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Physics-based modelling for ultrasonic testing in complex materials at CEA-List

Edouard Demaldent

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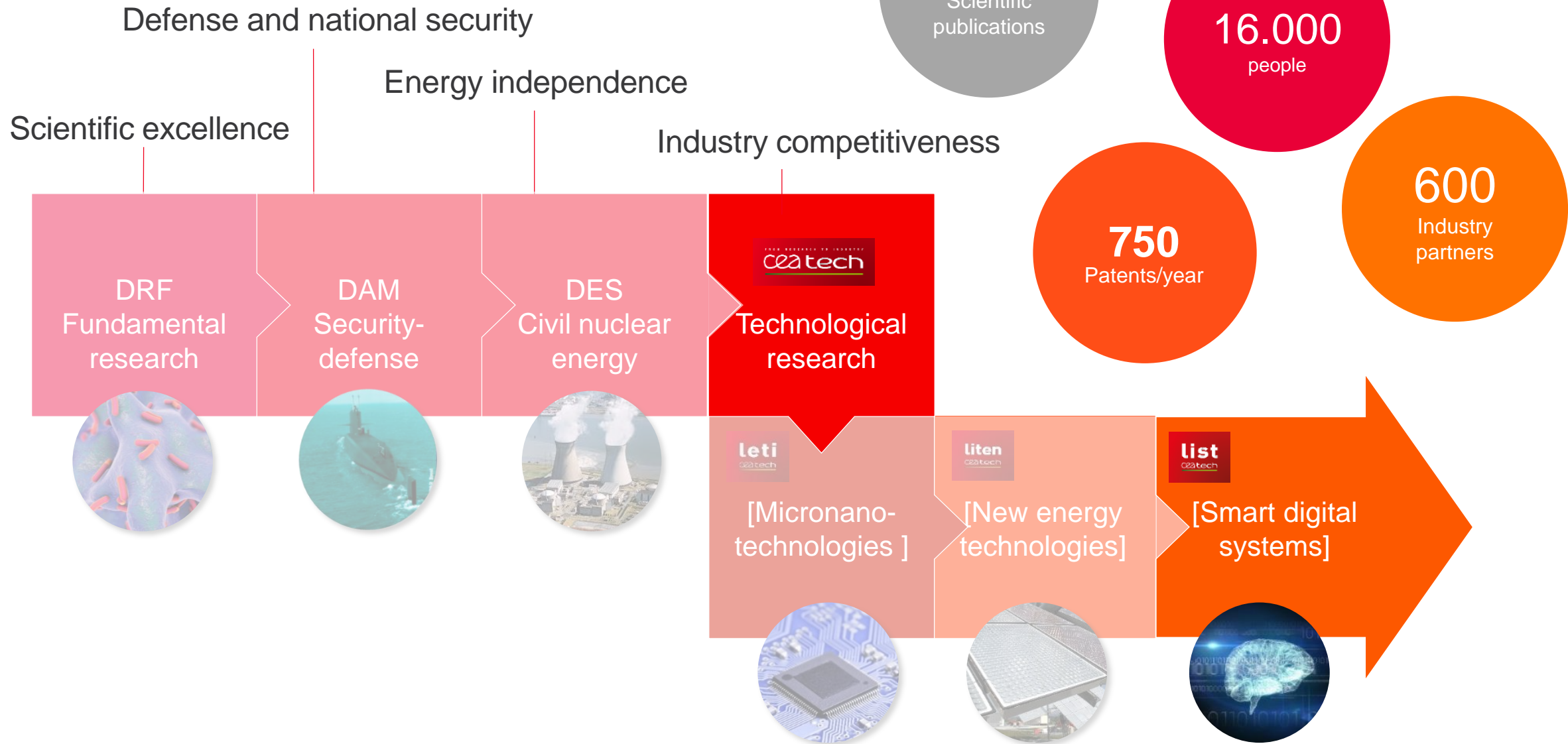
Physics-based modelling for ultrasonic testing in complex materials at CEA List

Edouard DEMALDENT, NDE Dpt, CEA List

FROM RESEARCH TO INDUSTRY



**5th International Workshop on
Laser-Ultrasound for Metals**
5-6 May 2022, Gif-sur-Yvette, France



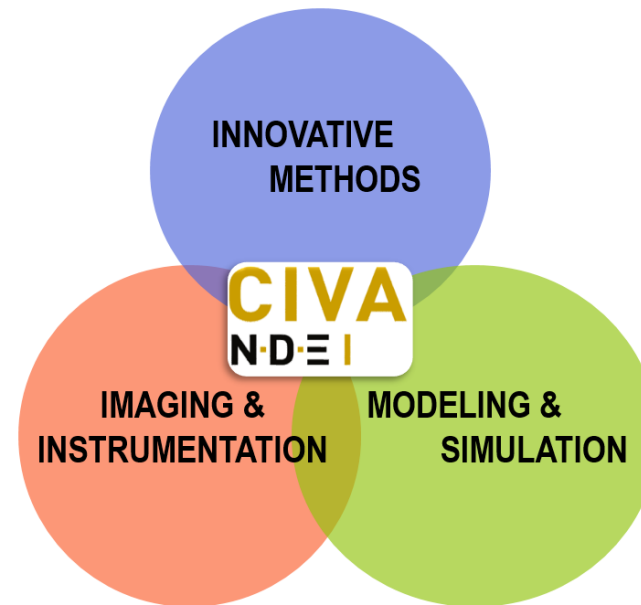
01

- NDE team at CEA List :
~ 100 staff members
(80 permanent people + PhD, postdoc, ..)
- Large industrial partnership in main sectors concerned by NDE
- Strong academic collaborations : through CIVA network, National, European and International projects, ...



02

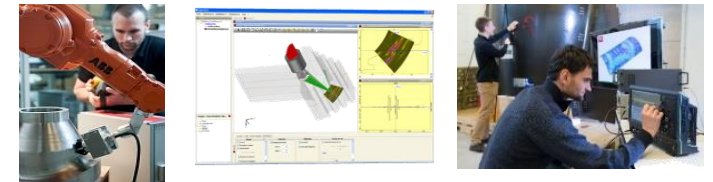
- Three-fold R&D activity



Addressing the main NDE modalities:
Ultrasound, Electromag. (ET,...), X-Ray & CT,
Guided Waves, Thermography (IR), ...

