# Research Retreat

# SHE

Ch.E. Düllmann for the SHE Subcollaboration in NUSTAR

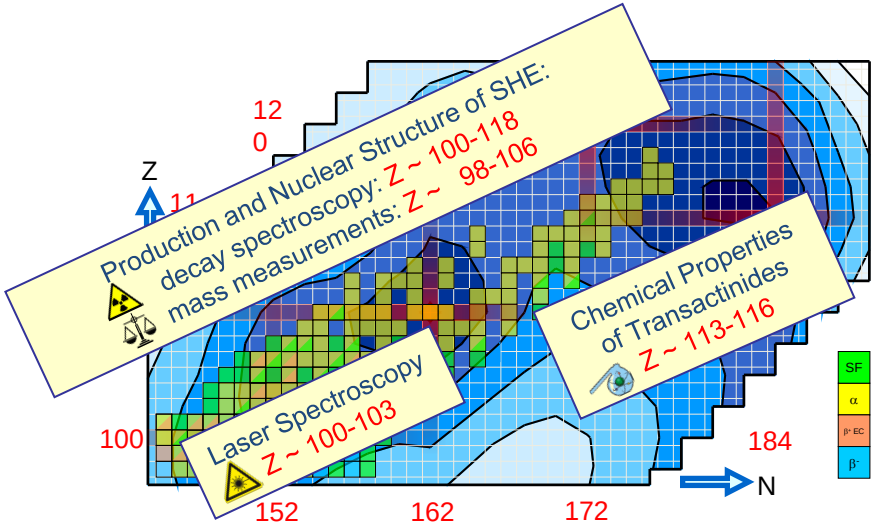
14.02.2023 @ Bensheim

Content:

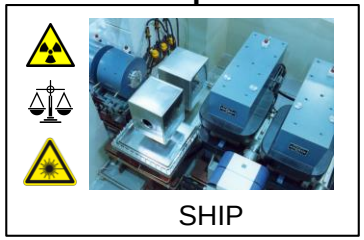
- Beamtime 2024 & 2025
- Engineering Run 2023
- SHE beamtime 2026+

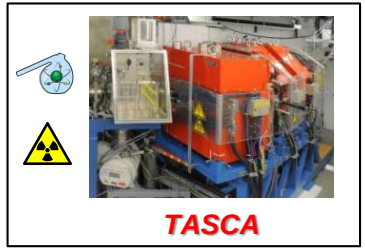
# The GSI superheavy element program





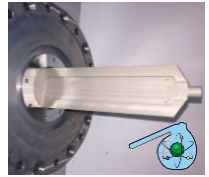

## Recoil separators



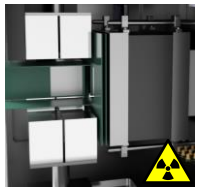




## Ancillary setups

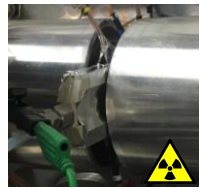

SHIPTRAP



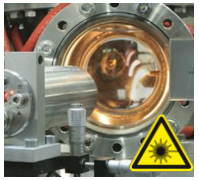
miniCOMPACT



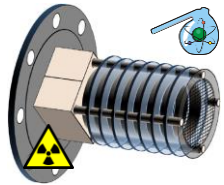
LUNDIUM



ANSWERS



RADRIS



UniCELL

Comprehensive investigation of **production** and of **atomic, chemical and nuclear properties** of elements **Z ~ 100 – 118** using **novel techniques** and the **GSI-unique suite** of experimental setups around recoil separators SHIP and TASCA

# Focus of SHE program: past (2022) and next (2024&25)



- **Nuclear properties**
  - Decay spectroscopy
  - High-precision mass measurements
  - Laser spectroscopy (hyperfine structure)
- **Atomic properties**
  - Laser spectroscopy of atomic levels
- **Chemical properties**
  - Chemical reactions, surface interactions

As reported at 2022 Beamtime Retreat

## Experiments run in 2022

D.M. Cox *et al*. (U319)
**N-deficient Pu isotopes with LUNDIUM**
Failed due to insufficient beam qualtiy

F. Giacoppo *et al*. (U324)
**SHE masses and isomer energies**
**→ ran in 2021**

S. Raeder *et al*. (U321)
**Laser spectroscpy of $_{103}$Lr**
Reached 100% of the goals

A. Yakushev *et al*. (U327)
**Ancillary data / setup test for $_{115}$Mc chem.**
Reached 80% of the goals; problems with one target from Mainz

