MAC – February 2009

# Heavy Ion Induced Desorption Studies using ERDA

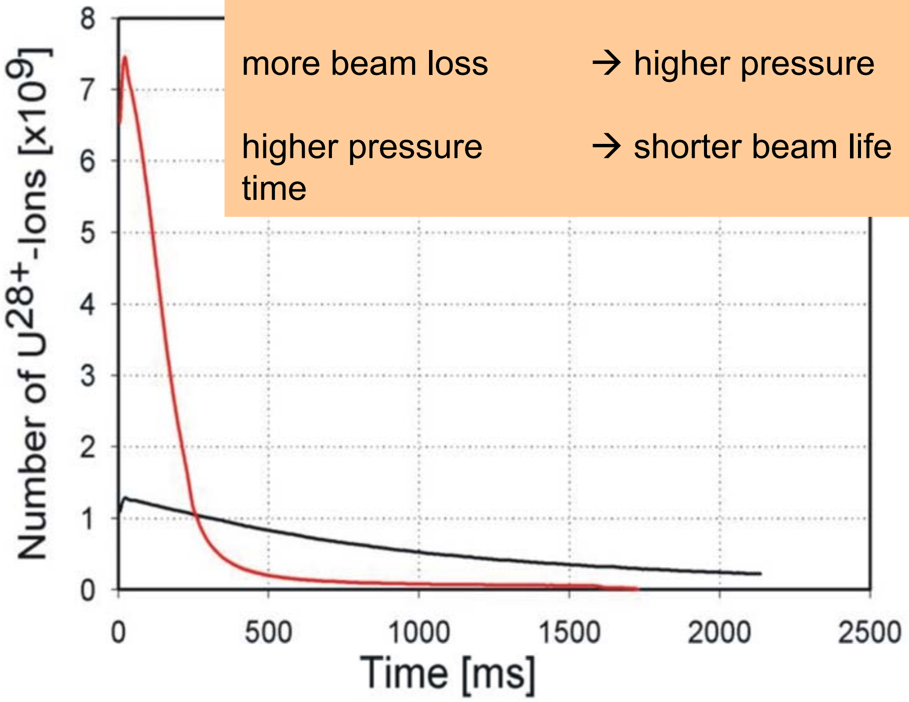
A Summary of Experimental and Theoretical Activities

# Motivation - SIS18 Beam Life Time

Dynamic Vacuum Evolution during Acceleration

• Ion Induced Desorption Decreases the Beam Life time

| | |
|---|---|
| higher intensity | → more beam loss |
| more beam loss | → higher pressure |
| higher pressure | → shorter beam life time |




Peter Spiller, December 2001, 8.75 MeV/u $U^{28+}$

**Desorption Yield Measurements of well characterized Materials using Elastic Recoil Detection Analysis and Rutherford Backscattering Spectroscopy**

✓ element specific depth profiling of samples
→ surface - bulk information
→ characterization of sample properties and possible modification under ion irradiation

→ **access to physics of ion induced desorption**

Goal: To find a sufficient ion catcher material and geometry

# Measured Desorption Yields (During Beam Operation)

- LEAR: 4.2 MeV/u $Pb^{54+}$
  - Pressure increase up to $10^{-9}$ mbar, Desorption yield: $10^5$ molecules/ion

  *J. Bosser et al., Part. Accel. 63, 171 (1999)*
- AGS-Booster (1999): 1 MeV/u $Au^{31+}$ ions
  - Desorption Yield: ~ $10^5$ molecules/ion

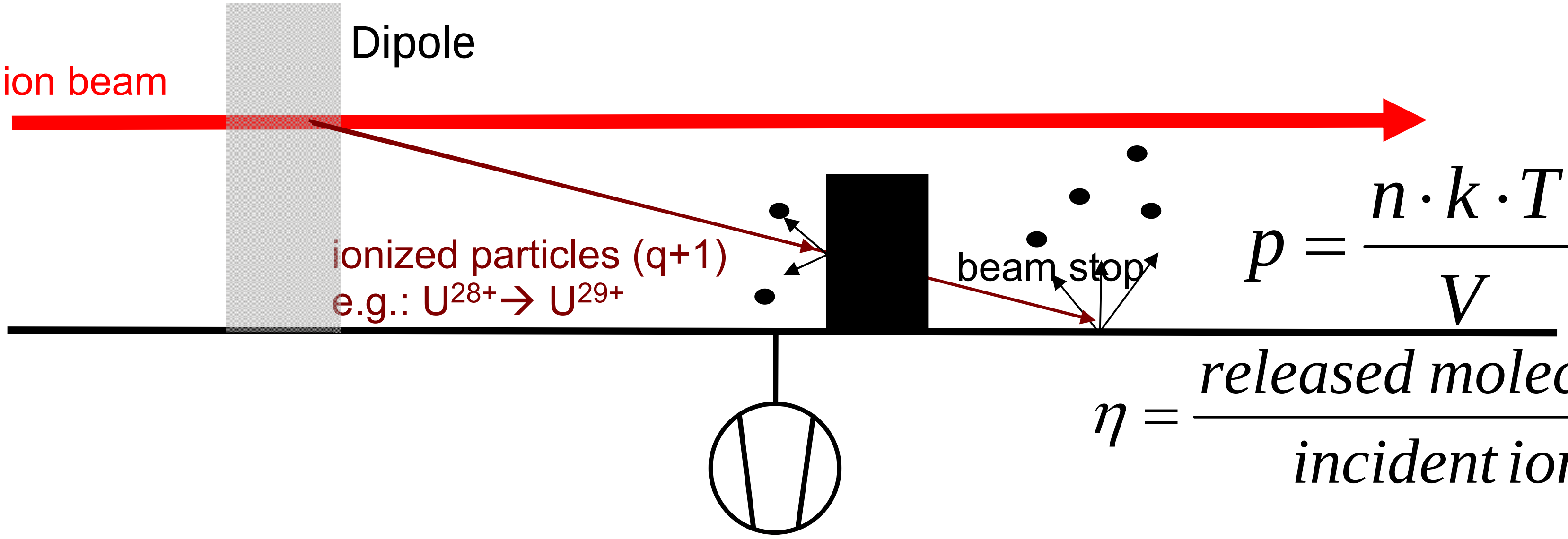
  *S.Y. Zhang et al., Proc. of PAC1999, New York, 3294 (1999)*
- RHIC (2002): 8.6 GeV/u $Au^{79+}$ ions (fully stripped)
  - Dynamic pressure increase up to > $10^{-5}$ mbar (~ 5 orders of magnitude, vacuum interlock)

  *W. Fischer et al., PRST-AB, 2002*
- SIS18 (2002): 8.9 MeV/u $U^{28+}$ ions
  - Desorption Yield: 4200....$10^4$ molecules/ion

  *A. Krämer et al., Proc. EPAC2002, Paris, 2547 (2002)*
- Studies at LINAC 3: 4.2 MeV/u $Pb^{53+}$ and $Pb^{27+}$ ions
  - First tests in Nov. 2000, intensive exp. program since May 2001

