Challenges of the FAIR Vacuum System

A. Kraemer
(GSI Helmholtzzentrum für Schwerionenforschung GmbH)

IPAC 2012

22nd of May 2012

FAIR – Facility for Antiproton and Ion Research Future Project at GSI

International Project: 1200M€, 65% Germany, 10% State of Hesse, 25% Int. partners

Shareholder in FAIR GmbH: Germany, Russia, India, Finland, Sweden, Romania

Signed the Convention: Poland, France, Slovenia

Signed EoI: Austria, China, Greece, Italy, Slovakia, Spain, UK, Saudi Arabia

FAIR – Facility for Antiproton and Ion Research
Future Project at GSI

International Project: 1200M€, 65% Germany, 10% State of Hesse, 25% Int. partners

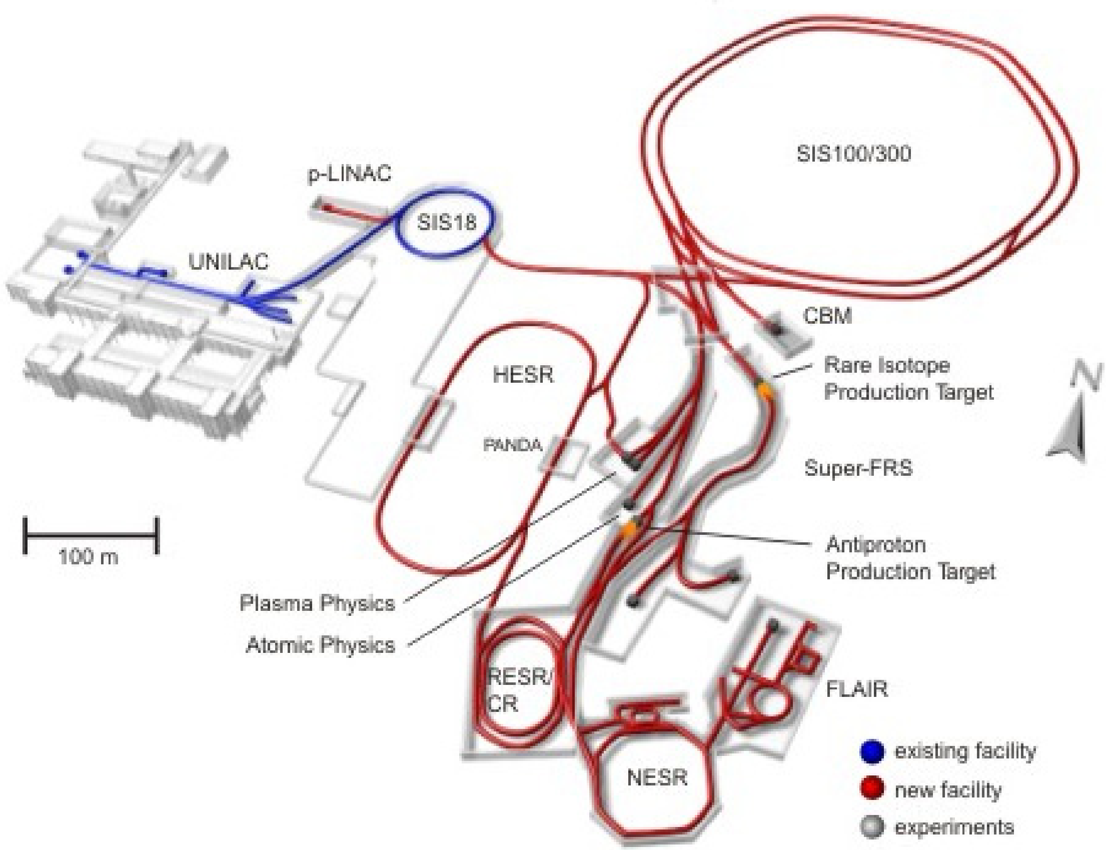
Shareholder in FAIR GmbH: Germany, Russia, India, Finland, Sweden, Romania

Signed the Convention: Poland, France, Slovenia

- Project start – 2007
- Founding of FAIR GmbH – 4th of October 2010
- Application for Building and Operating Permit – May 2011
- Site Preparation – December 2011
- Pouring first concrete – end 2012
- Hardware installation – late 2016 - 2018
- First stage ready for experiments – 2017/2018
- Module 0-3 completed – 2018

Signed EoI: Austria, China, Greece, Italy, Slovakia, Spain, UK, Saudi Arabia

Future Project at GSI
FAIR – Facility for Antiproton and Ion Research



Primary Beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 10-100 over present in intensity
- $2(4)\times10^{13}$/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
  (up to 90 GeV protons)

