PAUL SCHERRER INSTITUT PSI

CCMX Competence Centre for Materials Science and Technology

IAEA International Atomic Energy Agency

Wir schaffen Wissen – heute für morgen

Pierre Boillat

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Dynamic Neutron Imaging

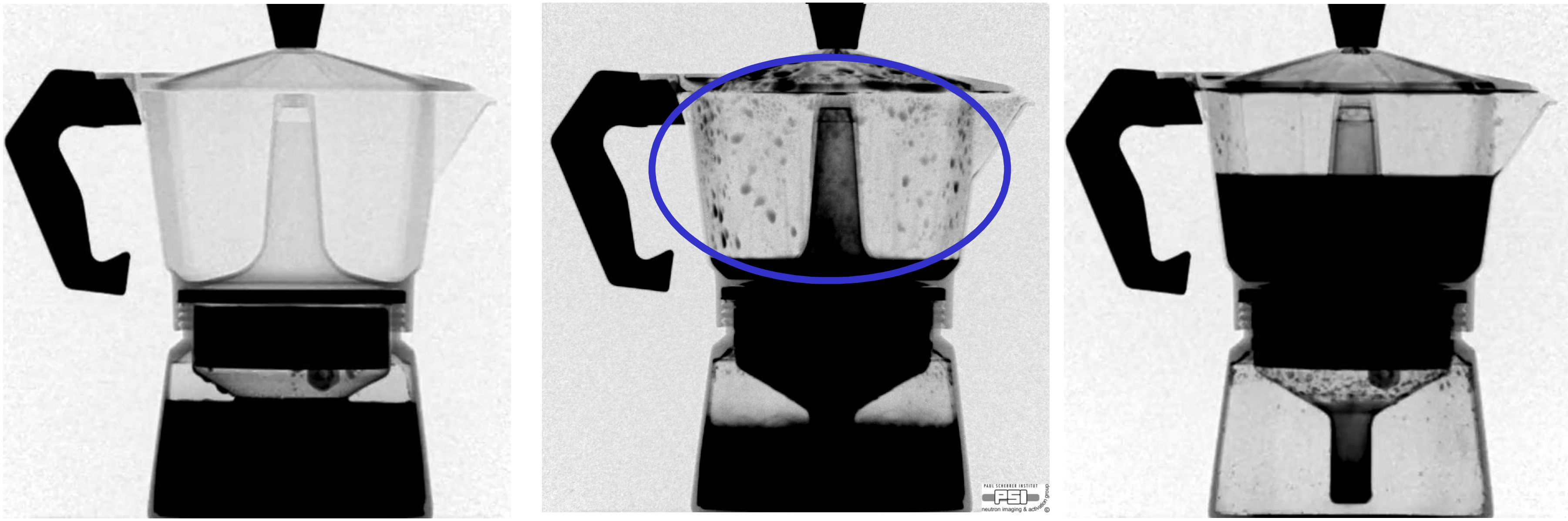
OUTLINE

1. Introduction
2. Basics of dynamic neutron imaging
    a. Typical experiment setup
    b. Signal to Noise Ratio
    c. Spatial/temporal resolution tradeoff
    d. Detectors
    e. Image processing specificities
3. Examples from fuel cell research
4. Conclusion

Introduction

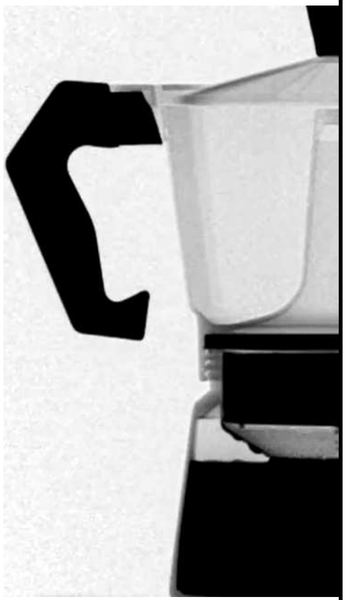
Why dynamic imaging ?

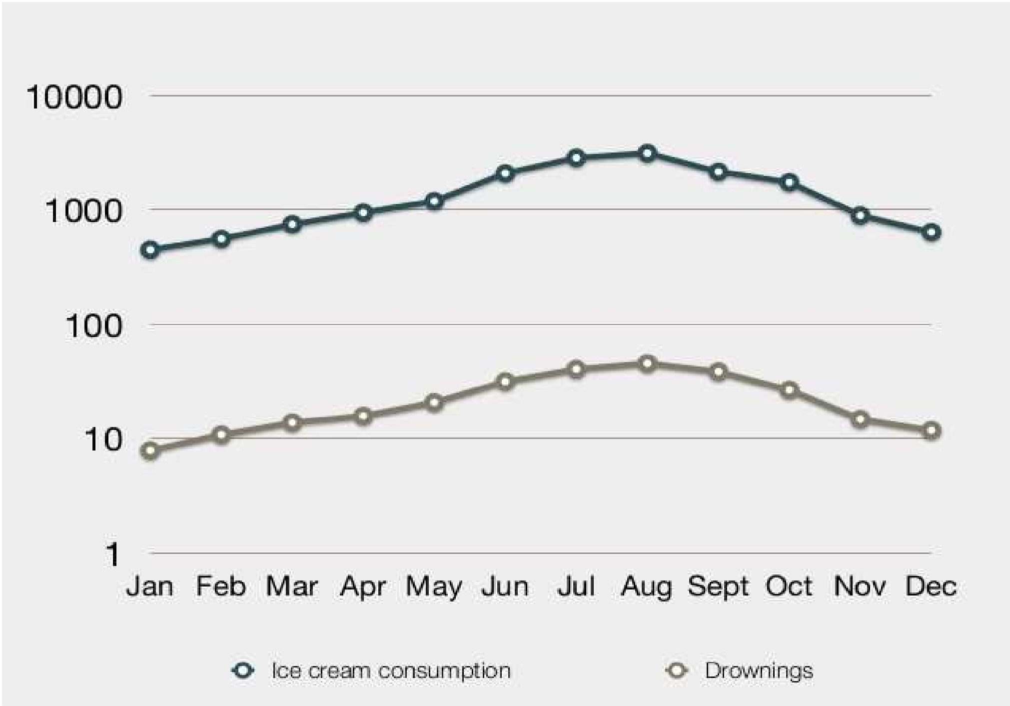
Why dynamic imaging ?



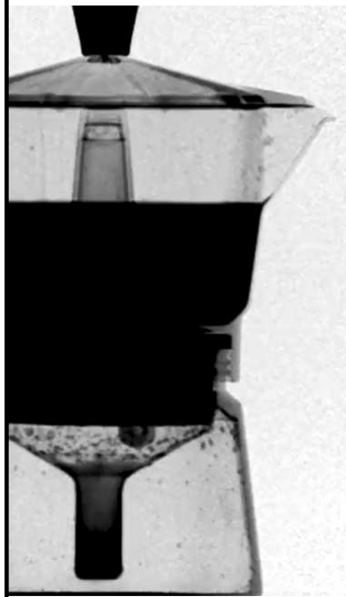
- Make observations which are not possible in steady state

Why dynamic imaging ?





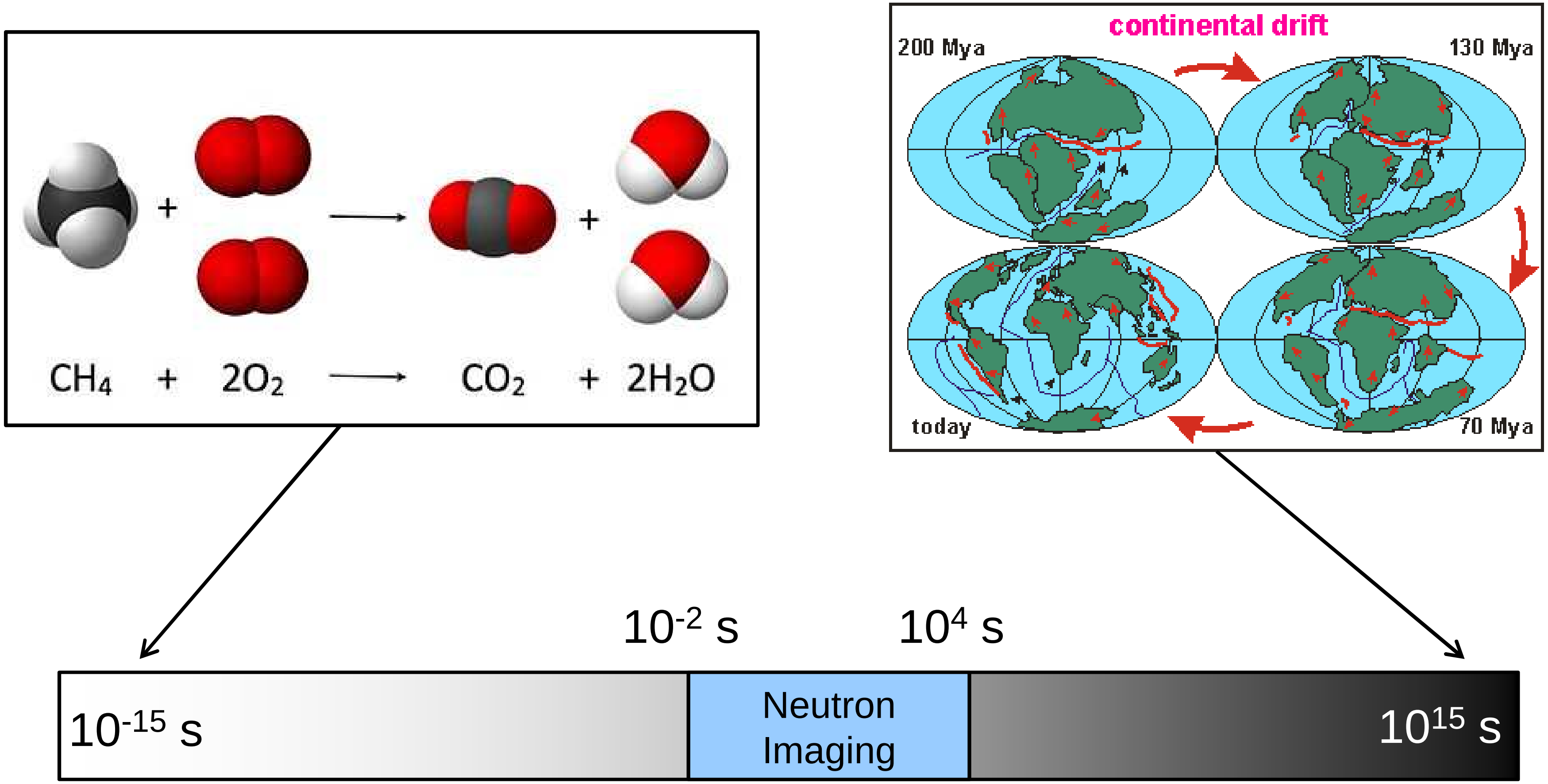
http://de.slideshare.net/Leananalytics/lean-analytics-overview-from-growtalk-montreal



- Make observations which are not possible in steady state

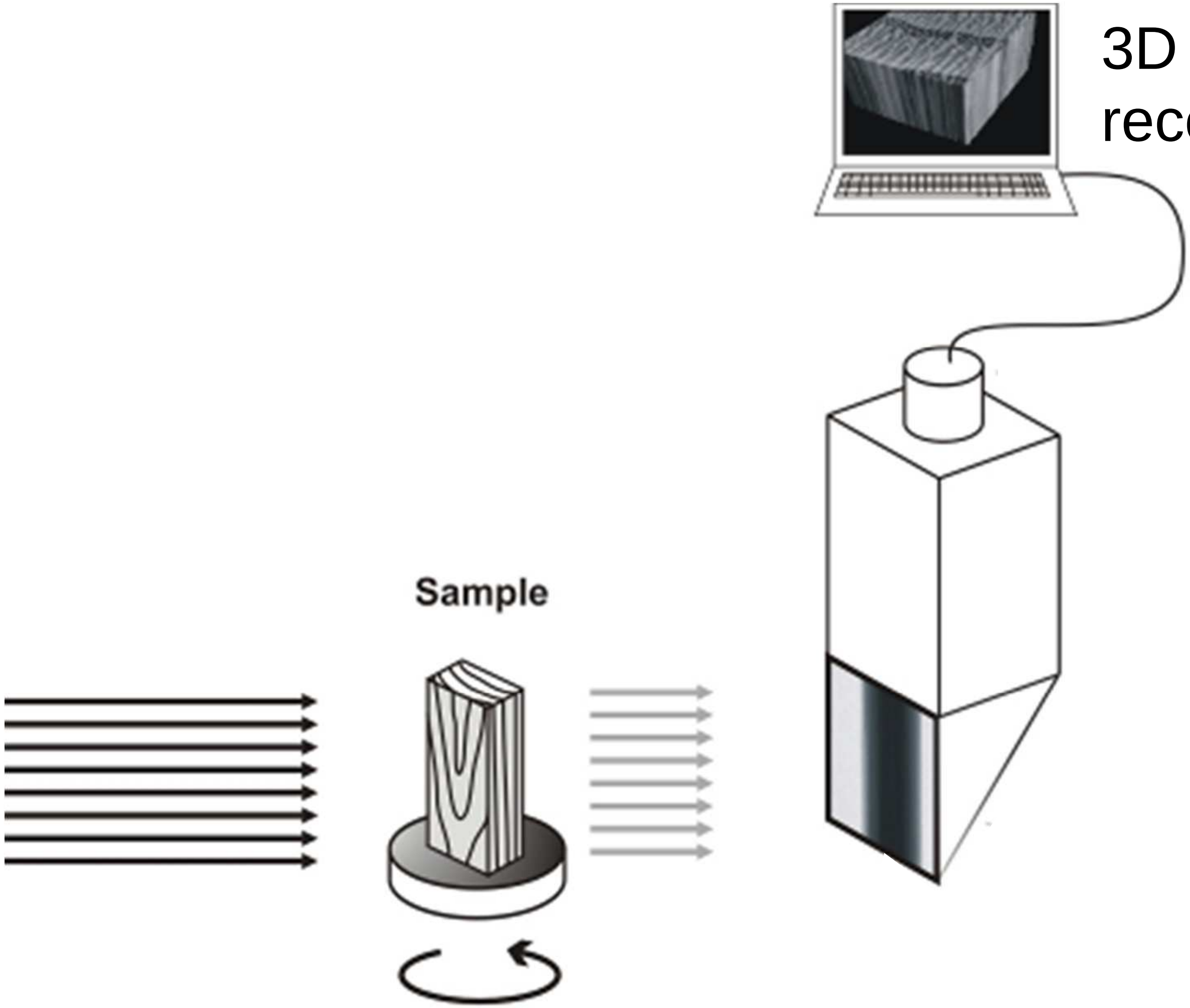
- Correlate processes using their time scale

Does «dynamic» mean «fast» ?



