High Intensity Issues at FAIR

Oliver Kester

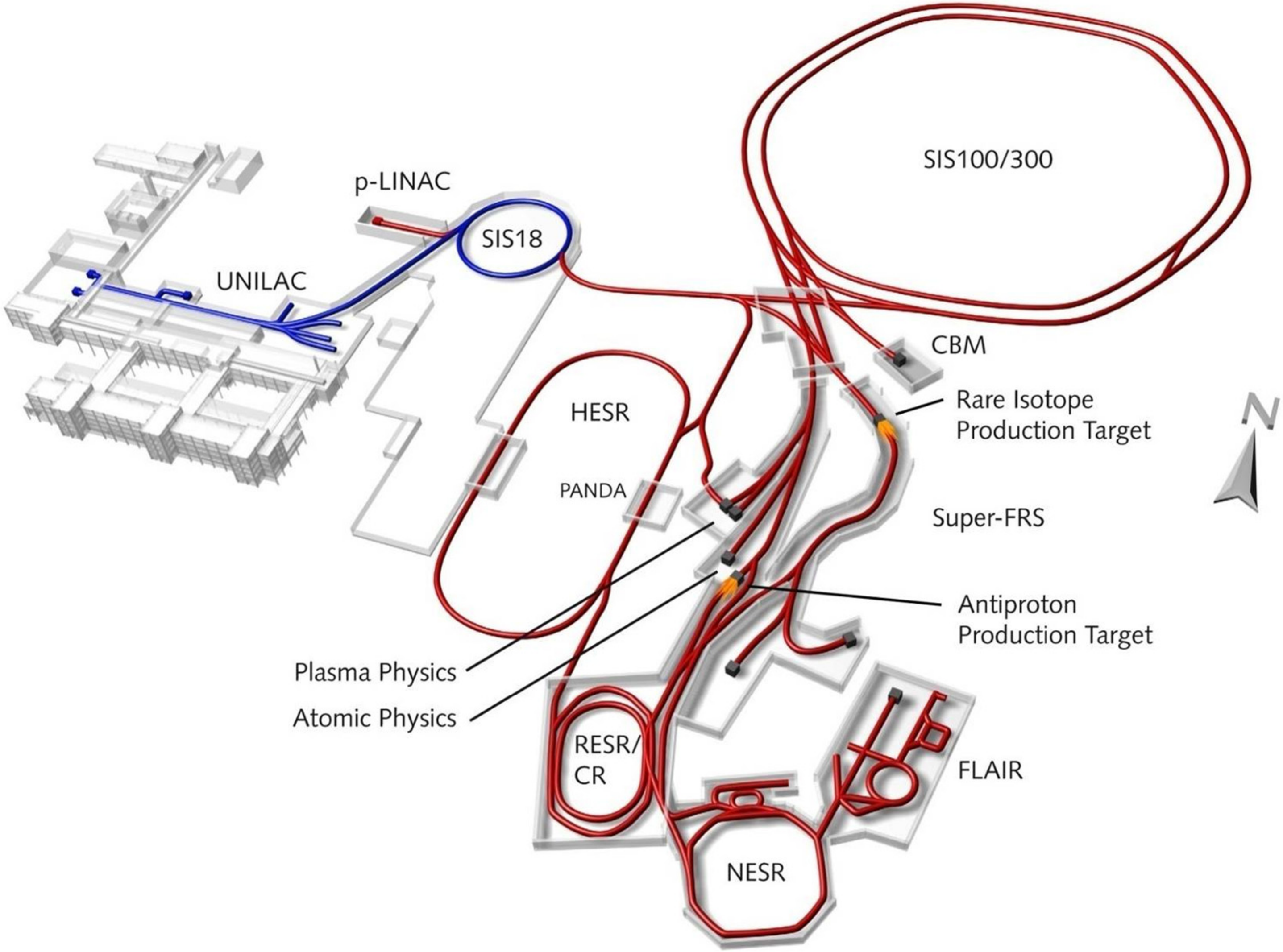
Institut für Angewandte Physik, Goethe-Universität Frankfurt and GSI Helmholtzzentrum für Schwerionenforschung

for the FAIR @ GSI section

Outline

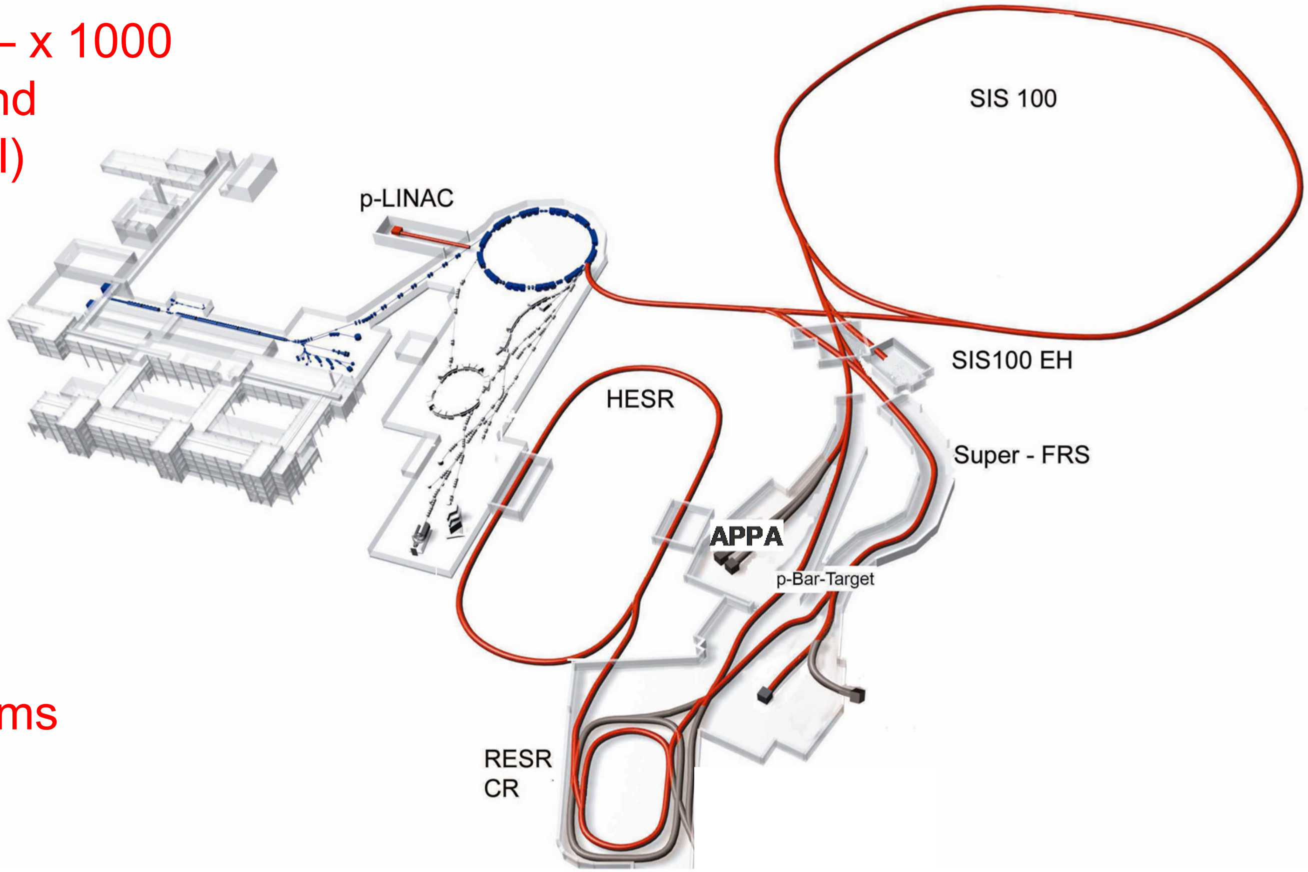
- Introduction
  - The FAIR heavy ion accelerators
  - The injectors at GSI
- FAIR accelerator challenges
  - High current ion sources
  - Linac beam dynamics and cavities
  - FAIR synchrotrons
- Outlook

Facility for Antiproton and Ion Research - FAIR



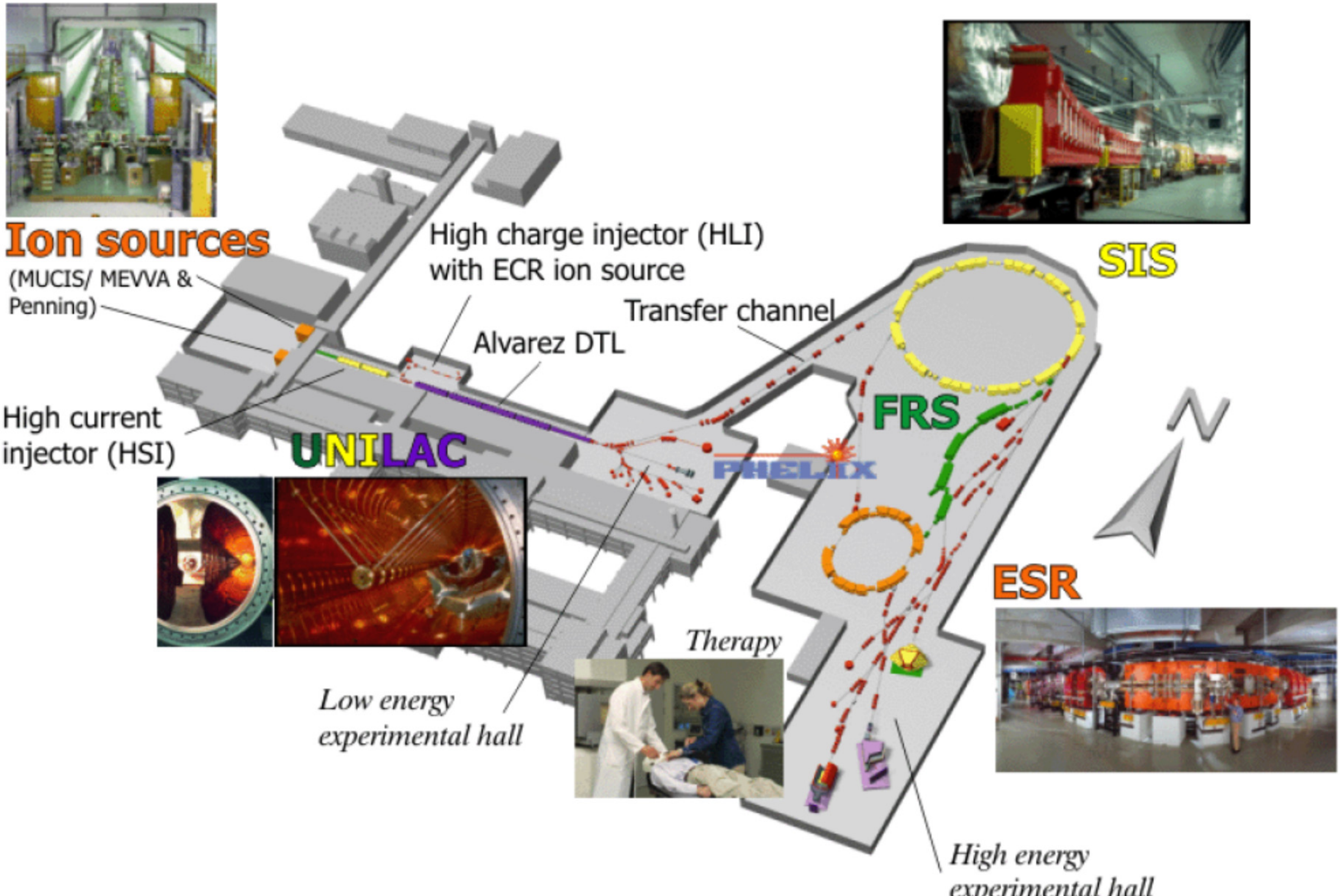
Requirements to conduct world class experiments

- Beam intensity increase:
  - Primary beams: x 100 – x 1000 (4*10[11] uranium ions and 2*10[13] protons per spill)
  - Secondary beams: x 10.000
- Beams:
  - Anti protons
  - Protons to uranium
  - RIBs
- Beam quality:
  - Cooled anti proton beams
  - Cooled, intense RIBs
- Beam pulse structure:
  extreme short pulses to quasi continuous



