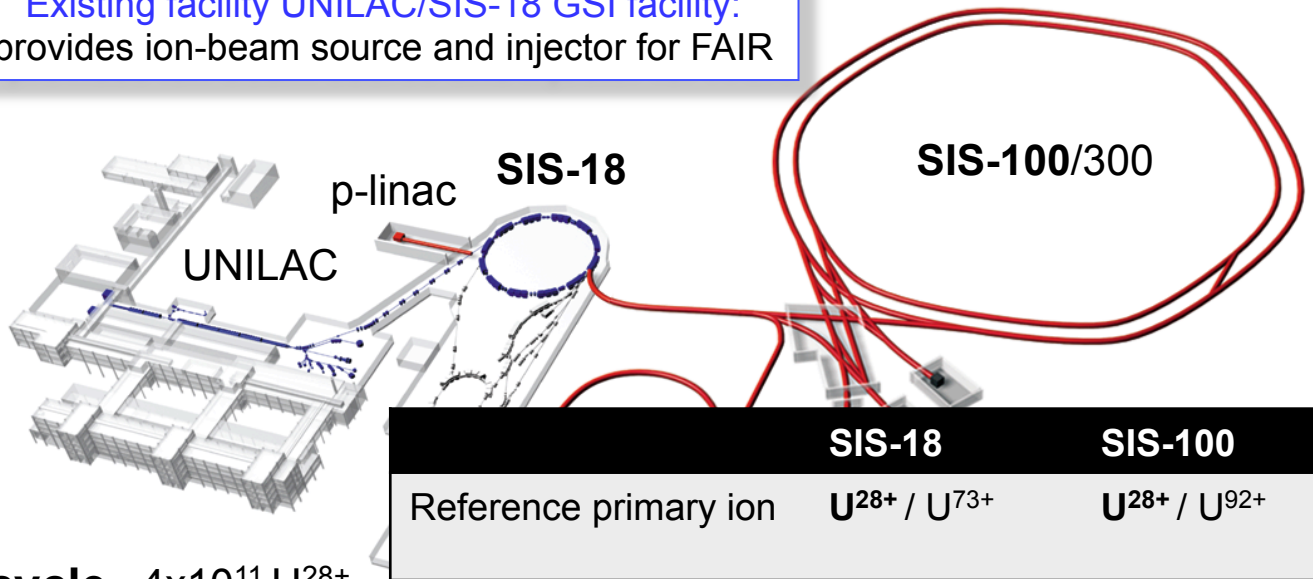
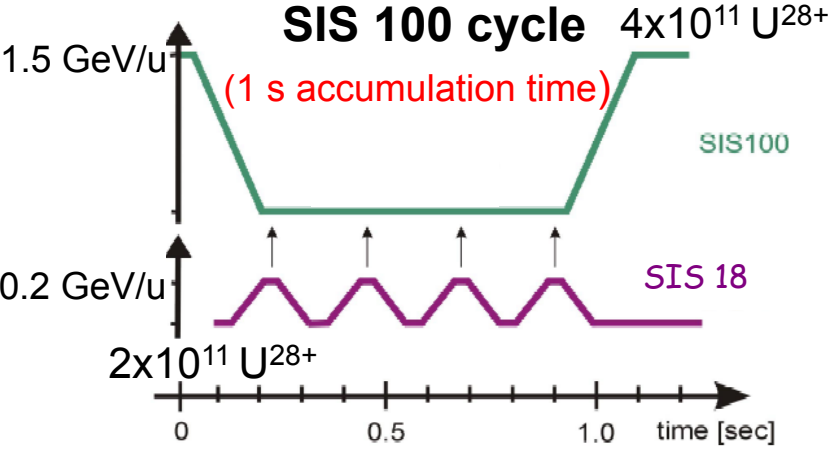
The Uranium Delivery Chain for FAIR

Existing facility UNILAC/SIS-18 GSI facility:
provides ion-beam source and injector for FAIR



SIS-100 extraction:
- short (60 ns) bunch
- slow extraction



	SIS-18	SIS-100
Reference primary ion	**U^{28+}** / U^{73+}	**U^{28+}** / U^{92+}
Reference energy	**0.2** / 1 GeV/u	**1.5** / 10 GeV/u
Ions per cycle	**1.2E11** / 2E10	**4E11** / 1E10
cycle rate (Hz)	2.7	**0.5** / 0.1
FAIR parameter booklet, **April 2007**, (Ed.) O. Boine-F., P. Spiller, M. Steck + corrections for MSV		

An update of the FAIR beam parameters is required.

