Development of the runaway electron modelling capabilities of the European Transport Simulator

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Goals

he EUROfusion Code Development for integrated modelling project (WPCD) facilitates this 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], so called "actors".

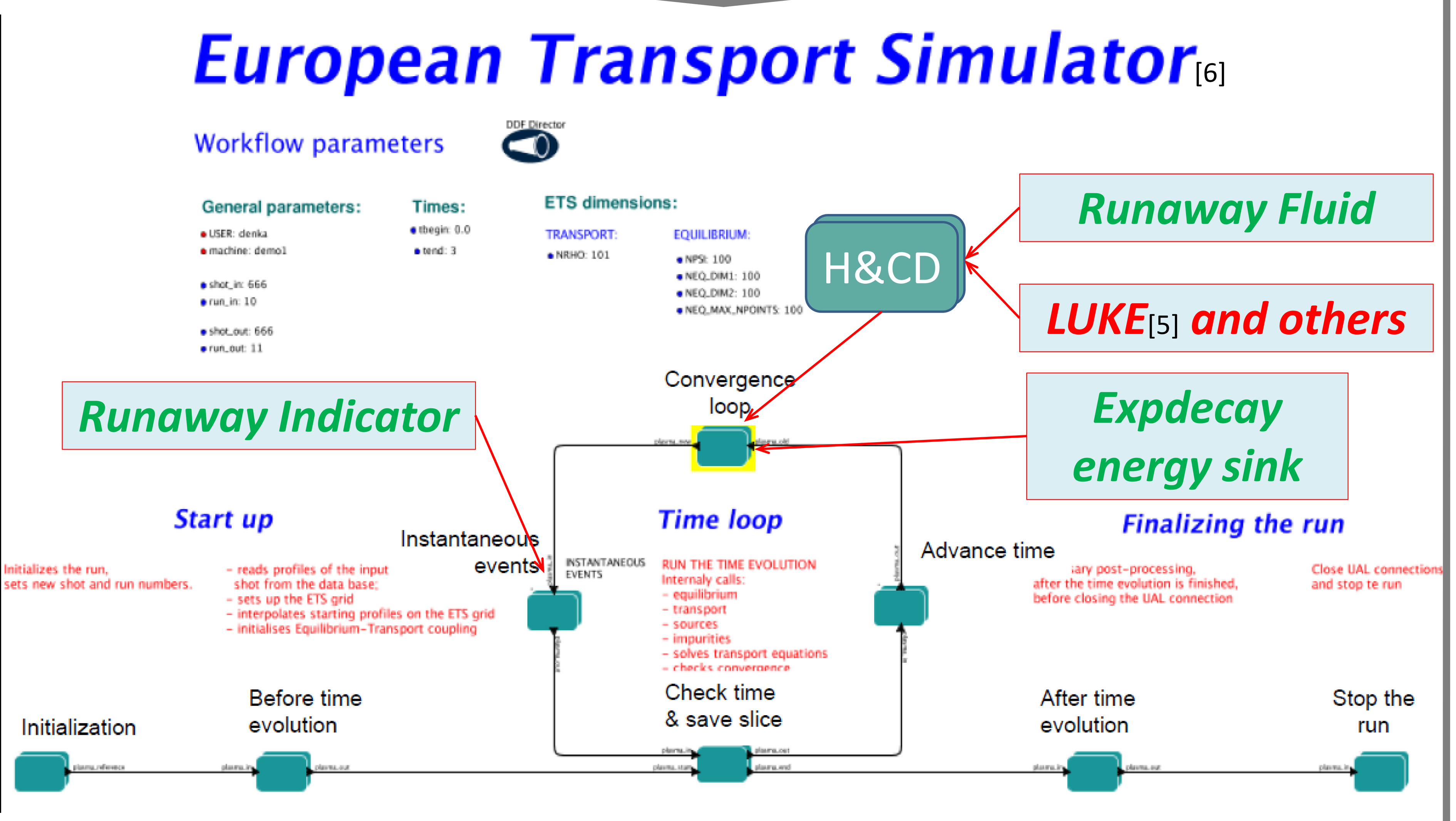
Step-by-step approach to RE modeling in EU-IM [3]:

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

Short-term goal:

- **Benchmark ETS with Runaway Fuid 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



	Runaway Indicator	*Runaway Fluid*
Dreicer generation	*Critical electric field* *Dreicer generation rate – [5] (67)*	*Dreicer generation rate – [5] (63, 66, 67)* *Toroidicity correction [7]*
Avalanche generation	-	*R&P growth rate [8]* *Threshold electric field [9]* *Toroidicity correction [7]*

- **ETS: 1D core transport** solver with **equilibrium, sources** and some **transient event** modelling
- **Standard ETS use cases: Steady state or slowly developing profiles**
- **→ Only steady state runaway production might be expected!**

- ***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**

References

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[7] J.W. Connor and R.J. Hastie, Nucl. Fusion 15, 415 (1975)
[8] A. Stahl, et al., Phys. Rev. Lett. 114, 115002 (2015)
[9] E. Nilsson, et al., Plasma Phys. Contr. Fusion, 57, 095006 (2015)
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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.

