Development Of Cooling Demonstrator For The CBM Silicon Tracking System (STS)

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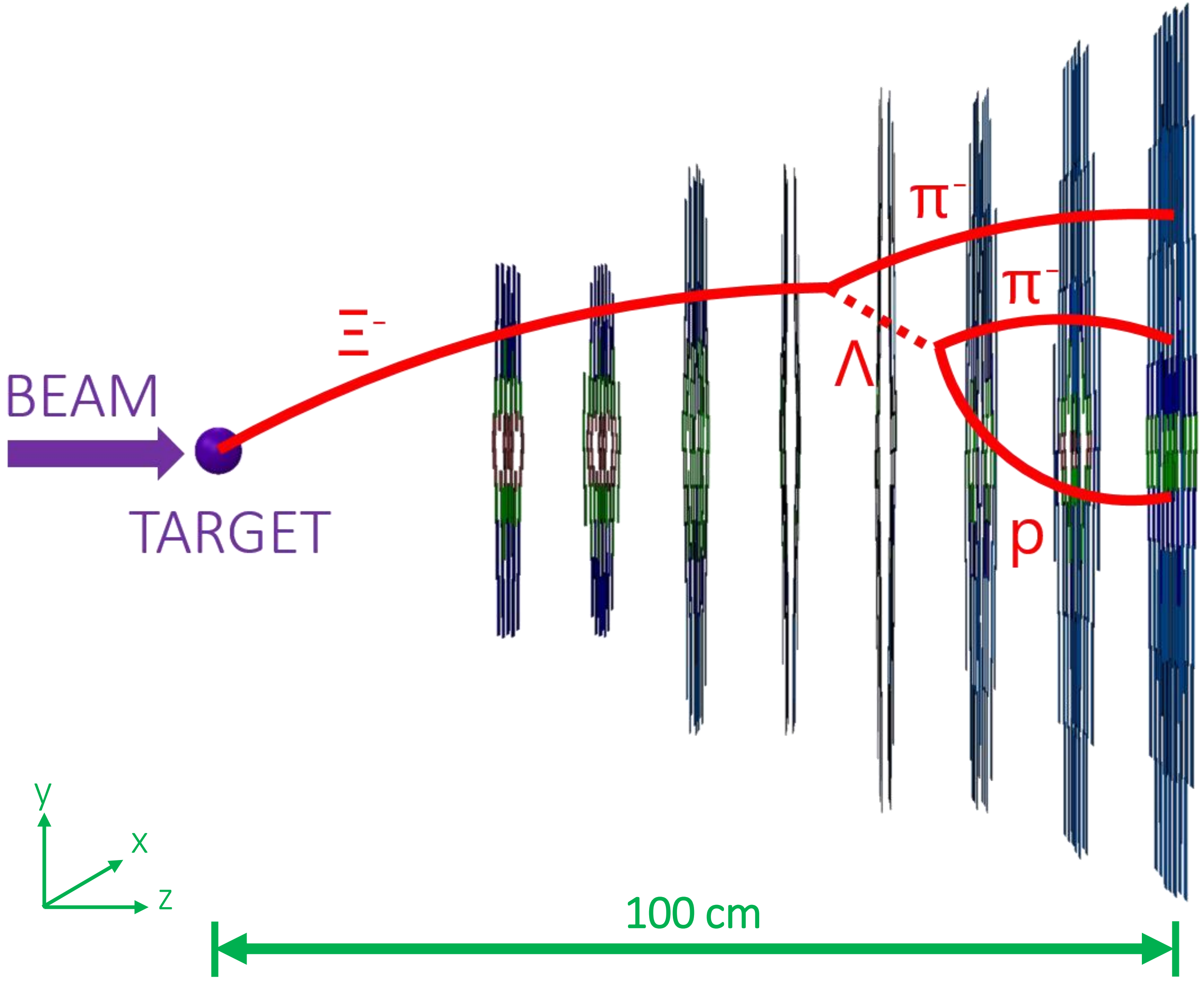
MATHEMATISCH-NATURWISSENSCHAFTLICHE FAKULTÄT
Physikalisches Institut
GSI
CBM
FAIR

Introduction To CBM-STS



STS Features:

- 8 layers → 896 silicon microstrip sensors
- Track Reconstruction, ε ≥ 98%
- Momentum Resolution, Δp/p ≈ 1.5%

Figure: Side-view of STS sensors with artistic illustration of a multi-strange hyperon (Ξ^-) decay in STS

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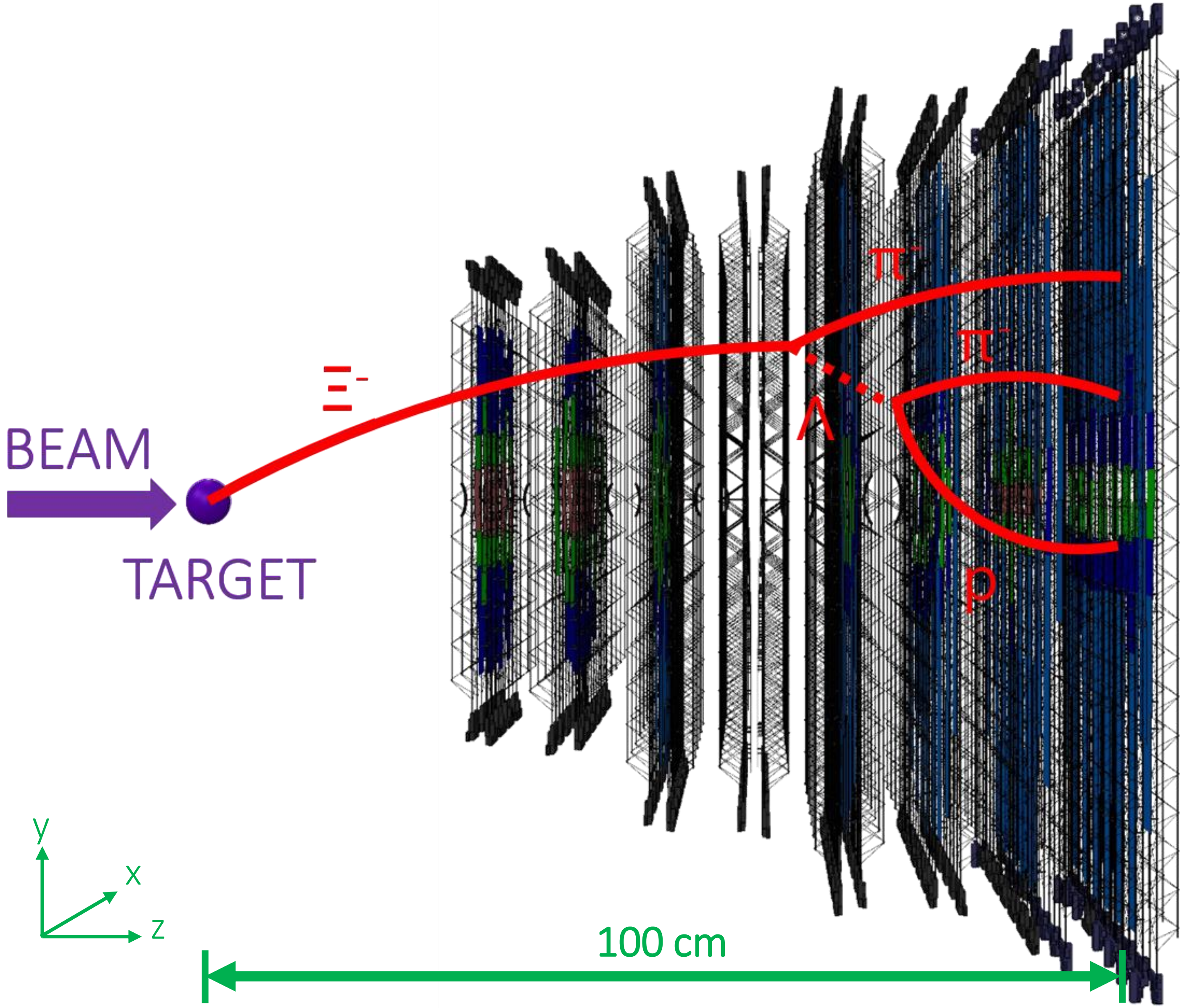

STS Features:

- 8 layers → 896 silicon microstrip sensors
- Track Reconstruction, ε ≥ 98%
- Momentum Resolution, Δp/p ≈ 1.5%

- Material Budget ~ 1.5 % X_0 per layer
- FEE and other detector infrastructure is placed outside detector acceptance
- Sensors connected to the FEE via microcables

Figure: Side-view of STS sensors on ladders with artistic illustration of a multi-strange hyperon (Ξ^-) decay in STS

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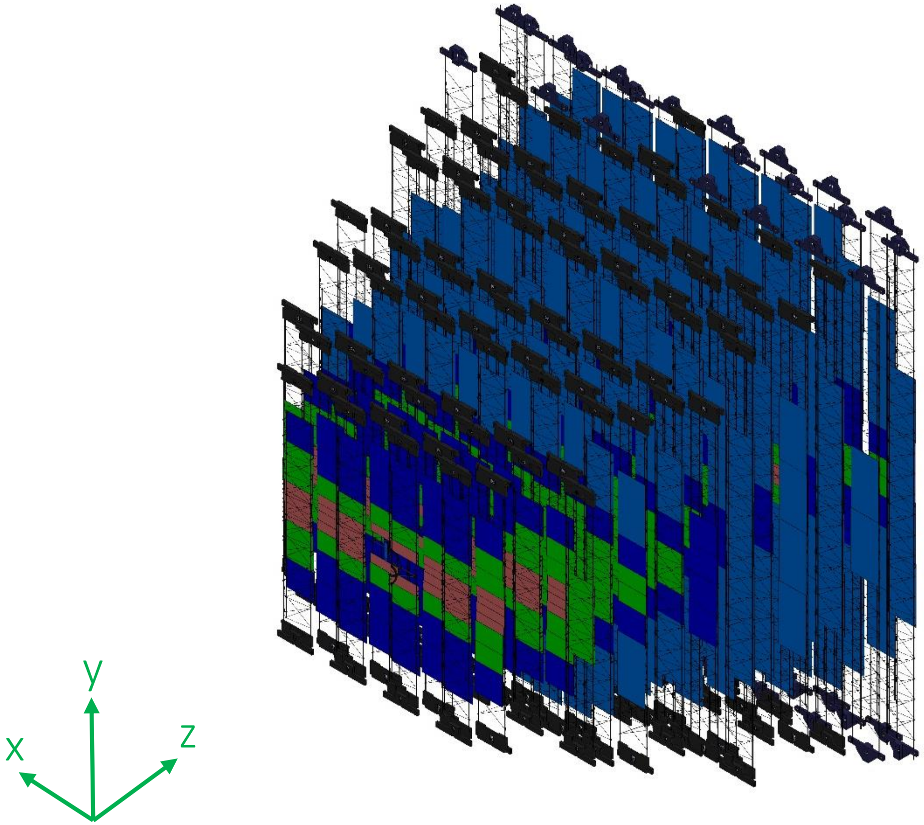


