Towards complete automation of circuit event simulations

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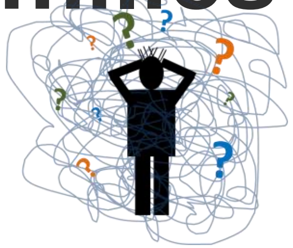
Motivation

- ➢ Simulate any LHC event on the fly 

- ➢ Automate the analysis of diverse circuit families 

- ➢ Perform periodic tests of validated circuit models 

Outline of my talk

Introduction to STEAM and softwares used

ABCD Analysis Strategy

Three Improvements

Where does automation begin?

Why is it a challenge: Complexity and diversity of LHC circuit families

Synergy between analysis techniques of magnets and circuits

An example of simulation plots generated

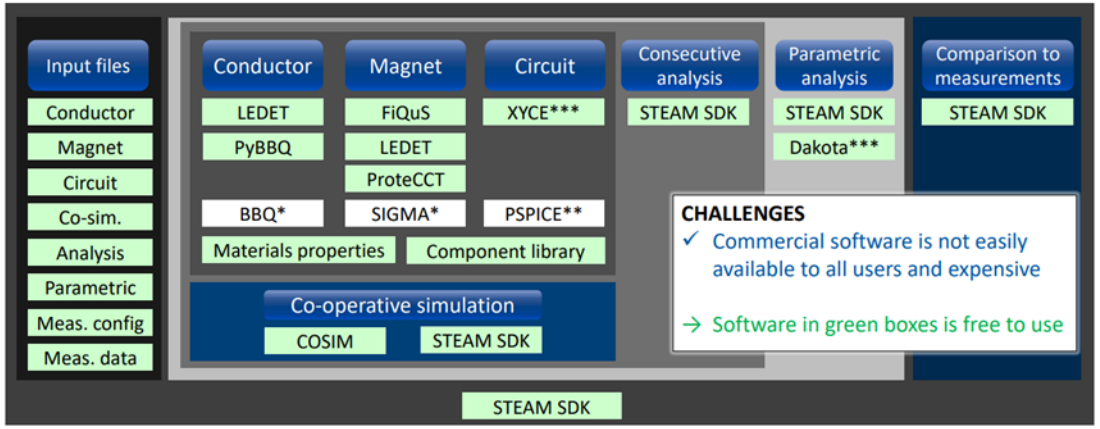
Periodic tests and sanity checks

Automation Flow

What is STEAM ?

- Simulation of Transient Effects in Accelerator Magnets
- Achieve specialized, trusted, consistent, repeatable and sustainable software tools and models
- Designed to model electrical, electromagnetic, and thermal transients in superconducting magnets and circuits

STEAM framework



some functionality is under active development

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

XYCE

- Xyce (zīs, rhymes with “spice”)
- Open source, SPICE-compatible, high-performance analog circuit simulator
- Developed by Sandia National Laboratories, USA

PSPICE

- Fully functional analog circuit simulator
- Supports digital components
- Integrates system-level interfaces with electrical designs

ABCD analysis strategy for all circuit families

A. Validation of existing circuits

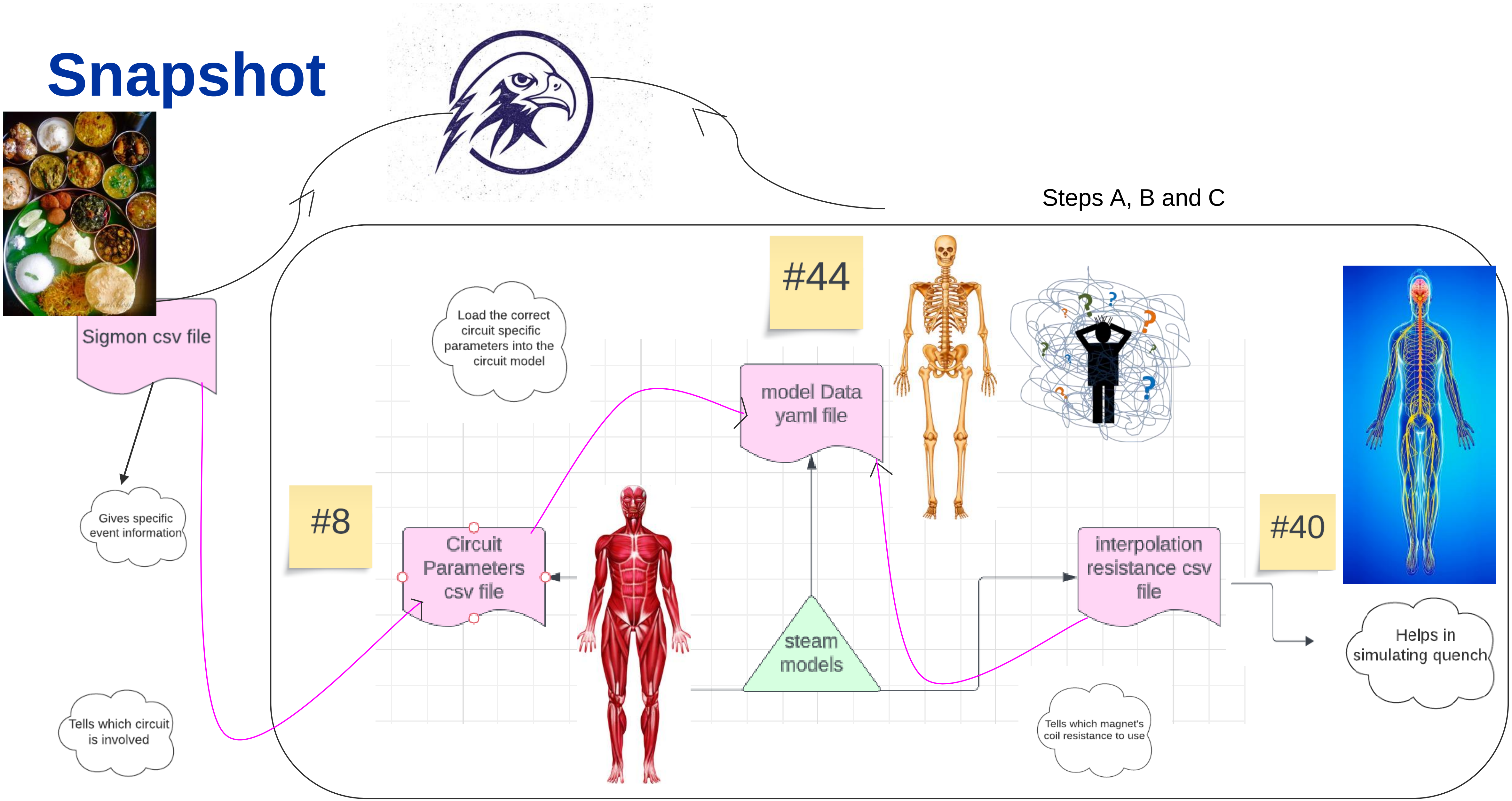
B. Making models of all remaining circuit types

