Runaway electron modelling in the ETS self-consistent core transport simulator

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Goals

The EUROfusion Code Development for integrated modelling project (WPCD) facilitates code coupling by providing an Integrated Modelling framework (EU-IM), implemented in Kepler [1], and a standard data structure for communication that enables relatively easy integration of different physics codes [2].

Step-by-step approach to RE modeling in EU-IM [3]:

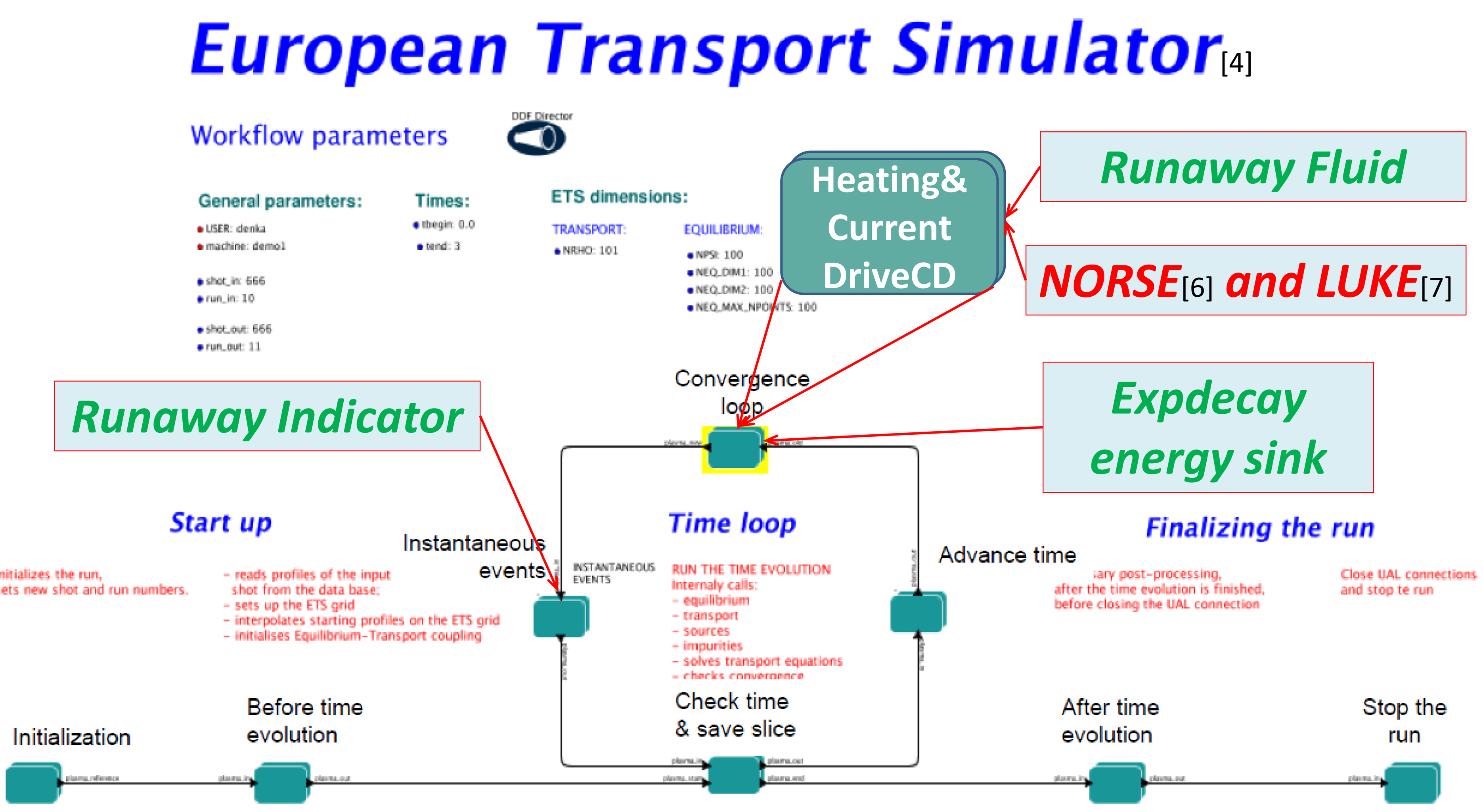
- **First step**: Indicate possible runaway electron tail formation – ***Runaway Indicator*** - ***IN ETS*** [4]
- **Second step**: Provide estimation of radial runaway current using analytical formulas of generation – ***Runaway Fluid*** (resembling GO [5]) - ***IN ETS***
- **Third step**: Full kinetic modeling of electron distribution – ***NORSE*** [6] and ***LUKE*** [7] – ***Integration in progress***

