**15th ETH-Conference on Combustion Generated Nanoparticles**
**June 26th – 29th 2011**

Author: C. Grünzweig[1]
Co-Authors: D. Mannes[1], F. Schmid[1], A. Kaestner[1], P. Vontobel[1], E. Lehmann[1], J. Hovind[1], M. Mehring[1], M. Vogt[2], H. Grützmacher[2], P. Comte[3], J. Czerwinski[3]

Affiliation: [1] Paul Scherrer Institut, CH-5232 Villigen-PSI
[2] ETH Zürich, CH-8093 Zürich
[3] Berner Fachhochschule, CH-2560 Nidau

Mailing address: Christian Grünzweig
Neutron Imaging and Activation Group
Paul Scherrer Institut
WBBA/108
CH-5232 Villigen-PSI

Phone: 056 310 4662 E-mail: christian.gruenzweig@psi.ch

# Visualization of soot and ash distributions in diesel particulate filters using neutron imaging

Although diesel particulate filters have already been in utilization for a fairly long time, only little possibilities of non destructive experimental analysis of the detailed distribution of soot inside these filters are given. With conventional means (e.g. gravimetrically) only the total amount of soot within the filter can be determined. X-ray techniques as non destructive testing methods only provide information about the ash distribution whereas the soot amount and soot distribution can not be detected.

In the presented project, we introduce the neutron imaging technique as a new approach to nondestructively determine the soot distribution inside particle filters. Neutron imaging allows for qualitative (spatial and temporal visualization) and quantitative determination of the soot distribution. Neutron tomography (NT) is currently a unique option for getting three-dimensional information of both the soot distribution as well as the ash distribution inside the sample. The determination of the soot distribution inside diesel particulate filters using NT is possible due to the very high sensitivity of neutrons for the element hydrogen. Even the relatively low remaining hydrogen content of the soot provides sufficient contrast in the neutron image. The presented measurements were performed at the neutron imaging beamlines at PSI.

We present results of NT investigations of a canned diesel particulate filter from a van. The examined filter had been loaded and regenerated for several times. As the steel casing is almost transparent for neutrons, the NT investigations permit the three-dimensional information of the load of the monolith, i.e. the soot and ash distribution in the filter as well as the visualization of metallic particles as shown in Fig. 1. The global overview (macro-tomography) of the whole filter with a resolution of 200 µm provides spatially resolved information of the soot and ash distribution within the whole filter volume. Hence, this measurement allows for conclusions of the local load rate and mass distribution of soot. By using this overview tomography relevant areas could be identified, which could subsequently be investigated in more detail using a micro-tomography setup with a nominal pixel size of 13.5 µm. This higher spatial resolution allows for the detailed visualization of the soot and ash distribution within the single filter

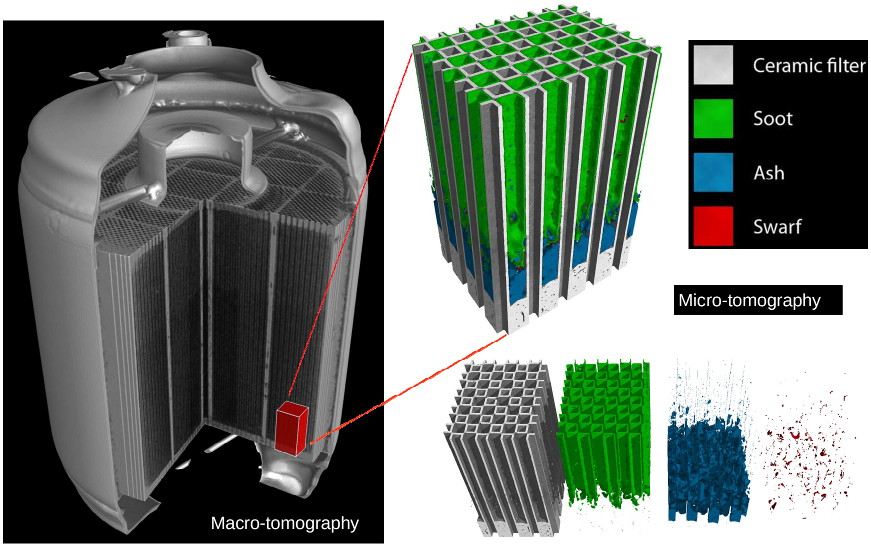



**Figure 1: Neutron tomography data of a canned diesel particulate filter. (left) Macro-tomography data. (right) Micro-tomography data of a selected area. The soot and ash distribution as well as metallic particles are visualized. Soot can only be detected by neutrons and this due to the high sensitivity of neutrons for the remaining small content of hydrogen.**

channels of the monolith. The obtained volume data set yields quantitative information on the amount of soot and ash as well as the soot layer thicknesses along filter channels.

To further enhance the soot's contrast and thus increase the detection accuracy a special diesel fuel containing a neutron tracer was developed. The tracer consists of a chemically dissolved Gadolinium (Gd) compound. Gd is an element with one of the highest attenuation coefficients for neutrons. Hence, only a small Gd-concentration (in the ppm range) in the fuel is sufficient to increase the contrast of the soot layer considerably as shown in Fig. 2. The contrast of the soot marked with the tracer element is increased by the factor four in comparison to the normal soot. The NT data show that a more efficient and precise visualization of the soot distribution in the filter is possible. Even the visualization of the soot load inside the filter walls is now possible.

The obtained data from the NT experiments were verified by complementary methods like scanning electron microscopy, energy dispersive X-ray spectroscopy and chemical analysis of soot and ash.

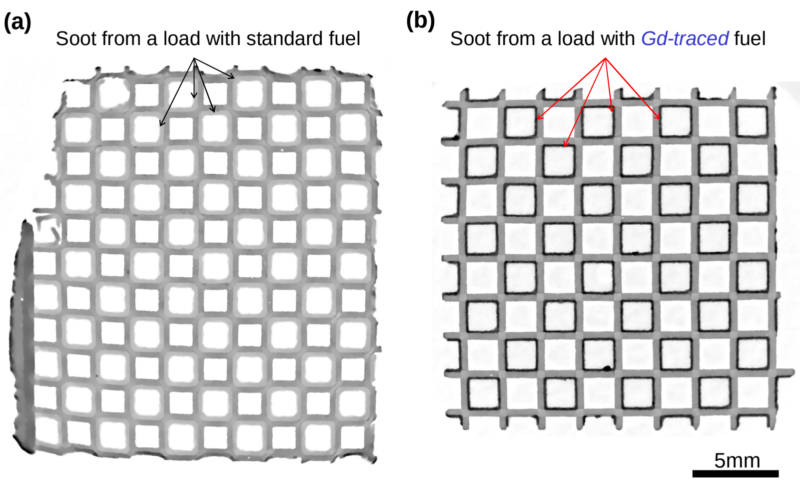



**Figure 2: Horizontal slices from micro-tomography measurements showing the soot distribution within the monolith. (a) Soot from a load with standard (untraced) diesel. The contrast of the soot is lower than the one from the filter material. (b) Soot from a load with Gd traced diesel (0.01 g pure Gd per 1 litre diesel). The contrast enhancement is clearly visible even for a thinner soot layer thickness.**

# Short CV:

| | |
|---|---|
| **Name:** | Dr. Grünzweig, Christian |
| **Profession:** | Diplom-Physiker |
| **Date of Birth:** | January 11, 1980 |
| **Place of Birth:** | VS-Schwenningen, Germany |
| **Nationality:** | German |
| **Marital Status:** | Single, 1 daughter |

## Career

since 04/2009 **Paul Scherrer Institut, Schweiz**
**Neutron Imaging Gruppe and Activation Group**
***Project manager "industrial Projects" for non destructive testing***

## Academic Studies

05/2006 – 03/2009 **Eidgenössische Technische Hochschule (ETH) Zürich, Switzerland**
**Dissertation at the department of Physics**
*"Neutron grating interferometry for imaging magnetic domain structures in ferromagnetic materials"*

04/2005 - 04/2006 **Diploma thesis at the Paul Scherrer Institut (PSI), Villigen, Switzerland**
Title:
*"Fabrication and testing of diffraction gratings for phase contrast imaging with neutrons"*

10/2000 - 04/2006 **Eberhard-Karls-Universität Tübingen, Germany**
**Studies of Physics**
Majors: Nanotechnology, Solid State Physics, Microstructures

15th ETH-Conference on Combustion Generated Nanoparticles
Zurich, 27th of June 2011

