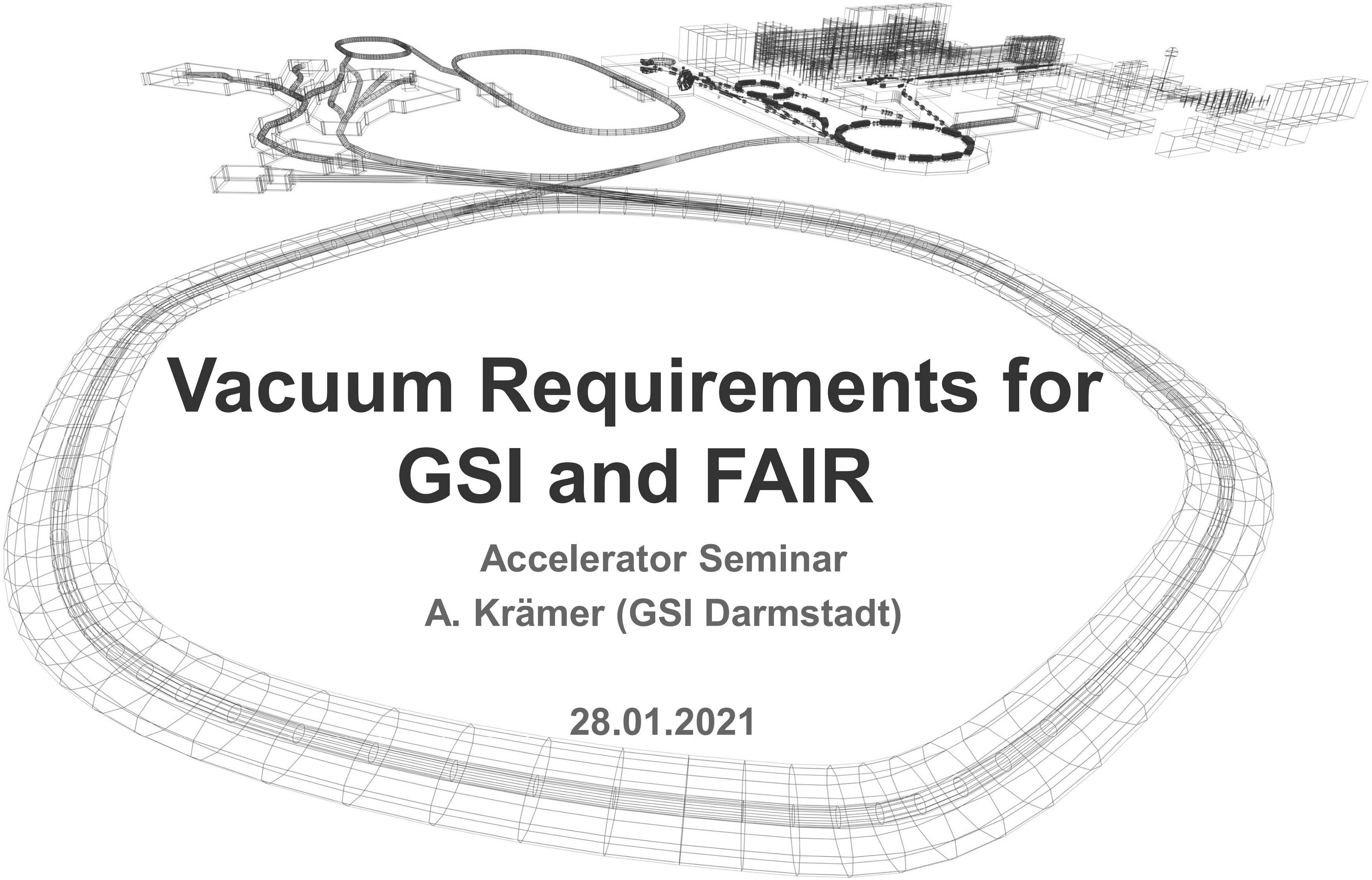


Vacuum Requirements for GSI and FAIR

Accelerator Seminar

A. Krämer (GSI Darmstadt)

28.01.2021

Outline

- Introduction
  - Ion Beam Lifetime and Vacuum Pressure
  - Pumping Surfaces
  - Dynamic vacuum
- GSI & FAIR Vacuum Requirements
  - GSI Vacuum Systems
    - UNILAC
    - SIS18
    - ESR
    - CRYRING
- FAIR Vacuum Requirements & General Concepts
  - FAIR Vacuum Systems
    - SIS100
    - HEBT
    - SuperFRS
    - p-Linac
    - pbar Separator
    - CR
    - HESR

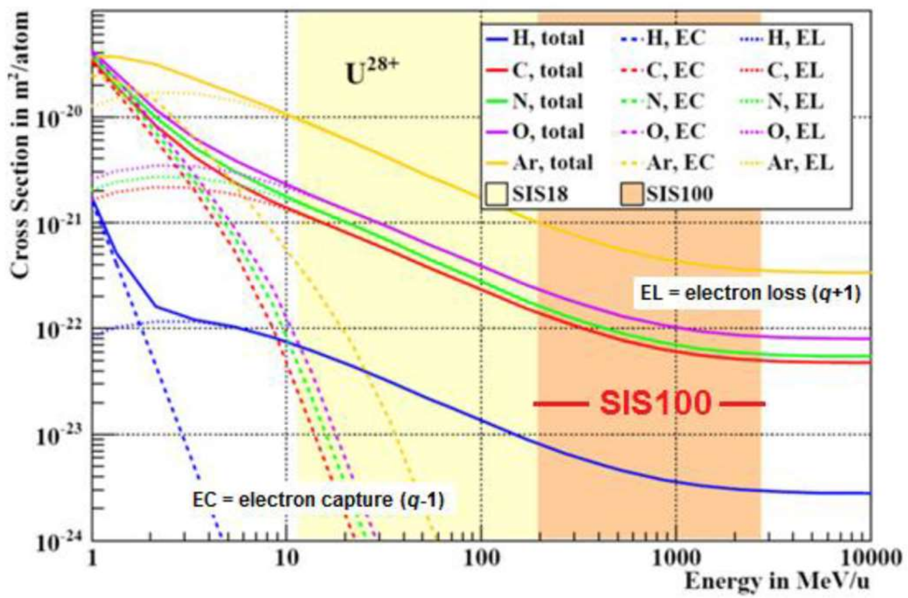
Ion Beam Lifetime

- Ions collide with a certain probability on their way through the accelerator with residual gas atoms / molecules.
- particles could undergo Coulomb scattering and/or undergo charge (electron capture or electron loss (ionization)).
- Charge exchanged ions will be lost due to charge separation in the dipole magnets.
- Mainly a problem for storage rings and synchrotrons, where the ions travel a long way.

$$\tau(E) = [v n_x \sigma_x(E)]^{-1}$$

$\tau(E)$	*Lifetime*
v	Ion velocity
n_x	particle density of residual gas atoms / molecules x
$\sigma_x(E)$	Charge exchange cross section (dependent on ion energy)

Charge exchange cross sections are higher for heavier gas atoms/molecules.



L Bozyk, Proc. IPAC2016, MOPOY055, ISBN 978-3-95450-147-2

- to guarantee required lifetime, reduce base pressure in accelerator and avoid heavy components (like Argon) in residual gas!

Achievable Ultimate Pressure

The ultimate pressure in a vacuum system is determined by:

- Desorption – Material property dependent of pre-treatment (e.g. cleaning, bake-out,...)
- Diffusion – Material property
- Permeation – Material property
- Leaks (real und virtual) – dependent of sealing, manufacturing and assembly technology
- Pumps – back streaming, ultimate pressure of pump
- Process gases
- Installed pumping throughput

$$p_{ultimate} = \frac{Q_{desorption} + Q_{diffusion} + Q_{permeation} + Q_{leak} + Q_{process}}{S_{eff}}$$

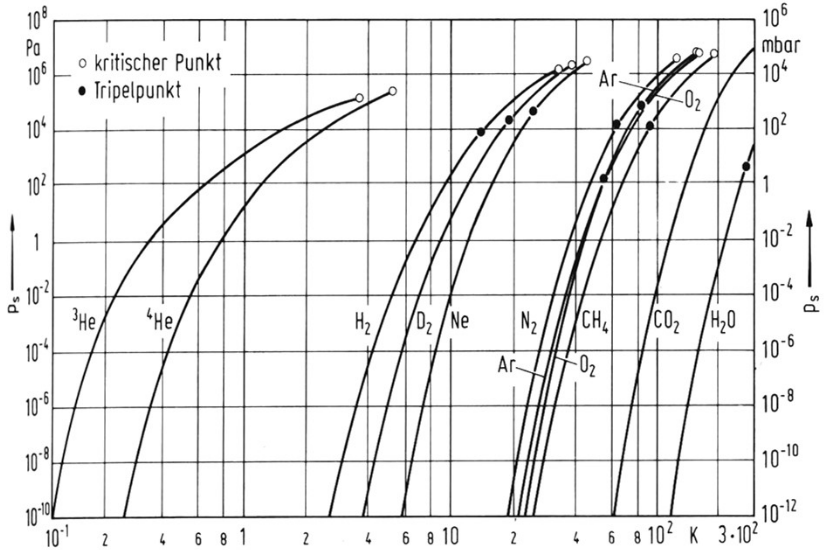
$Q_{desorption/diffusion}$ ~ 10^{-13} (mbar l)/(s cm^2)
$Q_{permeation}$ ~ 10^{-14} (mbar l)/(s cm^2)
Q_{leak} ~ 0 (in ideal case)
$Q_{process}$: dependent of the process, in accelerators zero (except gas targets and stripper)

- Careful choice of material: e.g. Stainless steel, Aluminium, Titanium, Copper, ceramics (e.g. Al2O3)
- Proper cleaning methods
- Thermal degassing (vacuum firing & bake-out)
- Surface treatment (cleaning procedures, possibly polishing, coating)

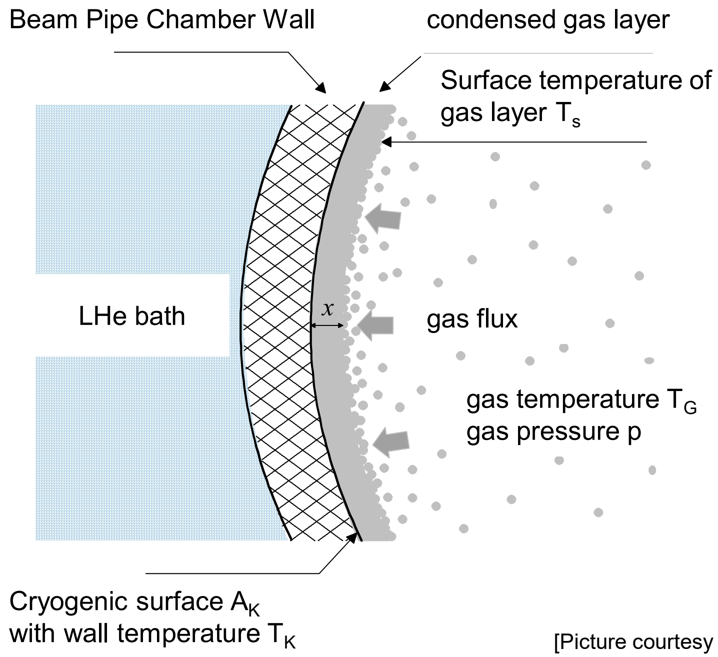
- **Problem to increase pumping speed due to conductance limitations in accelerators!**
- **Solution: converting the chamber wall into a pump (distributed instead of lumped pumping)!**

Pumping on cryogenic surfaces

Vapour Pressure Curves



(from: Haefer, R. A.: *Kryo-Vakuumtechnik,* Springer Verlag Berlin – Heidelberg 1981)



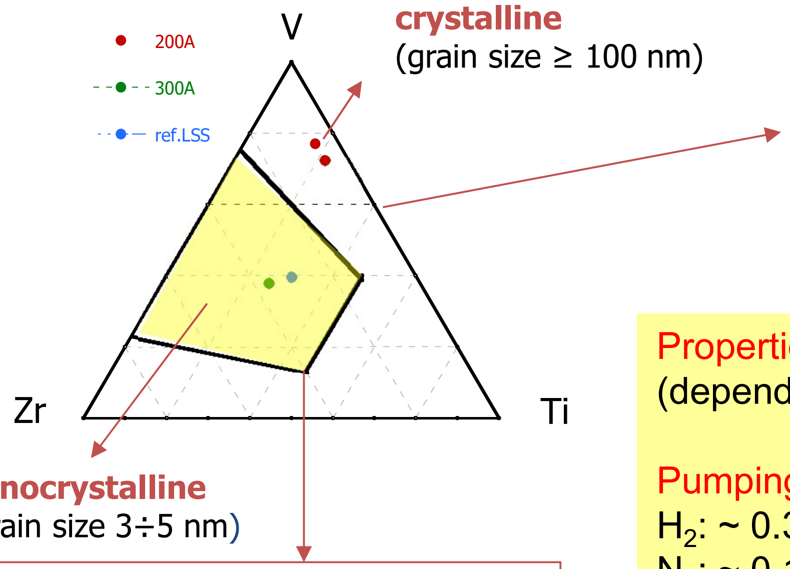
[Picture courtesy of S. Wilfert (GSI)]

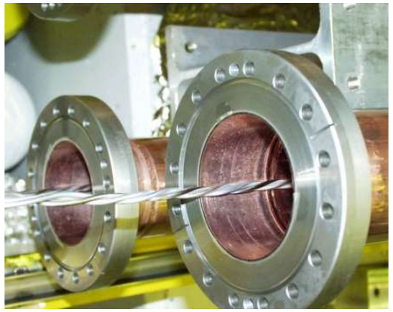
- Use of liquid Helium (LHe) existing in superconducting magnets to cool vacuum chamber.
- Surface temperature T = 1.9...4.2K
- Pressure in the range < 10^{-13} mbar achievable
- Gases will freeze at the chamber walls
- Conventional, external vacuum system not necessary and inefficient

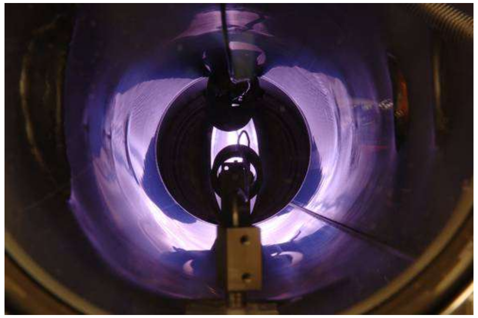
Pumping with NEG Coating

NEG (Non Evaporable Getter): Alloy of Titanium, Zirconium and Vanadium developed by CERN

- deposited via Magnetron Sputtering on the inner wall of the vacuum chamber (film thickness 1-3μm)
- Thermal activation under vacuum gives a pumping surface for all chemical active gases (not Methane, Noble gases)







Lowest Activation Temperature in a large area of various compositions of Ti-Zr-V: 180 °C (24 h bake-out).

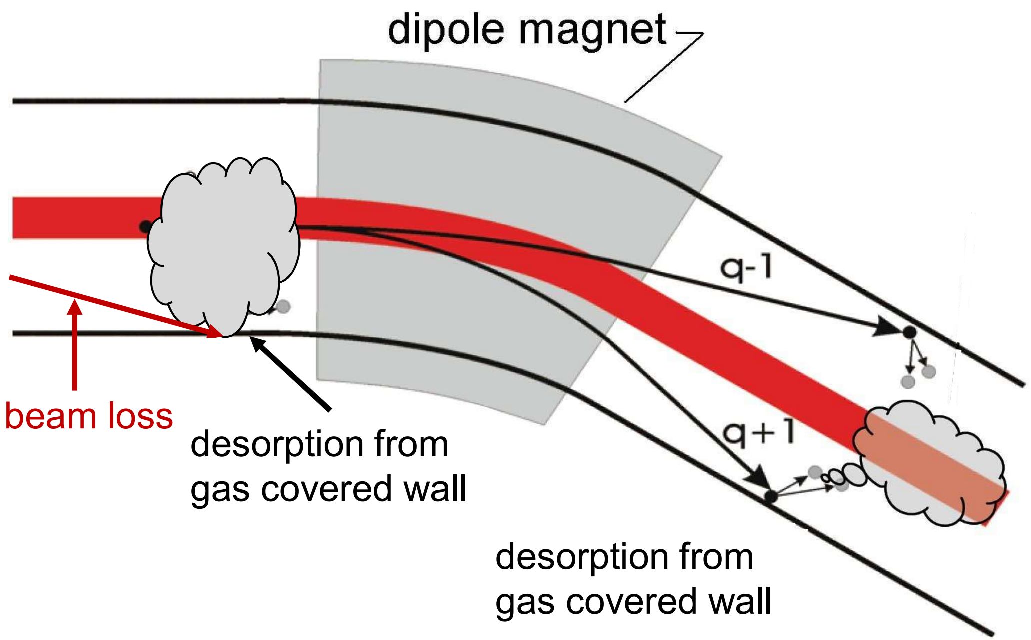
Properties of NEG coating
(dependent on surface roughness of coating)

Pumping speed:
H_2: ~ 0.35 – 1.3 l/s cm^2
N_2: ~ 0.17 – 0.34 l/s cm^2
CO: ~ 8 – 10.4 l/s cm^2

Capacity:
N_2: 1.5x10^{14} – 1.5x10^{15} mol/cm^2
CO: 8x10^{14} – 8x10^{15} mol/cm^2

Can be reactivated up ~30 times, performance can be kept up to 90% by applying higher temperatures and/or longer activation times

Dynamic Vacuum Effects



Desorption coefficient

$$\eta = \frac{\Delta p \cdot V}{N_{ion} k_B T}$$

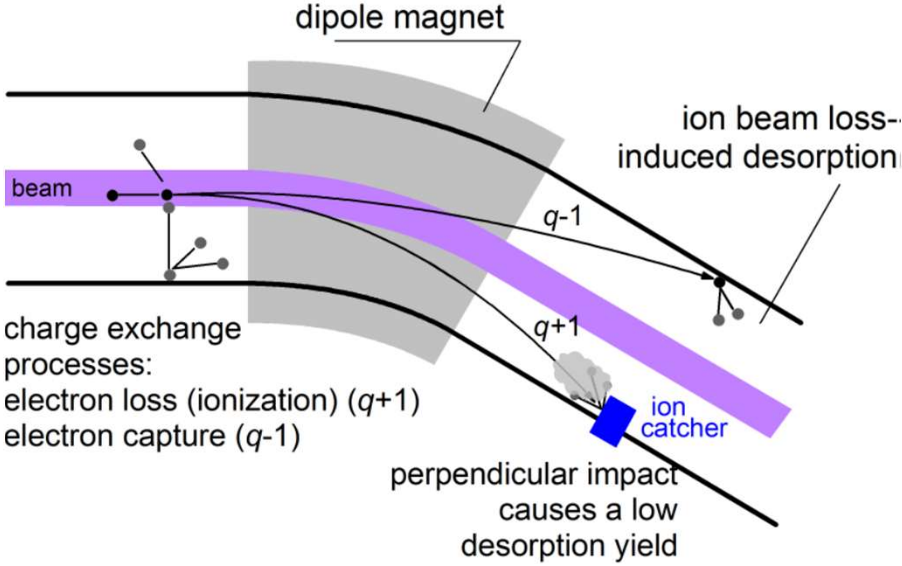
η dependend on energy, angle of incidence, surface properties, particles

η_{ion} ~ 1-10 (keV)
η_{ion} ~ 10^4 (MeV/u)
$\eta_{electron}$ ~ 10^{-1}-10^{-2}
η_{photon} ~ 10^{-5}

Losses due to charge exchange or initial losses at injection drive a local **pressure bump due to ion induced desorption**

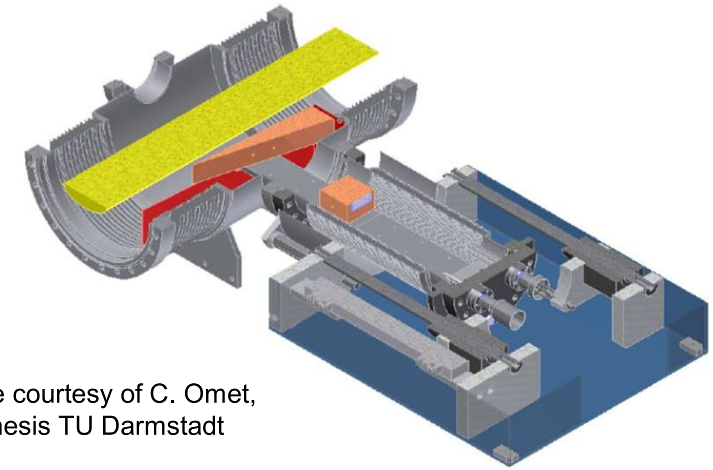
- **Self amplification** can develop up to **complete beam loss**
- Maximum number of accelerated ions is limited → **beam intensity limitation**
- **Can't be cured by higher pumping speed only!**

