The Future of Simulation in CIVA

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CIVA USERS
COMMUNITY EVENT

Foreword

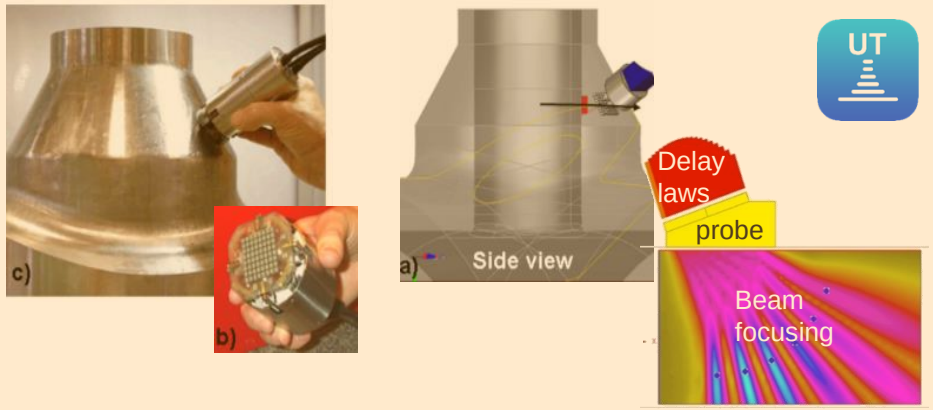
CIVA excels in fast semi-analytical simulation (full NDT study on a PC)

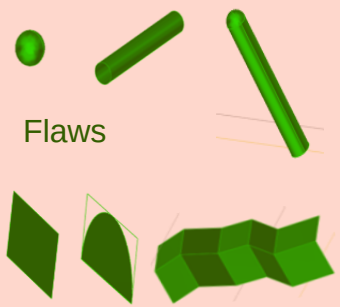
Gradual introduction of FEM-type and hybrid numerical solutions to validate/complete fast models

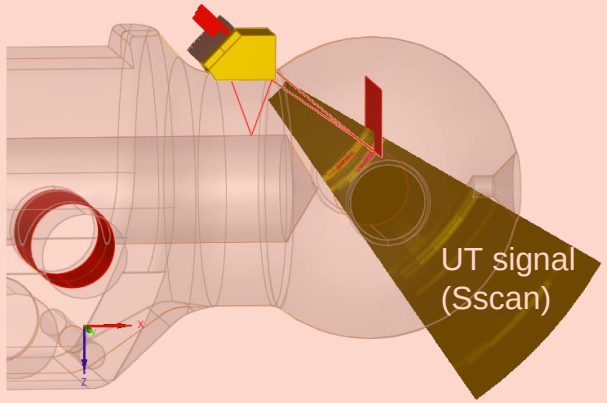
Focus on the evolution of the recent modules, the preparation of incoming modules and uses

Paraxial ray (beam calculation) & ray tracing (time of flight)

→ Signal interpretation, modal analysis, delay laws prediction







Hybridization with flaw response models

→ Full inspection simulation, performance demonstration…

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Early 2010s: Athena (edf), Fidel (airbus, FDTD) – 2D only

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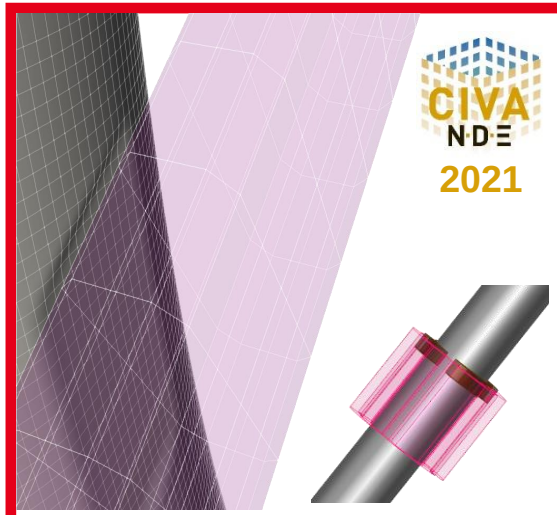
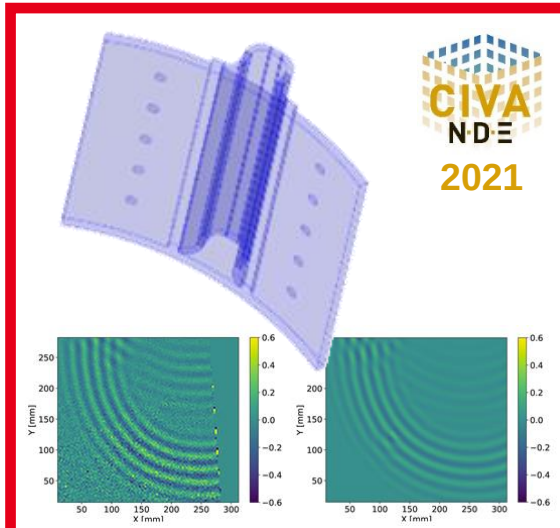
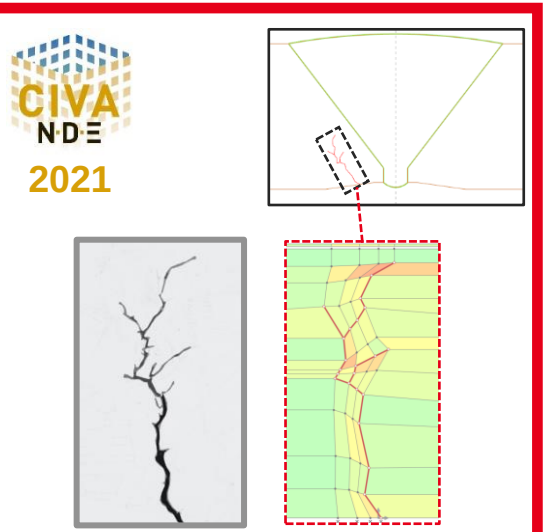


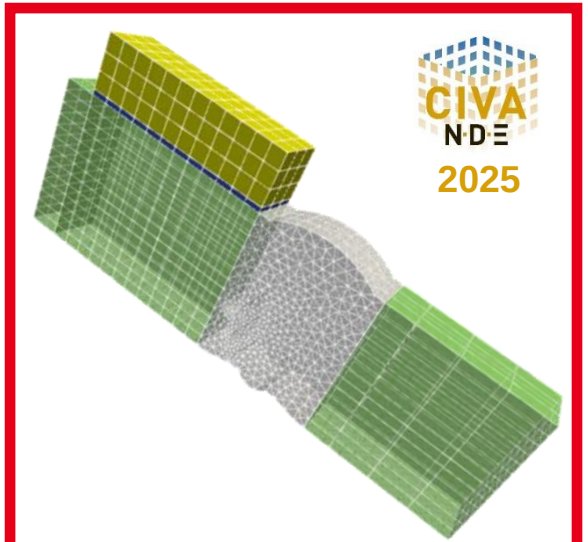
SG Tube (ET)



SHM



Flaw response (UT)



Part & Defect (UT)

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CIVA NEXT

SHOULD BE
IN CIVA NEXT
(2025 SPx / 2027)

CIVA 202?

COULD BE
IN CIVA NEXT
(CIVA 202?)

CIVA PoC

STUDY OF A
PROOF OF
CONCEPT

Ultrasonic Testing

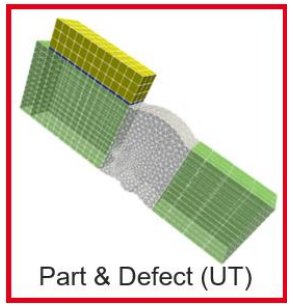
Improved Numerical Solutions

UT – Improved Numerical Solutions

Performances inherent to the FEM: NDT studies in 2D, a few shots in 3D

Challenge: automatic construction process for the simulated inspection scene

Ongoing work: regularizing performance and extending inspection configurations


Part & Defect (UT)

$$CPU\ Time = F^{d+1} \times C(config) \times Q(mesh)$$

Inspection frequency
$d = 2 \text{ or } 3$

Fluid-solid, Viscosity,
Thin layers, Anisotropy,
Heterogeneity …

Distorted finite elements,
small edges…

	1 MHz	5 MHz
2D	10 sec	20 min
3D	10 min	4 days

We have to live with

up to $\times$ 1000 !
(most often $\times$ 2 to 10)

