MU – CML

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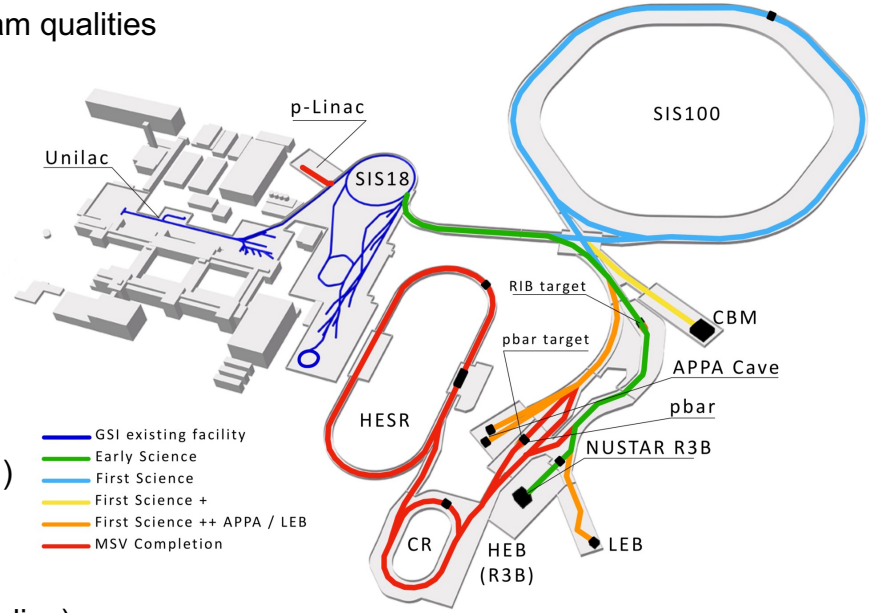
Cosmic Matter in the Laboratory

Introduction

- 2027 Early Science program (SIS18 beam into the S-FRS)
  - exotic nuclei available at higher intensities and with higher beam qualities

- 2028 First Science/ First Science+ program
  (SIS100 beam will be available in the S-FRS *and for CBM)*
  - higher energies/intensities
  - more exotic nuclei accessible

- In-house experimental research program will focus on
  the available experimental facilities at GSI/FAIR and
  - facilities at the HI Mainz and the JGU Mainz (TRIGA, MESA…)
  - participation in ALICE at LHC
  - in addition to complementary activities at other laboratories,
    e.g. RIKEN, TRIUMF, participation in JUNO (solar neutrino studies)



