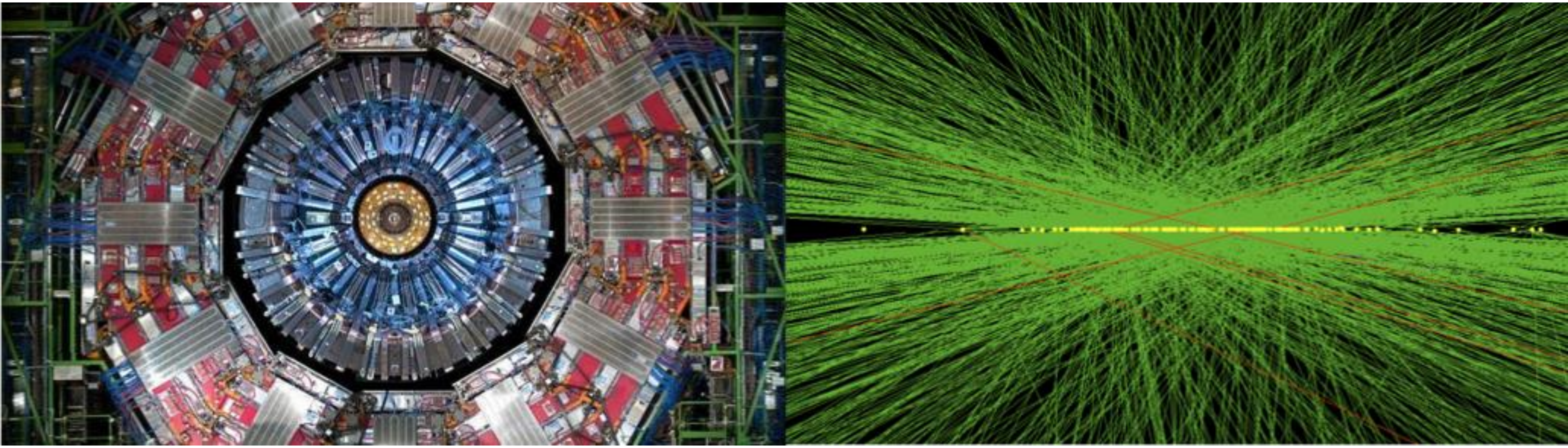
OT B01: CD3a and Sensors

Steve Nahn

CD1 Director’s Review

March 20, 2019

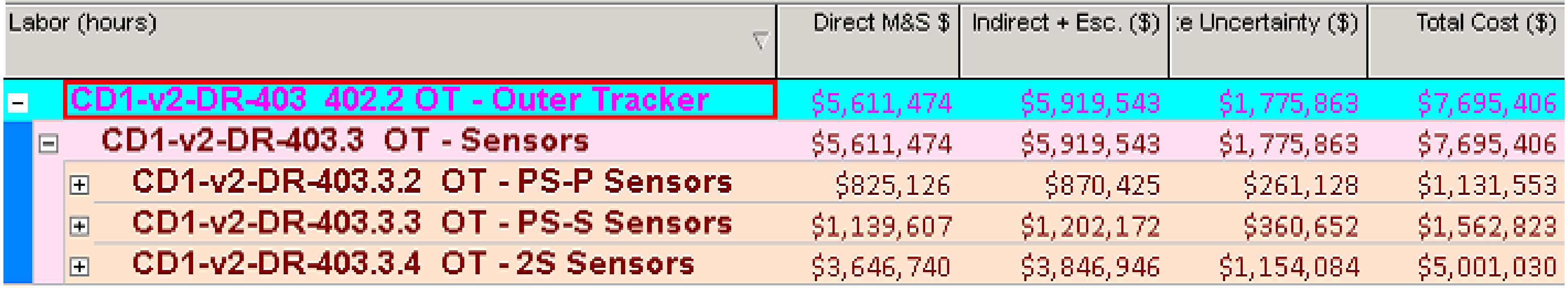


Outline

- Introduction
- Sensor Development for CD3a
- Vendor Negotiations
- Summary

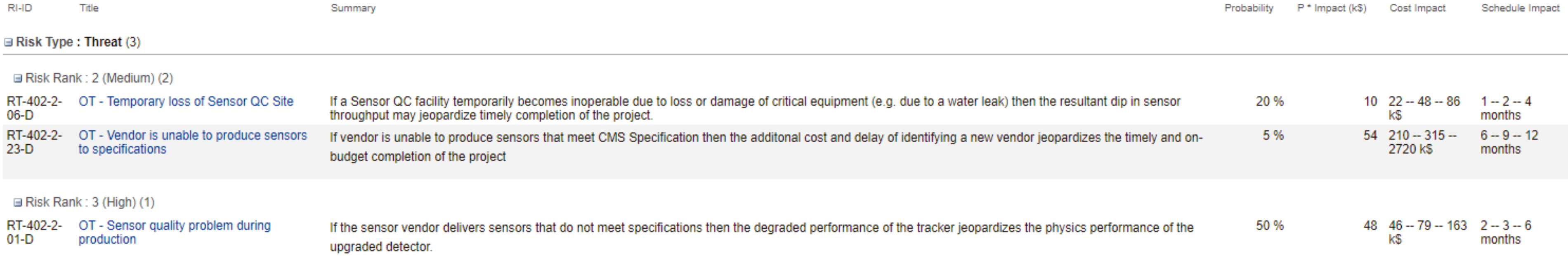
Introduction

- Sensor procurement needed to build modules
  - \$5.9M BAC plus 1.8M EU
  - Timeline currently drives critical path



Labor (hours)	Direct M&S \$	Indirect + Esc. (\$)	:e Uncertainty (\$)	Total Cost (\$)
− CD1-v2-DR-403 402.2 OT - Outer Tracker	\$5,611,474	\$5,919,543	\$1,775,863	\$7,695,406
⊟ CD1-v2-DR-403.3 OT - Sensors	\$5,611,474	\$5,919,543	\$1,775,863	\$7,695,406
⊞ CD1-v2-DR-403.3.2 OT - PS-P Sensors	\$825,126	\$870,425	\$261,128	\$1,131,553
⊞ CD1-v2-DR-403.3.3 OT - PS-S Sensors	\$1,139,607	\$1,202,172	\$360,652	\$1,562,823
⊞ CD1-v2-DR-403.3.4 OT - 2S Sensors	\$3,646,740	\$3,846,946	\$1,154,084	\$5,001,030

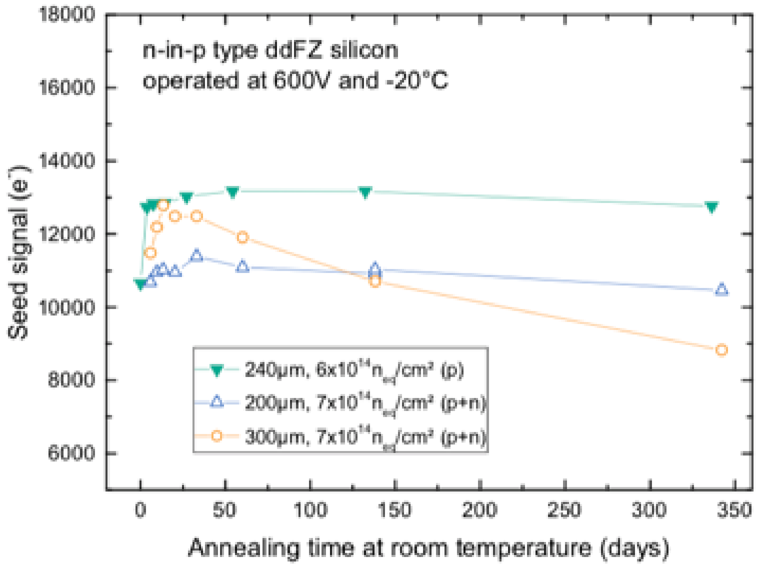
- Group procurement w/CMS to ensure homogeneity
  - CERN Market Survey qualifies vendor, manages procurement
  - U.S. CMS procures from CERN our share
- Three Risks Associated with Sensors

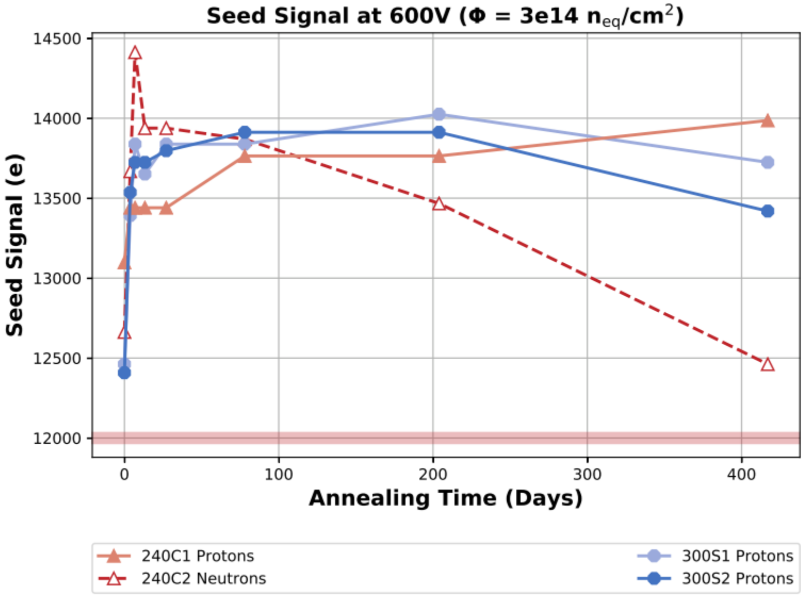


RI-ID	Title	Summary	Probability	P * Impact (k\$)	Cost Impact	Schedule Impact
⊟ **Risk Type : Threat** (3)						
⊟ Risk Rank : 2 (Medium) (2)						
RT-402-2-06-D	OT - Temporary loss of Sensor QC Site	If a Sensor QC facility temporarily becomes inoperable due to loss or damage of critical equipment (e.g. due to a water leak) then the resultant dip in sensor throughput may jeopardize timely completion of the project.	20 %	10	22 -- 48 -- 86 k\$	1 -- 2 -- 4 months
RT-402-2-23-D	OT - Vendor is unable to produce sensors to specifications	If vendor is unable to produce sensors that meet CMS Specification then the additonal cost and delay of identifying a new vendor jeopardizes the timely and on-budget completion of the project	5 %	54	210 -- 315 -- 2720 k\$	6 -- 9 -- 12 months
⊟ Risk Rank : 3 (High) (1)						
RT-402-2-01-D	OT - Sensor quality problem during production	If the sensor vendor delivers sensors that do not meet specifications then the degraded performance of the tracker jeopardizes the physics performance of the upgraded detector.	50 %	48	46 -- 79 -- 163 k\$	2 -- 3 -- 6 months

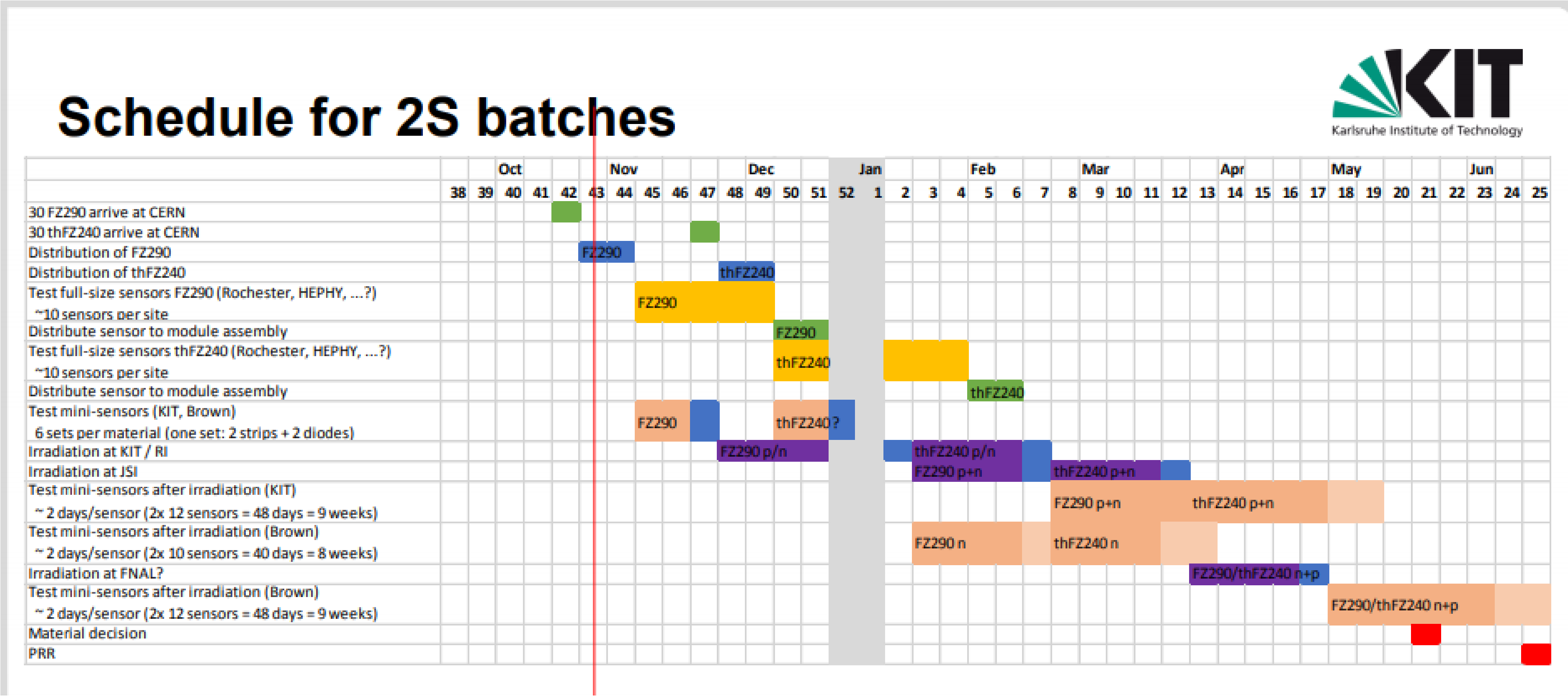
Progress on Sensor design

- Since June 2018 IPR
  - Single vendor left in Market Survey
    - One pulled out, one cannot satisfy throughput demands
  - Vendor withdraws default sensor doping option: Deep Diffused Float Zone
    - Concerned with yield
- Reverting to standard Float Zone silicon with two potential thicknesses
  - FZ290
    - Standard technology, robust
  - Thinned: thFZ240
    - Higher signal after irradiation
    - Better annealing properties - ?
    - More fragile, more expensive (15%)
- Decision aimed for May 2019





