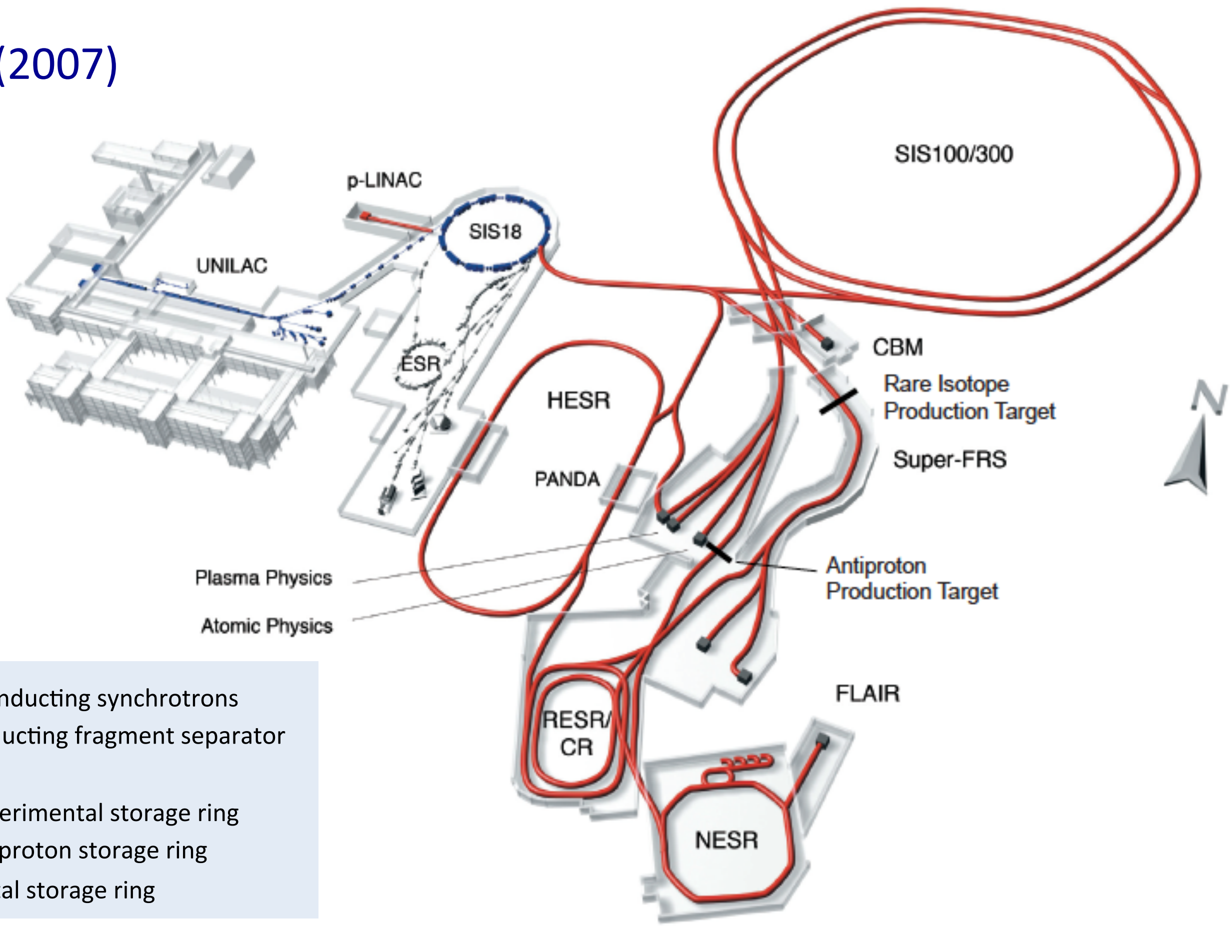
FAIR Accelerator Complex Progress

E. Mahner
(FAIR Deputy Technical Director)

NUSTAR Annual Meeting 2014
(5.3.2014)

FAIR Accelerator Complex

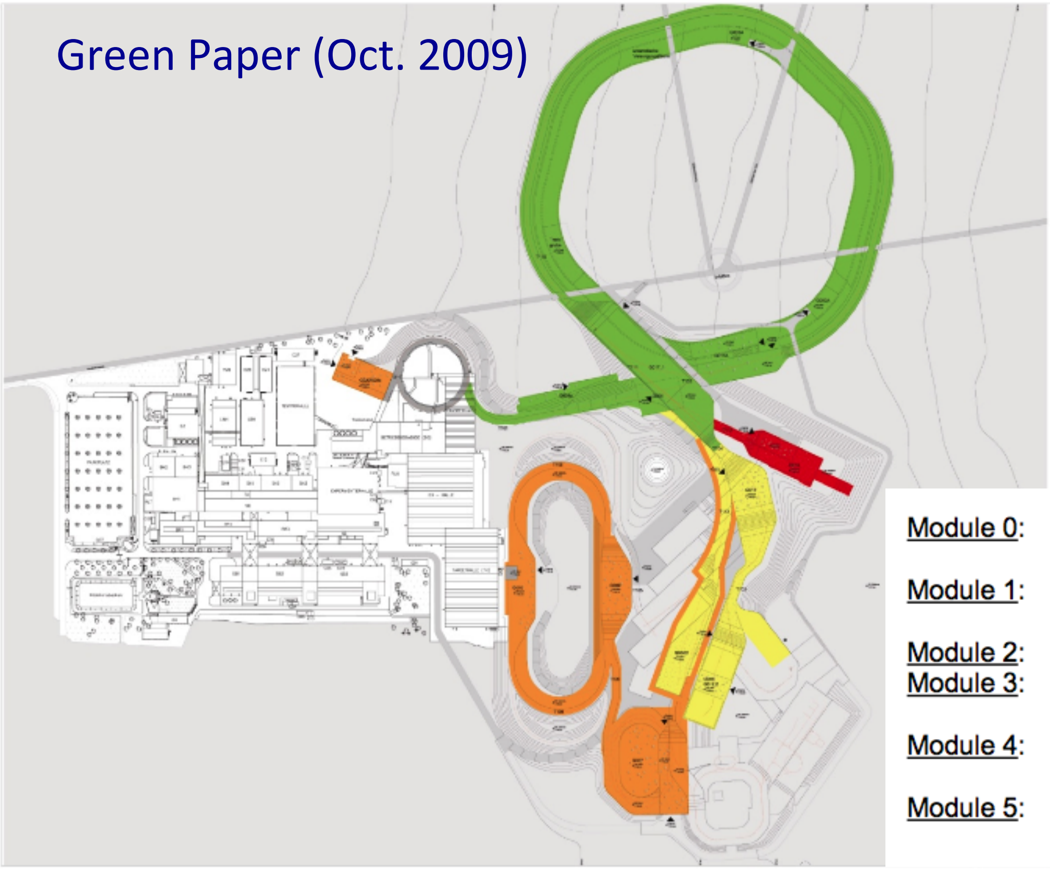
Start Version (2007)



SIS 100/300 superconducting synchrotrons
Super-FRS superconducting fragment separator
CR collector ring
RESR recuperated experimental storage ring
HESR high energy antiproton storage ring
NESR new experimental storage ring

Figure 2.1: Layout of the existing GSI facility (UNILAC, SIS18, ESR) on the left and the planned FAIR facility on the right: the superconducting synchrotrons SIS100 and SIS300, the collector ring CR, the accumulator ring RESR, the new experimental storage ring NESR, the rare isotope production target, the superconducting fragment separator Super-FRS, the proton linac, the antiproton production target, and the high energy antiproton storage ring HESR. Also shown are the experimental stations for plasma physics, relativistic nuclear collisions (CBM), radioactive ion beams (Super-FRS), atomic physics, and low-energy antiproton and ion physics (FLAIR).

FAIR Modularized Start Version



Module 0
SIS18 → SIS100
SIS100
Beam dump (upstream SIS 100)

Module 1
Beam dump (downstream SIS100)
CBM Cave
Beam lines → Appa hall

Module 2
SIS18→SFRS
SIS100→SFRS
SFRS High Energy Branch
SFRS Ring Branch
SFRS → CR

Module 3
SIS100 → pbarTarget
pbar Separator → CR
Antiproton Separator
CR
HESR

Module 0: Heavy-Ion Synchrotron SIS100 – basis and core facility of FAIR – required for all science programmes

Module 1: CBM/HADES cave, experimental hall for APPA and detector calibrations

Module 2: Super-FRS for NuSTAR

Module 3: Antiproton facility for PANDA, providing further options also for NuSTAR ring physics

Module 4: Second cave for NuSTAR, NESR storage ring for NuSTAR and APPA, building for antimatter programme FLAIR

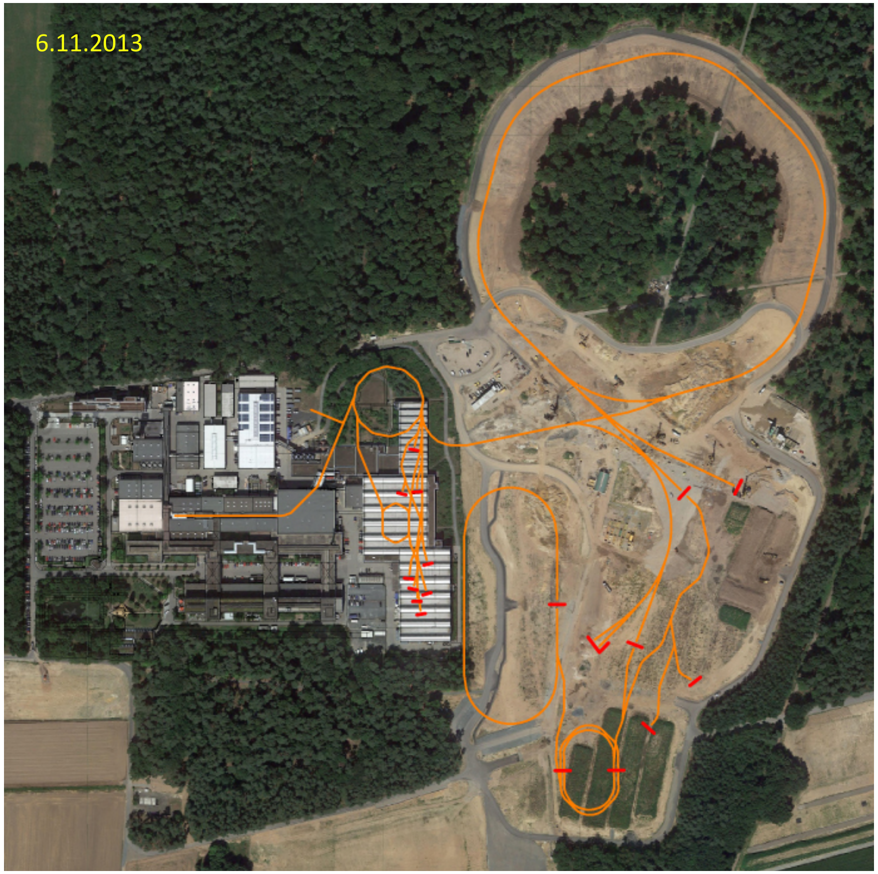
Module 5: RESR storage ring for higher beam intensity for PANDA and parallel operation with NuSTAR

Figure 1: The FAIR Modularized Start Version. Colouring of modules: 0 – green; 1 – red; 2 – yellow; 3 – orange. The Modules 4 and 5 are not marked in colour. Not shown is the additional experimental area above ground, which is part of Module 1. On the left hand side of the figure, the existing GSI facility is shown.

