Electrical Conductivity Measurements of Ion Driven High Energy Density Matter

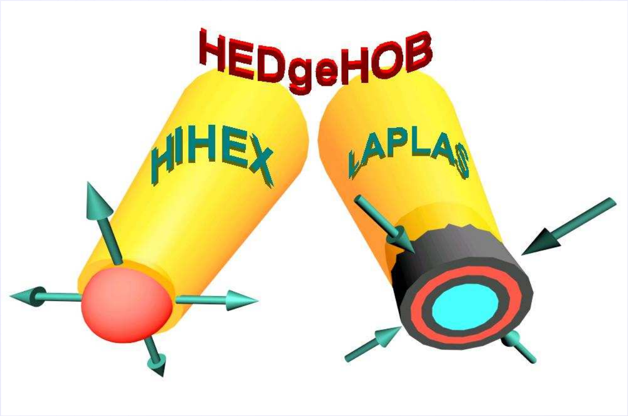
S. Udrea, C. Constantin, E. Dewald, J. Jacoby, N. Tahir,
D. Varentsov, D.H.H. Hoffmann

Technische Universität Darmstadt
GSI Darmstadt
Lawrence Livermore National Laboratory
Universität Frankfurt

HEDgeHOB Collaboration

- EOS of high energy density matter
- Phase transitions
- Transport and radiation properties
  - electrical conductivity
- Energy loss of heavy ions in HED matter

138 scientists



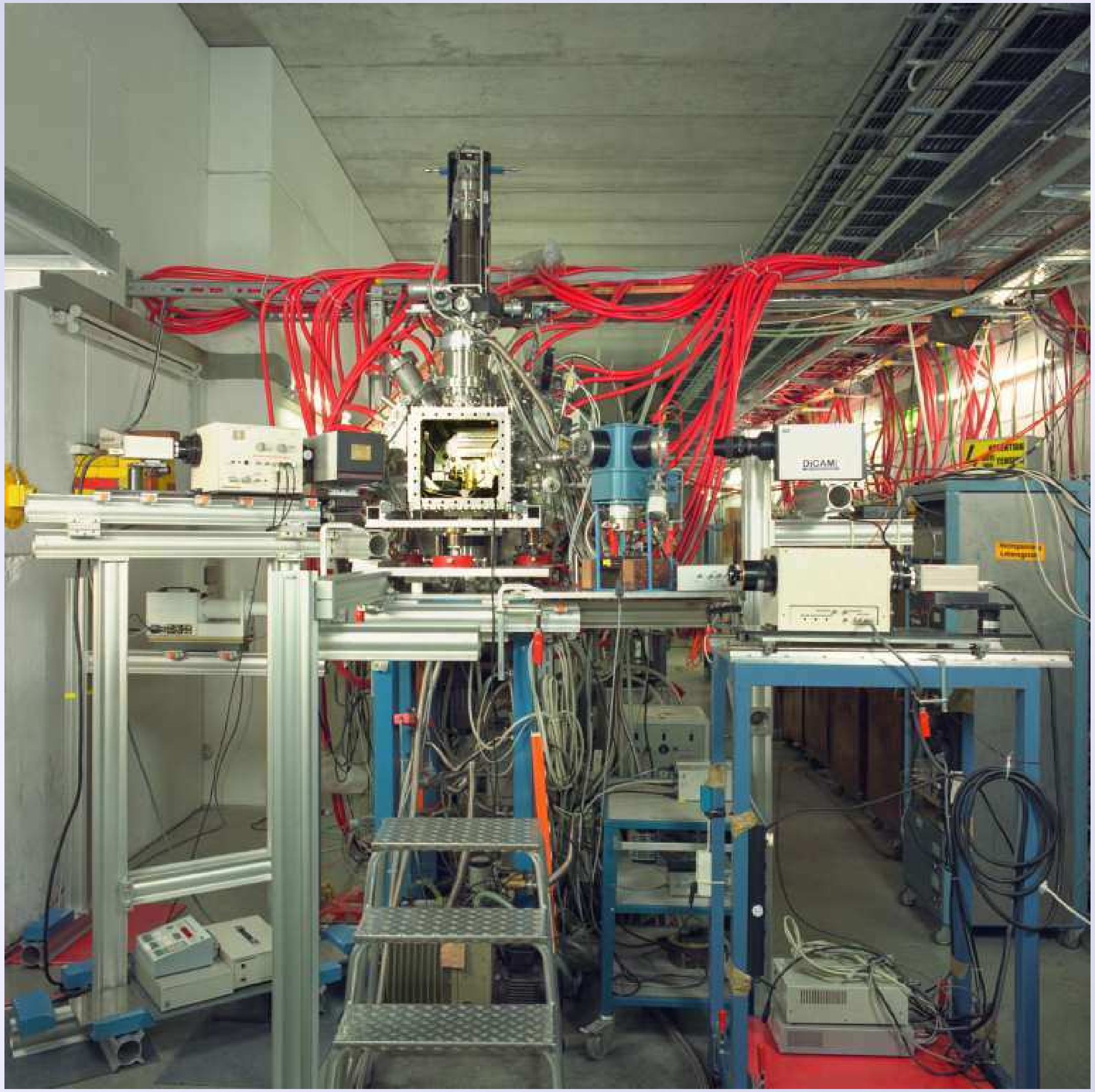
40 institutions

14 countries

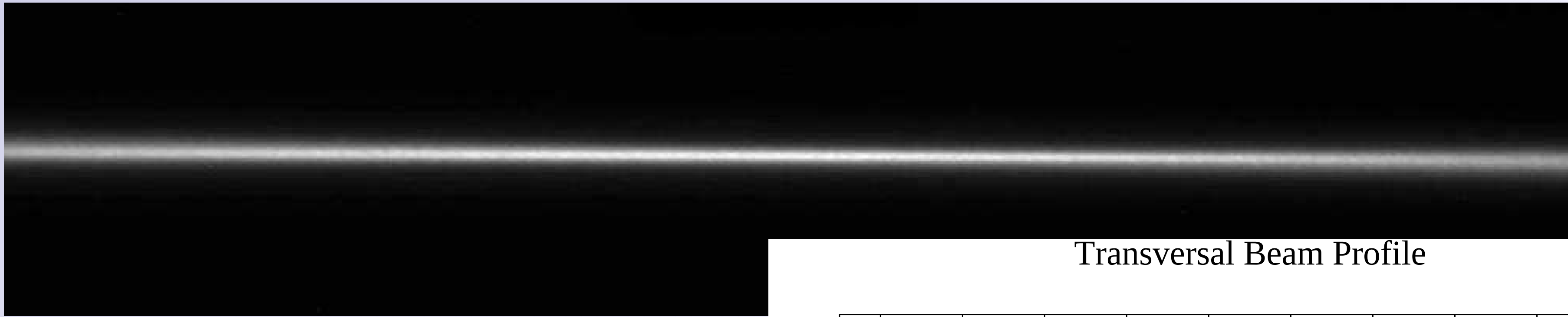
Why electrical conductivity?