Sensor Validation Schedule



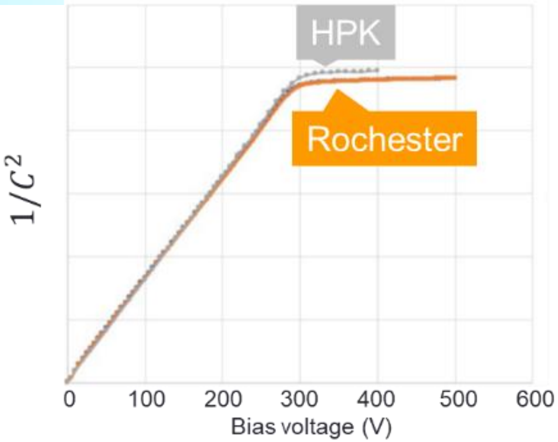
Schedule for 2S batches

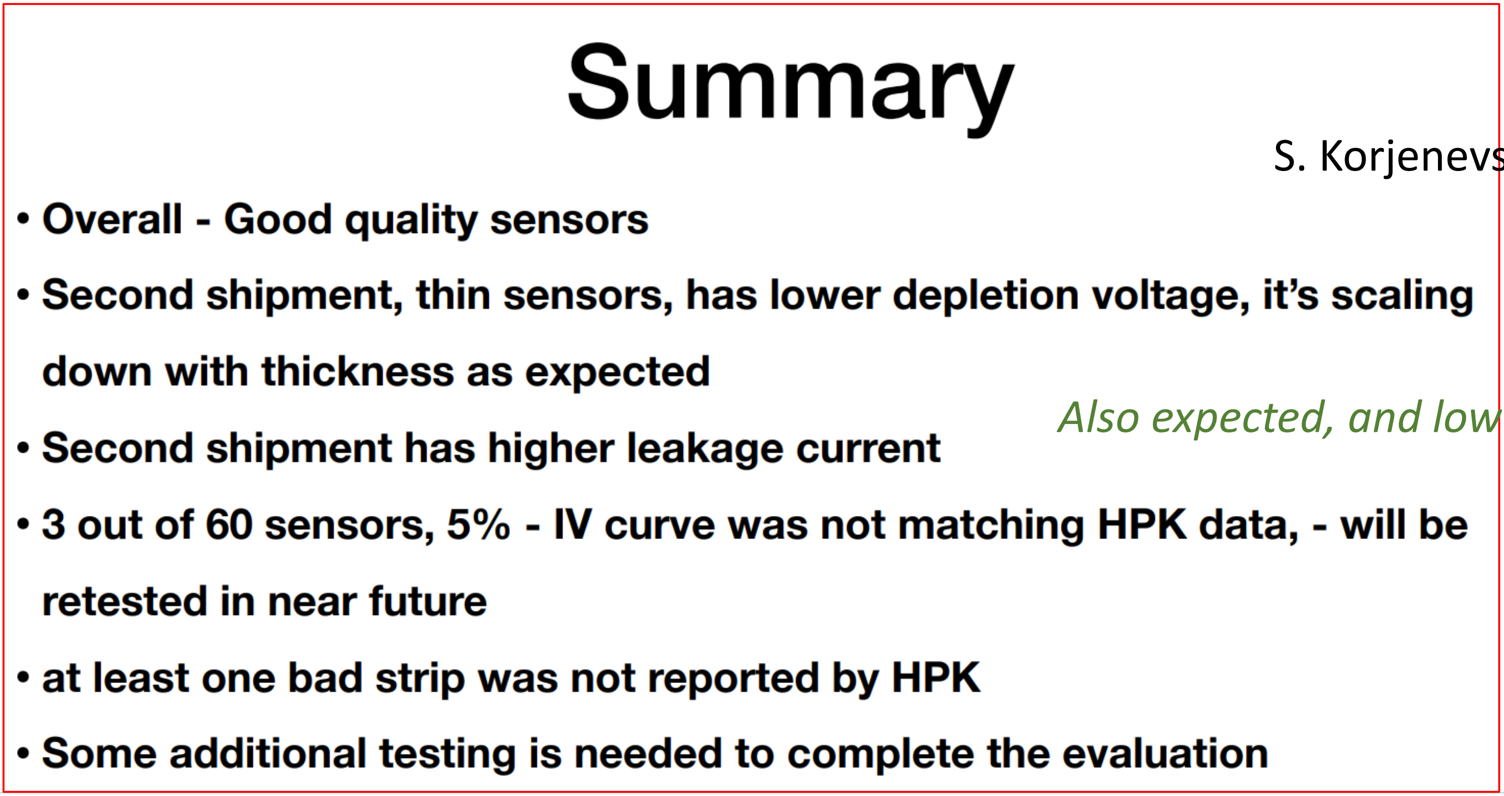
Karlsruhe Institute of Technology

			Oct				Nov					Dec				Jan				Feb				Mar					Apr				May					Jun		
	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
30 FZ290 arrive at CERN					🟩																																			
30 thFZ240 arrive at CERN										🟩																														
Distribution of FZ290						🟦 FZ290	🟦																																	
Distribution of thFZ240											🟦 thFZ240	🟦																												
Test full-size sensors FZ290 (Rochester, HEPHY, ...?) ~10 sensors per site								🟨 FZ290	🟨	🟨	🟨	🟨																												
Distribute sensor to module assembly													🟩 FZ290	🟩																										
Test full-size sensors thFZ240 (Rochester, HEPHY, ...?) ~10 sensors per site													🟨 thFZ240	🟨			🟨	🟨	🟨																					
Distribute sensor to module assembly																				🟩 thFZ240	🟩																			
Test mini-sensors (KIT, Brown) 6 sets per material (one set: 2 strips + 2 diodes)								🟧 FZ290	🟧	🟦			🟧 thFZ240	🟧	🟦 ?																									
Irradiation at KIT / RI											🟪 FZ290 p/n	🟪	🟪	🟪			🟦	🟪 thFZ240 p/n	🟪	🟪	🟪	🟦																		
Irradiation at JSI																		🟪 FZ290 p+n	🟪	🟪	🟪	🟦	🟪 thFZ240 p+n	🟪	🟪	🟪	🟦													
Test mini-sensors after irradiation (KIT) ~ 2 days/sensor (2x 12 sensors = 48 days = 9 weeks)																							🟧 FZ290 p+n	🟧	🟧	🟧	🟧	🟧 thFZ240 p+n	🟧	🟧	🟧	🟧	▨	▨						
Test mini-sensors after irradiation (Brown) ~ 2 days/sensor (2x 10 sensors = 40 days = 8 weeks)																		🟧 FZ290 n	🟧	🟧	🟧	▨	🟧 thFZ240 n	🟧	🟧	🟧	▨	▨												
Irradiation at FNAL?																												🟪 FZ290/thFZ240 n+p	🟪	🟪	🟪	🟦								
Test mini-sensors after irradiation (Brown) ~ 2 days/sensor (2x 12 sensors = 48 days = 9 weeks)																																	🟧 FZ290/thFZ240 n+p	🟧	🟧	🟧	🟧	🟧	▨	▨
Material decision																																				🟥				
PRR																																								🟥

New Sensor Pre-irradiation testing

- FX290 and thFZ240 samples procured early 2019
  - Pre-irradiation Testing at Rochester and Vienna
    - All Sensors look very good





Summary

- Overall - Good quality sensors
- Second shipment, thin sensors, has lower depletion voltage, it's scaling down with thickness as expected
- Second shipment has higher leakage current
- 3 out of 60 sensors, 5% - IV curve was not matching HPK data, - will be retested in near future
- at least one bad strip was not reported by HPK
- Some additional testing is needed to complete the evaluation

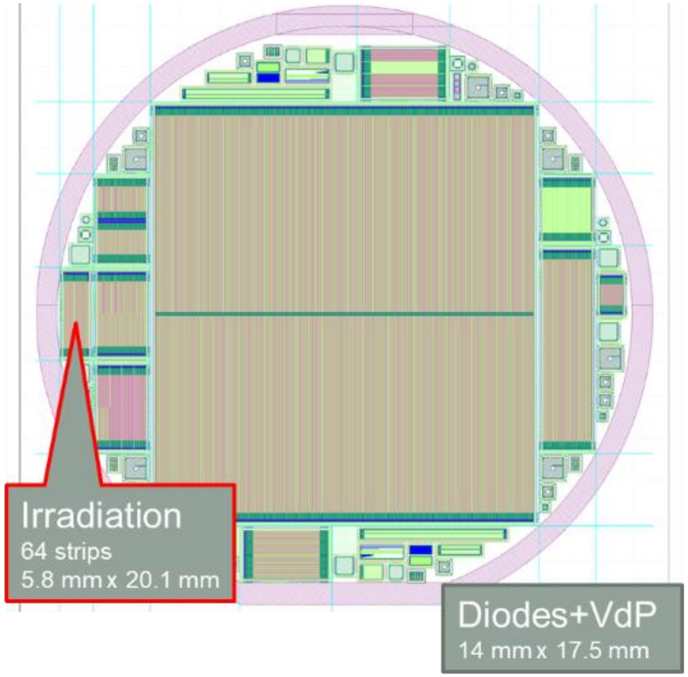
S. Korjenevski, TK Week 3/5/19

Also expected, and low in absolute terms

Sensor Irradiation campaign

- Irradiation campaign
  - Fluences ~ expected $\int \mathcal{L}dt$ at R=20 and 80 cm

	R=20 cm	R=80 cm
neutron fraction	40%	80%
2S (3000/fb)	$3 \times 10^{14}/\text{cm}^2$	$1 \times 10^{14}/\text{cm}^2$
PS (3000/fb)	$10 \times 10^{14}/\text{cm}^2$	$3 \times 10^{14}/\text{cm}^2$
PS (4000/fb)	$15 \times 10^{14}/\text{cm}^2$	$6 \times 10^{14}/\text{cm}^2$



  - Irradiation/measurement sites
    - Low E mixed: neutrons(JSI), protons(KIT) – measurements at KIT
    - Neutrons only: neutrons(RINSC) – measurements at Brown
    - High E mixed: neutrons(RINSC), protons(FNAL) – measurements at Brown

HPK Irradiation Campaign

- Measurement program
  - IV/CV @ 20 °C, sample strips
  - Irradiation with neutrons/protons
  - Anneal for 10 min @ 60°C
  - IV/CV @ -20°C, sample strips
  - Stepwise annealing to equivalent of 824 days @ 20°C
    - After every step measure pedestals, calibration, source run for 100V<V_{bias}<1000V @ -20°C on Alibava station
  - IV/CV @ -20°C, sample strips
- Status
  - Irradiations at JSI and KIT complete
  - Irradiations at RINSC in progress
  - Irradiations at FNAL after completion of irradiation facility

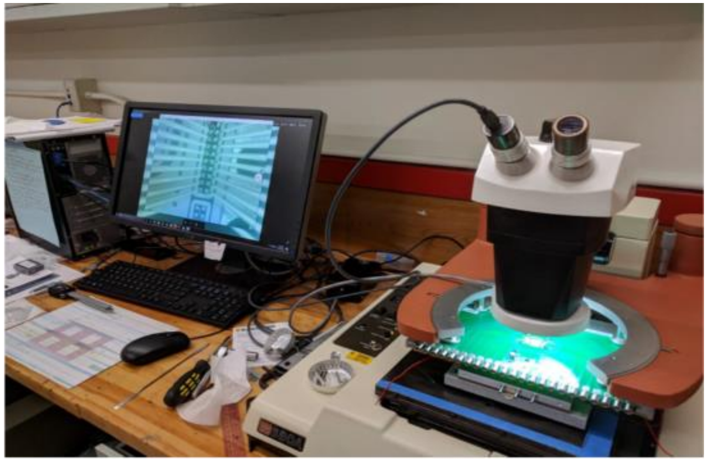
Annealing steps

Step	T(°C)	t(min)	RM Temp time (days)
1	60	10	3.8
2	60	20	6.9
3	60	40	13.3
4	60	80	27.9
5	60	100	53.7
6	60	140	100.0
7	80	25	203.1
8	80	57	407.4
9	80	120	824.1

Sensor QA progress

- Sensor production validation
  - Test at Vendor
  - Few % Sampling per batch
    - Sensors
    - Test structures (“Process”)
  - Irradiation at Brown/FNAL
- Current Progress
  - Sensor testing fully specified and regularly practiced
    - Some progress on Optimization
  - Process QC – test structures fully defined since June 2018 IPR, procurement of equipment nearly complete
  - Equipment being moved into clean room space
- Not CD3a scope
  - Testing labor needed well after CD3

	VQC	SQC	PQC	IQC
Global measurements (2S, PS-s, PS-p)				
Depletion voltage, current, break down	✓	✓	✓	✓
Longterm stability		✓		
Measurements after irradiation				
Breakdown and interstrip resistance				✓
Strip measurements (2S, PS-s)				
Strip current	✓	✓		✓
Bias resistor median	✓	✓	✓	
Bias resistor uniformity	✓	✓		
Coupling capacitance	✓	✓	✓	
Interstrip capacitance and resistance		✓	✓	✓
Pinhole check	✓	✓		
Bad strips	✓	✓		
Pixel measurements (PS-p)				
Pixel current, interpixel resistance			✓	
Number of bad pixels				
Test structure measurements				
Strip/pixel implant/aluminum resistivity			✓	
Dielectric breakdown			✓	



Market Survey and Procurement

Silicon Sensor production for Phase II Upgrades

- There was a long term effort to identify other vendors, in addition to HPK
  - Although technically promising, was ultimately not successful
    - Infineon has withdrawn from the development, for commercial reasons
    - Novati has been acquired by another company and, although the development continues, they are not in a position to offer large scale sensor production
- Focus the effort on ensuring successful single source Silicon Sensor procurement with HPK
  - For the ATLAS ITk, and CMS Tracker and HGCAL
  - Coordinated effort across the three projects, with support from CERN procurement office, to provide close coordination with HPK
- Work towards putting contract in place by Fall 2019
  - Mitigates commercial risks
    - Contractual framework to allow for detailed design changes prior to start of pre-series and/or pre-production, options for fine tuning of final quantities to match modules assembly yields etc.

Coordination Committee: scope and mandate

- Silicon Sensor procurements for these three large projects are on a very large scale

  Total largest so far for a HEP program: ~46’000 6” wafers + ~28’000 8” wafers

- Crucial to success of the ATLAS & CMS HL-LHC upgrades

  Need to ensure that requirements and constraints on Sensor specifications, quality, cost and delivery schedule are met

The aim is to put HPK in best position to meet the requirements and constraints for each of these three projects

A CERN-ATLAS-CMS Coordination Committee had been formed in order to:

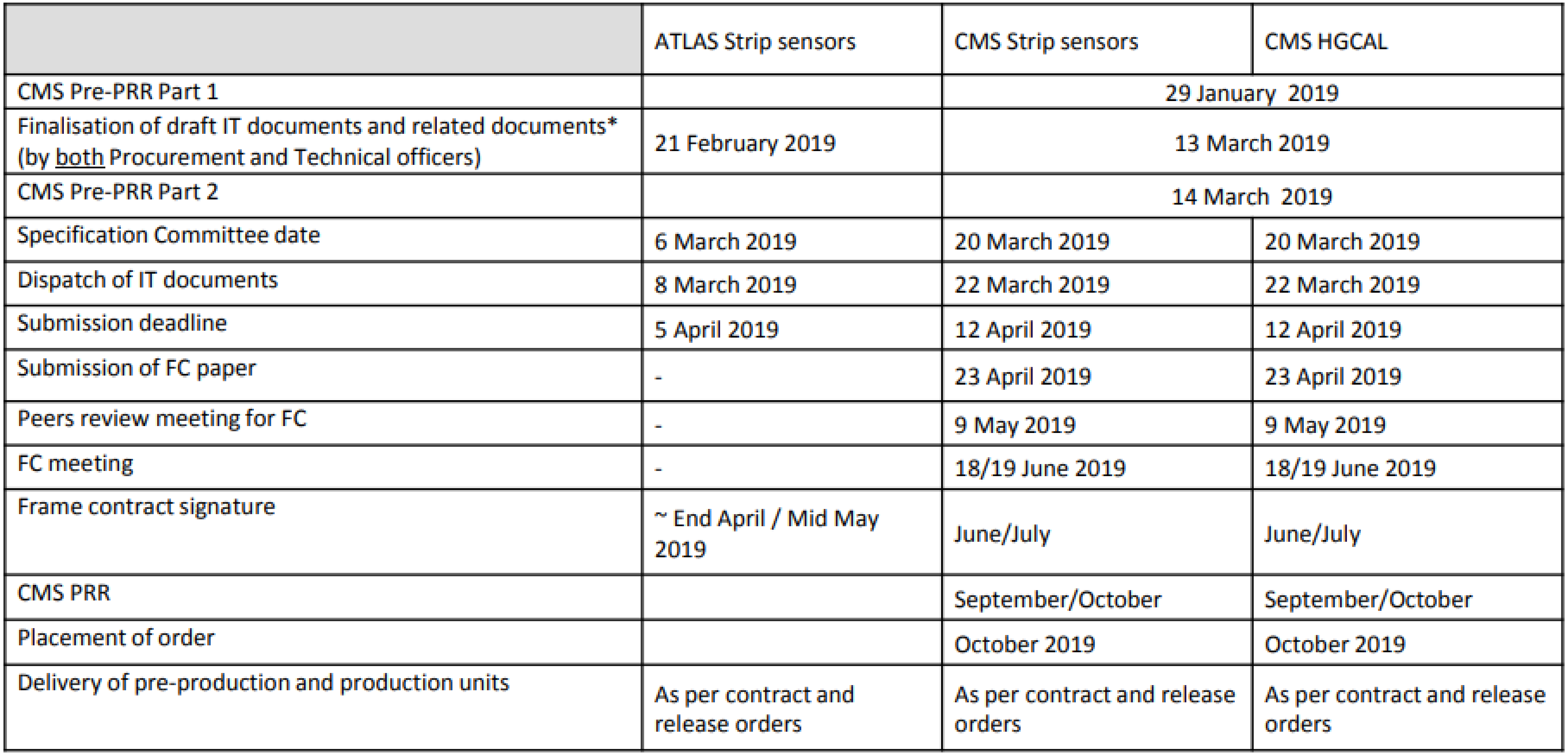
- Provide a single point of contact with HPK concerning these large procurements
  - While maintaining the technical and financial responsibility within each of the three projects
- Provide a coherent overview of Scope of procurement and Schedule so HPK can plan and prepare accordingly
  - Monitor, update and discuss on ongoing basis through to completion
- Provide a forum to discuss technical issues (eg. details of specs & quality requirements, test protocols, logistics etc.) to the extent that they may impact the delivery schedule
  - This may also provide some opportunity for cost optimization

Sensor Procurement Timeline and Activities

In the process of producing a set of specifications that will go to Hamamatsu and define parameters for "good" sensors, will lead to a frame contract this year.