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

- Radioactive beams
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

Physics at FAIR - Five Scientific Pillars

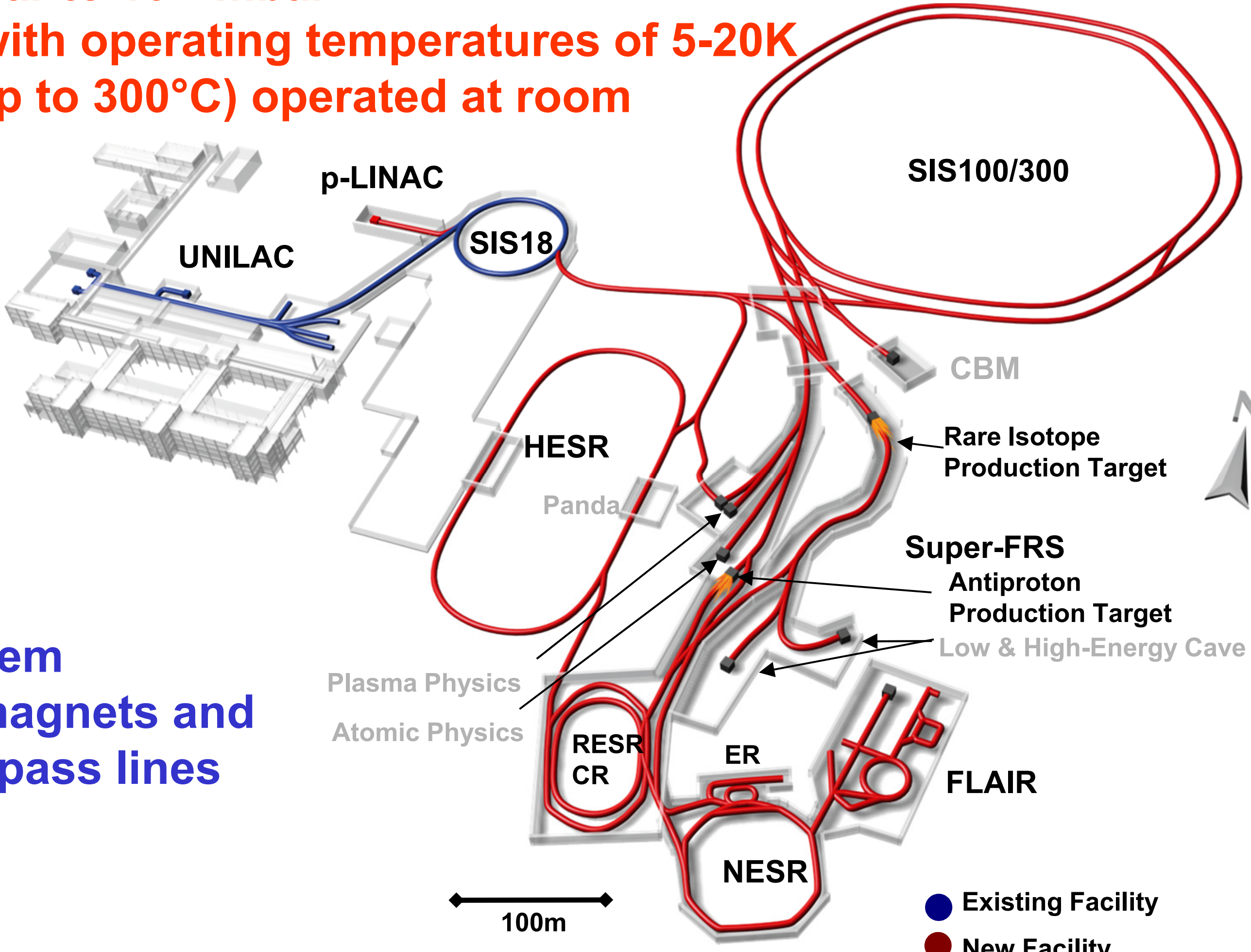
- **Nuclear Structure Physics and Nuclear Astrophysics**
  - Structure of exotic nuclei far off stability;
  - Nuclear synthesis in stars and star explosions;
  - Fundamental interactions and symmetries
- **Hadron Physics with Antiproton Beams**
  - Quark gluon structure and dynamics of “strong” interacting particles;
  - Origin of the confinement and mass of hadrons
- **Physics of Nuclear Matter**
  - Studies of hadronic matter at high densities;
  - Phase transitions in quark matter;
  - Properties of neutron stars
- **Plasma Physics**

  Bulk matter at: very high pressures, densities, and temperatures
- **Atomic Physics and Applied Science**

FAIR Vacuum Requirements

Beam Vacuum System:

- Total length: approx. 6km
- Vacuum: from 10^{-6}mbar to 10^{-12}mbar
- Cryogenic sections with operating temperatures of 5-20K
- Bakeable sections (up to 300°C) operated at room temperature



Isolation Vacuum System for superconducting magnets and cryogenic transfer&bypass lines

- Total length: 3km,
- large volumes
- Vacuum: <10^{-6}mbar

Pumping Concept

For Roughing, during Bakeout & Isolation Vacuum:

- Mobile & fixed stand alone Pumping Stations consisting of a Turbomolecular Pump, Roughing Pump & periphery

⇒ About 100 pcs for beam vacuum

⇒ About 60 pcs for isolation vacuum

For Keeping Vacuum:

- Sputter Ion Pumps (SIP)

=> about 300 pcs

- Titanium Sublimation Pumps (TSP)
- NEG Catridge Pumps
- NEG/SIP Combination Pumps

=> About 120 pcs

- NEG Coating of Chambers

=> Use of cryogenic wall pumping (cryopumping) and adsorption pumps

Vacuum Diagnostics

Total Pressure (Depending on the Pressure Range)

- Penning&Pirani Gauges => about 40 pcs
- Wide Range Ion Gauges => about 120 pcs
- Hot Cathode Ion Gauges => about 60 pcs
- Cold Cathode Gauges => about 70 pcs

Some of these types have to be radiation hard!

