Status of the FAIR Project and Accelerator R&D

Peter Spiller

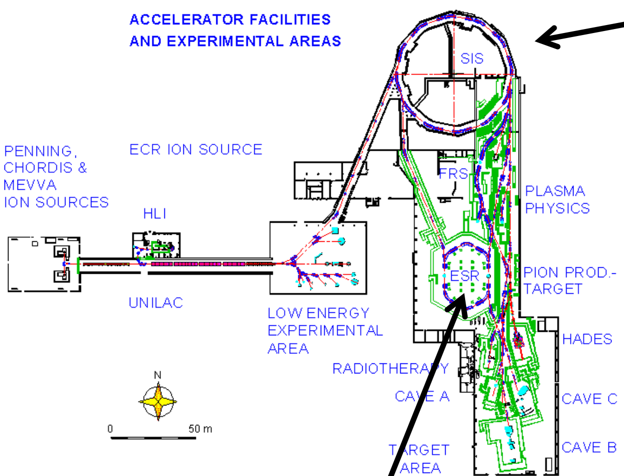
TIARA meeting

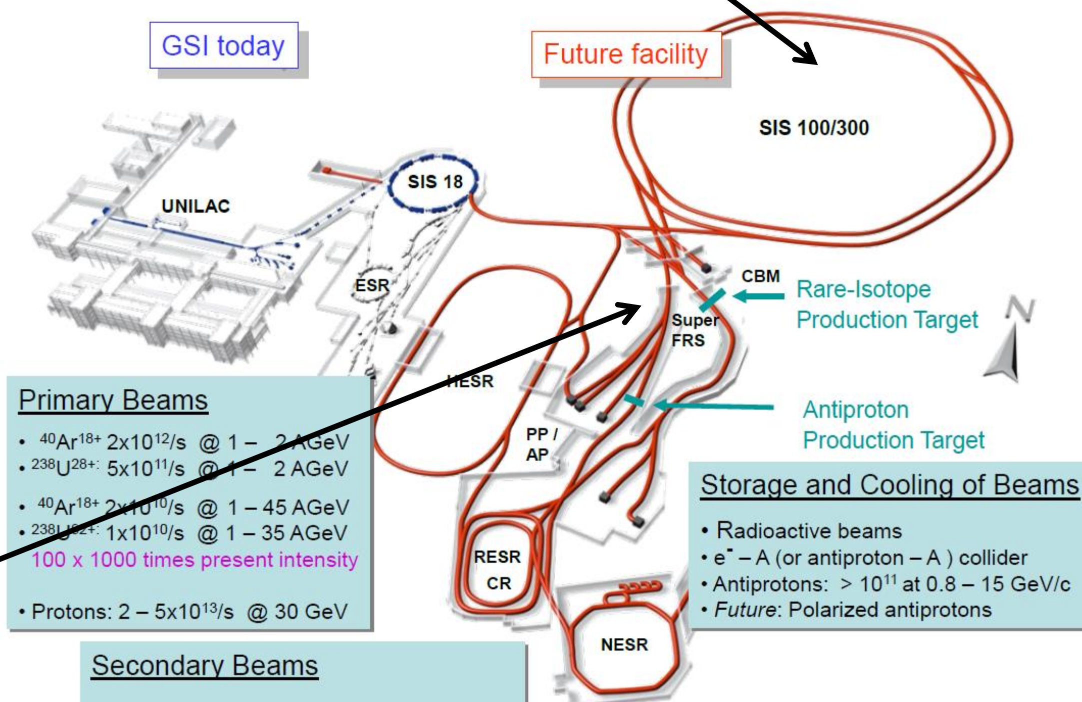
01.07.19

Primary Beams > Secondary Beams

FAIR is the big brother of GSI – the overall facility topology is identical

Primary Beams





Secondary Beams

Primary Beams

- $^{40}Ar^{18+}$ 2x10^{12}/s @ 1 – 2 AGeV
- $^{238}U^{28+}$: 5x10^{11}/s @ 1 – 2 AGeV
- $^{40}Ar^{18+}$ 2x10^{10}/s @ 1 – 45 AGeV
- $^{238}U^{92+}$: 1x10^{10}/s @ 1 – 35 AGeV

100 x 1000 times present intensity

- Protons: 2 – 5x10^{13}/s @ 30 GeV

Storage and Cooling of Beams

- Radioactive beams
- e^- – A (or antiproton – A) collider
- Antiprotons: > 10^{11} at 0.8 – 15 GeV/c
- *Future*: Polarized antiprotons

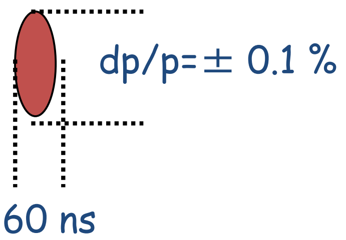
Secondary Beams

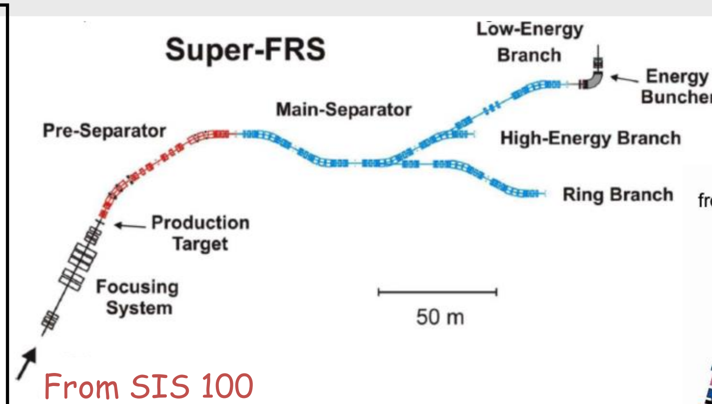
- Broad range of radioactive beams up to 1 – 2 AGeV
- RI- Intensities up to 10 000 over present
- Antiprotons

RIB generation and pre-cooling

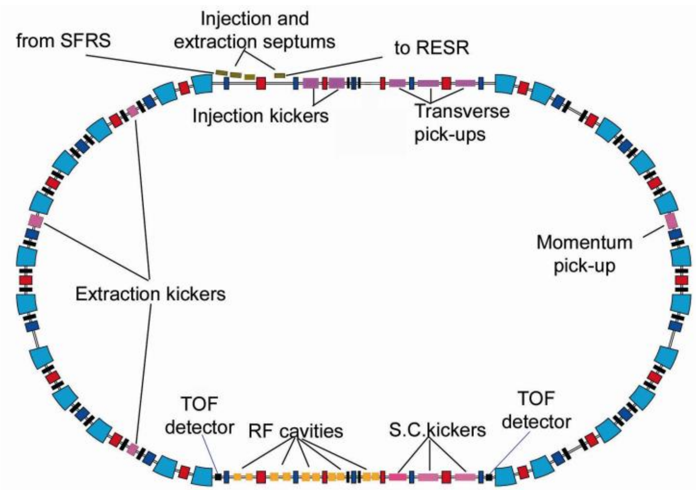
Target matching and fast bunch rotation in the CR

Short SIS 100 bunches:
- target matching
- RIB/pbar pre-cooling

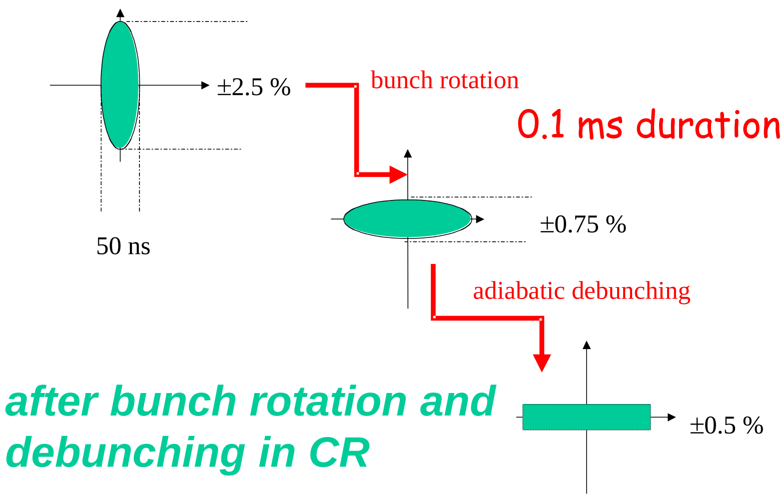




Collector Ring (CR)
circumference 212 m
rigidity 13 Tm



RF voltage in the CR: 200 kV (1.5 MHz)



CR ring properties:

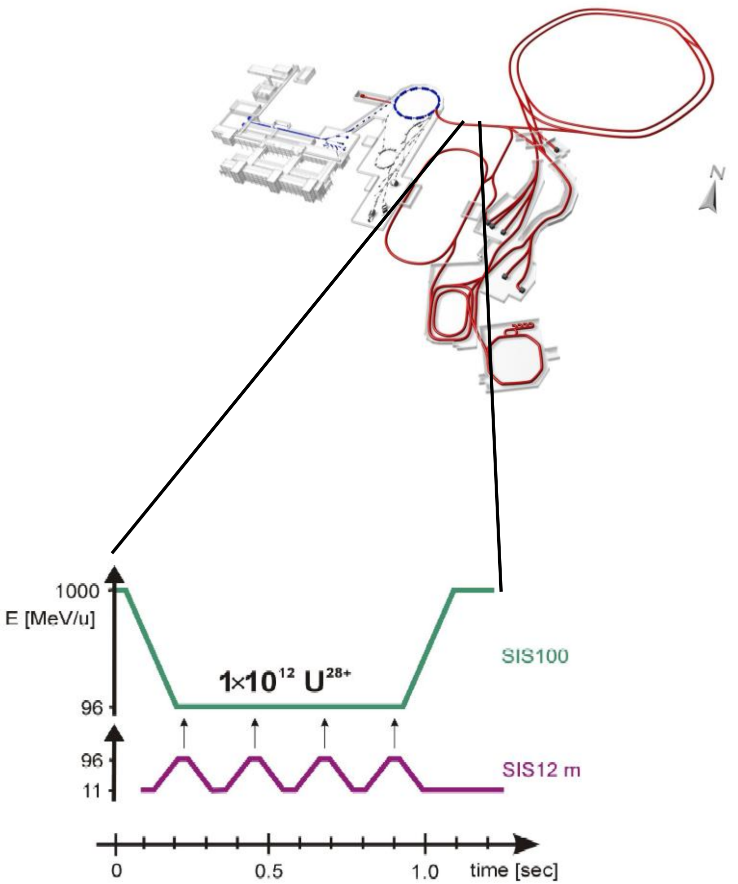
	RIB	pbar
energy	740 MeV/u	3.0 GeV
mom. accept.	± 1.5 %	± 3.0 %
transv. accept.	200×10^{-6} m	240×10^{-6} m
Cooling down time	1.5 s	10 s

Beam Parameters SIS18/SIS100

SIS18	Protons	Uranium
Number of ions per cycle	5 x 10^{12}	1.5 x 10^{11}
Initial beam energy	70 MeV	11 MeV/u
Ramp rate	10 T/s	10 T/s
Final beam energy	4.5 GeV	200 MeV/u
Repetition frequency	2.7 Hz	2.7 Hz

SIS100	Protons	Uranium
Number of injections	4	4
Number of ions per cycle	2.5x 10^{13} ppp	5 x 10^{11}
Maximum Energy	29 GeV	2.7 GeV/u
Ramp rate	4 T/s	4 T/s
Beam pulse length after compression	50 ns	90 - 30 ns
Extraction mode	Fast and slow	Fast and slow
Repetition frequency	0.7 Hz	0.7 Hz

... and all other ion species



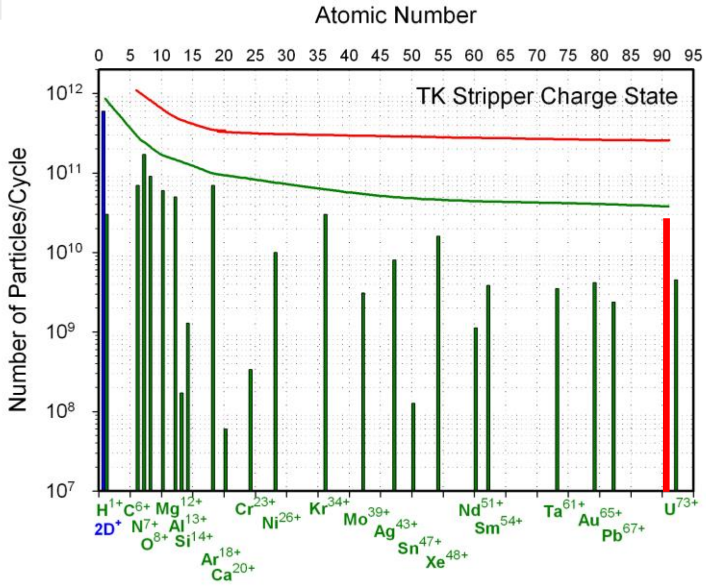
Intermediate Charge States for FAIR

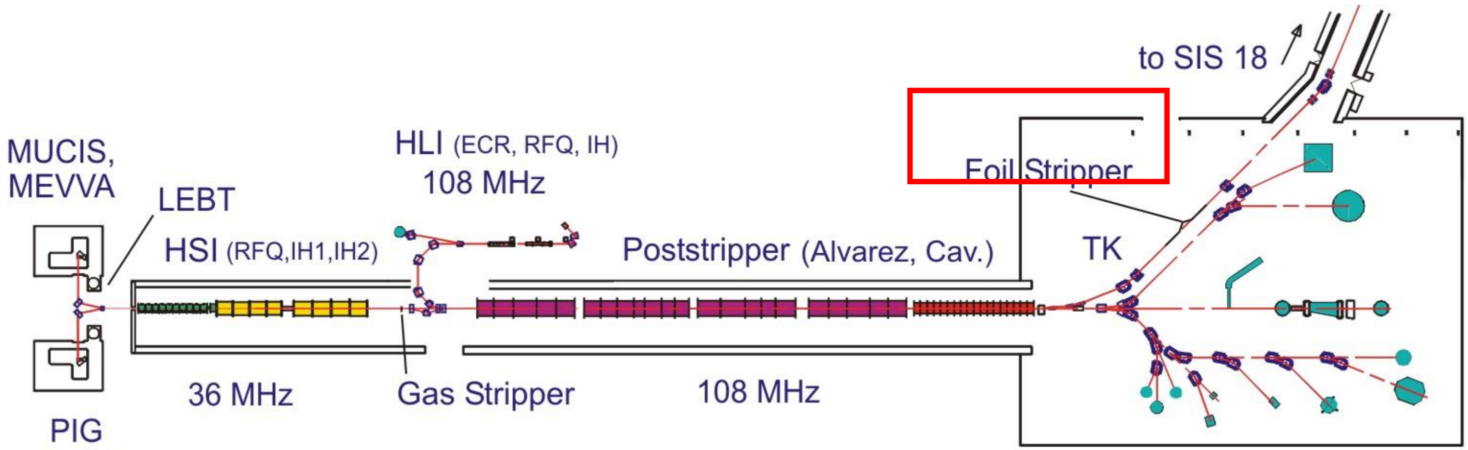
- FAIR intensity goals can only be reached by lowering the charge states
- Incoherent tune shift limits the maximum intensity in SIS18