Module 4
NESR
FLAIR Cave
SFRS → NESR
RESR → NESR

Module 5
RESR
CR → RESR

Birds View

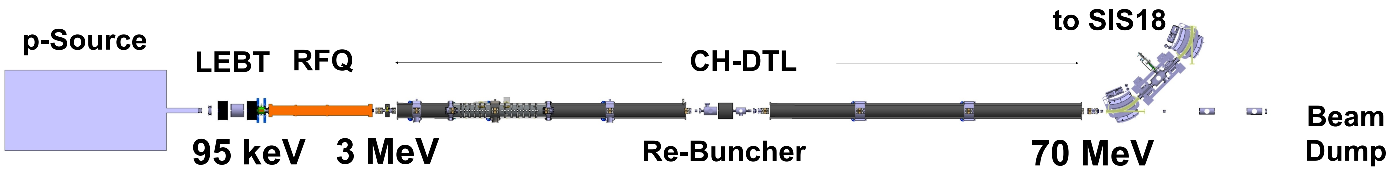


- FAIR Accelerator Tour today

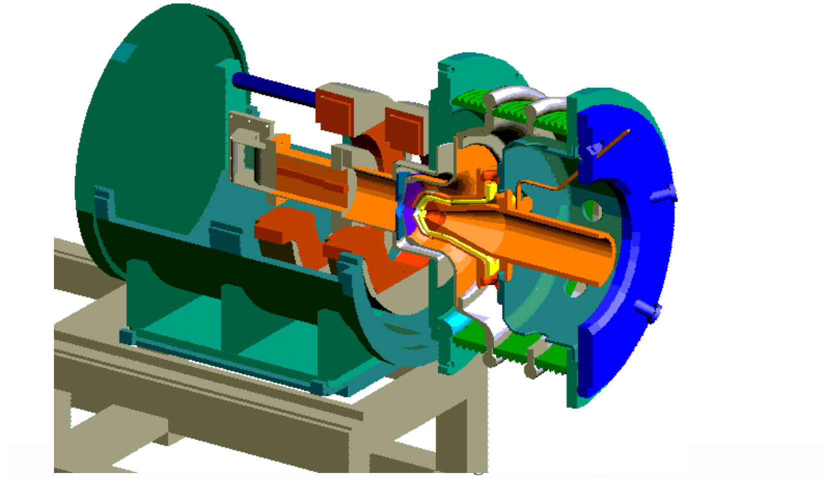
-> p-Linac, SIS100, HEBT, pbar, CR, HESR

-> Super-SFRS status (M. Winkler *et al.*)

p-Linac (Proton Source, LEBT)

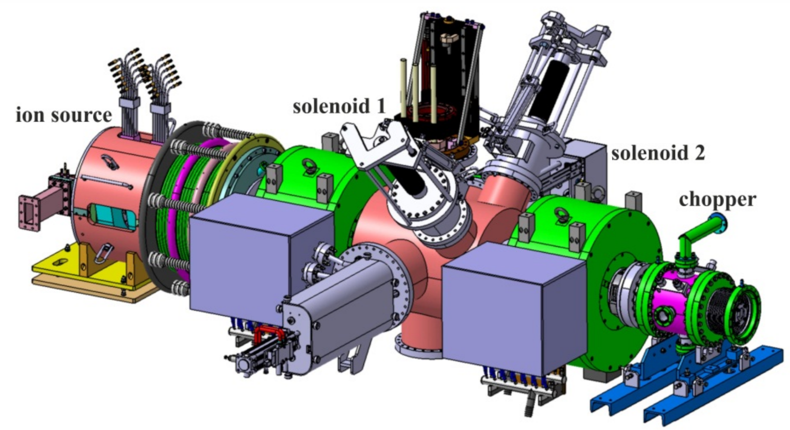


Sections	Contributors
p-Source and LEBT	CEA-DSM-IRFU
RFQ	IAP Frankfurt
CH Prototype	IAP Frankfurt
CH-DTL Structures	IAP Frankfurt + CNRS-IN2P3-CENBG
Beam Diagnostics (BPM)	CEA-DSM-IRFU
Magnets	CEA-DSM-IRFU
Power Converters	GANIL
RF test bench	CNRS-IN2P3-IPN Orsay
RF power sources	CNRS-IN2P3-IPN Orsay
Building	FAIR S&B + ion42 + Drees+Sommer



Source & LEBT

- ✓ 2.45 GHz ECR proton source of SILHI (Source of Light Ions with High Intensities) type, 95 keV, 100 mA, 5 electrodes extraction system, 4 Hz, 200 µs pulse length
- ✓ Short magnetic LEBT, comprising two solenoids (260 mT) and a beam chopper (36 µs) in front of the RFQ
- ✓ Compact diagnostic chamber with Allison scanner (emittance), SEM-Grid (profile), beam stopper, Wien filter (mass separator), transformer (beam current)

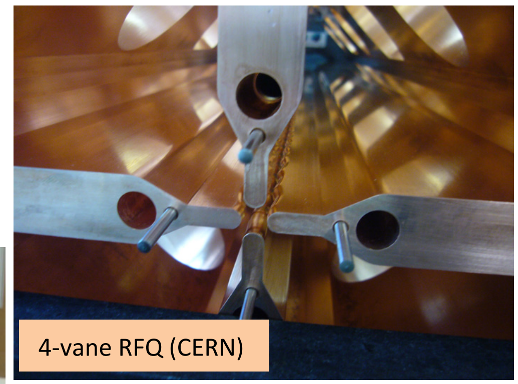


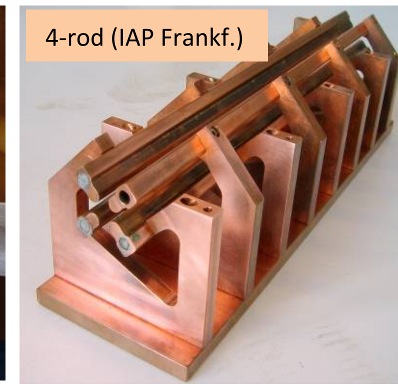
p-Linac (RFQ)

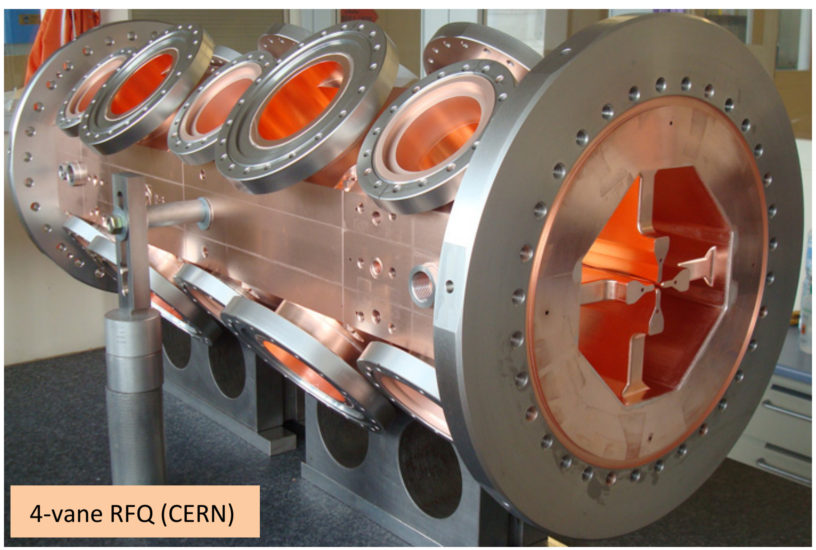
RFQ	Review, 20./21. Nov.'13
Cavity type	4-rod or 4-vane
Output energy	3.0 MeV
Output current(max.)	≥ 90 mA
Output emittance transv.	≤ 2.0 mm mrad
Output emittance longit.	≤ 930 keV deg
Cavity Q_0-value	2500 - 5000
Total RF-power (peak)	≤ 1.0 MW
Electric field strength	≤ 36.6 MV/m = 2.0 E_{kp}
Mean aperture radius	≤ 3.9 mm
Mechanical length	3.2 m

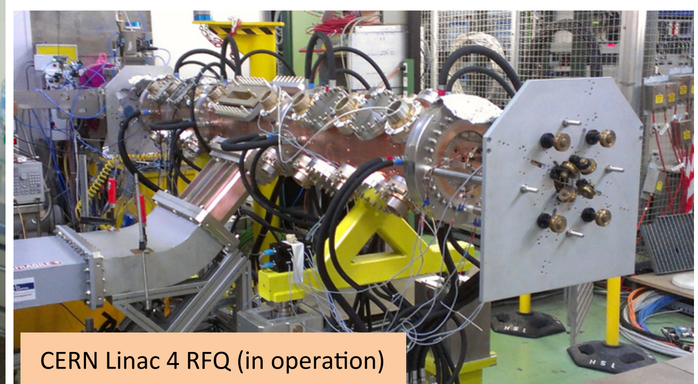
RFQ review results

- CERN offer to help with a 4-vane type cavity
- IAP Frankfurt to demonstrate the same performance with a 4-rod type cavity
- Final decision by Sept. 2014 (FAIR-MAC)


4-vane RFQ (CERN)

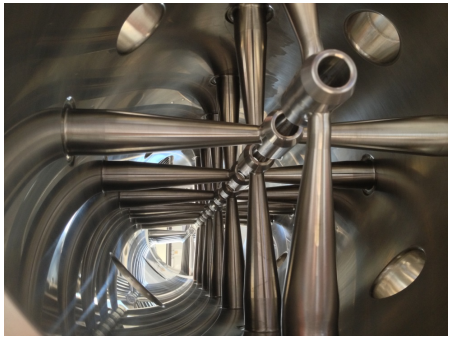

4-rod (IAP Frankf.)

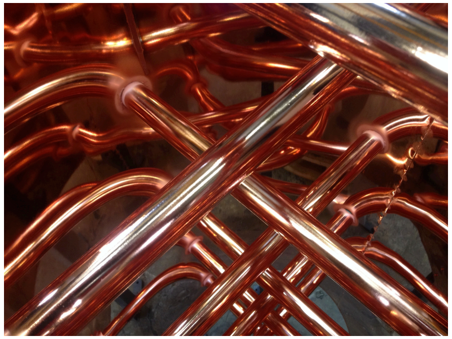

4-vane RFQ (CERN)

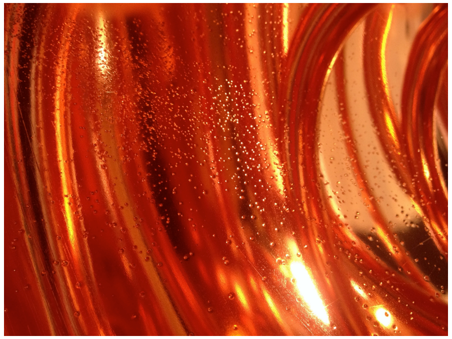

CERN Linac 4 RFQ (in operation)

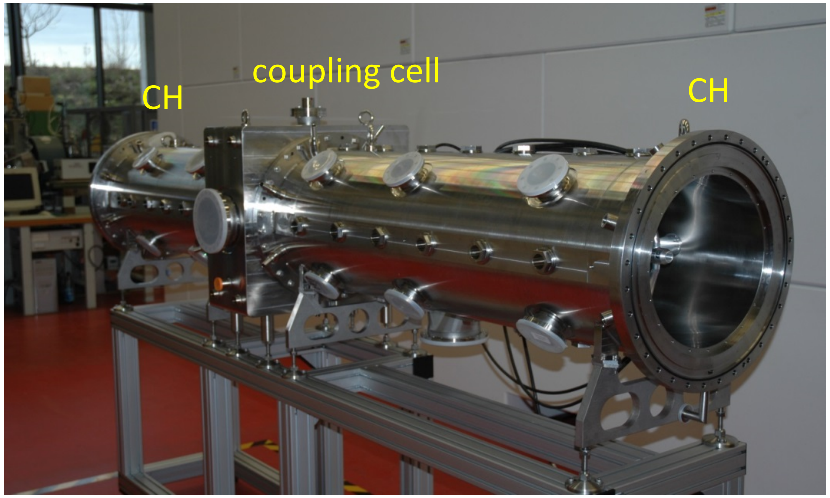
p-Linac (CH-Cavities) Crossbar H-210 Mode

Drift Tube Linac	
RF-cavities	6 [3 coupled (CCH)]
Cavity type	Crossed-bar H-cavity (CH)
Output energy	70.395 MeV
Max. design output current	70 mA
Current at injection SIS18	35 mA
Cavity Q_0-value	13000 – 14000
Single resonator length	1.58 – 3.34 m
Number of gaps per cavity	20 – 32
Total RF-power per cavity	≤ 2.5 MW (peak)
Focusing scheme (long.)	KONUS [2]
Mechanical length	≈ 24 m



