Application limits of runaway electron modeling based on analytical formulas of generation and loss rates

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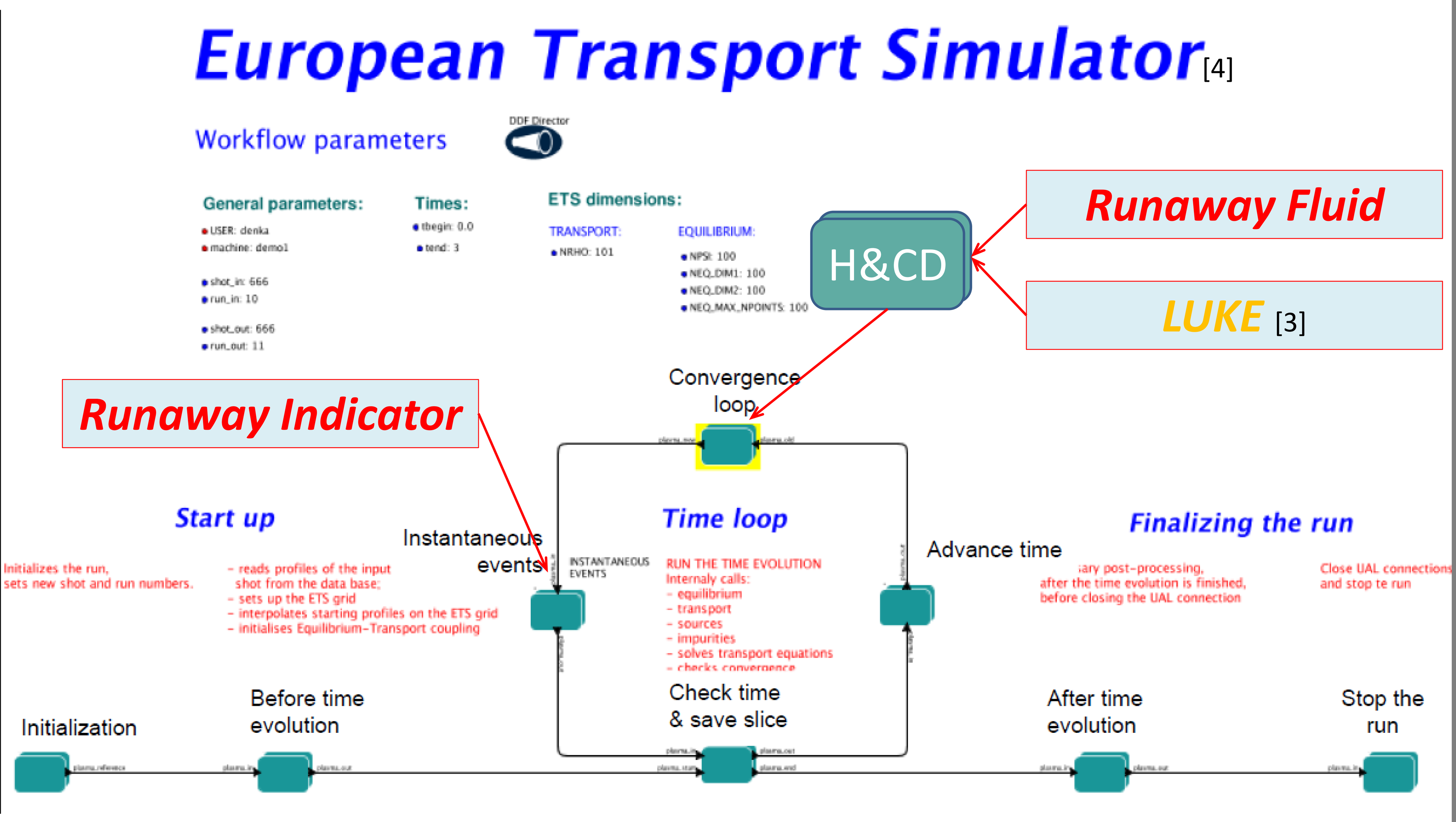
Goals

Three stages of runaway electron modeling in EU-IM [1]

- **First step**: Indicate possible runaway electron tail formation – ***Runaway Indicator***
- **Second step**: Provide estimation of radial runaway current using analytical formulas of generation and loss – ***Runaway Fluid*** (resembling GO [2])
- **Third step**: Full kinetic modeling of electron distribution – ***LUKE*** [3]

