GSI Facility for FAIR Phase 0 and FAIR

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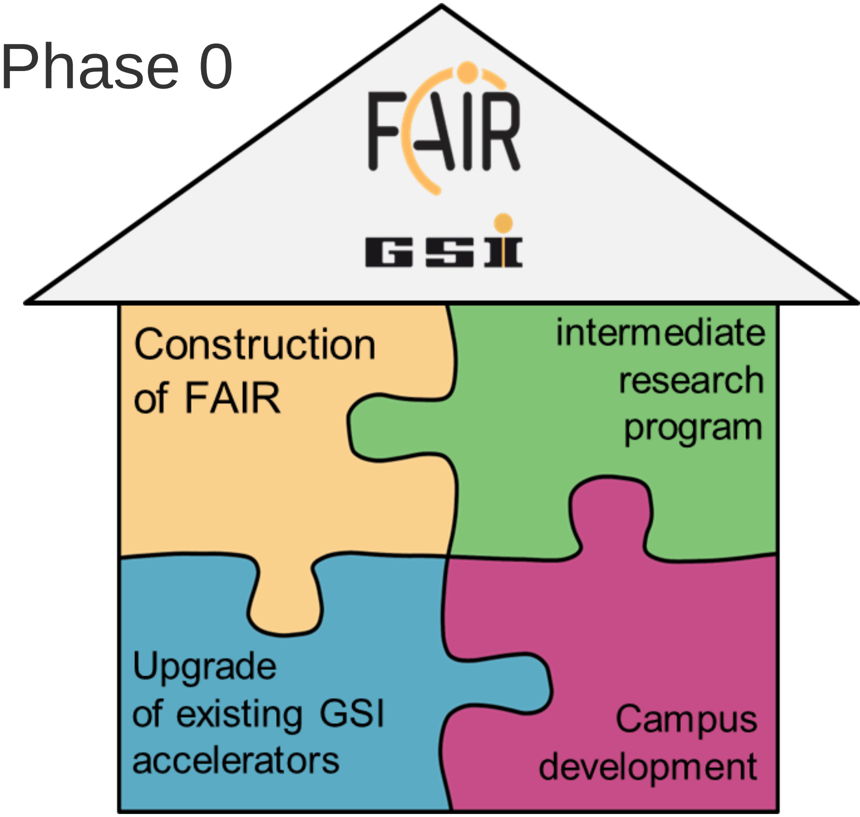
on behalf of GSI Accelerator Operations Division

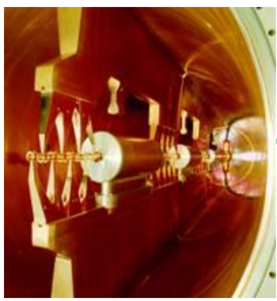
Outline

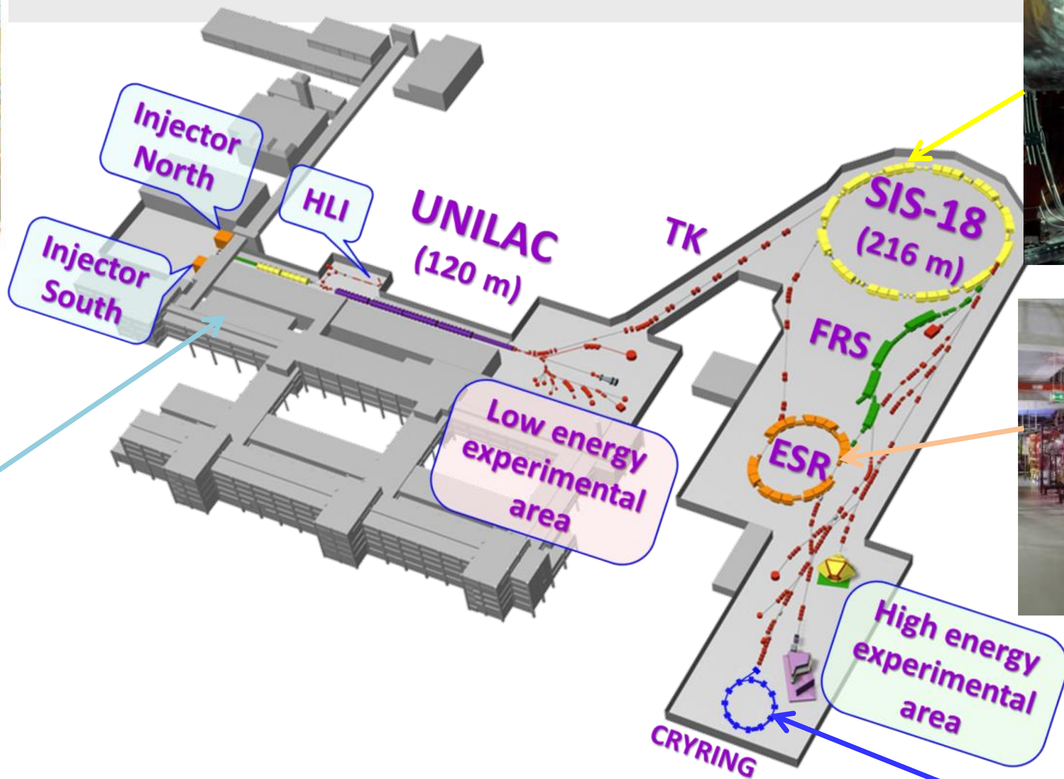
- Brief Introduction of GSI/FAIR accelerator facilities
  - core competences and uniqueness
- Charges and challenges of FAIR Phase 0
  - What is FAIR Phase 0?
  - Status and challenges
- Towards FAIR

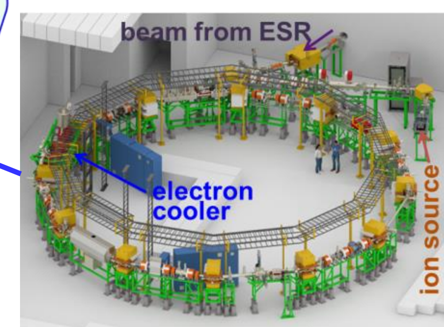


GSI/FAIR Accelerator Facilities

Ion sources



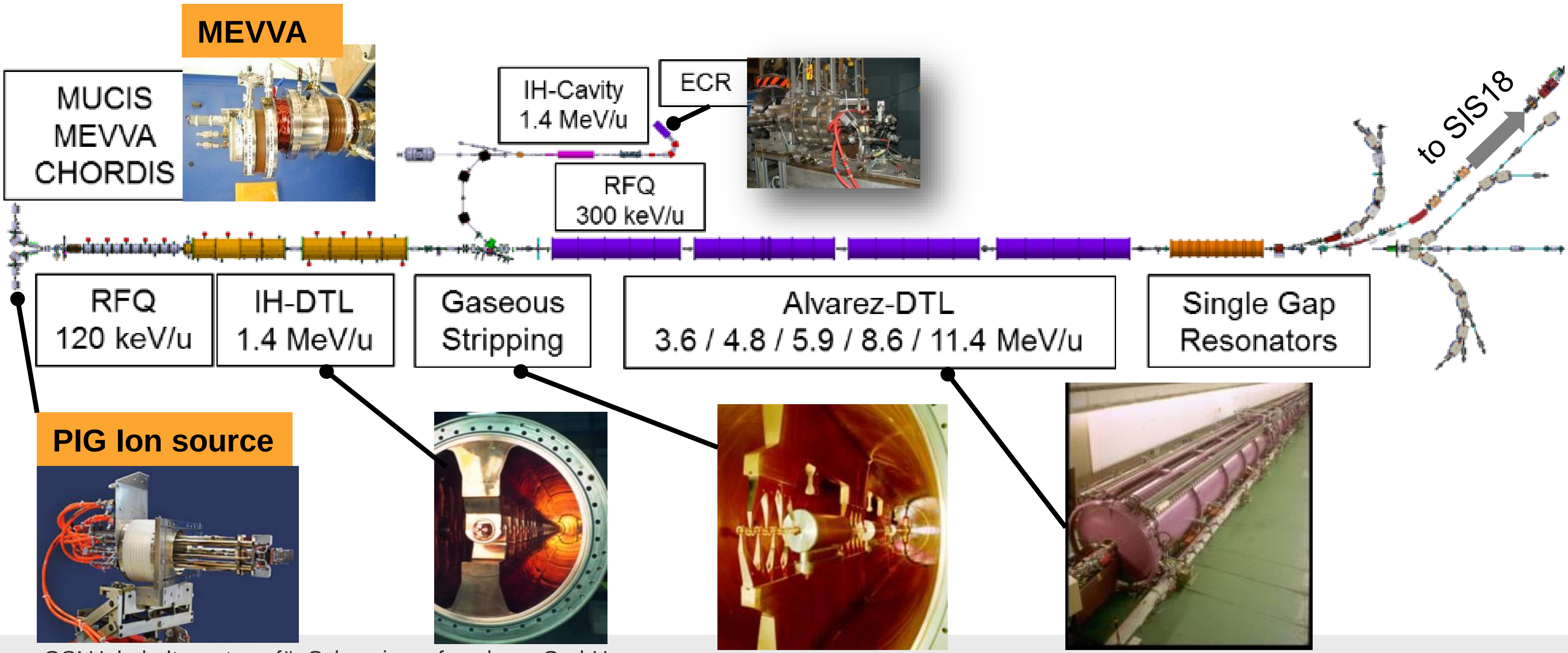




- Unique hadron facility for multi users
  - both dedicated operation as well as parallel operation mode
  - variety of operation modes, relative short transition in between
- Ultra high vacuum technique to reach highest intensity uranium beam!
- Comprehensive beam cooling to enable precision experiments at storage rings

UNILAC Overview

- High current ion sources and ECRIS for high charge state
  - ions: 14N, 16O, 18O, 50Ti, 40Ar, 48Ca, 107Ag, 124Xe, 208Pb, 238U
  - p+ and 12C from molecular beams (isobutane)
- High intensity and bright uranium beams!

