Vacuum System of CR and RESR

MAC Meeting #3
10.02.2010

Antiproton Lifetime Limiting Processes

Beam-Gas Interaction

- Nuclear Scattering
- Single Coulomb Scattering
- Multiple Scattering
- Inelastic Scattering

Only multiple scattering plays a role in RESR:

- for 3 GeV and $1x10^{-10}$ mbar N_2 $\partial\varepsilon/\partial t$ = 0.1 mm mrad / h

➡ can be compensated by cooling

Ion Production and Trapping

- Only expected at intensities $>10^{11}$ stored antiprotons
- Could be a problem for RESR, but can be resolved by clearing electrodes!

➡ Lifetime for RIBs more critical than for antiprotons

Basic Parameters of CR

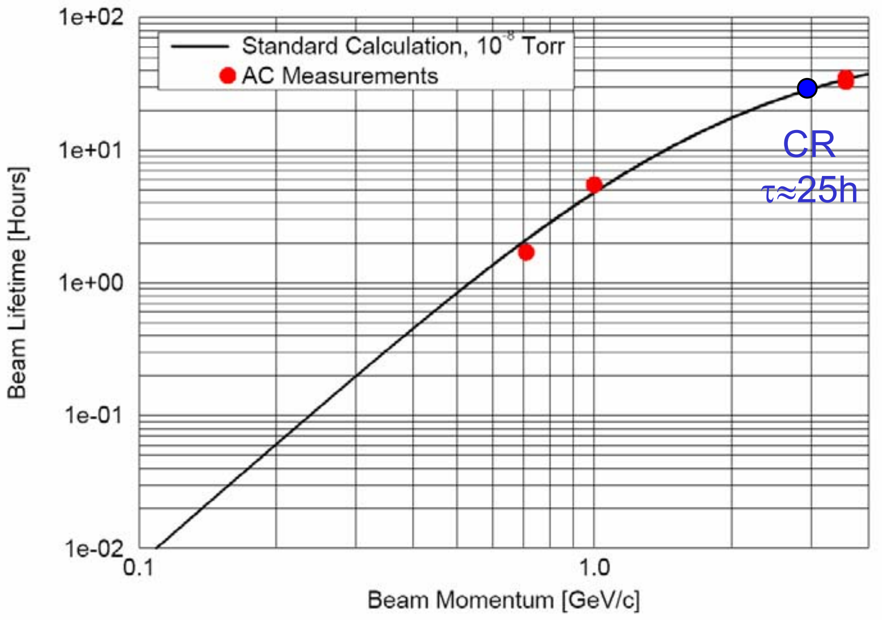
Storage ring for
1. stochastic cooling of radioactive ion beams (740 MeV/u)
2. stochastic cooling of antiproton beams (3 GeV)
3. Isochronous mass measurements

Circumference	215.011 m		
Max. magnetic rigidity	13 Tm		
	Antiprotons	Rare Isotopes	Isochronous Mode
Max. particle number	10^8	10^9	$1 - 10^8$
Kinetic energy	3 GeV	740 MeV/u	790 MeV/u
Velocity	0.971 c	0.830 c	0.840 c
Acceptance mm mrad	240	200	100
Cooling time [s]	10	1.5	-

- Almost similar parameters as AC at CERN
- Required beam lifetime in the order of 1000s for antiprotons, for RIBs vacuum is more critical
- UHV system with a pressure in the order of 10^{-9} mbar
- No in-situ bake out of vacuum system required, design criteria like for heavy ion therapy accelerator in Heidelberg

Lifetime for Antiprotons and Ions

Measurements in the AC



Spec.	Pressure [mbar] N_2 equiv.
H_2	4.47×10^{-9}
CH_4	5.45×10^{-10}
H_2O	1.55×10^{-9}
CO	1.36×10^{-9}
CO_2	7.54×10^{-11}
Total	8.00×10^{-9}

from: N. Madsen, PS/DI Note 99-06, AD Note 047, CERN 1999

Calculations for Ions

Beam energy: 740 MeV/u
Assumed residual gas composition: 79.5% H_2, 20.5% N_2
Assumed total pressure: 6.2×10^{-9} mbar

Lifetime [s]

Ion	bare	H-like	He-like
Uranium	3100	2300	1700
Tin	37000	550	280
Argon	3.6×10^{6}	48	24

