Metallic foams characterisation with X-ray microtomography using Medipix2

Lab for design and assembly of measurement devices – LIAS

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Motivations

• Large demand from foams community (solid and liquid) on characterization tools : geometry for CFD or finite elements simulations, hydraulic parameters (pore size distribution, …),

• Liquid foams

  • Drinks: champagne, beer, …

  • Food: chocolate mousse,

• Solid foams

  • Food: bread,

  • Industry: metallic and polymer foams.

• Our focus is on **metallic foams**

  • High performance (mechanical) materials,

  • Gas distributors (diffusion layer),

  • Heat exchangers (high exchange surface/volume).

• Necessity to develop skills to characterize foams in 3D (and even 4D):

X-ray microtomography

X-ray microtomography : 3 main components (of the lab)

Experimental

• Microfocus X-ray generator,
• Participation collaboration Medipix2&3,
• Flat Panel detector for larger field of view,
• Participation to a coming working group on estimation of microfocus generator spot size.

Tomographic reconstructions

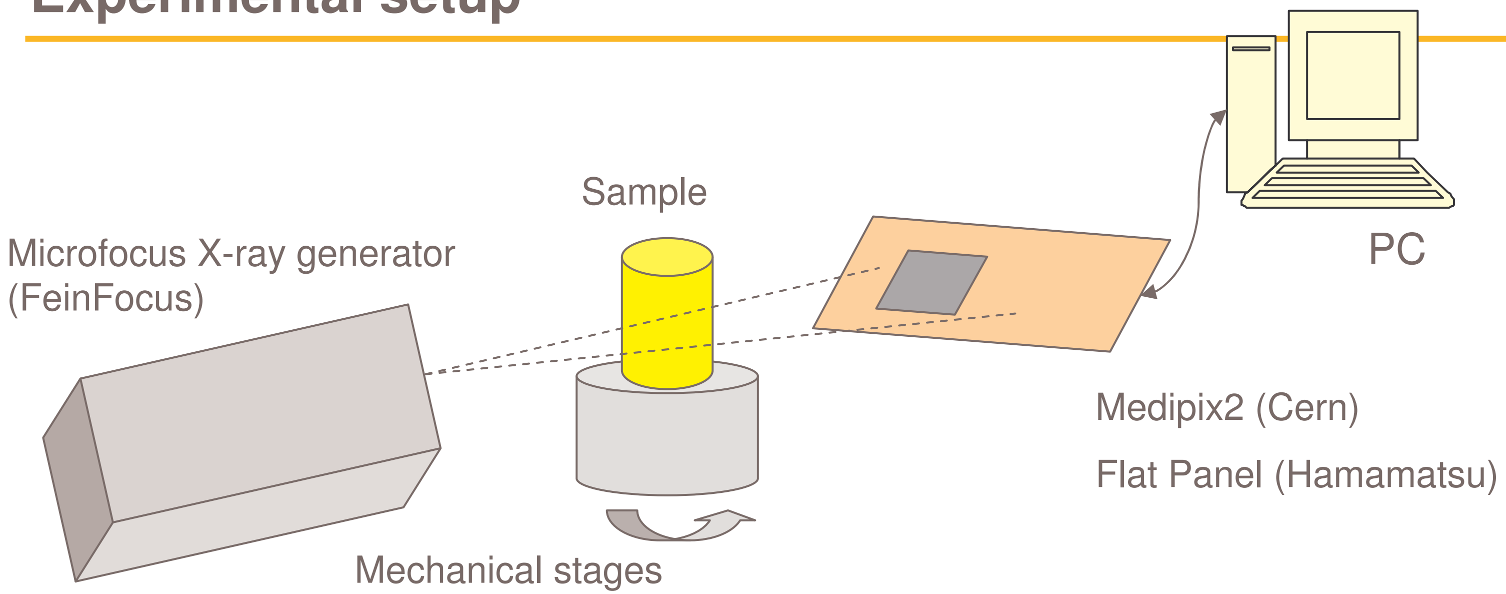
• PhD in progress,
• Limited angle, local tomography, multi-resolution.

3D image processing

• Post-doc in progress,
• Graph theory, Delaunay, Voronoï,
• Alpha-shape, …

Working conditions : drill 150 µm, pixels in the object 2 µm, generator 80 kV, 1W

