Towards complete automation of test campaign simulations

using STEAM

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With special thanks to my supervisor Emmanuele Ravaioli
and also to SM18 colleagues

5th May 2023

https://espace.cern.ch/STEAM

OUR VISION

Full automation of transient simulations in SC magnets in a reliable, sustainable, consistent and repeatable way

To achieve this we need 3 main ingredients:

1. Validated Magnet Models
2. A way to get magnet specific conductor parameters
3. A way to get event specific information

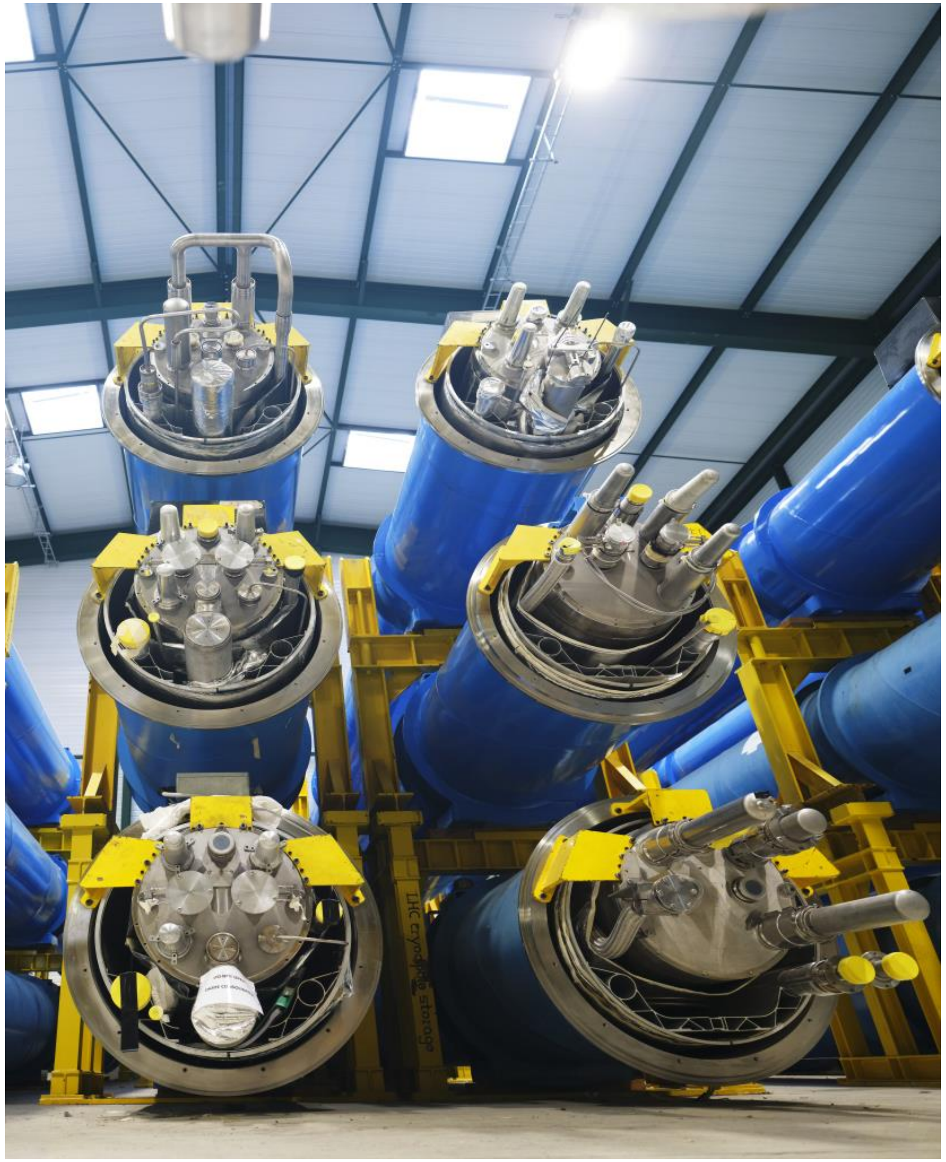
Motivation

My main use case:

- Model validation (e.g. HL HOC magnets) 100s of measurements

Many other use cases:

1. Comparison to measurement to identify unusual behaviour
2. Analyse large group of tests in a consistent manner
3. Provide tool for users outside of CERN
4. Regular tests of magnet models



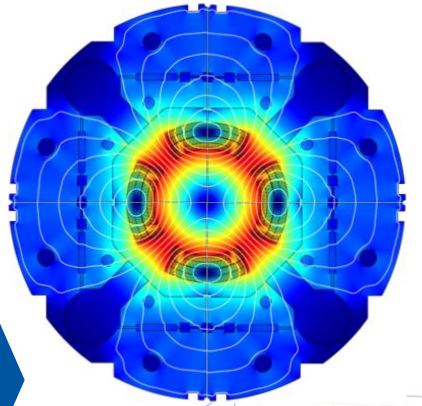
Short overview of STEAM Framework

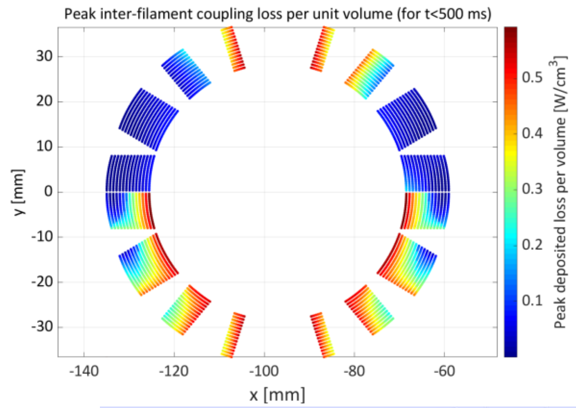
Simulation of **T**ransient **E**ffects in **A**ccelerator superconducting **M**agnet circuits

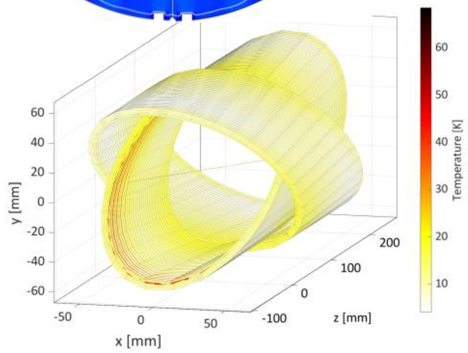
Goal: perform diverse **transient simulations** across all levels of detail, involving **circuits, magnets, conductors, wires and filaments**.

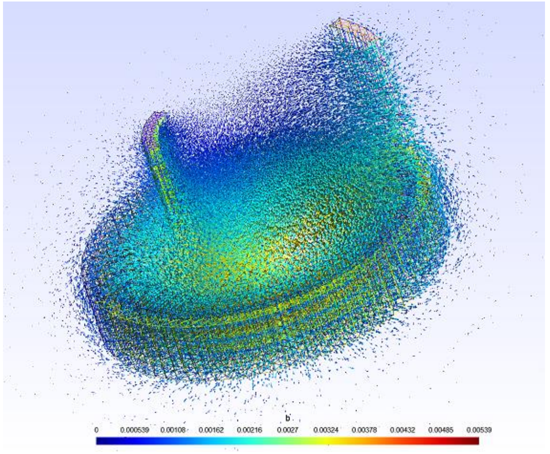
→ No single tool can do it all: STEAM **connects different tools**

Circuit	Magnet	Conductor
XYCE***	FiQuS	LEDET
	LEDET	PyBBQ
	ProteCCT	
PSPICE**	SIGMA*	BBQ*









*COMSOL license needed. **Commercial circuit solver from Cadence Design Systems. ***Free tools from Sandia Labs

How to use STEAM: a simplified simulation setup

STEAM is organized in steps:

- `SetUpFolder`
- `MakeModel`
- `ModifyModel`
- `ModifyModelMultipleVariables`
- `RunSimulation`
- `...`

