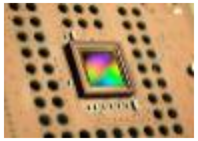
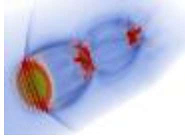
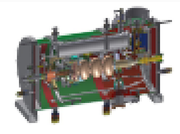






Status and Plans of the GSI ARD POF III Projects

Accelerator Research and Development

Peter Spiller, GSI

GSI Subtopic Coordinator ST2

Hadron Accelerators

January 31th , 2017
3. Matter & Technology Annual Meeting
GSI, Darmstadt

Overview on ARD Topic 2 at GSI/Jena: Hadron Accelerators

Primary Beams

1. Injectors

a) Superconducting ECR Ion Source (K. Tinschert)
b) High Intensity Heavy Ion Injector Linac (for Synchrotrons) (B. Schlitt)

2. Synchrotrons (focus at GSI in 2016)

c) Ultimate Heavy Ion Beam Intensities in Synchrotrons (see Poster) (L. Bozyk, P. Spiller)
d) Laser Cooling of Relativistic Heavy Ion Beams (see highlight talk) (D. Winters)
e) Advanced Superconducting Magnets (see poster) (K. Sugita)
f) Magnetic Alloy Broad Band Test Cavity (see poster) (J. Sandro)

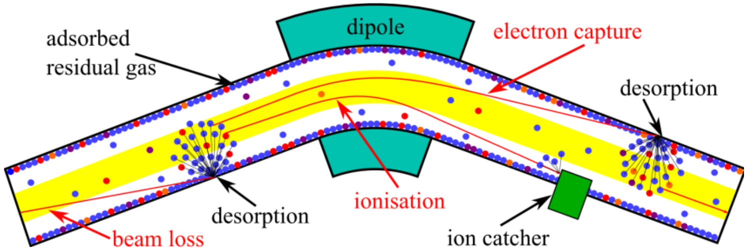
Secondary Beams

3. Storage Rings

f) High-Sensitivity Non-Destructive Cavity-Based In-Ring Particle Detectors (Y. Litvinov)
g) Development of Cryogenic Current Comparator (CCC) for Measurement in the nA Range (funded by Uni Jena) (see poster) (T. Siebert)
h) Target Development for Slow, Stored Beams (F. Herfurt)

Ultimate Heavy Ion Beam Intensities in Synchrotrons

The Dominating Intensity Limitation for Heavy Ion Beams in Synchrotrons is Ionisation in the Dynamic Vacuum.
This dominating loss mechanism appears much below the space charge limit.



Ionisation loss drives pressure bumps which itself accelerates the ionisation process.
> Dynamic vacuum instability

GSI has developed a world wide leading understanding of ionization beam loss and dynamic vacuum in heavy ion synchrotrons, including unique tools for self consistent simulations in time and space and technologies for curing these phaenomena.

Simulation: STRAHSIM code

Dynamic vacuum and charge exchange driven beam loss in time and space

- Machine optics and collimation system
- Atomic cross sections for charge exchange
- Properties of pumping system (conventional, crogenic, NEG etc.)
- Gas desorption processes
- Realistic machine cycles

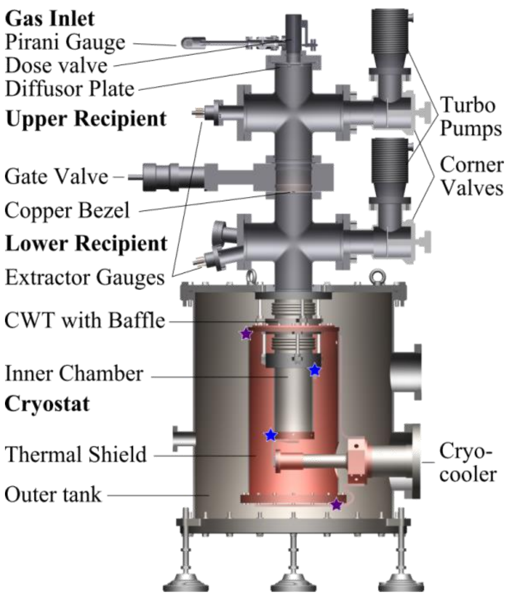
Technologies (examples):

- Machine optics – Charge separator lattice (peaked distribution of ionizaton loss)
- NEG coating (distributed pumping)
- Low desorption surfaces and materials
- Ion catcher systems - room temperature and cryogenic
- Cryogenic, actively cooled magnet chambers (distributed pumping)
- Cryo-adsorption pumps

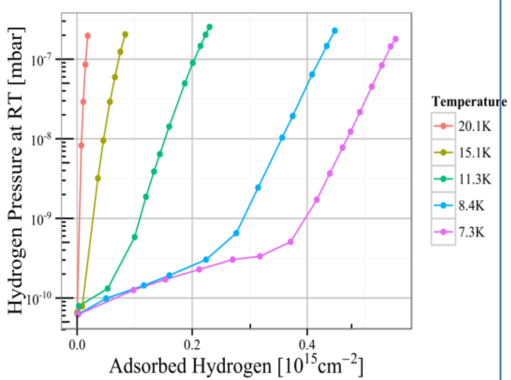
Ultimate Heavy Ion Beam Intensities in Synchrotrons

Within ARD, the data basis applied to the Dynamic Vacuum Simulations with STRAHLSIM, on the generation of pressure bumps by ion induced desorption and the properties of distributed cry- pumping has been extended.

Pumping properties of cryogenic surfaces



Pumping properties of cryogenic surfaces are investigated with a dedicated measurement setup

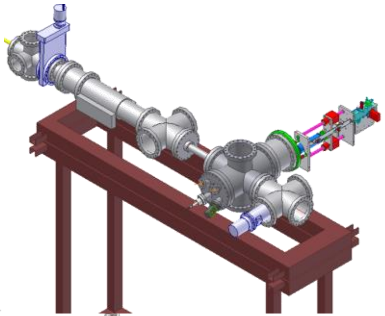


Adsorption isotherms are measured for different temperatures → included into dynamic vacuum simulations

PhD thesis, F. Chill, completed in 2016

Beam loss induced gas production on cryogenic surfaces

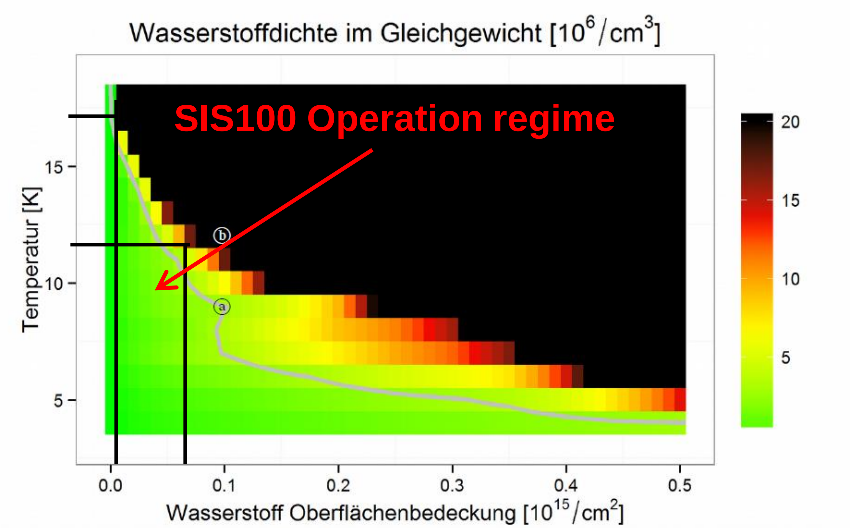
Heavy Ion induced gas desorption of cryogenic surfaces is measured and compared to room temperature data.



