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Optimizing the layout of tomographic diagnostics with Genetic Programming

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[#] Contributors list: <https://github.com/TokaLab/VirtualLab/blob/main/Contributors.md>



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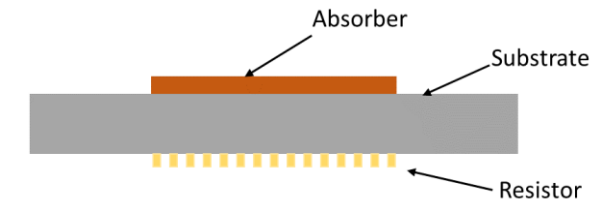
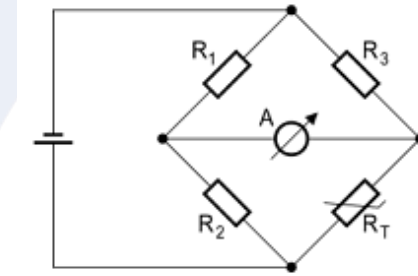
- Introduction to tomography
- TokaLab – Synthetic Diagnostic
- Genetic Algorithm
- Genetic Design application to Bolometer
- AI for Diagnostic Design





Radiation emitted from the plasma represents an energy loss. A high level of radiation can result in an electron temperature anomalies, which in turn can destabilize MHD (magnetohydrodynamic) modes and eventually lead to a disruption.

- Detachment → Divertor
- X point Radiator → X point
- ELM → Divertor and SOL
- Density limit → Divertor and SOL



Reconstructing the emissivity field is fundamental for studying the different radiative scenarios.

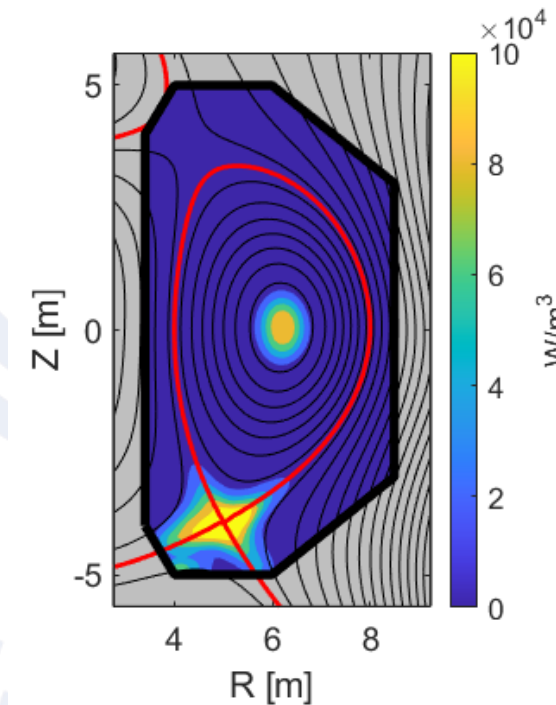
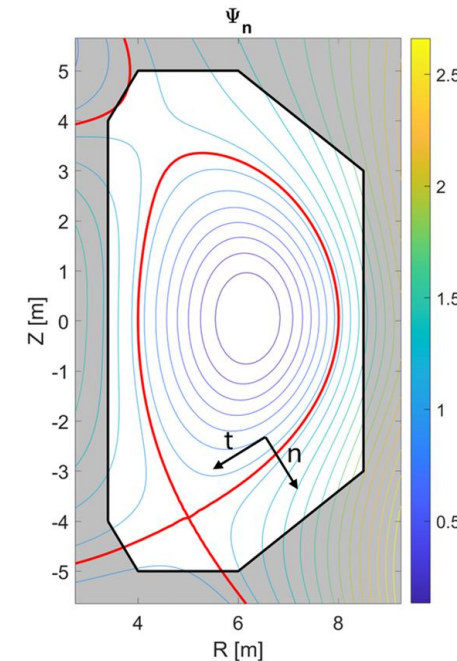
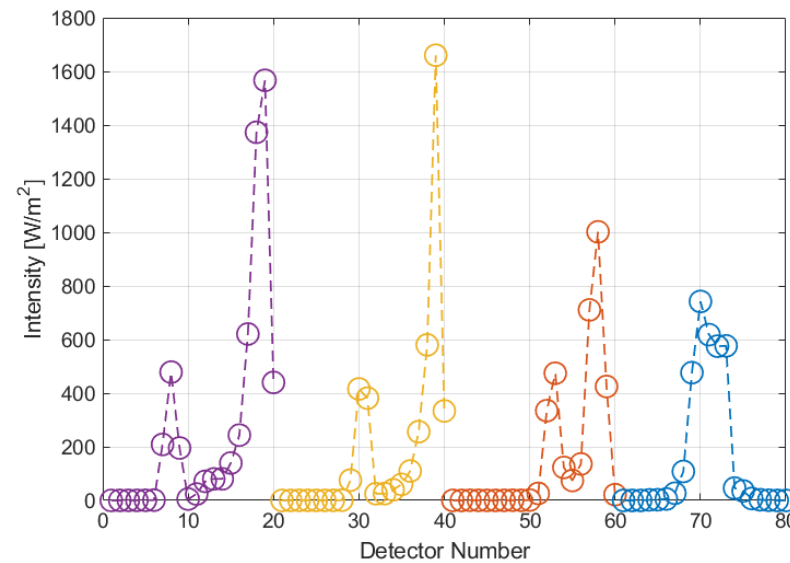
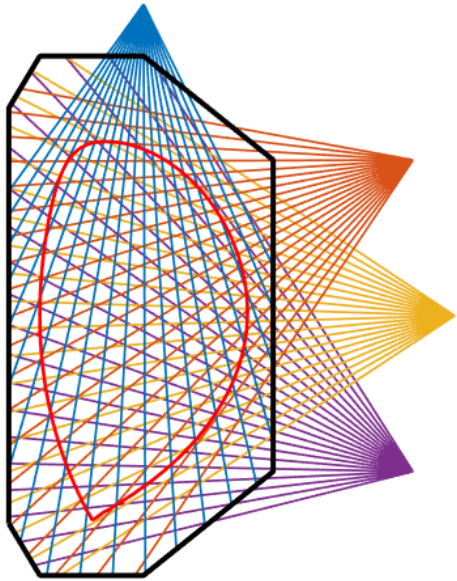


Tomography is an inverse problem

$$g_l = \int f \cdot ds, \quad l = 1, \dots, n_d$$

There are different algorithms to perform tomography inversion and different kinds of **Regularization**

