CE B02: 402.4 Endcap Calorimeter: Planning for CD-3a

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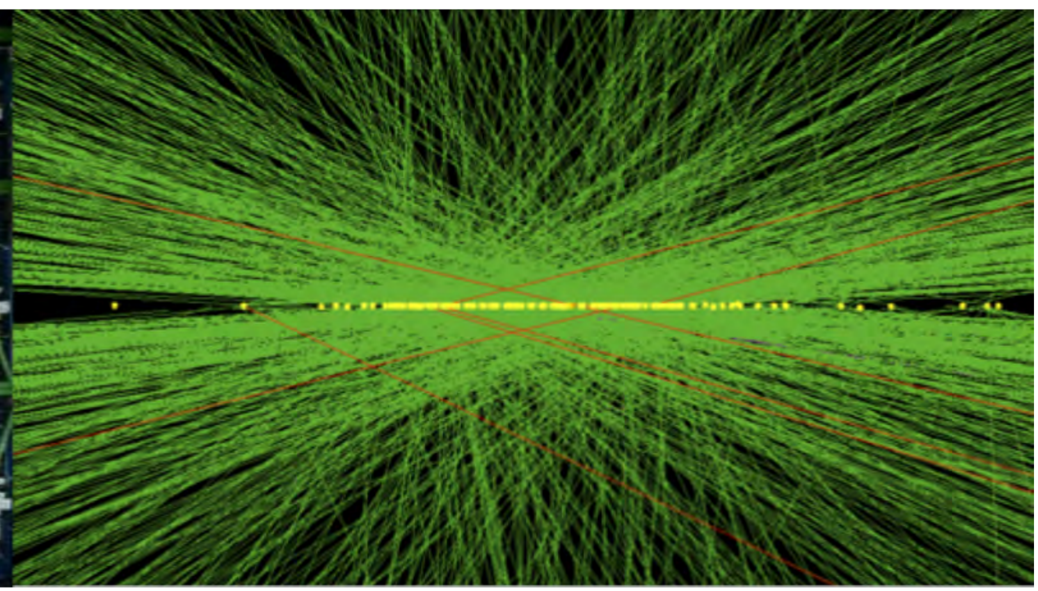
CD1 Director's Review

March 20, 2019



Outline

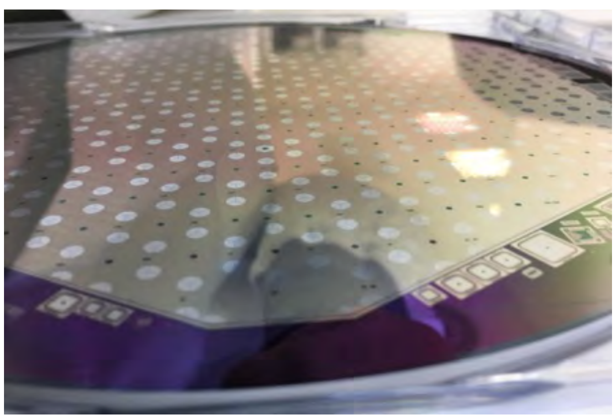
- Introduction: Silicon Sensors
  - CD-3a scope; Sensor Scope and Deliverables
  - Sensor Design
- Technical Progress with Updates since Jun 2018 IPR
  - Path to 8” wafer sensor qualification
- R&D Needed Before Production
- Schedule
- Risks
- Resource Optimization
- ES&H, QA and QC
- Cost
- Response to June 2018 IPR
- Progress towards CD-3a
- Summary

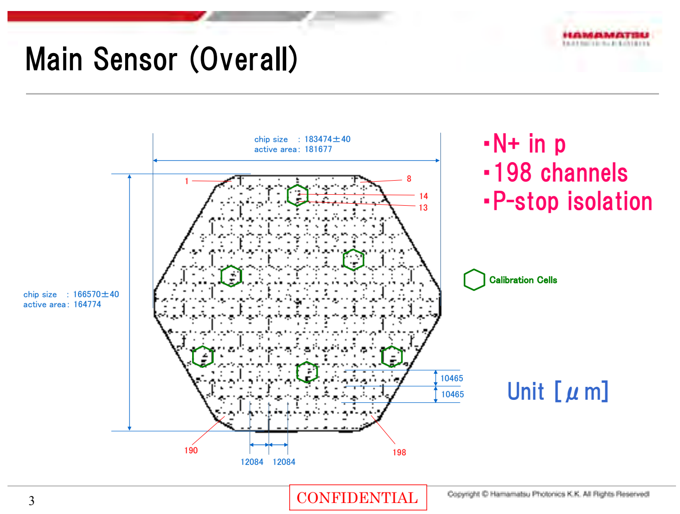
Scope for CD-3a

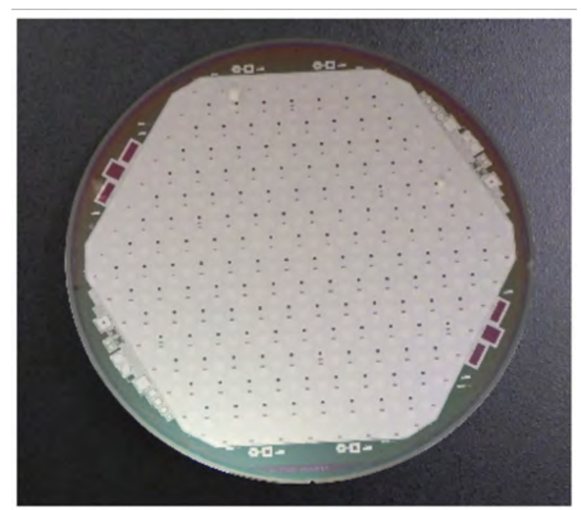
- Scope Planned for CD-3a
  - Preproduction and production silicon sensors
  - QC of these silicon sensors
- Sensors are a long lead item as the production takes time
  - Need to proceed with a single vendor who has finite production capacity
- Sensors are a critical component needed to start module production
  - Significant QC effort, important to get started early
  - Sensor design is close to final, and almost completely validated
  - Will be ready for a CD-3a

Scope - Sensors

- The US will purchase standard and odd-sized silicon sensors for the endcap calorimeter: the US commitment is fixed to 7290 standard (76%) and 1812 odd-sized sensors (100%) for the hadronic section (CE-H)
  - Quote from vendor specifies payment only for sensors which meet quality criteria on IV/CV, therefore the effective wafer yield is expected to be very high
- The US is responsible for design, specification, and testing (including radiation qualification) of the silicon sensors in collaboration with the international CMS
- The US has responsibility to carry out associated TCAD simulations







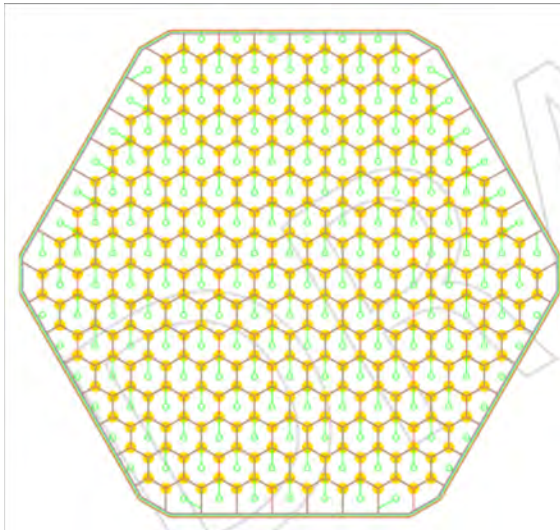
Design Considerations for Sensors

Charge #2

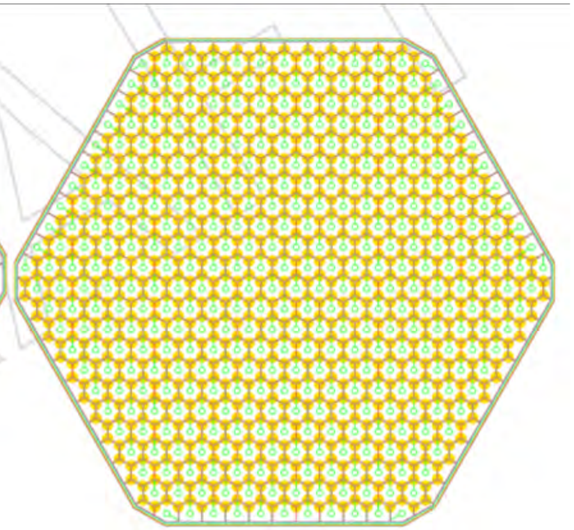
- The sensors must be sufficiently radiation hard to allow operation through the lifetime of HL-LHC, radiation tolerant to ~10^{16} n_{eq}/cm^2 at inner radius
  - Reconstruction of MIP and radiation hardness (EC-sci-engr-002 and EC-engr-021)
- Sensor design must be compatible with
  - High transverse and longitudinal granularity and cell size (EC-sci-engr-004, EC-engr-022)
  - Good energy resolution for EM, jet and Etmiss (EC-sci-engr-006))
  - Good pile-up mitigation (EC-sci-engr-007)
  - Precision timing of showers and time resolution (EC-sci-engr-009, EC-engr-023)
  - Minimal dead area (EC-engr-025)
- Robust design of internal and peripheral structures
  - Reliability and maintainability (EC-sci-engr-010)
- Large area hexagonal sensors, low cost per sensor, efficient tiling
  - EC sensors from 8-inch wafers (EC-engr-024)
- Low temperature (-30 ^{o}C) operation
- Production sensor quality must be monitored to insure that good channel, depletion voltage, and leakage current specifications are met
- All vendors and sensor types must be fully qualified for radiation hardness

Sensor Design - I

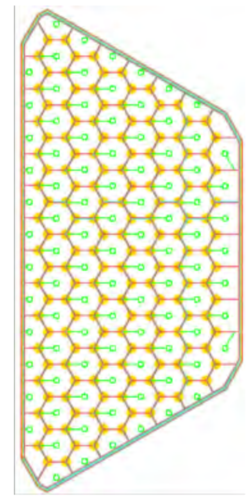
Charge #2



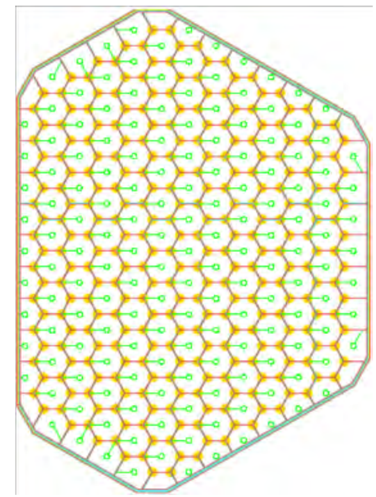
Standard
192 Large cells



Standard
432 Small cells



Odd-sized
Half sensor



Odd-size
Chop2 sensor

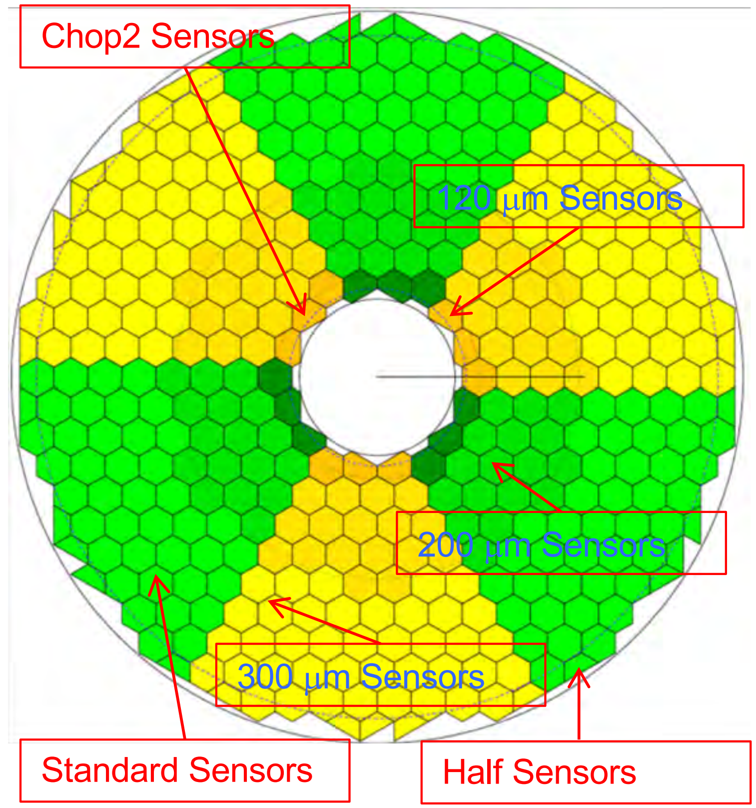
- Sensor design is practically done. Fundamental parameters (pad shapes, gaps, biasing, guard ring, and implants) are well-understood. Operational experience with 6-inch sensors is excellent. Starting to finalize 8” production specs with vendor.
- Two classes of 8-inch modules: standard and odd-sized
- Standard silicon sensors come either with large 1.18 cm^2 or small 0.52 cm^2 cells with three different active thicknesses: 120, 200 and 300 μm

Sensor Design - II

Charge #2

Active Thick. (μm)	120	200	300
Cell size (cm^2)	0.52	1.18	1.18
Cell cap. (pf)	50	65	45
Exp. fluence (n_{eq}/cm^2)	$0.2\text{-}1 \times 10^{16}$	$0.5\text{-}2.5 \times 10^{15}$	$1\text{-}5 \times 10^{14}$
Largest dose (MRad)	100	20	3
R_{in}, R_{out} (cm)	~35 : ~75	~70 : ~100	~100 : ~180
S/N MIP (initial)	4.5	6	11
S/N MIP (3,000 fb^{-1})	2.2	2.3	4.7

Sensor Tiling for Layer 32



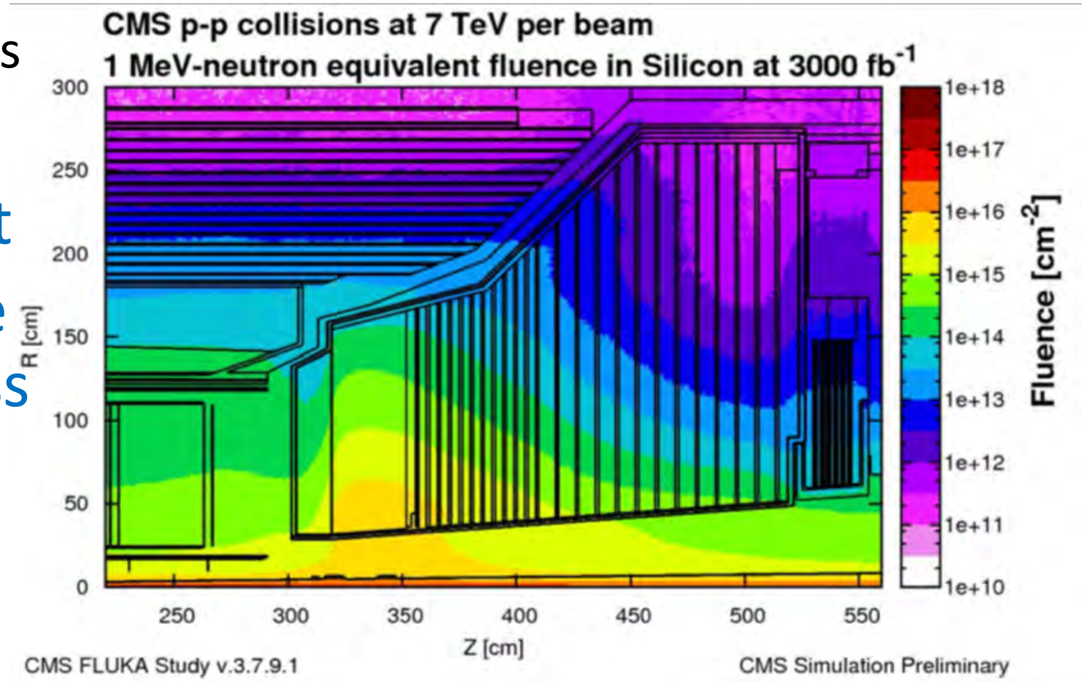
- Silicon sensor parameters are optimized such that good signal-to-noise (*S/N*) ratio for MIPs is maintained throughout the life of the detector (3,000 fb^{-1}) at HL-LHC
- Design of CE-H layers is optimized by geographically placing appropriate type of sensors transversally

Sensor Design - III

Charge #2

The high radiation drives sensor choices

- Thin active layer sensors have
  - + Lower total leakage current
  - + Higher fields, better charge collection per unit thickness
  - + Lower depletion voltage
  - - More difficult to fabricate
- Sensors on 8” (200 mm) wafers
- 3 different active layer thicknesses
  - 300 micron active thickness, FZ p-type with 300 micron physical thickness
  - 200 micron active thickness, FZ p-type with 200 micron physical thickness
  - 120 micron active thickness, epitaxial p-type with 300 micron physical thickness

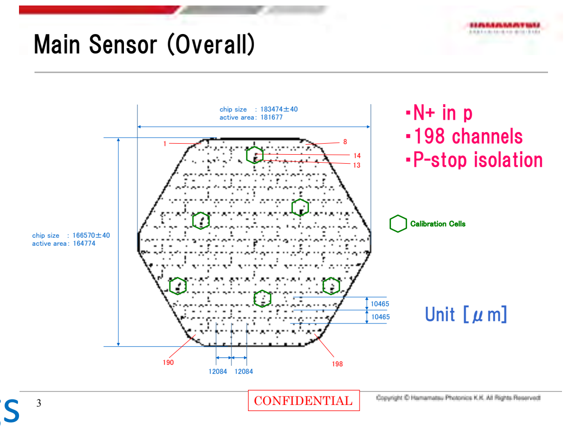


Need to operate at low temperature to control leakage current and depletion voltage (-30 °C)

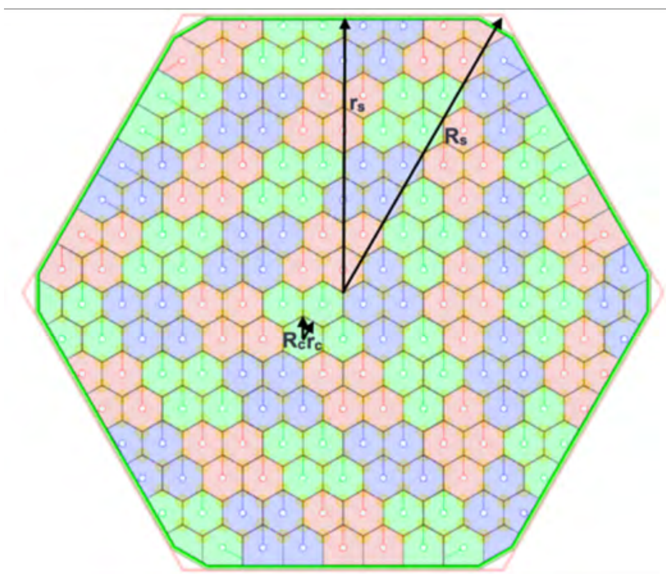
Sensor Design - IV

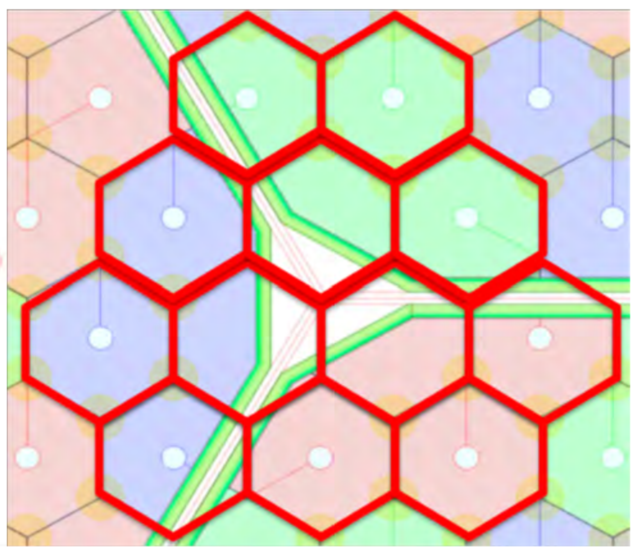
Charge #2

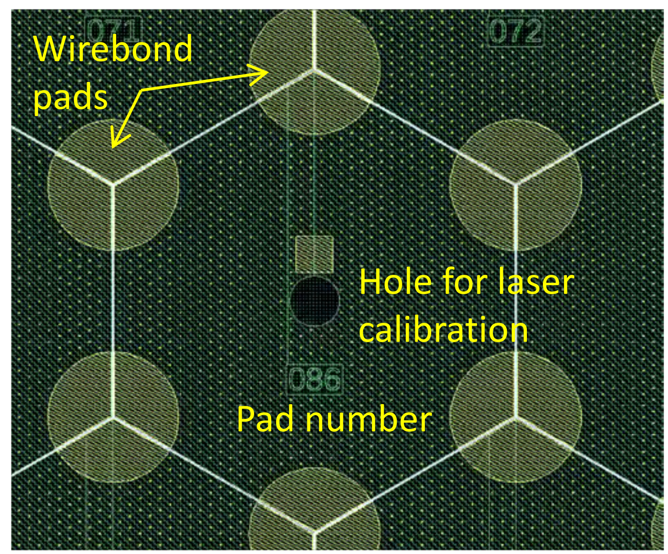
- Layout partially driven by trigger cells
  - Four cell trigger clusters
- Sensors are optimized for assembly and testing
  - Large pads
  - Laser test holes in metal
  - Calibration pads
  - Minimize gap between module active areas – thin guard rings



- Initial designs used in the test beam campaigns were finalized for 8” sensors partially based on US design concepts
  - Studied inter-pad gaps and guard ring designs
  - TCAD: capacitance, leakage current, jumper designs and radiation effects



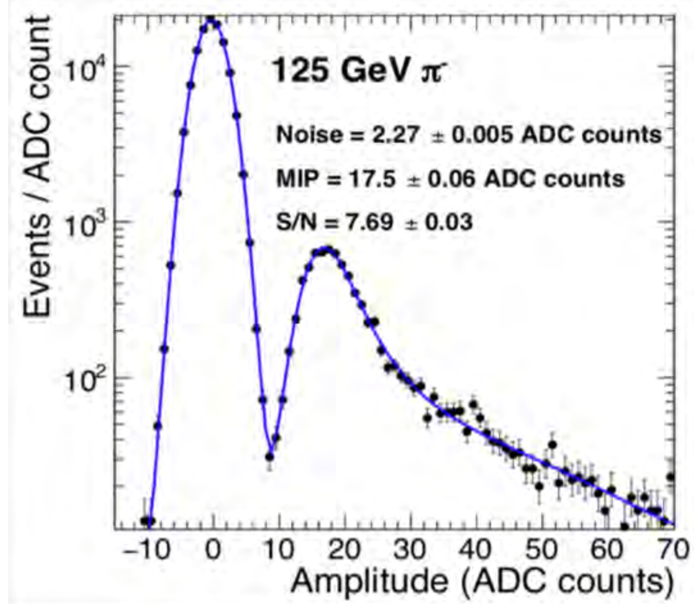


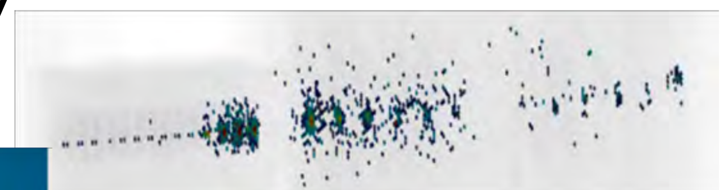


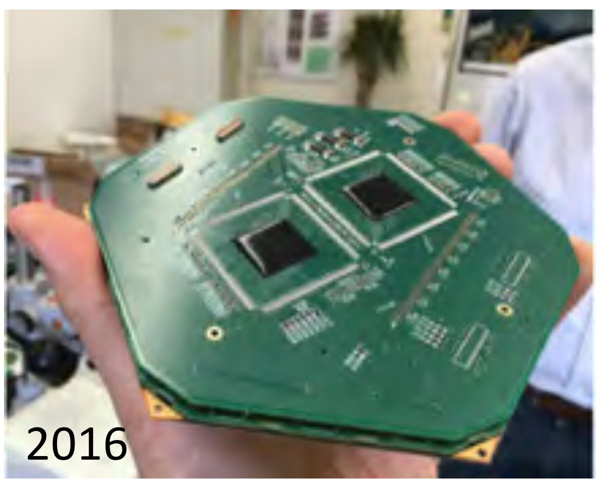
R&D Achieved so far - I

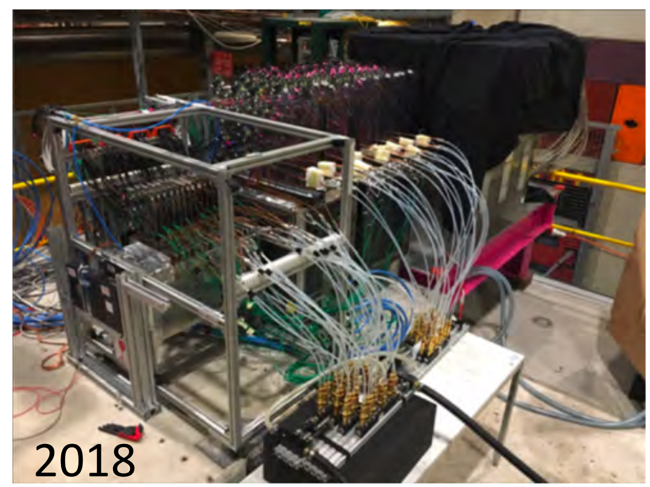
Charge #2

- The *S/N* performance goals are achieved: silicon sensors and module components function as expected
- Beam tests at Fermilab (2016) and CERN (2016-18) have been performed using fully functional 6-inch sensors with electrons and hadrons
- 16 modules with SKIROC in 2016 and 20 (94) modules with SKIROC2-CMS in 2017 (2018) have been tested



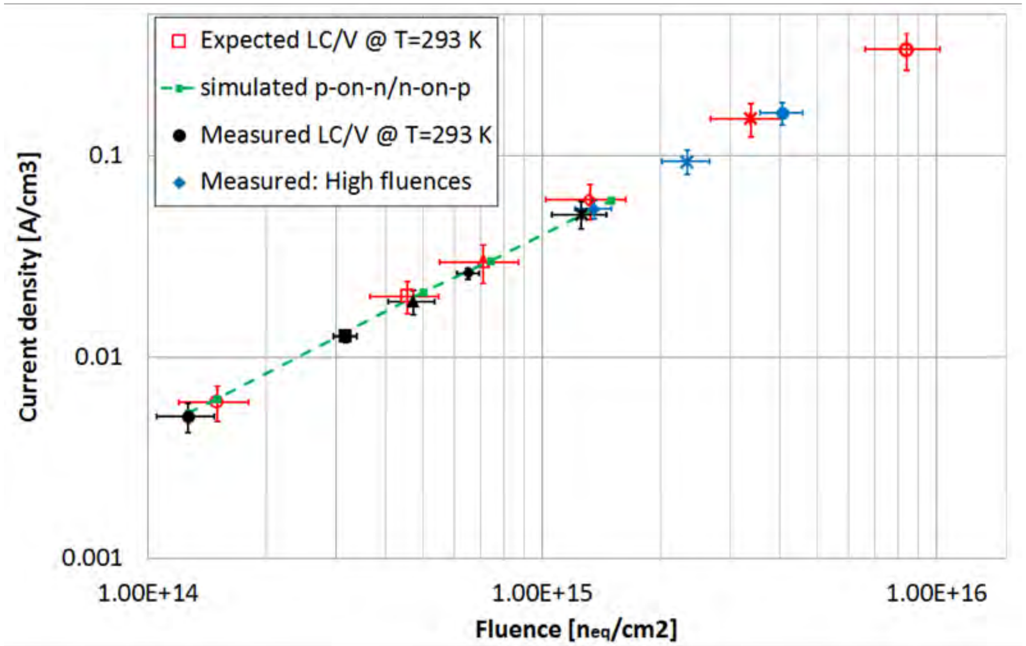


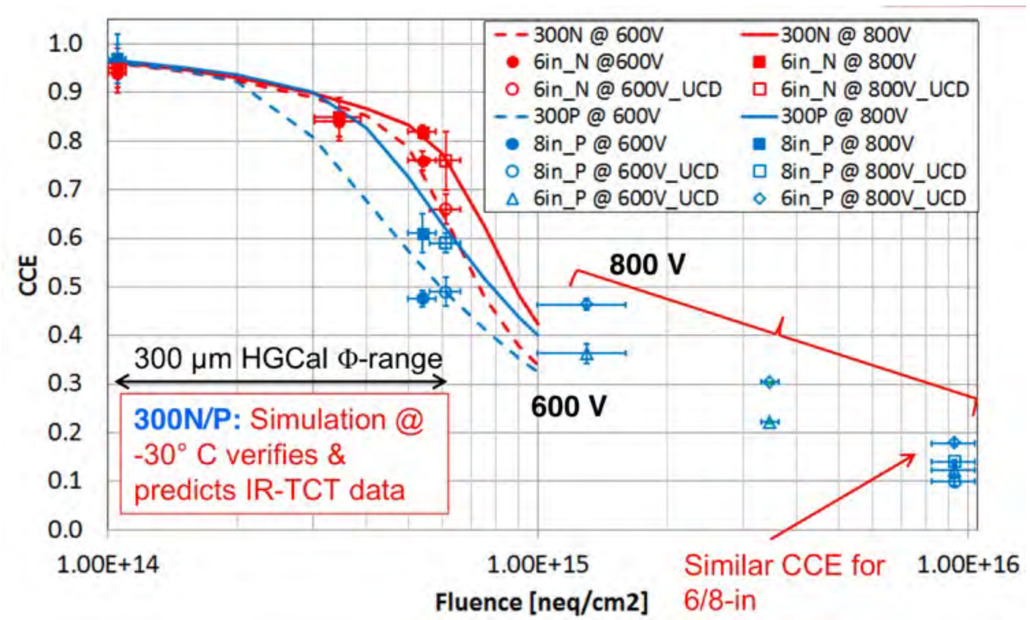




R&D Achieved so far - II

Charge #2





- Leakage current (LC) density increases with neutron fluence: expected, simulated and CV/IV measurements are in good agreement. $\Delta I = \alpha V \Phi$ where at room temperature $\alpha = 4.0\times10^{-17}$ A/cm
- LC extracted fluence and activation foil measurements are in good agreement (~x2 at highest fluences) in irradiation studies performed at RINSC with test structures

- The test structures prove extremely useful in irradiation studies and consequently in tuning many TCAD parameters
- Irradiation studies are ramping up for 8" wafer sensors

Path to 8" Sensor Qualification

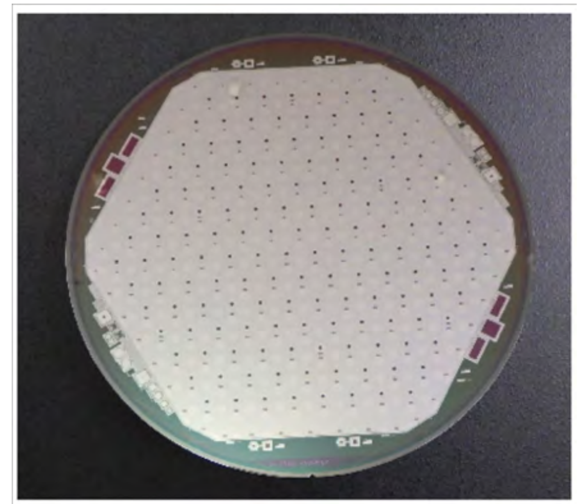
Charge #2

2017: First Prototype 8" HPK sensors, produced with stepper

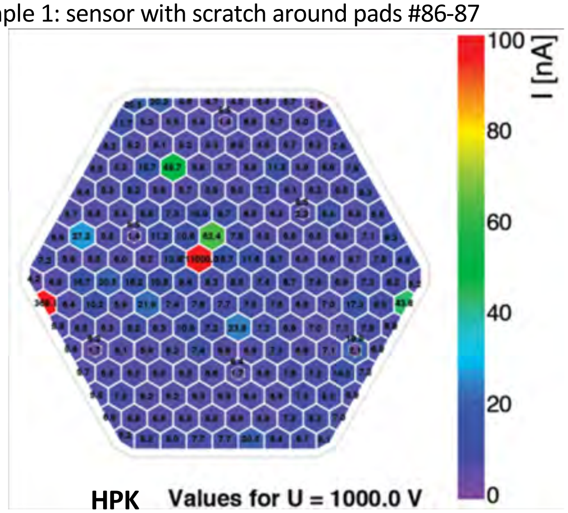
- Received 300 µm FZ (12), 200 µm FZ (12), & 120 µm epi (6)
  - Indicative of excellent underlying quality
    - Tooling issue (back-side scratches) identified & corrected

2018: Prototype 8" HPK sensors with full-wafer mask aligner

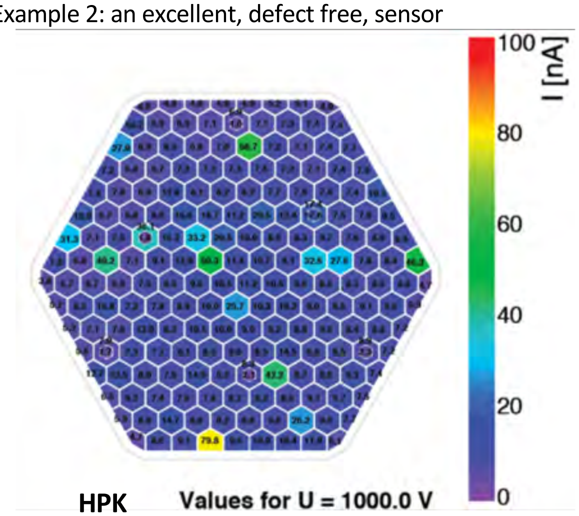
- Received 14 x 300 µm FZ, 14 x 200µm FZ in November 2018
  - Excellent underlying quality, but not yet perfect
    - Tooling issue (front-side scratches) identified & corrected
    - Back-side handling issue (increase LC in few cells)
- Received 12 x 120 µm epi in February 2019
  - Delayed by epi wafer procurement, then held until production of 300um/200um sensors understood and issues addressed



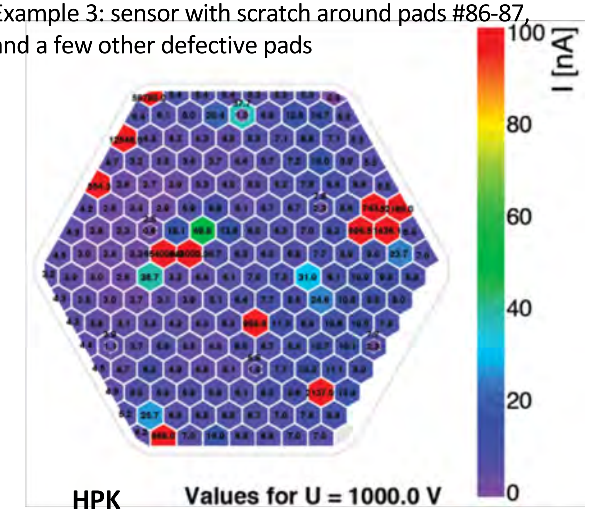
Example 1: sensor with scratch around pads #86-87



Example 2: an excellent, defect free, sensor



Example 3: sensor with scratch around pads #86-87, and a few other defective pads



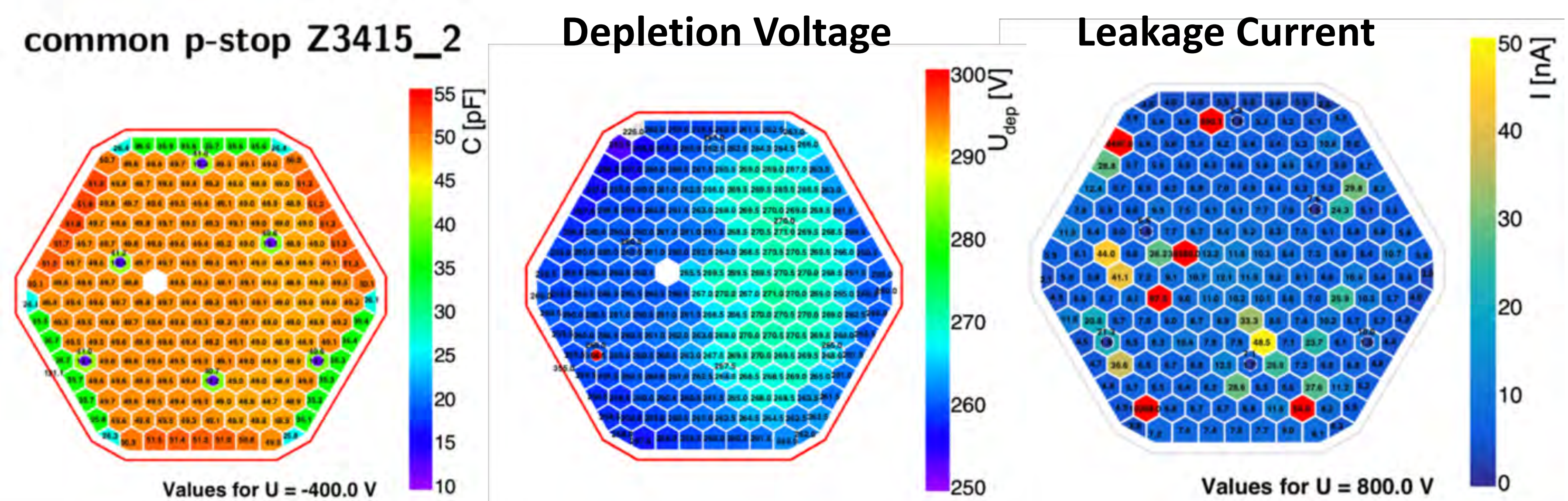
Full Lithography Sensor Tests

Charge #2

- CV and IV Measurements of 200 µm & 300 µm sensors
  - Results as expected, understanding variations across wafer
  - Some issues with scratches (HPK handling), and handling during testing; planned modifications to address these
  - Good comparison between HPK and CERN measurements, need to understand differences in detail for mass production.

300 µm sensors

Capacitance at full depletion



Irradiation of 8” Stepper Wafers

Charge #2

- Previous results from 6” wafers and ddFZ
- Results from test diodes on 300, 200, and 120 µm thick 8” FZ wafers match expectations
  - Irradiation at -30C
  - Testing at -30C

❑ **Radiation damage @ HGCAL mostly due to neutrons:**
- 30 test samples irradiated @ Rhode Island (RINSC) & UC Davis (MNRC) reactors → crosscheck dosimetries & methods for LC-extracted Φ (see backup 1 – 2)
- **Table: Red** - Rhode Island (RI), **Black** - UC Davis (UCD)

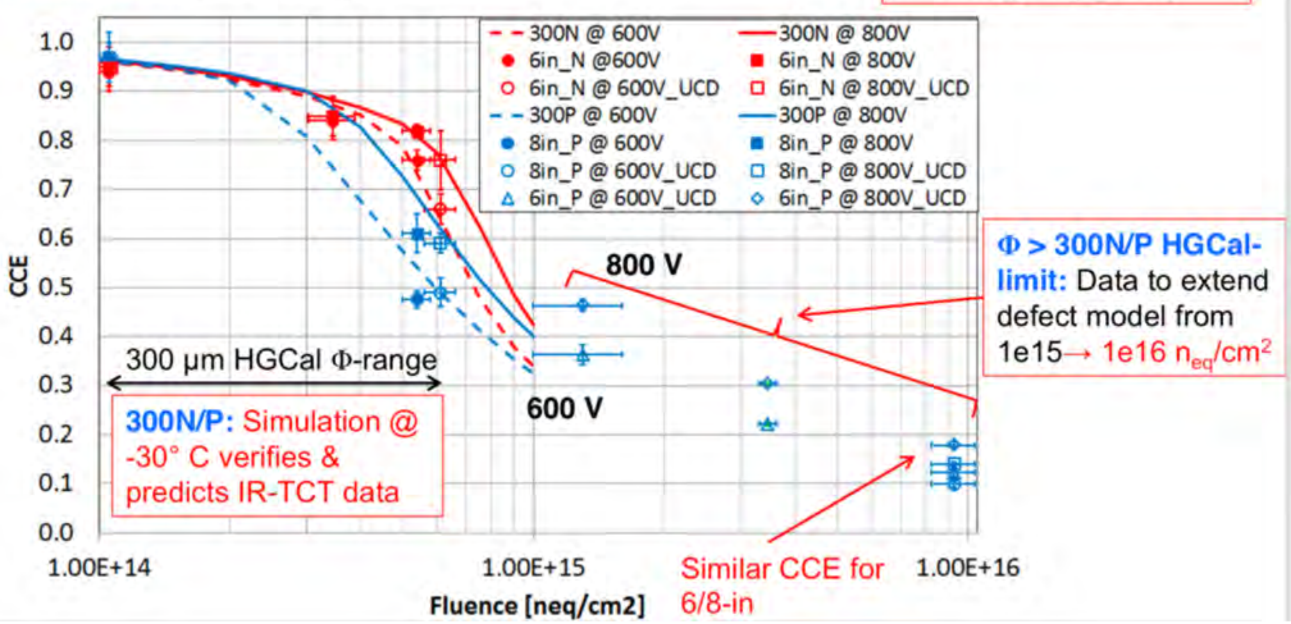
300P: 300 µm thick n-on-p diode

Wafer size	Sensor type & thickness	Target fluence [n_{eq}/cm^2]					
		1.5e14	5.0e14	7.5e14	1.5e15	3.8e15	1.0e16
8”	300P	1 + 0	1 + 0	2 + 2			0 + 1
	200P				1 + 0	1 + 1	0 + 1
	Epi 120P					0 + 1	
6”	300P				0 + 1	0 + 1	0 + 1
	120P				1 + 0	1 + 0	1 + 2
	300N	1 + 0	1 + 0	1 + 1			
	200N				1 + 0		
	120N					2 + 0	1 + 2

Samples:

❑ **Solid (800 V) & dashed (600 V) curves:** TCAD simulated 300N/P
❑ **Filled (RI) & hollow (UCD) markers:** Measured 300N/P
❑ $V_{default}$(HGCal) = 600 V → V_{max}(HGCal) = 800 V
❑ **Fluences:** IV-extracted Φ_{eff}

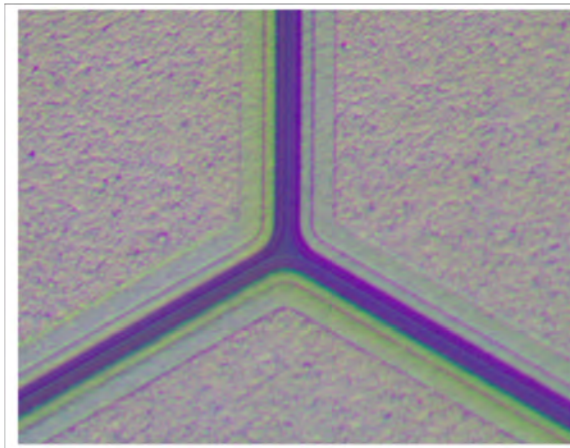
❑ **300N/P:** >10% benefit from operating @ V_{max} for high Φ(HGCal)



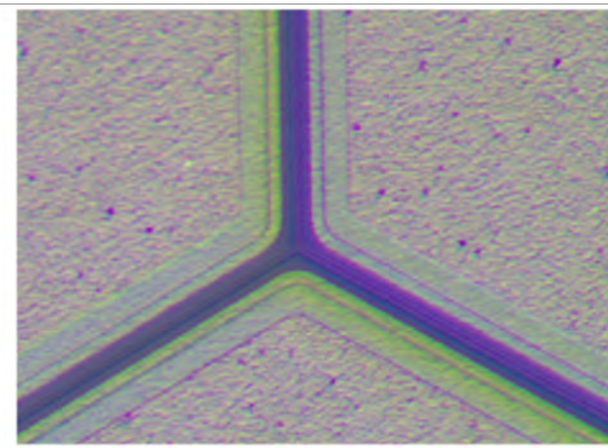
R&D needed before production

Charge #2

- Conduct radiation tests of 8” full wafer lithography silicon sensors
  - Will settle remaining issues like p-stop choice
  - Implement probing system to readout irradiated sensors
  - Search for any pre-irradiated characteristics that might be associated with onset of micro-discharge after irradiation
  - Understand evolution of high current pads with radiation
  - Work with HPK to improve robustness of the sensor backside contact
- Finish implementation of 432-cell sensor design and odd-sized sensors
- Construct & test modules with live 8-inch sensors for Major System Prototype 1
- Finish establishing testing infrastructure, and standardized qualification tests and procedures
  - Simplify testing at vendor
- Qualify vendor process and QC through prototype sensors in Major System Prototype 2
- Optimize sensor shapes and numbers, minimize variants (taking into account new radiation map)



Individual p-stop



Common p-stop

8” Silicon Sensor production time-line

- **Prototyping phase**: 2017-2019; use in Major System Prototype 1 in 2019-2020
  - Complete design development and validation
  - CERN to place sensor contract (December 2019 Milestone)
  - HPK to complete preparations for high volume 8” sensor production
- **Pre-series**: 2020; use in Major System Prototype 2 in 2020-2021
  - Qualify Silicon Sensors, Module, Motherboard and Cassette designs, assembly and QA/QC procedures
    - With Final Components
- **Pre-production**: Q1-Q2/2021
  - first 5% of sensors for use in HGCAL
  - Ramp up Silicon Sensor, Module and Cassette assembly and QA/QC procedures
    - Proceed with all due care to ensure and verify consistent quality
- **Production**: Q3/2021 -> Q3/2023
  - Remaining 95% (plus possible assembly yield losses)

8” Silicon Sensors Timeline I

- 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.
- CMS Silicon Sensor Specifications review on 29 Jan 2019, Follow-up 14 Mar

8” Silicon Sensors Timeline II

- In process of producing a set of specifications that will go to HPK and define “good” sensors
  - Part of the process that will lead to a frame contract this year
  - CMS Review of specs/timeline and negotiations with HPK is on-going

	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
PRR		June/July 2019	June/July 2019
Frame contract signature	~ End April / Mid May 2019	After PRR	After PRR
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

8” Silicon Sensors Timeline III

ATLAS ITk, CMS Tracker and HGCAL Production schedule under discussion with vendor

				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											21841			
Short Barrel	320um / >275um (85%)	6" P-type FZ AC	1			159	159		0	0	0	0	0											4400	4400	318	0.07
Long Barrel	320um / >275um (85%)	6" P-type FZ AC	1			159	159		976	976	976	976	976											8300	8300	318	0.04
Ring 0	320um / >275um (85%)	6" P-type FZ AC	1			23	23		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		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			

Need-by date for
last HGCAL sensor batch

- USCMS Sensor Milestones

Milestone	Start	Finish
Sensor order placed	29 Apr 2021	
Odd-sized sensors complete		10 Jan 23
Standard sensors complete		18 Jul 23

Risk Register

Charge #3

- RO-402-4-01-D. Use cheaper p-on-n Si wafers
  - Retired as HPK cannot get the n-type Si (on time)
- RT-402-4-05-D. US does not receive Si sensors to build all standard modules
  - Rejected as deemed inappropriate to have USCMS on the hook for components supplied by collaborators
- RT-402-4-10-D. Silicon sensor has low yield
  - Possible 2 – 4 month delay and cost of extra sensors
- RT-402-4-20-D. Boundary between Si and Scintillator is moved
  - Cost of additional sensors. Will know early enough to not incur a delay

Institutional Involvement (Sensors)

Charge #4

- Fermilab (sensor design, TCAD, testing, DBs)
  - R. Lipton, P. Rubinov, Z. Gecse, M. Alyari, U. Joshi
- Texas Tech University (sensor irradiation and testing, TCAD)
  - N. Akchurin, V. Kuryatkov, T. Peltola
- Carnegie Mellon University (sensor testing, DBs)
  - M. Paulini, M. Weinberg
- UC-Santa Barbara (odd-sized sensors)
  - J. Incandela, S. Kyre
- Florida State University (sensor irradiation and testing)
  - R. Yohay
- Brown University (sensor irradiation and testing)
  - U. Heintz, N. Hinton

Resource Optimization

Charge #4

- We have distributed and optimized the project across institutions and vendors. Teams with experience in calorimetry, detector design and construction, and electronics are responsible for the key elements:
- Silicon sensors
  - Fermilab has led sensor designs for trackers and has extensive experience in silicon detectors. Fermilab and UCSB have significant history with potential vendors
  - Use existing Sensor testing stations and expertise
  - Silicon sensors will be delivered by a vendor. Testing and qualifying will be carried out by multiple institutions (Brown, FSU) with previous silicon sensor/detector testing experience
  - Integrated with international CMS sensor team, design and QA/QC (CERN and Vienna)

ES&H

Charge #6

- Specific hazards for 402.4.3 (Sensors) are radiation, neutron activation, and lasers during characterization tests in a cleanroom environment.
- All ES&H aspects of the HL LHC CMS Detector Upgrade Project will be handled in accordance with the Fermilab Integrated Safety Management approach, and the rules and procedures laid out in the Fermilab ES&H Manual (FESHM)
- We are following our Integrated Safety Management Plan (cms-doc-13395) and have documented our hazards in the preliminary Hazard Awareness Report (cms-doc-13394)
- In General Safety is achieved through standard Lab/Institute practices
  - No construction, accelerator operation, or exotic fabrication
  - No imminent peril situations or unusual hazards
  - Items comply with local safety standards in site of fabrication and operation
  - Site Safety officers at Institutes identified in the SOW

Quality Assurance and Quality Control

Charge #6

- Silicon sensors:
  - QA: Design is based on industry standards, TCAD simulations and prior experience and verified by extensive bench (IV/CV, TCT) and beam tests
  - QA: Several types of test structures designed and produced on the same silicon wafers as the sensors to verify dopant concentrations and profile, capacitance, depletion voltage, leakage current, as well as other parameters. These test structures are irradiated with neutrons to verify radiation hardness
  - QA: Inter-pad gap is studied by 3D simulations and by measurements on full prototype sensors
  - QA: Full size standard and odd-sized prototype sensors will undergo radiation tests
  - QA: Will coordinate with Tracker for QC, and also HPK for testing
  - QC: Suite of acceptance tests will be performed on all channels on a sample of sensors from each production batch
- Conforms to cms-doc-13093

Quality Control I

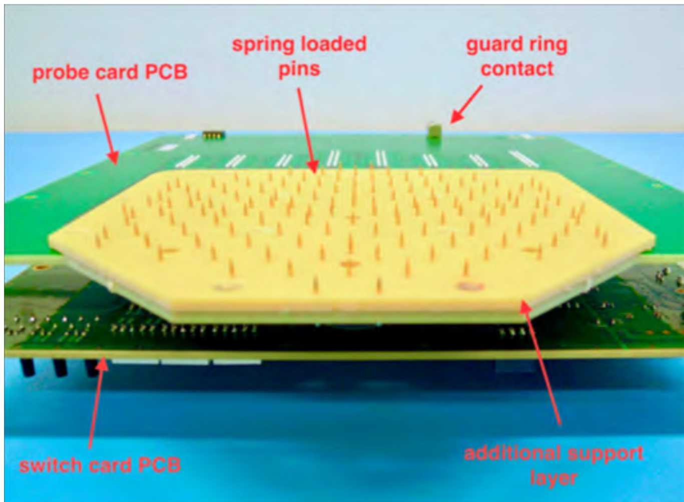
Charge #6

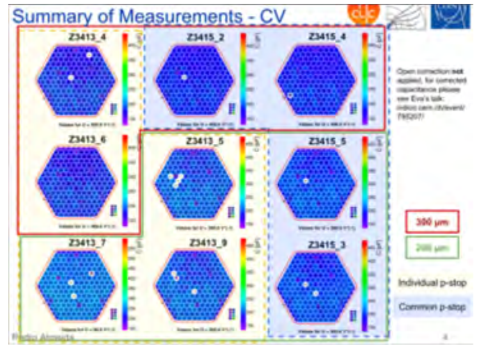
- CMS HGCal will follow Tracker scheme for Sensor QC
- Sensor testing will be performed at/by (TBD)
  - Vendor: 100%
  - By CMS "SQC" (Sensor Quality Control): sample tests (~5%)
    - At least 1 sensor per batch; assume min batch size = 20
  - At five Module Assembly Centers: reception tests (TBD)
  - On test structures at PQC (Process Quality Control)
    - Assume sensor and test structures behave identically
    - Some parameters are not accessible on main sensor
    - PQC results often apply to the whole batch
- Sensor Characterization
  - Establishing the list of measurements to be made based on experience with present sensors, e.g. CV, IV, C_{tot}, inter-pad capacitances, CCE, noise, etc. (in specs document)

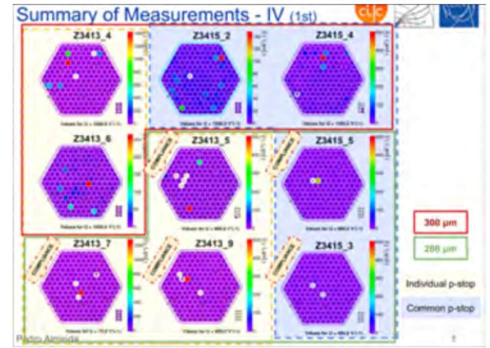
Quality Control II

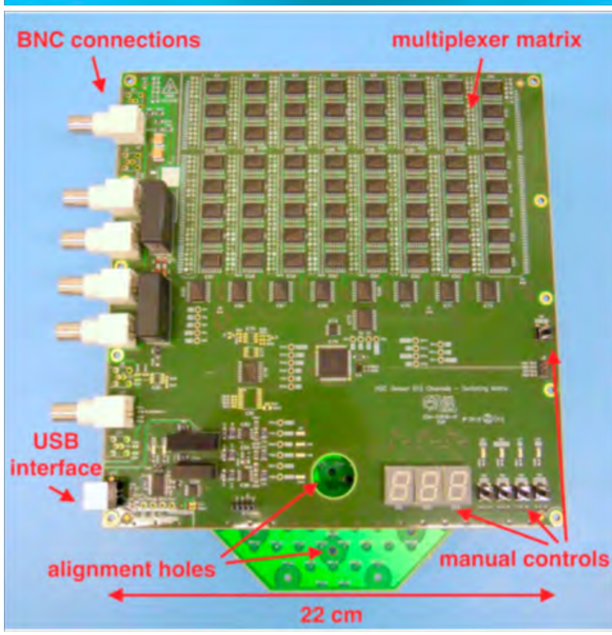
Charge #6

- Much of the testing infrastructure has been established

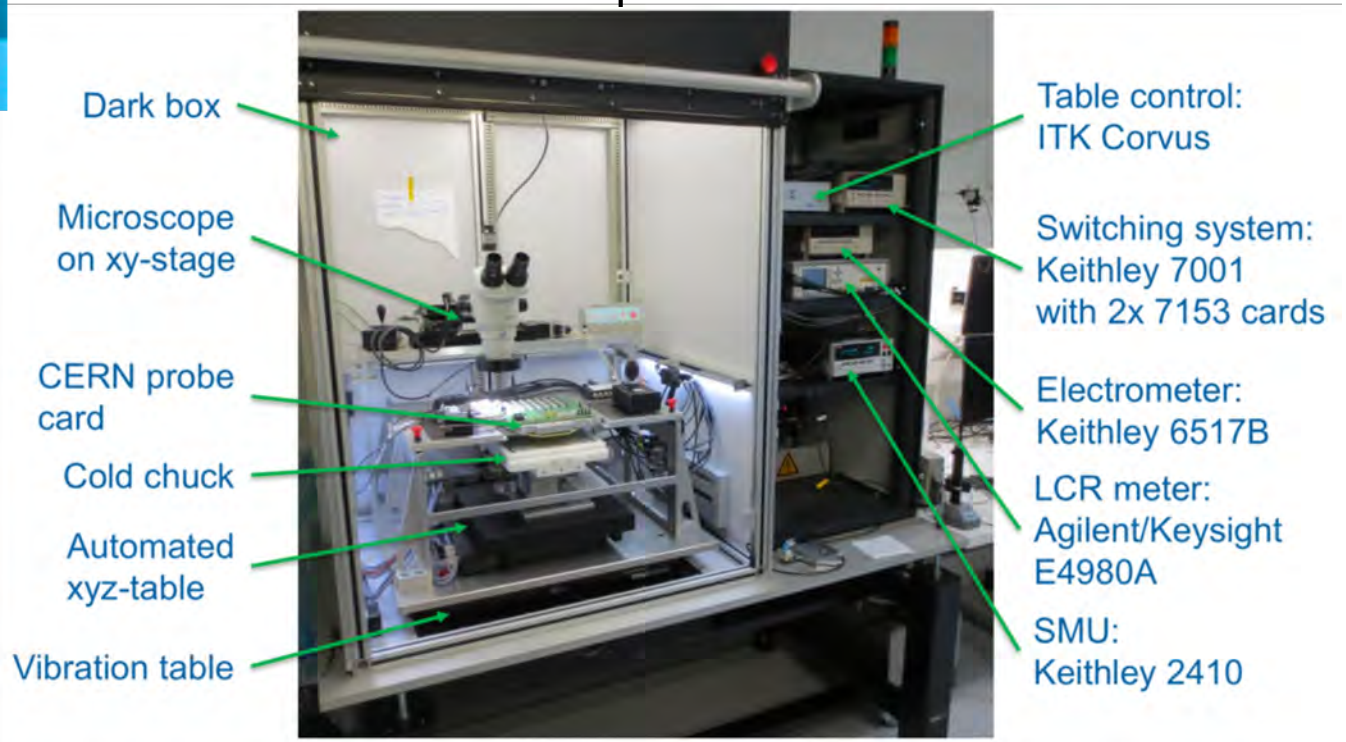








Test Setup at Vienna



402.4 CD-3a Cost Summary

Charge #3

- Cost for CD-3a scope
  - Does not include a portion of production sensor QC: irradiation testing and reviews

WBS	Direct M&S ($)	Labor (Hours)	Direct, Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
Production Silicon	6,853,236	0	7,171,912	2,151,573	9,323,485
Silicon QC	0	5830	171,291	51,388	222,679
CD-3a Scope Total	6,853,236	5830	7,343,203	2,202,961	9,546,164

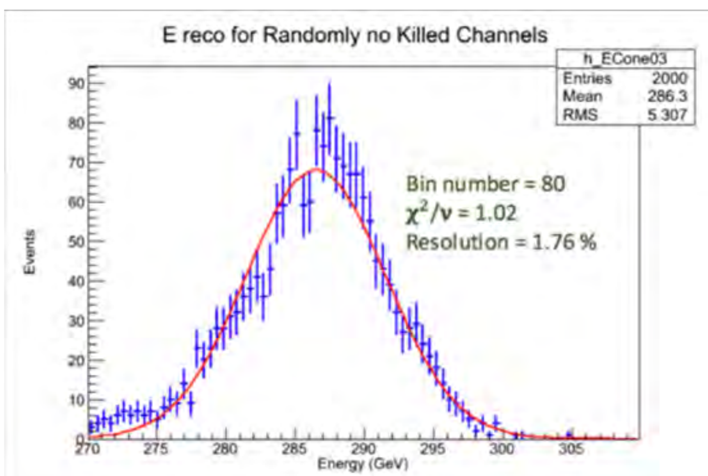
402.4 Response to Previous Reviews

Charge #8

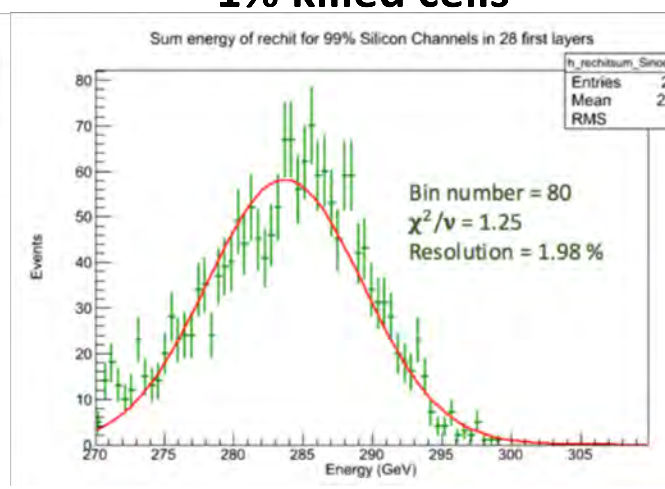
- June 2018 IPR Recommendation
  - For CD-2, develop simulation tools to determine the dependence of HGCAL performance on the assumed level and distribution of dead and noisy cells.
    - We have developed a standalone simulation to study the effect of random dead cells, and of failures of DC-to-DC converters and motherboards
      - **CMS DN-18-023** "Effect of dead silicon channels on the HGCAL energy resolution for photons", Sara Nabili and Sarah Eno (Maryland).

Resolution of 120 E_T Photons (E=282 GeV)

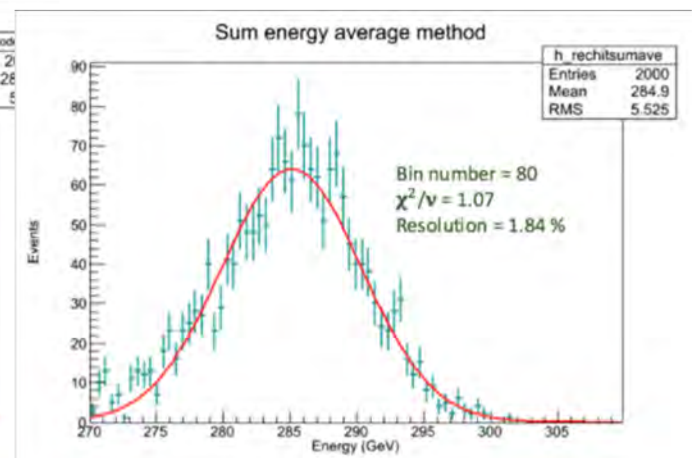
No killed cells



1% killed cells



1% killed cells - mitigated



402.4 Response to Previous Reviews

Charge #8

- June 2018 IPR Report Comments on CE
  - "The planned production model relies on the use of eight-inch sensors that remain to be qualified. The sensor requirements, such as fraction of dead or noisy cells, are tightly coupled to this plan and it is important for eight-inch sensor qualification to be completed and final sensor requirements defined prior to CD-2 or CD-3a. "
    - We are going through the 8" sensor qualification now, with full wafer lithography sensors in hand for all three thicknesses from the final vendor. An initial sensor specifications document has been written up and converging now with vendor for final agreement. This will be reviewed again by the CMS specifications reviewers

402.4 Progress towards CD-3a/CD-2

- Planned Scope for CD-3a
  - Preproduction and production silicon sensors
  - QC of these silicon sensors
- Technical issues to be addressed/done to be ready for CD-3a
  - Testing of 120 micron 8” full wafer lithography sensors
  - Irradiation studies of full wafer lithography sensors
  - Finalized specifications/options with HPK
    - Get endorsement by CMS Sensor Specifications Reviewers

Summary

- Progress since June 2018 IPR on 8” wafer sensor qualification
  - Irradiation results for 8” stepper wafer test diodes
  - IV/CV testing of 8” full wafer lithography sensors
- Technical progress in other related areas
  - Excellent operational experience with 6” silicon sensor modules in multiple test beam runs
  - Validation of mechanical and thermal performance of mockup 8” modules, leading to choice in module baseplate & mounting
  - Well advanced on QC equipment and tests, as well as test procedures for production testing and testing at vendor
- We will be ready for CD-3a
  - Sensor design is close to final, and almost completely validated

Backup

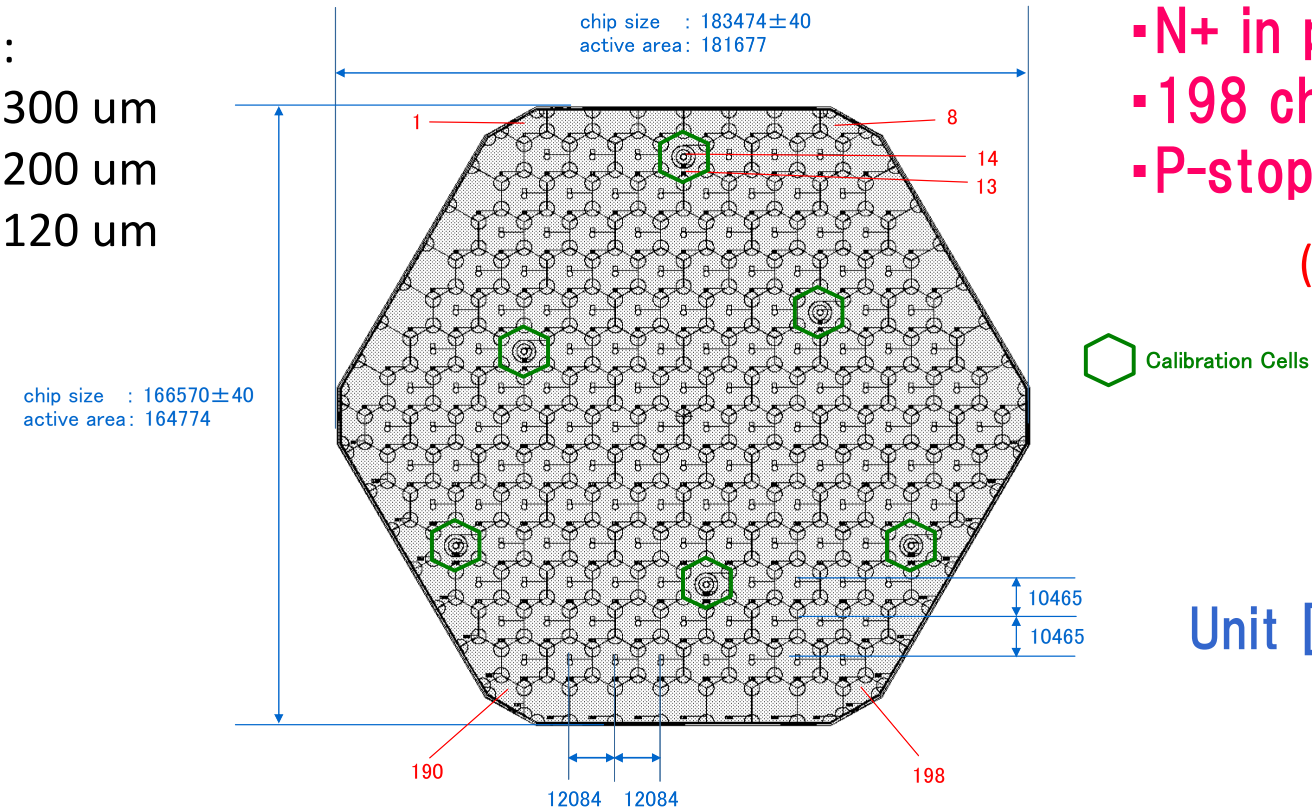
8” Silicon Sensor: 192 Cell Design

Main Sensor (Overall)

Full wafer lithography

HAMAMATSU
PHOTON IS OUR BUSINESS

In hand:
14 pcs. 300 um
14 pcs. 200 um
12 pcs. 120 um



- N+ in p
- 198 channels
- P-stop isolation

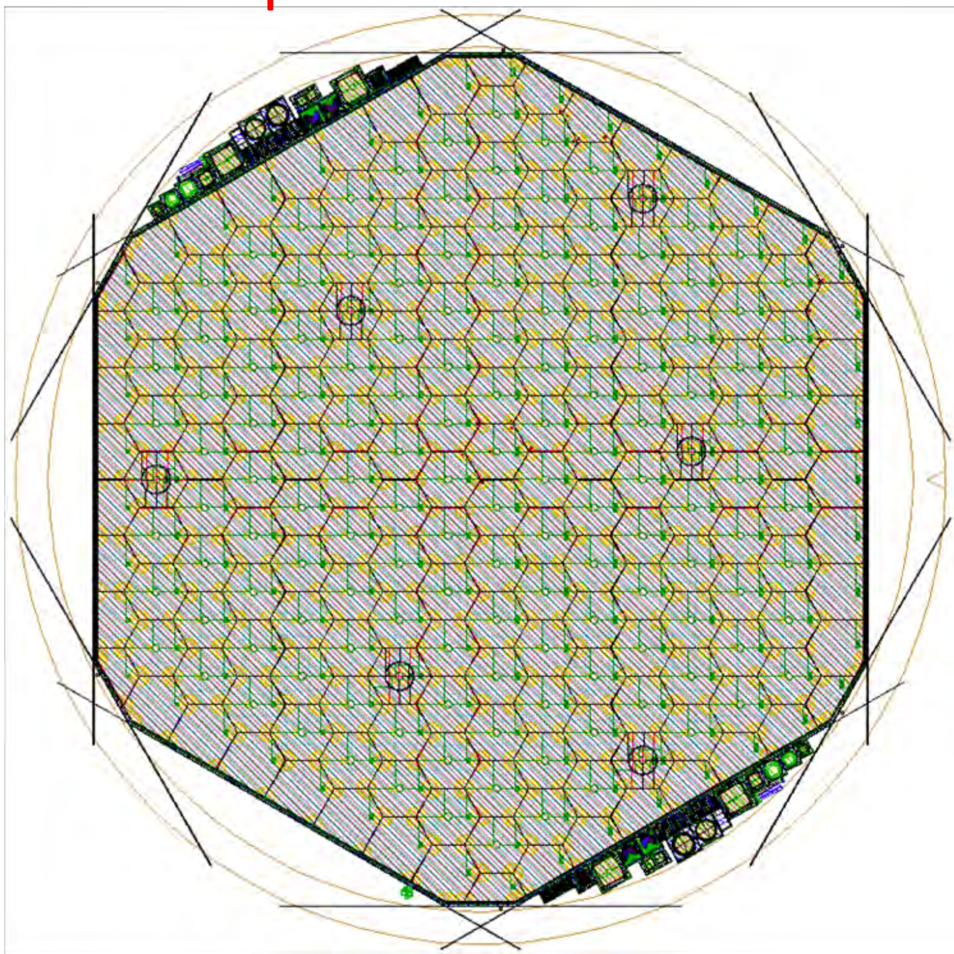
(Atoll or common)

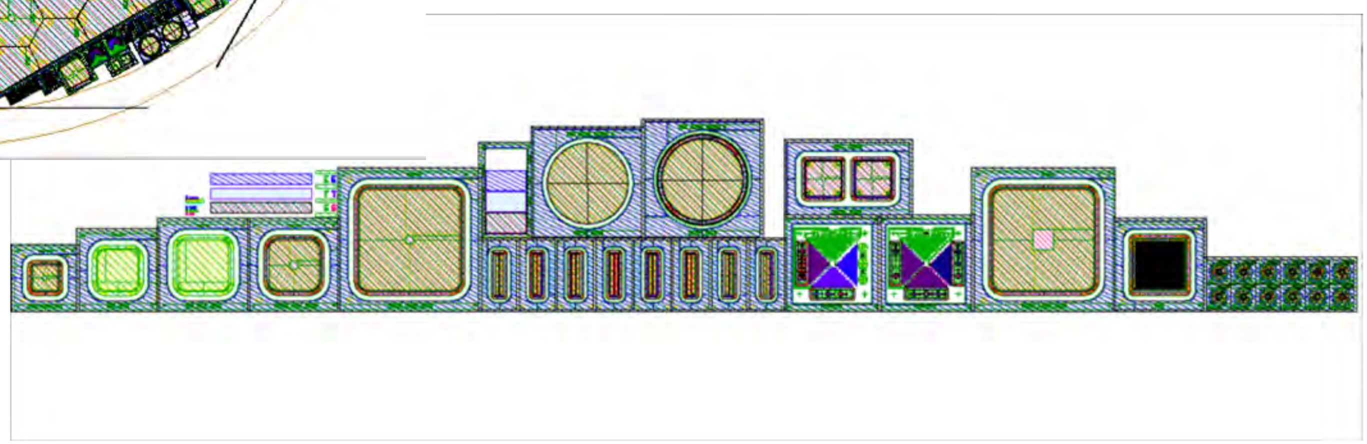
Unit [μm]

3

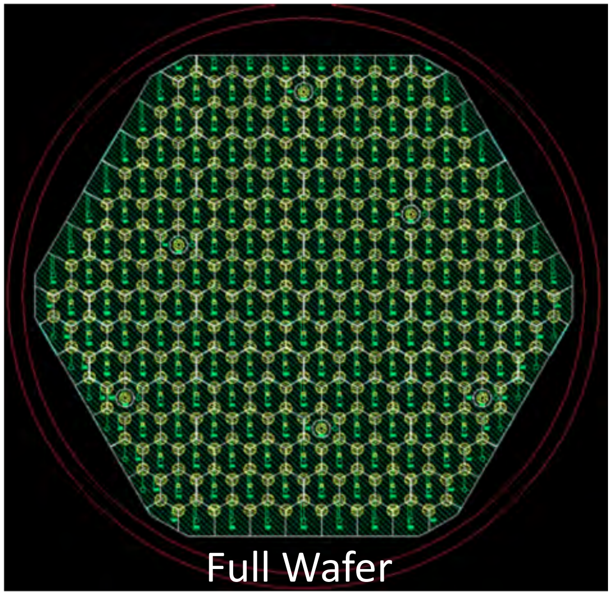
CONFIDENTIAL

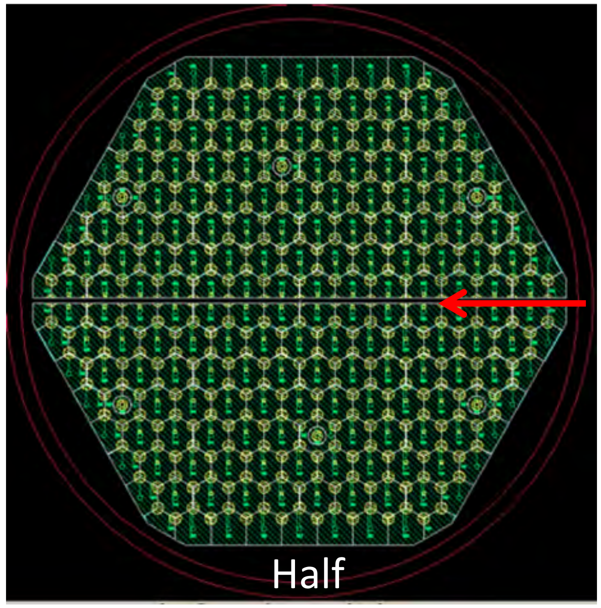
HGCAL sensor layout & design parameters

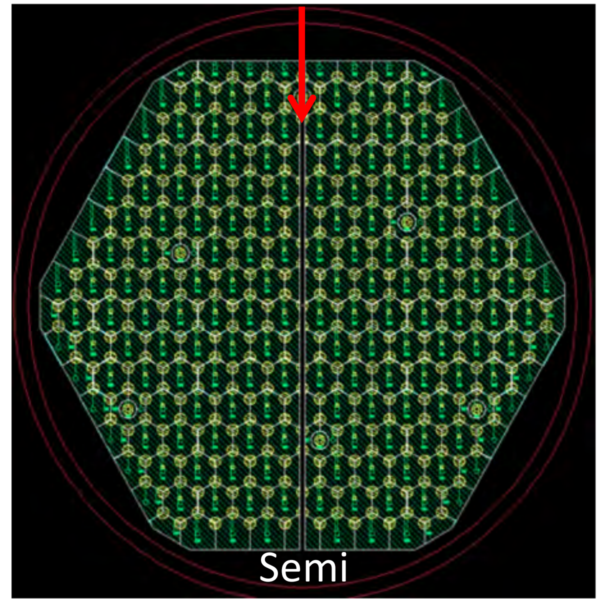


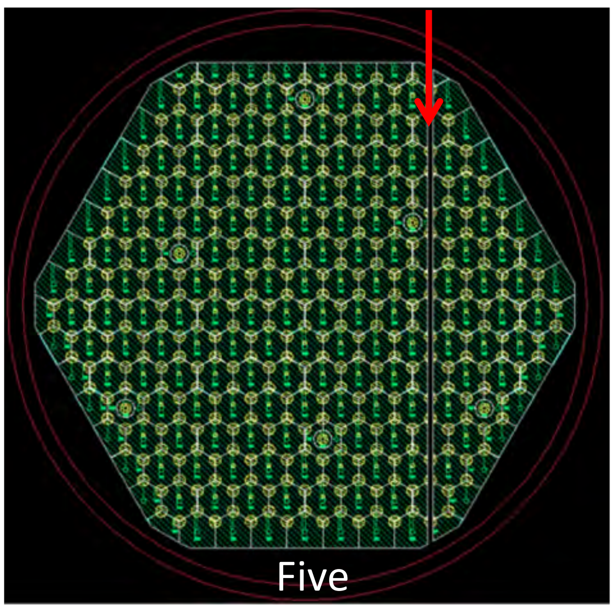


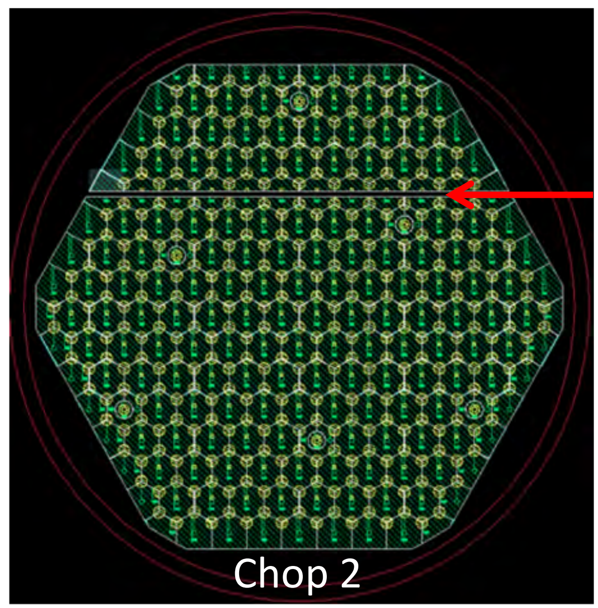
Geometry variants











Critical Path for Sensors

- Silicon sensors:
  - The module assembly will start Jan 2022, and end Sep 2023. Silicon sensor deliveries should start Apr-Sep 2021 and be completed by Oct 2022 (odd) and Mar 2023 (std).   Potential delay and/or yield problems (RT-402-4-10-D) in the beginning could put sensors on the critical path
  - Delay in module production can be mitigated by increased rate later

Coord Committee: scope and mandate

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

Total combined amount 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

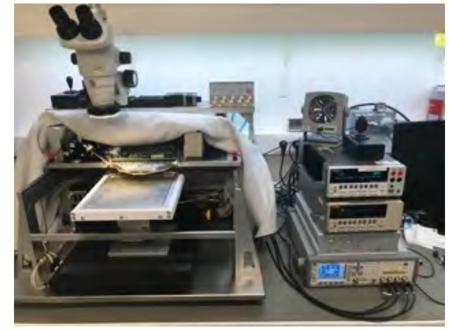
A CERN-ATLAS-CMS Coordination Committee had been formed in order to:

- 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

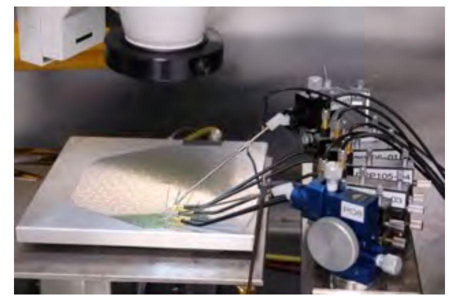
HGCAL sensor working group: presently active manpower

- CERN: E. Sicking, F. Pitters, P. Almeida, E. Brondolin,
  M. Pinto, P. Sieber, T. Quast
  - Development of pogo pin full wafer probe card, probe card station and readout, diode c.c. measurement system
  - Automatic probe station with cold chuck
- Vienna - Thomas Bergauer, M. Valentan, P. Paulitsch
  - Sensor & test-structure design
  - Automatic probe station with cold chuck
  - Probe card station and readout
- Florida State: R. Yohay, H. Prosper, R. Habibullah,
  C. Benetti, E. Jowers, K. Koetz
  - Probe card station with readout under construction
- Brown University (Irradiation): U. Heintz, N. Hinton
  - 8” Irradiation Facility, initial testing , TCT system
- Texas Tech: N. Akchurin, Timo Penolta, Sonaina Undleeb
  - Sensor and test-structure simulations
  - Probe station with cold chuck, TCT system
- Fermilab: R. Lipton, M.Alyari
  - Sensor & test-structure design & simulations
  - Automatic probe station with cold chuck, laser c.c. measurement
  - Proton irradiation facility (summer 2019?)

HEPHY HGC



HEPHY P3



CERN

FNAL