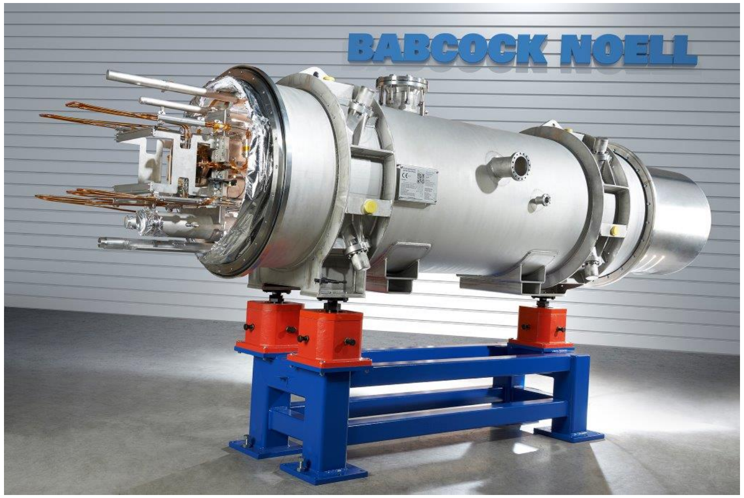






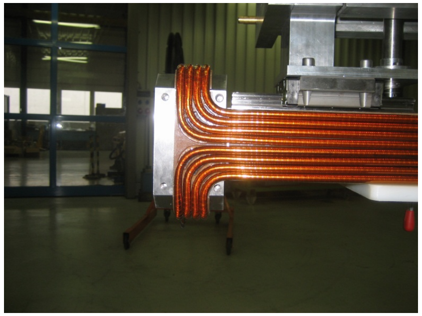
- Copper plating finished **before Easter 2014**
- Assembly (3 pieces), alignment, tuning and bead-pull-measurement until **end of August**
- Manufacturing, copper plating and mounting of the tuners until **mid of Septembe**r
- RF measurement until **end of September**
- Integration into test bench **during October**
- Start high power RF tests in **November 2014** (optimistic)

SIS100 (sc. dipoles)



Pre-series and series of sc. dipoles

- ✓ 109 units required for SIS100
- ✓ Production by BNG (Germany) started
- ✓ Pre-series module delivered (3.6.2013)
- ✓ Warm testing completed (20.6.2013)
- ➢ Cold testing under preparation
  - First cool-down in Dec. 2013
  - Very ambitious FoS time line
- ➢ Green light for series production on 28.7.2014 (E. Fischer, MAC10)



Coil head of pre-series dipole magnet

✓ Power converter cabinets and HTS current-leads commissioned @ GSI

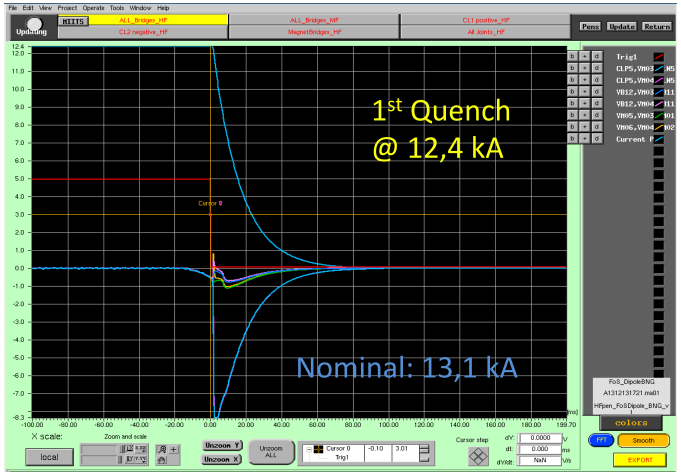
	specified	tested	
I_{max} (DC)	20 kA	17.2 kA	limitation: test load voltage drop
$(dI/dt)_{max}$	28 kA/s	29 kA/s	with HTS current lead (I_{max} = 12kA)

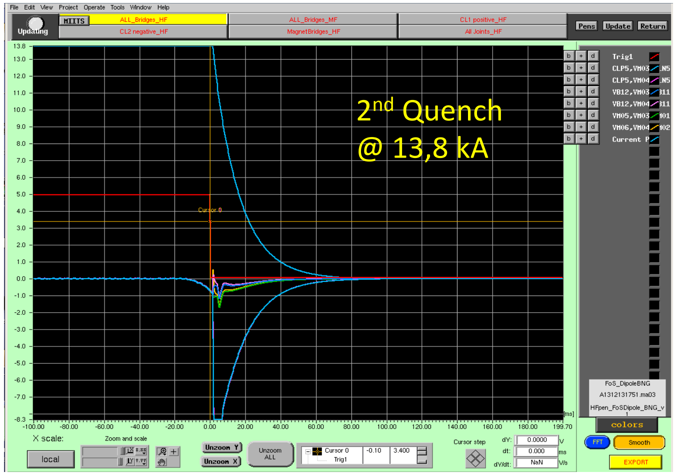
	specified	tested	
current			
I_{max} (DC)	14 kA	14 kA	
I_{max} (training)	17 kA	17 kA	75 A/s
$(dI/dt)_{max}$	28 kA/s	27 kA/s	I_{max} = 14kA
		29 kA/s	I_{max} = 12kA

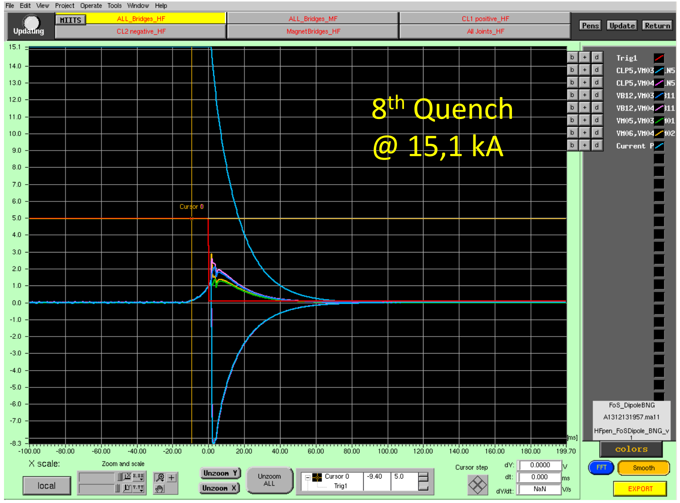
SIS100 (sc. dipoles)

First of Series Dipole @ 4.2 K

SAT 1 Run: Basic Security Tests, New Curve, Quench







First Quench on Fr. 13.12.2013

Quench behaviour -> clear understanding

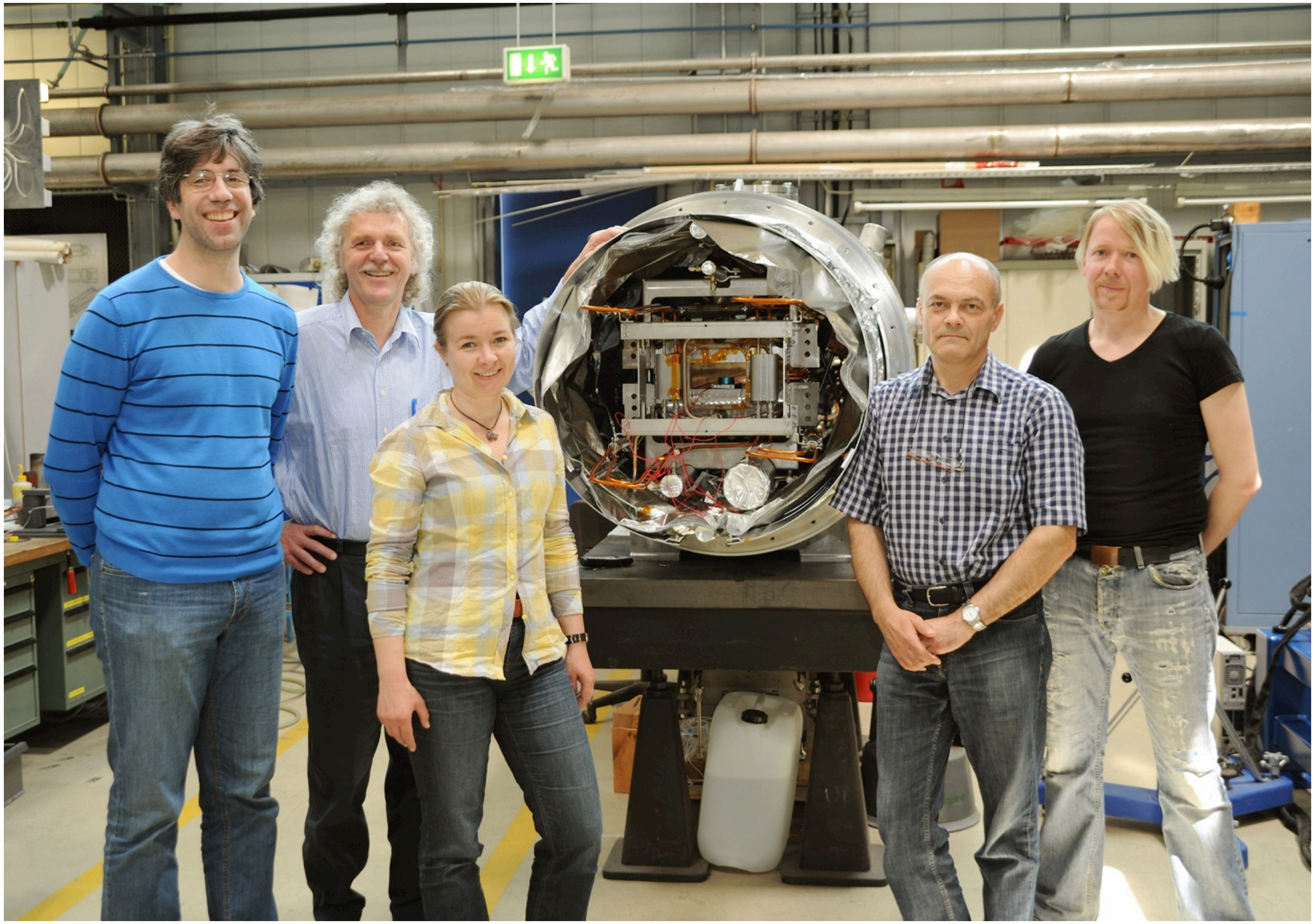
- Location: upper and lower half of the coil
- Reason: mechanical adjustment of the weak longitudinal single turn coil body on the yoke

✓ During the first high current tests on the SIS100 First of Series Dipole the nominal operation current was reached with 15 % margin (nominal 13.1 kA)

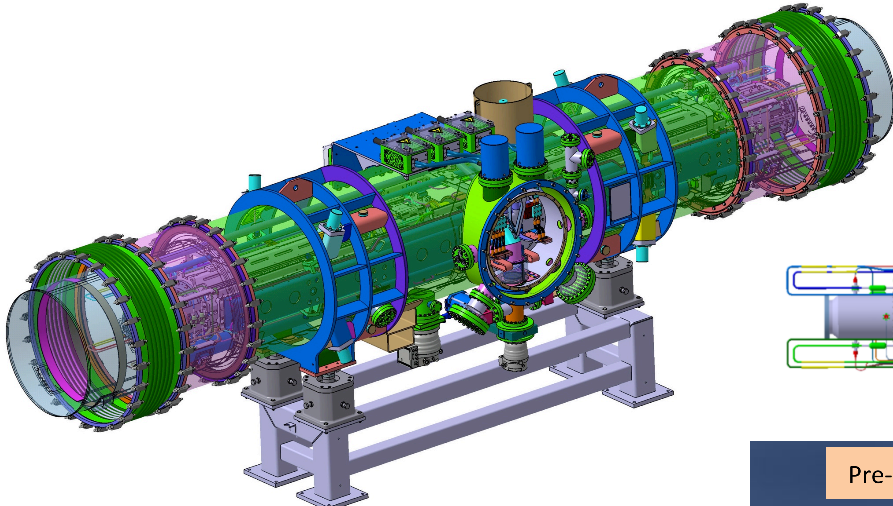
SIS100 (sc. dipoles)