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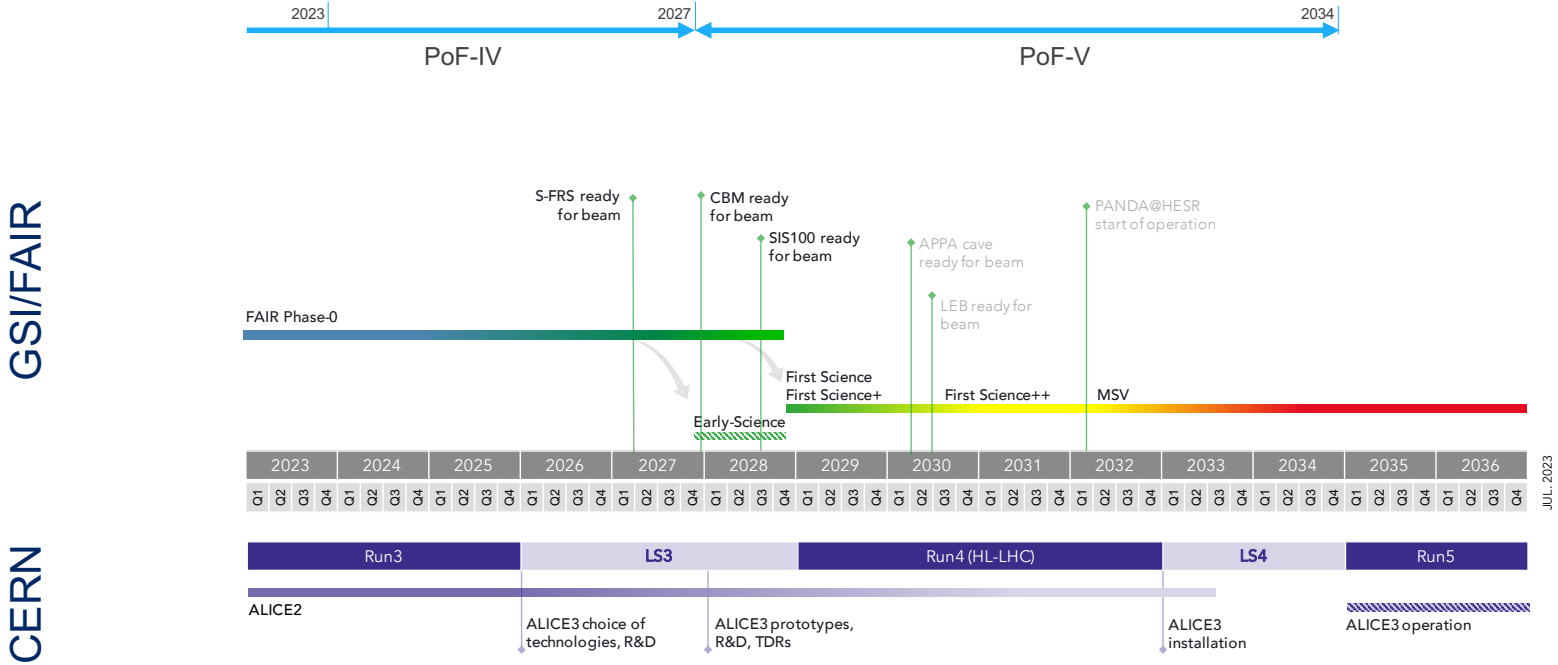
Timeline

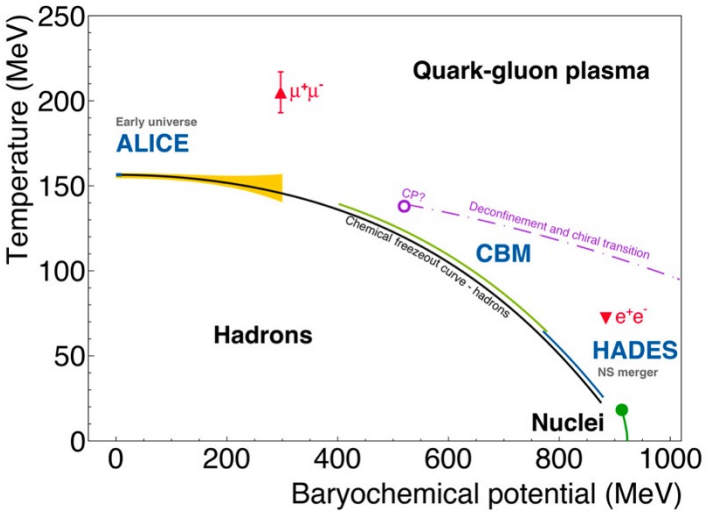


Working assumption pending decissions by the shareholders of FAIR.
Facilities already in operation are expected to continue to serve experiments during the phases of the FAIR project.
Steps beyond FS+ require additional funding, assumed to be in place by 2026, and alternative CR layout according to MAC recommendation

MU Cosmic Matter in the Laboratory

ST1: Hot and dense matter

Establish the QCD phase structure and understand the microscopic properties of QCD matter at vanishing and high net baryon densities



Experiment (HADES, CBM, ALICE)

- Excitation functions of thermal l^+l^- spectrum, (multi-) strange/charm particles their correlations, flow and polarization, fluctuations of conserved quantum numbers with utmost precision
- Phase transition and critical point (new phases)
- Equation of state of nuclear matter at high densities: hyperon-nucleon (YN), YNN and YY interaction; symmetry energy
- Employing artificial intelligence in data reduction and analysis