C. Verifying circuit-specific models

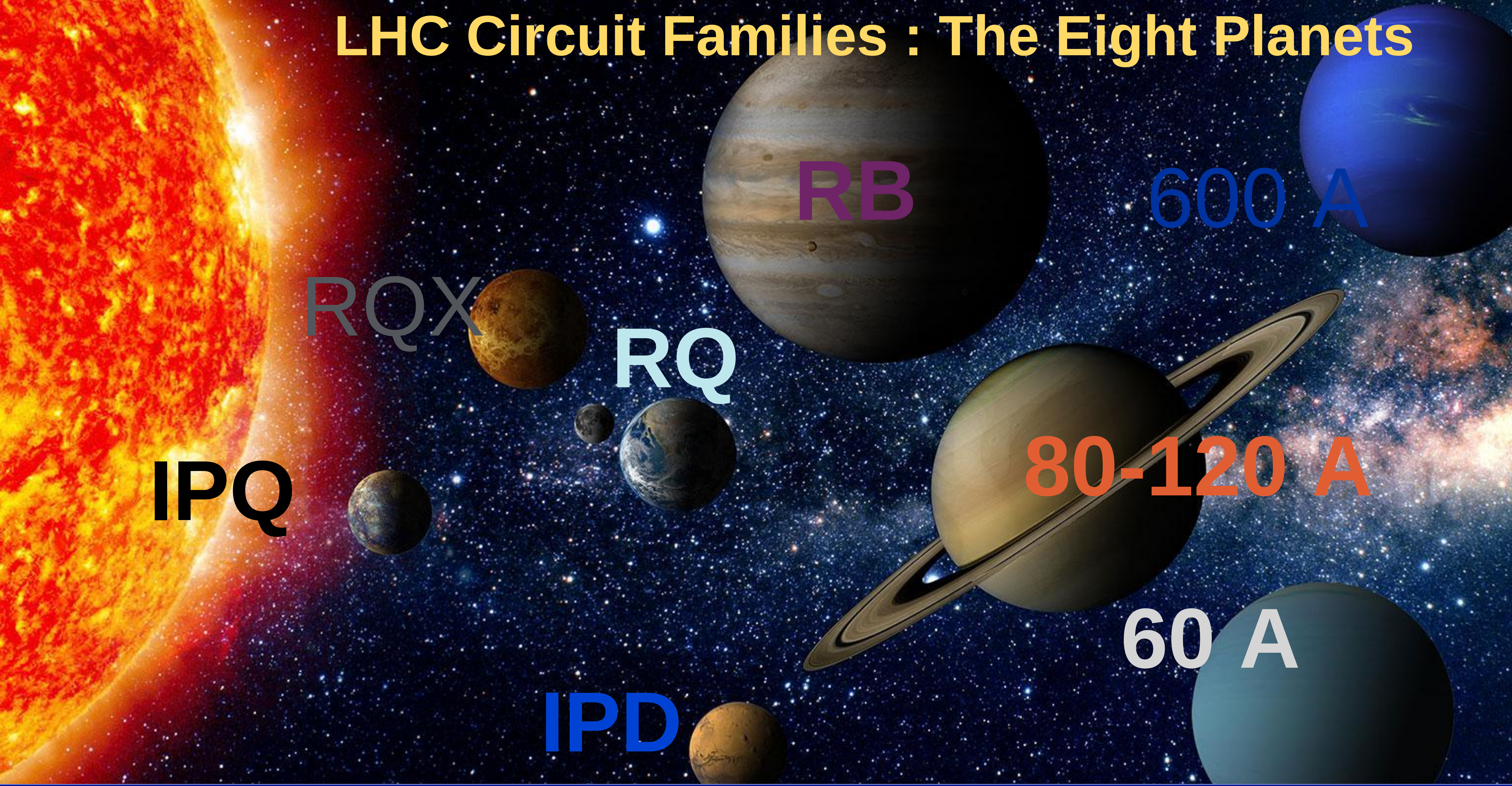
D. Improving model (A continuing process…)

All these steps have been successfully applied for all circuit types of all the 8 circuit families.

