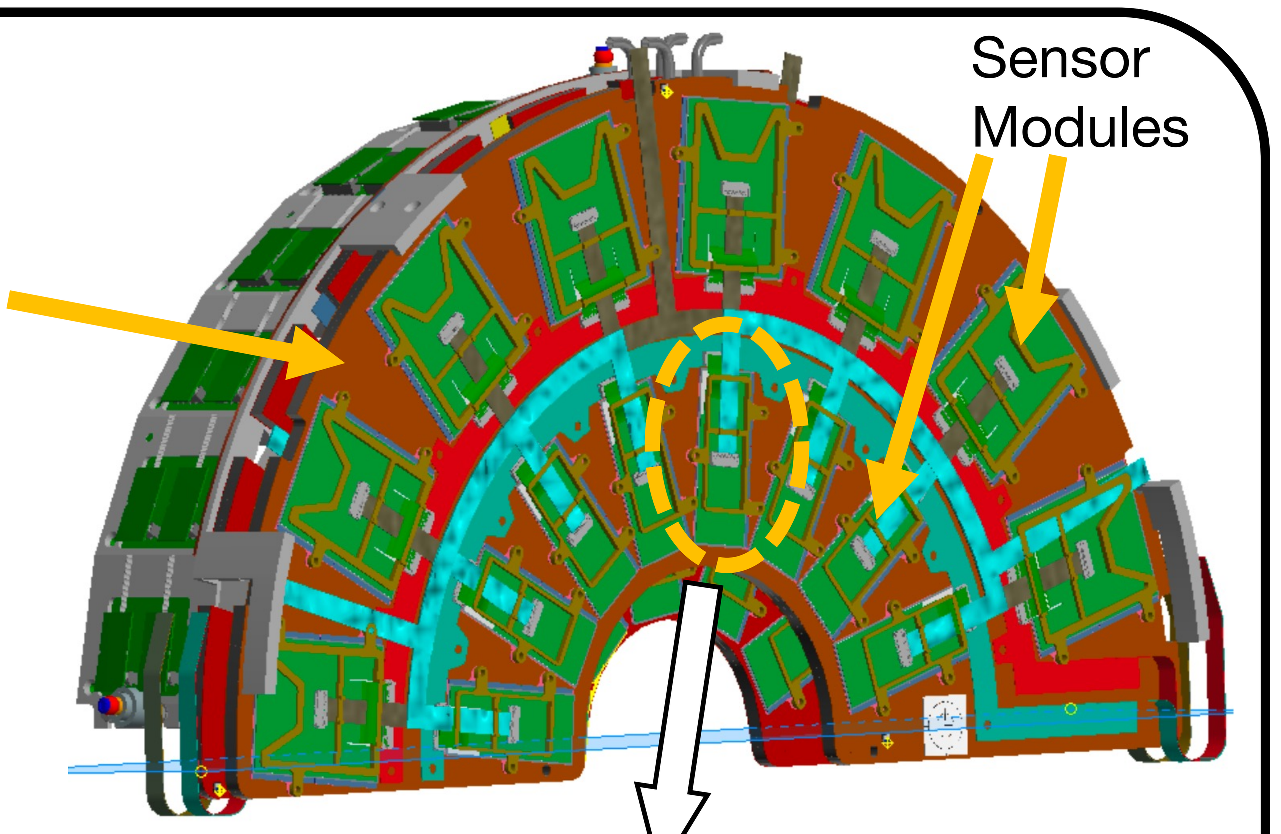
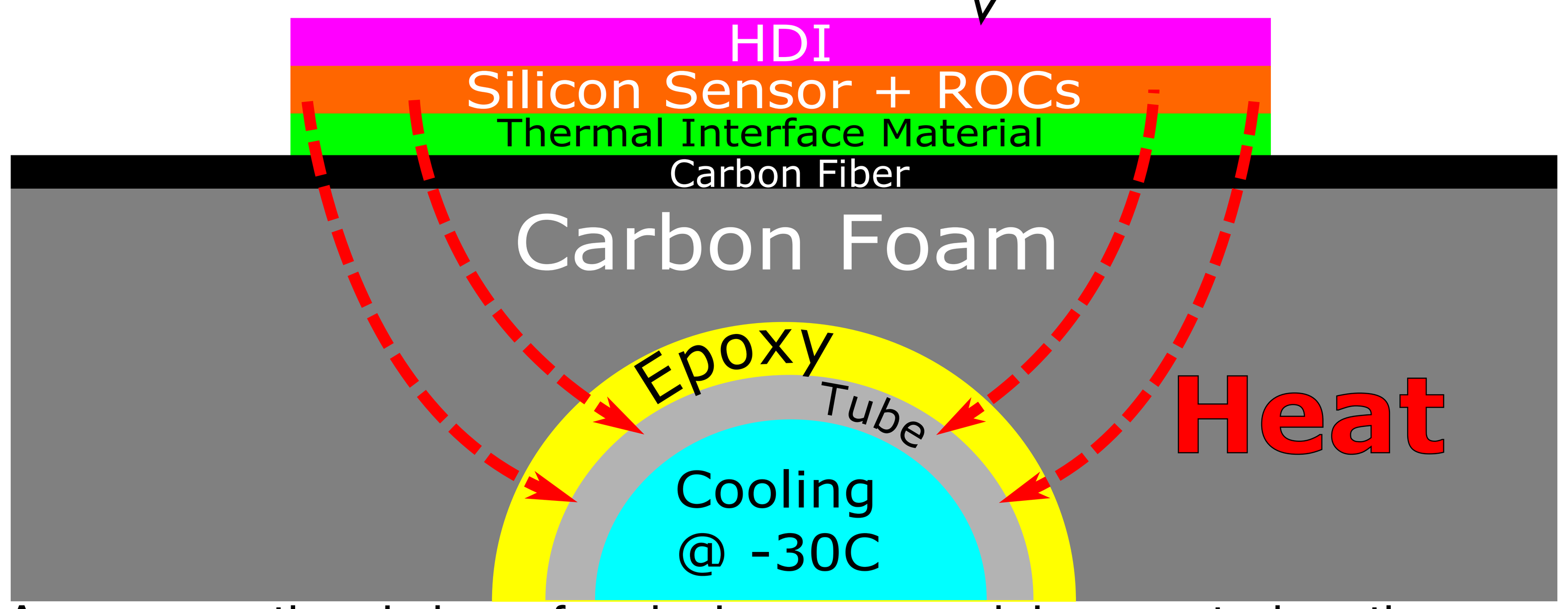
Efficiently Cooling Radiation-Damaged Silicon Pixel Sensors in the CMS HL-LHC Inner Tracker