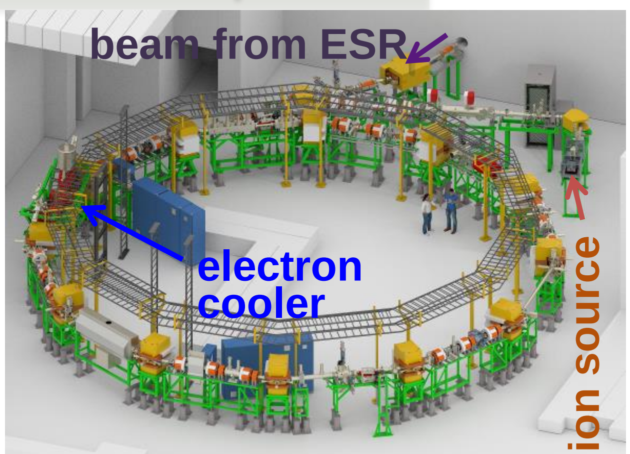


Storage, deceleration and trapping of ion beams

10^10, 10^8, 10^6, 10^4, eV, 10^-3

Experimental Storage Ring
- stable ions and RIBs
- multi-charge state
- beam accumulation
- fast/slow extraction

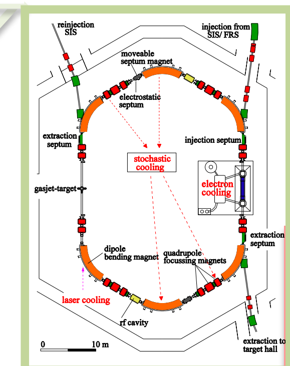
CRYRING
- electron cooling
- stand-alone operation



HITRAP

ESR R&D Highlights
- Comprehensive beam cooling
- Isochronous mode
- high precision Schottky spectrometry for single particle detection