Short-term goal:

- **Benchmark ETS with Runaway Fluid to GO code**
- **Test effect of corrections to generation formulas for high temperature (*T > 500 eV*), and low electric field (*E/E_c ~ 10*)**

Runaway modules in ETS

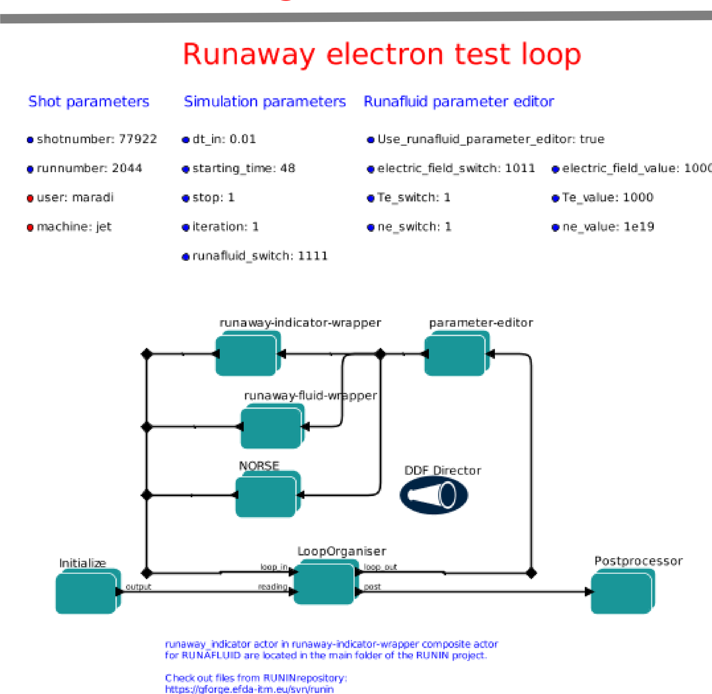
On ETS, see also:
P. Strand TH/P6-14
S. Nowak TH/P6-26



	Runaway Indicator	*Runaway Fluid*
Dreicer generation	*Critical electric field* *Dreicer generation rate [8] (67)*	*Dreicer generation rate [8] (63, 66, 67)* *Toroidicity correction [9]*
Avalanche generation	-	*R&P growth rate [10]* *Threshold electric field [11]* *Toroidicity correction [9]*

***Runaway Fluid* is not sufficient to accurately simulate low-E runaways, but can be used to provide a conservative estimate of the runaway current.**

1. ***Runaway Fluid* is OFF by default, but *Runaway Indicator* is ON**
2. **If *Runaway Indicator* warns of possible runaway generation**
   1. **Run simulation with no runaways, and repeat with conservative estimate by *Runaway Fluid***
   2. **If no significant difference → results are good**
   3. **If significant difference → kinetic modelling needed**



Runaway electron test loop in Kepler allows:

1. **Easy verification of runaway electron actors**
2. **Easy benchmarking of different runaway electron models**
3. **Advancing runaway electron models starting from measured or simulated input scenarios**

Can be easily extended further with other runaway electron modules.

Summary

Integration of *Runaway Indicator* and *Runaway Fluid* actors into ETS has extended its applicability:

1. Runaway electron generation can be detected

2. Maximum of runaway electron current can be estimated conservatively, thus it can be tested if one can neglect the runaway current.