Schedule:

Interpretation by Marko D, 3/5/2019



	ATLAS Strip sensors	CMS Strip sensors	CMS HGCAL
CMS Pre-PRR Part 1		29 January 2019	
Finalisation of draft IT documents and related documents* (by both Procurement and Technical officers)	21 February 2019	13 March 2019	
CMS Pre-PRR Part 2		14 March 2019	
Specification Committee date	6 March 2019	20 March 2019	20 March 2019
Dispatch of IT documents	8 March 2019	22 March 2019	22 March 2019
Submission deadline	5 April 2019	12 April 2019	12 April 2019
Submission of FC paper	-	23 April 2019	23 April 2019
Peers review meeting for FC	-	9 May 2019	9 May 2019
FC meeting	-	18/19 June 2019	18/19 June 2019
Frame contract signature	~ End April / Mid May 2019	June/July	June/July
CMS PRR		September/October	September/October
Placement of order		October 2019	October 2019
Delivery of pre-production and production units	As per contract and release orders	As per contract and release orders	As per contract and release orders

Considerations

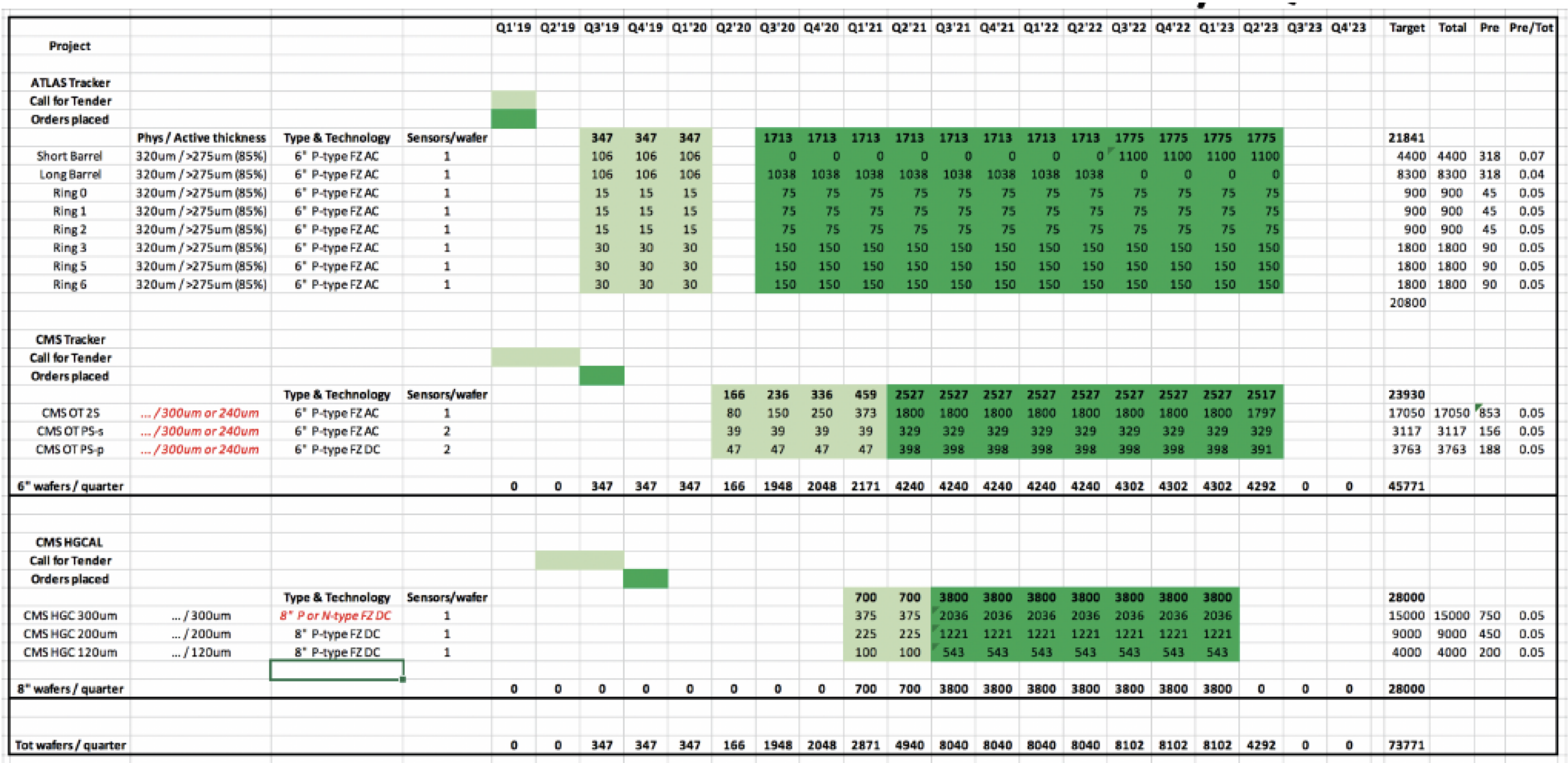
- Specification vs. Cost
    - tradeoffs between the tightness of the specification (i.e. leakage current), and yield (and therefore cost)
- Primary Concern: Noise due to microdischarge breakdown
    - Leakage current is best proxy for microdischarge in testing at HPK. This needs study in prototype testing.
- Specifications are intended to identify “bad” pads, strips and sensors.
    - Numbers in the specs are partially based on expected characteristics measured in a limited number of prototype samples.
    - Overall sensor leakage current provides an additional constraint on the sensor quality

Sensor Design Specification

- Design of the sensors including the full layout of the wafers shall be provided by CERN in the form of GDSII files
  - All dimensions mentioned in this technical specification document and in the GDS files refer to physical dimensions in the processed devices and not to dimensions in the lithography masks.
  - CMS provides gds format design files to HPK. HPK typically adapts these files to their process technologies.
  - HPK designs the guard rings, decides on implant widths and pad metal overlap
- HPK has the responsibility to insure that the design meets the technical specifications
  - The responsibility to ensure the compatibility of the designs with the contractor's process, and that the design of the sensors fulfills the technical requirements shall remain with the contractor.

ATLAS ITk, CMS Tracker and HGCAL Production schedule

Initial Proposal



Project				Q1'19	Q2'19	Q3'19	Q4'19	Q1'20	Q2'20	Q3'20	Q4'20	Q1'21	Q2'21	Q3'21	Q4'21	Q1'22	Q2'22	Q3'22	Q4'22	Q1'23	Q2'23	Q3'23	Q4'23	Target	Total	Pre	Pre/Tot
ATLAS Tracker																											
Call for Tender				🟩																							
Orders placed				🟩																							
	Phys / Active thickness	**Type & Technology**	**Sensors/wafer**			**347**	**347**	**347**		**1713**	**1713**	**1713**	**1713**	**1713**	**1713**	**1713**	**1713**	**1775**	**1775**	**1775**	**1775**			**21841**			
Short Barrel	320um / >275um (85%)	6" P-type FZ AC	1			106	106	106		0	0	0	0	0	0	0	0	1100	1100	1100	1100			4400	4400	318	0.07
Long Barrel	320um / >275um (85%)	6" P-type FZ AC	1			106	106	106		1038	1038	1038	1038	1038	1038	1038	1038	0	0	0	0			8300	8300	318	0.04
Ring 0	320um / >275um (85%)	6" P-type FZ AC	1			15	15	15		75	75	75	75	75	75	75	75	75	75	75	75			900	900	45	0.05
Ring 1	320um / >275um (85%)	6" P-type FZ AC	1			15	15	15		75	75	75	75	75	75	75	75	75	75	75	75			900	900	45	0.05
Ring 2	320um / >275um (85%)	6" P-type FZ AC	1			15	15	15		75	75	75	75	75	75	75	75	75	75	75	75			900	900	45	0.05
Ring 3	320um / >275um (85%)	6" P-type FZ AC	1			30	30	30		150	150	150	150	150	150	150	150	150	150	150	150			1800	1800	90	0.05
Ring 5	320um / >275um (85%)	6" P-type FZ AC	1			30	30	30		150	150	150	150	150	150	150	150	150	150	150	150			1800	1800	90	0.05
Ring 6	320um / >275um (85%)	6" P-type FZ AC	1			30	30	30		150	150	150	150	150	150	150	150	150	150	150	150			1800	1800	90	0.05
																								20800			
CMS Tracker																											
Call for Tender				🟩	🟩																						
Orders placed						🟩																					
		Type & Technology	**Sensors/wafer**						**166**	**236**	**336**	**459**	**2527**	**2527**	**2527**	**2527**	**2527**	**2527**	**2527**	**2527**	**2517**			**23930**			
CMS OT 2S	*... /300um or 240um*	6" P-type FZ AC	1						80	150	250	373	1800	1800	1800	1800	1800	1800	1800	1800	1797			17050	17050	853	0.05
CMS OT PS-s	*... /300um or 240um*	6" P-type FZ AC	2						39	39	39	39	329	329	329	329	329	329	329	329	329			3117	3117	156	0.05
CMS OT PS-p	*... /300um or 240um*	6" P-type FZ DC	2						47	47	47	47	398	398	398	398	398	398	398	398	391			3763	3763	188	0.05
6" wafers / quarter				**0**	**0**	**347**	**347**	**347**	**166**	**1948**	**2048**	**2171**	**4240**	**4240**	**4240**	**4240**	**4240**	**4302**	**4302**	**4302**	**4292**	**0**	**0**	**45771**			
CMS HGCAL																											
Call for Tender					🟩	🟩																					
Orders placed							🟩																				
		Type & Technology	**Sensors/wafer**									**700**	**700**	**3800**	**3800**	**3800**	**3800**	**3800**	**3800**	**3800**				**28000**			
CMS HGC 300um	... / 300um	*8" P or N-type FZ DC*	1									375	375	2036	2036	2036	2036	2036	2036	2036				15000	15000	750	0.05
CMS HGC 200um	... / 200um	8" P-type FZ DC	1									225	225	1221	1221	1221	1221	1221	1221	1221				9000	9000	450	0.05
CMS HGC 120um	... / 120um	8" P-type FZ DC	1									100	100	543	543	543	543	543	543	543				4000	4000	200	0.05
8" wafers / quarter				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**700**	**700**	**3800**	**3800**	**3800**	**3800**	**3800**	**3800**	**3800**	**0**	**0**	**0**	**28000**			
Tot wafers / quarter				**0**	**0**	**347**	**347**	**347**	**166**	**1948**	**2048**	**2871**	**4940**	**8040**	**8040**	**8040**	**8040**	**8102**	**8102**	**8102**	**4292**	**0**	**0**	**73771**			

19 September 2018 ATLAS ITk, CMS Tracker and CMS HGCAL Silicon Sensor Procurement 16

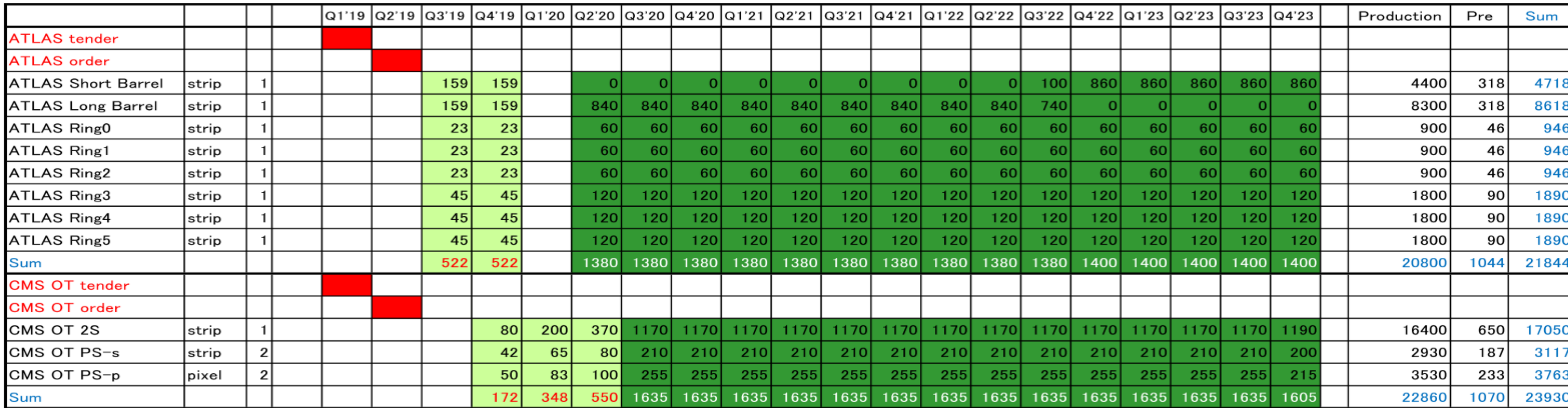
ATLAS ITk, CMS Tracker and HGCAL Production schedule

Modified Proposal, under discussion: 3 months from last sensor delivery to last module ready

				Q1'19	Q2'19	Q3'19	Q4'19	Q1'20	Q2'20	Q3'20	Q4'20	Q1'21	Q2'21	Q3'21	Q4'21	Q1'22	Q2'22	Q3'22	Q4'22	Q1'23	Q2'23	Q3'23	Q4'23	Target	Total	Pre	Pre/Tot
		prototypes	**estimated**																								
		pre-series																									
		pre-production																									
		production																									
ATLAS Tracker																								**45770**			
Call for Tender				🟩																							
Orders placed					🟩																						
	Phys / Active thickness	**Type & Technology**	**Sensors/wafer**			**521**	**521**		**1600**	**1600**	**1600**	**1600**	**1600**	**1600**	**1600**	**1600**	**1600**	**1601**	**1601**	**1601**	**1601**			**21841**			
Short Barrel	320um / >275um (85%)	6" P-type FZ AC	1			**159**	**159**		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**489**	**978**	**978**	**978**	**978**			4400	4400	318	0.07
Long Barrel	320um / >275um (85%)	6" P-type FZ AC	1			**159**	**159**		**976**	**976**	**976**	**976**	**976**	**976**	**976**	**976**	**488**	**0**	**0**	**0**	**0**			8300	8300	318	0.04
Ring 0	320um / >275um (85%)	6" P-type FZ AC	1			**23**	**23**		**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**			900	900	45	0.05
Ring 1	320um / >275um (85%)	6" P-type FZ AC	1			**23**	**23**		**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**			900	900	45	0.05
Ring 2	320um / >275um (85%)	6" P-type FZ AC	1			**23**	**23**		**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**	**69**			900	900	45	0.05
Ring 3	320um / >275um (85%)	6" P-type FZ AC	1			**45**	**45**		**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**			1800	1800	90	0.05
Ring 5	320um / >275um (85%)	6" P-type FZ AC	1			**45**	**45**		**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**			1800	1800	90	0.05
Ring 6	320um / >275um (85%)	6" P-type FZ AC	1			**45**	**45**		**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**	**138**			1800	1800	90	0.05
																								20800			
CMS Tracker																											
Call for Tender				🟩																							
Orders placed					🟩																						
		Type & Technology	**Sensors/wafer**						**172**	**348**	**550**	**1980**	**1980**	**1980**	**1980**	**1980**	**1980**	**1980**	**1980**	**1980**	**1980**	**1880**	**1179**	**23929**			
CMS OT 2S	*... / 300um or 240um*	6" P-type FZ AC	1						80	200	370	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1000	17050	17050	2050	0.12
CMS OT PS-s	*... / 300um or 240um*	6" P-type FZ AC	2						42	65	80	250	250	250	250	250	250	250	250	250	250	250	180	3117	3117	437	0.1402
CMS OT PS-p	*... / 300um or 240um*	6" P-type FZ DC	2						50	83	100	330	330	330	330	330	330	330	330	330	330	230		3763	3763	563	0.1496
6" wafers / quarter				**0**	**0**	**521**	**521**	**0**	**1772**	**1948**	**2150**	**3580**	**3580**	**3580**	**3580**	**3580**	**3580**	**3581**	**3581**	**3581**	**3581**	**1880**	**1179**	**45770**			
CMS HGCAL															stock												
Call for Tender				🟩	🟩										*8050*												
Orders placed					🟩	🟩																					
		Type & Technology	**Sensors/wafer**		*44*	*44*		*194*	*194*	*194*		**350**	**1050**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**0**		**28670**			
CMS HGC 300um	... / 300um	*8" P or N-type FZ DC*	1		*14*	*14*		*90*	*90*	*90*		188	563	1781	1781	1781	1781	1781	1781	1781	1781	0		15000	15000	750	0.05
CMS HGC 200um	... / 200um	8" P-type FZ DC	1		*14*	*14*		*64*	*64*	*64*		113	338	1069	1069	1069	1069	1069	1069	1069	1069	0		9000	9000	450	0.05
CMS HGC 120um	... / 120um	8" P-type FZ DC	1		*16*	*16*		*40*	*40*	*40*		50	150	475	475	475	475	475	475	475	475	0		4000	4000	200	0.05
8" wafers / quarter				*0*	*44*	*44*	*0*	*194*	*194*	*194*	*0*	**350**	**1050**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**3325**	**0**	**0**	**28670**			
Tot wafers / quarter				**0**	**44**	**565**	**521**	**194**	**1966**	**2142**	**2150**	**3930**	**4630**	**6905**	**6905**	**6905**	**6905**	**6906**	**6906**	**6906**	**6906**	**1880**	**1179**	**74440**			

New News

- HPK response last week of February
  - CMS 6 months advanced, 3000 wafers/quarter on 6” line, 50:50



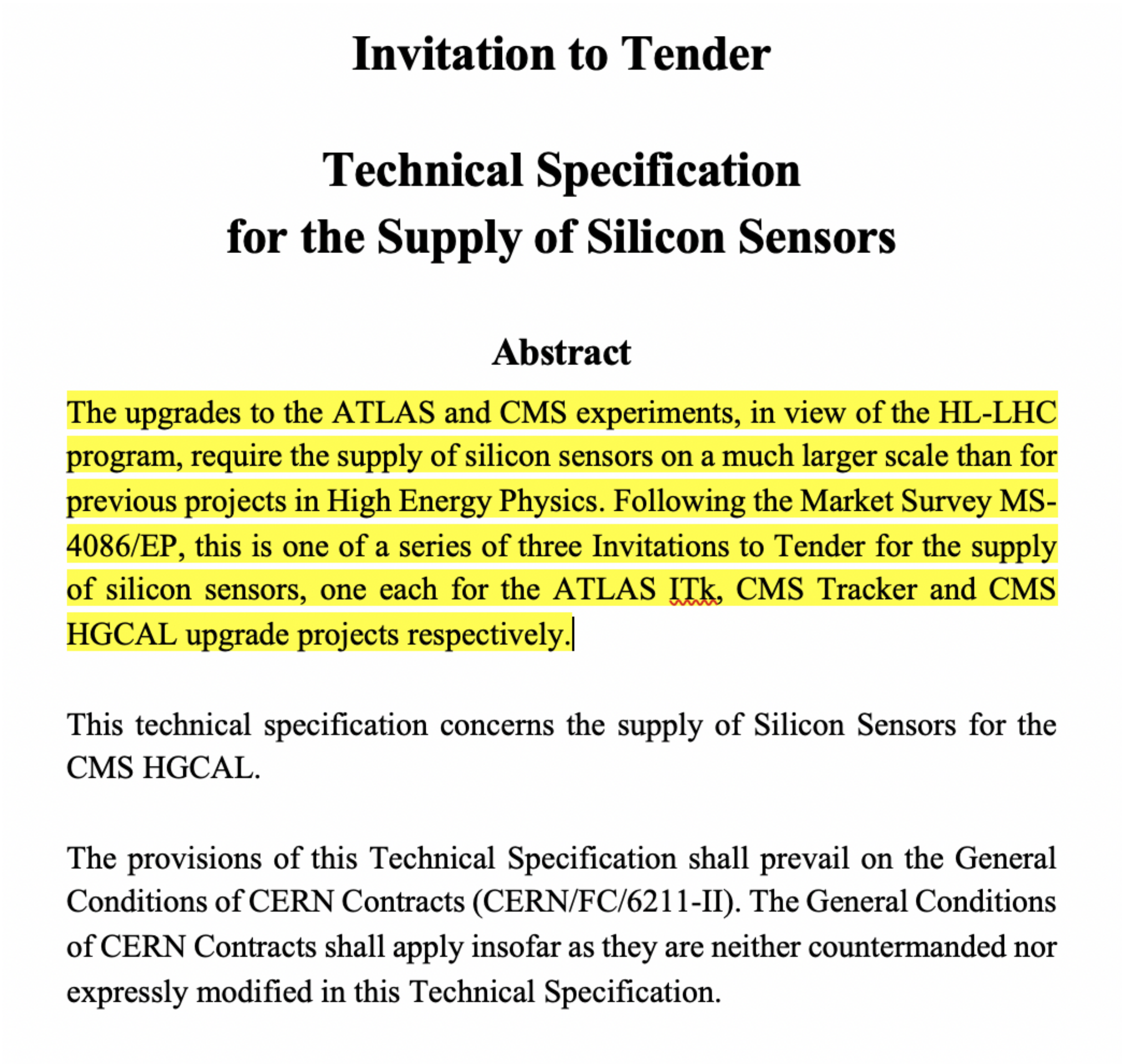
				Q1'19	Q2'19	Q3'19	Q4'19	Q1'20	Q2'20	Q3'20	Q4'20	Q1'21	Q2'21	Q3'21	Q4'21	Q1'22	Q2'22	Q3'22	Q4'22	Q1'23	Q2'23	Q3'23	Q4'23		Production	Pre	Sum
ATLAS tender				🟥																							
ATLAS order					🟥																						
ATLAS Short Barrel	strip	1				159	159		0	0	0	0	0	0	0	0	0	100	860	860	860	860	860		4400	318	4718
ATLAS Long Barrel	strip	1				159	159		840	840	840	840	840	840	840	840	840	740	0	0	0	0	0		8300	318	8618
ATLAS Ring0	strip	1				23	23		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60		900	46	946
ATLAS Ring1	strip	1				23	23		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60		900	46	946
ATLAS Ring2	strip	1				23	23		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60		900	46	946
ATLAS Ring3	strip	1				45	45		120	120	120	120	120	120	120	120	120	120	120	120	120	120	120		1800	90	1890
ATLAS Ring4	strip	1				45	45		120	120	120	120	120	120	120	120	120	120	120	120	120	120	120		1800	90	1890
ATLAS Ring5	strip	1				45	45		120	120	120	120	120	120	120	120	120	120	120	120	120	120	120		1800	90	1890
Sum						522	522		1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1400	1400	1400	1400	1400		20800	1044	21844
CMS OT tender				🟥																							
CMS OT order					🟥																						
CMS OT 2S	strip	1					80	200	370	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170	1190		16400	650	17050
CMS OT PS-s	strip	2					42	65	80	210	210	210	210	210	210	210	210	210	210	210	210	210	200		2930	187	3117
CMS OT PS-p	pixel	2					50	83	100	255	255	255	255	255	255	255	255	255	255	255	255	255	215		3530	233	3763
Sum							172	348	550	1635	1635	1635	1635	1635	1635	1635	1635	1635	1635	1635	1635	1635	1605		22860	1070	23930

