Budapest University of Technology and Economics

MŰEGYETEM 1782

Centre for Energy Research
Fusion Plasma Physics Department

Feasibility of the JT-60SA EDICAM system for runaway electron detection

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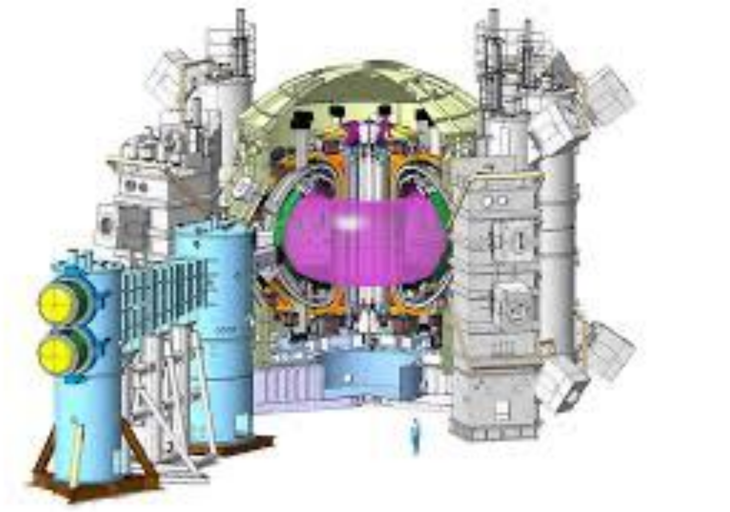
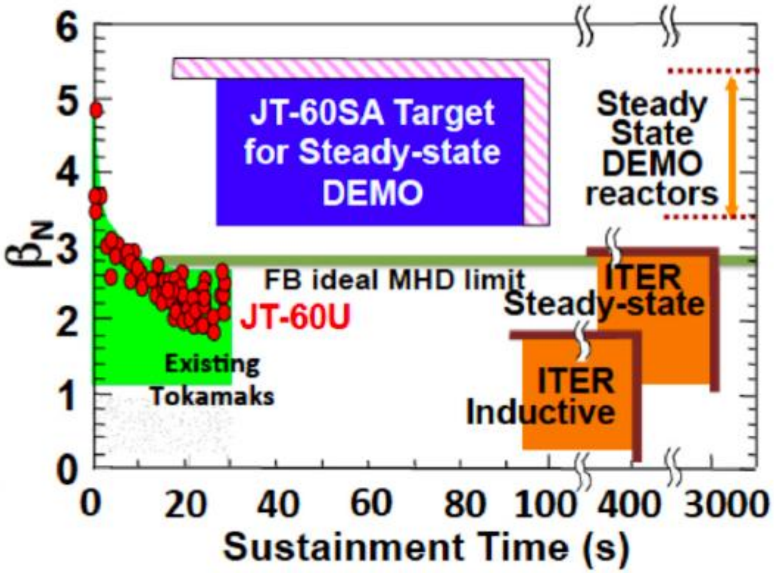
10th Runaway Electron Modelling (REM) meeting, **June 19 – 23 2023**

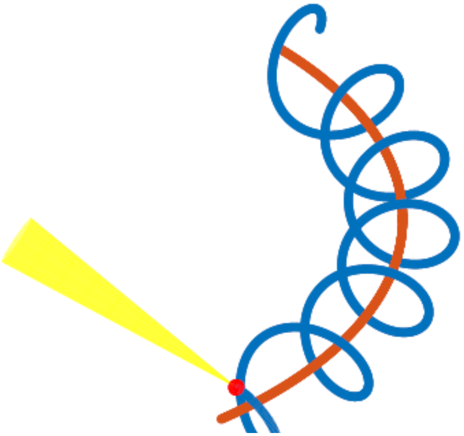
Motivation

- JT-60SA is the World's largest superconducting tokamak
  R~3.0 m, a~1.2 m
- High current
  I_P=5.5 MA, B_t=2.3 T
- **JT-60SA optimal for runaway electron mitigation studies.**
- **What can we use for detecting runaway electron radiation?**

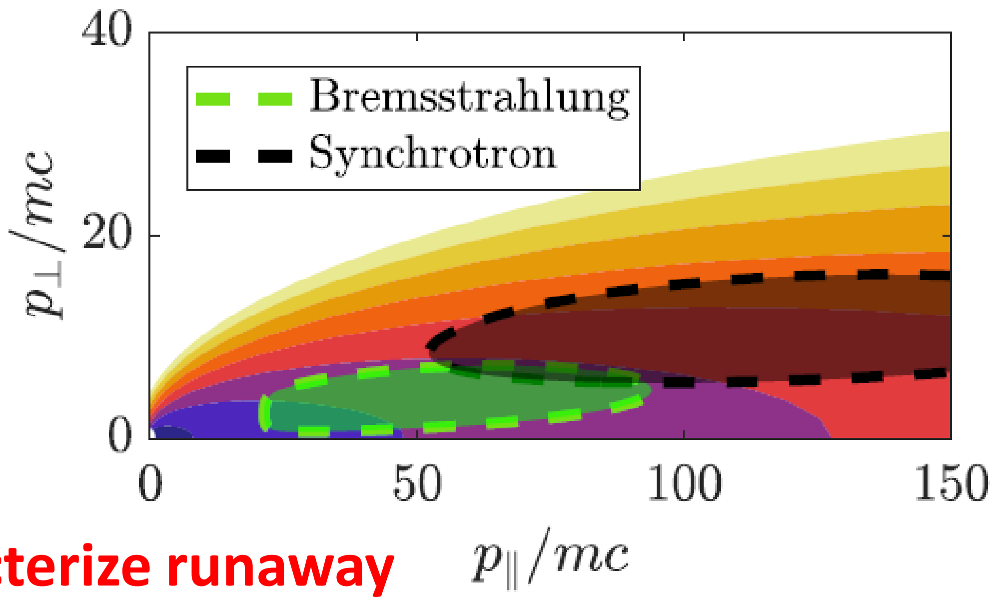




Motivation



- **EDICAM visible camera system has recently been installed to the JT-60SA tokamak** [1]
- **Runaway electrons can produce synchrotron radiation** in the visible range
- Similar cameras used at DIII-D, FTU, AUG, TCV, JET, ...)



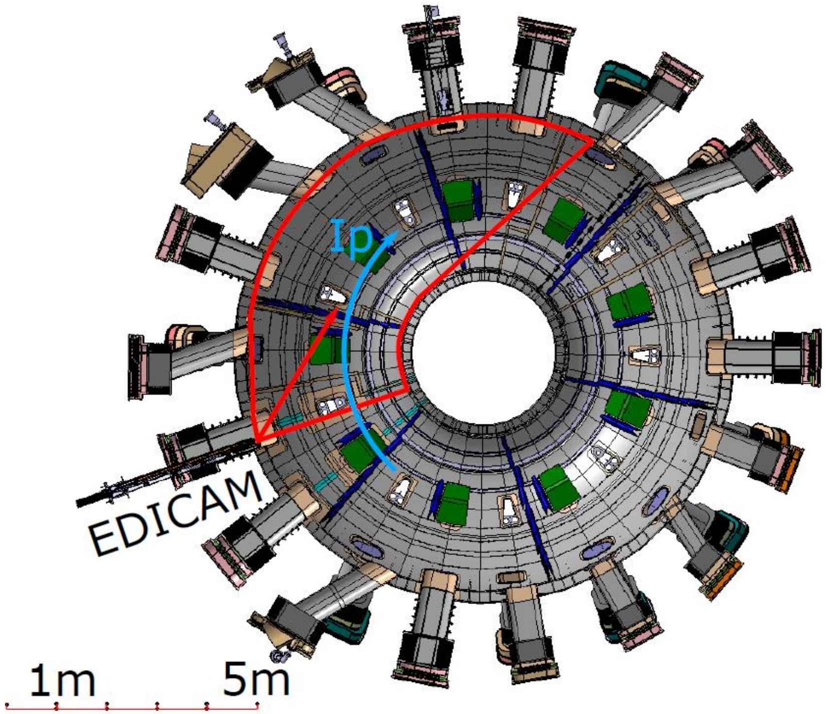
- **Can we detect and characterize runaway electrons with the EDICAM system?**

