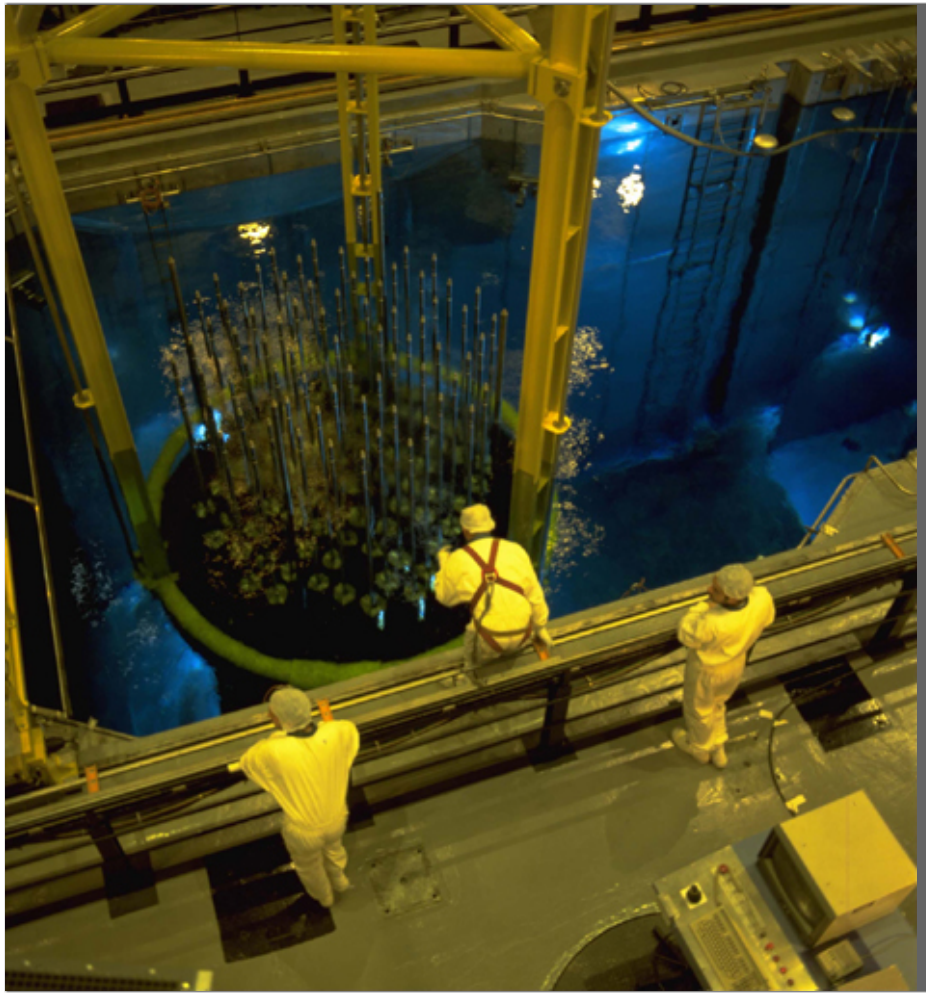


Influence of Stress Corrosion Crack Morphology on Ultrasonic Examination Performances

- 7th ICNDE in Relation to Structural Integrity for Nuclear and Pressurized Components -

O. Dupond – EDF R&D/Materials and Mechanics of Components Department
T. Fouquet – EDF R&D/ Neutronics simulation, information technologies and scientific calculations
J. Tirira – CEA/LIST, Centre de Saclay

Summary

- ✓ Context and objectives
- ✓ Defects description
- ✓ Simulation codes
  - ✓ Simulation of UT inspection in CIVA (CEA)
  - ✓ ATHENA FEM (EDF)
  - ✓ Hybrid code (EDF-CEA)
- ✓ Results
- ✓ Conclusions

Context and objective

UT simulation : *more and more used to …*

- ✓ Understand phenomena
- ✓ Help data interpretation
- ✓ Method qualification – performance demonstration
- ✓ Conception / design of new methods
- ✓ ‘Virtual testing’ …

Stress corrosion cracking : intergranular propagation

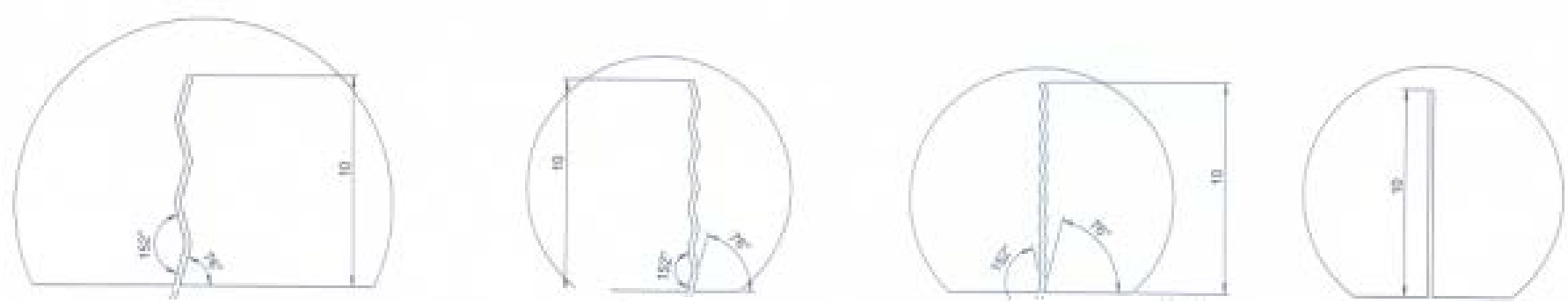
- ✓ Multi faceted
- ✓ Branched

Objective

- ✓ To study modelling of complex flaw scattering
- ✓ Limits of the study : isotropic and homogeneous material, CW.

