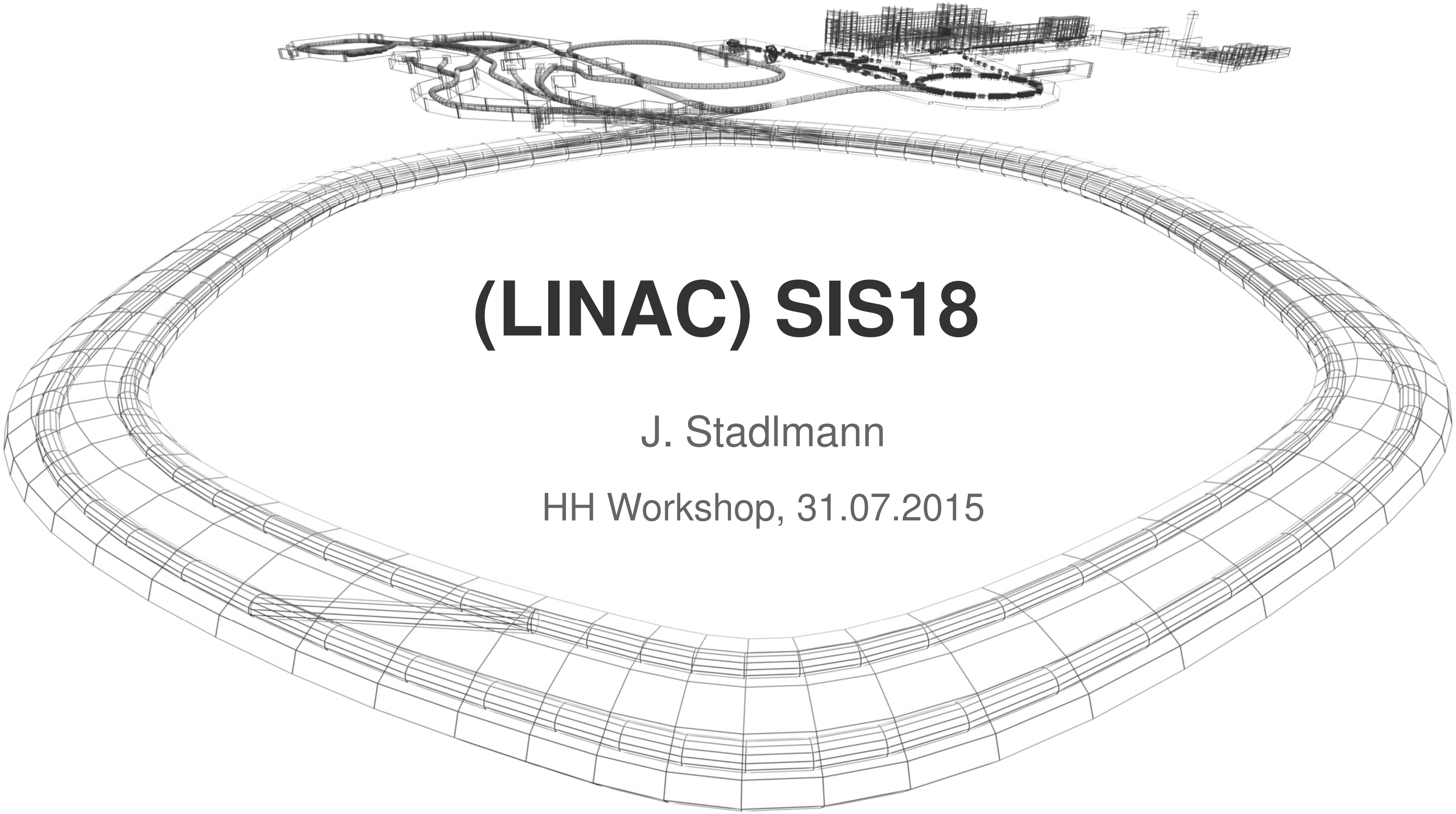
GSI Helmholtzzentrum für Schwerionenforschung GmbH



(LINAC) SIS18

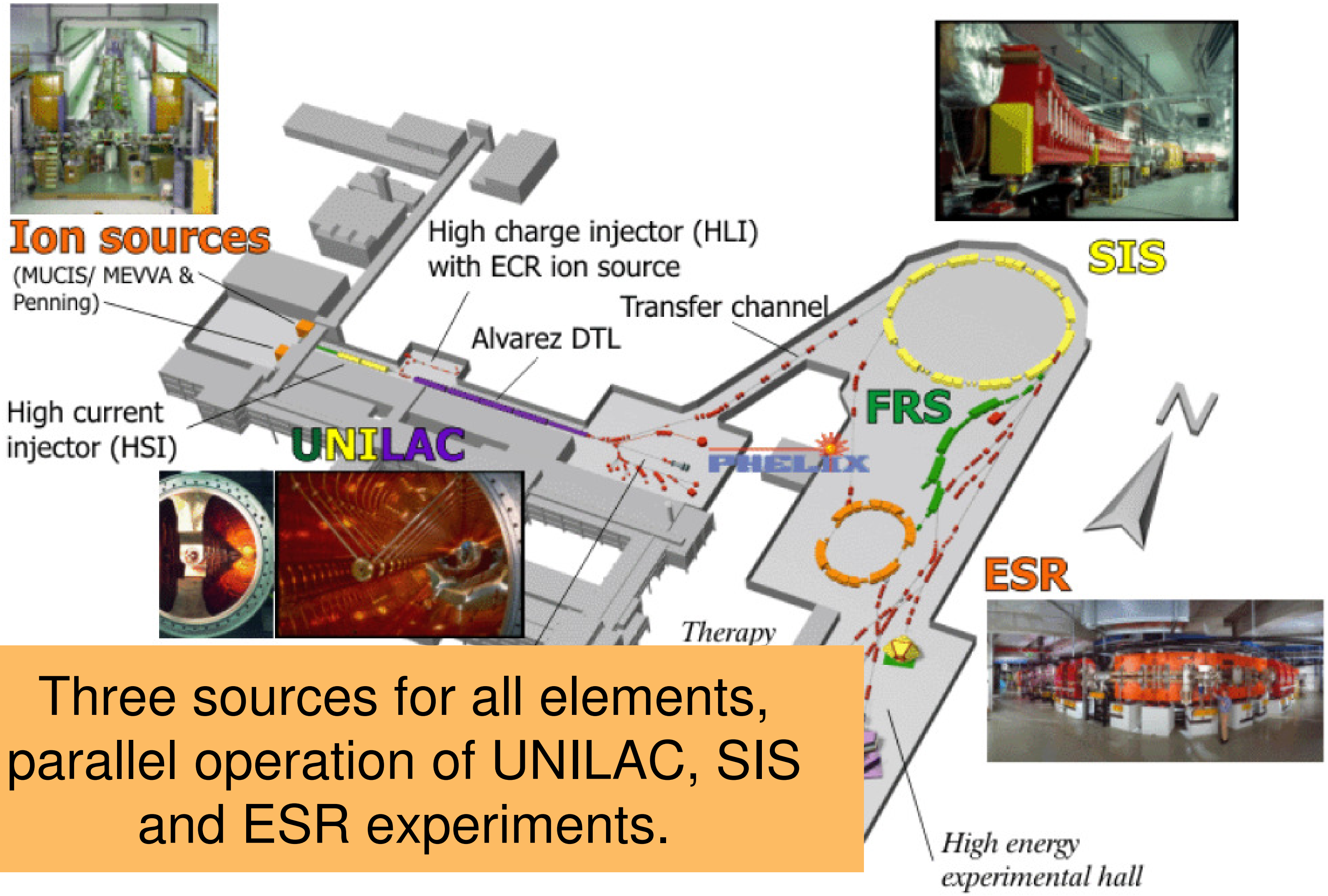
J. Stadlmann

HH Workshop, 31.07.2015

Content

- GSI today with outlook to 2018
- Wishes from Unilac for SIS operation
- SIS18 development
- Outlook to 2018

