Kinetic modeling of argon-induced disruptions in ASDEX Upgrade

K. Insulander Björk[1]

G. Papp[2], **O. Embréus**[1], **L. Hesslow**[1], **T. Fülöp**[1], **O. Vallhagen**[1], **A. Lier**[2], **G. Pautasso**[2], **A. Bock**[2], **the ASDEX Upgrade Team**[2*] **and the EUROfusion MST1 Team**[†]

[1] Chalmers University of Technology, Gothenburg, Sweden
[2] Max Planck Institute for Plasma Physics, Garching, Germany
[*] See author list of "*H. Meyer et al. 2019 Nucl. Fusion* **59** *112014*"
[†] See the author list of "*B. Labit et al. 2019 Nucl. Fusion* **59** *086020*"

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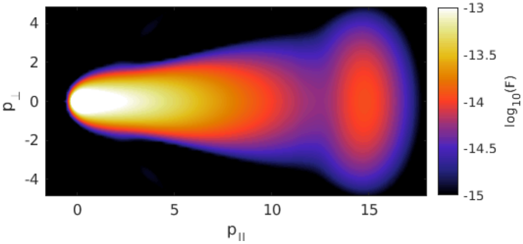
The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline



1. Argon induced disruptions in AUG
2. Temperature data
3. Density data
4. Current evolution
5. Distribution functions
6. RE generation rates by different mechanisms
7. Comparing model and experiment for 10 shots...
8. Summary

My first months as a plasma physicist

- Main take-home messages from REM 2019:

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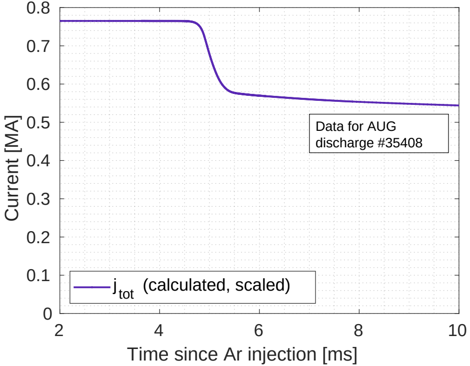

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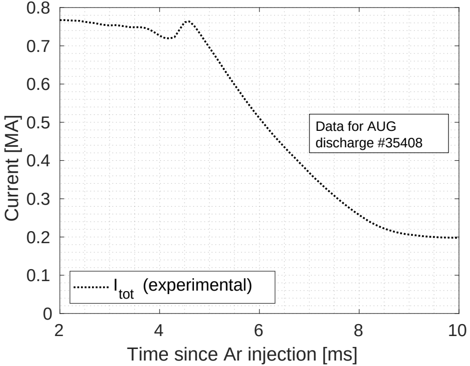

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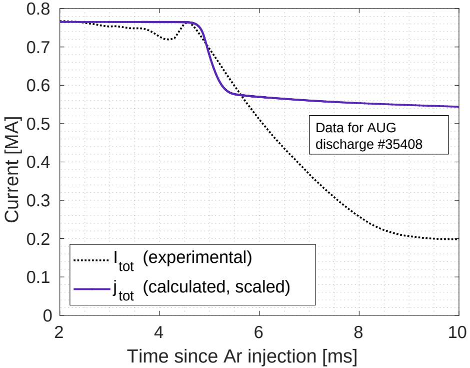

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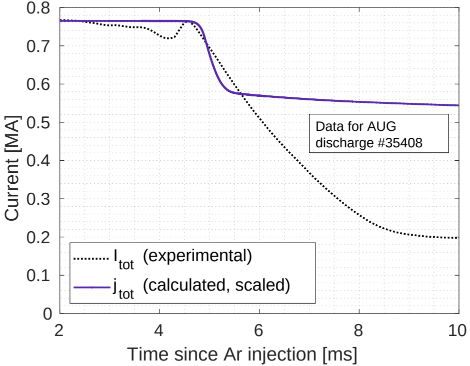

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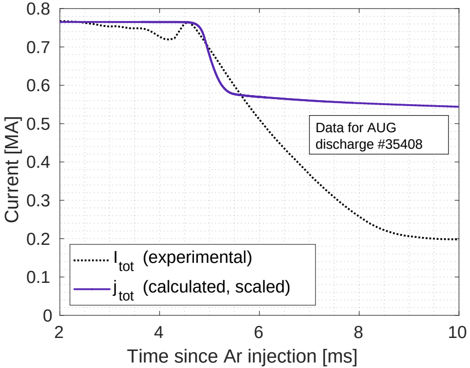

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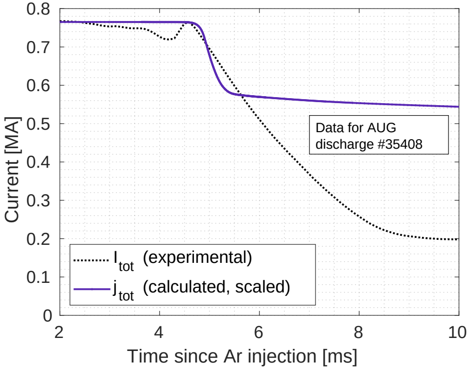

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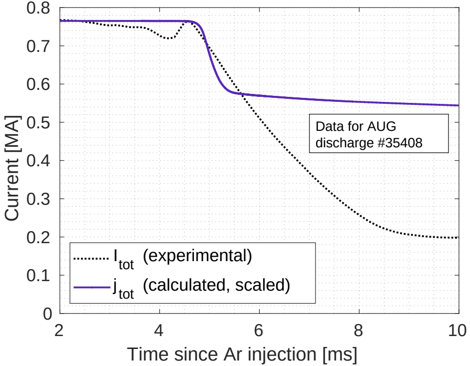

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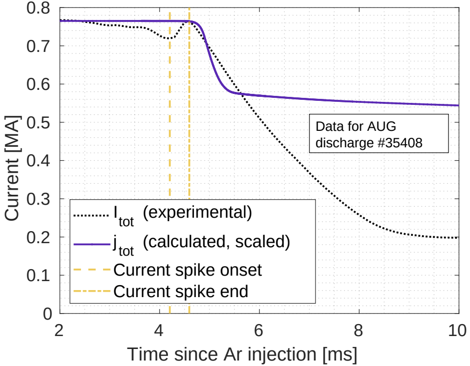

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  - Especially so during MHD events...