- CMS+ATLAS discussing counter proposal
  - Stay with 3000/quarter, but favor ATLAS early, CMS later

ATLAS + CMS Silicon Procurement Guidelines

- There will continue to be orders for prototype and pre-series sensors until the production orders are placed
- Quarterly summary of production schedule
  - Frequency (≥ monthly) and size of deliveries to be discussed and agreed
- Potential scope modifications
  - There can be +- 10% changes to the total quantities, depending on module assembly yields etc.
- Delay mitigation both before and during production
  - Should make allowance for possible increase from 8’000 up to 10’000~12’000 wafers/quarter sustained delivery rate, in order to maintain project completion dates (driven by overall CERN accelerator schedule)
    - Includes wafer procurement, sensor production, sensor testing

Technical Specification for the Supply of Silicon Sensors



Invitation to Tender

Technical Specification
for the Supply of Silicon Sensors

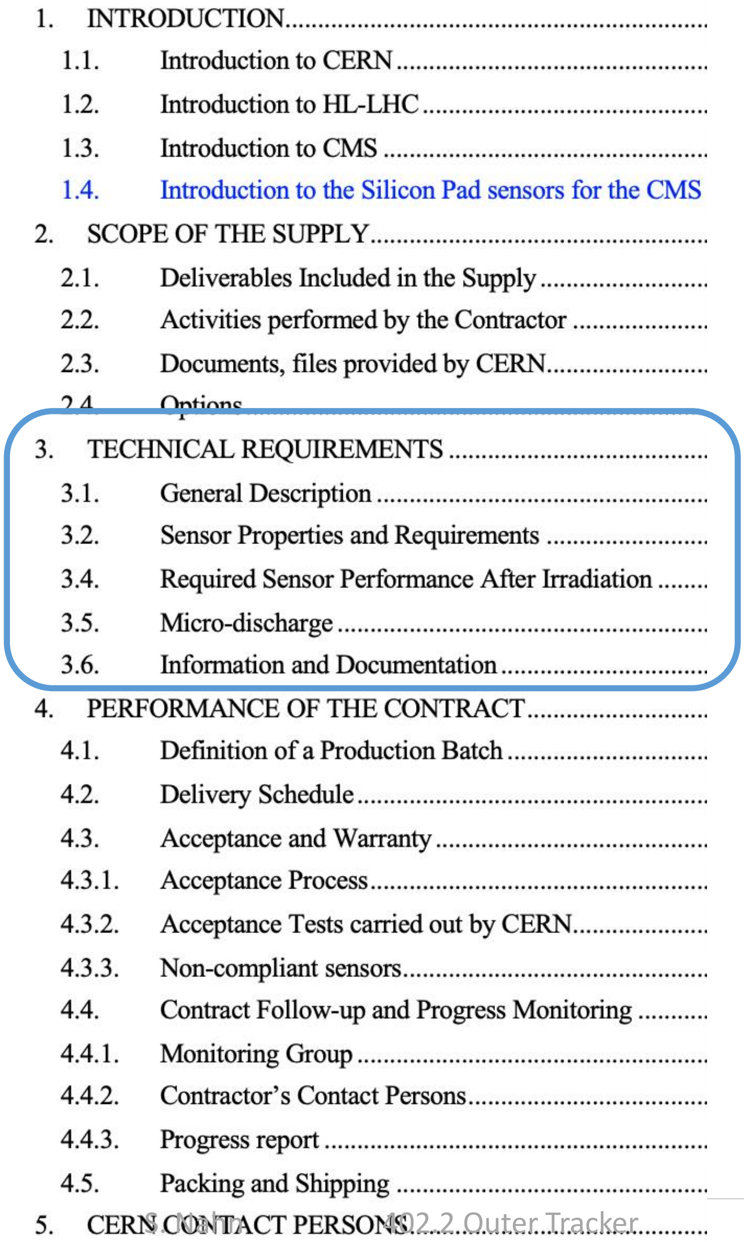
Abstract

The upgrades to the ATLAS and CMS experiments, in view of the HL-LHC program, require the supply of silicon sensors on a much larger scale than for previous projects in High Energy Physics. Following the Market Survey MS-4086/EP, this is one of a series of three Invitations to Tender for the supply of silicon sensors, one each for the ATLAS ITk, CMS Tracker and CMS HGCAL upgrade projects respectively.

This technical specification concerns the supply of Silicon Sensors for the CMS HGCAL.

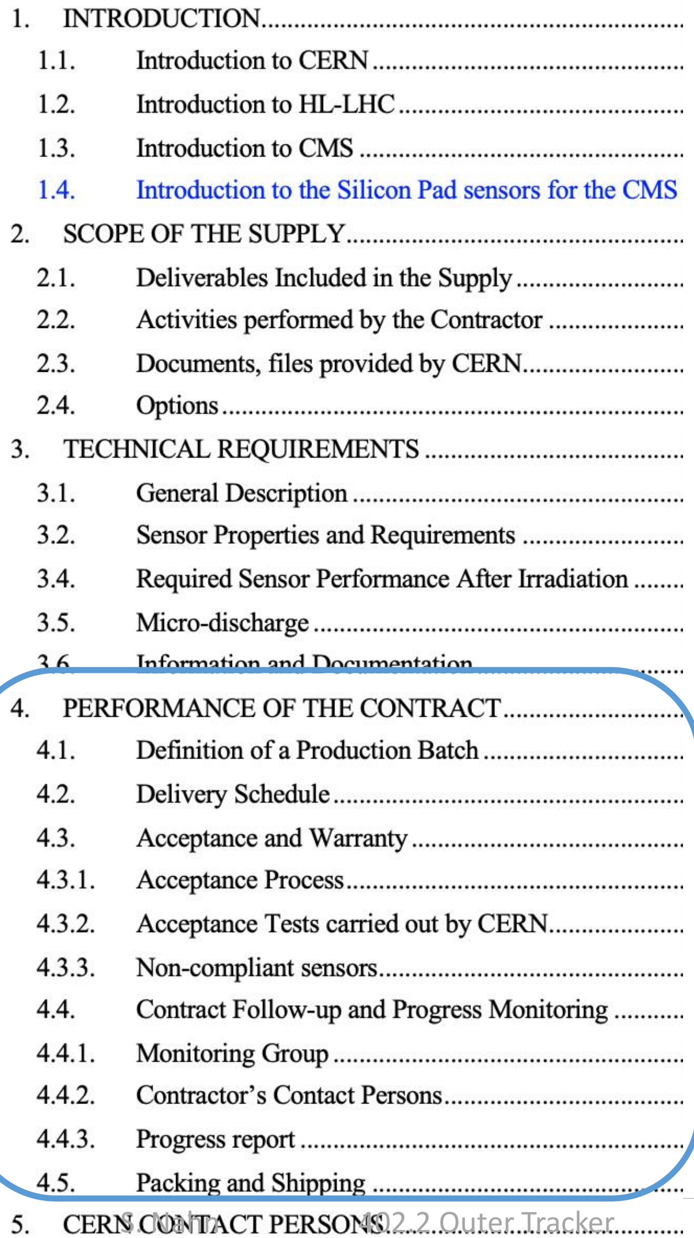
The provisions of this Technical Specification shall prevail on the General Conditions of CERN Contracts (CERN/FC/6211-II). The General Conditions of CERN Contracts shall apply insofar as they are neither countermanded nor expressly modified in this Technical Specification.

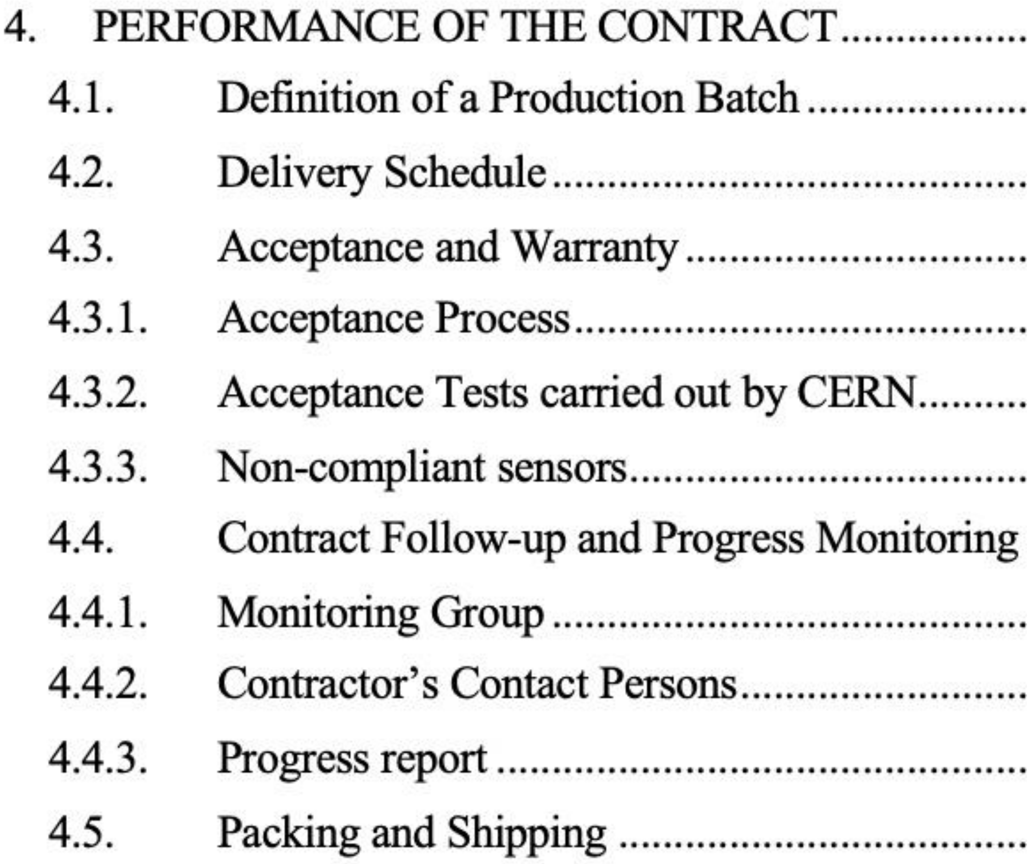
Technical Specification for the Supply of Silicon Sensors



- Technical Requirements
  - Responsibility for conformance and validation of conformity
  - Mask requirements
  - Mechanical properties, tolerances
    - Uniformity, Pull tests, defects, Alignment marks…
  - Pre-irradiation Properties
    - Environment control, Test structure, general silicon, and pixel/strip specifics
  - Post-irradiation Properties
    - After fixed dose and annealing, I_{max}(800V), V_{break}, R_{strip} …
  - Micro-discharge
    - Threshold on noise performance after assembly
  - Information and Data to be provided

Technical Specification for the Supply of Silicon Sensors

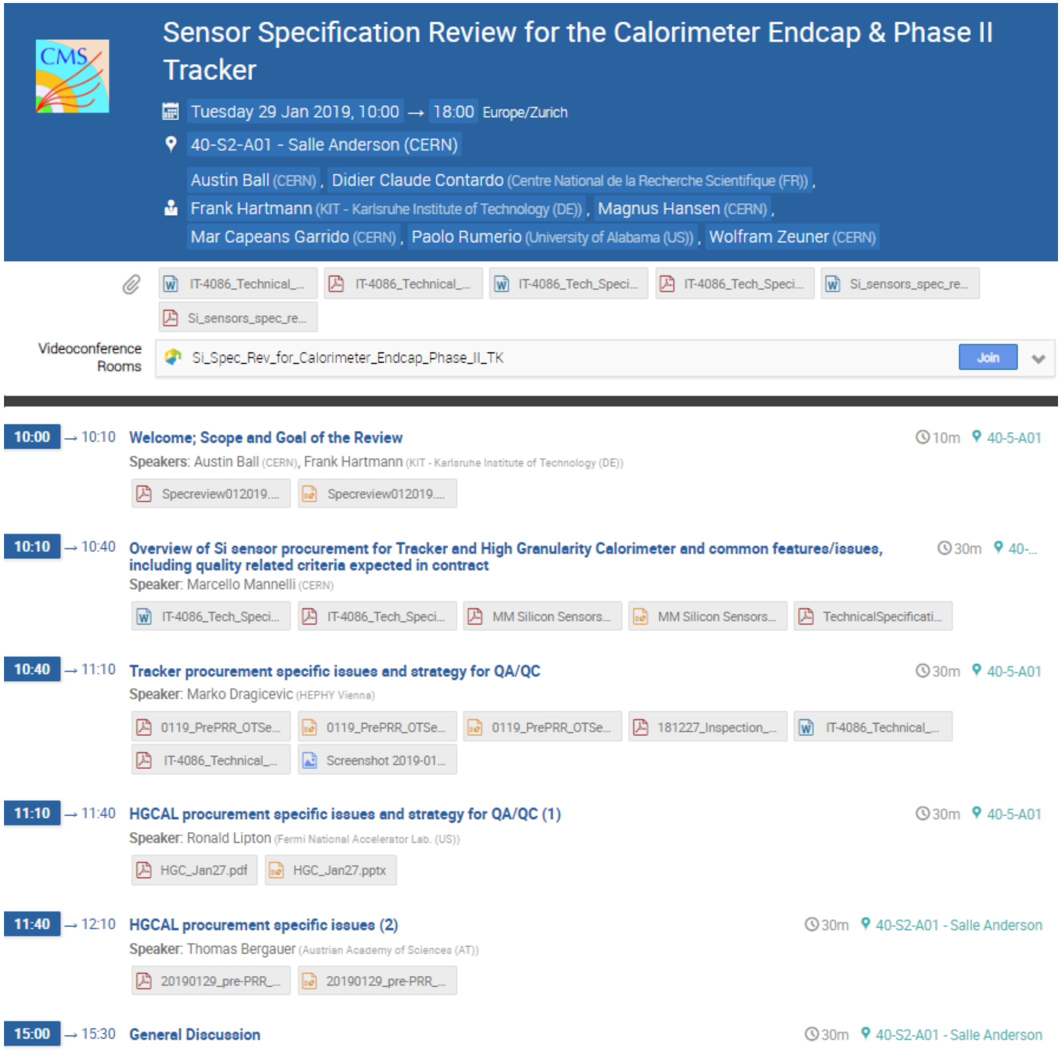




4. PERFORMANCE OF THE CONTRACT
  4.1. Definition of a Production Batch
  4.2. Delivery Schedule
  4.3. Acceptance and Warranty
  4.3.1. Acceptance Process
  4.3.2. Acceptance Tests carried out by CERN
  4.3.3. Non-compliant sensors
  4.4. Contract Follow-up and Progress Monitoring
  4.4.1. Monitoring Group
  4.4.2. Contractor's Contact Persons
  4.4.3. Progress report
  4.5. Packing and Shipping

Silicon Sensor pre-PRR and Committee review

- CMS Sensor Spec and Invitation to Tender reviewed, Jan 29, 2019
  - 10 Action items to improve/clarify aspects of the Invitation to Tender
  - Follow-up meeting March 20, 2019



Sensor Specification Review for the Calorimeter Endcap & Phase II Tracker

Tuesday 29 Jan 2019, 10:00 → 18:00 Europe/Zurich

40-S2-A01 - Salle Anderson (CERN)

Austin Ball (CERN), Didier Claude Contardo (Centre National de la Recherche Scientifique (FR)), Frank Hartmann (KIT - Karlsruhe Institute of Technology (DE)), Magnus Hansen (CERN), Mar Capeans Garrido (CERN), Paolo Rumerio (University of Alabama (US)), Wolfram Zeuner (CERN)

IT-4086_Technical_... IT-4086_Technical_... IT-4086_Tech_Speci... IT-4086_Tech_Speci... Si_sensors_spec_re... Si_sensors_spec_re...