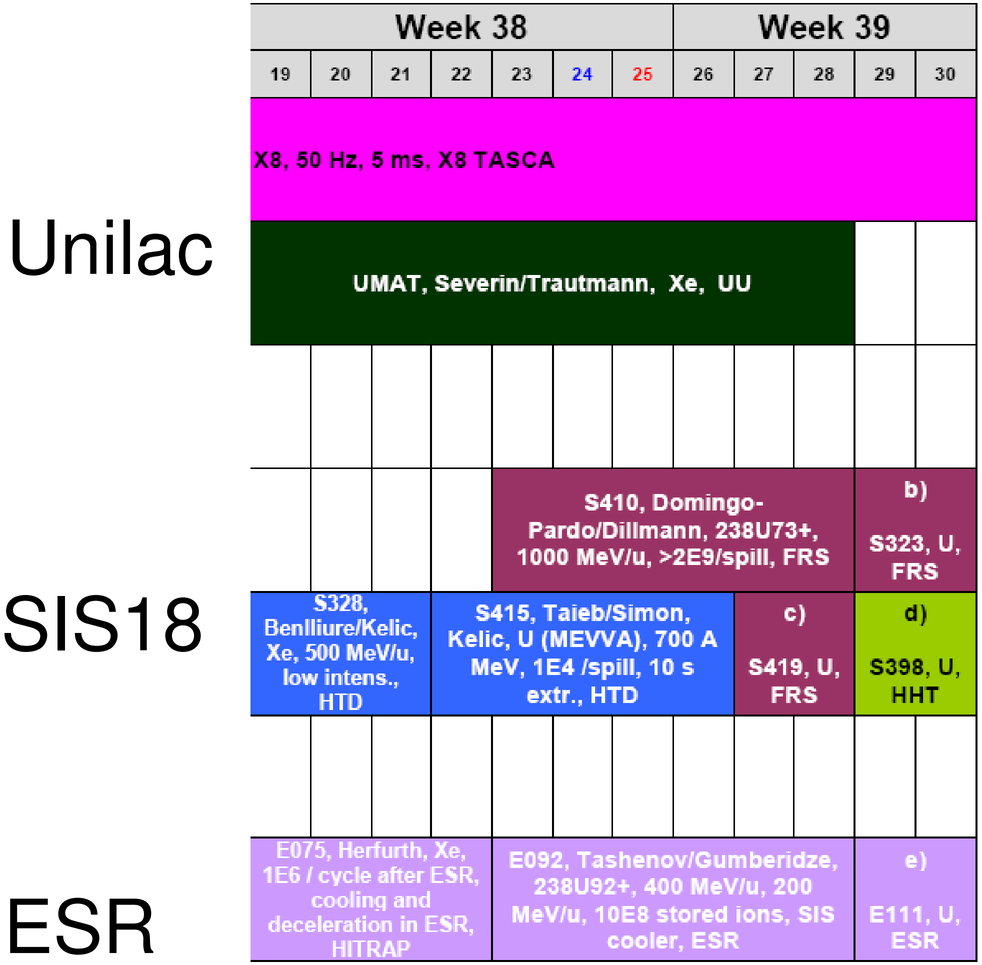
GSI Machines Today



Three sources for all elements, parallel operation of UNILAC, SIS and ESR experiments.

GSI Operation

Typical GSI beam time schedule

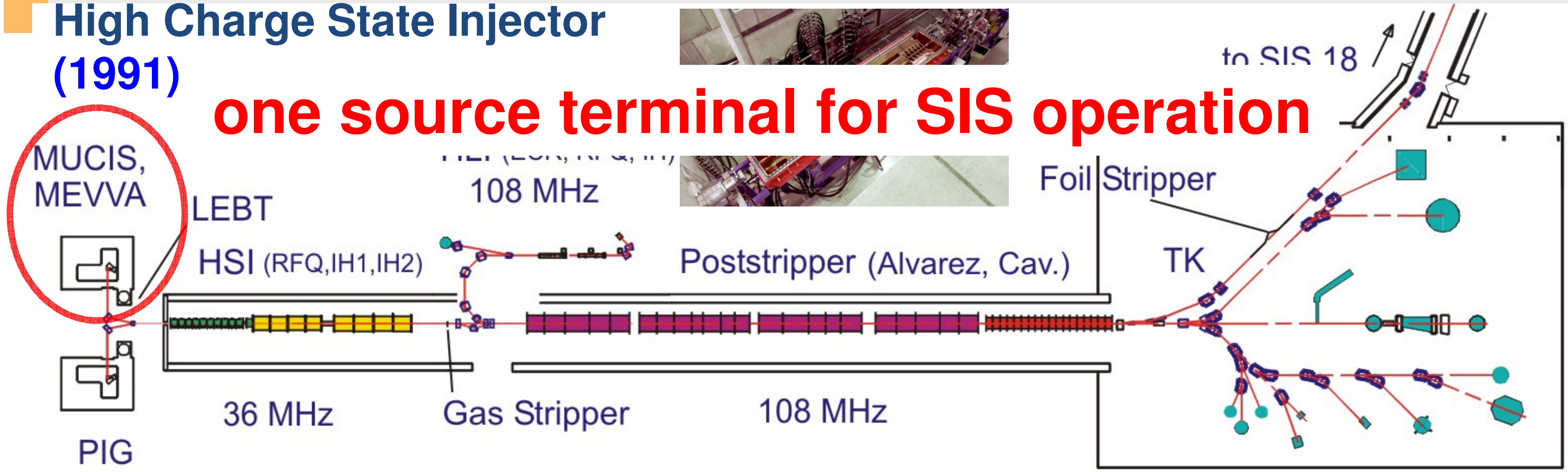


- GSI facility
  - 3 accelerators
  - 20 experimental areas
- Parallel operation
  - Unilac, SIS18, ESR independent
  - 3 different ion species
  - 5 parallel experiments
- Experiments demand high flexibility
  - Variation of beam parameters (daily)
    - energy, intensity
    - extraction type
    - number of bunches
  - Change of beam sharing (daily)
  - Switching of ion species (weekly)
  - Adjustment of schedule (monthly)

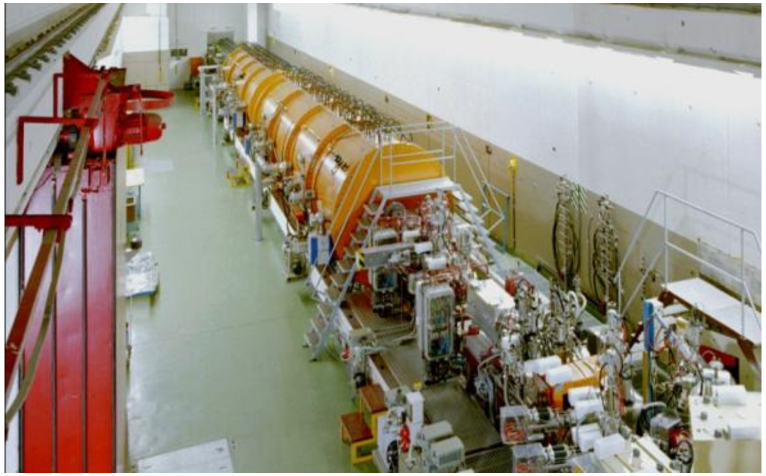
GSI UNIversal Linear ACcelerator

High Charge State Injector (1991)

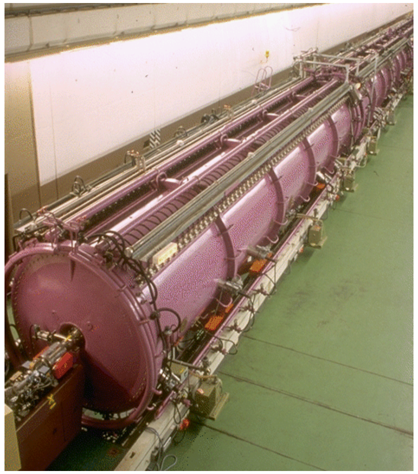
one source terminal for SIS operation



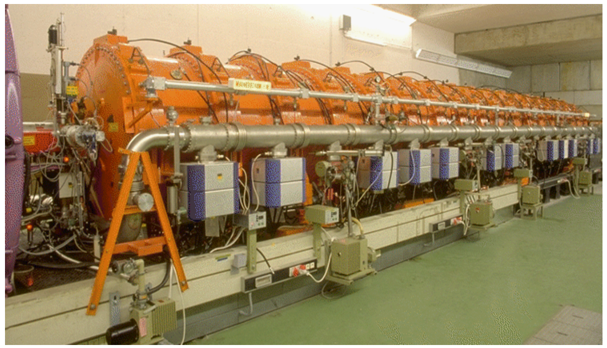
High Current Injector (1999)



Alvarez (1975)

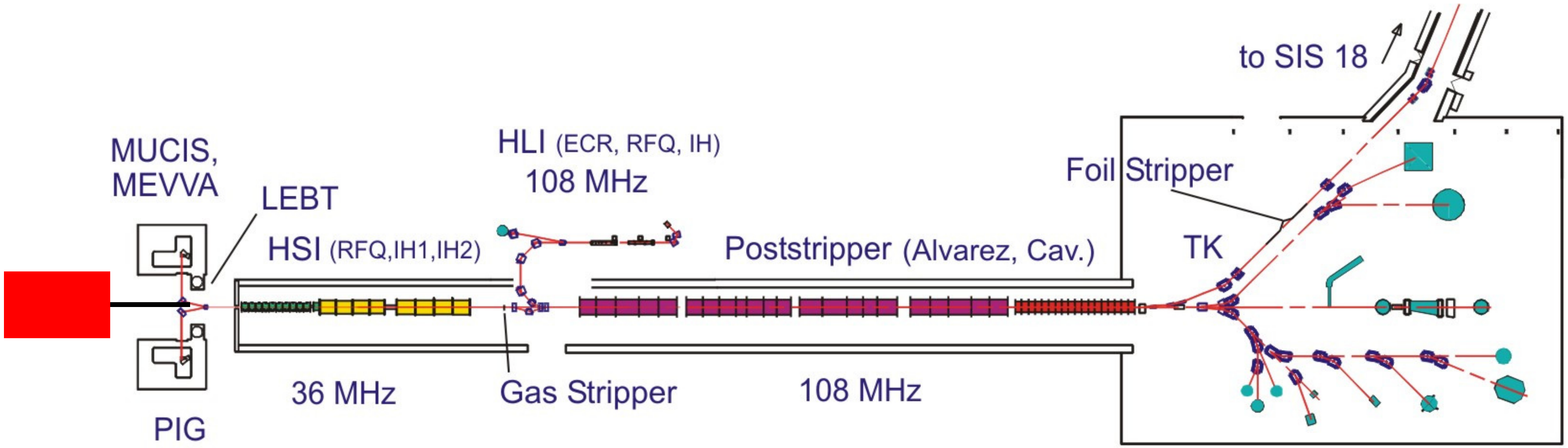


Single Gap Resonators (1975)