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- Collisions: relativistic test particle operator [2,3]
- Screening of partially ionized impurities [4]
- Radiation losses (synchrotron and Bremsstrahlung)
- No radial transport or instabilities.

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Awesome experiments: Argon induced disruptions in AUG

- Parameters that are (more or less) similar in all shots:
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Shot number #
35401
34149
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- Parameters that vary between shots:
    - Injected argon quantity (1 bar, 0.1 l, 300 K $\iff$ 2.4·10^{21} atoms)

Shot number	Injected argon [bar]
#	p_{Ar}
35401	0.15
34149	0.2
34183	0.3072
34140	0.31
34084	0.33
35649	0.39
35650	0.4
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  - Initial free electron density

Shot number	Injected argon [bar]	Initial density [m^{-3}]
#	p_{Ar}	n_0
35401	0.15	$2.6\cdot 10^{19}$
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34140	0.31	$2.3\cdot 10^{19}$
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    - Initial free electron density
    - Initial free electron temperature

Shot number	Injected argon [bar]	Initial density [m^{-3}]	Initial temperature [keV]
#	p_{Ar}	n_0	T_{e0}
35401	0.15	$2.6\cdot 10^{19}$	6.1
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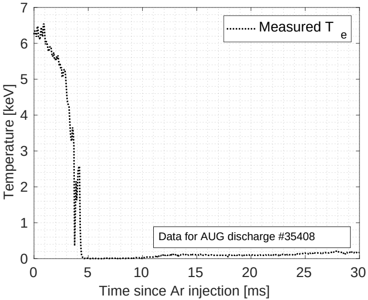
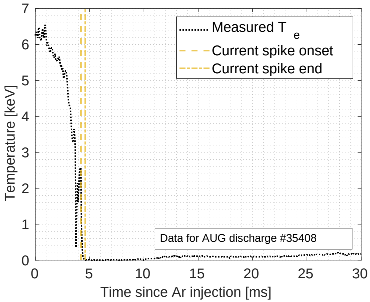
34183	0.3072	$2.8\cdot 10^{19}$	5.5
34140	0.31	$2.3\cdot 10^{19}$	5.8
34084	0.33	$3.0\cdot 10^{19}$	4.3
35649	0.39	$2.6\cdot 10^{19}$	6.2
35650	0.4	$2.4\cdot 10^{19}$	5.3
35408	0.5	$2.4\cdot 10^{19}$	6.0
33108	0.73	$3.1\cdot 10^{19}$	7.2
31318	0.9	$2.2\cdot 10^{19}$	11

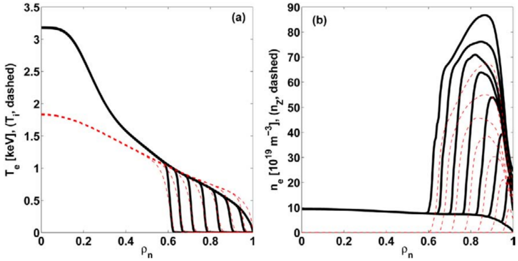
Temperature data



- Free electron temperature measured by ECE

Temperature data





- Free electron temperature measured by ECE
- ECE blocked by high e^- densities on edge $\approx$ 1 ms after injection

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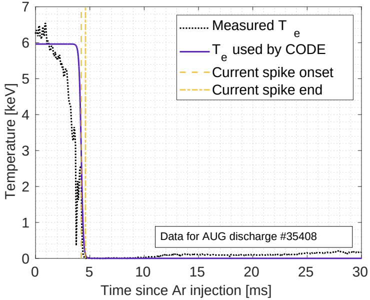
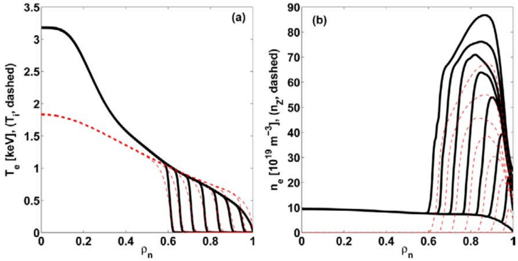
T_e and n_e profiles from [5] E. Fable, et al.: *Nuclear Fusion*, **56**, 2016

Temperature data





- Free electron temperature measured by ECE
- ECE blocked by high e^- densities on edge ≈ 1 ms after injection
- Assume exponential thermal quench

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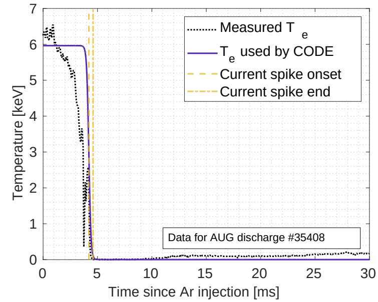

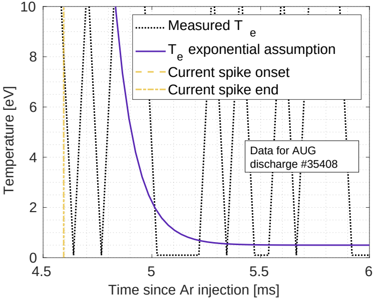

- Free electron temperature measured by ECE
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- But what is the final temperature?

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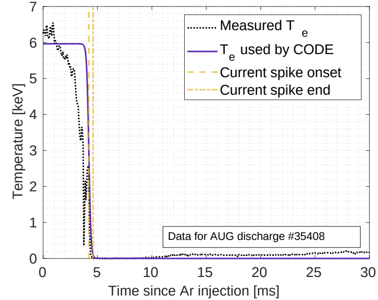

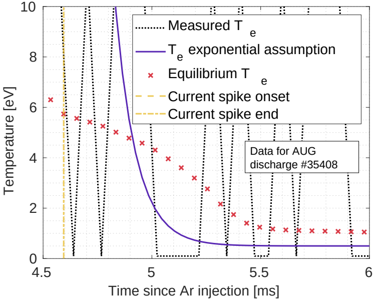

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- Best guess: Calculate assuming collisional-radiative equilibrium at prevailing D/Ar densities and current density

$$J^2\sigma(T_e, Z_{\text{eff}}(T_e)) = \sum_i n_{\text{e}}(T_e) n_i L_i(T, n_e(T_e))$$