We can act

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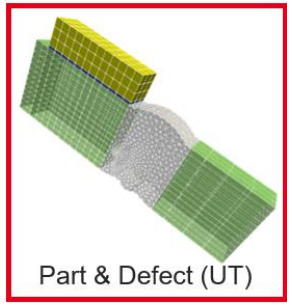
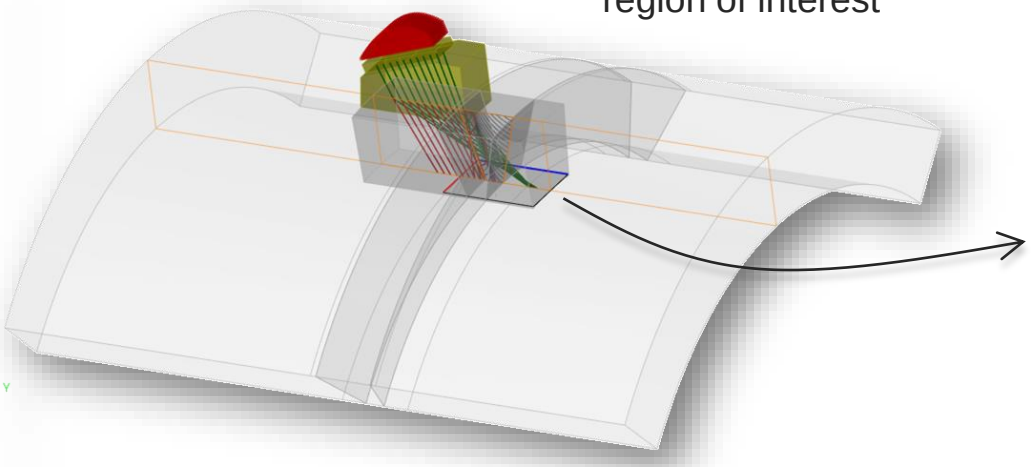
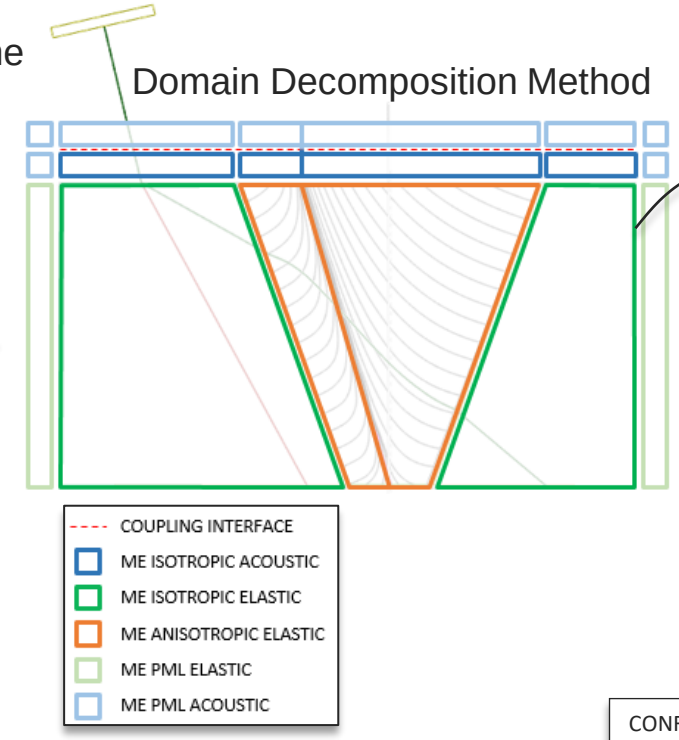


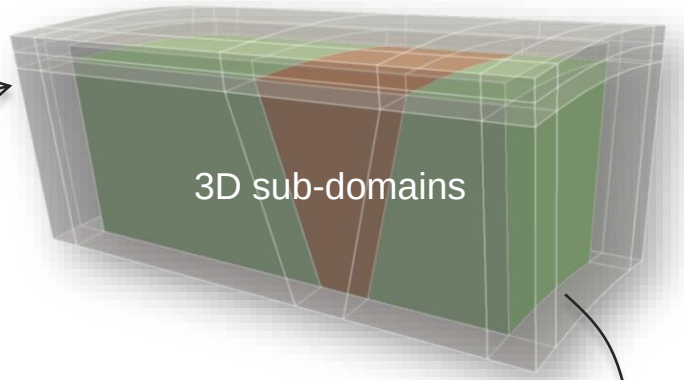
$$CPU\ Time = F^{d+1} \times C(config) \times Q(mesh)$$

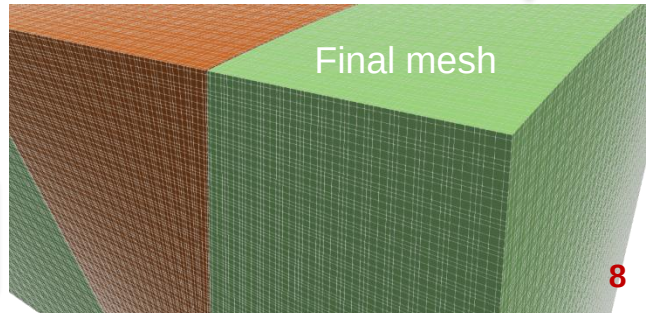
Ray tracing pretreatment to adjust the region of interest



Domain Decomposition Method







CONFORMAL MESH
4TH ORDER ELEMENTS
2 OR 3 ELEMENTS / λ_T

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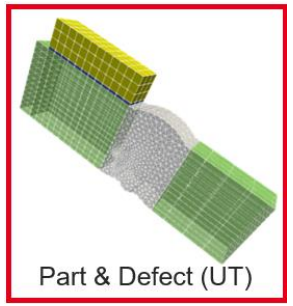


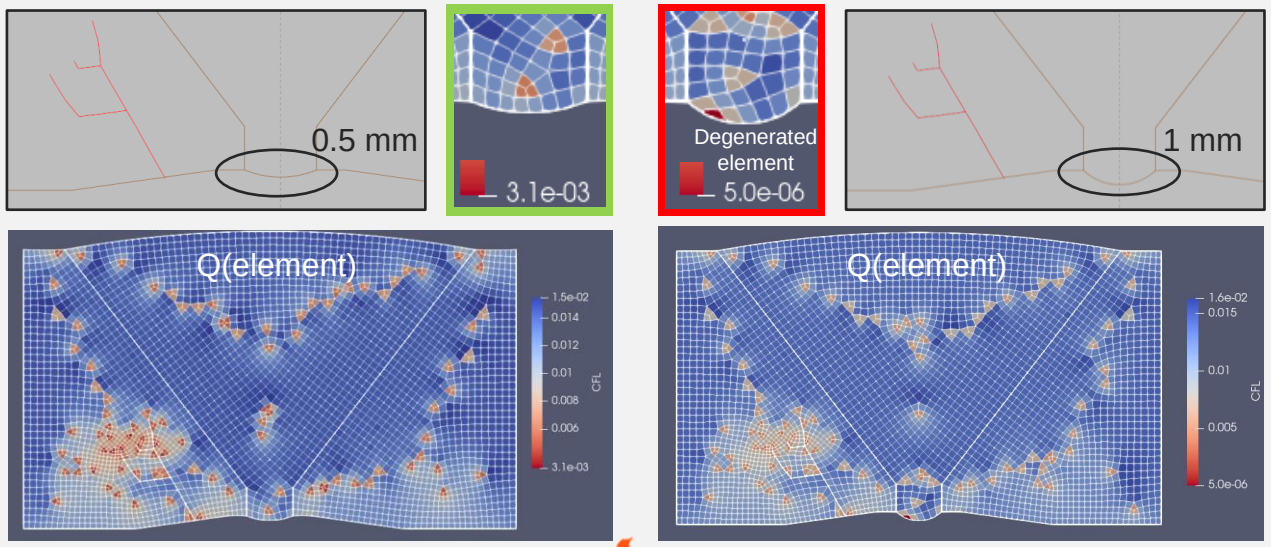
$$CPU\ Time = F^{d+1} \times C(config) \times Q(mesh)$$

CIVA NEXT

CIVA 202?

CIVA PoC

Automatic processing of mesh singularities



Meshing software in a complex zone (e.g. defect + weld)

A geometry variation may introduce a mesh singularity (up to x 1000!)

We are testing solutions to isolate and treat these singularities separately

The process should be operational by 2026

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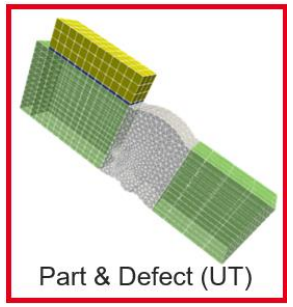


$$CPU\ Time = F^{d+1} \times C(config) \times Q(mesh)$$

CIVA NEXT

CIVA 202?

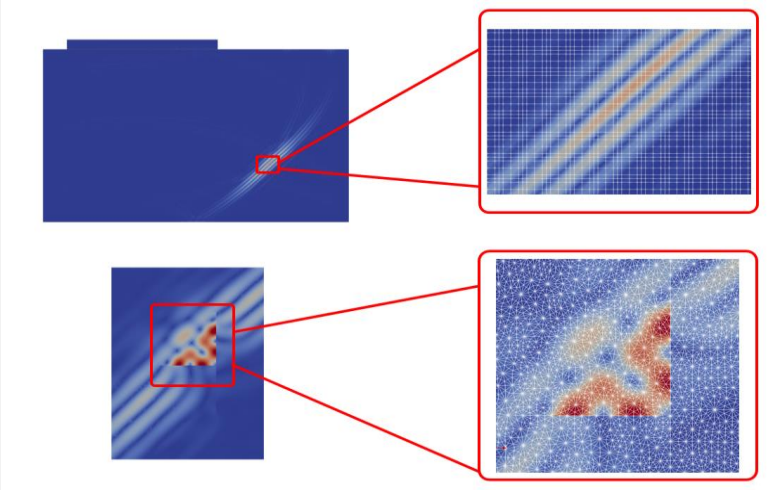
CIVA PoC

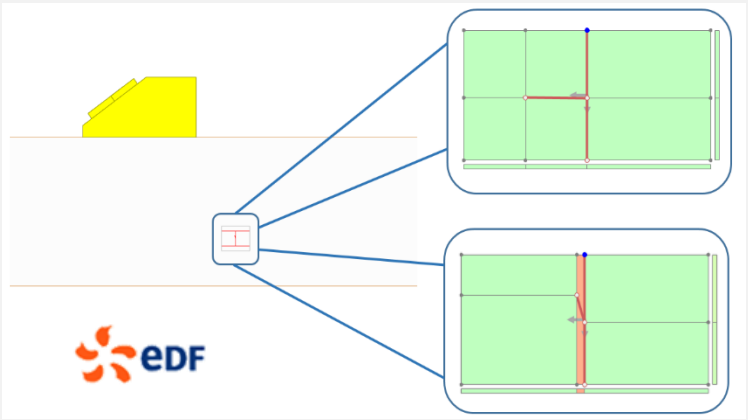
Hybridization between the healthy part and a flaw box