The user first defines the steps

```
AnalysisStepDefinition:
  setup_folder_LEDET: <3 keys>
  make_ref_model: <11 keys>
  modify_current: <8 keys>
  modify_resistances: <7 keys>
  RunSimList: <5 keys>
```

Then their order

```
AnalysisStepSequence:
  - setup_folder_LEDET
  - make_ref_model
  - modify_current
  - modify_resistances
  - RunSimList
```

Let's try to setup a test campaign to validate a magnet model →

- 100s of measurements
- For every measurement we need to change:
  - Bath temperature
  - Conductor: RRR, length, …
  - Initial current
  - Quench Heater: time, …
  - EE, CLIQ, …

  In total: 100s variables

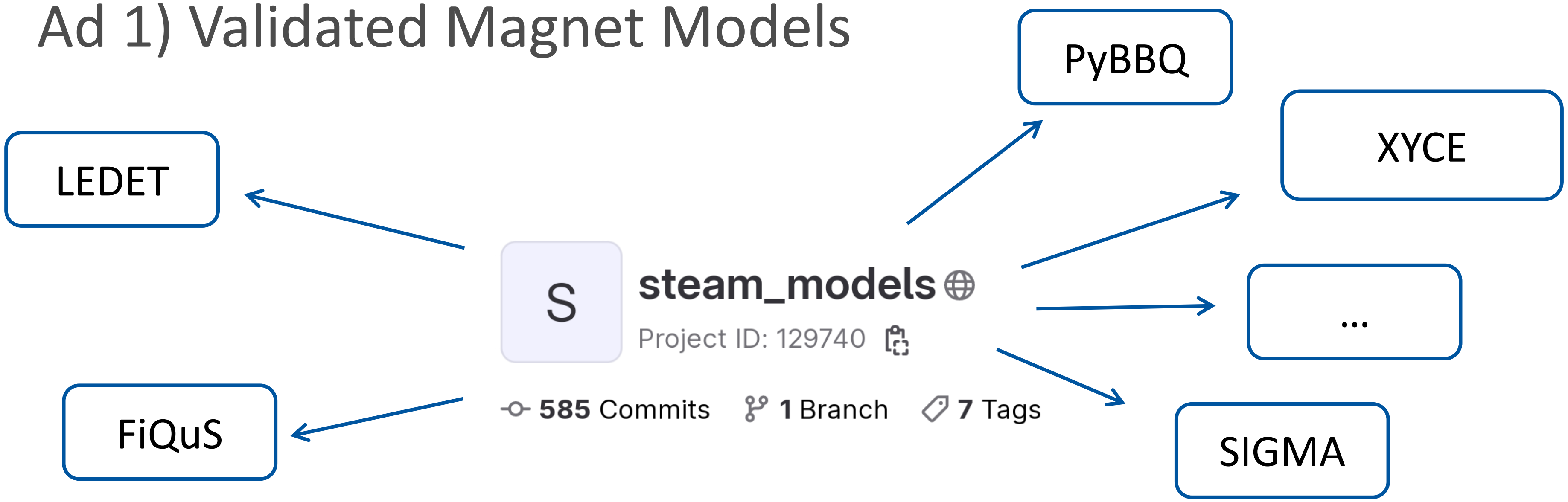
⇒ 100s*100s = 10.000s variables
⇒ 10.000s of hand crafted lines

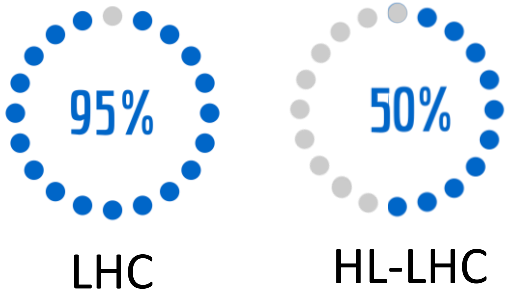
Back to our problem…

We need 3 main ingredients to run automated test campaigns:

1. Validated Magnet Models
2. A way to get magnet specific conductor parameters
3. A way to get event specific information

Ad 1) Validated Magnet Models





Ad 2) A way to get magnet specific conductor parameters

Introduction of new step: **ParsimConductor**

1. Reads conductor database

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Magnet	Coil	width [m]	Ns [-]	Ds [mm]	Ave Cu/noCu in SS	Ic(T=4.22 K,B=12 T)	Ic(T=4.22 K,B=15 T)	Estimated coil RRR	Tc0 [K]	Bc20 [T]	Fil twist-pitch [mm]	Ave Cu/noCu	Strand twist-pitch [m]	RT coil resistance [Ohm]	Cu/nocu from RT meas
2	MBRB	V1U	0.0151	36	0.825	1.19	720	393	190	9.2	14.5	16	1.95	0.712	0.6831	1.76369045
3	MBRB	V1L	0.0152	36	0.824	1.2	724	396	[190, 191]	9.2	16		1.95		0.6824	1.768538944
4	MBRB	V2U	0.015	36		1.190000	704	384	184		16		1.95	0.711	0.6815	1.774827829
5	MBRB	V2L	0.0151	36		1.20	693	377	193		16	14	1.95	0.713	0.6819	1.772025115

⋮

2. Calculates conductor parameters for all coils

Critical current measurements → Jc fit parameters (CUDI1, Summers, Bordini)

RT resistance measurement → Optimization of Variables with some uncertainty

3. Assigns parameters to all the correct conductors in the model → new Step: ParsimSweeper

Ad 3) A way to get event specific information

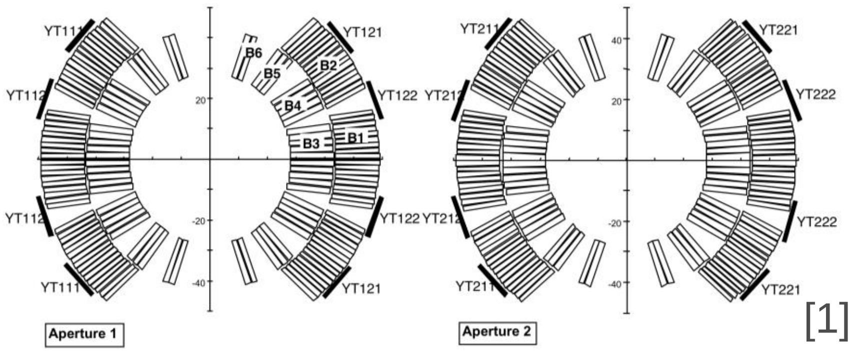
Introduction of new step: **ParsimEvent**