PhD thesis C. Maurer, planned completion in 2017

Ultimate Heavy Ion Beam Intensities in Synchrotrons

Loss of Heavy Ion Beams by Ionisation as Function of Chamber Surface Temperature - Predictions for SIS100



The equilibrium hydrogen density depends on the coverage of cryogenics suraces and their temperatures (measurement by F. Chill)

U^{28+}- operation

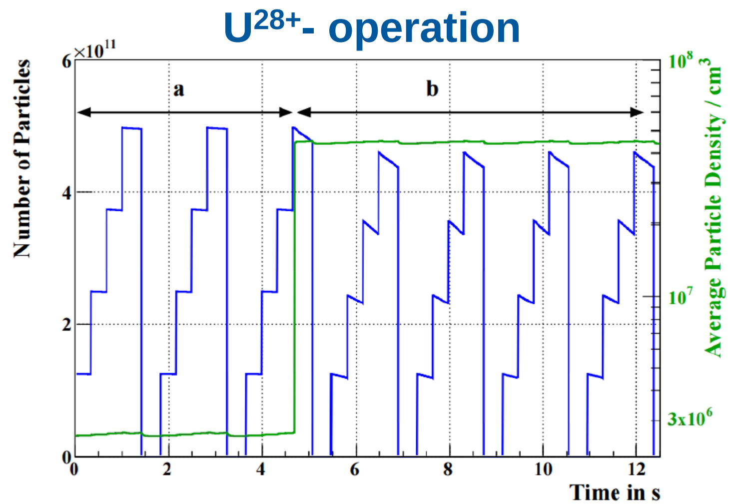


Abbildung 34: Reaktion auf eine plötzliche Temperaturerhöhung bei t = 4,8 s.

Strahlsim simulation of ionization beam loss in SIS100 cycles with sudden, artificially enhanced surface temperatures in all magnet chambers.

At release of cryosorped particles from SIS100 magnet chambers, a re-distribution takes place from a) the dipole chamber surface to the cryosorption pumps and b) from the qudrupole chambers to the cryocatcher surfaces.

PhD thesis F. Chill: „Vermessung der Pumpeigenschaften Kryogener Oberflächen“ completed in 2016
Prediction possible for all cryogenics synchrotrons operated with low charge state heavy ions, e.g. NICA booster.

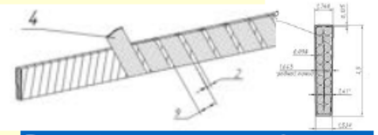
Advanced Superconducting Magnets

Sub-workpackages:

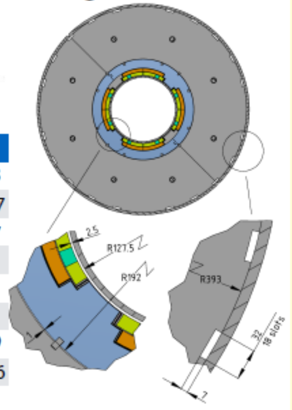
- **Fast ramped superconducting magnets**
- **Superconducting septa for beam extraction**
- **Large aperture superconducting quadrupoles**

Existing design

Rutherford cable + Cosine-theta magnet



Parameter	unit	
Operation current	kA	5.73
Central gradient	T/m	37.57
Maximum field	T	5.87
Iron yoke inner radius	mm	193
Iron yoke outer radius	mm	393
Iron yoke length	m	1.6
Coil length	m	1.89
Effective length	m	1.756
Ampere turns	kA×turns	487



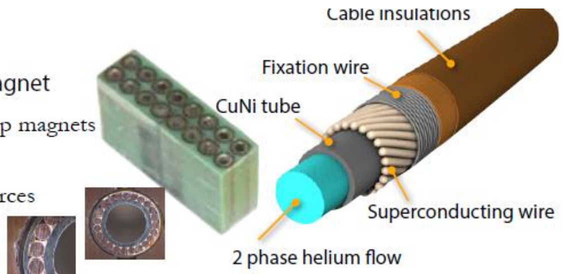
Fastest ramped, full size s.c. cos(theta) dipole magnet world wide (SIS300 prototype)

▶ Alternative design concept

Nuclotron cable + Cosine-theta magnet

High cooling efficiency, suited for fast ramp magnets (Nuclotron, SIS100, NICA)

Mechanically stable coil against Lorentz forces (Cables are embedded into G11 structure)



SIS100 main dipole cable

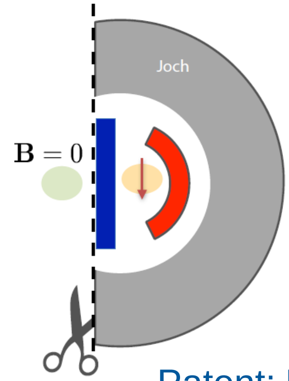
Possible applications:

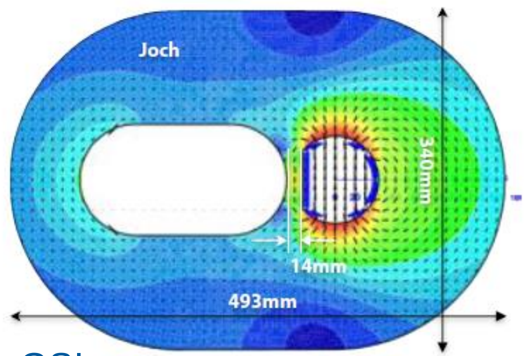
SISx00, SPS2, FCC injector chain

Advanced Superconducting Magnets

BNG Study „Concept Development Superconducting Septum Magnets for Beam Extraction

Two design strategies for Comparsion of Properties based on Nuklotron Cable and Rutherford Cable





Patent: K. Sugita, GSI

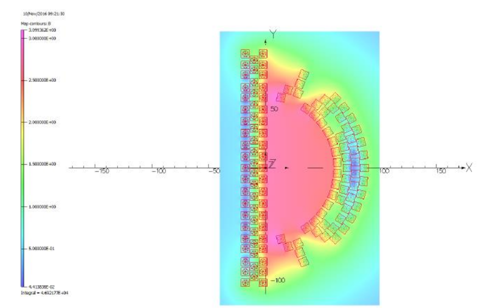


Figure 14: NTC coil model without ferromagnetic materials: Field map.

