

OPENTURNS AND CAST3M : STRUCTURAL COMPUTATION FOR MECHANICAL ASSEMBLIES WITH CONTACT AND FRICTION

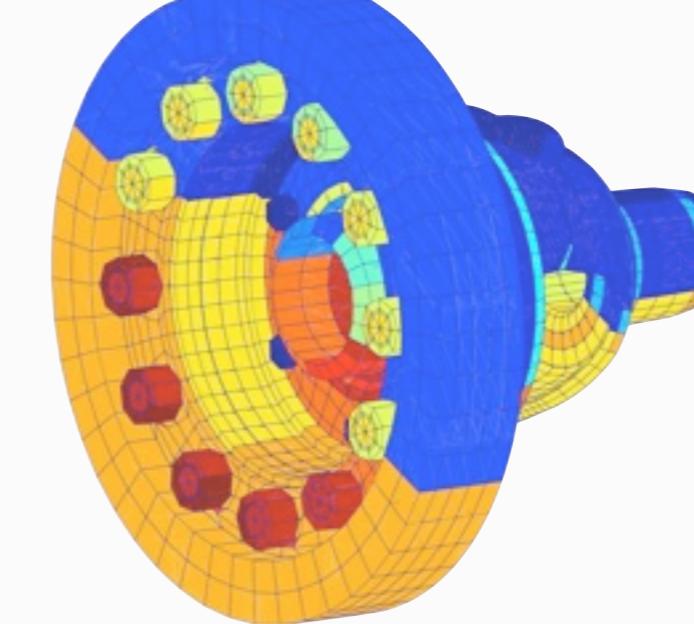
L. Champaney

Prof. ENS Cachan

Lab : LMT Cachan - Team : Robust Design and Engineering

contributions :

P.A. Boucard, P. Ladevèze, V. Roulet, B. Soulier, A. Stricher



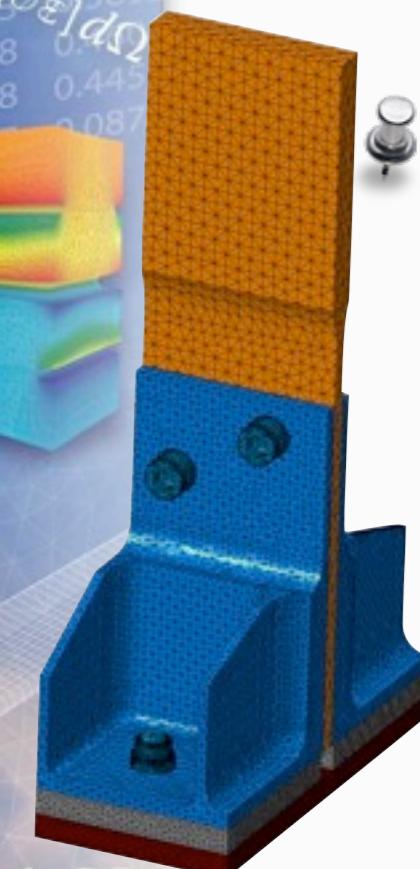
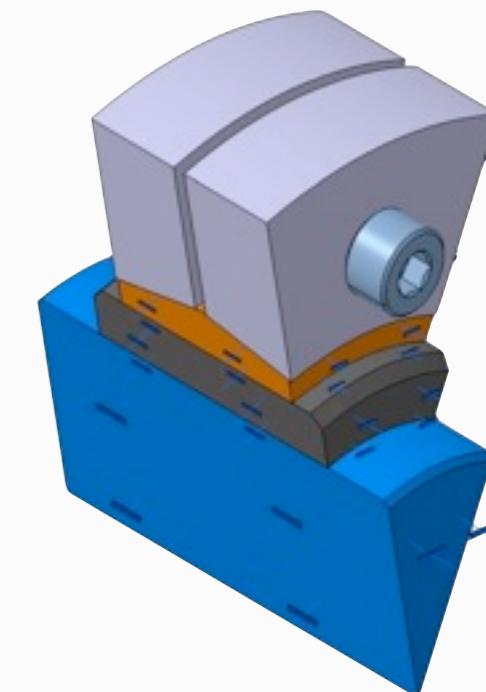
Start point

- family of **parametered** structures : assemblies (contact, friction, ...)
- Set of **similar** problems to solve
- **Parameters** : friction coefficients, gaps, geometrical details (tolerances), missing fastener (rivet, bolt), *material parameters...*



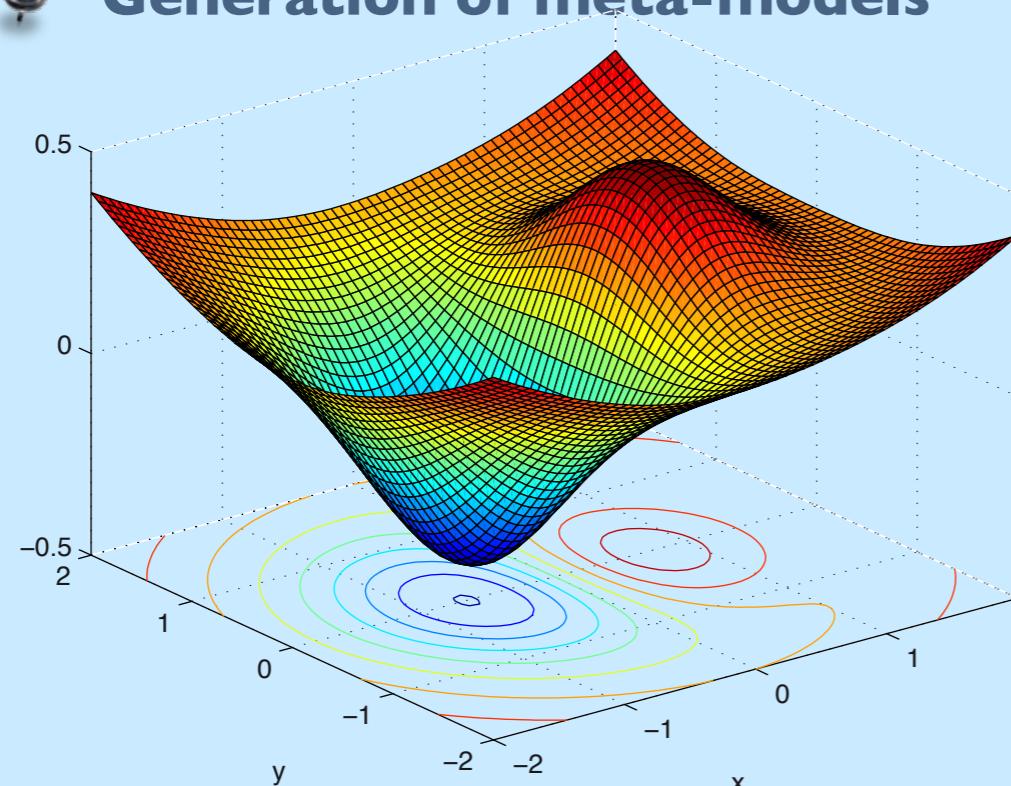
Objectives

- To get a **quantity of interest** (displacement or maximal stress) as a function of the parameters,
- Possibly, **probabilistic** informations:
 - *statistical moments (means, standard deviation...)*
 - *probability or specific events,*
 - *distribution of probability*

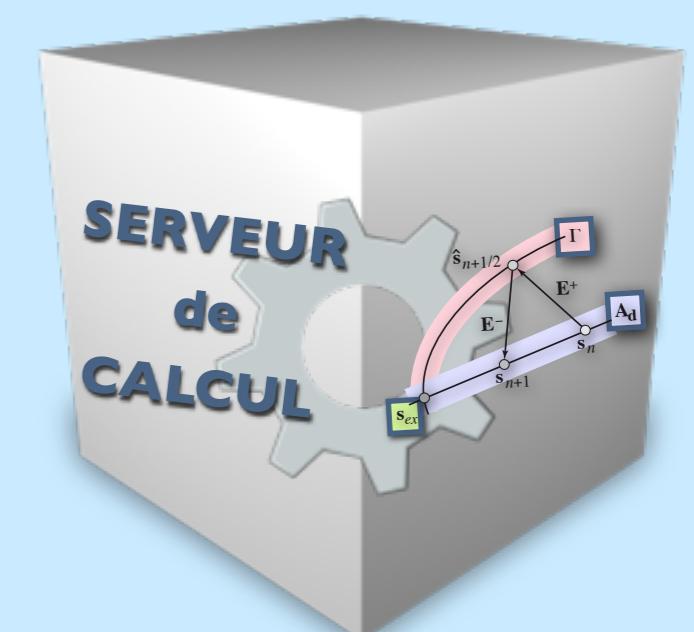


objectives...

- Sensitivity analysis
- Generation of meta-models

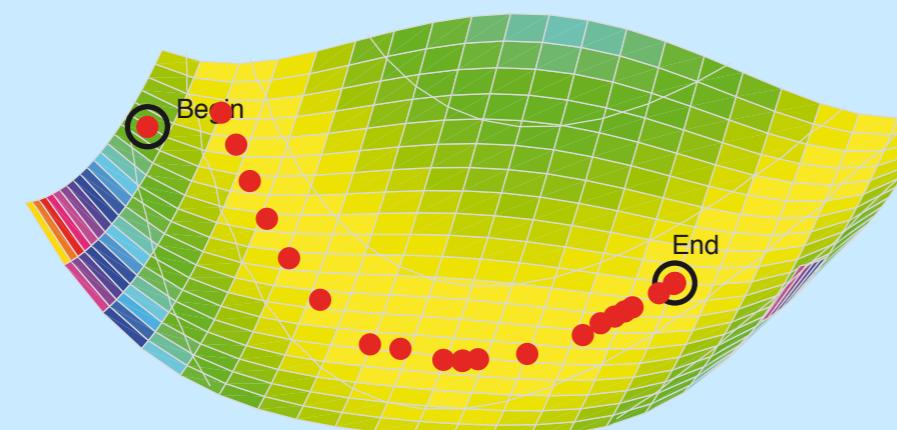


Set of parameters →
← Response



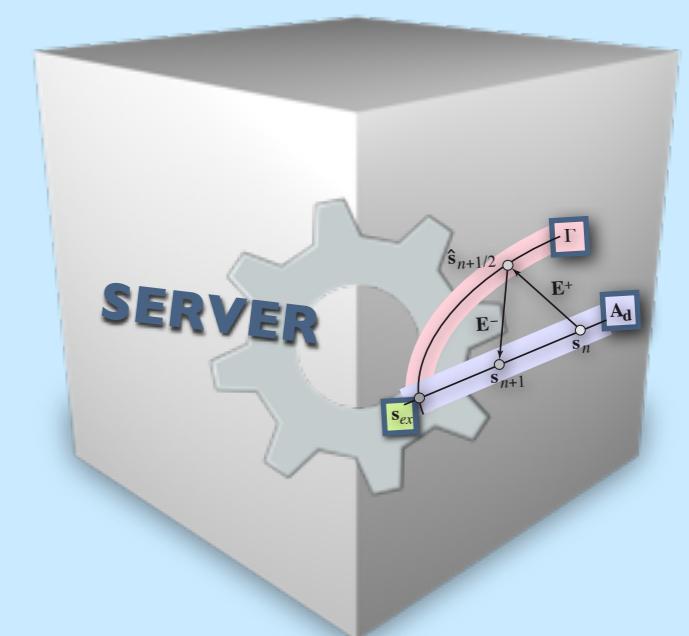
Objectives...

- Optimisation
- Minimisation of a distance (validation)



Set of
parameters

Cost function,
constraints...



Plan

1. Context

2. Tolerancing (Wrapper OpenTURNS-Cast3m)

3. Acceleration techniques

4. Examples

5. Conclusions

Plan

1. Context

2. Tolerancing (Wrapper OpenTURNS-Cast3m)

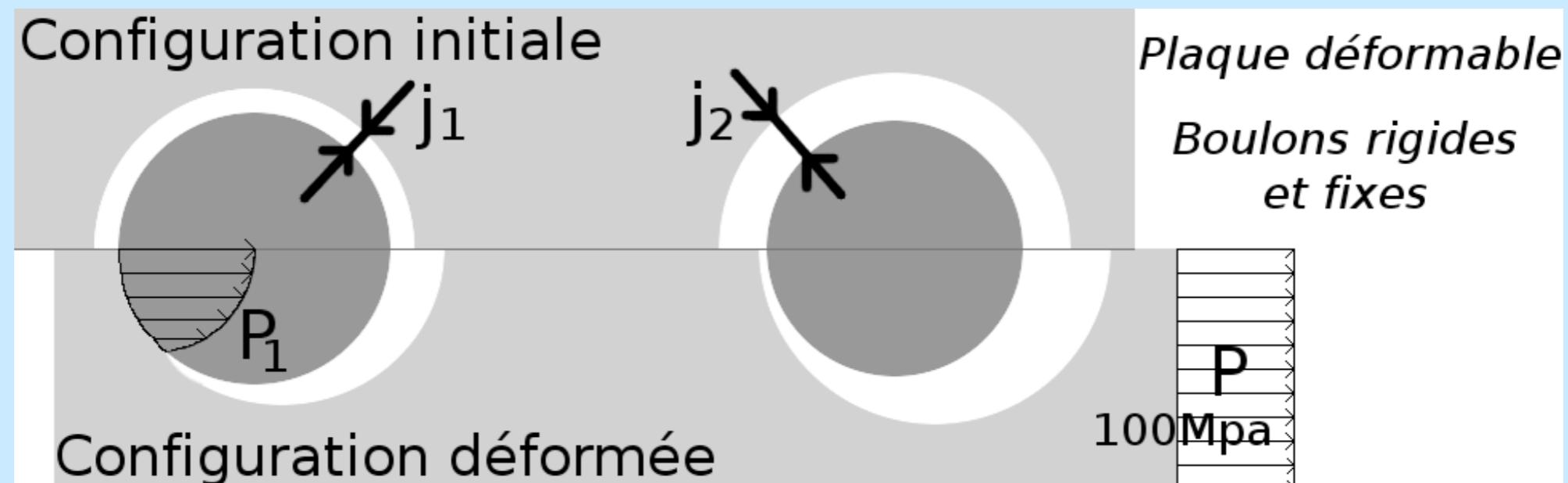
3. Acceleration techniques

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Example

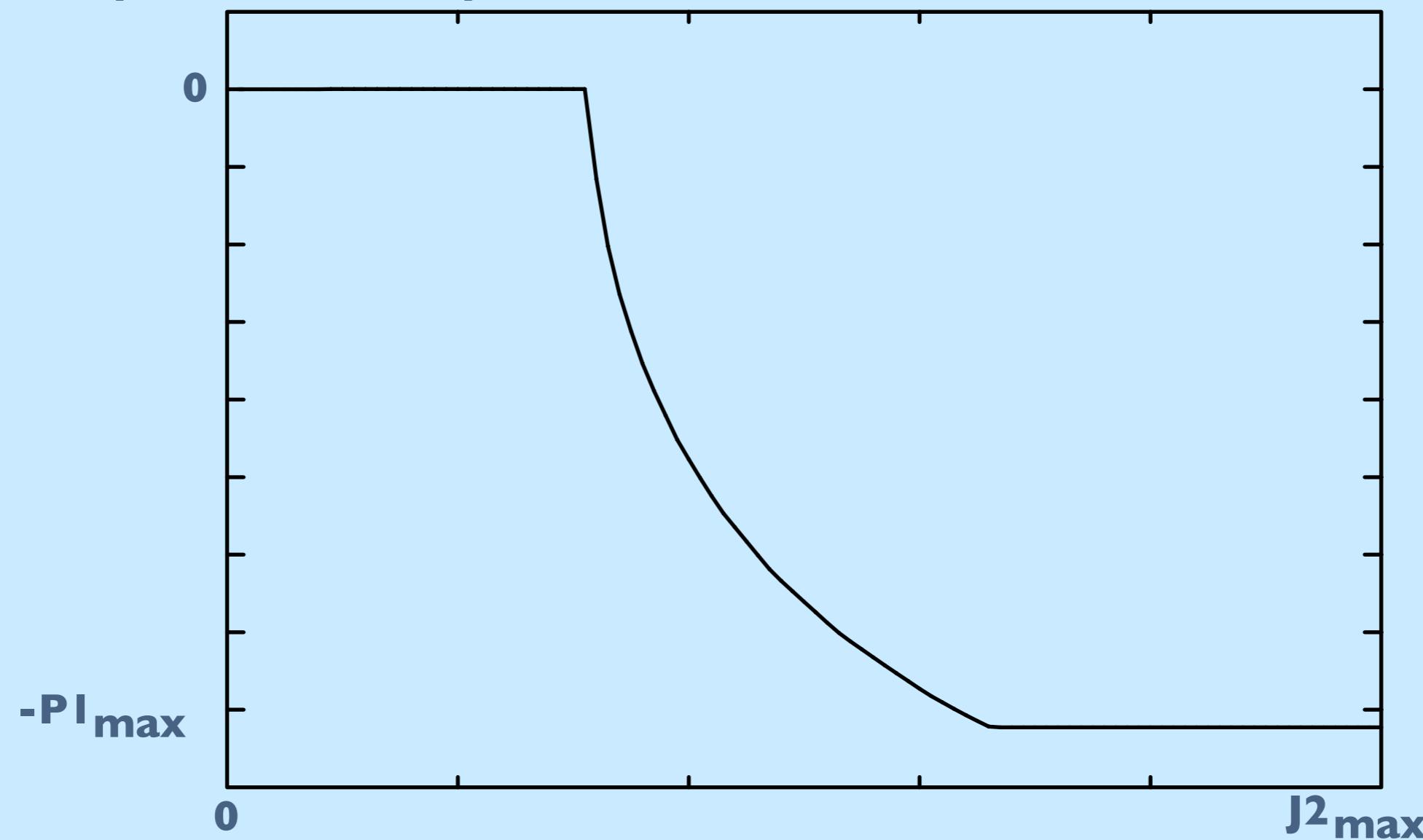
- Simple Assembly :
- Tolerancing : One uncertain gap
- Quantity of interest : Max pressure P_1



Example



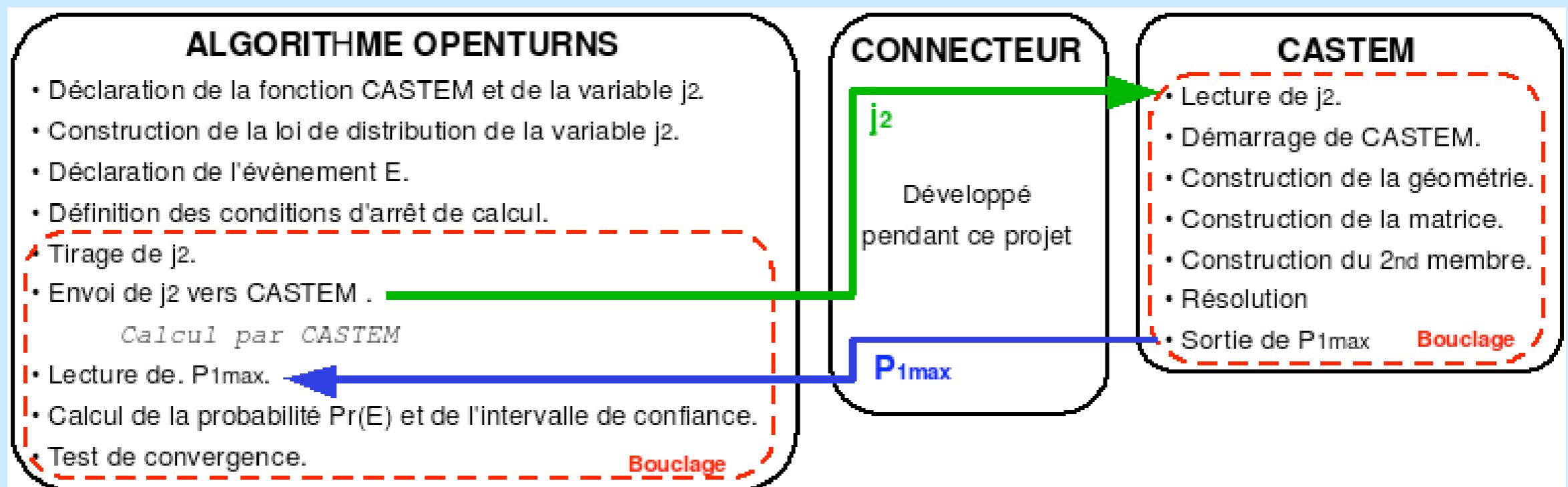
Response surface : pressure



OpenTURNS Wrapper for CAST3M

Cast3m Wrapper

- Cast3m wrapper for Cast3m
- OpenTURNS : Monte Carlo or LHS

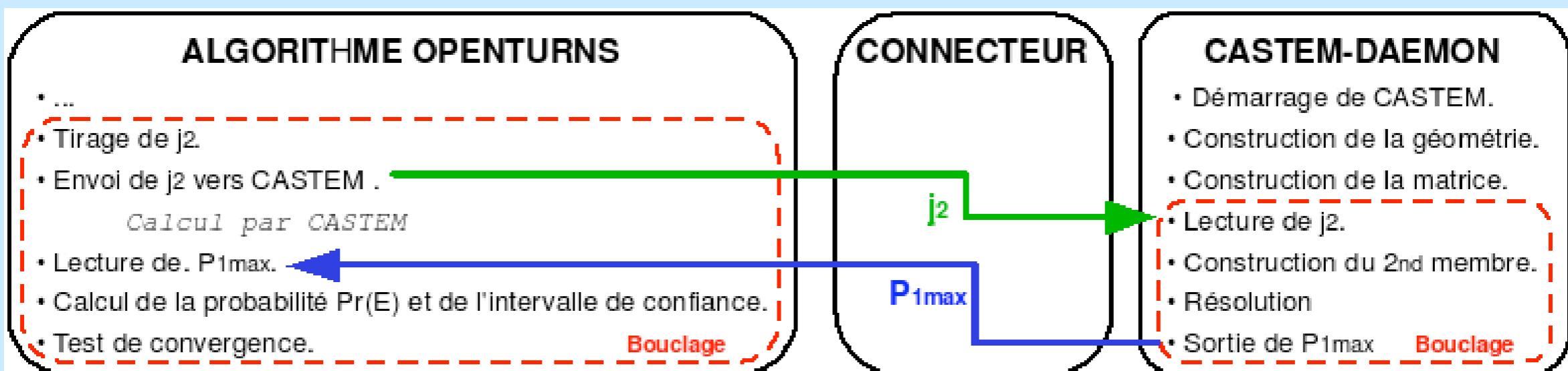


- Cast3m starts and stops at each calculation: waste of time

OpenTURNS Wrapper for CAST3M

Cast3m-daemon Wrapper

- Cast3m in daemon mode : (using perl/python routines)
- Cast3m is running during the complete OpenTURNS Algorithm



Generalisation for tolerancing (EADS/ENS Cachan)

[Stricher 2011]

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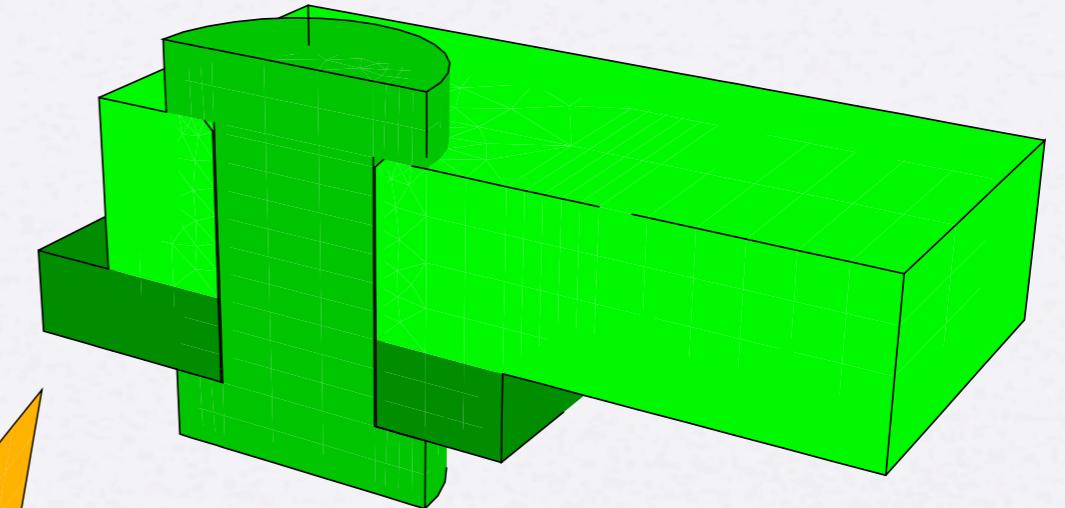
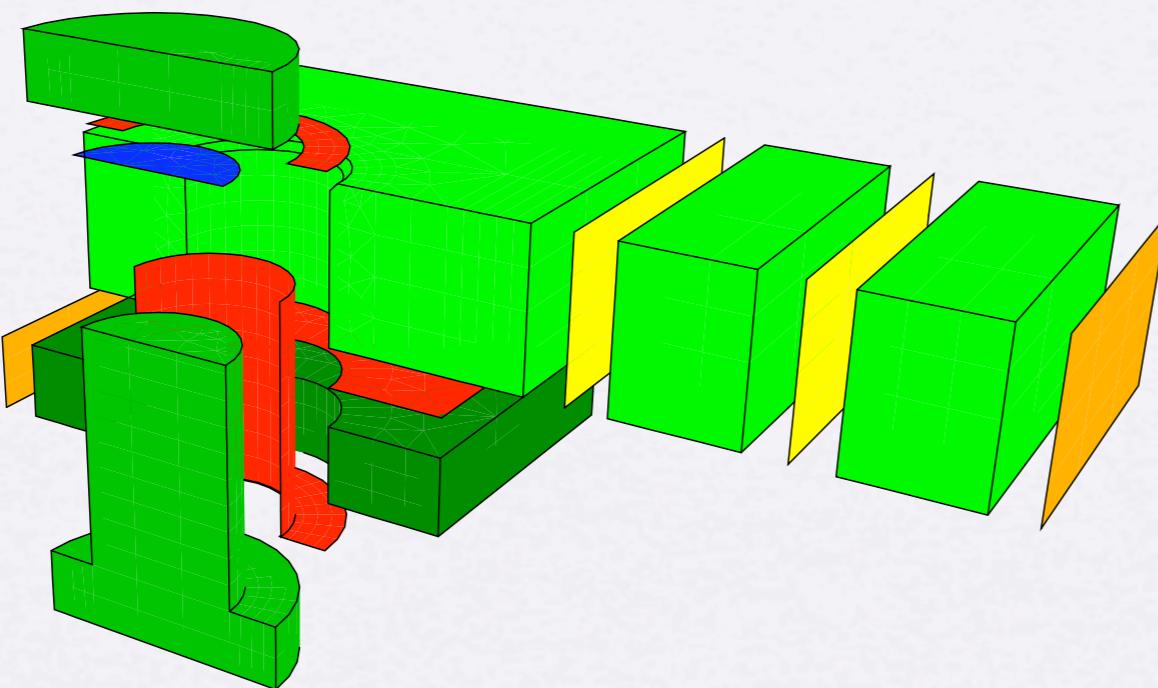
Description of the assembly