UNILAC — 400 MeV/u — SIS 18 — Stripper — 400 MeV/u — FRS — ESR



4 K

4 MeV/u

HITRAP

4 MeV/u … 100 keV/u

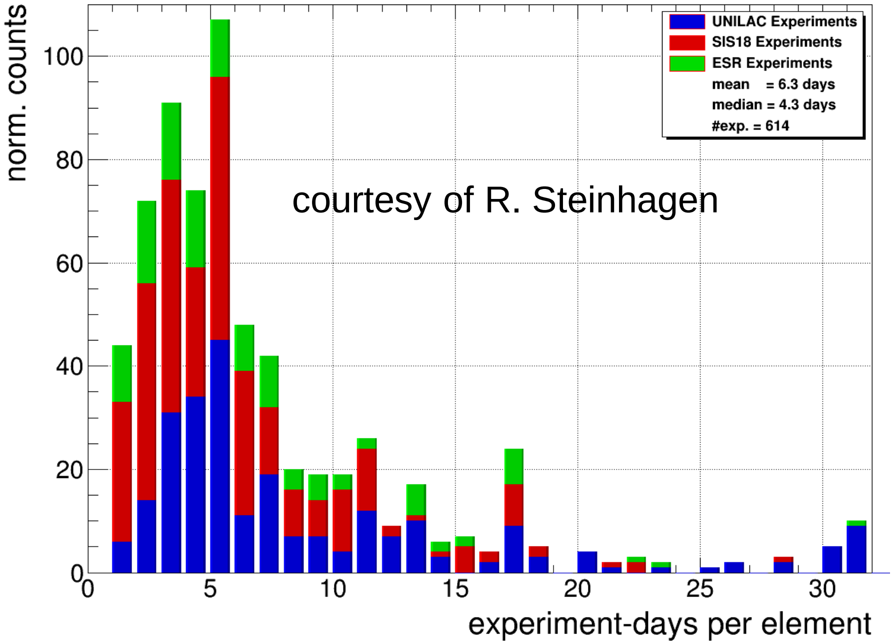
10 MeV/u

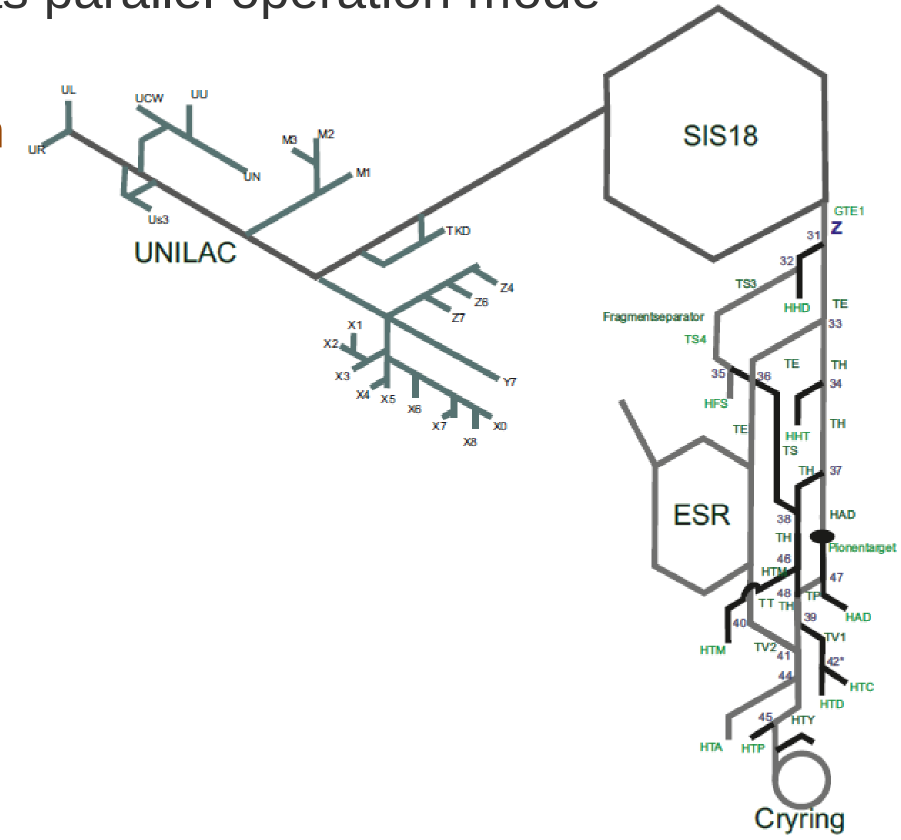
CRYRING

GSI Facilities uniqueness

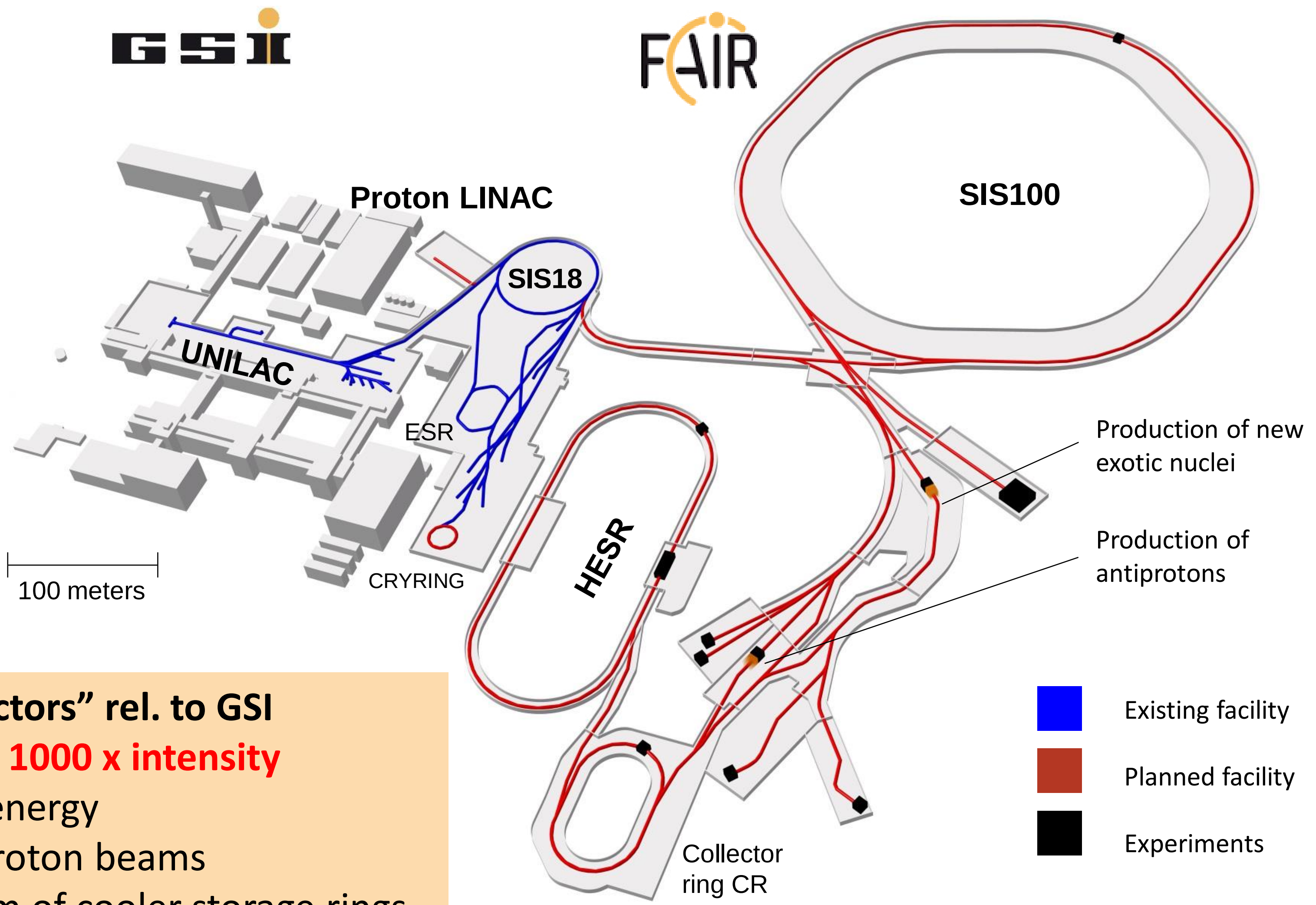
- Versatileness and flexibilities
  - unique hadron facility for multi users
  - both dedicated operation as well as parallel operation mode
    - variety of operation modes
    - relative short transition in between

Histogram of experiment durations





From GSI to FAIR

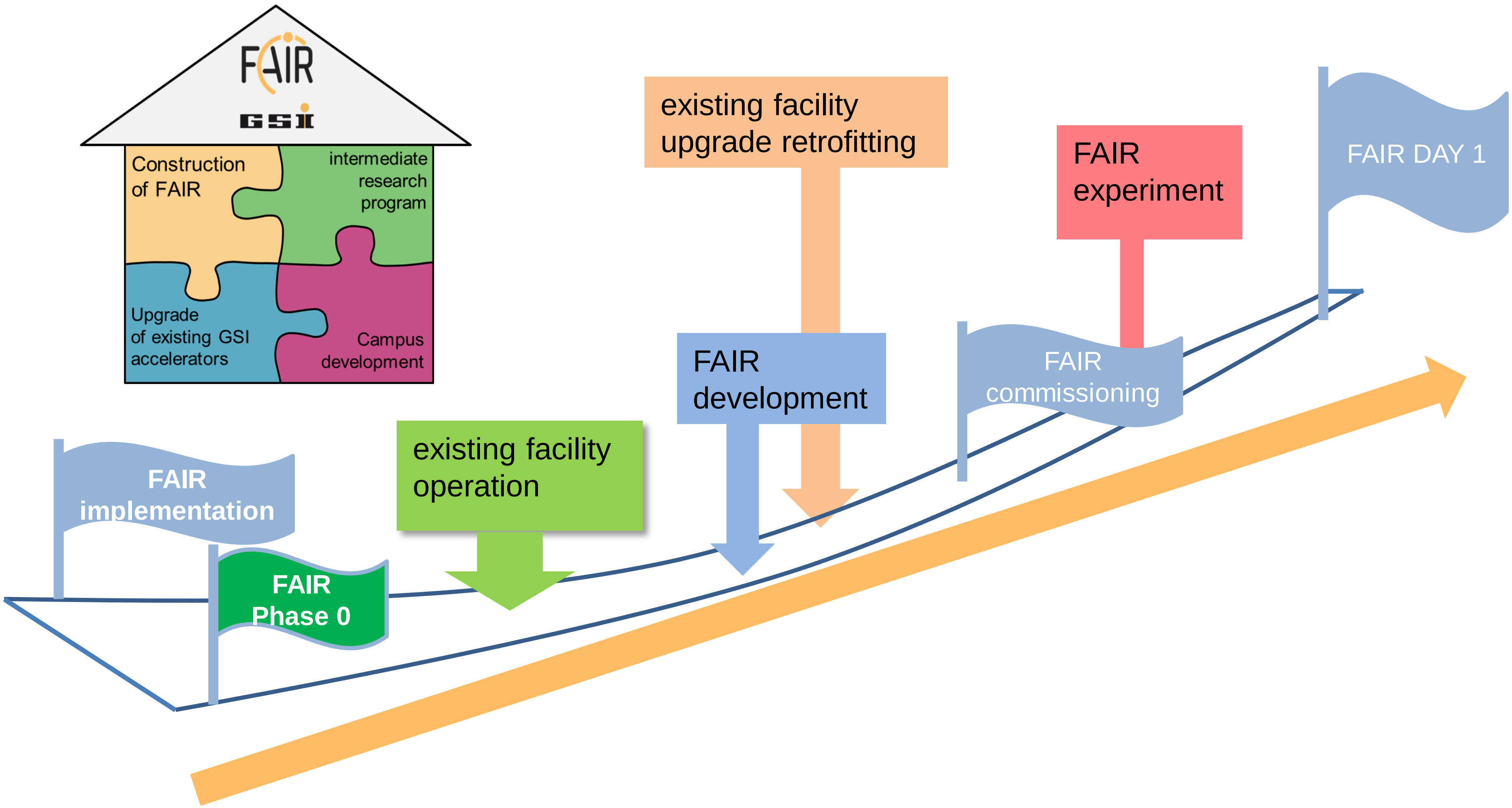


"Gain factors" rel. to GSI

- **100 – 1000 x intensity**
- 10 x energy
- antiproton beams
- system of cooler storage rings

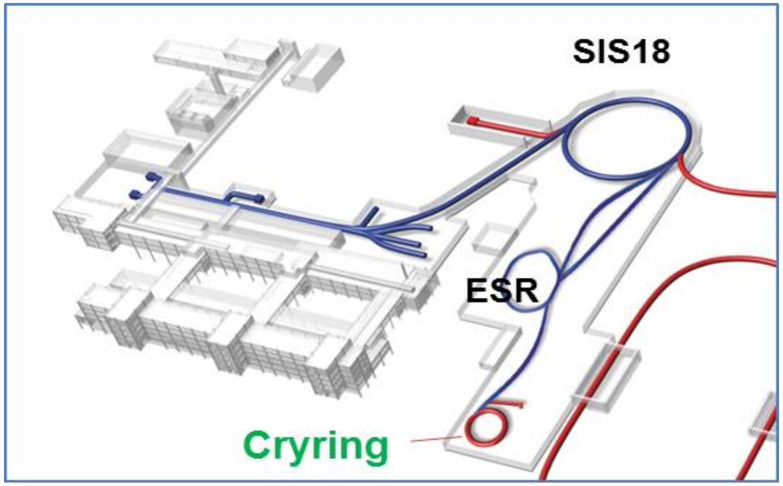
Roadmap

- From FAIR phase 0 to FAIR



FAIR Phase-0
intermediate research program

- Objectives:
  - Forefront research by employing and testing new FAIR detectors
  - Exploiting upgraded GSI accelerator facilities incl. the newly installed CRYRING
  - Education of young scientists
  - Maintain and extend skills and expertise
  - Serve national and international user community