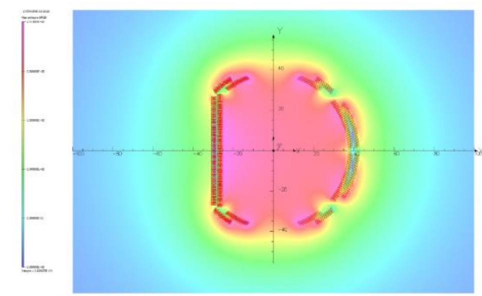
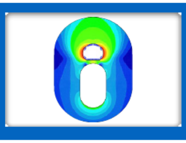
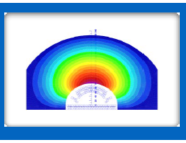


Figure 3: RC design: magnetic field without iron. The minimum shown is 0 T, the maximum 2.51 T.

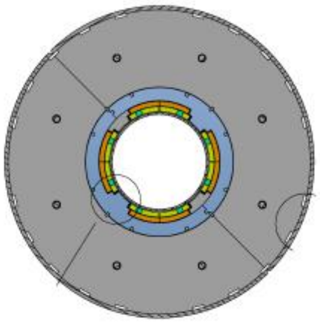
		Rutherford cable 	Nuclotron cable 
Magnet design		Iron-yoked, truncated cosine-theta (±2/3π)	Iron-yoked, truncated cosine theta (±1/2π)
2D/Cross section			
Nominal field	T	3.6 T	3.6 T
Current used	A	1894.7	500
Inductance	mH/m	14	470
Ramp rate	T/sec.	0.8	0.8
Inductive voltage	V	24	210
Stored energy	kJ	100	240
Peak field in the coil	T	4.0	3.8
Peak field in the yoke	T	3.4	2.2
Temperature margin (from 4.2 K)	K	0.29 K	0.77 K
Load line utilisation	%	93.0%	85.2%
Current sharing temperature		4.49 K	5.03 K

Presented at:
FCC annual meeting 2016 Rome
FCC annual meeting 2917 Berlin

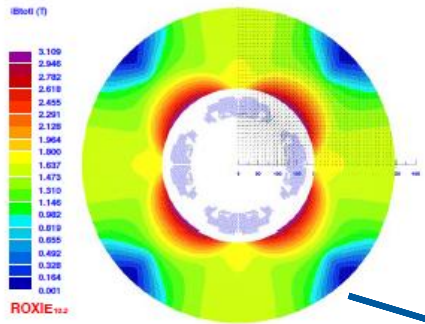
Advanced Superconducting Magnets

Large Aperture, High Gradient Superconducting Quadrupole Magnets
e.g. for Final Focusing of Heavy Ion Beams

Bestehendes Design Rutherfordkabel

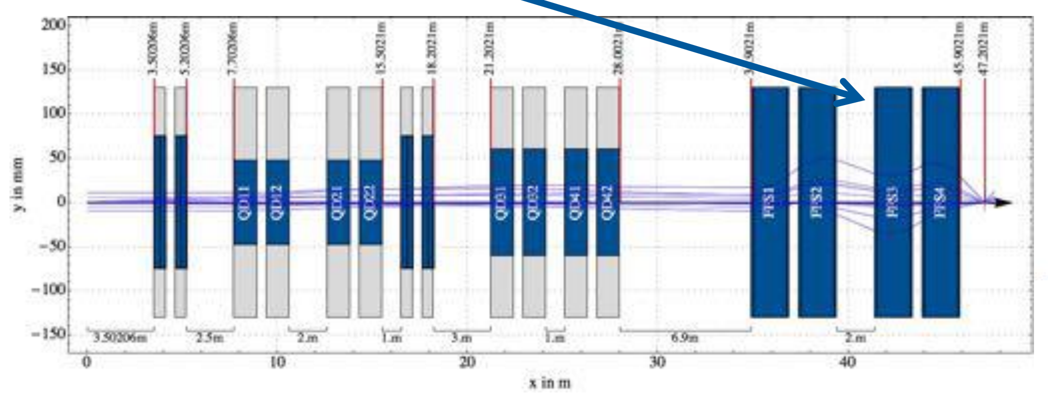


Alternatives Design Nuclotronkabel



Presented at the
„High Energy Density in Matter Workshop“,
Hirschegg,2016

Parameter	unit	
Operation current	kA	5.73
Central gradient	T/m	34.93
Maximum field	T	5.1
Iron yoke inner radius	mm	195
Iron yoke outer radius	mm	400
Truns/pole		79
Ampere turns	kA×turns	453
Temperature margin	K	0.3



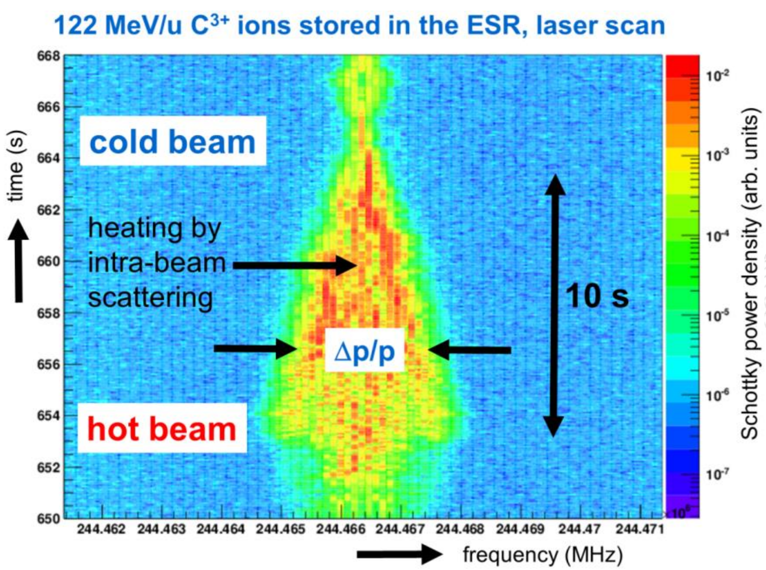
Plasma Physics Final Focusing System

Heavy Ion Laser Cooling Pilot Facility

Laser-cooled relativistic heavy ion beams

Goal: Cooling of relativistiv heavy ion beams at final energy
Extraction of very cold and very short heavy ion bunches