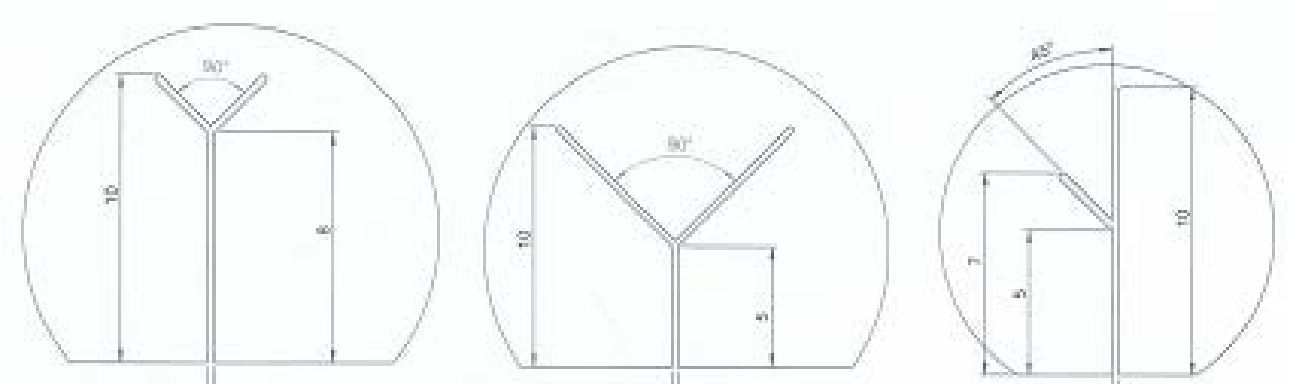
Defects description

✓ Multi faceted defects



D C B A

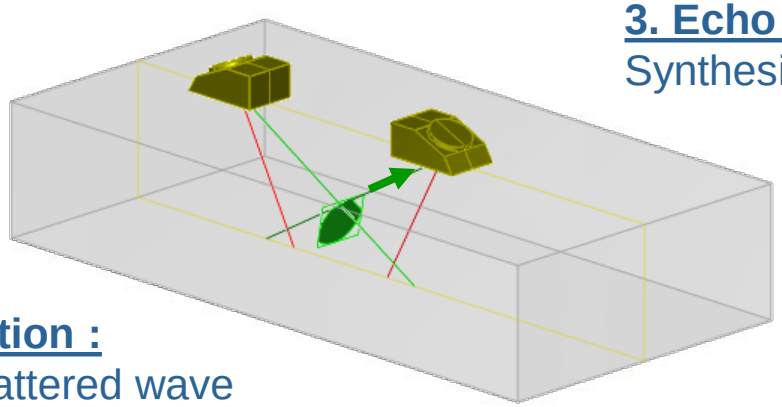
✓ Branched defects



E F G

Simulation of UT inspection in CIVA (CEA)

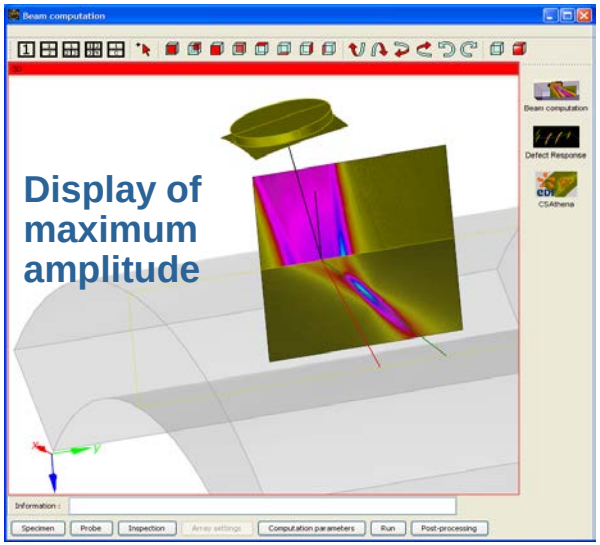
1. Transmitting probe :
Computation of L and/or T incident wave on the flaw



3. Echo at Reception :
Synthesis of the received signal

2. Beam/Flaw interaction :
Computation of the scattered wave

1. Field
Surface integral over probe's aperture



2. Flaw scattering
Diffraction coefficient depending upon the flaw (void, inclusion) or inspection type (pulse echo or TOFD) :
- ***Kirchhoff*** approximation for specular or corner echoes
- ***GTD*** (Geometrical Theory of Diffraction) for tip edges echoes
- **Born** for solid inclusions