03

- Experimental & numerical platforms

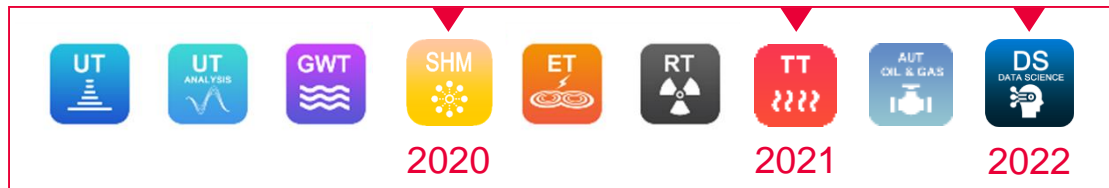




CIVA N·D·E |

Developed by CEA-List
Distributed by EXTENDE

A multi-technique software platform



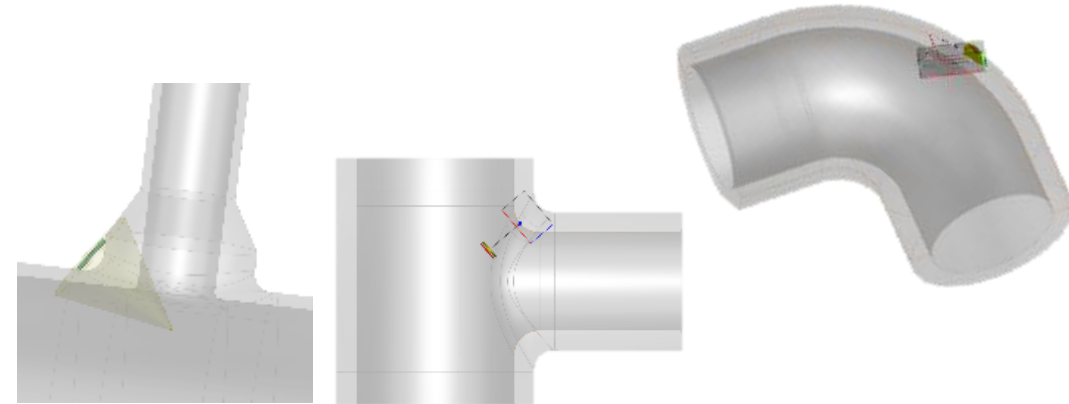
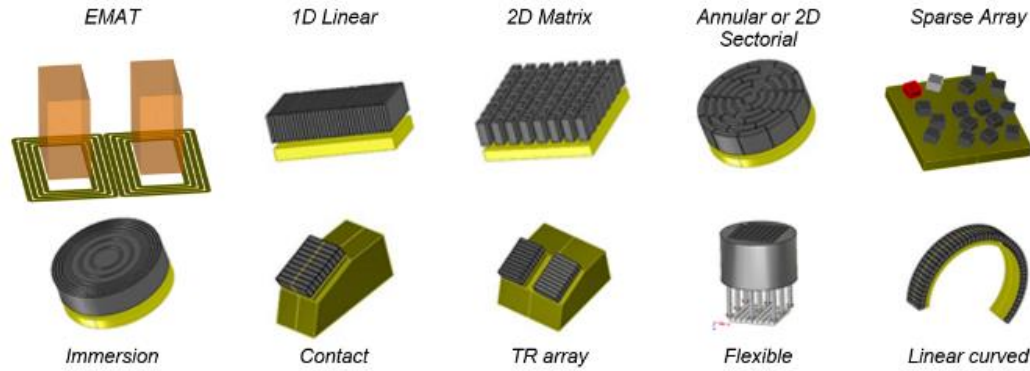
NDE Simulation and analysis

- Scientific strategy: To integrate within the platform the results of basic research (internal or collaborative) achieved at CEA List.
- Release of annual versions containing new tools based on this research
- CIVA is also a collaborative plat-form: Integration of modules developed by partners, Plug-In technology, dedicated tools for specific applications.

WORLD LEADER IN NDT SIMULATION

CIVA USERS: More than **300** companies
and Labs in **40** countries



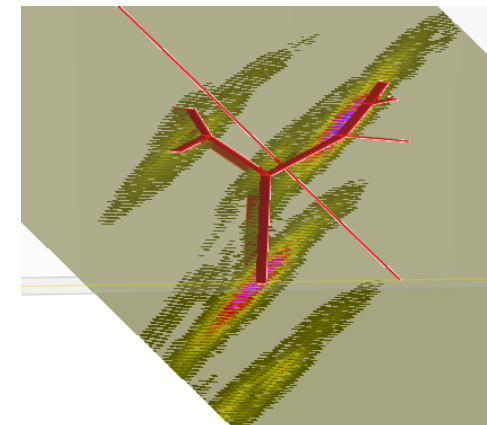
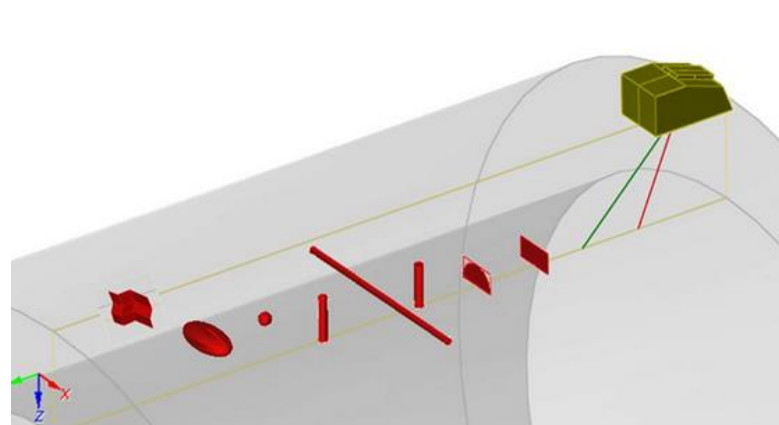
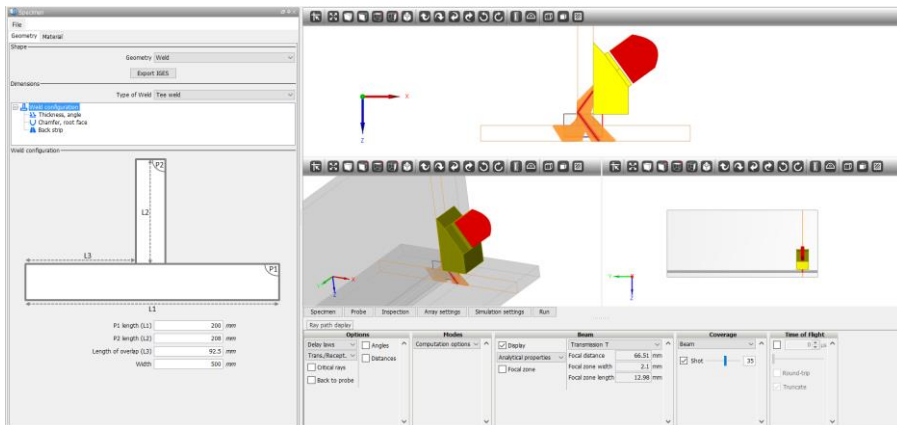


Probes and Materials Data Base
 Parametric and CAD specimens
 Parametric and robotic trajectories
 3D Visualization, User-friendly

Standard PC compatibility



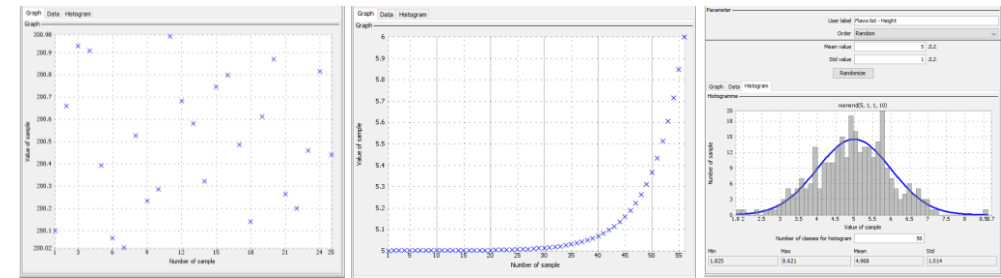
Simple case: less than a minute
 Complex case: less than an hour
 Very complex case: less than a day