Short-term goal: runaway modeling for **European Transport Simulator** (ETS) [4]
– **high temperature (*T > 500 eV*), low electric field (*E/E_c < 10*)**

Runaway modules in ETS



Runaway Indicator

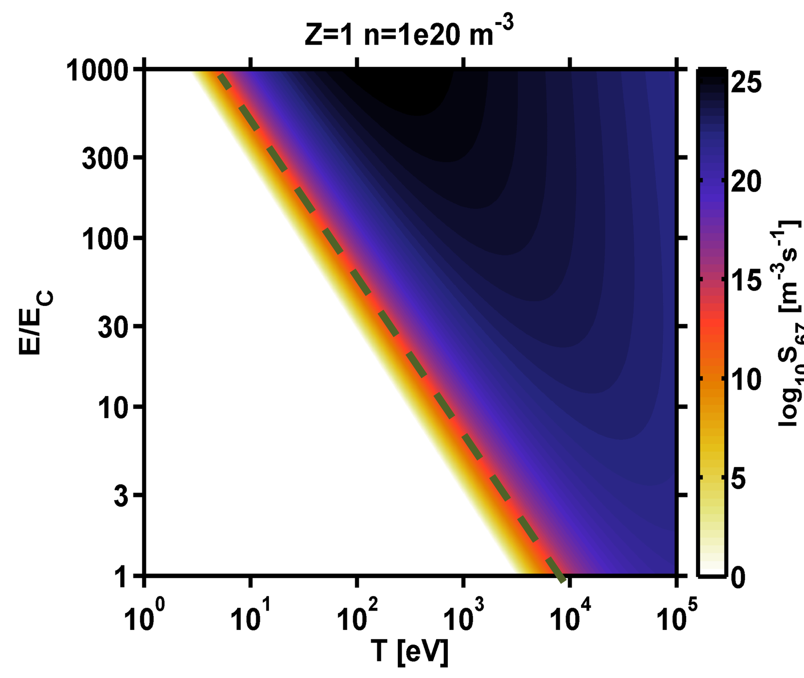
Purpose: provide an indication for when to expect run-away tail formation in a conservative manner

Models

1. Check is if the toroidal electric field exceeds the **critical electric field** needed for the existence of runaway electrons by definition at any radial location

$$E_c(\rho) = n_e(\rho)\frac{e^3 \ln\Lambda(\rho)}{4\pi\varepsilon_0^2 m_0 c^2}$$

2. Check is if the primary **Dreicer generation rate** (based on [5]) is **above a pre-defined threshold** [6] at any radial location



Dreicer generation rate formula (67) in [5]

Applications:

1. Provide warning messages of possible runaway electron generation **during simulation-time**
2. Check as **post-processing** of simulations in a separate workflow to provide confirmation that no runaway electrons were generated

References

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Summary

Minimum level of detail for the first and second stage models of runaway electron simulation in European Transport Simulator [4]:

	Runaway Indicator	*Runaway Fluid*
Dreicer generation	*Critical electric field* *Dreicer generation rate – [5] (67)*	*Dreicer generation rate – [5] (63)* *Synchrotron correction [6]* *Toroidicity correcton [7,12]*
Avalanche generation	-	*R&P growth rate [8]* *Threshold electric field [9]* *Toroidicity correction [7,12]*
Runaway losses	-	*Diffusive radial transport [10]* *Non-diffusive transport [11] ?*