Decomposition



Two types of entities :

- Substructures : components
- Interfaces : connections



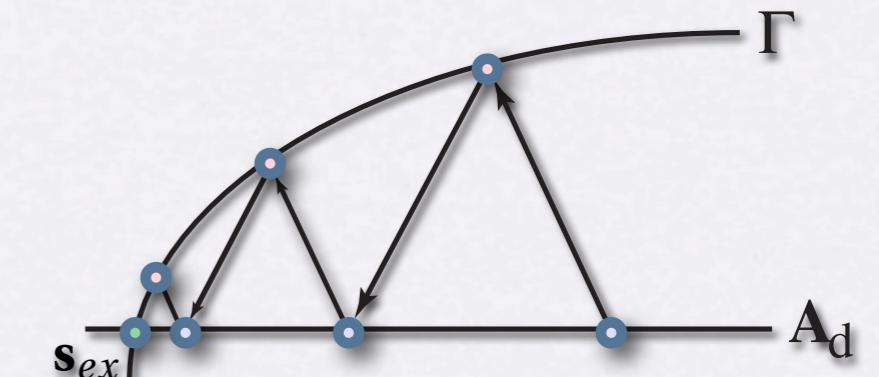
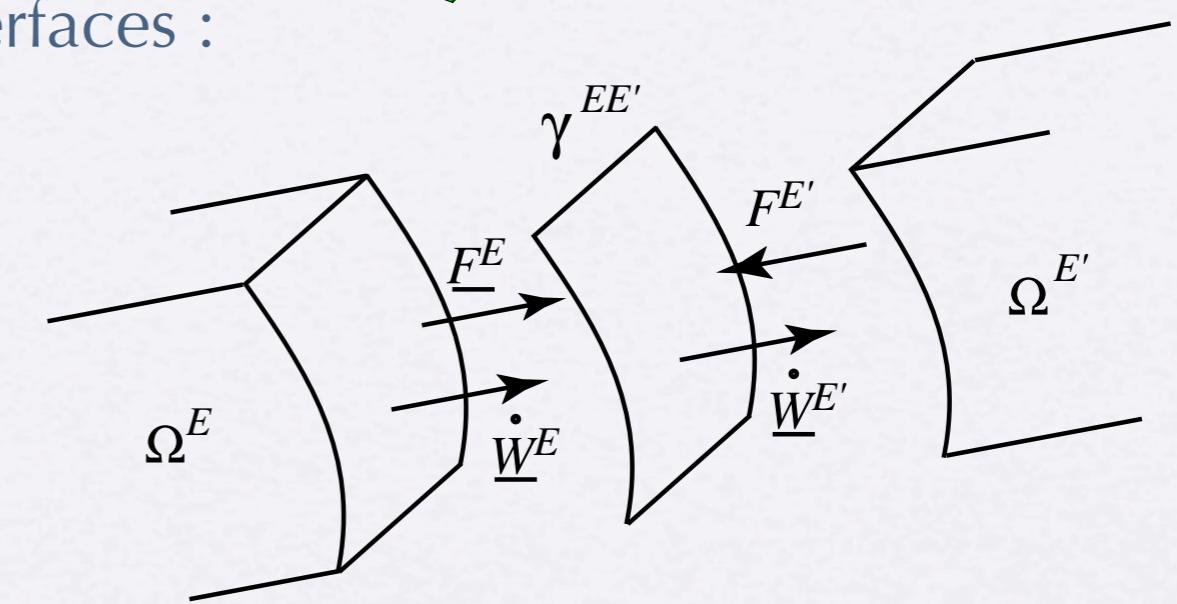
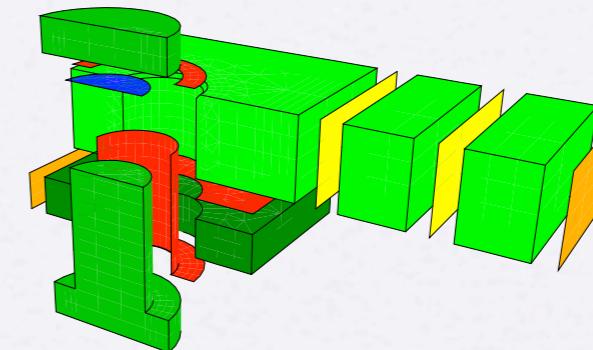
Interest :

- Isolate the elements that must be modified
- Isolate the difficulties
(contact nonlinearities)

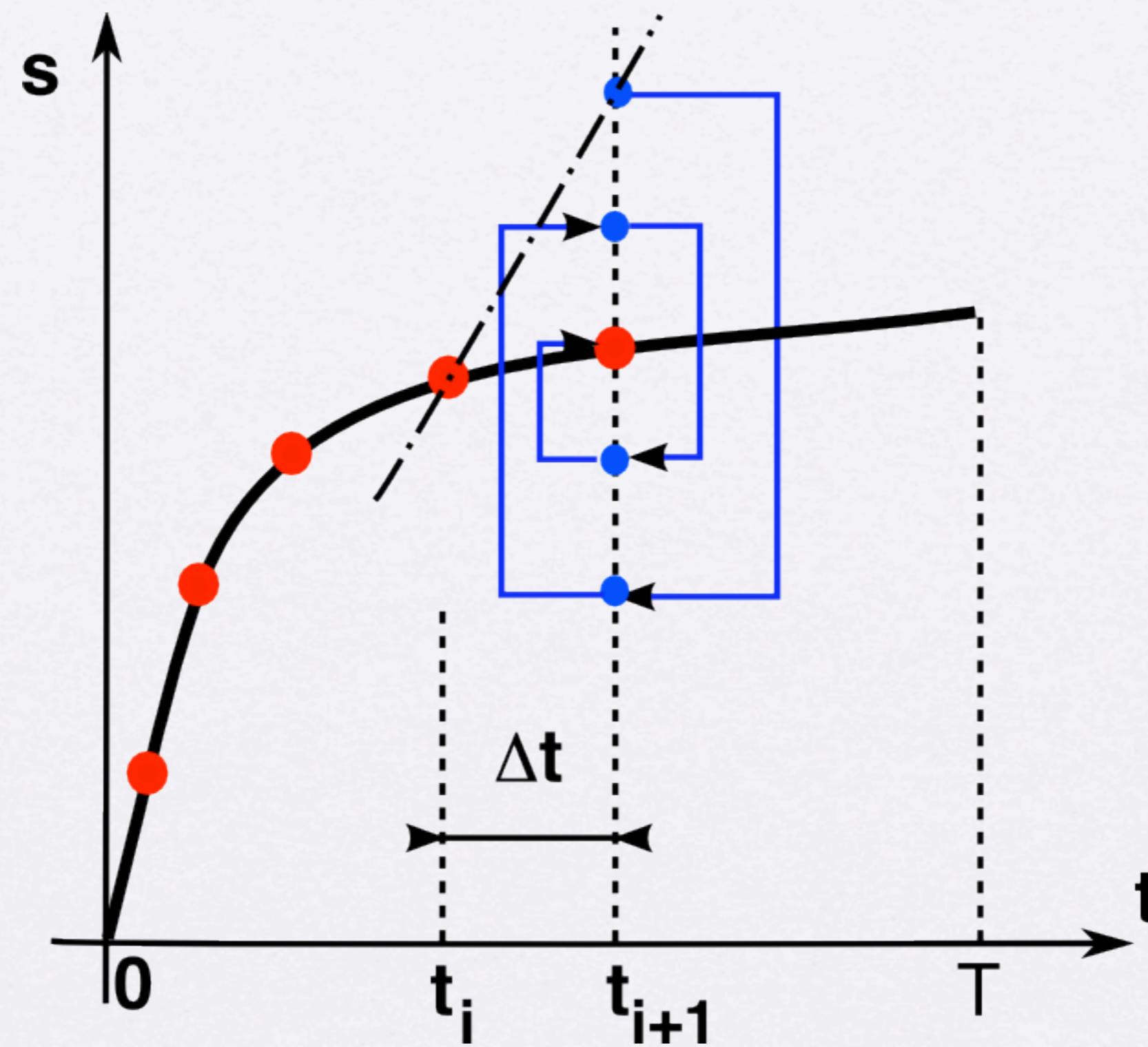
Monoscale LATIN Method

[Ladeveze, 99]

- Domain decomposition
 - flexibility
 - parallelism
- Mixed approach : on the interfaces :
 - Force fields
 - Velocity fields
- Separation of difficulties
 - local nonlinear problems
 - global linear problems
- Two stage iterative scheme
 - **linear search directions**
 - approximation **on the whole time interval** at each iteration
 - operators are **not dependent** of the interface parameters

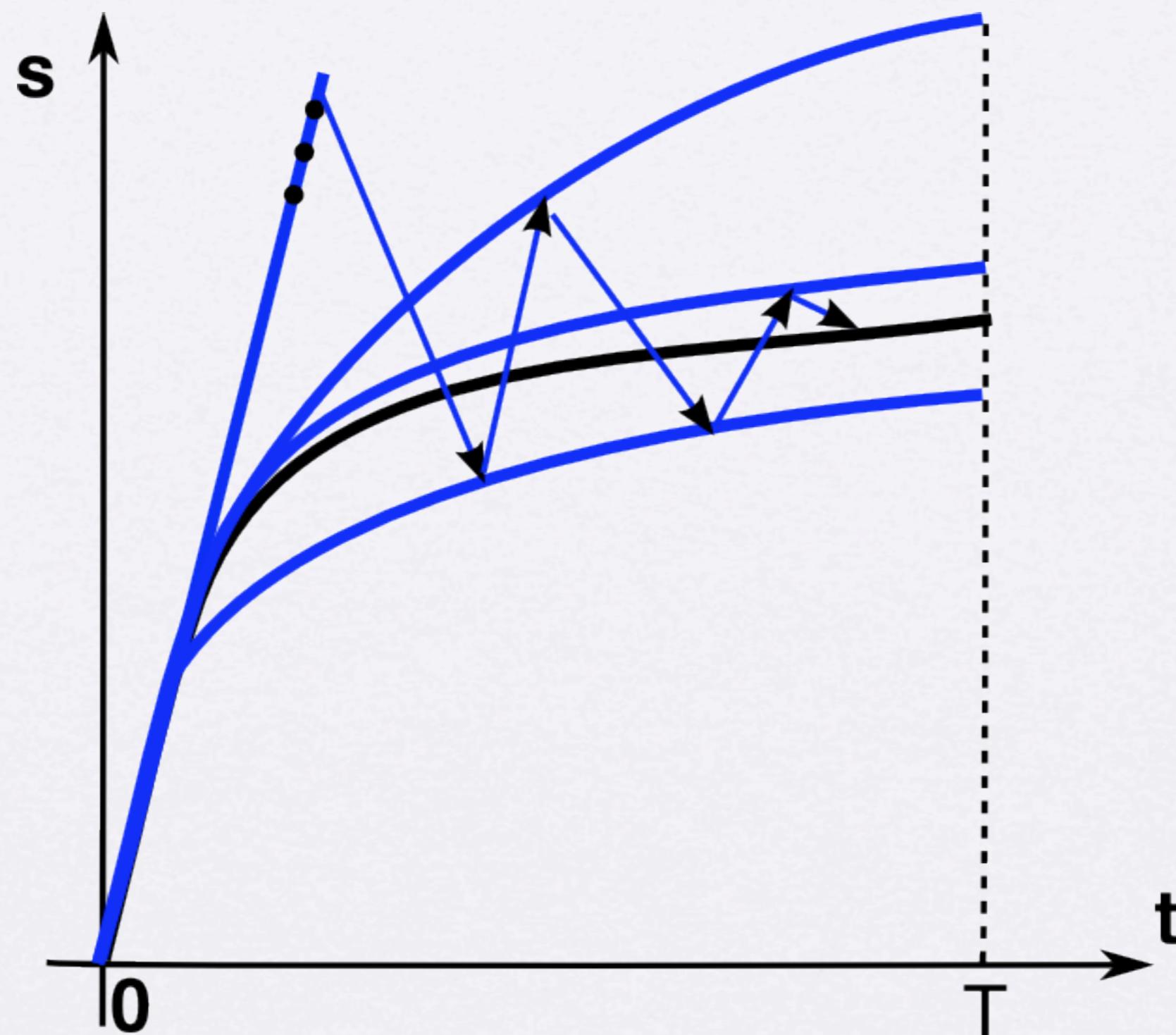


Classical Step by Step Methods

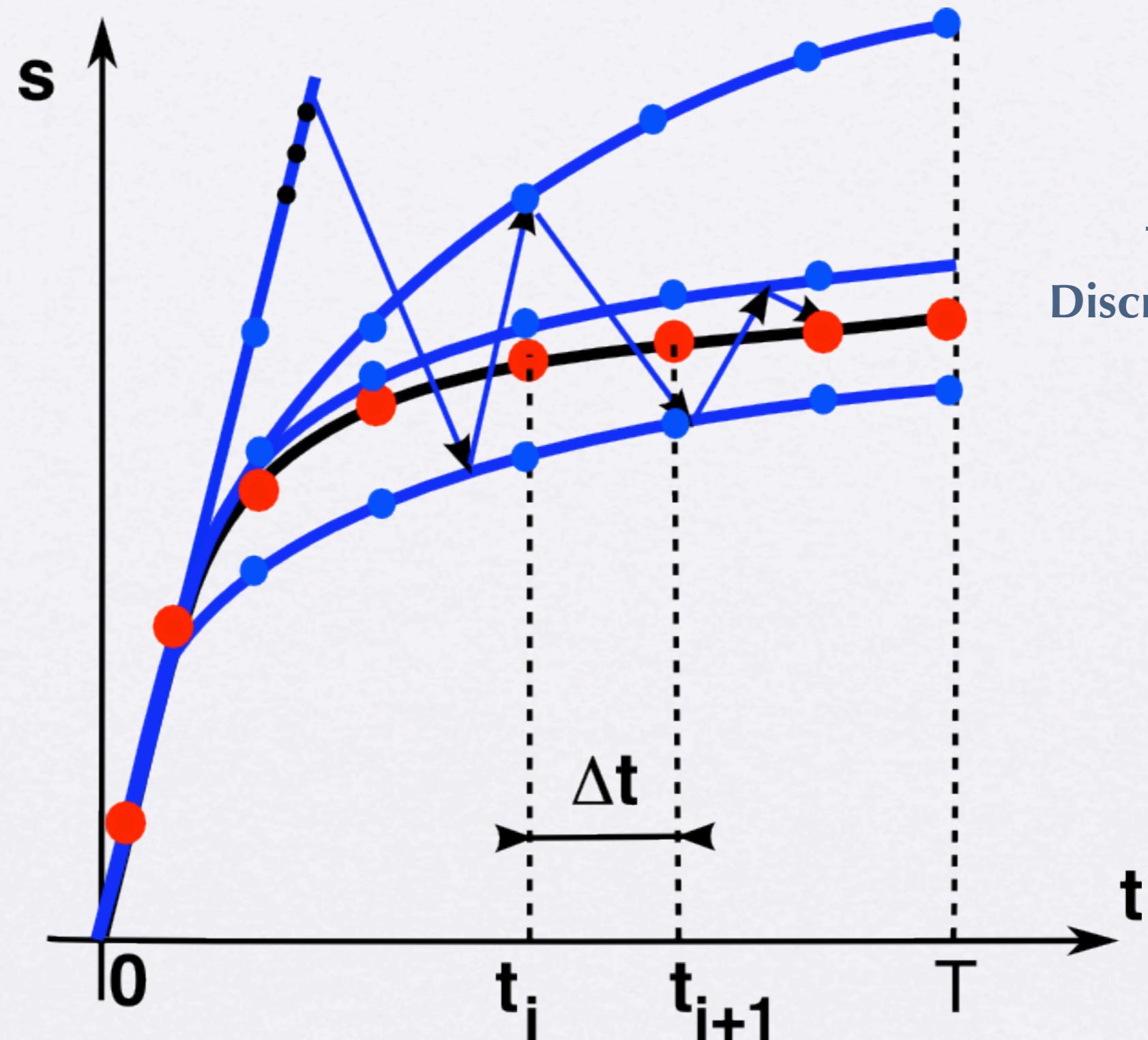


Large Time Increment Method

Large Time Increment Method

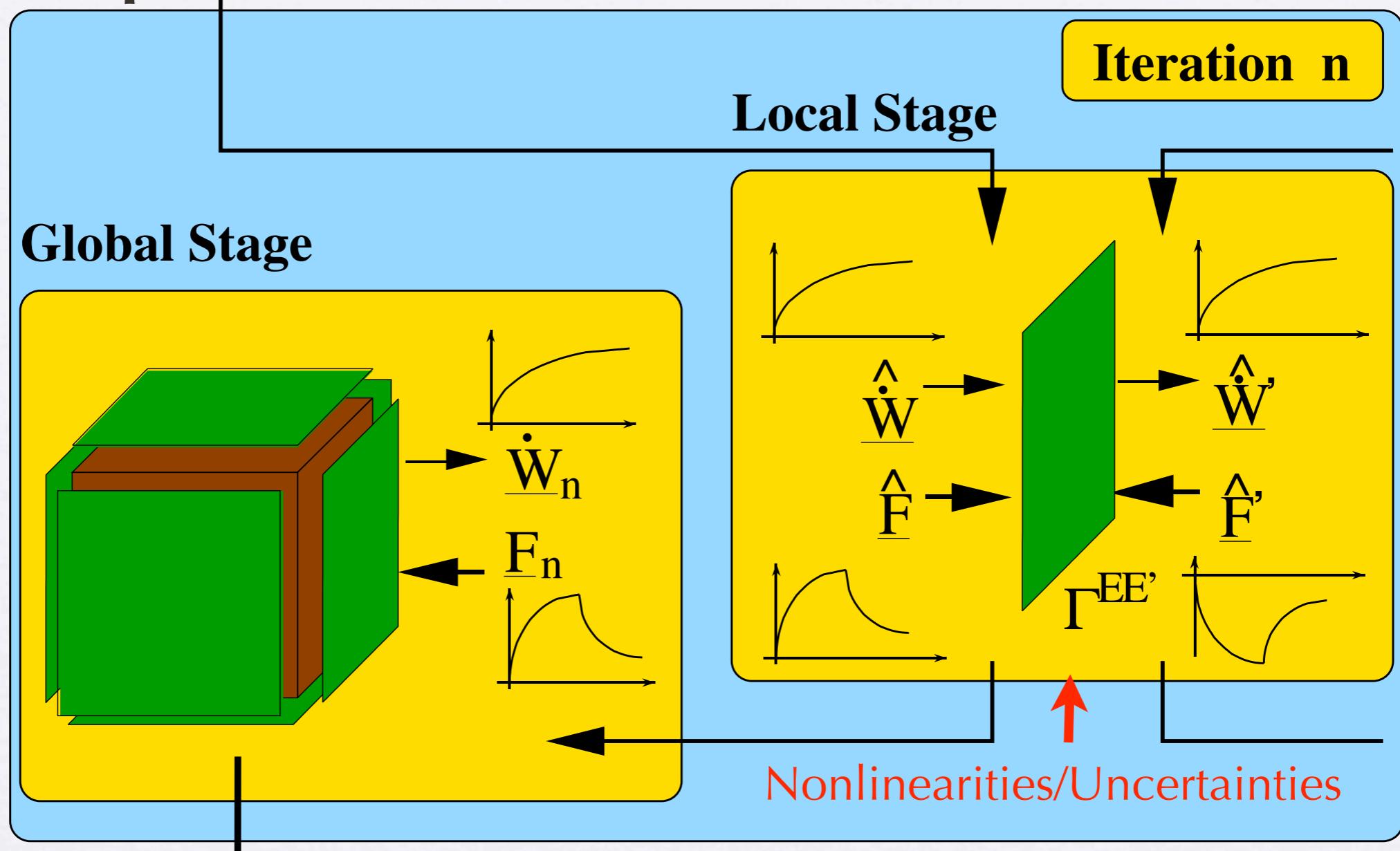


Large Time Increment Method



Algorithm

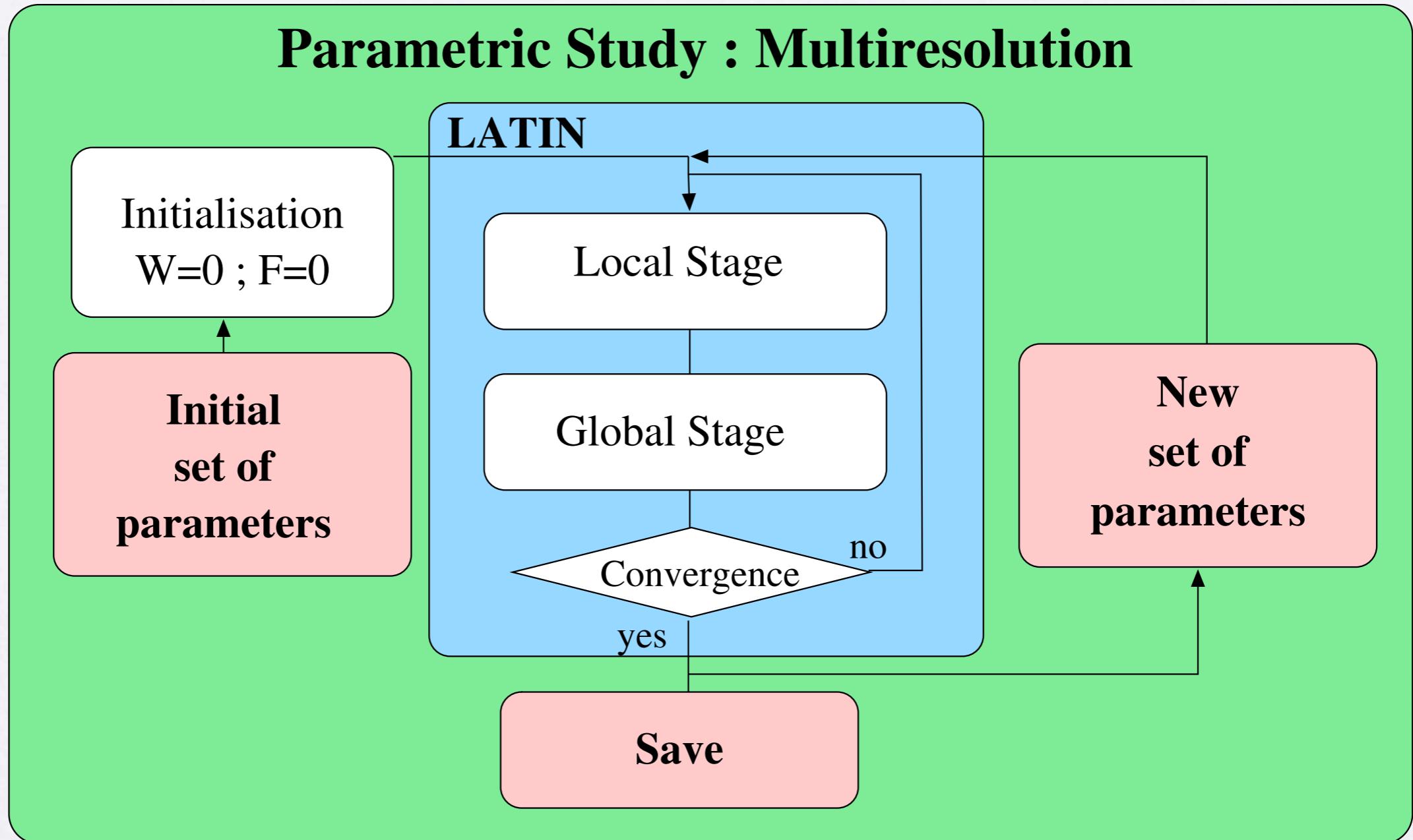
Iterative procedure



- Separation of global and local problems
- Isolation of the effect of the parameter of the connections

Multiparametric procedure

Parametric Study : Multiresolution



- **Initialization** of the computation of a solution for a set of parameters by the solution computed for the previous one
- **Very easy** : due to the decomposition of the assembly

