HESR vacuum requirements for beam stability

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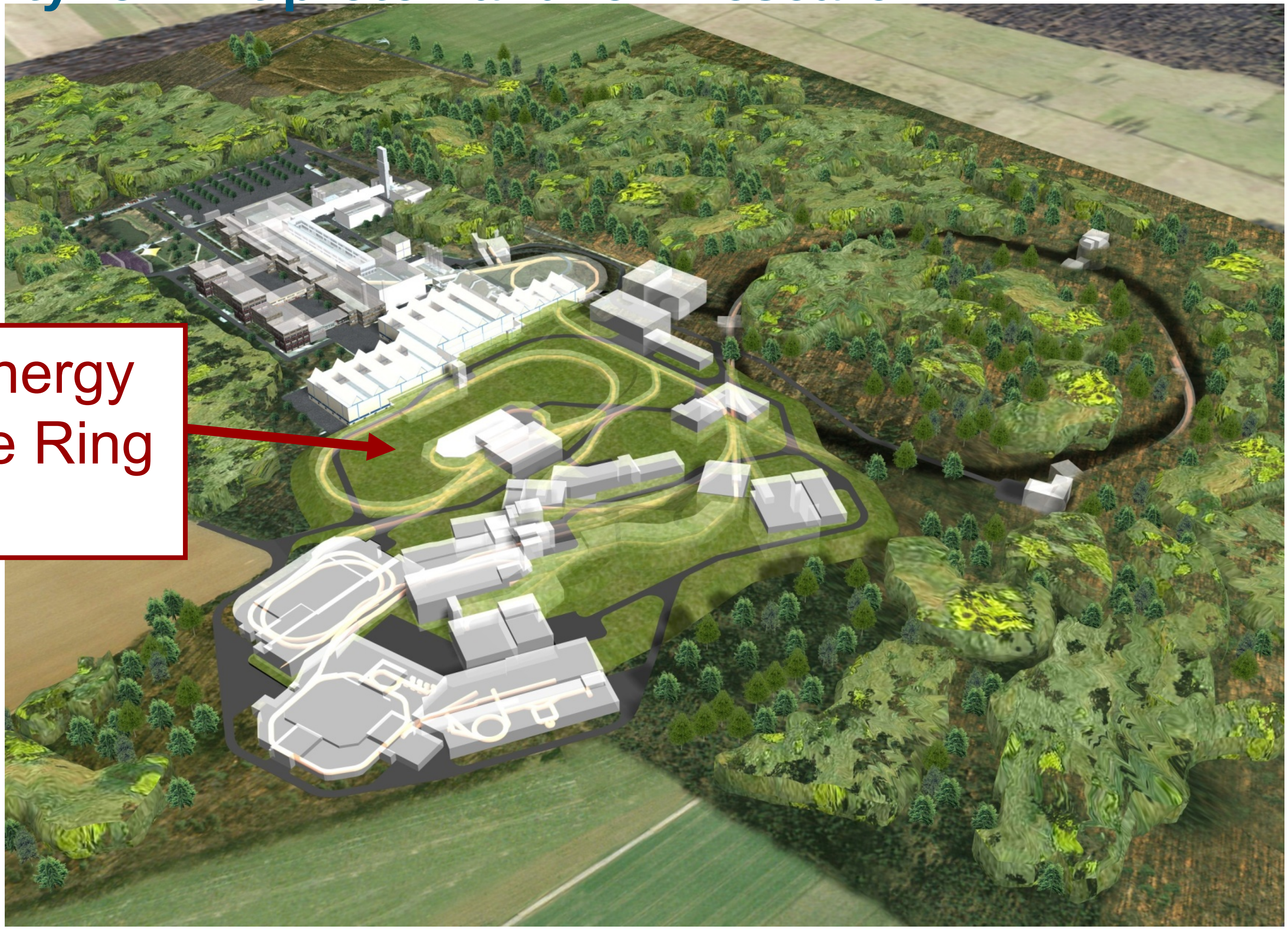
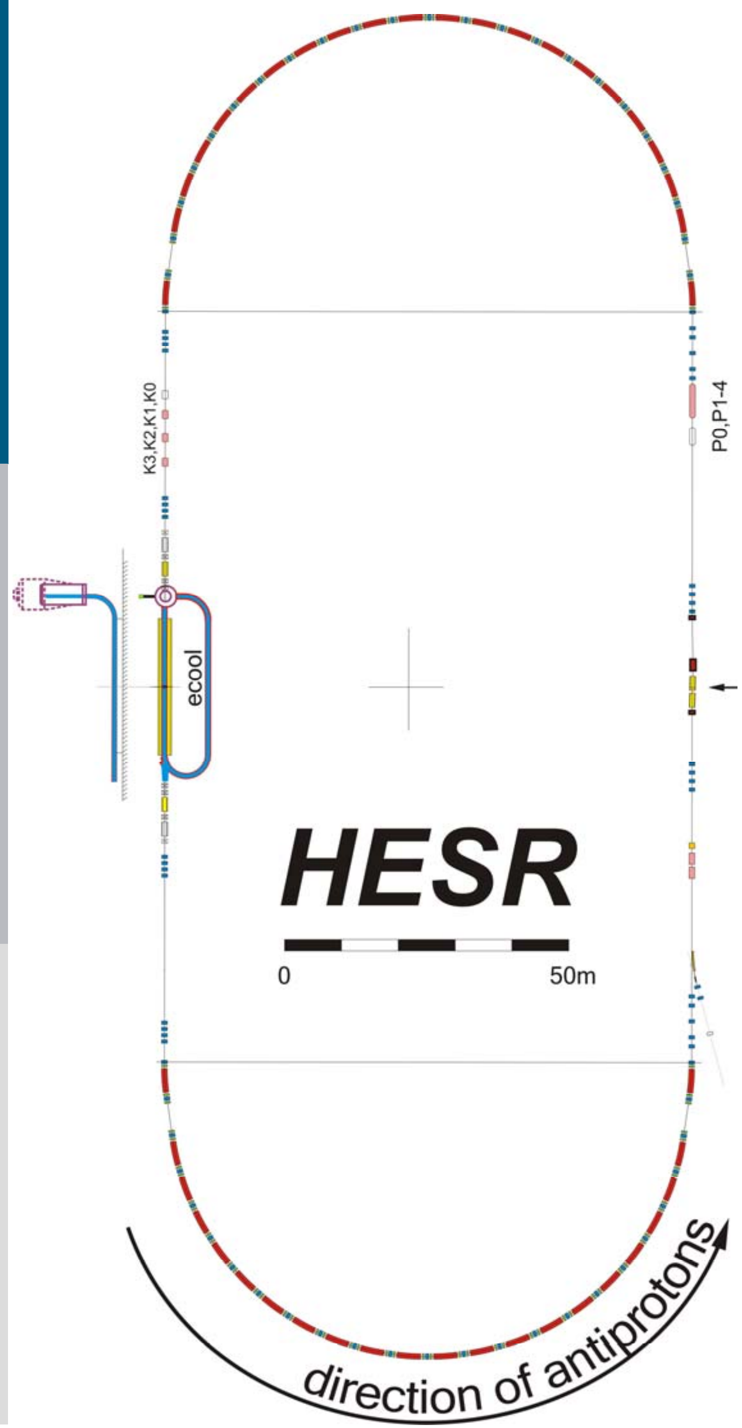
Outline

- Basic data of HESR
- Modes of operation
- Layout of the vacuum system
- Consequences of the vacuum to beam behaviour:
    - Beam life time limits due to single Coulomb scattering
    - Trapped ions
- Further causes for instabilities

Facility for Antiproton and Ion Research



High Energy
Storage Ring
HESR



Basic Data of HESR

- Circumference 574 m
- Momentum (energy) range
  1.5 to 15 GeV/c (0.8-14.1 GeV)
- Injection of (anti-)protons from CR / RESR at 3.8 GeV/c
- Maximum dipole field: 1.7 T
- Dipole field at injection: 0.4 T
- Dipole field ramp: 0.025 T/s
- Acceleration rate 0.2 (GeV/c)/s

