DE LA RECHERCHE À L'INDUSTRIE

USE OF INTENSIVE SIMULATION SUPPORTING SFR UNCERTAINTY DRIVEN CORE DESIGN PROCESS : PRESENTATION OF MULTI-PHYSICS TRIAD PACKAGE

Edouard Hourcade, Fabrice Gaudier, Gille Arnaud, Karim Ammar, Cyril Patricot
Damien Schmitt, Sandra Poumerouly (EDF)

www.cea.fr

SNA MC 2013 | 27TH OCTOBER 2013

CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance / uncertainties
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

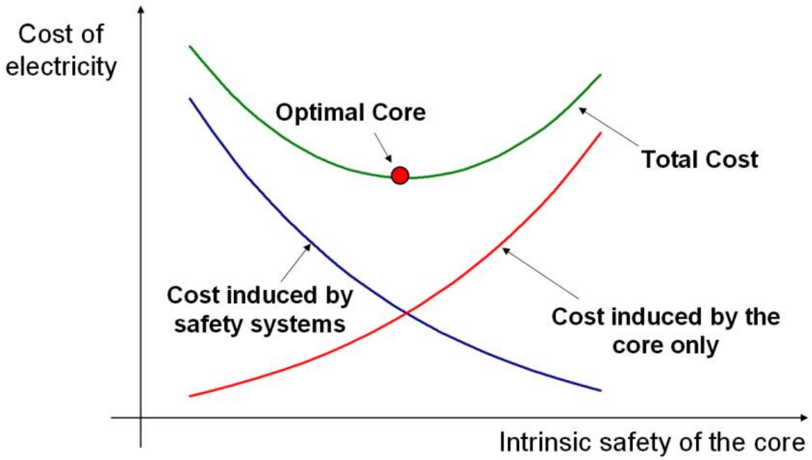
CONTEXT (1)

- Early stage developement of ASTRID prototype
  - Preliminary specifications are underway in parallel with design studies

- Criteria and constraints are subject to regular changes

- At each stage, core designers should be able to provide:
  - An optimal solution panel
  - With transversal macroscopic indicators (for comparison sake)
  - Clear visualization of compromises to be made

Within a reasonable time frame…



CONTEXT (2)

BUT !

- Core Design is an iterative process between core physics disciplines… (Neutronics, fuel mechanics, hydraulics etc.) …often performed by separate teams of experts
  - Possibly a lengthy process especially in the early stage of design
  - Sources of errors are increasing with interface number

- Design space can be very large (8-10 dimensions with millions of possible configurations) …and design constraints very numerous

- Finding best compromises ?

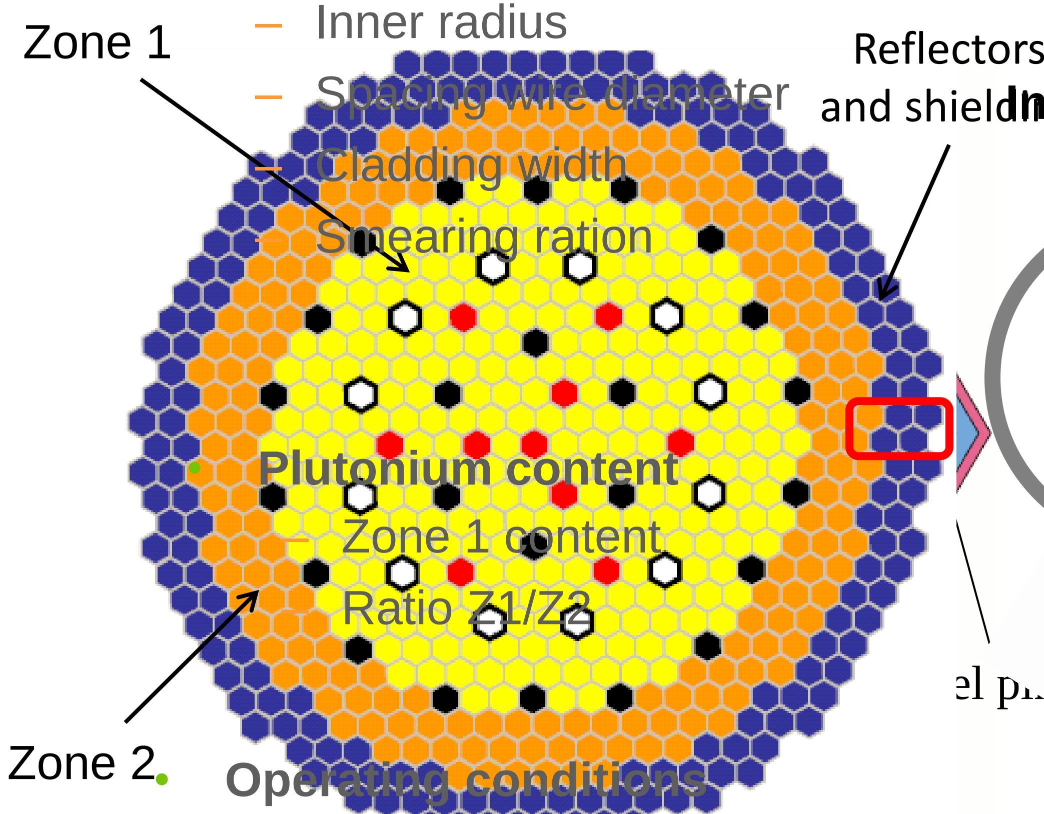
- Possibility to miss non-intuitive solutions ?

