# From photons to scientific publications

## A few examples of tomographic based scientific workflows performed at the SYRMEP beamline of Elettra

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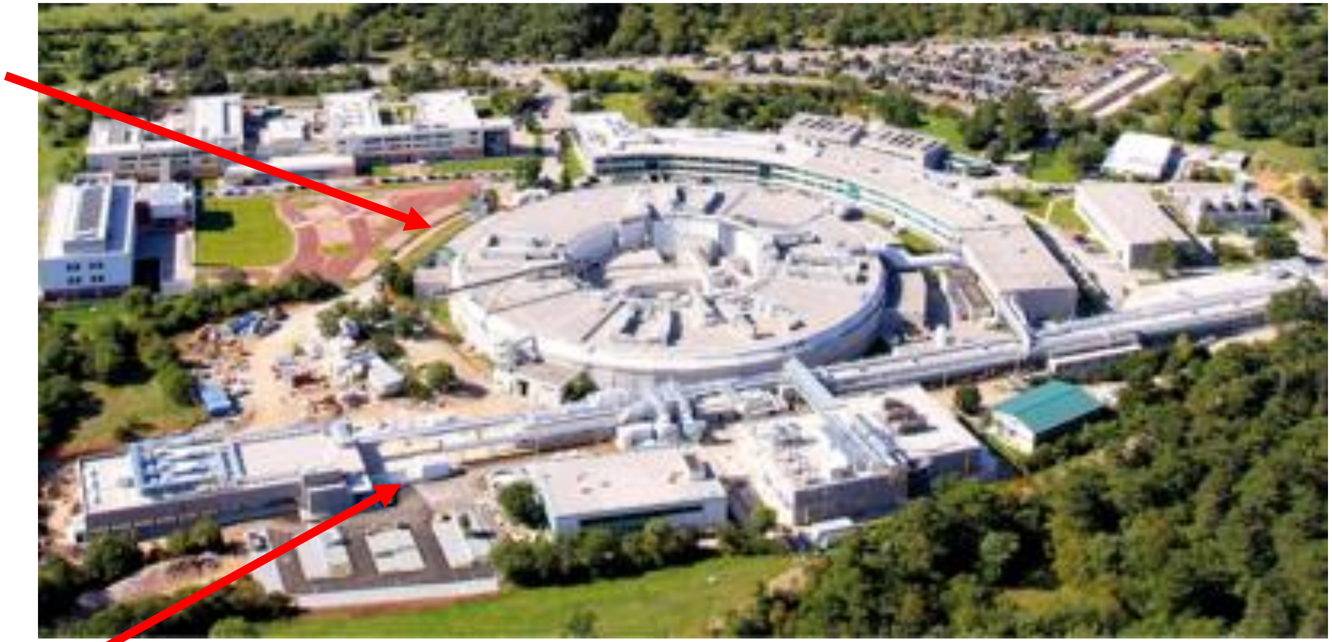
Elettra Sincrotrone Trieste

# Elettra – Sincrotrone Trieste S.C.p.A.

Elettra is a non-profit company established in 1986

Two laboratories: **Elettra** and **Fermi**



3rd generation 2.4 GeV synchrotron radiation laboratory (**Elettra**)

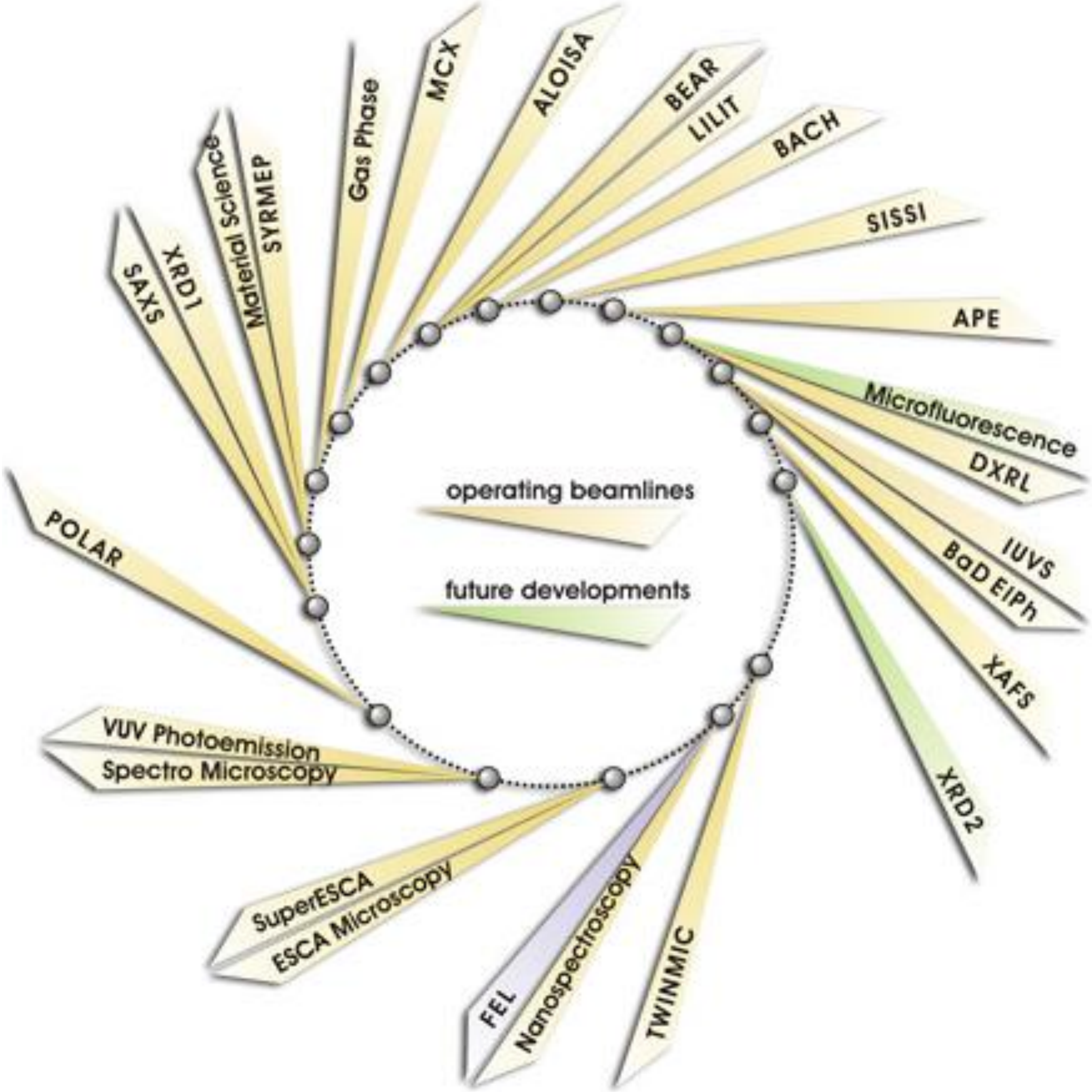
4th generation light source free-electron laser (FEL): **Fermi**

# The Elettra laboratory

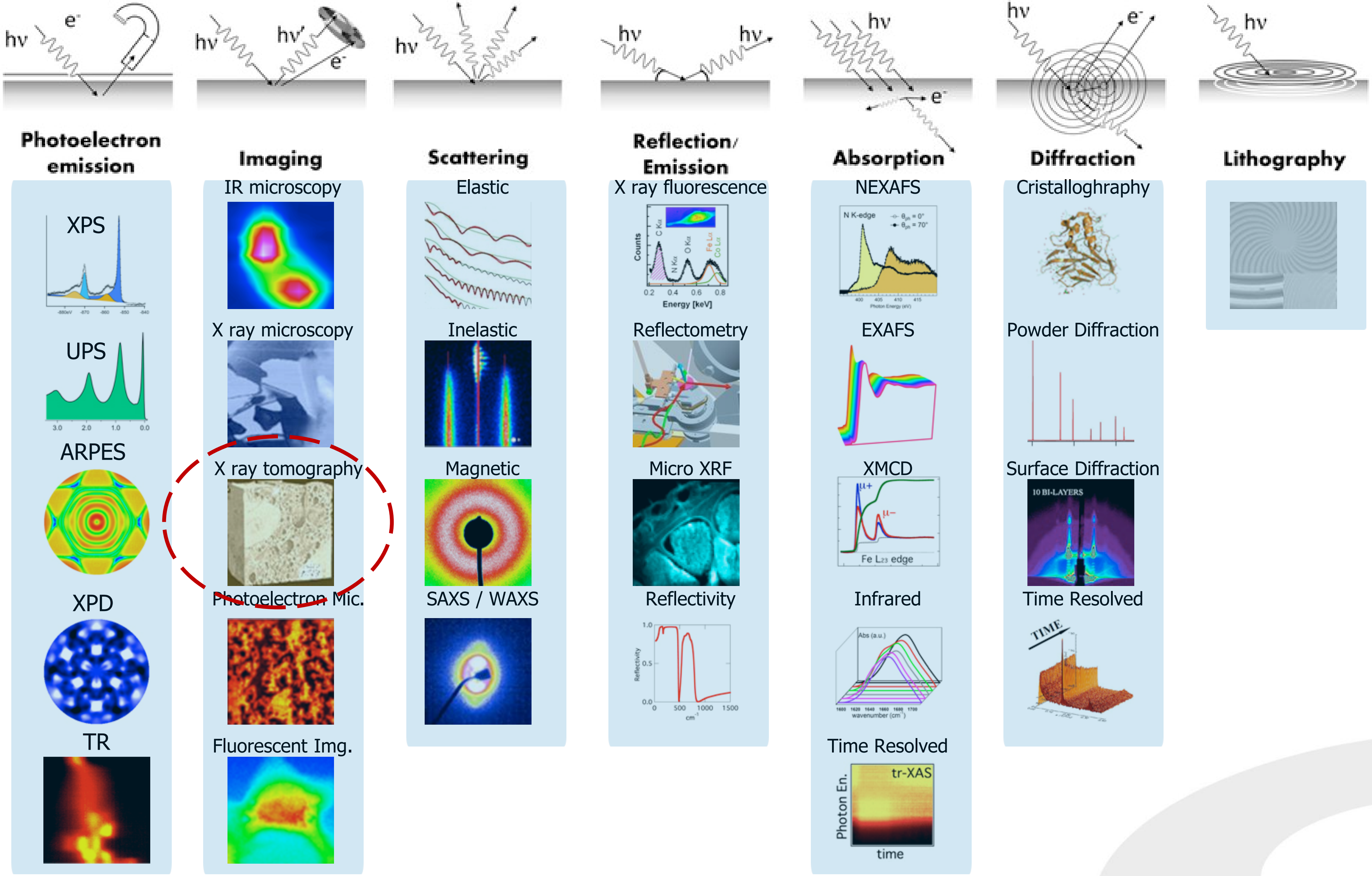
Several beamlines with different techniques

