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Physik EIV

Power Dissipation Studies on n^+-in-n Pixel Sensors

27th RD50 Workshop
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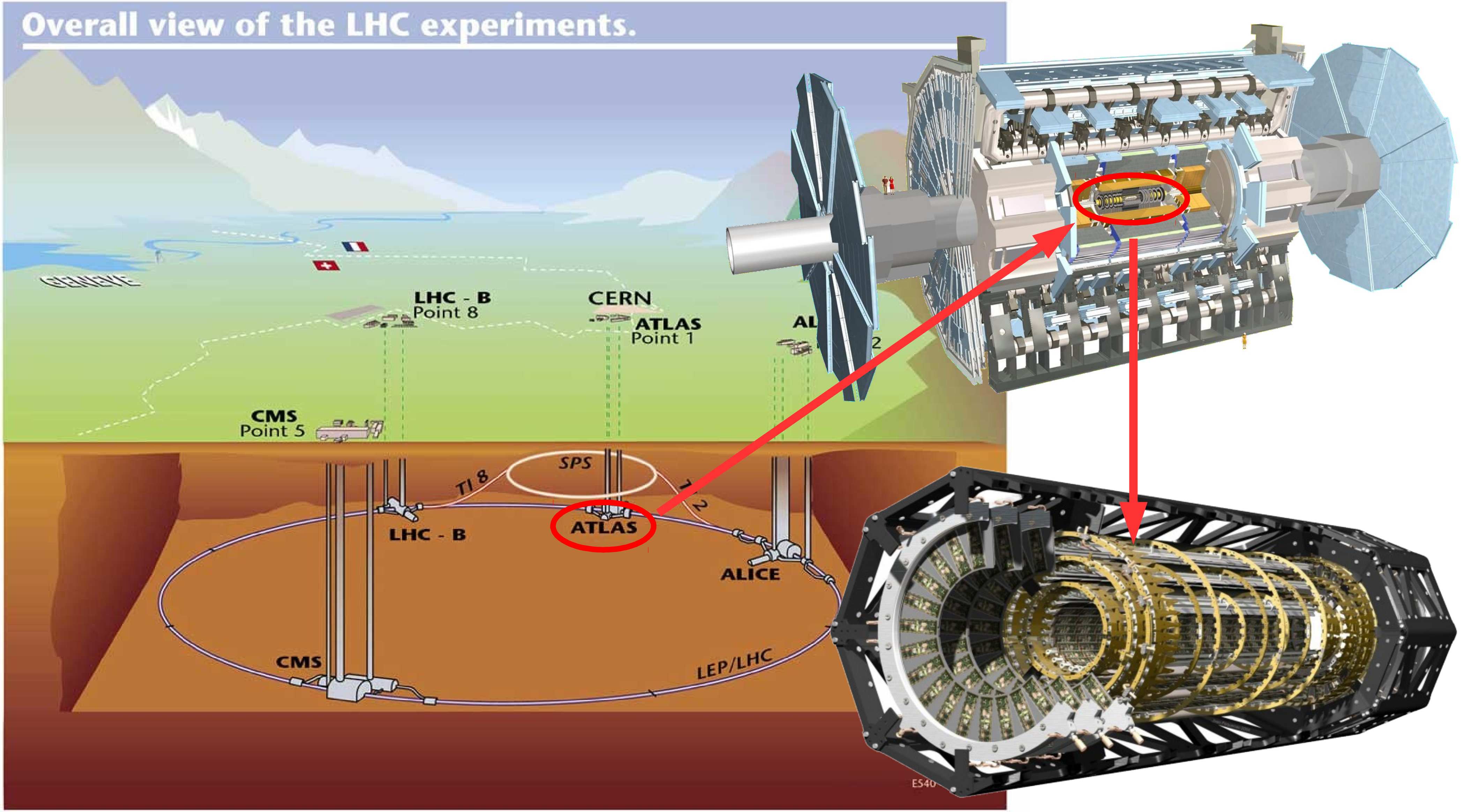
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

FSP 101
ATLAS

CERN

The ATLAS pixel detector



LHC/HL-LHC roadmap (July 2015)

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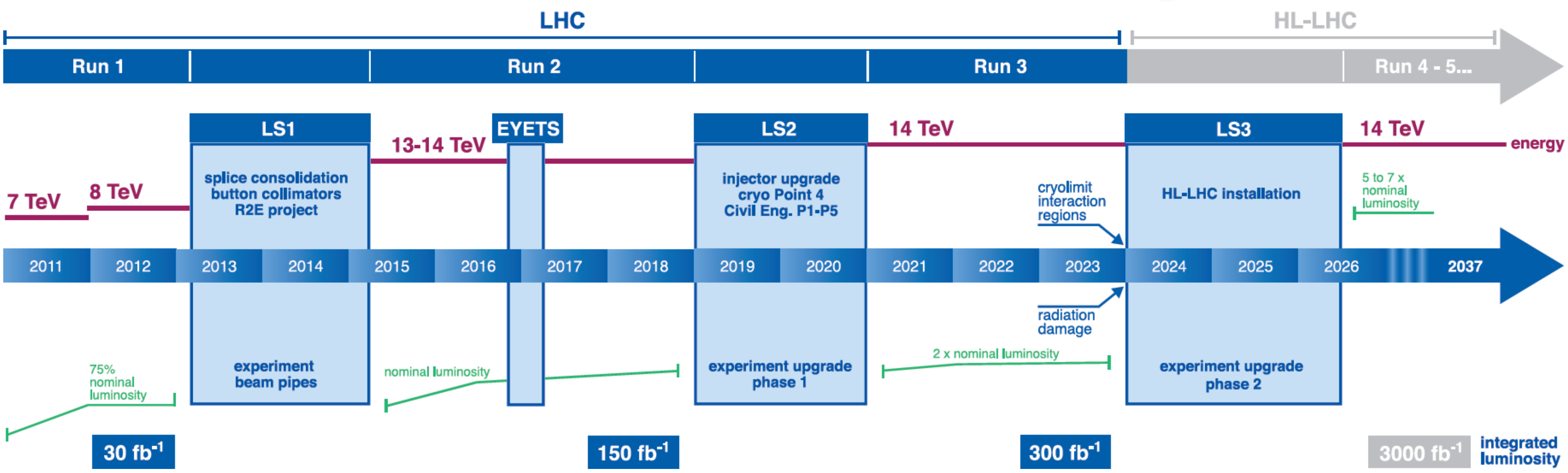

- 3-layer detector sensors: 10^{15} $n_{eq}cm^{-2}$, 250 µm
  - FE-I3: 400×50 µm^2
- 4th layer (IBL) sensors: 5×10^{15} $n_{eq}cm^{-2}$, 200 µm
  - FE-I4: 250×50 µm^2
- Inner Tracker (ITk) sensors: 2×10^{16} $n_{eq}cm^{-2}$, ≤150 µm
  - RD53 ASICs: 50×50 µm^2

