STEAM notebooks

2nd *STEAM Workshop – 10.2021*

Marvin Janitschke (TU Berlin)
on behalf of the STEAM team

TECHNISCHE UNIVERSITÄT BERLIN

Generation superconducting magnet models

- Superconducting magnets are complex system that require challenging models

- The generation of these models should be:
  - Easy & user-friendly
  - Consistent throughout all tools, so they can be easily combined
  - Scalable to account for both, easy & simple as well as large & complex model
  - Integrated into the framework
  - In case of changes to the framework tools, it should allow for easy versioning
  - Freeware software and machine independent

STEAM notebooks are Jupyter notebooks, developed to easily generate & adjust models of superconducting magnets

What are Jupyter notebooks?

- Jupyter notebooks are a web-based, interactive environment, supporting different programming languages (STEAM: Python)

- Allows an interactive combinations of code, text, equations, plots…

- Notebooks are based on cells: Each cell has an input & an output sub-cell

Advantages	Disadvantages
Simple, tidy & clear layout	Not meant to be used for software development
Easy to run - can be run on every machine	Major debugging might be more difficult - Does not have a debugger
Easy to alter & debug - no consequences on the remaining code if cell is changed	
Highly visible & cached data - no need to re-run cells, if shared etc. to see plots	
Self-living cells - single cells can be executed without the need to run the full script	Perfect for user-friendly prototyping! ☺
Can be converted to HTML, PDF, Latex, presentations…	

Short tutorial on how to use STEAM notebooks

- At CERN, we use STEAM notebooks with SWAN

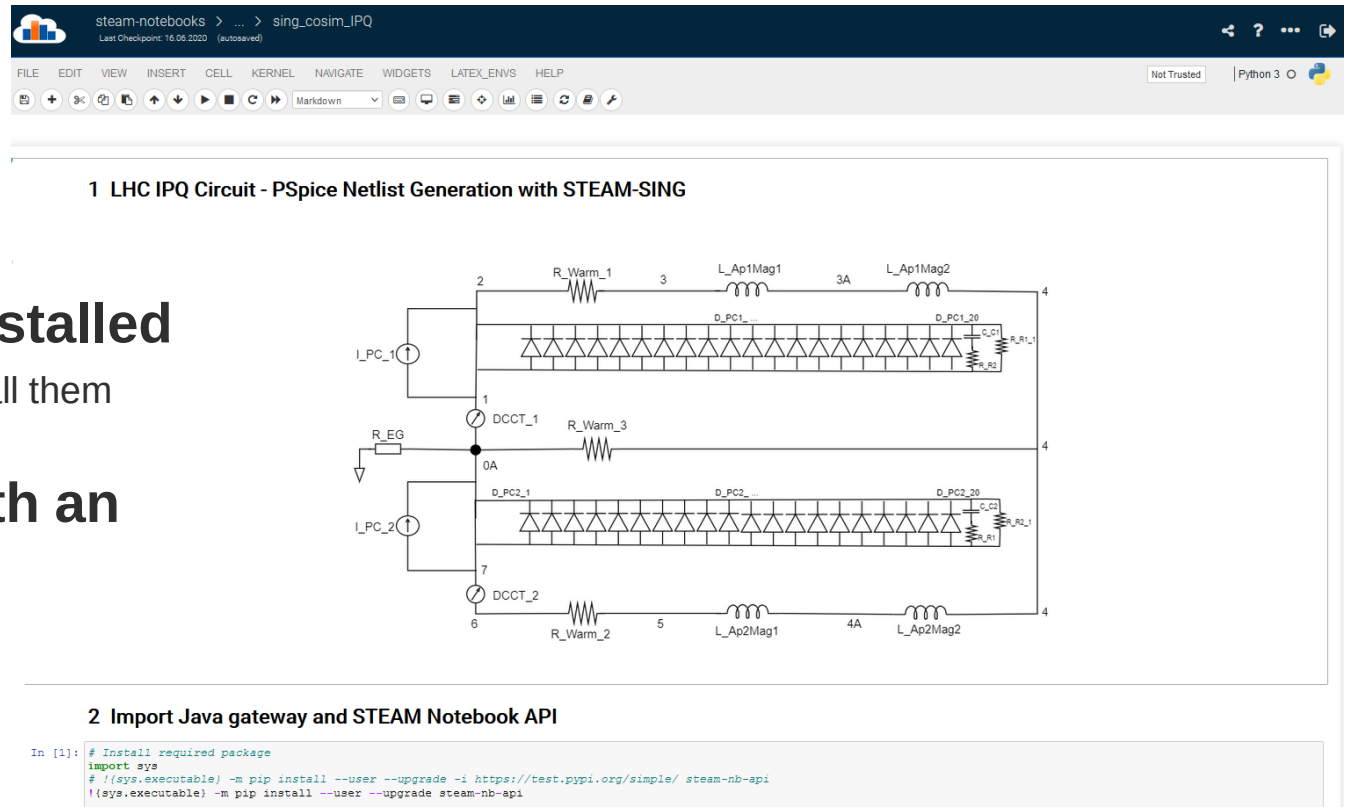
- Else: Jupyter notebook app comes with most python environments, e.g.