Geometry: Rectangular
 Length: 20 mm
 Height: 5 mm

VAR: Add to variation
 VAR: Add to parameter monitored

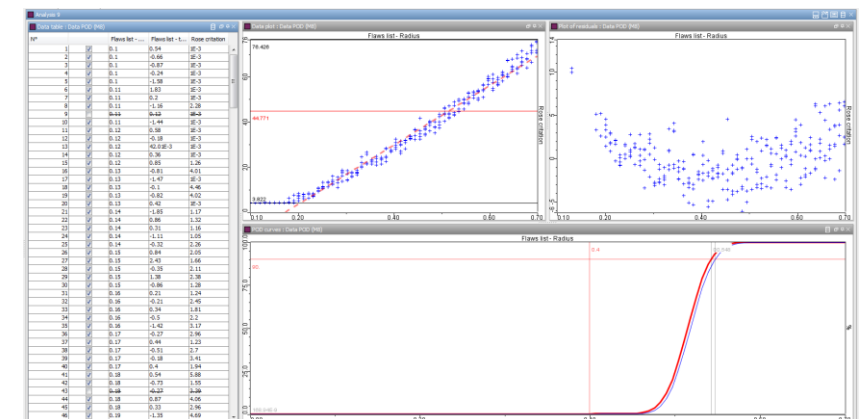
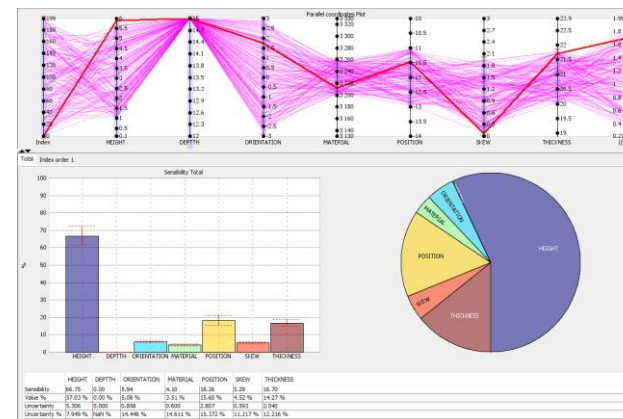
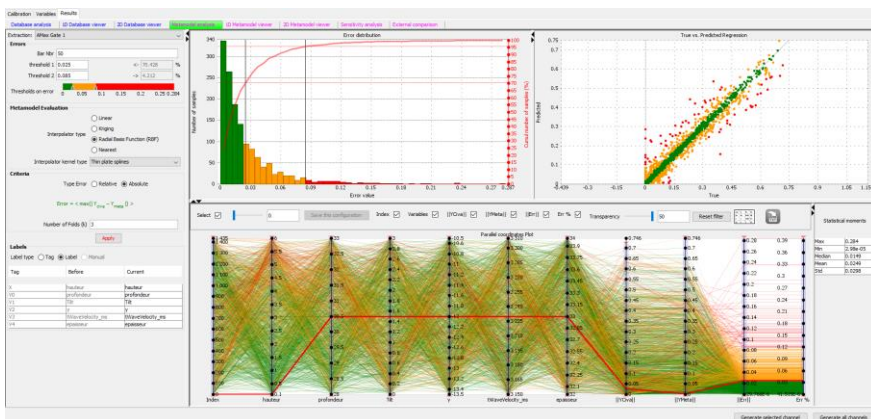
Nu...	Category	Tag	Type	Min	Max	Size	Curren...	Dim
1	Characteristic	LENGTH	Linear spacing	20	21.5	20		+
2	Characteristic	HEIGHT	Linear spacing	5	6.5	5		+
3	Variable	X	LHS	200	201.25	200		X
4	Variable	DISORIENTATION	LHS	0	1.25	0		X



Choice of Drawing laws

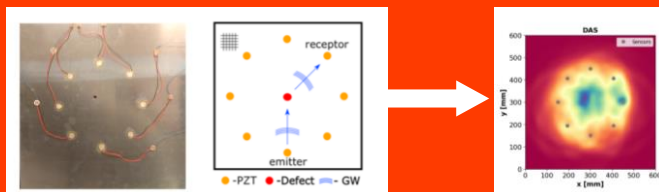
Parametric variations
 Metamodeling
 Sensitivity studies
 POD

Any parameter can be considered as a "variable"

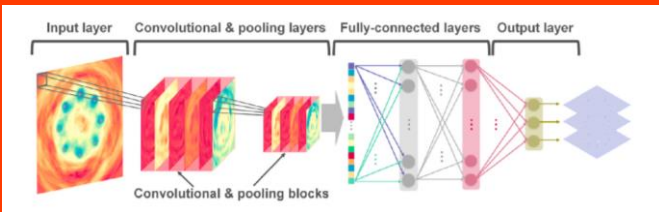


CIVA can overcome the lack of data on defects and provide numerical data bases to train algorithms
Simulation can assist the conception of a ML based diagnostic algorithm

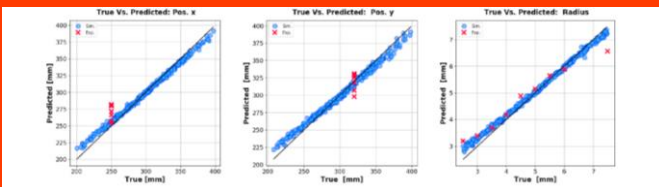
DEFECT SIZING IN GUIDED WAVE IMAGING SHM



PZT sensors on a plate structure



Convolutional Neural Network trained on simulated images



Localization

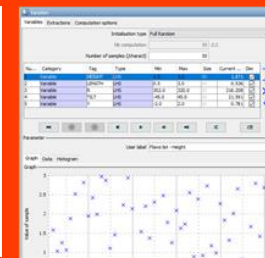
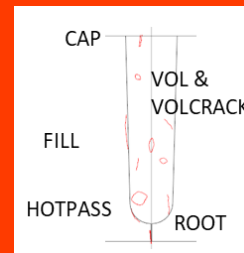
Sizing

Validation on experimental data

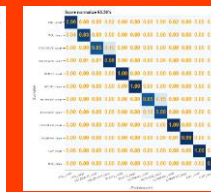
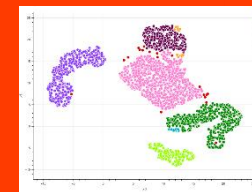
UNDER PROGRESS : CIVA DATA SCIENCE



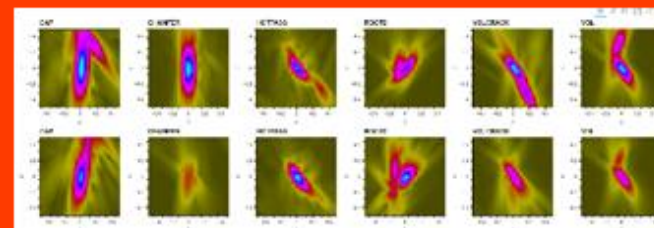
Classification of defects in welds by UT



