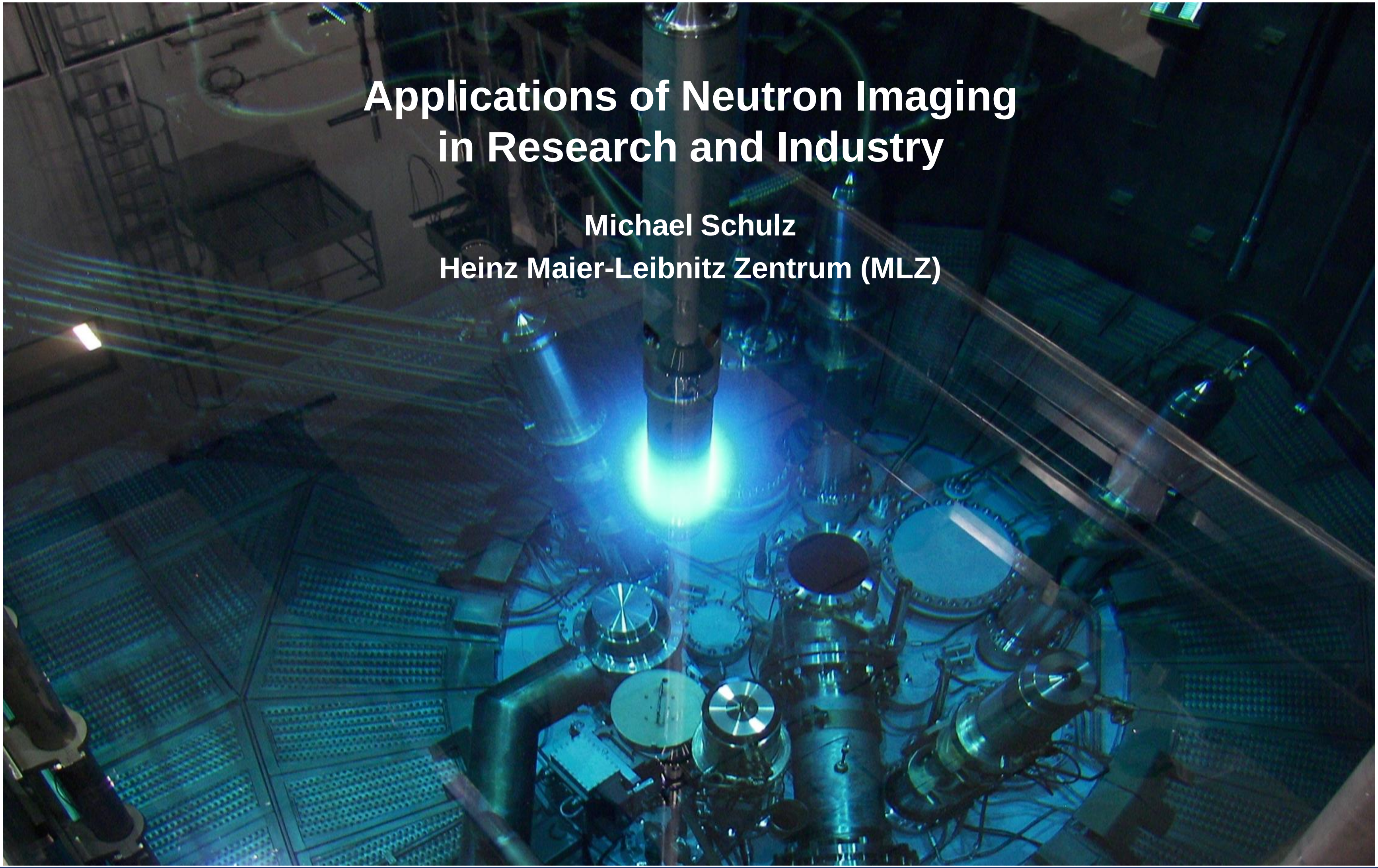
FRM II
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz

MLZ
Heinz Maier-Leibnitz Zentrum



Applications of Neutron Imaging in Research and Industry

Michael Schulz
Heinz Maier-Leibnitz Zentrum (MLZ)

MLZ is a cooperation between:

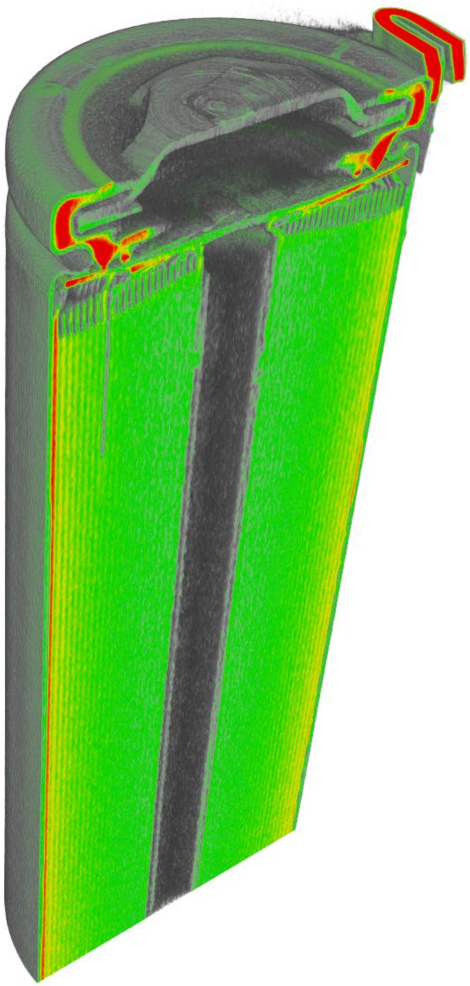
JÜLICH FORSCHUNGSZENTRUM

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

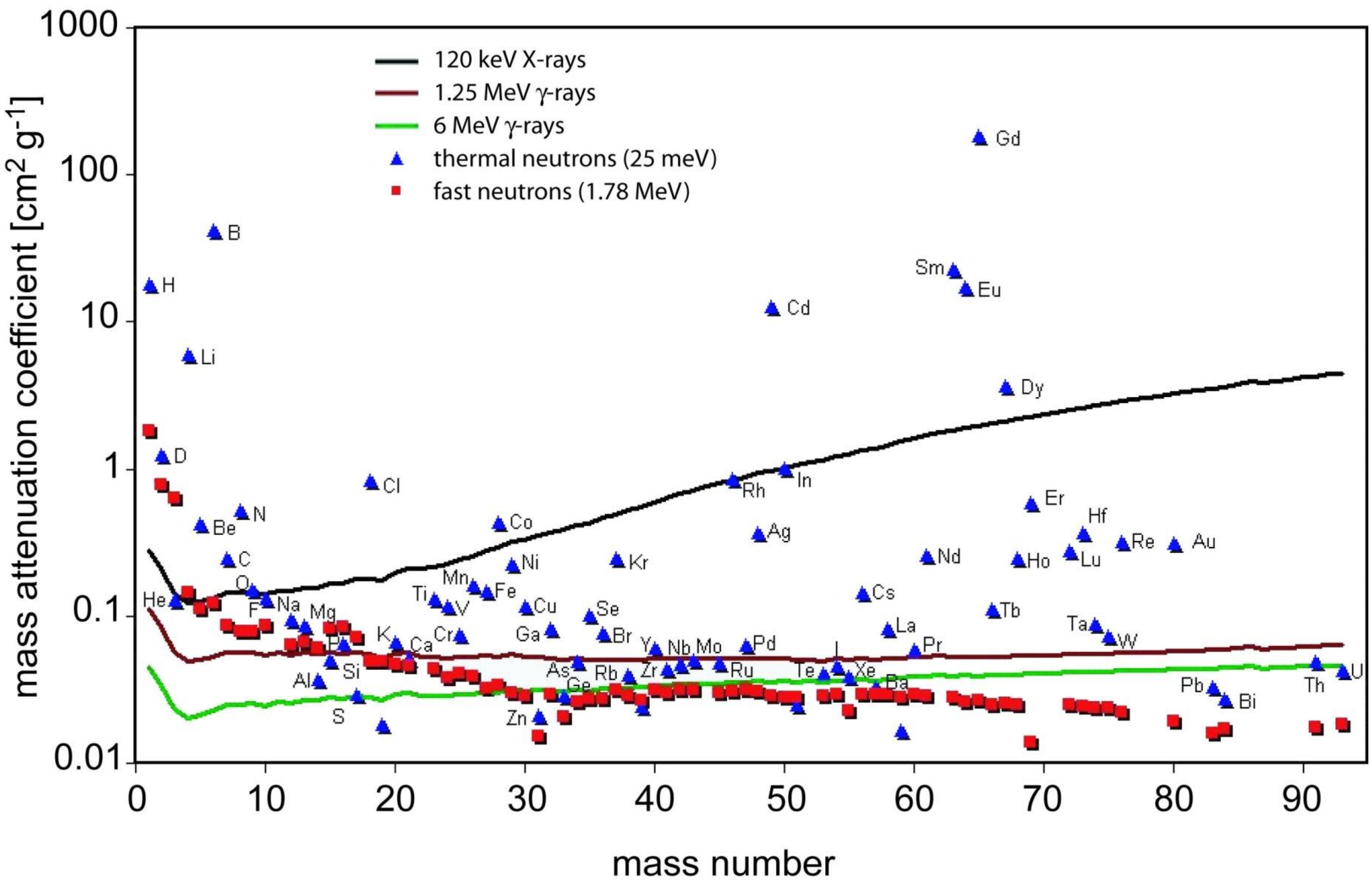
TUM
Technische Universität München

Outline

- Complimentarity of neutrons and X-rays
- Why is it difficult to show industrial projects?
- Examples of some industrial and scientific applications
- Conclusions



M. Mühlbauer, KIT


120 keV X-rays
1.25 MeV γ-rays
6 MeV γ-rays
thermal neutrons (25 meV)
fast neutrons (1.78 MeV)
mass attenuation coefficient [cm² g⁻¹]
mass number
1000
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
H
D
He
Li
Be
B
C
N
O
F
Na
Mg
Al
Si
P
S
Cl
K
Ca
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Te
I
Xe
Cs
Ba
La
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Lu
Hf
Ta
W
Re
Au
Pb
Bi
Th
U

How to obtain beam time at MLZ?

