Nonlinear control perspectives in Tokamak plasmas: applications to FTU and JET

Luca Zaccarian

University of Rome, Tor Vergata (Italy)

With FTU plasma control team, CREATE group, JET plasma operation group

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Advantages of nonlinear control solutions

- May overcome **intrinsic limitations** of linear control (eg, overshoots, disturbance rejection, etc)

- Can handle **soft and hard constraints** more efficiently

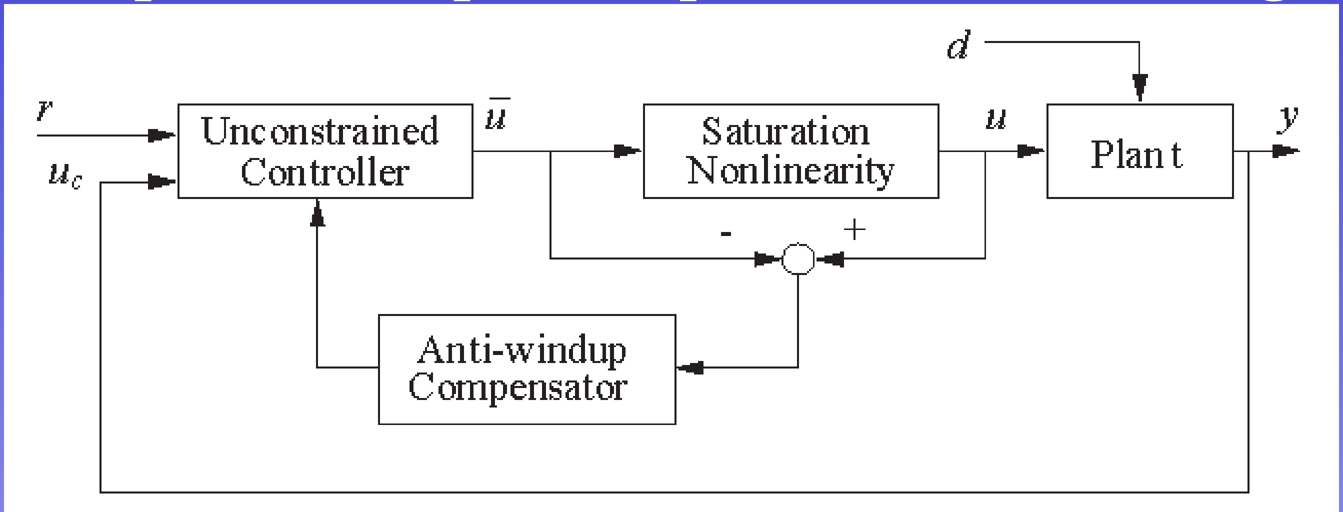
- Can directly address **nonlinearities** in a plant (saturations, quantization, general nonlinearities)

- Allows bumpless **switching** between different controllers

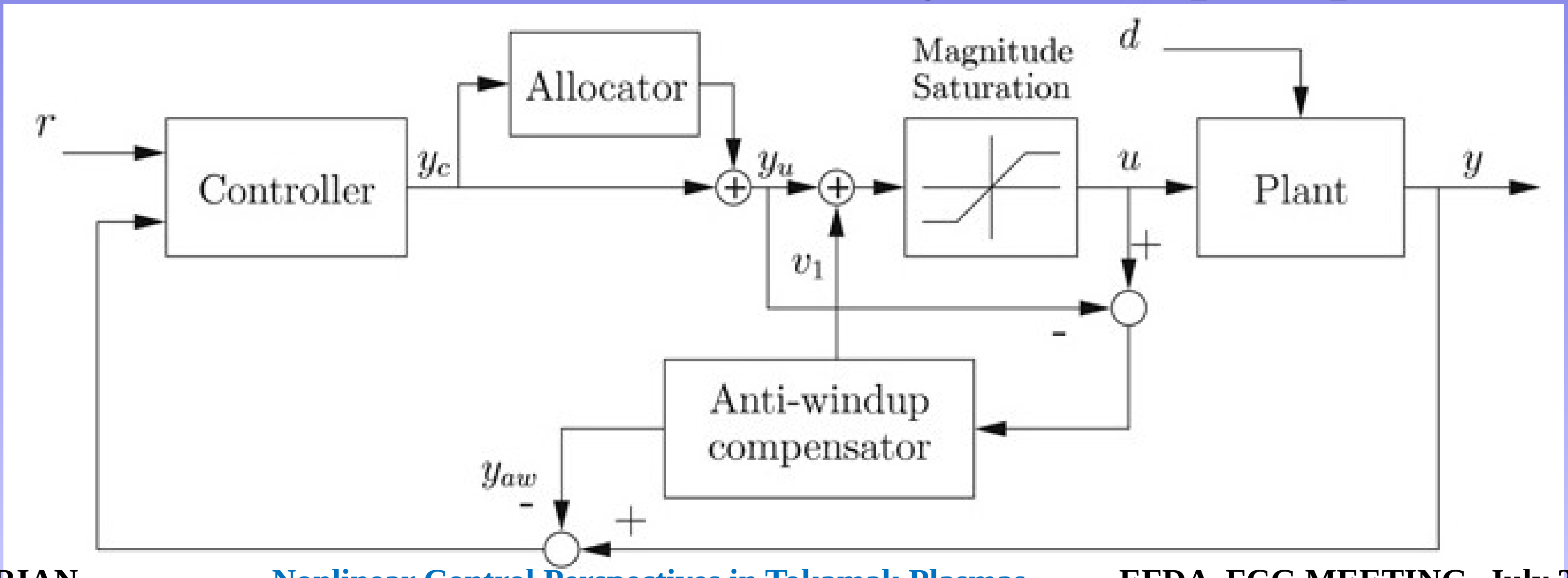
- Often **small extensions** and modifications of substantially linear control schemes lead to **large** stability and performance improvement