Theory

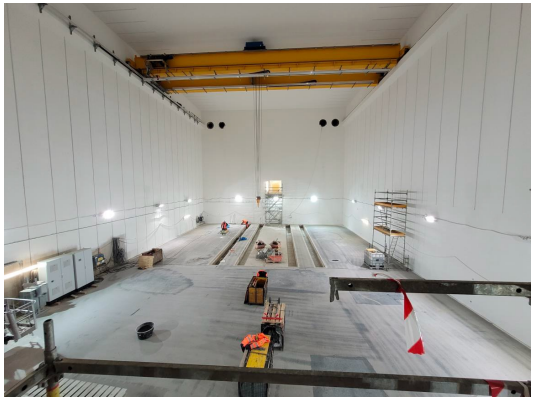
- QCD at finite net baryon density
- Constrain EoS from both HIC and binary neutron star merger
- Extending transport models to obtain consistent description between 0,1 to 10 GeV/u (fully relativistic and off-shell transport)

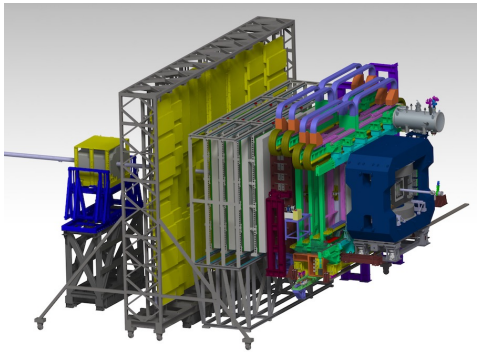
MU Cosmic Matter in the Laboratory

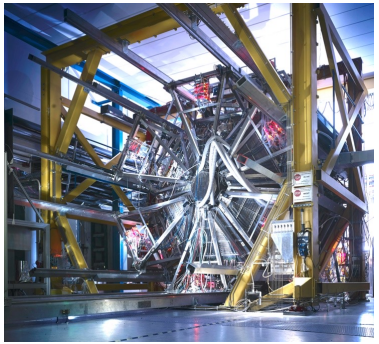
Compressed Baryonic Matter

- 2023 CBM cave ready, heavy infrastructure
- CBM dipole magnet procured by FAIR (Jul. 2023)
- CBM to be ready for beam by the end of 2027
- ~1y contingency until SIS100 “ready for physics” (used for CBM global commissioning)
- Detector components - series production
- 2028 first SIS100 beam, physics with CBM

- Until then – rich physics program with HADES at SIS18
- Commission subdetectors and analysis algorithms of the CBM experiment with real data mCBM, STAR, ALICE
- 2031 HADES at SIS100







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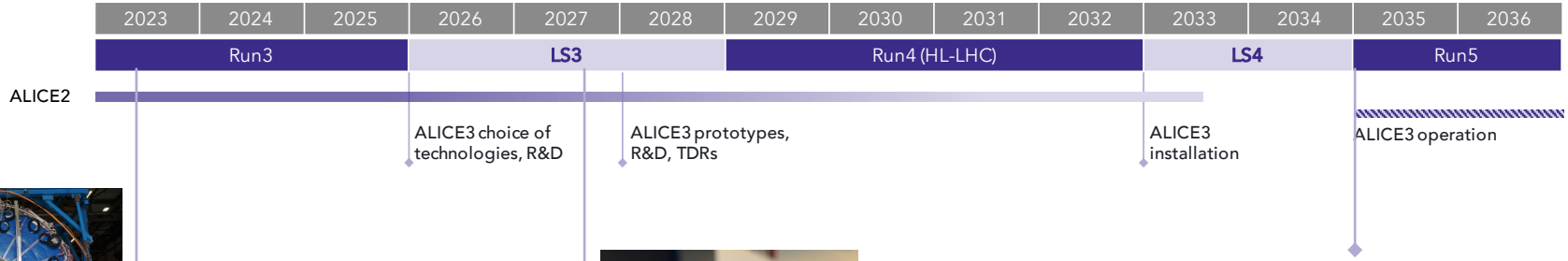
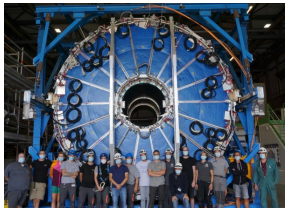
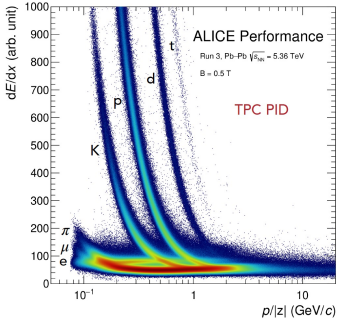
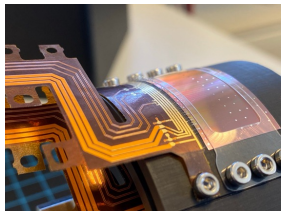
LHC schedule and ALICE plans