1.) **scientific proposal (2 pages)**:

- 2x per year; next deadline: **08.09.2017**

- Referees select ~30-50% of all proposals

- several days of beam time in next ½ year

or

- „Rapid access„ (within a few weeks): ~12h beam time (on selected instruments)

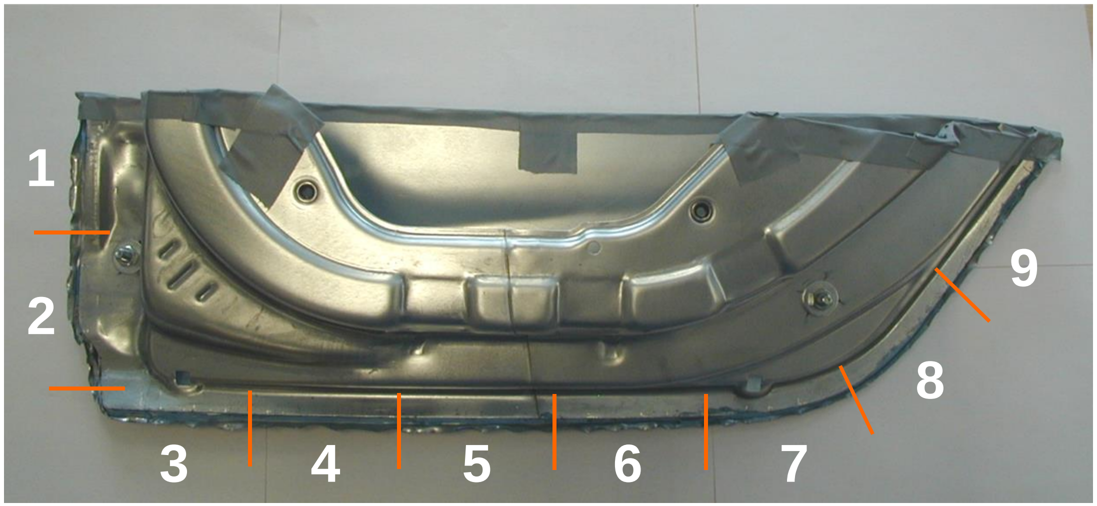
-> results must be published -> beam time is free of charge + travel support!

2.) **commercial beam time:**

- no full proposal, no publication required, NDA can be set up.

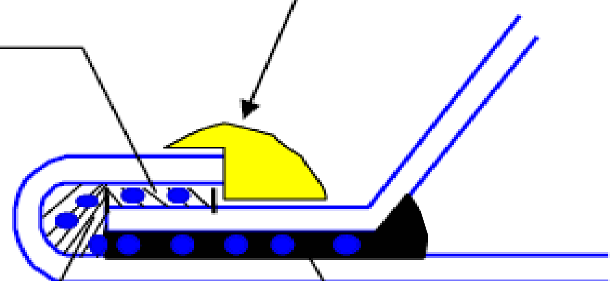
- costs: 7.000€/day

Cooperation with FORD



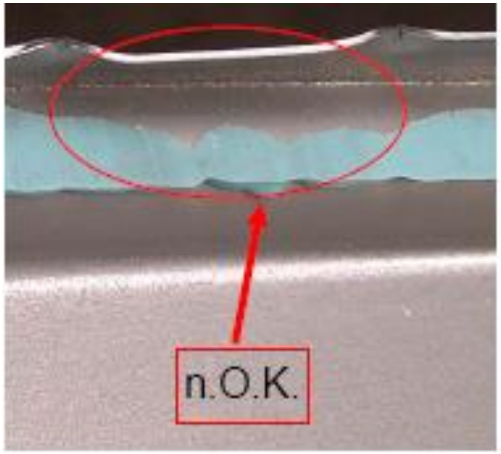
Car door prepared for test experiment

Requirements for filling level:

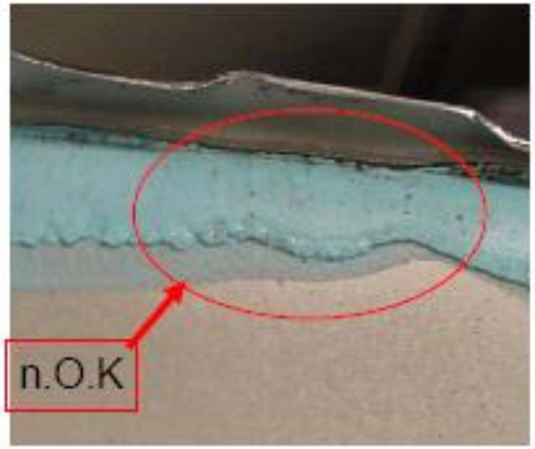


I. Wehmeyer (Ford)

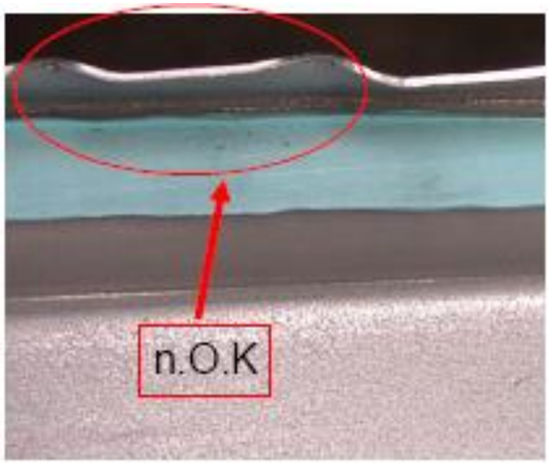
Visual (destructive) check of filling level