Snapshot


Steps A, B and C
Sigmon csv file
Gives specific event information
Tells which circuit is involved
Load the correct circuit specific parameters into the circuit model
#44
model Data yaml file
#8
Circuit Parameters csv file
steam models
interpolation resistance csv file
#40
Tells which magnet's coil resistance to use
Helps in simulating quench

LHC Circuit Families : The Eight Planets



Challenge: Complex diversity of the eight planets

RQX has three PCs each with different ramp rate, acceleration and current

IPQ has 2 different magnet configurations (2 apertures and 4 ape

Although IPD circuits have just one magnet, they employ four different circuit types and corresponding different magnets.

RQ family has defocusing and focusing circuits and employs a hierarchical sub-modular structure for the PC.

600 A circuits may have EE and/or parallel resistors or may be self-protected.

RB and RQ must include diodes with heating modeling across the magnets that quench.

Nested magnets pose another challenge.

Improvement 1: Coil Resistance Interpolation

The Coil resistances used for interpolation are derived from earlier work of PSPICE-LEDET co-simulation by the STEAM team. *(Thanks Marvin!)*

Lumped-Element Dynamic Electro-Thermal (LEDET) model includes non-linear dynamic effects such as the dependence of the magnet's differential self-inductance on the presence of inter-filament and inter-strand coupling currents in the conductor.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	7179.061			6799.062			6119.064			5439.067			4759.07			4079.073	
2	time_vect	R_CoilSections_1		time_vect	R_CoilSections_1		time_vect	R_CoilSections_1		time_vect	R_CoilSections_1		time_vect	R_CoilSections_1		time_vect	R_Co
3	-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00
4	-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00E+00		-1.00E-01	0.00
5	-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00
6	-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00E+00		-9.99E-02	0.00
7	-9.98E-02	0.00E+00		-9.98E-02	0.00E+00		-9.98E-02	0.00E+00		-9.98E-02	0.00E+00		-9.98E-02	0.00E+00		-9.98E-02	0.00
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11	-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00
12	-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00E+00		-9.96E-02	0.00
13	-9.95E-02	0.00E+00		-9.95E-02	0.00E+00		-9.95E-02	0.00E+00		-9.95E-02	0.00E+00		-9.95E-02	0.00E+00		-9.95E-02	0.00
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15	-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00
16	-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00E+00		-9.94E-02	0.00
17	-9.93E-02	0.00E+00		-9.93E-02	0.00E+00		-9.93E-02	0.00E+00		-9.93E-02	0.00E+00		-9.93E-02	0.00E+00		-9.93E-02	0.00
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19	-9.92E-02	0.00E+00		-9.92E-02	0.00E+00		-9.92E-02	0.00E+00		-9.92E-02	0.00E+00		-9.92E-02	0.00E+00		-9.92E-02	0.00
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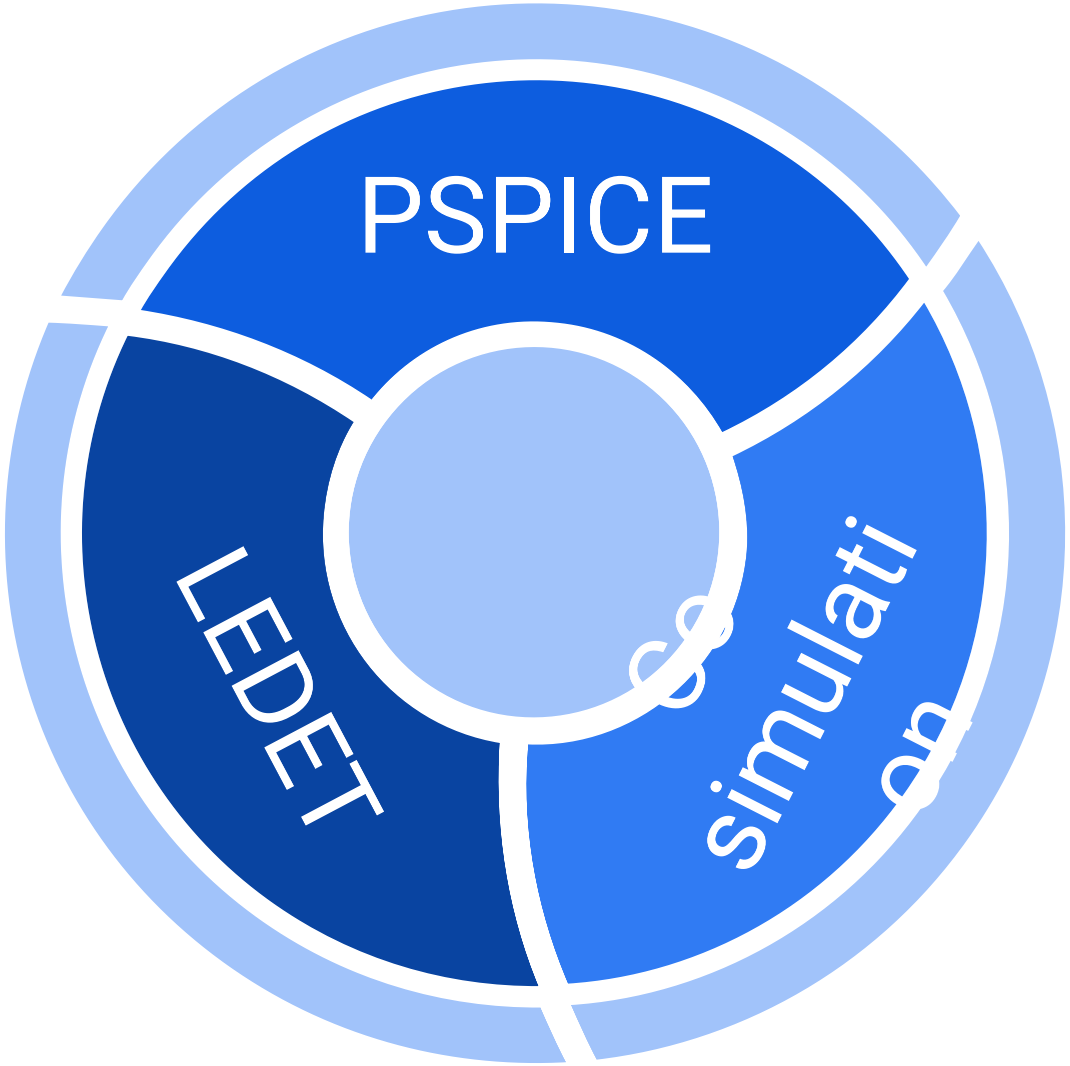
29	-9.87E-02	0.00E+00		-9.87E-02	0.00E+00		-9.87E-02	0.00E+00		-9.87E-02	0.00E+00		-9.87E-02	0.00E+00		-9.87E-02	0.00