Handling input nonlinearities

- Anti-windup: address plant input distortion during transients

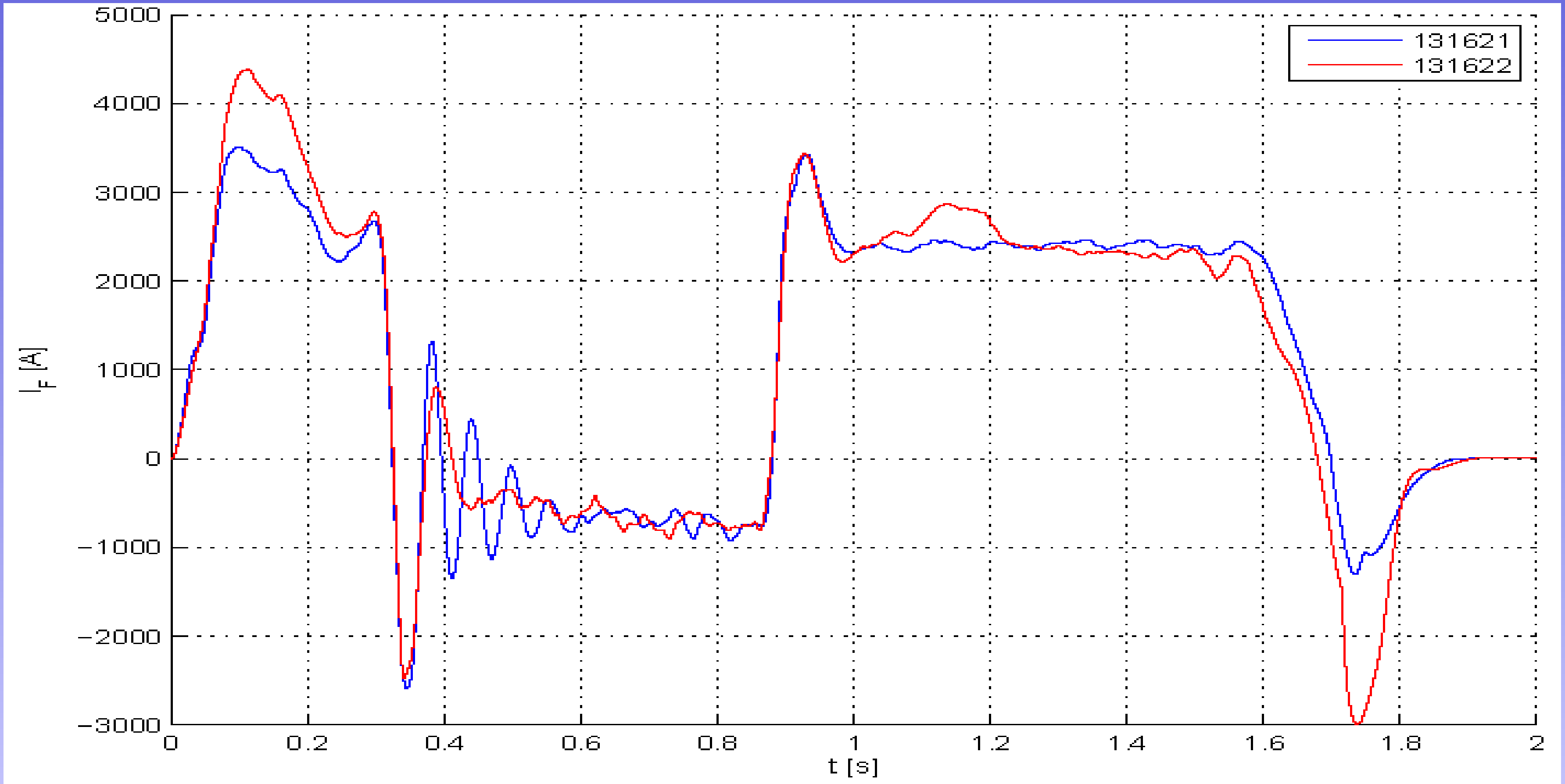


- Dynamic allocation: address steady-state input specs



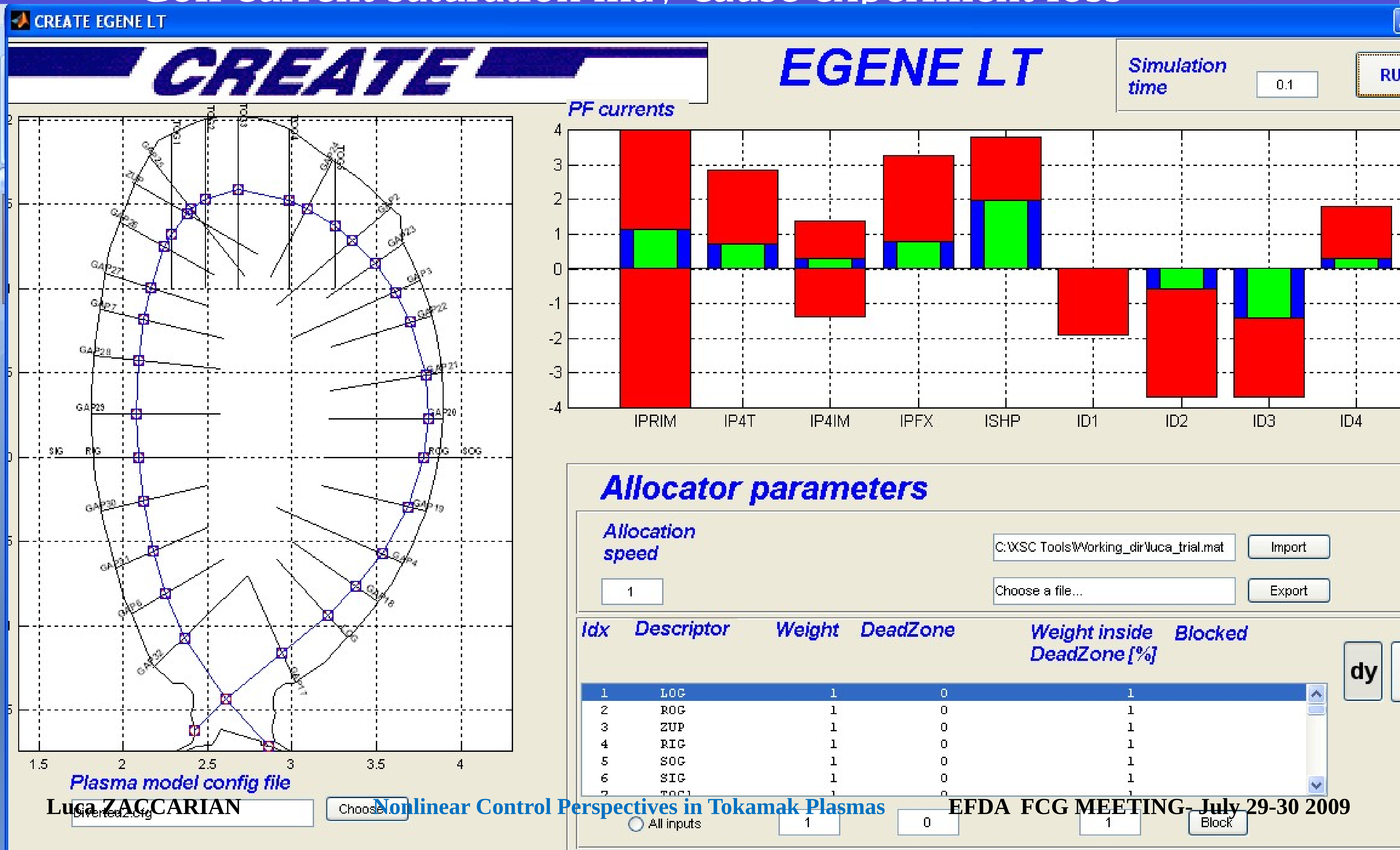
Anti-windup application: FTU

- Small signal nonlinearity in current control of F coils
- Circulating current in thyristor bridges causes nonlinear response and destabilizes the closed-loop
- Anti-windup solution recovers closed-loop stability



