EUROfusion JET

Software for protection of PFCs at JET

Valentina Huber

EUROfusion Imaging Meeting 2020, Greifswald, Germany

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

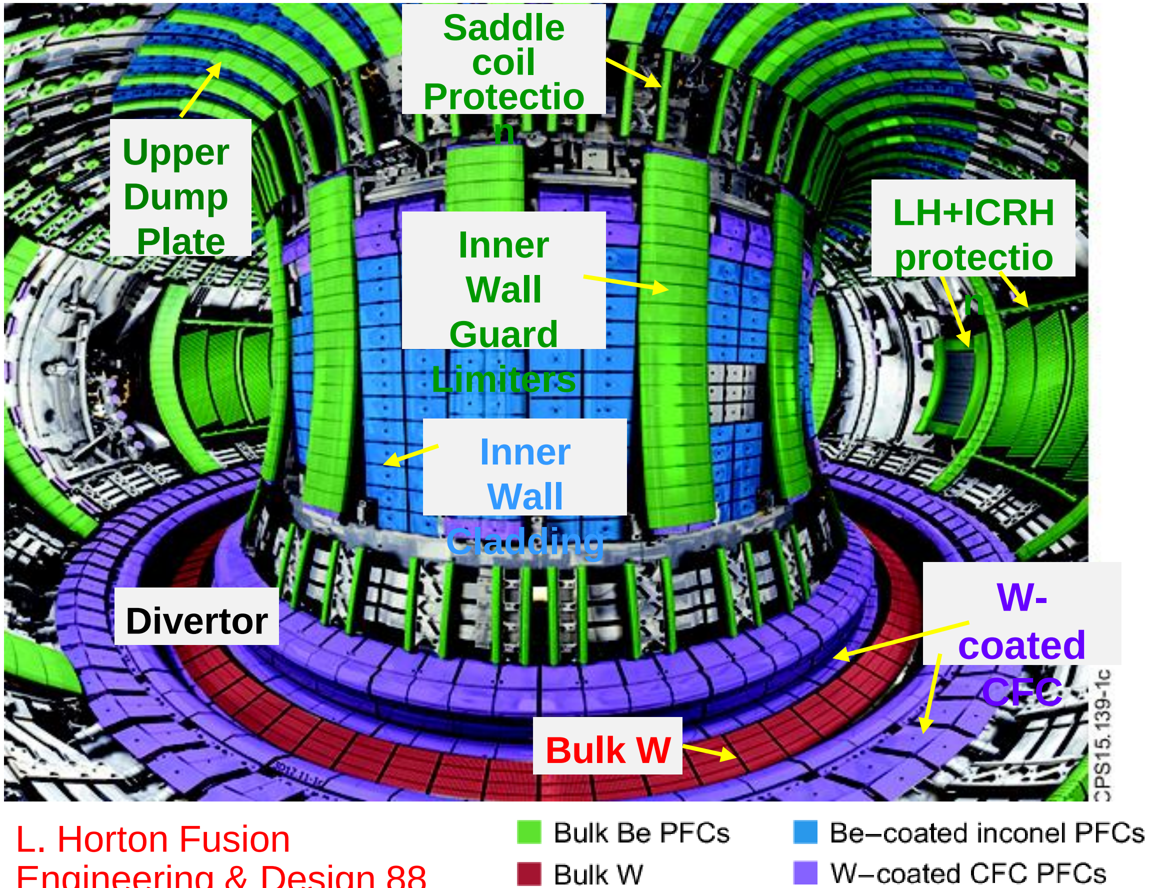
Outline

- Motivation and Objectives of the Real Time Imaging System
- Overview of the imaging diagnostics for the real-time protection of PFCs at JET
  - Existing protection imaging systems
  - New imaging diagnostics compatible with JET operation during D-T campaign
- Real-time protection system overview
- Software framework and tools for post-pulse analysis of data of JET imaging systems
  - JUVIL Functionality for Study of Plasma Physics
  - VSO Tools for Machine Operational Safety
  - Hotspot Editor for Study of Hot Spots
  - Calibration Tools for the calibration of JET cameras

Motivation

- **JET's ITER-like wall was installed in 2011**

  Carbon CFC replaced with
  - **Tungsten,**
  - **Tungsten-coated CFC and**
  - **Beryllium**



L. Horton Fusion Engineering & Design 88 (2013)

The risk of damaging the metallic PFCs caused by beryllium melting or cracking of tungsten. Significant risk of damage to the wall mitigated by multiple strategies, including a real time protection system comprising newly installed imaging diagnostics, real time algorithms for hot spot detection and alarm-handling strategy.

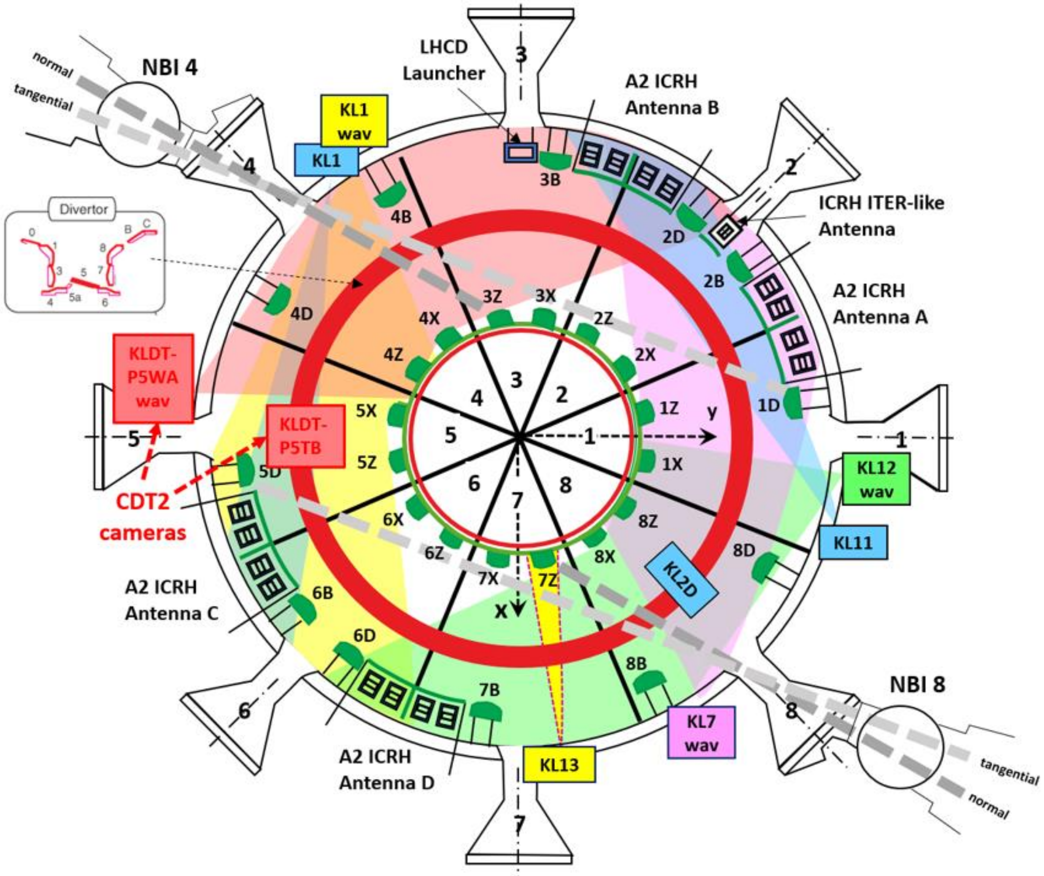
Objectives of the Real Time Imaging System