Experimental setup

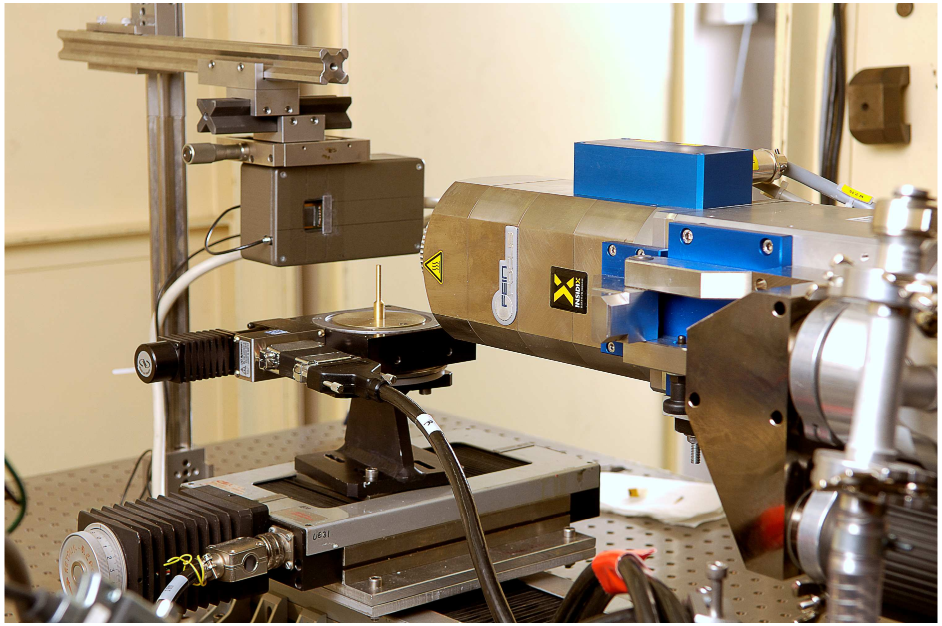


2400 x 2400 pixels

300 µm CsI

12 bits

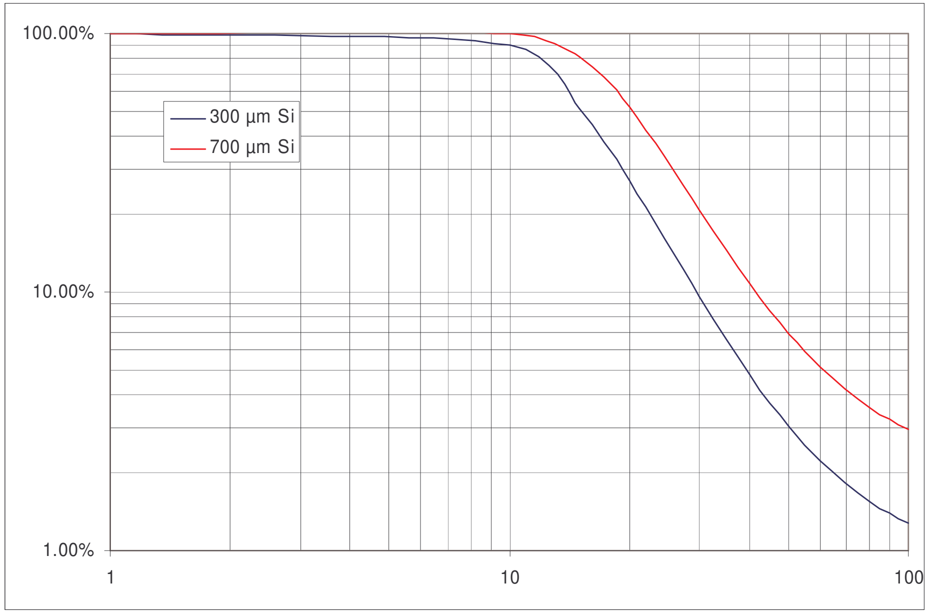
$FTM_{50\%}$ 150µm



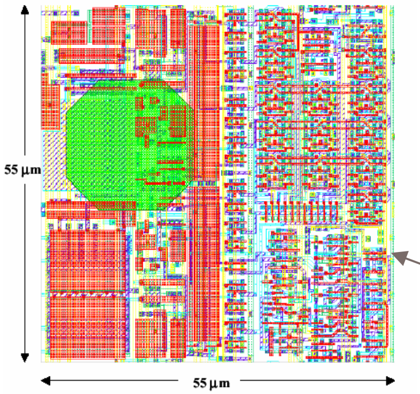
Experimental setup – detector

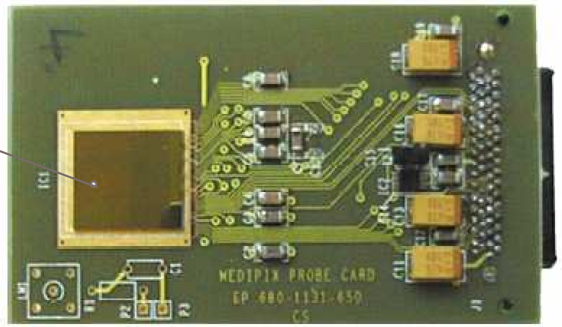
Medipix2 detector:

- Si substrate of 300 and 700 µm thick
- pixelized, 256 x 256 pixels
- pixel size: 55 µm
- low noise



= 500 transistors in (55 µm)²…





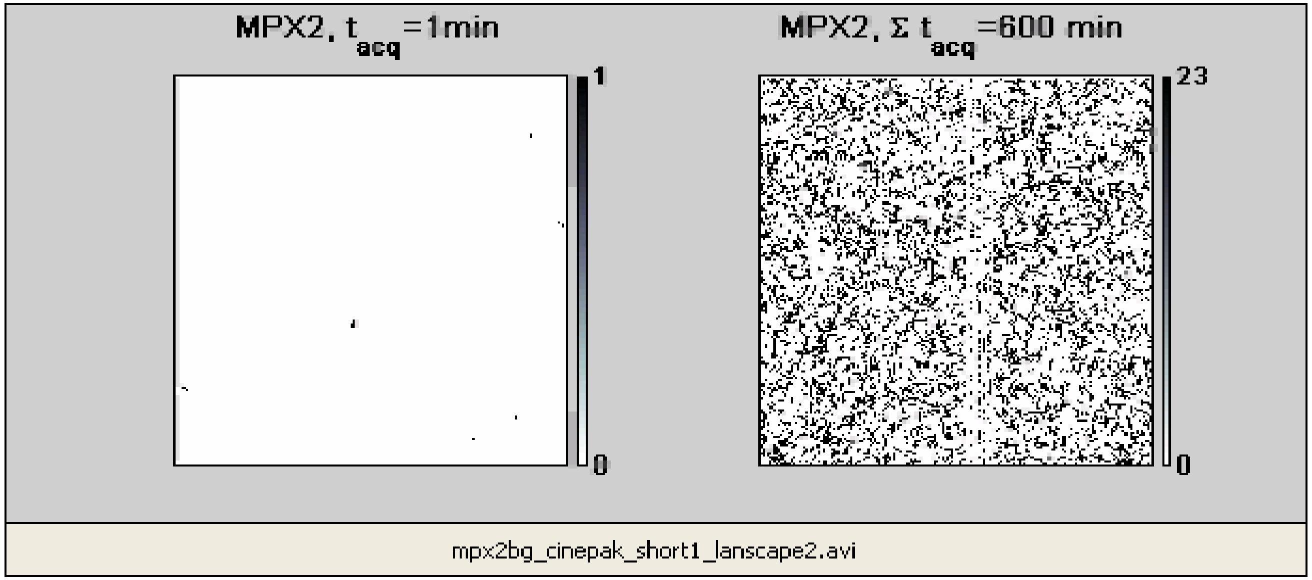
Medipix2 : Performances : characterization

Characterization with
300 µm Si detector
(CERN team)

minimum threshold ~ 830 e⁻ (3 keV for Si)
threshold dispersion σ ~ 90 e⁻
electronic noise σ ~ 190 e⁻
read-out ~100ms serial, ~1ms parallel
dissipation 8 µW/pixel

= Conform to specifications

no noise…except 1 count from time to time… coming from the sky !!!



