Charge Exchange Induced Losses
&
Dynamic Vacuum

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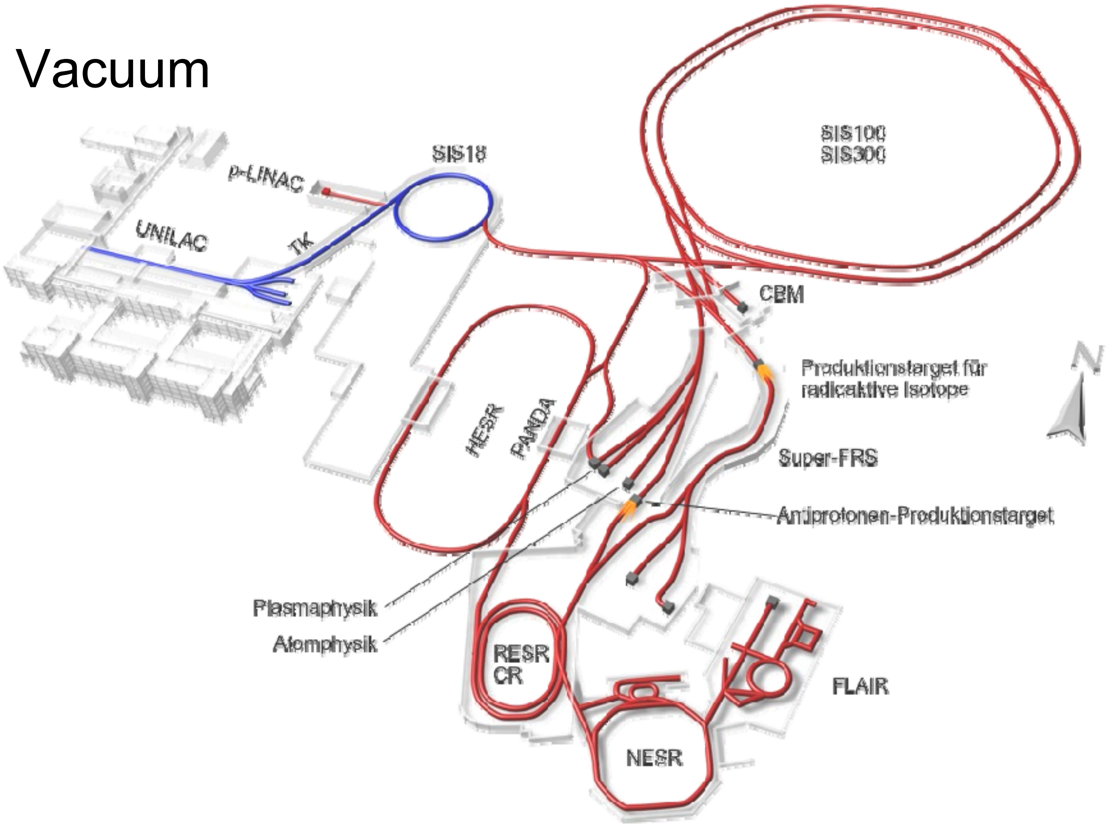
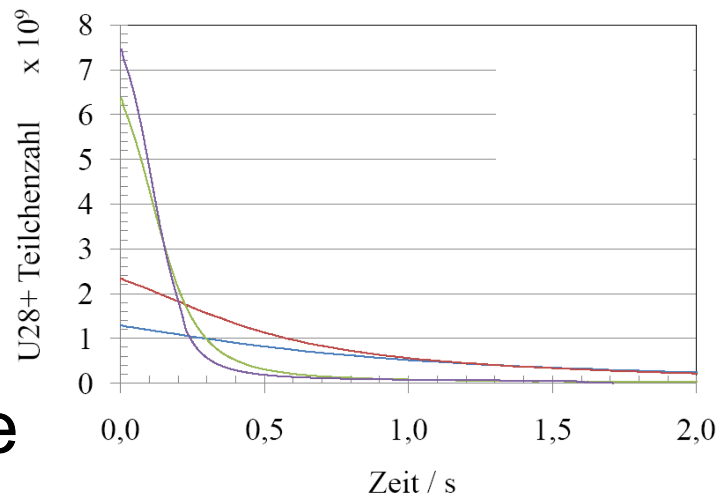
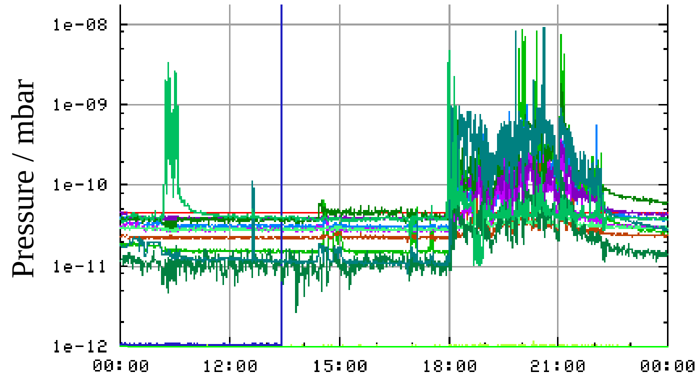


- SIS18 Operation with U^{28+} shows fast and intensity dependent Beam Losses
  - Intensity far below space charge limit
  - Huge Pressure rise at the same time
- Beam Loss and Pressure Rise depend on each other:
  - High initial pressure → Huge losses
  - Huge losses → High pressure rise