- avoid the melting of Beryllium wall components ($T^{Be}_{melting}$ = 1287ºC)
- minimize the risk of delamination of the tungsten coated tiles (T_{surf} should be below 1200ºC)
- keep the T_{surf} below threshold at which the bulk tungsten re-crystallizes (1200ºC)

The typical alarm temperature thresholds used for the real-time protection of the first wall on JET-ILW are:

- **Beryllium: 950ºC** for Be to avoid melting
- **W-coated CFC: 1120ºC** to avoid damage of the coating
- **Bulk W: 1000ºC** to avoid fatigue of tungsten (variable limit with budget managed by JPEC)

Protection Imaging Systems: Locations and Fields of Views



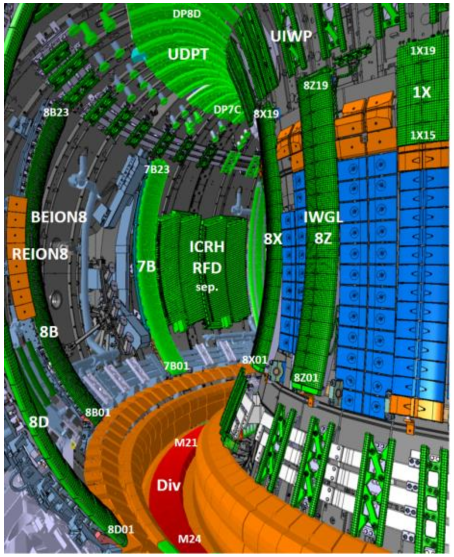
PIW camera views cover 66% of the first wall and up to 43% of the divertor

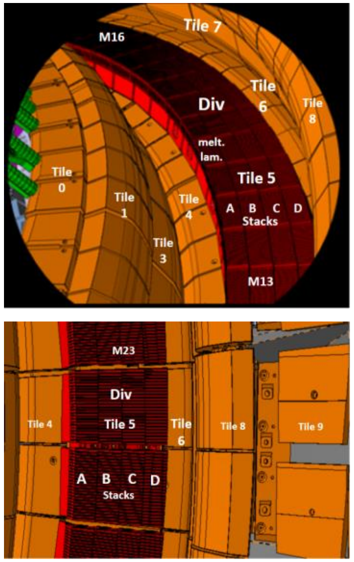
10 NIR CCD Hitachi cameras

- 3 Wide-angle views: **KL1, KL7, KL12**
- 4 Divertor tangential views: 2***KL1**+**2*KL11**
- 2 Divertor from top views: 2***KL2D**
- Shine through view: **KL13**

2 new NIR SWIR WiDY cameras

- Wide-angle view: **KLDT-P5WA**
- Divertor from top view: **KLDT-P5TB**



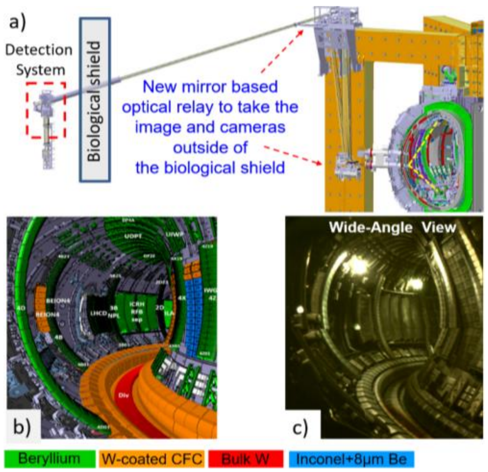


New Imaging Protection Systems Compatible with JET Operation during the D-T Campaign

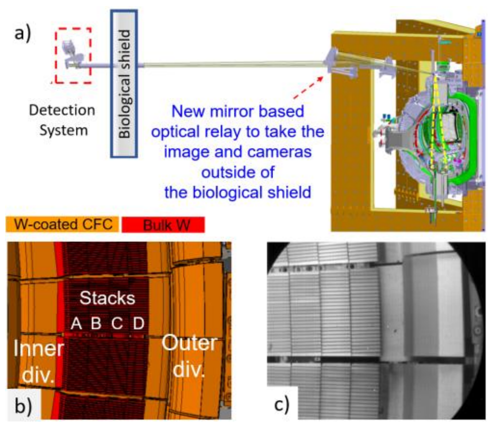
- The coming DTE2 campaign on JET with the total neutron budget of $1.55*10^{21}$ 14MeV neutrons will cause failure of camera electronics within the Torus hall due to significant increase of the hard radiation level in comparison to DTE1 campaign with $0.3*10^{21}$ neutrons.
- To provide the reliable wall protection needed during the coming D-T campaign, two new imaging systems equipped with new optical relays to take the images and the cameras outside of the biological shield have been installed on JET

- Long distance optical relay (≈40m long) from the torus hall to the middle lab in J1F
- Mirror based optical design
- Protection NIR (logarithmic), operation visual color, scientific infrared and visual CDT cameras
- The remaining issue is the image movements on CDT cameras

Wide-angle view

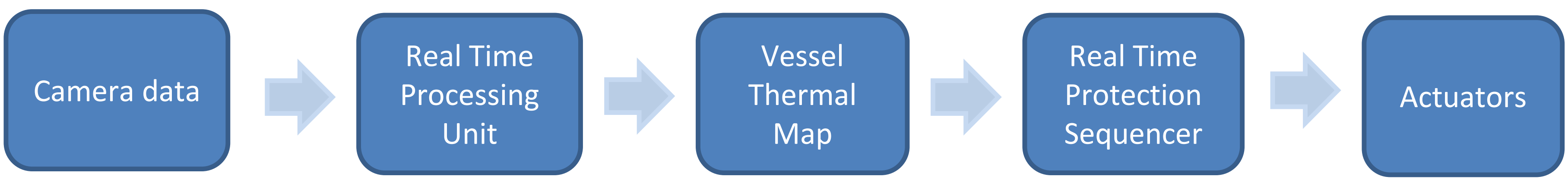


Divertor from top



Real-Time Protection System Overview

- Cameras act as temperature sensors
- Each camera monitors multiple regions of interest (ROIs) for their maximum temperature
- A real time processing unit (**RTPU**) for each camera calculates the temperature and sends the result across JET's Real Time Data Network (RTDN) to a separate real time system, the Vessel Thermal Map (**VTM**)
- The Vessel Thermal Map (**VTM)** assimilates all temperature inputs and using the knowledge of how camera ROIs map to physical components identifies **Events**
- Events are communicated to the Real Time Protection Sequencer (**RTPS**), which decides how the control actuators should respond
- The overall system, from the ROIs to the responses, is **highly configurable**.



