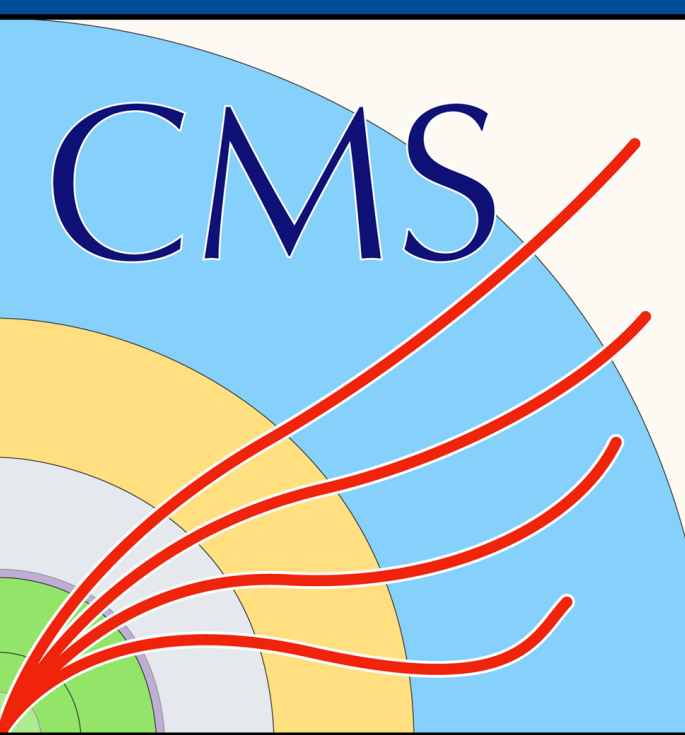


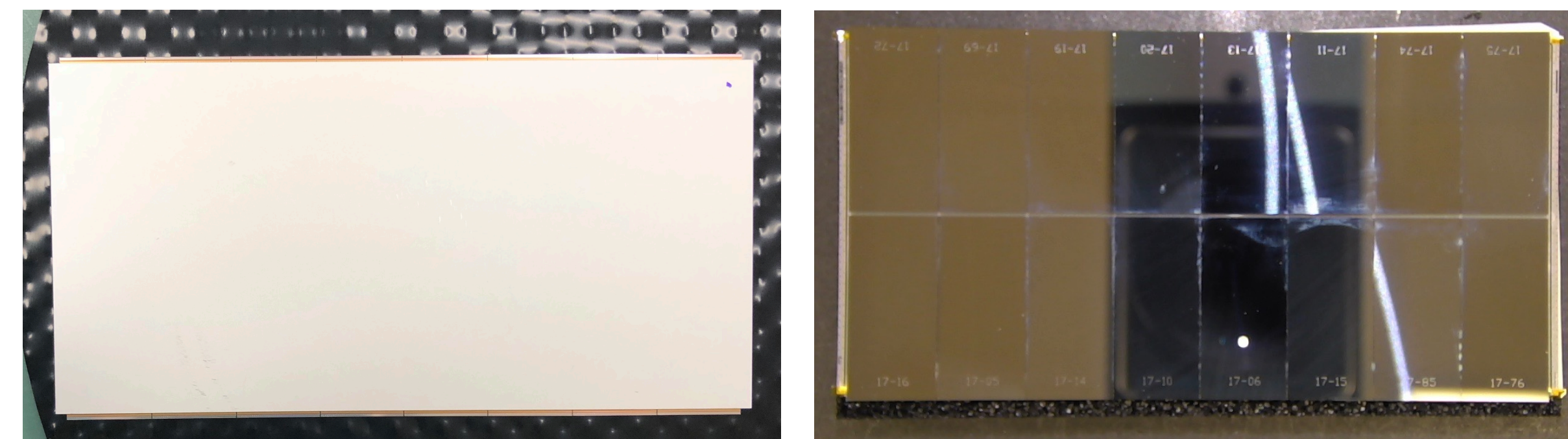
Design and Prototype Performance of Macro-Pixel Sub-Assemblies for the CMS Outer Tracker Upgrade

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Macro-Pixel Sub-Assembly (MaPSA)

A MaPSA is a silicon macro-pixel sensor bump-bonded to 16 macro-pixel ASICs (MPA).