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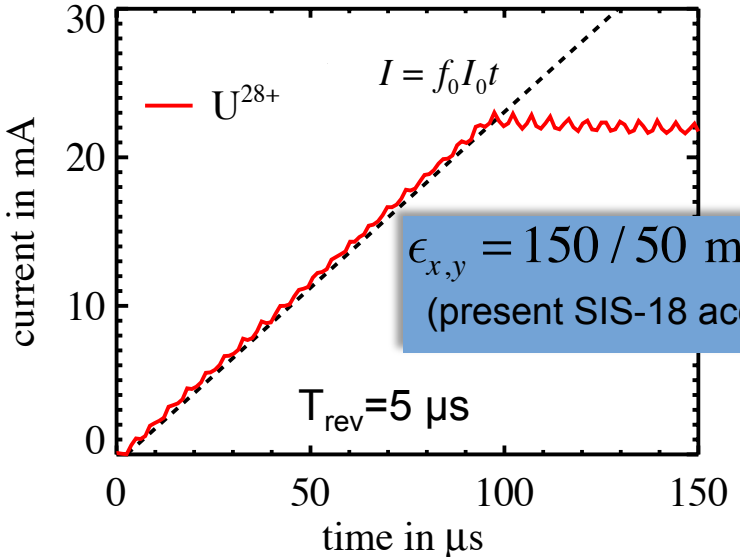
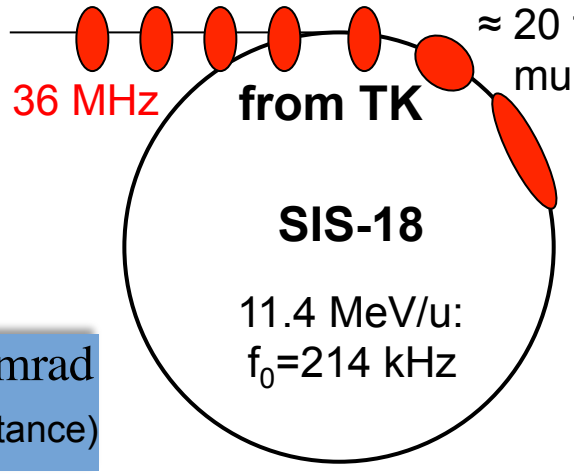
Injection into SIS-18 from the UNILAC

UNILAC (≈ 15 mA, 5/15 mm mrad)

Measured MTI performance (low intensities)



$\epsilon_{x,y} = 150 / 50$ mm mrad
(present SIS-18 acceptance)



≈ 20 turn horizontal multi-turn injection (MTI)

rf is off !

The micro-bunches debunch and form a 'coasting' beam within a few turns.

Final momentum spread after injection should be within the rf bucket area:

$\Delta p / p \leq 10^{-3}$

Initial momentum spread determined by longitudinal space charge !
-> More MTI details in the presentation by S. Appel