$-dQ \propto Z^2/A$ > Poststripper charge states will be used

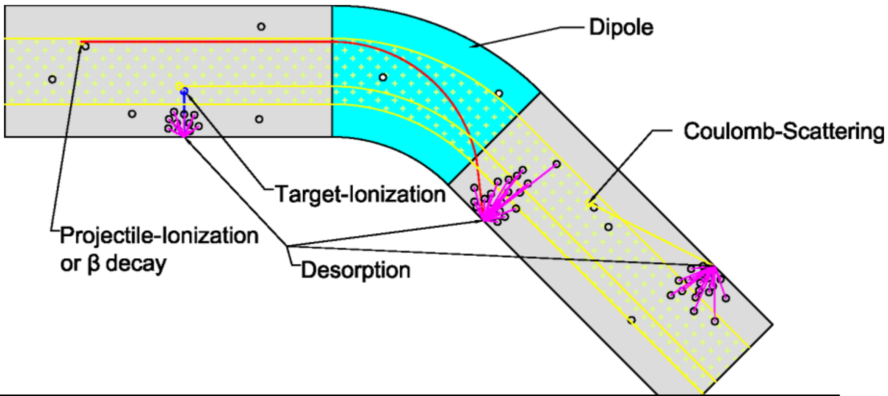
(e.g.: $Ar^{18+} > Ar^{10+}$..........$U^{73+} > U^{28+}$)

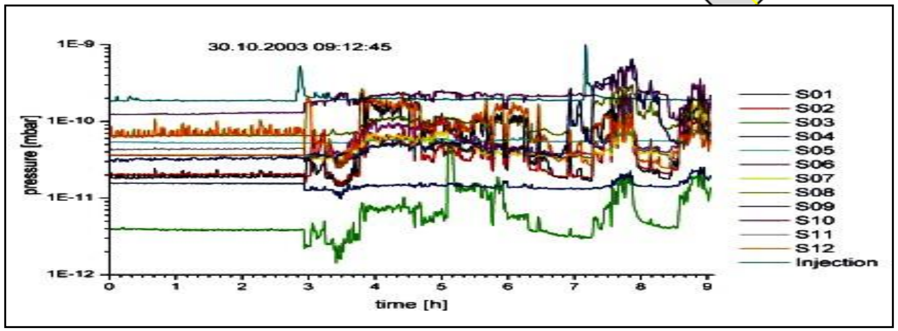
- Without stripping loss (charge spectrum) significantly enhance particle current ($N_{uranium}$ x7) !





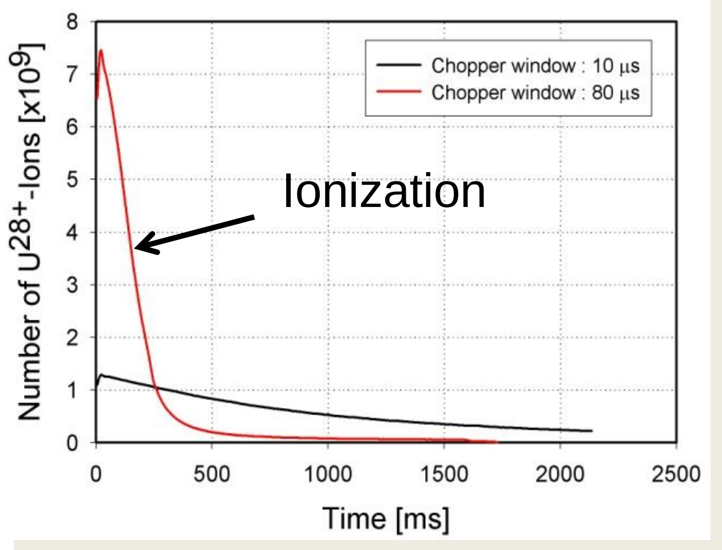
Ionization and Dynamic Vacuum





Static Dynamic

U^{28+}- operation in 2001



Main beam loss mechanism in SIS18 and SIS100 (far below the space charge limit)

- Life time of U^{28+} is significantly lower than of U^{73+}
- Life time of U^{28+} depends strongly on the residual gas pressure
- Ion induced gas desorption ($\eta \approx$ 10 000) generates local pressure bumps
- Beam loss increases with intensity (dynamic vacuum)

Dynamic Vacuum versus Space Charge

The Dominating Intensity Limitation for (low charge state) 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**
- **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

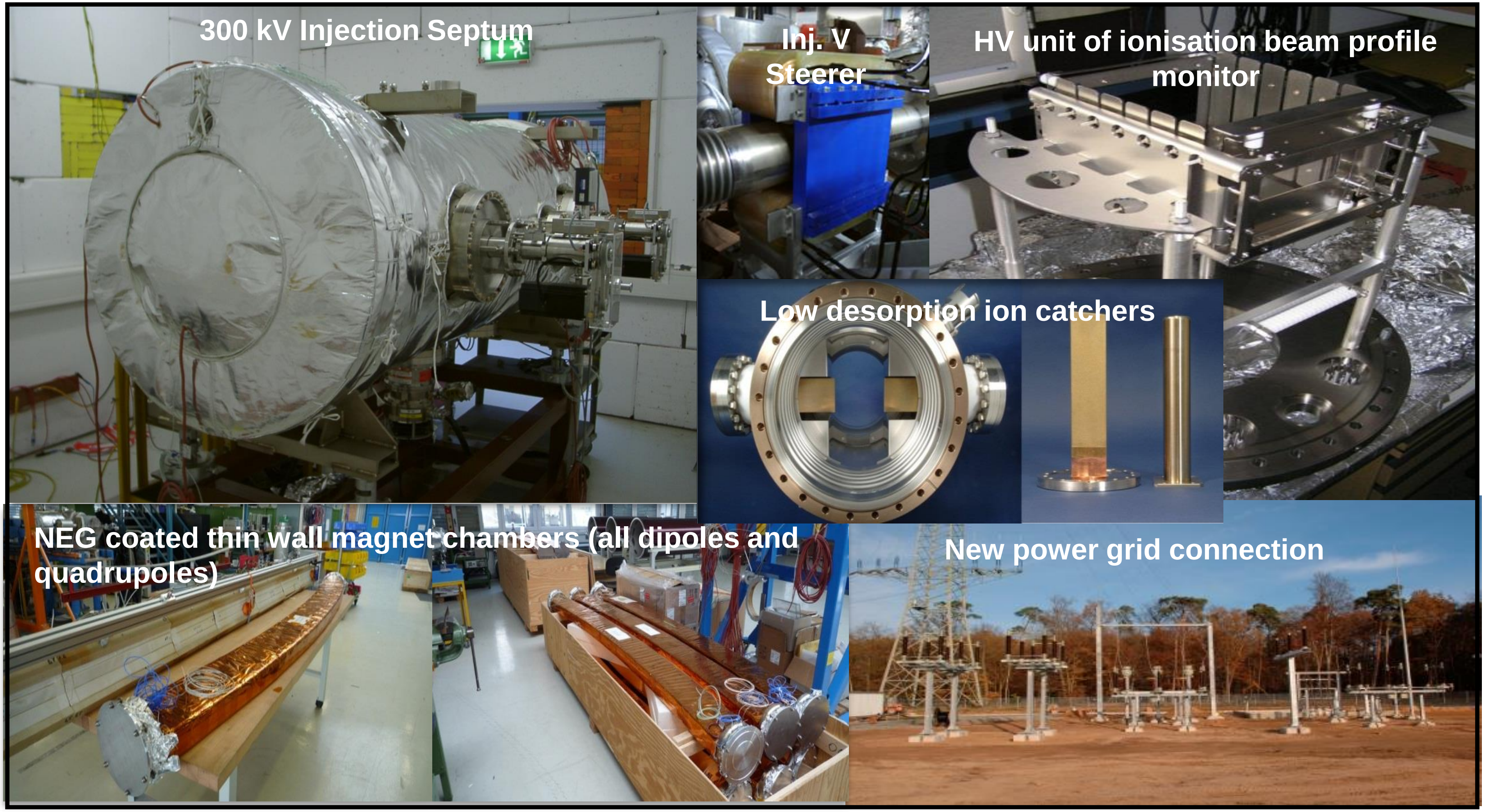
Technologies (examples):

- 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

SIS18 Upgrade Program 2005 – 2013

Implementation of New Key Technologies

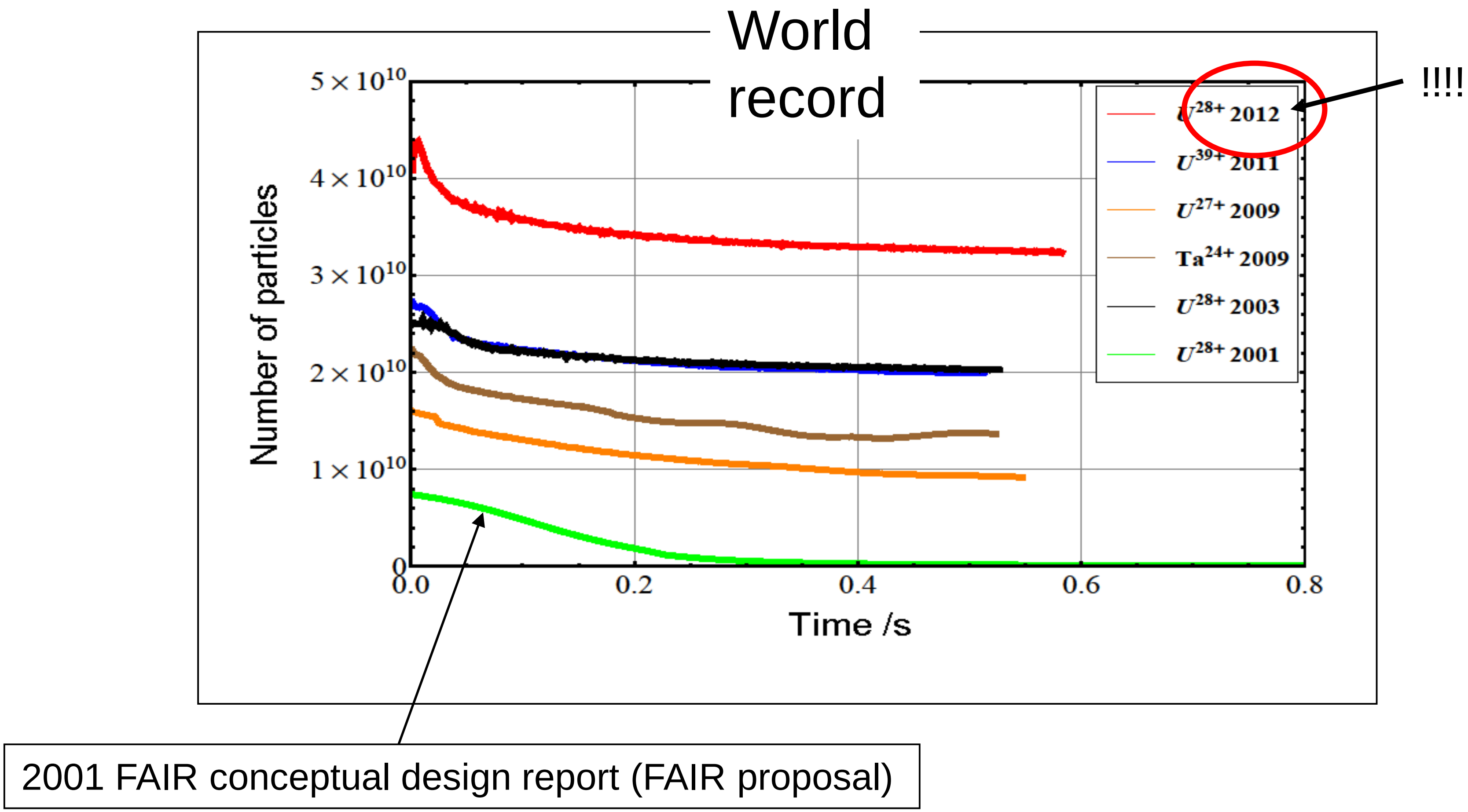
The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR



U^{28+} - Beam Intensity

World record intensity for intermediate charge state heavy ions.

The feasibility of high intensity beams of intermediate charge state heavy ions has been demonstrated.



SIS18 Upgrade Program 2013 – 2018

Implementation of New Key Technologies

The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR

Three new MA acceleration cavities installed (50 kV, h=2) and power converters

Replacement of main dipole power converter (for 10 T/s, 50 MW)

The EU has supported the upgrade program as an investment in a major European Research Infrastructure.

SIS18/SIS100 IPM magnet system manufactured and delivered

Bipolar dipole magnet and power converter for the connection of transfer line to SIS100

The originally defined SIS18upgrade program will be completed in 2019.

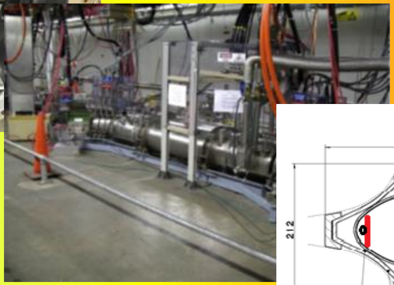
Proposals for SIS18 Upgrade 2

The SIS18 upgrade 2 program addresses issues at
a) operation of SIS18 for the running experiments in FAIR phase 0 and b) the FAIR booster operation.