Metallic foams of PEMFC

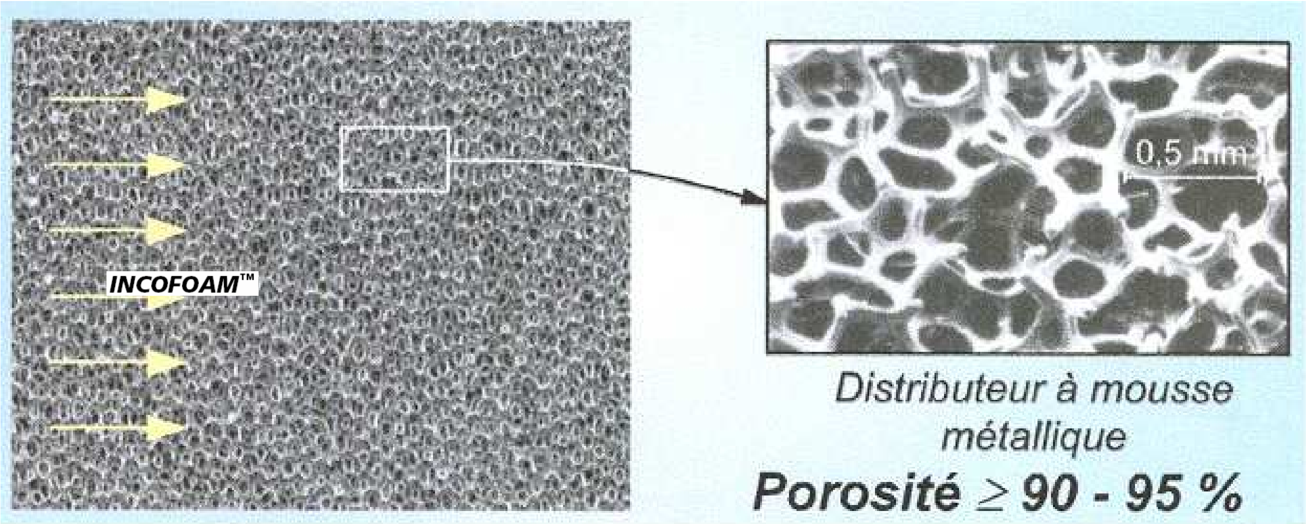
X-ray generator:

- voltage 30 kV
- power 20 W

First experiments , 2004

Objects : Ni foams (gas distributor of fuel cells, PEMFC)

Measurement of water drying properties



Nickel foam

Porosity > 90 – 95 %
(even 99%, hollow structure)