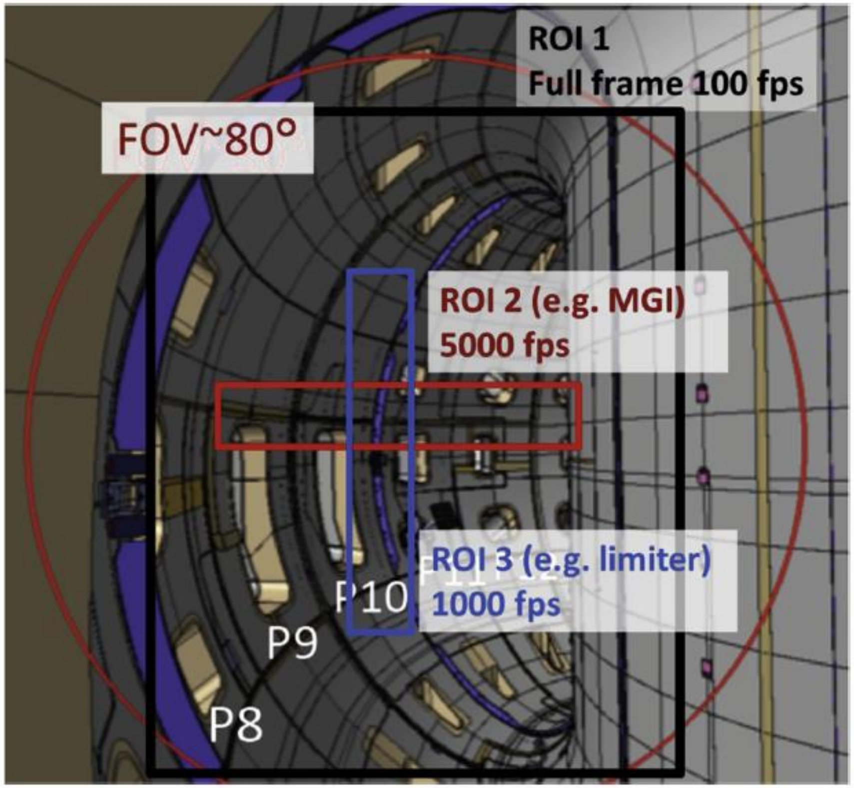
[1] Szepesi, et al., Fusion Engineering and Design 153, 111505, (2020)