~40 / 0 / 0



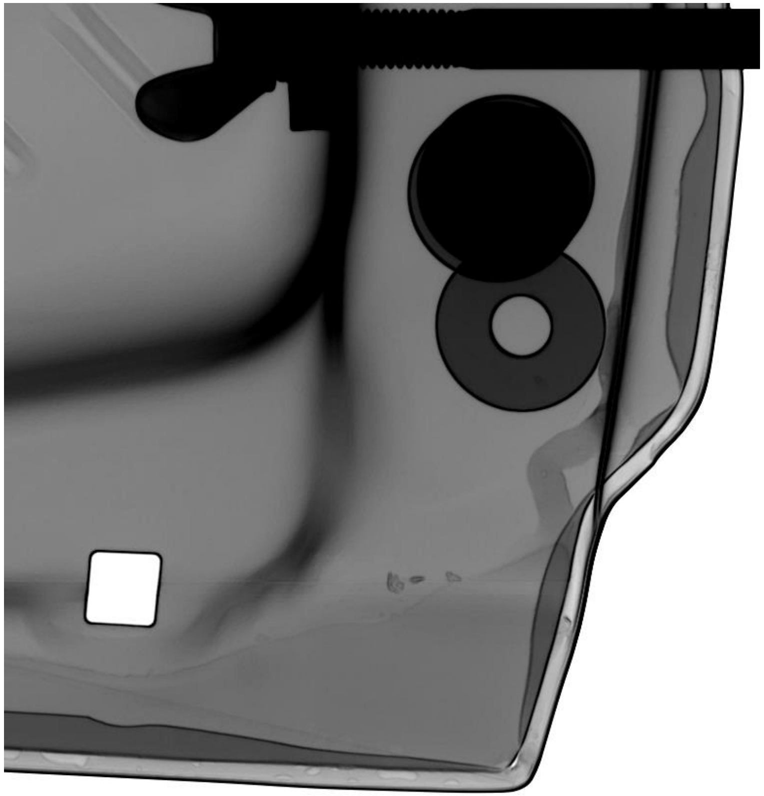
~60 / ~40 / 0



~100 / ~40 / 0

I. Wehmeyer (Ford)

Comparison
X-rays & Neutrons

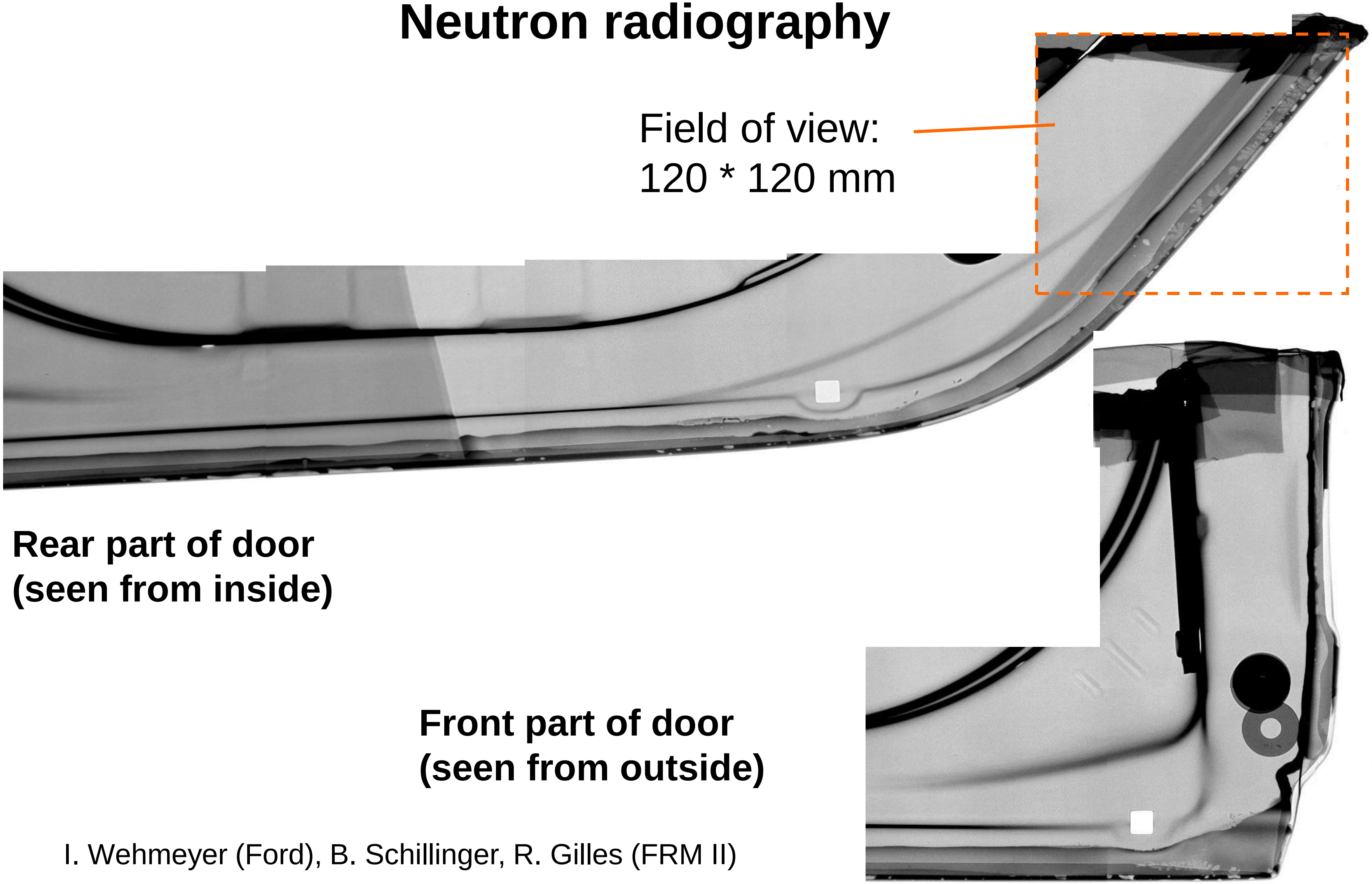


X-Rays

Neutrons

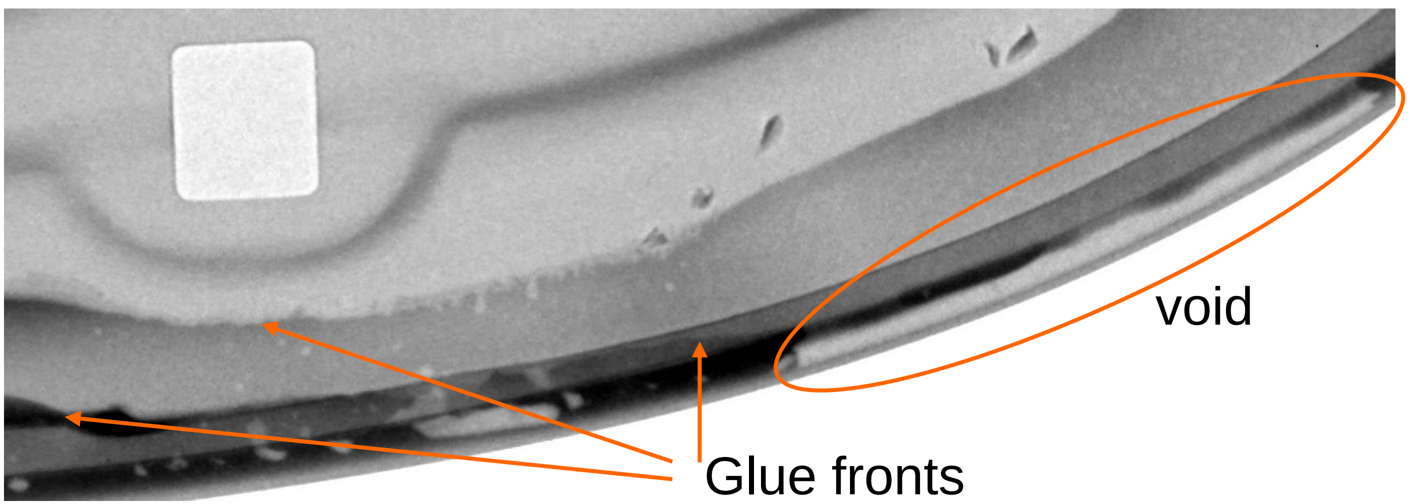
I. Wehmeyer (Ford), B. Schillinger, R. Gilles (FRM II)

Neutron radiography



I. Wehmeyer (Ford), B. Schillinger, R. Gilles (FRM II)

Validation of neutron radiography

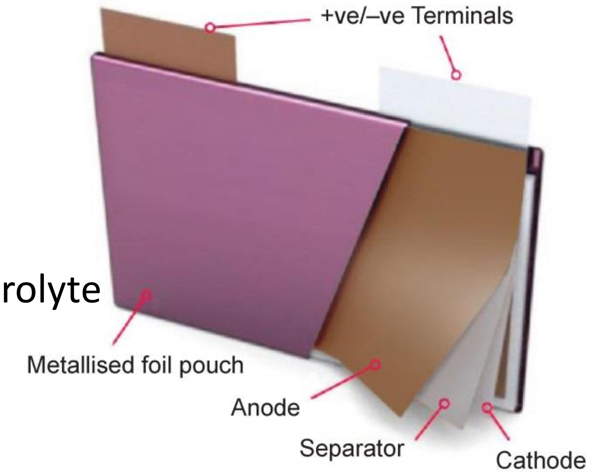


I. Wehmeyer (Ford), B. Schillinger, R. Gilles (FRM II)

In-situ filling of Li-ion Pouch Batteries

Pouch Batteries

- High potential for electro mobility and stationary energy storage
- Electrolyte filling is a key process in cell production
- So far only limited knowledge about the process
- Phenomenological: pressure cycles to optimize wetting with electrolyte



Why Neutron Imaging?

- Cell housing optically intransparent
- Other approaches not successful
- Neutrons offer high contrast due to H-content in electrolyte

Goals

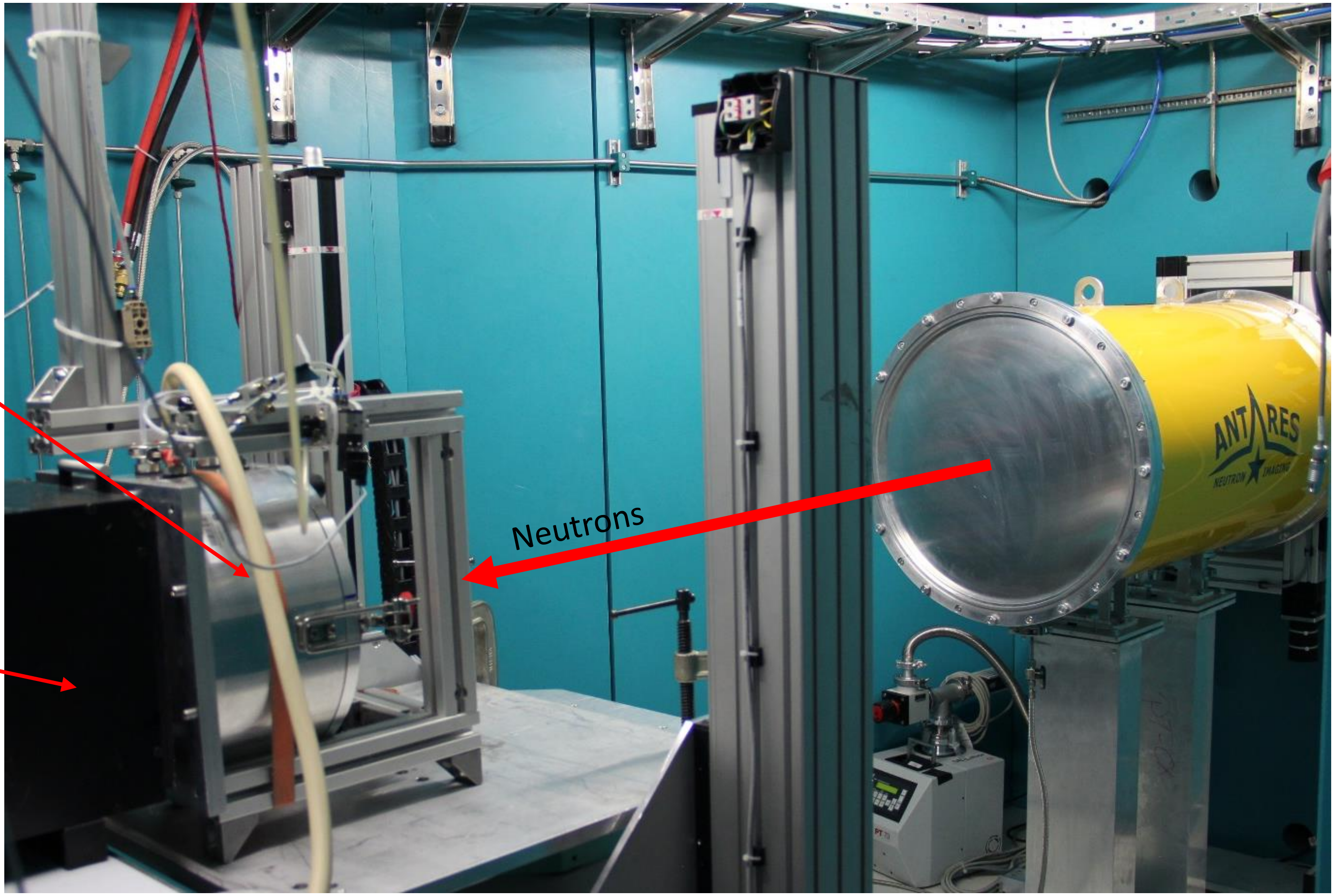
- Establish a new technique
- In-situ visualization of the wetting process
- Study and optimize influence of process parameters

Technique

Setup

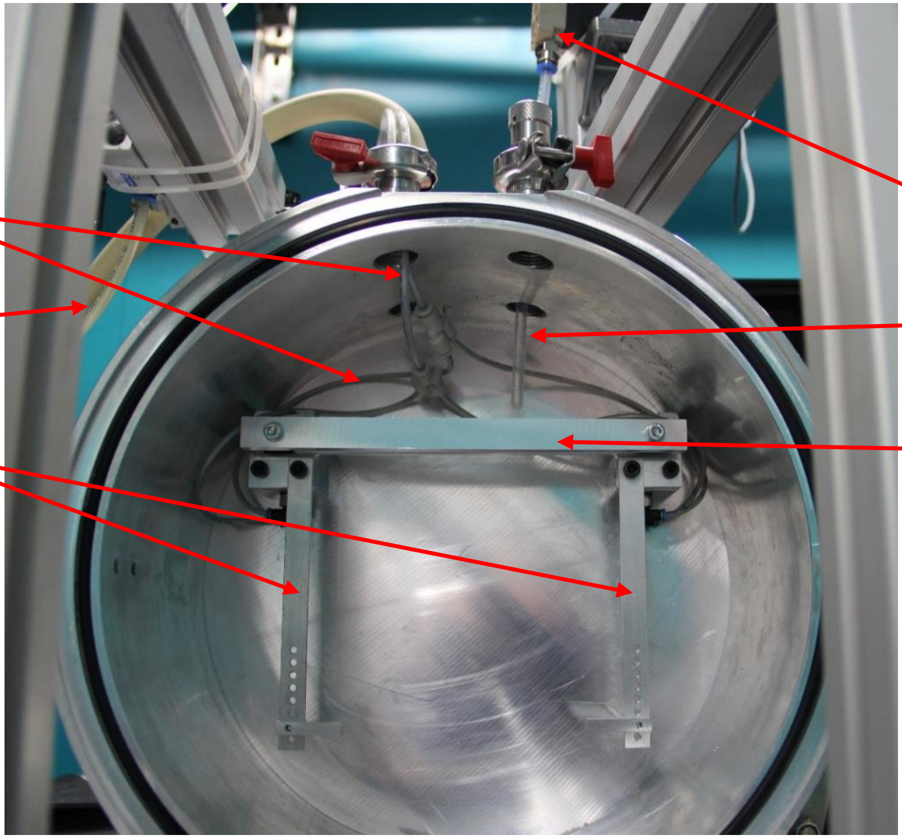
Vacuum chamber: modified pressure test stand