Official solution: Plan A

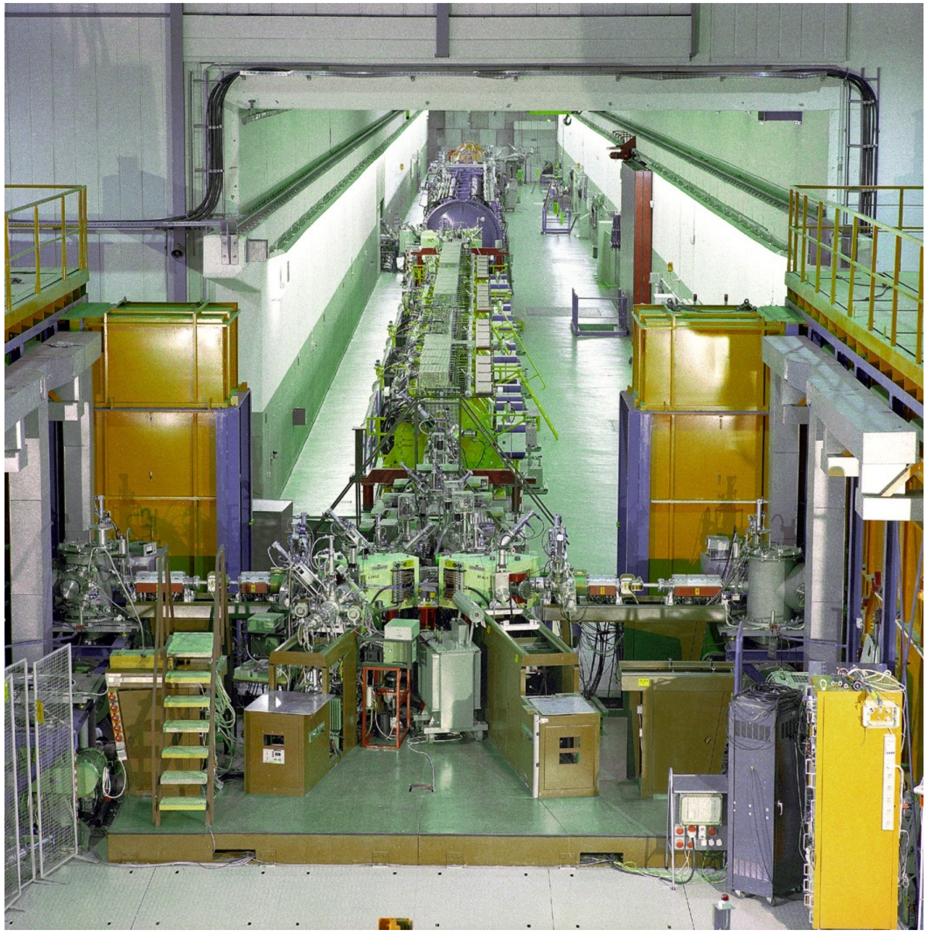
- New uranium terminal planned with straight injection into the HSI.
- Will lead to 4 sources, 2 well suited for SIS and FAIR operation.



Provocative solution: Plan B

Get rid of the penning source!

- New options for beam time scheduling.
- Faster change between different ion species for SIS
- Reliable operation and possible redundancy
- No 50 Hz operation with long pulses in HSI (good! or only bad for SHE and BIOMAT?)
- Interleaving mode for 3 Hz booster operation?!
- Even good WITH new terminal (three sources are better than two)
- Exotic nuclei only from ECR



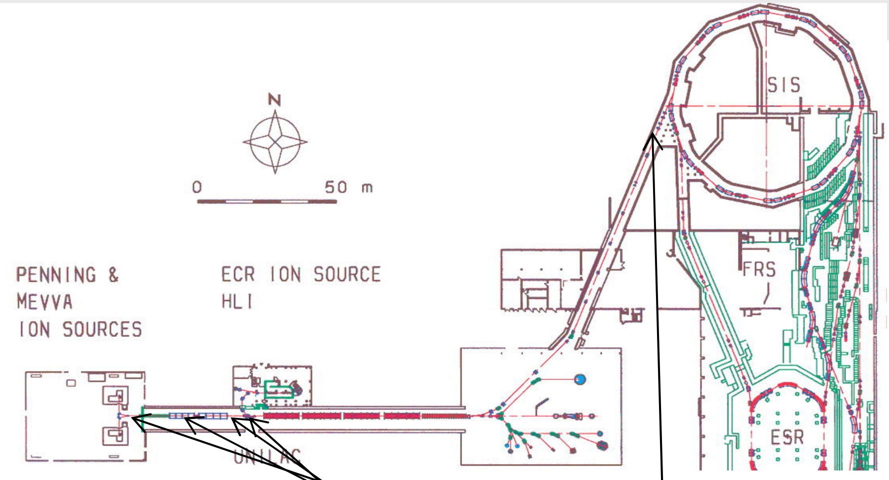
Looks symmetric here

Summary of requirements to Unilac

- Stable high beam current in short (100-150 µs) pulse
- high beam brilliance for multi turn injection
- longitudinal phase-space major issue in the recent runs
- Best uranium performance (like 2005 and 2007) needed
- reproducible settings for SIS injection to reduce setup time

- Beam time schedule with few nuclide changes preferred
- automatic TK settings possible (shown by Y. el Hayek)

Summary: Achieved $^{238}U^{28+}$ Performance



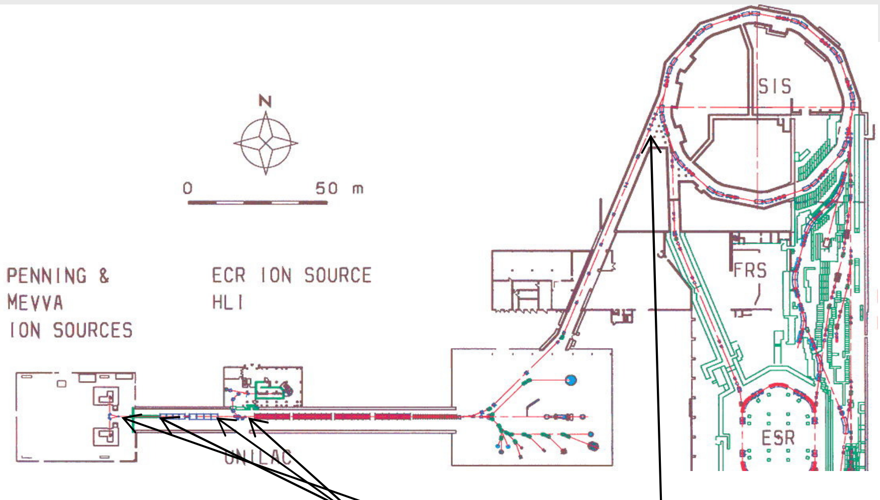
beamline section	current change factor	rel. emit. growth [%]	hor. brill. change factor	current [mA]	hor. emittance (norm., tot.90%)	reference
				15,3	0,38	measurements Nov.4th, 2014
LEBT + RFQ	0,49	0	0,49			measured transmission
				7,5	0,38	
superlens + IH-DTL	0,74	0	0,74			measured transmission
				5,5	0,38	
gaseous stripper (to US3)	1,4	5	1,33			
				7,7	0,70	measured Nov. 4th, 2014
EmTEx	1	0	1,00			not yet installed
				7,7	0,70	
Alv-DTL, transf. to SIS18	0,8	200	0,27			extrapolation from meas. growth
				6,2	**2,10**	
target value				**15,0**	**0,56**	

measured
estimated / extrapolated

Summary of Upgrade Activities

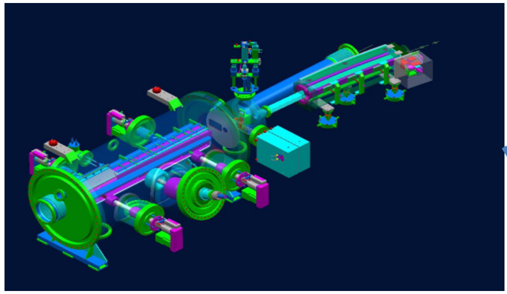
- source: improved extraction system, operation at 2.7 Hz with uranium
- LEBT: no bends, uranium only
- RFQ: lower surface fields & acceptance
- MEBT: replace RFQ superlens with: 2 triplets, 1 buncher, i.e. more knobs
- stripper section:
  - light stripping gases & high pressure
  - include option for hor → ver emittance transfer
- new post-stripper Alvarez DTL:
  - no mixed rf-pulse length operation
  - new drift tube shape
  - optimized stem orientations
  - stronger & asymmetric transverse focusing
  - improved inter-tank envelope matching

