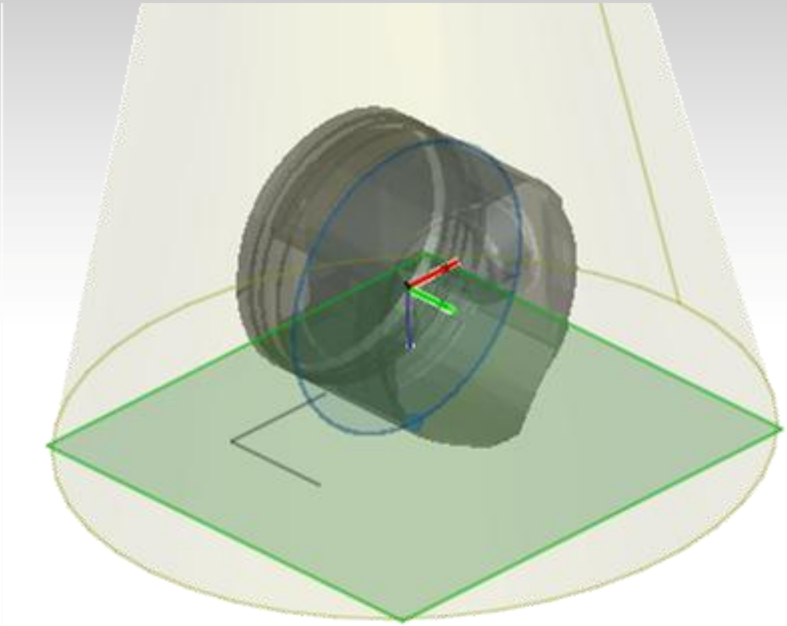
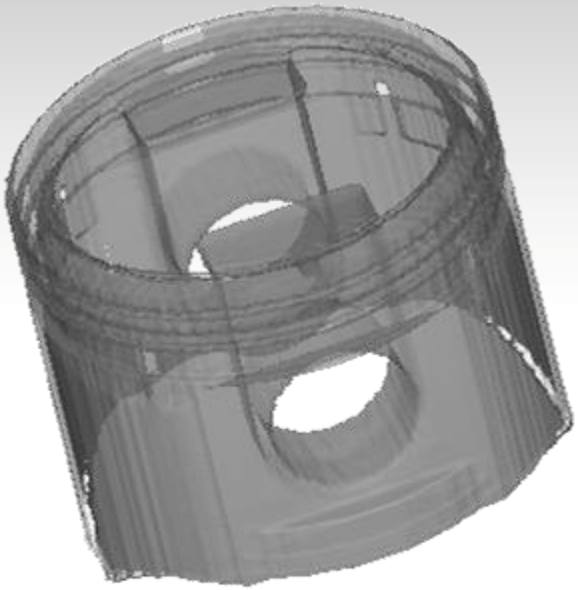
CIVA Computed Tomography Modeling





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EXTENDE CIVA

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Summary

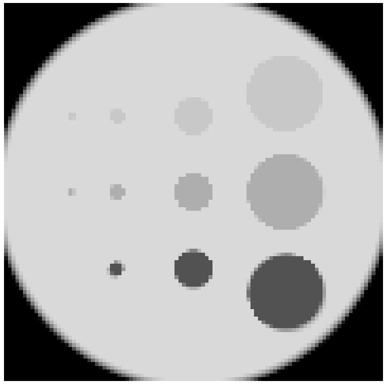
- Context
- From CIVA RT to CIVA CT
- Reconstruction Methods
- Applications
  - Example of Source/detector misalignment
  - Comparison study

Context

- Computed Tomography (CT) is becoming a standard tool in many domains:
  - Material Structure, Earth science, archeology
  - Medical imaging…
- In NDT, tomography is mostly used to provide internal information such as:
  - Inclusions, Cracks, Porosities,
  - Characteristics of the internal structure…
- Experimental CT is a relatively complex process
- Simulation allows to:
  - Test and evaluate the performances of an experimental CT system
  - Optimize the performance by a correct choice of parameters

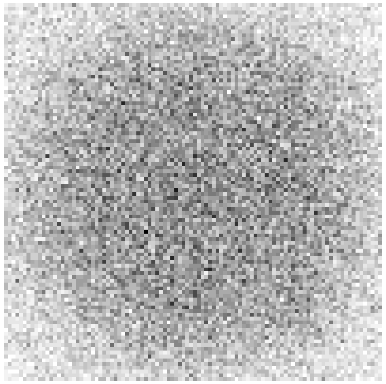
From CIVA RT to CIVA CT

- Simulation studies of radiographic inspections with CIVA (since 2007)
  - Simulation of complex parts
  - Direct and scattered radiation
  - Gamma and X sources



