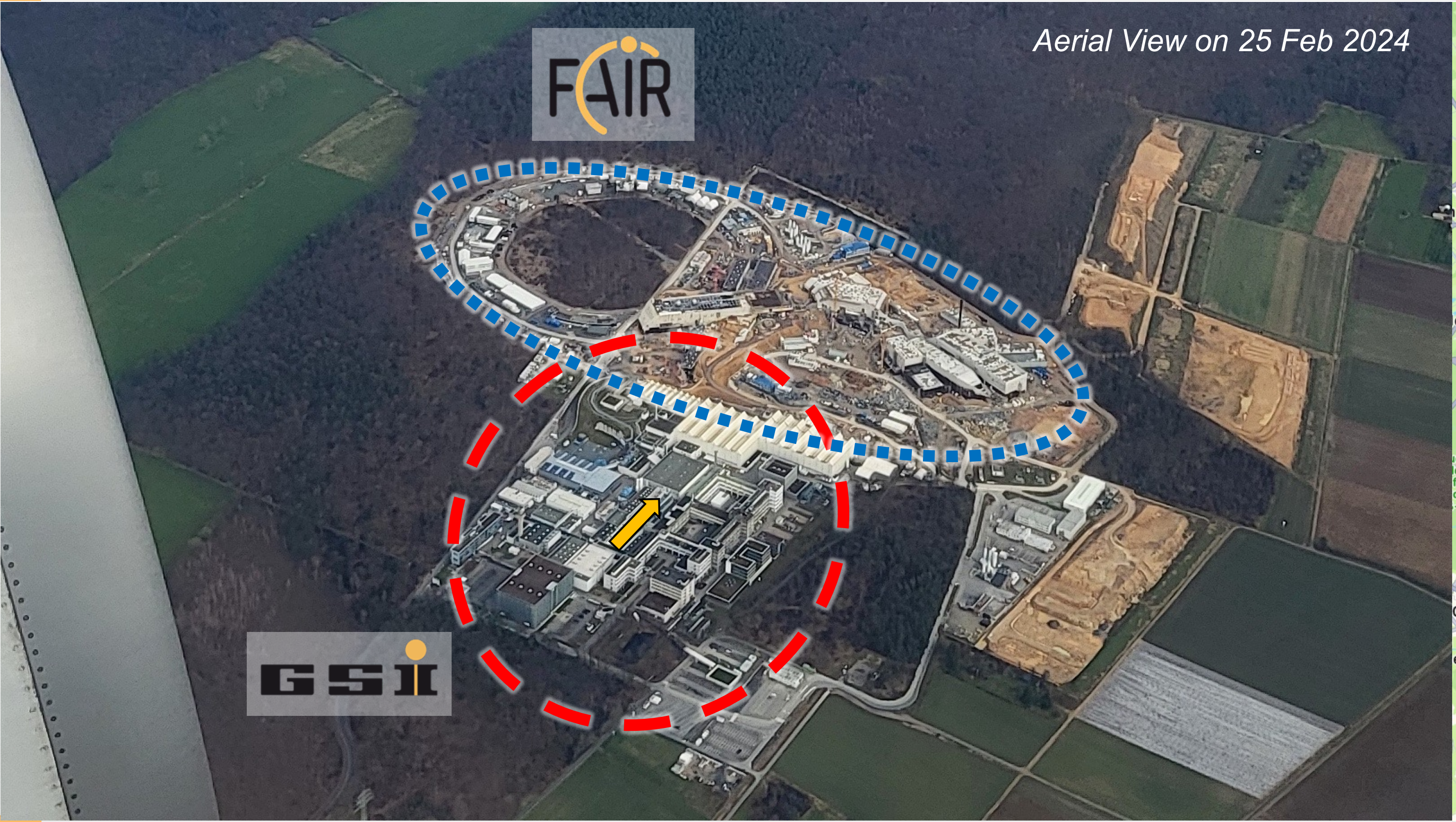
GSI Accelerator Complex

R. Assmann
Head „Accelerator Operations & Development“

CERN-GSI Collaboration Steering Committee

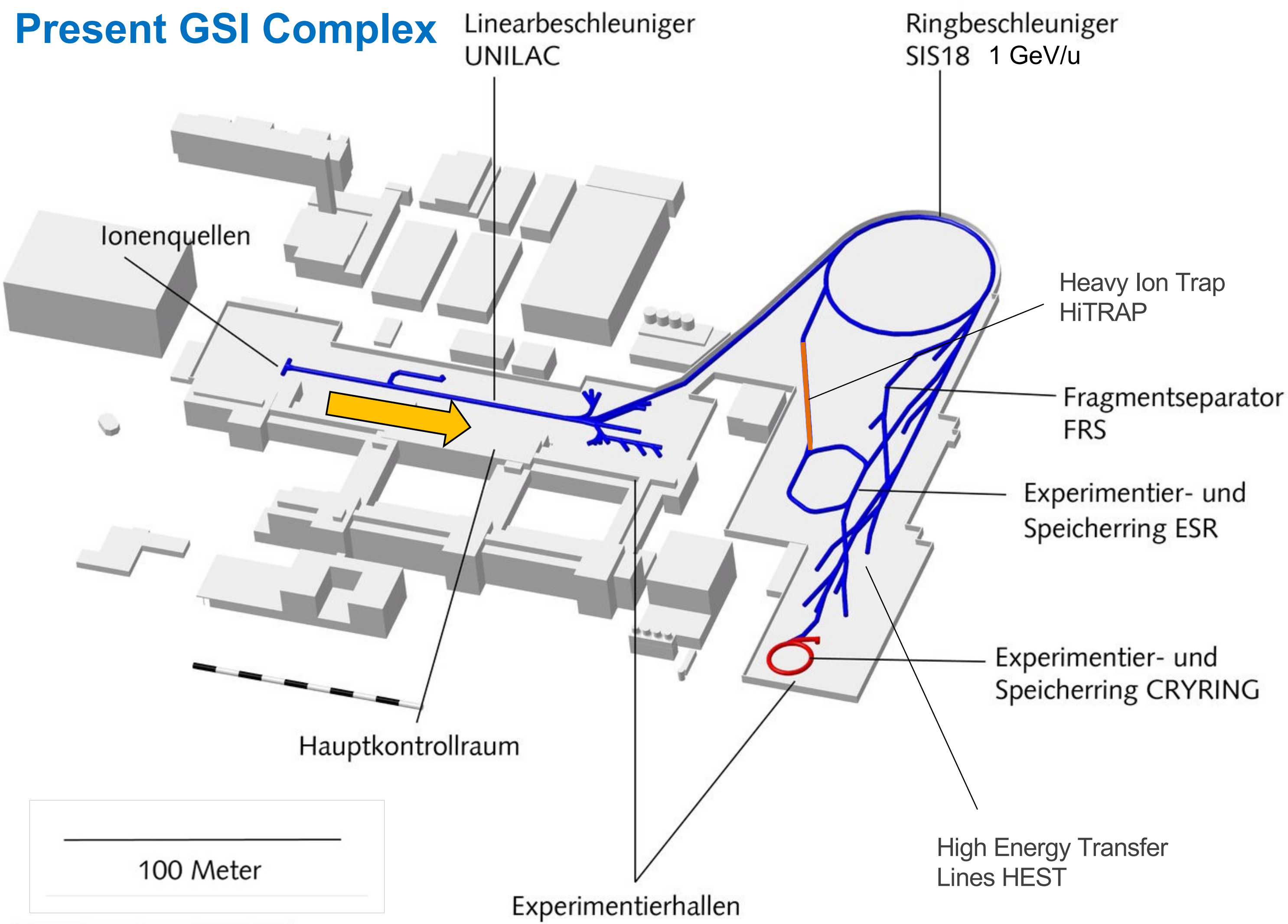
26.04.2024

GSI and FAIR


Aerial View on 25 Feb 2024
FAIR
GSI


Bad Soden am Taunus
Frankfurt am Main
am Taunus
ersheim
Zeppelinheim
Frankfurt Airport
Dreieich
Mörfelden-Walldorf
GSI FAIR
Worfelden
Groß-Gerau
Weiterstadt
Stadt Darmstadt
Darmstadt
Griesheim
Riedstadt

Present GSI Complex

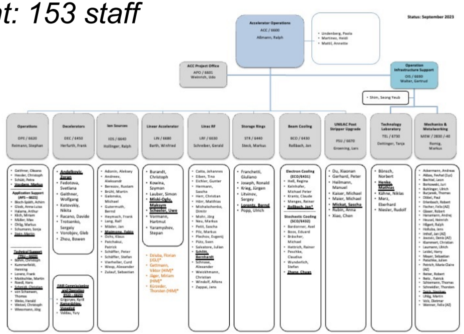


- **World-class ion accelerator facilities**
  - Ion linac
  - Storage ring
  - Synchrotron
  - Beam cooling
  - Ion traps
  - Decelerators
- **55 years and getting stronger → plus FAIR**

Mission "Accelerator Operations and Development"