3. Synthesis at Tx/Rx
Reciprocity principle

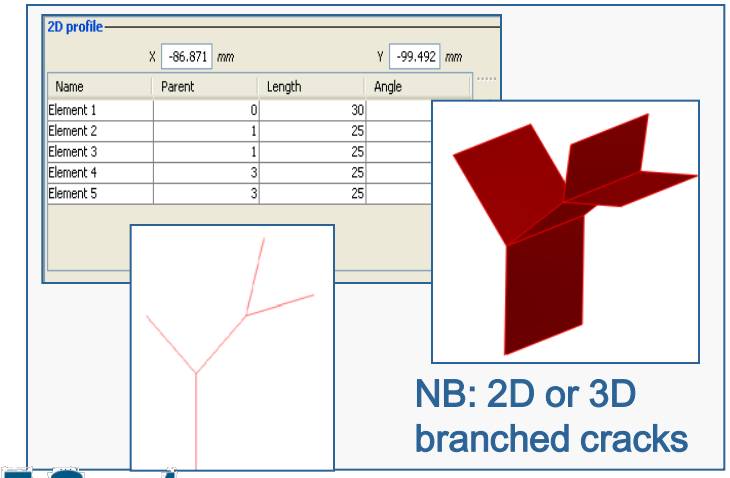
Simulation of UT inspection in CIVA

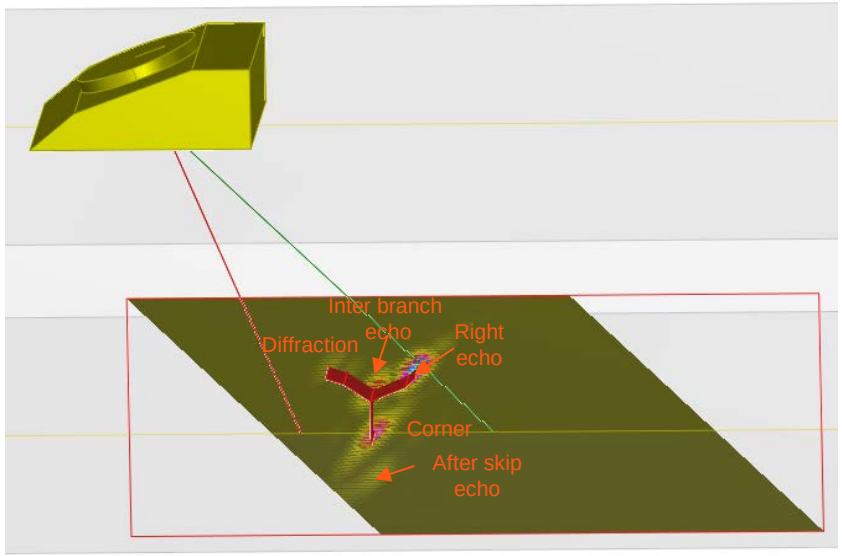
- Computation of echoes : For **each flaw** + specimen boundaries (front and backwall)
- **each elementary echo** is formed from :
  - diffraction echo in L or T mode
  - corner echoes
  - converted modes

Echo at Tx/Rx = sum of individual echoes
- **No multiple scattering between flaws**

Developments achieved in CIVA for complex and branched cracks (available in CIVA10, end 2009)

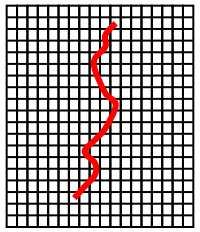
- parametric tools for definition of branched flaws
- internal reflections and mode conversions inside branched flaws
- (self)shadowing effects between parts of the flaw



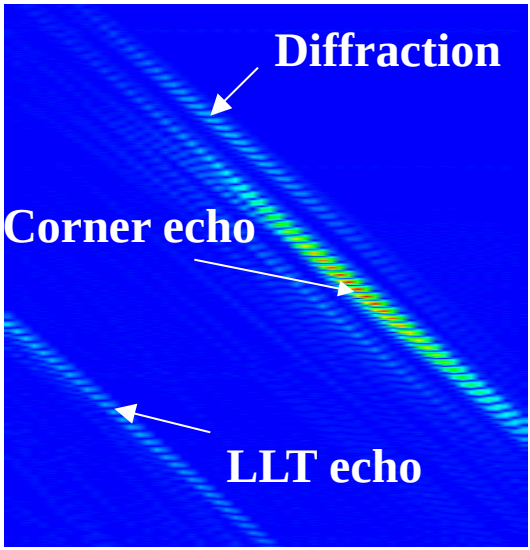


ATHENA finit elements code (EDF)

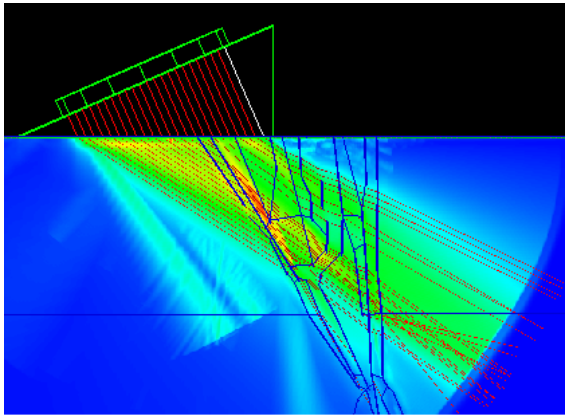
- ✓ 2D finite elements code for elastodynamics
- ✓ Modelling of complex defects by the fictitious domain method (multi faceted, branched defect implemented)