Partial Pressure

- Residual Gas Analyzer => about 15 pcs

Valves

Valves for roughing chambers (viton, DN100-DN150CF)
=> about 40pcs

Valves for roughing chambers (all-metall, DN100-DN150CF)
=> about 95pcs

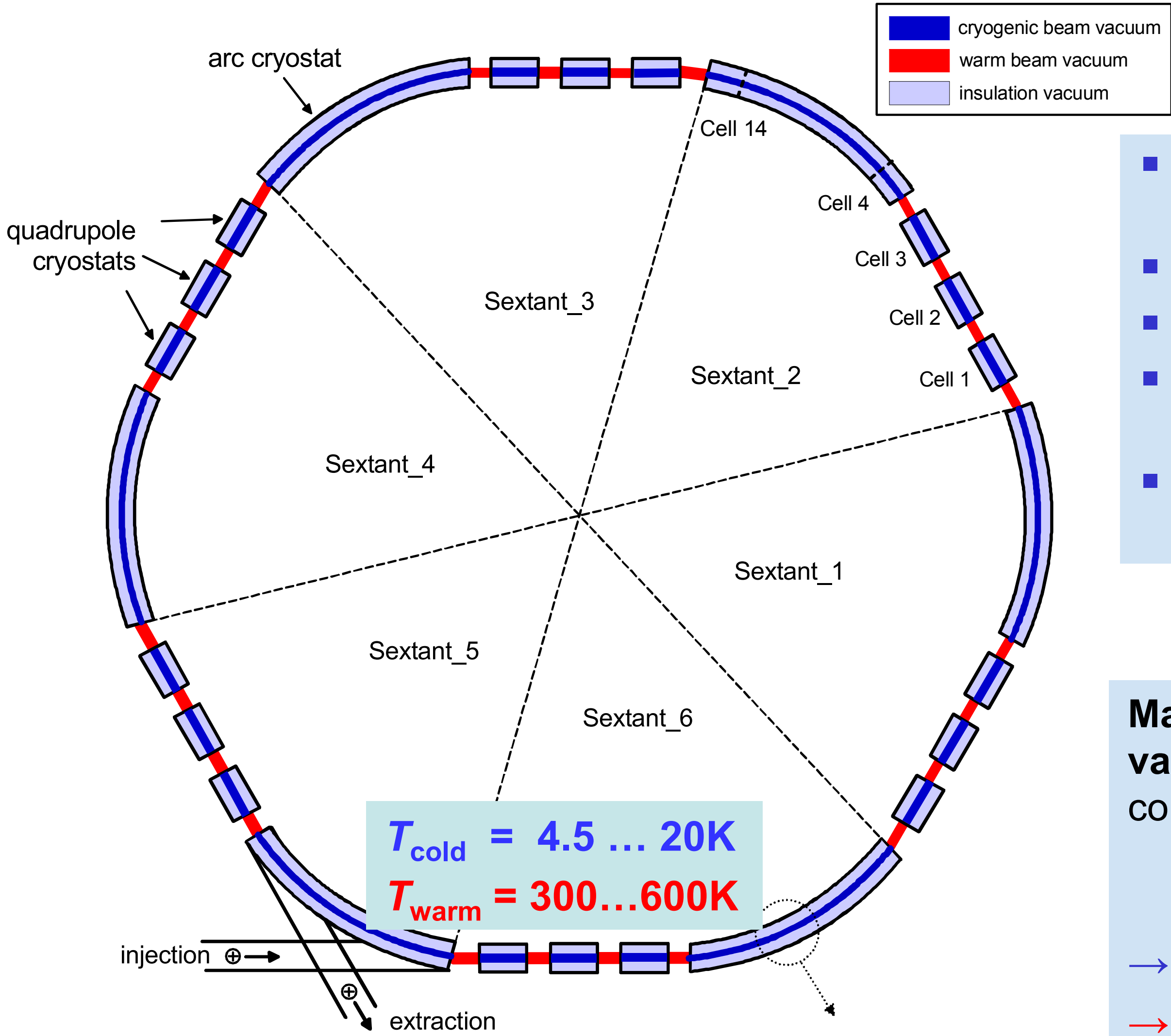
Gate valves (viton, DN100-DN400CF)
=> about 60pcs

Gate valves (all-metall, DN100-DN400CF)
=> about 65pcs

Fast valves
=> about 20 pcs

Valves for roughing Isolation Vacuum
=> about 100pcs

Vacuum Systems of SIS100



T_{cold} = 4.5 … 20K
T_{warm} = 300…600K

- Total length of SIS100: 1083.6 m (82% cold, 18% warm)
- basic structure: hexagonal
- six straights and six arcs
- 23 warm sections (22 x 8.6 m long, 1x 22 m)
- 23 cold sections (6 long arcs: 135m, 17 short straight: 4.3 m)

Maximum allowed average beam **vacuum pressure** under dynamic conditions is given by beam life time

$$N_{max} < 4\cdot10^{+12}\ m^{-3}\ (H_2)$$

→ $p_{cold} < 5\cdot10^{-12}$ mbar (T = 10K)
→ $p_{warm} < 1\cdot10^{-10}$ mbar (T = 300K)

Cryogenic Beam Vacuum Section of SIS100

- Aperture with some exceptions DN160CF
- appr. 885 m of the 1084 m long beam line are operated at cryogenic temperatures
- appr. 644 m are represented by magnet chambers (dipole, quadrupoles, sextupoles, steerer)
- UHV/XHV generation will be realized by cryogenic wall pumping (cryopumping) and additional cryosorption pumps (for H_2 +He)
- chamber wall temperatures range from: **30% -> 5K**, **70% -> 10…15K** (magnet chambers)
- Beam pipes pumped down to p_{av} ~10^{-6} mbar before cool-down with mobile pumping stations, after cool-down they will be valved off
- Material for vacuum chambers: 1.4429 (= AISI 316 LN)
- Special stainless steel for magnet chambers: Böhler P506
- 1 burst disc/ arc (p_{over} ~ 0.3 bara)

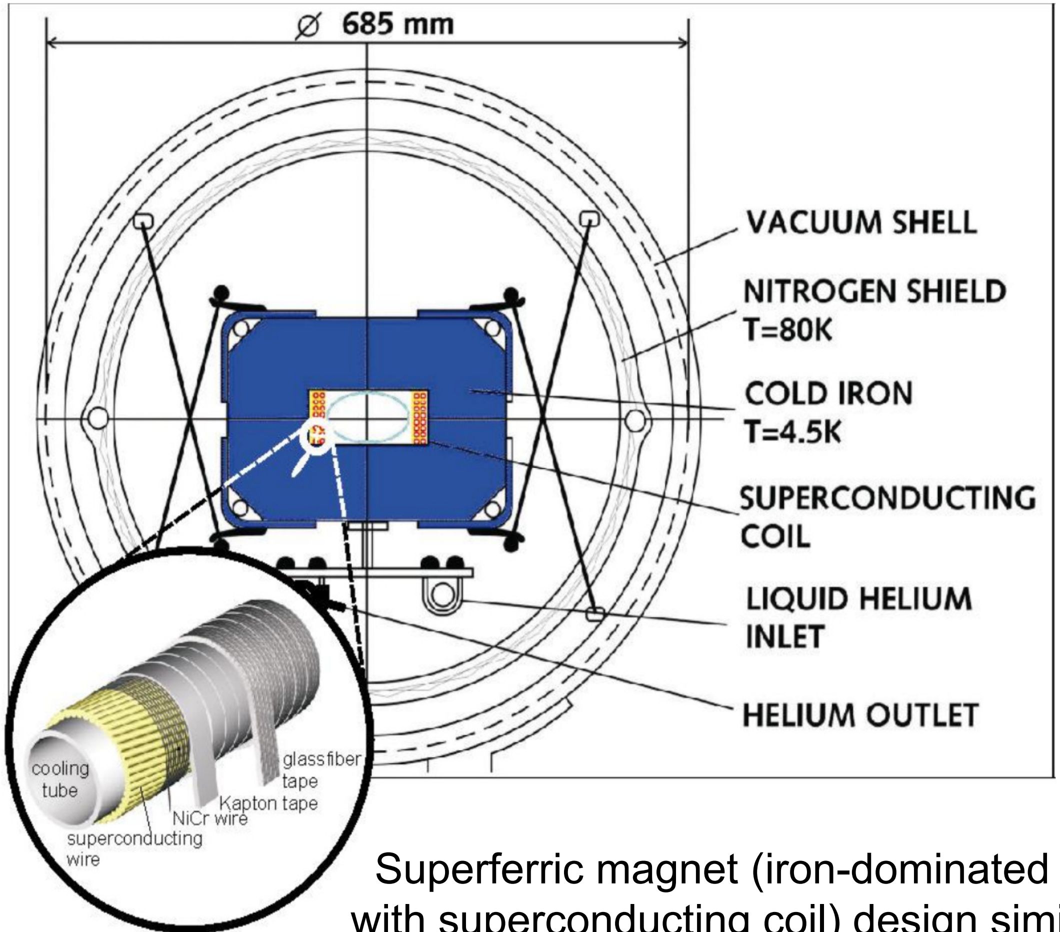
SIS100 cold arc:

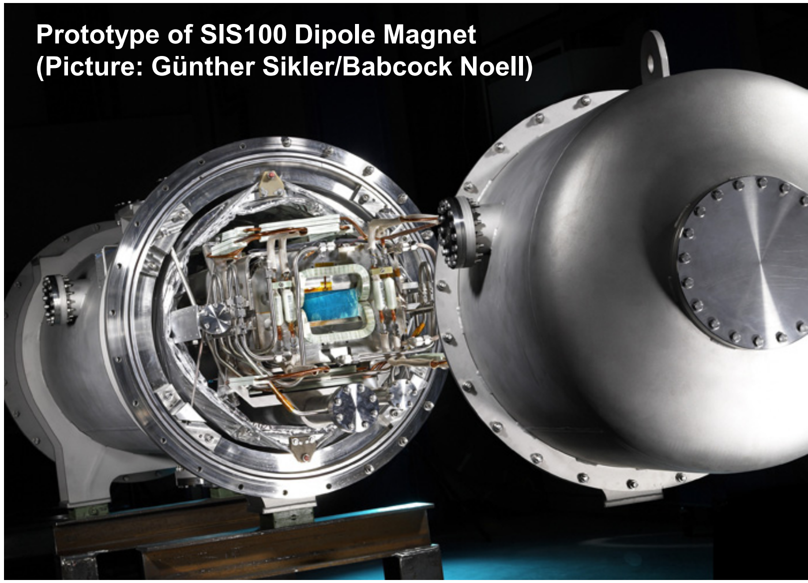
Cold area surface: ~ 47 m²

gas volume enclosed ~ 1300 ℓ

static base pressure expected: ~ 10^{-12} mbar @5K or lower

SIS100 Dipole Magnets and their Chambers





Babcock Noell won the call for tender for the construction of 113 super conducting dipole magnets.

Superferric magnet (iron-dominated with superconducting coil) design similar to the Nuclotron, LHe cooled yoke (via channels) and coil, beam vacuum chamber not part of the cryostat

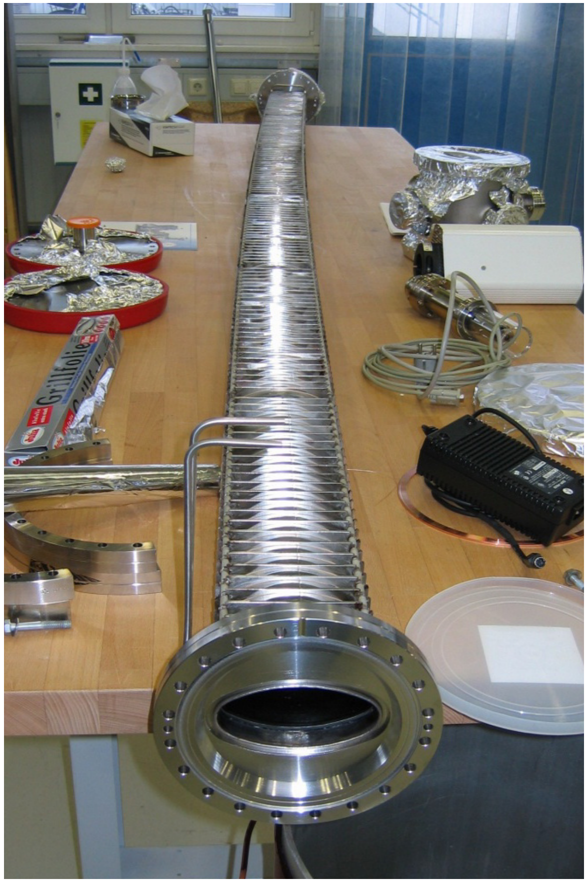
- B_{max} = 1.9T
- **dB/dt = 4 T/s**
- f_{rep} = 1 Hz.

See Poster THPPD021: SC Magnet Development for FAIR by E. Fischer

SIS100 Dipole Chamber Design

Vacuum physical requirements on the magnet chamber design

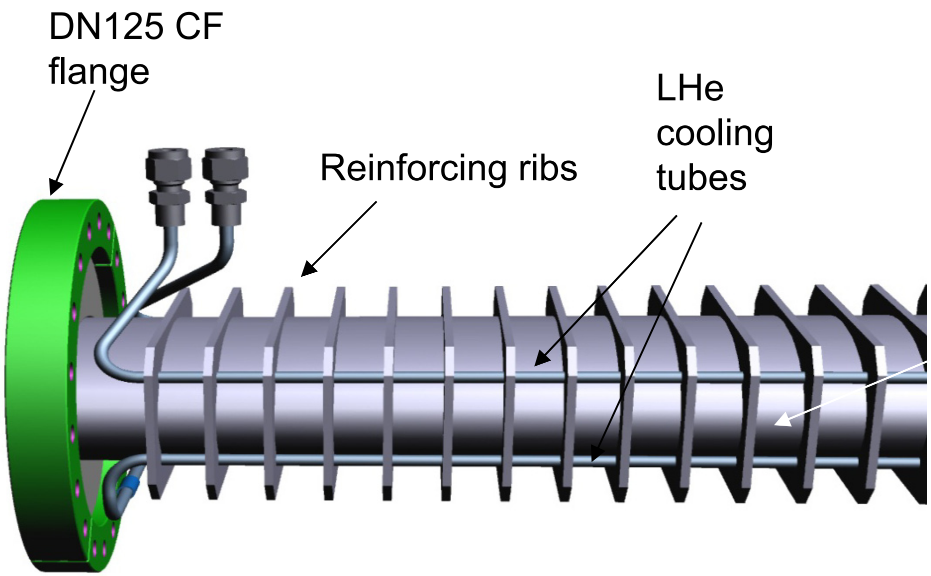
- all dipole chambers represent 45% of the total cold surface in the cryogenic arcs
- the inner beam pipe wall will be used as expanded cold surface of an efficient cryopump with practically infinite capacity for nearly all condensable gas species -> wall temperatures as low as possible -> **$T_{chamber} < 20K$**
- static vacuum pressure inside the chamber 10^{-12} mbar, under dynamic conditions < 10^{-11} mbar
- Length of chamber: 3.35m
- Aperture: 120 x 60mm^2