Numerical design of experience on representative defects



Classification by AI



Simulated data base

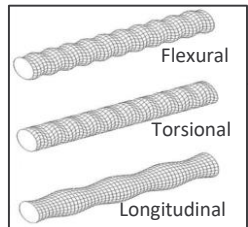
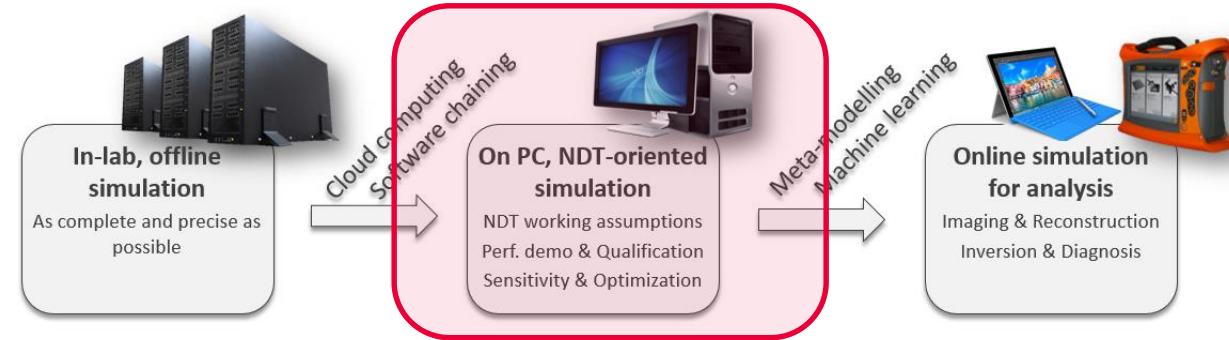
Basics of physical modelling **for ultrasonic inspection of complex materials**

Challenges of accuracy/rapidity/easiness of use

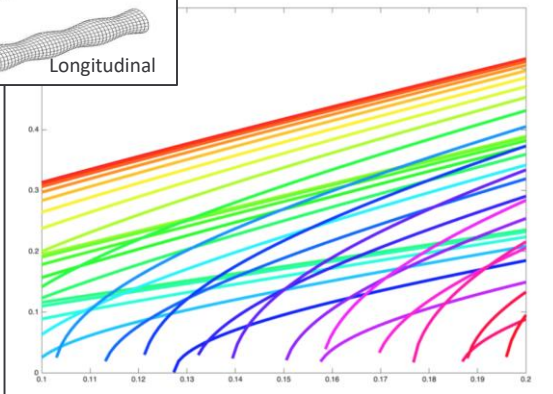
Based on NDT, ultrasonic & numerical expertise

Hybridization allows optimizing each step of the simulation

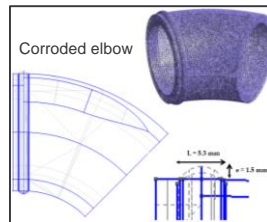
Complementarity semi-analytical/numerical



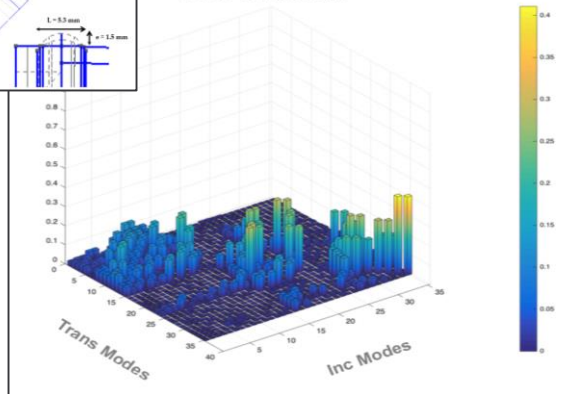
Wave Number



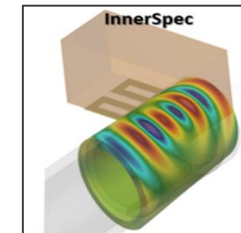
Modal propagation (SAFE)



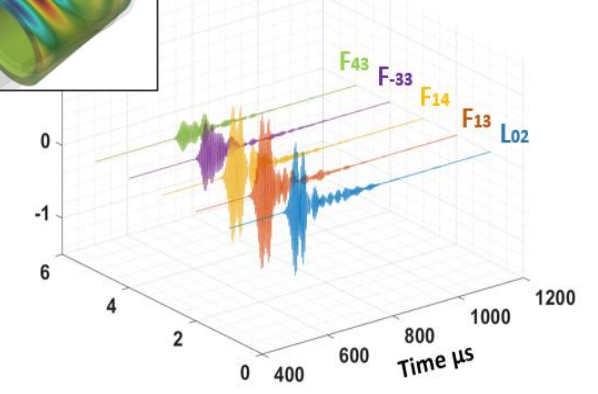
Power Transmission
With Corrosion



Modal conversion (FEM)



Reflection_Weld



Modal excitability & signal reconstruction



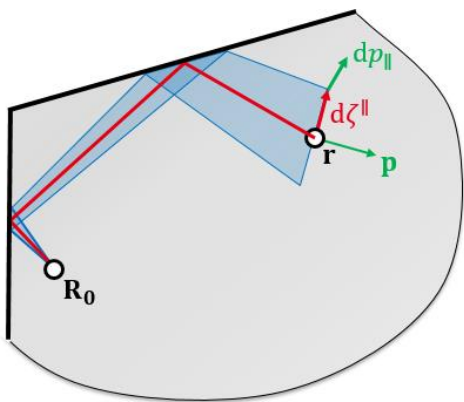
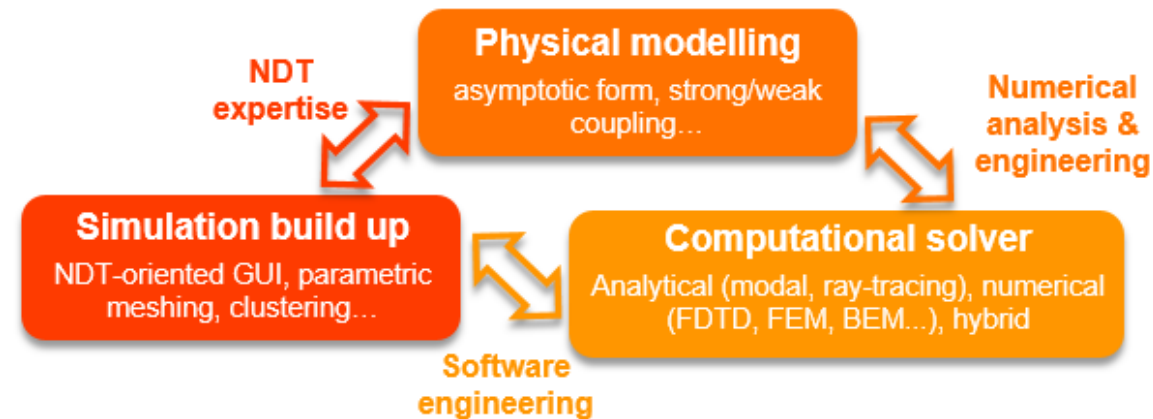
Guided Wave Testing simulation for unidirectional waveguides (train rails, bars, pipes...)