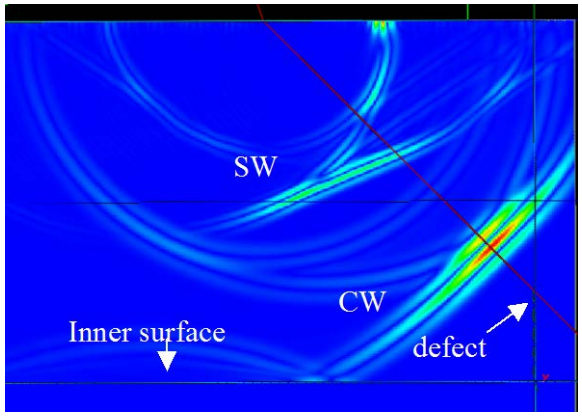


- ✓ Contact or immersion transducers
- ✓ Anisotropic and heterogeneous structure

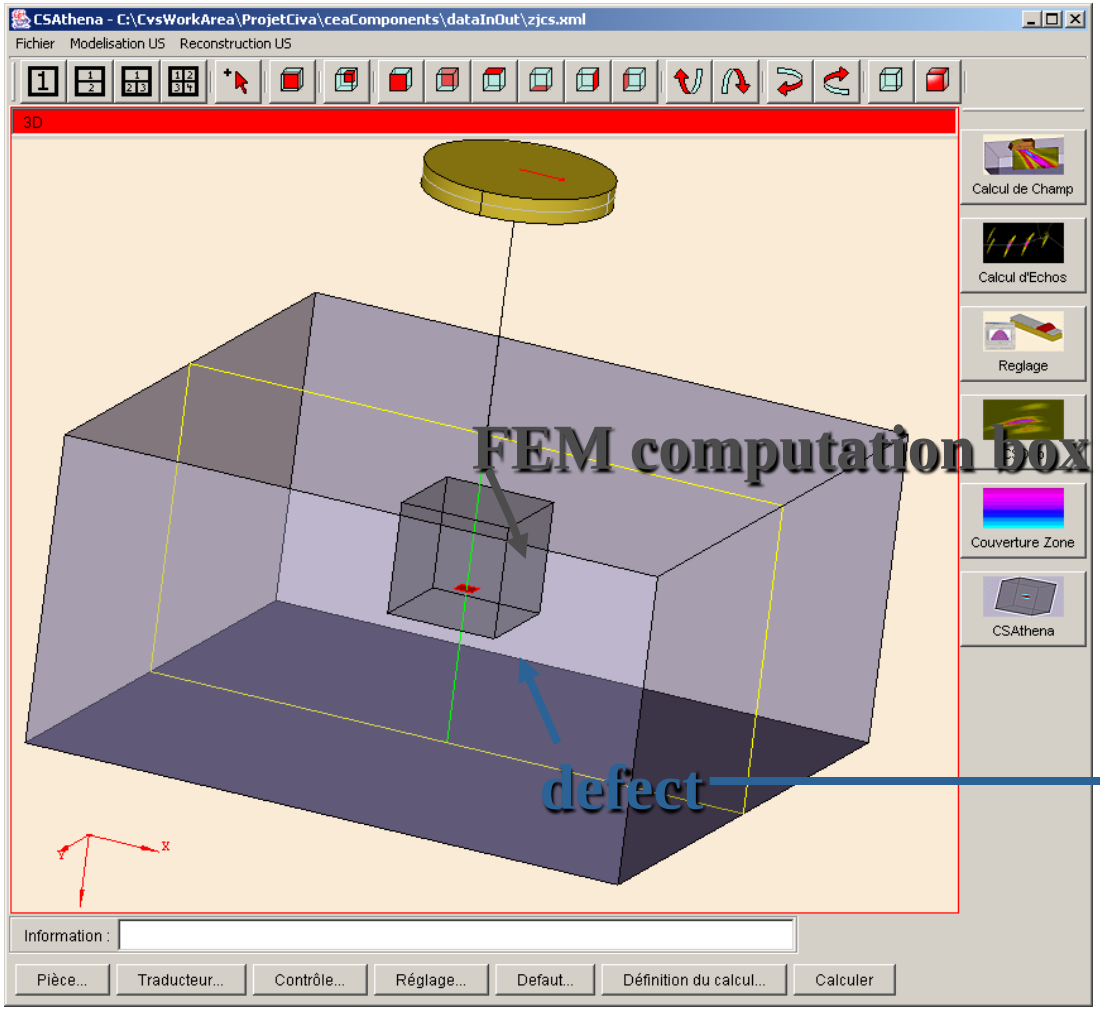


- ✓ Beam propagation and beam/defect interactions with all mode conversions





Hybrid code (EDF-CEA)



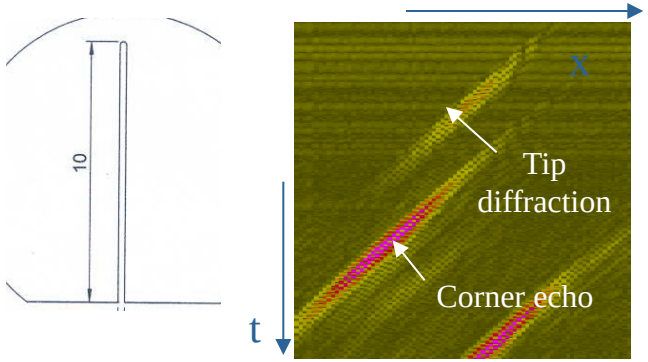
Automatically defined. Parallelepipedal box allows simplifications (3 rather than 9 surface integrals in box-related co-ordinate system)

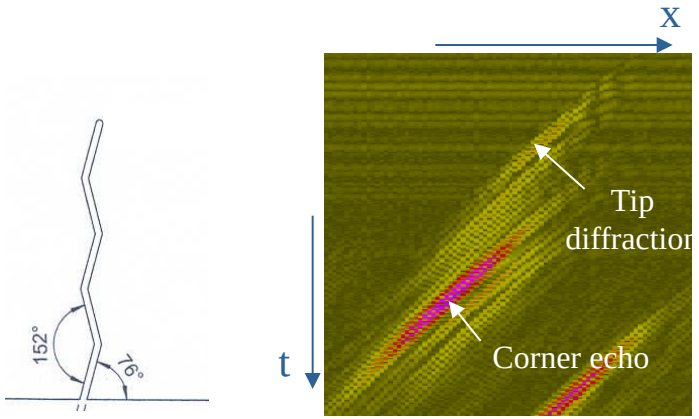
Defined by CAD for surface meshing

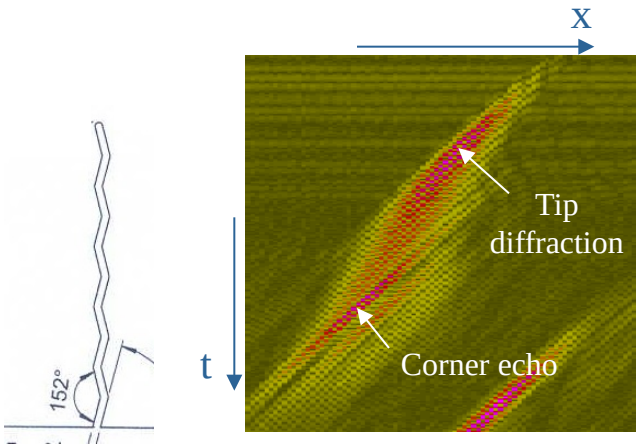
See EDF-CEA paper in Review of Progress in QNDE, 2004 by N. Gengembre et all.