Regularization is fundamental when the problem is strongly ill-conditioned



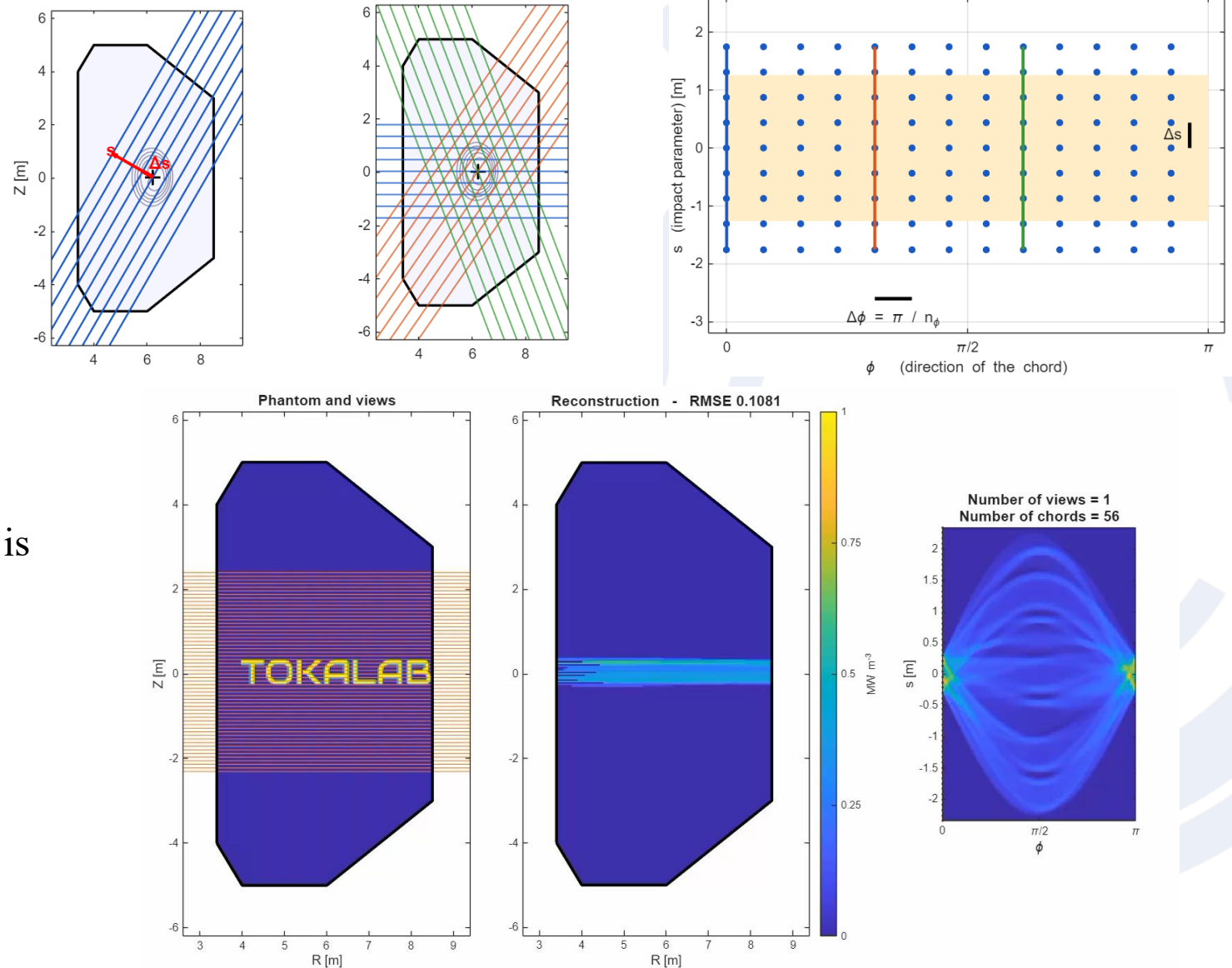


The ideal Geometry has enough views and lines to fully resolve the target emissivity.

$\Delta\phi$ = Number of views. It defines the angular structure

Δs = Number of chords. It defines the resolution

In optimal condition the acquisition geometry is fixed by spatial information of target source



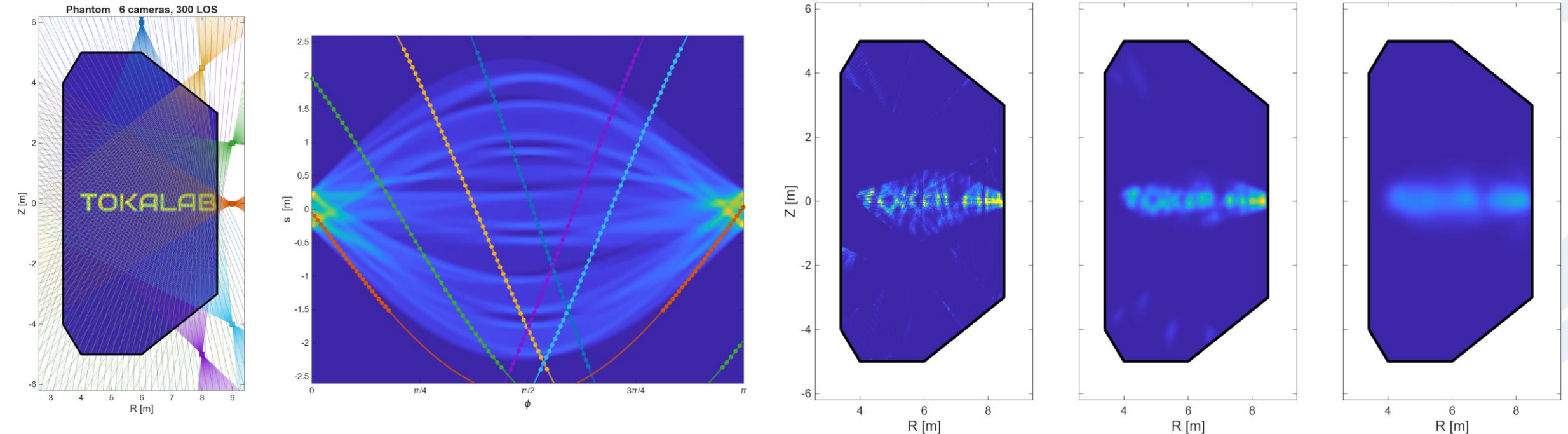


Tomography Geometry

The fixed geometry in tokamak has a strong lack of information making regularization fundamental

Requirements for diagnostic are strongly related to space and mechanical integration and to capabilities to reconstruct important radiative scenarios.

With limited information, optimization is fundamental.





TokaLab is a **Virtual Tokamak**: an **Open Source** framework able to generate tokamak-like plasma configurations, developed and maintained in both Python and MATLAB.