Problem: due to the fast magnet ramping eddy currents heat up the chamber wall to temperatures > 20K

Solution:
Wall thickness: 0.3mm
Rib thickness: 3.0 mm
Cooling of Chamber with supplementary electrically isolated cooling tubes

Beam Pipe with Supplementary Cooling Tubes



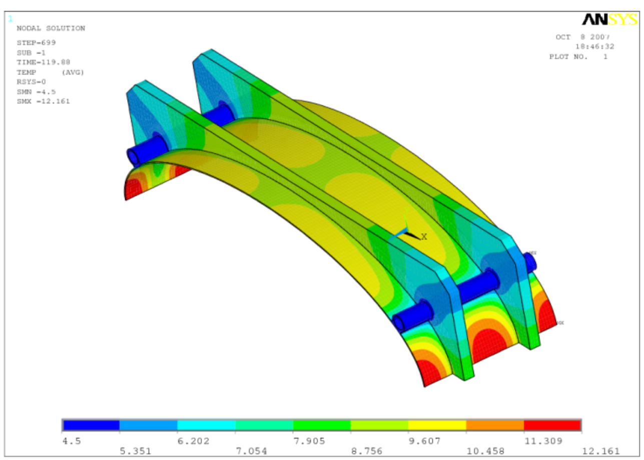
Important requirement:

Relative permeability of chamber material must be low and temporarily constant at cryogenic temperatures

$$\mu_{rel} < 1.005$$

**Bö P506 (Böhler Stainless Steel)*
= X 2 Cr Mn Ni Mo N 19 12 11 1**

developed by CERN in collaboration with Böhler Edelstahl (Austria) as beam screen material for cryogenic LHC sections



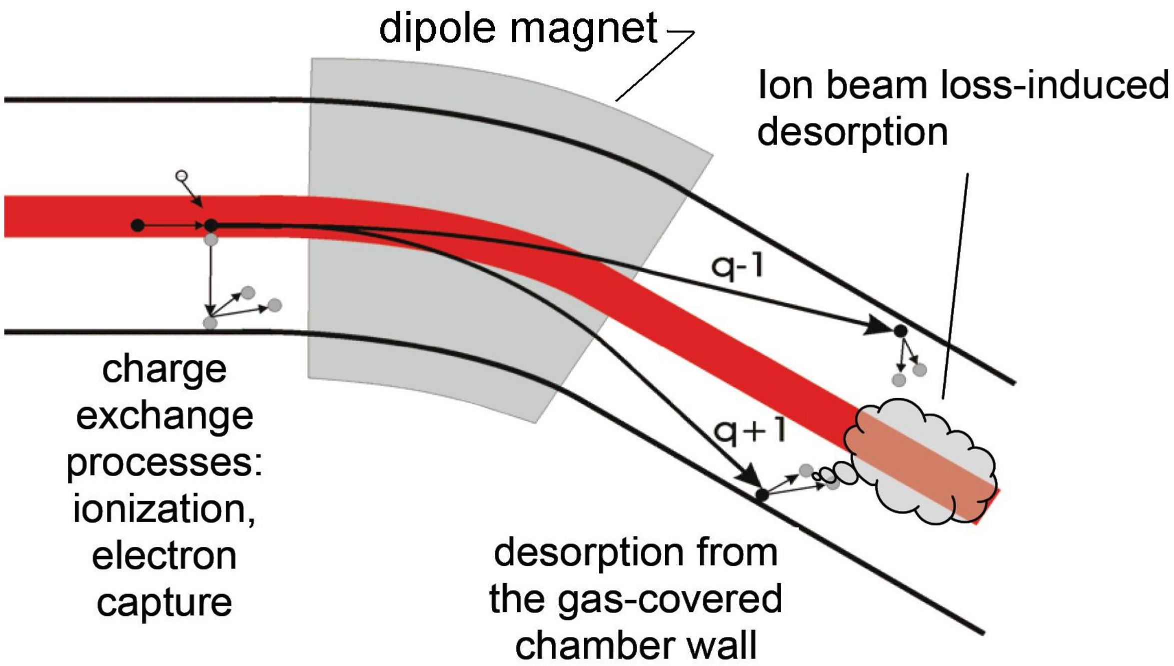
Calculated by: S.Y. Shim (GSI)

- The position of cooling tubes was optimized by ANSYS simulations
- maximum temperature during magnet operation is less than 15K
- Problem: Cooling tubes generate harmonics in the magnetic beam guidance field!

*) S. Sgobba and G. Hochörtler: **A new non-magnetic stainless steel for very low temperature applications;** Proc. Int. Cong. Stainless steel Science and Market, Chia Laguna, Sardinia, Italy (1999), p. 391-401