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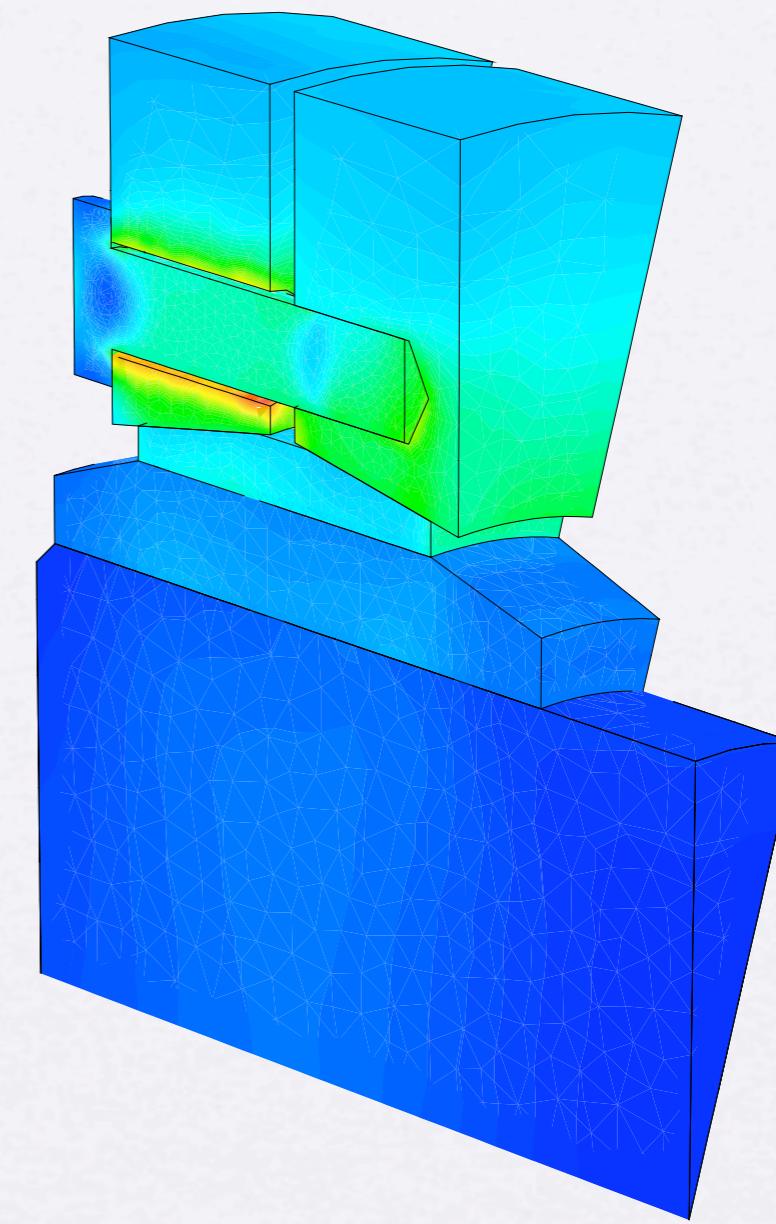
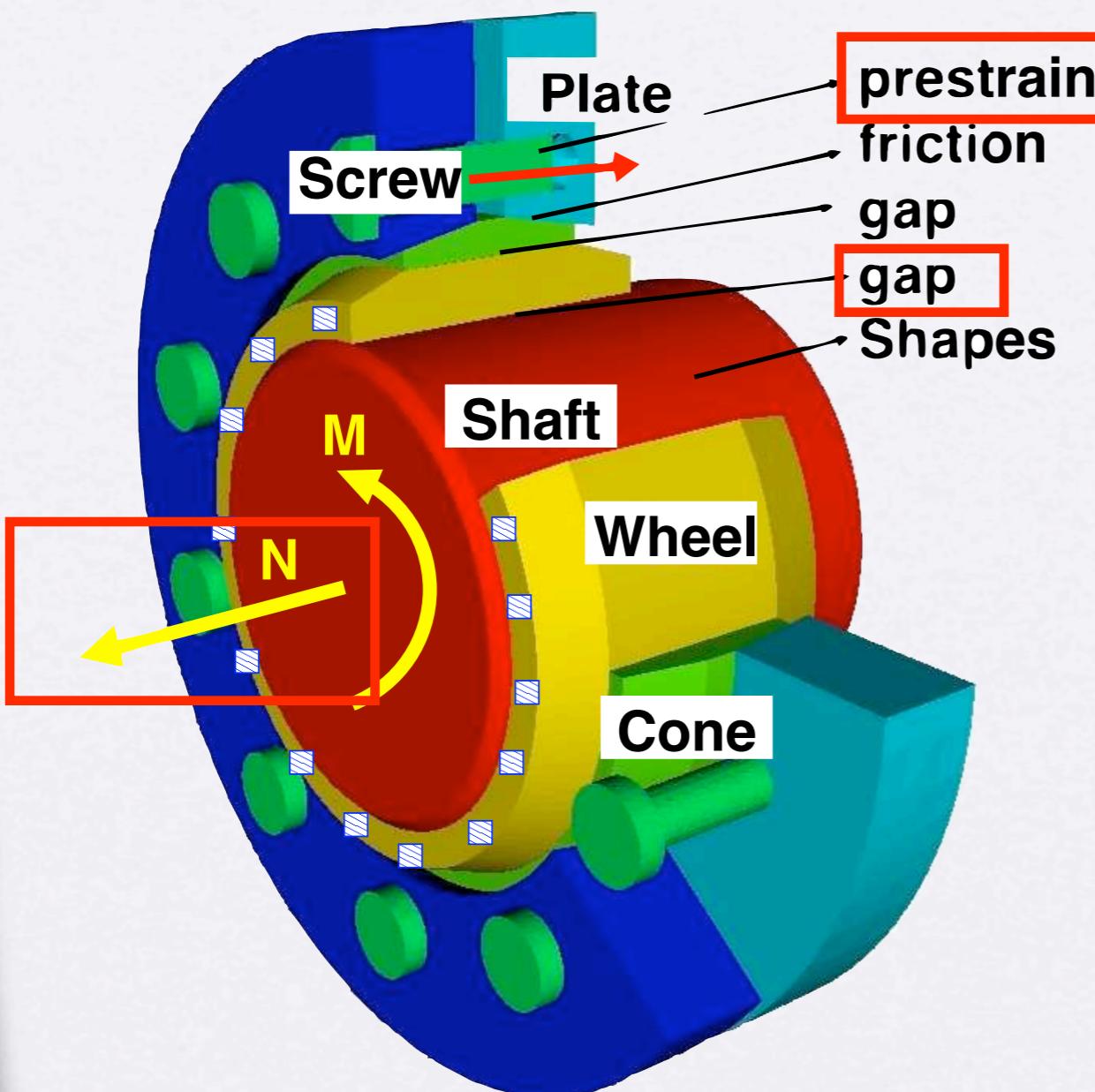
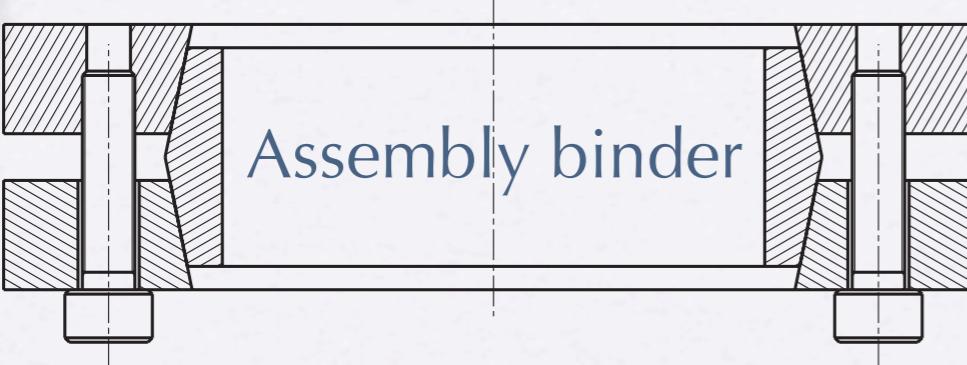
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Multi-résolution

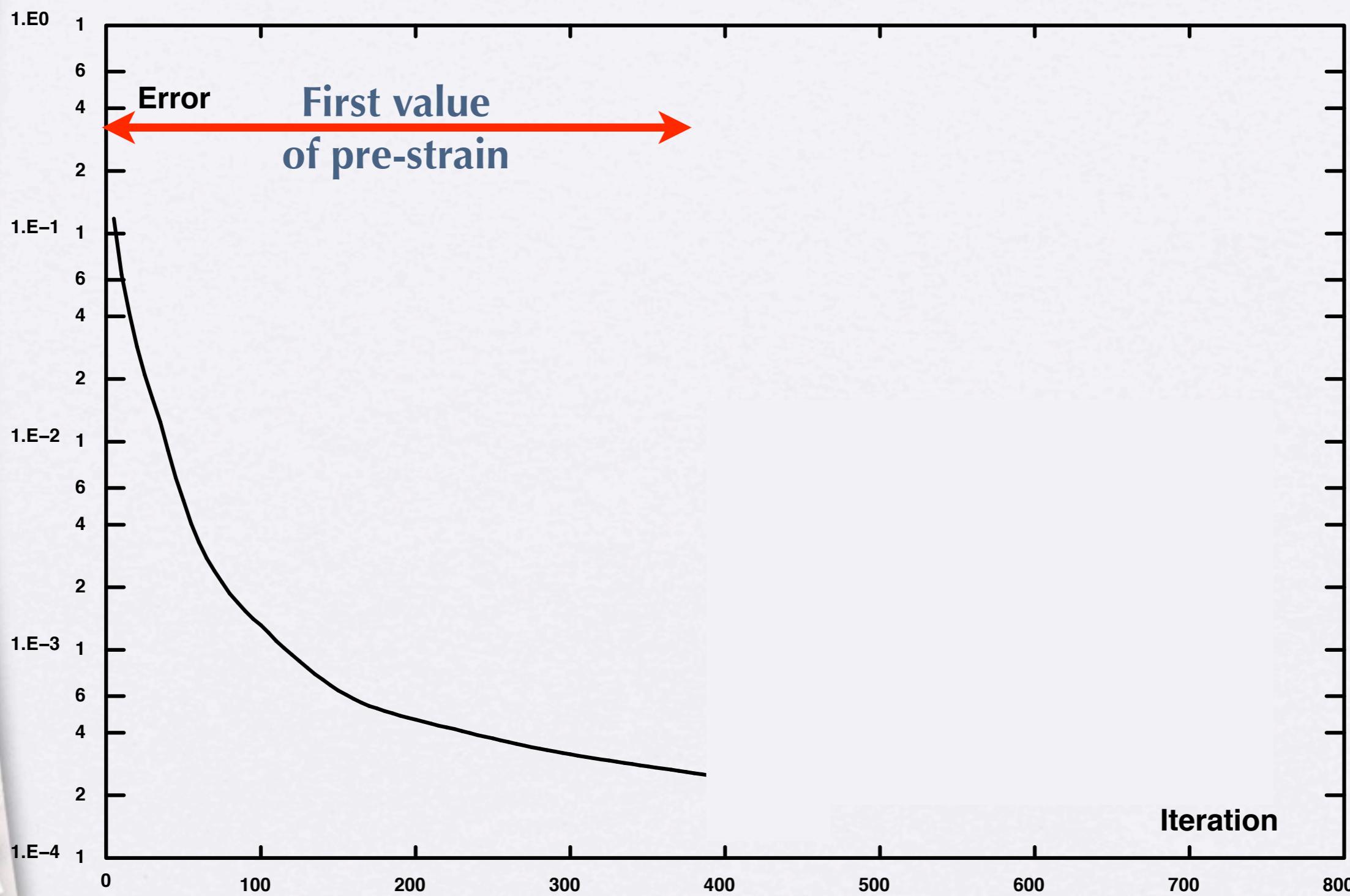
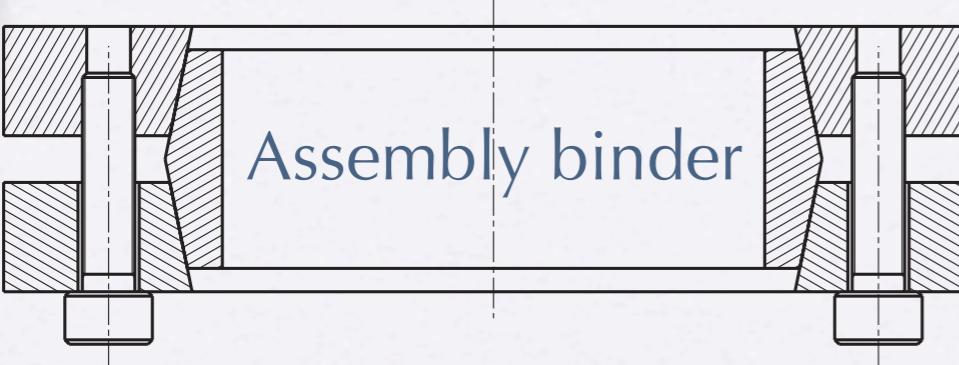


Study

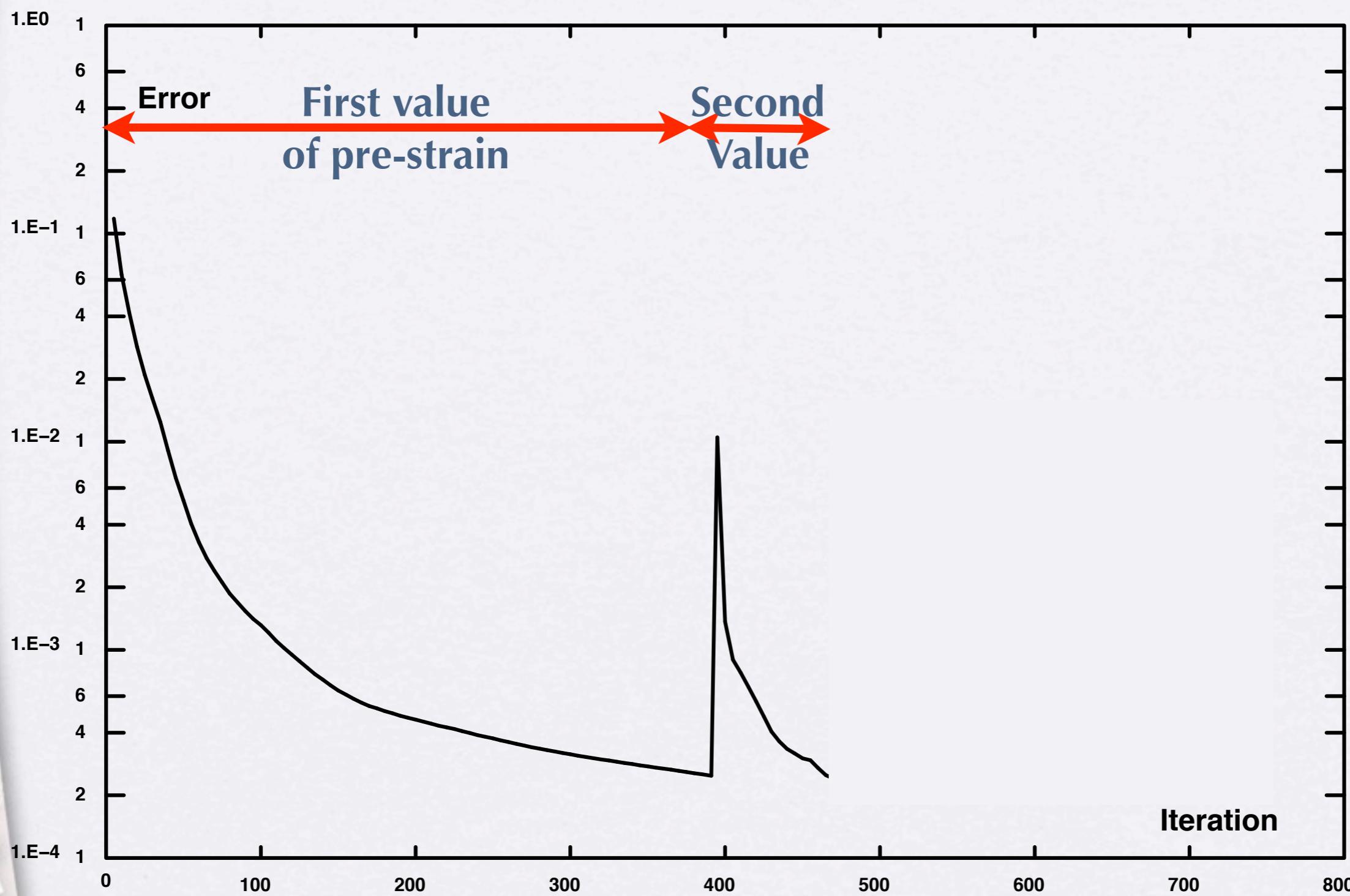
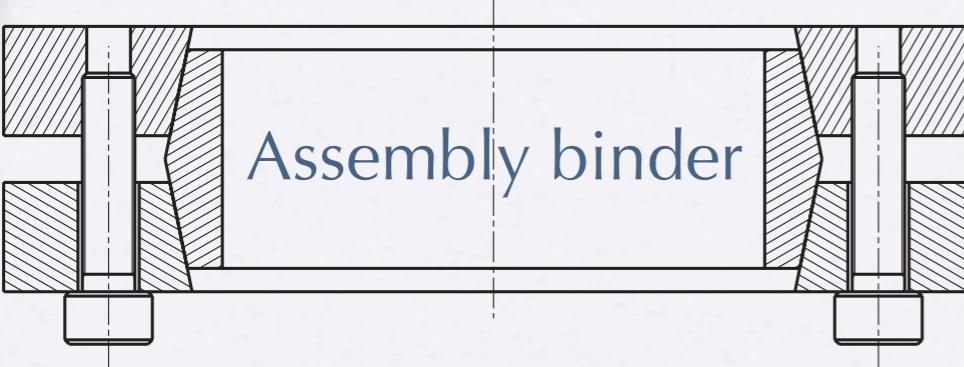
- Variation of the prestrain :
 - 7 values
- Variation of the wheel-shaft gap
 - 10 values

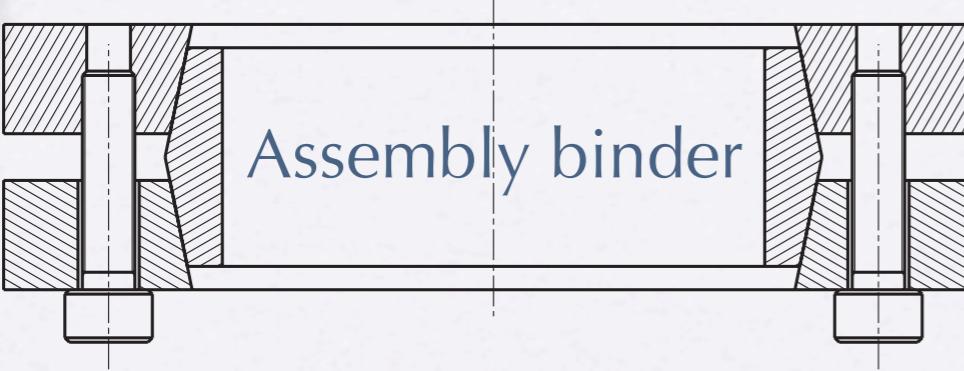


Multi-résolution

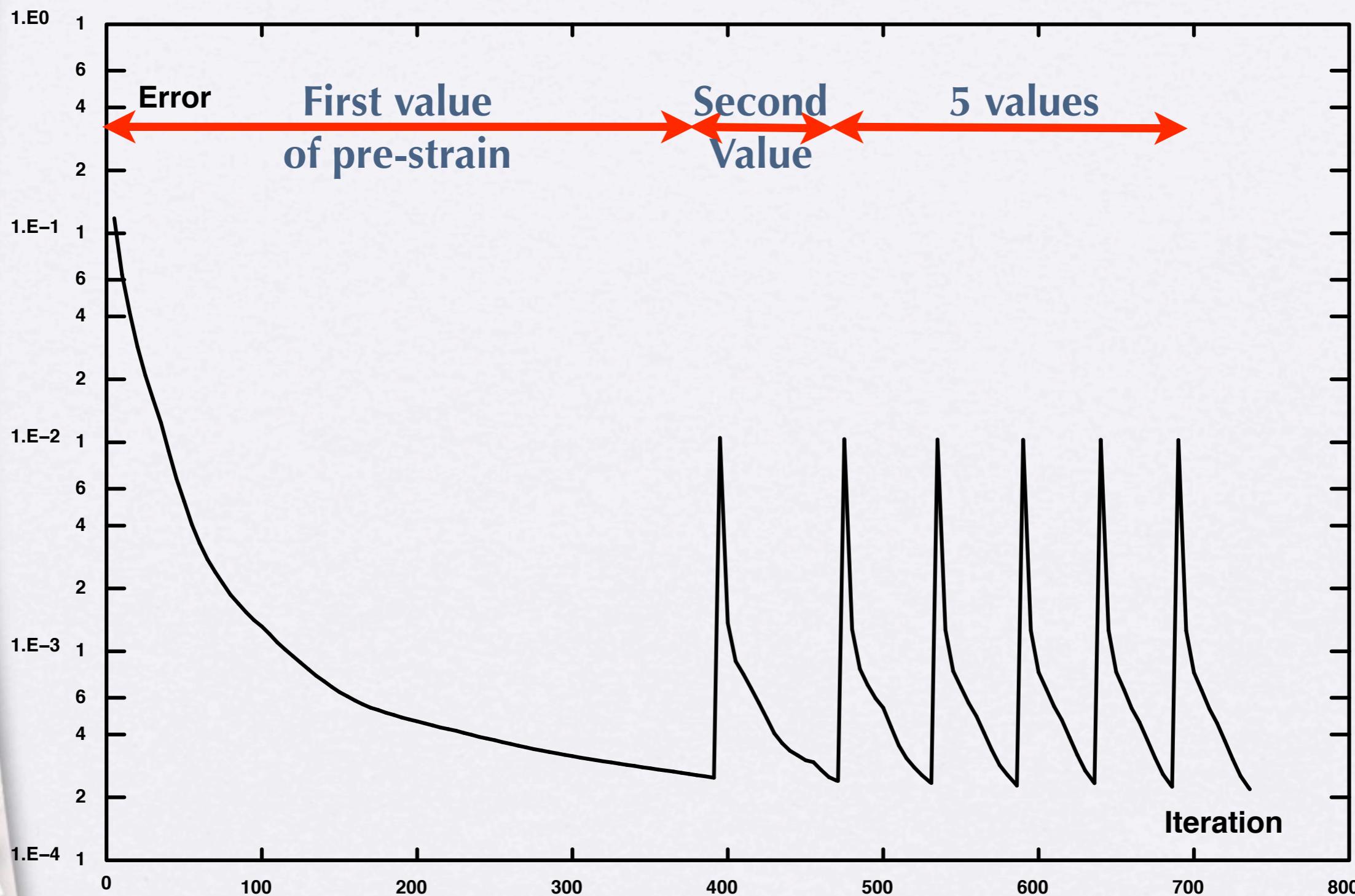


Multi-résolution

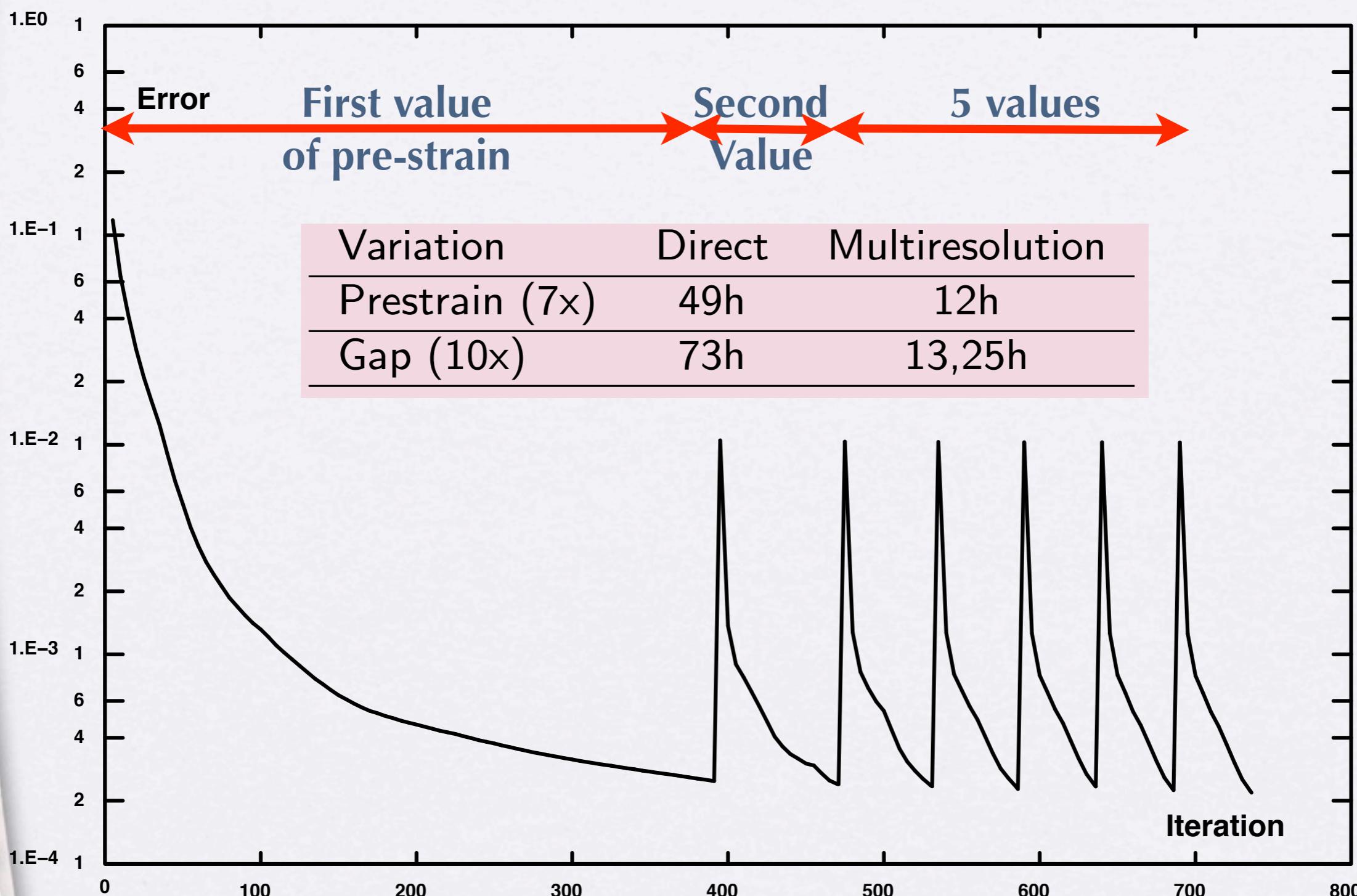
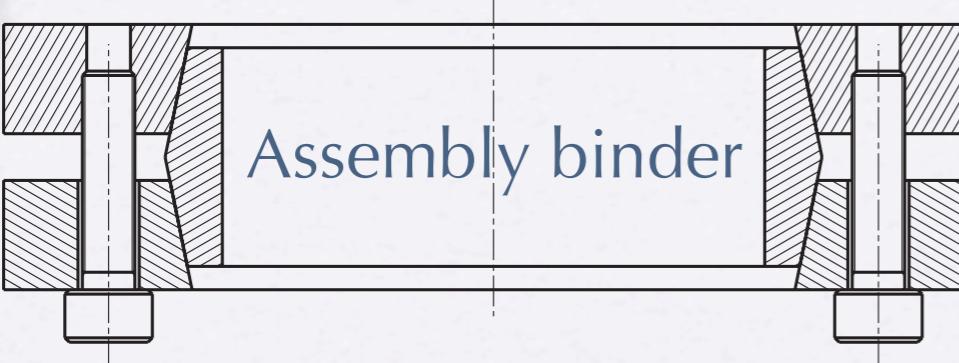