Modes of Operation with PANDA

Experiment Mode	High Resolution Mode	High Luminosity Mode
Target	Hydrogen Pellet target with $4*10^{15}$ cm^{-2}	
rms-emittance	1 mm mrad	
Momentum range	1.5 – 8.9 GeV/c	1.5 – 15.0 GeV/c
Intensity	$1*10^{10}$	$1*10^{11}$
Luminosity	$2*10^{31}$ cm^{-2} s^{-1}	$2*10^{32}$ cm^{-2} s^{-1}
rms-momentum resolution	$5*10^{-5}$	$1*10^{-4}$

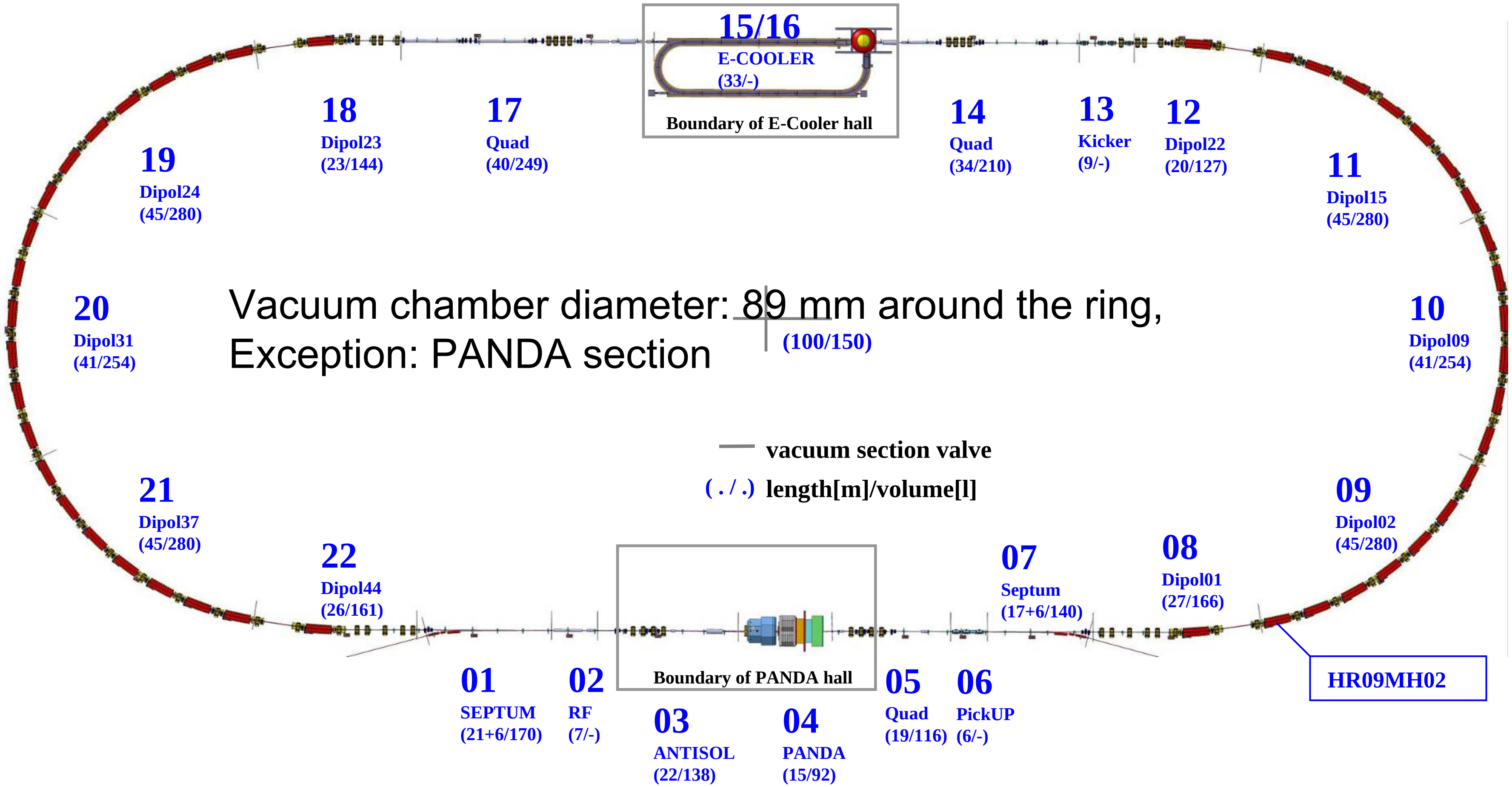
Layout of the vacuum system

Vacuum System for the HESR @ FAIR

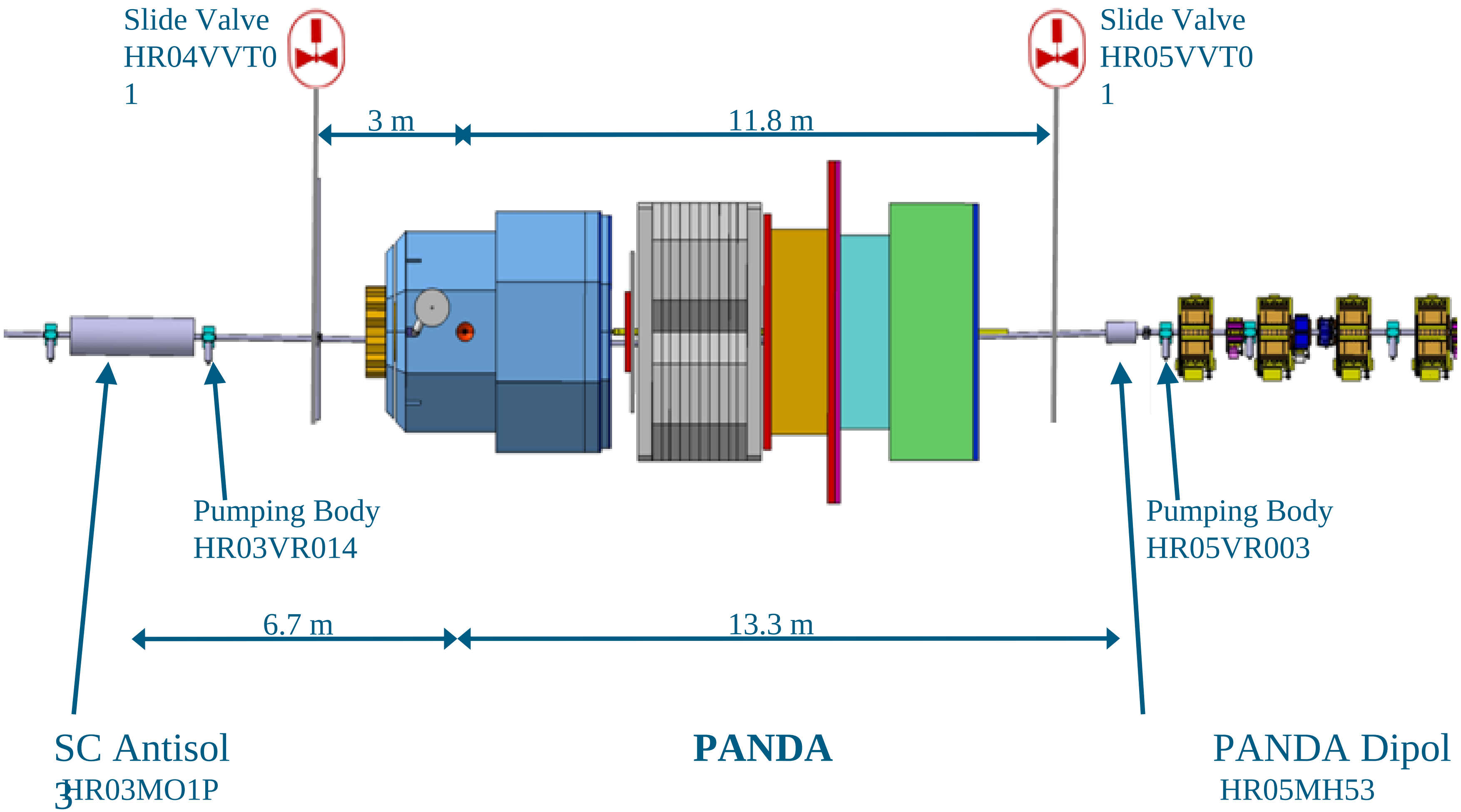
Design parameters

- Total average pressure smaller than 1 x 10^{-9} mbar at room temperature.
- No baking system or NEG pumping system planned.
- 22 sections (incl. 2 for E-Cooler, 1 for PANDA)
- Section length range between 6 m and 45 m, max. volume of 280 l.
- All vacuum chambers made from AISI 316 LN stainless steel with low hydrogen content and low permeability