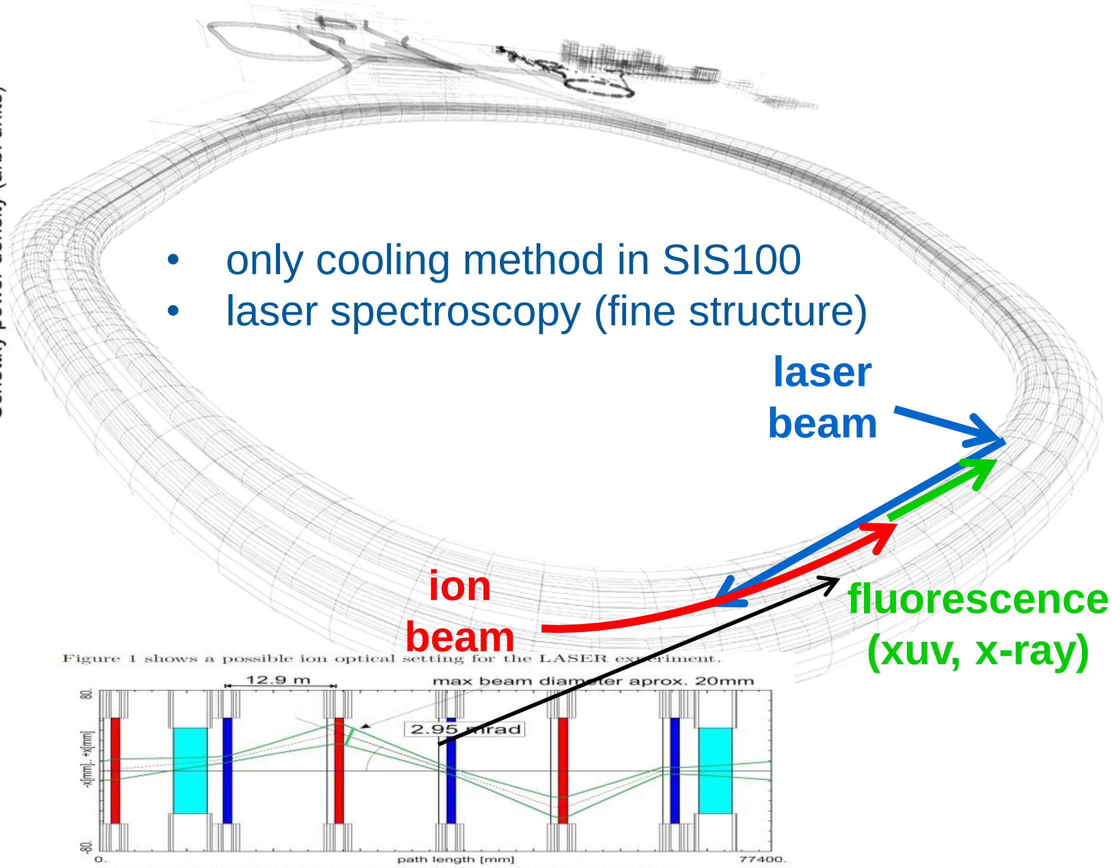
- **Z_{ion}= 10 – 60** **(3 – 19 electrons)**
- **γ up to 13** **(huge Doppler-shift)**



Components used for laser cooling experiments in ESR

Laser Cooling Facility included in SIS100 Tunnel Layout

- only cooling method in SIS100
- laser spectroscopy (fine structure)



Heavy Ion Laser Cooling Pilot Facility

Components for the Laser Cooling Facility in SIS100

gentec-eo

high-vacuum compatible

Power Detector (vacuum compatible)

Heidelberg Photonik

Manx Precision Optics

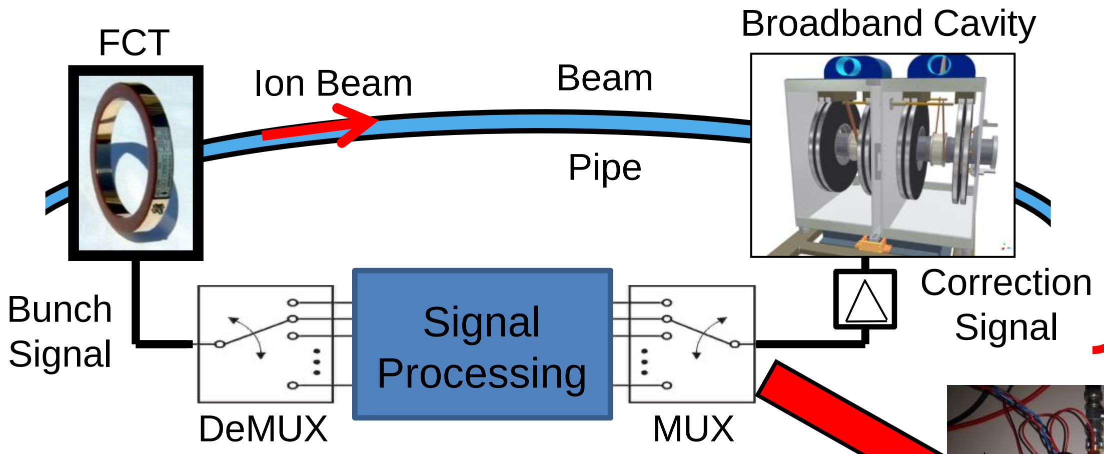
PBSC Polarizing Beam Splitter Cube

- Two laser tables
- Laser beam stabilization system
- High-quality optics for the laser beamline (mirrors, lenses, PBSC, etc.)
- High-quality optical components (mounts, posts, etc.)
- Vacuum compatible and normal, piezo-controlled mirror holders
- Basic lab kit containing components for cleaning, mounting, testing, etc.
- Osci, cupboard and trolley for safe and proper storage of components and ease of use

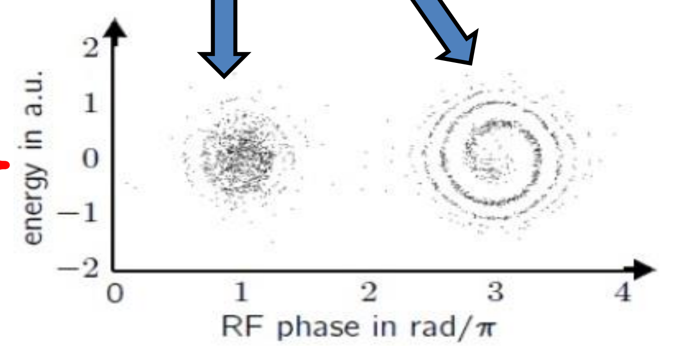
Longitudinal Feedback Signal Processing

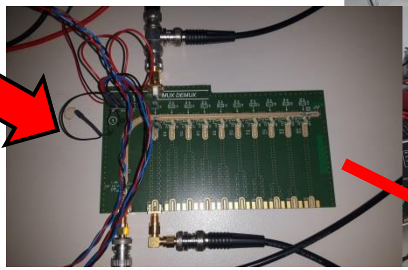
ARD Subtopic 2 – Hadron Accelerators

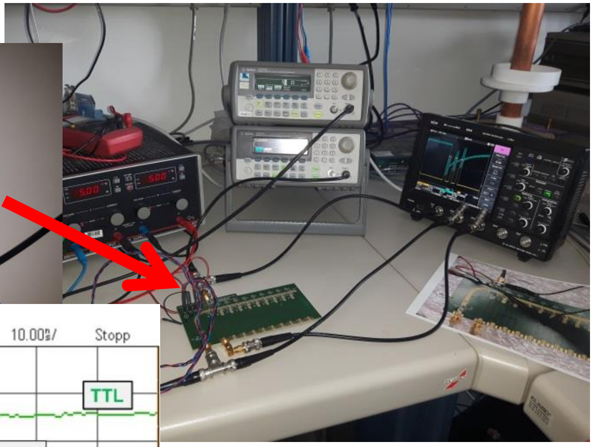
Layout of the longitudinal feedback system for FAIR