- **Operation of GSI accelerators** and delivering beams for world-class heavy ion research
- Development of GSI accelerators and **preparing them step-wise for the future**
- **Supporting the FAIR project** and its completion
- Preparation and organization of **FAIR accelerator commissioning** *(headed by S. Reimann)*
- **Operating** costs working group *(headed by U. Weinrich)*
- **Merging** of certain GSI/FAIR accelerator-related activities – work with **regional universities** and **international** labs
- Leadership team (see photos) and young talents in depts → excellent options for future shaping of **world-class GSI/FAIR accelerator area**

At the moment: 153 staff



present GSI/ACC structure

Our Ion Beams at GSI

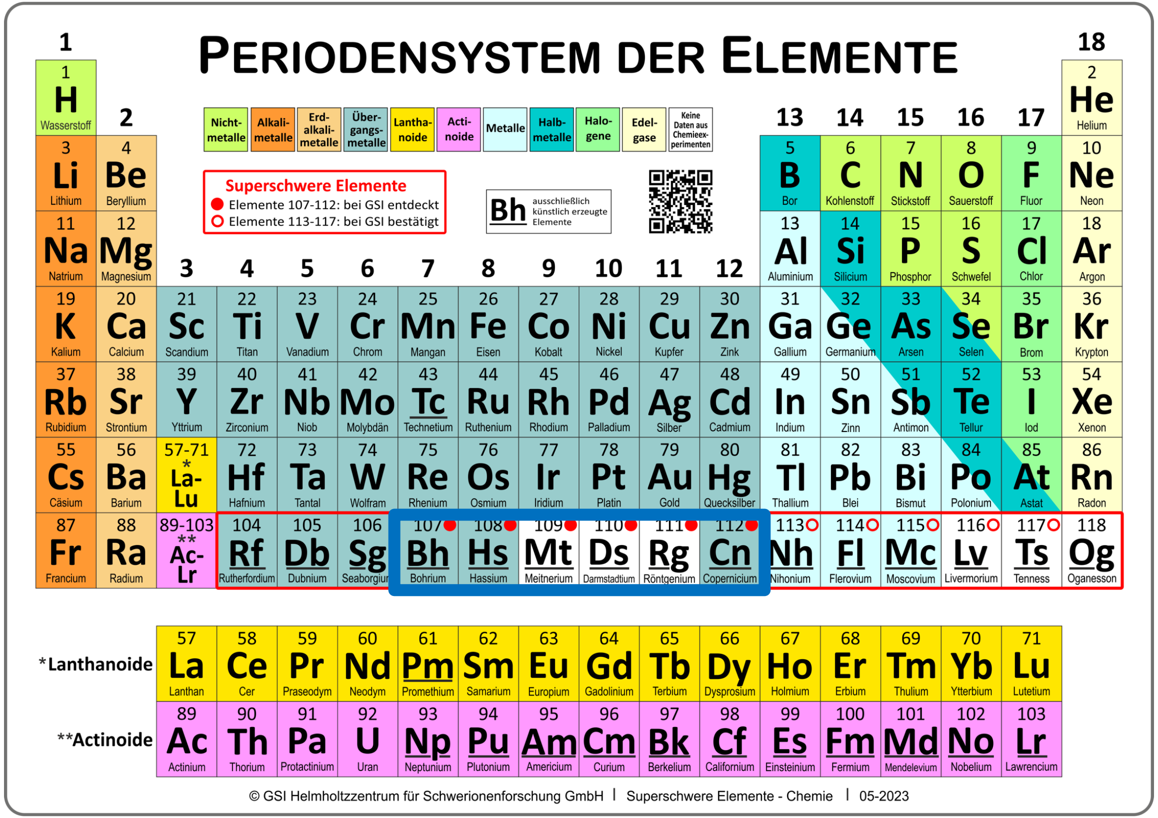
(Nominal Intensities 13.03.2024)