➢ Beam Lifetime depends on Dynamic Residual Gas Pressure

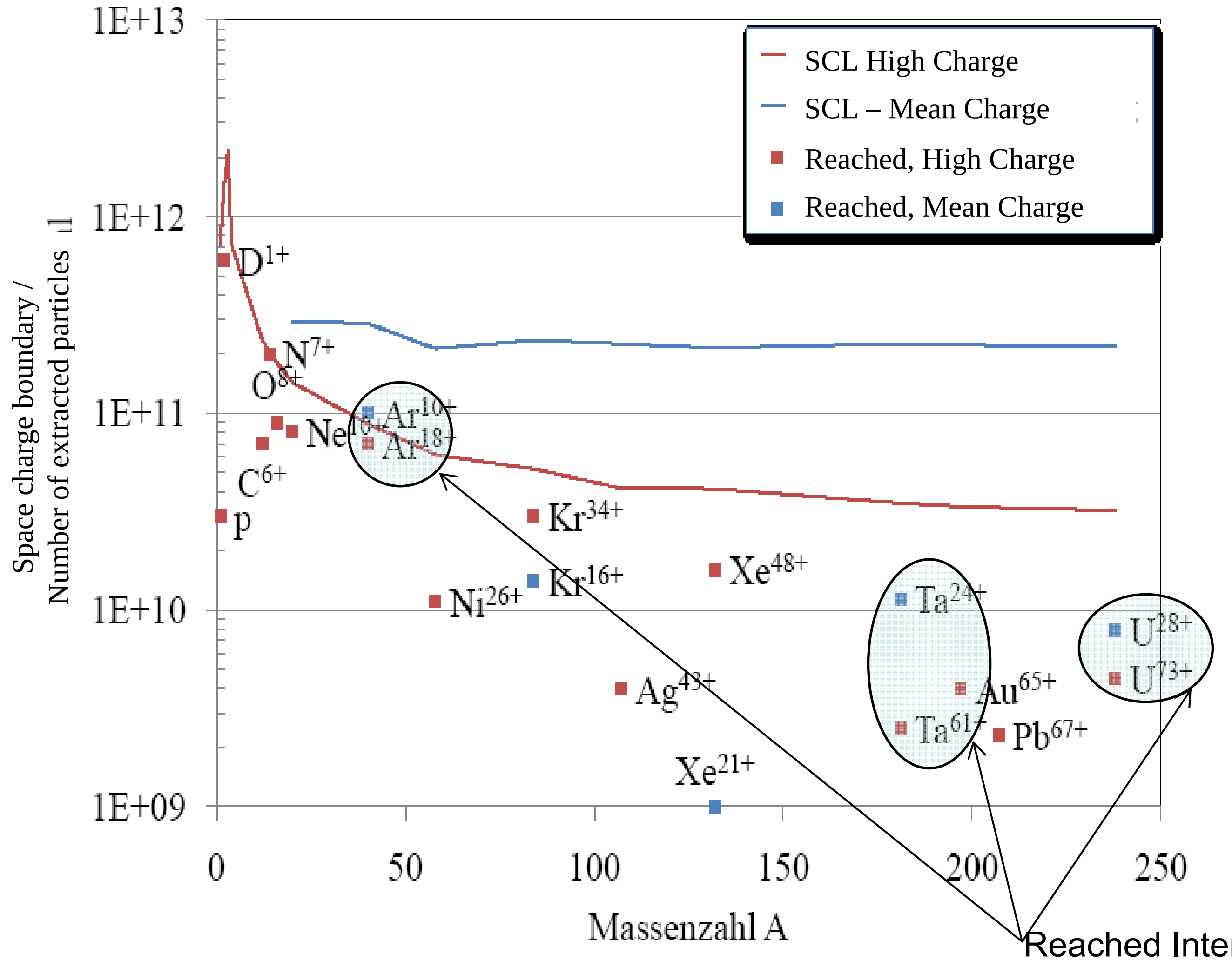


P. Spiller, 2001



Omet, 2008

Motivation – Space Charge Limit is not the Limit!



Reached Intensity should be much higher at low charge states

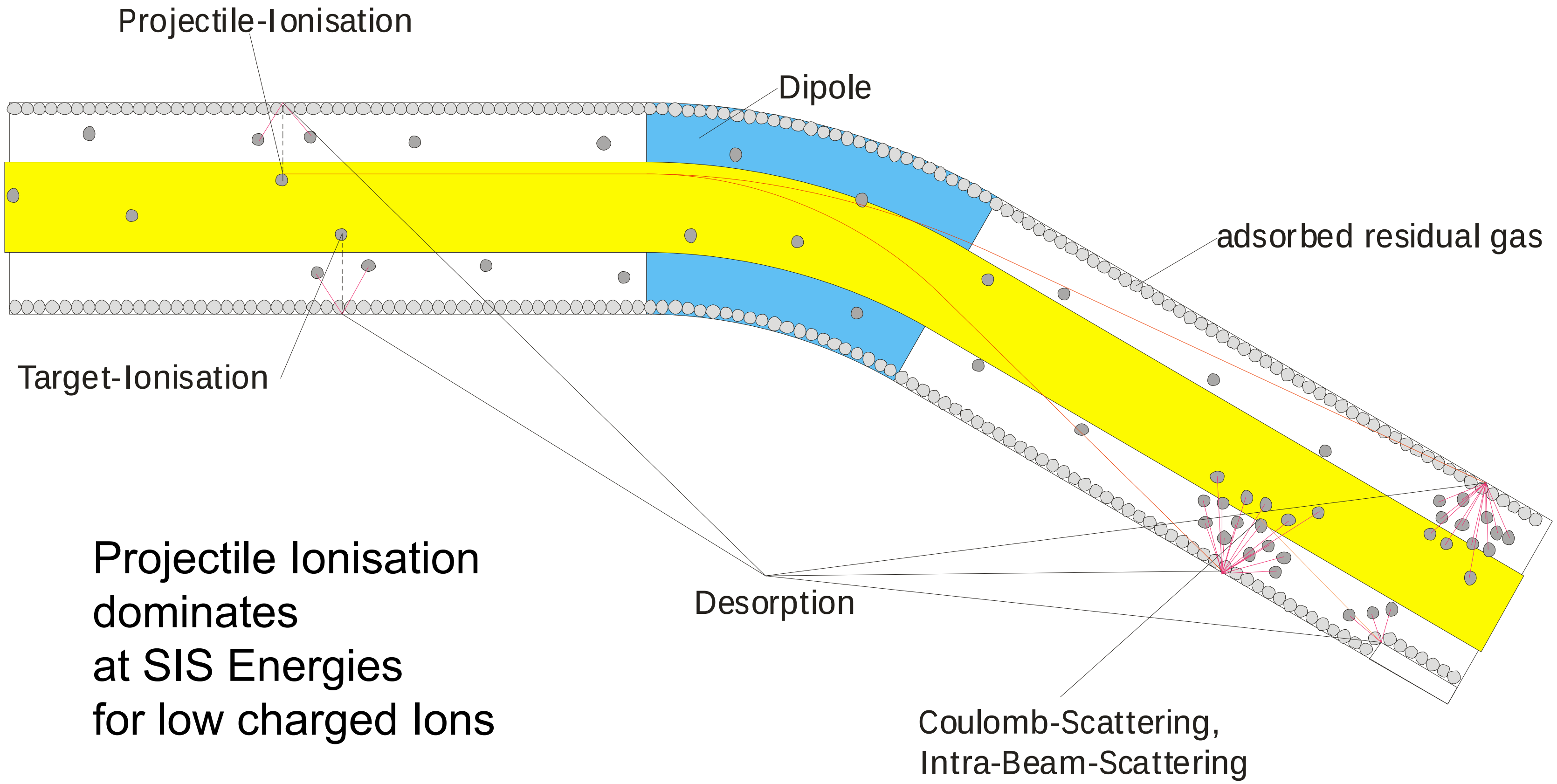
Loss Mechanisms

- Systematic Losses
  - Injection: Multi-Turn-Injection
  - HF-Capture: Frequency not properly adjusted
  - ...
  - ➢ Can be minimized by careful machine adjustment
- Charge Exchange induced Losses
  - Projectile Ionisation and recombination
  - Target Ionisation