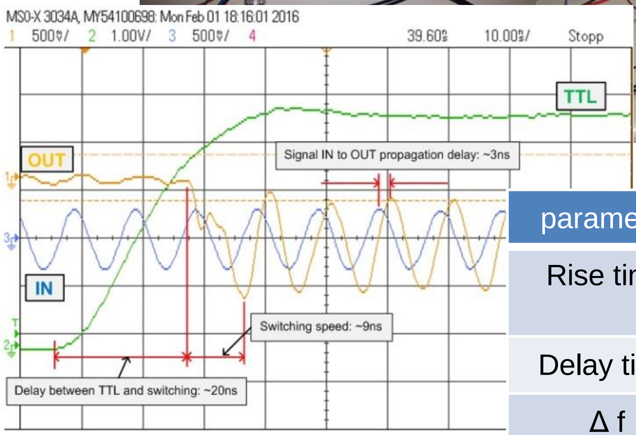


Bunch with and without feedback









ARD PoF III 2016

- Feasibility study (MUX & DeMUX) has been completed by Novotronik
- Conceptual Design of Signal processing in discussion

Outlook

- Implementation of MUX & DeMUX
- Assembling of overall system

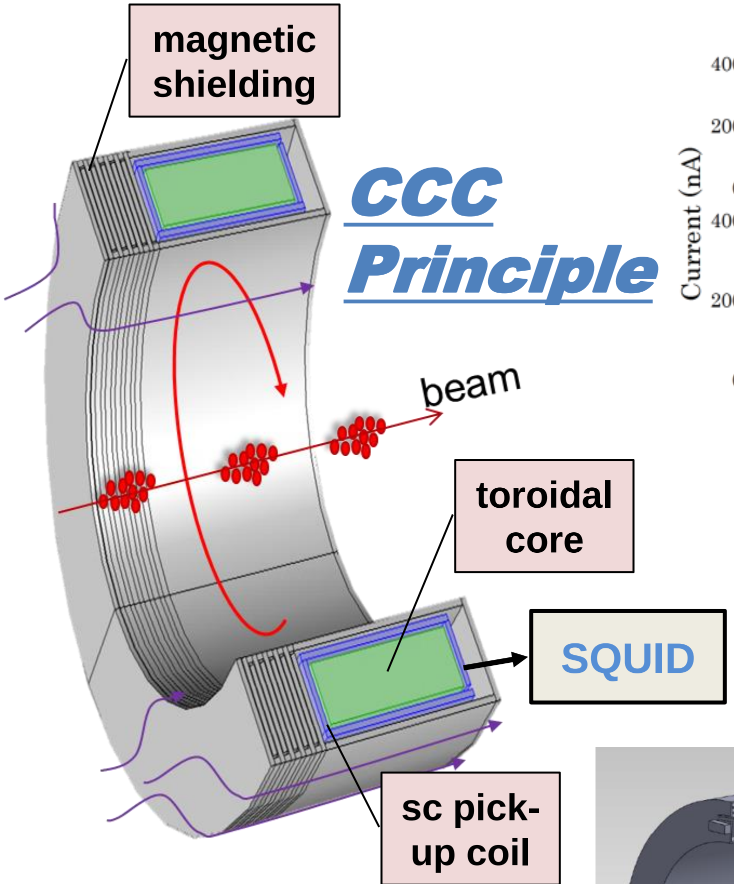
parameter	measurement
Rise time	9 ns (max. required 15 ns !)
Delay time	20 ns
Δ f	0.3 ... 100 MHz

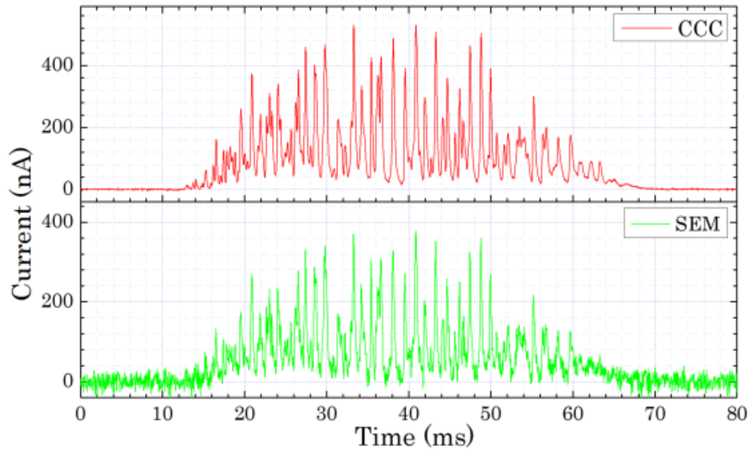
S. Jatta, D. Lens, K. Gross, H. Klingbeil
GSI Helmholtzzentrum für Schwerionenforschung GmbH
Ring RF Department
3rd Annual M&T Meeting at GSI 31.1. - 2.2.2017