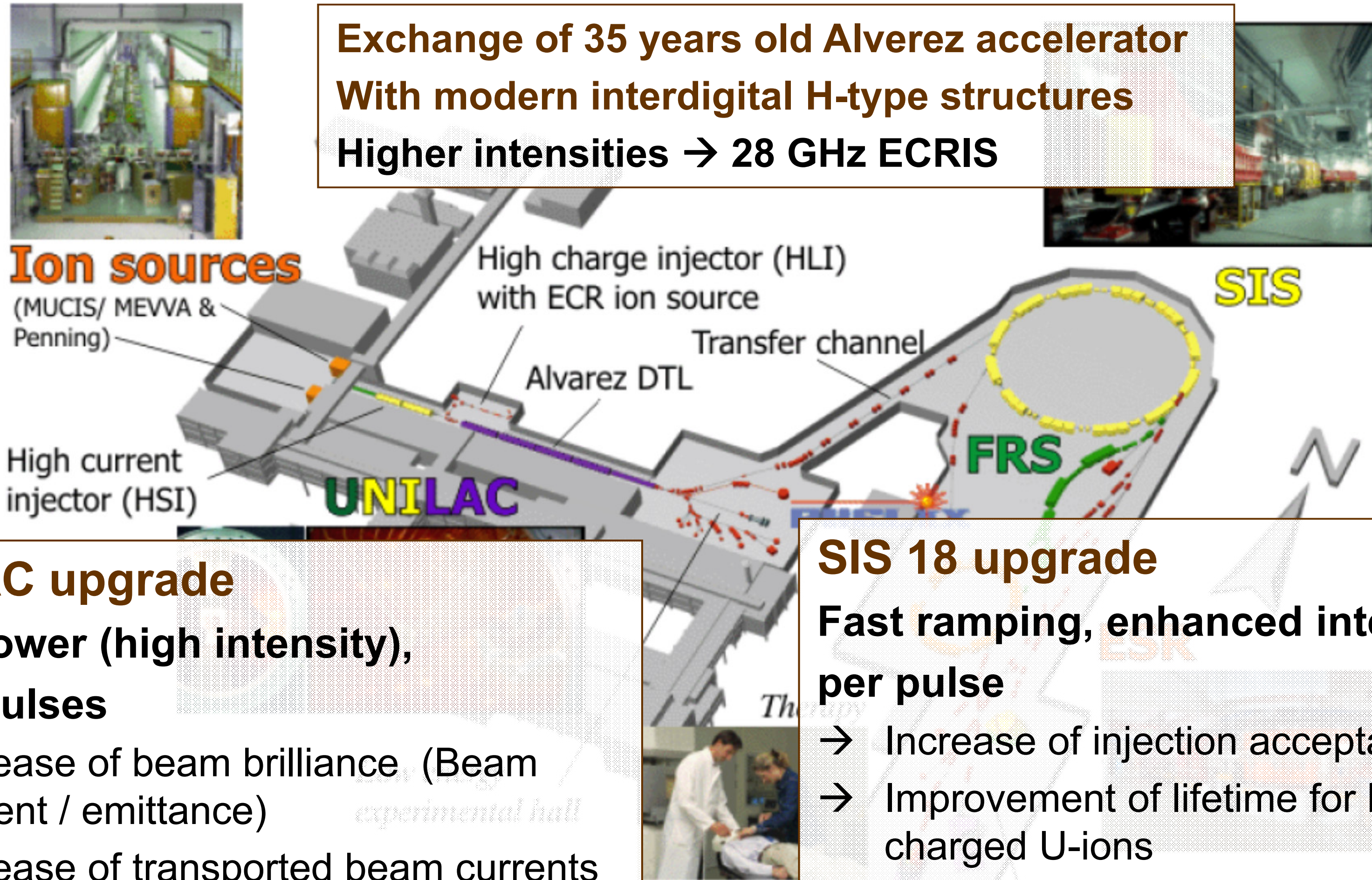
Modularized start version

Preparing the Injector Chain



Preparing the Injector Chain

Exchange of 35 years old Alverez accelerator
With modern interdigital H-type structures
Higher intensities → 28 GHz ECRIS



UNILAC upgrade

High power (high intensity), short pulses

- → Increase of beam brilliance (Beam current / emittance)
- → Increase of transported beam currents
- → Improvements of high current beam diagnostics / operation

SIS 18 upgrade

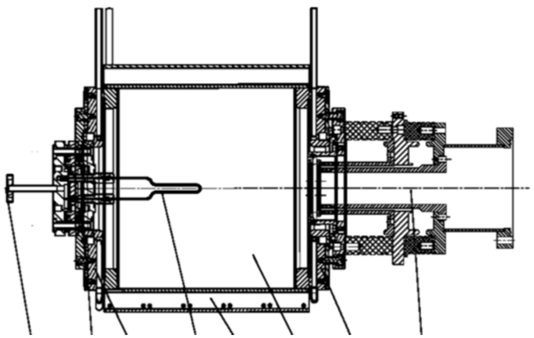
Fast ramping, enhanced intensity per pulse

- → Increase of injection acceptance
- → Improvement of lifetime for low-charged U-ions
- → Increase of beam-intensity per time due to reduction of SIS18- cycle time

High current ion source issues

GSI high current sources

Filament driven

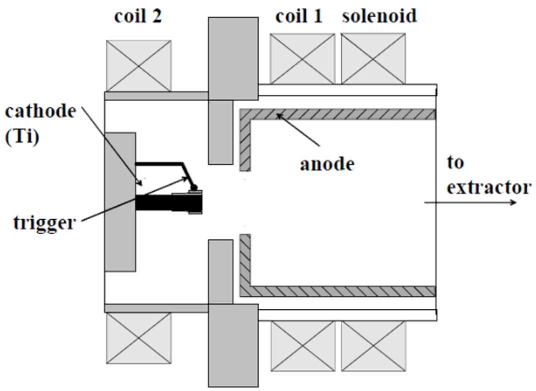


MUCIS, MUCIS New, CHORDIS

Working material:

Gases

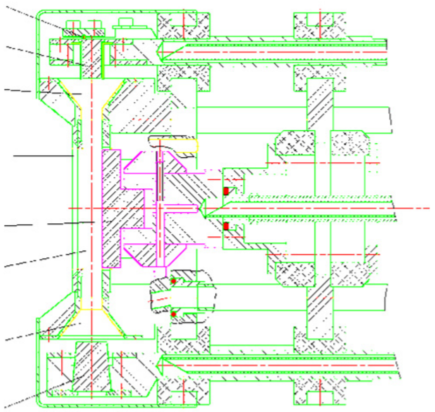
Vacuum Arc driven



MEVVA, VARIS

Metalls and Gases

High Duty factor

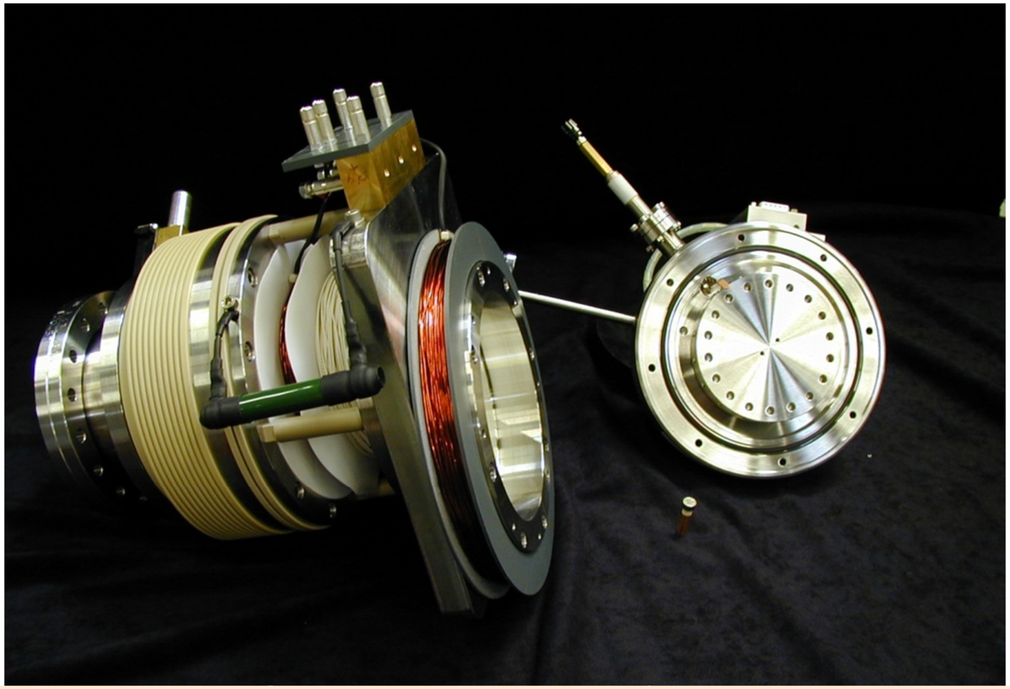


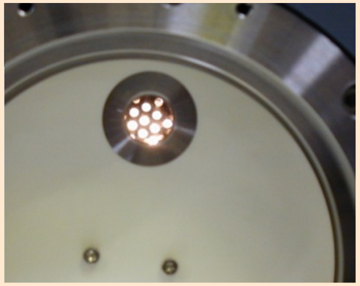
PIG

Metalls and Gases

Vacuum Arc Driven Sources

VARIS (Vacuum Arc Ion Source)





- Optimized for Uranium (67% of $238U^{4+}$)
- Emission current density
  170 mA/cm^2

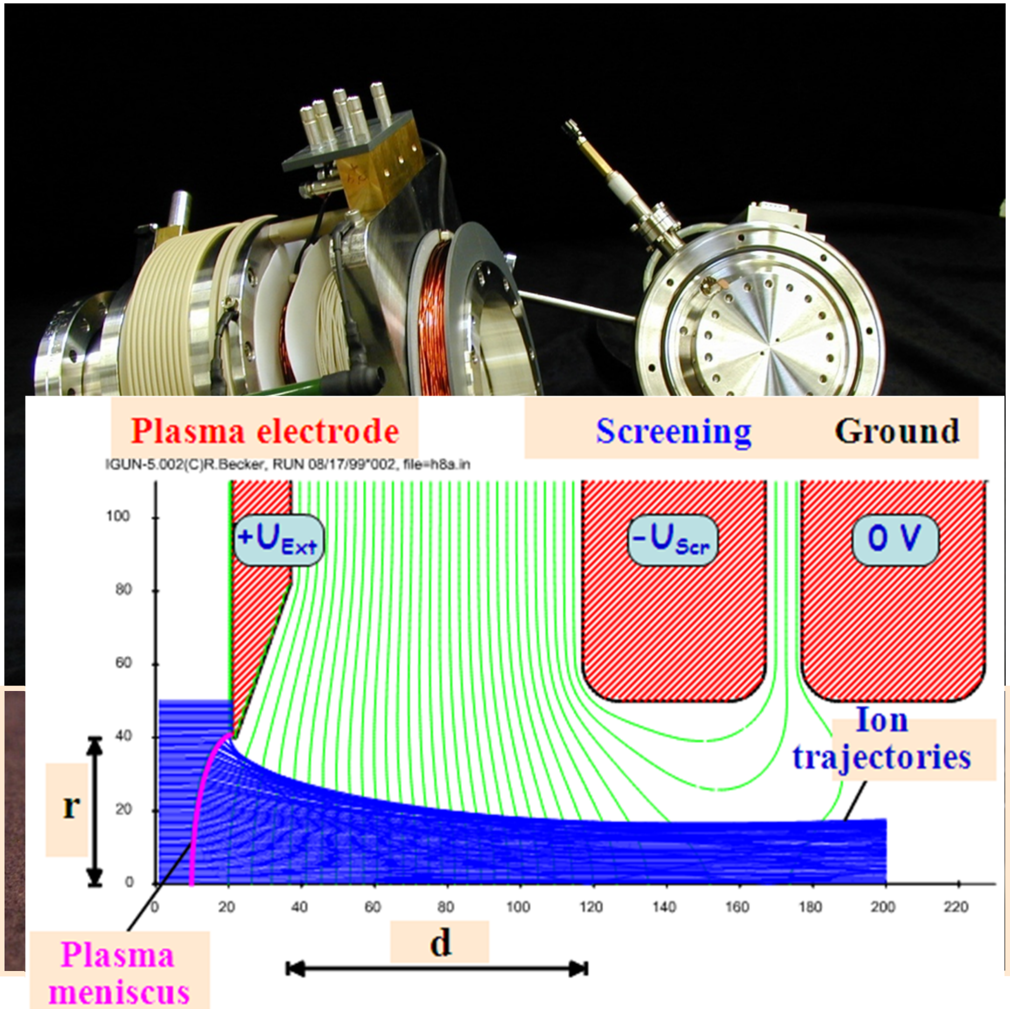
  → 156 mA @ 32 kV
  55 mA @ 131 kV
  20 mA in front of the RFQ
  9 mA behind the RFQ

→ Improving the beam quality at plasma extraction

→ Improvement of beam transport
→ Lifetime of cathodes
→ 3 Hz operation

Vacuum Arc Driven Sources

VARIS (Vacuum Arc Ion Source)



- ➢Optimized for Uranium (67% of 238U^{4+})
- ➢ Emission current density 170 mA/cm^2

