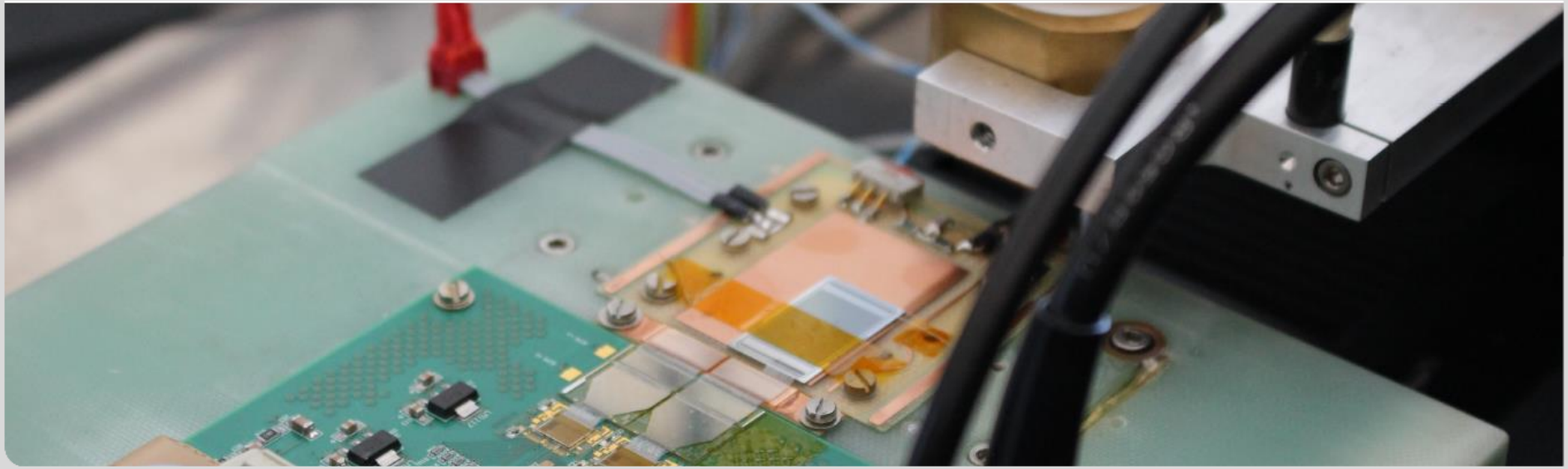
Karlsruher Institut für Technologie

Silicon Sensor Studies within the Scope of the Phase-2 Upgrade of the CMS Outer Tracker

KSETA Workshop 2019 – Marius Metzler

Institut für Experimentelle Teilchenphysik (ETP)



HL-LHC Upgrade in a Nutshell

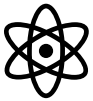
- What do we want?

More interesting data

More significant statistics / decrease uncertainties

Decrease amount of time we need for that to happen

Expand physics potential



- How do we achieve that?

Accelerator upgrades

Higher luminosity

Detector upgrades

CMS Phase-2 Upgrade

- New frame-conditions

Higher pile-up

Higher data output

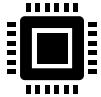
Higher radiation levels

Efficient and reliable performance for at least 10 years

- Solutions

Increase of sensor granularity

Transition from analog to binary read-out of channels



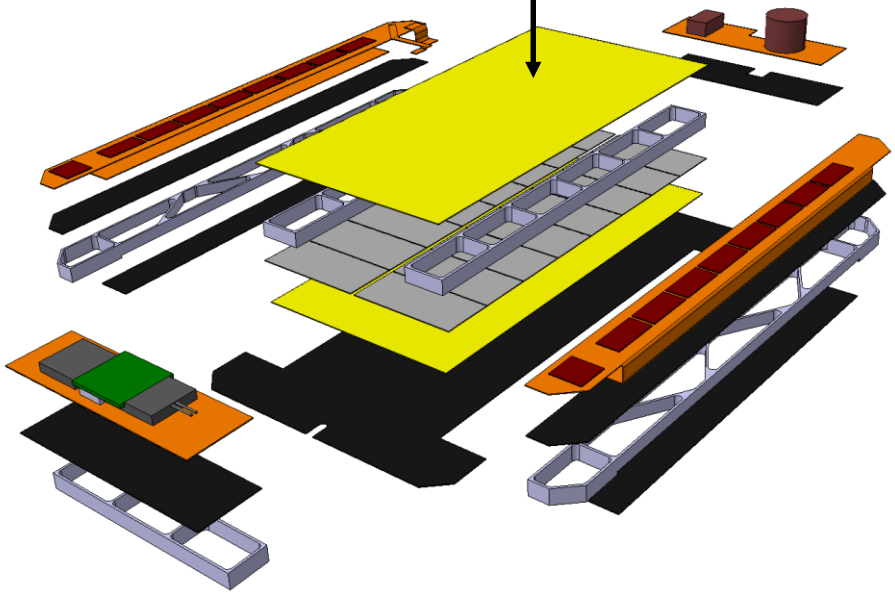
Introduction of low-level data filter

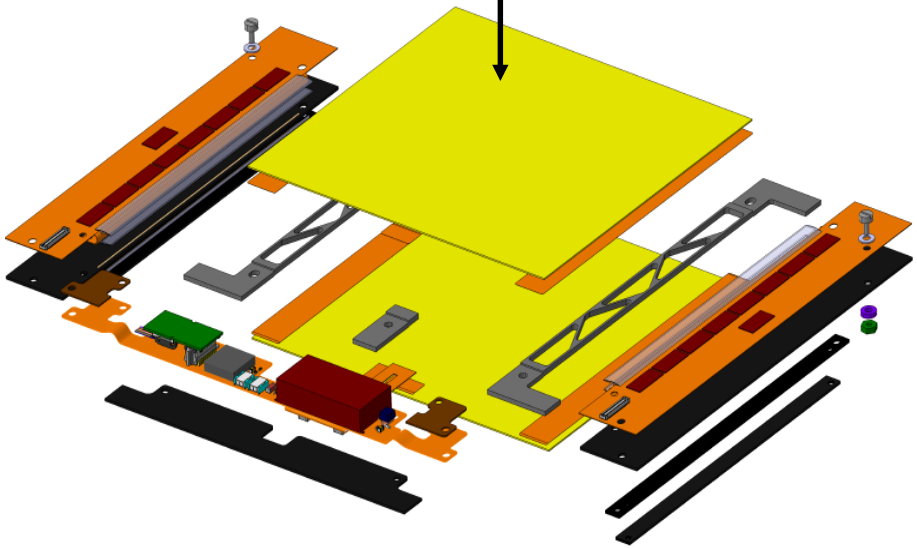
Production of radiation-harder sensors and electronics