*	*50Hz is possible only with exclusive operation mode*
**	*in parallel operation mode with high MAZ and adopted synchronous phase (higher intensity possible only during exclusive proton operation)*
***	*C + H parallel high-current operation from molecule source*
****	*for A4 operation (11.4 MeV/u), repitition rate is limited to 10 Hz and pulse length to 1 ms*
3E+09	*positive changes compared to 2022 table*
1E+07	*negative changes compared to 2022 table*

This table contains examples of the most frequently requested scenarios. For other ion species, isotopes and charge states, ask your local contact

		UNILAC			**SIS18**			**ESR**			**Cryring**	
ion species	**ion source**	max. rep. rate****	charge state	nominal average particle current	max. rep. rate (fast ext.)	charge state	nominal intenity per cycle @ extraction	charge state	energy / u	stored intensity	charge state	nominal intensity per cycle @ injection
U-238	VARIS				0.5 Hz - 1 Hz	73+	3E+09	91+/92+	300-400 MeV	1E+08		
								91+/92+	40 MeV	4E+07		
								91+/92+	10 MeV	5E+06	91+/92+	1E+06
Bi-209	VARIS				0.5 Hz - 1 Hz	68+	2E+09					
Pb-208	VARIS				0.5 Hz	67+	3E+09				78+	5E+06
Au-197	VARIS	25 Hz*	26+	0.1 pμA	0.5 Hz - 1 Hz	65+	2E+09				75+	5E+06
Xe-124	MUCIS				0.5 Hz - 1 Hz	48+	4E+09					
Xe-136	MUCIS				0.5 Hz - 1 Hz	48+	5E+08					
Ag-107	VARIS				0.5 Hz - 1 Hz	45+	2E+09				47+	5E+06
Ti-50	PIG	50 Hz	12+	0.8 pμA	0.5 Hz - 1 Hz	22+	2E+08					
Ca-48	ECR	50 Hz	10+	0.8 pμA	0.5 Hz - 1 Hz	20+	5E+08					
Ar-40	MUCIS				0.5 Hz - 1 Hz	18+	4E+10					
Mg-24	Cryring ECR										1+	2E+06
O-18	VARIS		3+		0.5 Hz - 1 Hz	8+	5E+10					
N-14	MUCIS				0.5 Hz - 1 Hz	7+	7E+10					
C-12	ECR	50 Hz	2+	2.4 pμA	0.5 Hz - 1 Hz	6+	4E+09					
	MUCIS (from CH3 molecule***)				0.5 Hz - 1 Hz	6+	2E+10					
	Cryring ECR										1+	2E+06
H-1	MUCIS (from H3 molecule**)				0.5 Hz - 1 Hz	1+	1E+09					
	MUCIS (from CH3 molecule***)				0.5 Hz - 1 Hz	1+	8E+10					

Did You Hear about Bohrium, Hassium, Meitnerium, Darmstadtium, Roentgenium, Copernicium?

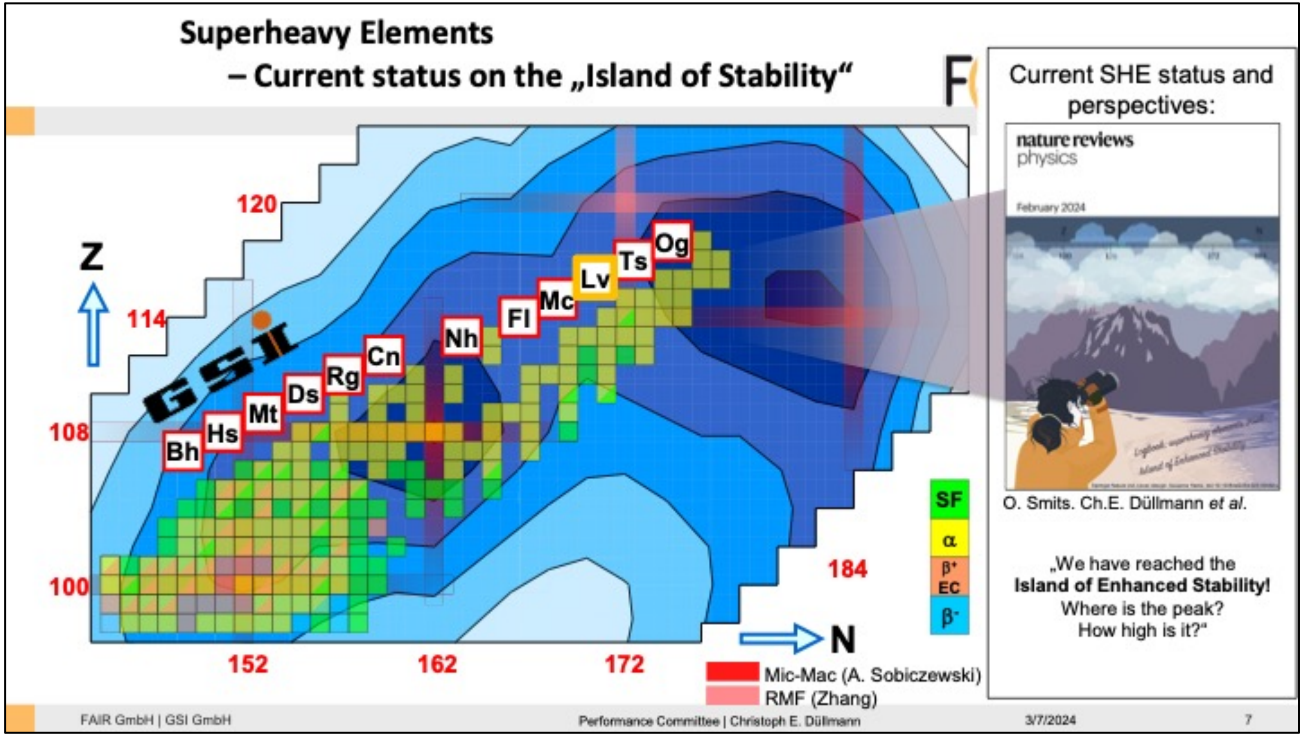


- Use ion beams from accelerators to **discover new heavy elements**!
- Study **properties** of heavy elements!
  - How did our universe form from the big bang?
  - Where do heavy elements on earth come from (not from the sun)?
- New push from gravitational wave detectors

  → detection of neutron star collisions

  → forming of heavy elements observed in nature

The Island of Stability



Performance Committee | Christoph E. Düllmann

Groups of super heavy elements with the **potential to have longer half-lives**, in the order of several minutes, than their place on the periodic table would suggest.