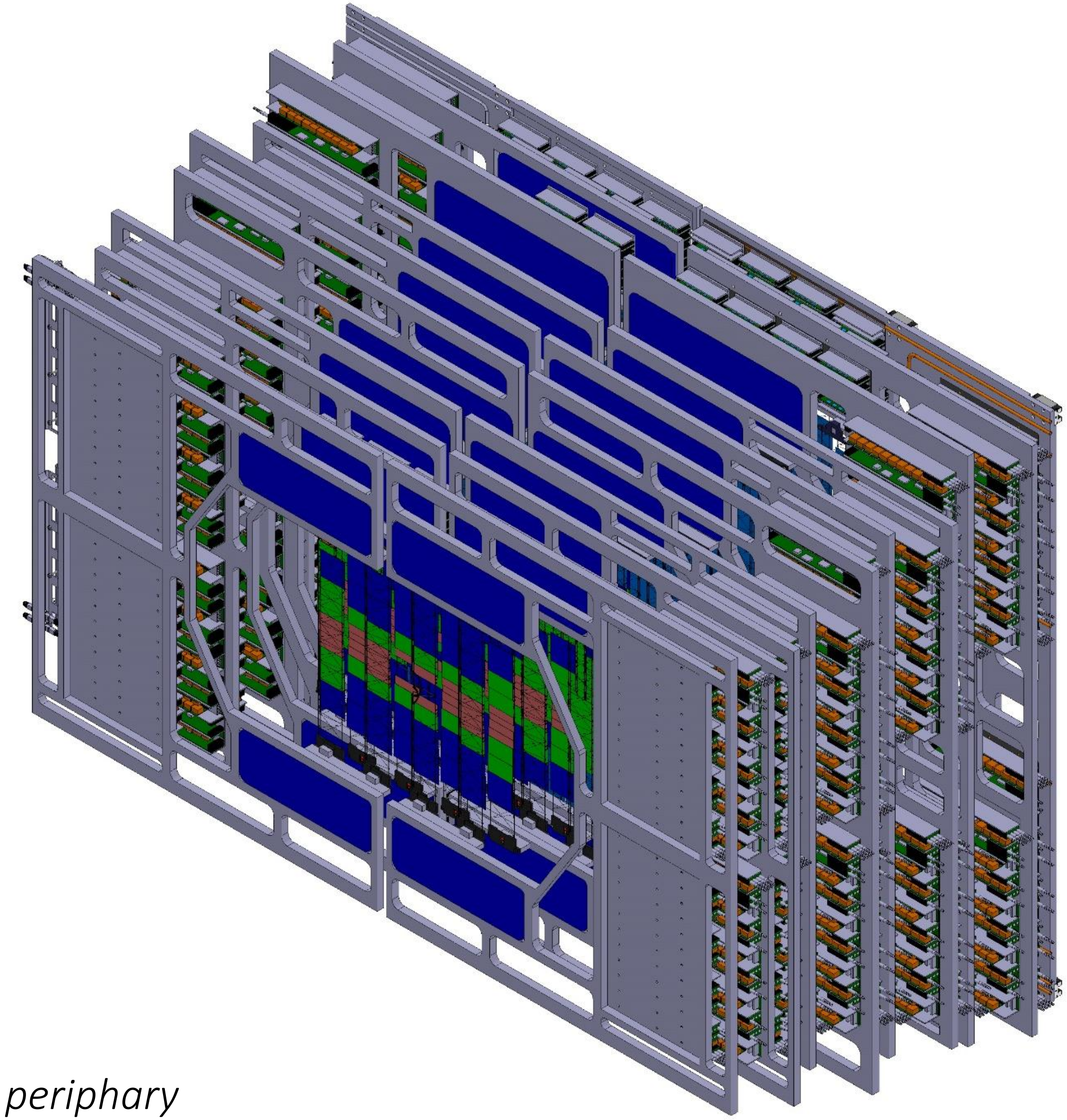


Figure: Isometric-view of STS; Left – Sensors on ladders;
Right – Sensors with relevant infrastructure located at acceptance periphary

(Thermal) Introduction To CBM-STS

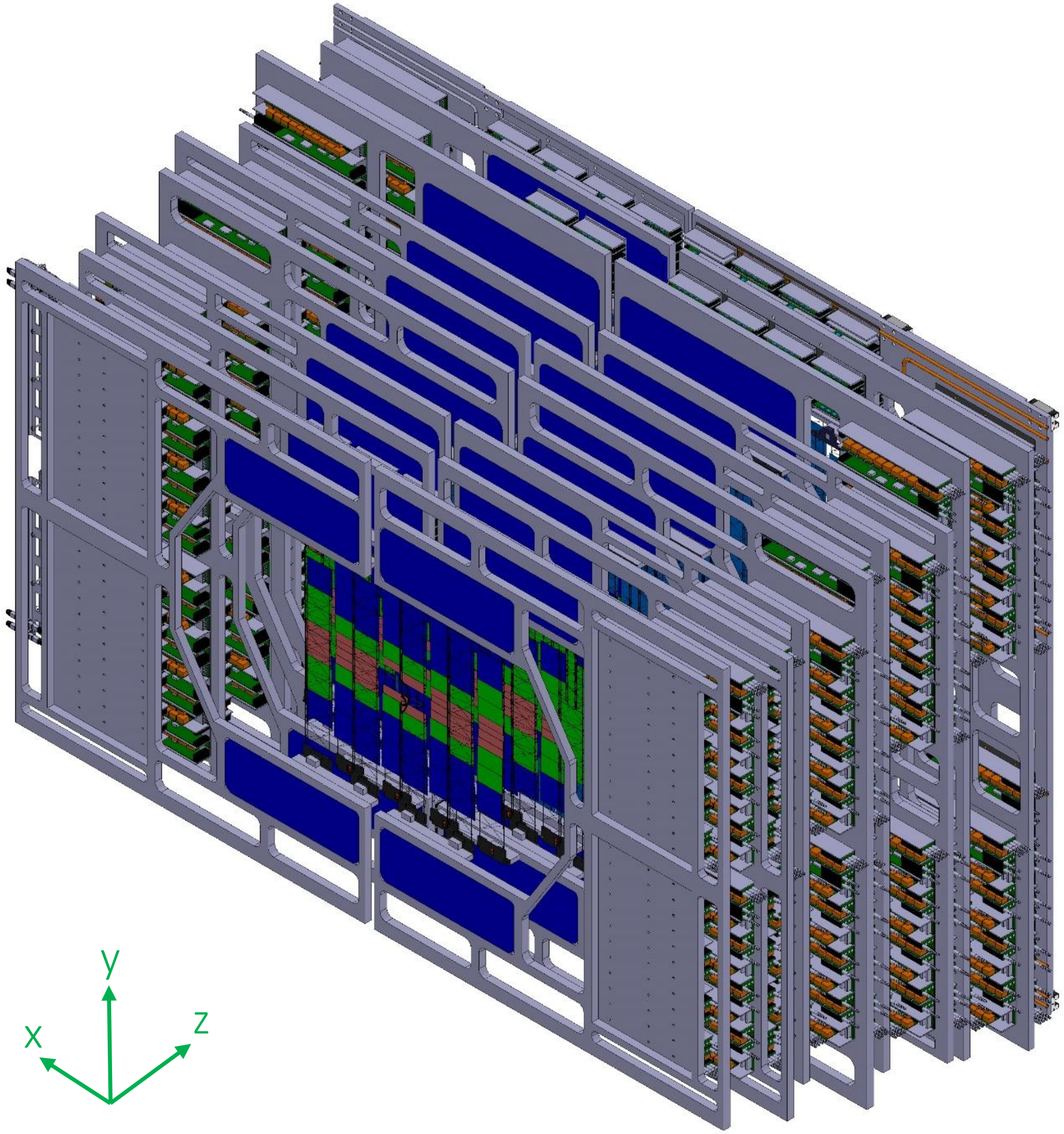
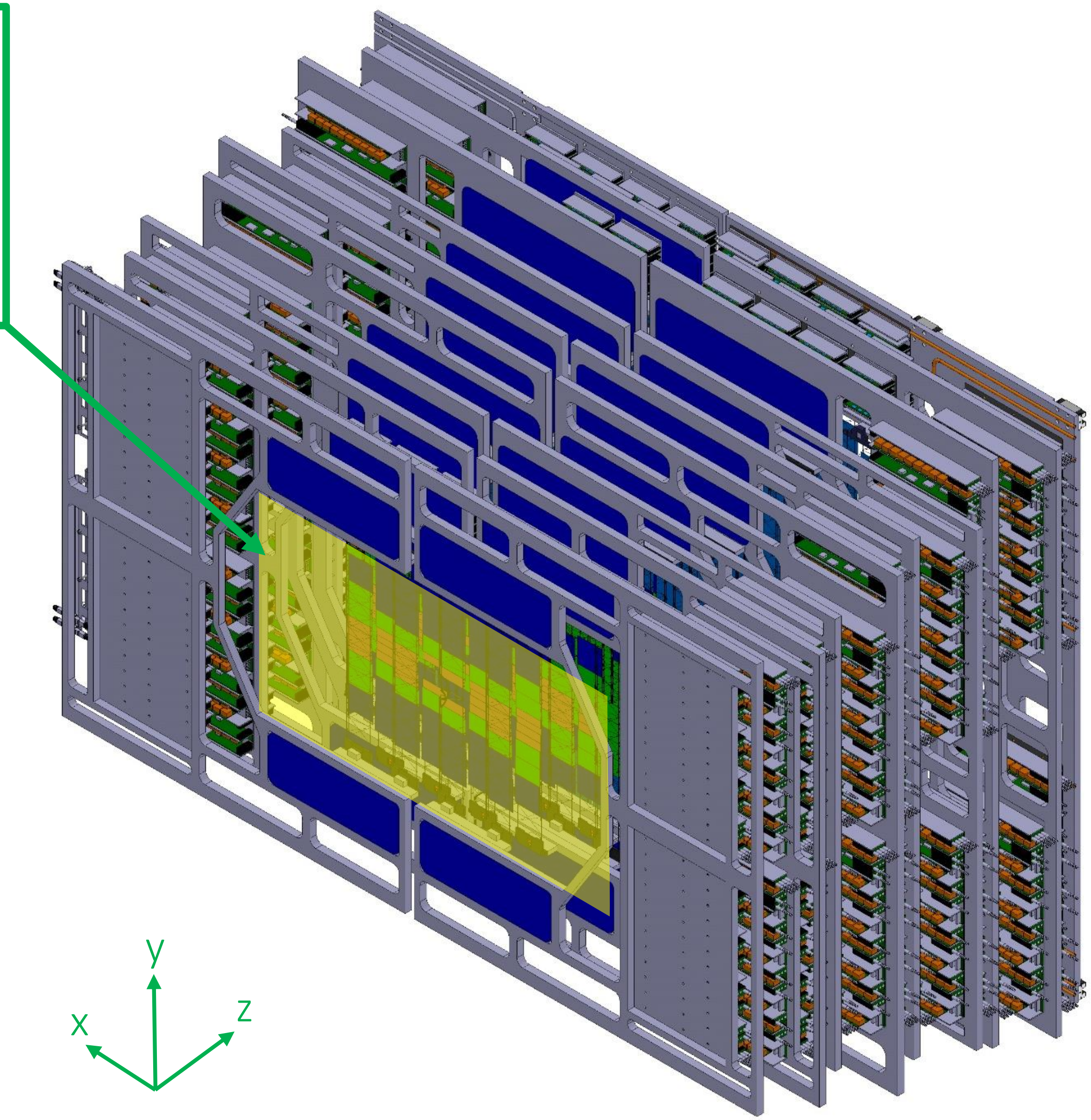