Phase-2 Outer Tracker Modules

- New module concept with 2 sensors on top of each other
- 2 module types:
  - 2S (2 strip sensors)
  - PS (macro pixel + strip sensor)

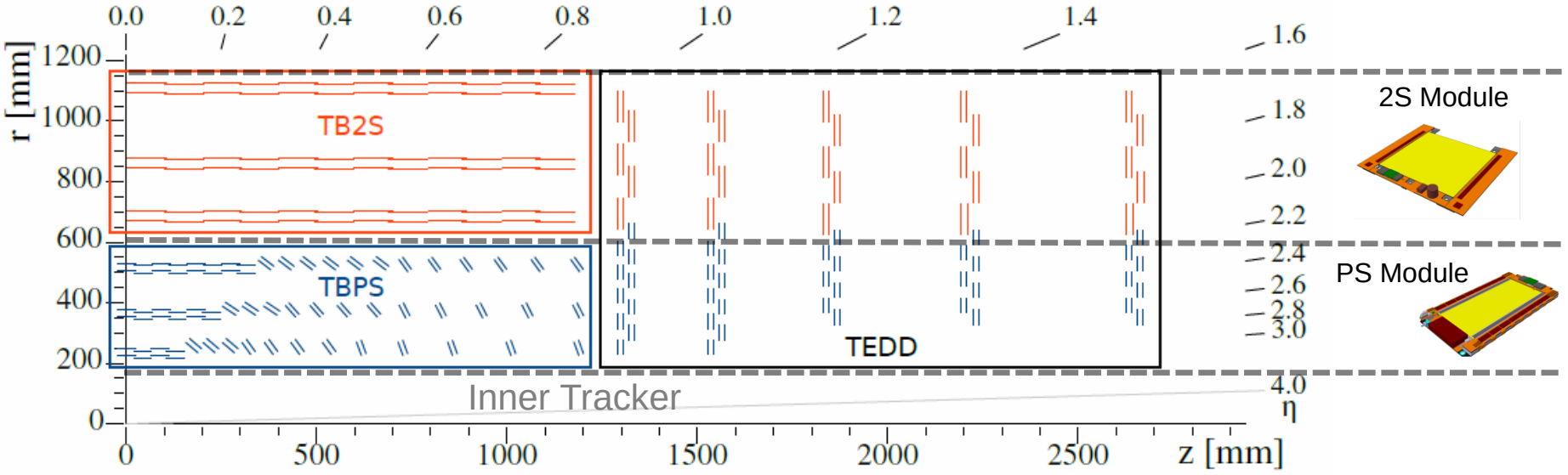
Check-out presentation by Stefan Maier for more information





Phase-2 Outer Tracker Modules

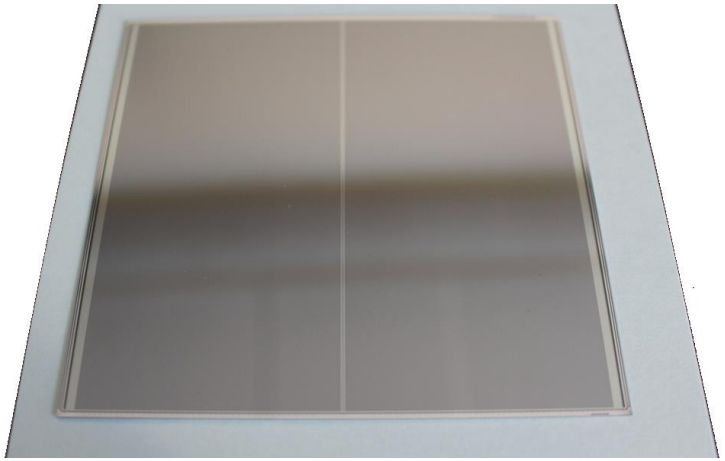
- New module concept with 2 sensors on top of each other
- 2 module types:
  - 2S (2 strip sensors)
  - PS (macro pixel + strip sensor)
- Sensor granularity decreases from center outwards



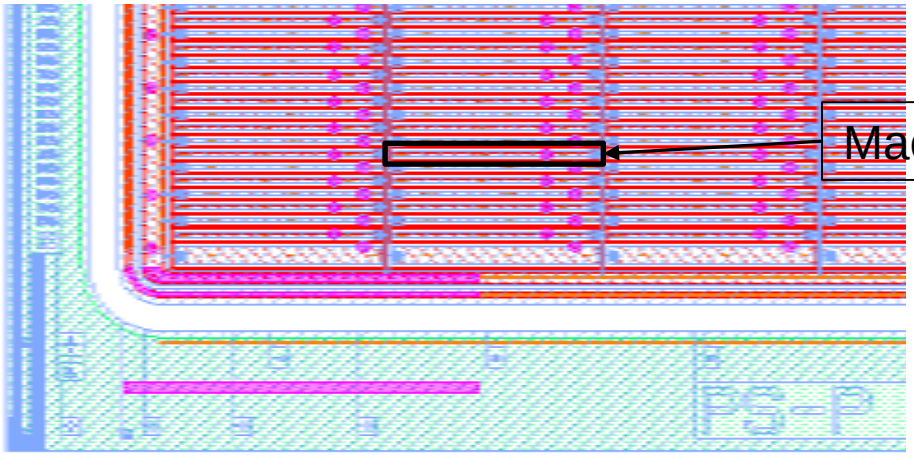
The Phase-2 Outer Tracker Sensors

- **2S**:
  - A = 10 x 10 cm^2
  - Strips: 2 x 1016 = 2032
  - Pitch: 90 µm
- **PS-s**:
  - A = 5 x 10 cm^2
  - Strips: 2 x 960 = 1920
  - Pitch: 100 µm
- **PS-p**:
  - A = 5 x 10 cm^2
  - Macro pixel: 32 x 960 = 30208
  - Pixel size: 100 x 1500 $µm^2$