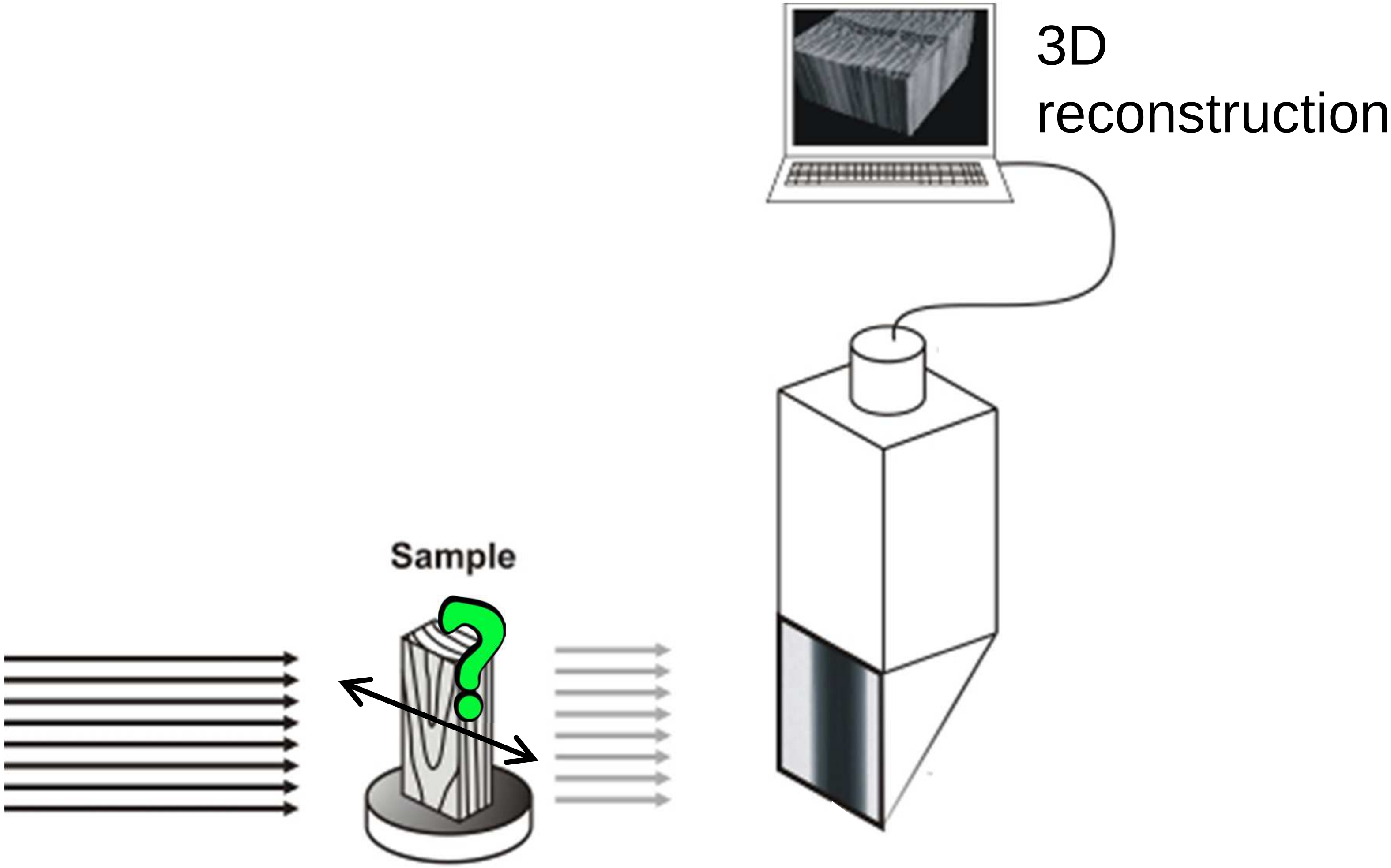
Typical experiment setup

Classical «non dynamic» application

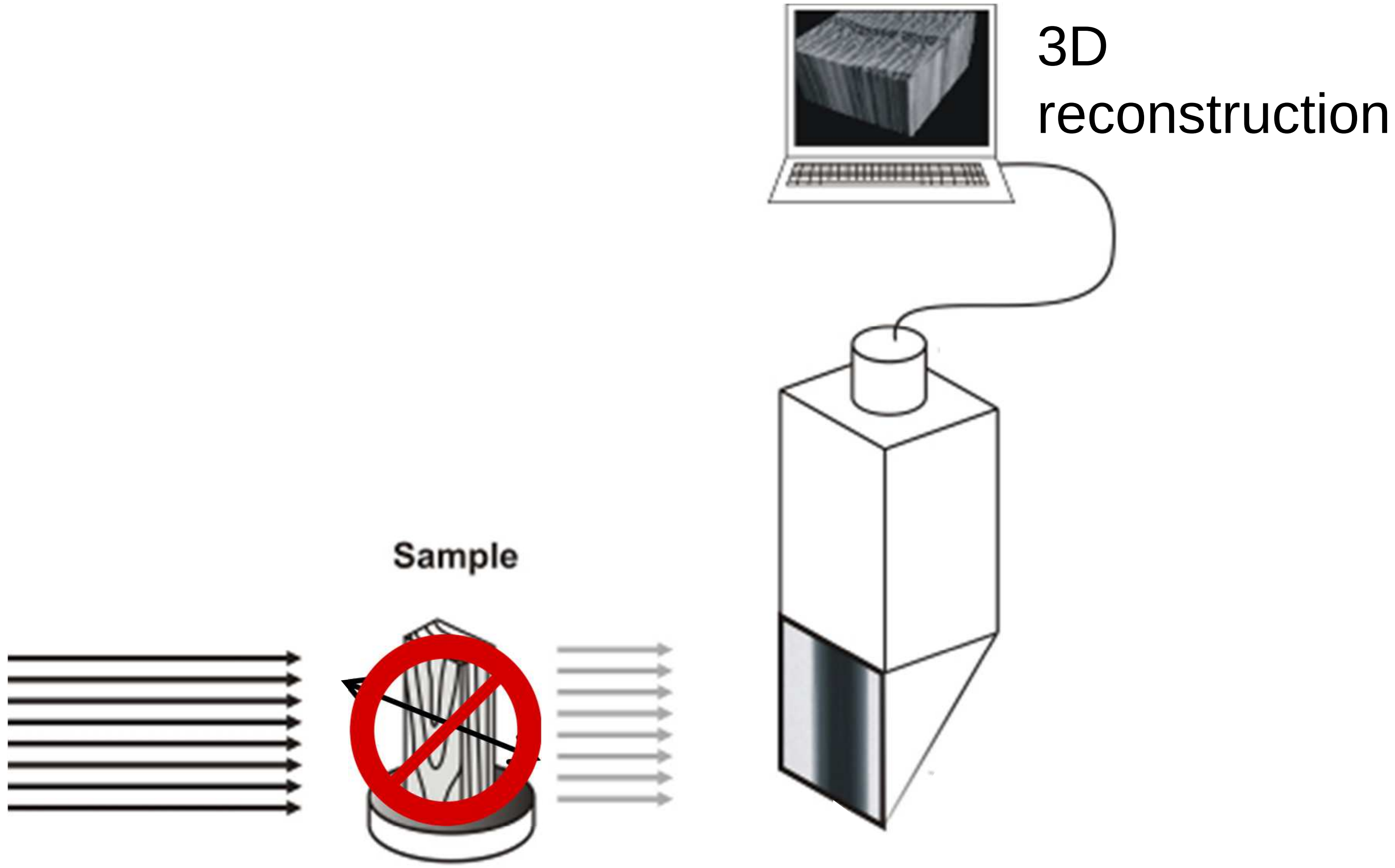


3D reconstruction

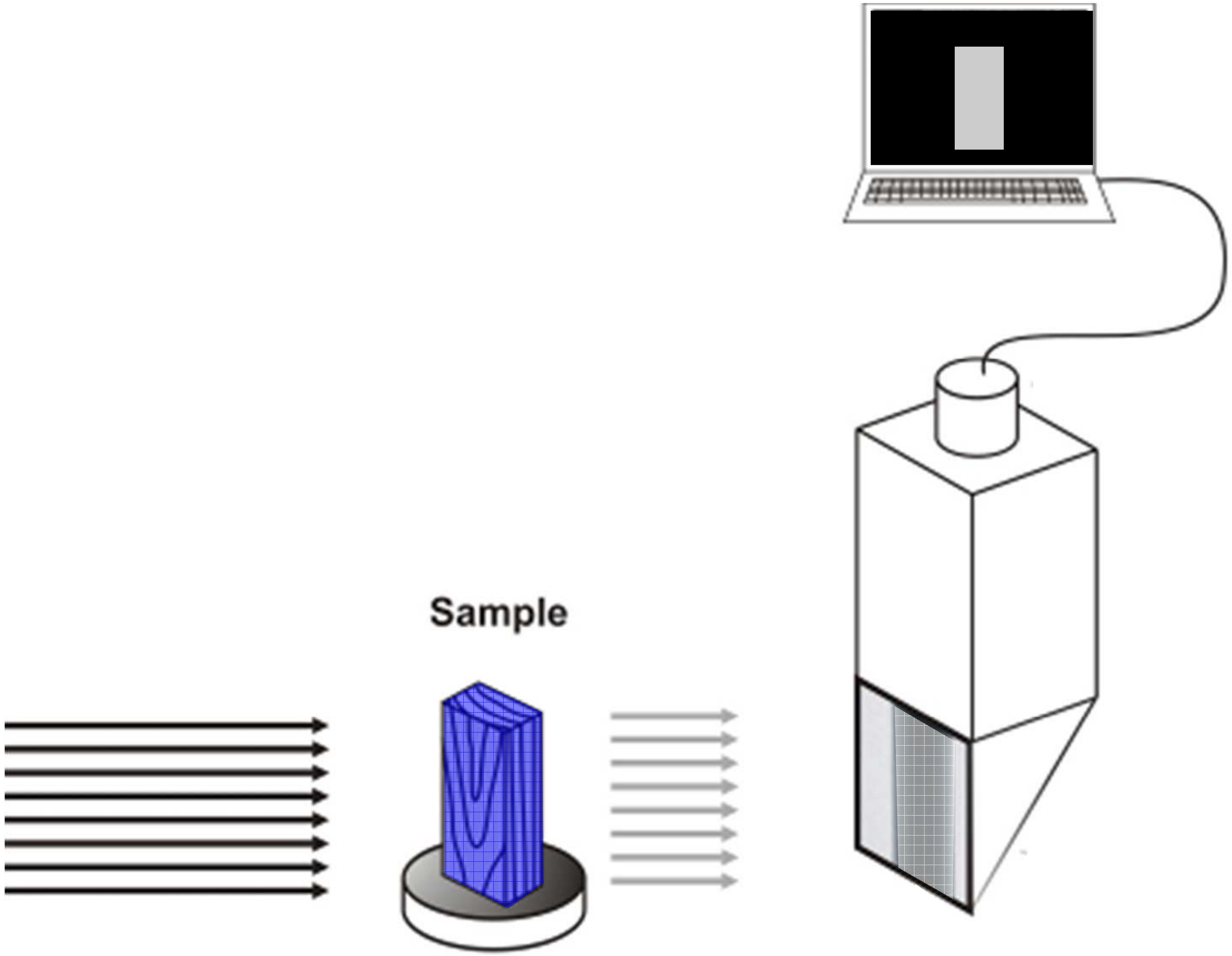
Dynamic radiography



Dynamic radiography



Dynamic radiography

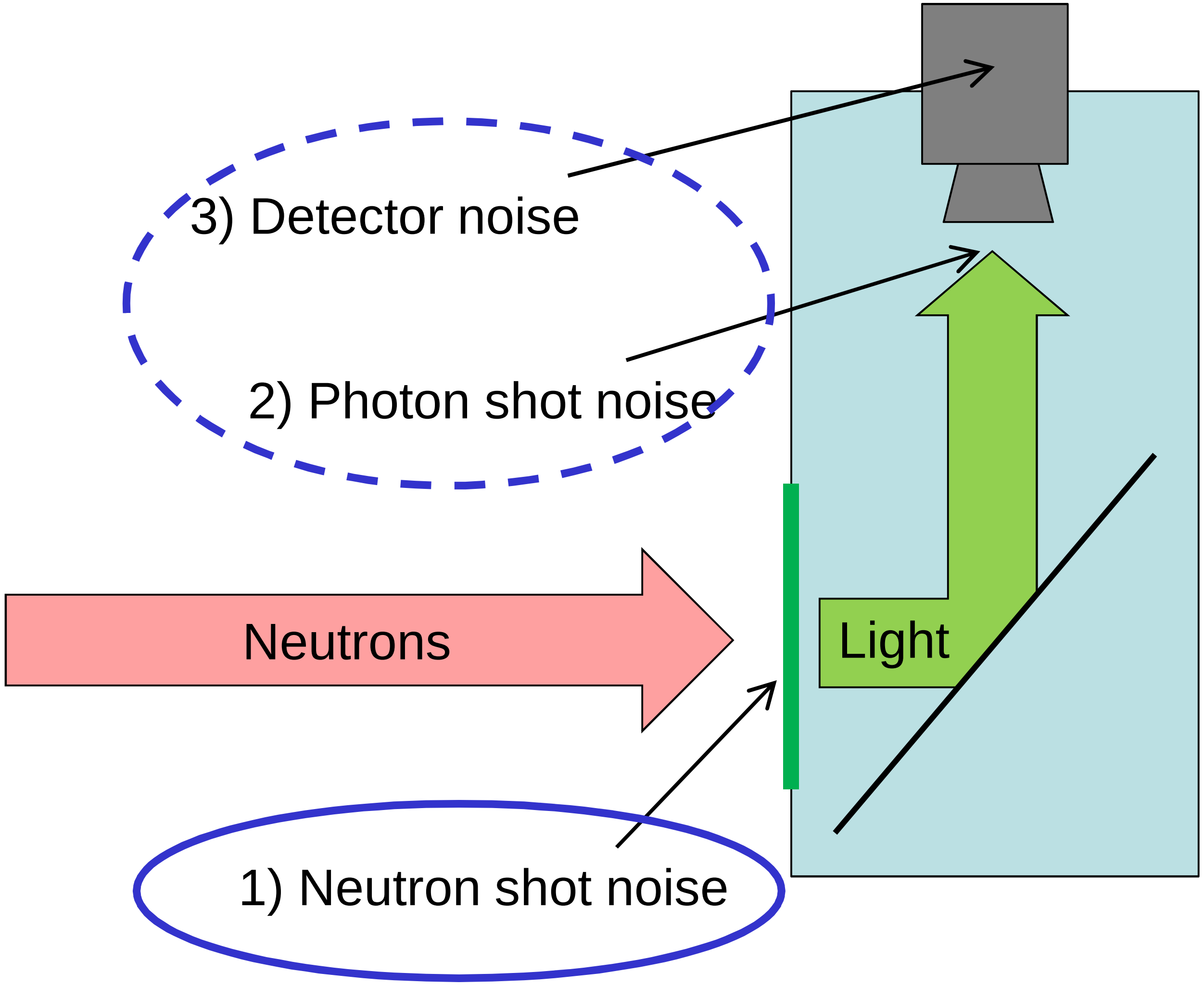


Typical time resolution: 1 – 60 s

Down to a few ms in specific cases

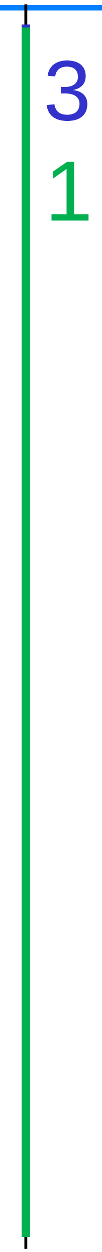
Signal / Noise Ratio (SNR)

Classical setup: scintillator + camera



Shot noise

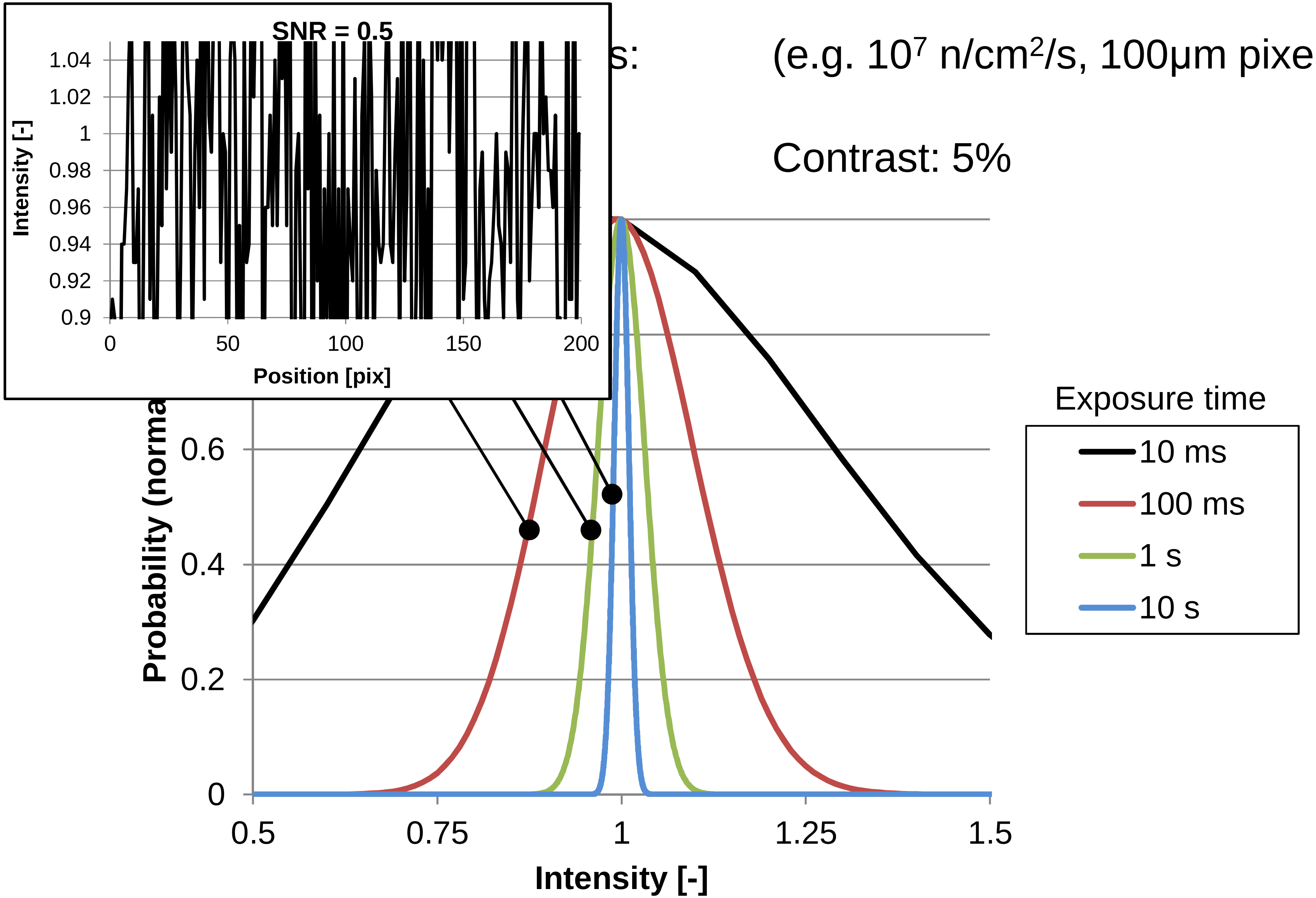
Average: 2 n/s



Neutron statistics

s: (e.g. 10^7 n/cm^2/s, 100µm pixels)

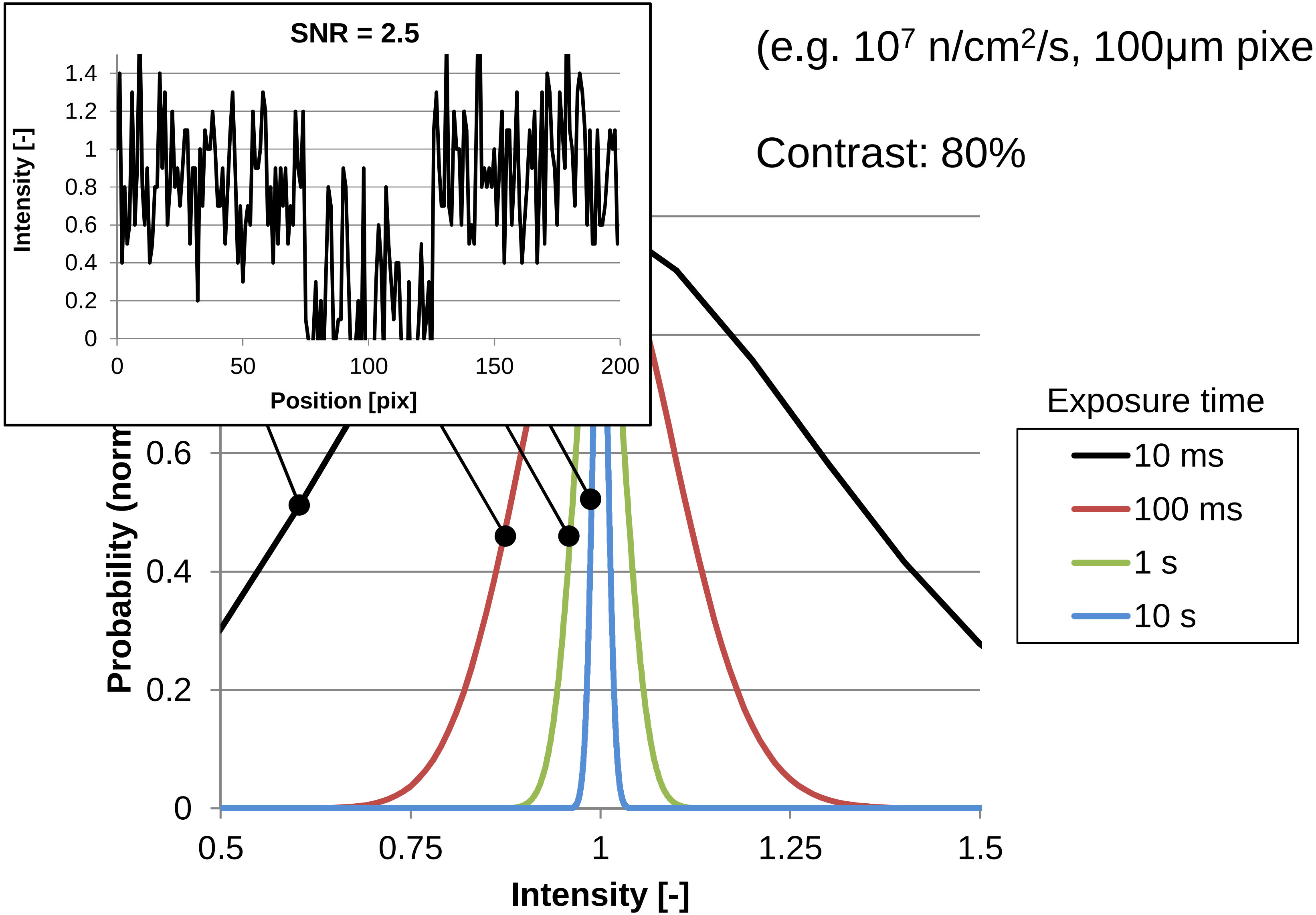
Contrast: 5%



Neutron statistics

(e.g. 10^7 n/cm^2/s, 100µm pixels)

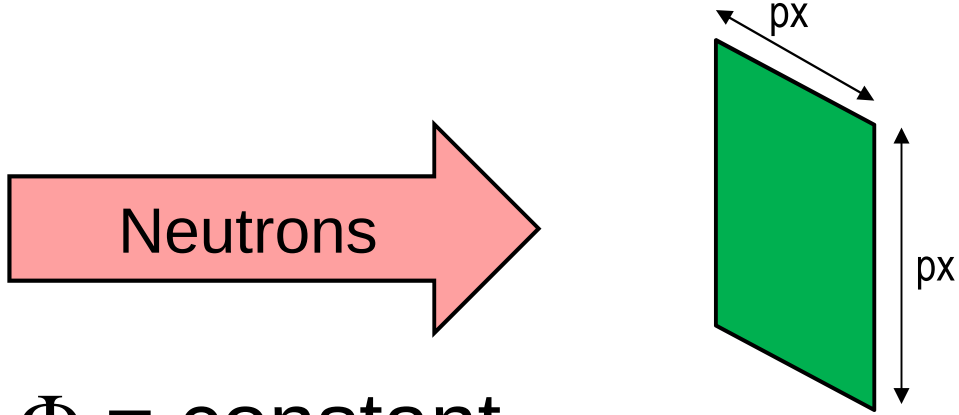
Contrast: 80%



Spatial / temporal resolution tradeoff

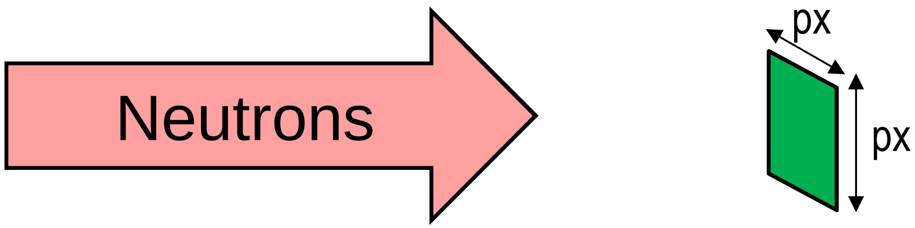
Scaling laws

Effect of pixel size, for a given neutron flux:



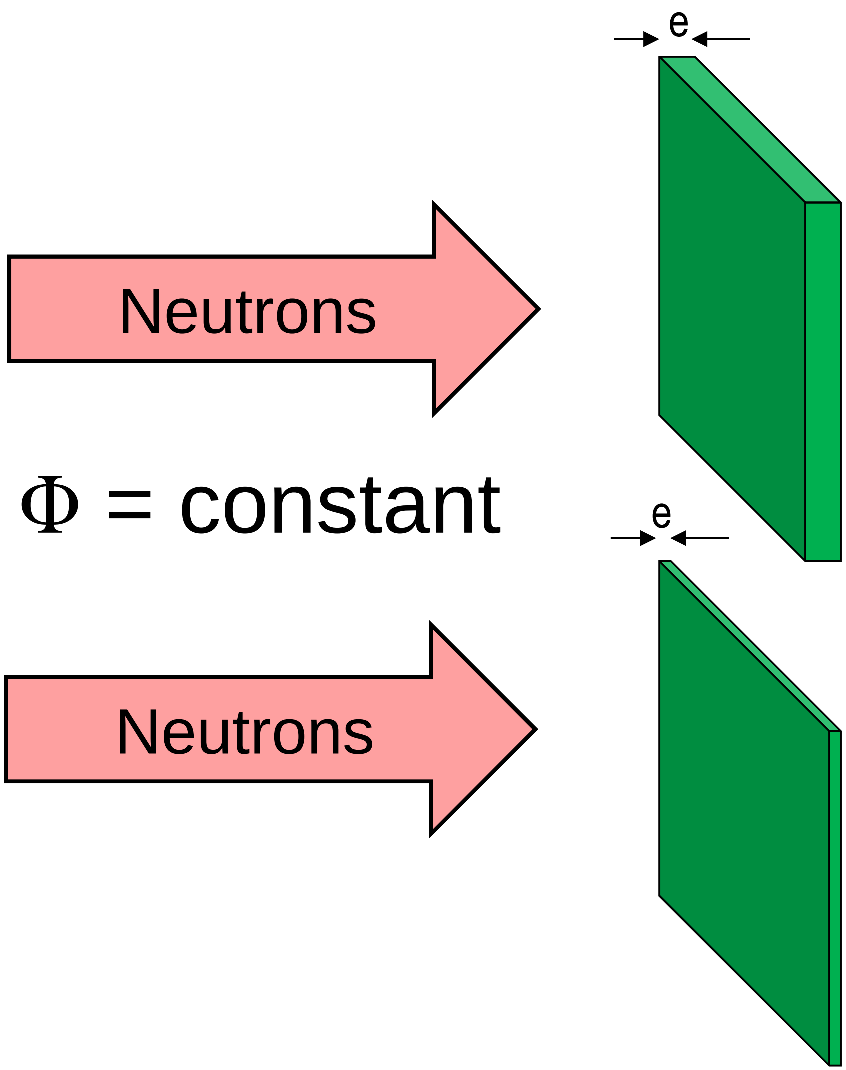
$N \,\alpha\, 1/px^2$

Φ = constant



Scaling laws

Effect scintillator resolution, for a given neutron flux:

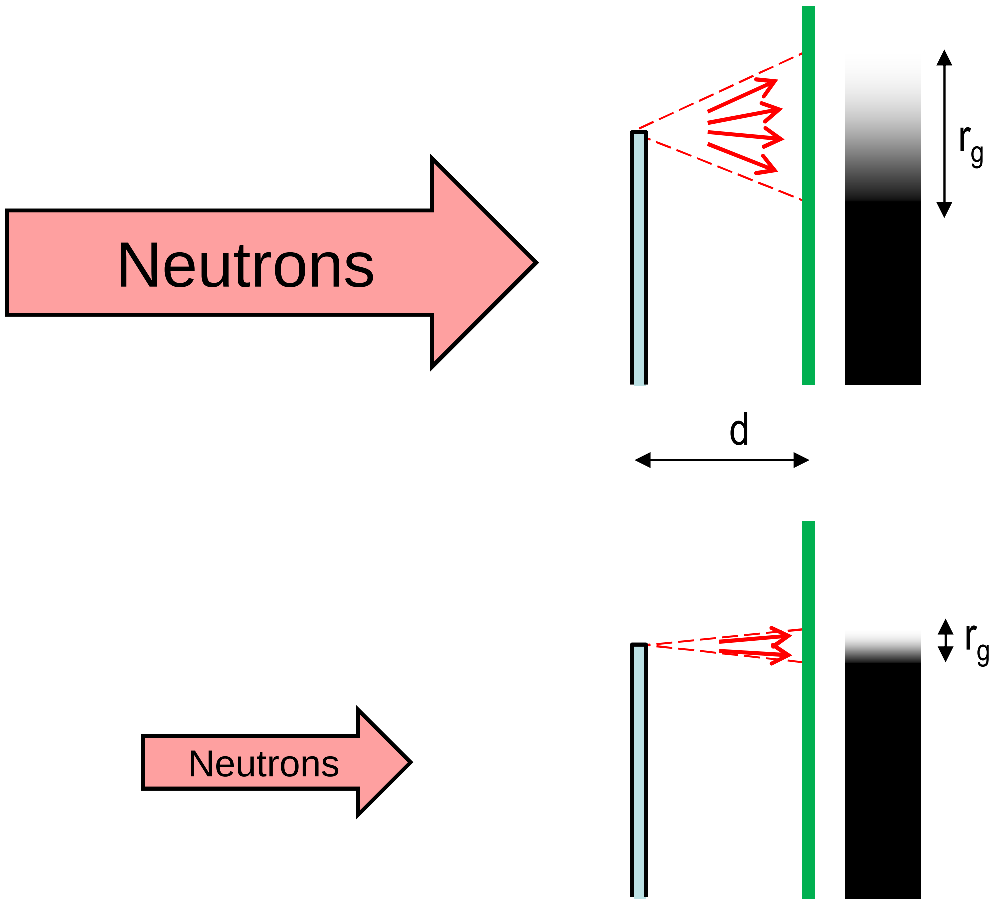


Φ = constant

eff α 1/e

Scaling laws

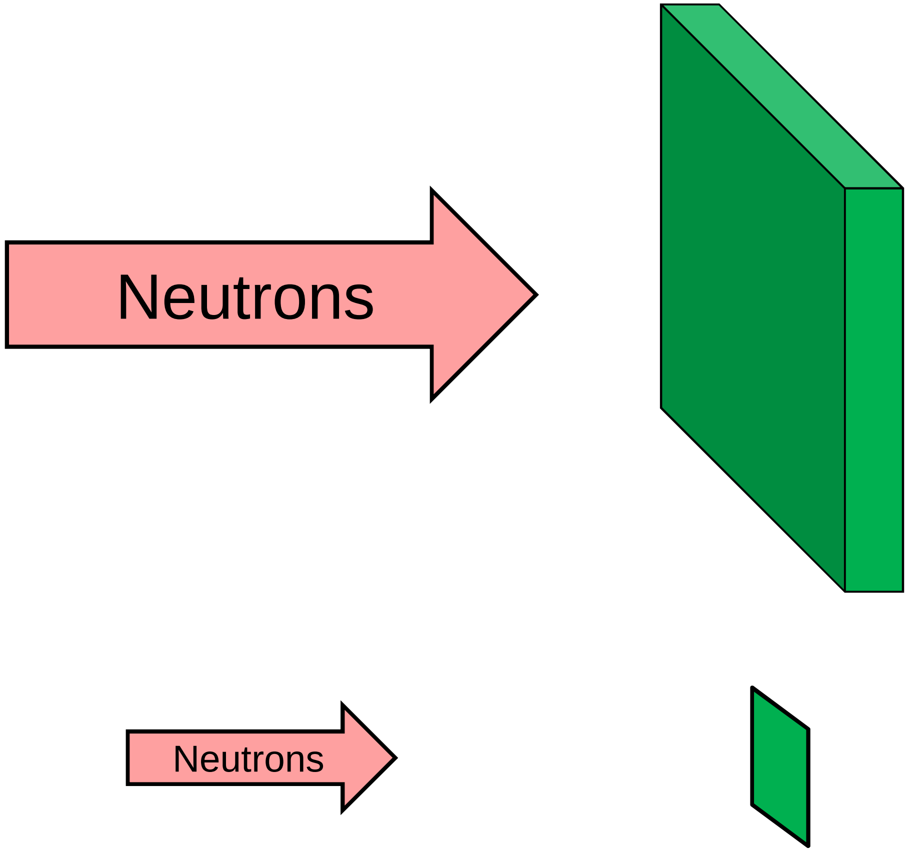
For a constant sample-detector distance



$$\Phi \propto 1/r_g^2$$

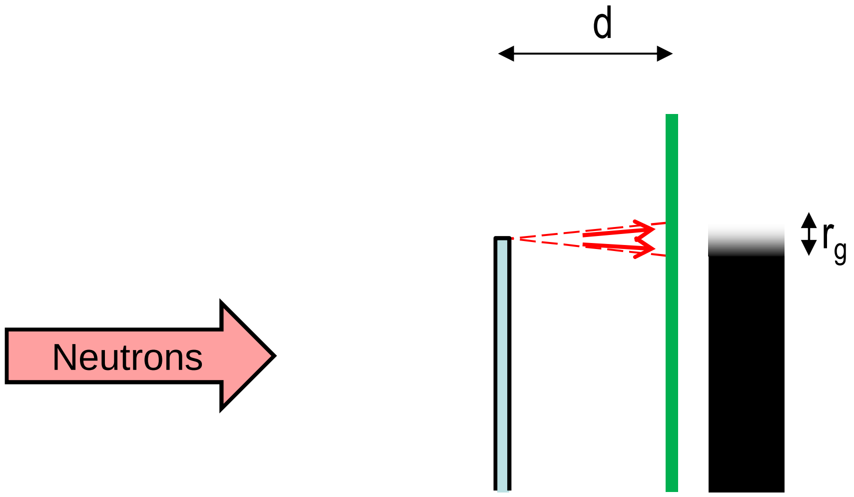
Scaling laws

Combination of all:

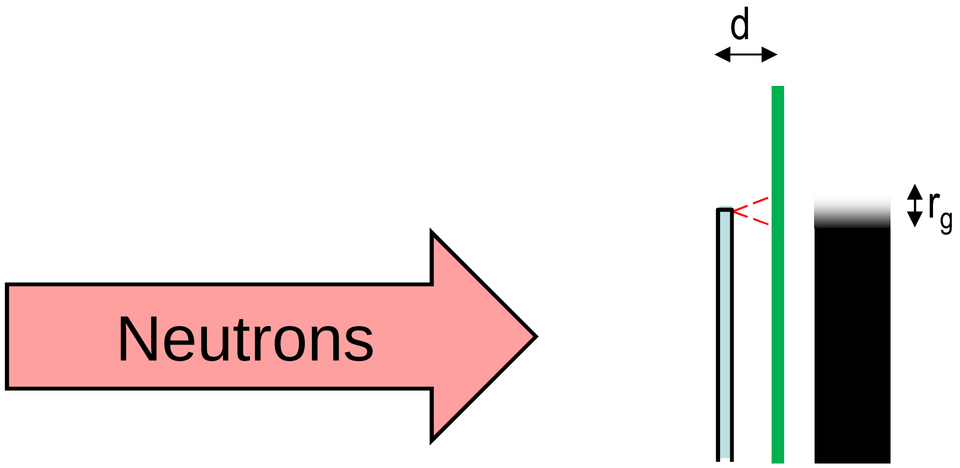


$N \propto 1/r^5$!!!!!