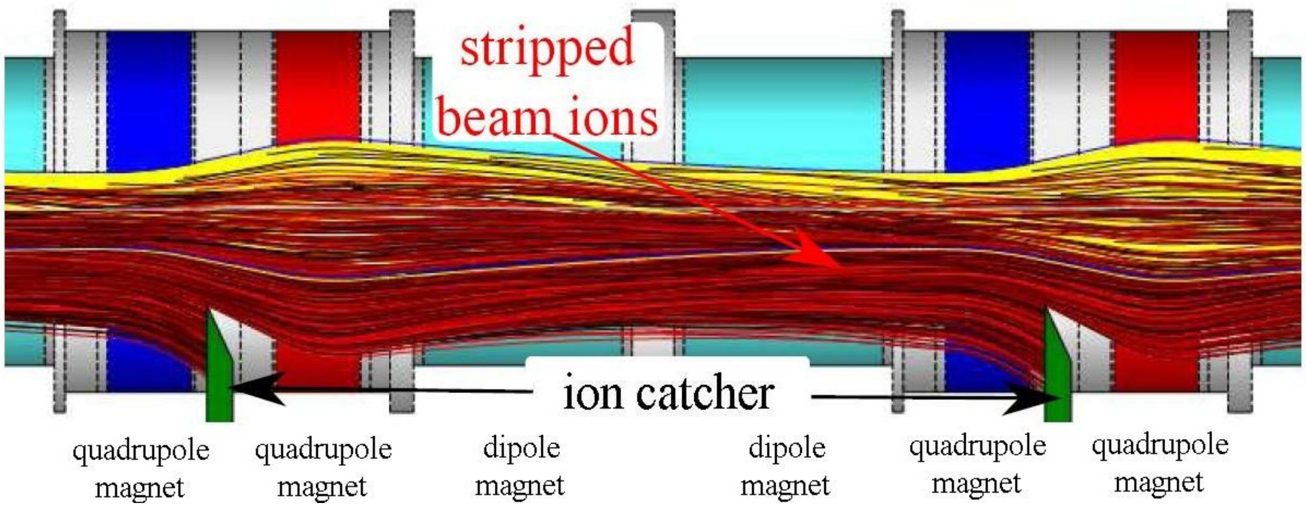
Problem: Ion beam loss-induced desorption effects

- Probability for beam ion ionization depends on residual gas density, gas composition, and beam energy
- Losses drive a **pressure bump**
- Self amplification can develop up to complete beam loss



Cryocatcher Design for SIS100

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



Simulated with StrahlSim by:
P. Puppel, L. Bozyk (GSI)

SIS100 lattice has been optimized to reach a maximum catching efficiency.

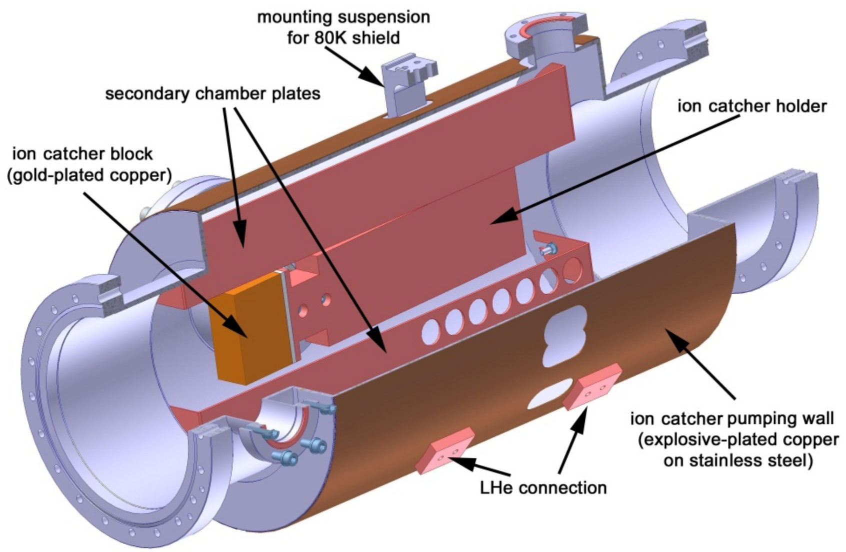
Loss distribution is strongly localized between the quadrupole magnets.

Cryocatcher System for SIS100

Solution: Controlled collection of charge-exchanged ions at localized positions using an ion catcher system

- Controlled catching of charge exchanged ions on low desorption surfaces
- Ions hitting the wall release cryosorbed gases and produce a local pressure bump
- Desorption yield is lowest for perpendicular incidence
- Most charge exchanged ions are caught by the ion catcher
- Significant reduction of gas desorption
- → **Dynamic gas pressure is stabilized**
- Lower total ionization loss
- Activation and radiation damage of magnets by ionization beam loss are reduced

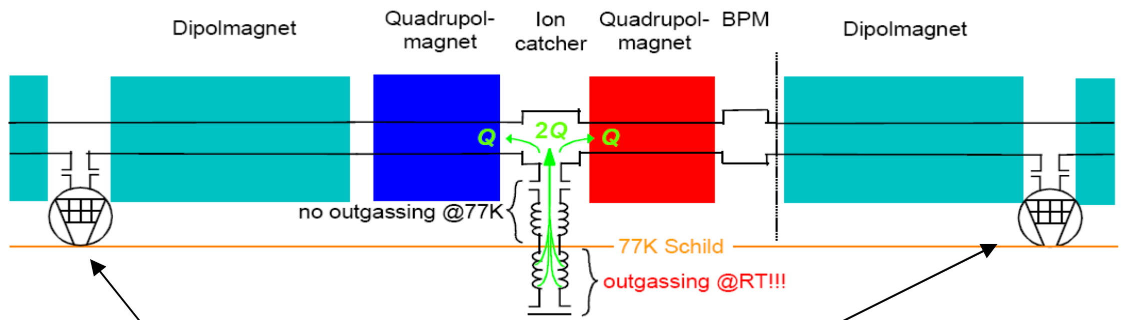
aim: $p_{dyn} < 5\cdot10^{-12}$ mbar @5K