Several levers to operate behind the software interface

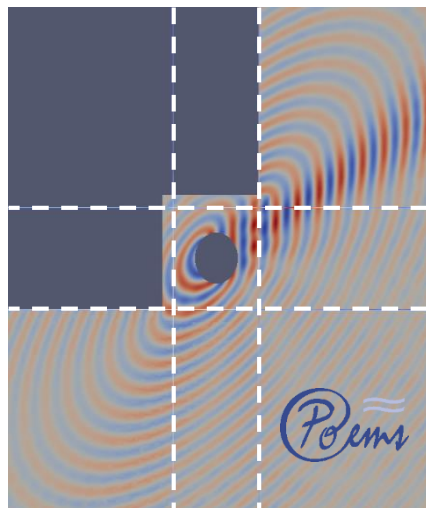
Idealized framework: modelling assumptions are ensured

Operational framework: their validity must be evaluated

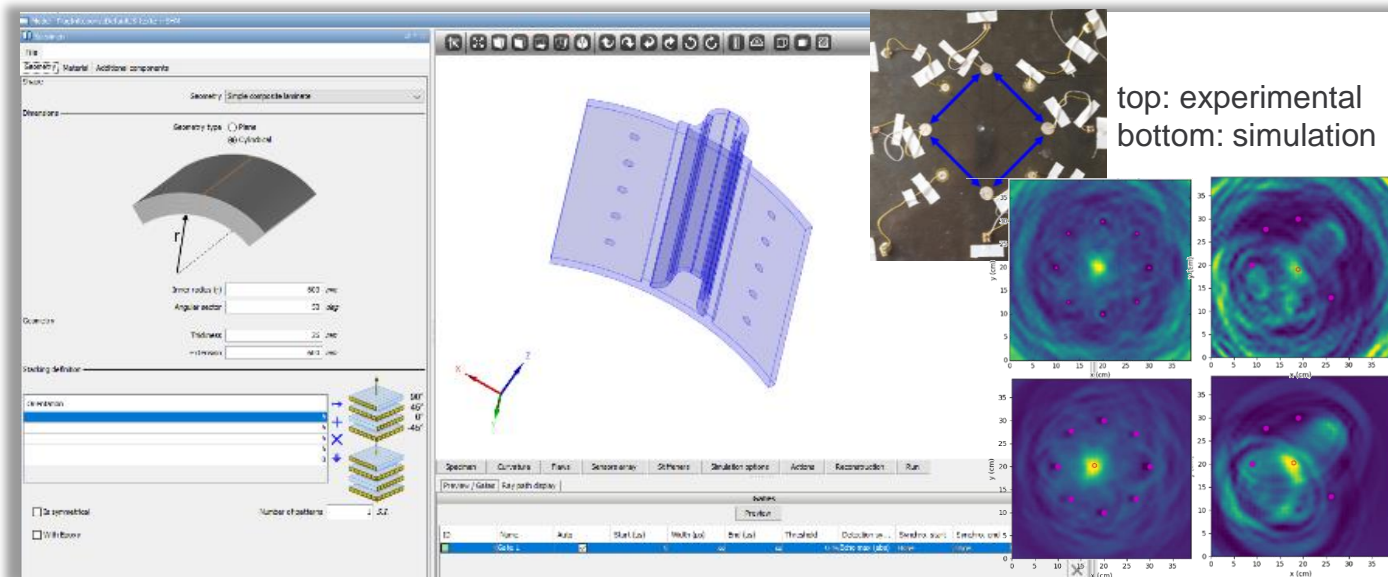
Raise awareness among casual users and train expert users



Modal ray pencil
GW propagator



FEM defect
diffraction



In progress: GW formalism extended to plates
Defect hybridization – Ph.D. A. Allouko ENHAnCE



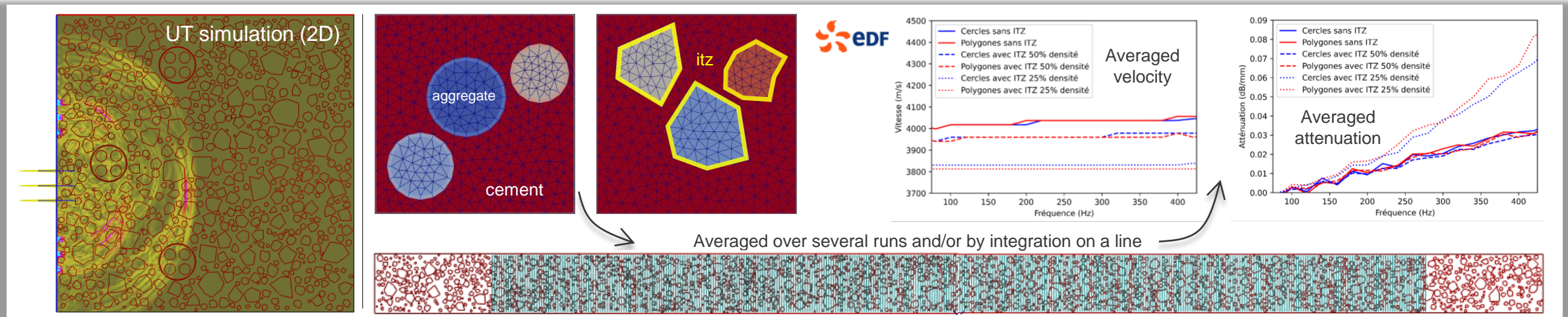
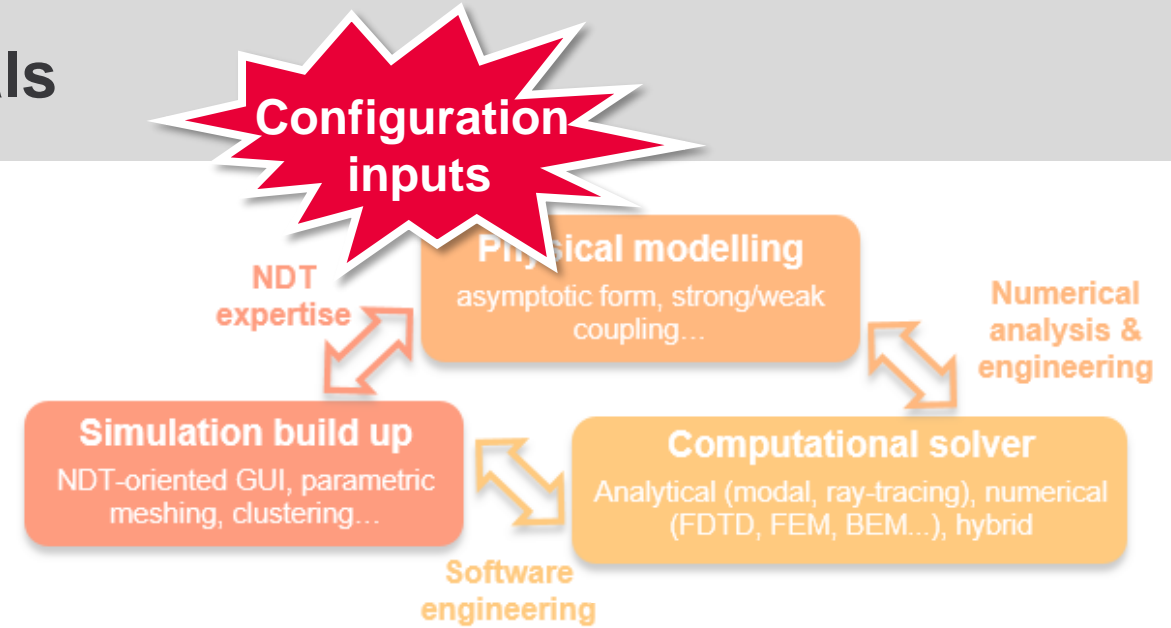
GW-SHM module based on Transient Spectral Finite Element Method
Loading conditions in pre-stressed structures – Ph.D. A. Dalmora

