Perspectives for GSI, FAIR and Beyond

R. Assmann
Head „Accelerator Operations & Development“

IFAST Workshop „Roadmap for Future Accelerators“

1 – 3 Sep 2024

Acknowledgements

Input and slides from the following persons are acknowledged (many thanks and apologies if your slide could not be shown due to limited time):

A. Adonin, A. Andreev, S. Appel, V. Bagnoud, W. Barth, R. Berezov, J. Blaurock, A. Blazevic, O. Boine-Frankenheim, T. Dettinger, C. Düllmann, P. Forck, M. Galonska, O. Geithner, T. Giacomini, R. Ghagi, L. Groening, H. Hähnel, F. Herfurth, F. Heymach, R. Hollinger, S. Löchner, F. Maimone, J. Mäder, S. Mickat, M. Miski-Oglu, P. Niedermayer, C. Noficioro, H. Podlech, R. Lang, S. Reimann, B. Schlitt, G. Schreiber, M. Schwickert, T. Sieber, R. Singh, P. Spiller, M. Steck, M. Vossberg, B. Walasek-Hoehne, G. Walter, U. Weinrich, P. Wieczorek, C. Zhang, …

iFAST HFHF

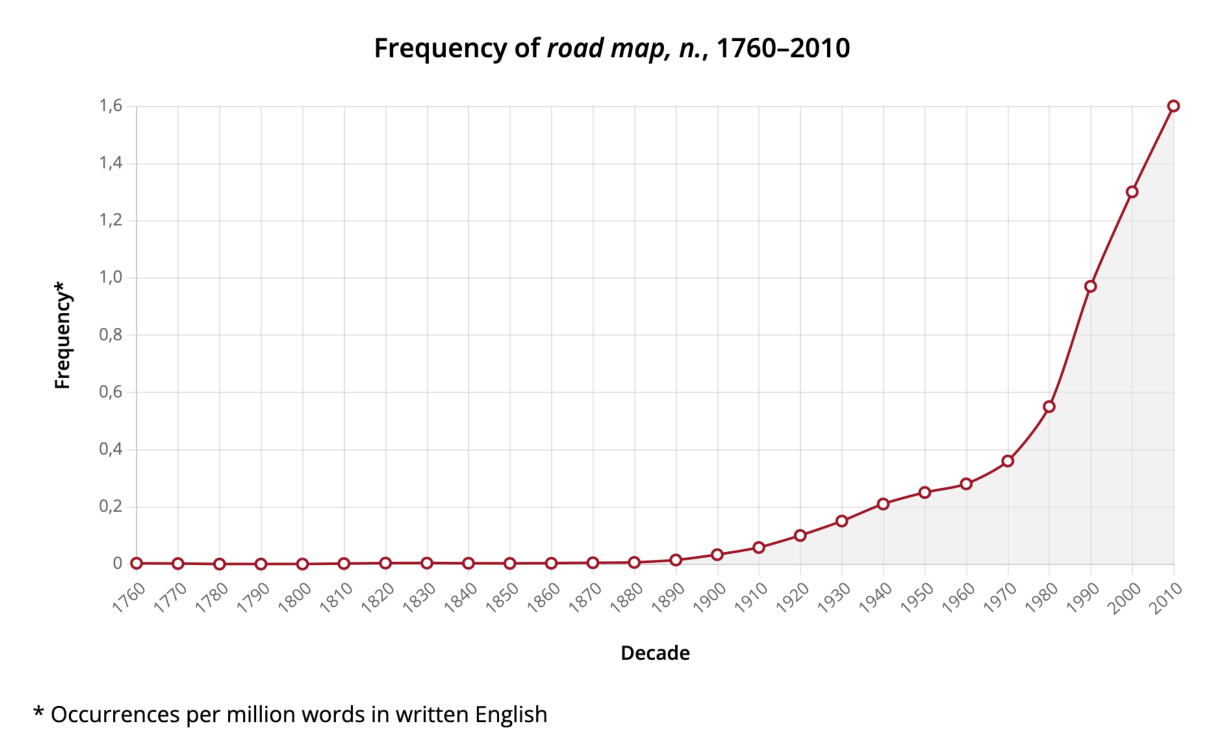
Roadmap for Future Accelerators

OED | Oxford English Dictionary

1. A map that shows the roads of a country or area, sometimes also giving basic local information of interest to a traveller; …

2. figurative. Frequently with to, for. A means of bringing about or reaching something; an outline or representation of something, used as a guide. Now often: spec. **a plan or strategy intended to achieve a particular (political) goal**, as road map to (also for) peace, etc.

The Use of the Term Roadmap



Roadmaps are a growth business

Can we have ONE Roadmap?

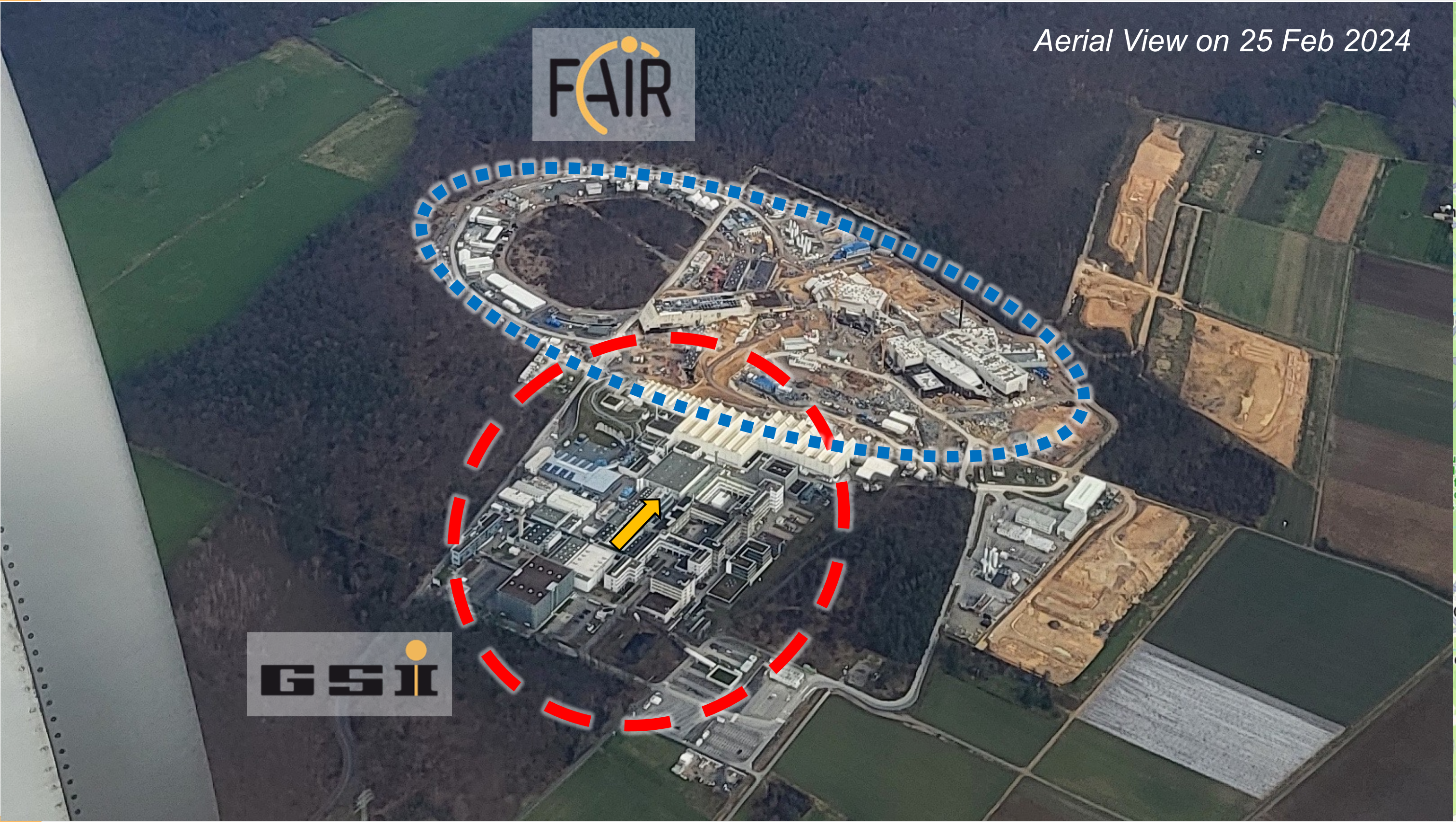
- The dream of funding authorities: one roadmap that specifies the accelerator R&D and roadmap for future accelerators in one piece
- One roadmap requires a common list of goals:
  → define common and over-arching goals
  → **common roadmap**
  → this workshop
- Then every lab has its own, specific goals:
  → separate, lab- or project-dependent goals
  → **separate lab roadmaps**
- In the following: some insight into FAIR/GSI specific challenges and goals, as well as input to some common and overarching goals

GSI and FAIR Goals

and

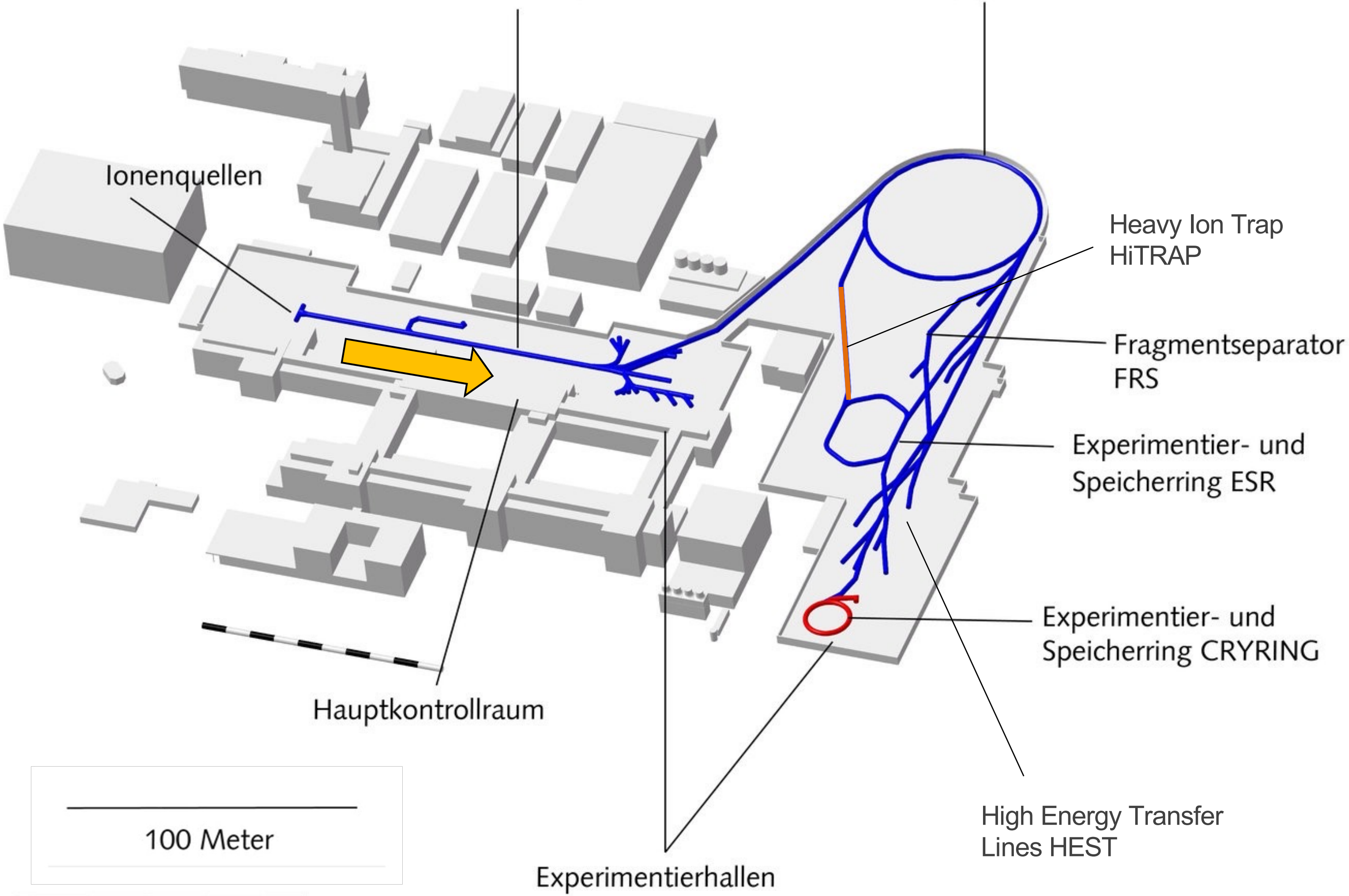
Progress

GSI and FAIR


Aerial View on 25 Feb 2024
FAIR
GSI


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

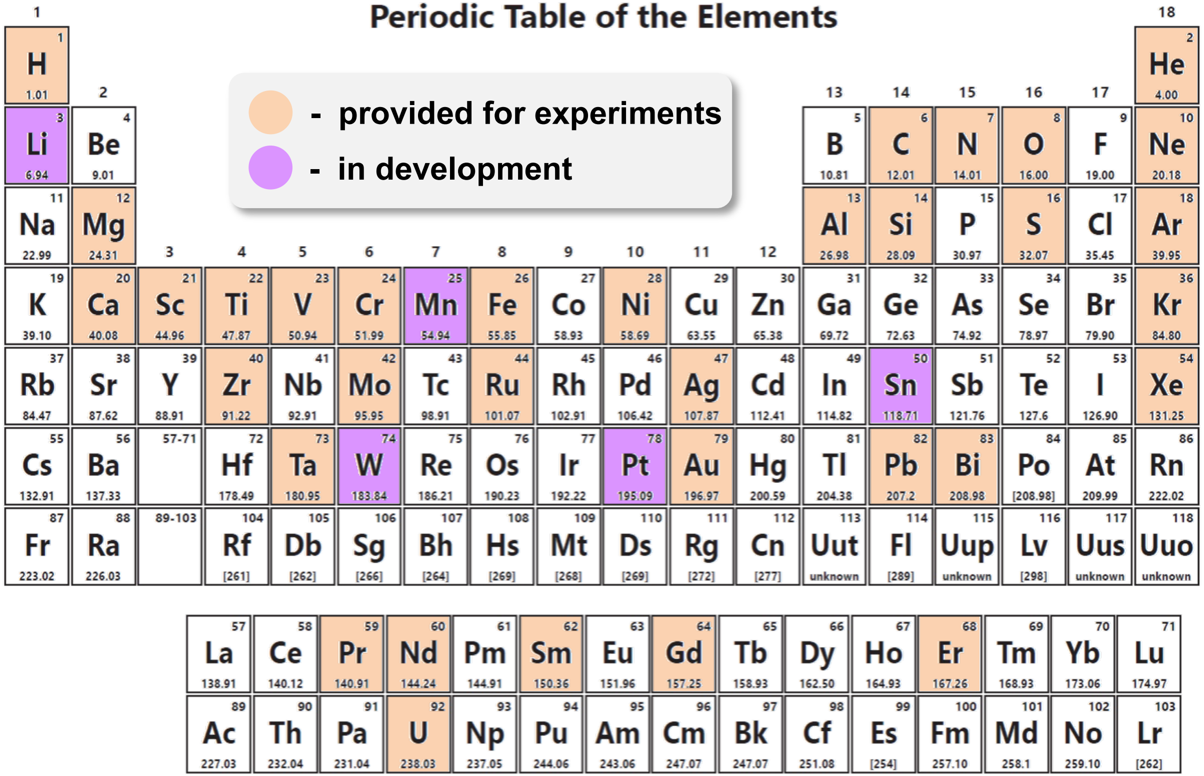
Present GSI Complex



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

Ion Species Provided at GSI

- **34 elements** are available for accelerator operation at GSI:
  - 28 - from high current sorces
  - 19 - from PIG sources
  - 22 - from ECR source
- **5 new elements** are in development



R. Hollinger, F. Maimone, A. Adonin, A. Andreev, R. Berezov, M. Galonska, F. Heymach, J. Mäder, R. Lang

Our Ion Beams at GSI

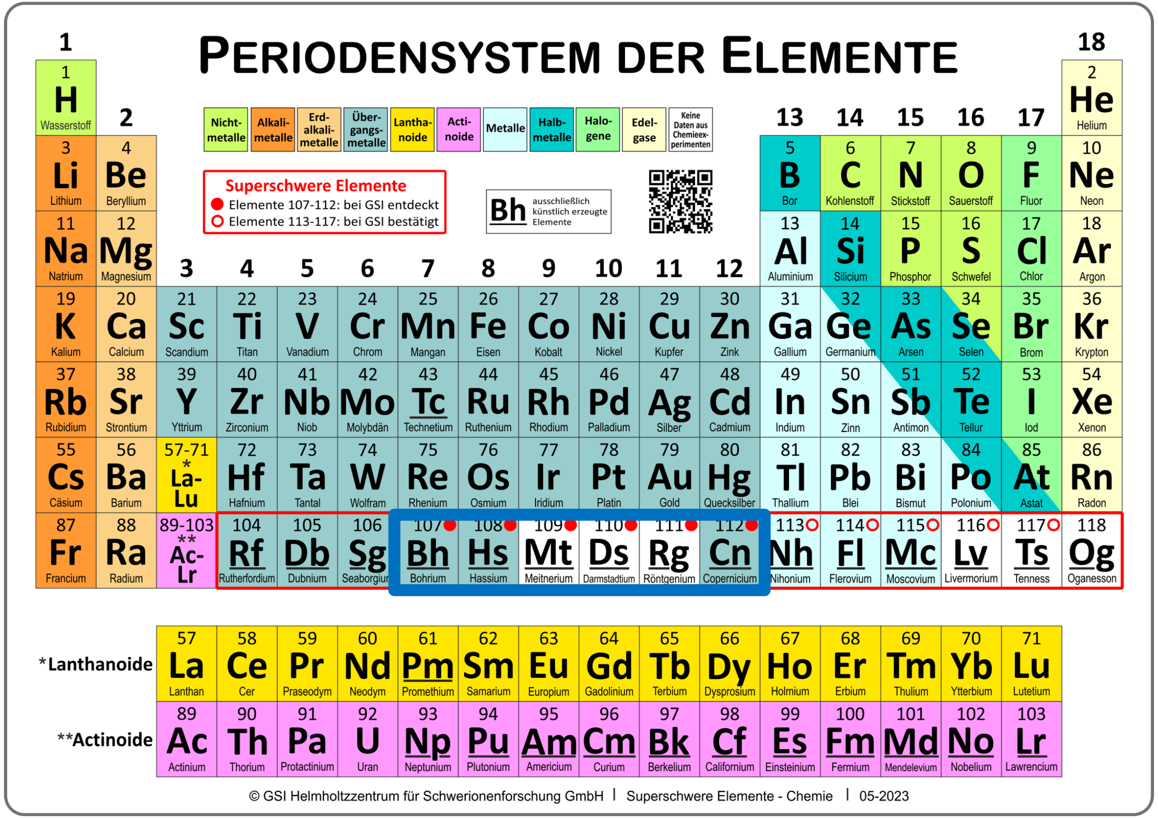
(Nominal Intensities 13.03.2024)

* 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					

Discovery of Bohrium, Hassium, Meitnerium, Darmstadtium, Roentgenium, Copernicium.