Multi-résolution



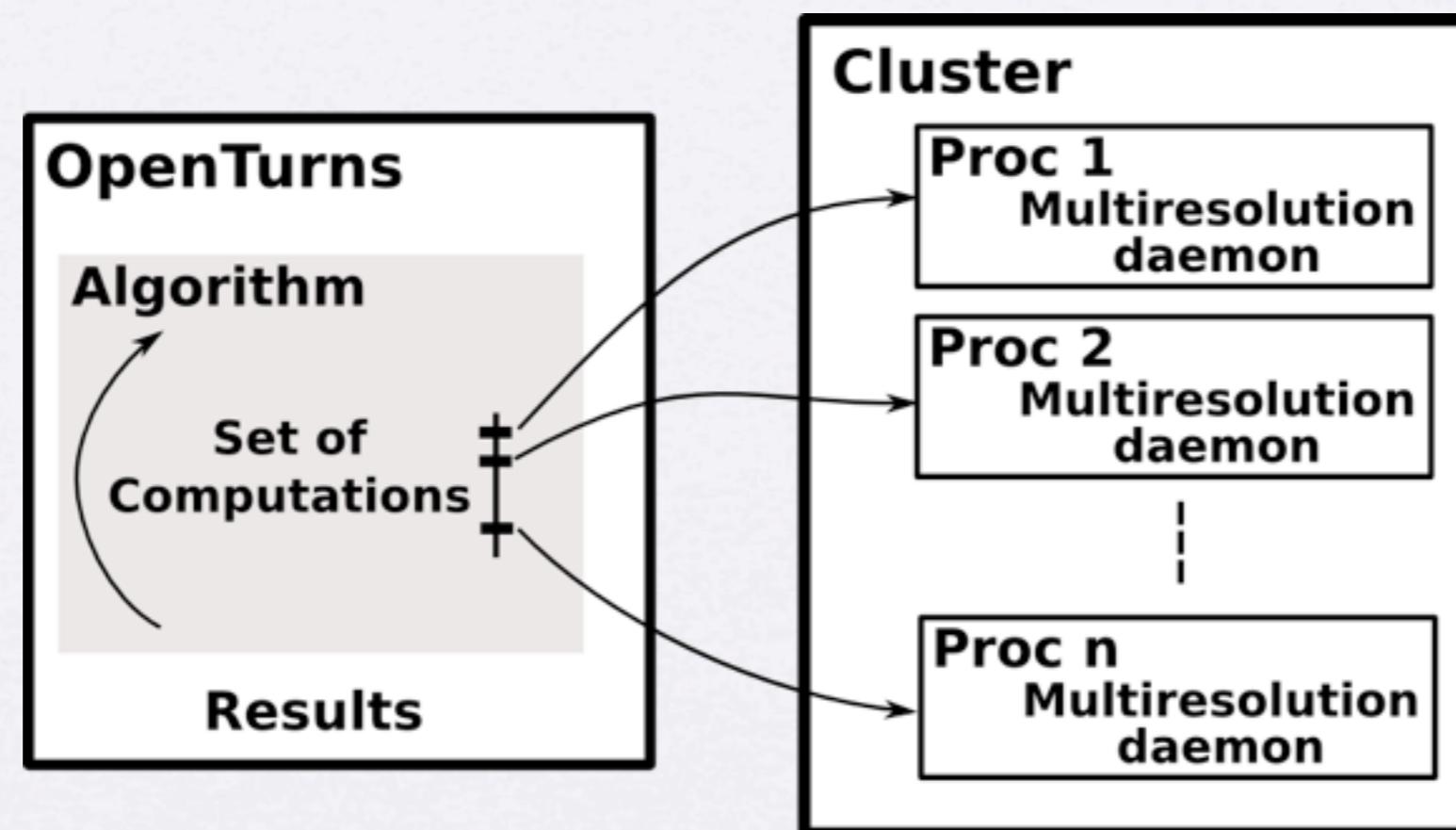
Multi-résolution



Parallel multiresolution

Using OpenTurns python librairy

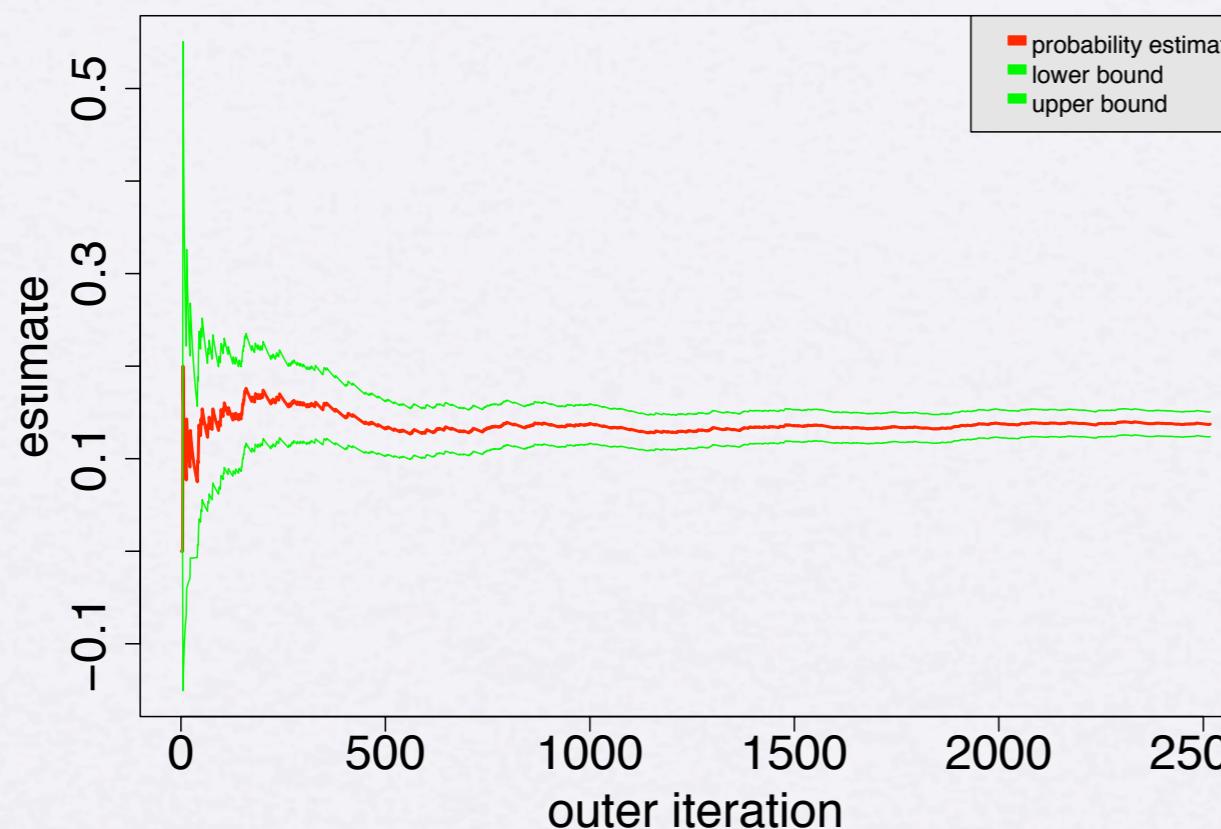
[Andrianov et Al, 2007]



Parallel multiresolution

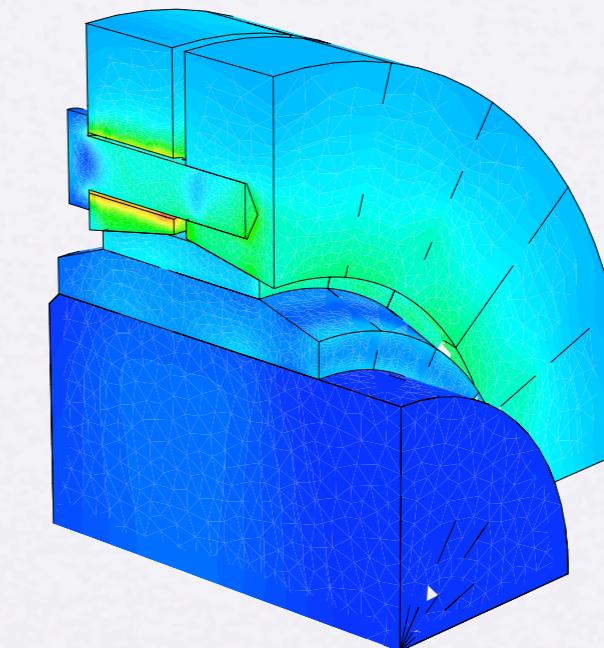
LHS Algorithm in OpenTurns

LHS convergence graph at level 0.95



Model

- Five sectors :
 - Symmetry conditions
 - 793 585 degrees of freedom
- 30 substructures
- 73 interfaces



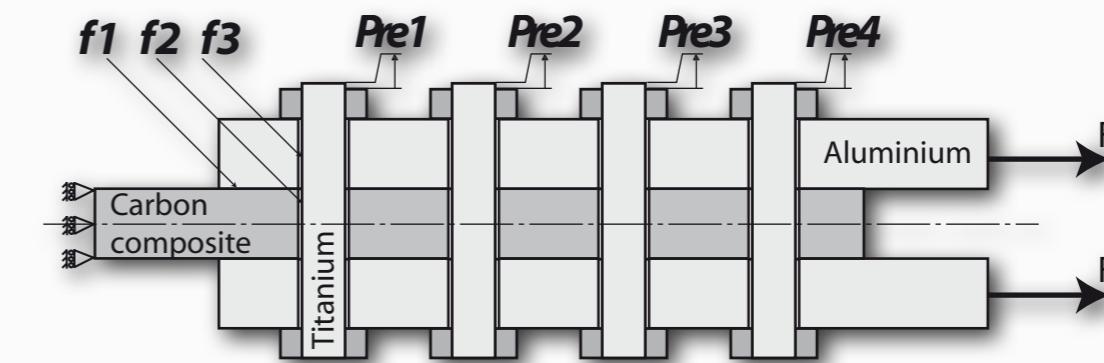
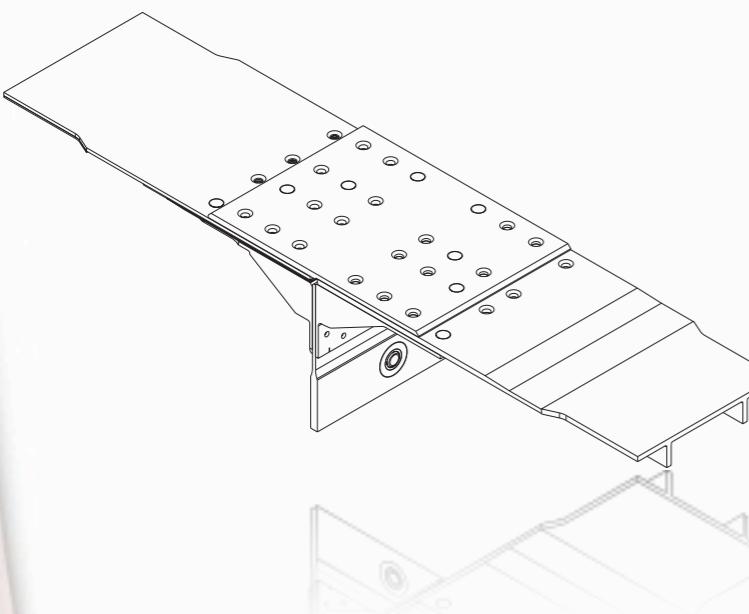
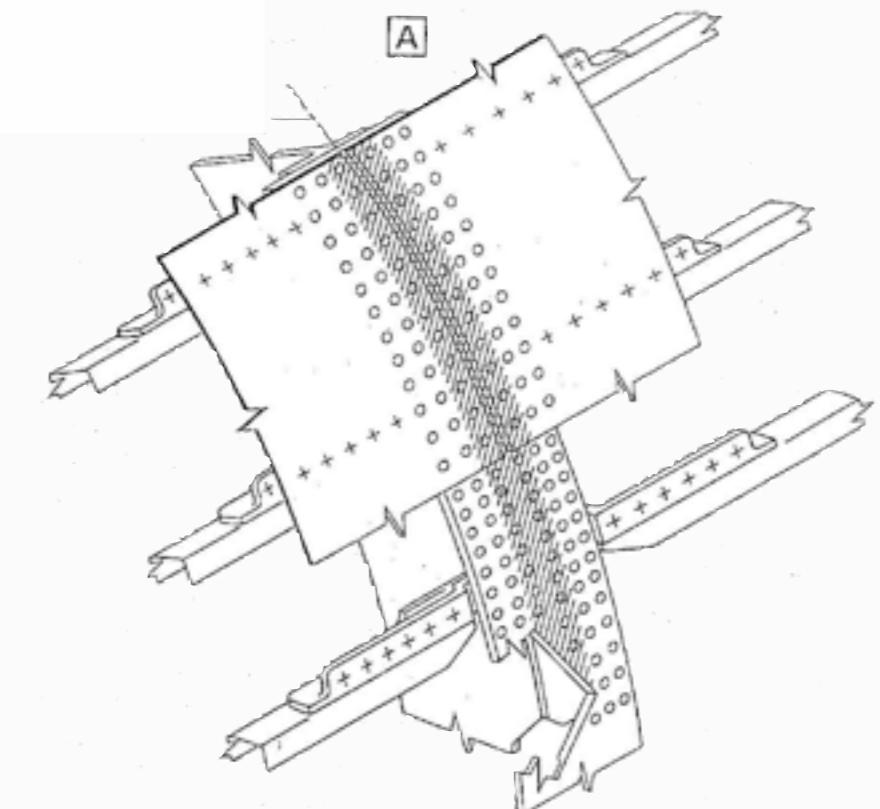
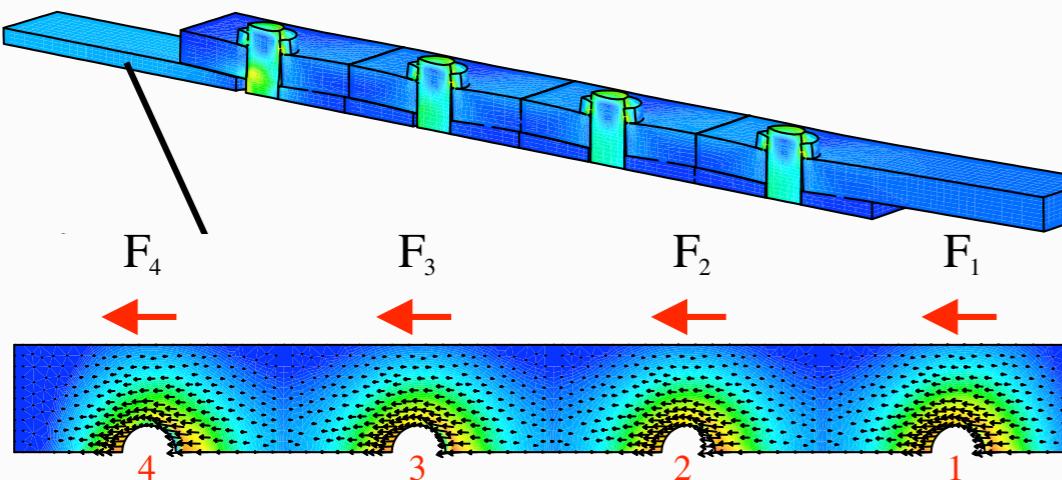
Nb of draws (conf. length 0.05)	Direct (estimation)	Parallel LHS (20 procs)	Multi-résolution (20 procs)
2517	950 days	48 days	10 days

Illustrations

[Boucard et Champaney 2003], [Champaney et al 2008],
[Roulet et al 2011]

Aeronautic Joint

Parametric study on preloads and friction coefficients

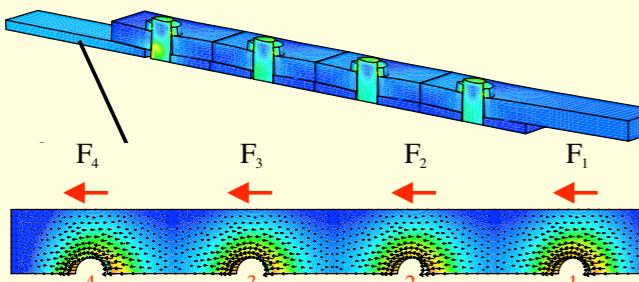


[Boucard et Champaney 2003], [Champaney et al 2008],
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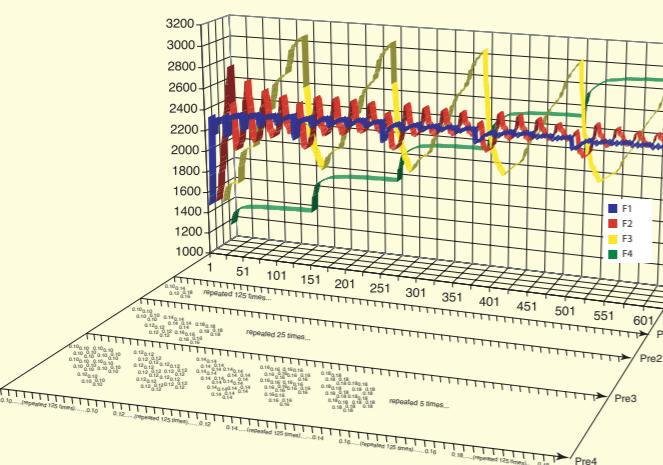
Illustrations



Problème posé



Parametric Model
(preload and μ)



Influence of
parametrer

Simulations réalisées

Model with contact/friction
90 000 dofss

Comparison with ABAQUS
(Lagrange/penalisation)

Monoproc. and parallel calculation
(cluster)

Calculation with 125 then 625
sets of parameters

[Boucard et Champaney 2003], [Champaney et al 2008],
[Roulet et al 2011]

Illustrations

Aeronautic Joint

Résultats obtenus

Résultats for 625 sets of parameters

	without multiparametric	Multiparametric			
Number of CPU	CPU time (h) (estimated)	CPU Time(h)	Ratio vs no multi.	Ratio vs ABAQUS	Speedup
1	311.8	23.1	13.5	21,7/53.2	1
4	112.3	10.1	11.1		2.3
8	67.5	5.8	11.6		4

$10^{-5} / 10^{-6}$

sliding parameter

[Boucard et Champaney 2003], [Champaney et al 2008],
[Roulet et al 2011]

Illustrations

Aeronautic Joint

Résultats obtenus

Résultats for 625 sets of parameters



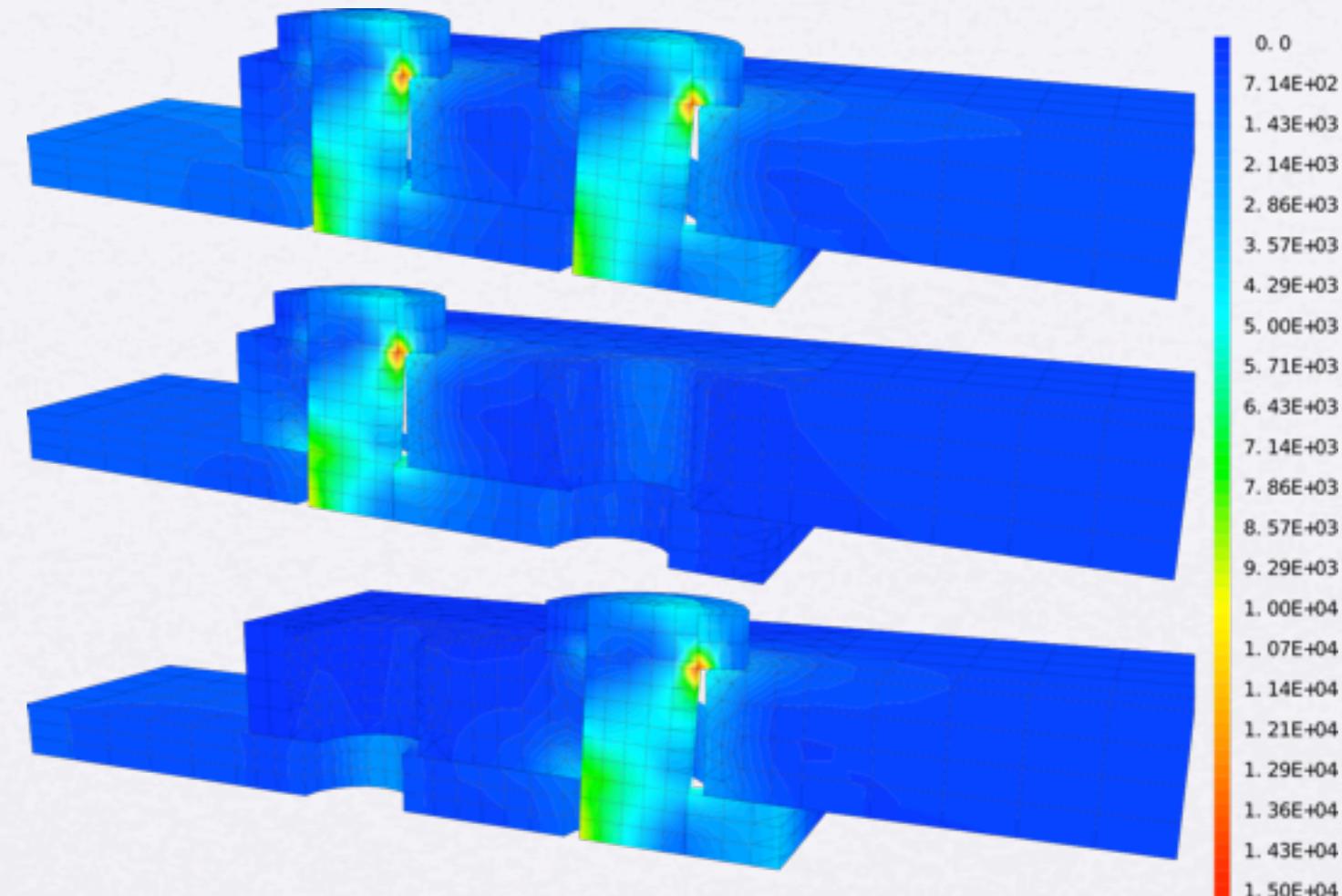
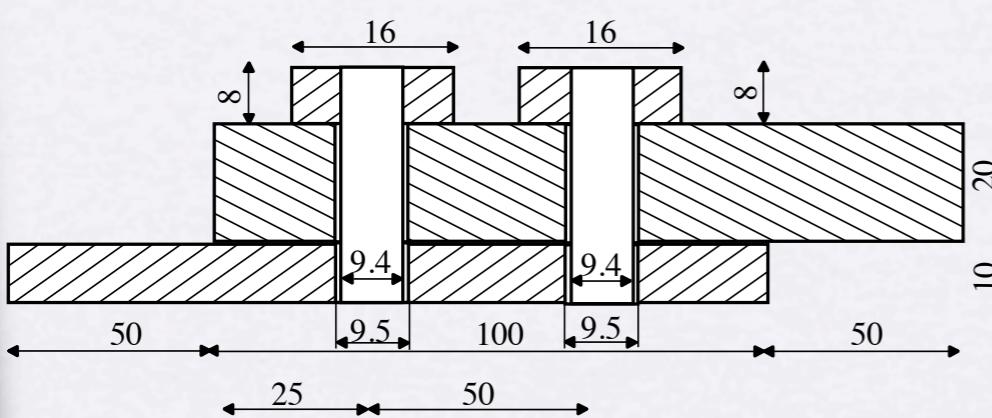
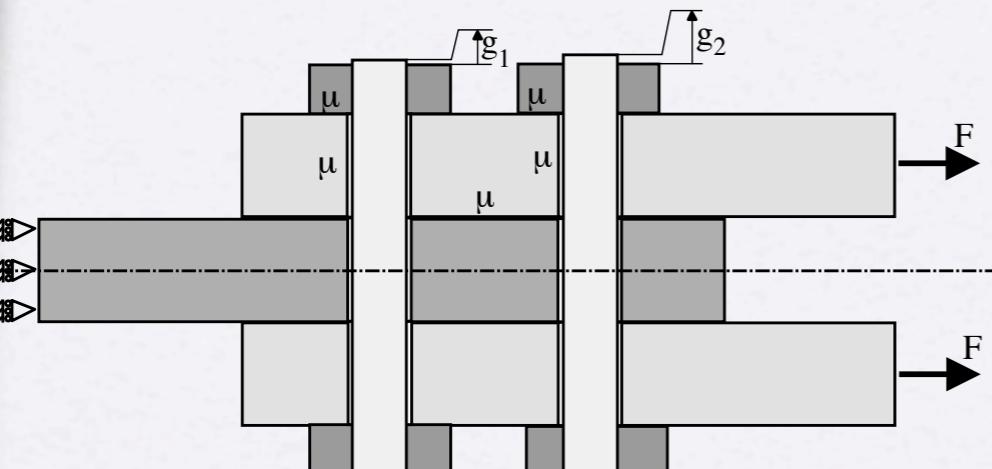
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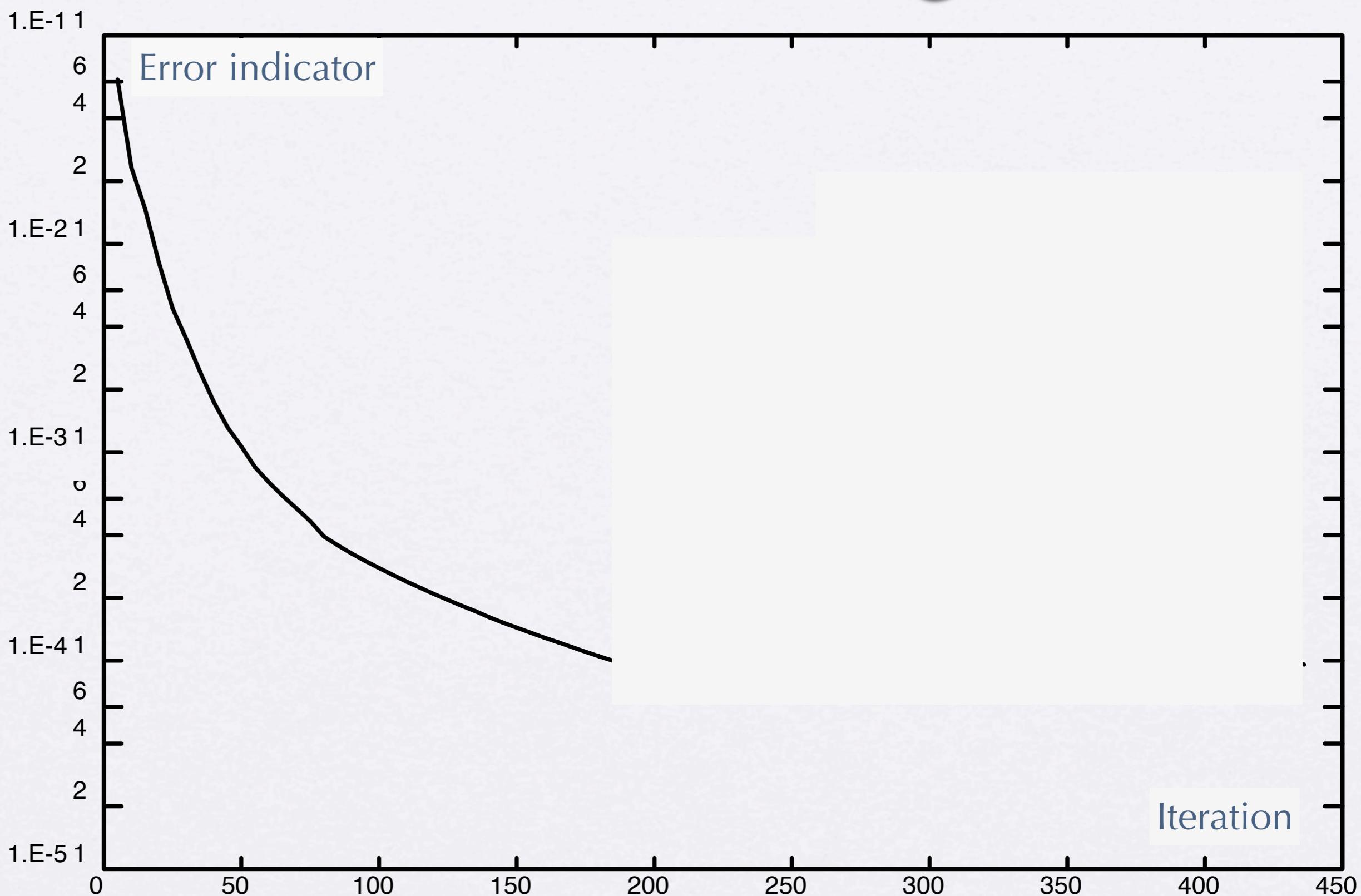
sliding parameter