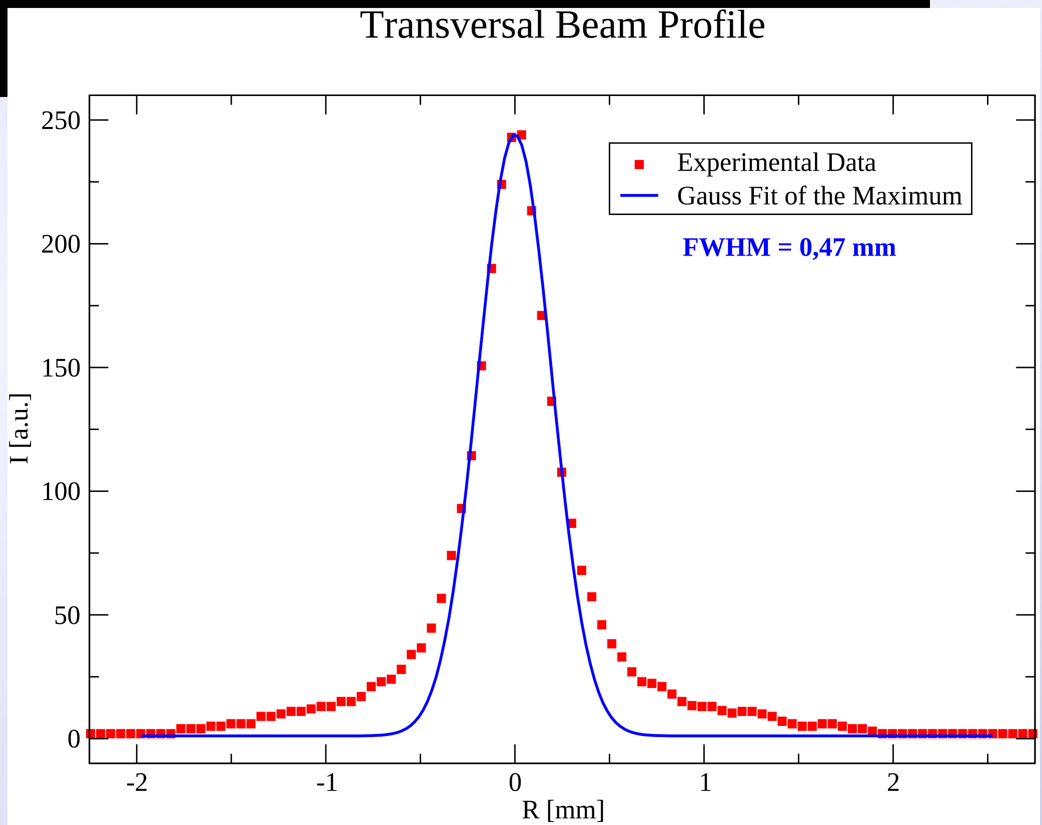
- Fundamental transport coefficient
- Provides complementary information to EOS
- Related to other physical properties:
  - Thermal conductivity
  - Free electron contribution to energy loss
  - Reflectivity and radiation transport