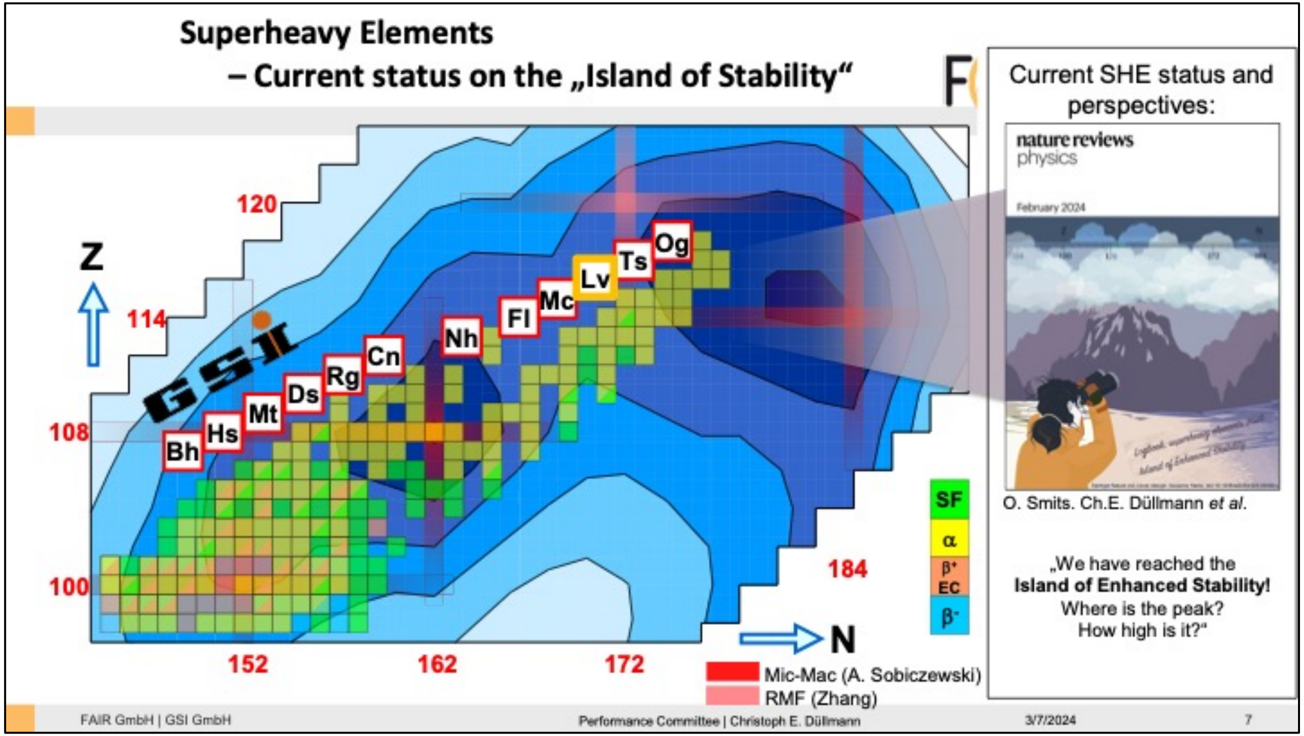


- Use ion beams from accelerators to **discover new heavy elements**!
- Study **properties** of heavy elements!
  - How did our universe form from the big bang?
  - Where do heavy elements on earth come from (not from the sun)?
- New push from gravitational wave detectors

  → 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.

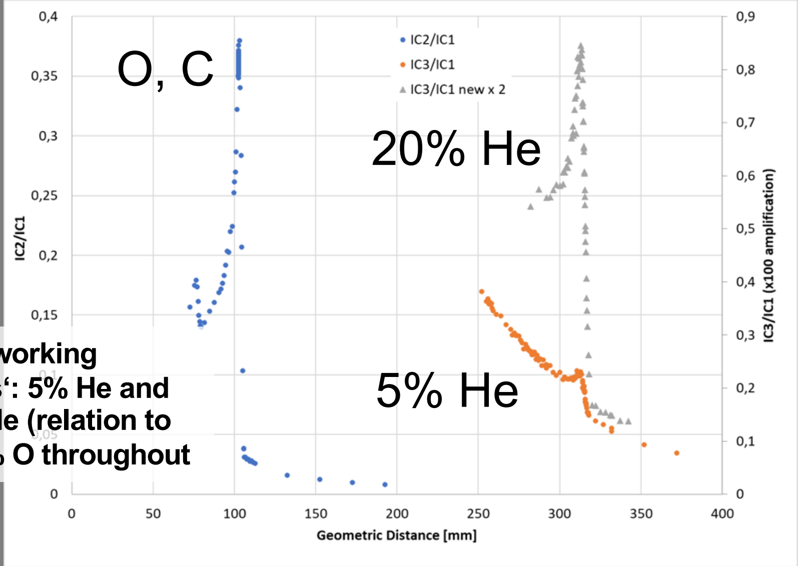
Ion mass	He + C (5-20% He)
Ion charges	$^{4}He^{+}$ und $^{12}C^{3+}$ from CH_4
Energy	225 MeV/u
Beam intensity	10^{8}, Slow extraction
Stability	No variation of He, C and O
Contamination of $^{16}O^{4+}$	As low as possible

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:
$12C^{6+}$: 0.167%
$4He^{2+}$: 99.833%

Integrals over one spill for the depth dose

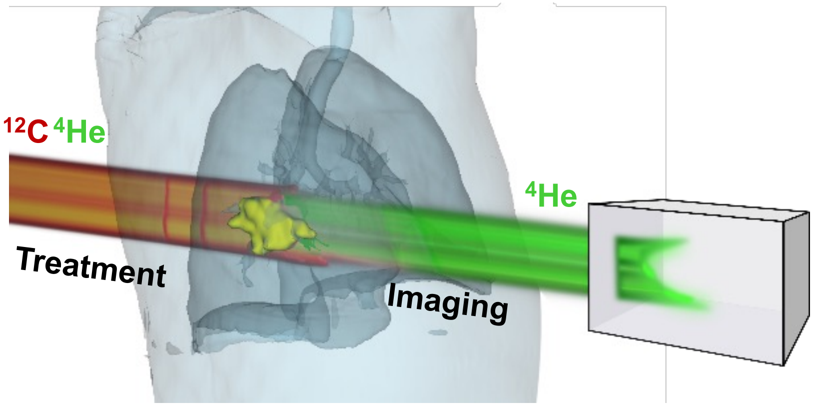


Two 'working points': 5% He and 20% He (relation to C), 7% O throughout

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

Dual Isotope Beams: Carbon Radiotherapy and Helium Online Monitoring



courtesy of C. Graeff / L. Volz

- C. Graeff et al (2018), https://doi.org/10.1016/j.ejmp.2018.06.099
- L. Volz et al (2020), Phys. Med. Biol. 65 055002
- D. Mazzucconi et.al (2018), https://doi.org/10.1002/mp.13219
- Ch. Graeff, L. Volz, M. Durante, Prog. Part. Nucl. Phys., vol. 131, p. 104046, Jul. 2023
- Jennifer J Hardt et al., 2024 Phys. Med. Biol. in press.

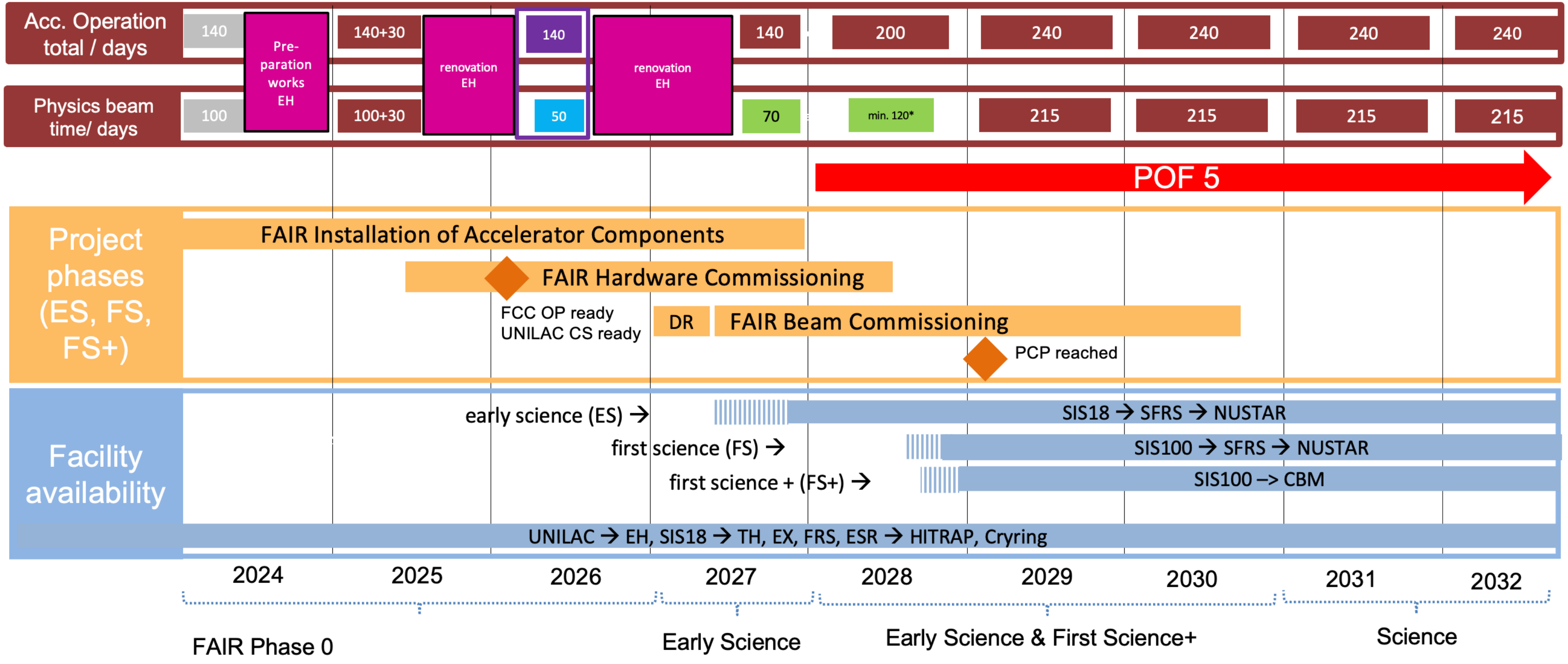
- **Particle therapy: Bragg peak based**
- **Highly localised dose distribution / highly conformal**
- **But: steep dose gradient → sensitivity to range uncertainties**
  - **inter-/intra-fractional anatomic changes**
  - **Uncertainties in planning**
  - **Patient set-up**
  - **Motion induced range variation**
- **One solution: mixed carbon-helium ion beams (90 % C, 10 % He*)**
  - **Similar mass-to-charge-ratio**
  - **Range of He ~3 times larger than C at same energy/nucleon**
  - **Carbon for irradiation**
  - **Helium passes patient for online monitoring**

➢ **Online range verification: extraordinary increase in precision of conformal dose**

***extra dose < 1 %**

Courtesy J. Blaurock et al

FAIR/GSI strategic operation scenario towards FAIR



FAIR 3.3 b€ facility being completed!

Beam commissioning planned in 2027/28

DARMSTÄDTER ECHO

Mehr Polizeipräsenz bewirkt Angst
Studie: Bürger fühlen sich durch Streifen eher verunsichert. ▸ MEINUNG & ANALYSE/HINTERGRUND

Alles da für die Reiseapotheke
Apotheker sehen die Lage entspannt, aber der Mangel ist nicht ganz vorbei. ▸ SEITE 21

D2107 | Nr. 179 | 80. Jahrgang | VRM, Postfach 3120, 55021 Mainz — www.echo-online.de — Samstag, 3. August 2024 — Preis: 3,30 Euro

NEU: E-Paper am Sonntag Kostenlos für Abonnenten
epaper.echo-online.de

WETTER
Wochenendwetter
Samstag Sonntag

Fair-Ring bekommt Innenleben

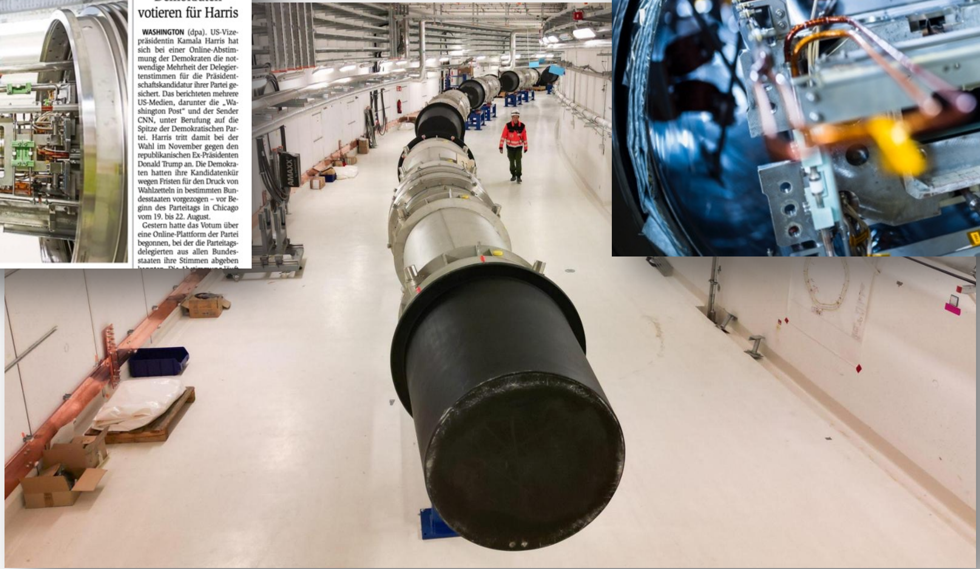
Der Teilchenbeschleuniger-Tunnel ist fertig betoniert, jetzt läuft der Einbau der Technik auf der Riesen-Baustelle im Wald bei Wixhausen. Derzeit lässt ein Kran die jeweils drei Tonnen schweren Magnete ab, die die Ionenteilchen im Rundkurs halten sollen. ▸ SEITE 9

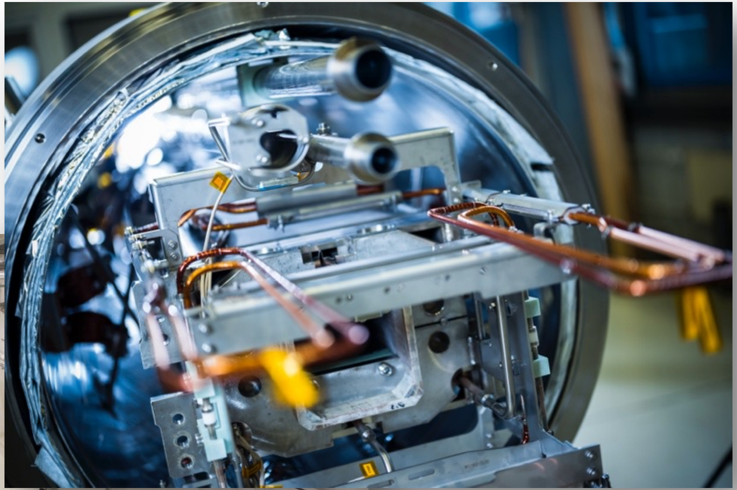
Foto: Guido Schiek

Demokraten votieren für Harris

WASHINGTON (dpa). US-Vizepräsidentin Kamala Harris hat sich bei einer Online-Abstimmung der Demokraten die notwendige Mehrheit der Delegiertenstimmen für die Präsidentschaftskandidatur ihrer Partei gesichert. Das berichteten mehrere US-Medien, darunter die „Washington Post" und der Sender CNN, unter Berufung auf die Spitze der Demokratischen Partei. Harris tritt damit bei der Wahl im November gegen den republikanischen Ex-Präsidenten Donald Trump an. Die Demokraten hatten ihre Kandidatenkür wegen Fristen für den Druck von Wahlzetteln in bestimmten Bundesstaaten vorgezogen – vor Beginn des Parteitags in Chicago vom 19. bis 22. August.