→ 156 mA @ 32 kV
55 mA @ 131 kV
20 mA in front of the RFQ
9 mA behind the RFQ

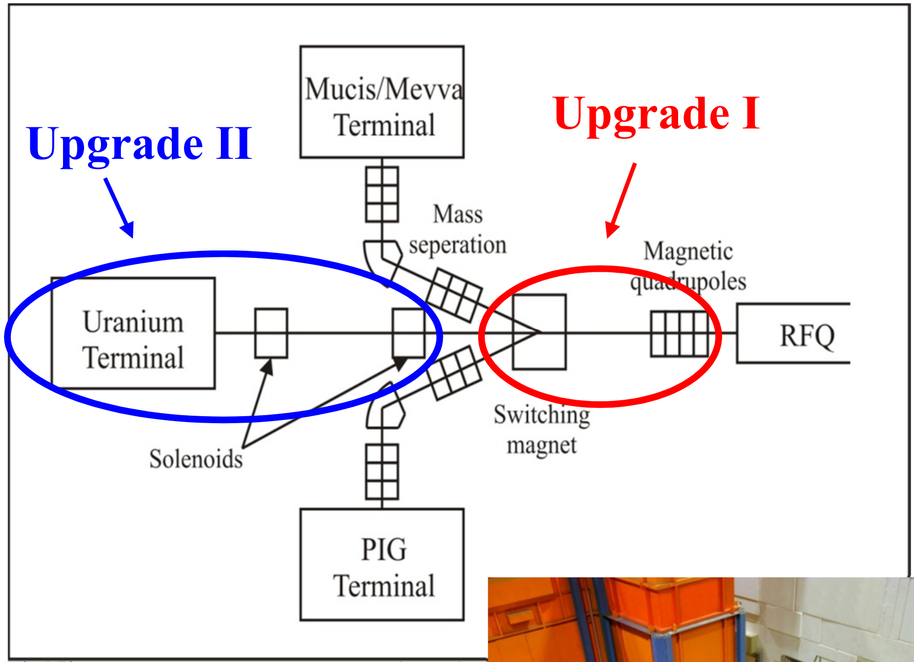
→ Improving the beam quality at plasma extraction

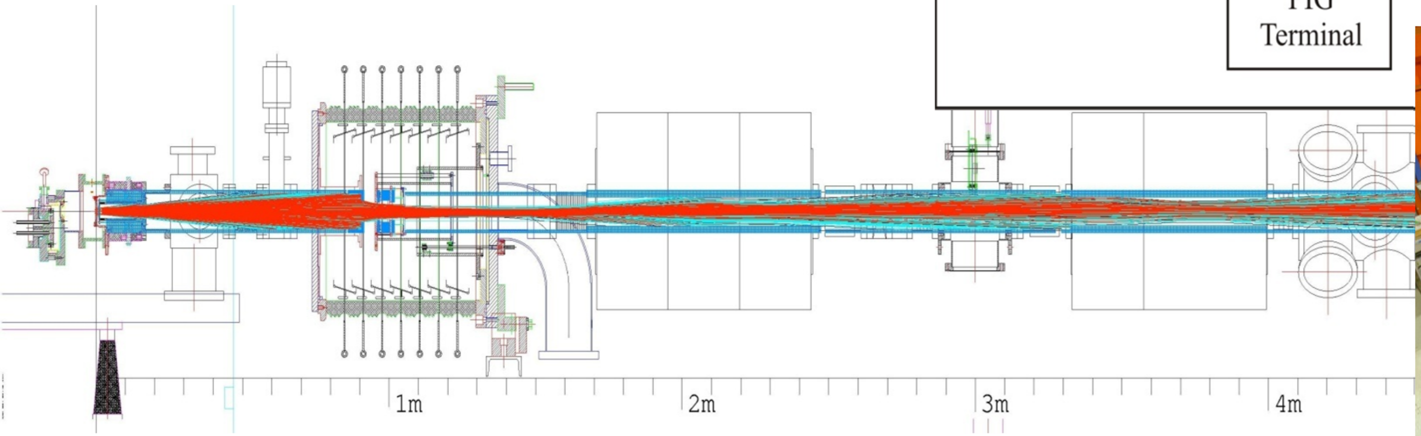
→ Improvement of beam transport
→ Lifetime of cathodes
→ 3 Hz operation

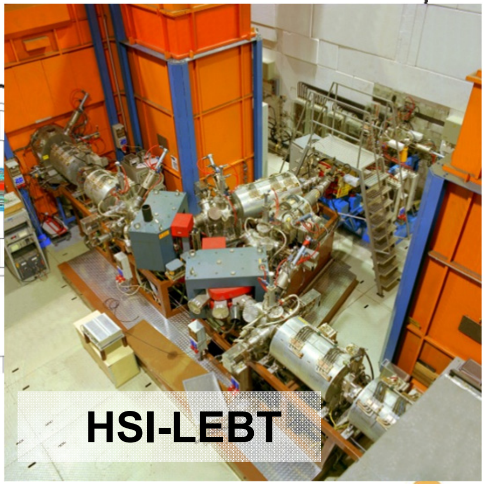
Beam transport → compact LEBT

Beam transport from the source to the RFQ was designed for several orders of magnitude lower intensities!

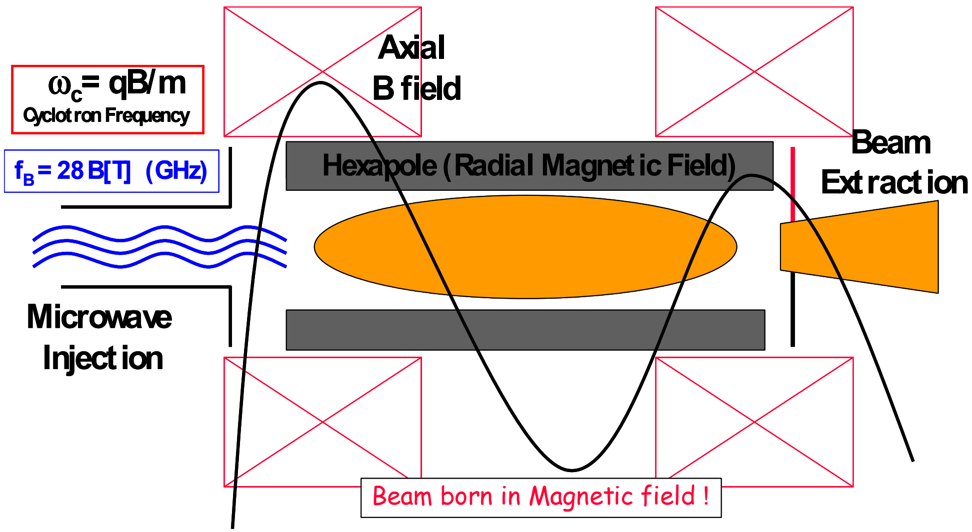
→ New Terminal and direct injection
→ Larger acceptance of LEBT components

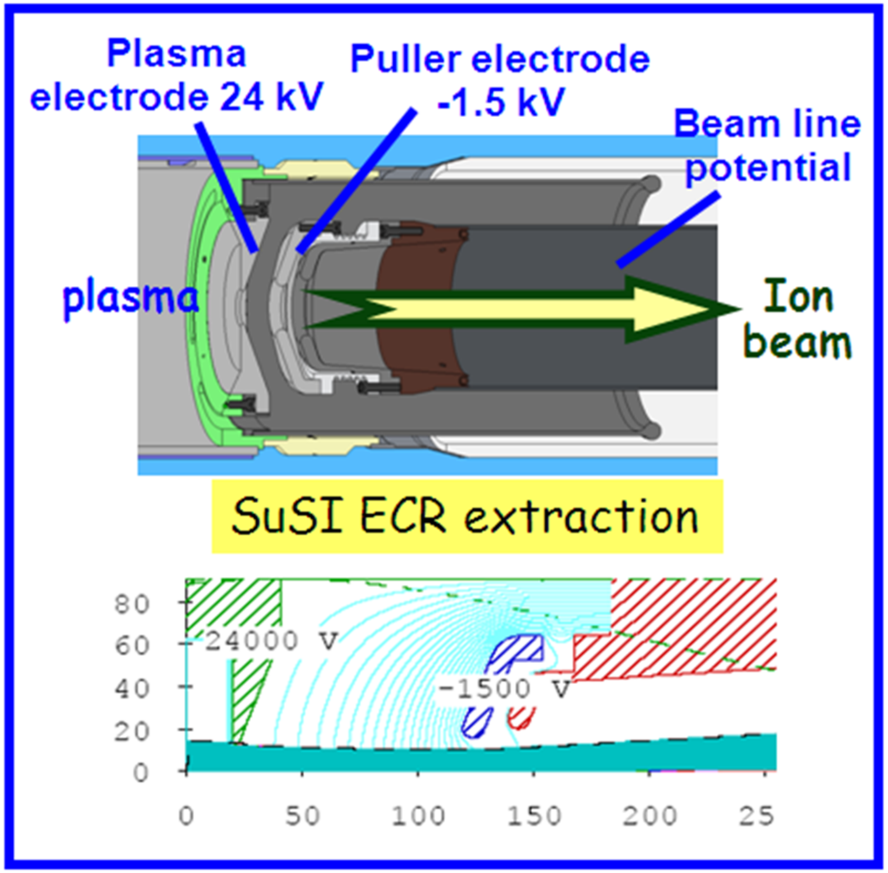






ECR – Ion extraction and beam transport studies

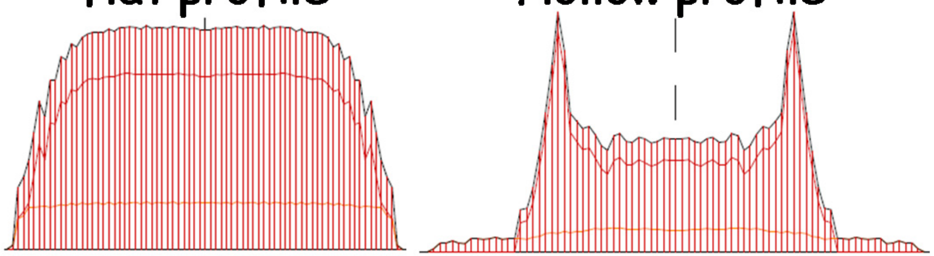




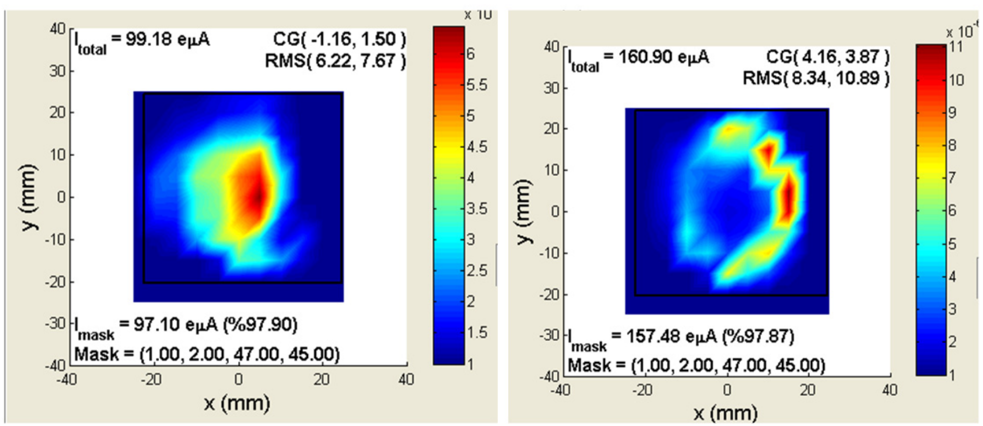
ECR – Ion extraction and beam transport studies