Ion Catcher System



- **Counter Measure: Controlled collection of charge-exchanged ions at exactly-defined ring positions using an ion catcher system**

Prototype Collimator (Ion Catcher)@SIS18



Picture courtesy of C. Omet, PhD thesis TU Darmstadt 2008

- Controlled catching of ionized ions on surfaces with low desorption yield (gold) → most ionized ions are caught by the ion catcher
- Provide increased pumping speed in surrounding chamber to quickly remove desorbed gases

→ dynamic vacuum effects are suppressed effectively

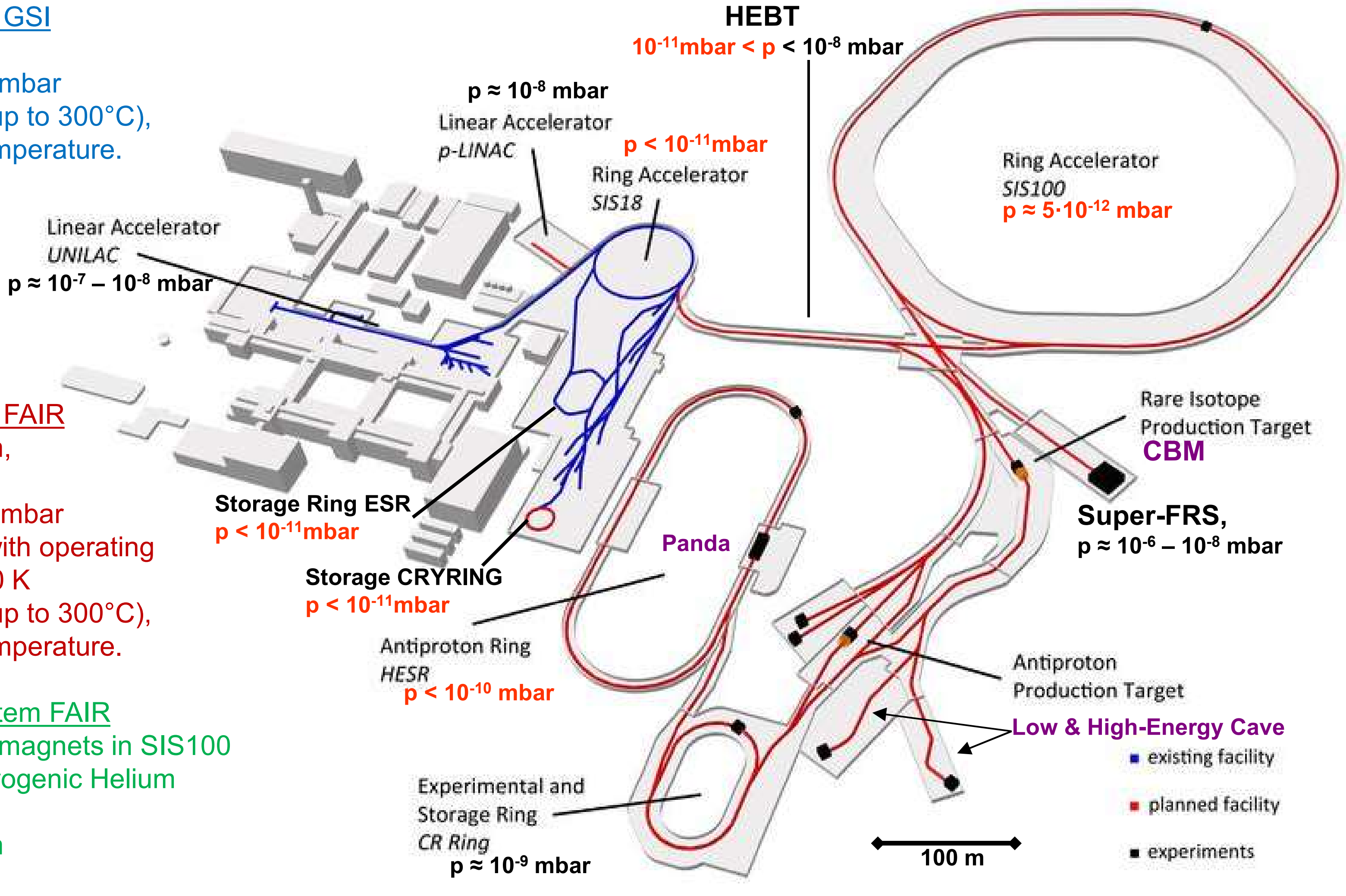
GSI&FAIR Vacuum Requirements

Beam Vacuum System GSI
- Total length ~1,1km
- Vacuum: $10^{-7} – 10^{-12}$ mbar
- Bakeable sections (up to 300°C), operated at room temperature.

Beam Vacuum System FAIR
- Total length ~ 3,9 km,
- Volume ~ 65 m^3
- Vacuum: $10^{-6} – 10^{-12}$ mbar
- cryogenic sections with operating temperatures of 5-20 K
- Bakeable sections (up to 300°C), operated at room temperature.

Insulation Vacuum System FAIR
- for superconducting magnets in SIS100 & SuperFRS and cryogenic Helium transfer lines
- Total length ~ 2,8 km
- Volume ~ 300 m^3
- Vacuum <10^{-6} mbar

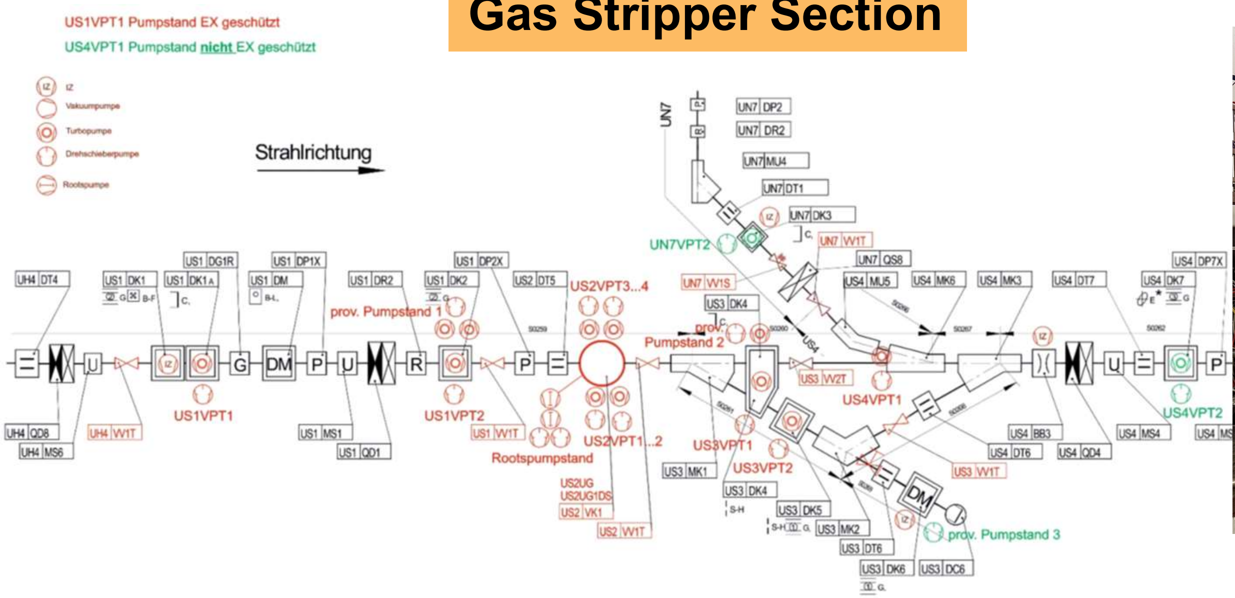
(not part of this talk)

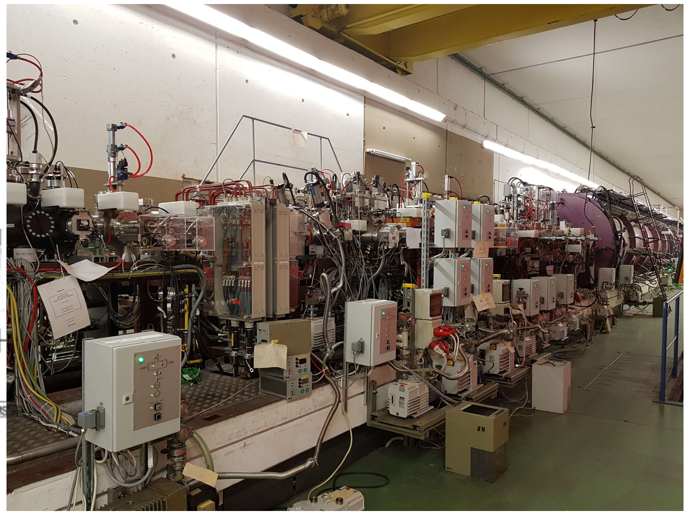


Vacuum System of UNILAC, EH & TK

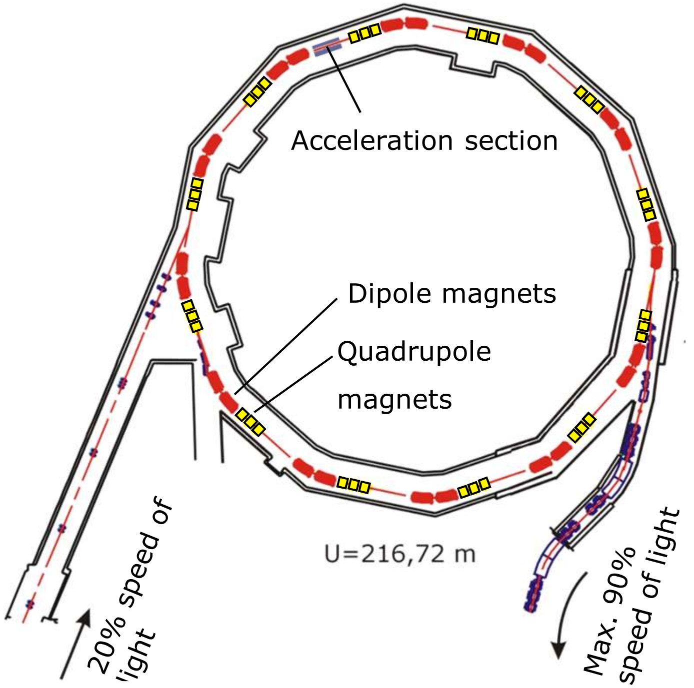
- Operation pressure: ~1x10^{-6} - 5x10^{-8} mbar (depending on section, partially higher during stripper operation)
- 55 independent High Vacuum Sections separated by Viton sealed gate valves
- Ion Getter- (~100pcs.) & Turbo Molecular Pumps (~70pcs.) with Roughing Pumps (Rotary Vane Pumps, Roots Pumps,...)
- UNILAC-Tanks: large Volumes, Copper coated
  - additional medium vacuum system for protection of critical metal seals and for static relief of large dividing walls
- Beam transport lines (outside of tanks): narrow, long tubes and chambers made out of stainless steel with small volumes and surfaces.

Gas Stripper Section





Vacuum System of SIS18



- Circumference=216 m
- Magnets up to 1.8 T (18Tm magn. rigidity)
- Ramp rate: 10T/s

- Operating pressure ~10^{-11} mbar
- Bakeable up to 250°C
- 7 Vacuum Sections
- Ion Getter Pumps (57pcs.), Titan Sublimation Pumps, NEG wafer modules,and NEG coating, TMP only during Roughing and Bakeout
- 9 All-Metal Valves
- Apertures:
  - Dipole: 190 x 70 mm^2,
  - Quadrupole: 200 x 116 mm,
  - Pumping- & Diagnostic Chambers: ∅=200mm
- Vacuum Diagnostics:
  - 31 Total Pressure Gauges (Extractor)
- Upgrade Measures: additional pumping speed with NEG Cartridge pumps

SIS18:
Dipole & Quadrupole Chamber Design

Problem:
Fast ramping of the magnets induces eddy currents
- The chamber walls are heated => no problem here
- Generation of additional harmonics in field.

Chamber design was optimized in terms of:

- field quality (additional harmonics)
- beam dynamic aspects (e.g. impedances)

Solution:
- Thin-walled chamber (d = 0.3 mm) with ribs for stiffening
- Stainless steel 1.4429 with $\mu_r \leq 1.005$

Quadrupole Chamber

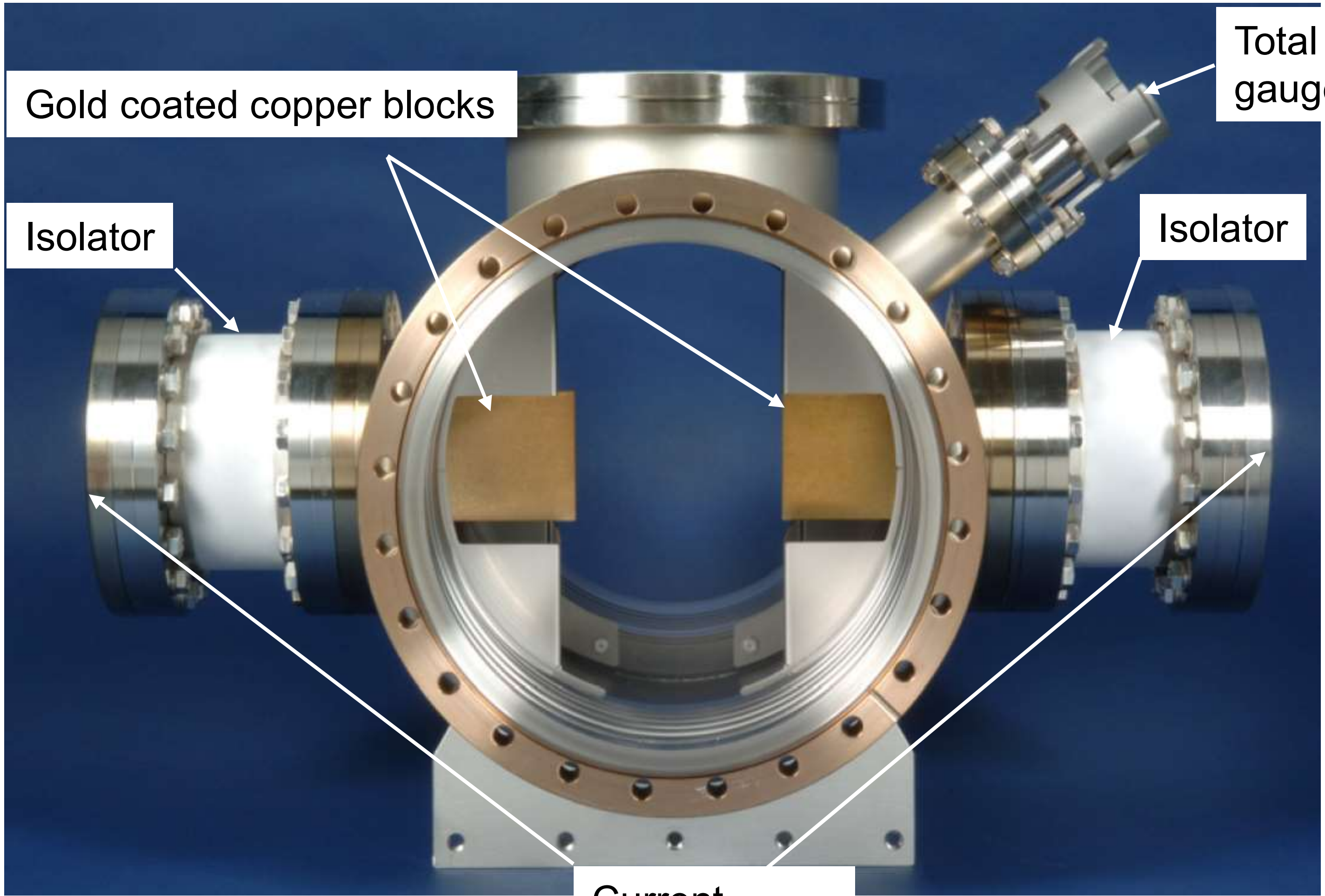
NEG coating SIS18

NEG coating of all dipole and quadrupole chambers (in total about 65% of the surface) done at GSI

- CERN Patent, Technology transfer and licence agreement between CERN and GSI in 2005
- Two Coating facilities at GSI

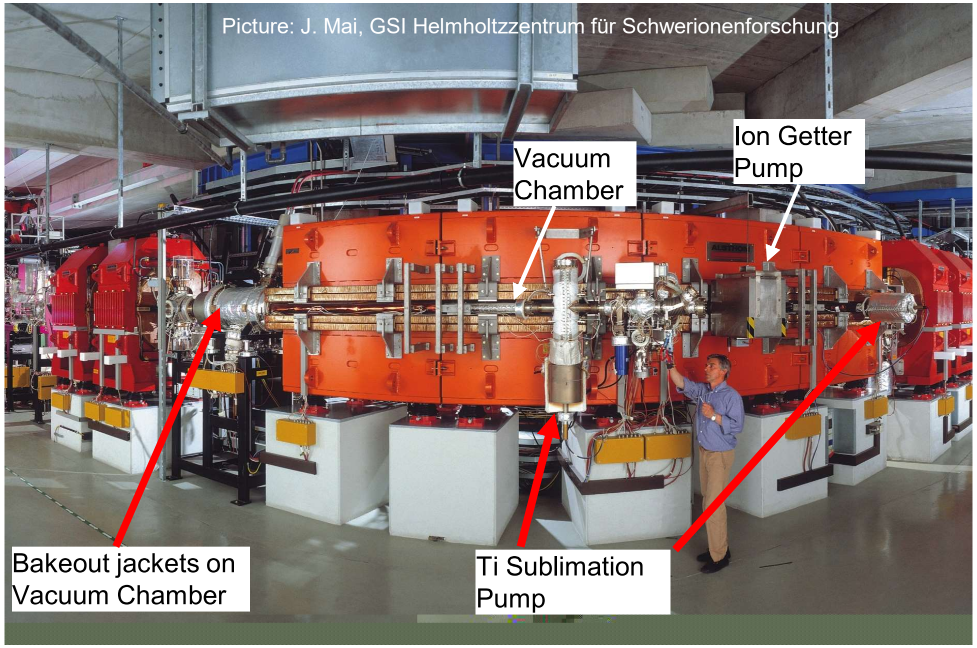
Collimators/Ion Catcher SIS18

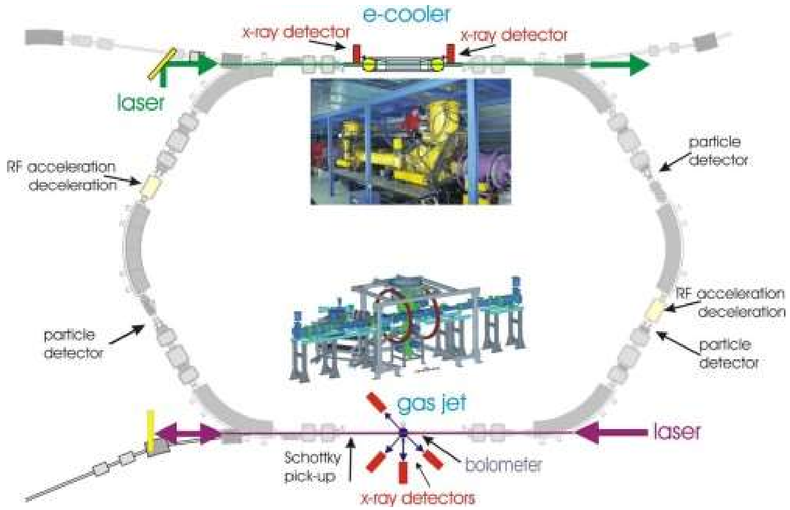
11 collimators are installed in SIS18



P. Spiller et al., Proc. IPAC'10, MPOD002, 669, Kyoto (2010)

Vacuum System of Experimentierspeicherring (ESR)





- Operating pressure: 10^{-11} to 10^{-12} mbar
- Bakeable up to 300°C
- 4 Vacuum Sections
- Ion Getter Pumps (41pcs.), Titan Sublimation Pumps, TMP only during Roughing and Bakeout
- All-Metal Valves
- Vacuum diagnostics:
  - 13 Total Pressure Gauges (Extraktor) & 3 RGAs