Relieves meshing constraints

Should allow disorientation of the defect in the part

Should ease a variation study on the defect





x 60%

x 30%

Software issues: multi-elements, memory access…

Modelling issues in heterogeneous materials

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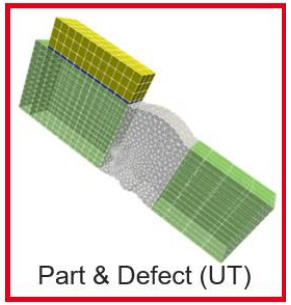


$$CPU\ Time = F^{d+1} \times C(config) \times Q(mesh)$$

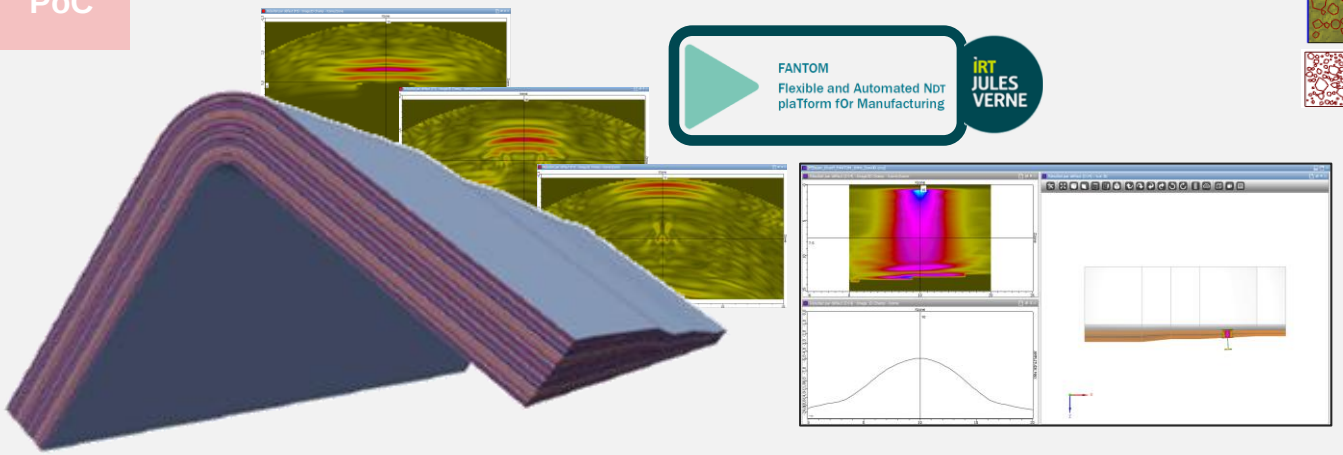
CIVA NEXT

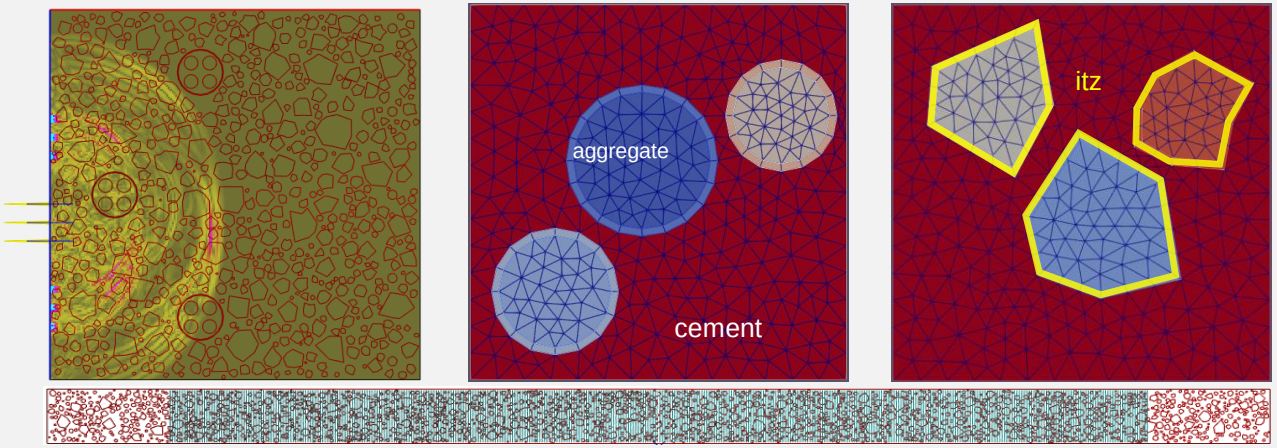
CIVA 202?

CIVA PoC

Extension to composites & concrete

Increased complexity: CIVA plugins to date (ply waviness & loss, porosities, itz…)





EDF

Used halfway between inspection and effective material characterization (inputs for a fast model)

Ultrasonic Material Characterization

NEW MODULE

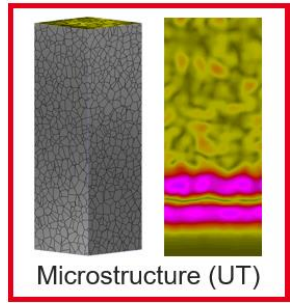
Ultrasonic Material Characterization

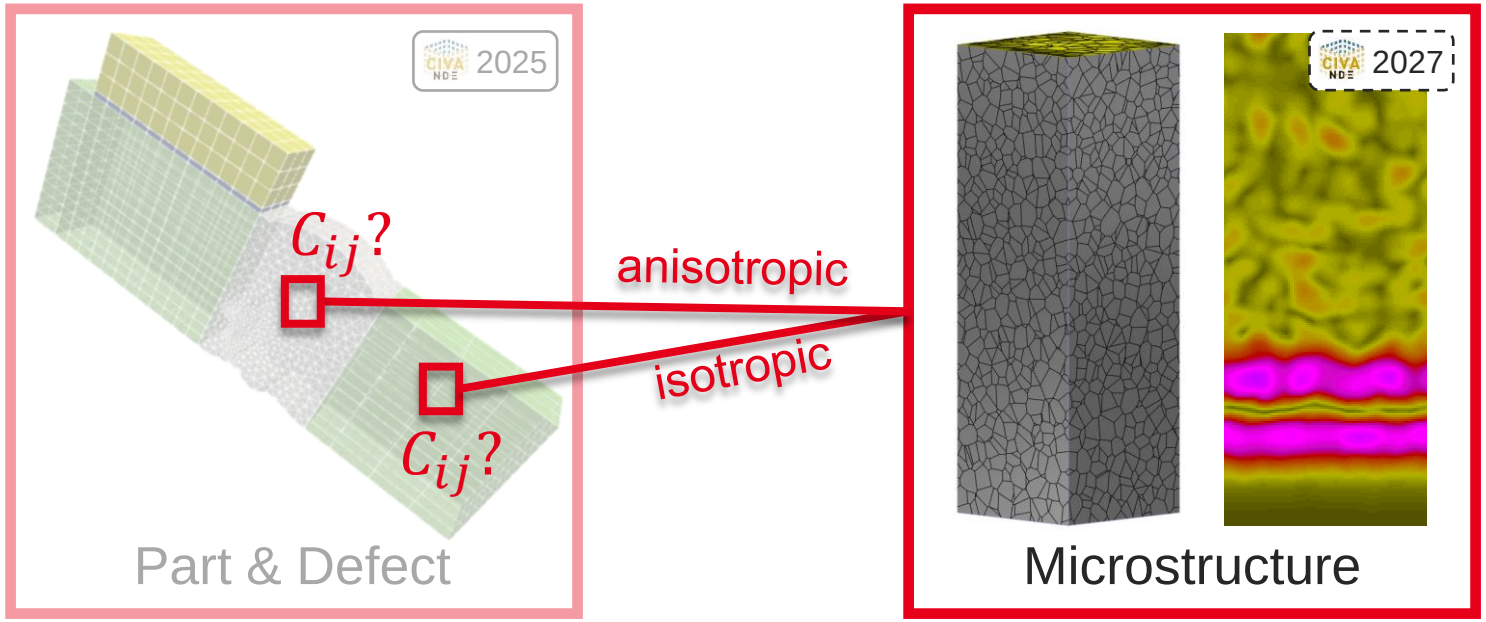
Describing a complex material for inspection sim: average speed, attenuation, noise

Extending CIVA to material characterization applications

Simplified grid-FEM, dedicated post-processing, statistical study

Equiaxed & textured polycrystalline materials, titanium, cast steels, concrete...





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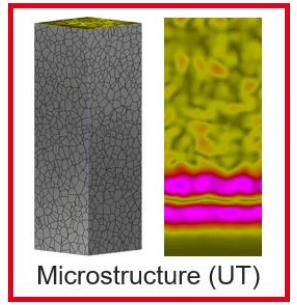
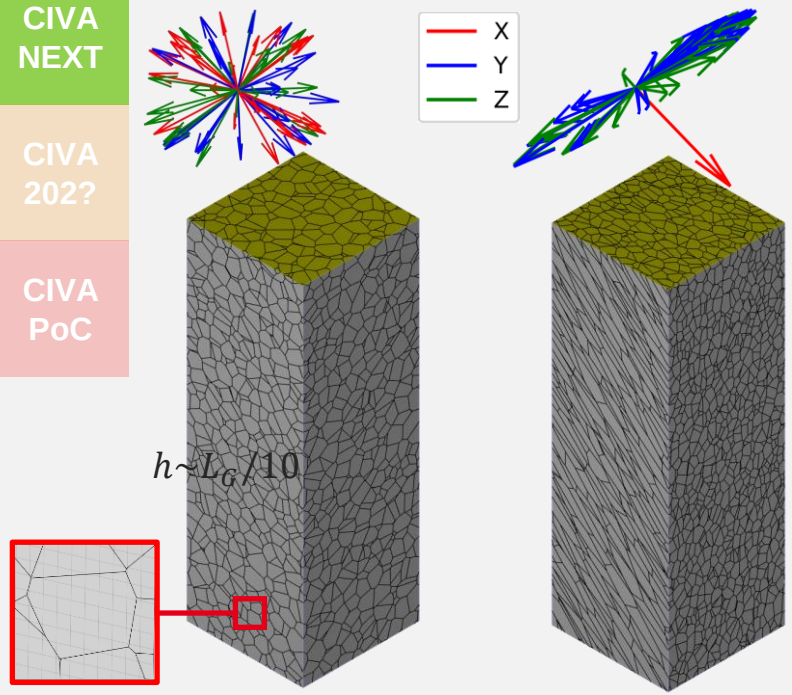


CIVA NEXT

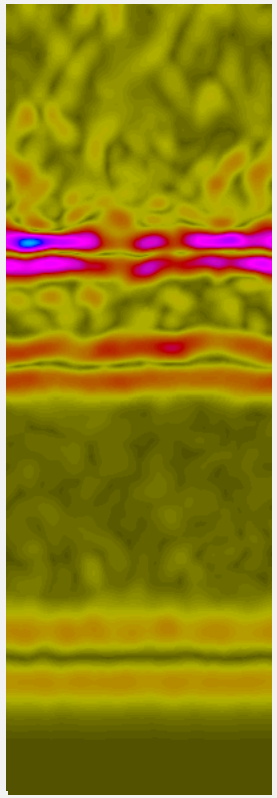
CIVA 202?