JUVIL Software Framework

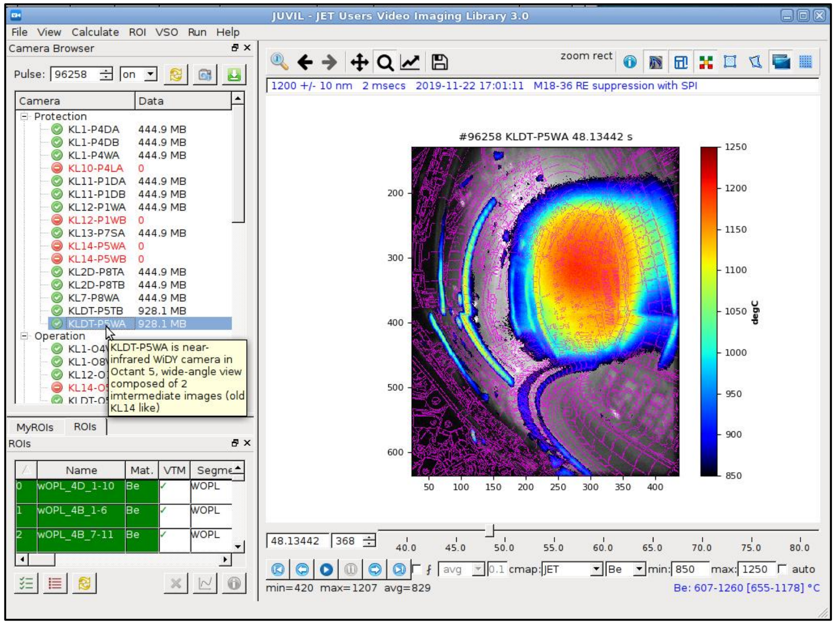
JUVIL (**J**ET **U**ser **V**ideo **I**maging **L**ibrary) powerful and user-friendly framework for loading of videos from all types of JET cameras and quick analysis of imaging data

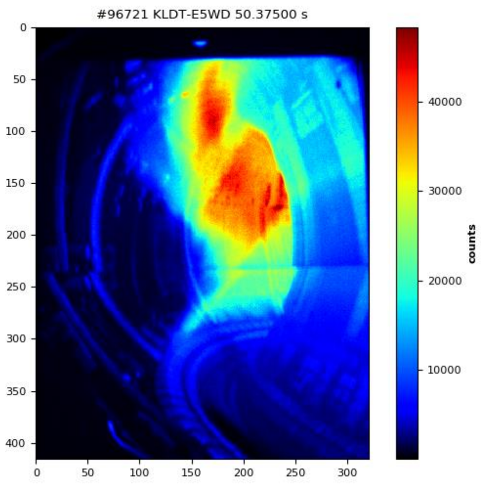
It consists of object-oriented modules implemented in Python to simplify work with JET scientific data and provides:

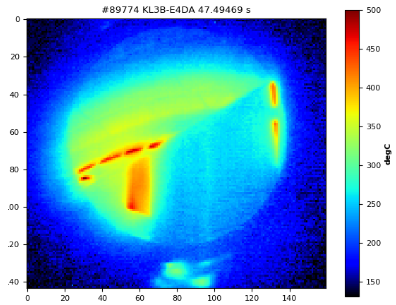
- standard interfaces to access video data
- basic imaging post-processing routines
- JET specific implementations are separated from the basic framework into the **juvil.jet** package and it's sub-packages (e.g. **juvil.jet.vso** contains VSO tools)
- is highly configurable and can be easily extended and adapted for new imaging data formats or new cameras

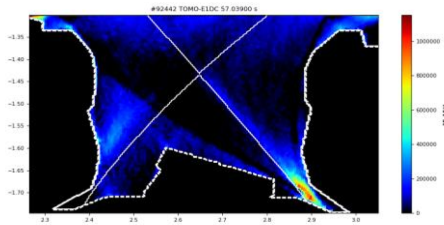
JUVIL Functionality for Study of Plasma Physics

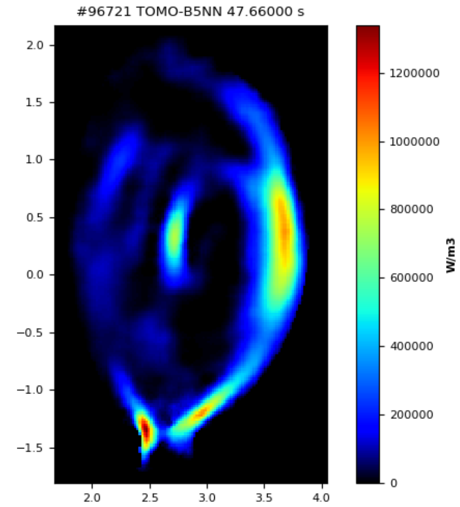
- Loads the videos of all types of imaging systems on JET and tomographic reconstructions stored in JET data store
- Performs post-processing (pre-defined image rotation, data format conversion, extension of non-interlaced fields to full frames) automatically
- Enables to display high temperatures and overlay them with a camera image and/or a wireframe





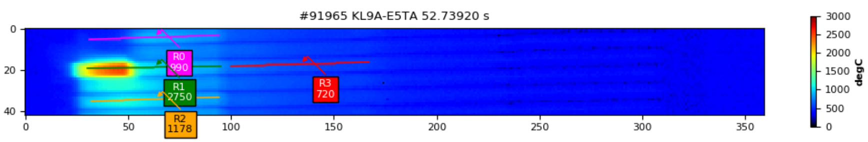


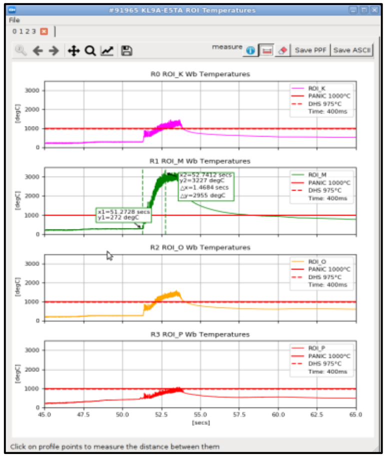


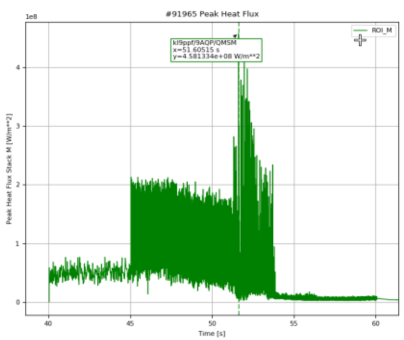


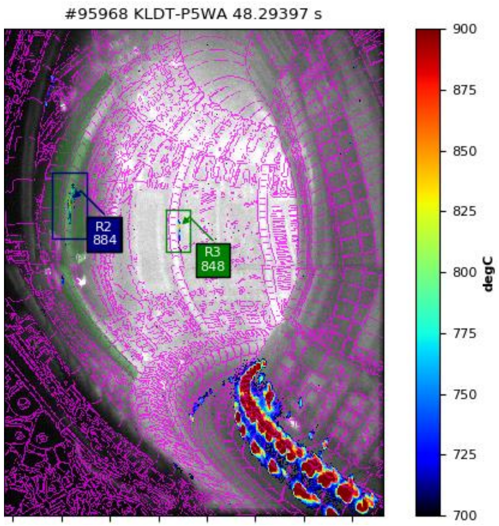
JUVIL Functionality for Study of Plasma Physics

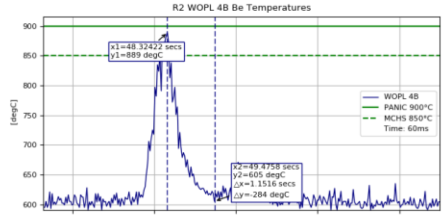
- Subtracts a background, performs dead pixels and flat field corrections, and converts the pixels intensities to the corresponding temperatures
- Loads pre-defined ROIs and their temperatures, plots peak heat fluxes
- Enables to specify own ROIs and calculate their temperatures as well as compare the temperatures in several pulses
- Calculates average, maximum, standard deviation frames and profiles
- Provides information about imaging systems and video settings
- User-friendly context menus and tooltips