  *E. Mahner et al., PRST-AB 6, 013201 (2003)*

# Beam Loss Induced Desorption in SIS18

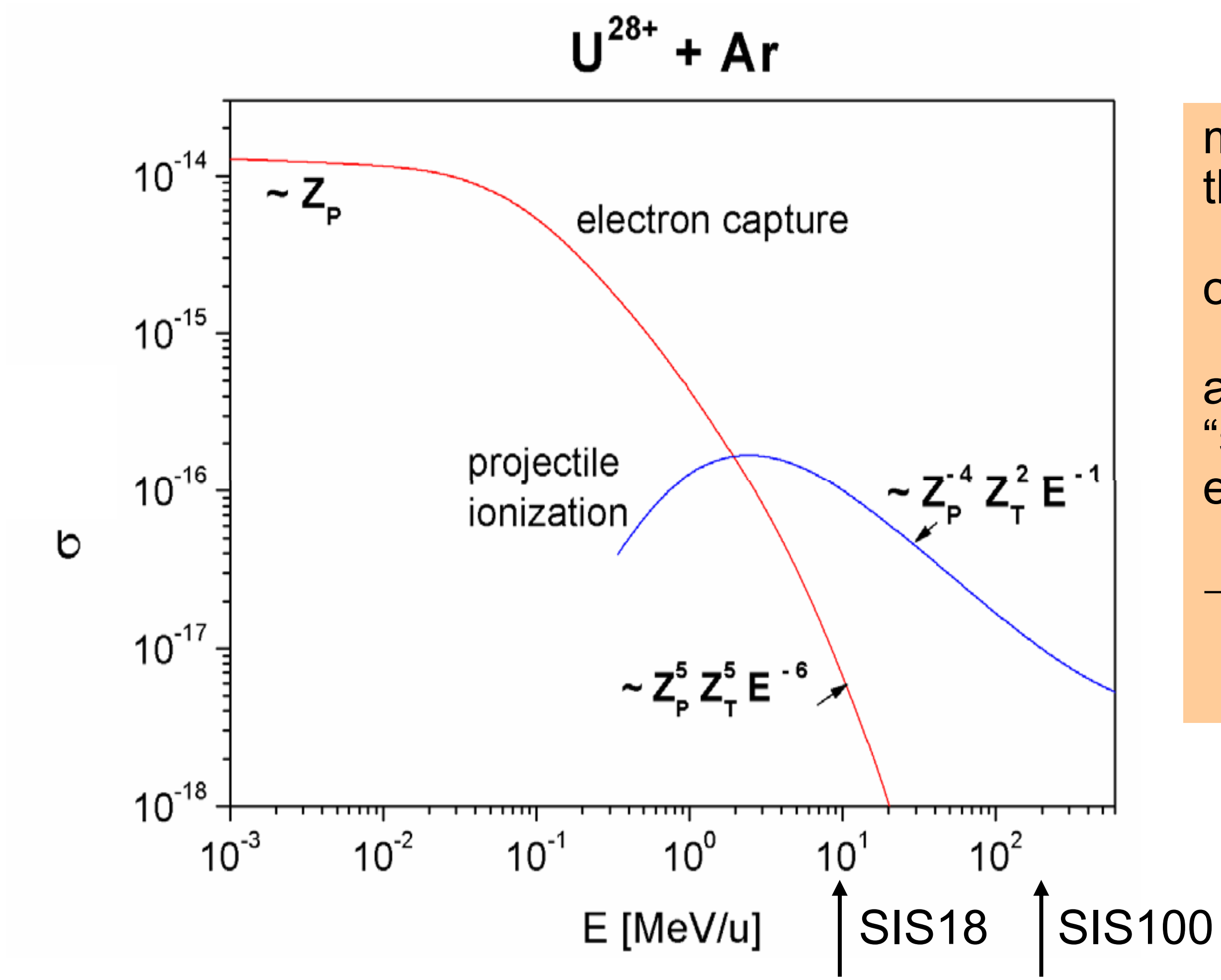



$$p = \frac{n \cdot k \cdot T}{V}$$

$$\eta = \frac{released\ molecules}{incident\ ion}$$

- lowest static pressure $\rightarrow$ NEG coating ($10^{-12}$ mbar)
- controlled loss on a dedicated ion catchers
- loss $\rightarrow$ perpendicular
- extra pumping speed
- <u>low desorbing material</u>

# Capture and Loss Cross Sections




multiple ionization scales with the perturbation to

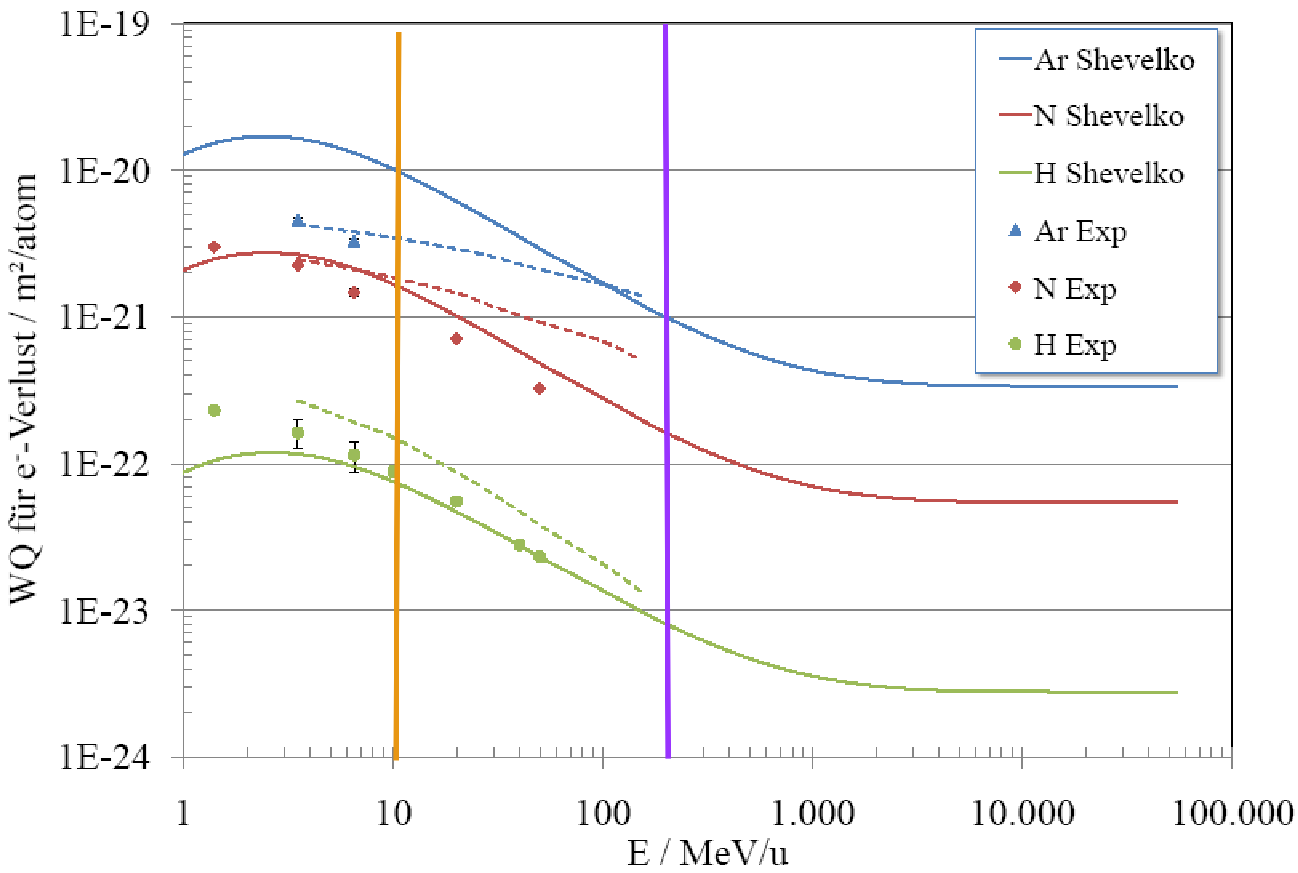
$\sigma \sim q/v$

and is in it's high energy "shake off" limit at SIS100 energies

$\rightarrow$higher catching efficiency with increasing ion beam energy

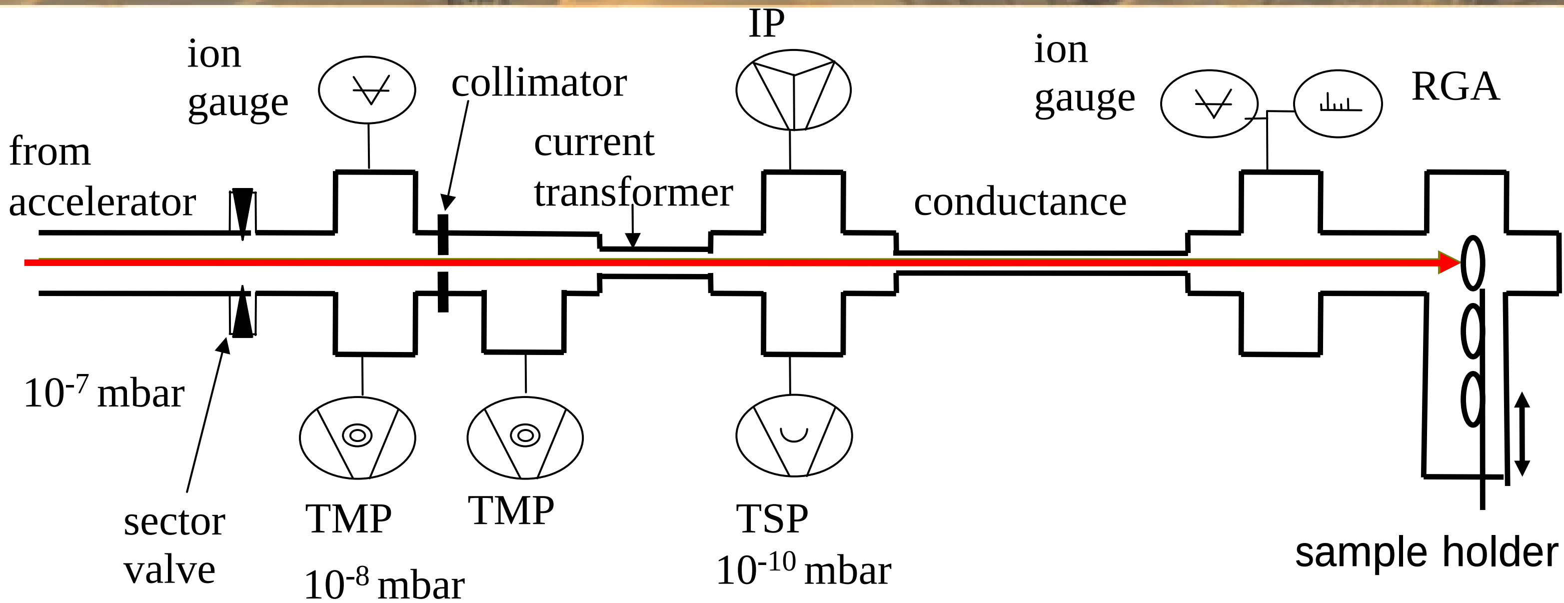
LOSS and CAPTURE code by V. Chevelko et al.