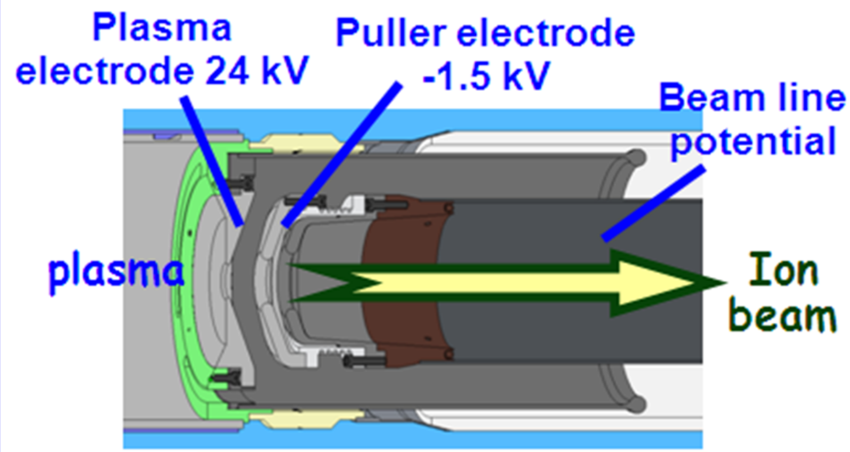
simulated beam profiles

flat profile | Hollow profile

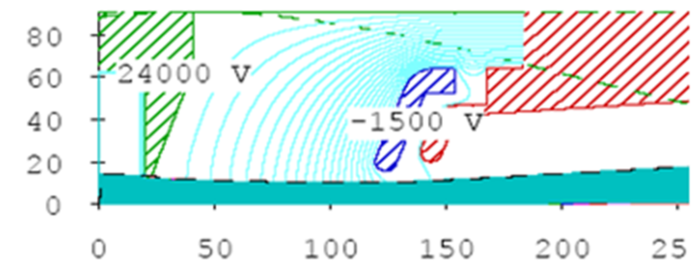


Matched extraction | Mismatched extraction





SuSI ECR extraction



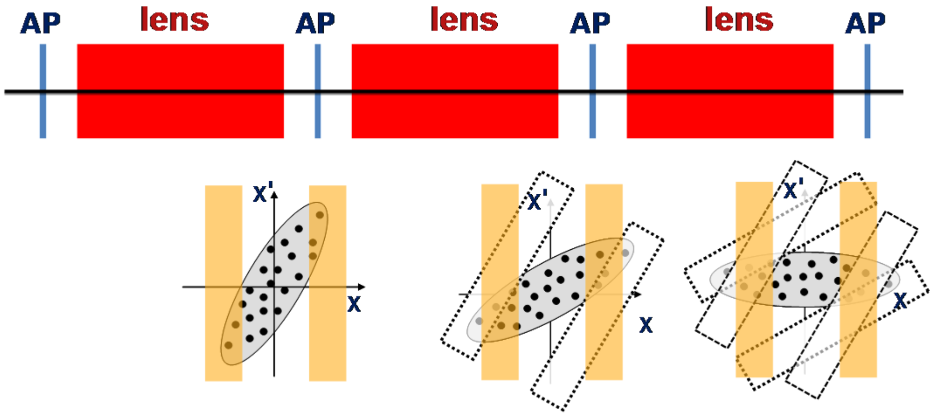
FAIR – HELMHOLTZ | ASSOCIATION GSI

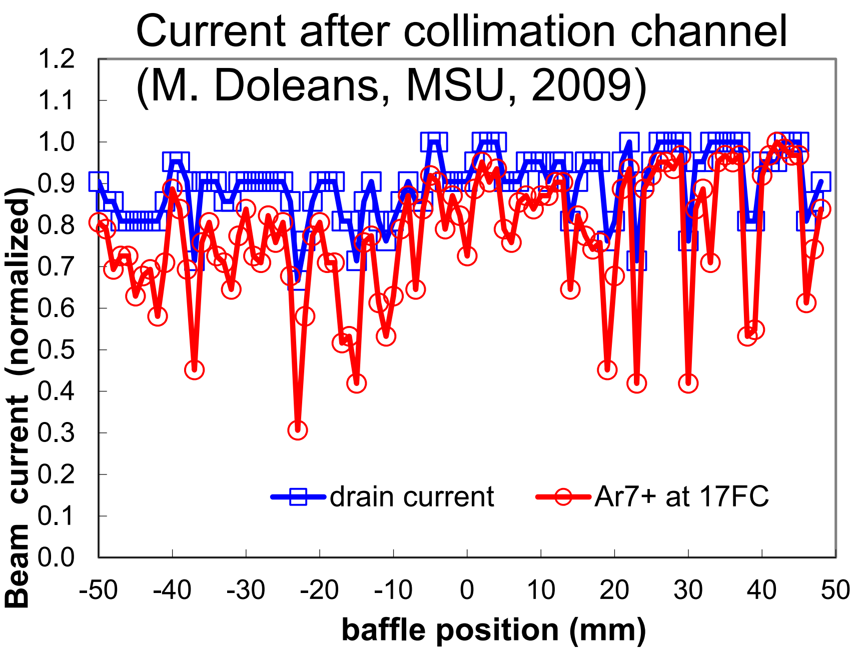
Unique tool: transverse beam collimation channel

Goal: Increase beam intensity into a given phase space →examples:
- NSCL - SUSI ECRIS collimation channel (M. Doleans et al.)
- Hahn Meitner Institute (ISL) ECR heavy ion injector (A. Denker et al.)

Use the channel as a tuning tool for optimized ion extraction parameters

➢ Set the channel at a given acceptance and optimize the beam brilliance





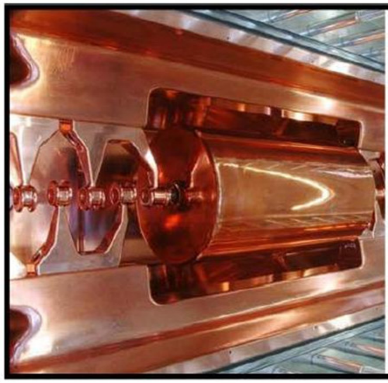
LINAC issues

Status of the UNILAC Uranium-Performance

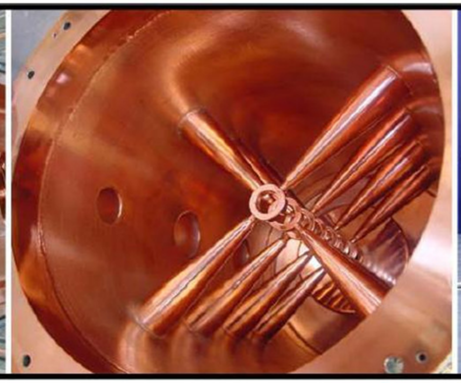
	Measured	Design (1999)	required for FAIR
$^{238}U^{4+}$ Max. Beam Intensity I, (2.2 keV/u)	16 emA	16 emA	20 emA
I_{max}@beam power, (1.4 MeV/u)	6.5 emA @587 kW	15 emA@1250 kW	18 emA@1500 kW
Transv. Emittance (LEBT) (90%, total)	140 $\pi\cdot$mm$\cdot$mrad	120 $\pi\cdot$mm$\cdot$mrad	120 $\pi\cdot$mm$\cdot$mrad
Macropulse Length	150 μs	150 μs	150 μs
Reproducibility/Transversal Emittance	±4.5%	-	-
Beam loading, 7emA (IH2)	350 kW	590 kW (15 emA)	710 kW (18 emA)
U^{28+}			
Max. Beam Current, (1.4 MeV/u)	6.25 emA	12.6 emA	15.0 emA
Max. Beam Intensity, 11.4 MeV/u, I_{max}@beam power Transfer to the SIS18 *Ions/100µs*	5.7 emA@567 kW *$1.3\cdot10^{11}$*	12.6 emA@1221 kW *$2.8\cdot10^{11}$*	15.0 emA@1453 kW $3.3\cdot10^{11}$
U^{73+} Max. Beam Intensity, 11.4 MeV/u, *Ionen/100µs*	2.7 emA *$2.3\cdot10^{10}$*	4.6 emA *$3.9\cdot10^{10}$*	3.5 emA $3.0\cdot10^{10}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	11.0 $\pi\cdot$mm$\cdot$mrad	5.0 $\pi\cdot$mm$\cdot$mrad	7.0 $\pi\cdot$mm$\cdot$mrad

H-type structures for FAIR

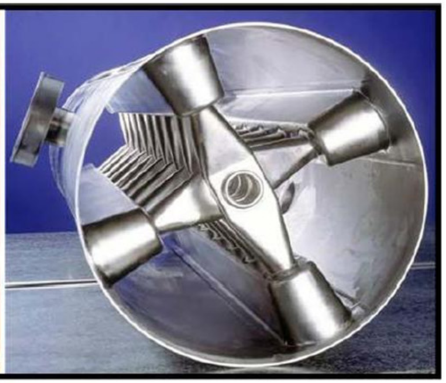
- FAIR-p-linac → 325 MHz-CH-prototype, room temperature
- ALVAREZ replacement → IH-structures (108 MHz)



Room Temp. IH-DTL

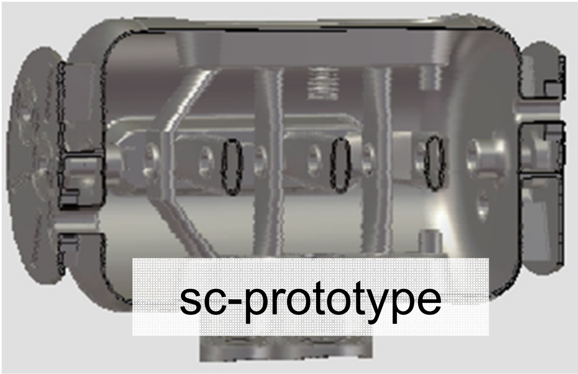


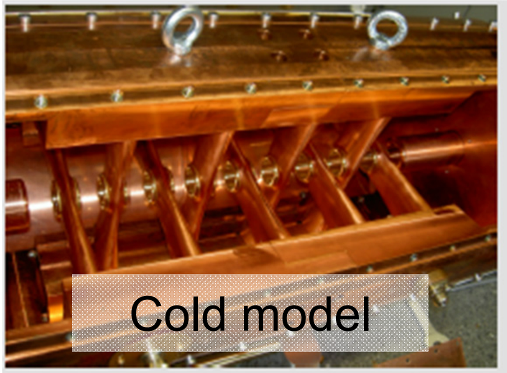
Room Temp. CH-DTL



Supercond. CH-DTL

- Prototyping of a SC 325 MHz-CH structure @ Frankfurt

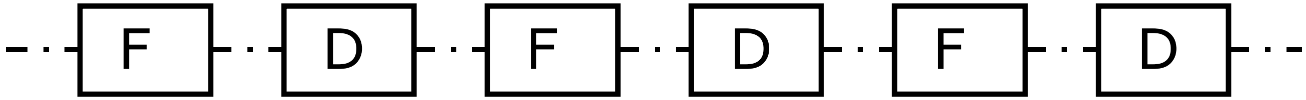




FAIR — HELMHOLTZ | ASSOCIATION GSI

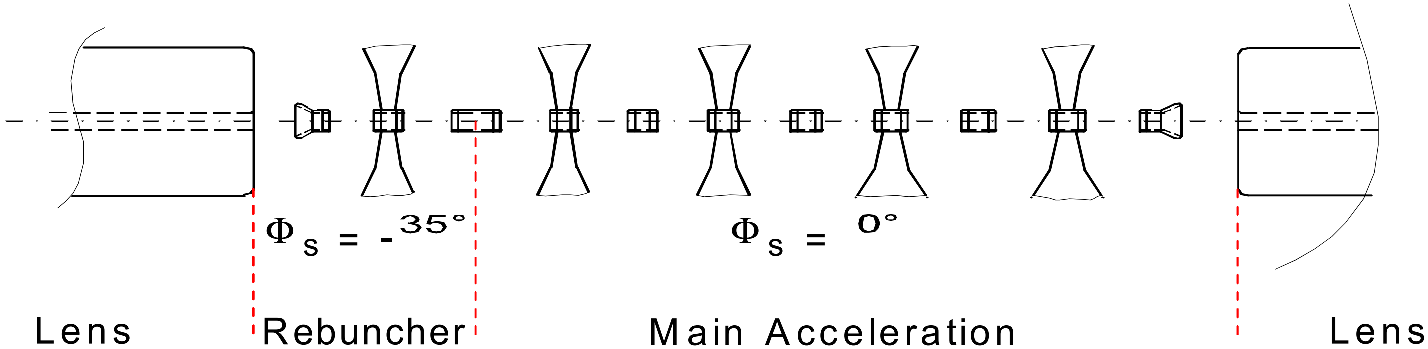
H-type structures and KONUS

- Negative synchronous phase structure: $\Phi_s = -30^0$
  drift tubes with integrated quadrupoles



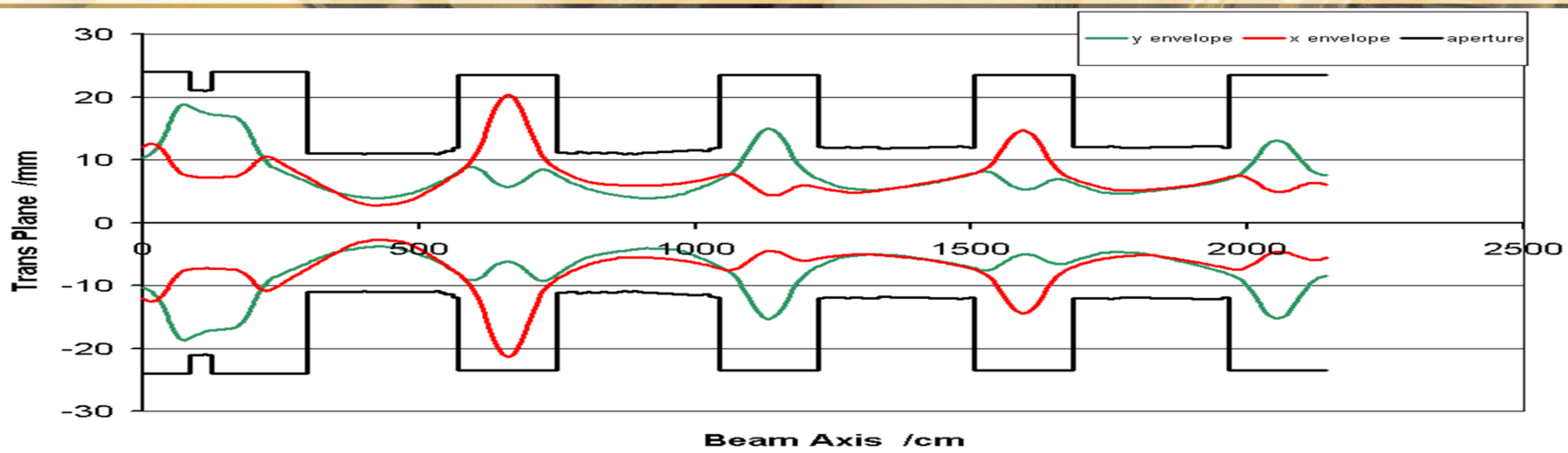
  Focusing (longitudinal & transversal) and acceleration