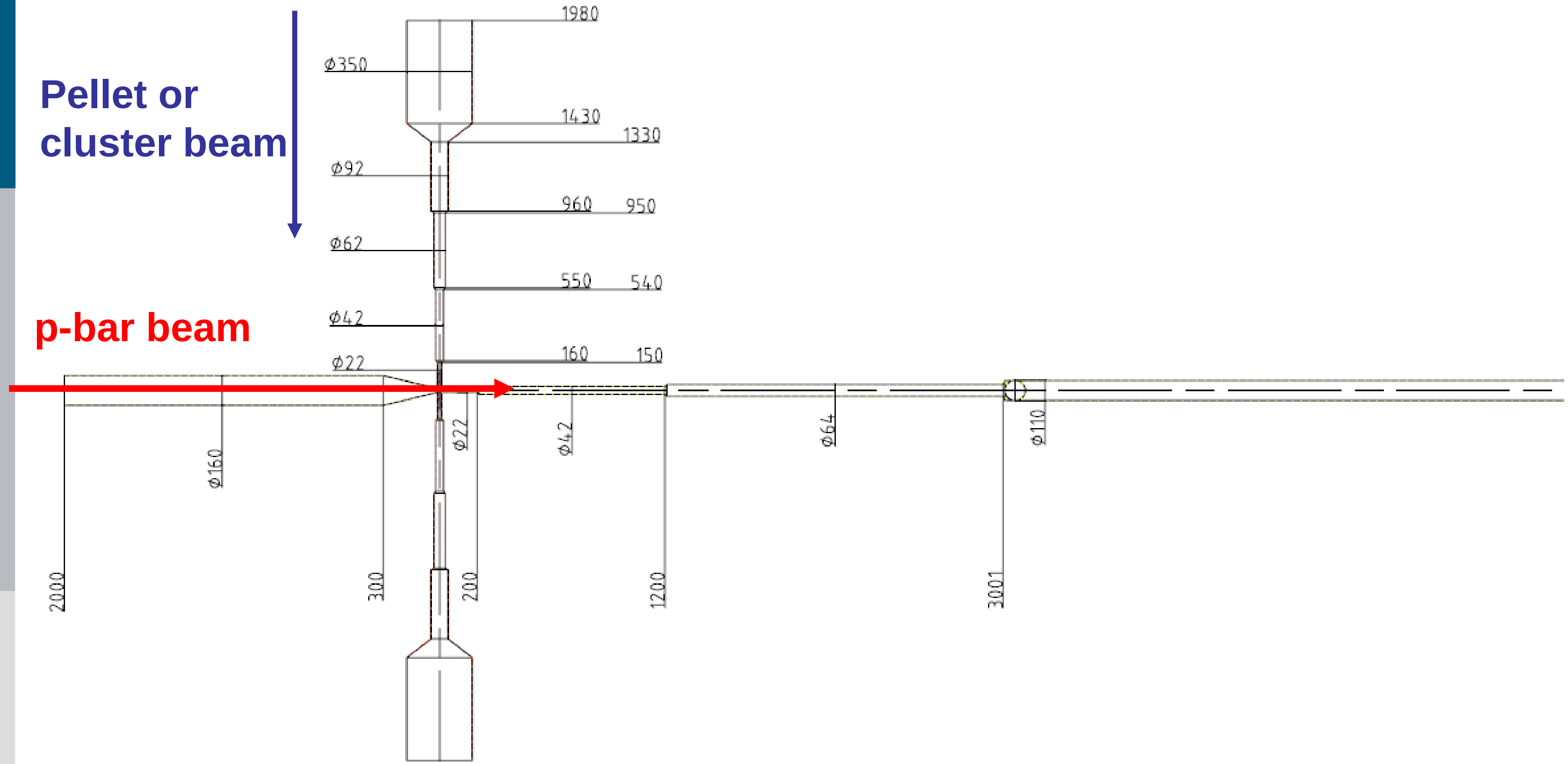
Vacuum sections in the HESR



The PANDA section with magnets and detectors



The vacuum system in the PANDA section



All diameters are outer diameters

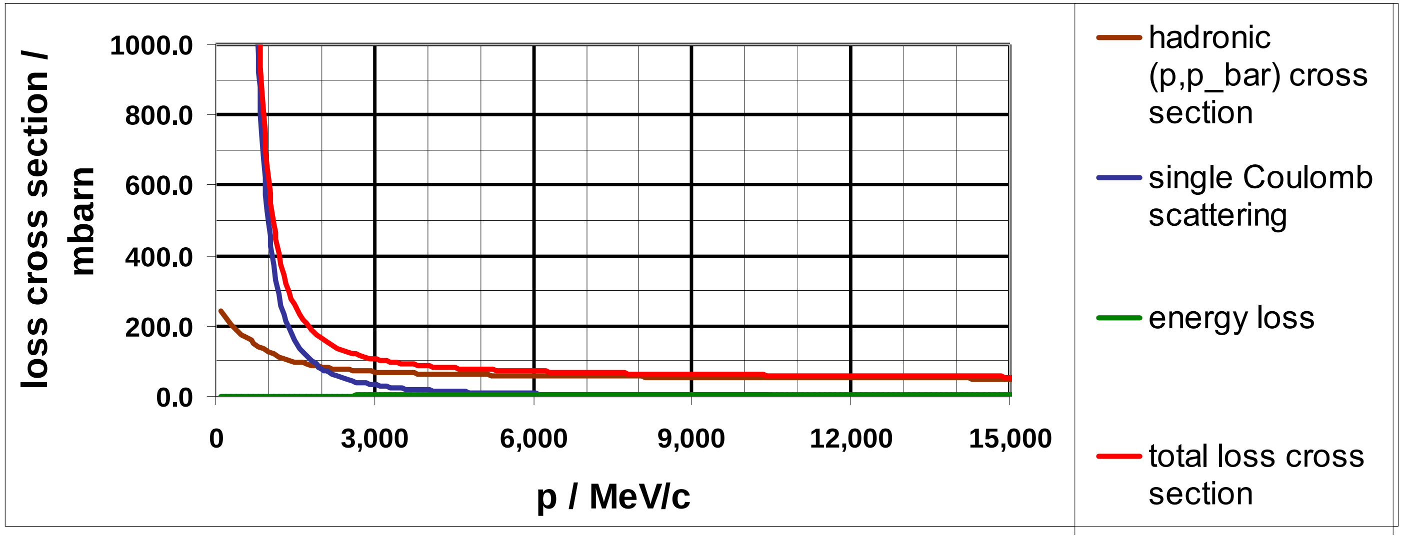
Wall thickness is 1mm

Consequences of the vacuum to the beam behaviour

Causes for beam losses

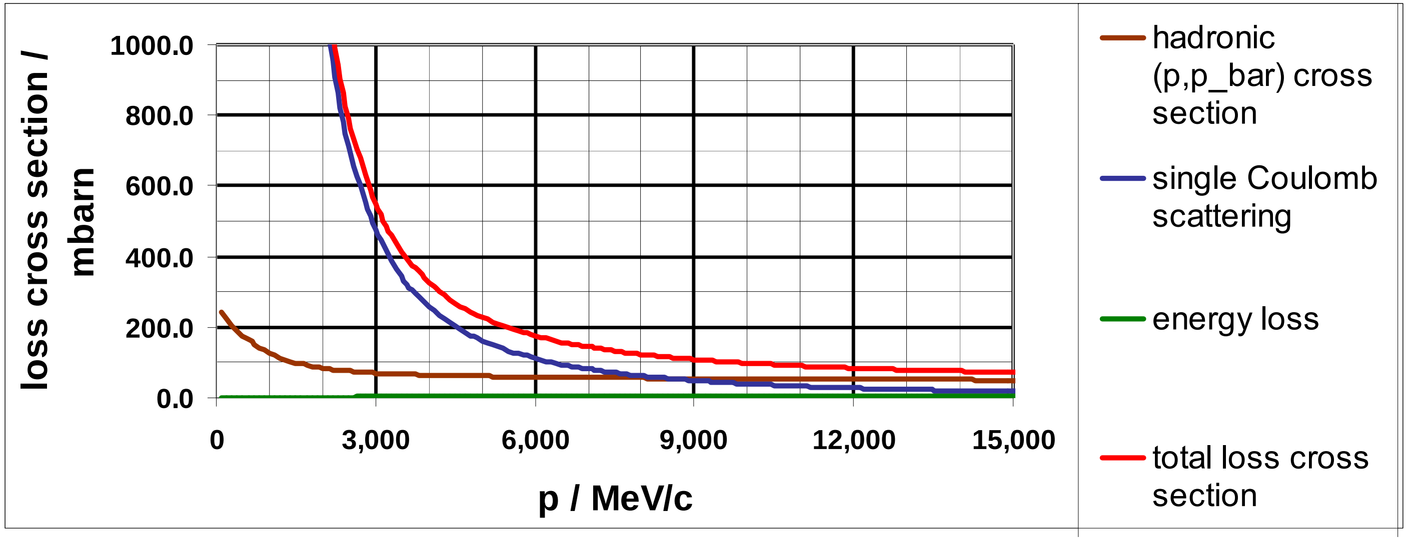
- Hadronic interaction, single Coulomb scattering and energy loss due to target interaction
