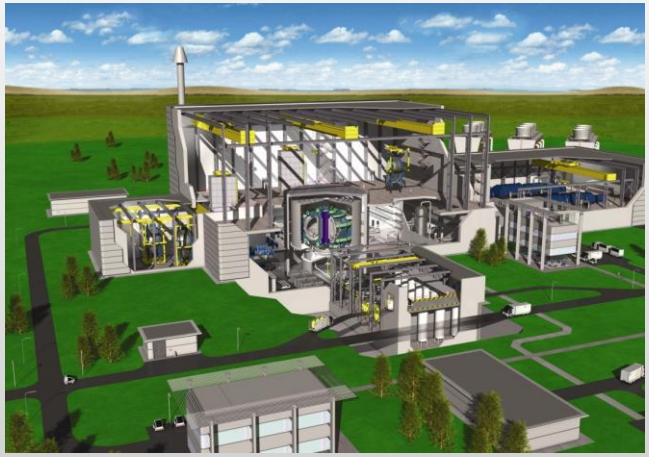
Fusion Plasma topics



Gergő Pokol and colleagues

MŰEGYETEM 1782

BME Institute of Nuclear Techniques

BME-TTK Fizikus Témaválasztó Nap

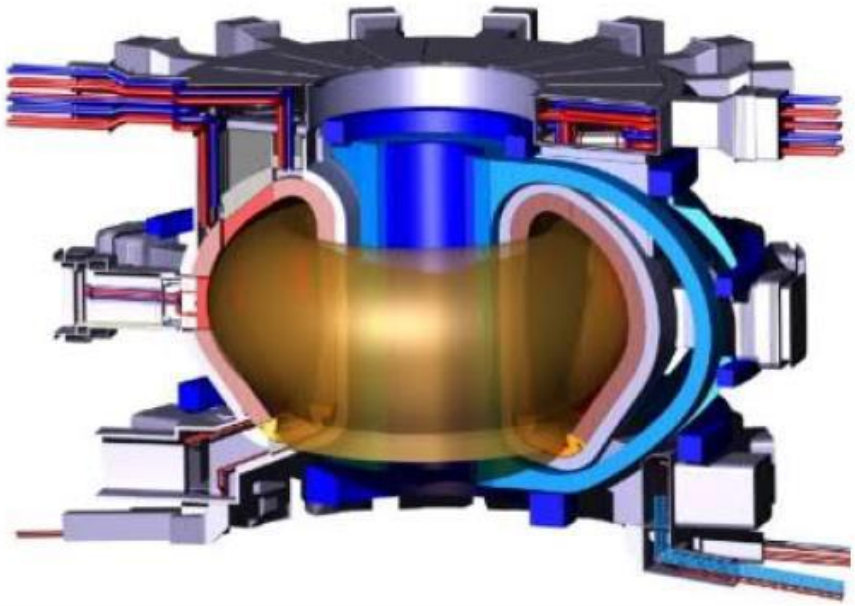
2025. november 26.

EU Fusion Roadmap (2012, 2018)

EU-DEMO demonstration power plant conceptual design phase

Conservative approach: well-established technologies

- **Pulsed tokamak-**type device with low-temperature superconductors
- **Aiming early identification of show-stoppers → Disruptions**



Parameters	DEMO G1
R_0, a (m, m)	9, 2.9
A	3.1
B_0(T)	5.9
I_p (MA), q	18, 3.6
H	1.1
t_{burn} (hrs)	2
f_{bs} (%)	39
P^*_{CD} (MW)	<10
P_{fus} / $P_{e,net}$ (MW)	2014, 500

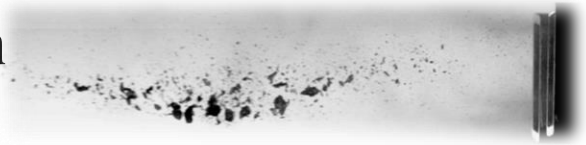
Disruptions

- **Plasma terminating events**
  (ms time scale)
  1. Plasma temperature drops
  2. Plasma resistivity rises
  3. Plasms current drops
  4. Large electric field due to self-induction of plasma loop
  5. Current in wall or relativistic electron beam