Missing fasteners

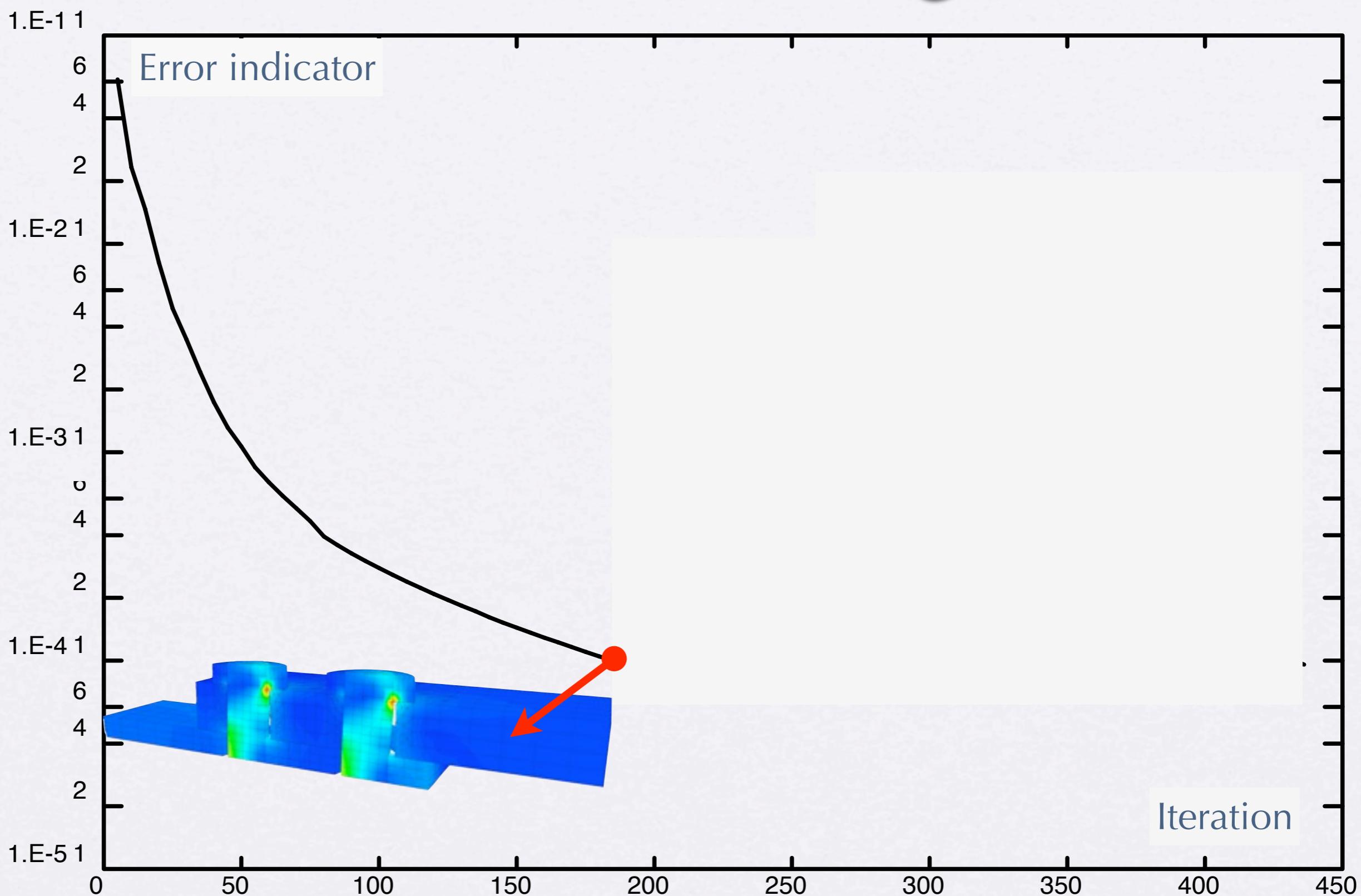
[Champaney 2011]



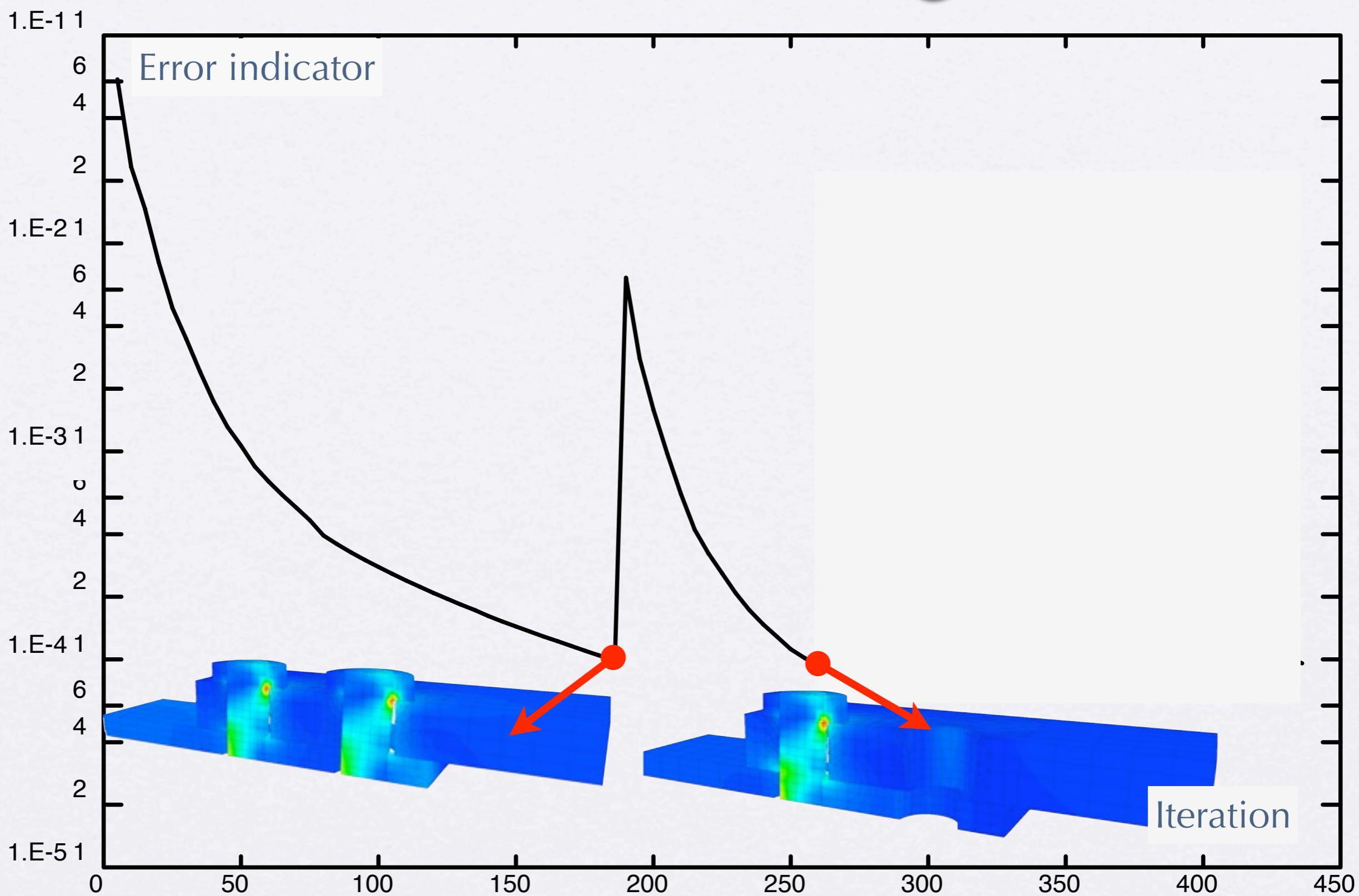
Missing fasteners



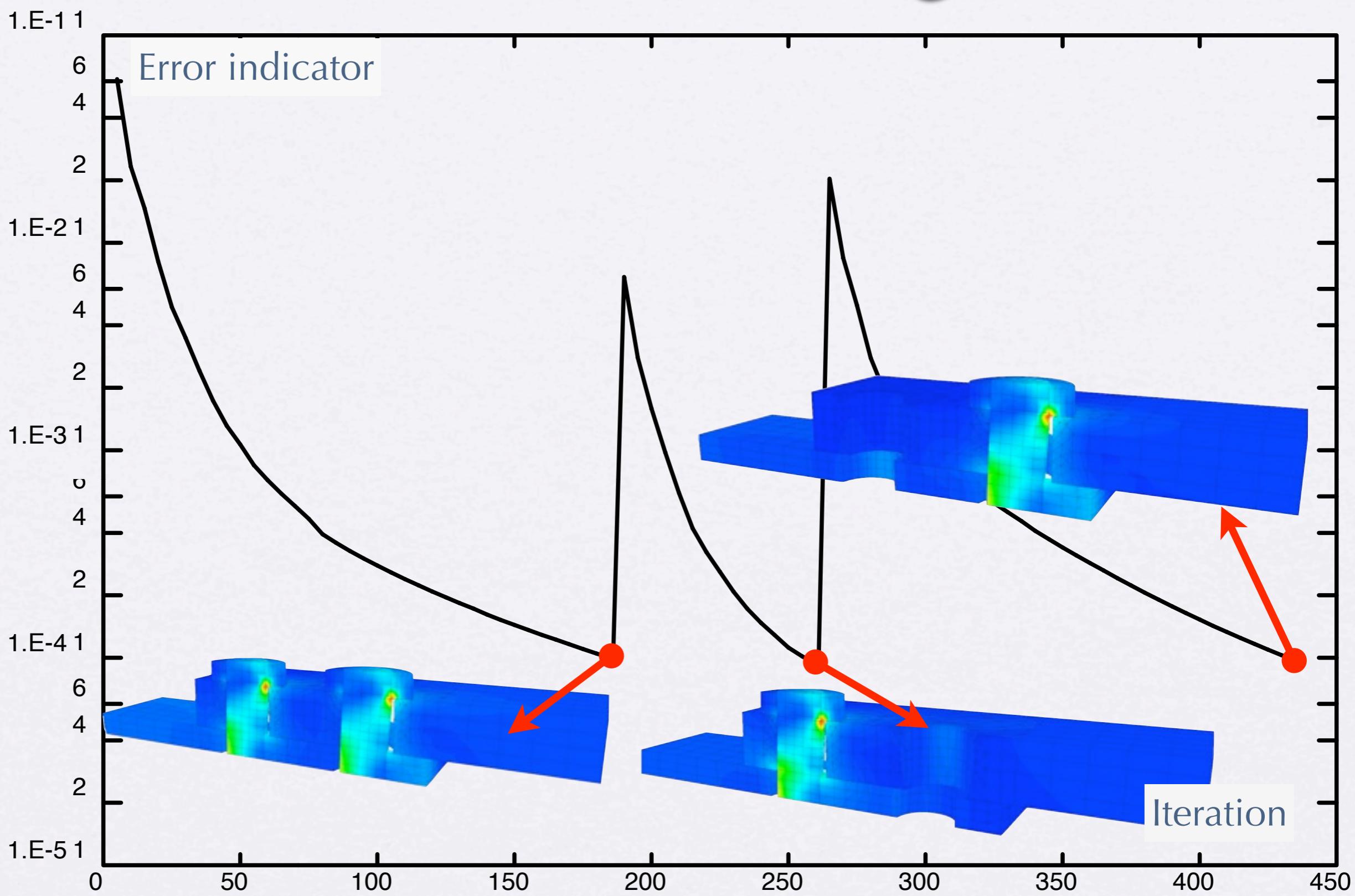
Missing fasteners



Missing fasteners



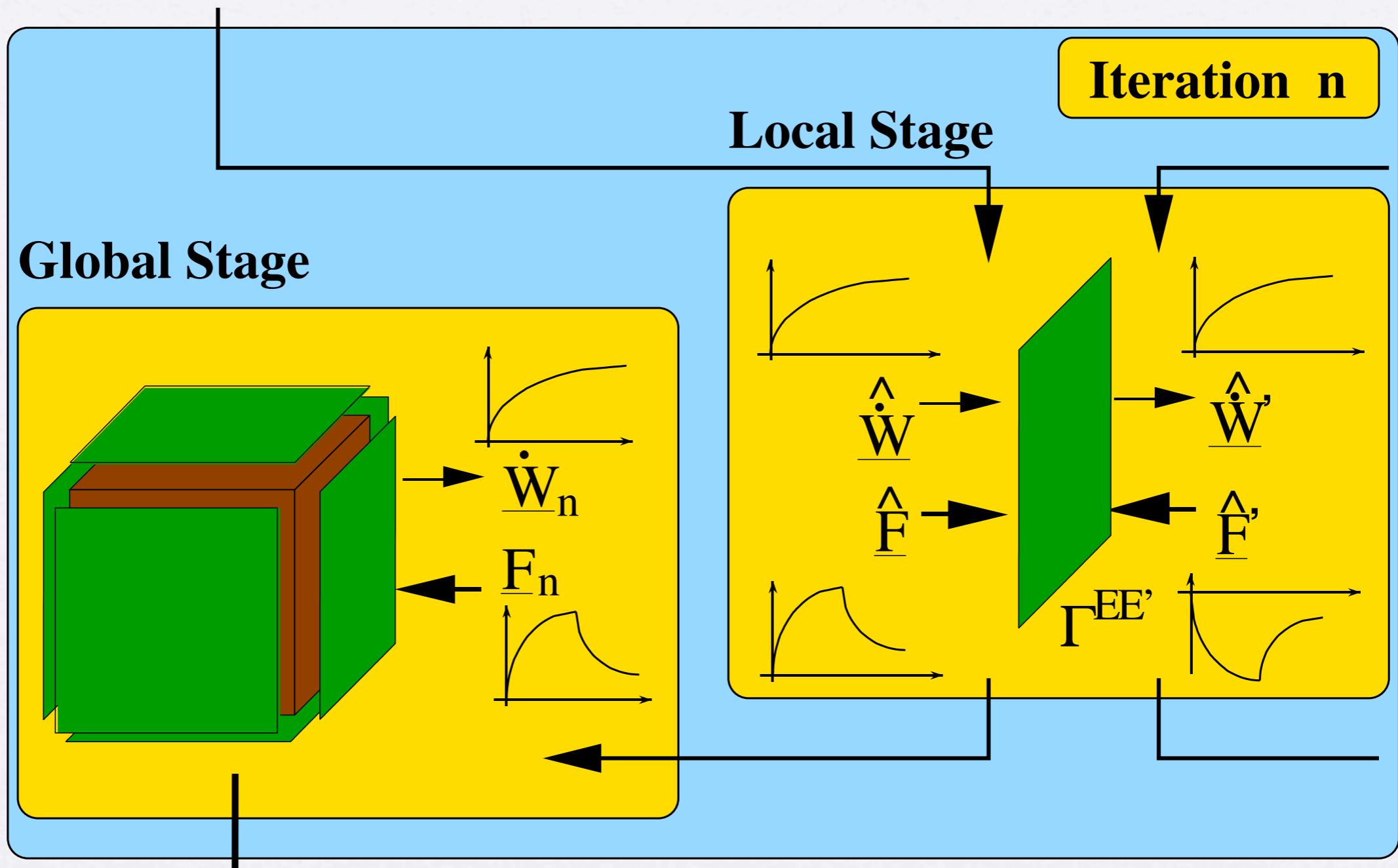
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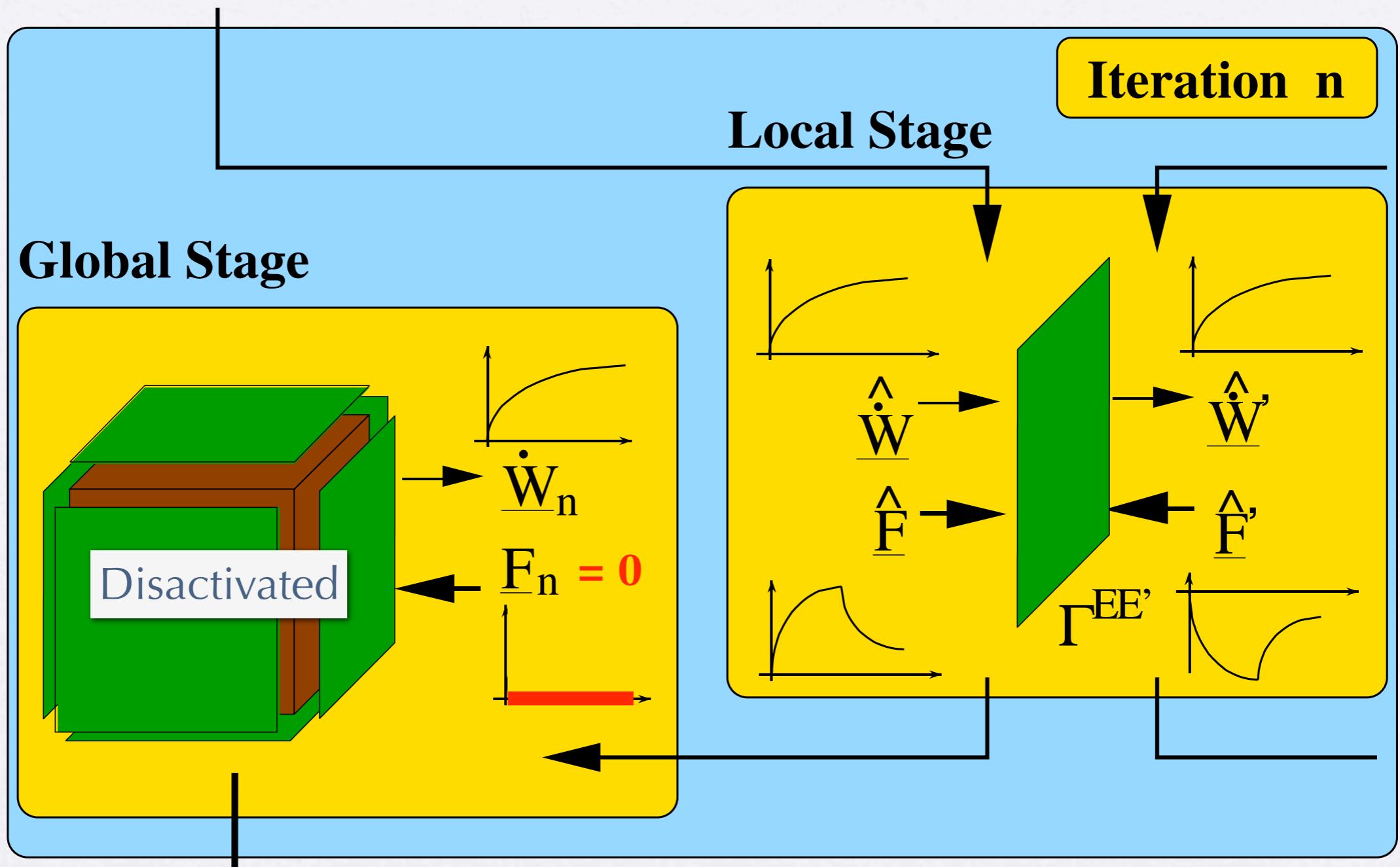
Disactivation of substructures