EDICAM in JT-60SA

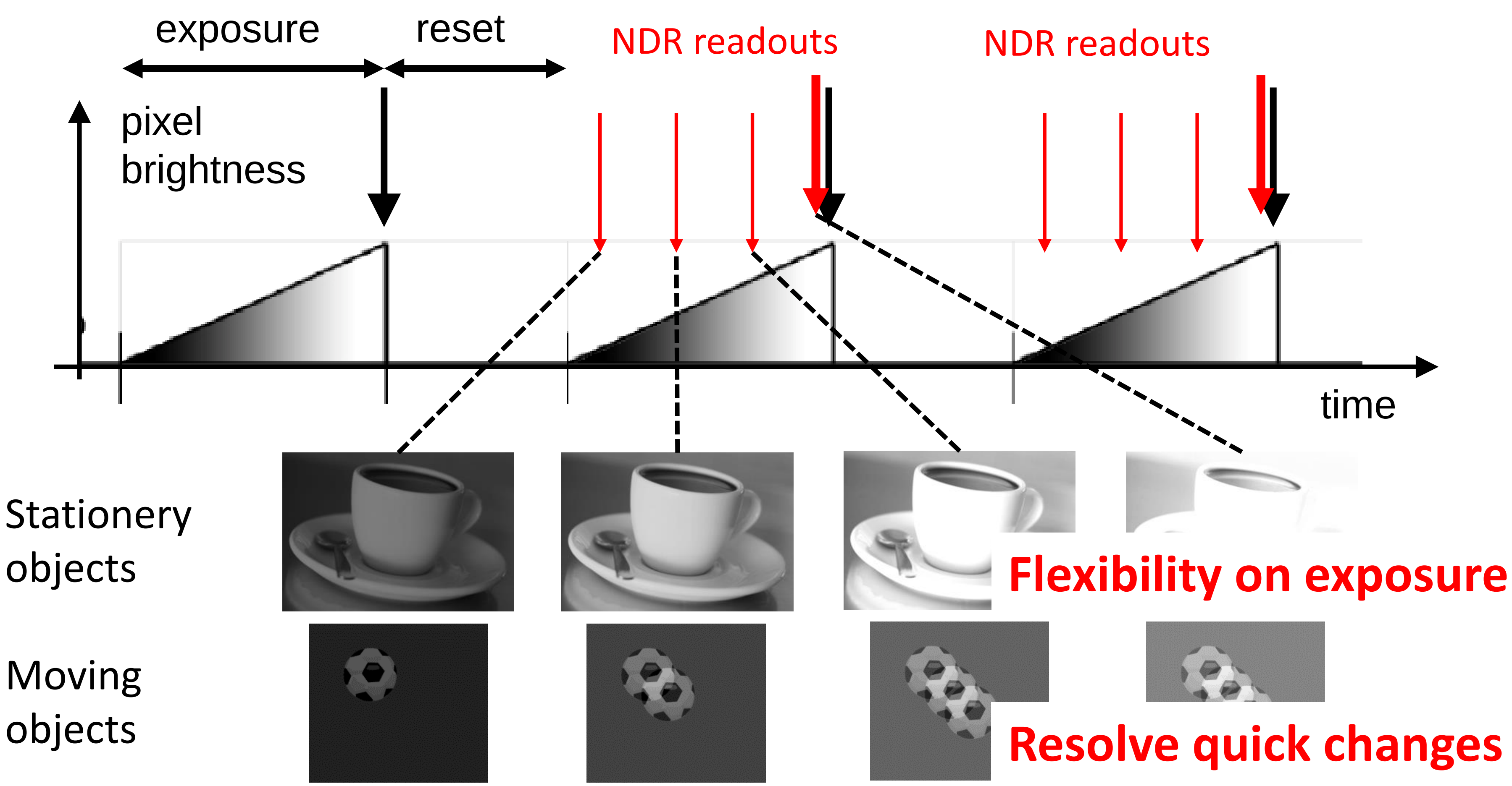
Event Detection Intelligent CAMera

- CMOS camera with Non-Destructive Readout (NDR)
- Real-time control with FPGA





Options with non-destructive readout

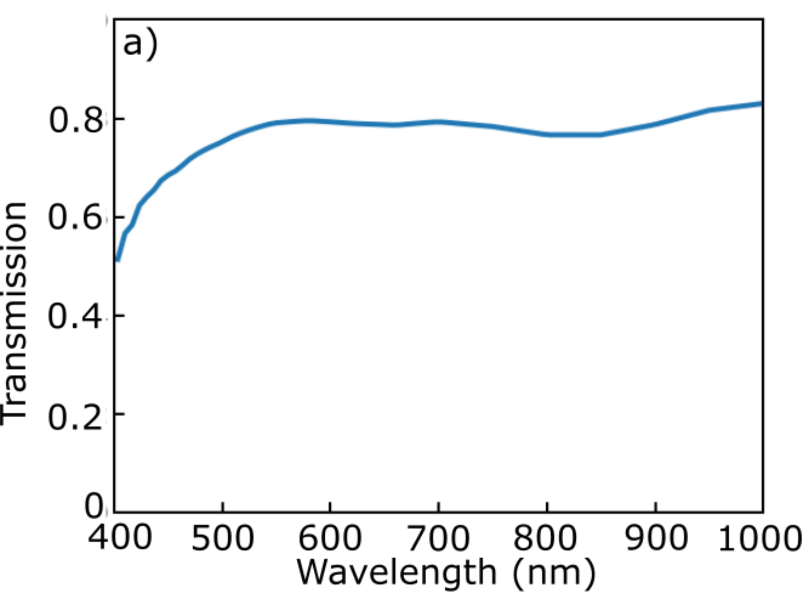


EDICAM spectral response

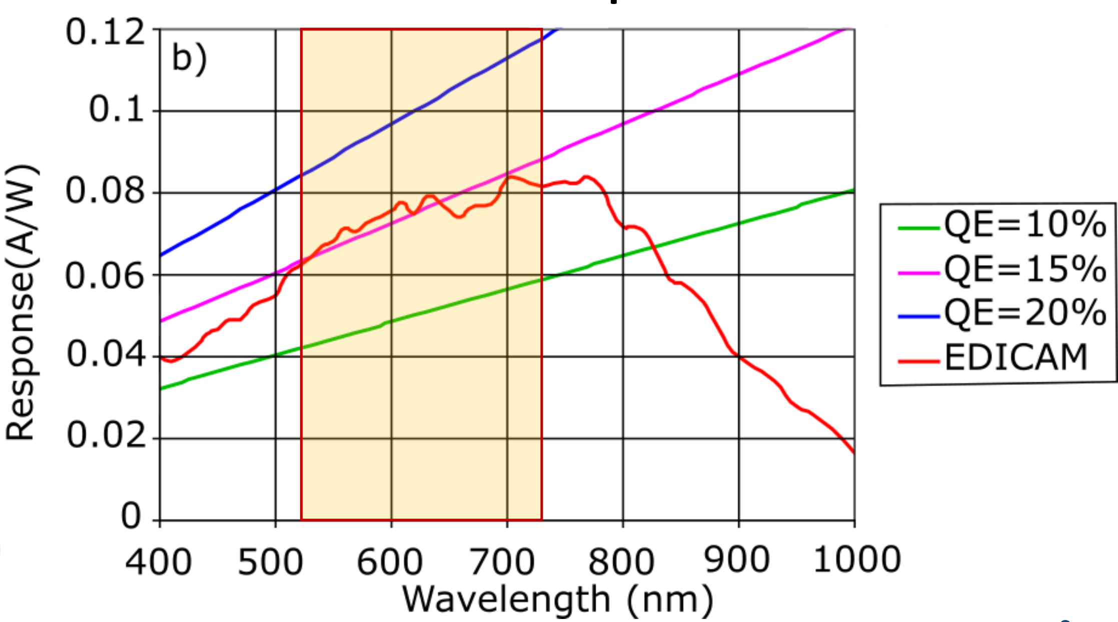
The EDICAM system has the following parameters:

- **Nominal spectral range: 520-720 nm**
- Option to install a filter – **no filter** at the moment

Optical transmission efficiency



Camera sensor response



DREAM simulation

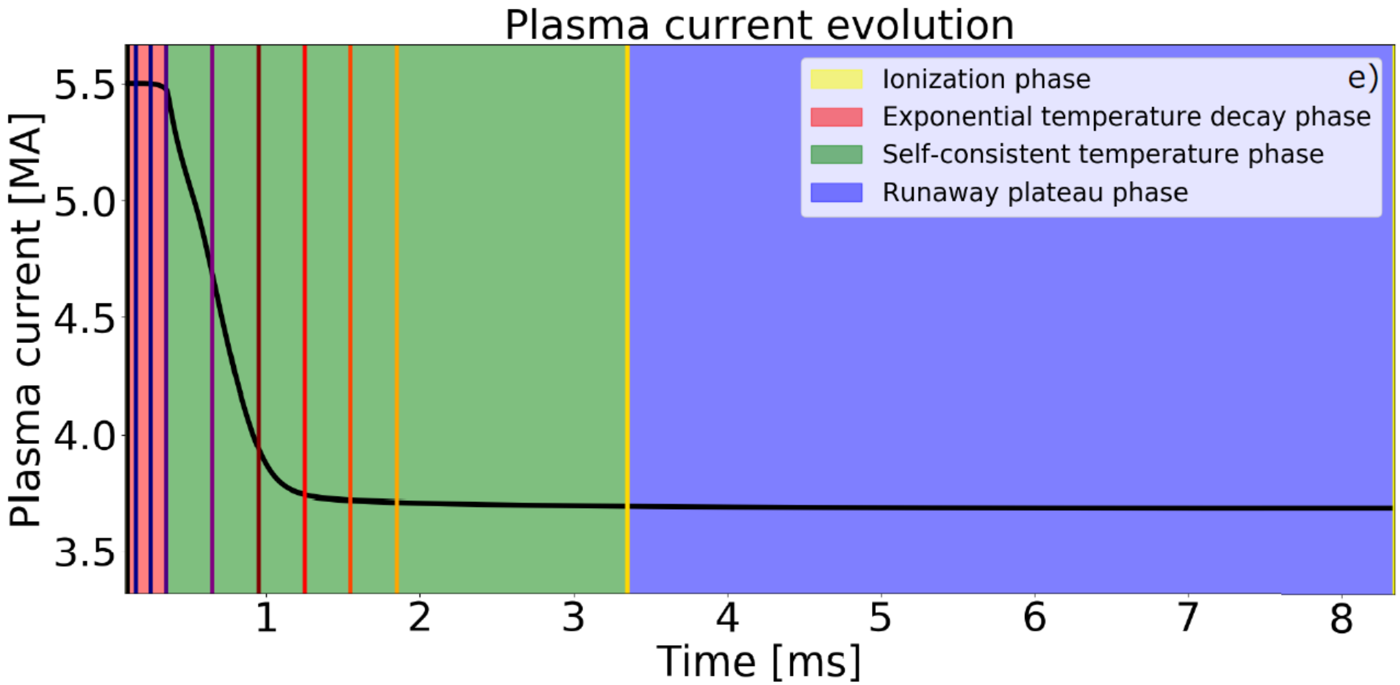
- Simple **disruption simulation of JT-60SA** disruption induced by **Ar injection**
- **Initial profiles** taken from EFIT simulations based on scenario 2 in the **JT-60SA research plan** [2]
  - Temperature, density, current density
- Instantaneous introduction of **uniform Ar profile, 10^{20} m^{-3}**
- **Prescribed exponential T decay** until temperature drops to **100 eV** in the centre, **self-consistent after**
- **Full kinetic simulation of electrons**

Plasma current, I_p (MA)	5.5
Toroidal magnetic field, B_T (T)	2.25
Major radius, R_p (m)	2.96
Minor radius, a (m)	1.18
Aspect ratio, A	2.5
Elongation, κ_x, κ_{95}	1.87, 1.72
Triangularity, δ_x, δ_{95}	0.50, 0.40
Safety factor, q_{95}	3.0
Shape Factor (=q95Ip/(aBt))	6.3
Plasma Volume (m3)	131
Fusion output, P_{fus} (MW)	-
Fusion gain, Q (SA: QDT equivalent)	~0.5
Heating Power (α + external), Pheat (MW)	41
Current drive power , PCD (MW)	10
N-NB, P-NB, ECH power (MW)	10, 24, 7
Ion Temperature, Vol-ave., Central (keV)	6.3, 13.5
Electron Temp., Vol-ave., Central (keV)	6.3, 13.5
Electron Density, line-average, Vol-ave., Central (E20/m3)	0.63, 0.56, 0.77
Stored Energy (Thermal, Fast ion) (MJ)	22.2, 4.0
Energy Confinement Time τE(s) thermal, total	0.54, 0.64
Current DiffusionTime (s)	32.7
Flattop Duration (s)	100

[2] JT-60SA Research Unit, 'JT-60SA Research Plan. Research Objectives and Strategy', (2018)