# Theory versus Experiment




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

# Desorption Yield Measurements at GSI (2003)




**Experiments by: M. Bender, A. Krämer, H. Kollmus (GSI), E. Mahner (CERN)**

**desorption yield out of pressure increase: (short single pulse, no pumping)**

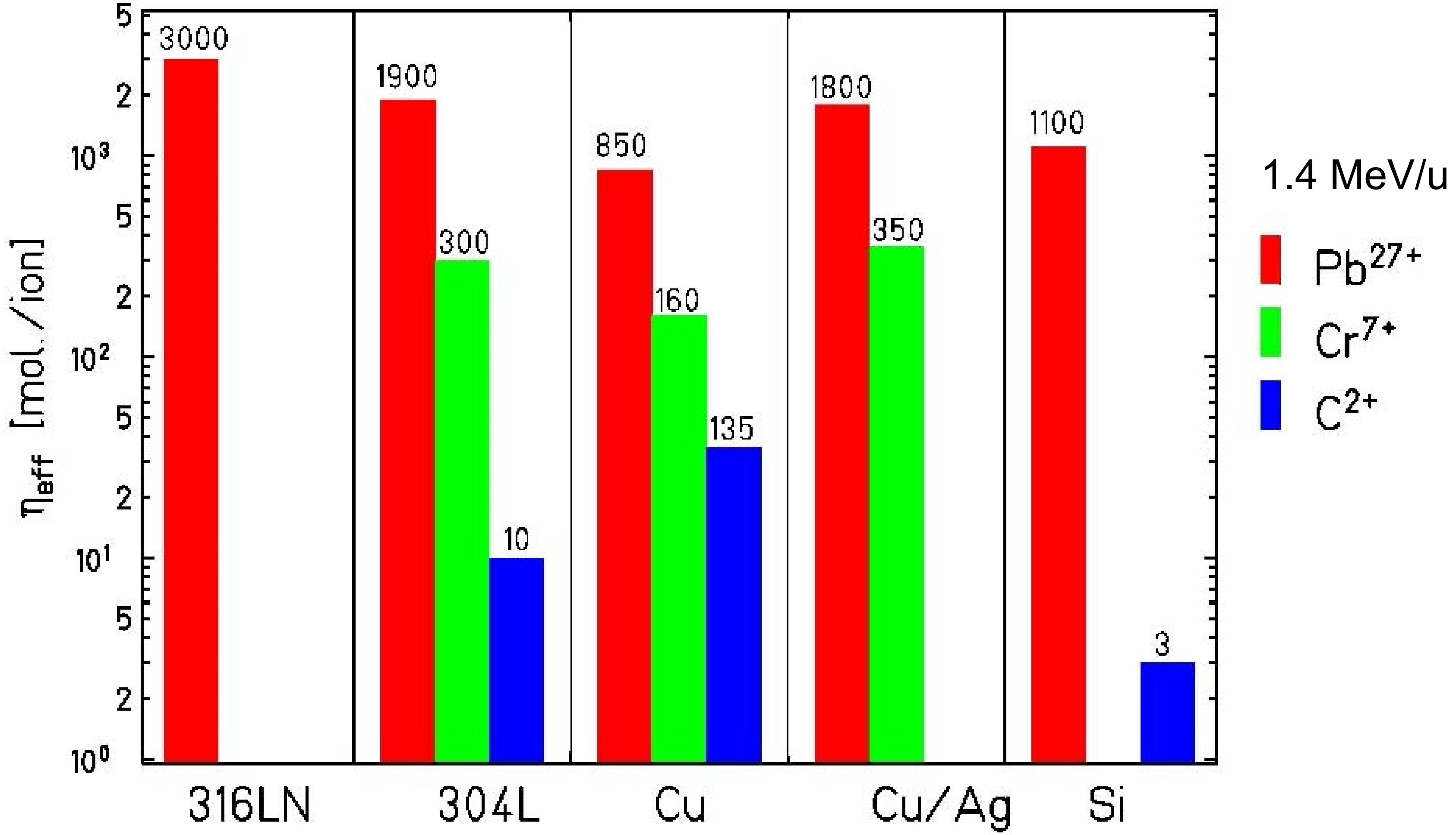
$$\eta = \frac{\Delta p \cdot V}{N_I \cdot k_B \cdot T}$$

**time dependent: (continuous bombardment)**

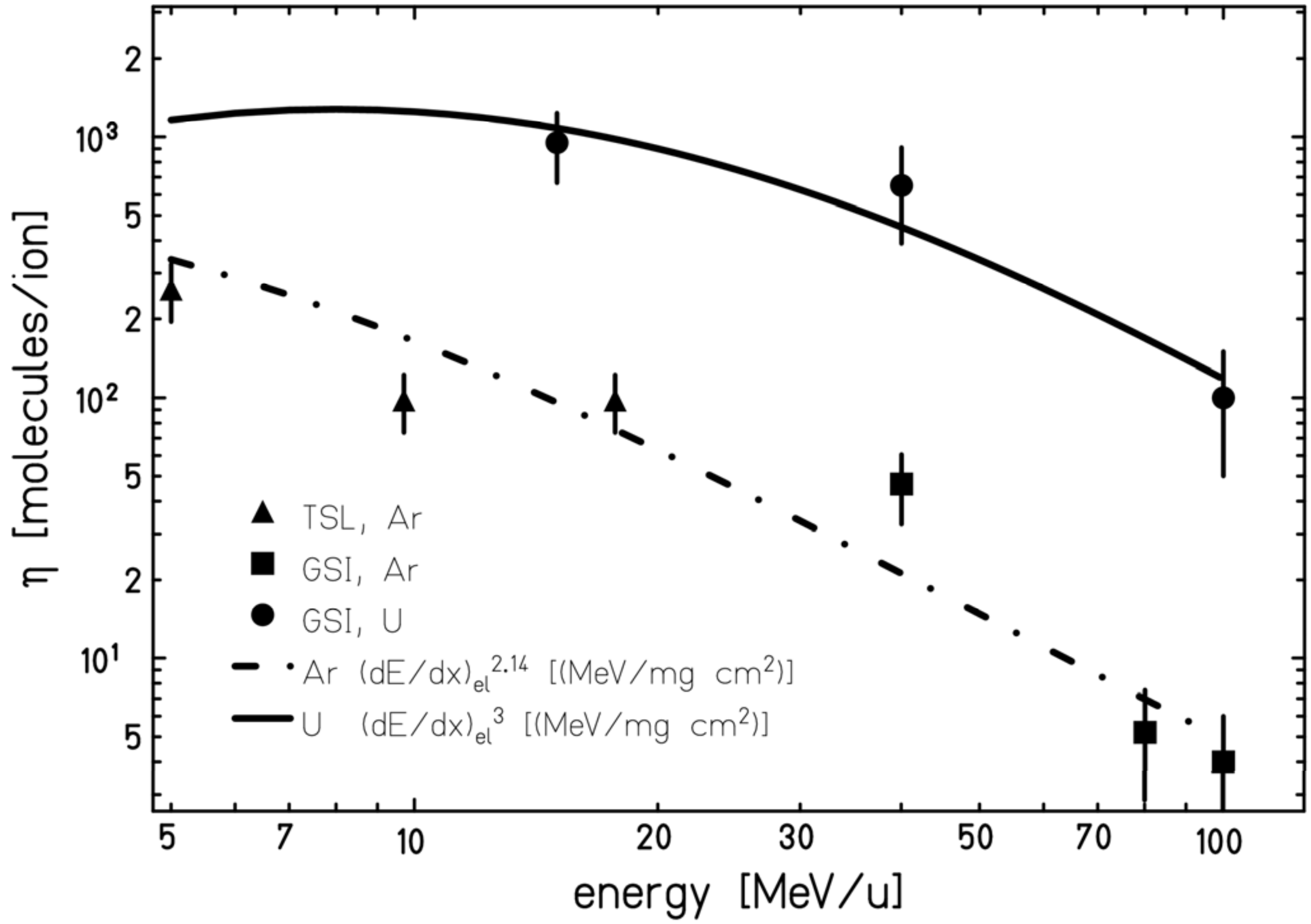
$$\eta = \frac{\Delta p \cdot \dot{V}}{\dot{N}_I \cdot k_B \cdot T} = \frac{\Delta p \cdot S_{eff}}{\dot{N}_I \cdot k_B \cdot T}$$

# Results of the Desorption Yield Measurements (1)

effective desorption yields ($N_2$ equivalent)