ANACONDA®

(Pro only)

GitHub (Visible only)

CERN‘s Notebook Service
Directly integrated into CERN‘s cloud
& comes with pre-installed package stack
Computation runs on CERN kernel



- Required python-packages need to be installed

  STEAM team provides comprehensive notebook to install them

- STEAM team supports the notebooks with an own python package

All set, you‘re ready to start!

What do we use STEAM notebooks for?

Used to develop, generate & adjust various models of superconducting magnets for various software

PSpice®

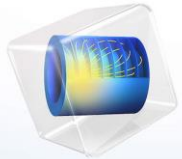
STEAM - SING

Generation of
electrical, netlist-based models for
simulation in PSPICE

STEAM - LEDET

Generation of
Electro-thermal magnetic model
for simulation using
lumped-elements

COMSOL MULTIPHYSICS®

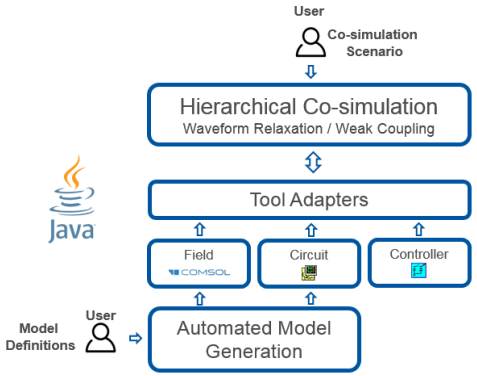


STEAM – SIGMA

Generation of
COMSOL-based transient models

STEAM - COSIM

Generation of
multi-physics models for
co-operative simulations



Let's have a closer look!