Coil Resistance Interpolation

Once the coil resistances are taken from the LEDET output, we can use them to interpolate coil resistances for current levels in the range.

Other options can be fine tuned, like how many magnets and apertures are there, what time offset should be used, etc.



For interpolation, we use the good old formula

Interpolation Formula

$$y = \frac{(y_2 - y_1)}{(x_2 - x_1)} \times (x - x_1) + y_1$$

Improvement 2 :Stimulus File Generation

Once we have the interpolated coil resistances, we can feed that into our next step of stimulus (.stl) file generation.

R_coil_1_M1 in the adjacent image acts as an external stimulus to the parametrized magnet component in the magnets library file.

This way of using interpolated coil resistances to determine exact stimulus for the parametrized magnet helps us with automation of simulations of very different magnet types.

Thus, we replace the magnet component to include coil resistances.

```

.STIMULUS R_coil_1_M1 PWL
+ TIME_SCALE_FACTOR = 1
+ VALUE_SCALE_FACTOR = 1
+ ( 0s, 0.0 )
+ ( 757.70505s, 0.0 )
+ ( 757.71005s, 0.0 )
+ ( 757.71505s, 0.0 )
+ ( 757.72005s, 0.0 )
+ ( 757.72505s, 0.0 )
+ ( 757.73005s, 0.0 )
+ ( 757.73505s, 0.0 )
+ ( 757.74005s, 0.00024080550000000003 )
+ ( 757.74505s, 0.0014309271 )
+ ( 757.7500500000001s, 0.0016714044 )
+ ( 757.7550500000001s, 0.0017625471 )
+ ( 757.7600500000001s, 0.0018631272749999998 )
+ ( 757.7650500000001s, 0.00197258625 )
+ ( 757.7700500000001s, 0.00219744255 )
+ ( 757.7750500000001s, 0.002380548675 )
+ ( 757.7800500000001s, 0.00253927455 )
+ ( 757.7850500000001s, 0.0027746855250000003 )
+ ( 757.7900500000001s, 0.0029600976000000003 )
+ ( 757.7950500000001s, 0.0031303468499999996 )
```

Improvement 3: Change of Power Converter Model

Inclusion of global parameters like ramp rate, acceleration to control the power converter with an analytical equation, as described below

```
* PSPICE Generic Power Converter components library
* Version 1.0: 2022/06/01, Emmanuele Ravaioli, STEAM, TE-MPE-PE, CERN, Geneva, CH
* This library includes models of power supplies, i.e. power converters (PC), that can be used for multiple circuits

*$*********************************************************************************

* Subcircuit: PC_controlled_equations
* Power supply, i.e. power converter (PC), controlled with an analytical equation
* Notes:
* - The PC is modelede as two voltage-controlled current sources in parallel governed by analytical equations
* - One current source models the first phase (I_start-->I_end_1) and the other the second phase (I_end_1-->I_end_2)
* - The PC current is set to follow this pattern:
* --- stay at I_start until t>t_start
* --- change parabolically, then linearly, then parabolically from I_start to I_end_1
* --- wait at I_end_1 for a time t_plateau
* --- change parabolically, then linearly, then parabolically from I_end_1 to I_end_2
* --- if at any time the simulation time reaches t_PC_off, the PC is switched off and its current set to 0 A even if the ramp is not finished
* - The transition from parabolic to linear phases is set so that the dI_dt does not change abruptly
* - To simplify the lunderstanding of the logic, virtual voltage nodes are used to calculate relevant times
* - Parasitic components are included. The default settings improve numerical convergence in many practical cases.
```

Where do we begin?

LHC Magnet circuits,

Powering and

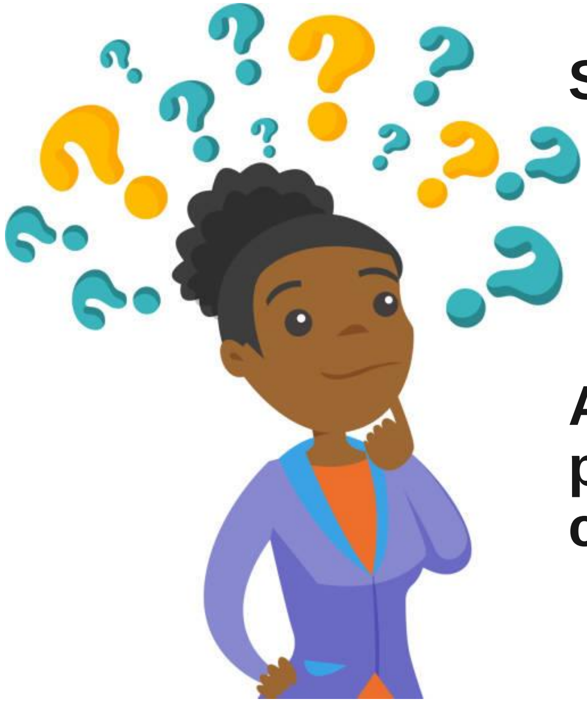
Performance Panel (MP3)

Repository

Fast Power Abort (FPA)

Circuit Events

Produced by SigMon- Signal Monitoring project



What do we begin with?