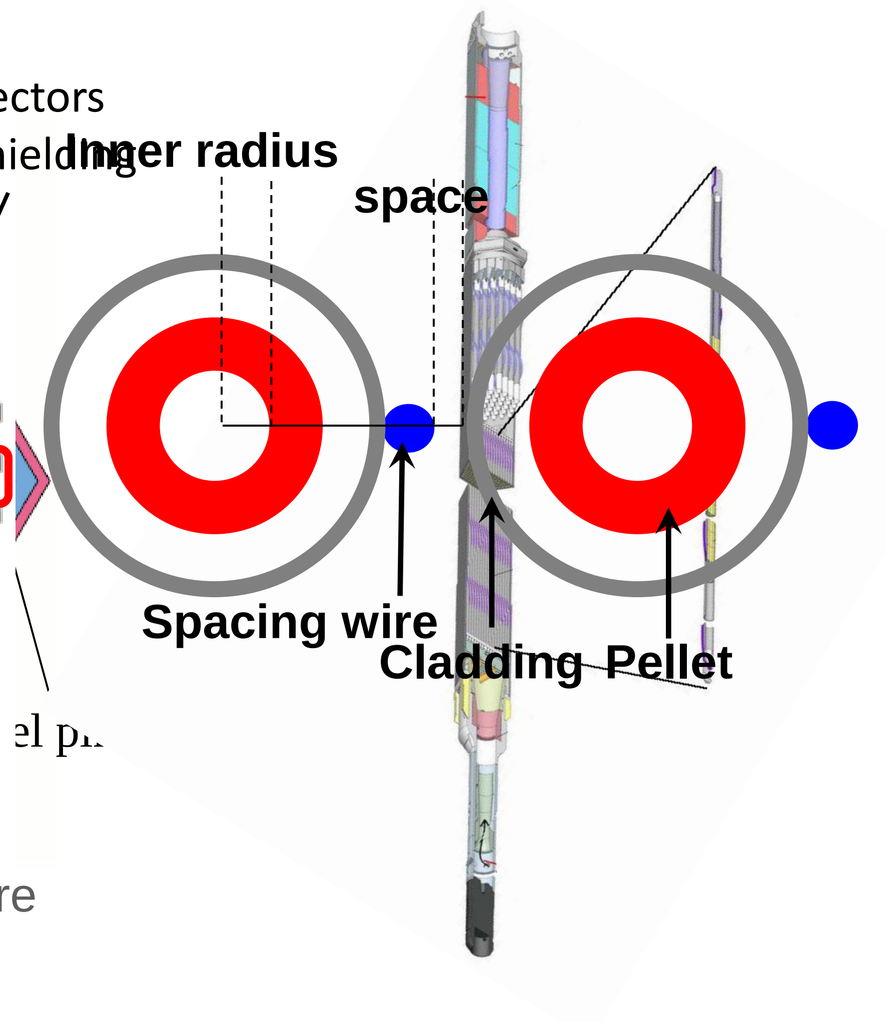
CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

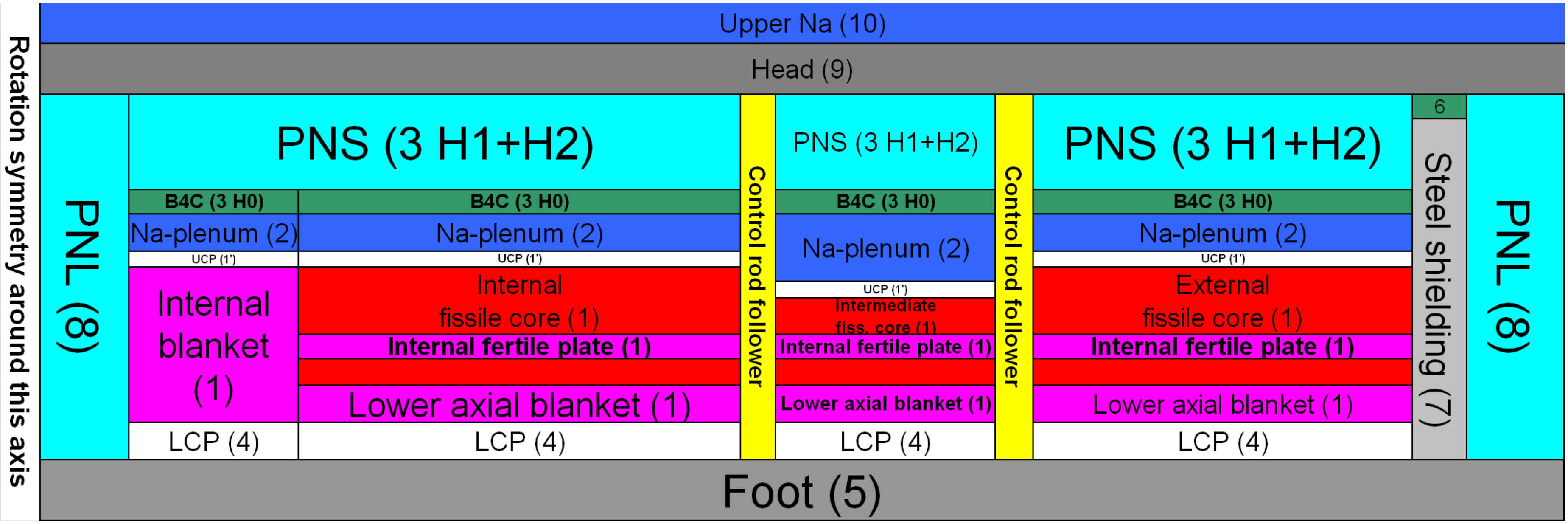
EXAMPLE OF CORE DESIGN PROBLEM (SFR)

- **Geometrical parameters**
  – Inner radius
  – Spacing wire diameter
  – Cladding width
  – Smearing ration
- **Plutonium content**
  – Zone 1 content
  – Ratio Z1/Z2
- **Operating conditions**
  – Sodium Inlet/outlet temperature





A MORE COMPLEX EXAMPLE…



CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

TOOLS SPECIFICATION

- Inter-disciplinary design tools allowing « systematic » exploration of design parameter space

- Based on performing data processing software (URANIE, ROOT…)
  - Allowing super-computing application
  - With advanced sampling / optimizing tools
  - With complex problem vizualization capabilities

- Possibility to access either reference codes OR simple models
  - The objective is to eveluate one core performance within less than 1 second of CPU time !
  - Calculation Time vs precision trade-off is the key
  - Adapting meta-model type (polynoms, neural networks, kriging)

- With sufficient user-friendliness for all designers use

CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

OPTIMISATION RATIONALE

- Core performance evaluation
  - Create large data base using High Performance Computing (once and for all)
  - Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
  - Define simplified models using data base as reference