CIVA PoC



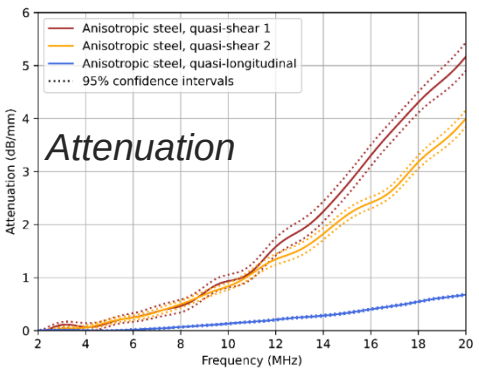
Equiaxed grain
Untextured crystal. orient.

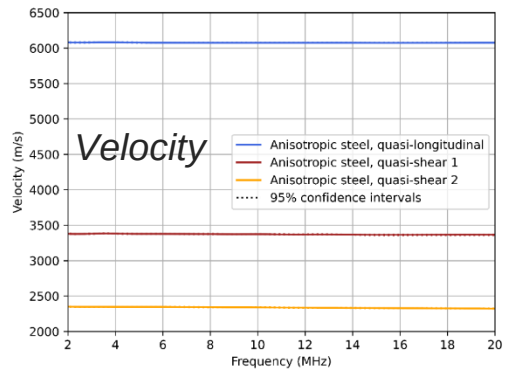
Elongated grain
Textured crystal. orient.



Problem: separate mode contributions

Proposed solution: project the field on expected polarization directions (Hill average)





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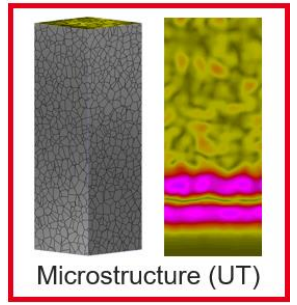


CIVA NEXT

CIVA 202?

CIVA PoC

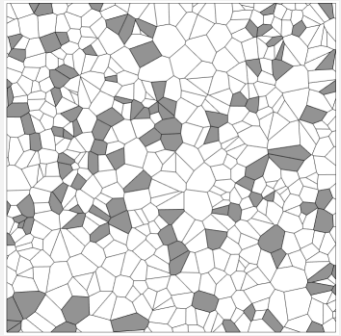
Successive measurements during temperature and phase changes

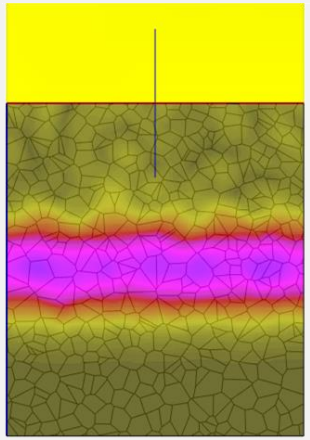
Representation of ferrite → austenite transition

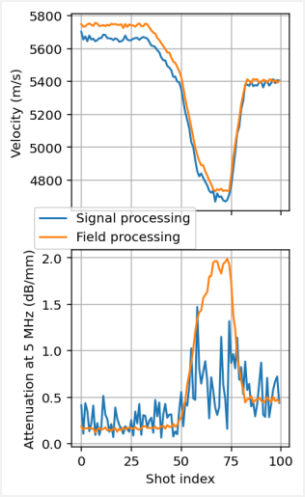
Simulation of measurements for a series of temperatures and phase percentages

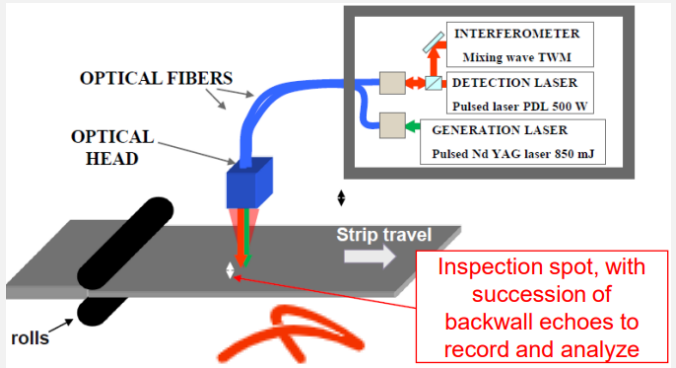
Velocity & attenuation estimations

Research Fund for Coal & Steel









ArcelorMittal

Ultrasonic Testing

Confidence in Fast Simulation

NEW USE ?

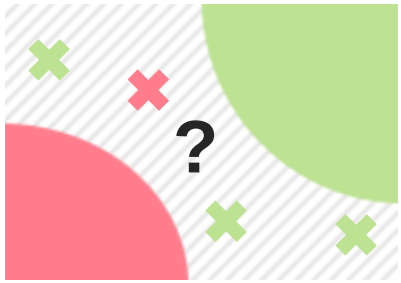
UT – Confidence in Fast Simulation

Ensure or reject *a priori* fast simulation is possible on a restricted perimeter

Benchmarking, expe or numerical validation enables us to statuate in grey areas

The ability to detect an anomaly and alert *a posteriori* the user remains critical

A new concept of ‘spy report’ in simulation is being studied



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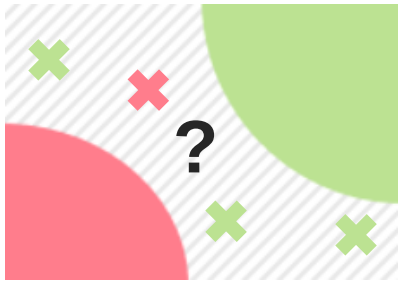
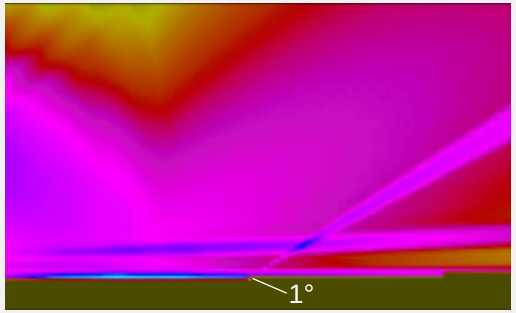
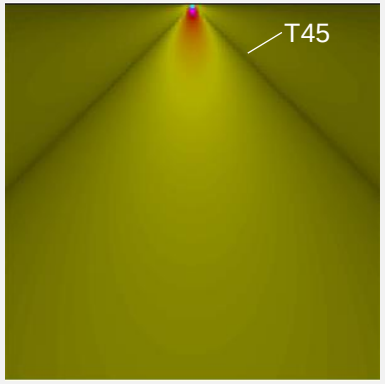


Detection and warning of critical phenomena in paraxial simulation (field calculation)

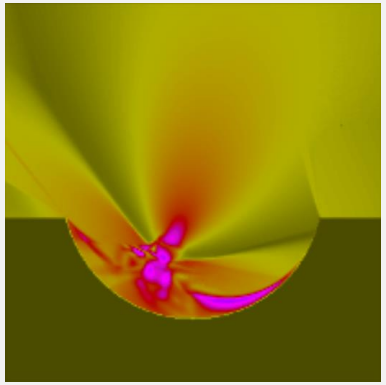
Some typical examples:



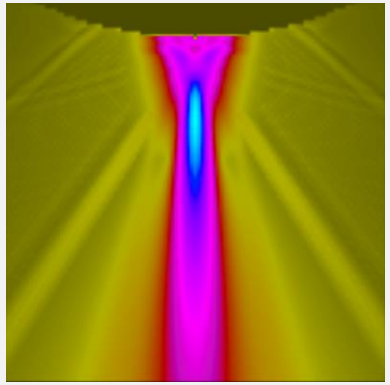
Field recovery



Critical angle



Caustic at weld root



Faceted curved surface

■ ■ ■

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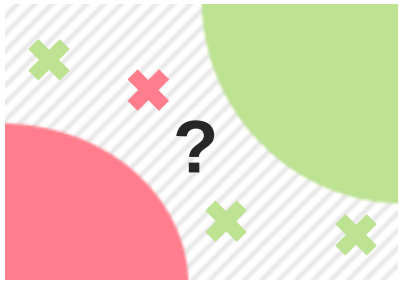


CIVA NEXT

CIVA 202?