➢ **All** losses lead to a pressure bump

➢ Avalanches up to complete Beam Loss

Charge Exchange Loss Mechanisms



Projectile Ionisation
dominates
at SIS Energies
for low charged Ions

$U^{28+} + R^0 \rightarrow \mathbf{U^{29+}} + R^0 + e^-$

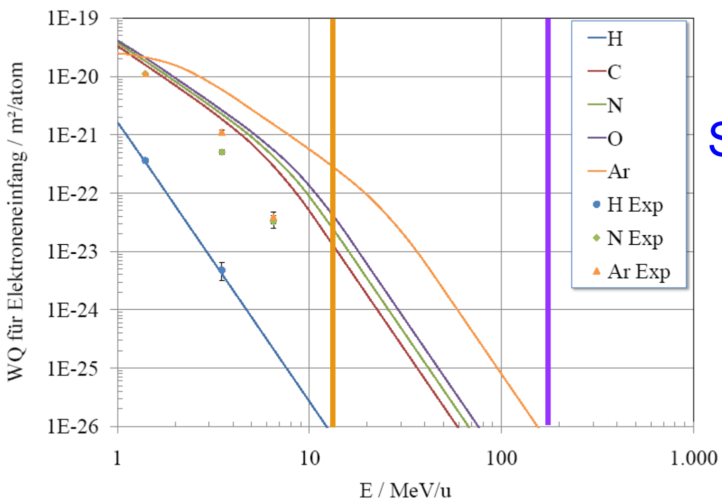
Projectile Ionisation

1) Beam Ion encounters residual gas atom and looses electron(s)
   - Electron Capture also possible
   - Multiple charge exchange possible
2) Ion's charge differs from reference ion
   - Ion gets separated from beam in dispersive elements (dipole)
   - Hits the wall
3) At the point of impact:
   - Via ionstimulated desorption adsorbed gas molecules are released (Desorption rate $\eta \geq 10^4$)
   - Local pressure increase
4) If there is still beam, Goto 1)
   - Avalanche-like pressure increase and beam losses

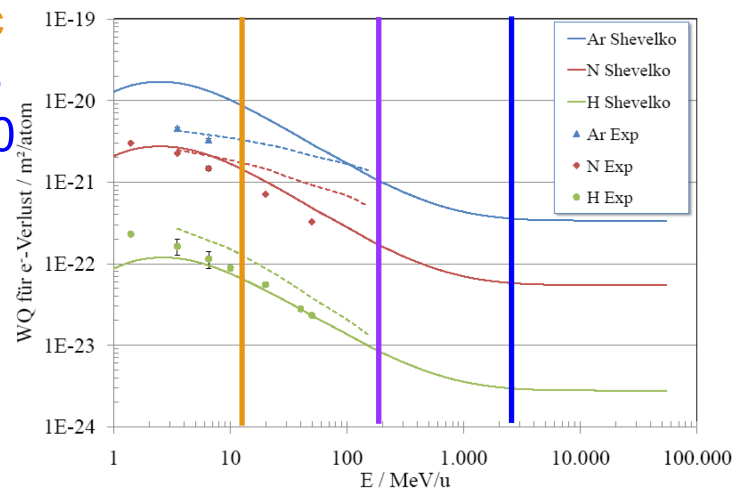
Electron Capture | U^{28+} | Electron Loss

- Empirical formula by Schlachter
  - Usually in good agreement with measurements
  - No measurements at high beam energy available
- No relevant contribution at SIS18 energies

- No empirical formula
- No measurements at high beam energy
- Theoretical models:
  - Olson, n-CTMC ≲ 100 MeV/u (dashed lines)
  - Shevelko LOSS-R



Unilac
SIS18
SIS100

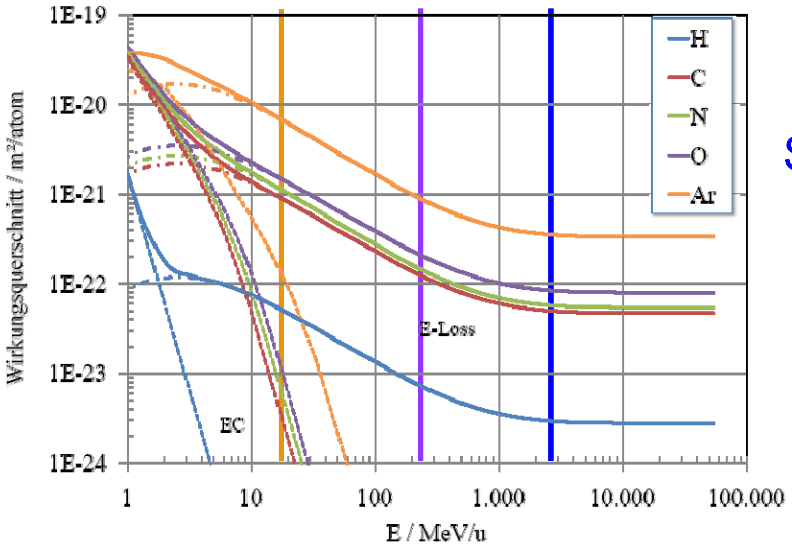


1,4 MeV/u: GSI, Franzke | 3,5/6,5 MeV/u: Texas A&M, Olson | Rest: GSI, Stöhlker, Weber