Estimate of attainable $^{238}U^{28+}$ Performance

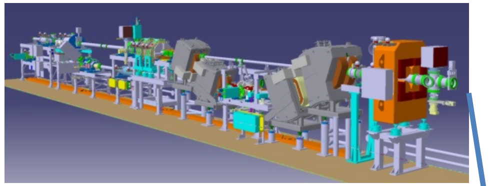


beamline section	current change factor	rel. emit. growth [%]	brilliance change factor	current [mA]	hor. emittance (norm., tot.90%)	upgrade activity
				18,0	0,38	source development
LEBT + RFQ	0,9	15	0,78			RFQ upgrade
				16,2	0,44	
MEBT + IH-DTL	0,9	70	0,53			new MEBT
				14,6	0,74	
gaseous stripper (to A1)	1,26	15	1,10			routine operation pulsed stripper
				18,4	0,85	
EmTEx	0,9	-60	2,25			installation
				16,5	0,34	
Alv-DTL, transf. to SIS18	0,85	50	0,57			new DTL
				14,1	**0,51**	
target value				**15,0**	**0,56**	

SIS18 upgrade program: done 2016
(talk: P. Spiller)

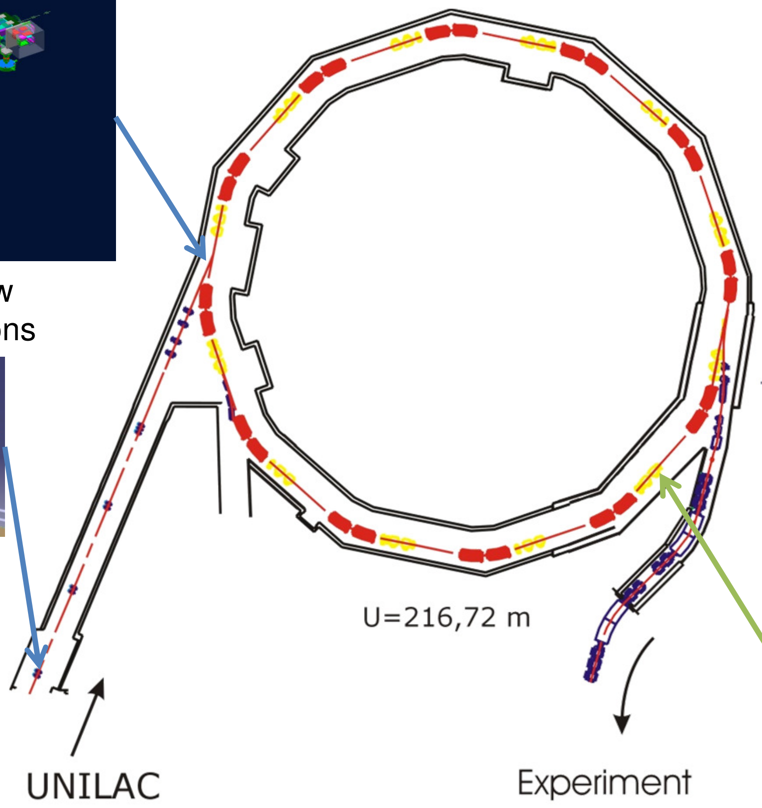


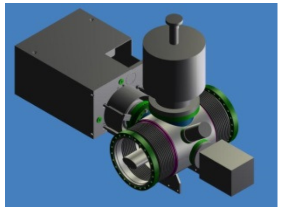
Injection system for low charged state heavy ions



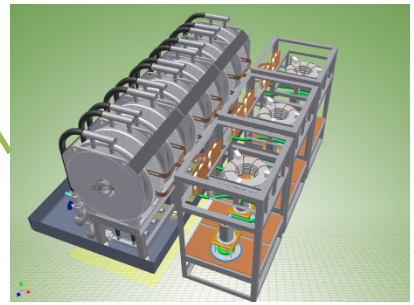
Charge separator for higher intensity and high quality beams

Power grid connection





Scrapers and NEG coating for pressure stabilization



h=2 acceleration cavities for faster ramping

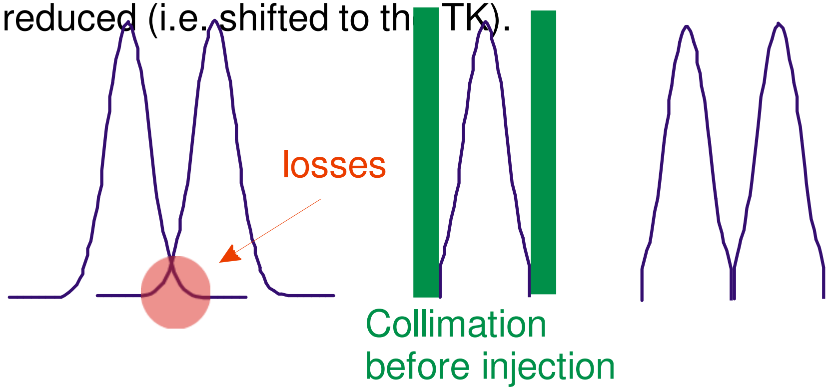
The SIS18 upgrade program aimed for booster operation with low charge state heavy ions

Requirements SIS18

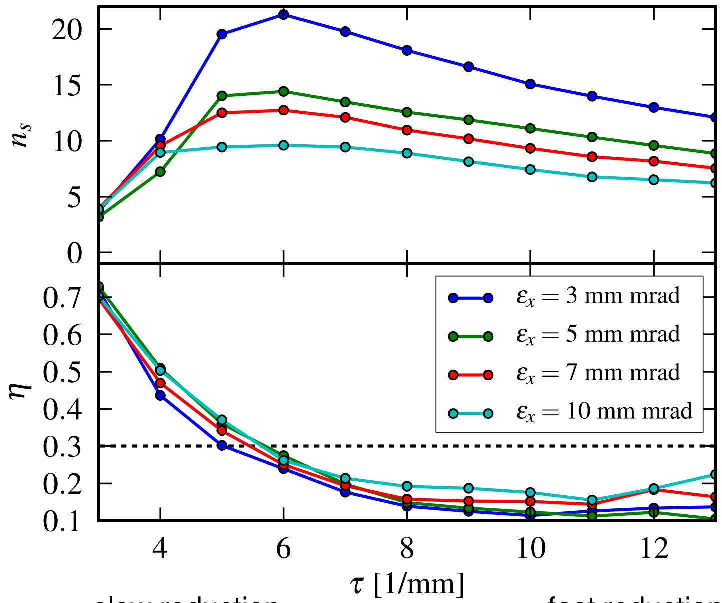
- Operation with new control system and data generation in 2018(16?). “new machine”, train experts and operators
- High current operation requires setup time (beamtime scheduling -> see 2014 machine experiments)
- “Cleaner” injection for FAIR operation (dynamic vacuum)
- Increase slow extraction efficiency (better performance, lower machine activation) and micro spill structure
- Get KO extraction to normal operation. Spill abort and spill feedback possible but not available today

Required UNILAC beam

- UNILAC beam parameters as FAIR booster have been calculated for an optimized MTI process for the SIS18 acceptance of 150 x 50 mm mrad. Parameters:
  - Velocity of orbit bump reduction and
  - Beam emittance.
- Beam emittance can be reduced by the collimation system in the transfer channel (TK).
- Beam emittance (hor) can be reduced by EMTEX without beam loss.
- Beams with smaller emittance and lower current can be injected over a longer time leading to the same final intensity in SIS18. Initial MTI losses in the SIS18 are reduced (i.e. shifted to the TK).



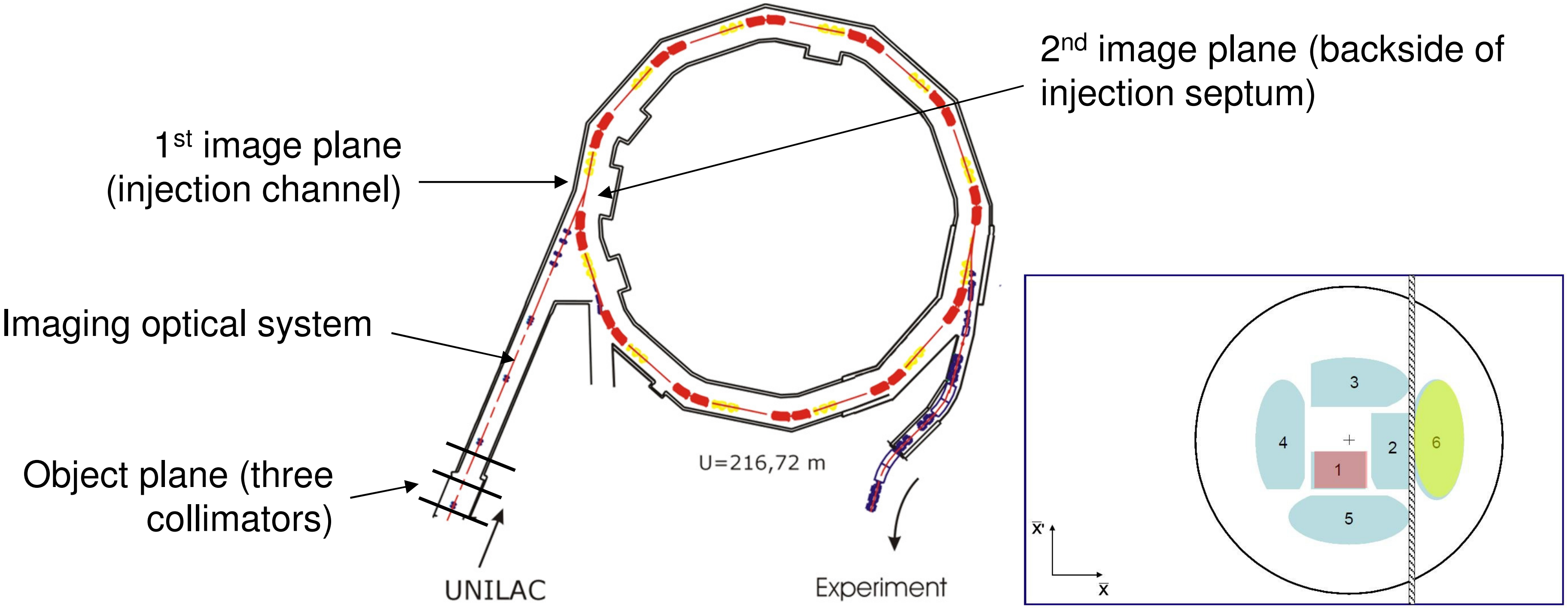
Cutting of tails in the TK, using the brilliant core for injection.