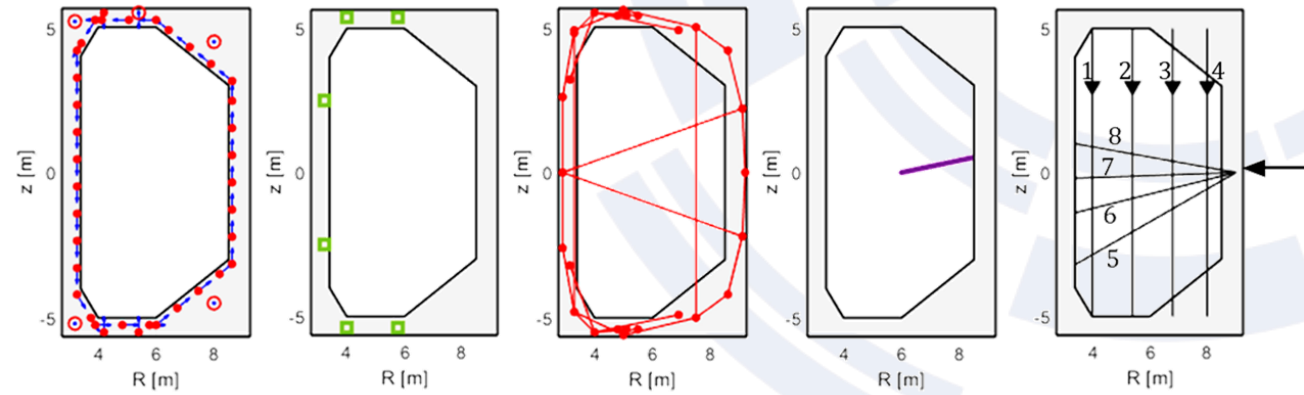
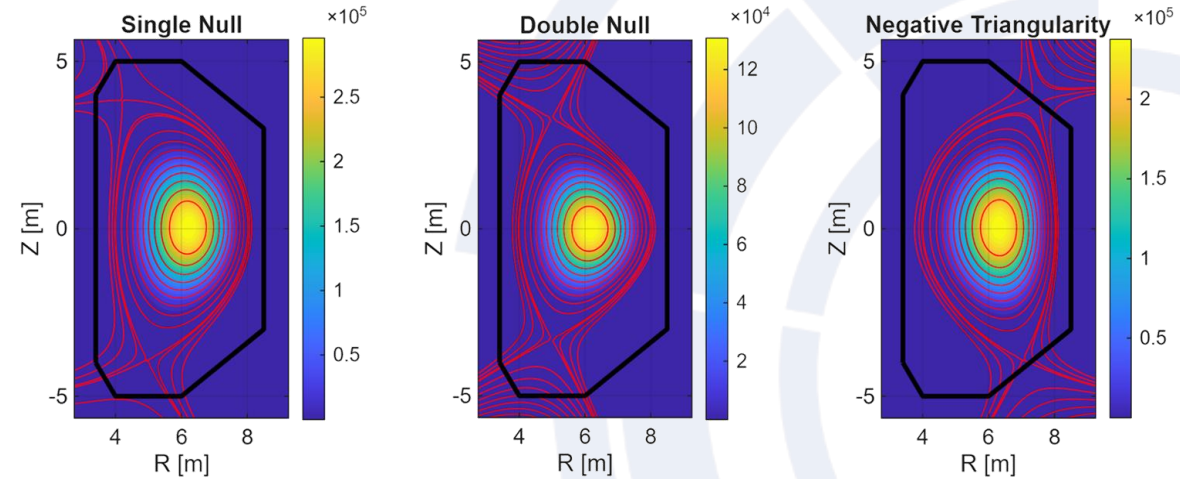
It allows to generate different plasma scenarios

- Density
- Temperature
- Plasma Emissivity
- Magnetic Configuration

Synthetic Diagnostic

- Pick-up
- Flux Loops
- Thomson Scattering
- Bolometer

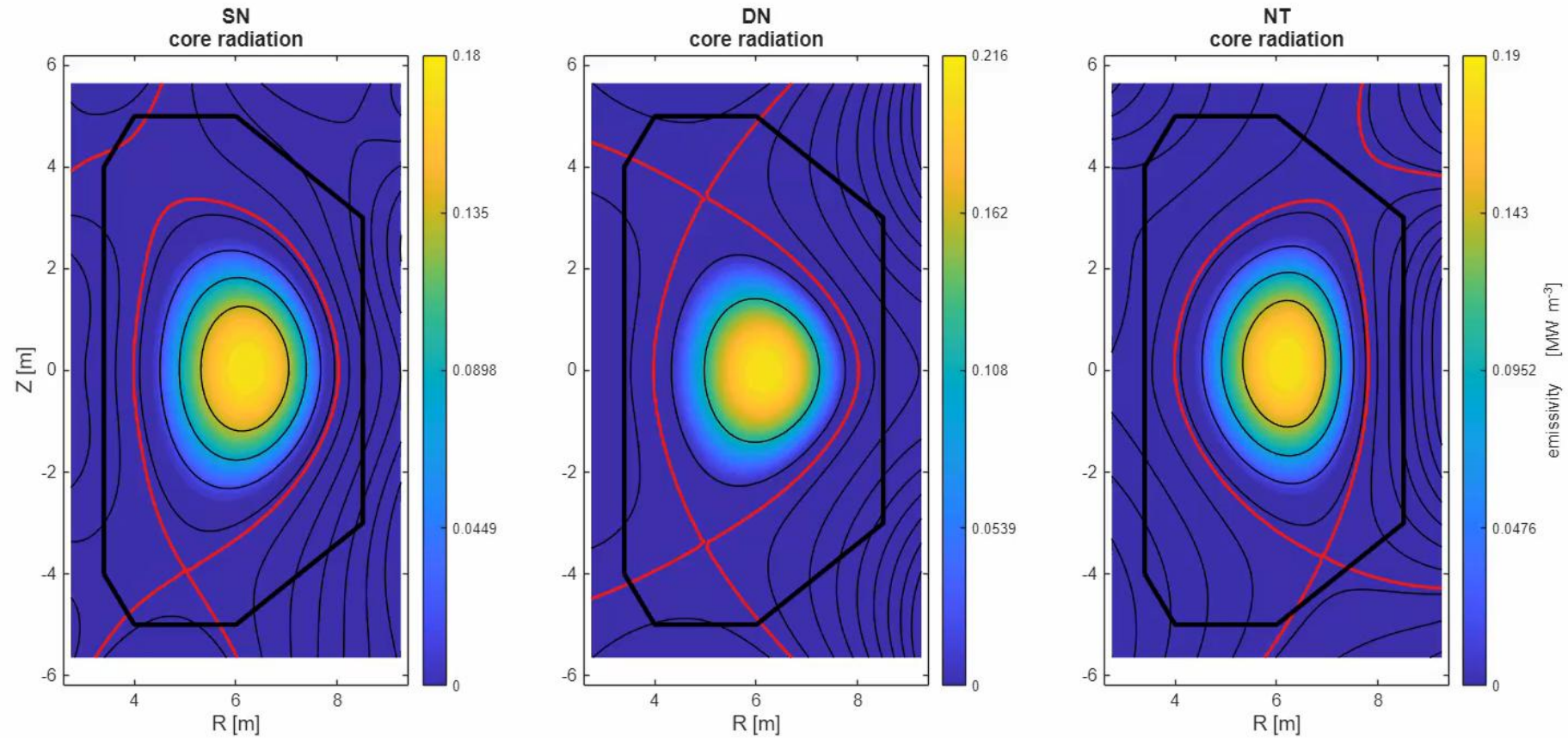
Design and Validate





How can improve Design?