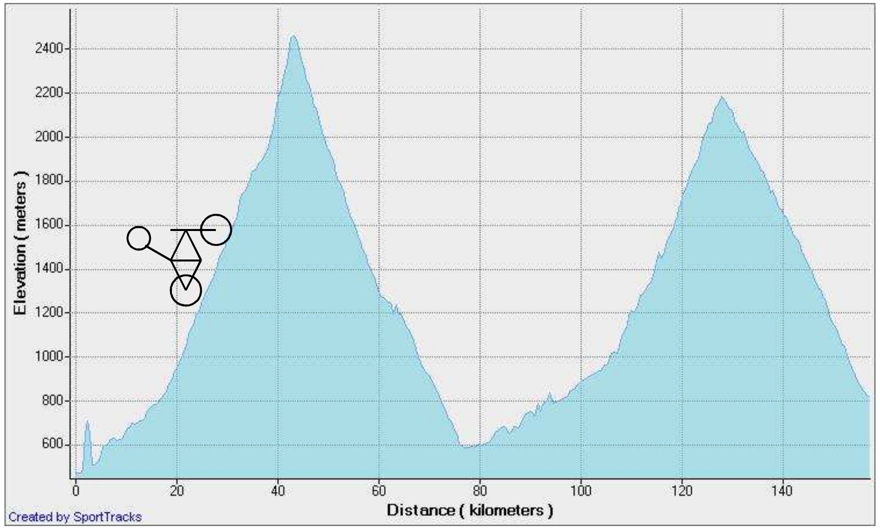
Tradeoff mitigation: reduction of distance



