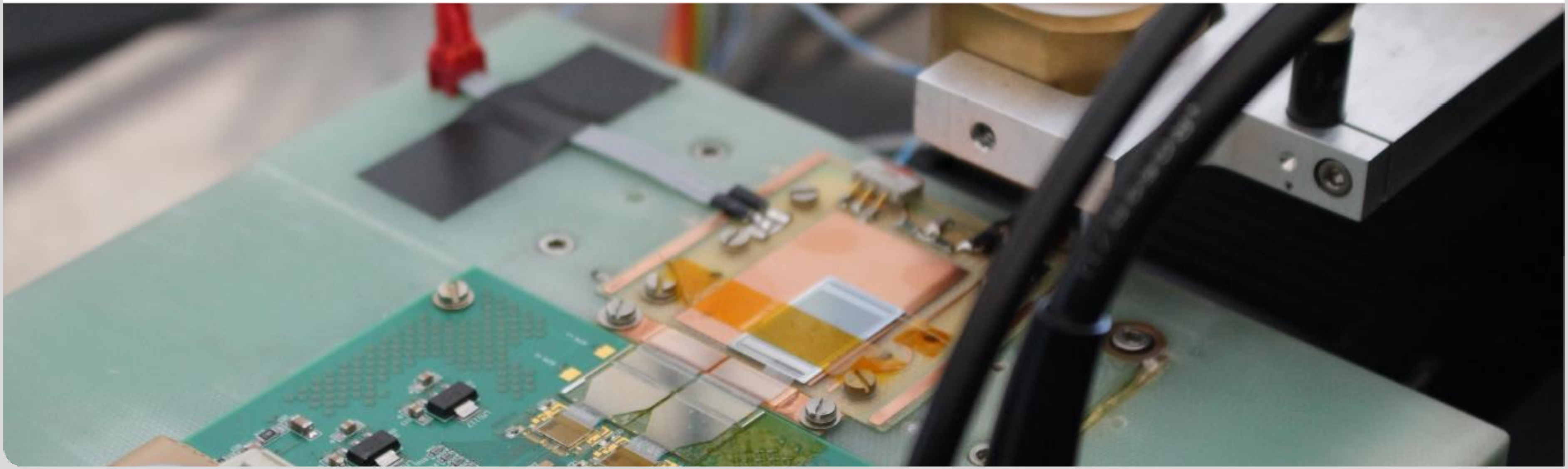
Silicon Strip Sensors for the Phase-2 Upgrade of CMS

DPG Aachen 2019

Tobias Barvich, Alexander Dierlamm, Umut Elicabuk, Jan-Ole Gosewisch, Ulrich Husemann, **Marius Metzler**, Thomas Müller, Anita Weddigen

Institut für Experimentelle Teilchenphysik (ETP)



CMS Phase-2 Outer Tracker Upgrade in a Nutshell

HL-LHC Upgrade

Higher luminosity

Detector upgrades

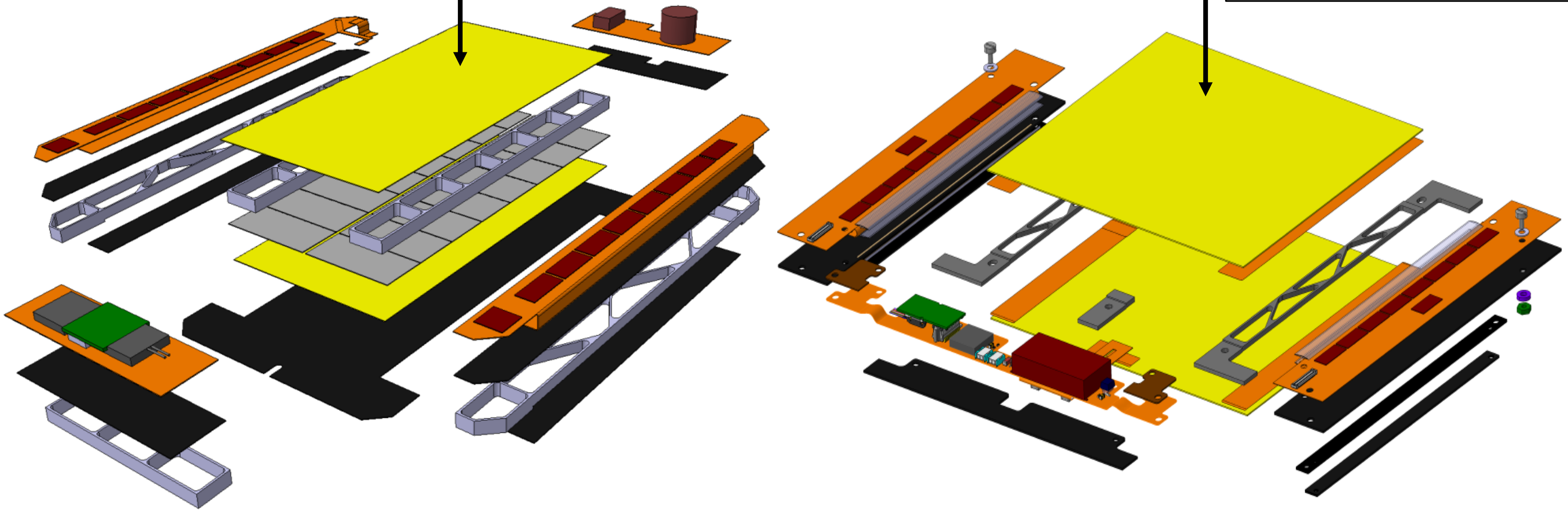
- **Increase of sensor granularity**
- **Transition from analog to binary read-out of channels**
- **Introduction of low-level data filter**
- **Production of radiation-harder sensors and electronics**