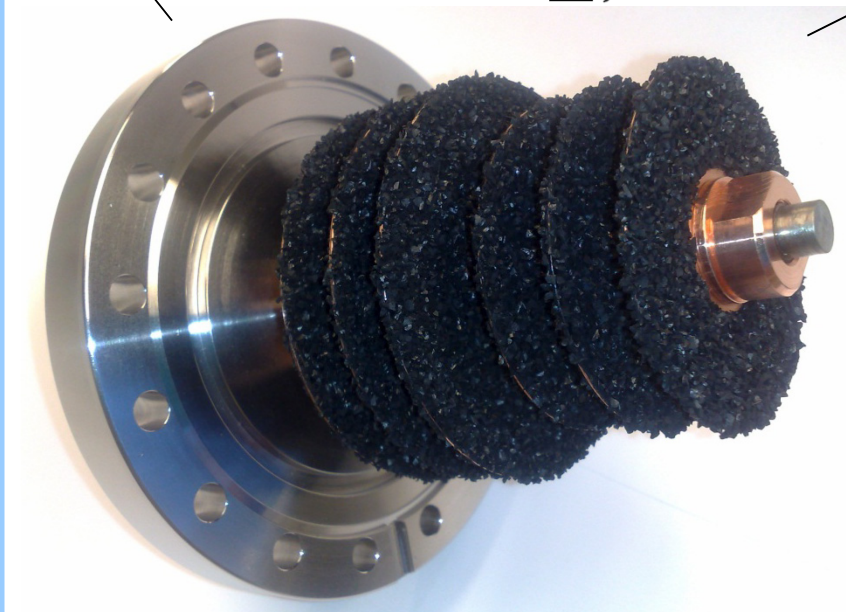


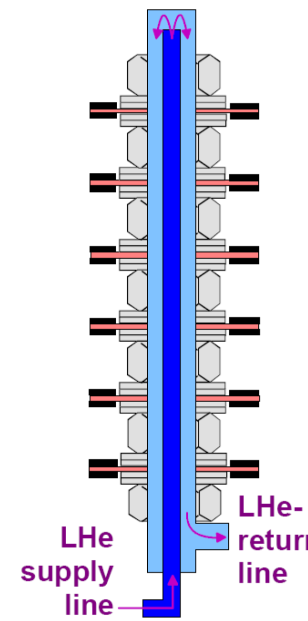
For more details see poster THEPPB04: Development of a Cryocatcher System for SIS100 by Lars Bozyk

Cryosorption Pumps

- **auxiliary pumps** are used primarily to lower the partial pressures of H_2 and He
- **10 cryosorption pumps per arc** (each 13 m) and **one per short quadrupole doublet in the straight sections**
- **2 different pump layouts**
- cryosorption pump consists of several round cryopanels (i.e. copper disks coated with charcoal of SC2 type made by CHEMVIRON, coating by KIT, Karlsruhe, Germany)
- panels stacked on a central cooling tube cooled down to $T \sim$ 4.5K
- $S_{He} \sim 1$ ℓ/s cm² for He and $S_{H2} \sim$ 10 ℓ/s cm² for H_2