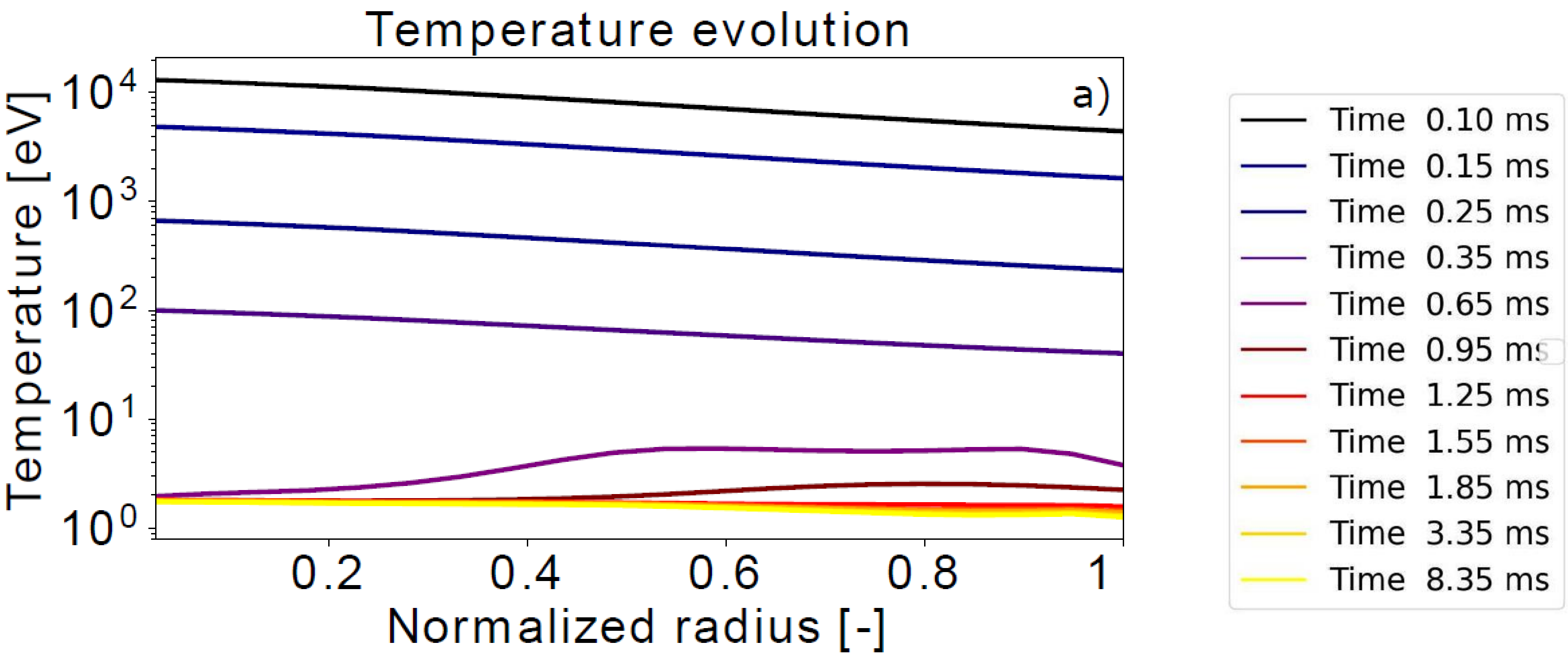
Disruption – instantaneous Ar injection

- Simulation in several phases
- **Significant plasma current remains**
- **t_{CQ}~ 1ms**



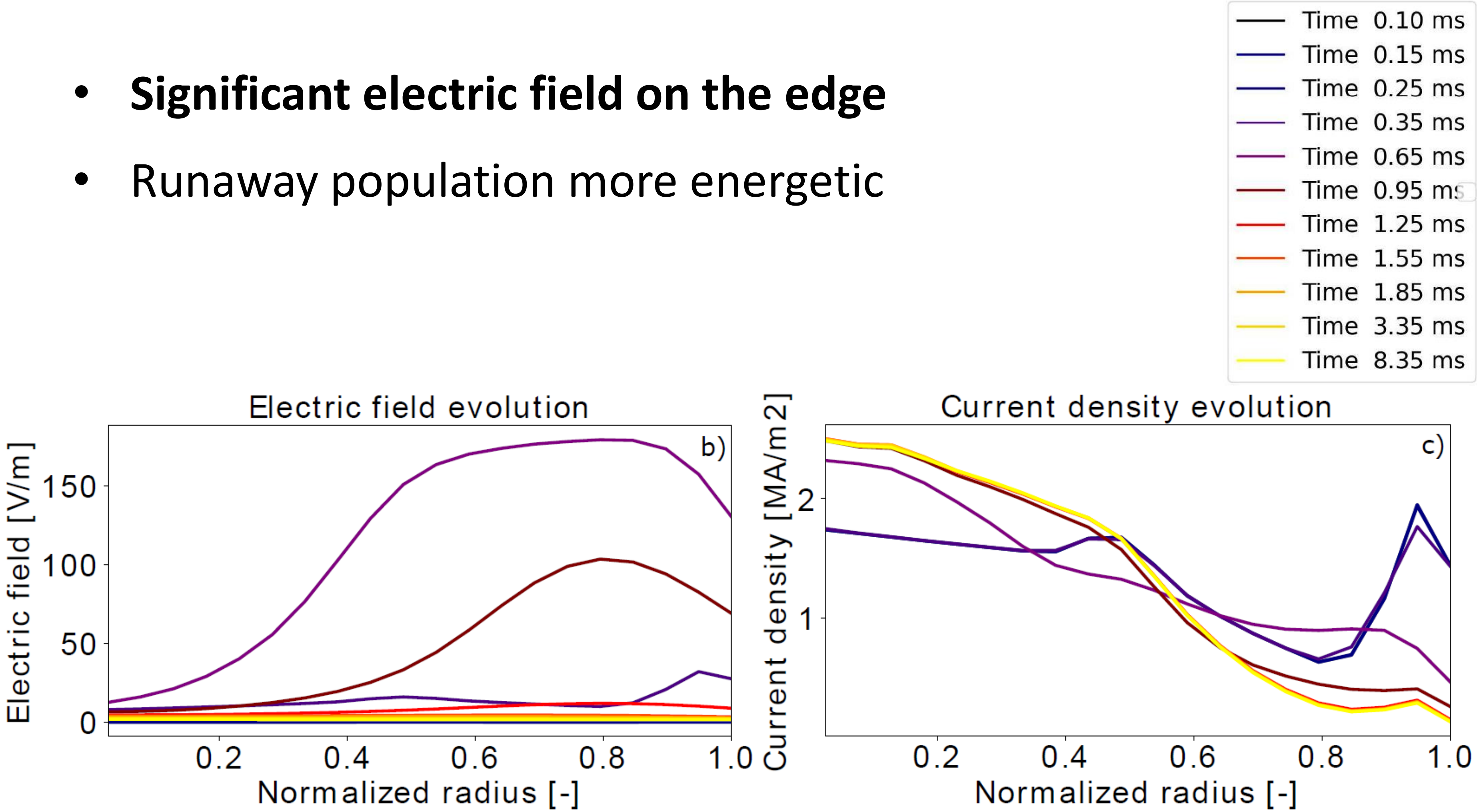
Disruption – instantaneous Ar injection

- Exponential decay until **100eV** on axis
- **Slower cooling at the edge** in the self-consistent phase