Circumference 108 m

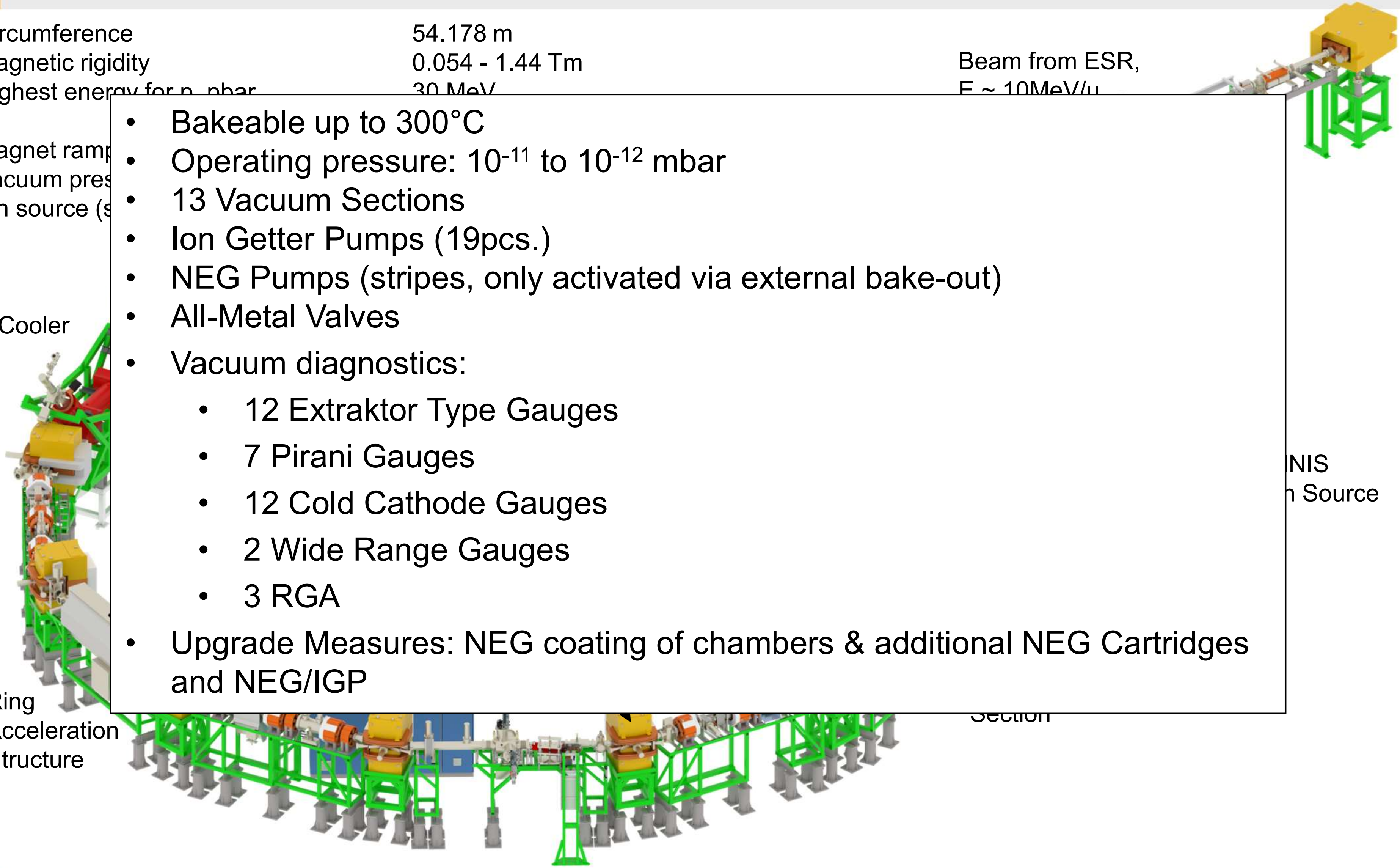
Apertures:

- Dipole: 380 x 140 mm^2,
- Quadrupole: 200 x 116 mm,
- Pumping- & Diagnostic Chambers: ∅=200mm

Vacuum System of CRYRING@ESR

Circumference	54.178 m
Magnetic rigidity	0.054 - 1.44 Tm
Highest energy for p, pbar	30 MeV
Magnet ramp	
Vacuum pres	
Ion source (s	

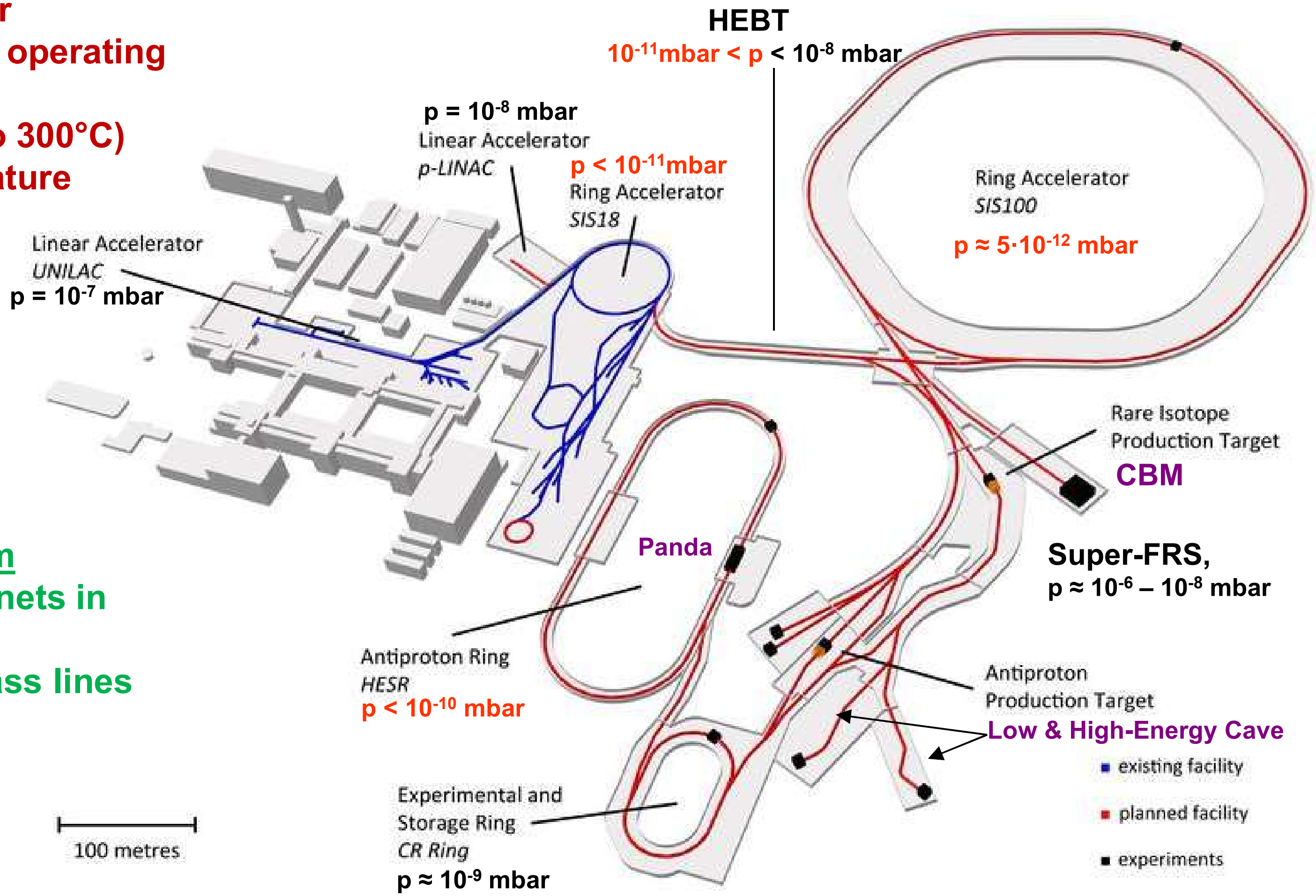
- Bakeable up to 300°C
- Operating pressure: 10^{-11} to 10^{-12} mbar
- 13 Vacuum Sections
- Ion Getter Pumps (19pcs.)
- NEG Pumps (stripes, only activated via external bake-out)
- All-Metal Valves
- Vacuum diagnostics:
  - 12 Extraktor Type Gauges
  - 7 Pirani Gauges
  - 12 Cold Cathode Gauges
  - 2 Wide Range Gauges
  - 3 RGA
- Upgrade Measures: NEG coating of chambers & additional NEG Cartridges and NEG/IGP



FAIR Vacuum Requirements

Beam Vacuum System:
- Total length: ~ 3.9 km
- Volume: ~ 65 m^3
- Vacuum: $10^{-6} – 10^{-12}$ mbar
- Cryogenic sections with operating temperatures of 5-20 K
- Bakeable sections (up to 300°C) operated at room temperature

Insulation Vacuum System
for superconducting magnets in SIS100 & SuperFRS and cryogenic transfer & bypass lines
- Total length: 2.8 km
- Volume: ~ 300 m^3
- Vacuum: $<10^{-6}$ mbar



Principles and Status of System Design

1. The concept for the design of the vacuum system is **based on the operation experience** with existing GSI accelerators.
2. **Use of standard components** (catalogue items) for pumps, gauges and valves, no further development from manufacturer needed
3. In UHV systems with very low gas load, **only capture pumps** for keeping up the vacuum.
4. Keep all **electronics out of the accelerator tunnel** and install controllers and controls racks in dedicated electronic/supply rooms.
   - Operation experience at GSI shows a **high failure rate** of active vacuum gauges and gauge controllers **inside of the accelerator tunnel**:
     - In the HEST (high energy beam transport lines at GSI) we have to exchange about **10% of active wide range gauges** per year.
     - During high intensity runs in SIS18 almost **50% of the controllers** for passive ion gauges (extractor type) failed. ⇨ extractor gauge controllers were removed out of the tunnel.

   - ➢ In case of a failure of the electronics the controller can be changed without access to the tunnel
   - ➢ long cables (power and signal) for all devices required

Status:

- The system design is **95% finalized** yet.
- Therefore the concepts, types and numbers of components may slightly change in one or the other place during finalization of the system design.

Properties of Vacuum Chambers

- All vacuum chambers will be made out of stainless steel grades: 1.4301, 1.4306/1.4307, 1.4404, 1.4429, 1.4435, Böhler P506
- Most of the flanges will be ConFlat type flanges with Cu-sealing
- Flange material: 1.4429 ESU, 1.4307
- Dimensions of the flanges: DN40 – DN450
- High complexity of accelerators, high number of different components

⇨ Magnetic Permeability for magnet vacuum chambers: ≤1.01

⇨ Outgassing rate: $\leq 5 \times 10^{-10}$ mbar l/s/cm^2 ($\leq 1 \times 10^{-12}$ mbar l/s/cm^2, baked)

⇨ Leak rate: $< 1 \times 10^{-10}$ mbar l/s

⇨ Vacuum firing to reduce stress and magnetic permeability after welding and – for bakeable machines – low hydrogen outgassing rates

Pumping Concept Beam Vacuum

For roughing and during bake-out:

- Mobile & fixed stand alone pumping stations consisting of a turbomolecular pump, roughing pump & periphery

⇒ ~140 pcs for beam vacuum (~50 fixed, ~90 mobile)

For Keeping the Vacuum:

- Fixed Turbomolecular Pumps with Roughing Pumps (Super-FRS and p-Linac) ⇨ ~ 50 pcs
- Ion Getter Pumps (contract with Agilent Technologies) ⇨ ~ 500 pcs
- NEG/IGP Combination Pumps (contract with SAES getters) ⇨ ~ 180 pcs
- NEG Cartridge Pumps (contract with SAES getters) ⇨ ~ 130 pcs
- NEG wafer modules ⇨ ~ 40 pcs
- Cryosorption Pumps in SIS100 (design by GSI and built by ILK Dresden) 85 pcs
- NEG Coating of Chambers (done by GSI or external partners)
- Use of cryogenic wall pumping (cryopumping) in SIS100.

Pumping speed and detailed type of pumps based on vacuum pressure calculations and vacuum requirements.

Sectorization of Beam Vacuum System

- The beam vacuum system will be divided into 169 sections separated by gate valves.
- Length of sectors given by physical constraints (cold or warm sectors, branching beam line, maintenance,...).
- Type of valve (all-metal or Viton) defined by radiation level and requirements for bake-out.

  - HEBT: 46 sectors
  - SIS100: 46 sectors
  - CR/TCR1: 8 sectors
  - p-Linac: 8 sectors
  - p-bar Separator: 2 sectors
  - Super-FRS: 37 sectors
  - HESR: 22 sectors

Each sector can be pumped down and operated individually.

System Design – Vacuum Diagnostics

Keep all **electronics out of the accelerator tunnel** and install controllers and controls racks in dedicated electronic/supply rooms.

- Operation experience at GSI shows a **high failure rate** of active vacuum gauges and gauge controllers **inside of the accelerator tunnel**:
  - In the HEST (high energy beam transport lines at GSI) we have to exchange about **10% of active wide range gauges** per year.
  - During high intensity runs in SIS18 almost **50% of the controllers** for passive ion gauges (extractor type) failed. In SIS18 all extractor gauge controllers were removed out of the tunnel.

- ➢ In case of a failure of the electronics the controller can be changed without access to the tunnel
- ➢ long cables (power and signal) for all devices required

Vacuum Diagnostics Beam Vacuum

Use of passive gauges with dedicated controllers!

Total Pressure (type depending on the pressure range)

- Penning/Cold Cathode Gauges → ~ 350 pcs
- Pirani Gauges (at least one per vacuum sector) → ~ 200 pcs
- Hot Cathode Ion Gauges → ~ 55 pcs

Some of these types have to be radiation hard!
Some Cold Cathode Gauges will be installed in cryogenic environment.

Partial Pressure

- Residual Gas Analyzer (only in rings) → ~ 10 pcs

Insulation Vacuum

- VAC is responsible for the pumping and diagnostics of the insulation vacuum for:
  - super conducting magnets in SIS100 and Super-FRS
  - the cryogenic transfer lines and local cryogenics.
- Considered to be a “dirty” vacuum: high content of water and hydrocarbons
- Roughing with mobile & fixed stand alone Pumping Stations consisting of a Turbomolecular Pump, Roughing Pump & peripheral equipment
- Pump down to 10^{-2} mbar before cool down starts, when magnets/He lines are cold, pumping stations will be valved off. Mobile stations will be removed.
- To keep the machines running in the case of a minor leakage in the insulation vacuum, one fixed pumping station per insulation vacuum sector foreseen.

Vacuum Controls and Bake-Out System: Industrial Control System

Realisation of vacuum controls and vacuum bake-out system is a close collaboration between Controls Department and Vacuum department:

- Controls Department is responsible for controls hard- and software
- Vacuum Department is responsible for vacuum hardware controllers (pumps, gauges, …)

Control system implemented on CRYRING as a prototype for the FAIR vacuum control system (operational since 2017).

UNILAC vacuum control system upgraded in 2019 to FAIR standards.

The operational experience gained here, is taken into account for the design of FAIR.

Vacuum Control System Principles

The Vacuum control system and the vacuum bake-out systems are industrial control systems based on:

  - Siemens SIMATIC S7 PLC's
  - WinCC OA SCADA System running on CentOS LINUX server
  - UNICOS framework from CERN, which provides automatic code generation for PLC and SCADA database

- Communication between SCADA server and PLC's via ACC network
- Communication between PLC's via completely isolated Ind. Ethernet
- SCADA HMI will be accessible from FCC as well as locally and from office machines
- Operation of vacuum gate valves and visualisation of the main pressure value of each section will be integrated into the GUI's of ACC control system
- Long term archiving will be available within the Controls Archive
- Short term archiving will be available within the WinCC OA SCADA

Transparency provided by C. Betz (GSI)

Vacuum Equipment to be controlled

Number of Vacuum Components to be controlled:

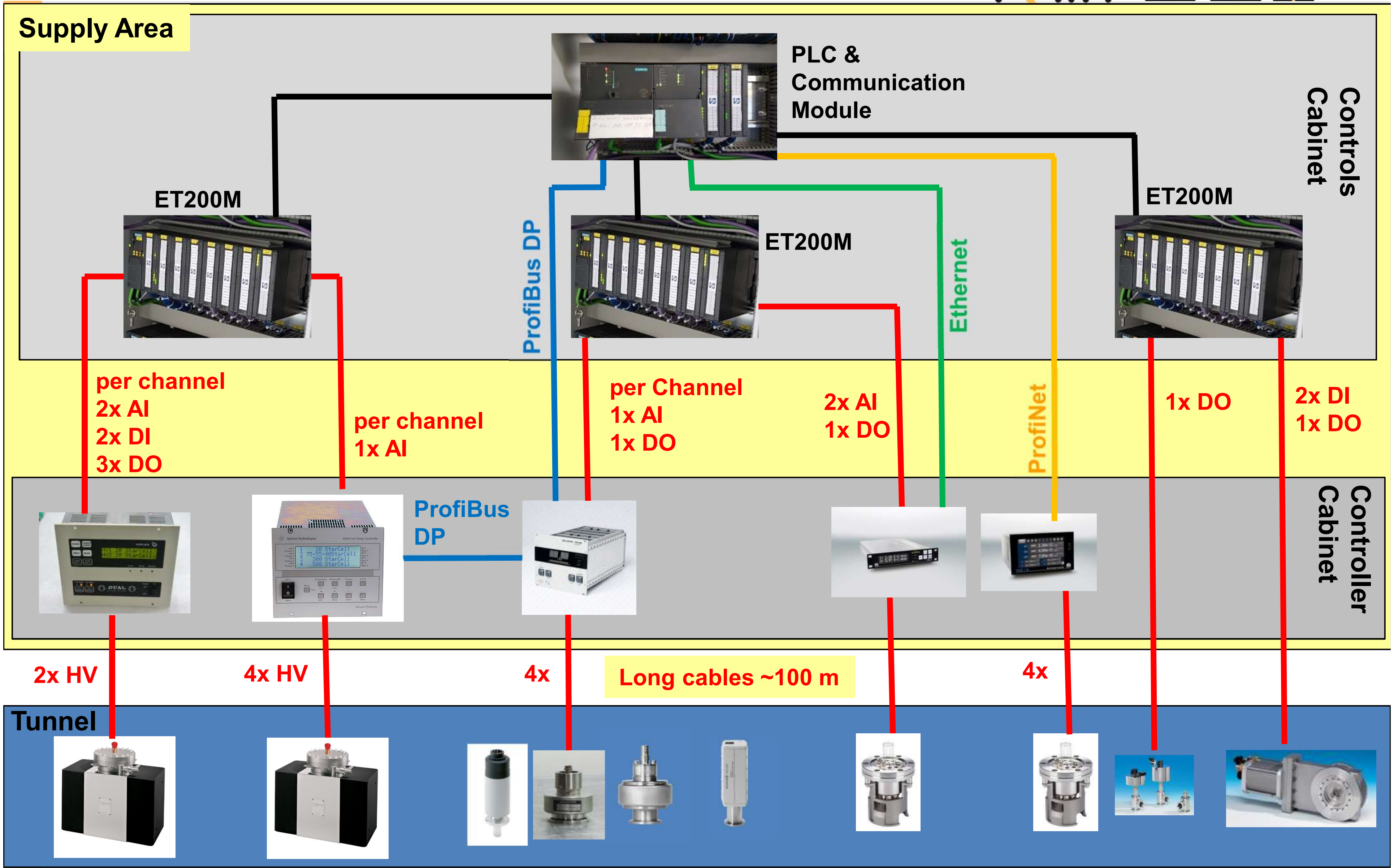
- Pumps: ~ 1250
- Gauges: ~ 1000
- Valves: ~ 500
- Bake-out Jackets, Thermocouples, thermal cut-out devices: ~ 4000 each

Chosen Interface/Protocol Type

- ProfiNet DP (to control the controllers) 1. Choice!
- ProfiBus (to control the controllers)
- Modbus TCP under evaluation
- in addition: Combination of Digital and Analogue I/O's (for redundancy, reboot,...)