(Fur accurate modelling of runaway current one will need kinetic simulation, that the next step.)

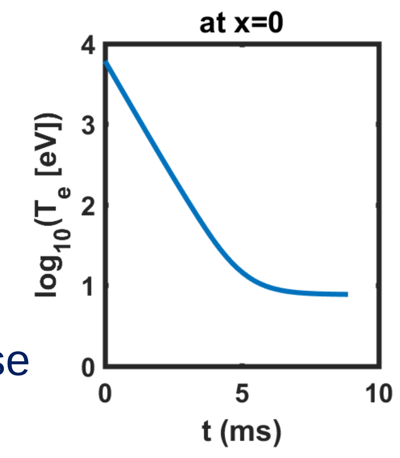
ETS with *Runaway Fluid was* benchmarked to GO code [4] with good qualitative agreement, but differences in electric field diffusion.

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

Runaway modelling by ETS

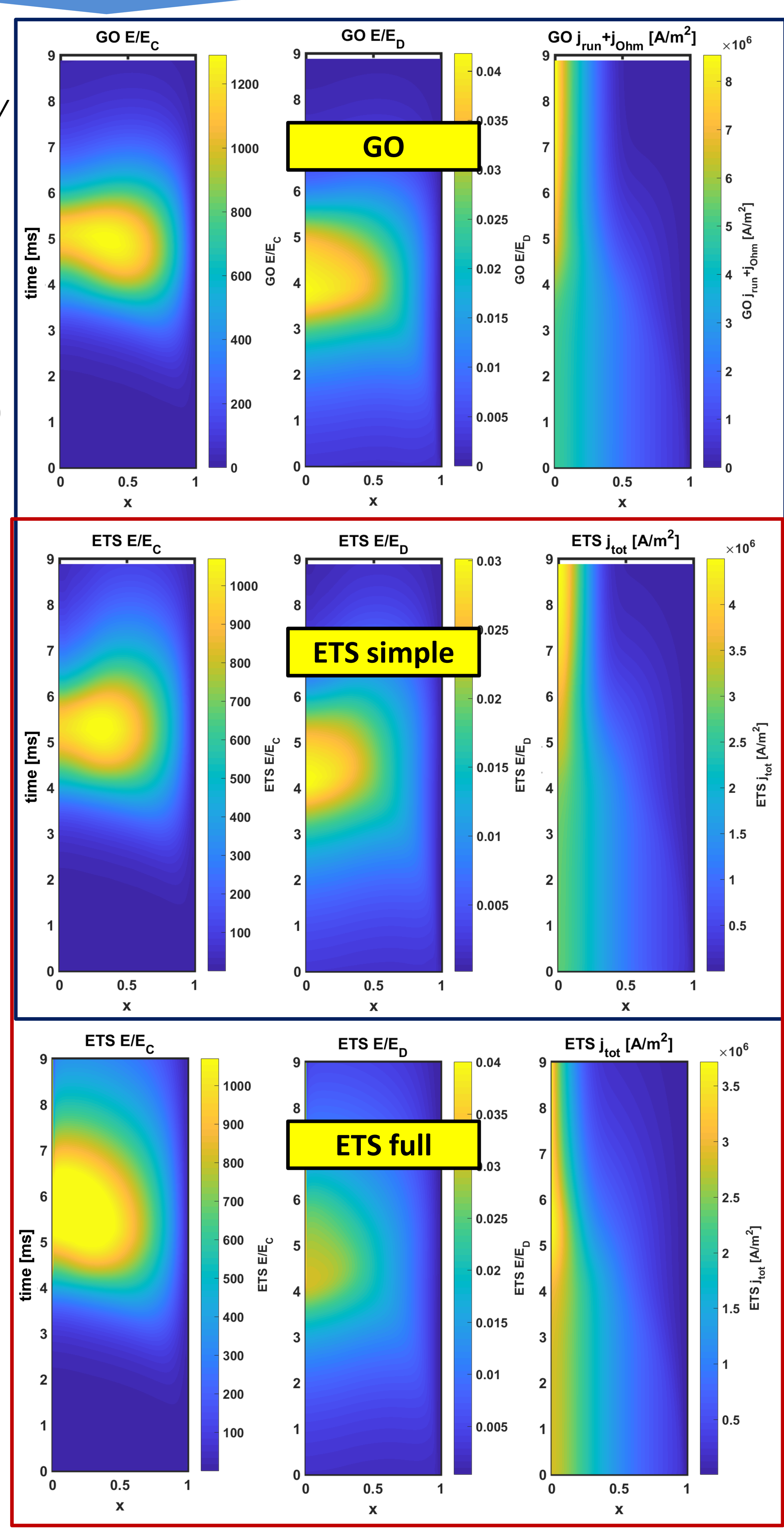
Purpose: **Benchmark runaway current evolution with self-consistent electric field** diffusion using **GO** for **high E** disruption-like case