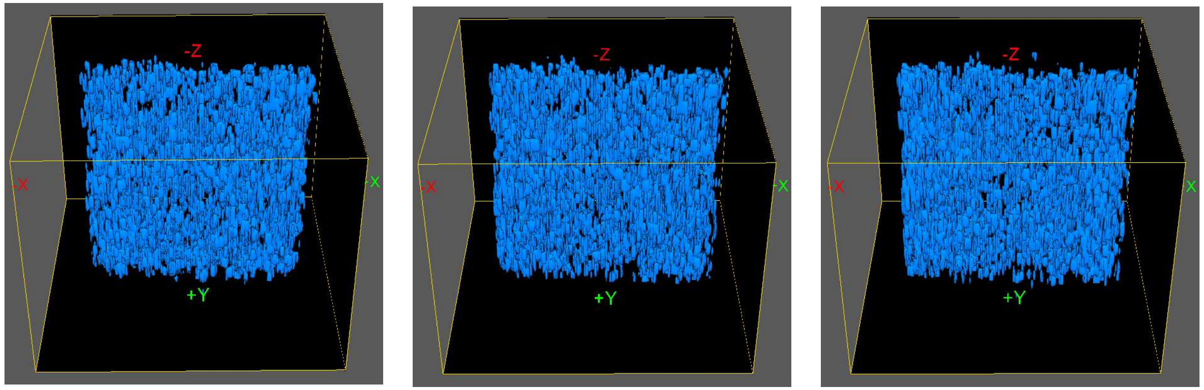
Foam drying versus time

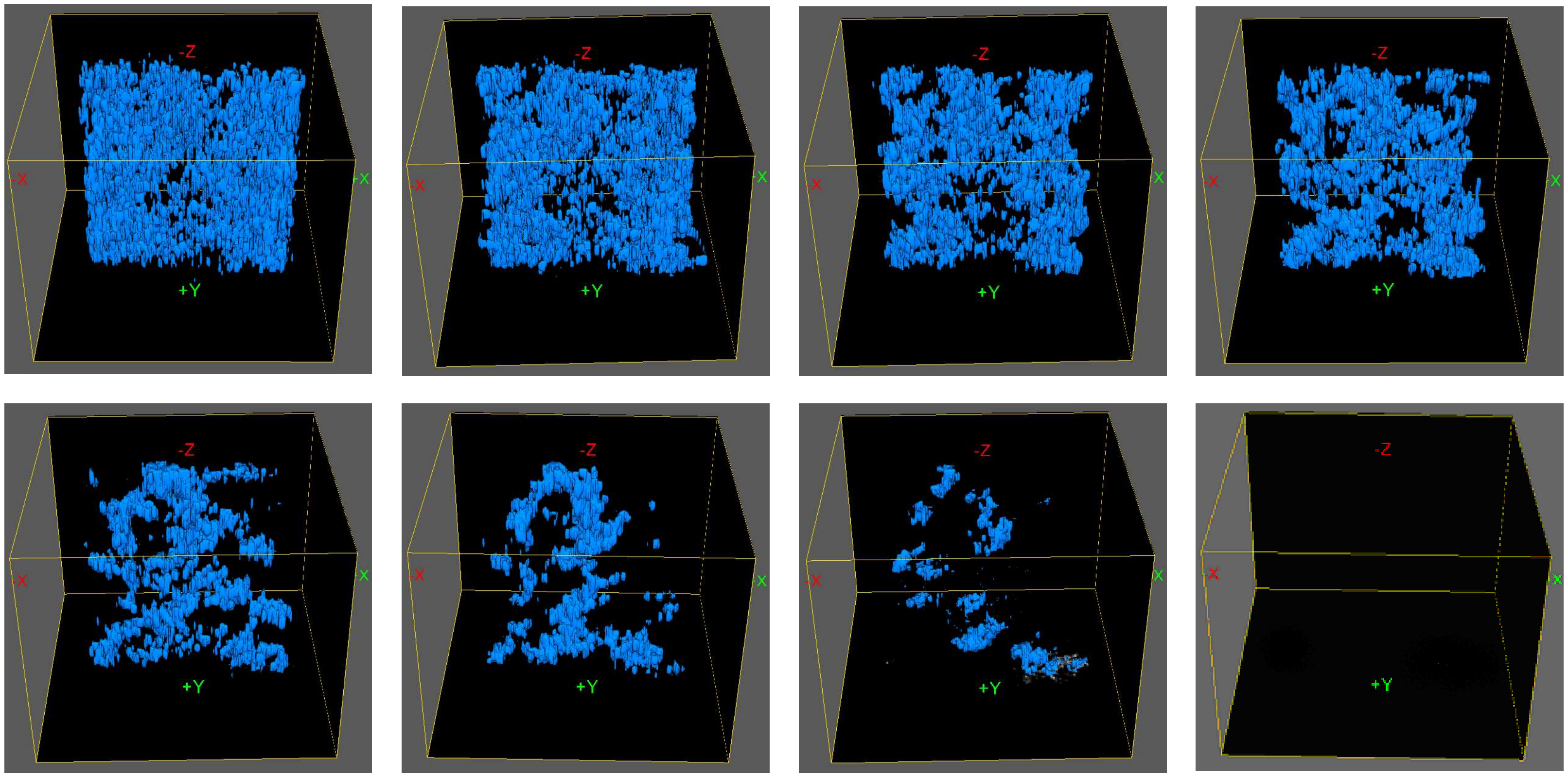
Foam drying

INCO ep. 1.6 mm

100 minutes exp.