1. Reads quench dictionary

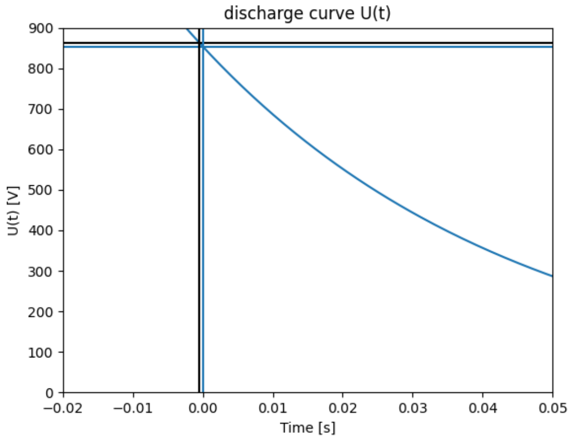
	F	M	AD	AE	AH	AJ
1						
2	**File name**	**Temperature [K]**	**QH Name**	**QH Voltage [V]**	**QH Start time [s]**	**QH Capacitance [F]**
3	HCMQXFM001-CR000072__C2109031300_b039(0)	1.9	U_Heater1; U_Heater2; U_Heater3; U_Heater4; U_Heater5; U_	919.7; 917.9; 906.7; 901; 913.7; 928; 935.6; 913.2	0.00281; 0.00281; 0.00281; 0.00281; 0.00261; 0.00241; 0.00241; (	0.007227; 0.007149; 0.006481; 0.007076; 0
4	HCMQXFM001-CR000072__C2109031142_b038(0)	1.9	U_Heater1; U_Heater2; U_Heater3; U_Heater4; U_Heater5; U_	924.9; 929.2; 905.7; 912.9; 913.4; 927.9; 934.9; 919.1	0.00261; 0.00241; 0.00281; 0.00241; 0.00261; 0.00241; 0.00241; (	0.007212; 0.007126; 0.006478; 0.007042; 0
5	HCMQXFM001-CR000072__C2109031439_b040(0)	1.9	U_Heater1; U_Heater2; U_Heater3; U_Heater4; U_Heater5; U_	921.5; 925.6; 902; 909.1; 915.9; 929.7; 937.4; 915.2	0.00281; 0.00261; 0.00301; 0.00261; 0.00261; 0.00241; 0.00241; (	0.007234; 0.007148; 0.006492; 0.00707; 0.0
6	HCMQXFM001-CR000072__C2109031652_b044(0)	1.9	U_Heater1; U_Heater2; U_Heater3; U_Heater4; U_Heater5; U_	907.5; 911.4; 894; 894.7; 907.3; 920.8; 923.1; 907.1	0.00301; 0.00281; 0.00301; 0.00281; 0.00261; 0.00241; 0.00261; (	0.007253; 0.007167; 0.006494; 0.007096; 0

⋮

2. Calculates various simulation parameters



[1]



- → CLIQ
- → Quench Heaters
- → Energy Extraction
- → warm resistance
- → Initial current
- → Bath temperature
- → …

3. Setup initialization files for Viewer (mark data for conversion, find paths and timestamps)

4. Assigns parameters to the model → new Step: ParsimSweeper

95%

Workflow: campaign setup

How to use STEAM campaigns:

```
AnalysisStepSequence:
  - setup_folder_LEDET
  - make_ref_model
  - runParsimConductor
  - runParsimEvent
  - RunSimList
  - runViewer
```

ParsimConductor definition:

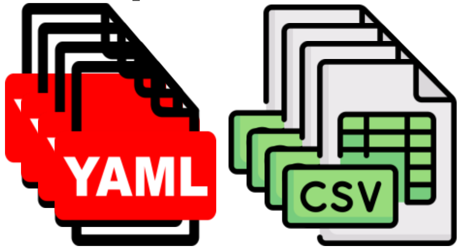
```
software: [LEDET]
input_file: conductor_database.csv
strand_critical_current_measurements:
  - column_name_I_critical: Ic(T=4.22 K,B=12 T)
    reference_mag_field: 12
    reference_temperature: 4.22
    column_name_CuNoCu_short_sample: Ave Cu/noCu in SS
    coil_names: [ V1U, V1L, V2L ]
  - column_name_I_critical: Ic(T=4.22 K,B=15 T)
    reference_mag_field: 15
    reference_temperature: 4.22
    column_name_CuNoCu_short_sample: Ave Cu/noCu in SS
    coil_names: [ V2U, V2L ]
groups_to_coils:
  V1U: [ 1, 2,  9, 10, 17, 18, 25, 26 ]
  V1L: [ 3, 4, 11, 12, 19, 20, 27, 28 ]
  V2U: [ 5, 6, 13, 14, 21, 22, 29, 30 ]
  V2L: [ 7, 8, 15, 16, 23, 24, 31, 32 ]
length_to_coil:
  V1U: 130.0
  V1L: 132.0
  V2U: 131.0
  V2L: 129.0
```

ParsimEvent definition:

```
software: [LEDET]
input_file: Quench_Dictionary.csv
rel_quench_heater_trip_threshold: 0.99
dict_QH_circuits_to_QH_strips:
  U_Heater1: [1, 2]
  U_Heater2: [8, 7]
  U_Heater3: [3, 4]
  U_Heater4: [6, 5]
```