The 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)

2S Sensor

- A = 10 x 10 cm^2
- Strips: 2 x 1016 = 2032
- Pitch: 90 µm



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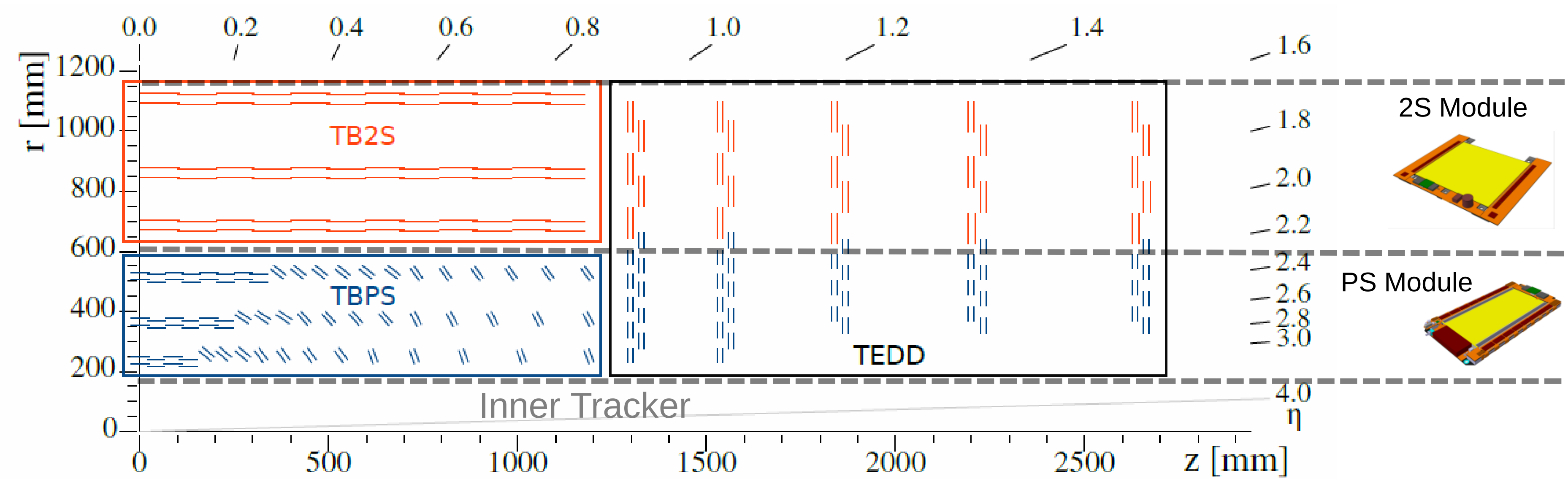
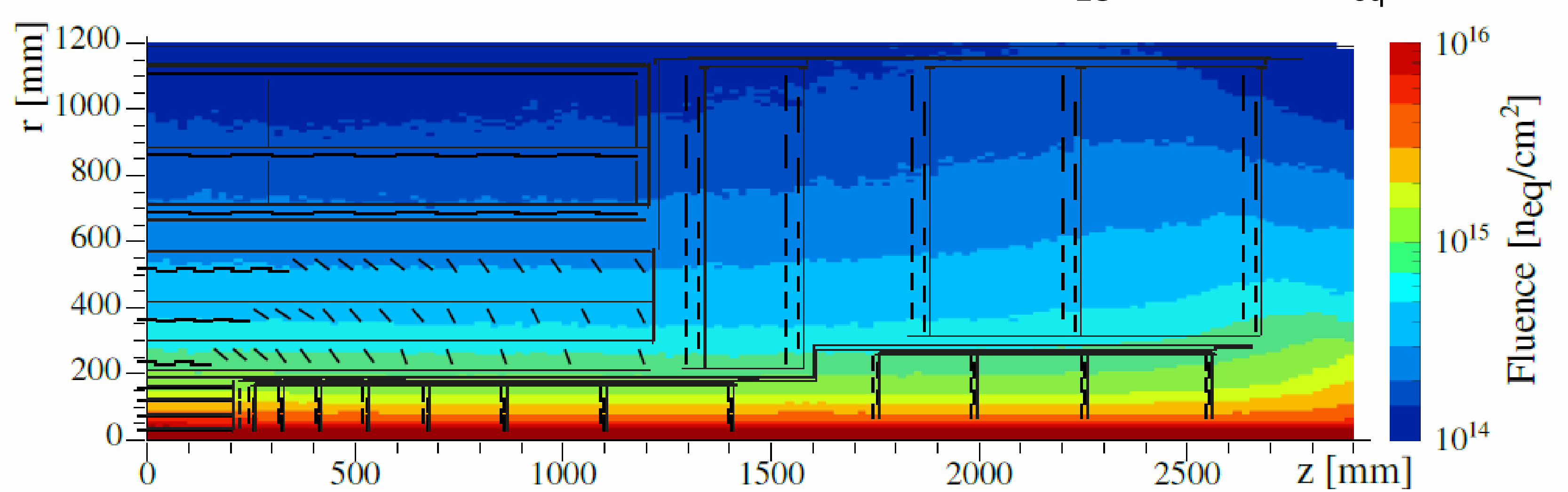