- **Risks device integrity:**
  - Rapid **heat deposition**
  - Large **current in wall structures**
  - **Relativistic electron beam**

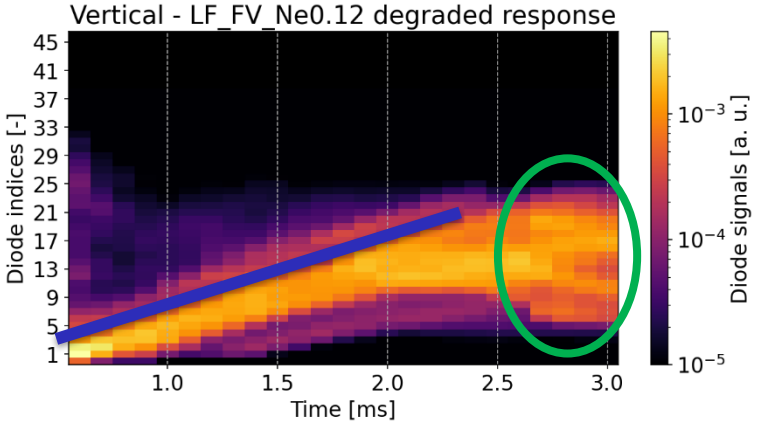
[Capone MSc 2014]

Shattered pellet injection

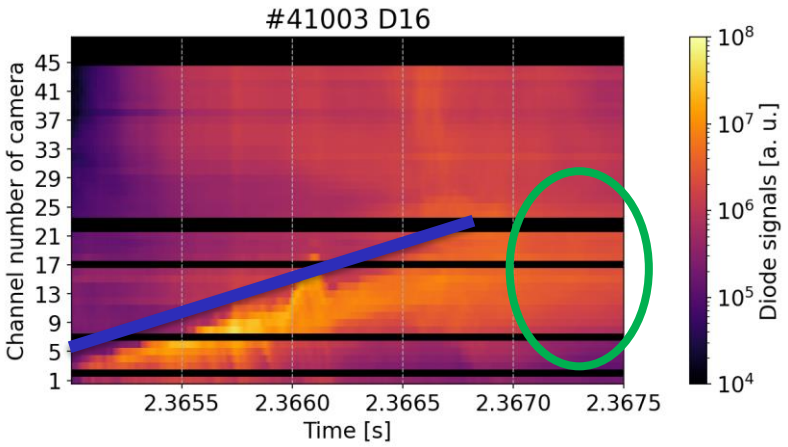


- Modelling
  - DREAM disruption simulator for DEMO [Lengyel BSc 2023]
  - Successive injection of different types of pellets
  - No successful strategy in the nuclear phase!
- Validation to ASDEX-Upgrade experiments
  - Synthetic diagnostics for AXUV bolometers [Lengyel EPS 2025]
  - Non-linear MHD simulations + synthetic diagnostics vs. measurements
- SPI hardver R&D @ EK FPL [Réfy Simpózium 2025]