- KONUS beam dynamics

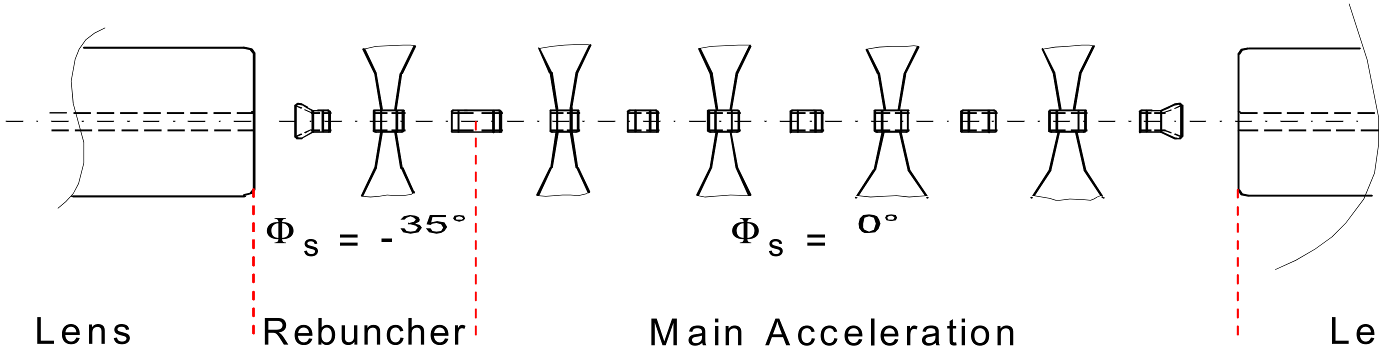


separated sections of transverse and longitudinal focusing and of acceleration
Combined 0-deg synchronous particle structure

H-type structures and KONUS

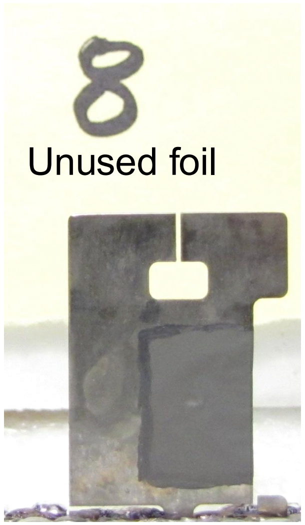


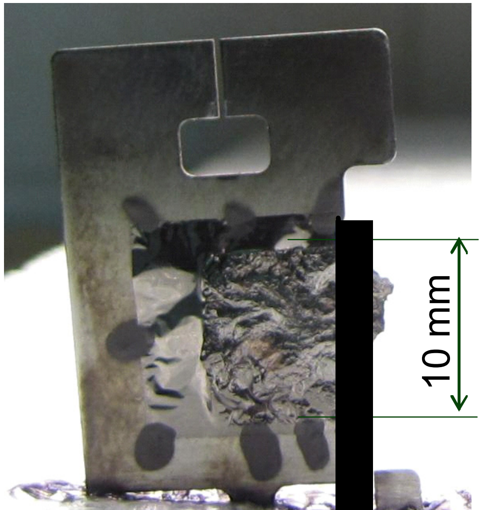
- KONUS beam dynamics



separated sections of transverse and longitudinal focusing and of acceleration
Combined 0-deg synchronous particle structure

Charge state stripper for intense heavy ion beams





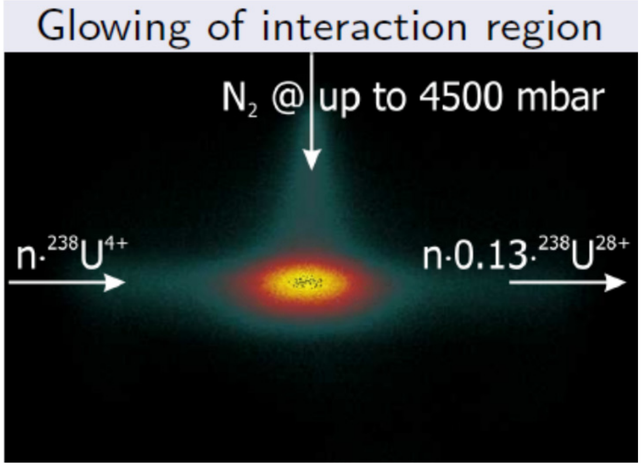
Edge of the foil before irradiation

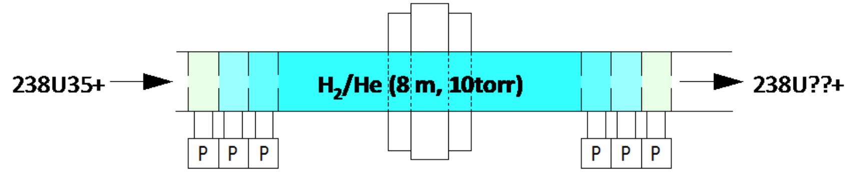
C-foil stripper

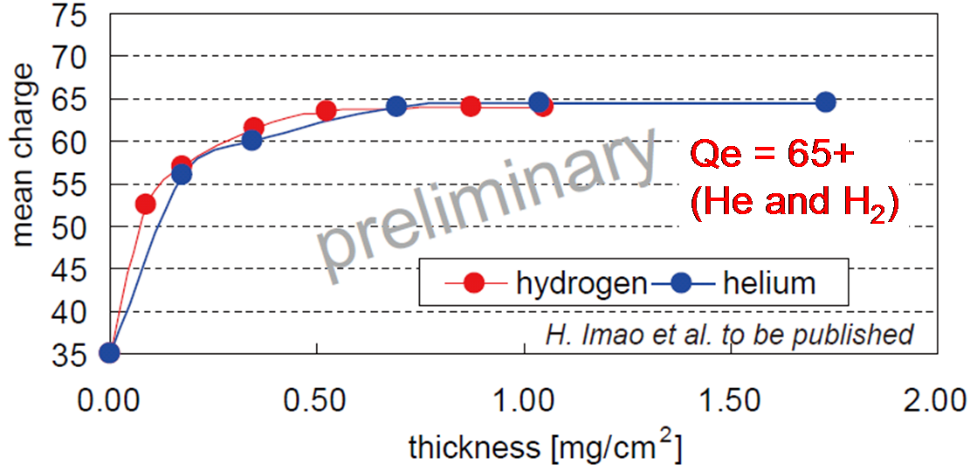
- short lifetime at highest intensities, but highest charge states

gas stripper

- High intensity capabilities, but lower charge states
- Equilibrium charge state (efficiency)



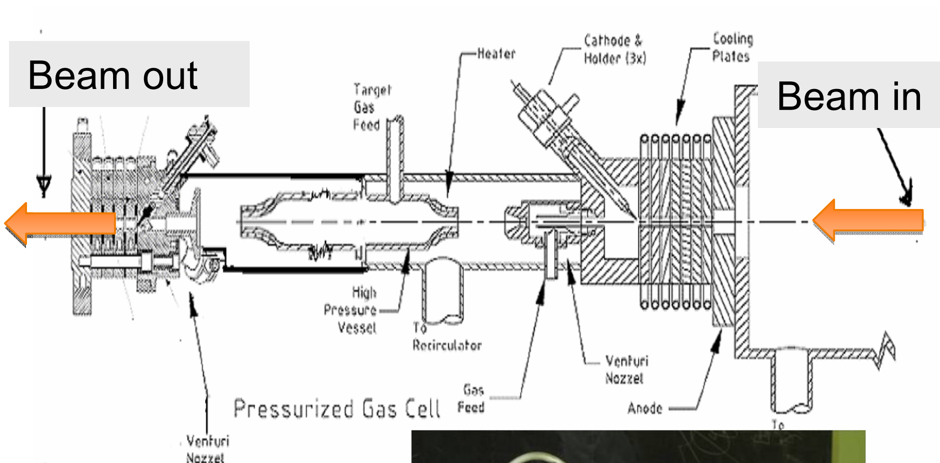


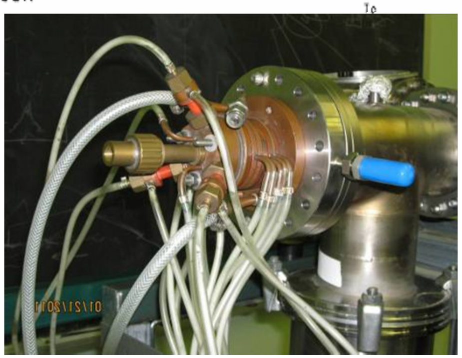


Alternatives: Liquid Lithium or plasma stripper

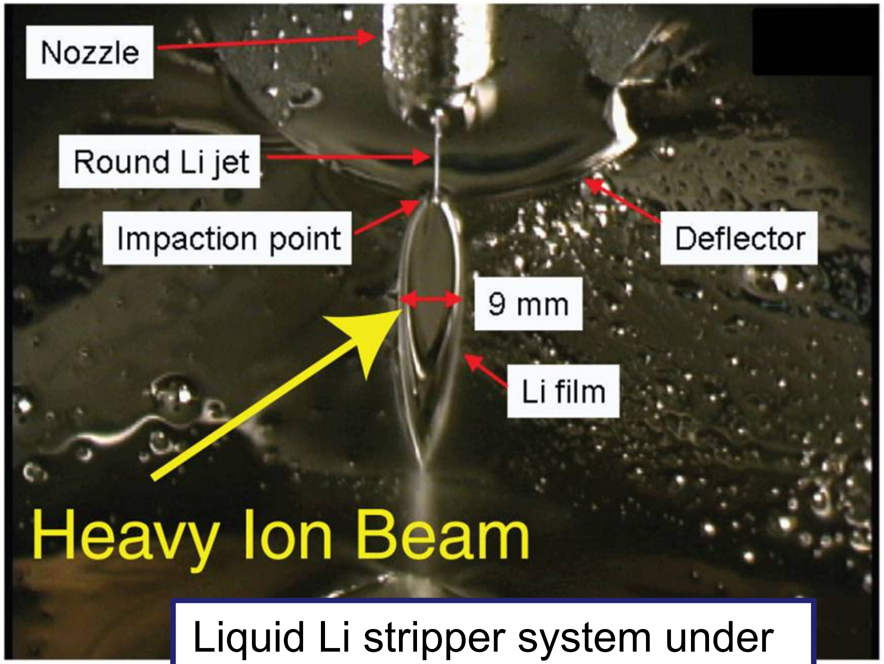
Plasma stripper

- Need to increase the gas density – plasma window for differential pumping
- Dense plasma channel separated by plasma windows





MIT Plasma window in a test setup at BNL



Liquid Li stripper system under development at ANL

Liquid Li-stripper

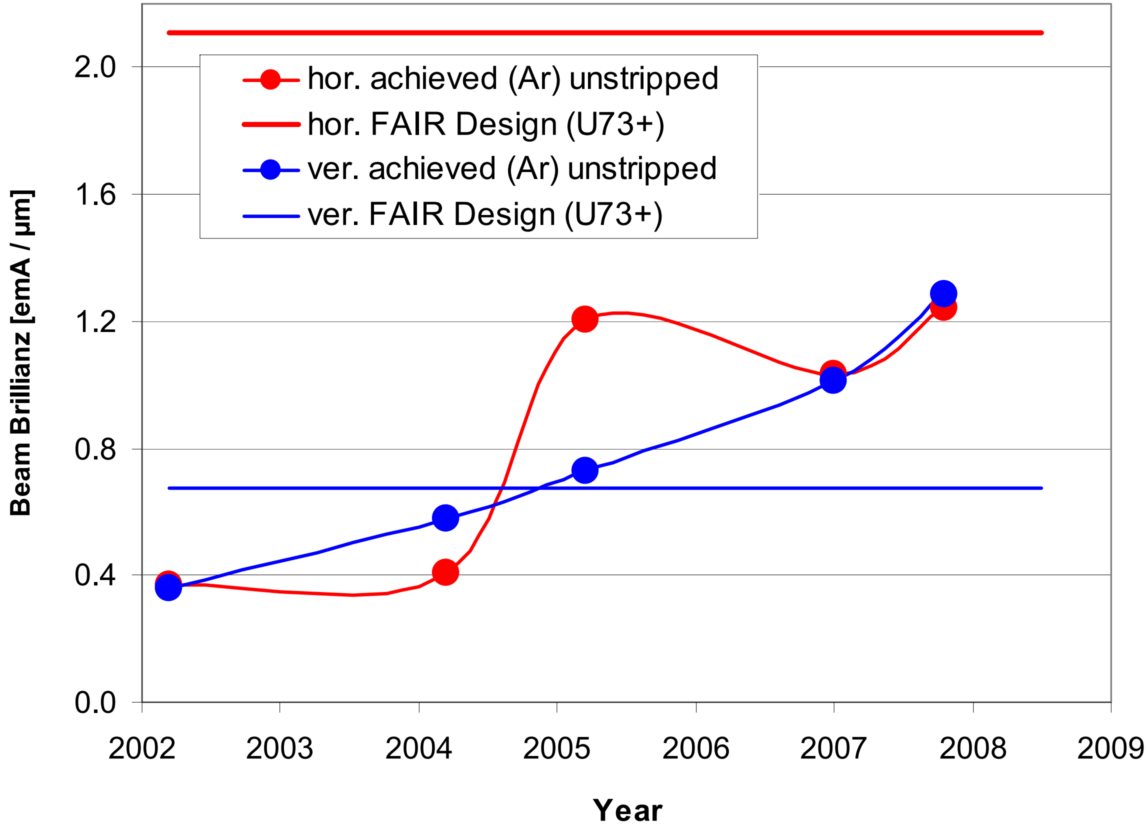
- Challenging to established a thin Li-film, stable with time and controllable thickness