Photos of a MaPSA. Left: sensor side. Right: MPA side. Each macro-pixel measures 1.5mm x 100 μm, and the entire MaPSA is about 5cm x 10cm. Wirebond pads of each MPA extend beyond the edge of the sensor

MaPSA + silicon strip sensor forms a CMS Outer Tracker **PS module**. Pattern of hits in the two sensors gives track p_T information to the CMS **Level 1 trigger**.

In the latest prototyping round (Round 2), MaPSAs were constructed by **two bump-bonding vendors** and tested at Fermilab.

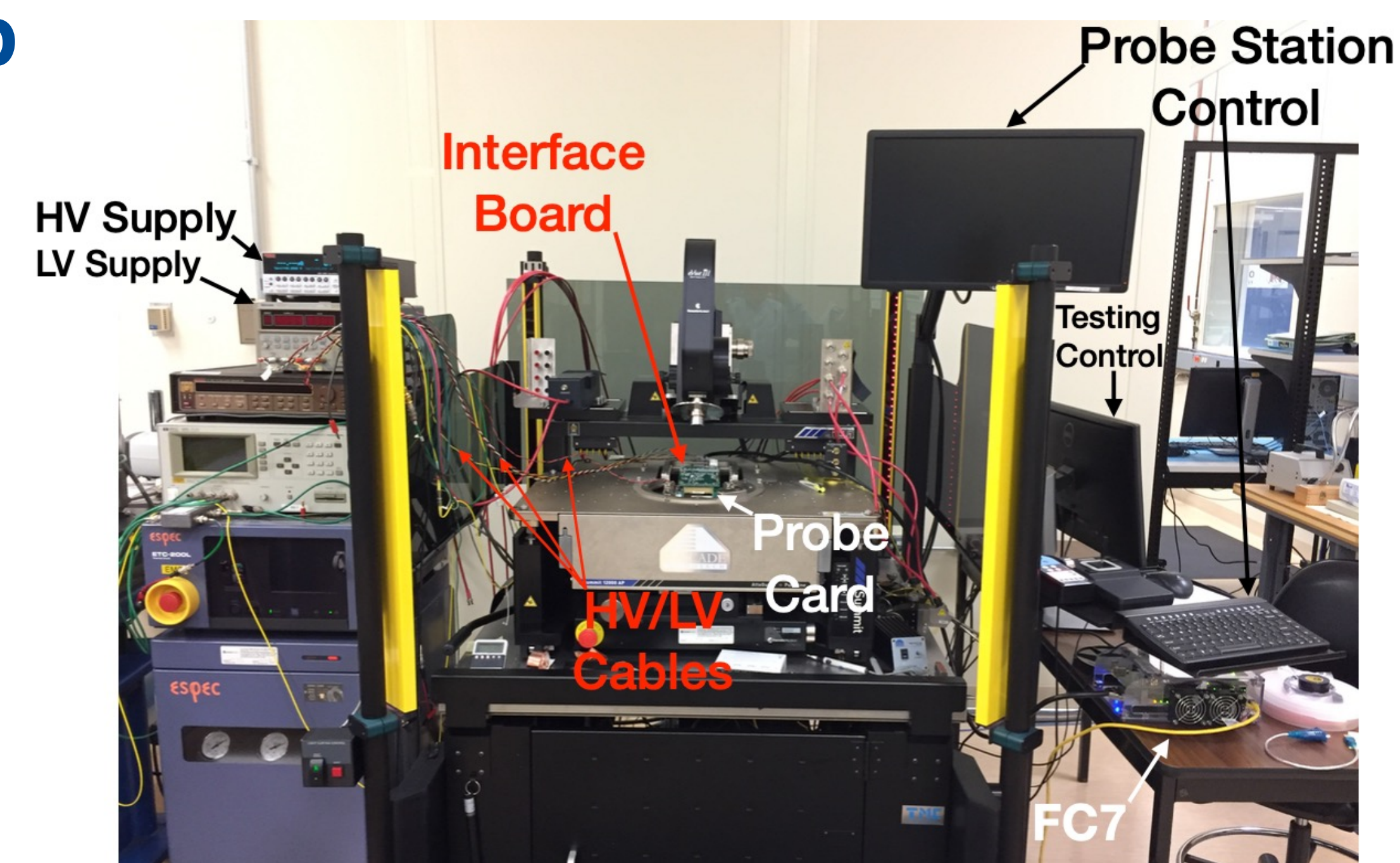
Probe testing setup at Fermilab