Videoconference Rooms: Si_Spec_Rev_for_Calorimeter_Endcap_Phase_II_TK

10:00 → 10:10 **Welcome; Scope and Goal of the Review** 10m 40-5-A01
Speakers: Austin Ball (CERN), Frank Hartmann (KIT - Karlsruhe Institute of Technology (DE))
Specreview012019.... Specreview012019....

10:10 → 10:40 **Overview of Si sensor procurement for Tracker and High Granularity Calorimeter and common features/issues, including quality related criteria expected in contract** 30m 40-...
Speaker: Marcello Mannelli (CERN)
IT-4086_Tech_Speci... IT-4086_Tech_Speci... MM Silicon Sensors... MM Silicon Sensors... TechnicalSpecificati...

10:40 → 11:10 **Tracker procurement specific issues and strategy for QA/QC** 30m 40-5-A01
Speaker: Marko Dragicevic (HEPHY Vienna)
0119_PrePRR_OTSe... 0119_PrePRR_OTSe... 0119_PrePRR_OTSe... 181227_Inspection_... IT-4086_Technical_... IT-4086_Technical_... Screenshot 2019-01...

11:10 → 11:40 **HGCAL procurement specific issues and strategy for QA/QC (1)** 30m 40-5-A01
Speaker: Ronald Lipton (Fermi National Accelerator Lab. (US))
HGC_Jan27.pdf HGC_Jan27.pptx

11:40 → 12:10 **HGCAL procurement specific issues (2)** 30m 40-S2-A01 - Salle Anderson
Speaker: Thomas Bergauer (Austrian Academy of Sciences (AT))
20190129_pre-PRR_... 20190129_pre-PRR_...

15:00 → 15:30 **General Discussion** 30m 40-S2-A01 - Salle Anderson

Procurement Process at FNAL

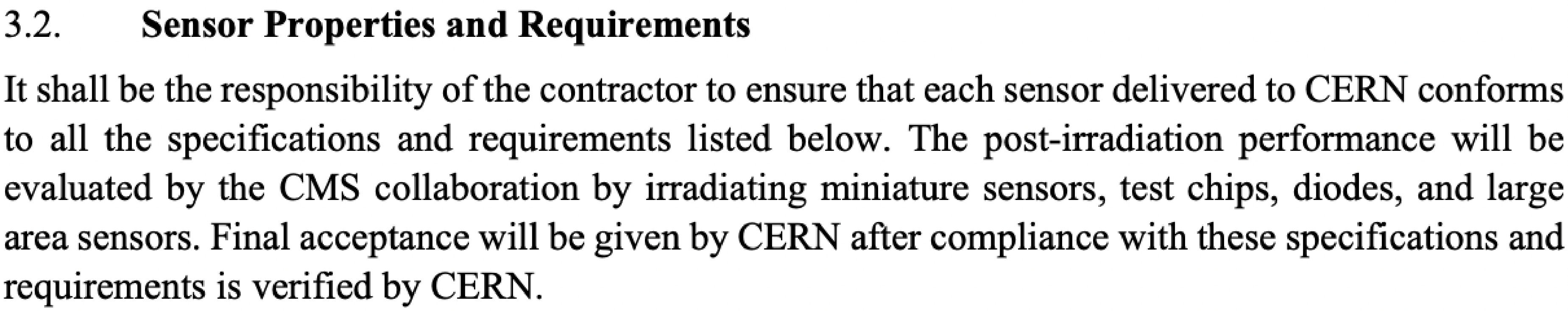
- Project Office is working actively with Fermilab Management, Procurement and General Counsel Office to put together Acquisition Plans (APs) for Silicon sensors to be bought through CERN for the Outer Tracker and Endcap Calorimeter.
- The timeline for the preparation and execution of the two procurement packages has been established and the OT process has started.
- The Outer Tracker AP will be reviewed by FRA's Procurement Review Board in April 2019 and because the anticipated cost is more than $5M it will be reviewed by DOE Fermilab Site Office as well.
- The Request for Proposal is expected to be submitted to CERN between August and September 2019.
- It is expected that the Outer Tracker procurement package will be fully executed between November 2019 and January 2020.

Summary

- CD3a scope for OT is sensor procurements
- R&D for remaining design decision, thickness, in progress, aimed to converge by this summer
- LHC Silicon Consortium working on procurement documentation
  - Specification of good working sensors
  - Contractual terms to ensure reliable and timely delivery
- Fermilab and Project Office working on procurement of U.S. share
- All of this should be ready for a CD3a late this year or early next year

Backup

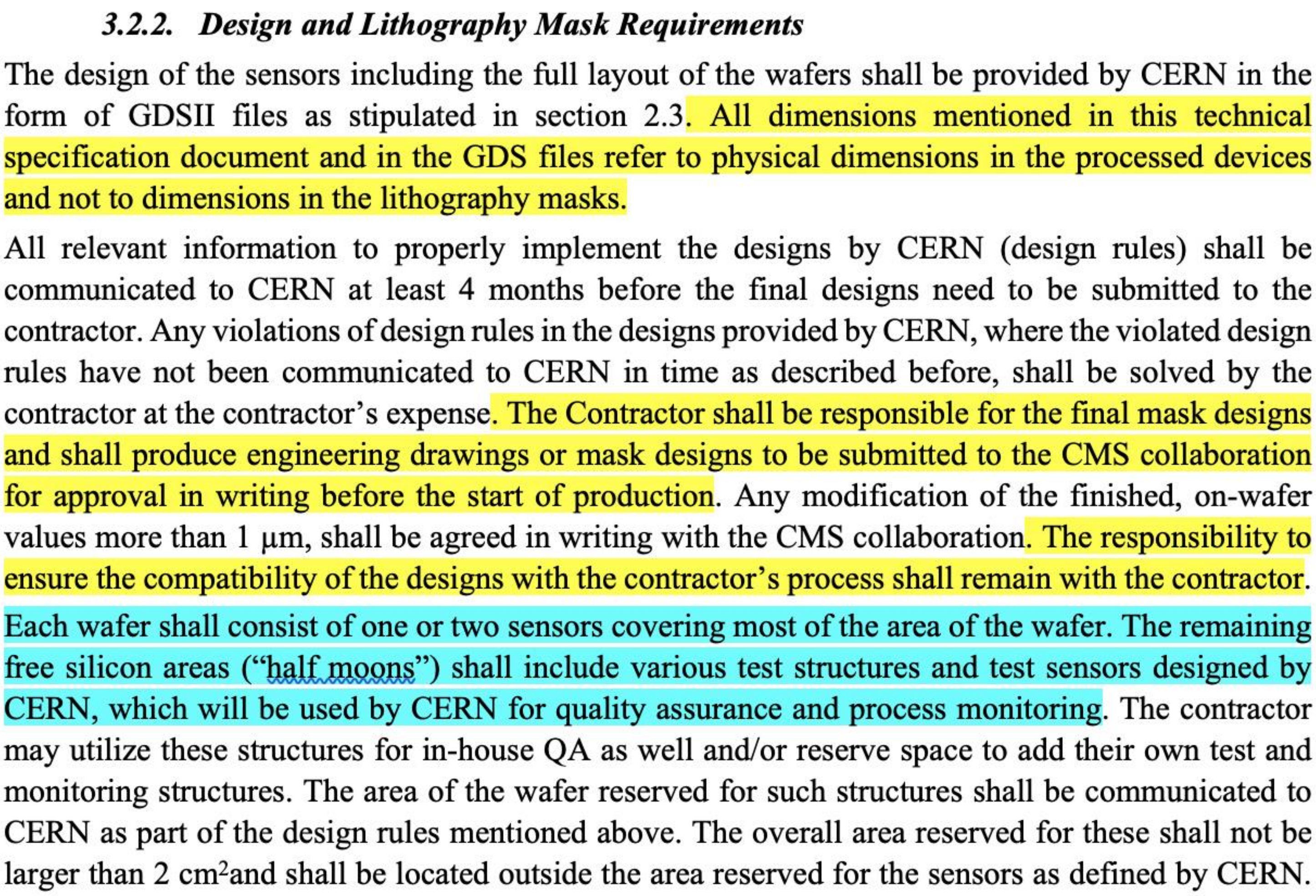
Technical Specification for the Supply of Silicon Sensors



3.2. Sensor Properties and Requirements

It shall be the responsibility of the contractor to ensure that each sensor delivered to CERN conforms to all the specifications and requirements listed below. The post-irradiation performance will be evaluated by the CMS collaboration by irradiating miniature sensors, test chips, diodes, and large area sensors. Final acceptance will be given by CERN after compliance with these specifications and requirements is verified by CERN.

Technical Specification for the Supply of Silicon Sensors



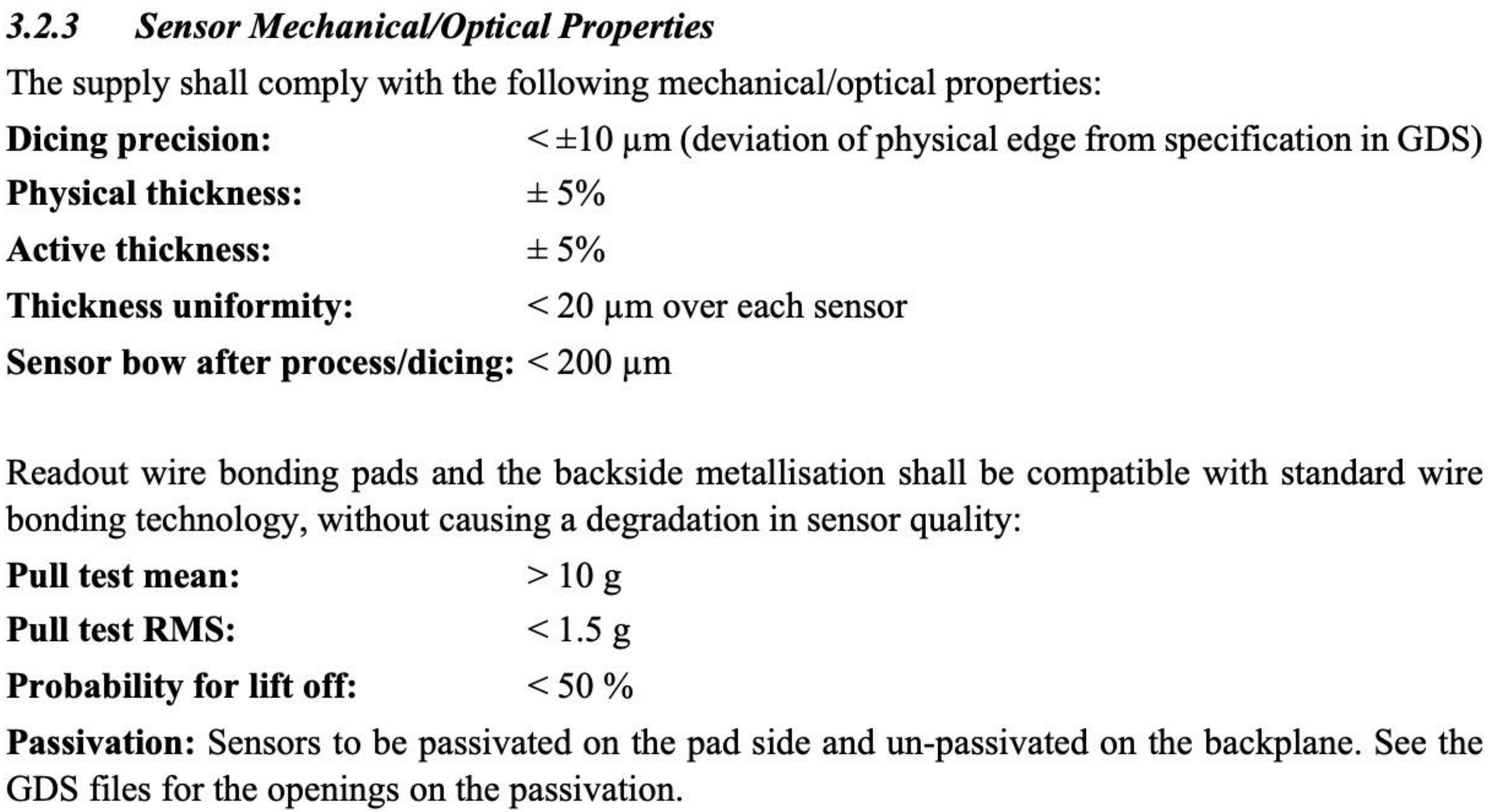
3.2.2. Design and Lithography Mask Requirements

The design of the sensors including the full layout of the wafers shall be provided by CERN in the form of GDSII files as stipulated in section 2.3. All dimensions mentioned in this technical specification document and in the GDS files refer to physical dimensions in the processed devices and not to dimensions in the lithography masks.

All relevant information to properly implement the designs by CERN (design rules) shall be communicated to CERN at least 4 months before the final designs need to be submitted to the contractor. Any violations of design rules in the designs provided by CERN, where the violated design rules have not been communicated to CERN in time as described before, shall be solved by the contractor at the contractor's expense. The Contractor shall be responsible for the final mask designs and shall produce engineering drawings or mask designs to be submitted to the CMS collaboration for approval in writing before the start of production. Any modification of the finished, on-wafer values more than 1 μm, shall be agreed in writing with the CMS collaboration. The responsibility to ensure the compatibility of the designs with the contractor's process shall remain with the contractor.

Each wafer shall consist of one or two sensors covering most of the area of the wafer. The remaining free silicon areas ("half moons") shall include various test structures and test sensors designed by CERN, which will be used by CERN for quality assurance and process monitoring. The contractor may utilize these structures for in-house QA as well and/or reserve space to add their own test and monitoring structures. The area of the wafer reserved for such structures shall be communicated to CERN as part of the design rules mentioned above. The overall area reserved for these shall not be larger than 2 $cm^2$and shall be located outside the area reserved for the sensors as defined by CERN.

Technical Specification for the Supply of Silicon Sensors



3.2.3 Sensor Mechanical/Optical Properties

The supply shall comply with the following mechanical/optical properties:

Dicing precision: < ±10 µm (deviation of physical edge from specification in GDS)

Physical thickness: ± 5%

Active thickness: ± 5%

Thickness uniformity: < 20 µm over each sensor

Sensor bow after process/dicing: < 200 µm

Readout wire bonding pads and the backside metallisation shall be compatible with standard wire bonding technology, without causing a degradation in sensor quality:

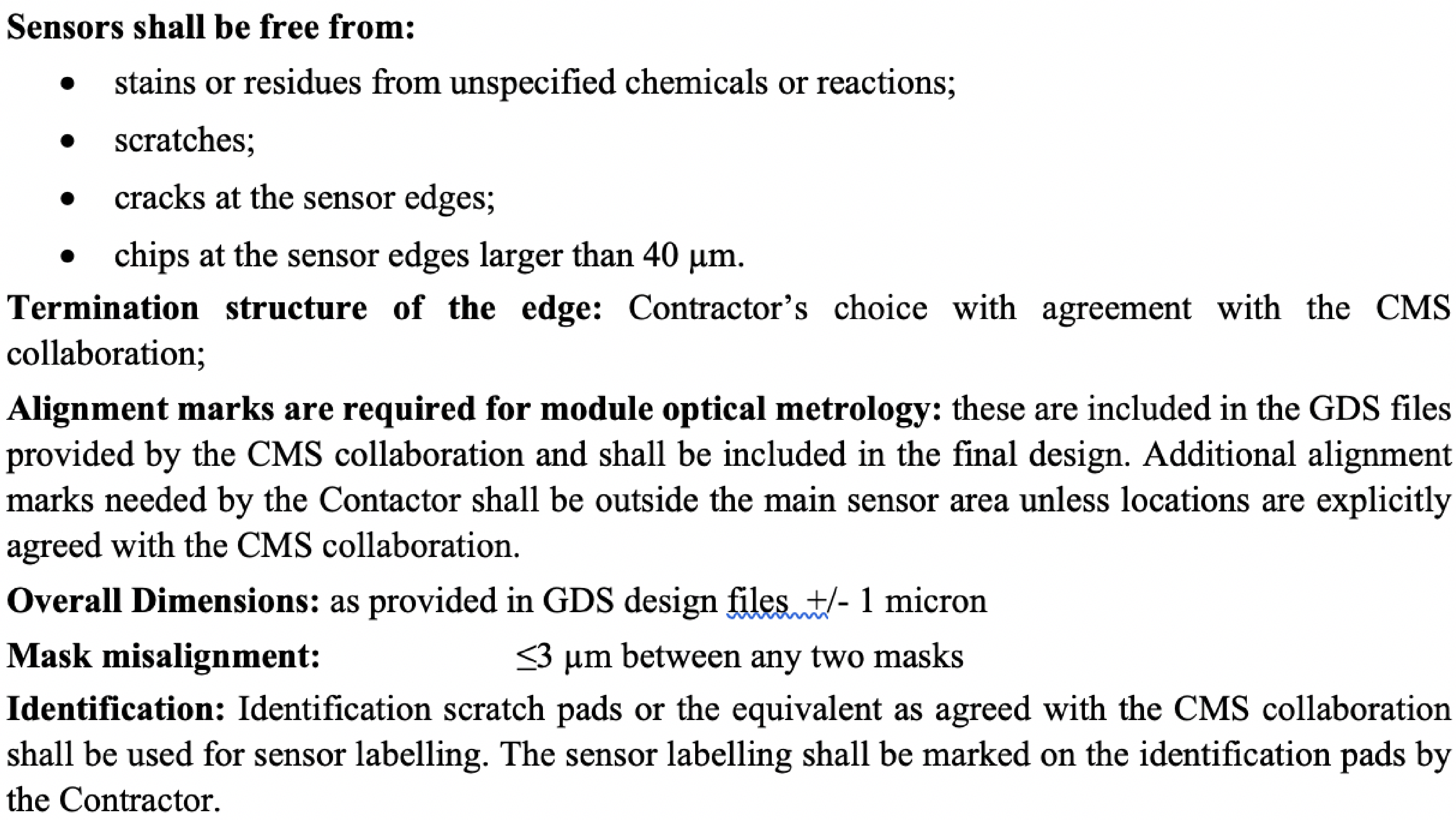
Pull test mean: > 10 g

Pull test RMS: < 1.5 g

Probability for lift off: < 50 %

Passivation: Sensors to be passivated on the pad side and un-passivated on the backplane. See the GDS files for the openings on the passivation.