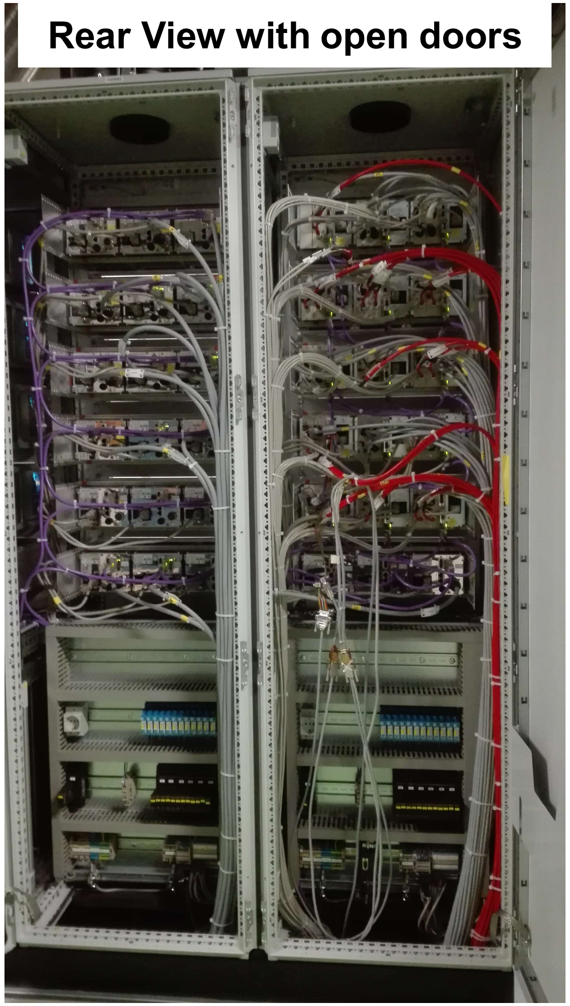
The full functionality of the controller should be available via the interface!

Schematic Setup of Vacuum Controls (from CRYRING)



Controller Cabinets for Vacuum Control System
(example from UNILAC)

Controller Cabinets (UH011-UH22)



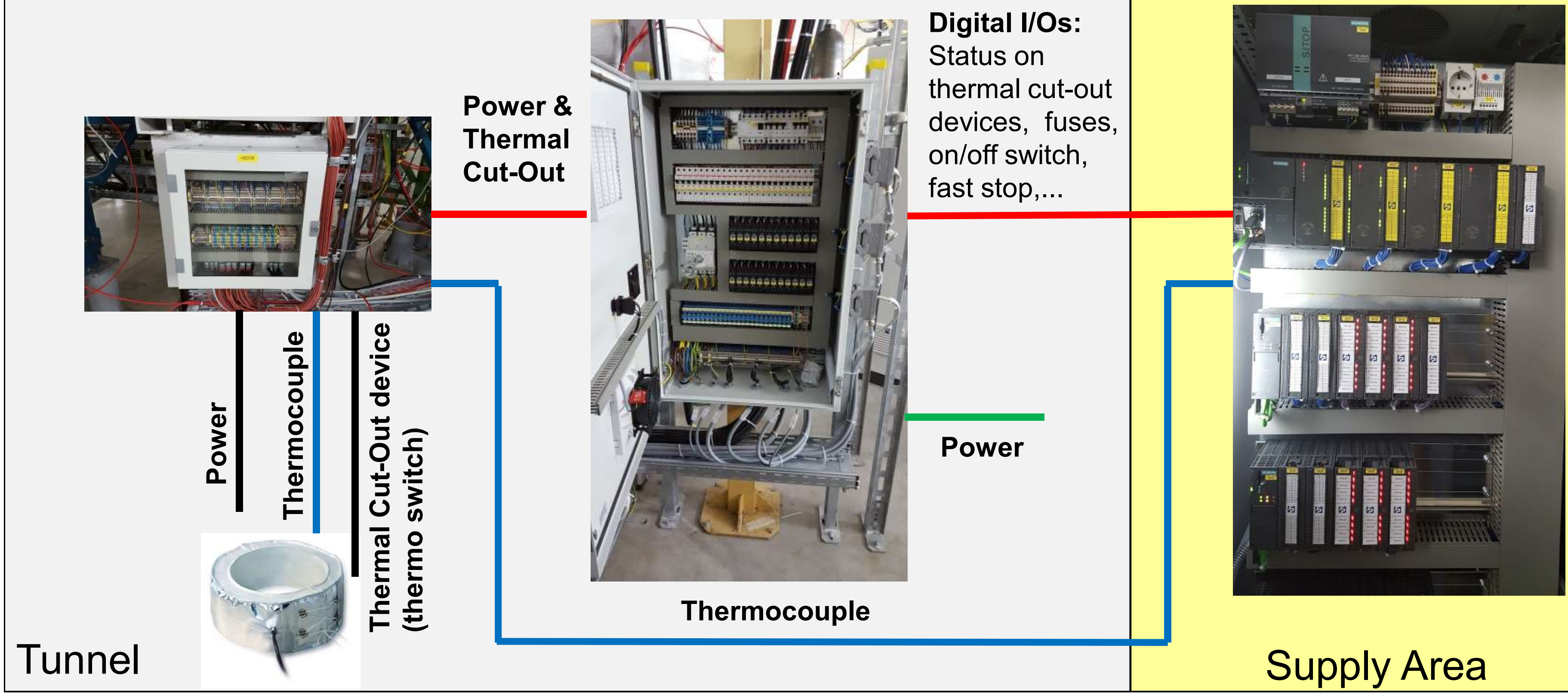
Controls Cabinets
(for PLC components)

Bake-Out Control System
(example CRYRING)

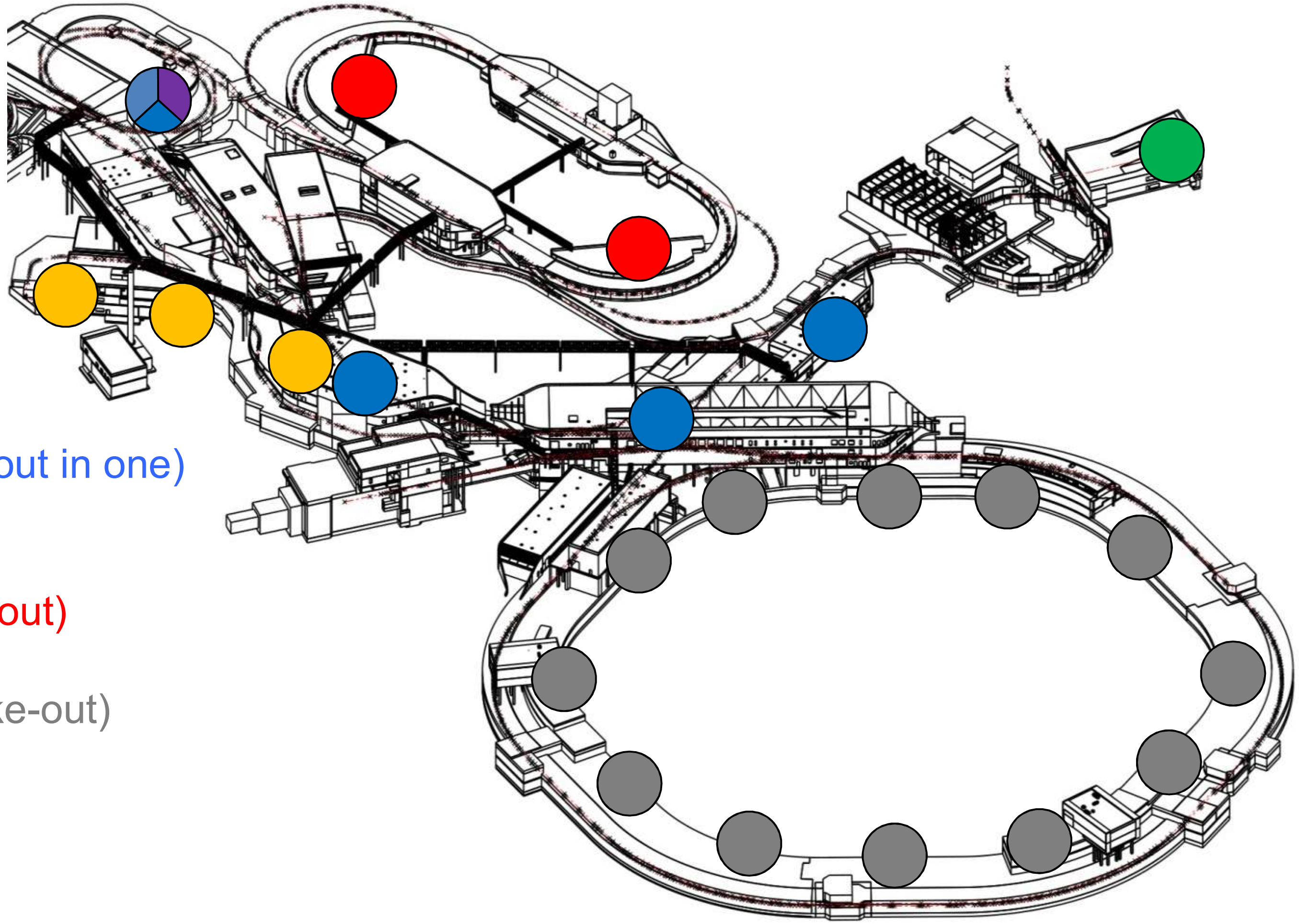
Terminal Box
(Power for Bake-Out Jackets,
Thermocouple,
Thermal Cut-Out Device)
Temperature Compensation
(transition from thermocouple to Cu wire)
8 Channels (in total 42 pcs)

Power Control Rack
Cabinet with Solid State Relay & Fuses
(deliver Power to bake-out jackets)
24 Channels (Supplies three Terminal Boxes)
(in total 14 pcs)

PLC rack
contains PLC & PID controllers,
I/O modules
Controls six Power Controls Racks
with max 144 control circuits each
(in total 3pcs with 336 control circuits)



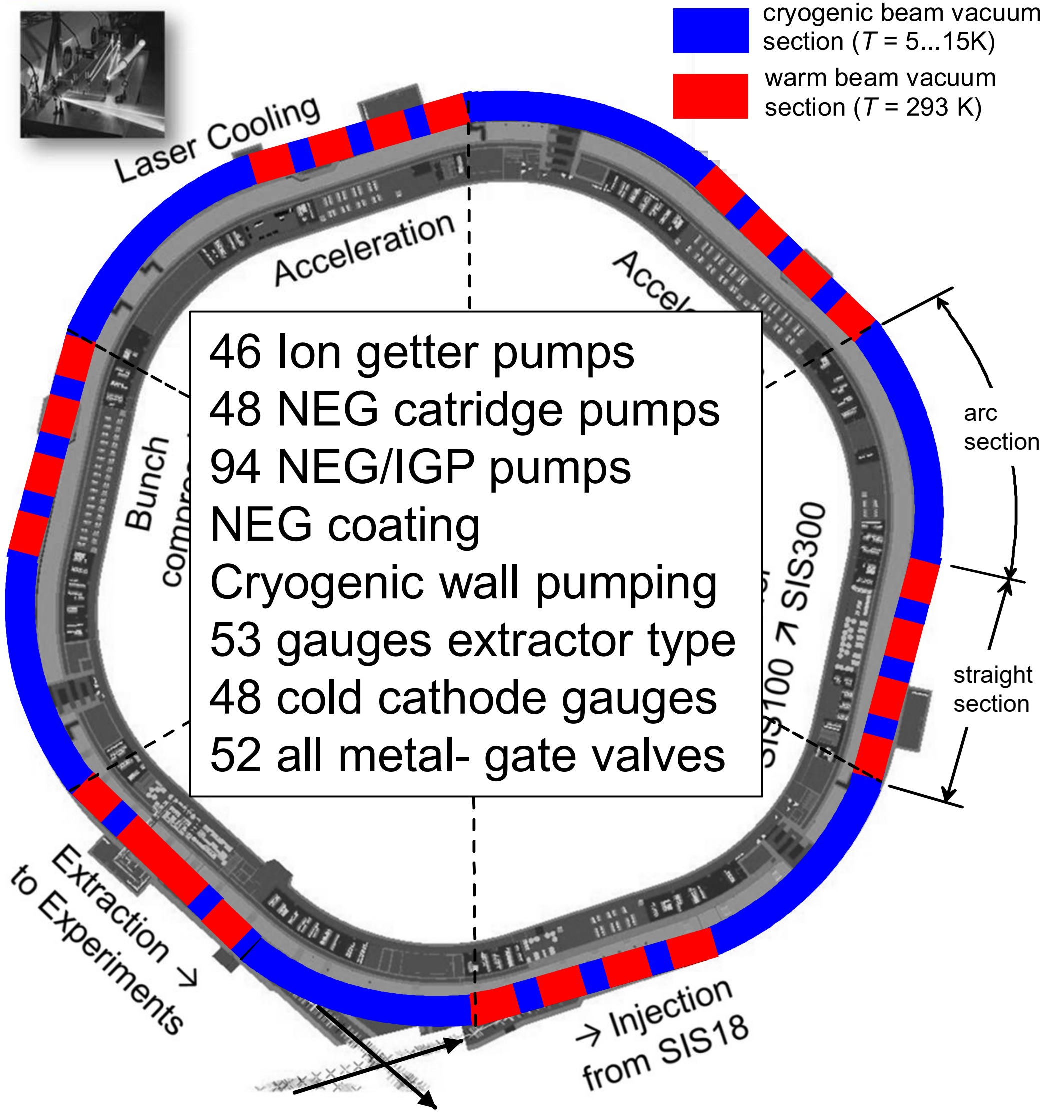
Vacuum Supply Areas (Electronic rooms)
Beam Vacuum



- 4x HEBT (incl. bake-out in one)
- 1x CR
- 1x pbar
- 2x HESR (incl. bake-out)
- 3x Super-FRS
- 10x SIS100 (incl. bake-out)
- 1x p-Linac

Vacuum controls and controllers for beam vacuum and bake-out are distributed over 22 different electronic rooms at FAIR to keep cables „short“. But still the lenght is up to ~300m in some cases.

Vacuum System SIS100



- Circumference: ~1083m
- 46 vacuum sectors
- ~895 m (82%) beam vacuum system will be operated at cryogenic temperatures (5…15 K), → 23 cryogenic sections (6 long arcs à 135 m, & 17 short straights à ~5 m)
- ~187 m (18%) are designed as bakeable room temperature operated UHV system → 23 straight warm sections (22 à ~7 m + 1 à ~19 m)

Average residual hydrogen density must be

$\mathbf{N_{max} < 8 \cdot 10^{+11}\ m^{-3}\ (H_2)}$

accepting 2% beam losses (aim for reference cycle RIB cycle 2.7GeV U^{28+})

Maximum allowed average beam **vacuum pressure must be**

→ $\mathbf{p_{cold}\ (H_2) < 1 \cdot 10^{-12}\ mbar\ (T = 10K)}$

→ $\mathbf{p_{warm}\ (H_2) < 3 \cdot 10^{-11}\ mbar\ (T = 293K)}$

SIS100: Dipole & Quadrupole Chamber Design

The dipole and quadrupole chambers represent 81% of the total surface in the cryogenic sectors.

Problem:
Fast ramping of the magnets induces eddy currents
- The chamber walls are heated up.
- Generation of additional harmonics in field.

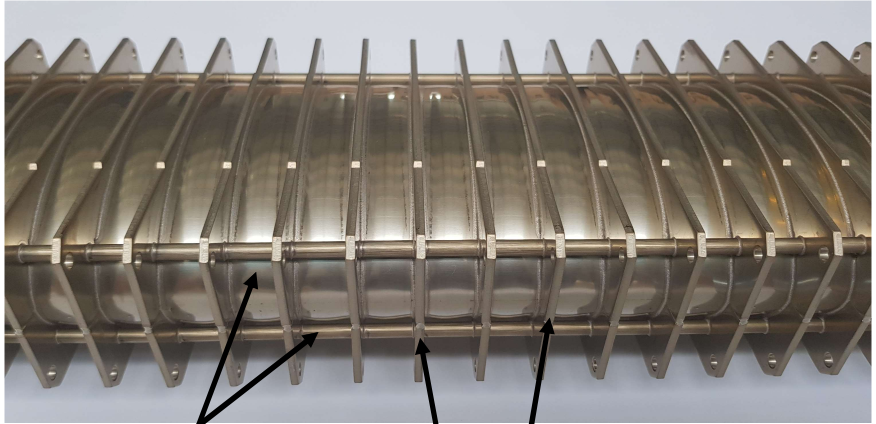
Chamber design was optimized in terms of:

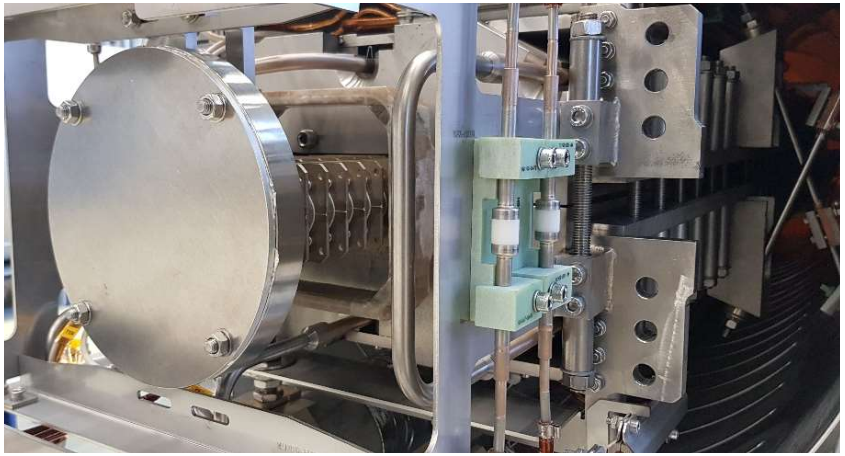
- Low wall temperatures during magnet ramping to assure effective H_2 cryopumping
- field quality (additional harmonics)
- beam dynamic aspects (e.g. impedances)

Solution:
- Thin-walled chamber (d = 0.3 mm) with ribs for stiffening
- Special stainless steel Böhler P506 (X 2 Cr Mn Ni Mo N 19 12 11 1) with μ_r = 1.002 at 4.2 K [also used for LHC beamscreen]
- Cooling of chamber with supplementary cooling tubes

Dipole Chambers SIS100

L~3,4m
Aperture: 120x60mm^2
Bending angle 3.33°



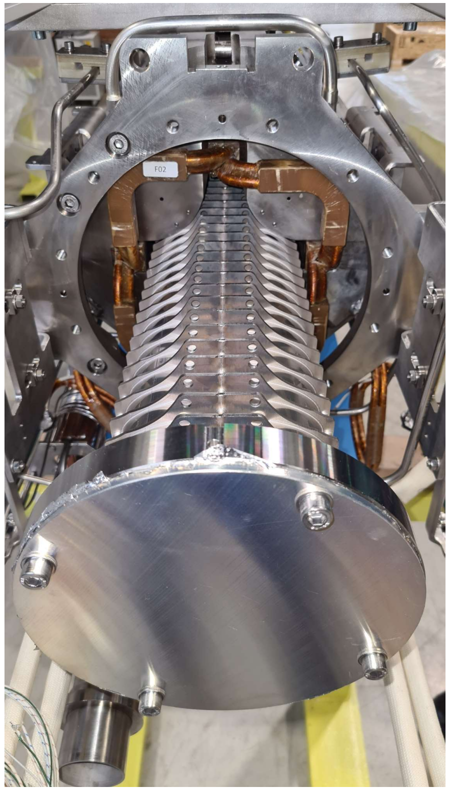


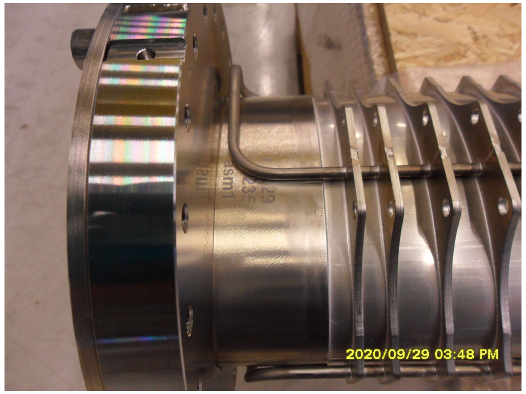
Status

- Series production running at Pink Vakuumtechnik.
- 55 out of 115 chambers delivered
- Integration on dipole magnets will start 02/2021

Quadrupole chambers SIS100

11 different types (short and long)
Length: between ~1.3m and ~2.7m
Aperture: 133x65mm^2