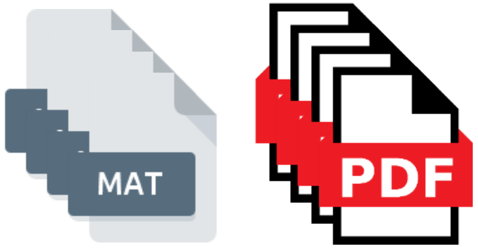
result

Input files



guaranteed reproducibility

Simulation results



result files & reports

Viewer

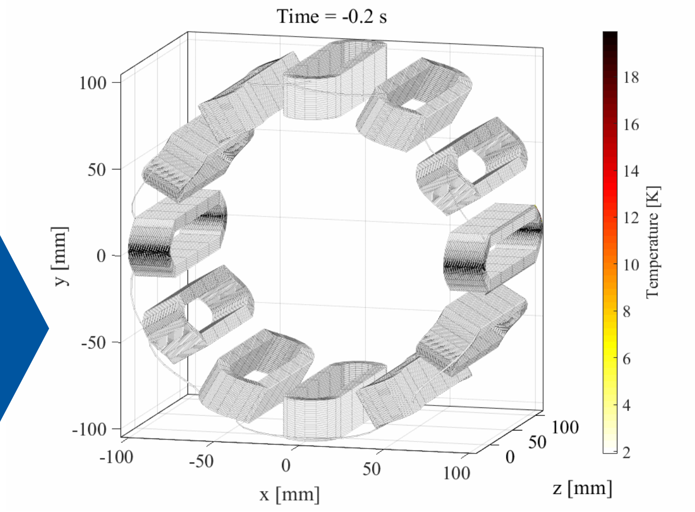
compared meas & sim

Example Application: validation of HL HOC magnets

my main project and Master's thesis

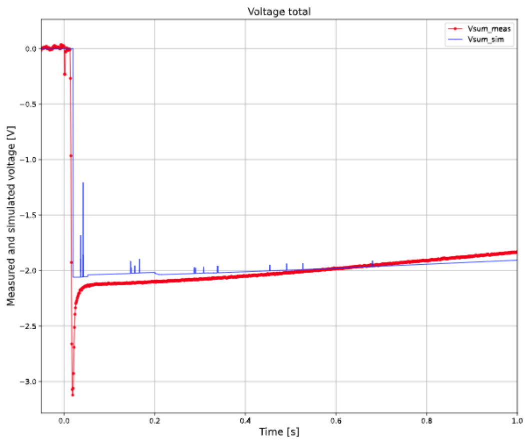
```
AnalysisStepSequence:
  - setup_folder_LEDET
  - make_ref_model
  - runParsimConductor
  - runParsimEvent
  - RunSimList
  - runViewer
```