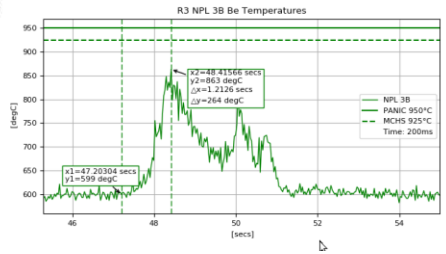






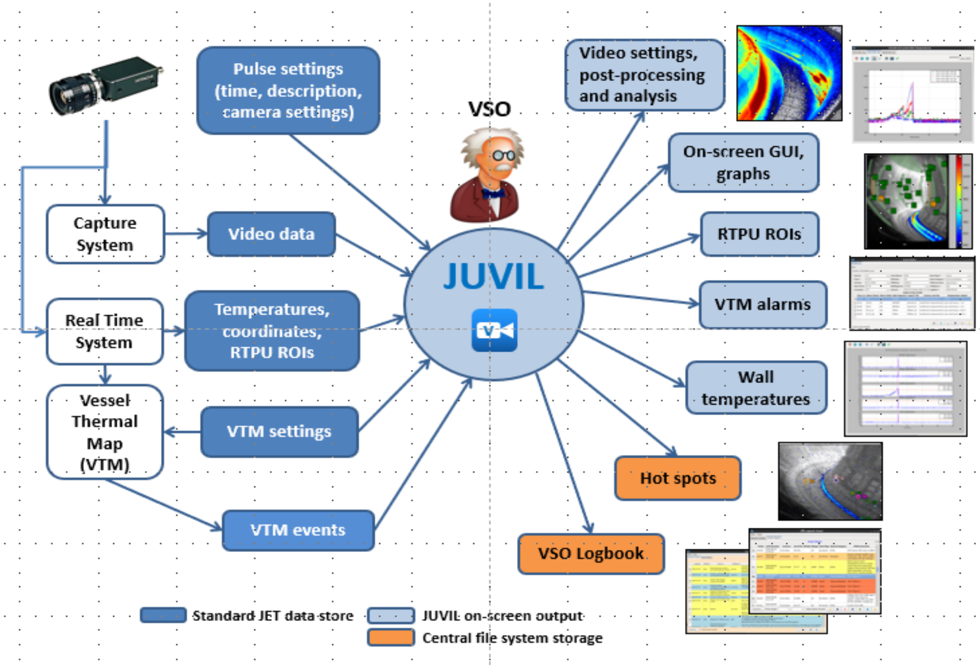






VSO Tools for Machine Operational Safety

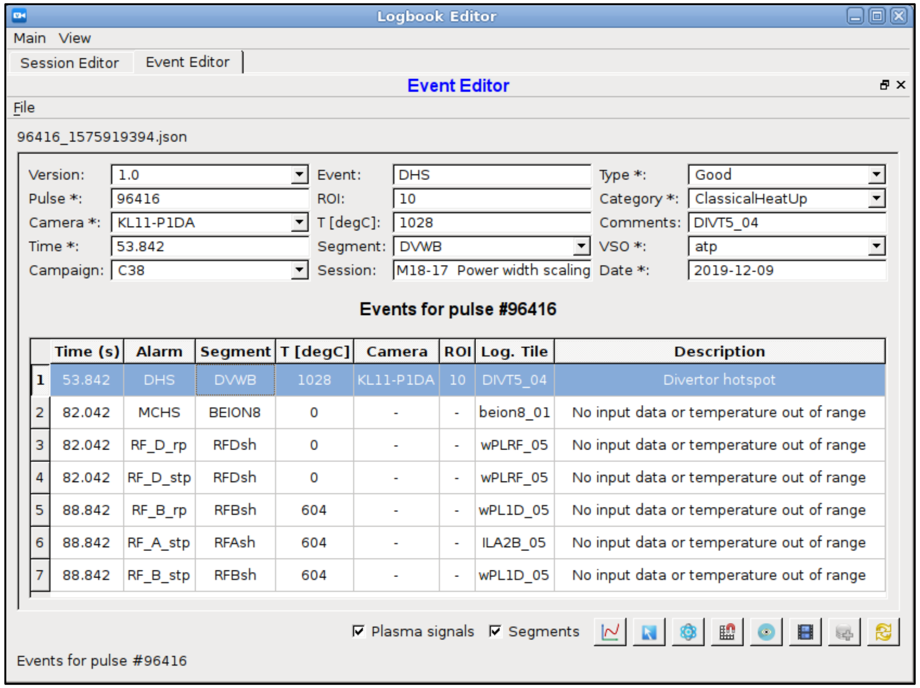
The primary role of the viewing system operator (VSO) is to assist the session leader, engineer in charge and scientific coordinator in the interpretation of an alarm sent by the VTM due to a protection camera during experiments.

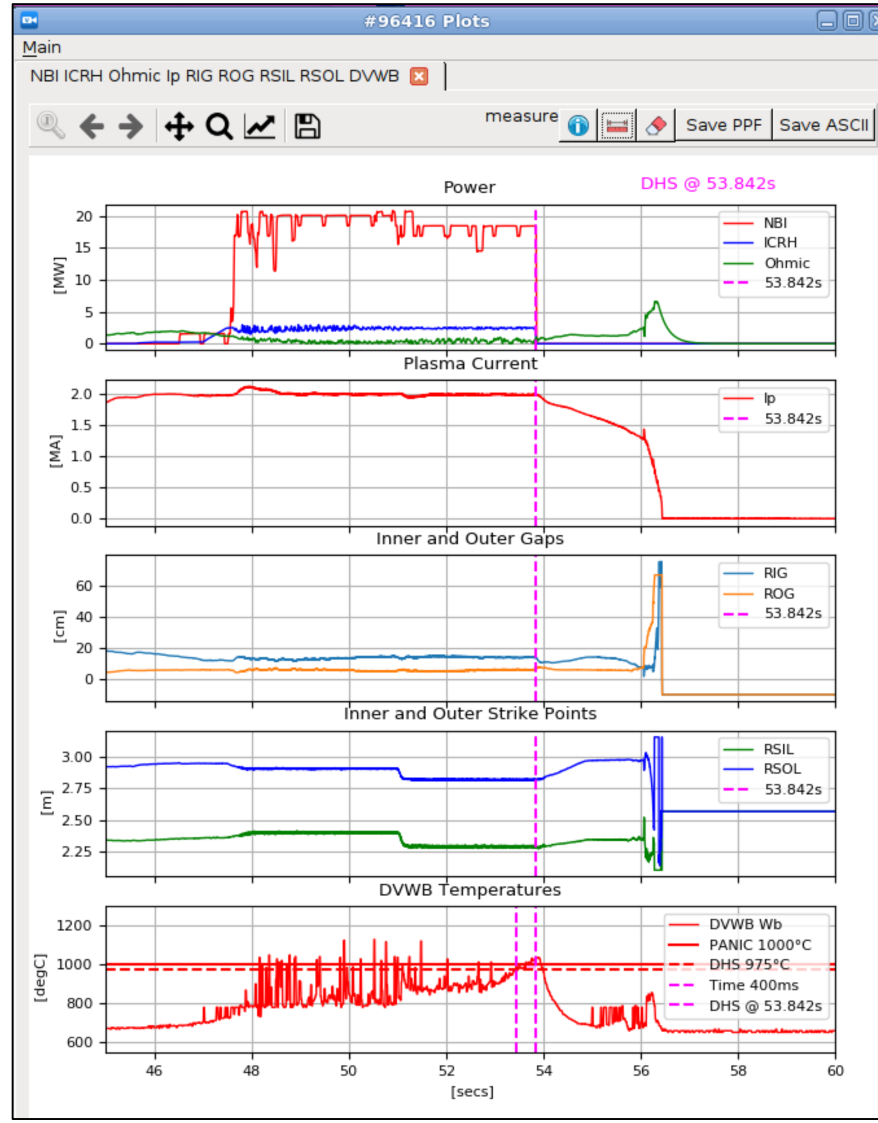


To simplify the job of the VSO, some new features, the so-called **VSO tools**, were integrated into JUVIL for the interpretation of VTM events and for the quick post-pulse analysis of video data required for the preparation of the next pulse.