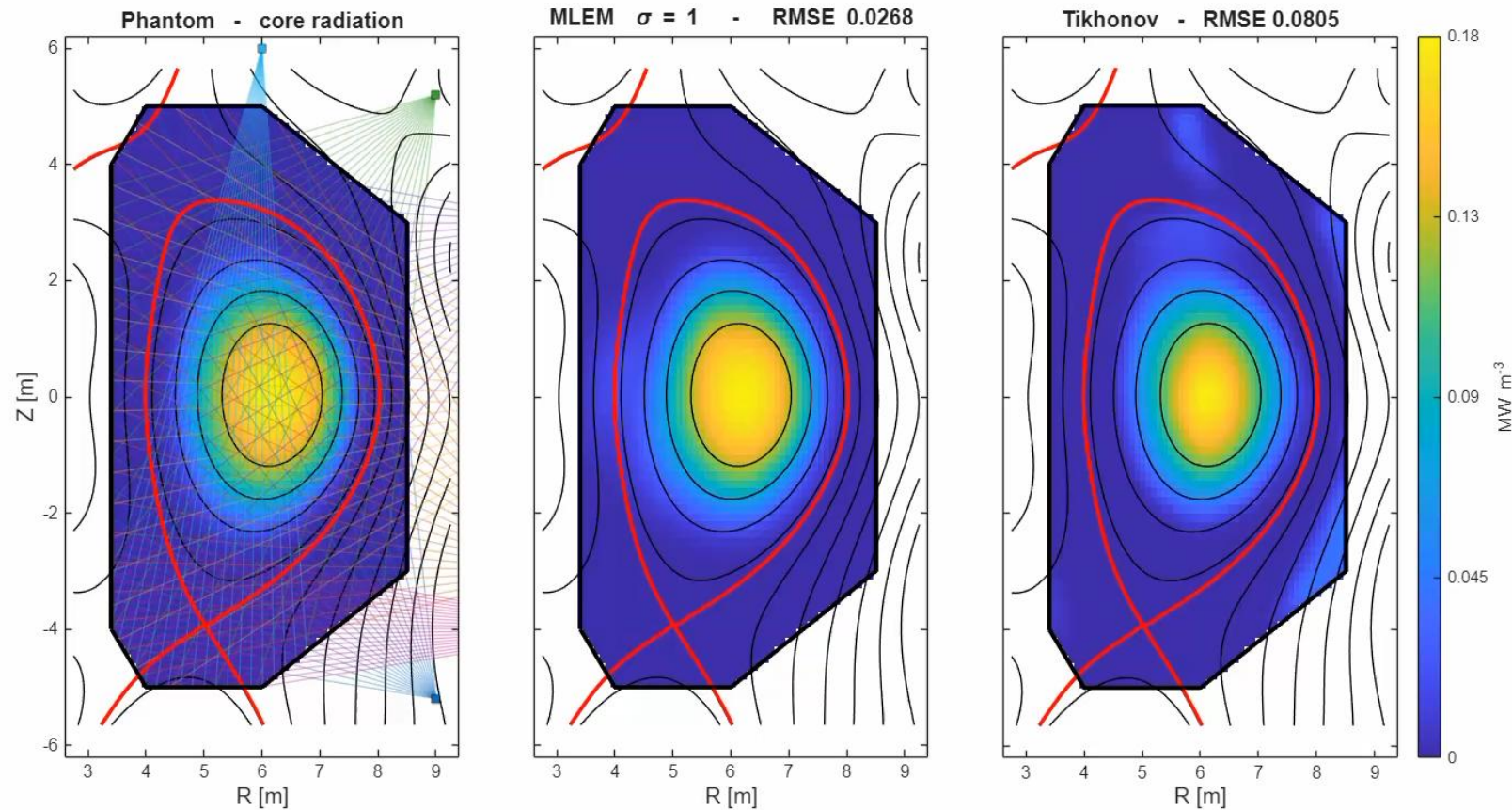
It can simulated different plasma scenarios





How **Synthetic Diagnostic** can improve Design?

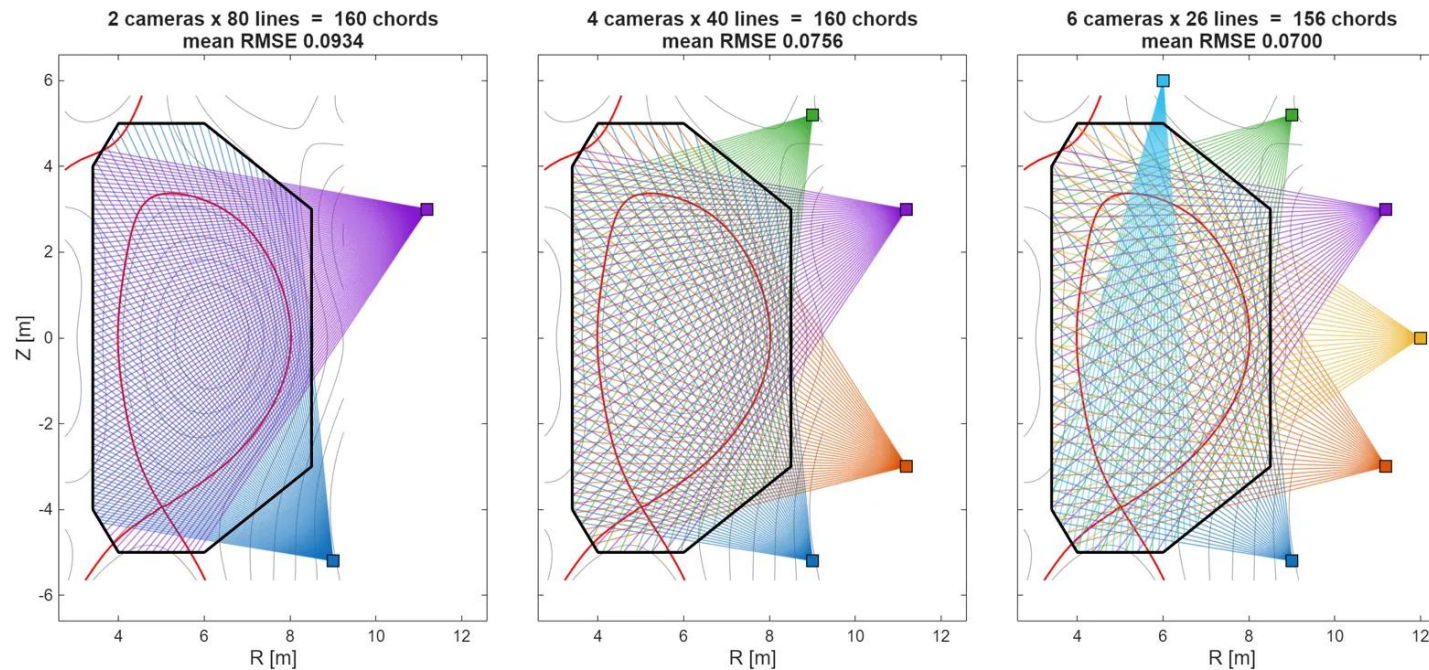
It can produce different **Synthetic Measurements** to be used for **validating** Algorithm for **inverse problems**.