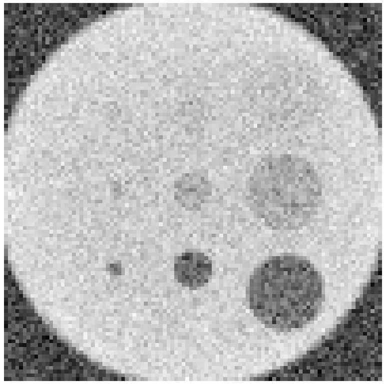
Direct radiation

+



Scattered radiation

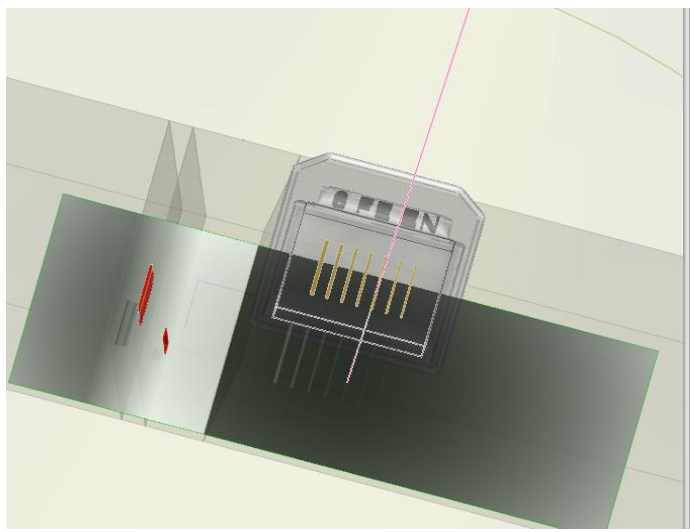
→



Final image

From CIVA RT to CIVA CT

- Simulation studies of radiographic inspections with CIVA (since 2007)
  - Different types of detectors
  - Influential parameters accounting for
  - IQI available



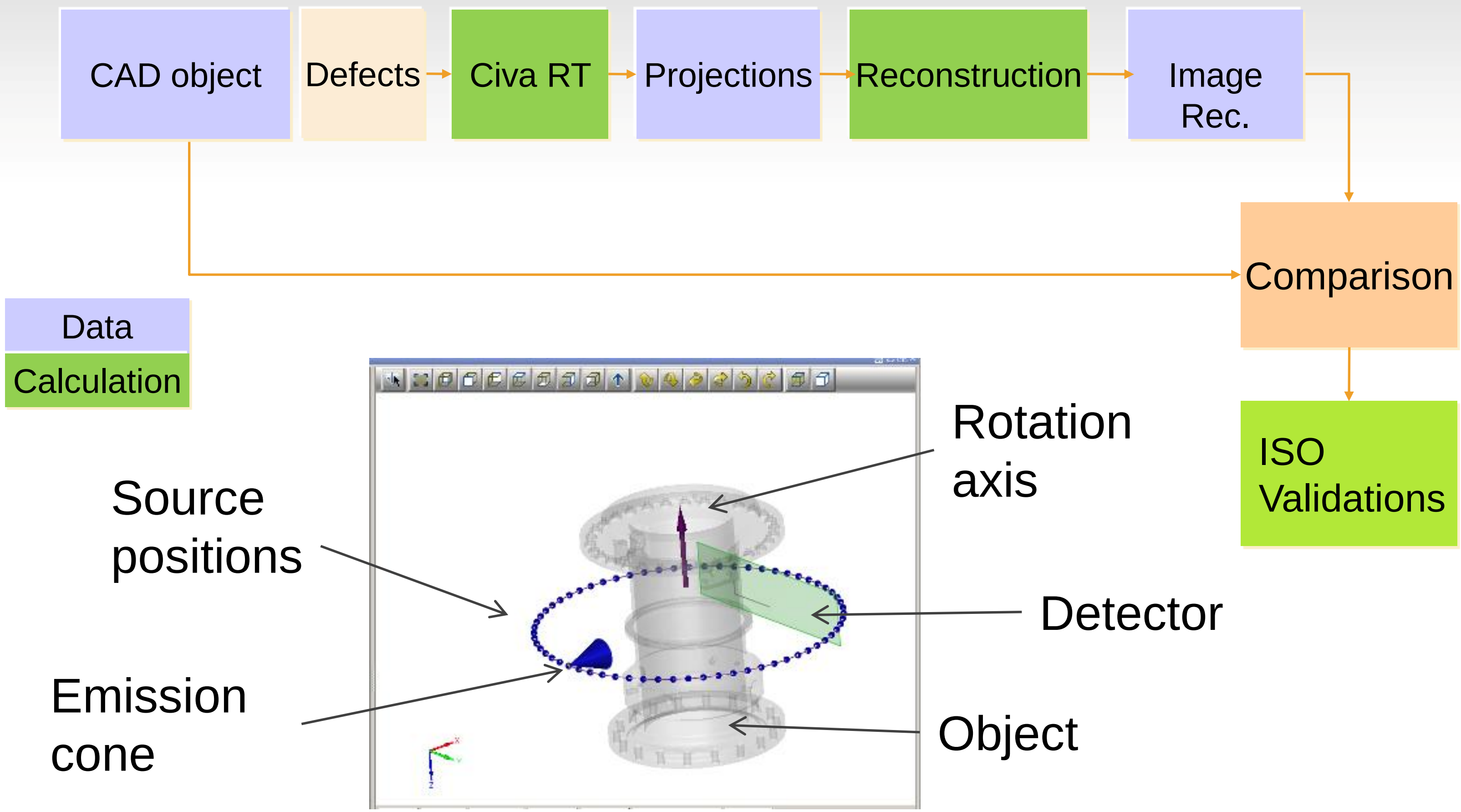
Parameters in CT

- « Radiology » parameters
  - Geometry
  - Spectra, intensity, exposure time
  - Filters
  - Processing (for digital radiology)

- Specific « CT » parameters
  - Projections angles/positions
  - Number of projections
  - Reconstruction algorithms
  - Post processing