Development of the Cryogenic Current Comparator (CCC) for nA Measurements

T. Sieber, F. Kurian, M. Schwickert, T. Stoehlker, R. Neubert, V. Tympel, GSI Darmstadt, HIJ and FSU Jena

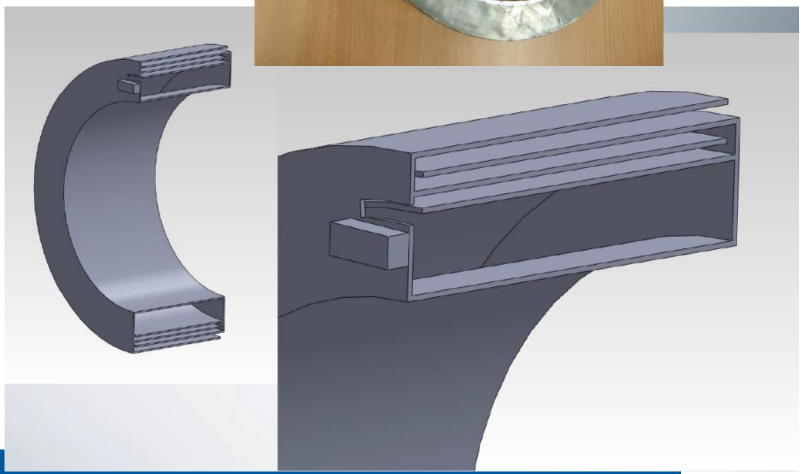
CCC Principle



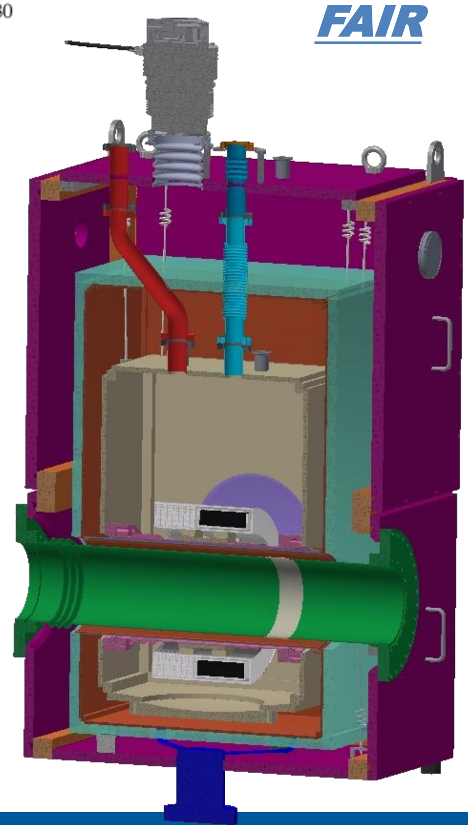


Spill Analysis with nA Resolution at SIS18 at slow extraction

Investigation of new Shielding Geometries



CCC Design for FAIR



Anhang

28 GHz SC-ECRIS for High Intensity Heavy Ion Beams

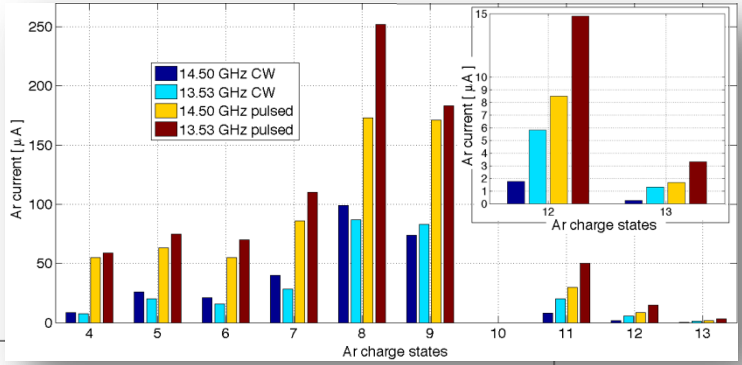
Increased intensities for highly charged medium and heavy ions

Increase microwave frequency: $\omega_{RF} = \omega_{ECR} \sim B$ (Klystron-HPA, TWTA, Gyrotron)

Higher magnetic flux density (superconducting magnet system)

High versatility of SC-ECRIS:

- **Adjustable axial and radial magnetic fields – optimum adaptation to different working points**
- **High charge states – injection into LINAC without post-acceleration**
- **High duty cycle mode or special pulsed mode for high pulse intensities**
- **High efficiency, good stability and low beam noise**



Roadmap:

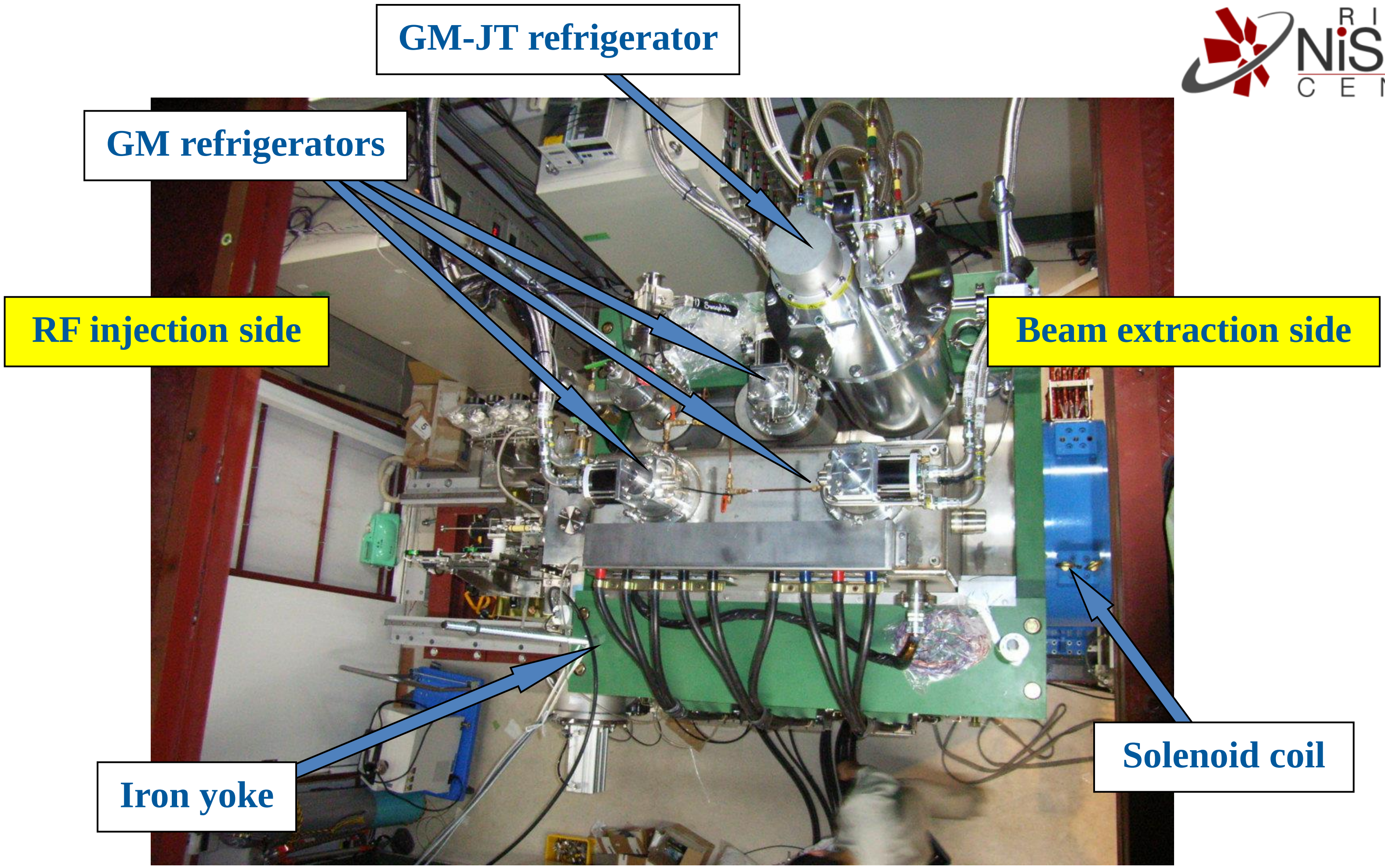
Acquisition of the SC-magnet system including cryostat (tendering procedure)