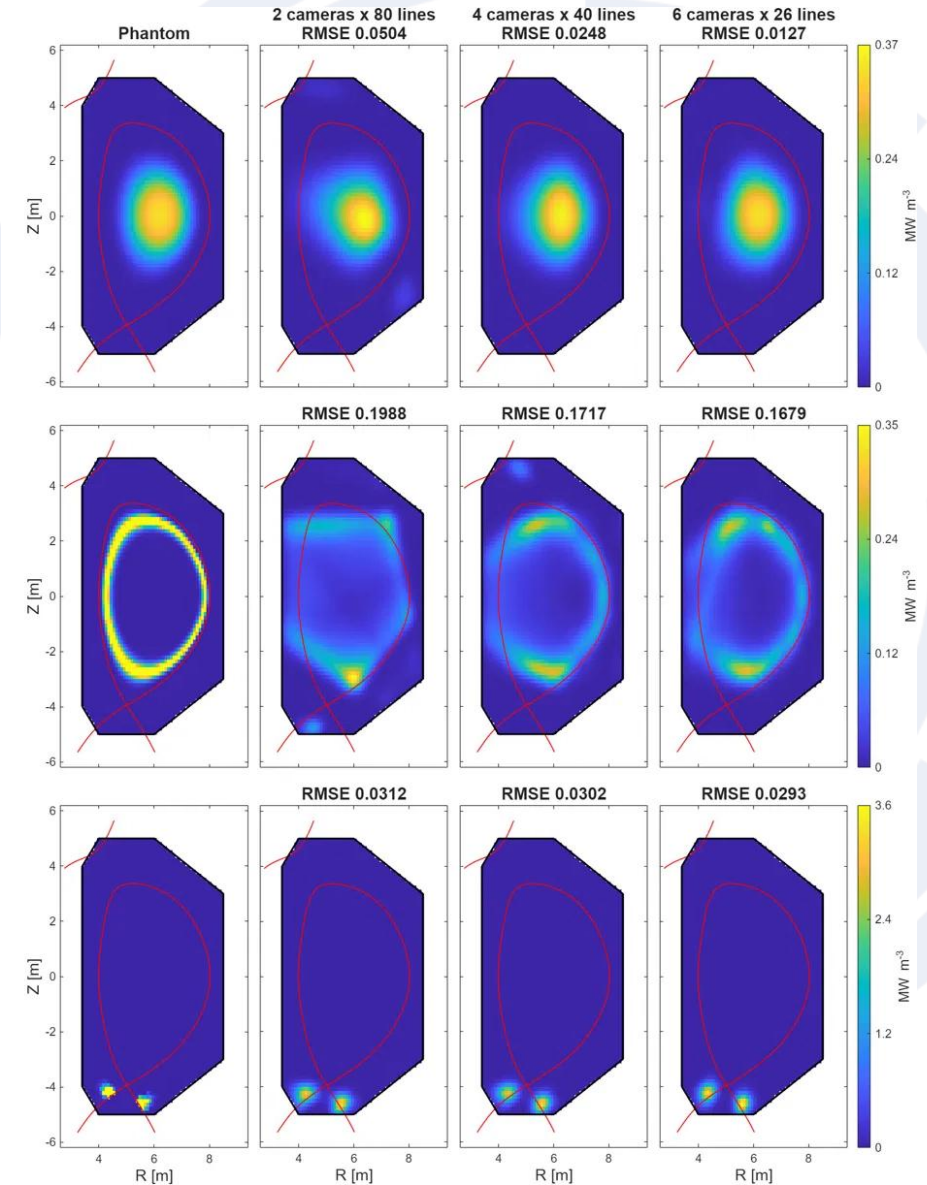


How Synthetic Diagnostic can improve Design?

We can test different geometries and analyze the entire chain of measurements

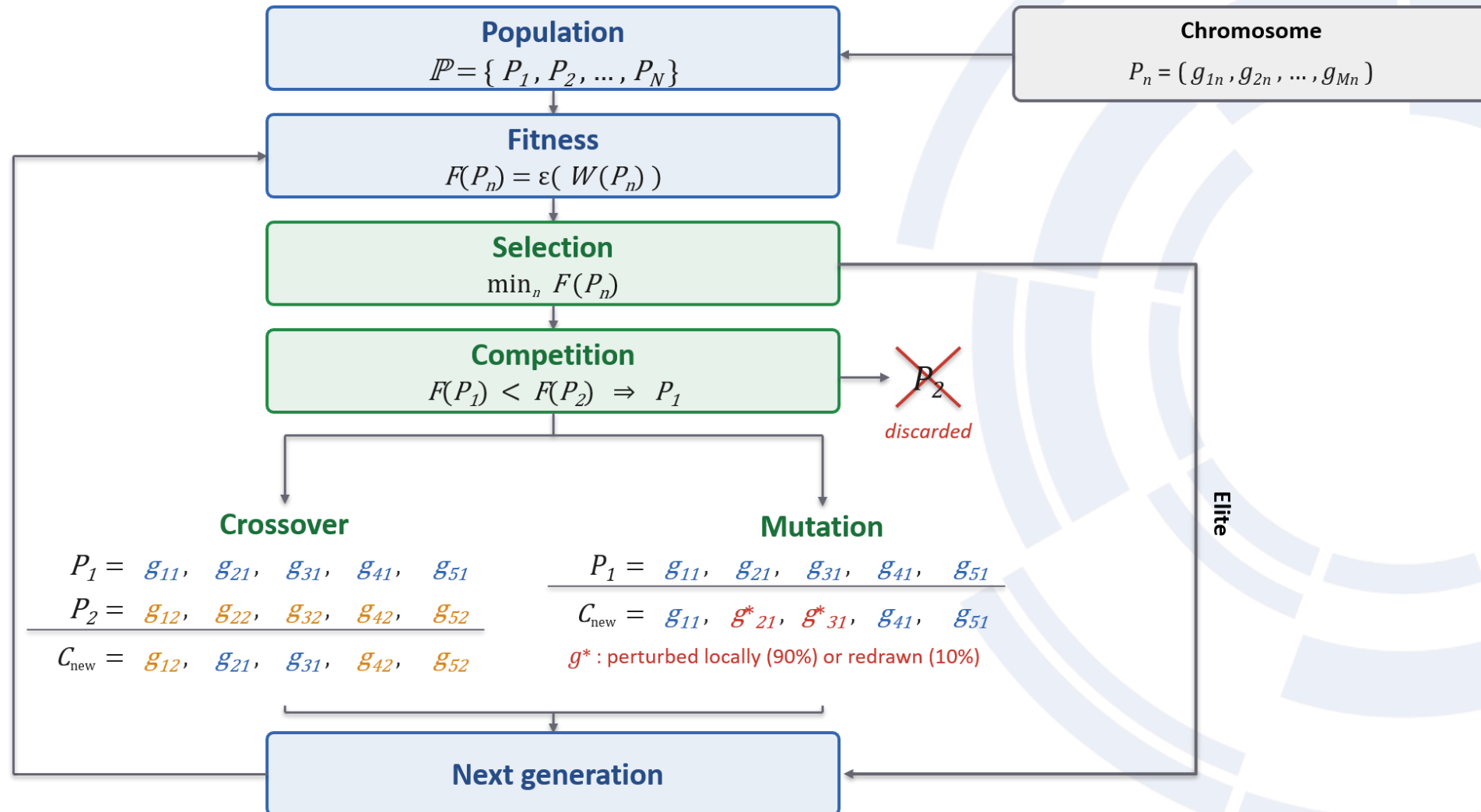


How to select optimal Geometry?





Genetic algorithm is a technique to generate optimized solution via biologically inspired process.





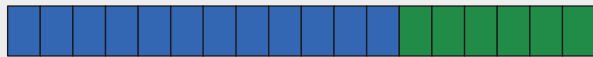
Simple Configurations

A simplified idea is to find the optimal geometries given **camera position and fixed number of lines (80)** by minimizing RMSE between fixed phantom and Tomography reconstruction.

Genes Representation

$$N = 50 \quad M = 86$$

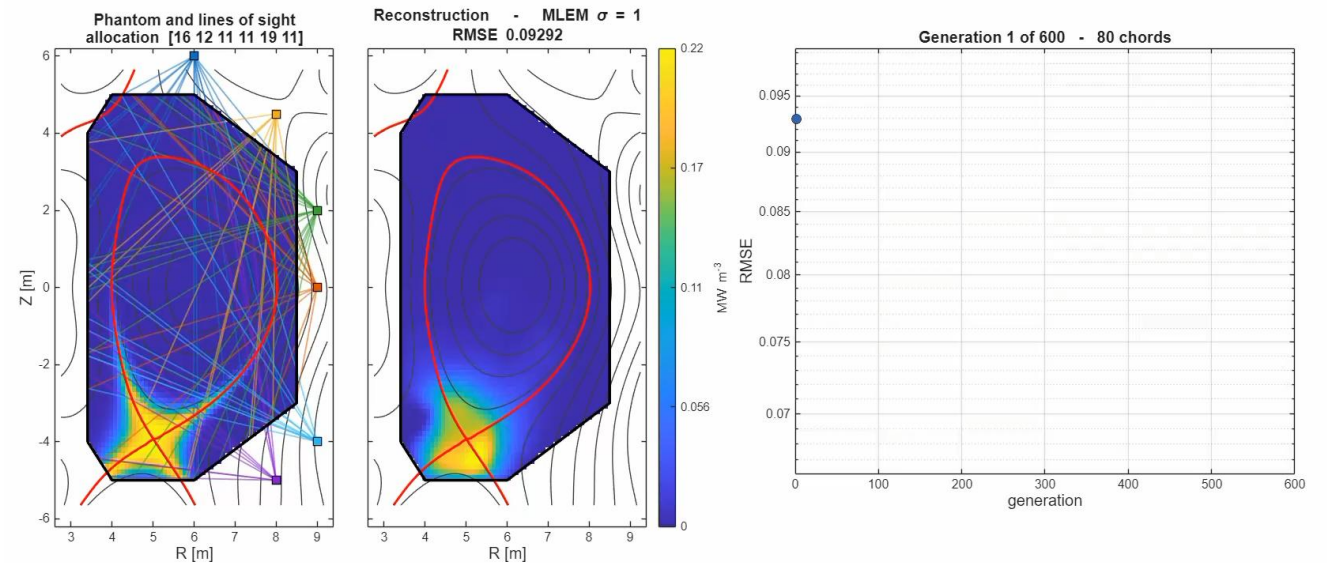
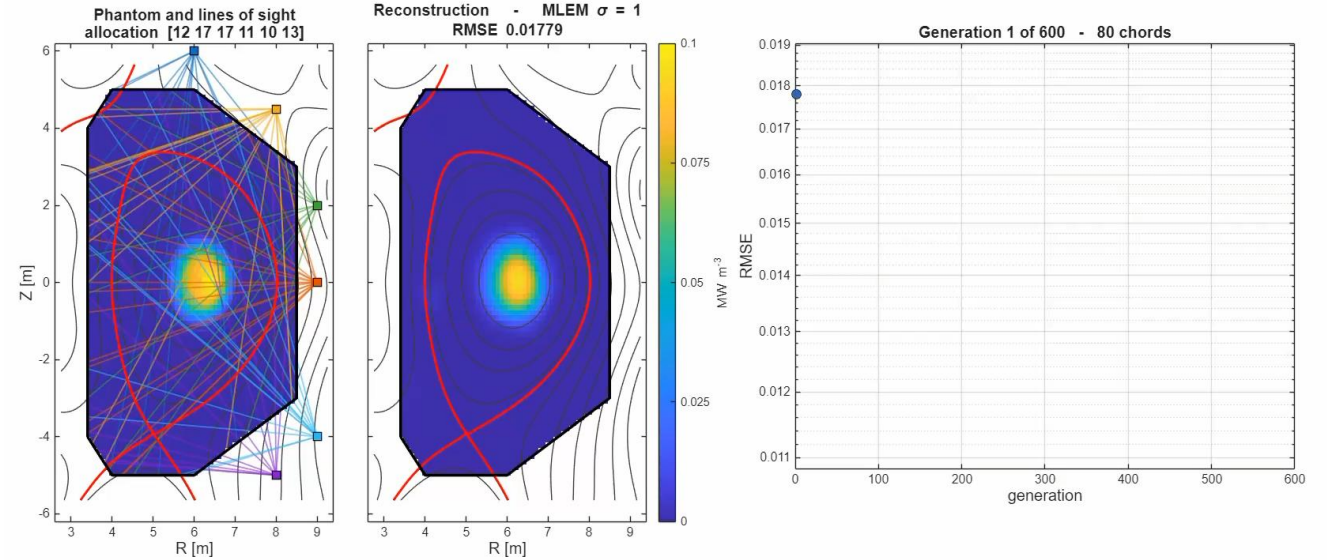
$$P_n = [u_1..u_{80} \mid n_1..n_6]$$



Angles | Number of Lines, per camera

Fitness

$$F = RMSE(Phantom, Reconstruction)$$





Fan configuration

The optimal conditions given the fixed camera position can also be established as the optimal number of lines given in a fan geometry.