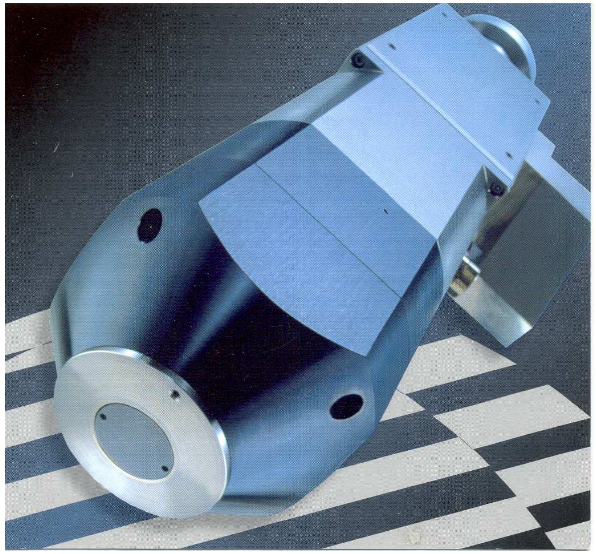
binning 3x3 of the detector pixels

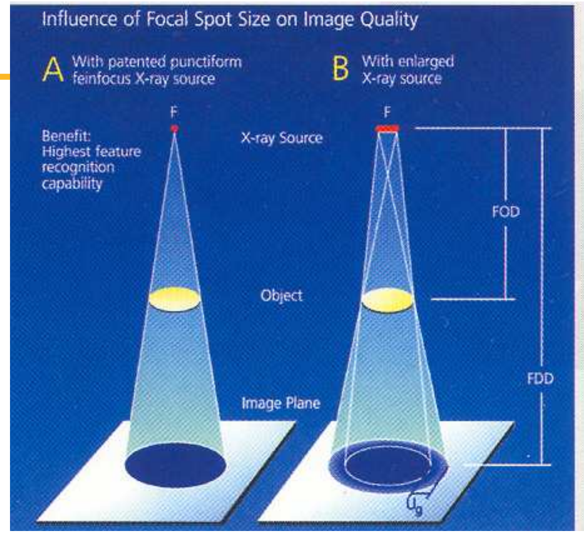


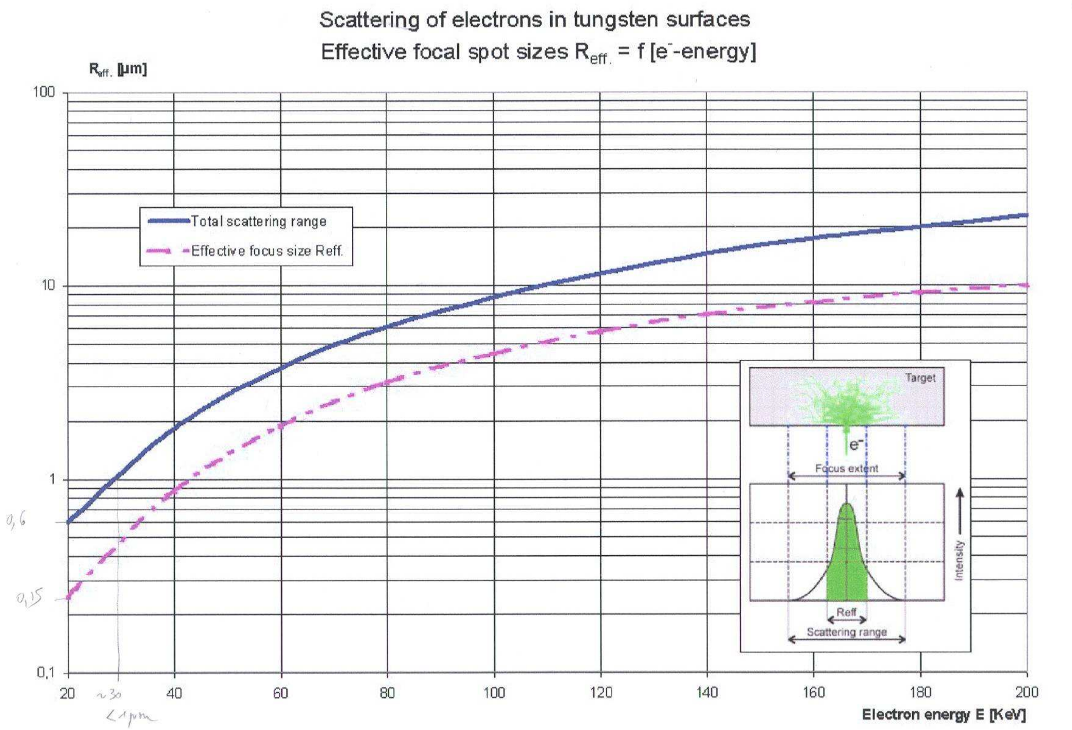


Experimental setup – generator

- Microfocus X-ray generator:
    - focus : < 1 µm (150 nm for 20 kV)
    - 160 kV – 9 W





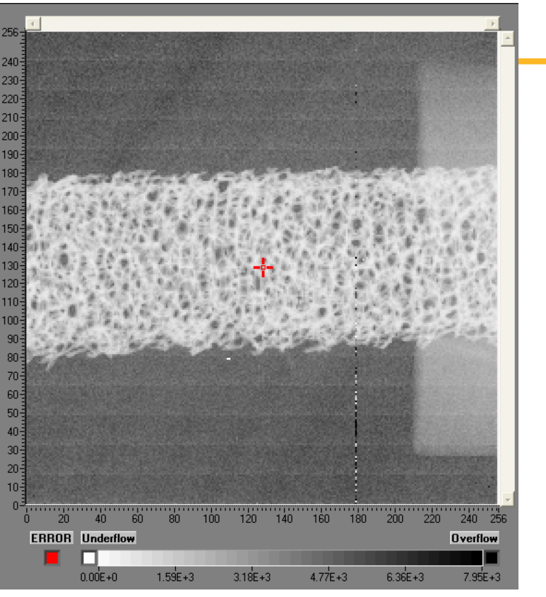


First images of foams

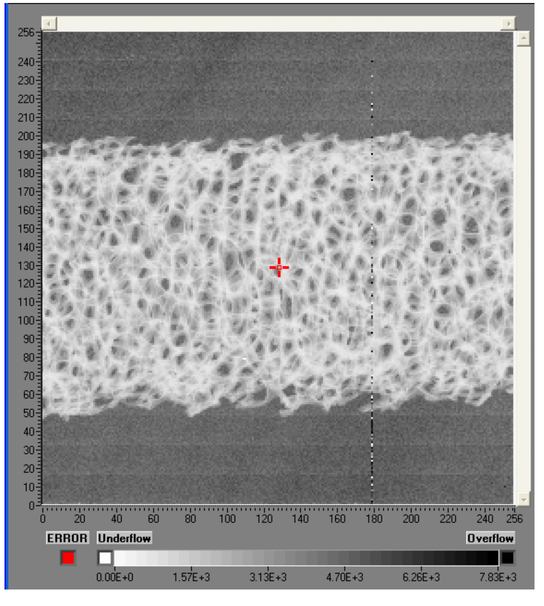
Working conditions:

- voltage: 30 kV
- current: 500 µA
- acq. duration: 5 s

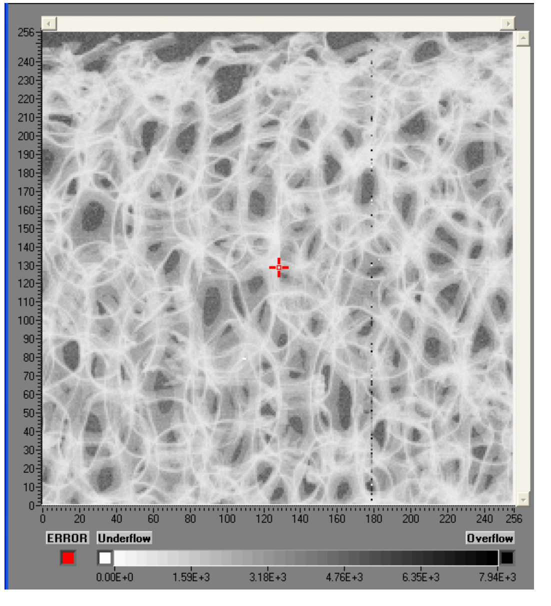
m= 1.6 – pixels 34.4 µm



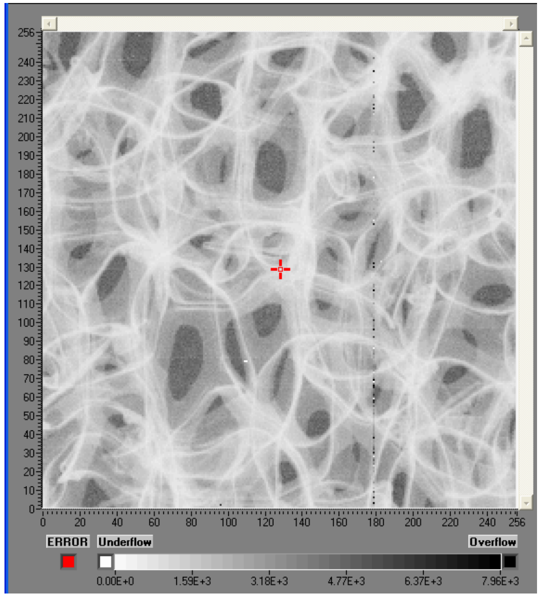
m= 2.6 – pixels 21.2 µm



m= 5.8 – pixels 9.5 µm



m= 11.5 – pixels 4.8 µm



Experimental component

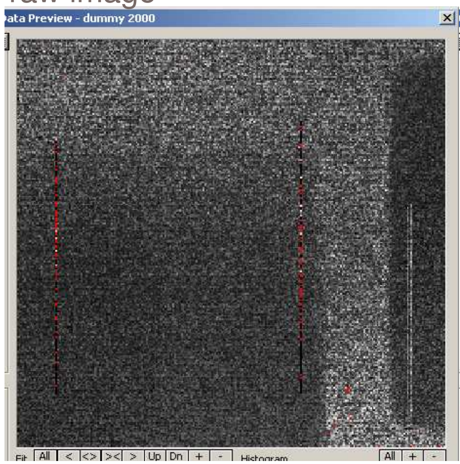
Participation to Medipix2 collaboration

A partner is particularly active, UTEF de Prague:

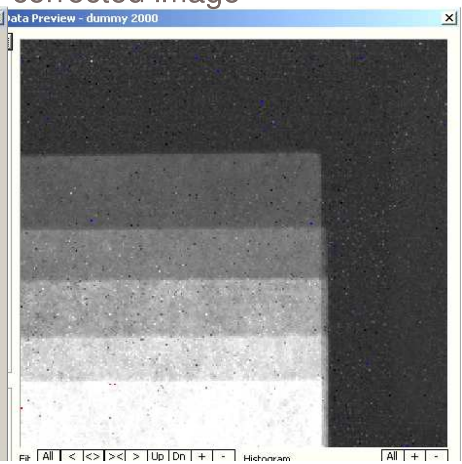
- new acquisition software → Pixelman, open source
- USB portable acquisition electronic (box 50x65x20 mm^3),
- beam-hardening plug-in

Consequence for LIAS : plug-in for tomography, included beam hardening, result on images !!

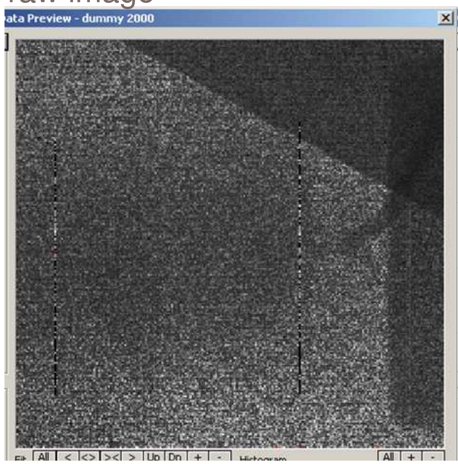
raw image



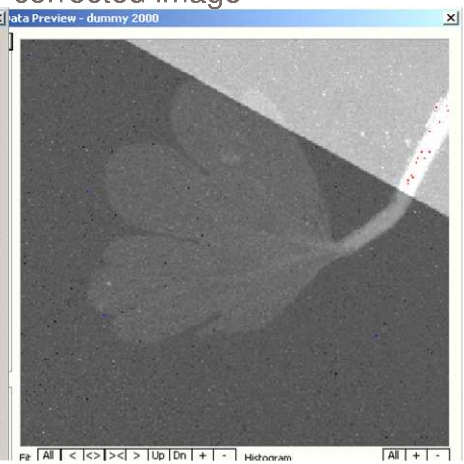
corrected image



raw image

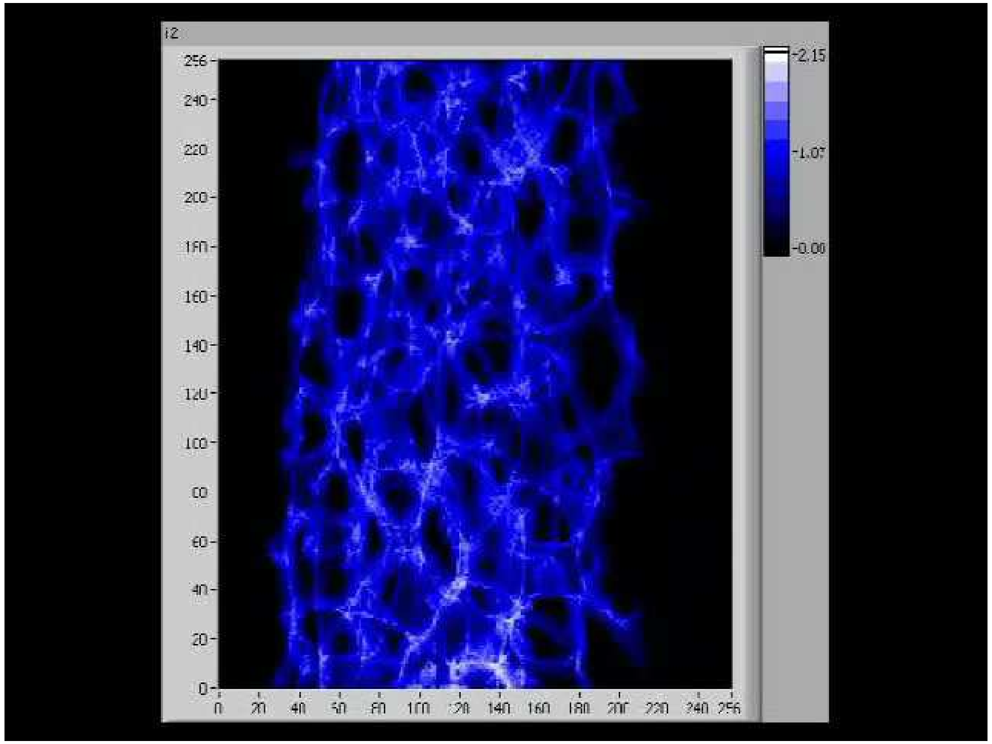


corrected image

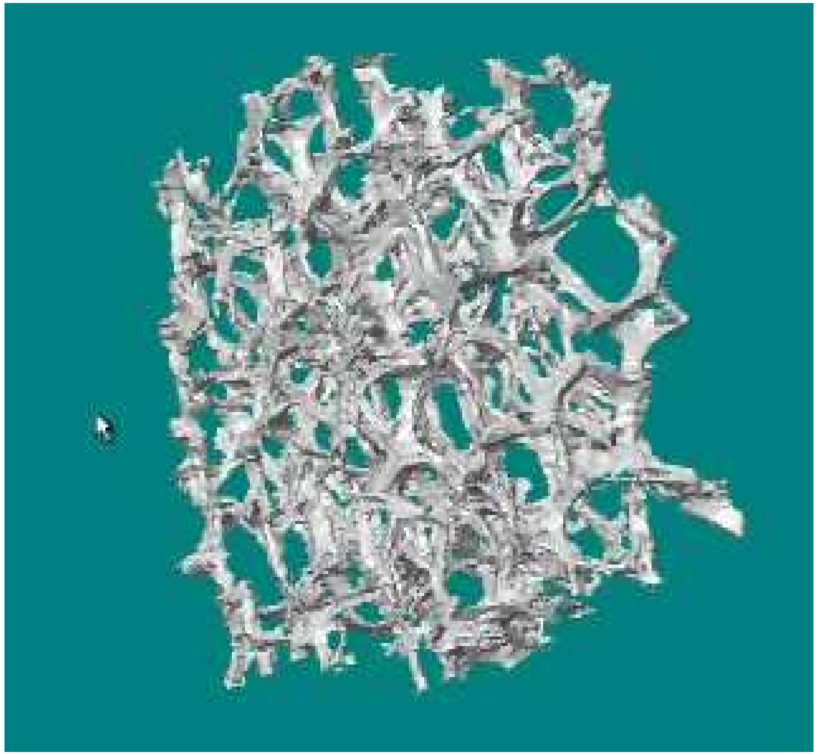


Results on foams

acquisitions



reconstructions



Working conditions:

- **foam 1 mm², pixels in the object 8 µm,**
- **generator 50 kV, 1W**