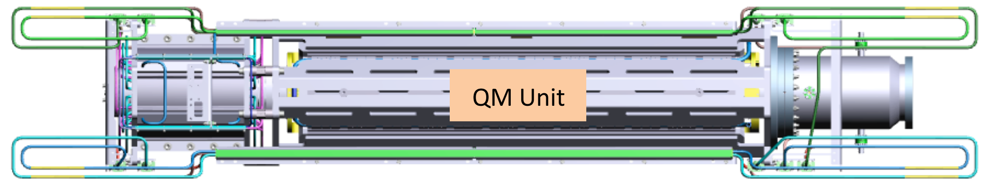
Congratulations to the GSI-Team

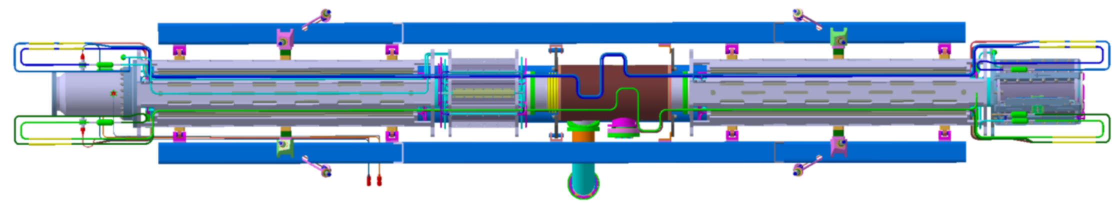
… but hard work continues

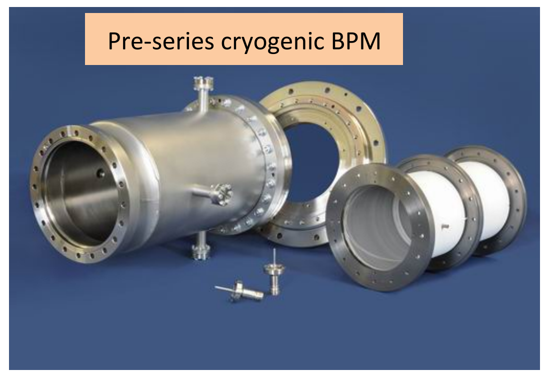


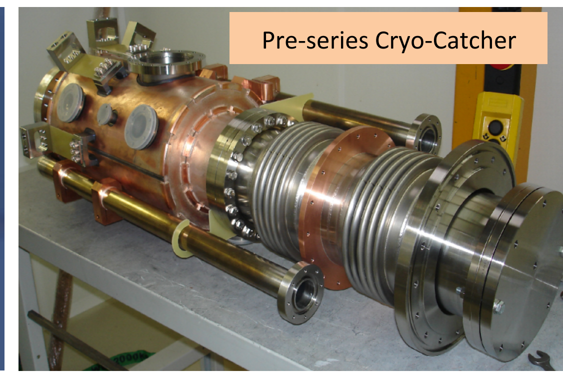
SIS100 s.c. QDM's – Collaboration with Dubna





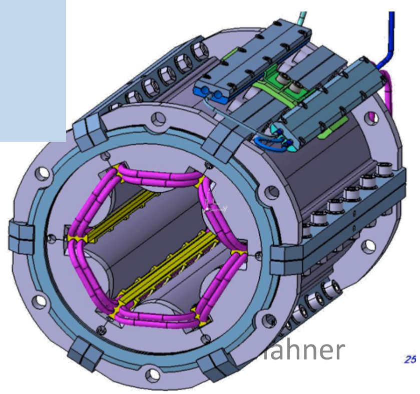


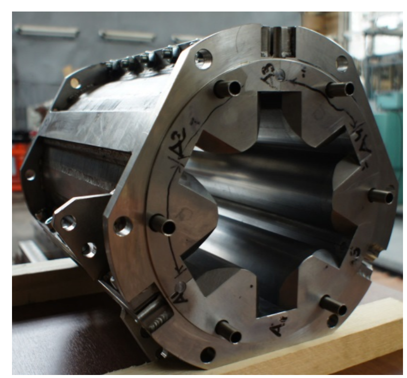


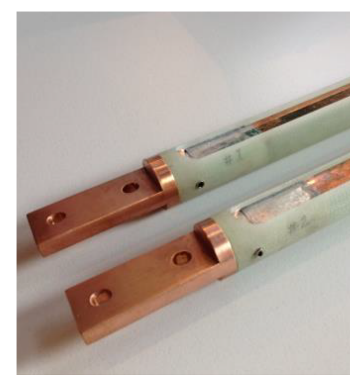


- ✓ 84 units required for SIS100.
- ✓ Engineering design of pre-series module completed by GSI.
- ✓ Negotiations for design service contract for overall cryogenic quadrupole modules completed.
- ➢ SIS100 QM units will be build by Dubna
- ➢ Cryo-collimator (German in-kind)
- ➢ Cryostat procured by GSI
- ➢ Integration into cryostat -> GSI

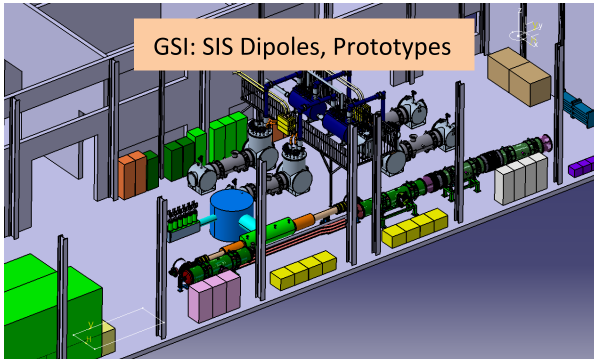
Yoke of SIS100 Chromaticity Sextupole magnet model (left), prototype yoke (middle), HTS current leads (right)







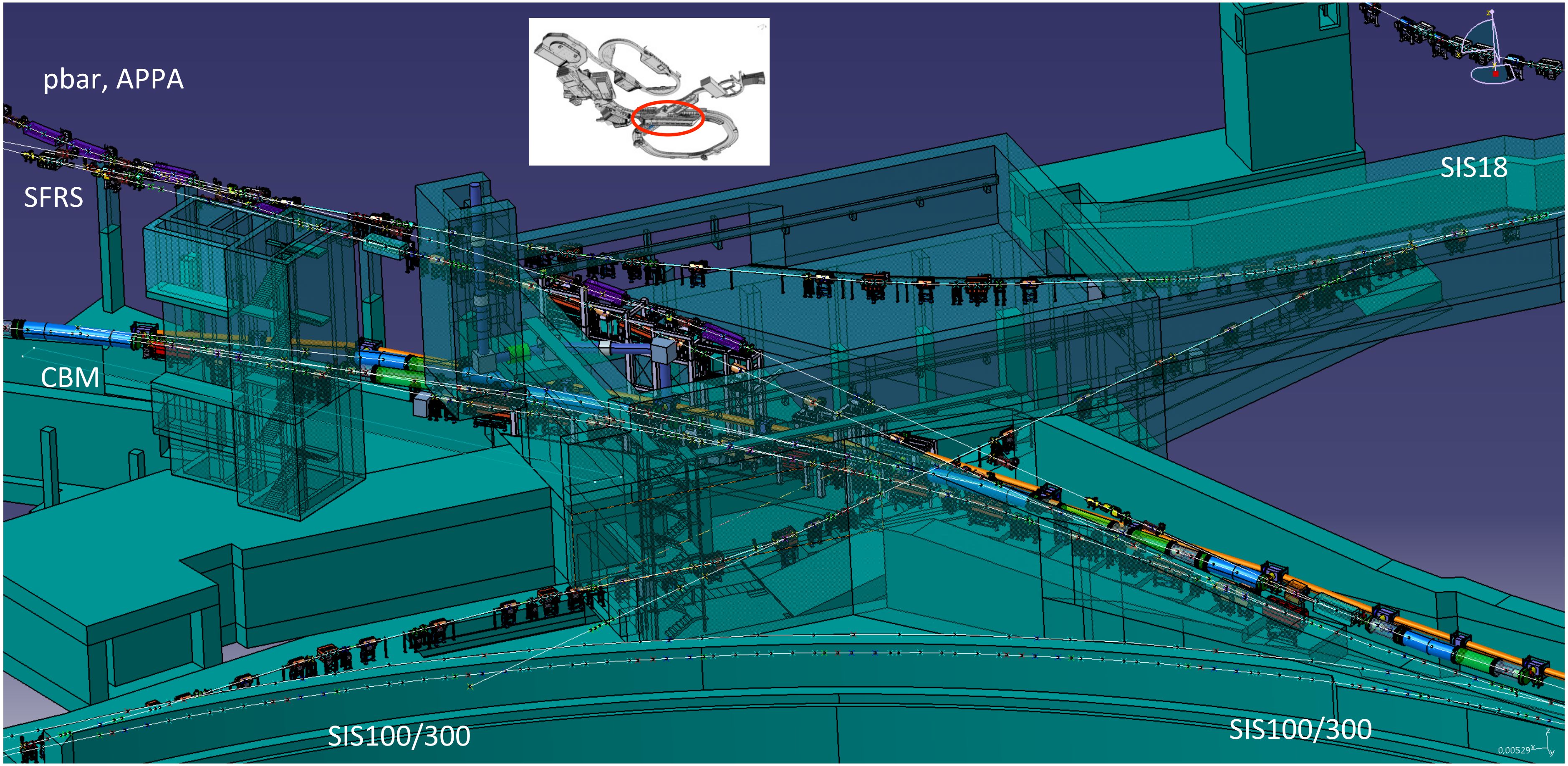
FAIR Magnet Testing Facilities @ CERN, Dubna, GSI



Preparation of Series Test Facility @ GSI

- 4 test benches, string test preparation in parallel; cryoplant and infrastructure ordered from Linde
- SH5 to be finished in spring 2014; start of testing planned for autumn 2014

HEBT (High Energy Beam Transfer)



