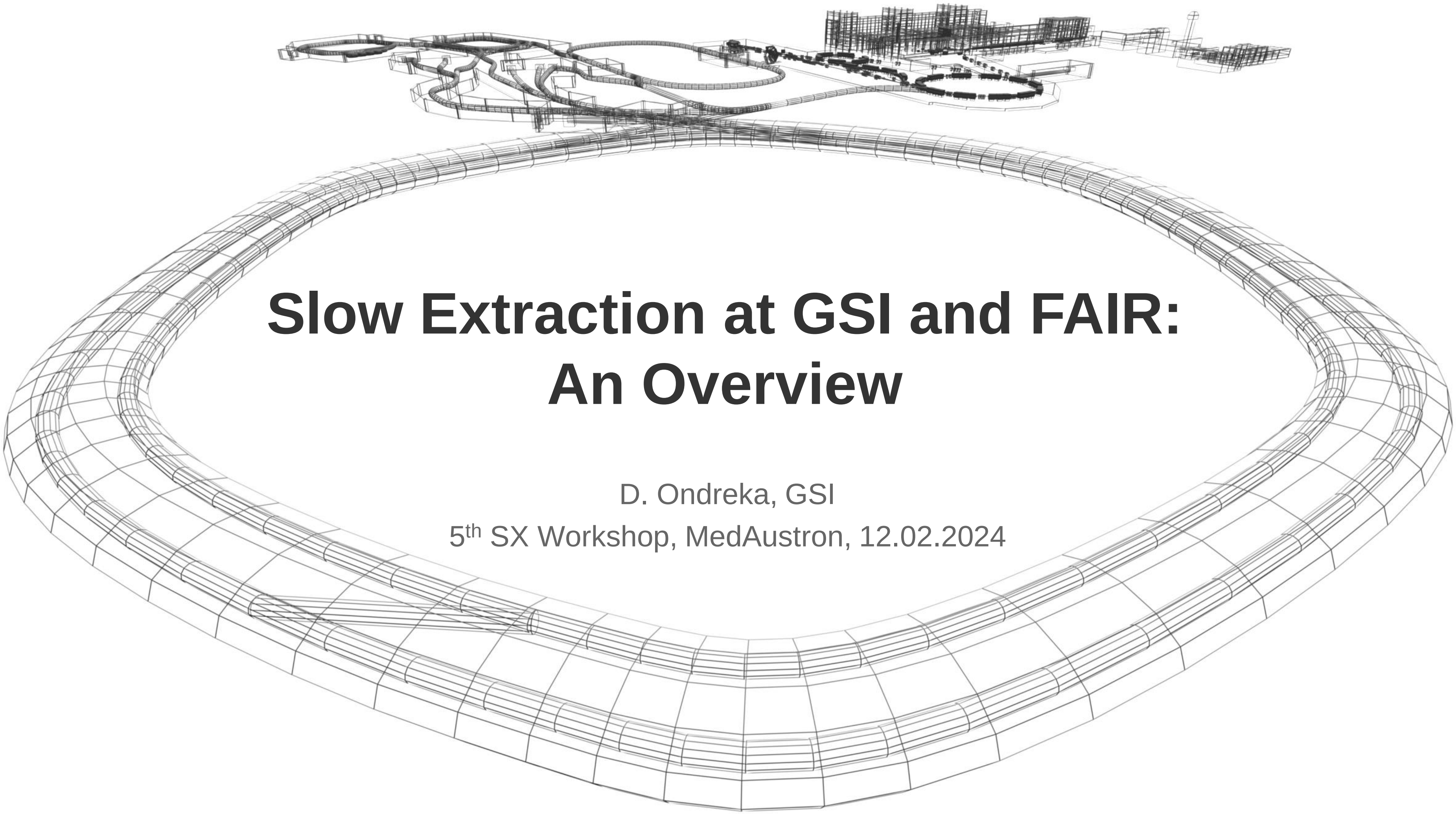


Slow Extraction at GSI and FAIR: An Overview

D. Ondreka, GSI

5th SX Workshop, MedAustron, 12.02.2024

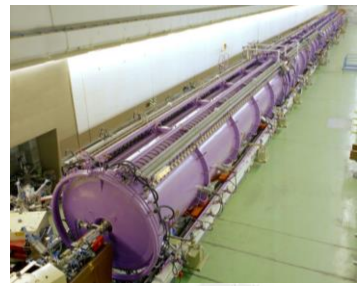
Contents

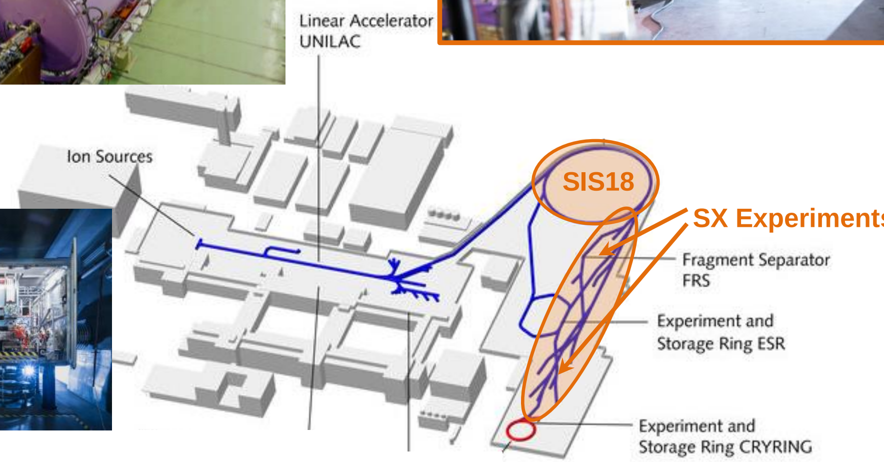
- Overview of GSI and FAIR
- Slow extraction from SIS18 and SIS100
- Slow extraction development priorities

GSI and FAIR: Location

GSI

- Heavy ion research since 1969
  - About 1500 employees
  - About 1200 scientific users/year
- Accelerator facility
  - Linear accelerator UNILAC
  - Synchrotron SIS18