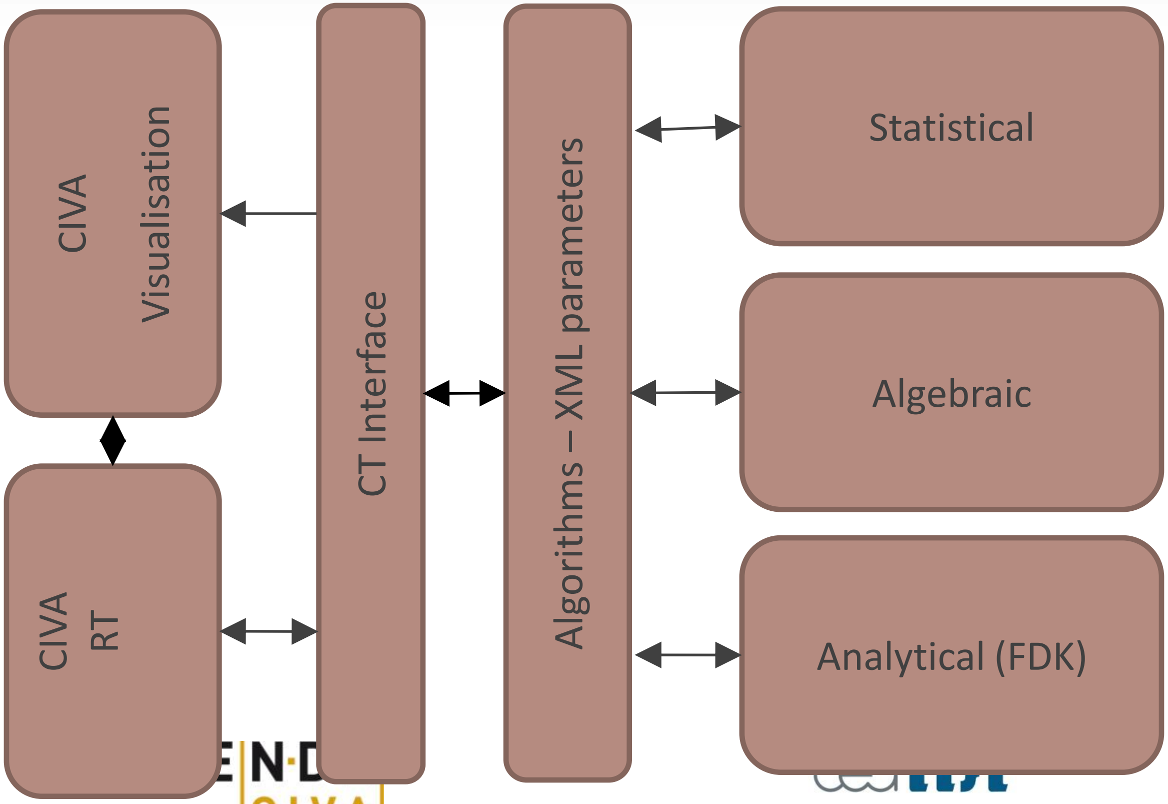
From CIVA RT to CIVA CT

- New Computed Tomography module in CIVA



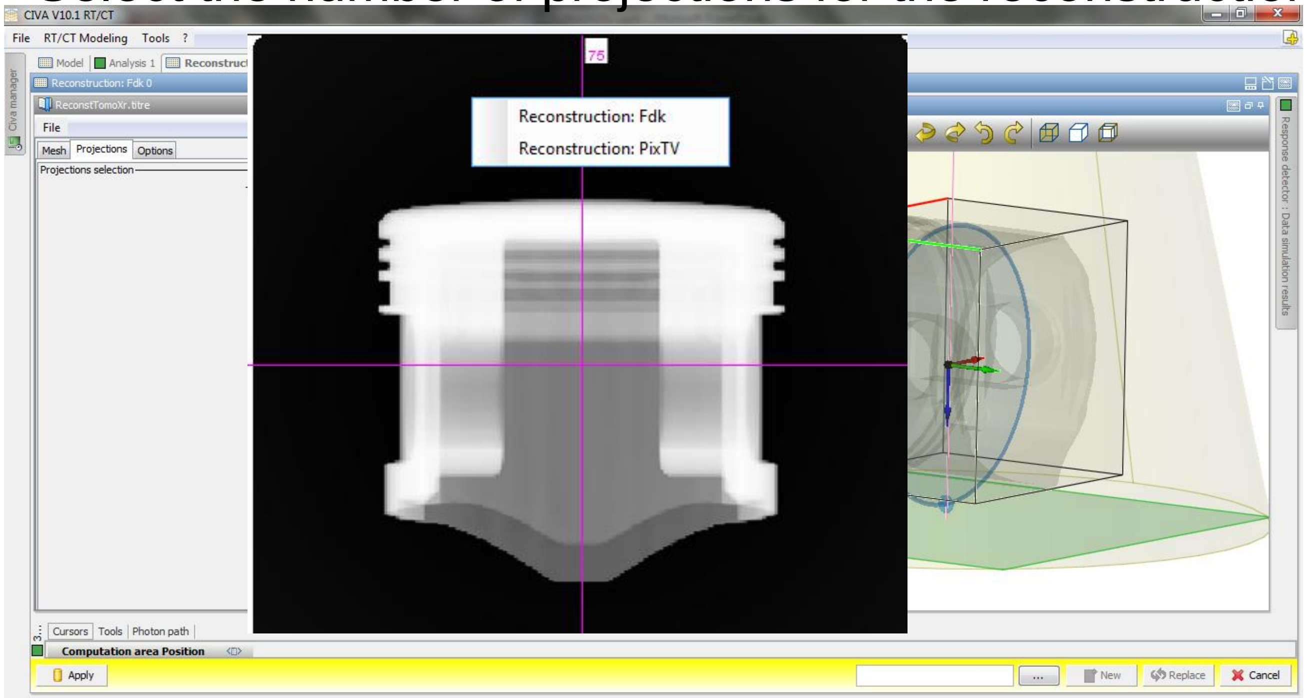
From CIVA RT to CIVA CT

- Several CT reconstruction algorithms are implemented as plugins:
  - possibility to implement various algorithms on different hardware
  - Possibility to compare the different algorithms



