Generation and mitigation of runaway electrons: spatio-temporal effects in dynamic scenarios

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ABSTRACT

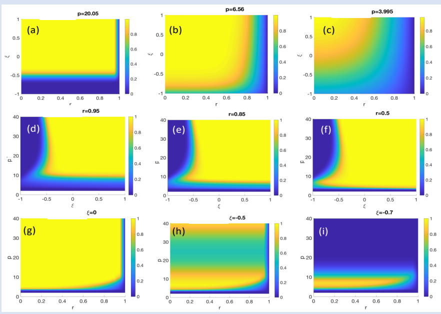
- A numerical study of generation of seed runaway electrons (RE) and mitigation of post-disruption RE is presented focussing on spatial transport effects in dynamic scenarios
- RE seed generation computations were done using the BMC (Backward Monte Carlo) code [1-3]
- The dependence of the seed production on different physics mechanisms in the presence of radial diffusion caused by magnetic field stochasticity is studied
- Radial loss of confinement is shown to have a significant impact on seed production
- RE mitigation computations were done using KORC (Kinetic Orbit Runaway electron Code) [4-5]
- It is found that, in addition to the energy dissipation effects of the impurities, the loss of confinement resulting from the delicate balance of the low-field-side collapse of the magnetic flux and the high-field-side orbit drift plays an important role [6]

BACKGROUND

- Understanding and control of RE is a top priority of the fusion program because if not avoided or mitigated, RE can severely damage the plasma facing components of a tokamak
- Here we address two critical issues: RE seed generation and dissipation of post-disruption RE
- Up to now, most studies on RE seed generation have either neglected radial transport or limited attention to non-chaotic magnetic fields.
- However, MHD studies reveal the ubiquity of magnetic stochasticity during the thermal quench
- Motivated by this, we extended the BMC code to perform parameter scans of the RE seed production dependence on radial diffusion caused by magnetic stochasticity
- On the other hand, there is a pressing need of model validation to be able to extrapolate RE mitigation strategies from existing devices to ITER
- In response to this, we extended KORC to enable model validation through detailed comparisons of shattered pellet injection (SPI) and massive gas injection (MGI) mitigation of REs using different collisional models.
- Results of recent KORC modelling using Ne MGI for RE dissipation are presented

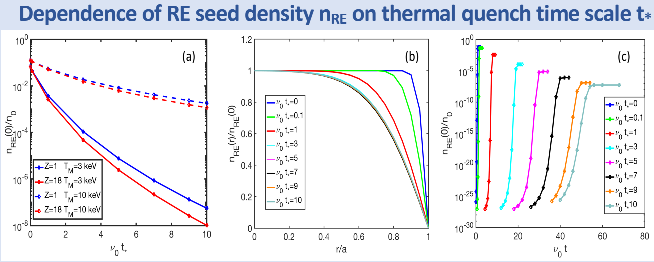
GENERATION OF SEED RUNAWAY ELECTRONS

3D probability of runaway in (p,r,ξ) space



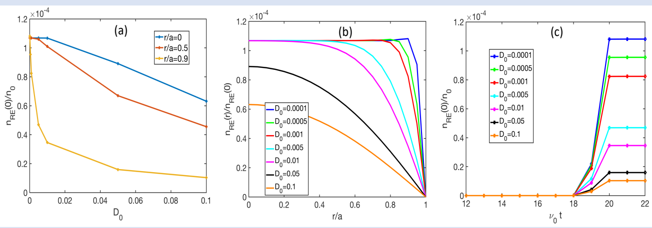
The runaway boundary exhibits nontrivial time-dependent shape that questions isotropy assumptions used in simplified models of RE seed production