  - Storage rings ESR and CRYRING
- Capabilities of GSI’s accelerators
  - Big variety of ions from p to uranium
  - Large range of energies and intensities
  - Flexible parallel operation
  - Short turn-around times
  - Many experimental places
  - Slow extraction from SIS18





FAIR

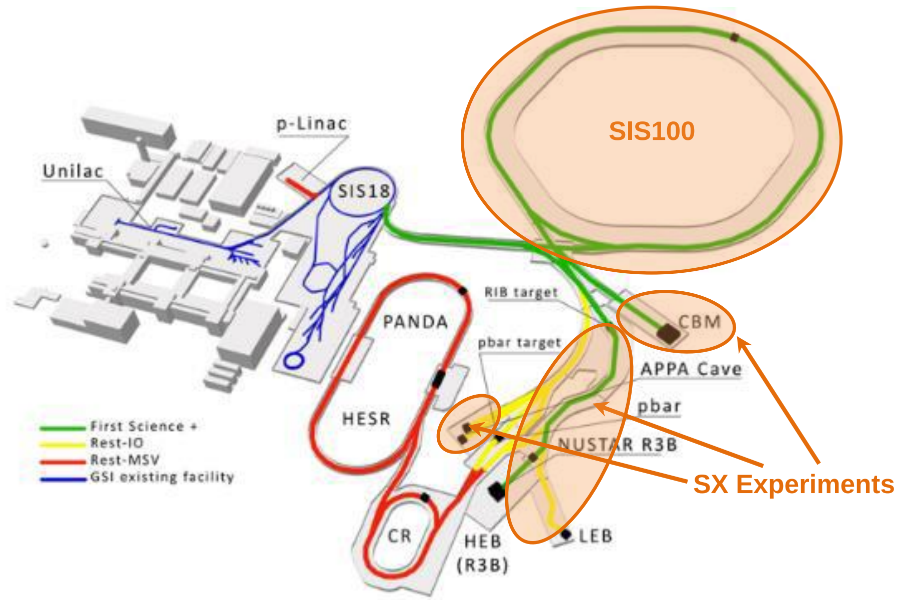
- Next generation heavy ion research
  - Large accelerator and experiment complex
  - Built in stages next to GSI site
  - Natural extension of experimental program
  - Slow extraction from synchrotron SIS100

