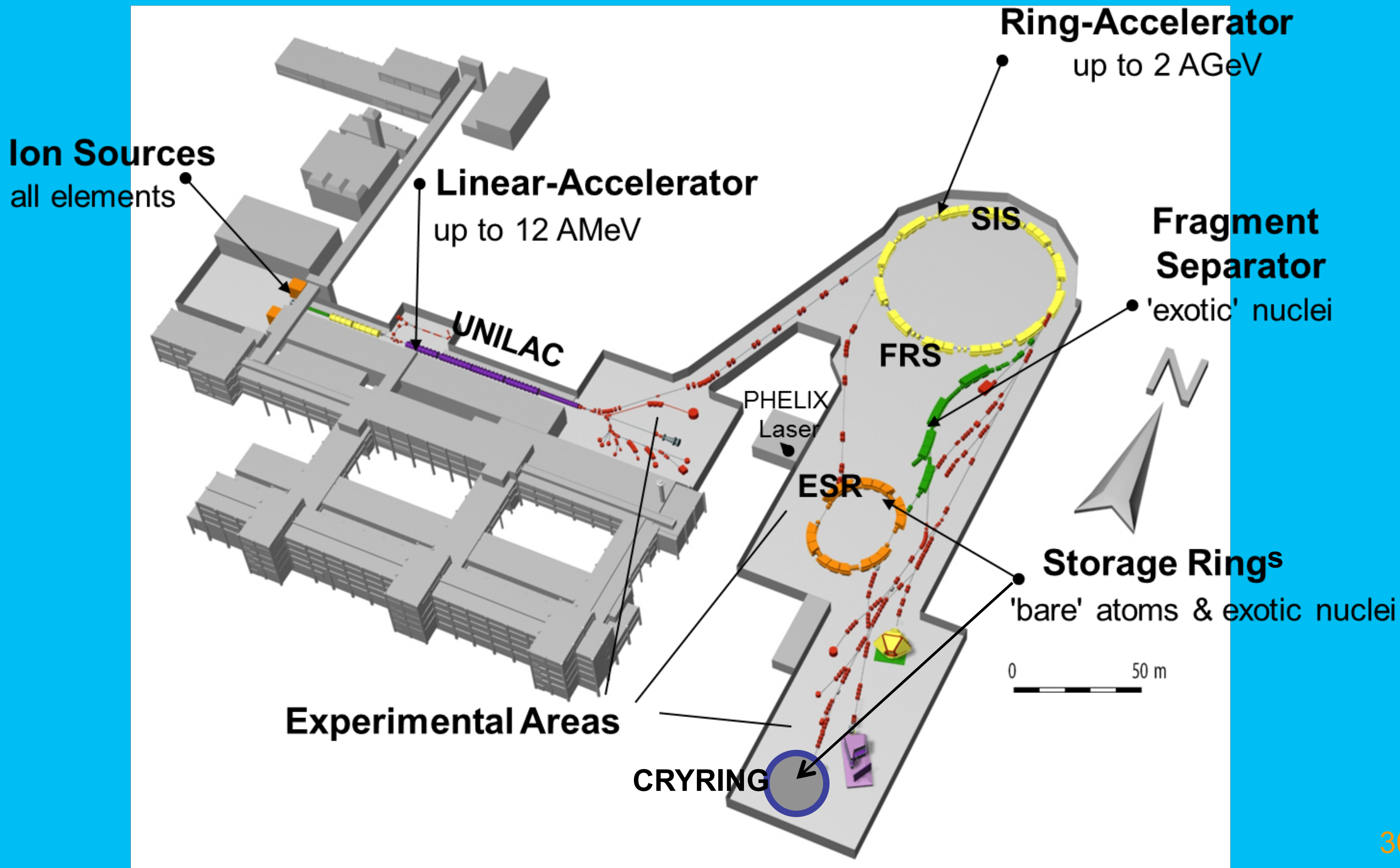
Testing of FAIR detectors and physics concepts

works at GSI Campus for APPA, NUSTAR and restricted for CBM (HADES)