HHT Experimental Area



The ion beam





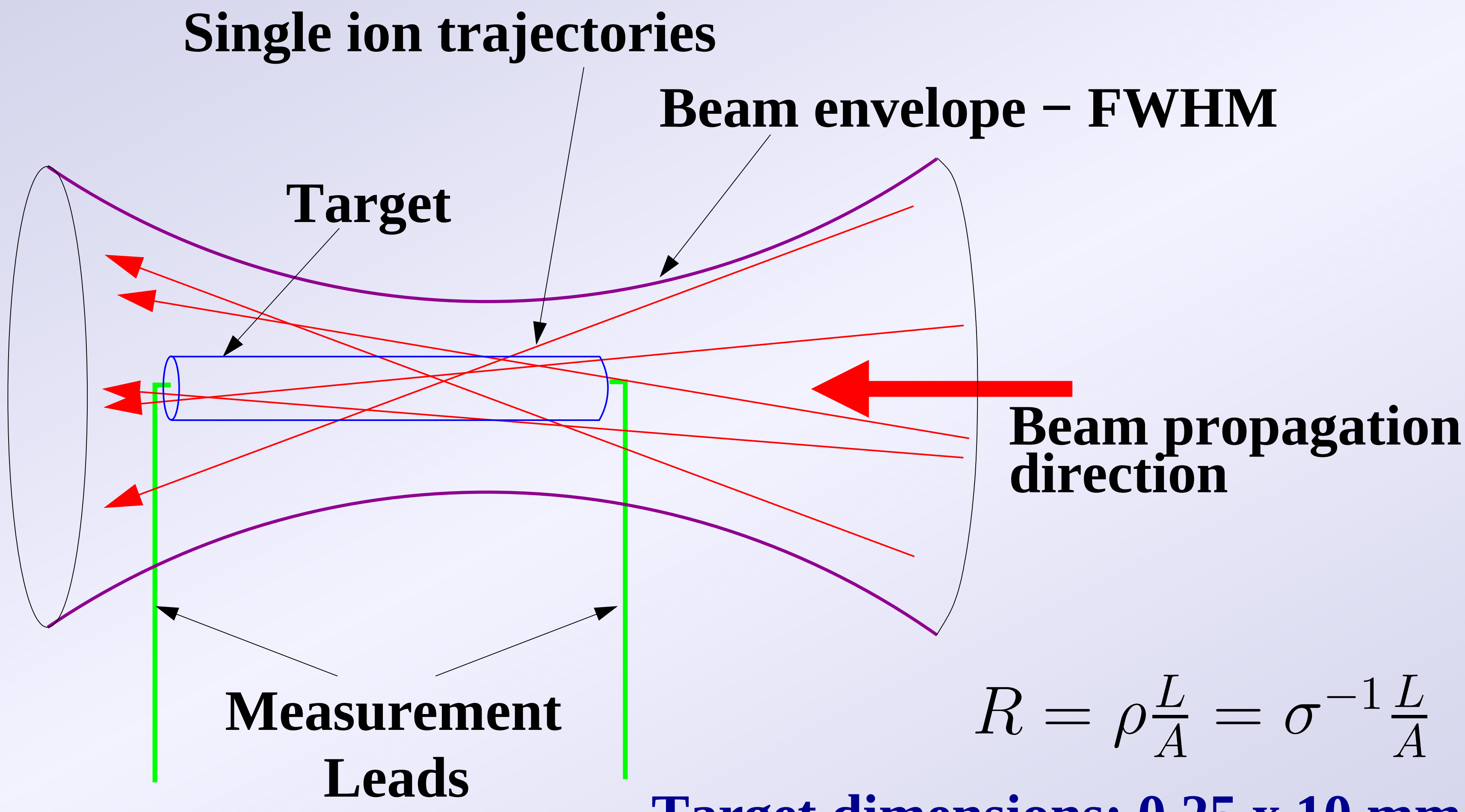
$^{238}U^{+72}$ **Ion beam**

Energy: 250 MeV/u

Intensity: $2 \cdot 10^9 \text{ ions/shot}$

Pulse duration: $1\mu s$

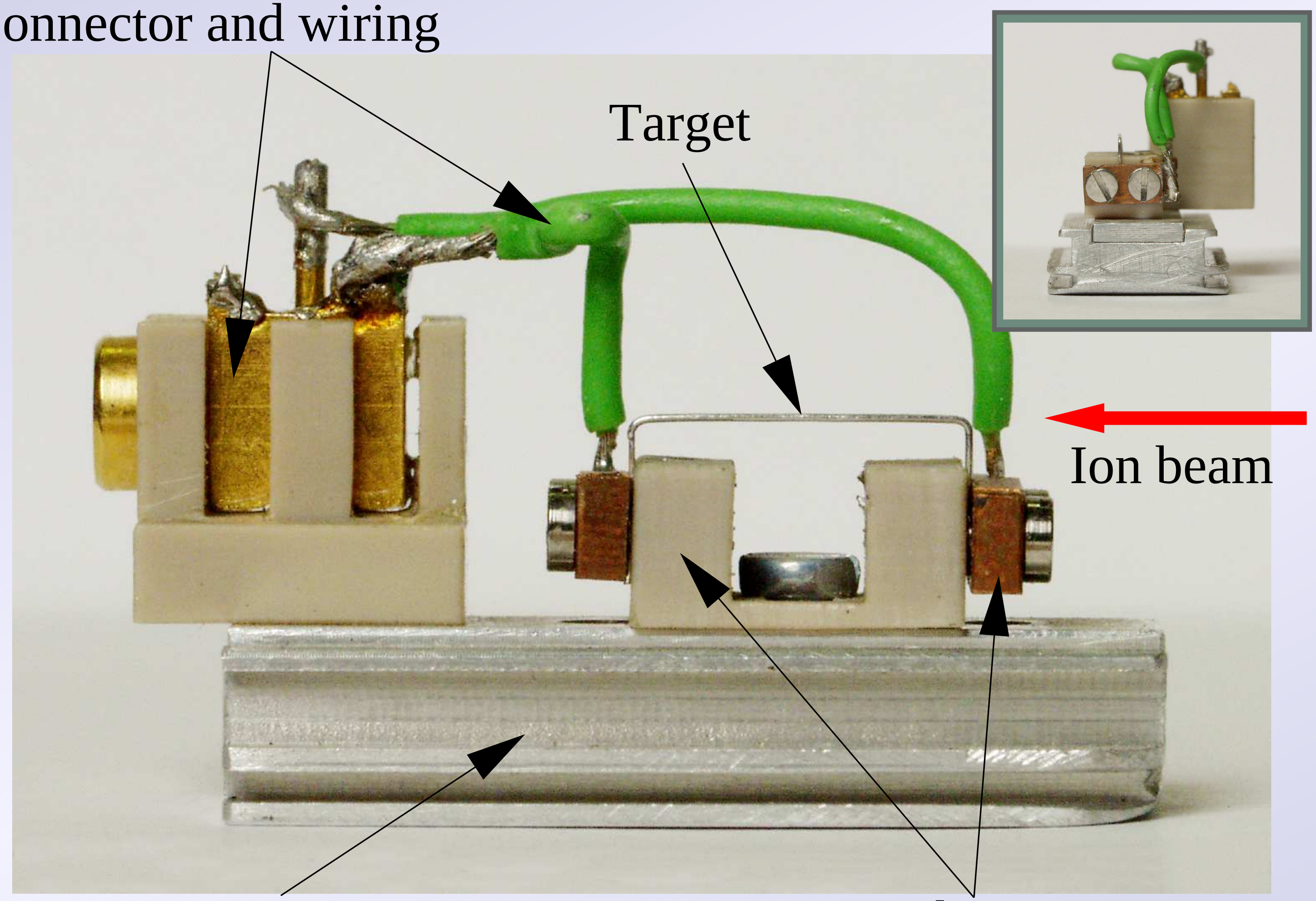
Target Design



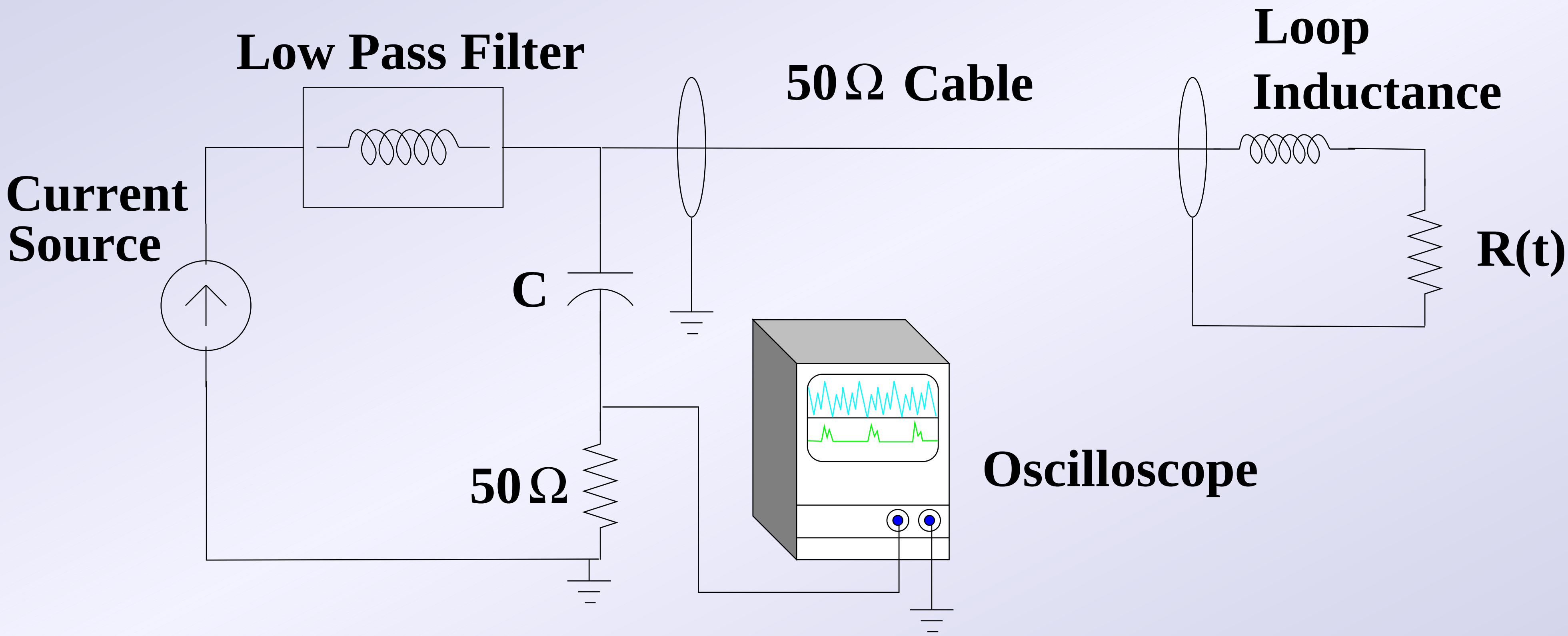
$$R = \rho \frac{L}{A} = \sigma^{-1} \frac{L}{A}$$

Target dimensions: 0.25 x 10 mm
Focus FWHM: 0.45 − 1.0 mm

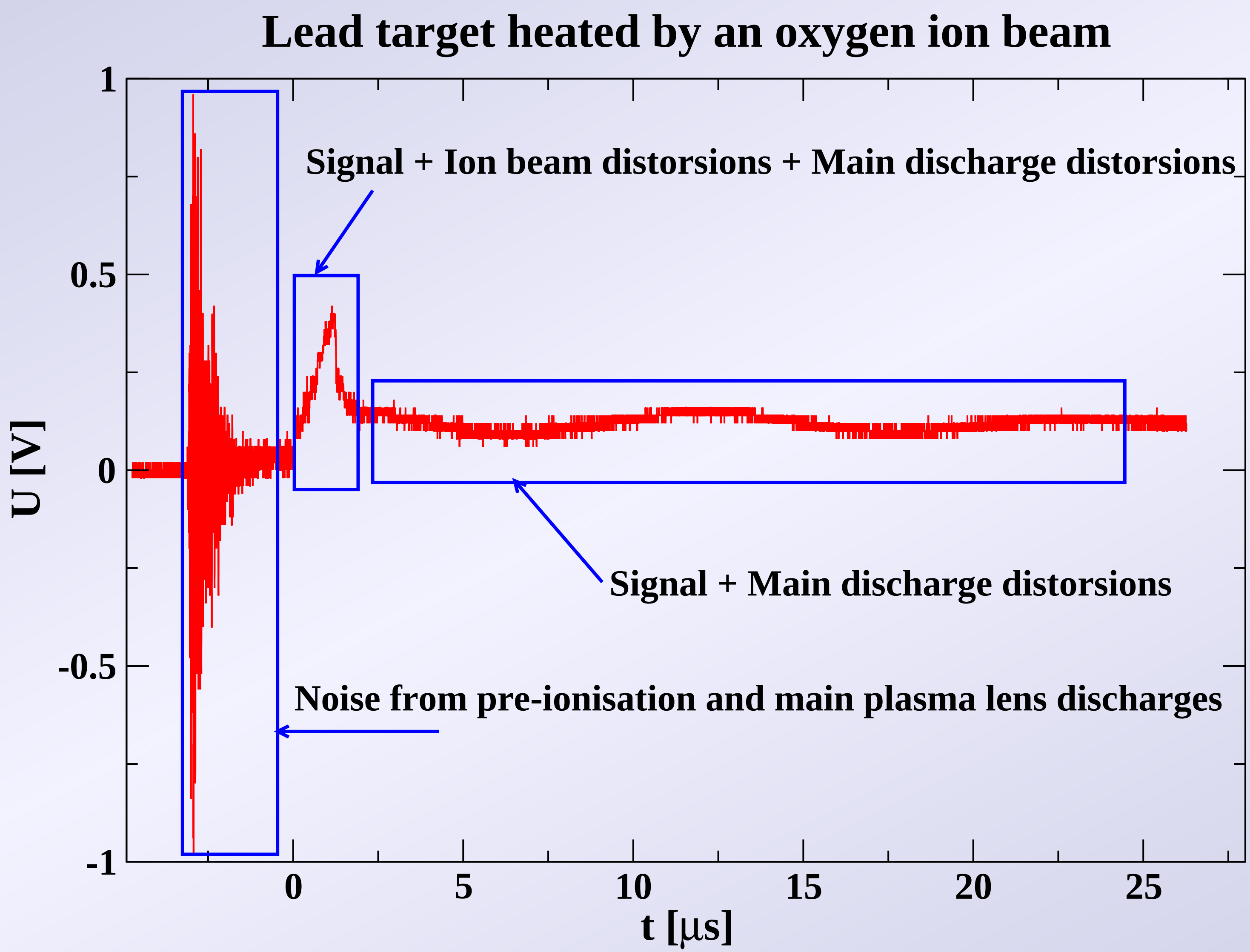
The Target


Connector and wiring
Target
Ion beam
Target table
Target support with copper connectors