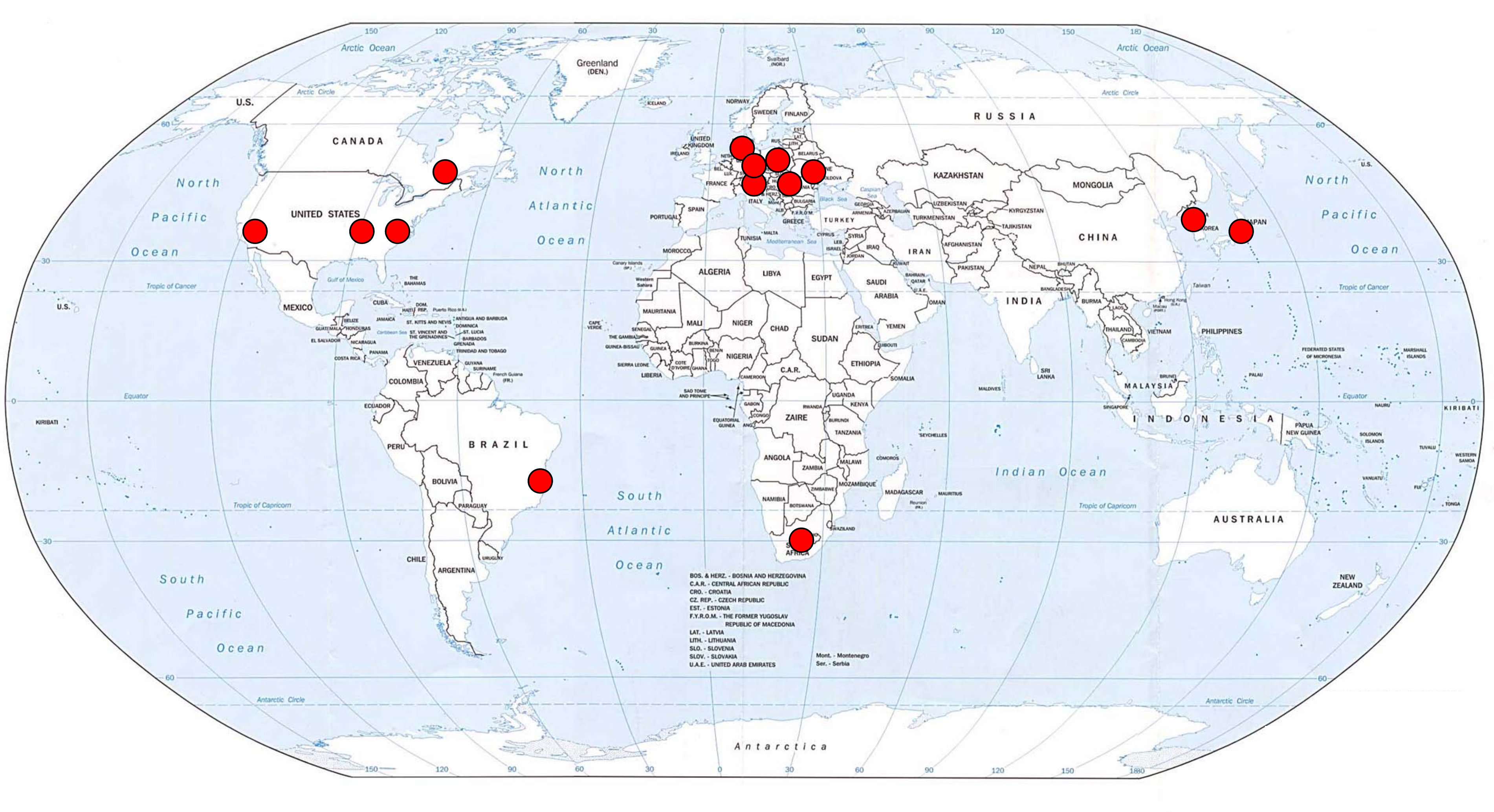
# Visualization of soot and ash distributions in diesel particulate filters using neutron imaging

**C. Grünzweig, D. Mannes, F. Schmid, A. Kaestner, P. Vontobel, E. Lehmann, J. Hovind, M. Mehring**
*Neutron Imaging and Activation Group, Paul Scherrer Institut*

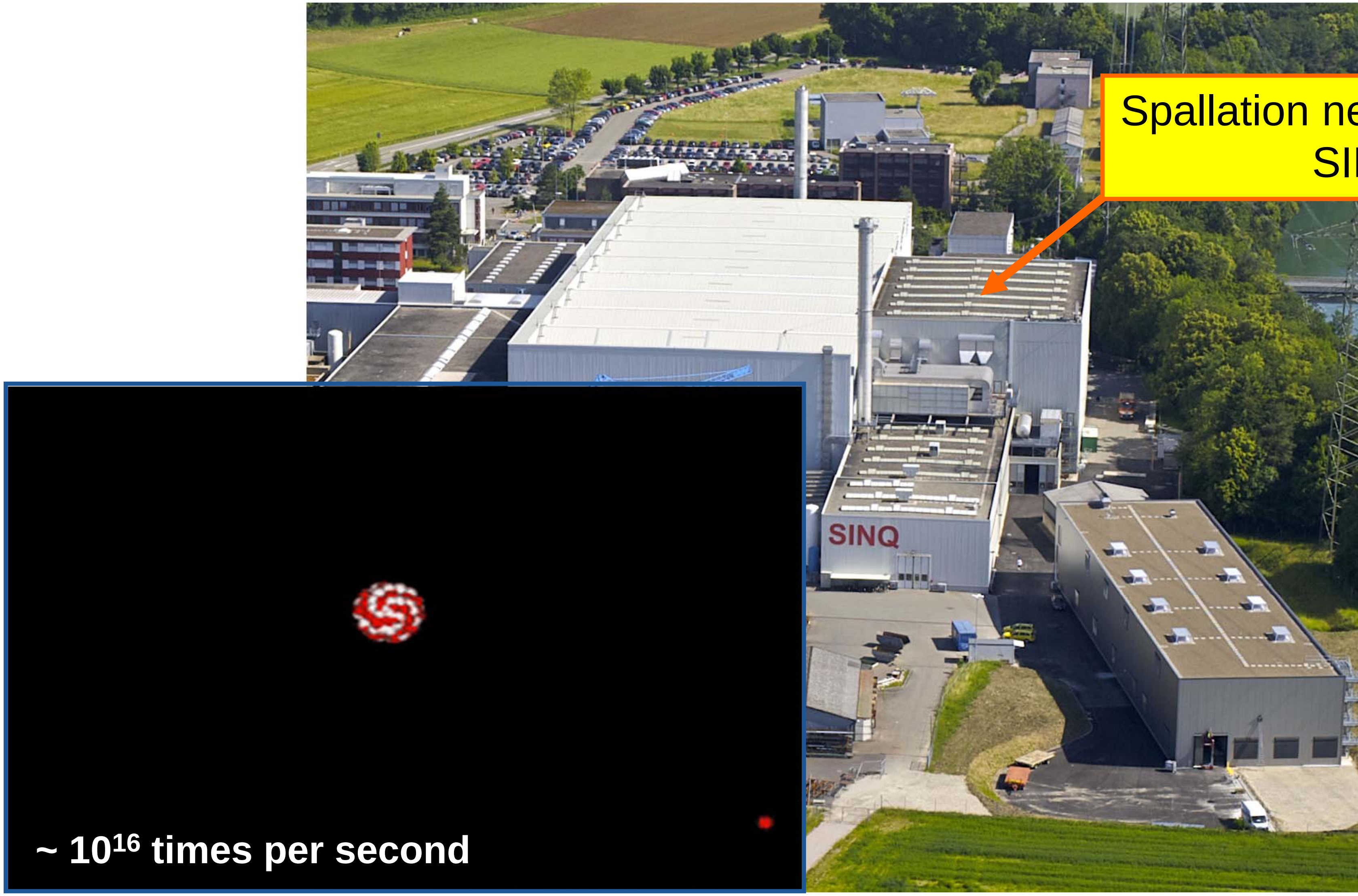
**M. Vogt, H. Grützmacher**
*Laboratory for Anorganic Chemistry, ETH Zurich*