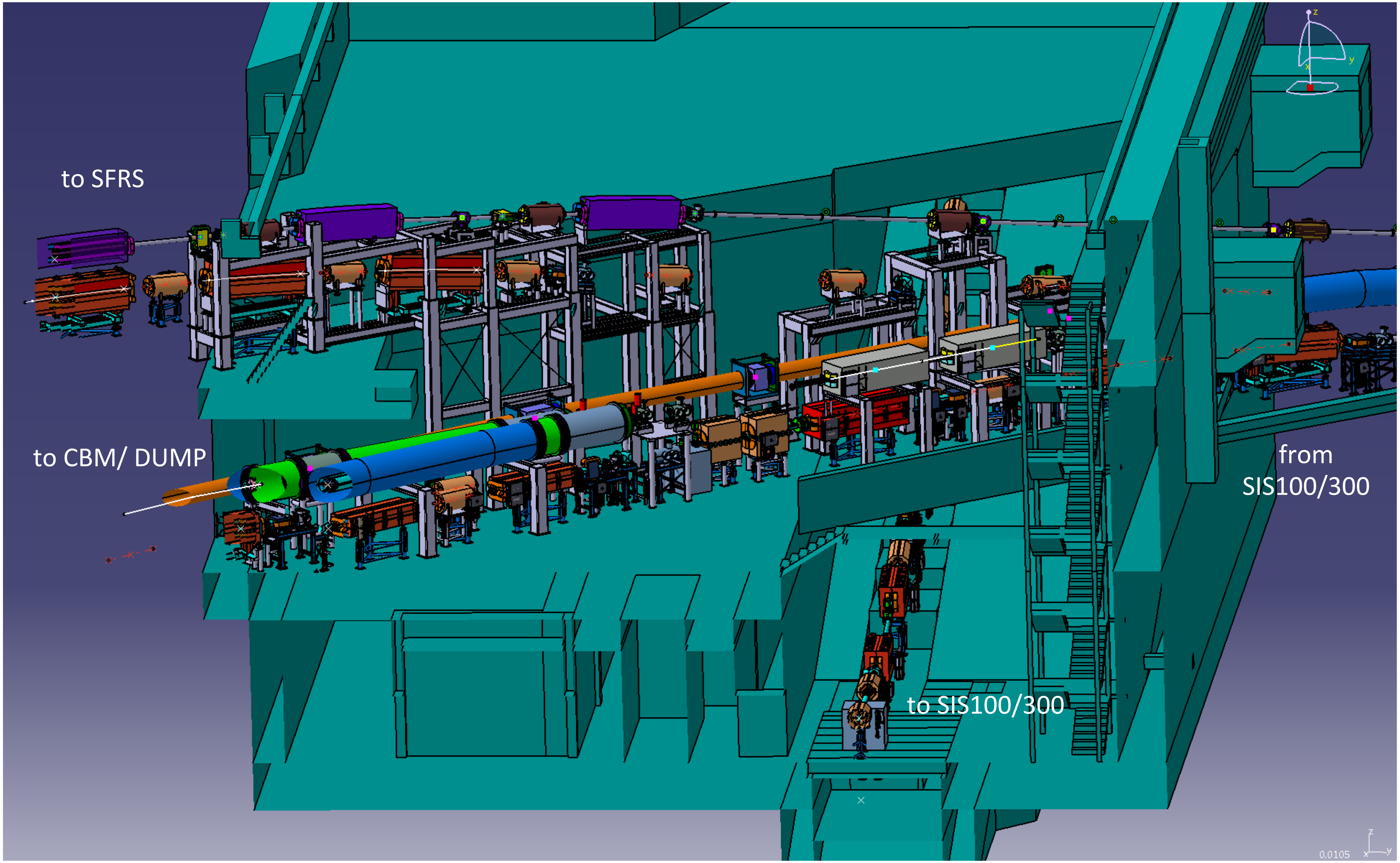
Batch 1 -> 51 dipoles, vacuum chambers

Batch2 -> 17 dipoles, 102 quadrupoles, 80 steering magnets, vacuum chambers

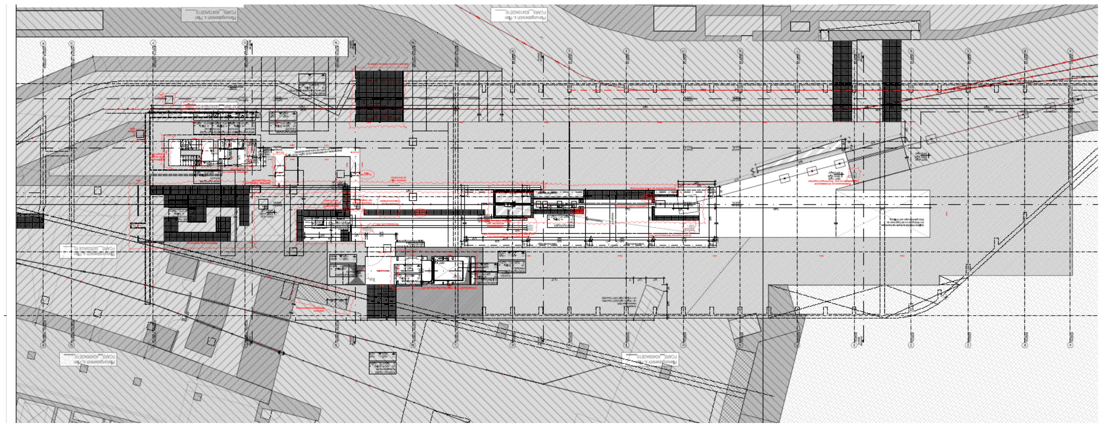
Batch3 -> 5 dipoles, 71 quadrupoles, 12 steering magnets, vacuum chambers

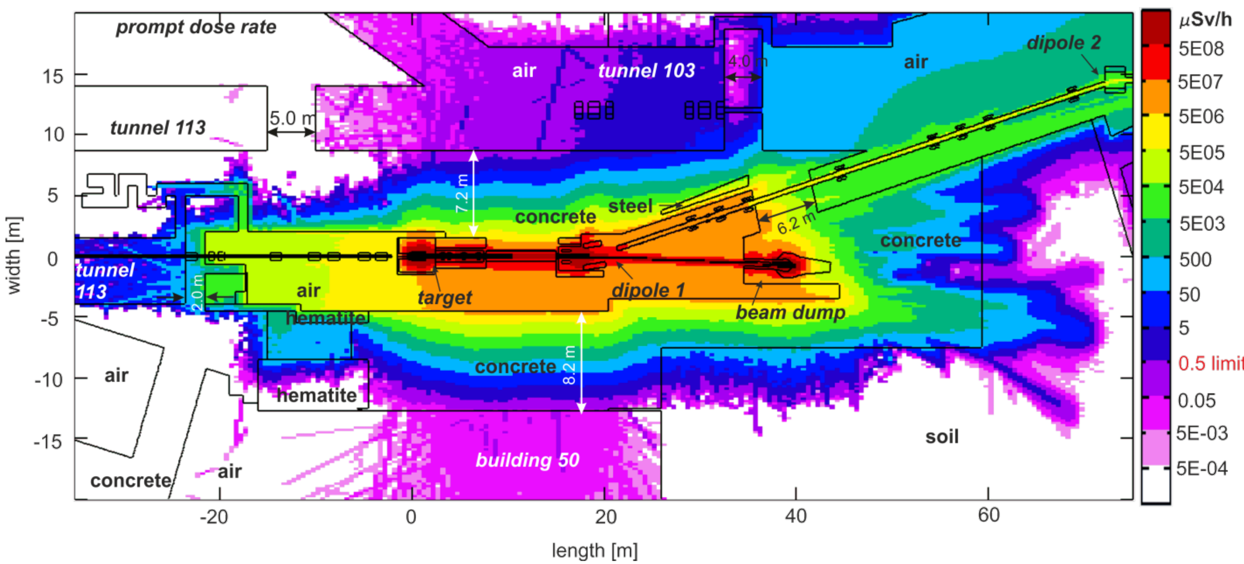
Suppliers -> BINP (magnets) and Efremov Institute (vacuum chambers)

HEBT (High Energy Beam Transfer)



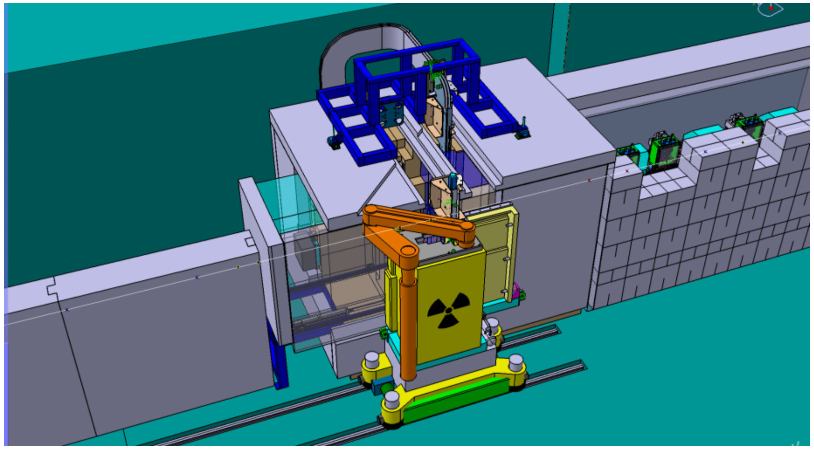
pbar Separator (Radiation Protection)



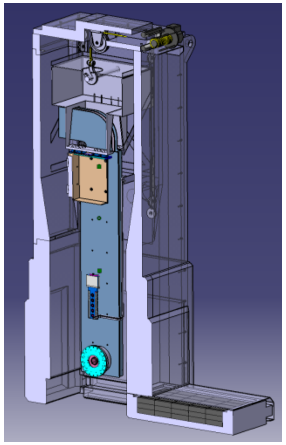


- ✓ FLUKA simulation of the radiation levels in the pbar-separator area are done
- ✓ Input of the newest data from:
  - ○ Civil construction including all ducts and shafts
  - ○ Beam parameters (5e12 p/s, 29 GeV) and magnetic fields of all components
- ✓ Consideration of a multitude of beam loss scenarios
- ✓ After implementation of the suggested changes in civil construction, radiation levels do not exceed the limits in the whole pbar separator area

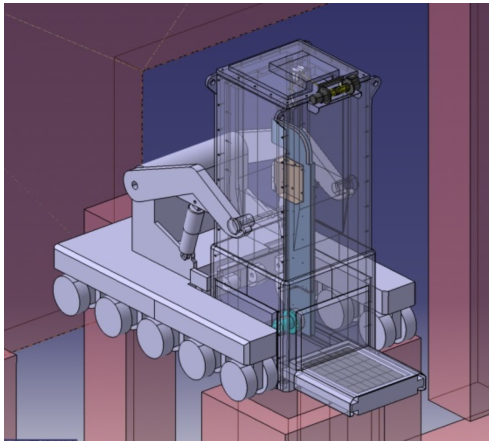
pbar Separator (Target)



Target station with transport container for remote target exchange



Shielding flask (m=30 t)...

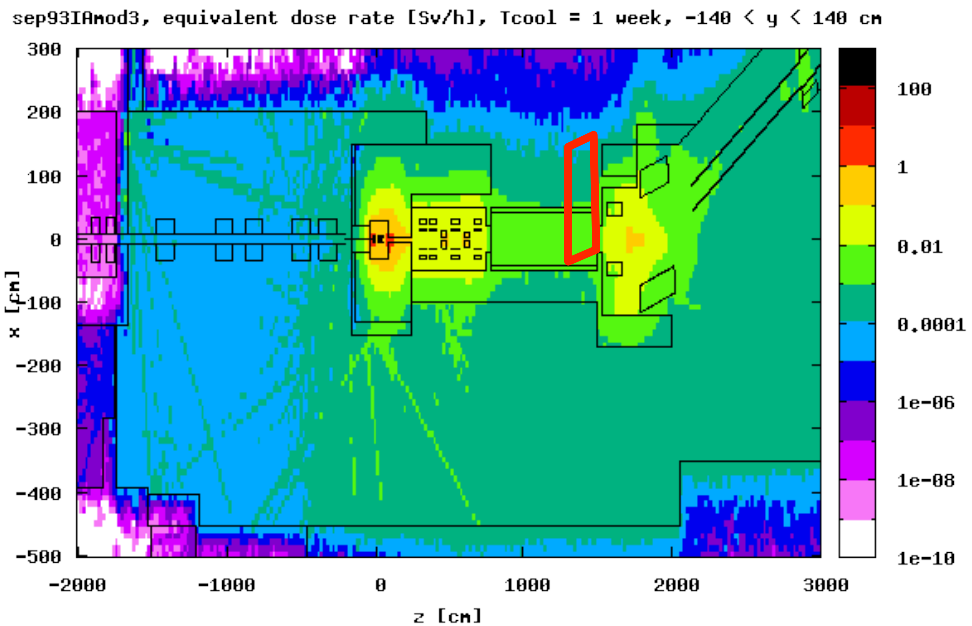


and dedicated transport vehicle.

Exchange and Disposal of Targets (10^{11}Bq)

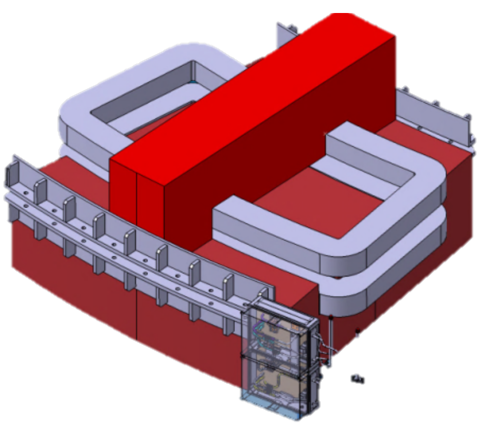
- ✓ Necessary adaptions (e.g. remote handling) for civil construction, **done**
- ✓ Development of a procedure for the exchange and disposal of highly activated components with a minimum radiation exposure for the personnel, **done**
- ✓ Conceptual design (including detailed FLUKA simulations) of a shielding flask and a vehicle for the transport of the components to the hot cell, **done**
- ➢ Initiation of an external study on the legal aspects during the application for the construction permit and for the operation license: to be started in **March 2014**

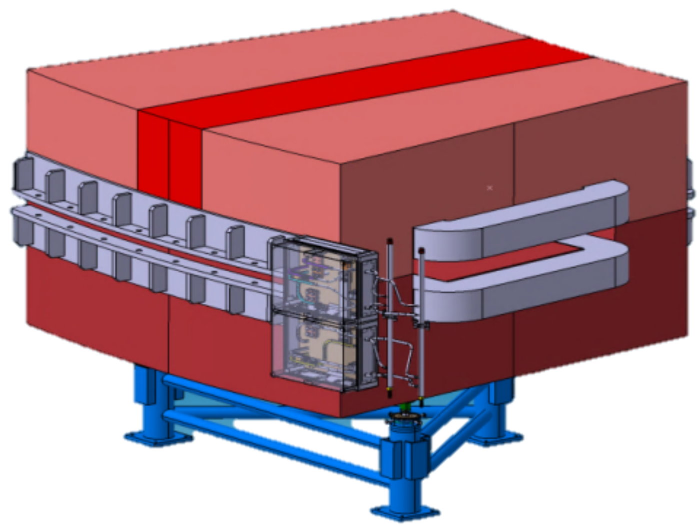
pbar Separator (1st dipole after target)