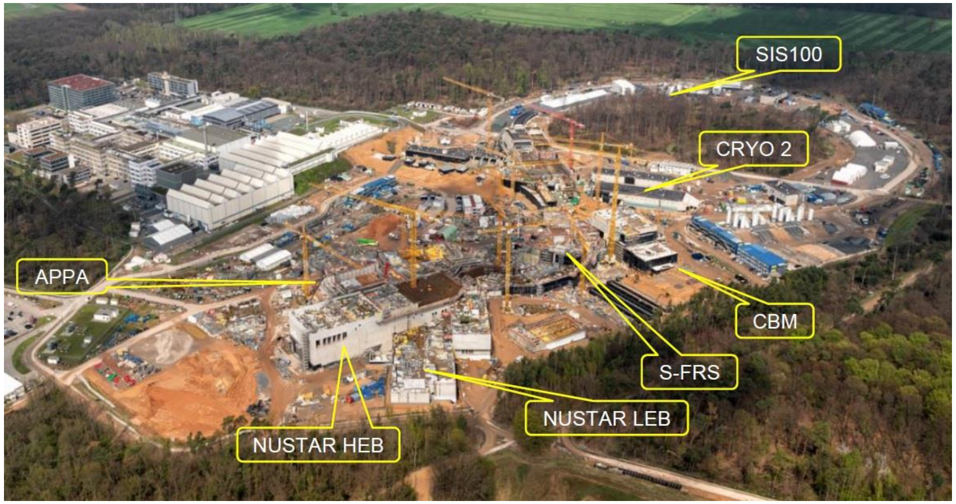
- Performance increase compared to GSI
  - Primary beam intensities: 100x
  - Secondary beam intensities: 10000x
  - Primary beam energies: 10x

Primary Beam Intensities at GSI and FAIR

		p	Ar	Xe	U
Charge number	GSI	1	18	48	73
	FAIR	1	10	21	28
Energy [GeV/u]	GSI	4.7	1.7	1.3	1.0
	FAIR	28.8	6.6	4.0	2.7
Intensity [Ions/s]	GSI	10^{11}	$8\cdot10^{10}$	$2\cdot10^{10}$	$4\cdot10^{9}$
	FAIR	10^{13}	10^{12}	$5\cdot10^{11}$	$3\cdot10^{11}$

Visit FAIR site and buildings on YouTube:
FAIR Construction Site – November 2023



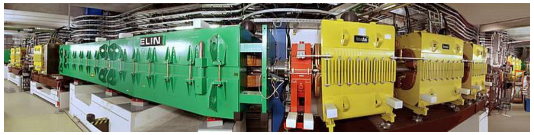


Experiments Requiring Slow Extraction at GSI and FAIR

- Experiments from a wide range of fields
  - Hadron physics and strong interactions
  - Nuclear and atomic physics
  - Material sciences and biophysics
- Fixed target experiments
  - Primary beams from protons to Uranium
  - Frequently rate limited by detection systems
  - Typically extraction times of a few seconds
- Secondary beam production
  - Standard for FRS and Super-FRS
  - Also applied for HADES and CBM
  - Requires highest intensities of primary beams
- High intensity slow extraction for FAIR
  - Major challenge for machine protection in SIS100
  - Electrostatic septa operated at their limits