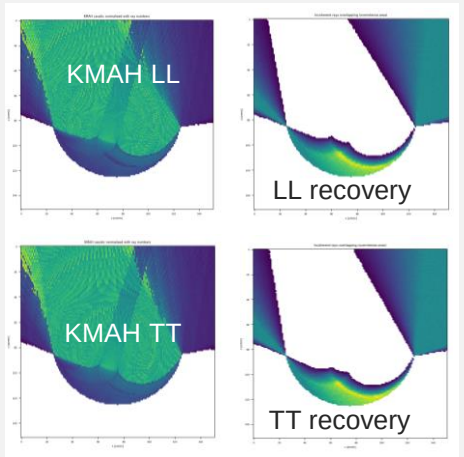
CIVA PoC

Detection and warning of critical phenomena in paraxial simulation (field calculation)

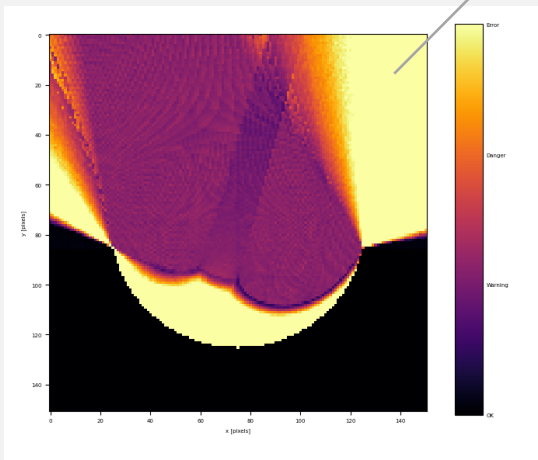
A dozen criteria associated with each paraxial ray

Image synthesis by combination (NDT expertise)

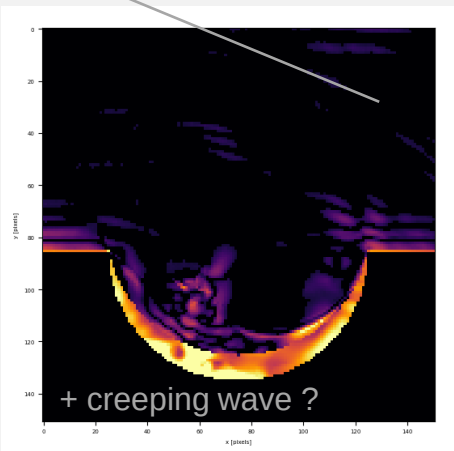
Motivating (or not) an investigation



Indicators by criteria



Combined cartography



Error vs FEM

Electromagnetic & Thermographic Testing

NEW MODULES

Electromagnetic & Thermographic Testing

BEM 3D solution dedicated to the ECT of steam generator tubes

Extension to a new weld inspection module

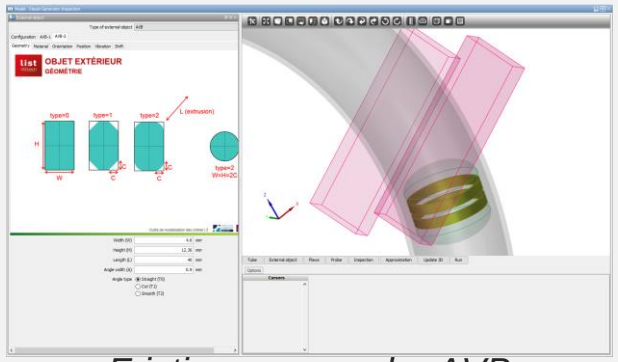
Heating module on 3D CAD for induction thermography

Thermal diffusion & IR camera module on 3D part + defect

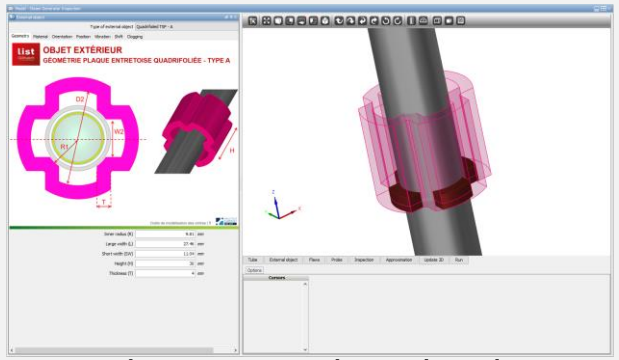
Electromagnetic material characterization module

Simulates most inspection issues with bobbin coils (2021), rotating & multi-element probes (2025)

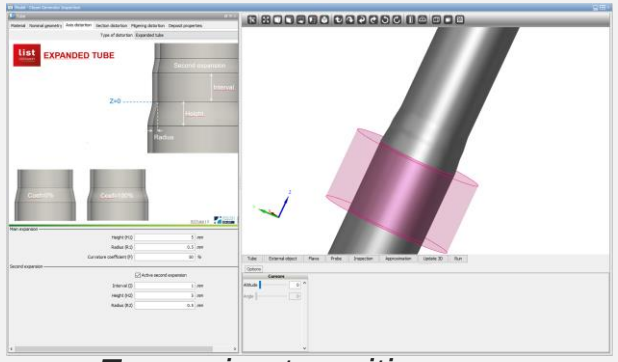
We will now be working to improve performance



Friction wear under AVB



Tube support plate clogging



Expansion transition zone

Electromagnetic & Thermographic Testing

BEM 3D solution dedicated to the ECT of SG tubes

Extension to a new weld inspection module

Heating module on 3D CAD for induction thermography

Thermal diffusion & IR camera module on 3D part + defect

Electromagnetic material characterization module

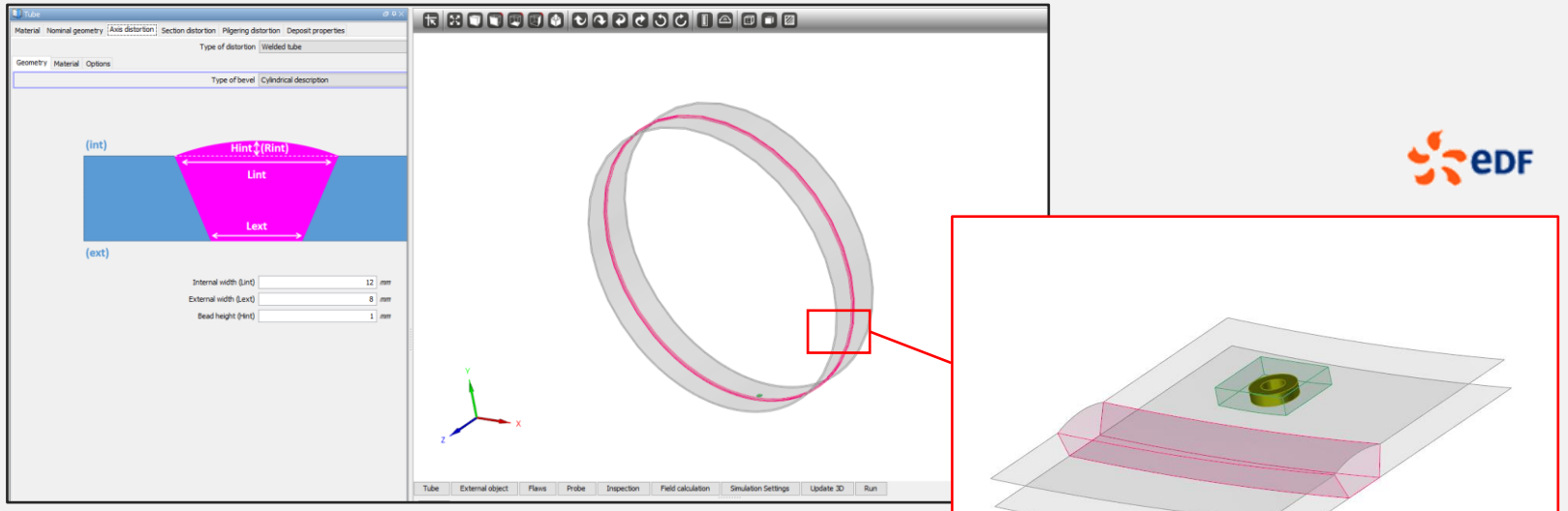
CIVA NEXT

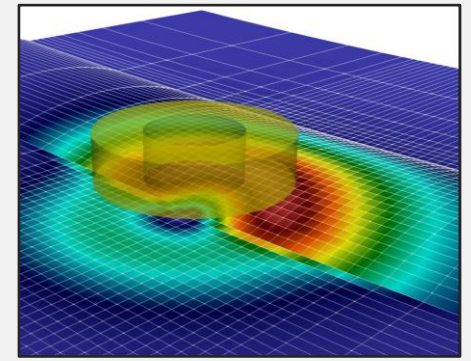
CIVA 202?

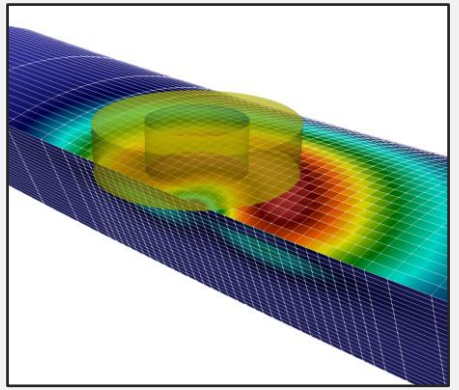
CIVA PoC

Increased difficulty with the combination of geometric & material effects

Search for hybrid solutions (2D5 heterogeneous part + 3D defect)







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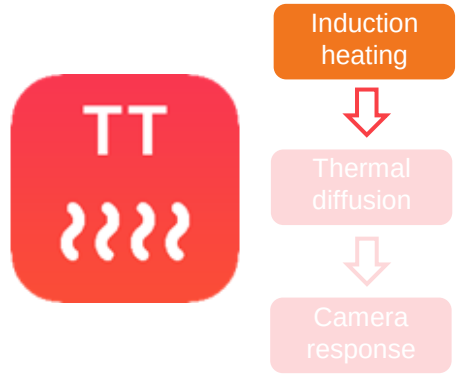


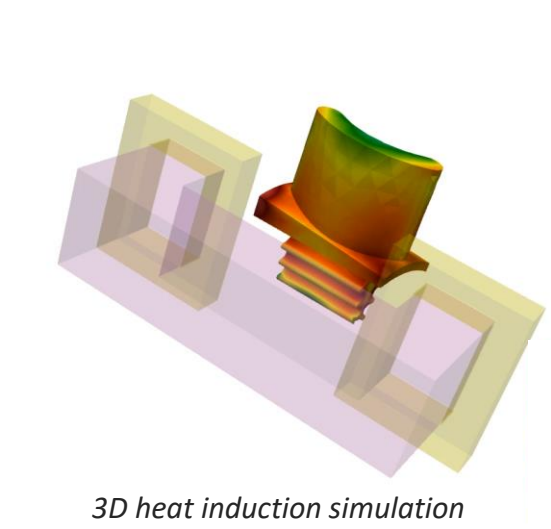
CIVA NEXT

CIVA 202?