This is due to these elements having **'magic numbers'** of protons and neutrons.

Royal Society of Chemistry

Courtesy F. Maimone et al

Dual Ion Beam for Tumor Therapy *(new, world-wide first)*

Carbon used for tumor irradiation. Helium penetrates through body and is used for real time imaging.

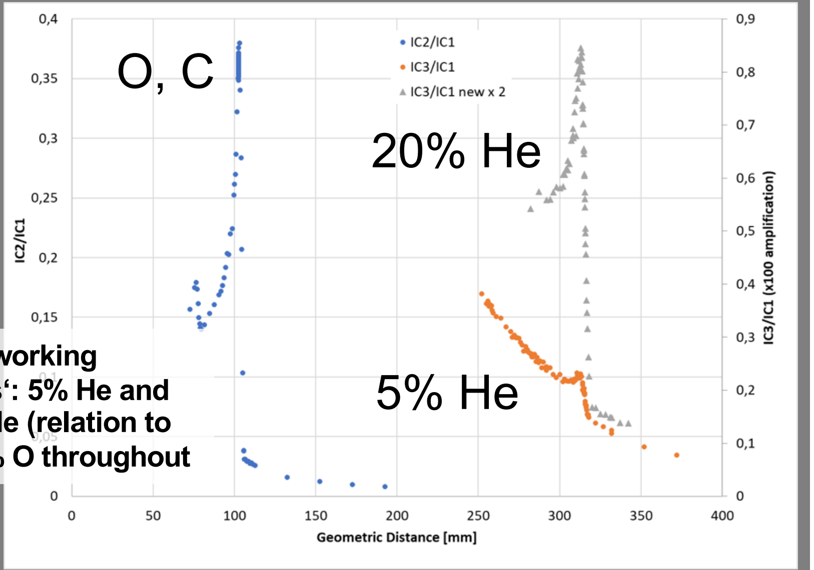
Ion mass	He + C (5-20% He)
Ion charges	$^{4}He^{+}$ und $^{12}C^{3+}$ from CH_4
Energy	225 MeV/u
Beam intensity	10^8, Slow extraction
Stability	No variation of He, C and O
Contamination of $^{16}O^{4+}$	As low as possible

Possible contrast at low-density differences

A gummy bear in addition to other density calibration targets in a gelatin block (edge length 6 cm), can be imaged exclusively with the helium portion of the beam.

Measured ion contributions to image:
12C6+: 0.167%
4He2+: 99.833%

Integrals over one spill for the depth dose



Two 'working points': 5% He and 20% He (relation to C), 7% O throughout

Measurements with a matrix IC detector (also time-resolved) and films providing location information collected as well.

- IC2: front chamber with O and C peak
- IC3 : back chamber with 5% He concentration
- IC3 : back chamber with 20% He concentration

Ion source
Courtesy
R. Hollinger

GSI Accelerator Competences, Challenges and Collaboration Opportunities

1. *Operating and consolidating 50 years old accelerators*
2. *Building equipment for RF accelerators: wide aperture, high intensity, high rate, large components*
3. *Facility design and beam dynamics for high intensity hadron accelerators*
4. *Modern and efficient control systems*
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Operating and consolidating 50 years old accelerators

- Fast response repairs → workshop capabilities
- Project management (CERN Consolidation)
- Procedures in shutdowns, installations, …

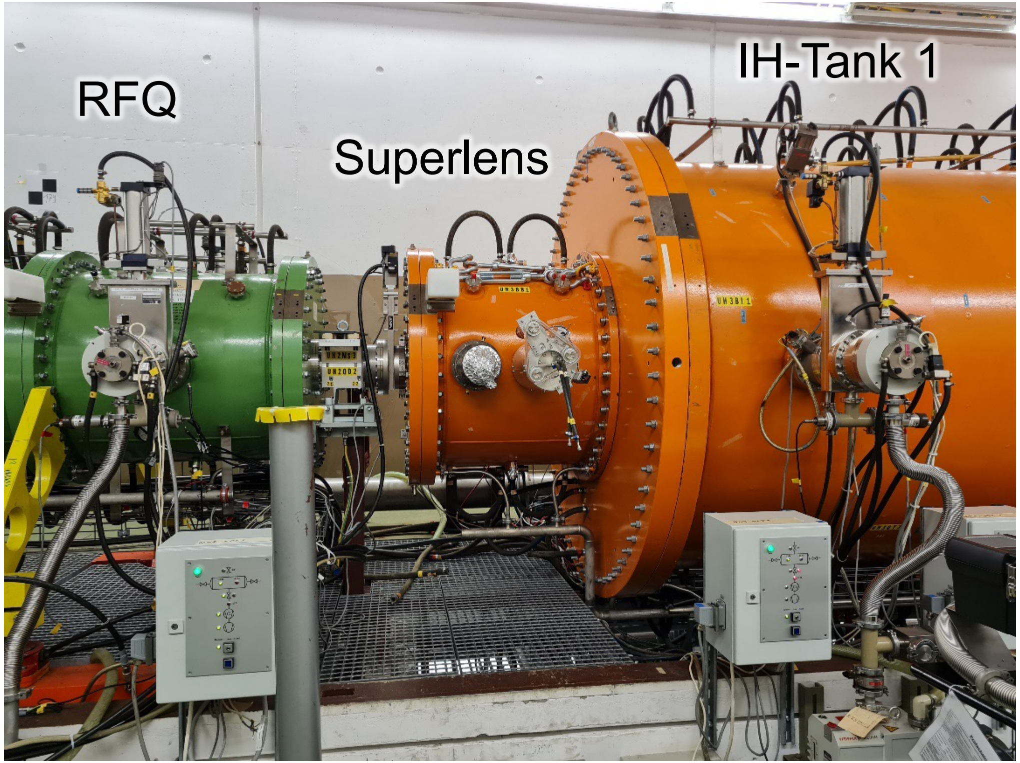
Example: Maintaining and optimizing the quite outdated RF system at the UNILAC linear accelerator. No spares, age-related failures.

Last week: fault in 400 V line & crumbling insulation of cables during repair.

Repaired but 1.5 days lost.