Technical Specification for the Supply of Silicon Sensors



Sensors shall be free from:

- stains or residues from unspecified chemicals or reactions;
- scratches;
- cracks at the sensor edges;
- chips at the sensor edges larger than 40 µm.

Termination structure of the edge: Contractor's choice with agreement with the CMS collaboration;

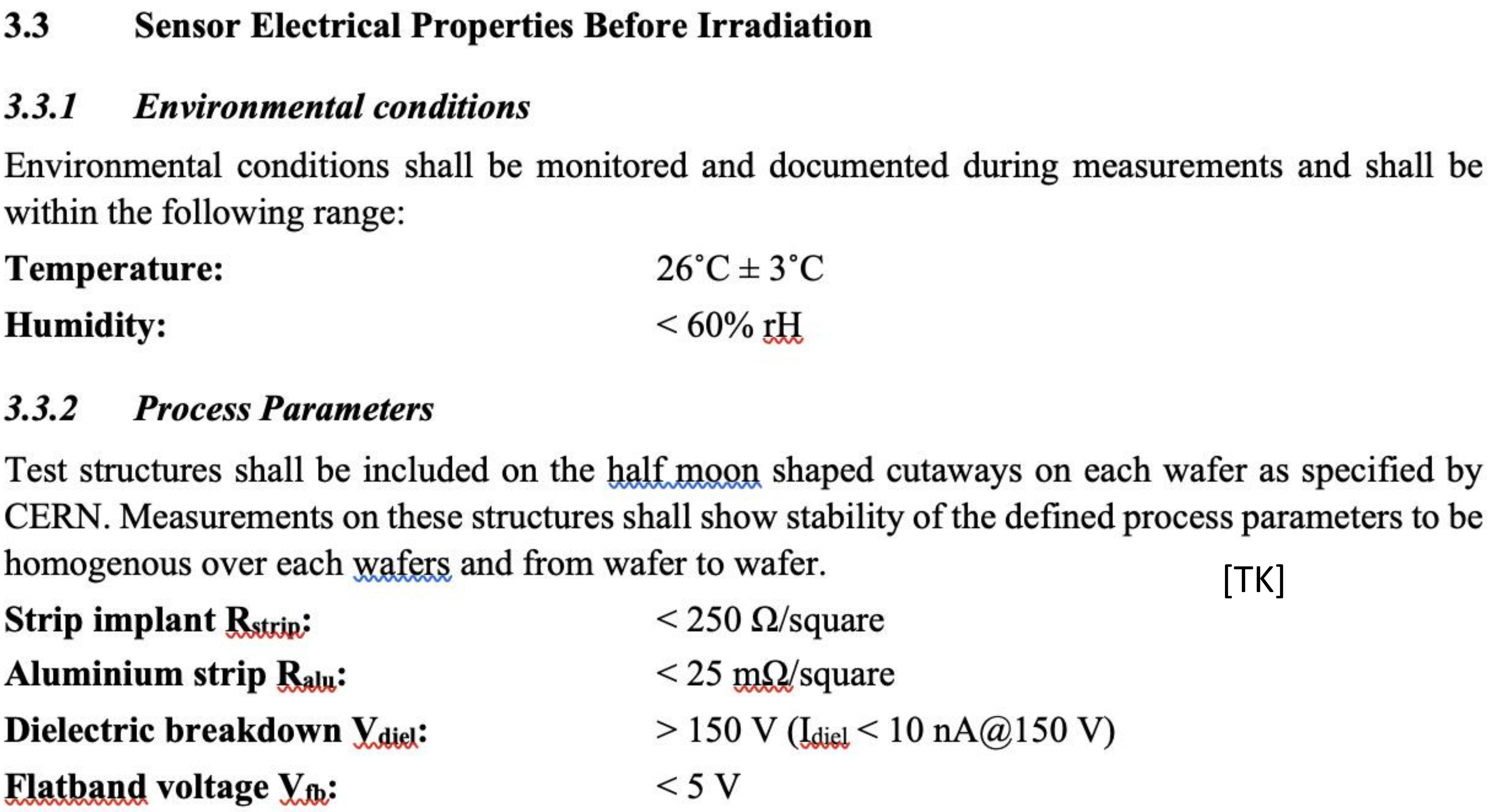
Alignment marks are required for module optical metrology: these are included in the GDS files provided by the CMS collaboration and shall be included in the final design. Additional alignment marks needed by the Contactor shall be outside the main sensor area unless locations are explicitly agreed with the CMS collaboration.

Overall Dimensions: as provided in GDS design files +/- 1 micron

Mask misalignment: ≤3 µm between any two masks

Identification: Identification scratch pads or the equivalent as agreed with the CMS collaboration shall be used for sensor labelling. The sensor labelling shall be marked on the identification pads by the Contractor.

Technical Specification for the Supply of Silicon Sensors



3.3 Sensor Electrical Properties Before Irradiation

3.3.1 Environmental conditions

Environmental conditions shall be monitored and documented during measurements and shall be within the following range:

Temperature:	26˚C ± 3˚C
Humidity:	< 60% rH

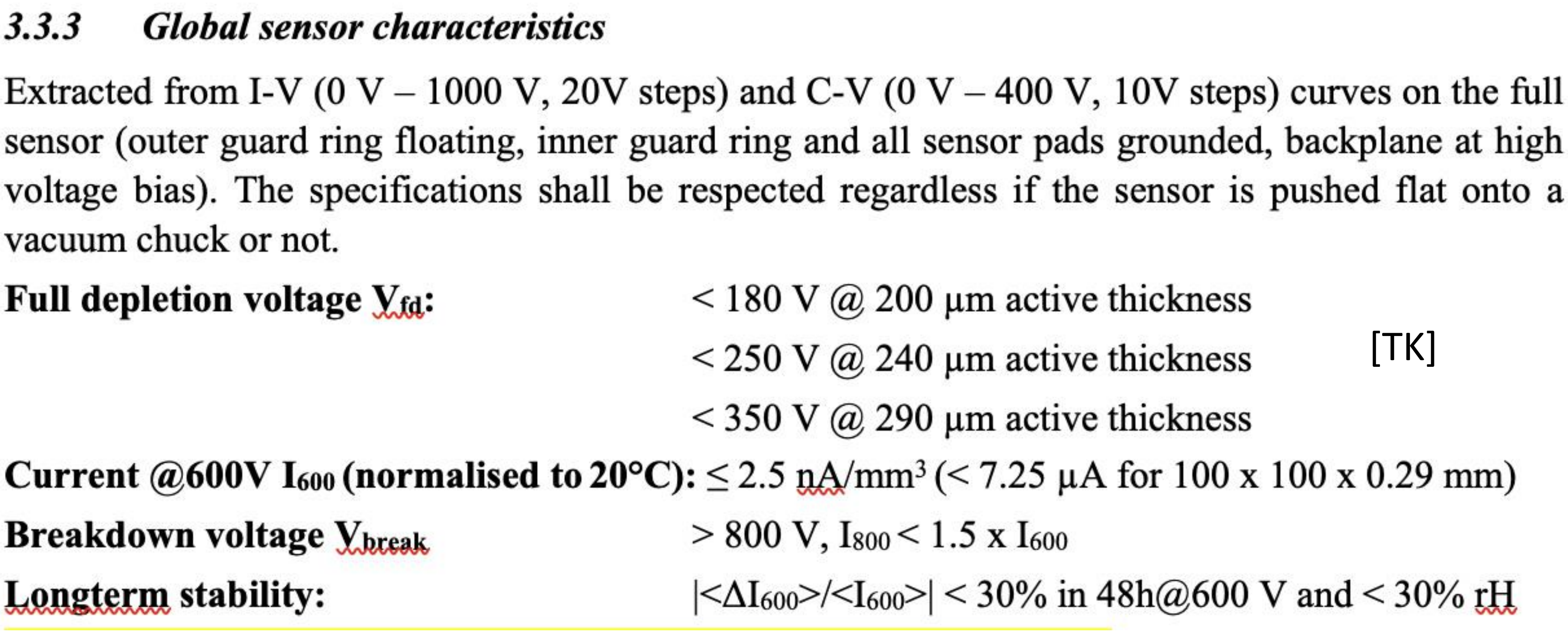
3.3.2 Process Parameters

Test structures shall be included on the half moon shaped cutaways on each wafer as specified by CERN. Measurements on these structures shall show stability of the defined process parameters to be homogenous over each wafers and from wafer to wafer.

Strip implant R_{strip}:	< 250 Ω/square
Aluminium strip R_{alu}:	< 25 mΩ/square
Dielectric breakdown V_{diel}:	> 150 V (I_{diel} < 10 nA@150 V)
Flatband voltage V_{fb}:	< 5 V

[TK]

Technical Specification for the Supply of Silicon Sensors



3.3.3 Global sensor characteristics

Extracted from I-V (0 V – 1000 V, 20V steps) and C-V (0 V – 400 V, 10V steps) curves on the full sensor (outer guard ring floating, inner guard ring and all sensor pads grounded, backplane at high voltage bias). The specifications shall be respected regardless if the sensor is pushed flat onto a vacuum chuck or not.

Full depletion voltage V_{fd}: < 180 V @ 200 µm active thickness
< 250 V @ 240 µm active thickness
< 350 V @ 290 µm active thickness

Current @600V I_{600} (normalised to 20°C): ≤ 2.5 nA/mm^3 (< 7.25 µA for 100 x 100 x 0.29 mm)

Breakdown voltage V_{break} > 800 V, $I_{800} < 1.5 \times I_{600}$

Longterm stability: $|\langle \Delta I_{600} \rangle / \langle I_{600} \rangle| < 30\%$ in 48h@600 V and $< 30\%$ rH

[TK]

Technical Specification for the Supply of Silicon Sensors

3.3.4 Characteristics of each strip

This subsection only applies to strip sensors!

Strip current I_{strip} at 350 V:	< 2 nA/cm^2
Bias resistor R_{poly}	
median(R_{poly}):	1.5 ± 0.3 MΩ (calculated for **each sensor)**
R_{poly}:	median(R_{poly}) ± 5% (for each strip with respect to the median of the corresponding sensor)
Coupling capacitance C_{ac}:	> 1.2 pF/cm µm (LCR settings: < 1 V and 1 kHz)
Pinholes	Readout strip shall be isolated from implant strip (no pinholes)
Interstrip resistance R_{int}:	> 10 GΩcm (strip to one nearest neighbour)
Interstrip capacitance $C_{int,1N}$:	< 0.5 pF/cm (strip to one nearest neighbour, LCR settings: < 1 V and 1 MHz)
Metal and strip implant:	Strips shall be free of metal or implant breaks and / or shorts to neighbouring strips and / or P-stop implants

If any of these requirements are not met, a strip is considered as bad.

A sensor is rejected if:

Percentage of bad strips:	> 1 % per sensor
Clustering of bad strips:	more than two bad strips in any set of 5 consecutive strips

Technical Specification for the Supply of Silicon Sensors

3.3.5 Characteristics of each pixel

This subsection only applies to macro-pixel sensors!

Pixel current I_{pixel} at 350 V:	< 300 pA/pixel
Interpixel resistance R_{int}:	> 1 GΩ to each neighbouring pixel

Additionally, pixels shall not be:

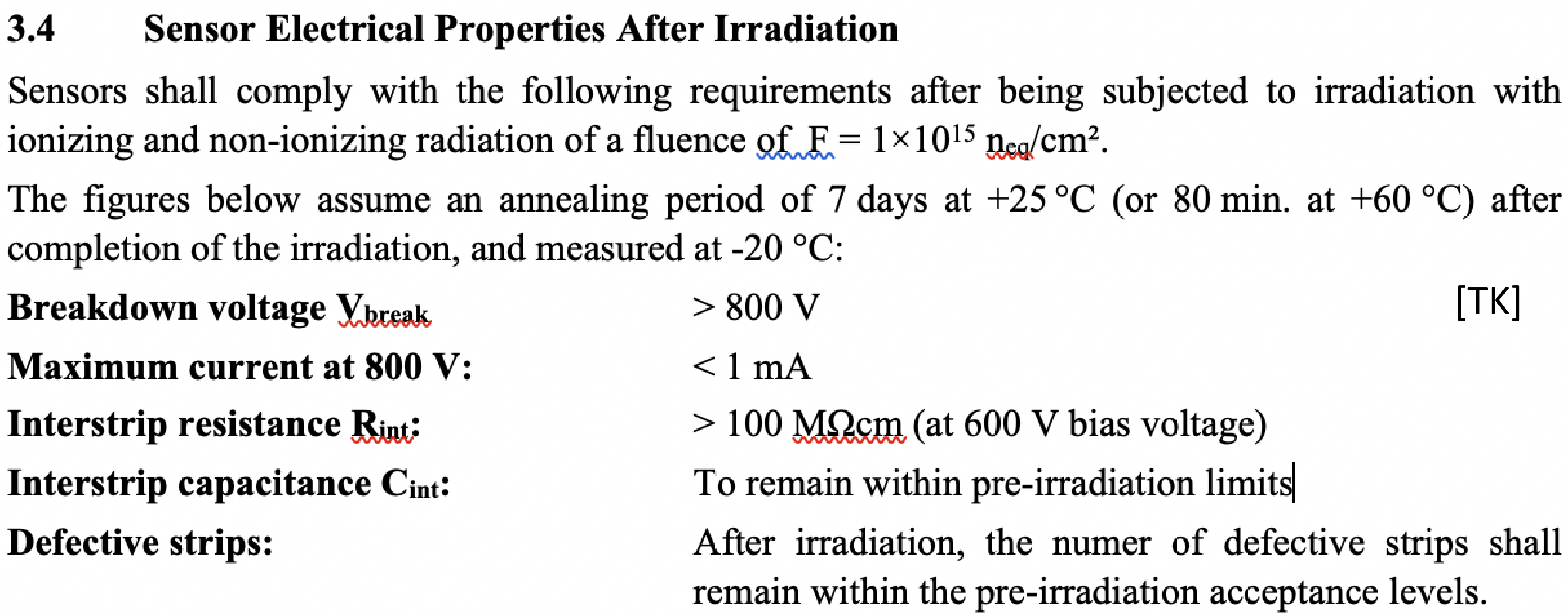
Shorts:	Pixel implant or aluminium readout is short-circuited with any of its neighbours

If any of these requirements are not met, a pixel is considered as bad.

A sensor is rejected if:

Number of bad pixels:	> 0.5 % per sensor
Clustering of bad pixels:	more than two bad pixels within any cluster of 4 x 4 pixels

Technical Specification for the Supply of Silicon Sensors



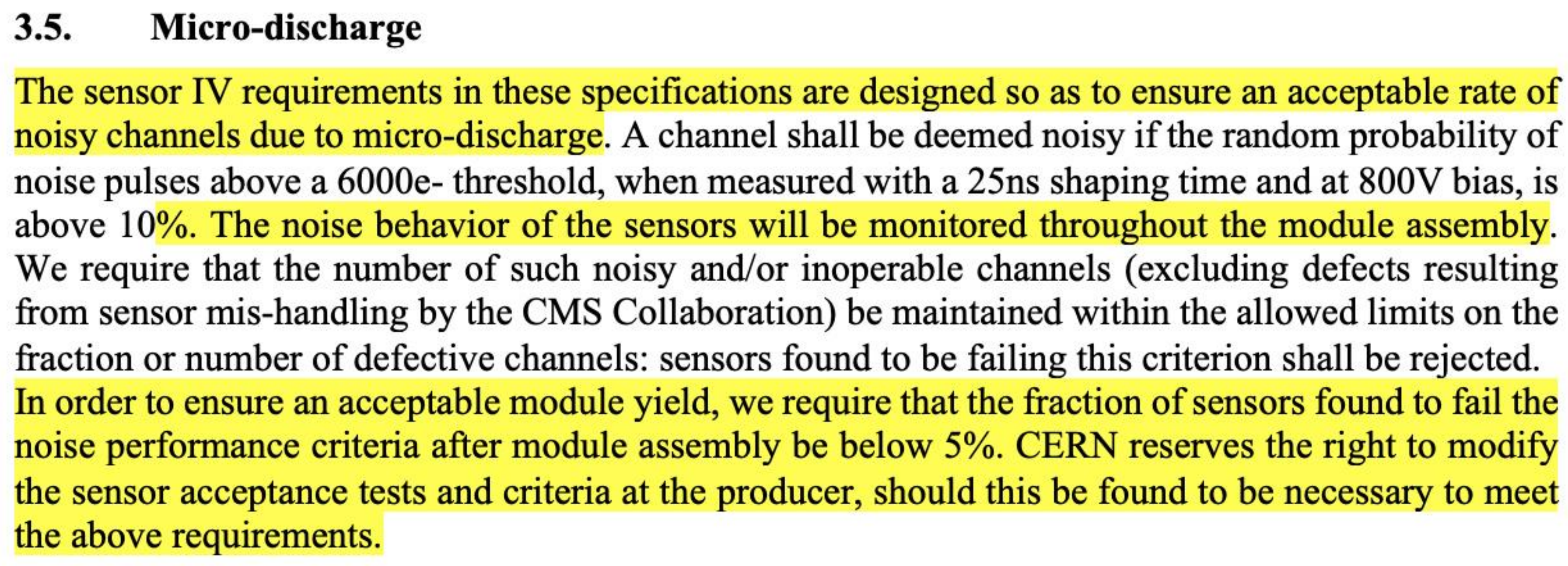
3.4 Sensor Electrical Properties After Irradiation

Sensors shall comply with the following requirements after being subjected to irradiation with ionizing and non-ionizing radiation of a fluence of $F = 1 \times 10^{15}\ n_{eq}/cm^2$.