Design and construction of injection and extraction system (ancillary equipment)

R&D at the test facility (achieve optimum operating conditions)

Installation and commissioning

28 GHz SC-ECRIS @ RIKEN



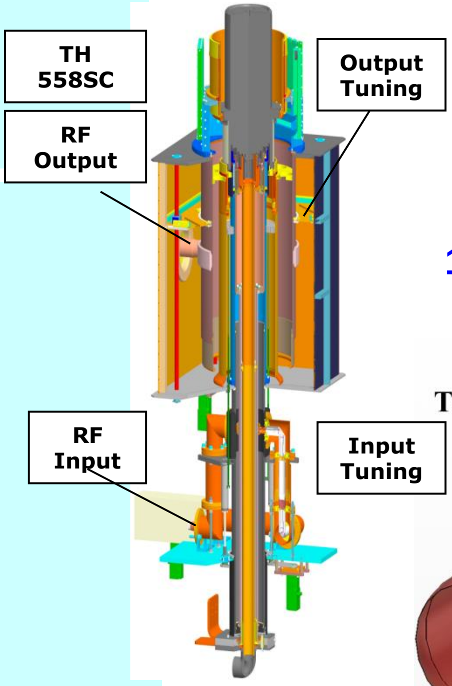
Courtesy of T. Nakagawa, RIKEN Nishina Center, Japan

High Intensity Heavy-Ion Injector Linac

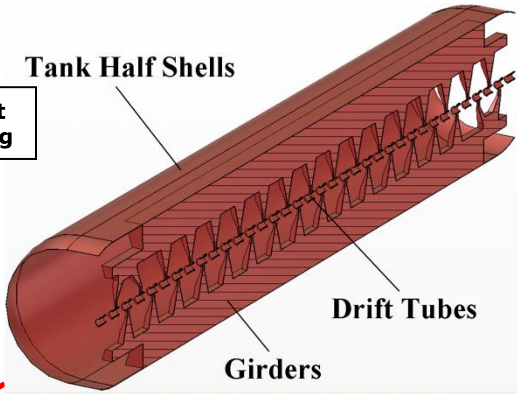
- **Heavy ions up to $^{238}U^{28+}$**
- **Very high beam currents (15 emA)**
- **MW beam pulse power**
- **Short beam pulses (≤100 µs)**

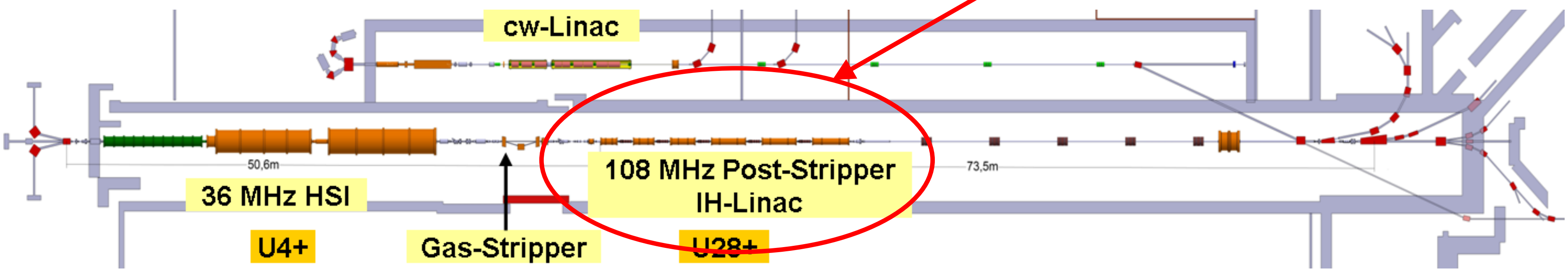
Activities in 2015:

- **Manufacturing and assembly of a 1.8 MW, 108 MHz tetrode amplifier circuit at an industrial supplier**
- **Modeling of the high power amplifier at GSI (field simulations & equivalent circuit models)**
- **Preparation of an amplifier test bench at GSI, development of a PLC system for amplifier control**
- **RF tests of a solid state amplifier module for the 150 kW solid state driver amplifier**
- **Development of a new digital LLRF system**

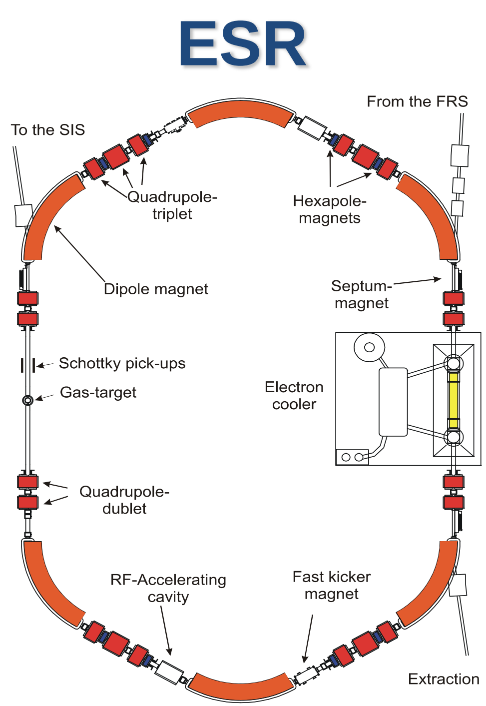


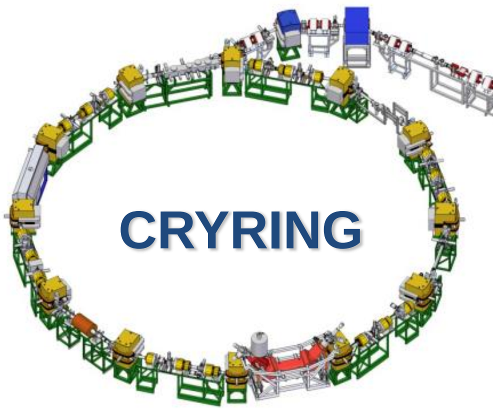
108 MHz IH-DTL Cavity (Design Study)