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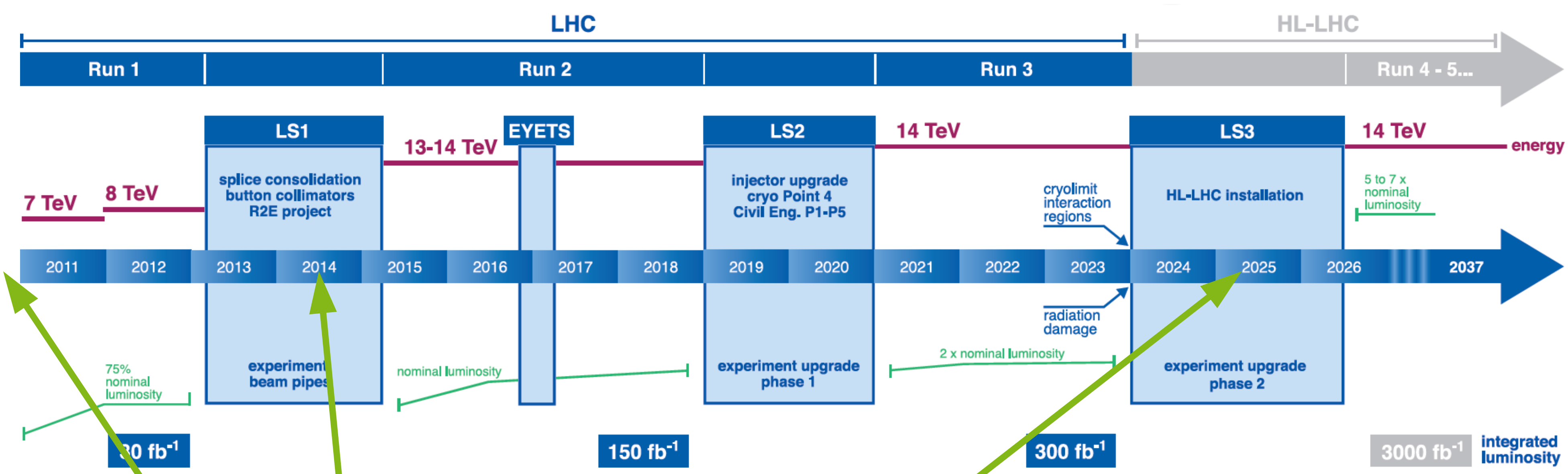

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Impact of Power dissipation

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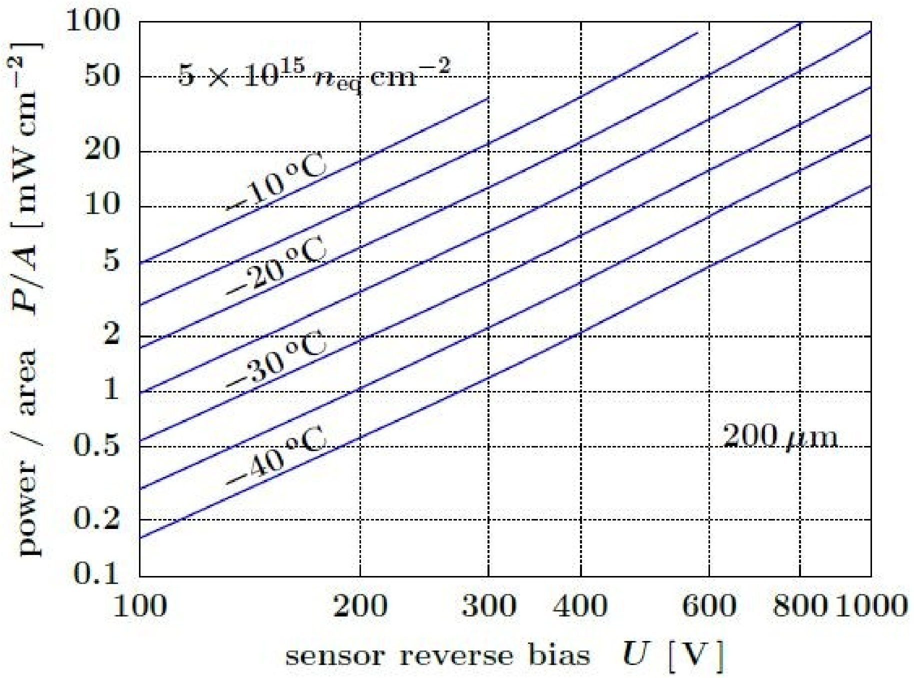
- Sensor leakage current rises with irradiation
- Limits detector operational capability
- Can be lowered by cooling
- Assumed on-sensor temperature in ATLAS-ITk: -25°C

- Sensor temperature depends on balance of power dissipation and cooling
  - Worst case: Thermal runaway
- Need for reliable values for power dissipation