Simple csv file

All relevant information about that particular FPA event for a particular circuit

Including ramp rate, acceleration, plateau duration, type of quench, position in the magnet, date, time etc.

Synergy between analysis of magnets and circuits

Integration of the analysis of circuit events into the ParsimEvent step (the skin of our human body analogy)

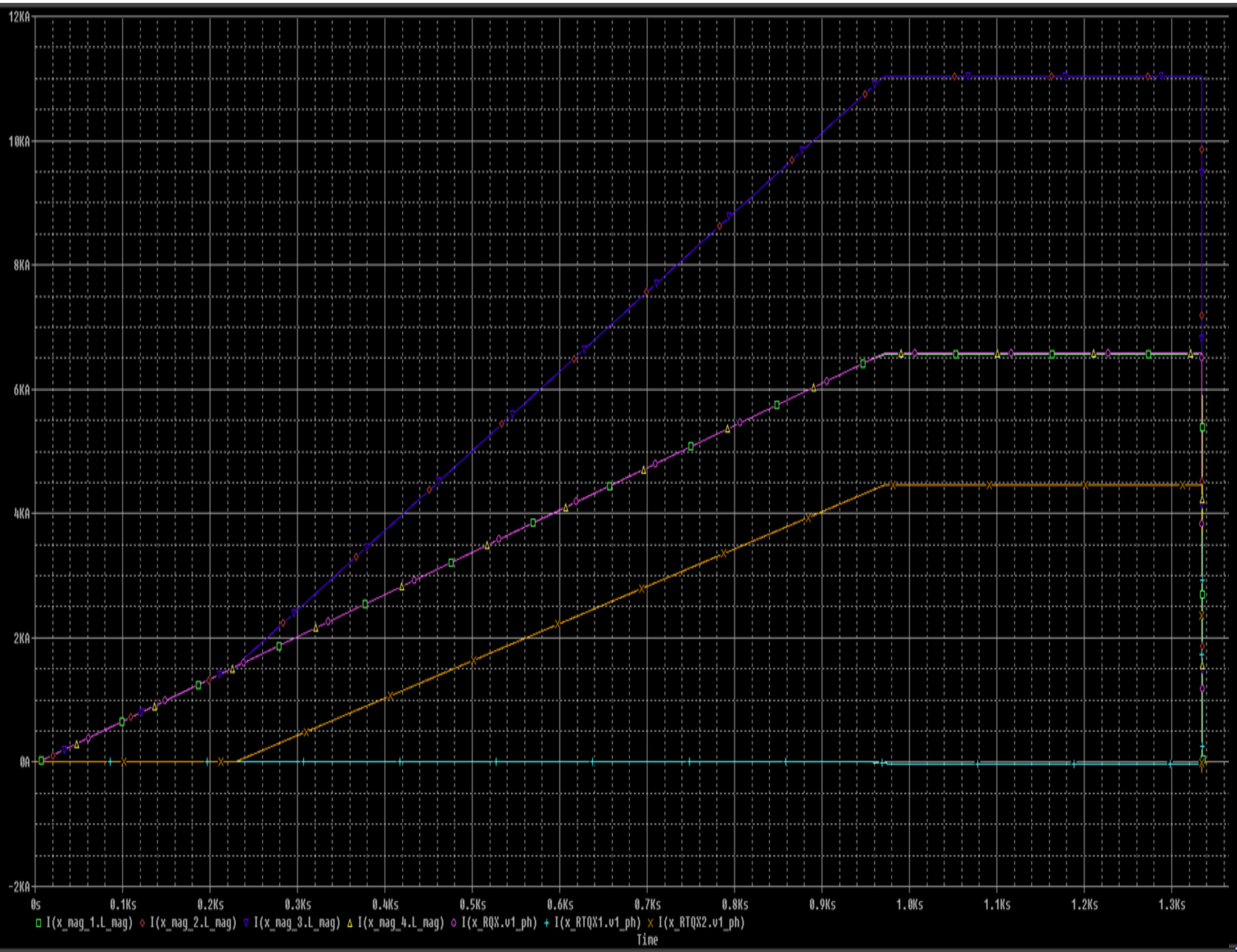
Just change case_model from ‘magnet’ to ‘circuit’