- diffraction
- scattering
- photoemission
- …

Several support laboratories



# The techniques



**Photoelectron emission**
- XPS
- UPS
- ARPES
- XPD
- TR

**Imaging**
- IR microscopy
- X ray microscopy
- X ray tomography
- Photoelectron Mic.
- Fluorescent Img.

**Scattering**
- Elastic
- Inelastic
- Magnetic
- SAXS / WAXS

**Reflection/ Emission**
- X ray fluorescence
- Reflectometry
- Micro XRF
- Reflectivity

**Absorption**
- NEXAFS
- EXAFS
- XMCD
- Infrared
- Time Resolved

**Diffraction**
- Cristalloghraphy
- Powder Diffraction
- Surface Diffraction
- Time Resolved

**Lithography**

# The SYRMEP beamline and TOMOLAB

At the SYRMEP (**SY**nchrotron **R**adiation for **ME**dical **P**hysics) beamline [1]:

- absorption and **phase contrast** X-ray CT
- **monochromatic** and white beam synchrotron radiation (SR)
- **parallel-beam** geometry

At the TOMOLAB [2]:

- **polychromatic** micro-focus source
- **cone-beam** geometry

Both are **open facilities**

Custom devices can be included and considered

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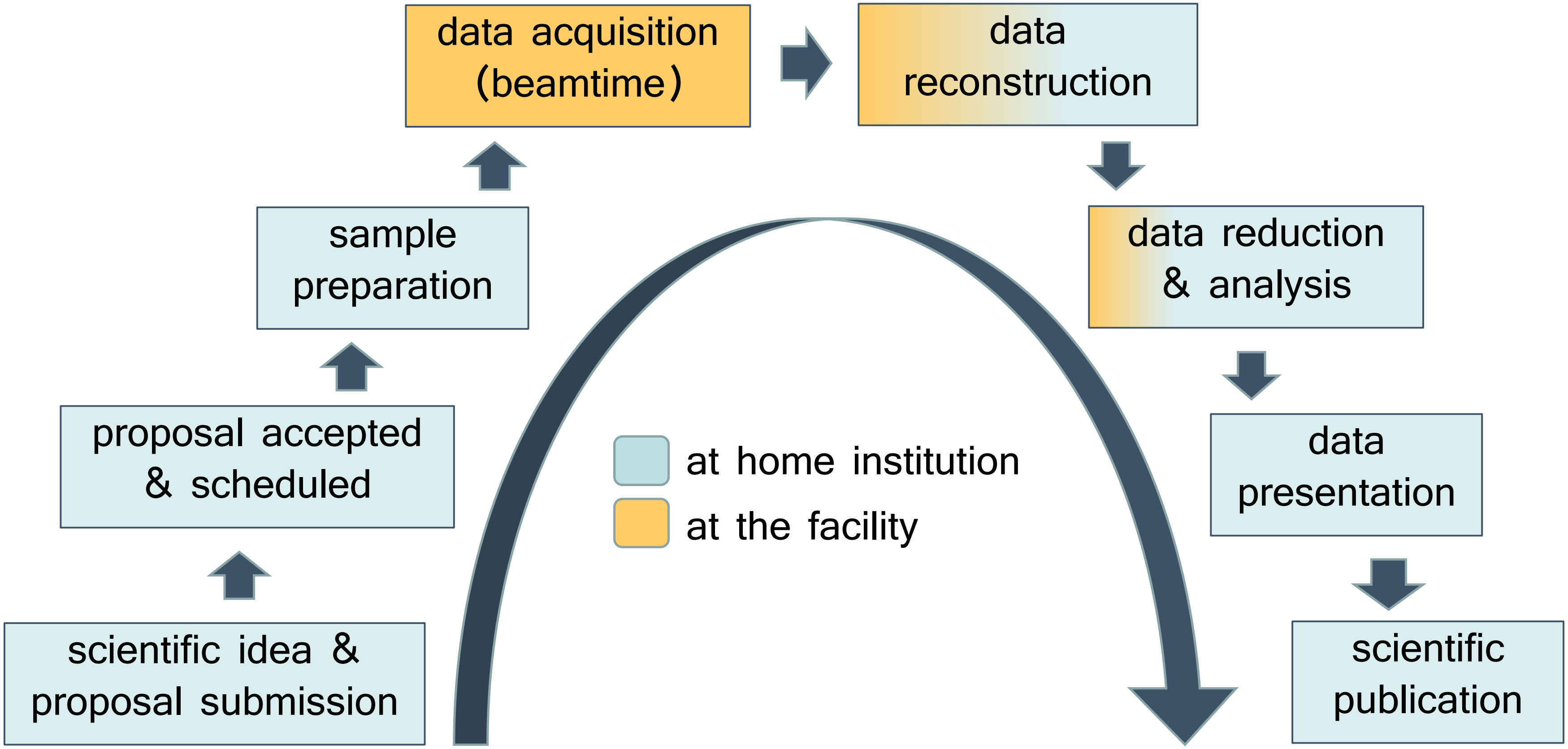
[1] http://www.elettra.eu/elettra-beamlines/syrmep.html

[2] http://www.elettra.eu/lightsources/labs-and-services/tomolab/tomolab.html

# The whole workflow at a CT beamline

The beamline staff supports (collaborative) users in each of the following steps:



scientific idea & proposal submission

proposal accepted & scheduled

sample preparation

data acquisition (beamtime)

data reconstruction

data reduction & analysis

data presentation

scientific publication

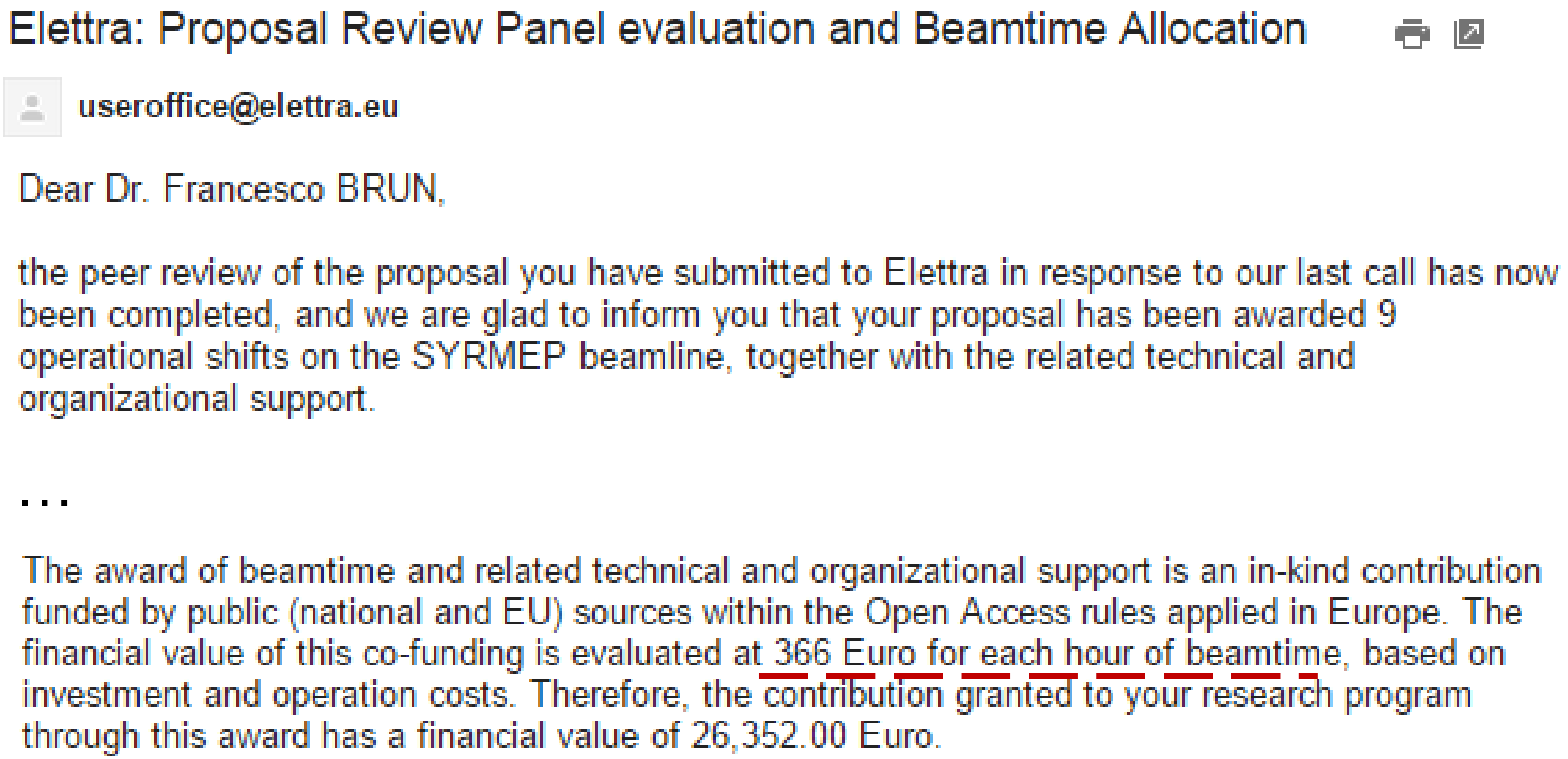
🟦 at home institution

🟨 at the facility

The priority for a beamline is the optimization of the user's beamtime

The priority for users is how to get the most from their data

# Optimize the beamtime: Why?



Elettra: Proposal Review Panel evaluation and Beamtime Allocation

**useroffice@elettra.eu**

Dear Dr. Francesco BRUN,

the peer review of the proposal you have submitted to Elettra in response to our last call has now been completed, and we are glad to inform you that your proposal has been awarded 9 operational shifts on the SYRMEP beamline, together with the related technical and organizational support.