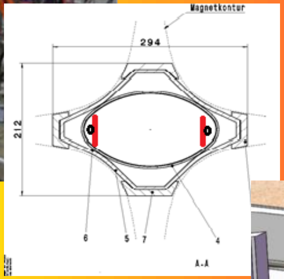
Injection Chopper

Microspill Cavity

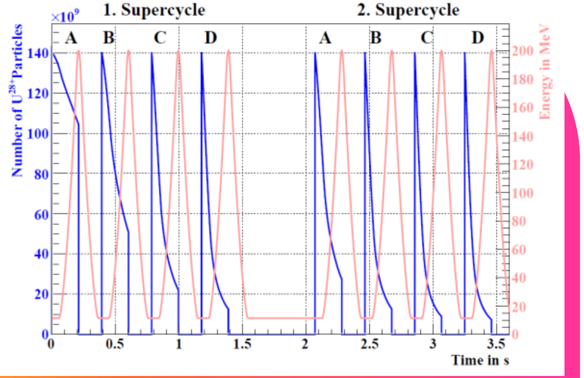
Extraction Septum



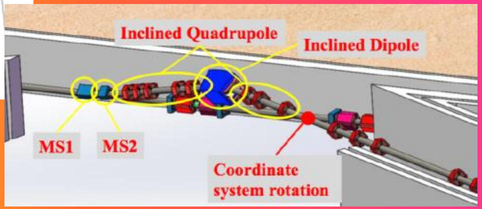
Space Charge Lens



Cryo Pumping



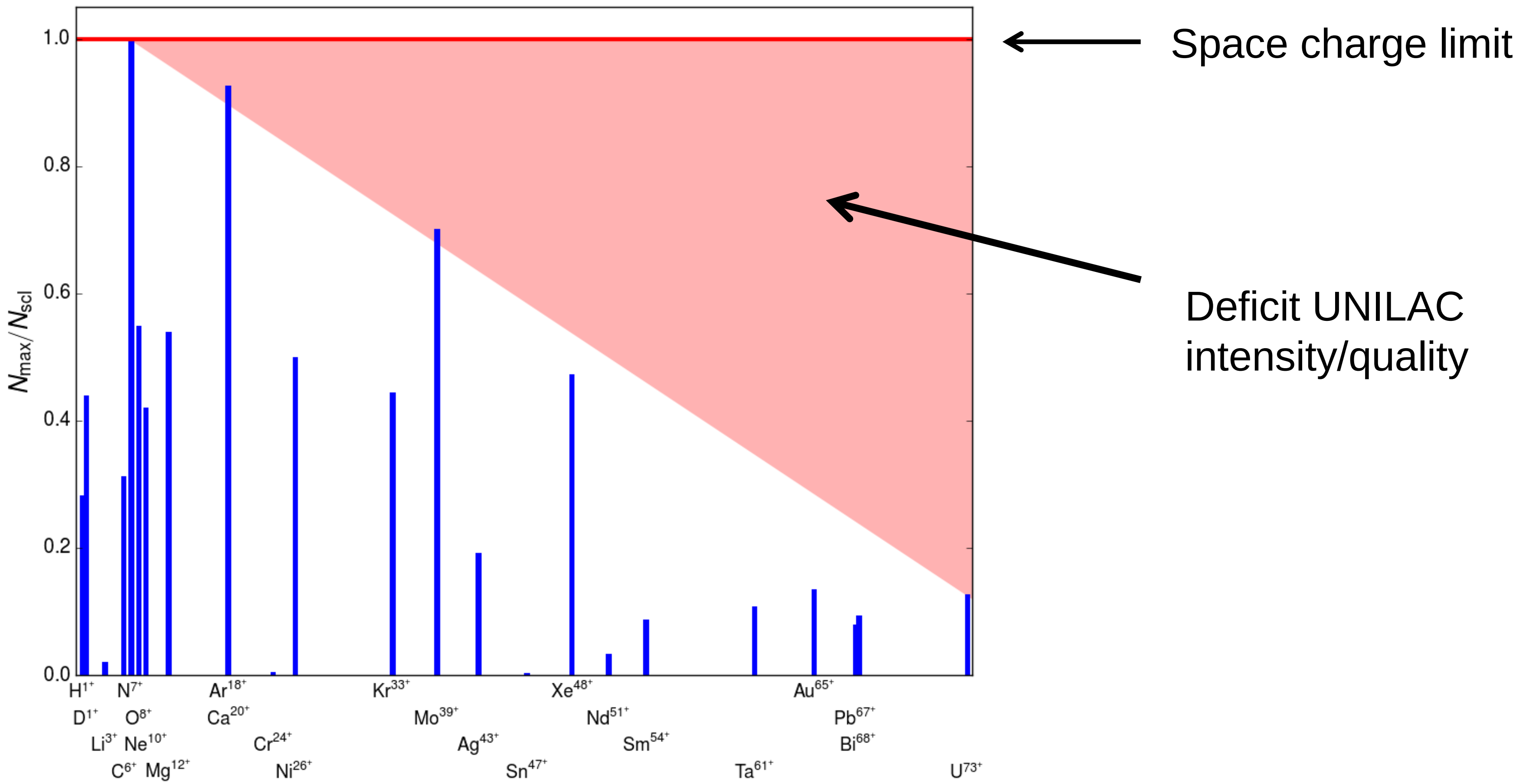
Ionization beam loss at high intensity and high repetition rate operation



Two Plane Injection
or/and Pulsed Skew Quad

2017 2018 2019 2020 2021 2022

Actual Peak Intensity versus Space Charge Limit



With the completion of the SIS18upgrade program, the deficit from medium to high mass particles will not be closed without major improvements at the UNILAC:

Influence of Injection Loss on Dynamic Vacuum and Ionization Beam Loss

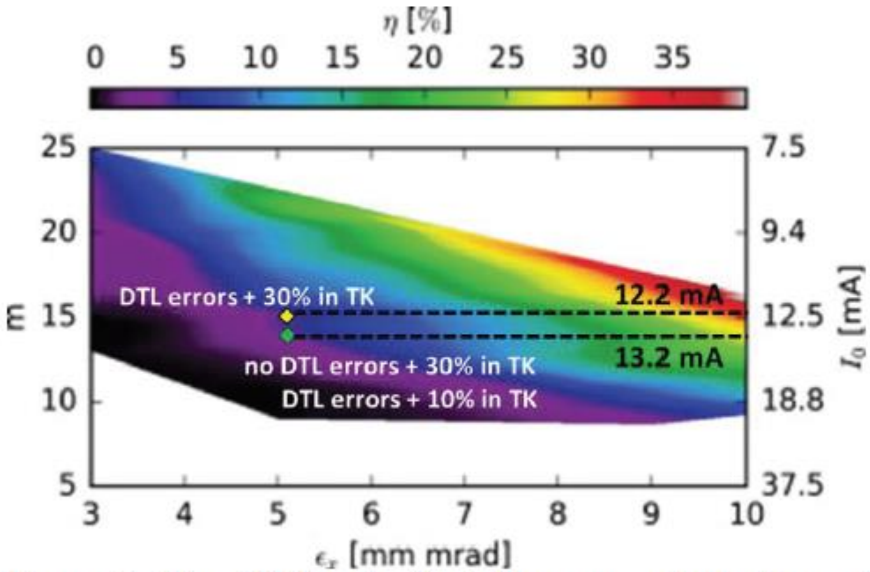
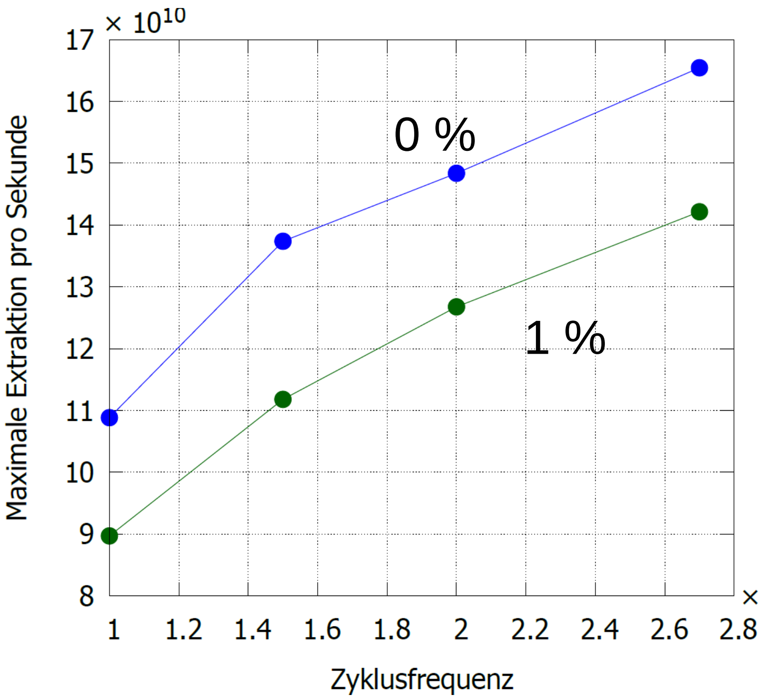
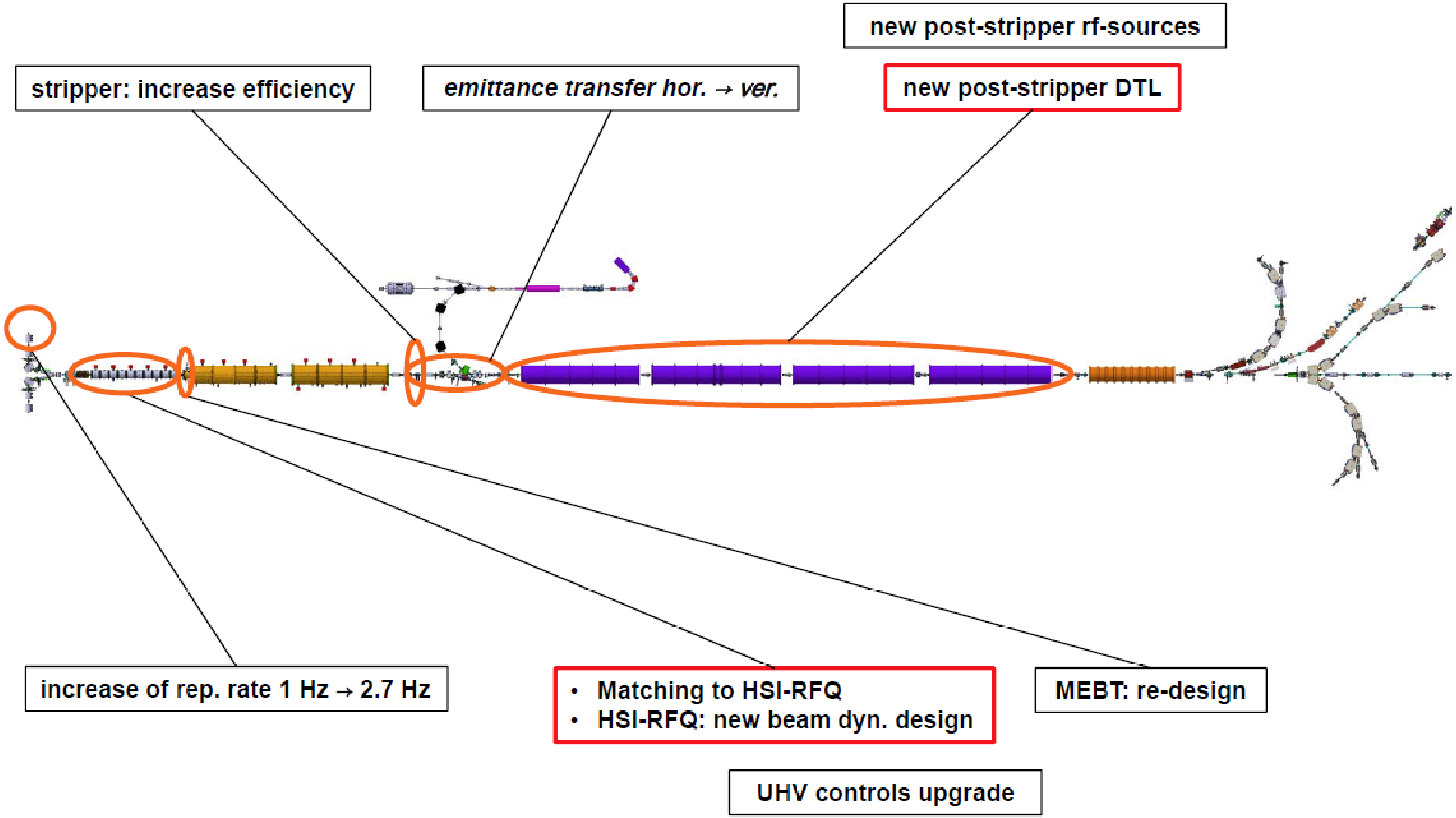


Figure 2: The 3D Pareto front from an optimization of multiplication factor, loss, and emittance with the data achieved behind new DTL assuming emittance growth in the transport channel to SIS18 [4].



UNILAC Development



SIS18 Re-Commissioning in 2018

- For the first time at GSI, 8 „dry-runs“ have been scheduled and executed for the re-commissioning (without beam) in an early phase. At most used for debugging of issues with the new FAIR control system.

  Dry run I (24.-26.10.17): no SIS18
  Dry run II (14.-16.11.17): AEG and Rf tests without power
  Dry run III (8.-12.12.17): AEG
  Dry run IV (22.-24.1.18): LSA + control system, magnet and Rf ramping and SPS
  Dry run V (14.-16.2.18): AEG tests (SAT PC) incl. correction PCs
  Dry run VI (13.-15.3.18): AEG tests (SAT PC), Rf, septa (w/o power)
  Dry run VII: (16.-20.4.18): LSA, timing, applications, controls, septa, kicker, Rf
  Dry run VIII: (14.-18.5.18): Bumper, e-cooler, remaining

  > Beam Extraction of SIS18m two days after commissioning with beam

- Goal for FAIR commissioning:

Development of a sequencer for semi-automized (fast) device validation and commissioning, including documentation of the execution results started.

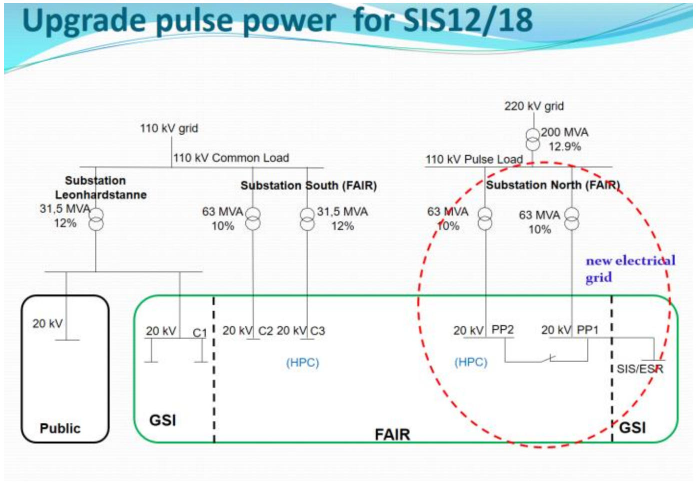
- Due to the full implementation of the new FAIR control system hard and software at SIS18, the new LSA set value generation system and the new BI standards (FESA front end etc.) the developments and oportunities for corrective measures at the commissioning of SIS18, will lead to a major time saving at the commissioning of the new FAIR machines.