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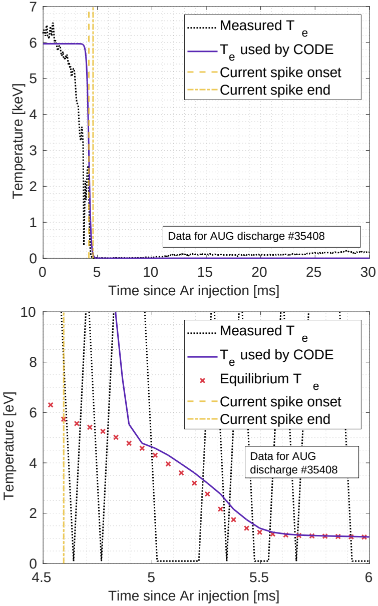

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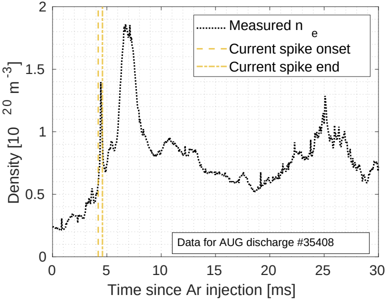

- Free electron density n_e measured by CO_2 interferometry

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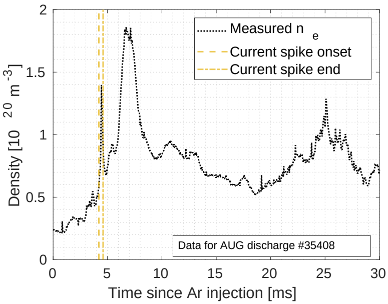

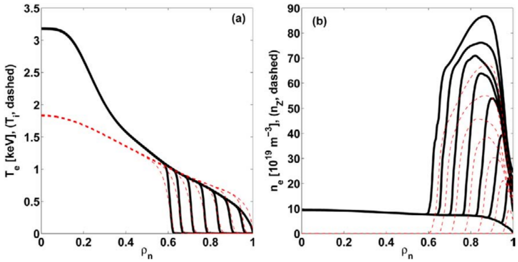

- Free electron density n_e measured by CO_2 interferometry
- Initial increase at the plasma edge

T$_e$ and n$_e$ profiles from [5] E. Fable, et al.: *Nuclear Fusion*, **56**, 2016

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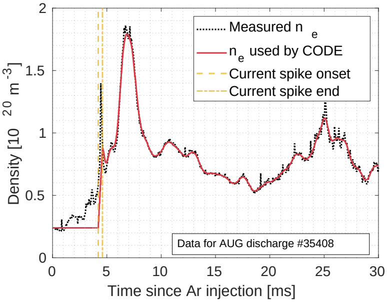

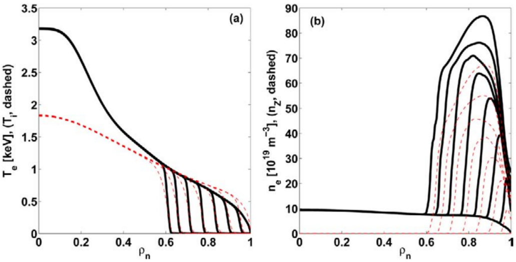

- Free electron density n_e measured by CO_2 interferometry
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- Density on-axis constant until MHD mixing

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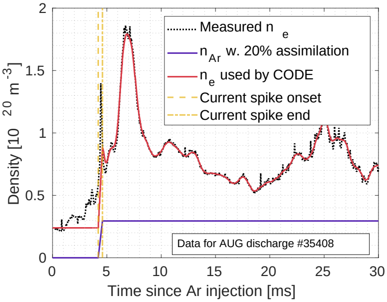

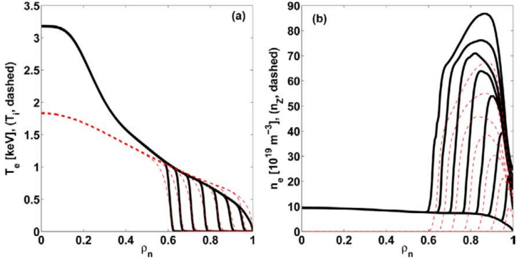

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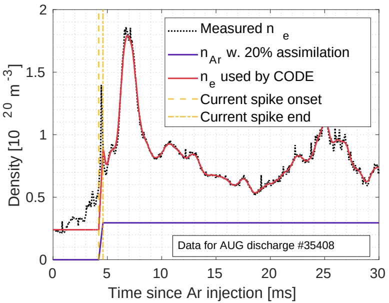

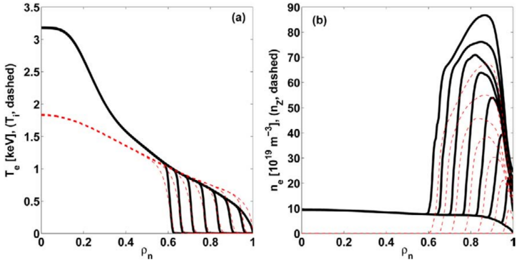

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- Argon density after MHD mixing assumed constant, corresponding to homogenous distribution within pressure vessel (20% assimilation*)

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* 20% of total Ar in the plasma volume = 20% of vacuum vessel volume.

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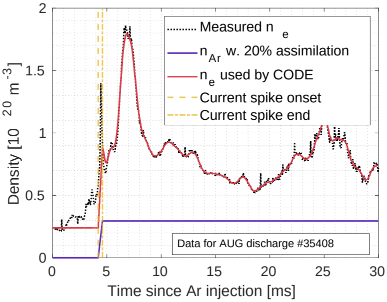

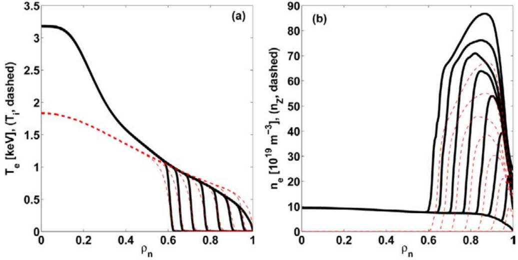

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- Initial increase at the plasma edge
- Density on-axis constant until MHD mixing
- On-axis argon density assumed to evolve similarly
- Argon density after MHD mixing assumed constant, corresponding to homogenous distribution within pressure vessel (20% assimilation*)
- "Average" ionization state of argon chosen to give the measured n_e

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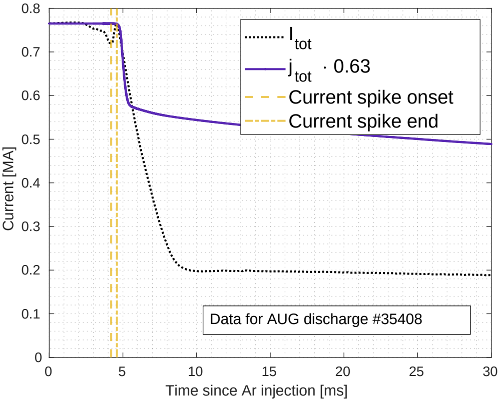
Current evolution



- CODE is 0D, so I and j are not directly comparable...