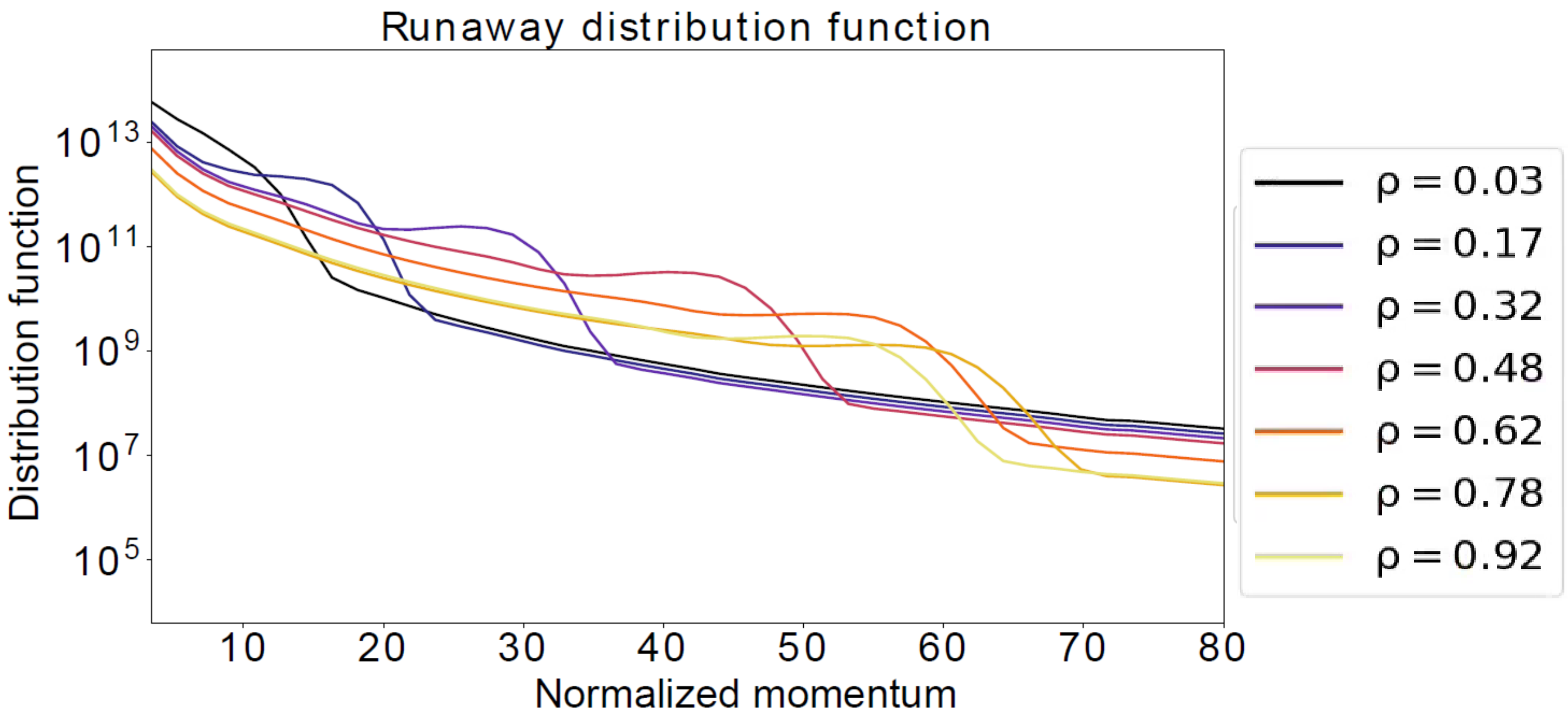
Disruption – instantaneous Ar injection

- **Significant electric field on the edge**
- Runaway population more energetic



Disruption – instantaneous Ar injection

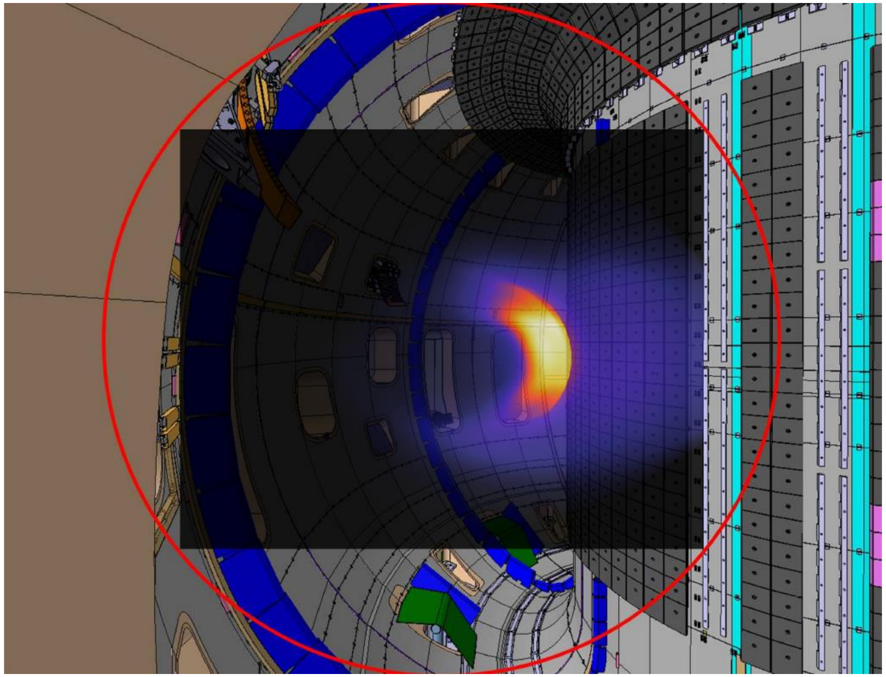
- Runaway electron distribution function at the last time step
- Population has **higher energies at the edge**



SOFT

SOFT is a synthetic synchrotron diagnostic framework calculates runaway electron radiation from electron distribution functions for specific camera settings [3]

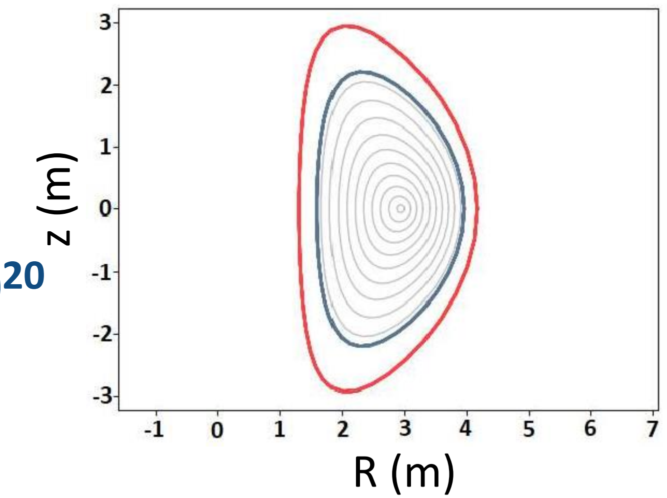
- The **EDICAM camera parameters** are added **to the SOFT code [4]**
- DREAM runaway electron distribution function is used to calculate the expected radiation
- **Resembles images measured on other machines [5]**

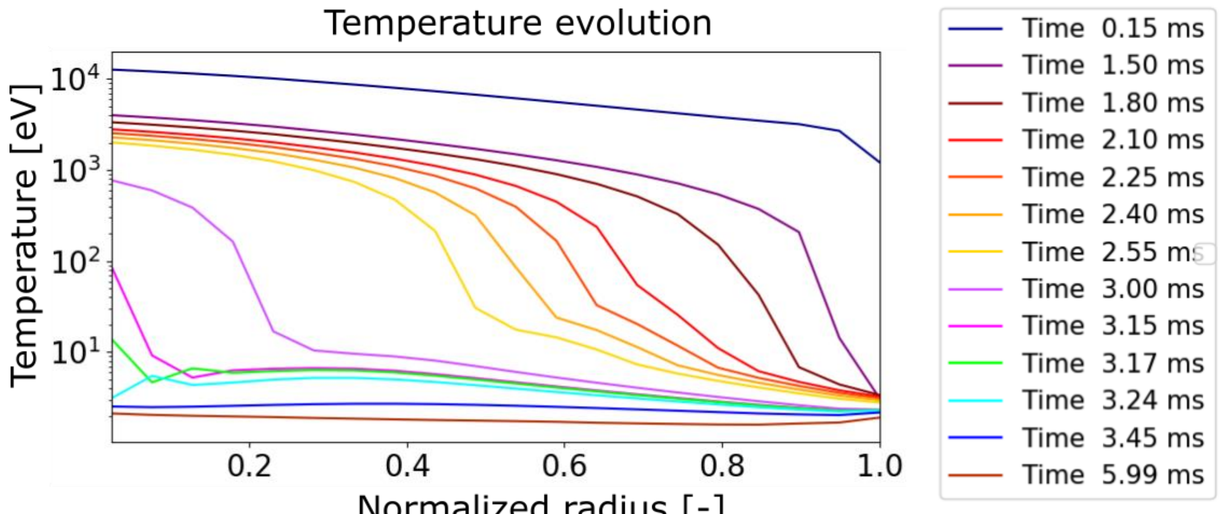


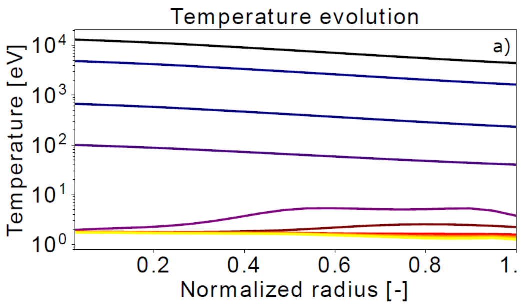
[3] M. Hoppe, et al., Nuclear Fusion 58 (2), 026032, (2018)
[4] S. Olasz, et al., submitted to FED (2023)
[5] C. Reux, et al., PRL , (2021)