Goals for FAIR operation: Strong operator support by means of beam based feed-back systems, semi-automated machine setting algorithms etc.

Transformer Stations

New transformer station North for the pulse power supply of SIS18 and SIS100 completed and commissioned.

First preparation with new power grid connection (separate 110 kV line) in 2006



	Pulse Power	Field Rate
SIS18	5 MW	1.3 T/s
SIS18	45 MW	10 T/s
SIS100	37 MW	4 T/s
SIS300	26 MW	1 T/s

New transfomer station south (Commons) is also completed and serves the FAIR construction site.

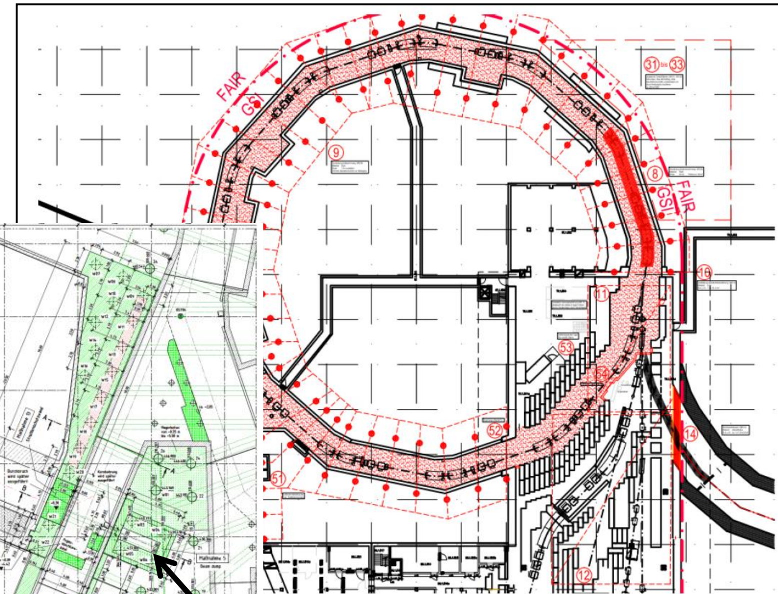
Preparation of the Existing Accelerator Tunnels and Buildings

SIS18 Civil Construction GAF and WTK

GAF (Gebäude Anbindung FAIR):

- **Shielding enhancement** on top of the existing SIS18 tunnel and at other locations for fast cycled operation with $5x10^{12}$ Protons per Second. (3% Proton beam loss at final energy)

- **Radioactive air management** system
- **Fire prevention system** (nitrogen venting)
- **Interface** to the FAIR tunnel 101
- An inner and outer **reinforment wall**
- **Power link** of main operation building to new transformer station North



GAF

WTK

WTK (Westwand Transfer Kanal)

- **Beam dump** for the proton linac on the western side of the transfer channel (TK)
- Shielding enhancement of the TK eastern wall and interface for an early construction of the p-linac building

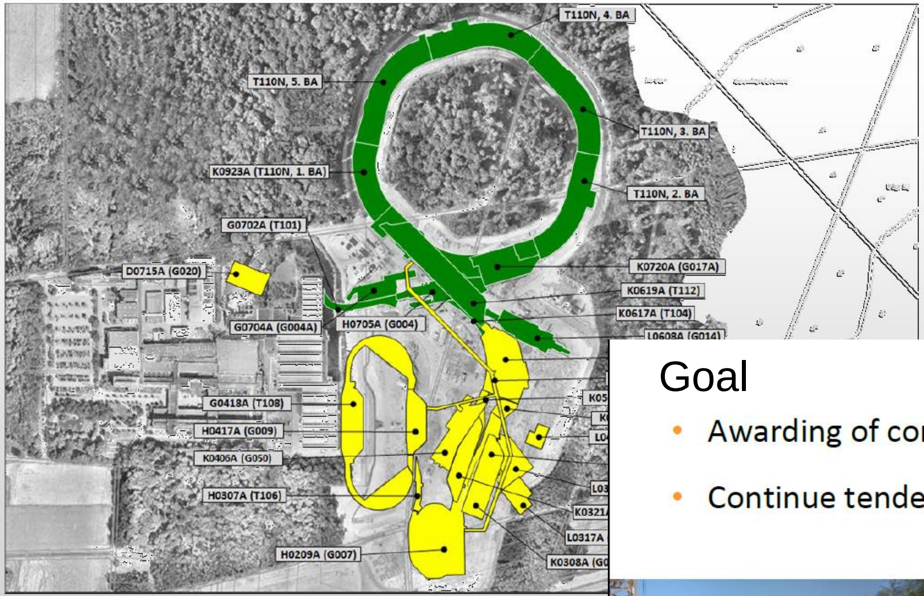
All works are completed.

Status GAF and WTK Project

- All concrete and earth works completed.
- Link to FAIR tunnel 101 and p-Linac building completed.
- Power link to new transformer station North, via new technical building to PC completed.
- VOB acceptance of underground engineering, building shell, interior works
- HVAC installations in tunnel completed.
- Successfull commissioning of new N-fire prevention system completed.
- Visitor platform completed.

FAIR Civil Construction Structure

FAIR Site & Buildings



Goal

- Awarding of construction area south in full
- Continue tender process for technical building installation (MEP)

Construction of SIS100 Tunnel

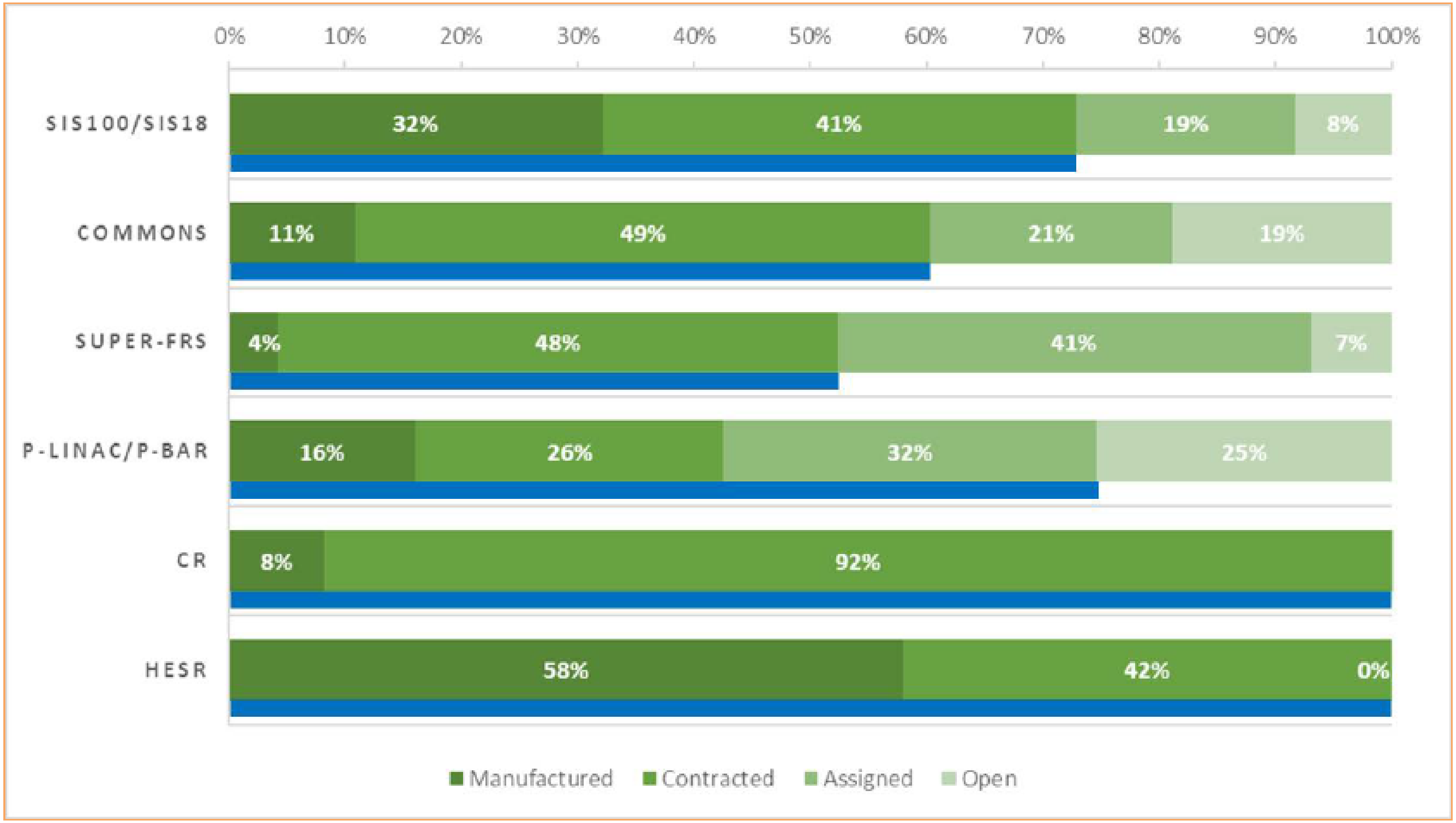
1st SIS100 tunnel segment

concreting completed in April 2019

Transfer Building G004

construction progressing

FAIR Accelerator Procurement Status



Heavy Ion Synchrotron SIS100 – Unique Features

SIS100 is a world wide unique synchrotron designed and optimized for the generation of high intensity heavy ion beams.

- It has a **flexible lattice structure**, enabling different optical settings for different user modes.
- It has a lattice cell (**charge separator lattice**) with an optimized design for the control of beam loss by ionization at highest intensities of Uranium beams.
- It has a unique and **extreme XHV system**, making extensive use of cryo-pumping to suppress vacuum instabilities at highest heavy ion intensities
- It is a **fast ramped superconducting** synchrotron with ramp rates up to 4 T/s and a minimum cycle time of less than 1 second.
- It is equipped with **powerful Rf systems** for acceleration, compression, generation of barrier buckets and buckets for longitudinal stabilization.
- It provides **different extraction modes** for fixed target experiments and optimal time structures for matching to production targets and storage rings.
- Its cyrogenics system is designed to **control of a dynamic heat load** of up to 75 % (3.4 kW <> 14,7 kW) with big difference from cycle to cycle in a parallel operation of multiple users.

SIS100

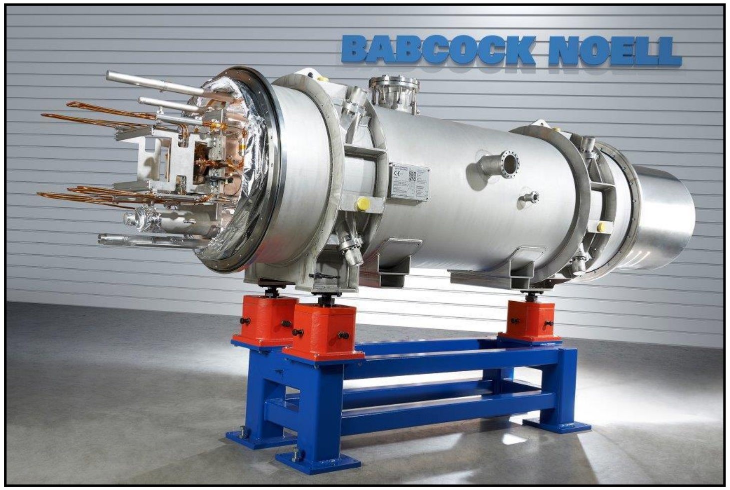
- 40 sc dipole modules manufactured at BNG and 23 shipped to GSI and 22 cold tested
- Quadrupole (QP) modules:
  - Contract for integration and manufacturing signed with BNG
  - FOS quadrupole units shipped from JINR to BNG for integration into FOS module
  - Contract for series testing of quadrupole units at JINR signed.
  - Quadrupole module testing INFN, Salerno (Italy). Collaboration contract signed in 06.2019
- FOS acceleration cavity accepted after extensive SAT test at GSI
- All bunch compression cavities manufactured at Aurion, Seeligenstadt.
- Series production released for thin wall dipole chambers with LHe cooling
- Contract for electrostatic extraction septum signed and manufacturing started
- Production of injection septa almost completed and injection kicker system FOS commissioned.
- Series production of cryo-catchers launched and for cryo-adsorption pumps completed.