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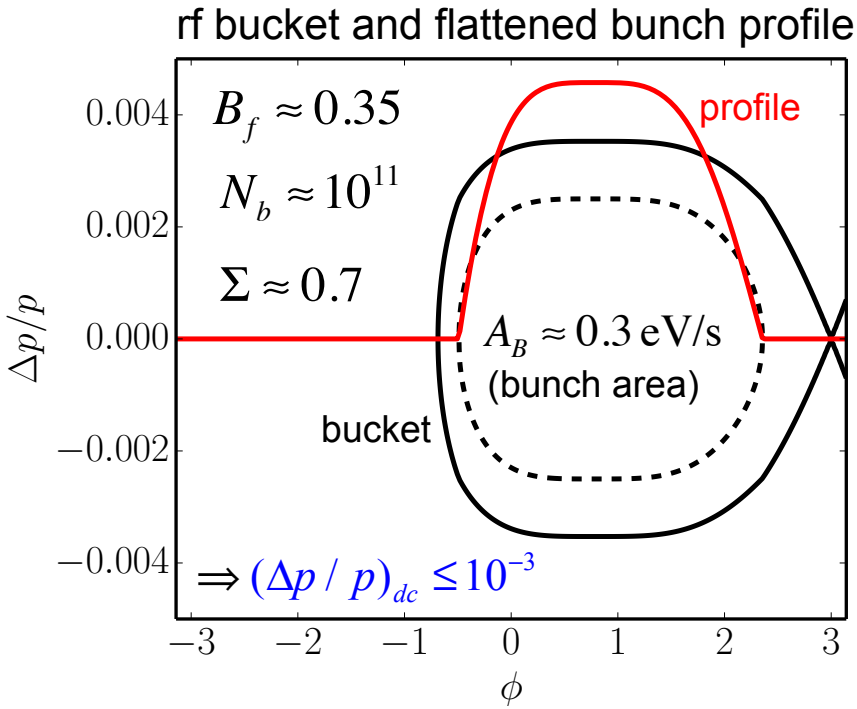
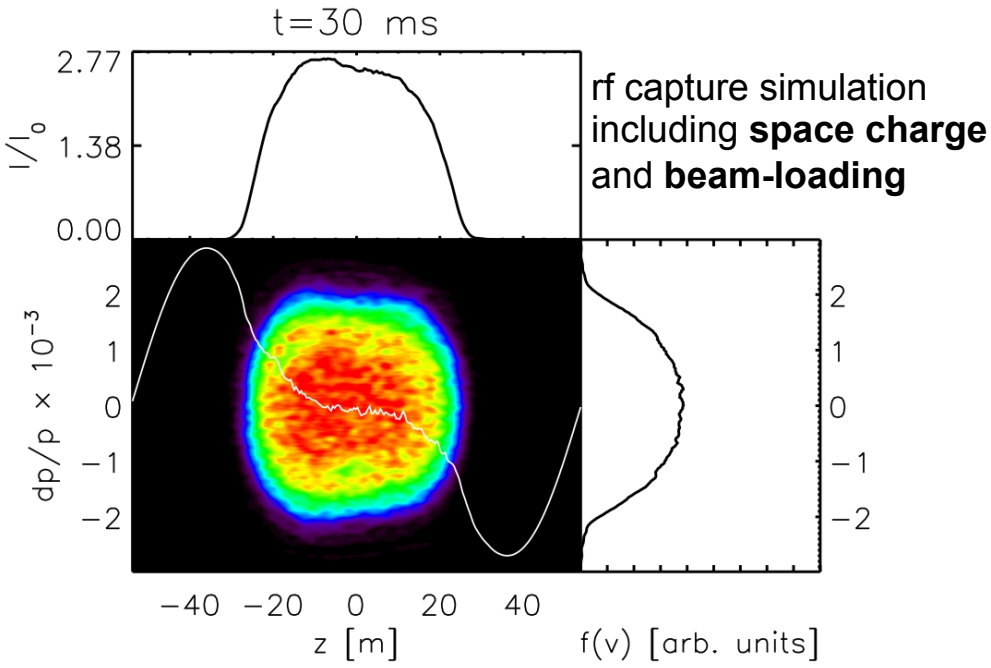
RF capture and fast ramping in SIS-18 (dual rf buckets)