Reconstruction methods

- Two algorithms available in the current version :
  - FDK
  - PIXTV
- Possibility to:
  - Define the reconstruction zone
  - Select the number of projections for the reconstruction



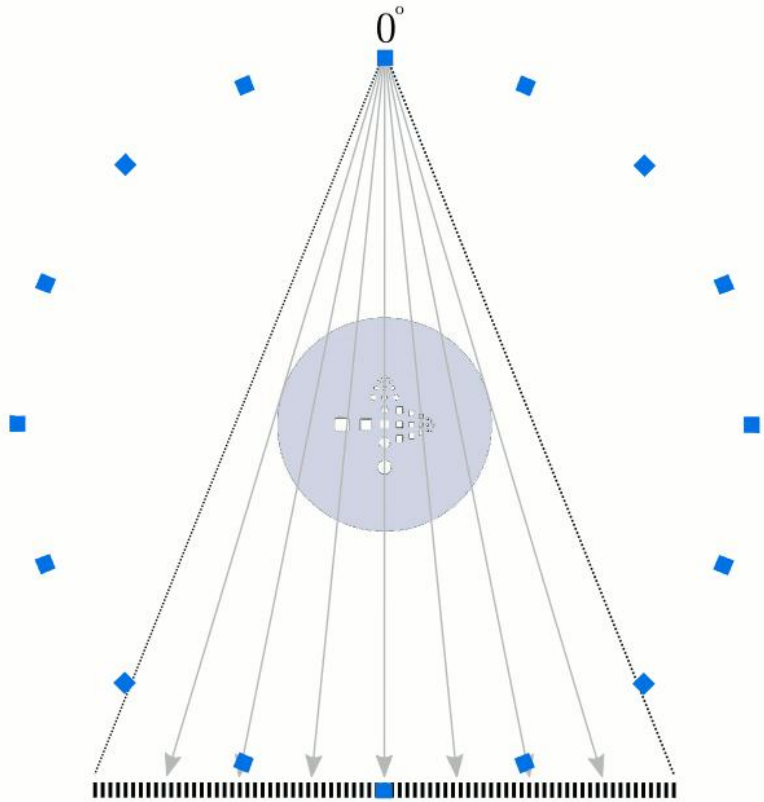
Reconstruction with FDK algorithm

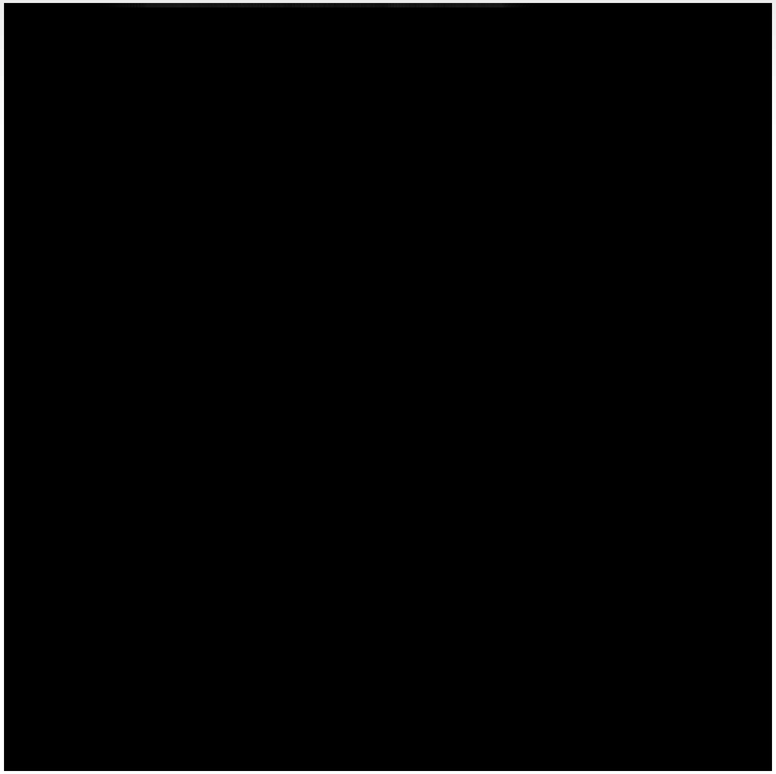
- FDK (Feldkamp-Davis-Kress) algorithm is a 3D analytic reconstruction method:
  - Reconstructs the function *f(x,y,z),* which is a map of the linear attenuation coefficients of the imaged sample
  - It is a three step algorithm of the filtered back-projection type (FBP) for cone-beam data:
    - Weighting: $R_\beta^{'}(p,\zeta)=\dfrac{D_{SO}}{\sqrt{D_{SO}^2+\zeta^2+p^2}}R_\beta(p,\zeta)$
    - Filtering (convolution): $Q_\beta(p,\zeta)=R_\beta^{'}(p,\zeta)*g(p)$
    - Backprojection: $f(x,y,z)=\int_0^{2\pi}\dfrac{1}{U^2}Q_\beta\left(\dfrac{x\cos(\beta)+y\sin(\beta)}{U},\dfrac{z}{U}\right)d\beta$