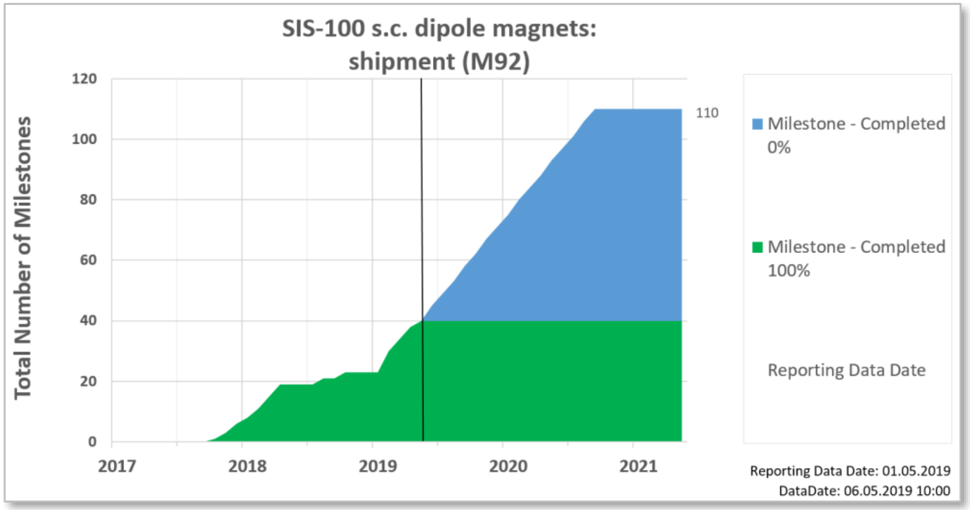
sc dipole modules in GSI storage area

QP Unit @ BNG

First Unit Integration Test at BNG

Series Production of S.C. Dipole Modules

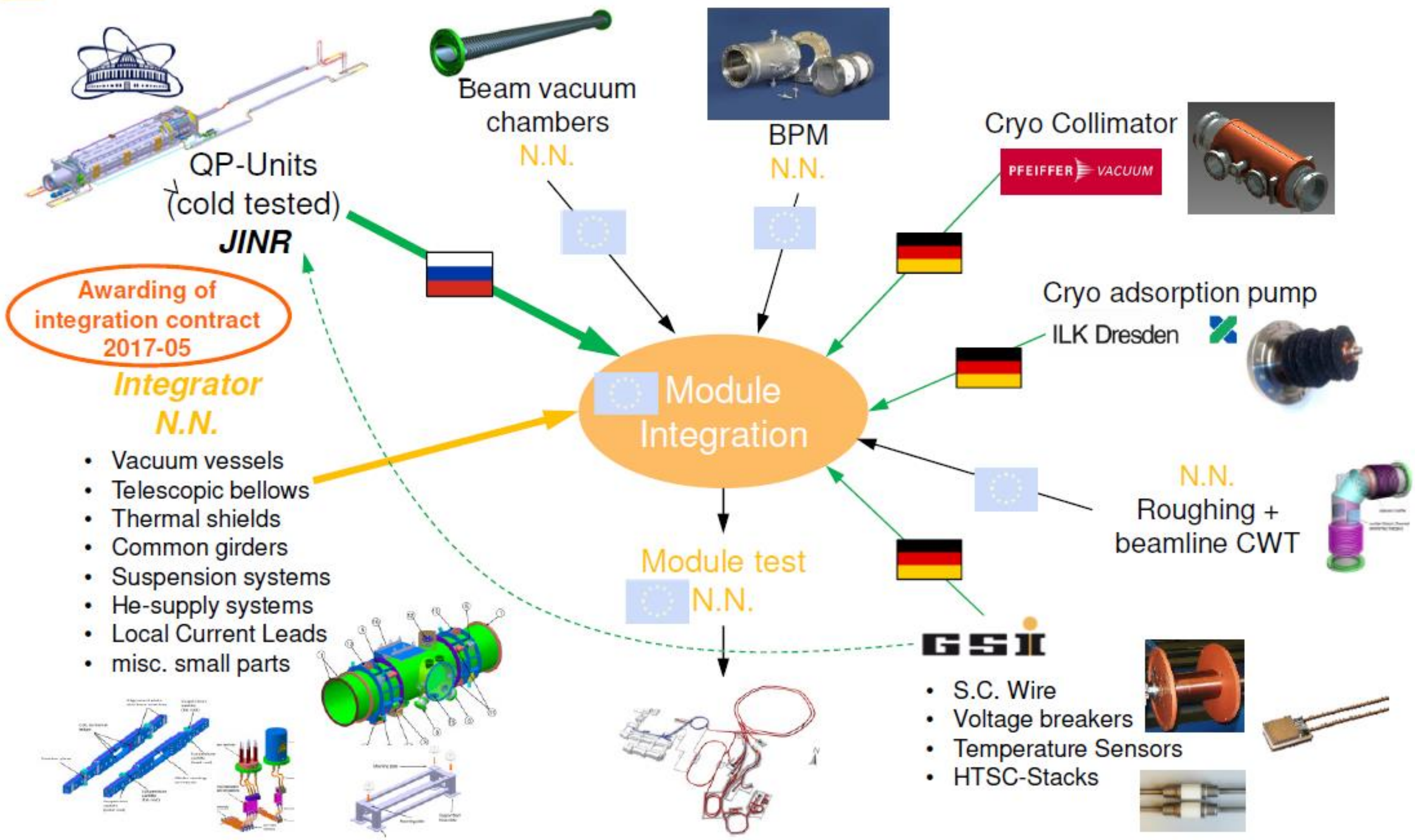




- Excellent mechanical precision within apertur
- Very small random error of field harmonics

Quadrupole Module Procurement Status

SIS100 Critical Path



Quadrupole Module and Integration

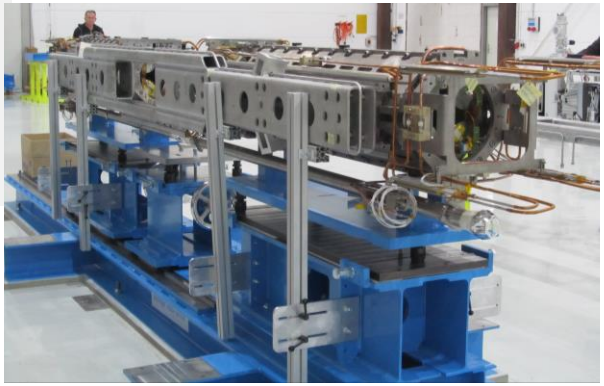
- The contract for the quadrupole module manufacturing and integration has been awarded to BNG.
- The FOS quadrupole module is currently under production.

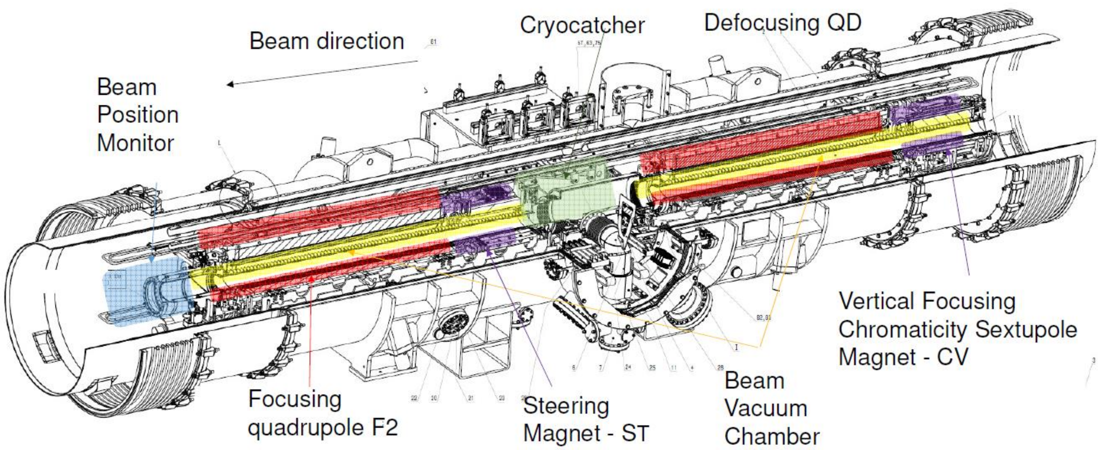
Items supplied for FOS integration:

- FOS QD units
- FOS cryo catcher
- Roughing Cold Warm Transition
- FOS Quadrupole vacuum chambers (planned for end of November)
- FOS BPM with cable and transfomers (planned for end of November)

Planned delivered of FOS quadrupole module: July 2019


Vacuum vessel by leak test



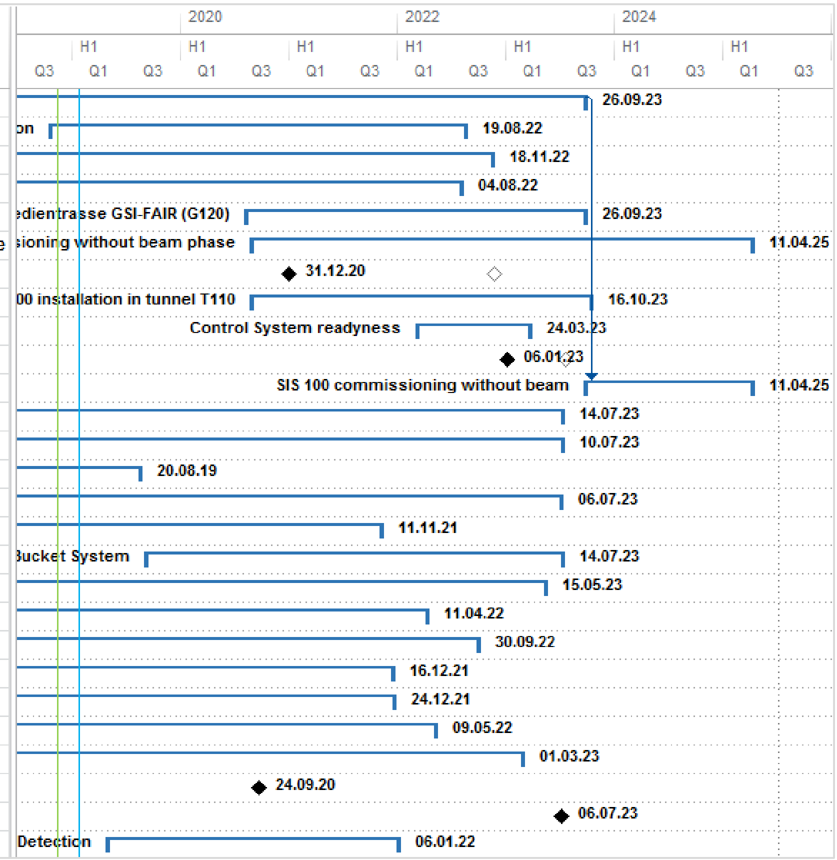


Downstream unit SF2 (F2 + steerer)

Upstream unit VQD (QD + sextupole)

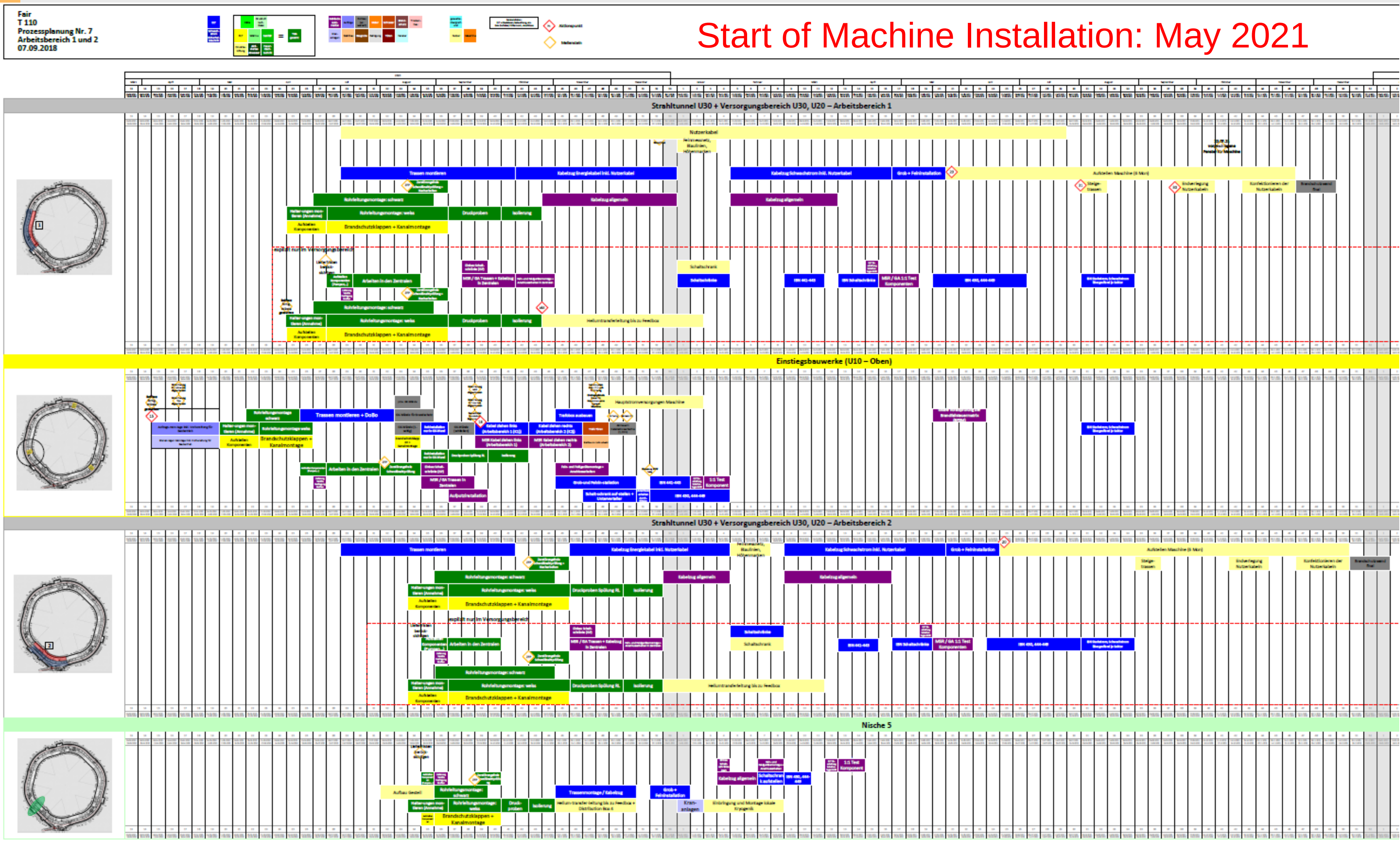
Level 2 Plan SIS100

	Vorgangsname	Anfang	Ende	Dauer
4737	FSB Milenstone needed for installation	31.10.16	26.09.23	1802 Tage
4738	Hauptversorgung Nord 17.1 (H0719A) for information	25.10.18	19.08.22	997 Tage
4754	SIS100/300: T110 (K0923A)	04.08.17	18.11.22	1381 Tage
4803	Kryoversorgung 17A (K0720A)	31.10.16	04.08.22	1504 Tage
4810	Medientrasse GSI-FAIR (G120)	12.08.20	26.09.23	815 Tage
4814	SIS 100 installation into tunnel, commissioning without beam phase	31.08.20	11.04.25	1204,66 Tage
4815	Data supply readyness	31.12.20	31.12.20	0 Tage
4817	SIS 100 installation in tunnel T110	31.08.20	16.10.23	816 Tage
4831	Control System readyness	09.03.22	24.03.23	273 Tage
4837	Global Cryogenics (Cryo2) readyness	06.01.23	06.01.23	0 Tage
4839	SIS 100 commissioning without beam	26.09.23	11.04.25	402,66 Tage
4856	SIS 100/ SIS18 WP View	14.10.11	14.07.23	3064,9 Tage
4857	Magnets	14.10.11	10.07.23	3061 Tage
4977	SIS100 sc electrical systems	06.03.13	20.08.19	1685 Tage
4990	SIS100 Power Converters	24.03.17	06.07.23	1638,2 Tage
5107	RF Systems	01.11.12	11.11.21	2355 Tage
5136	SIS100 Barrier Bucket System	11.09.19	14.07.23	1001,9 Tage
5147	SIS100 Injection/Extraction	10.05.12	15.05.23	2873 Tage
5196	SIS100 Beam Instrumentation	21.08.15	11.04.22	1731 Tage
5357	SIS100 Vacuum	01.02.12	30.09.22	2782 Tage
5691	SIS100 Laser Cooling	22.03.17	16.12.21	1236 Tage
5713	SIS100 Special Installations	15.10.13	24.12.21	2138 Tage
5747	SIS100 Cryogenics	02.10.13	09.05.22	2243 Tage
5781	SIS100 Quadrupole Units	20.03.15	01.03.23	2074 Tage
5793	Magnet Testing SIS100 Dipoles (Infrastructure only)	24.09.20	24.09.20	0 Tage
5795	Magnet Testing SIS100 Quadrupoles (Infrastructure only) in Work	06.07.23	06.07.23	0 Tage
5797	SIS100 Quench Detection	02.05.19	06.01.22	700 Tage