- Losses due to interaction with the residual gas
- Trapped ions
- Other instabilities

Loss cross section due to target effects



for 1 m β-function at the target

and for 15 m β-function at the target



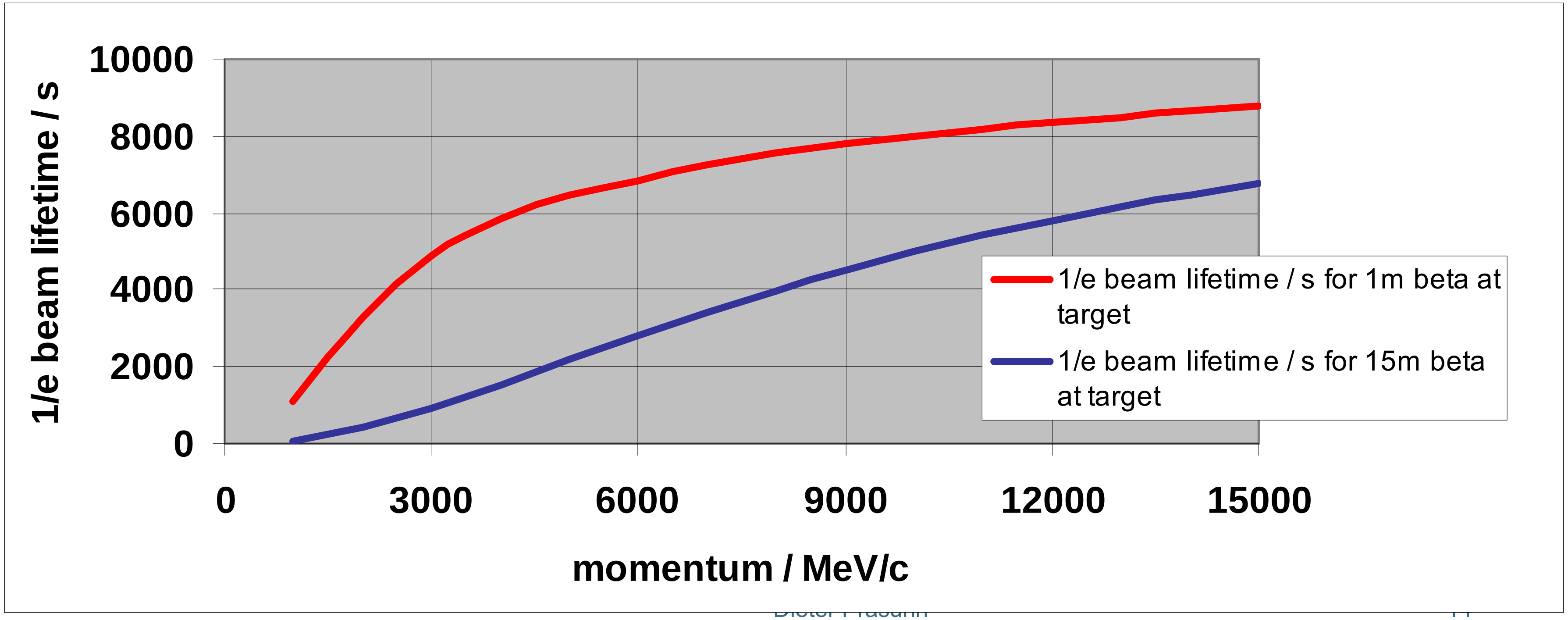
Beam lifetime due to target interaction

Target material: Hydrogen

Target thickness: $4 \cdot 10^{15}$ atoms / cm^2

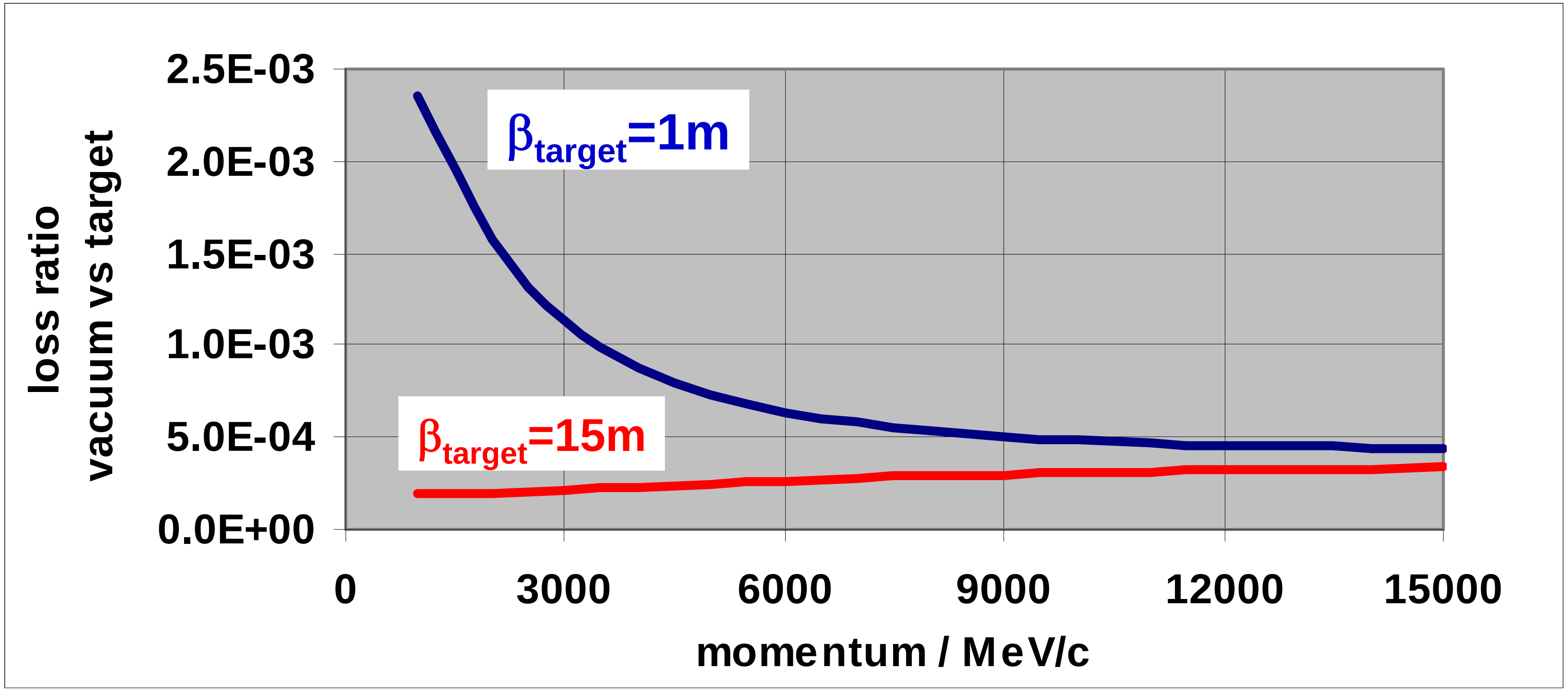
β-function at target: $1\text{m} < \beta_{target} < 15$ m