Gestern hatte das Votum über eine Online-Plattform der Partei begonnen, bei der die Parteitagsdelegierten aus allen Bundesstaaten ihre Stimmen abgeben





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Frankfurter Allgemeine

Startseite Politik Wirtschaft Finanzen Feuilleton Karriere Sport Gesellschaft Stil Rhein-Main Technik **Wissen** Reise

Physik & Mehr

ATMOSPHÄRE

Was passiert mit verglühtem Raumfahrtmaterial?

Immer mehr Raketen schicken immer mehr Hardware ins All, die schließlich in der Erdatmosphäre verglüht. Was weiß man eigentlich über die Auswirkungen der Substanzen, die dabei entstehen?

Ulf von Rauchhaupt

QUANTENINTERNET AM START

Erster deutscher Quantensatellit ist gestartet

Das Abhören vertraulicher Nachrichten soll auch in Europa bald ein Ende haben. Jetzt ist der erste deutsche Quantensatellit gestartet. Er wird abhörsichere Quantencodes zur Erde schicken.

Manfred Lindinger

FORSCHUNGSANLAGE FAIR

Beschleunigung bis fast auf Lichtgeschwindigkeit

Der Bau der Forschungsanlage FAIR in Darmstadt schreitet voran: Im 17 Meter tiefen Tunnel werden Magneten eingesetzt, die als Antriebskraft dienen.

Jan Schiefenhövel

hessenschau

Video & Podcast Wetter Verkehr Ort oder Thema suchen

Start Regionen Politik Gesellschaft Wirtschaft Kultur Sport **Panorama** Freizeit

hessenschau.de > Panorama > Megaprojekt in Darmstadt: Bau des Teilchenbeschleunigers Fair geht in entscheidende Phase

Megaprojekt in Darmstadt

Bau des Teilchenbeschleunigers Fair geht in entscheidende Phase

In Darmstadt entsteht eine gigantische Forschungsanlage, die das Universum neu ergründen soll. Mit dem Einbau der Hightech-Komponenten erreicht der Teilchenbeschleuniger Fair jetzt seine entscheidende Phase.

Veröffentlicht am 02.08.24 um 17:14 Uhr

Techniker arbeiten auf der Baustelle des Teilchenbeschleunigers Fair an einem Dipolmagneten. Damit werden Teilchenstrahlen auf ihre gewünschten Bahnen gebracht. Bild © picture-alliance/dpa

FAIR 3.3 b€ facility being completed!

Beam commissioning planned in 2027/28


Frankfurter Allgemeine

Startseite Politik Wirtschaft Finanzen Feuilleton Karriere Sport Gesellschaft Stil Rhein-Main Technik **Wissen** Reise

Physik & Mehr

Rhein-Main

FORSCHUNGSANLAGE FAIR

Beschleunigung bis fast auf Lichtgeschwindigkeit

Von Jan Schiefenhövel 02.08.2024, 16:45 Lesezeit: 2 Min.

NGSANLAGE FAIR

eunigung bis fast auf schwindigkeit

Forschungsanlage FAIR in Darmstadt ran: Im 17 Meter tiefen Tunnel werden ingesetzt, die als Antriebskraft dienen.

hövel


hessenschau

Video & Podcast Wetter Verkehr

Start Regionen Politik Gesellschaft Wirtschaft Kultur Sport **Panorama** Freizeit

hessenschau.de > Panorama > Megaprojekt in Darmstadt: Bau des Teilchenbeschleunigers Fair geht in entscheidende Phase

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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*
5. *Commissioning (HW, beam) of a new facility (FAIR)*
6. *Dreams for the future (beyond FAIR)*

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Operating and consolidating 50 years old accelerators

- Fast response repairs → workshop capabilities
- Project management
- Procedures in shutdowns, installations, …

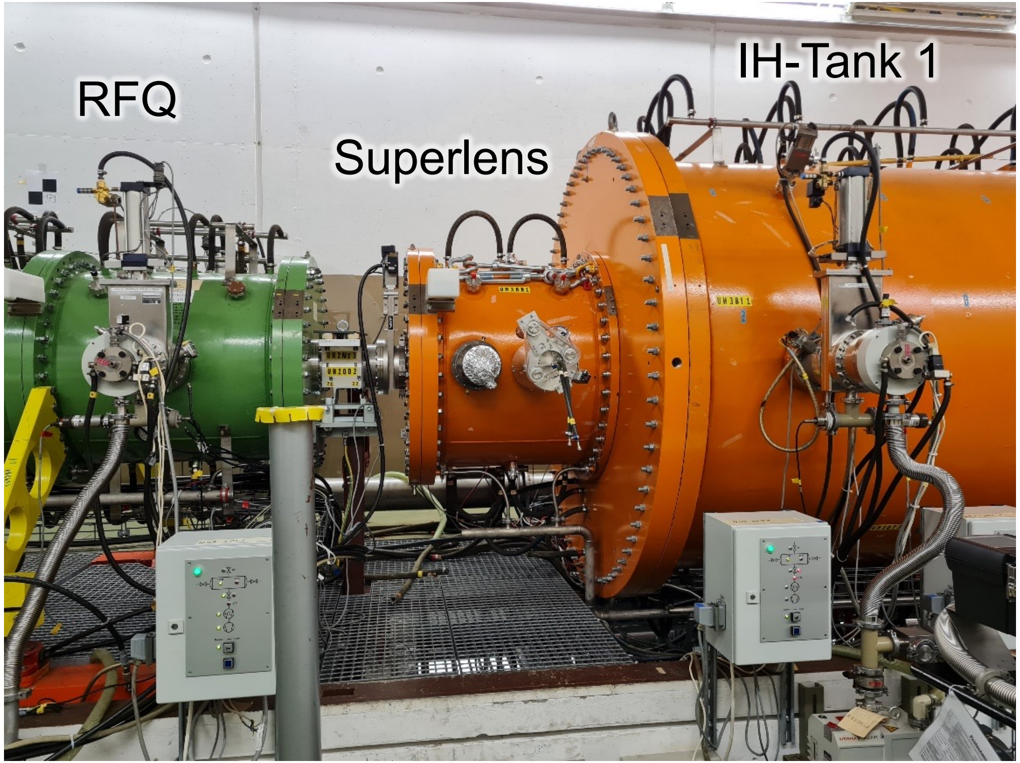
Example: Maintaining and optimizing the quite outdated RF system at the UNILAC linear accelerator. No spares, age-related failures.

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

Repaired but 1.5 days lost.

→ Defining technical roadmap

UNILAC – Superlens Repair & Upgrade (2022/23)



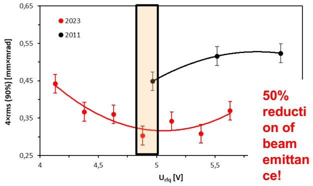
Courtesy W. Barth et al

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

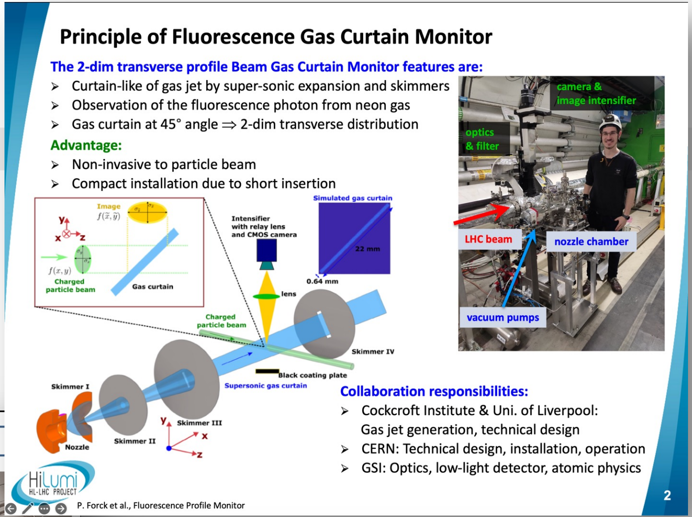
⇒ compensate (unwanted) shift of rf-frequency

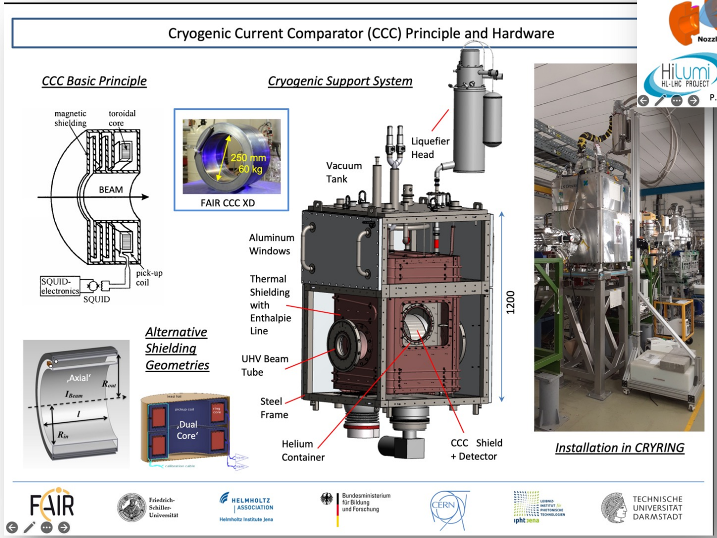
UNILAC Short Pulse Heavy Ion Operation
→ New best values recently achieved

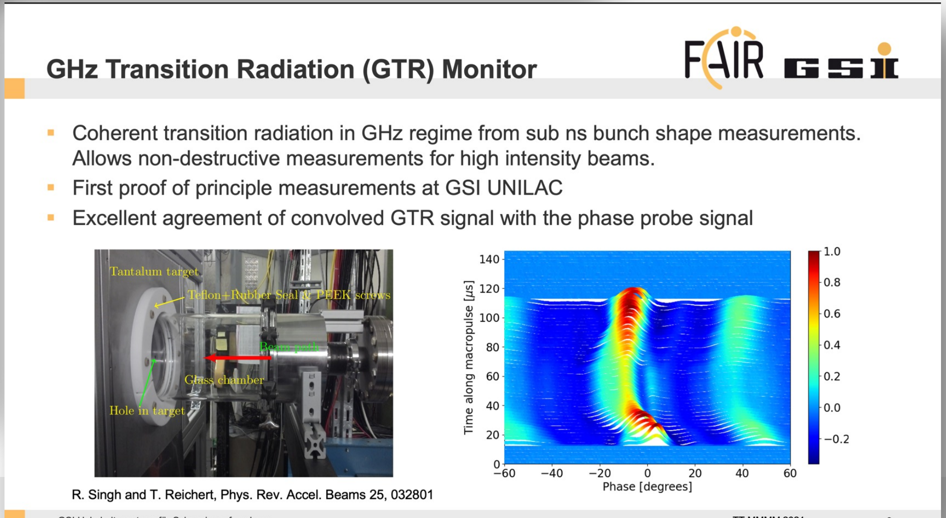
Early Science: U238, final rep rate 2.6 Hz, final charge state 28+, SIS18-Choppertime 80e-6 s, Spill macro time length 5-15 ms, achieved									
Location along chain	**Sources exit / entry UNILAC**	**UNILAC pre-stripper**	**UNILAC post-stripper, entry Alvarez linac**	**UNILAC exit Alvarez linac**	**Transfer channel / entry SIS-18**	**SIS-18 exit**	**SIS-100 exit**	**HEBT exit / entry target**	**Target (goal experiment)**
Postion name / measurement device name for intensity measurement	HSI, LEBT UH1DT1/DE1	UH4DT4	US4DT7	UA4DT5	TK7DT3				
If measured: Date of measurement / saved on	7.16	12.23	12.23	12.23	12.23	12.23	n/a	n/a	
Energy E [MeV/u]	0,0022	1,394	1,394	11,4	11,4	100,0	n/a	n/a	100,0
Goal Energy E [MeV/u]	0,0022	1,394	1,394	11,4	11,4	100,0	1500	1500	1500
Charge state	4	4	28	28	28	28	28	28	28
Number of Strippings N_{strip} in section	0	1	0	0	0	0	0	0	n/a
Pulse Current I_p [emA]	10,75	6,05	20,0	7,47	6,24	n/a	n/a	n/a	n/a
Number of Ions Ni per Pulse and Cycle [1e9], formula used Ni=Ip T / (Nq e)	***16773,8***	***9440,1***	***891,6***	***333,0***	***111,3***	**42,0**	**n/a**	**n/a**	**20,0**
Transmission of particles $N_i/N_{i,in}$ [%]	*n/a*	*56,3%*	*9,4%*	*37,4%*	*33,4%*	*37,7%*	n/a	n/a	
Commissioning: 2020 goal N_i [1e9]	n/a	n/a	n/a	n/a	n/a	5	20,0	**20,0**	
Operation: 2020 goal N_i [1e9]	n/a	n/a	n/a	n/a	n/a	125,0	500,0	**500,0**	

Good beam quality for FAIR commissioning. Developing further improvements for FAIR operation.

Crucial Importance of Diagnostics I

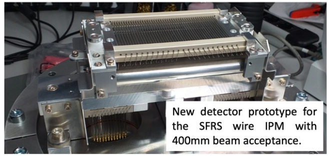




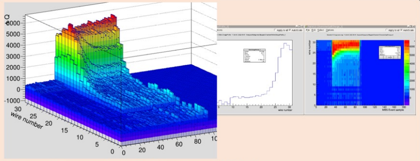


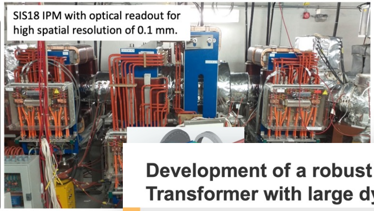
Crucial Importance of Diagnostics II

IPM- new profile detector development and fast profile readout


New detector prototype for the SFRS wire IPM with 400mm beam acceptance.

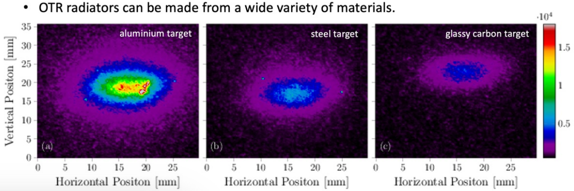
- Development of a new large-aperture IPM detector for FAIR SFRS (400 mm beam pipe) with a transverse spatial resolution of 2.1 mm.
- The new AWAGS DAQ system was tested as a readout device for the Wire IPM as a proof of principle, with a profile rate of up to 1 MHz measurement frequency.

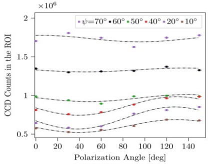

Testing of the new AWAGS DAQ system at SIS18 Wire IPM – half grid connected – very fast and sensitive.


SIS18 IPM with optical readout for high spatial resolution of 0.1 mm.

OTR-based ion beam diagnostics – profile measurements

- OTR offers advantages over scintillation, being broadband, radiation-hard and prompt in nature with lower photon yield.
- Tested extensively at SIS18 injection and extraction energies. Observed higher OTR yield for rough target surfaces and higher angles of partice incidence*.
- OTR radiators can be made from a wide variety of materials.





CCD counts as a function of incidence angle and polarization angle for steel target.

…m profile for Ca^{10+}, 8.6 MeV/u, average of 250 pulses with 5.10^{9} ppp

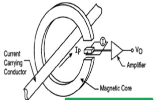
…oehne. "Optical transition radiation based transverse beam diagnostics for …*accelerators and beams* 25.7 (2022): 072801.

Towards an OTR-based charged particle counter → Systematic studies are ongoing for the optimization of target geometry and surface roughness to achieve a high photon yield per ion.