Ion	Energy	RF voltages	harmonics	ϕ_s	ϕ_{m0}	Σ	B_f	A_B [eVs/u]	A_B^0 [eVs/u]
U^{28+}	11.4 MeV/u	40 kV	$h = 2$	32^0	29^0	0.5	0.24	0.3	0.34
U^{28+}	11.4 MeV/u	40/16 kV	$h = 2/4$	45^0	16^0	0.7	0.35	0.31	0.36
U^{73+}	11.4 MeV/u	36/13 kV	$h = 2/4$	53^0	19^0	0.45	0.34	0.3	0.33

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‘Space charge limit’ in SIS-18/100

SIS-18: Multi-turn injection should fill the available (horizontal) acceptance.

$$\epsilon_{x,y} = 150 / 50 \text{ mm mrad}$$

We presently assume that the maximum beam intensities in SIS-18 and SIS-100 are ‘space charge limited’.

Space charge tune spread:

$$\Delta Q_y^{sc} \propto -\frac{Z^2}{A}\frac{N}{B_f}\frac{g_f}{\varepsilon_y \beta_0^2 \gamma_0^3}\frac{2}{1+\sqrt{\varepsilon_y/\varepsilon_x}}$$

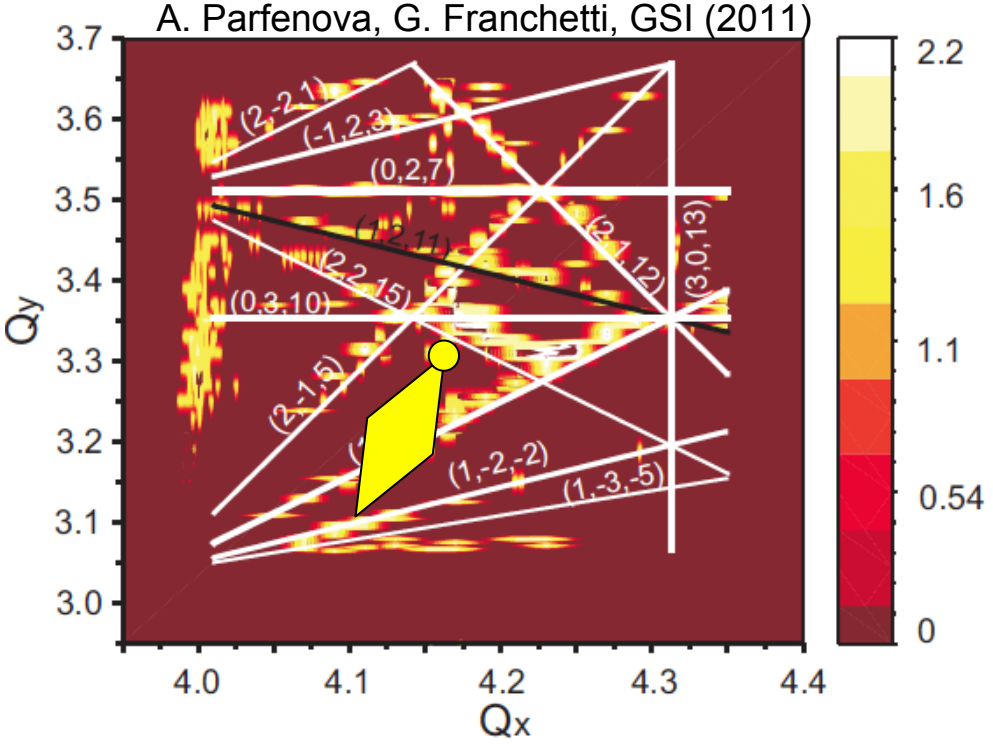
$B_f^{-1} = \frac{I_p}{I_0}$: bunching factor

N: number of particles in the ring

‘Space charge limit’: $|\Delta Q_y| \lesssim 0.5 / 0.3$

High current working point: $(Q_x, Q_y) = (4.17, 3.29)$

A. Parfenova, G. Franchetti, GSI (2011)



Space charge ‘cures’ in SIS-18/100:

- fast acceleration (SIS-18)
- flattened bunch profiles
- resonance compensation

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Intensities and transmission