Complex in the sense that the configuration description

- is not deterministic (simulations around a nominal state)
- results from prior material assumptions

Motivates fast simulation with only relative accuracy

Strongly related description & inspection models



FEM simulation of concrete inspection and influence of the aggregate description on effective material properties 

Ongoing: research of a semi-analytical model – Ph.D. N. Khalid 

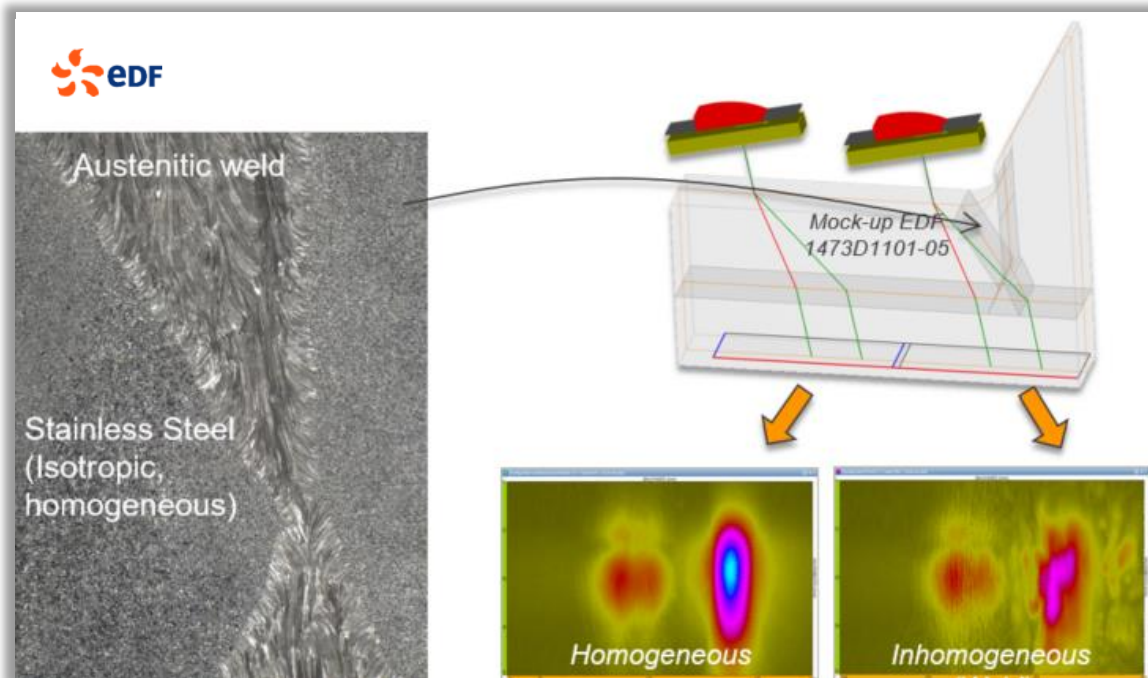
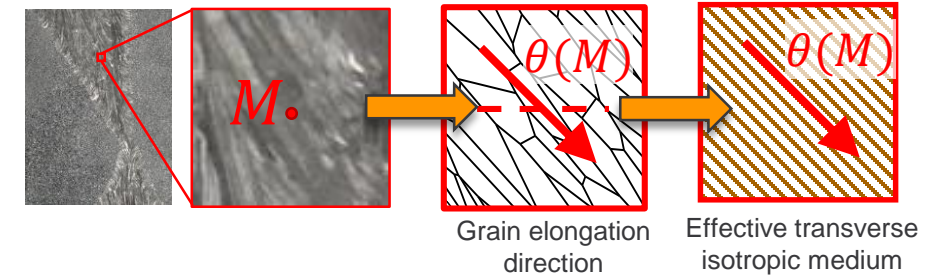
Weld bead inhomogeneity causes beam deflection and attenuation

Modelling of the coherent wave at the morphological scale

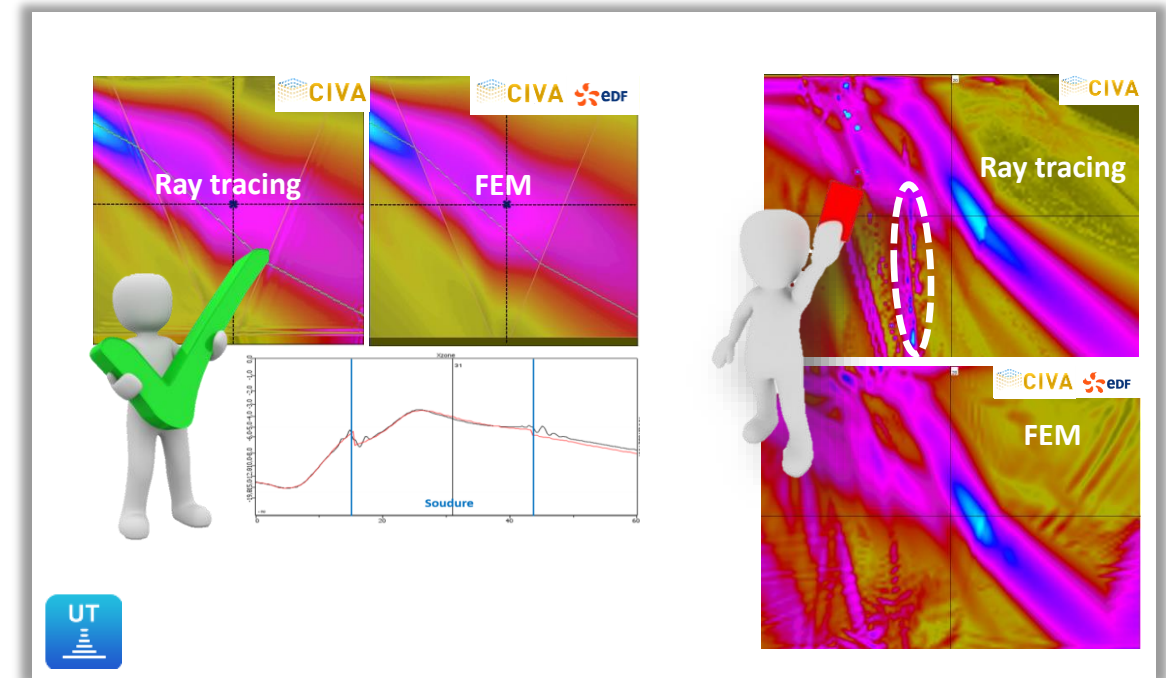
Transverse isotropic medium with continuously variable orientation map