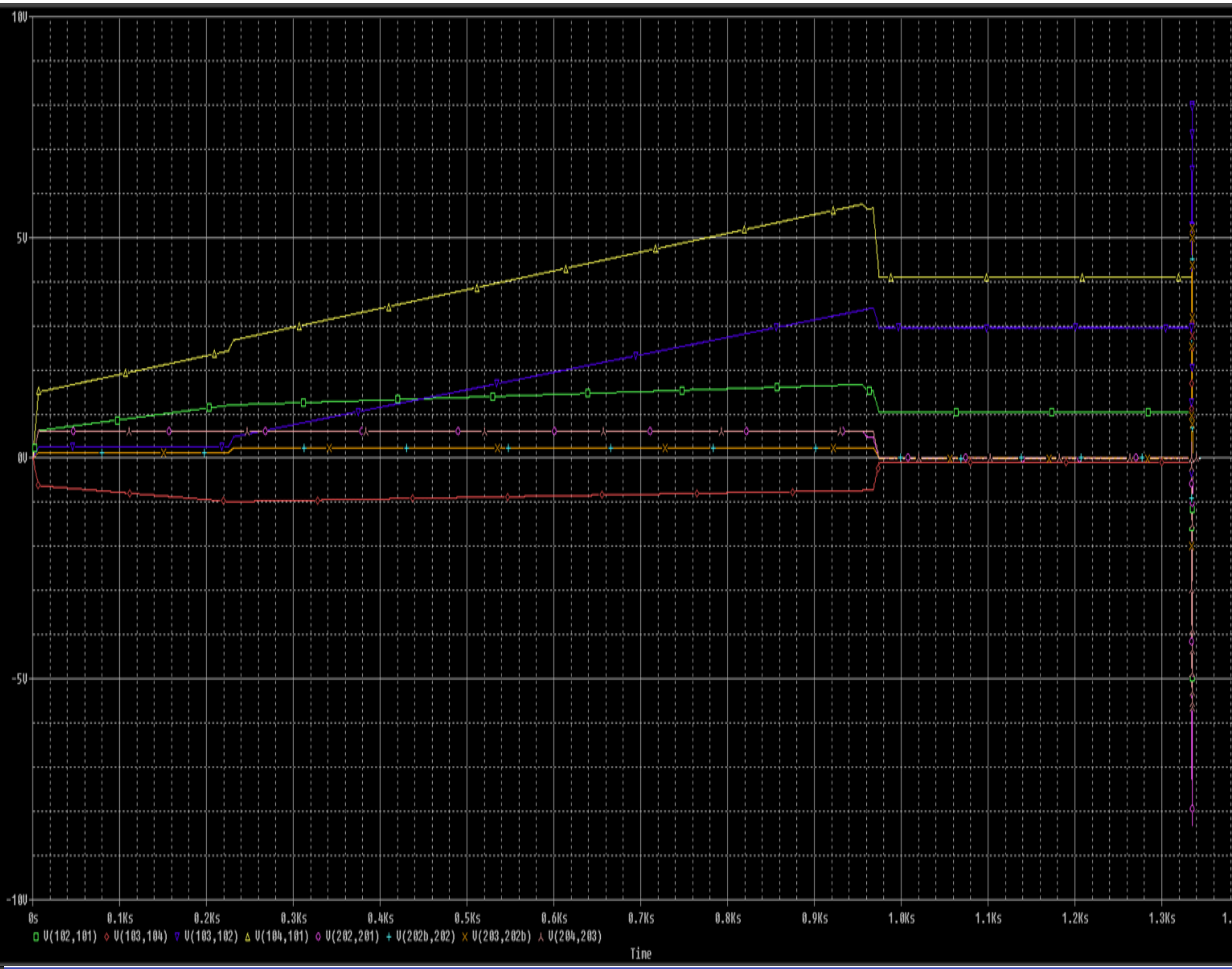
For example, reading FPA circuit event files instead of quench dictionaries as done for magnets

Simulation Plots: RQX

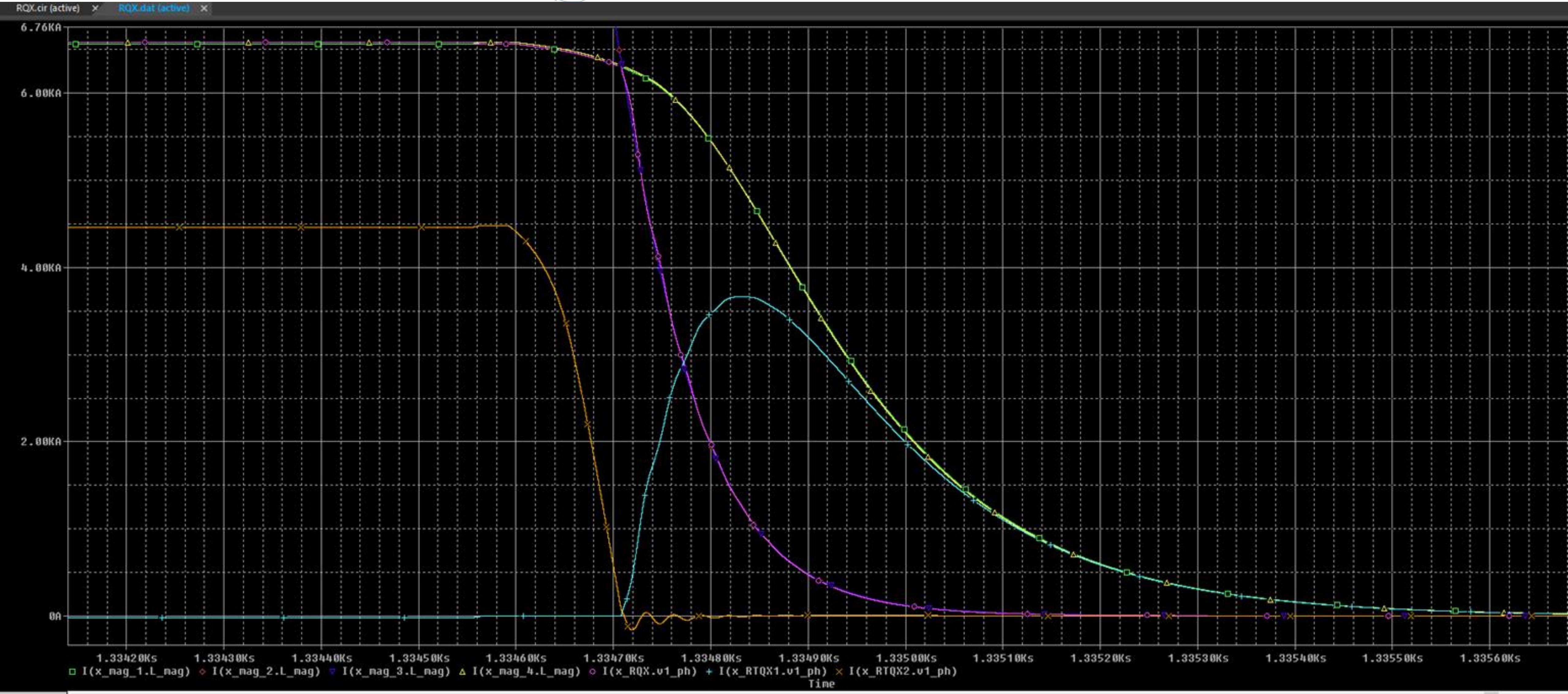
- Automate the analysis of diverse circuit families