Detector



Technique

Setup details



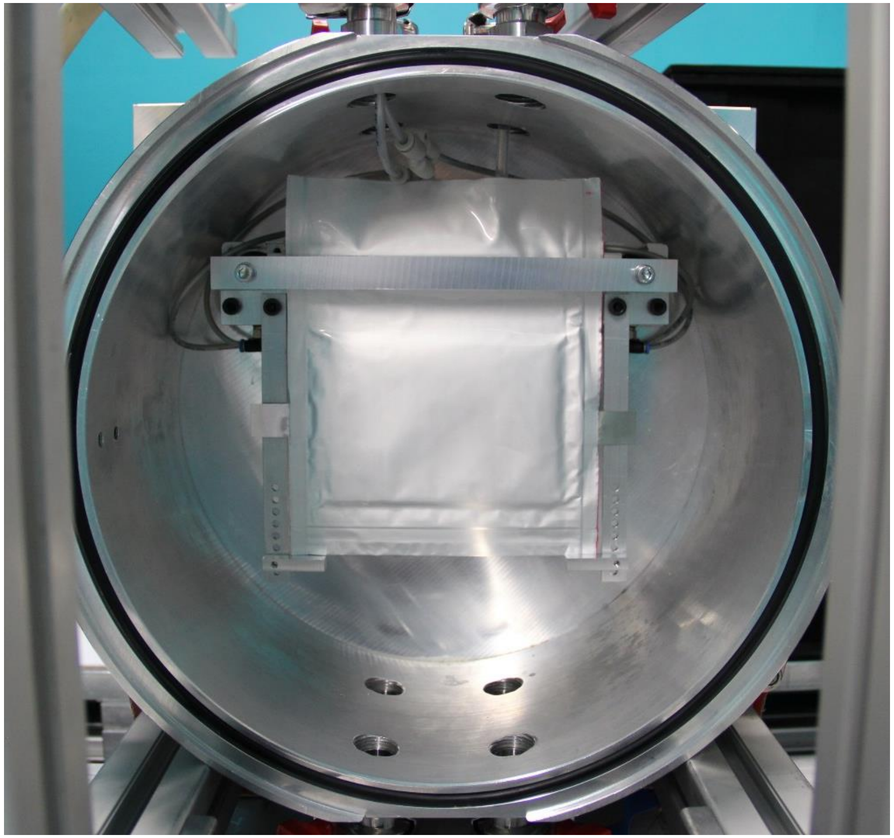
Technique

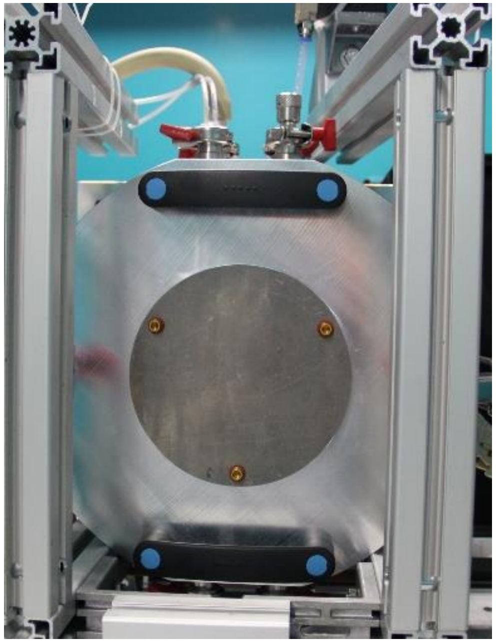
Setup with cell

Materials

Cell
- 5 Anodes,
- 4 Cathodes,
- z-folded
- ExZellTUM-format

Elektrolyte
- EC:EMC 3:7
- No $LiPF_6$,
- No VC

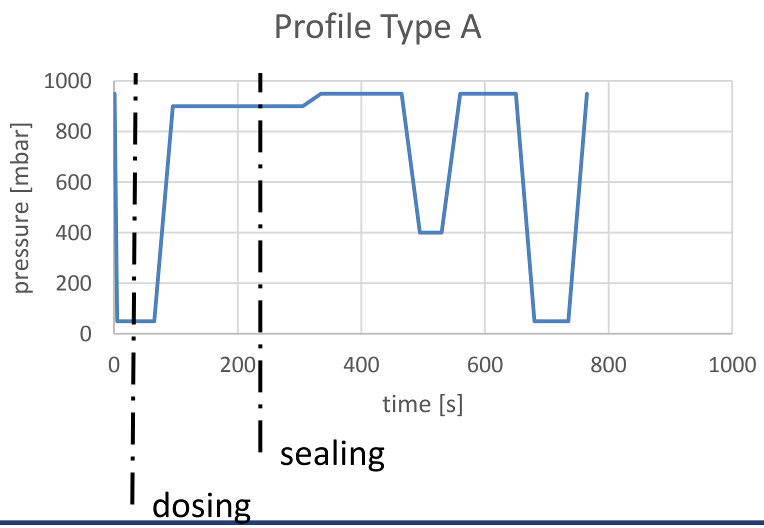


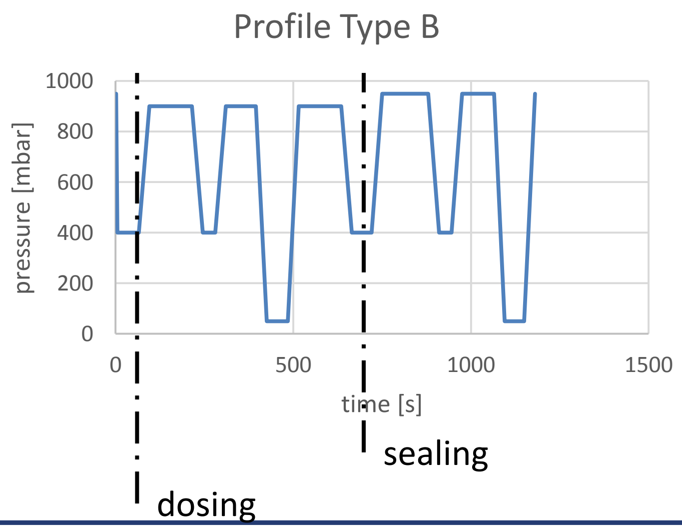


Technique

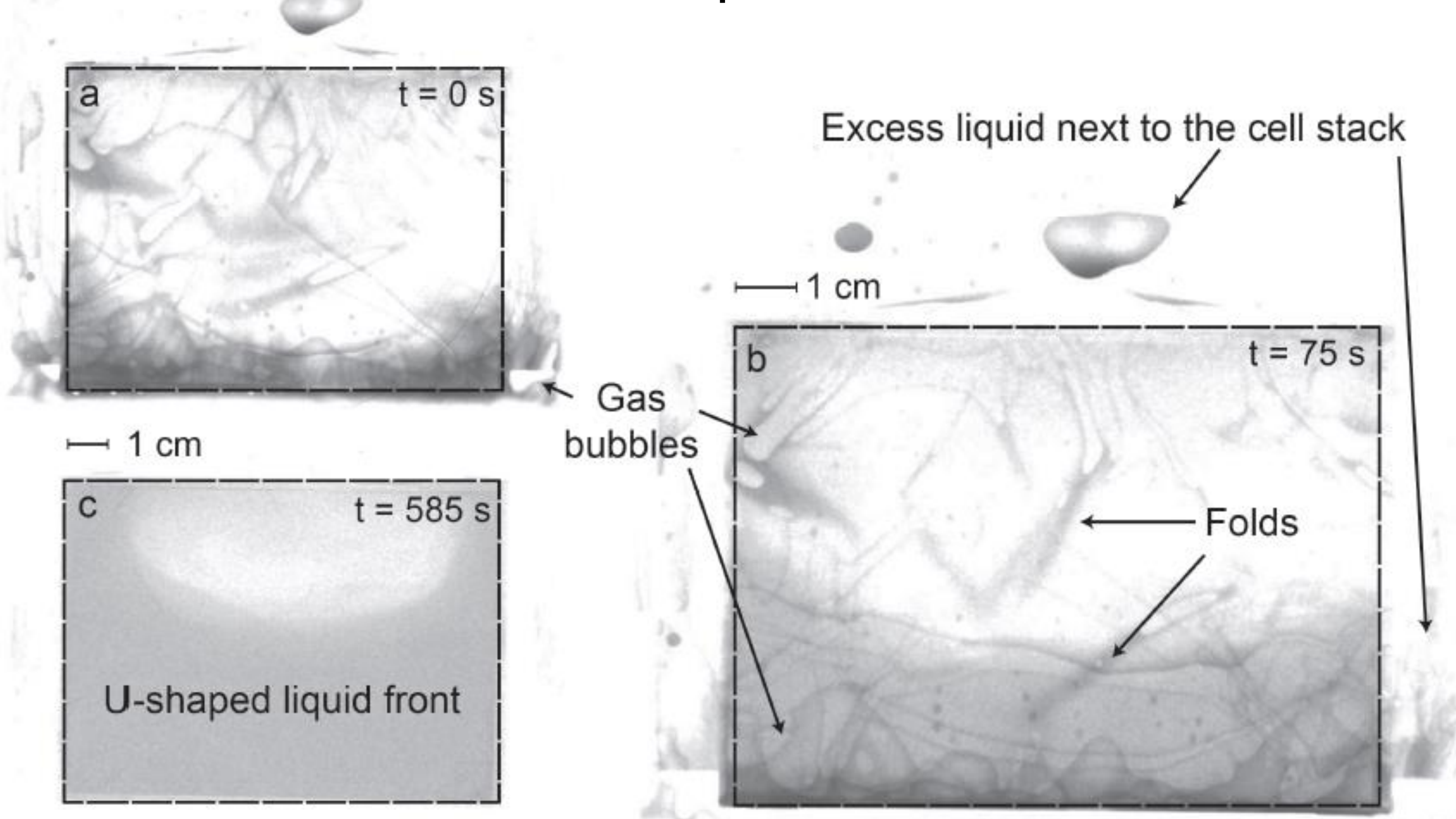
Experiments

- 25 pre-defined pressure profiles
  - Two fundamental types: w/ and w/o wetting cycles before sealing
  - Reference experiments w/o pressure variation
  - Variation of pressure levels
  - No variation of of timing for pressure levels, filling and sealing within one profile
- Image acquisition every 15s
- Control of injection and sealing by the instrument control software