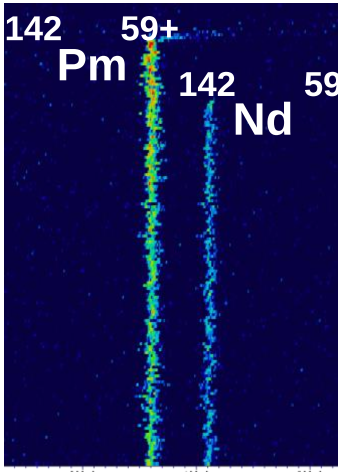
High-Sensitivity Non-Destructive Cavity-Based In-Ring Particle Detectors

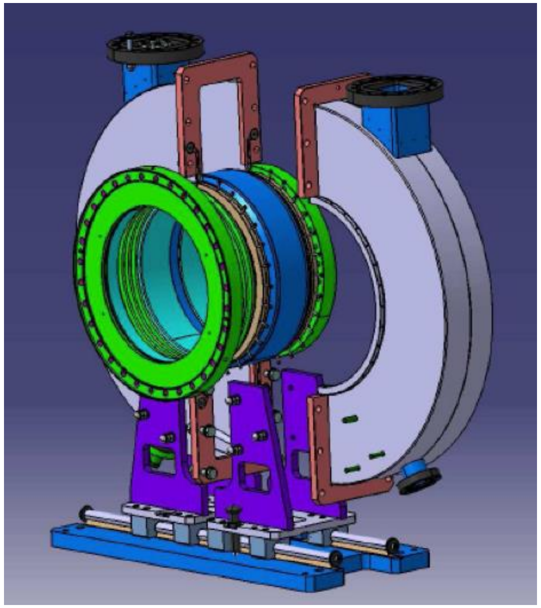




ESR and CRYRING are unique facilities which offer beams of stable as well as short-lived radioactive isotopes in a wide range of kinetic energies from a few hundred MeV/u down to a few 100 keV/u.

Dedicated diagnostics is therefore needed which would allow to monitor in a real time the beam intensities in a wide range starting from milliamps down to single stored ions. Furthermore, high time resolution is required to be able to see short-lived ion species.





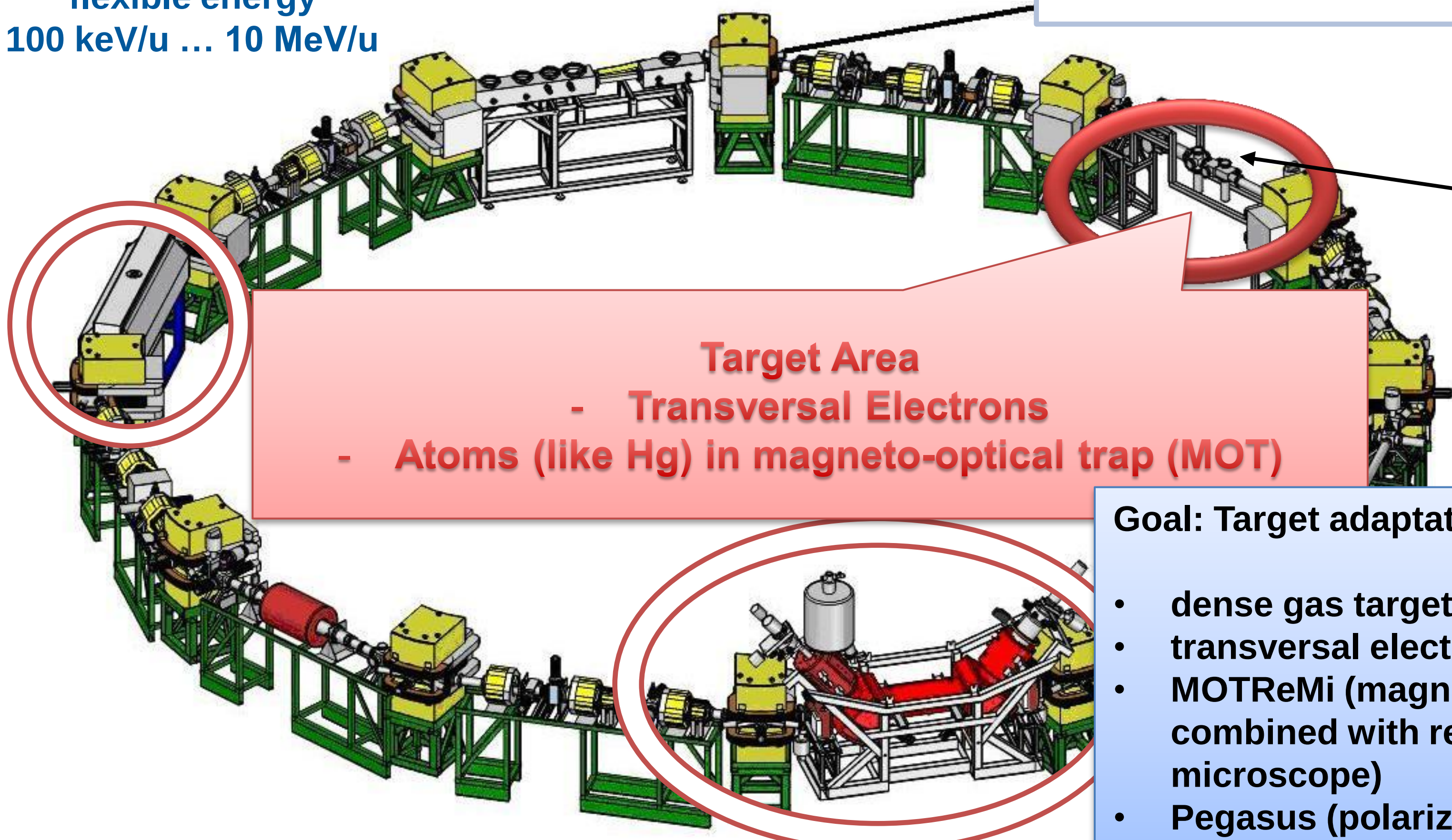
As a starting point for the proposed development a resonant Schottky pick-up, designed for single-ion decay spectroscopy in ESR will be used.

Target Development for Slow, Stored Beams

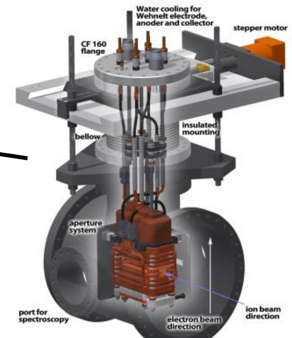
Using CRYRING@ESR

Highly charged Ions (from ESR)
< 1.4 Tm up to U^{92+}
Ion Source & RFQ
300 keV/u for A/Q < 4

Wide Band RF
flexible energy
100 keV/u … 10 MeV/u



Target Area
- **Transversal Electrons**
- **Atoms (like Hg) in magneto-optical trap (MOT)**



Goal: Target adaptation to slow beams:

- dense gas target
- transversal electron target
- MOTReMi (magneto optical trap combined with reaction microscope)
- Pegasus (polarized electrons)

Electron Cooler
with adiabatic expansion