This saves a significant amount of time, which can be used by the VSO for actual analysis of the event.

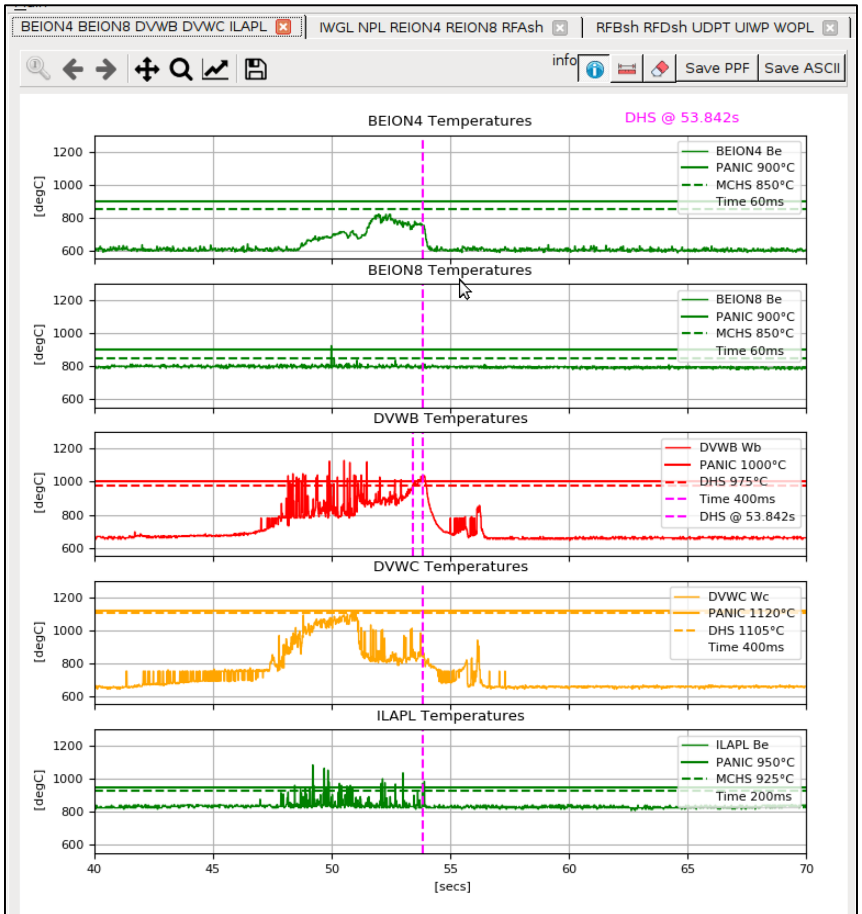
VSO Tools for Machine Operational Safety

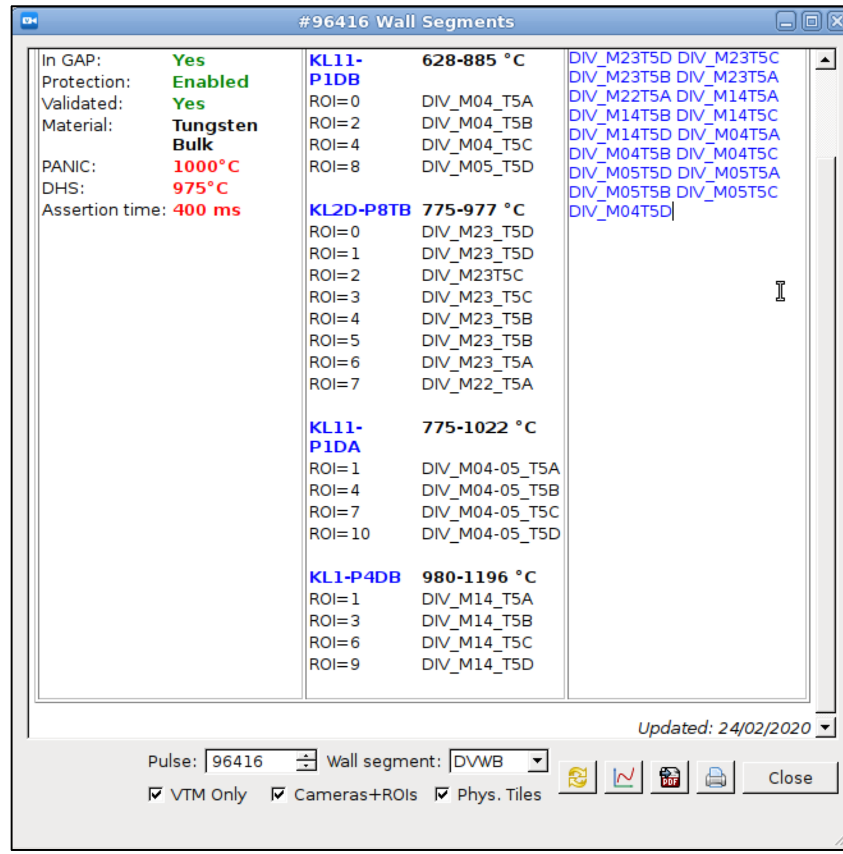


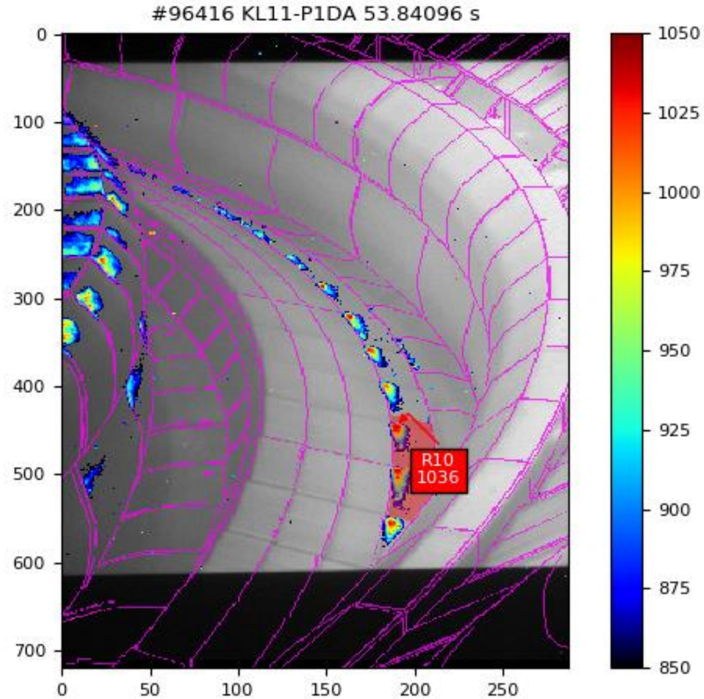


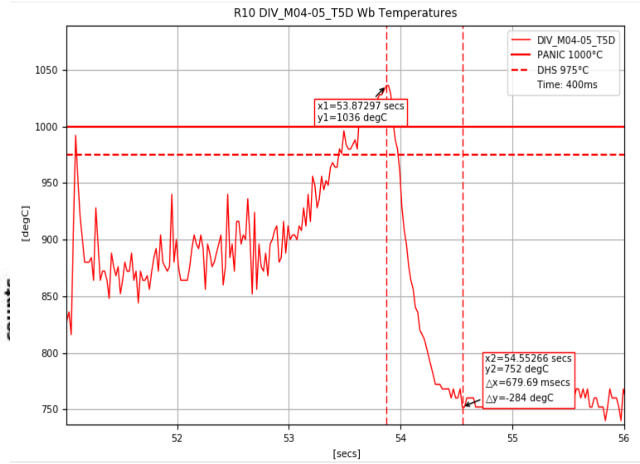
- Automatic loading the list of VTM events and alarms raised for a specific pulse
- Plotting of max. T_{surf} of a wall segment, its VTM alarm thresholds and assertion times as well as main plasma signals