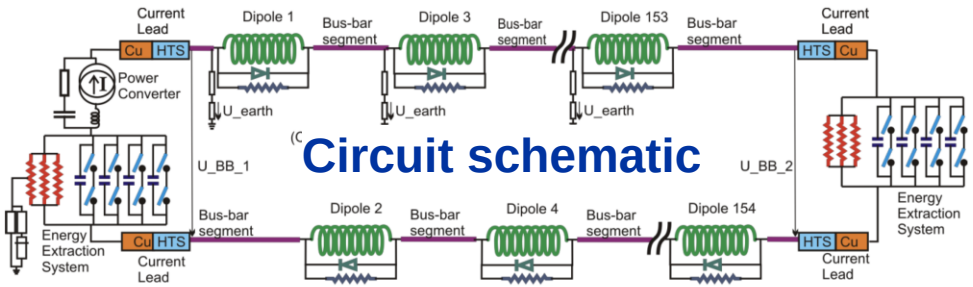
STEAM-SING notebooks

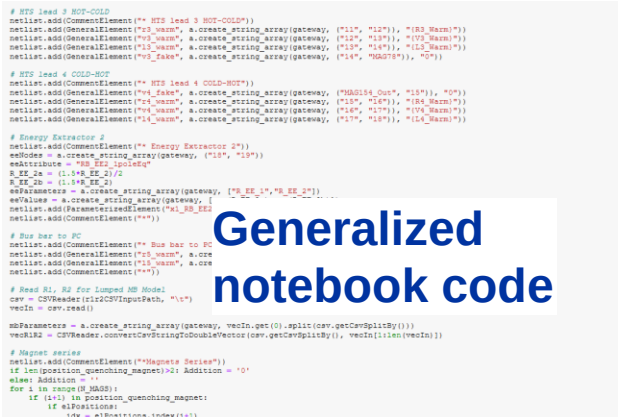
Electrical, netlist-based model

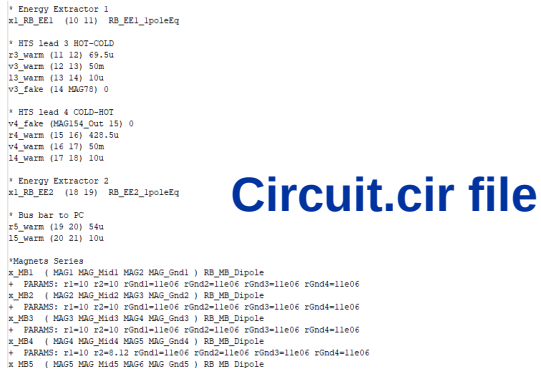
Can also be used for other SPICE based programs

Notebooks based on re-usable Java and Python api

- STEAM-SING notebooks generate netlist-based SPICE model, using:
  - Generalized components from the STEAM library, that can be tailored to every circuit
    e.g. Energy extraction system with >20 sub-elements, all values can be adjusted
  - Generalized functions for components, that can be used in e.g. For-loops
    e.g. chain of 154 magnets can be generated with 5 lines of code
  - Generalized functions to include simulation options & provide interfaces with other STEAM tools







Notebooks provide an easy, fast and re-usable way to quickly generate complex circuit models!

STEAM-LEDET notebooks

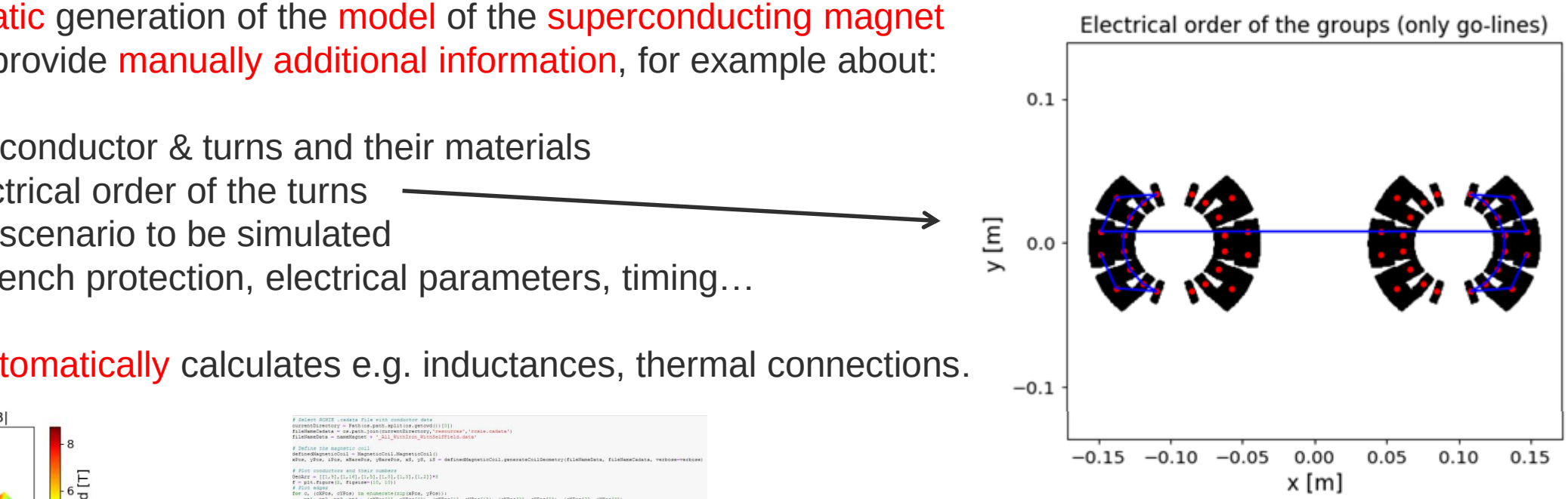
Lumped-Element Dynamic Electro-Thermal model