Simulation

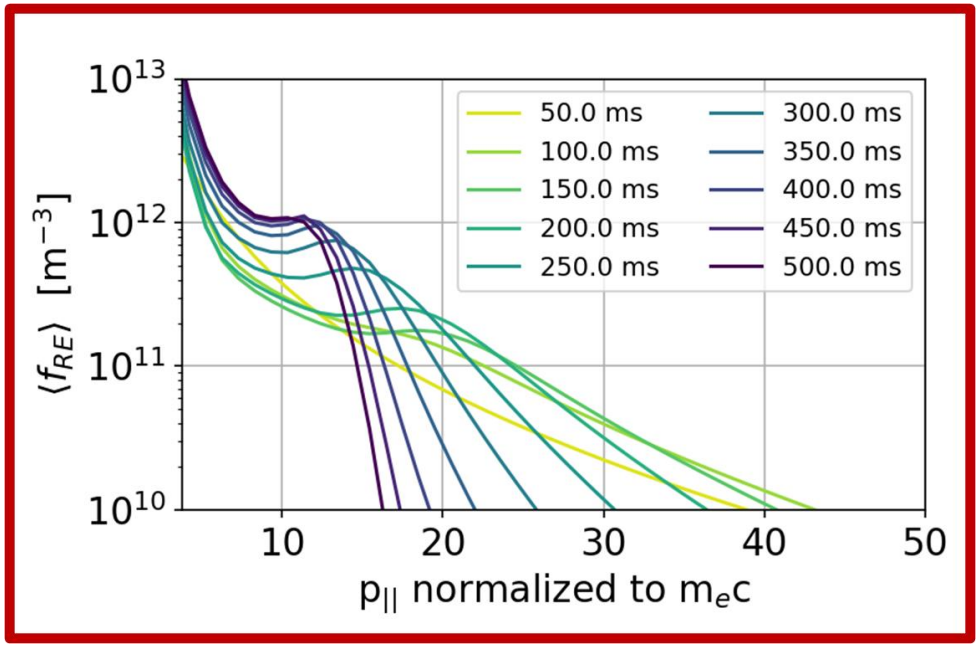


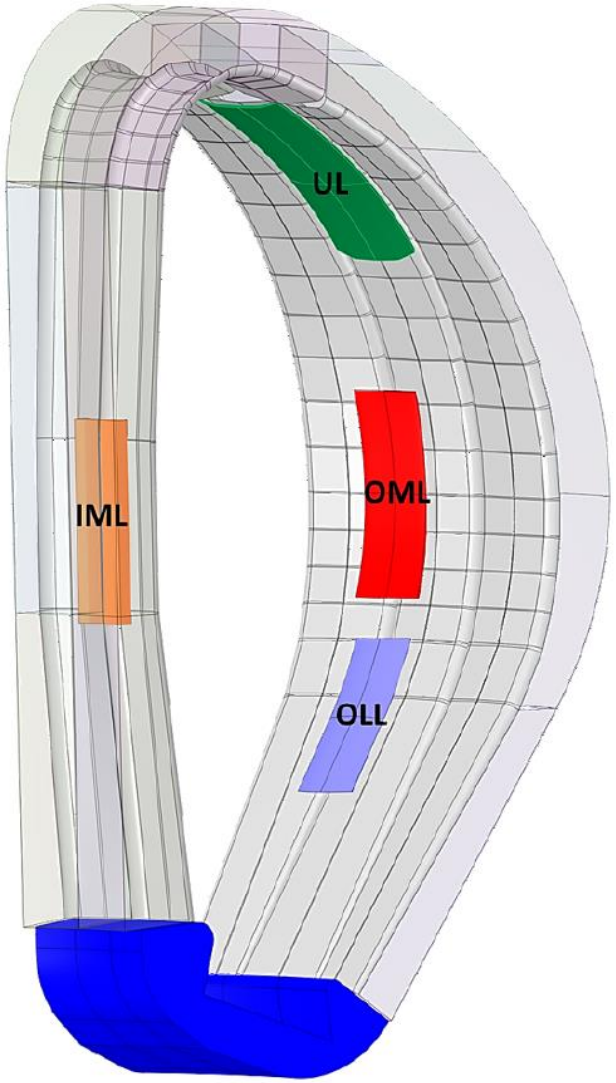
Measurement



Sacrificial limiters

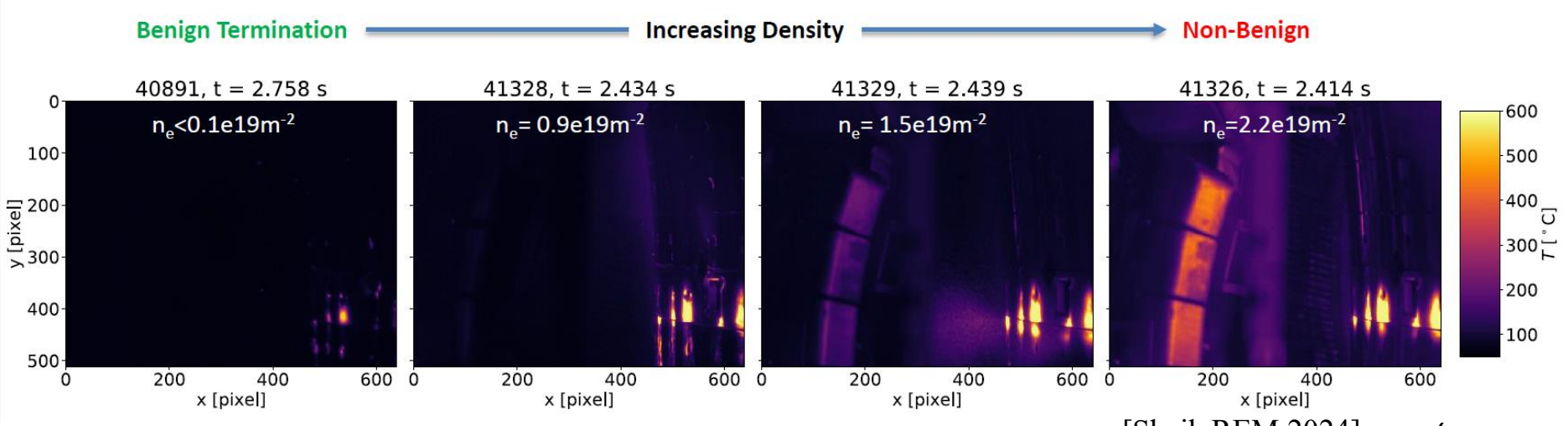
- Simulation of **electron beam impact on wall elements** [Ratynskaia NF 2025]
- **Modelling of electron distribution functions with** DREAM [Lengyel TTF 2025]





Benign beam termination

- **Inhibiting electron beam impact**
- Formula:
  1. Stabilize beam position
  2. Wipe out impurities → pure hydrogen plasma
  3. **Hydrogen recombination → electron beam in neutral gas**
     - **Measurement of hydrogen gas density with beam emission spectroscopy?** [Tőkési, Asztalos, Angyal, Pokol 2025]