The Phase-2 Outer Tracker Modules

- 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
- Fluences decrease from center outwards
  - Expected maximum fluence for 2S region: $\Phi_{2S} \approx 3 \times 10^{14}\ n_{eq}cm^{-2}$

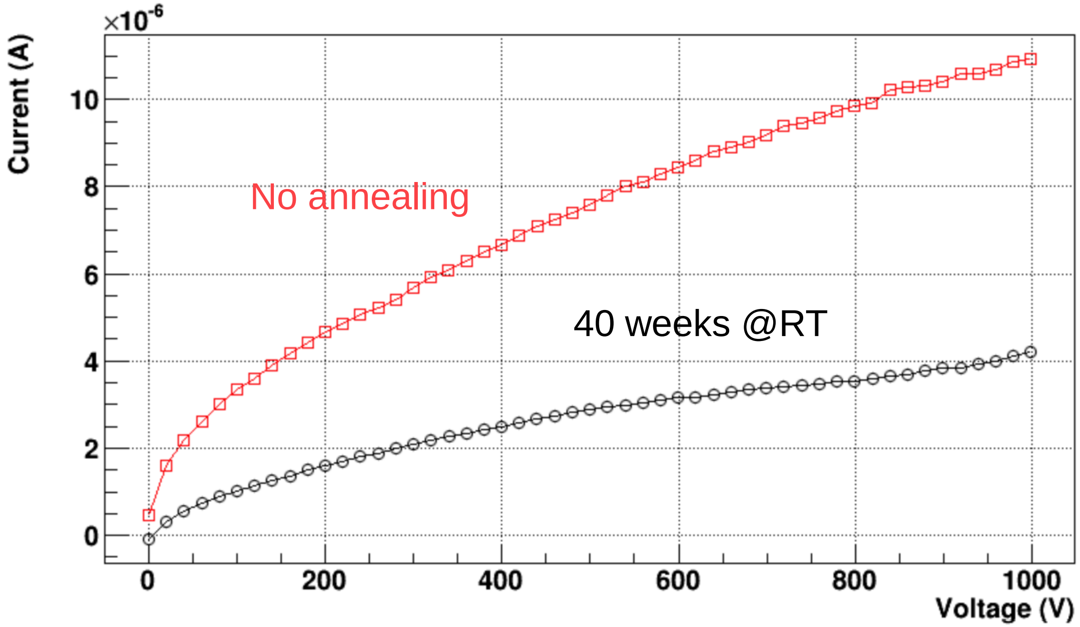


Sensor R&D

- Most important parameters for sensors:
  - **Resolution**
  - **Efficiency**
- Resolution is determined by the sensor design (distance of strips)
- Sensor R&D studies focus on efficiency and thermal performance
- Studies performed with setups at ETP mainly focus on
  - **Charge collection**
  - **Leakage current**

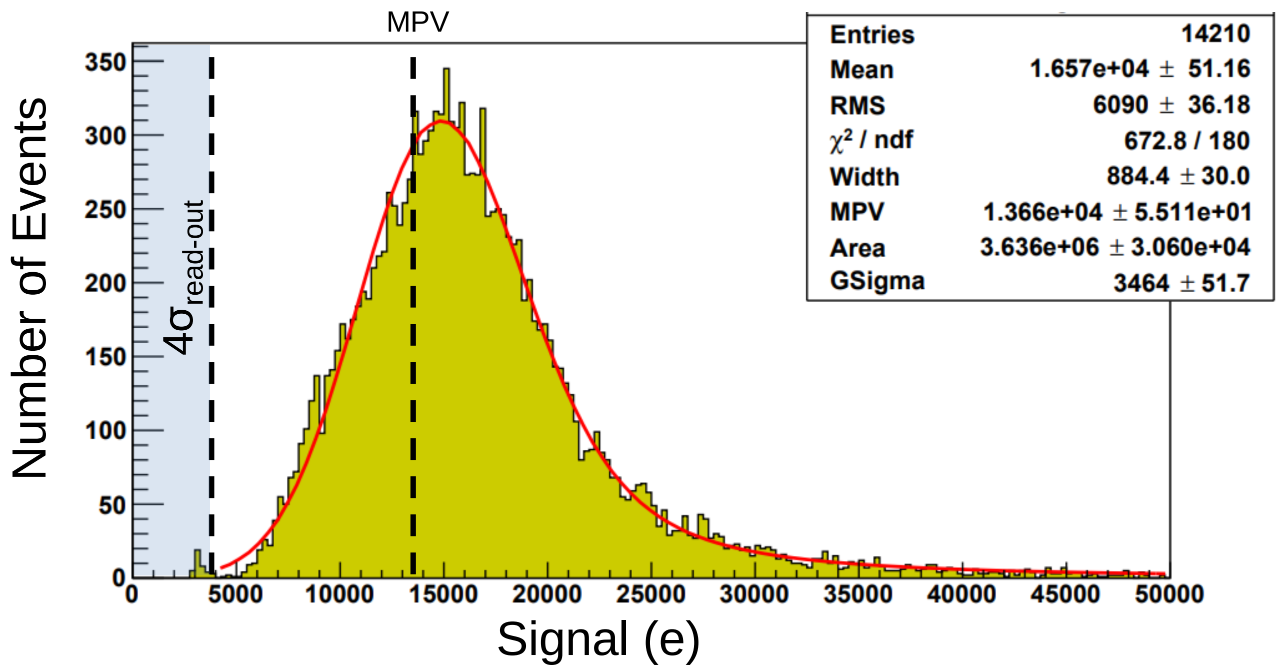
Sensor R&D – Leakage Current

- $I_{leak} \sim d_a$ (active sensor thickness)
- Source of **noise** and main source of **heat dissipation** (especially after irradiation)
- Methods for reducing leakage current during operation:
  - **Cooling & annealing**

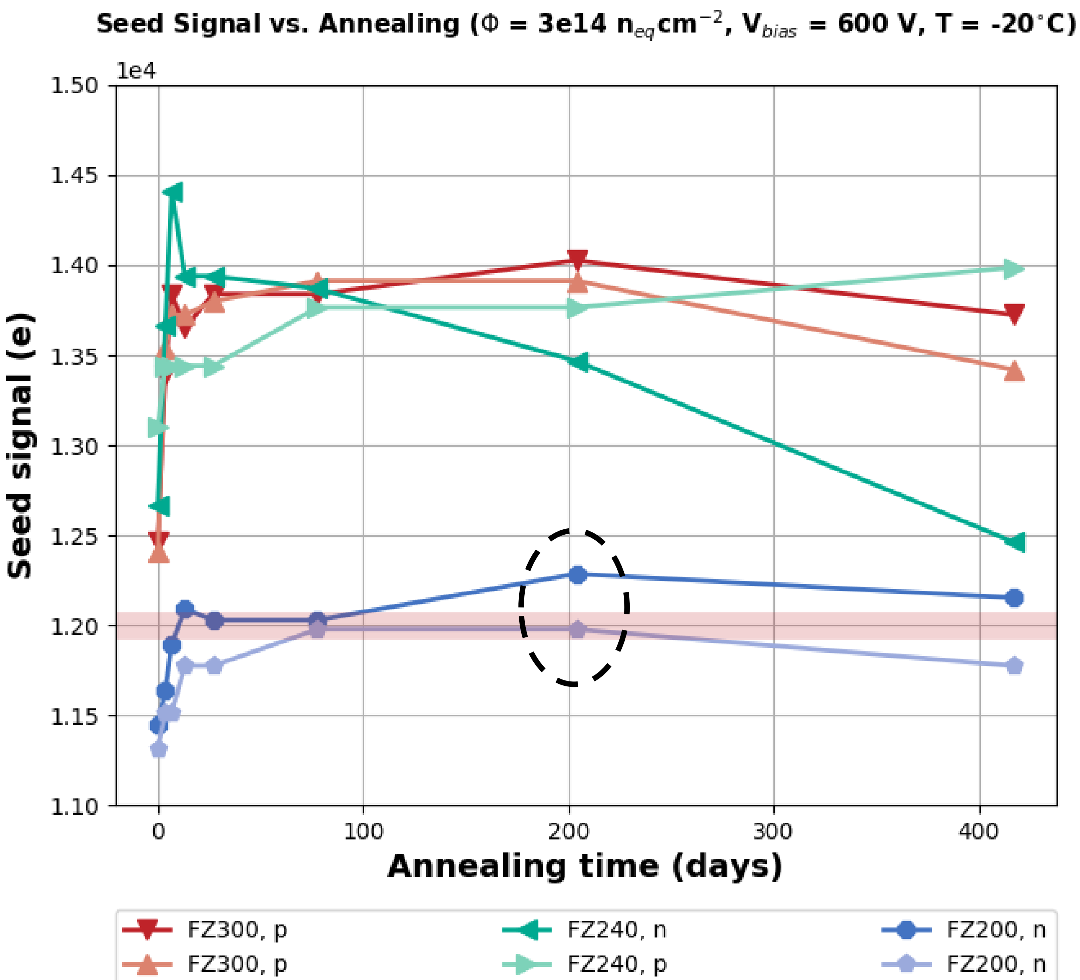


Sensor R&D – Charge Collection

- **Signal** → MPV of signal distribution
- **Signal >> $\boldsymbol{\sigma}_{\textbf{read-out}}$** → **Threshold** ≈ $4\sigma_{\text{read-out}}$
- **Efficiency** → $\frac{Signals > Threshold}{Signals}$
- Rule of thumb for being efficient → $\frac{\boldsymbol{MPV}}{\mathbf{3}}$ **>** $\mathbf{4}\boldsymbol{\sigma}_{\textbf{read-out}}$ → **$\mathbf{MPV_{2S}}$ > 12000 e**



Irradiation Studies at ETP – Results from 2018



Measurement uncertainty: ± 1000e

- Comparison of 200, 240 and 300 µm material for
  - $\Phi_{2S} \approx 3 \times 10^{14}\ n_{eq}cm^{-2}$
  - $V_{bias} = 600$ V
- Signal of 200 µm material too low

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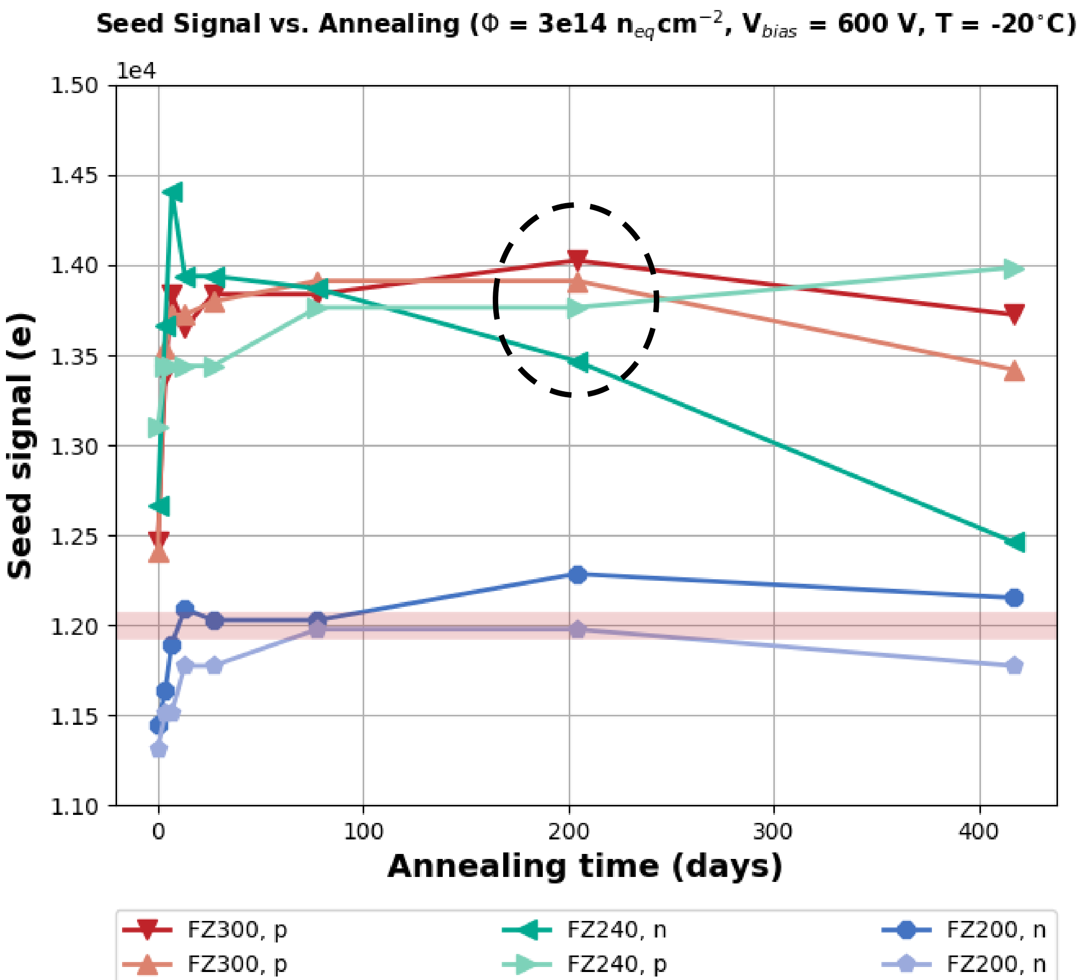

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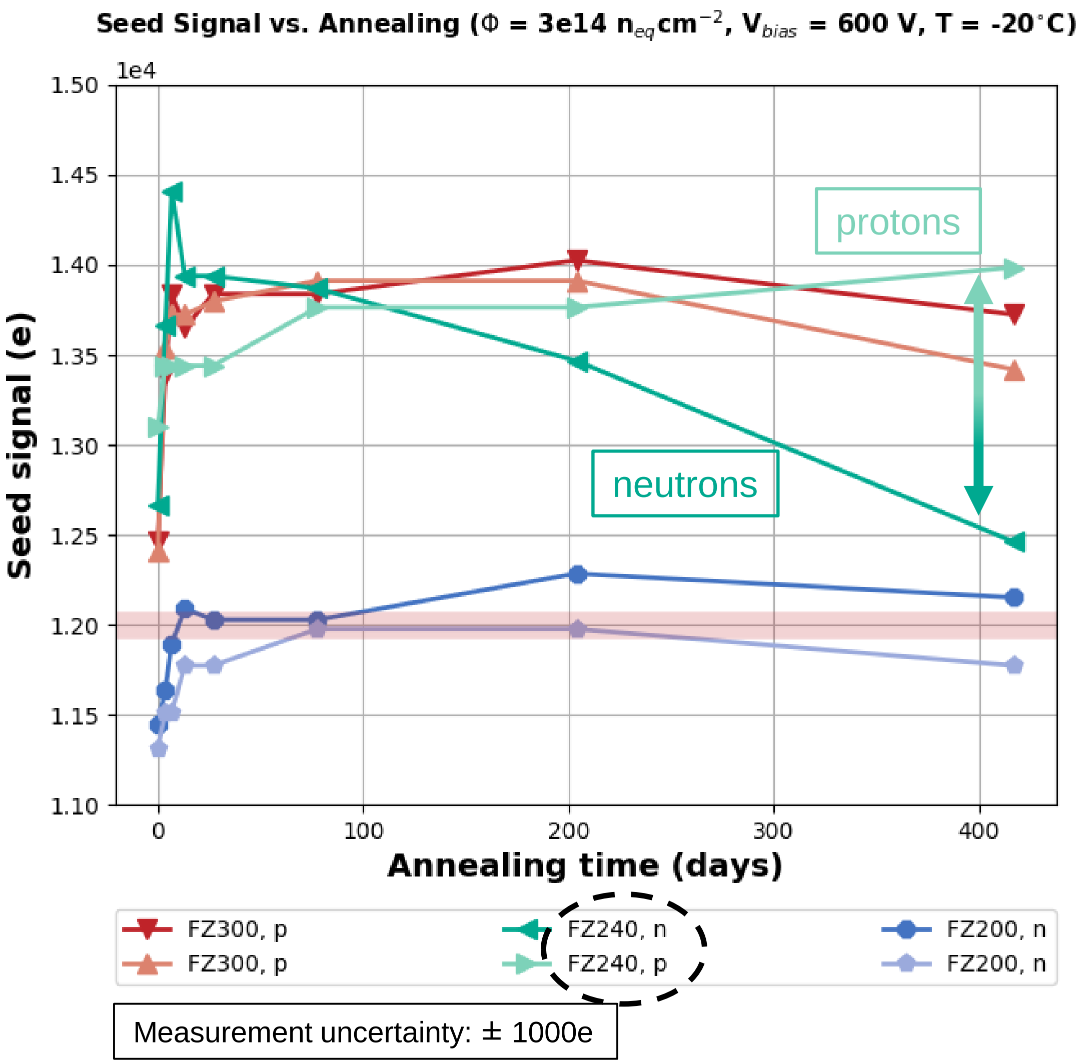

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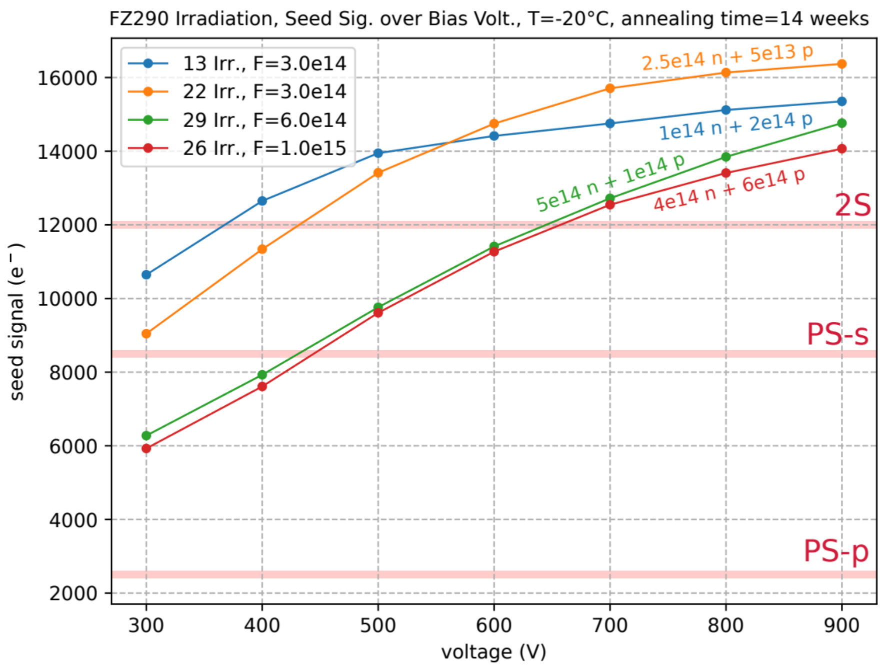
  - $V_{bias} = 600$ V
- Signal of 200 µm material too low
- 240/300 µm provide similar signal and annealing characteristic at 600 V
- Difference between neutron and proton irradiation observed for thicker materials

Sensor R&D – Final Irradiation Campaign

- Results of our studies limit the range of the active thickness d_a:
  - $240\ \mu m \leq d_a \leq 300\ \mu m$
- Final material needs to be qualified again
- 2 candidates remaining:
  - Thinned float-zone of 240 µm → thFZ240
  - Float-zone with active thickness of 290 µm → FZ290
- Particle type matters! – fluences will correspond to the expected particle composition in the tracker
  - $\Phi_{2S} \approx \underbrace{2.5 \times 10^{14}}_{\text{neutrons}}\ n_{eq}cm^{-2} + \underbrace{0.5 \times 10^{14}}_{\text{protons}}\ n_{eq}cm^{-2}$

Sensor R&D – Campaign Status & Outlook

- Received over a 100 test sensors of each material in Nov 18 / Jan 19
  - Qualification and radiation campaign on-going
- Preliminary result for FZ290:
  - Sufficient signal at $\Phi_{2S} \approx 3 \times 10^{14}\ n_{eq}cm^{-2}$ and $V_{bias} = 600$ V

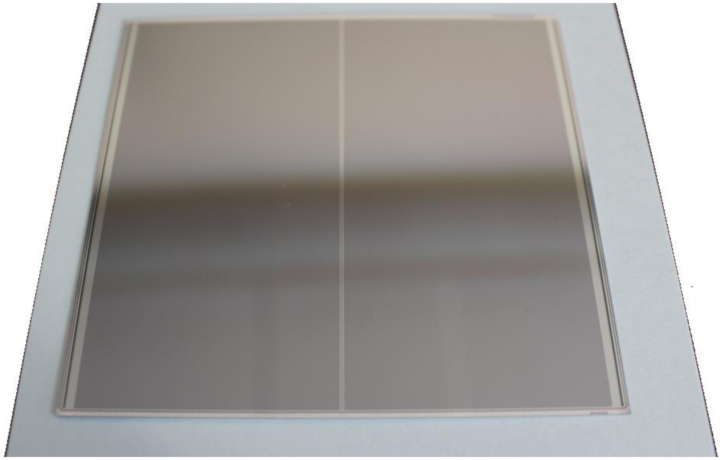


Back Up

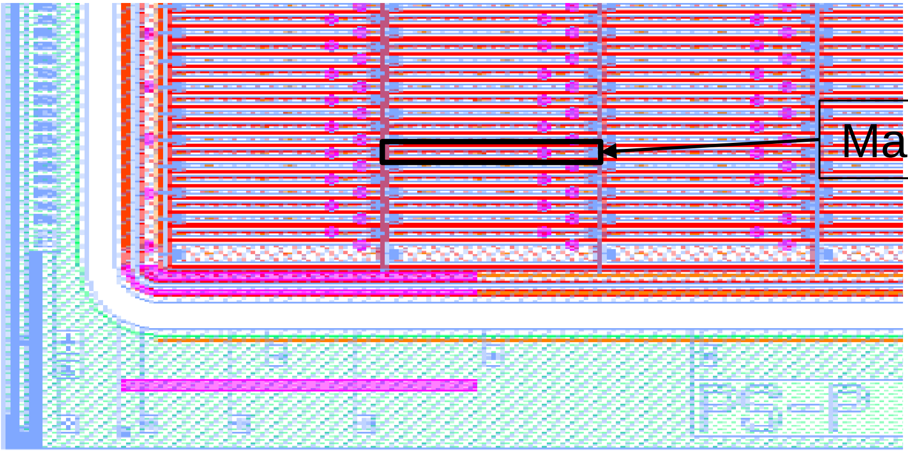
The Phase-2 Outer Tracker Sensors

- **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



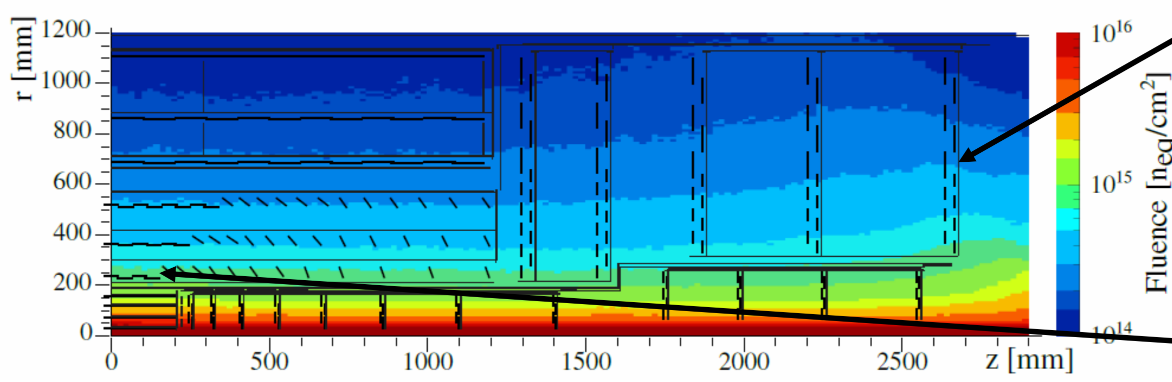
PS-p Sensor



Irradiation Campaign with FZ290 and thFZ240

Set	Neutrons $10^{14} n_{eq}/cm^2$	Protons $10^{14} n_{eq}/cm^2$	Total $10^{14} n_{eq}/cm^2$	Fraction n	Dose 23MeV kGy	Dose 24GeV kGy
Low outer	0.8	0.2	1	80%	30.8	6.8
Low inner	1.2	1.8	3	40%	271.2	55.2
Mid outer	2.4	0.6	3	80%	92.4	20.4
Mid inner	4	6	10	40%	904	184
Max outer	4.8	1.2	6	80%	154	34
Max inner	6	9	15	40%	1356	276

(max. nominal dose: 700kGy)



Highest 2S fluence:

Z_0 = 2e14n + 1e14r

Z_{260} ≈ 2.8e14n + 1.1e14r

→ 3.9e14

Highest PS-s fluence:

Z_{20} ≈ 4.8e14n + 6.7e14r

Z_{250} = 4.2e14n + 4e14r

→ 1.15e15

Sensor R&D – Leakage Current

Leakage current

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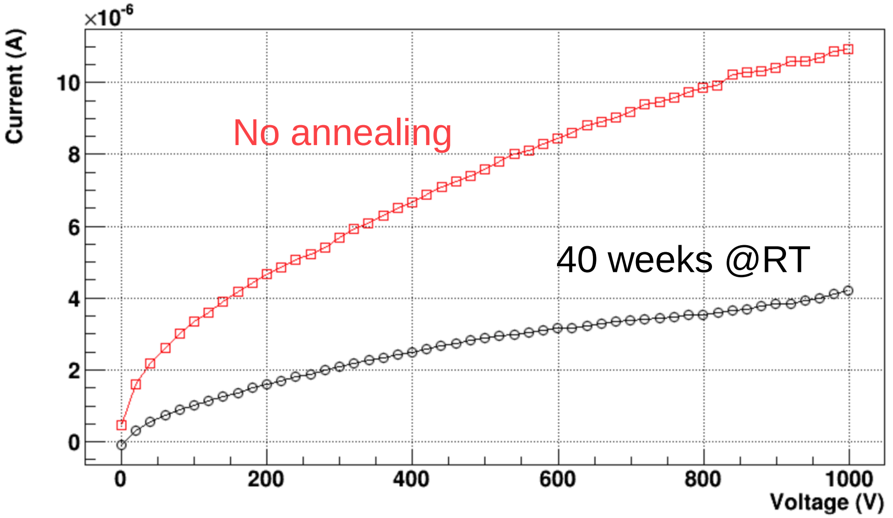
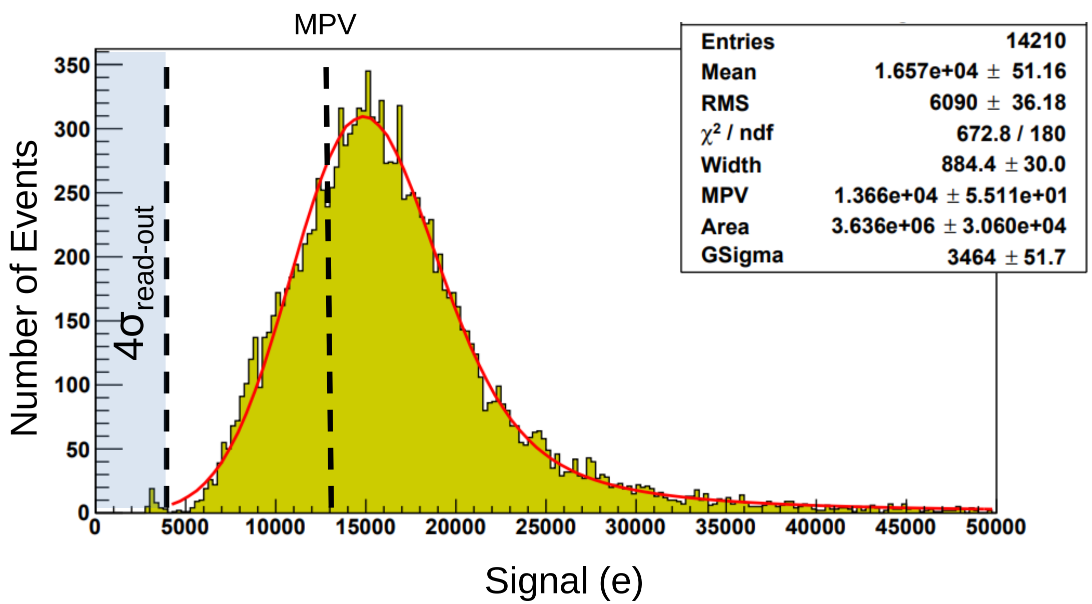


Sensor R&D – Signal vs. Noise

- Most important parameters for sensors: **resolution & efficiency**
- Studies concentrate on efficiency: charge collection vs. leakage current



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  → $\frac{MPV}{3}$ **>** $4\sigma_{\text{read-out}}$

  → **MPV_{2S} > 12000 e**