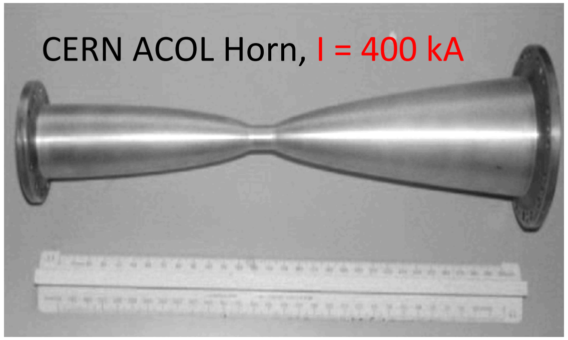
Remanent dose rate after 1 week of cool-down

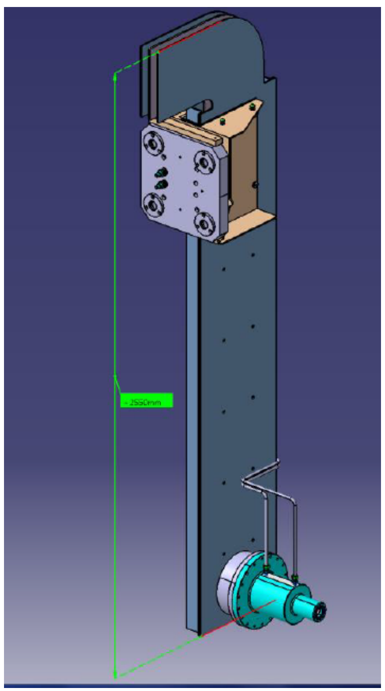
- Magnet without vacuum chamber
- Radiation hard coil (100 MGy) with polyimide insulation
- Induced activity too high for hands-on maintenance -> upper part of yoke divided into pieces of < 10 t, is needed for remote exchange of the coil with a 10 t crane

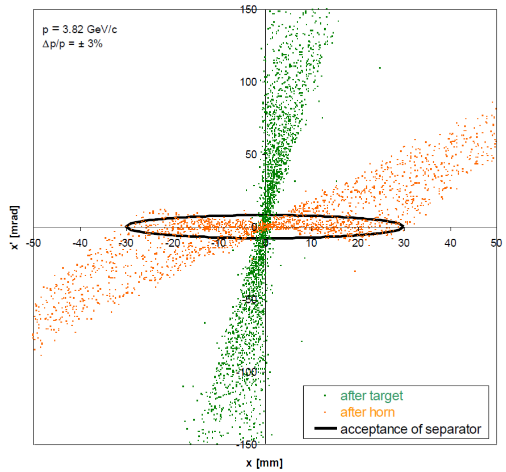


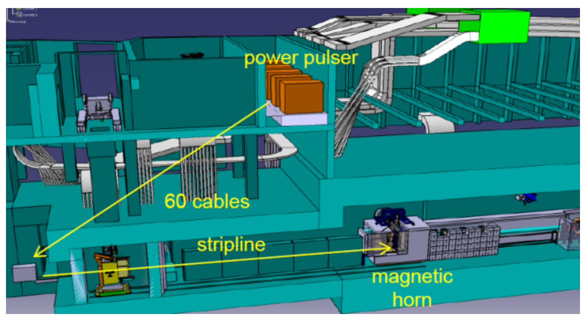


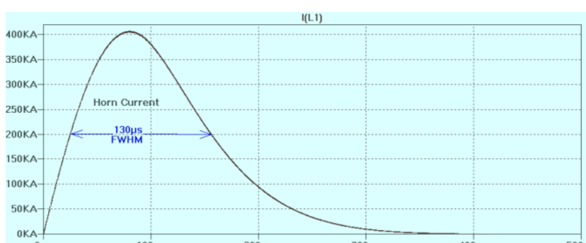
pbar Separator (Magnetic Horn System)











Conceptual design of a high power focusing system with a magnetic horn

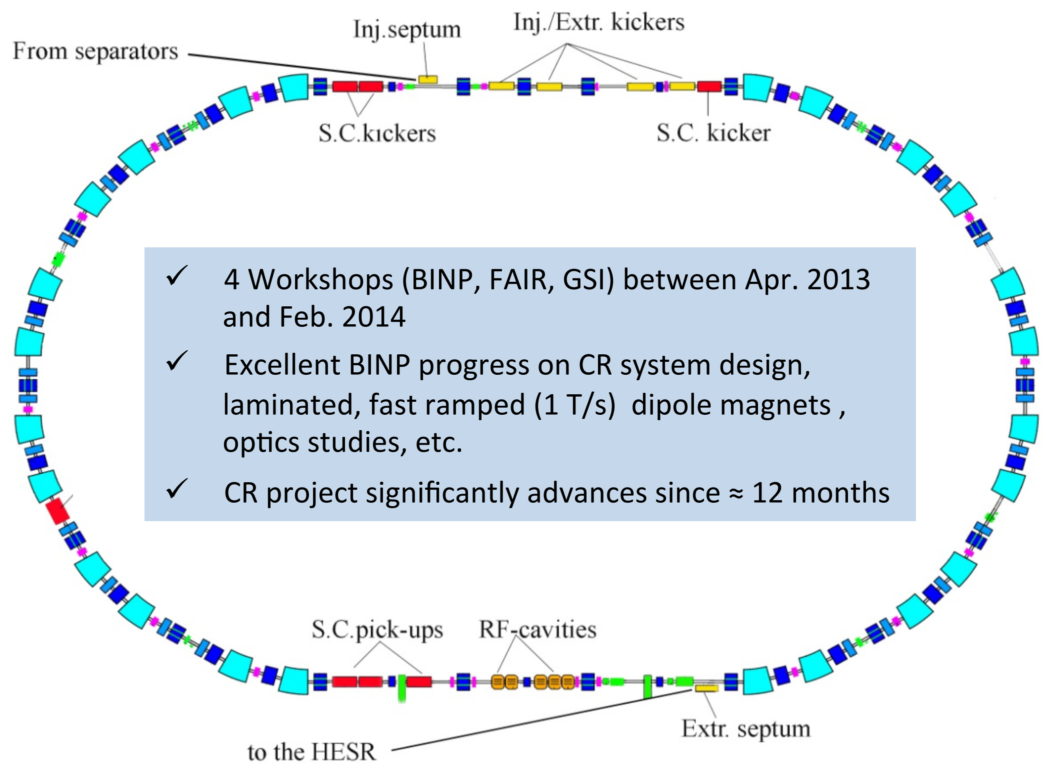
- ✓ Ion-optical calculations for the layout of the horn geometry, **done**
- ✓ Integration of the system (65 m total length) into the building, **done**, considering all radiation safety aspects
- ✓ LTSpice simulation of all electrical parameters of the system, **done**
- ✓ Conceptual design for the integration of the horn into the target station and for the exchange of the activated horn, **done**
- ✓ Conceptual design of a high power pulser with I = 400 000 A, **done**

Collector Ring
Transfer of CR Project Responsibility to Budker

- BINP, FAIR, and GSI are considering the entire CR machine, except the stochastic cooling and RF systems, as Russian contribution
- MoU signed during a first visit in Novosibirsk (Oct. 2013)
- Technical Addendum of MoU signed in Darmstadt (Nov. 2013)
- Updated TDR approved (Feb. 2014), next step in Apr. 2014 (FAIR IKRB)

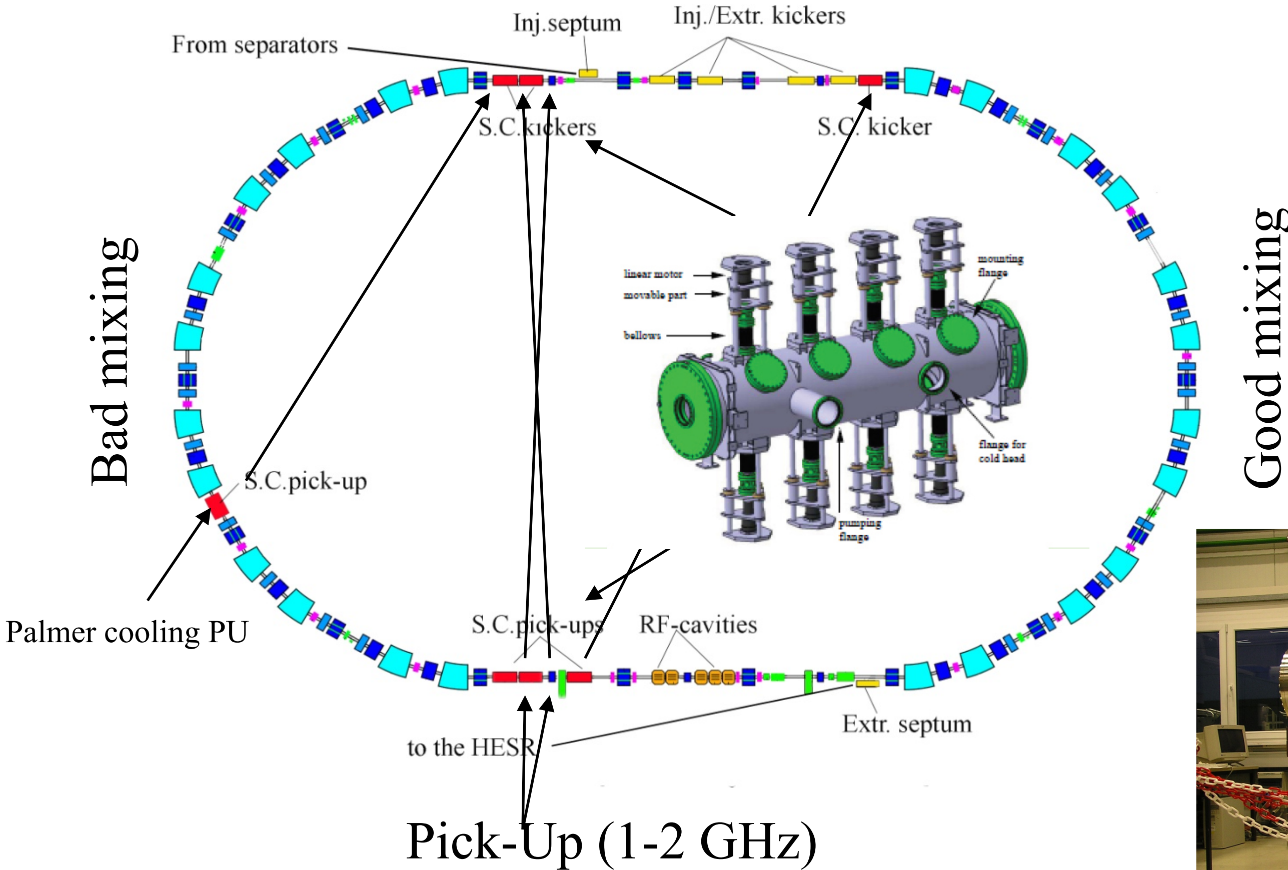

Memorandum of Understanding (MoU)
between
Budker Institute of Nuclear Physics (BINP, Novosibirsk)
and
Gesellschaft für Schwerionenforschung mbH (GSI, Darmstadt)
and
Facility of Antiproton and Ion Research in Europe GmbH (FAIR, Darmstadt)
on the
Realization of the FAIR Collector Ring (CR)

Prof. Dr. A. Skrinsky for BINP	Prof. Dr. Y. Shatunov for BINP
Prof. Dr. O. Kester for GSI	21.10.2013 Dr. O. Dolinskyy for GSI
Prof. Dr. B. Sharkov for FAIR	E. Mahner, Novosibirsk 21.10.2013 Dr. E. Mahner for FAIR