GEM TPC readout
Online/Offline system (O2)
Silicon tracker (ITS2)
Fast Interaction Trigger



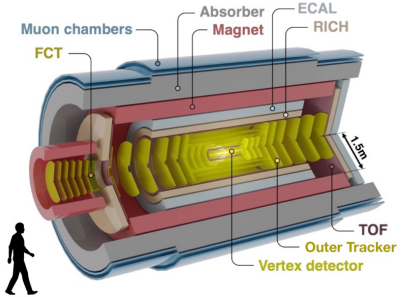


Silicon tracker (ITS3) - cylindrical, wafer-size sensors with ultra-low material budget, synergies with LHC, FAIR, EIC

Forward Calorimeter (FoCAL)

ALICE3: A next-generation heavy-ion experiment at the LHC

ALICE CERN-LHCC-2022-009



2023: continuous readout, Pb-Pb at 50 kHz

Preserve excellent particle identification

ALICE Run 3&4 ~100 times more statistics 13 nb^{-1} (0.5T, 0.2T) Pb-Pb collisions

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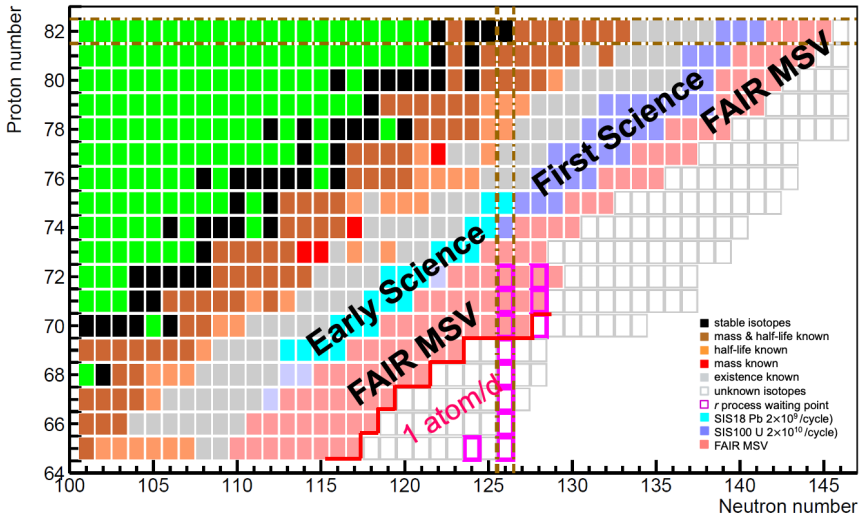
ST2: Nuclear structure, nuclear reactions, and superheavy elements

- Understanding the nucleosynthesis of heavy elements: 3rd *r*-process abundance peak by studying neutron-rich isotopes towards the N=126 shell closure and their ground-state and decay properties
- Equation of state of asymmetric nuclear matter: neutron skin systematics
- Shell effects and implications for the *r*-process: fission of exotic nuclei
- Short range correlations in nuclei
- Laser spectroscopy in exotic nuclei
- Chemistry of super-heavy elements: relativistic effects and continuation of the periodic table
- *Characteristics and production of super-heavy elements (search for new elements)*

Advance understanding of the origin of the elements in our universe



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ST2: Nuclear structure, nuclear reactions, and superheavy elements

Phase-0 is very successful and needs to continue until start of FAIR

- Unique scientific opportunities within Phase-0 due to unique conditions and novel detectors.
- Development and optimisation of experimental set-ups ongoing.
- First storage-ring experiments with very short-lived nuclei → further promising improvements.