One simulation per measurement

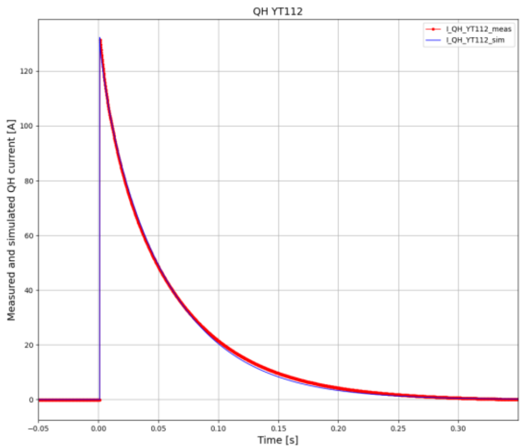


x100s

Comparison plots for all variables
and for each simulation-measurement pair



x100s



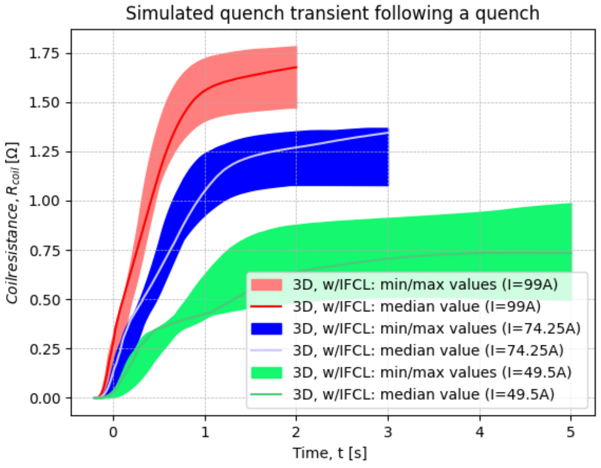
x100s

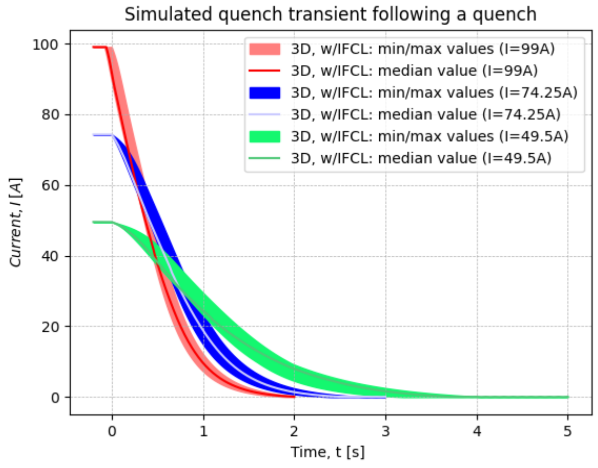
x100s

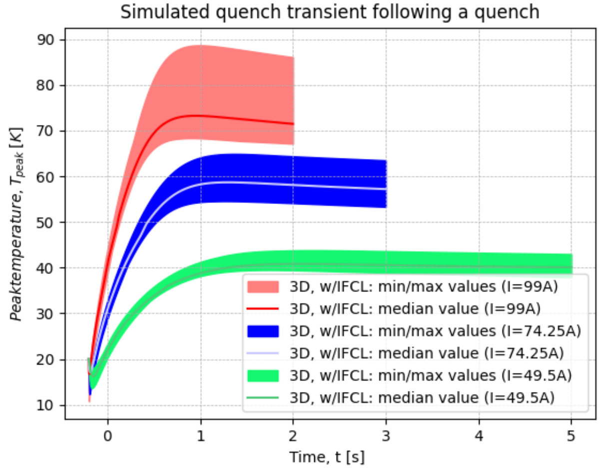
This would be impossible by manually crafting input files!

Outlook

Improve the Viewer:
→ More flexible
→ Allow 2D plots
→ Allow multiple tools in one plot