Figure: Isometric-view of STS; Sensors with relevant infrastructure (i.e., FEE, cabling and cooling) located at acceptance periphary

(Thermal) Introduction To CBM-STS

Silicon Sensors:

- Expected power dissipation ~ 6 mW/cm² at -10°C at end-of-lifetime (fluence – 10^{14} n_{eq}(1 MeV)/cm²)
- Target Temp. ≤ -10°C, by min. additional % X_0 per layer
- Forced convective gas cooling



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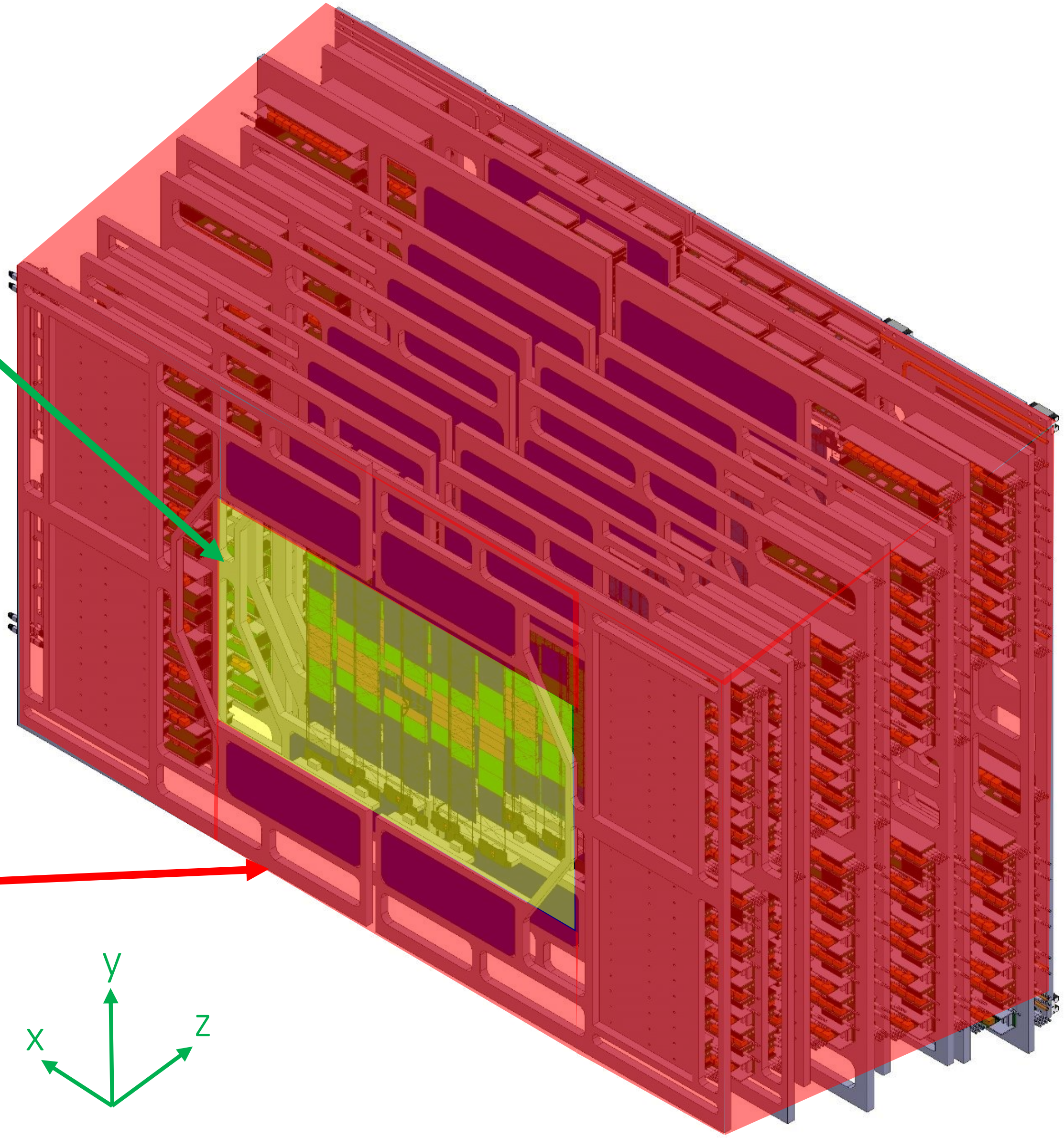
Electronics and Power Cables:

- Expected power dissipation ~ 40kW in < 3.5 m³
- Target Temp. ≤ -10°C, to avoid any heat transfer to silicon sensors (only 10 – 50 cm away)
- Bi-phase CO_2 cooling is the first choice
  - High Volumetric HTC → Smaller tubes
  - GWP = 1 → Longer operational lifetime
  - Radiation hard
- Monophase 3M Novec 649 fluid as a backup



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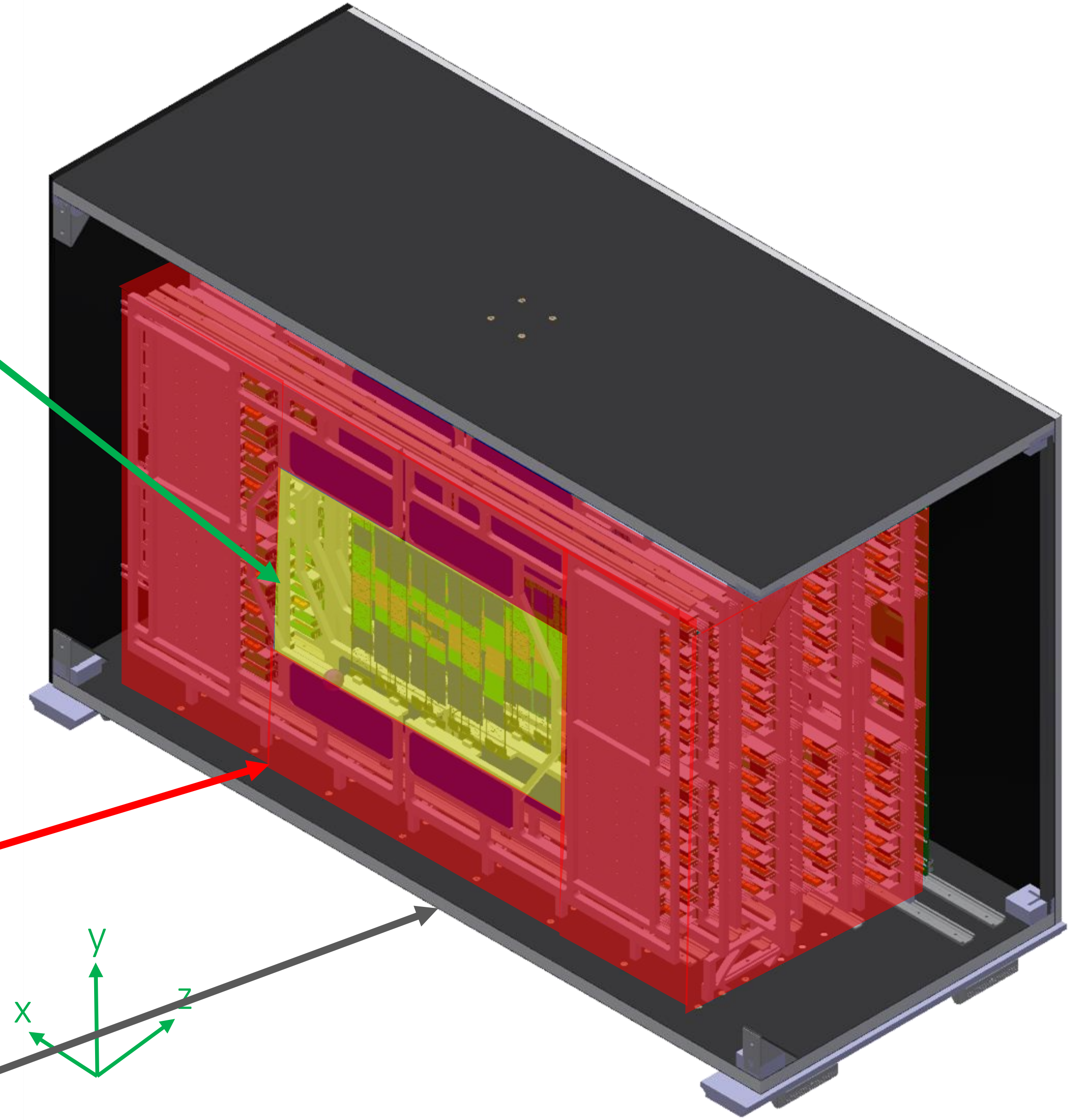
Thermal Enclosure:

- CF sandwiched foam (~ 20 mm) → Structural support
- Thermal and moisture tight (RH < 0.5% at 20°C)



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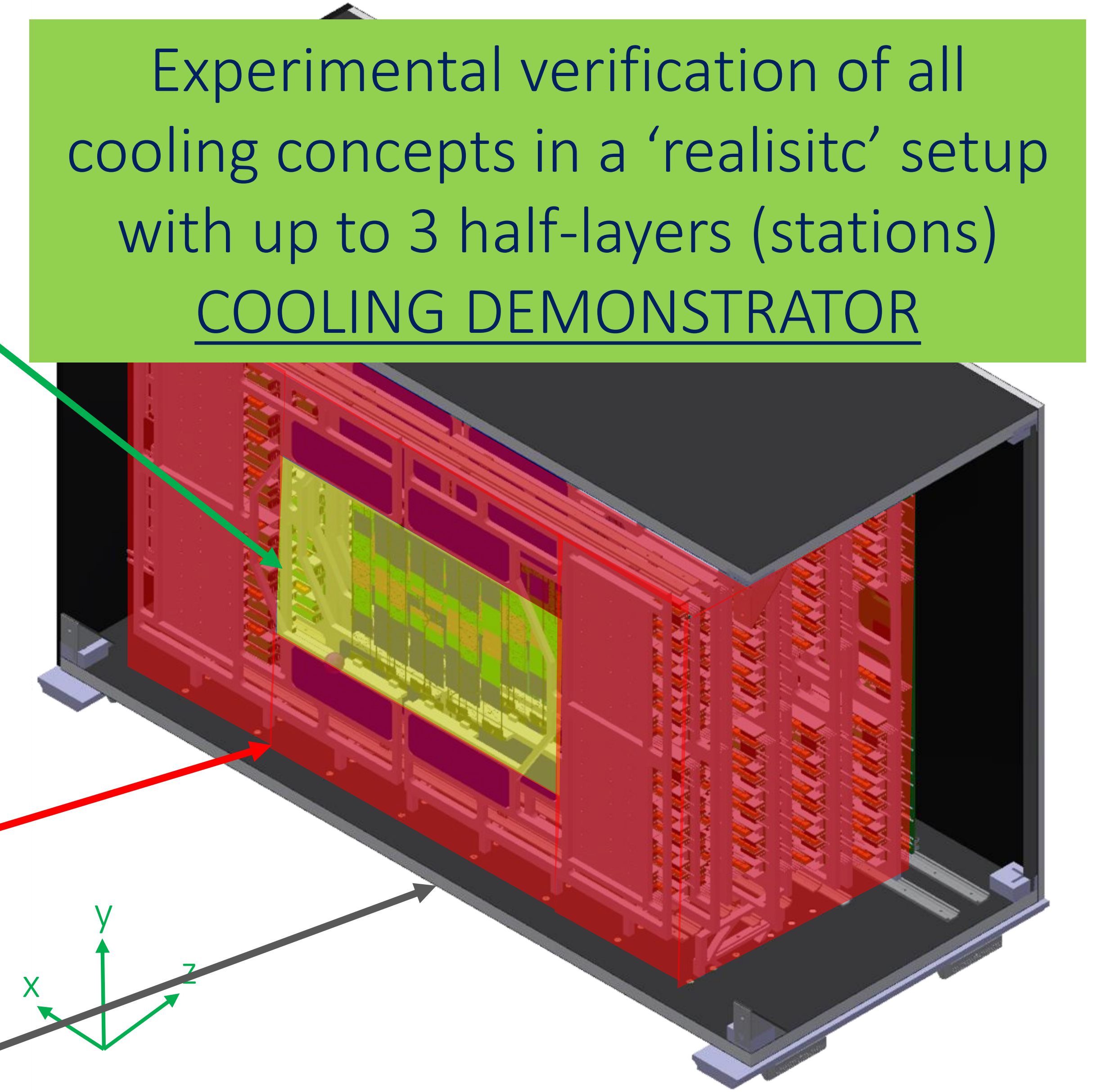
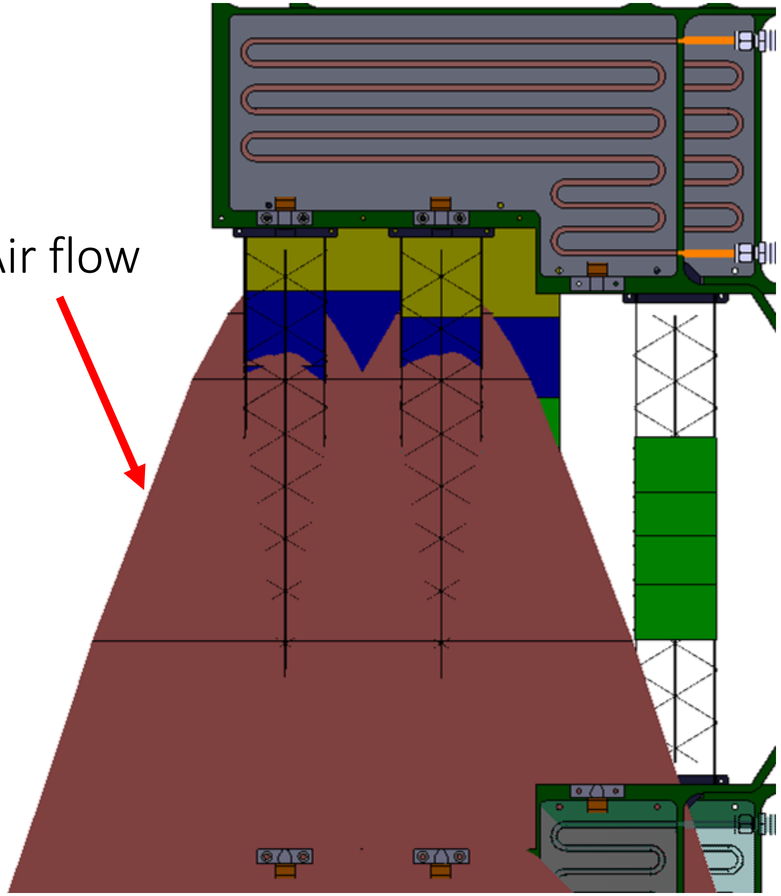
Experimental verification of all cooling concepts in a 'realisitc' setup with up to 3 half-layers (stations)
COOLING DEMONSTRATOR



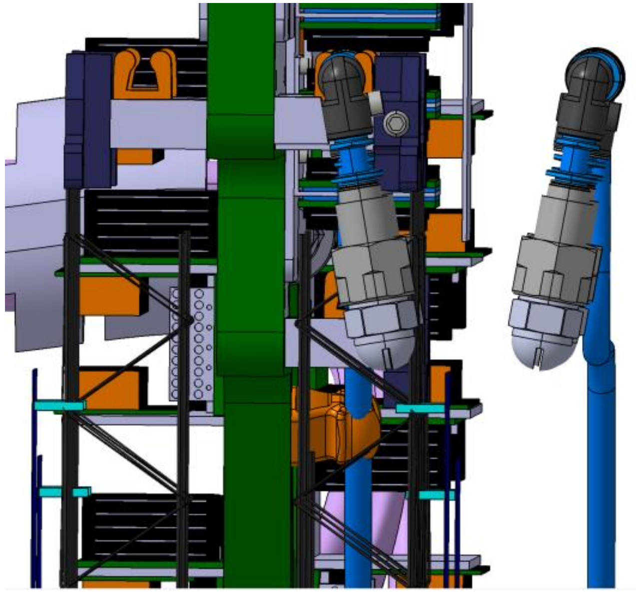
Silicon Sensor Cooling

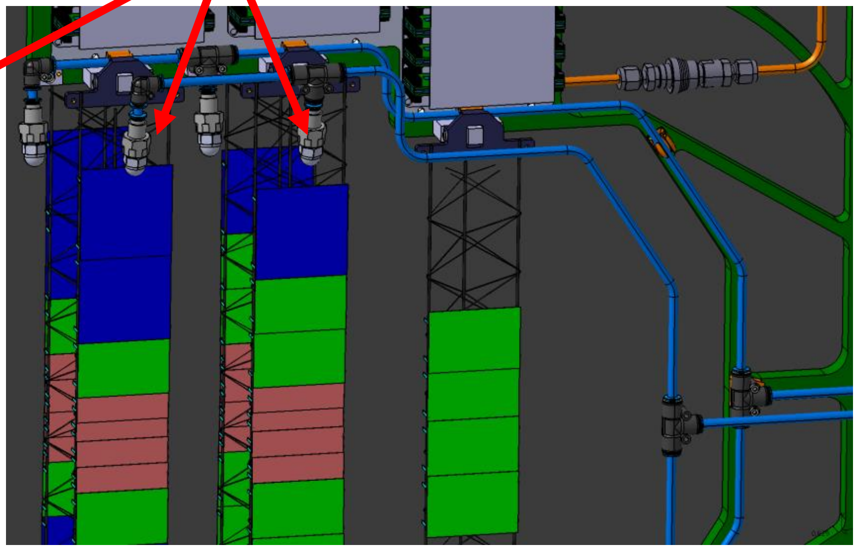
- Air nozzles outside detector acceptance delivers cold gas directly on the (dummy) sensors
- No additional % X_0 per layer
- Located between the ladders
- Easy integration
- Vibrational studies of the sensors will be subsequently studied