CBM and PANDA need participation in experiments at external research facilities

ALICE → participation in physics analysis of LHC Run 2
and upgrade for LHC RUN 3

GSI Accelerator and Experimental Facilities



GSI Accelerator and Experimental Facilities
- improved accelerator performance after upgrade

Ion Sources
all elements

Uranium *(the „Gold“ of GSI)*		**SIS operation today**	**SIS operation after upgrade (2018-2021)**	**SIS operation booster mode >2021**
Reference Ion		U^{73+}	U^{73+}	U^{28+}
Maximum Energy		1 GeV/u	1 GeV/u	0,2 GeV/u
UNILAC Current		1 emA	3 emA	15 emA
Maximum Intensity per Cycle		$4 \cdot 10^{9}$	$1{,}5 \cdot 10^{10}$	$1{,}5 \cdot 10^{11}$
Magnet Cycle	**Fast Extraction**	2,2 s 0,46 Hz	0,37 s 1 Hz (*)	0,37 s 2,7 Hz
	Slow Extraction (5 s Spill)	7,2 s 0,14 Hz	5,37 s 0,19 Hz	-
Maximum Intensity per Second	**Fast Extraction**	$1{,}8 \cdot 10^{9}$ /s	$1{,}5 \cdot 10^{10}$ /s	$3 \cdot 10^{11}$ /s (**)
Maximum Intensity per Second	**Slow Extraction**	$5{,}6 \cdot 10^{8}$ /s	$2{,}8 \cdot 10^{9}$ /s	-
Slow extr. efficiency		50 %	75%	