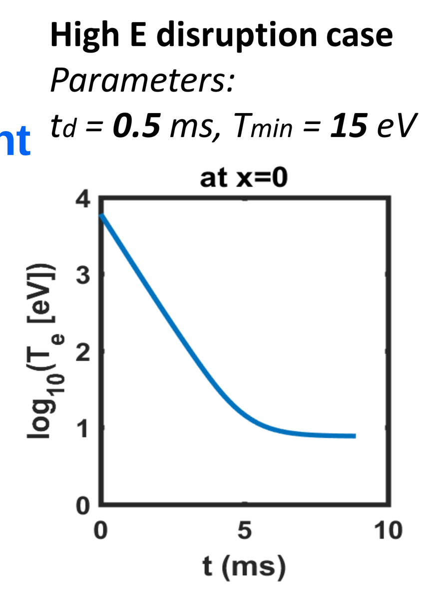
3. For accurate modelling of runaway electron behaviour, kinetic codes are being integrated (NORSE, LUKE).

ETS with *Runaway Fluid was* benchmarked to GO code with good qualitative agreement, but differences in electric field diffusion.

More accurate Dreicer formulas and toroidicity correction have a detectable effect at moderate electric field.

Runaway modelling by ETS

Benchmark runaway current evolution with self-consistent electric field diffusion using **GO** for **high E** disruption case



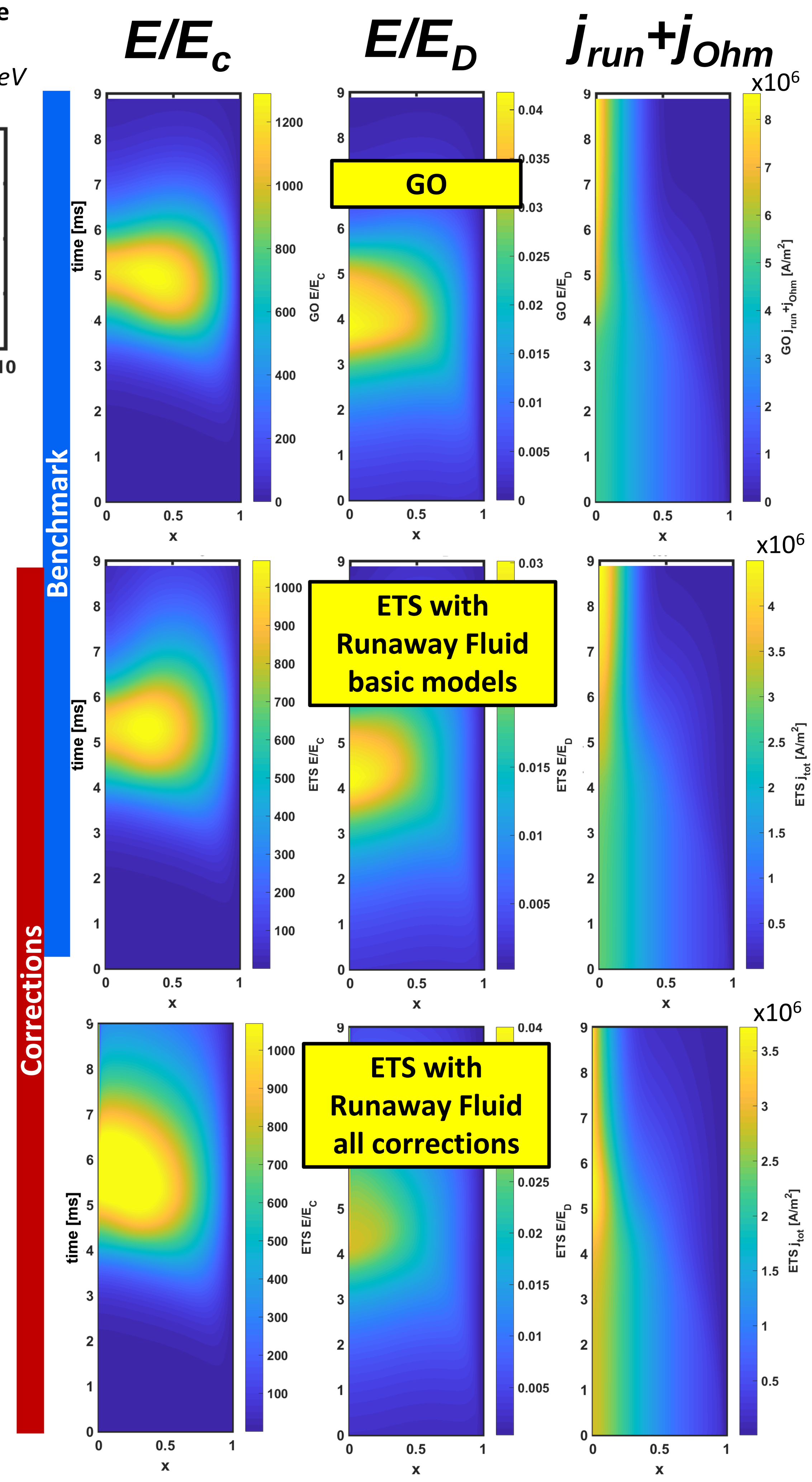
ETS model:
Temperature dependent energy sink ***Expdeday*** actor introduced → sudden cooling with preset t_d decay time with T_{min} minimum temperature.
All transport OFF; fixed equilibrium; Spitzer resistivity – no neoclassical correction; boundary condition set to U_{loop}=0; GO-like runaway generation; ASDEX-like initial state