Outcome of GPAC 45

## Approved for 2024 & 2025

L.G. Sarmiento *et al*. (G-22-00123; resubmiss.)
**N-deficient Pu isotopes with LUNDIUM**

J. Khuyagbaatar *et al*. (G-22-00040)
**SHE decay spec. with ANSWERS**

F. Giacoppo *et al*. (G-22-00154)
**SHE masses and isomer energies**

S. Raeder *et al*. (G-22-00051)
**$_{98}$Cf, $_{100}$Fm, $_{102}$No, $_{103}$Lr laser spectroscopy**

A. Yakushev *et al*. (G-22-00034)
**$_{106}$Sg and $_{107}$Bh carbonyl complexes**

# Beamtime 2024 & 2025

- Approved experiments
- Boundary conditions

# Approved beamtime (GPAC 45)



| | Beams | Main shifts | Parasitic shifts |
|---|---|---|---|
| L.G. Sarmiento *et al*. (G-22-00123; resubmission)<br>**N-deficient Pu isotopes with LUNDIUM** | **$^{48}$Ca** | A- 15 | A- 27 |
| J. Khuyagbaatar *et al*. (G-22-00040)<br>**SHE decay spec. with ANSWERS** | **$^{48}$Ca**<br>$^{36\text{-}40}$Ar/$^{48}$Ca/$^{48\text{-}50}$Ti/$^{50\text{-}54}$Cr/$^{58\text{-}64}$Ni | A 63 | A 61 |
| F. Giacoppo *et al*. (G-22-00154)<br>**SHE masses and isomer energies** | **$^{50}$Ti**<br>$^{48}$Ca<br>$^{40}$Ar/$^{48}$Ca/$^{50}$Ti/$^{54}$Cr | A 25<br>A- 45 | A 21<br>A- 18 |
| S. Raeder *et al*. (G-22-00051)<br>**$_{98}$Cf, $_{100}$Fm, $_{102}$No, $_{103}$Lr laser spectroscopy** | **$^{48}$Ca**<br>**$^{36}$S**<br>$^{40}$Ar/$^{48}$Ca/$^{50}$Ti/$^{54}$Cr | A 65 / A- 30<br>A- 6 | A 42 |
| A. Yakushev *et al*. (G-22-00034)<br>**$_{106}$Sg and $_{107}$Bh carbonyl complexes** | **$^{54}$Cr**<br>$^{48}$Ca/$^{50}$Ti/$^{54}$Cr/$^{56}$Fe/$^{58}$Ni | A 42 | A 24 |
| ***Approved shifts*** | | ***A 195***<br>***A- 96*** | ***A 148***<br>***A- 45*** |

# Summary of requested beams & boundaries



| Beam | Main shift | Para. shifts | A / A⁻ |
|---|---|---|---|
| $^{36}$S | 6 | | |
| $^{48}$Ca | **128** | **103** | |
| | 90 | 27 | |
| $^{50}$Ti | **25** | **21** | |
| $^{54}$Cr | **42** | **18** | |
| A~36-64 | | **6** | |
| | | 18 | |
| *Total* | **195** | **148** | |
| | 96 | 45 | |

| Approved Beams | | |
|---|---|---|
| $^{36}$S | 2% | |
| $^{48}$Ca | 75% | 67% |
| $^{50}$Ti | 9% | 11% |
| $^{54}$Cr,… | 14% | 9% |
| Any | | 12% |

- **High intensity $^{48}$Ca, $^{50}$Ti and $^{54}$Cr beams** are crucial for successful SHE program
- **$^{48}$Ca is 75% of all main shifts** and a similar fraction of all parasitic shifts
  → Each $^{48}$Ca main shift should be accompagnied by an SHE $^{48}$Ca parasitic shift (SHIP/TASCA parallel operation)
- **$^{54}$Cr beam** was not run for some time
  → need for long-term test
- **Long pulses** (≥5.0 ms, 50 Hz) and energy adjustment by ERs required
- Scheduling of **parasitic beamtime needed** for successful „main beam“ experiments

- Engineering Run 2023
  - To-do list to ensure the 2024 & 2025 beamtime goals can be reached

# Engineering run 2023: *TASCA*

- Verify **intensity and long-term stability of $^{54}$Cr ion beam** (long-pulse 5 ms, 4.8 MeV/u) on target @ TASCA.
- Verify shielding factor of the new shielding hut around TASCA focal with **intense HI beam (e.g., $^{40}$Ar**,…; long-pulse 5 ms, 4.8 MeV/u, 1 particle-μA on target) @ TASCA to measure background conditions.
- Engineering run with beam will also allow verifying full functionality of the upgraded TASCA control system, including the new cabling that needed to be implemented after the removal of the “Messstation”.