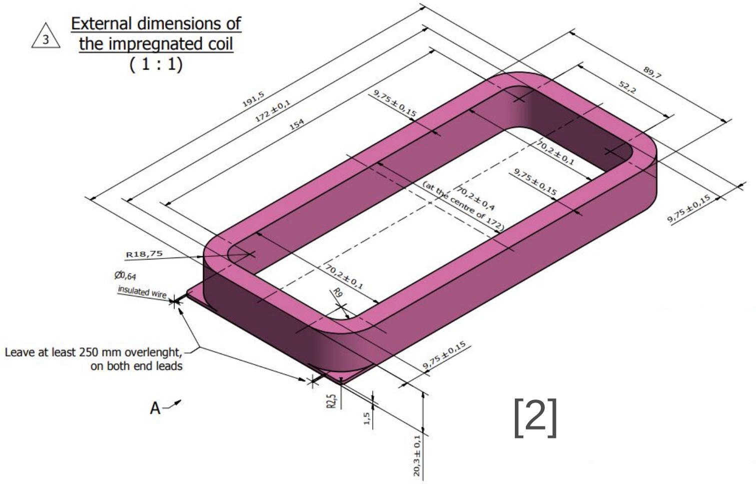




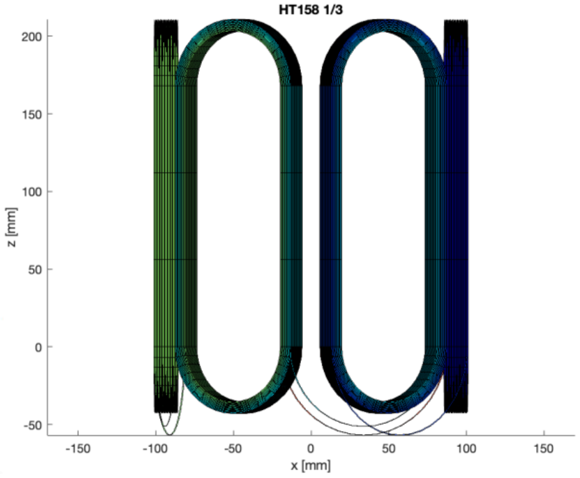


More efficient way to deal with different quench locations

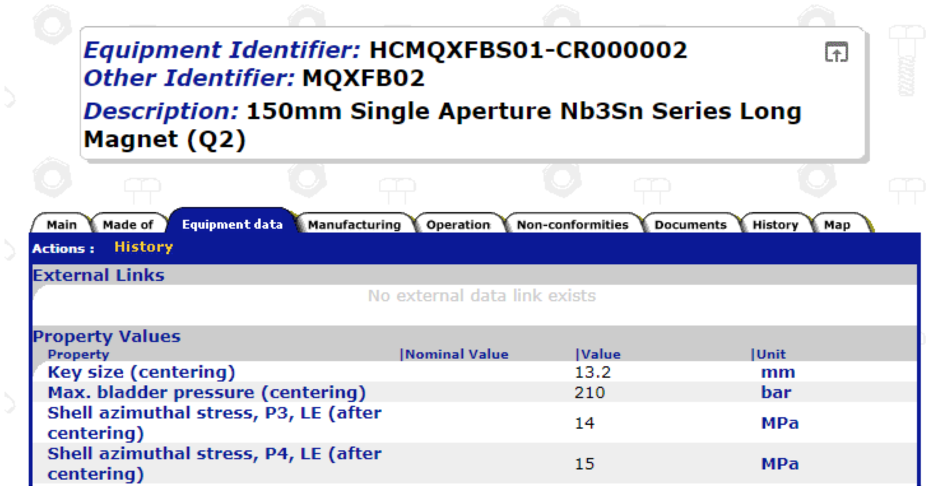
Guide on Gitlab how to use ParsimConductor and ParsimEvent



[2]



correct 2D-to-3D geometry parser



Equipment Identifier: **HCMQXFBS01-CR000002**
Other Identifier: **MQXFB02**
Description: **150mm Single Aperture Nb3Sn Series Long Magnet (Q2)**

Main | Made of | Equipment data | Manufacturing | Operation | Non-conformities | Documents | History | Map

Actions : History

External Links

No external data link exists

Property Values

Property	Nominal Value	Value	Unit
Key size (centering)		13.2	mm
Max. bladder pressure (centering)		210	bar
Shell azimuthal stress, P3, LE (after centering)		14	MPa
Shell azimuthal stress, P4, LE (after centering)		15	MPa

[3]

retrieve conductor data automatically from MTF

Conclusion

We are in the process of solving the problems needed for a fully automated campaign analysis:

1. Validated Magnet Models — 95% LHC, 50% HL-LHC
2. A way to get magnet specific conductor parameters — 90%
3. A way to get event specific information — 95%

We are much closer to reliably **automate transient simulations** for accelerator magnets, ensuring **consistency and repeatability**.

Image Sources

[1]https://indico.cern.ch/event/311824/contribution/10/attachments/597262/821989/QuenchHeaters_FRM.pptx

[2]https://edms.cern.ch/ui/file/2317707/AC/lhcmcsxfc0003-vAC.pdf

[3]https://edms5.cern.ch/pls/asbuilt/mtf_equip.eqp_main_top?p_rec_type=A&p_rec_id=HCMQXFBS01-CR000002

Last accessed: 04.05.2023