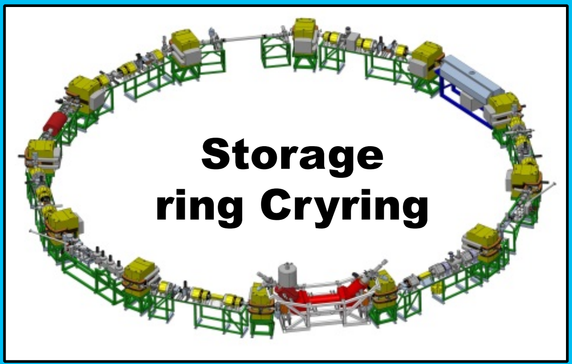
lerator
AGeV

ragment
eparator
otic' nuclei

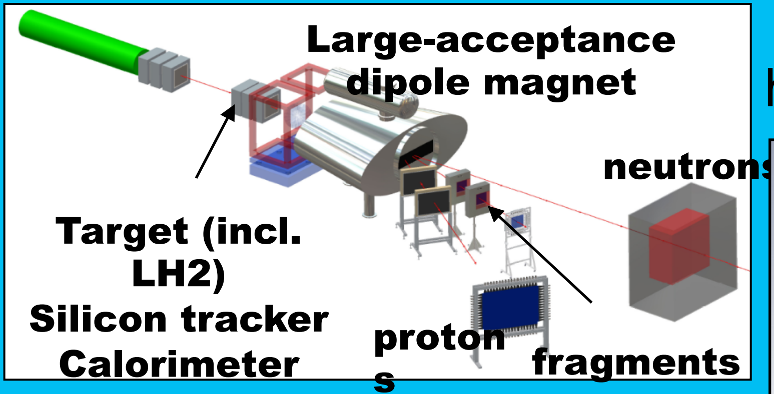
Rings
& exotic nuclei

FAIR Phase 0: Research opportunities with new equipment starting in 2018

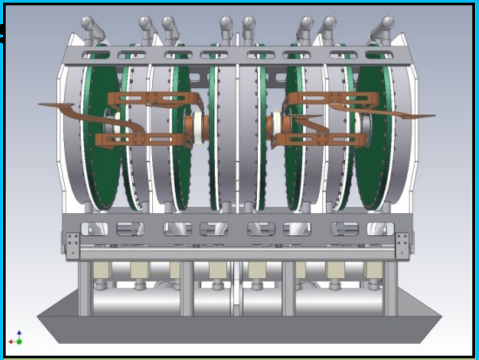
Exploiting new FAIR facilities,



available FAIR detectors and



higher beam quality



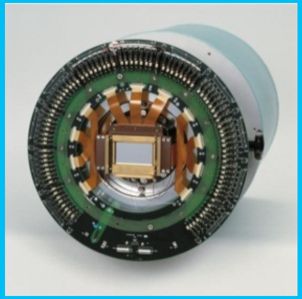
Design studies for new, high duty cycle h=2 acceleration cavities (0.5 MHz - 50 kV)

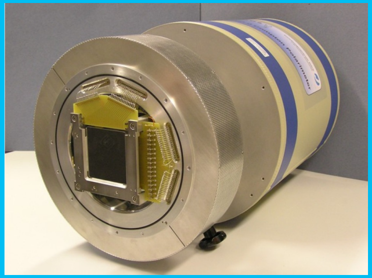
- first rate experiments
- unique at GSI
- employing new FAIR detectors
- education of young scientists
- maintain skills and expertise

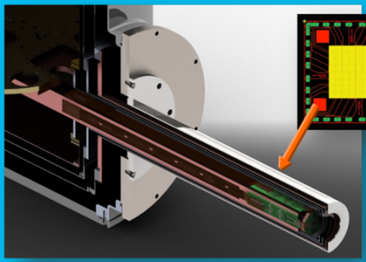
FAIR Phase 0
APPA: Sophisticated & Versatile Instrumentation