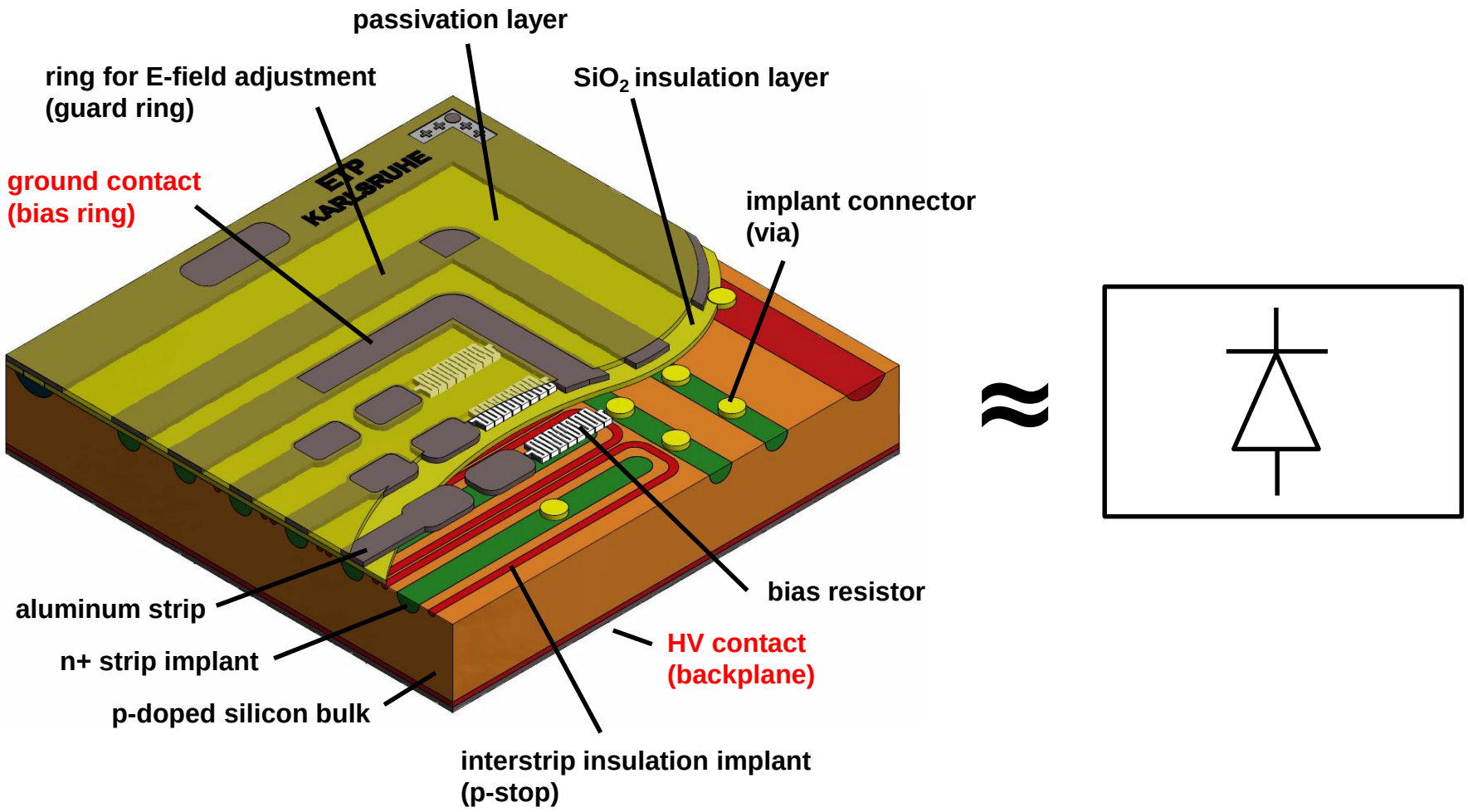
2S Sensor



PS-p Sensor



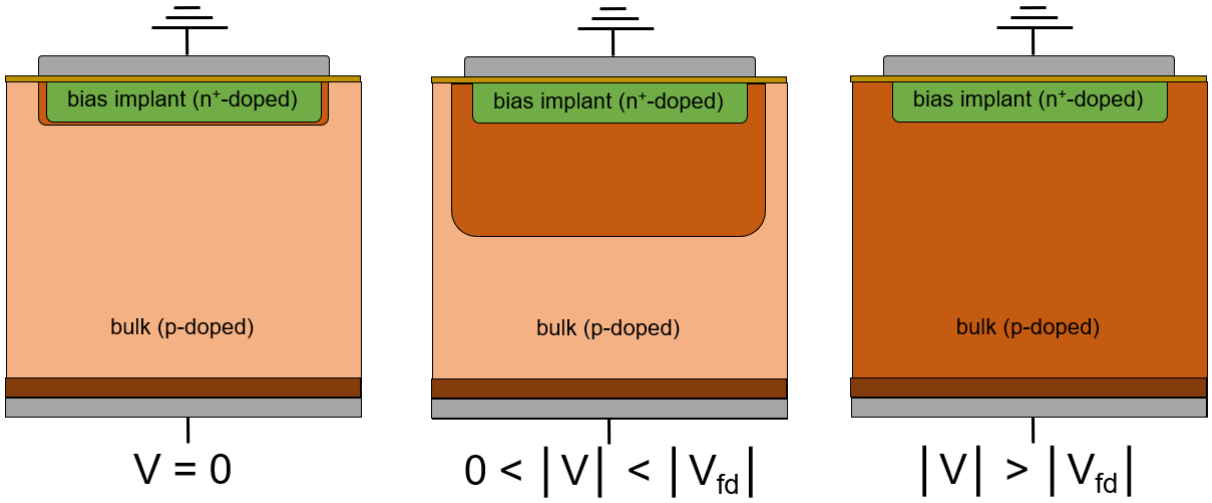
Silicon Strip Sensor - Basics



Silicon Strip Sensor - Basics

1) Operation under reverse bias at full depletion

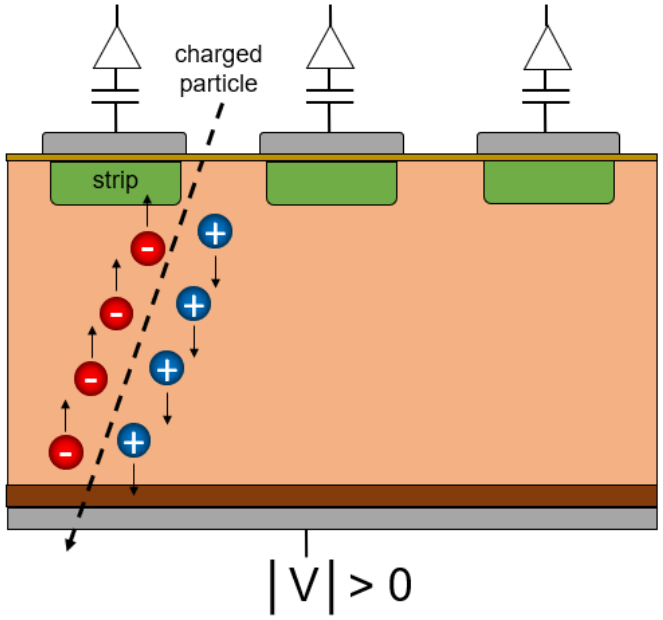
- $N_{\text{free charge carriers}} \approx O(10^8)$ >> $S_{\text{particle}} \approx O(10^5)$
  → full depletion is mandatory
- Leakage current I_{leak} of sensor is a significant quantity
  - $I_{leak} \sim V_{bias}$
  - $I_{leak} \sim T$ → operation temperature in tracker T < 0