Horizontal and vertical beam brilliances

Reminder:

$B_{x/y}$:= (q/A)*Current / Emittance$_{x/y}$

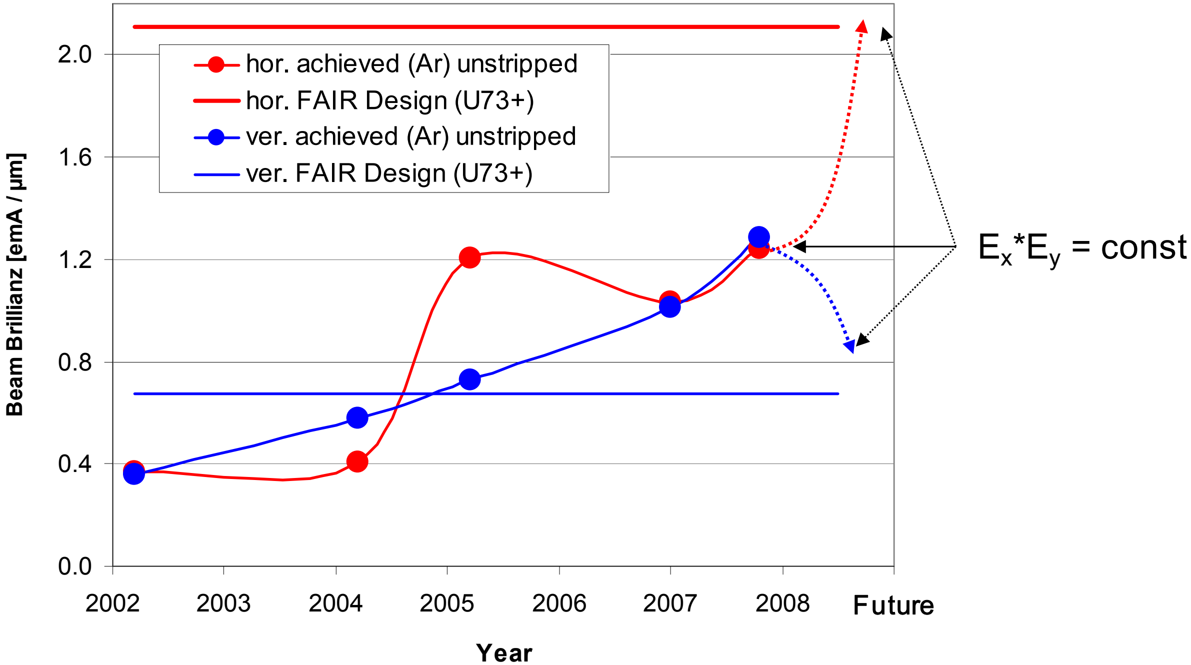
- achieved UNILAC brilliances are similar
- horizontally we are not ok
- vertically we are ok



→ emittance transfer from horizontal to vertical plane should help

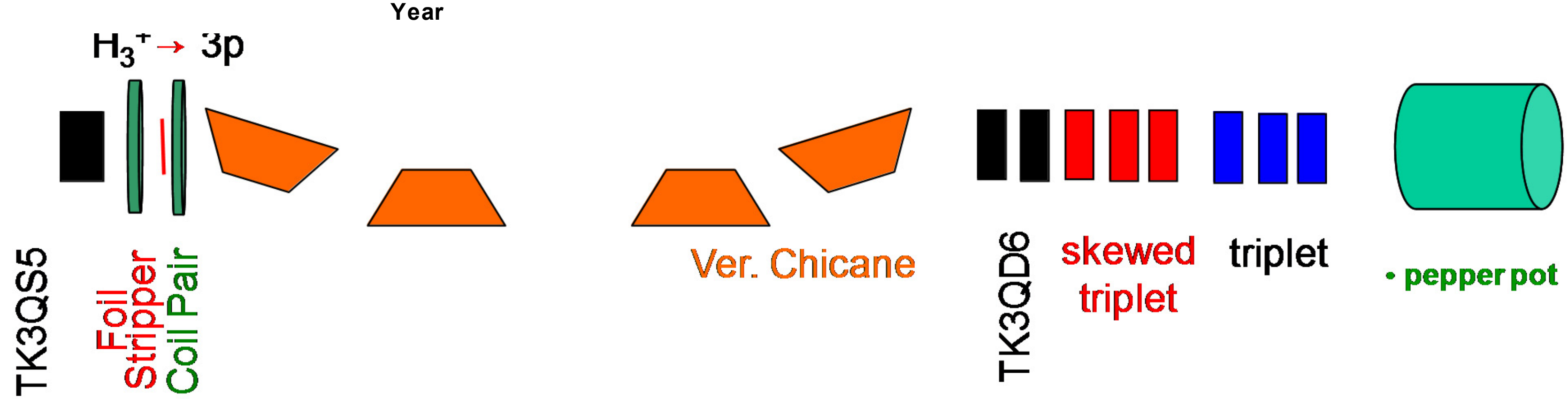
→ transfer should preserve $\varepsilon_x * \varepsilon_y$

Emittance transfer



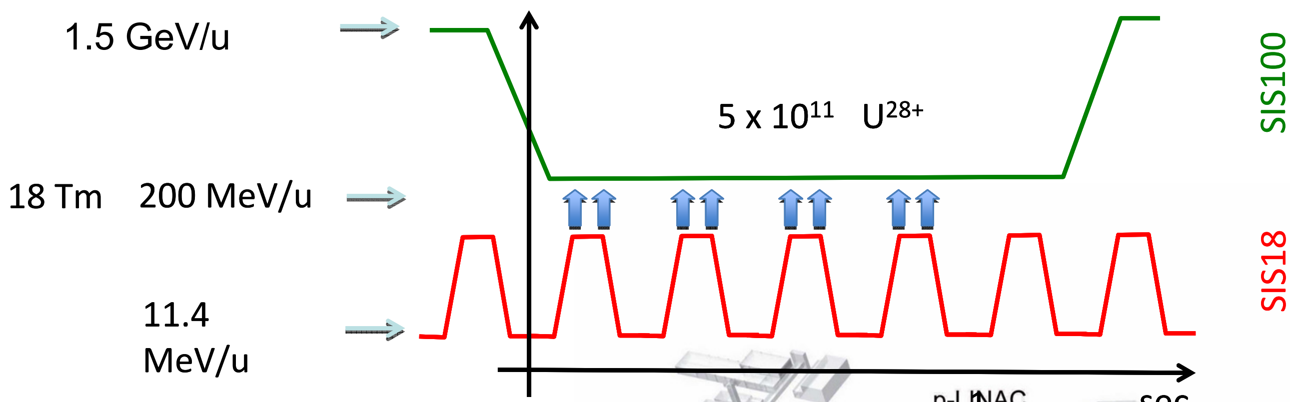
Emittance transfer via Eigen Emittance shaping

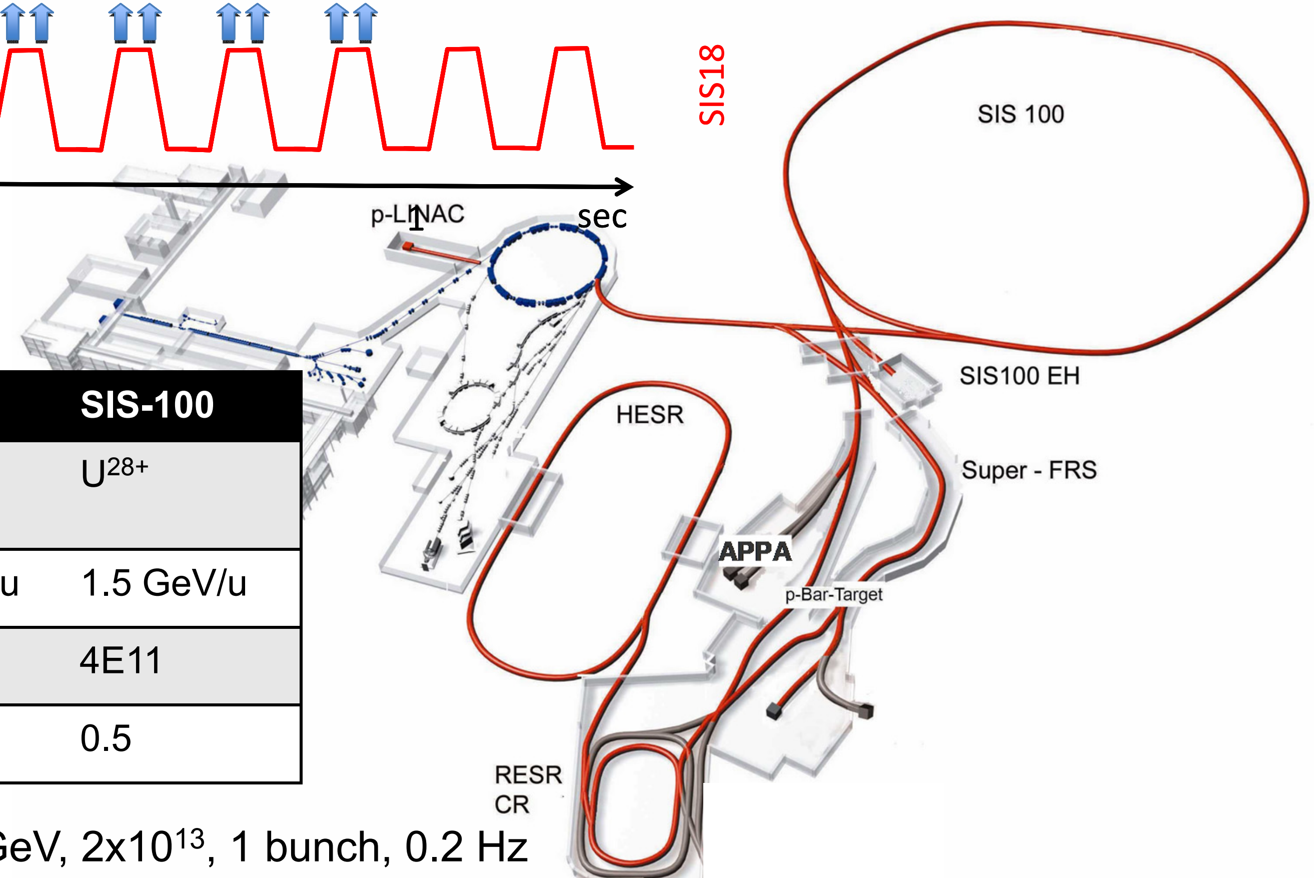
→See poster of Chen Xiao (MOP207)



Synchrotron related issues

Requirements to conduct world class experiments





	SIS-18	SIS-100
Reference primary ion	U^{28+}	U^{28+}
Reference energy	200 MeV/u	1.5 GeV/u
Ions per cycle	1.5E11	4E11
cycle rate (Hz)	2.7	0.5

Protons from SIS-100: 29 GeV, $2x10^{13}$, 1 bunch, 0.2 Hz

Collective effects in the FAIR rings

Incoherent space charge:

→**Tune shift**
→ **Beam losses and modification of coherent effects**

Impedances:
* image currents in the beam pipe
* magnetic/resistive materials: ferrite, magnetic alloy
→ coherent instabilities and feedback requirements

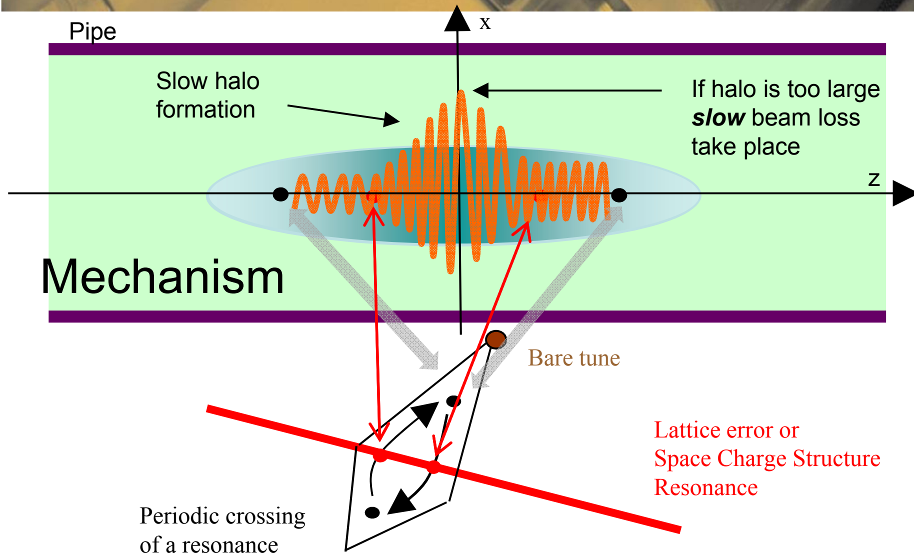
Secondary particles:
electron clouds created by residual gas ionization and secondary electron emission
→trapping of electrons during slow extraction
two-stream instability.