Expected 1/e-beam lifetimes as function of the momentum for 1 mm mrad transverse and $2.5 \cdot 10^{-3}$ momentum acceptance:



Beam life time due to residual gas interaction

- Average gas pressure: 10^{-9} mbar
- Corresp. Target thickness: $1.5 \cdot 10^{12}$ atoms / cm^2
- Design tune for HESR: close to 7.6
- Aver. β-function (= C / (2π Q): 12.0 m



Conclusion

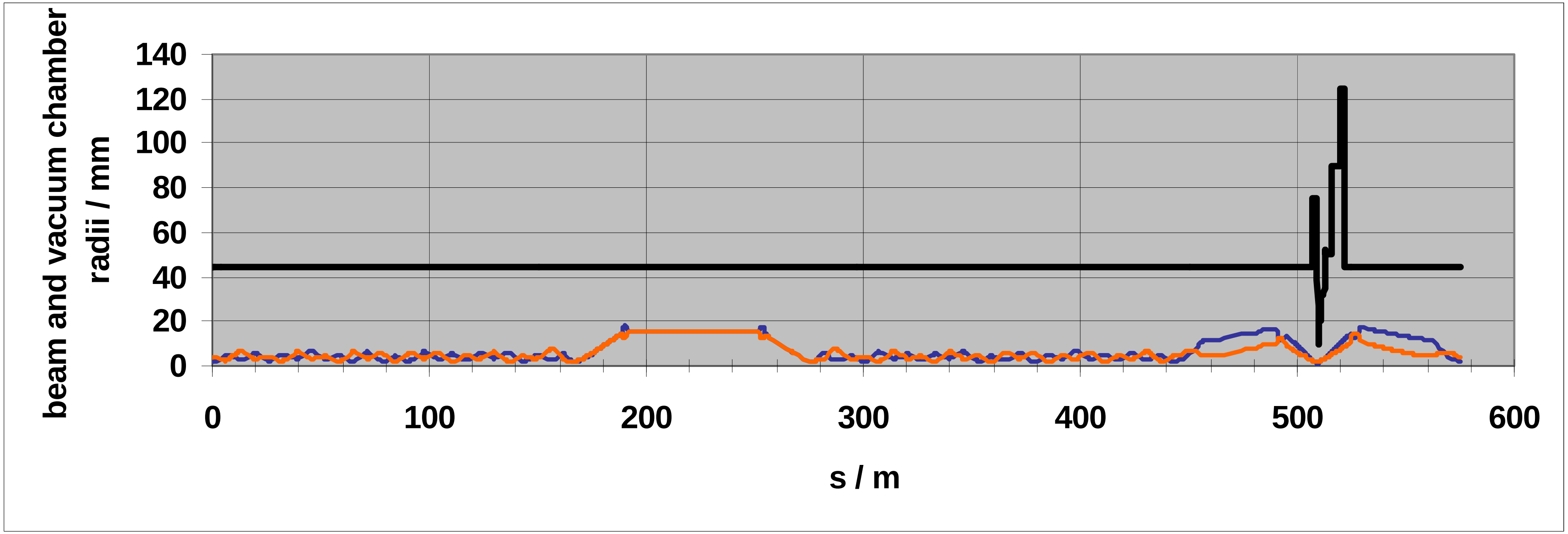
Compared to the beam – target interaction a residual gas pressure of 10^{-9} mbar is sufficient!

Ion trapping

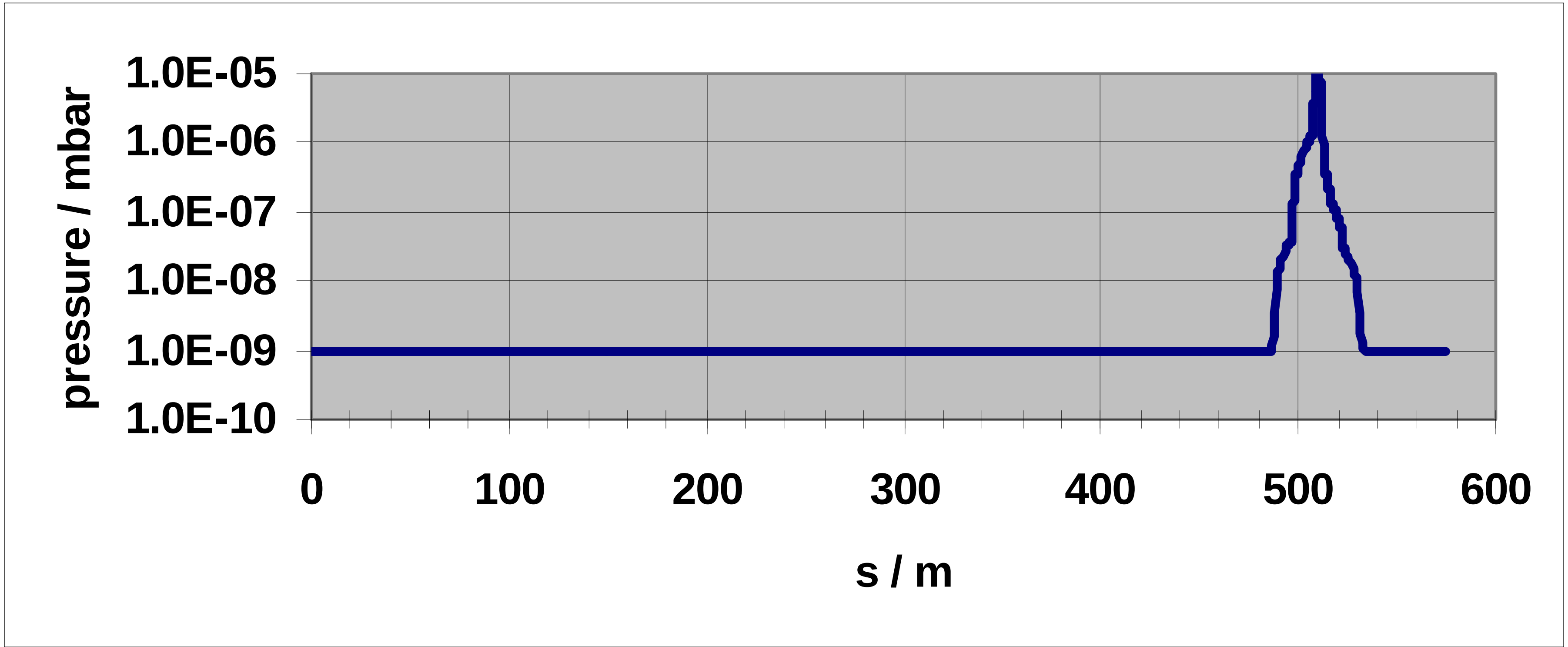
- Estimates of the production rate of residual gas ions
- The potential of the p-bar beam
- Neutralisation
- Clearing electrodes
- Beam shakers