slow reduction fast reduction

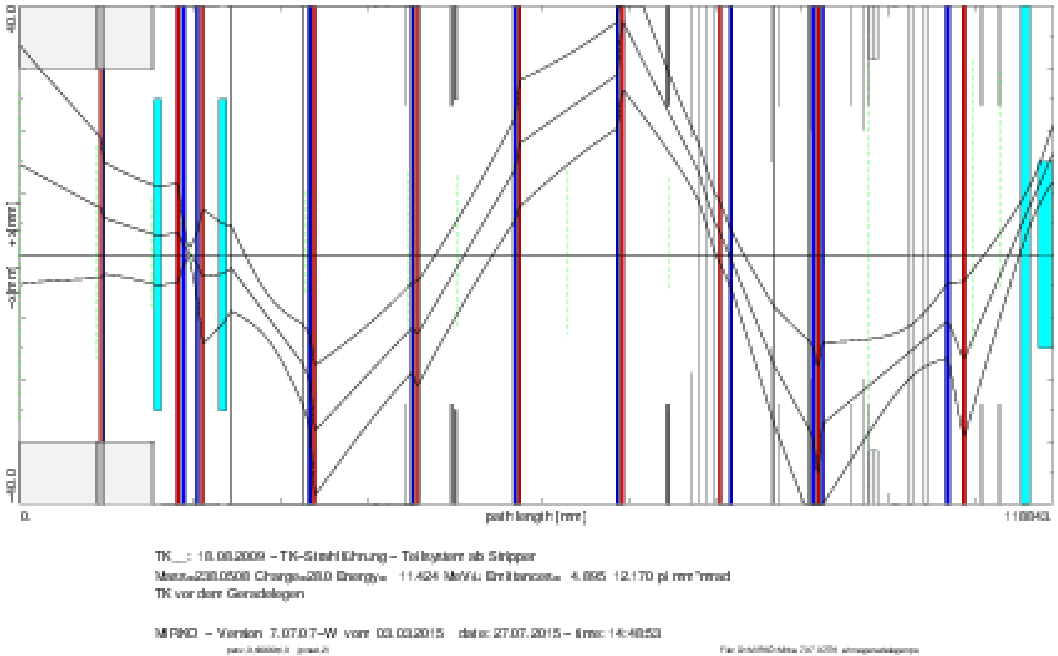
ε_x [mm mrad]	I [mA]	t [µs]	B (norm) [mA / mm mrad]
3	10	140	3.3 (21)
5	15	80	3.0 (19)
7	16	75	2.3 (15)
10	20	60	2.0 (13)

Injection of a sharp edge beam

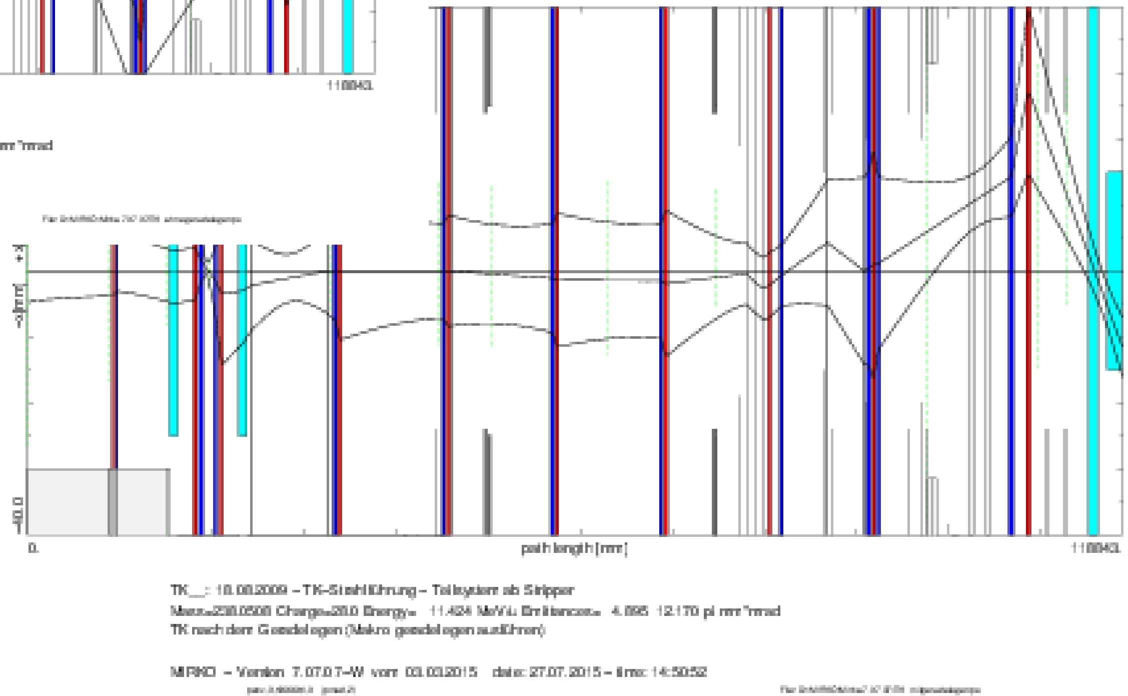


Imaging system from the collimators up to the injection channel and the backside of the septum. Phase space matching from TK to SIS18 was done.

Better operation: Automatic TK settings



Even sets the TK to a 360° phase advance from slids to septum

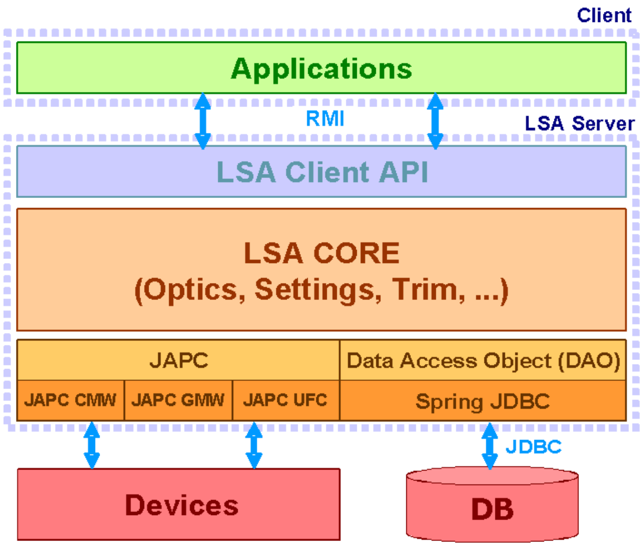


Observations relevant for MTI at high currents

- The longitudinal emittance
  - UNILAC: grows with increasing beam current
  - SIS18: the coasting beam momentum spread depends on the current
- The center energy
  - UNILAC: changes with increasing emittance (beam loading in buncher cavities?)
  - TK: changes according to the degradation of the stripper thickness during operation with stripper (highly charged ions).
  - is slowed down after injection into SIS18 by resistive wall impedance
  - SIS18: fast capture (2 ms and acceleration start), the RF frequency must be tuned according to the current
- The horizontal tune for highest injection efficiency
  - changes with increasing current
  - SIS18: the tune has to be changed for different beam current
- Debunching may be improved by a more effective debuncher cavity at the end of UNILAC

Setting Generation for FAIR using LSA

- Setting generation component of FAIR control system will be realized using the LSA framework from CERN
  - LHC Software Architecture: CERN setting generation system
  - Framework for accelerator modeling
    - Modern (JAVA/DB based 3-tier architecture)
    - Mature (production use for LHC, SPS, LEIR)
    - Maintained (CERN INCA project, FAIR!)
- Realization by project group 'FAIR DV' (since 12/2009)
  - Joint expertise
    - Machine physics divisions (synchrotrons, storage rings)
    - Controls and operations divisions
  - Main tasks
    - Development of physics model for all FAIR machines
    - Compilation of reference cycles for specifications
    - Development of applications for setting management
    - Adaptation of LSA framework to FAIR requirements
- Collaboration with CERN established to adapt LSA
- CRYRING will be the testbed for the new control system

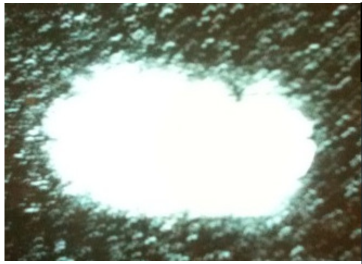


Testing the Physics Model

- LSA not yet productive at GSI, but...
- ...LSA system can be used to run SIS18!