- Visualization of feasability zones
  - 3D mapping

- Selecting core configurations
  - Applying optimization algorithms using uncertainties
  - Use iso-values representation

- Display compromise
  - Multi-1D cobweb

OPTIMISATION RATIONALE

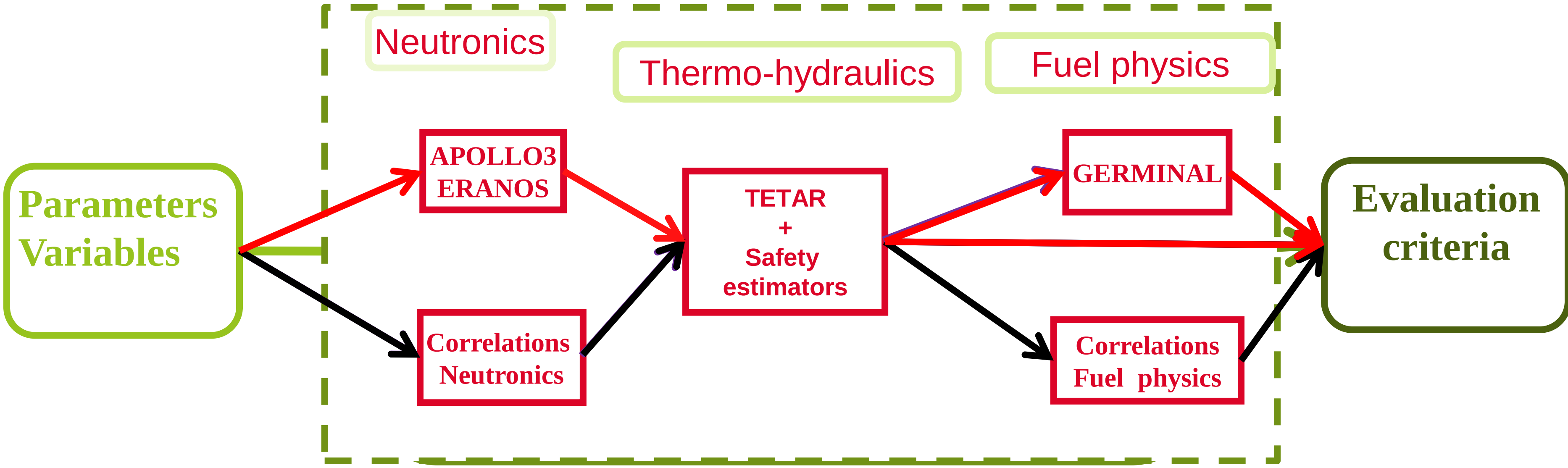
- Core performance evaluation
  - Create large data base using High Performance Computing (once and for all)
  - Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
  - Define simplified models using data base as reference

- Visualization of feasability zones
  - 3D mapping

- Selecting core configurations
  - Applying optimization algorithms using uncertainties
  - Use iso-values representation

- Display compromise
  - Multi-1D cobweb

CORE PERFORMANCE EVALUATION



- Evaluation of core performance
  - With « direct » indicators (Void coefficient, fusion margin)
  - With indirect indicators « Safety estimators »
  - Accounting for transient core configuration
- With various modeling accuracies :
  - With fine tools (long but accurate, coupling codes requires dedicated platform)
  - With correlations <u>(calculated once and for all</u>)
  - With mixed accuracy (for certain disciplines or certain cores only)

OPTIMISATION RATIONALE

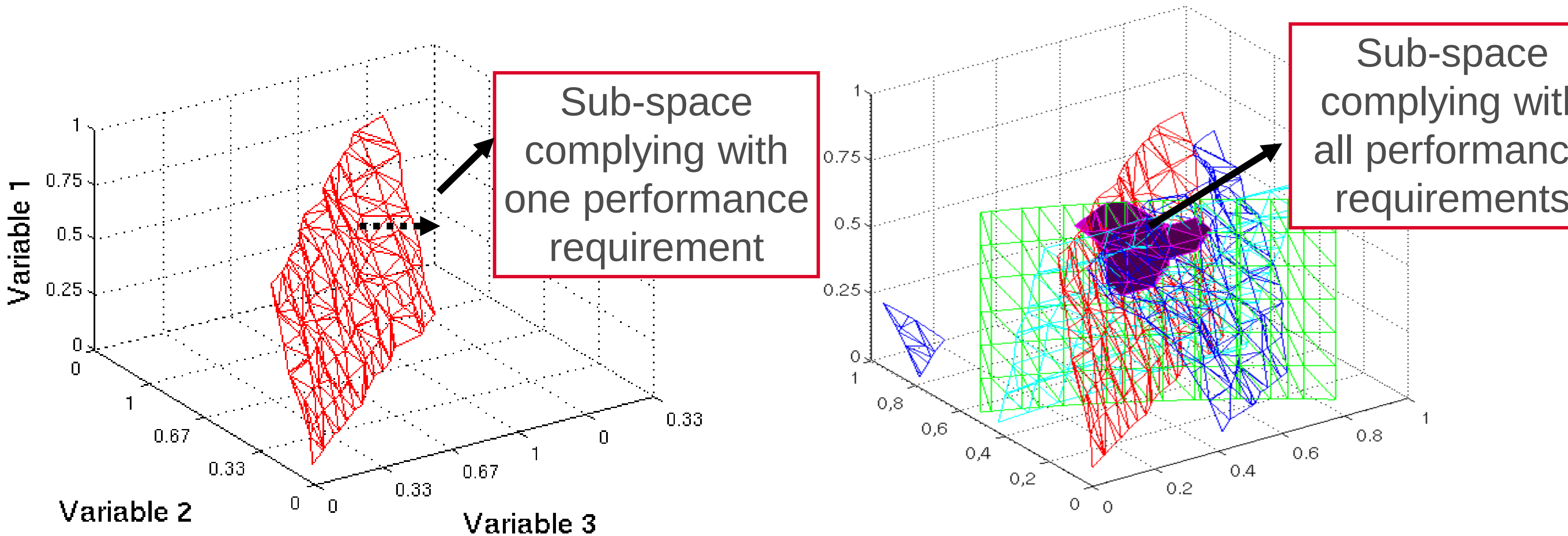
- Core performance evaluation
  - Create large data base using High Performance Computing (once and for all)
  - Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
  - Define simplified models using data base as reference