# $(dE/dx)^{2-3}$ Scaling with Impact Energy



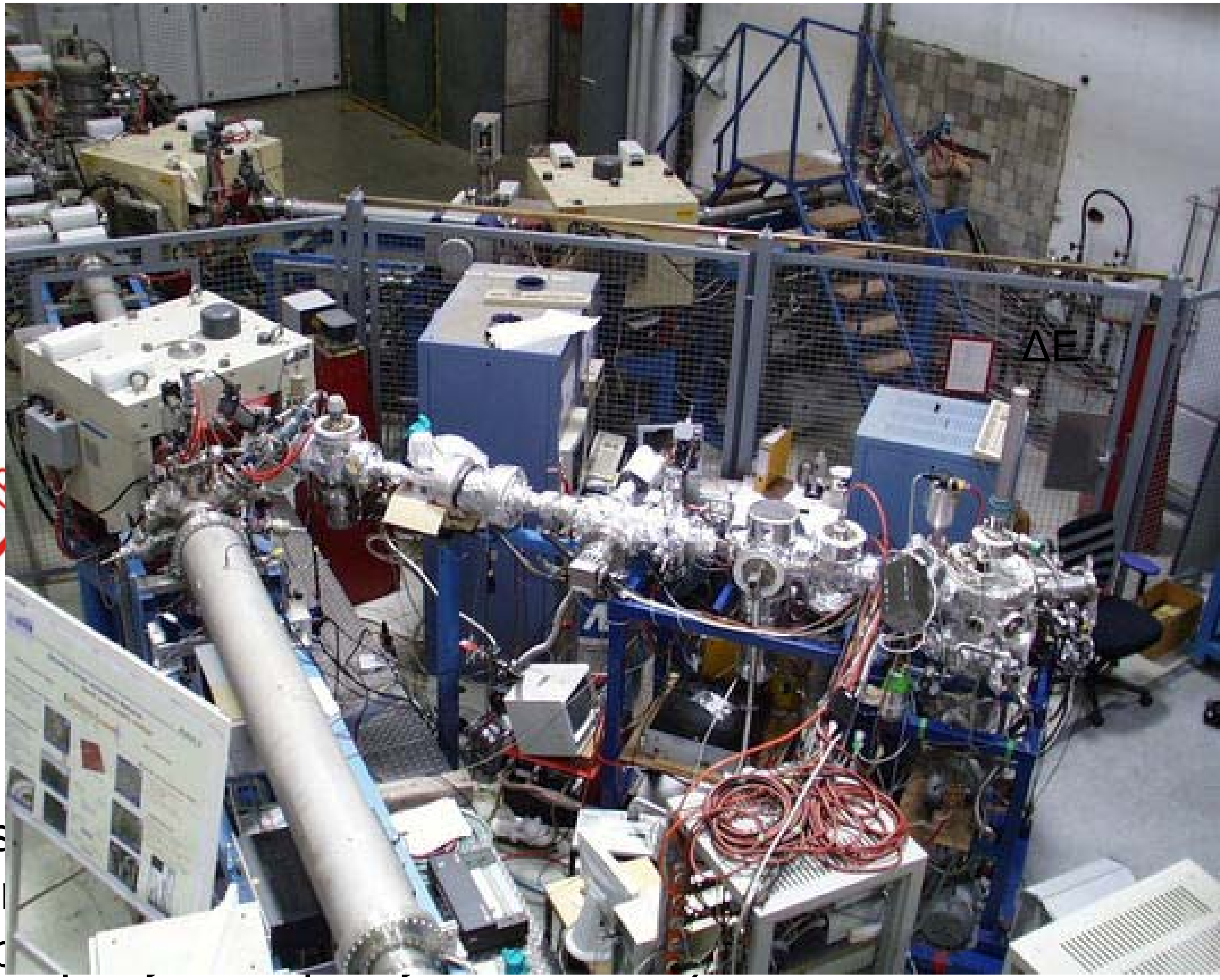
# Summary of Pure Desorption Yield Measurements

- $(dE/dx)^2$ scaling with mass and atomic number of projectile
- $(dE/dx)^{2-3}$ scaling with incident projectile energy ($\perp$ incident)
- grazing incident > perpendicular incident
- cleaning effects visible (beam scrubbing)
- no 'magic material' for ion catchers

# Still open Questions

- How can one ion desorbe up to 10000 molecules?
  - a macroscopic many particle effect can be excluded in our investigations due to low impact current!
- Is desorption a surface or a bulk effect?
  - from a typical track radius the desorption yield can not be explained as a surface effect!
- Is the pressure rise due to sputtering of material impurities?
  - stainless steel contains C, N and O which might form CO, $CO_2$, and $N_2$!

# Material Investigation with ERDA



n

is (Z)