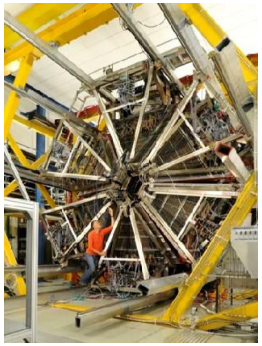
Talk on Tuesday

Fragment Separator FRS



Medical Physics Cave

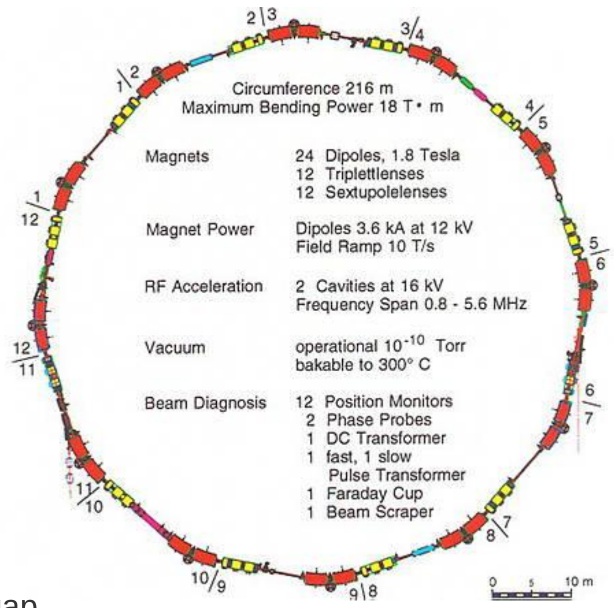
HADES Detector



NUSTAR · R3B · LaSpec · MATS · CBM · HADES · sparc · BIOMAT

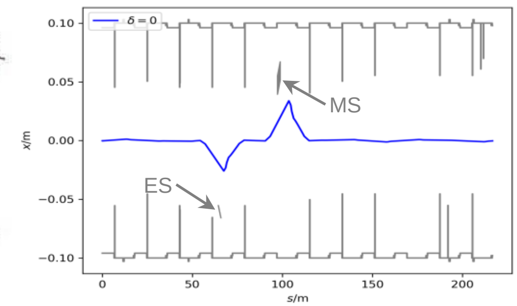
SIS18: SX Overview

- Third-order resonant extraction
  - Resonance excitation by six sextupoles
  - Chromaticity correction optional
  - Independent orbit bumps at ES and MS
- Standard extraction modes
  - Quadrupole-driven extraction
  - Transverse RF KO extraction
  - Both DC and bunched beams
- Extraction devices
  - Fast quadrupole pair for quad-driven SX
  - ES: 100µm W/Rh wires, 160kV @ 18mm gap
  - Horizontal exciter for KO-SX

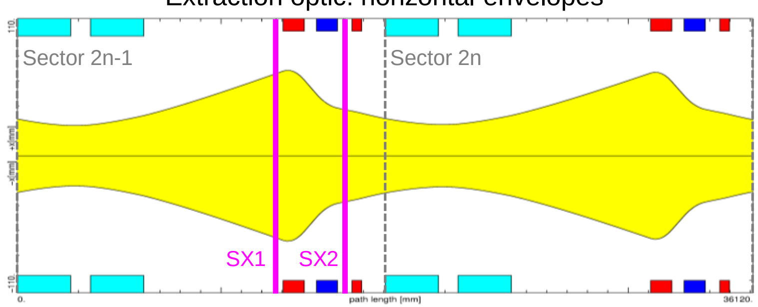


SX parameters	
Hor. tune	4.33
Hor. chromaticity	-6
Sextupole amplitude	0.05 m^{-2}