Sam Bright-Thonney (skb93@cornell.edu), on behalf of the US-CMS TFPX Mechanics Group

The CMS Inner Tracker

- In the forward region of the inner tracker, pixel sensors are mounted on carbon fiber/foam support discs (**Dees**)
- Sensors will receive a **lifetime dose of 2 x 10^{16} n_{eq}/cm^2 / 1.2 GRad TID**
- **Dark current** increases as a function of fluence
  → Positive feedback between temperature and current can cause **thermal runaway** in highly irradiated sensors
- Modules held near -30C using **two-phase CO_2 cooling** to maintain performance and mitigate some effects of radiation damage

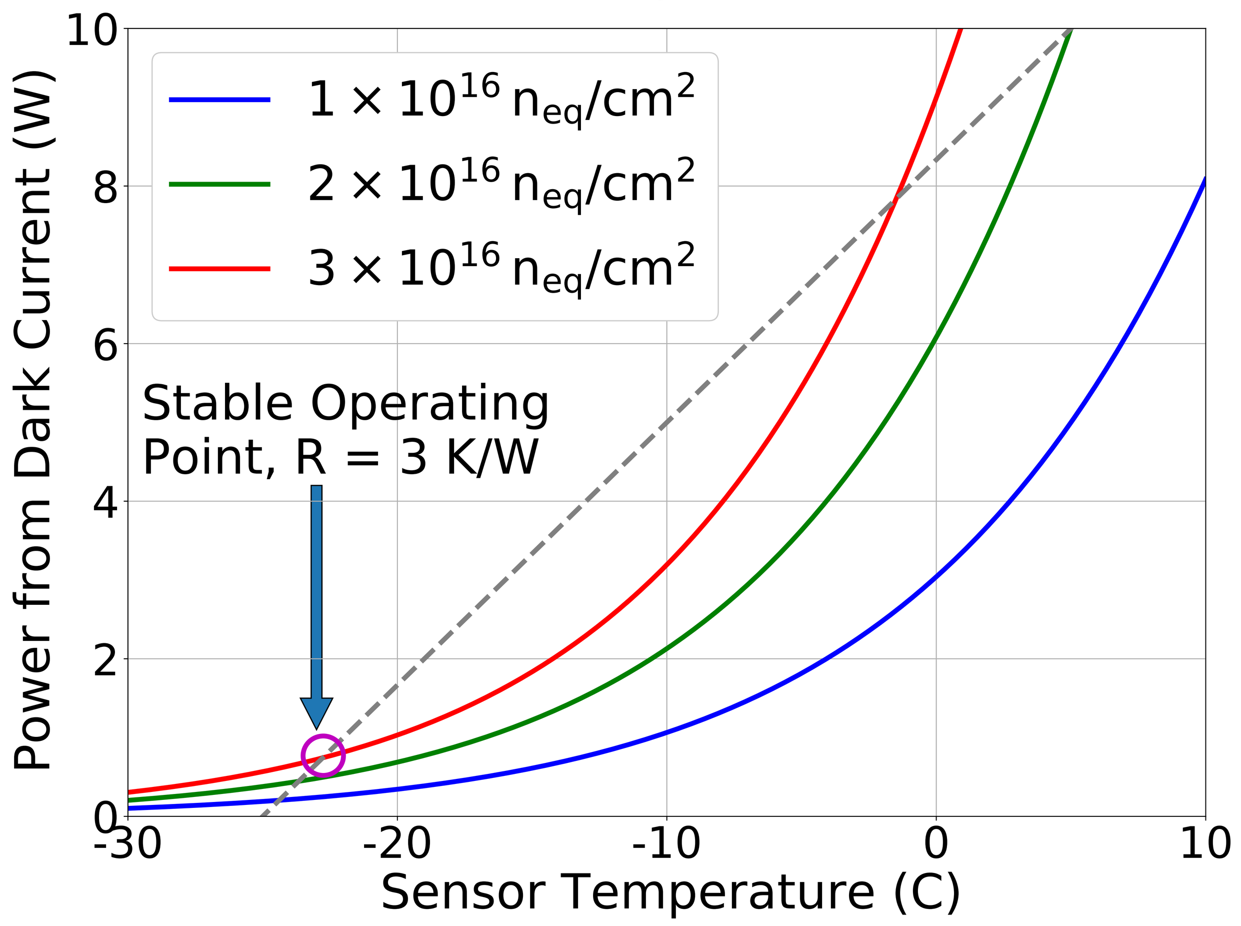




A cross-sectional view of a pixel sensor module mounted on the Dee with sub-surface CO_2 cooling