Beam size and vacuum chamber radius in the HESR

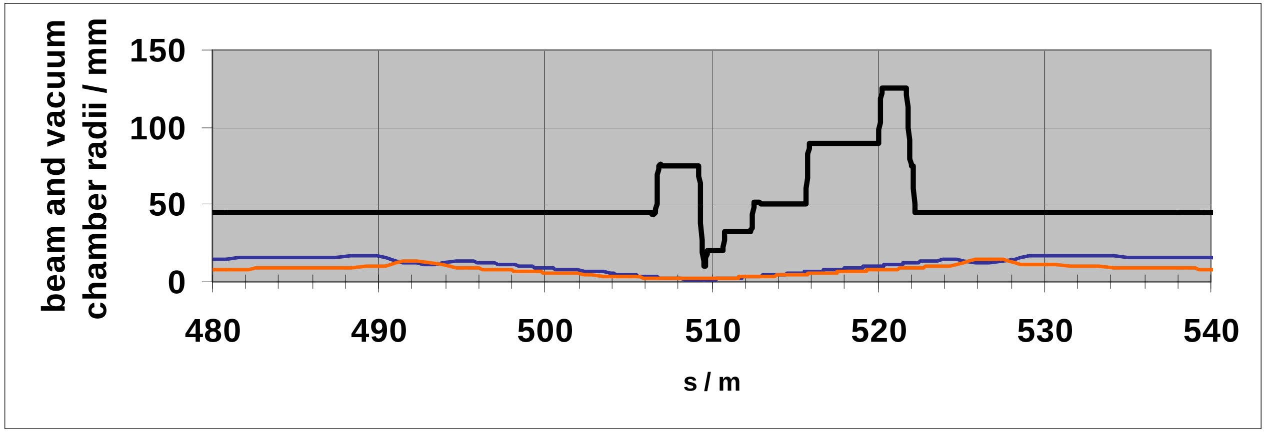
The beam radius corresponds to 3σ of a 1 mm mrad rms emittance