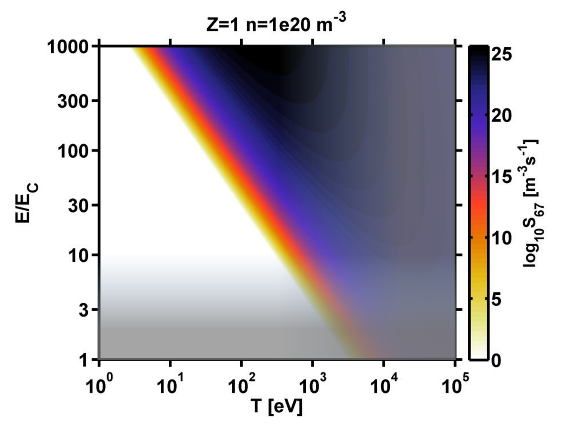
Runaway Fluid

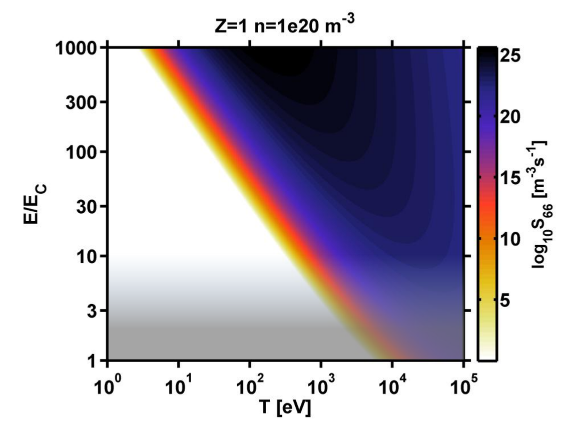
Purpose: provide an estimate of the runaway current profile without kinetic modeling of the electron distribution function

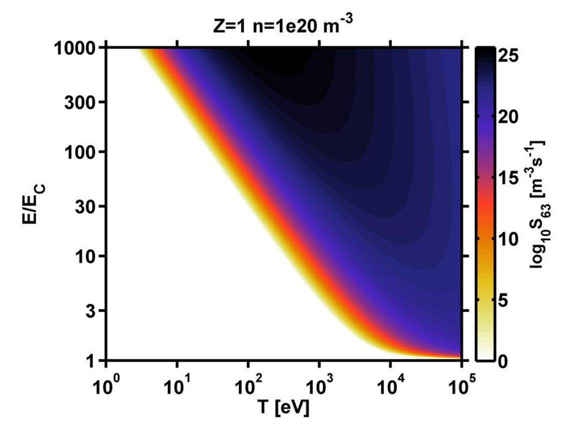
Model: Dreicer generation + avalanche generation + losses

Dreicer generation:

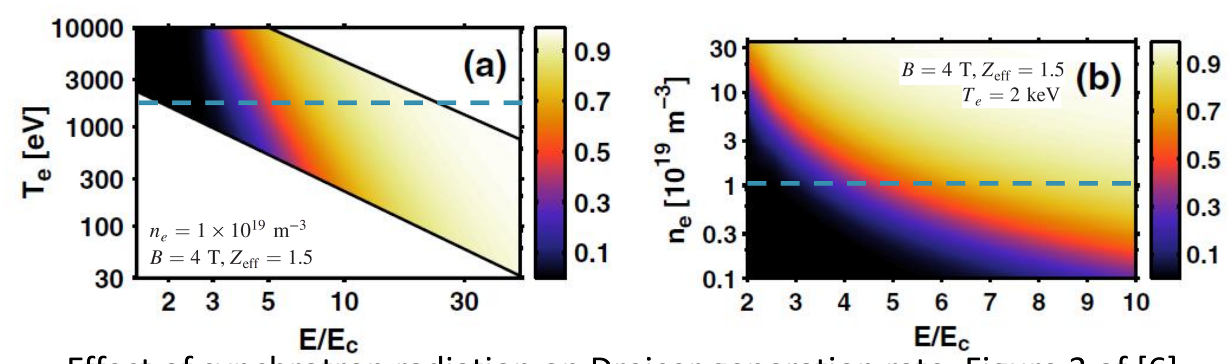
1. **Analytical generation rate formula** (63) from [5]


Dreicer generation rate formula (67) in [5]


Dreicer generation rate formula (66) in [5]

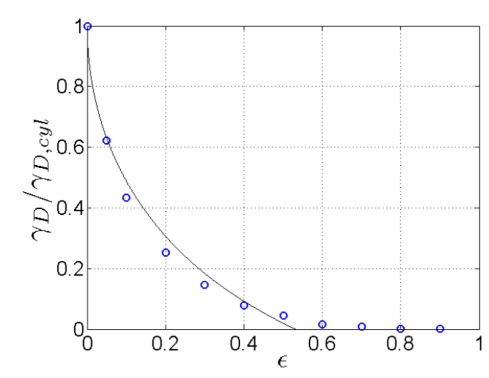

Dreicer generation rate formula (63) in [5]