# Engineering run 2023: SHIP

Several changes at SHIP during the extended shutdown are implemented

- Installation of new quadrupole magnet power supplies
- rerouting of the cables for the control of the manget PS
- new cabling of required signals from the “Messstation”.

Mandatory re-commissioning of SHIP in advance of the 2024 physics beamtime request: **2 small blocks, ideally $^{54}$Cr or $^{50}$Ti, parasitic beam ≥ 5Hz, 5 ms**

- SHE beamtime 2026+
  - SHE Requirements

# SHE beamtime 2026+

## UNILAC / SHE Program …

After several years that allowed only for experiments with short beamtime requirements, a ramping up is needed for a competitive SHE program

A staged approach could include:

2026 3 months of SHE beamtime for SHIP & TASCA

2027 6 months of SHE beamtime for SHIP & TASCA

2028+ 9 months of SHE beamtime for SHIP & TASCA

## ...and future HELIAC beams

**Outcome of GSI Research Retreat 2021:**

[…] the timely installation of minimal config. **cw-linac (HELIAC)** delivering long-duty cycle, comprising a new (18 GHz) ECR ion source and LEBT, existing 25%-duty-cycle injector and three accelerator cryomodules […]

HELIAC GSI DARMSTADT

**HELIAC in current KHuK recommendations:**

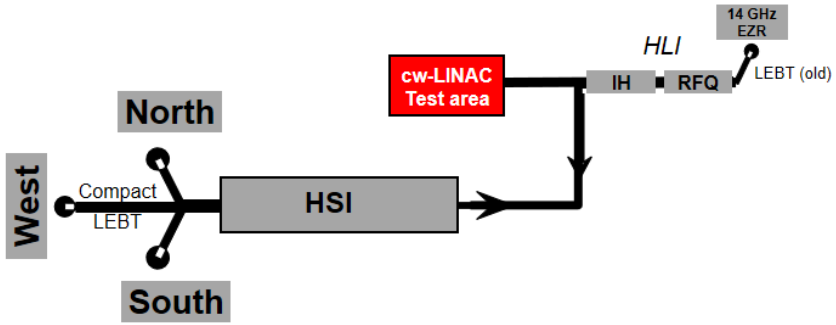
**5.3 F&E-Beschleuniger**

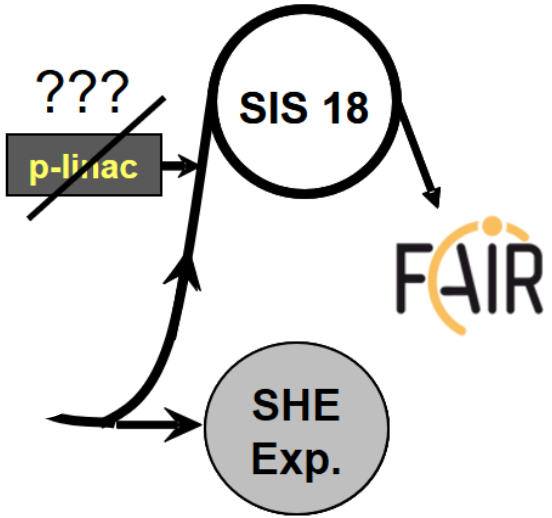
[…]Entwicklungen im Bereich Beschleunigertechnologien im Fokus des Interesses von KHuK.
• Supraleitende Dauerstrich-Teilchenbeschleuniger für Elektronen (MAMI, MESA/Univ. Mainz) bzw. Protonen (PSI/Schweiz) und Schwerionen (FRIB/U.S.A., SPIRAL/Frankreich, **HELIAC/GSI**) sind weltweit Gegenstand generischer Beschleunigerentwicklung. Diese Entwicklung von Schlüsseltechnologien sollte weiter vorangetrieben werden“

https://indico.gsi.de/event/13777/contributions/67280/attachments/42456/59231/KHuK_Empfehlungen_Strategiegespr%C3%A4ch02022023.pdf