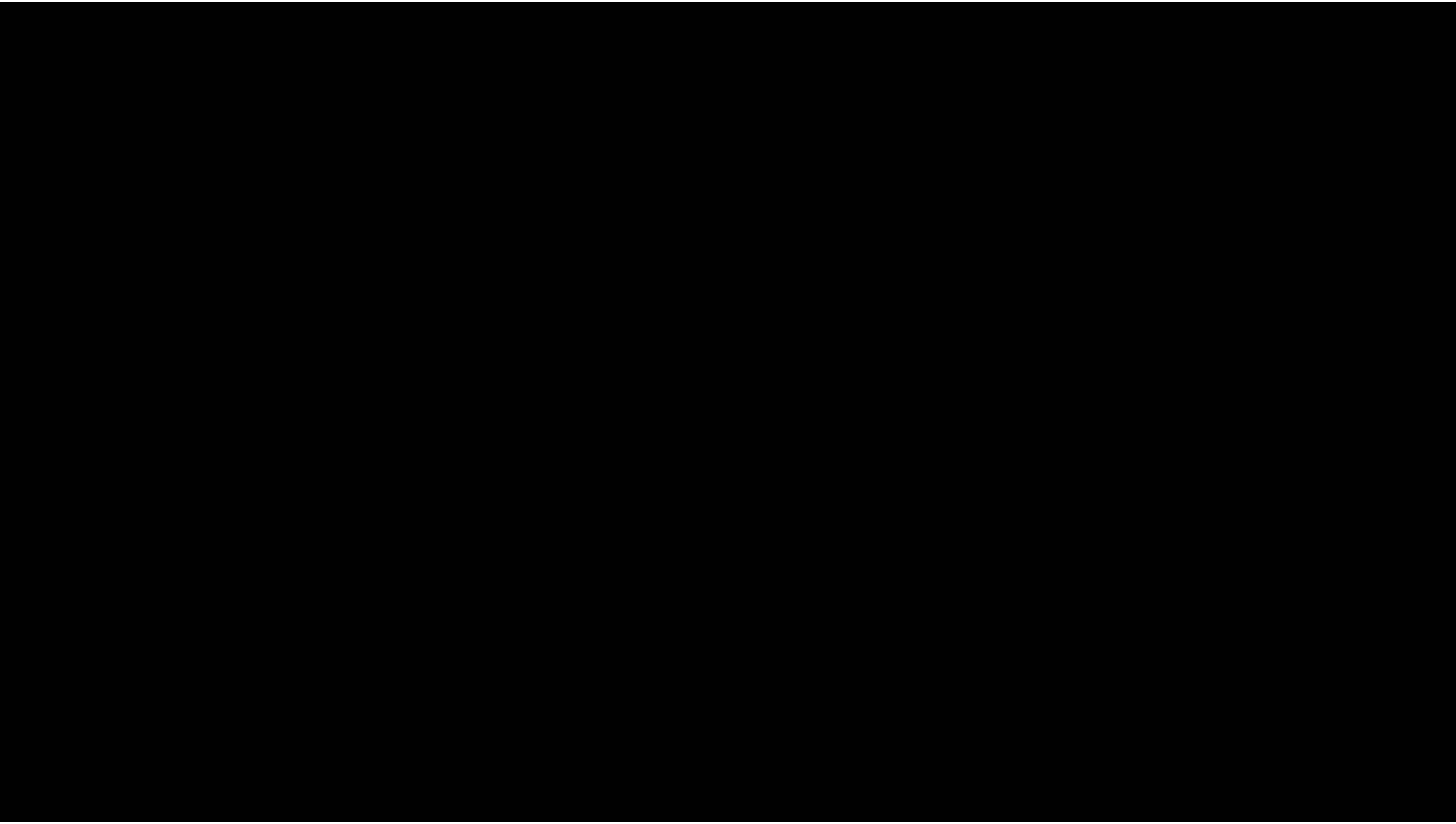


Example Data

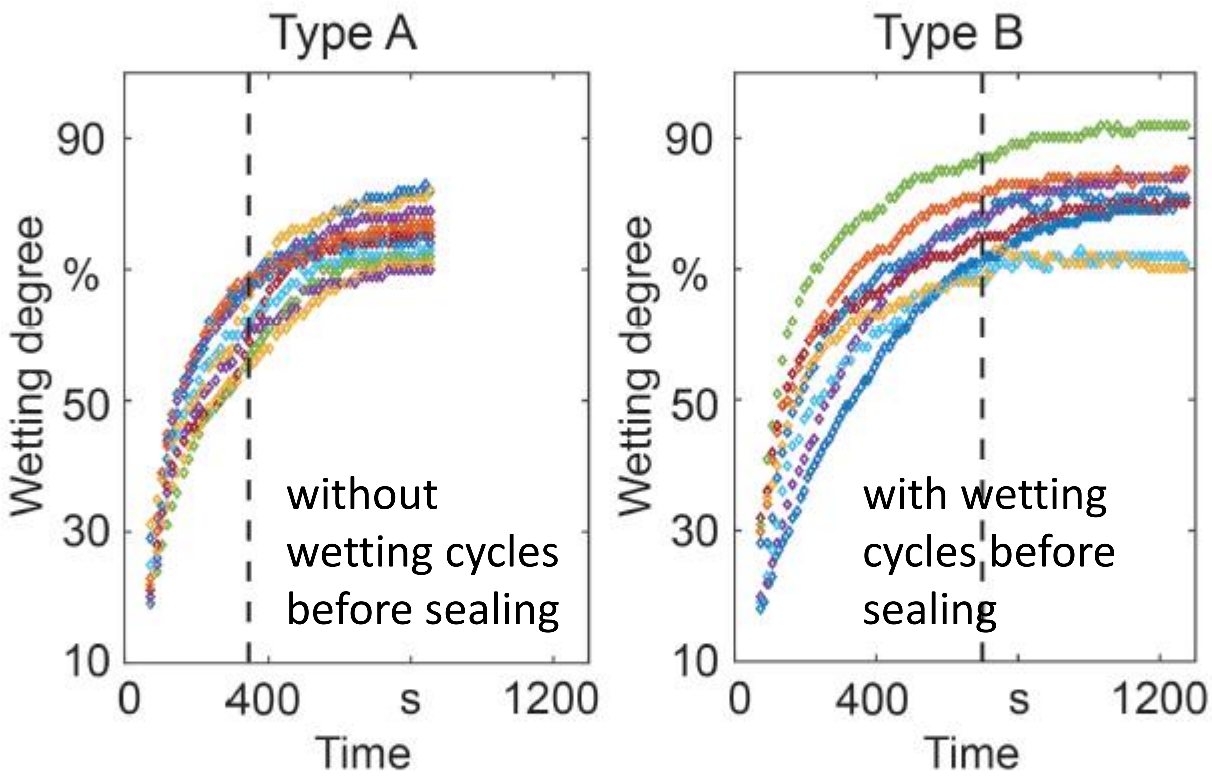


Homogenous distribution of liquid

Heterogenous distribution of liquid

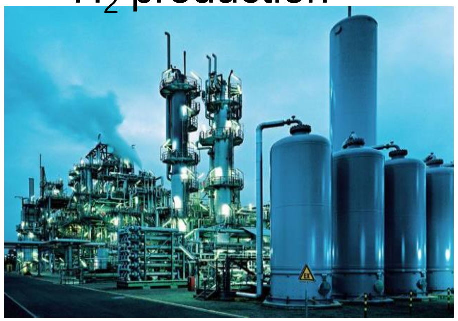


Quantitative Evaluation



- Higher wetting degree (t=850s) when applying wetting cycles
- No significant influence of wetting cycles after sealing
- Initial wetting degree depends on dosing pressure

Hydrogen storage

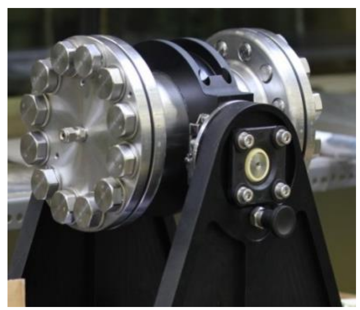
H_2 production	H_2 storage	Conversion to power
		
high selectivity + efficiency	low weight + volume	low cost + high efficiency

www.linde-le.com

www.toyota.de

Lab scale
[mg…g]

ANTARES



Scale-up

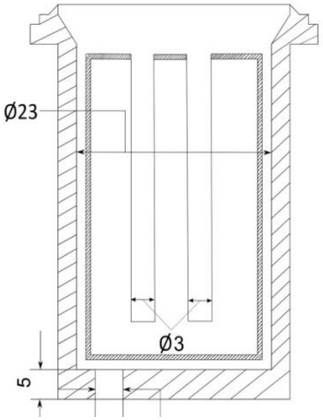
Storage tank [kg]

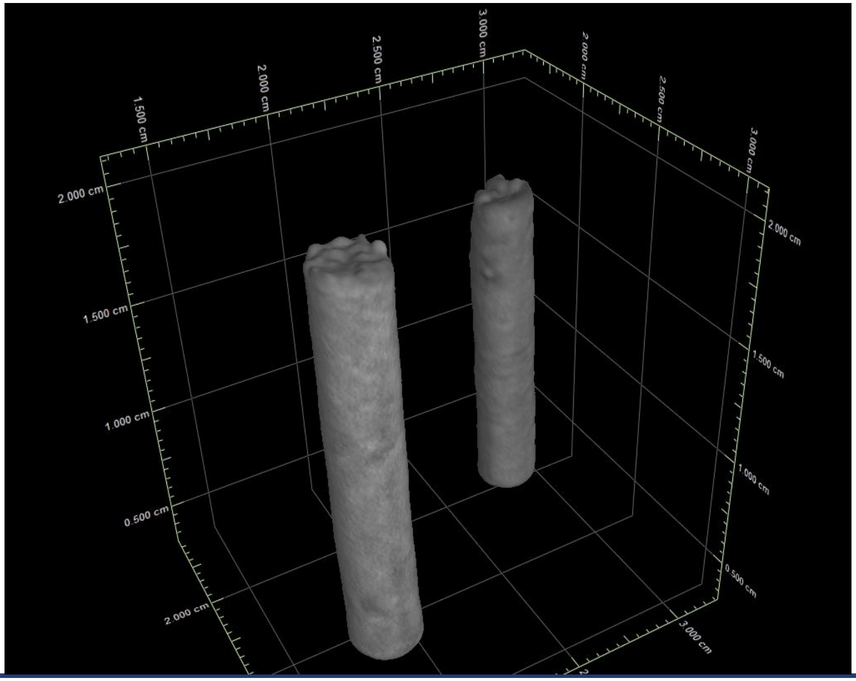
NECTAR

H_2 storage @ ANTARES: high resolution

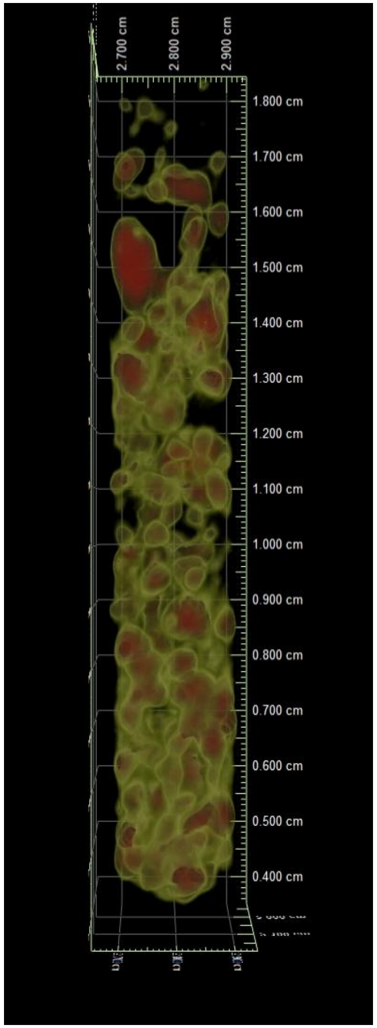
Neutron Imaging study of promising class of Reactive Hydride Composite Materials

- powder samples in 3 mm boreholes of aluminum sample inlet (2 x ~75 mg)
- pressure (100 bar) & temperature (400° C) resistant cell made of 1.4401 steel
- Liquid phase of $LiBH_4$ (melting point 275° C) at operating conditions
- in situ monitoring of temperature, H_2 flow and pressure