where: $U=\dfrac{D_{SO}+x\sin(\beta)-y\cos(\beta)}{D_{SO}}$

Reconstruction with FDK algorithm

$$\mu \mapsto f(x, y, z)$$

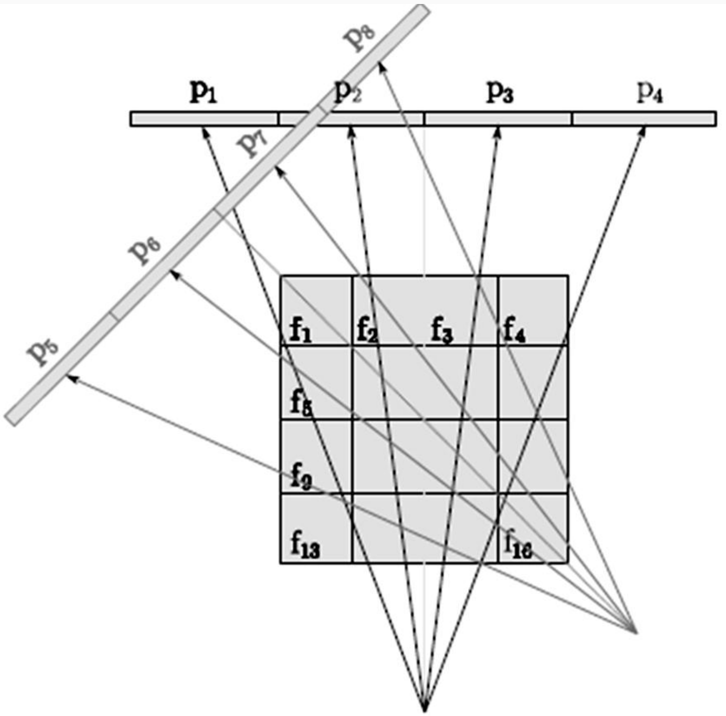




CT image

Reconstruction with PIXTV algorithm

- PixTV is an iterative reconstruction algorithm which minimizes the TV (total variation) norm:
  - Uses the linear data model for the CT problem
  - Projection and image space discretized and represented as a



$$p_k = \sum_{l=0}^{N} a_{k,l} \cdot f_l$$

- pk is a vector containing the projection data for a ray k,
- N = n² is the total number of pixels,
- a is the system matrix,
- f is the image to be reconstructed (reshaped as a vector containing the attenuation values)

Reconstruction with PIXTV algorithm

- Reconstruction → solving a convex optimization problem

$$\min_{f} \frac{\mu}{2}\|Af - p\|^2 + \|f\|_{TV}, s.t. f \in C$$

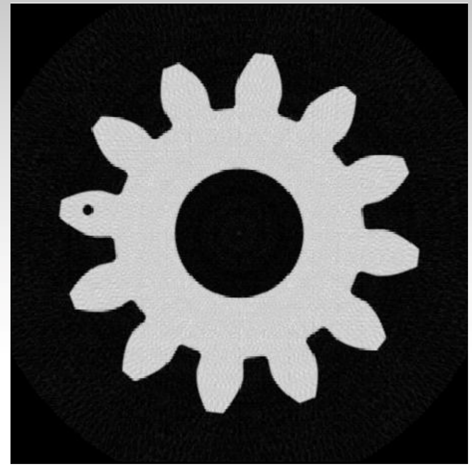
  - where μ is a penalty coefficient,
  - A represents the system matrix,
  - f the CT image, p the projection data (sinogram)
  - *C* a constraint set of possible solutions.

- TV (total variation) regularization

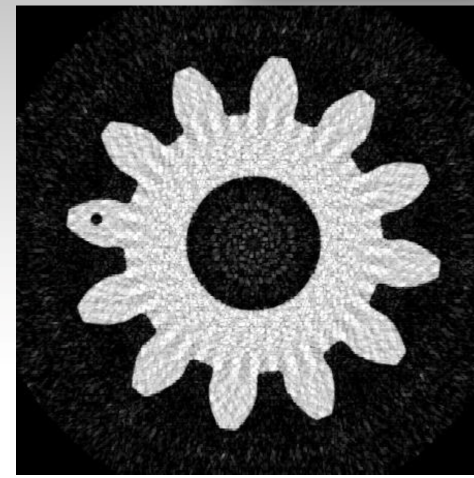
Comparaison FDK vs PIXTV

- FDK
  - Analytic algorithm: fast
  - Implemented on CPU (multithread)
  - An important number of projections is needed
  - Robust

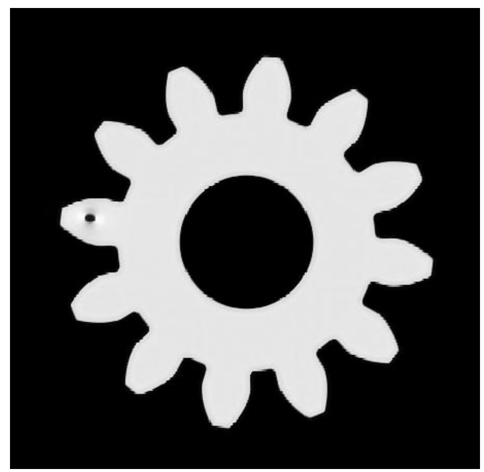
- PIX TV
  - Iterative algorithm: slower
  - Implemented on GPU
  - Less projections are needed
  - Many parameters
  - Difficult parameter choice (μ)