MaPSAs are tested on **Summit 12k Semi-Automated Probe Station**. MaPSA rests on custom chuck, held in place by vacuum.

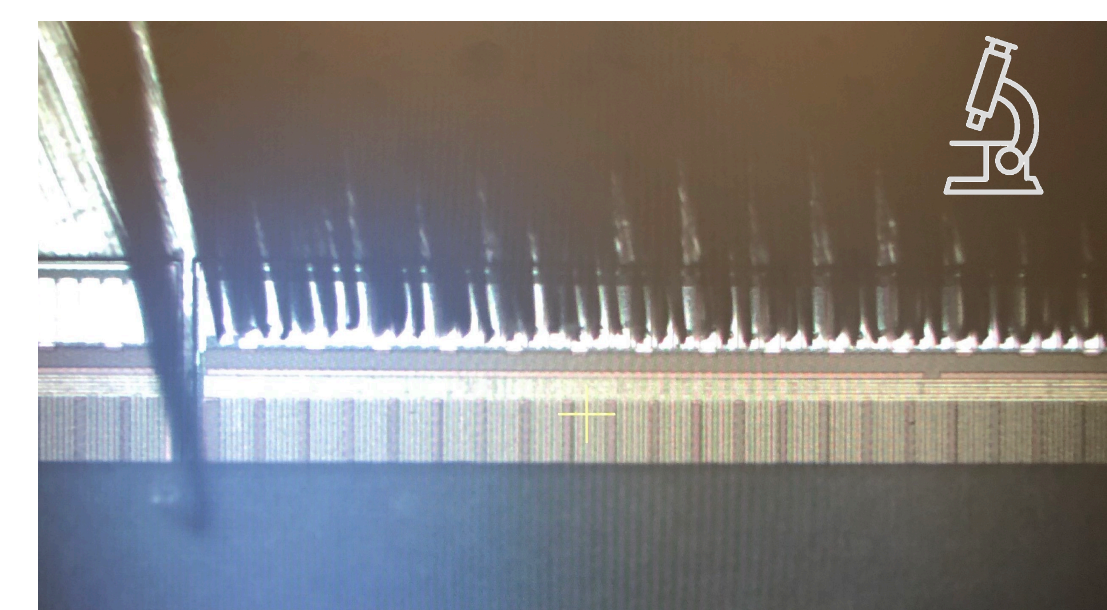
ReW needles of custom **Probe Card** make electrical contact with wirebond pads on each MPA.

Interface board connects probe card to readout system: **FC7 μTCA crate**, developed for CMS Outer Tracker prototyping phase.

Prototype test time is **~15 mins / MPA**. Test menu will be reduced for production



MaPSA probe testing station, Silicon Detector Facility, Fermilab



MaPSA probe card
Probe needles aligned over MPA wirebond pads. Long needle biases the sensor.