…

The award of beamtime and related technical and organizational support is an in-kind contribution funded by public (national and EU) sources within the Open Access rules applied in Europe. The financial value of this co-funding is evaluated at 366 Euro for each hour of beamtime, based on investment and operation costs. Therefore, the contribution granted to your research program through this award has a financial value of 26,352.00 Euro.

# The art of X-ray CT

A CT scan is a trade-off among the following parameters

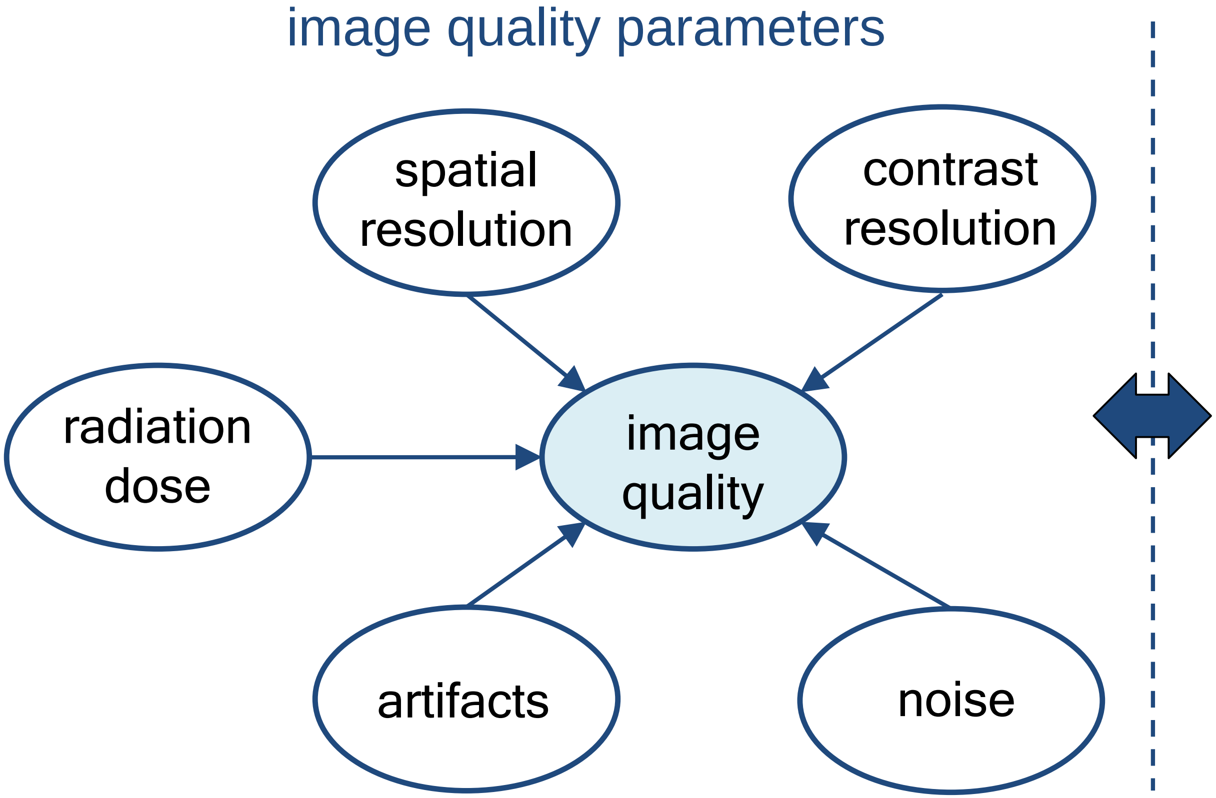


image quality parameters

spatial resolution

contrast resolution

radiation dose

image quality

artifacts

noise

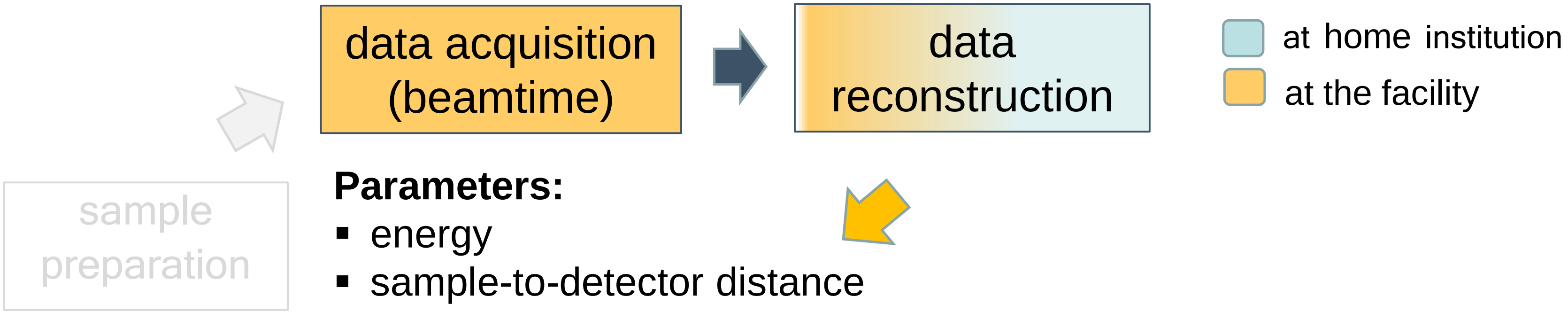
scanning parameters:

- energy (monochromatic)
- beam filter (polychromatic)
- sample-to-detector distance
- detector exposure time
- number of projections
- …

The available resources (e.g. the detector) are of course the first constraints

# What drives the acquisition

The scanning parameters are selected in sight of what happens next



sample preparation

data acquisition (beamtime)

data reconstruction

🟦 at home institution

🟧 at the facility

**Parameters:**

- energy
- sample-to-detector distance
- number of projections
- …

The reconstruction technique might require a specific data acquisition scheme

A simple example is the **Equally Sloped Tomography** (EST)[1] reconstruction

Non equally spaced angles are required for the EST

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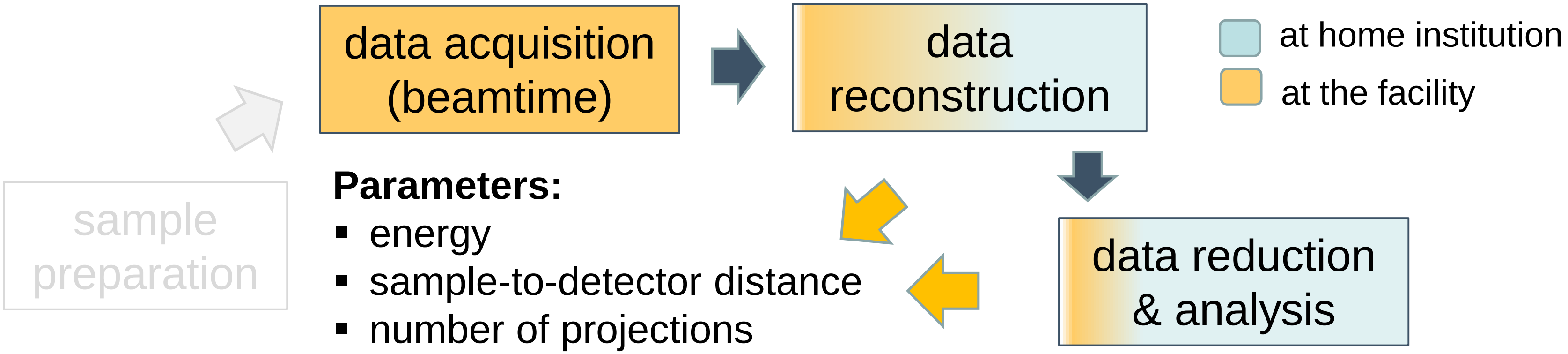
[1] J. Miao, O. Levi, *Equally Sloped Tomography with Oversampling Reconstruction*, Phys. Rev. B. 72, 052103 (2005).