The figures below assume an annealing period of 7 days at +25 °C (or 80 min. at +60 °C) after completion of the irradiation, and measured at -20 °C:

Breakdown voltage V_{break}	> 800 V	[TK]
Maximum current at 800 V:	< 1 mA	
Interstrip resistance R_{int}:	> 100 MΩcm (at 600 V bias voltage)	
Interstrip capacitance C_{int}:	To remain within pre-irradiation limits	
Defective strips:	After irradiation, the numer of defective strips shall remain within the pre-irradiation acceptance levels.	

Technical Specification for the Supply of Silicon Sensors

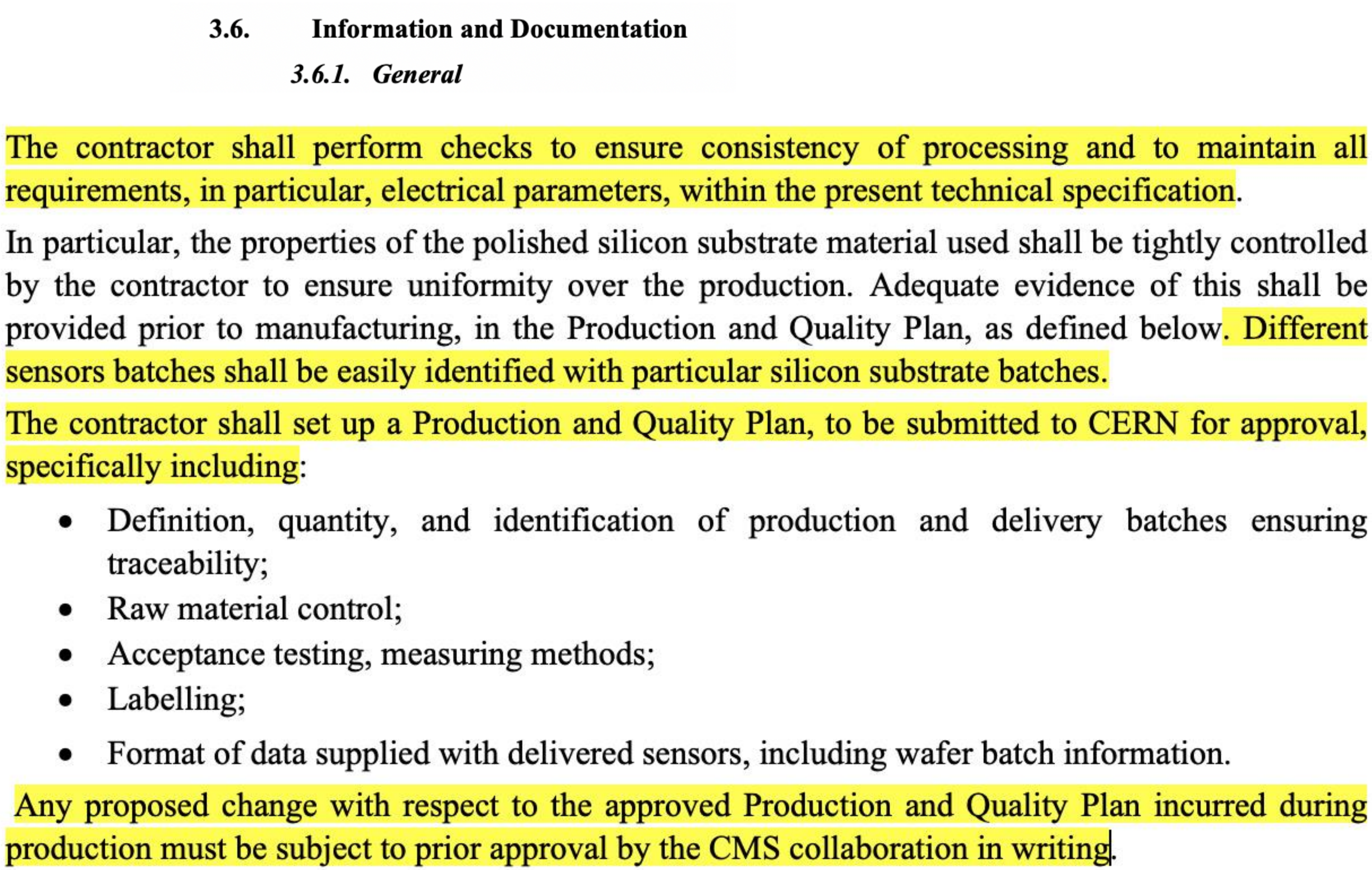


3.5. Micro-discharge

The sensor IV requirements in these specifications are designed so as to ensure an acceptable rate of noisy channels due to micro-discharge. A channel shall be deemed noisy if the random probability of noise pulses above a 6000e- threshold, when measured with a 25ns shaping time and at 800V bias, is above 10%. The noise behavior of the sensors will be monitored throughout the module assembly. We require that the number of such noisy and/or inoperable channels (excluding defects resulting from sensor mis-handling by the CMS Collaboration) be maintained within the allowed limits on the fraction or number of defective channels: sensors found to be failing this criterion shall be rejected. In order to ensure an acceptable module yield, we require that the fraction of sensors found to fail the noise performance criteria after module assembly be below 5%. CERN reserves the right to modify the sensor acceptance tests and criteria at the producer, should this be found to be necessary to meet the above requirements.

Nb acceptance cut values to be tuned, may be somewhat different between Tracker and HGCAL (HGCAL has a higher level of redundancy compared to the Tracker)

Technical Specification for the Supply of Silicon Sensors



3.6. Information and Documentation

3.6.1. General

The contractor shall perform checks to ensure consistency of processing and to maintain all requirements, in particular, electrical parameters, within the present technical specification.

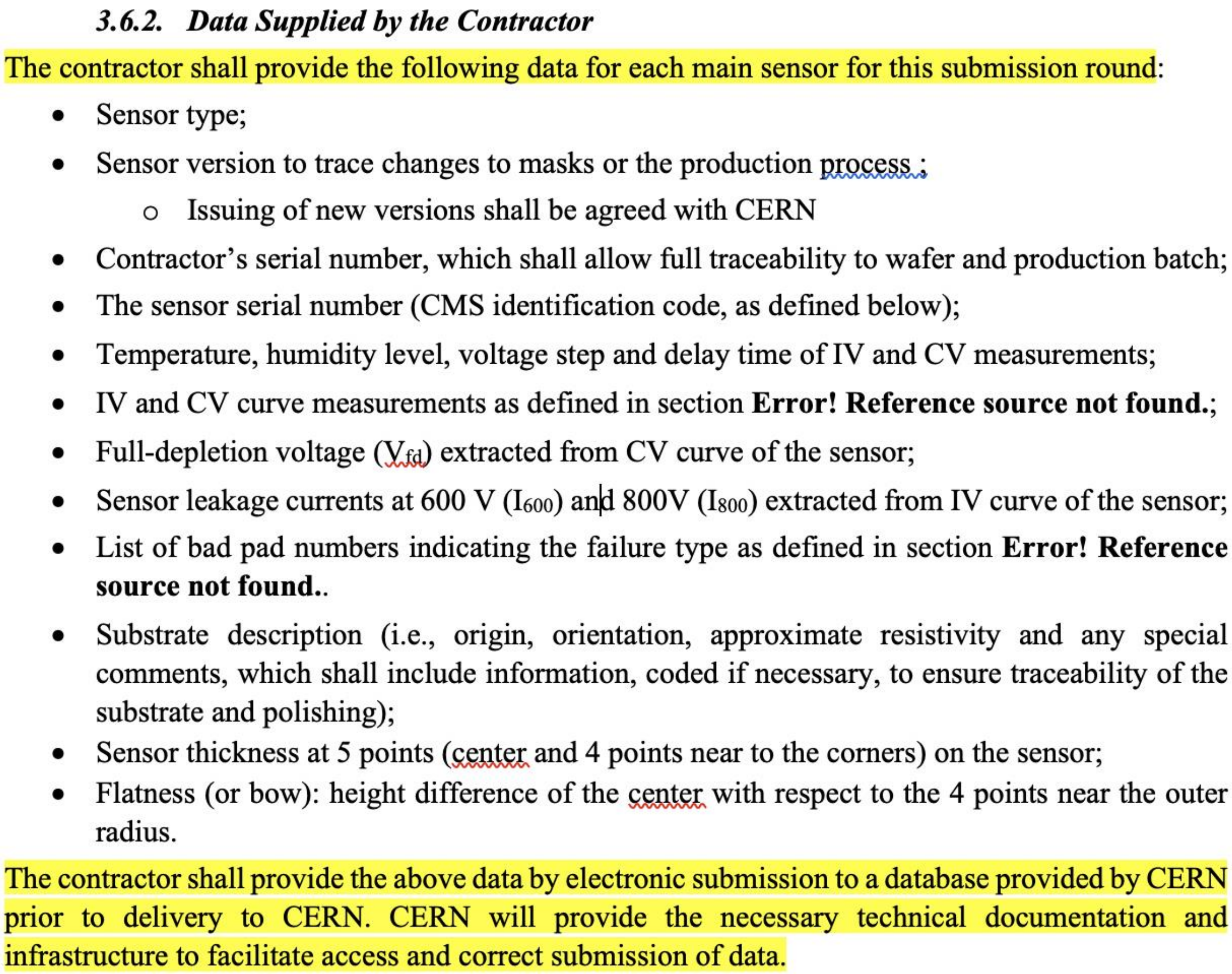
In particular, the properties of the polished silicon substrate material used shall be tightly controlled by the contractor to ensure uniformity over the production. Adequate evidence of this shall be provided prior to manufacturing, in the Production and Quality Plan, as defined below. Different sensors batches shall be easily identified with particular silicon substrate batches.

The contractor shall set up a Production and Quality Plan, to be submitted to CERN for approval, specifically including:

- Definition, quantity, and identification of production and delivery batches ensuring traceability;
- Raw material control;
- Acceptance testing, measuring methods;
- Labelling;
- Format of data supplied with delivered sensors, including wafer batch information.

Any proposed change with respect to the approved Production and Quality Plan incurred during production must be subject to prior approval by the CMS collaboration in writing.

Technical Specification for the Supply of Silicon Sensors



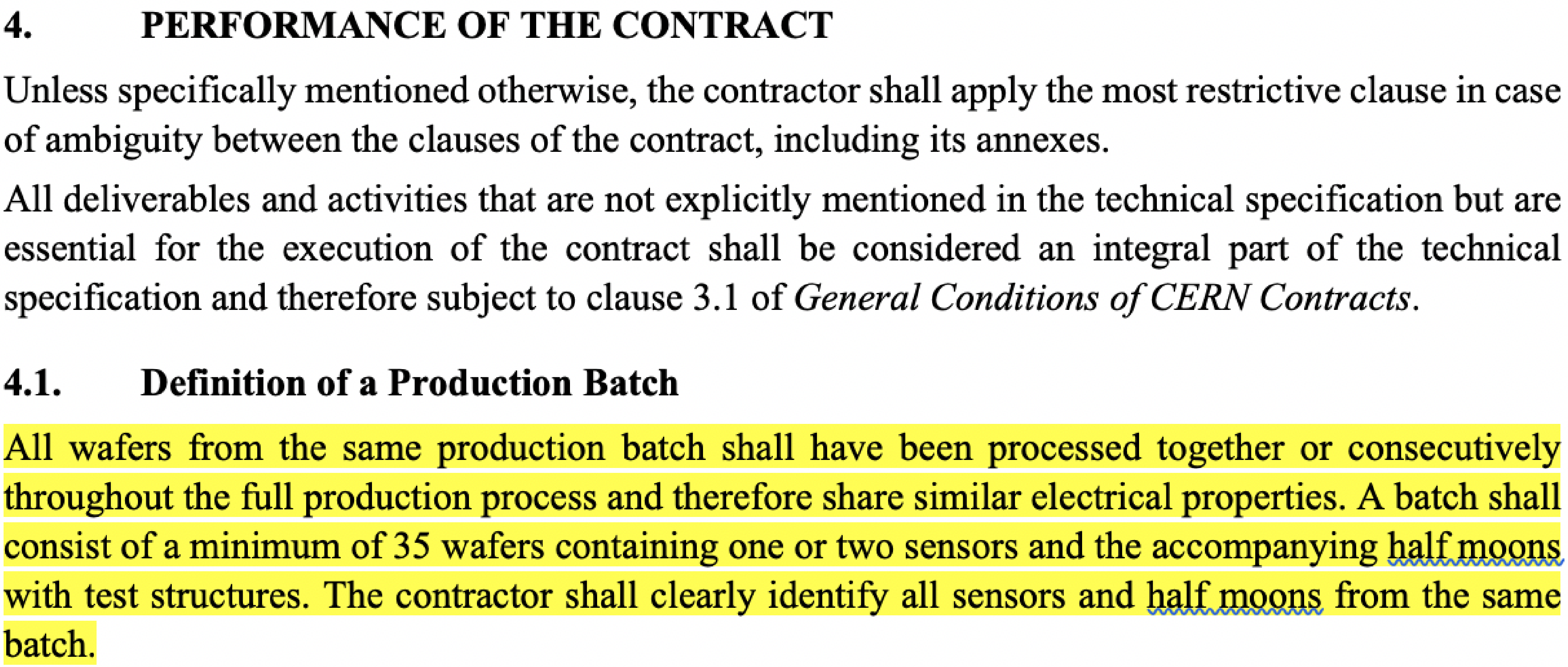
3.6.2. Data Supplied by the Contractor

The contractor shall provide the following data for each main sensor for this submission round:

- Sensor type;
- Sensor version to trace changes to masks or the production process ;
    - Issuing of new versions shall be agreed with CERN
- Contractor's serial number, which shall allow full traceability to wafer and production batch;
- The sensor serial number (CMS identification code, as defined below);
- Temperature, humidity level, voltage step and delay time of IV and CV measurements;
- IV and CV curve measurements as defined in section **Error! Reference source not found.**;
- Full-depletion voltage (V_{fd}) extracted from CV curve of the sensor;
- Sensor leakage currents at 600 V (I_{600}) and 800V (I_{800}) extracted from IV curve of the sensor;
- List of bad pad numbers indicating the failure type as defined in section **Error! Reference source not found.**.
- Substrate description (i.e., origin, orientation, approximate resistivity and any special comments, which shall include information, coded if necessary, to ensure traceability of the substrate and polishing);
- Sensor thickness at 5 points (center and 4 points near to the corners) on the sensor;
- Flatness (or bow): height difference of the center with respect to the 4 points near the outer radius.

The contractor shall provide the above data by electronic submission to a database provided by CERN prior to delivery to CERN. CERN will provide the necessary technical documentation and infrastructure to facilitate access and correct submission of data.

Technical Specification for the Supply of Silicon Sensors



4. PERFORMANCE OF THE CONTRACT

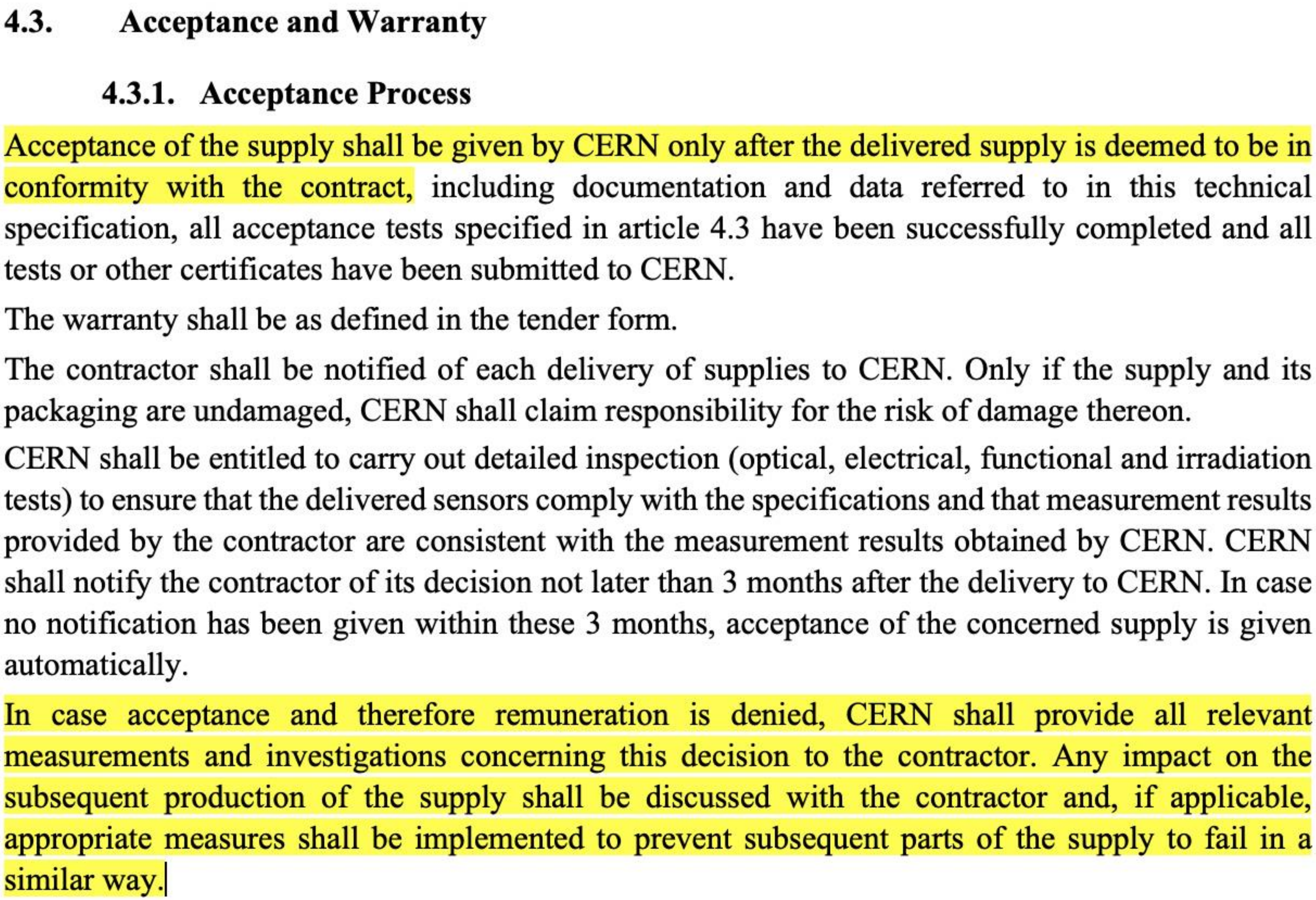
Unless specifically mentioned otherwise, the contractor shall apply the most restrictive clause in case of ambiguity between the clauses of the contract, including its annexes.

