

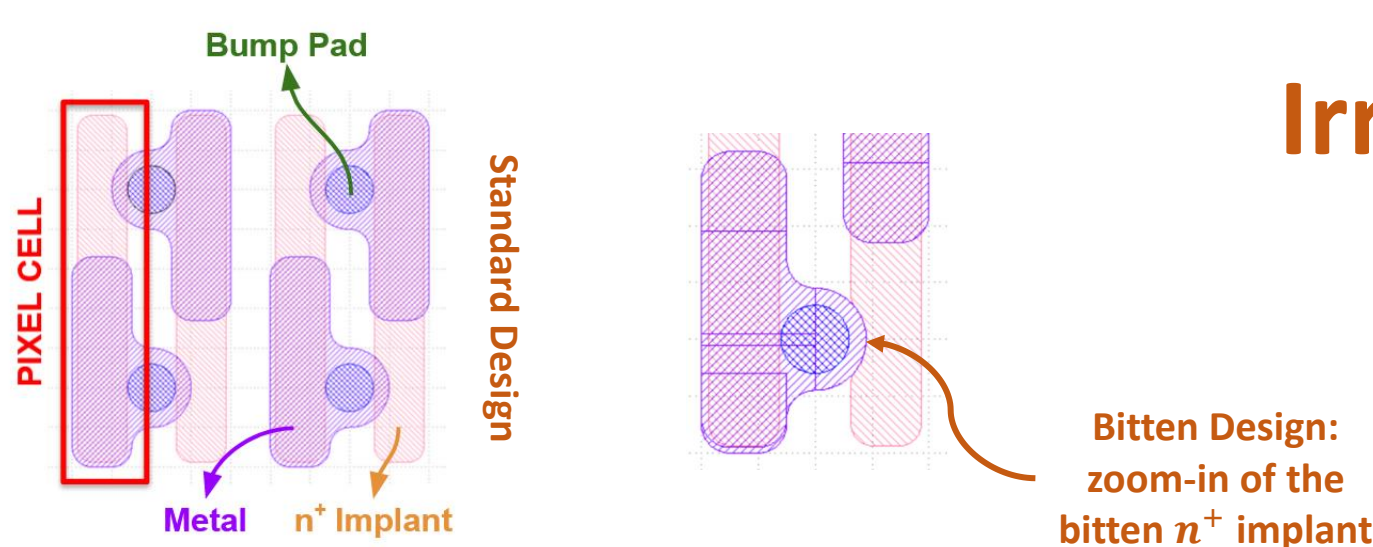


Overview

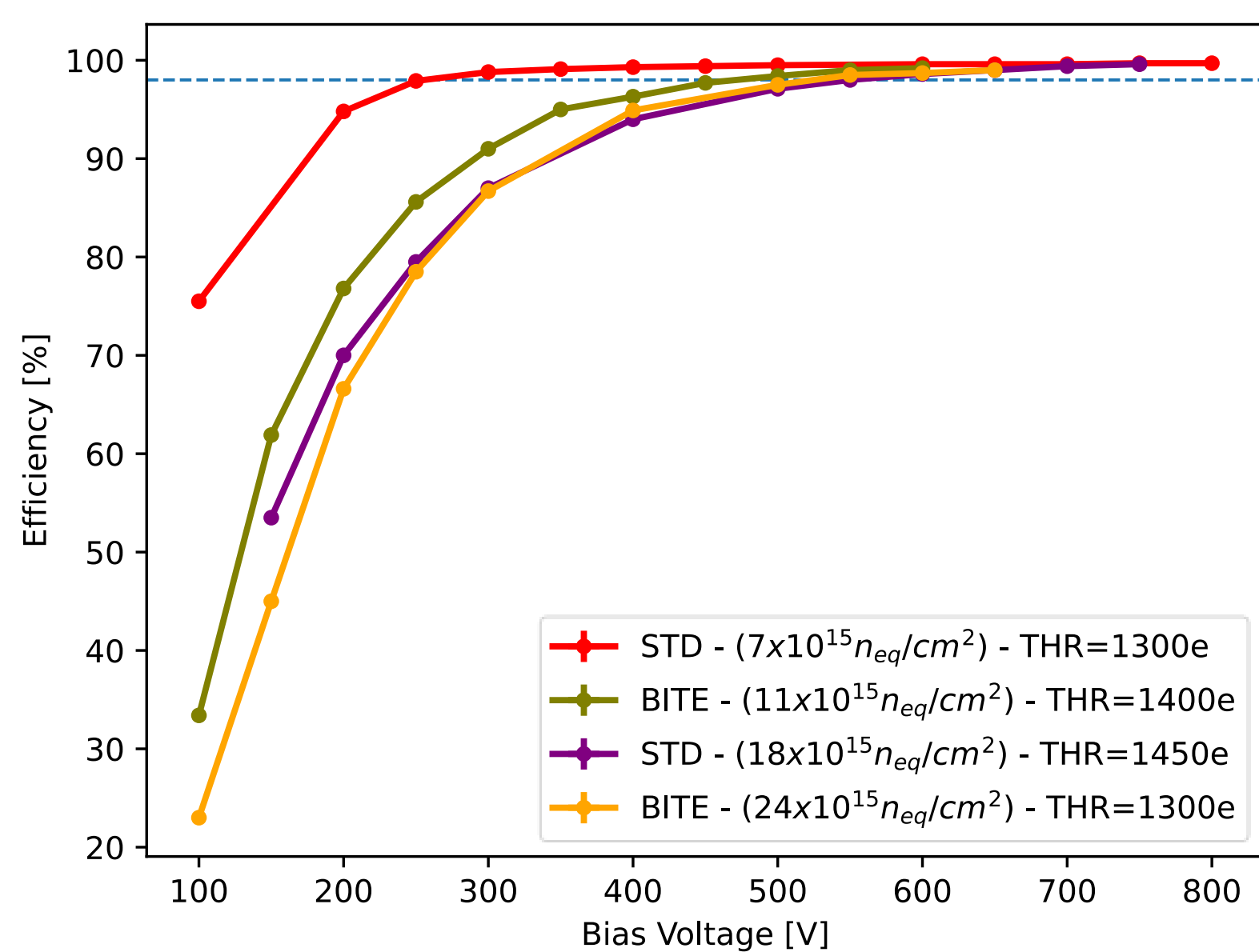
- Two types of pixel sensors are considered for the future CMS Inner Tracker, during High Luminosity LHC:
 - Traditional planar pixel sensors
 - 3D pixel sensors → **Higher radiation resistance**, but difficult and expensive production
- The baseline pixel geometry is $25 \times 100 \mu\text{m}^2$ with $150 \mu\text{m}$ active thickness
- Pixel sensors studied for this work, both 3D and Planar, were developed in a collaboration between INFN and FBK Foundry
- The pixel sensors were interconnected (through bump-bonding) with the **RD53A** readout chip
 - The pixel modules were tested on beam at DESY, after being irradiated up to $24 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$ (using 23 MeV protons at KIT)

Very high TID!

Irradiated Planar Pixel Modules



- Four irradiated planar pixel modules were tested on DESY beam
 - Two with the “standard” design and two with the “bitten” design