Plans for Early Science and First Science

- Day-1 set-ups for ES and FS are ready for operation.
- Many new experimental ideas which are currently being scrutinized.

Facility	U beam intensity/spill	$\mathcal{L}$ [fb^{-1}]
Today at GSI with FRS (Phase-0)	1...2×10^{9}	~0.1
Early Science with Super-FRS and UNILAC/SIS18	2...5×10^{9}	1 – 2
First Science with SIS100	2×10^{10}	5
First Science+ with SIS100 (full intensity)	3-4×10^{11}	100

preparation
0.1 fb^{-1}
(near) stability

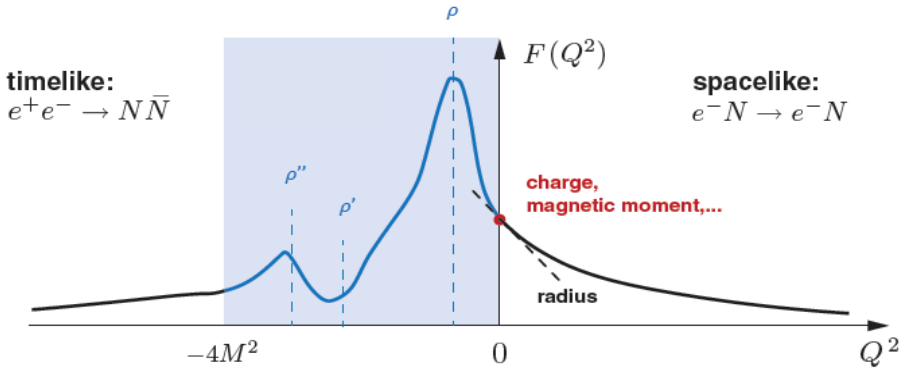
→ **discovery**
2-5 fb^{-1}
exotic

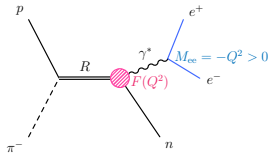
→ **detailed studies**
100 fb^{-1}
very exotic nuclei

MU Cosmic Matter in the Laboratory

ST3: Properties of hadrons and their excitation spectrum

Conduct rich hadron physics program with FAIR (anti-)proton beam to advance understanding of the strong force in the non-perturbative regime





Experiments

- Electromagnetic structure of baryons
- Hyperon-nucleon (YN), YNN and YY interaction
- SU(4) estimates for (exclusive) charm hyperon production:100 nb at SIS100
- Perspectives to study for the first time near-threshold charm production
- New detector concepts for hadron physics

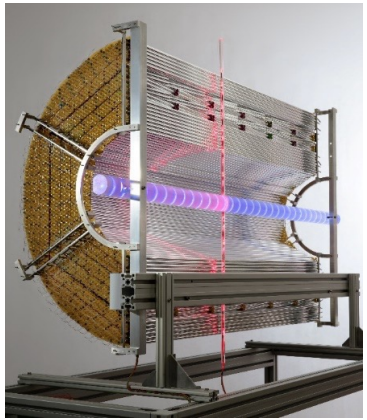
Theory

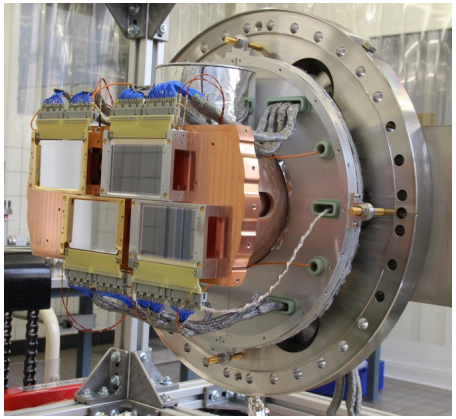
- Predict spectroscopy and structure
- Validity of pQCD at SIS100 energies?