Summary of prototype performance

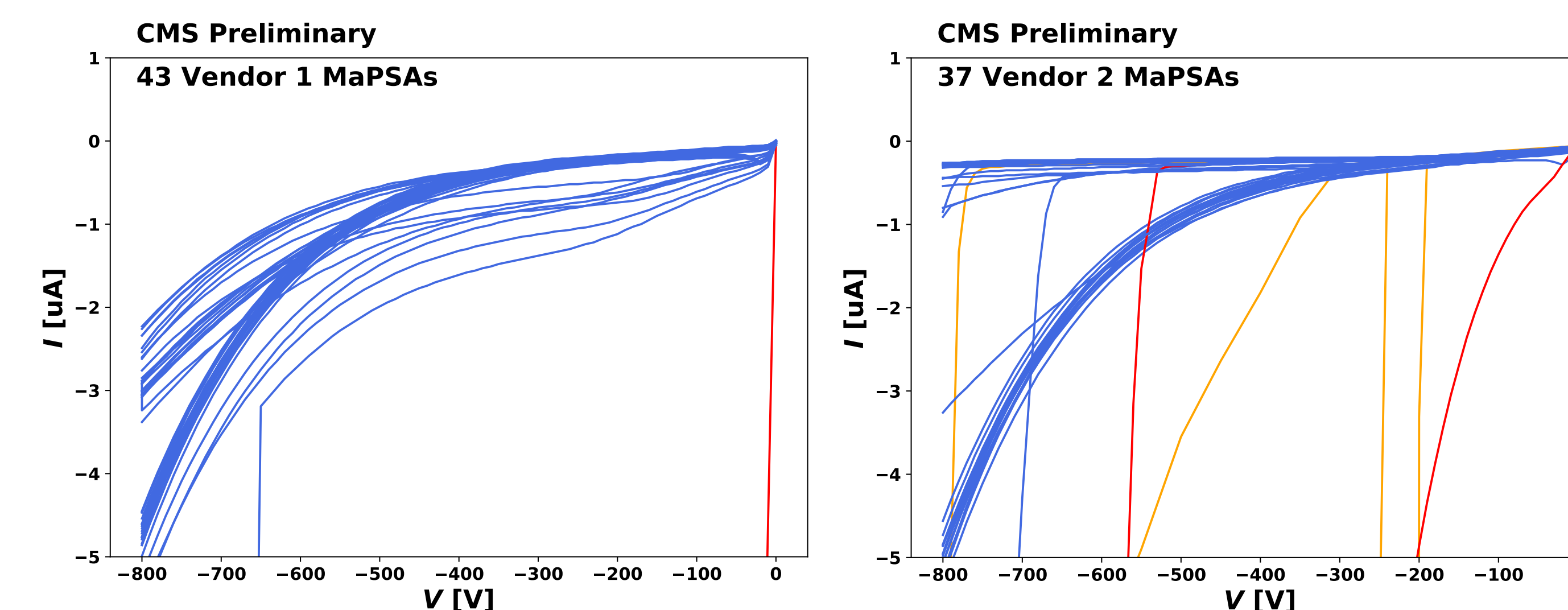
The quality of Round 2 MaPSAs from each vendor is summarized below. The yield of perfect + OK MaPSAs satisfies the desired threshold of 80% for both vendors.

Vendor	Total	Perfect	OK	Bad MPA	Bad IV
1	43	38	2	2	1
2	37	22	8	4	3

Results of prototype testing

Each Round 2 prototype MaPSA was probe tested and classified according to its quality.

★ **IV curves: Leakage current** measured as a function of bias voltage. Perfect MaPSAs have $I < 10\mu A$ at 600V. Slightly earlier breakdown → OK MaPSA

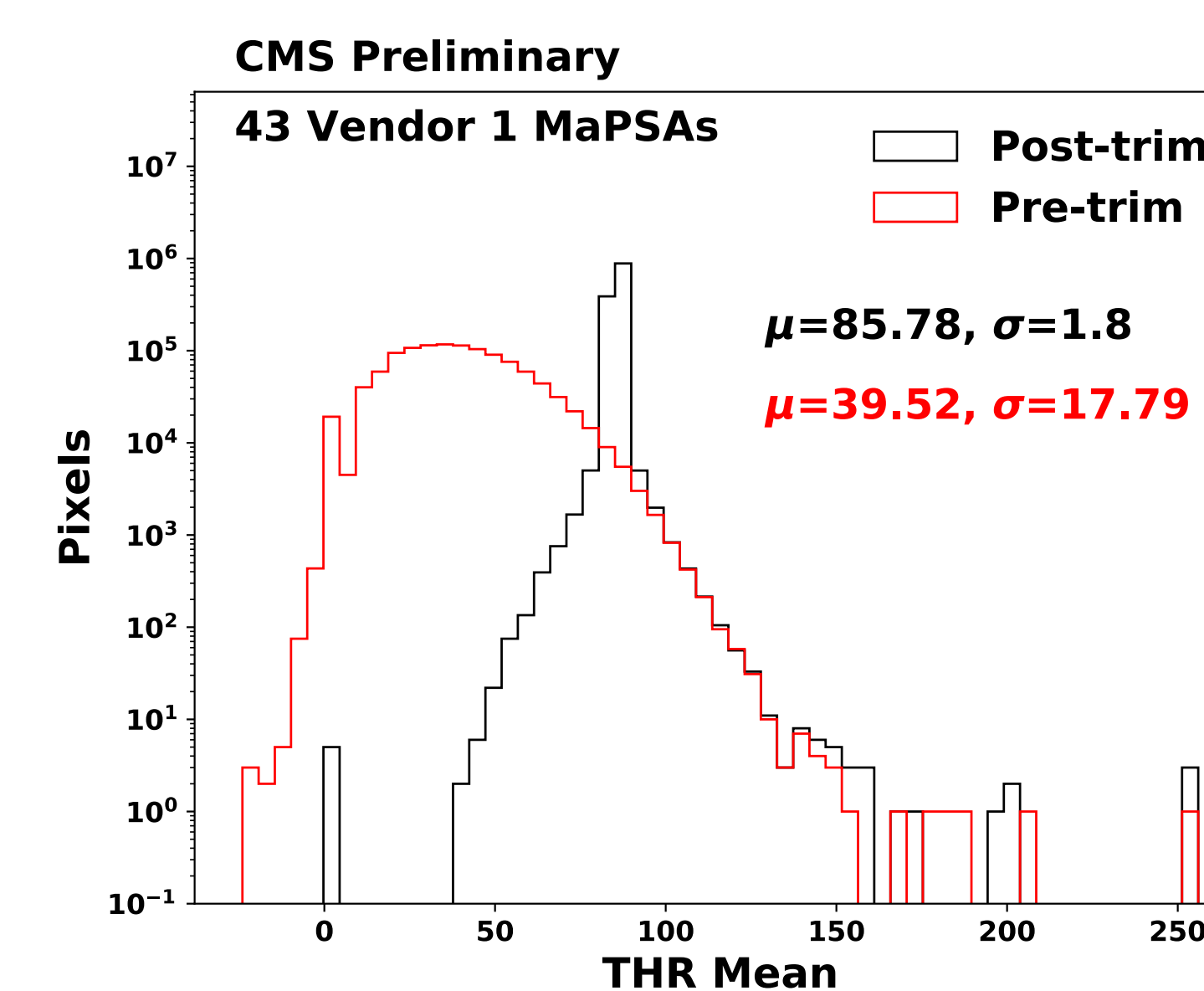


Summary of the IV scan results
Red curves: MaPSA failed the requirement of $I < 10\mu A$ at 600V.
Orange curves: earliest prototypes from Vendor 2
Leakage current is dominated by probe card, but sensor breakdowns are still evident

★ **Pixel alive:** A fully efficient pixel records 100/100 injected pulses. A MaPSA fails if there is a region of **dead pixels** on any MPA

★ **Pixel masking:** A pixel can be disabled completely by setting a dedicated mask bit. A MaPSA fails if there is an **unmaskable** pixel on any MPA. Seen on 3 Vendor 2 MaPSAs.