Silicon Strip Sensor - Basics

2) Particle detection

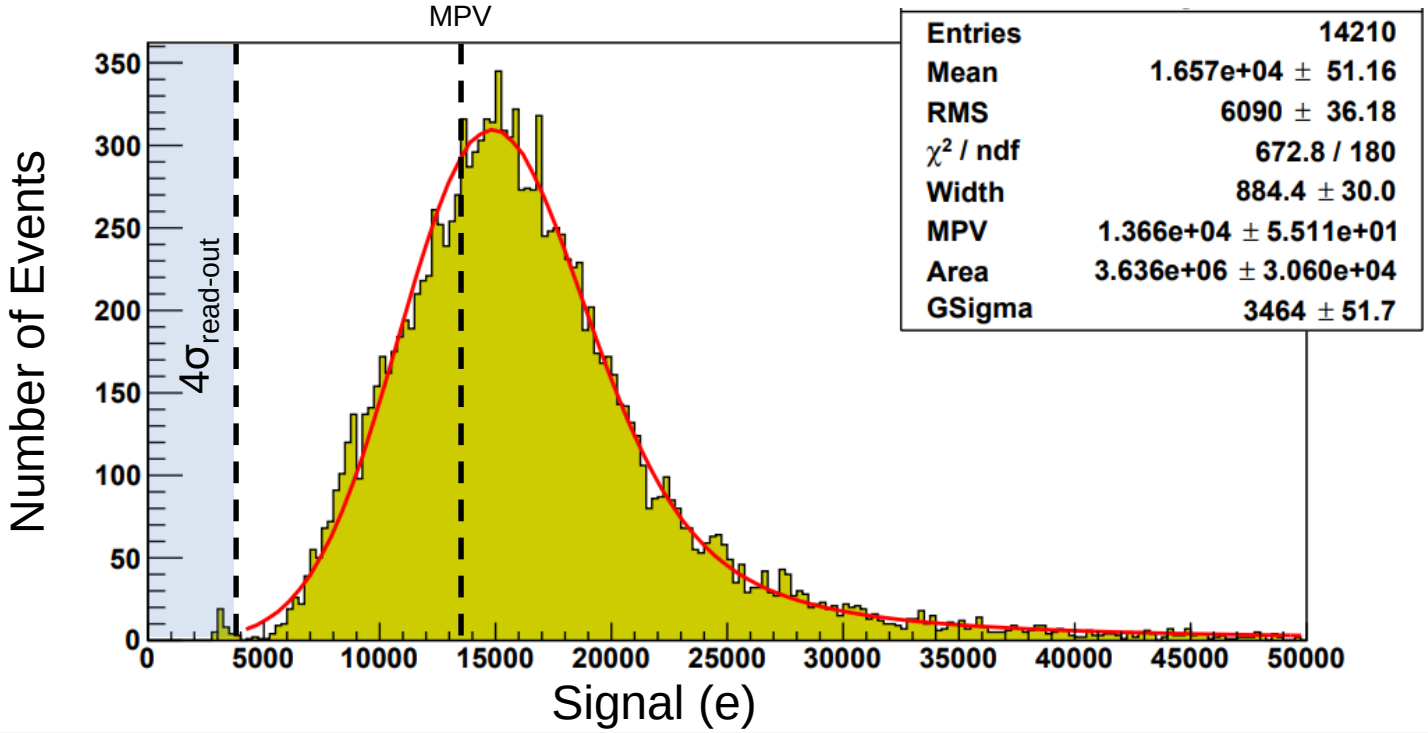
- Traversing charged particles generate eh-pairs → eh-pairs are separated by E-filed → charge is collected by strips
- $S_{particle}$ is dependent on sensor thickness (~ 75 eh/µm)



Silicon Strip Sensor - Basics

3) Signal

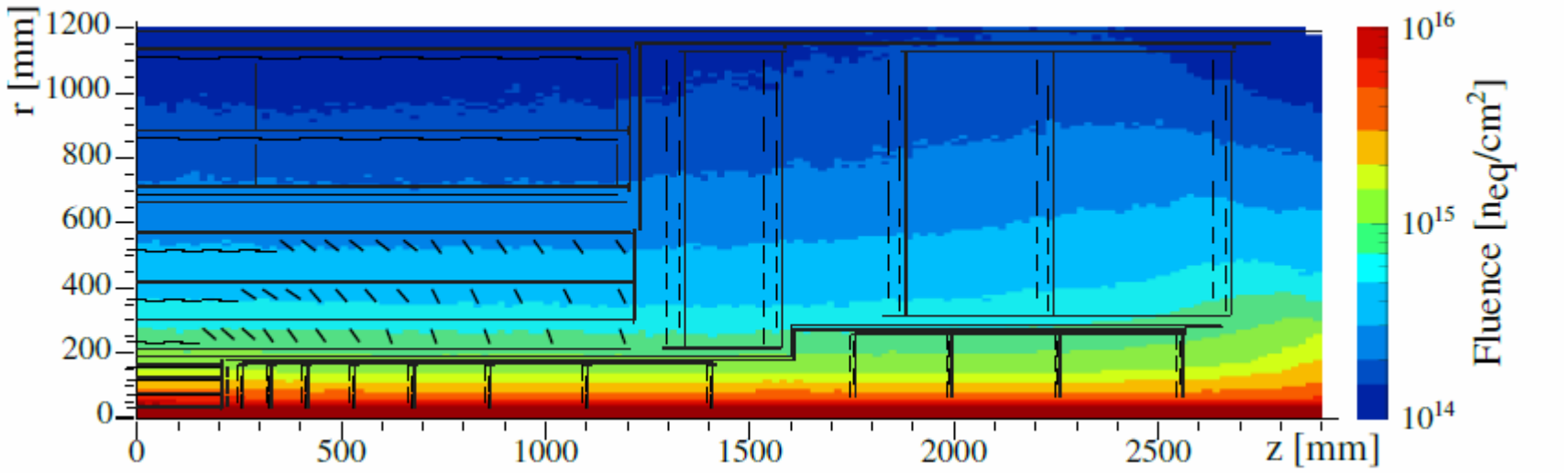
- *Signal* = most probable value (MPV) of signal distribution
- Sensor's MPV has to be well-above the noise of read-out electronics to make its operation efficient (rule of thumb: MPV/3 > $4\sigma_{\text{read-out}}$)