All deliverables and activities that are not explicitly mentioned in the technical specification but are essential for the execution of the contract shall be considered an integral part of the technical specification and therefore subject to clause 3.1 of *General Conditions of CERN Contracts*.

4.1. Definition of a Production Batch

All wafers from the same production batch shall have been processed together or consecutively throughout the full production process and therefore share similar electrical properties. A batch shall consist of a minimum of 35 wafers containing one or two sensors and the accompanying half moons with test structures. The contractor shall clearly identify all sensors and half moons from the same batch.

Technical Specification for the Supply of Silicon Sensors



4.3. Acceptance and Warranty

4.3.1. Acceptance Process

Acceptance of the supply shall be given by CERN only after the delivered supply is deemed to be in conformity with the contract, including documentation and data referred to in this technical specification, all acceptance tests specified in article 4.3 have been successfully completed and all tests or other certificates have been submitted to CERN.

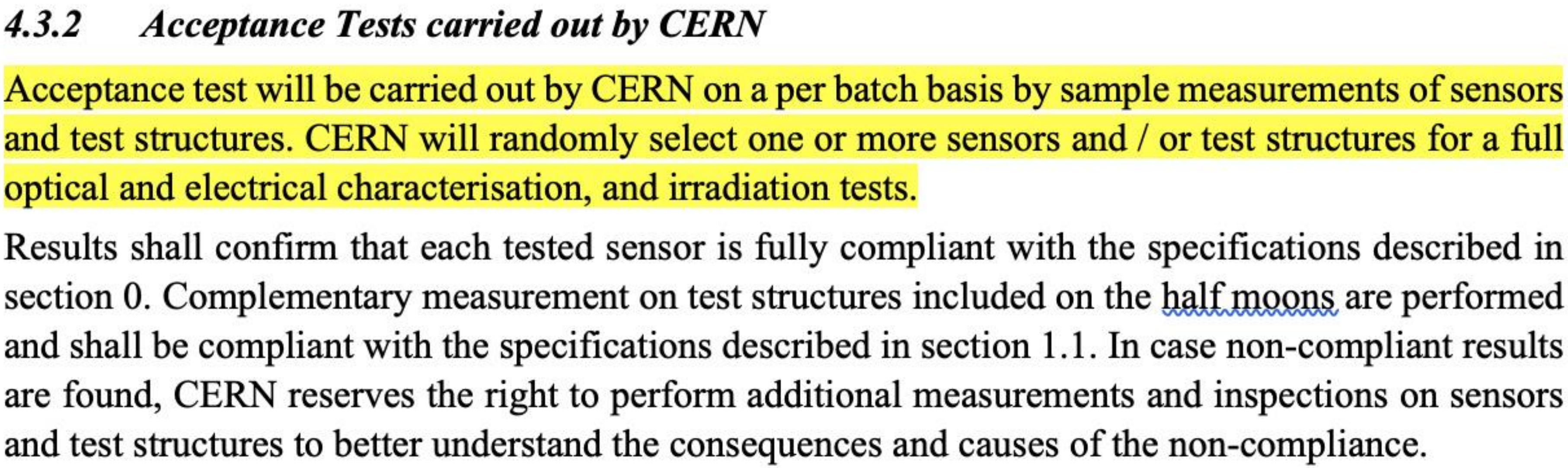
The warranty shall be as defined in the tender form.

The contractor shall be notified of each delivery of supplies to CERN. Only if the supply and its packaging are undamaged, CERN shall claim responsibility for the risk of damage thereon.

CERN shall be entitled to carry out detailed inspection (optical, electrical, functional and irradiation tests) to ensure that the delivered sensors comply with the specifications and that measurement results provided by the contractor are consistent with the measurement results obtained by CERN. CERN shall notify the contractor of its decision not later than 3 months after the delivery to CERN. In case no notification has been given within these 3 months, acceptance of the concerned supply is given automatically.

In case acceptance and therefore remuneration is denied, CERN shall provide all relevant measurements and investigations concerning this decision to the contractor. Any impact on the subsequent production of the supply shall be discussed with the contractor and, if applicable, appropriate measures shall be implemented to prevent subsequent parts of the supply to fail in a similar way.

Technical Specification for the Supply of Silicon Sensors

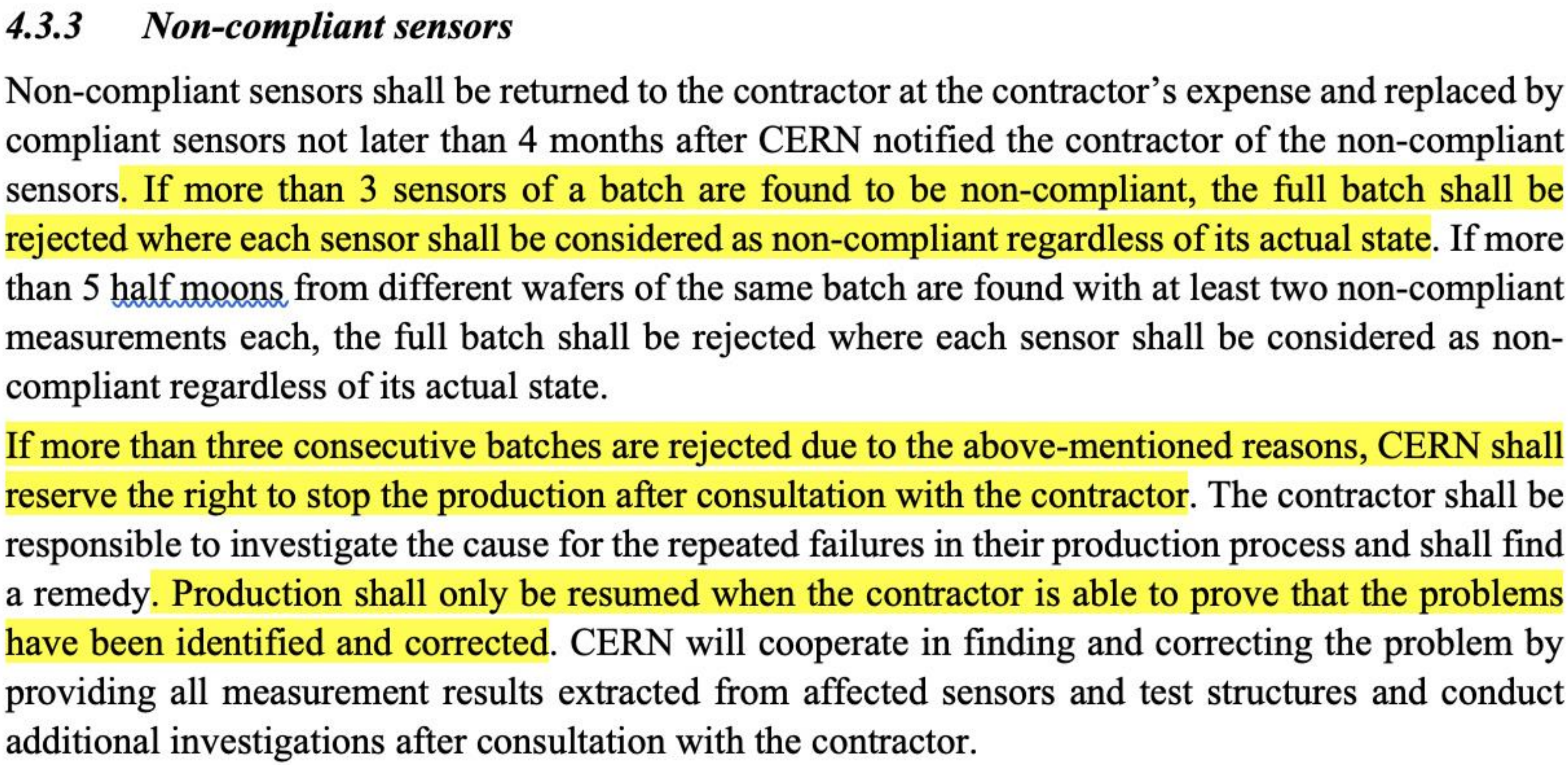


4.3.2 *Acceptance Tests carried out by CERN*

Acceptance test will be carried out by CERN on a per batch basis by sample measurements of sensors and test structures. CERN will randomly select one or more sensors and / or test structures for a full optical and electrical characterisation, and irradiation tests.

Results shall confirm that each tested sensor is fully compliant with the specifications described in section 0. Complementary measurement on test structures included on the half moons are performed and shall be compliant with the specifications described in section 1.1. In case non-compliant results are found, CERN reserves the right to perform additional measurements and inspections on sensors and test structures to better understand the consequences and causes of the non-compliance.

Technical Specification for the Supply of Silicon Sensors

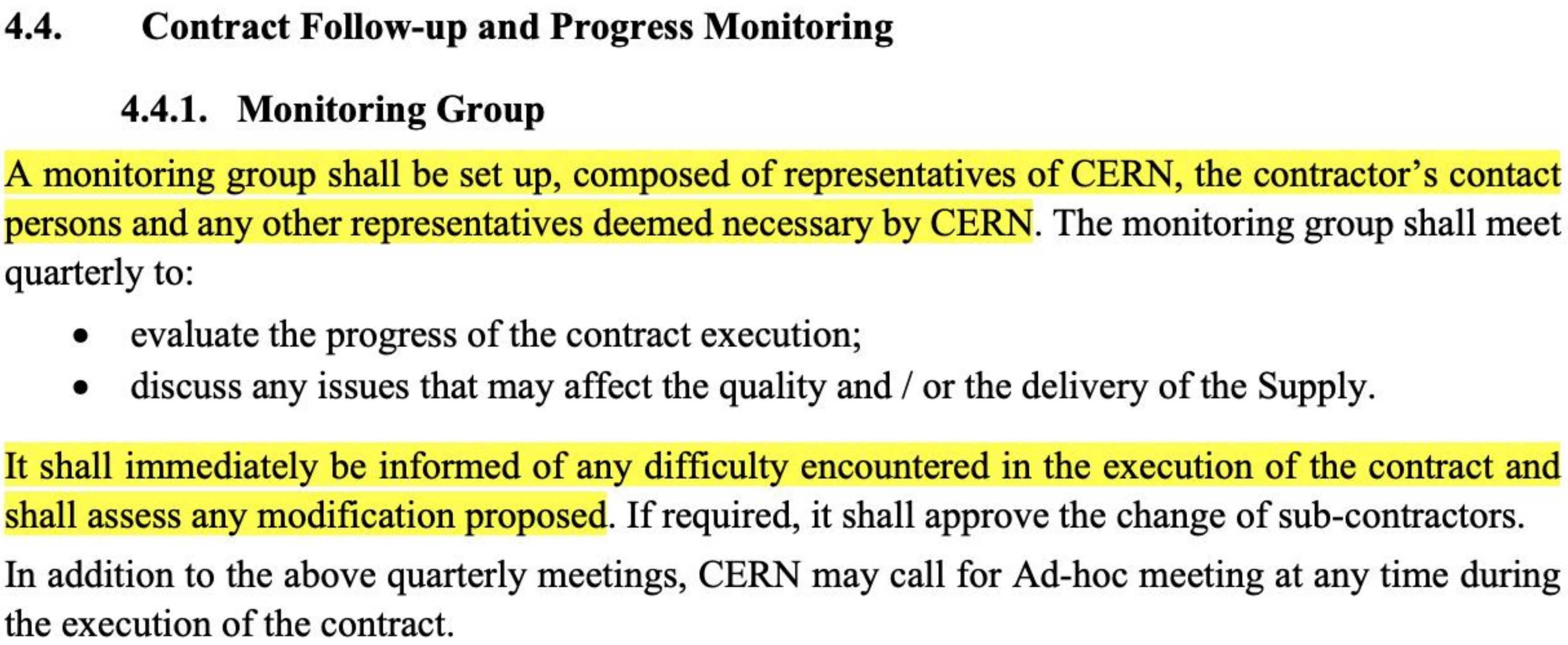


4.3.3 *Non-compliant sensors*

Non-compliant sensors shall be returned to the contractor at the contractor's expense and replaced by compliant sensors not later than 4 months after CERN notified the contractor of the non-compliant sensors. If more than 3 sensors of a batch are found to be non-compliant, the full batch shall be rejected where each sensor shall be considered as non-compliant regardless of its actual state. If more than 5 half moons from different wafers of the same batch are found with at least two non-compliant measurements each, the full batch shall be rejected where each sensor shall be considered as non-compliant regardless of its actual state.

If more than three consecutive batches are rejected due to the above-mentioned reasons, CERN shall reserve the right to stop the production after consultation with the contractor. The contractor shall be responsible to investigate the cause for the repeated failures in their production process and shall find a remedy. Production shall only be resumed when the contractor is able to prove that the problems have been identified and corrected. CERN will cooperate in finding and correcting the problem by providing all measurement results extracted from affected sensors and test structures and conduct additional investigations after consultation with the contractor.

Technical Specification for the Supply of Silicon Sensors



4.4. Contract Follow-up and Progress Monitoring

4.4.1. Monitoring Group

A monitoring group shall be set up, composed of representatives of CERN, the contractor's contact persons and any other representatives deemed necessary by CERN. The monitoring group shall meet quarterly to:

- evaluate the progress of the contract execution;
- discuss any issues that may affect the quality and / or the delivery of the Supply.

It shall immediately be informed of any difficulty encountered in the execution of the contract and shall assess any modification proposed. If required, it shall approve the change of sub-contractors.

In addition to the above quarterly meetings, CERN may call for Ad-hoc meeting at any time during the execution of the contract.

CMS Sensor Committee Review Report

- Action item: Close the loop
  - Several specifications were still not fully defined and an iteration with HPK is necessary. Specification must be technically sound and cost-optimized. The big options of TK, sensor thickness FZ290 and thFZ240 relevant for costing, can go into the tender. Other smaller definitions/decisions of specifications defining cost must be optimized BEFORE submission of tender. Otherwise it is preferred to delay the tendering process.

  Given the iteration and definition on specifications happens timely and successfully, the committee supports the plan to have the CERN Specification Committee review around the 06.03.2019 to dispatch the tender beginning of March. Technical or cost risk shall not be taken. The committee requests a follow-up meeting to endorse the remaining choices/change timely before the CERN Specification Committee review.

  In this meeting, the committee requests a summary talk of past tests conducted, which evaluated the technology, e.g. n-in-p. This should contain, e.g. charge collection efficiencies, resolution, test beam, operation with most recent electronics.

Now 20.03.19

Review Report Action Items

- Action Item: Fine Tuning
  - A small number of specifications need some fine tuning.
  - The IV shape criteria need to be well defined. This is one of the main points to ensure good noise-free sensors without decreasing production yield unreasonably. The criteria must prevent sensors with too low breakdown voltage passing the QA.
    - There might even be a different definition for different thickness.
  - The term micro-discharge must be well defined.
  - Define "number of sensors bad" per batch to reject a full batch without further testing. Numbers 2 or 3 seemed reasonable to the panel. It was noticed that a higher "number of bad test structures" was mentioned compared to the "number of bad sensors"; the panel believes the same quantity could be used.
  - The term 'batch' must be well defined. Sensors processed consecutively AND from the same ingot! Numbering of batches should be ordered in sequence of production.
  - More parameters to fine tune (also cost optimized): Oxygen concentration; thickness uniformity and sensor bow (and measurement at supplier), sensor cut line, total HGCAL current 100uA, pad current; depletion voltage; percentage on bad strips (this could affect price)

More action items

- Action item: Verify peak throughput
  - Clarify with HPK the delivery schedule and confirm that they can increase the peak load to 10000 to 12000 wafers/quarter. The committee takes note that this is an ongoing process.
- Action Item: Clarify Frame contract
  - Clarify if HPK feels at ease to provide a cost optimized offer for the specifications proposed and how potential changes would be possible after the IT.
- Action item: Progress with GDS files
  - Prepare all GDS files for all sensor types and iterate with HPK. The committee takes note that this is an ongoing process and supports that HPK will adapt them for final mask production taking over the responsibility to deliver sensors in specs and also take care of defining the periphery.
- Action item: PRR
  - The committee recognizes that a strategy for QA is already much advanced. Prepare a full PRR including QA and readiness of centers.

Even more action items

- Action item: Choose design
  - TK, demonstrate the path and plan to choose between FZ290 and FZ2x0.
- Action item: Prepare CERN Finance Council
  - Organize a dedicated session with projects and procurement to prepare well for the FC. The material for the FC should be shown to the panel beforehand.
- Action item: Double check robustness of thin sensors
  - The committee takes note on the recent positive results on the thin implant backplane ‘robustness’ – see reported scratch tests of last batches. The committee still considers it a risk factor and encourages the projects strongly to thoroughly investigate the fragility of the thin implant backplane (HGCAL 300 and 200, Tracker FZ2x0), especially with later module production in mind.
- Action item: Spellchecking
  - The committee is invited to thoroughly read the two tender documents.