Air flow



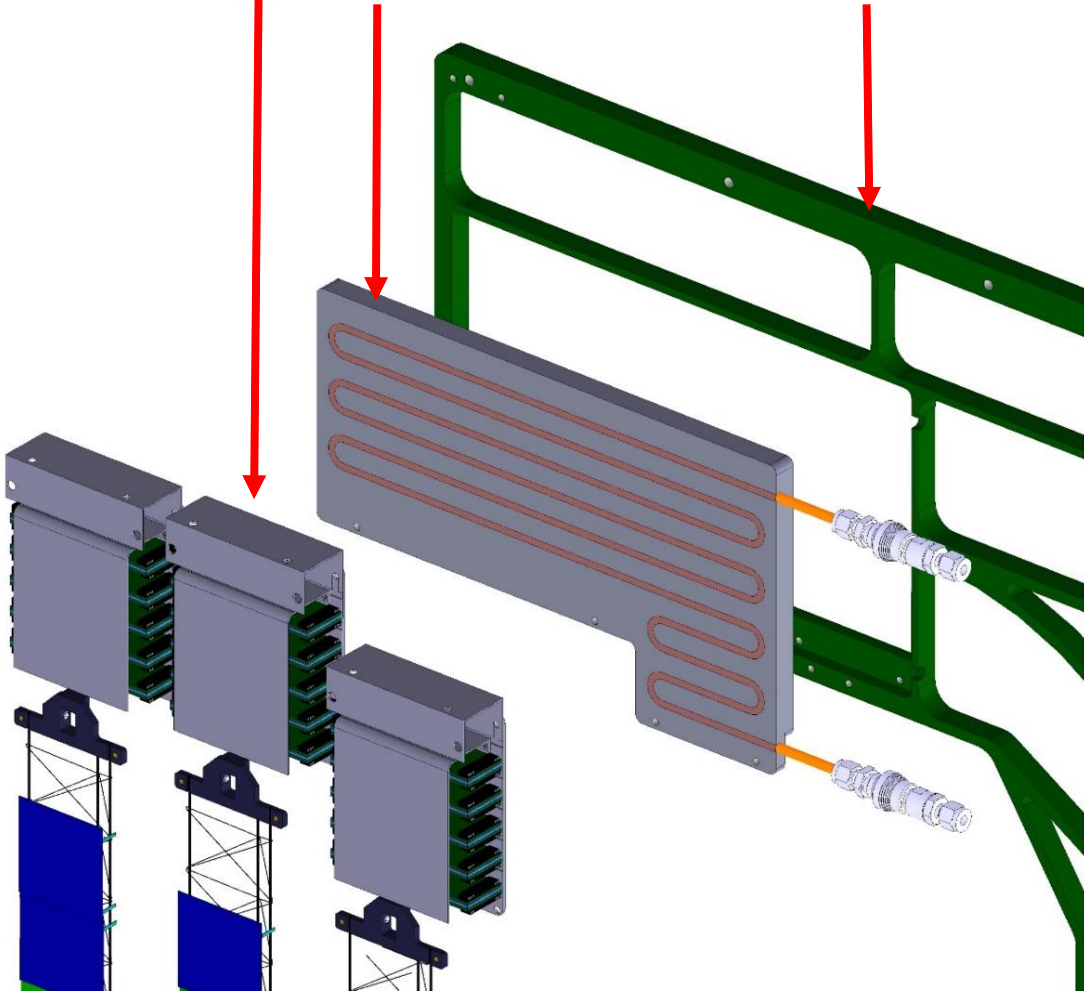
Nozzles





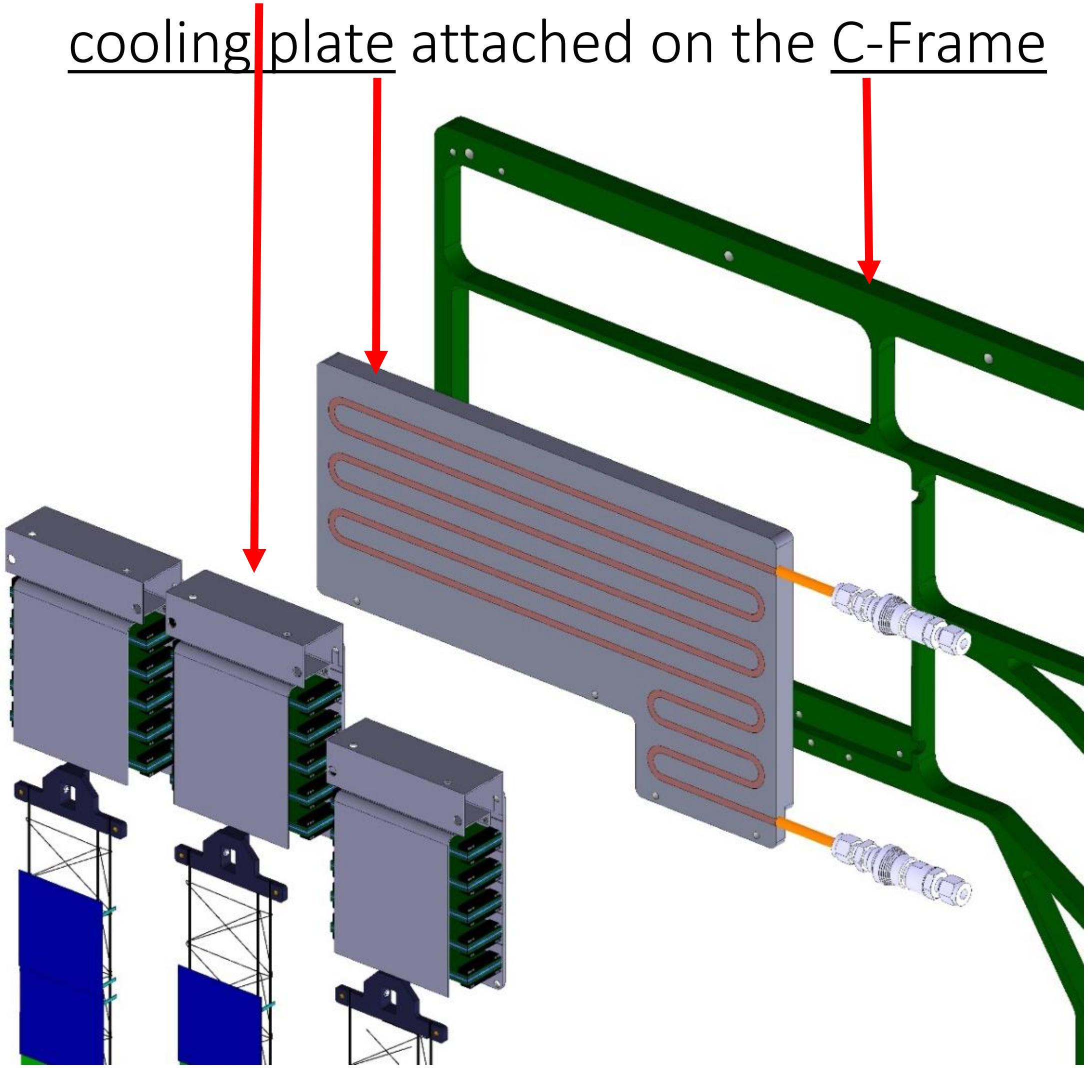
FEE Cooling

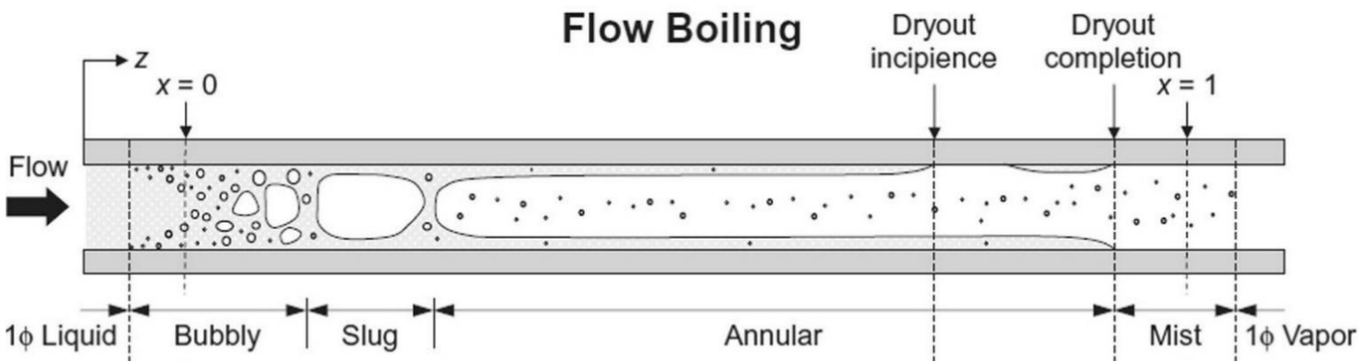
Each FEB Box derives it cooling from a cooling plate attached on the C-Frame



FEE Cooling – Biphase CO_2

Each FEB Box derives it cooling from a cooling plate attached on the C-Frame



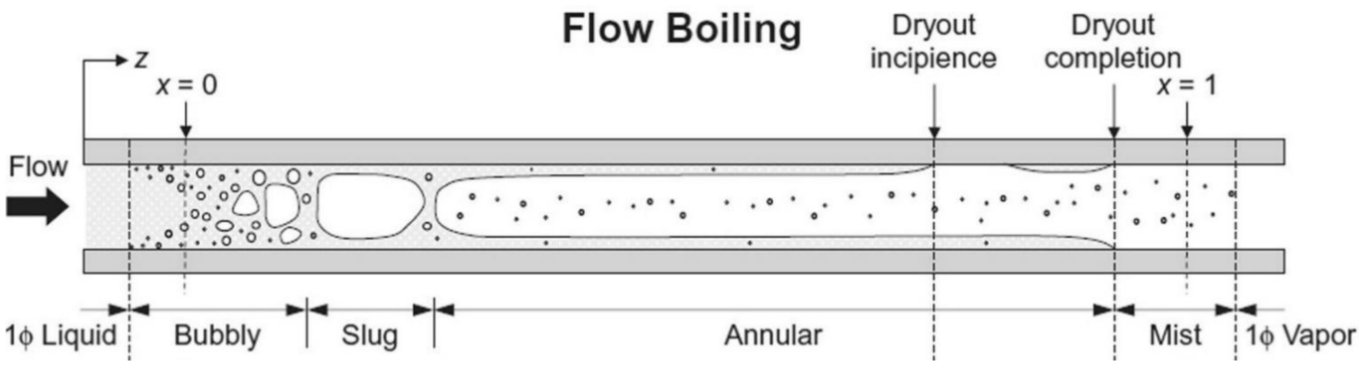


THERMAL SIMULATIONS OF FEE – BIPHASE CO_2

- Semi-emperical boiling flow model
  - Heat Transfer Coefficient
  - Pressure Drop
  - Dry-out onset

↓

✓ Cooling line dimensioning
✓ Mass flow estimation



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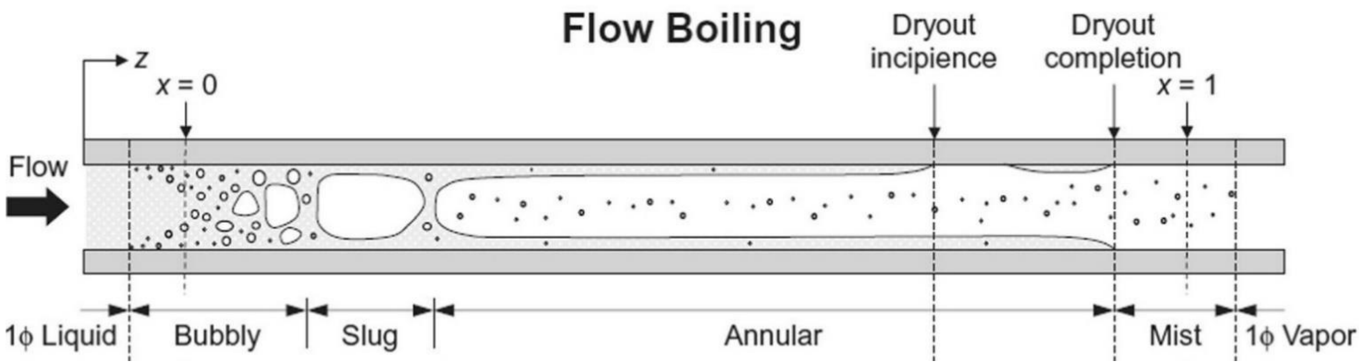
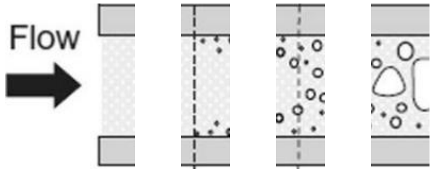
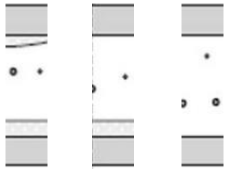


1. Set boundary conditions
(power dissipated, tube dimensions, initial fluid conditions)



2. Break it down into small elements



3. Calculate thermodynamical properties for 1st element

P_{i+1} , HTC_i → H_{i+1} → T_{i+1} , $x_{i+1} = f(T_{i+1}, x_{i+1})$ → ....

4. Repeat till the end

Emperical Model ΔP, HTC

$$H_{i+1} = H_i + \dot{Q}_i / \dot{m}$$

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✓ Mass flow estimation

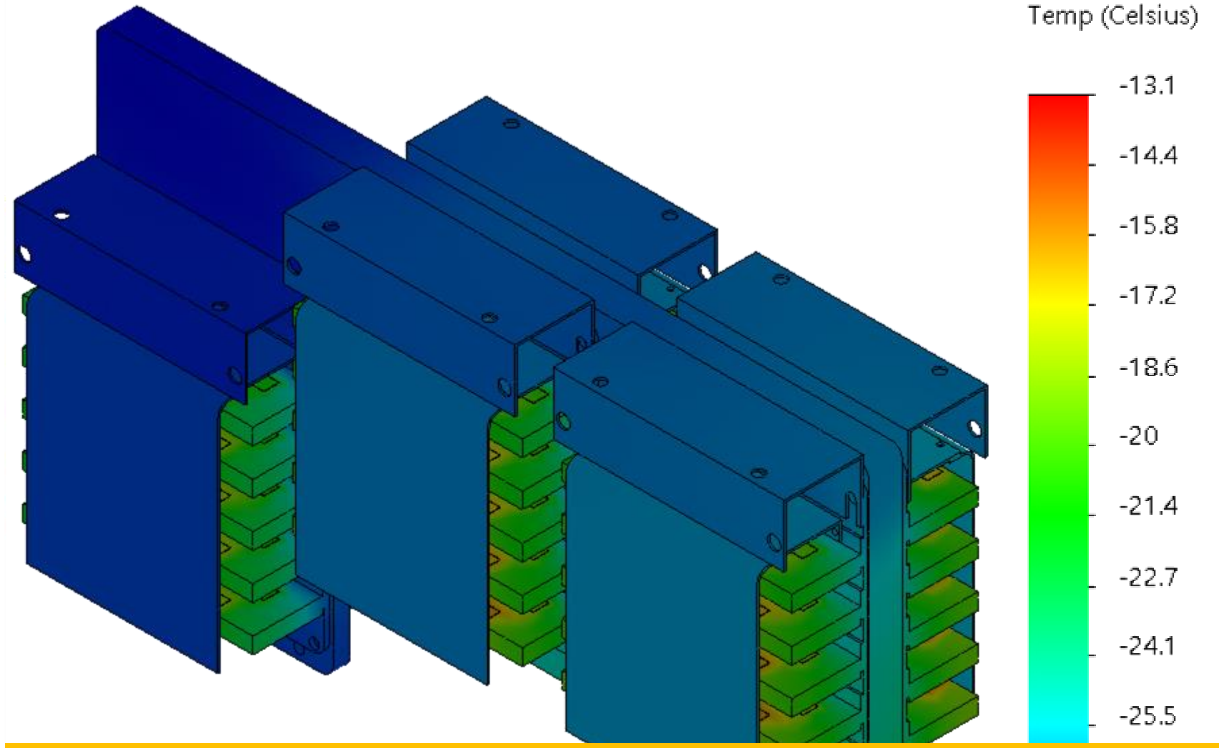
✚

- Thermal FEA model (SolidWorks)
  - Conduction (and Radiation, Convection)
  - (Thermal Interface Materials)

↓

✓ Maximum Temp.

- Coolant Temp. = -30°C
- Heat Load = 594 W
- Tube ID = 3.6 mm
- Tube Length = 2 m
- Mass Flow = 7 g/s
- Pressure Drop = 0.14 bar
- Dry-out margin = 56% (x_{dryout} = 0.63)



- Fair amount of flexibility in input parameters which could be determined compuatationally
- 1 kW CO_2 cooling plant in development at GSI

Thermal Simulations Of FEE – Monophase Novec 649

- Biphase CO_2
  - ✓ Great performance
    - less mass flow
    - low pressure drop
    - smaller tubes
    - uniform temperature
  - ✗ Potentially difficult for commercial manufacturing (2PACL-type system)

- Monophase NOVEC
  - ✗ Relatively lower performance
    - higher mass flow
    - higher pressure drop
    - larger tubes
    - non-uniform temperature
  - ✓ Easier commercial manufacturing

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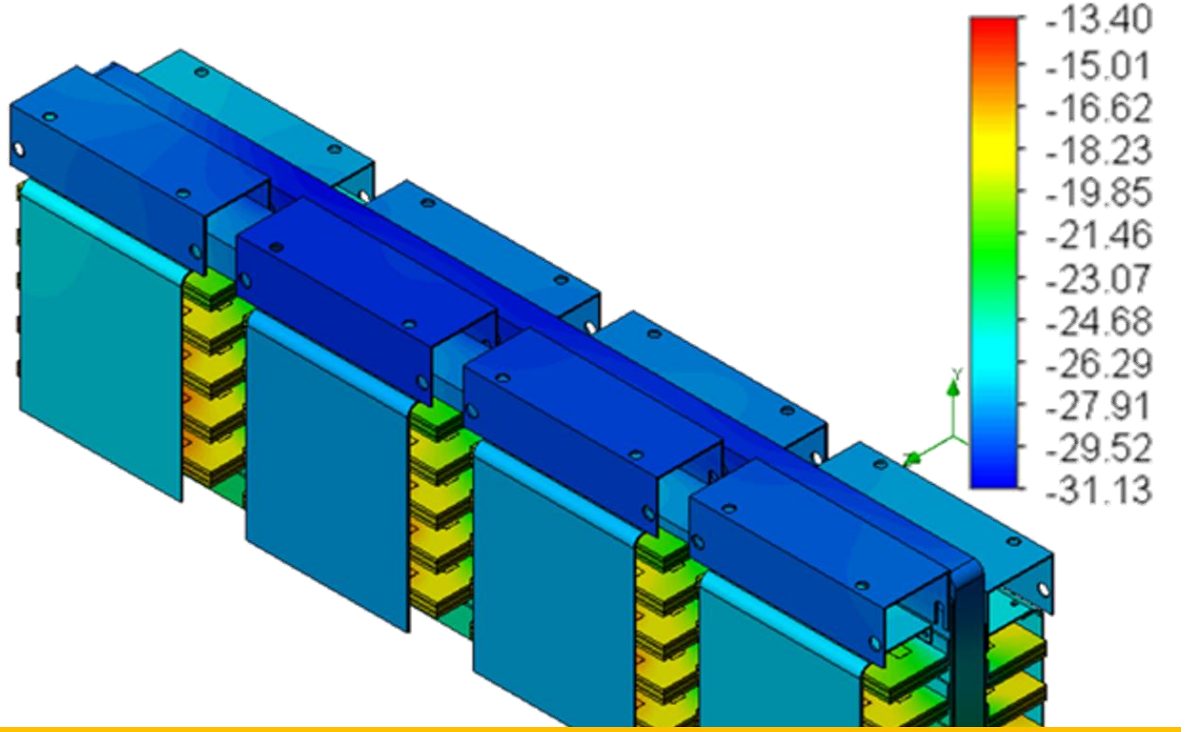
- Coolant Temp. = -40°C
- Heat Load = 1080 W
- Tube ID = 5.4 mm
- Tube Length = 2.7 m
- Mass Flow = 150 g/s
- Pressure Drop = 1.25 bar

WORST CASE
INITIAL CONDITIONS



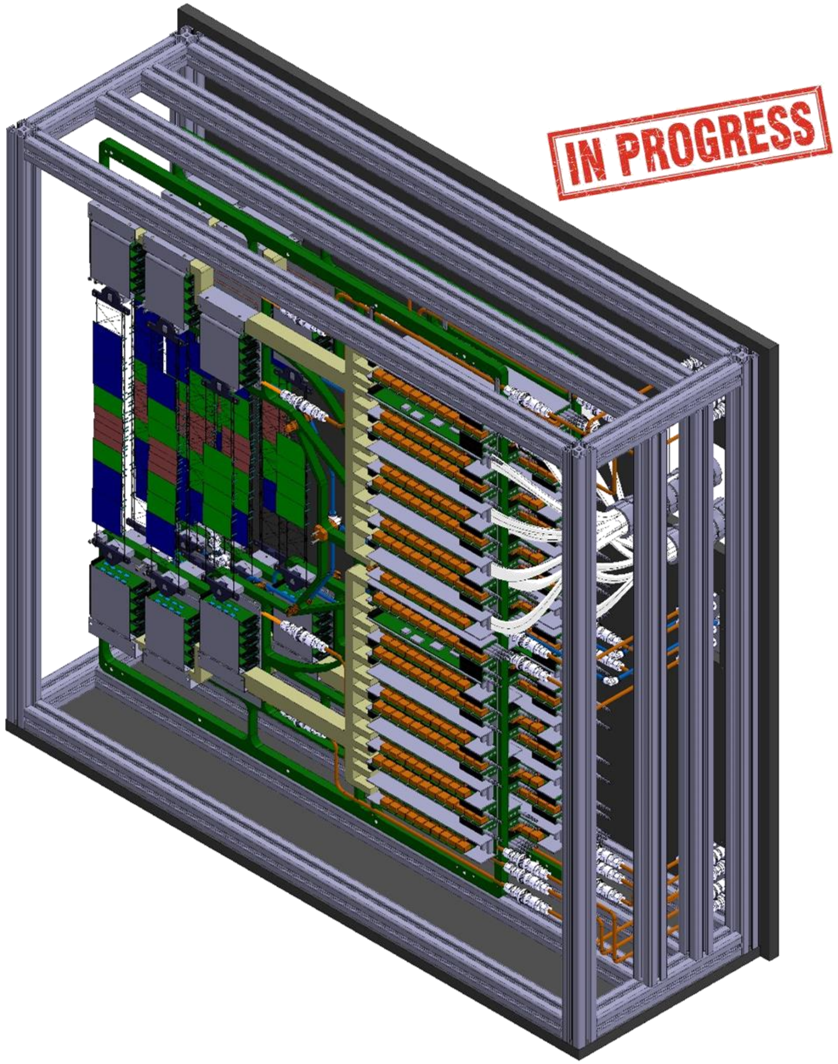
- Fair amount of flexibility in input parameters which could be determined compuatationally
- Feasible alternative and details are in progess

Conclusions & Outlook

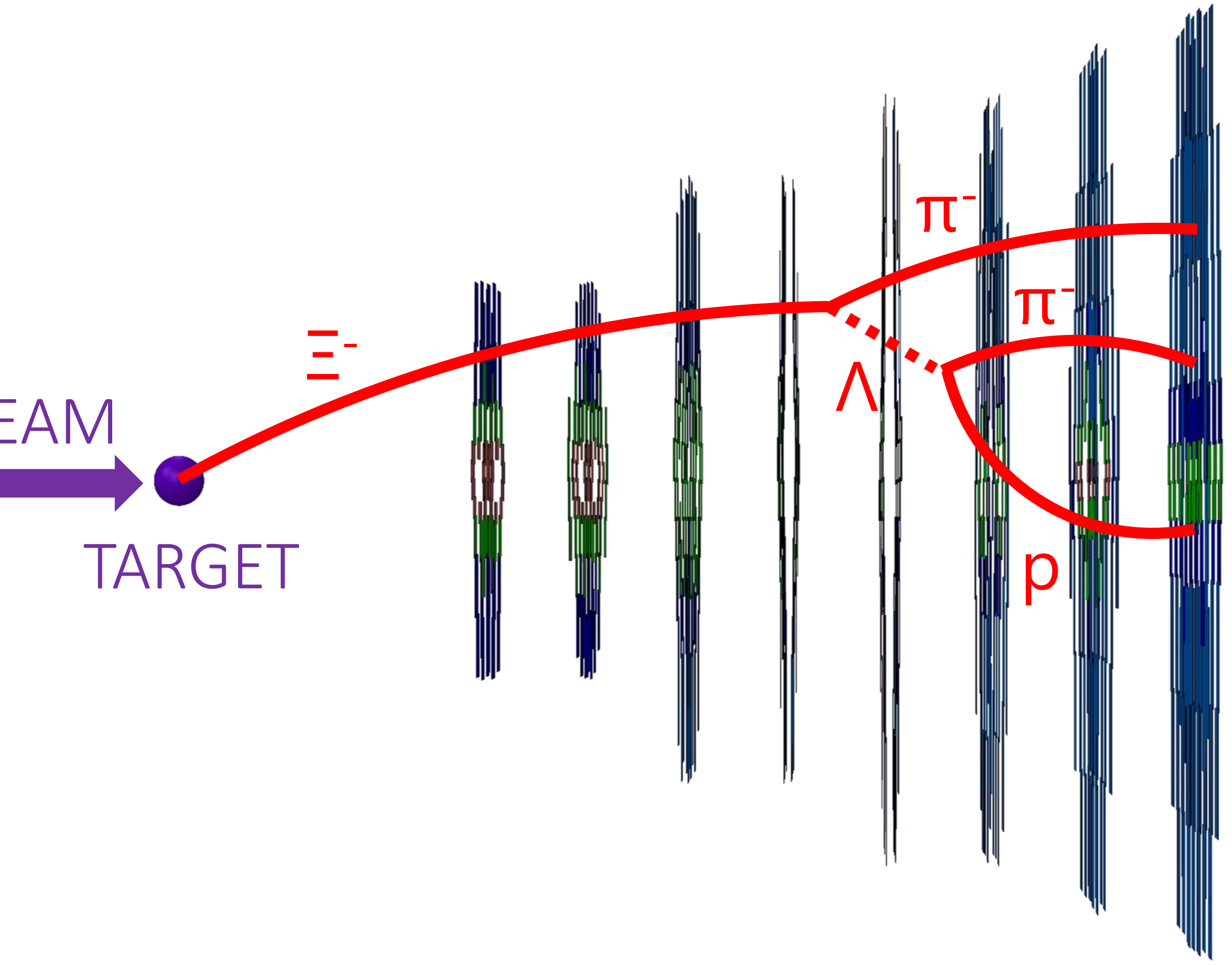
- STS Heat Sources
  - Silicon sensors: 6 mW/cm² at -10°C → Forced gas convection via nozzles
  - Electronics: 40 kW → Biphase CO_2 or Monophase NOVEC cooling
  - Ambient: 40 W/m² with 20 mm CF-Foam sandwich

- Models developed to do computational characterisation done for electronics cooling
  - Useful to determine operational parameters
  - Parallel efforts to check with CO_2 and NOVEC cooling with respective cooling plants

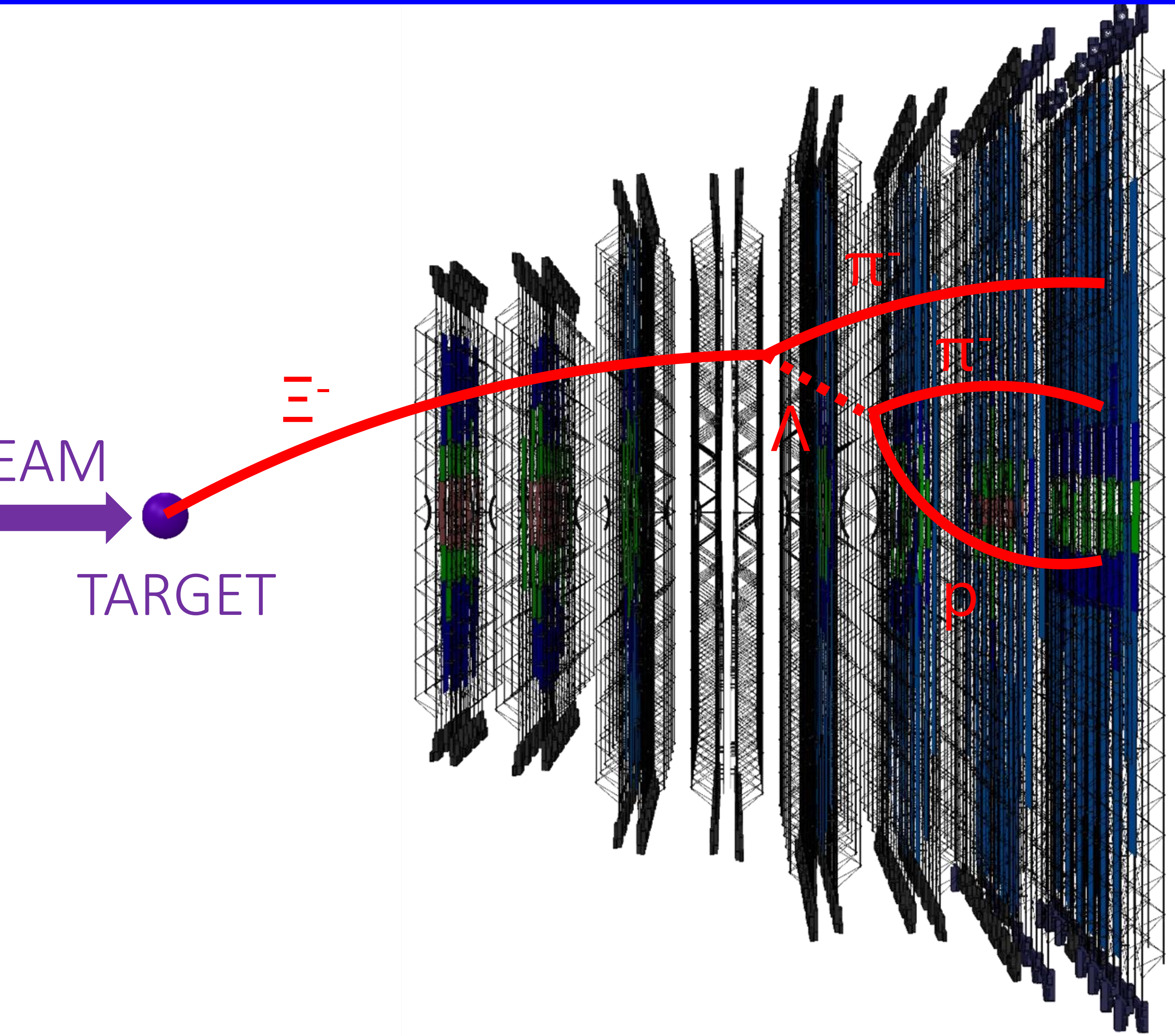
- Cooling demonstrator in progress to experimentally validate the cooling concepts
  - Testing upto 3 STS half-layers (or stations) in realistic constraints
  - Most of the part ordering done or is in progress



Thanks A Lot
For Your Attention ☺



STS Features: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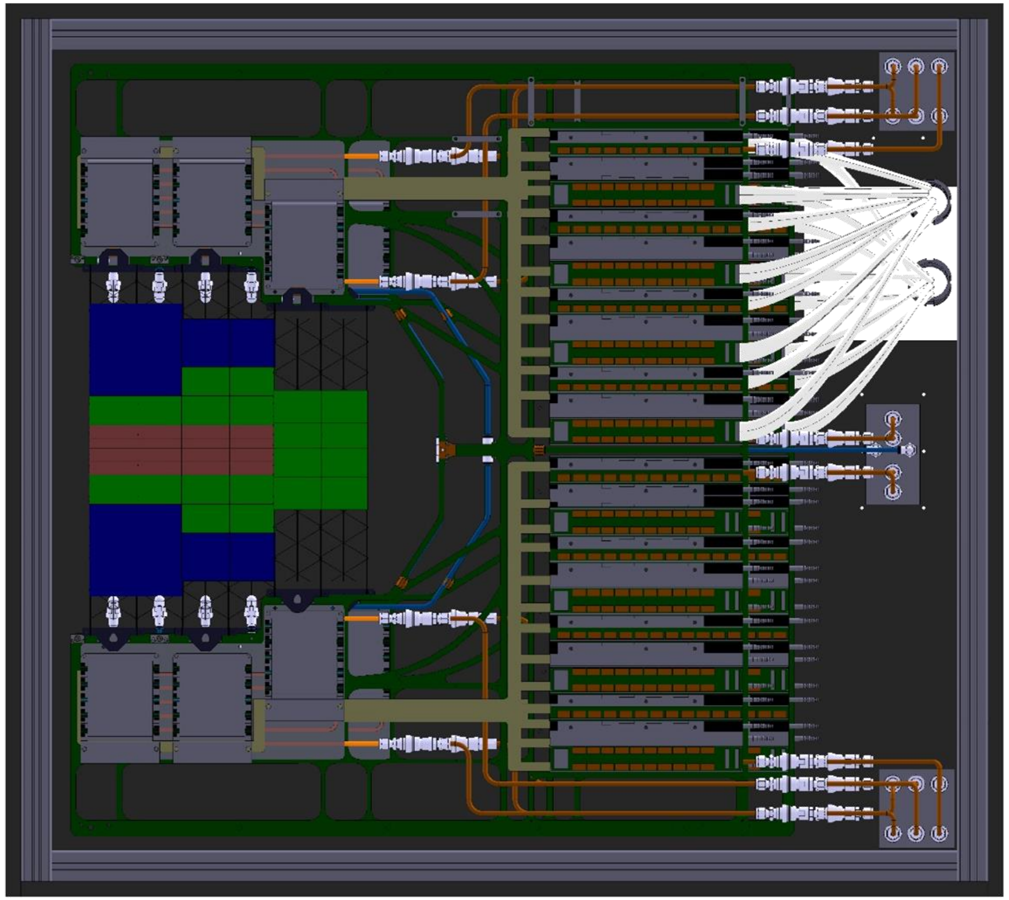
STS Cooling Demonstrator



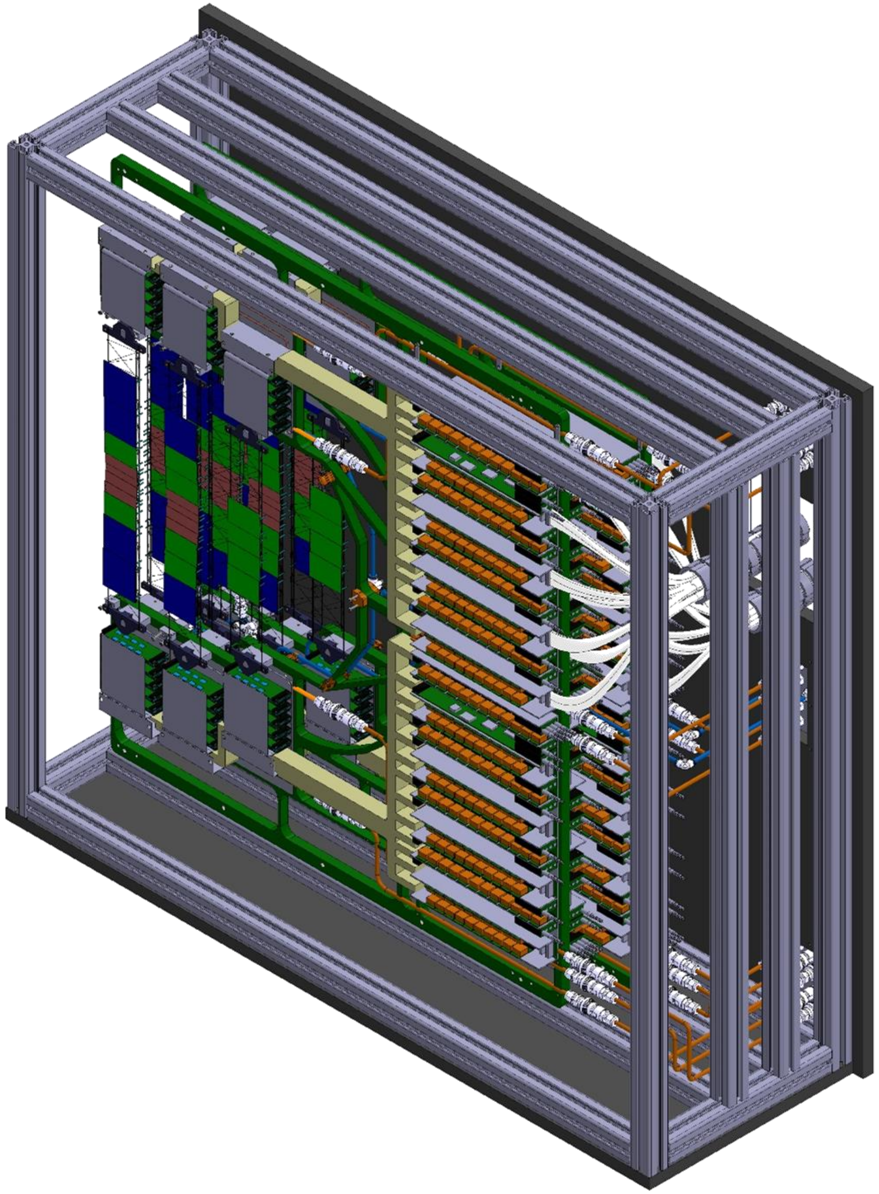
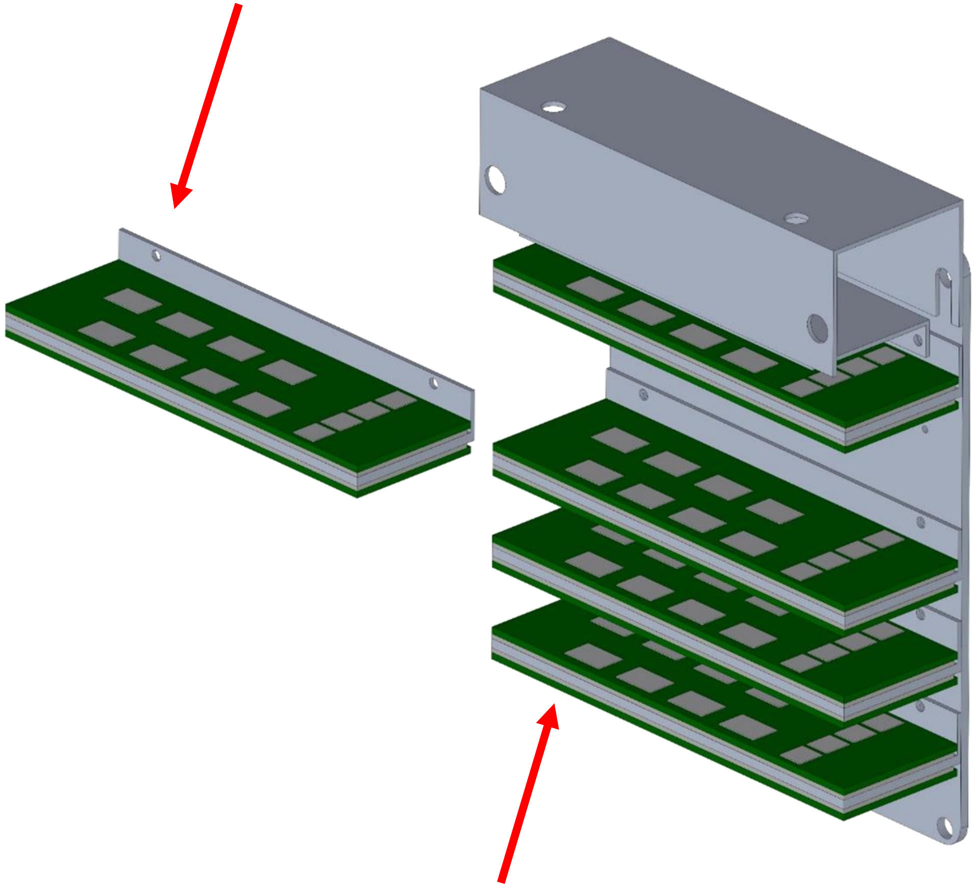


Figure: CAD Front-view (Left) and Isometric-view (Right) of the upcoming STS Cooling Demonstrator (still in progress)

Electronics Cooling

1. Pair of Front-end Electronics Boards (FEBs) [Readout for 1 silicon sensor]



2. Series of FEBs assembled together: FEB Box [Readout for 5 sensors = ½ ladder]

3. Each FEB Box derives it cooling from a cooling plate attached on the C-Frame