→ Defining technical roadmap, we will then discuss common interests

UNILAC – Superlens Repair & Upgrade (2022/23)



Courtesy W. Barth et al

Operating issues

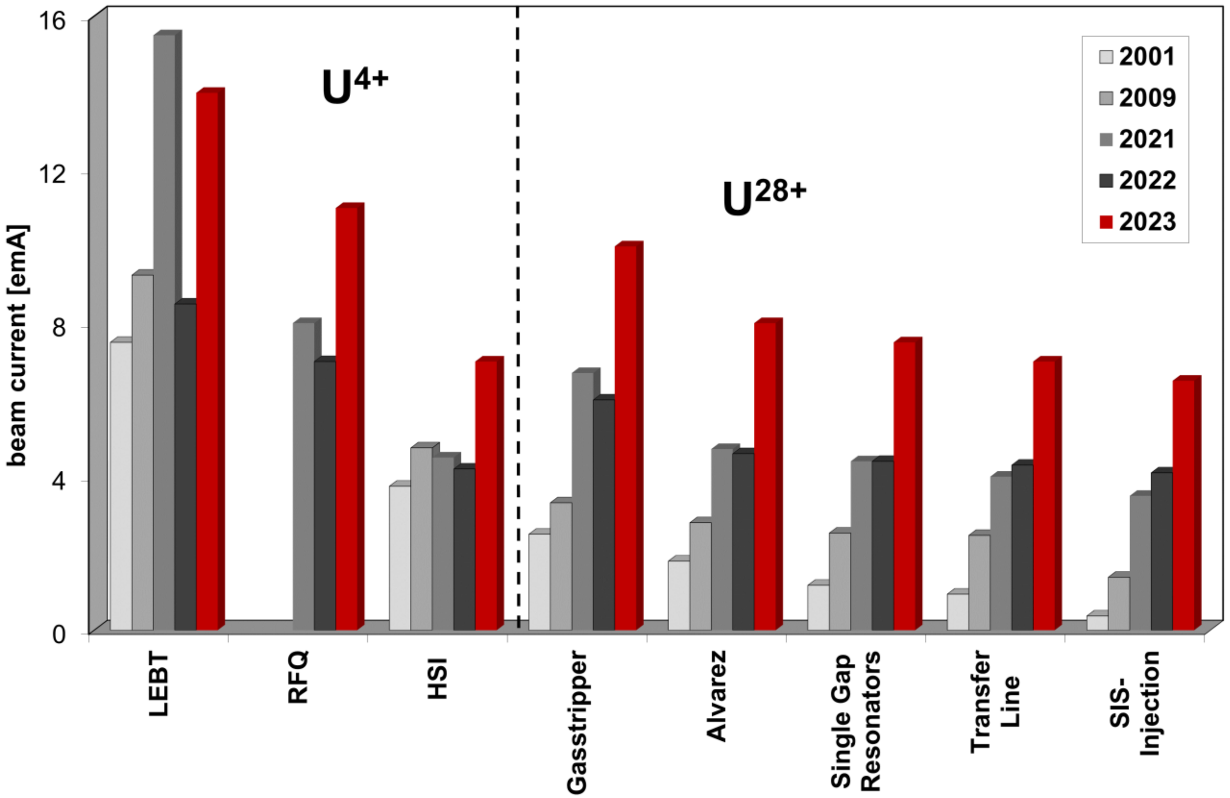
- Unacceptable beam losses
- Performance degradation
- Increased reflected power @high current operation

Measures

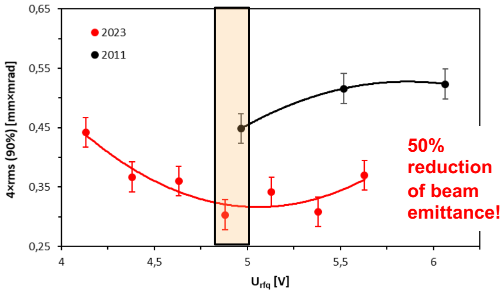
- Replacing old rods
- New rods
  - massive copper
  - galvanic copper coated
- Advanced plunger design
  - enlarged size
  - closer positioned to the girders
  - w/o tuner extensions

⇒ compensate (unwanted) shift of rf-frequency

UNILAC Short Pulse Heavy Ion Operation
→ New Records



about 50% of FAIR intensity goal reached



Result courtesy W. Barth et al

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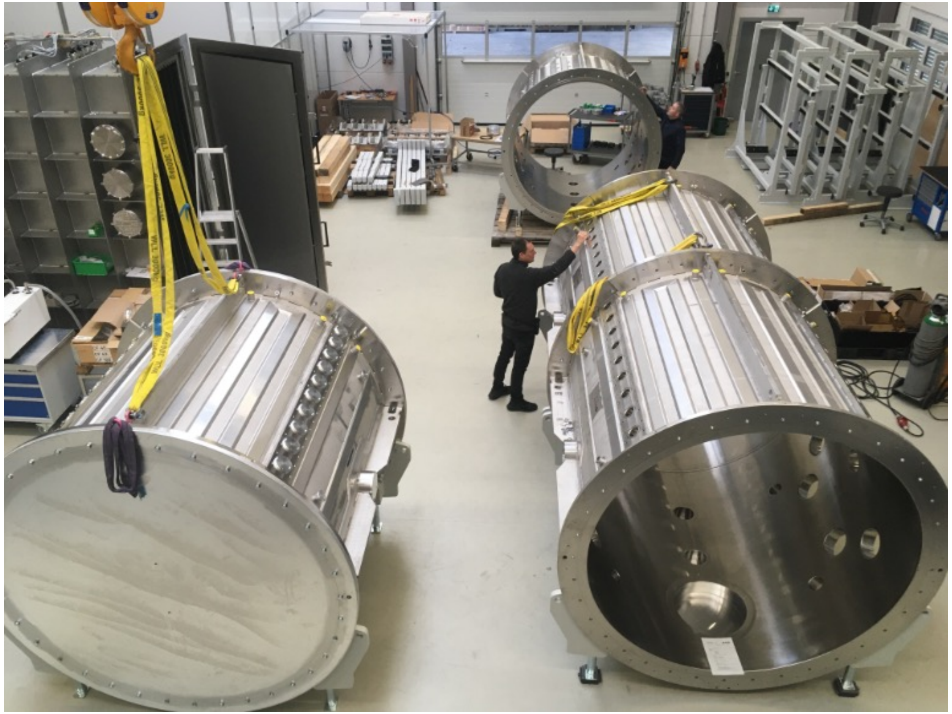
Building equipment for RF accelerators: wide aperture, high intensity, high rate, large components

- Large parts galvanic workshop at GSI
- Availability RF equipment: tubes, klystrons, …
- Fast ramping dipoles (4T/s), s.c. magnets
- Copper-plating of drift tubes at CERN



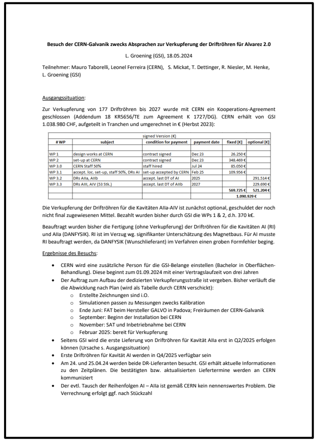
Copper-plating of drift tubes at CERN:

- → Signed Dec 2023. Working visit on 18.5. at CERN. Well on track.
- → Many thanks for CERN support.