Development of a robust DC Current Transformer with large dynamic Range

Goals:

- precise non-intercepting measurement of accelerated and stored ion beams
- large dynamic range of beam intensities and bunch frequencies (eg. MHz → standard DCCT)
- possibility for combination of tow different transformers on one core

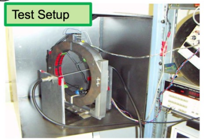


$$B_{gap} = \mu_o \frac{I}{d}$$

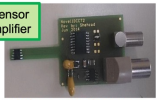
Design Concept:

- clamp-on ammeter design
- split toroid to allow dismounting before bake-out
- soft-magnetic flux concentrator (amorph. VITROVAC®)
- gap with induction of 80 µT @ 1 A beam current
- amplifier on the sensor PCB to increase sensitivity.
- Tunneling Magneto Resistance (TMR) sensors integrated circuits are commercially available
- present prototype features sensitive TMR sensor (resolution down to 10^{-11} T/√Hz)

Test Setup



TMR Sensor and Amplifier



Present Status:

- test setup with VITROVAC core and magnetic shielding commissioned
- prototype of TMR sensor PCB and integrated amplifier successfully tested with calibration current
- next steps: develop closed-loop structure with Operational Transconductance Amplifiers for zero current feedback

More information / contact: m.schwickert@gsi.de

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*
5. *Commissioning (HW, beam) of a new facility (FAIR)*
6. *Dreams for the future (beyond FAIR)*

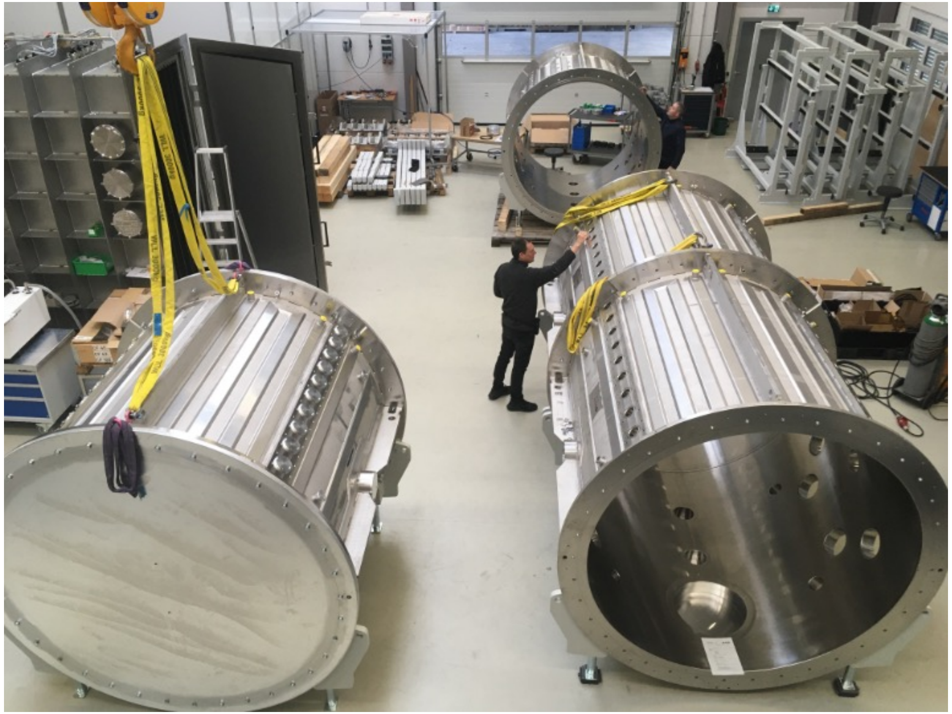
Building Equipment for RF Accelerators: Wide Aperture, High Intensity, High Rate, Large Components

- 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.



S. Mickat, L. Groening et al

GSI Galvanic Workshop

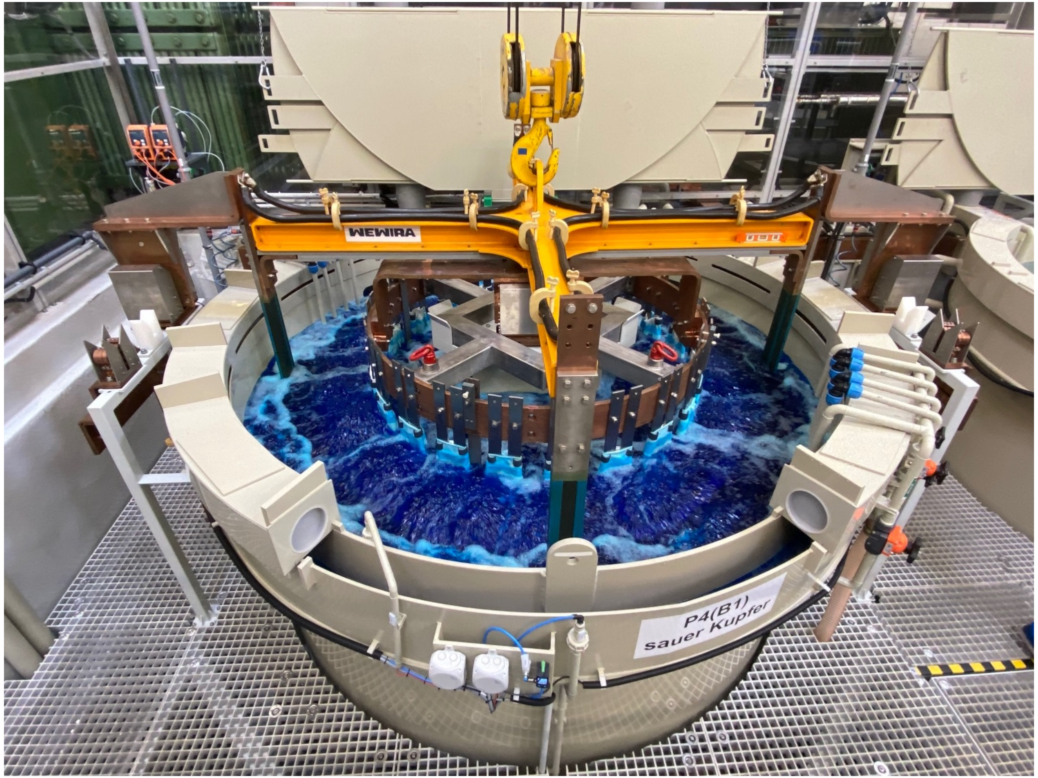
- **Refurbishment is completed** – addressing last non-conformities
- Next steps towards series plating:
  - Hiring 2 **additional staff** for reinforcing team.
  - Preparation of **electroplating chemicals** and set-up of system → next week
  - Cu plating **of test tank** – last step of site acceptance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

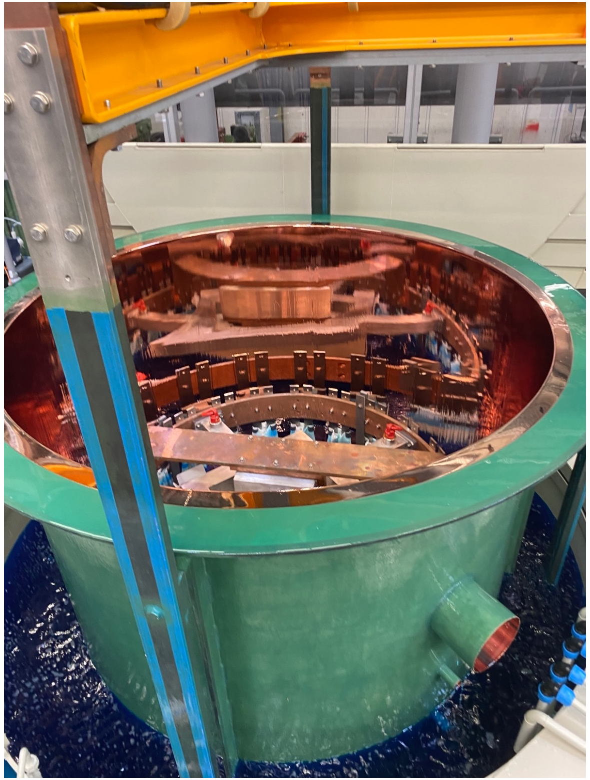
T. Dettinger, G. Walter et al

- 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

T. Dettinger, G. Walter et al

GSI Galvanic Workshop in Operation





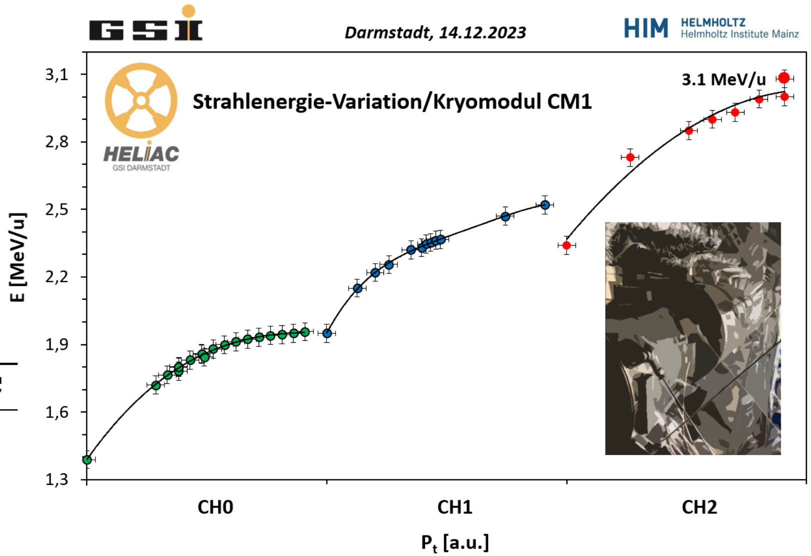
* HElmholz LInear ACcelerator

Superconducting cw HELIAC* (Demonstration)

Development of energy efficient super-conducting RF technology for heavy ion linacs (HELIAC)

<u>Result:</u> Potential to reduce energy required for particle acceleration by up to 90%

Design parameters sc cw-LINAC		
A/q		≤ 6
Frequency	MHz	216.816
Beam current	mA	≤ 1
Injection energy	MeV/u	1.4
Output energy	MeV/u	3.5-7.6
Length	m	20
CH cavities	#	12
Rebuncher	#	4
Solenoids	#	8



Measurement of the beam energy when varying the accelerating voltage (Pt) of the superconducting crossbar H-mode cavities used

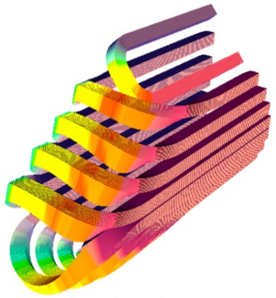
Maksym Miski-Oglu and Winfried Barth (GSI, HIM, Johannes Gutenberg Universität Mainz)

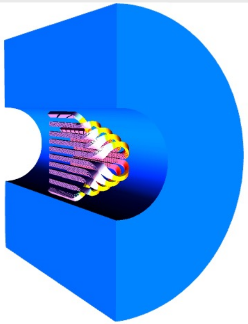
S.C. Magnet R&D

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:

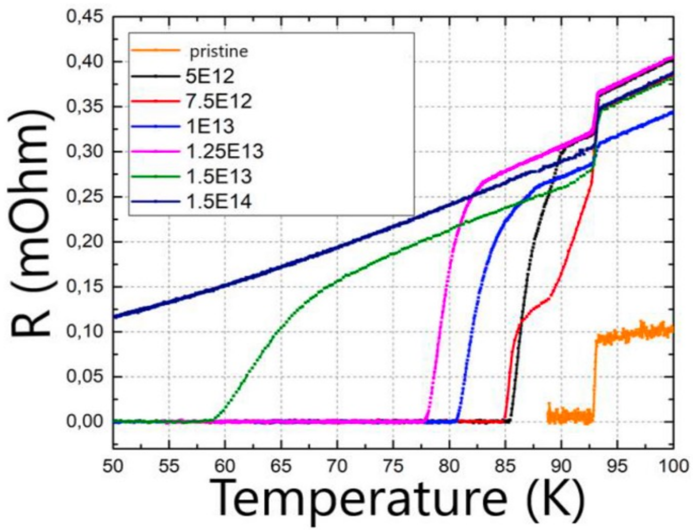
Kei Sugita
Group Leader: Superconducting Magnet Technology

Peter Spiller

Christian Roux

Heavy Ion Irradiation of HTS Tapes

- Irradiation has an effect on the properties of superconductors, which is beneficial up to a point, going higher leads to degradation.
  - https://dx.doi.org/10.1088/1361-6668/ad2fda
  - https://dx.doi.org/10.1088/1361-6668/ac1523
- GSI wants to investigate and quantify the effect of heavy ion irradiation on HTS tapes, i.e. critical current, magnetization.
- GSI can provide a wide variety of heavy ions, i.e. carbon, argon, uranium, at different fluences and energies.



HTS irradiation with 6.3 MeV Cu^{2+}

https://dx.doi.org/10.1109/TASC.2022.3164629

→ P. Spiller

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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)

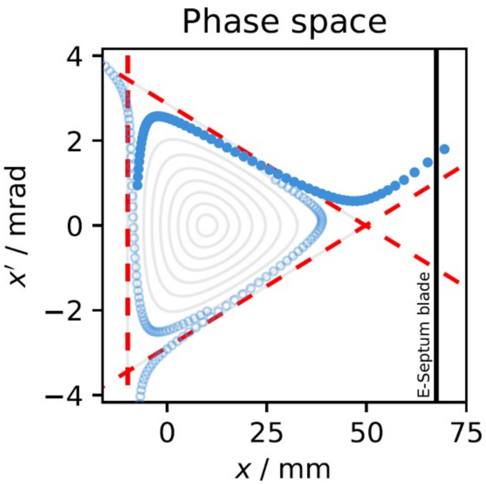
To produce ultimate high-brightness hadron beams, synchrotrons need to overcome a most prominent intensity limitation, i.e., space charge. This Letter characterizes the potential of pulsed electron lenses in detailed 3D tracking simulations, key to which is a realistic machine and space charge model. 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.

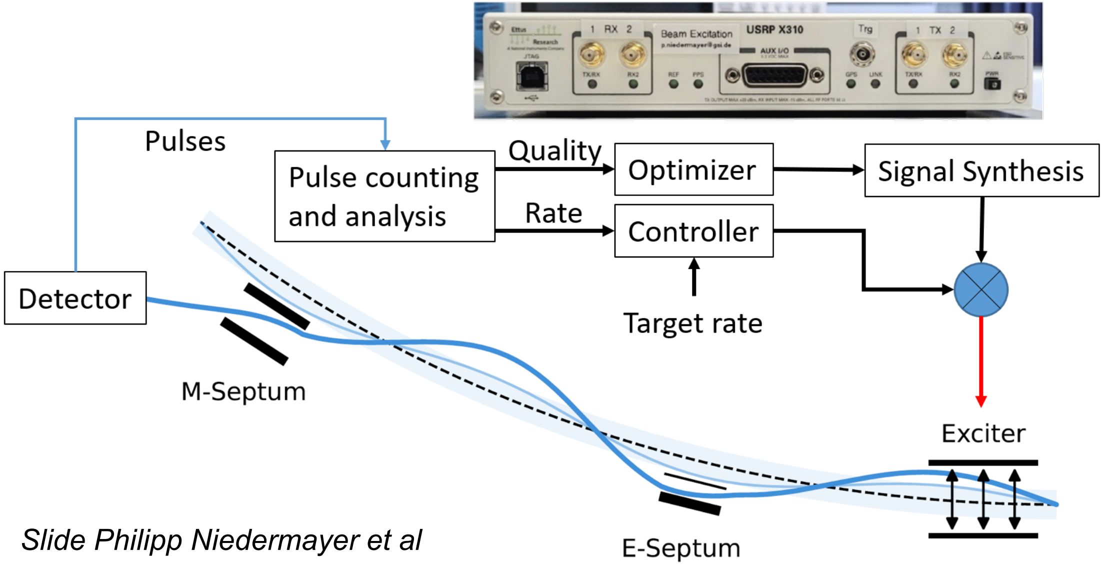
DOI: 10.1103/PhysRevLett.132.175001

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

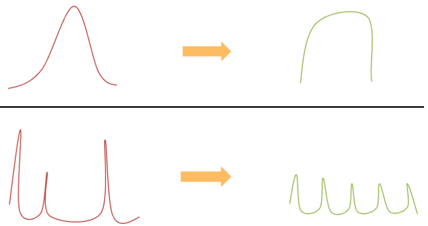
Major Improvement of Ion Beam Quality at GSI

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

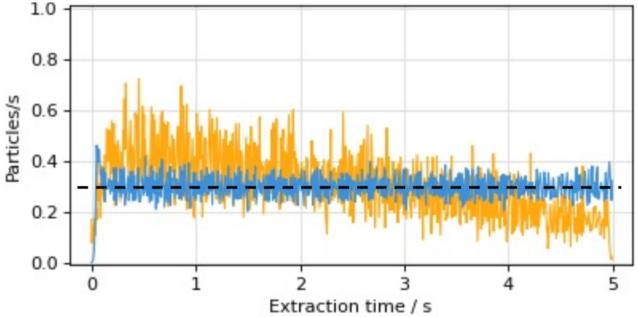
The spill issue has 2 aspects

a) **Macro spill structure**

b) **Micro spill structure**



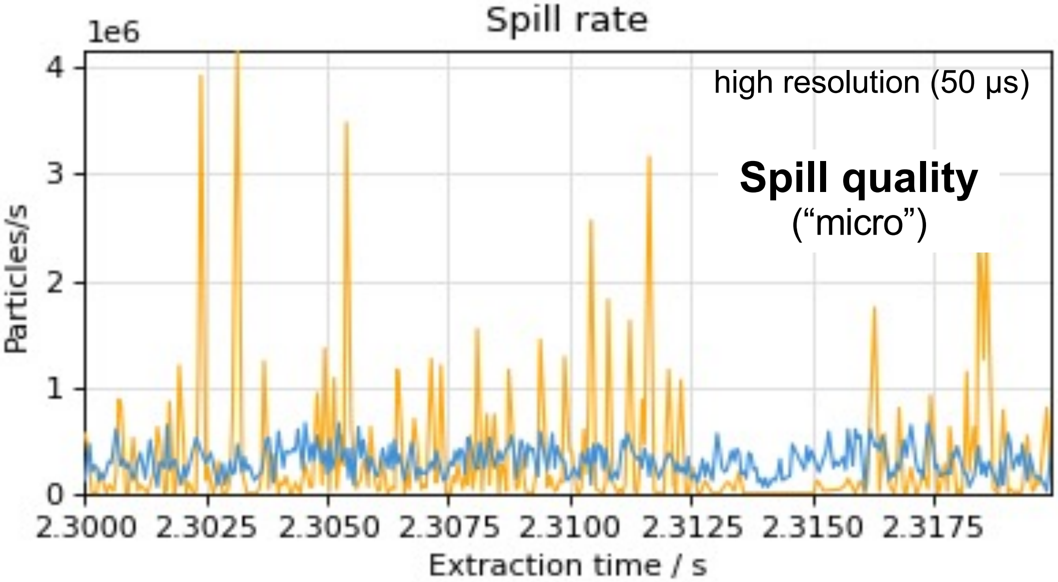
Spill shape ("macro" – 5 s spill length)