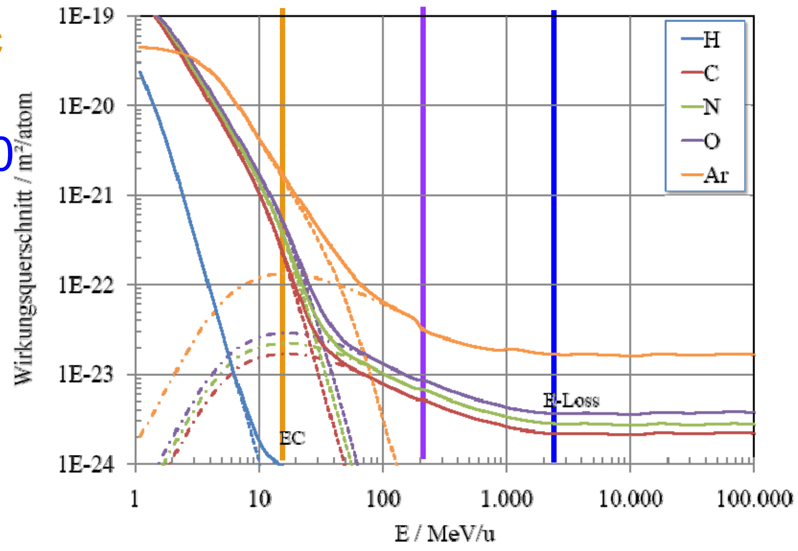
U^{28+} Cross Sections U^{73+}

- Electron Loss dominates for E>7 MeV/u
- σ remains large for high energies

- Electron Capture dominates for E< 70 MeV/u
- σ almost vanishes for high energies



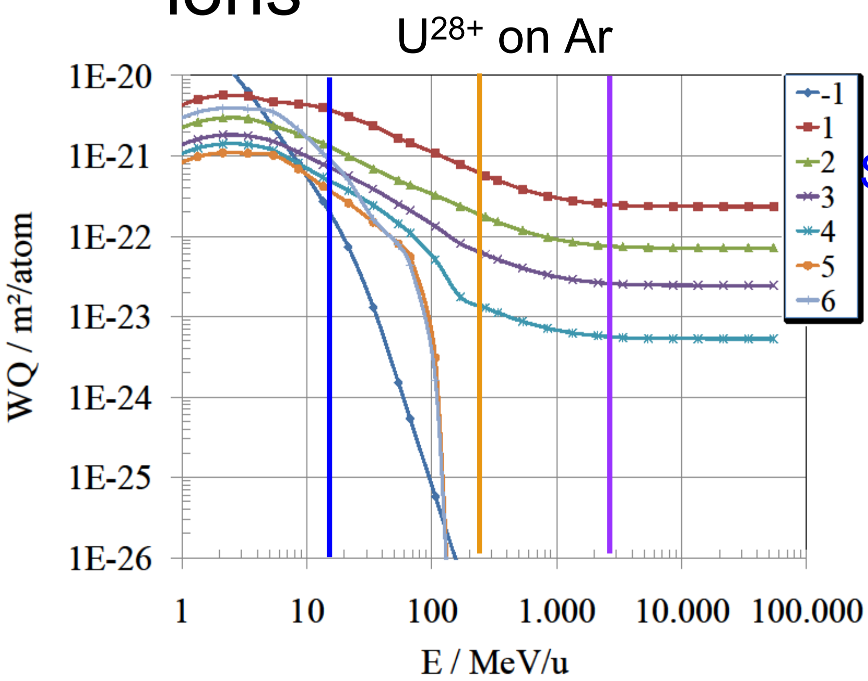
Unilac
SIS18
SIS100



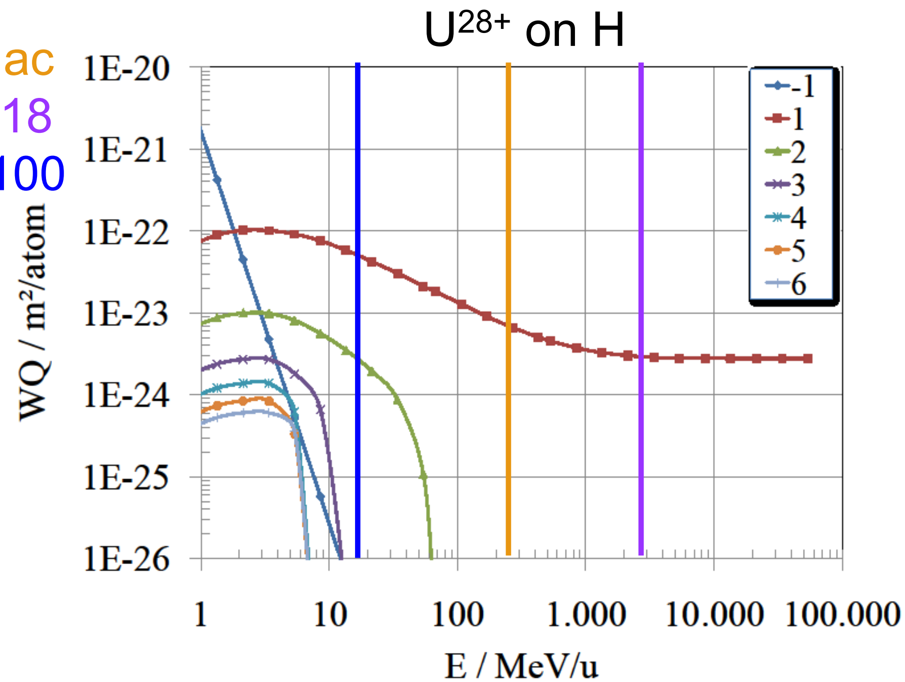
Heavy residual gas components have the largest cross sections, therefore they have to be avoided in the accelerator's vacuum.

Multiple Ionisation

- The heavier the residual gas atom, the bigger the cross sections for multiple ionisation
- Different points of impact for different ionized ions