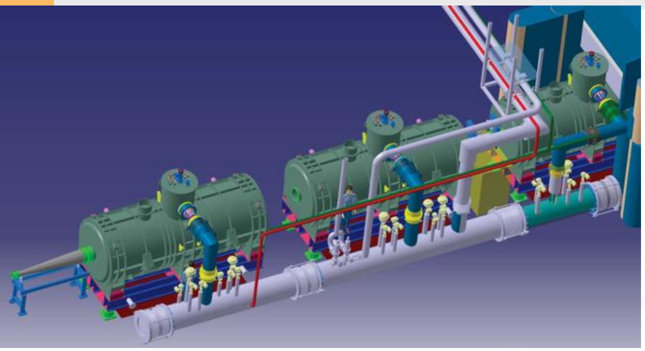


LCM (Lean Construction Management)

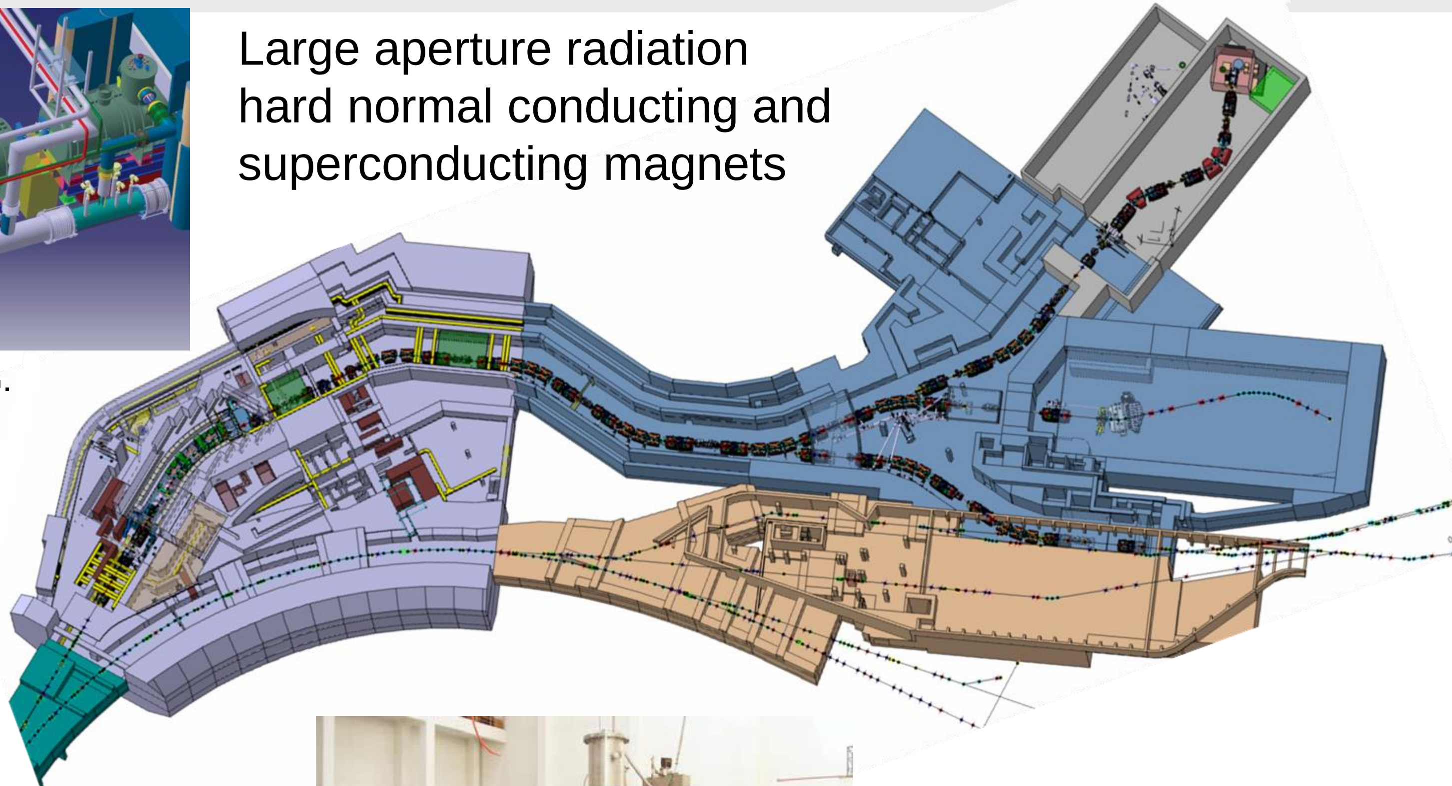
Start of Machine Installation: May 2021



Super-FRS



S.c multiplett awarded to ASG.
FOS short multiplett under production



Large aperture radiation hard normal conducting and superconducting magnets

Radiation hard dipole. Prototype build by BINP. Tendering planned for Q1 2018.

Prototype s.c dipole magnets: Re-dedign completed by CEA, Negotiations has been started. Contracting planned within 2017.

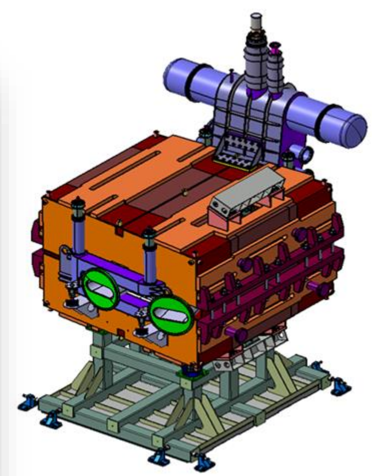
Super-FRS

- Production of FoS sc short multiplets (25 t) completed. Shipment to CERN for testing and preparation of cold testing (July).
- Production of FoS sc long multiplet (60 t) started.
- Testing Facility for sc magnets at CERN is ready for operation at CERN.
- Production of sc "standard" dipole magnet started at ELYTT.
- Design phase of sc branching dipole finalized (not contracted).
- Contract signed with BINP on radiation hard dipole magnets.
- Negotiations with BINP on several types of Super-FRS vacuum chambers.
- 1st version quench detection electronics developed (included in PC).
- Various IKC for detector systems drafted and in negotiation with in-kind partners
- Production of slit systems running

FoS of the Super-FRS short SC Multiplet arrived in Feb. 2019 at CERN test facility for execution of the Site Acceptance Test

Coils for long multiplett

Cryostat of long multiplett



Model of s.c. dipole magnet

World Wide Testing Infrastructure for the Series of Superconducting Magnets

GSI: Series test facility for the SIS100 s.c. dipole magnets, string test, current leads and local cryogenics components.

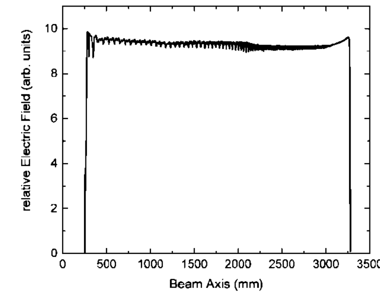
CERN: Test facility completed for the Super-FRS s.c. dipoles and multipletts

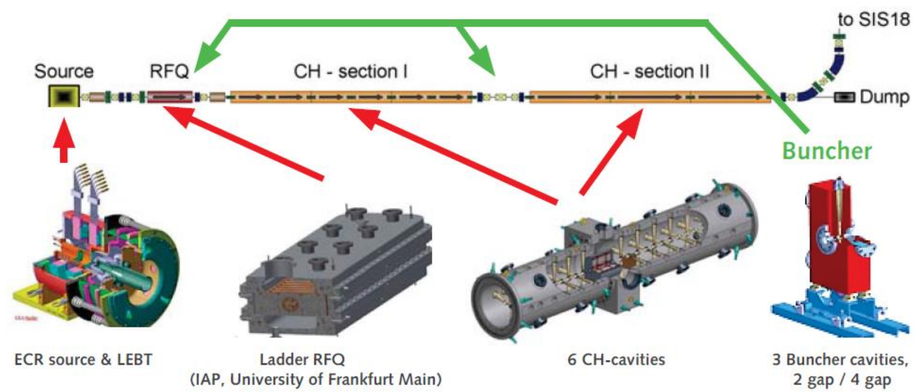
INFN: Test facility in Salerno for testing the series of SIS100 quadrupole modules

JINR, Series test facility in Dubna for testing of the series of SIS100 s.c. quadrupole units

pLinac/ pbar Target

- Commissioning of ion source at CEA continued. FAIR beam parameters reached.
- RFQ tuning ongoing. Excellent agreement of E-field with theoretical predictions in terms of field flatness and resonance frequency.
- Seven Klystrons on site. SAT progressing. All parts for modulators ordered.
- Continuation of the development for manufacturing and engineerng of CH cavities (presently e-beam welding tests)
- Design study on magnetic horn pulser completed at Rheinmetall.



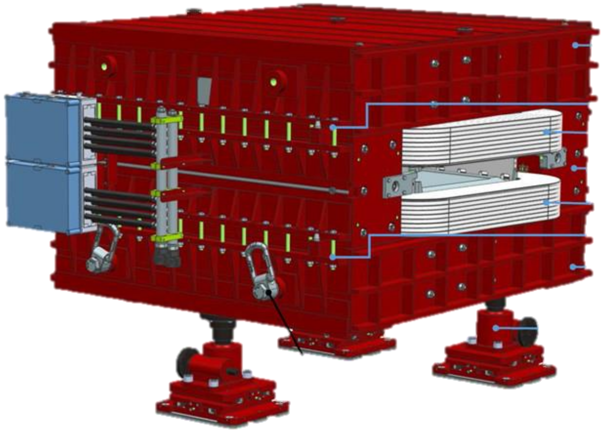


Collector Ring

- German inkind contribution: De-buncher cavities and stochastic cooling system.
- All other components are inkind contribution of Russia. BINP is in charge of the subproject CR.
- 90 % of CR specifications have been released
- The series production of RF – debunchers cavities (GSI inkind) is completed. Acceptance tests of power converters for cavities (OCEM) planned to be completed in summer.
- Power amplifier prototype for Stochastic Cooling system has been produced and SAT successfully tested. Series production started.

FoS RF-debuncher

CR dipole design



High Energy Storage Ring

- All Dipoles are produced, in Jülich and 36 of 46 dipoles are delivered to FAIR (Weiterstadt).
- Quadrupoles (QP) are all produced in Jülich
- Two pre-assembly lines for the quadrupole groups in the arcs are in preparation
- Sextupoles, steerers and their power converters are in production (Romania), magnets arriving continuously in Jülich
- All quadrupole power converters are produced and delivered to FZJ.
- RF equipment is in mechanical design
- Stochastic cooling equipment (slot ring coupler) installed in COSY for beam tests.
- Injection dipole, injection septa and PANDA dipoles manufactured and delivered.


Commons + HEBT

- Collaboration contracts with EFREMOV (delivered 30 of 51 dipole magnets) and BINP (delivered 12 of 280 magnets)
- Delivery of 6 series Power Converter from India, (ECIL, India), FAT of series quadrupole power converter (67 of 190 pcs.) passed.
- 51 dipole chamber manufactured and delivered by BINP
- Batch 2 and 3 vacuum chambers (270 pcs.) collaboration contract signed with BINP.

BINP dipole chambers at GSI

- Cable data base set-up finalized with all cable parameters required for reliable cost estimation and execution of cable related tasks for the project (in total about 6000 km). Procurement start end of 2019.
- Procurement process for central cryogenic plant started. Difficult negotiations with potential providers.

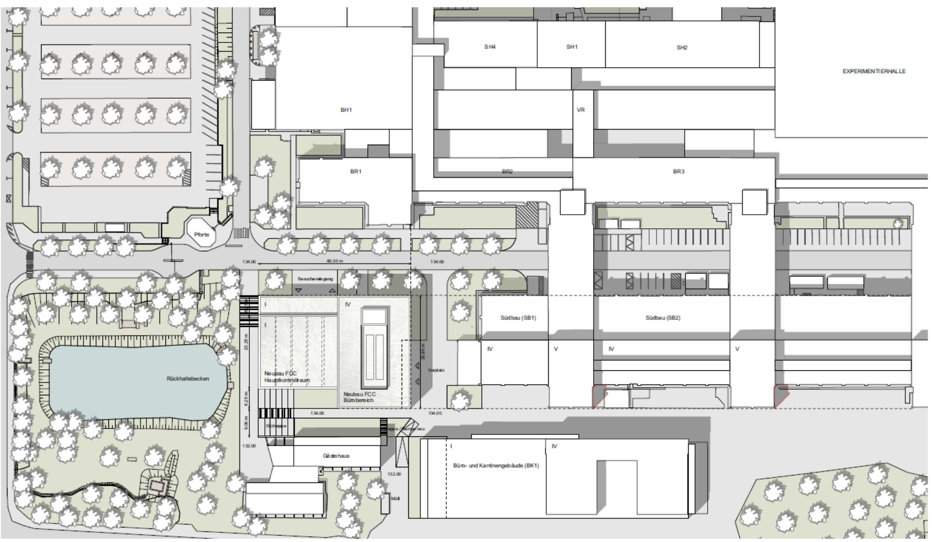
HEBT dipole magnets at GSI

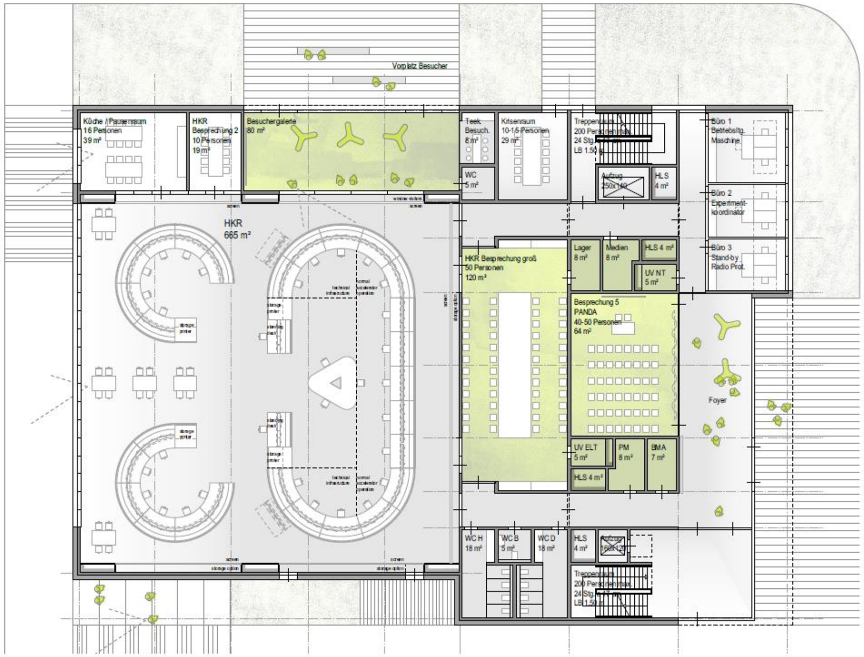
HEBT Quadrupole Power Converter after FAT in India

FAIR Control Centre (FCC)

Mechanical Console and Fixed-Display Pre-Design

- Detailed specification approved by SPLs and main users incl. experiments.
- Existing GSI control room refurbished with new prototype FAIR consoles and fixed displays, 1st basic and generic set of control room applications developed
- Planned of building construction in 2020.