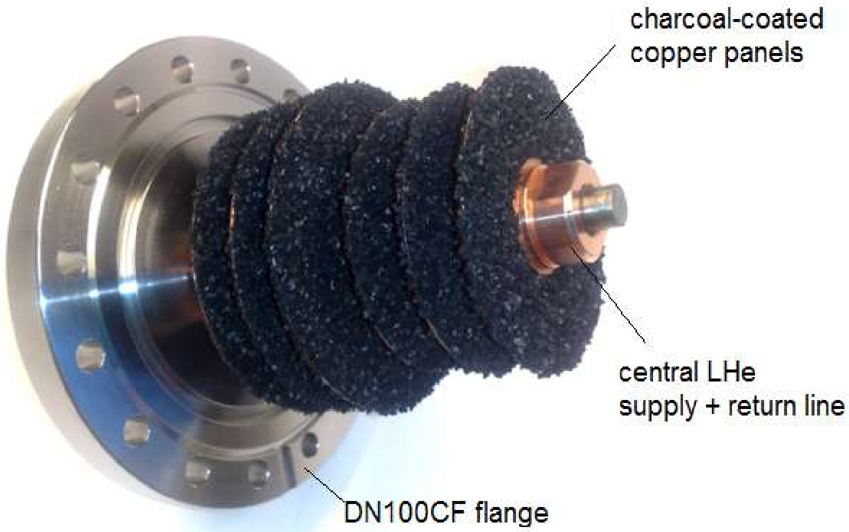
Status

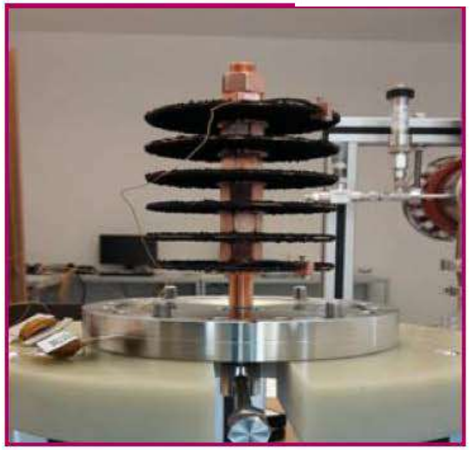
- Elliptical Chambers series production at Research Instruments ongoing, 12pcs out of 185pcs produced
- Integration into quadrupole module at Babcock Noell (BNG) started

Development of SIS100 Cryosorption Pumps for Cryogenic Sections

In-house development of a pump prototype with charcoal type SC2

Status:
Contract with ILK Dresden
All 87 pumps delivered and tested

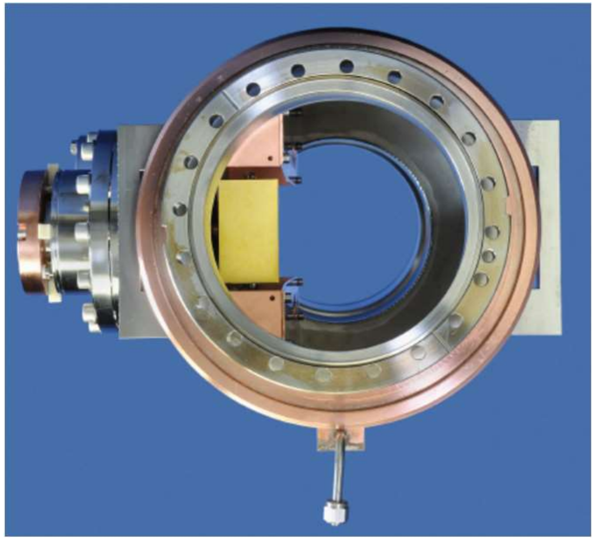


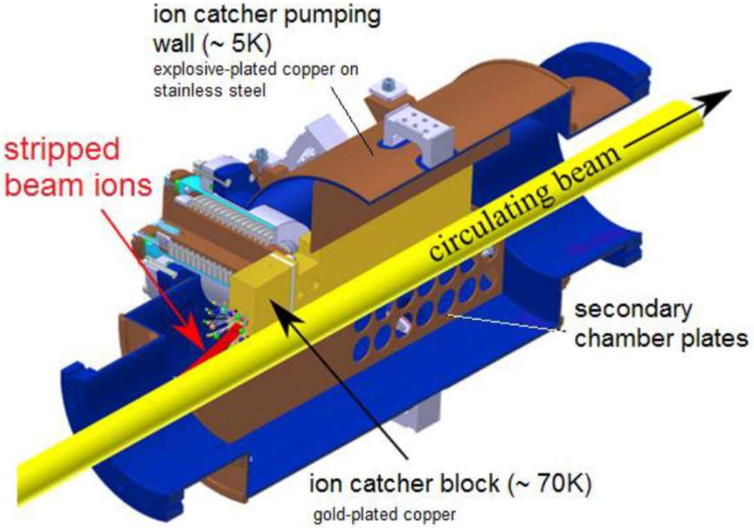


Adsorption pump prototype developed and tested at GSI with outstanding hydrogen pumping characteristics

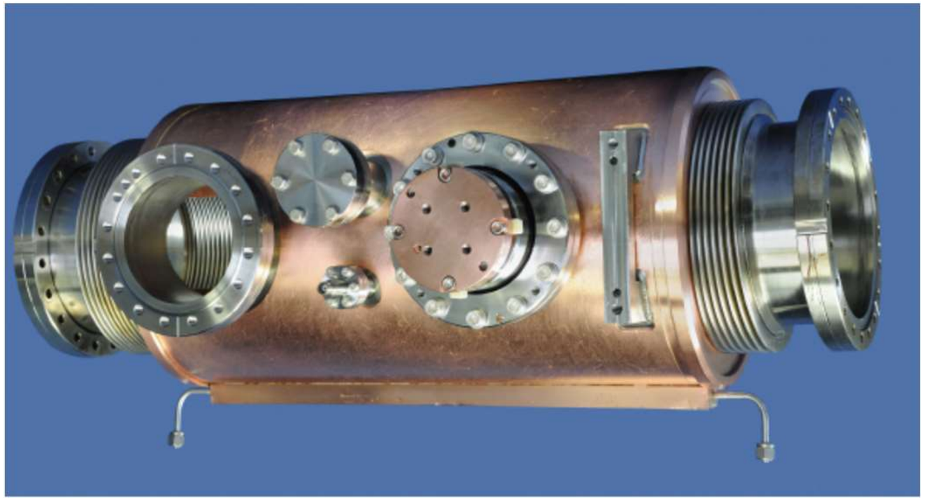
SIS100 Cryocatcher

- Controlled catching of ionized ions on surfaces with low desorption yield (gold) → most ionized ions are caught by the ion catcher
- Surrounding cold chamber acts as cryopump quickly removing desorbed gases
- Cryocatcher block will be kept at a higher temperature to prevent gases from cryosorbing on the surface of incidence
- Significant reduction of gas desorption → dynamic vacuum effects are suppressed effectively
- Activation and radiation damage of magnets by beam losses are reduced



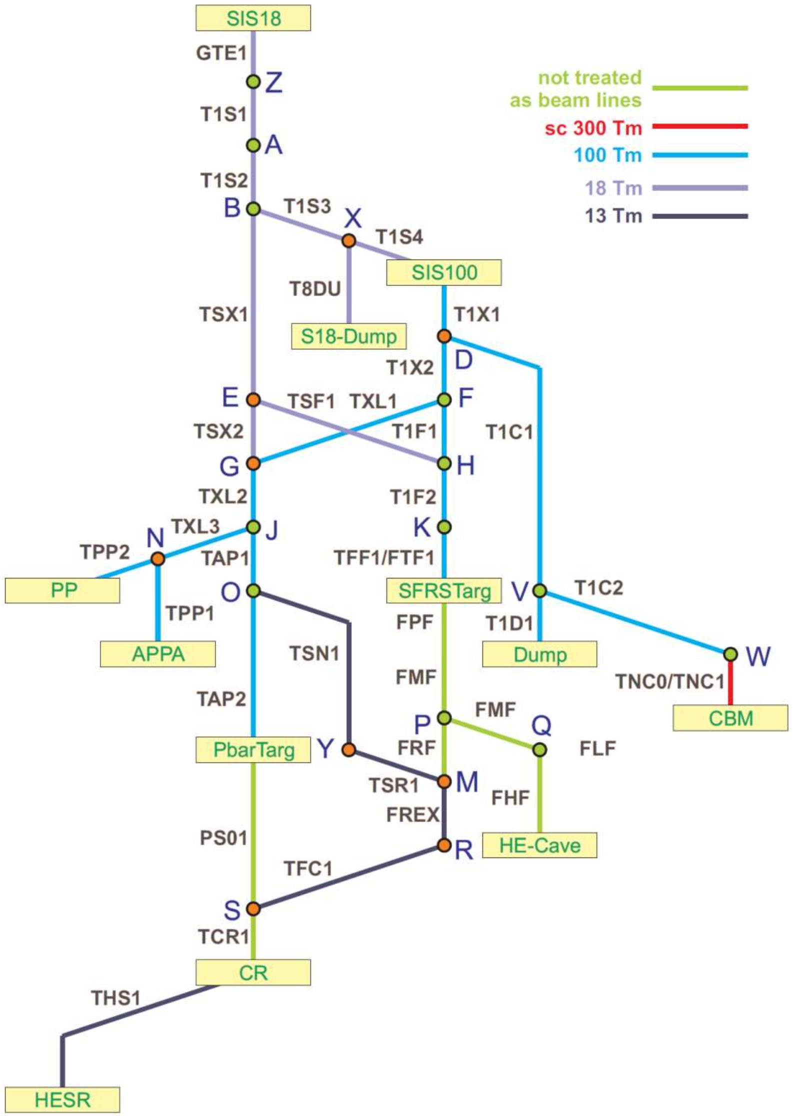


developed by L Bozyk (GSI)
PhD thesis, University Darmstadt (Germany), 2012



Pictures courtesy of L. Bozyk, Proc. IPAC 2018,
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF084

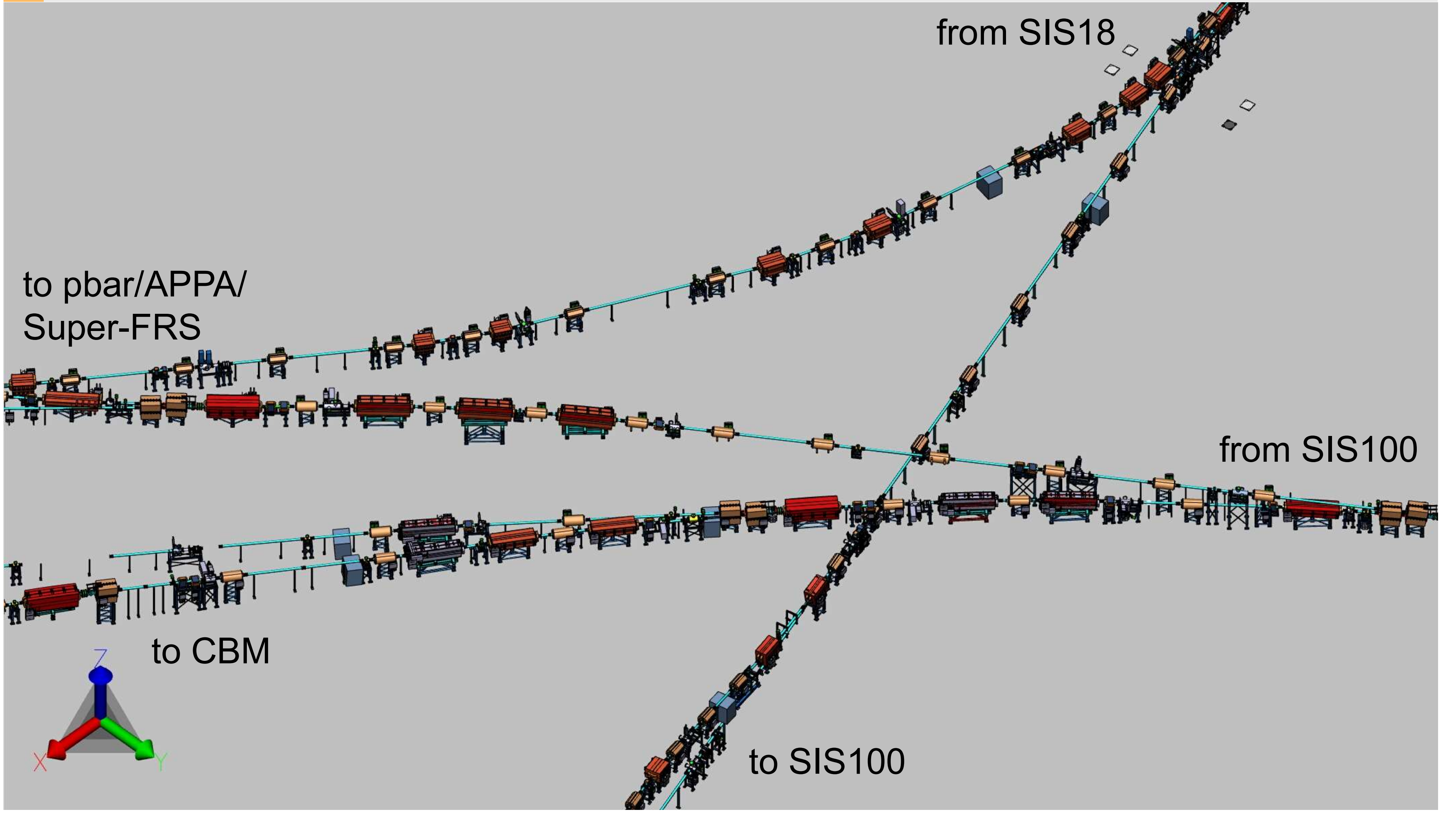
Schematic Layout of HEBT



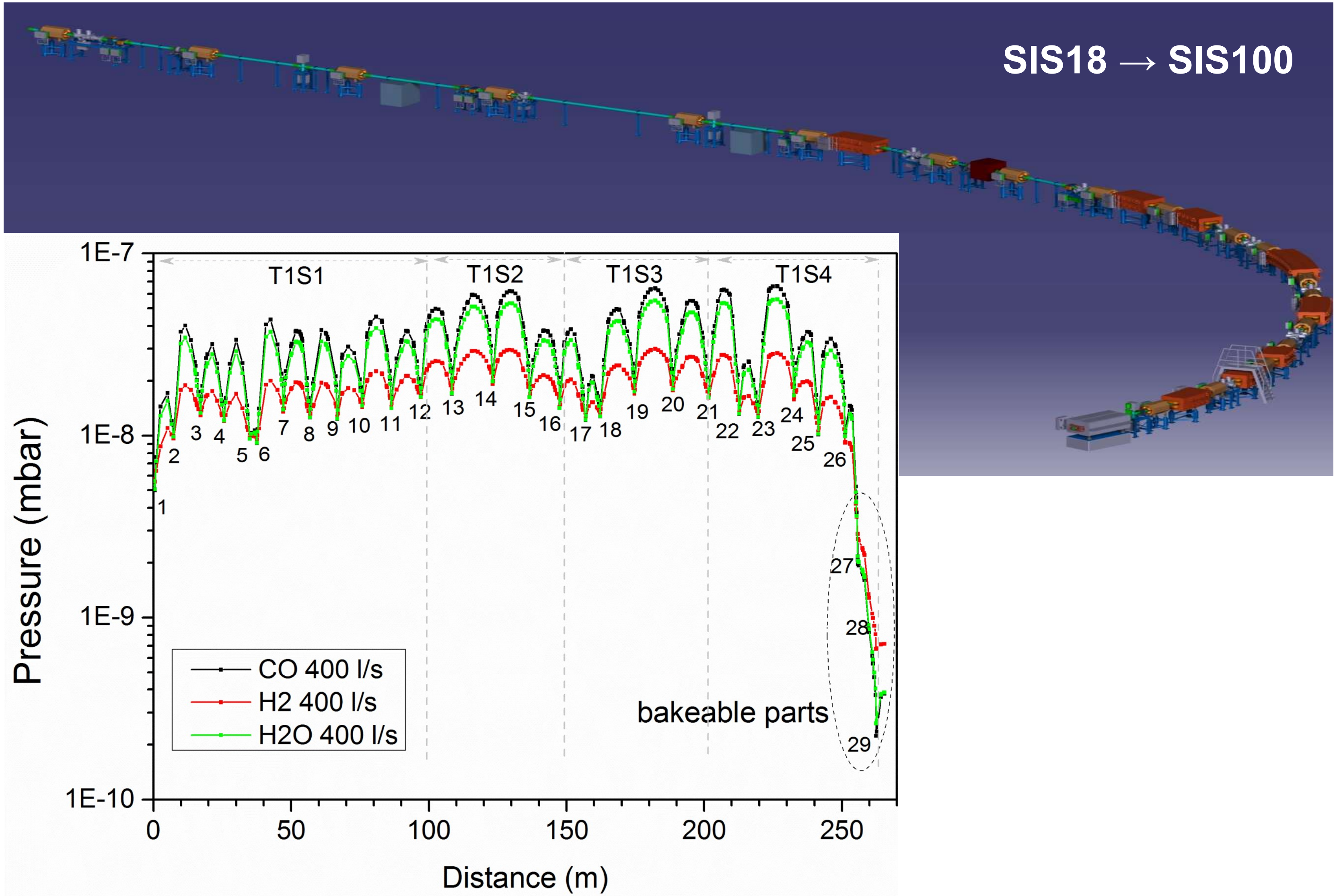
- Beam line length: about 1500 m
- p ≈ 1×10^{-8} mbar, non bakeable
- only sections directly connected to SIS100, will be baked up to 300°C to achieve a vacuum of 1×10^{-10} to 1×10^{-11} mbar
- 46 vacuum sectors, length between 10 and 50 m
- 55 gate valves (Viton and all-metal)
- Pumped by ~150 ion getter pumps
- Beam Pipe Aperture DN100CF – DN400CF

Most vacuum chambers to be produced by Budker Institute of Nuclear Physics BINP, Russia

3D Model of part of HEBT

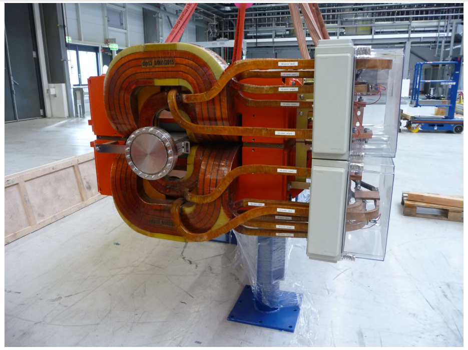


Pressure Profile Simulations of HEBT (using MOLFLOW+)



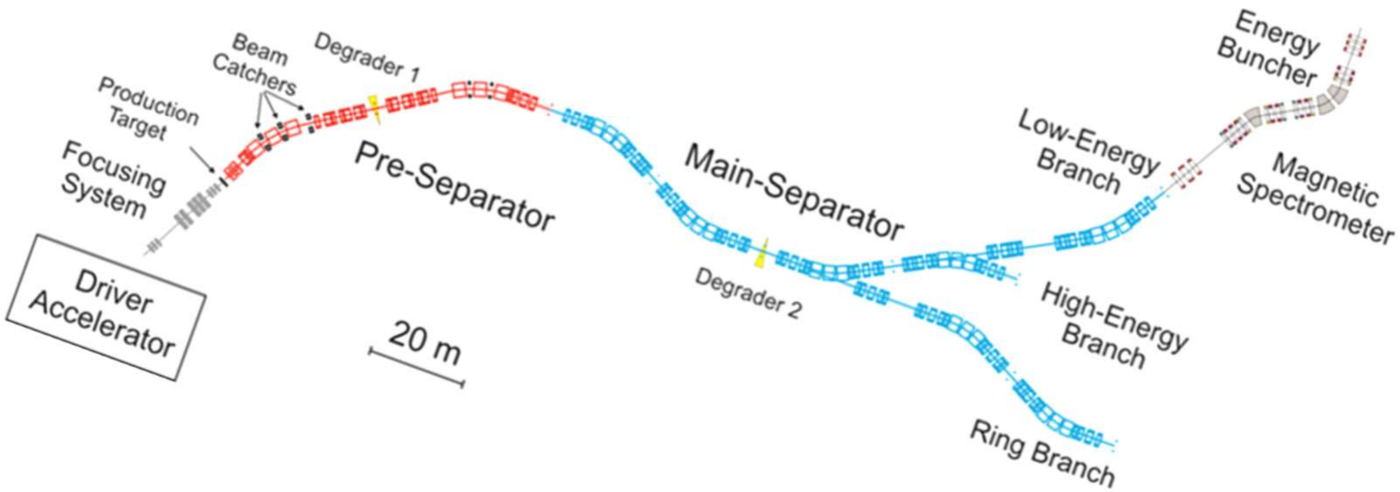
Dipole Chambers of HEBT produced by BINP (Russia)