Fast, iterative ray-based simulation but non-trivial domain of validity

“Morphological Scale” – Wave-scale Simulation



Beam deflection and attenuation



Non trivial domain of validity

Qualify the ray-based simulation & replace it beyond its validity domain

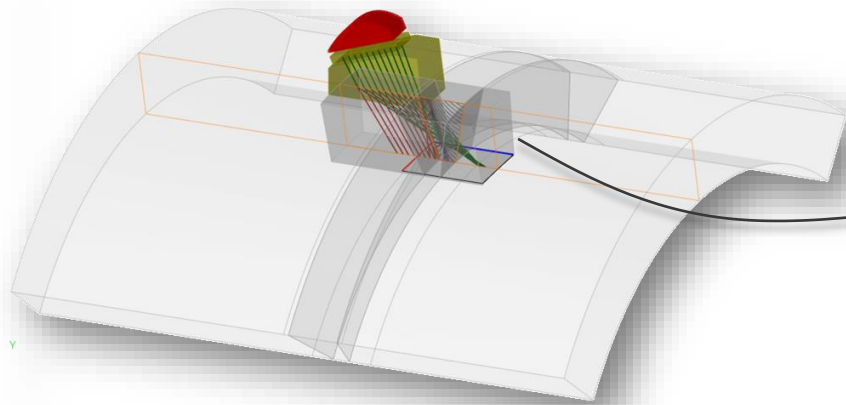
Identical wave-scale description of the weld chamfer

Automated build-up of a high-order, PC compatible, spectral-like FEM solution

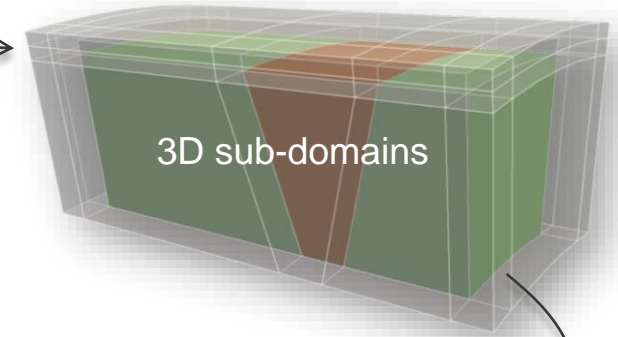
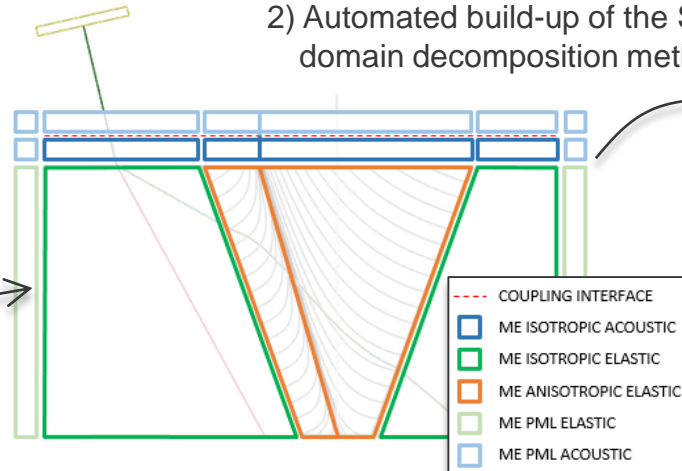
In progress: field & signal simulations in various weld geometries with defects



1) Ray tracing pretreatment to adjust the region of interest ($30 \times 30 \times 75 \text{ mm}^3$)



2) Automated build-up of the SFEM domain decomposition method



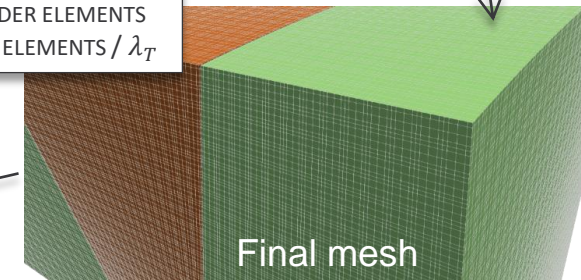
0) Straight or V-shaped weld chamfer
Plane or cylindrical extrusion

Ogilvy description with constant attenuation
Cartesian observation grid

3) 2D or 3D calculation on PC
Intel(R) Core(TM) i9-9880H CPU @ 2.30GHz

20 μs	SFEM 3D	SFEM 2D	Ray 3D
1 MHz	20 min < 1GB	<30 sec	L ~ 2 min T ~ 10 min
2 MHz	200 min < 7 GB	<40 sec	...

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

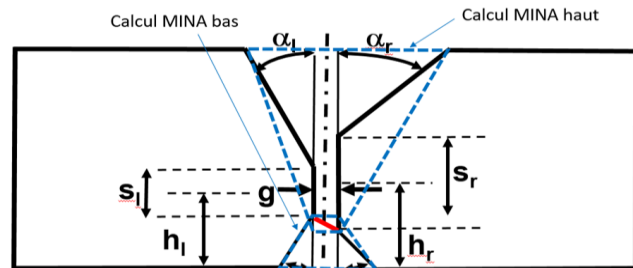
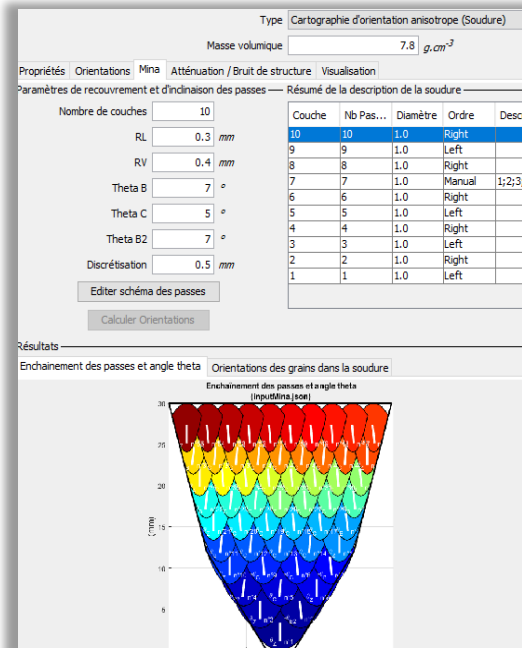
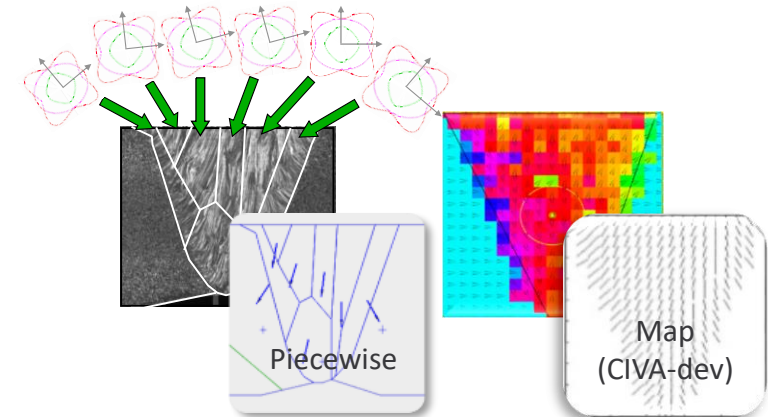


Several descriptions available: piecewise homogeneous, parametric...