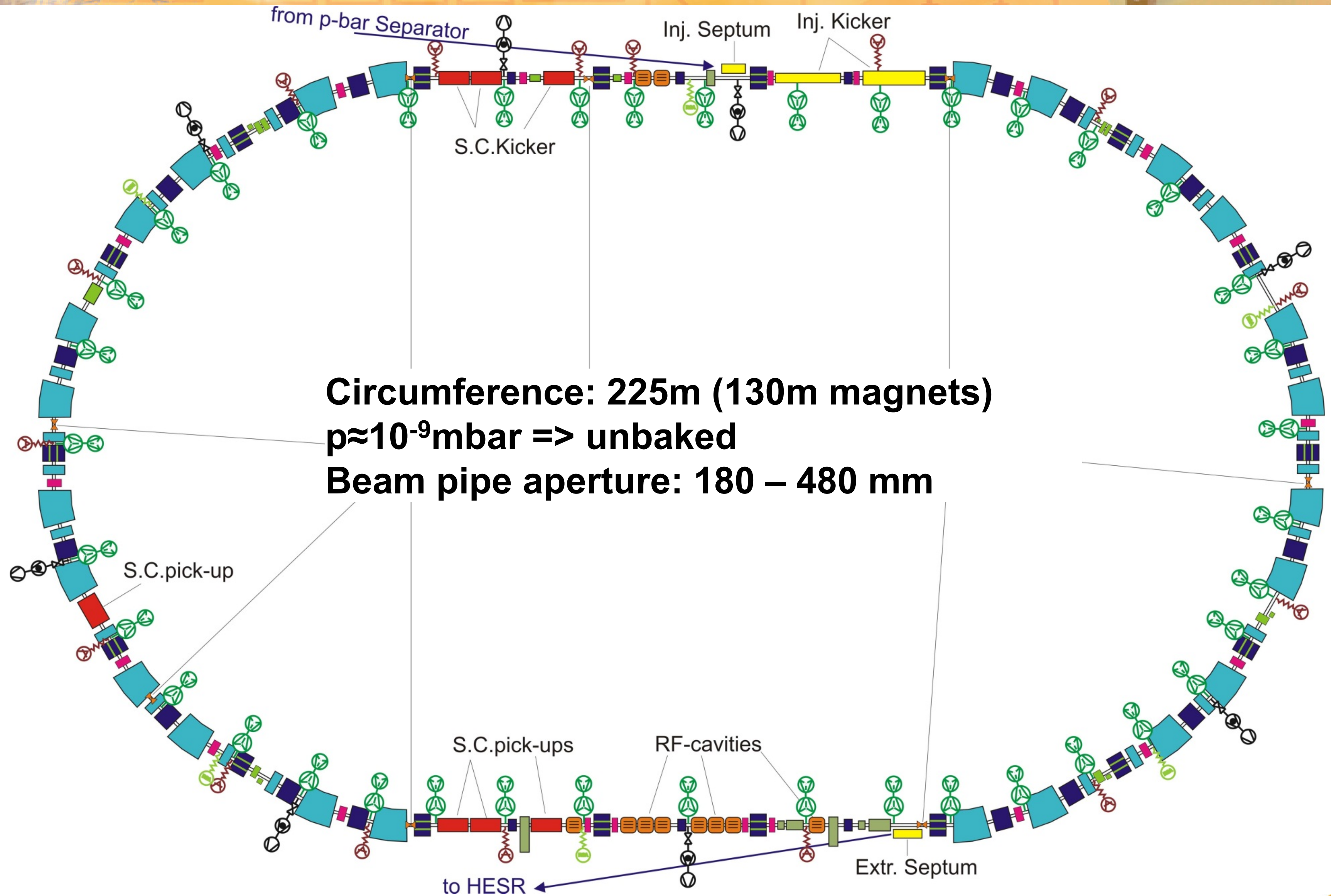






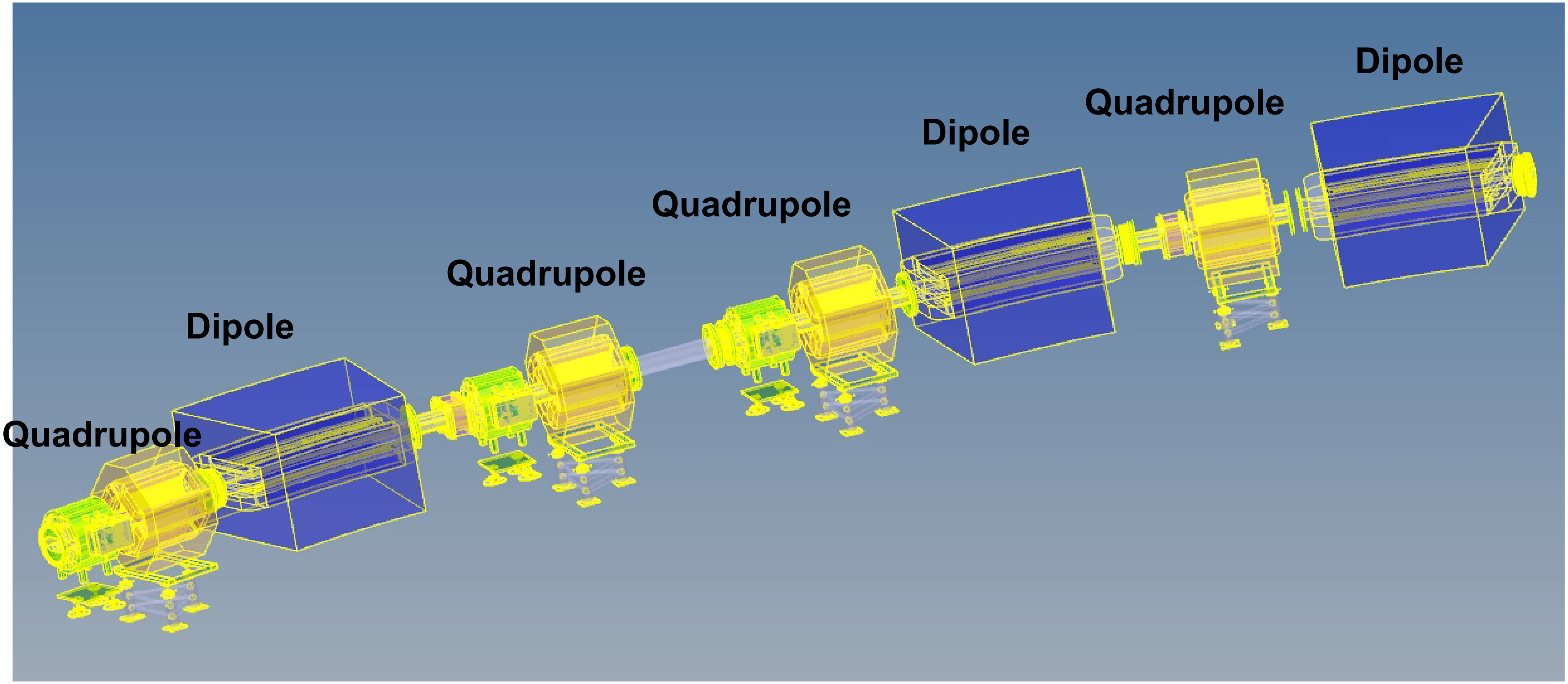
m_{char}	A_{char}	C_{char}	S_{pump}
~ 24 g	~ 34000 m²	~ 0.25 mbar.ℓ	~ 50 ℓ/s

Schematic Vacuum Layout of Collector Ring



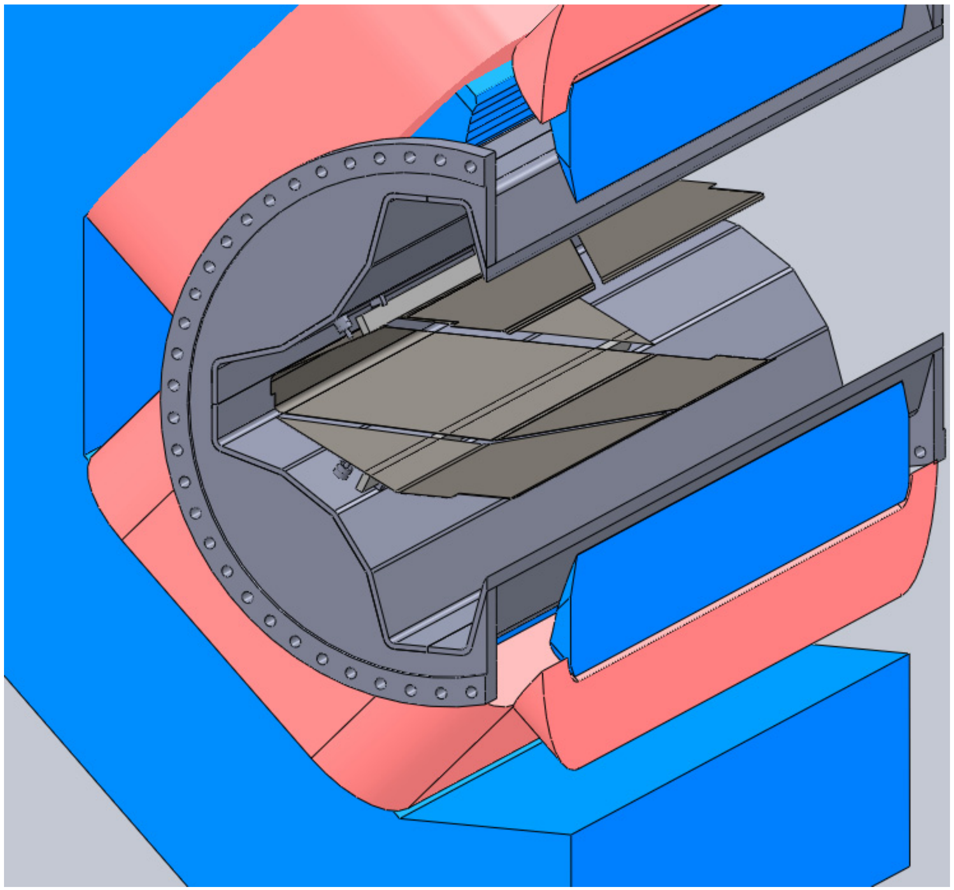
Circumference: 225m (130m magnets)
p≈10^{-9}mbar => unbaked
Beam pipe aperture: 180 – 480 mm

3D Sketch of Part of CR



Problem: Large Apertures, narrow space in beam direction
⇒ GSI constructed DN500CF Flange, tests running
⇒ Use of SIP/NEG Catridge combination pumps

Integration of BPM in Quadrupole Chamber



Beam Position Monitors (BPM) has to be integrated into the quadrupole magnets and chambers.

Aperture of star-shaped chambers: 480 x 480 mm

Thanks to all people in the Vacuum Group of GSI!

Thank you for your attention!!!!