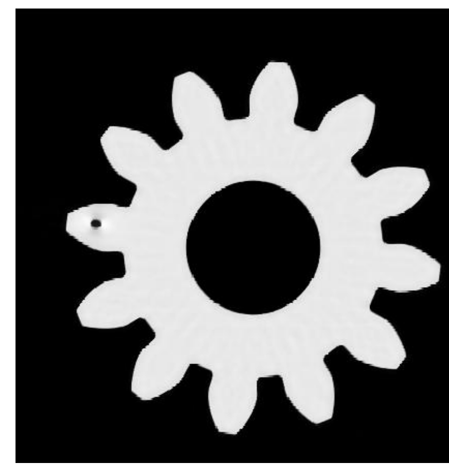


360 projections



90 projections



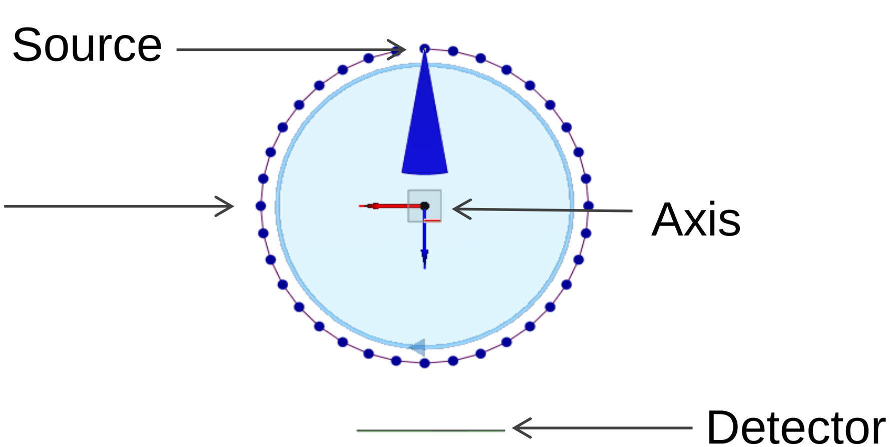


Applications:
Example of Source/detector misalignment

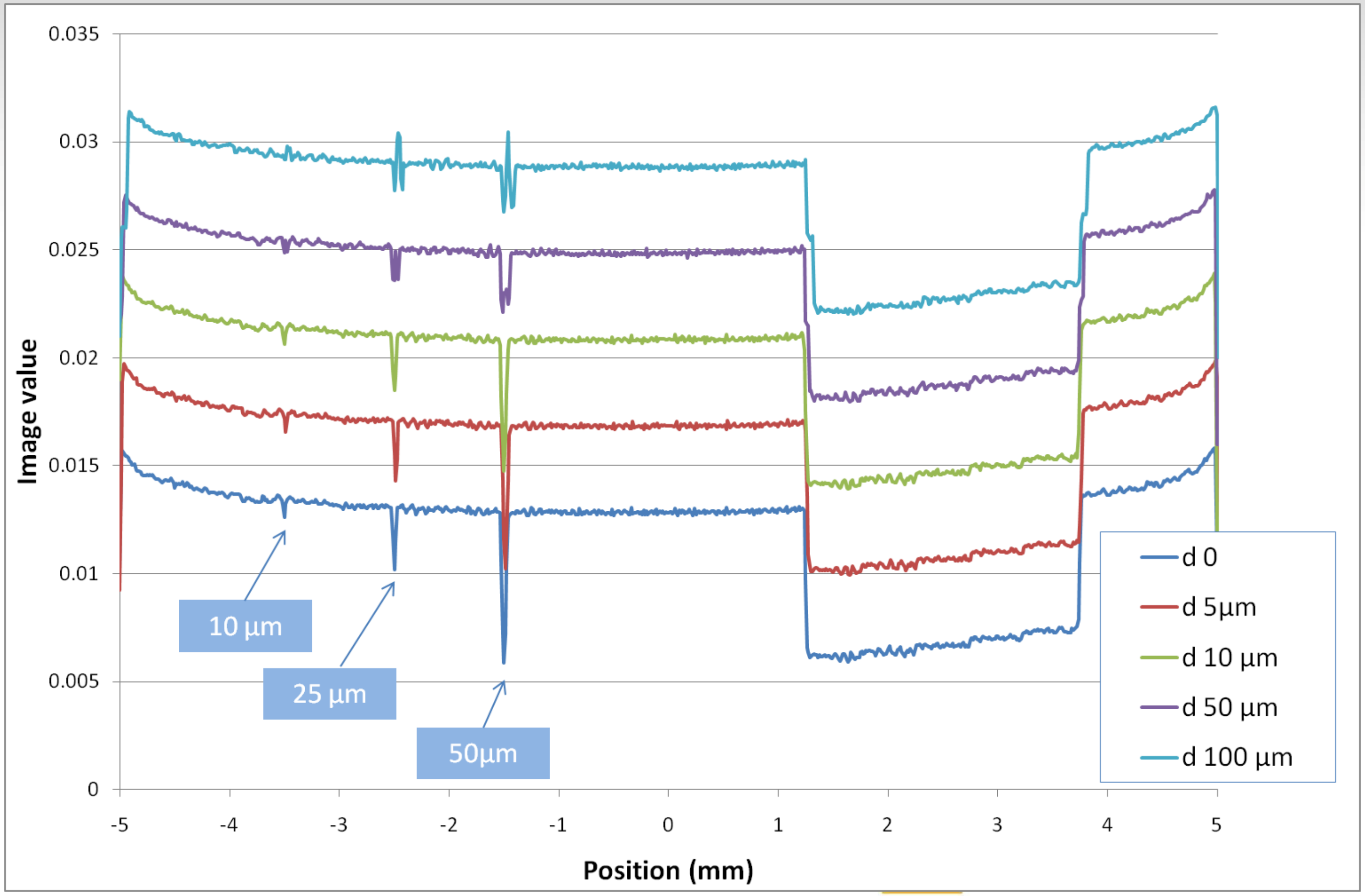
- Estimate the influence of the rotation axis mispositioning
  - Detector:
    - CsI X-ray detector
    - Thickness 300µm ; 1024 x 128 pixels ; 50µm/pixel
  - Source to object distance : 50mm
  - Source to detector distance : 200mm
  - Object :
    - Aluminum cylinder of 10mm in diameter
    - Two sets of aligned holes of diameter 5, 10, 25, 50µm and 50,100, 250 and 500µm and 5 stacked carbon blocks
  - 90kV X-ray generator