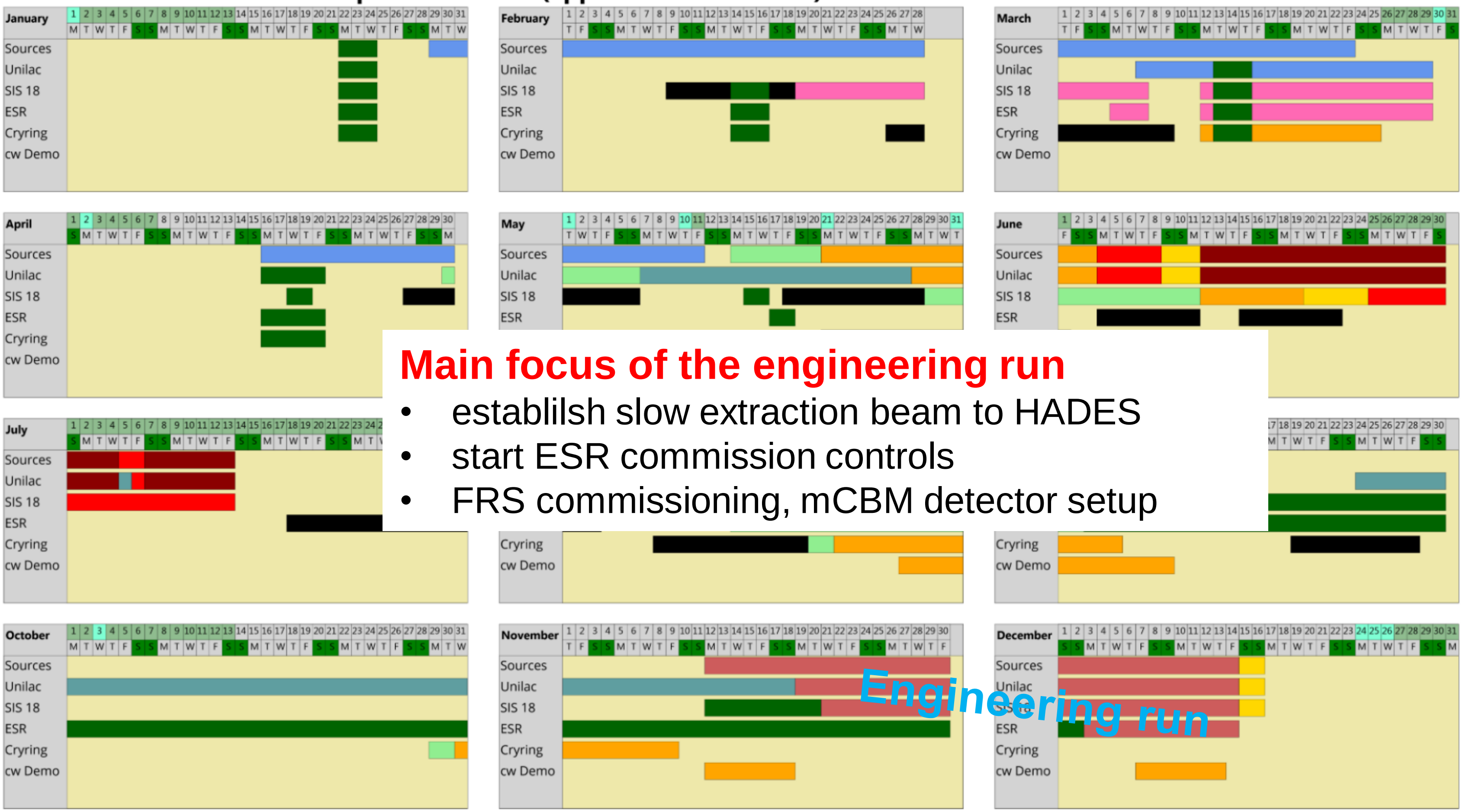


- requires careful techn. preparation:
  - full re-commissioning of the UNILAC/SIS18/ESR complex incl. new controls
  - gradual implementation of the intensity increase to avoid any damage and activation

Beamtime for FAIR Phase 0

2018

General Plan of Accelerator Operations 2018 (approved: 2018-09-16)

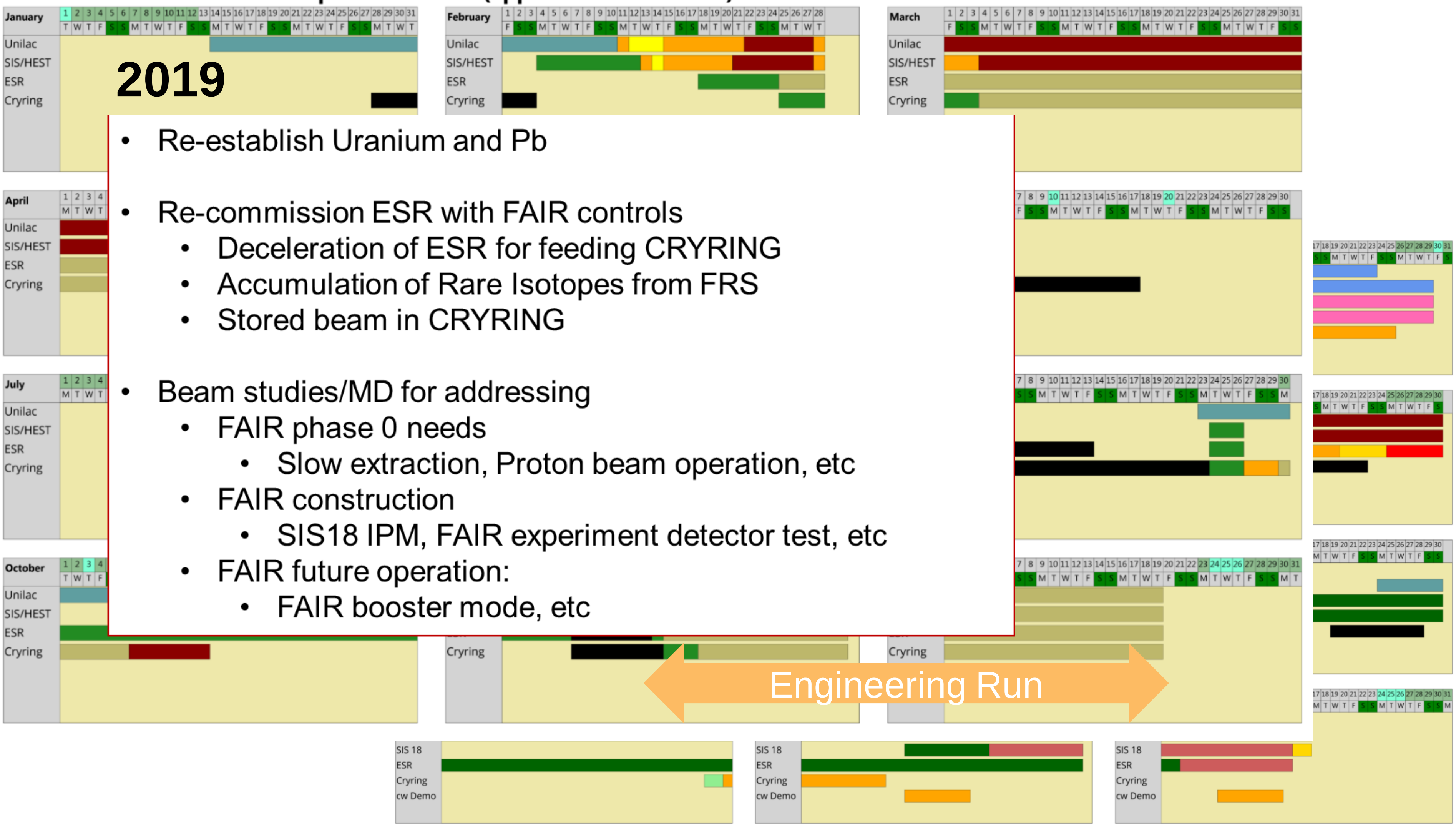


Main focus of the engineering run

- establilsh slow extraction beam to HADES
- start ESR commission controls
- FRS commissioning, mCBM detector setup

Beamtime for FAIR Phase 0

General Plan of Accelerator Operations 2019 (approved: 2018-10-24)



2019

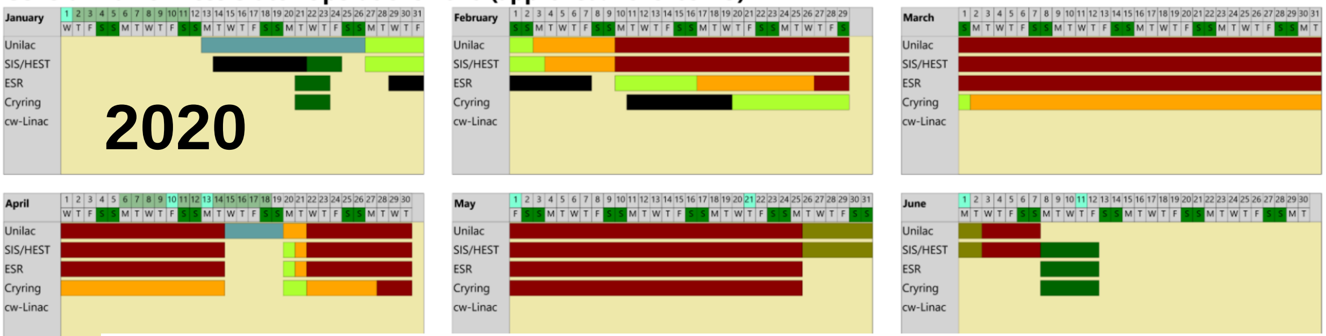
- Re-establish Uranium and Pb

- Re-commission ESR with FAIR controls
  - Deceleration of ESR for feeding CRYRING
  - Accumulation of Rare Isotopes from FRS
  - Stored beam in CRYRING