$\Delta t_{count} = 5$ ms

without SOS System

with SOS System



$\Delta t_{count} = 50$ 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

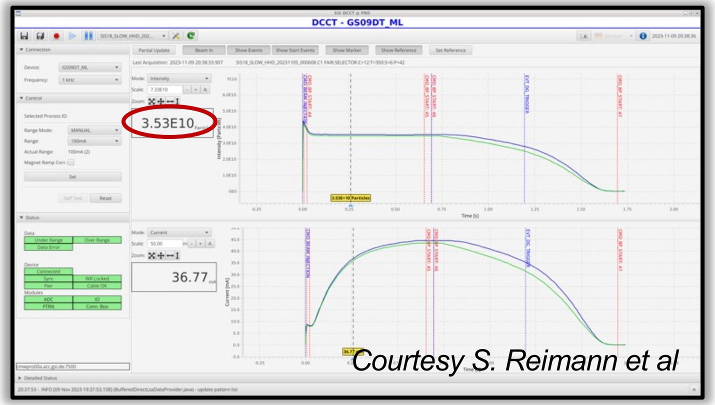
→ FAIR/GSI is using the architecture of the CERN control system

→ GSI accelerators are being upgraded to FAIR controls standard

→ We already start profiting from enhanced features

→ **FAIR/GSI controls review in June 2024 chaired by Jörg Wenninger from CERN.**

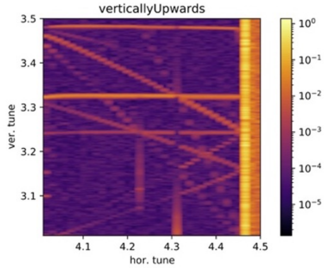
→ Further collaborations and synergetic efforts easily imagined. The review helped identifying areas of common interests.



factor 10 improved C beam for users
(Dec 2023)

python bridge

S. Appel
O. Boine-Frankenheim
et al



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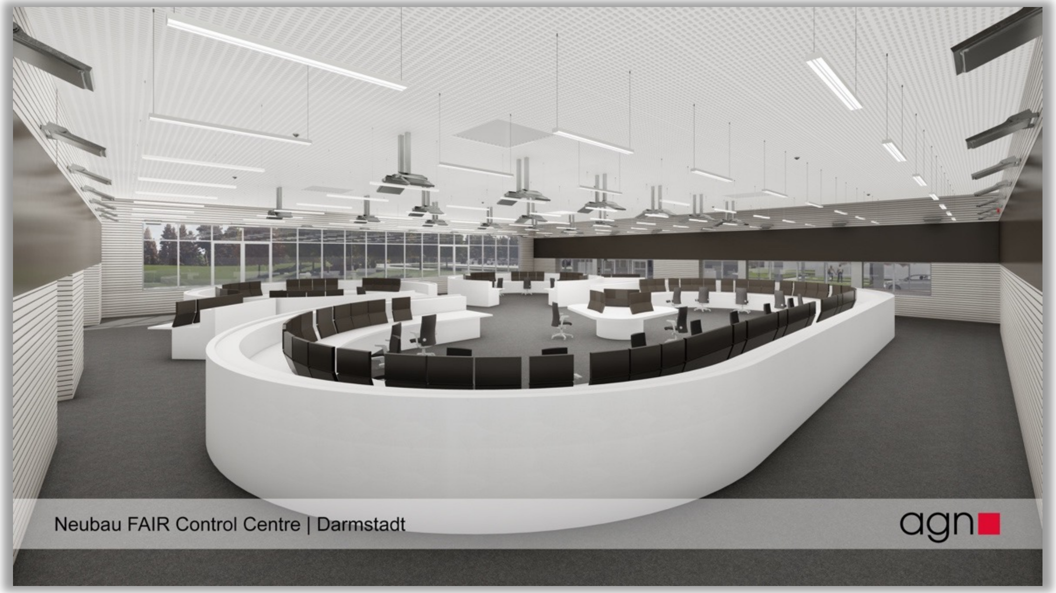
Commissioning (HW, beam) of a new facility (FAIR)

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

Work ongoing for preparing **commissioning workshop in November → S. Reimann**, FAIR/GSI with few external experts from CERN, ESS, DESY, HZB

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



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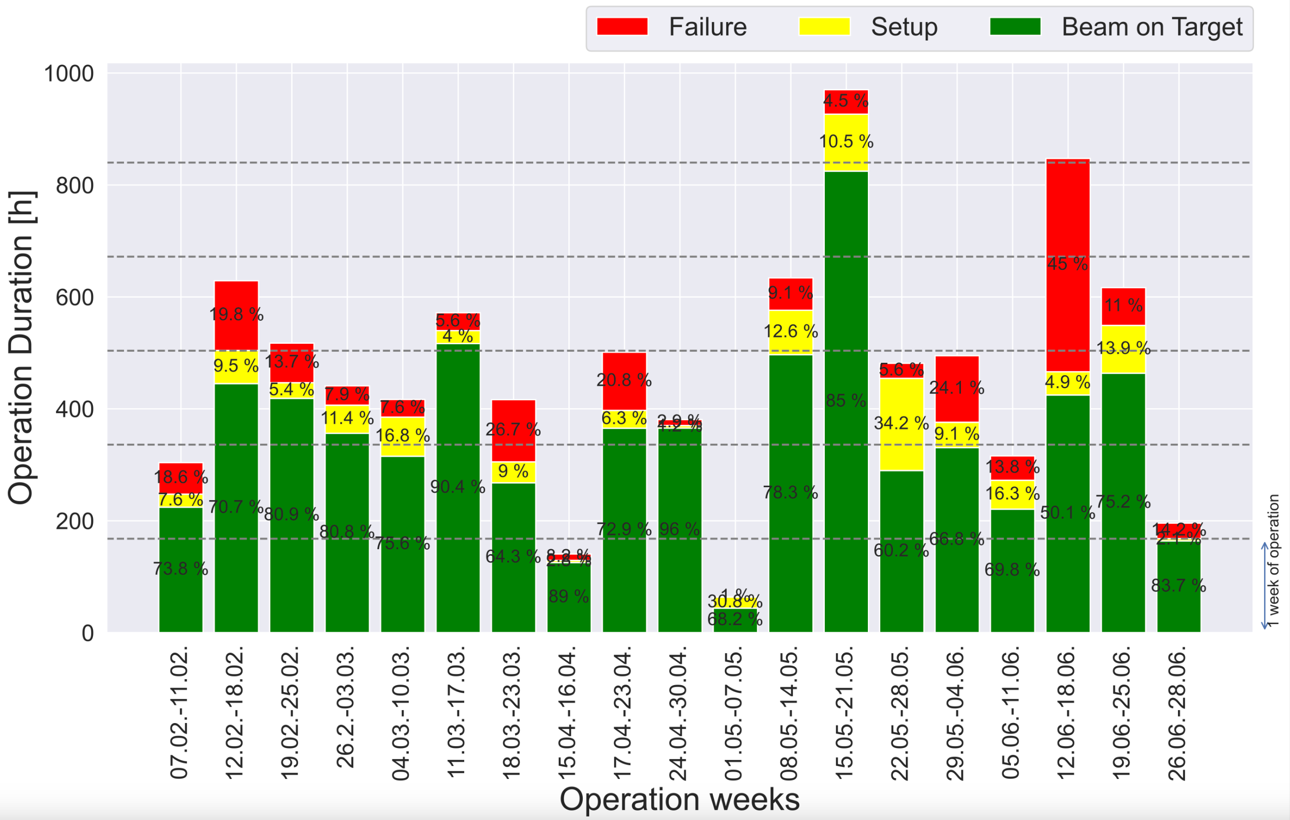
Disclaimer: My **personal** “dreams” for our brainstorming workshop. This is not the official roadmap of FAIR/GSI. I do not talk about FAIR MSVc, which is presently not funded and another talk.

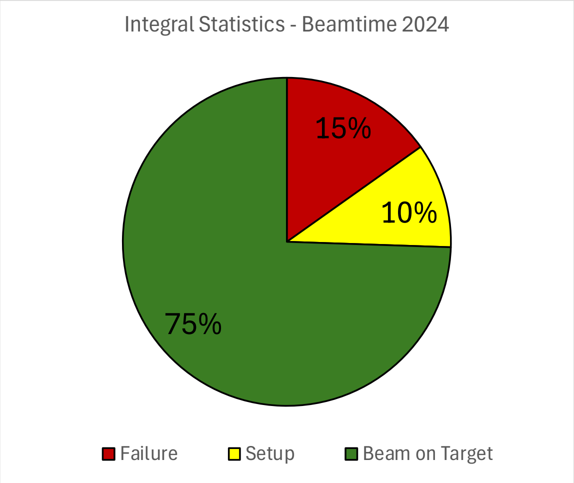
Dream 1:

*Semi-Autonomous Accelerator Operation**

**We are defining this as a flagship goal in Helmholtz Matter & technology for POF-5 (2028 – 2034)*

Availability Statistics 2024





average parallel factor: 2.8

Beam Time 2022
beam on target: 74%
average parallel factor: 2.7

Dashboard User Run

7 experiments in parallel

Status 24.05.

Sources / *Experiments*

May	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
2024	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
IS N							58-Ni						100-Mo										238-U								
IS S							52-Cr																								
ECR																															
UNILAC	ACC						0034, X8, 52-Cr																				BIO, X6, 238-U				
							0051, Y7, 52-Cr																								
													0089, Z6, 52-Cr																		
SIS	ACC								0110, HTD, 58-Ni						0160, HFS, 1[illegible]	0092, HFS, 100-Mo		0143, HFS, 100-Mo						0117, HFS, 238-U					0179, HFS, 238-U	0180, HFS, 238-U	
																MAT, (b), HHT, 100-Mo								MAT, HHT, 238-U			0137, HHT (HIHEX), 238-U				
ESR	ACC															0018, ESR, 100-Mo												0095, ESR-HTA, 238-U			
CRY						0072, CRY-intern, 10-Ne										0198, CRY-intern, S 3+														0201, CRY-intern, 6-Li 3+	

Semi-Autonomous Accelerator Operation

- We deliver ion beams to up to **7 experiments at the same time** (today)
- We will **add the SFRS fragment separator** and experiments (2027)
- We will **add the SIS-100 synchrotron** (2028)
- We will go from **140 days** operation (today) **to 240 days** (from 2029) in a given year: +70 %
- We cannot double our person-power for operation
- Conclusion: We will need to rely on modern **controls tools to automize and to reduce work load for operators and machine departments** → semi-autonomous accelerator operation
- *Note: Shorter shutdowns → rely on external resources in short shutdowns*

The Green IT Cube on the GSI site

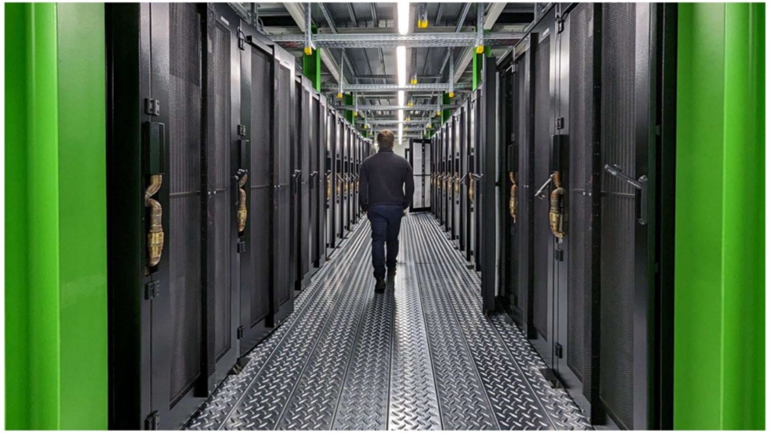
“Accelerator” for Artificial Intelligence

Startseite › Rhein-Main › Darmstadt

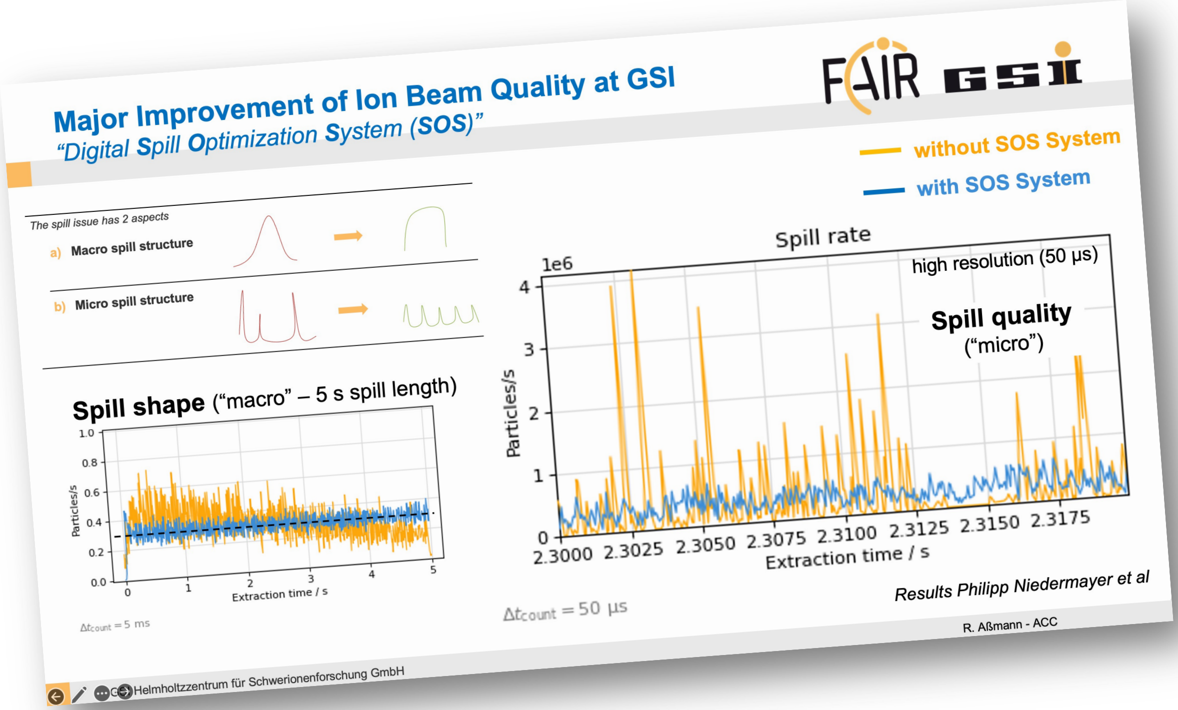
Neuer Supercomputer in Darmstadt: Beschleuniger für Künstliche Intelligenz

22.03.2023, 15:47 Uhr
Von: Claudia Kabel

Kommentare   Drucken   Teilen



Plan to Build up “Accelerator Development” Effort in Business Area ACC



- Close collaboration with
  - Machine departments
  - Accelerator physics department (O. Boine-Frankenheim)
  - University accelerator groups
- New effort will
  - bundle some of our competences
  - start small
  - link from R&D tasks (PhD’s) to our needs (operation) → attract the young talents

Dream 2:

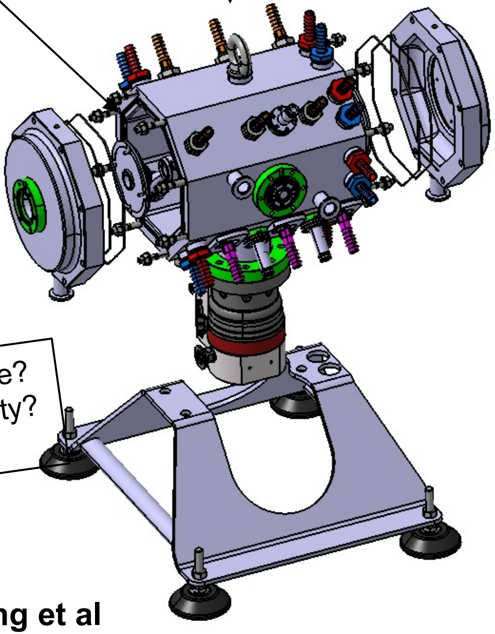
Fast Production of Complicated Accelerator RF Structures*

*Opens collaboration opportunities with Goethe Univ. Frankfurt, TU Darmstadt, …

Research Direction: High power RF structures for ion accelerators with additive machining (3D)

Tank (printed with steel and later copper plated)

12 x electrodes (copper)

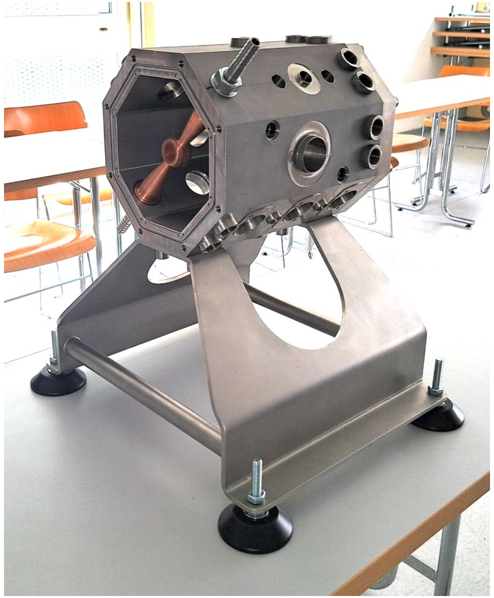


R&D: Performance?
Reachable intensity?
Application?