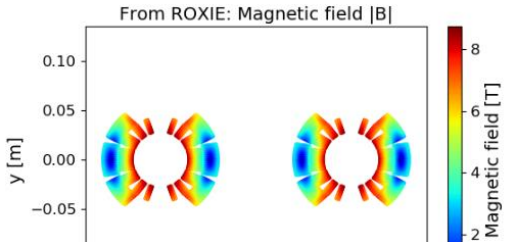
Notebooks based on re-usable Python api

- Semi-automatic generation of the model of the superconducting magnet
- User has to provide manually additional information, for example about:

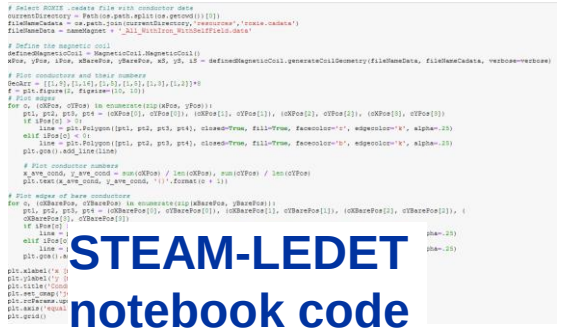
  - the conductor & turns and their materials
  - electrical order of the turns
  - the scenario to be simulated
    (Quench protection, electrical parameters, timing…

- Notebook automatically calculates e.g. inductances, thermal connections.





Magnetic field maps & manual user information



STEAM-LEDET notebook code

Initial temperature [K]	T00	1,9		
Magnetic length [m]	l_magnet	14,3		
Initial current [A]	I00	11850		
Conductor parameters				
Define the coil section where each group of cables is located	GroupToCoilSection	1	1	1
Polarity of the current in each group of strands	polarities_inGroup			1
Number of half-turns in each group	nT			5
Number of strands in each cable belonging to a particular group	nStrands_inGroup			28
length of each half turn [m] (default=l_magnet)	l_mag_inGroup			14,3
strand diameter [m]	ds_inGroup			0,001065
fraction of superconductor in the strands	f_SC_strand_inGroup			0,384615385
Effective transverse resistivity parameter (default=1)	f_ro_eff_inGroup			1
Filament twist-pitch [m]	Lp_f_inGroup			0,018
RRR of the conductor in each group of cables	RRR_Cu_inGroup			92,08103131
type of superconductor (1=Nb-Ti, 2=Nb3Sn with Summers' fit, 3=BSCCO2212, 4=Nb3Sn with E	SCtype_inGroup	1	1	1

LEDET excel input file

Notebooks provide an highly visible & interactive way, to set up and cross-check complex magnet models!

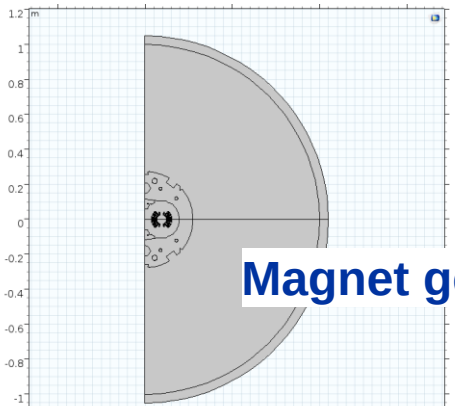
STEAM-SIGMA notebooks

COMSOL-based transient models

Notebooks based on re-usable Java and Python api

- STEAM-SIGMA generates COMSOL-based transient models as Java code to be compiled with COMSOL API into COMSOL models

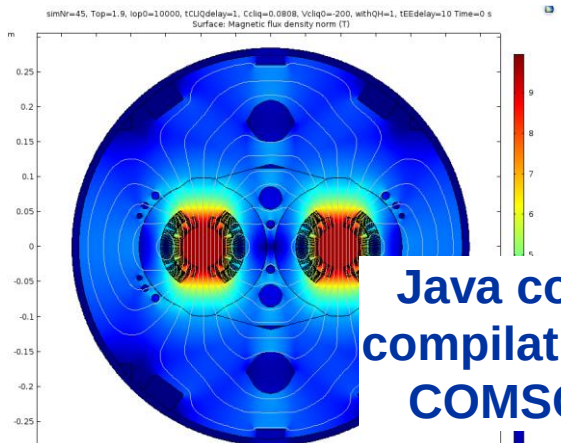
- Similar to STEAM-SING notebooks, STEAM-SIGMA notebooks utilizes:
  - Generalized functions to generate geometries, material properties, boundary conditions…
    e.g. functions to set points, lines, arcs, windings, areas…. & to combine them with each other
  - Generalized functions to generate & compile the output files
  - Setting all simulation options