2. Reduction of Dreicer generation rate by **synchrotron radiation** [6]



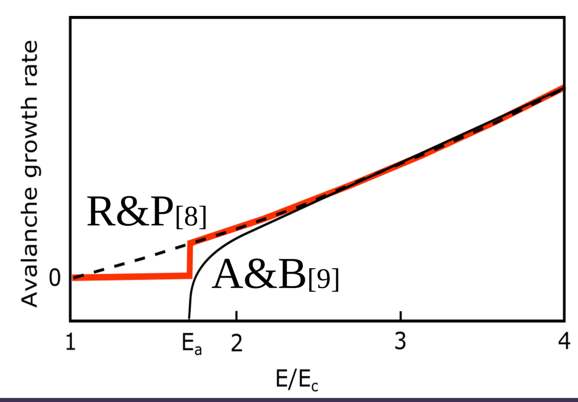
Effect of synchrotron radiation on Dreicer generation rate, Figure 3 of [6]

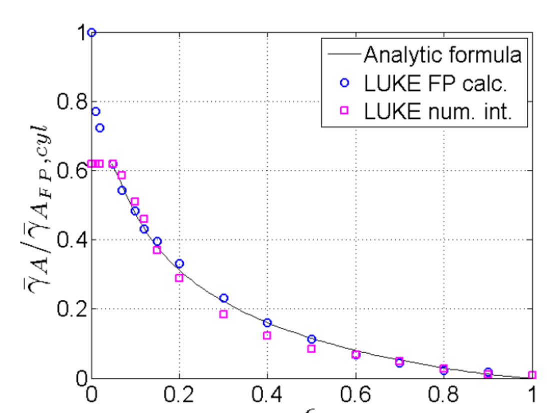
3. Reduction of Dreicer generation rate by **toroidicity effects** [7,12]


Reduction of Dreicer generation due to toroidicity, as calculated by LUKE, Figure 7 of [7] and Figure 2 of [12]

Avalanche generation:

1. **Analytical generation rate** formula from [8]
2. Reduction of avalanche generation rate by **toroidicity effects** [7,12]
3. Reduction of avalanche generation rate at **near-critical electric field** [9]

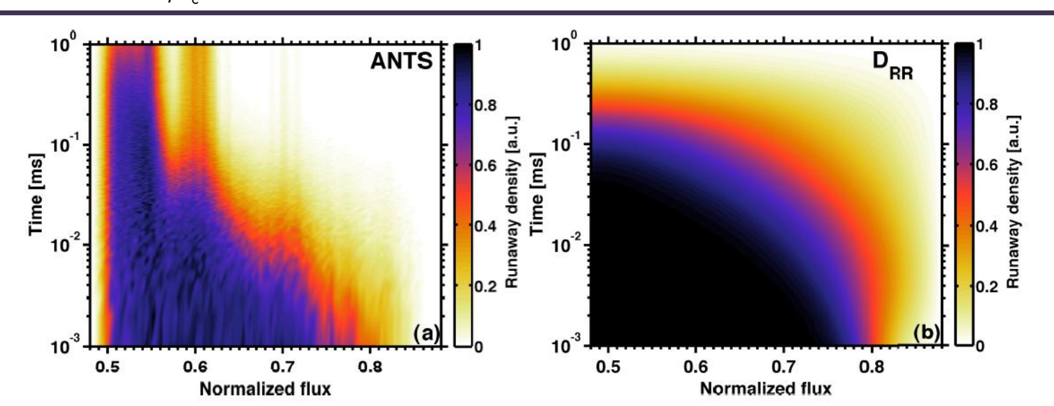




Reduction of avalanche generation due to toroidicity, as calculated by LUKE, Figure 8 of [7] and Figure 2 of [12]

Loss mechanisms:

1. **Diffusive transport** of runaway electrons – **collisional and magnetic perturbations** [10]
2. Convective losses [11] ?



RE transport with RMP – orbit following vs. Diffusive, Figure 3 of [11]

Applications:

1. Provide a **small non-Ohmic current contribution in ETS** for non-disruptive plasmas
2. Possible further field of application based **on future benchmarks with LUKE** [5].

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