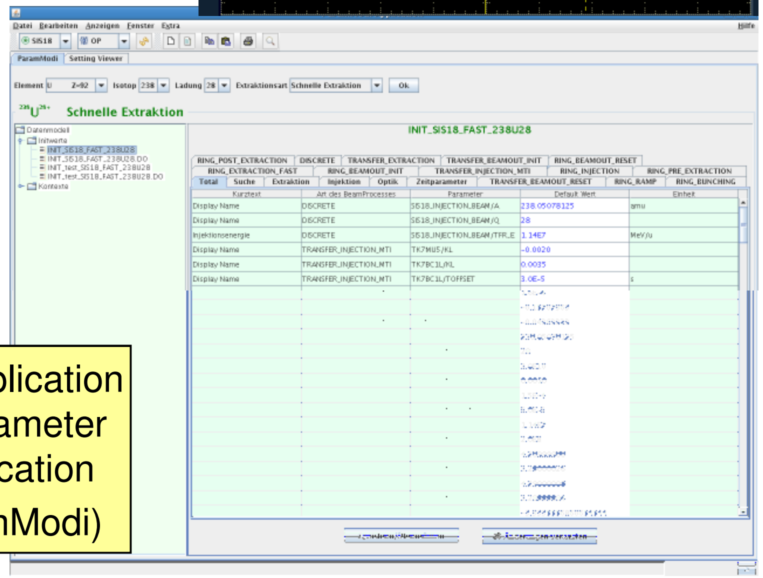
- First test with beam performed 2010 and worked from the first moment !
- Many machine experiments 2014 done with new system:
  - FAIR booster mode
  - Dual harmonic acceleration and other RF tests

Beamtime in 2018 has to run with the new system



12.03.2010

First LSA generated beam from SIS18 (U^{73+}, 300 MeV/u, fast extraction)

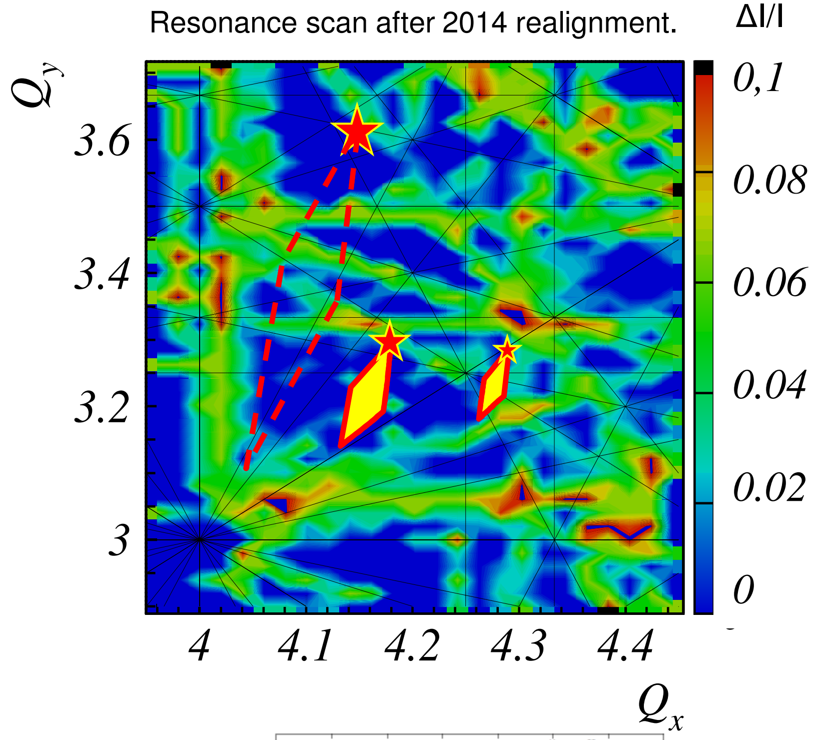


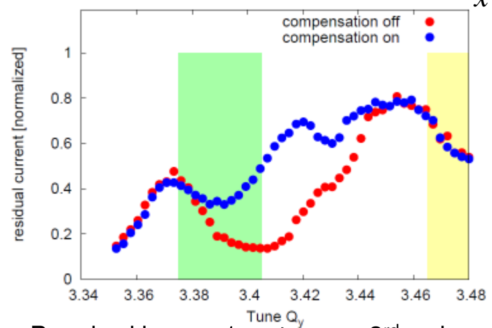
LSA application for parameter modification (ParamModi)

SIS18 high current working point

- Present standard working point
  $Q_{x,y}$ = (4.28; 3.29)
- Good results for larger currents with
  $Q_{x,y}$ = (4.17; 3.29)
- Planned final high current working point
  $Q_{x,y}$ = (4.14; 3.6)
  - Compensation of different resonances necessary:
    $Q_y = 3.5$
    $Q_y = 3.33$
    $Q_x - Q_y = 1$
    $2Q_x - Q_y = 1$
- Resonance correction system installed (skew quads, sextupoles, octupoles).
- Proof of principle machine experiments in SIS18 showed successful partial compensation of single resonances.

Resonance scan after 2014 realignment.

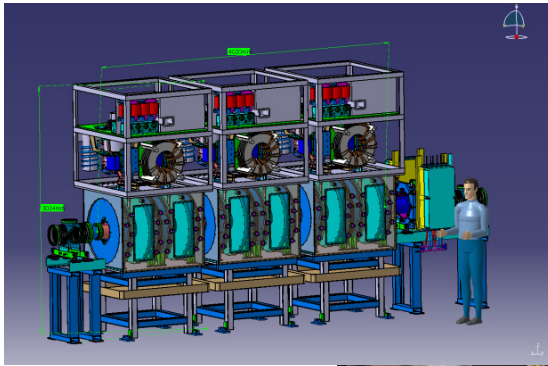


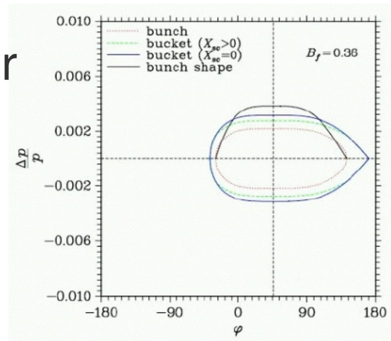


Bunched beam, 1 s storage, 3rd order resonance partially compensated.

New SIS18 h=2 acceleration system

- Sufficient RF voltage for fast ramping with low charge state heavy ions
  - *2×10^{10} U^{73+} acceleration with 4 T/s*
  - *1.5×10^{11} U^{28+} acceleration with 10 T/s*
- Sufficient bucket area for minimum loss (30% safety)
- 50 kV (0.5 – 50 kV) – high power requirements
- Flat bunch profile (high Bf) for lower incoherent tune shift
- *Two harmonic acceleration*
  - *h=4 (existing cavities)*
  - *h=2 (new cavities)*
- Compatibility with SIS100 RF cycle





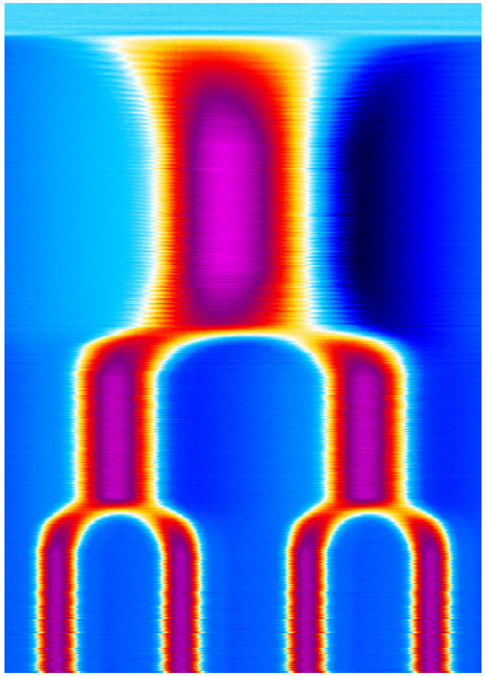
Installation of first module completed, tested with beam.

Test of digital RF controls

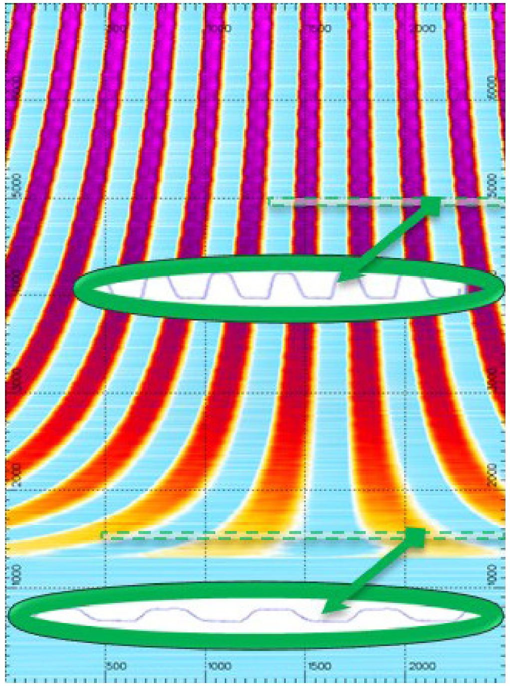
Status:

- Multi-harmonic cavity synchronization system available in SIS18
- Several beam experiments successfully performed
- Optimization and control system integration ongoing