**P. Comte, J. Czerwinski**
*Laboratory for IC-Engines and Exhaust Gas Control, FH Bern*

# *Neutron Imaging beamlines*

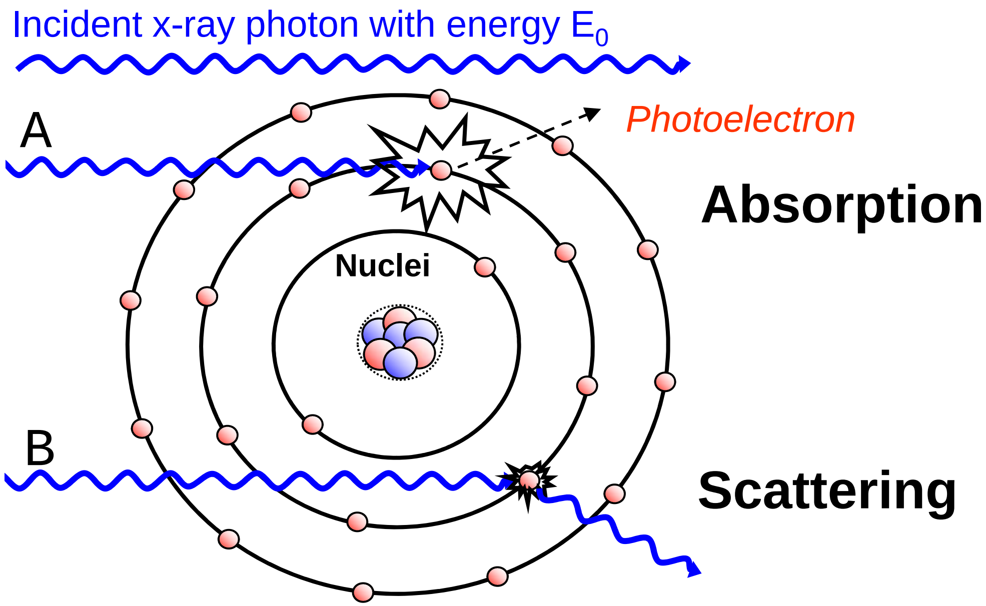


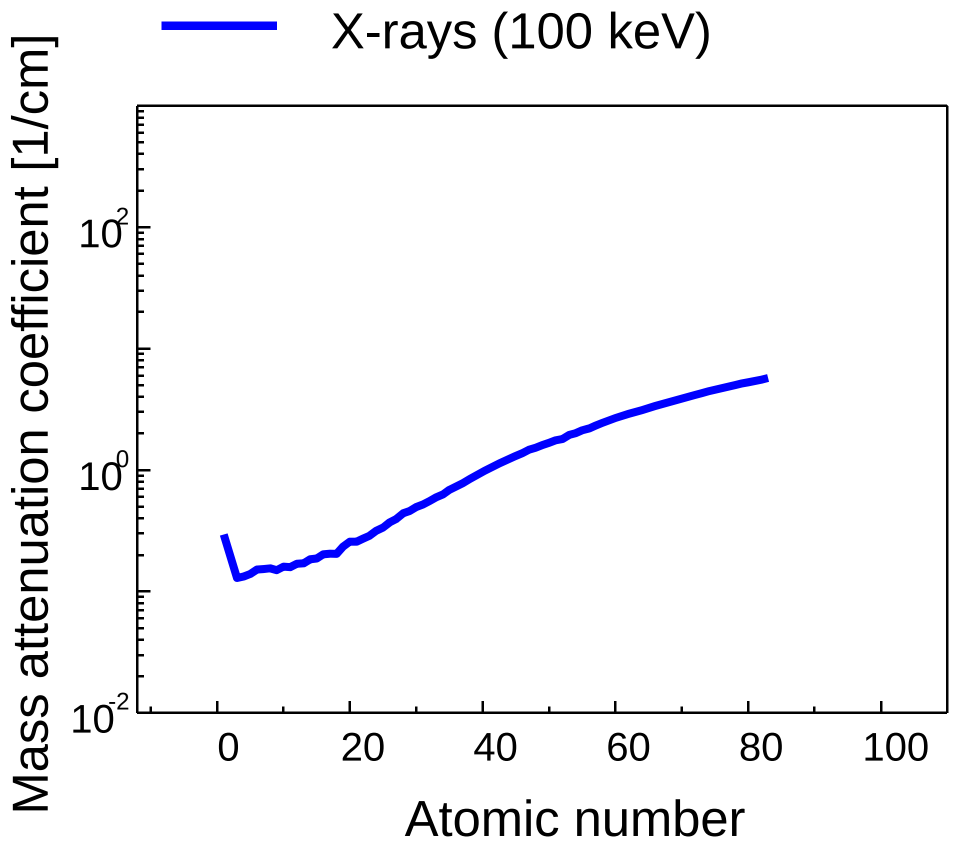
# *Production of neutrons at PSI*



# *X-rays vs. neutrons*

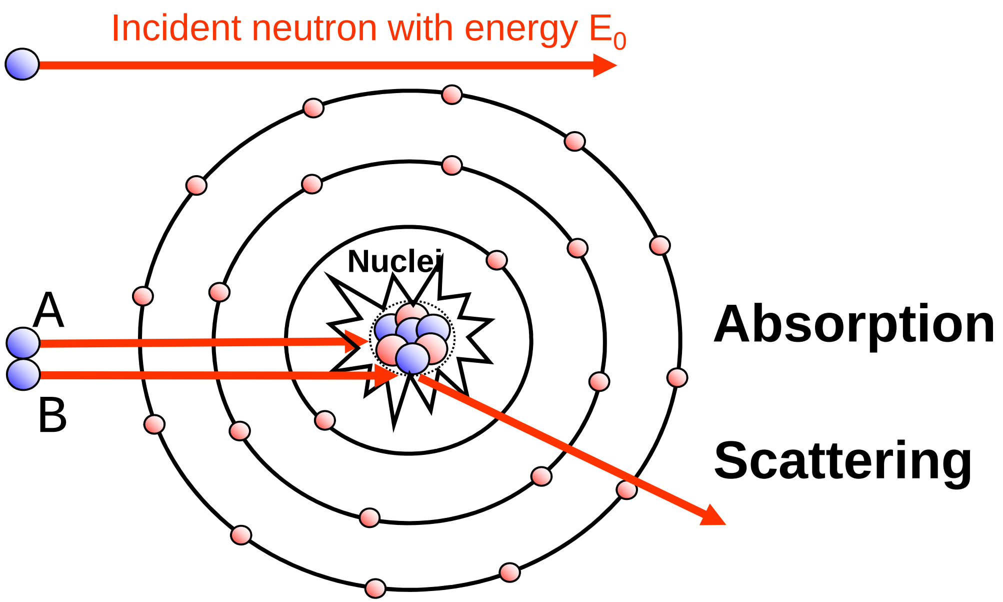
X-Rays

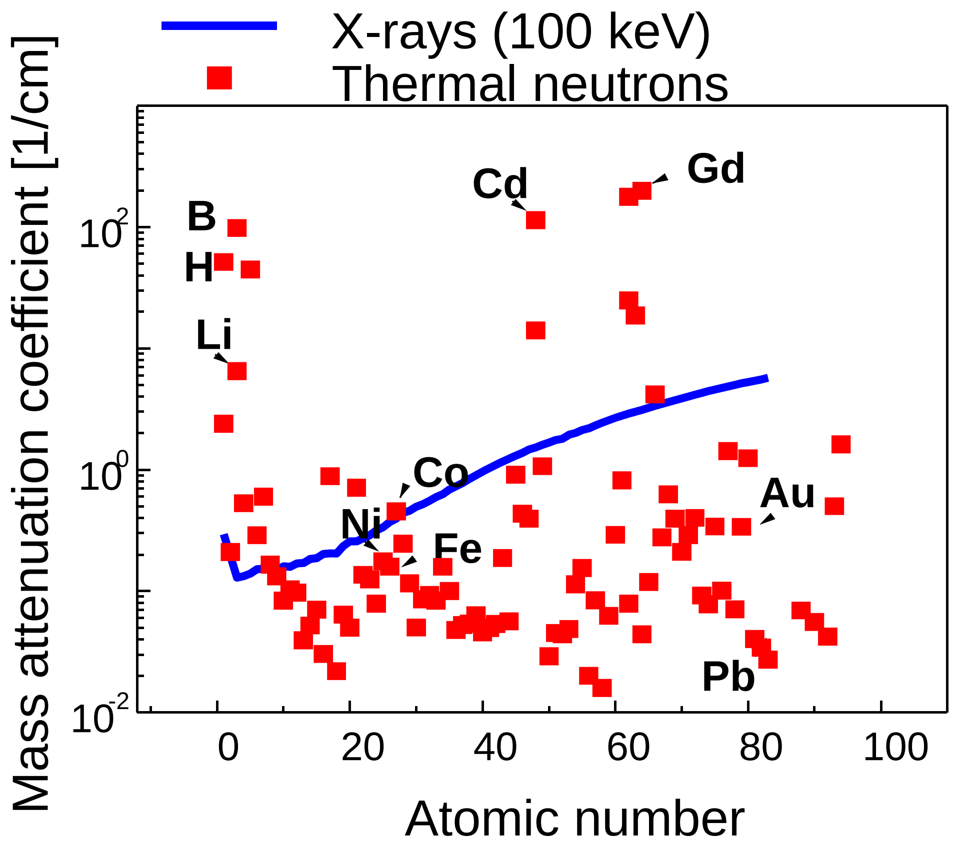


# *X-rays vs. neutrons*

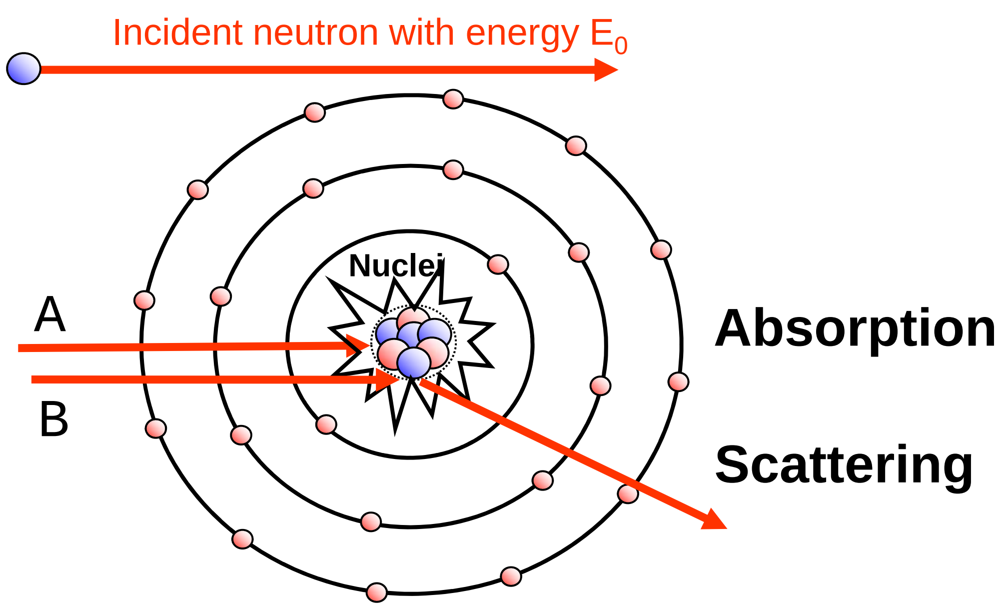