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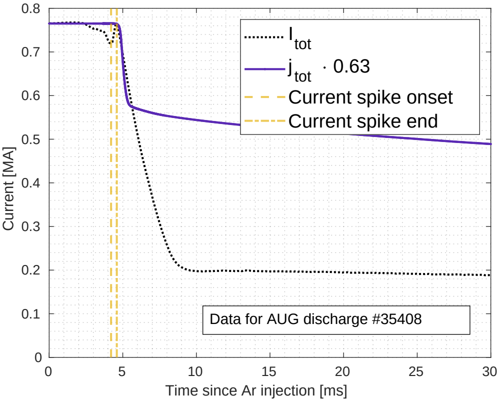

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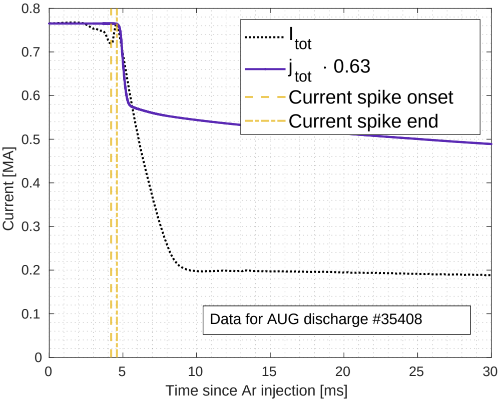
- Scaling factor 0.63 chosen to get $j_0 \approx$ 1.2 MA/m^2

Current evolution



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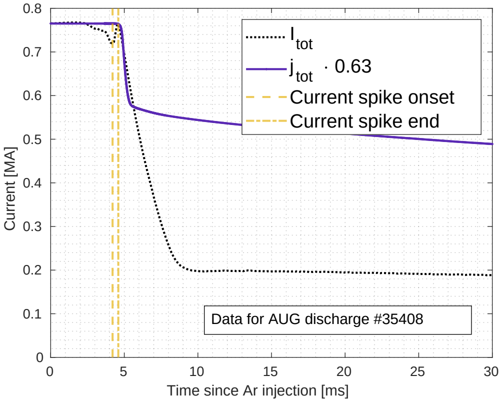

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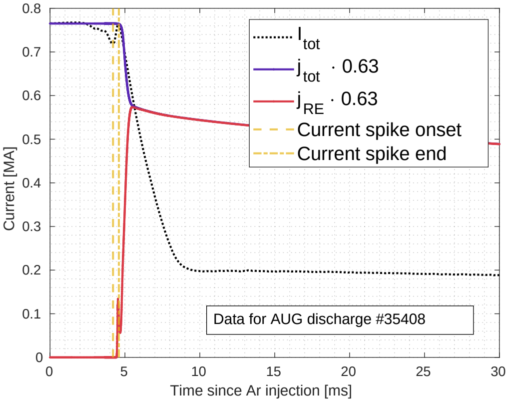

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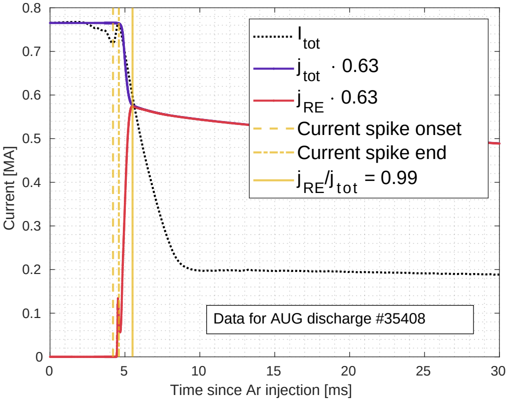

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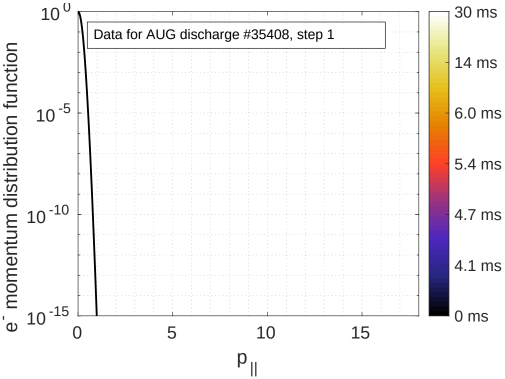
- Some ms after injection, 99% of the current is runaway!

The birth of a runaway current as told by CODE



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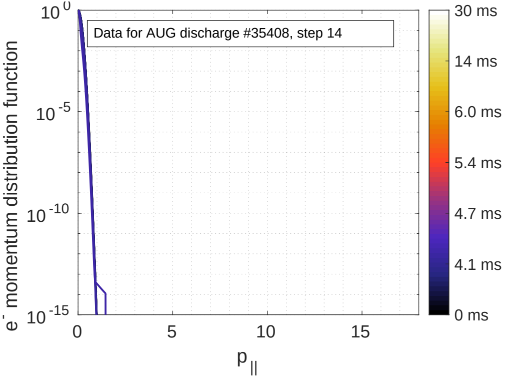

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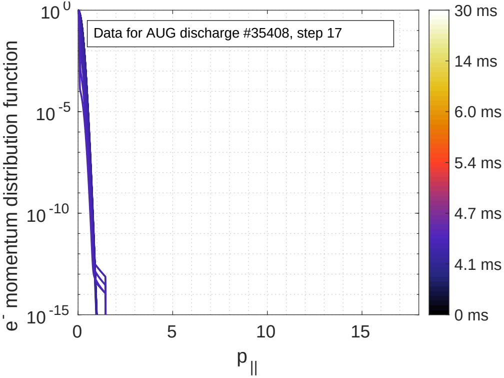