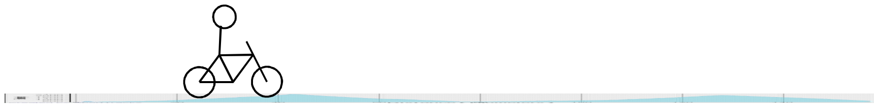
$$\Phi \propto 1/d^2$$

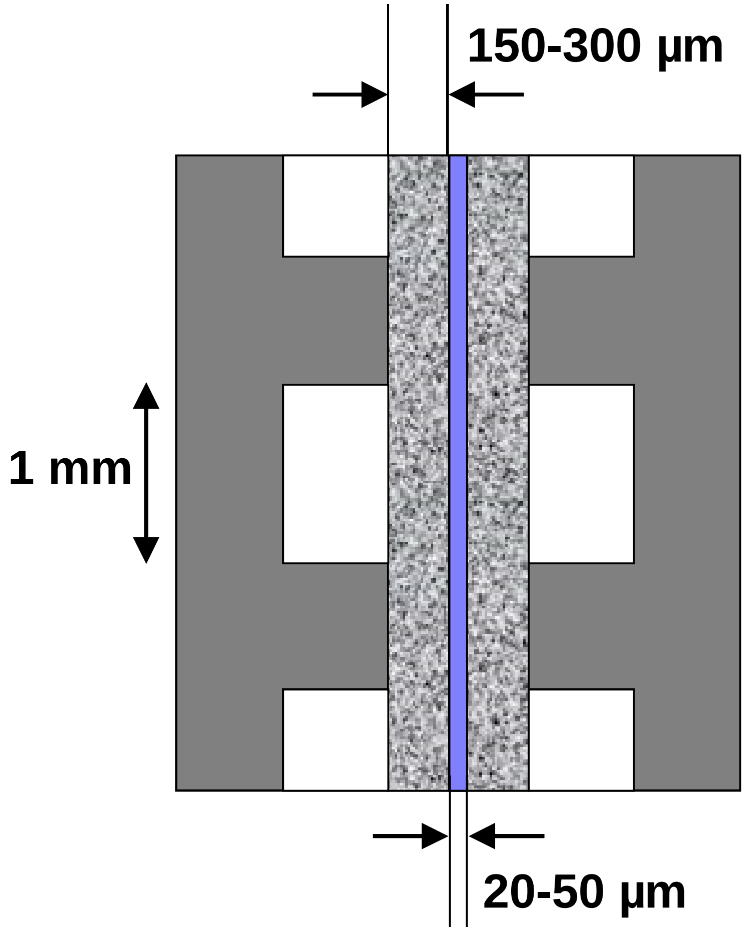


Tradeoff mitigation: anisotropic resolution

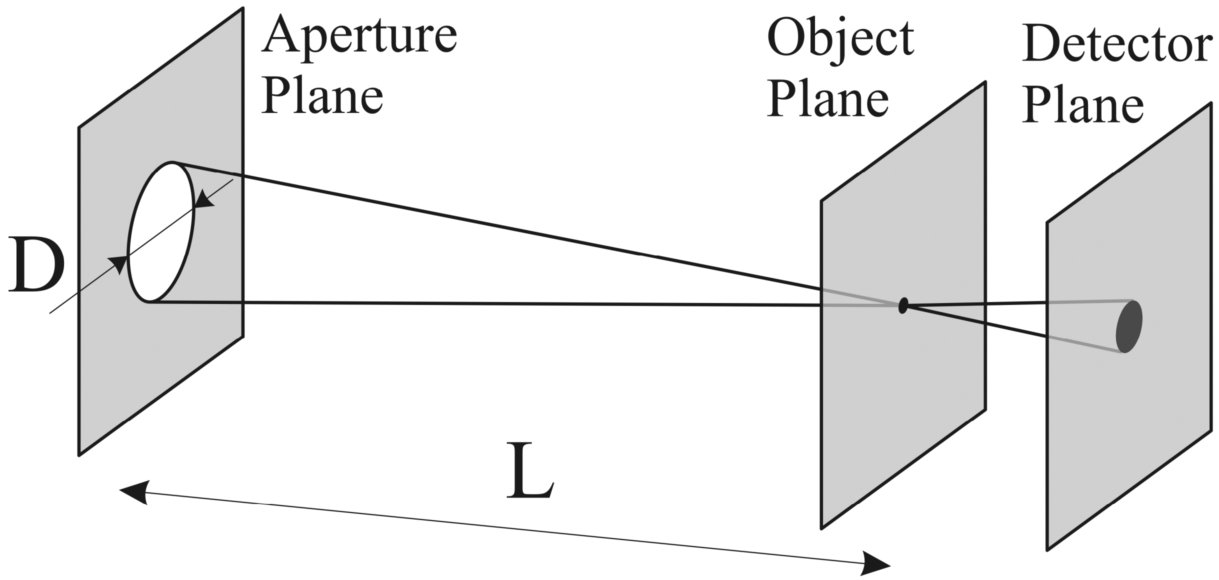


Source: http://www.cycling-challenge.com



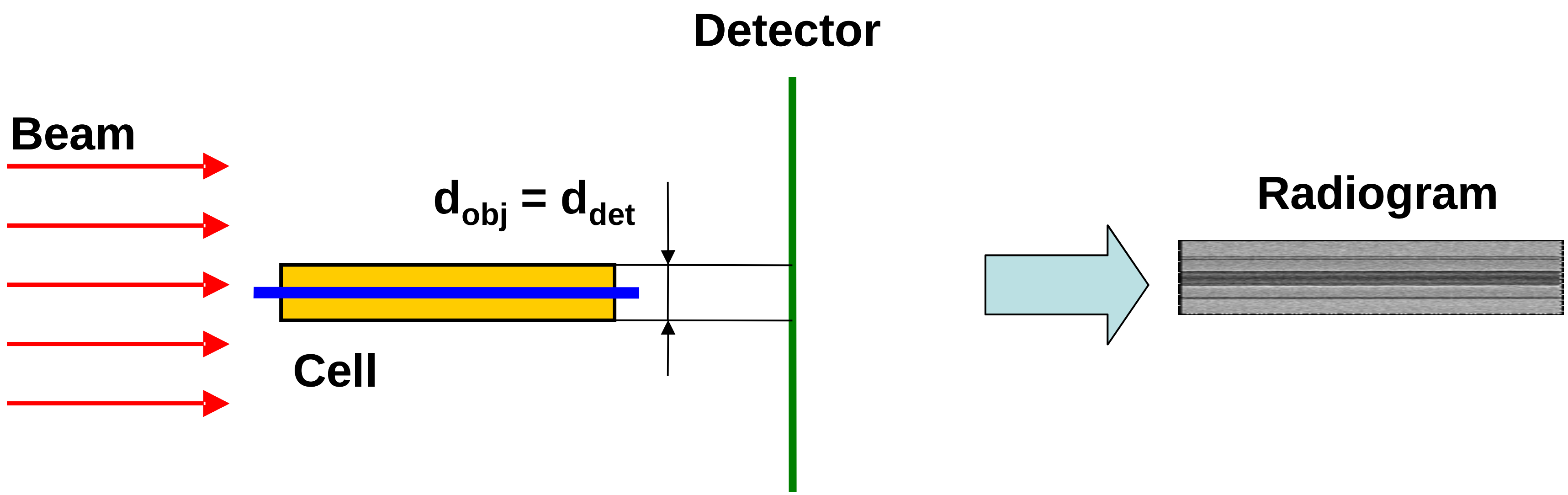


Tradeoff mitigation: anisotropic resolution



$$\Phi \sim \pi/4 \cdot D^2$$

Tradeoff mitigation: anisotropic resolution

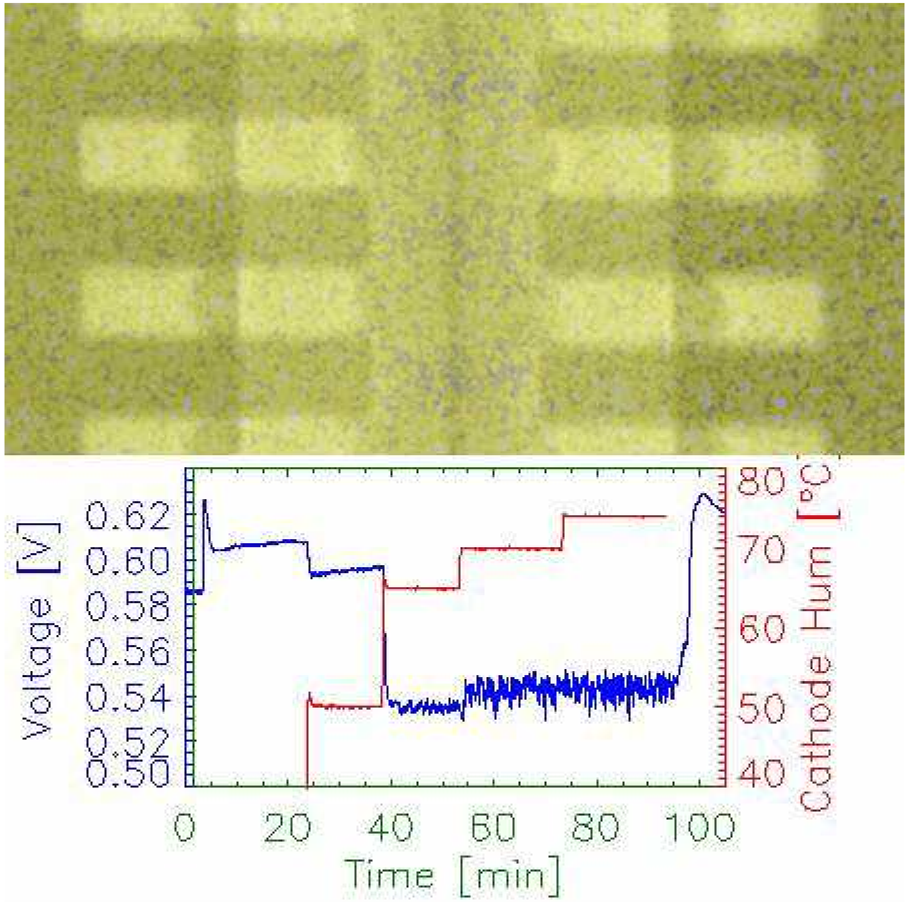


Dynamic imaging

Effective resolution
20 μm

Exposure time
10 s

Readout time
4 s



P. Boillat, *PhD Thesis No 18397, ETH Zürich.* (2009)

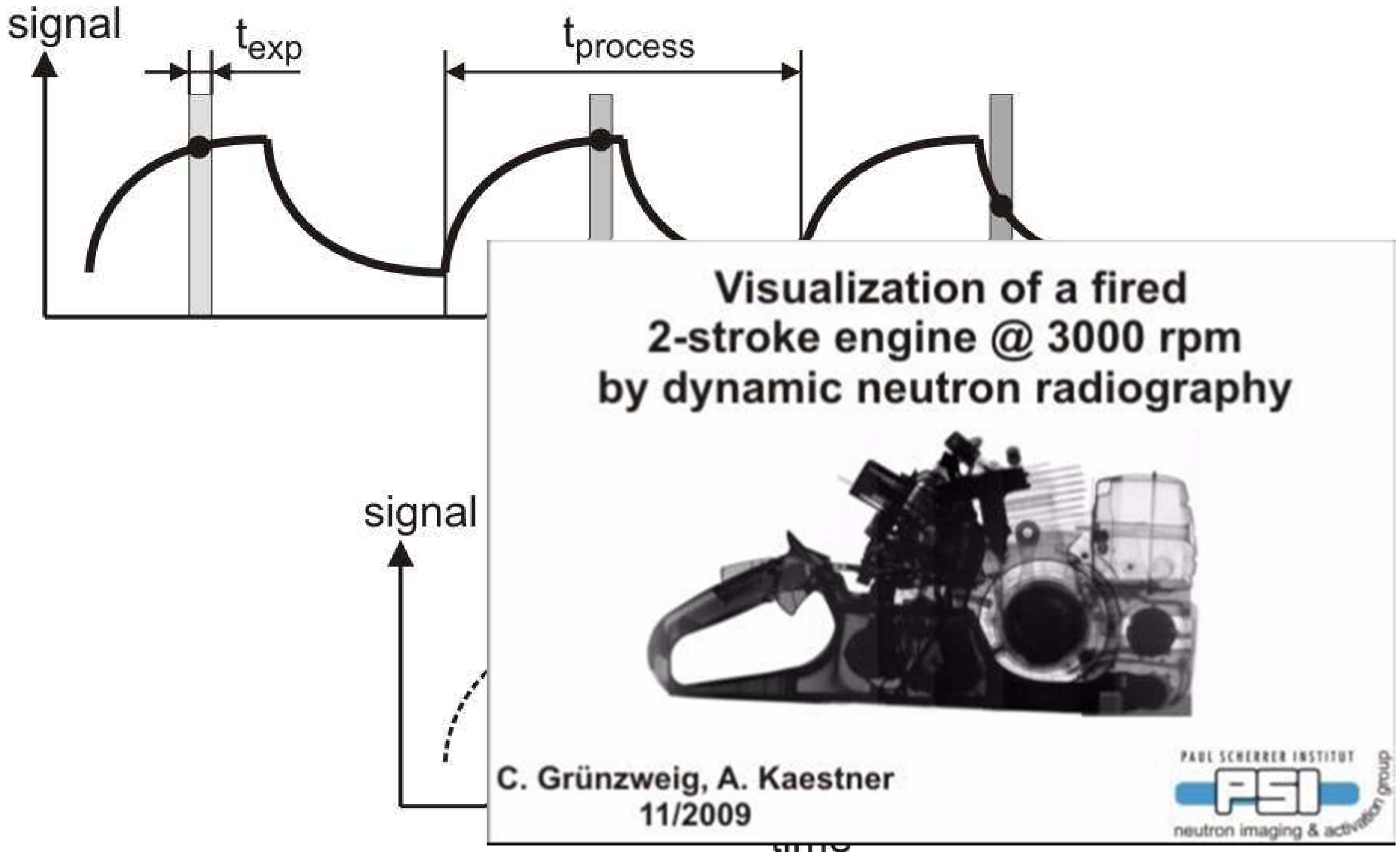
Tradeoff mitigation: cyclic processes

Stochastic process

Cyclic process

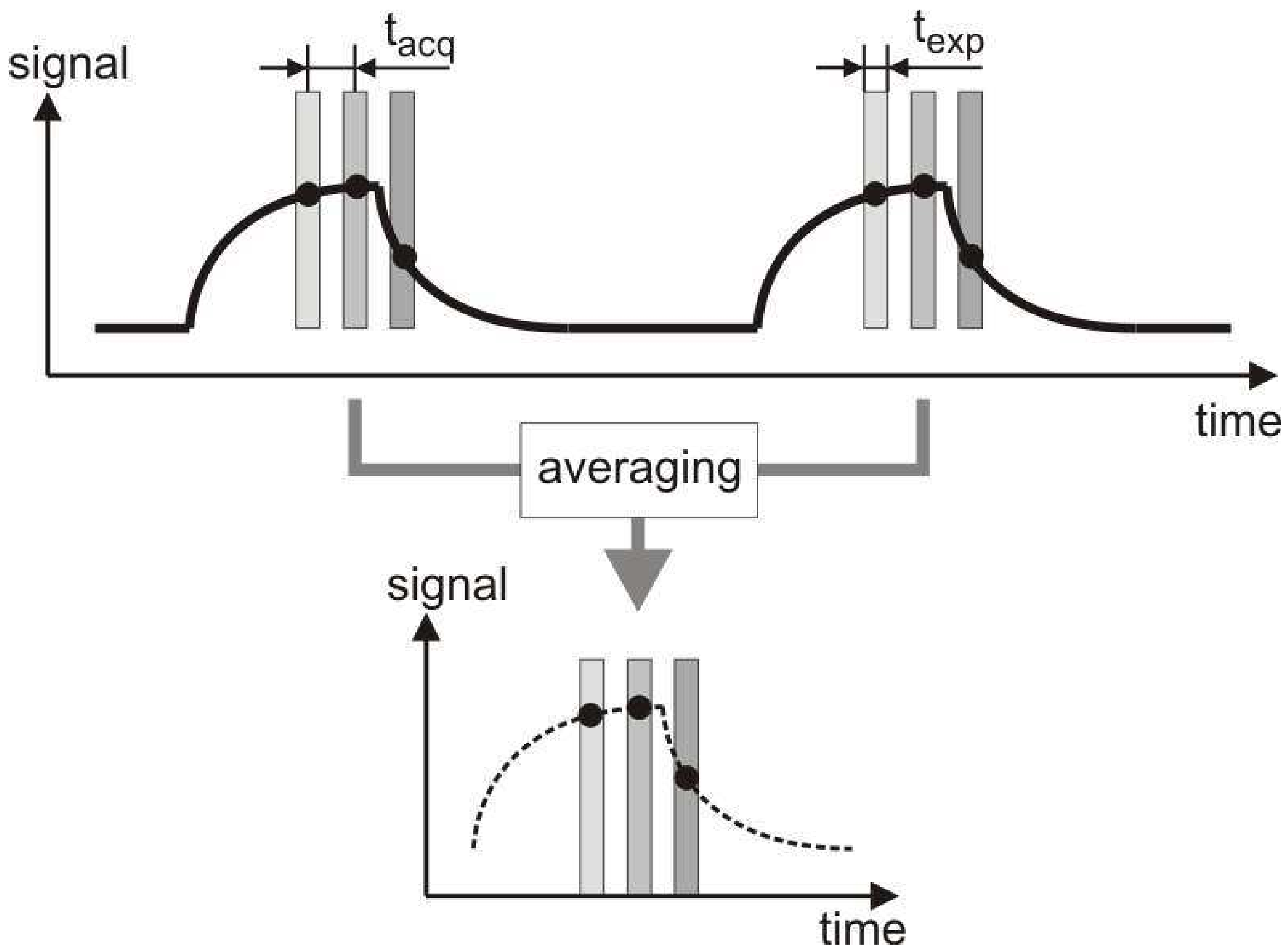
Tradeoff mitigation: cyclic processes

1) Stroboscopic imaging



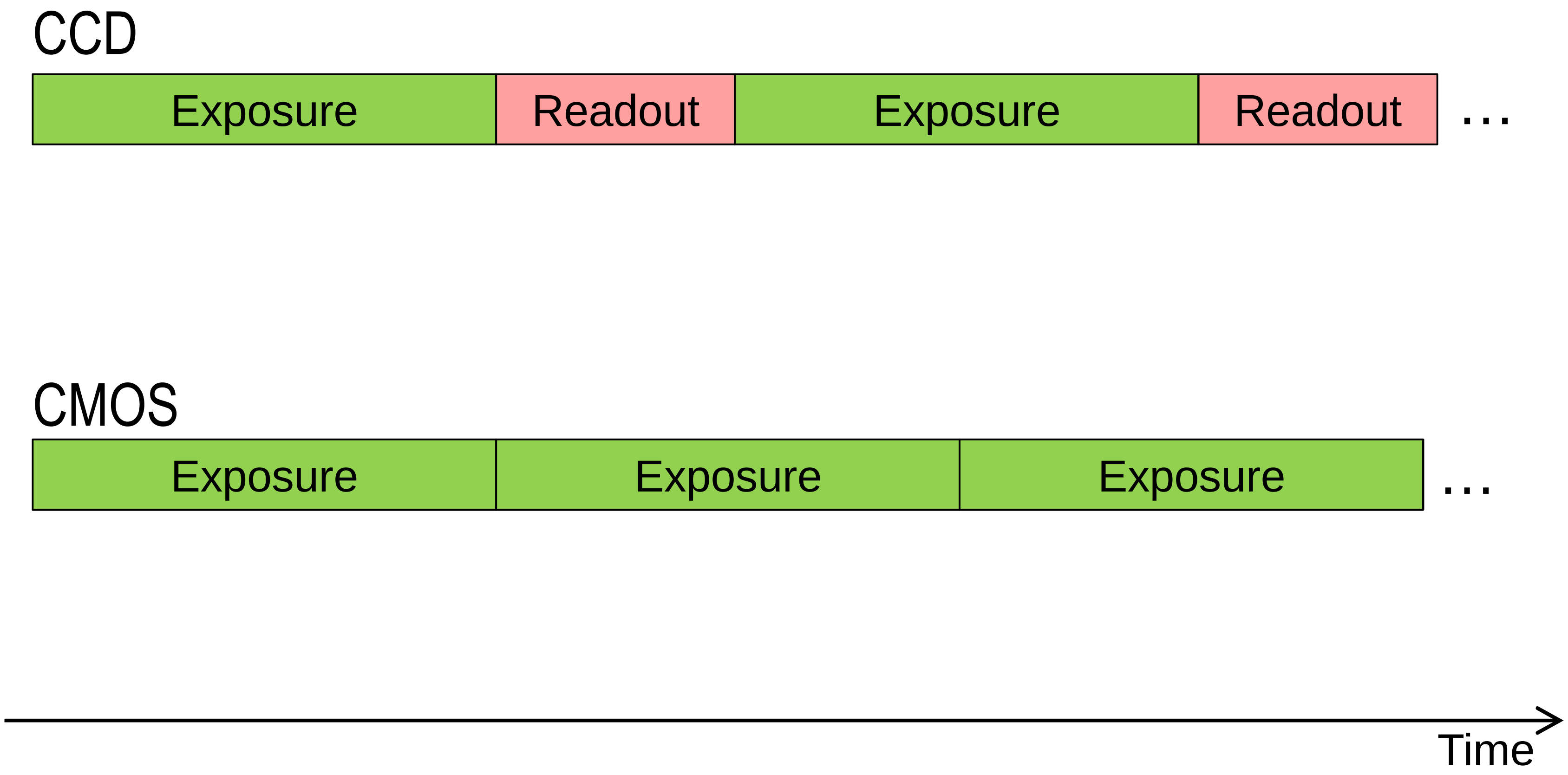
Tradeoff mitigation: cyclic processes

2) Cumulative imaging



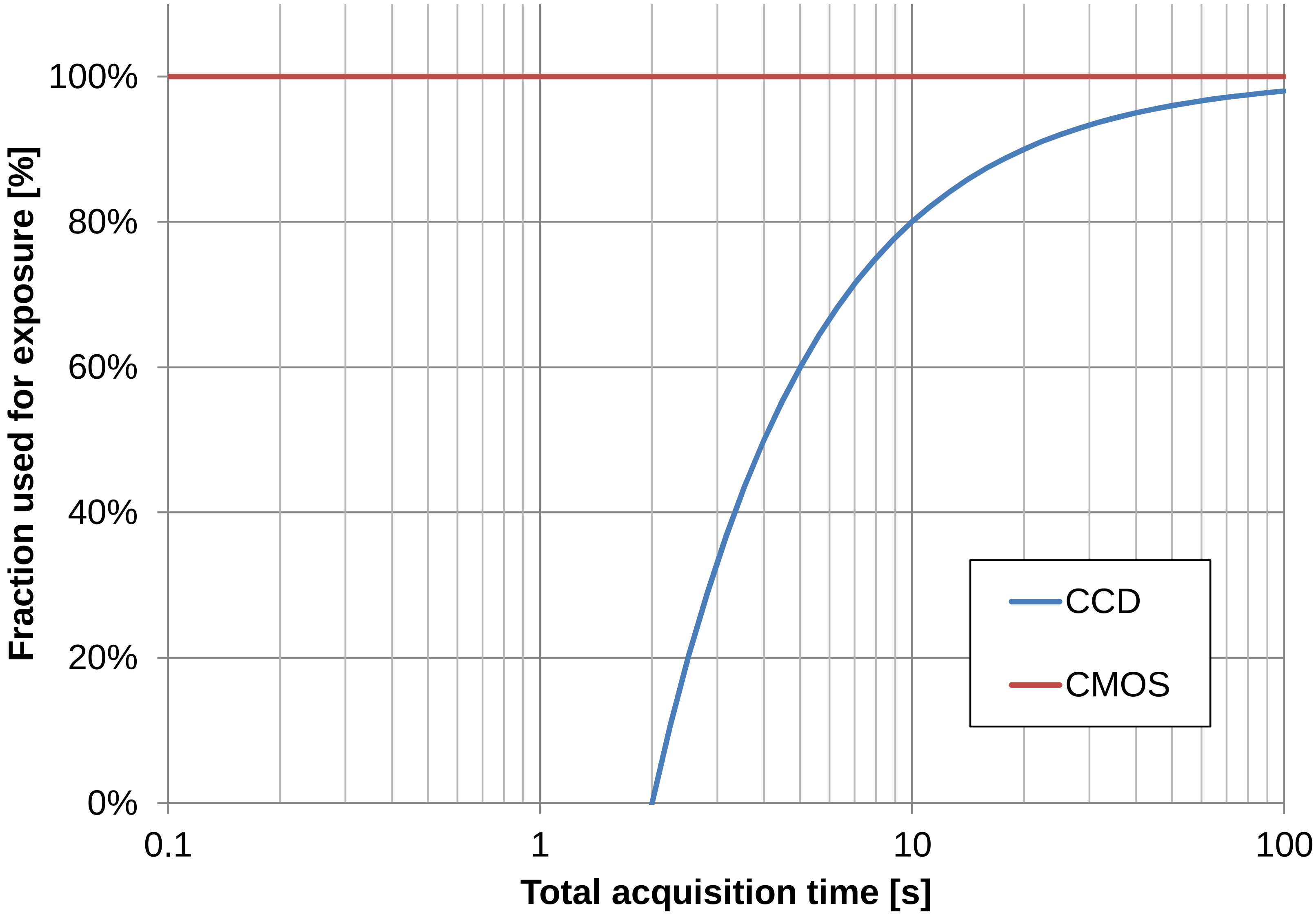
Detectors

CCD vs CMOS


CCD
Exposure
Readout
Exposure
Readout
...
CMOS
Exposure
Exposure
Exposure
...
Time

CCD vs. CMOS

Assuming a total readout time of 2 seconds for the CCD:



Photon detection efficiency

Assuming a quantum efficiency of 95% for the CCD and 60% for the CMOS

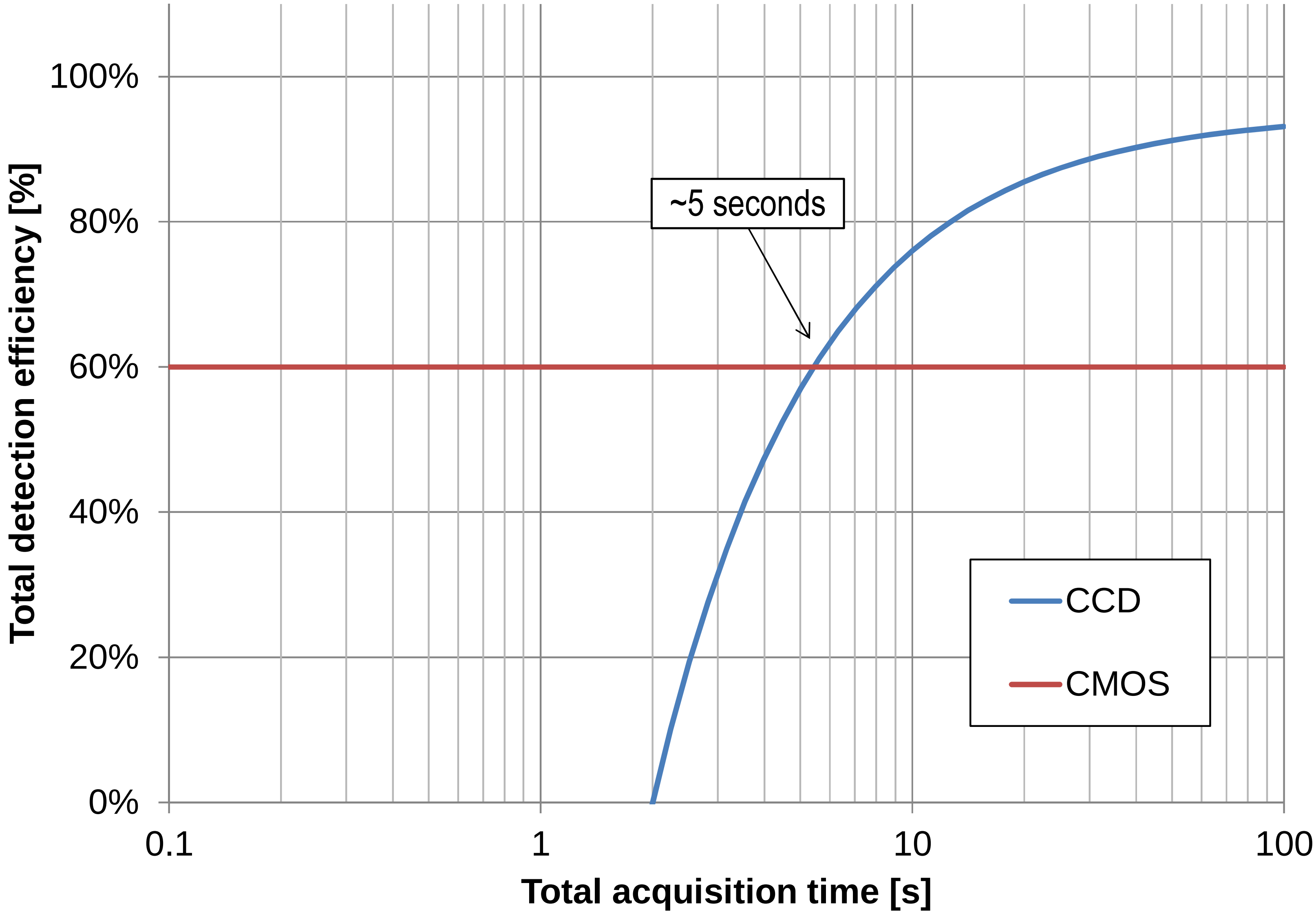
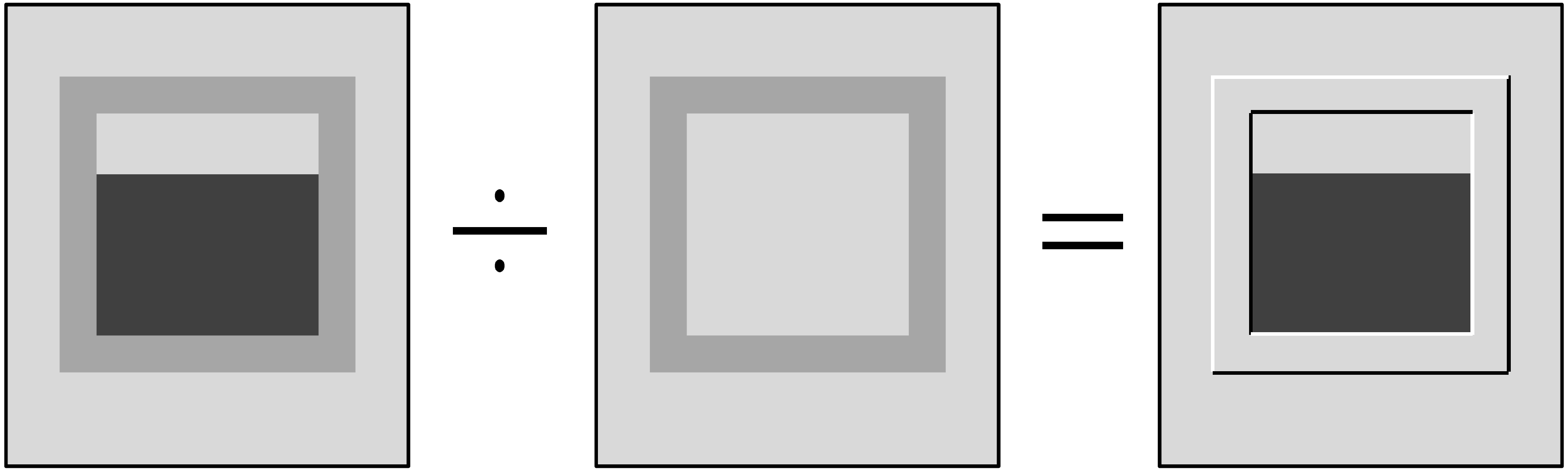
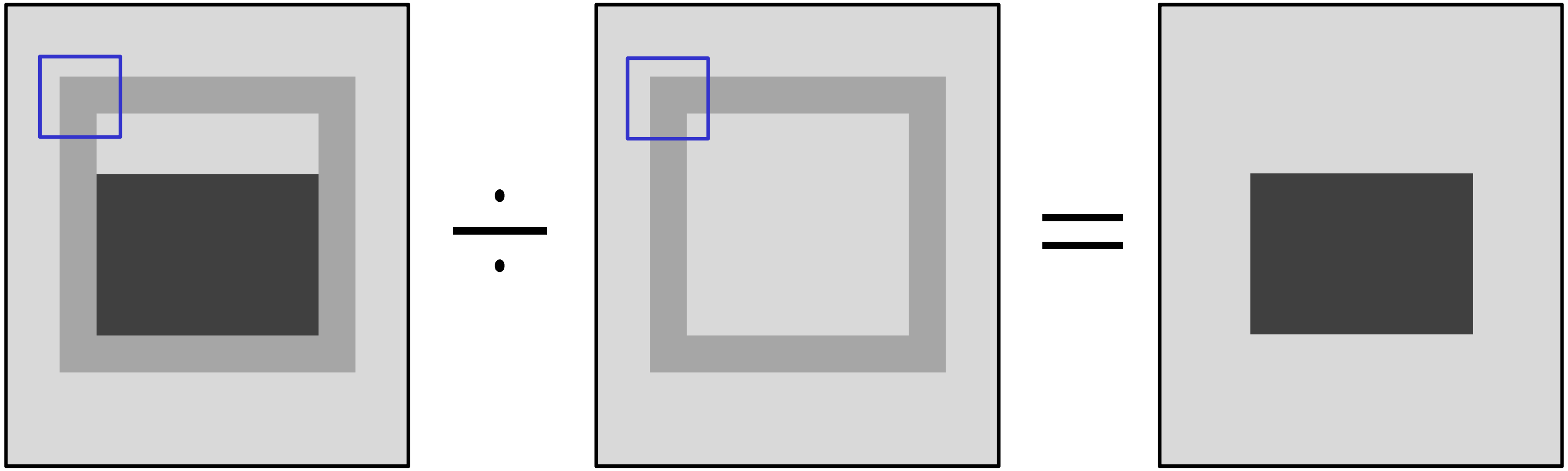


Image processing: specificities of dynamic imaging

Referencing and registration

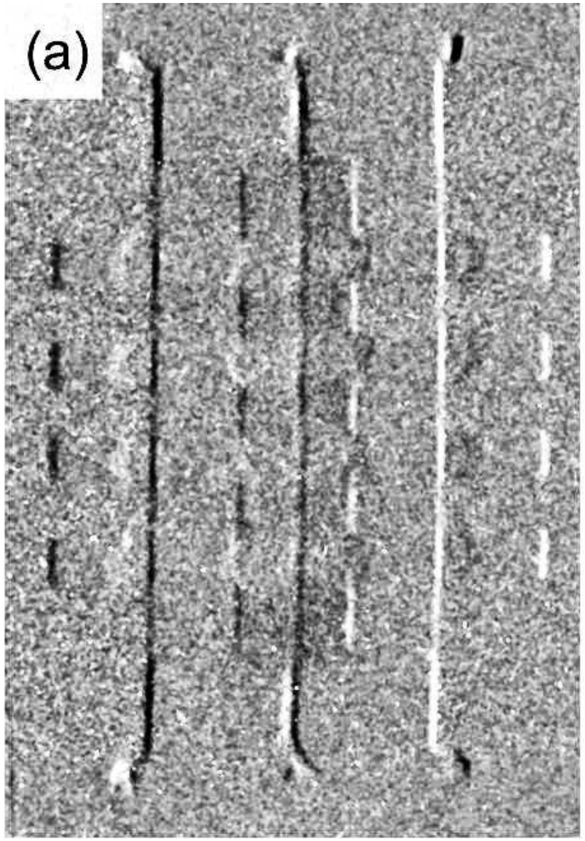


Referencing and registration



Referencing and registration

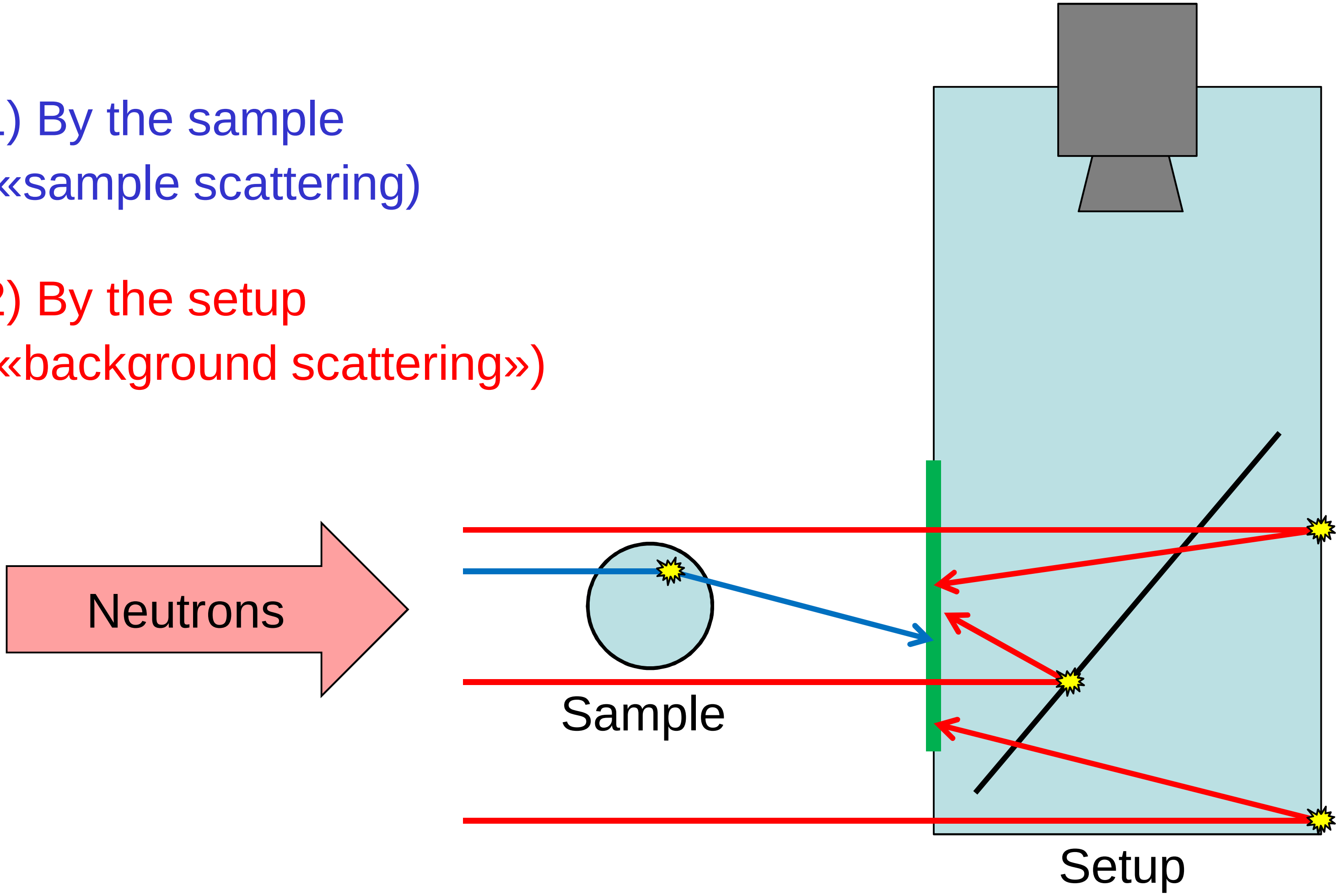
Without registration



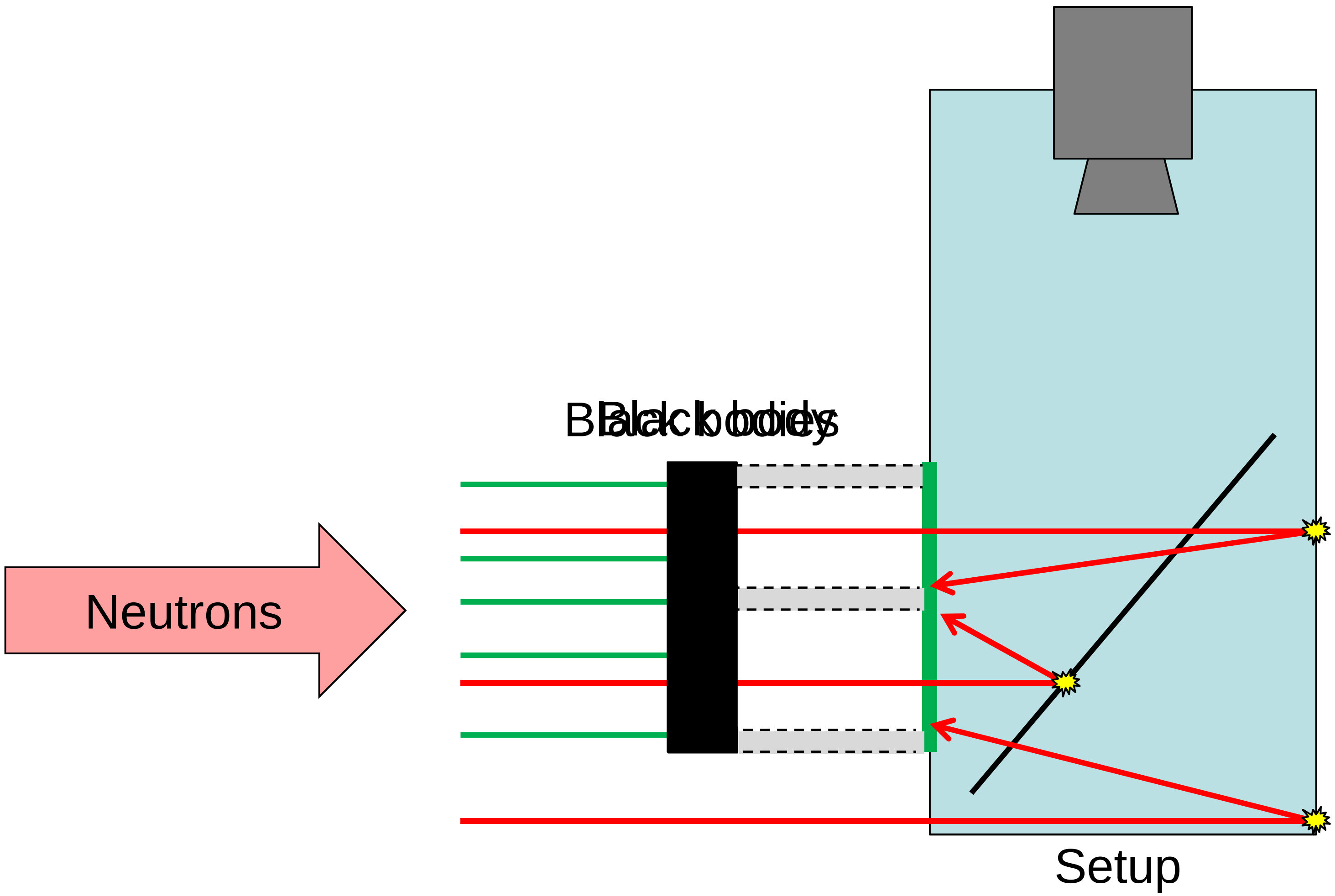
Scattered neutrons

1) By the sample
(«sample scattering)