## Neutrons

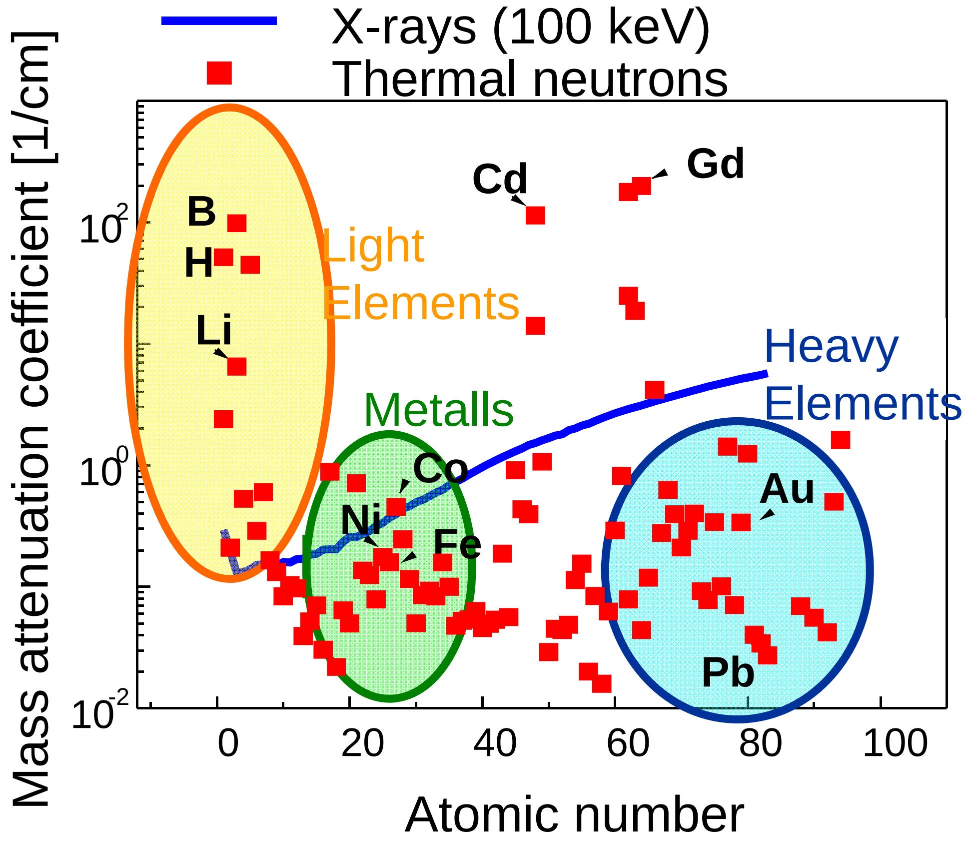


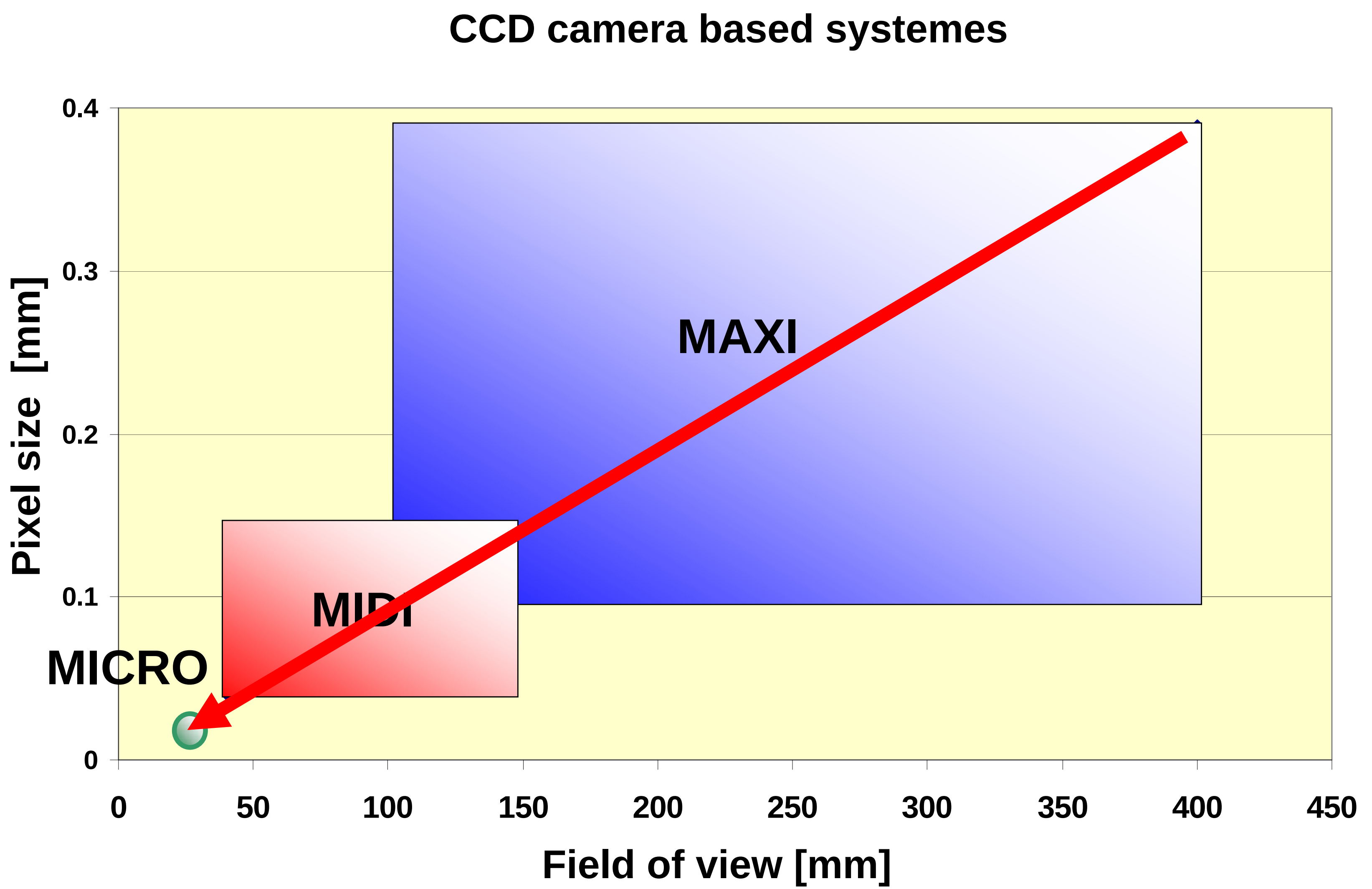
# *X-rays vs. neutrons*

Neutrons



# *Object dimensions vs. resolution*



# *Soot particle filter, Maxi-setup*


**<u>Tomography</u>**

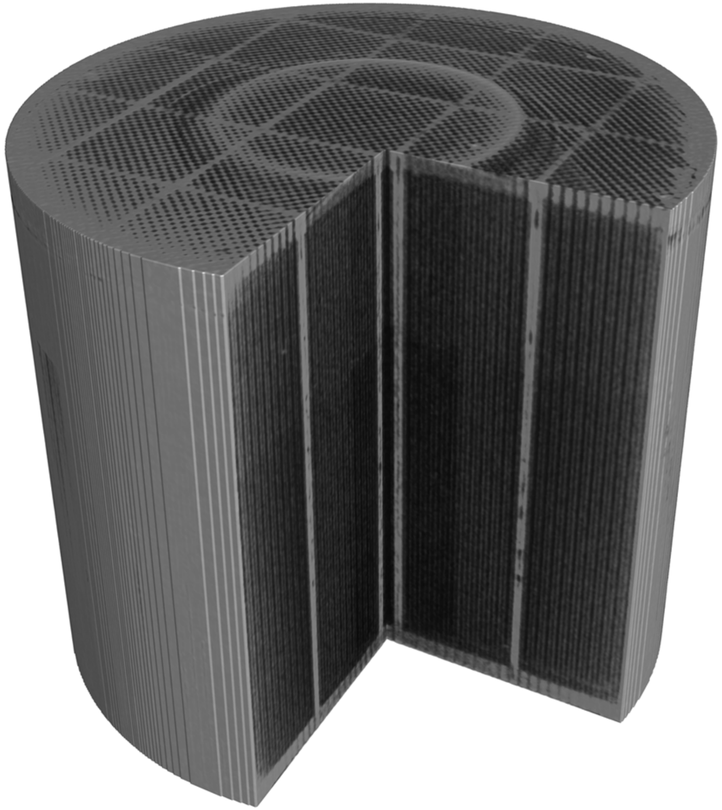
**Projections: 675 over 360°**

**Exposure time per projection: 20 s**

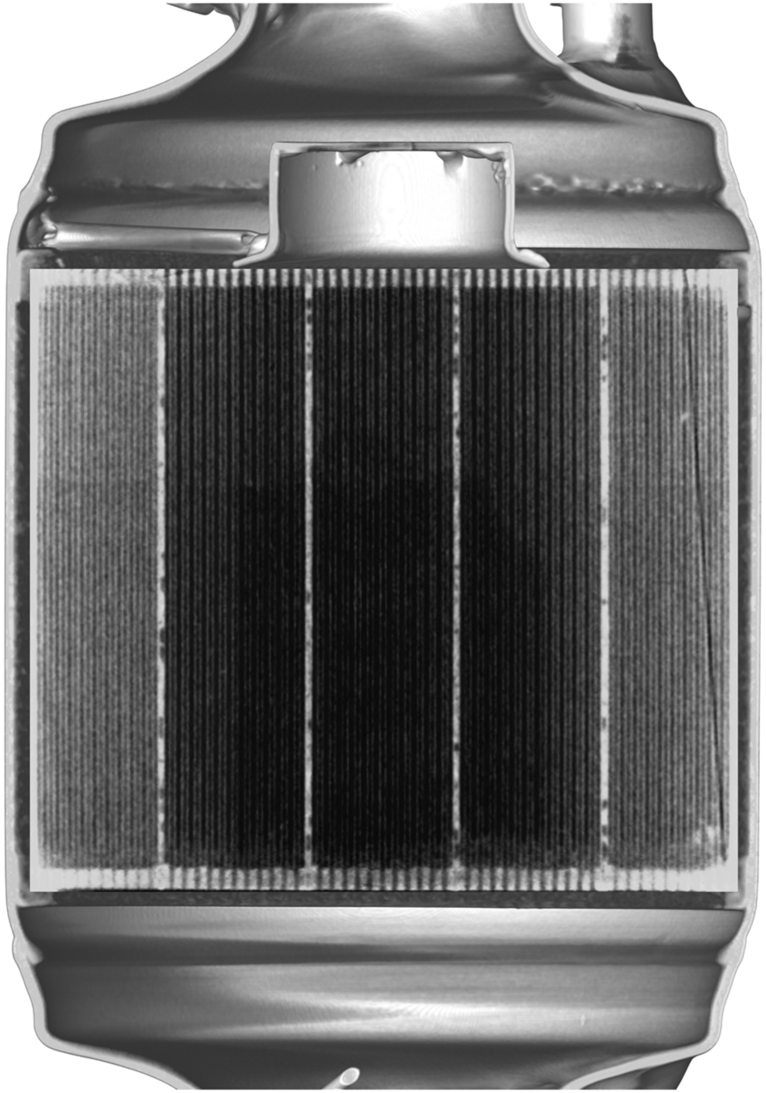
**Pixel resolution: 150 µm**

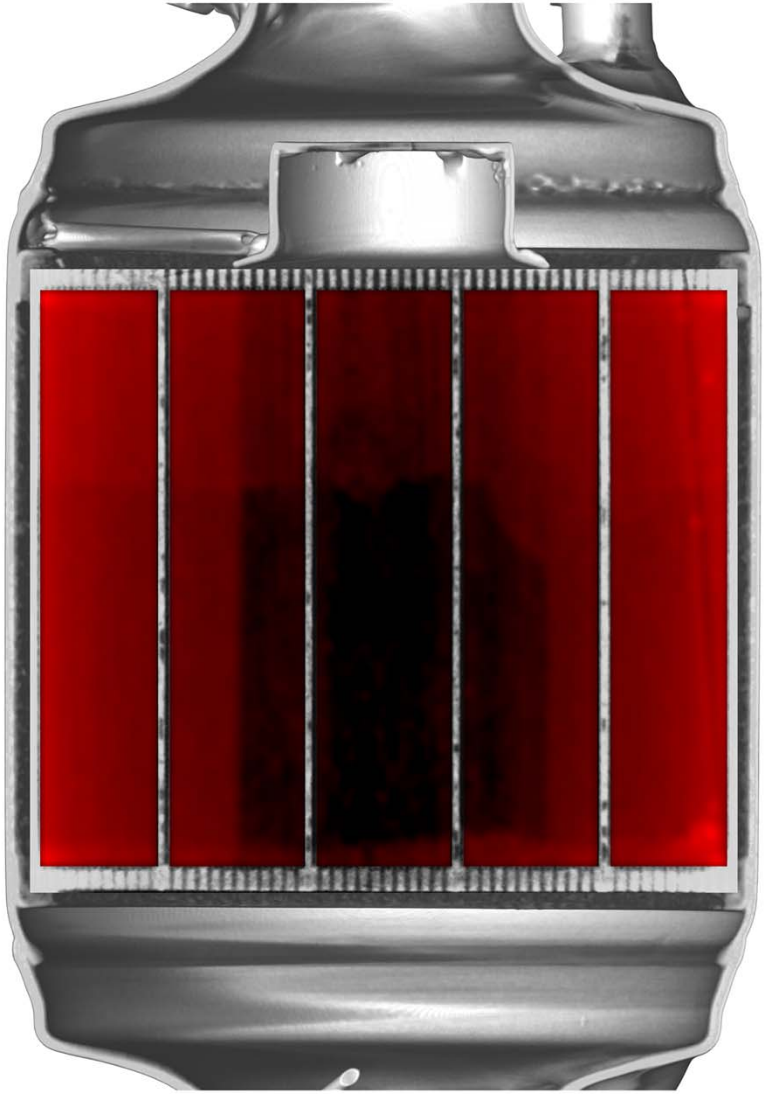