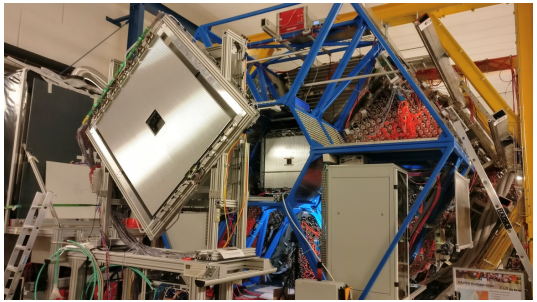
MU Cosmic Matter in the Laboratory

ST3: Properties of hadrons and their excitation spectrum

- Unique physics program with PANDA and its use of a stored anti-proton beam possible with completion of FAIR MSV
- Until then – provide the opportunity of hadron physics for young researchers
- 2025 – 2029: FAIR Phase-0 with HADES at SIS18 (π, p beams) (strange-) baryon spectroscopy and electromagnetic structure
- Commission subdetectors and analysis algorithms of the PANDA experiment with real data BES-III, GlueX, MAMI, *ELSA*
- > 2028: Explore strangeness and charm physics aspects at SIS100 with proton beam and CBM setup







Strategie der GSI bzw. des Topic CML für die POF-V

Neue Beteiligungen

- Beteiligung an ALICE3, dem neuen Schwerionenexperiment am LHC (die Höhe der Beteiligung wird diskutiert)
- Partner von DZA – The German Centre for Astrophysics: relevante Theorieentwicklungen bei der GSI

Forschungspolitische Ziele IV

Status/Einschätzung der Zielerreichung der Forschungspolitischen Ziele in PoF IV?

Aus den Forschungspolitischen Zielen zur POF-IV (s.17):

- „Der Aufbau und die schrittweise Inbetriebnahme der FAIR-Beschleuniger und Speicherringe sowie der Detektorsysteme … für die erste Hälfte der PoF IV-Periode.
- Es folgt die Datennahme der Detektoren CBM, NUSTAR und PANDA (das APPA-Projekt ist dem Programm MML zugeordnet).
- Bis dahin: FAIR Phase-0 und Forschungsaktivitäten an anderen internationalen Forschungsinfrastrukturen.

Status

- Forschungspolitische Ziele bzgl. Der FAIR Phase 0 erfüllt. Großer Bedarf an Strahlzeit an der GSI.
- Physikprogramm ausserhalb der GSI: am CERN mit ALICE bzw. mit BES-III wie geplant.
- Verzögerung beim Bau von FAIR verschiebt den Beginn der Nutzung von FAIR in das erste Jahr der POF-5 Periode (2028).

Forschungspolitische Ziele IV

Zusammenarbeit mit den Hochschulen

Helmholtz Forschungsakademie Hessen für FAIR (HFHF) - permanent
https://hfhf-hessen.de

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research
https://hgs-hire.de

ELEMENTS, 2021-2025
https://elements.science

Cluster of Excellence PRISMA+
https://prisma.uni-mainz.de

NRW-FAIR Netzwerk
NRW-FAIR Exzellenz-Netzwerk, 2022-2026
https://nrw-fair.ep1.rub.de/index.php/de/

EMMI
Helmholtz Alliance EMMI

Strategie der GSI bzw. des Topic CML für die POF V

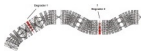
Vorstellung und Diskussion der Planungen und der Strategie für PoF V (Hauptteil)

Beteiligte Zentren:

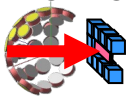
GSI wieder mit der Froschung in vollem Umfang in der PoF V in MU, MML und MT.

- TransFAIR ist vollzogen.
- HI Mainz engagiert sich wie bisher in MU und MT.
- Sichtbare Beteiligung der Zentren an den internationalen Großgeräten, insbesondere an den Detektoren ALICE am LHC (CERN), an BES III am BEPC II (IHEP).