- Visualization of feasability zones
  - 3D mapping

- Selecting core configurations
  - Applying optimization algorithms using uncertainties
  - Use iso-values representation

- Display compromise
  - Multi-1D cobweb

VISUALIZE « CORE VIABILITY » ZONE



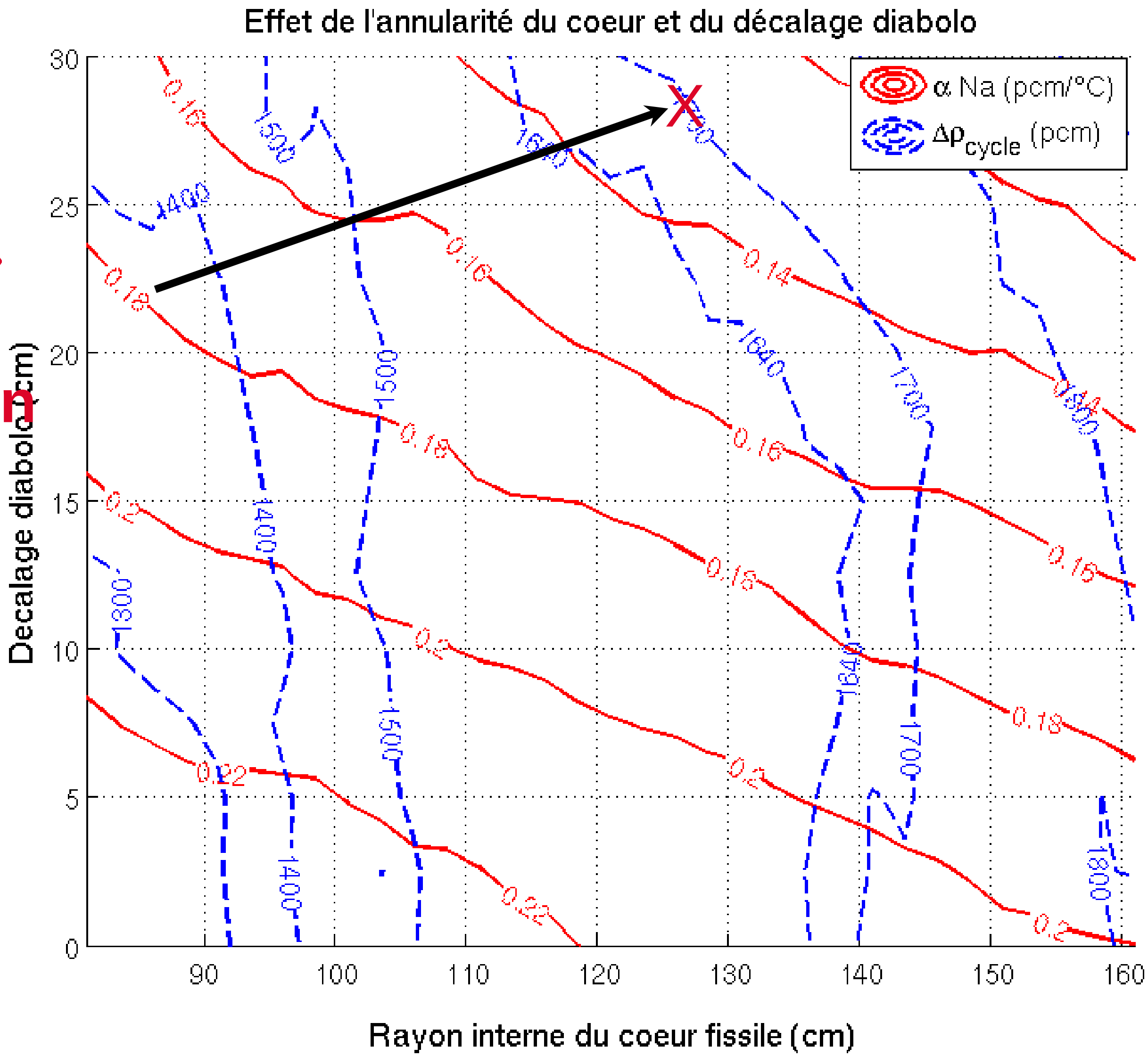
- Possibility to visualize feasability space reduction by adding design constraints
- Once sub-set is defined; optimisation of core performance within this space can be performed

OPTIMISATION RATIONALE

- Core performance evaluation
  - Create large data base using High Performance Computing (once and for all)
  - Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
  - Define simplified models using data base as reference
- Visualization of feasability zones
  - 3D mapping
- Selecting core configurations
  - Applying optimization algorithms using uncertainties
  - Use iso-values representation
- Display compromise
  - Multi-1D cobweb