# cw-Linac@SH2/3 (>2030)

Slide from W. Barth

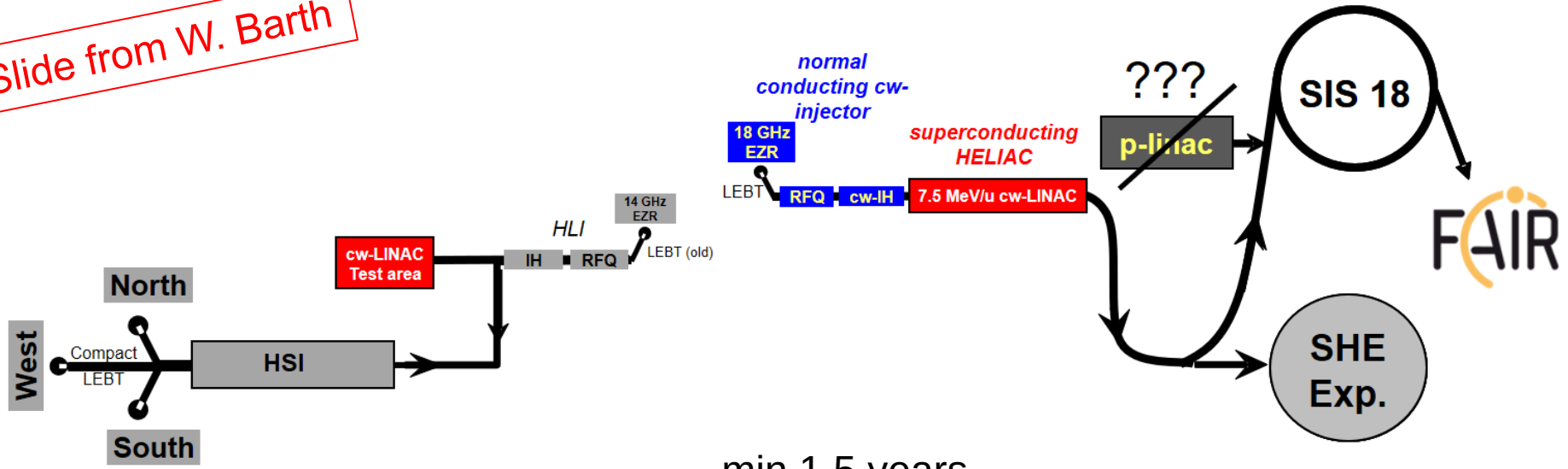



min.1.5 years
PSU commissioning
**no beam from UNILAC!**

# cw-Linac@SH2/3 (>2030)

Slide from W. Barth

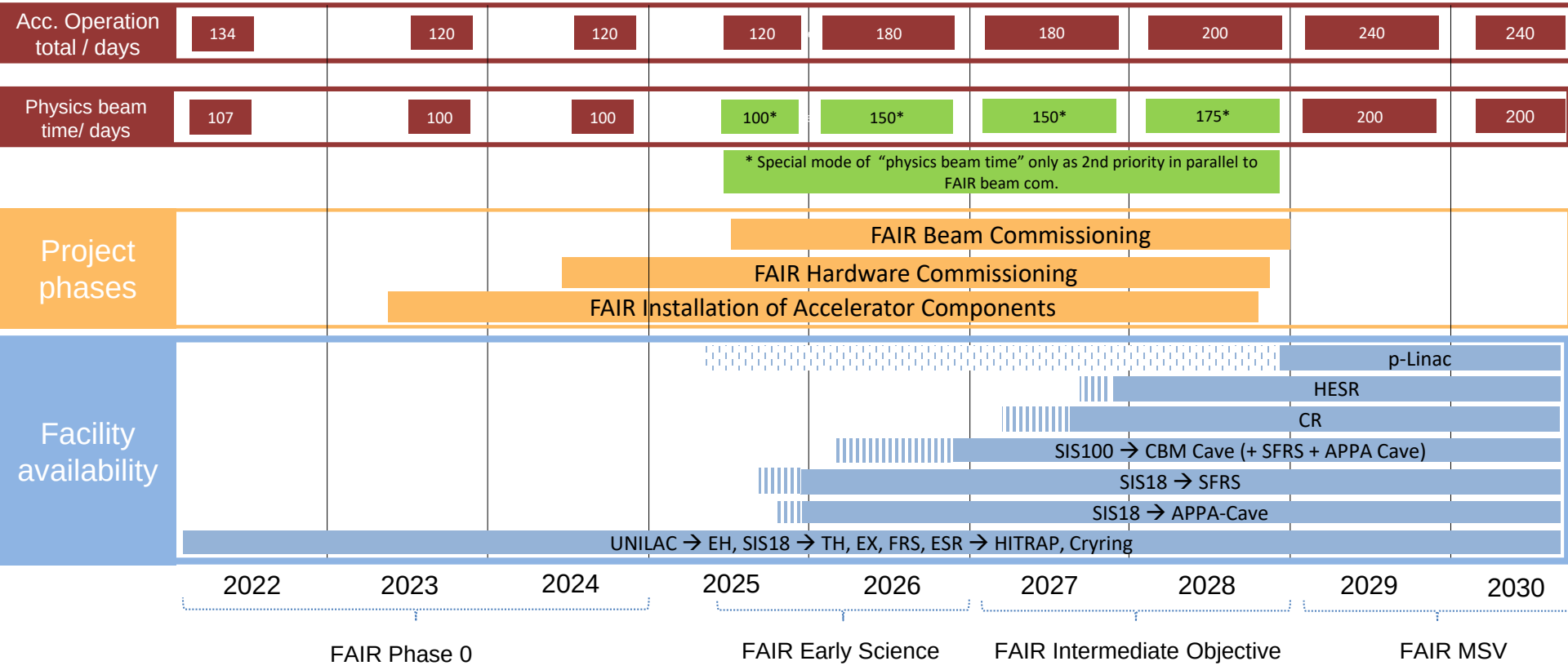



min.1.5 years
PSU commissioning
**no beam from UNILAC!**

# Status Jan. 2022

## FAIR/GSI strategic operation scenario

Slide from S. Reimann / D. Severin



# Time schedule/HELIAC

Slide from W. Barth

- **2023** BIG “HELIAC-Strahlenschutzbunker”
- **2025** Start Aufbau/HELIAC-Bunker
- **2026** HELIAC-Bunker bezugsfertig
- **2026** Ionenquelle + HELIAC-Injektor Installation und Inbetriebnahme
- **2027** CM1 Aufbau+Inbetriebnahme + Link2UNILAC
- **2028** CM2&3 Aufbau+Inbetriebnahme + **Start Nutzerbetrieb**
- **>2028** HELIAC Vollausbau + Anschluss M1-M3

# Conclusion



- **Beamtime 2024 & 2025**
  - High intensity $^{48}$Ca, $^{50}$Ti and $^{54}$Cr beams are crucial
  - $^{48}$Ca shall be used with „isotope crisis“ in mind
  - $^{50}$Ti, $^{54}$Cr beams need development & verification & potentially isotope procurement
- **Engineering run 2023**
  - Highly important to verify $^{54}$Cr intensity, TASCA shielding upgrade, new SHIP power supplies, new cabling to SHIP and TASCA,…