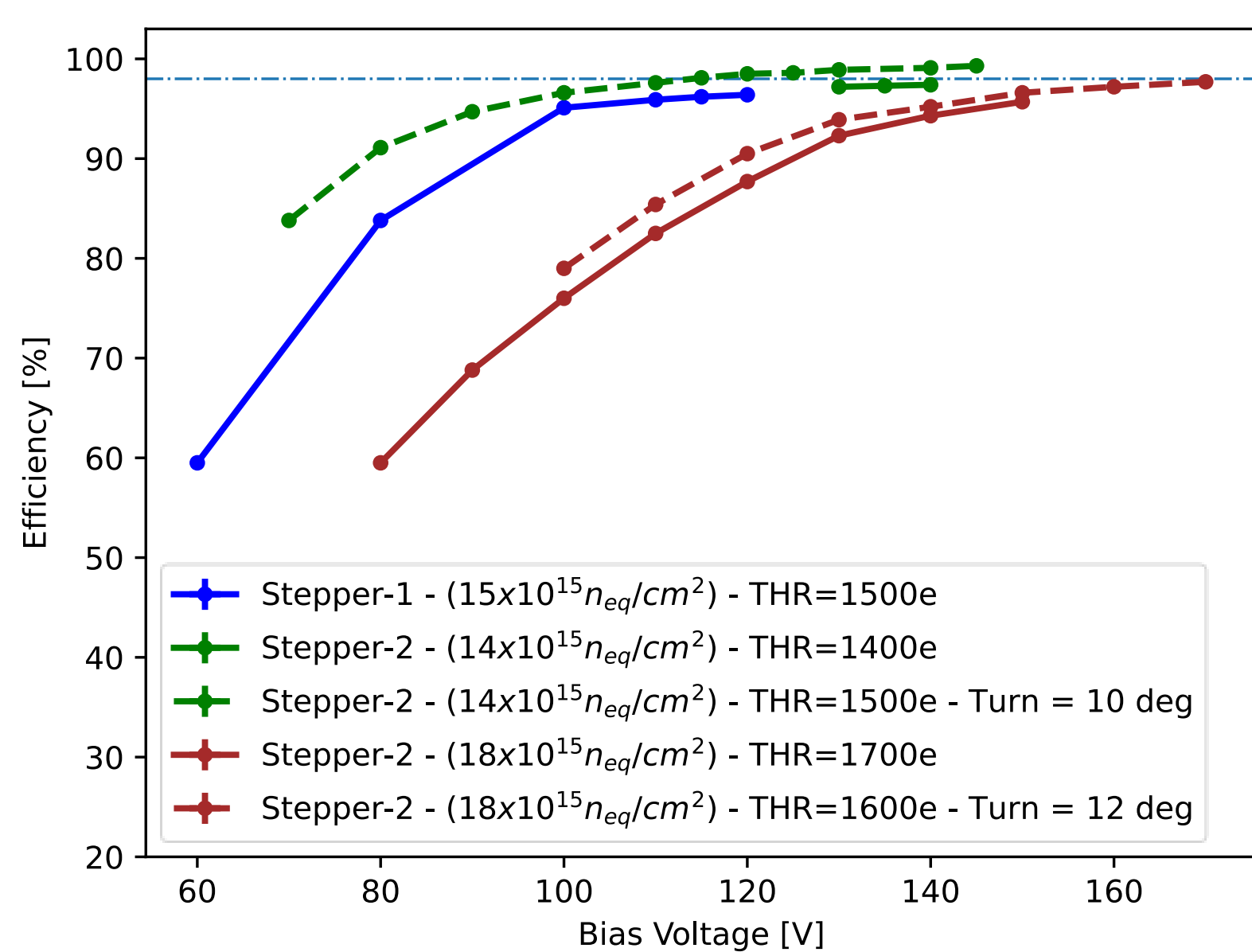
- In order to reach a hit detection efficiency $> 98\%$:
 - $V_{\text{bias}} > 200 \text{ V}$ after a fluence of $7 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$
 - $V_{\text{bias}} > 500 \text{ V}$ after a fluence of $24 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$
- Planar pixel modules can survive HL-LHC Runs 4+5 (2200 fb^{-1}) ...
 - ...in the innermost tracker layer (only 3 cm from the beam line)
 - However, very high bias voltages are required
 - Cooling** becomes challenging, especially in the innermost tracker layer

Reduced Cross-Talk effect!