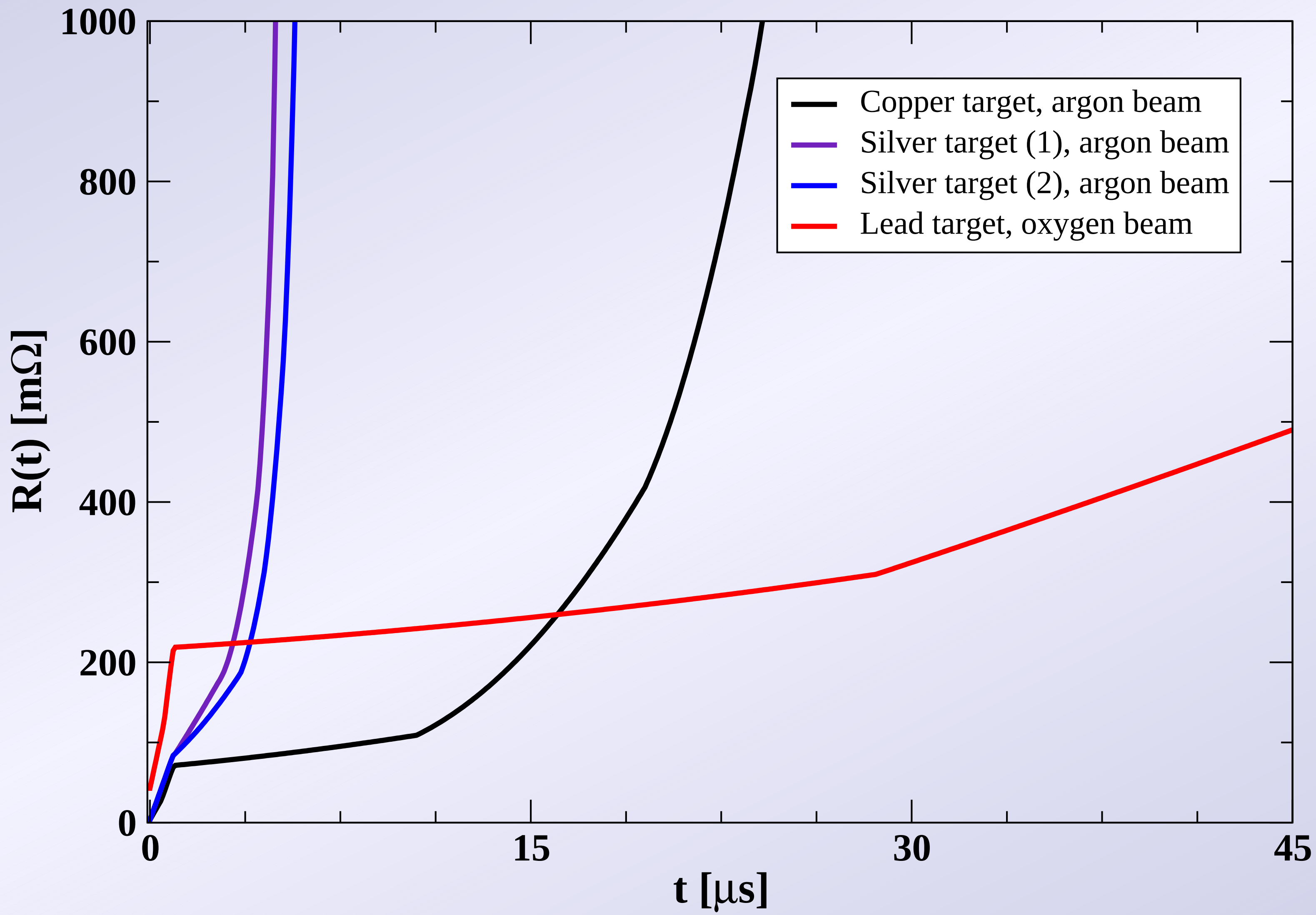
Measurement Circuit



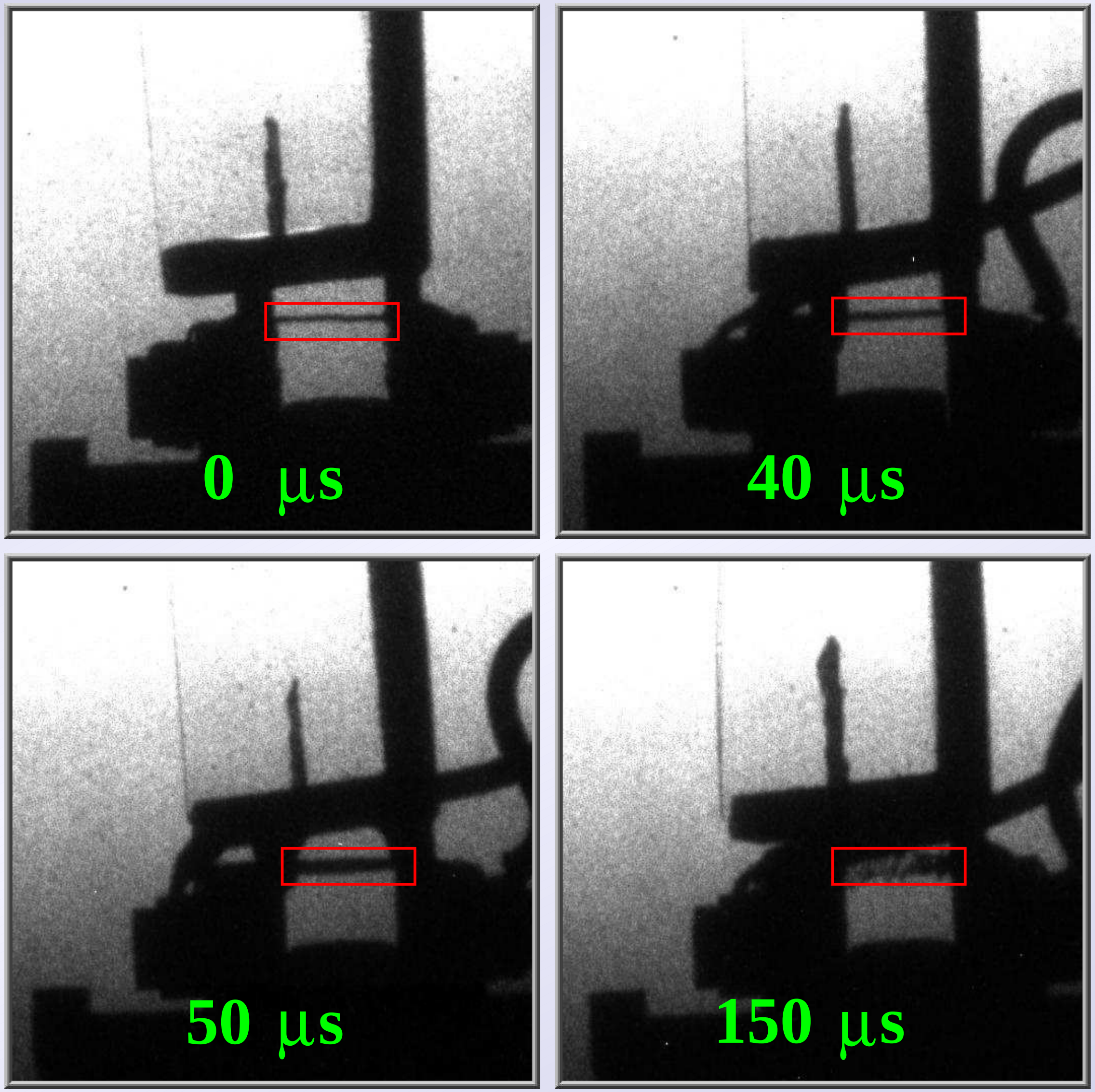
Experimental Signal



Recovered signals



Hydrodynamics: Lead



Simulation Procedure

1. BIG2 - 2D hydrodynamic code

   $\Rightarrow \rho_{\mathbf{m}}(\mathbf{r},\mathbf{z},\mathbf{t}),\ \mathbf{T}(\mathbf{r},\mathbf{z},\mathbf{t})$