Observables: Photons, electrons, positrons, ions

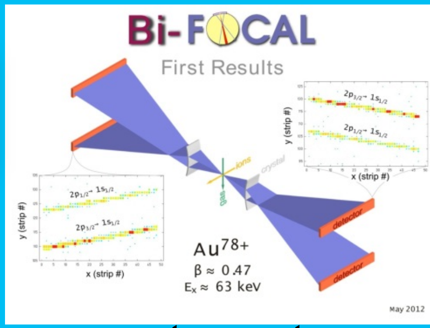
Targets



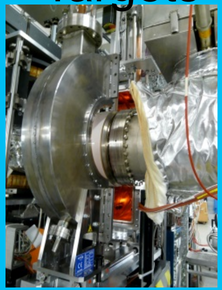


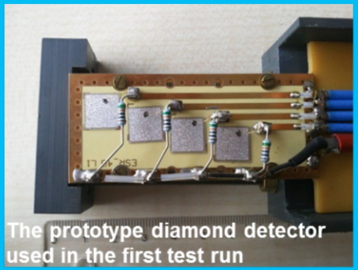


Position-sensitive solid-state detectors

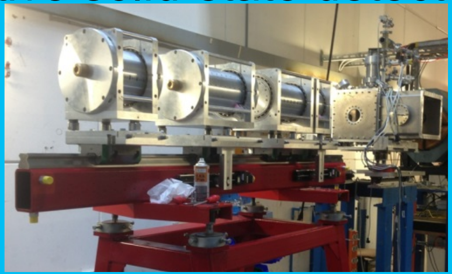


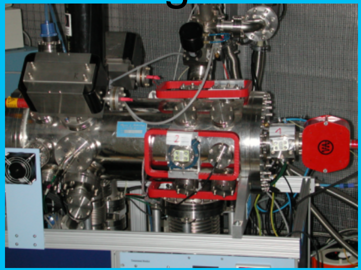
High-resolution spectrometers





Particle detectors

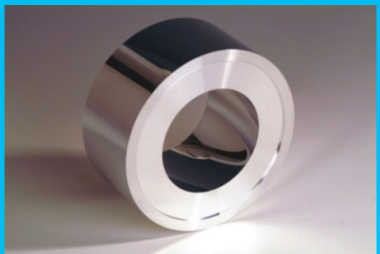


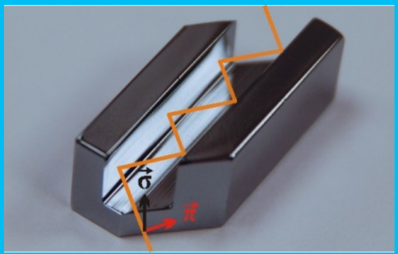


Particle spectrometers

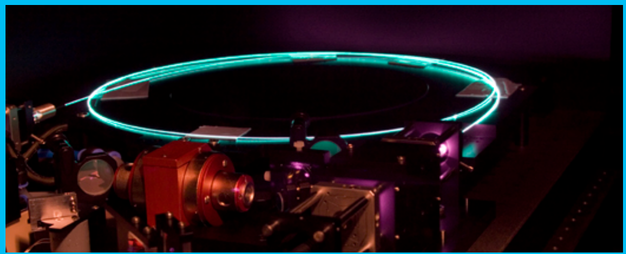
High pressure cell

Traps





X-ray optics, channel-cut crystals



Laser systems

FAIR Phase 0
NuSTAR: SC R^{3}B Dipole GLAD arrived at GSI

With the help of a 500-t crane, th
transport into the experimental h

With the help of a 500-t crane, the GLAD magnet was l
transport into the experimental hall (photos: A. Herlert

7

ionized stable calcium isotopes ... Ca in the 4s $^2S_{1/2} \rightarrow$ 4p $^2P_{3/2}$ tran
Measurements were performed using collinear laser spectroscopy, utiliz
reference of the 4s $^2S_{1/2} \rightarrow$ 4p $^2P_{1/2}$ transition in a Paul trap for beam-en
a result, the accuracy of the isotope shifts in the 4s $^2S_{1/2} \rightarrow$ 4p $^2P_{3/2}$ trans
improved by about an order of magnitude. Comparison with the trap me
King-plot-type analysis revealed that the electronic expectation value in
about 1.8(13) % larger in the 4p $^2P_{1/2}$ level than in the 4p $^2P_{3/2}$ level. This
relativistic contributions to the 4p$_{1/2}$ wave function. The results have bee
Journal of Physics B. It is the first physics result that has been obtained v
prototype and demonstrates its feasibility to perform high accuracy isot
measurements. Additionally, we provided important reference data for i
of stable calcium ions and helpful calibration data for collinear laser spe
measurements on the neutron-rich isotopes beyond ^{48}Ca, in investigatio
transition currently being performed at the COLLAPS setup at ISOLDE/CE

Heavy element studies with collinear laser spectroscopy at JYFL

Recently, a new program to study heavy actinide elements using a comb
resonance ionization and collinear laser spectroscopy has been initiated

8 / 11

GLAD in the target hall at GSI

Vacuum test successful

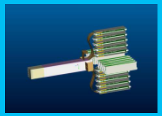
Transport and installation at Cave C scheduled for 2016

Commissioning und first tests 2016/17

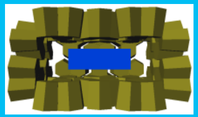
In 2018, start of physics program with GLAD

using beams from SIS18 and FRS Strahlen at 1 GeV/u

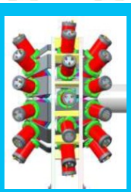
FAIR Phase 0
NuSTAR equipment for γ-spectroscopy



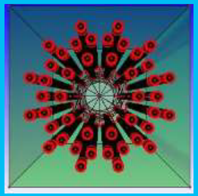
AIDA built and commissioned at RIKEN



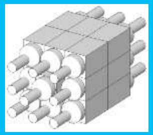
Degas being built and commissioned hopefully at GSI



FATIMA _0 built and commissioned at RIKEN



BELEN built and commissioned at GSI, Jyvaskyla, RIKEN



DTAS built and commissioned at Jyvaskyla

LYCCA built and commissioned at GSI

The FAIR Chance: New Horizons

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