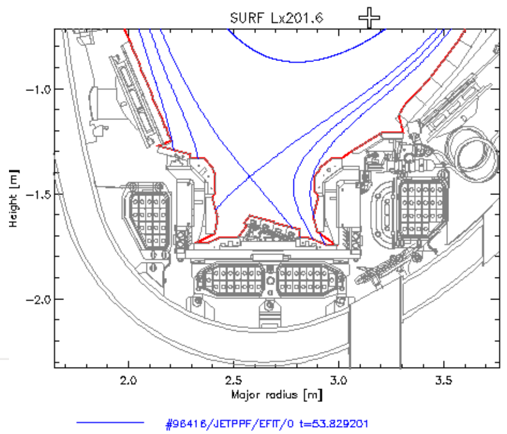
- Displaying temperatures of all wall segments and looking cameras and ROIs for each wall segment

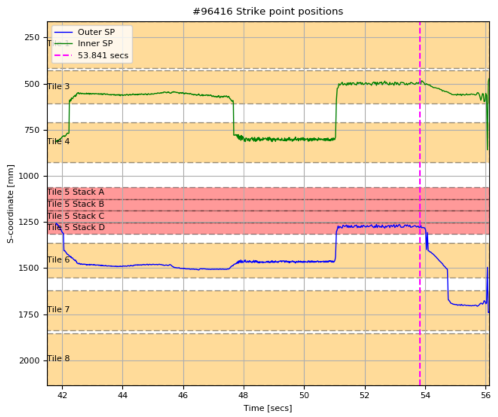


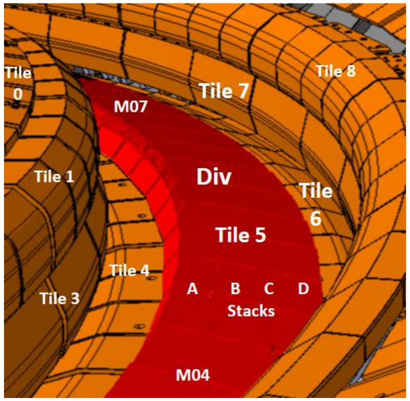








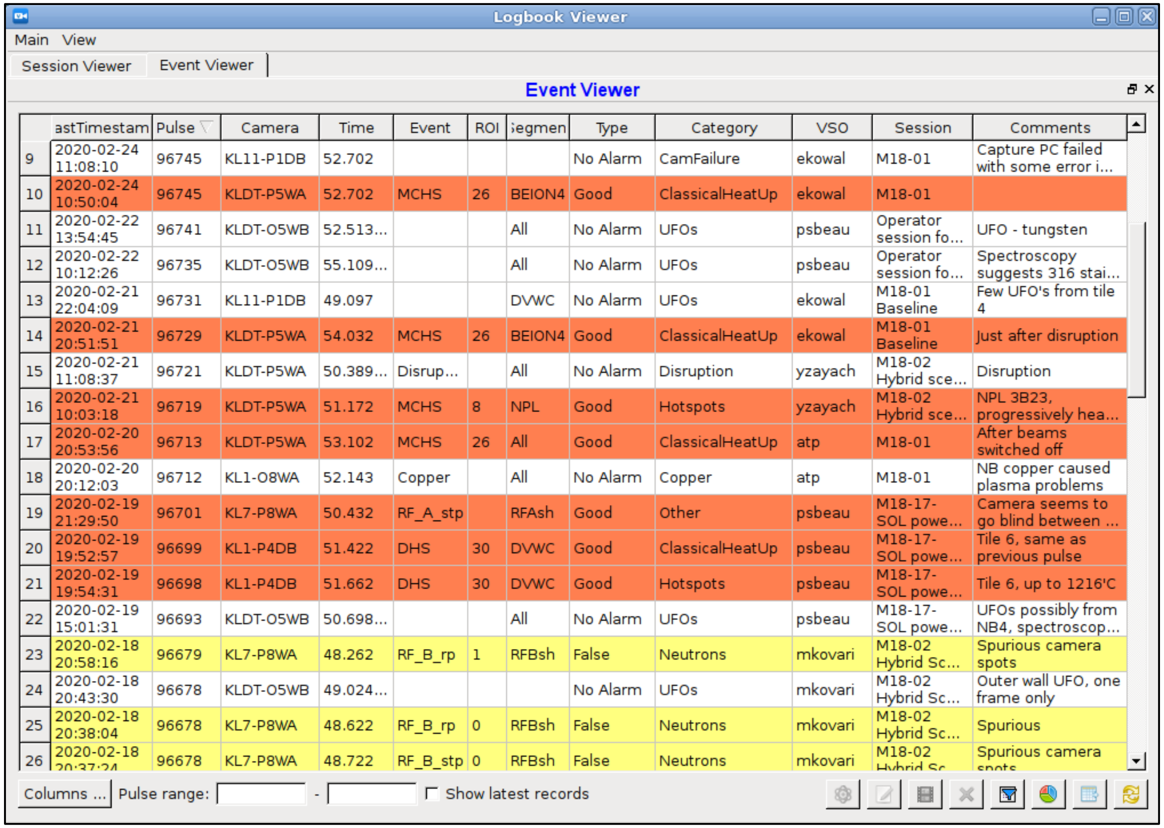




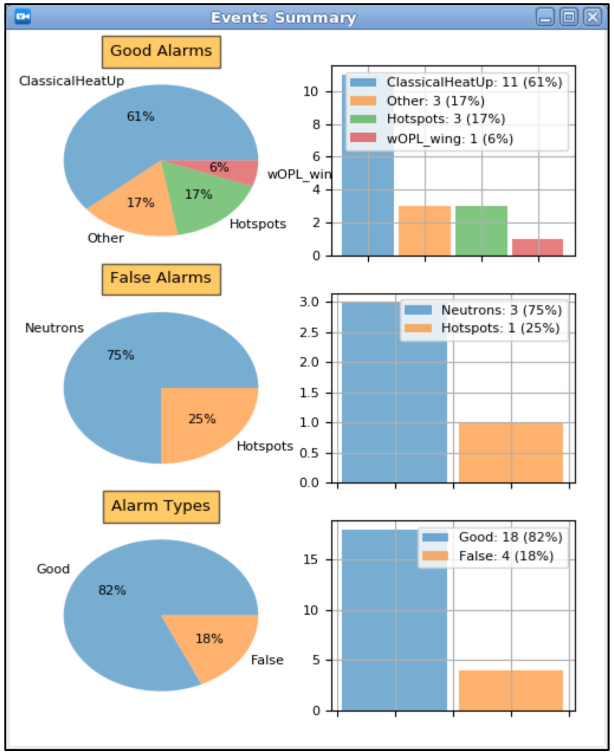
- Loading of a camera video with automatically pre-configured settings
- Loading of RTPU ROIs, selection of a ROI caused an alarm, displaying its max. temperature and location
- Displaying a magnetic field, strike point positions and the FoV of the camera

