Karlsruher Institut für Technologie

Outer Tracker Sensor R&D

FSP Meeting 09/18 – Tobias Barvich, Jan-Ole Gosewisch, Alexander Dierlamm,
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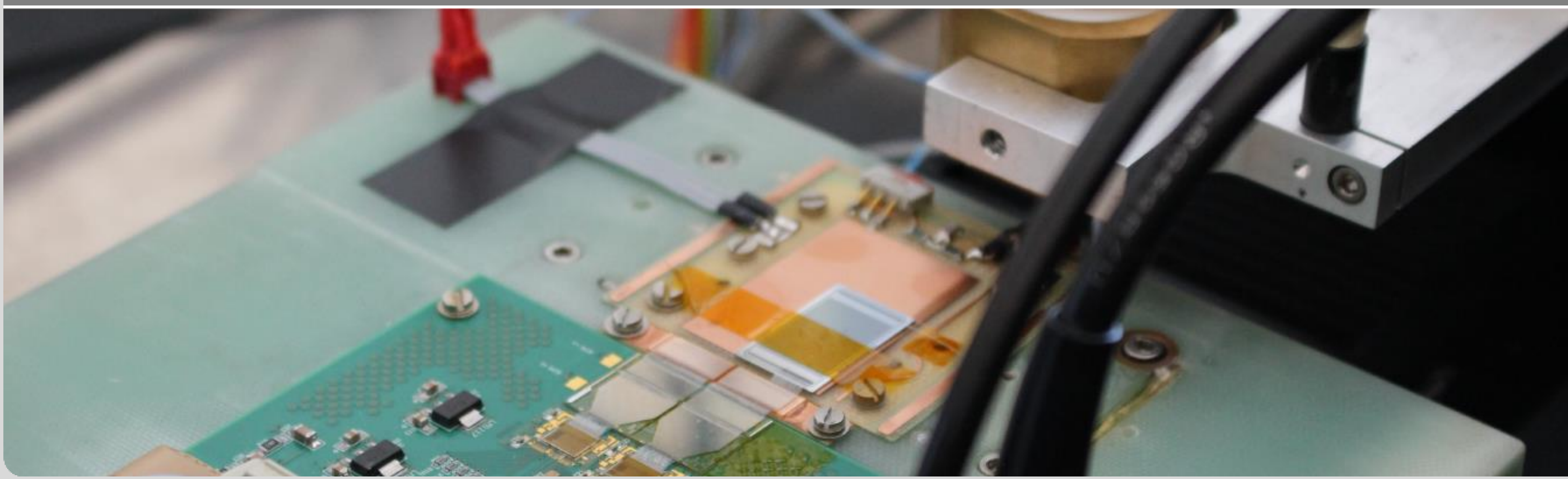
Institut für Experimentelle Teilchenphysik (ETP)



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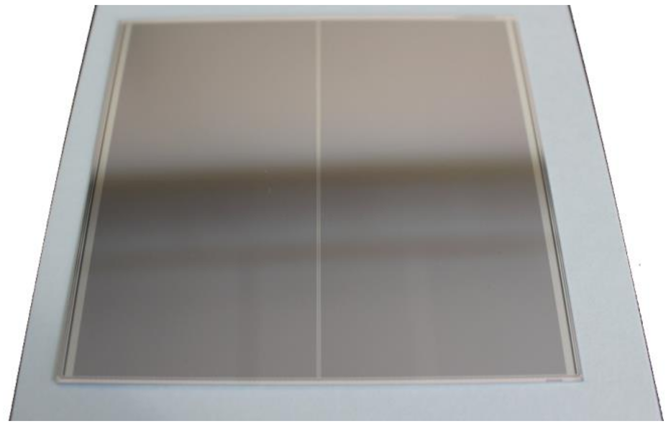
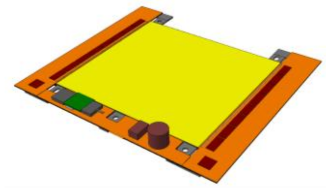
Introduction – OT Sensors

- **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 $µm^2$

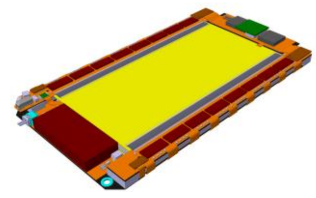
2S Sensor

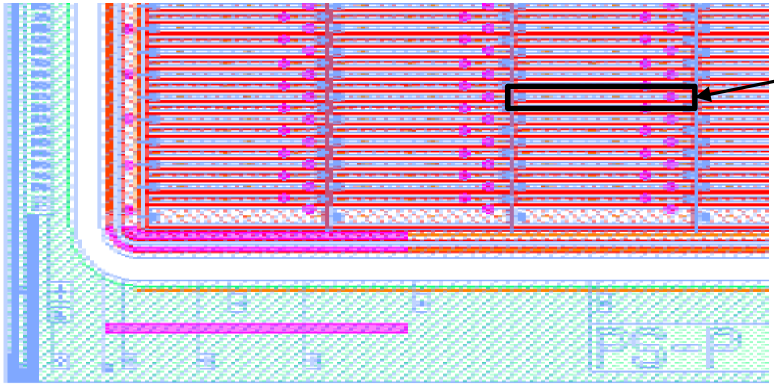


2S Module



PS Module





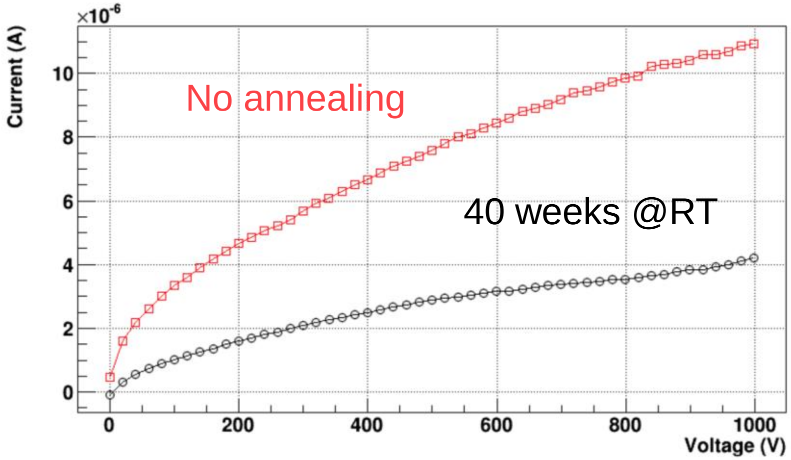
Macro pixel

Introduction – Signal vs. Noise

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

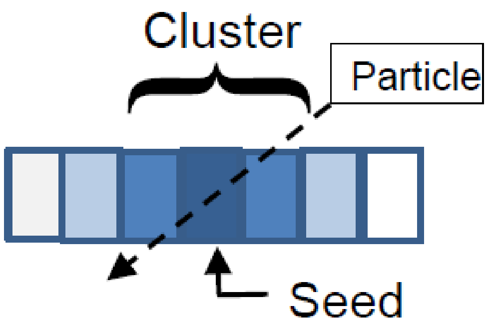
Leakage current

- Source of noise and heat dissipation (especially after irradiation)
- Methods for reducing leakage current during operation:
  - Cooling & annealing



Charge collection

- Cluster signal = sum of collected electrons in strip cluster per MIP
- In order to be efficient, signal needs to be well above the noise of the read-out chip
- Phase-2 read-out is binary:
  - Seed is more important than cluster signal



Introduction – R&D

- Given frame conditions for CMS Outer Tracker:
  - 10 years of run-time
  - Desired maximum operation voltage $V_{op} = 600V$
  - Expected fluence at 3000 fb^{-1}:
    - $\Phi_{2S} \approx 3e14\ n_{eq}cm^{-2}$
    - $\Phi_{PS} \approx 1e15\ n_{eq}cm^{-2}$
  - Annealing period at RT during year-end technical stop possible
- Desired sensor characteristics:
  - Low mass
  - Low depletion voltage
  - Low leakage current
  - High signal
  - Radiation hardness

} most important factor for tuning these parameters:

active sensor thickness

Introduction – Sensor Materials

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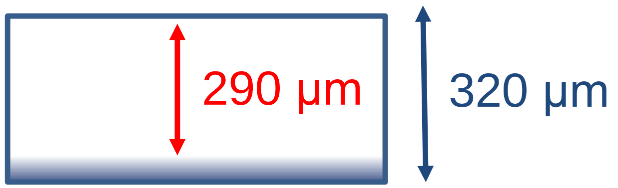
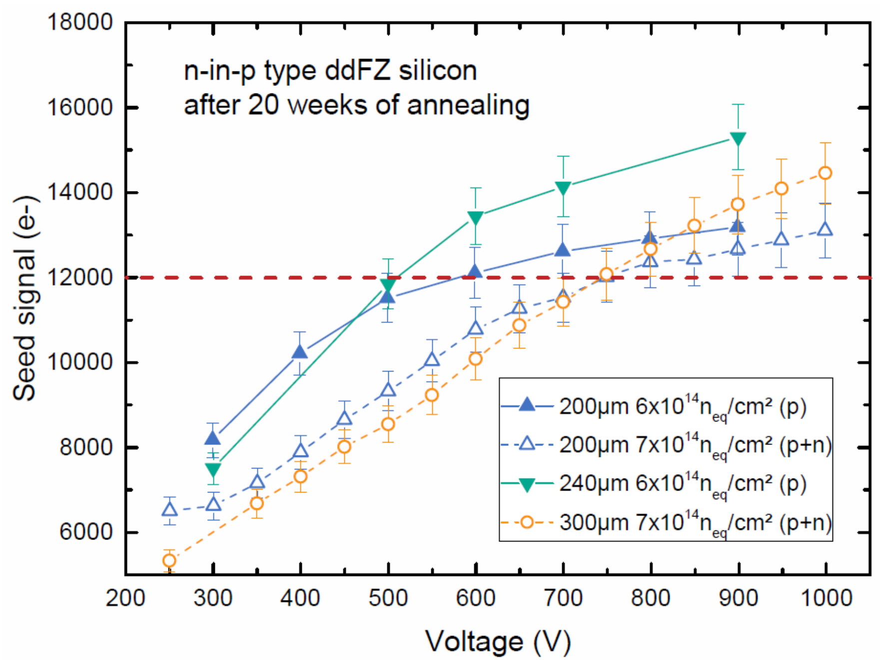
- Initial sensor material offered by HPK:
  - **FZ290** (formerly called FZ300 or FZ320):
    - HPK standard material
    - Standard price
    - Fixed thickness
  - **ddFZ** material:
    - Standard price
    - Flexible solution
    - Active thickness d_a selectable
  - **thFZ** material:
    - More expensive
    - Thickness can be selected ($d_a \approx d_p$)



Signal Studies – Results presented in TDR

- Results for $\Phi_{2S}^* > 6e14\ n_{eq}cm^{-2}$ (former expected value for 2S region):
  - Annealing characteristic of 200/240 µm material is more favorable
  - Signal of 200/300 µm is below 12000 e margin (V_{bias} = 600 V, t_A = 20 weeks)
  - Signal of 240 µm is well above 12000 e margin (V_{bias} = 600 V, t_A = 20 weeks)



Rule of thumb for being efficient:

- MPV/3 > $4\sigma_{noise}$
- $\sigma_{CBC} \approx 1000$ e

→ S_{2S} = **12000**

ALiBaVa uncertainty: ± 1000e
Fluence uncertainty: ± 20%

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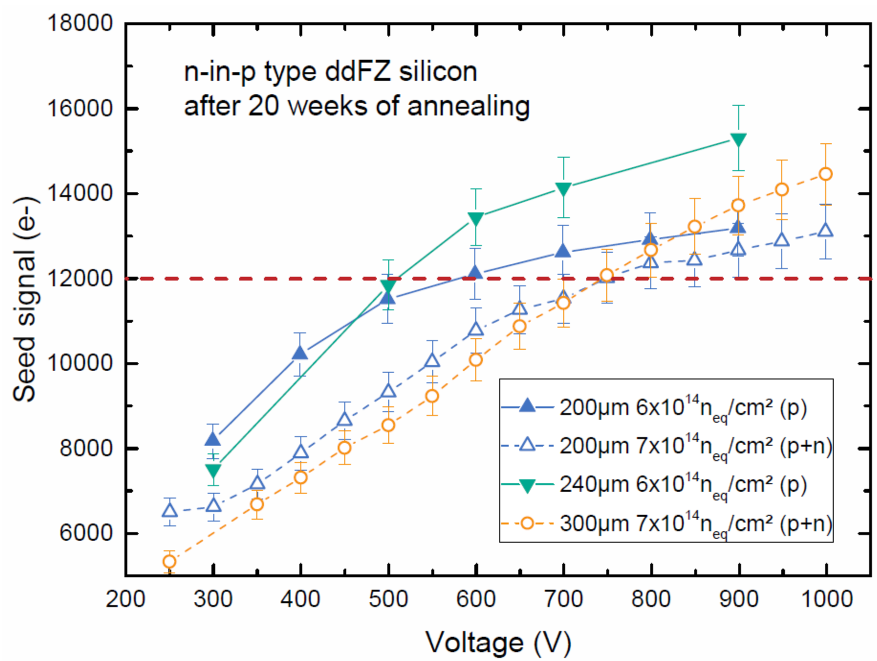
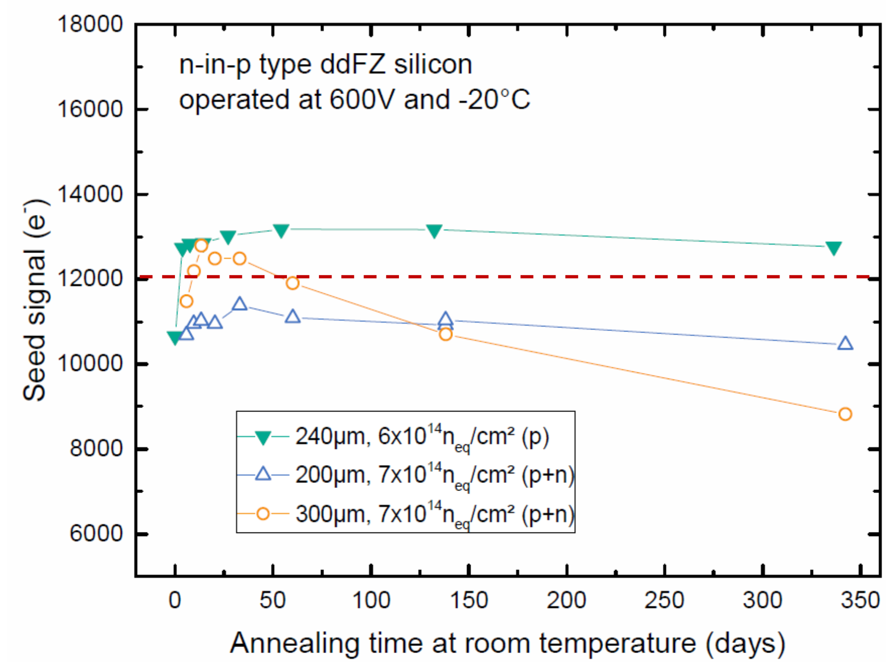
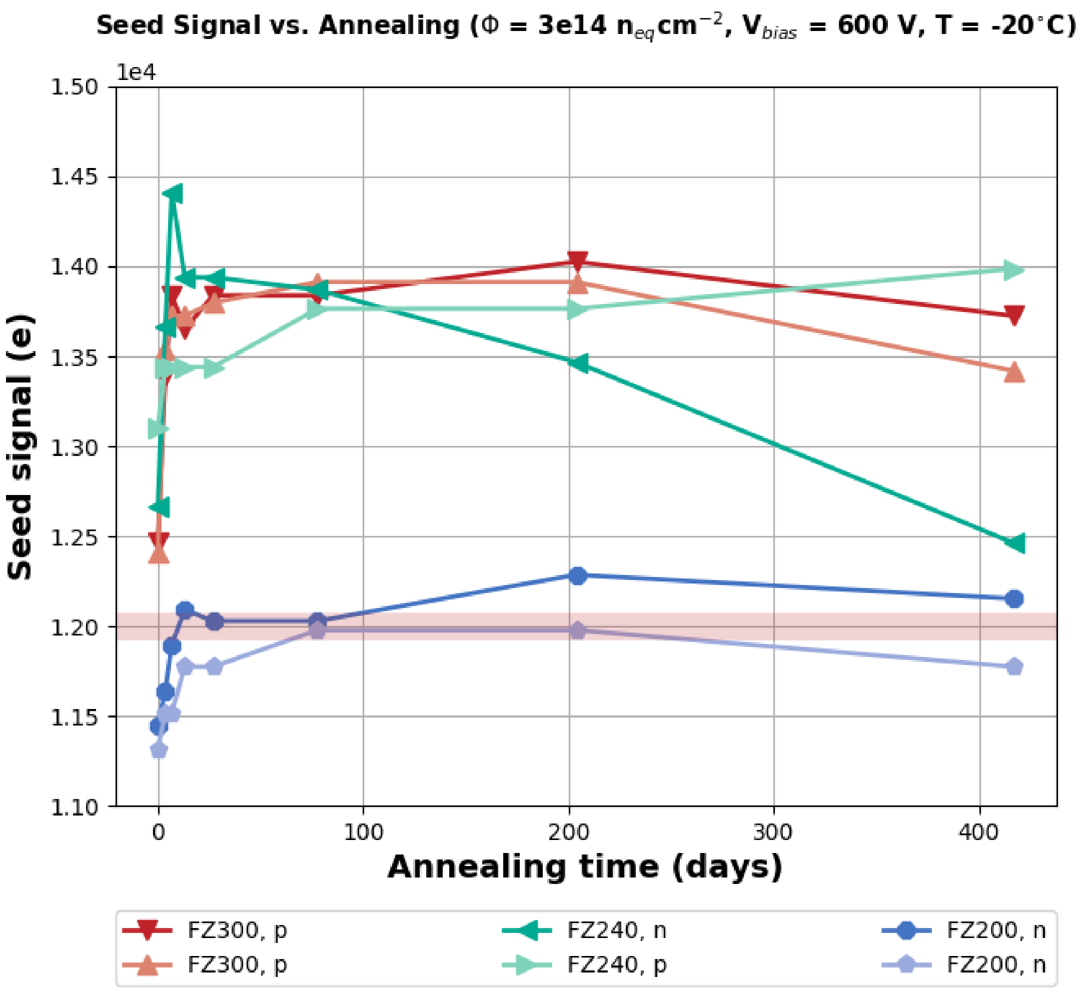




Signal Studies – Recent Results



- For $\Phi_{2S} \approx$ 3e14 $n_{eq}cm^{-2}$: 240/300 µm provide similar signal and annealing characteristic at 600 V
- Neutron irradiation influences long-term annealing characteristic of 240/300 µm material

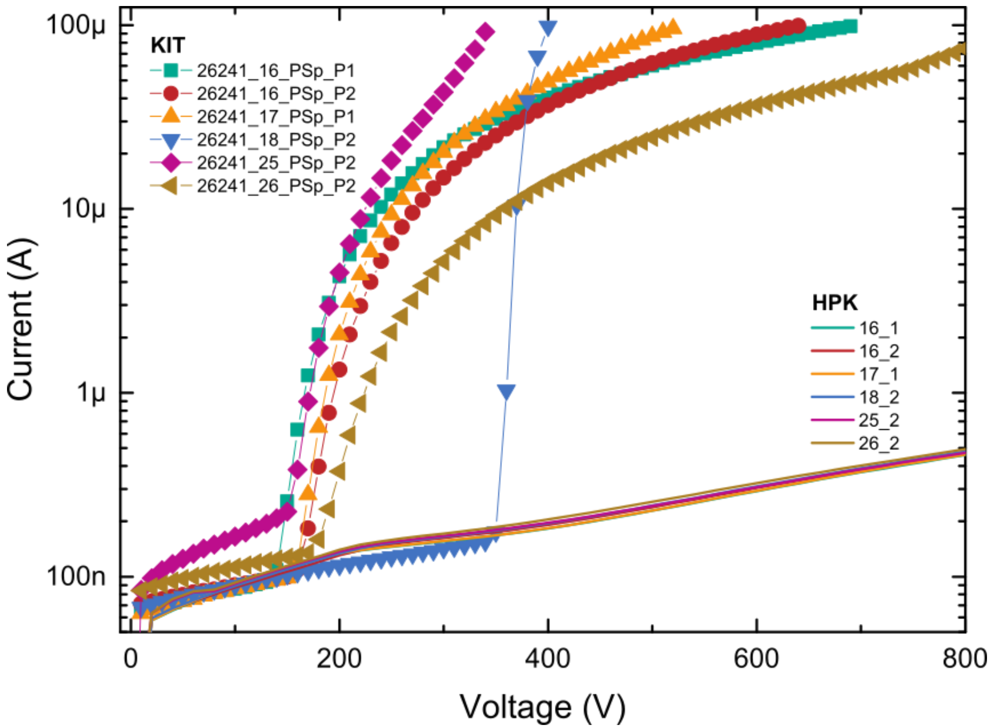
Material Issue

- Only HPK can meet requirements for the Phase-2 production
- The initial offer regarding deep diffused wafers is off the table
- 2 possible solutions:
  - **FZ290**
    - Material was qualified 5 years ago with different sensor design
    - Properties might have changed
  - **thFZ240**
    - thFZ240 has never been qualified before
      - Properties of thinned material unknown
    - ddFZ240 yielded optimal results regarding signal vs. annealing

      → 240 µm material is expected to be optimal thickness

Issue with thFZ200

- IV curves from HPK not reproducible
- Low breakdown voltages which might be related to
  - Sensitive backside (scratches)
  - Mechanical stress (vacuum fixation)



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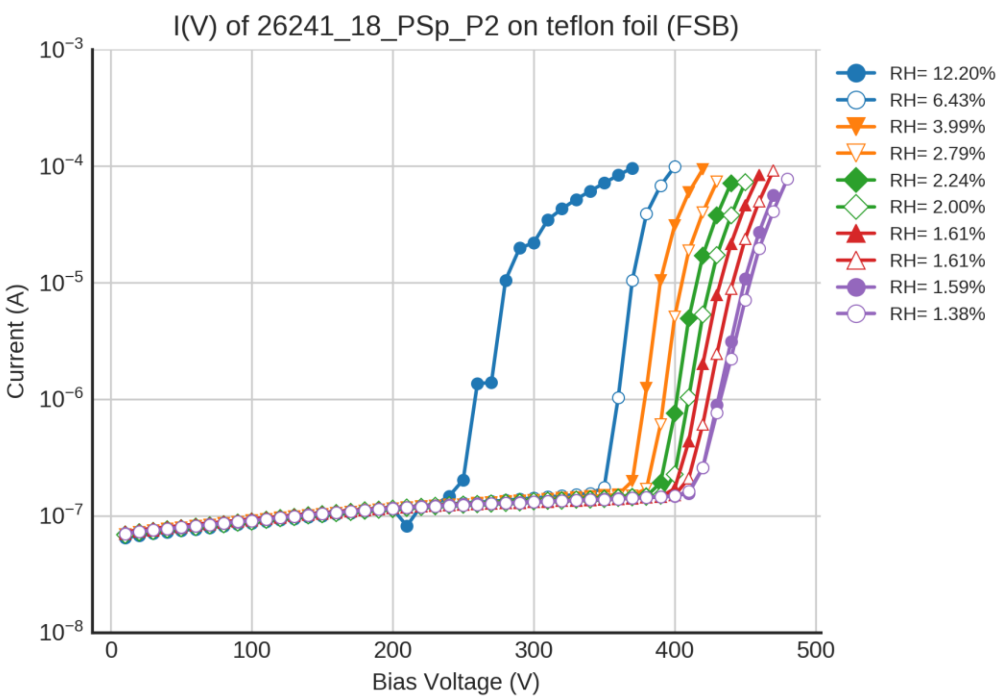
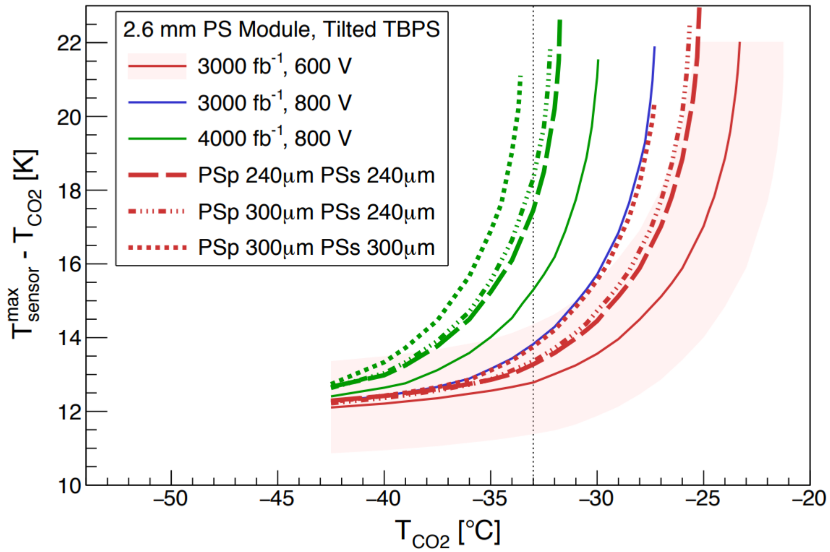


- Breakdown voltage affected by humidity

Irradiation Campaign with FZ290 and thFZ240

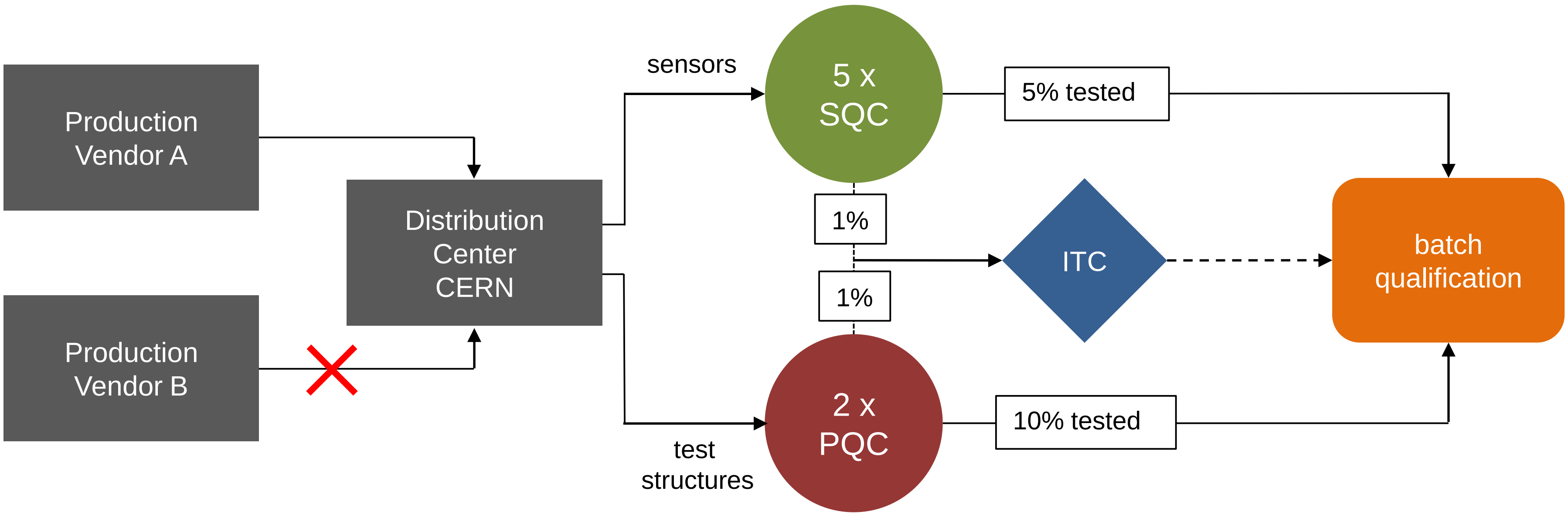
- Irradiation with similar particle composition as expected in tracker
- Cover expected maximum fluences (+ safety margin + 4000 fb^{-1} extension)
- Check seed signal and compare leakage current
- Check annealing characteristics
- Check signal boost and additional leakage current at 800 V
- Deliver information about leakage current for thermal studies

  → impacts final module design



Plot by Andreas Mussgiller – https://indico.cern.ch/event/699061/contributions/3130133/attachments/1710957/2758358/180905_PS_Module_FEA.pdf

Phase II OT Quality Control – Overview



SQC	–	Sensor Quality Control
PQC	–	Process Quality Control
ITC	–	Irradiation Test Center

Phase II OT Quality Control - Requirements

- Infrastructure
  - Clean room
  - Reliable equipment (fallback solutions if possible)
- Sufficient personnel (at least 1 experienced person)
- Desired SQC throughput: **1 sensor per day!**
  - 2 sensors per batch (25): 8% → ~1700 sensors to be tested
  - 400 days of testing → min. 4.25 SQCs required
- Desired PQC throughput: **2 - 4 wafers per day!**
  - 10% of test structures per batch
  - ~ 840 batches in 400 working days → min. 2 PQCs required
- …
- Final requirements are yet to be defined

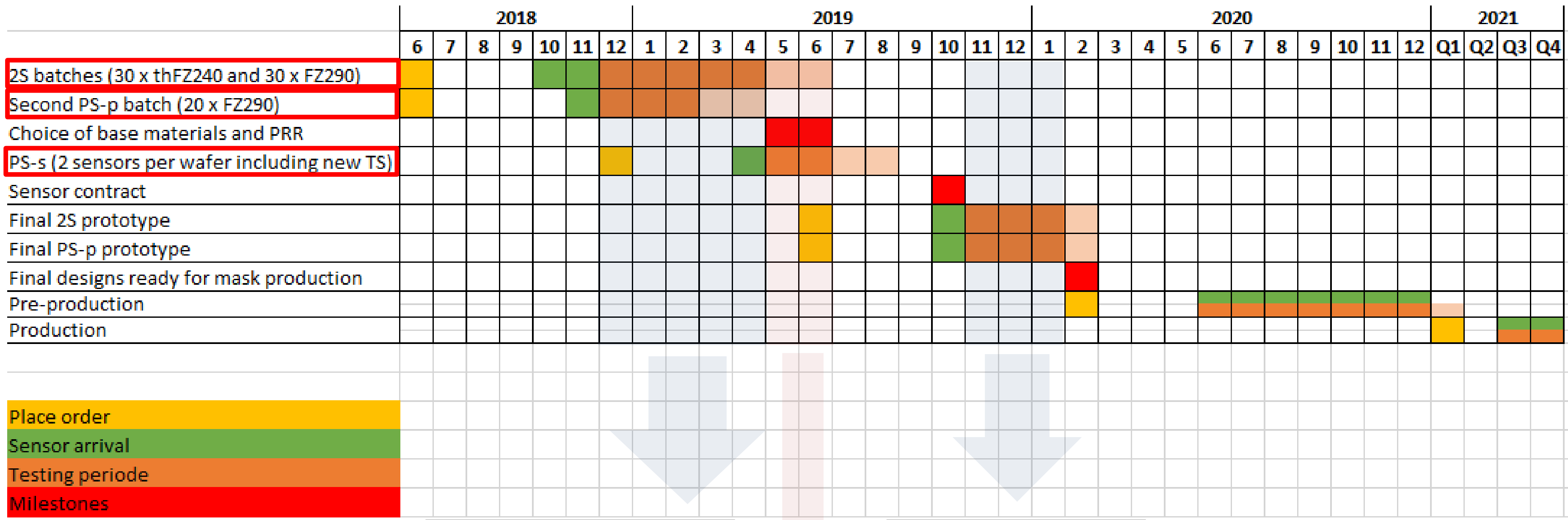
Phase II OT Quality Control – Current Status

- Working on "Phase-2 Sensor Bible" to define measurement procedures
- Phase-0 sensors were distributed to provide test sensors
- Test boards were produced at KIT and will be distributed for first calibration campaign
- 6 SQCs, 3 PQCs, 2 ITCs would cover the demand
- No center qualification performed so far
- Everyone is working hard on updating and refurbishing equipment and lab infrastructure

Candidate	Origin	Center Type	Part of Phase-0
KIT	GER	SQC & IT	yes
HEPHY	AUT	SQC & PQC	yes
Perugia	ITA	PQC	yes
Demokritos	GRC	undecided	no
Rochester	US	SQC	yes
Brown	US	SQC & PQC & IT	no
Delhi	IND	SQC	no
NCP	PAK	SQC	no

Prototype and Production Schedule

- Awaiting 2 additional 2S batches + 1 PS-p and 1 PS-s batch for testing



New irradiation campaign to finalize base material choice for 2S/PS sensors

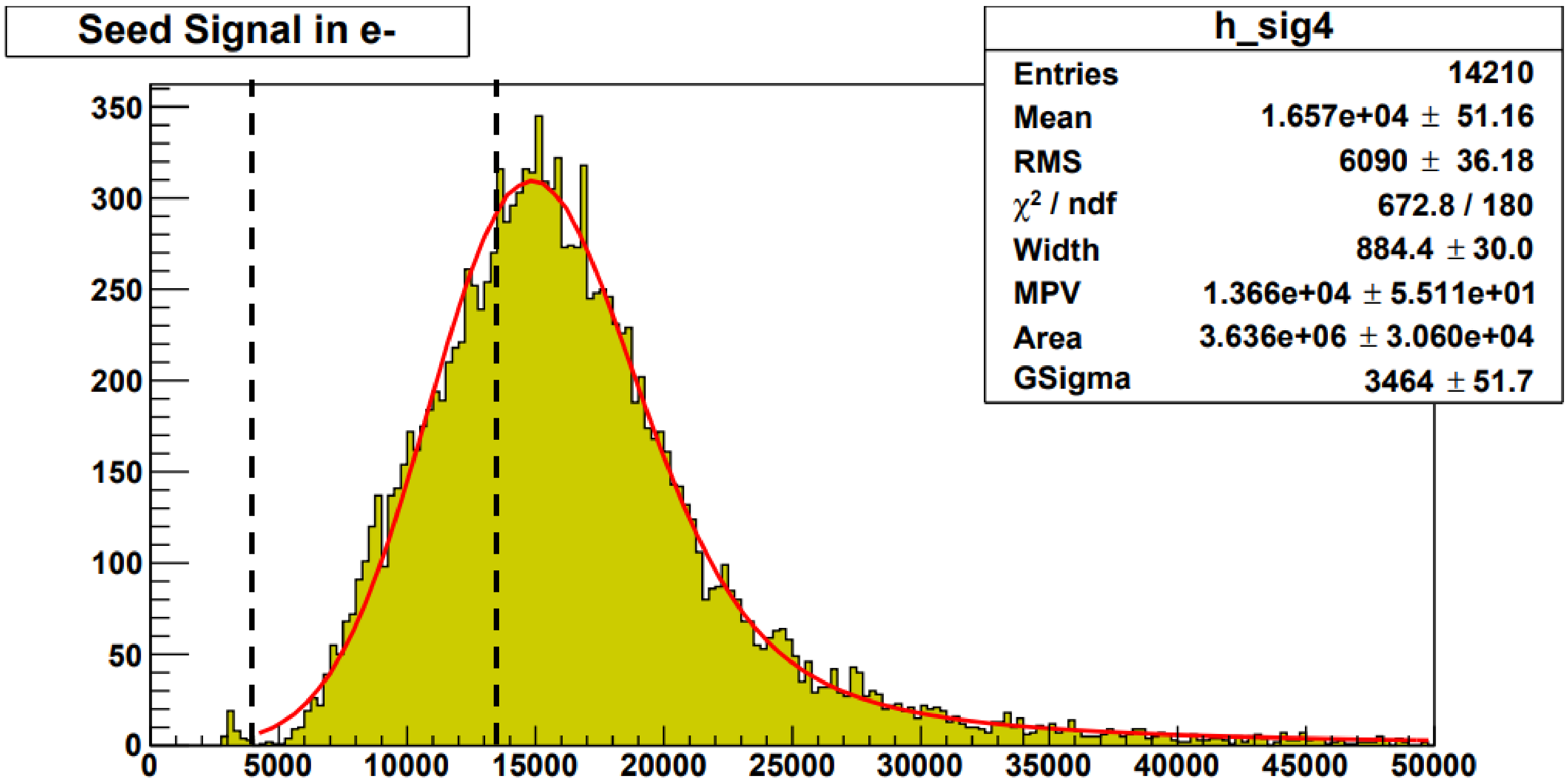
Final assembly tests

Finalize choice of test structures

Final prototypes

Back Up

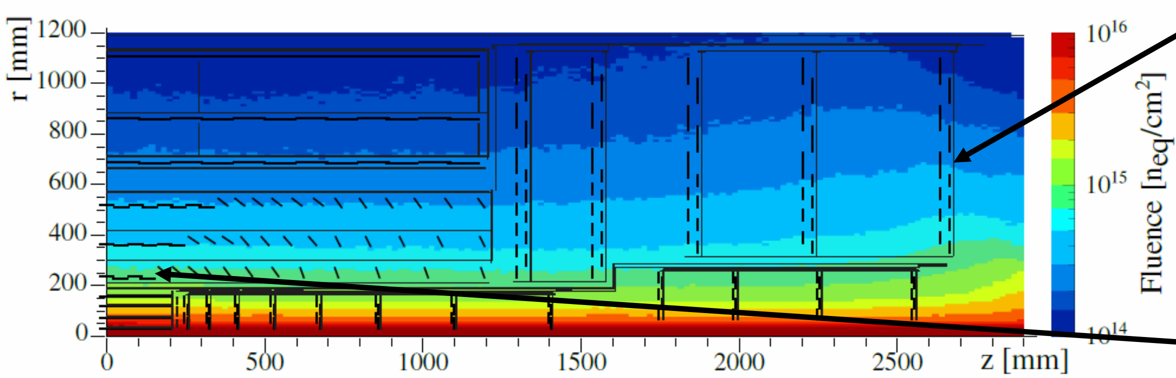
Seed Signal


Seed Signal in e-
h_sig4
Entries 14210
Mean 1.657e+04 ± 51.16
RMS 6090 ± 36.18
χ2 / ndf 672.8 / 180
Width 884.4 ± 30.0
MPV 1.366e+04 ± 5.511e+01
Area 3.636e+06 ± 3.060e+04
GSigma 3464 ± 51.7
350
300
250
200
150
100
50
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

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

Phase II OT Quality Control – Irradiation Centers

- Irradiation facilities:

Facility	Origin	Particle Type	Status
KIT	GER	23 MeV protons	
JSI	SVN	1 MeV neutrons	Available until end of AIDA-2020 (t.b.n.)
RI	US	1 MeV neutrons	Qualified by Brown and available
FNAL	US	300 MeV protons	Beam line ready by next year

- Enough radiation facilities to cover the demand for irradiations during production