OPTIMISATION PROCESS : ISOVALUE REPRESENTATION

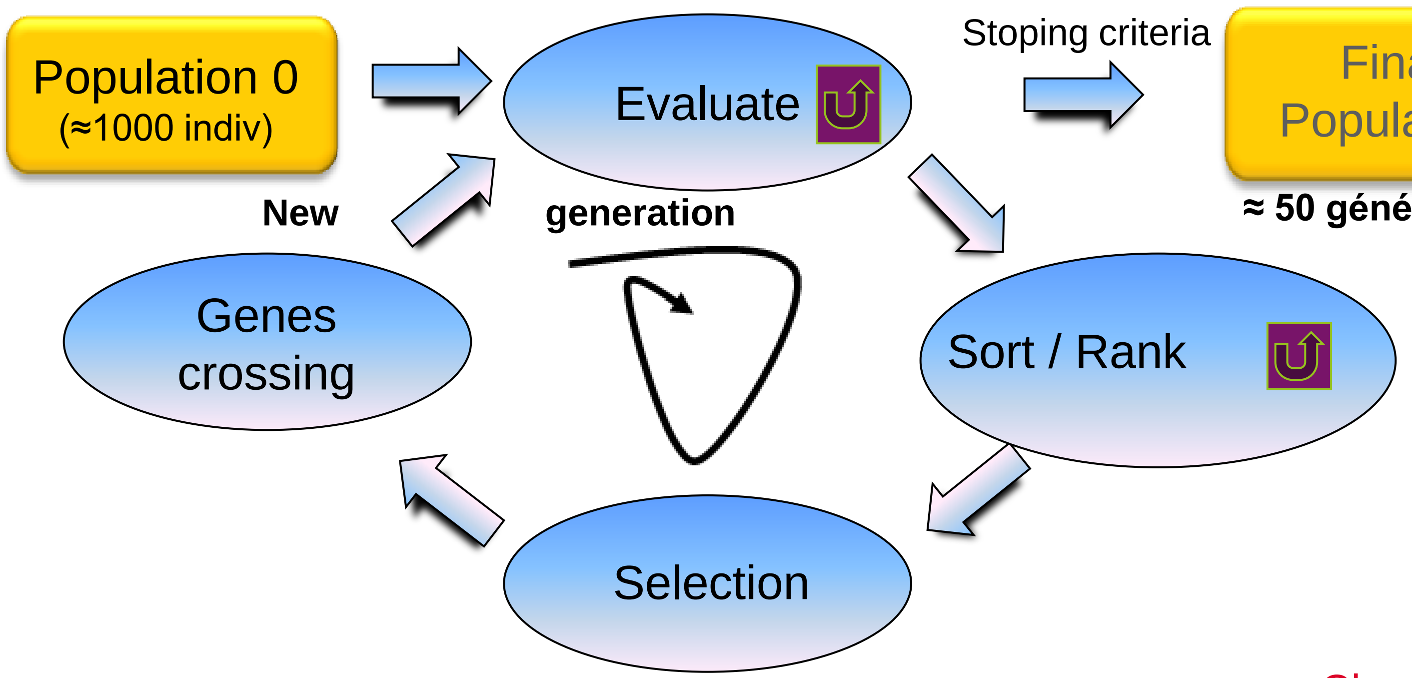
« Chosen » optimal configuration

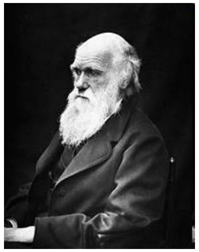


OPTIMISATION PROCESS : GENETIC ALGORITHMS

Principle :

Approach optimal configuration with a natural selection process





Charles Darwin

Advantages : Excellent exploring capacity on multi-criteria optimisation problems

Drawback : Requires many core performance evaluation

OPTIMISATION RATIONALE

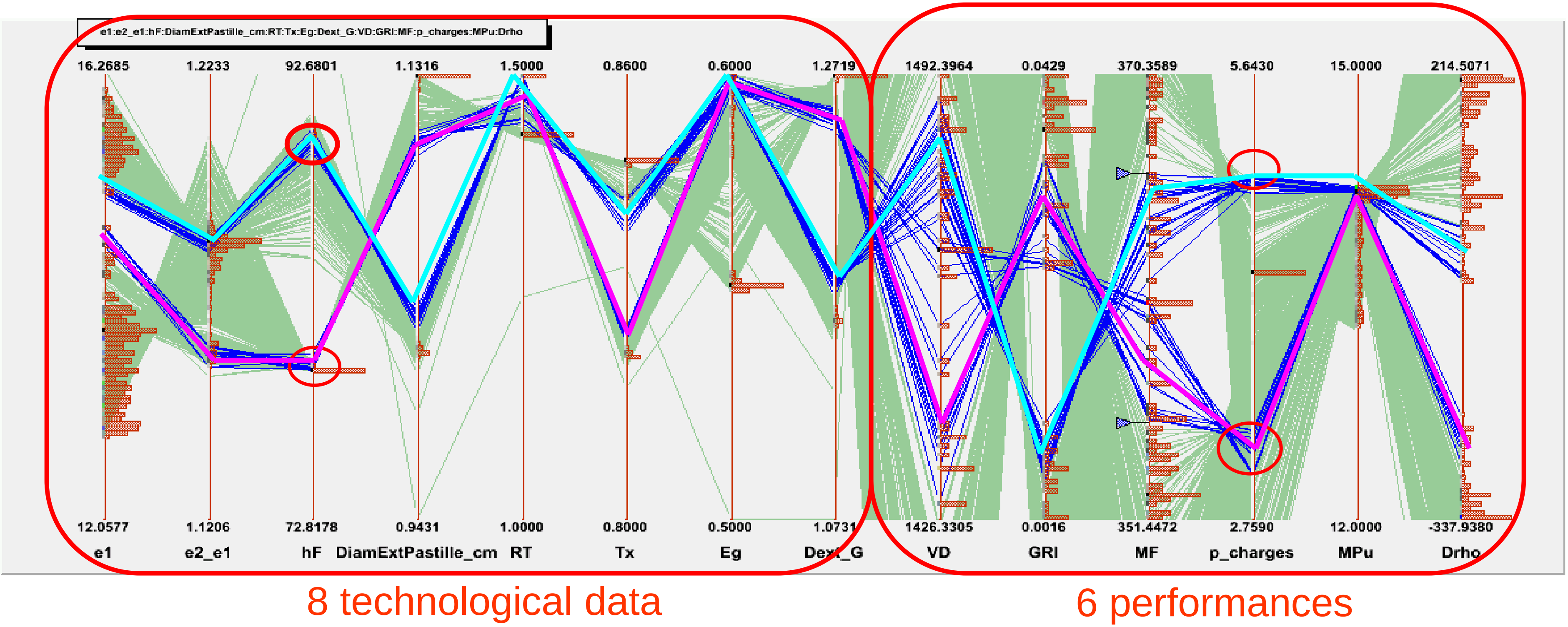
- Core performance evaluation
  - Create large data base using High Performance Computing (once and for all)
  - Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
  - Define simplified models using data base as reference

- Visualization of feasability zones
  - 3D mapping

- Selecting core configurations
  - Applying optimization algorithms
  - Use iso-values representation