Electron stripping is a dominant loss mechanism for intermediate charge state ions at low energies ('dynamic pressure'):

$$U^{28+} + X \rightarrow U^{29+} + X + e$$

(Lifetime)$^{-1}$: $\tau^{-1} = \beta_0 c \sigma_{loss} \frac{P(N,t)}{k_B T}$

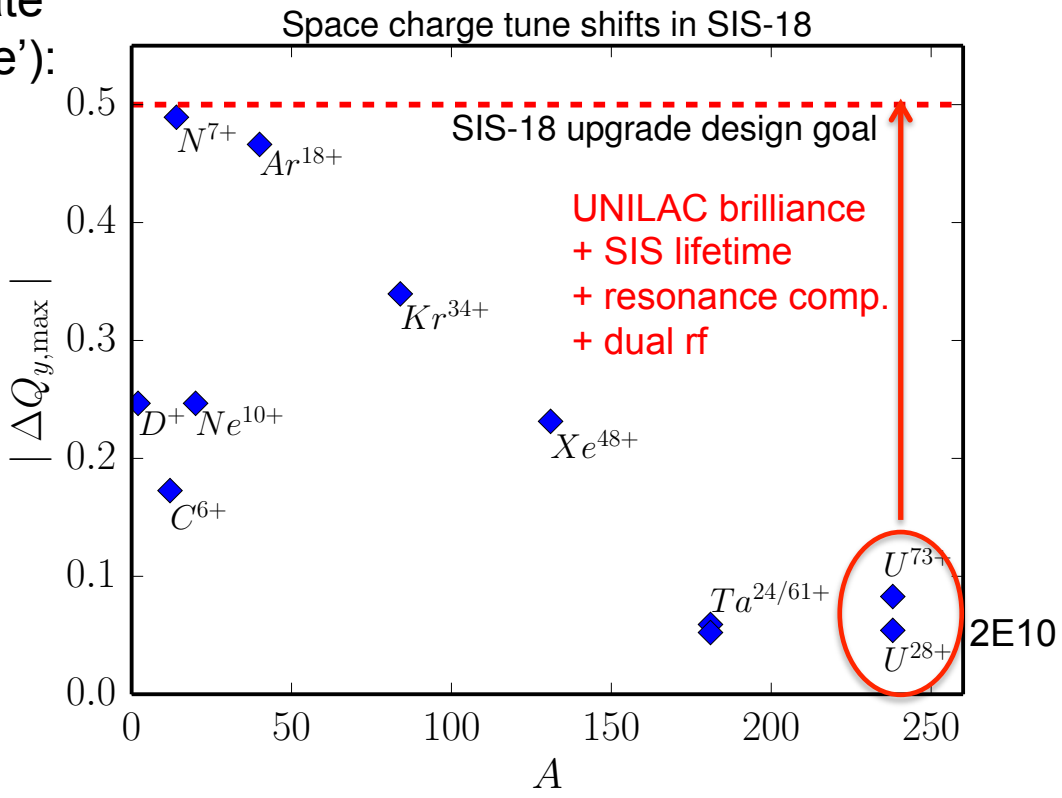
FAIR beam parameters: losses

SIS-18 beam loss/cycle	Fractional (%)	
injection		**30**
rf capture		5
space charge	2E11->1.2E11	**10**
ionization		**30**
fast extraction		2

SIS-100 beam loss/cycle	Fractional (%)	
injection		2
rf capture		5
space charge	4.5E11->4E11	**10**
ionization		**5**
fast extraction		2

Estimated beam loss due to stripping in SIS-18: 30-40 %

SIS-18: Present performance



Remark: The loss predictions carry large error bars !