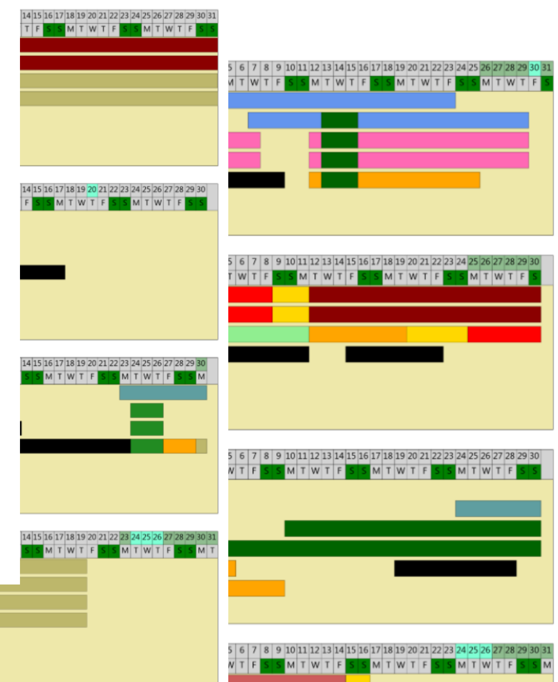
- Beam studies/MD for addressing
  - FAIR phase 0 needs
    - Slow extraction, Proton beam operation, etc
  - FAIR construction
    - SIS18 IPM, FAIR experiment detector test, etc
  - FAIR future operation:
    - FAIR booster mode, etc

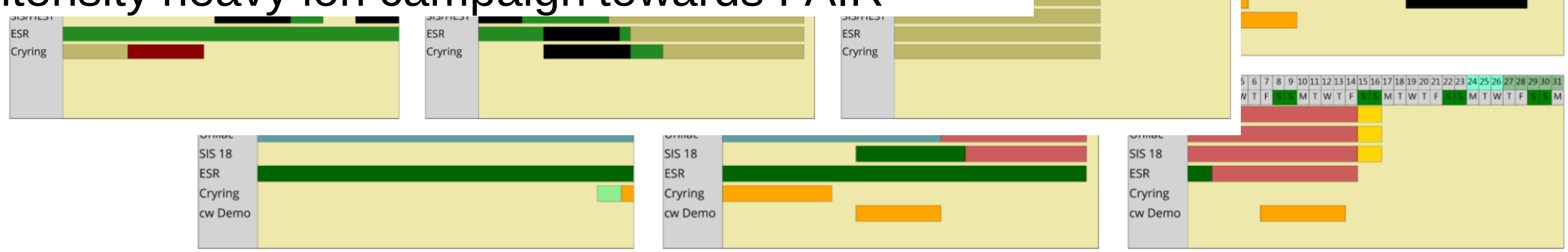
Beamtime for FAIR Phase 0

General Plan of Accelerator Operations 2020 (approved: 2019-09-13)



- Despite of the COVID-19, 2/3 of the experiments including the challenging ones such as bound state beta decay were fulfilled
- Heavy ion beams established throughout the chain
- Re-establish ESR for its storage ring operation mode including beam stacking
\
- CRYRING is commissoned with beam from ESR
- High intensity heavy ion campaign towards FAIR





Current nominal performance

- https://www.gsi.de/work/beschleunigerbetrieb/betrieb.htm

Nominal Intensities at Experiment for UNILAC and SIS18 Operation 2021-2022

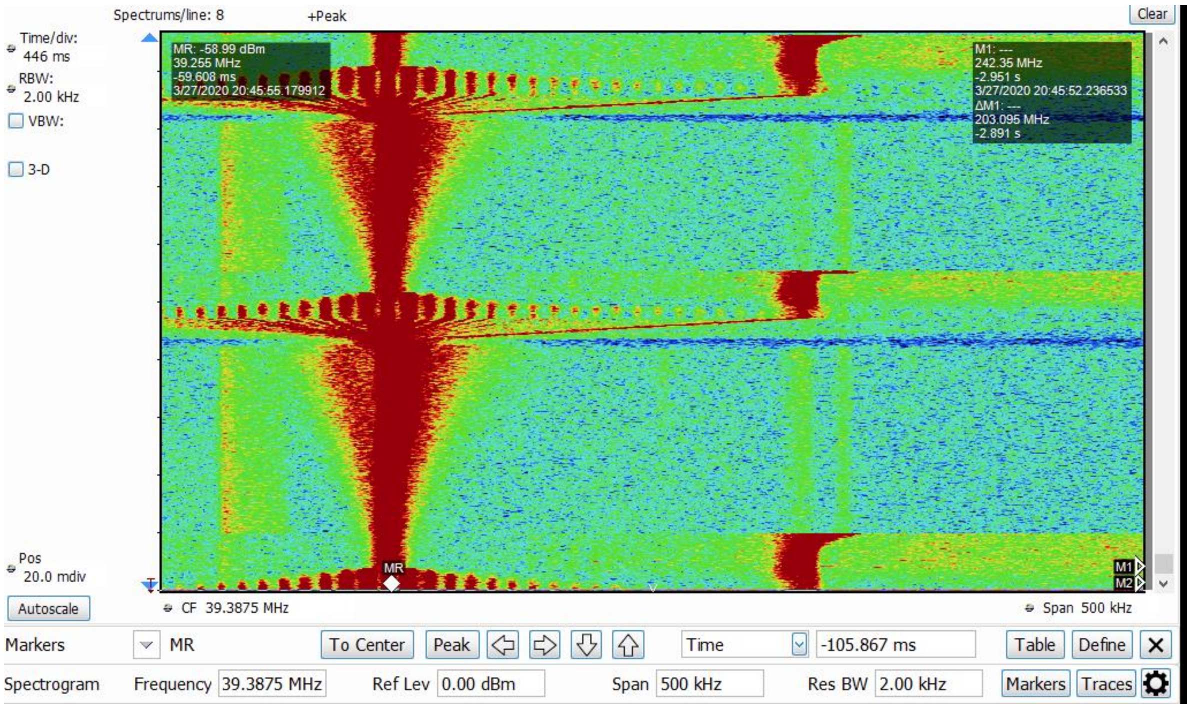
* 50Hz Operation for the UNILAC Experiments will be restricted by the MAX Energy of 8.4 MeV/u.
** Beam energy upto 8.6MeV/u: 1) lower charge state especially for heavy ions 2) limitation on highest energy for heav ions 3) could be limitation for beam quality, which can limit the development of high intensity development towards FAIR
*** nominal intensity for slow extracted SIS18 depends on the beam energy. Currently, the SIS18 electrostatic septum efficiency scales down from rigidity 12Tm.
**** bold green ions have been used in the current ongoing operations since 2019

			UNILAC			SIS18				
Projectile	Charge	Isotope	Average particle current	MAX Rep rate*	Ion Source	Nominal Intensity (per Cycle)	MAX Rep Rate (fast extraction)	Maximum energy [GeV/u]	Ion Source	Comments
U	73/68	238				2.00E+09	1Hz	1/0.9	VARIS	1)The standard operation with pulsed gas stripper is not supported in 2021-2022 2) The HSI RFQ currently reached 85% of the nominal voltage required for U4+ beam
Bi	68/64	209				2.00E+09	1Hz	1.1/1.0	VARIS	
Pb	67	208				1.00E+09	0,5Hz	1.075	VARIS	The enriched 206 Material is in house (was bought for the EXP Litvinov). The enriched materila for 208 Isotope must be procured extra.
Au	65	197				1.50E+09	1Hz	1.11	VARIS	
	26		0.1 pμA	50Hz	PIG				PIG	
Xe	48	124				2.00E+09	1Hz	1.4	MUCIS	The MUCIS Projectile production ist 5Hz
Ag	45	107				1.00E+09	1Hz	1.57	VARIS	
Ti	22	50				2.00E+08	1Hz	1.67	PIG	
	12		0.8 pμA	50Hz	PIG					
Ca	20	48				5.00E+08	1Hz	1.55	EZR	
	10		0.8 pμA	50Hz	EZR					
Ar	18	40				3.00E+10	1Hz	1.72	MUCIS	
Ni	26	58				5.00E+09			VARIS	offered in 2014
Ne	10	22				5.00E+09	1Hz	1.72	MUCIS	offered in 2011
O	8	18				5.00E+10	1Hz	1.69	VARIS	
	3	16/18	1 pμA	50Hz	EZR					
N	7	14				7.00E+10	0,35Hz	1.99	MUCIS	Approved by Radiation Protection
Li	1,3	7				2e10/1e9			PIG	offered in 2010
C	6	12				4.00E+09	1Hz	1.99	MUCIS	
	2		2.4 pμA	50Hz	EZR					possible basic attenuation
P	3	H3 molecule				1.00E+09	0.1Hz		MUCIS	parallel option limited to A/Q upto 6
p	1	CH3 molecule				8.00E+10	0.1Hz	4.67	MUCIS	The operation with protons has the following restrictions from teh UNILAC site: - Operaiton with Gasjet-Stripper, not pulsed - CH3 from High current Ion Source - exclusive operation, no other beams in Poststripper