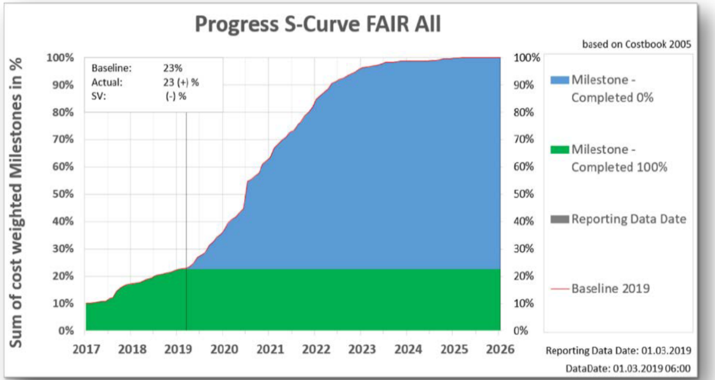
Re-Baselining and International Project Evaluation 2019

- Final re-baselining workshop performed in January 2019
- new FAIR Project time schedule baseline frozen in February 2019

- International Project Review completed and conclusions presented to 26th Extraordinary FAIR Council on 29th April 2019

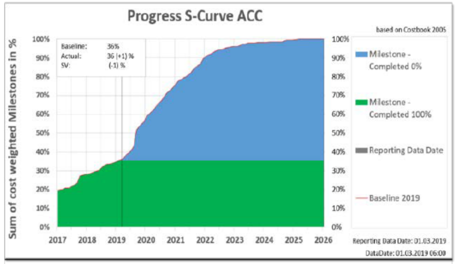
- Conclusions of the Review Panel
  - Science case of FAIR MSV as world class science confirmed
  - First experiments are expected end 2025
  - FAIR project execution works are recognized as very good
  - Full scope of civil works should be executed at once
  - Solutions for providing the necessary additional funding should be implemented shortly to allow full continuation of project execution works
- Next Steps
  - Each shareholder to inform their financing bodies
  - Preparation of the next 27th and 28th FAIR Council where proposed decisions need to be taken.

Status of S-Curves (Project Progress)



There are several essential prerequisites for reaching this progress curve:

- Full support of international shareholder for In-kind contracts signatures and delivery machine components as per FAIR schedule requirements
- Civil work to continue in full for MSV, without interruptions
- No major technical issues of components during commissioning

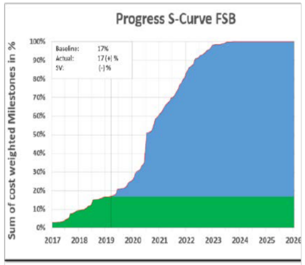


Status:

- Substantial progress in the area of ACC achieved

Challenges:

- In-kind contracts placement and execution to follow new baseline
- Recruitment of additional ACC resources to be continued

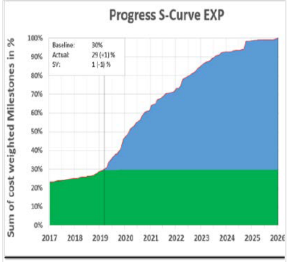


Status:

- Civil activities progressing overall well

Challenges:

- Full continuation of civil works to be ensured



Status:

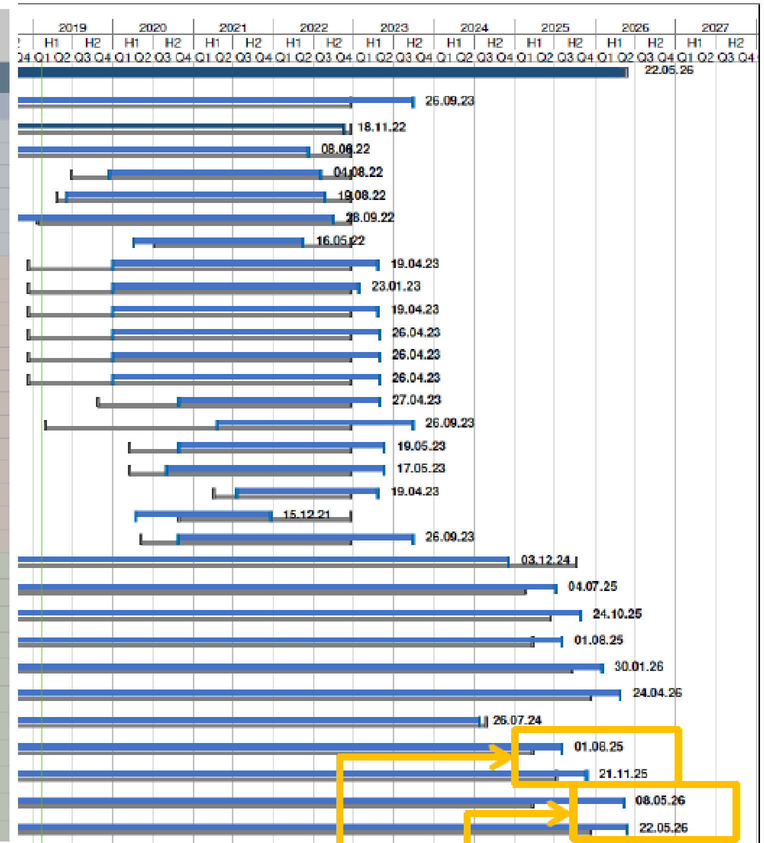
- New baseline has been frozen in February 2019 including the Day-1 configuration

FAIR Schedule after Re-Baseling

ID	Name	Start	Finish	Baseline Start	Baseline Finish
0	**Level 1 - FAIR Integrated Master Schedule**	21.05.09	22.05.26	08.08.08	11.12.25
1	FAIR Buildings	14.08.17	26.09.23	08.06.17	16.12.22
2	K0923A [T110] - SIS100	14.08.17	18.11.22	08.06.17	16.12.22
13	H0705A [G004] - Transfer Building / T104N Transfer SIS100 / T112N Tran	16.10.17	08.06.22	29.11.17	16.12.22
24	K0720A [G017A] - Cryo Compressor Building	16.12.19	01.08.22	27.06.19	16.12.22
34	H0719A [G017.1] - Main Supply Building North	03.06.19	19.08.22	23.04.19	16.12.22
41	L0608A [G014] - CBM / T112S Transfertunnel SIS100-CBM	05.03.18	28.09.22	24.01.19	16.12.22
52	G0704A [G004A] - Transfer Supply / G0702A [T101] - Transfer Line SIS18	06.04.20	16.05.22	08.07.20	16.12.22
63	[G006] - SFRS HE-Cave	02.01.20	19.04.23	17.12.18	16.12.22
73	[G017.2] - Main Supply Building South	02.01.20	23.01.23	17.12.18	16.12.22
82	[G006A] - SFRS Supply	02.01.20	19.04.23	17.12.18	16.12.22
92	[G006B] - SFRS LE-Branch	02.01.20	26.04.23	17.12.18	16.12.22
102	[G006C] - pbar-Target	02.01.20	26.04.23	17.12.18	16.12.22
112	[G050] - APPA	02.01.20	26.04.23	17.12.18	16.12.22
122	[G018] - SFRS / [T103N] - Transfer SFRS-Experimente / [T113N] - Transfer	29.10.20	27.04.23	24.10.19	16.12.22
135	[G007] - CR / [T106] Transfer CR-HESR	21.04.21	26.09.23	27.02.19	16.12.22
146	[G009] - HESR PANDA	27.10.20	19.05.23	18.03.20	16.12.22
156	[T108] - HESR	02.09.20	17.05.23	18.03.20	16.12.22
166	[G021] - Storage	19.07.21	19.04.23	01.04.21	16.12.22
174	[G020] - p-linac	14.04.20	15.12.21	26.10.20	16.12.22
184	[G120] - Supply Line	22.10.20	26.09.23	07.05.20	16.12.22
191	pLINAC	07.01.11	03.12.24	06.01.11	08.10.25
201	SIS100	17.10.11	04.07.25	17.10.11	20.02.25
217	SuperFRS	01.01.13	24.10.25	02.06.14	[illegible]
237	p-bar Separator	30.08.13	01.08.25	05.09.13	20.03.25
256	Collector Ring	23.08.11	30.01.26	24.08.11	[illegible]
273	HESR	21.05.09	24.04.26	26.03.09	[illegible]
292	HEBT	06.11.12	26.07.24	02.01.14	22.08.24
329	CBM	05.07.13	01.08.25	08.07.13	20.03.25
345	NUSTAR	03.06.13	21.11.25	15.09.14	10.07.25
368	APPA	16.12.09	08.05.26	16.12.09	20.03.25
403	PANDA	01.02.11	22.05.26	08.08.08	11.12.25

New Baseline Dates

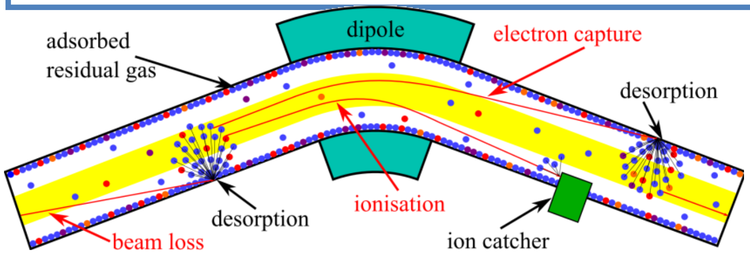
Baseline Dates 2016



- Early Science in the second half of 2025
- Completion of the full FAIR MSV expected until mid of 2026

R&D – Dynamic Vacuum

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

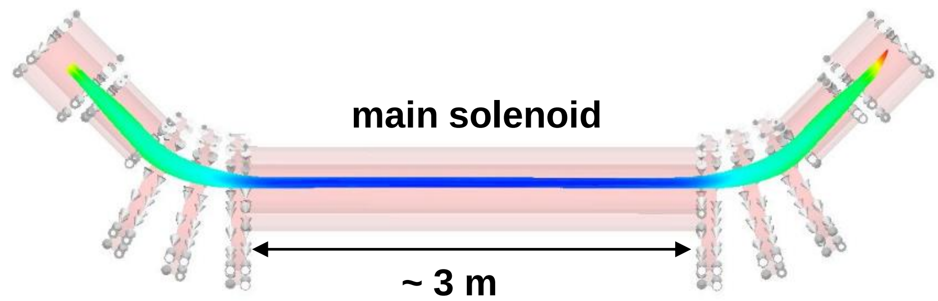
R&D – Space Charge Compensation

Electron Lens for Space Charge Compensation (SCC)

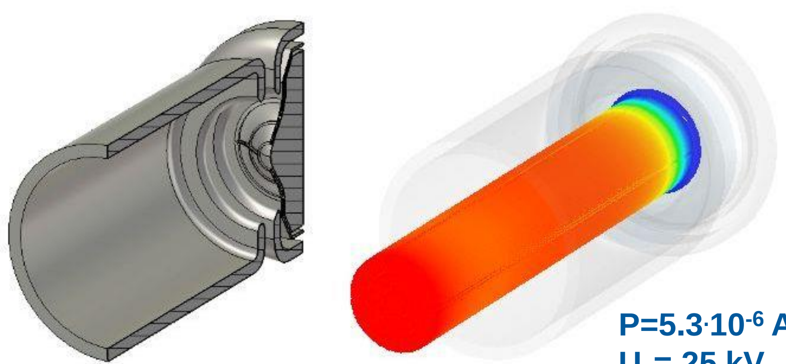
Goals:

- Upgrade of SIS18 to overcome enable further intensity enhancement
- Partial compensation of space charge tune spread
- Bunched ion beams requiring longitudinal e-beam modulation
- Matching of transverse profile to flat ion beam
- Electron currents about 10 A
- Modulation bandwidth about 5 MHz

Layout of SCC lens and electron beam dynamics



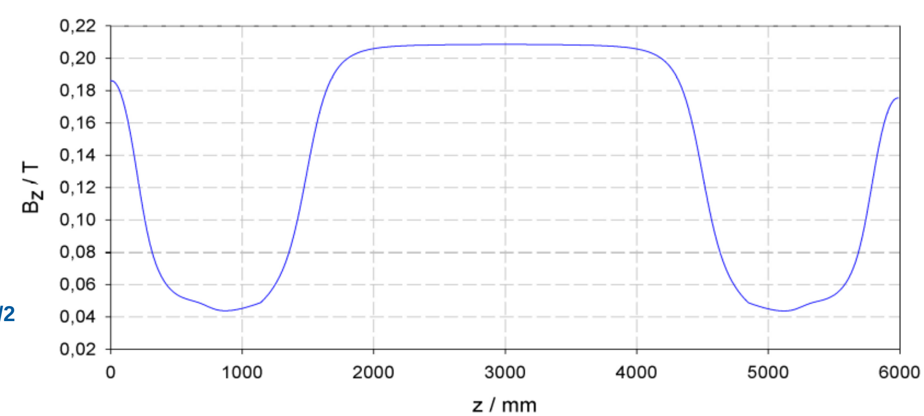
Layout of electron gun



$P = 5.3 \cdot 10^{-6}$ A/V$^{3/2}$
$U_a = 25$ kV
$I_b = 10$ A
$B_z = 0.2$ T

within ARIES WP16

Longitudinal magnetic field



R&D – Fast Ramped Superconducting Magnets

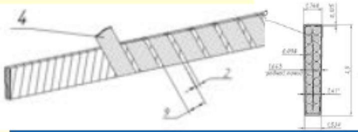
Sub-workpackages:

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

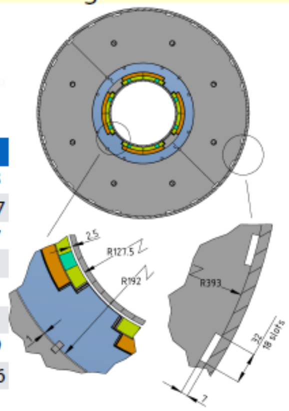
Fastest ramped, full size s.c. cos(theta) dipole magnet world wide (SIS300 prototype)

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

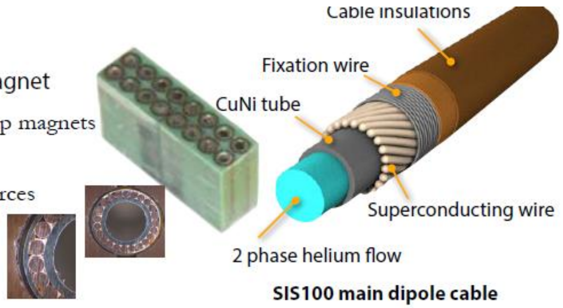


▶ Alternative design concept

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)



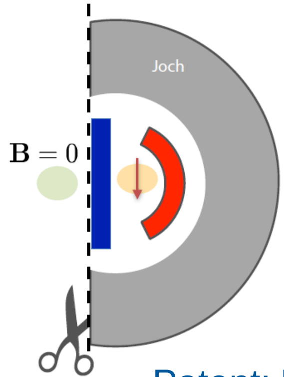
SIS100 main dipole cable

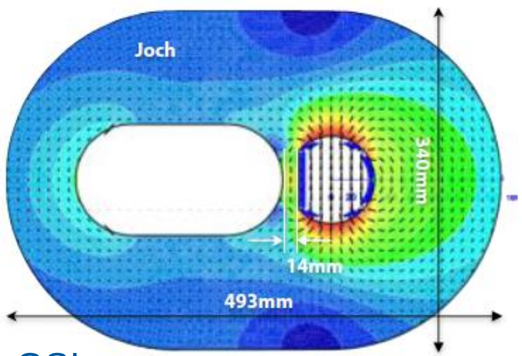
Possible applications:

SISx00, SPS2, FCC injector chain

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

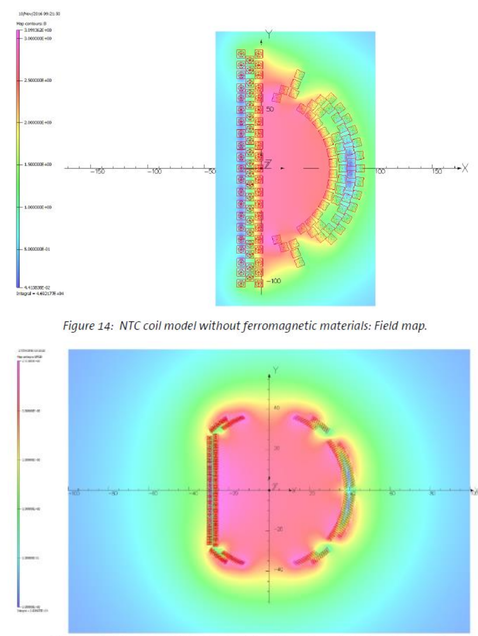
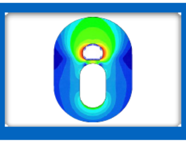
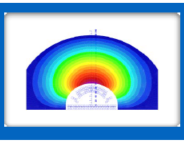


Figure 14: NTC coil model without ferromagnetic materials: Field map.

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

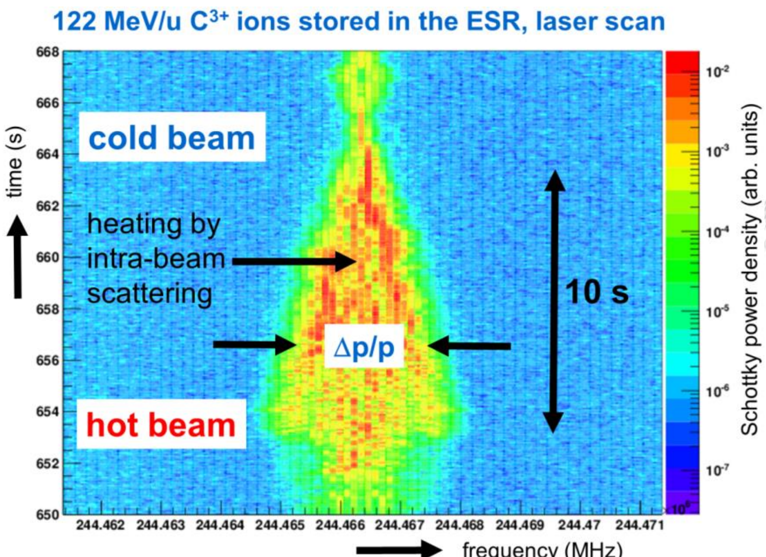
Presented at:
FCC annual meeting 2016 Rome
FCC annual meeting 2017 Berlin

R&D – Laser Cooling of Heavy Ion Beams

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

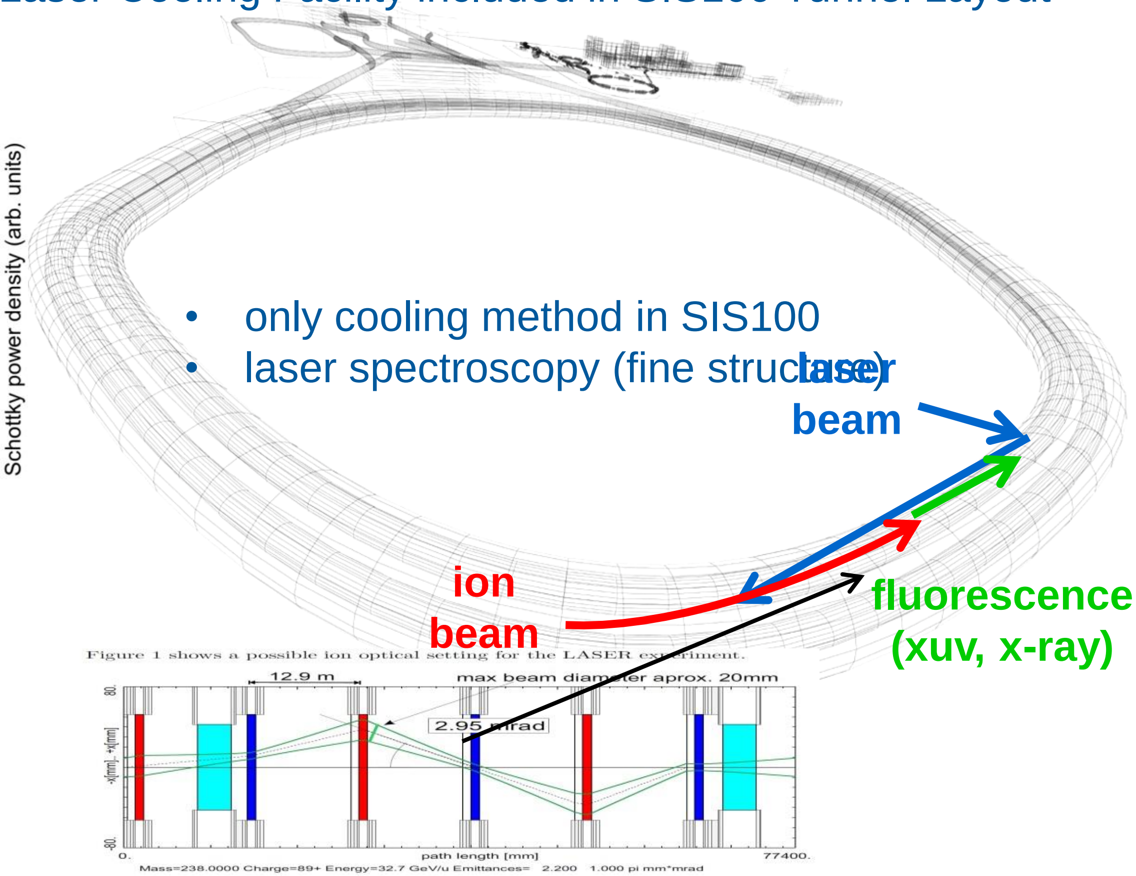
- **Z_{ion}= 10 – 60 (3 – 19 electrons)**
- **γ up to 13 (huge Doppler-shift)**



Components used for laser cooling experiments in ESR

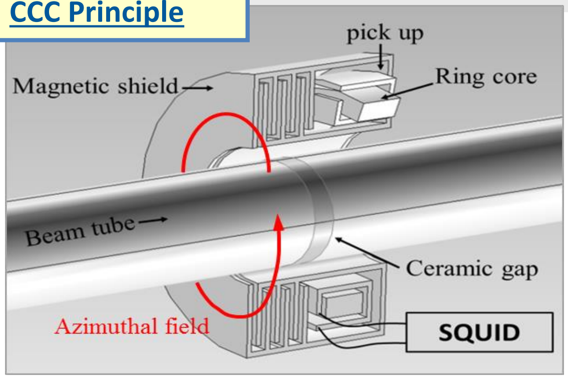
Laser Cooling Facility included in SIS100 Tunnel Layout

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

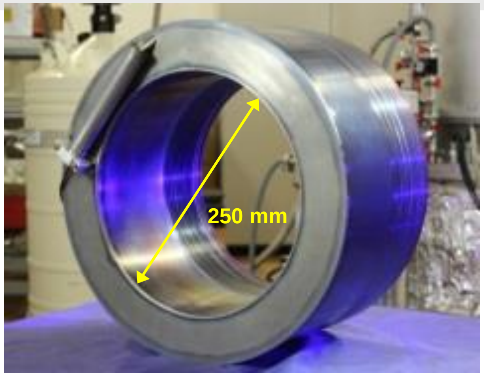


R&D – Cryogenic Current Comparator

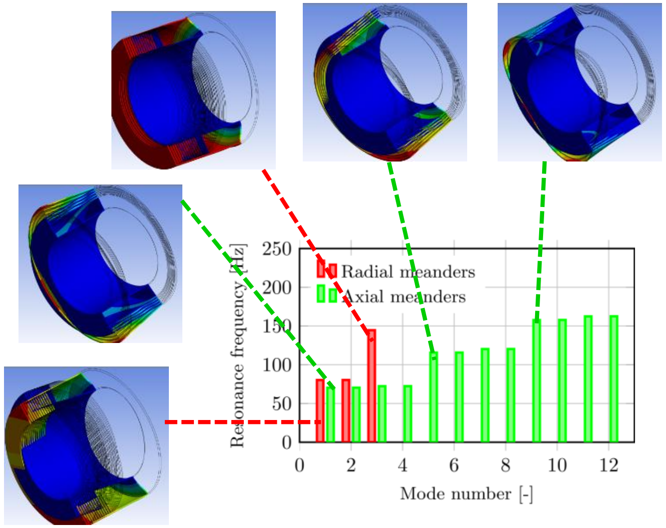
CCC Principle



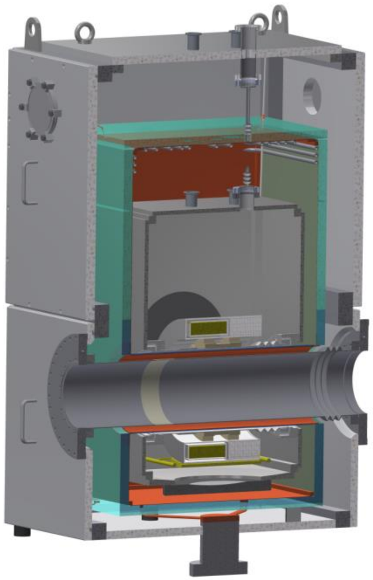
Superconducting shield/pickup -> detection of beam azimuthal field with SQUID sensor



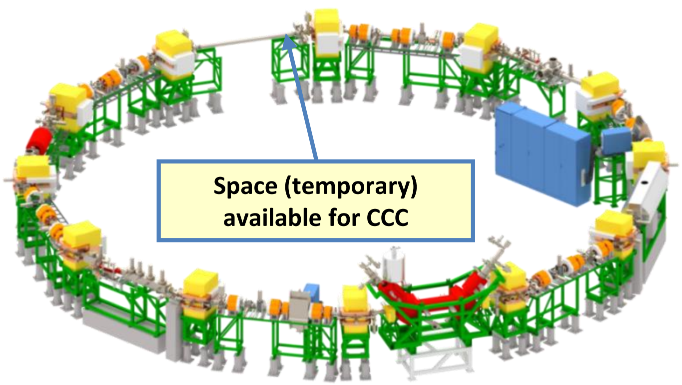
CCC-XD Nb detector and shield for 150 mm beam tubes. Tested and ready for operation



Mechanical Eigenmode calculations (ANSYS) for improved geometry of shielding and cryostat



Design of new UHV cryostat finished, production starts 06/2018



<u>CCC in CRYRING (2018/2019):</u>

→ tool for commissioning

→ support for exp. program

→ test bench for further development

<u>CCC R&D in CRYRING (start 2019):</u>

- Demonstration of cryostat + CCC-XD functionality under UHV conditions
- Improvement of system robustness
- Improvement of cost efficiency

→ Material tests Pb vs. Nb

- Shielding with axial meanders
- Pickup without toroid

R&D - Sources and LINACs

- ECRIS (ion sources (e.g. oven development, afterglow-mode)
- High repetition high current heavy ion sources
- Low energy beam transport systems (high resolution spectrometer)
- R&D for (heavy) ion cw-RFQs)
- Prototyping of low beta
- Advanced beam dynamics for Linacs
- R&D/Rf-amplifiers for LINACs
- Heavy ion stripping
- R&D and prototyping for accelerating cryo module
- Design investigations for multigap-Crossbar H-field-structures low beta
- Development and testing of advanced preparation methods for multi gap cavities (HPR, BCP, plasma cleaning)
- Development of beam dynamics for energy variable LINAC`s
- cw-application
- Non destructive high current beam instrumentation
- Cold BPMs
- Beam Based Feed Back Systems