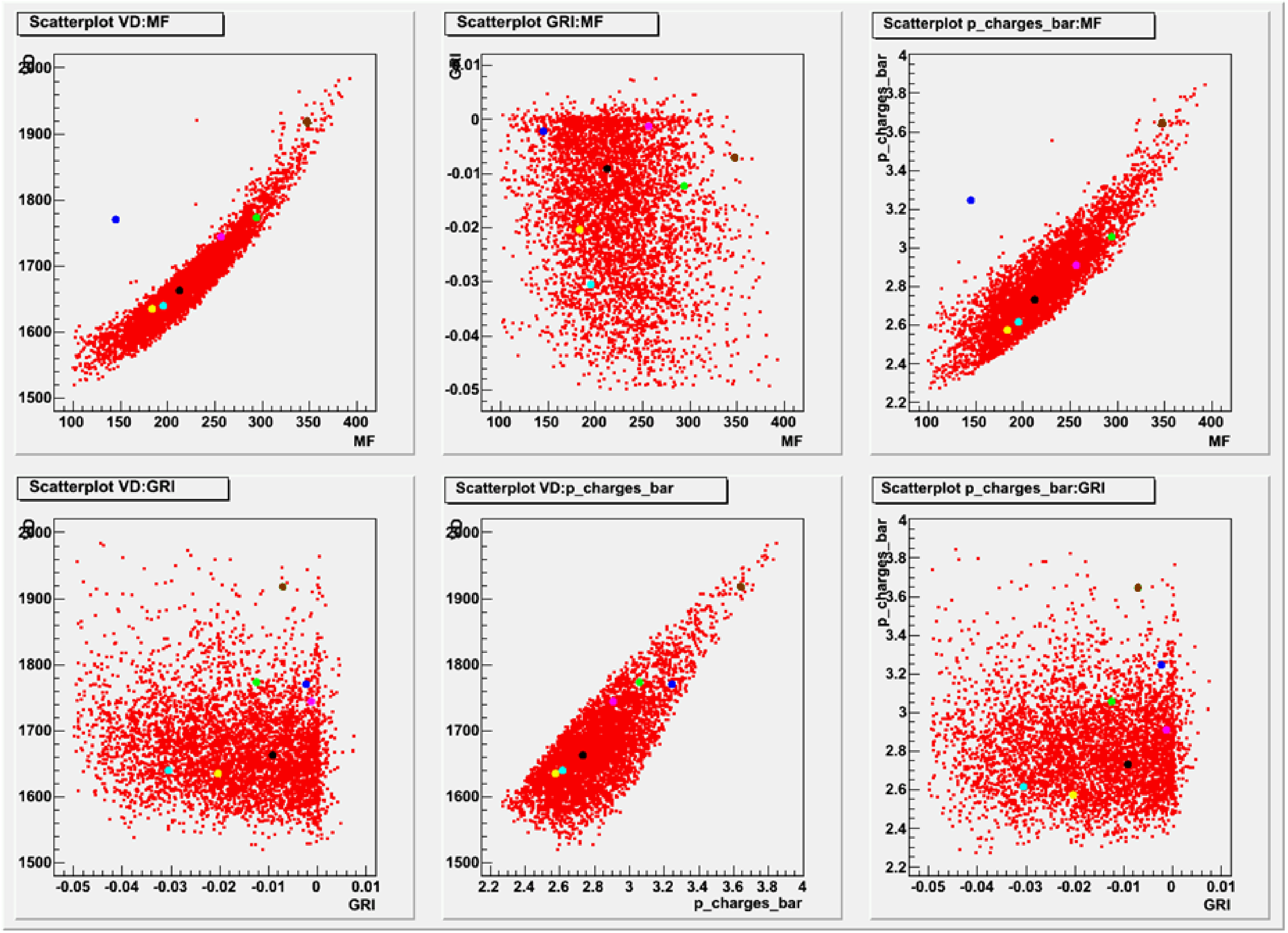
- Display compromise
  - Multi-1D cobweb

DISPLAY COMPROMISE (1)



- Linking core performance and characteristics
  - One core (individual) = one broken line running from left to right
  - Each Vertical bar represents either a data (left) or a performance (right) with statistical dispersion
- Blue lines represent cores fullfilling similar constraints (Void coefficient and Margin to fuel melting)
- 2 possible technological paths with similar performance are showing :
  - **Core with low pressure drop (light blue)**
  - **Core with low diameter (purple**)

DISPLAY COMPROMISE (2)



CONTENT

- Context
- Examples of core paterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion

CONCLUSIONS (1)

- TRIAD is an optimisation package for complex core design
  - Making the most of High Performance Computing
  - Using softwares dedicated to Large data Flow management (ROOT)
  - Using advanced visualization techniques for data mining
  - Implementing advanced algorithms accounting for uncertainties

- Defining best compromise (precision vs CPU time) for core performance evaluation is still a key issue

- Efficient Use of developed tools requires a thorough understanding of core design disciplines