Beam time 2020 Achieved

- Despite of the COVID-19, 2/3 of the experiments including the challenging ones such as bound state beta decay were fulfilled
- Heavy ion beams established throughout the chain
  - 1.3e9 uranium beam was established at the end of 2nd Engineering run
  - Stable Pb and Bi beam throughout beam time. 2e9 Bi beam was established at SIS18 flattop with and without the last tank of UNILAC Alvarez (A4)
- Re-establish ESR for its storage ring operation mode including beam stacking
- Highly charged Pb beam from ESR were injected, stored, cooled and decelerated in the CRYRING. Lifetime at different energy was measured. Pb82+ lives between 10-20 seconds
- Proton beam for FAIR phase 0
  - Proton beam@4.5GeV was established and slow extracted to the target
  - 5e10 beam intensity at flattop was achieved. Higher intensity for 2021 beam time is foreseen if ample time is available for machine optimization
- High intensity heavy ion campaign towards FAIR
  - 4e10 Bi28+ was established at SIS18 injection, and upto 3e10 were at flattop

Highlights: ESR

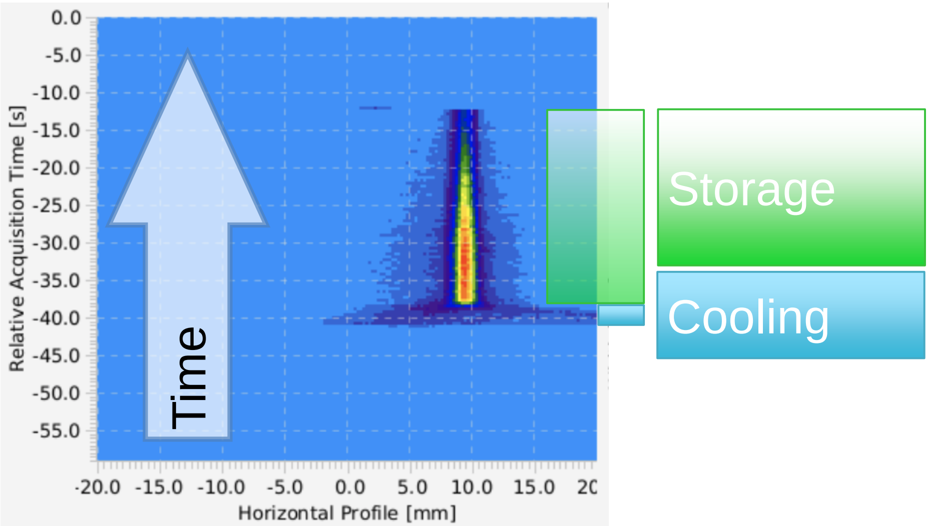


- Beam stacking is now operational
- Pb beam decelerated, and extracted to CRYRING

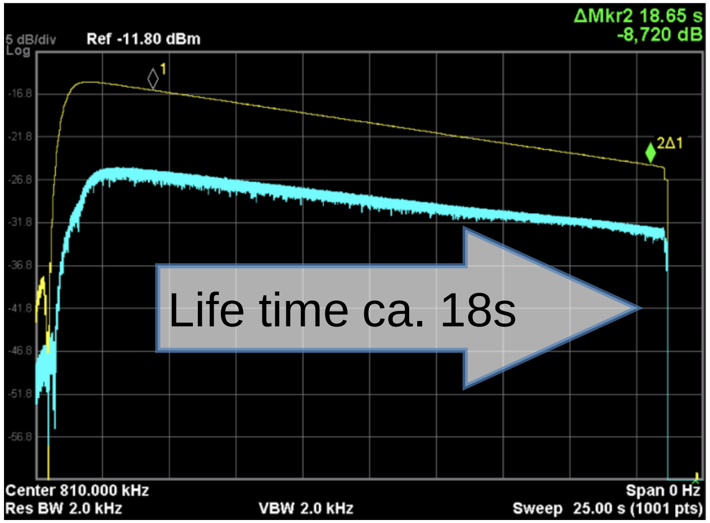
Highlights: CRYRING

- Captured, Stored and Cooled Pb^{78+} and Pb^{82+} (bare)
  - 6 x 10^6 particles delivered from ESR at 10 MeV/nucleon
  - 3 x 10^5 particles available for experiments in CRYRING@ESR after cooling
  - Ion beam deceleration to 4 MeV/nucleon has been successfully tested
- Lifetimes measured for different energies and ions
  - Pb^{82+} lives between 10 and 20 seconds

Electron Current	Lifetime Measured / s	Lifetime beamcalc / s	@10 MeV/u
12 mA	24(1)	33	Pb78+
22 mA	8(1)	28	Pb78+
12 mA		23	Pb82+
12 mA		18	U92+
			@4 MeV/u
0 mA	5(1)	7.5	Pb78+



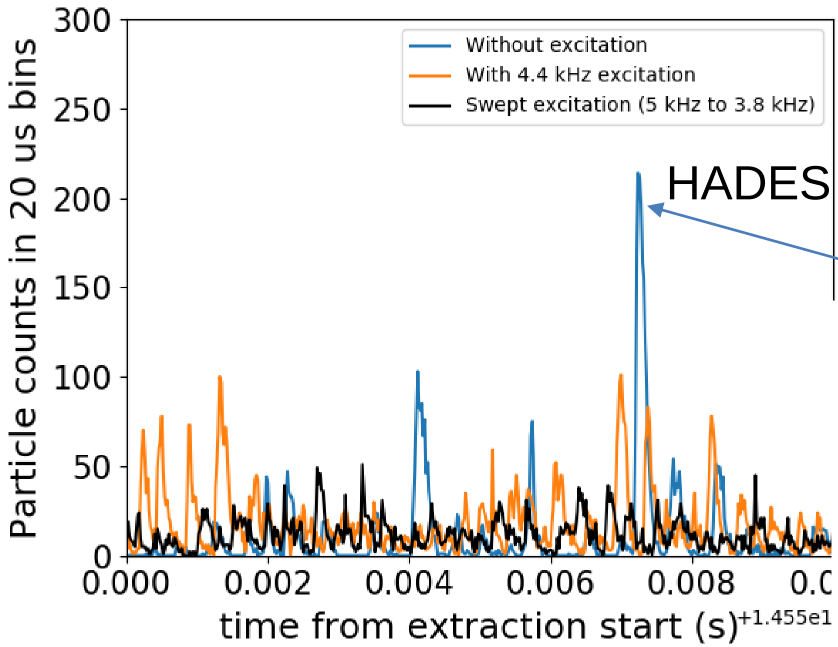
Horizontal beam profile over time



Lifetime, i.e. time for a signal drop of 8 dB

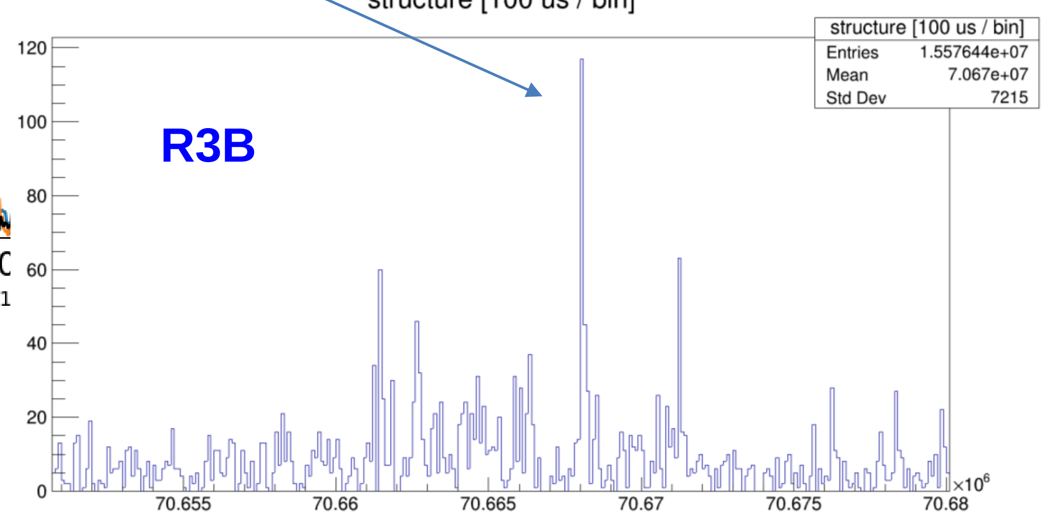
Highlights: SIS18 slow extraction

- **sporadic spill structure**
  - Not yet comprehensive measurements to ping down the smoking gun(s)
  - Cause deadtime on the detectors



