GRAAL meeting: MINERVA RF/Cryo modelling for C&C optimization studies

ACCELERATORS AND CRYOGENIC SYSTEMS

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C. LHOMME

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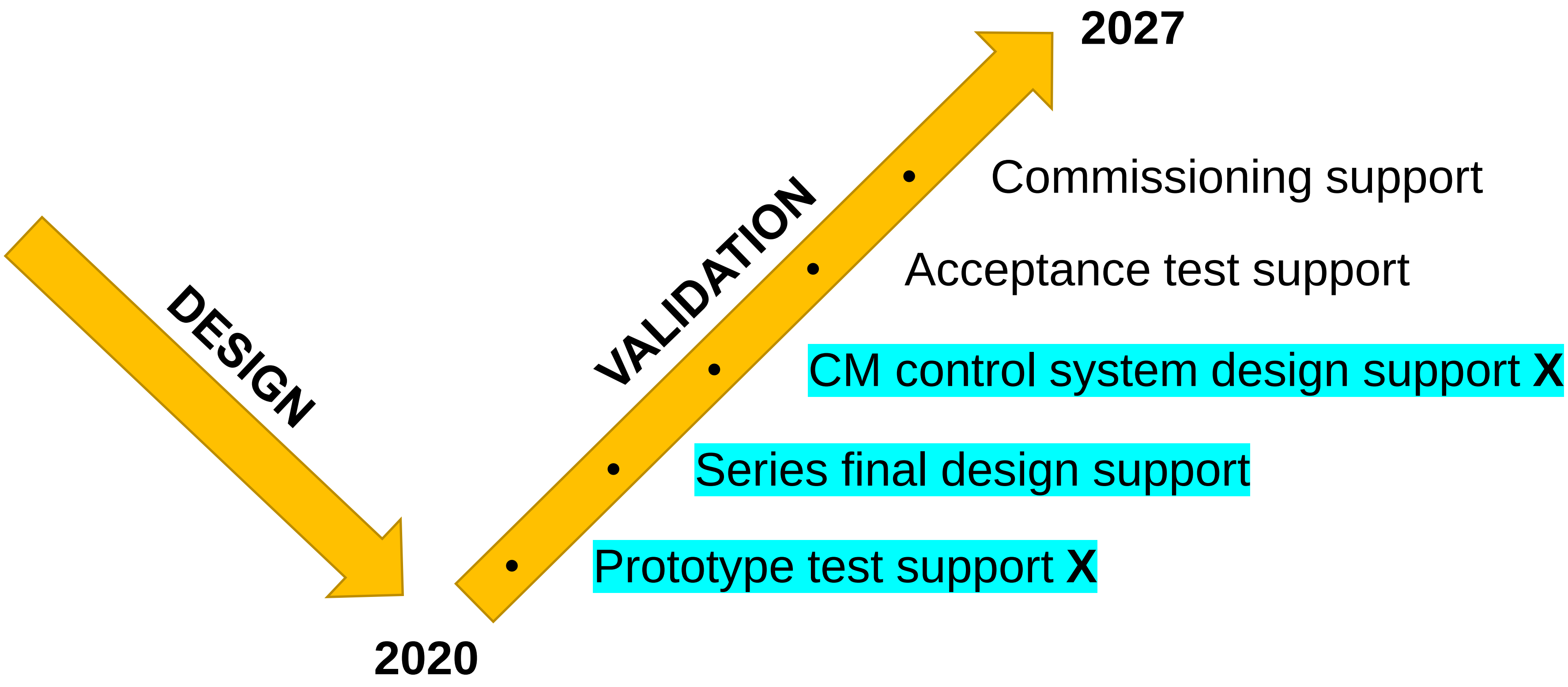
Outline

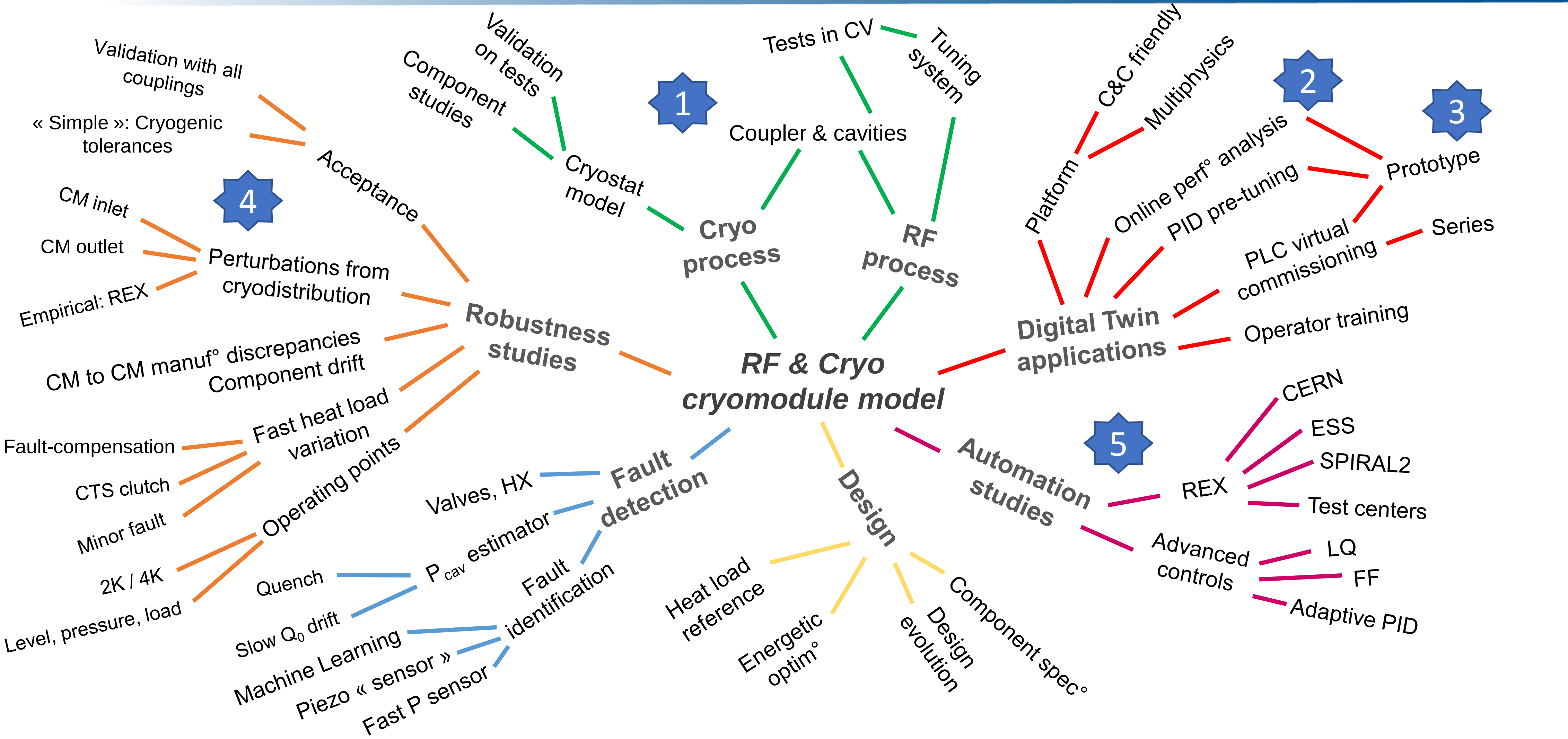
- Application of the model by project phase
- Brainstorming results
- On-going C&C-oriented studies → 5 illustrations

Application by project phase



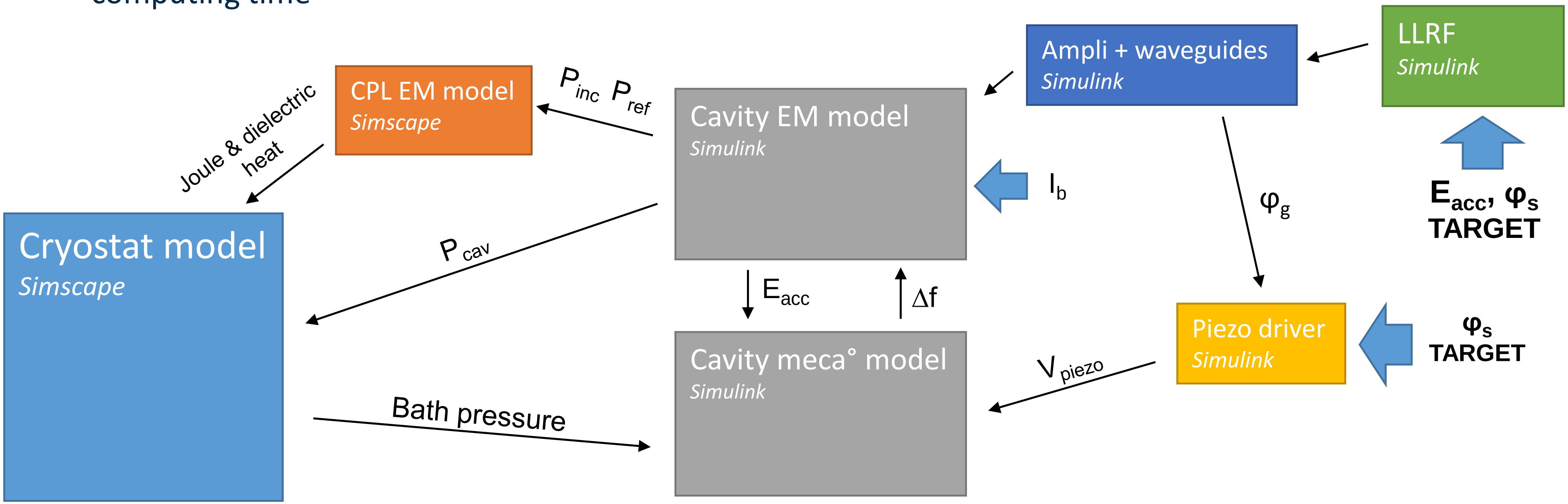
→ **Need for a model which follows the project cycle**

Brainstorming result = an organized mess !



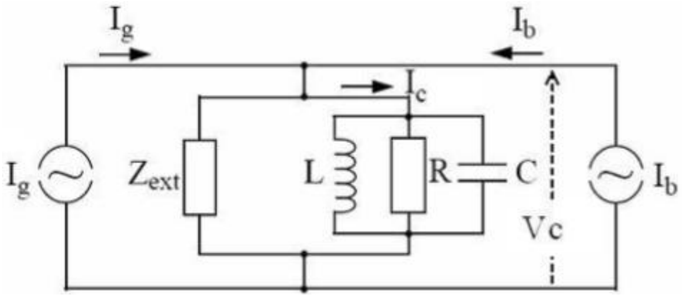
1. Coupling together RF and cryo models

- RF and cryo strongly coupled → **modelling them together is necessary** to check the "cohabitation" !
- But those processes have **much different characteristic times** → find a way to save computing time



1. Implementation of RF models

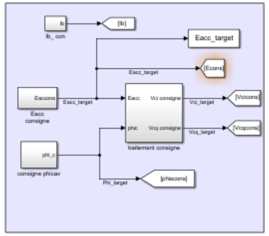
- Simulink models of the cavity (same than FPGA HIL studies)
  - Cavity envelope equation
  - Closed loop on E_{acc} and φ_s
  - Outputs P_{cav} / P_{inc} / P_{ref} / φ_g
  - As a function of Δf, Q_0, E_{acc}, φ_s

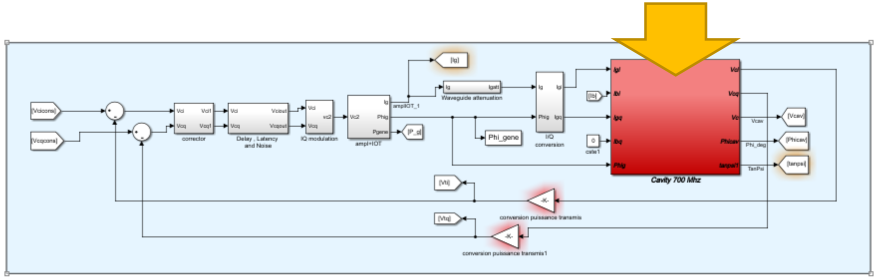


$$\frac{d^2V_c}{dt^2} + 2\omega_{1/2}\frac{dV_c}{dt} + \omega_0^2 V_c = 2\omega_{1/2}R_L\frac{dI}{dt}$$

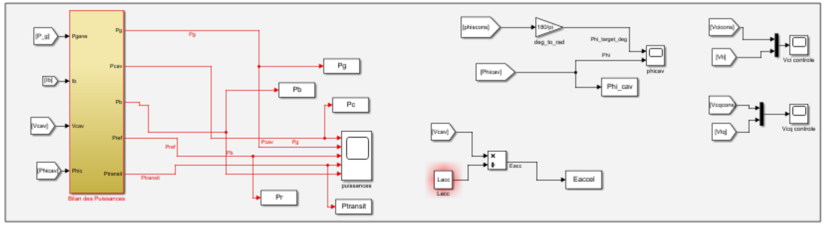
Cavity baseband equation: $$\frac{d\vec{V}_c}{dt} + (\omega_{1/2} - j\Delta\omega)\vec{V}_c = \omega_{1/2}R_L\vec{I}$$

- Detuning models
  - Piezo and motor tuner $\Delta f = f$ (command)
  - He bath pressure: $\Delta f = f(P)$
  - Lorenz force: $\Delta f = f(E_{acc})$
  - Piezo dynamic TF





- As usual, crucial to **model** the feedback loop I/O with the **physical** attenuations and phase shifts
  - The transmitted signals from the cavity (Vti, Vtq)
  - The cavity detuning error $(\varphi_g - \varphi_s)$

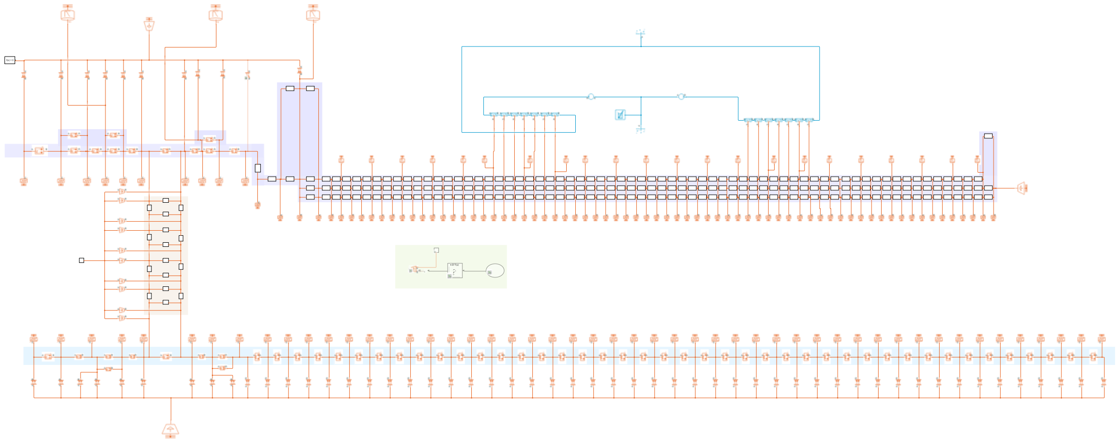


***LLRF Lecture Part 3.1 S. Simrock, Z. Geng - ITER / PSI**

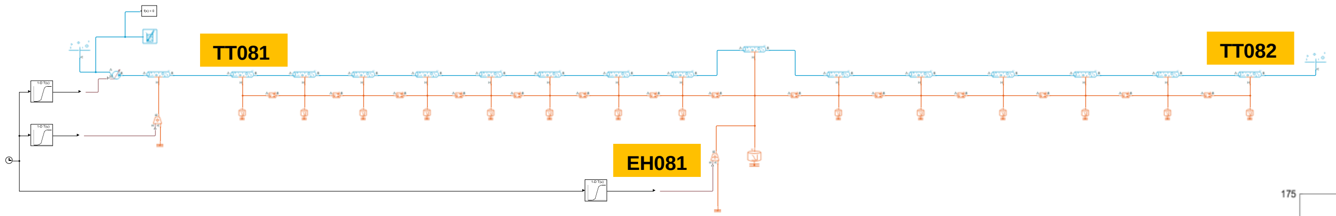
**** Thesis F. Bouly 2011***

1. Implementation of RF models

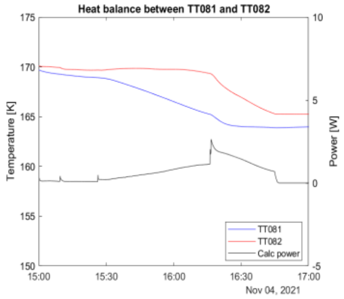
- **Joules & dielectric** heat loads calculated from:
  - RF field imported from EM code (CST, HFSS)
  - Material electrical properties = f(T)
- To do
  - Implement a simple RF field model to cover all cases without an EM code
  - As a function of P_{inc}, P_{ref} from the cavity model

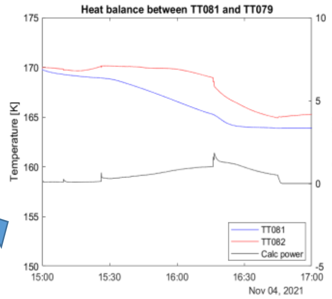


2. Support to prototyping phases

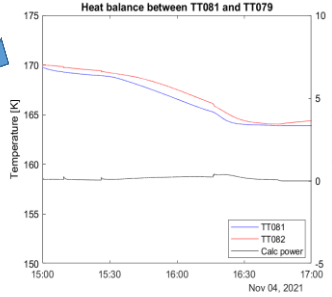


Experiment





Model
→ heaters ON

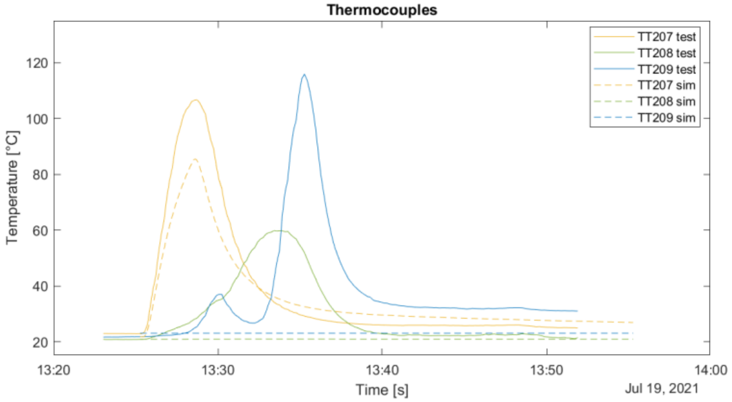


Model
→ heaters OFF

Mock-up coupler heat load measurement calibration
→ unsteady heat balance analysis

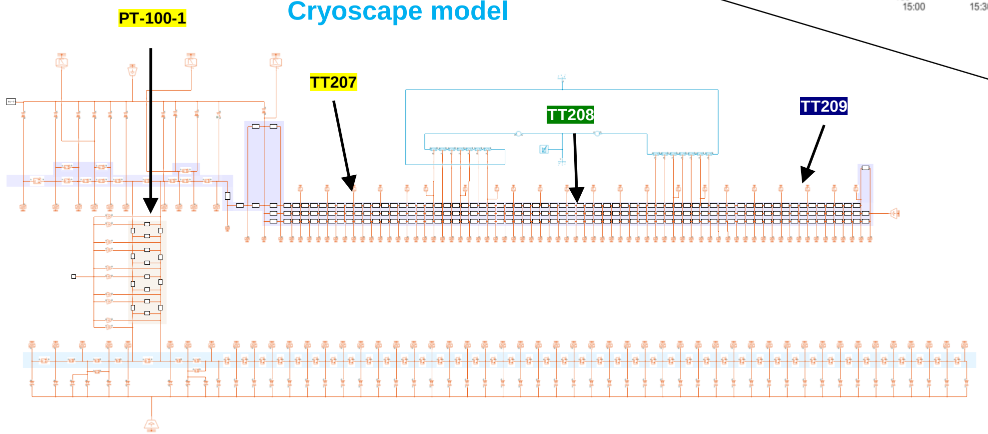
Coupler conditioning
multipacting heat load simulations

Cross-check with CST / SPARK 3D



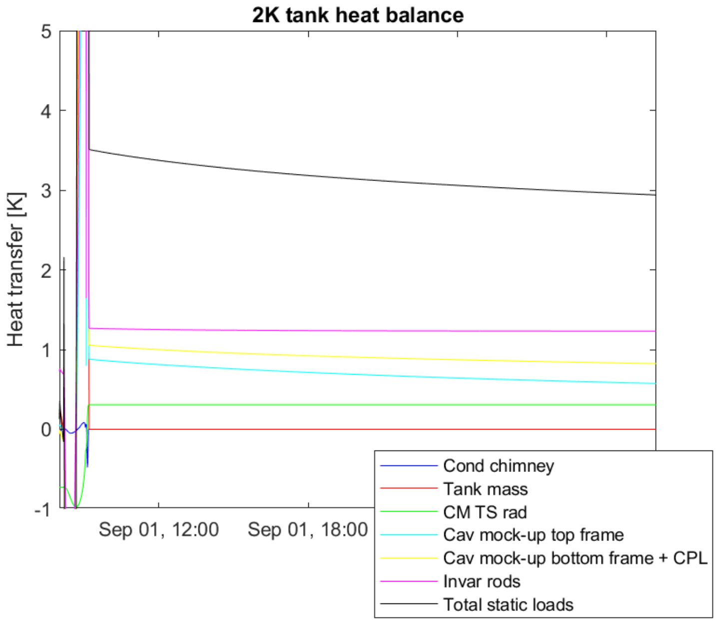
Coupler tube temperatures: test VS Cryoscape

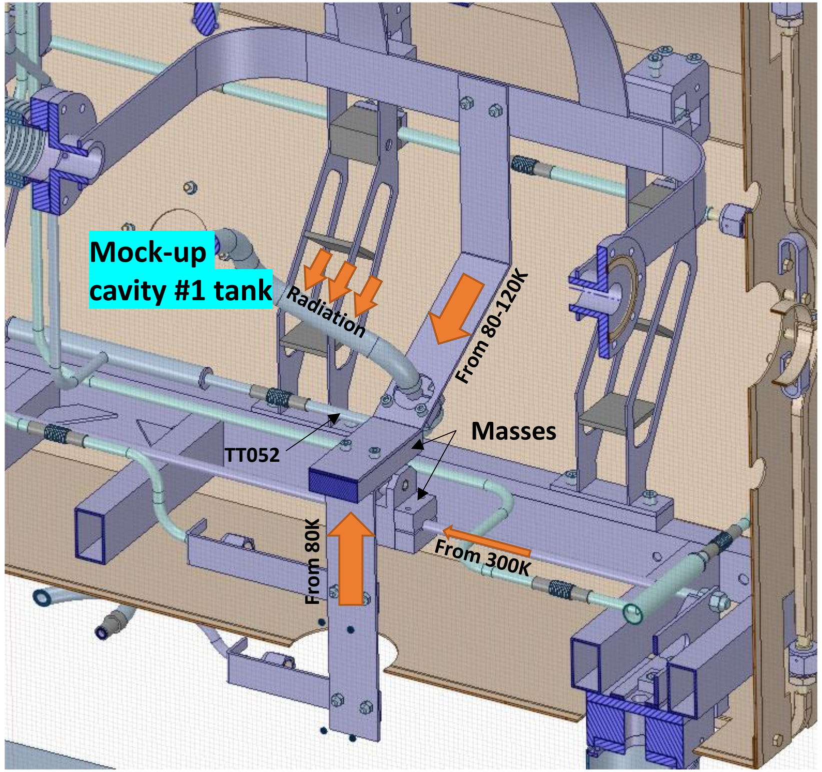
Cryoscape model



2. Support to prototyping phases

- ***testQVB & QM heat load analysis***
- ***Pointing out the need for additional instrumentation***





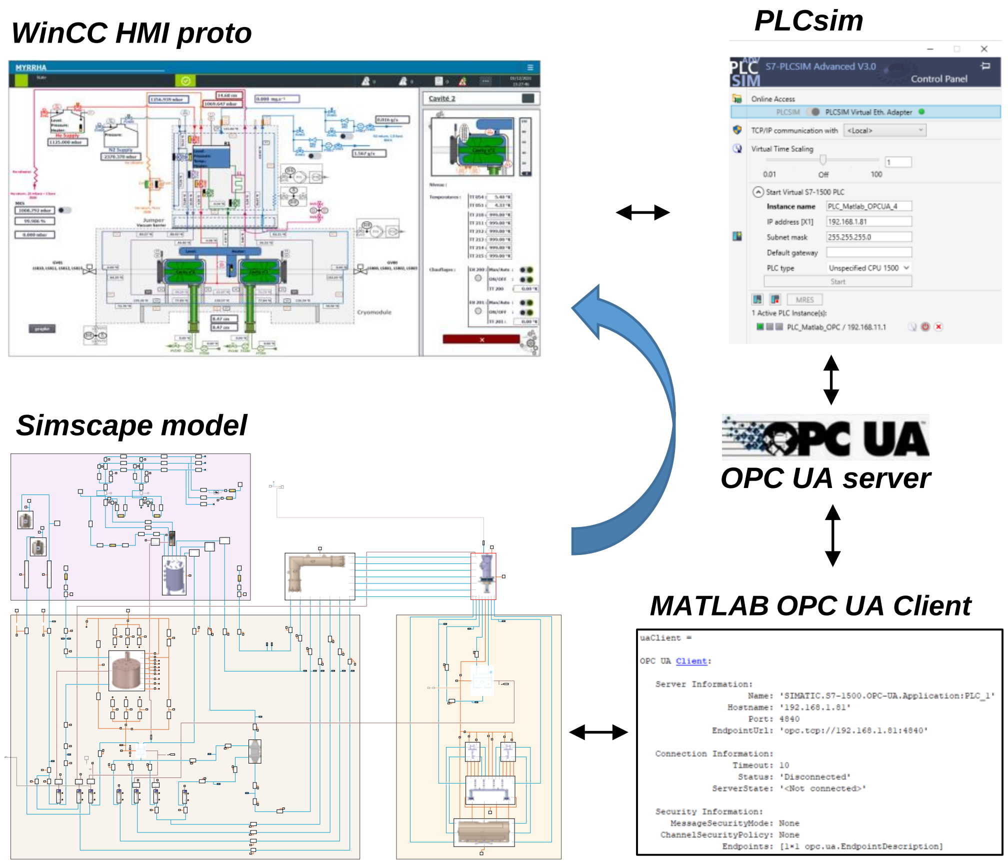
3. Digital Twin supporting the prototyping PLC code dvpt

- Main problem
  - The PLC code developer needs the process hardware asap for debugging
    - ***Sequence virtual commissioning***
    - HMI development
    - PID tuning
  - Idea: the model is connected to the PLC and mimics the process

- **Step 1,** done on the prototype in CD
  - PID gain pre-tuned on Simscape and used as start values in TIA Portal
  - Need similar PID controller architecture Model VS TIA Portal

		Simscape pre-tuning		Online tuned	
Actuator	***Sensor***	P	Ti	P	Ti
CV01	LT01	0,1	50	0,5	1
CV04	LT050	0,1	50	0,5	1
CV601	TT620	-0,5	1666	-0,35	3000
CV651	TT651	-0,5	1666	-0,5	1666
CV06	PT01	-120	60	-200	8
MKS	PT50/51	*From MKS conditioner*			

- **Step 2**, on-going
  - Originally, Simscape is controlled by Simulink (sequences and feedback loops) → control from PLC instead
  - Hardware or Software in the loop approach (Real or simulated PLC)
  - Need to run in real time
  - Thorough work to connect all I/O



4. Target for the cryogenic feedback loops

- Context
  - The bibliographic studies and REX points toward cryogenic pressure regulation tolerances about +/- 5 mbar
  - Often **based on what is achievable**, not **what is required**

- Problematic
  - In principle, on MINERVA, the piezo can compensate for 200 mbar pressure deviation → **no stress at all ?**
  - Not safe nor feasible → there should be a tolerance anyway !

  → Suppose that the piezo will not compensate for the pressure oscillations

- Approach
  - Set a criteria on the maximum acceptable cavity detuning
  - Translate it into pressure regulation tolerances

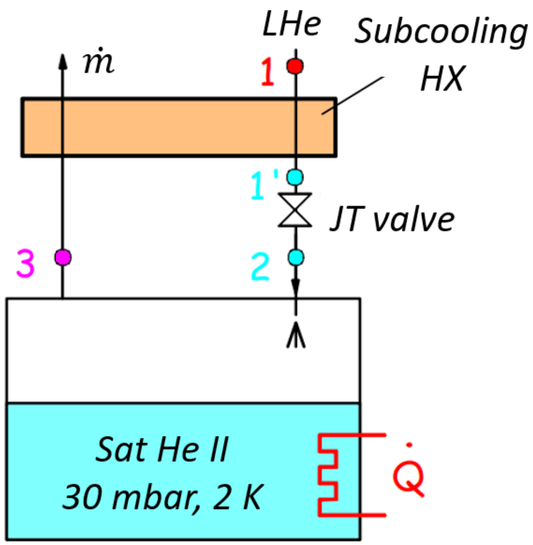
5. Automation studies on pressure and level regulations

- DSBT and GANIL teams demonstrated the advantage of an LQ over a double PID
  - In the context of a 4K LINAC

→ Same conclusion in the case of a 30 mbar bath with an additional process (subcooling + expansion) ?

- Abdelouadoud, preparing the Centrale-Supélec **ATSI Master** is taking the challenge !

- **Good point**: compared to SPIRAL2, these automation studies are starting at an earlier project phase



MOTTO
- Cryogenic availability
- Minimize the calibration work
- Minimize the electrical consumption


Not sure if thank you for your attention
or thank you for not sleeping during the presentation