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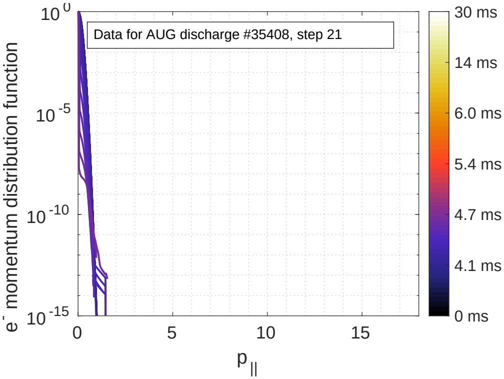

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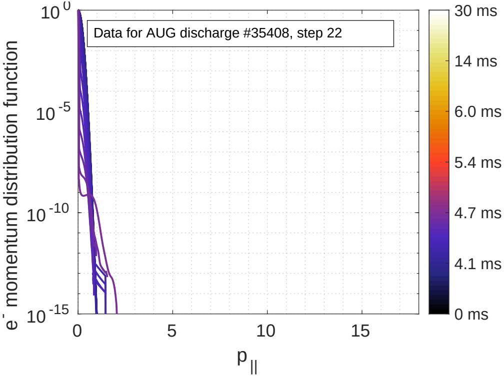

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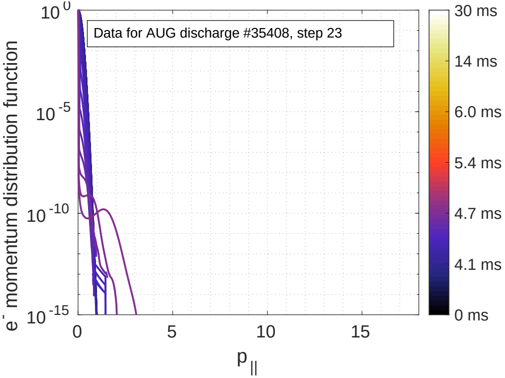

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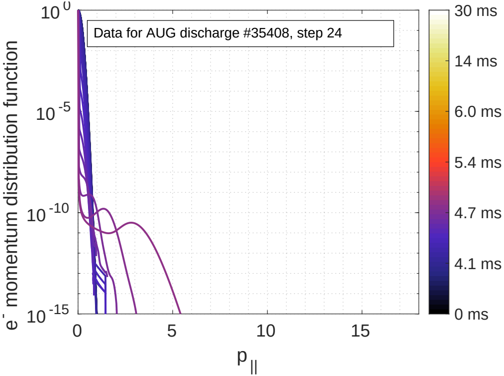

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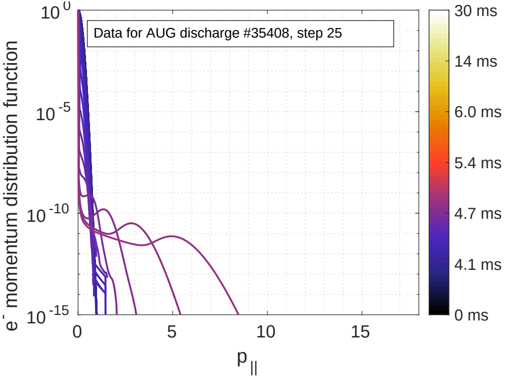

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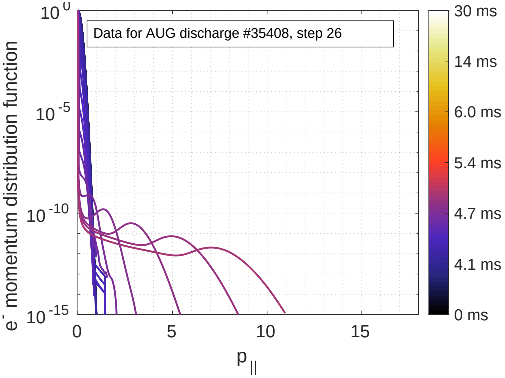

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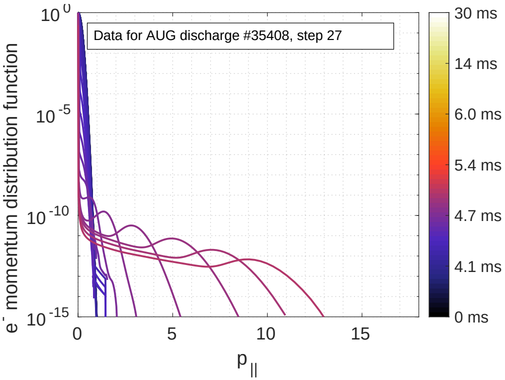

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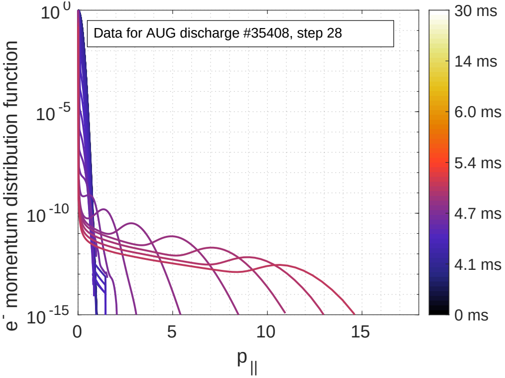

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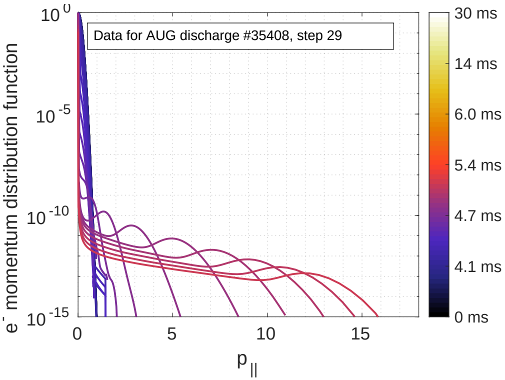