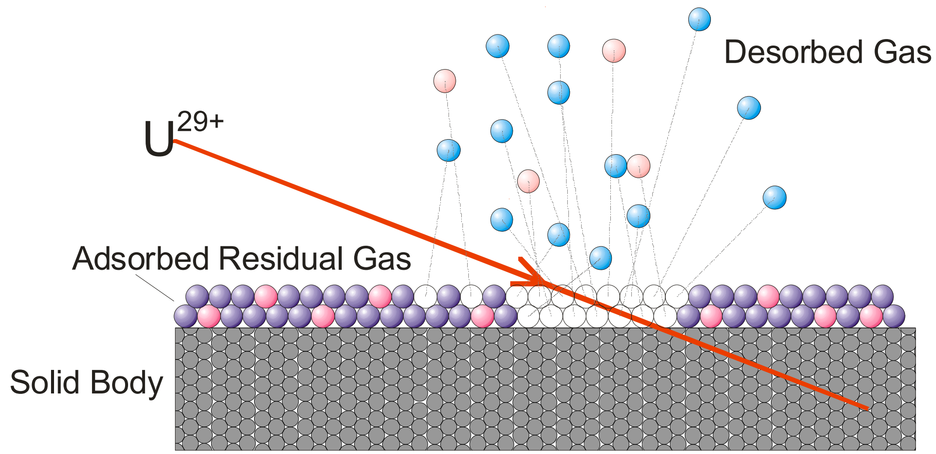


Unilac
SIS18
SIS100



Ion Stimulated Desorption

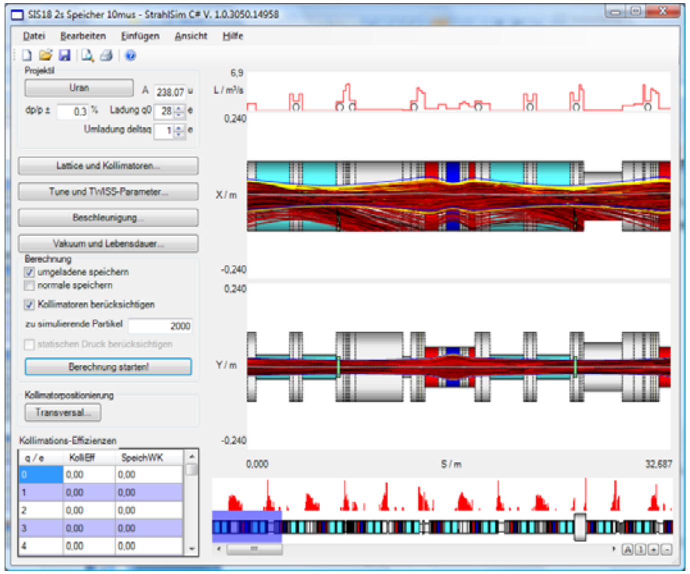
- On vacuum surfaces residual gas molecules get adsorbed
  - Binding Energy few eV
  - Can be released by ion bombardment
- Desorption Rate η
  - Scales with specific energy loss $(dE/dx)^2$
    (Max. at SIS18 injection)
  - Depends on
    angle of incidence
    - $\eta_{\perp}$ ~ 100 molecules/Ion
    - $\eta_{\angle}$ ~ $3...20 \cdot 10^4$ molecules/Ion, not measured at SIS100 energies
  - Perpendicular incidence → Low desorption

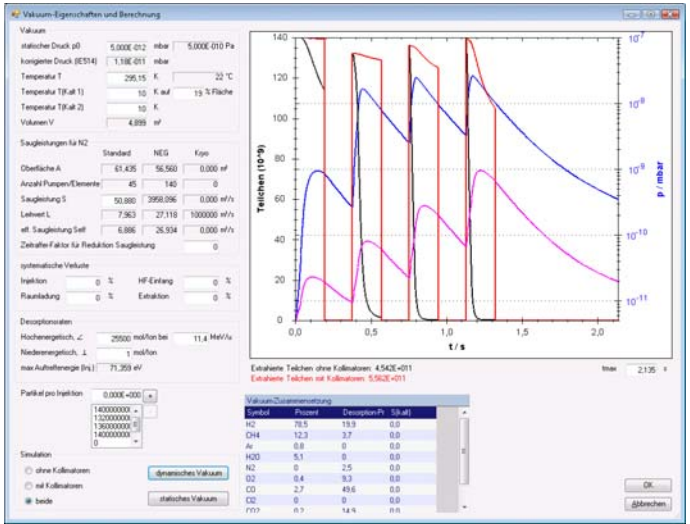


➤ See also talk by Holger Kollmus

Simulation with StrahlSim

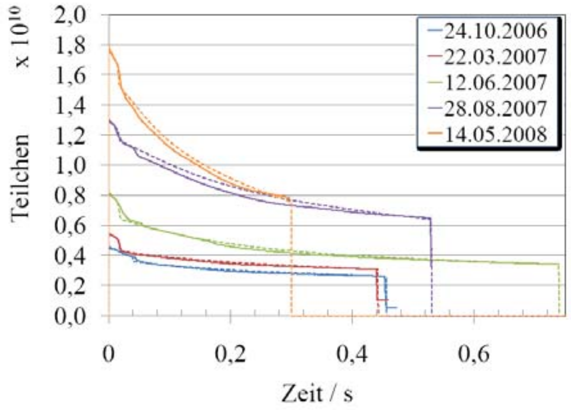
- Linear Beam Optics
  - Longitudinal loss distributions
  - Collimation efficiency
- Static Vacuum
  - Molecular Raytraycer to get longitudinal pressure distribution, vacuum conductance, ...
  - NEG, cryogenic surfaces, residual gas components
- Dynamic Vacuum
  - Synchrotron-cycle with systematic losses
  - Projectile Ionisation
  - Ion stimulated desorption (Desorption rate scaled with $(dE/dx)^2$), couples beam losses to pressure rises





Simulation with StrahlSim

- Simulation has been compared and benchmarked with many machine experiments in SIS18
- Application at GSI, CERN (beta beams) and BNL (AGS Booster)
- Publication: Charge change-induced beam losses under dynamic vacuum conditions in ring accelerators, C.Omet et al 2006 *New J. Phys.* 8 284 doi:10.1088/1367-2630/8/11/284