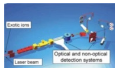
Super-FRS EC



HISPEC/ DESPEC

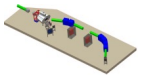


LASPEC

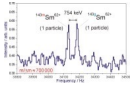


MATS

R3B



ILIMA



SHE

ELISE

EXL

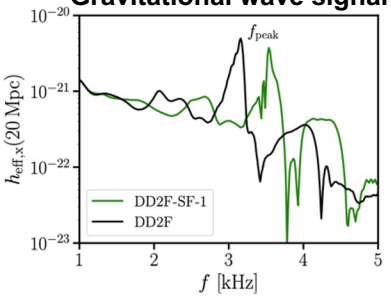
	Super-FRS EC	HISPEC/DESPEC	LASPEC	MATS	R3B	ILIMA	SHE	ELISe	EXL
Masses		Q-values, isomers		dressed ions, highest precision	unbound nuclei	bare ions, mapping study	precision mass of SHEs		
Half-lives	ps...ns-range	ground state and isomers µs...s			resonance width, decay up to 100ns	bare ions, ms…years	µs...days		
Matter radii	interaction x-section				interaction cross sections				matter densitiy distribution
Charge radii	charge-changing cross sections		mean square radii		charge-changin… cross sec…			charge density distribution	
Single-particle structure	high resolution, angular momentum	high-resolution particle and γ-ray spectroscopy	magnetic moments, nucl. spin…	evolution o… shell…	…out, short-range & tensor correlations	evolution of shell closures, pairing corr.	shell structure of SHEs		low momentum transfers
Collective behavior		electromagnetic… transition… str… …nts		halo structure	dipole response, fission	changes in deformation		electromagnetic transition strength	monopole resonance
EoS					polarizability, neutron skin			neutron skin	neutron skin, compressibility
Exotic Systems	b… …ons, hy… …nuclei, nucleon resonances	rare and exotic e.m. and particle decays			n-rich hypernuclei	exotic decay modes			

The strength of NUSTAR is the variety and versatility of its experiments

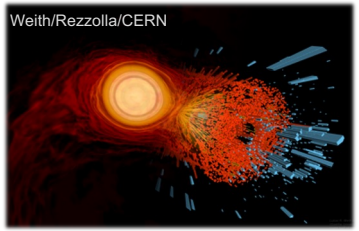
Theory: future opportunities and challenges

High density equation of state

Gravitational wave signal

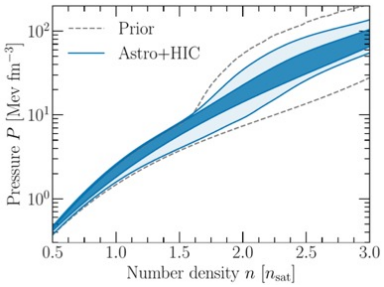


Bauswein *et al.*,
PRL 112 (2019) 061102

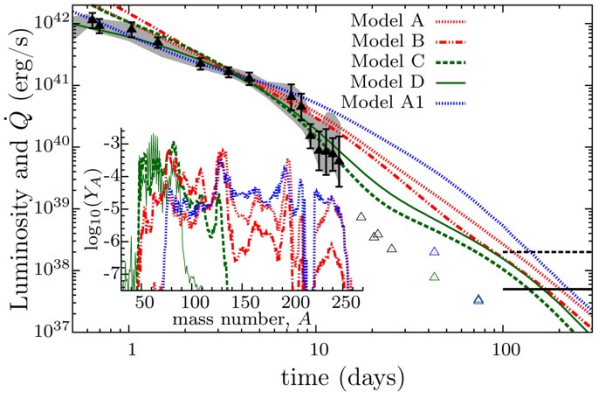


Huth *et al.*,
Nature 606, 276-280 (2022)

Heavy ion collisions



Modelling r-process electromagnetic transients



Constrain EoS from both HIC and BNS merger

Study impact of **quark deconfinement** on observables:

- Qualitative signatures for HI experiments
- Characteristic imprint of quark matter on postmerger GW emission
- Influence on nucleosynthesis and kilonova lightcurves

- Determine role of neutrinos on light curve
- Develop a complete database of atomic opacities
- Identify key nuclei affecting light curves
- Guide experiments at GSI/FAIR