Applications: source/detector misalignment

- Estimate the influence of the rotation axis mispositioning
  - 360 projections (for all simulations)
  - Images are reconstructed with FDK.
  - The rotation axis shifted perpendicularly in the horizontal plane with 5, 10, 50 and 100µm



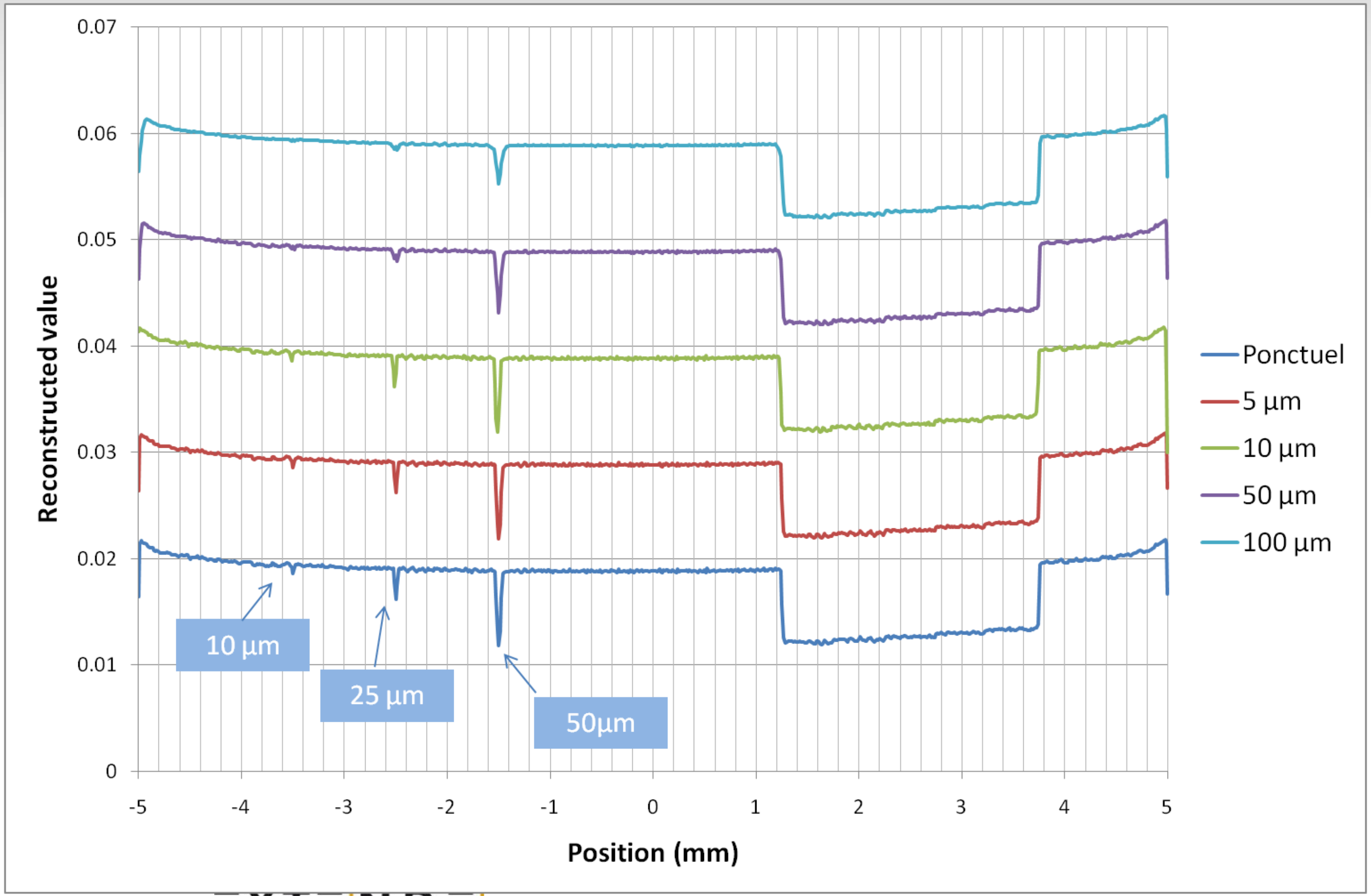
Applications: source/detector misalignment