without Catchers, 2c

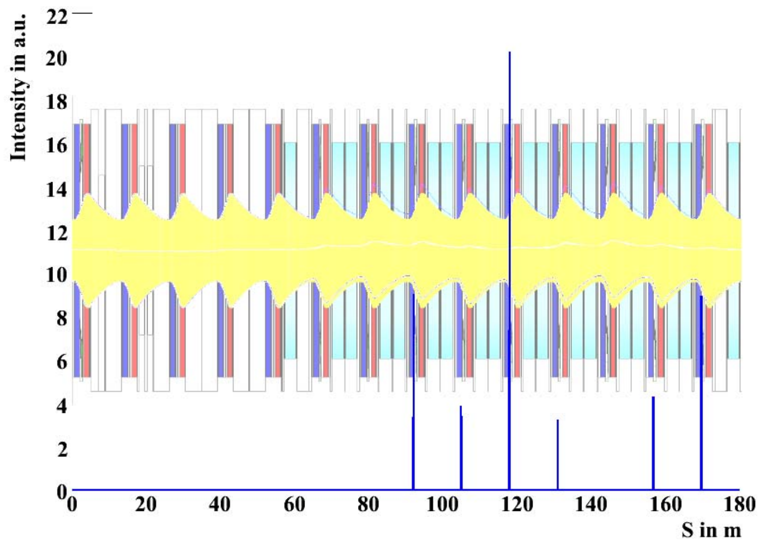
without Catchers

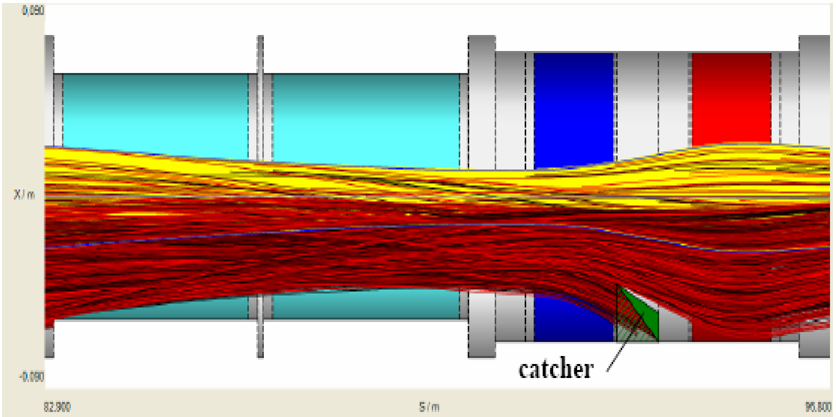
with Catchers, 2σ

with Catchers

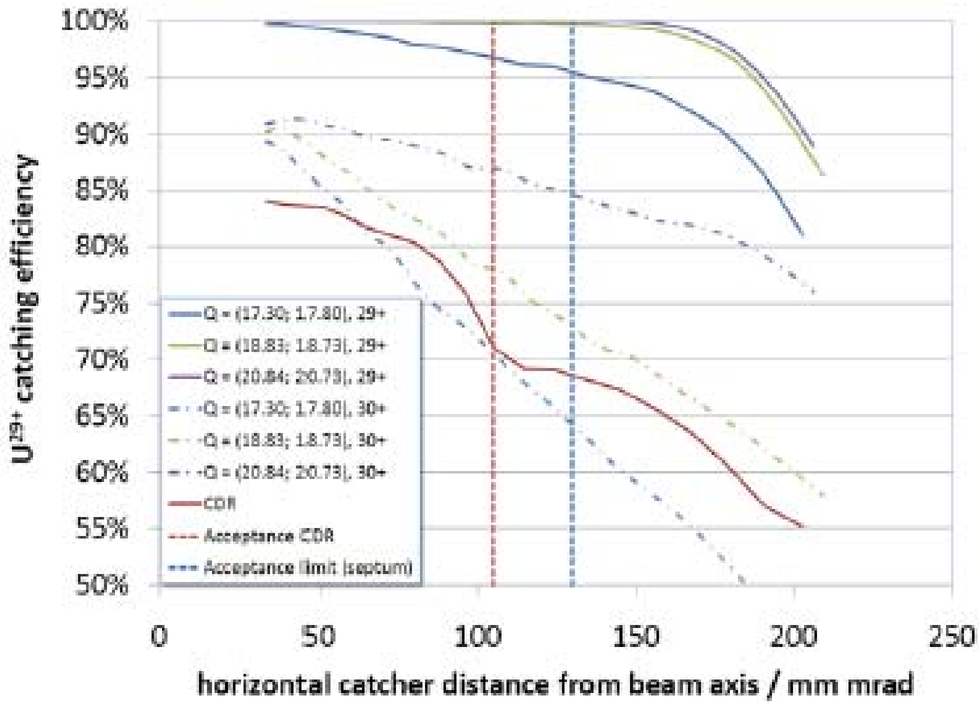
Ion Catching

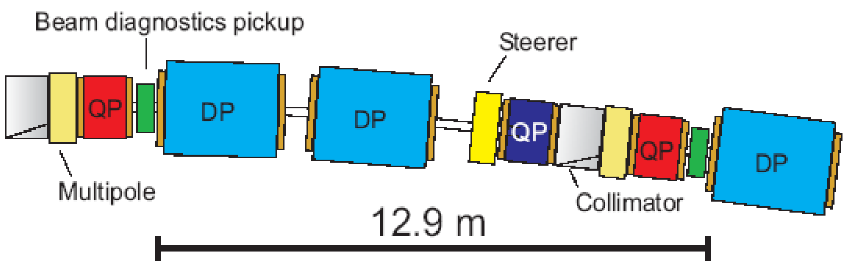
- SIS100 lattice has been optimized for the usage of Ion Catchers
  - Loss distribution is strongly localized between the quadrupoles
  - There the catchers are located
- Surrounding cold vacuum chamber works as cryo-pump for fast pumping of desorbed molecules





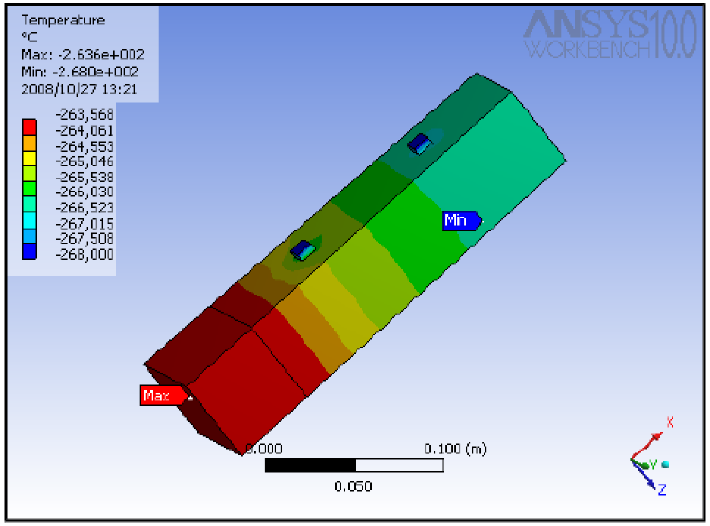
- Careful lattice desing leads to a high collimation efficiency
  - For U^{29+} almost 100%
  - For U^{30+} ~85%
  - For Xe^{21+}-→Xe^{22+} ~92%





Ion Catching

- Cryo-Ion-Catcher
  - By choosing an appropriate temperature, on the catcher less gas is adsorbed than on the surrounding cold chamber walls
  - Most lost ions get cached by the ion catcher
  - This leads to a significant reduction of gas desorption and such improves the dynamic vacuum, which in turn reduces the losses induced by charge exchange
  - The surrounding magnets get less activated by lost ions
  - Is part of the EuCARD WP8: ColMat
- Research is ongoing