- All 51 Chambers of Batch 1 delivered to GSI, SAT passed, 10 installed in magnets LUKAS????
- Batch2&3 (~280 additional magnet vacuum chambers)
- contracted, chambers under production

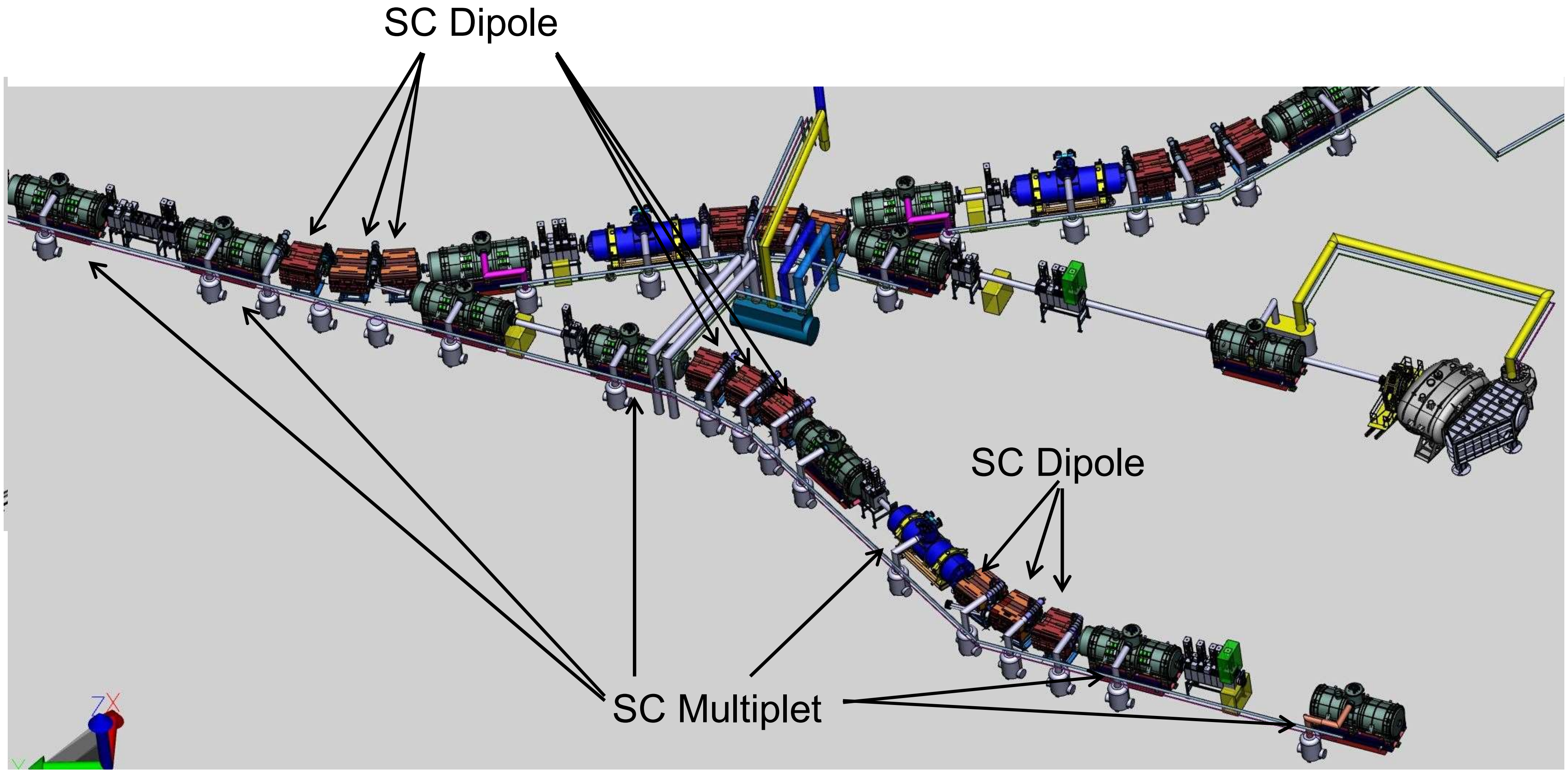


Schematic Layout of the Super-FRagment Separator (Super-FRS)

- High radiation at target area and first separator stage
- Large aperture vacuum chambers and valves (DN400), normal conducting and superferric magnets (insulation vacuum)
- Total length: ~350 m
- Required vacuum: ~ $1x10^{-6}$ - $1x10^{-7}$ mbar
- Complex vacuum system due to remote handling in target area (pillow seals and inflatable bellows) and large number of focal plane chambers (20 pcs) with a lot of insertions for the experiments
- 21 diagnostic chambers, 21 standard sc dipole chambers and most of other chambers to be produced by Budker Institute of Nuclear Physics (BINP) Russia, contracts signed
- Pumped by combination of ~55 ion getter pumps & ~30 TMPs (1000l/s)

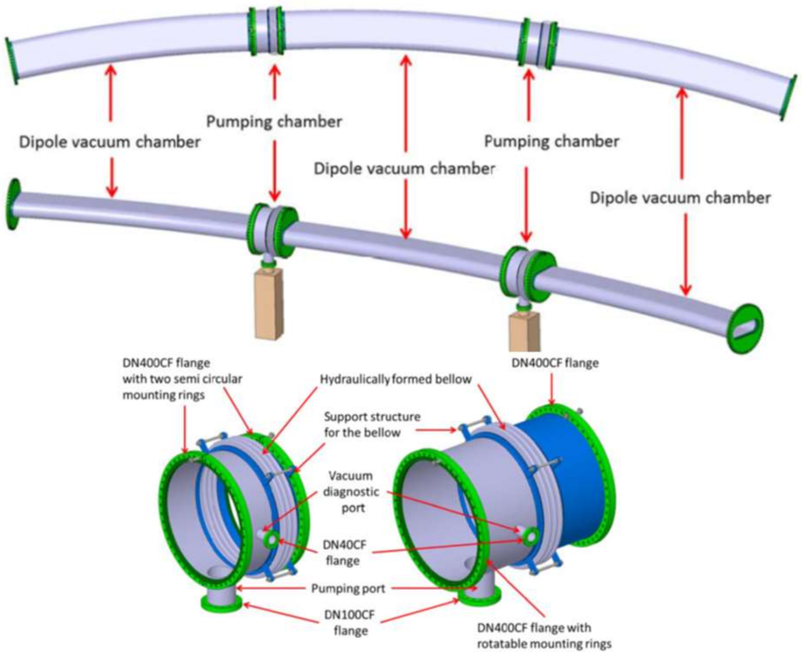


3D Model of Super-FRS

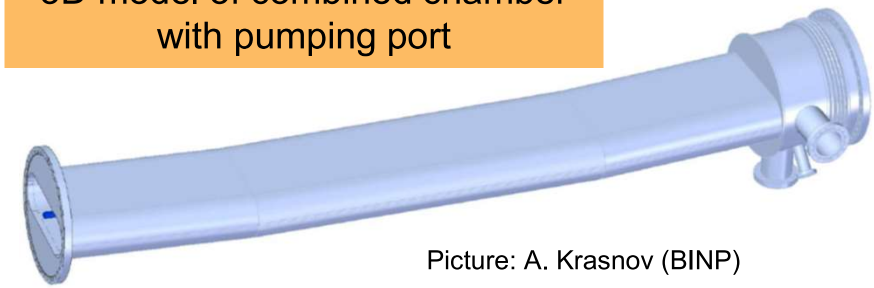


SuperFRS SC Dipole Chambers

Standard Dipole Stage

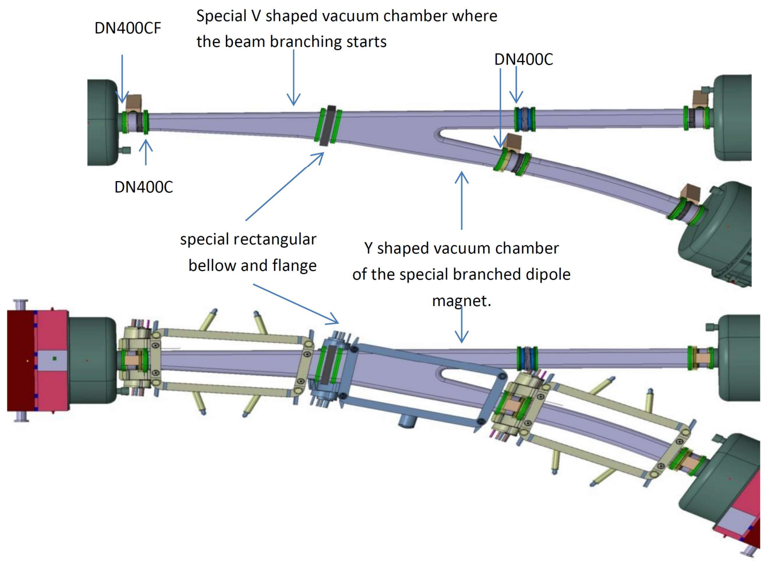


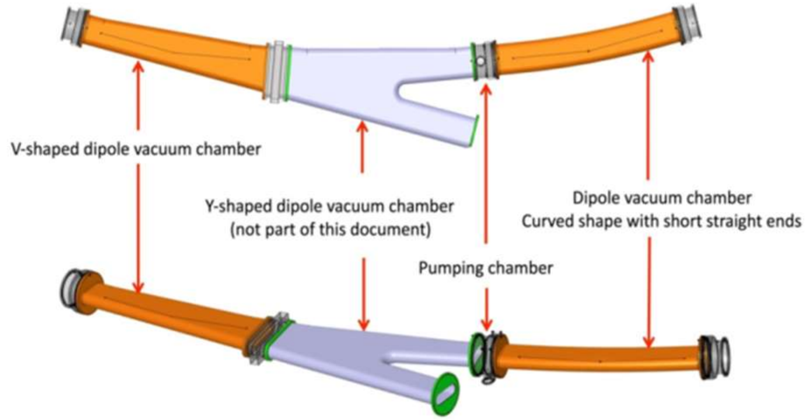
3D model of combined chamber with pumping port



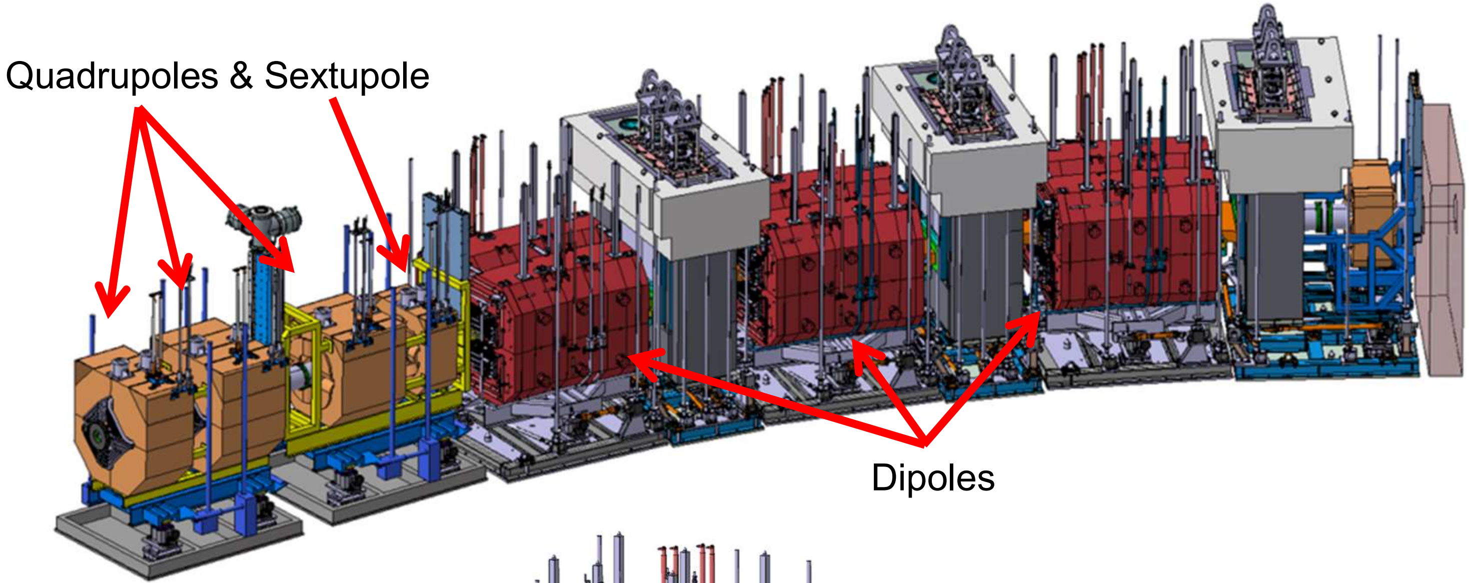
Picture: A. Krasnov (BINP)

Branching Dipole Stage





Chambers for Radiation Resistant Dipole Magnets in Target Area SuperFRS

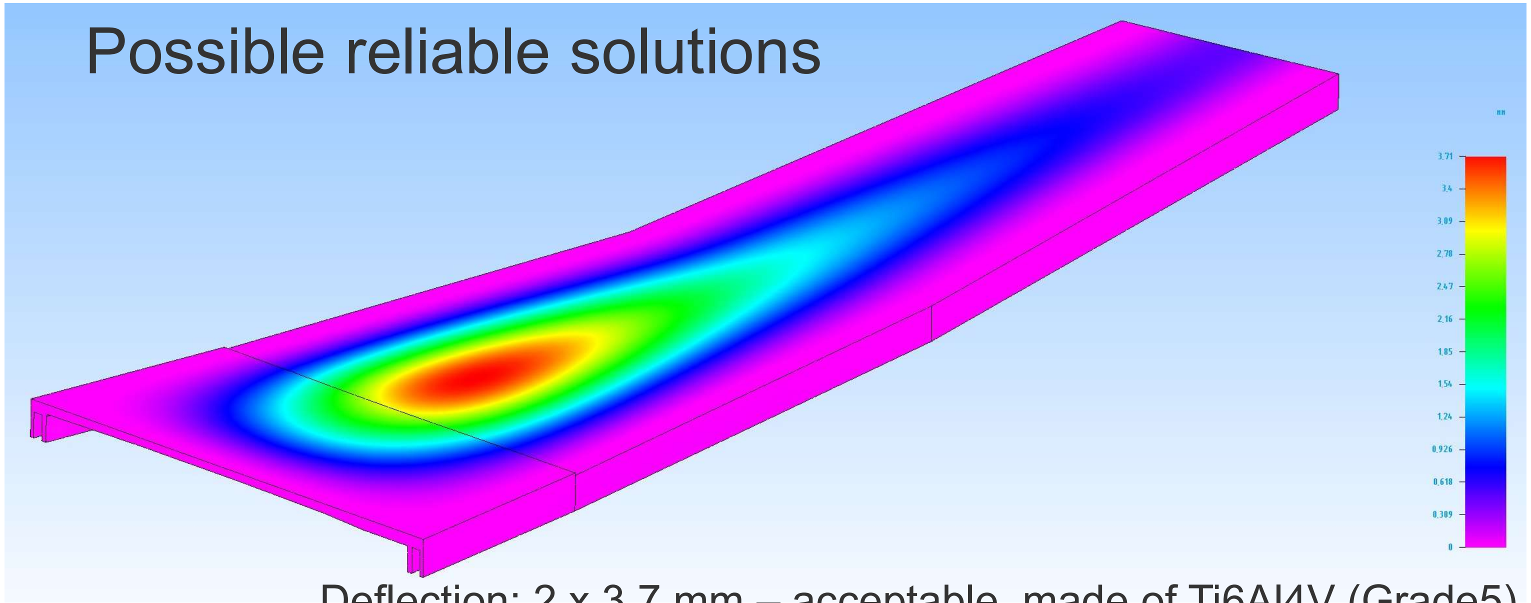


dipole magnet ≈95 ton
aperture of yoke: 1200x180mm
overall length of magnet: 3.2m

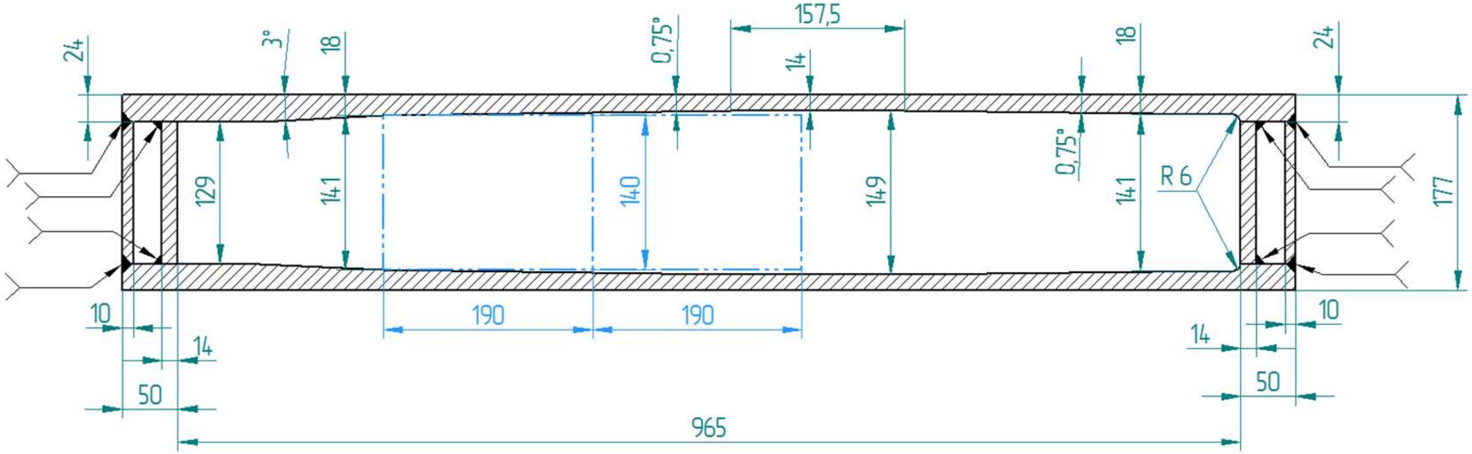
Problem:
Dipole chamber will absorb P = 3 W/cm^2, Energy 4.5 J per pulse

R&D for SFRS NC dipole chamber

Possible reliable solutions

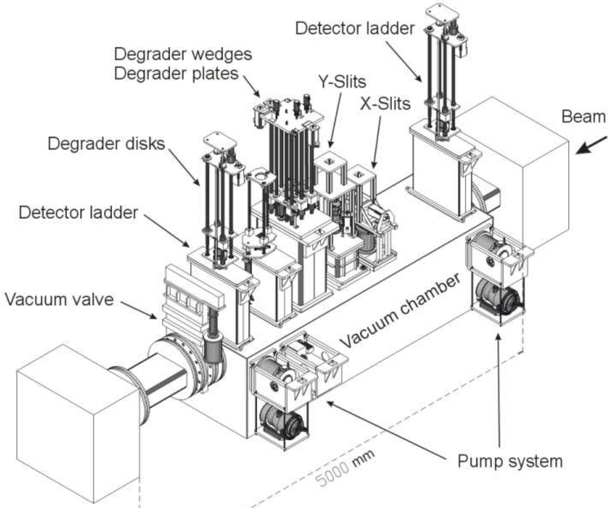


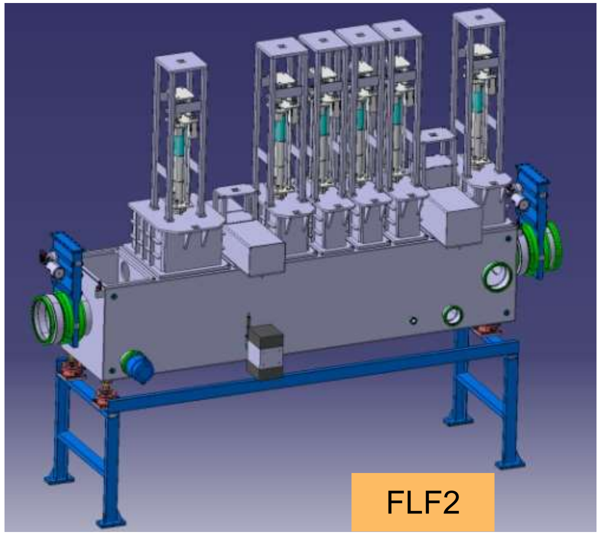
Deflection: 2 x 3.7 mm – acceptable, made of Ti6Al4V (Grade5)

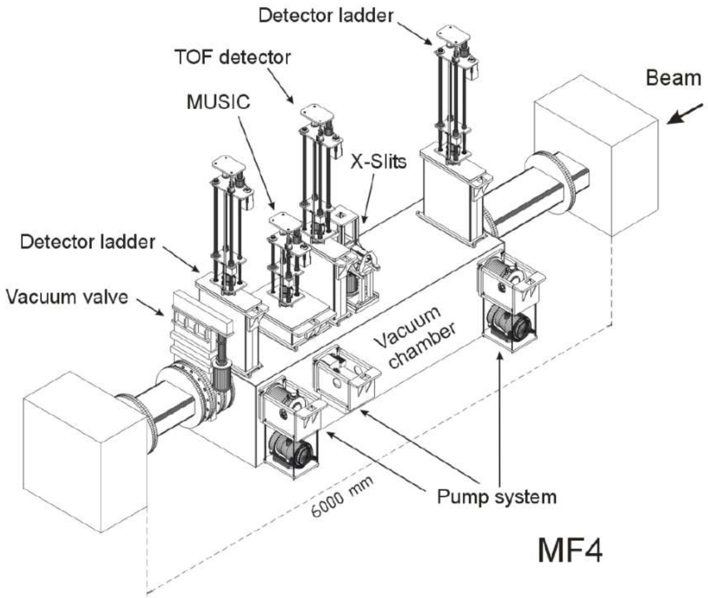


Pictures courtesy of A. Krasnov (BINP)

SuperFRS Diagnostic Chambers

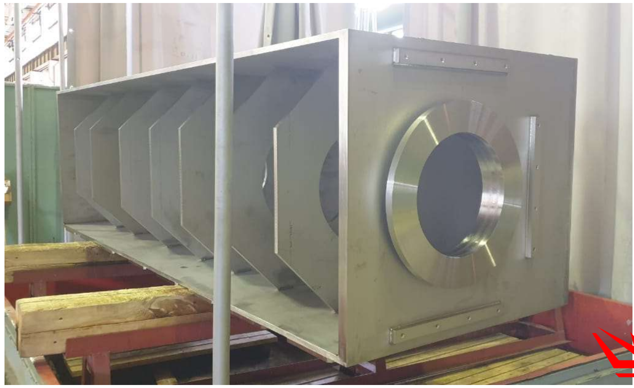






FoS is produced@BINP!