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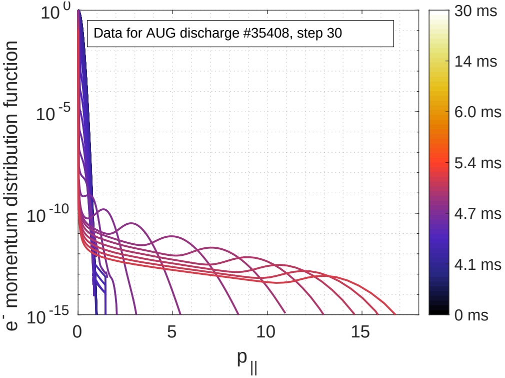

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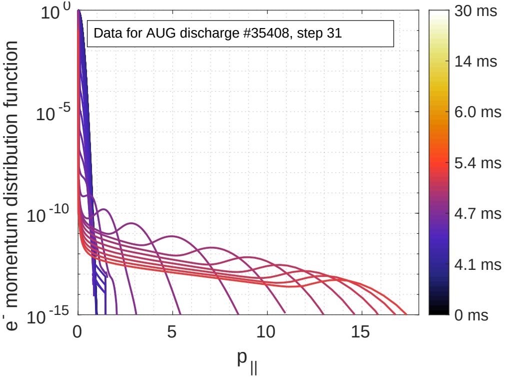

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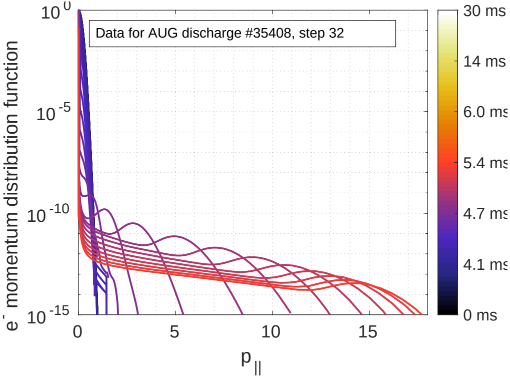

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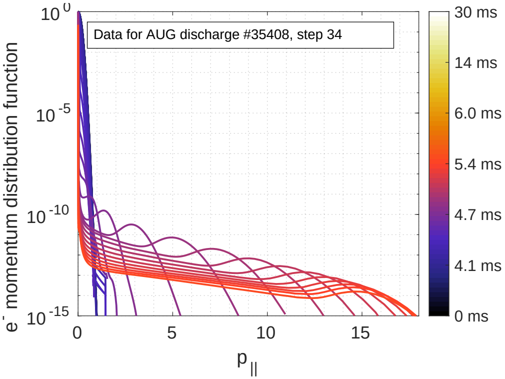

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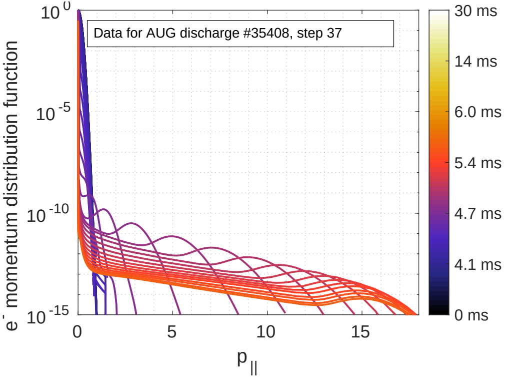

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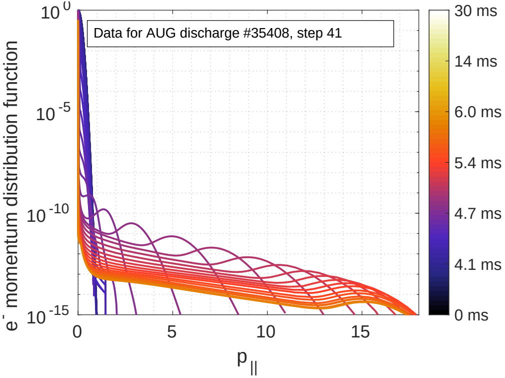

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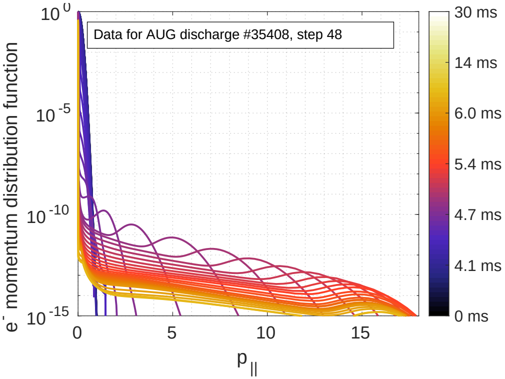

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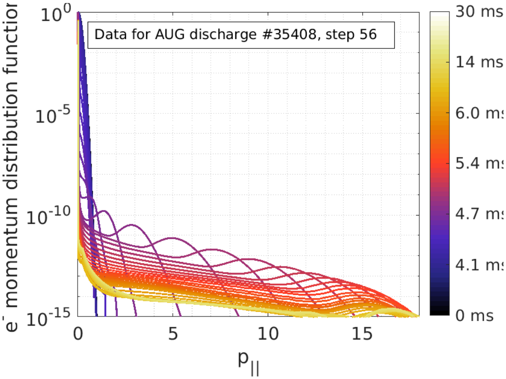

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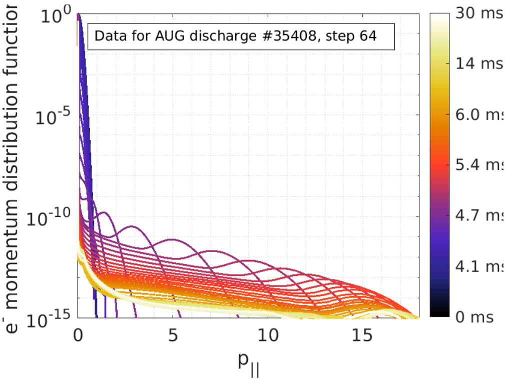

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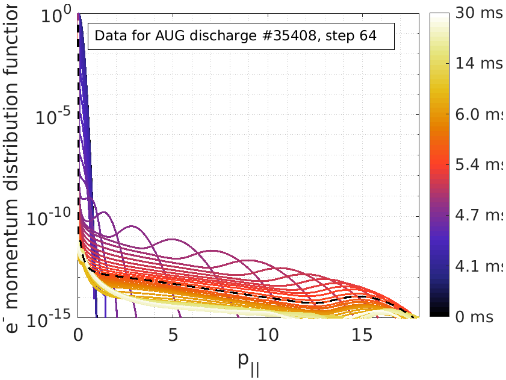