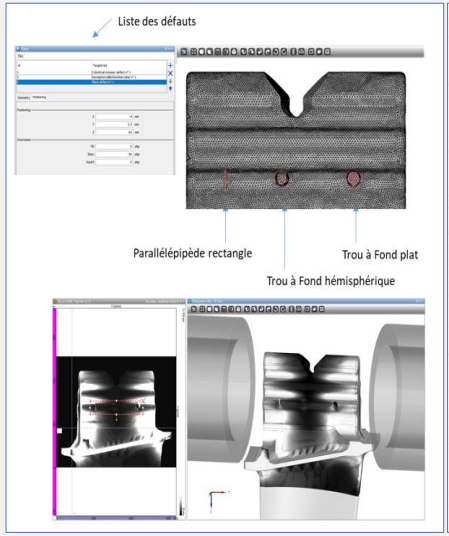
CIVA PoC

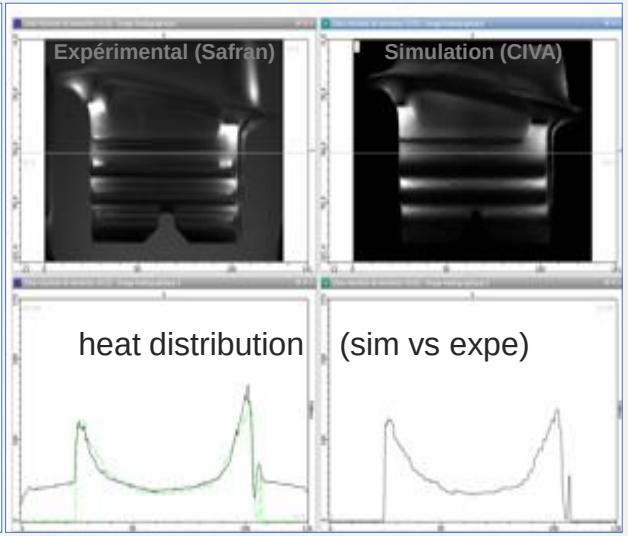
Excitation at short times using electromagnetic induction (eddy currents)

Computation of the dissipated power volume density (Joule effect)



3D heat induction simulation





Key issues include automatic meshing of 3D CAD, sensor landing, optimization of the ferrite/part coupling…

SAFRAN

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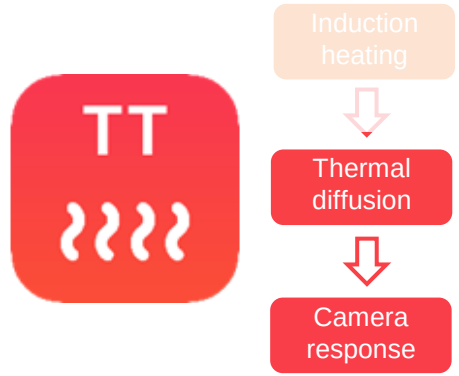


CIVA NEXT

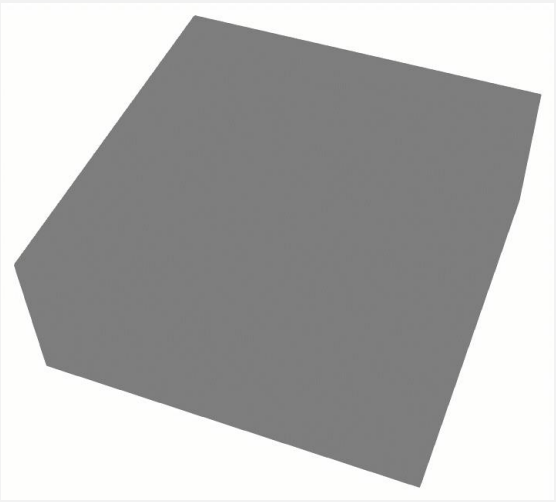
CIVA 202?

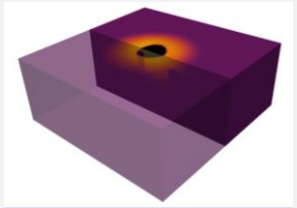
CIVA PoC

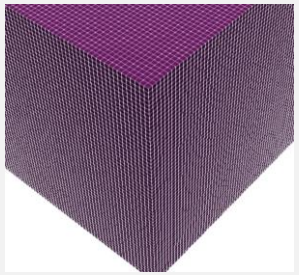
Quantitative simulation on simple geometries including defects and wedge effects, qualitative on 3D CAD

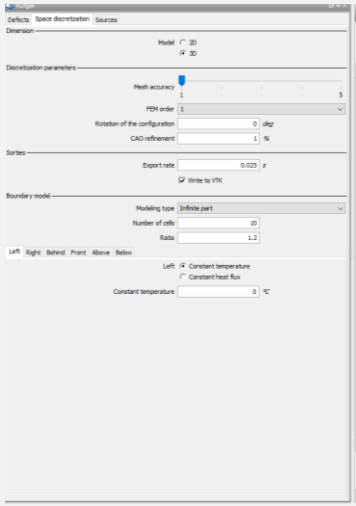
Various heat sources: electromagnetic induction, flash, laser

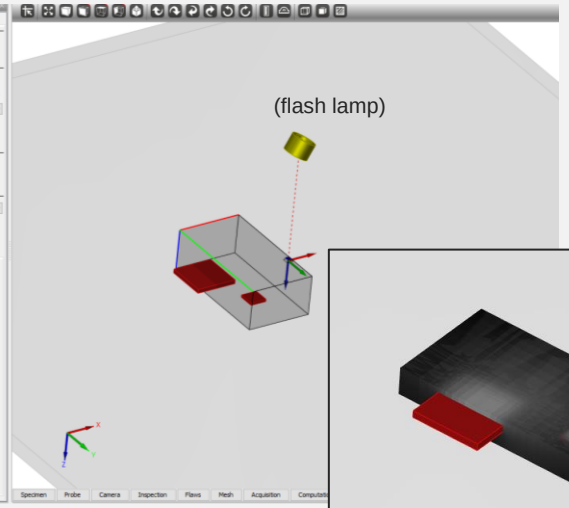
Accelerated FEM solver on grid (1M unknowns in a few minutes on a laptop)

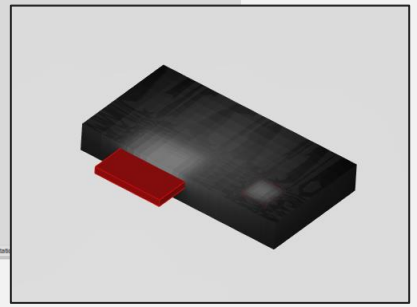












Work in progress: numerical settings & experimental validation

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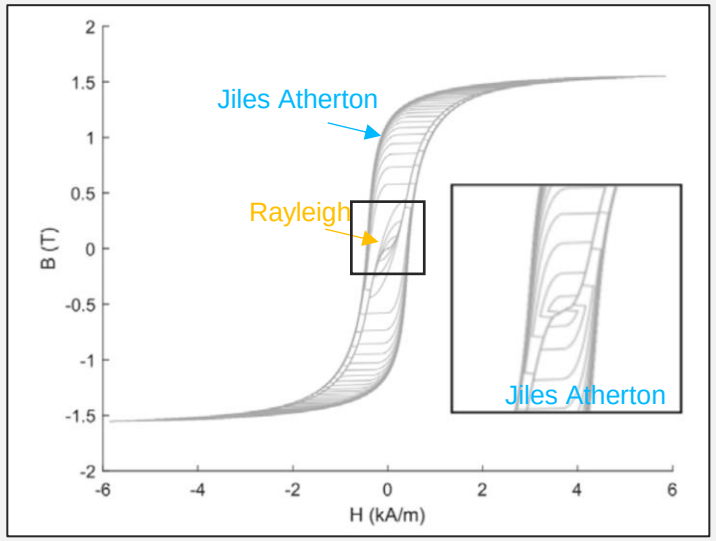
CIVA NEXT

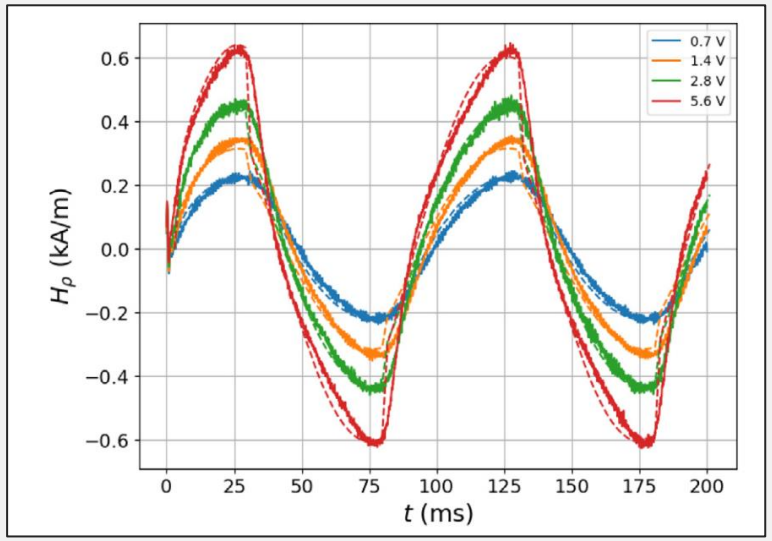
CIVA 202?