Magnet geometry

```
kp11 = Point.ofCartesian(138.42e-3, 25.3e-3)
kp12 = Point.ofCartesian(58.5e-3, 25.3e-3)
kp13 = Point.ofCartesian(58.5e-3, 3.5e-3)
kp14 = Point.ofCartesian(138.42e-3, 3.5e-3)

kp21 = Point.ofCartesian(138.42e-3, 47.6e-3)
kp22 = Point.ofCartesian(58.5e-3, 47.6e-3)
kp23 = Point.ofCartesian(58.5e-3, 25.5e-3)
kp24 = Point.ofCartesian(138.42e-3, 25.8e-3)

kp31 = Point.ofCartesian(138.42e-3, 70.9e-3)
kp32 = Point.ofCartesian(45.18e-3, 70.9e-3)
kp33 = Point.ofCartesian(45.18e-3, 49.1e-3)
kp34 = Point.ofCartesian(138.42e-3, 49.1e-3)

kp41 = Point.ofCartesian(138.42e-3, 93.2e-3)
kp42 = Point.ofCartesian(45.18e-3, 93.2e-3)
kp43 = Point.ofCartesian(45.18e-3, 71.4e-3)
kp44 = Point.ofCartesian(138.42e-3, 71.4e-3)

ln11 = Line.ofEndPoints(kp12,kp11)
ln12 = Line.ofEndPoints(kp12,kp13)
ln13 = Line.ofEndPoints(kp13,kp14)
ln14 = Line.ofEndPoints(kp11,kp14)

ln21 = Line.ofEndPoints(kp22,kp21)
ln22 = Line.ofEndPoints(kp22,kp23)
ln23 = Line.ofEndPoints(kp23,kp24)
ln24 = Line.ofEndPoints(kp21,kp24)

ln31 = Line.ofEndPoints(kp32,kp31)
ln32 = Line.ofEndPoints(kp32,kp33)
ln33 = Line.ofEndPoints(kp33,kp34)
ln34 = Line.ofEndPoints(kp31,kp34)

ln41 = Line.ofEndPoints(kp42,kp41)
ln42 = Line.ofEndPoints(kp42,kp43)
ln43 = Line.ofEndPoints(kp43,kp44)
ln44 = Line.ofEndPoints(kp41,kp44)

hallp = Area.ofHyperLines(a.create_hyper_line_array(gateway, (ln11,ln12,ln13,ln14)))
```

STEAM-SIGMA notebook code

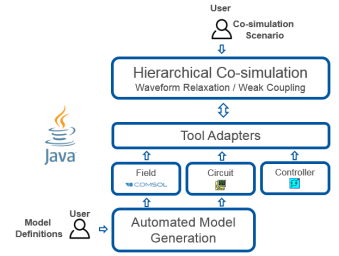


Java code for compilation with COMSOL API

Notebooks allow a generalized & consistent generation of models, that can be combined with the other tools!

STEAM-COSIM notebooks

Multi-physics model for co-operative simulations

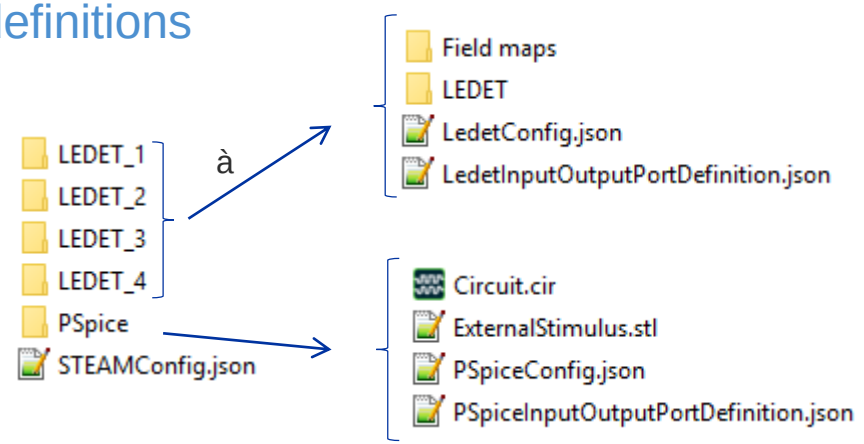


(!) *Notebooks, with semi-automatic generation currently only support COSIM with LEDET & PSPICE*