$E_{Res.}$

$\Delta E$

or

surement

*molecules*

*ent ion*

E, Z, m (

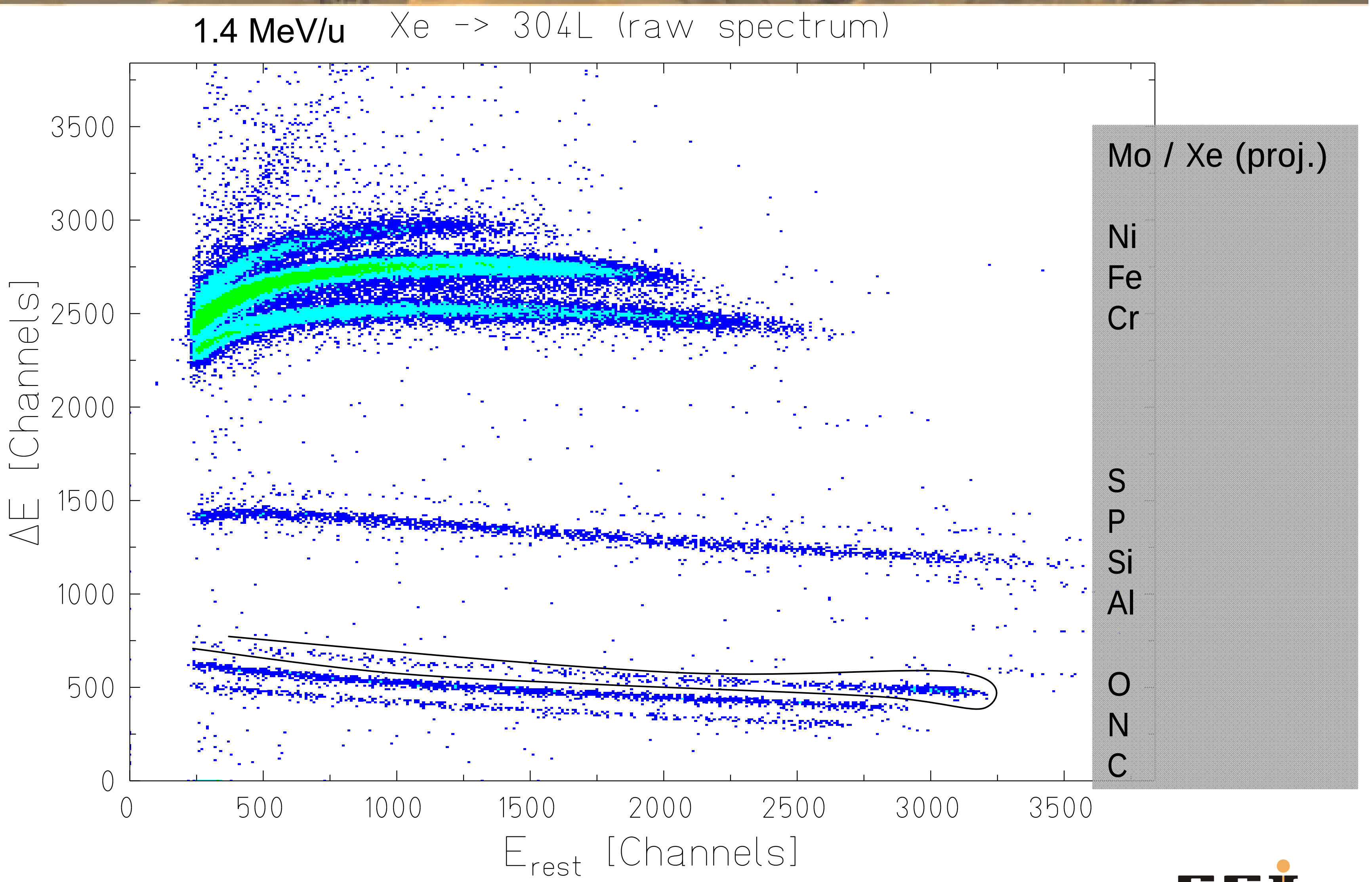
element-s

→ How a

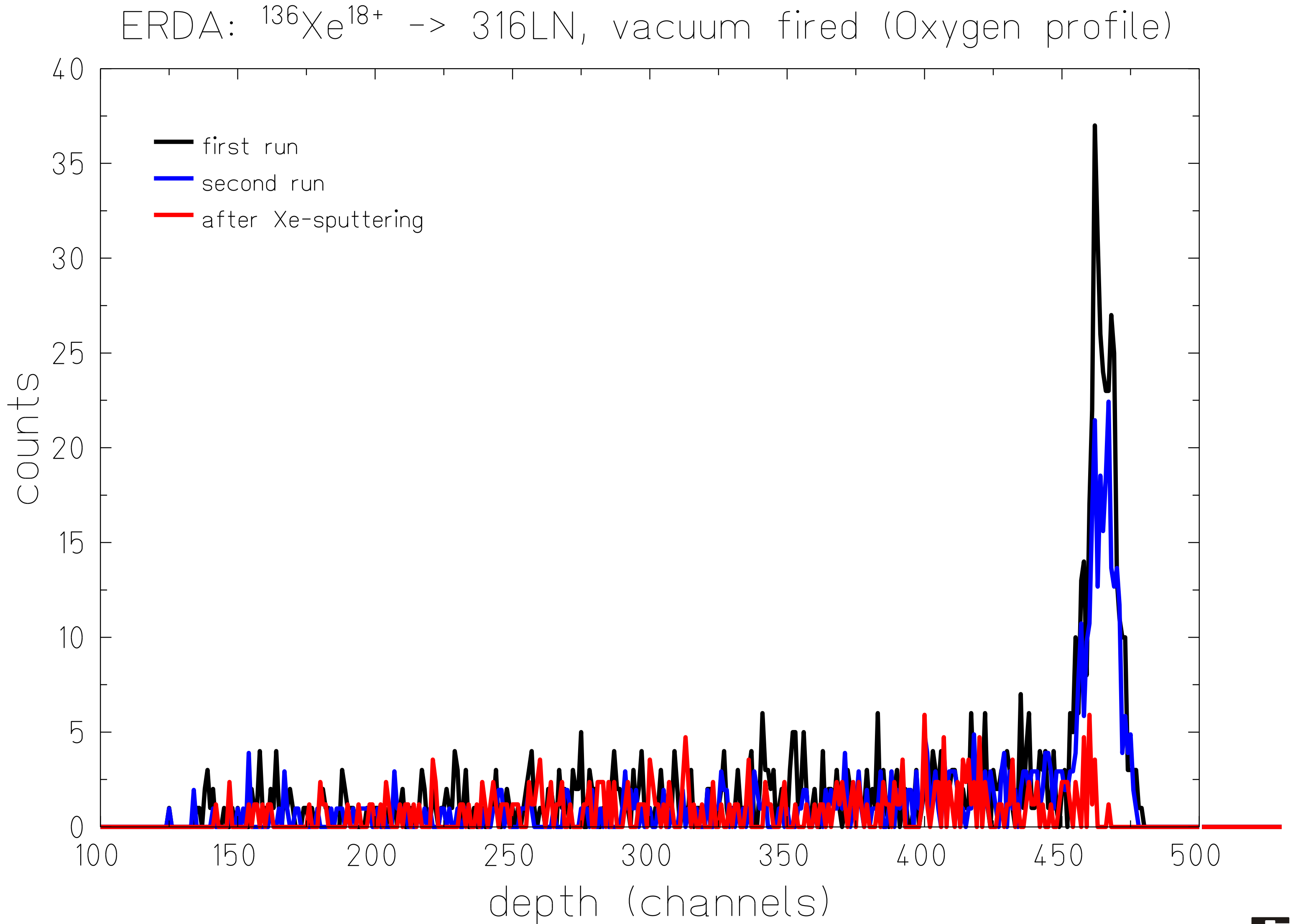
(surface p

# ERDA Spectra

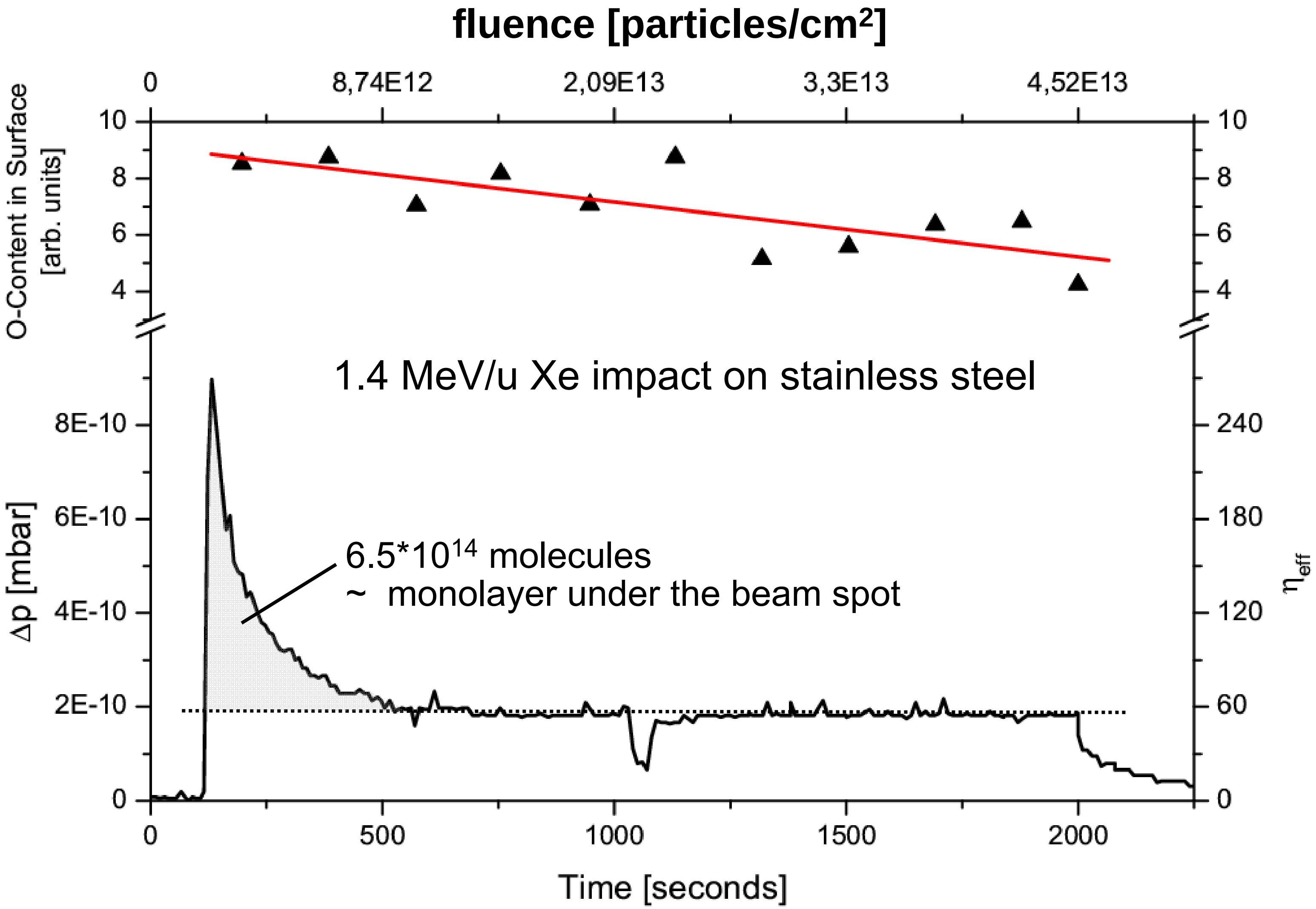
1.4 MeV/u



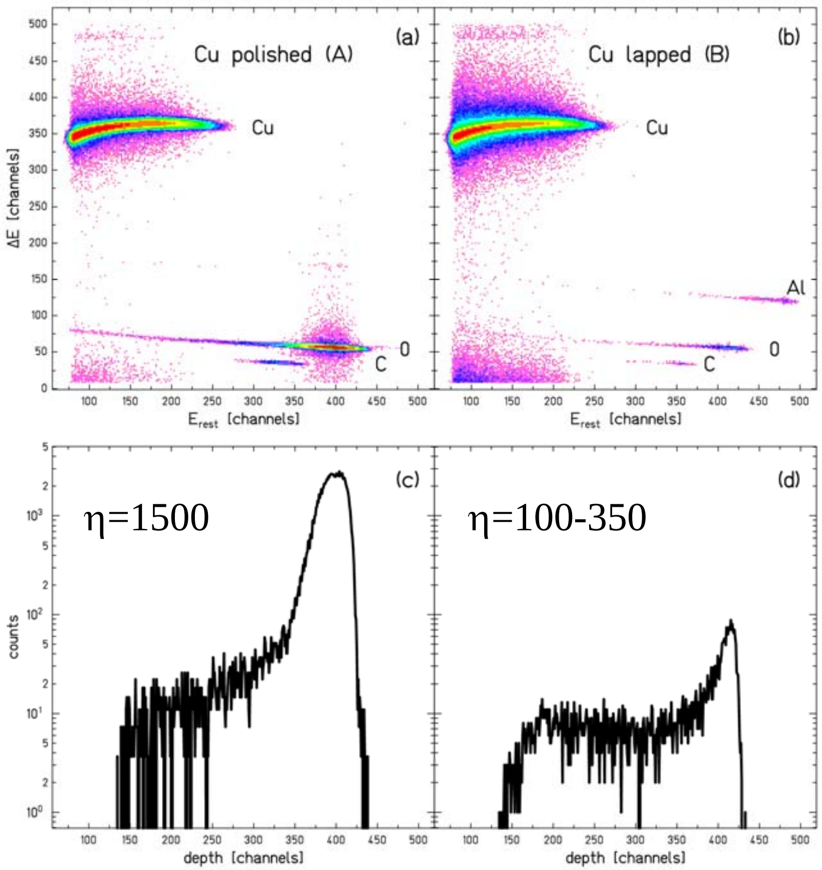
# ERDA Spectra



# Desorption versus Sputtering



# Influence of Oxide Layer on Copper




1.4 MeV/u Xe impact

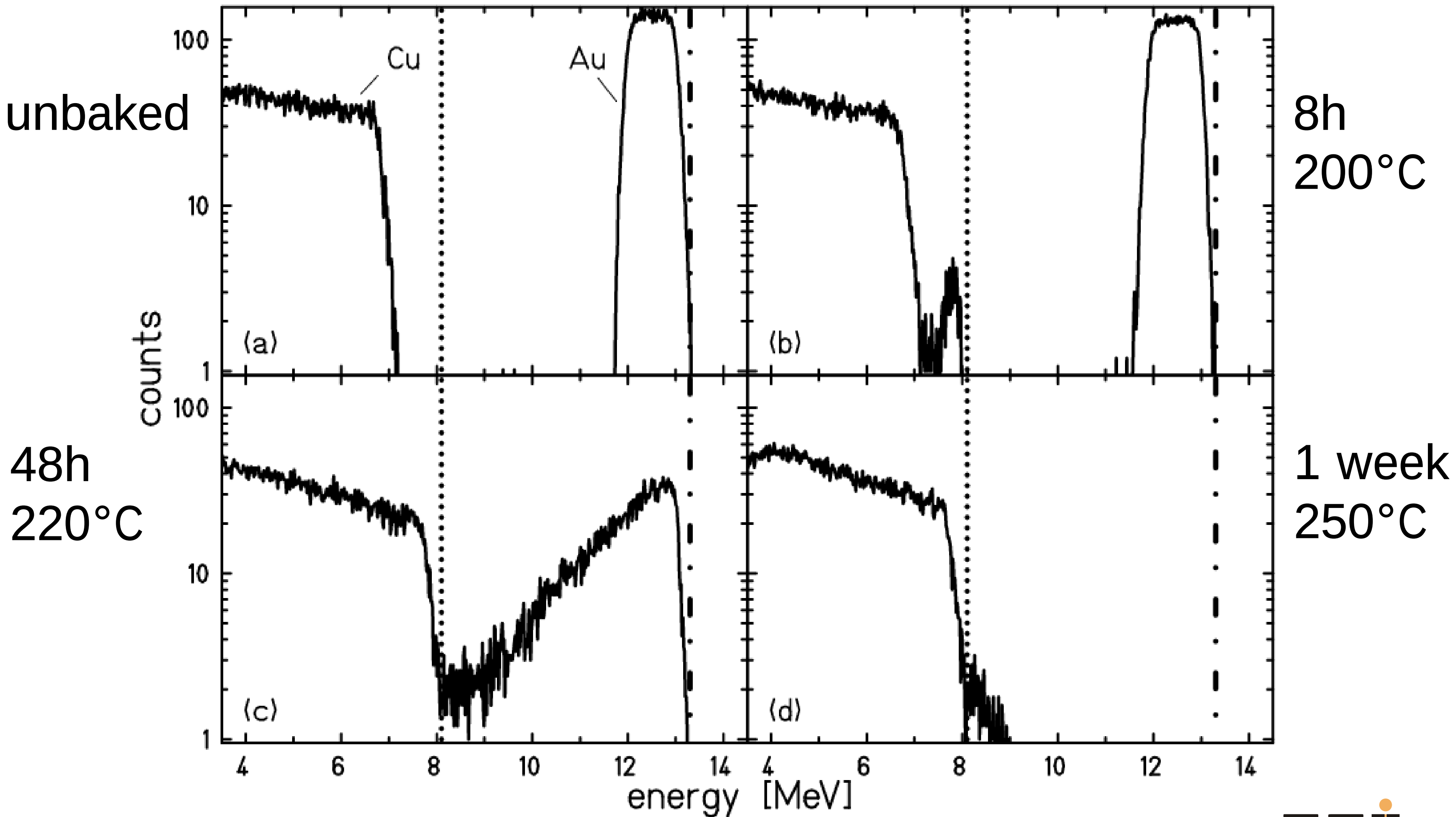
- **higher desorption yield from copper oxide surfaces compared to raw copper**