- **Deadtime resulted a factor of 5 reduction of physics rate!**

Lot of empty and overfilled bins without excitation

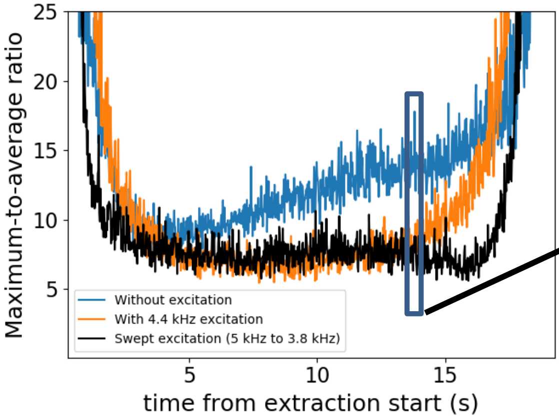


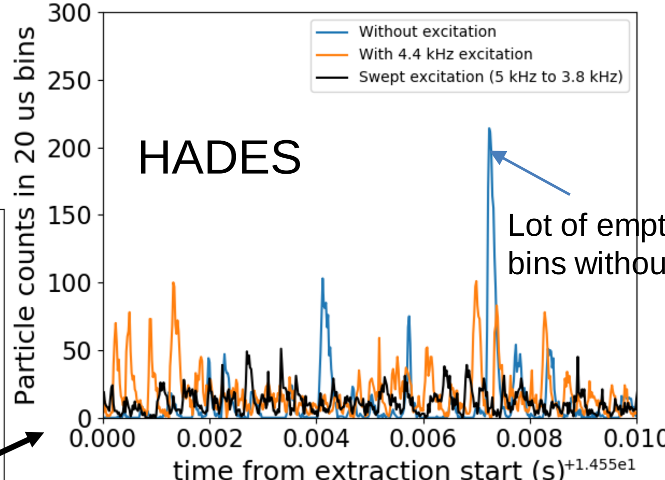
Highlights: SIS18 slow extraction

- sporadic spill structure
  - Not yet comprehensive measurements to ping down the smoking gun(s)
  - Cause deadtime on the detectors

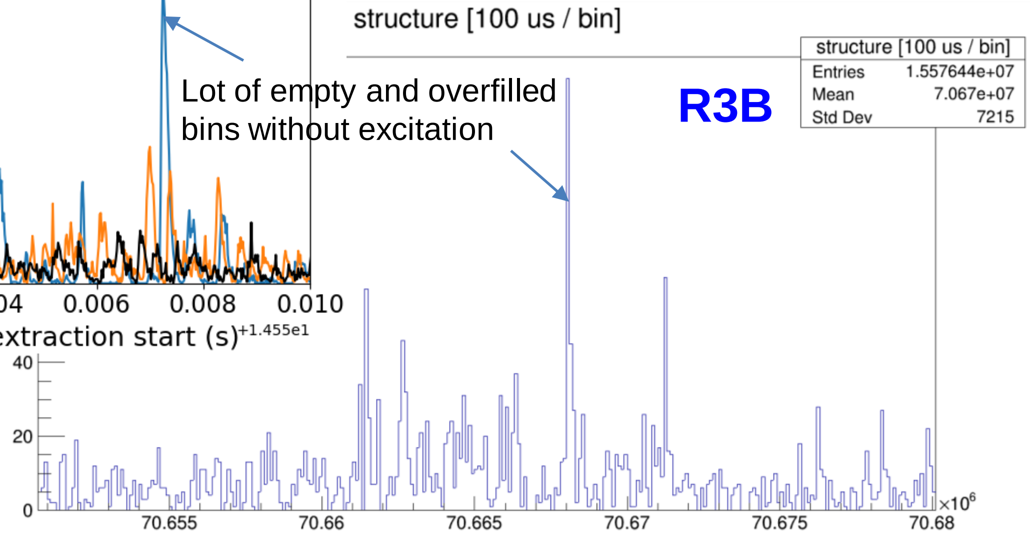
- **Deadtime resulted a factor of 5 reduction of physics rate**
  - Knockout instead of res. extraction

Significant improvement of extraction beam quality w.r.t that HADES!





Lot of empty and overfilled bins without excitation



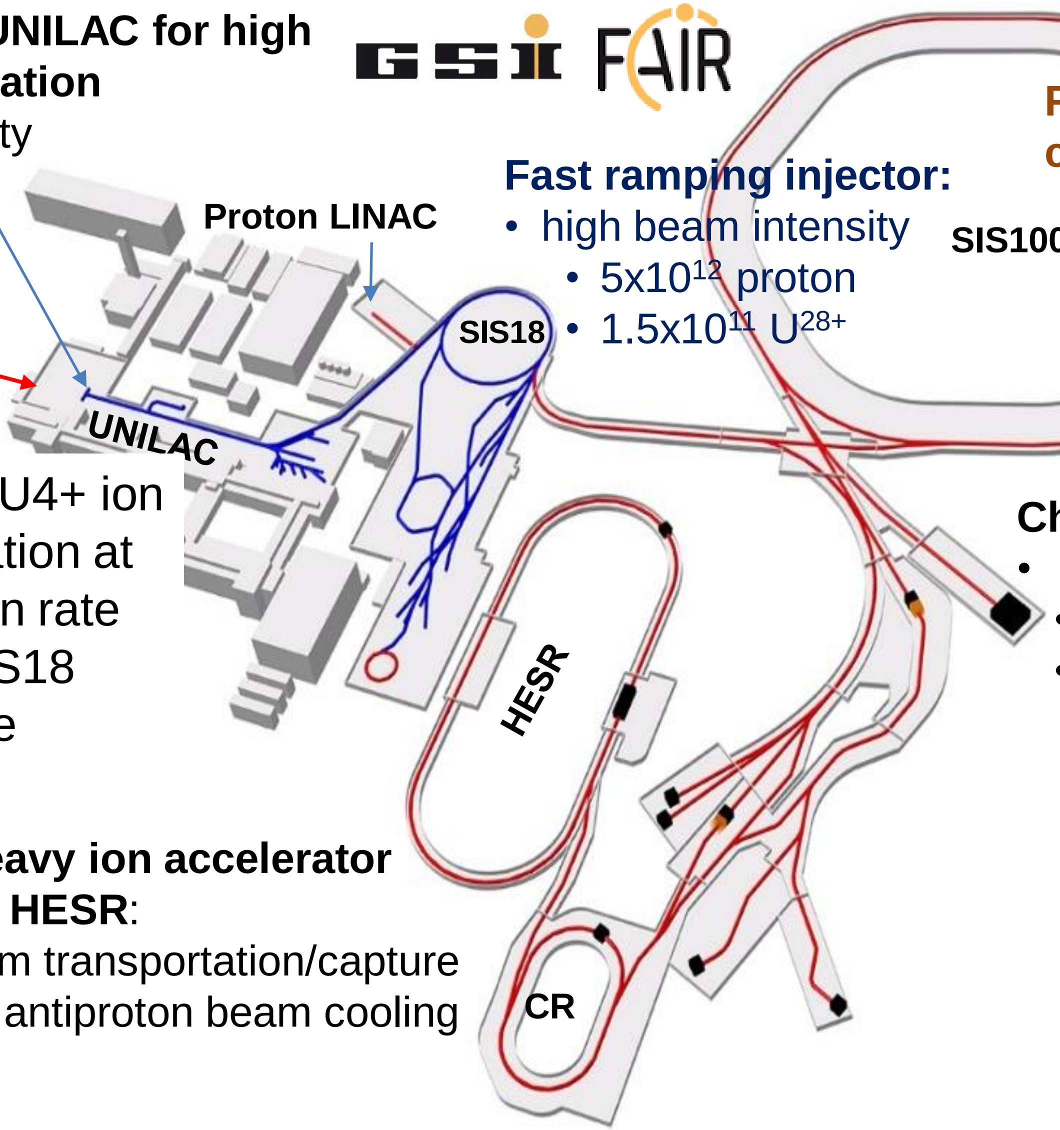
R. Singh et al, PHYSICAL REVIEW APPLIED **13,** 044076 (2020)

Challenges in Accelerator Science & Technology

Upgrade the UNILAC for high intensity operation
- beam intensity
- reliability

Ion sources

High current U4+ ion source operation at high repetition rate 2.7 Hz for SIS18 booster mode



Fast ramping injector:
- high beam intensity
  - 5×10^{12} proton
  - 1.5×10^{11} U^{28+}

Fast ramping super-conducting synchrotron:
- Fast ramping superconducting magnet
- **5×10^{13} proton**
- **4.5×10^{11} U^{28+}**