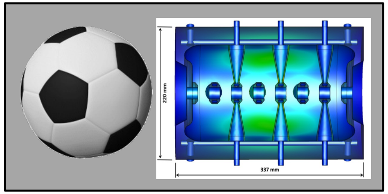
Courtesy C. Zhang et al

704.4 MHz CH prototype

copper-electrodes



704 MHz-CH (size compared with a football)



Note: Related Activity at University Frankfurt

Hendrik Hähnel:

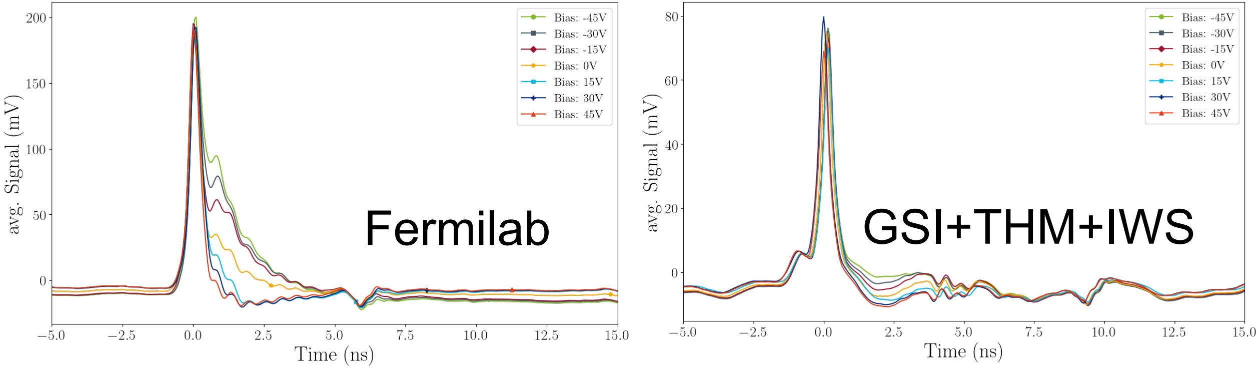
IH structure

Tested with 25 kW RF power

5 MV/m effective gradient reached

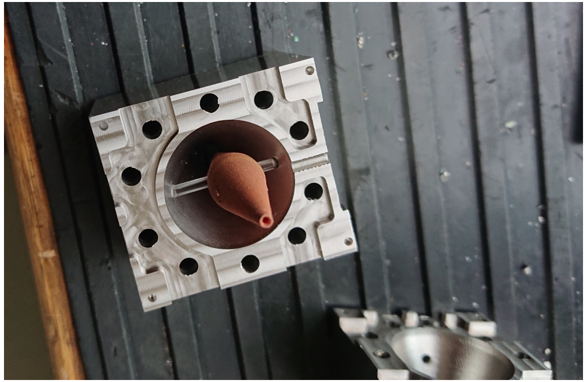
At GSI: 3D Printed Copper FFC

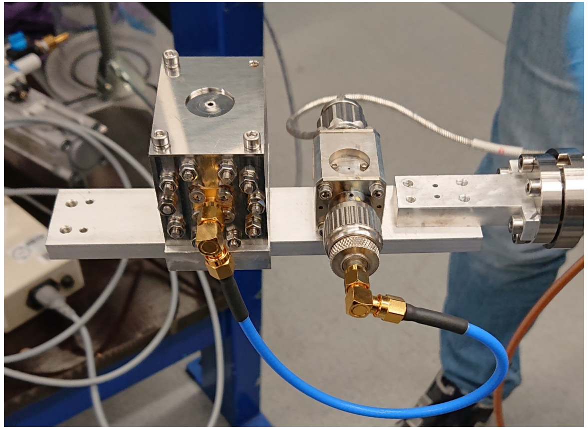
- A tapered design with a larger entrance hole for higher SNR at the cost of lower time resolution
- First additive manufactured RF beam diagnostic component (manufactured at: **IWS Fraunhofer Institute**)
- Demonstration of secondary electron suppression "by-design"



Single Bunch shape measured as a function of bias voltages

S. Klaproth, R. Singh et al. Manuscript in preperation





Dream 3:

*Reduced Size of Particle Accelerators**

**Pursued at Helmholtz Institute Jena (ass. to GSI) for e-, also working with EuPRAXIA*

See Size of Ion Therapy Center → Cost Problem

Heidelberg Ion-Beam Therapy Center (HIT)

Carbon beam therapy for oncological treamtent

Outstanding GSI technology with usage for many patients

Participation of IAP, Univ. Frankfurt: U. Ratzinger for I design, A. Schempp for RFQ design

Further developments at GSI in 2023: **World-wide first mixed C/He ion beam** for therapy

Facilities limited by **high cost of investment and operation costs**

Semi-autonomous operation helps for operation costs

Light Project at GSI

Courtesy A. Blazevic. Dep. V. Bagnoud

- **LIGHT**: Laser Ion Generation Handling and Transport
- 2004-2008: VIPBUL-Virtual Institute for generation of intense Particle Beams with Ultra-intense Laser fields, funded by BMBF

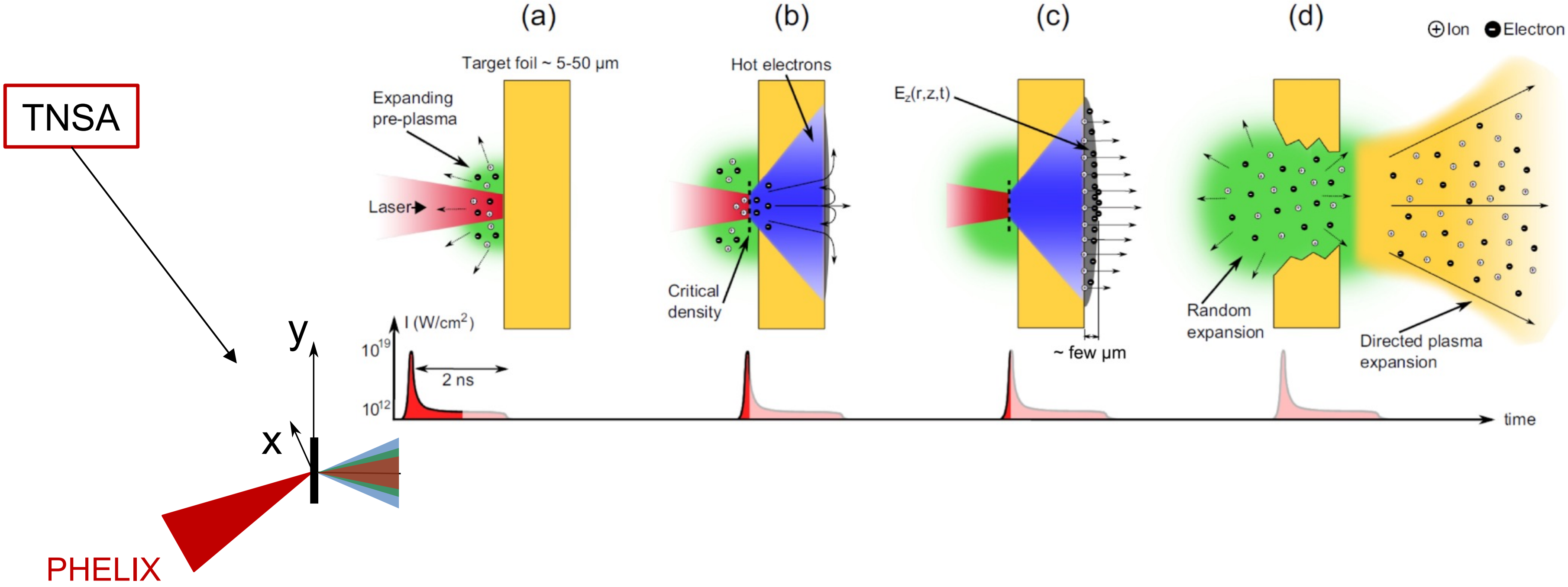
  participants: TUD, GSI, LMU, FSU and Weitzman Institute in Tel Aviv.
  - ✓ Set up of compressor and laser beam line to Z6 target chamber.
  - ✓ First experiments with solenoids and permanent quadrupoles at PHELIX
- 2008: foundation of LIGHT collaboration – GSI, TUD, HIJ, HZDR, GUF
  later LMU, LBNL, CLPU
  - ✓ Investigation of TNSA mechanism
  - ✓ Implementation of solenoid by HZDR
  - ✓ Implementation of rf cavity by GSI
  - ✓ Second target chamber for experiments
- 14 bachelor/master theses, 11 PhD, >17 papers

Light Project at GSI

Courtesy A. Blazevic. Dep. V. Bagnoud

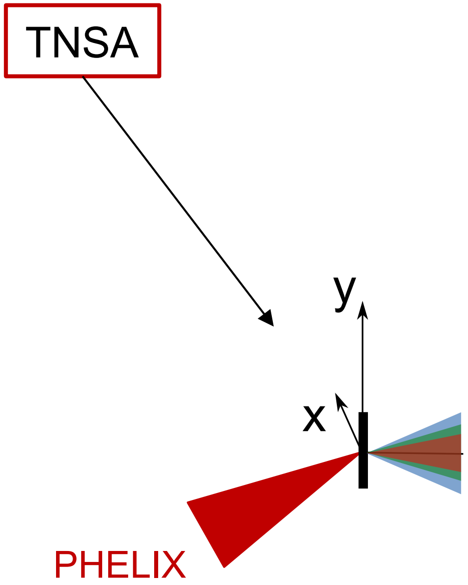
- **LIGHT**: Laser Ion ... d Transport
- 2004-2008: VIPB ... Beams with Ultra-intense Laser fie...
  participants: TUD...
  - ✓ Set up of comp...
  - ✓ First experime...
- 2008: foundatio...
  - ✓ Investigation ...
  - ✓ Implementati...
  - ✓ Implementati...
  - ✓ Second target chamber for experiments
- 14 bachelor/master theses, 11 PhD, >17 papers

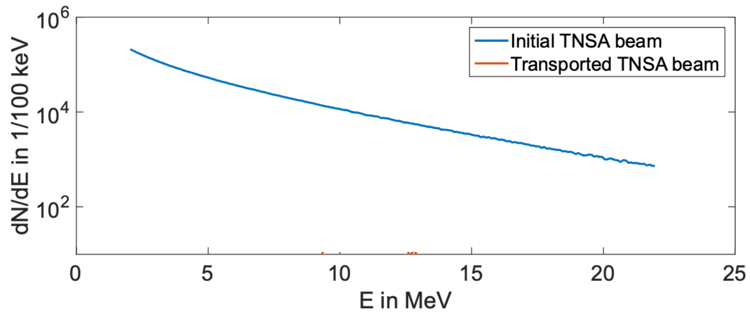
Overview of the LIGHT beamline



Overview of the LIGHT beamline

Courtesy A. Blazevic.
Dep. V. Bagnoud



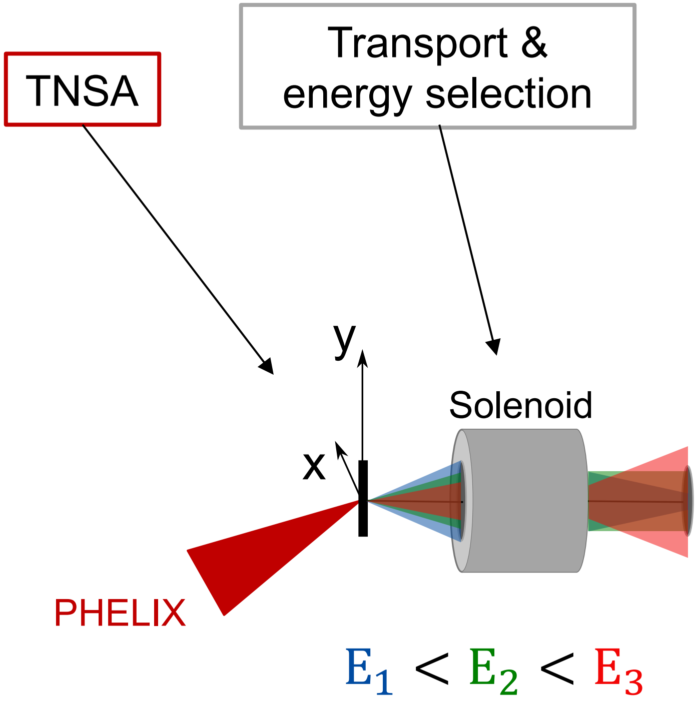


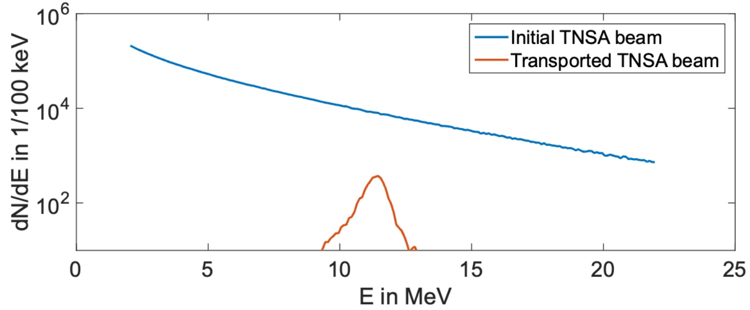
Initial TNSA beam parameter (Z6):

- $E_{max} \approx$ 28 MeV
- $k_B T \approx$ 7 MeV
- $\varepsilon_{rr'}^{2\sigma} <$ 1.5 mm mrad
- $N_{total} \approx 10^{12}$ (protons)

Overview of the LIGHT beamline

Courtesy A. Blazevic.
Dep. V. Bagnoud



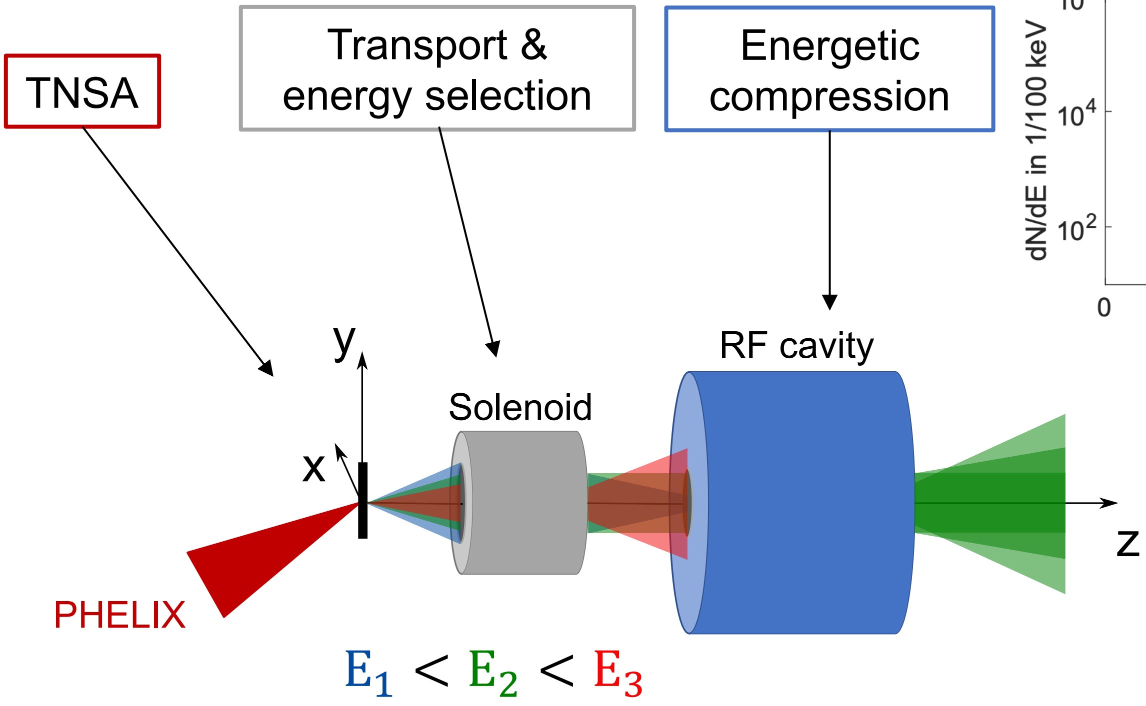


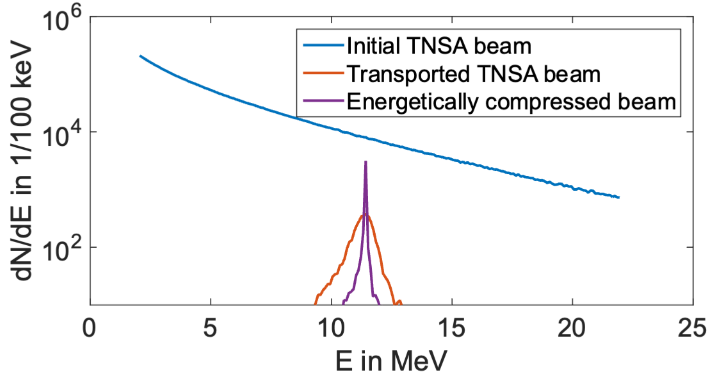
Transported TNSA beam:

- E_{peak} = 11.4 MeV
- **$\Delta E/E$ = 10 %**
- $\varepsilon_{rr'}^{2\sigma}$ = 83.2 mm mrad
- $N_{total} \approx 10^9$