Expected pressure distribution in the HESR

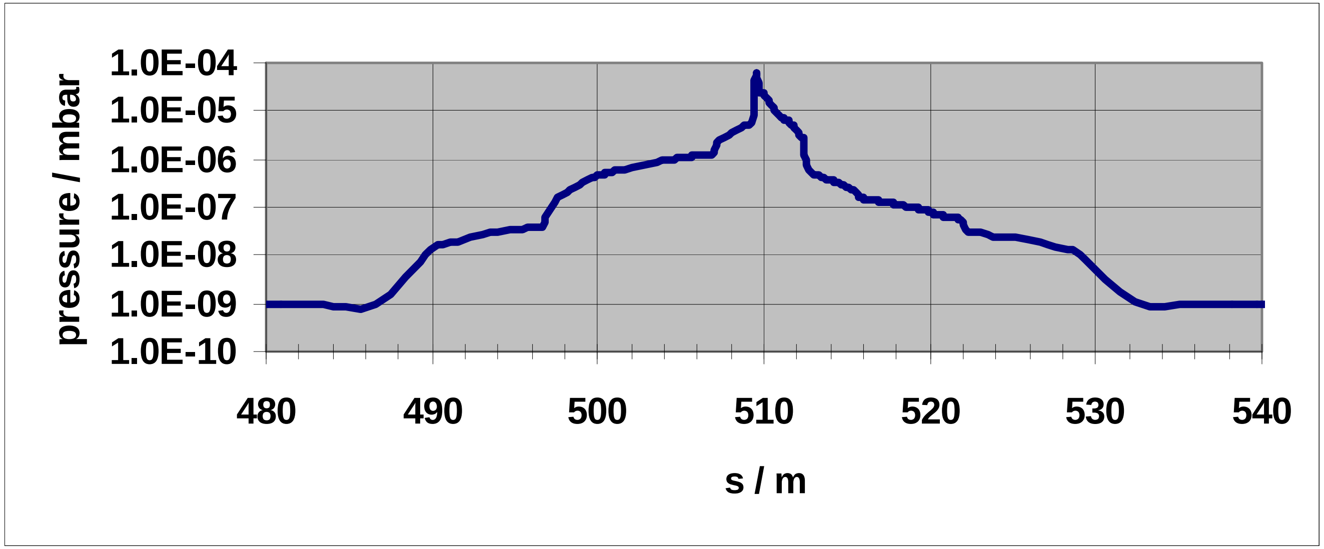


Conditions around PANDA



beam size and vacuum chamber

pressure bump due to Pellet target

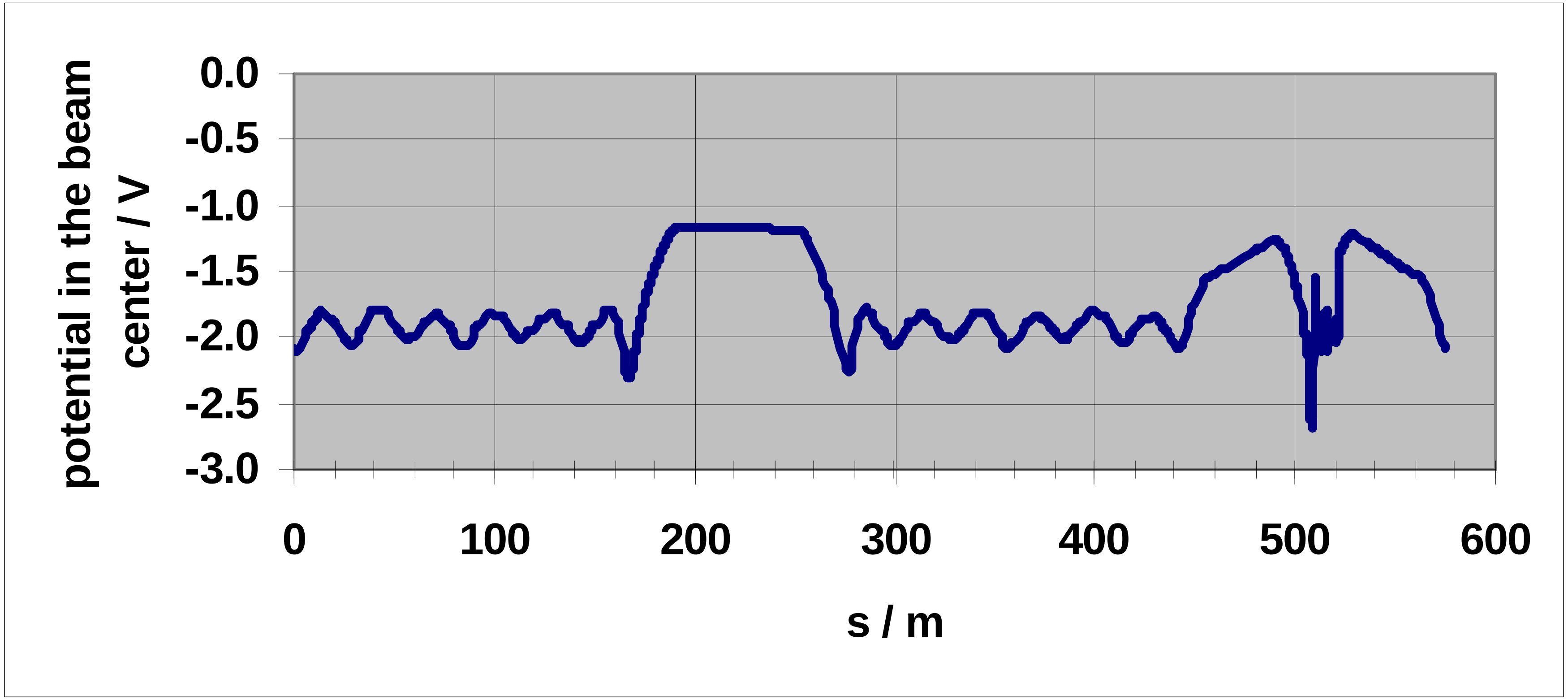


The potential on axis for 10^{11} p-bars

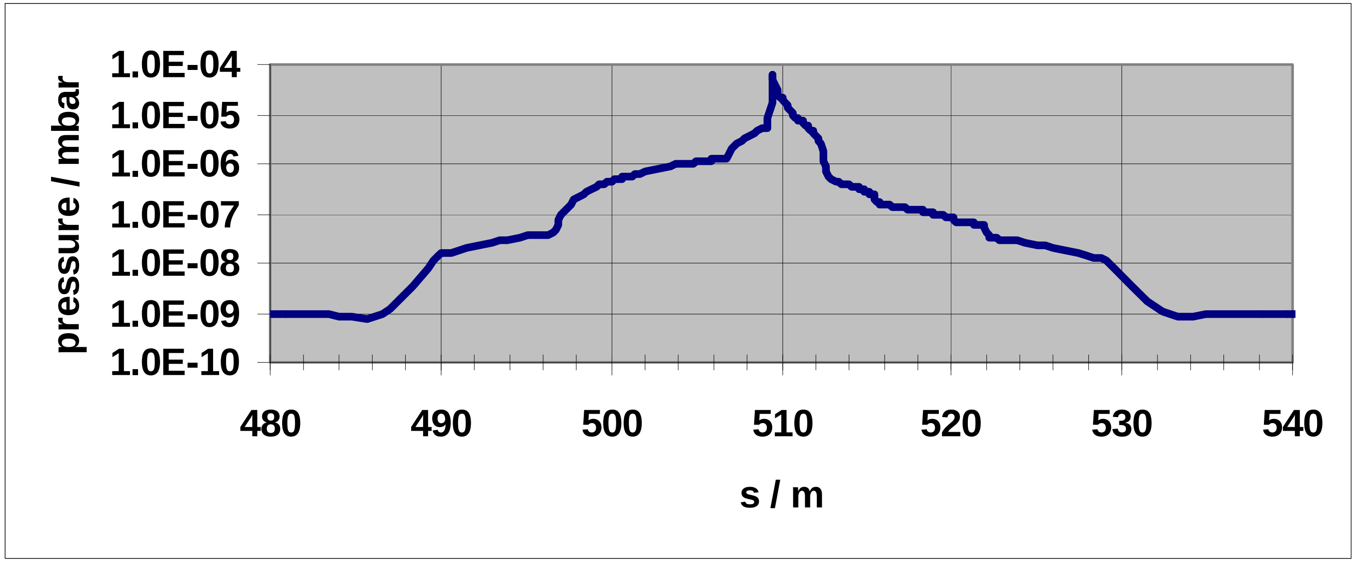
$$U(s) = \frac{\lambda}{2\pi\varepsilon_0}\left[\frac{1}{2} + \ln\left(\frac{r_c}{a}\right)\right]$$

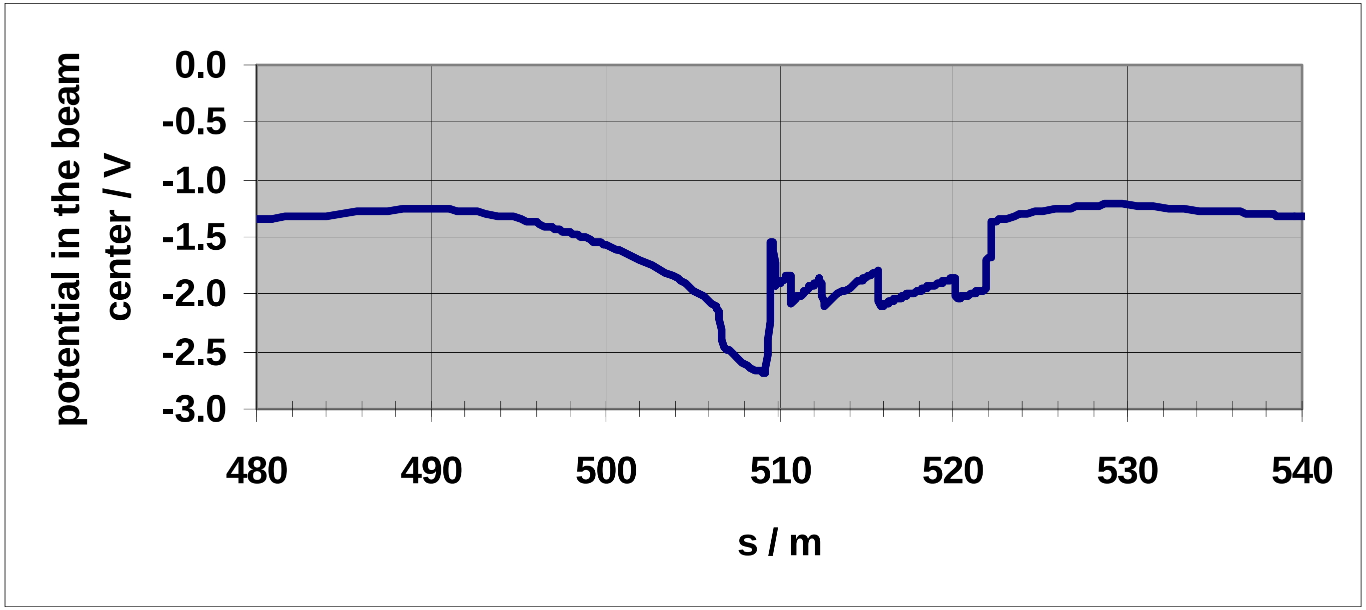
Charge density $\lambda = -\frac{N_p e}{l_b}$