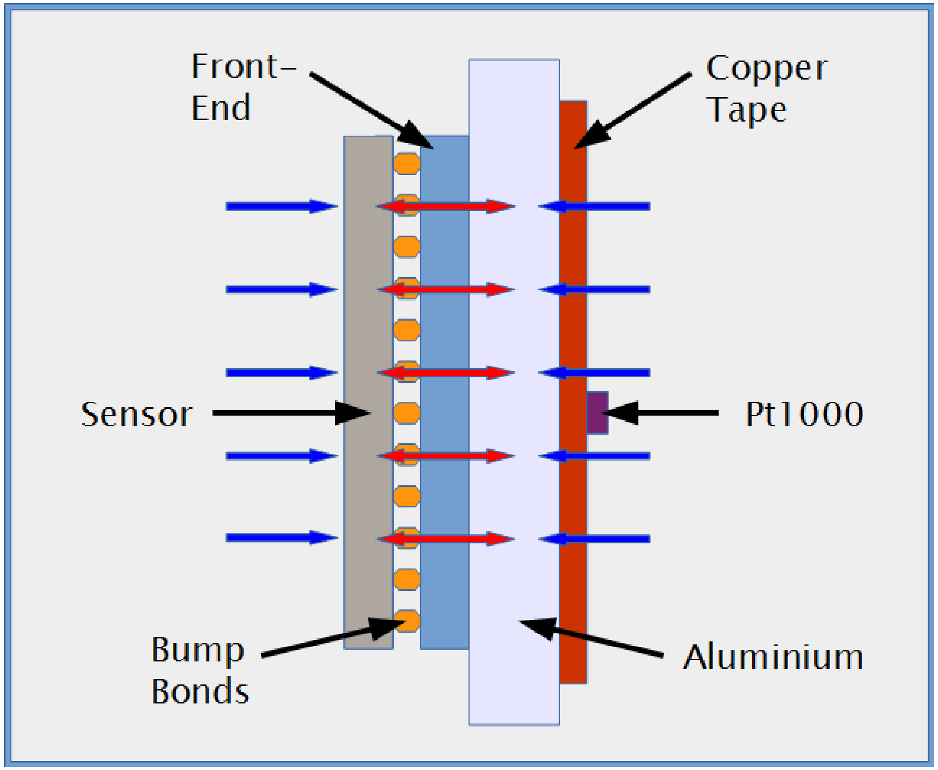
Detailed study for n-in-n sensors

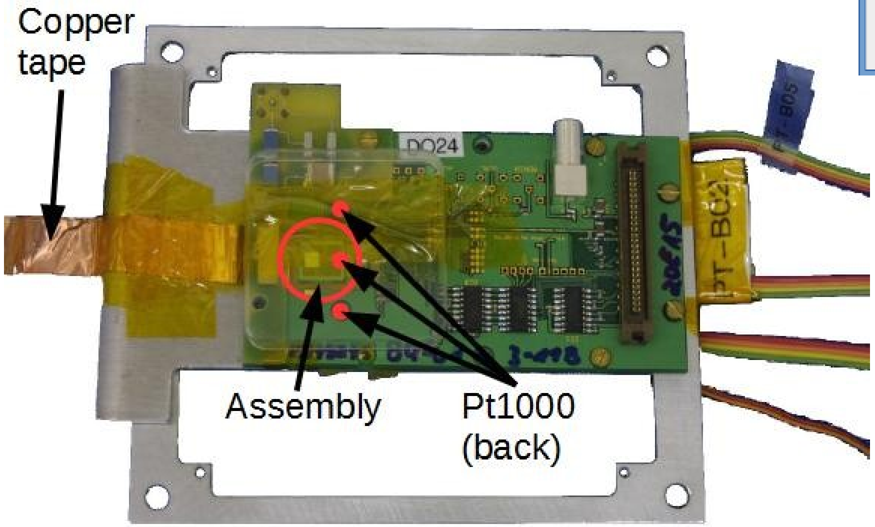
- 6 irradiated Single Chip Assemblies
- Thicknesses: 150, 200, 250 µm, each 2 times
- Fluence: $5x10^{15}\ n_{eq}cm^{-2}$
- Range: 0-1000 V
- Temperature: -10 to -40°C
- Repeated measurement of the same sensors



Lab setup for assemblies

- Placed on chiller cooled plate
- Additional cooling by chilled dry air
- Front-End not used nor powered
- Sensor temperature measured on FE side
- Looking for an effective scaling parameter considering this setup





Measurement approaches

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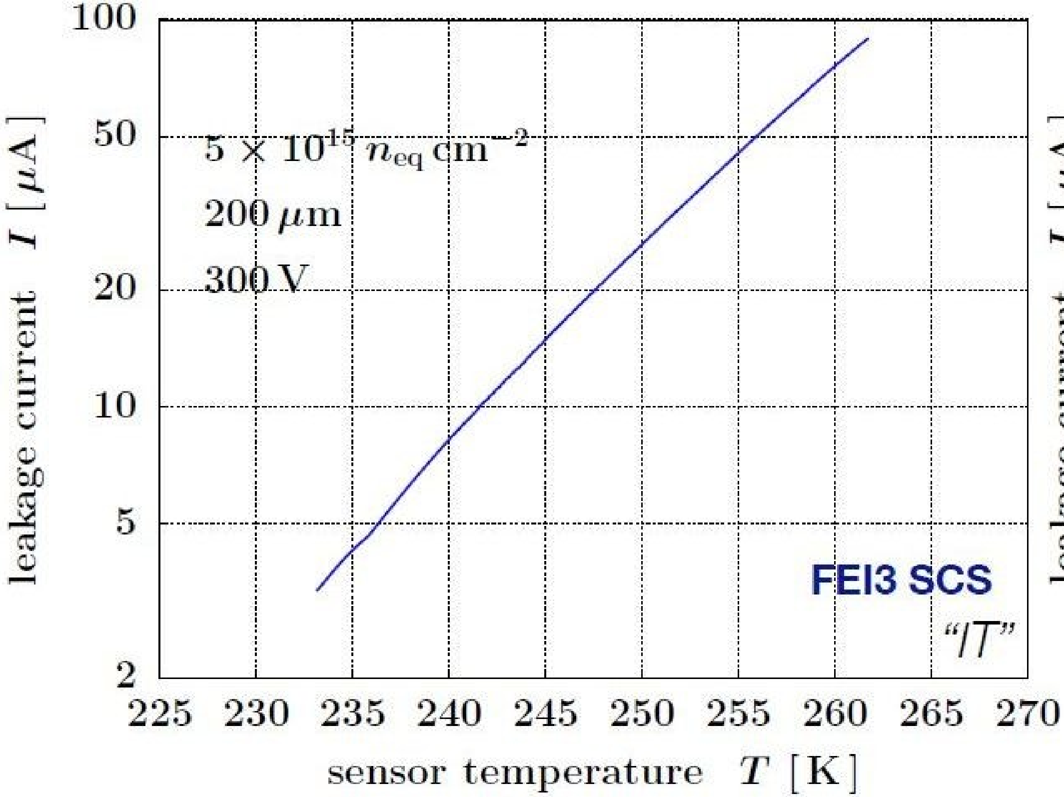
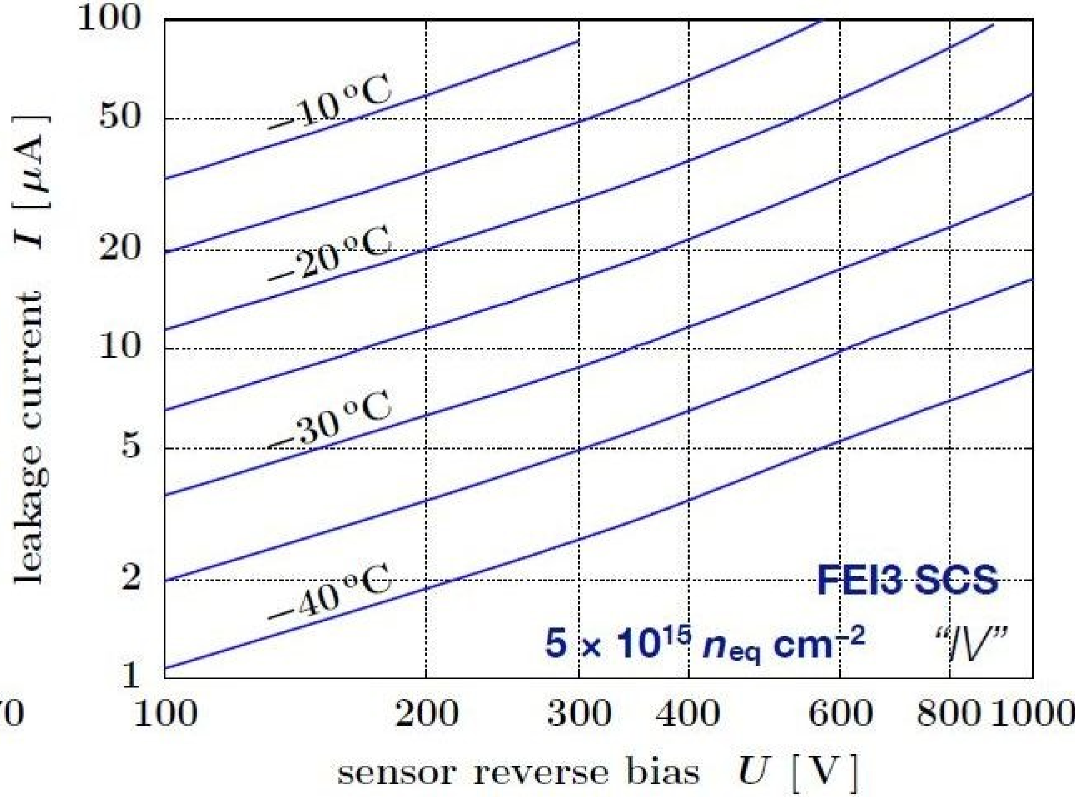