Building equipment for RF accelerators: wide aperture, high intensity, high rate, large components

Addendum 18 KR5656/TE zum Agreement K 1727/DG

signed Version (€)					
# WP	**subject**	**condition for payment**	**payment date**	**fixed [€]**	**optional [€]**
WP 1	design works at CERN	contract signed	Dec 23	26.250 €	
WP 2	set-up at CERN	contract signed	Dec 23	348.469 €	
WP 3.0	CERN Staff 50%	staff hired	Jul 24	85.050 €	
WP 3.1	accept. loc. set-up, staff 50%, DRs AI	set-up accepted by CERN	Feb 25	109.956 €	
WP 3.2	DRs AIIa, AIIb	accept. last DT of AI	2025		291.514 €
WP 3.3	DRs AIII, AIV (53 Stk.)	accept. last DT of AIIb	2027		229.690 €
				569.725 €	**521.204 €**
				1.090.929 €	



Besuch der CERN-Galvanik zwecks Absprachen zur Verkupferung der Driftröhren für Alvarez 2.0

L. Groening (GSI), 18.05.2024

Teilnehmer: Mauro Taborelli, Leonel Ferreira (CERN), S. Mickat, T. Dettinger, R. Niesler, M. Henke, L. Groening (GSI)

Ausgangssituation:

Zur Verkupferung von 177 Driftröhren bis 2027 wurde mit CERN ein Kooperations-Agreement geschlossen (Addendum 18 KR5656/TE zum Agreement K 1727/DG). CERN erhält von GSI 1.038.980 CHF, aufgeteilt in Tranchen und umgerechnet in € (Herbst 2023):

signed Version (€)					
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				569.725 €	**521.204 €**
				1.090.929 €	

Die Verkupferung der Driftröhren für die Kavitäten AIIa-AIV ist zunächst optional, geschuldet der noch nicht final zugewiesenen Mittel. Bezahlt wurden bisher durch GSI die WPs 1 & 2, d.h. 370 k€.

Beauftragt wurden bisher die Fertigung (ohne Verkupferung) der Driftröhren für die Kavitäten AI (RI) und AIIa (DANFYSIK). RI ist im Verzug wg. signifikanter Unterschätzung des Magnetbaus. Für AI musste RI beauftragt werden, da DANFYSIK (Wunschlieferant) im Verfahren einen groben Formfehler beging.

Ergebnisse des Besuchs:

- CERN wird eine zusätzliche Person für die GSI-Belange einstellen (Bachelor in Oberflächen-Behandlung). Diese beginnt zum 01.09.2024 mit einer Vertragslaufzeit von drei Jahren
- Der Auftrag zum Aufbau der dedizierten Verkupferungsstraße ist vergeben. Bisher verläuft die die Abwicklung nach Plan (wird als Tabelle durch CERN verschickt):
  - Erstellte Zeichnungen sind i.O.
  - Simulationen passen zu Messungen zwecks Kalibration
  - Ende Juni: FAT beim Hersteller GALVO in Padova; Freiräumen der CERN-Galvanik
  - September: Beginn der Installation bei CERN
  - November: SAT und Inbetriebnahme bei CERN
  - Februar 2025: bereit für Verkupferung
- Seitens GSI wird die erste Lieferung von Driftröhren für Kavität AIIa erst in Q2/2025 erfolgen können (Ursache s. Ausgangssituation)
- Erste Driftröhren für Kavität AI werden in Q4/2025 verfügbar sein
- Am 24. und 25.04.24 werden beide DR-Lieferanten besucht. GSI erhält aktuelle Informationen zu den Zeitplänen. Die bestätigten bzw. aktualisierten Liefertermine werden an CERN kommuniziert
- Der evtl. Tausch der Reihenfolgen AI – AIIa ist gemäß CERN kein nennenswertes Problem. Die Verrechnung erfolgt ggf. nach Stückzahl

GSI Galvanic

- **Refurbishment is completed** – addressing last non-conformities
- Next steps towards series plating:
  - Hiring 2 **additional staff** for reinforcing team.
  - Preparation of **electroplating chemicals** and set-up of system → next week
  - Cu plating **of test tank** – last step of site acceptance → end of June

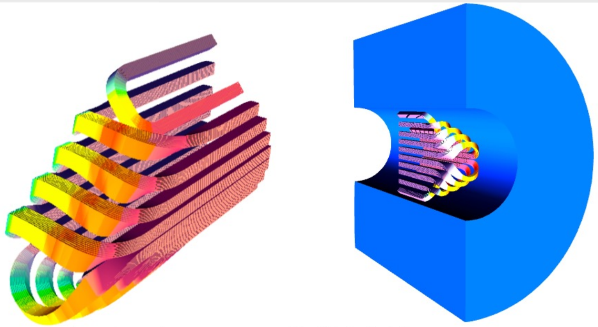
- Cu plate an additional p-linac structure to orderly freeze this project
- start **series tanks for Alvarez upgrade** planned in **Q4 2024** (monitoring delays)
- Faster: additional **space for pre- and post-treatment** of series tanks needed

S.C. Magnet R&D

proposed

purpose/benefit

Superconducting cosine-theta septa might be used at future accelerators (e.g. FCC, SIS400, medical, …). For feasibility studies the concept must be transferred to an engineering design.



truncated cosine-theta septa coil , high field septum magnet

collaborations

FCC

- Sc. septa concepts expertise (electromagnetic design) from GSI

- **GSI has signed the MoU for the FCC feasibility study and joins the governing board**
- GSI has special expertise in fast ramped s.c. magnets (SIS100, SIS300), septa design
- Benefit from **complementary expertise**

CERN contacts: Jan Borburgh

GSI contacts:

Kei Sugita
Group Leader: Superconducting Magnet Technology

Peter Spiller

Christian Roux

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Facility design and beam dynamics for high intensity hadron accelerators