Calculations by T. Stöhlker, GSI

Measures to Avoid the In-situ Bake Out

- Use of only UHV compatible materials
- Ultrasonic cleaning of all components by manufacturer
- Ex-situ bake out of all components by manufacturer
- Venting of components with dry nitrogen (grade 4.5) by manufacturer
- Components covered in Al-foil and sealed in PE-Foil, done by manufacturer
- Shipping to FAIR
- The flanges will only be removed for final assembly
- Pre-assembly of components under flow hood with vertical laminar flow
- Assembly of smaller components in the accelerator under dynamical confinement or under mobile flow hood where applicable
- Mounting with clean gloves and clean room adequate clothes
- Use of cleaned tools and materials

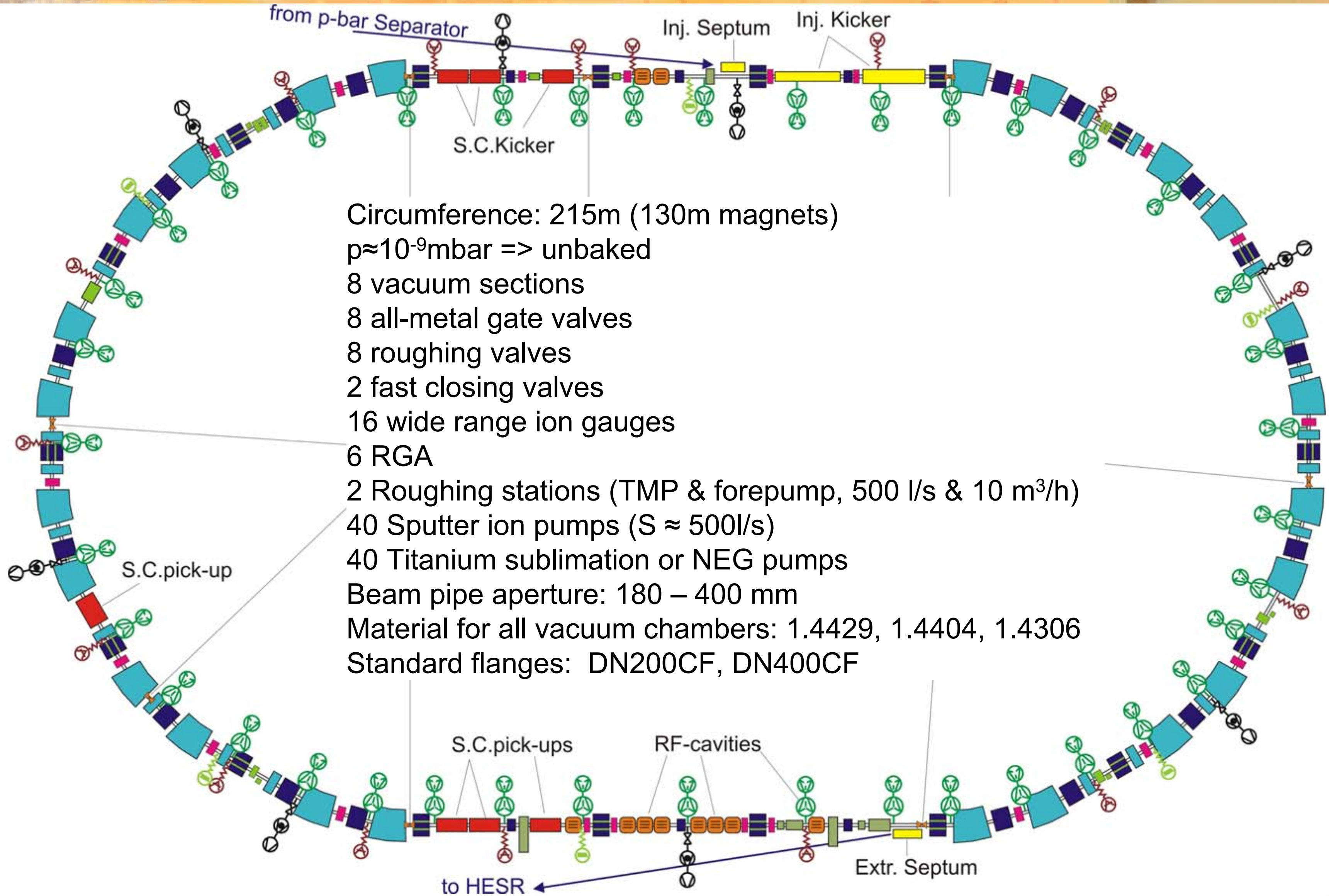
Estimation of Required Pumping Speed

- Circumference: 215 m
- Typical UHV chamber diameter 200 – 400 mm
- Overall inner surface: approx. 250 m^2
- Overall volume: approx. 18.5 m^3
- Required pressure: $1x10^{-9}$ mbar
- Typical surface related outgassing rate of unbaked stainless steel: $1x10^{-11}$ mbar l s^{-1} cm^{-2}