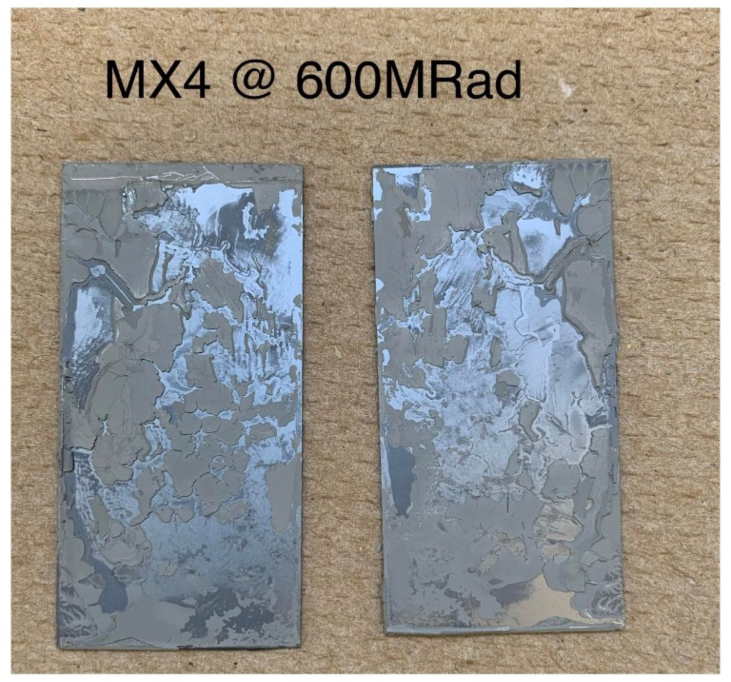
Avoiding Thermal Runaway

- A thin layer of **thermal interface material (TIM)** beneath each sensor helps move heat out of the module and toward cooling tubes
- TIMs must be:
  - **Radiation hard –** texture and thermal properties do not degrade
  - **Conductive** – at least ~1 W/mK
  - **Spreadable** into thin, uniform layers
- TIMs chosen to ensure **low net thermal resistance between sensor and cooling system**
- Net thermal resistance determines operating temperature
  - If R too large, **no stable operating temperature → runaway!**

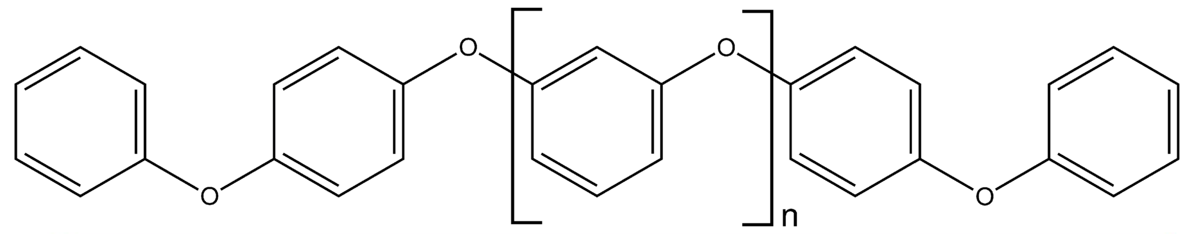


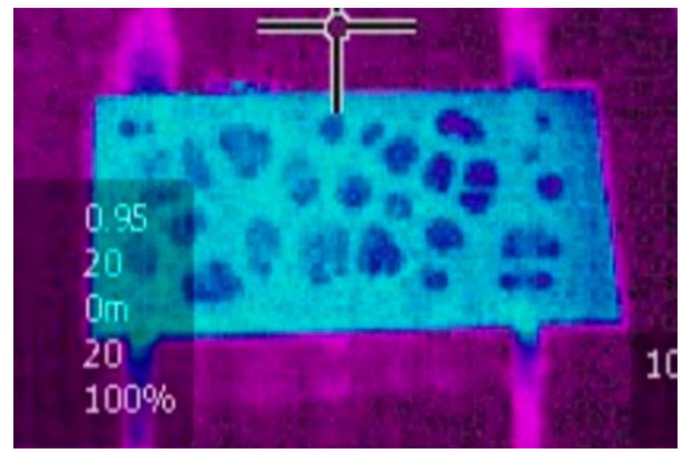
$$Q(T) = I(T_{\text{ref}})V_{\text{bias}}\left(\frac{T}{T_{\text{ref}}}\right)^2 e^{-T_A\left(\frac{1}{T}-\frac{1}{T_{\text{ref}}}\right)}$$

Radiation Hard Thermal Materials



- Commercial thermal greases **fail** irradiation tests – they become **hard, brittle, and develop voids & bubbles** which degrade thermal performance
- **Polyphenyl Ether (PPE) –** high radiation vacuum grease, remains smooth & spreadable up to 1.5 GRad





Infrared image showing voids in irradiated commercial grease

Material	k (W/mK)
Pure Moresco PPE	**0.20 ± 0.02**
PPE + 33% diamond (20 um)	**0.33 ± 0.03**
PPE + 70% diamond (20 um)	**1.17 ± 0.11**
PPE + Mixed-diameter diamond	**0.78 ± 0.08**

Measurements performed by Souvik Das, Purdue University

- TIMs that remain smooth enable module removal should it be necessary (repairs, damage, etc.)
- PPE is not thermally conductive
  → **Increase conductivity by doping with micron-size diamond particles** (current benchmarks are 30 and 70% diamond by mass, giving acceptable conductivities)

Lab Testing PPE

- **In-lab simulation of thermal runaway** using dummy "heater" modules
  - Power is dynamically adjusted to **mimic temperature-dependent dark current**; cooling system similar to the Dee
- **Future**: runaway experiments using realistic dummy modules, cryogenic CO_2 cooling, and a more sensitive thermal camera