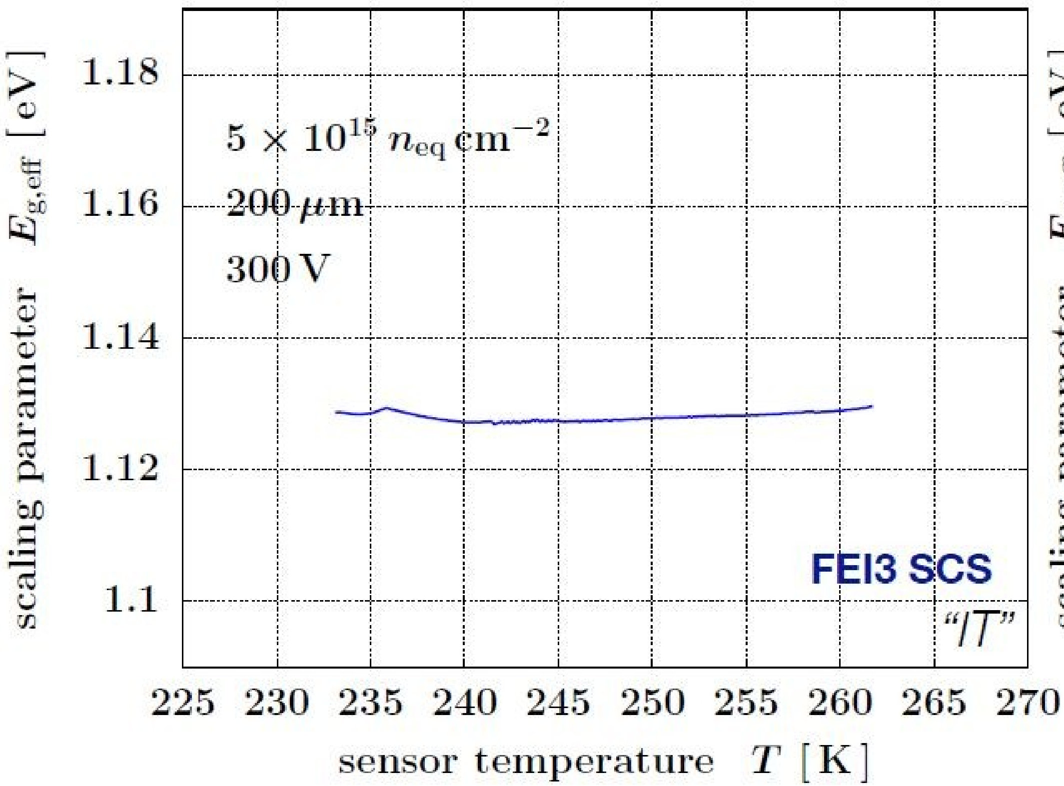


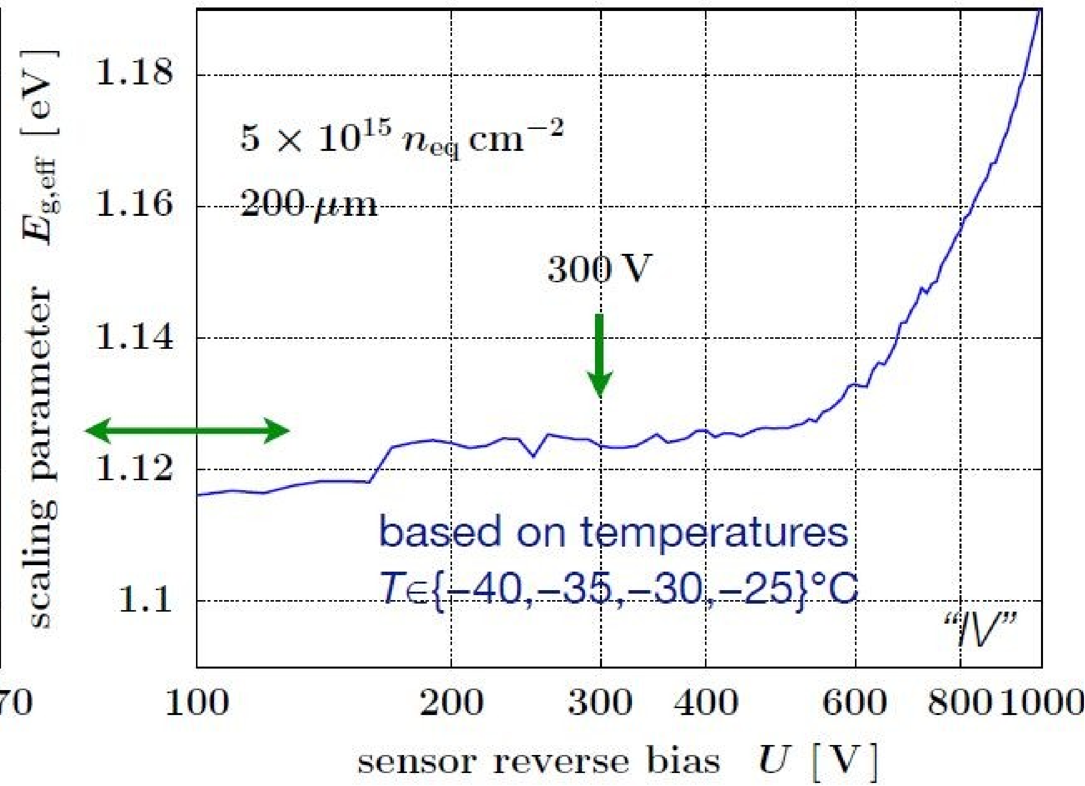
- Current vs temperature
- Fixed voltage

- Current vs bias voltage
- Fixed temperature

$$I = A \cdot T^2 \exp\left(\frac{-E_{\mathrm{g,eff}}}{2k_B T}\right)$$

Determine scaling parameter





- Nearly constant with temperature
- $E_{g,eff}$ = 1.13 eV

$$E_{\mathrm{g,eff}} = -2k_B T \cdot \ln\left(\frac{I}{A \cdot T^2}\right)$$

- Value of scaling parameter depends on voltage
- $E_{g,eff}$ = 1.16 eV (800 V)
- $E_{g,eff}$ = 1.19 eV (1000 V)