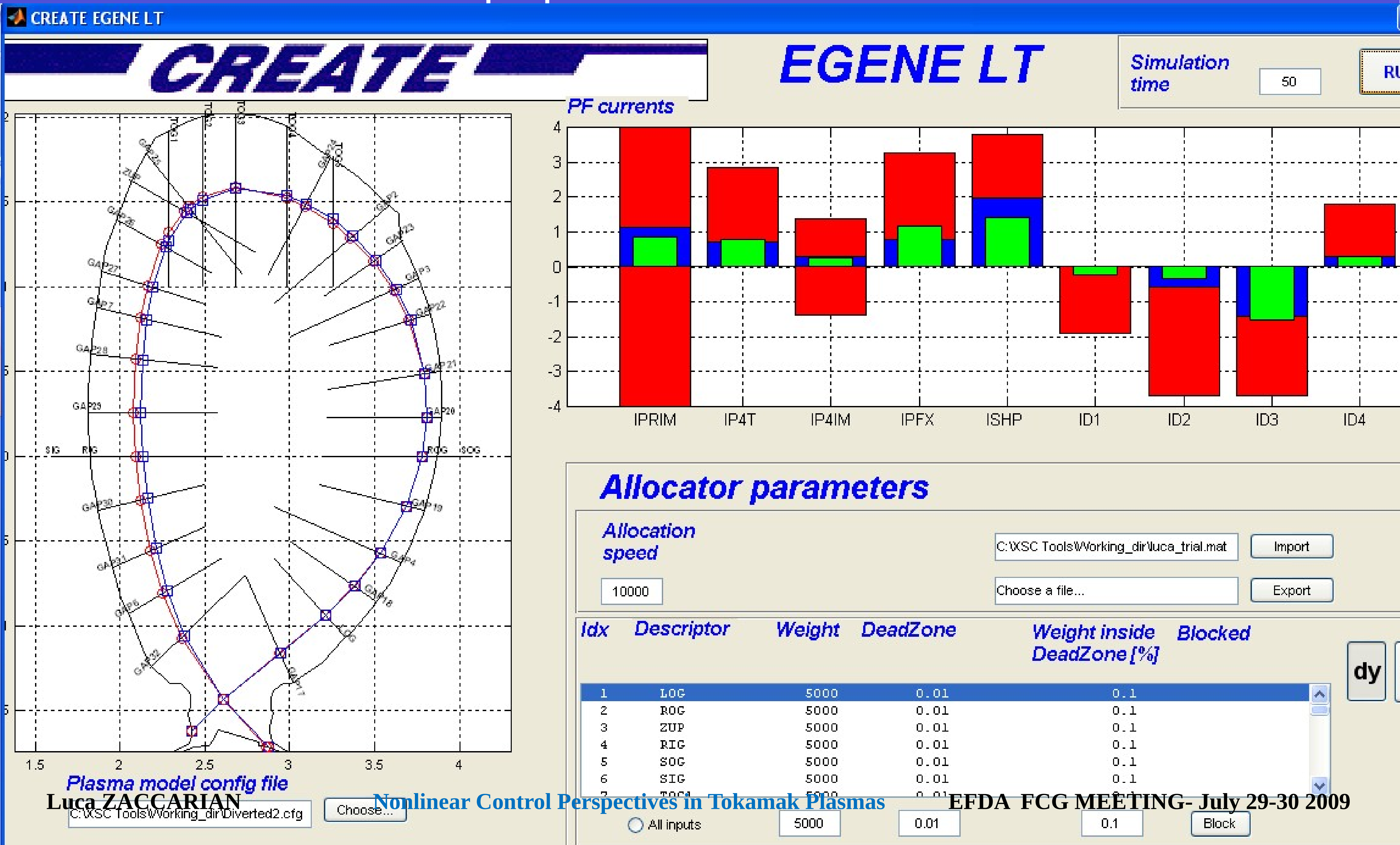
Dynamic allocation application: JET

- Coil current saturation may cause experiment loss



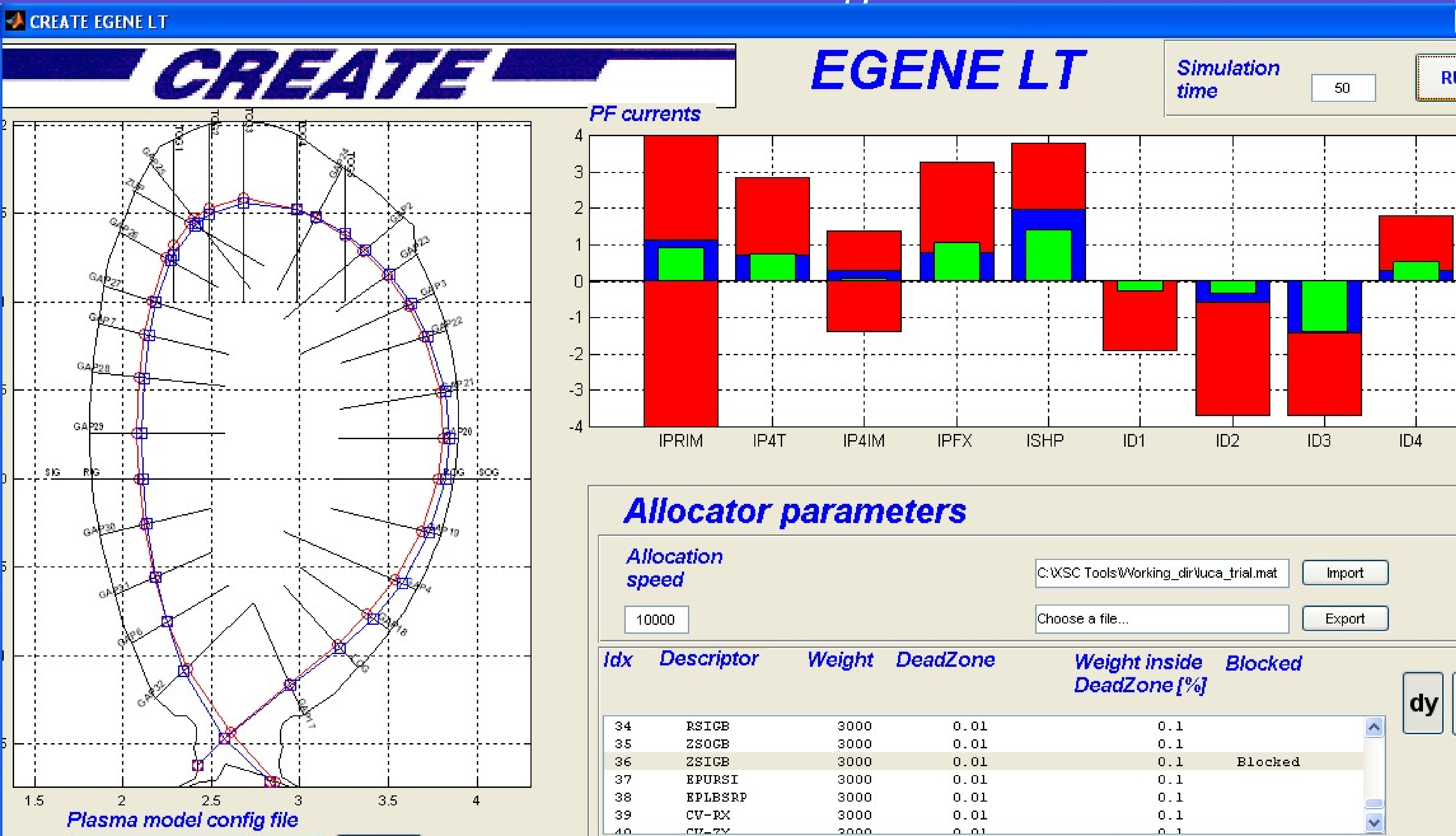
Dynamic allocation application: JET