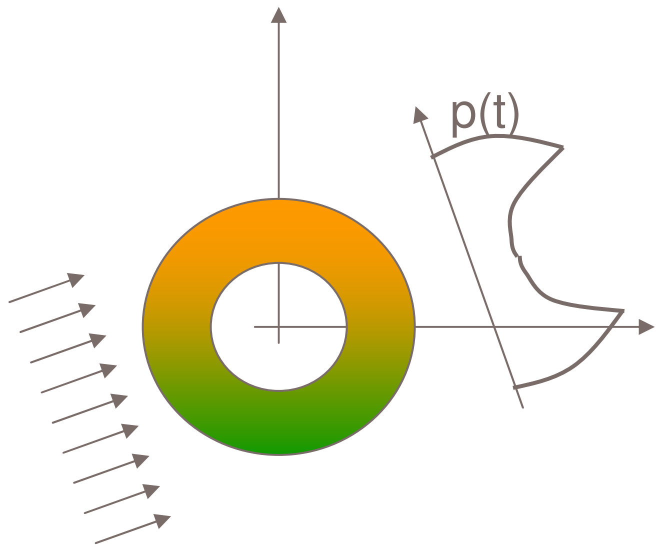
Tomographic reconstruction component

Analytical formulation

$$I_\theta(t) = I_\theta^0(t)\, e^{-\int_{ligne(\theta,t)} f(x,y)\,dl}$$

Back-projection
of filtered projections

$$f(x,y) = \int_0^{\pi} p'(u,\theta)\,d\theta \quad \text{avec} \quad p'(u,\theta) = \int_{-\infty}^{+\infty} P(\rho,\theta)\,|\rho|\,e^{i2\pi\rho u}\,d\rho$$



Algebraic formulation

$$\frac{I}{I_0} = \exp\left[-\sum_{j\in I_i} l_{ij} f_j\right]$$

EM

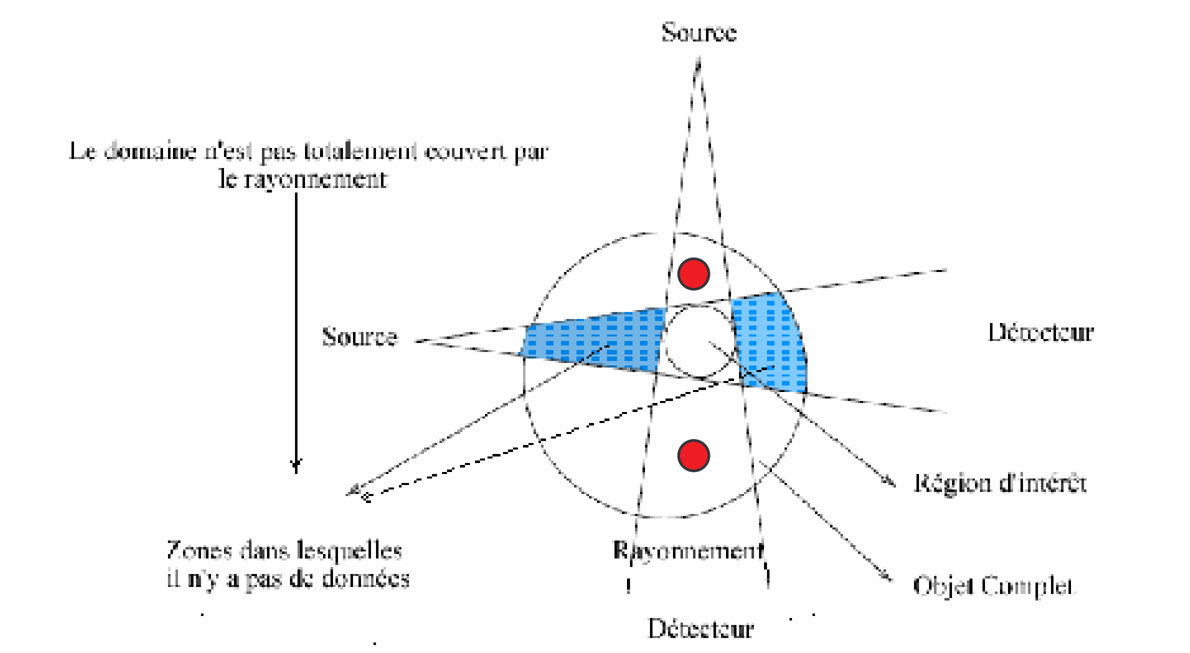
$$\mu_j^{n+1} = f_j^n \frac{\sum_{i\in J_j} b \exp\left[-\sum_{k\in I_i} l_{ik} f_k^n\right] l_{ij}}{\sum_{i\in J_j} p_i l_{ij}}$$