- Total outgassing rate: Q = $2.5x10^{-5}$ mbar l s^{-1}

- Required effective pumping speed: S_{eff} = 25000 l s^{-1}

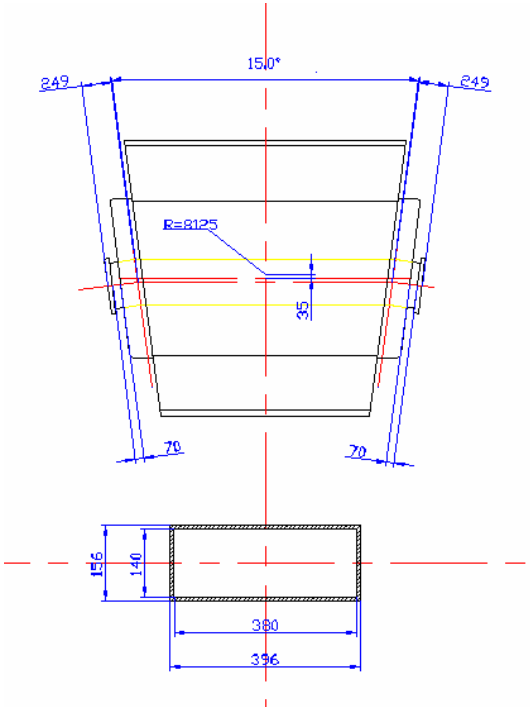
Schematic Vacuum Layout of CR



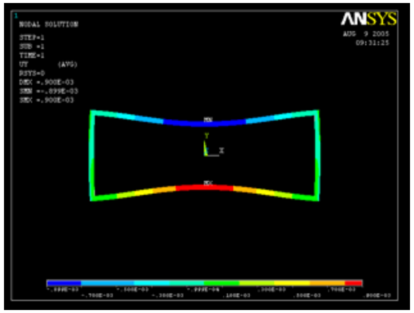
Circumference: 215m (130m magnets)
p≈10^{-9}mbar => unbaked
8 vacuum sections
8 all-metal gate valves
8 roughing valves
2 fast closing valves
16 wide range ion gauges
6 RGA
2 Roughing stations (TMP & forepump, 500 l/s & 10 m^3/h)
40 Sputter ion pumps (S ≈ 500l/s)
40 Titanium sublimation or NEG pumps
Beam pipe aperture: 180 – 400 mm
Material for all vacuum chambers: 1.4429, 1.4404, 1.4306
Standard flanges: DN200CF, DN400CF

Calculations on Mechanical Stability of Magnet Vacuum Chamber

Dipole



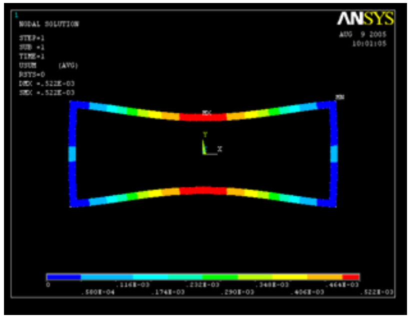
Deformation and Stress Calculations



for 8 mm thickness:

D_{max}=0.9 mm

S_{max}=138 MPa

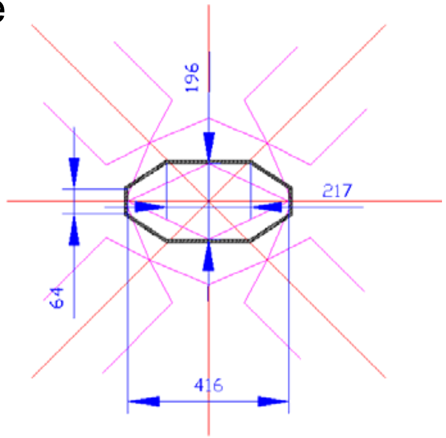


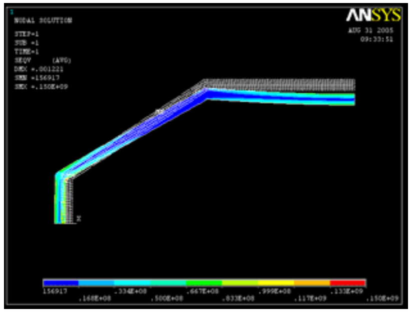
for 10 mm thickness:

D_{max}=0.52 mm

S_{max}=99 MPa

Quadrupole





for 8 mm wall thickness:

D_{max}=1.2 mm

S_{max}=150 MPa

Calculations by Junhui Zhang (IMP, Lanzhou)

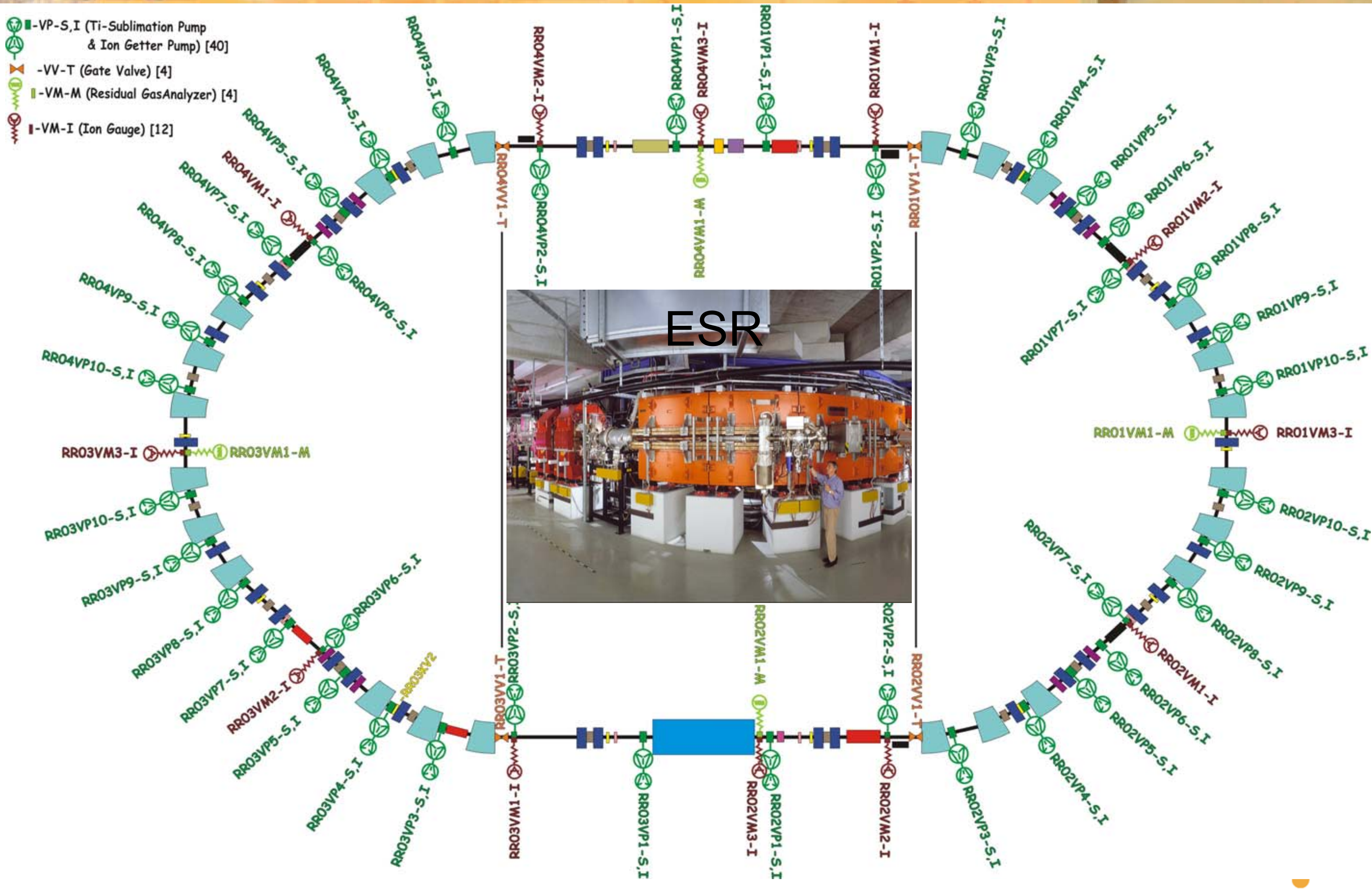
Basic Parameters of RESR

Storage ring for
1. Accumulation of antiprotons with 10^8 from the CR every 10s
2. Fast deceleration of RIBs to 100 MeV/u for injection into NESR (collider mode)
3. Deceleration of antiprotons to 120 MeV for injection into ER (AIC mode)