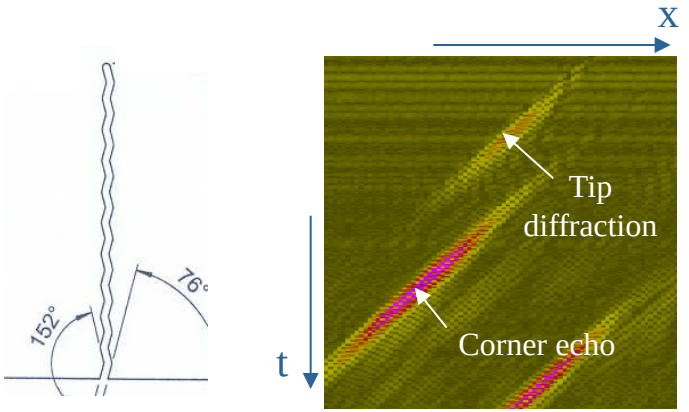
Multi faceted defect scattering : experimental results for CW 45° (B Scan images)

✓ **CW45°** ; 2.25 MHz



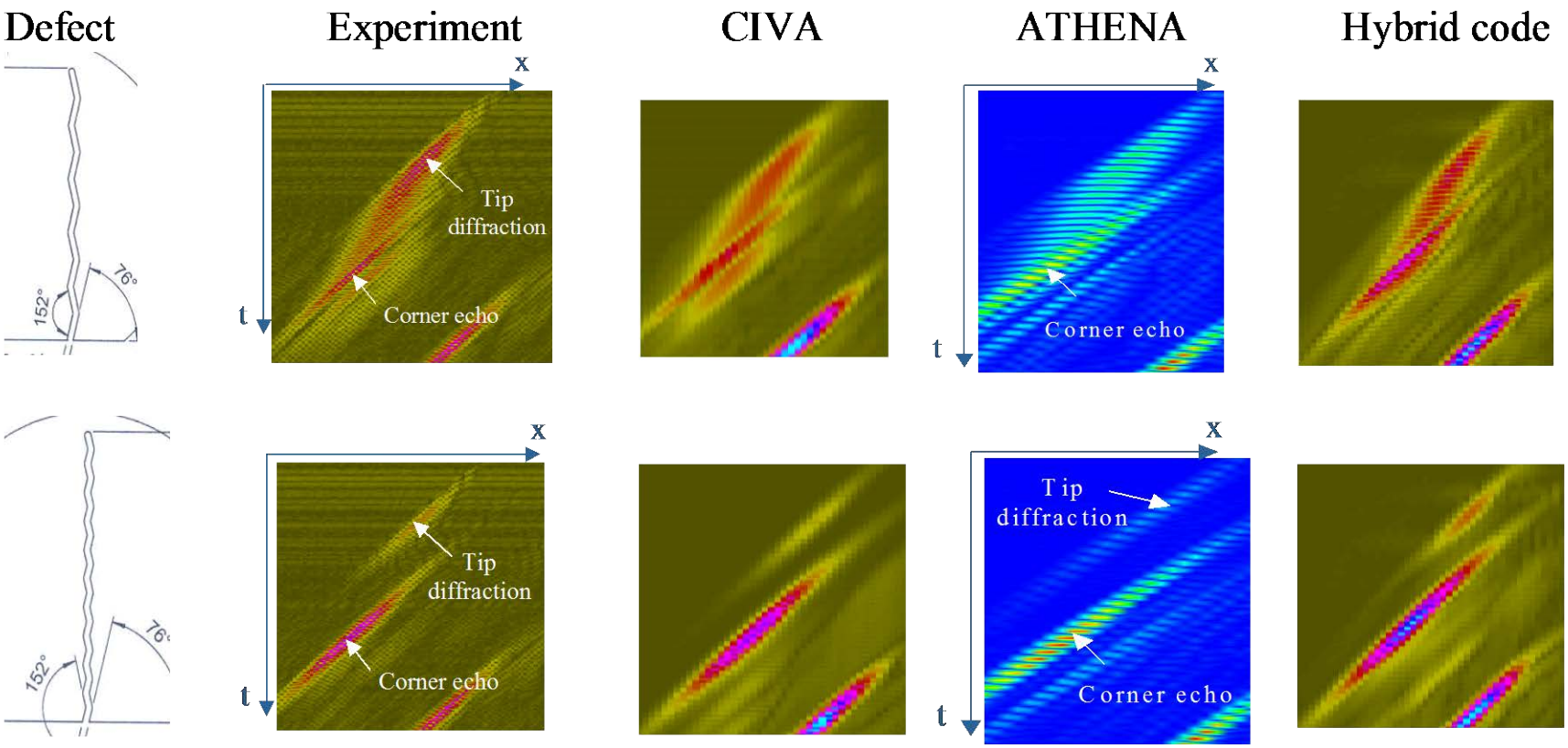






✓ Sensitivity to the number of facets : good agreement between experiment and modelling

Multi faceted defects scattering : modelling results for CW 45°



✓ Good agreement between experiment and modelling

Evaluation of the amplitude of the Corner echo

✓ Comparison between experiments and modelling (CW45°)