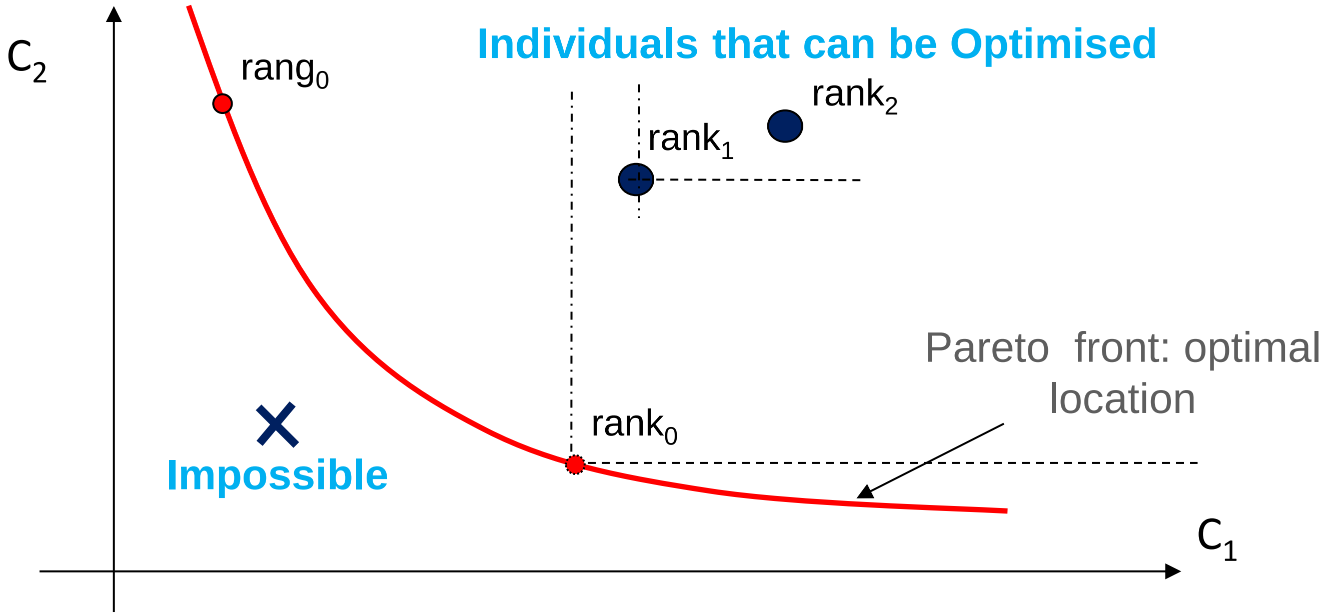
CONCLUSIONS (2)

- Progressive implementation of proper code chaining/coupling (via SALOME tool for example) of best estimate codes for data base creation (and optimizing?)
- Implementation of new performance « estimators » are under development (robustness to Loss of Flow transients etc.)
- Efforts to make these tools available to a wider core designer community is underway (GUI for TRIAD)

PARETO FRONT

- Result of multi-criteria optimzation is the so called Pareto front
  - when an « individual » (a core) is located on Pareto front, designer can not improve one of its performance without downgrading another.

- Pareto front individuals are considered as the best individual of their generation
  - Other individuals have less chance to breed…