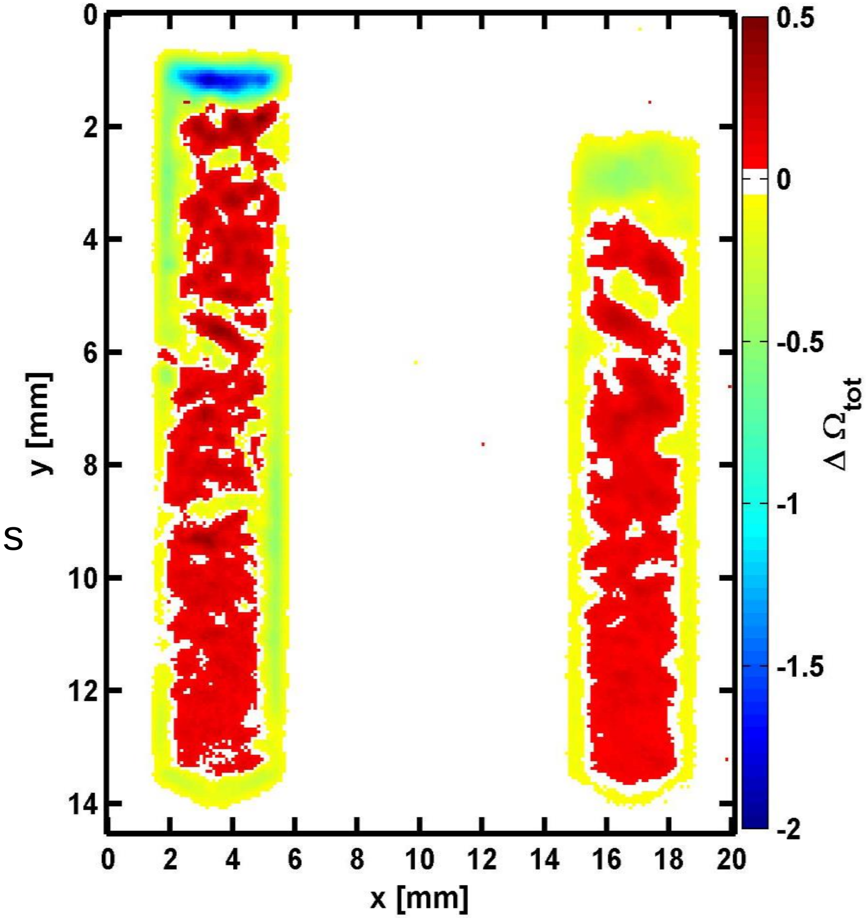


H_2 storage @ ANTARES: high resolution



Tomography analysis of heated (355 ° C) and pressurized (15 bar) sample after induction of phase transition (melting of $LiBH_4$):

- densification / sintering
- counteracts homogeneous material distribution and therewith absorption process

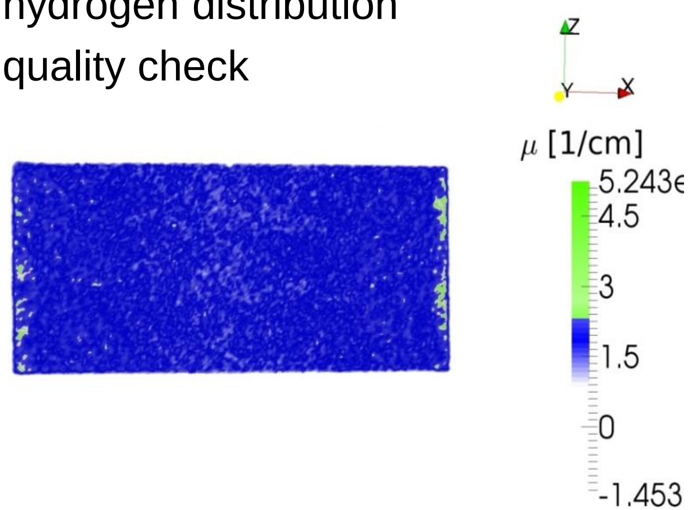


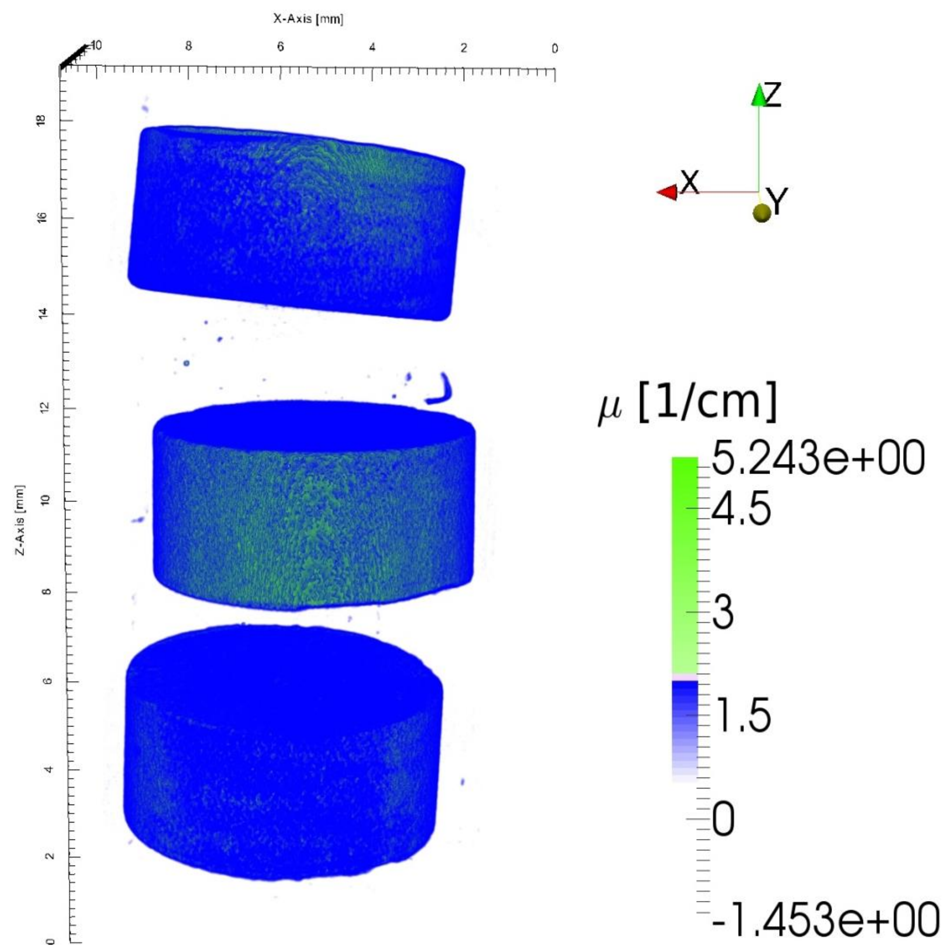
In situ Neutron Radiography study of sintering process: Difference data set, fast sintering (Δt < 200 s) – heavily influencing material structure

H_2 storage @ ANTARES: high resolution

Neutron Tomography of MgH_2 pellets:

- effects of cycling on material structure
- effects of material processing conditions
- hydrogen distribution
- quality check

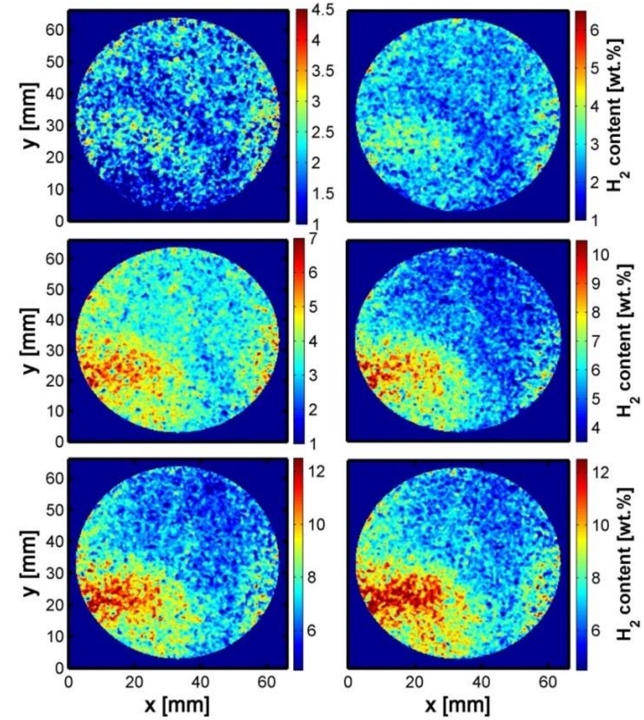


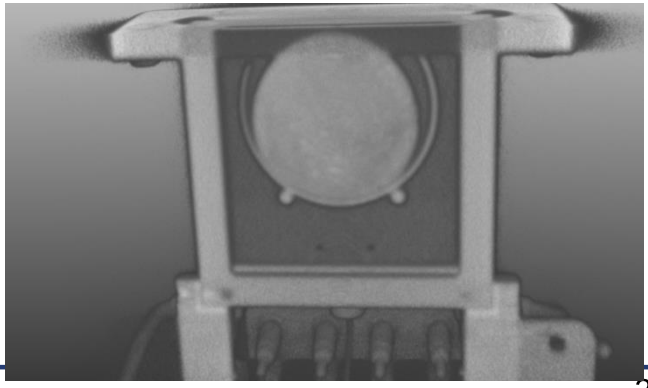


- Optimized processing parameters: homogeneous hydrogen distribution

H_2 storage @ NECTAR: large sample scales

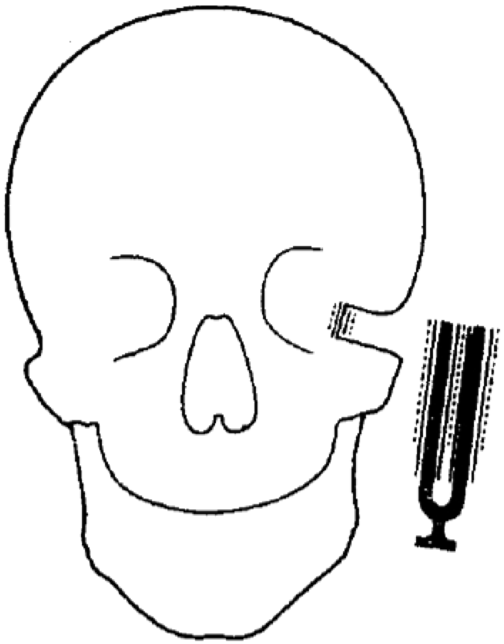
- Investigation of scaled-up & pilot plant hydrogen storage tanks
- In situ Neutron Radiography & ex situ Neutron Tomography studies
- t_{exp} ≥ 120 s @ pixel size 293 µm
- sample thickness up to 200 mm (100 mm steel)
- Investigation of macroscopic material structures, driving forces





