Kinetic simulation of runaway electrons in tokamaks

Hungarian Plasma Physics and Fusion Technology Workshop

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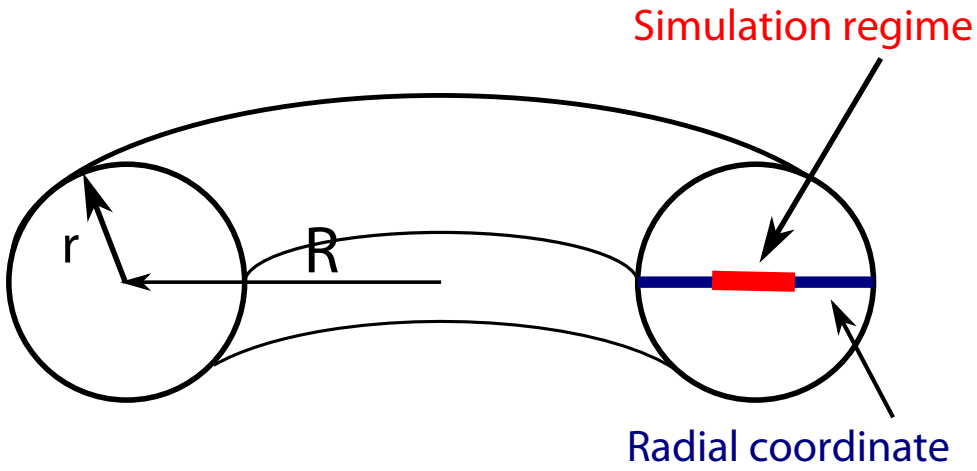
CHALMERS

ARENA

Analysis of Runaway Electrons by Numerical Algorithms

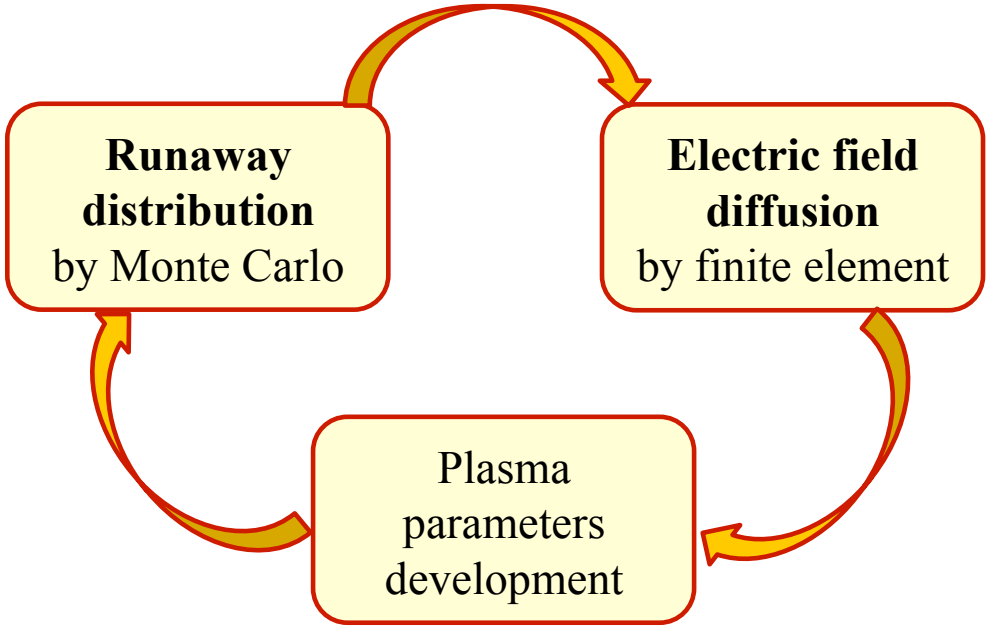
- Runaway electrons are dangerous for large tokamaks $\Rightarrow$ numerical simulation is essential
- Written in 1998, developed until 2004[1,2]
- Solves the bounce-averaged kinetic Fokker Planck equation by Monte Carlo methods in 1+2D phase space



[1] L.G. Eriksson and P. Helander, Computer Physics Communications, 154 (2003)(3), 175–196.
[2] L.G. Eriksson et al., Physical Review Letters, 92 (2004)(20), 1–4.