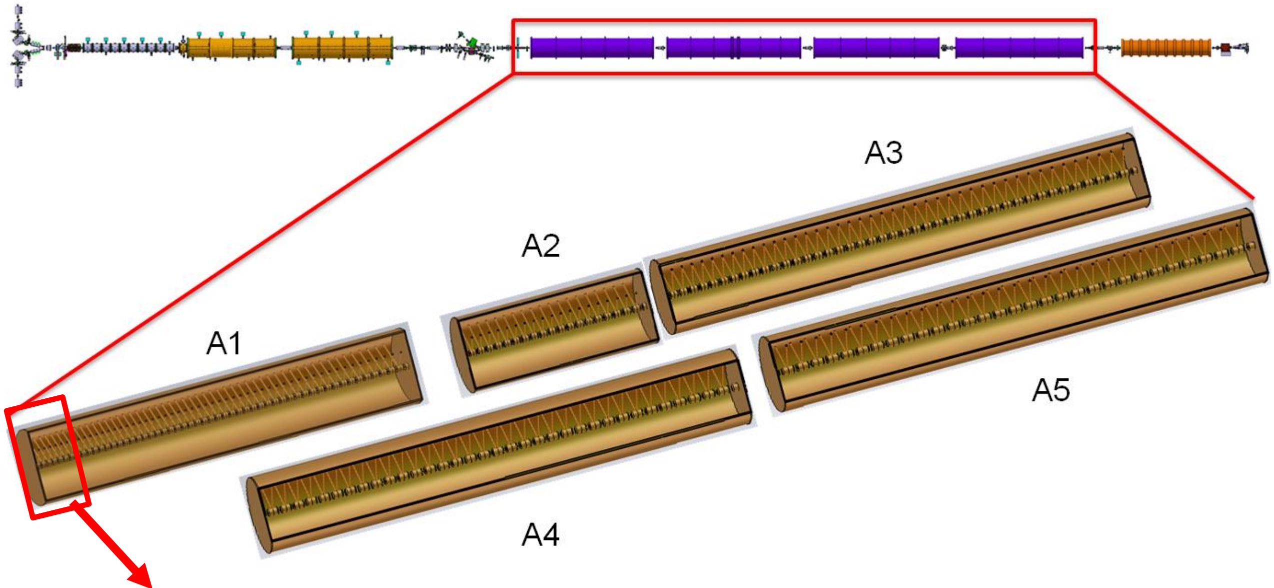
Challenging beam technique
- Extraction:
  - spill structure
  - Beam position stability

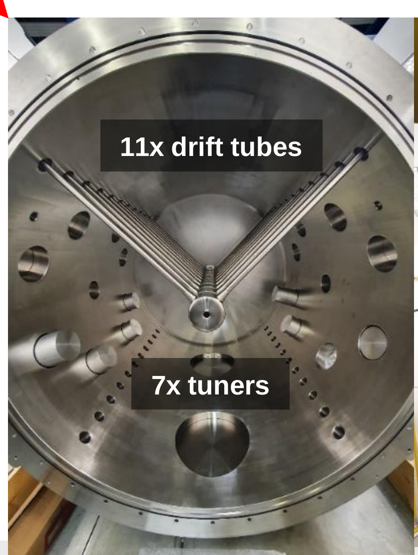
Antiproton/heavy ion accelerator chain CR and HESR:
- Efficient beam transportation/capture
- High energy antiproton beam cooling

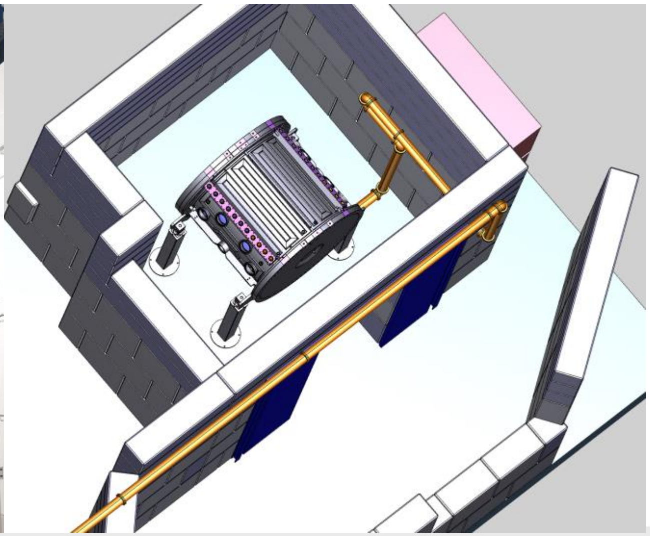
Measures for meeting FAIR requirements

	Upgrade measures	Status	Timeline
Ion source	2.7 Hz high current uranium source	ongoing	2018 to 2021
	dedicated uranium terminal	planned	2020 to 2023
UNILAC	HSI RFQ upgrade Redesign of RFQ beam dynamics and matching to subsequent pre-stripper, LEBT, RFQ dynamics, MEBT	proposed	• Corresponding strategy will be formed after carefully evaluating the systematic high intensity heavy ion beam performance during the upcoming operations • Implementation of the strategy depends on the budget availability
	HSI MEBT upgrade	proposed	Similar as above
SIS18	Cryo pumps to mitigate the dynamic vacuum instability	proposed	Similar as above
	Advanced techniques to address beam intensity limitations	Under investigation	Similar as above
	Systematic evaluation of beam parameters including 6D emittance	Proposed	**Q4 2019 to FAIR commissioning**
CRYRING	Upgrade of RF and vacuum	Proposed	Depending on budget and resource availability

The Alvarez Poststripper Replacement







Path towards FAIR

Targeted R&D

-- UNILAC upgrade measures

high intensity RFQ, heavy ion stripping, end2end optimization, etc

-- SIS18:

1) intensity limitation mechanism: dynamic vacuum,
   other beam instability mechanisms, etc

2) mitigation: feedbacks. etc

-- Storage rings: precision beam controls

Systematic evaluation of the UNILAC and SIS18 performance for meeting long term needs

-- UNILAC - SIS18 high intensity/high brilliance MDs

-- full commissioning of SIS18 upgrade measures

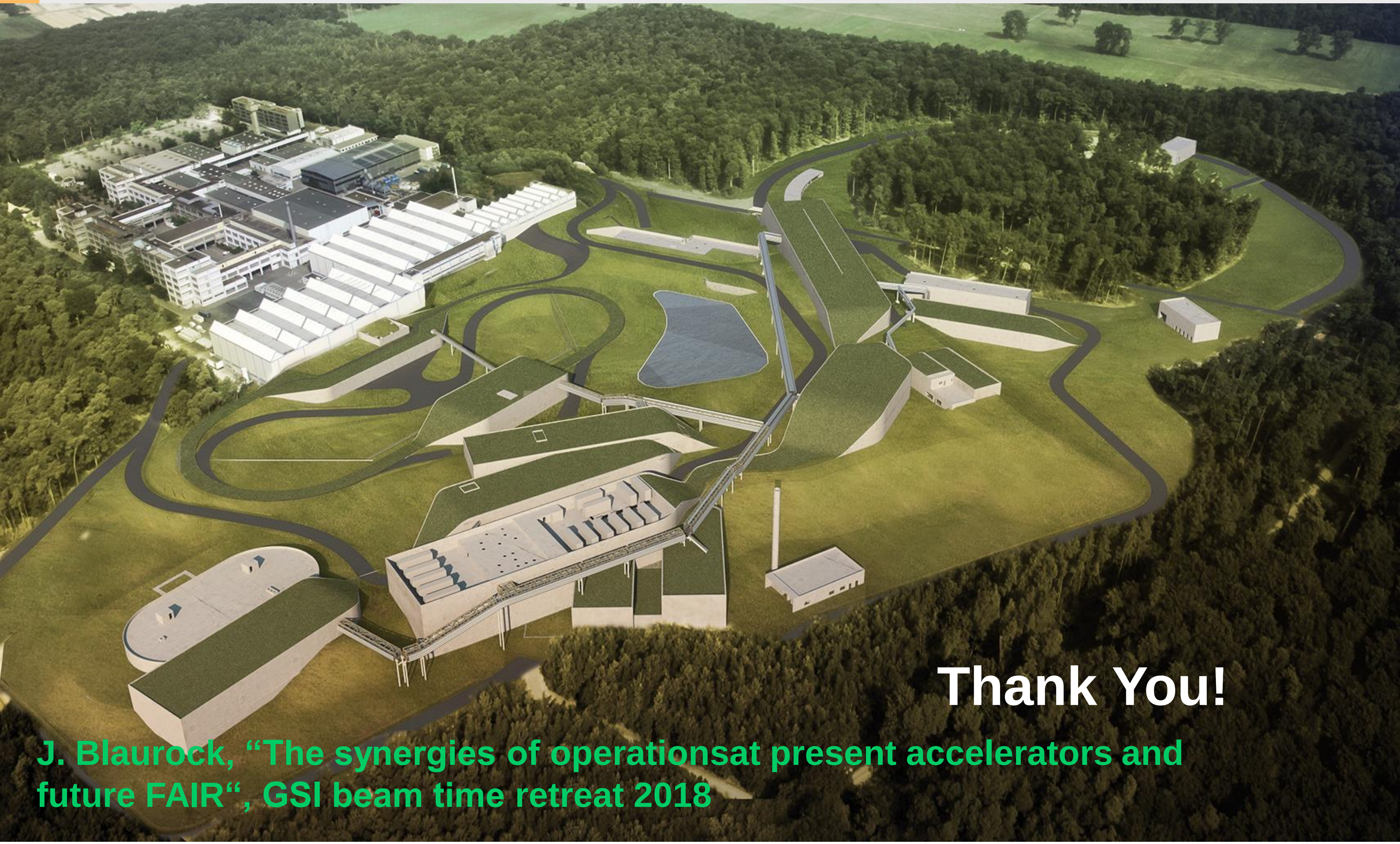
-- continue 2.7Hz ion source development and UNILAC new post stripper (Alvarez) implementation

present

Implementation of all identified mitigation measures

-- mitigating all UNILAC and SIS18 limitations

FAIR 2025


Thank You!
J. Blaurock, “The synergies of operationsat present accelerators and future FAIR“, GSI beam time retreat 2018