- Trade in some shape performance to move coils out of sat



Dynamic allocation application: JET

- Similar tools allow to achieve elongation control at FTU



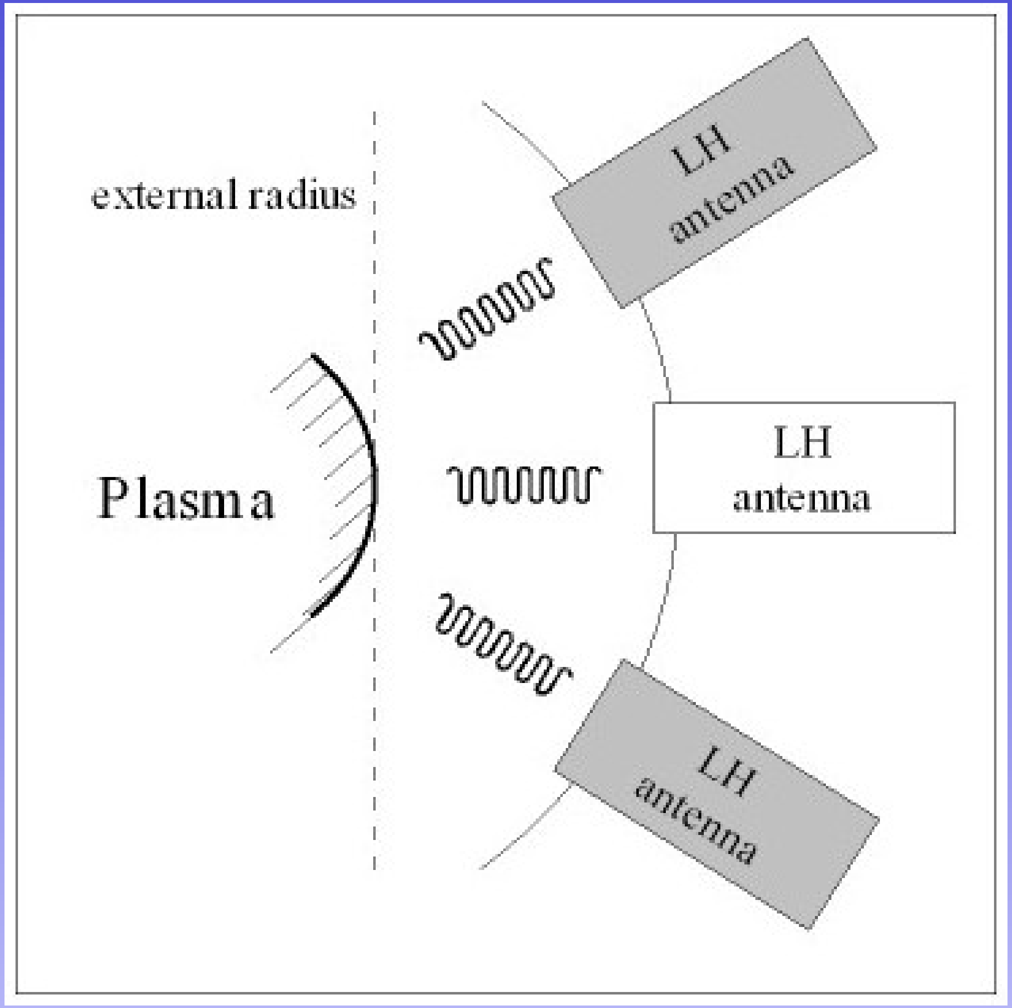
FTU: NL extremum seeking application

Framework:

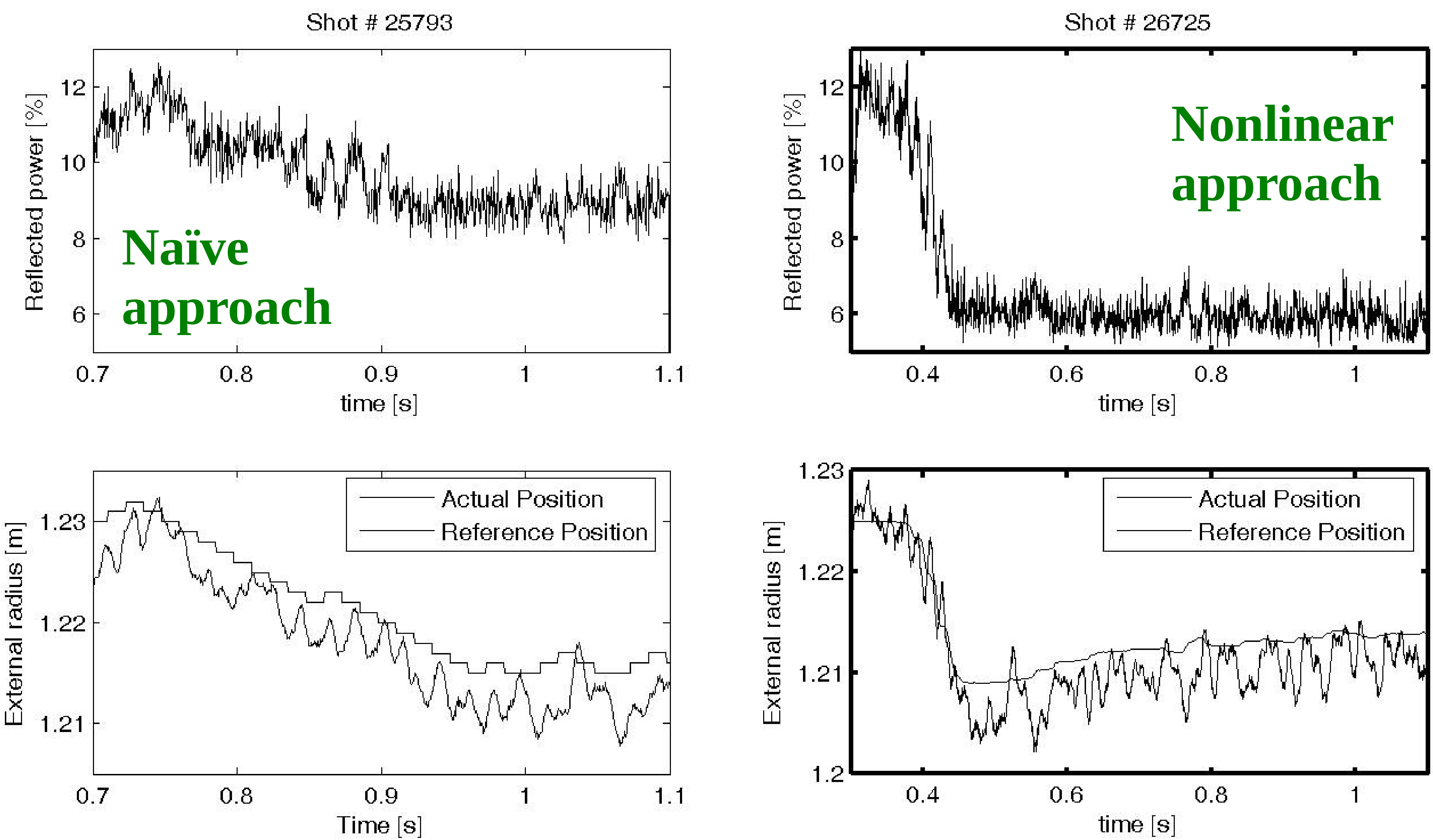
Additional RadioFrequency heating injected in the plasma by way of Lower Hybrid (LH) antennas: plasma reflects some power

Goal:

Optimize coupling between the Lower Hybrid antenna and tha plasma, during the LH pulse