Circumference	240 m	
	Antiprotons	RIBs
Injection energy	3 GeV	740 MeV/u
Extraction energy	3 GeV	100 – 740 MeV/u
Accumulation rate	3.5×10^{10}/h	no accumulation
Max. particle number	1×10^{11}	1×10^{9}
Accumulation time for max. particle number	3 h	no accumulation

- Intensities and lifetime requirements comparable to Recycler Ring at Fermilab
- Required beam lifetime in the order of 100h for antiprotons
- UHV-system with a pressure in the order of 10^{-10} mbar
- In-situ bake out of vacuum system up to 200°C (designed for 300°C), design follows the experience from existing ESR ($p_{Ave} \leq 1 \times 10^{-11}$ mbar)

Schematic Vacuum Layout of RESR



RESR Vacuum Chambers

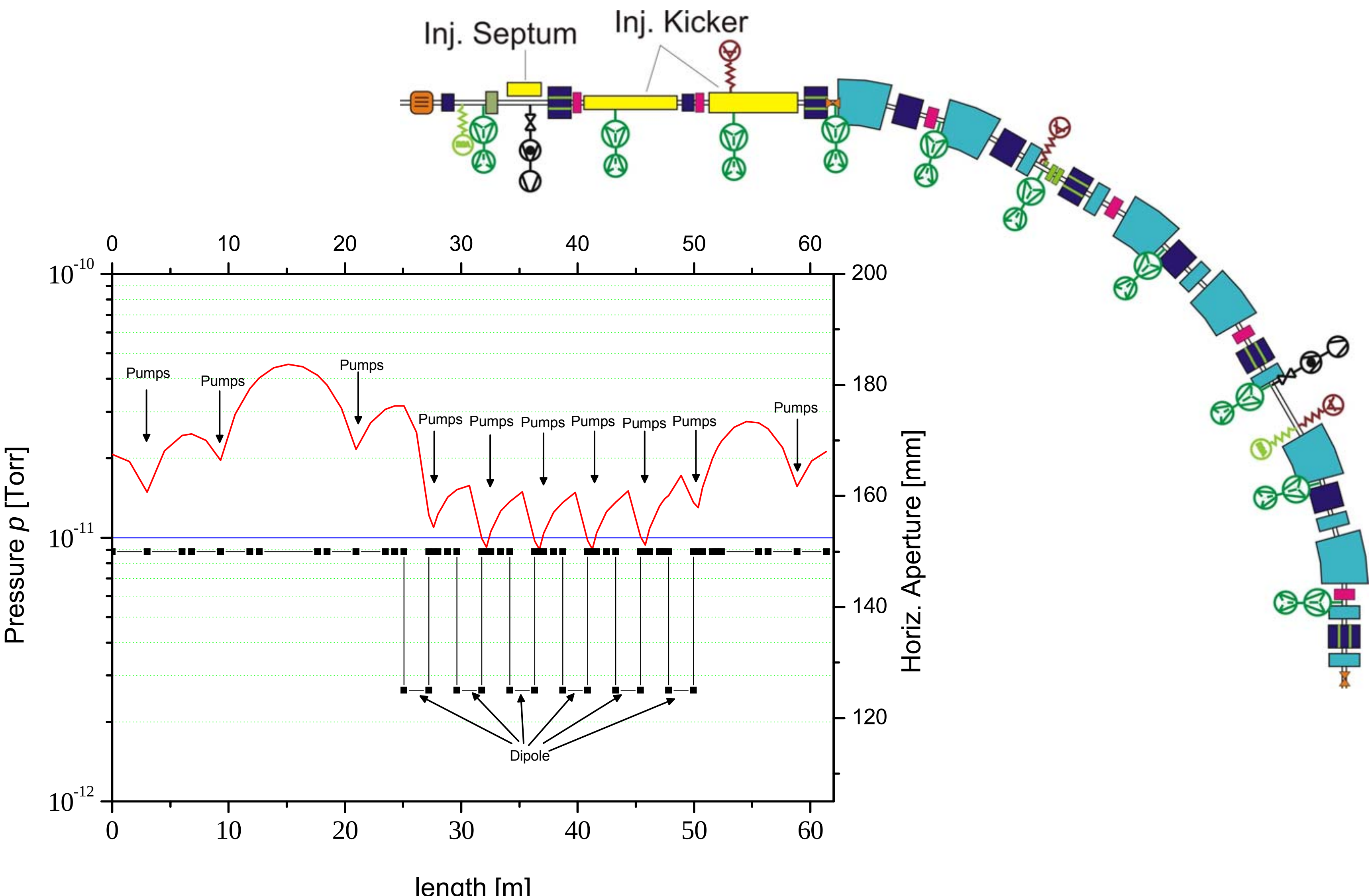
Total of 240m (113m magnets) of vacuum system:

- Dipole vacuum chambers (2.7 m long, 250x70mm^2, 15°)
- Quadrupole vacuum chamber (1.15m, 300x150mm^2)
- Sextupole vacuum chambers (0.5m, 300x150mm^2)
- Corrector vacuum chambers (0.5m, 300x150mm^2)
- 4 roughing chambers (one or two different types)
- 40 pumping and vacuum diagnostic chambers (one or two different types)
- Bellows (different length and apertures)
- Straight vacuum chambers (different length and apertures)
- Diagnostic chambers, RF-chambers, Septa, Kicker

Material for all vacuum chambers: stainless steel 1.4429, 1.4404, 1.4306
Standard flanges: DN160CF, DN250CF, DN320CF

Bake out of vacuum system with commercially available bake out jackets, tailored individually for each chamber. Temperature control with thermocouples and computer based control.

Vacuum Calculations RESR, one quarter



RESR Pumps, Valves and Gauges

Pump type	Number	Pumping speed	comments
Pumping station roughing	2	500 l/s & 10 m^3/h	TMP & dry forepump
Sputter ion pumps	40	500 l/s	DN160CF
Ti sublimation pumps	40	2000 l/s	DN160CF
NEG coating			of chambers

	Number	Type	Dimension
Gate valve	4	all-metal	DN 250 CF
Valve for roughing	4	all-metal	DN 160 CF
Fast valve	2	all-metal	DN 160 CF

Gauge Type	Number	Flange
Hot Cathode Gauge	10	DN35CF
Residual Gas Analyzer	4	DN35CF

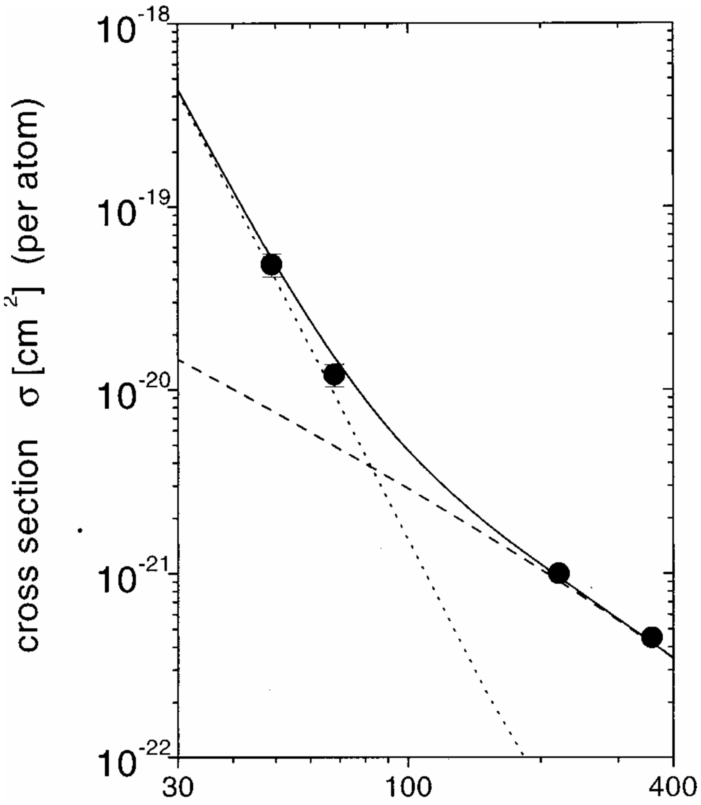
Summary

With the described techniques it is possible to fulfill the required vacuum conditions for RIBs and antiprotons in CR and RESR.

- First analytical calculations of pressure profiles in the rings done, input based on length and apertures. Detailed calculations are going on.
- Detailed design of whole CR and RESR vacuum system, regarding the positions and size of pumps and position of vacuum diagnostics is going on.
- Detailed design of the vacuum chambers started.