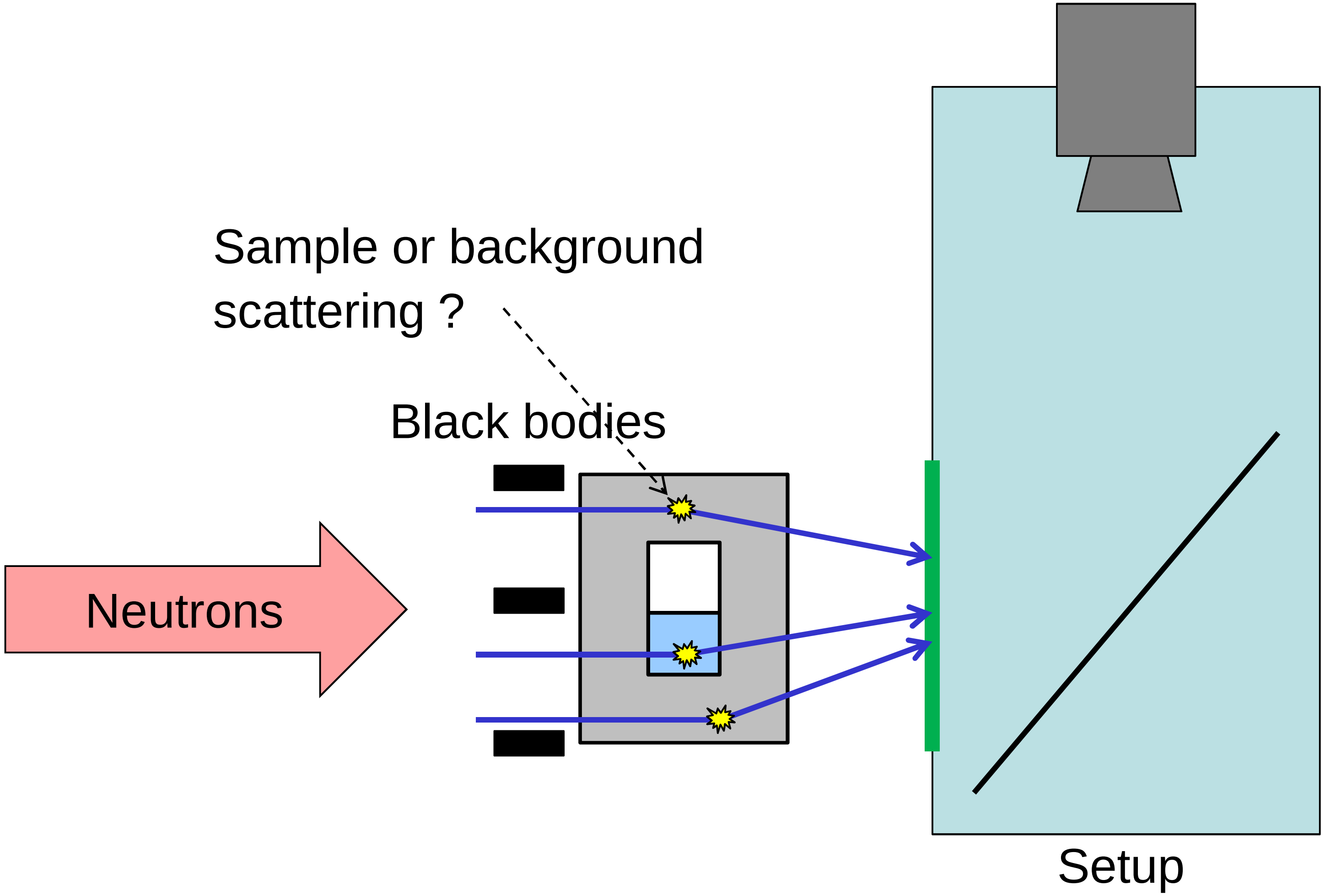
2) By the setup
(«background scattering»)



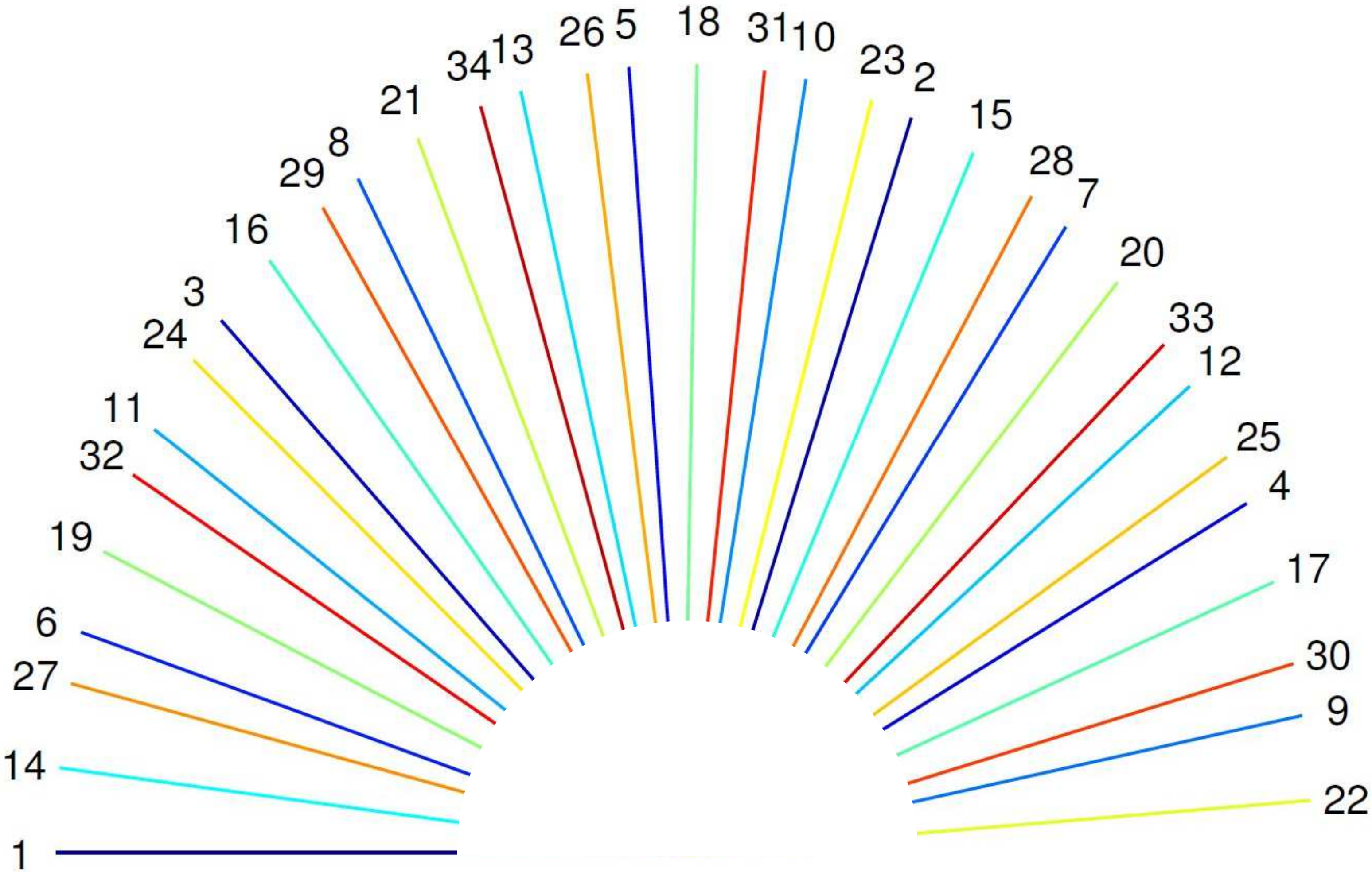
Correction of scattered background



Correction of scattered background



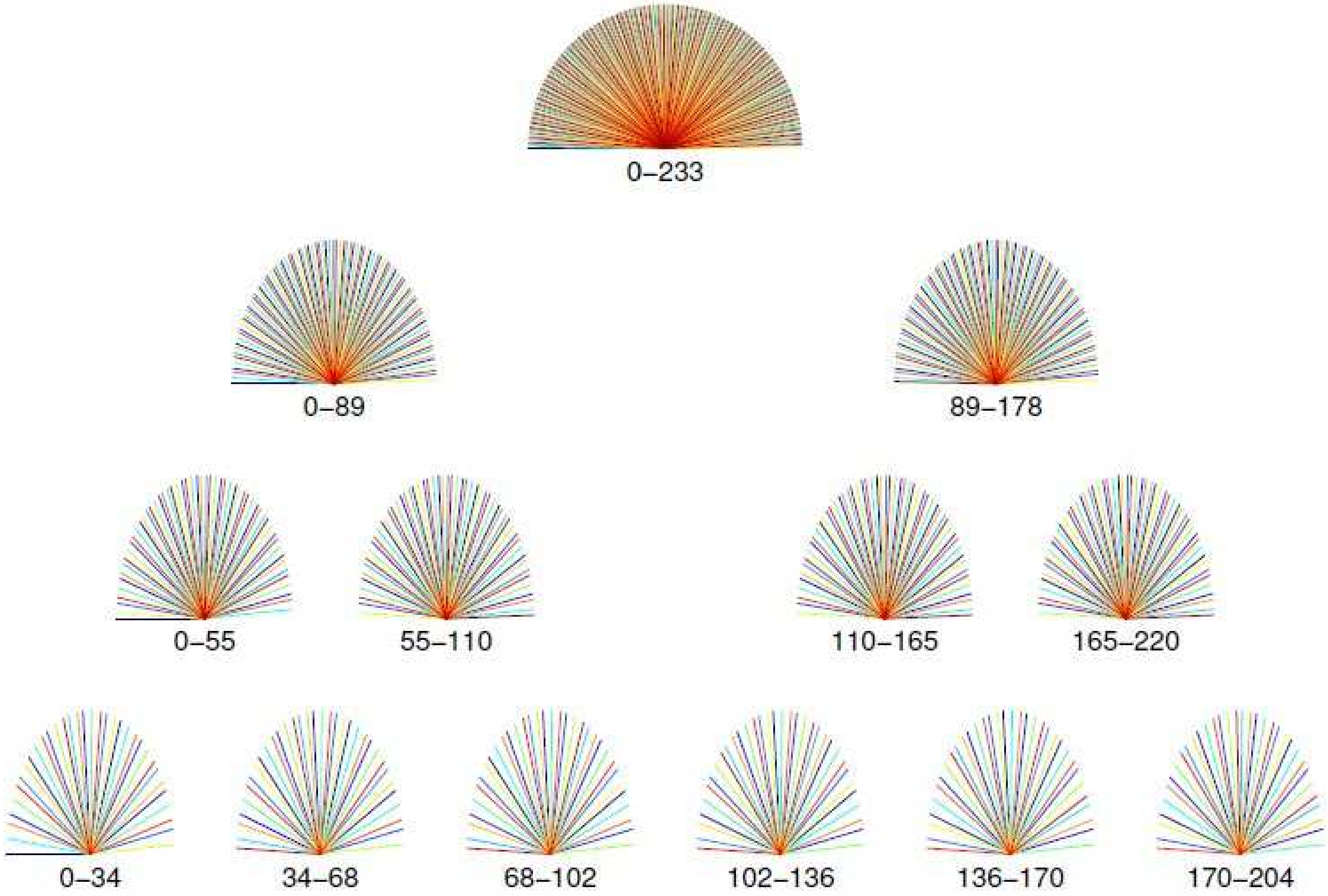
Golden ratio tomography



Golden ratio tomography

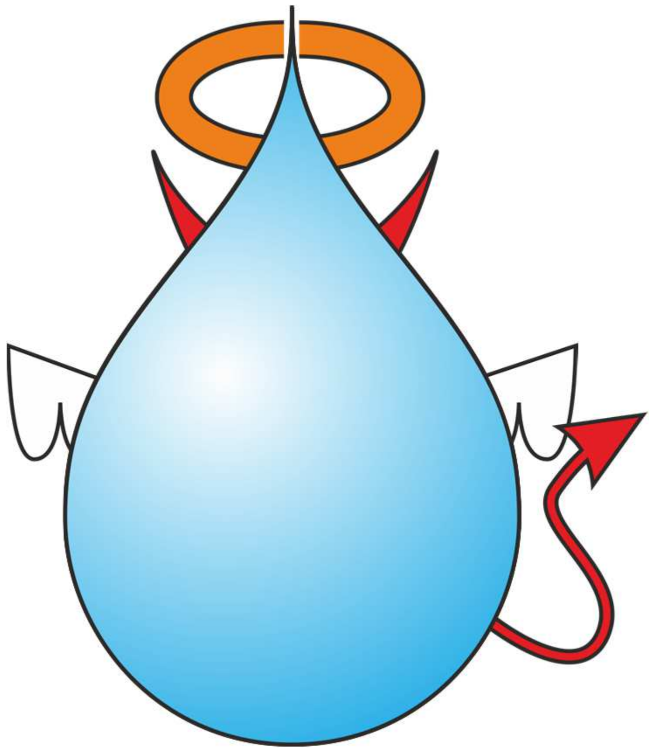
4D imaging

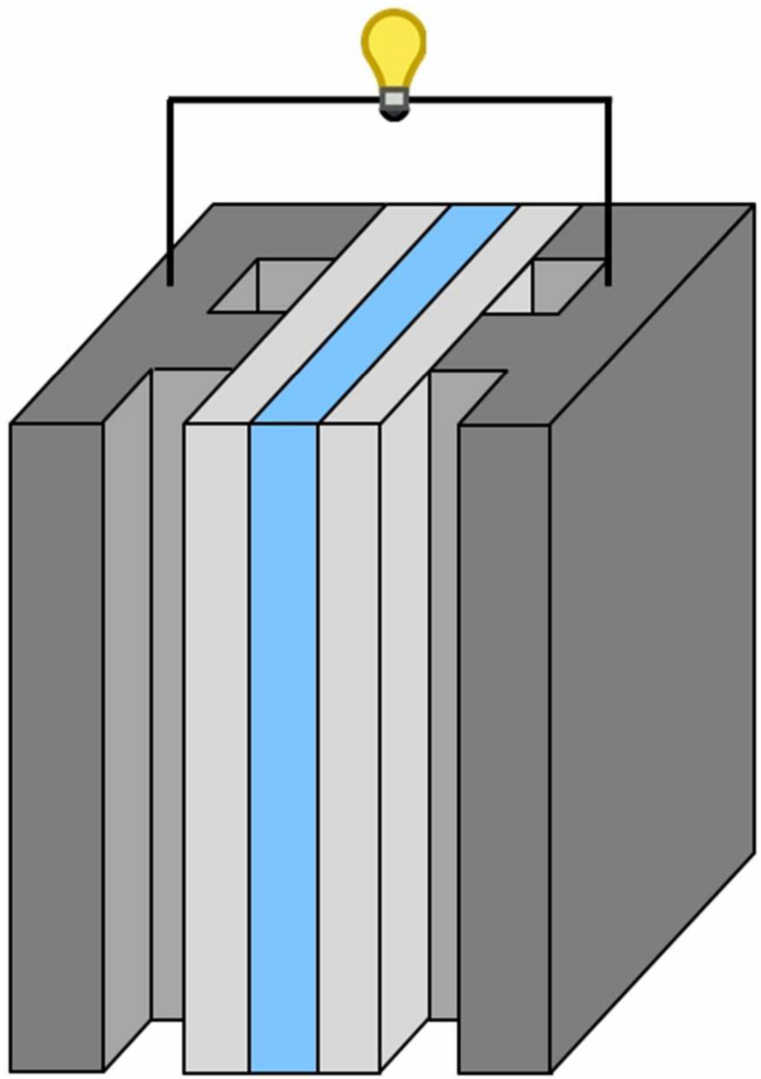
Golden ratio tomography: each subset is well distributed



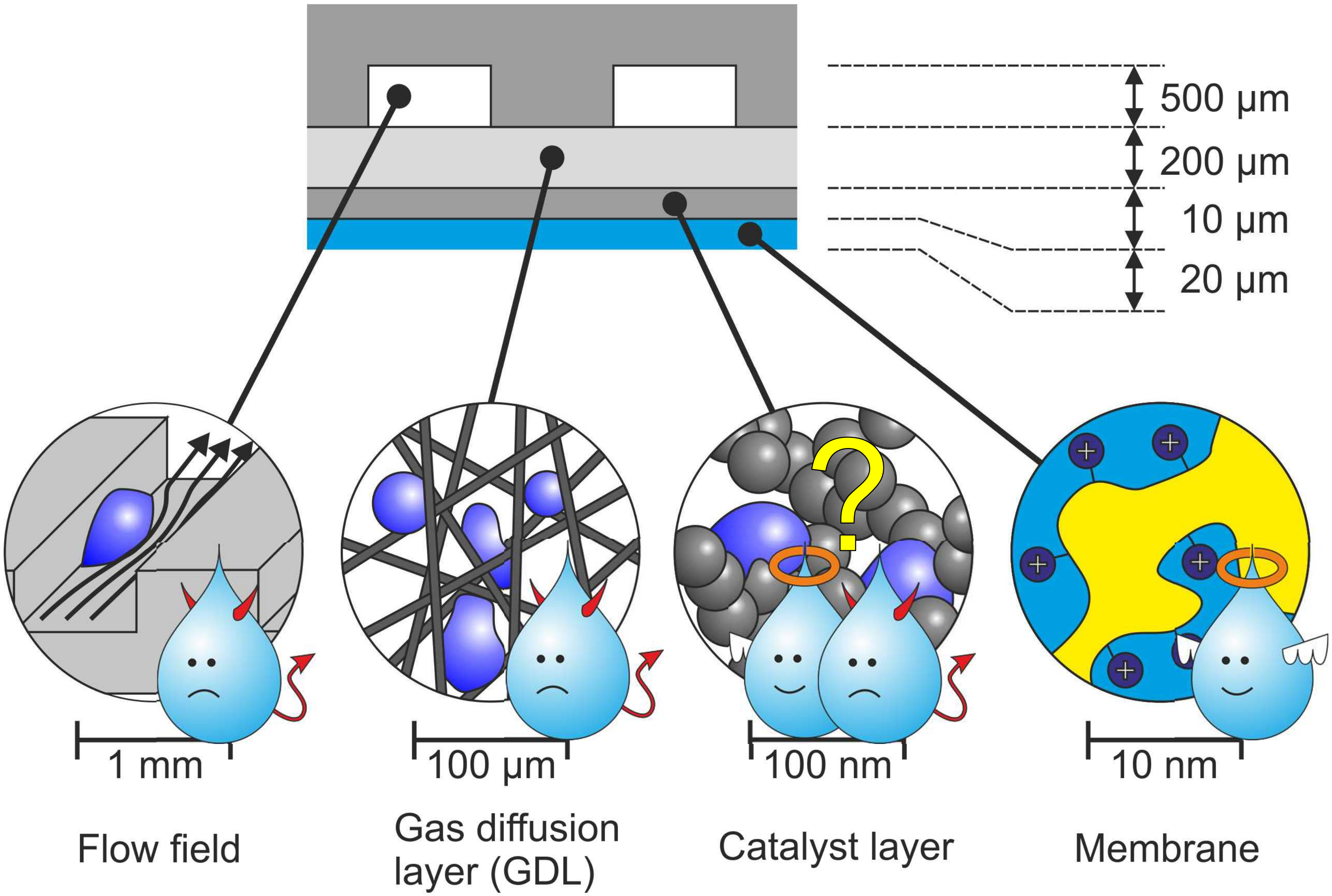
Examples from fuel cell research

Water management – what‘s the problem ?





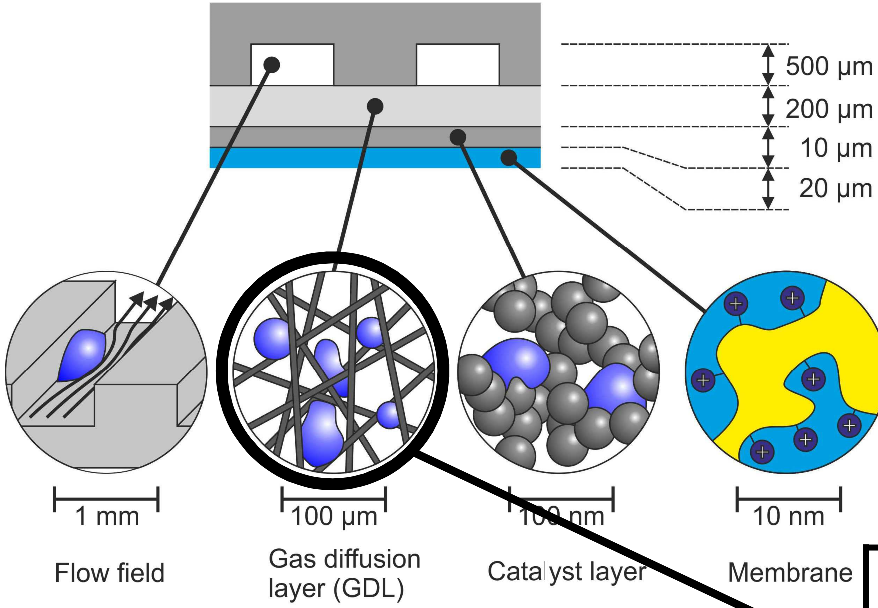
Water management – what's the problem ?