ARENA Basics

- **Runaway electron growth rate** calculation (primary and secondary)
- **Self-consistent** calculation of the electric field



- **Promising results** for ITER and JET parameters[2]
  - Was too slow for thorought simulations

Motivation

- **Bring ARENA back to life**
  - „It had worked" once
  - No documentation
  - No released versions or source code versioning
- **Speed up**
  - The fusion group would warmly welcome a released version
  - Use for more realistic scenarios
  - Opens the possibility to include new features
- **Extend it**
  - Introduce new physical effects
  - Implement a collision operator valid for arbitrary energies [*Papp et al., NF 2011*]
  - Modularize the disruption simulation

Code works

- **In the beginning** we had
  - Fortran 77 code (development version)
  - Two articles (as „documentation”)
- **Finished** works
  - Conversion to Fortran 90
  - Decrypt most of the 6-letter variable names
  - Write developer documentation
- **Work in progress**
  - Testing and benchmarking
  - User documentation
  - ITM integration

```
TEDOTN =-1.0 / TTEDEC * (ZTEMP0 - TEMIN) *
        EXP(-TIME(IT) / TTEDEC)

TEDOTNB =-2.0 / TTEDEC * (ZTEMPEB0 - TEMIN) *
        EXP(-2.0*TIME(IT) / TTEDEC)

PVTRAT  = SQRT(TEMPE0 * PVTRAT)

ED0 = ZED0 * ZTEMP0 / TEMPE0
```

Numerical tests

Why do we need a numerical test?

- To see that we didn't brake the code while working on it

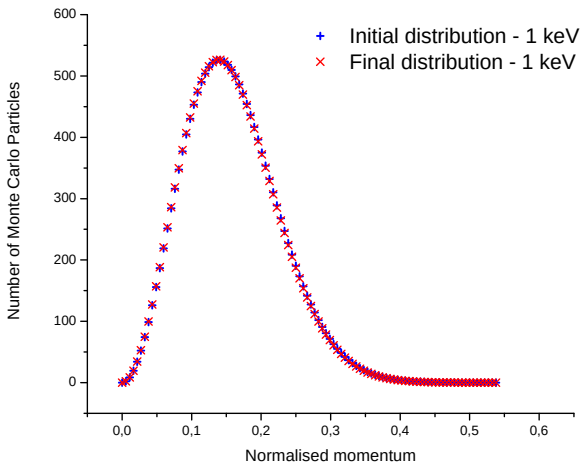
How can a numerical simulation tested?

- Ideal case
  - All functions and routines are documented and each tested automatically by unit tests
- ARENA case
  - Basically one huge routine
  - Tailored to do a disruption simulation
  - Not much individual modules and „old" Fortran 77
  - Make it unit testable means almost a total rewrite
- Solution
  - Set up a test disruption run which uses most of the code
  - Run the original and every sequential version with these parameters

Physical tests

Make sure the code calculates what we want

- **Maxwellian-test**: the collision operator should keep the Maxwellian without external forces
  - Status: Done and OK, up to 15 keV



- **Dreicer-test**: growth rate of the primary generation
  - Status: In progress, qualitatively OK
- **Avalanche-test**: growth rate of secondary generation
  - Status: Planned

What is ITM?

Integrated Tokamak Modelling

Aim: create a tokamak simulator based on European codes

Problem: Simulations use different data structures, physical units and programming languages

Solution: Standardized units, data structure and common programming platform.