Shipment to FAIR in Q1/2021

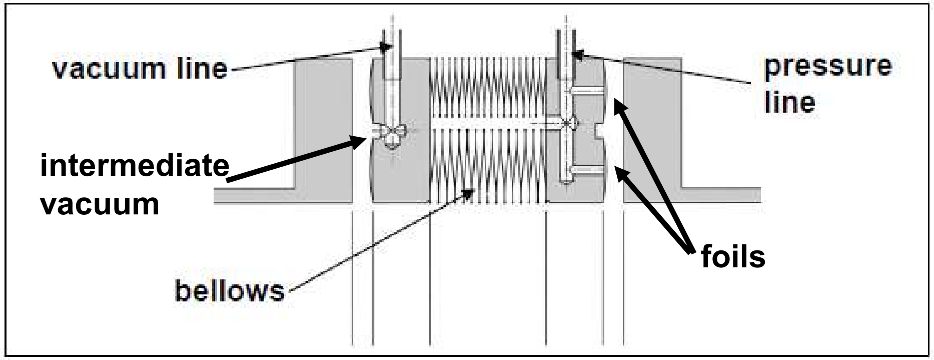


Pictures courtesy of A. Krasnov (BINP)

Remote Controlled Pillow Seal for Super-FRS

(Transparancy provided by Super-FRS group)

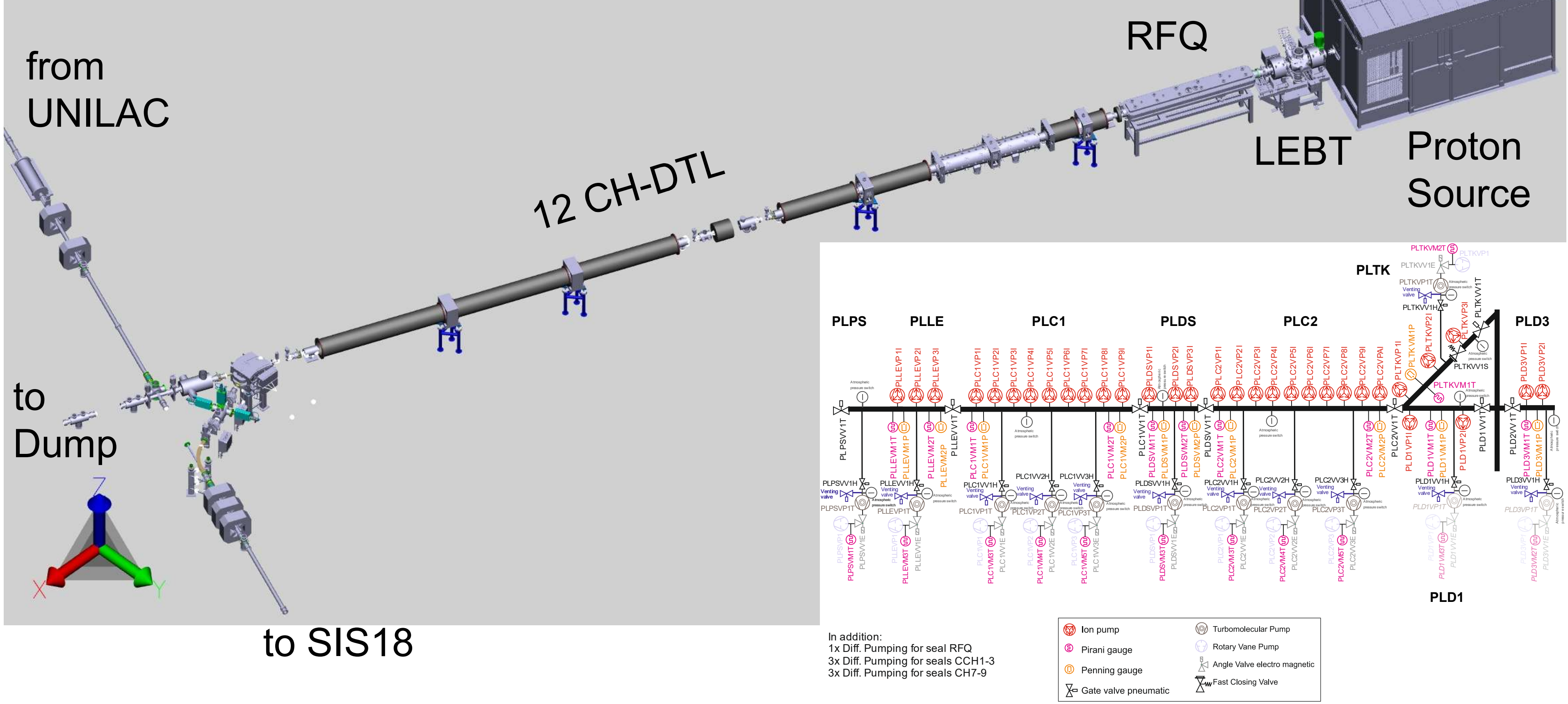
Principle



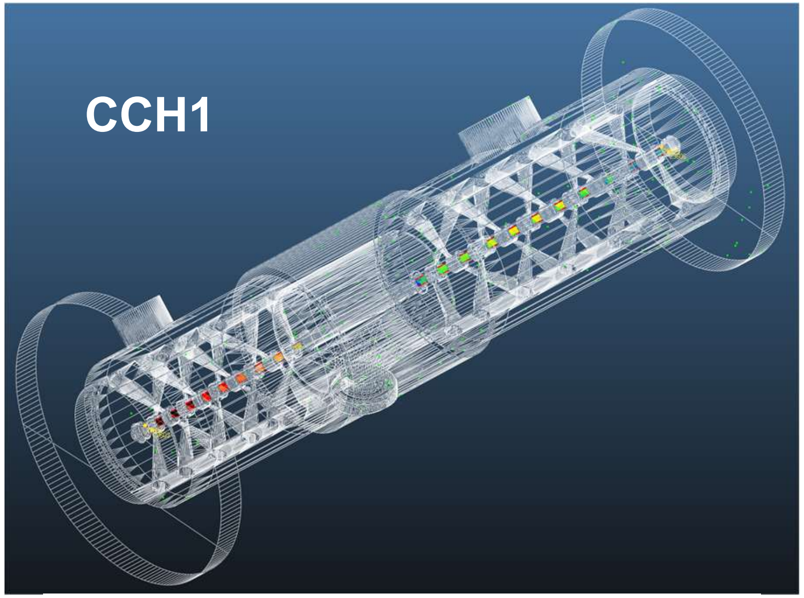
MEWASA

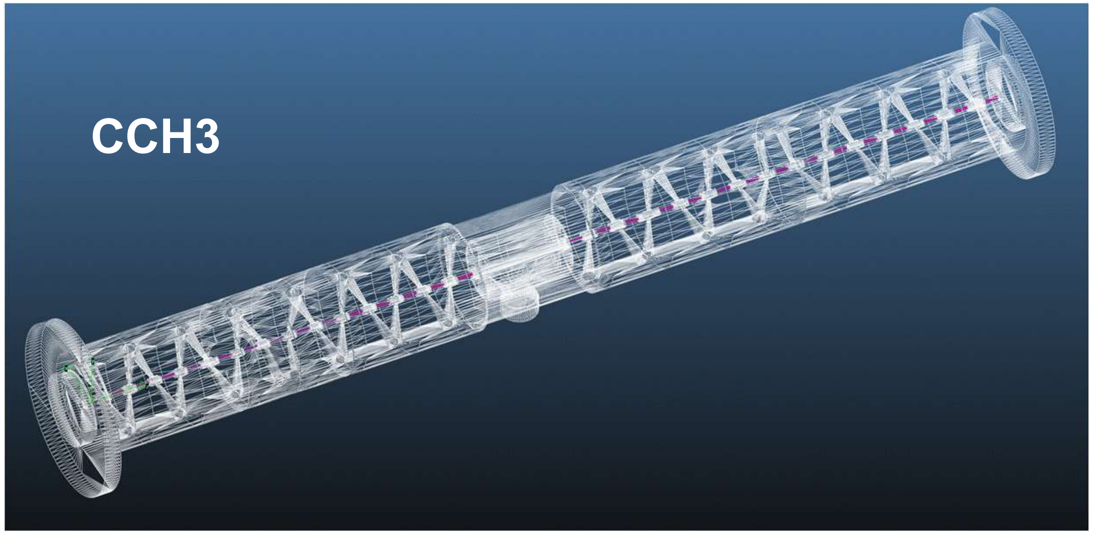
Proton-LINAC (p-Linac)

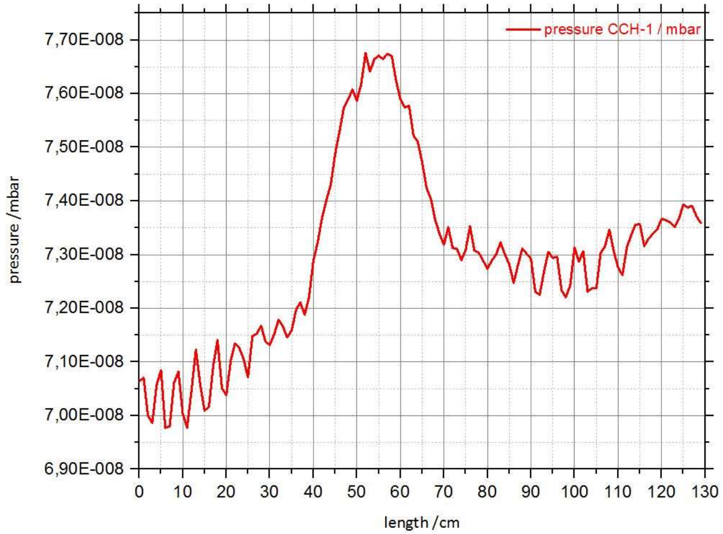
- Length: 35 m, small aperture ~30-100 mm
- Required Vacuum ~10^{-7} - 10^{-8} mbar
- Pumped with ~30 ion getter pumps & ~12 TMP pumping stations
- 8 vacuum sectors
- ~16 Penning and Pirani gauges

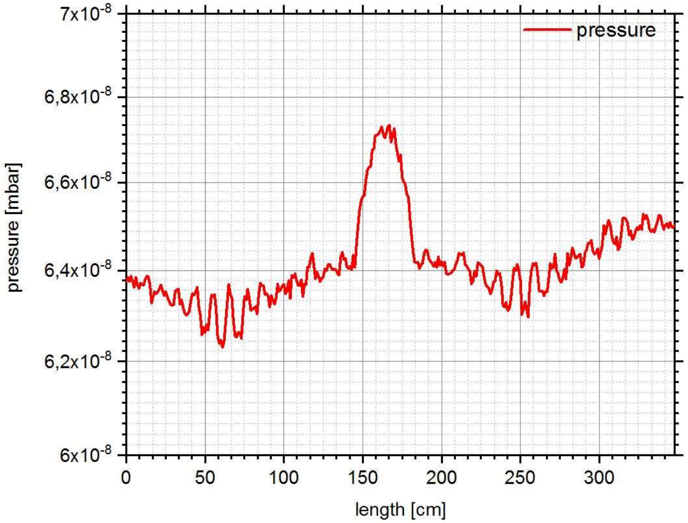


Vacuum Simulation p-Linac

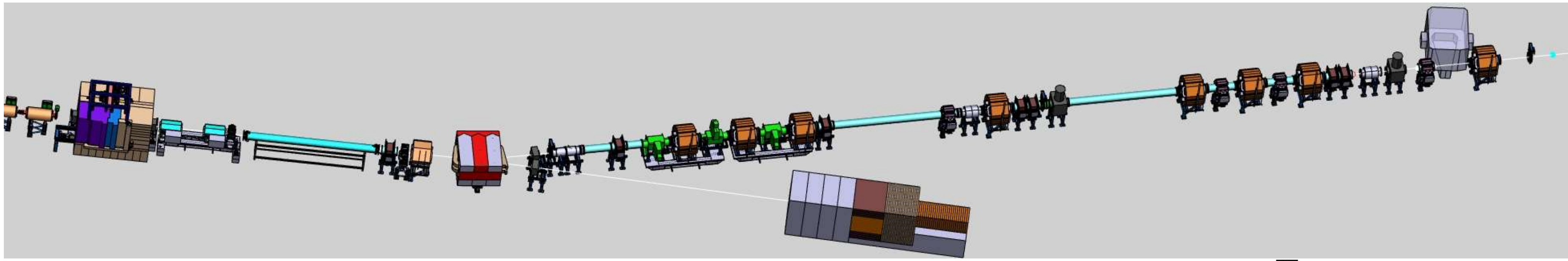


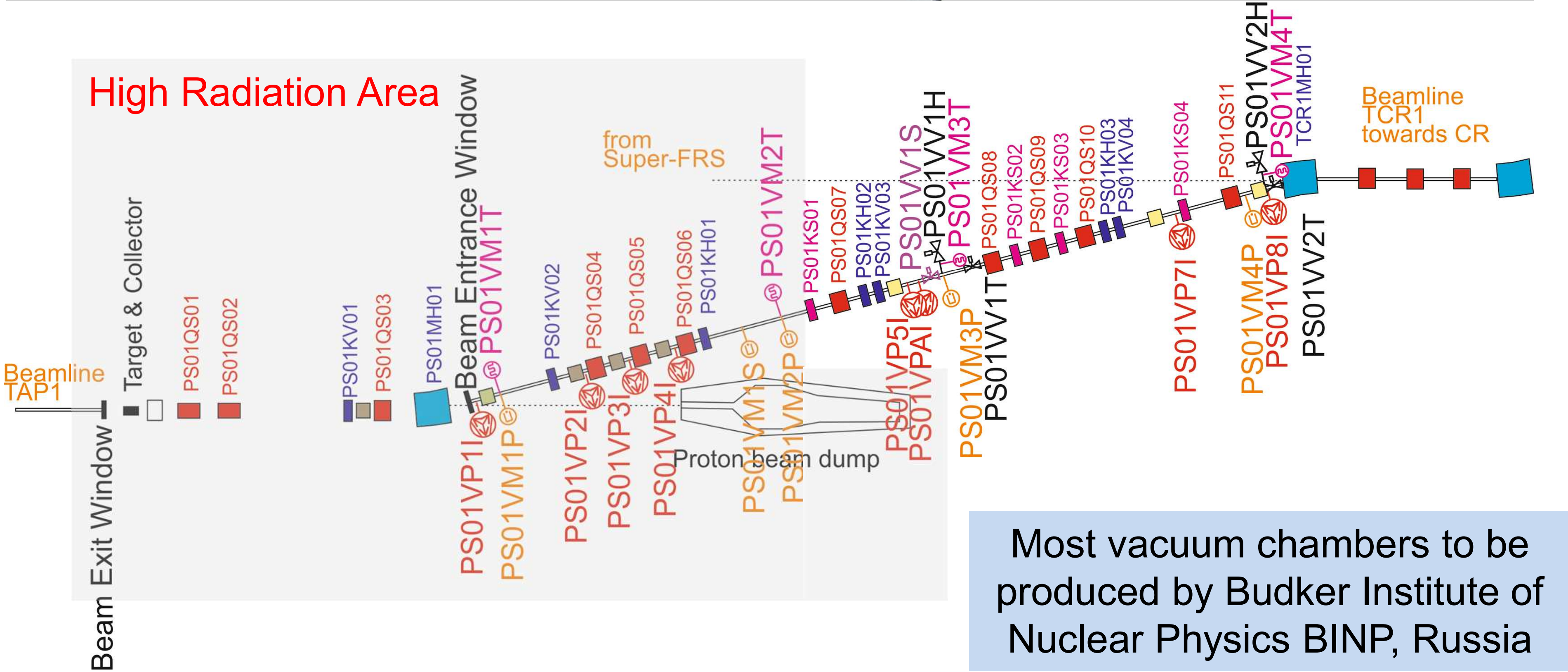






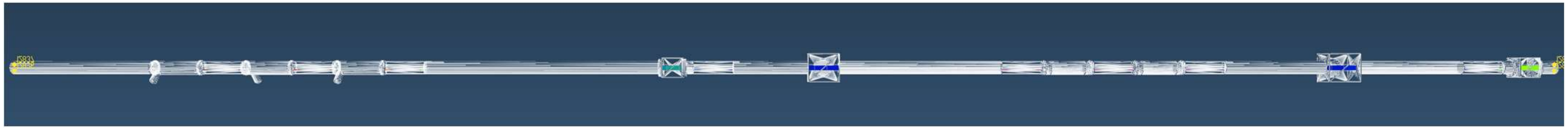
pbar-Separator:
3D Model and Vacuum Layout

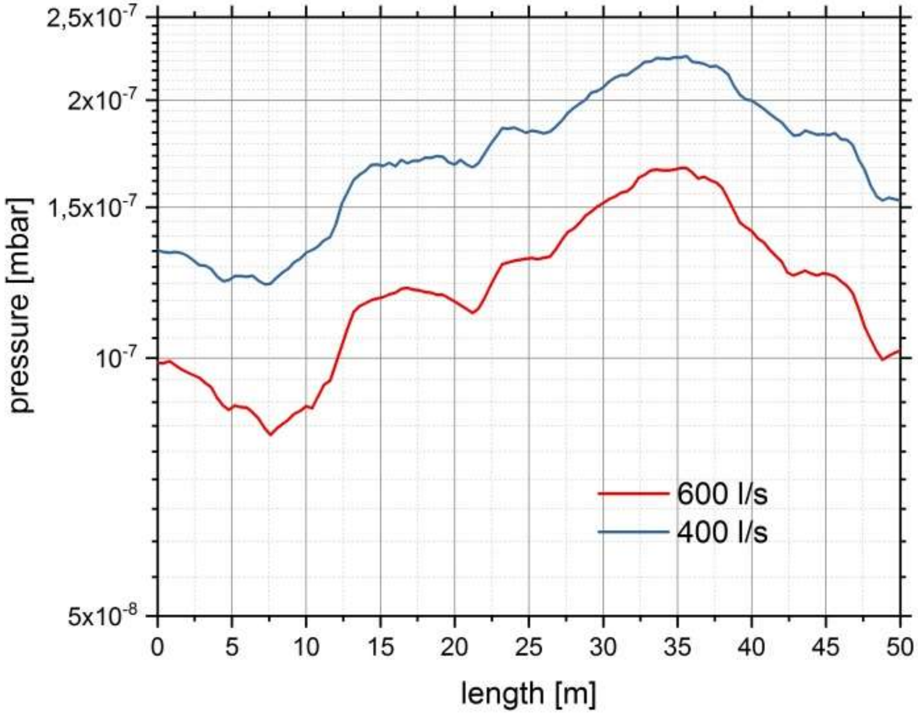




Most vacuum chambers to be produced by Budker Institute of Nuclear Physics BINP, Russia