  4. Magnetic field of beam destabilizes → scattering of beam electrons
  5. No plasma background → no re-generation of electron beam

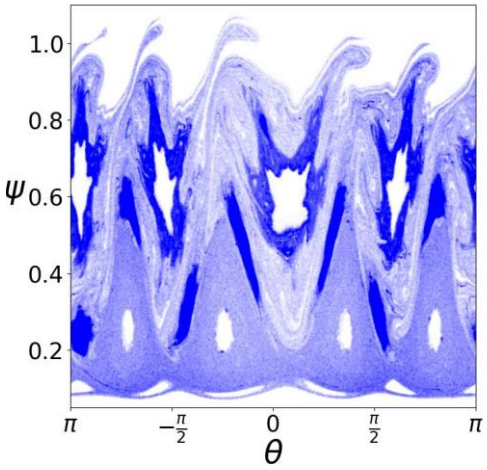


[Sheik REM 2024]

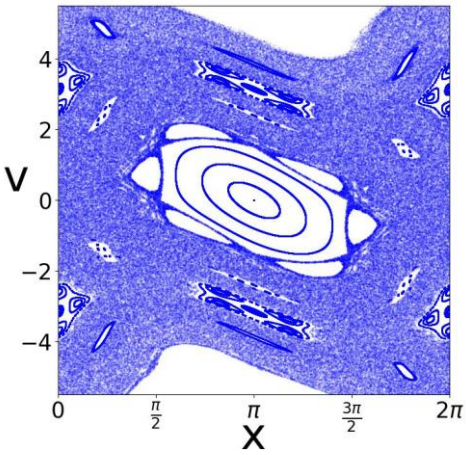
Resonant magnetic perturbations

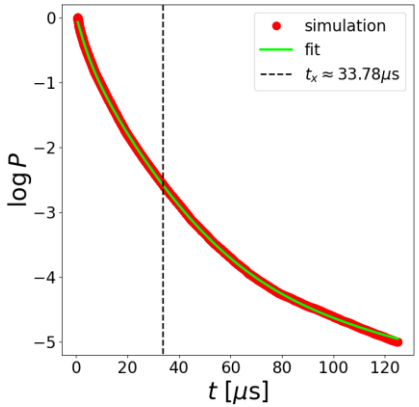
- Stochastization of magnetic geometry by external coils or internal perturbations → **beam electron losses**
- Incomplete stochastization
- **Non-linear MHD simulations:** JOREK
- Modelling of losses in **analogy with trajectories of chaotic systems** [Jánosi TFF 2025]
- **Analogy with transient chaos?**

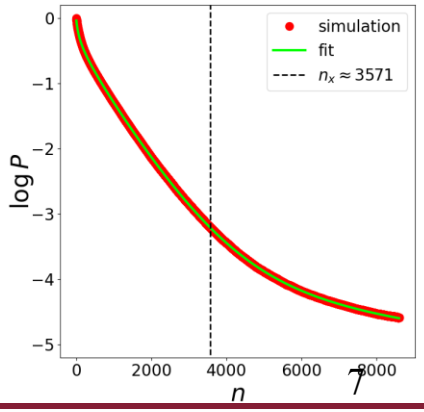
JOREK



Standard map

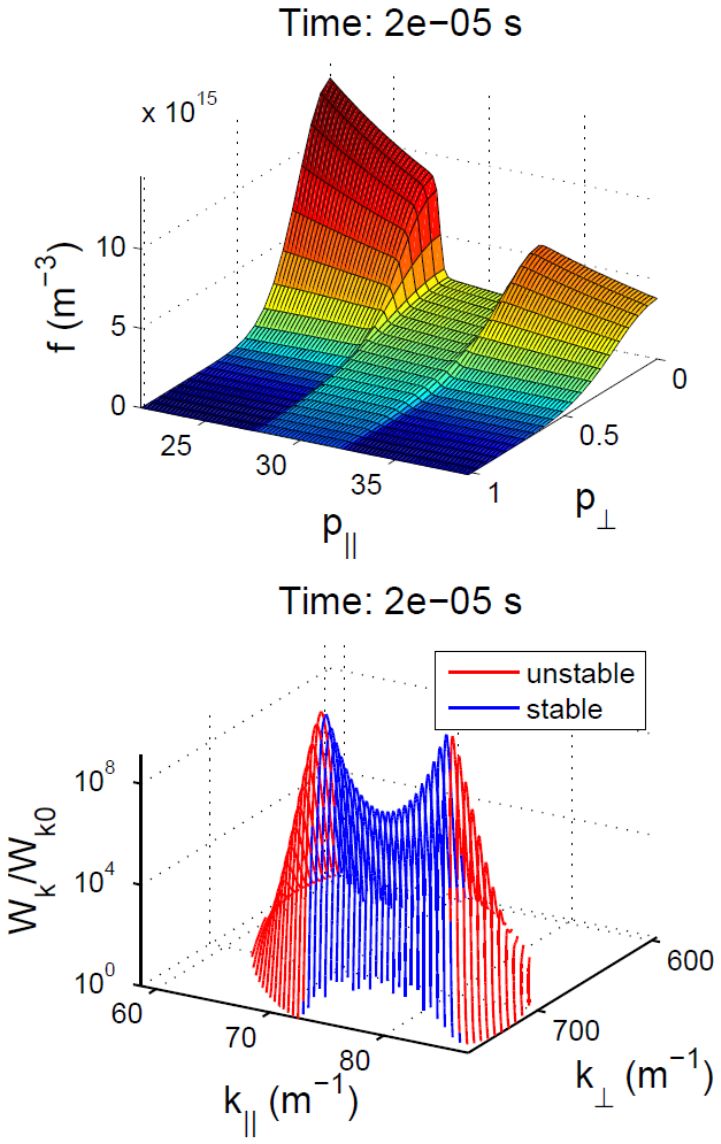






Resonant plasma waves

- **Plasma waves** can be destabilized and **cause rapid losses of resonant electrons** [Fülöp PP 2006, Pokol PPCF 2009]
- 2010': **experimental observation for beam-generated waves**
  → beam too strong for effective mitigation
- 2020' (2025): **first experiments with externally injected plasma waves**
  → difficult coupling to plasma, but promising!
- **Participation is planned in experiments and simulations**



Plan B: HELIAS 5-B