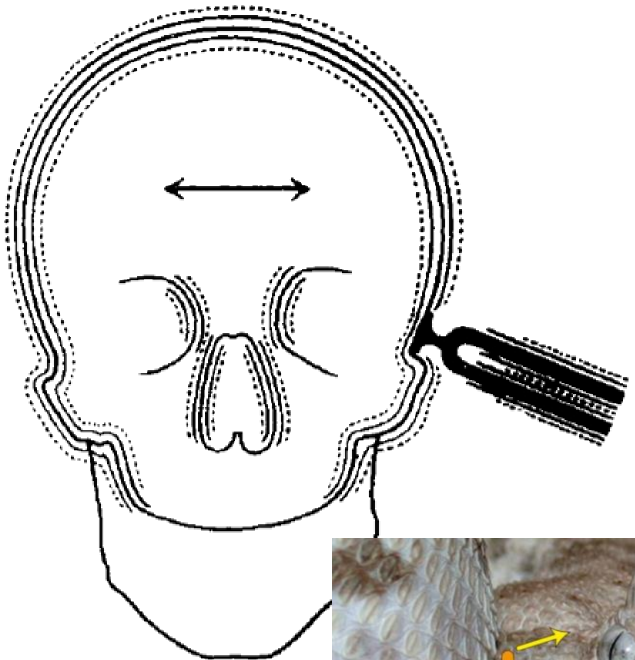
Tympanic Hearing and bone-conduction hearing

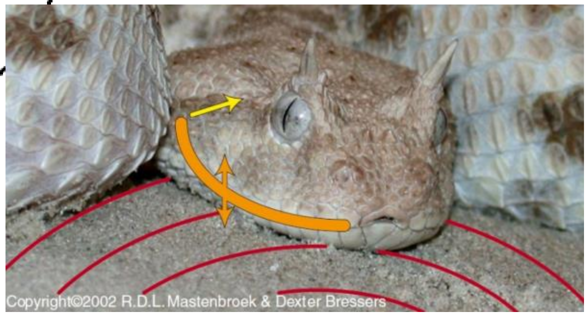
Hearing with tympanic membrane and middle ear bones