- **Outlook 2026+**
  - Successively ramping up of SHE beamtime
  - Towards HELIAC in the „post Unilac“ time
- **Enriched isotope crisis**
  - Steps underway that hopefully lead to GSI/HIM-based $^{48}$Ca enrichment capabilities

Input to this talk from

W. Barth (GSI/HIM)
M. Block (GSI)
J. Khuyagbaatar (GSI)
T. Kieck (HIM)
B. Lommel (GSI)
S. Raeder (GSI)
A. Yakushev (GSI)

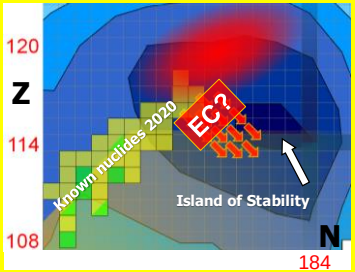
is gratefully acknowledged

**Thank you for your attention!**

# The long-term view

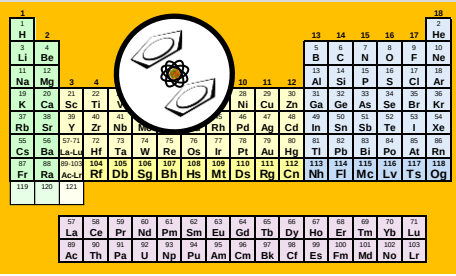
## The “Island of stability of superheavy elements” at the end of the periodic table






**Island of stability in the chart of nuclei**

**The periodic table: elements beyond $_{118}$Og**



- extending the region of known nuclei to higher Z (new elements) and N using intense stable beams
- fixing the center, the extension and the topography of the Island of Stability
- chemical classification of heaviest known elements to elucidate the validity of the periodic table
- expect disruptive, unplanned findings in the field of superheavy elements
- linking laboratory experiments to astrophysical studies
- New opportunities with HELIAC