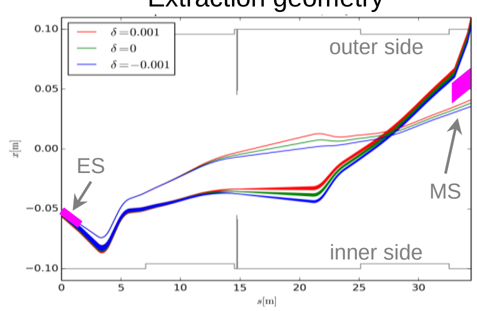
Extraction orbit



Extraction optic: horizontal envelopes

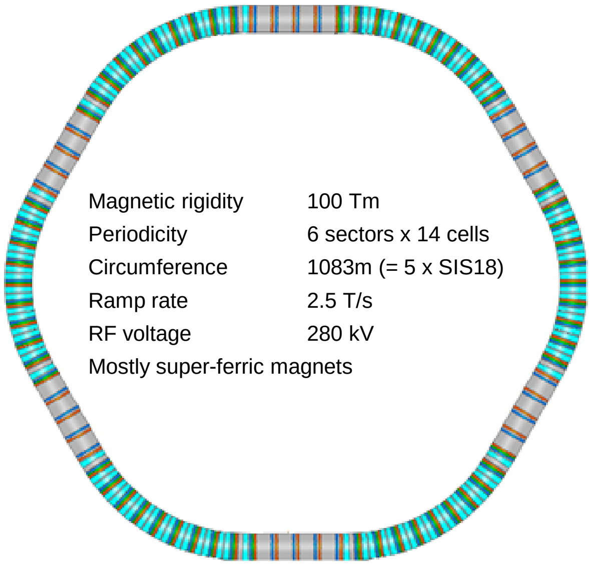


Extraction geometry



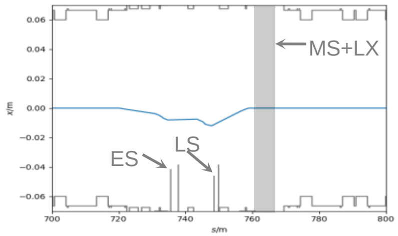
SIS100: SX Overview

- Lattice optimized for reference ion U^{28+}
  - Super-conducting machine for XHV (<10^{-12} mbar)
  - Strong DF focusing for best collimation of U^{29+}
  - Large tunes (~18) and chromaticities (~ -20)
- Third order resonant extraction
  - Six NC sextupoles with harmonic distribution
  - Chromaticity corrected by 42 SC sextupoles
  - Vertical extraction through Lambertson septum
  - Single orbit bump at ES/LS
- Foreseen extraction modes
  - Baseline: transverse RF KO extraction
  - Alternative: magnet-driven scheme
  - Both DC and bunched beams
- Extraction devices
  - ES: 100µm W/Rh wires, 180kV @ 20mm gap
  - LS: Lambertson septum for vertical deflection
  - Horizontal exciter for KO-SX

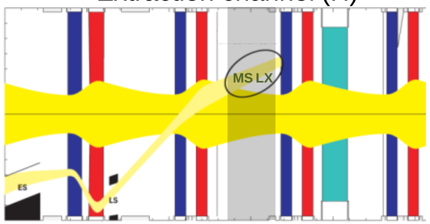


SX parameters	
Hor. tune	17.33
Hor. chromaticity	-1 (-20)
Sextupole amplitude	0.5 m^{-2}

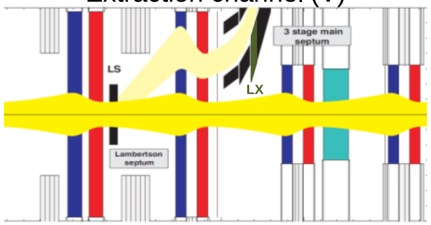
Extraction orbit



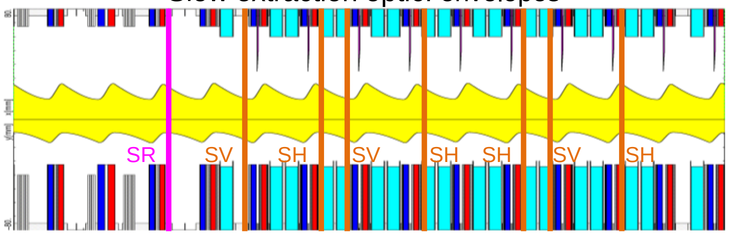
Extraction channel (H)