# *Soot particle filter, Maxi-setup*

# *Soot particle filter, Maxi-setup*



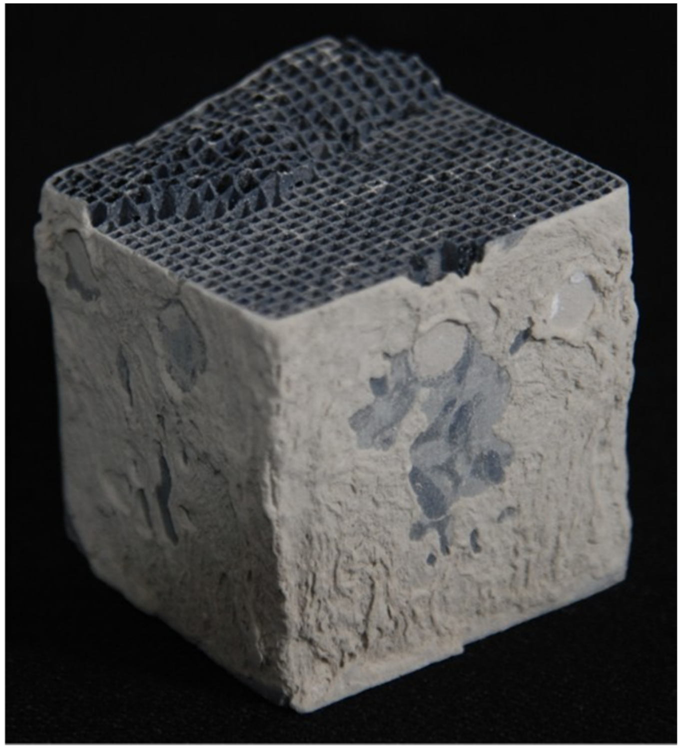
# *Soot particle filter, Maxi-setup*

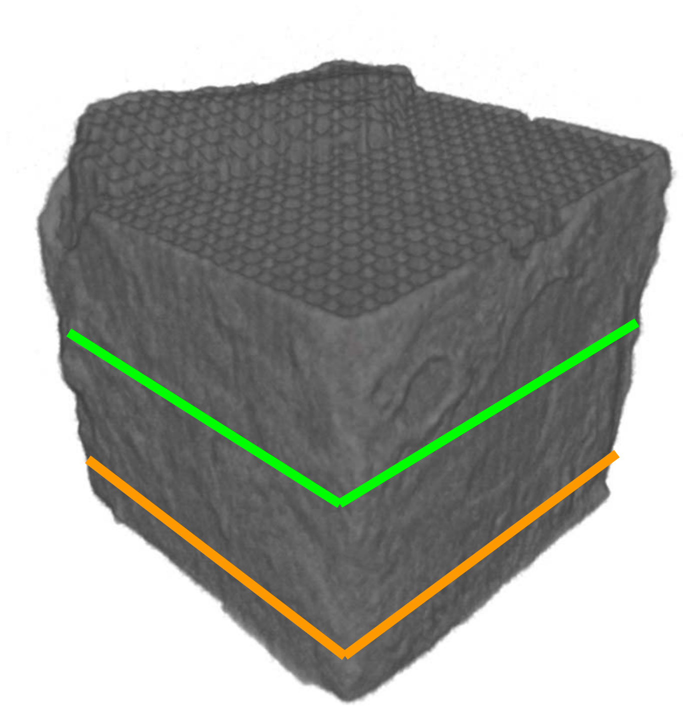




# ***Soot particle filter, Midi-setup***

# *Soot particle filter, Midi-setup*





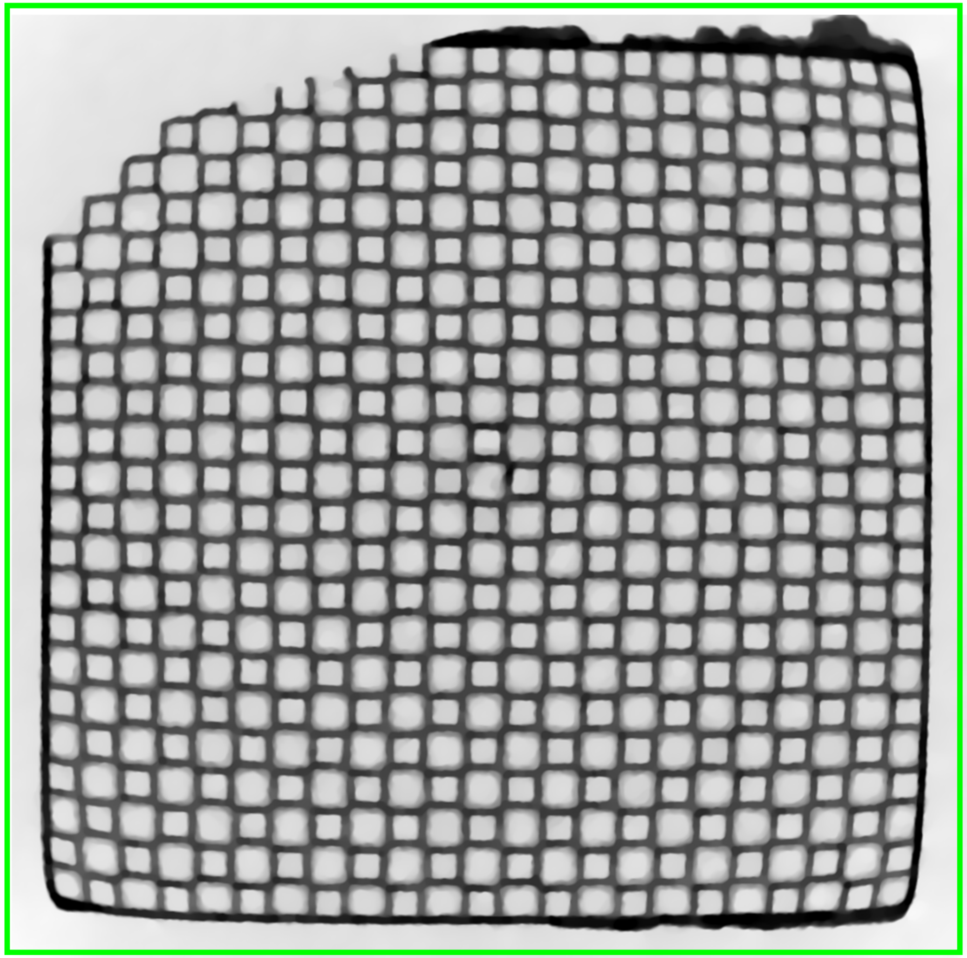
**Tomography**

**Projections: 675 over 360°**
**Exposure time per