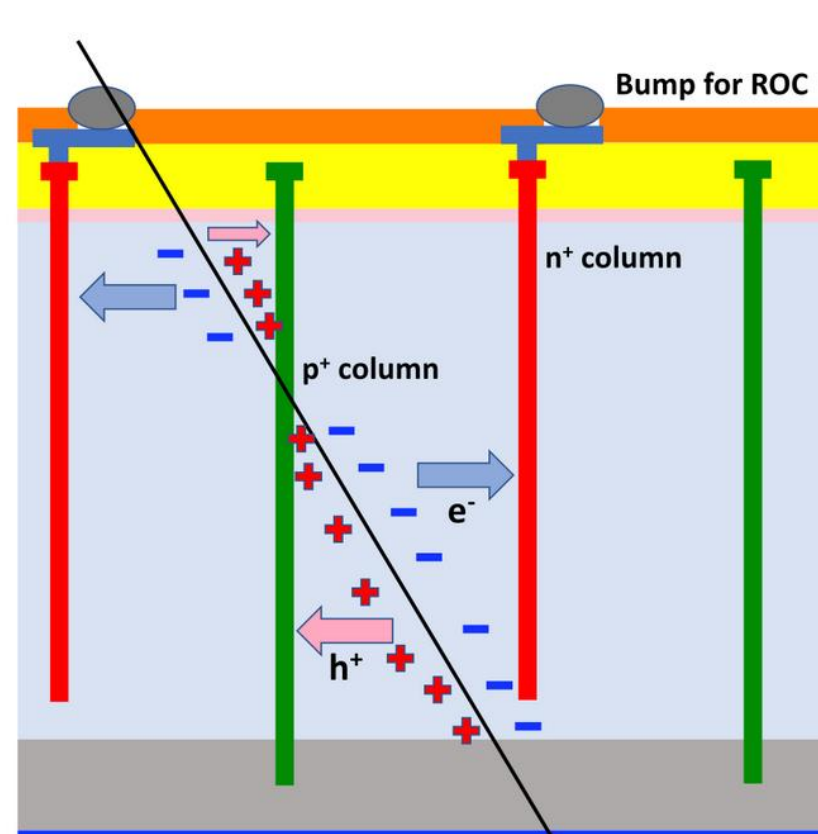
3D pixel modules are now the baseline option for this region

Irradiated 3D Pixel Modules

Dashed lines refer to measurements with the DUT rotated with respect to the beam



- Three irradiated 3D pixel modules were tested on DESY beam
- In order to reach a hit detection efficiency $> 98\%$:
 - $V_{\text{bias}} > 110 \text{ V}$ after a fluence of $15 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$
 - $V_{\text{bias}} > 160 \text{ V}$ after a fluence of $18 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$
- A sudden increase in the number of noisy channels was observed...
 - ...at high bias voltages (greater than 130 – 170 V, depending on the module)
 - The problem was more severe with **Stepper-1** modules ($> 10\%$ of channels)
 - The cause is still under investigation: might be related to the very high TID



3D pixel layout

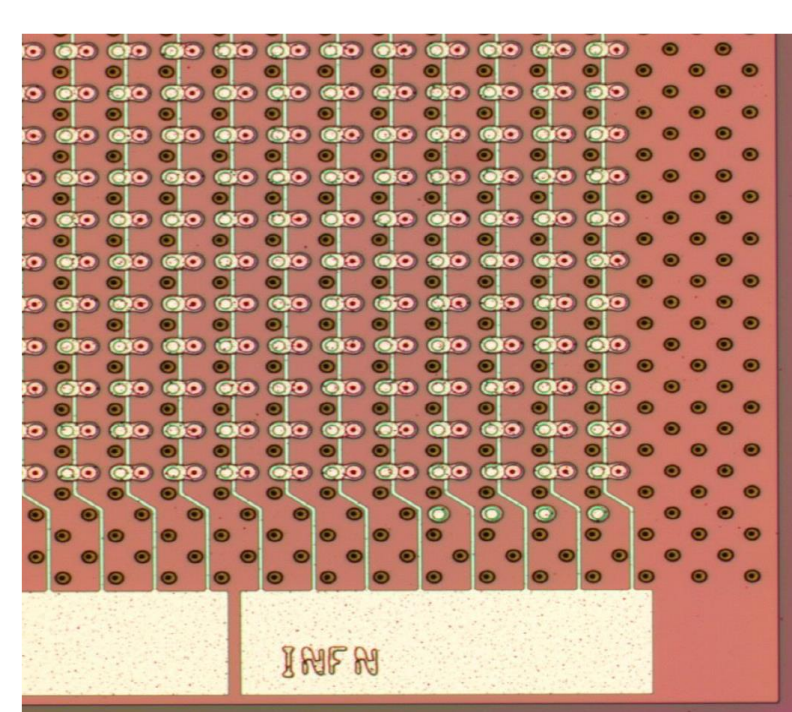


Photo from wafer

- n^+ and p^+ columns penetrate the substrate from the same silicon face
- Two FBK 3D productions: **Stepper-1** and **Stepper-2**
 - Step-And-Repeat photolithography technology
 - Same pixel design, but in Stepper-2 production the distance between n^+ columns and the backside of the sensor (low resistivity silicon) is increased