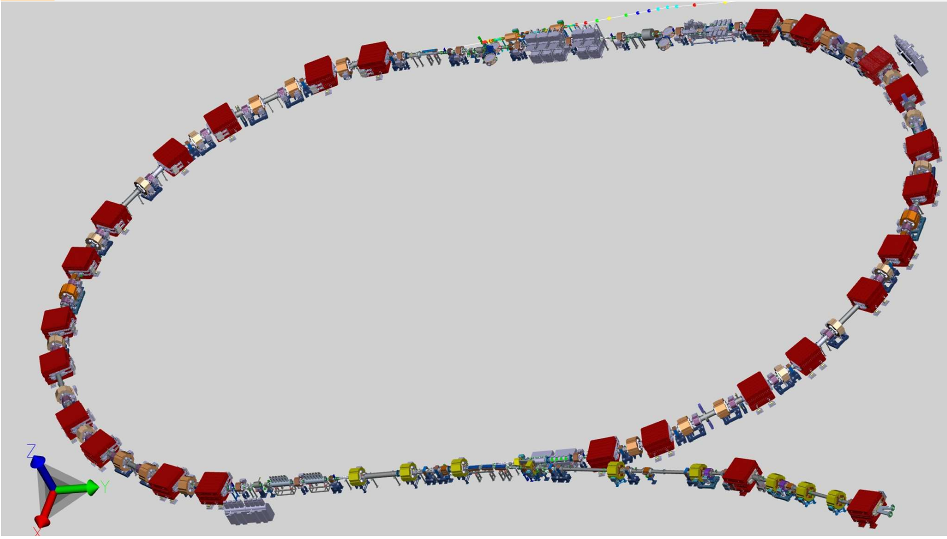
pbar-Separator
Pressure Profile Calculations (MOLFLOW+)



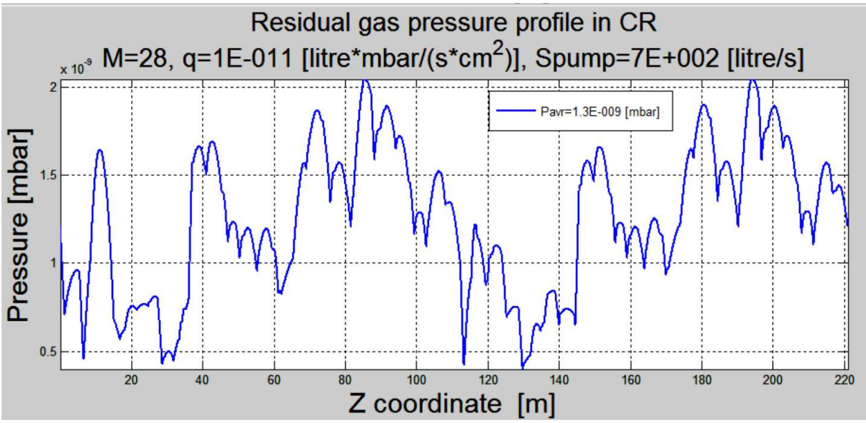


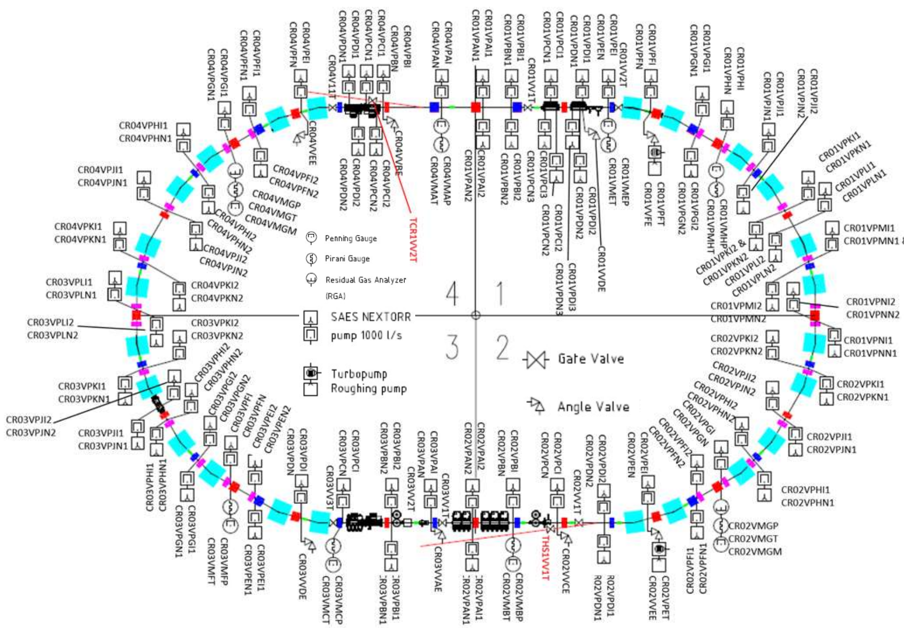
- Required Vacuum ~10^{-8} mbar
- Large Aperture Vacuum Chambers with d=400mm
- 2 vacuum sectors
- Pumped by eight ion getter pumps

Collector Ring (CR)
(Design & Construction by BINP)



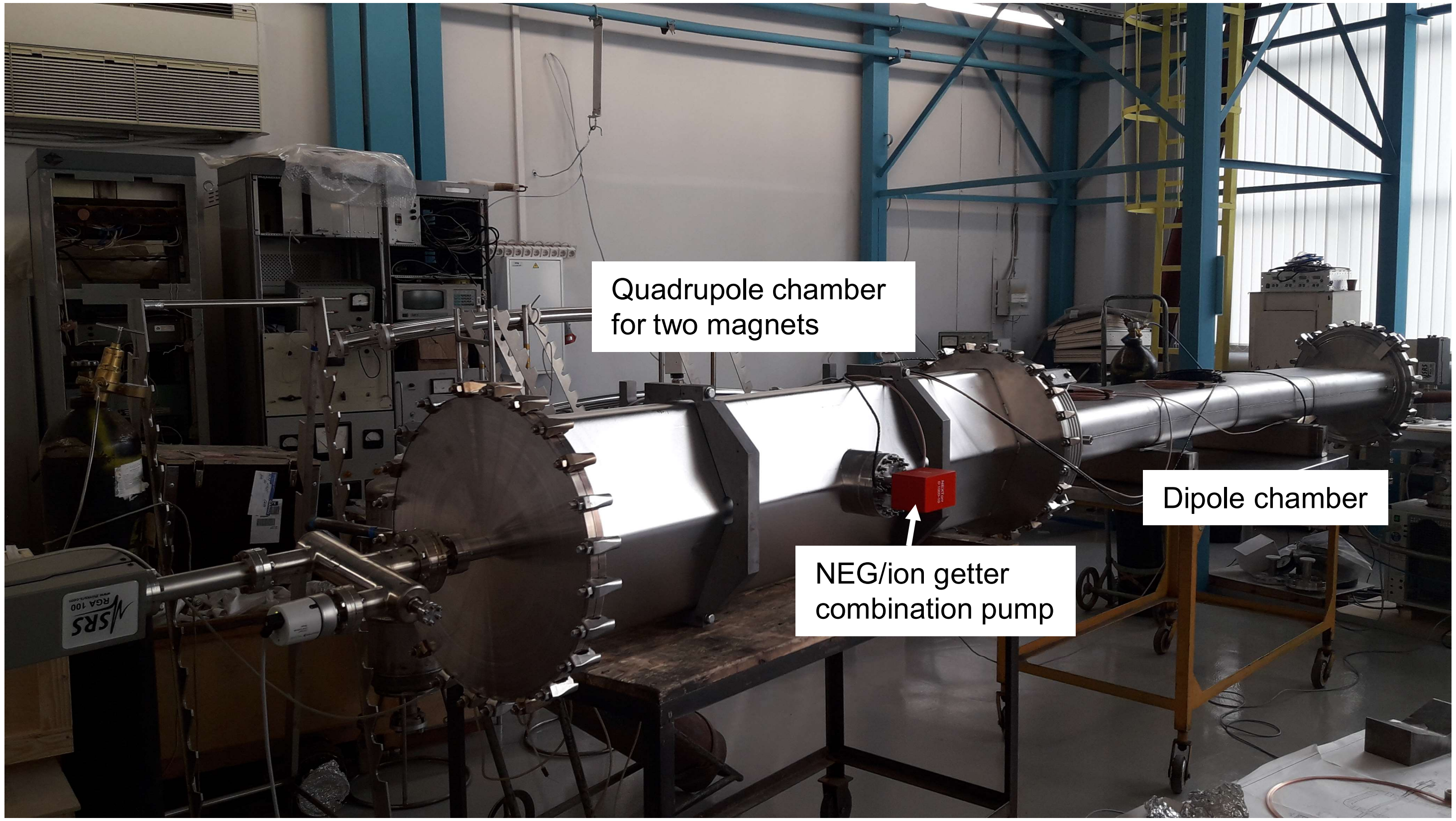
- Circumference: 225m (130m magnets)
- Required vacuum for beam life time for heavy ion and antiproton operation of 100 s: p≈10^{-9}mbar => unbaked
- Beam pipe aperture: 180 – 480 mm
- Narrow Space in beam direction
- Use of 75 SIP/NEG Cartridge Combination pumps
- 6 vacuum sectors





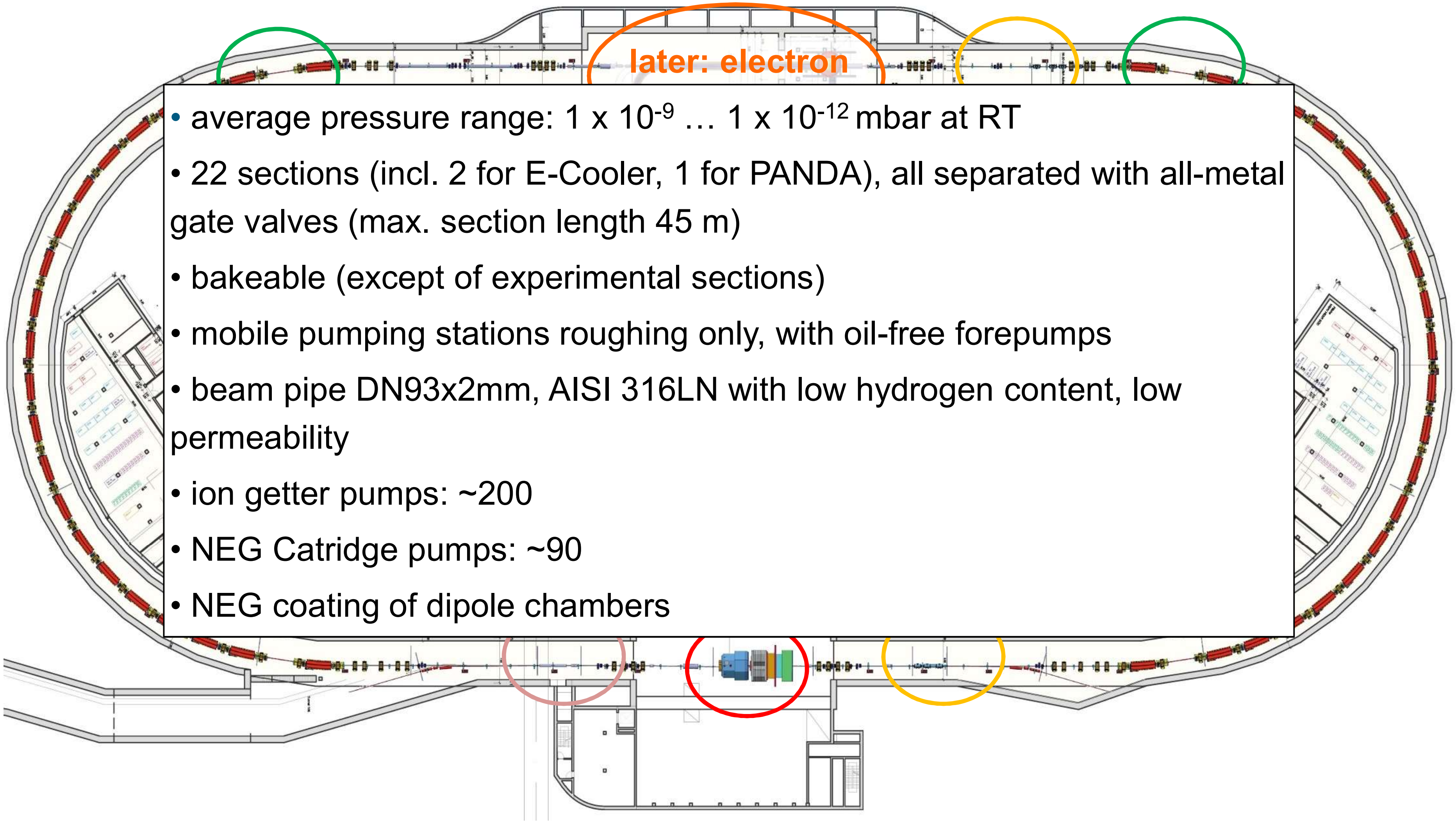
Mock-up installation at BINP

2 pumps for dipole + quadruple chambers – average pumping ‘density’ per meter in CR
Pressure level **2.3E-9** mbar after **1 month** pumping and 3 getter activation



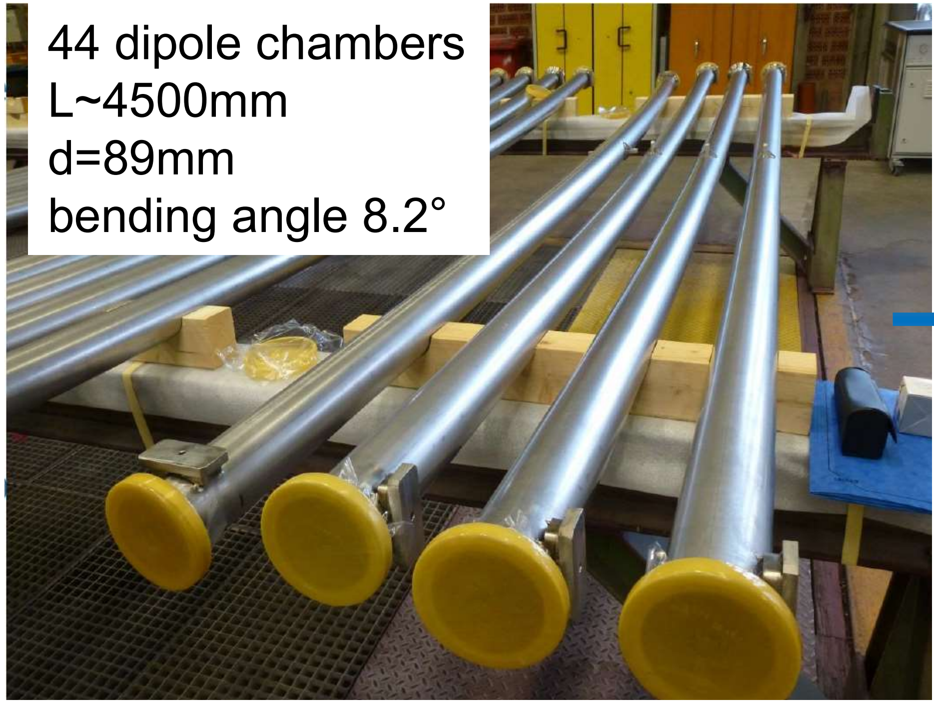
Picture courtesy of A. Krasnov (BINP)

High Energy Storage Ring (HESR)
(Design and Construction by FZ Jülich)

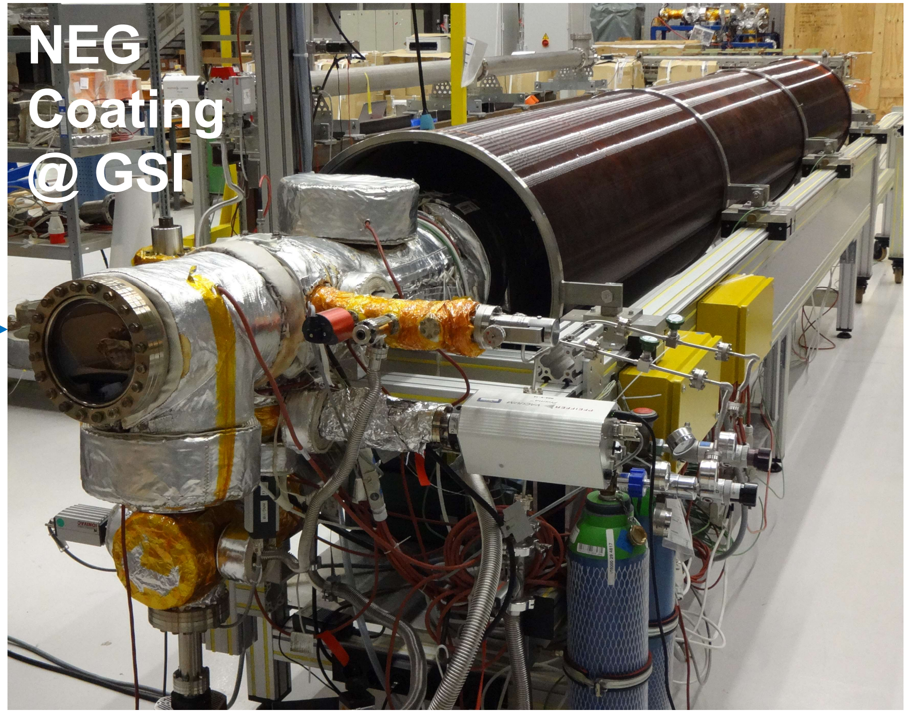


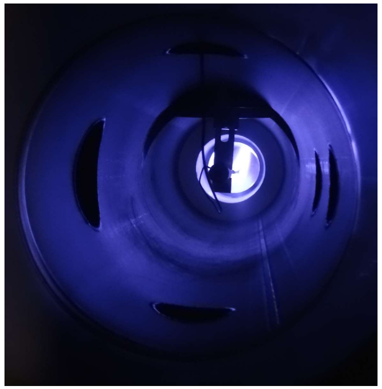
- average pressure range: 1 x 10^{-9} … 1 x 10^{-12} mbar at RT
- 22 sections (incl. 2 for E-Cooler, 1 for PANDA), all separated with all-metal gate valves (max. section length 45 m)
- bakeable (except of experimental sections)
- mobile pumping stations roughing only, with oil-free forepumps
- beam pipe DN93x2mm, AISI 316LN with low hydrogen content, low permeability
- ion getter pumps: ~200
- NEG Catridge pumps: ~90
- NEG coating of dipole chambers

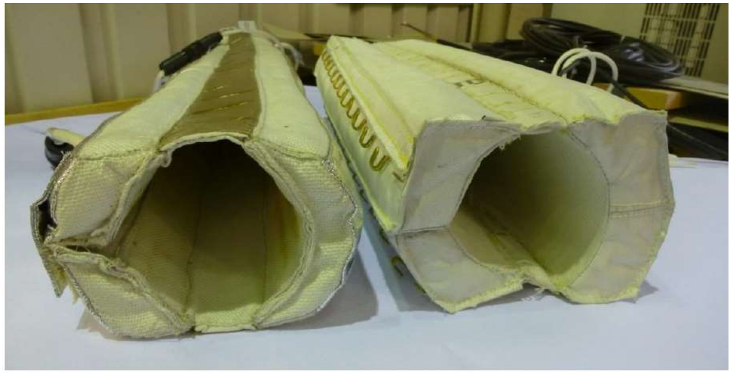
NEG coating of dipole chambers @GSI



44 dipole chambers
L~4500mm
d=89mm
bending angle 8.2°







Thank you for your attention!!!!

Acknowledgement:
The author would like to thank all the colleagues from GSI, FAIR, FZ Jülich and BINP.