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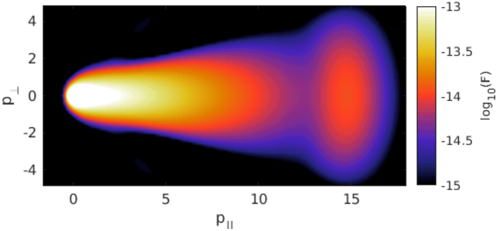
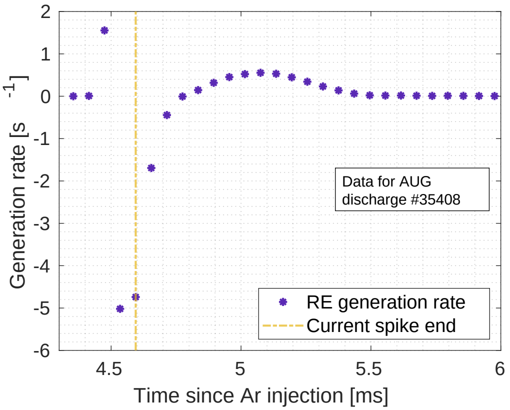


Generation rates



- REs defined as e$^-$ with p > p_c

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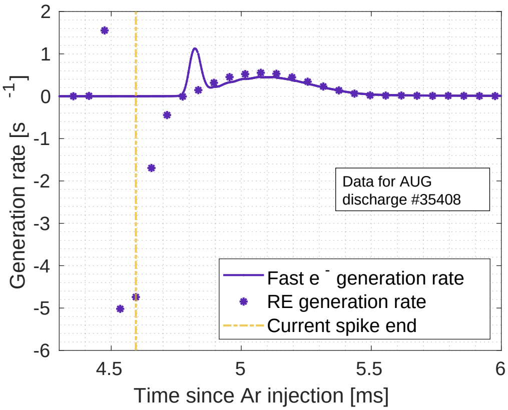

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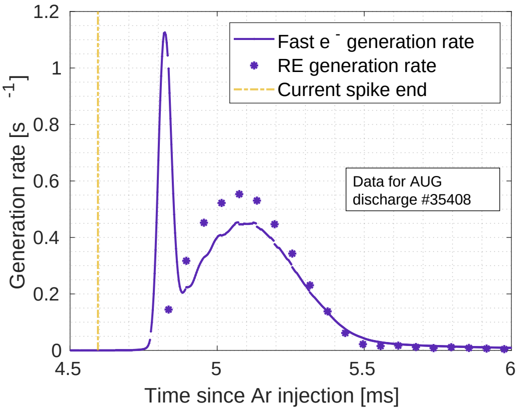

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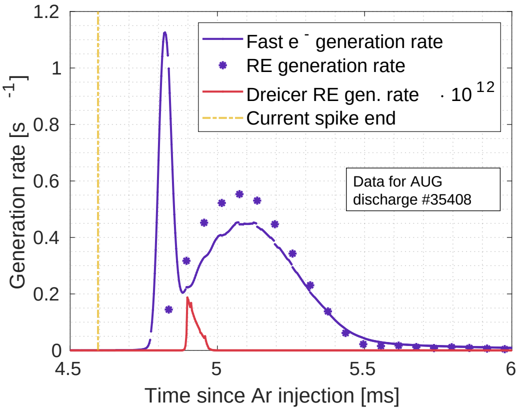

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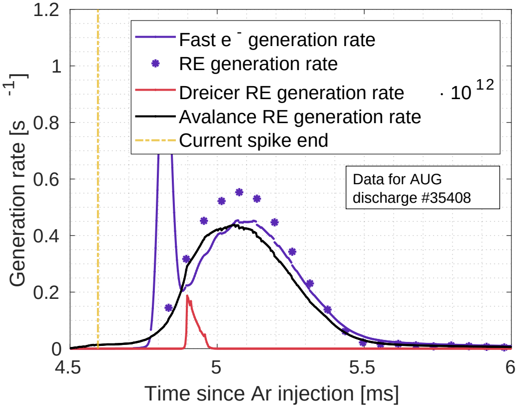

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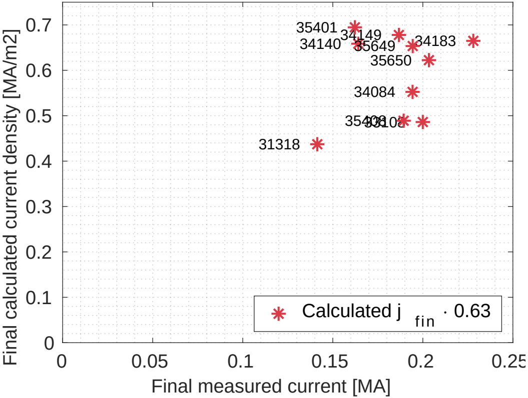

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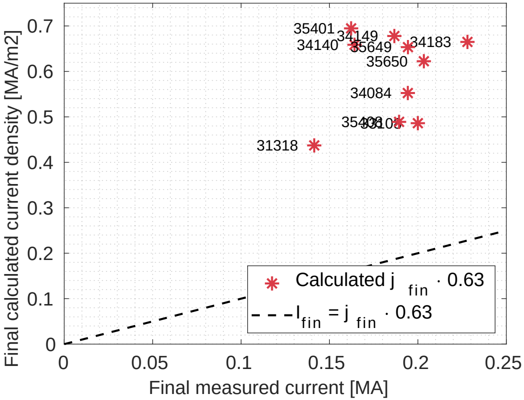

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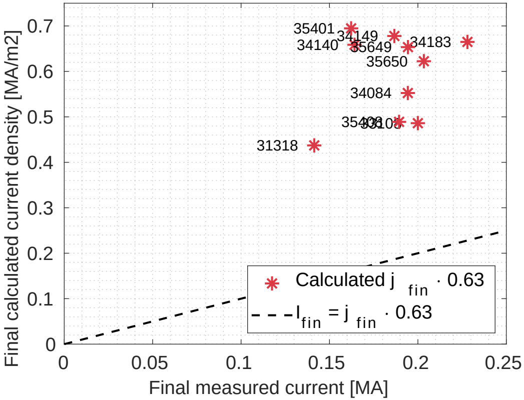