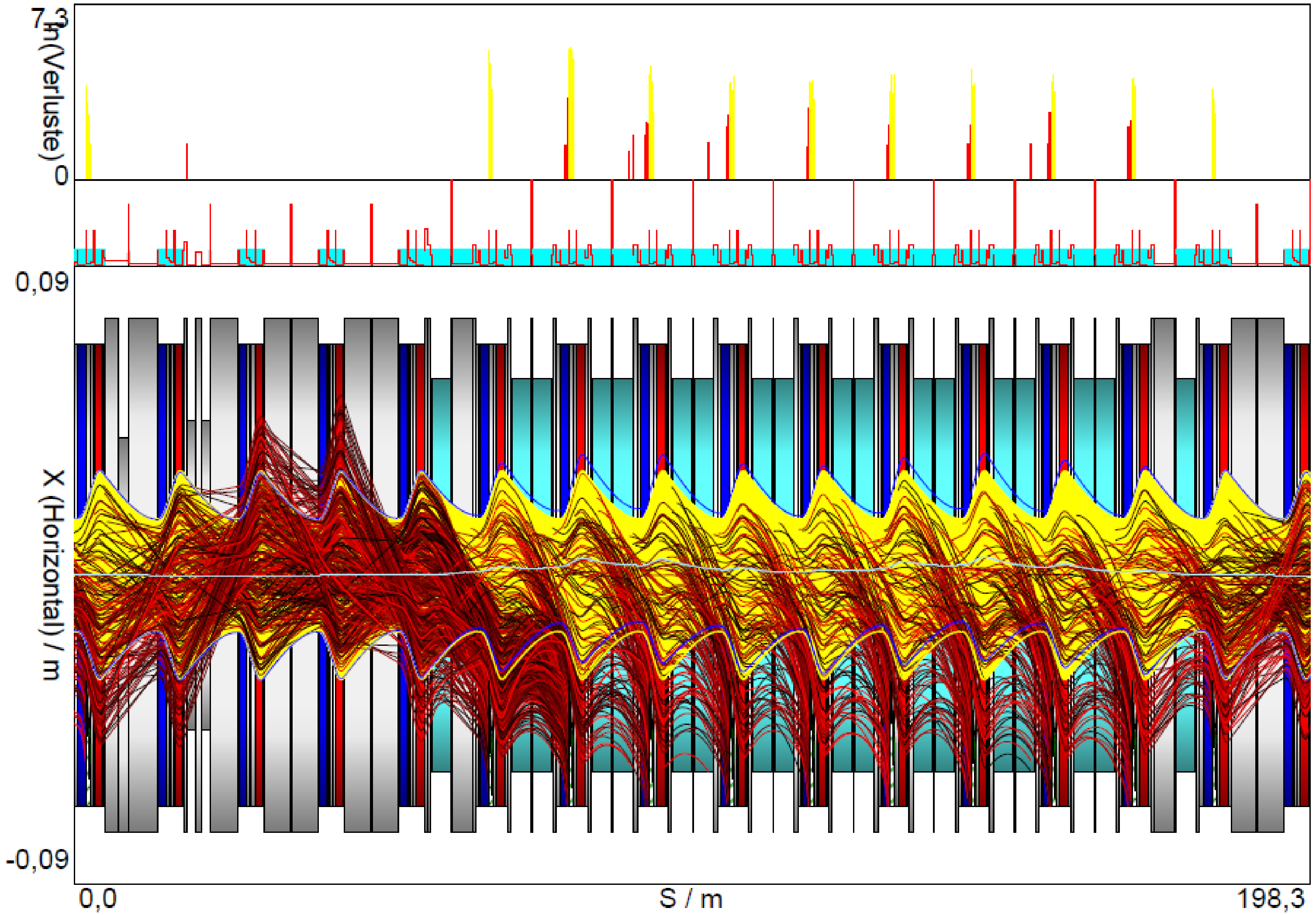
Summary

- Dynamic Vacuum is the limiting factor for particle intensities in heavy ion synchrotrons
- The usage of Ion Catchers can shift this limit
- Uncertain are the absolute values of the cross sections and desorption rates

Acknowledgment:

- C. Omet
- GSI FSY-Group
- GSI UHV-Group
- GSI AP-Group (Atomphysik)