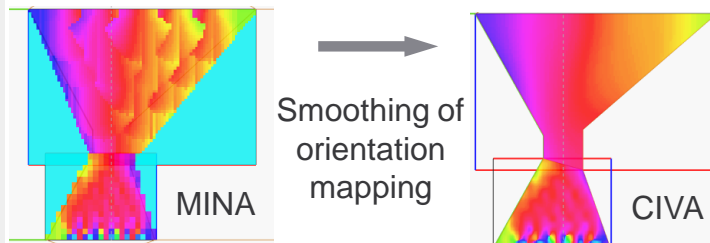
Ongoing software chaining with

- Modelling of an isotropy from the arc welding book - MINA 

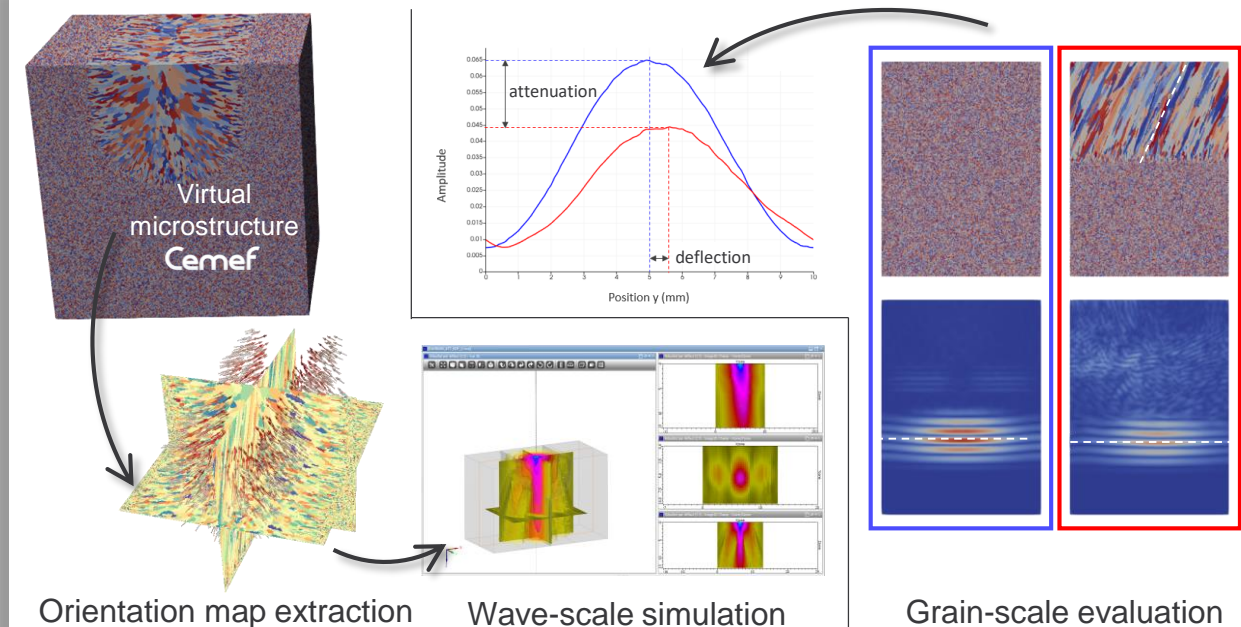
- Virtual microstructures - CAFE 



Adaptation to the parametric weld geometries of CIVA



MINA model - CIVA



Virtual microstructure - CIVA - ANR NEMESIS

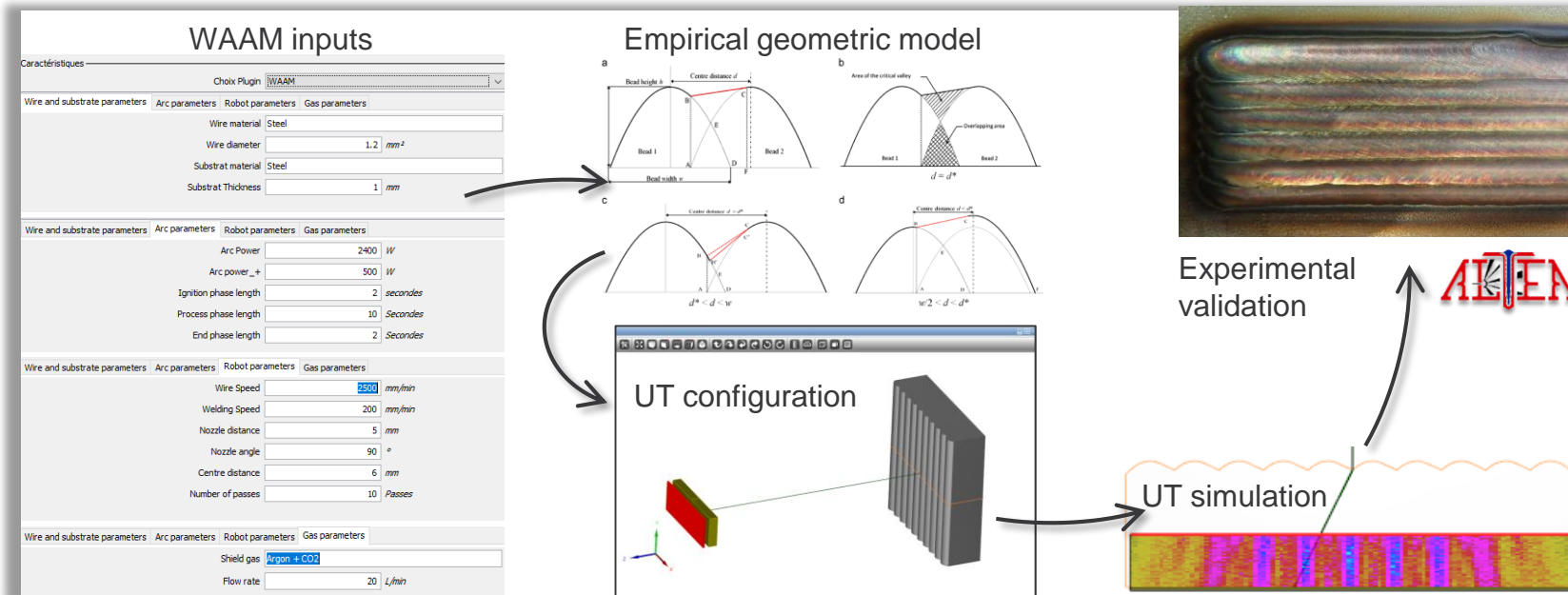
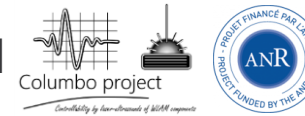
Grain-scale to wave-scale: CASS  EDF , Laser powder bed fusion additive manufacturing

Grain-scale & LUS: Assessment of grain size during hot rolling - P.D. T. Kadi



Surface roughness: early stage of a (high quality) WAAM (~TIG) inspection module - C. Larran

Grain-scale to wave-scale, surf. roughness, LUS, towards online monitoring of WLAM



WAAM inspection module (early stage): empirical geometric roughness model & evaluation of available physical models

At the crossroads of research and engineering towards new NDT software capabilities

Physics-based modelling for ultrasonic testing in complex media

edouard.demaldent@cea.fr

THANK YOU !



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