- ✓ 4 Workshops (BINP, FAIR, GSI) between Apr. 2013 and Feb. 2014
- ✓ Excellent BINP progress on CR system design, laminated, fast ramped (1 T/s) dipole magnets , optics studies, etc.
- ✓ CR project significantly advances since ≈ 12 months

CR (Stochastic Cooling)



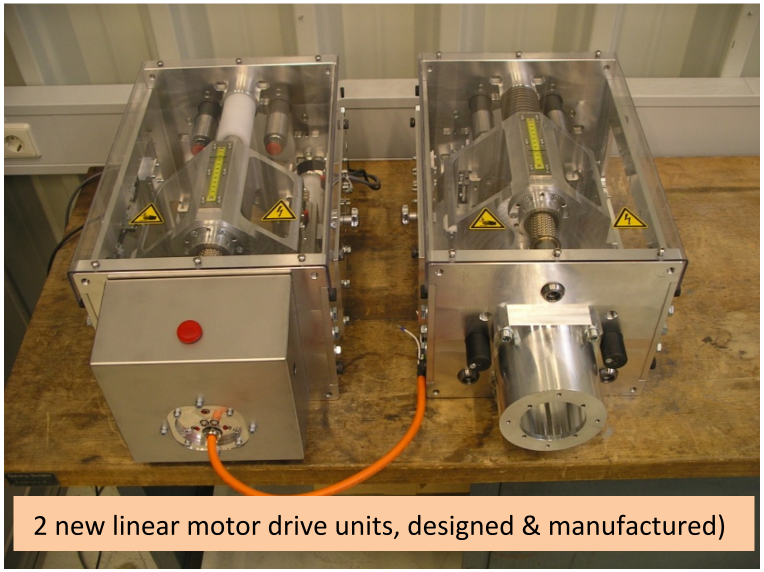
Equipment needed
2 - Pickup tanks (1-2 GHz)
2 - Kicker tanks (1-2 GHz)
1 - Palmer Pickup tanks
1 - Pickup tank (2-4 GHz)
1 - Kicker tank (2-4 GHz)

C. Dimopoulou: “The CR is designed to have required lattice parameters for both antiproton and RIB beam cooling. Ring optic and positions of PU and KI are optimized to have required phase advances and mixing properties for all pairs of PU-KI.”

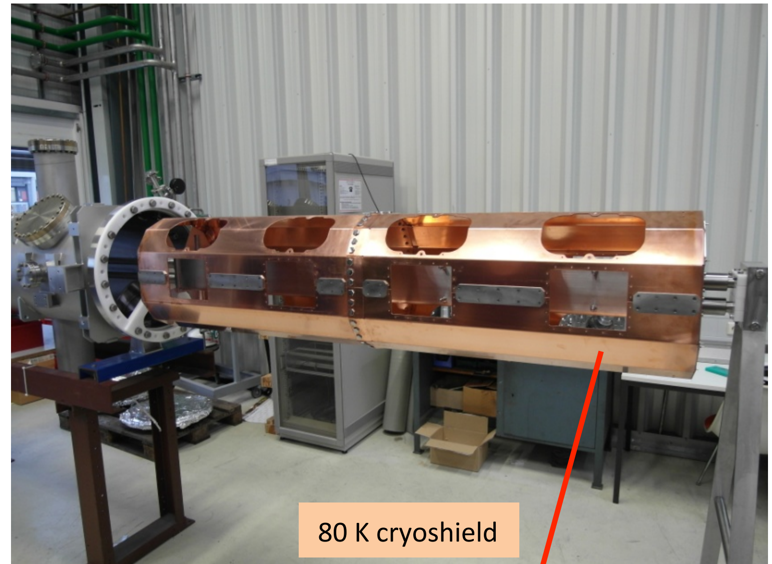
CR (Stochastic Cooling)

Courtesy C. Dimopoulou
Status 10/2013

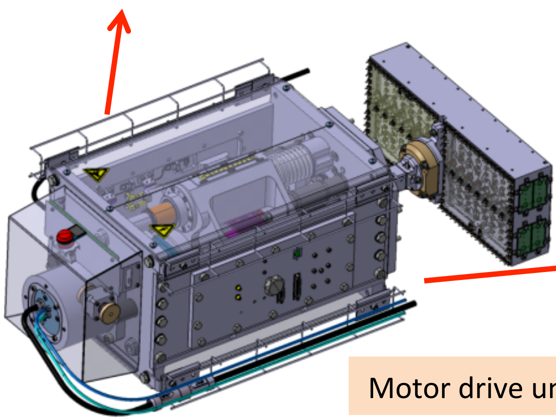
Preparation of mounting pieces and test-assembly of the copper cryo-shield in the prototype pick-up tank in July 2013.



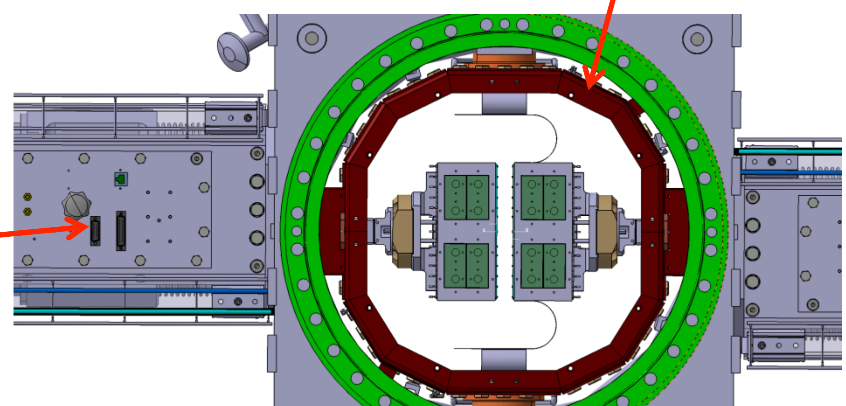
2 new linear motor drive units, designed & manufactured)



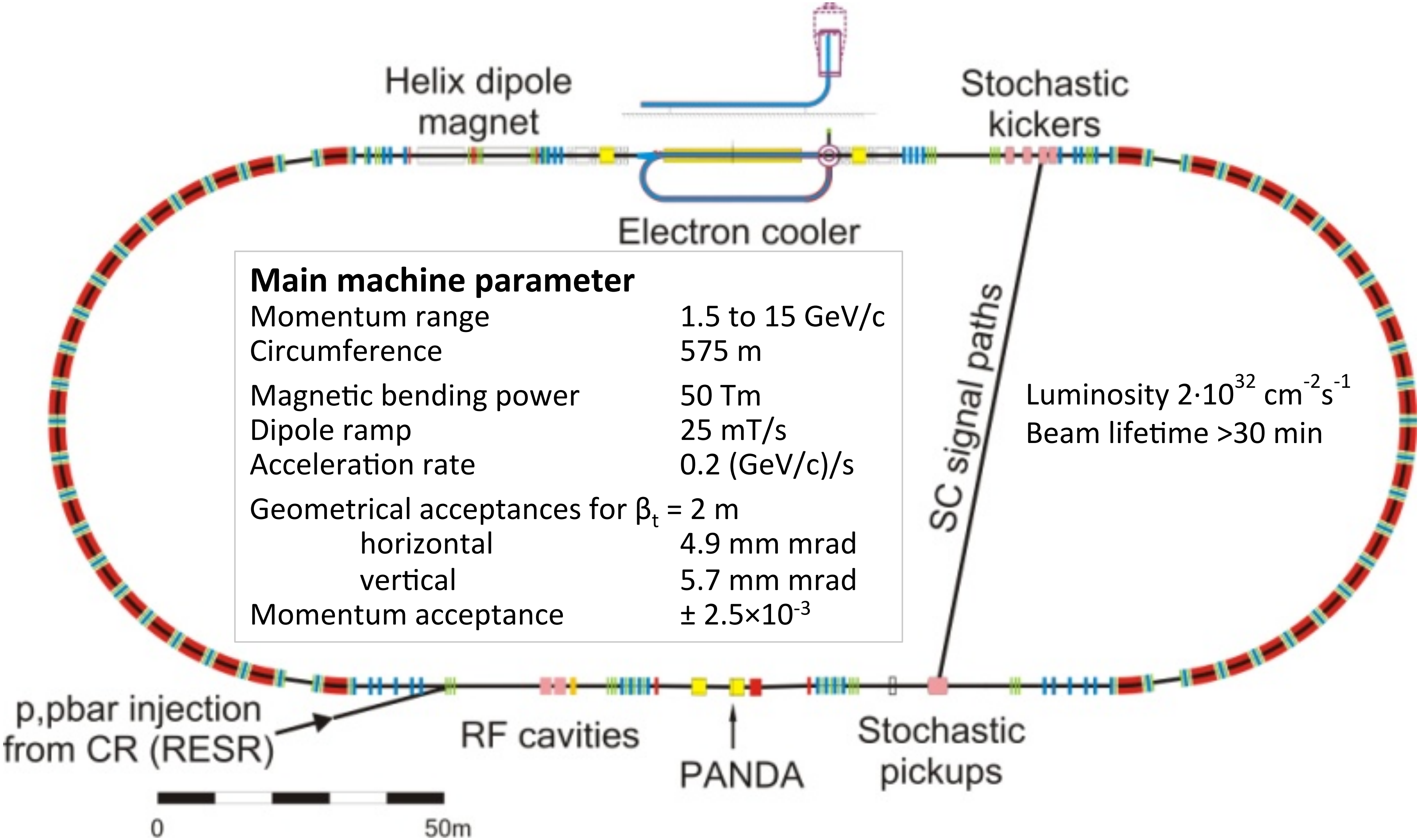
80 K cryoshield



Motor drive unit



HESR (Layout)

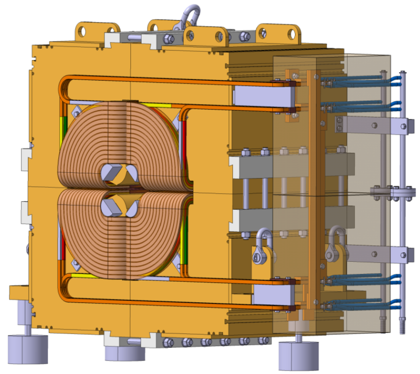


Main machine parameter

Momentum range	1.5 to 15 GeV/c
Circumference	575 m
Magnetic bending power	50 Tm
Dipole ramp	25 mT/s
Acceleration rate	0.2 (GeV/c)/s
Geometrical acceptances for β_t = 2 m	
horizontal	4.9 mm mrad
vertical	5.7 mm mrad
Momentum acceptance	$\pm 2.5\times10^{-3}$

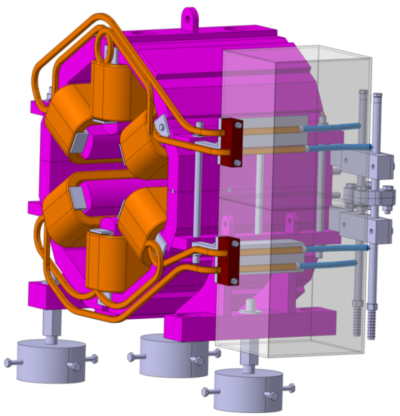
Luminosity $2\cdot10^{32}$ $cm^{-2}s^{-1}$
Beam lifetime >30 min

HESR (Magnets)



Quadrupoles

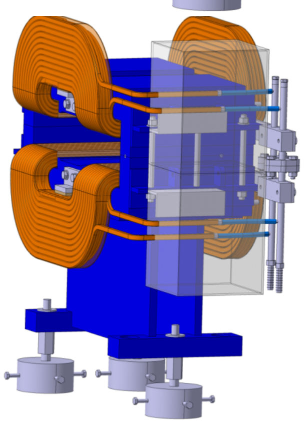
Number	84
Magnetic length	0.6 m
Iron length (arc)	0.58 m
Max gradient	20 T/m
Aperture	100 mm