- **results can be qualitatively explained within the Thermal Spike and the Coulomb Explosion Model**
- **Copper is a good candidate if we prevent oxidation**

**→Gold coating of copper**

**disadvantage:**
- **diffusion of gold and copper**

✓ Influence of secondary electrons and ions tested in parallel

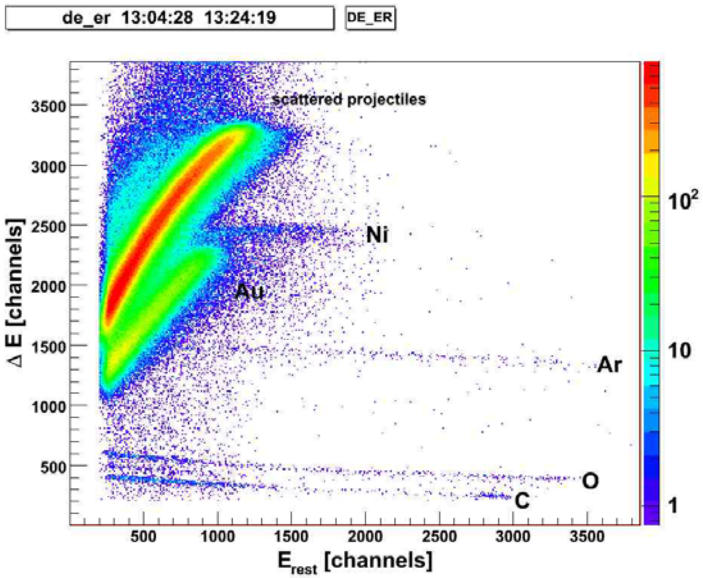
# Oxidation Prevention – Gold Coating (RBS)

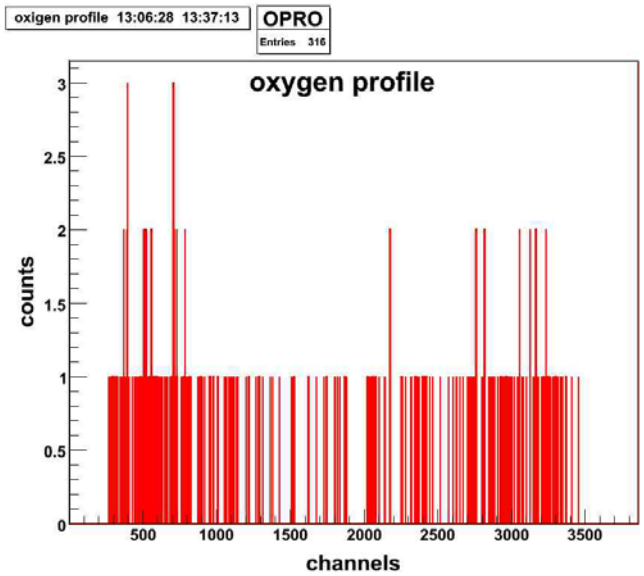


# Material of Choice for the Absorber Plates

- 300 nm Au
- 200 nm Ni as diffusion barrier
- on copper

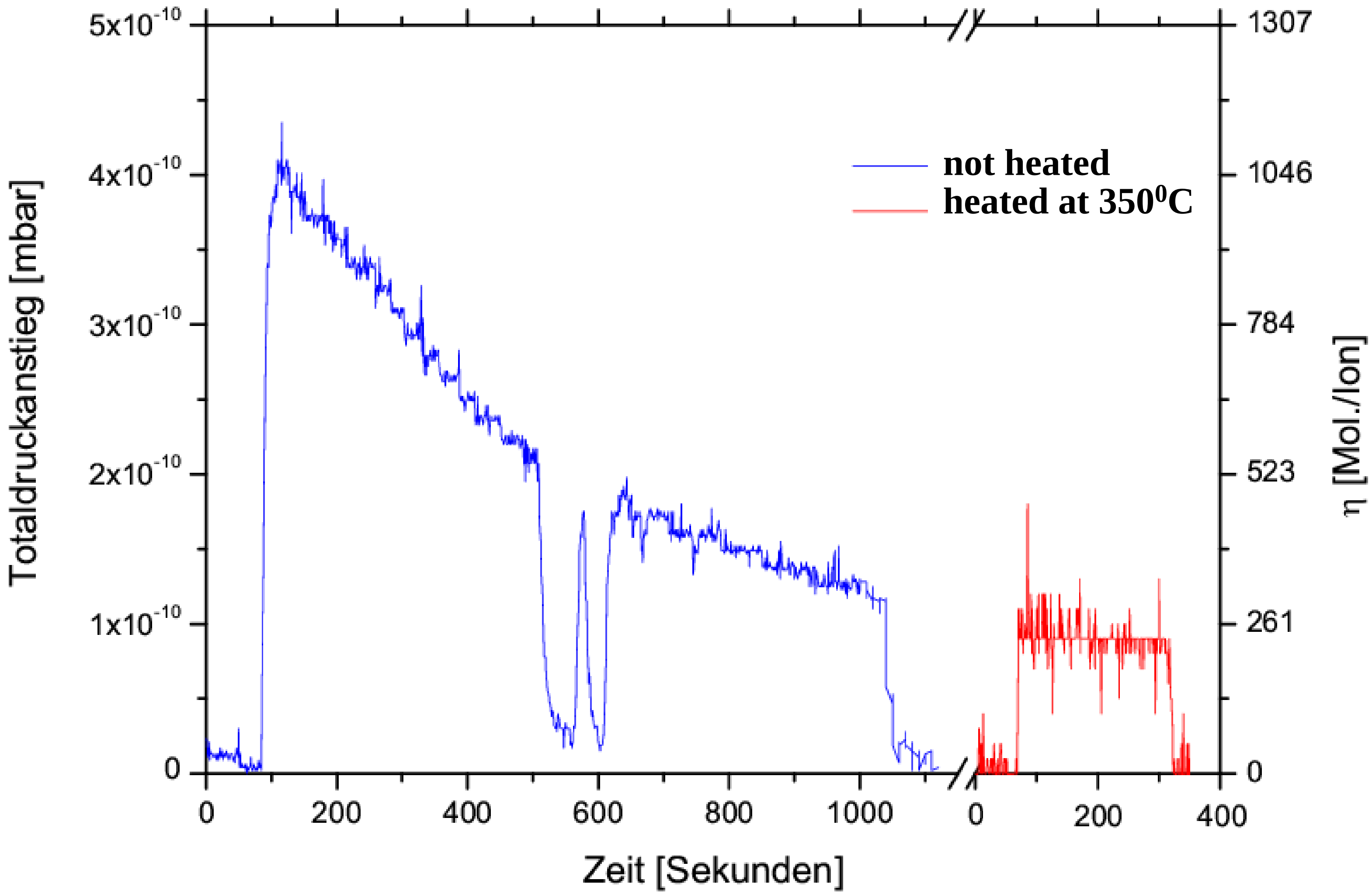
ERDA spectrum after bake-out cycle
1.4 MeV/u Xe