VSO Tools for Machine Operational Safety

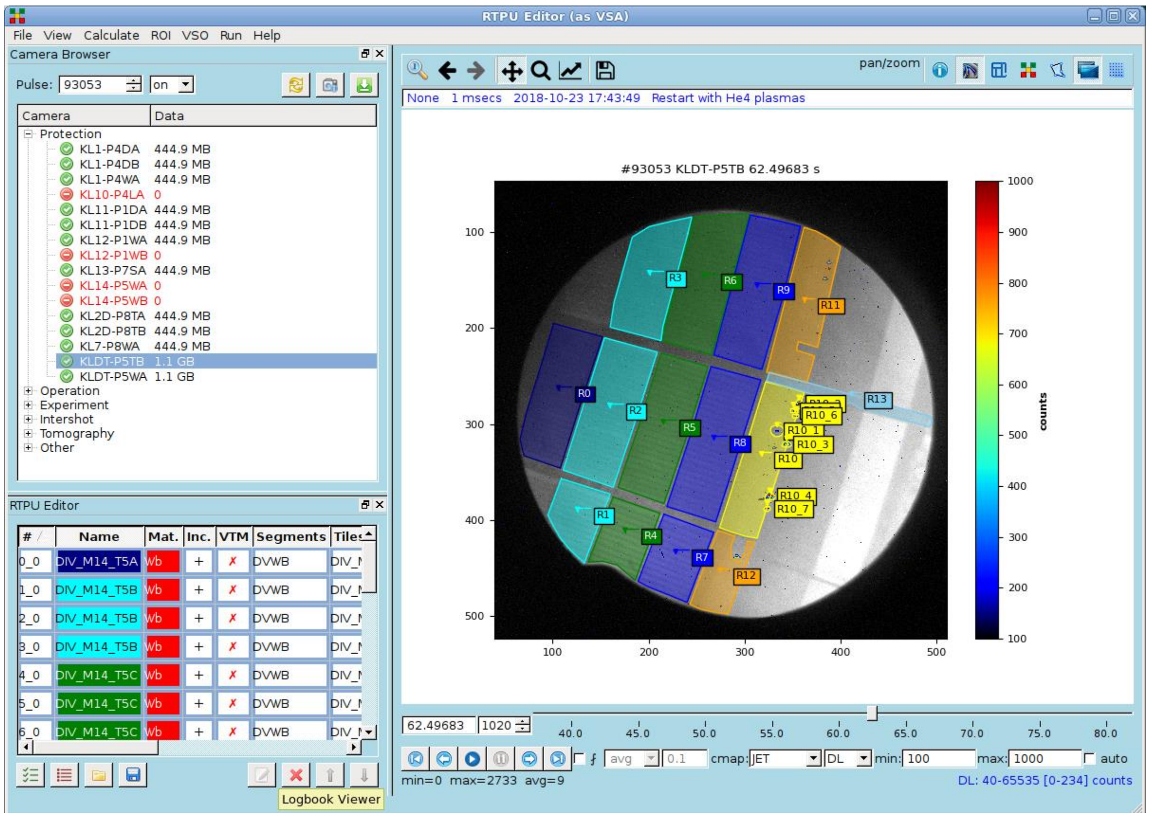
- VSO Logbook to store all categorised alarms and events ad well as session summaries
- Browsing and search of specific events and session summaries
- Statistics chart of filtered VTM alarms



	astTimestam	Pulse	Camera	Time	Event	ROI	;egmen	Type	Category	VSO	Session	Comments
9	2020-02-24 11:08:10	96745	KL11-P1DB	52.702				No Alarm	CamFailure	ekowal	M18-01	Capture PC failed with some error i...
10	2020-02-24 10:50:04	96745	KLDT-P5WA	52.702	MCHS	26	BEION4	Good	ClassicalHeatUp	ekowal	M18-01	
11	2020-02-22 13:54:45	96741	KLDT-O5WB	52.513...			All	No Alarm	UFOs	psbeau	Operator session fo...	UFO - tungsten
12	2020-02-22 10:12:26	96735	KLDT-O5WB	55.109...			All	No Alarm	UFOs	psbeau	Operator session fo...	Spectroscopy suggests 316 stai...
13	2020-02-21 22:04:09	96731	KL11-P1DB	49.097			DVWC	No Alarm	UFOs	ekowal	M18-01 Baseline	Few UFO's from tile 4
14	2020-02-21 20:51:51	96729	KLDT-P5WA	54.032	MCHS	26	BEION4	Good	ClassicalHeatUp	ekowal	M18-01 Baseline	Just after disruption
15	2020-02-21 11:08:37	96721	KLDT-P5WA	50.389...	Disrup...		All	No Alarm	Disruption	yzayach	M18-02 Hybrid sce...	Disruption
16	2020-02-21 10:03:18	96719	KLDT-P5WA	51.172	MCHS	8	NPL	Good	Hotspots	yzayach	M18-02 Hybrid sce...	NPL 3B23, progressively hea...
17	2020-02-20 20:53:56	96713	KLDT-P5WA	53.102	MCHS	26	All	Good	ClassicalHeatUp	atp	M18-01	After beams switched off
18	2020-02-20 20:12:03	96712	KL1-O8WA	52.143	Copper		All	No Alarm	Copper	atp	M18-01	NB copper caused plasma problems
19	2020-02-19 21:29:50	96701	KL7-P8WA	50.432	RF_A_stp		RFAsh	Good	Other	psbeau	M18-17- SOL powe...	Camera seems to go blind between ...
20	2020-02-19 19:52:57	96699	KL1-P4DB	51.422	DHS	30	DVWC	Good	ClassicalHeatUp	psbeau	M18-17- SOL powe...	Tile 6, same as previous pulse
21	2020-02-19 19:54:31	96698	KL1-P4DB	51.662	DHS	30	DVWC	Good	Hotspots	psbeau	M18-17- SOL powe...	Tile 6, up to 1216'C
22	2020-02-19 15:01:31	96693	KLDT-O5WB	50.698...			All	No Alarm	UFOs	psbeau	M18-17- SOL powe...	UFOs possibly from NB4, spectroscop...
23	2020-02-18 20:58:16	96679	KL7-P8WA	48.262	RF_B_rp	1	RFBsh	False	Neutrons	mkovari	M18-02 Hybrid Sc...	Spurious camera spots
24	2020-02-18 20:43:30	96678	KLDT-O5WB	49.024...				No Alarm	UFOs	mkovari	M18-02 Hybrid Sc...	Outer wall UFO, one frame only
25	2020-02-18 20:38:04	96678	KL7-P8WA	48.622	RF_B_rp	0	RFBsh	False	Neutrons	mkovari	M18-02 Hybrid Sc...	Spurious
26	2020-02-18	96678	KL7-P8WA	48.722	RF_B_stp	0	RFBsh	False	Neutrons	mkovari	M18-02	Spurious camera