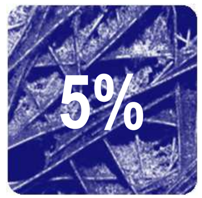


Examples from fuel cell research

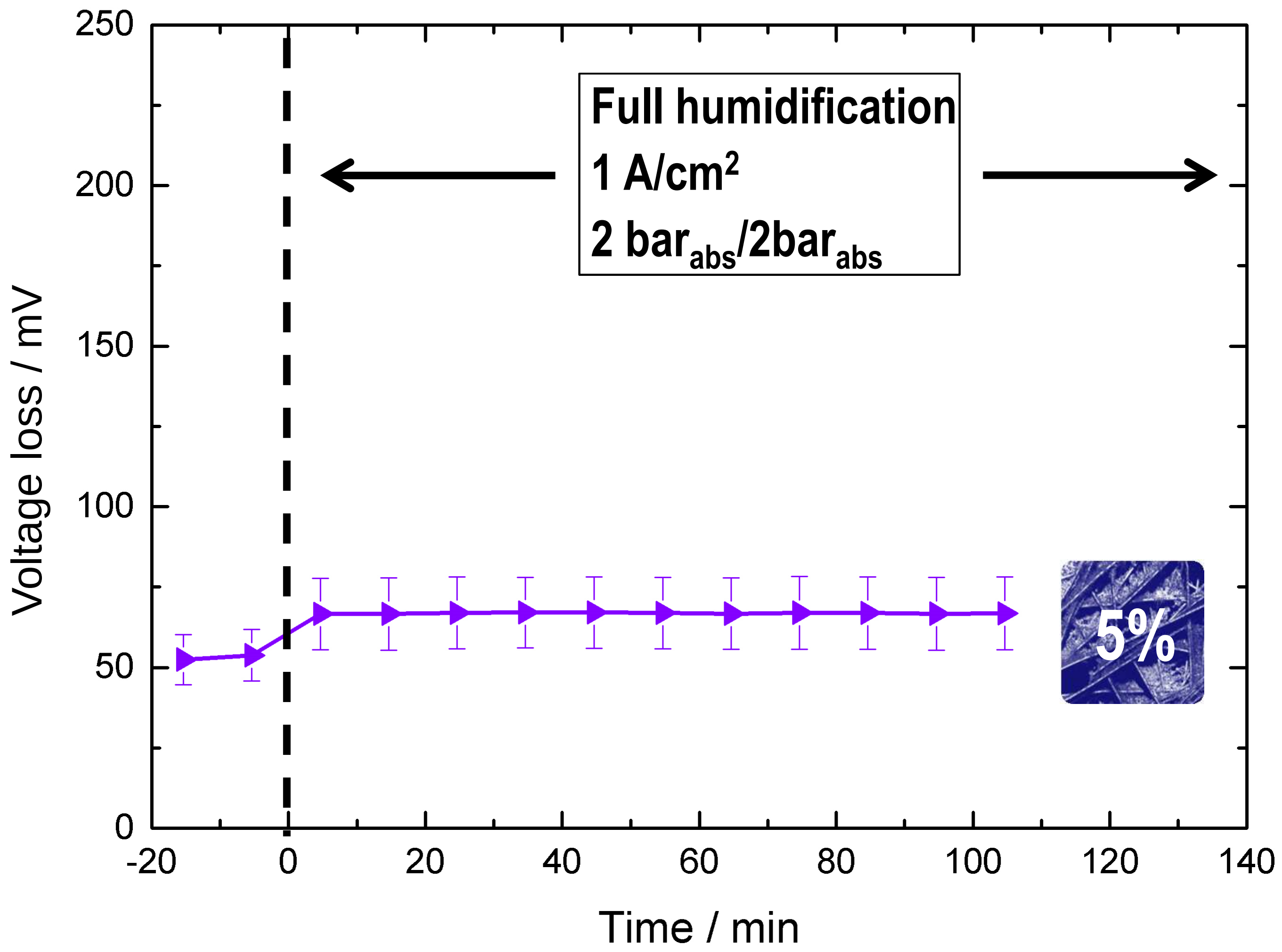
1) Impact of water accumulation on performance

Water in GDL – Materials

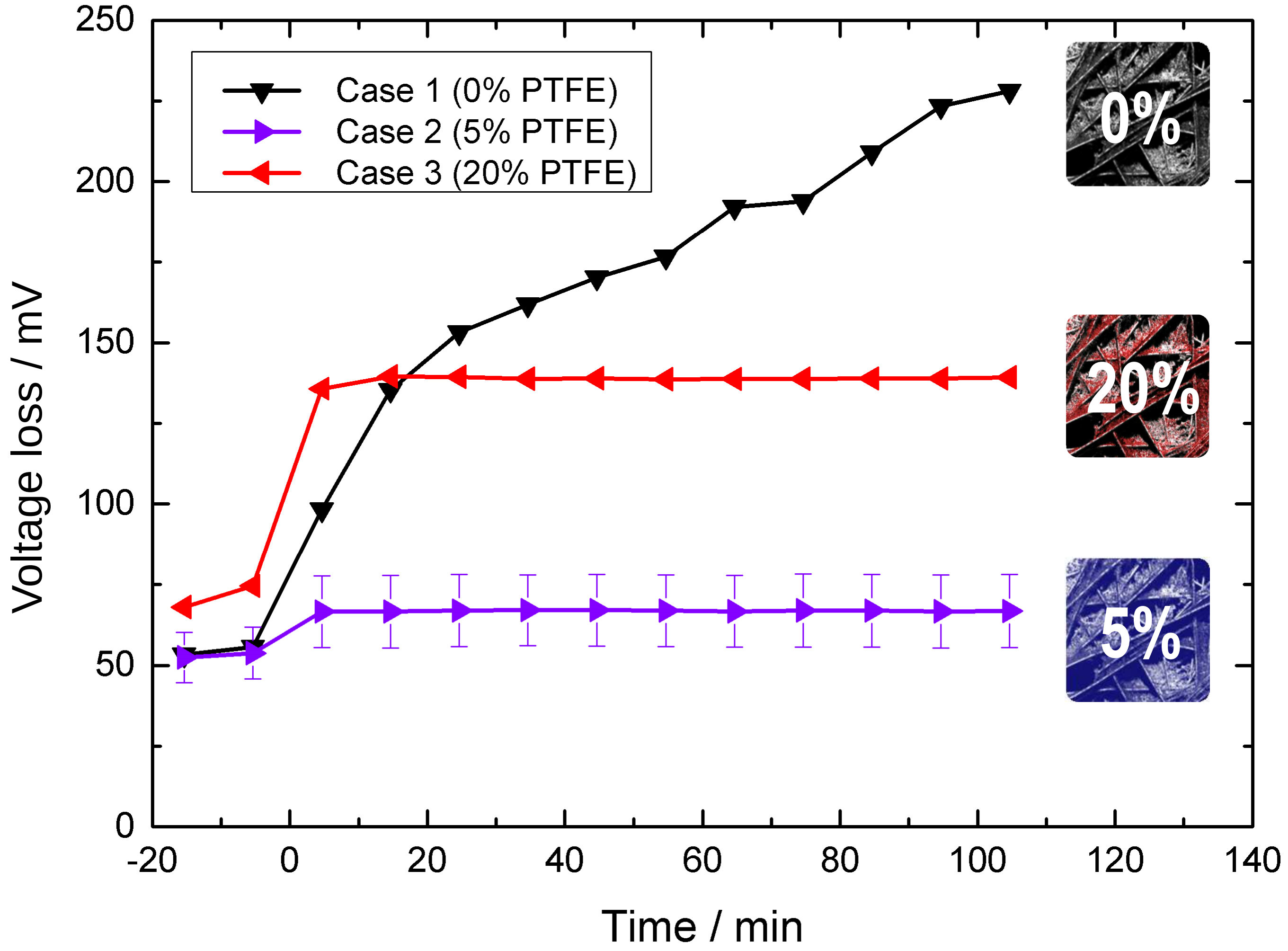


			
	Case 1	**Case 2**	**Case 3**
Cathode GDL	No PTFE	Optimal PTFE content	Too high PTFE content