Notebooks based on re-usable Python api

- Notebooks automatically generate the required folder structure & port definitions
  e.g. for LHC MQXF [COSIM with 4x LEDET and 1x PSPICE]

  - Generating 24 directories
  - Copying 20 model files
  - Generating 5 port files with 16 ports in total
    & 5 config files

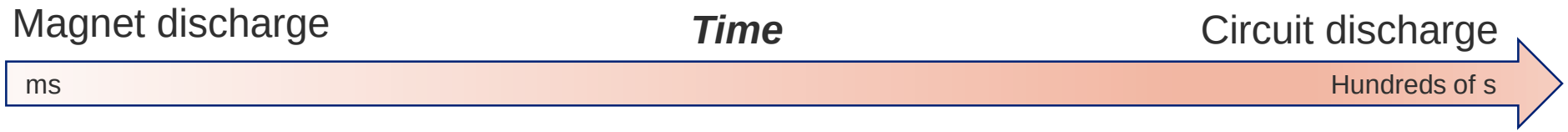


- Notebook re-uses the same PSPICE/LEDET/SIGMA models from the library
- Generation of an excutable, to run COSIM with one click
- Further features & adjustment can be realized in the notebooks

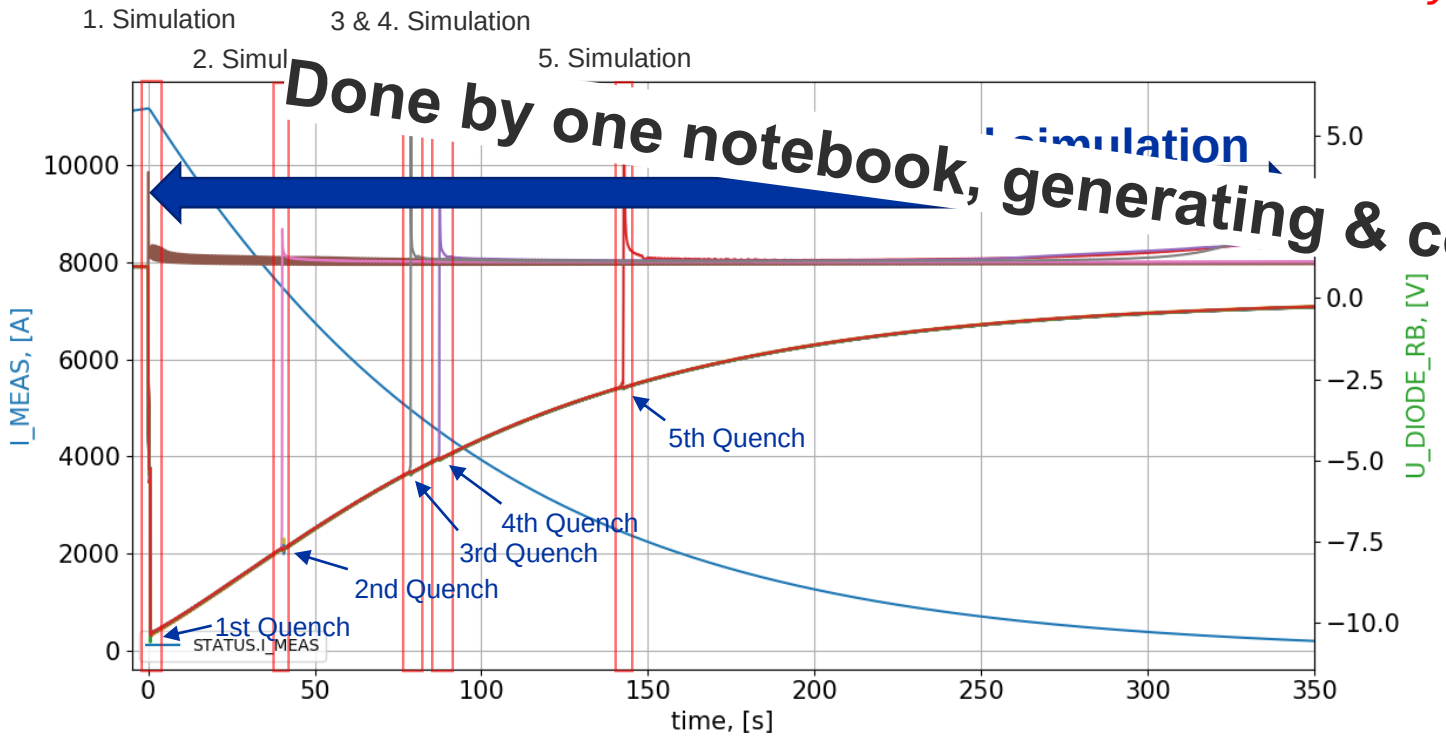
Notebooks take over and automatize repetitive work & ensure consistency