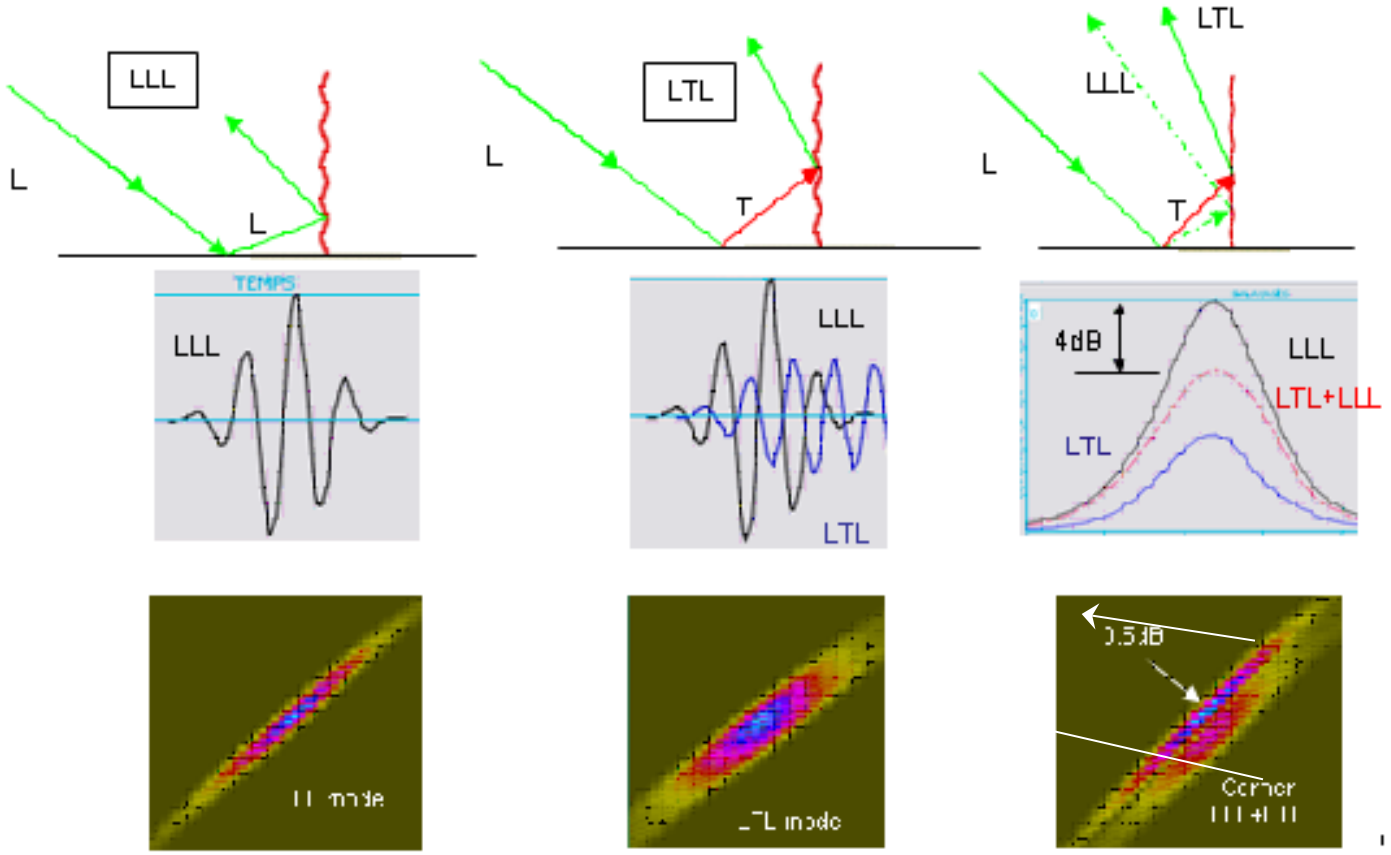
	Experiment d1	CIVA d1	ATHENA d1	Hybrid d1	Experiment d2	CIVA d2	ATHENA d2	Hybrid d2
Defect	A (dB)	A (dB)	A (dB)	A (dB)	A (dB)	A (dB)	A (dB)	A (dB)
A	3.0	4.5	2.5	4.0	4.0	4.5	2.5	4.0
B	4.0	5.0	4.0	5.0	4.5	4.5	4.5	4.5
C	1.0	0.5	1.5	1.0	6.5	8.0	5.5	7.5
D	4.0	5.5	3.0	4.5	3.0	5.0	2.5	3.5

✓ Good agreement between modelling and experimental results

✓ Sensitivity to the direction of inspection observed for the defect C

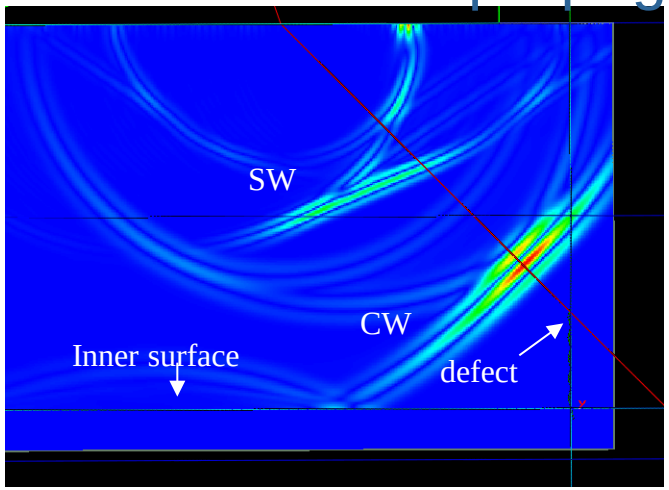
Use of modelling for the understanding of the effects

✓ CIVA software : mode decomposition

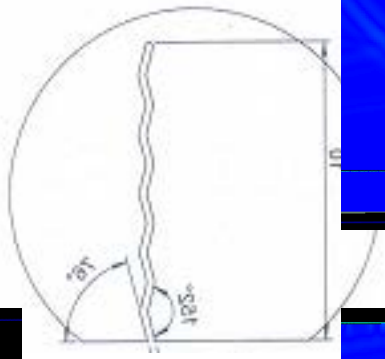


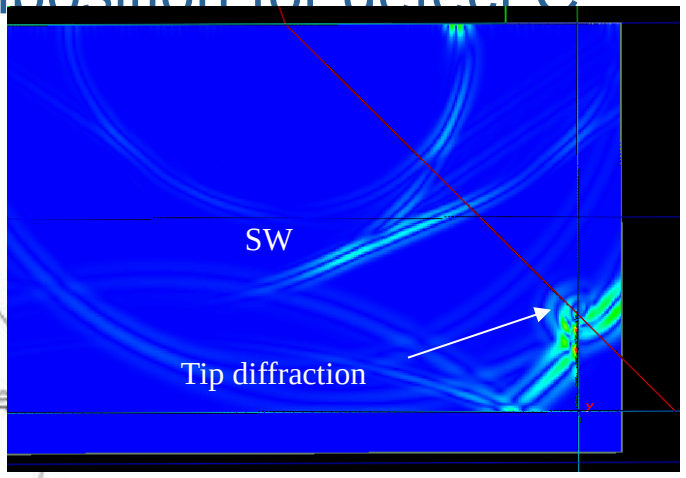
Use of modelling for the understanding of the effects