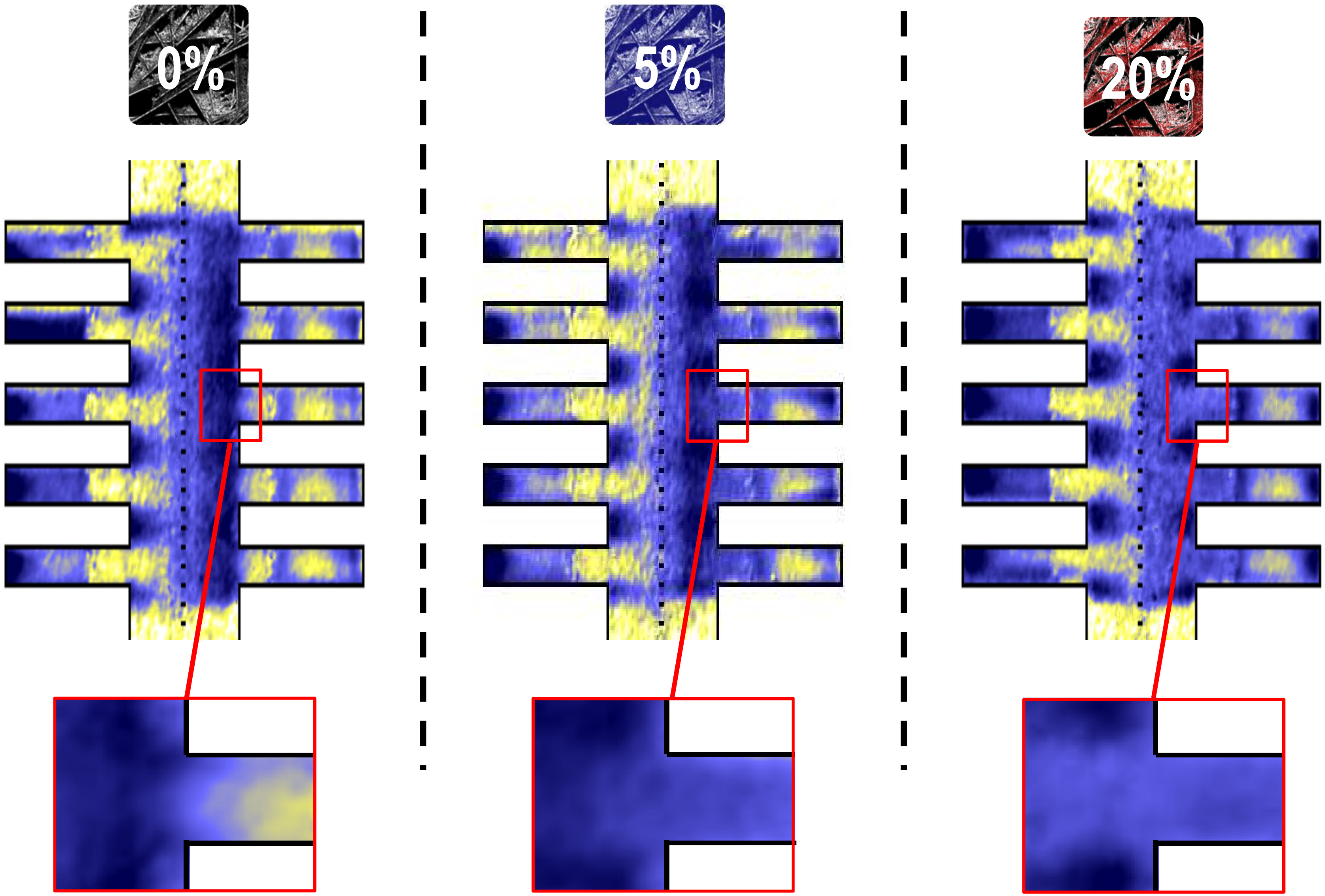
Water in GDL – Results



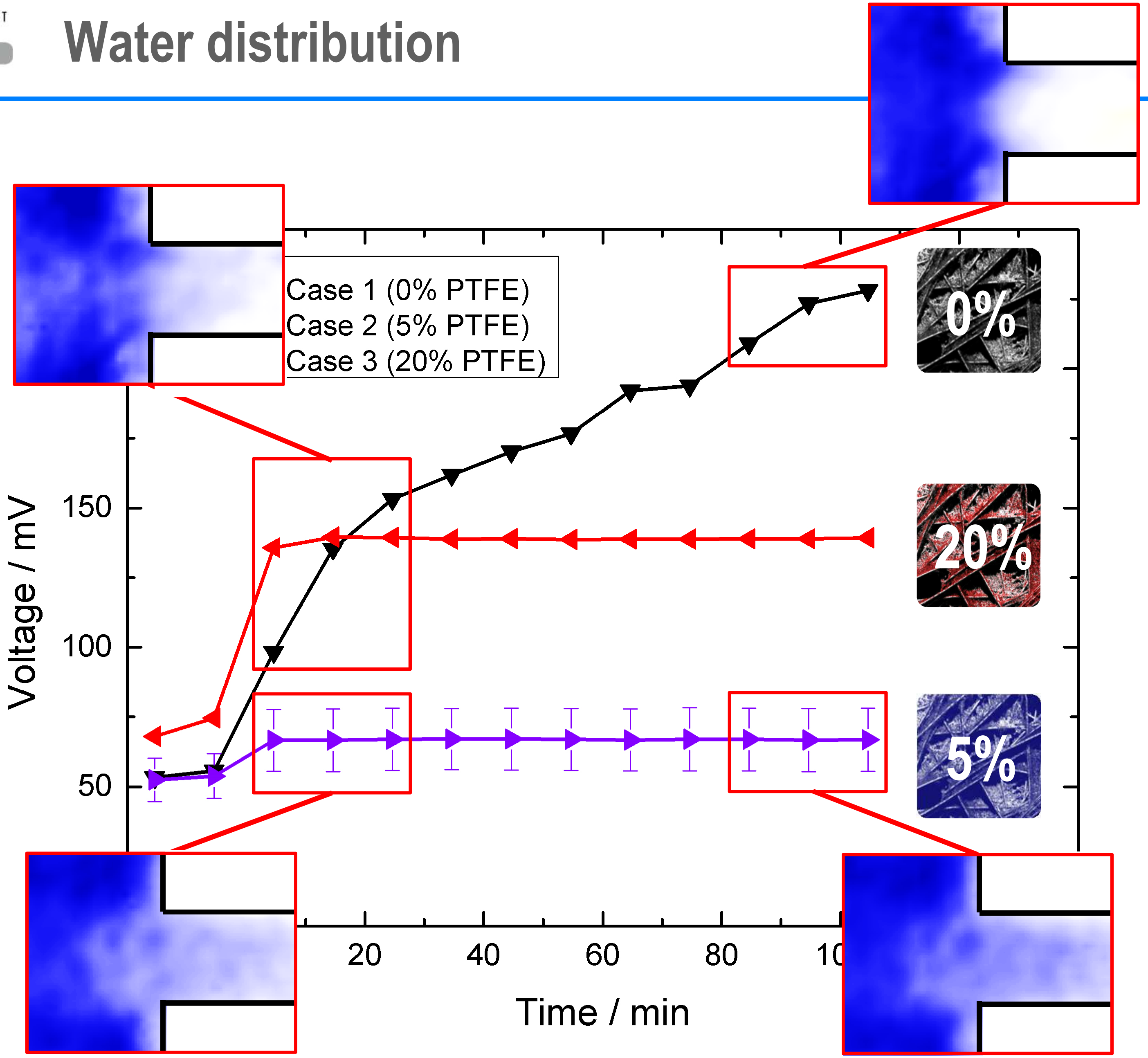
Mass transport losses



Water distribution



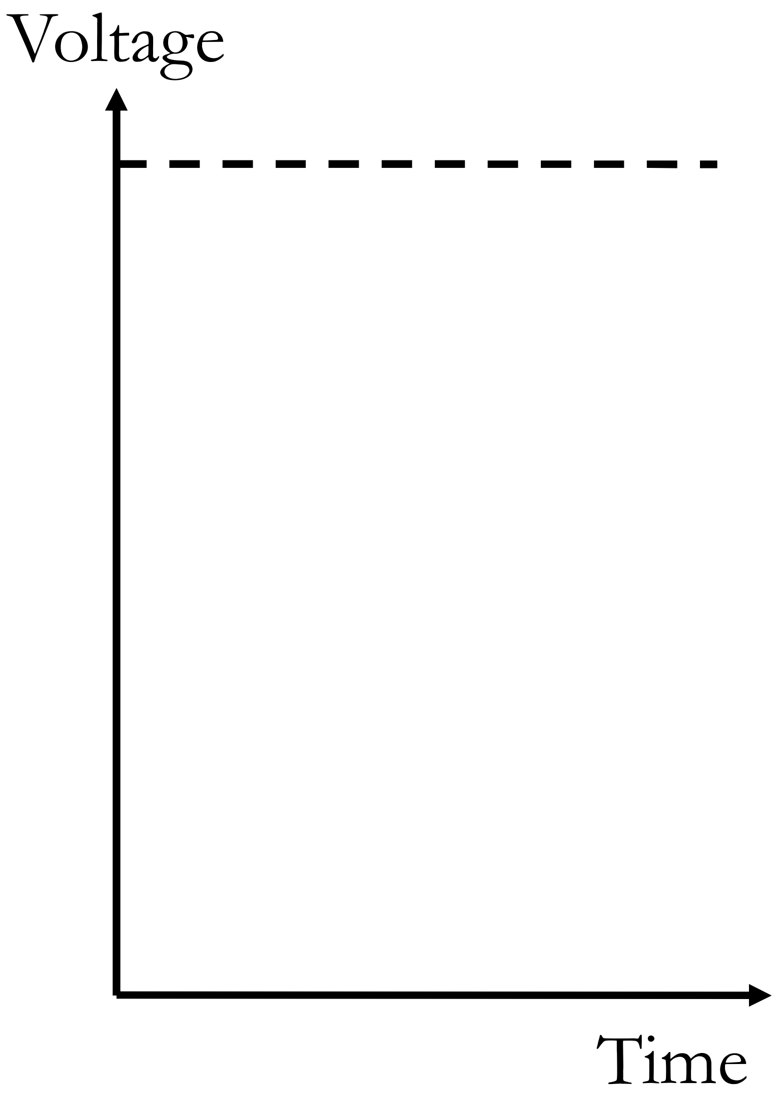
Water distribution

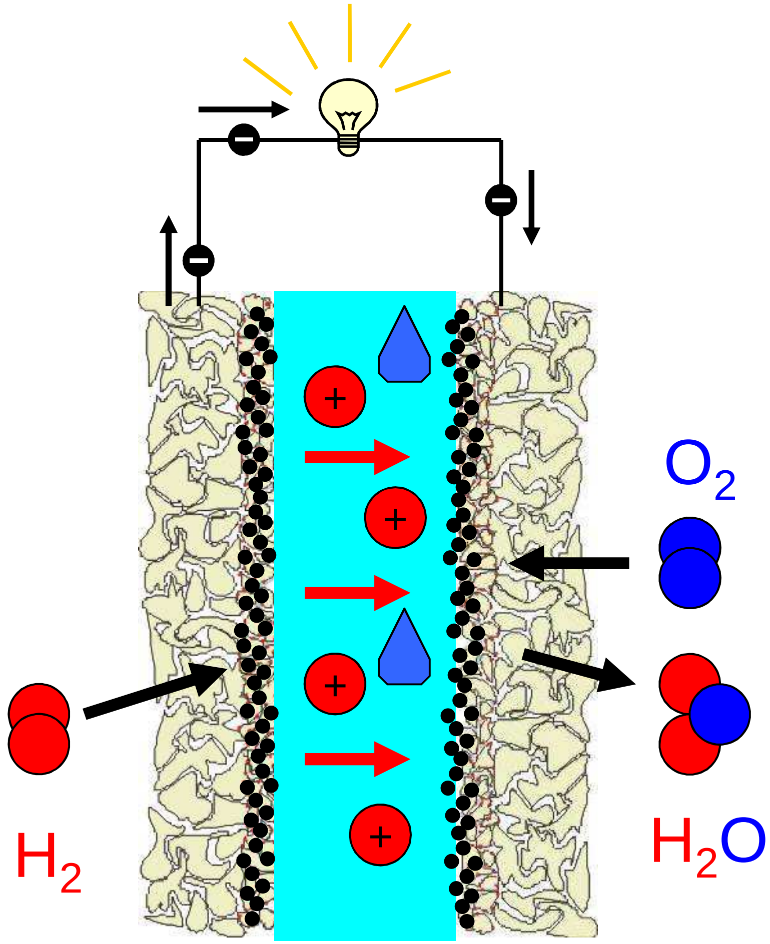


Examples from fuel cell research

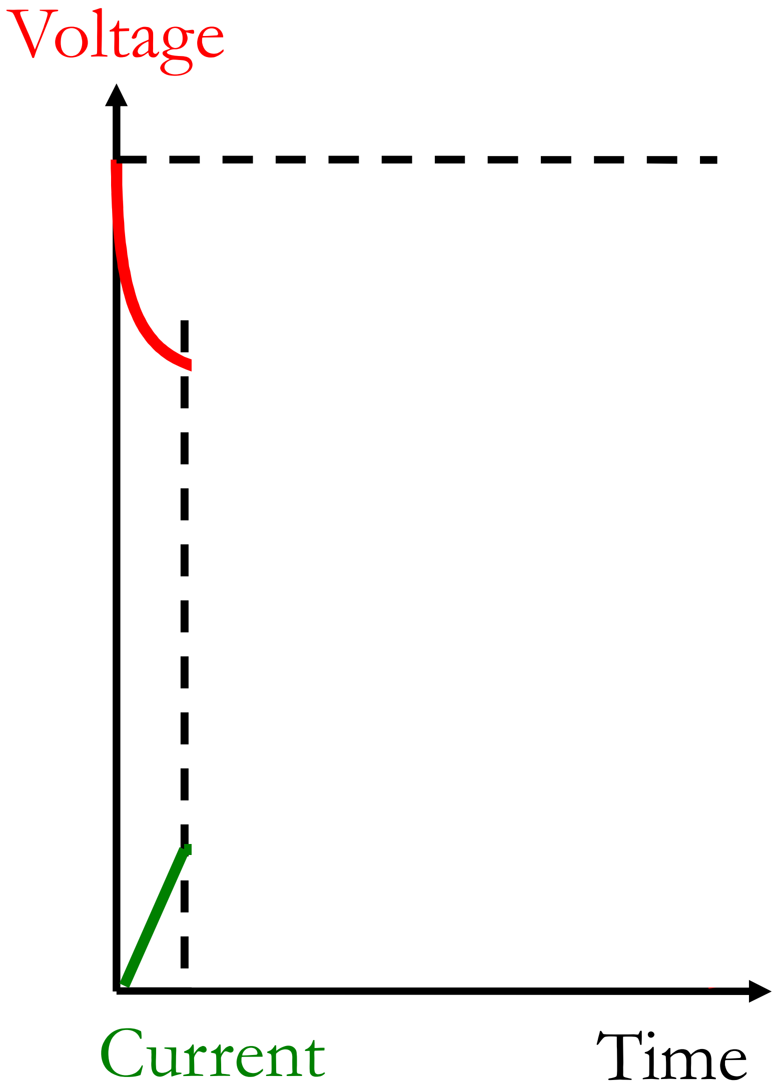
2) Startup at sub-freezing temperatures

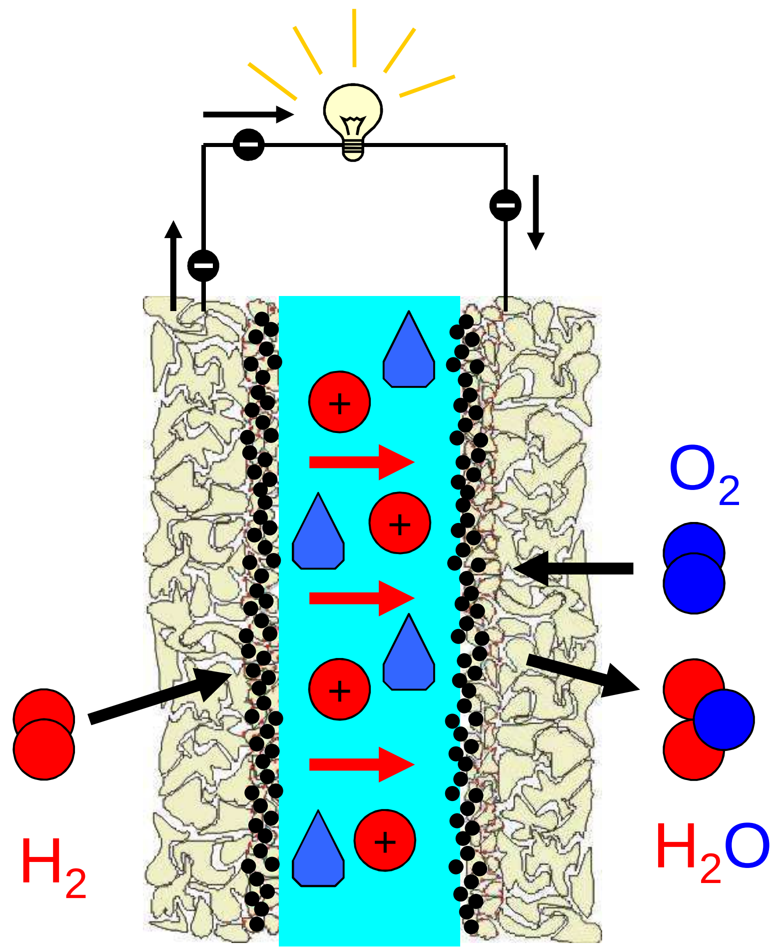
Sub-zero startup – Motivation



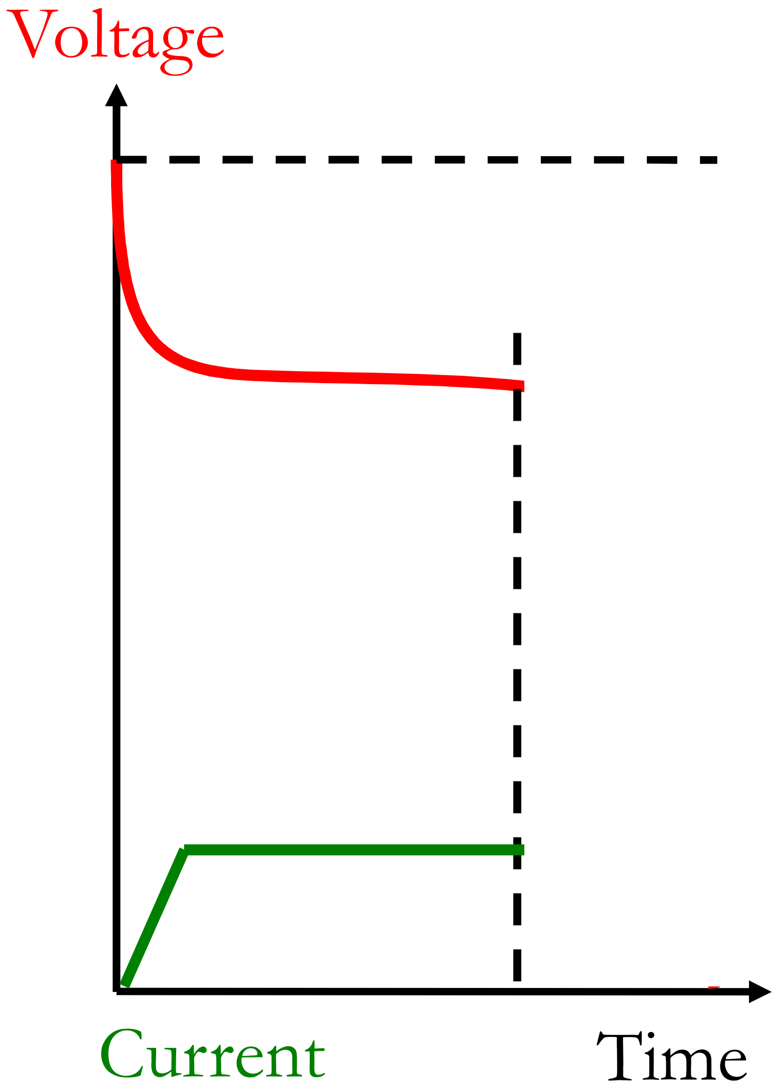


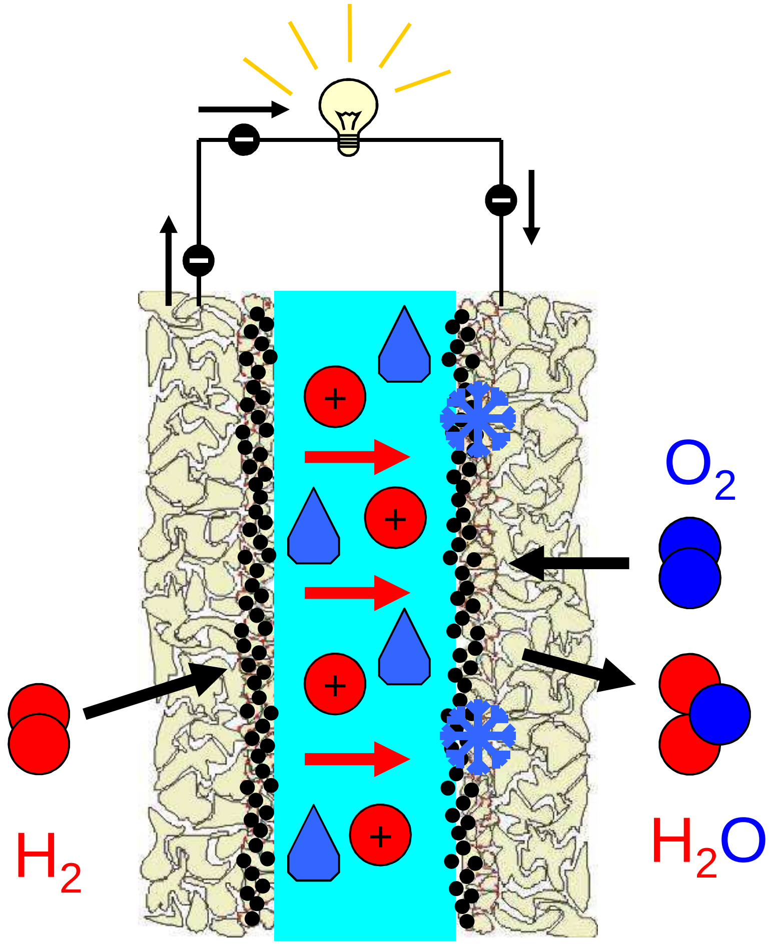
Sub-zero startup – Motivation



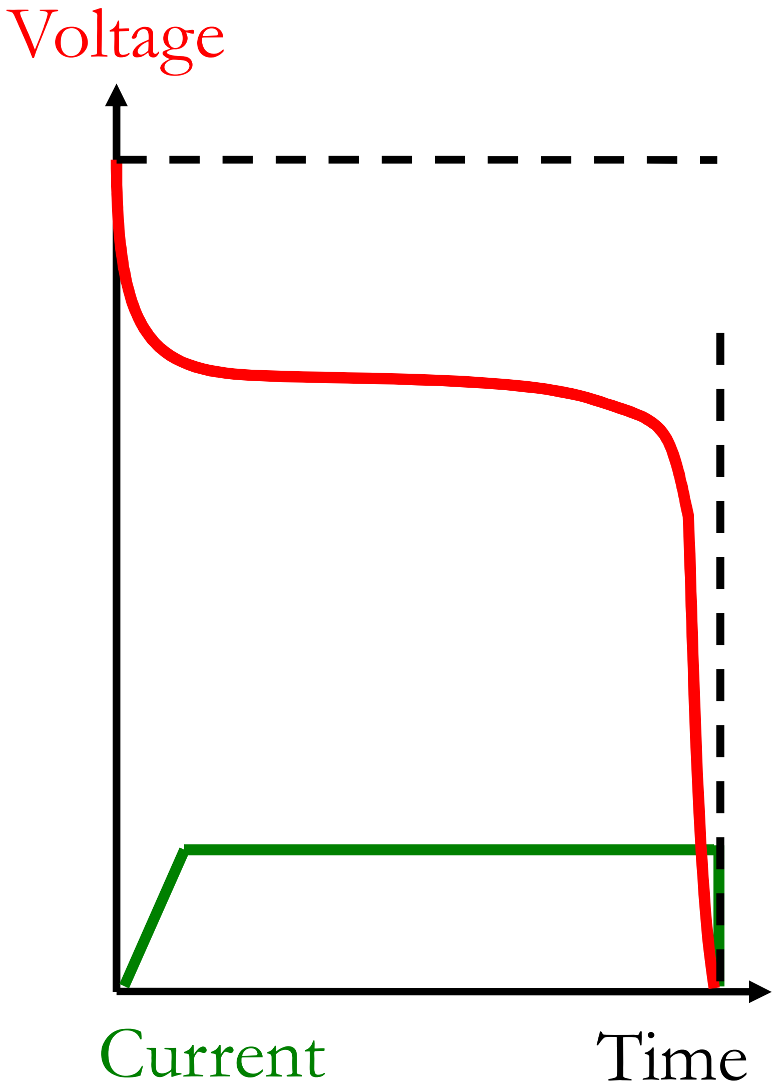


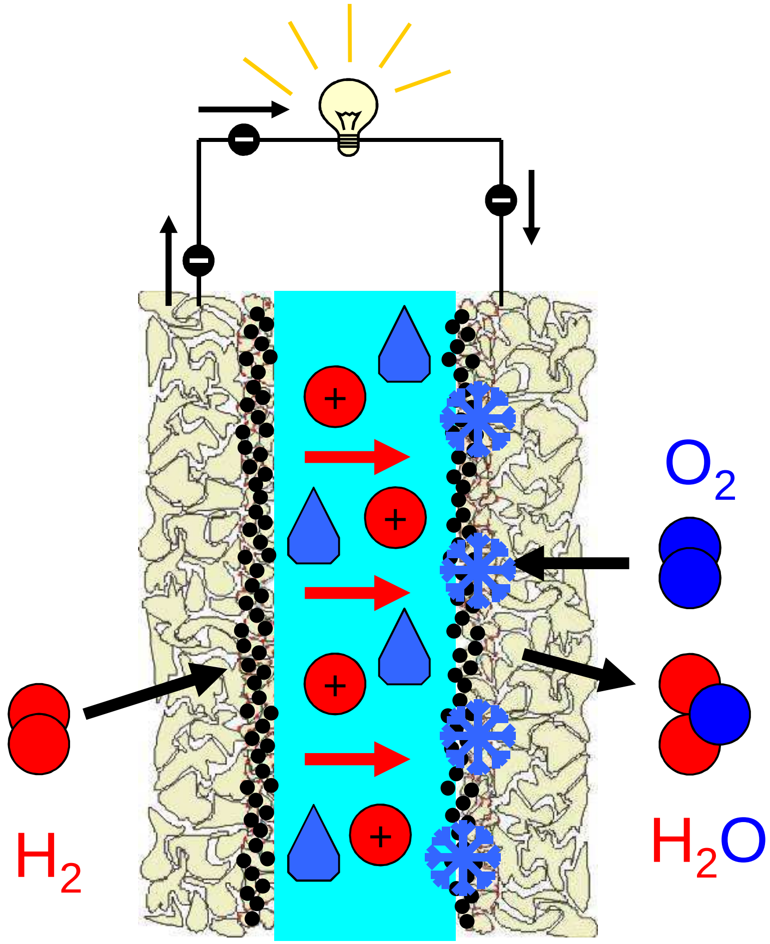
Sub-zero startup – Motivation



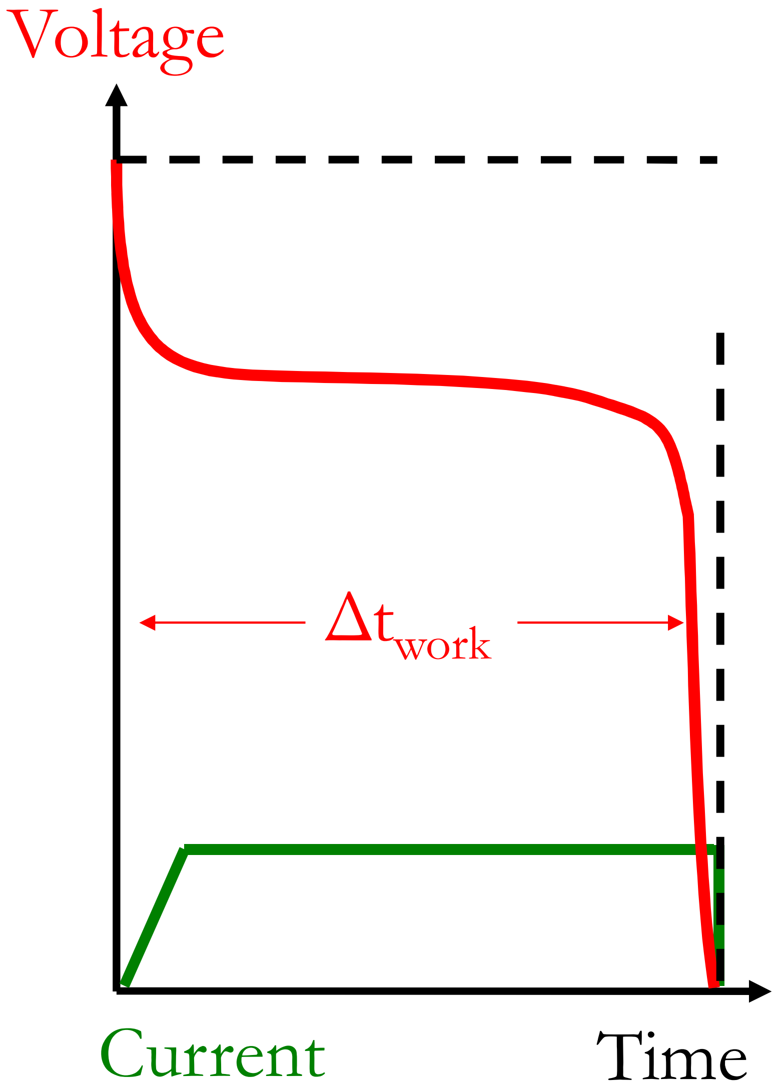


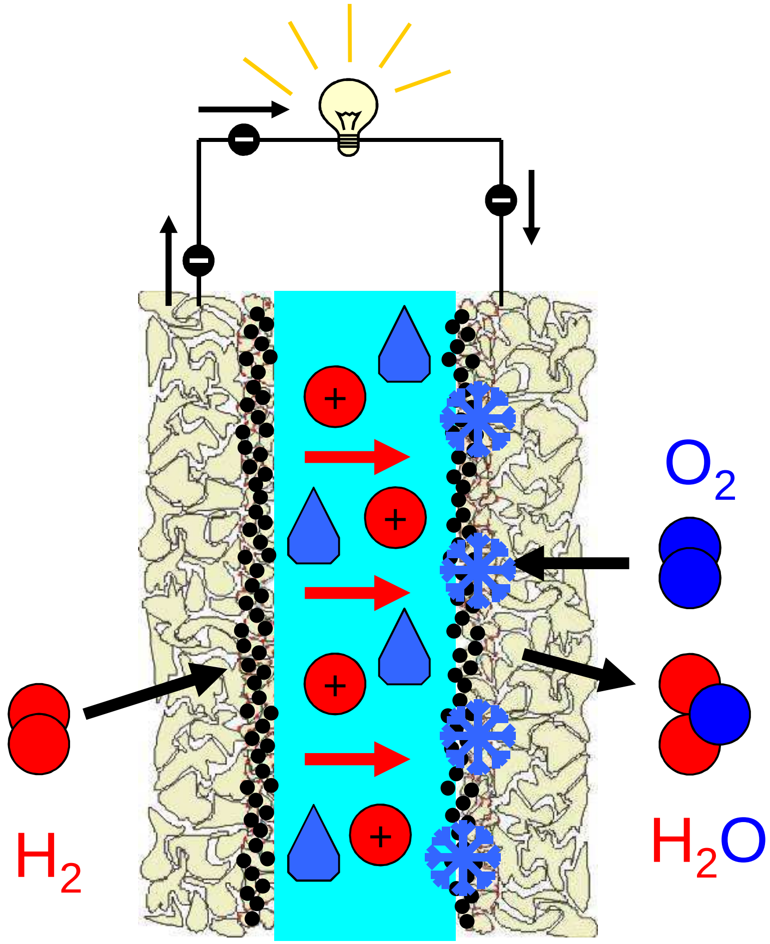
Sub-zero startup – Motivation



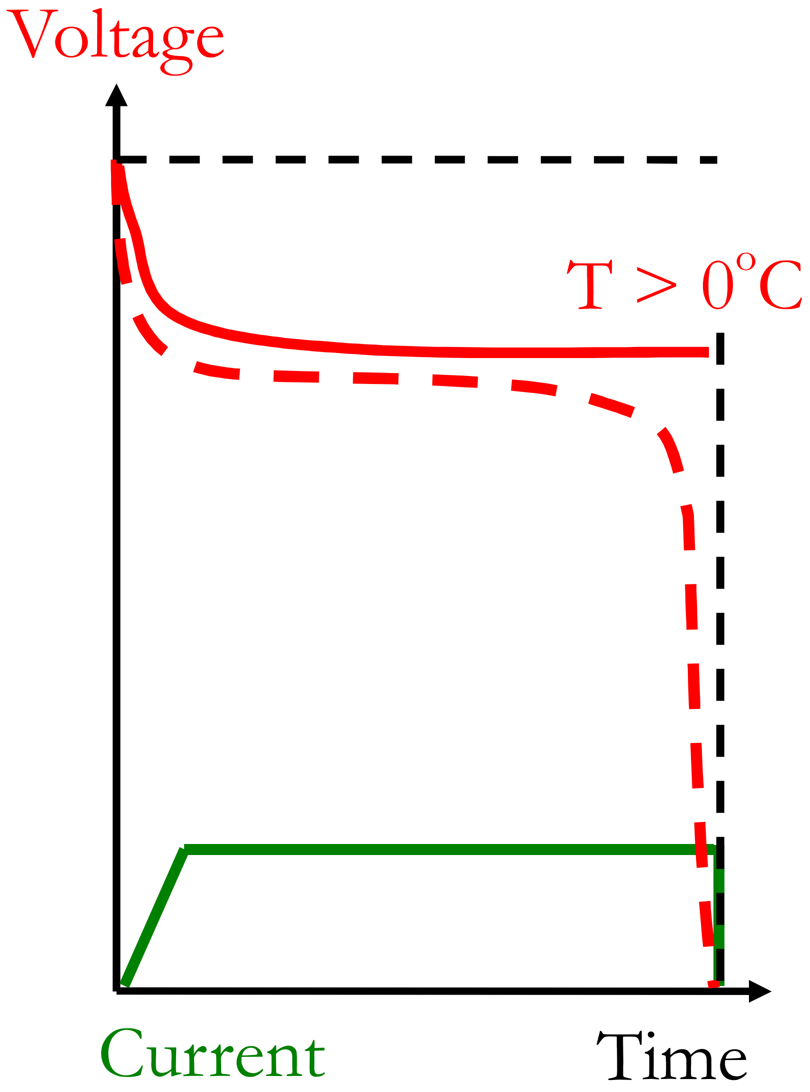


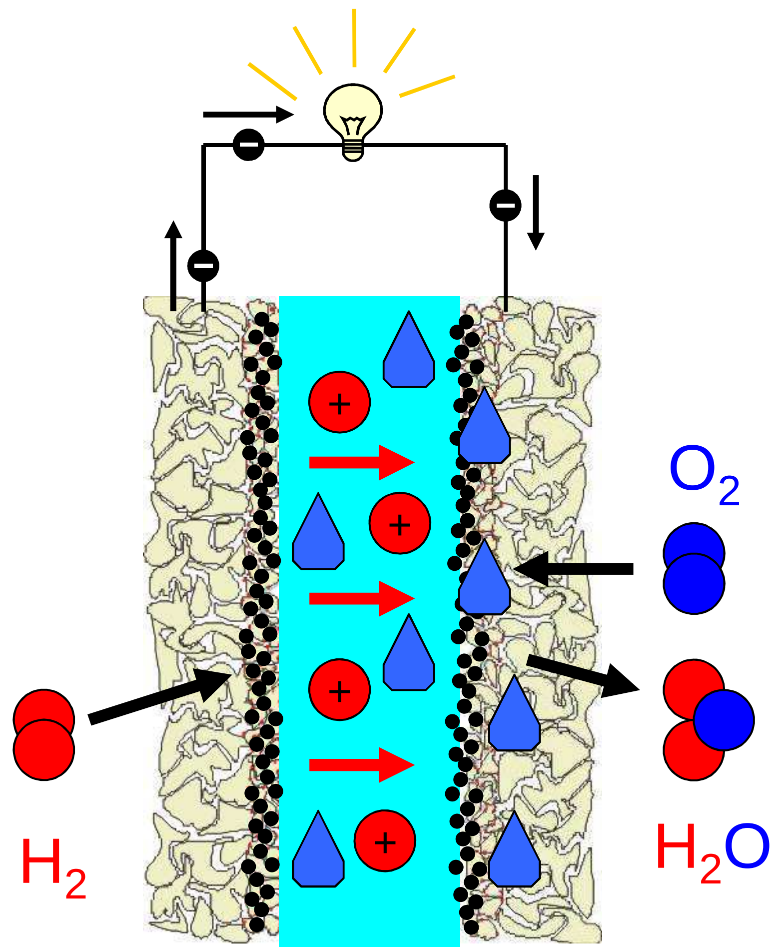
Sub-zero startup – Motivation





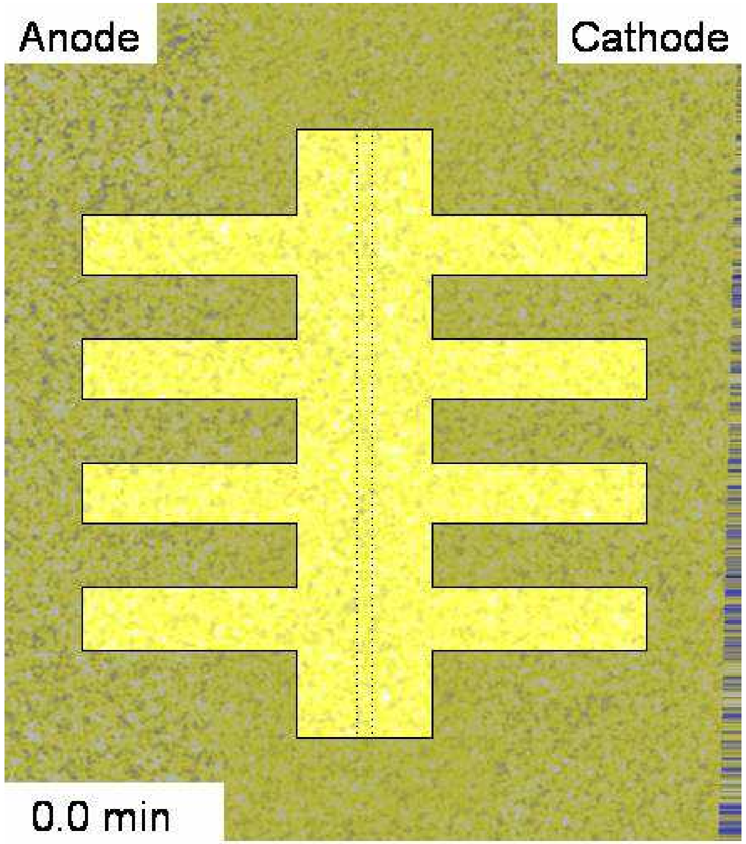
Sub-zero startup – Motivation





Sub-zero startup – Results

T = -10^{o}C, i = 0.2 A/cm^2

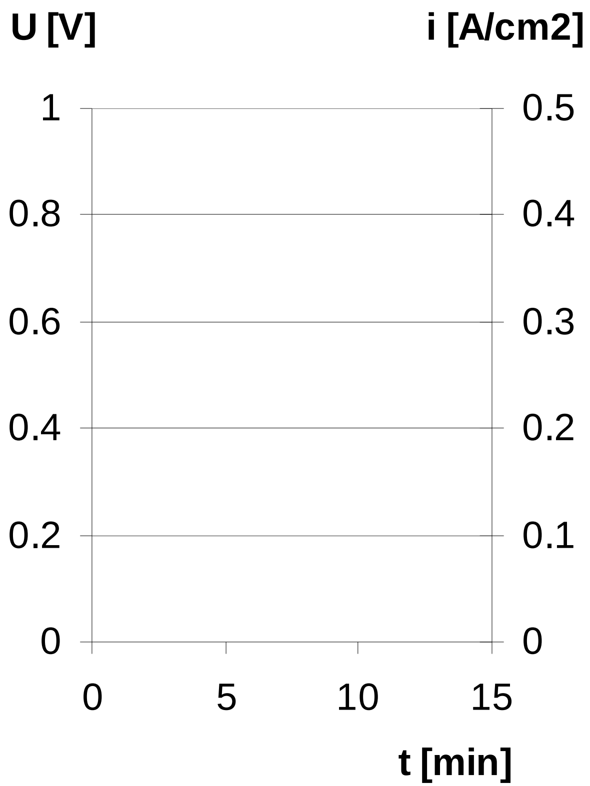


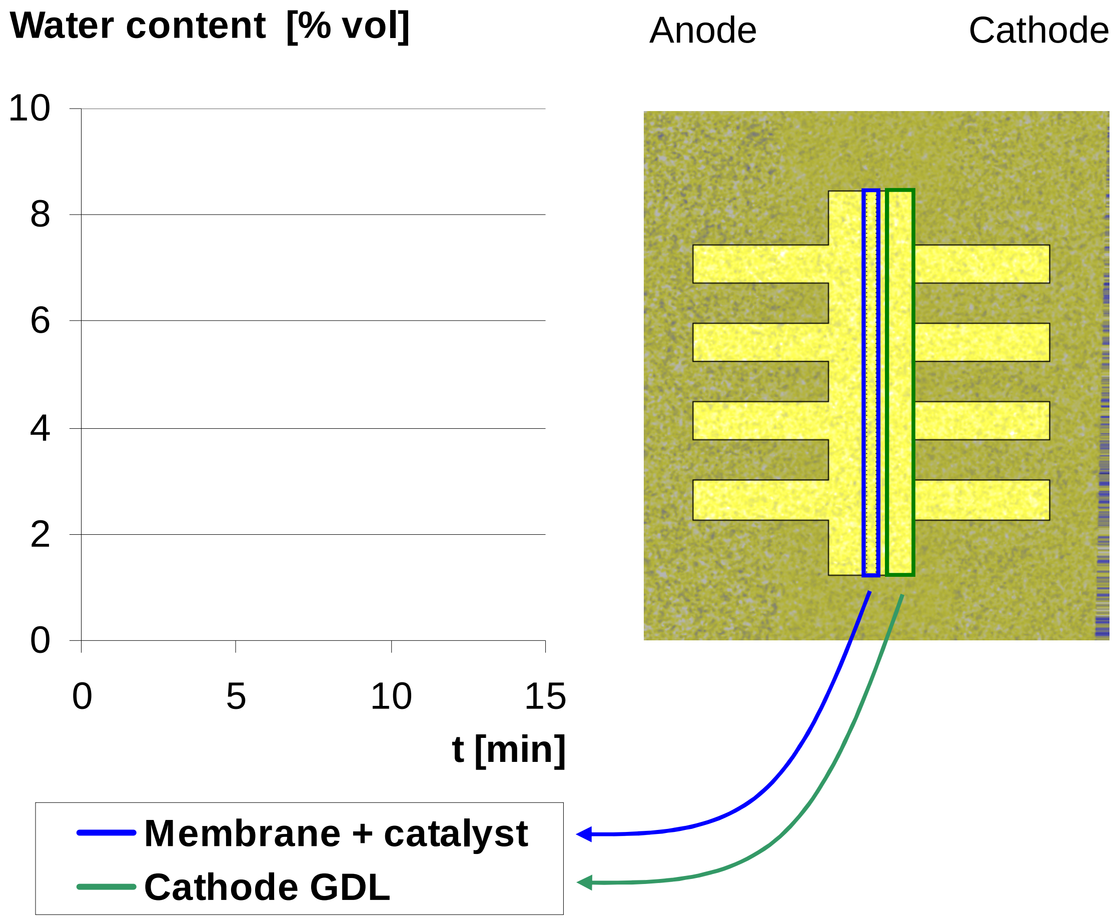
Cold-start at -10°C and 0.2 A/cm2 of a PEFC
(Polymer Electrolyte Fuel Cell).