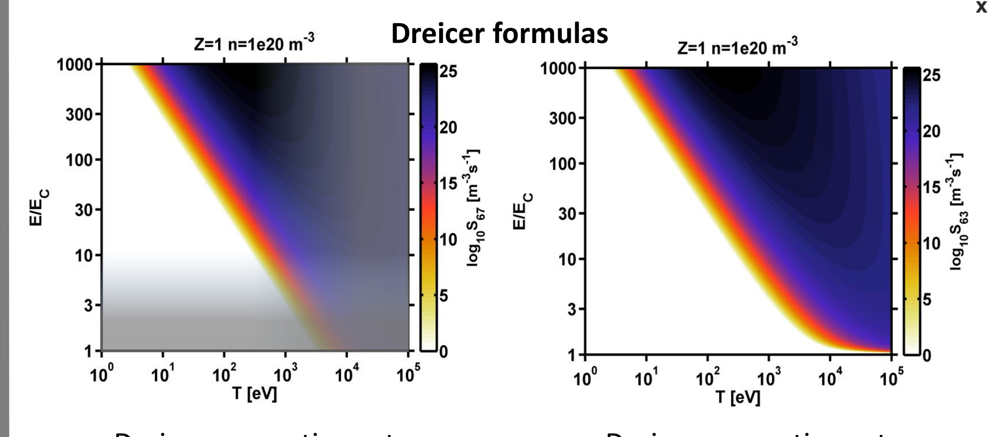
GO model:
Temperature and density evolution from ETS; energy balance OFF; atomic physics OFF; conducting wall boundary at plasma boundary

Study the effect of corrections to generation formulas

Method:
Add **corrections terms one by one;**
Study **high E disruption case,** but also **moderate E transient case** (E/E_c ~ 80)
Compare current (j_r) and electric field evolution

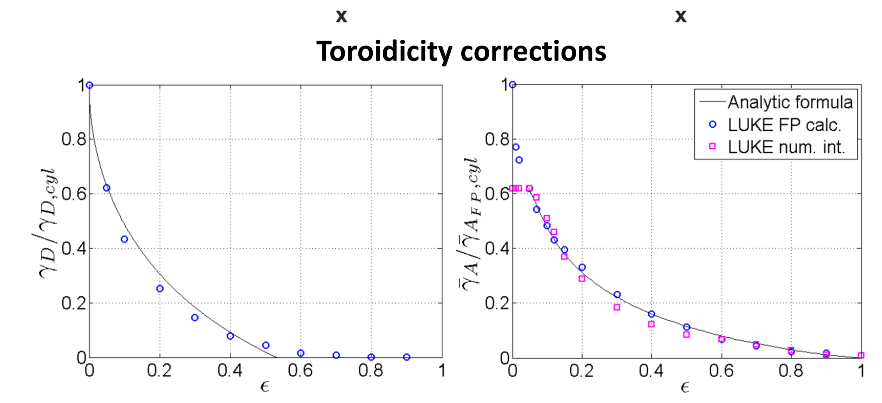
Correction terms:





Dreicer generation rate formula (67) in [8]

Dreicer generation rate formula (63) in [8]



Reduction of Dreicer generation due to toroidicity [9]

Reduction of avalanche generation due to toroidicity [9]

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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27th IAEA Fusion Energy Conference | Ahmedabad, India | 22-27 October 2018 | TH/P8-15