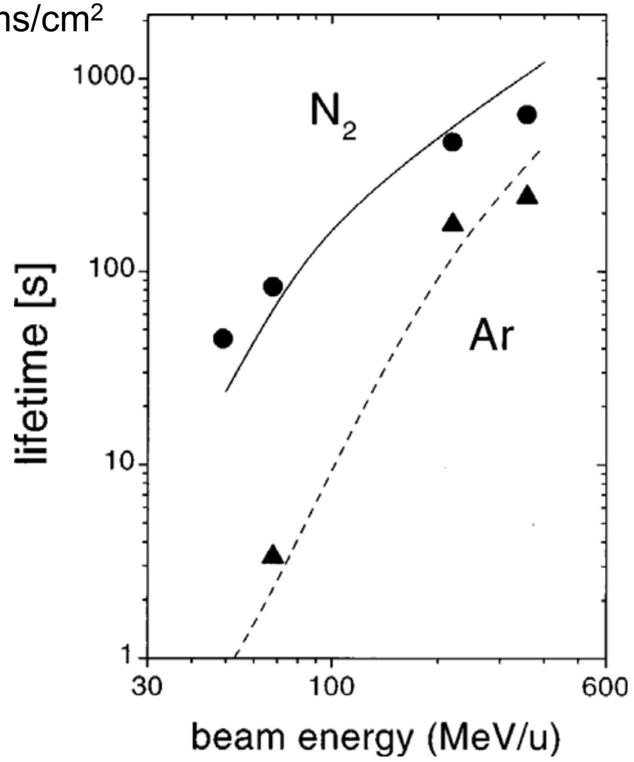
Back-up Folien

Lifetime for Decelerated Ions



Theoretical total electron-capture cross sections for U^{92+} on a N_2 target versus projectile energy (dotted line NRC, dashed line REC). The solid line refers to the sum of both predictions.

Target thickness
CR: $6\text{x}10^{11}$ atoms/cm^2
RESR: $6.4\text{x}10^{10}$ atoms/cm^2
Lifetime: $1/\tau = \rho\,\sigma\,f$

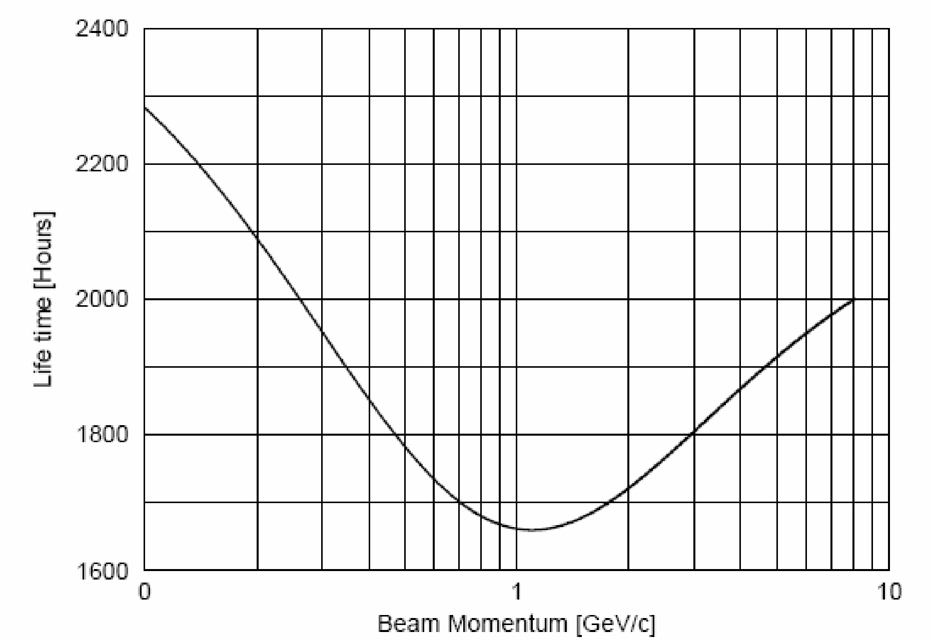


Experimental lifetimes for U^{92+}-ions obtained at the various beam energies for the case of a N_2 (solid points) and an Ar (solid triangle) gaseous target ($1\text{x}10^{12}$ particles/cm^2). The solid line and the dashed line (for the N_2 and Ar target) represent theoretical lifetime estimates.