Genes Representation

$N = 50$ $M = 18$

$P_n = [a_1..a_6 \mid p_1..p_6 \mid n_1..n_6]$

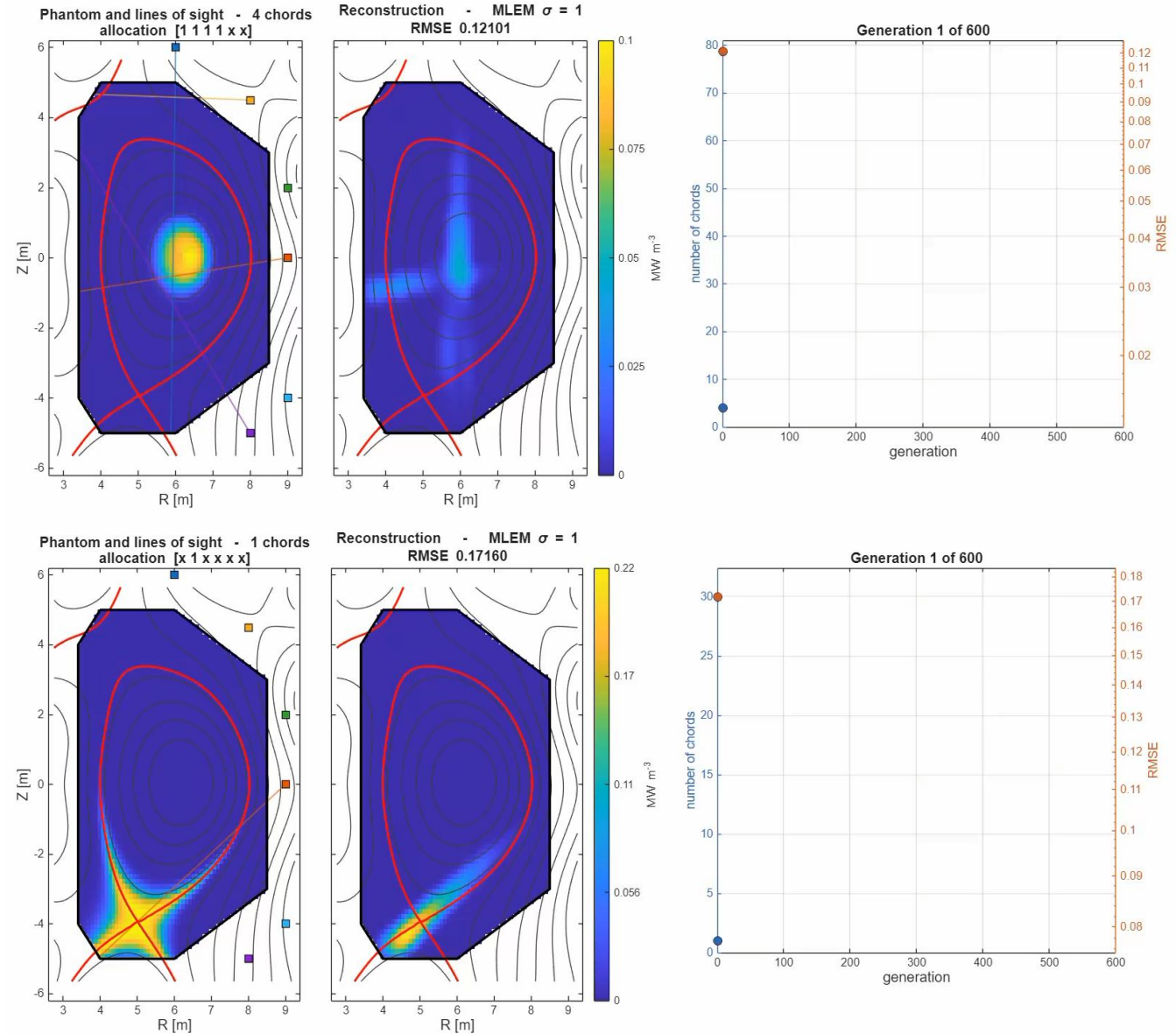


axis | pitch | channels, per camera

Fitness

$$F = AIC = 2n_{pixels} \log(RMSE) + 2k$$

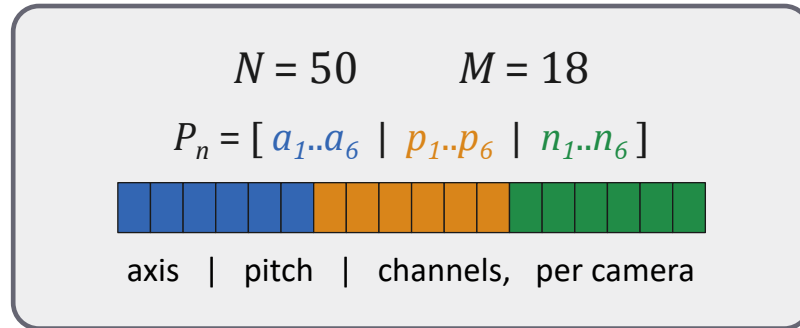
$k = \text{number of los}$





Determining a generalized geometry can be done by exploring the evolution among representative phantoms.