+ priors

PhD in progress

PhD (end 2005-07), tomographic reconstruction algorithms, main issues:

- purely 3D reconstruction (algebraic)
- local microtomography
- limited angle
- partial view of the object
- multi-resolution
- test of coupling methods between segmentation / classification and reconstruction



Post-Doc:

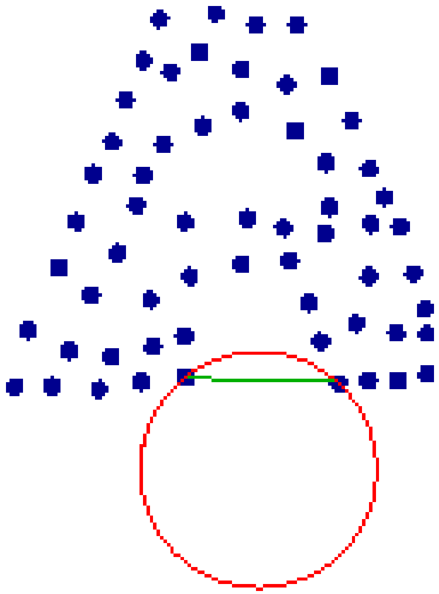
- 3D image processing of data coming for tomographic reconstructions, physical parameters determination
  - developed surfaces
  - pore size
  - curvature radius

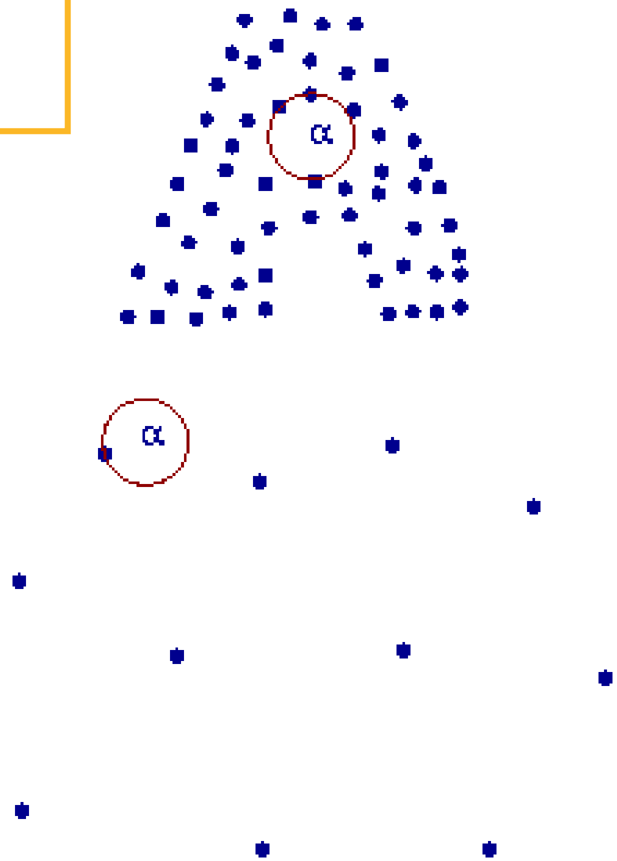
- tool development based on graphe theory : Voronoi, Delaunay, α-shape, …

Alpha-shape of a set of points: example (1)

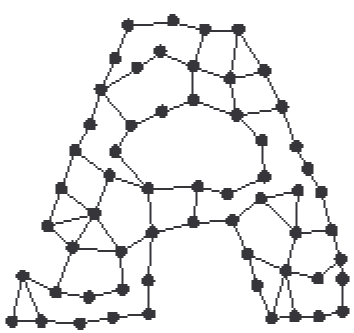
σ_T is a k - simplex, $0 \leq k \leq 3$, of α – shape of S iff there exists a ball b_α of radius $\alpha > 0$ such that :

$$b_\alpha \cap S = \phi \text{ et } \partial b_\alpha \cap S = T.$$

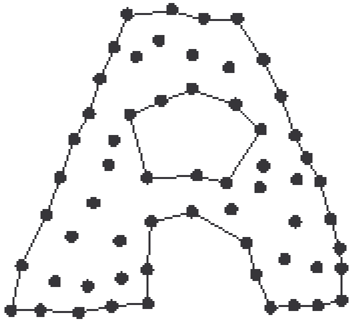




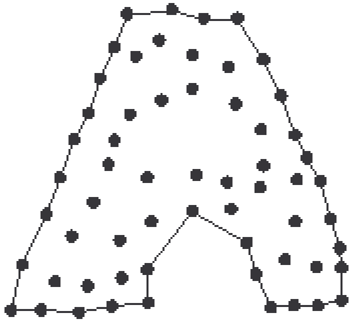
Alpha-shape of a set of points: example(2)



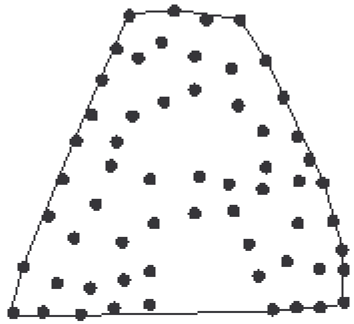
alpha = 10



alpha = 20



alpha = 40



alpha = 60

Summary and future works

- First results very encouraging, ready to incorporate generated geometries in CFD,
- Experiments: works on the generator, acquire diamond target for higher heat transfer (1 → 15W),
- Tomographic reconstruction: first algorithm for aspect ratio running,
- 3D image analysis: graph theory very promising,

- Experiments: Monte-Carlo simulations in progress to find optimal target material (Z, fluo) : W → Mo, Ag, Ni, …
- Experiments: thinking to neutron imaging (H_2O, H2, …),
- Coming works on liquid foams with Danone.

thanks for your attention, …