Disruption – more realistic Ar injection

- **Shaped plasma** based on JT-60SA parameters from research plan
- **Ar injection from the side, $n_{Ar} \approx 0{,}23 \cdot 10^{20}$**
- Ar diffusion coefficient: 1000 m^2/s
- Cooling front is moving inwards

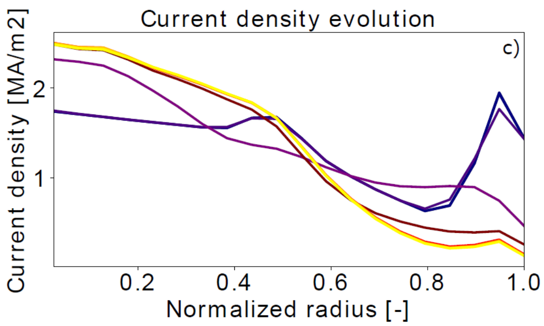


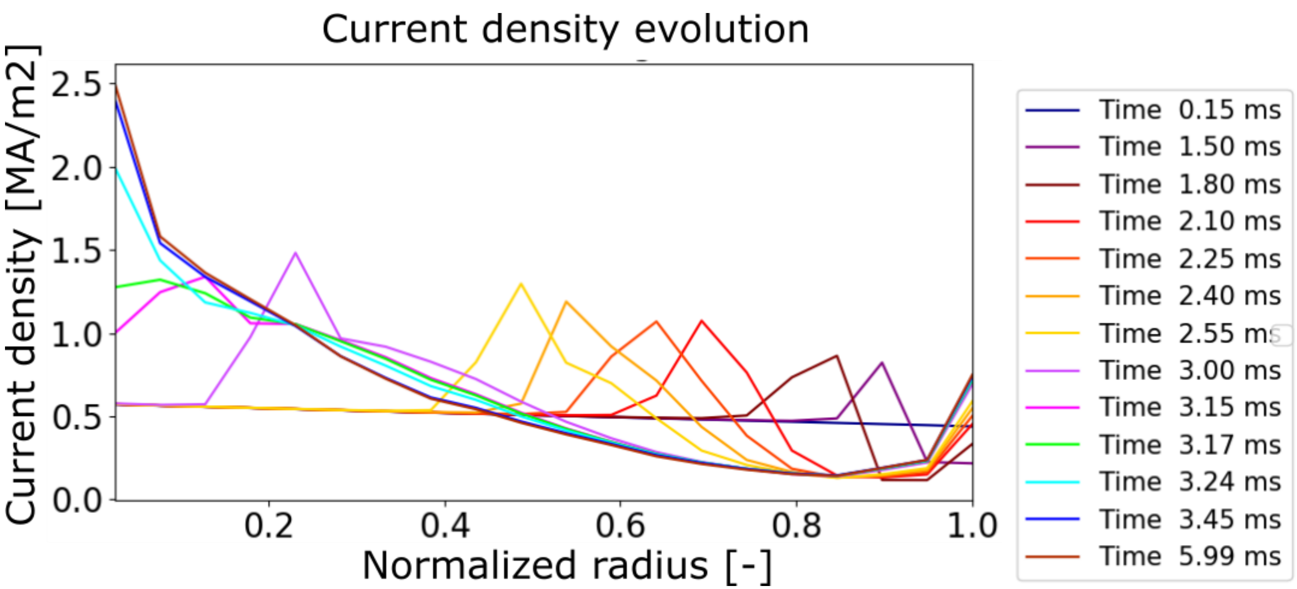




Disruption – more realistic Ar injection

- Current density diffuses inwards with the cooling front
- **Significant current peak at the axis**
- The final current is entirely made of runaway electrons





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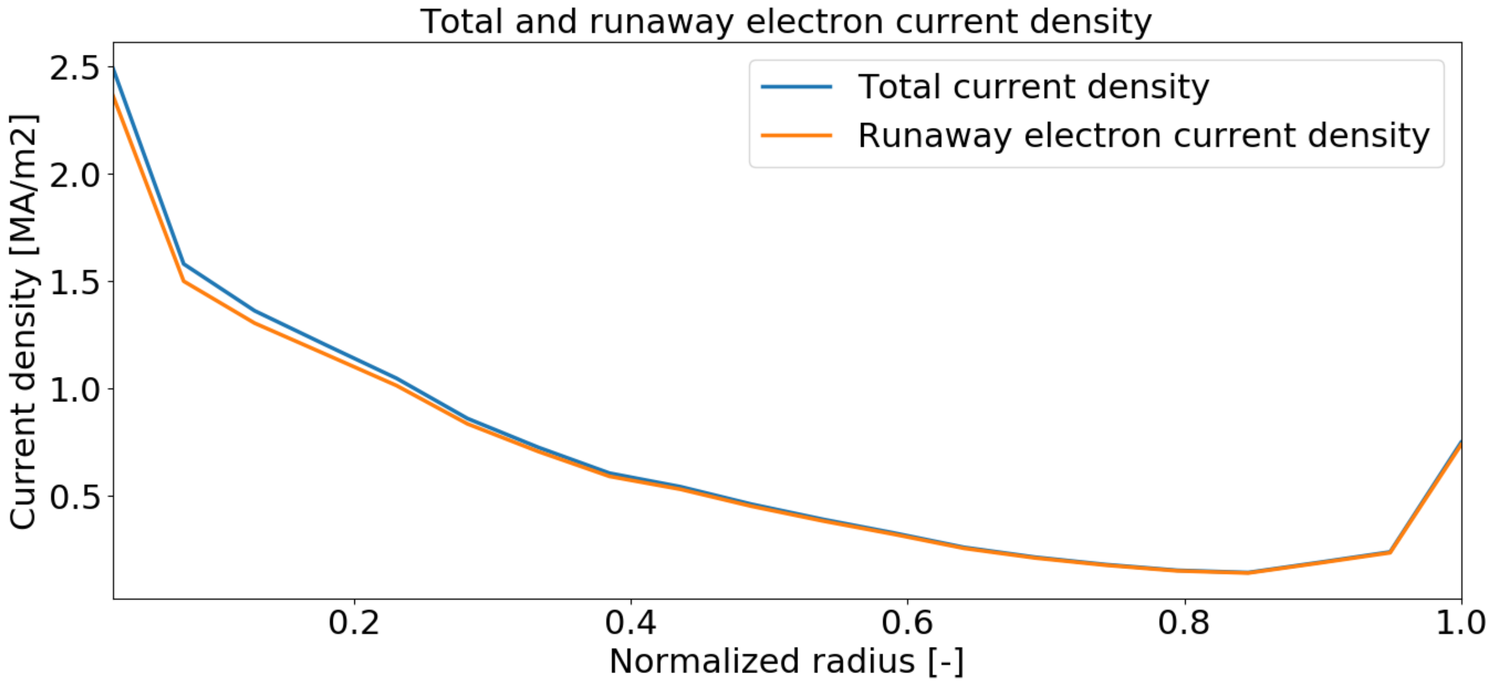
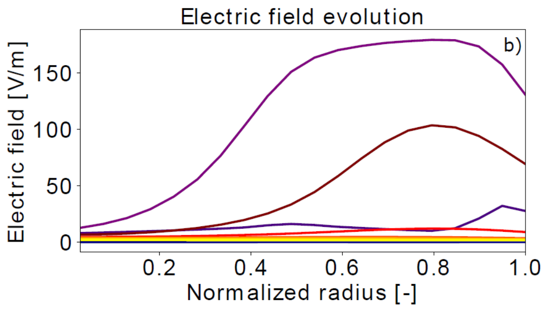
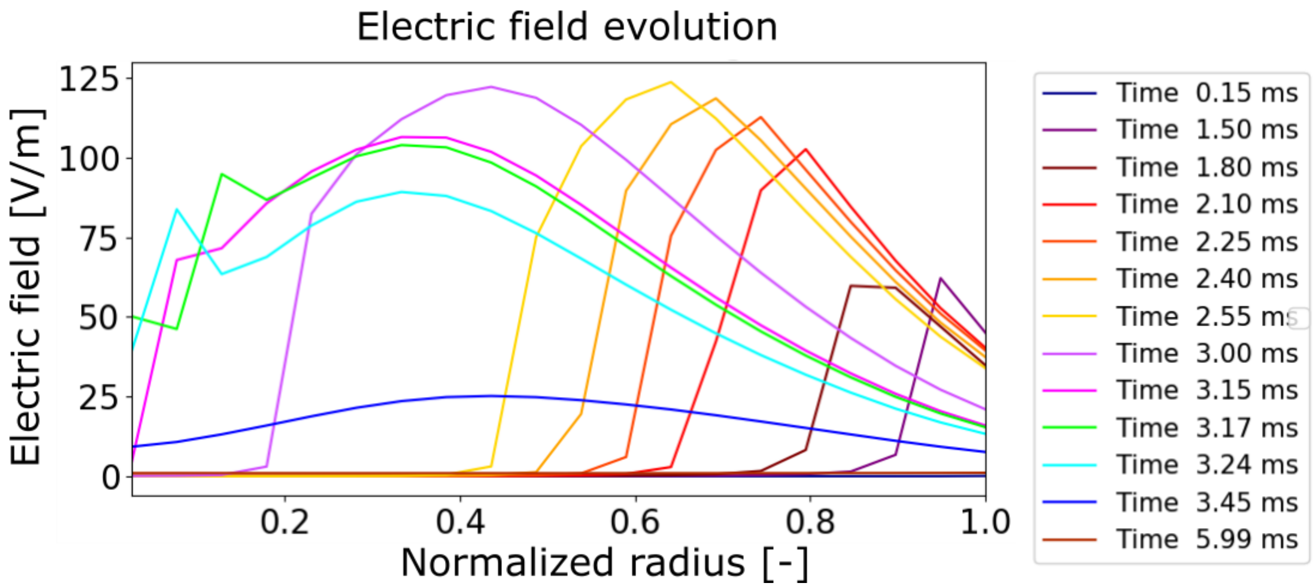