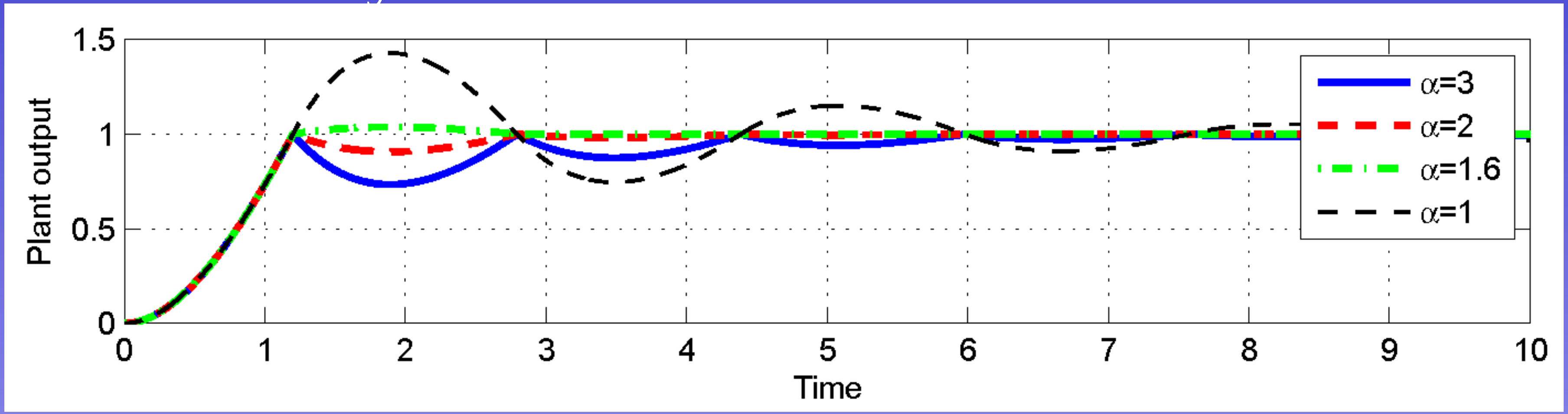


Nonlinear extremum seeking for RH heating

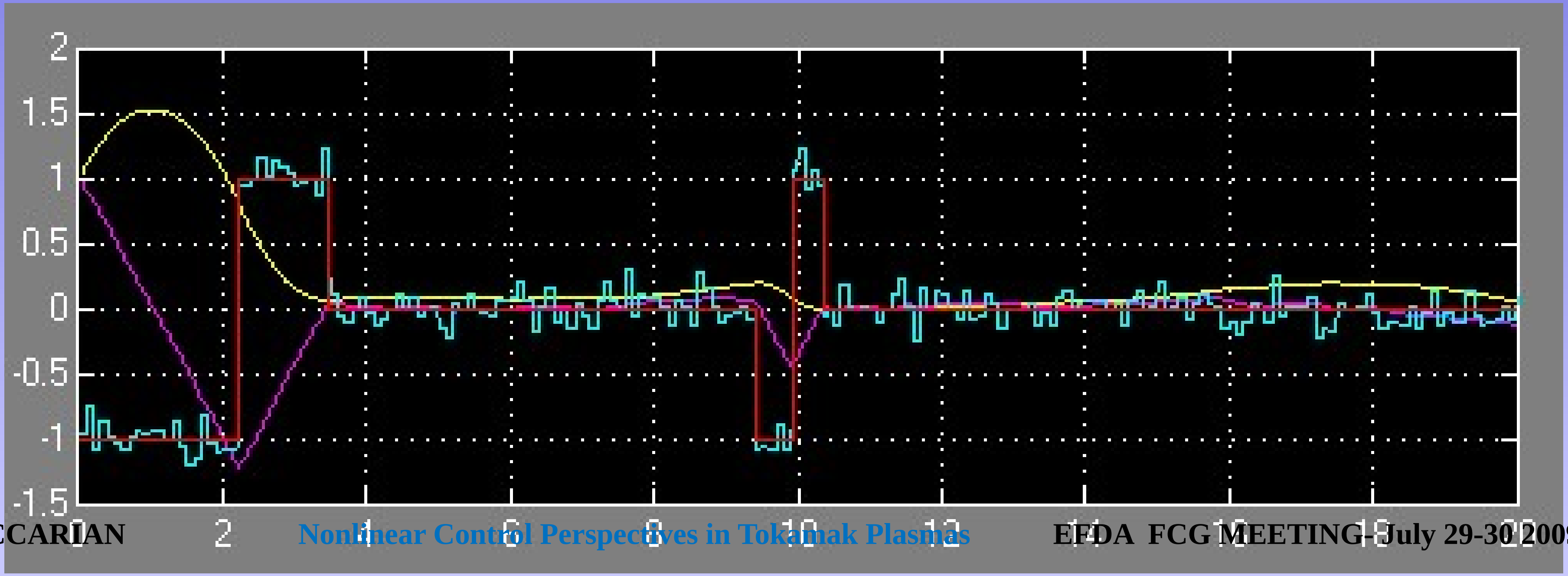