- Units: SI, conventions for coordinate systems, signs, currents, betas, etc.
- Data: Consistent Physical Object[3]: hierarchical structure (CPO)
- Platform: ITM Gateway[4], a joint computing facility

[3]F. Imbeaux et al., Computer Physics Communications, Volume 181, Issue 6, June 2010, Pages 987-998
[4] `http://www2.efda-itm.eu/`

Infrastructure

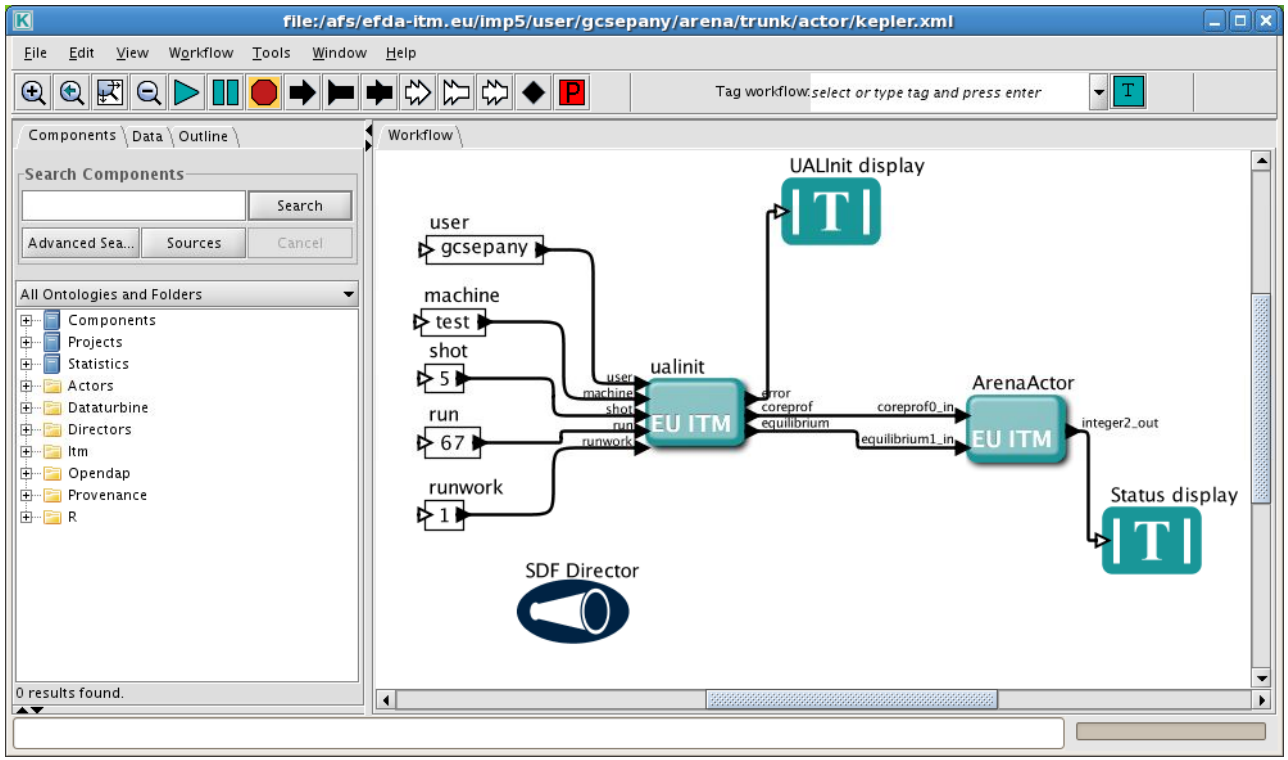
ITM gives a significant support to acheive its aim

- **Gateway**: Multicomputer environment with all necessary softwares
  - Official support to resolve problems
- **GForge**: Collaborative Development Environment
  - Task and bug tracker
  - Mailing list
  - Wiki
  - SVN
- **Doxygen**: Standardized documentation system

ITM workflows

Codes are connected in Kepler[5] workflows

- Java based, easy-to-use program
- Codes can be compiled in Kepler (as shared objects)
- Kepler runs the programs, connects them and outputs results



[5] https://kepler-project.org/

LUKE and ARENA

LUKE: fast numerical solver for the 3D relativistic bounce-averaged electron Drift Kinetic Equation[6]

Benchmark

- Both LUKE and ARENA can calculate growth rate from the primary generation
- They use different approach to calculate it (MC vs FE)

Connecting

- LUKE is much faster than ARENA for primary generation
- LUKE cannot calculate secondary generation
- Long term solution: connect them in ITM and serve as the basic disruption simulation

[6] Y. Peysson et al., Aip Conference Proceedings 1069, 176-187 (2008).