Apply on power dissipation

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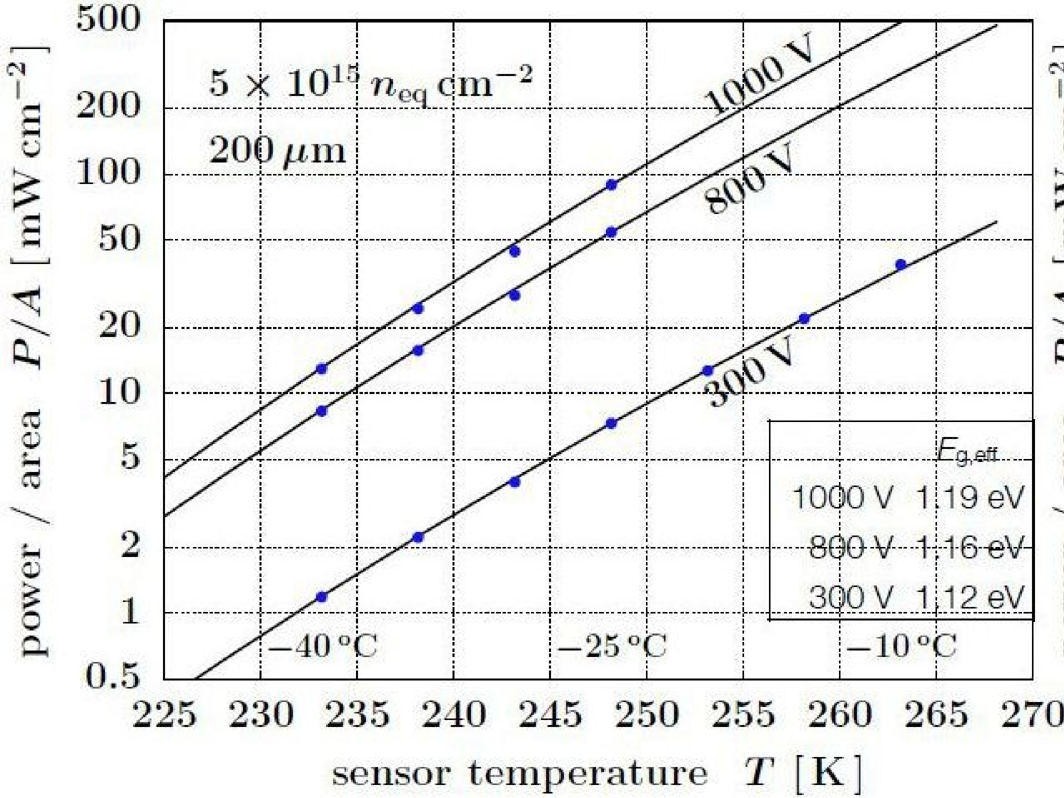

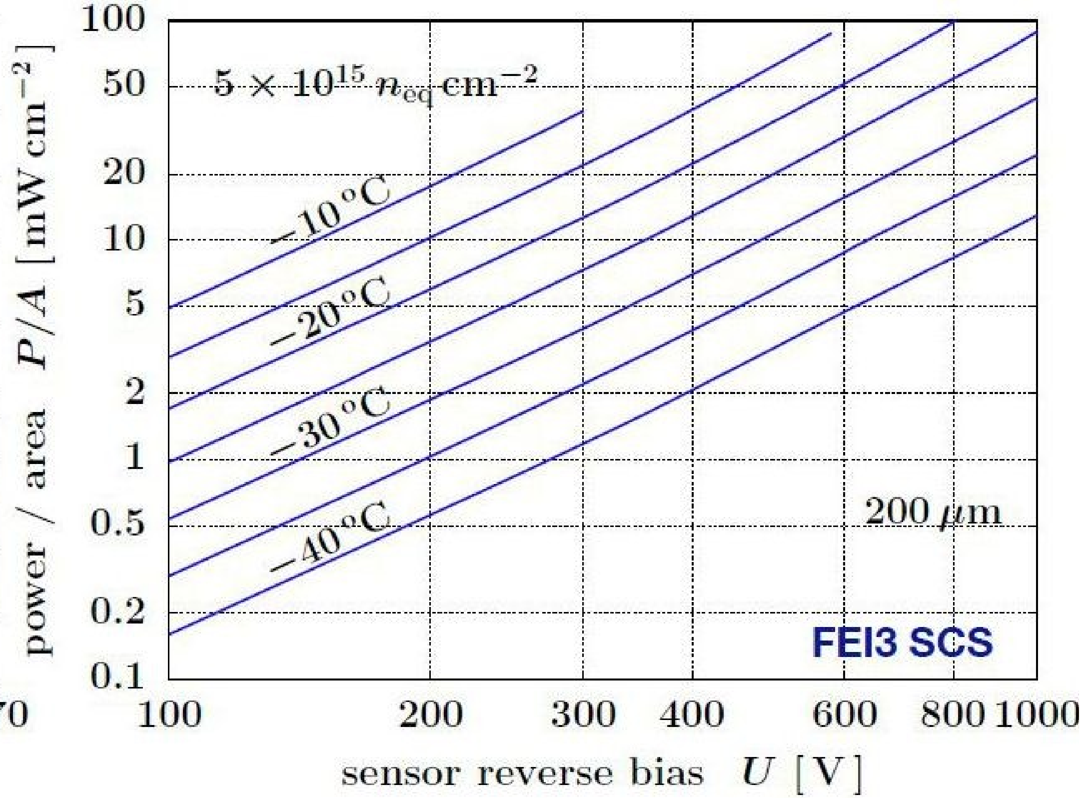

- Scaling possible for wide temperature range
  - e.g. 200 mW/cm² @ 1000V @ 255K
- Power dissipation as a function of voltage and temperature

June 2015 irradiation

Thanks to Daniel Muenstermann, Sally Seidel & Martin Hoeferkamp

- Repeat study with similar sensors but HL-LHC fluence
- Irradiation at Sandia National Lab Annular Core Research Reactor facility (SNL ACRR), Albuquerque, NM
- 3 thicknesses, each 2 times, $1.6 \times 10^{16}\ n_{eq} cm^{-2}$
- At a bucket temperature of 150°C, reactor was stopped
- Temperature decreasing over 1,5h to 60°C

- Additional: Single Chip Assemblies
- Activity of Tantalum-182 (90 days after irradiation)
  - 4 kBq @$5.5 \times 10^{15}\ n_{eq} cm^{-2}$,
  - 11 kBq @$1.6 \times 10^{16}\ n_{eq} cm^{-2}$