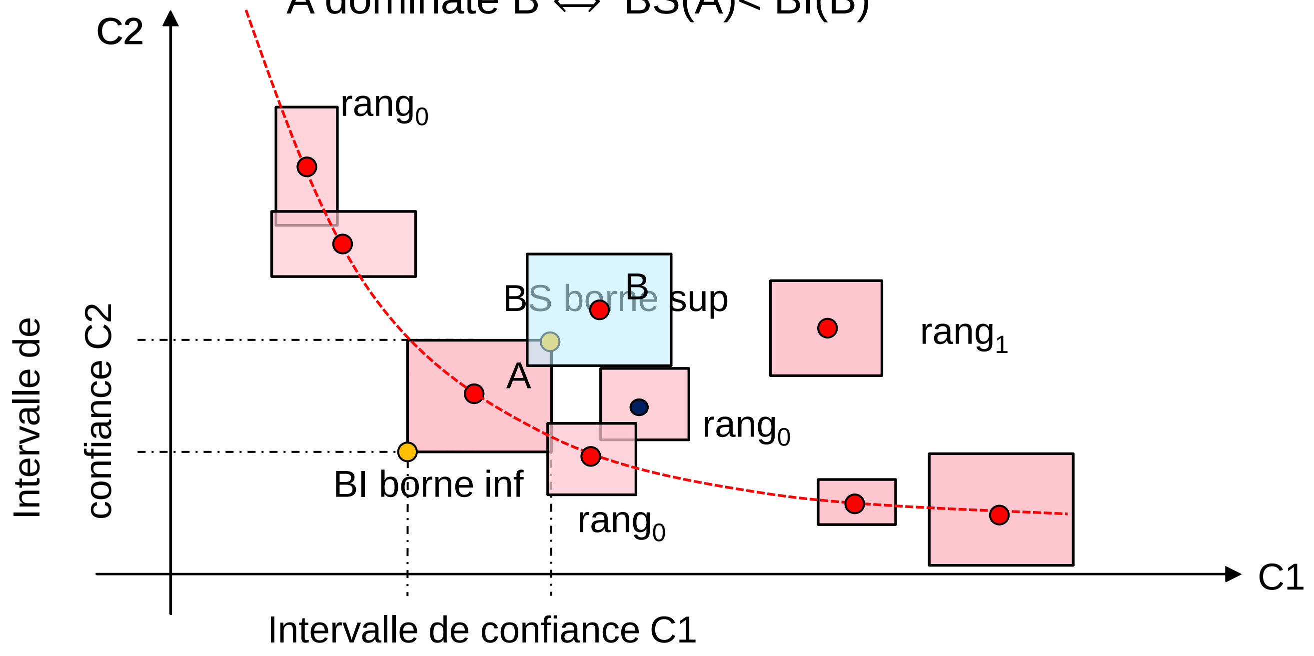


Exemple of 2D Pareto front, C1 et C2 criteria are antagonists

OPTIMISATION WITH UNCERTAINTIES

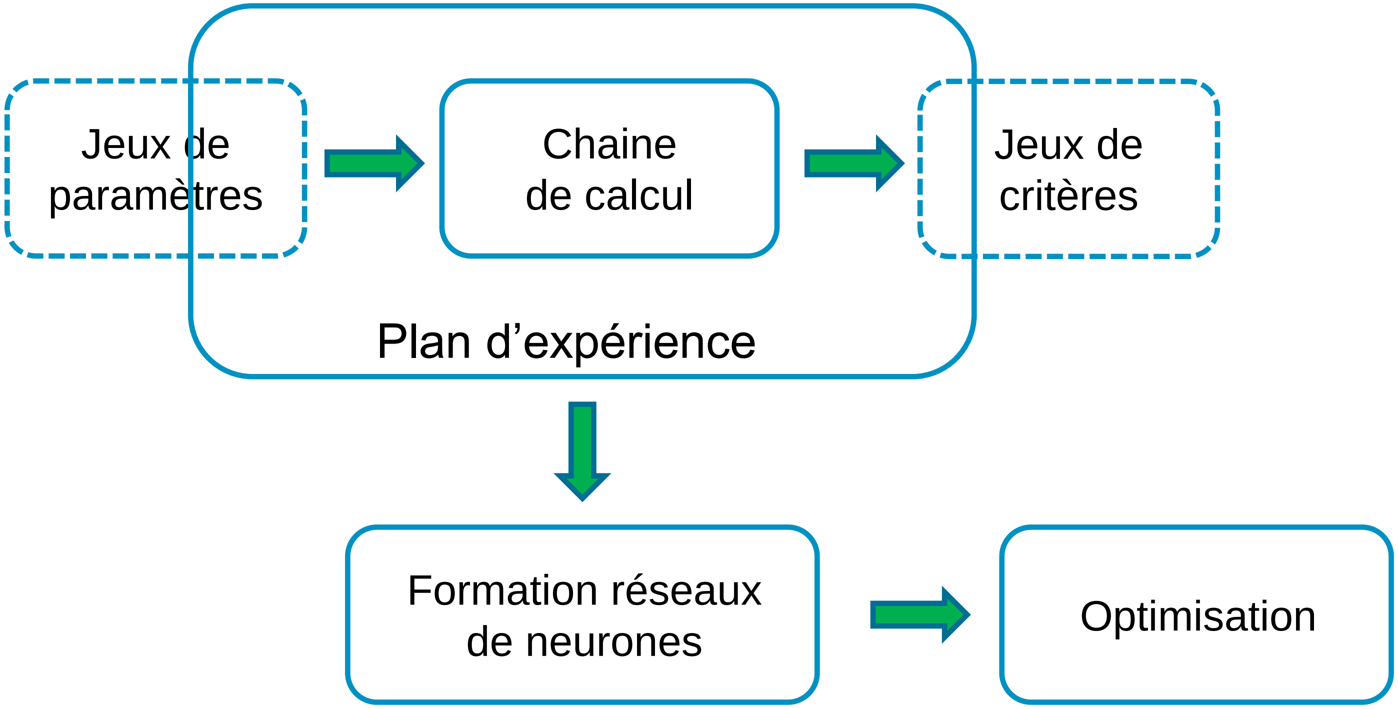
- « Smartly » accounting for uncertainties within optimisation processes is still a hot R&D field
- A prerequisite, of course, is to have a first estimation of uncertainties for each core design discipline
- Then those uncertainlties can be used with PareBRO method (V. Baudoui) for example : generalization of ranking process

A dominate B ⇔ BS(A)< BI(B)



I. OBJECTIF ET CONTEXTE

- Démarche de TRIAD :



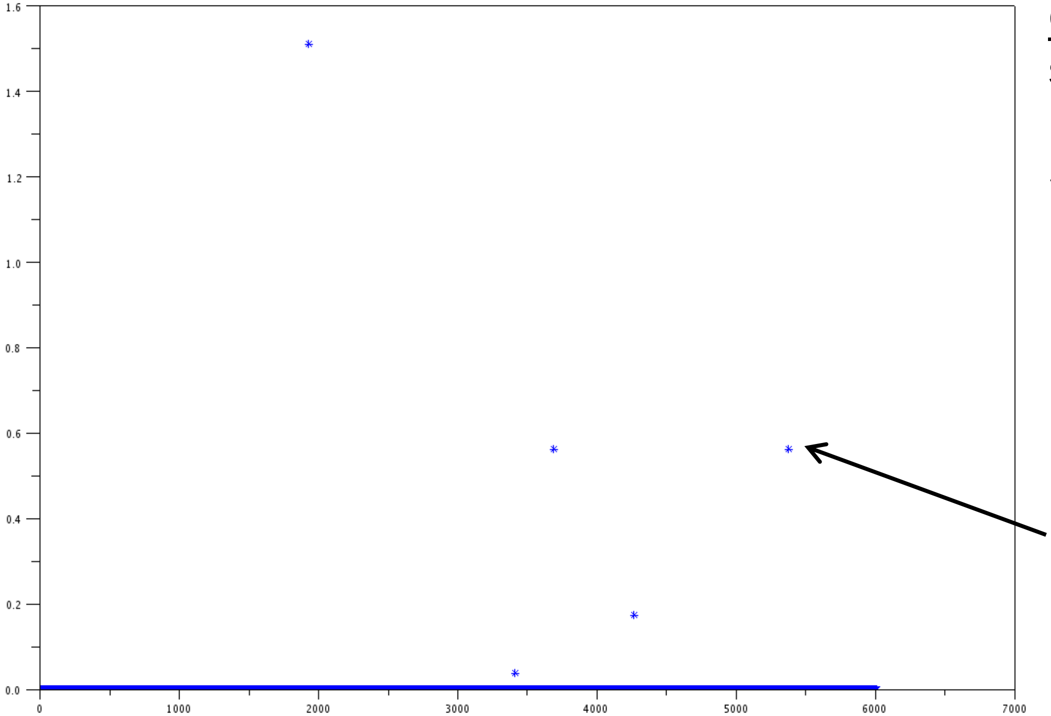
II. UTILISATION D'URANIE

- Lanceur local et batch
  - Utilisation de la fonction de mise en donnée xml
- Analyse de sensibilité / Statistique
  - Morris
  - Sobol
  - Krigeage (via longueur de corrélation)
- Méta-modèles :
  - Réseau de neurones
  - Krigeage (en cours)
- Algorithmes génétiques
- Qt-Root pour IHM d'optimisation

ANALYSE STATISTIQUE :
DÉTECTION D'INDIVIDU STATISTIQUEMENT ABERRANT

Méthode de Leave One Out :

1. On retire un point de la base support
2. On compare la prédiction du Krigeage avec la valeur du code
3. **Si le delta code / krigeage > 5sigma on vas voir si le code à correctement fonctionné**



Courbe :

si $Y_{code} - Y_{krigeage} < 5\sigma_{krigeage}$

$f(y) = 0$

Sinon :

$f(y) = \sigma(Y_{code} - Y_{krigeage}) - 5\sigma_{krigeage}$

Probalité d'avoir une erreur dépassant 5 sigma :
1 individu pour 1,744,278

Erreur de code :

- Porosité négative
- Matrice singulière
- Maillage dégénérer….