Genes Representation

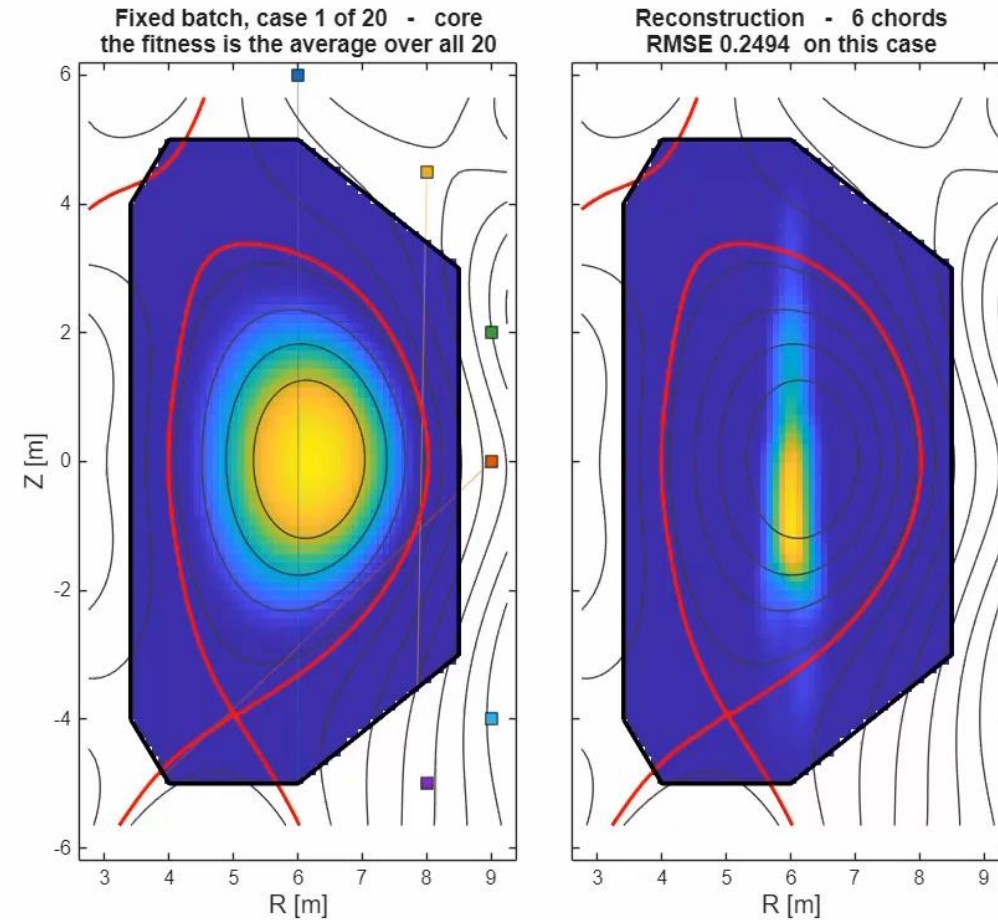


Fitness

Each element reconstructs 20 phantoms

$$F_N = 2 n_{pixels} (\text{mean}(\log(RMSE)) + 2 k)$$

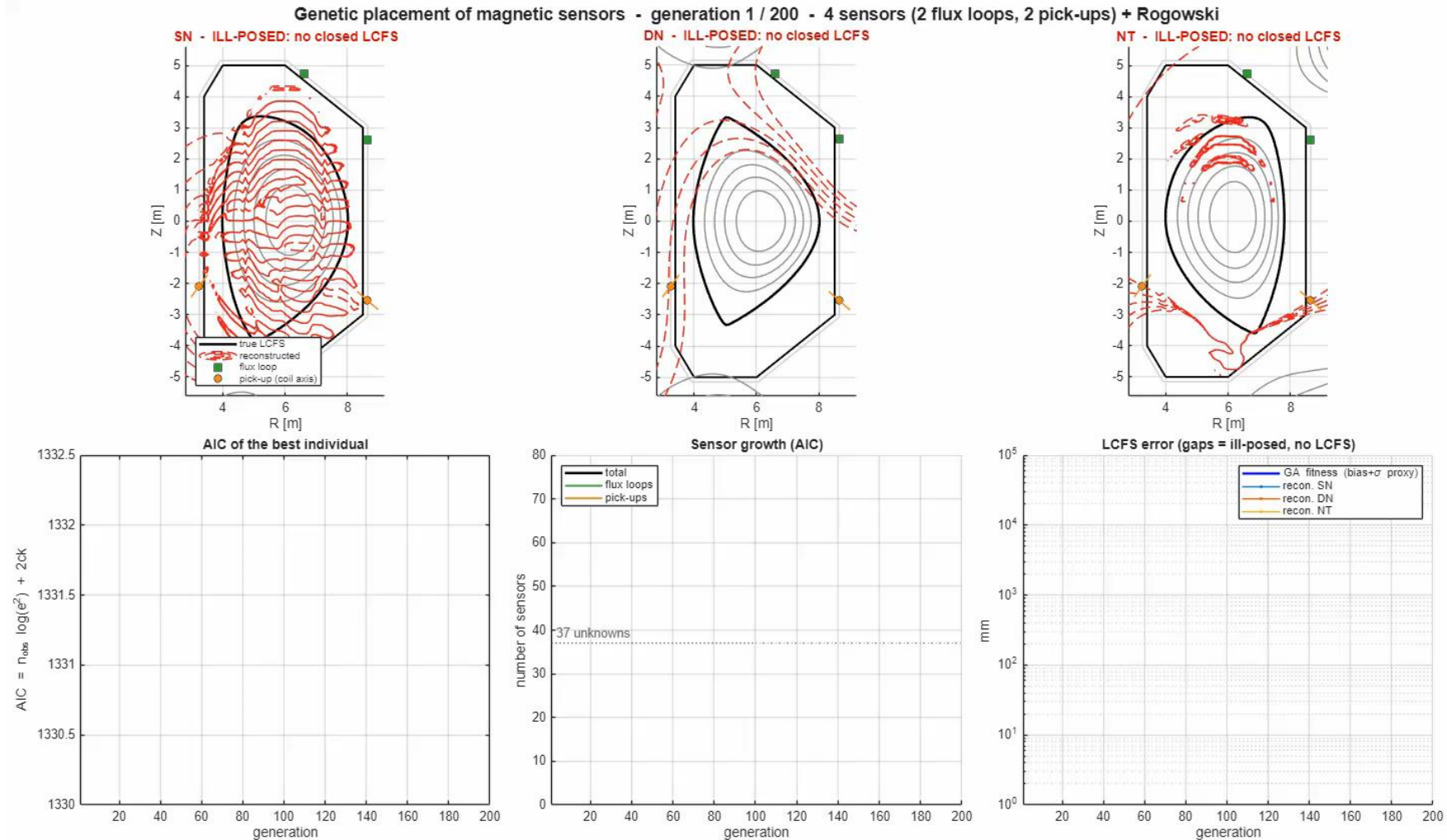
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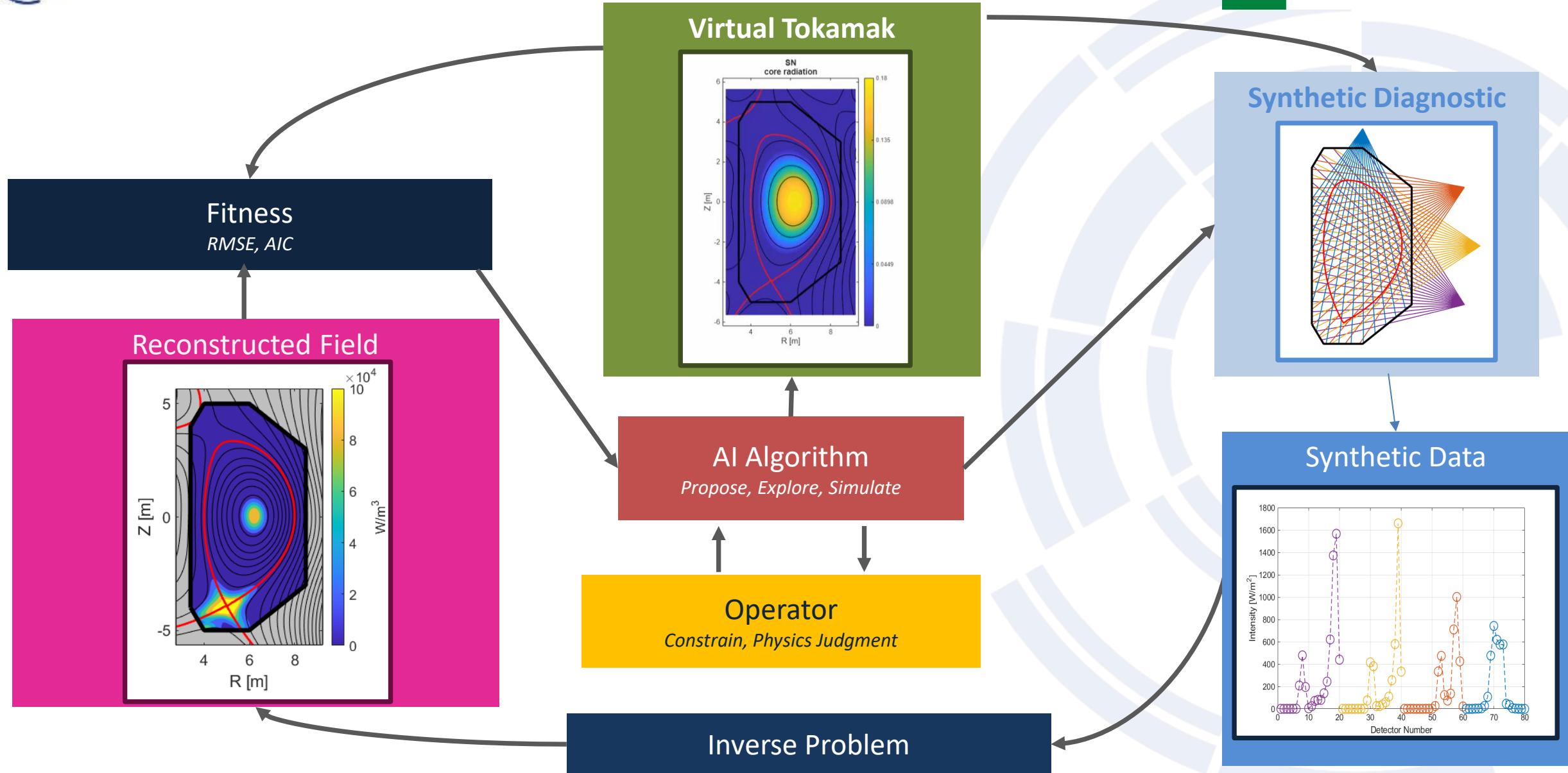
Equilibrium Reconstruction

The same approach can be used for different diagnostic systems where inverse problems have to be solved.





AI-Enhanced Diagnostic Design





- The design of tokamak diagnostics involves a trade-off between measurement quality and engineering constraints.
- Diagnostics relying on **inverse problems** require careful investigation to ensure accurate and reliable reconstructions despite the limited information available from measurements.
- **Synthetic diagnostics** can significantly improve the diagnostic design process by providing deeper insight into the relationship between plasma parameters, diagnostic measurements, and reconstruction algorithms.
- This framework also enables the integration of **AI-assisted design** strategies.
- As a first approach, **genetic algorithms** can be employed to optimize sensor placement, with the objective of improving the performance and accuracy of the inversion algorithms.

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