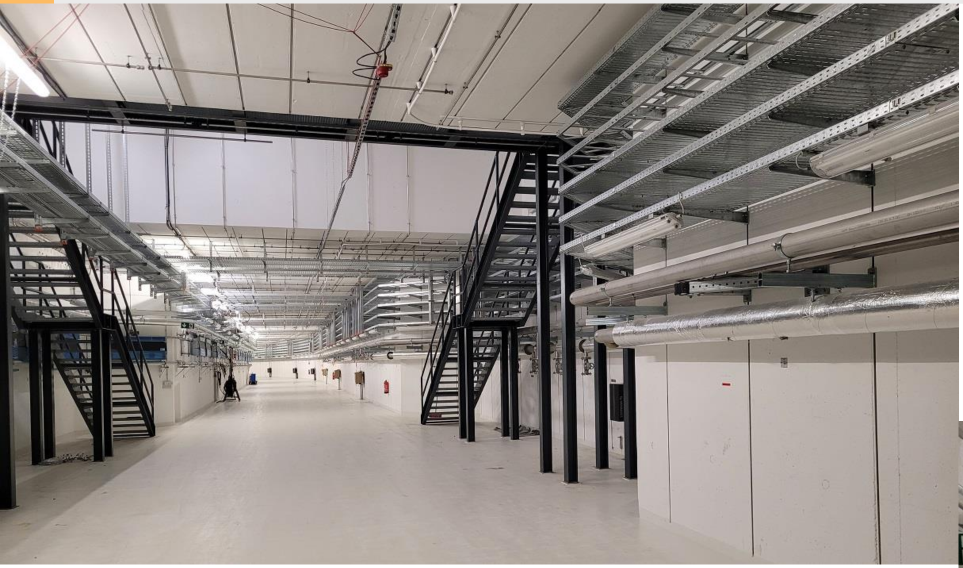
Extraction channel (V)