Disactivation of substructures

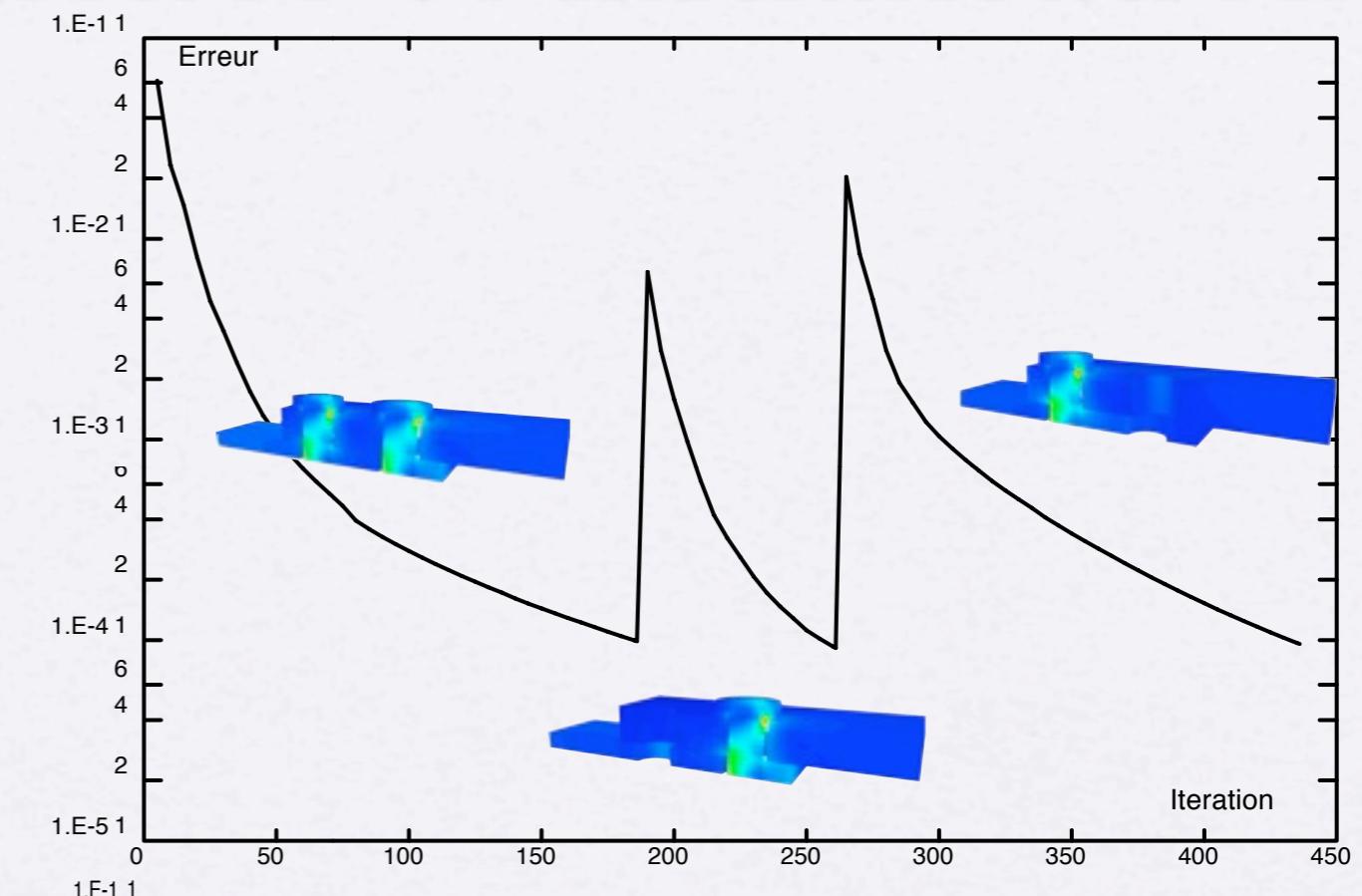


Disactivation of substructures



Influence of initialisation

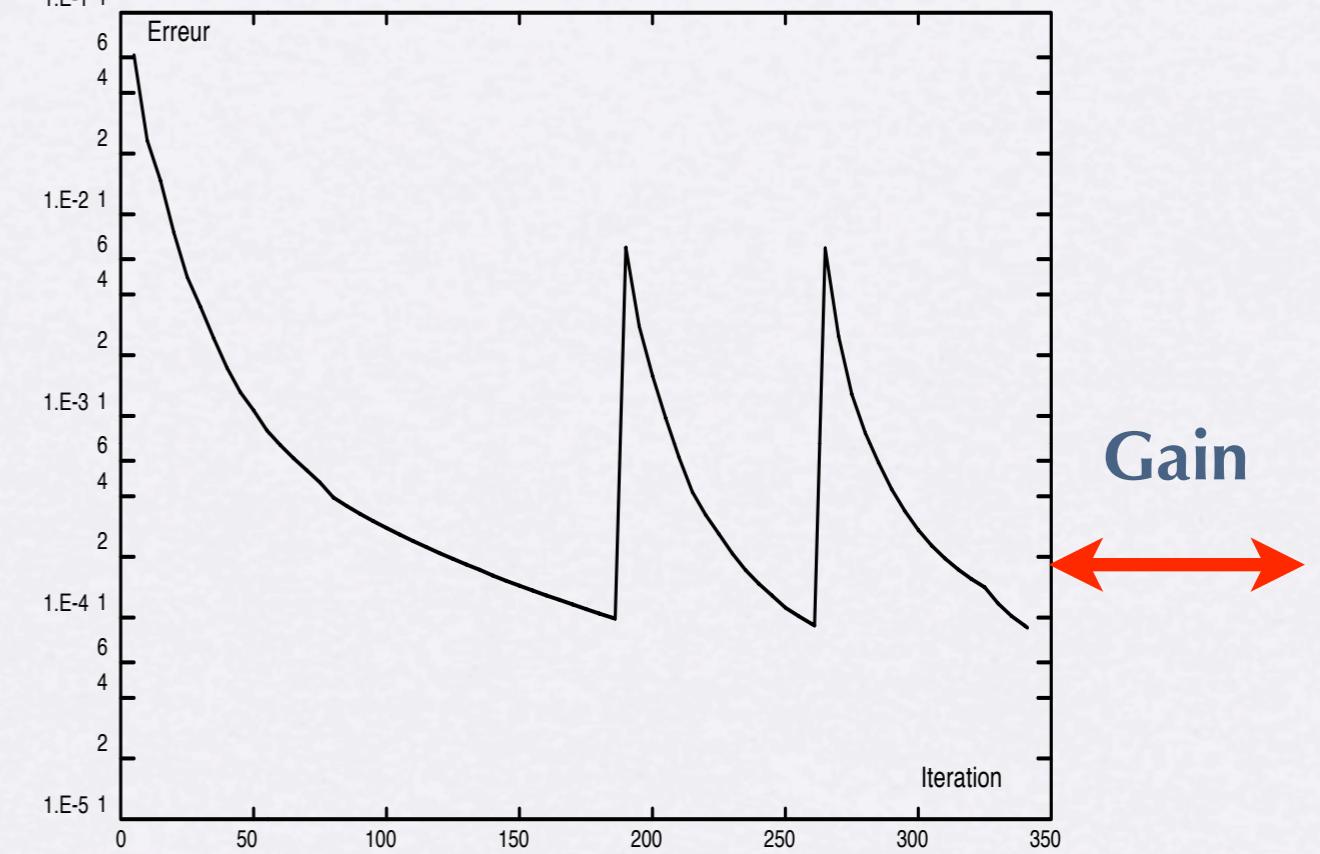
Initialisation from the solution
of the **previous computation**



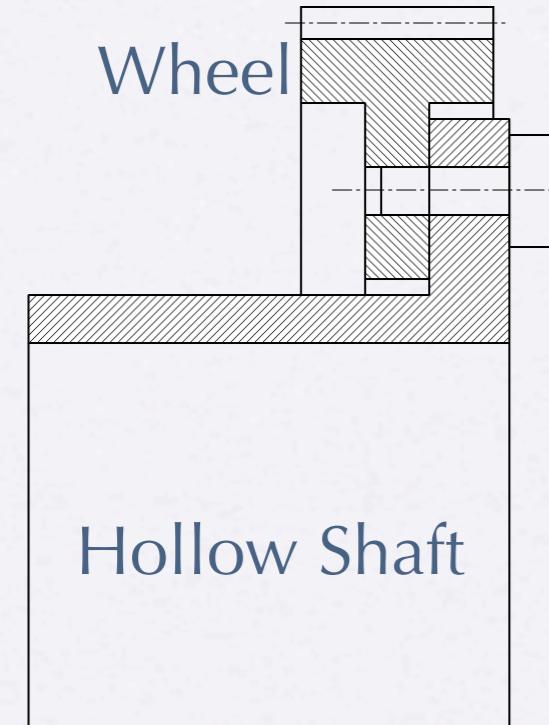
Initialisation from the solution
of the **first computation**

Solution saving :
Small amount of data !
only Forces and Velocities
on the interface

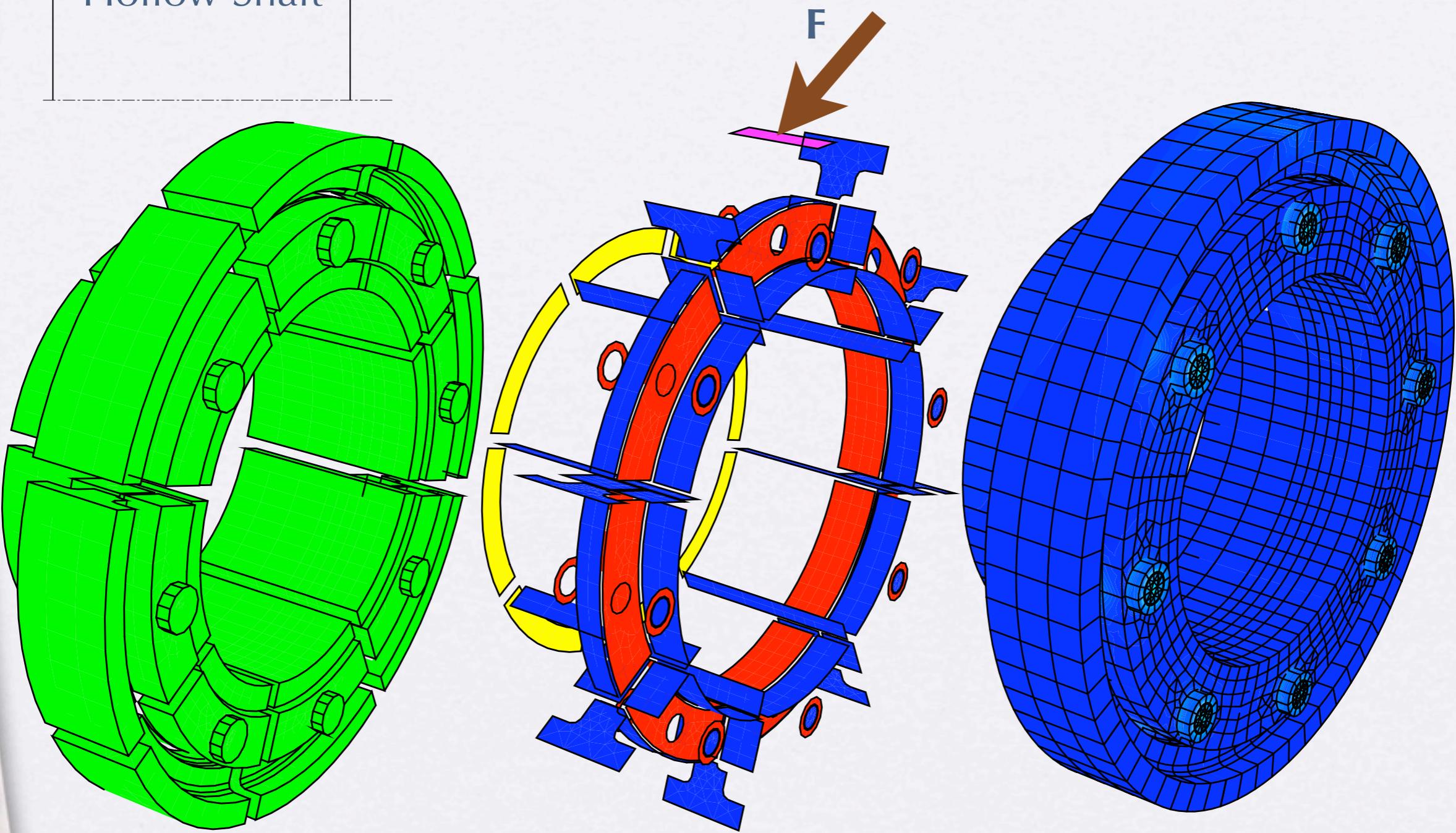
Also used for other works
[Soulier, Boucard, 09]



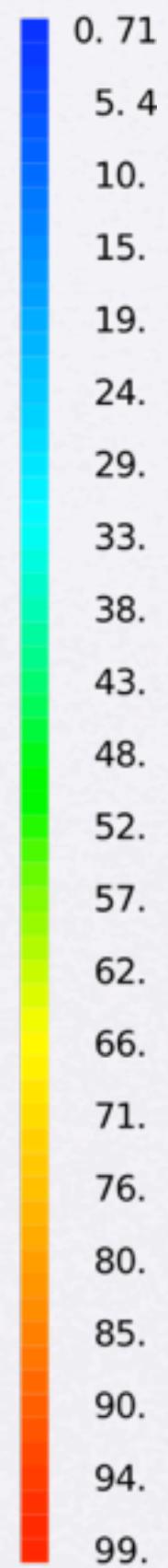
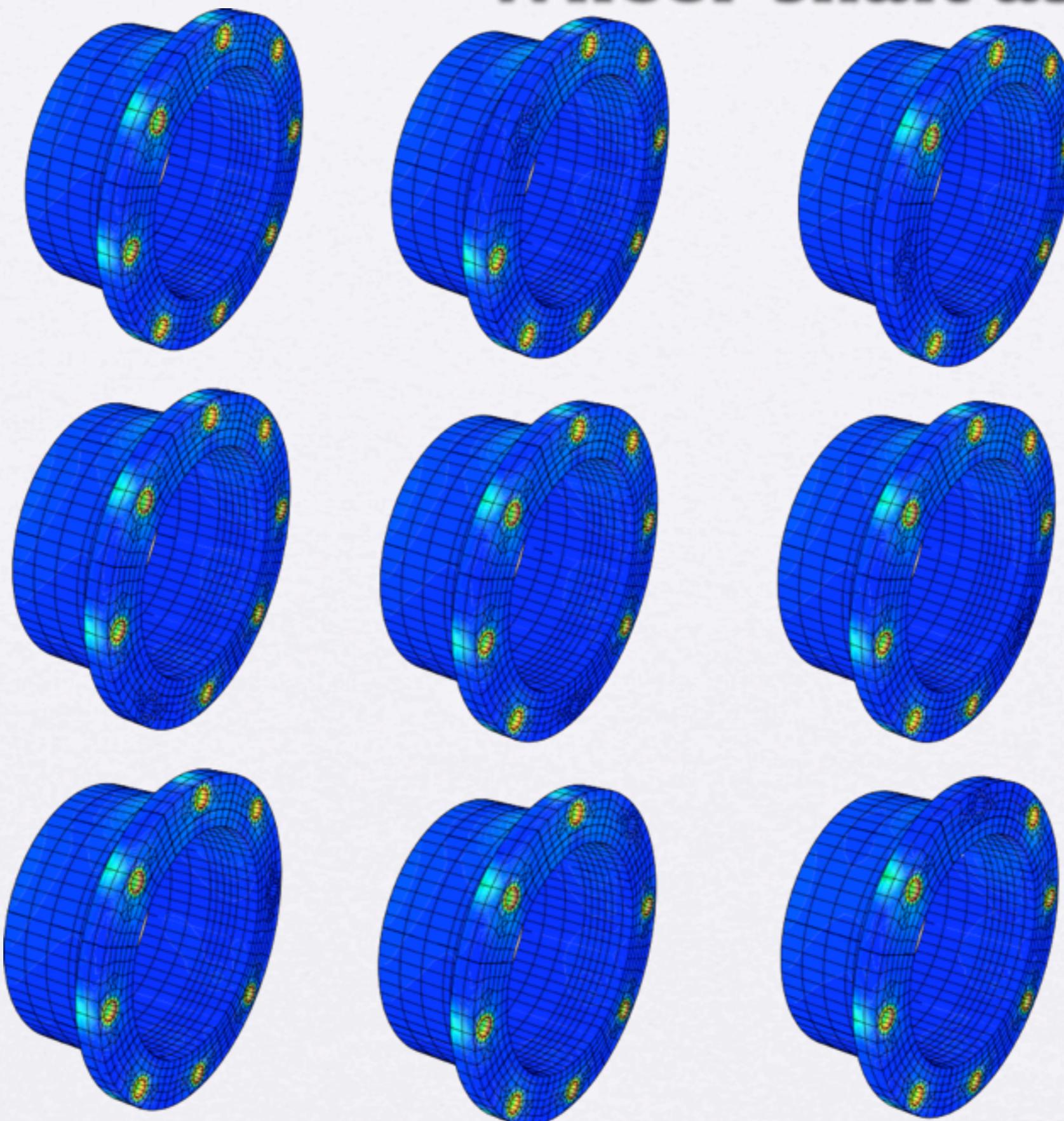
Wheel-shaft assembly



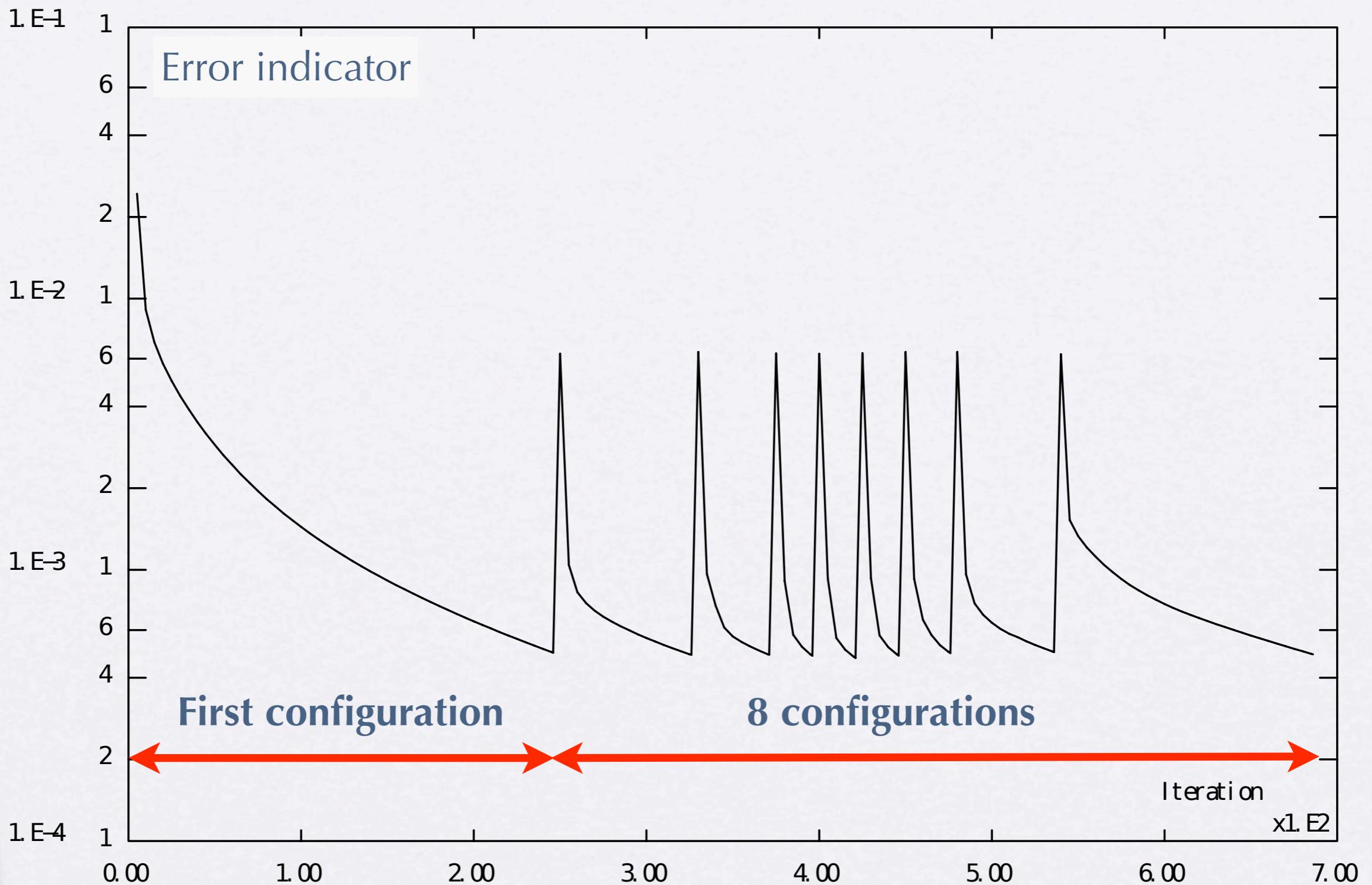
- 48 substructures
- 97 interfaces
- 43000 dof



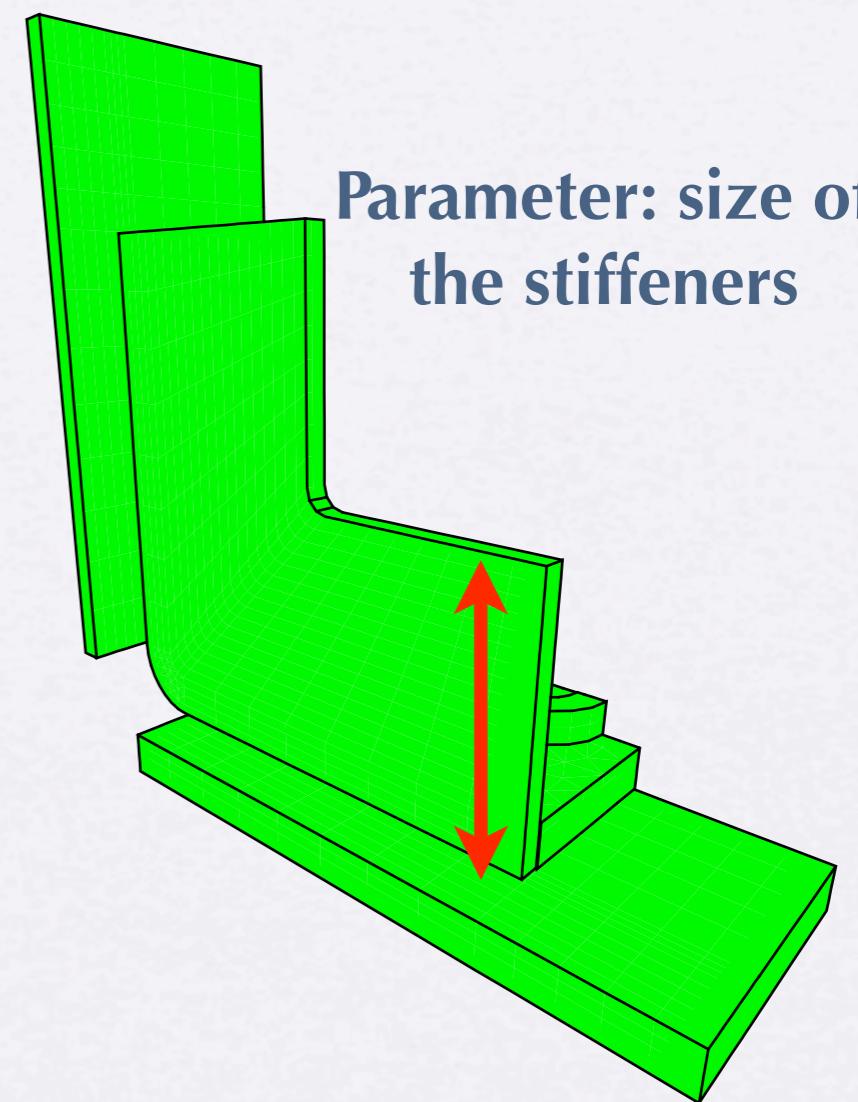
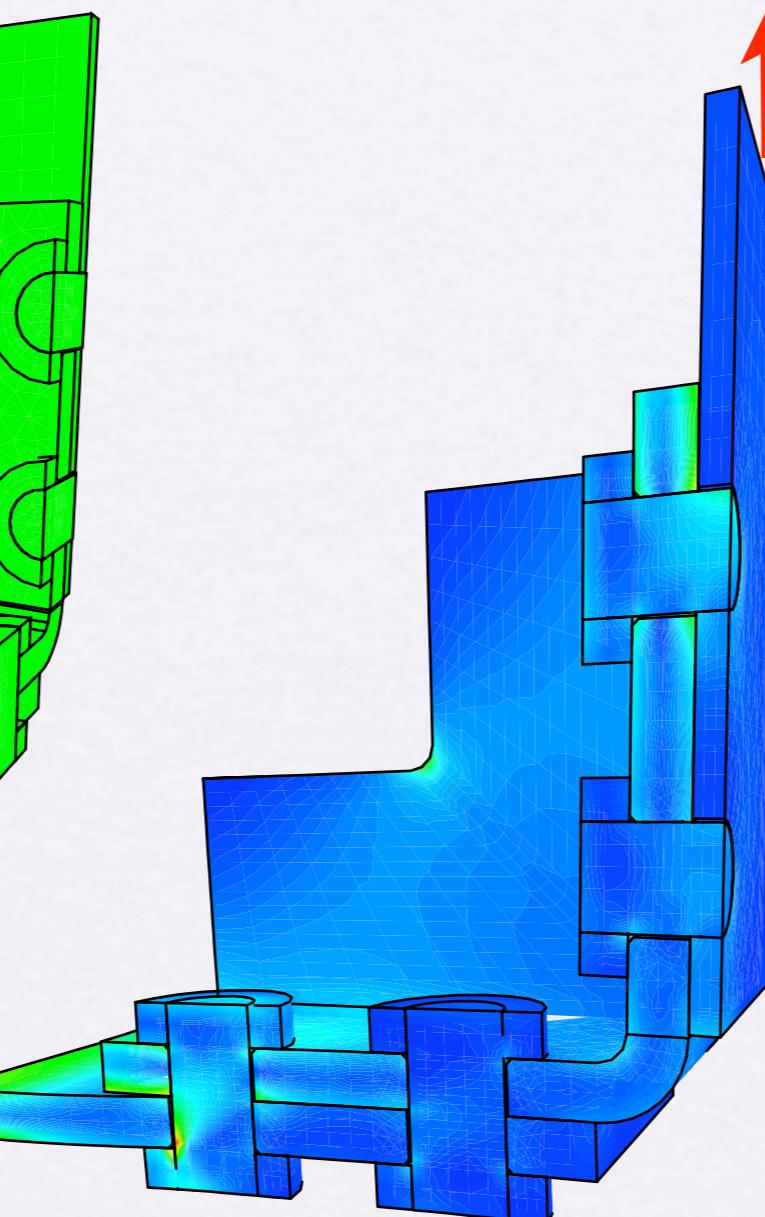
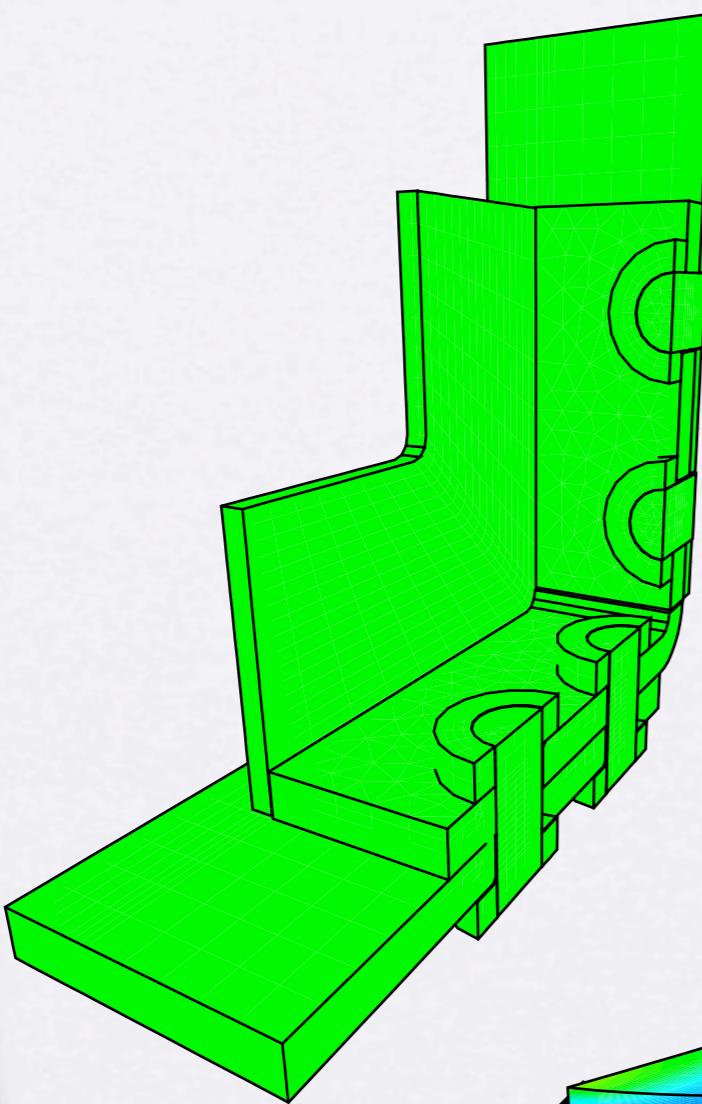
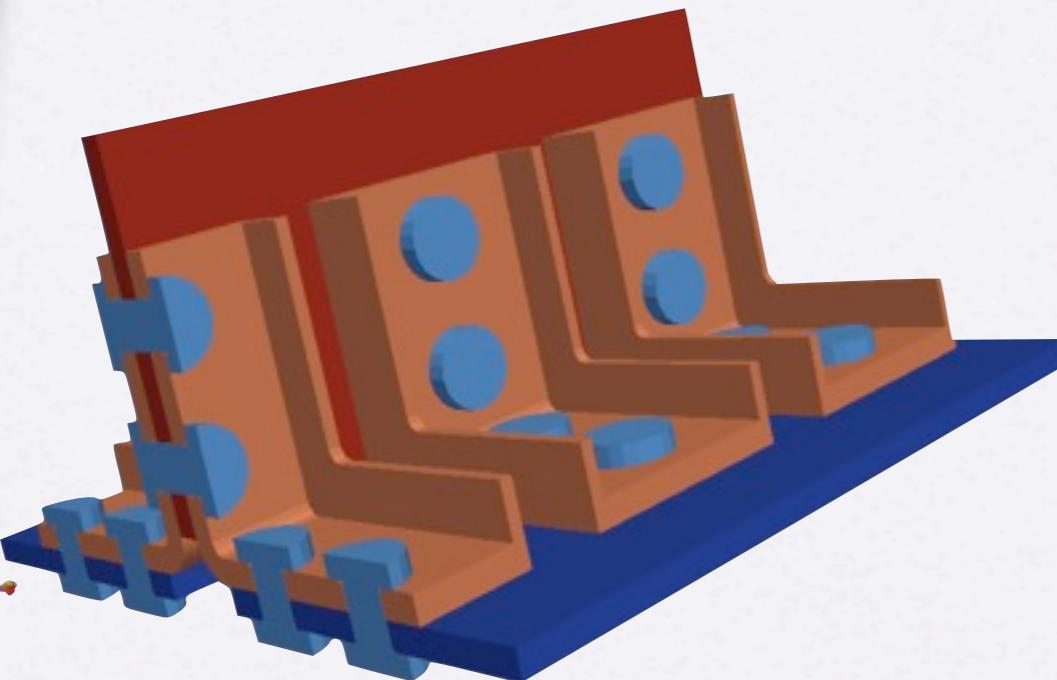
Wheel-shaft assembly