Lab setup for bare sensors

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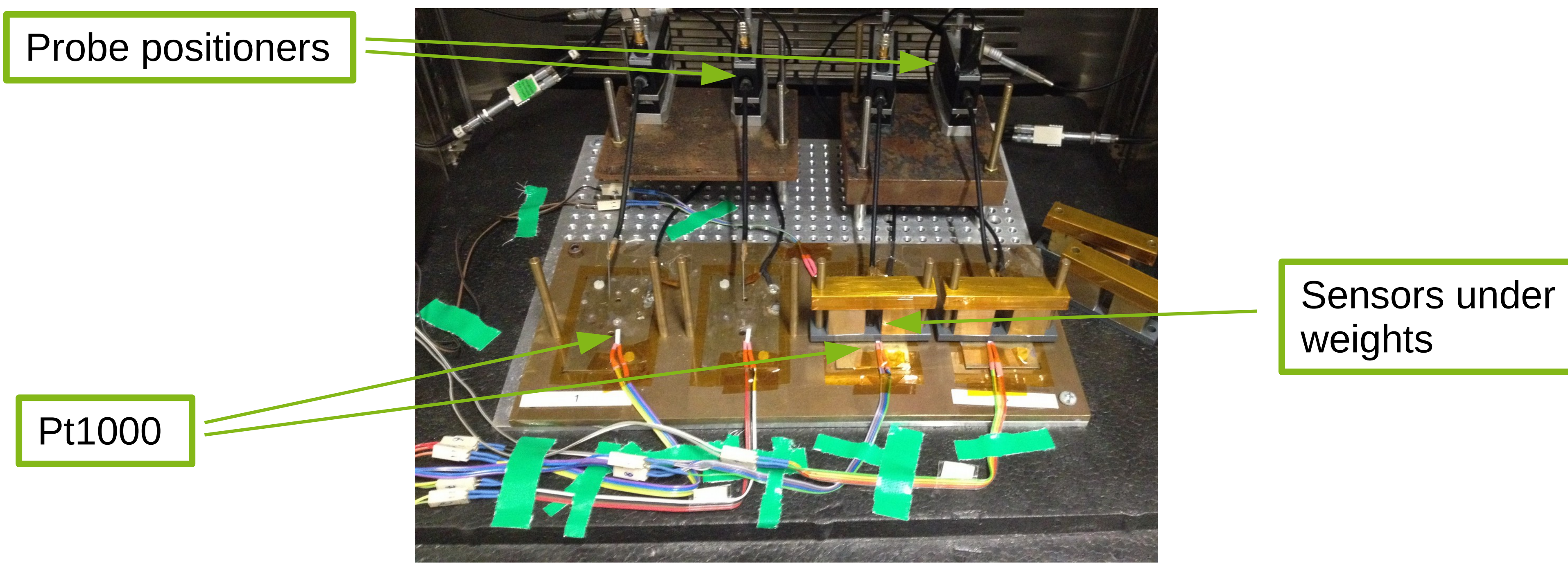
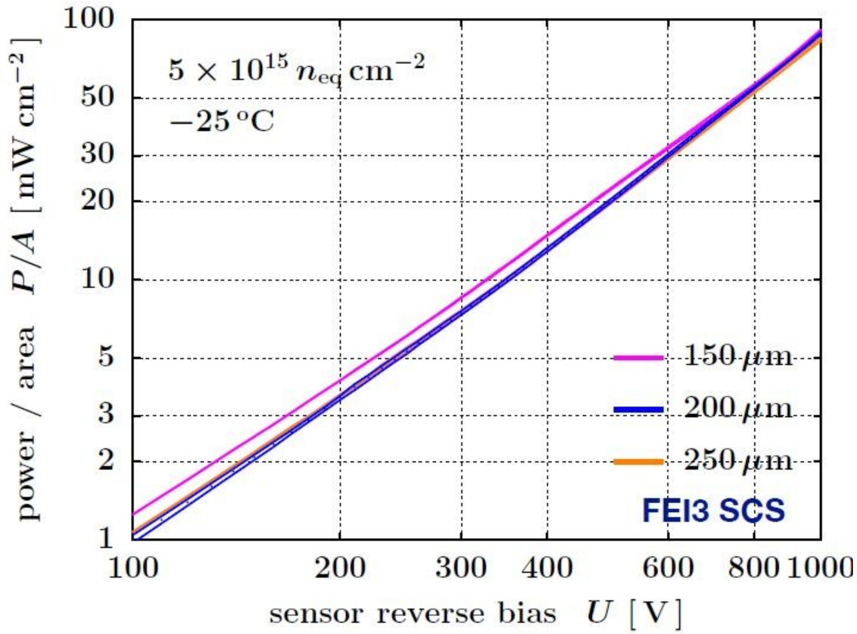
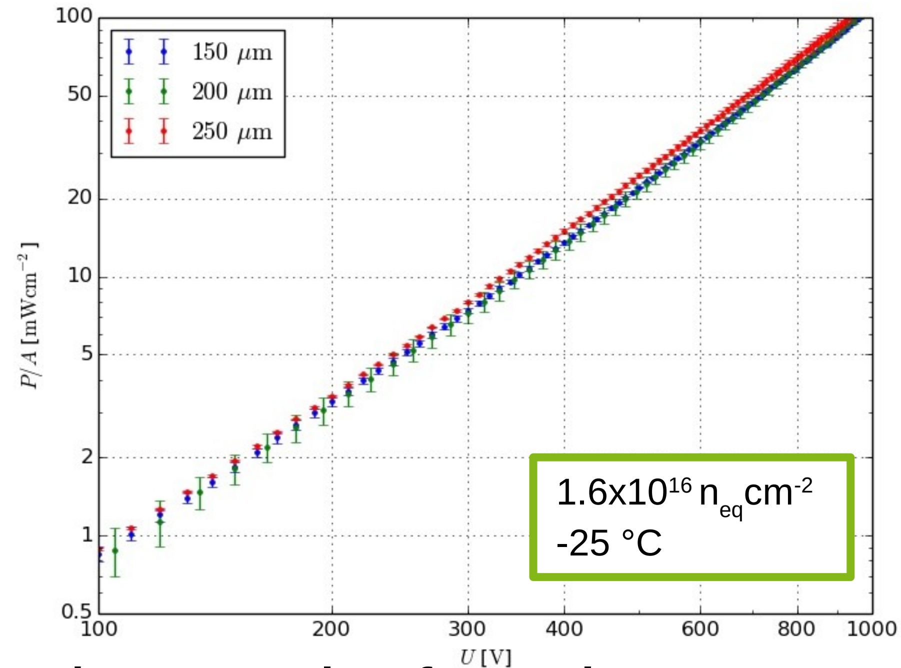
- Cooling by climate chamber
- Pt1000 directly on sensor
  - Best achievable sensor temperature
- IV measurement done with probe heads
- FE-I3 SCs almost finished
- FE-I4 SCs no negligible amount of self-heating



Results for n-in-n sensors



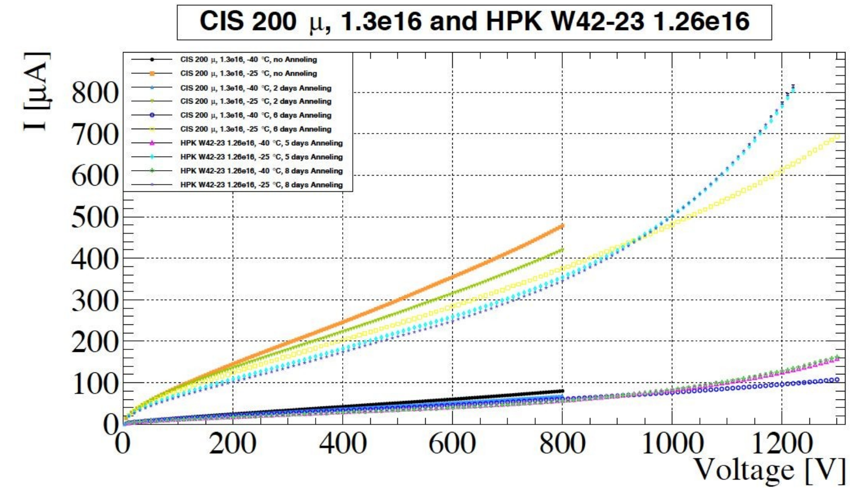


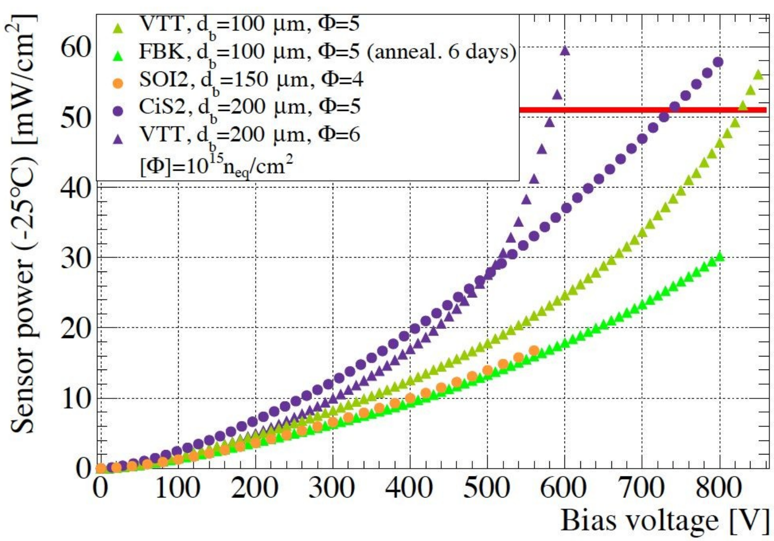
- Combined result for detailed study
- No large deviations between thicknesses