Test with bunch merging



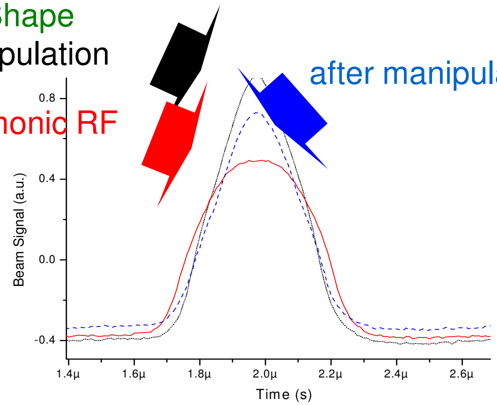
Test with dual harmonic operation



Ion Bunch Shape
before manipulation

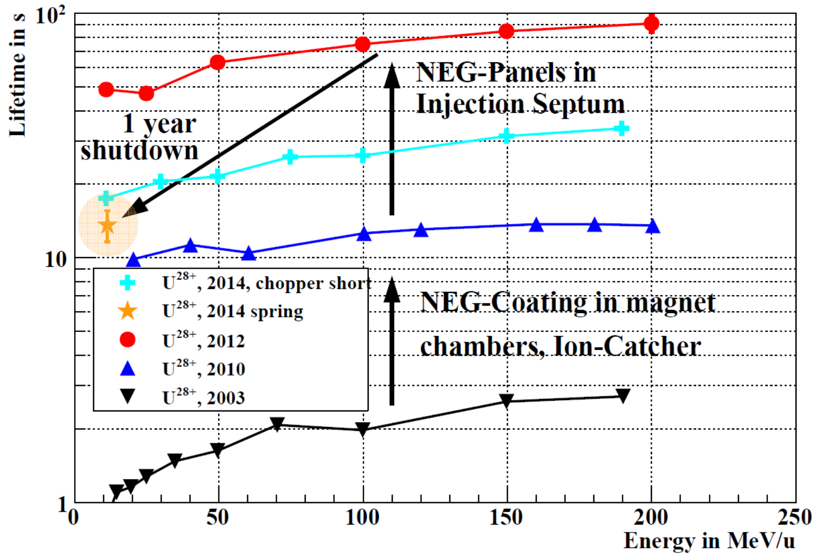
during dual harmonic RF

after manipulation

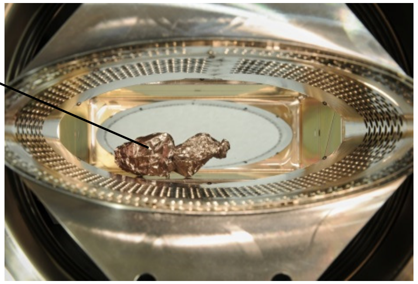


U^{28+} - beam life time status

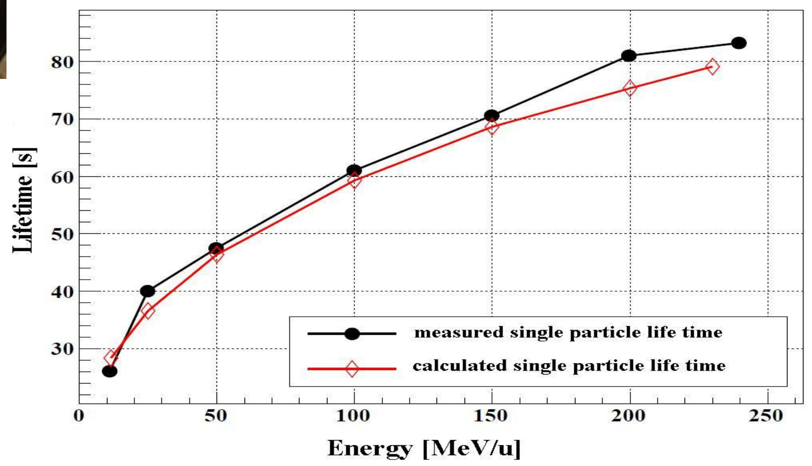
- As a result of the various upgrade stages, the beam lifetime was continuously increased.
- Lifetime of U^{28+} was significantly reduced by one year shutdown and heavy modifications of the SIS18.



SIS18 "UFO"

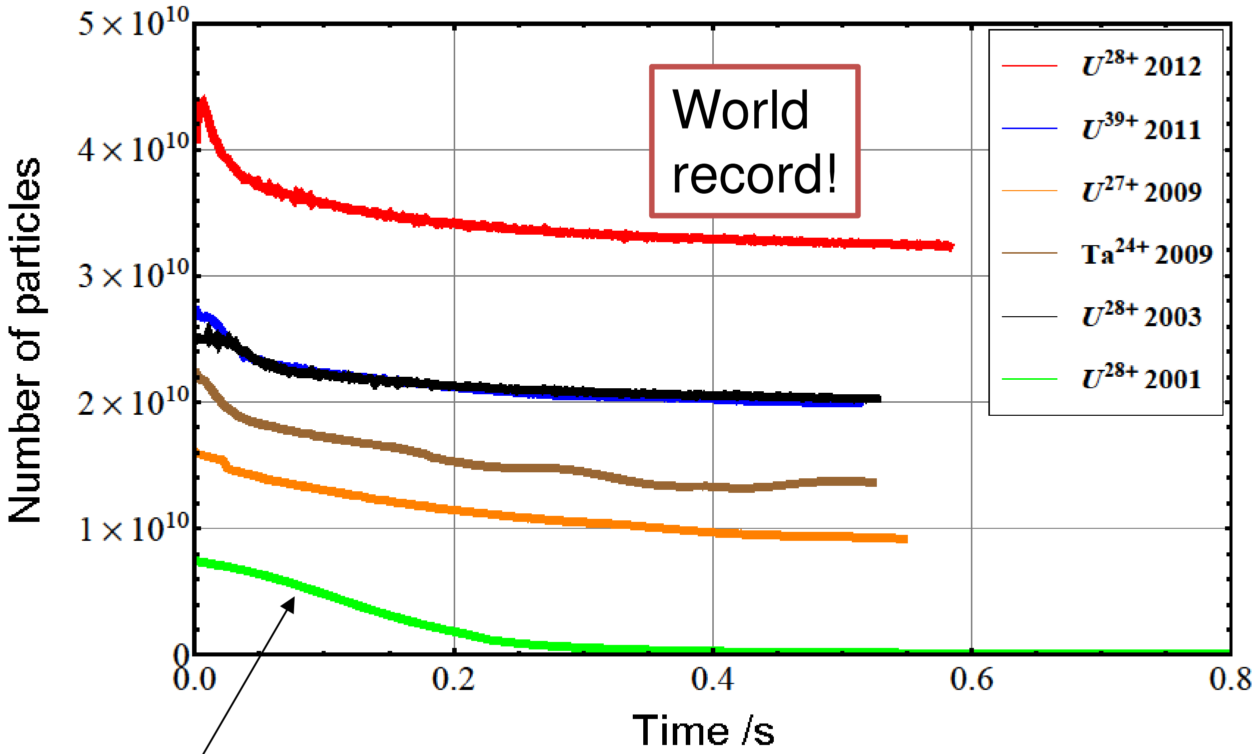


- After the installation of NEG panels in the injection septum, a perfect agreement between the measured and expected beam lifetime and its energy dependence (STRAHLSIM code) has been achieved.



SIS18 beam intensity progress

World record intensity per cycle for low charge state heavy ions has been achieved in SIS18.



2001 FAIR conceptual design report (FAIR proposal)

SIS18 booster operation outlook

Further improvement of nominal synchrotron operation:

- Optimization of MTI with collimation in TK, study linear coupling during injection
- Conservation of longitudinal emittance
- Implementation of transverse feed back system
- Optimization spill microstructure during slow extraction.

Development of high current operation (light ions):

- Low loss high current operation with tune shifts in the order of $\Delta Q= -0.5$
- Setting generation considering intensity dependent effects
- Fast bunch compression with space charge (short term crossing of multiple resonances)
- Longitudinal stability in dual harmonic bucket, space charge effects
- Slow extraction with high intensity
- Intensity effects at MTI

Microspillstructure studies till now

"Knobs" tried, all more or less unsuccessfully

- Detuned RF on Flatop
- Extract bunched beam
- chromaticity changes

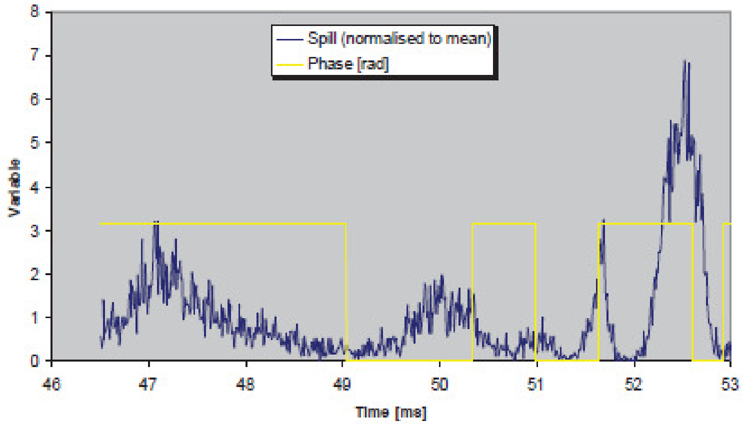
.....

- KO extraction and Hardt condition are advantageous for some experiments but sensitivity to ripples increases.
- The micro structure looks like it originates from power supply ripples. In simulation with a PS ripple there is an effect but not as strong as seen in experiments.
- The means of KO noise generation has an impact on the spill structure.