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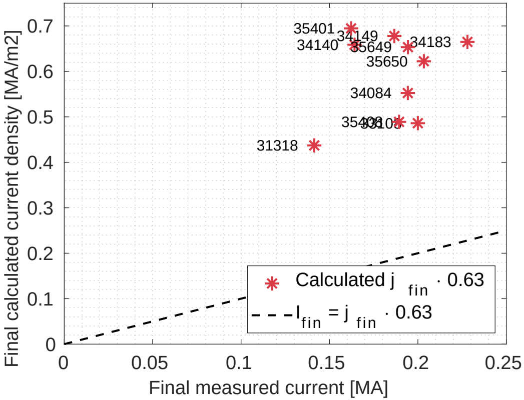

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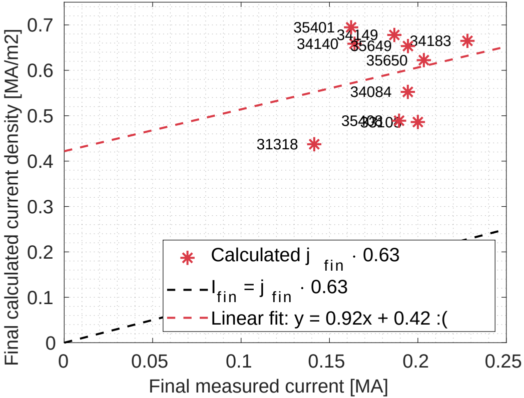

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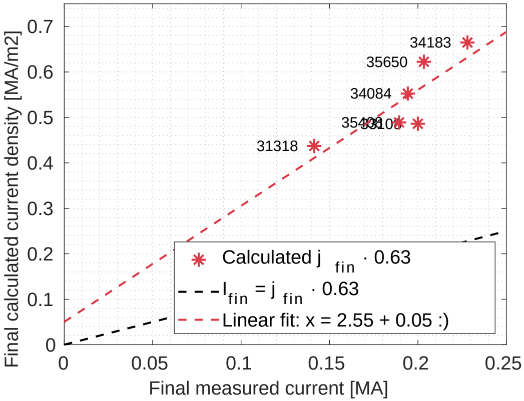

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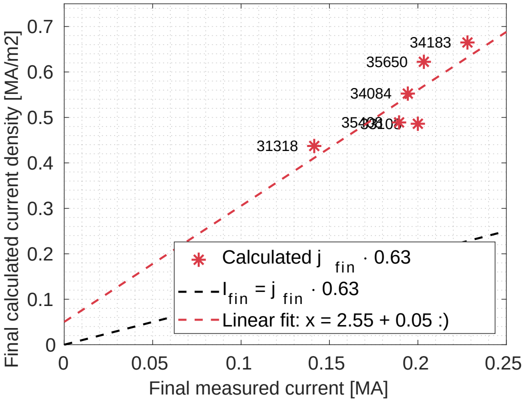

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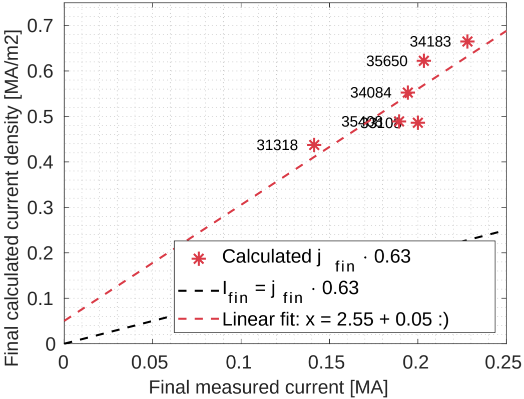

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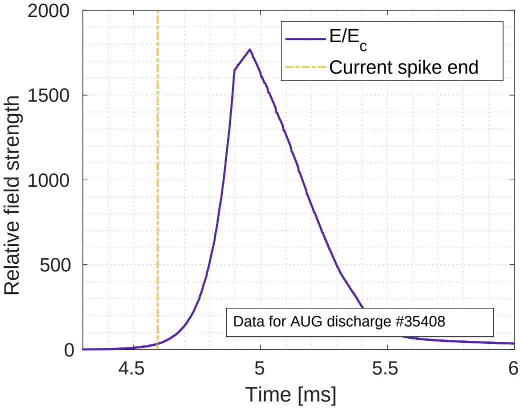
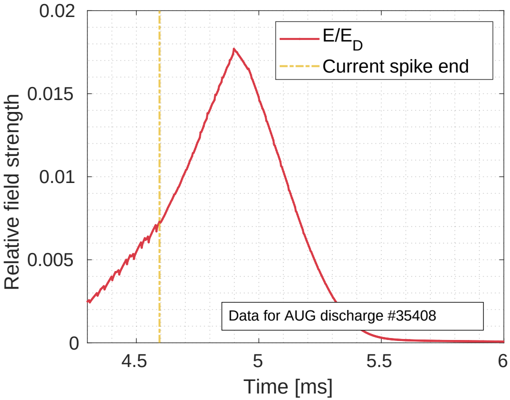
- Conclusion: CODE captures important features of RE generation

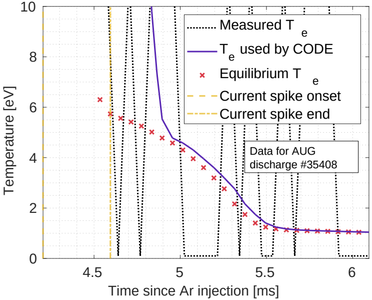
Fields

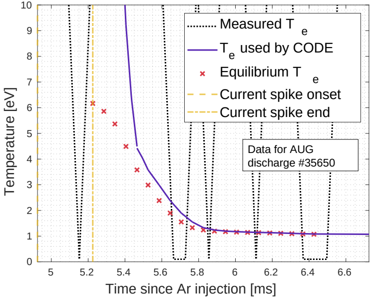

2000
1500
1000
500
0
Relative field strength
4.5
5
5.5
6
Time [ms]
E/E_c
Current spike end
Data for AUG discharge #35408


0.02
0.015
0.01
0.005
0
Relative field strength
4.5
5
5.5
6
Time [ms]
E/E_D
Current spike end
Data for AUG discharge #35408

What the h**k do I mean by "fishy"?

Non-fishy shots:





Fishy shots: