

# STEAM

## Revival of SIGMA and Extended STEAM-SDK Coupling

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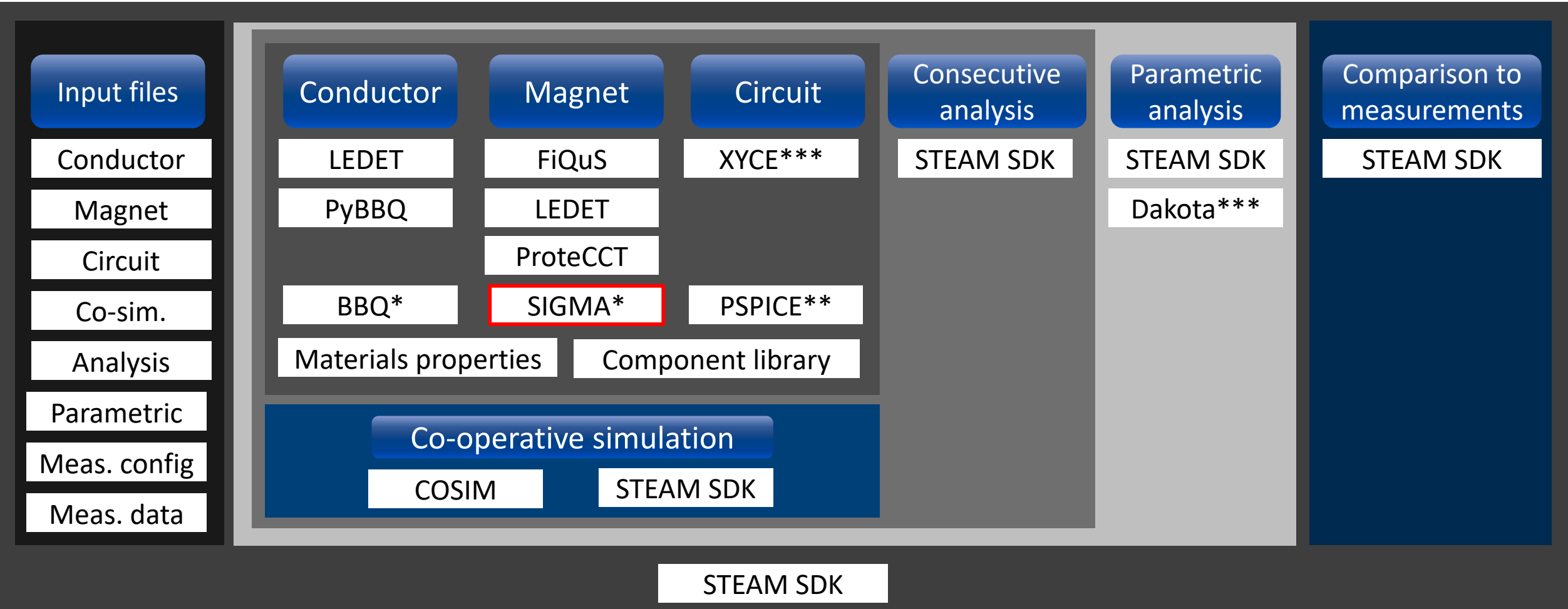


<https://espace.cern.ch/steam>

# Outline

- SIGMA in the STEAM-Framework
- Background: What is SIGMA?
- Development of SIGMA
- Lessons learned and future of SIGMA
- Additional Work in STEAM-SDK & FiQuS

# STEAM framework

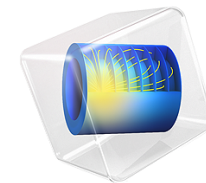
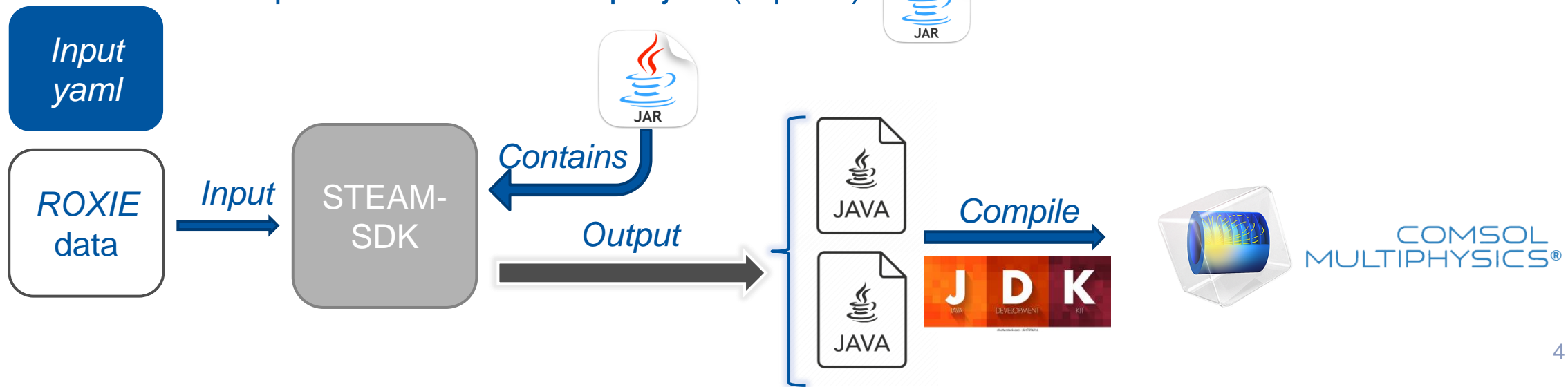


some functionality is under active development

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

# Background: What is SIGMA?

- SIGMA – Simulation of Transient Effects in Accelerator Magnets
- Java application developed 2017-2020 at CERN
- Generate COMSOL-based transient models of accelerator magnets
- Official development stopped in 2020 (before steam-sdk)
- STEAM-SDK integration:
  - Gradle (build tool) build SIGMA project to jar file
  - Jar file – compact version SIGMA project (Zip file)



COMSOL  
MULTIPHYSICS®

# Generated Magnet Model

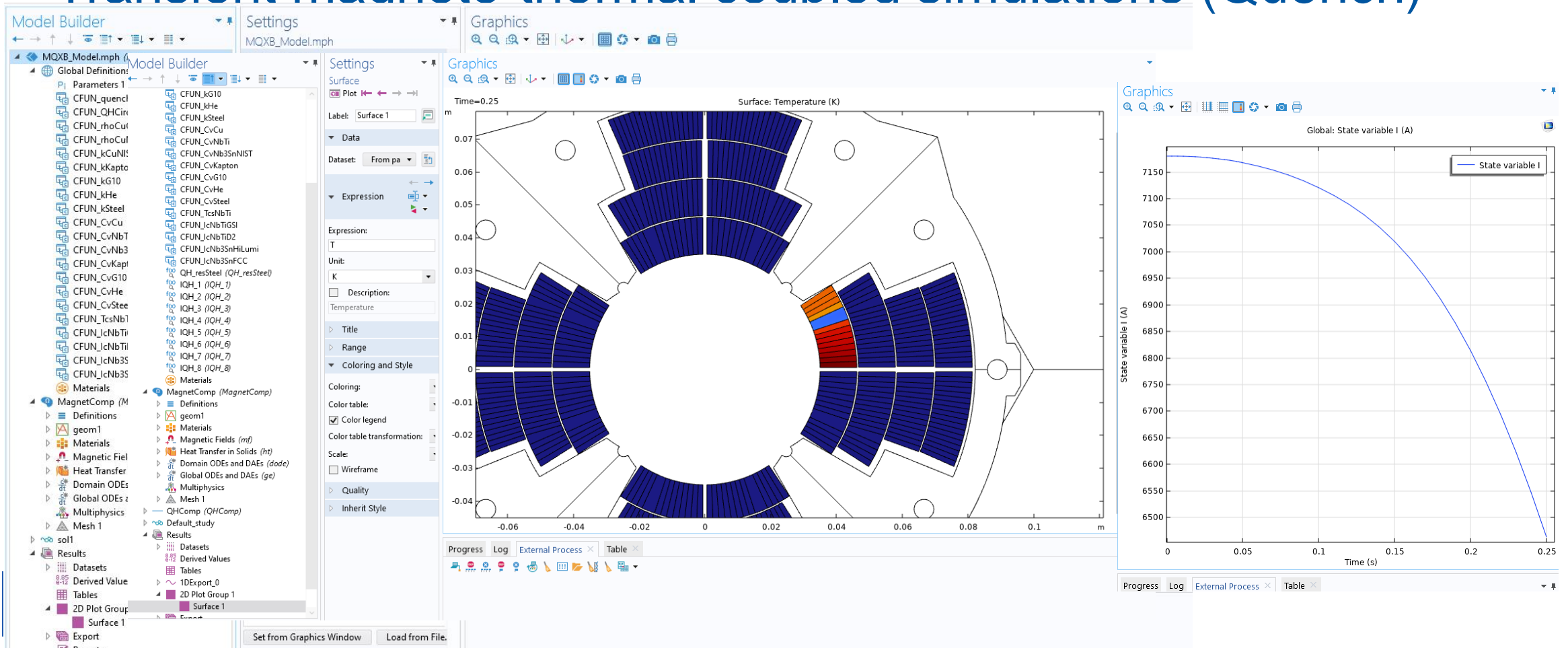
The image shows a software interface for a magnet model. The interface is divided into three main sections: Model Builder, Settings, and Graphics.

- Model Builder:** Shows a tree view of the model structure. The root is **MQXB\_Model.mph (root)**. Under **Global Definitions**, there are **Parameters 1** and a list of material properties (e.g., **CFUN\_quenchState**, **CFUN\_QHCircuit**, etc.). Under **Materials**, there is a sub-section **MagnetComp (MagnetComp)** containing **Definitions**, **geom1**, **Materials**, **Magnetic Fields (mf)**, **Heat Transfer in Solids (ht)**, **Domain ODEs and DAEs (dode)**, **Global ODEs and DAEs (ge)**, **Multiphysics**, **Mesh 1**, **sol1**, and **Results**.
- Settings:** Shows the configuration for the selected geometry **geom1**. It includes:
  - Geometry:** **Build All**
  - Label:** **geom1**
  - Units:** **Scale values when changing** (unchecked), **Length unit:** **m**, **Angular unit:** **Degrees**
  - Constraints and Dimensions:** **Use constraints and dimension:** **Off**
  - Advanced:** **Default repair tolerance:** **Relative**, **Default relative repair tolerance:** **5E-5**, **Build new operations automatically** (checked), **Build automatically when I click** (checked)
- Graphics:** Shows a 2D cross-section of the magnet model. The model is a semi-circular structure with a central bore. The bore is filled with a mesh of vertical lines. The outer boundary is a semi-circle. The x-axis ranges from -0.04 to 0.04, and the y-axis ranges from 0.02 to 0.07. The model is rendered in a light gray color.



# Examples of Solutions with SIGMA

- Magnetostatic field solver
- Transient magneto-thermal coupled simulations (Quench)



# So, what was the problem?

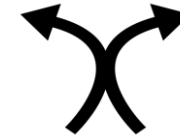


**Single jar file in STEAM-SDK:**



**Jar unversioned:**

- No connected repository to generated jar



**Scattered source code:**

- 4 repositories with multiple branches each



**Broken gradle dependencies:**

- Dependencies when building SIGMA broken.



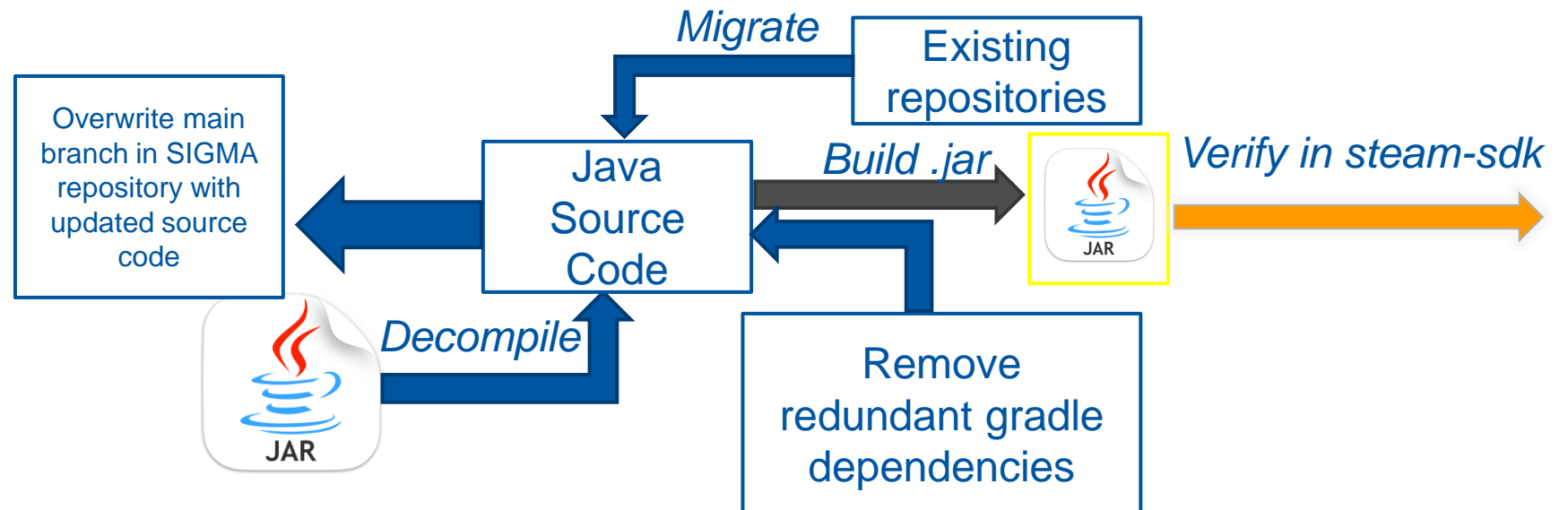
**No verification:**

- Simulations accurate?
- For which magnets does SIGMA work?
- Missing functionalities

# First stage: Revive SIGMA

Time spent: 2-3M

- How to recover source code?
- Retrieve SIGMA source code by decompiling .jar file
- Remove redundant gradle dependencies to build jar
- Generate and solve model in COMSOL with new jar
- Migrate latest features from repositories to SIGMA including tests





# Second stage: Automation of Quench Simulations & Upgrade COMSOL version

- Only COMSOL 5.3a version supported (2017)
  - COMSOL not backward compatible
  - Implement SIGMA support COMSOL 6.0



# Example: 5.3a vs 6.0

Model Builder

- MBRD\_Model.mph (root)
  - Global Definitions
    - Parameters 1
      - CFUN\_quenchState
      - CFUN\_QHCircuit
      - CFUN\_rhoCuCUDI
      - CFUN\_rhoCuNIST
      - CFUN\_kCuNIST
      - CFUN\_kKapton
      - CFUN\_kG10
      - CFUN\_kHe
      - CFUN\_kSteel
      - CFUN\_CvCu
      - CFUN\_CvNbTi
      - CFUN\_CvNb3SnNIST
      - CFUN\_CvKapton
      - CFUN\_CvG10
      - CFUN\_CvHe
      - CFUN\_CvSteel
      - CFUN\_TcsNbTi
      - CFUN\_IcNbTiGSI
      - CFUN\_IcNbTiD2
      - CFUN\_IcNb3SnHiLumi
      - CFUN\_IcNb3SnFCC
    - Materials
      - MagnetComp (MagnetComp)
        - Definitions
        - geom1
          - Materials
            - MAT\_AIR\_geom1\_AFF\_dom (MAT\_AIR\_geom1\_AFF\_dom)
            - MAT\_AIR\_geom1\_AIR\_dom (MAT\_AIR\_geom1\_AIR\_dom)
            - BHiron1\_geom1\_area1\_dom (BHiron1\_geom1\_area1\_dom)
            - BH\_air\_geom1\_area3\_dom (BH\_air\_geom1\_area3\_dom)
              - Basic (def)
                - HB curve (HBCurve)
                  - Interpolation (HB)
              - BH air geom1\_area2\_dom (BH air geom1\_area2\_dom)
              - MAT\_KAPTON\_geom1\_CO\_P0\_W0\_bnd (MAT\_KAPTON\_geom1\_CO\_P0\_W0\_bnd)
              - MAT\_KAPTON\_geom1\_CO\_P0\_W1\_bnd (MAT\_KAPTON\_geom1\_CO\_P0\_W1\_bnd)

Settings

Interpolation

Plot Create Plot

Label: Interpolation

Definition

Data source: Local table

Function name: HB

| t           | f(t)      |
|-------------|-----------|
| 2.00057E-4  | 159.2     |
| 3.69954E-4  | 294.4     |
| 2.674123667 | 2128000.0 |
| 3.565958989 | 2837700.0 |
| 5.349126979 | 4256700.0 |

Interpolation and Extrapolation

Interpolation: Piecewise cubic

Extrapolation: Linear

Units

| Function | Unit |
|----------|------|
| HB       |      |

| Argument | Unit |
|----------|------|
|          |      |

Graphics



# Second stage: Automation of Quench Simulations & Upgrade COMSOL version

- Only COMSOL 5.3a version supported (2017)
  - COMSOL not backward compatible
  - Implement SIGMA support COMSOL 6.0
- Missing features set from input files:
  - Quench initialization
  - Quench heater positions
  - Propagation of settings from steam-sdk for quench simulations



# Missing Features & Propagation of Input Parameters

```
modelData_MQXA.yaml
673 voltageToGroundOutputSelection: null
674 plots:
675   withPlots: null
676   plotPauseTime: null
677 Options_SIGMA:
678   time_vector_solution:
679     time_step: [[0.0, 0.001, 0.05], [0.05, 0.01, 0.25]]
680 simulation:
681   generate_study: true
682   study_type: Transient
683   make_batch_mode_executable: true
684   nbr_elements_mesh_width: 4
685   nbr_elements_mesh_height: 1
686 physics:
687   FLAG_M_pers: 0
688   FLAG_ifcc: 0
689   FLAG_iscc_crossover: 0
690   FLAG_iscc_adjw: 0
691   FLAG_iscc_adjn: 0
692   tauCC_PE: null
693 quench_initialization:
694   PARAM_time_quench: null
695   FLAG_quench_all: 0
696   FLAG_quench_off: 0
697   num_qh_div: [10, 10, 10, 10, 10, 10, 10, 10]
698   quench_init_heat: 500000.0
699   quench_init_HT: [CO_P0_W0_B0_HT0]
700   quench_stop_temp: 10.0
701 postprocessing: <3 keys>
702 quench_heaters:
703   quench_heater_positions: [[4878, 4880, 4882, 4884, 4886, 4888, 4890,
704   th_coils: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
```

Model Builder

- lw\_CO\_P0\_W3\_EXT (lw\_CO\_P0\_V
- lw\_CO\_P0\_W4\_EXT (lw\_CO\_P0\_V
- lw\_CO\_P0\_W5\_EXT (lw\_CO\_P0\_V
- lw\_CO\_P1\_W0\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P1\_W1\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P1\_W2\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P1\_W3\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P1\_W4\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P1\_W5\_EXT (lw\_CO\_P1\_V
- lw\_CO\_P2\_W0\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P2\_W1\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P2\_W2\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P2\_W3\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P2\_W4\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P2\_W5\_EXT (lw\_CO\_P2\_V
- lw\_CO\_P3\_W0\_EXT (lw\_CO\_P3\_V
- lw\_CO\_P3\_W1\_EXT (lw\_CO\_P3\_V
- lw\_CO\_P3\_W2\_EXT (lw\_CO\_P3\_V
- lw\_CO\_P3\_W3\_EXT (lw\_CO\_P3\_V
- lw\_CO\_P3\_W4\_EXT (lw\_CO\_P3\_V
- lw\_CO\_P3\_W5\_EXT (lw\_CO\_P3\_V

Selections

- QH\_1\_Selection
- QH\_2\_Selection
- QH\_3\_Selection
- QH\_4\_Selection
- QH\_5\_Selection
- QH\_6\_Selection
- QH\_7\_Selection
- QH\_8\_Selection

Step 2: Time Dependent

- Solver Configurations
- Job Configurations

Settings

Explicit

Label: QH\_1\_Selection

Input Entities

Geometric entity level:

- 4878
- 4880
- 4882
- 4884
- 4886
- 4888

All boundaries

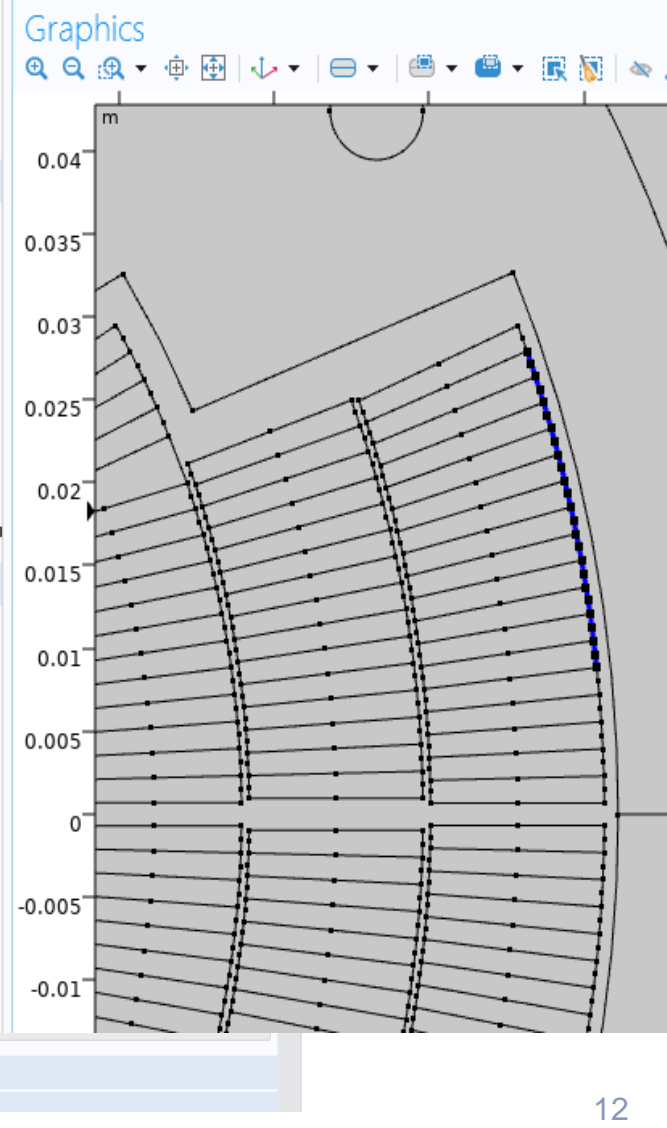
Group by continuous tangen

Output Entities

Selected boundaries

Mesh Selection

Adaptation



# Second stage: Automation of Quench Simulations & Upgrade COMSOL version

- Only COMSOL 5.3a version supported (2017)
  - COMSOL not backward compatible
  - Implement SIGMA support COMSOL 6.0
- Missing features set from input files:
  - Quench initialization
  - Quench heater positions
  - Propagation of settings from steam-sdk for quench simulations
- No automatic execution of simulations



# Execution problem:

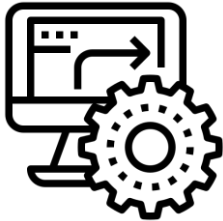
The screenshot displays the COMSOL Multiphysics software interface. On the left is the Model Builder tree, where the 'Cluster Computing' node under 'sol1' is highlighted with a red box. The middle window shows the 'Settings' for 'Cluster Computing', including options for 'Batch Settings' such as 'Number of nodes' (set to 1) and 'Use batch license' (checked). The right window shows a 'Graphics' view of a 2D cross-section of a complex mechanical part, with a coordinate system ranging from -0.7 to 0.5 on the x-axis and -0.5 to 0.5 on the y-axis.

Execution from python possible!

# Second stage: Automation of Quench Simulations & Upgrade COMSOL version

Time spent: 2M

- Only COMSOL 5.3a version supported (2017)
  - COMSOL not backward compatible
- Missing features set from yaml input:
  - Quench initialization
  - Quench heater positions
  - Propagation of settings from steam-sdk for quench simulations
- No automatic execution of simulations
- **Problem: Architecture not in line with other steam-sdk tools**

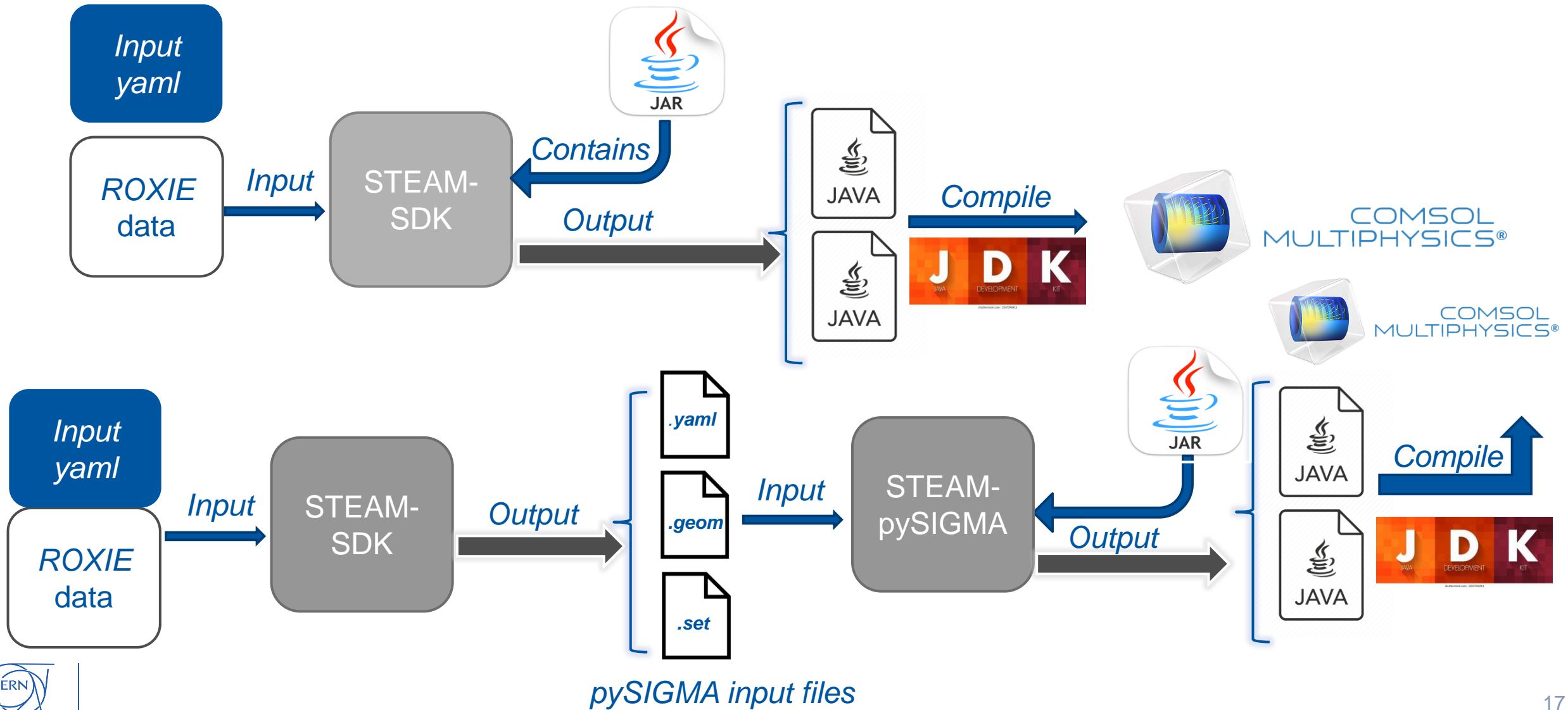


# Stage 3. Update Architecture and Track Performance

- Problem: Architecture not in line with steam-sdk tools
  - Builder\_ 'tool'.py generates input files
  - Not the case for BuilderSIGMA.py

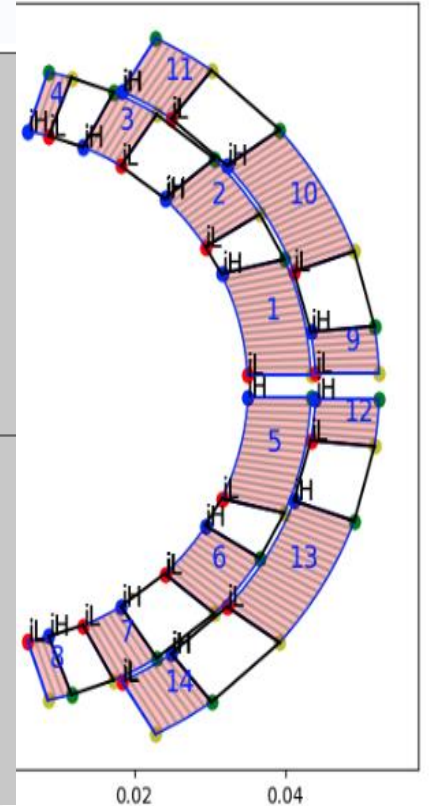
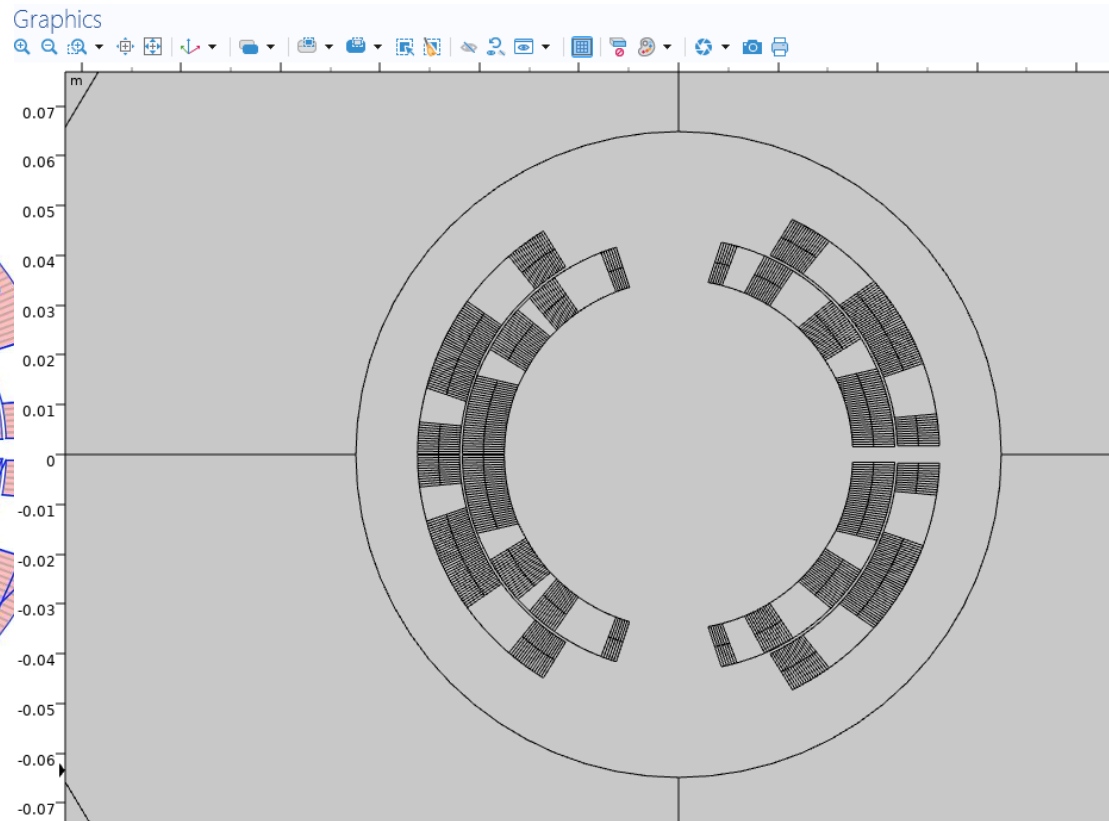
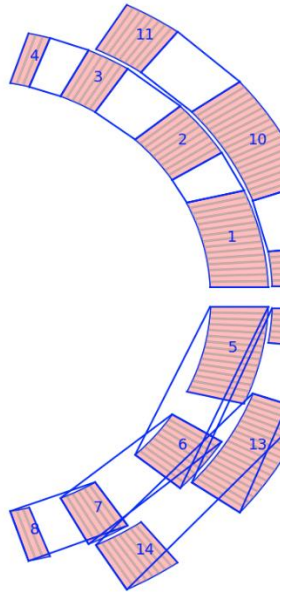
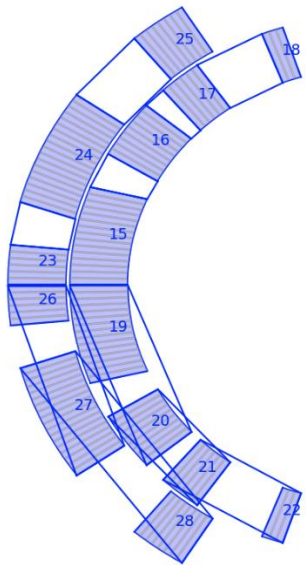


# Change of Architecture



# Benefits of new Architecture

- Example: MED\_C\_COMB magnet
  - Goal: Fix in FiQuS
  - SIGMA, FiQuS share same geom file => SIGMA fixed too!
- Maintainability



# Third Stage. Update Architecture and Track Performance

Time spent: 1-2M

- Problem: Architecture not in line with steam-sdk tools
  - Builder\_ 'tool'.py generates input files
  - Not the case for BuilderSIGMA.py
- Analysis file to run through magnet library
  - Which magnets work in SIGMA?
  - What error to Roxie?

# WIP: SIGMA status sheet

| Magnet name    | Work for COMSOL 5.3a and 6.0 | Stationary work | Transient work                  | Bmod_difference_max stationary (T) | Comment                      |
|----------------|------------------------------|-----------------|---------------------------------|------------------------------------|------------------------------|
| MB_2COILS      | Yes                          | Yes             | Yes                             | 0.49041654                         |                              |
| MBH_1in1       | Yes                          | Yes             | Yes                             | 0.346706827                        |                              |
| MBH_2in1       |                              |                 |                                 | 0.4                                |                              |
| MBRB           | Yes                          | Yes             | Yes                             | 0.8                                |                              |
| MBRC           | Yes                          | Yes             | Yes                             | 0.6872                             |                              |
| MBRD           | Yes                          | Yes             | Yes                             | 0.338124228                        |                              |
| MBRS           | Yes                          | Yes             | Not for 5.3a with default input | 0.630181906                        |                              |
| MBX            | Yes                          | Yes             | Not for 5.3a with default input | 0.693816773                        |                              |
| MBXF           | Yes                          | Yes             | Yes                             | 0.426043698                        |                              |
| MQY_2in1       | Yes                          | Yes             | Yes                             | 1.12656387                         | High field difference        |
| MQ_1AP         | Yes                          | Yes             | Yes                             | 0.805922383                        |                              |
| MQML_2in1      | Yes                          | Yes             | Not with default input          | 0.26578566                         |                              |
| MQMC_2in1      | Yes                          | Yes             | Not with default input          | 0.26578566                         |                              |
| RMM_V1         | Yes                          | Yes             | Yes                             | 0.304899581                        |                              |
| MCO            | Yes                          | Yes             | Yes                             | 0.149070424                        |                              |
| MED_C_COMB     | Yes                          | Yes             | Yes                             | 0.083625566                        |                              |
| MQXB           | Yes                          | Yes             | No convergence 6.0              | 0.410811943                        |                              |
| MQXA           | Yes                          | Yes             | Yes                             | 0.263152777                        |                              |
| MQXF_V2        | Yes                          | Yes             | Yes                             | 0.49051579                         |                              |
| ERMC_V1        | Yes                          | Yes             | Yes                             | 0.471448028                        |                              |
| MCBXFH         | Yes                          | Yes             | Yes                             | 0.6                                | High field difference        |
| MQM_2in1       | Yes                          | Yes             | Not for 5.3a with default input | 3.007019248                        | High field difference        |
| HEPDipo_4COILS | Only 6.0                     |                 |                                 | 2.642629678                        | High field difference        |
| FERMI_20T_5    |                              |                 |                                 | 90T                                | High field difference        |
| MO_1AP         |                              |                 |                                 |                                    |                              |
| MO             |                              |                 |                                 |                                    | Fix mesh tolerance           |
| MCDO           |                              |                 |                                 |                                    | Fix mesh tolerance           |
| MQT_1AP        |                              |                 |                                 |                                    |                              |
| MQTLH_1AP      |                              |                 |                                 |                                    |                              |
| MQTLI_1AP      |                              |                 |                                 |                                    |                              |
| MQS_1AP        |                              |                 |                                 |                                    |                              |
| MBRD_short     |                              |                 |                                 |                                    | Fix iron as for MBRD         |
| MCBH_1AP       |                              |                 |                                 |                                    | data file naming error       |
| MCD            |                              |                 |                                 |                                    | Geom error debug parserRoxie |
| MCS            |                              |                 |                                 |                                    | Ribbon cable not supported   |
| MCBX_HV        |                              |                 |                                 |                                    | Ribbon cable not supported   |
| MCBXH          |                              |                 |                                 |                                    | Ribbon cable not supported   |
| MCBXV          |                              |                 |                                 |                                    | Ribbon cable not supported   |
| MCBYH_1AP      |                              |                 |                                 |                                    | Ribbon cable not supported   |

# Lessons learned and future of SIGMA

- Providing a simple interactive model in COMSOL
  - Many applied physicists already know how to use COMSOL
  - Edit geometry, mesh, QH and materials within COMSOL
- SIGMA use-cases:
  - Starting point with correct geometry of accelerator magnet in COMSOL:
    - Magnetostatic
    - Transient
  - Possibility to extend model within COMSOL limitations using GUI or API
- No SIGMA use-cases:
  - Heat propagation between layers manual operation in COMSOL GUI - Optimizing certain params not feasible
  - Large models (Ribbon) and computationally heavy simulations
- **Workflow makes SIGMA development slow – No possibility of debugging from Python**

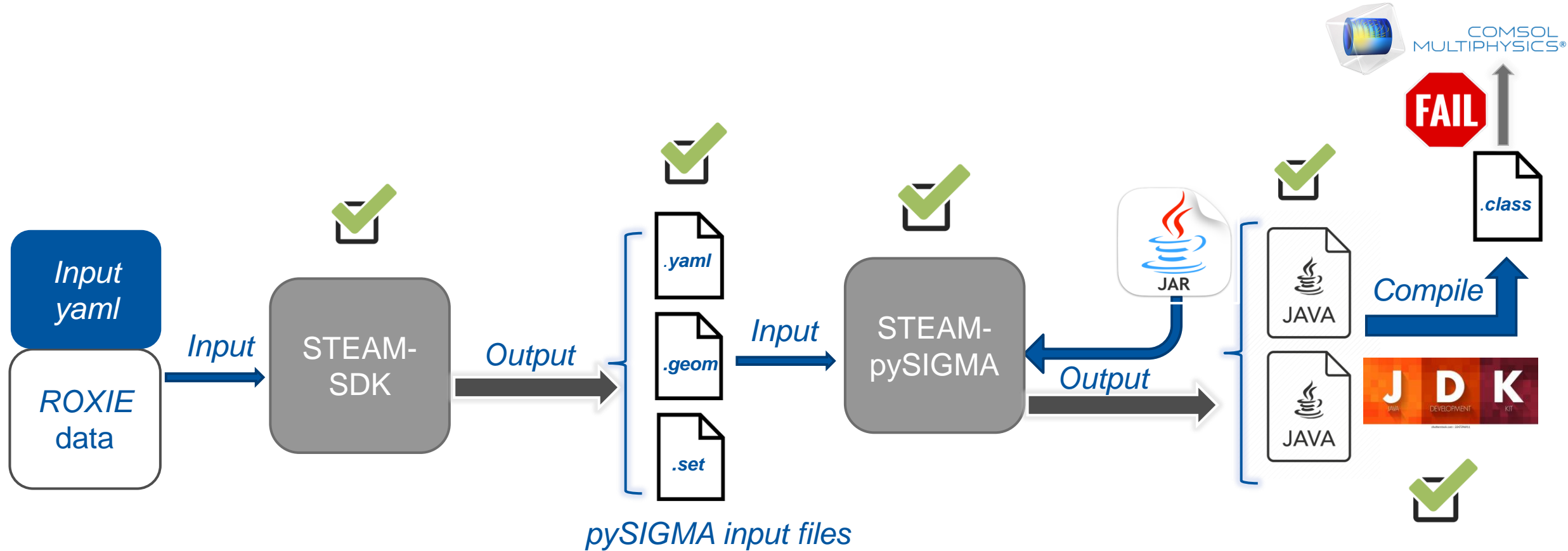
# Example

```
modelData_MQXA.yaml
673 voltageToGroundOutputSelection: null
674 plots:
675   withPlots: null
676   plotPauseTime: null
677 Options_SIGMA:
678   time_vector_solution:
679     time_step: [[0.0, 0.001, 0.05], [0.05, 0.01, 0.25]]
680 simulation:
681   generate_study: true
682   study_type: Transient
683   make_batch_mode_executable: true
684   nbr_elements_mesh_width: 4
685   nbr_elements_mesh_height: 1
686 physics:
687   FLAG_M_pers: 0
688   FLAG_ifcc: 0
689   FLAG_iscc_crossover: 0
690   FLAG_iscc_adjw: 0
691   FLAG_iscc_adjn: 0
692   tauCC_PE: null
693 quench_initialization:
694   PARAM_time_quench: null
695   FLAG_quench_all: 0
696   FLAG_quench_off: 0
697   num_qh_div: [10, 10, 10, 10, 10, 10, 10, 10]
698   quench_init_heat: 500000.0
699   quench_init_HT: [CO_P0_W0_B0_HT0]
700   quench_stop_temp: 10.0
701 postprocessing: <3 keys>
702 quench_heaters:
703   quench_heater_positions: [[4878, 4880, 4882, 4884, 4886, 4888, 4890,
704     th_coils: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
```