Wheel-shaft assembly



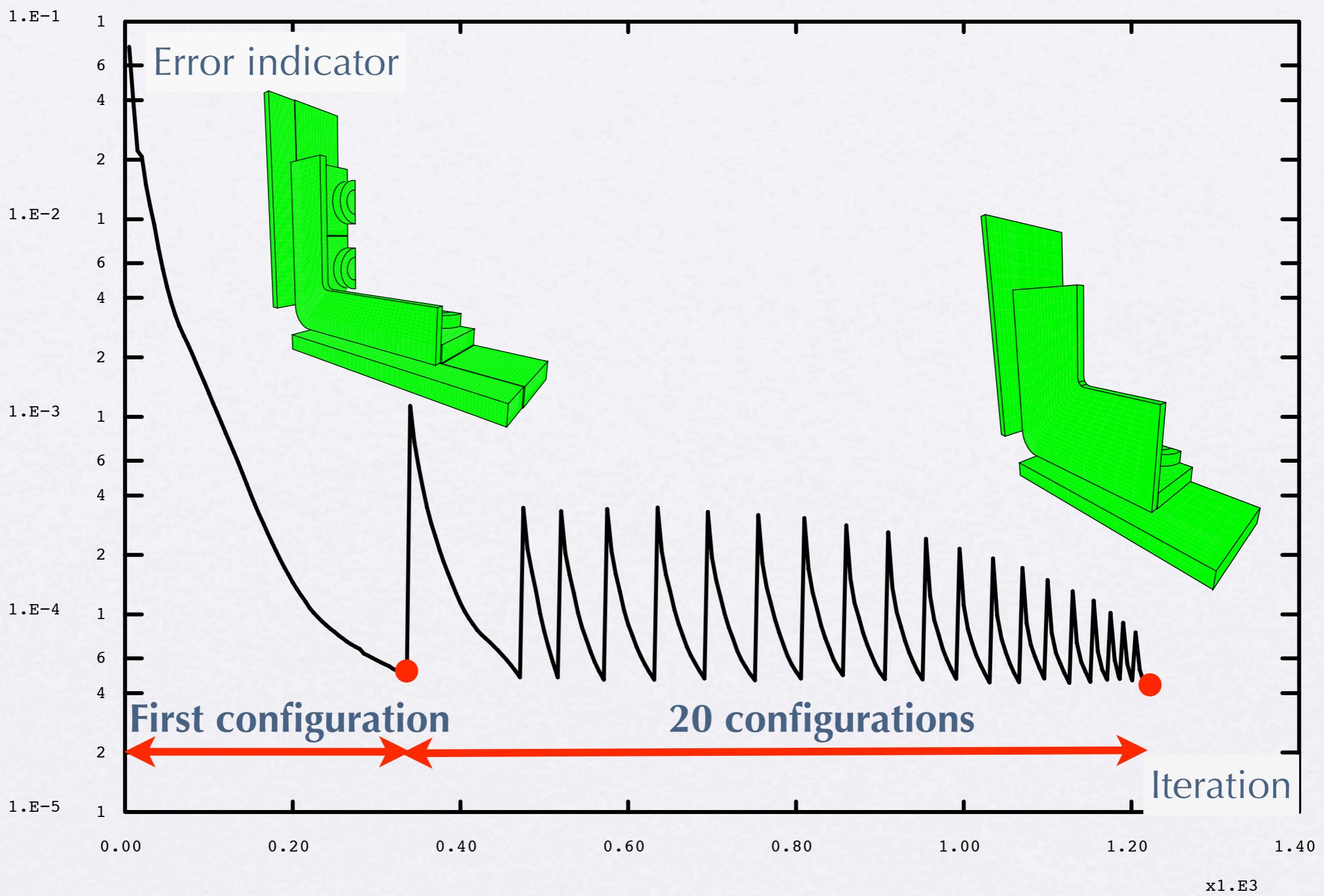
Changing geometry



79,645 elements
221,469 dof

Parameter: size of
the stiffeners

Changing geometry



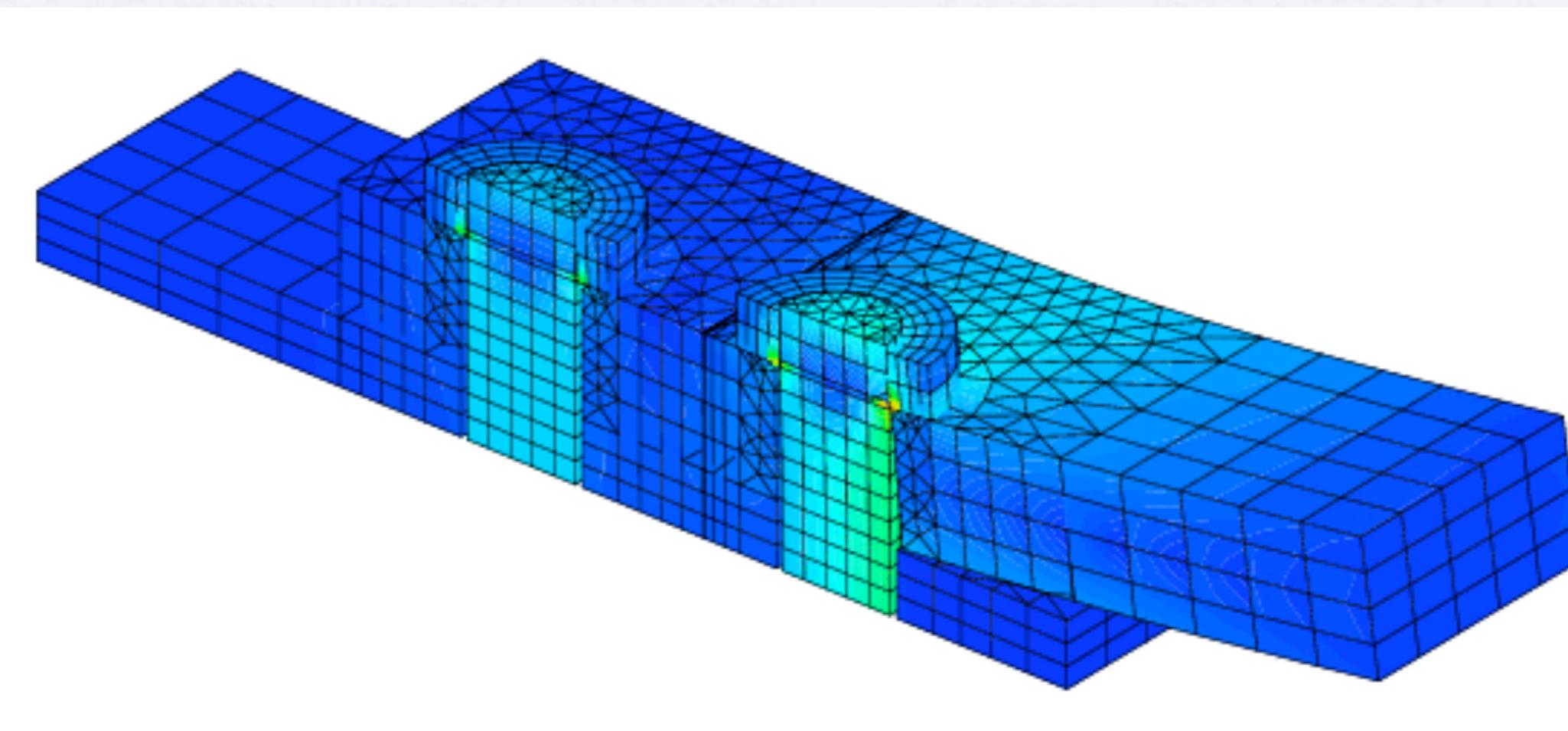
Changing geometry

Position of the connector?



Changing geometry

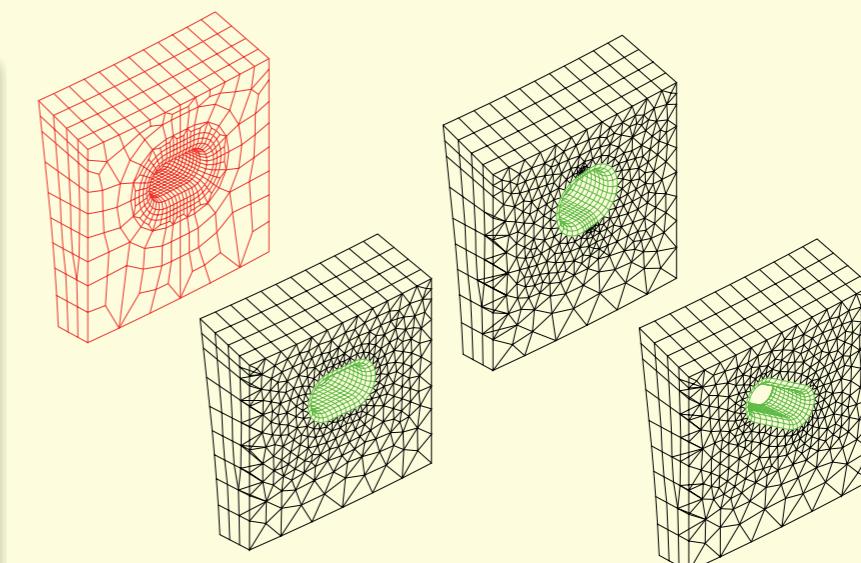
Position of the connector?



Changing geometry

- Study the severity of the hole below the flange of DAM1 (Disque Aubagé Monobloc) on Sam146 motor

Problème posé



Variation of the size,
and location of the hole

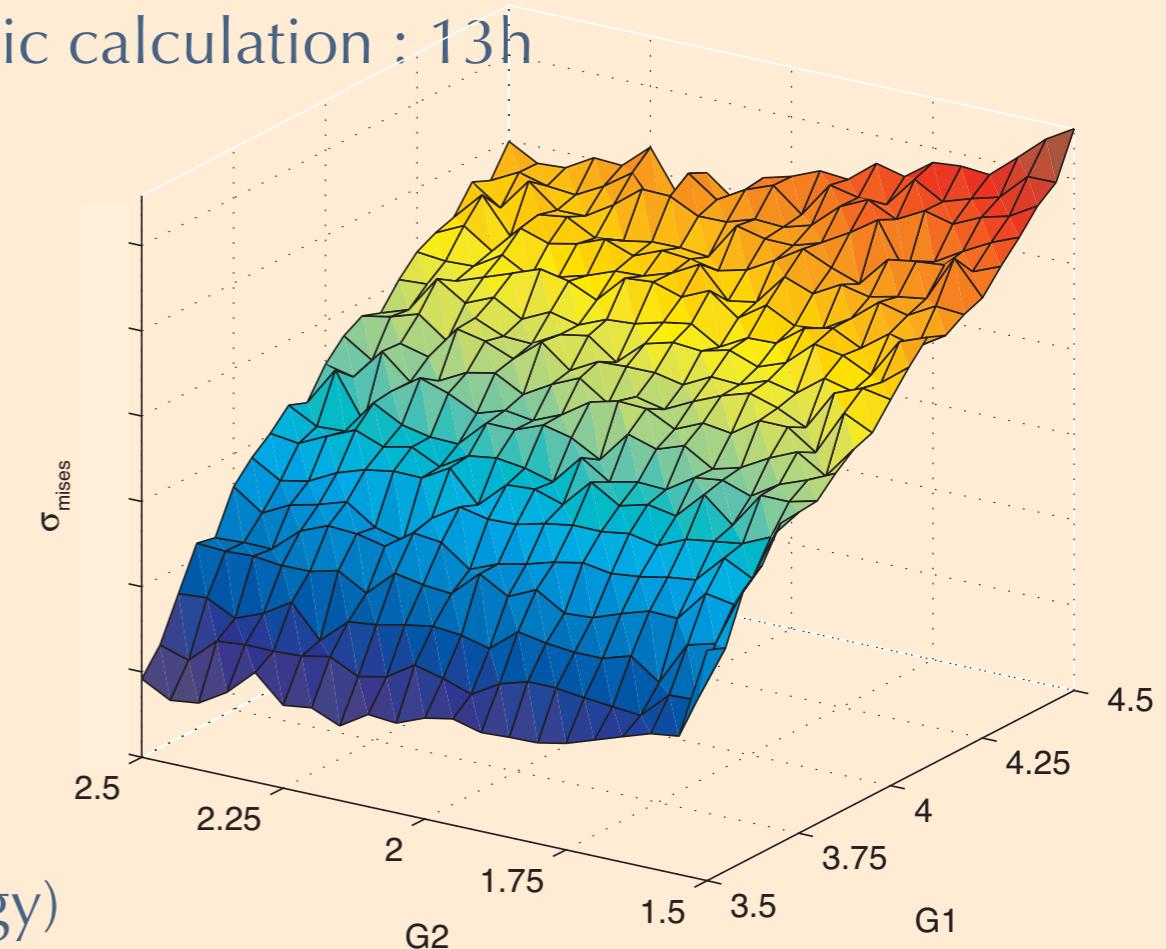
Résultats obtenus

Results

- Variation of the size of the hole (441 realisations)
- Gain in computational time : ~50
1 calculation = 1h30, 441 multiparametric calculation : 13h
(to be compared to 29 days otherwise)

Complete study

- Shape of the hole, preloads, revolving speed, forces, Young modulus, Masses
- More than 2500 calculations
- 4 days of calculation (to be compared to 4 months with no multiparametric strategy)



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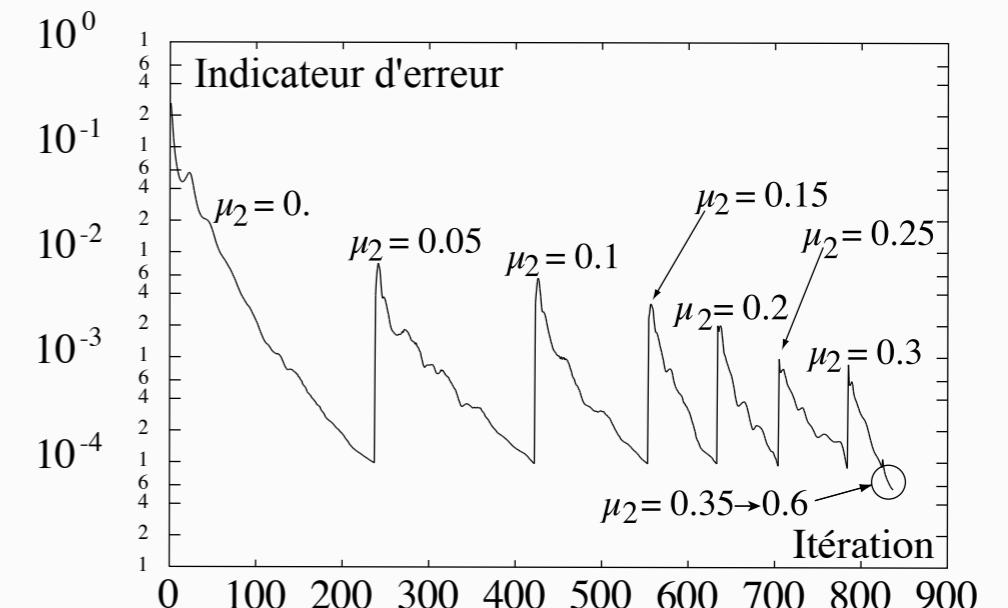
5. Conclusions

Conclusions: : Multiparametric Strategies



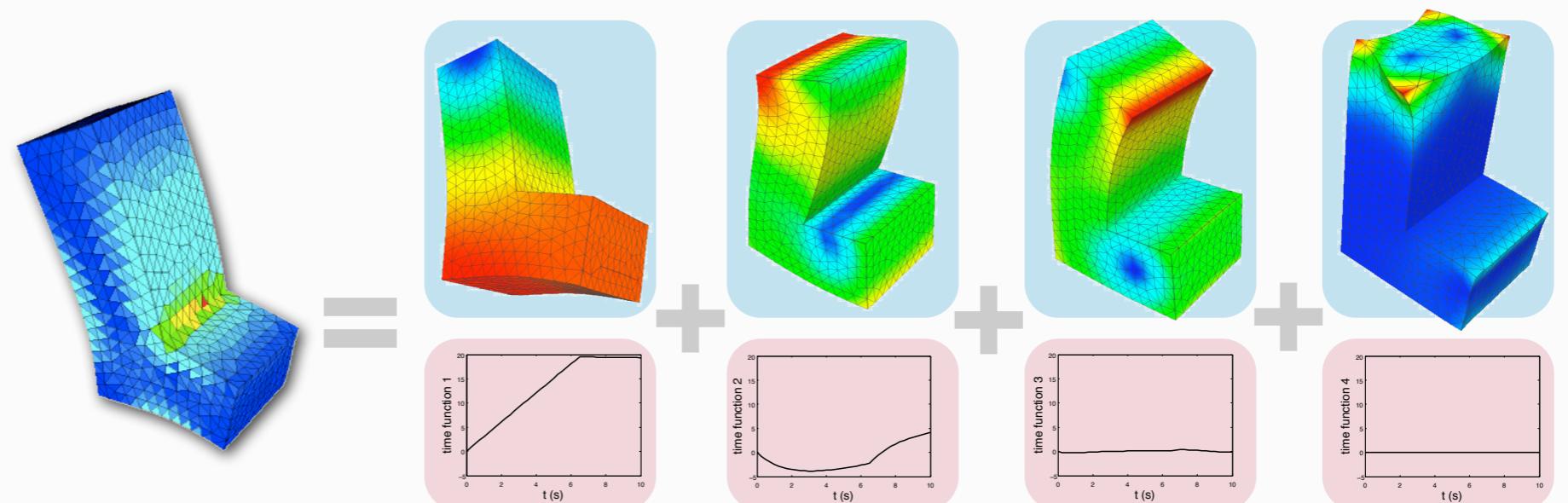
Elastic linear Behavior

- Constant operators!
- Inner solutions depends only of interface solutions
- Re-use interface solutions** when parameters change.

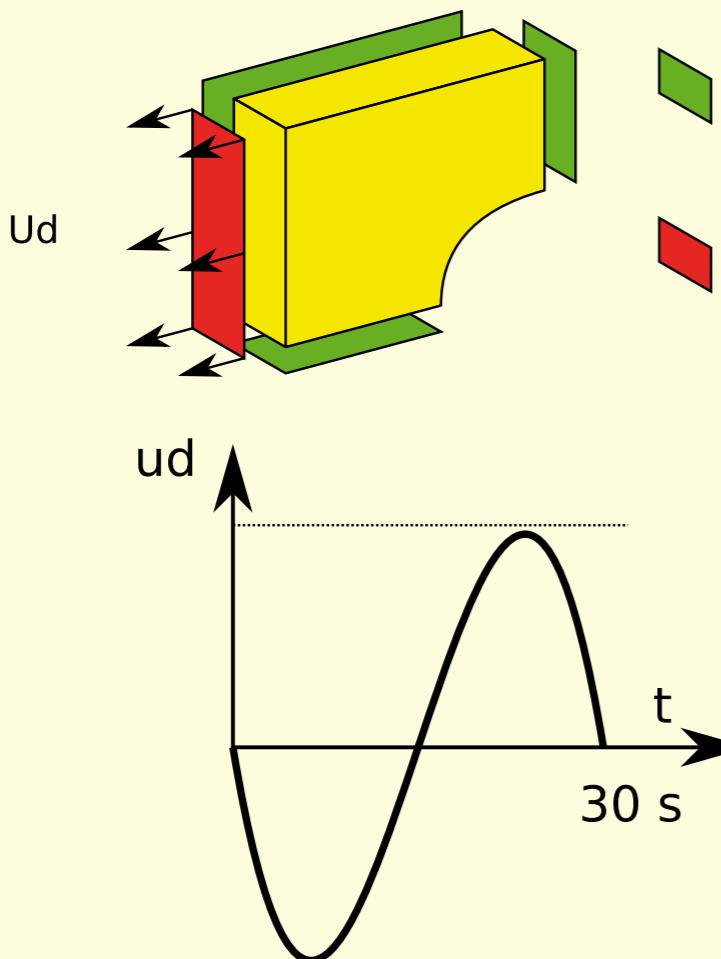


Non-Linear Behavior: PGD

- Construction of solution basis during the first calculation
- Re-use the basis** (partially or completely) when parameters change.