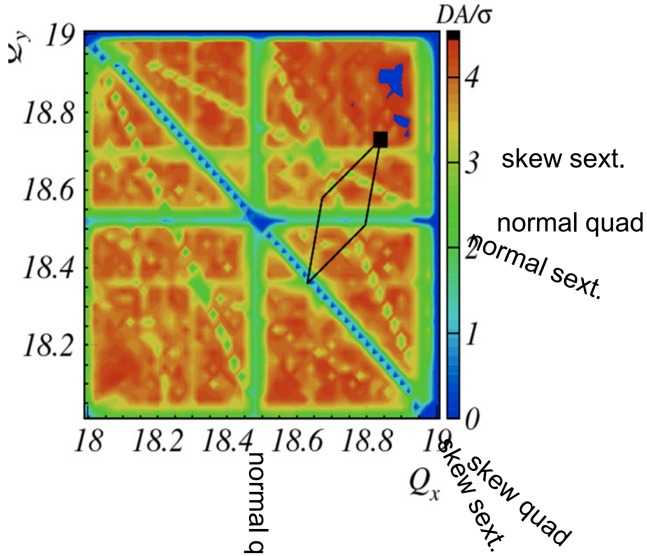
Numerical models are essential!

→See talk of Oliver Boine-Frankenheim in TUO1A

In the FAIR synchrotrons SIS-18 and SIS-100 different incoherent/ coherent effects occur simultaneously.

Long term beam loss for a intense bunched beam

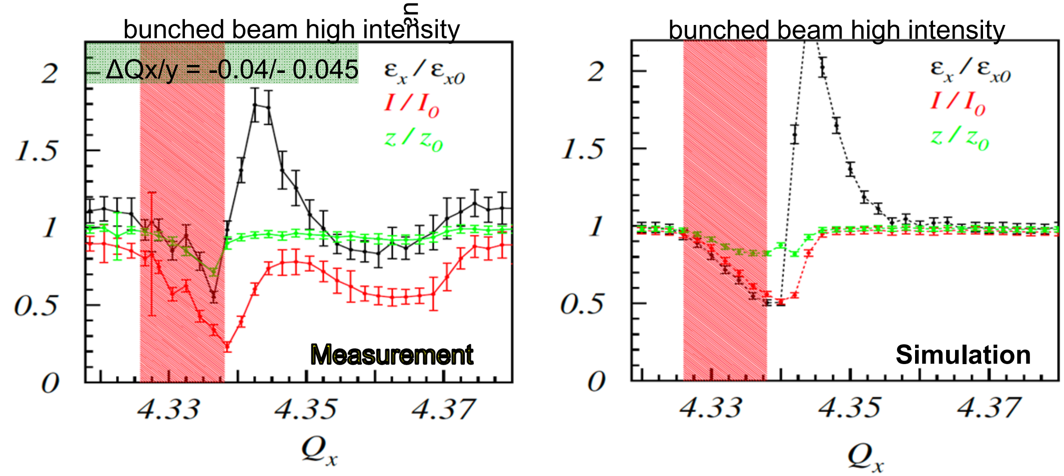




Example of resonances on SIS100: the space charge tune-spread crosses several resonances

Massive benchmarking effort

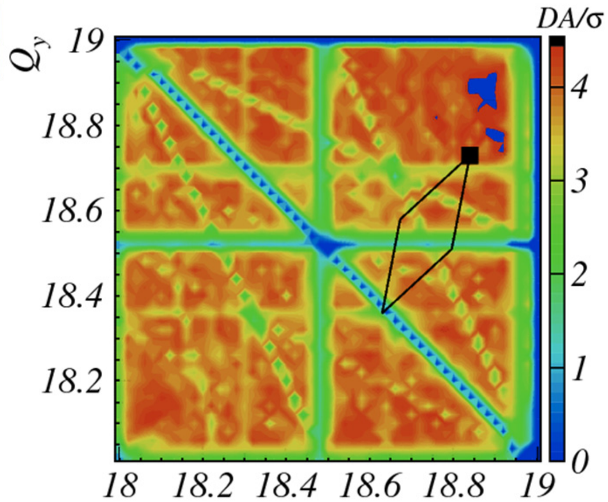
→Talk of G. Franchetti in session WEO1C

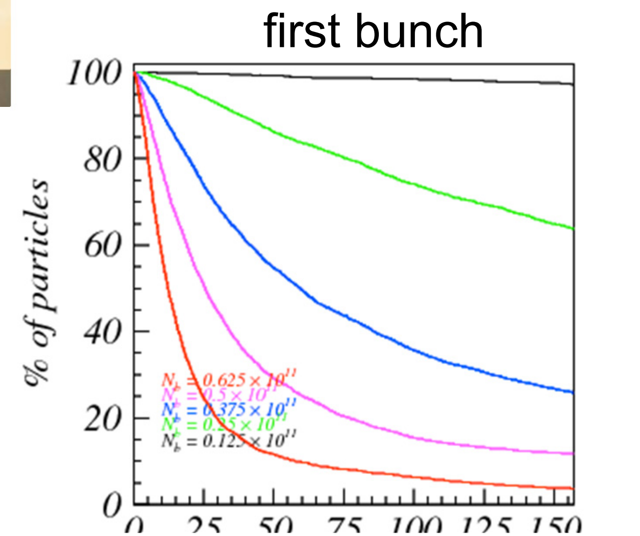


G. Franchetti, O. Chorniy, I. Hofmann, W. Bayer, F. Becker, P. Forck, T. Giacomini,
M. Kirk, T. Mohite, C. Omet, A. Parfenova, and P. Schuett PRSTAB **13**, 114203 (2010)

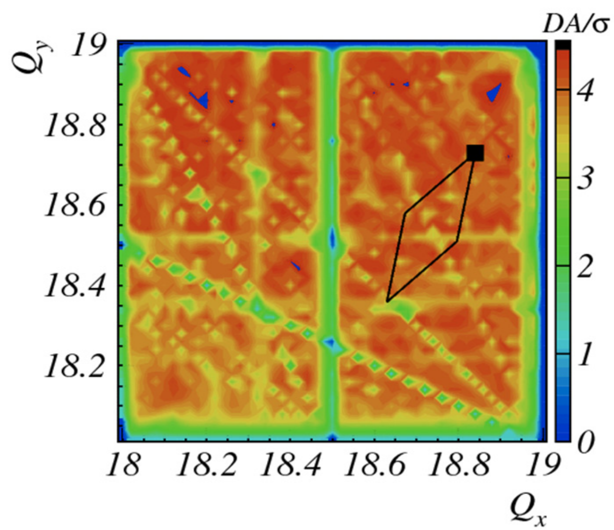
Mitigation strategy

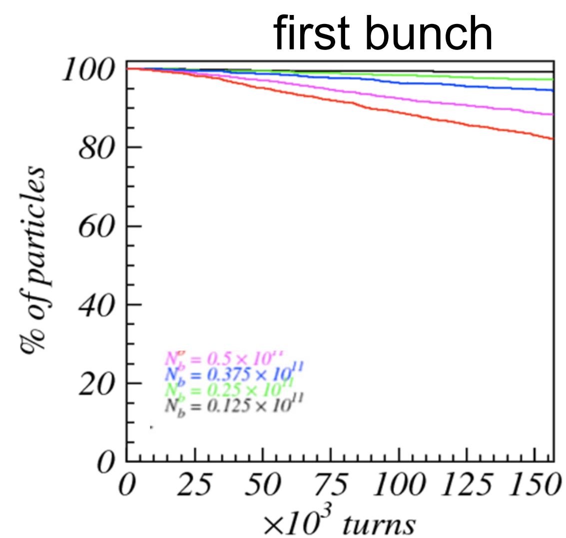
without resonance compensation





compensating the lattice resonances





Ongoing effort for including self-consistency

measurement and control of the tune are mandatory

→ See talk of R. Singh in TUO1C

Longitudinal effects

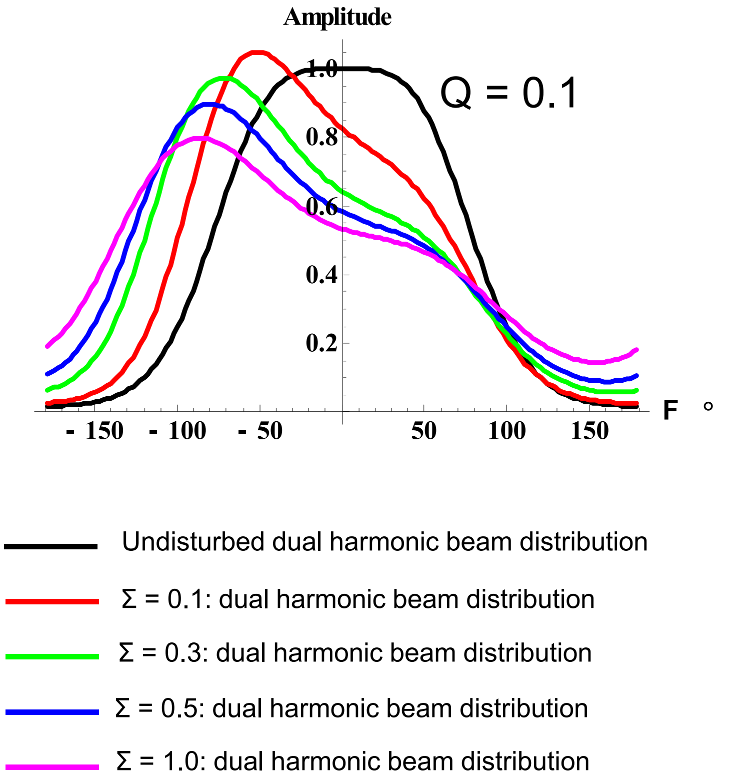
Bunch distribution is altered due to space charge effects (by wake fields)

→ Potential-well distortion
→ Ion bunch form deformation

Challenges:

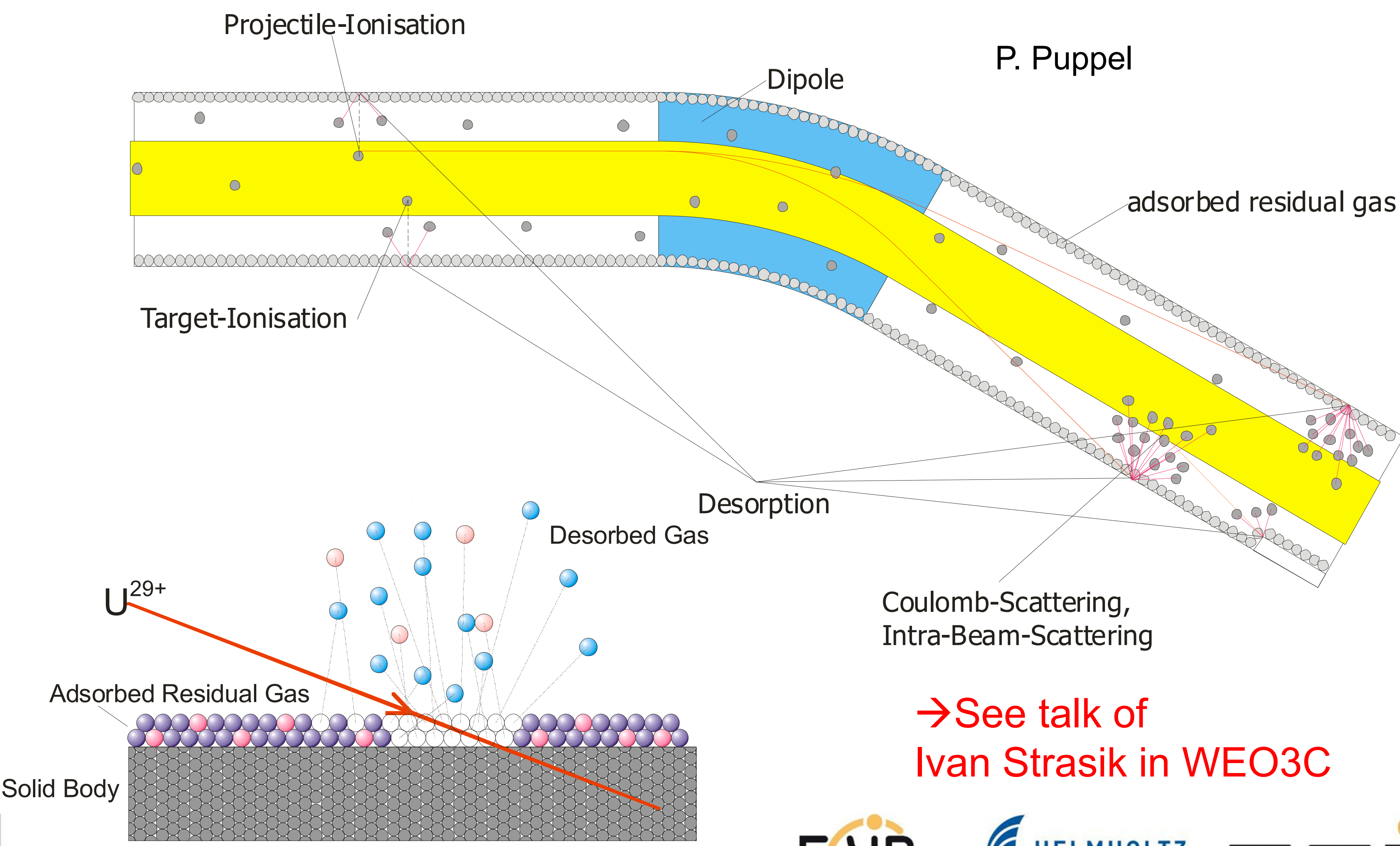
- Space charge induced voltage reduction
- Bunch stability with space charge
- Control of bunch deformation by rf-operation