# What drives the acquisition - II

The scanning parameters are selected in sight of what happens next



**Parameters:**
- energy
- sample-to-detector distance
- number of projections
- …

The data analysis protocol affects the acquisition

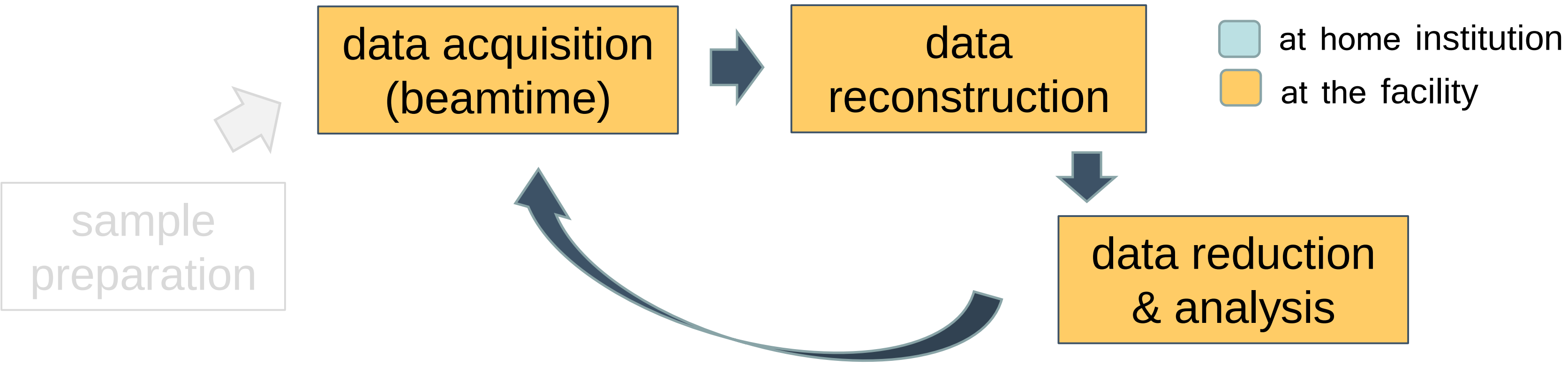
An example is **image segmentation**

Contrast might be privileged instead of spatial resolution to ease segmentation

Segmentation can part of data reconstruction (e.g. **discrete tomography**)

# The ideal scenario

This (sub-) loop should be **as fast as possible** and performed at the facility



data acquisition (beamtime)

data reconstruction

data reduction & analysis

sample preparation

🟦 at home institution

🟨 at the facility

The acquisition time is non negligible (from 20 minutes to 2 hours)

Ideally the whole sub-loop should be completed **while scanning a new sample**

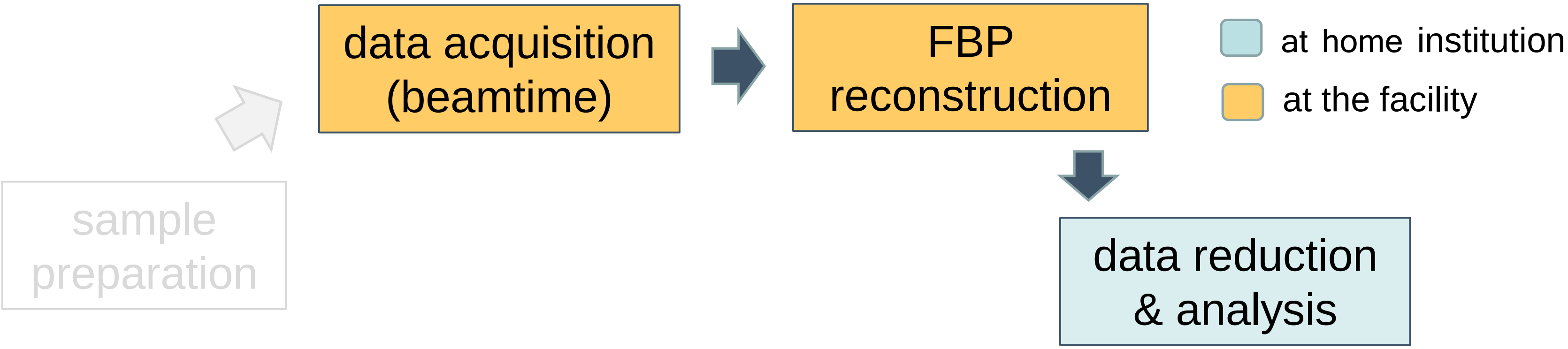
Reconstruction and a preliminary data analysis give feedback to the acquisition

Feedback also to the preparation of samples (and the scientific idea)

# The real scenario

A “standard” reconstruction (FBP) is usually available at the facility

Fine tuning of parameters might be difficult for some users and time consuming



sample preparation

data acquisition (beamtime)

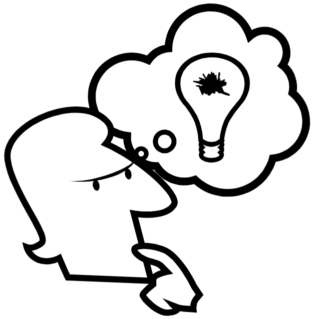
FBP reconstruction

data reduction & analysis

🟦 at home institution

🟨 at the facility

In most of the experiments users do not have an analysis protocol yet



**Nice images! … and now?**

# The main issue of practical SR μ-CT

The main issue is related to the **big data** handling

Detector size is usually 4096 × 4096 pixels

New detectors with 8k size are on the market

Extended field-of-view acquisition is sometimes required

Subpixel image processing steps are also sometimes required

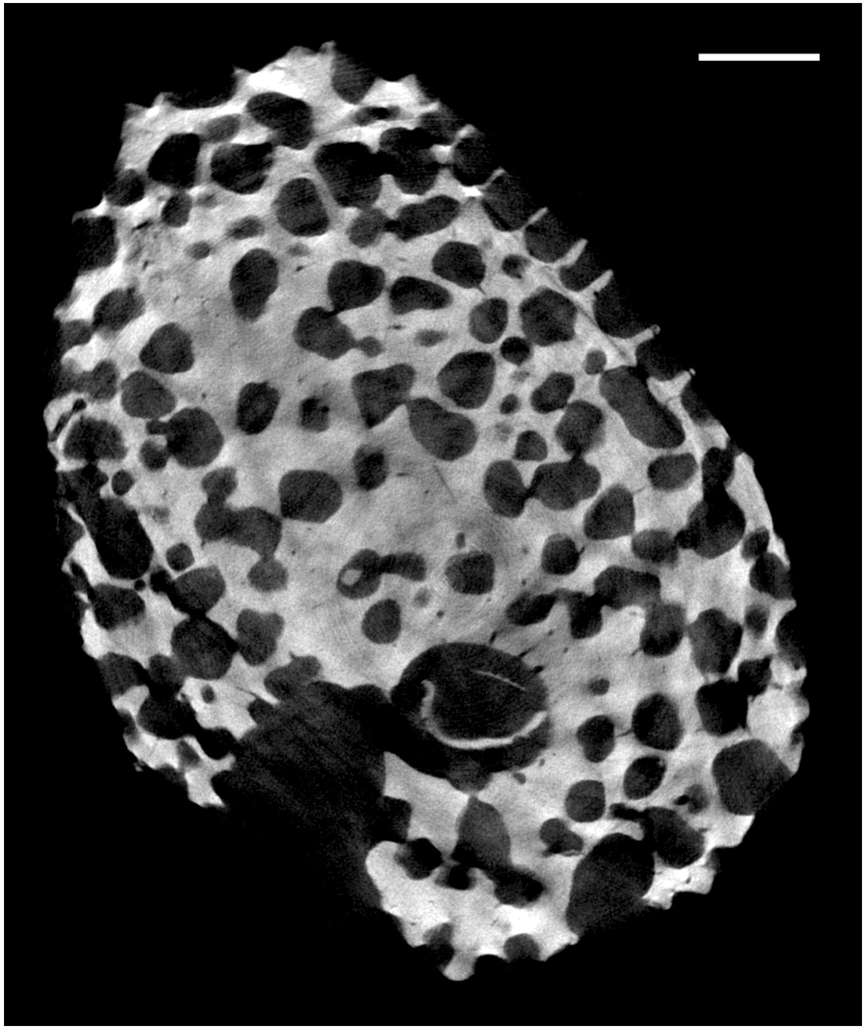
It is quite easy to deal with 8k × 4k acquired images

With single precision (32 bits) a 8k × 8k reconstructed image means 256 MB

It is quite easy to collect a dataset of more than 30 GB

The throughput is now measured in **TB per beamtime**

# Example 1: Analysis of porous media



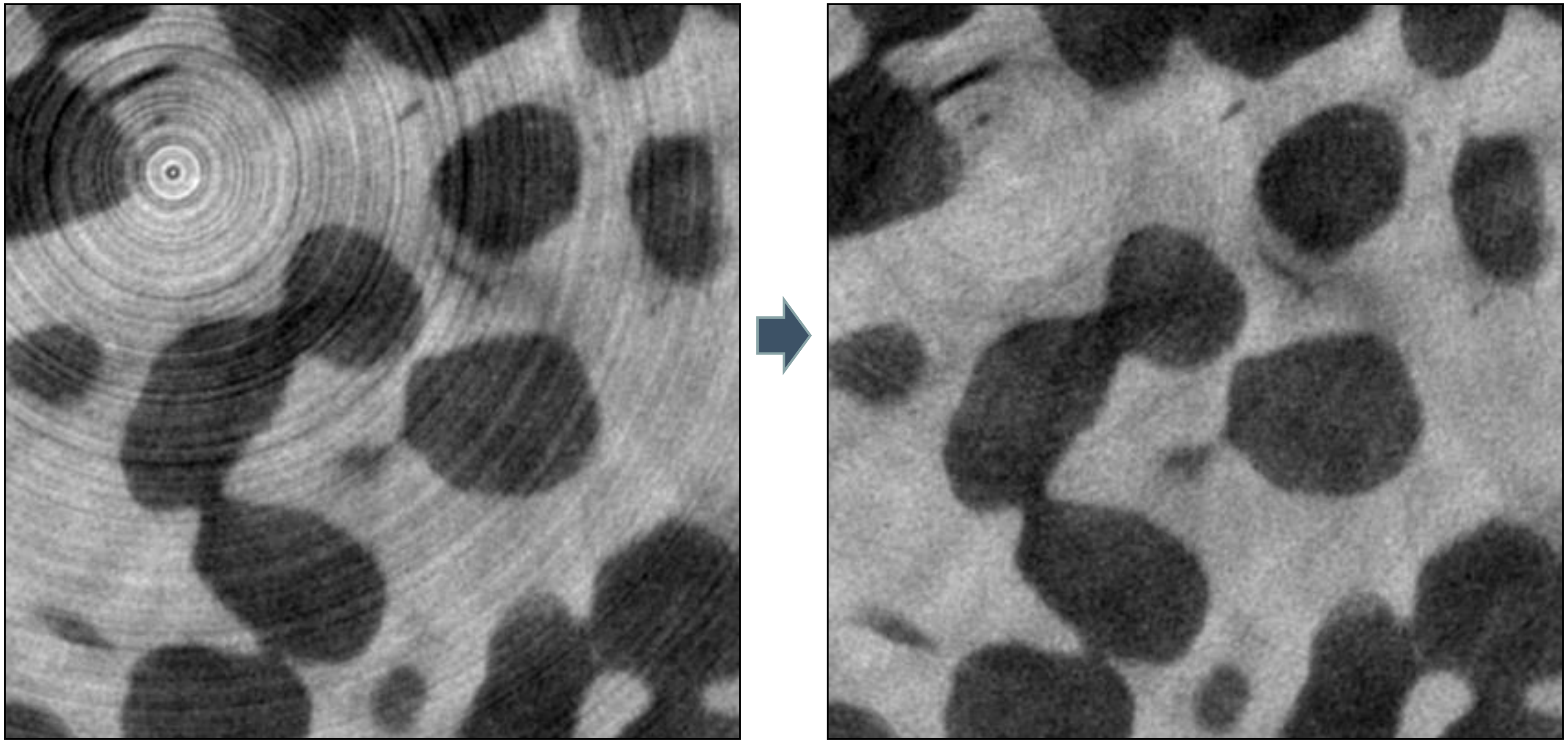
For this application users were interested in finding the answer to:

1. What is the average pore size?
2. Is the pore space fully interconnected?
3. Is there a preferred orientation (anisotropy) of the pore space?
4. …

The goal is to derive this (quantitative) information directly from the images

# Ring removal

In real experiments the detector and the beam are not perfect



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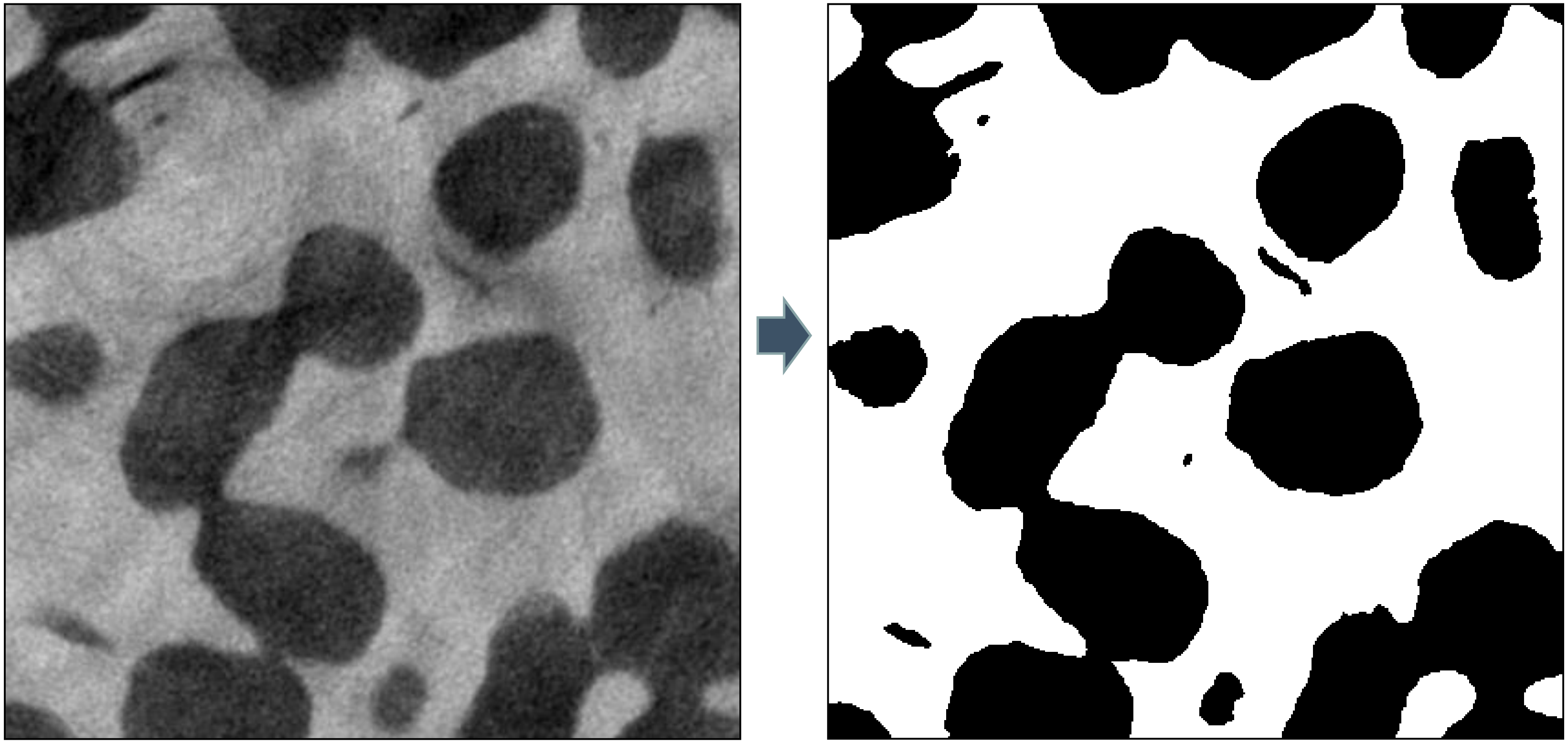
[1] F. Brun et al, *A Comparative Evaluation of Ring Artifacts Reduction Filters for X-ray Computed Microtomography Images*, Proc. of the 18th IEEE International Conference on image Processing, 2011.

# Segmentation

After reconstruction users might want to segment the data for further analysis



From this **binary model** of the pore space further analysis can be performed

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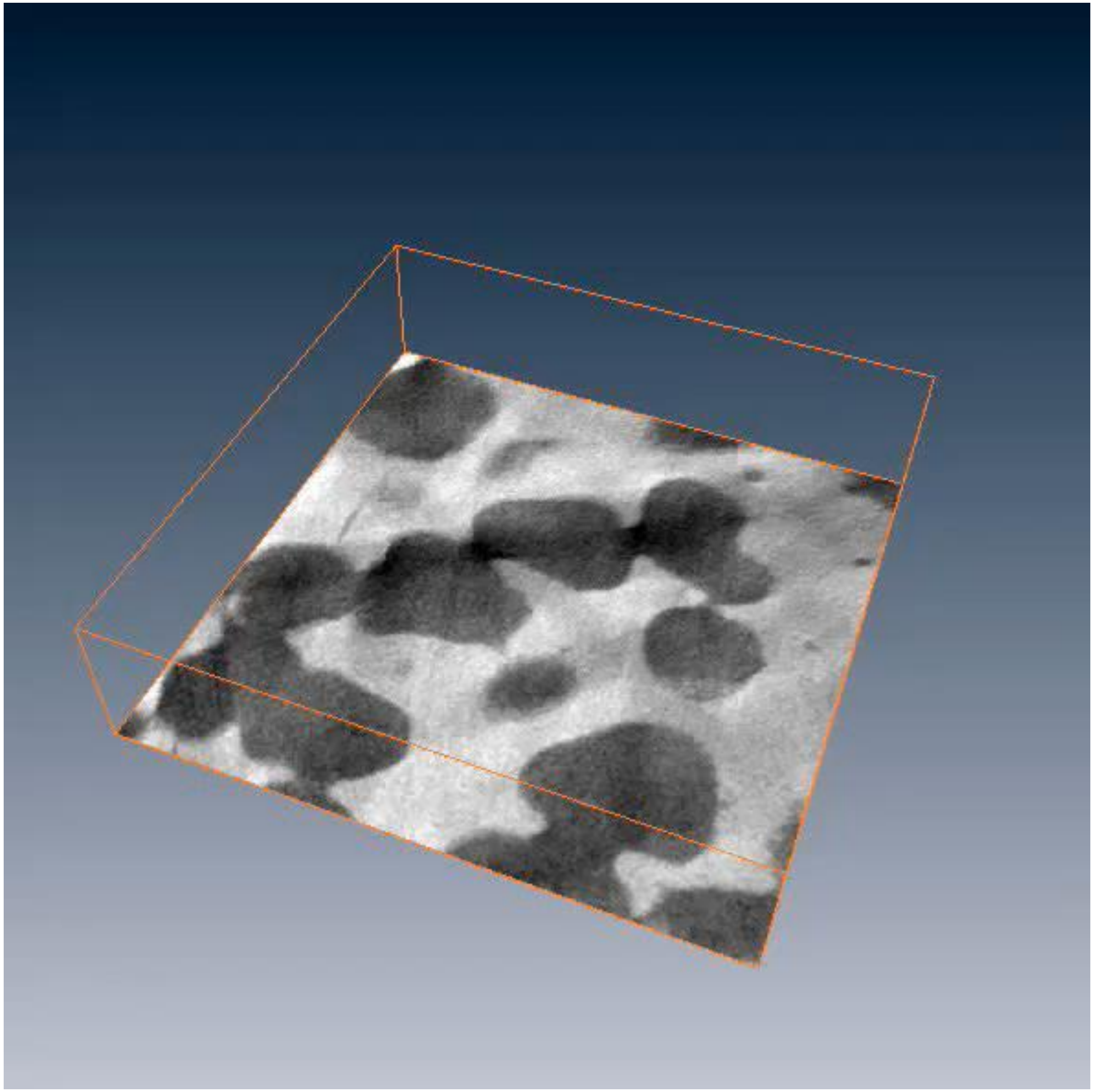
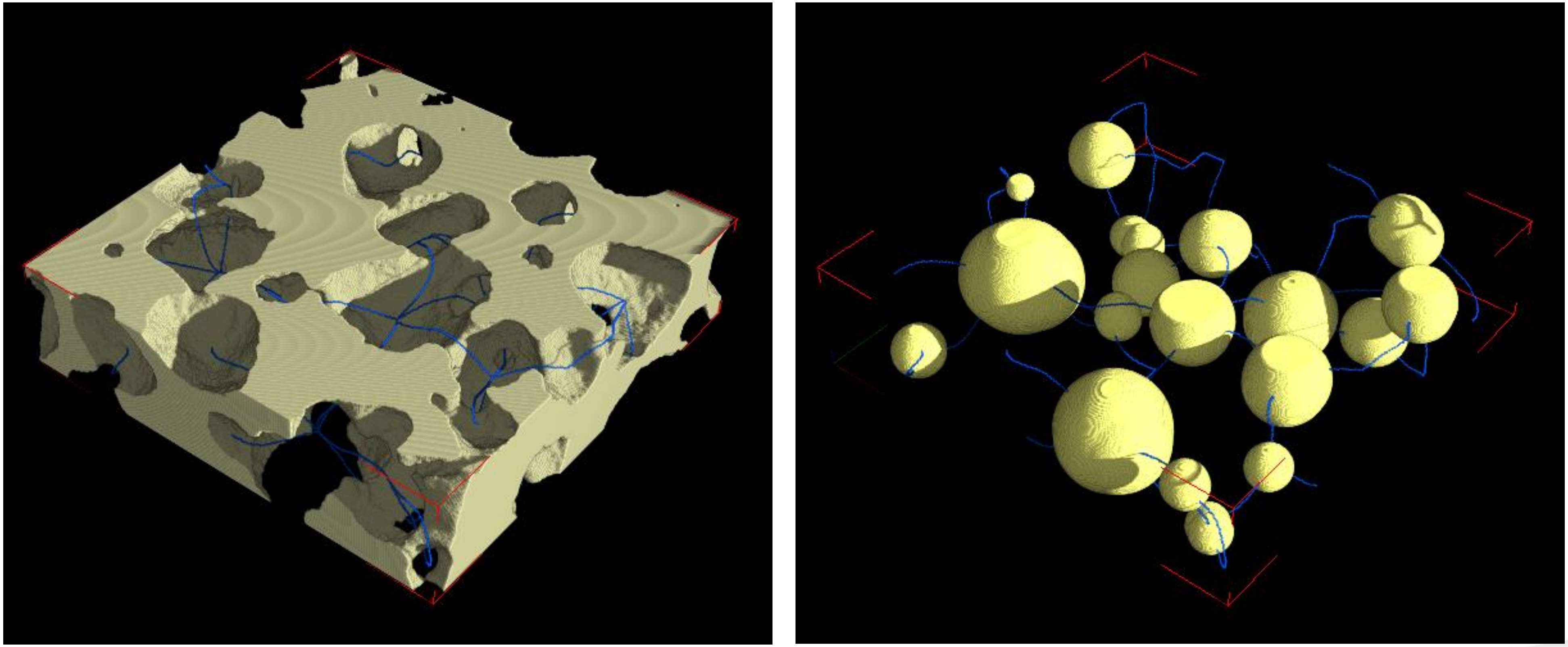
# Skeletonization