Paul Scherrer Institut, Switzerland
P.Oberholzer, P.Boillat, R.Siegrist, R.Perego, A.Kaestner, E.H.Lehmann
G.G.Scherer, A.Wokaun

Sub-zero startup – Results

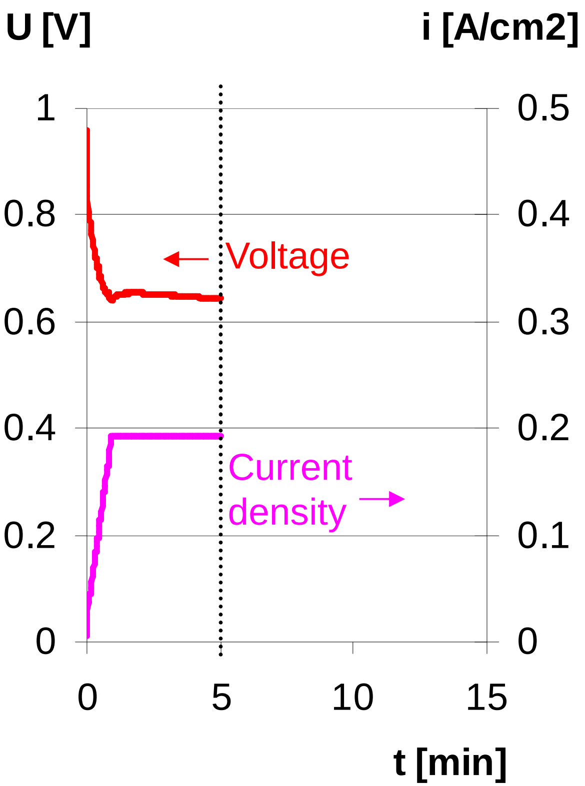
T = -10°C, i = 0.2 A/cm²

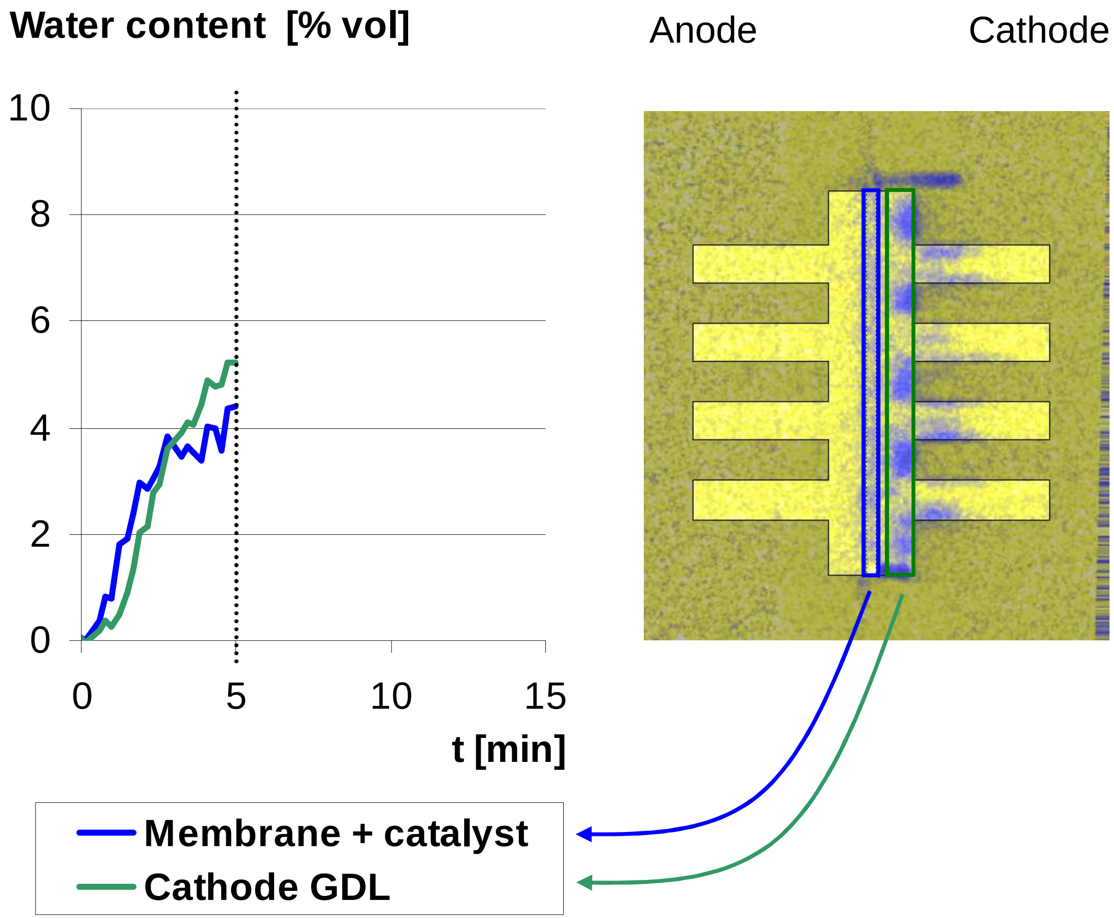




Sub-zero startup – Results

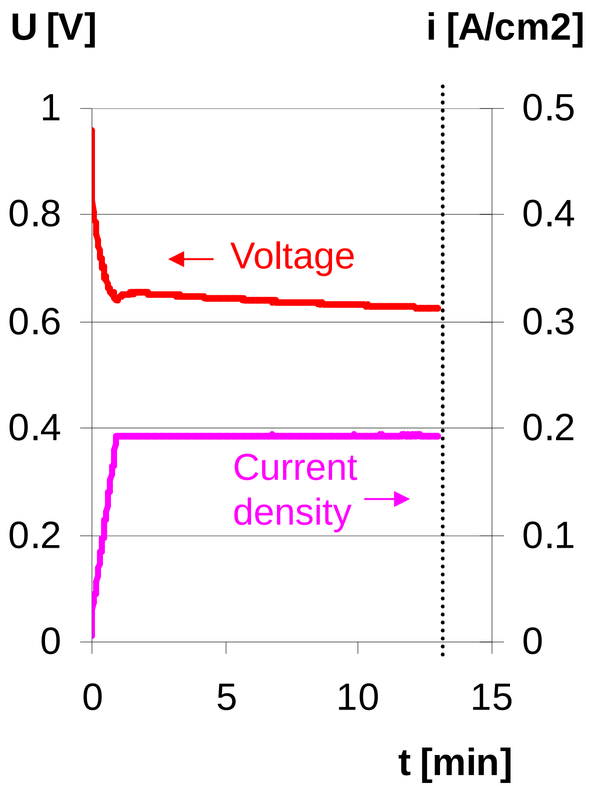
$T = -10^{o}C$, $i = 0.2\ A/cm^2$

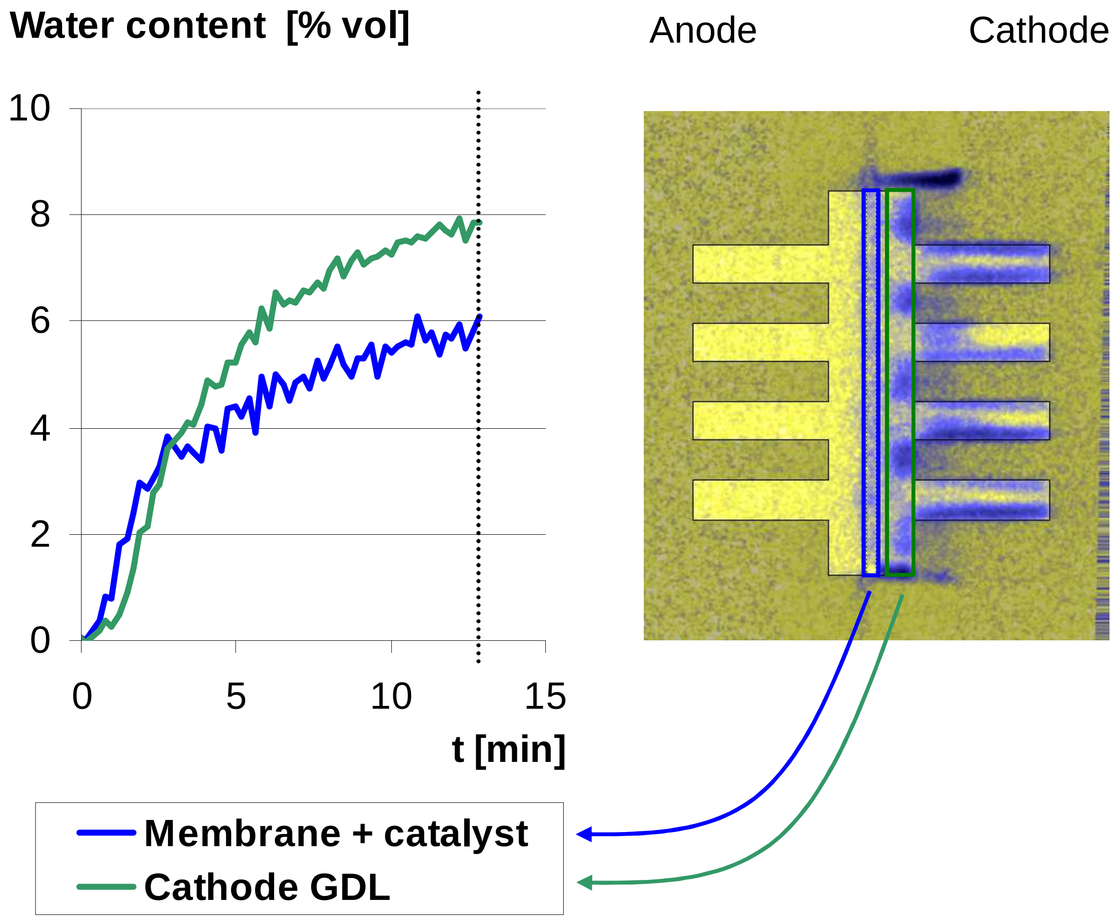




Sub-zero startup – Results

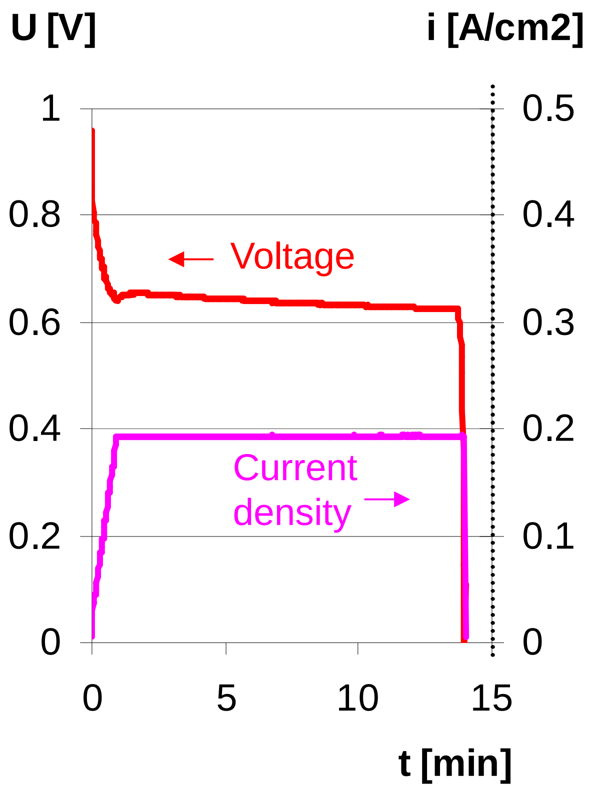
T = -10°C, i = 0.2 A/cm²

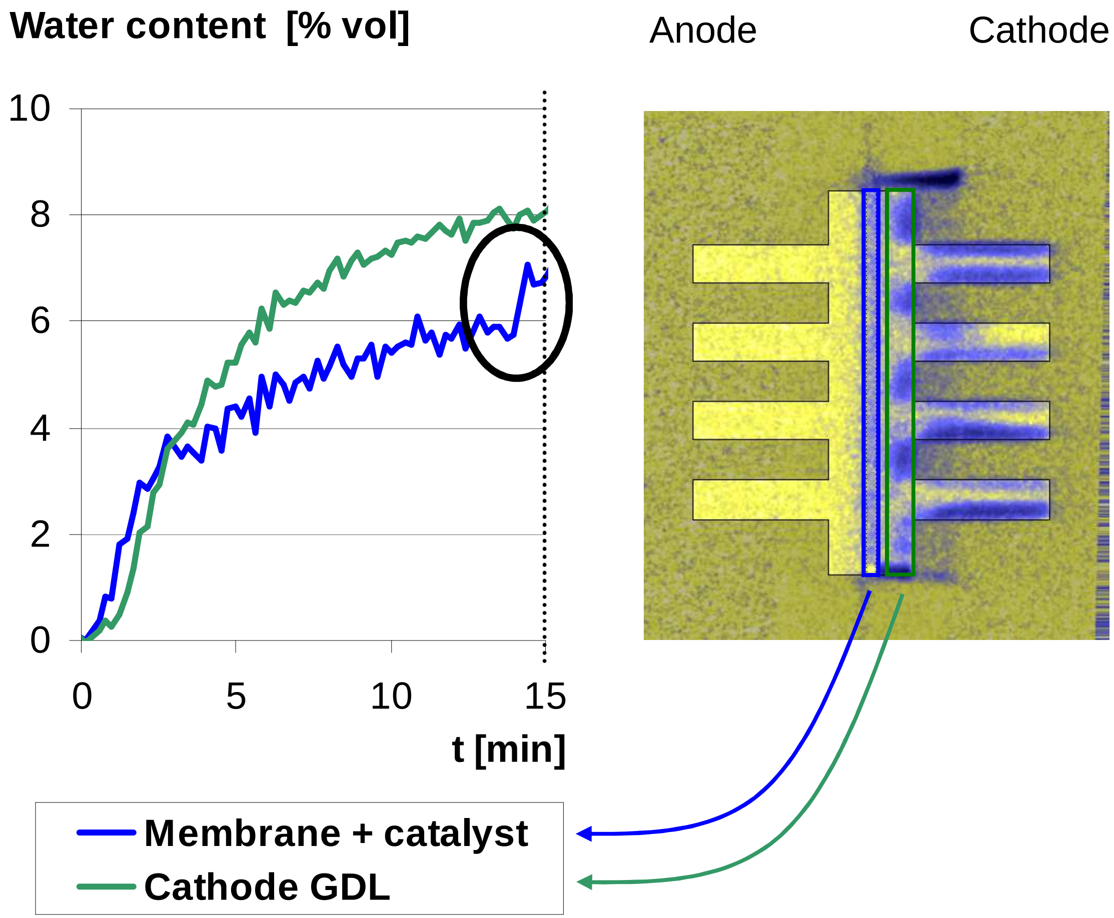




Sub-zero startup – Results

T = -10°C, i = 0.2 A/cm^2





Sub-zero startup – Interpretation

- How can liquid water be in there ?
  - Super-cooled water ?

Source:
http://www.youtube.com/watch?v=DpiUZI_3o8s

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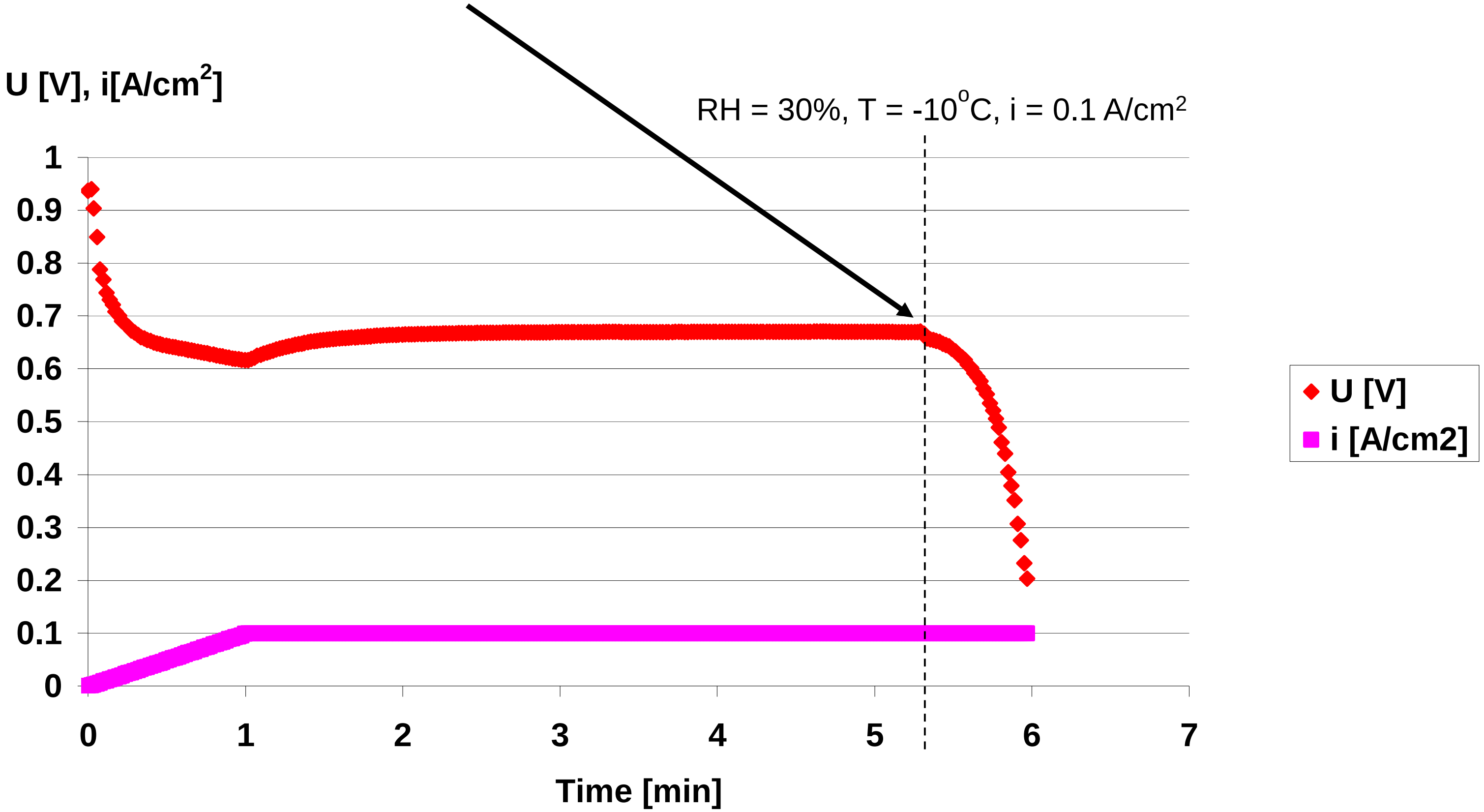
Sub-zero startup – Interpretation

- Repeated experiments without neutron imaging
  - Mechanical shock on the cell ? Yes.



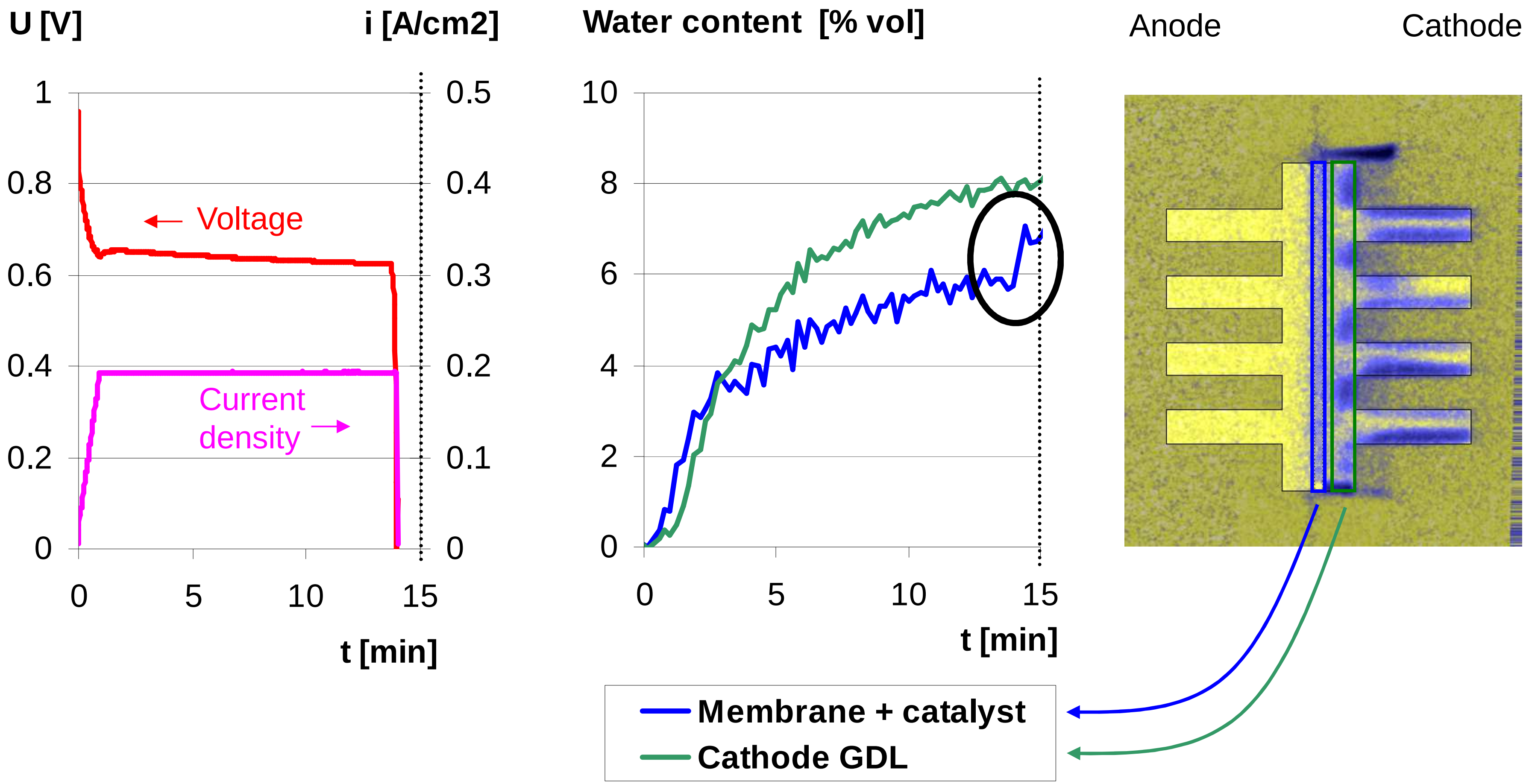
Sub-zero startup – Interpretation

- Repeated experiments without neutron imaging

  - Mechanical shock on the cell ? Yes.

Sub-zero startup – Interpretation

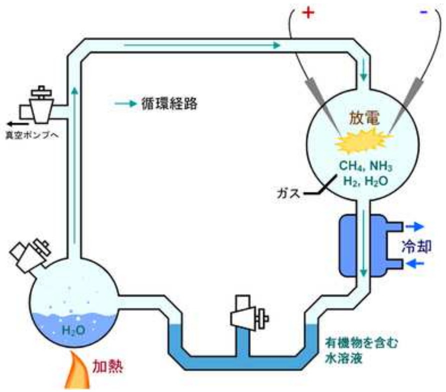
T = -10°C, i = 0.2 A/cm²



Conclusions

Find good tradeoff between spatial and temporal resolution

Some methods (anisotropic, stroposcopic) can help you improve the tradeoff



Prepare well you experiment !
In particular: sample-detector distance