Slow extraction optic: envelopes



SIS100: Installation coming soon…



Magnet string test
at serial test facility

Components waiting to be installed

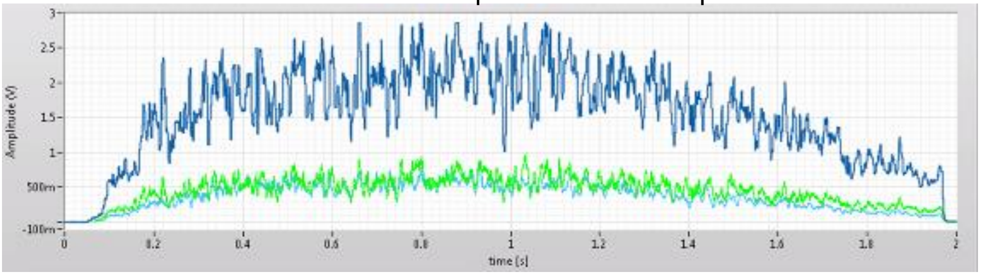
Acceleration
cavities

Dipole
modules

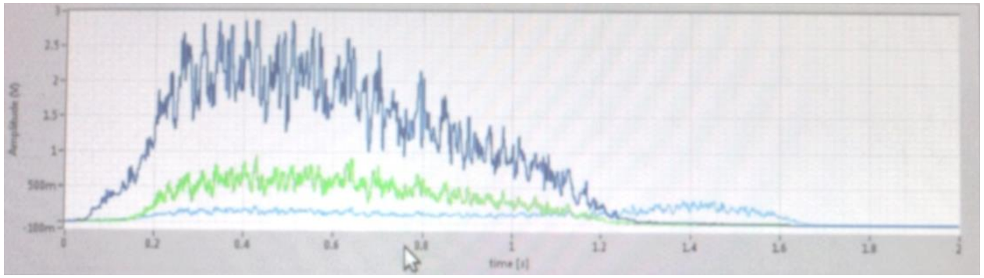
Highlight: SX of Dual Isotope Beam

- Mixed carbon/helium beam for ion therapy
  - Final goal: online-monitoring of applied dose
    - Carbon stopped in tumor, helium exiting patient
  - Requires beam with constant mixing ratio
- Delivery of mixed $^{12}C/^{4}He$ beam from SIS18
  - Achieved for the first time world-wide in Nov. 2023
  - KO SX with reduced chromaticity used, sufficiently insensitive to mass difference of $6 \cdot 10^{-4}$
  - Quad-driven SX with natural chromaticity actually separates the two isotopes!

Distribution of isotopes over KO-SX spill



Distribution of isotopes over quad-SX spill



The Big Challenge: Spill Structure

- Top priority for many experiments using SX
  - Potential gain of factors in statistics
    - Optimized duty-cycle through rectangular spill-shape
    - Suppression of spill-ripple at the kHz scale
- Significant progress in recent years
  - Micro-structure improvements for quad-driven SX
    - Smoothing by transit time spread (weak sextupoles)
    - Smoothing by bunching at low harmonics
    - Smoothing by tune modulation at few kHz
  - Backed by simulation studies
  - Transferred to operation where possible
- Ongoing efforts to improve further
  - Many activities embedded in I-FAST.REX
  - Exciting new results

Selection of recent publications on spill micro-structure

Study on spill quality and transit times for slow extraction from SIS18	J. Yang et al.	IPAC 2023
Spill ripple mitigation by bunched beam extraction with high frequency synchrotron motion	S. Sorge et al.	PRAB 26 (2023)
Transverse Excitation and Applications for Beam Control	P. Niedermayer et al.	IPAC 2022
Improvement of Spill Quality for Slowly Extracted Ions at GSI-SIS18 via Transverse Emittance Exchange	J. Yang et al.	IPAC 2022
Sub-ns Single-Particle Spill Characterization for Slow Extraction	T. Milosic et al.	IBIC 2021
Beam Characterization of Slow Extraction Measurement at GSI-SIS18 for Transverse Emittance Exchange Experiments	J. Yang et al	IBIC 2021
Reducing Fluctuations in Slow-Extraction Beam Spill Using Transit-Time-Dependent Tune Modulation	R. Singh et al.	PRA 14 (2020)
Slow Extraction Spill Characterization From Micro to Milli-Second Scale	R. Singh et al.	IPAC 2018
Measurements and Simulations of the Spill Quality of Slowly Extracted Beams from the SIS-18 Synchrotron	S. Sorge et al.	IPAC 2018

New 80MHz spill cavity in SIS18

Courtesy K. Groß, GSI

SDR for KO spill feedback at SIS18

Courtesy R. Singh, GSI

Presentations at the Workshop

Category	Title	Presenter	Type
Spill structure	Studies on Spill Micro Structures for SIS100 KO Extraction and Transit Times for SIS18 Tune Sweep Extraction	Stefan Sorge	Talk
	Knock-out extraction feedback dynamics	Rahul Singh	Talk
	Tailored excitation signals for RFKO	Philipp Niedermayer	Talk
	Investigations of transit times for tune scan slow extraction at SIS18 GSI	Jiangyan Yang	Poster
	A New 80 MHz Cavity in the Heavy Ion Synchrotron SIS18	Kerstin Groß	Poster
	The Cryogenic Current Comparator (CCC) for nondestructive spill measurement in the nA range	Thomas Sieber	Talk
Extraction efficiency	SIS100 extraction layout: Influence of non-linear beam dynamics	David Ondreka	Talk
	Application of numerical optimisers to the particle loss minimization at the SIS18 septum during slow extraction	Olha Kazinova	Talk
Septum protection	Electrostatic septa with heavy ions: challenges for machine protection	Björn Galnander	Talk

Thanks for your attention!

Thanks to all who have contributed and continue to contribute to the success of GSI and FAIR.