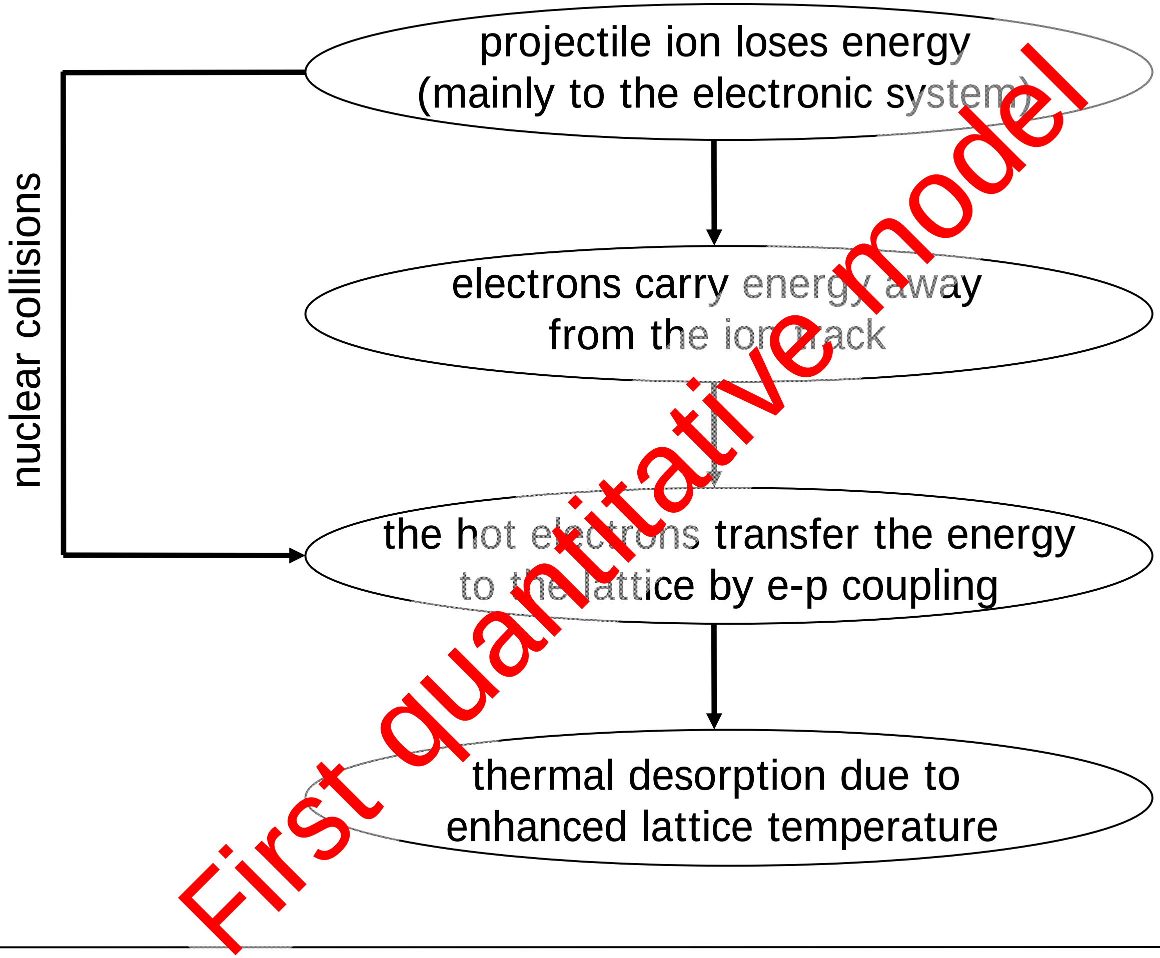

❖no diffusion, oxigen only on ppm level
❖desorption yield 90, resp. 25 mol./ion after ion conditioning

# Conditioning due to Special Bake-out Treatment

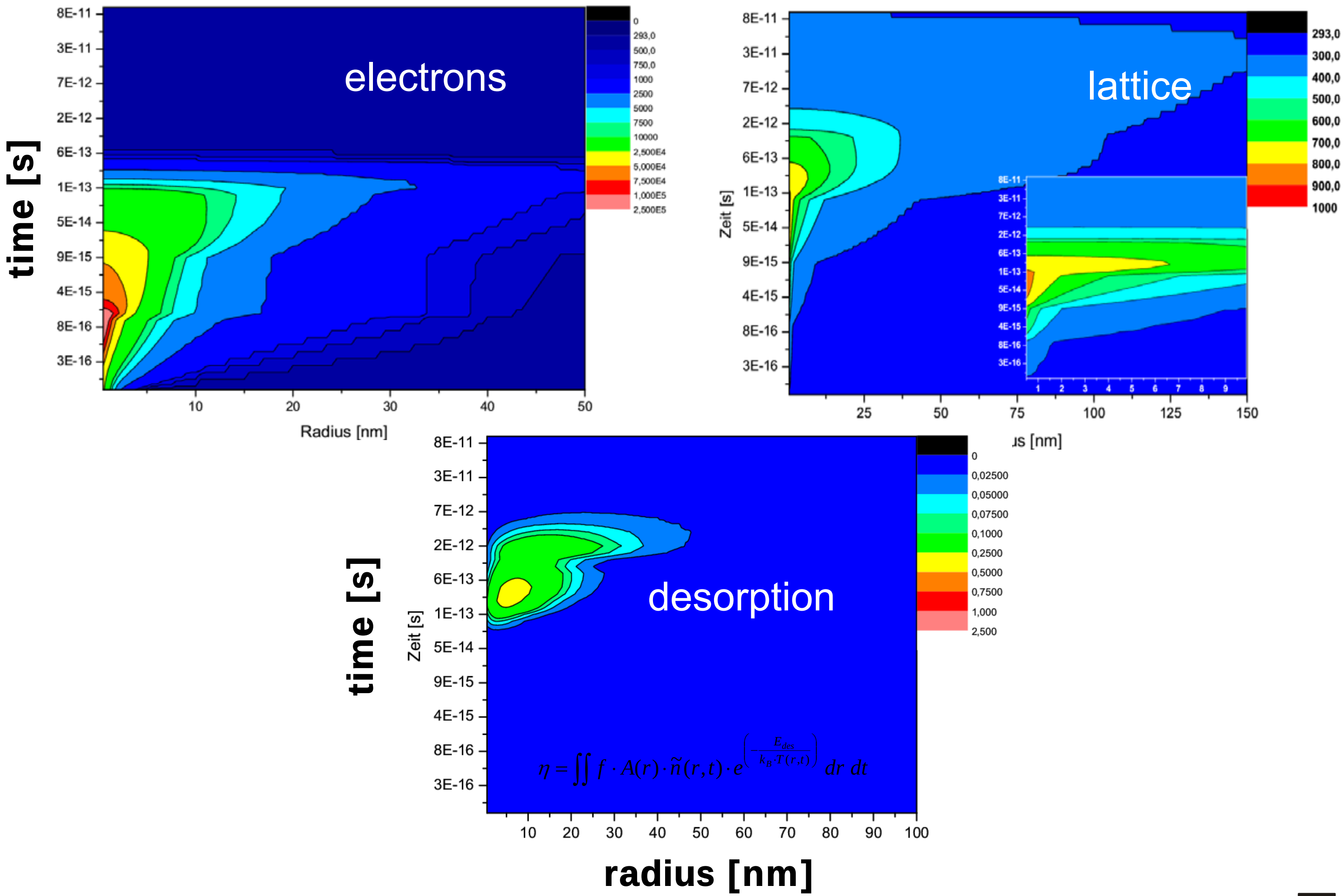


# Idea of thermal moderated Desorption

How can 1 ion trigger the desorption of some 100-1000 gas molecules?