projection: 60 s**
**Pixel resolution:  40 µm**

# *Soot particle filter, Midi-setup*

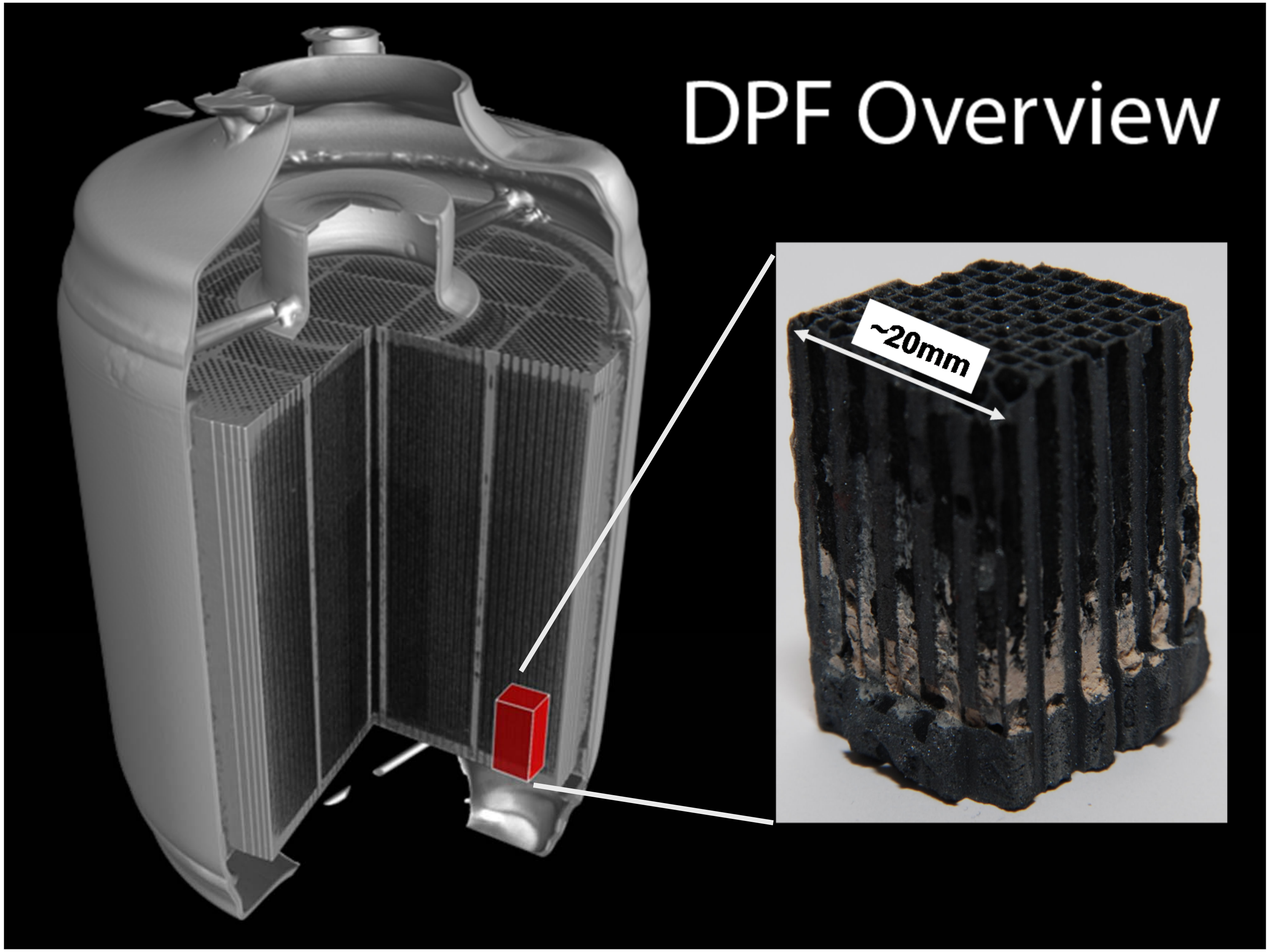
Ash

Soot



# *Soot particle filter, Micro-setup*

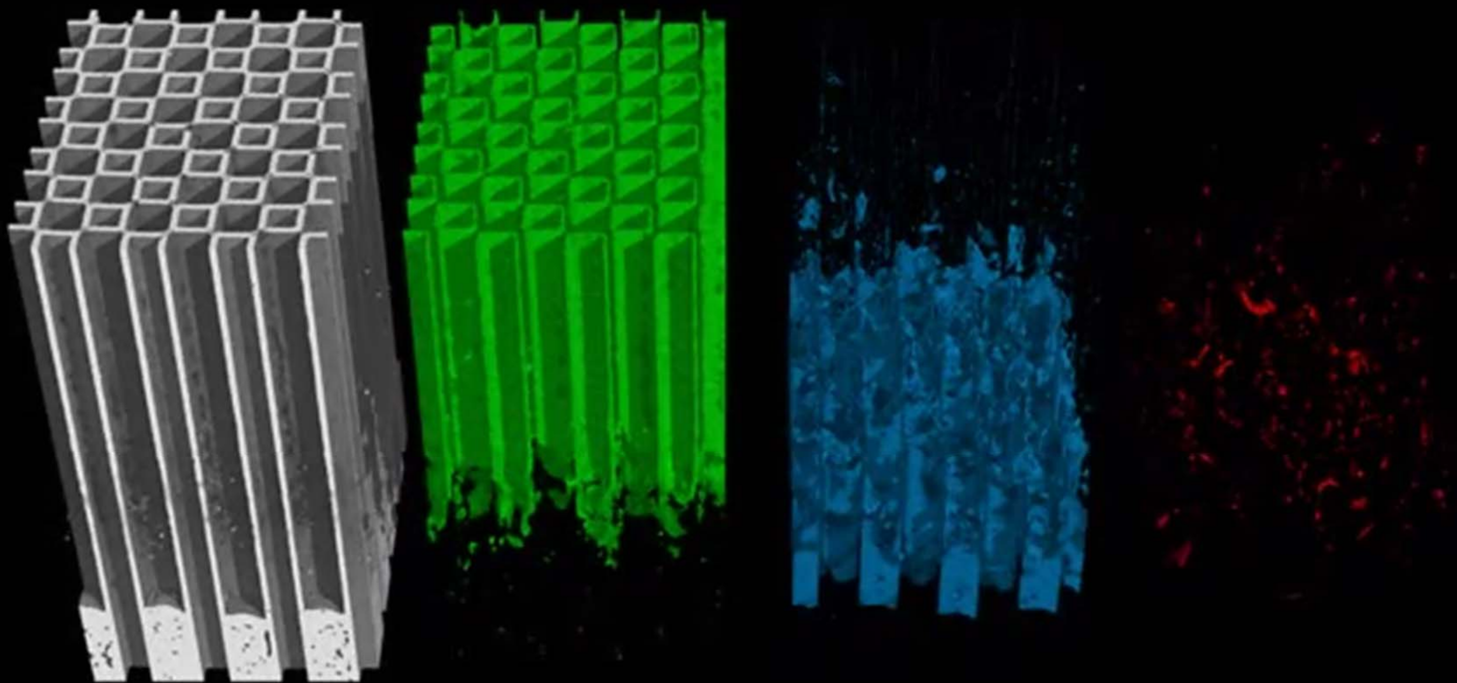
# *Soot particle filter, Micro-setup*



PAUL SCHERRER INSTITUT PSI

ICON
Imaging with Cold Neutrons

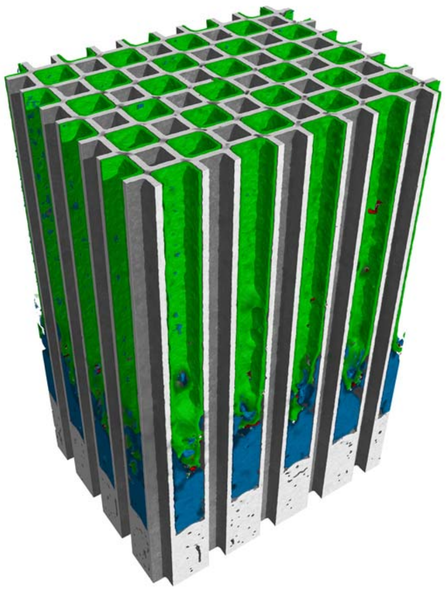
# Neutron microtomography
# Diesel particulate filter (DPF)