# Pore space modeling

Skeletonization[1] models the pore space as a network of **nodes** and **branches**



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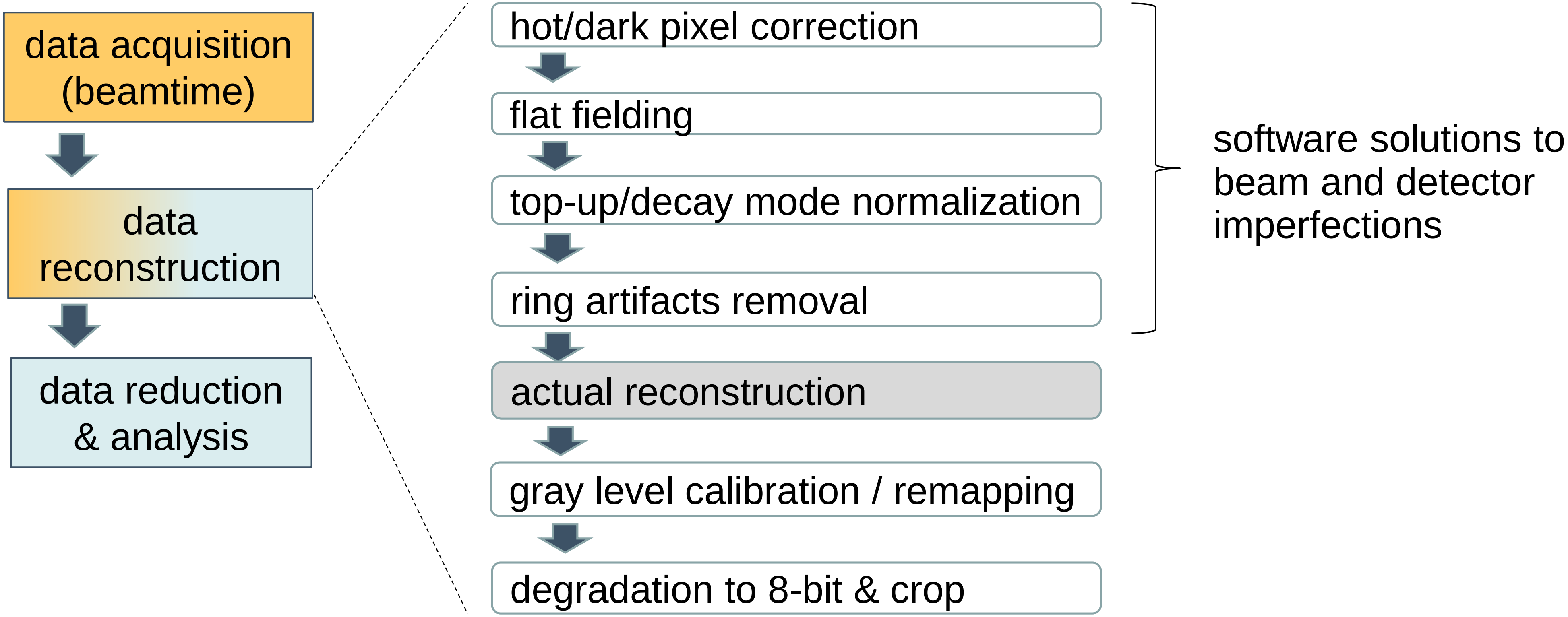
[1] F. Brun and D. Dreossi, *Efficient curve-skeleton computation for the analysis of 3D biomedical images*. Biomedical Science Instrumentation, vol. 46, pp. 475-80, 2010.

# Post-acquisition pipeline

For this specific example the **image processing** pipeline was



data acquisition (beamtime)

data reconstruction

data reduction & analysis

hot/dark pixel correction

flat fielding

top-up/decay mode normalization

ring artifacts removal

actual reconstruction

gray level calibration / remapping

degradation to 8-bit & crop

software solutions to beam and detector imperfections

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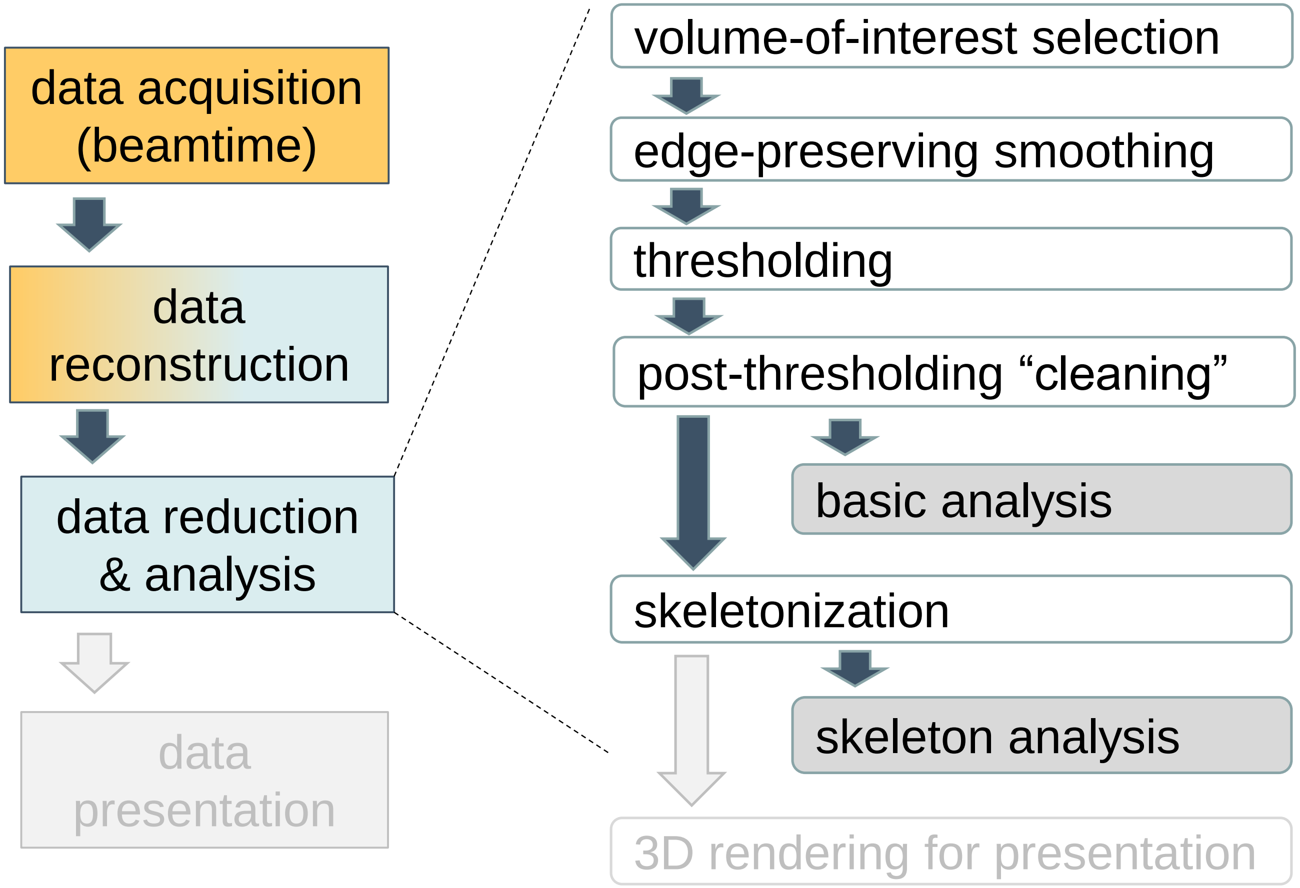
Sincrotrone
Trieste

# Post-acquisition pipeline - II

For this specific example the **image analysis** pipeline was



data acquisition (beamtime)

data reconstruction

data reduction & analysis

data presentation

volume-of-interest selection

edge-preserving smoothing

thresholding

post-thresholding “cleaning”

basic analysis

skeletonization

skeleton analysis

3D rendering for presentation

a cube, cylinder or sphere?