Dual harmonic operation
→ Increase of bucket area
→ Flattened bunch profile



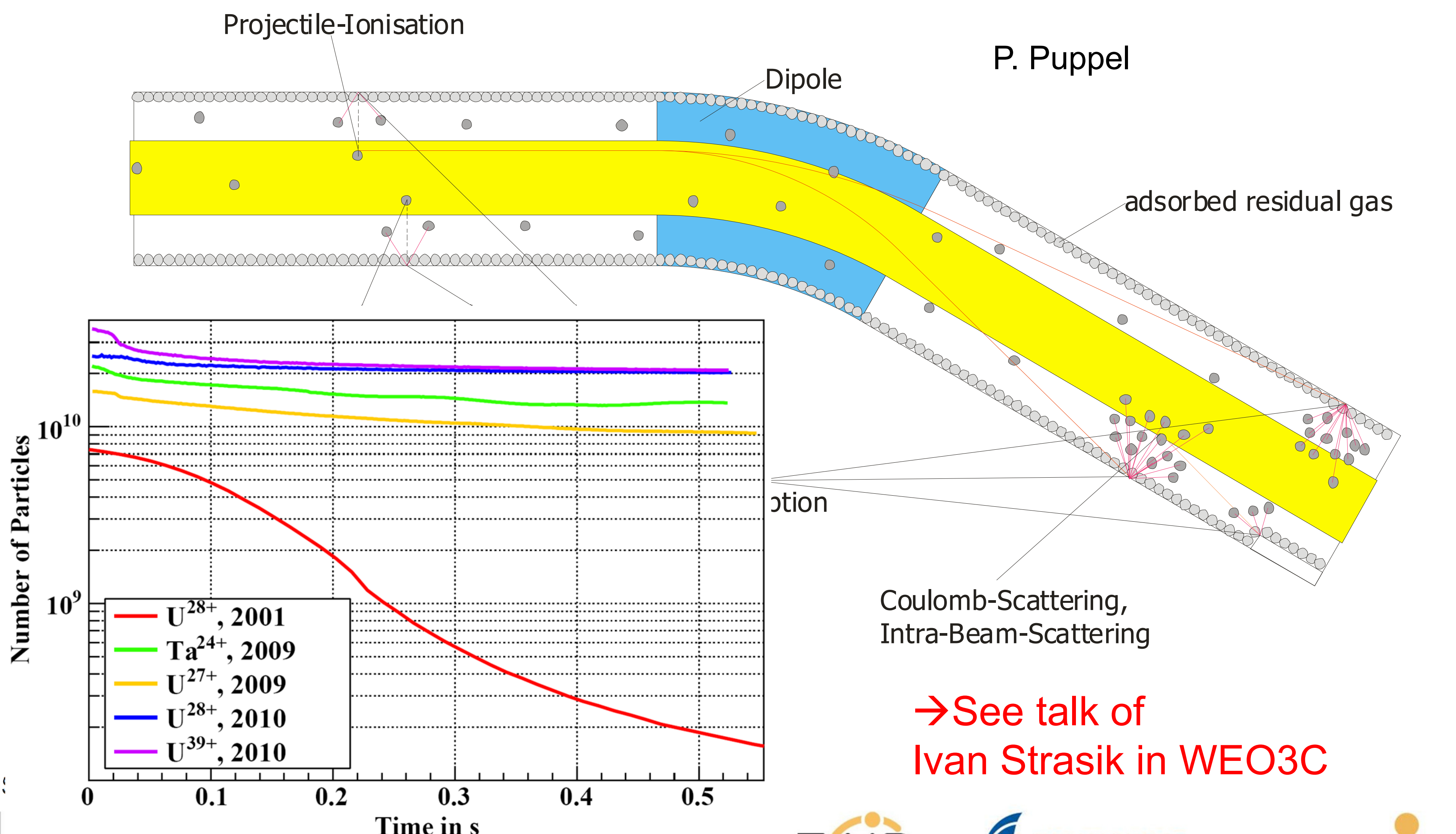
→See poster of Monika Mehler today (MOP205)

Dynamic Vacuum effect and collimation



→See talk of
Ivan Strasik in WEO3C

Dynamic Vacuum effect and collimation



→See talk of
Ivan Strasik in WEO3C

FAIR ‘materials’

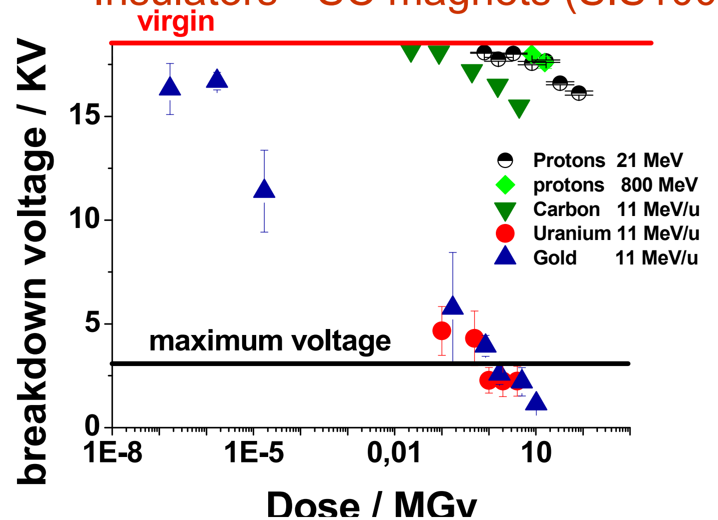
Carbon materials for Super-FRS:

- ➢ Mechanism of radiation damage, critical dose
- ➢ Structural and thermo-mechanical properties degradation

Insulators:

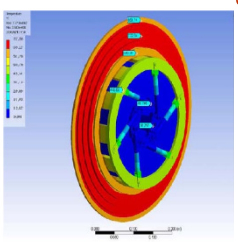
- ➢ critical dose determined
- ➢ break down voltage of insulating material after irradiation

Insulators - SC magnets (SIS100)

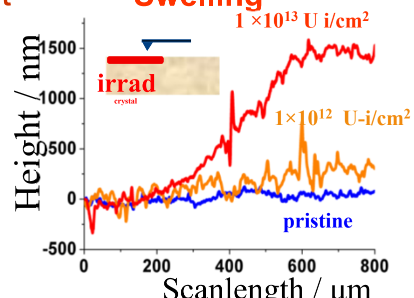


Targets and Beam Catchers - Super-FRS

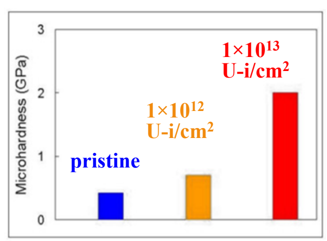
Production target



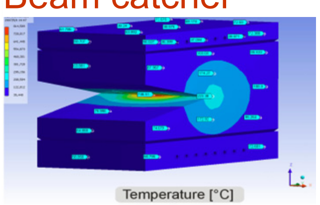
Swelling

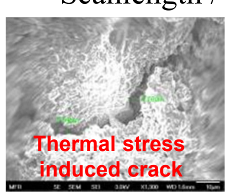


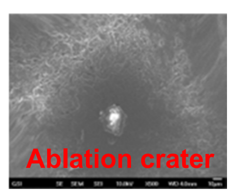
Hardening



Beam catcher





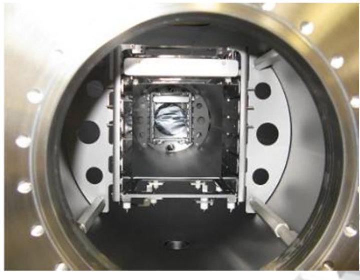


- ➢ Investigate radiation damage and failure mechanism of FAIR accelerators materials
- ➢ Lifetime estimations for FAIR components
- ➢ Innovative materials for extreme conditions

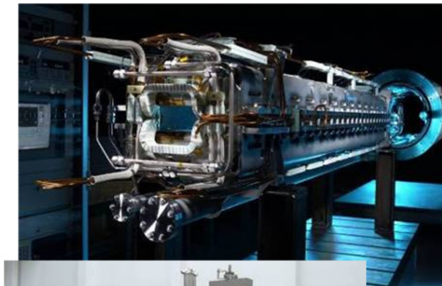
→ Talk of Marilena Tomut in WEO3C

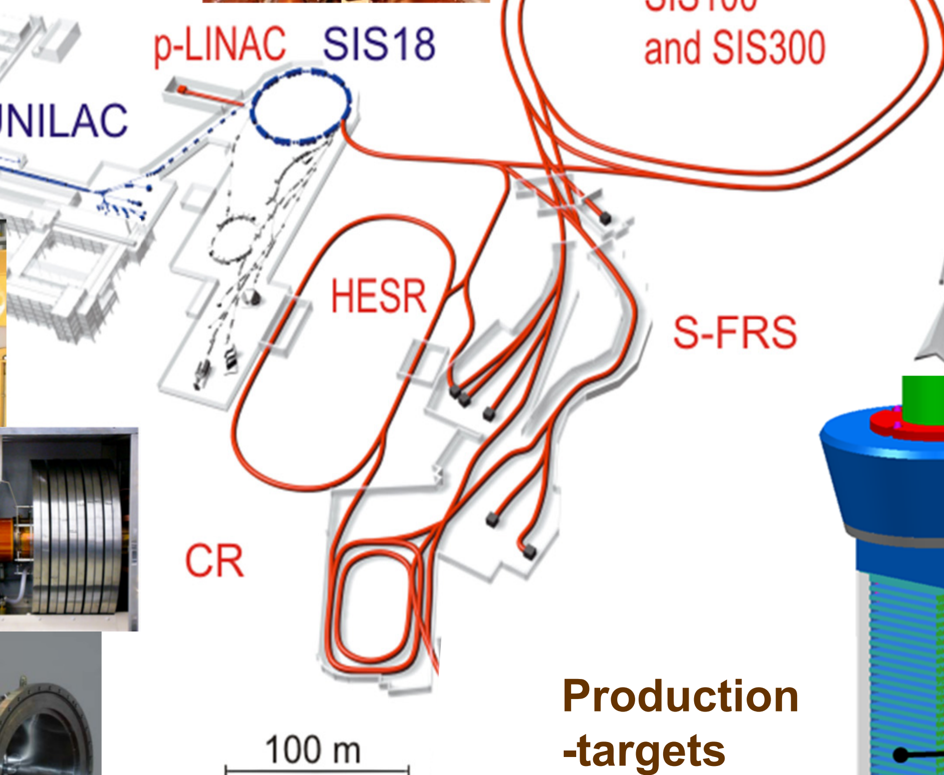
I did not talk about….

Diagnostic and XHV at highest intensities

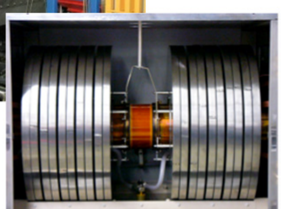


Superconducting magnets

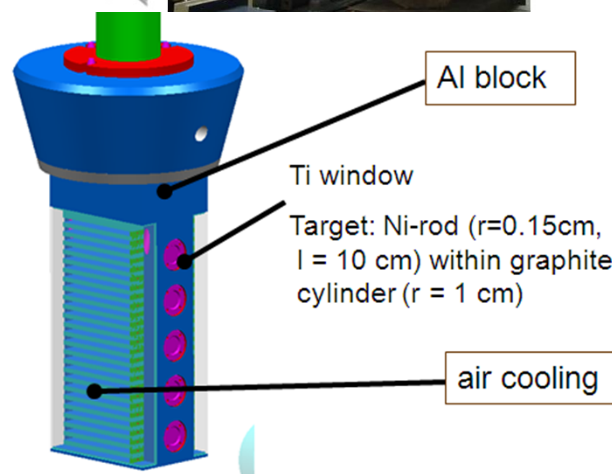




Rf-cavities



Production -targets



FAIR HELMHOLTZ ASSOCIATION GSI

The FAIR project is moving forward

The FAIR project is moving forward

The FAIR project is moving forward

- German funding available
- Procurement of components for SIS100, HEBT and CR started
- Preparation of the test facilities for the SC magnets at GSI, Dubna and CERN

Acknowledgement

Thanks for providing information:

Oliver Boine-Frankenheim

Giuliano Franchetti

Lars Groening

Winfried Barth

Jochen Pfister

Ralph Hollinger

Peter Spiller