l_b=bunch length



Pressure bump and potential in the PANDA section

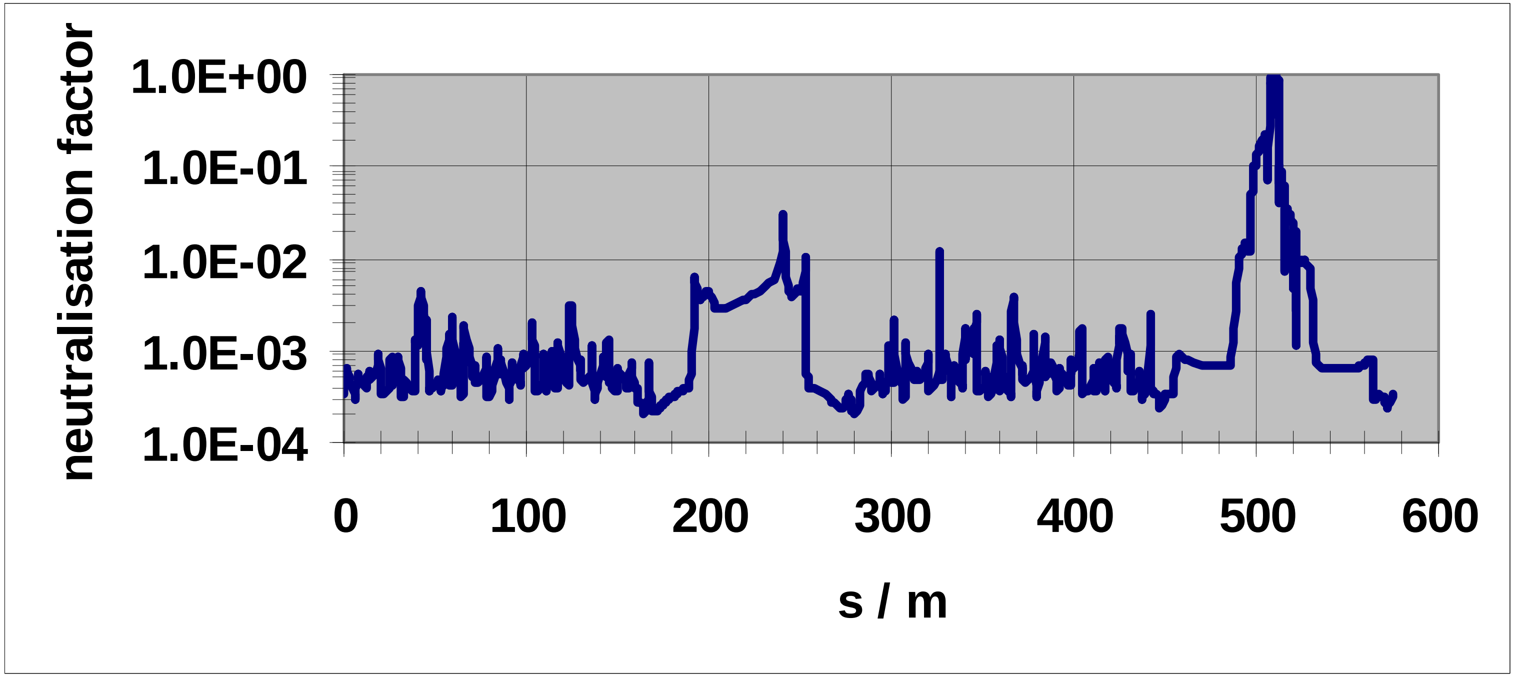




Neutralisation factor η

The mean time for residual gas ions in the p_bar beam T_c in relation to the time of ion production T_p:

$$\eta = \frac{T_c}{T_p}$$



Assumption: an average distance of clearing electrodes of 10 m, with a clearing voltage of 200 V

Tune spread caused by rest gas ions

$$\Delta Q = \frac{N_p r_p}{2\pi\beta^2}\frac{1}{2\varepsilon}\left(\eta - \frac{1}{\gamma}\right)$$

With $N_p=10^{11}$ p-bars, rms-emittance=1 mm mrad:

- for average neutralisation $\eta = 1.25*10^{-2}$: $\Delta Q=6.6*10^{-5}$
- full neutralisation $\eta=1$: $\Delta Q=5.3*10^{-3}$

Details can be found in: F. Hinterberger, Ion Trapping in the HESR ring (in preparation)

Summary

- A barrier bucket cavity will produce a clearing gap in the longitudinal beam distribution
- All beam position monitors are designed as clearing electrodes
- 200 V clearing voltage guarantee sufficient acceleration for the rest gas ions
- Even a large neutralization factor results in an acceptable small tune spread

- For clearing in the dipoles a stripline unit in the vertical plane will be used as beam shaker

Further sources for further instabilities

- Beam intensity and phase space requirements are far away from stability limits
- The vacuum chamber is designed smooth with an inner diameter of 89 mm all around the ring
- In the PANDA section vacuum chamber transitions are designed with tapers with a smooth angle
- All feedthroughs and pumping stations are equipped with RF grids

⇒ The impedances of the vacuum chamber should be small

⇒ We do not expect instabilities by beam wall interaction

Conclusion

A residual gas pressure of 10^{-9} mbar

- leads to a negligible loss rate compared to the target interaction,
- leads to an acceptable neutralization factor, when all BPMs are designed as clearing electrodes.
- The layout of the vacuum chamber leads to small impedances to guarantee stable beam conditions

Thank you for your attention

Impedance estimates

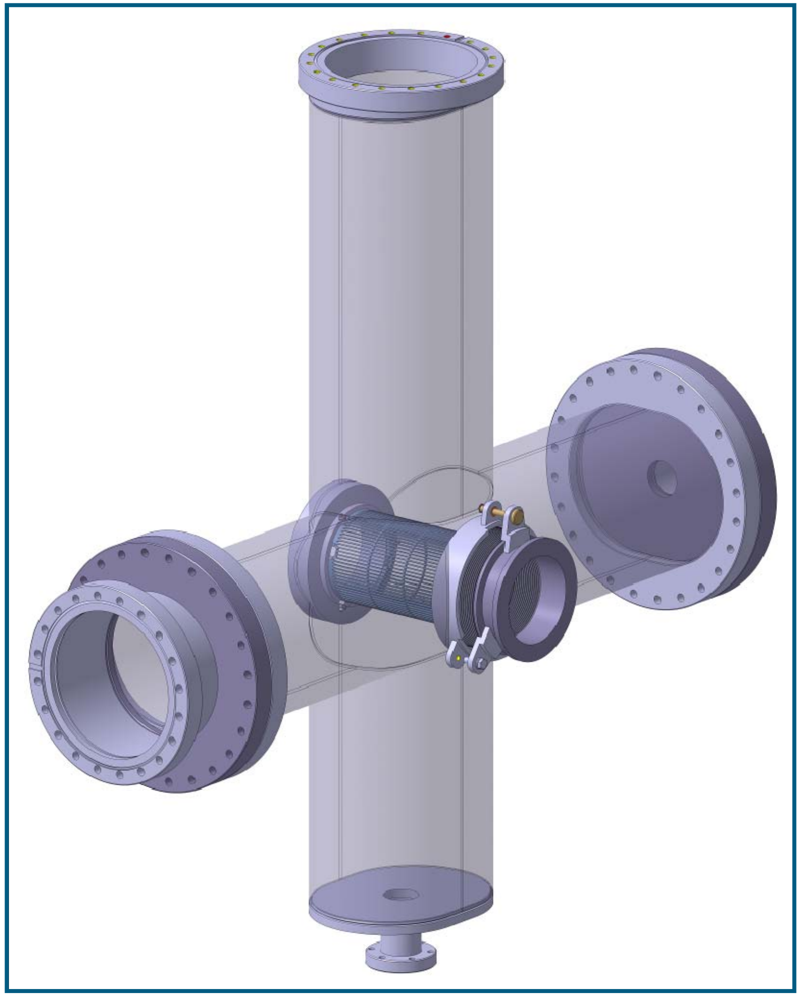
Conditions: HR mode; 10^{10} antiprotons; $\Delta p/p=4\cdot10^{-5}$; $\gamma_{tr}=6.3$;
500m bunch length, 4σ emittance with σ=1 mm·mrad (norm.)

Momentum [MeV/c]	**1500**	**1696**	**3824**	**9000**
Long. Boussard-Keil-Schnell limit $Z_{\|\|}/n$ [Ω]	1238.0	1007.6	225.9	536.8
Long. space charge $Z_{\|\|}/n$ [Ω]	324.5i	268.1i	67.5i	14.2i
Transv. Boussard-Keil-Schnell-like limit $Z_\perp$ [MΩ/m]	581.5	598.7	991.5	2174.5
Transv. space charge $Z_\perp$ [MΩ/m]	433.0i	383.7i	171.4i	73.1i

Formulae taken from A. W. Chao, "Handbook of Accelerator Physics and Engineering"
K.Y. Ng, B. Zotter, "Space Charge and Beam Stability of the Proposed Fermilab Proton Driver in Phase I", Proc. of PAC 2001

Vacuum System for the HESR @ FAIR

pumping body for the arcs



140 pieces in three variations (2 x arc, 1 x straights)

Vacuum System for the HESR @ FAIR

Technical design of the curved beam tube

- Ø93x2 mm, 1.4429 ESR
- positioning on the yoke
- adjust with set screws
- arc length of 4.203 m
- bending radius 29.432 m
- bending angle 8.1818°
- EVAC chain clamps (roller chain with flange)
- outer centering Al sealing