Courtesy A. Blazevic.
Dep. V. Bagnoud

Overview of the LIGHT beamline

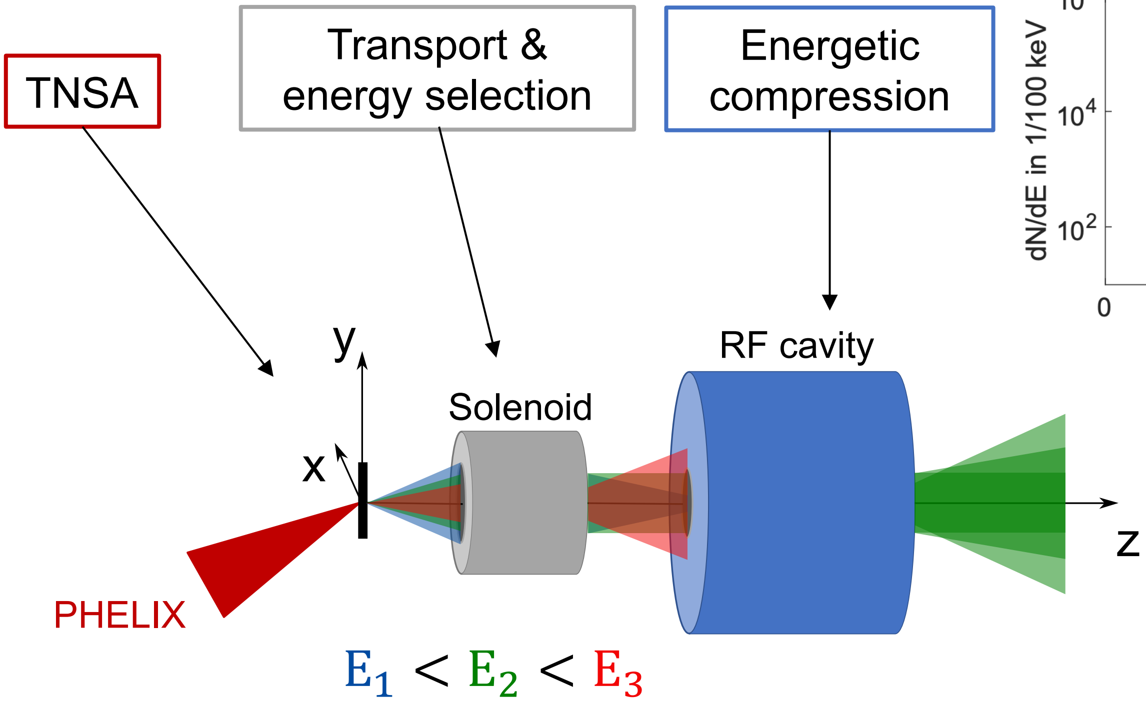


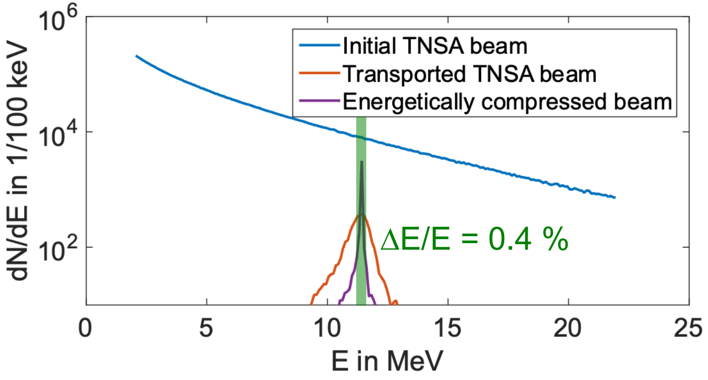


E_{peak} = 11.4 MeV
$\Delta E/E$ = 0.21 %
$\varepsilon_{rr'}^{2\sigma}$ = 63.1 mm mrad
$N_{total} \approx 10^9$

Courtesy A. Blazevic.
Dep. V. Bagnoud

Overview of the LIGHT beamline

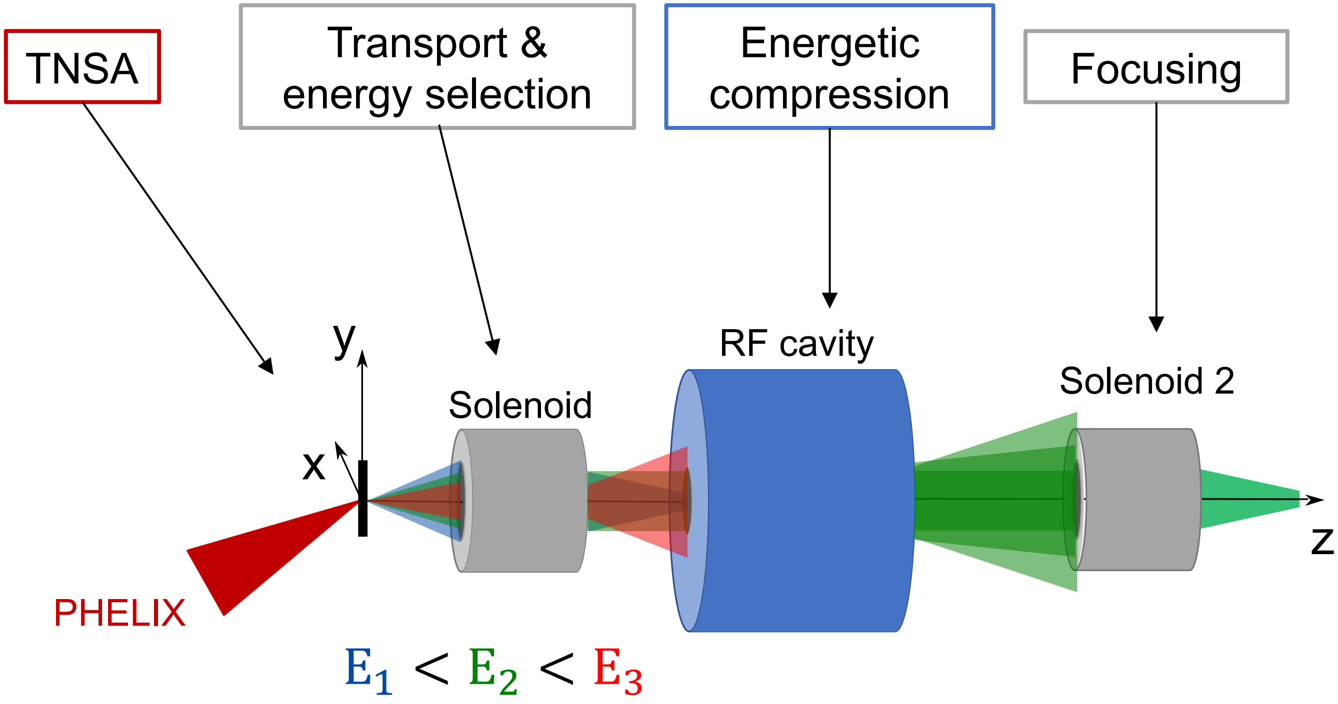


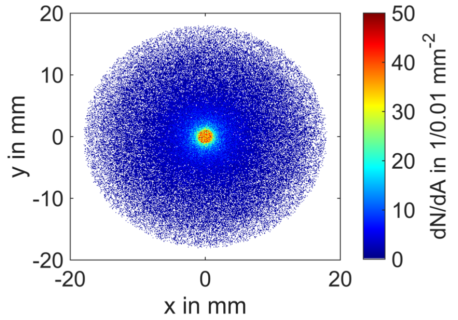


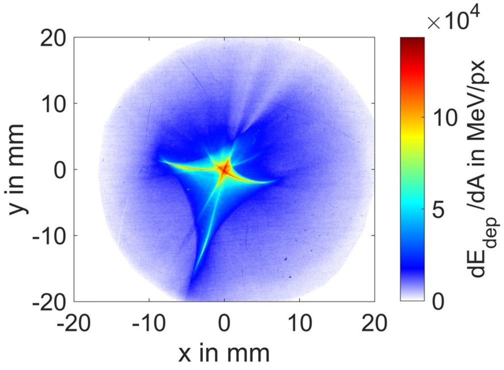
E_{peak} = 11.4 MeV
$\Delta E/E$ = 0.21 %
$\varepsilon_{rr'}^{2\sigma}$ = 63.1 mm mrad
$N_{total} \approx 8.2 \times 10^8$

E_{peak} = 8.0 MeV
$\Delta E/E$ = 0.32 %
$\varepsilon_{rr'}^{2\sigma}$ = 65.5 mm mrad
$N_{total} \approx 1.2 \times 10^9$

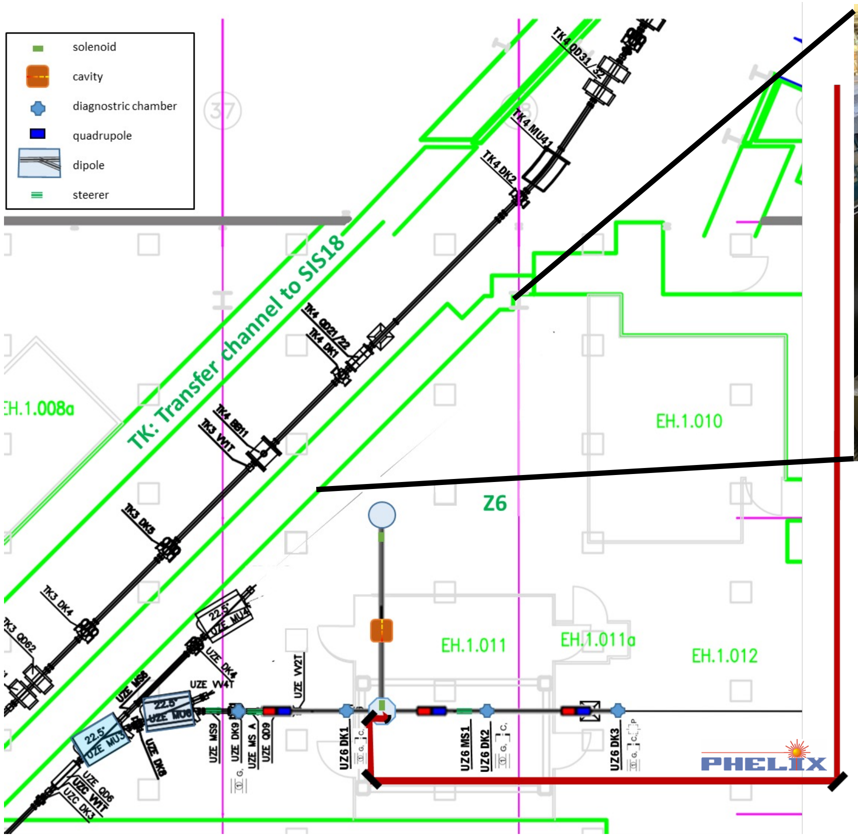
Overview of the LIGHT beamline



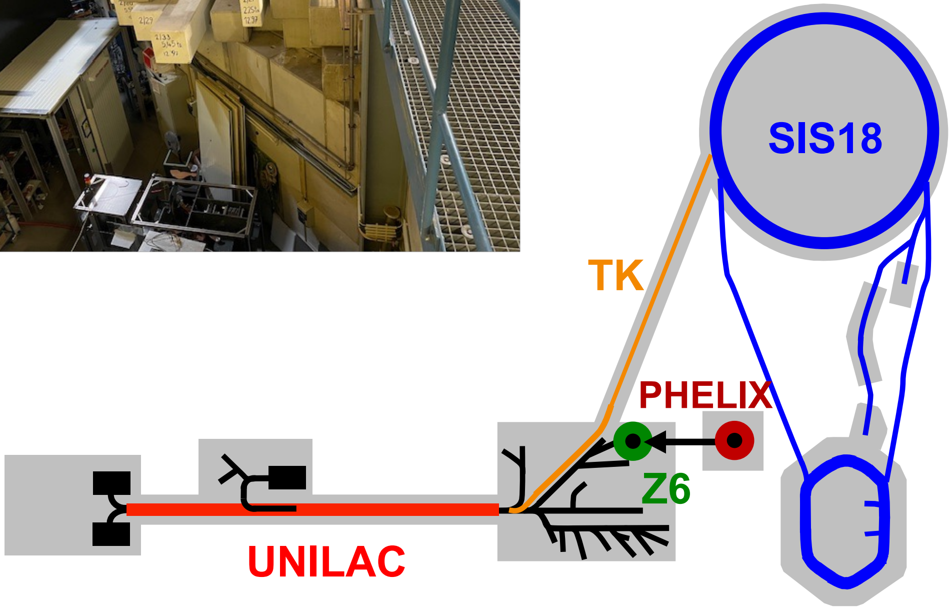




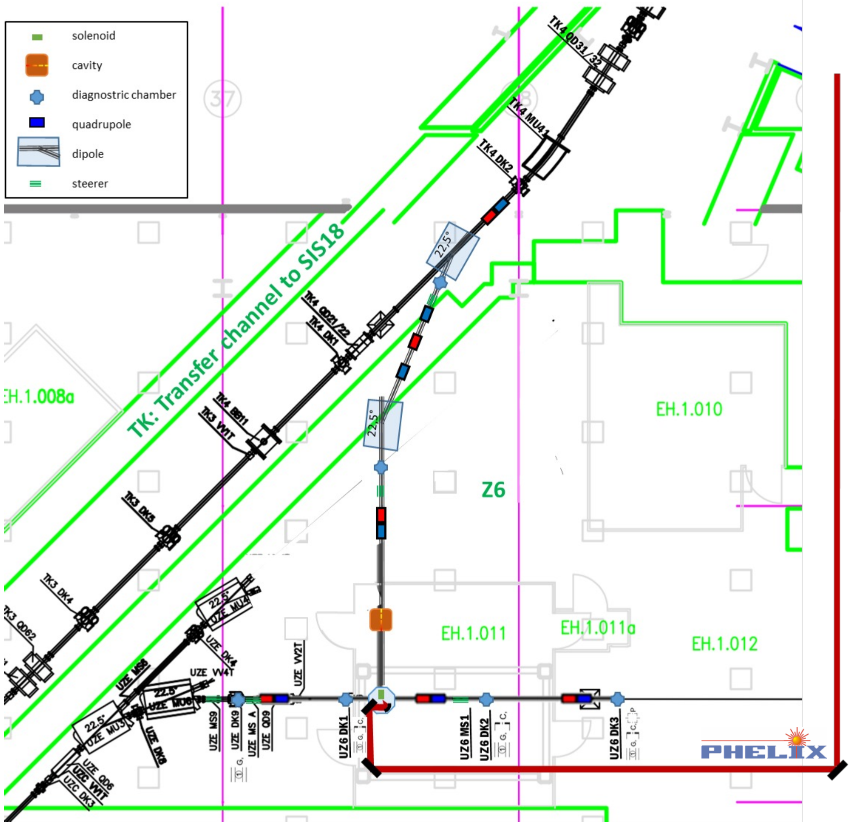
The LIGHT beam line at Z6-GSI → Inject into our Complex



Courtesy A. Blazevic.
Dep. V. Bagnoud



The iLIGHT beam line at GSI → Inject into our Complex



Main goal:

Proof of principle

- ELI: 1 Hz operation
- GSI: injection

Chances:

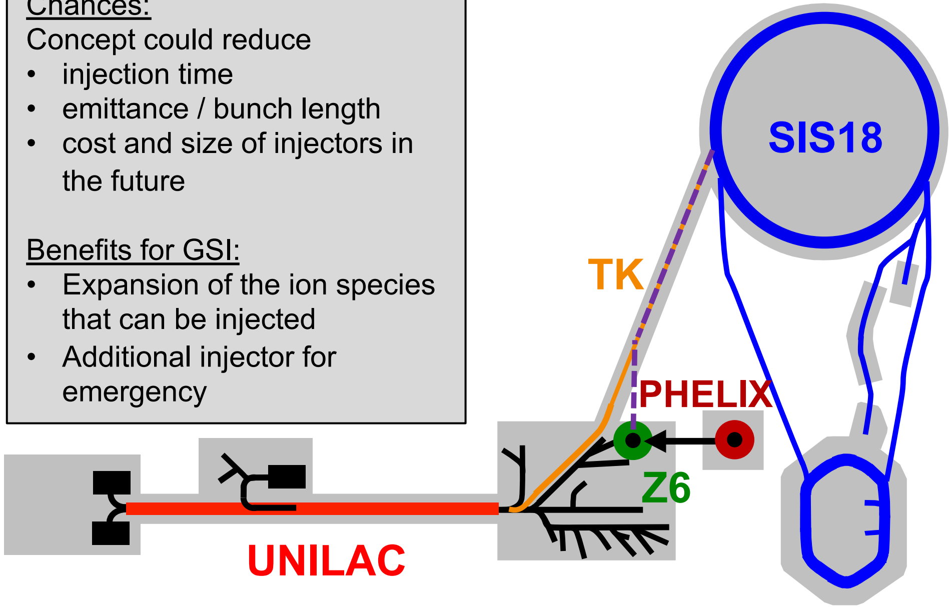
Concept could reduce

- injection time
- emittance / bunch length
- cost and size of injectors in the future

Benefits for GSI:

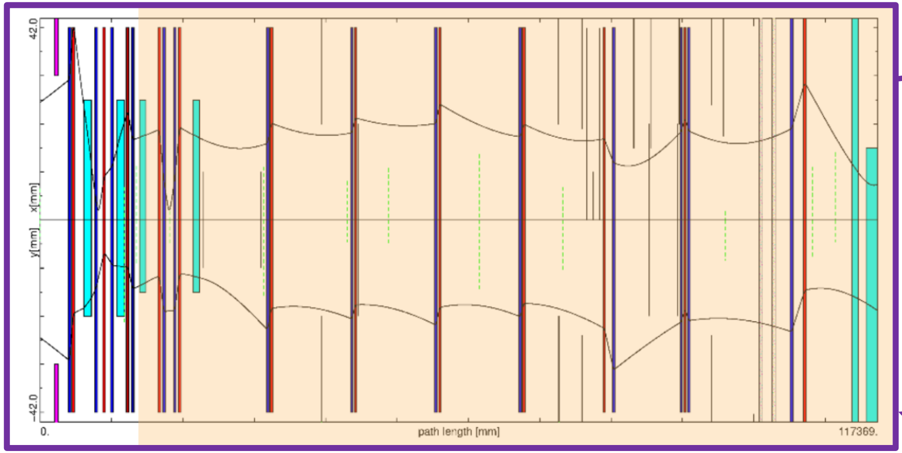
- Expansion of the ion species that can be injected
- Additional injector for emergency

Courtesy A. Blazevic.
Dep. V. Bagnoud



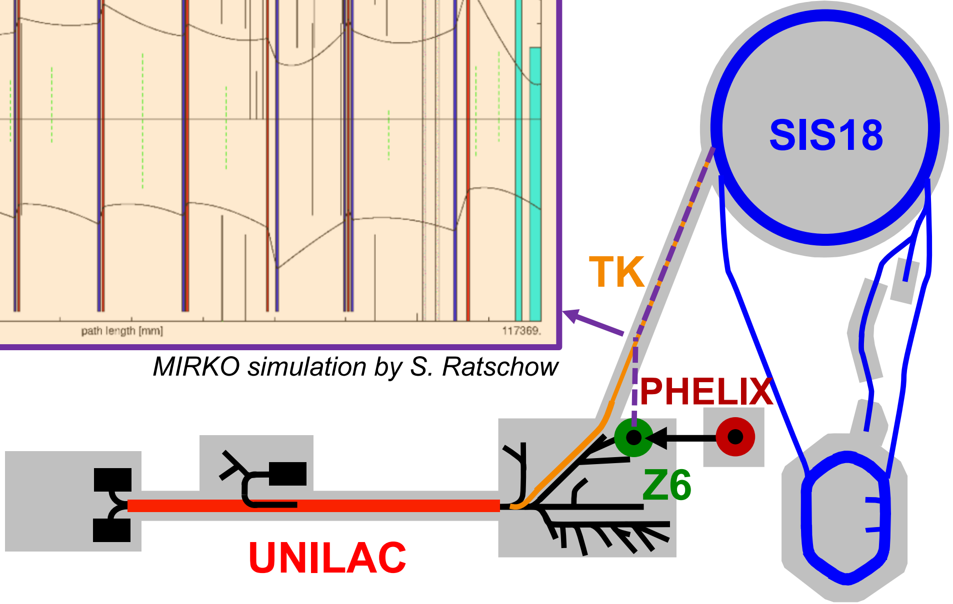
Beam Transport Simulation

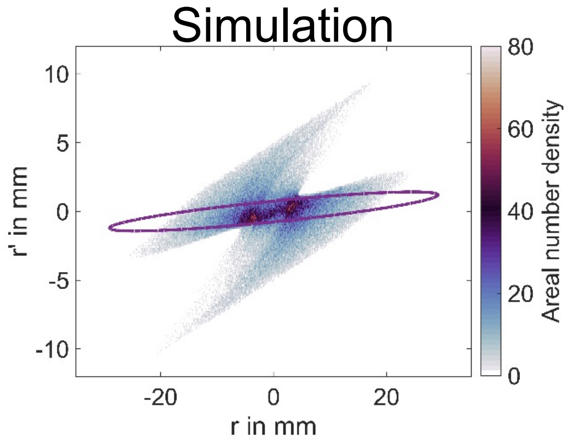
Courtesy A. Blazevic.
Dep. V. Bagnoud



MIRKO simulation by S. Ratschow

- $\varepsilon_{geo} = 22$ mm mrad
- $(\Delta E/E)_{max} = \pm 0.2\ \%$





N_{sim} = 6.14(43)×10^8
(within acceptance range)

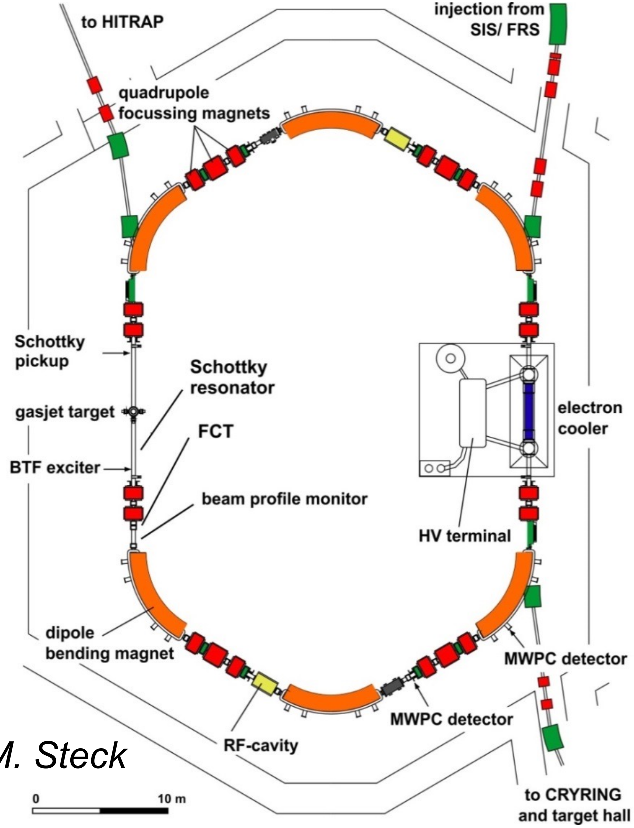
Dream 4:

Low Energy* Collider

**Cold ion beams (in the past crystalline beams), using flexibility of our facilities*

Experimental Storage Ring ESR: Capabilities

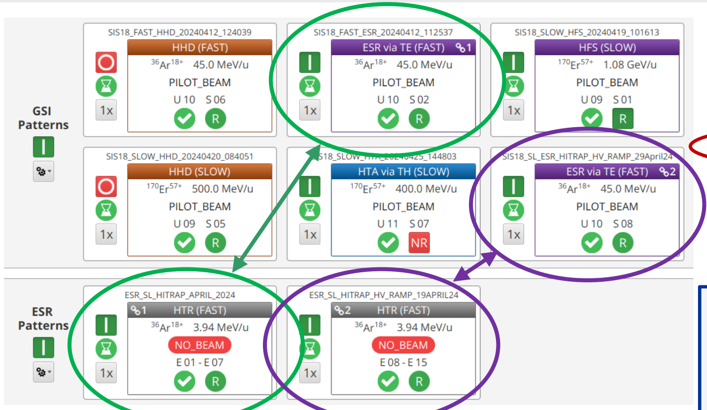
→ See also talk later today by Bernd Lorentz

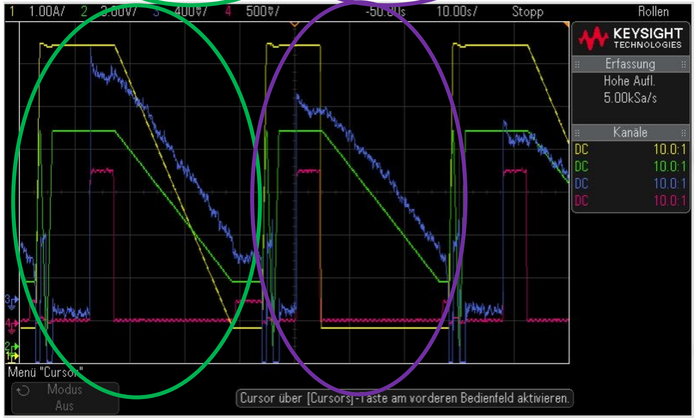


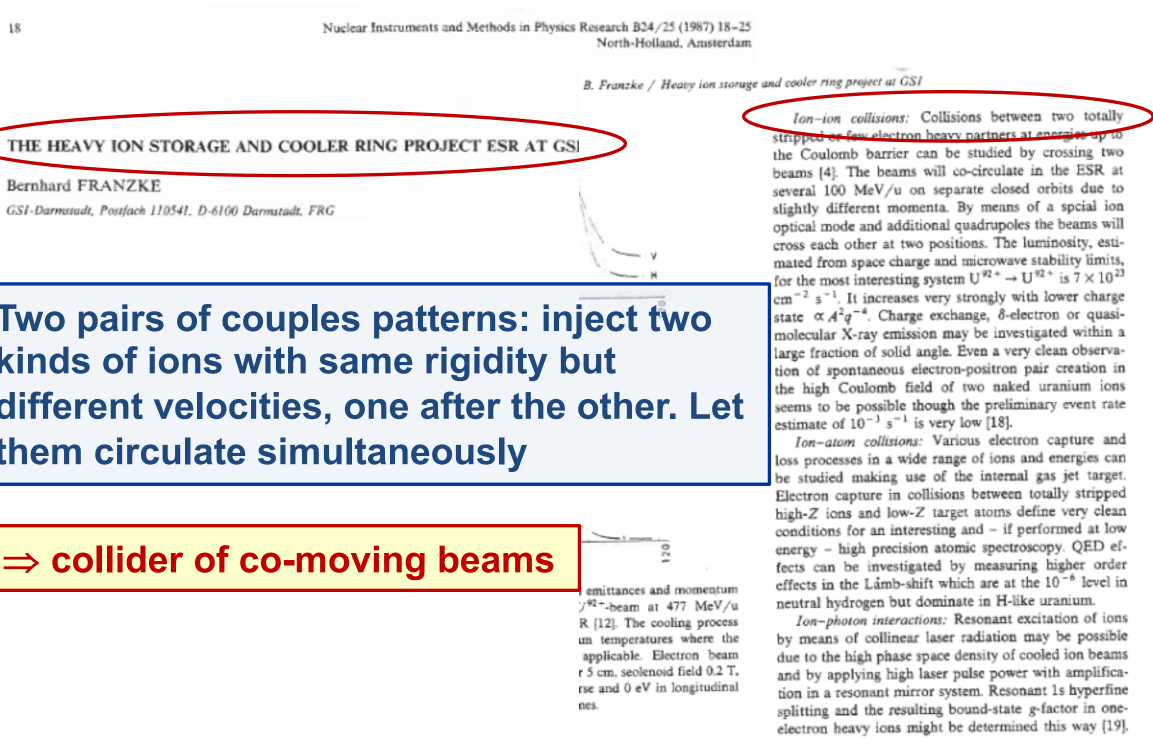
Courtesy M. Steck

- Injection of cooled beams from SIS-18
- Storage of highly charged ions (primary or secondary beams from FRS)
- Stochastic cooling (400 MeV/u)
- Electron cooling (3 - 420 MeV/u)
- Internal Gas-jet target
- Deceleration (down to 3 MeV/u)
- Fast extraction
- Recharge extraction
- Accumulation
- Mode: isochronous optics
- **Schottky mass spectroscopy of RIB's**
- **Slow resonance extraction**

Using flexibility of ESR: Low Energy "Collider"







18 Nuclear Instruments and Methods in Physics Research B24/25 (1987) 18–25
North-Holland, Amsterdam

B. Franzke / Heavy ion storage and cooler ring project at GSI

THE HEAVY ION STORAGE AND COOLER RING PROJECT ESR AT GSI

Bernhard FRANZKE

GSI-Darmstadt, Postfach 110541, D-6100 Darmstadt, FRG

... emittances and momentum ... beam at 477 MeV/u ... R [12]. The cooling process ... temperatures where the ... applicable. Electron beam ... 5 cm, seolenoid field 0.2 T, ... and 0 eV in longitudinal ...

Ion–ion collisions: Collisions between two totally stripped or few electron heavy partners at energies up to the Coulomb barrier can be studied by crossing two beams [4]. The beams will co-circulate in the ESR at several 100 MeV/u on separate closed orbits due to slightly different momenta. By means of a spcial ion optical mode and additional quadrupoles the beams will cross each other at two positions. The luminosity, estimated from space charge and microwave stability limits, for the most interesting system $U^{92+} \to U^{92+}$ is 7×10^{23} cm^{-2} s^{-1}. It increases very strongly with lower charge state $\propto A^2 q^{-4}$. Charge exchange, δ-electron or quasi-molecular X-ray emission may be investigated within a large fraction of solid angle. Even a very clean observation of spontaneous electron-positron pair creation in the high Coulomb field of two naked uranium ions seems to be possible though the preliminary event rate estimate of 10^{-3} s^{-1} is very low [18].

Ion–atom collisions: Various electron capture and loss processes in a wide range of ions and energies can be studied making use of the internal gas jet target. Electron capture in collisions between totally stripped high-Z ions and low-Z target atoms define very clean conditions for an interesting and – if performed at low energy – high precision atomic spectroscopy. QED effects can be investigated by measuring higher order effects in the Lamb-shift which are at the 10^{-6} level in neutral hydrogen but dominate in H-like uranium.

Ion–photon interactions: Resonant excitation of ions by means of collinear laser radiation may be possible due to the high phase space density of cooled ion beams and by applying high laser pulse power with amplification in a resonant mirror system. Resonant 1s hyperfine splitting and the resulting bound-state g-factor in one-electron heavy ions might be determined this way [19].

Two pairs of couples patterns: inject two kinds of ions with same rigidity but different velocities, one after the other. Let them circulate simultaneously

⇒ collider of co-moving beams

Courtesy M. Steck

Dream 5:

*Compact Ion Storage Ring as Powerful Quantum Computer**

**Quantum computers partially relying on ion traps. Our storage rings are big traps!*

Paper of Suleiman and Derbenev

→ *See talk later today by Vasiliy Morozov*

15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEAN2

PARTICLE ACCELERATOR SPIN-TRANSPARENT STORAGE RINGS FOR BEYOND STATE-OF-THE-ART SCIENCE*

R. Suleiman†, Ya. S. Derbenev
Thomas Jefferson National Accelerator Facility, Newport News, VA, USA
M. Grau, Old Dominion University, Norfolk, VA, USA
V. S. Morozov, Oak Ridge National Laboratory, Oak Ridge, TN, USA

Table 1: ST Ring Parameters for $^{171}Yb^{+}$ Ion

Kinetic energy, K	10 keV
Momentum, p	56.4 MeV/c
Velocity, β	3.54×10^{-4}
Relative longitudinal momentum offset, $\Delta p_{\parallel}/p$	$< 10^{-3}$
Longitudinal temperature, $T_{\parallel} = mc^2\beta^2(\Delta p_{\parallel}/p)^2/k_B$	< 200 K
Angular deviation, $\Delta\theta_{\perp}$	1 mrad
Transverse temperature, $T_{\perp} = mc^2\beta^2\gamma^2(\Delta\theta_{\perp})^2/k_B$	232 K
Ring circumference, L	33.5 m
Circulation frequency, f_c	3.17 kHz
No. of qubits / RF harmonic number	3, 300
Time separation of qubits, Δt	95.7 ns
Electric bending field, E	17.3 kV/m

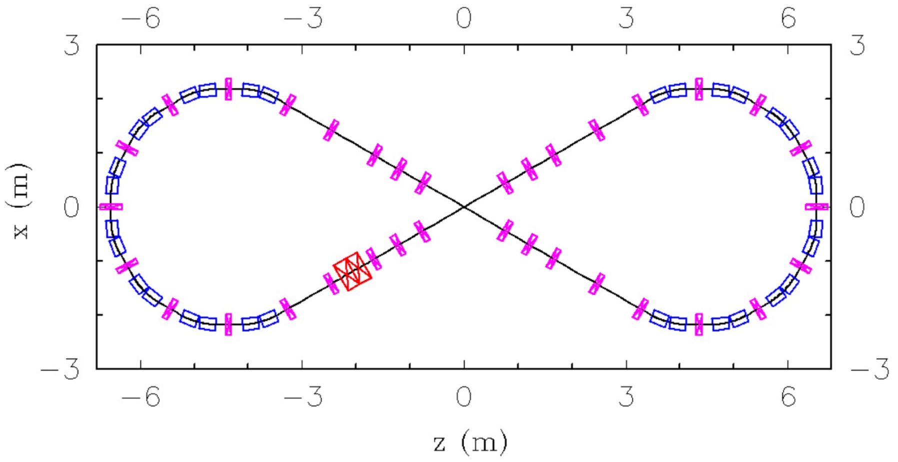


Figure 2: Layout of an all electric ST ring for $^{171}Yb^{+}$ ions. Shown are the bending electrodes (blue), focusing elements (magenta), and the RF bunching cavity (red).

Is this realistic and an optimum scheme? Are there other interesting schemes? Basic academic R&D…

Conclusion

- Very **clear direction and short/medium term roadmap at FAIR/GSI**, which demands also significant efforts on accelerator developements, with universities and collaborators:
  - Complete the FAIR project
  - Prepare commissioning of FAIR, also in the existing GSI accelerator complex
  - Commissioing FAIR and putting it into operation
- Several **long term developments** interesting for us and formulated for our **roadmap brainstorming** as dreams (my personal collection, not complete, not official):
  - Semi-Autonomous Accelerator Operation (Helmholtz flagship goal)
  - Fast Production of Complicated Accelerator RF Structures (additive manufacturing)
  - Reduced Size of Particle Accelerators (low intensity ion injectors, ion therapy)
  - Low Energy Collider (low energy, cold beams, atomic physics)
  - Compact Ion Storage Ring as Powerful Quantum Computer (GSI expertise matches challenge)

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Thank You for Your Attention