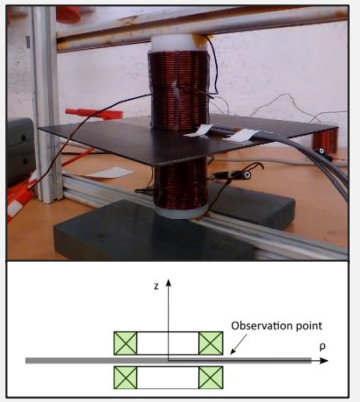
CIVA PoC

Calibration of standard non-linear B(H) laws from acquisition data, non-linear simulations in isotropic media

Active research programs: extension to anisotropic media, modelling of magneto-mechanical effects…







Combination of two hysteretic magnetic models to follow experimental trends

Guided Wave Testing
&
Structural Health Monitoring

GWT & SHM

Analytical propagation of modes in the healthy guide (bar, pipe, rail…)

FEM simulation in the vicinity of the geometric/material perturbation

Coupling using a scattering matrix (conversion of incoming and outgoing modes)

CIVA NEXT

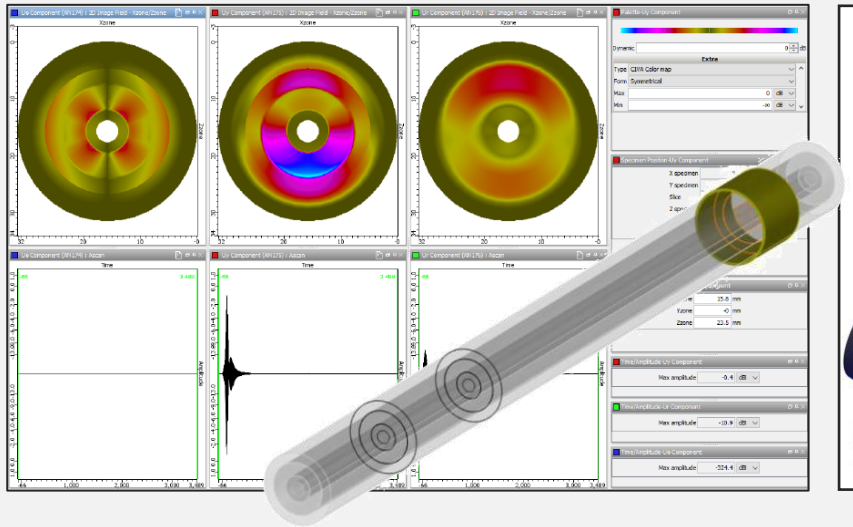
CIVA 202?

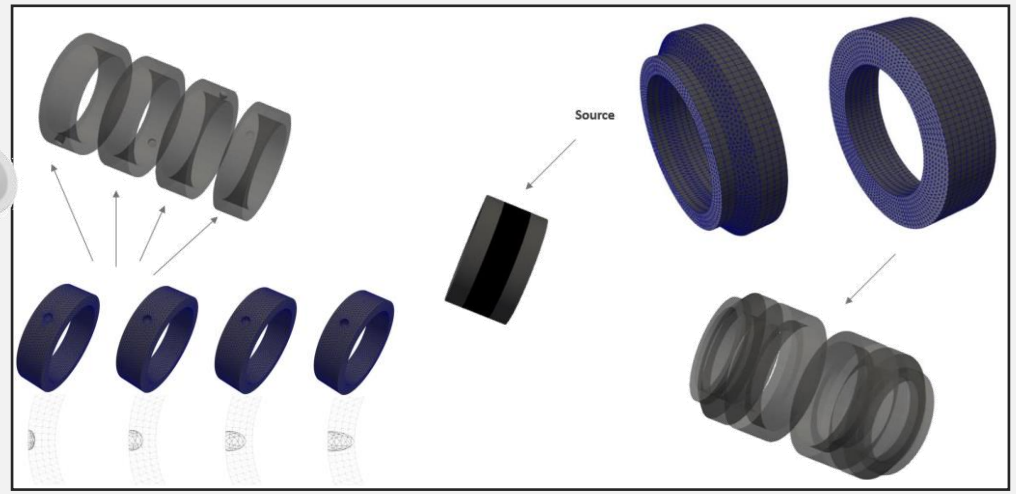
CIVA PoC

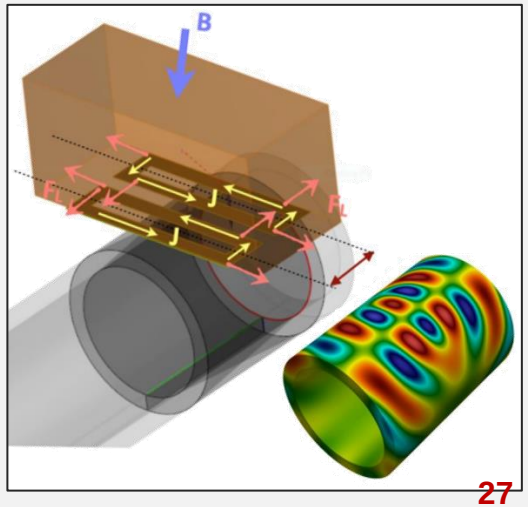
3D field & flaw in a submerged zone

Combining flaw numerical boxes in a 3D inspection scene

Loading generic sources: EMAT, magnetostrictive patches...







GWT & SHM

Full-FEM simulation in the time domain (non-modal)

Restricted to parametric geometries to date

Compatible with multi-directional guides (CFRP…)

SHM

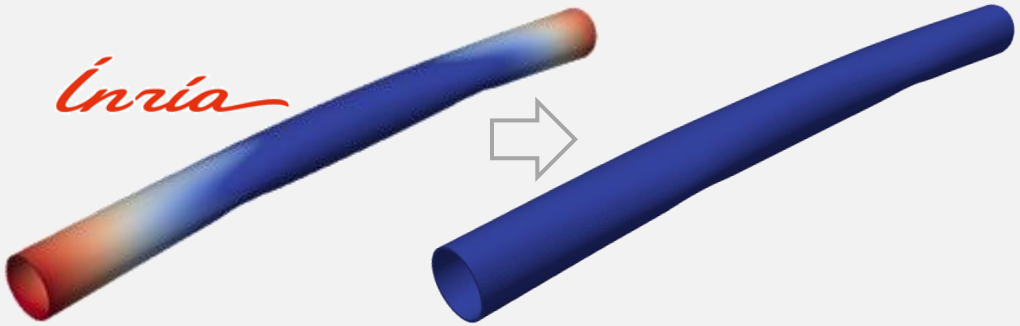
CIVA NEXT

CIVA 202?

CIVA PoC

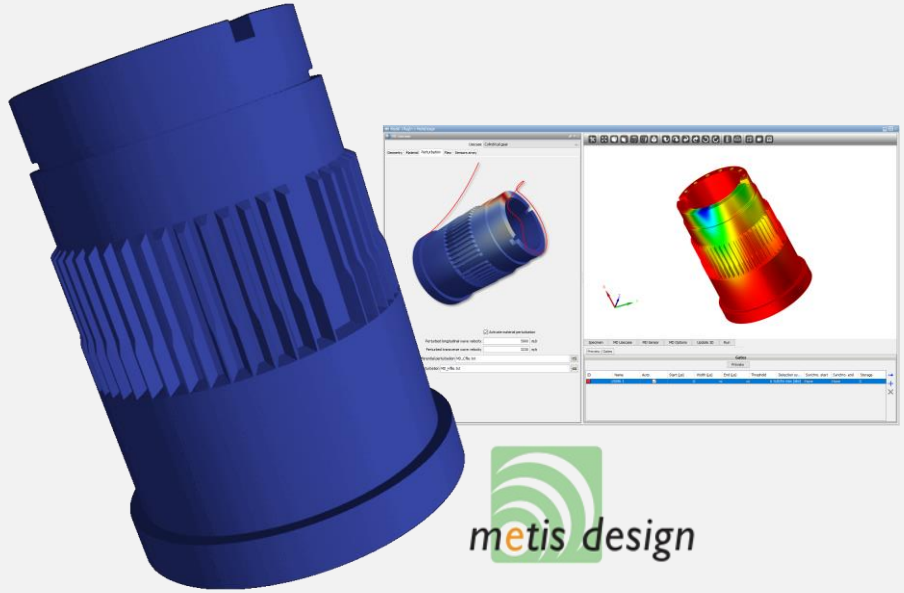
Loading a description of mechanical or environmental constraints (plate, tube, bar)

Extending the parametric mesher to more complex geometries



Non-linear static calculation of structural deformation

Modified linearized wave propagation



metis design

Radiographic Testing
&
Computed Tomography

RT & CT

Photon counting detector (PCD)

Electron transport modelling & darkening of silver bromide grains caused by electrons

X-ray phase contrast imaging model

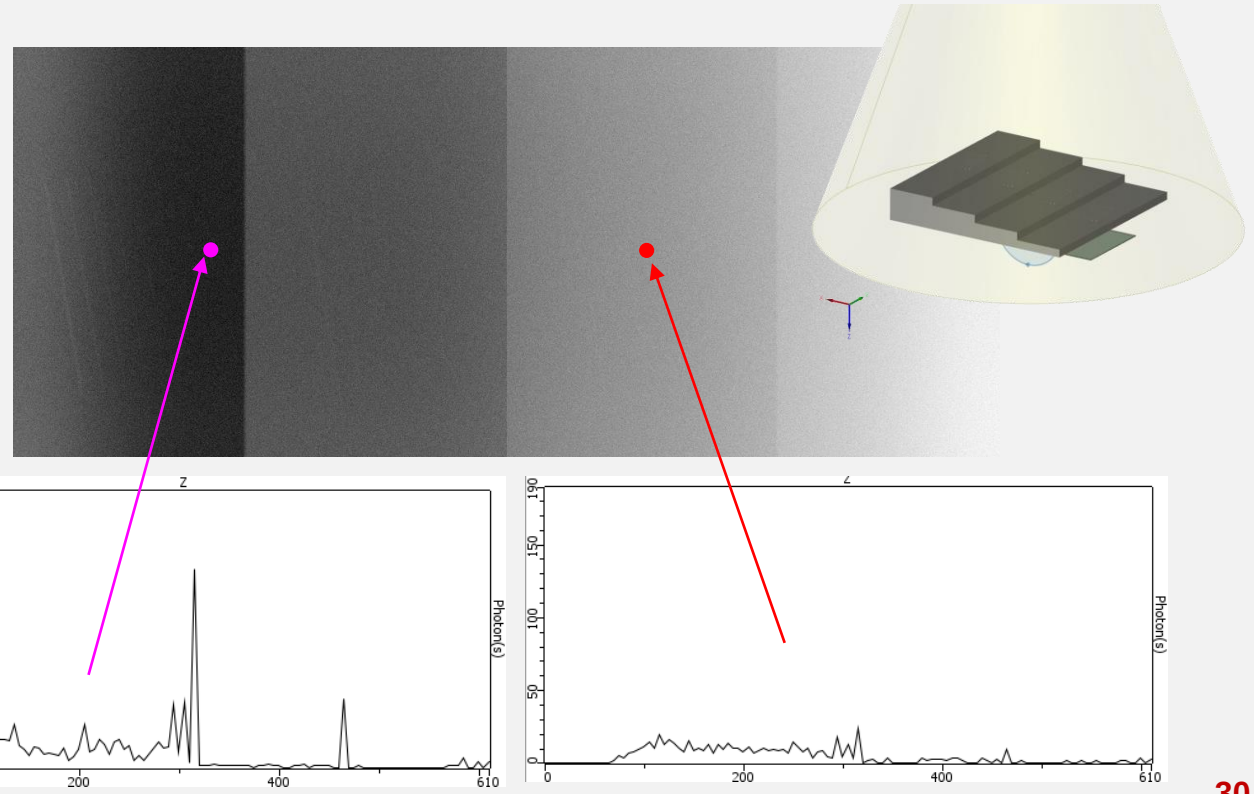
CT: towards a demonstrator of advanced reconstruction algorithms

CIVA NEXT

CIVA 202?