Sextupoles

Number	40 in arcs
	12 in straights
Magnetic length	0.3 m
Max d^2B/dx^2	42.5 T/m^2
Aperture	135 mm

allow insertion of BMPs



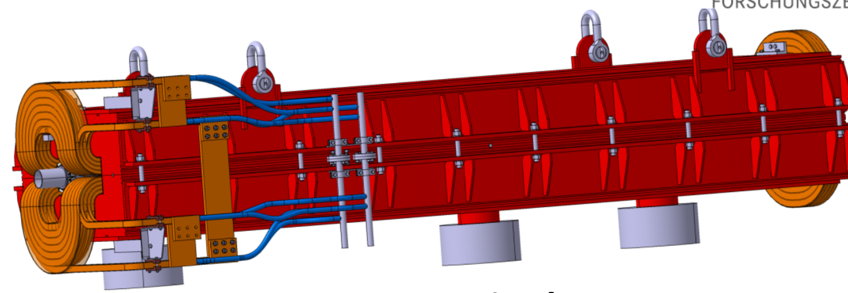
Dipole Correctors

Number	24 in arcs
	12 in straights
Magnetic length	0.3 m

Max deflection angle:

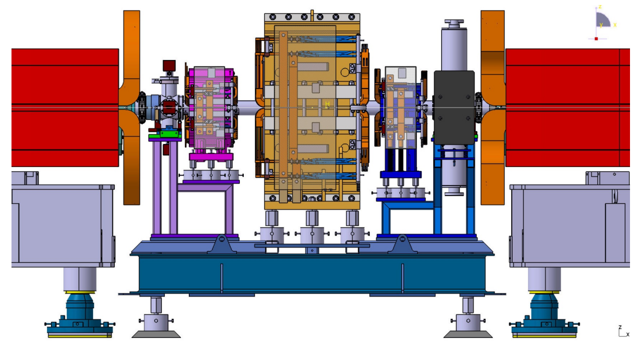
2 mrad for orbit correction and local bumps

Aperture	100 mm



Dipoles

Number	44
Magnetic length	4.2 m
Deflection angle	8.182°
Max B-field	1.7 T
Min B-field	0.17 T
Aperture	100 mm

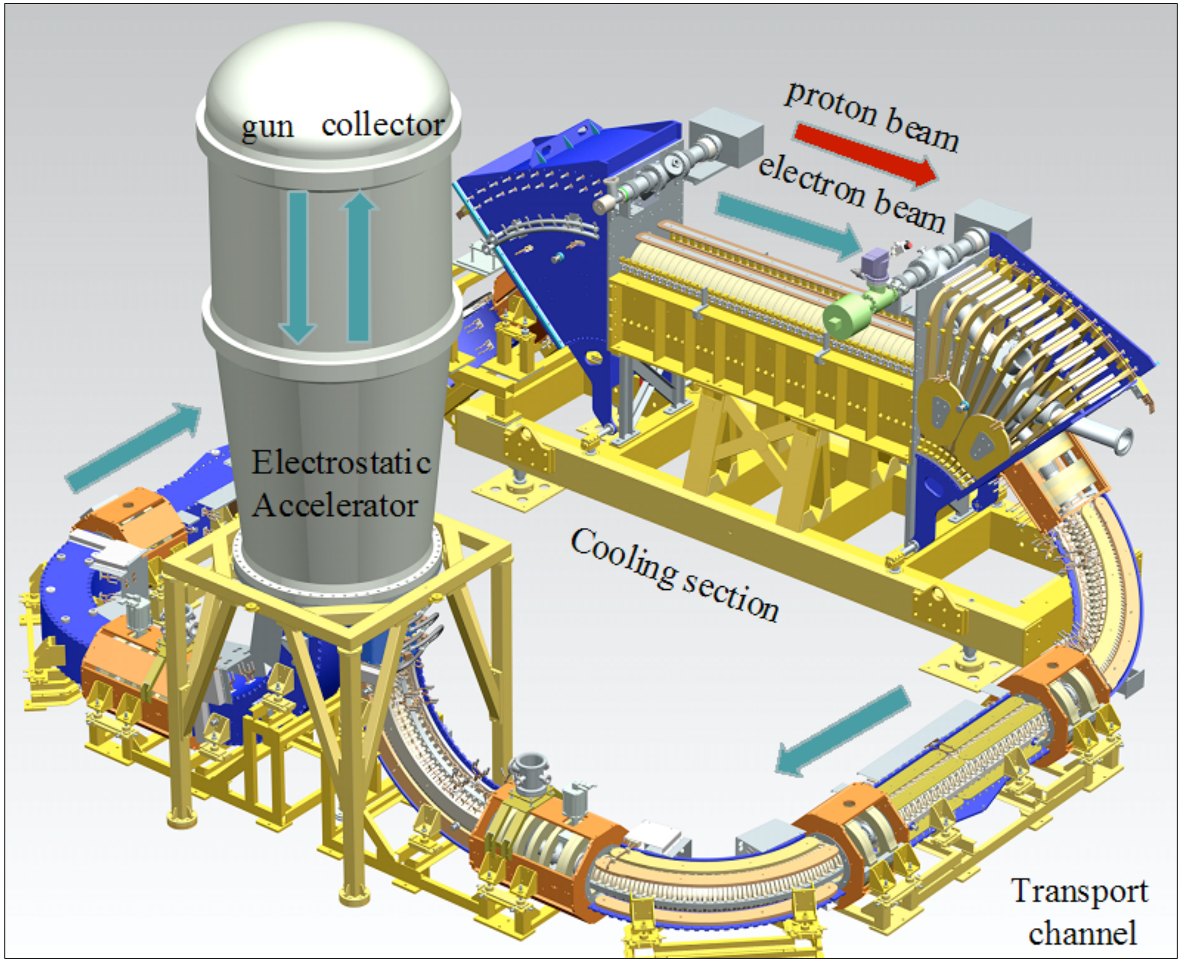


Straight section between HESR dipoles

- ✓ In-Kind contract between FAIR and Jülich signed in 2012
- ✓ Ordered components: dipoles, quadrupoles + power converters, RF components for stoch. cooling and acceleration cavity, injection kicker
- ✓ All other components are specified and will be ordered according to Jülich's time schedule and spending profile

HESR 2 MeV electron cooler installed and commissioned at COSY

JÜLICH FORSCHUNGSZENTRUM



Electron Cooler build and commissioned by BINP Novosibirsk

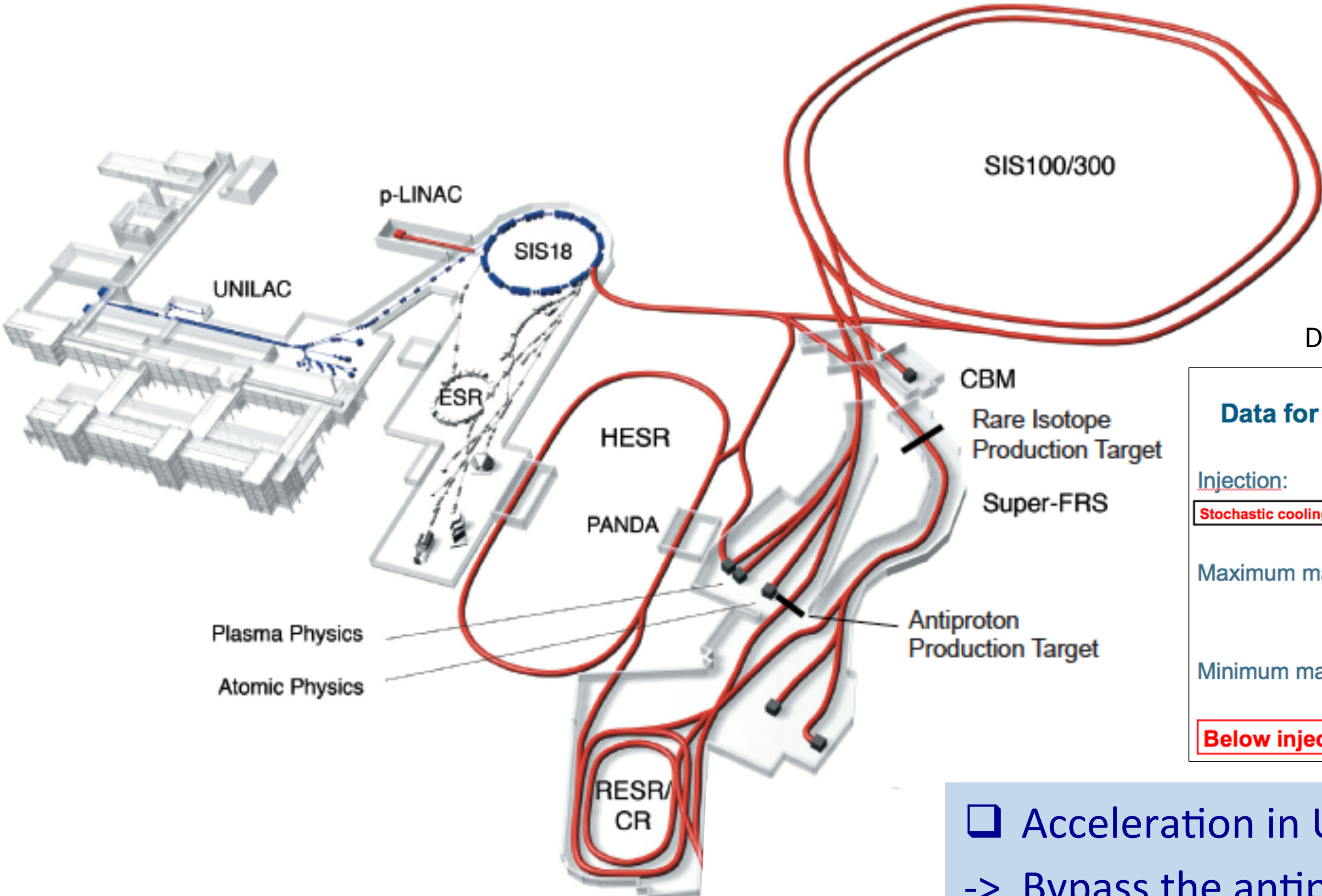
Parameter

Energy Range: 0.025 - 2 MeV
Maximum Electron Current: 1-3 A
Cathode Diameter: 30 mm
Cooling section length: 2.69 m
Toroid Radius: 1.00 m
Magnetic field in the cooling section: 0.5 ... 2 kG
Vacuum at Cooler: 10^{-9} ... 10^{-10} mbar
Available Overall Length: 6.39 m

First cooling on 17.10.2013
Cooling of 645 MeV/c protons
109 keV electron energy
Magnetic field: 0.5 T
Electron current 250 mA
Protection gas vessel filled with 3 bar Nitrogen

Courtesy D. Prasuhn (MAC Nov. 2013)

Possible ways for beams into the HESR (MSV)



D. Prasuhn (MAC Nov. 2013)

JÜLICH

Data for Heavy Ions ($^{238}U^{92+}$)

Injection:	B*ρ=12 Tm (740 MeV/u)
Stochastic cooling possible at injection	β = 0.83
Maximum magn. rigidity	B*ρ=50 Tm (5 GeV/u)
	β =0.98
Minimum magn. rigidity	B*ρ= 5 Tm (170 MeV/u)
	β =0.53

Below injection only electron cooling is available

- ❑ CR and HESR commissioning with protons
- -> Interesting option in case of SIS100 challenges
- -> Chain: p-Linac, SIS18, CR, HESR

- ❑ Acceleration in UNILAC and SIS18
- -> Bypass the antiproton target
- -> Collection, pre-cooling in the CR
- -> Ion transfer with 12 Tm to the HESR
- -> Storage, acceleration, cooling in HESR

FAIR Accelerator Complex
Preparation & Start-up-Scenarios

FAIR Accelerator Preparation

- UNILAC, p-LINAC, and SIS 18 must be prepared for 2018 to deliver nominal FAIR beams. Similar to what was done over many years with great care for the CERN LHC injector chain: LINAC 2, PSB, PS, SPS (protons); LINAC 3, LEIR, PS, SPS (ions)
- Be prepared to deliver ions and protons to FAIR
- Reliable and stable beam operation will be essential for all machines and experiments
- Dedicated committees would strengthen collaborations & interfaces

FAIR Start-up Scenarios

- Essential for planning, fabrication, installation, commissioning of all accelerators and transfer lines. Holds identically for all experiments
- Civil construction is presently the lead process. FAIR accelerator complex pushed as much as possible, big steps forward achieved in 2013, momentum increase needed!
- Shall prepare NOW first-beam scenarios and FAIR day-one experiments (6 months)
- First proton and/or heavy ion beams must be and are under consideration also without a timely availability of SIS100, which comprises the largest technological challenges
- Experiments are supported but have to remain flexible; get tuned with the machine people!