Thickness of QH insulation to the coil



# 10 Minutes to find Input problem!

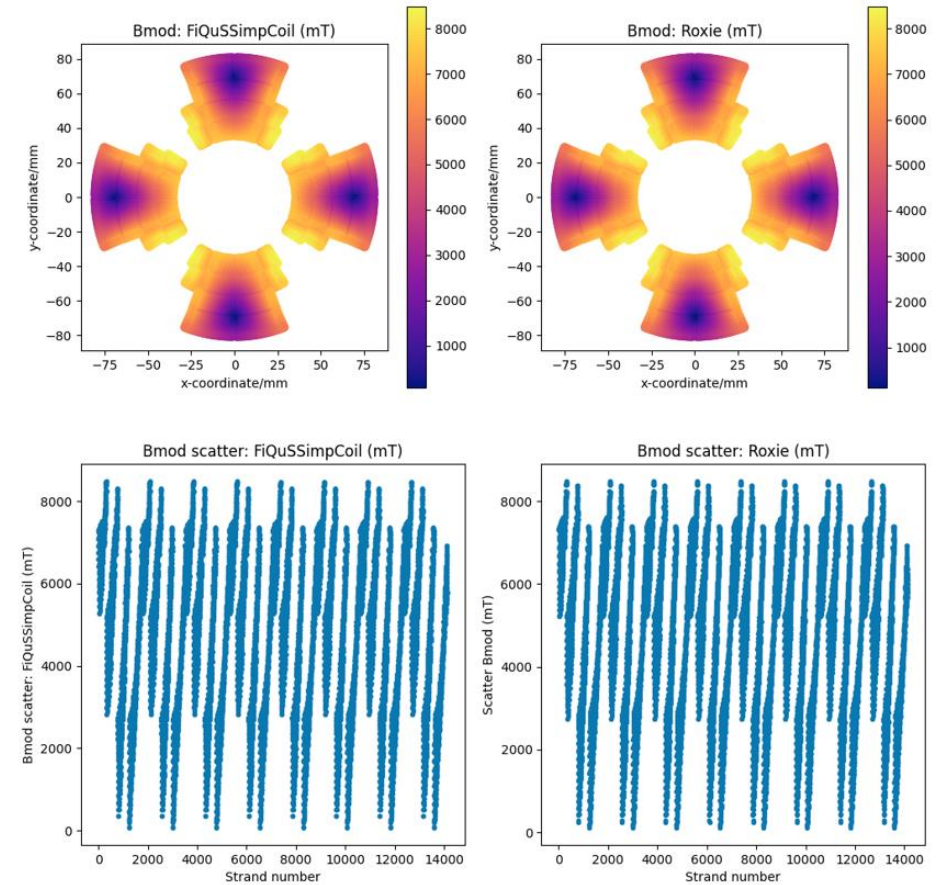


# Additional Work

- SIGMA evaluation report:
  - Explaining errors in SIGMA compared to Roxie
- 2D plotter tools in steam\_sdk
- FiQuS and SIGMA analysis files



Bmod: FiQuSSimpCoil and Roxie (mT)

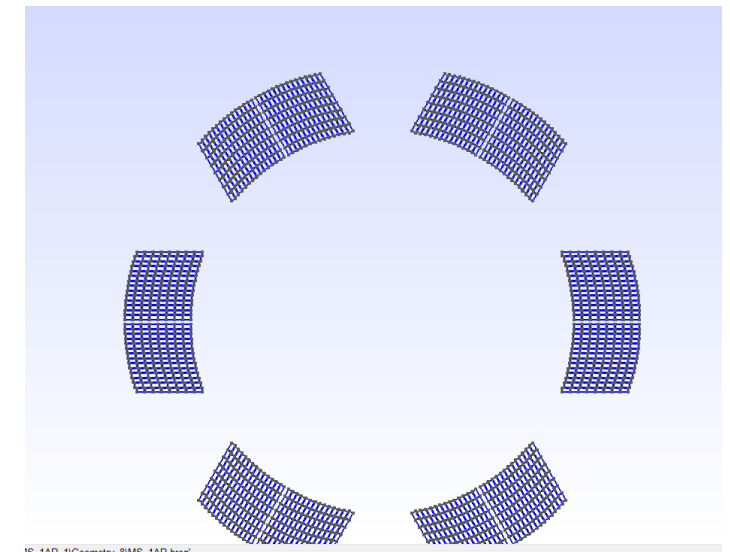
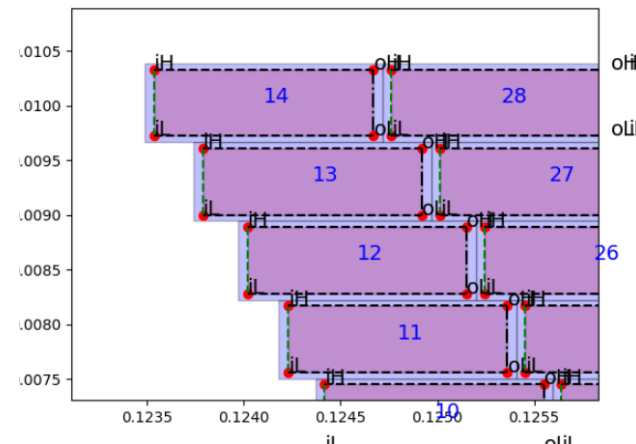
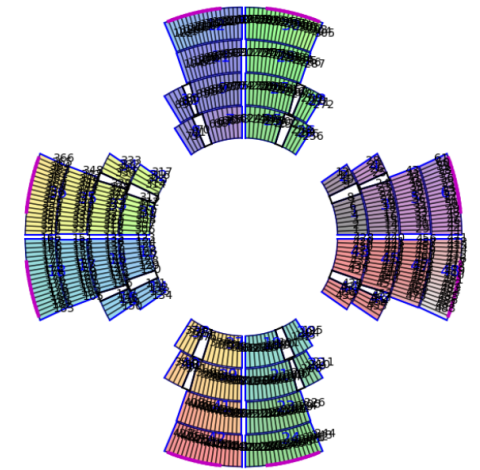
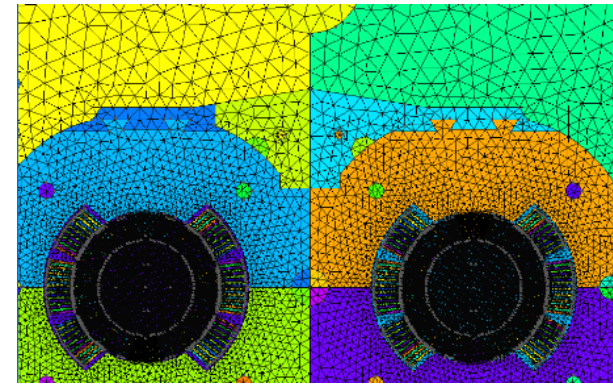




# Additional Work

Time spent 3M

- FiQuS development:
  - Increase robustness, meshing, visualization tools
  - Ribbon cable implementation for FiQuS
- Robustness in ParserRoxie e.g support asymmetric coils (FiQuS and SIGMA)



# Thank you for your attention!

Special thanks: Andrea Vitrano and Mariusz Wozniak  
&  
Entire steam-team for a great year at CERN!

# Links to SIGMA related repositories

- pySIGMA: [https://gitlab.cern.ch/steam/steam\\_pysigma](https://gitlab.cern.ch/steam/steam_pysigma)
- SIGMA: <https://gitlab.cern.ch/steam/steam-sigma>
- STEAM-SDK: [https://gitlab.cern.ch/steam/steam\\_sdk](https://gitlab.cern.ch/steam/steam_sdk)

# Questions?