Additional promising NL techniques

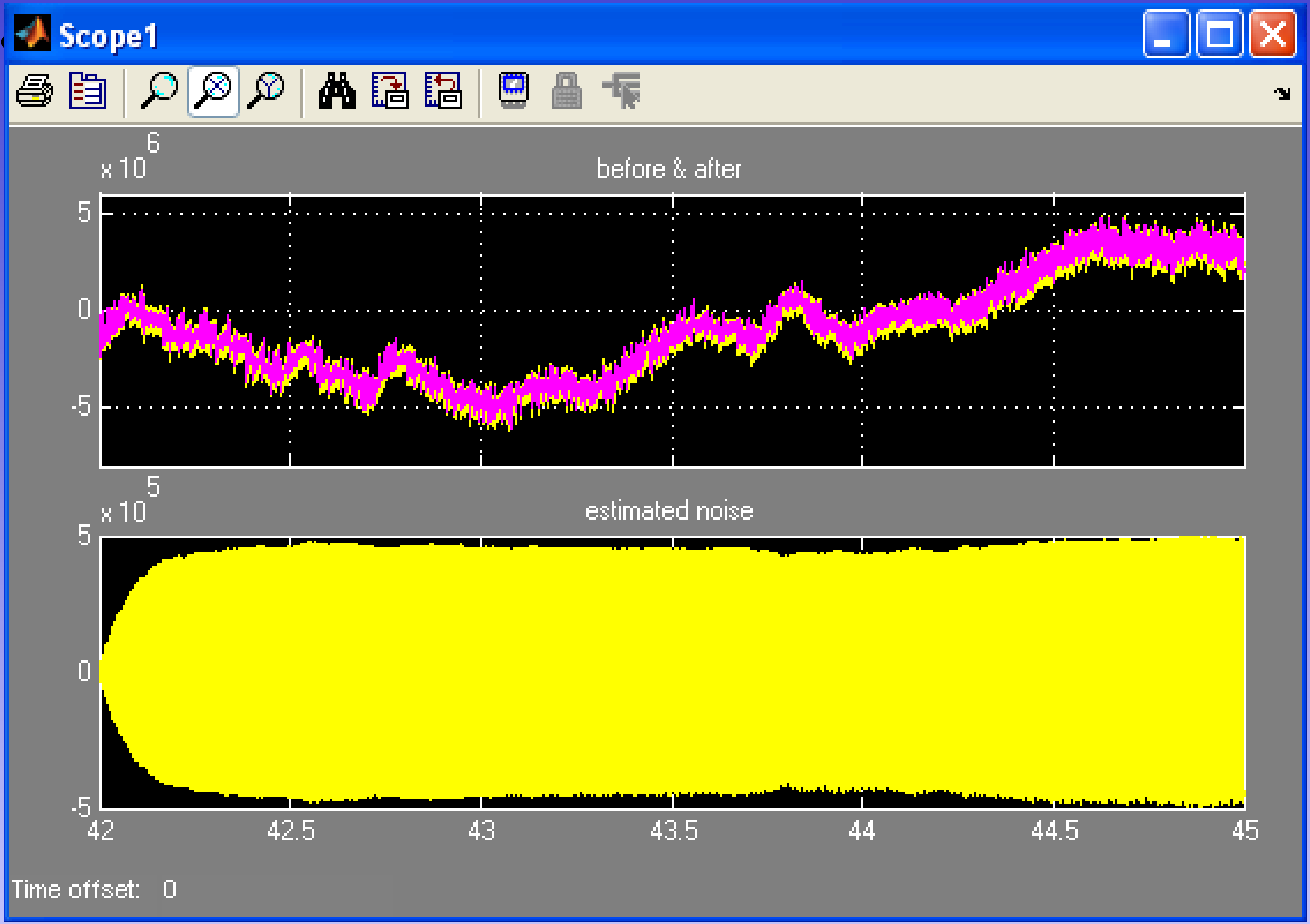
- Reset control systems: overcome limitations of linear sols