(see internal note M. Kirk)

Spill under 2 separately tested forms of KO: BPSK and Dual FM

a) BPSK: U_{eff} = 1.3 kV



b) Dual FM: U_{eff} = 4.5 kV

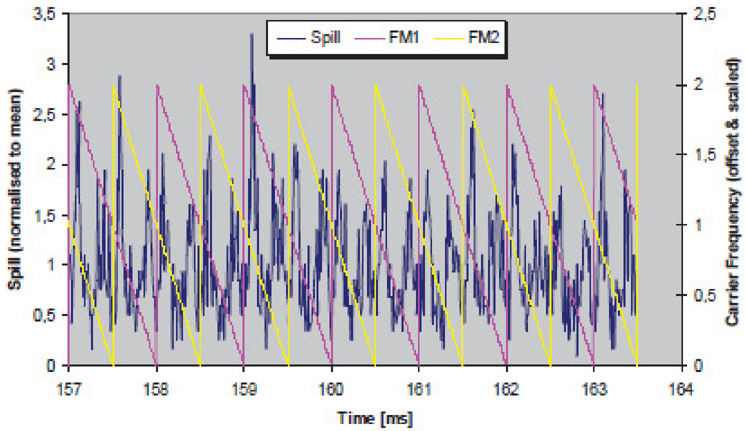
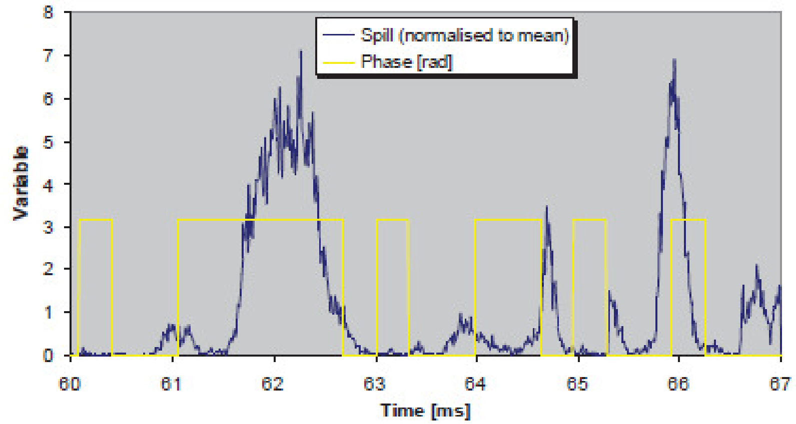


Figure 1: (Colour) Spill with a) BPSK and b) Dual FM. Horizontal chromaticity Q_h'=-6.94 (=$\Delta\nu/\delta$), unadjusted from natural value. Bin size 10 μs (ca. 10 turns), $^{12}C^{6+}$, 6.35 Tm.

a) BPSK: U_{eff} = 1.1 kV



b) Dual FM: U_{eff} = 5.3 kV

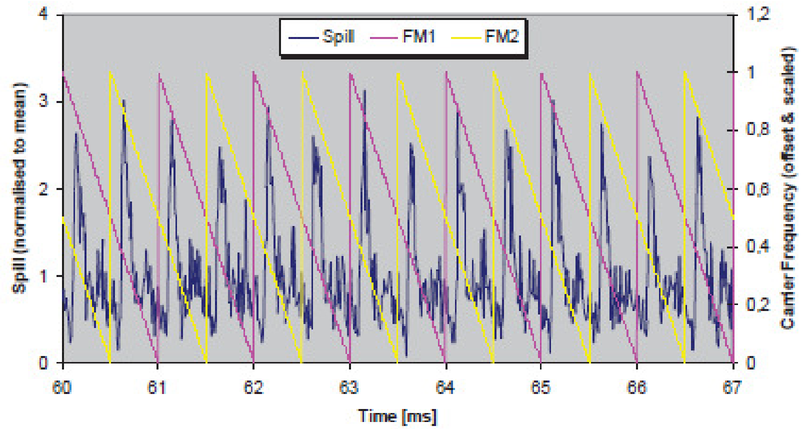


Figure 3: (Colour) Spill with a) BPSK and b) Dual FM. Low chromaticity Q_h'=-0.29 for the Hardt condition. Bin-size 10μs (ca. 10 turns). Beam ions: $^{12}C^{6+}$, rigidity 6.35 Tm.

Spill under 2 separately tested forms of KO: BPSK and Dual FM

Continued...

Nominal operation

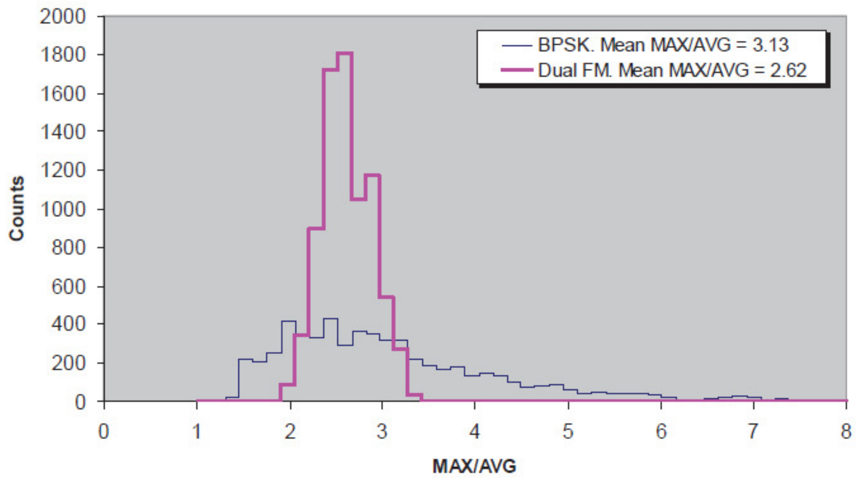


Figure 2: (Colour) Roughness parameter distribution. Beam/machine parameters same as Fig. 1. Histograms formed with 'sliding' window 1ms (100 spill-bins) in size.

Hardt optical settings

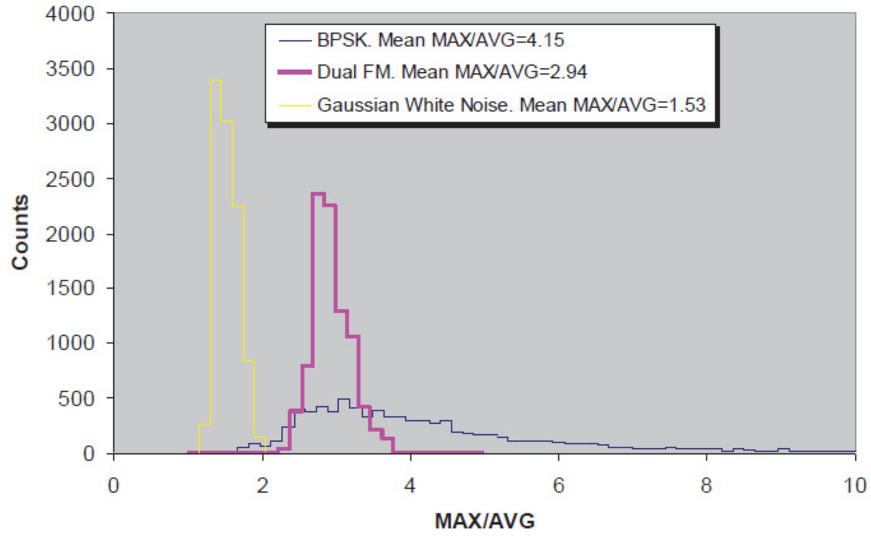
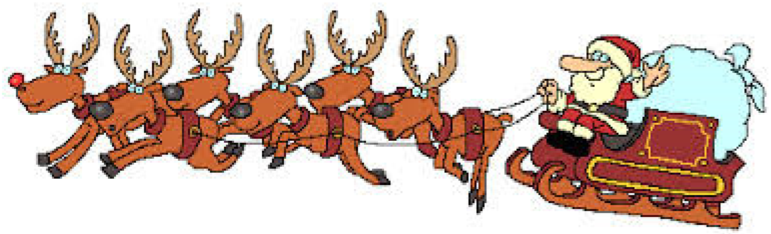


Figure 4: (Colour) Roughness parameter distributions. Beam/machine parameters same as Fig. 3. Histograms formed with 'sliding' window 1ms (100 spill-bins) in size.

SIS 18 Performance from 2018 till 2021

- available now:
  - $5x10^9$ U^{73+}, up to 1 GeV/u, uncooled
  - $3x10^9$ U^{73+}, up to 1 GeV/u, cooled
  - $3x10^{10}$ U^{28+}, up to 200 MeV/u
  - special exclusive mode: $3x10^{10}$ U^{39+}, 350 MeV/u
    (striper foil instead of gas stripper in UNILAC)
  - 4.5 GeV protons with fast extraction. 3 GeV with slow extraction
  - bunch compression
- projected:
  - increased U^{73+} intensity (uncooled) to about 10^{10} particles/spill
  - U^{28+} intensity to $4\text{-}5x10^{10}$
  - higher proton intensity even from UNILAC (CxHy accelartion)

Summary (Wishlist)



- more high current injector terminals
- Settings-generation-driven "automatic" machine setup
- Extra machine time to get used to the new control system
- Machine development time for spill structure, new device commissioning, high current operation
- Setup time and regular machine shifts during operation