✓ ATHENA beam propagation decomposition for defect C

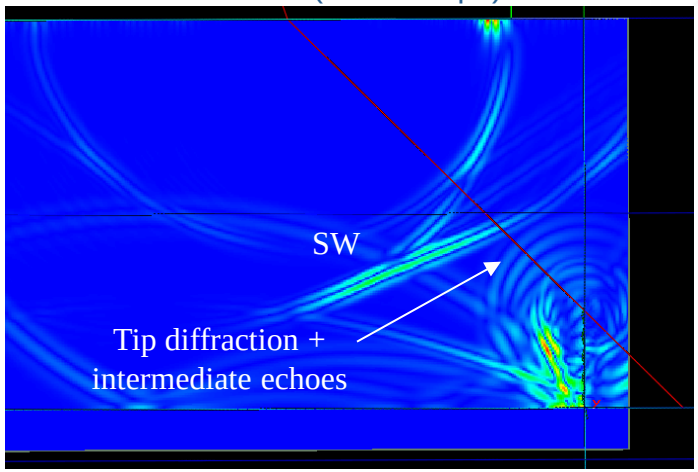


Instant 15 (t = 7.626 µs)

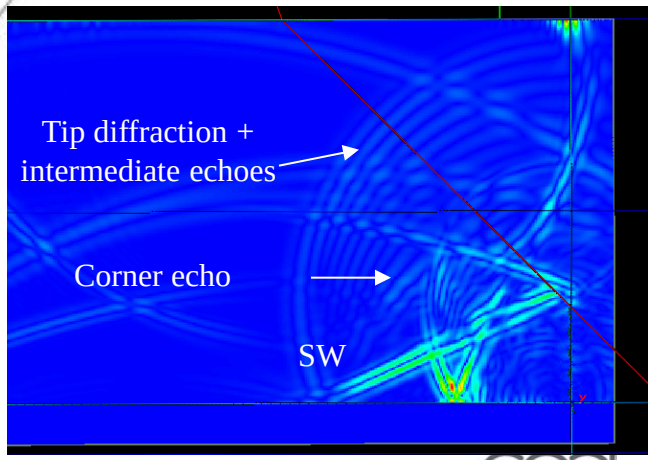




Instant 18 (t = 9.1512 µs)



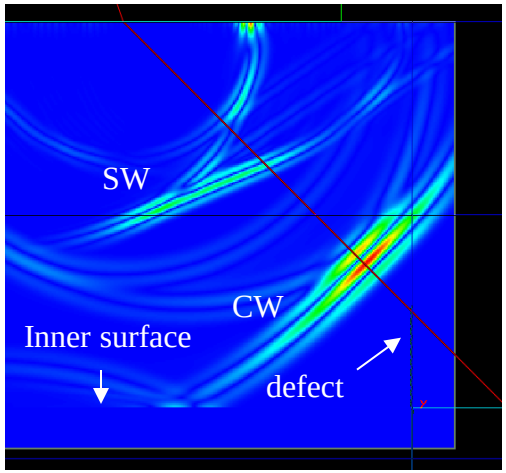
Instant 20 (t = 10.168 µs)



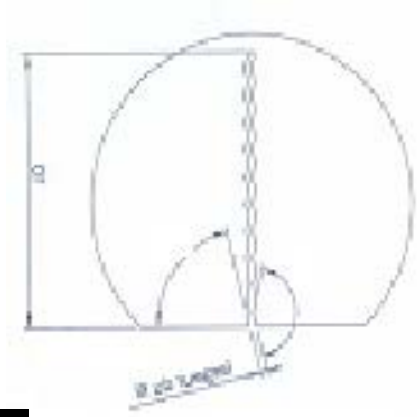
Instant 26 (t = 13.2184 µs)

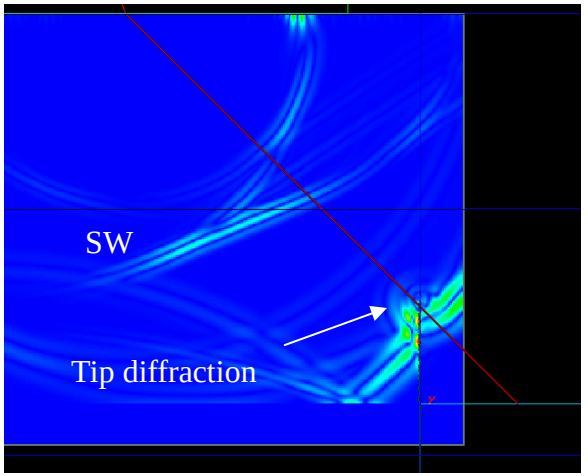
Use of modelling for the understanding of the effects

✓ ATHENA beam propagation decomposition for defect D

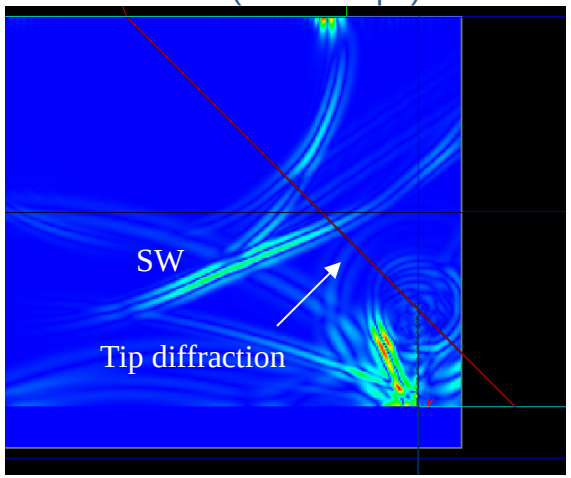


Instant 15 (t = 7.626 µs)

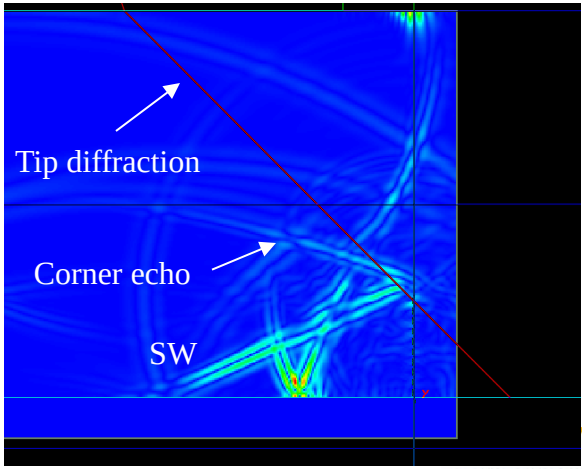




Instant 18 (t = 9.1512 µs)