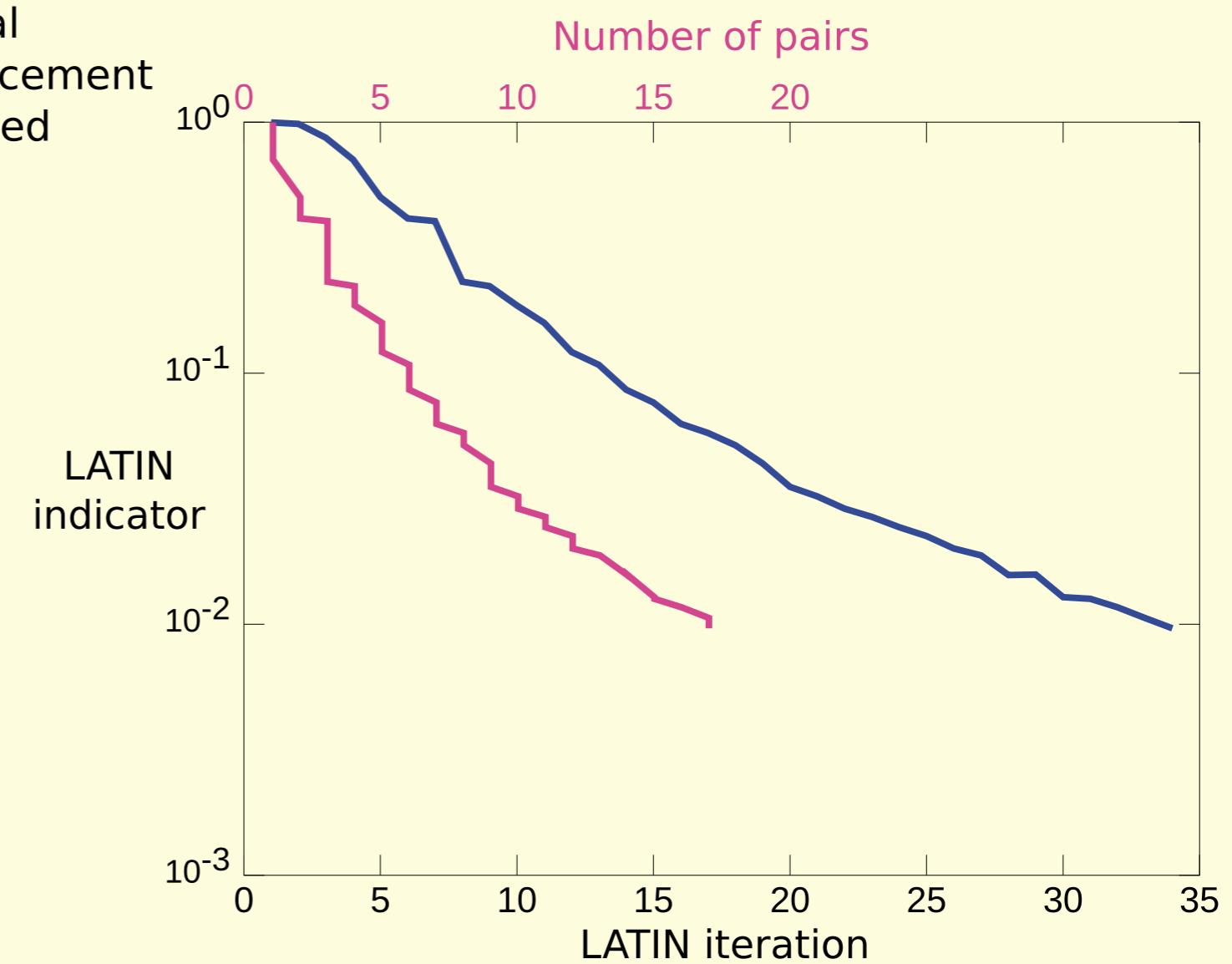
Example : perforated plate



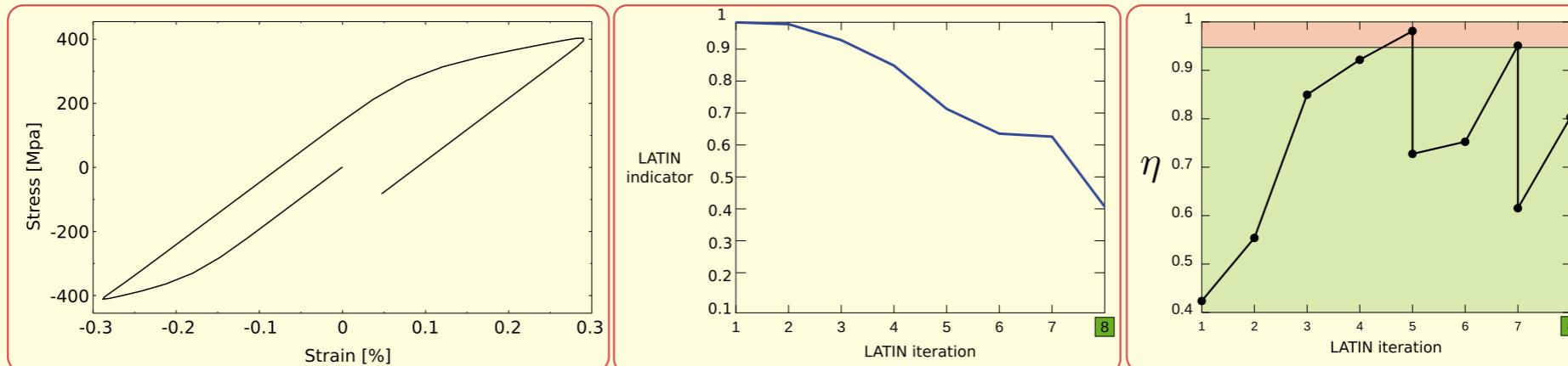
symmetry
condition

normal
displacement
imposed

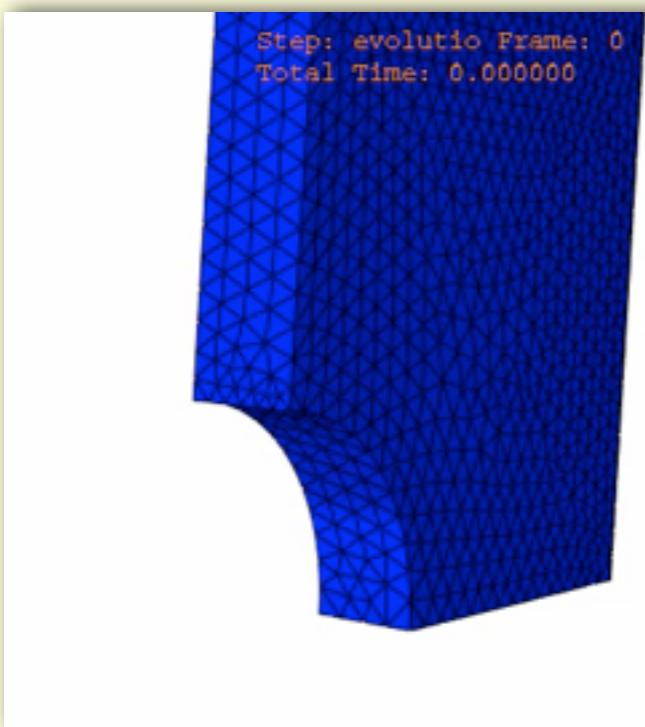
36954 dofs
40 time steps
visco-plastic behavior
(Chaboche)



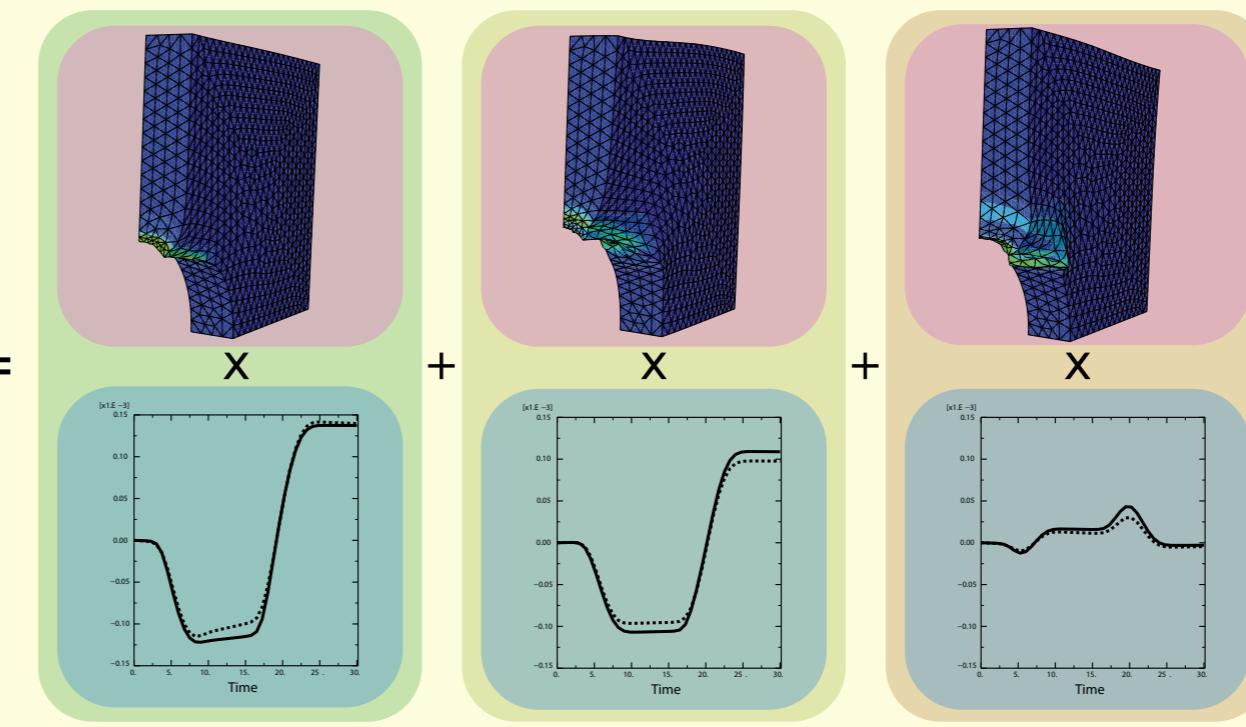
Example : perforated plate



Space functions



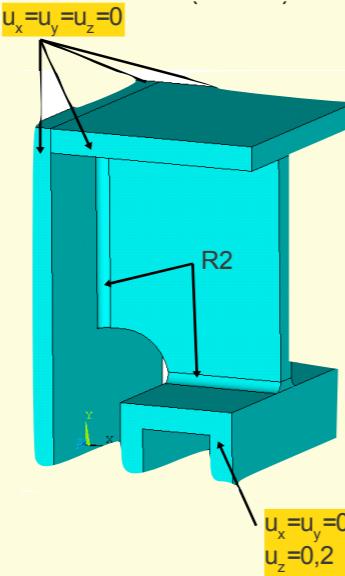
=



Time functions

WITH PGD

Problème



- Viscoplastique behavior (Chaboche)
- 141753 dofs, 60 steps
- 17 pairs of time/space functions

Illustrations

[Relun et al 2011]

ANR APPRoFi



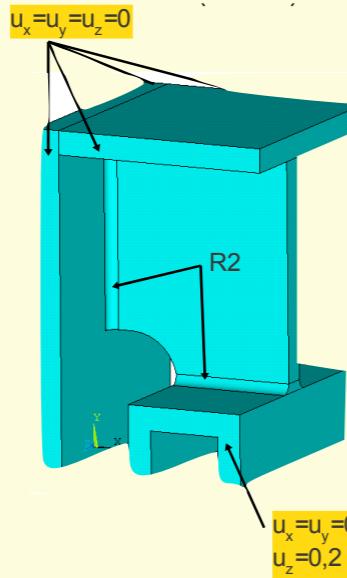
LATIN

Comparison

ABAQUS

WITH PGD

Problème

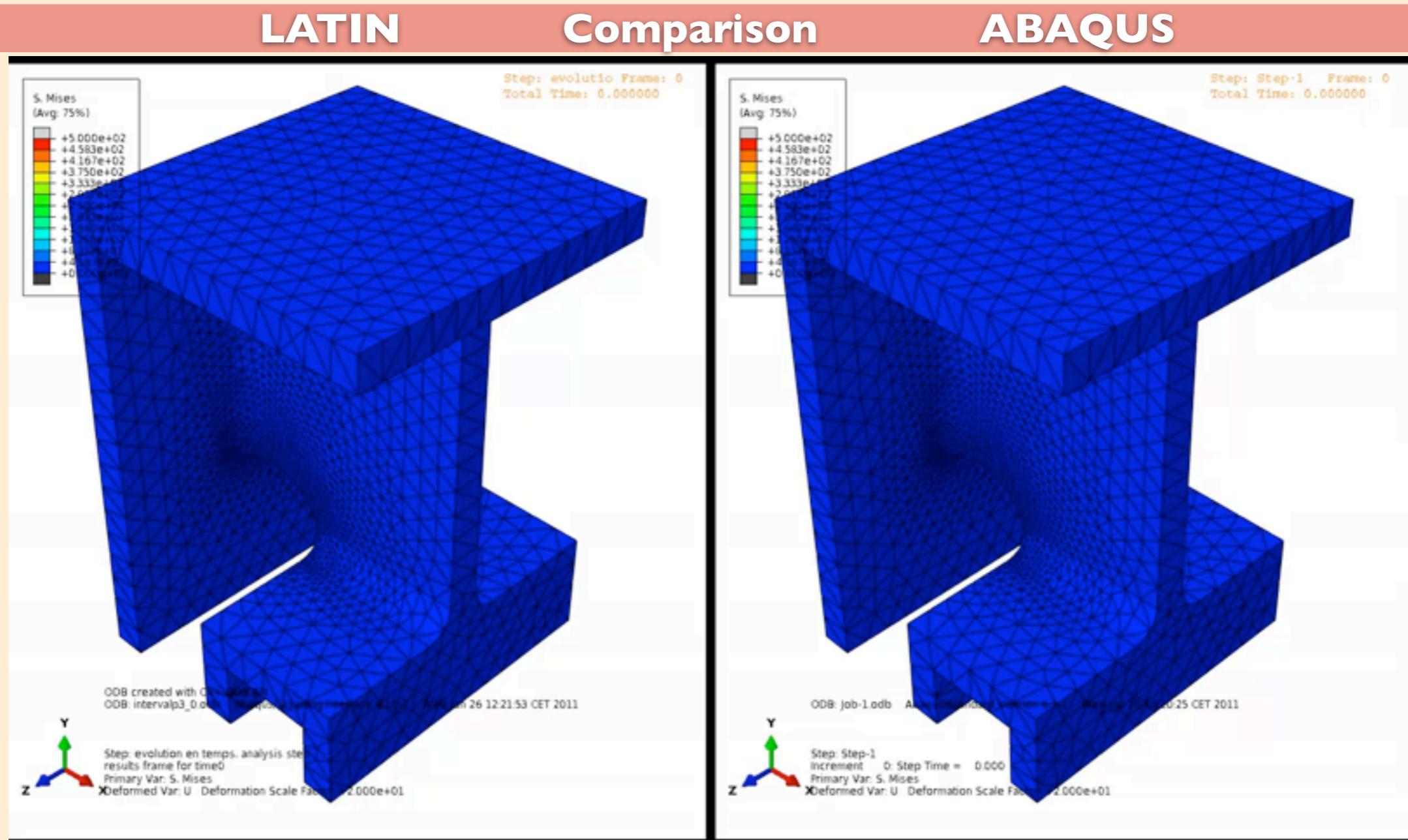


- Viscoplastique behavior (Chaboche)
- 141753 dofs, 60 steps
- 17 pairs of time/space functions

Illustrations

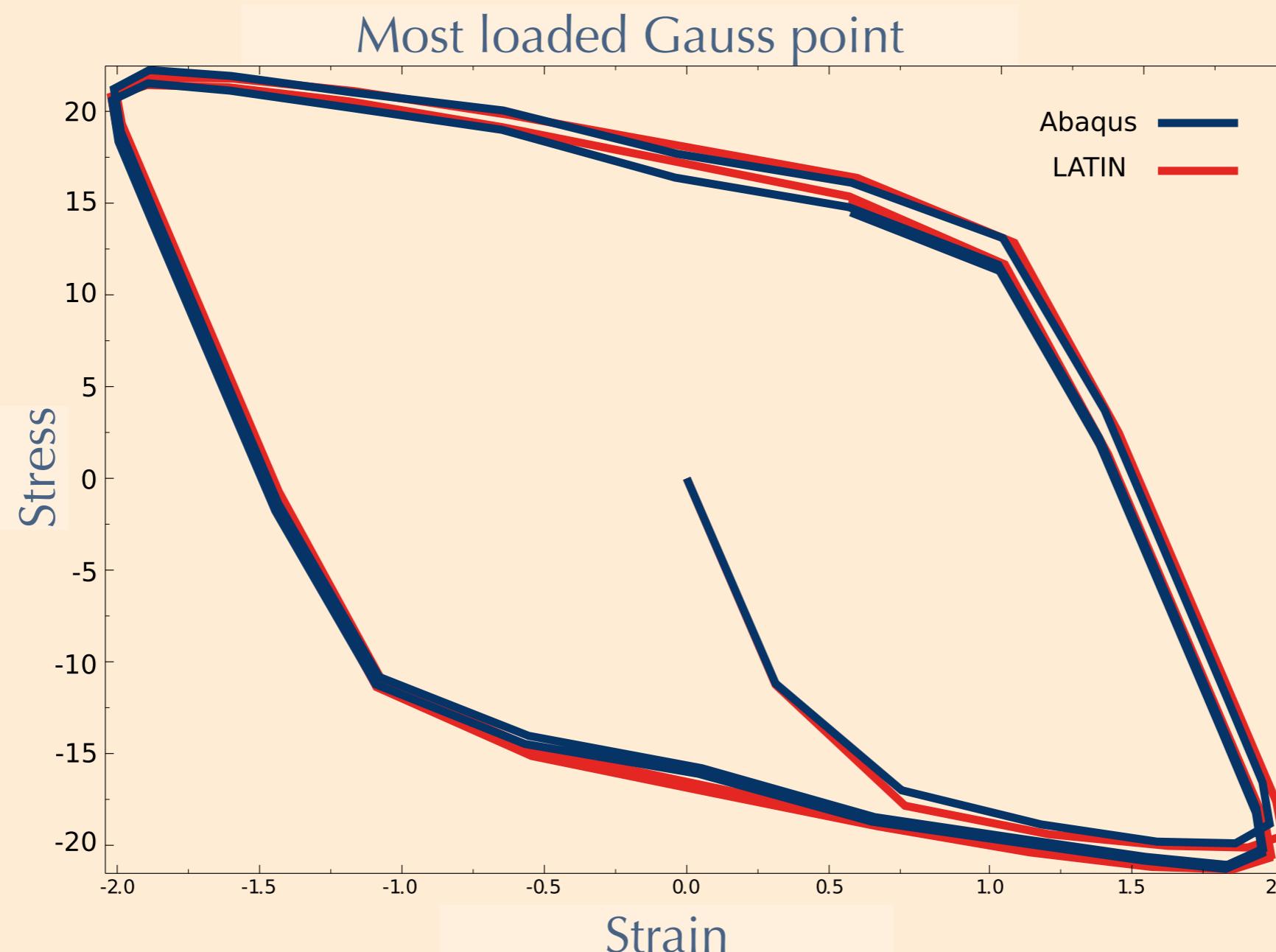
[Relun et al 2011]

ANR APPRoFi



Results

Comparison with ABAQUS



Cas test Vernon (DMS)

Results



One calculation

- ABAQUS ~ 2200 sec (ZMAT)

- LATIN ~ 1600 sec

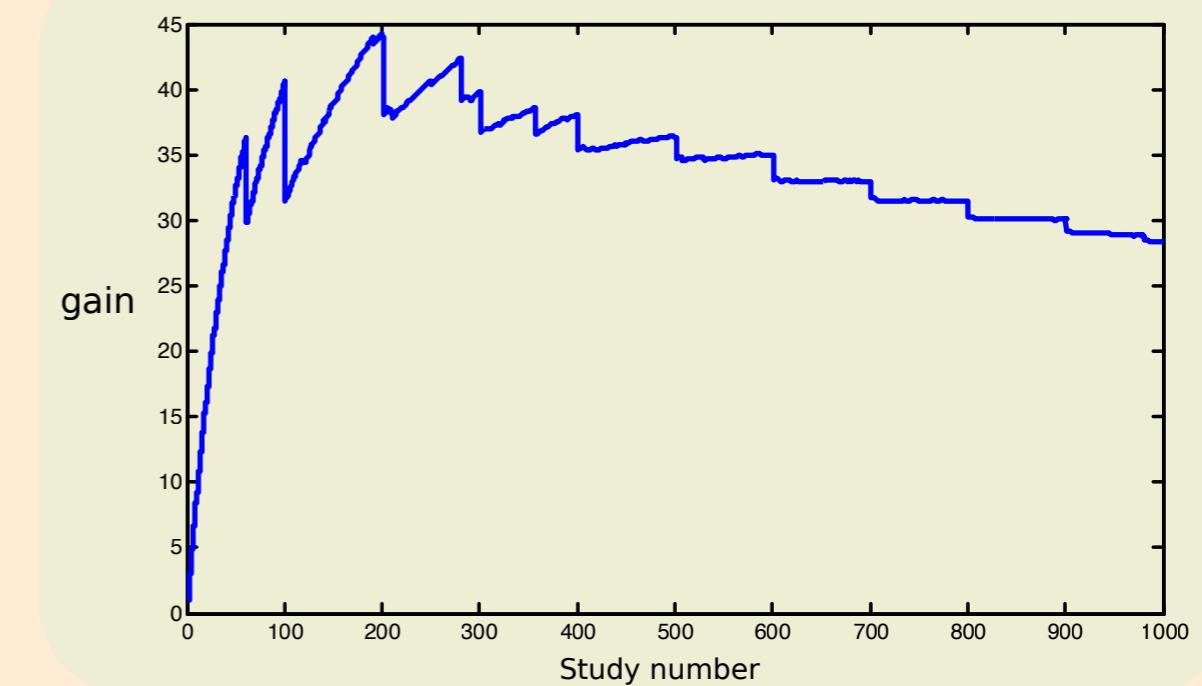
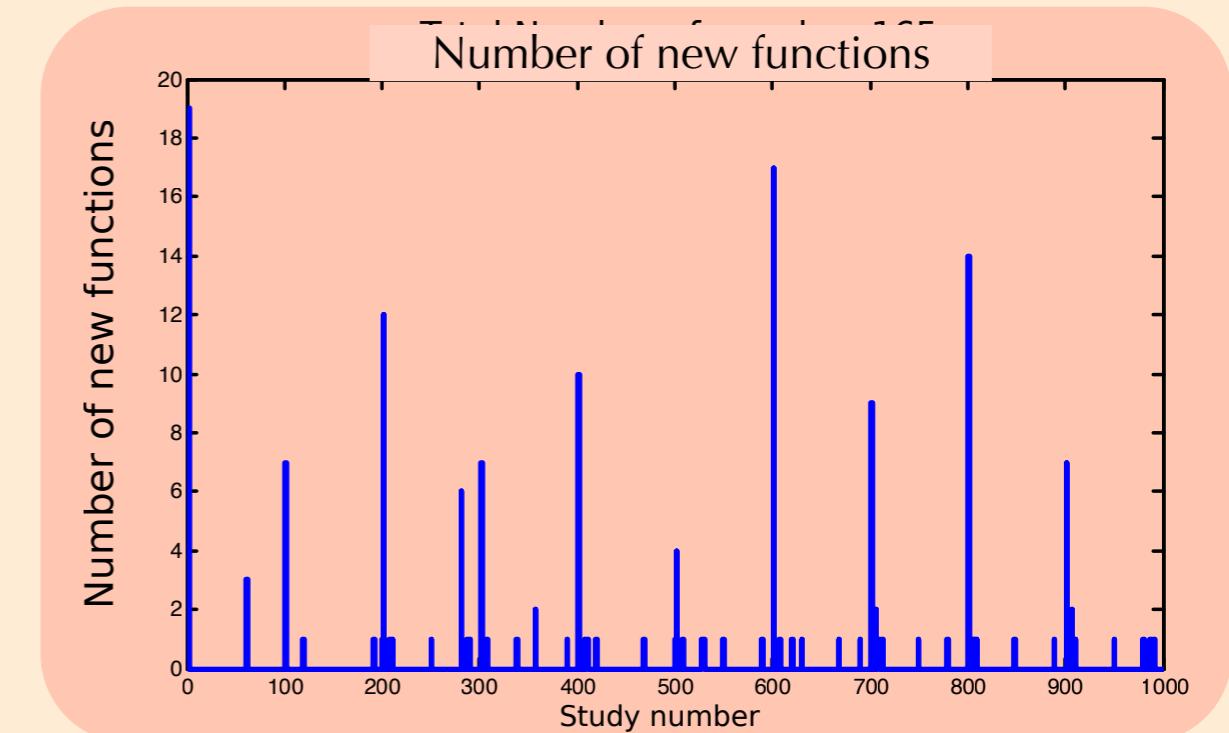
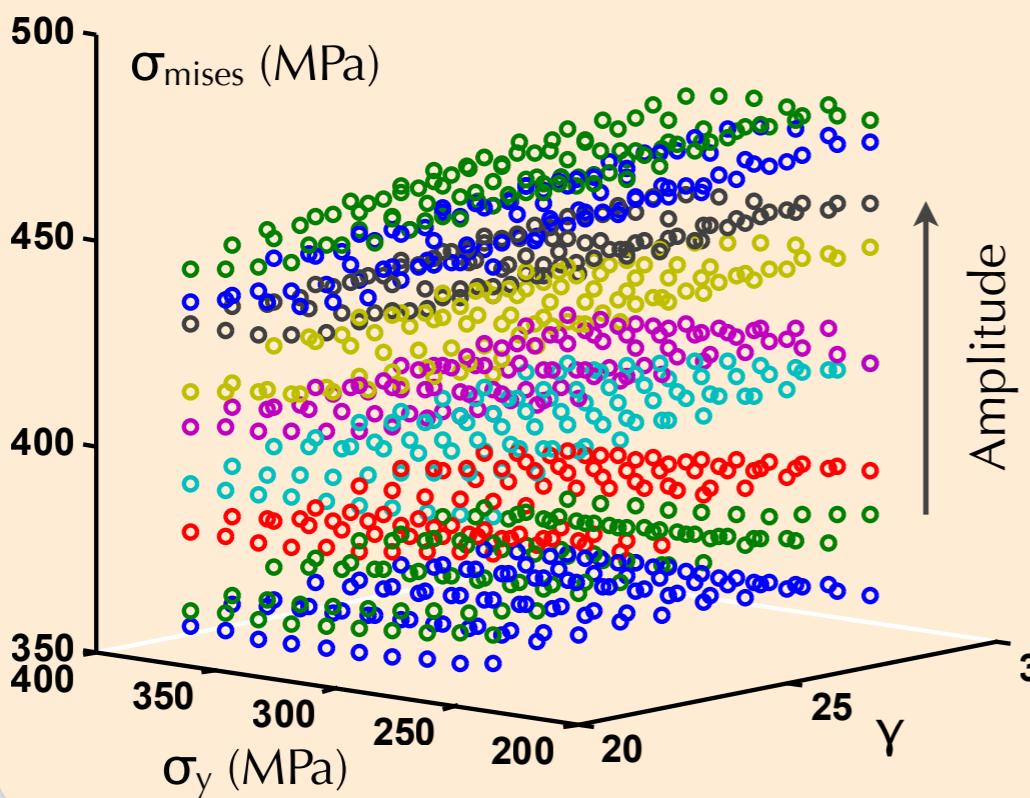


Parametric Study

- loading amplitude, yeald stress

σ_y , kinematic hardening γ

- 1000 sets of parameters, gain ~30



Acceleration

- Sorting of PGD basis [*C. Heyberger*]
- Partial Convergence [*B. Soulier*]
- Meta-models (co-kriging) [*L. Laurent*]
- Parallelisme
- HPC
- ...



Wrappers

- Cast3M (Cofast)
- Matlab
- Abaqus
- Local codes (LMT Plateform)



Datas: pre/post treatment



Methods

- Response Surface
- Meta-models
- Polynomial Chaos
- ...