Loss Distribution for $Xe^{21+} \rightarrow Xe^{22+}$



HELMHOLTZ GEMEINSCHAFT GSI FAIR

Saturation Vapor Pressure

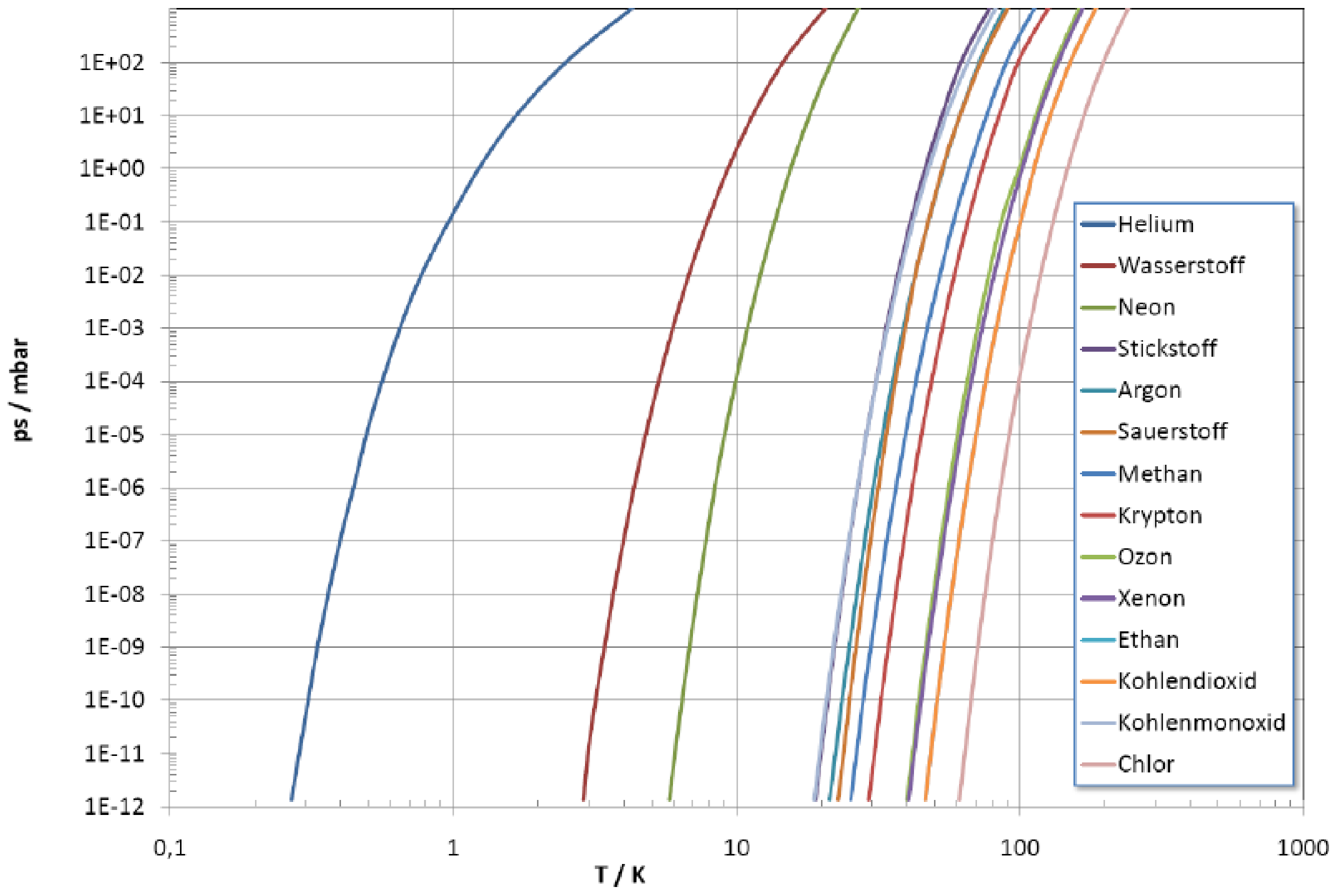


Abbildung 65: Sättigungsdampfdrücke für verschiedene Vakuumkomponenten als Funktion der Temperatur, aus [74].

Residual Gas Spectrum

Tabelle 3: Vakuum-Parameter.

Parameter	Symbol	Wert	Einheit
Gleichgewichtsdruck	p_0	$5 \cdot 10^{-12}$	mbar
Temperatur	T	22	°C
Volumen	V	4,9	m^3
eff. Saugleistung	S_{eff}	6,9	m^3/s
eff. Saugleistung NEG	$S_{eff,NEG}$	26,9	m^3/s
Volumen H_2		78,5	%
Volumen CH_4		12,3	%
Volumen Ar		0,8	%
Volumen H_2O		5,1	%
Volumen O_2		0,4	%
Volumen CO		2,7	%
Volumen CO_2		0,2	%
Desorptionsrate (11,4 MeV/u)	$\eta_\angle$	25 500	Moleküle/Ion
Desorptionsrate (keV)	$\eta\_\perp$	1	Moleküle/Ion
Desorption H_2		19,9	%
Desorption CH_4		3,7	%
Desorption N_2		2,5	%
Desorption O_2		9,4	%
Desorption CO		49,6	%
Desorption CO_2		14,9	%

- Target-Ionisation: Desorption by ionised residula gas moleculeResidual gas molcule gets ionised
  - Is accelerated towards the wall by the beam potential
  - Hits the wall perpendicular
- Cross section for TI described by Bethe:

$$\sigma_B = \frac{4 \cdot \pi \cdot a_0^2 \cdot \alpha^2}{\beta^2} \cdot \left[M_i^2 \cdot \left(\ln\left(\frac{\beta^2}{1-\beta^2} \right) - \beta^2 \right) + C_i + \frac{\gamma_i \cdot \alpha^2}{\beta^2} \right]$$

NEG

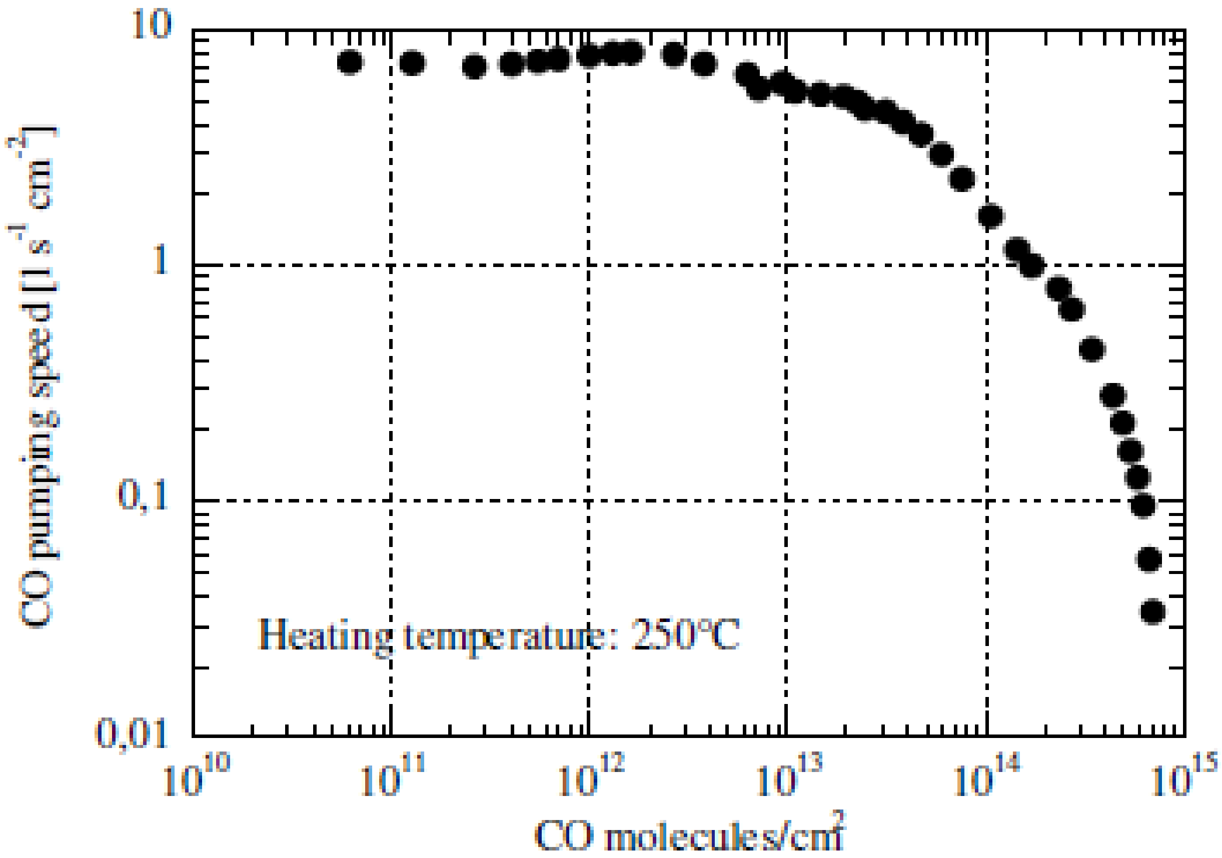


Figure 2: CO saturation curve obtained after activation of the sample at 250°C for about 4 hours.