- Ion sources
- Ion beam dynamics: space charge, space charge compensation, simulation, theory, cooling theory, decelerator theory, …
- Beam cooling technology (e-beam cooling, stochastic cooling)
- Fast and slow extraction techniques




MUCIS NEW (MUlti Cusp Ion Source) 2010	MUCIS (MUlti Cusp Ion Source)	CHORDIS (Cold or HOt Reflex Discharge Ion Source)	VARIS (Vacuum ARc Ion Source)

PHYSICAL REVIEW LETTERS 132, 175001 (2024)

Editors' Suggestion

Pulsed Electron Lenses for Space Charge Mitigation

Adrian Oeftiger[1,*] and Oliver Boine-Frankenheim[1,2]
[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstrasse 1, 64291 Darmstadt, Germany
[2]Technische Universität Darmstadt, Schlossgartenstrasse 8, 64289 Darmstadt, Germany

(Received 6 October 2023; accepted 27 March 2024; published 22 April 2024)

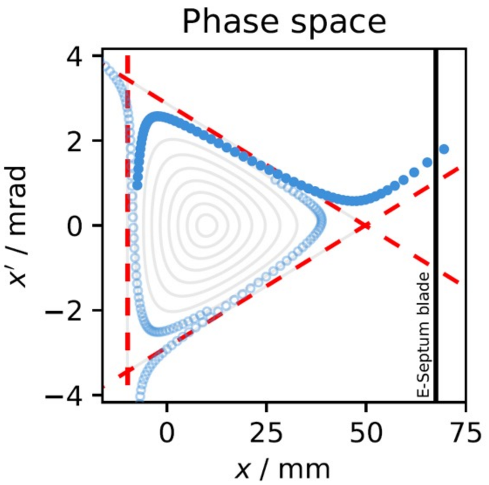
To produce ultimate high-brightness hadron beams, synchrotrons need to overcome a most prominent intensity limitation, i.e., space charge. This Letter characterizes the potential of pulsed electron lenses in detailed 3D tracking simulations, key to which is a realistic machine and space charge model. The space charge limit, imparted by betatron resonances, is shown to be increased by up to 50% using a low symmetric number of electron lenses in application to the Facility for Antiproton and Ion Research SIS100 synchrotron. Conceptually, a 100% increase is demonstrated with a larger number of electron lenses, which is found to rapidly saturate near the theoretical 2D limit.

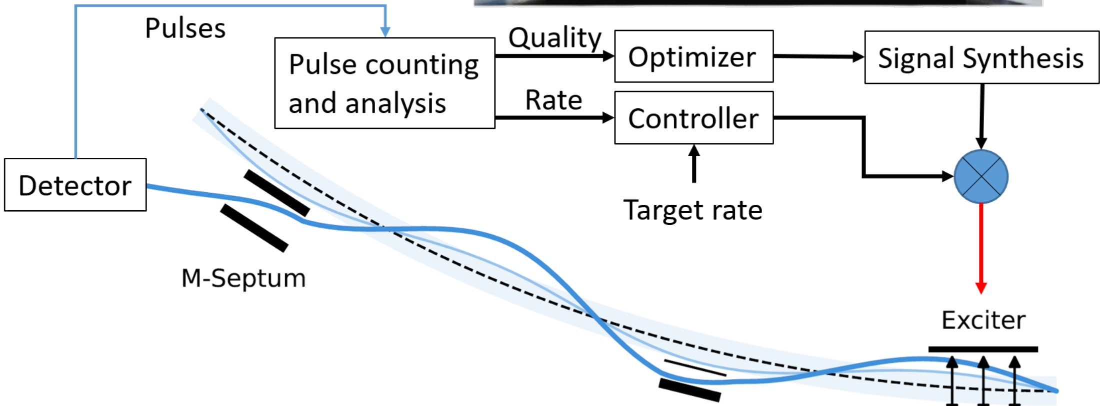
DOI: 10.1103/PhysRevLett.132.175001

ESR electron cooler during Dec 2023 reassembly

Knock-Out (KO) slow beam extraction

- Machine tune near 3rd order resonance and transverse excitation "around" beam eigenfrequencies
- KO → constant optics during extraction, minimal beam movement on target, fast stop (medical application)
- Excitation signal amplitude (deflection) provides a control over extraction rate (a.k.a. **macrospill feedback**)
- Excitation frequency spectra gives control over particle rate fluctuation (a.k.a. **microspill optimization**)





Slide Philipp Niedermayer et al

Major Improvement of Ion Beam Quality at GSI

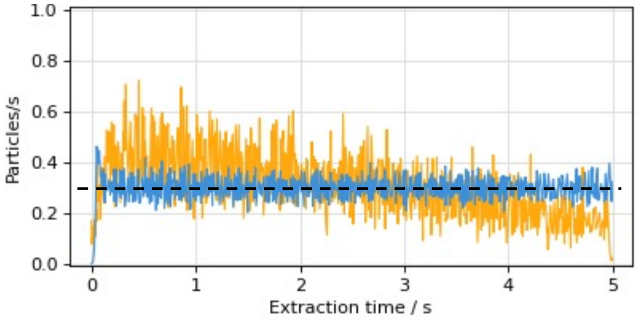
*"Digital **S**pill **O**ptimization **S**ystem (**SOS**)"*

The spill issue has 2 aspects

a) **Macro spill structure**

b) **Micro spill structure**

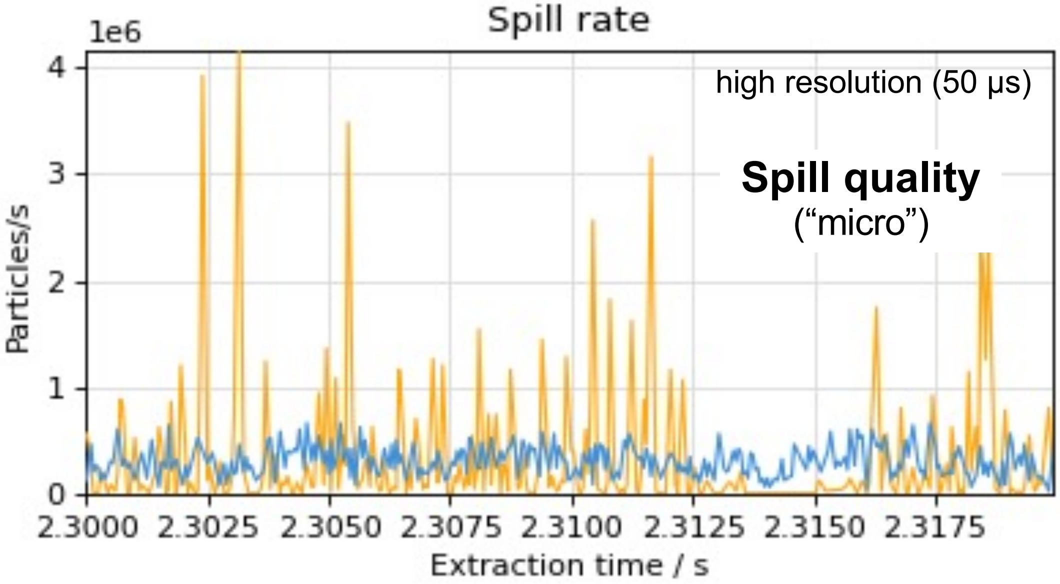
Spill shape ("macro" – 5 s spill length)