- porosity
- specific surface area
- degree of anisotropy
- …

- connectivity
- pore size distribution
- throat size distribution
- …

# Example 1: Comments

The **actual reconstruction is just one step** of the whole computational workflow

More time is spent for the other steps (flat fielding, ring removal, segmentation, …)

The data acquisition is pretty fast with synchrotron sources

Where there are no radiation concerns, thousands of projections can be collected

In this case Filtered Back Projection works fine (and fast)

Reconstruction approaches including some of the pre- or post- steps are interesting

- e.g. ring removal + reconstruction
- e.g. reconstruction + segmentation (discrete tomography)

A CT beamline is still interested in pure reconstruction algorithms (see next)

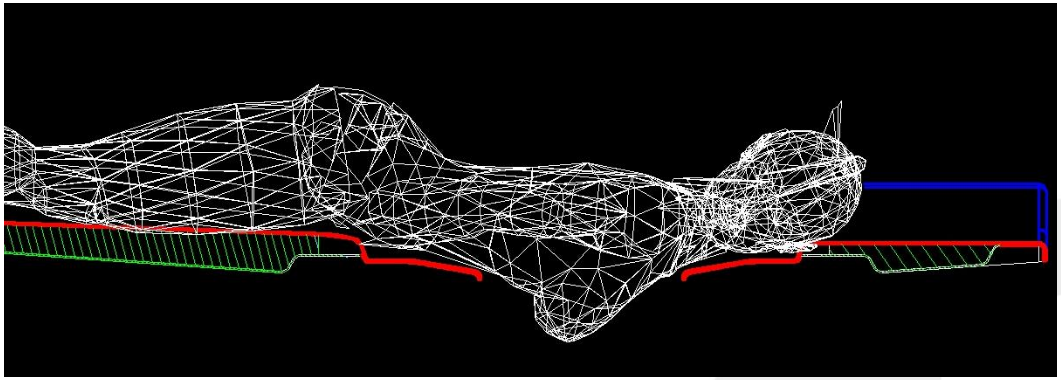
# Example 2: mammographic CT

A specific setup for mammographic CT is available at SYRMEP

Formal authorization to scan live patients

The project is named **SYRMA-CT**

The aim is to show the possibility to have tomographic images (3D volume) with the **same radiation dose** of clinical mammography (2D projection)



# Example 2: mammographic CT

More than 20 reconstruction workflows were tested [1]

Different combination of the previous steps

- with and without **phase retrieval**
- different reconstruction algorithms
    - FBP, SIRT, SART
    - TV-minimization
    - EST
    - …

Radiologists were involved in the qualitative evaluation of the images

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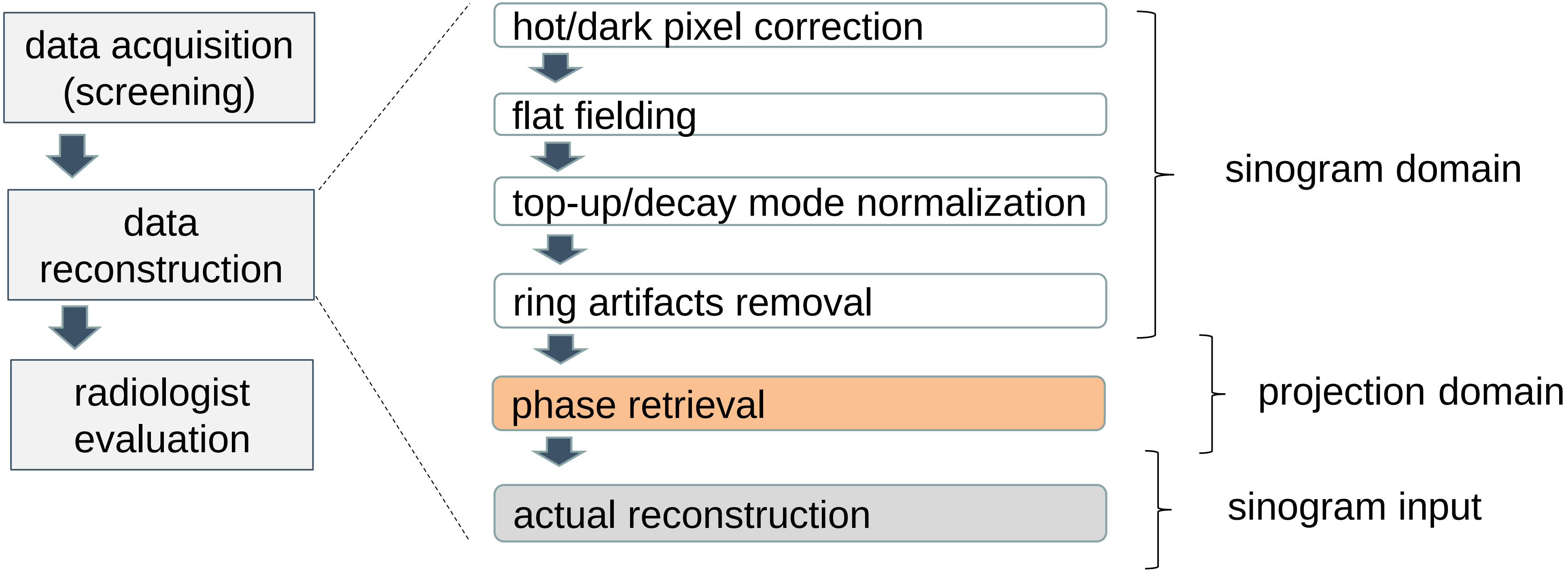
[1] S. Pacilè et al. *Towards clinical application of low dose phase contrast CT for breast imaging: optimization of the reconstruction workflow,* submitted

# Example 2: mammographic CT

For this application the **image processing** pipeline was



data acquisition (screening)

data reconstruction

radiologist evaluation

hot/dark pixel correction

flat fielding

top-up/decay mode normalization

ring artifacts removal

phase retrieval

actual reconstruction

sinogram domain

projection domain

sinogram input

The diagnosis is based on the morphology of the details (rather than contrast)

There is the need to have a reconstruction workflow focused on this aspect

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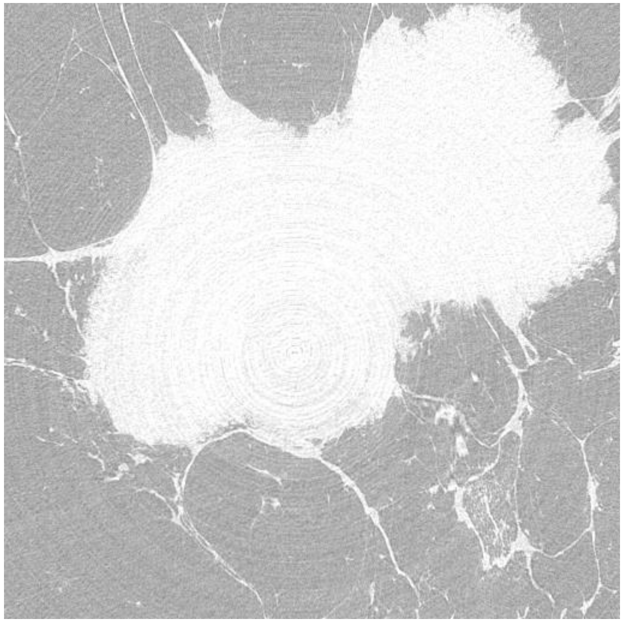
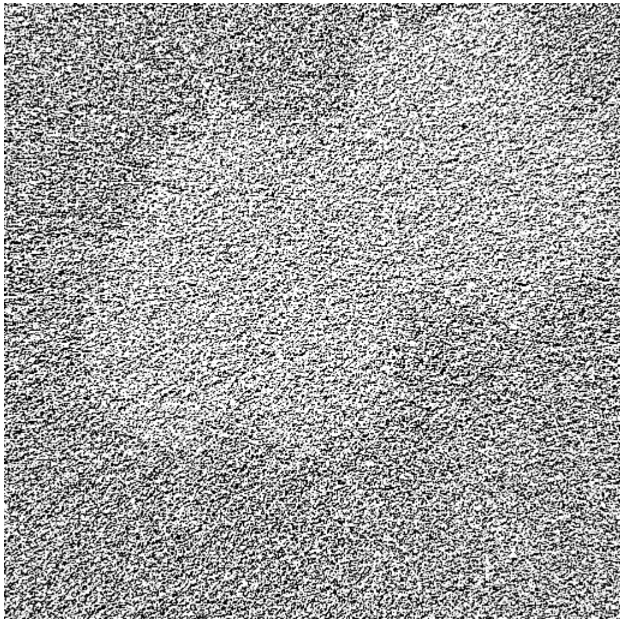
# Example 2: mastectomy sample