Dependence of RE seed density n_{RE} on thermal quench time scale t_*



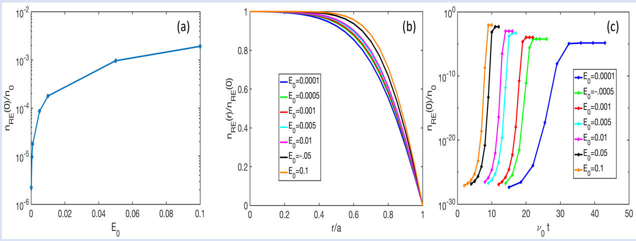
RE seed production is very sensitive to thermal quench time scale and initial temperature of Maxwellian. Dependence on Z important but less notable

Dependence of RE seed density n_{RE} on radial diffusivity D_0



Radial dependence of RE seed production can be significantly affected by diffusion

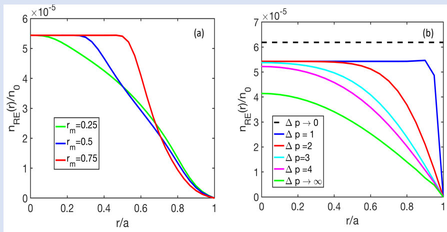
Dependence of RE seed density n_{RE} on electric field E_0



BMC recovers the typical dependence of seed production on electric field but adds information on the radial dependence due to diffusive losses

Dependence of RE seed density n_{RE} on:

(a)Spatially dependent diffusion (b) Momentum dependent diffusion



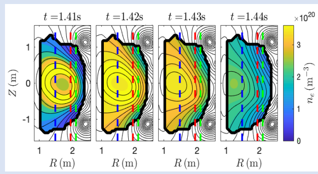
(a) Radial profile of seed production develops a pedestal in the presence of magnetic field stochasticity in the edge

(b) High momentum suppression of diffusion affects seed production

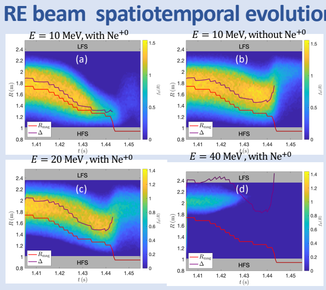
MITIGATION OF RUNAWAY ELECTRONS

KORC simulations using experimental JFIT reconstructed time-sequenced magnetic fields, collisional models for partially ionized impurities, and models of thermal electron and impurity spatiotemporal dynamics fitted to experimental data.

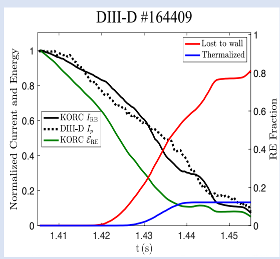
Magnetic field and impurity evolution



RE beam spatiotemporal evolution



Modeling of RE dissipation



In addition to the energy dissipation effects of the impurities, the loss of confinement resulting from the delicate balance of the low-field-side collapse of the magnetic flux and the high-field-side orbit drifts plays an important role

ACKNOWLEDGEMENTS / REFERENCES

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[1] G. ZHANG and D. DEL-CASTILLO-NEGRETE, *Phys. Plasmas* **24**, 092511 (2017).
[2] M. YANG, G. ZHANG, D. DEL-CASTILLO-NEGRETE, M. STOYANOV, and M. BEIDLER,. https://arxiv.org/abs/2001.05800 Springer Verlag Lecture Notes (2020).
[3] M. YANG, G. ZHANG, D. DEL-CASTILLO-NEGRETE, and M. STOYANOV, "A Feynman-Kac based numerical method for the exit time probability of a class of transport problems." Under review in *Journal of Computational Physics* (2021).
[4] BEIDLER, M.T., DEL-CASTILLO-NEGRETE, D., BAYLOR, L.R., SHIRAKI, D., SPONG, D.A., Phys. Plasmas **27** (2020) 112507.
[5] L. CARBAJAL et al., Phys. Plasmas 24, 042512 (2017).
[6] M. BEIDLER et al., 28th IAEA Fusion Energy Conference (FEC 2020).