Silicon Strip Sensor - Basics

4) Radiation damage

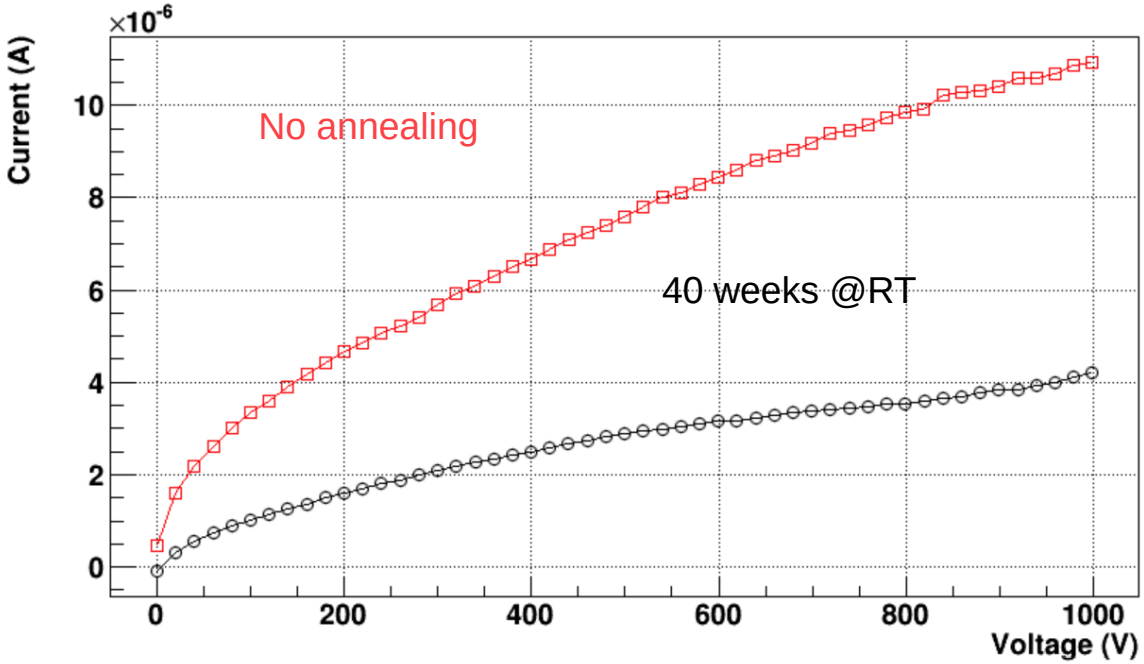
- Introduces defects in silicon lattice → additional states within the band gap → reduction of signal and increase of leakage current
- Expected maximum fluences after 10 years:
  - $\Phi_{2S} = 3 \times 10^{14}\ n_{eq}cm^{-2}$
  - $\Phi_{PS} = 1 \times 10^{15}\ n_{eq}cm^{-2}$



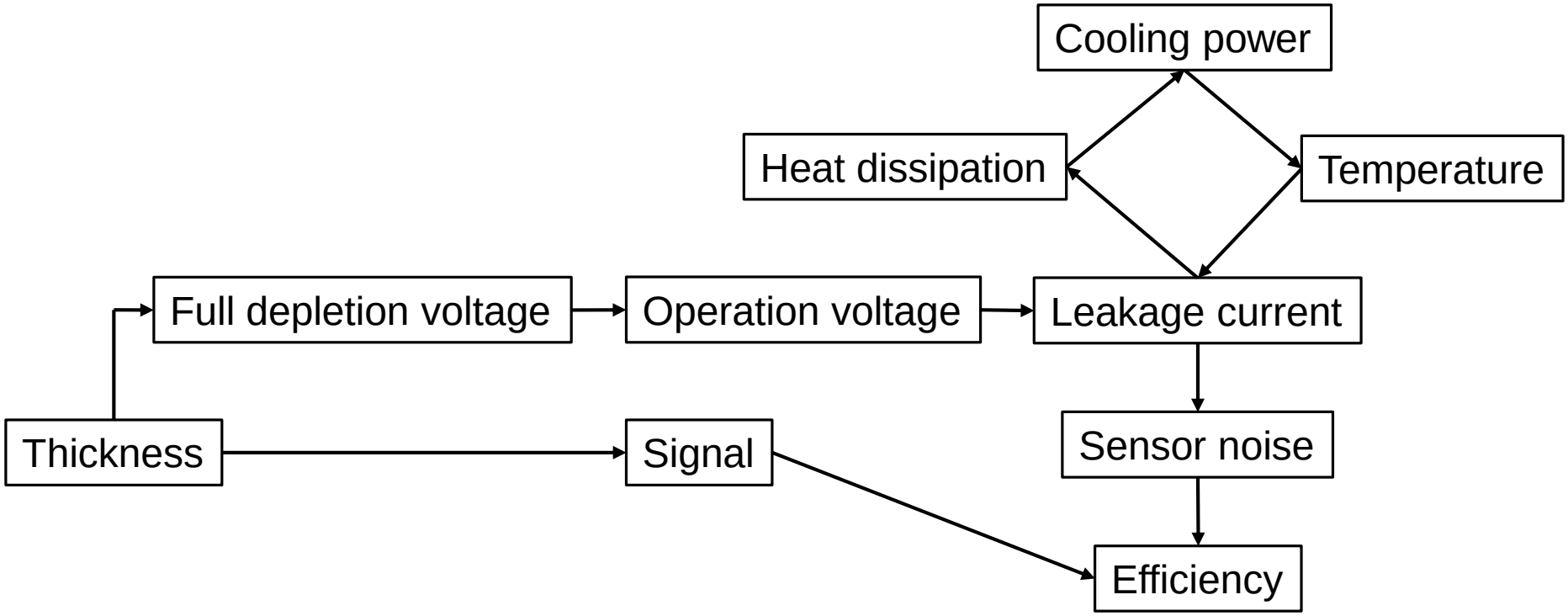
Silicon Strip Sensor - Basics

5) Annealing

- Irradiated sensors anneal at room temperature (RT) → reduces leakage current and affects signal
- Annealing period during year-end technical stop possible



Relation of Sensor Parameters



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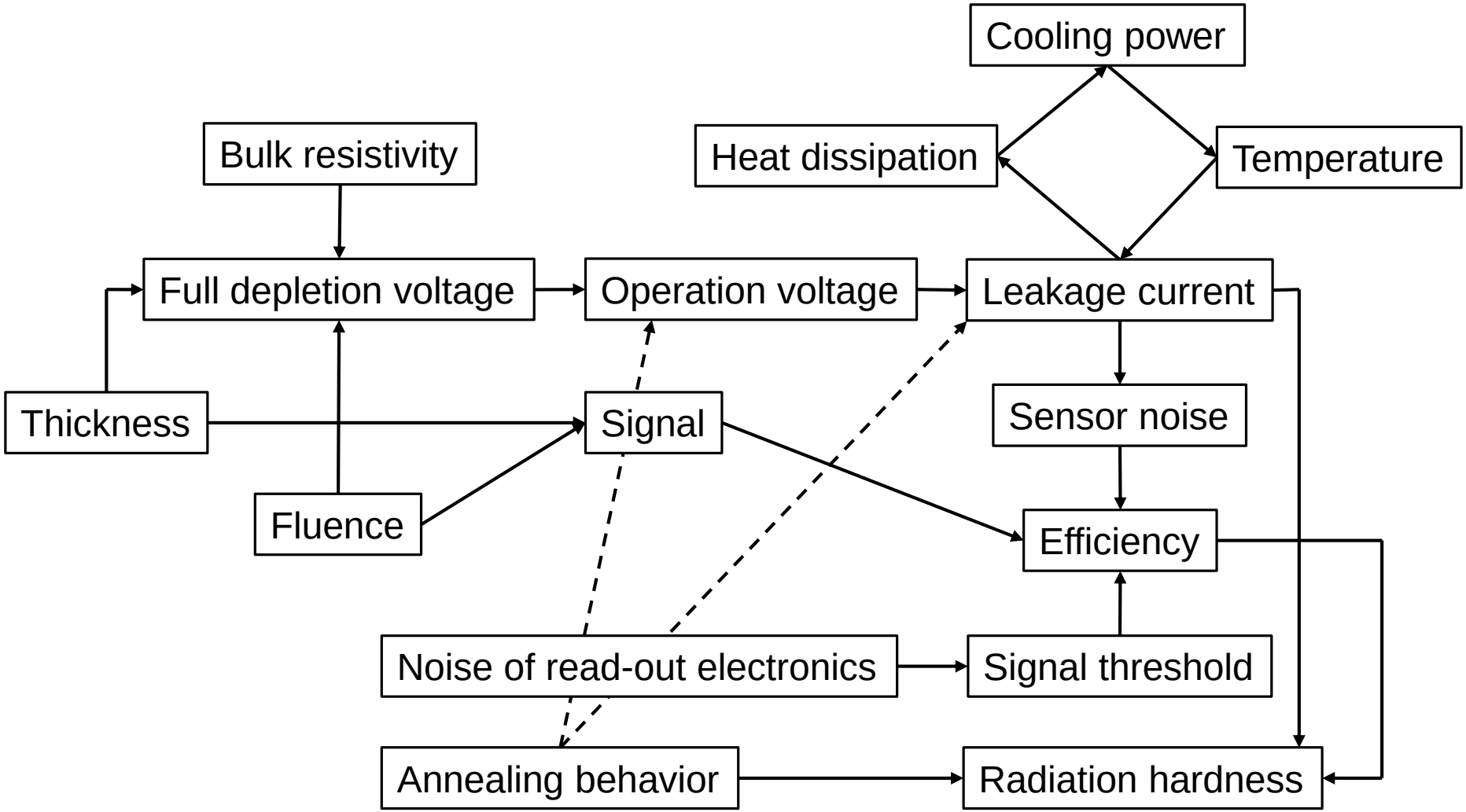

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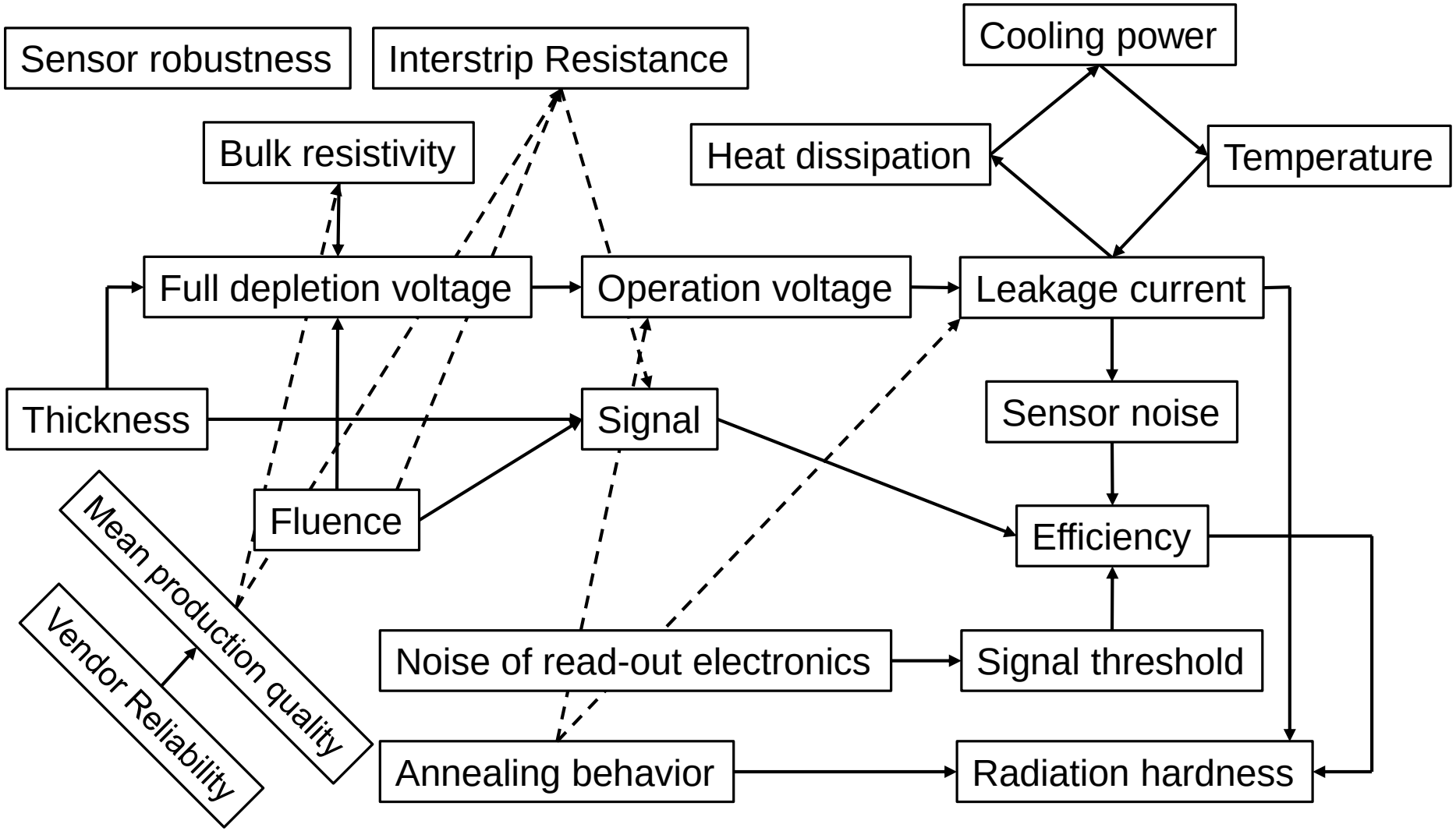


Relation of Sensor Parameters

Sensor robustness

Interstrip Resistance

Cooling power

Temperature

Thickness

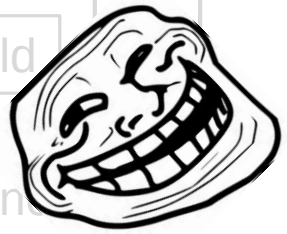
Mean production quality

Vendor Reliability

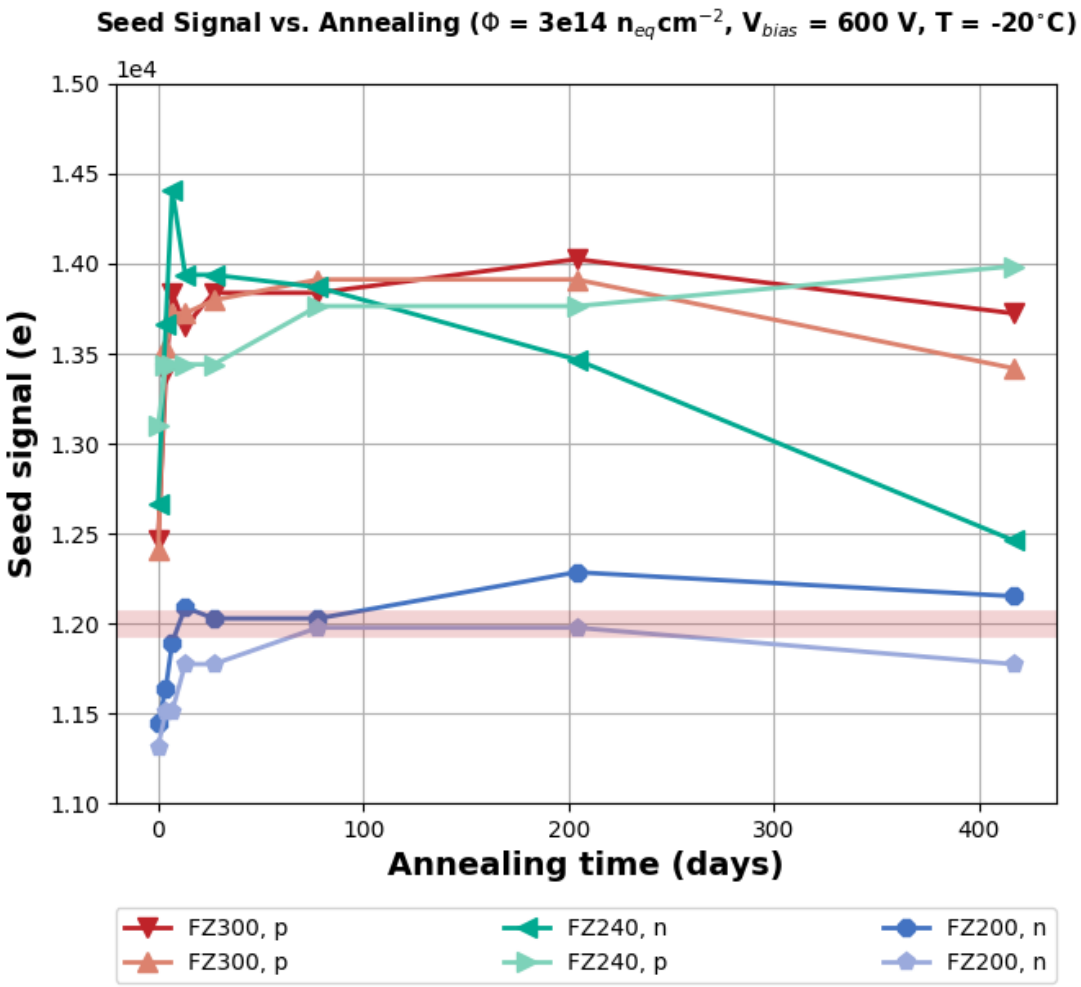
Noise of read-out electronics

Signal threshold

Annealing behavior



Material Studies at ETP – Recent Results

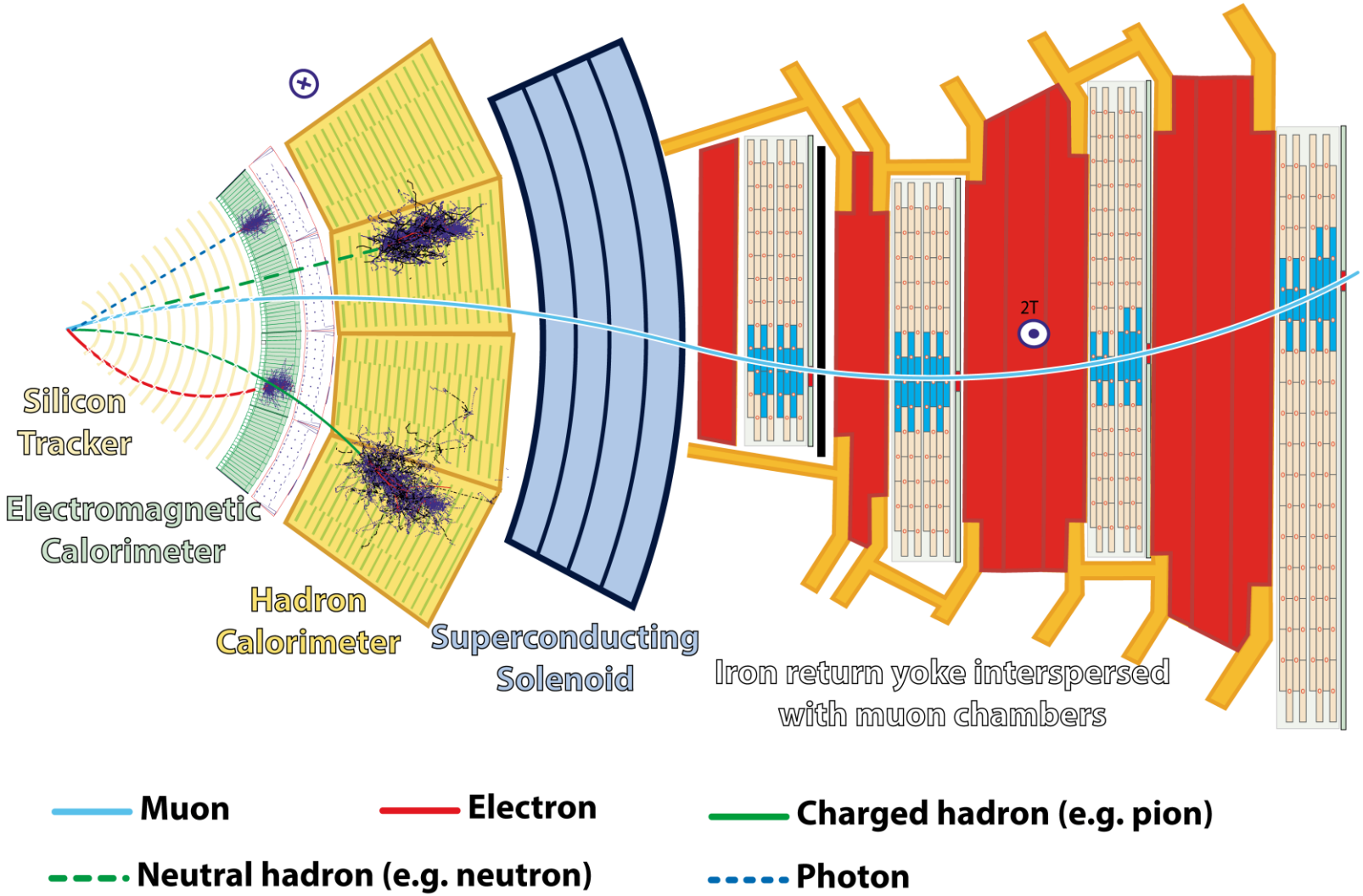


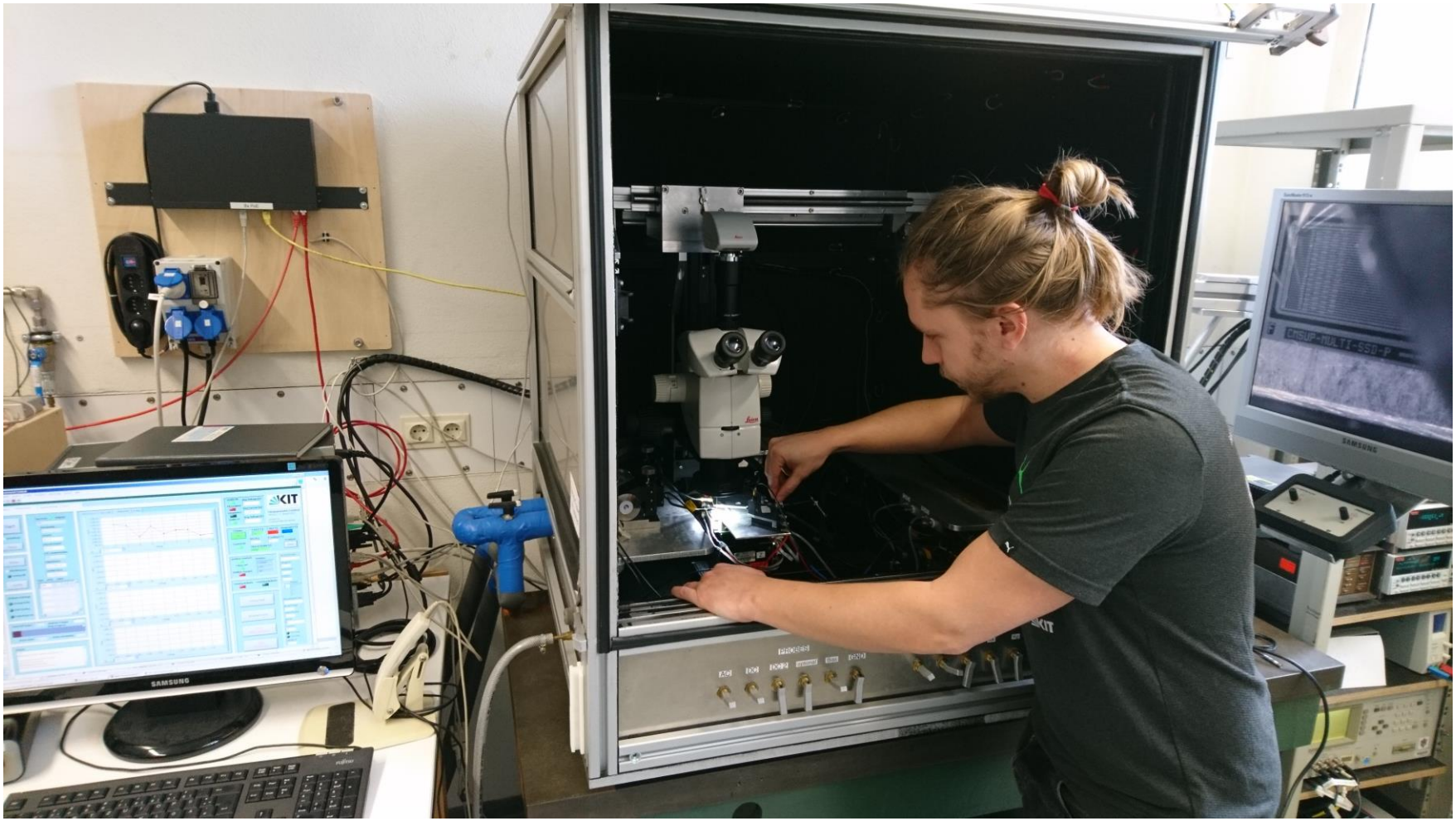
- Comparison of 200, 240 and 300 µm material for
  - $\Phi_{2S} \approx$ 3e14 $n_{eq}cm^{-2}$
  - V_{bias} = 600 V
- Signal of 200 µm material too low
- 240/300 µm provide similar signal and annealing characteristic at 600 V

Material Studies at ETP – Irradiation Studies

- ETP is leading institute in terms of irradiation studies due to powerful self-built setups and infrastructure
- Material decision will be made almost exclusively based on our studies
- More than 10 years of
  - Irradiation studies
  - Sensor qualification
  - Vendor qualification
- Final irradiation campaign on-going (material decision this summer)

Back Up


Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with muon chambers
2T
Muon
Electron
Charged hadron (e.g. pion)
Neutral hadron (e.g. neutron)
Photon


SAMSUNG
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Vorsicht
Erhöhte Strahlung