An example of two different reconstruction workflows (and the reference):



high statistics 3000 projections

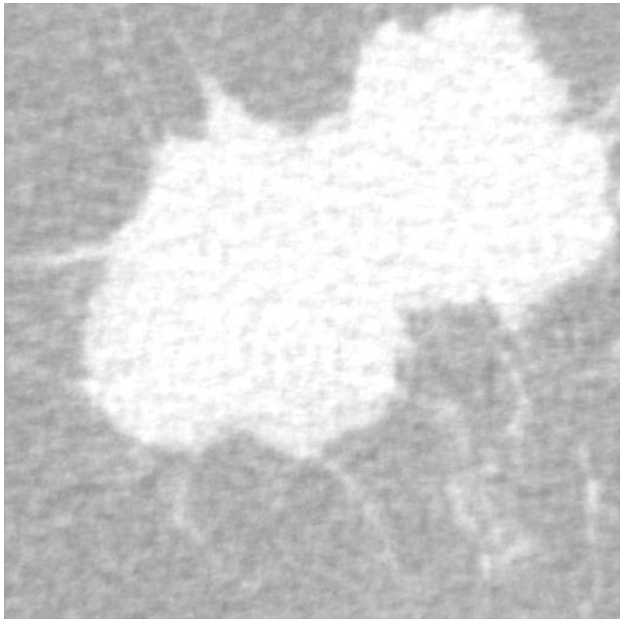
FBP



300 noisy projections

FBP

radiation dose = 2 mSv



300 noisy projections

phase retrieval + EST

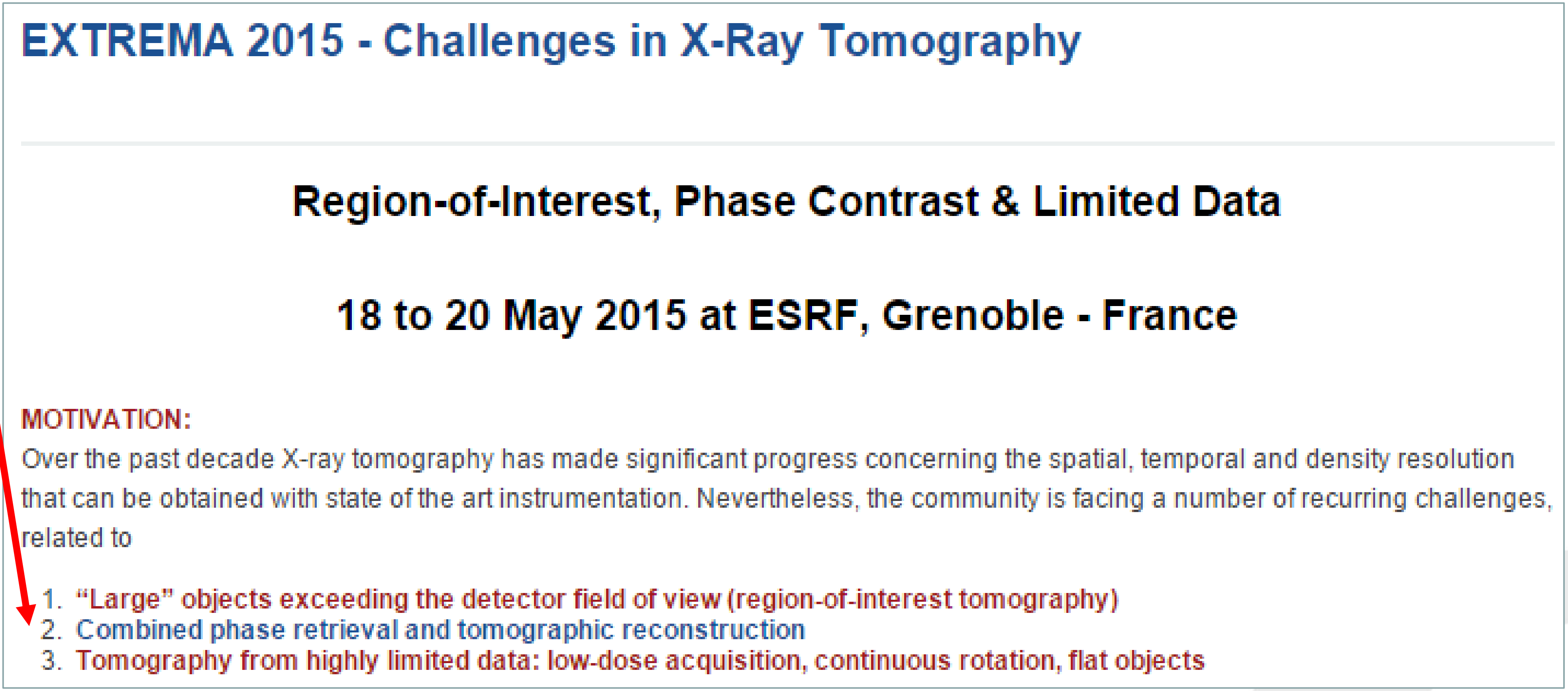
radiation dose = 2 mSv

Radiologists confirmed that the image on the right has a diagnostic value

# Example 2: Comments

When radiation dose is a concern, a few noisy projections are collected

Reconstruction approaches including phase retrieval are interesting



## EXTREMA 2015 - Challenges in X-Ray Tomography

**Region-of-Interest, Phase Contrast & Limited Data**

**18 to 20 May 2015 at ESRF, Grenoble - France**

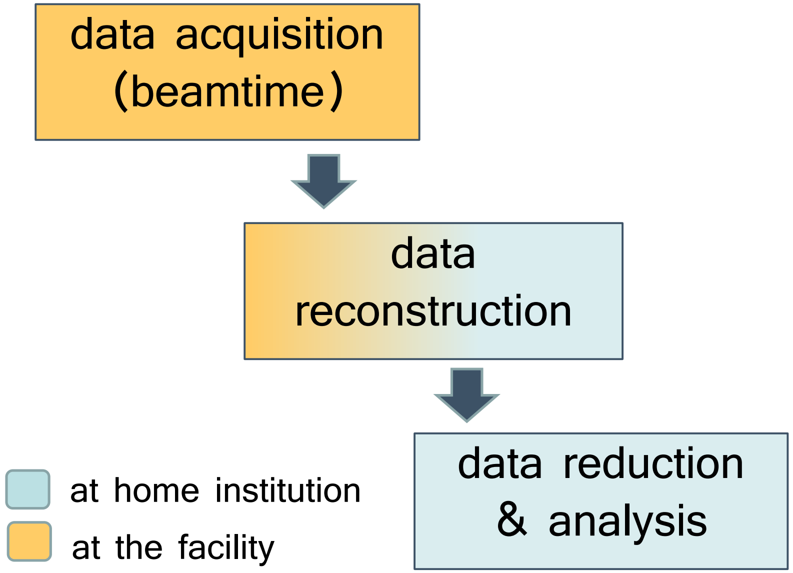
**MOTIVATION:**

Over the past decade X-ray tomography has made significant progress concerning the spatial, temporal and density resolution that can be obtained with state of the art instrumentation. Nevertheless, the community is facing a number of recurring challenges, related to

1. "Large" objects exceeding the detector field of view (region-of-interest tomography)
2. Combined phase retrieval and tomographic reconstruction
3. Tomography from highly limited data: low-dose acquisition, continuous rotation, flat objects

# Conclusion

A challenge for SR CT is to have **more feedback as possible** at the facility



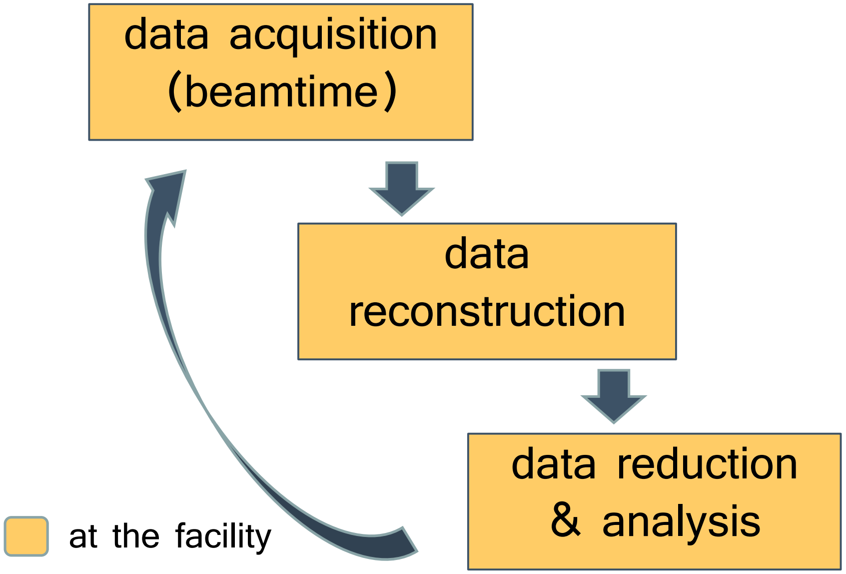
data acquisition (beamtime)

data reconstruction

data reduction & analysis

🟦 at home institution

🟨 at the facility



data acquisition (beamtime)

data reconstruction

data reduction & analysis

🟨 at the facility

There is the need to have an **integrated** and **comprehensive** approach

There is the need to have reconstruction and analysis sw close to the facility

Behind this there is the **big data** issue

# Conclusion

The computational post-acquisition workflow is application dependent

Two applications were presented

Two software projects are currently maintained at SYRMEP

- **SYRMEP Tomo Project** [1]

  recently re-designed to exploit the ASTRA toolbox

- **Pore3D** [2] (www.elettra.eu/pore3d)

  to help users for the analysis of 3D images

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[1] F. Brun et al., *Enhanced and flexible software tools for X-ray computed tomography at the Italian synchrotron radiation facility Elettra,* Fundamentae Informatica, accepted

[2] F. Brun et al. *Pore3D: A software library for quantitative analysis of porous media*, NIM A, 615(3): 326-332, 2010.

# The SYRMEP family

Many thanks to the SYRMEP family:

- Giuliana Tromba
- Lucia Mancini
- Franco Zanini
- Diego Dreossi
- Nicola Sodini
- Francesco Brun

Quick reminder: we are available for Short Term Scientific Missions (STSMs) within the activities of the MP1207 COST Action

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