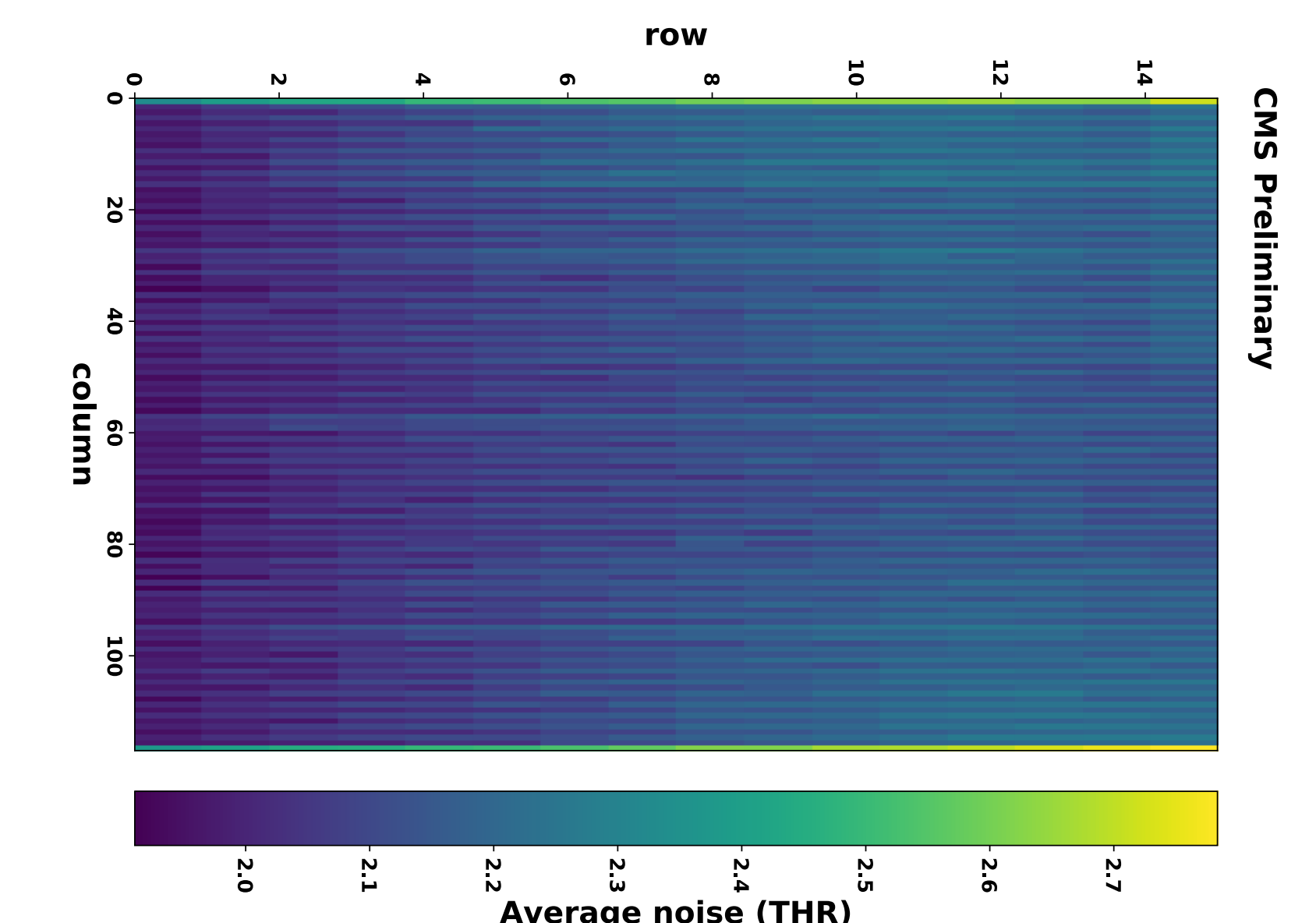
★ **Threshold and noise** are extracted for each pixel by fitting the **S-curve** to an error function. **Trim bits** are set per pixel so that all have similar threshold. Measured on two types of S curves: THR (fixed pulse, different thresholds), CAL (varying pulse amplitude)



Left: **Pixel threshold (THR)**
Red: before trimming. Black: after trimming.

Right: **Average pixel noise (THR)** at each location on the MPA chip.

Shown for Vendor 1 only. Similar results are obtained for both vendors



MaPSAs with MPAs containing regions of high noise are designated as OK.

★ **Bad bump test:** Noise is measured at low bias voltage, and low noise indicates bad bump bonds. **No bad bumps** are identified, even after thermal cycling a MaPSA between 50° and -35° C.

Additional tests: MPA current draw, memory, and register tests all look good.