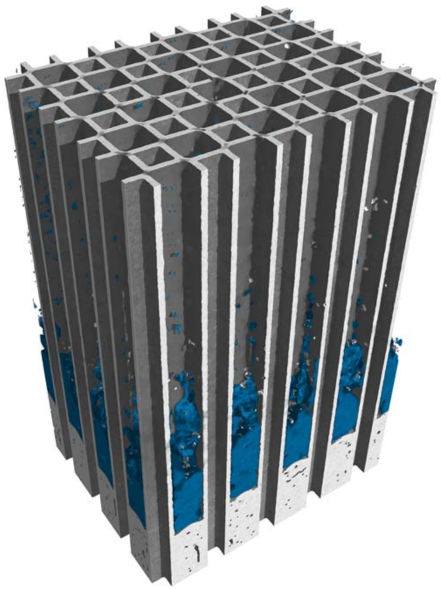


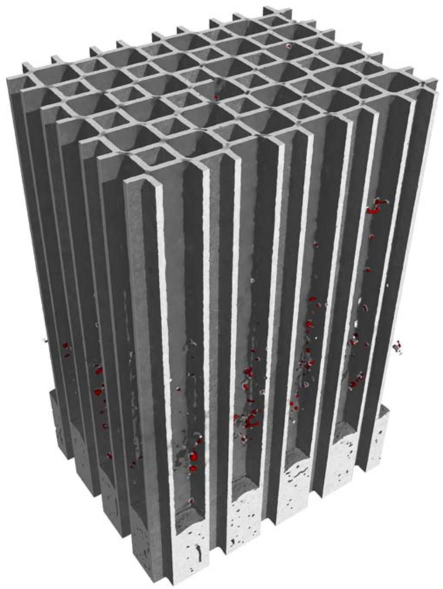
Sample size 10mm × 13mm × 18mm

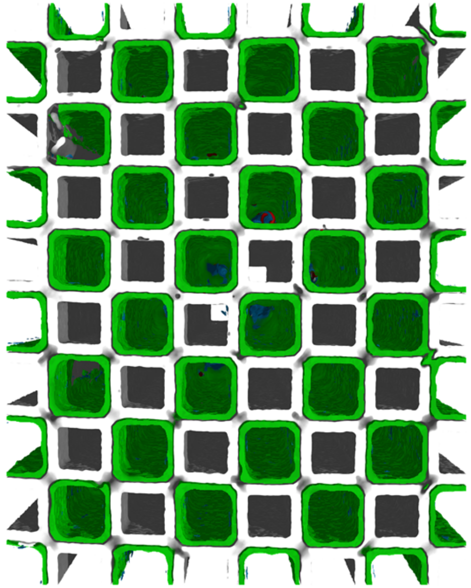
Voxel size 13.5μm$^3$

# *Soot particle filter, Micro-setup*





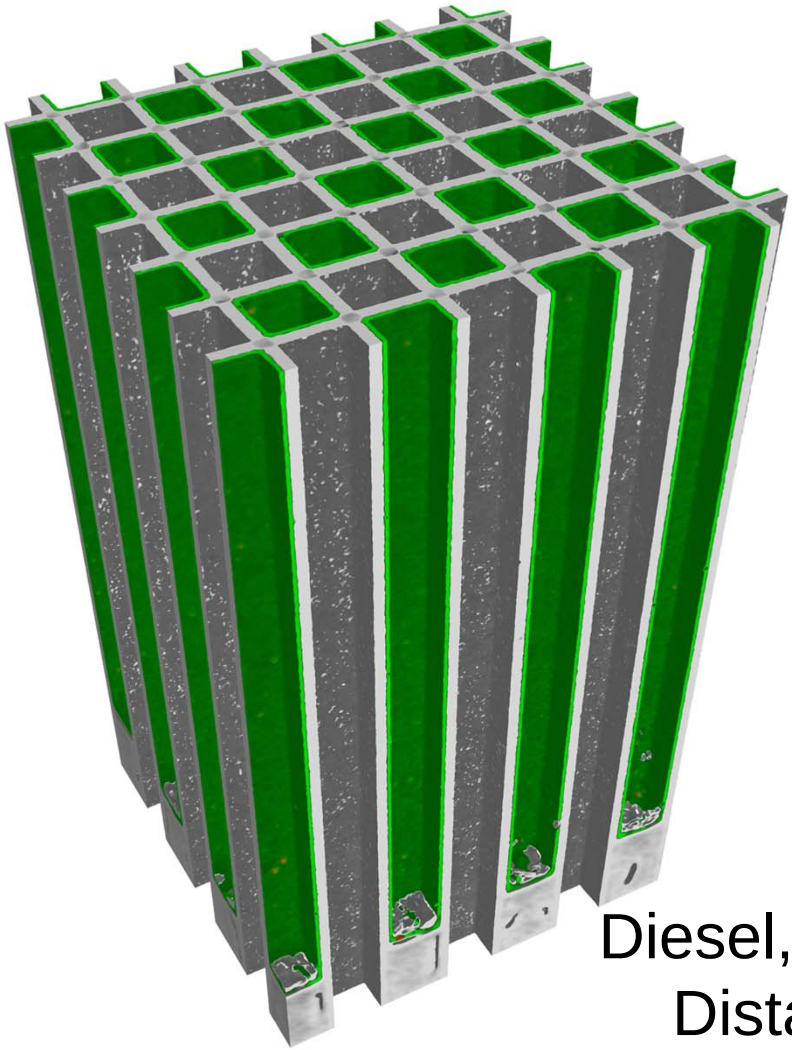


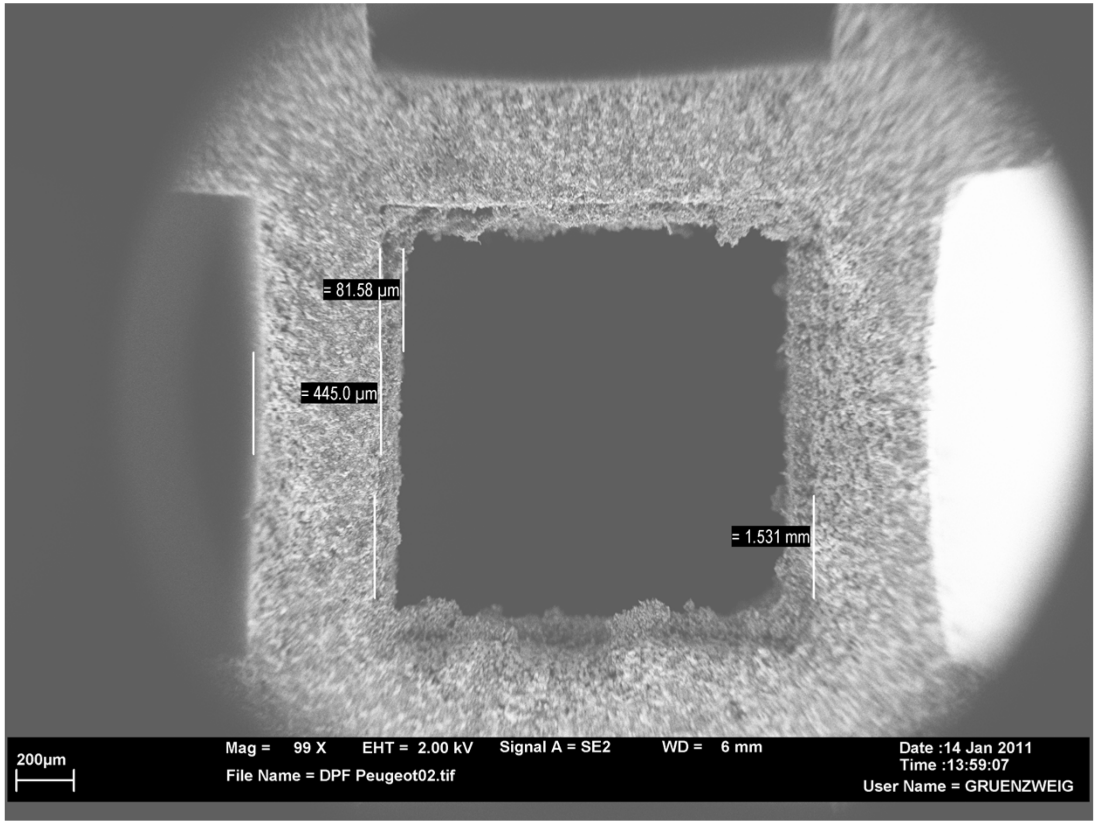


**<u>Tomography</u>**

**Projections: 675 over 360°**
**Exposure time per projection: 90 s**
**Pixel resolution: 13.5 µm**