Disruption – more realistic Ar injection

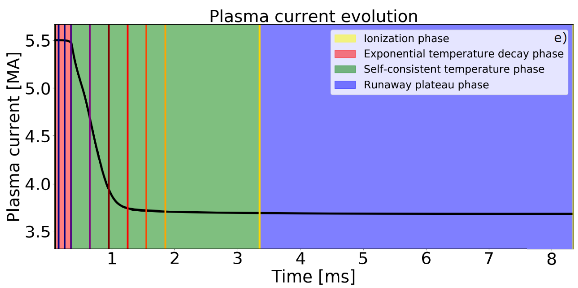
- The electric field propagates inwards
- The **maximum value** is similar to previous results – **location shifted towards the centre**

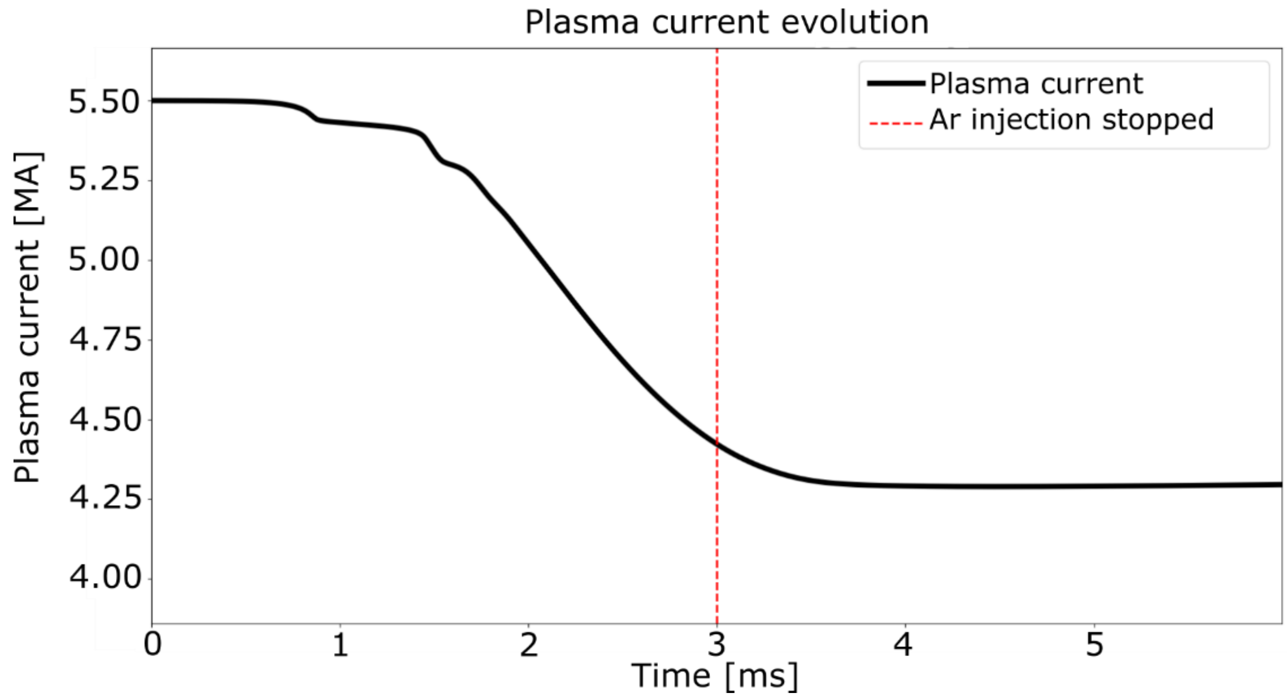




Disruption – more realistic Ar injection

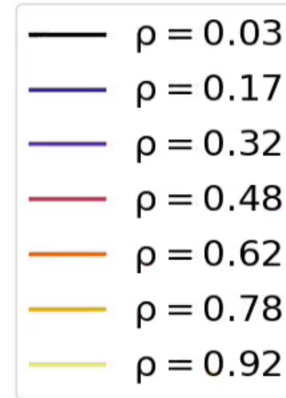
- Higher final current compared to uniform deposition
- **Current quench time ~3ms** – still short

