Max Planck Institute for Plasma Physics

Runaway electron formation and termination in mitigated ITER disruptions

V. Bandaru*[1], M. Hoelzl[1], F. J. Artola[2], M. Lehnen[2]

[1] IPP Garching, Germany, [2]ITER Organization, Saint Paul Lez Durance, France

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

Motivation

- Runaway electron (RE) formation can affect plasma equilibrium and stability
- MHD activity (stochastization or flux-surface reformation) can in turn affect RE transport/loss
- Plasma MHD ⇄ REs determines the nature of eventual RE loss & impact on the first wall

Aim: Study the non-linear evolution of mitigated disruptions in ITER with runaway electrons

Setup

- 15MA, 15KeV ITER free-boundary equilibrium

Artificial TQ (to $T_{e,axis}$~20eV) + Current flattening

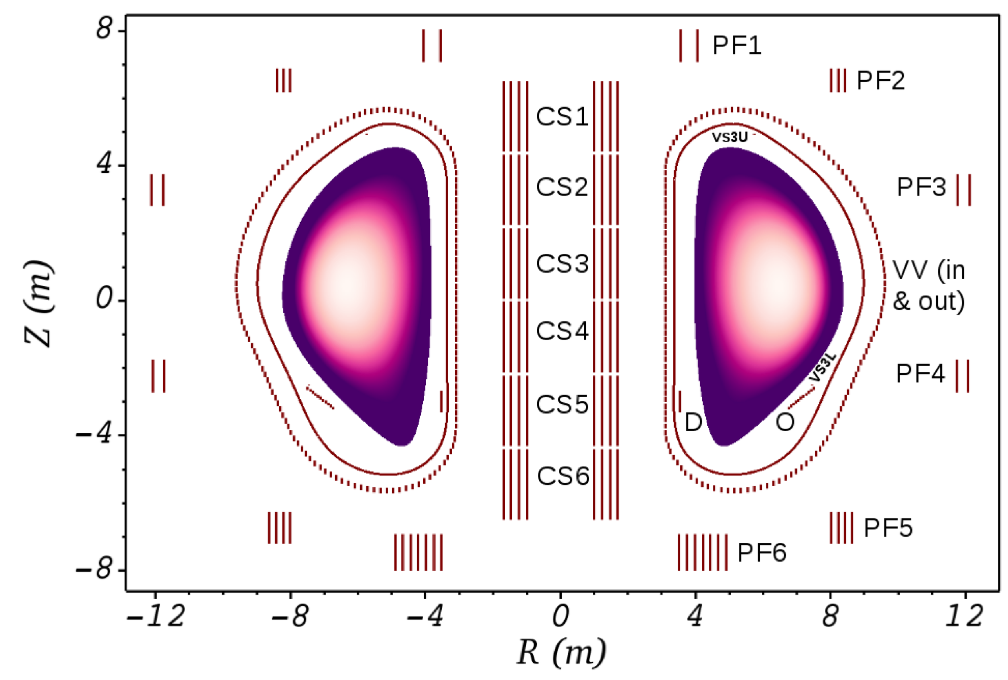
↓

1st injection of Ne+D; + RE seed introduced (uniform)

↓

2nd Ne injection (uniform) or Ne flushout with D injection

Plasma domain and conducting structures



Physical model

- MHD coupled with a runaway electron fluid model [1]
- Impuritites, D-ion and D-neutral densities evolved
- Impurities treated via coronal equilibrium
- RE fluid model
  - Compton, Tritium and Avalanche sources inlcuding effects of partially-ionized impurities [2,3]
  - Transport: Parallel, ExB drift and curvature drift
- Model benchmarked with GO [4] and DINA [5] codes
- Test particle model available allowing to study detailed RE orbits and trapped/passing particle losses [6]

JOREK [7,8]

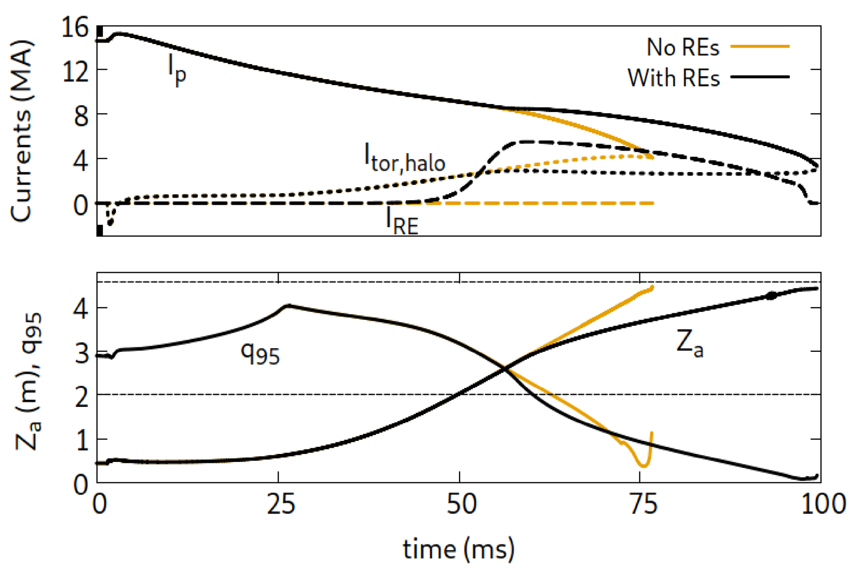
- Non-linear MHD code for tokamak X-point plasmas
- Galerkin FEM with 2D Bezier elements + toroidal Fourier
- Fully implicit time-stepping; preconditioned GMRES solver
- Accuracy: >=4th order in space, 2nd order in time

STARWALL extension [9]

- Free-boundary; includes the effect of coils, walls etc.
- Non-local EM boundary conditions through Green's functions

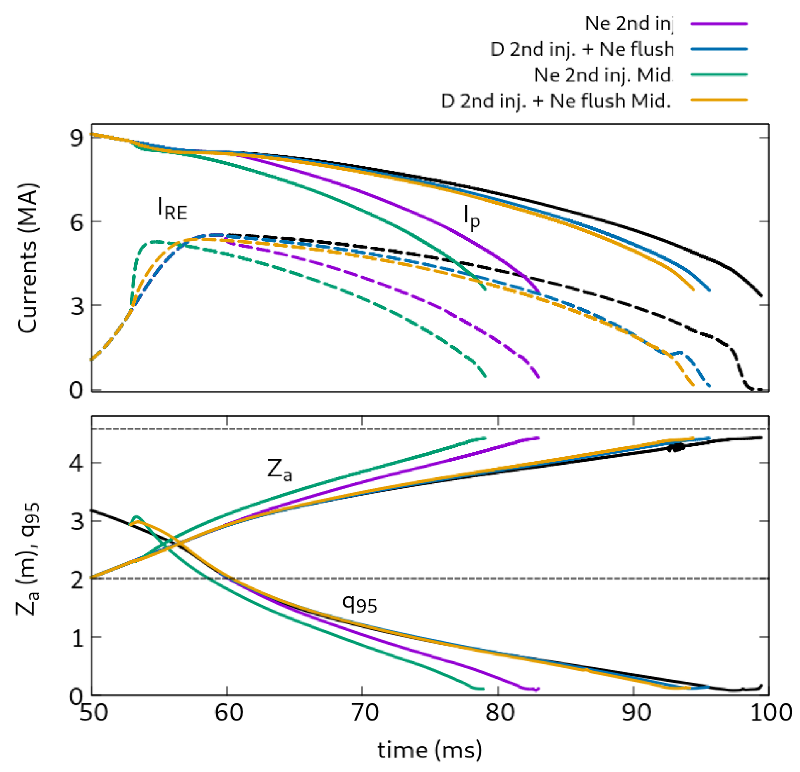
Simulation results

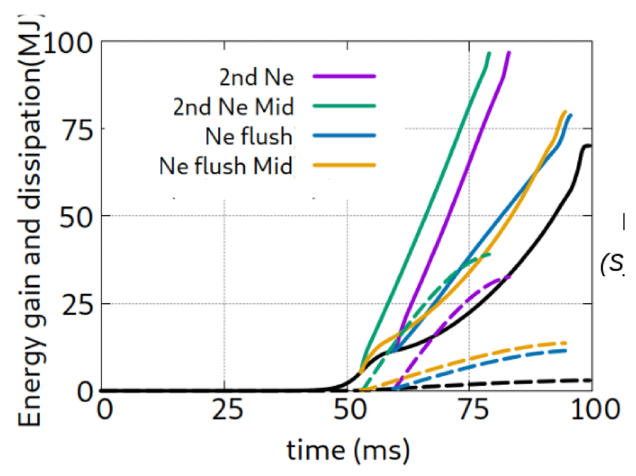
Axisymmetric simulations



- Multi-MA RE beams observed for Ne injections relevant for disruption radiation target in ITER [4]
- RE formation slows down plasma vertical motion
- But I_p at final-loss remains similar

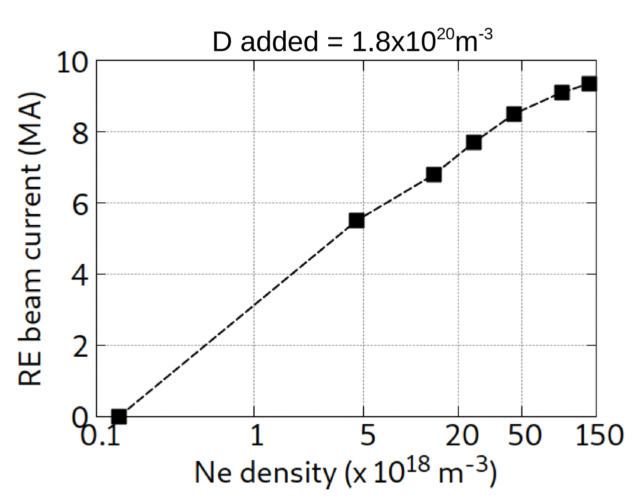
Effect of Ne 2nd injection and Ne flushout

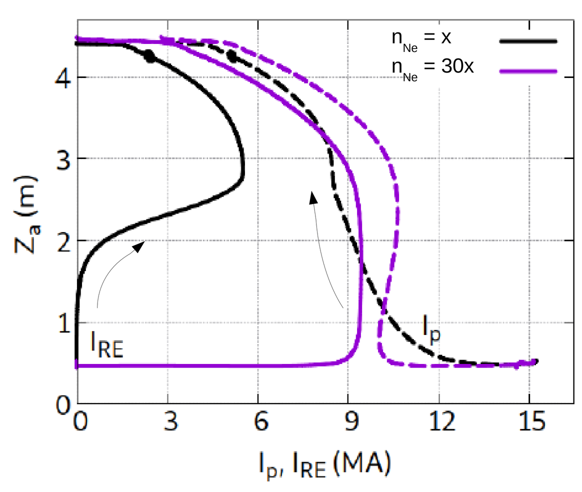




- Ne 2nd injection accelerates RE current decay and plasma motion to wall
- However, undissipated RE energy remains largely similar

Effect of Ne 1st injection quantity



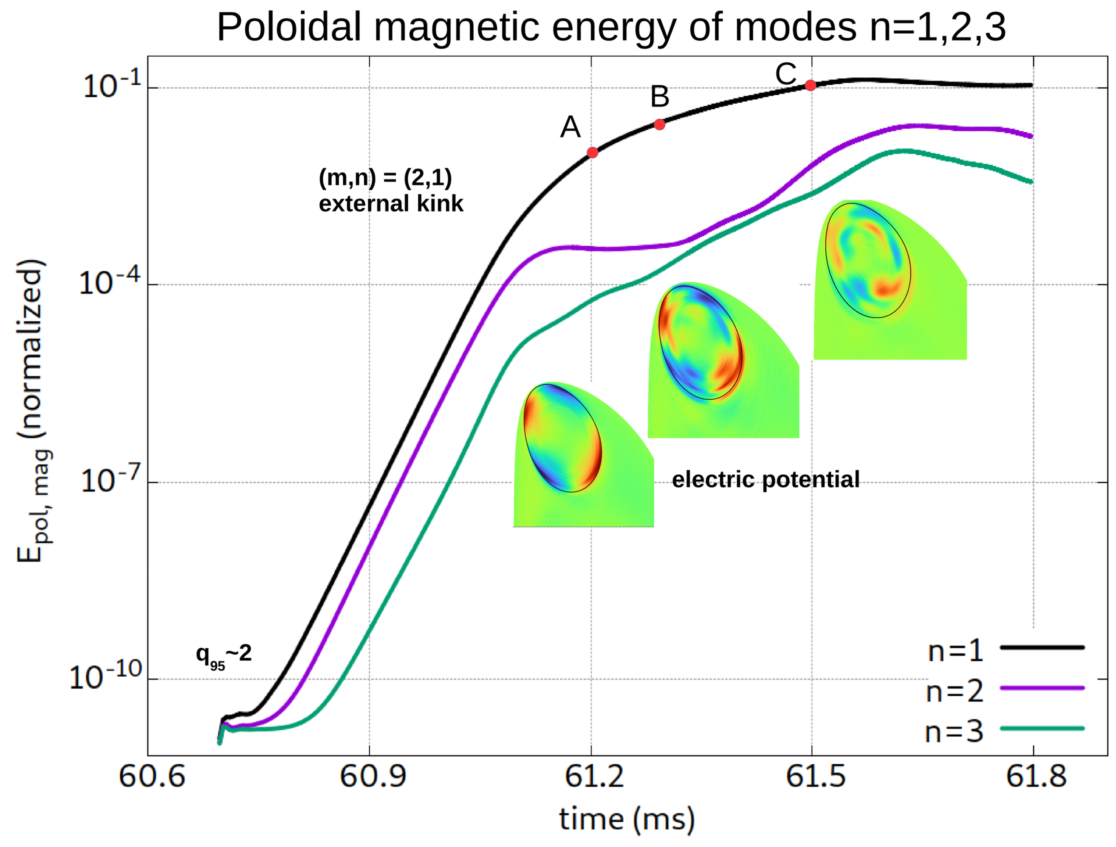


- Higher Ne → prompt and large RE conversion
- Lower Ne → prompt scrape-off and RE decay after RE beam formation

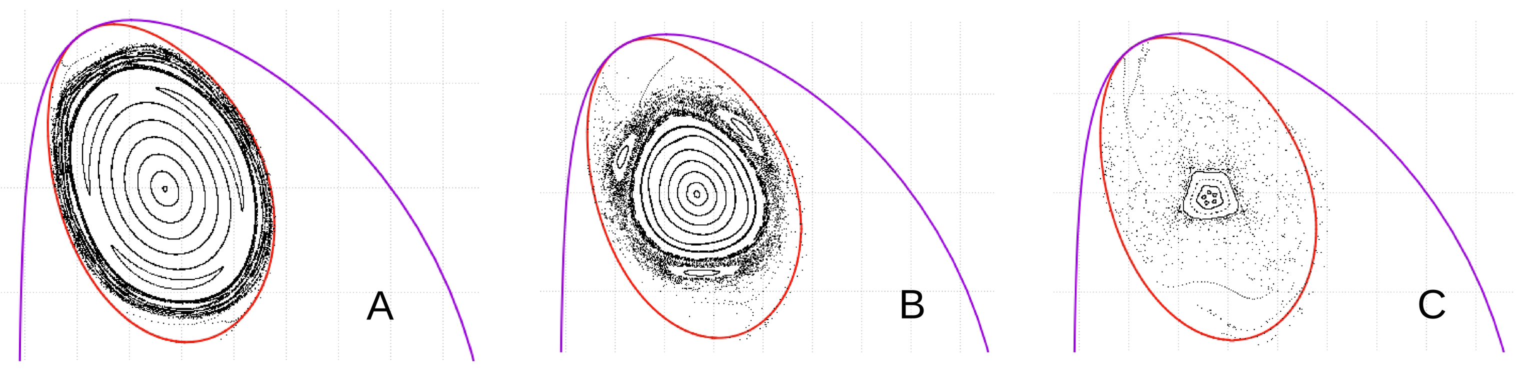
Non-axisymmetric simulations

- After RE formation, $q_{95} \sim a^2/I_p$ tends to decrease due to stalling of current decay
- Can help trigger external kink modes and magnetic stochastization

Poloidal magnetic energy of modes n=1,2,3



Magnetic stochastization



Summary

- In most relavant scenarios, a multi-MA RE beam is to be expected in ITER
- Neon 2nd injection might be ineffective in dissipating RE energy before final loss
  - additional energy channeled to REs offsets the extra dissipation
- Drop in q-edge (inherent during plasma vertical motion after RE formation) presents a possible *natural* pathway for stochastization and distributed loss of REs. First ITER simulations shown here exhibit this effect.

Outlook: Effect of remant imputities/injection scenarios on RE reformation

References

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*Corresponding author:
vkb@ipp.mpg.de

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