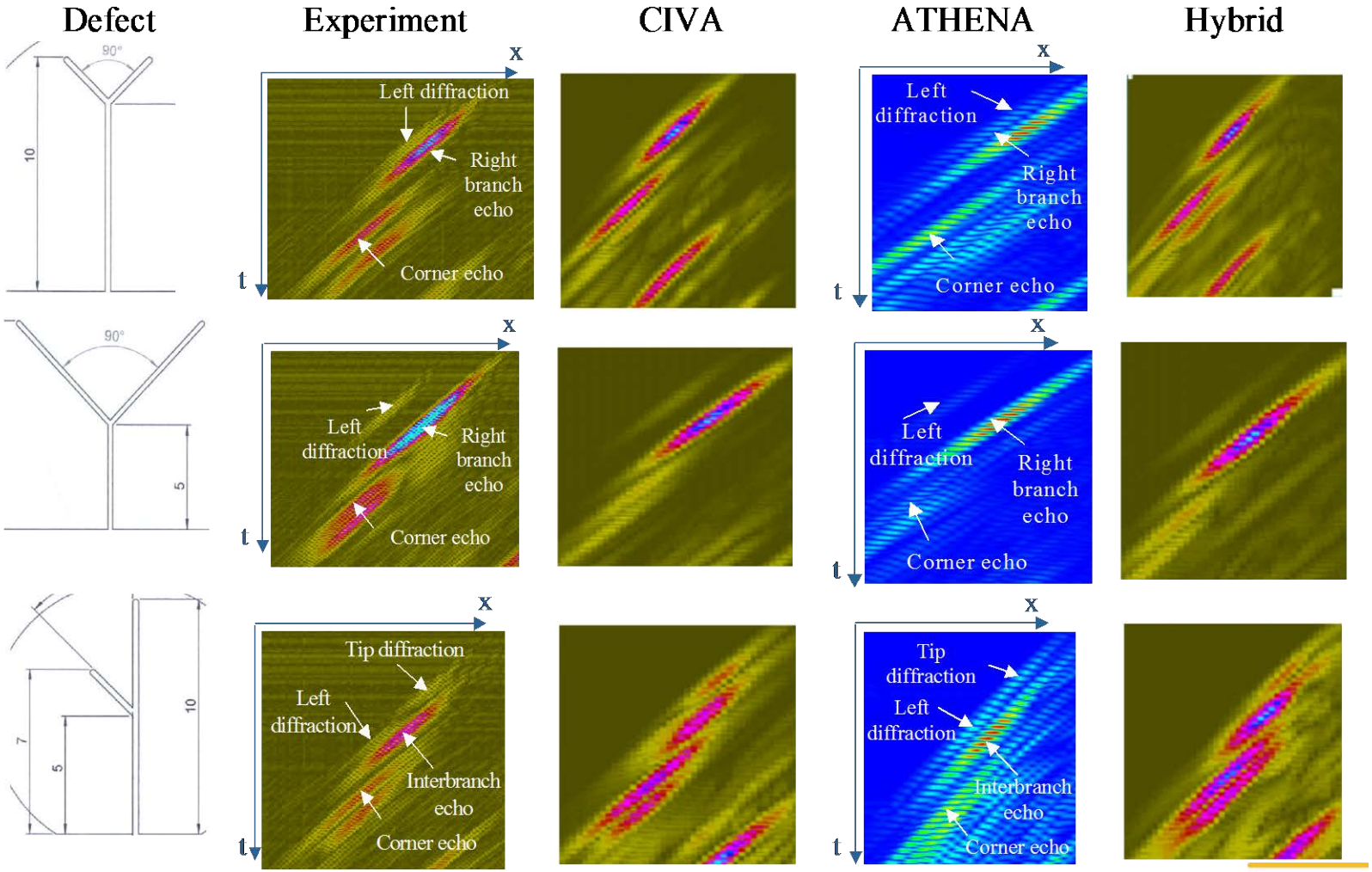


Instant 20 (t = 10.168 µs)



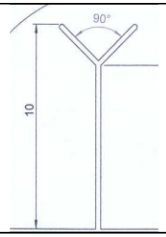
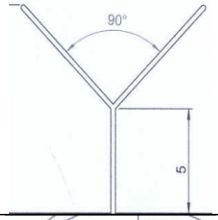
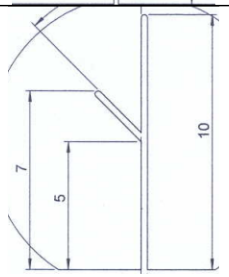
Instant 26 (t = 13.2184 µs)

Branched defect scattering (B scan images)



✓ Modelling B scan images show all echoes observed experimentaly

Results for branched defects

Echo	Test	CIVA	ATHENA	Hybrid	Defect
Defect E					
Corner	3.0	4.5	2.5	4.0	
Left branch	-8.0	-9.0	-11.0	-9.0	
Right branch	7.0	5.5	4.0	5.0	
Defect F					
Corner	3.0	1.5	-2.5	2.0	
Left branch	-8.0	-10.5	-10.5	-13.5	
Right branch	14.0	14.0	12.5	13.5	
Defect G					
Corner	0.5	1.0	-1.5	1.5	
Left branch	-11.0	ND*	-10.0	ND*	
Right branch	-9.0	-9.0	-10.5	-9.5	
Inter branch	3.4	-2.0	1.2	1.0	

* ND : echo not detected

- ✓ Some significant differences observed for :
  - ✓ ATHENA : transducer description + 2D
  - ✓ CIVA doen't take into account multiple reflection

Conclusions

- ✓ ATHENA 2D : complex defect scattering validated
- ✓ CIVA : multiple reflection not correctly reproduced
- ✓ Hybrid code : sensitivity to the box orientation identified

PERSPECTIVES

- ✓ Validation for shear waves under progress
- ✓ New hybrid code (2D and 3D)
- ✓ 3D approach (experimental and modelling)