Applications: Spot size influence

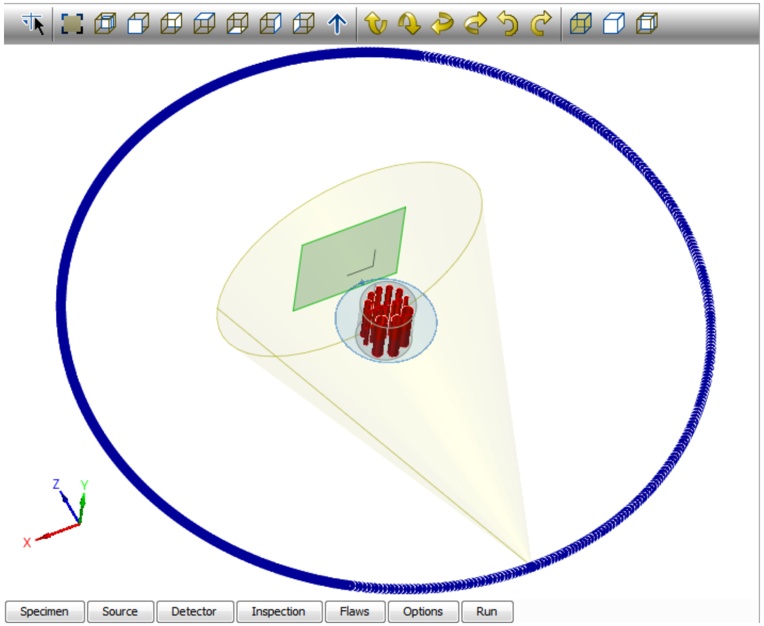
- Evaluate the influence of the X-ray spot size in a micro-CT configuration
  - Same nominal configuration as the previous one
  - X-ray spot size has been set to 0, 5, 10, 50 and 200µm

Applications: Spot size influence



Applications: comparison study

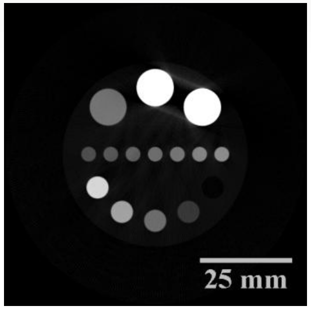
- Evaluate the performance of the presented reconstruction algorithms
  - The X-ray source is a reflection type X-ray generator
  - Acceleration voltage of 100kV
  - Target current of 10mA
  - The sample is a Plexiglas cylinder of 50mm in diameter
  - 15 cylindrical insertions of different materials and densities

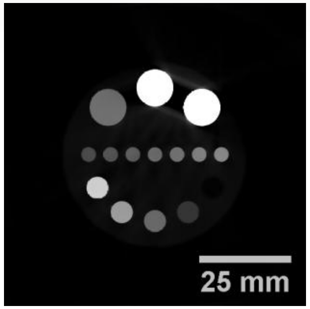


Applications: comparison study

- Performance of the reconstruction algorithms
  - Simulation of 512 projections equally distributed over a full rotation
  - Reconstructions of the central plane from the complete set of projections.

FDK

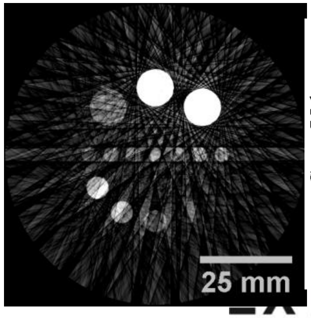


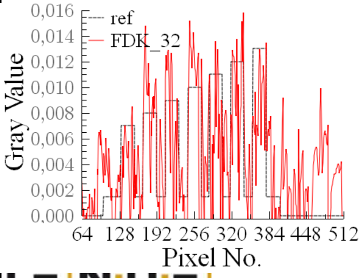


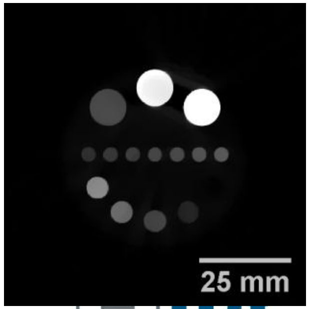
PIXTV

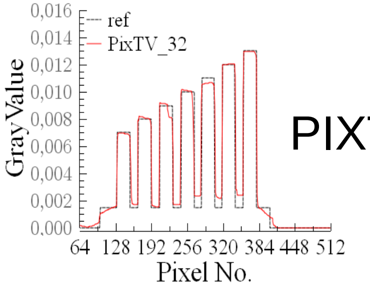
  - evaluation for the cases of reconstruction from a lower number of projections: 32 equi-distributed projections

FDK









PIXTV

Conclusion and future works

- Full modeling of Computed Tomography in CIVA for:
  - Performances estimations
  - Optimization of control parameters
  - Benchmark of reconstruction algorithms with realistic data
- Future works:
  - Import and reconstruct experimental data
  - Integrate quantitative criteria to enhance benchmarking
  - POD module
  - Accelerating Monte Carlo computation (scattering photons)
  - Development of a specific image processing module
  - Implementation of new reconstruction algorithms