Use case: Simulating RB events

- **Simulation of RB events is a challenging matter, as complex phenomena have to be combined on a variety of time scales**



How to simulate these events with a sufficient accuracy & little computation time?



Plot taken from one LHC-SIGMON HWC Analysis notebook from May 2021

Approach:

1. Simulate each of the sub-events in rather short time frames [about 1-3 s], [illegible] physical phenomena and small [illegible]
2. Combine all sub-events to one long simulation with more coarse time-stepping by using the calculated coil-resistance developments in each quenched magnet

Agenda


Mon 11/10
Tue 12/10
Wed 13/10
Thu 14/10
Fri 15/10
Hands-on session: STEAM Notebooks + materials properties database - recommended for users in Asia
Notebooks
11:00 - 12:00
Hands-on session: STEAM Notebooks + materials properties database - recommended for users in Europe
Notebooks
14:00 - 15:00
Hands-on session: STEAM Notebooks + materials properties database - recommended for users in Americas
Notebooks
18:30 - 19:30
Welcome
STEAM framework
Mariusz Wozniak
16:10 - 16:40
New STEAM developments
Dr Emmanuele Ravaioli
16:40 - 17:10
Break
STEAM notebooks
Marvin Janitschke
17:30 - 18:00
Hands-on session: SIGMA - recommended for users in Asia
SIGMA
Hands-on session: ProteCCT - recommended for users in Asia
ProteCCT
Hands-on session: SIGMA - recommended for users in Europe
SIGMA
Hands-on session: ProteCCT - recommended for users in Europe
ProteCCT
Quench protection of HEPDipo magnet using STEAM-LEDET
Xabier Saras
Powering and protection of the MQXF test facility at FNAL using STEAM-CO…
Vittorio Marinc
Analysis of fast discharge of the SIS100 dipole circuit using a SING-generated P…
Dimitri De
Hands-on session: SIGMA - recommended for users in Americas
SIGMA
Hands-on session: ProteCCT - recommended for users in Americas
ProteCCT
Hands-on session: LEDET - recommended for users in Asia
LEDET
Hands-on session: BBQ - recommended for users in Asia
BBQ
Hands-on session: LEDET - recommended for users in Europe
LEDET
3D magnet quench simulations using STEAM-LEDET
Ola Tranum Arnegaa
Analysis of thermal transients in a superconducting combined function magnet for…
Vittorio
[to be confirmed] Simulation of CLIQ transients in a cos-theta dipole magnet using STEAM-L
Hands-on session: LEDET - recommended for users in Americas
LEDET
Hands-on session: BBQ - recommended for users in Americas
BBQ
Hands-on session: SING and PSPICE - recommended for users in Asia
SING & PSPICE
Hands-on session: COSIM - recommended for users in Asia
COSIM
Hands-on session: SING and PSPICE - recommended for users in Europe
SING & PSPICE
Hands-on session: COSIM - recommended for users in Europe
COSIM
test coils to full-scale systems
Daniel Davis
Thermal analysis of quench
ing stations using STEAM-BBQ
Marvin Janitschke
Quench protection simulations of HEL Solenoid using STEAM-LEDET
Mariusz Wozniak
Hands-on session: SING and PSPICE - recommended for users in Americas
SING & PSPICE
Hands-on session: COSIM - recommended for users in Americas
COSIM
STEAM future
Dr Emmanuele Ravaioli et al.
16:00 - 16:30
Discussion
16:30 - 17:00
Don‘t miss the Hands On Sessions!
Repeated sessions

Future work on the STEAM notebooks

We‘re constantly developing new features & model and try to improve the notebooks!

If you have ideas, wishes & feedback, we‘re interested! ☺

https://espace.cern.ch/steam/

steam-team@cern.ch