$\Delta t_{count} = 5$ ms

without SOS System

with SOS System



high resolution (50 µs)

Spill quality
("micro")

$\Delta t_{count} = 50$ µs

Results Philipp Niedermayer et al

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Modern and efficient control systems

- Setting management and loading. Reproducibility of machine.
- Feedbacks, machine learning, automatic algorithms, AI

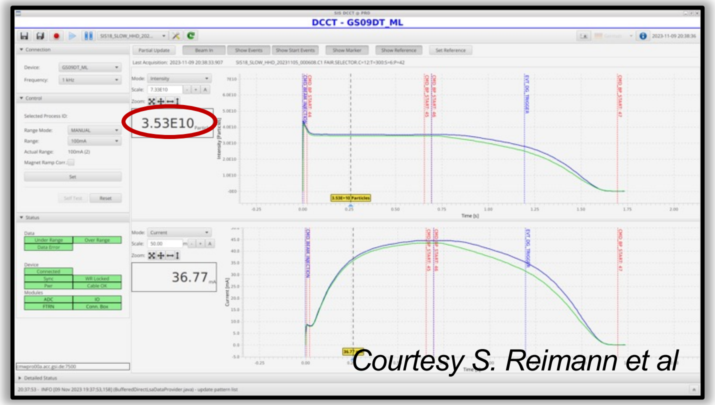
→ FAIR/GSI is using the architecture of the CERN control system

→ GSI accelerators are being upgraded to FAIR controls standard

→ We already start profiting from enhanced features

→ **Planning a FAIR/GSI controls review in June 2024. Thanks to Jörg Wenninger for accepting to chair it.**

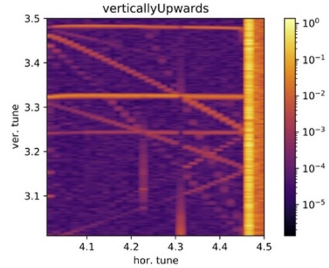
→ Further collaborations and synergetic efforts easily imagined. The review will help identifying areas of common interests.



factor 10 improved C beam for users
(Dec 2023)

python bridge

S. Appel
O. Boine-Frankenheim
et al



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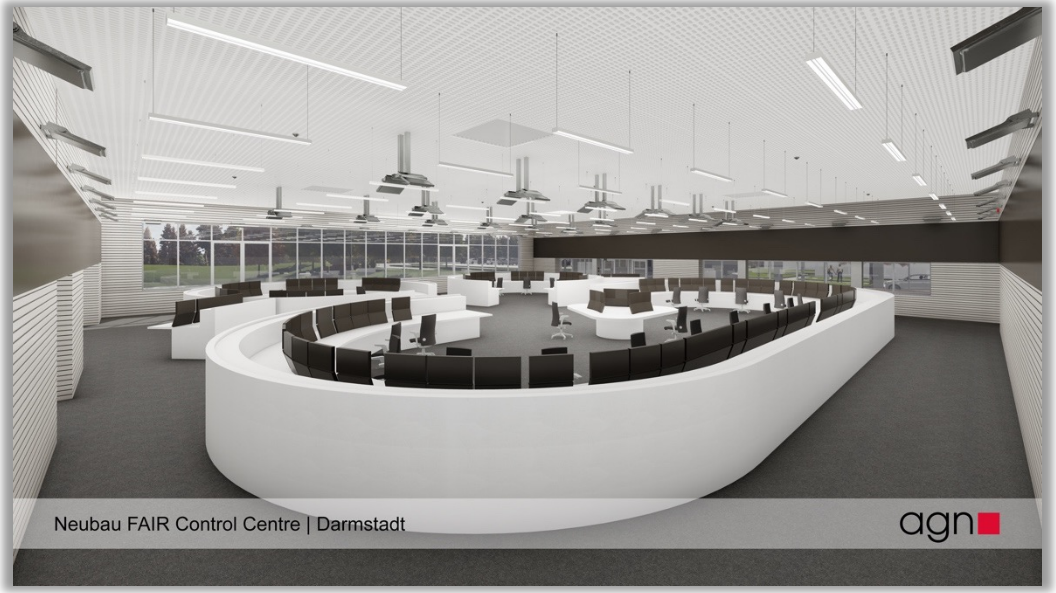
Commissioning (HW, beam) of a new facility (FAIR)

- Procedures and documentation
- Control room organization (FCC)
- Expectation management and communication with experiments

Work ongoing for preparing **commissioning workshop in November** → S. Reimann

Performance committee studying performance (present and future) and establishing a technical roadmap.



Collaboration & Scientific Exchange are Crucial

GSI Accelerator Seminar Series

Re-establishing a more active series – here with Fanny Farget from GANIL at GSI

Conclusion

- CERN and GSI have a very **close historic and present collaboration**.
- For me personally (with my CERN history) a pleasure to be here.
- Very **important collaborations** ongoing, in addition to other topics:
  - CERN collaborates with us, performing copper-coating of the drift tubes for the Alvarez 2.0 project.
  - CERN collaborates with us, supplying us with controls technology, algorithms and help for a review.
  - CERN collaborates with us, advising on facility commissioning and organization.
- GSI/FAIR brings into our collaboration **expertise and technologies in ion accelerators** but also in large facilities and RF accelerator technology:
  - Long-standing interest in CERN´s accelerator complex and its technologies – several ex-CERN persons at GSI/FAIR
  - We are interested in CERN´s FCC project and in collaborating in concepts, schemes and technologies (SC septum, …).
- We are also considering **collaboration on future projects or R&D through our connected universities (e.g. Frankfurt)** and Genthner PhD students.

Thank You for Your Attention