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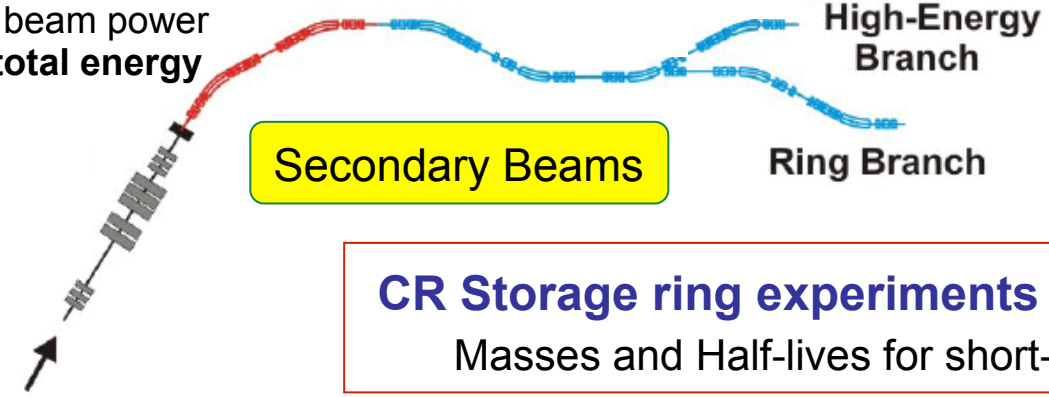
End of the uranium chain: Bunch compression and production of exotic nuclei

High energy branch:
Reactions with Relativistic Radioactive

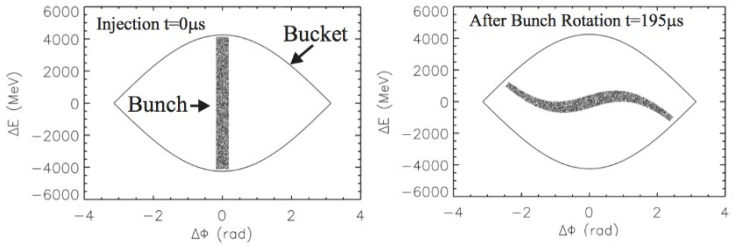
Super-FRS

Primary Beams

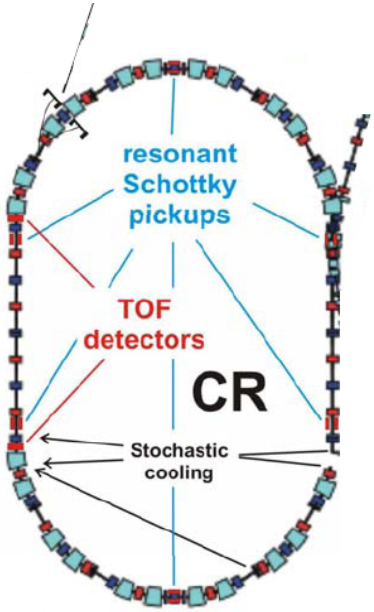
15 kW beam power
30 kJ total energy



Bunch rotation in the CR



CR Storage ring experiments with RIBs:
Masses and Half-lives for short-lived ions



	SIS-100
Reference primary ion	U^{28+}
Reference energy	1.5 GeV/u
Ions per cycle	4E11
Bunch length	60 ns
Momentum spread	± 1 %
cycle rate (Hz)	0.5

NuSTAR: Primary heavy-ion beam intensity from SIS-100 is essential !

-> 2E11/s (short bunch)
-> 1E11/s (slow extraction)

Remark: CDR/2001 -> 1E12/s
(NuPECC/2000 recommendation)

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Summary: Uranium chain
intermediate charge states

'Initial' intensity in SIS-18 determined by:
- MTI efficiency (-> presentations by S.Appel/D.Ondreka)
- 'space charge limit' (after rf bunching)
- rf bucket area (reduced by space charge)

SIS-18/100 transmission determined by:
- charge exchange and dynamic vacuum (-> presentation by P.Spiller)
- space charge and resonance crossing

SIS-18/100 loss budget determined through:
- desorption, damage, activation

Final user requirement (RIB production):
- fast extraction of a short bunch (< 60 ns) or slow extraction (≥ 1 s)
- extracted intensity: N/s > 1E11/s (was 1E12/s in the CDR/2001)

An update of the FAIR beam parameters is required, allowing also for possible changes in the injector performance.