# Loading with Gd-traced fuel



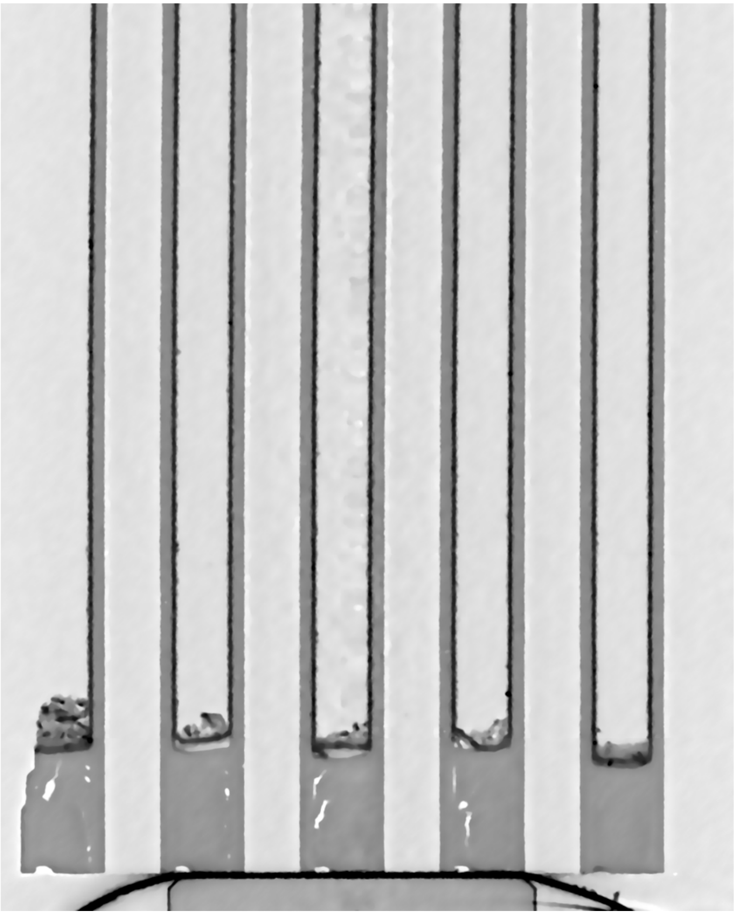



New filter
Diesel, with 0.01g/L Gd
Distance: 106 km
Consumption : 5.3 L

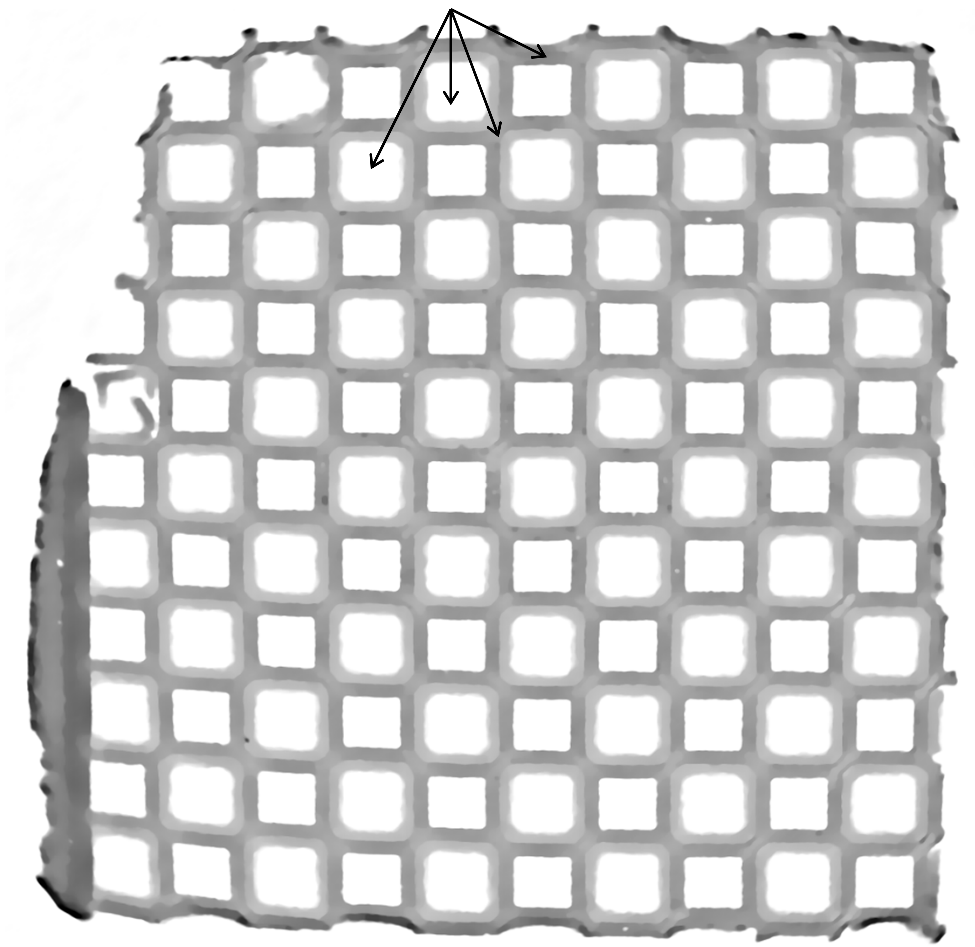
# Loading with Gd-traced fuel

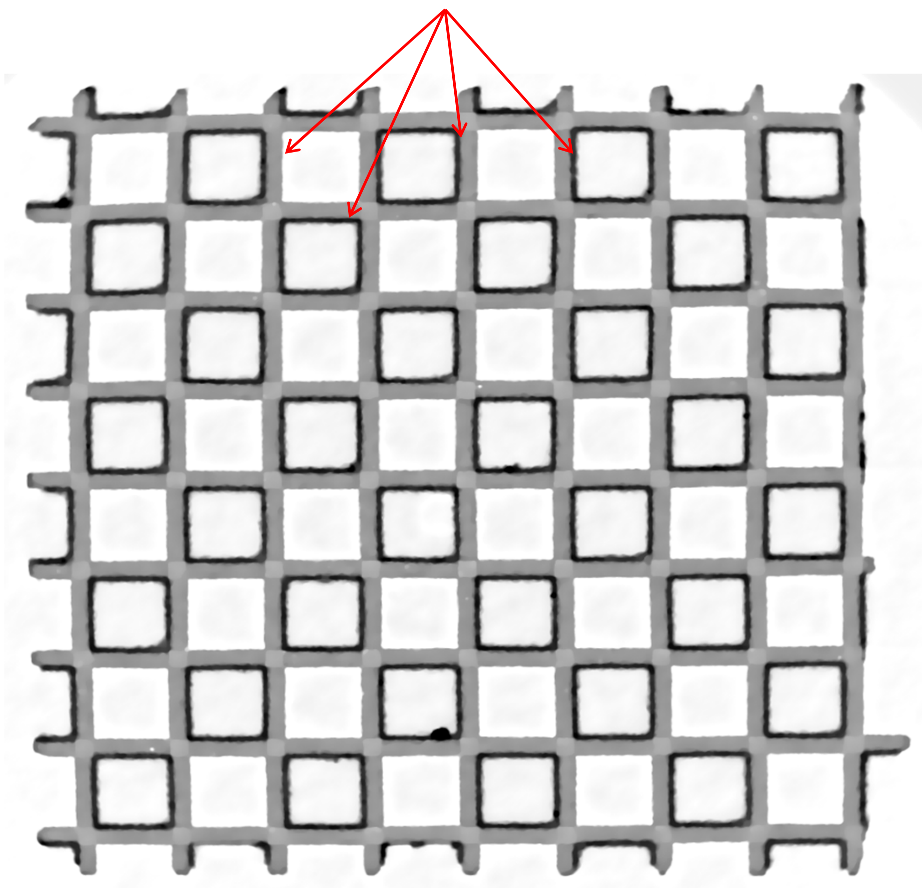
Standard fuel

Gd traced fuel

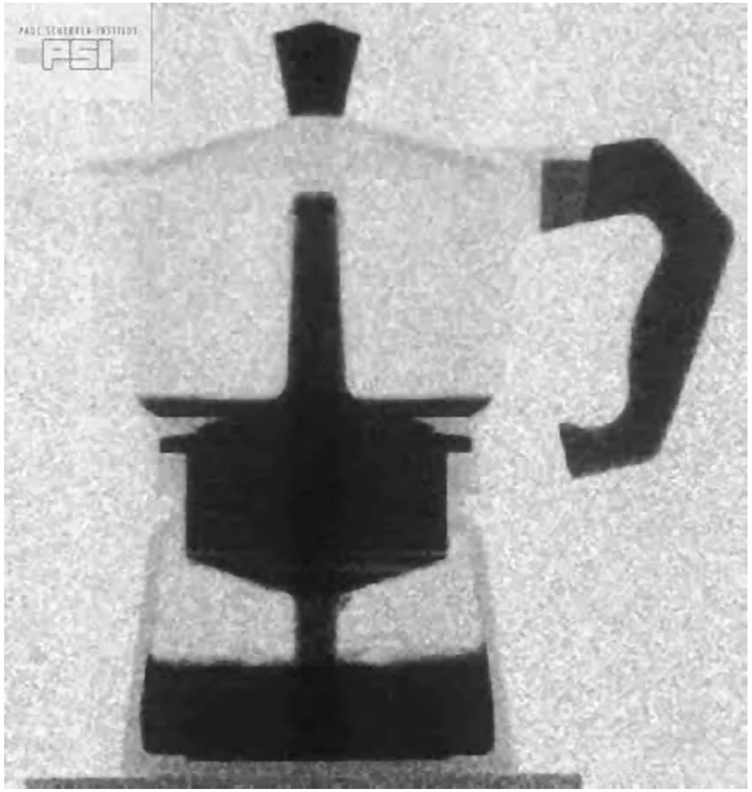


# Loading with Gd-traced fuel



# Thank you for the attention




christian.gruenzweig@psi.ch