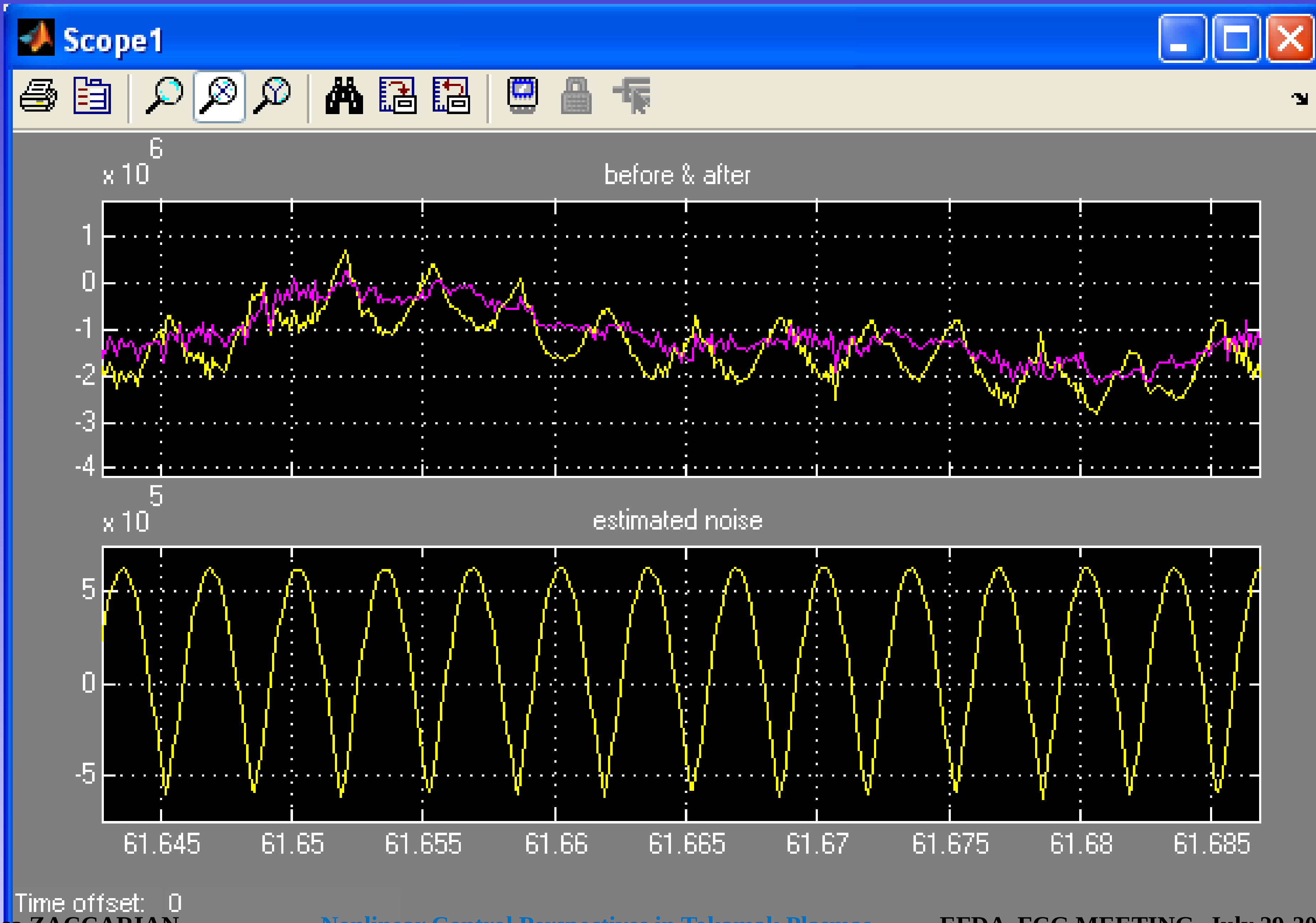
- Quantized actuation via (quasi) time-optimal control



Noise suppression via nonlinear filtering



Nonlinear filtering: zoom



Summary

- Nonlinear control solutions have been illustrated on **examples**
  - with input nonlinearities causing **transient** problems
  - with input nonlinearities causing **steady-state** problems
  - in the **extremum seeking** context maximizing RFH efficiency

- More generally **several tools are available** and can be used to improve upon what is achieved by linear tools

- Typically, **interaction** between control theorists and applied control people uncovers directions where **nonlinear control can help**