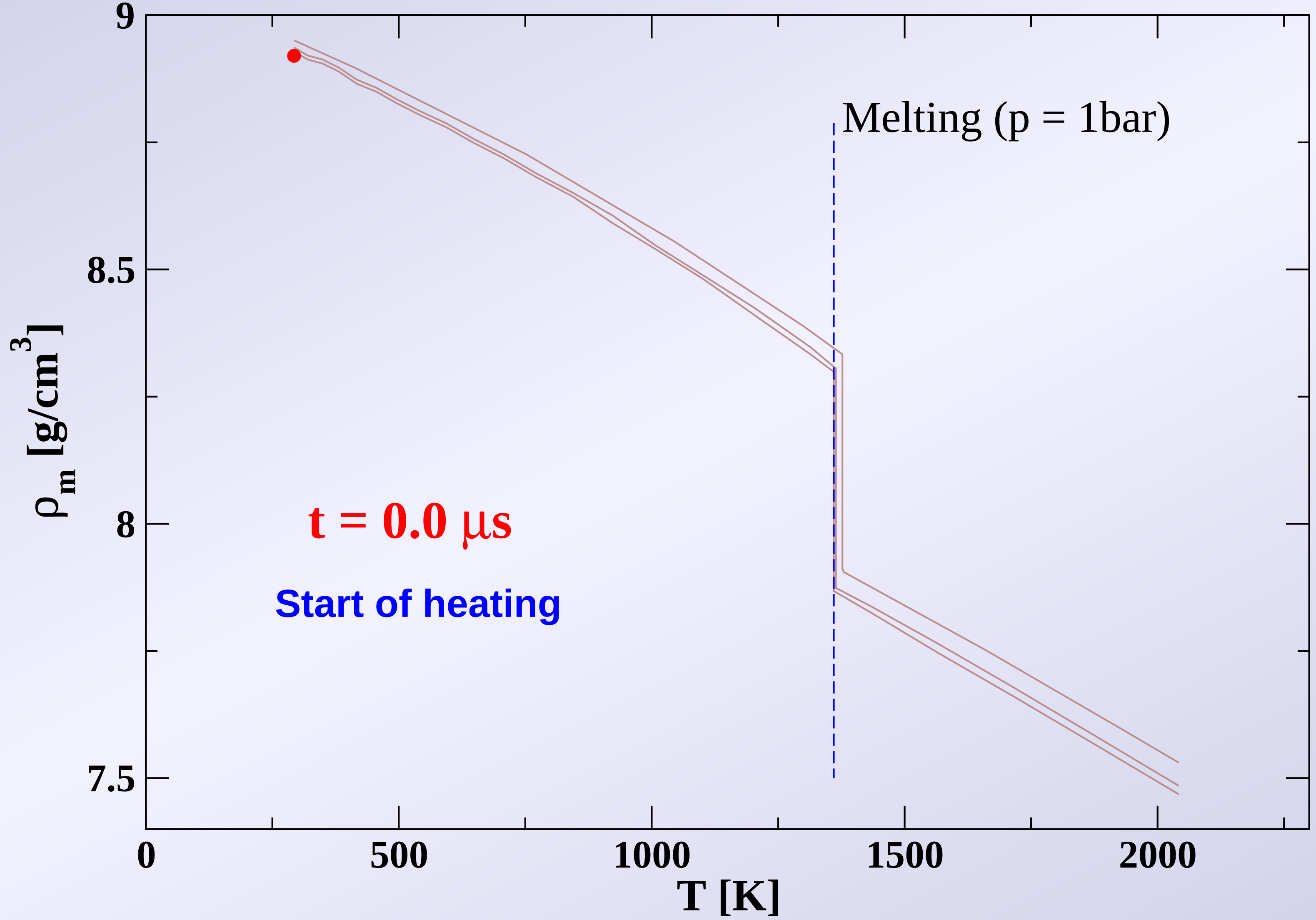
2. Tables with available experimental conductivity data

   $\sigma(\rho_{\mathbf{m}},\mathbf{T}) \Rightarrow \sigma(\mathbf{r},\mathbf{z},\mathbf{t})$

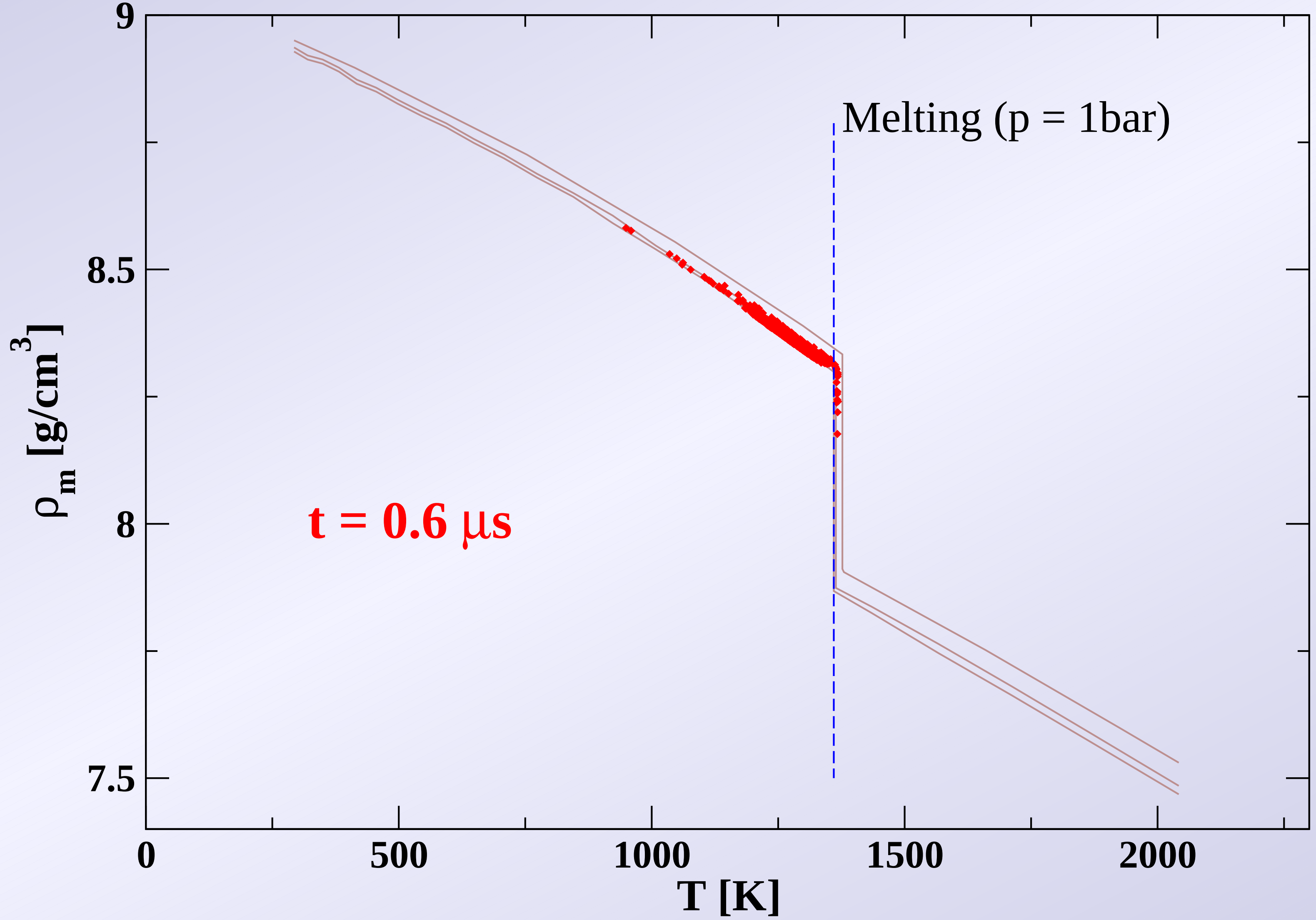
3. FreeFem++ - 2D finite elements code

   $\phi(\mathbf{r},\mathbf{z},\mathbf{t}),\vec{\mathbf{j}}(\mathbf{r},\mathbf{z},\mathbf{t}) \Rightarrow <\rho>(\mathbf{t})$