CIVA PoC

Spectral detector for processing the energy of incident photons improving the sampling of the X-ray spectrum in multiple energy bins



Cuts off scattered radiation
New image: number of photons integrated for each pixel

RT & CT

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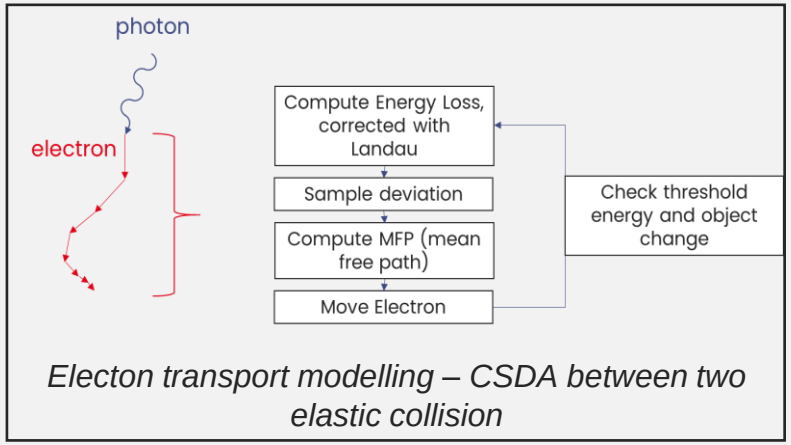
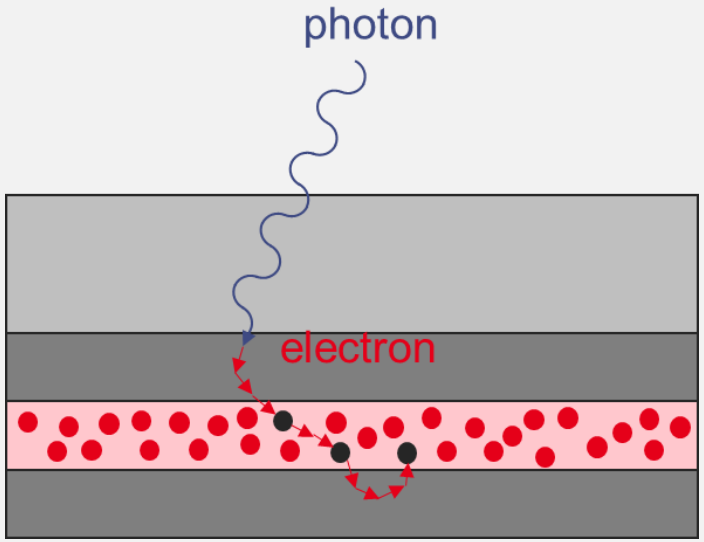
CIVA NEXT

CIVA 202?

CIVA PoC



Electon transport modelling – CSDA between two elastic collision



Argentic film characterization

Calculation of the flux-optical density conversion efficiency

Estimation of the intrinsic blurring of the X-ray cassette

RT & CT

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CT: towards a demonstrator of advanced reconstruction algorithms

CIVA NEXT

CIVA 202?

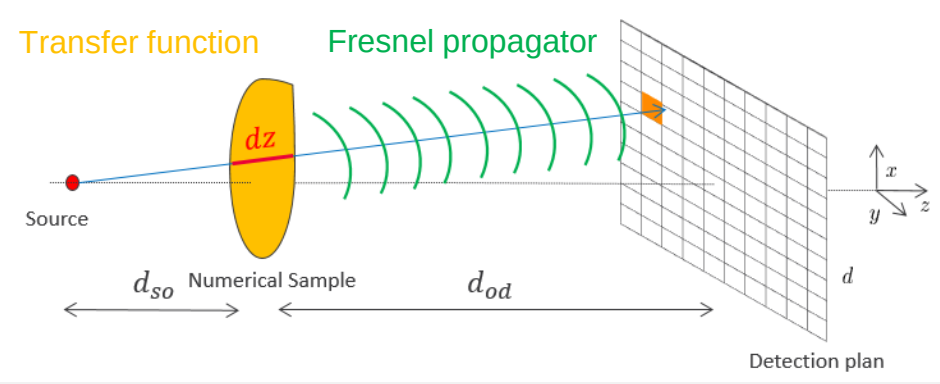
CIVA PoC

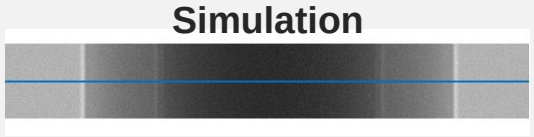
Hybrid approach based on a ray tracing and wavefront propagation

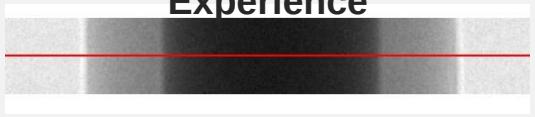
Ray tracing : fast numerical scene description under a cone-beam configuration

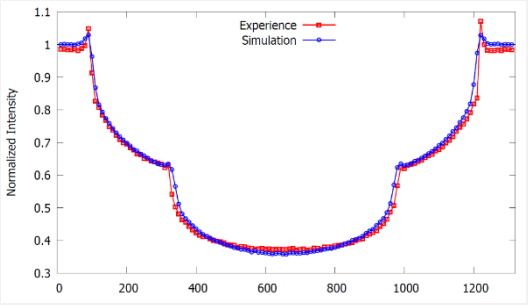
Wavefront : model interferences and wave propagation

Approximation: thin object with no propagation inside









Plot profile comparison between simulated and experimental data

RT & CT

Photon counting detector (PCD)

Electron transport modelling & darkening of silver bromide grains caused by electrons

X-ray phase contrast imaging model

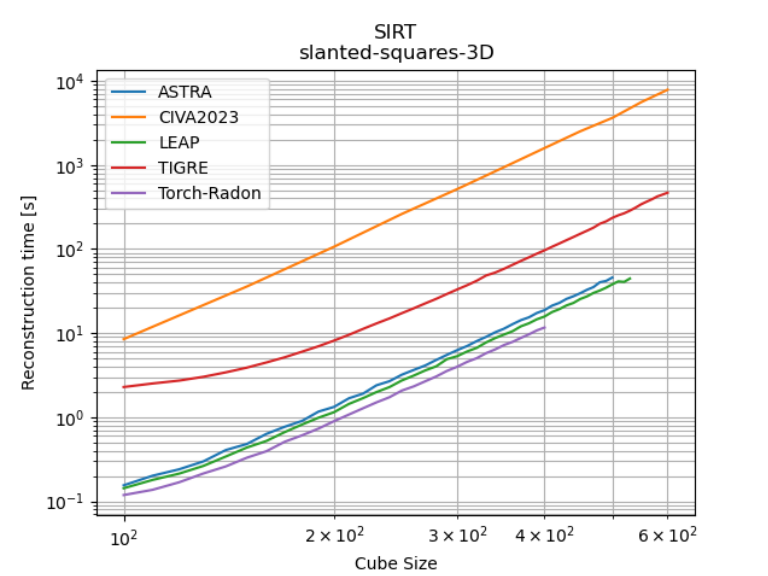
CT: towards a demonstrator of advanced reconstruction algorithms

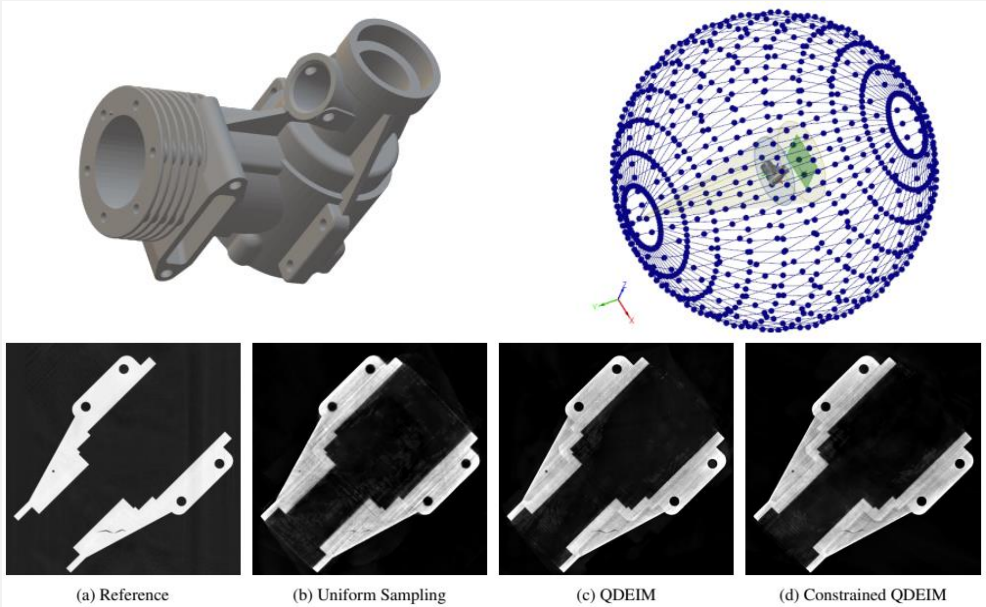
CIVA NEXT

CIVA 202?

CIVA PoC

Our aim is to reduce reconstruction time by an order of magnitude…





…and then offer new capabilities (sparse views selection, CAD mask...).

The Future of Simulation in CIVA

edouard.demaldent@cea.fr

Thank you for your attention