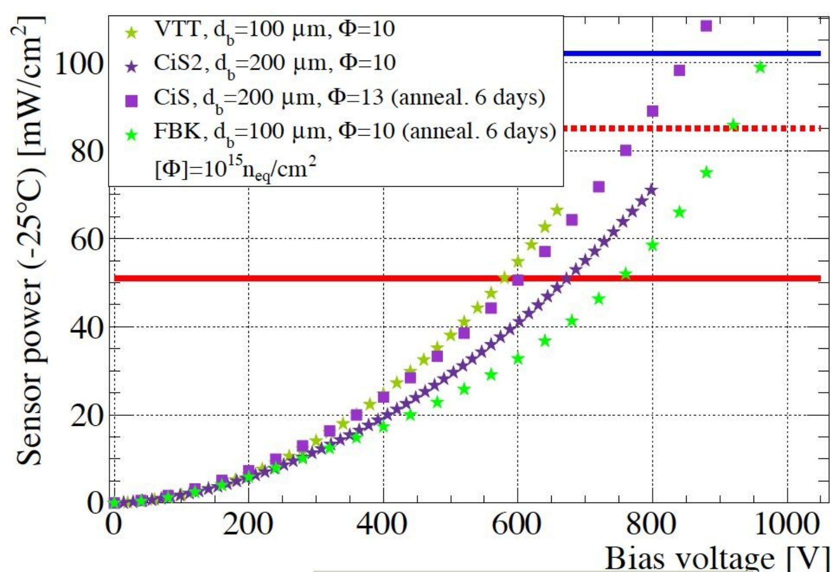
- First result of newly irradiated sample
- Values are self-consistent
- Same order of magnitude
- ➔ Annealing?

Results for n-in-p sensors

- Several sensors from various vendors
- Thicknesses: 75, 100, 150, 200, 320 µm
- Fluences: $2,4,5,6,10,13 \times 10^{15}\, n_{eq}cm^{-2}$







S. Terzo, Ph.D. thesis, TUM

Combined n-in-n & n-in-p results

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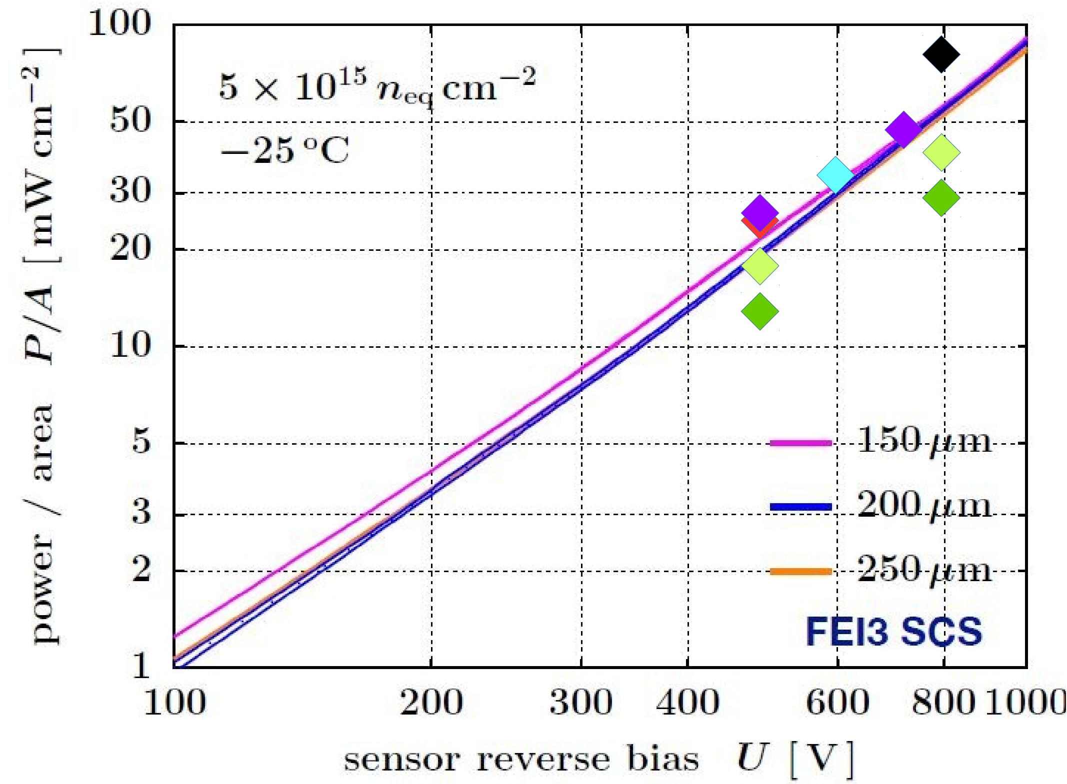
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- Comparison of data taken under the same conditions
- Good agreement for both types of bulk
- Thin sensors (100 µm) have lower power at high voltages
- Thinner sensors require lower voltages for same efficiency



$\Phi = 5 \times 10^{15}\, n_{eq}\, cm^{-2}$

Thickness [um]	Op. Vbias	Ileak(-25C) [uA/cm²]	Power [mW/cm²]
75	500	59	27
100	500		
150	600	50	35
200	700	65	45
320	800	96	77

A. Macchiolo, ITk week, Sep 15

Power vs fluence

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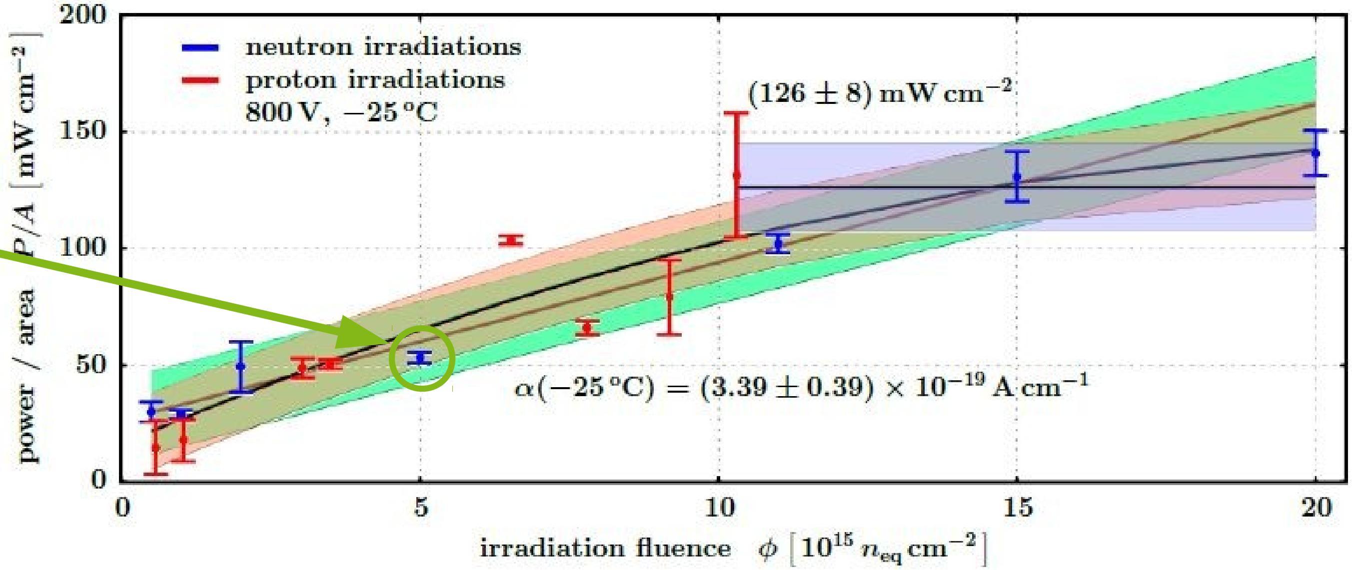

First presented study

- Power at fluences up to HL-LHC's fluence?
- Wide range of irradiated FE-I3 from previous studies:
  - Linear, quadratic, constant fit all feasible
  - Possible saturation of charge carrier generation
- Mean power dissipation area density of (126±8) $mWcm^{-2}$

Power vs fluence

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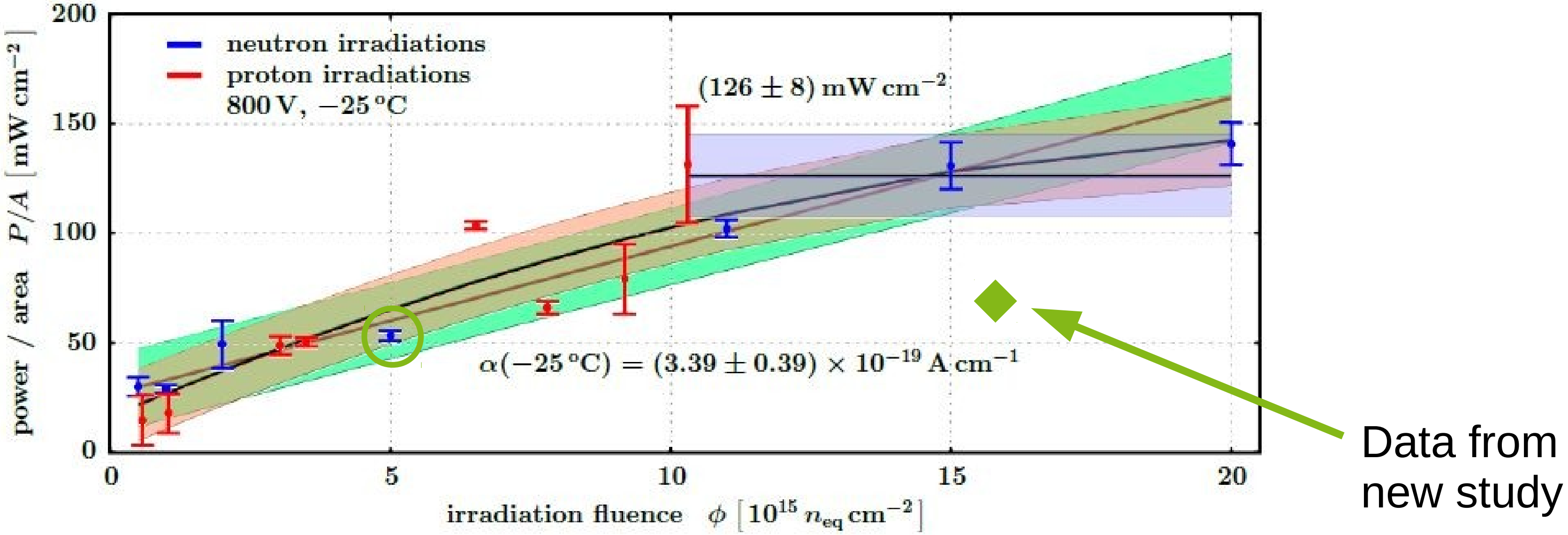
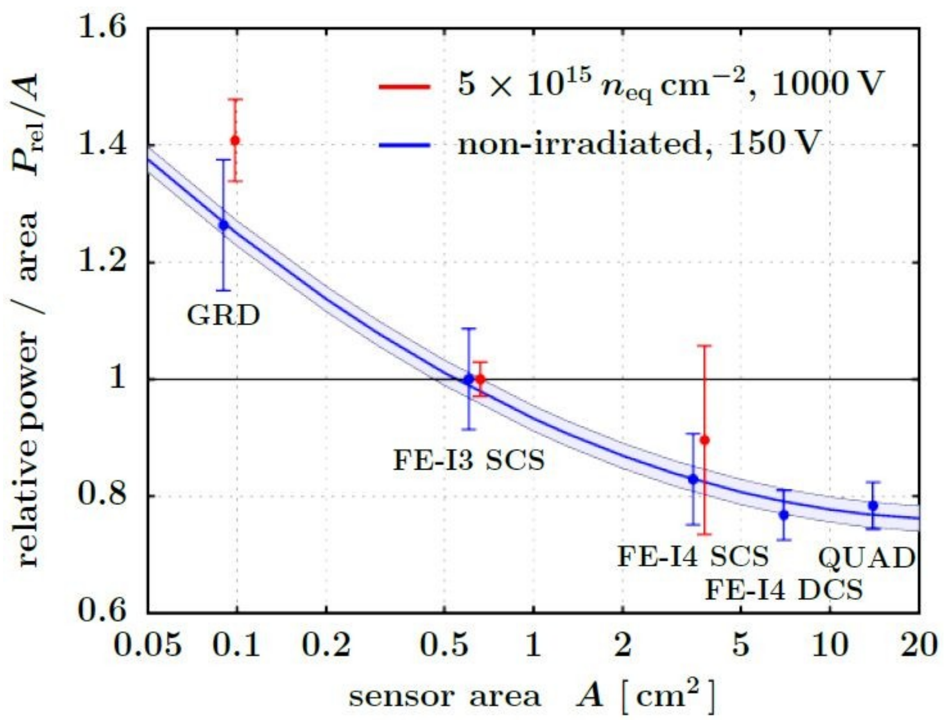


- Add new data point
- Lower than expected
  - Annealing!
  - Corresponds to ~many weeks @ room temperature
- Mean power dissipation area density of (126±8) $mWcm^{-2}$

Power vs sensor area

- Most investigations executed with single chips
- Larger sized sensors in detector later
- All structures on a non-irradiated IBL prototype wafer (250µm)
- Power/area decreases with sensor size
- Similar results for irradiated sensors, but luck of dater for larger ones



Summary

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- Effective leakage current temperature scaling possible for our setup under various conditions
  - Determination of power dissipation
- Estimates on power dissipation for ITk:
  - 126mW/cm² @-25°C & 800V on sensors similar to 3-layer ones
  - Reduced for thinner sensors (<150 µm)?
  - Reduced for larger sized sensors
  - Reduced by annealing