High E disruption case
Parameters:
*t_d = **0.5** ms, T_{min} = **15** eV*

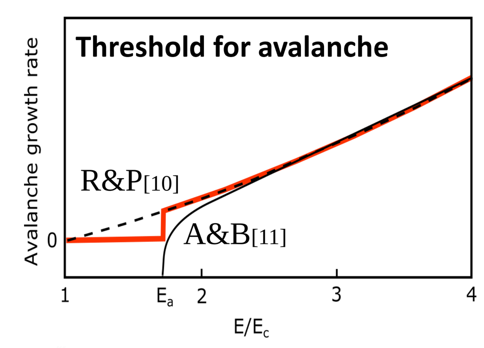


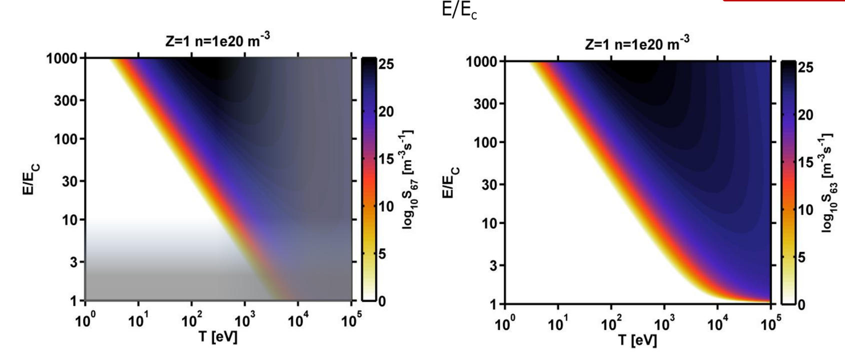
ETS model:
Temperature dependent energy sink ***Expdeday*** actor introduced → sudden cooling with preset t_d decay time with T_{min} minimum temperature
All transport OFF; fixed equilibrium;
Spitzer resistivity – no neoclassical correction; boundary condition set to U_{loop}=0; GO-like runaway generation;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

GO model: Temperature and density evolution from ETS; conducting wall boundary at plasma boundary



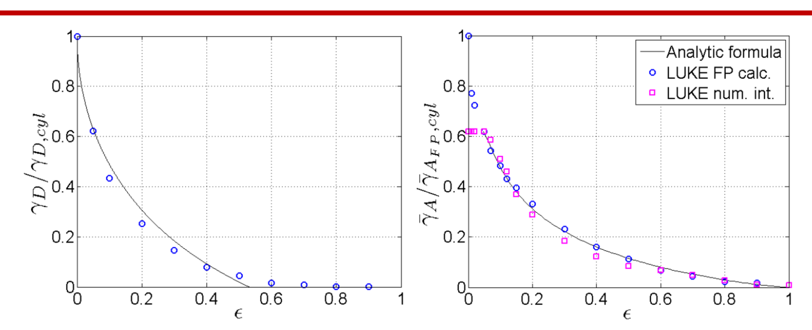
Purpose:
Study the effect of corrections to generation formulas
Method:
Add **corrections terms one by one;**
Study **high E disruption case**, but also **moderate E transient case** (*E/E_c ~ 80*)
Compare current and electric field evolution
Correction terms:





Dreicer generation rate formula (67) in [7]

Dreicer generation rate formula (63) in [7]



Reduction of Dreicer generation due to toroidicity [9]

Reduction of avalanche generation due to toroidicity [9]

Correction term	**High E disruption case** *Parameters:* *t_d = **0.5** ms, T_{min} = **15** eV*	**Moderate E transient case** *Parameters:* *t_d = **10** ms, T_{min} = **100** eV*
Dreicer formula valid for **high temperature** [7] (66)	*~0.1% decrease in j_r compared to (67)*	*~22.9% decrease in j_r compared to (67)*
Dreicer formula valid for **low electric field** [7] (63)	*~0.1% decrease in j_r compared to (67)*	*~21.2% decrease in j_r compared to (67)*
Threshold for avalanche generation [11]	*No change*	*No change* *(due to still too high E)*
Toroidicity corrections [9]	*~25% decrease in j_r*	*~15% increase in j_r* *(decrease in total current)*

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