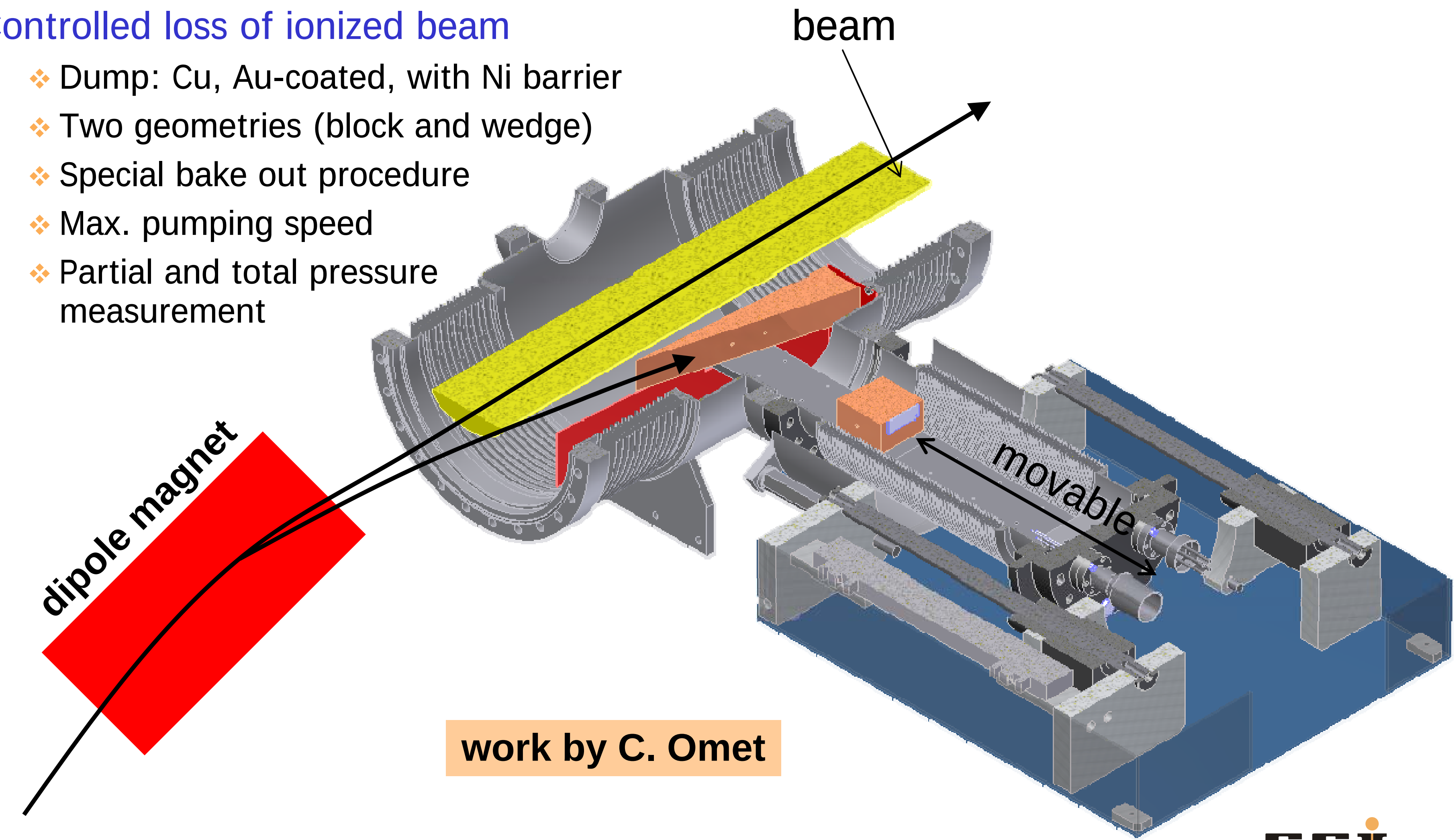


# Thermal Distribution in Space and Time
(1.4MeV/u Xe→Cu)



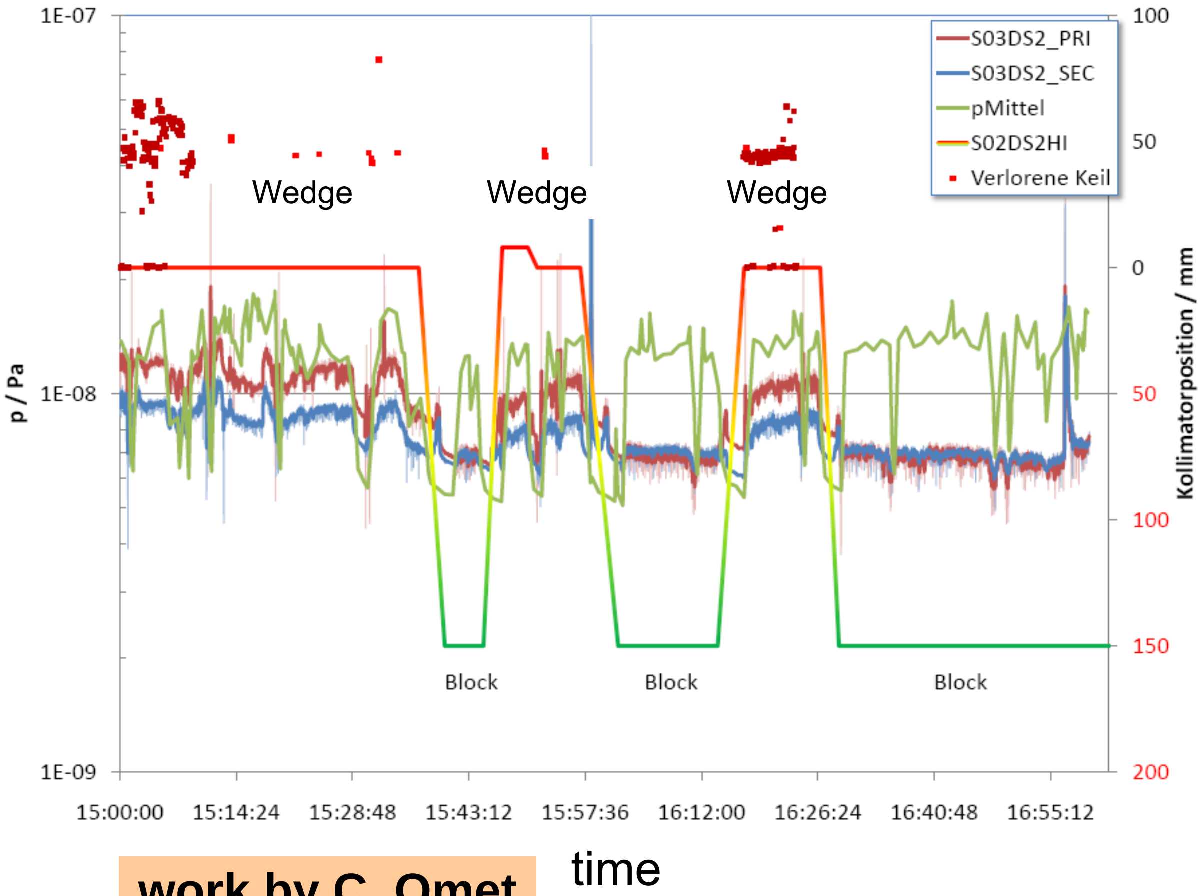
# SIS18 Ion Catchers for Loss Regions

- Controlled loss of ionized beam
  - Dump: Cu, Au-coated, with Ni barrier
  - Two geometries (block and wedge)
  - Special bake out procedure
  - Max. pumping speed
  - Partial and total pressure measurement




**work by C. Omet**

# Ion Catcher Tests (20.-22.02.2008)




**work by C. Omet**

Block better than wedge shaped geometry

Pressure increase in the collimator chamber
Wedge: $3.30^{-11}$ mbar
Block: $0.63*10^{-11}$ mbar

Desorption yields:
Wedge: >119 mol/Ion
Block: >24 mol/Ion (!)

Overall pressure is dominated by the injection section!

# Summary

- First time combination of desorption yield measurements with *in-situ* target characterization in UHV environment (worldwide only UHV-ERDA)
- Pressure rises in the accelerator are surface effects
- Link to the substrate properties
    - Insulators (e.g. $Cu_2O$) desorbe more than conductors (e.g. Cu)
- Dedicated bakeout of loss regions reduces desorption
- First model to calculate desorption yields
    - treated as thermally moderated process
    - calculated within the inelastic thermal spike model
    - $(dE/dx)^2$-scaling for the MeV/u range
- Implementation into the SIS18 ion catchers
    - from the charge exchange point of view the FAIR goal is achievable

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- R. Dörner (Atomic Physics Group, Frankfurt University)

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# Publications

- **UHV-ERDA Investigations on Ion-Induced Desorption**
  H. Kollmus, M. Bender, W. Assmann, R. Dörner
  *GSI Scientific REPORT 2005 (2006)*
- **UHV-ERDA Investigations on Ion-Induced Desorption**
  H. Kollmus, M. Bender, W. Assmann, R. Dörner
  *Jahresbericht Beschleunigerlabor, LMU München 2005 (2006)*
- **Understanding of Ion-Induced Desorption using the ERDA Technique**
  M. Bender, H. Kollmus, W. Assmann
  *European Particle Accelerator Conference 2006, Proceedings, TUPCH174 (2006)*
- **Heavy ion-induced desorption investigations using UHV-ERDA**
  H. Kollmus, M. Bender, W. Assmann, A. Krämer, M.C. Bellachioma, H. Reich-Sprenger
  *Vacuum, Volume 82, Issue 4, 12 December 2007, Pages 402-407*
- **Desorption Yields of Differently Treated Copper Samples Characterized With ERDA**
  M. Bender, H. Kollmus, W. Assmann
  *Nuclear Instruments and Methods in Physics Research Section B: Vol. 256, Issue 1, March 2007, Pages 387-391*
- **Untersuchung der Mechanismen Schwerioneninduzierter Desorption an Beschleunigerrelevanten Materialien**
  Dissertation Markus Bender, Universität Frankfurt am Main
- **An Inelastic Thermal Spike Model to calculate Ion Induced Desorption Yields**
  M. Bender, H. **Kollmus**, H. Reich-Sprenger, M. Toulemonde, W. Assmann
  *Nuclear Instruments and Methods in Physics Research Section B: **In Press, Accepted Manuscript**,*