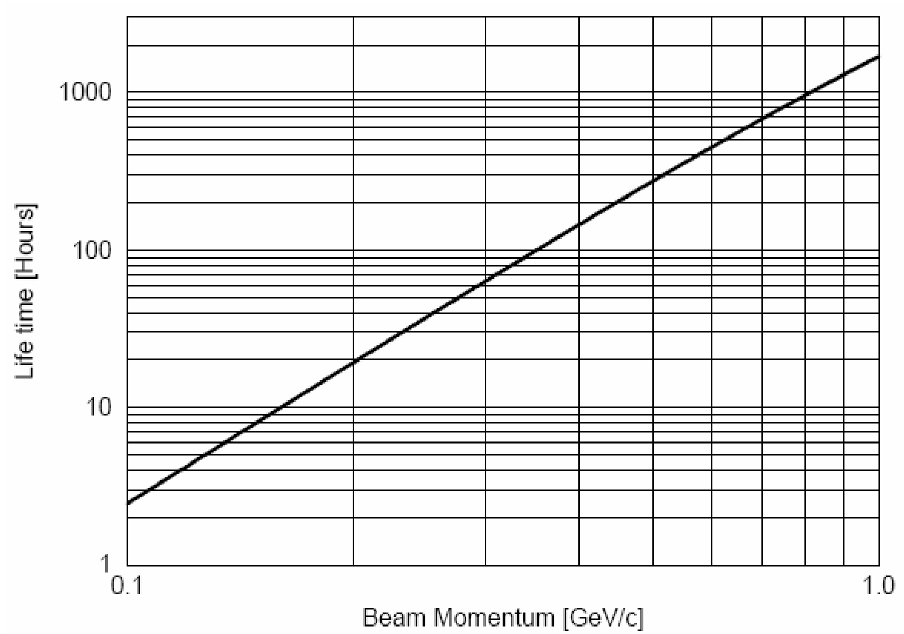
from: T. Stöhlker et al., Phys. Rev A 58, 2043 ,1998

Lifetime Calculations for Antiprotons in AD

Nuclear Scattering



Single Coulomb Scattering



$p=4x10^{-10}$ mbar
acceptance 150 π mm mrad

from: N. Madsen, PS/DI Note 99-06, AD Note 047, CERN 1999

Beam Neutralization at Recycler Ring

The lifetime comparisons with full neutralization (each antiprotons traps one ion) of the $2.0\text{x}10^{12}$ antiproton beam with case of no neutralization ($p_{Tot} = 5.37\text{x}10^{-10}$ Torr)

Physical Process	No Ions (Normal Case) [hours]	Neutralization (100%) [hours]
Single Coloumb	4.64×10^2	4.62×10^2
Inelastic Scatt.	8.06×10^2	8.02×10^2
Mult. Coloumb	5.55×10^1	5.53×10^1
Nuclear Scatt.	1.61×10^3	1.60×10^2
Total Life Time	4.54×10^1	4.50×10^1

Effect of neutralization on lifetime <1%,
but trapped ions cause a tune shift!

from: K. Gounder et al., Proc. of PAC 2003, 2928, 2003

CR Vacuum Chambers

Total of 215m (130m magnets) of vacuum system with large apertures:

- Dipole vacuum chambers (2.6 m long, 380x140mm^2)
- Quadrupole vacuum chamber wide (1.3m, 400x180mm^2)
- Quadrupole vacuum chamber narrow (0.75m, 180x180mm^2)
- Quadrupole chamber ESR type wide (1.15m, 400x180mm^2)
- Quadrupole chamber narrow septum (1.3m, 400x180mm^2)
- Two different sextupole chambers (0.6m, 180x180mm^2; 0.85m, 400x180mm^2)
- Three different corrector chambers (0.4m&0.6m, 180x180mm^2, 400x180mm^2)
- 8 roughing chambers (one or two different types)
- 40 pumping and vacuum diagnostic chambers (one or two different types)
- Bellows (different length and apertures)
- Straight vacuum chambers (different length and apertures)
- Diagnostic chambers, RF chambers, Septa, ...

Material for all vacuum chambers: stainless steel 1.4429, 1.4404, 1.4306
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	Number	Type	Dimension
Gate valve	5	all-metal	DN200CF
Gate Valve	3	all-metal	DN400CF
Valve for roughing	8	all-metal	DN160CF
Fast valve	2		DN160CF

Gauge Type	Number	Flange
Wide Range Ion Gauge	16	DN35CF
Residual Gas Analyzer	6	DN35CF