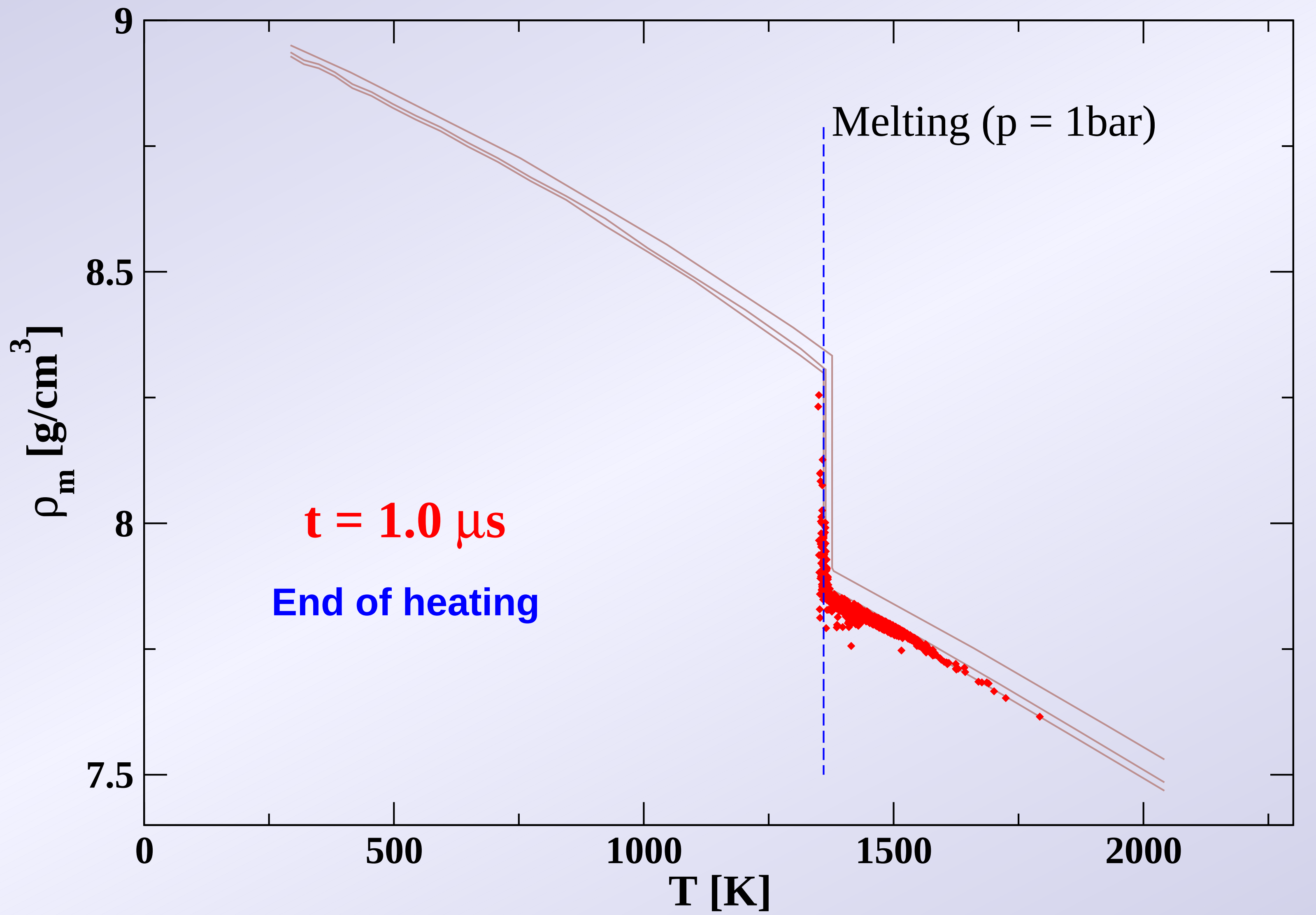
Thermodynamic Parameters



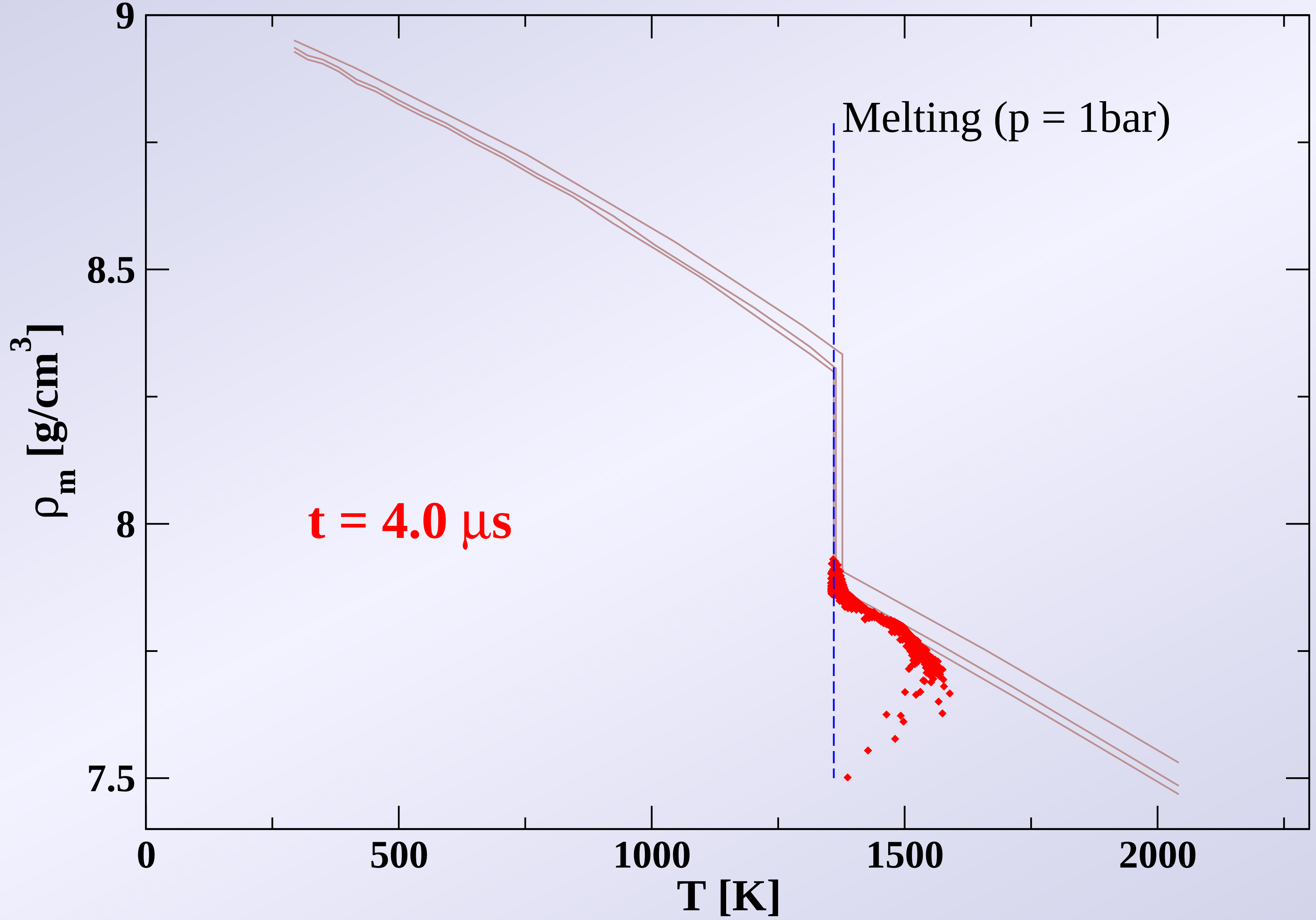
Thermodynamic Parameters



Thermodynamic Parameters

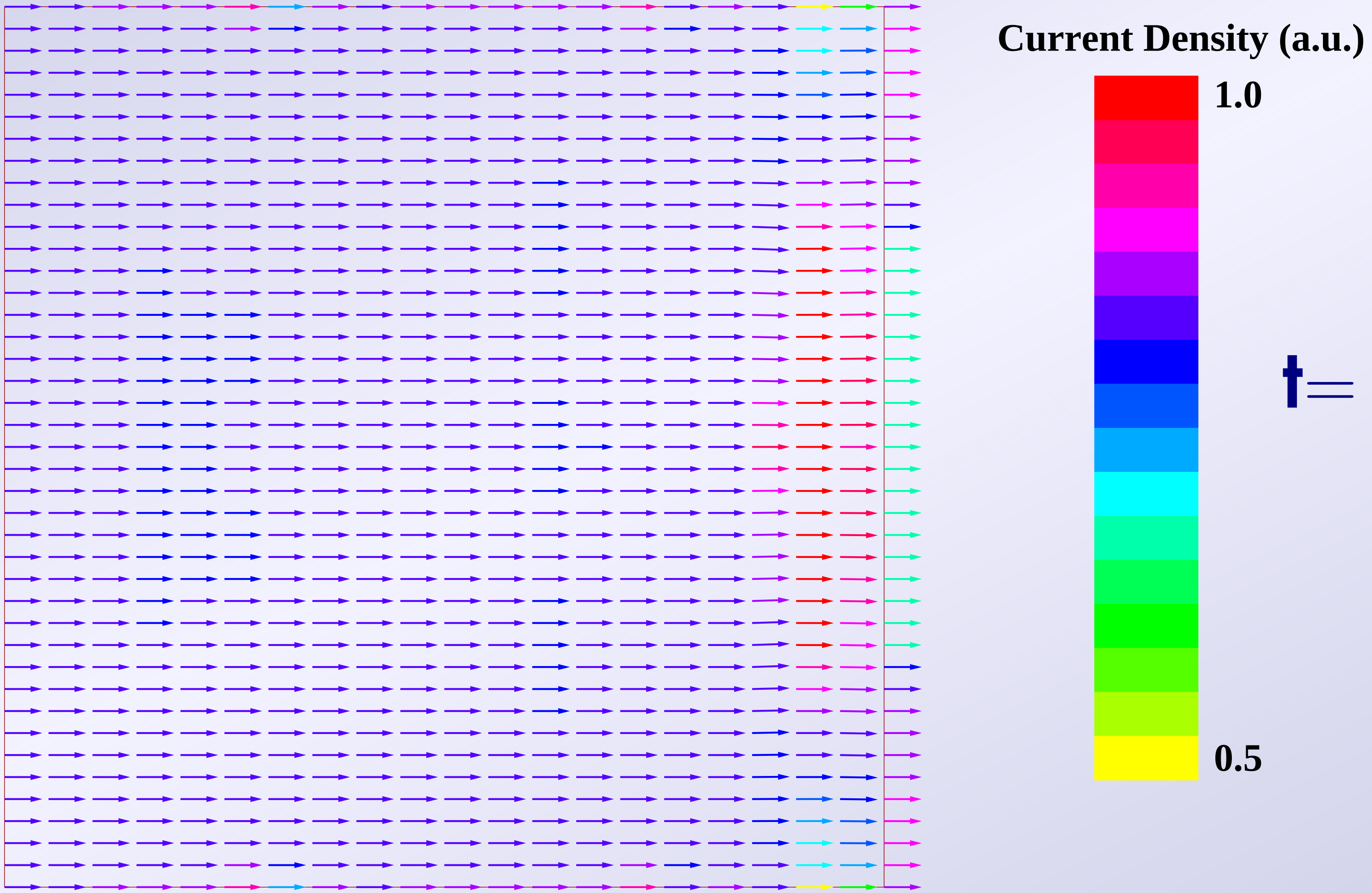


Thermodynamic Parameters



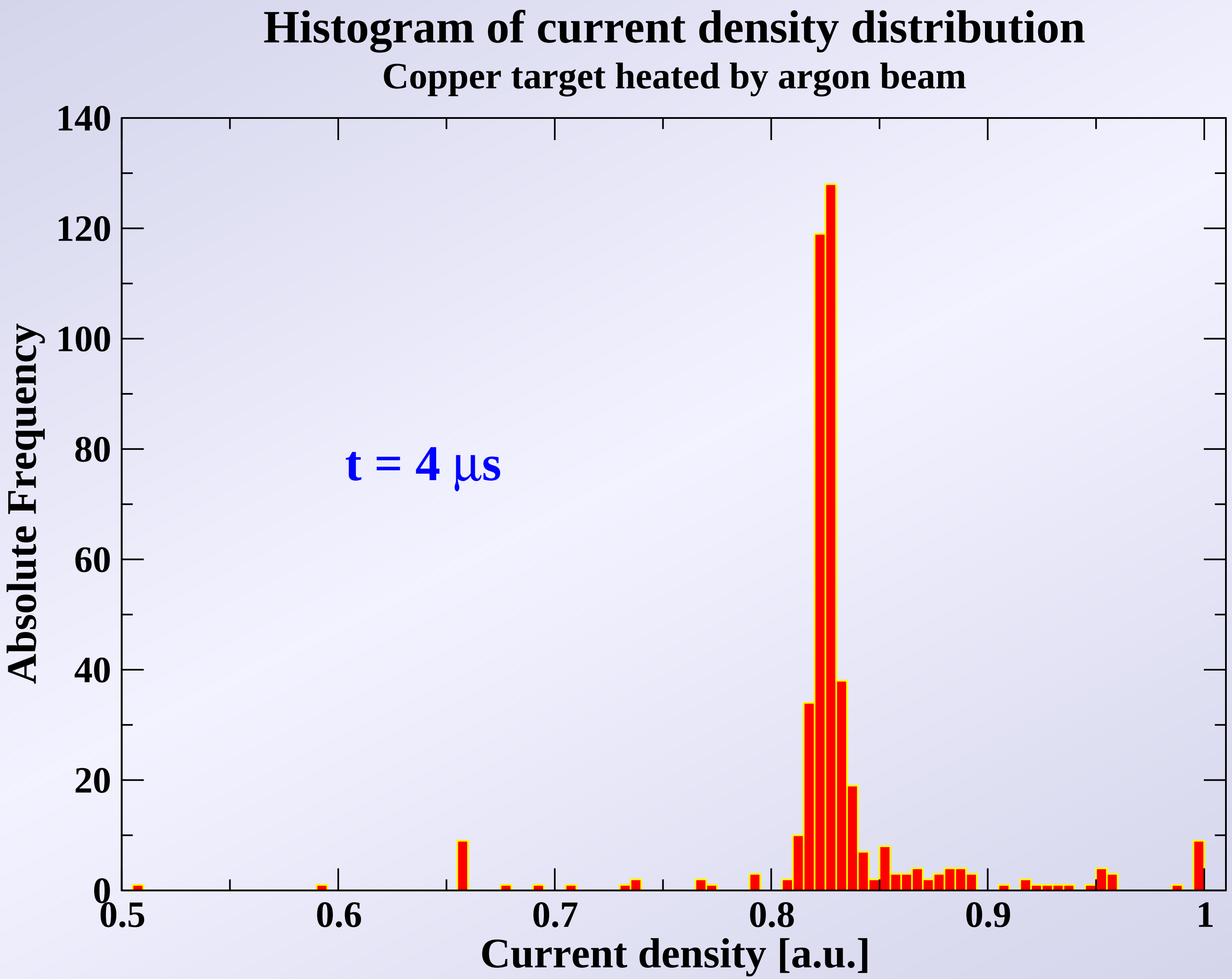
Current Distribution

Copper target heated by an argon beam



$t = 4\mu s$

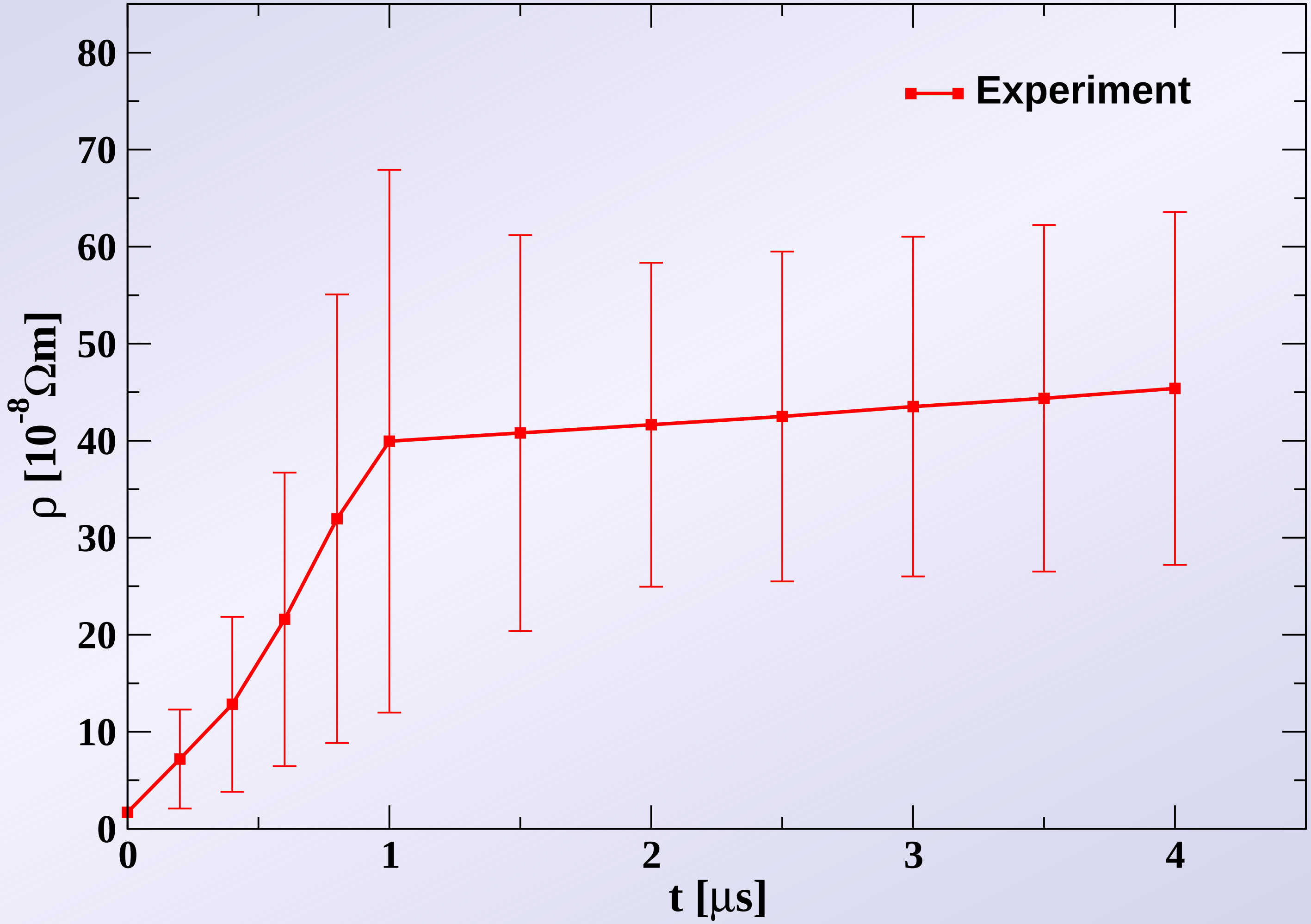
Current Distribution



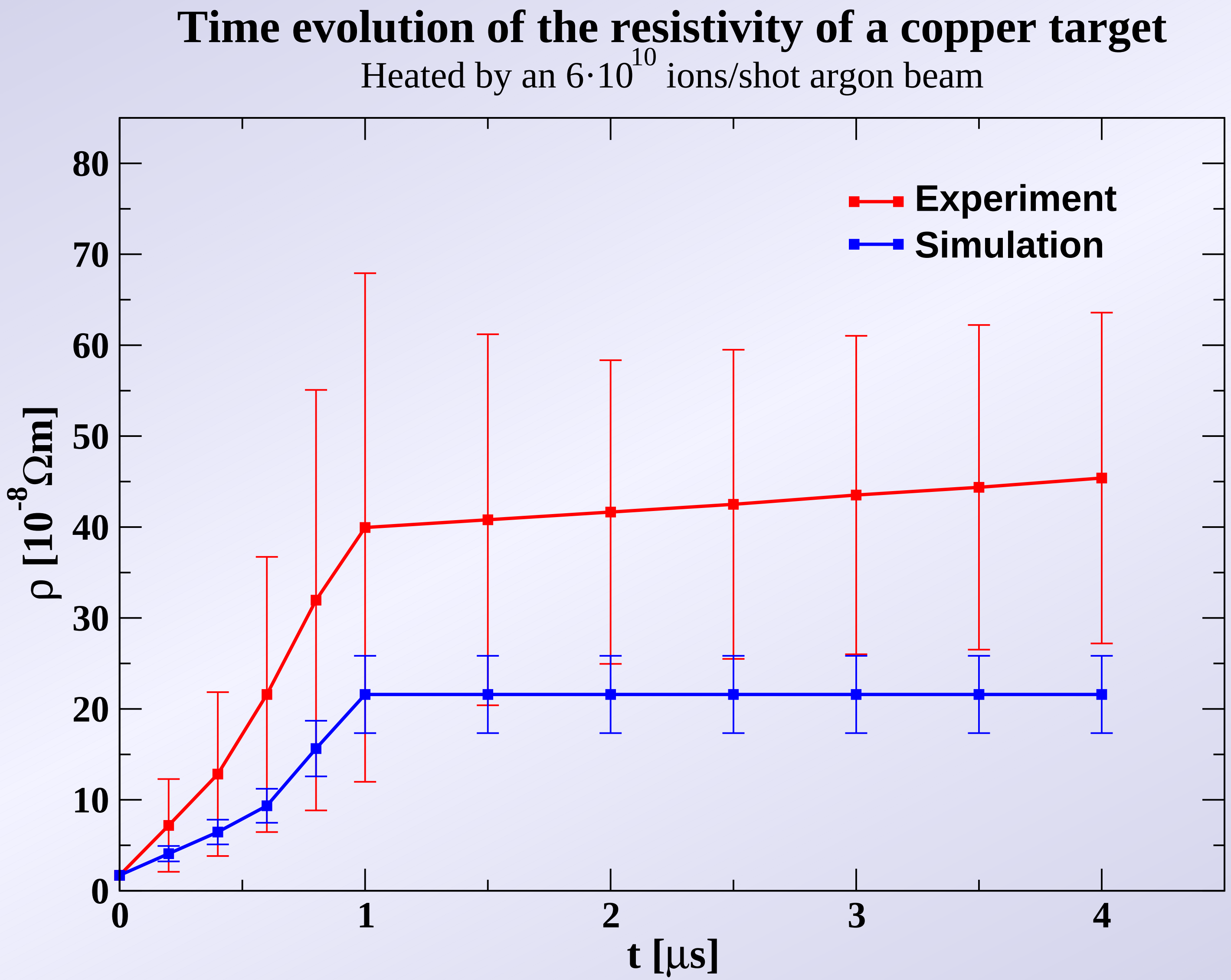
Results

Time evolution of the resistivity of a copper target

Heated by an $6 \cdot 10^{10}$ ions/shot argon beam



Results



Time evolution of the resistivity of a copper target
Heated by an 6·10^10 ions/shot argon beam
Experiment
Simulation
ρ [10^-8 Ωm]
t [μs]
0
10
20
30
40
50
60
70
80
1
2
3
4

Conclusions

- First experimental results on changes of the electrical conductivity of various metals (Pb, Cu, Ag) heated by intense beams of ^{18}O and ^{40}Ar
- Extensive 2D hydrodynamic and current transport modelling of the performed experiments
- Further experimental and theoretical work has been stimulated

Outlook

- Improvement of electrical measurements (eg. noise, better statistics, 4-point scheme)
- Precise determination of thermodynamic parameters: $\mathrm{T}(\mathrm{r}, \mathrm{z}, \mathrm{t})$ and $\rho_{\mathrm{m}}(\mathrm{r}, \mathrm{z}, \mathrm{t})$
- Theoretical description of metal-to-insulator transition
- Experiments on metallization (phase) transitions (HEDgeHOB)

Acknowledgements

A. Shutov and I.V. Lomonosov (IPCP Chernogolovka)

for support with EOS-modell and the 2D hydrocode

German Ministry for Education and Research (BMBF)

for financial support