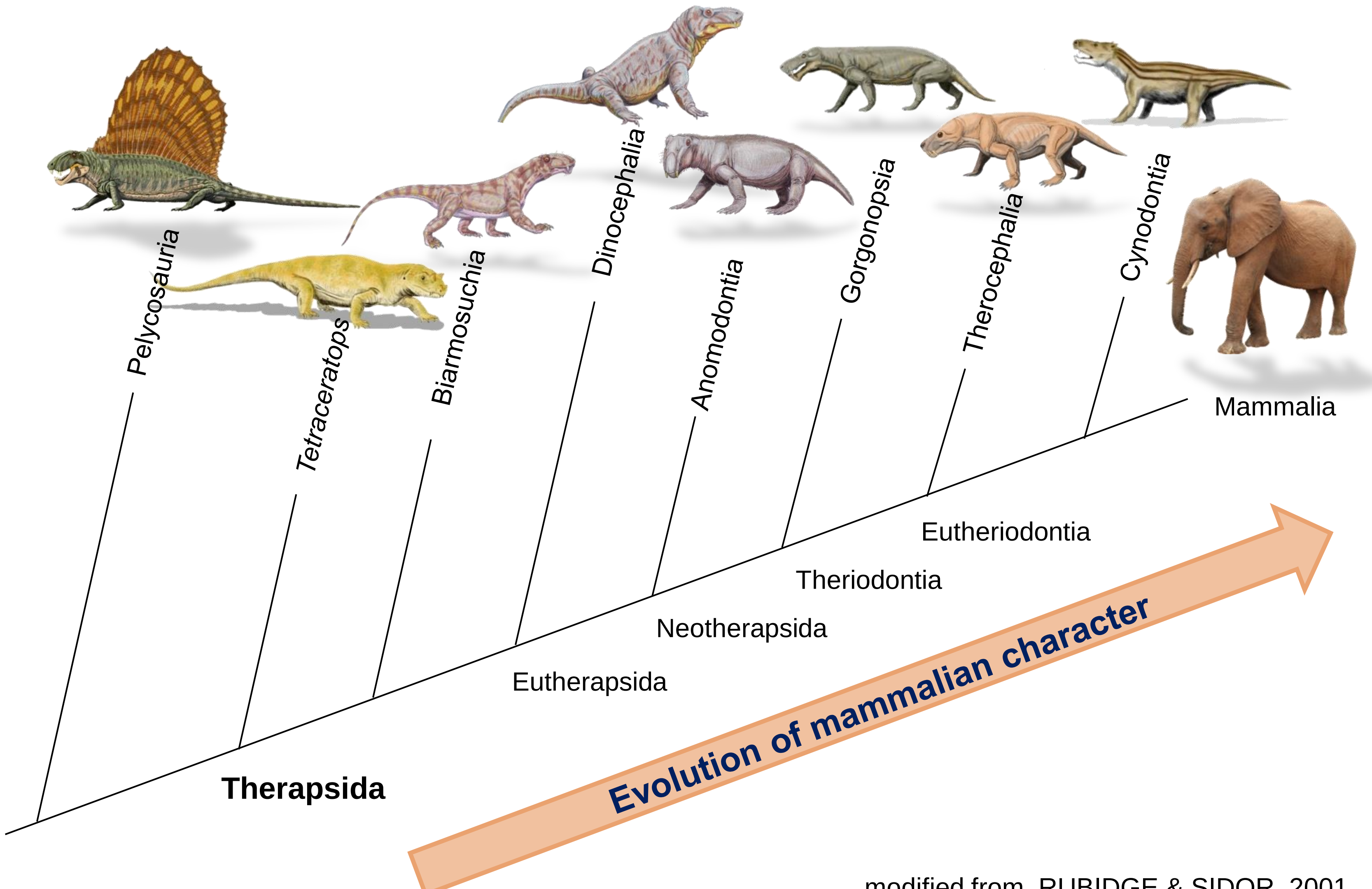
from Tumarkin 1968

Hearing by bone conduction



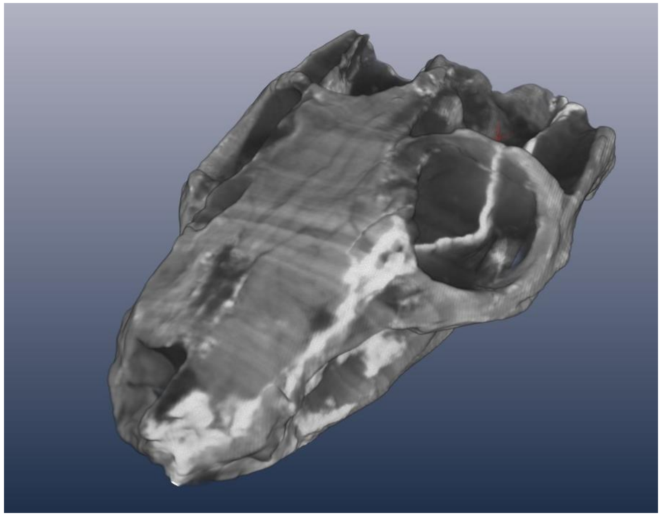


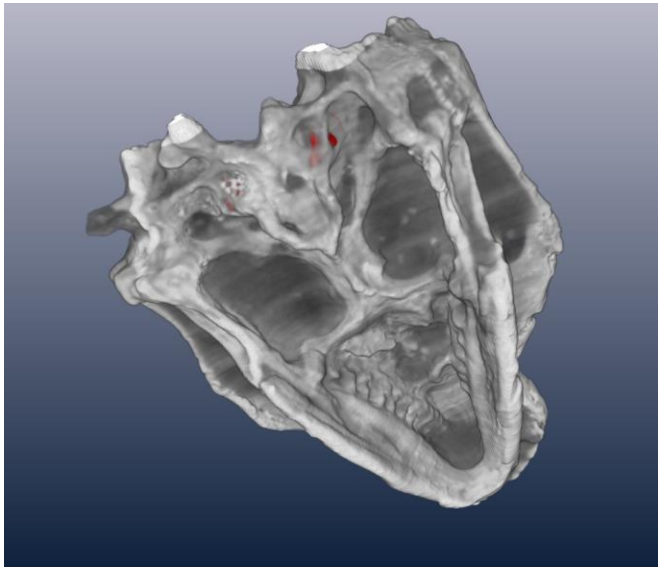
Synapsid evolution



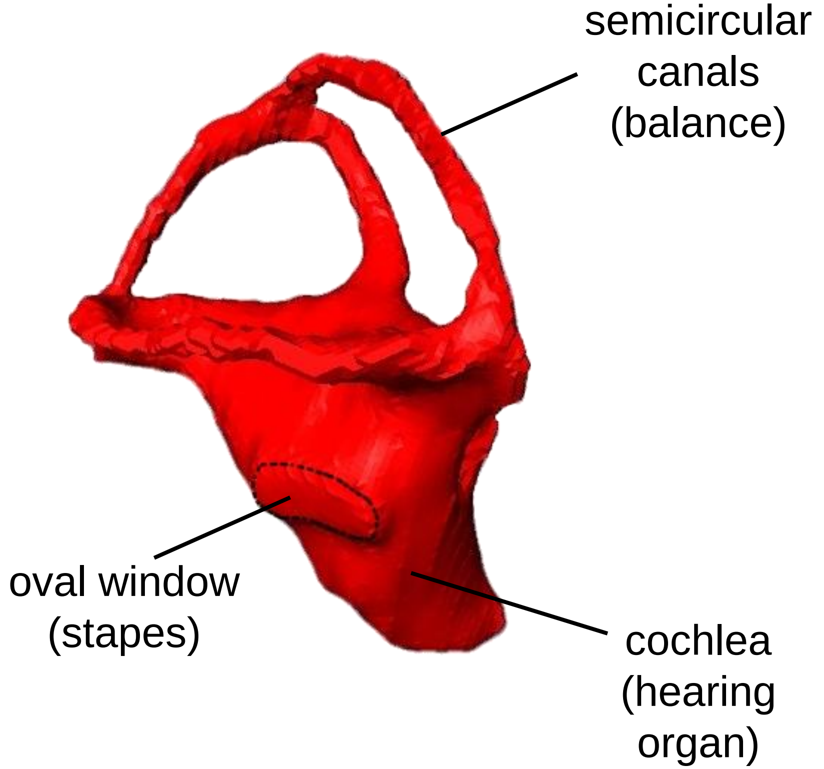
modified from RUBIDGE & SIDOR, 2001

The origin of tympanic hearing





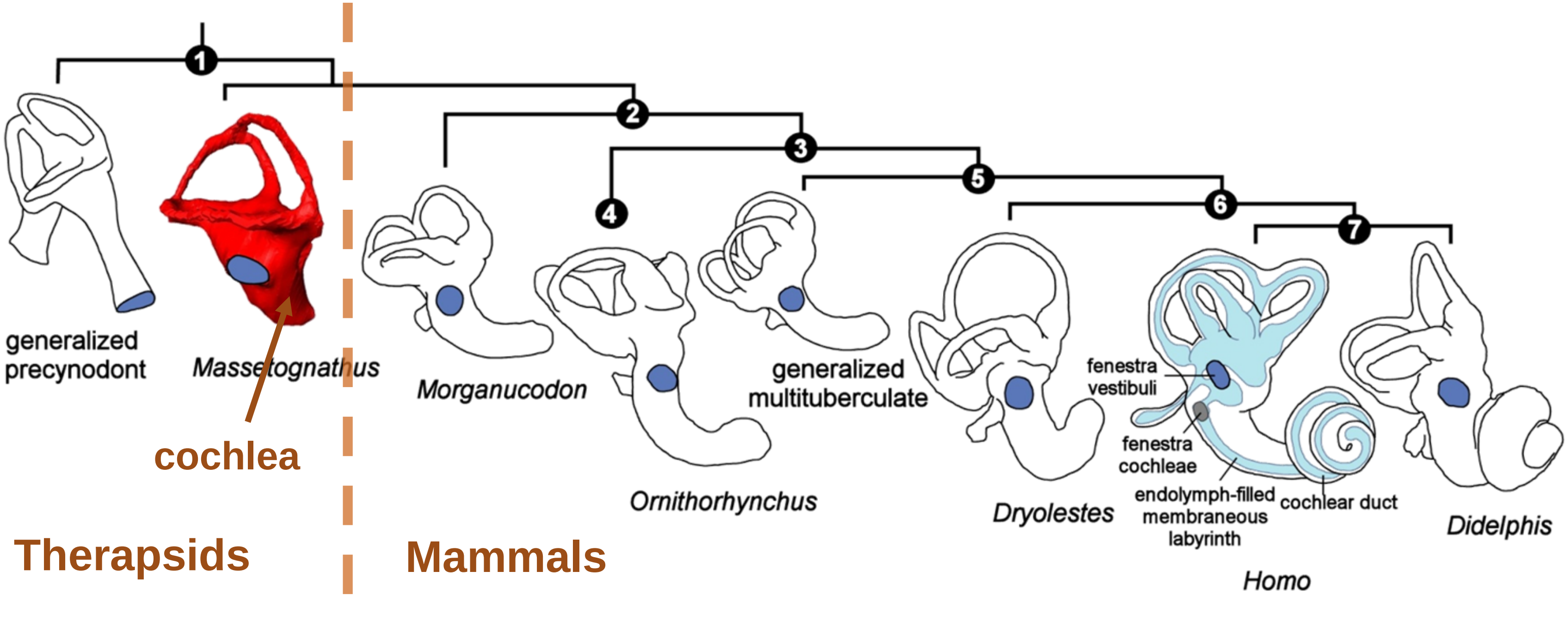
Massetognathus (Cynodontia), approx. 230 million years old



inner ear of *Massetognathus*

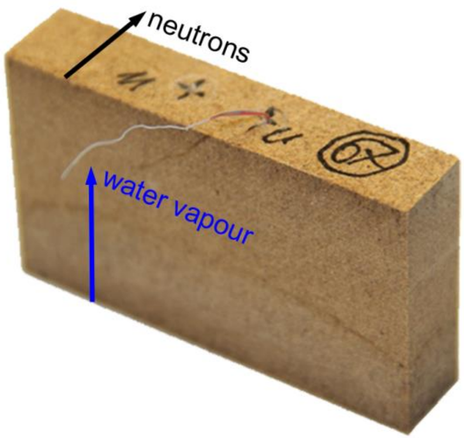
The origin of tympanic hearing

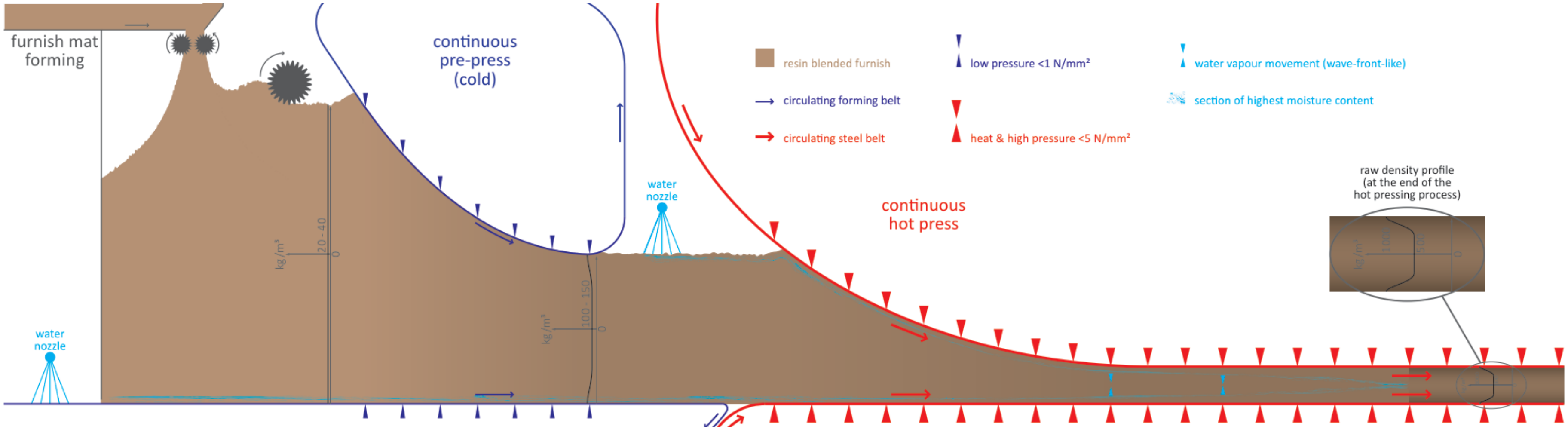
- short, tube-like cochlea in the cynodont therapsid *Massetognathus*
- 3,9 mm long
- enhanced sensitivity to high-frequency air-borne sound
- small stapedial footplate area (1,69 mm^2)

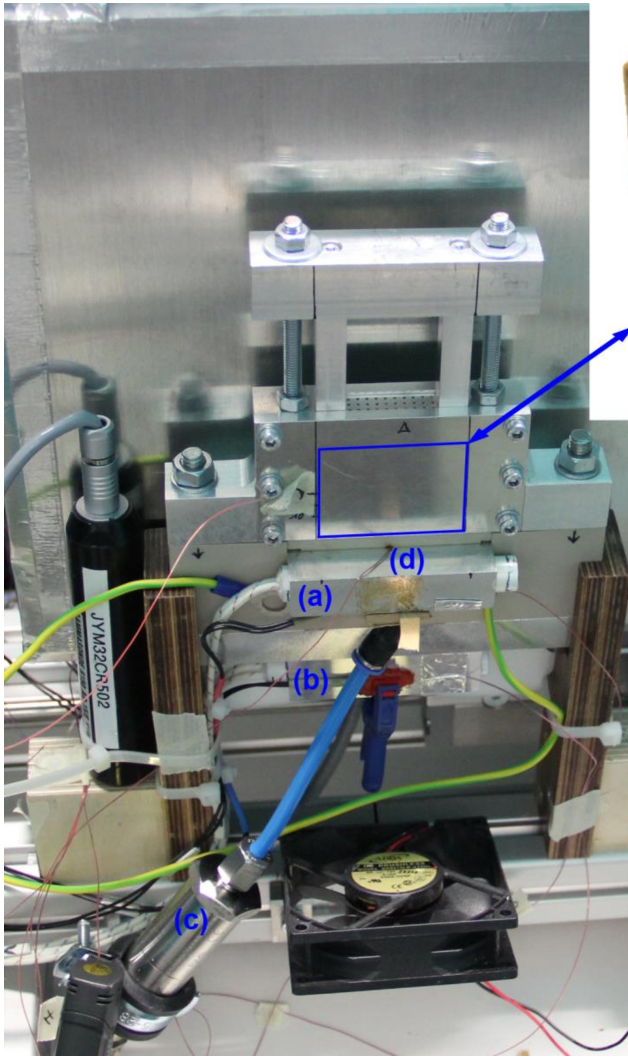


Vapour transport in Wood Based Composites

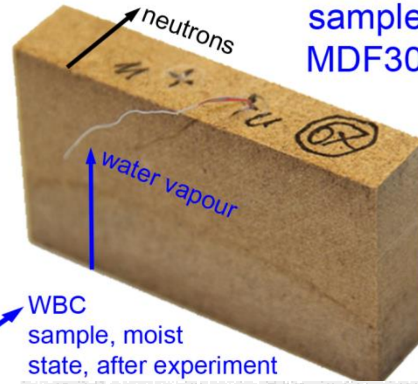
- Mixture of fibres & resin
- Fabrication of panels by cold & hot pressing
- How does vapour move during hot pressing?
- Theories predict wavefront-like movement

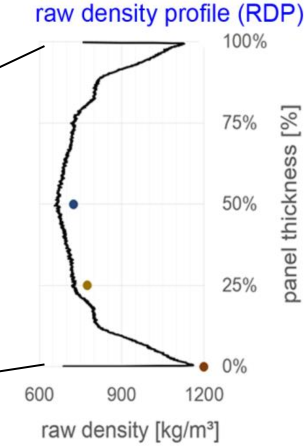


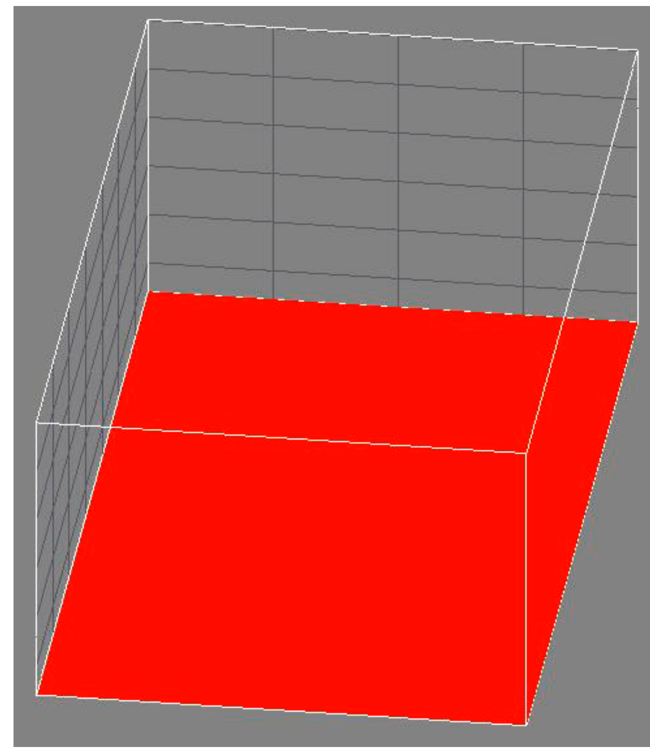




WBC
sample, moist
state, after experiment







Conclusion

- Neutron imaging has applications in many fields of science and technology
- Complementarity to X-rays justifies the effort
- Particularly the high sensitivity for hydrogen and the good penetration of many metals define the fields of applications
- There are many industrial projects which we can not show...

Thank You!