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	
1	Circuit Na	Circuit Far	Period	Date (FGC	Time (FGC	FPA Reasc	Timestam	Delta_t(F(	Ramp rate	Ramp rate	Ramp rate	Plateau dı	Plateau dı	Plateau dı	I_Q_RQX	I_Q_RTQX	I_Q_RTQX	MIITS_RQ:	MIITS_RT(	MIITS_RT(	I_Earth_m	Delta_t(Q	I_Q_Q1	I_Q_Q2	I_Q_Q3	Type of Q	Quench oı	Quench c(	QDS trigge	dU
2	RQX.R1	RQX	Operation	#########	35:37.7	Magnet qı	35:37.8	-32	0	0	0	359.96	359.96	359.96	6581	-20.3	4460	8.506	0	2.243	-38.0859	-1	6559.4	11039	6585.2	Beam-ind	Q2		QPS	-





A closer look…

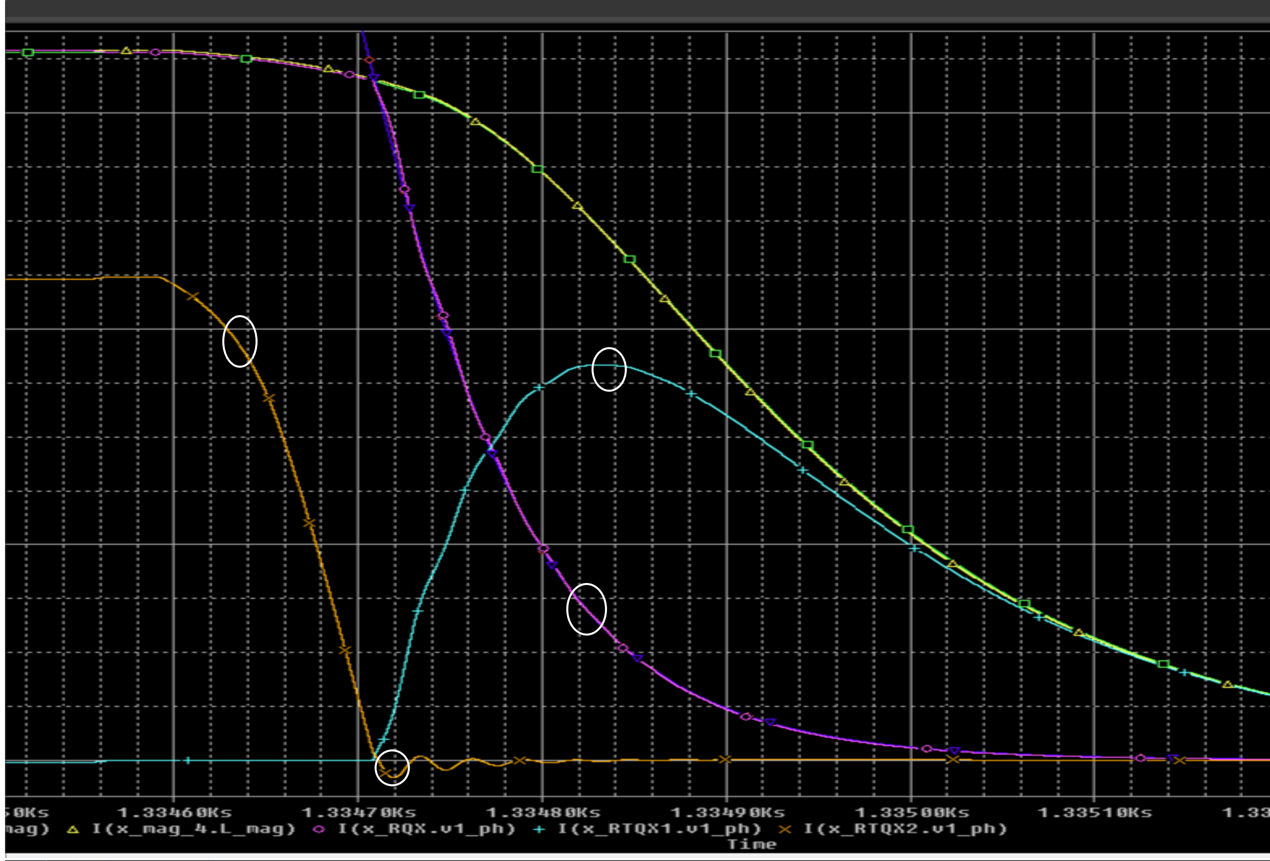


Periodic Tests and Sanity Checks

Sanity checks are exercised upon the

signal values at points of interest. For example:

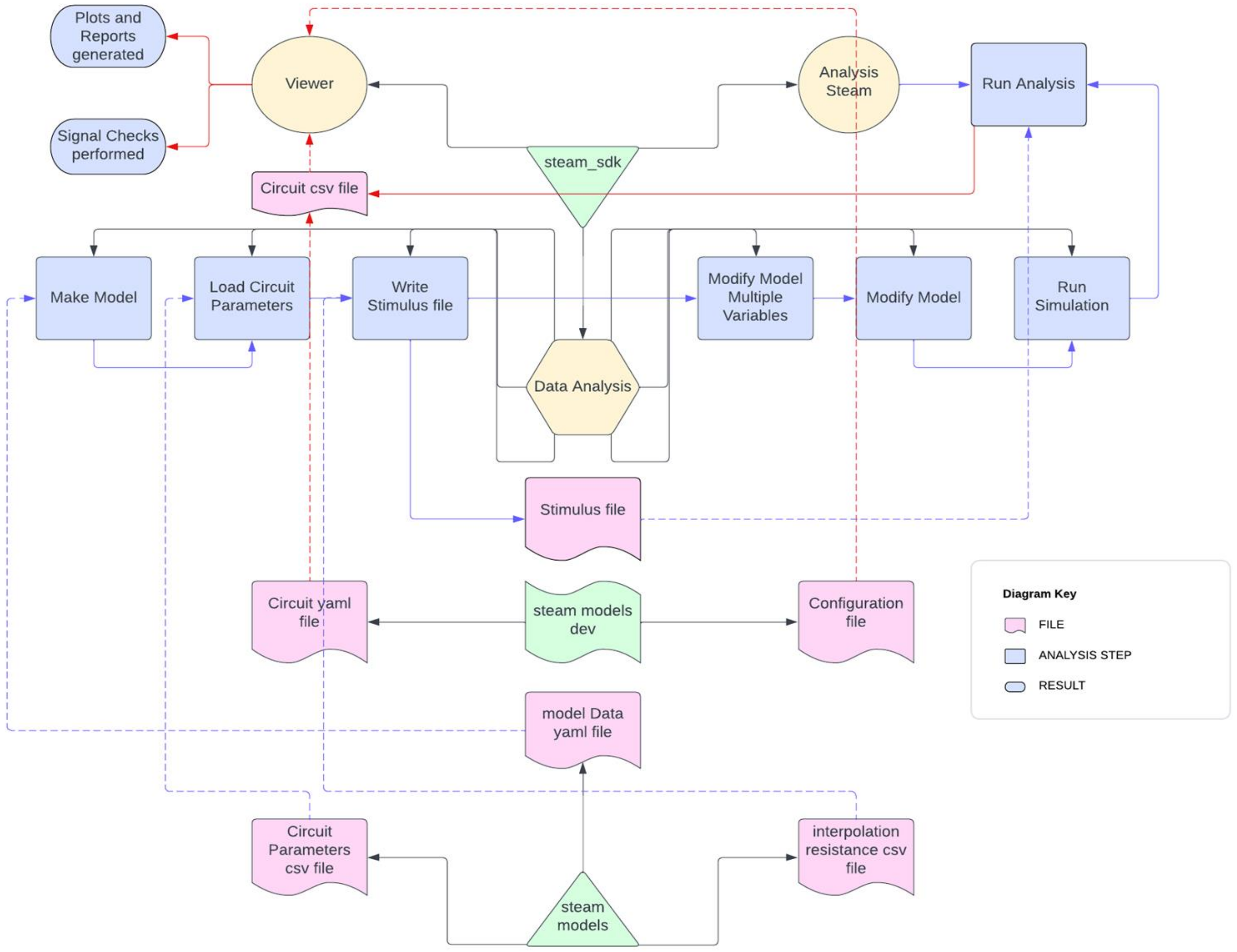
- currents during discharge and ramp up
- voltages across power converters
- minimum/maximum values
- checking at certain points of time




```yaml
check_against_targets:
  first_check:
    operation: 'value_at_time'
    variable: 'I(x_mag_1.L_mag)'
    target_time: 200.0
    target_value_range: [ 844, 845 ]
  second_check:
    operation: 'value_at_time'
    variable: 'I(x_mag_2.L_mag)'
    target_time: 400.0
    target_value_range: [ 4612, 4613 ]
  third_check:
    operation: 'value_at_time'
```

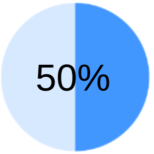
➢ **Perform periodic tests of validated circuit models**

Automation Flow ➢ Simulate any LHC event on the fly

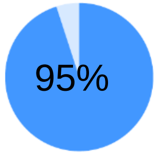


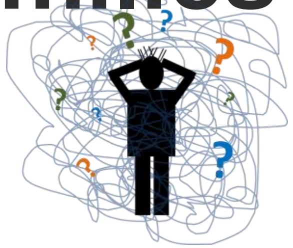
Conclusion

- ➢ **Simulate any LHC event on the fly**

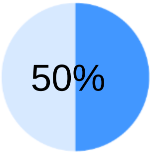


- ➢ **Automate the analysis of diverse circuit families**





- ➢ **Perform periodic tests of validated circuit models**



CERN