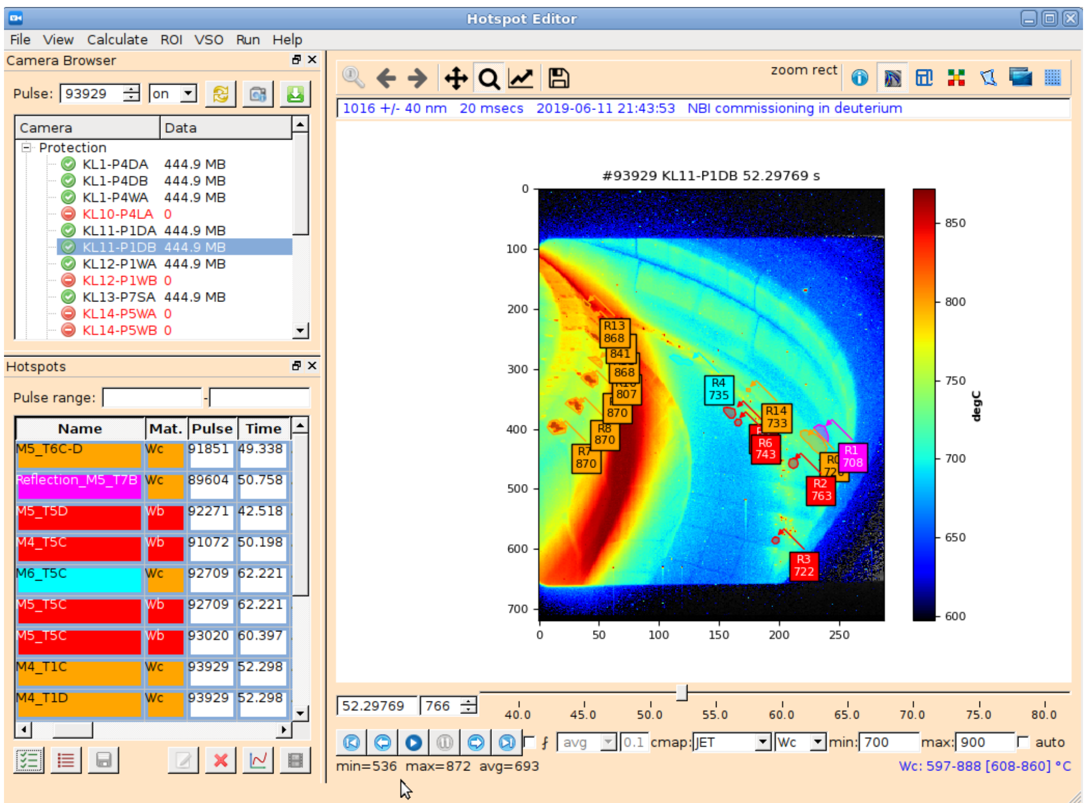
RTPU ROI Editor is a tool for the creation of RTPU ROIs by VSOs. It helps very quick to adjust positions of ROIs due to the changes of camera alignments and enables to add or remove ROIs from the protection system.



- Full functionality of JUVIL for loading and analysis of video data and VTM events
- Editors for modifying ROI attributes: locations, materials, physical tiles, …
- Mapping between ROIs and events stored in the VSO Logbook to avoid detected hot spots and check the ROI alignments.

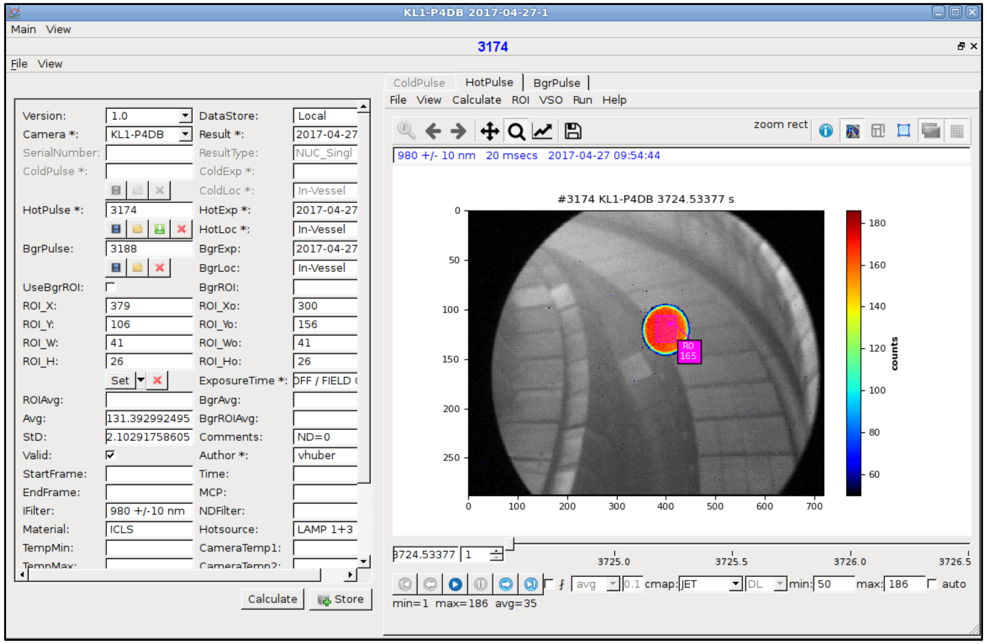
Hotspot Editor for Study of Hot Spots

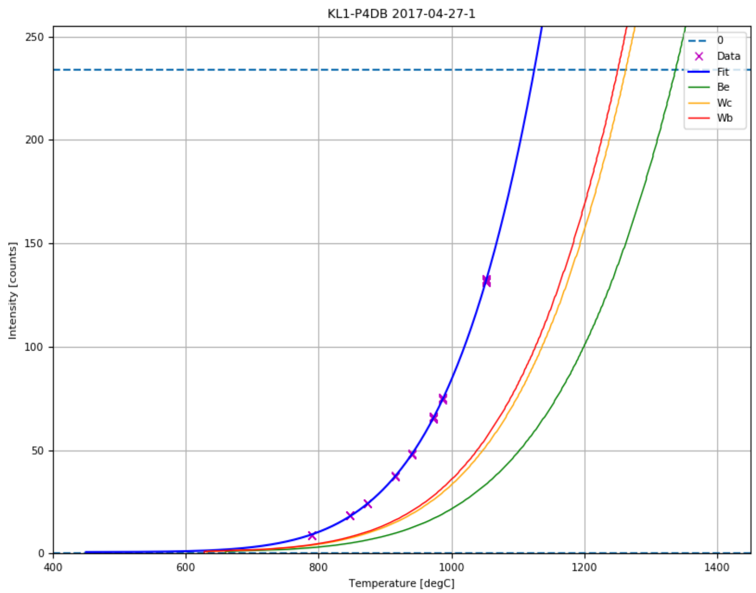
Because the hot spots raise VTM alarms, which can cause the protection system to stop a pulse where it may not be necessary, it is important to study the appearances of new hot spots, their locations and temperatures as well as the conditions of disappearance of the existing hot spots. For this aim, the Hotspot Editor was integrated into JUVIL.



- Displays all detected hot spots stored in the catalogue and shows their evolution.
- Provides a filter for the extraction of hot spots during a pulse range.
- Loads automatically the corresponding videos from times when a hot spot was detected or modified as well as to plot its temperatures.

All protection cameras were calibrated using the In-Vessel Light Source (ICLS) positioned inside the JET vacuum vessel by means of the remote-handling arm (RHA). Because the calibration activities with RHA are restricted in time, very expensive and cannot be repeated, special software for the quick data acquisition and analysis has been developed and successfully used during the calibration of the protection cameras.





Questions ???

Thank you for you attention !!!