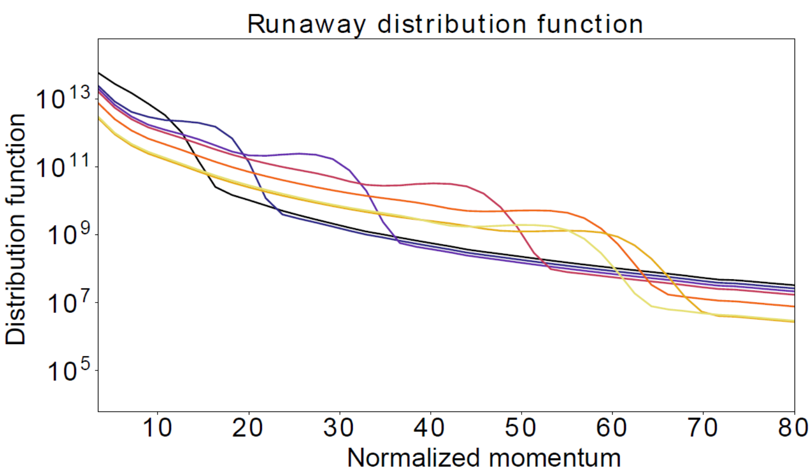


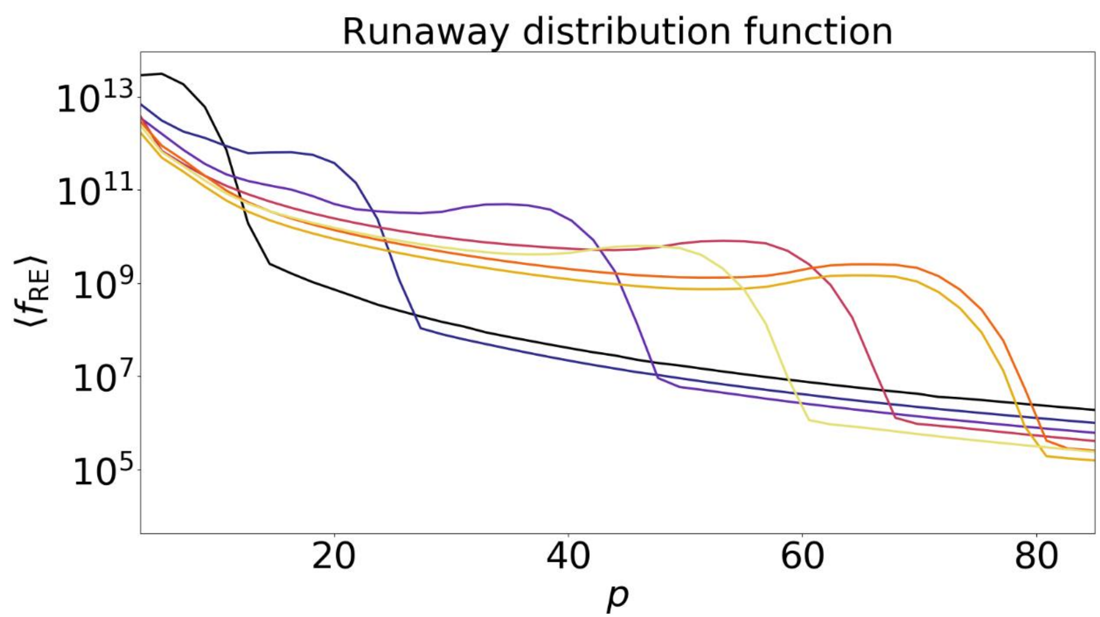


Disruption – more realistic Ar injection

- **Higher maximum particle energy**
- **High energy population is still towards the edge,** but more inwards compared to previous scenario

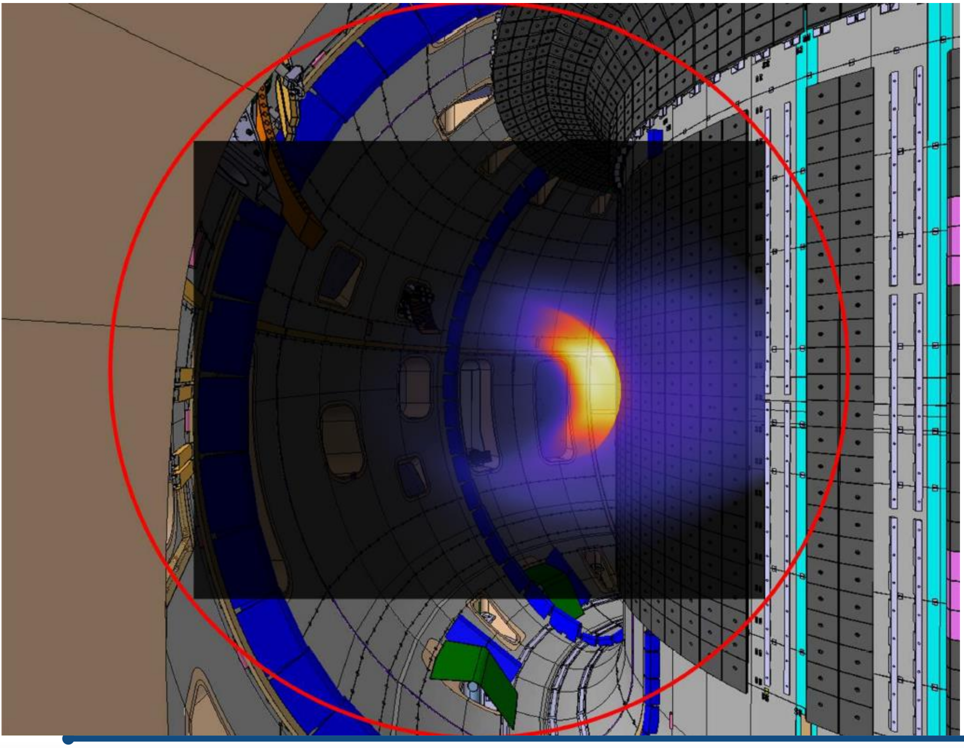


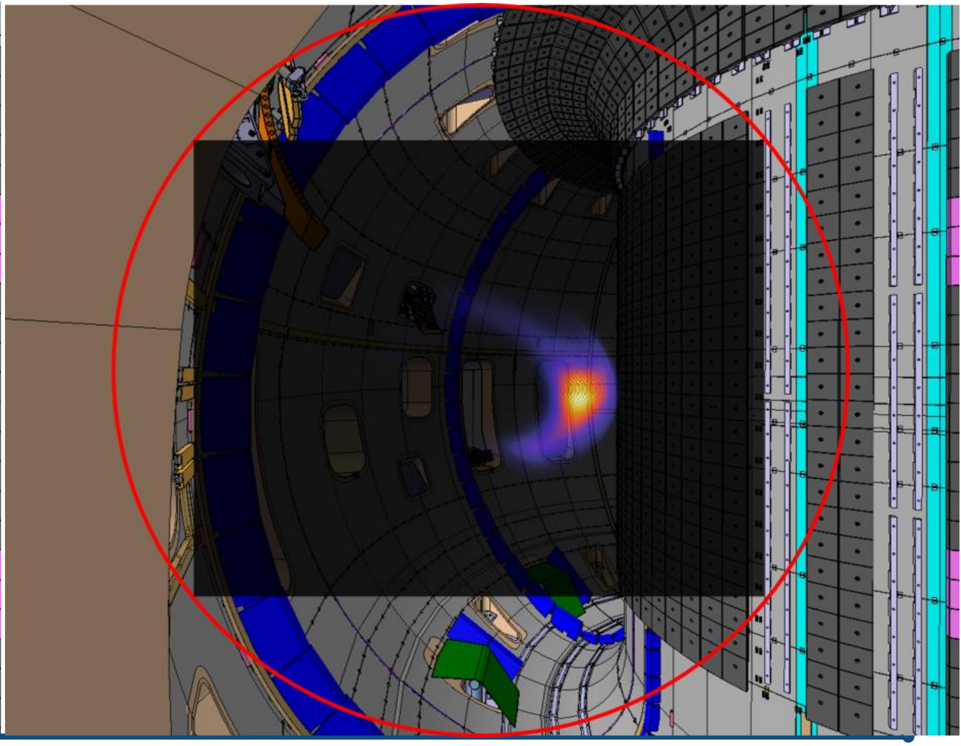




Disruption – more realistic Ar injection

- Smaller radiation spot, but located closer to the centre
- **Radiation is more concentrated**





Summary

- **The EDICAM visible camera** system is installed on the JT-60SA tokamak
- **Simple JT-60SA disruption** with Ar injection
- **Second disruption simulation** with more **realistic injection** method
- Runaway electron **distribution function is used by SOFT** to calculate the **radiation image**
- **Similar radiation images** with some differences
- Outlook:
  - Check scenarios with less current
  - Background radiation (CHREAB)