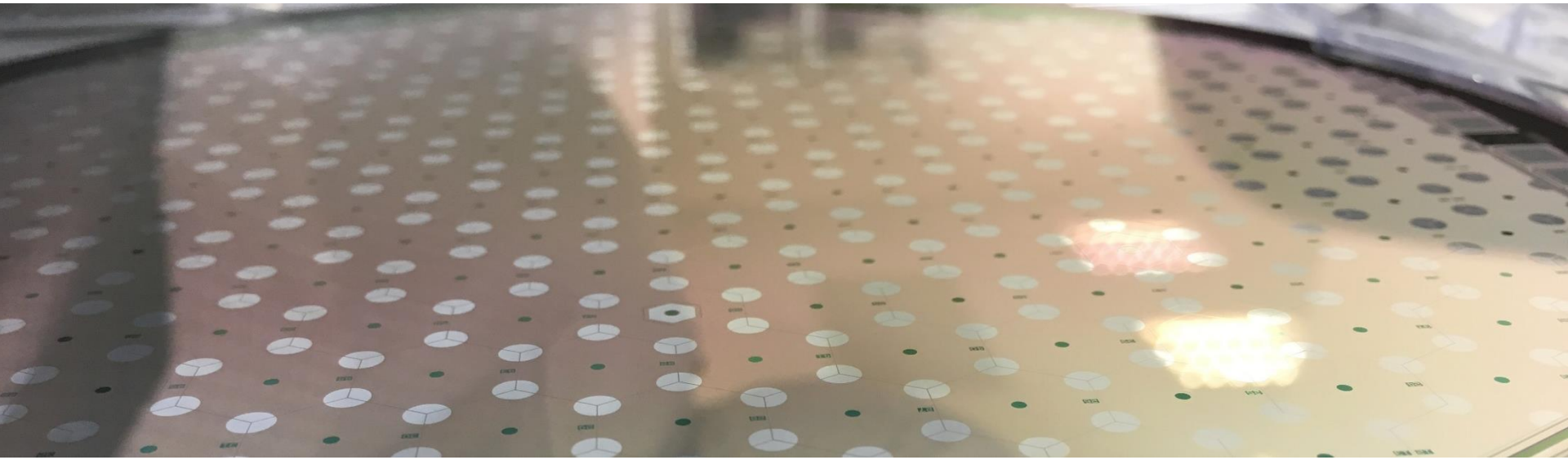
HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

ÖAW
AUSTRIAN ACADEMY OF SCIENCES



AIDA-2020 4th annual meeting Oxford

Task 2.5 Pre-industrialisation of large area silicon detectors

T. Bergauer

4 April 2019

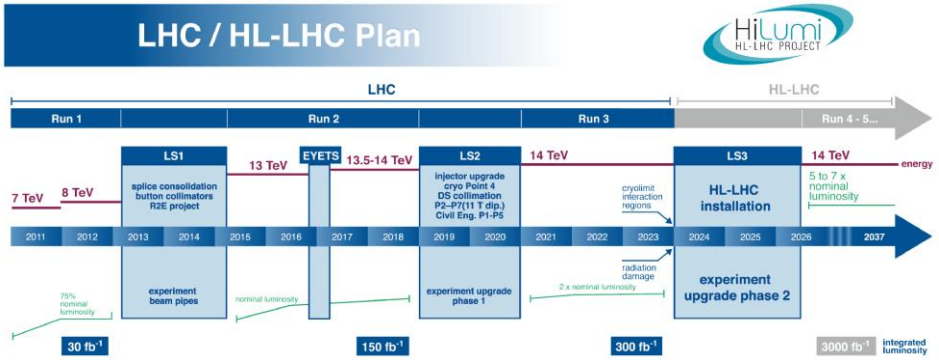
Content

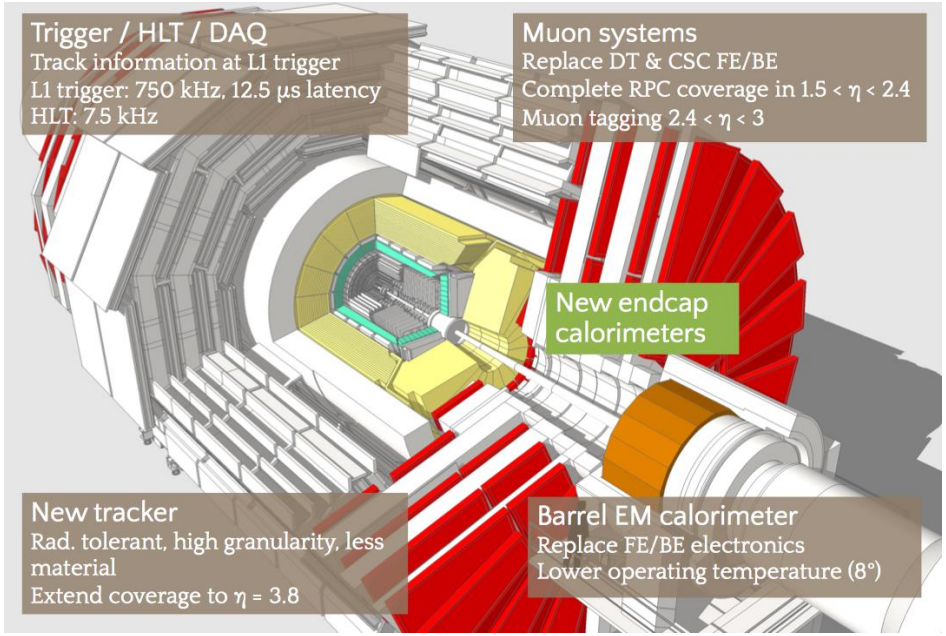
- CMS Phase-II Upgrades
  - Tracker
  - HGCal
- Detector Development with Infineon
- From Market Survey to Invitation to Tender

CMS Phase-II Upgrade

CMS Phase-II Upgrade

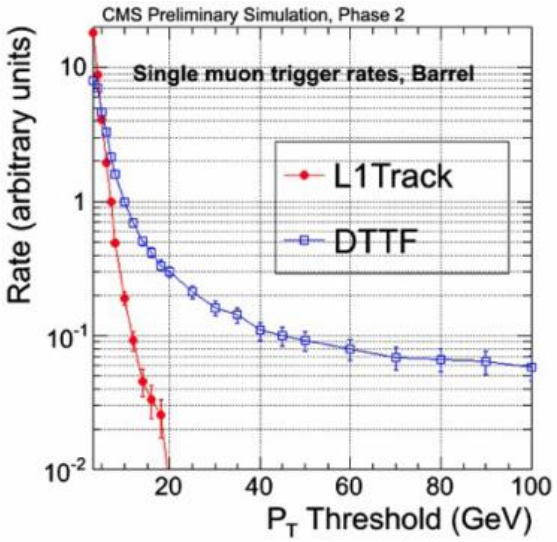
- CMS Phase 2 upgrade during LS-3 (around 2024-2026) for HL-LHC Phase
  - 5-7 times higher instantaneous luminosity
  - 10x integrated luminosity (3000 fb^{-1})
- A major challenge for detector design
  - New tracker, trigger, muon and calorimeters

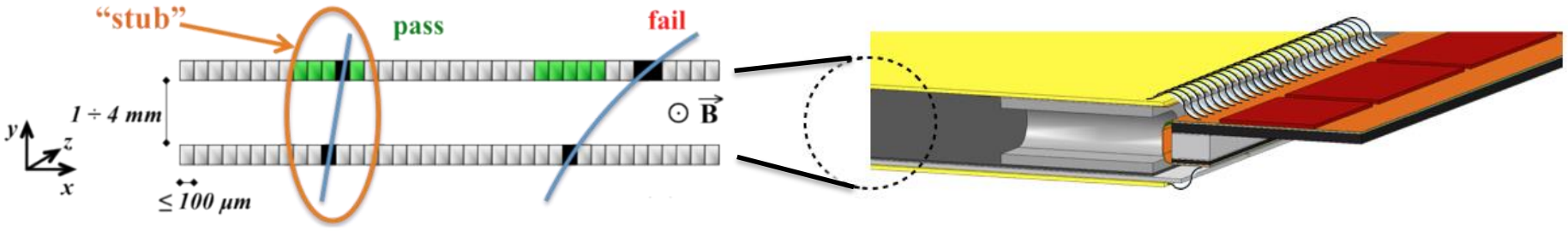




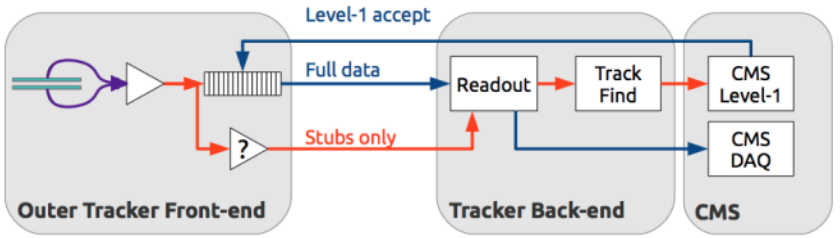
CMS Tracker

- Muon and calorimeter-based triggers will not be able to stand the rates due to PU and limited resolution
- Muons: no p_T threshold can limit the rate
  - due to strong magnetic field in the tracker high-p_T tracks can be discriminated





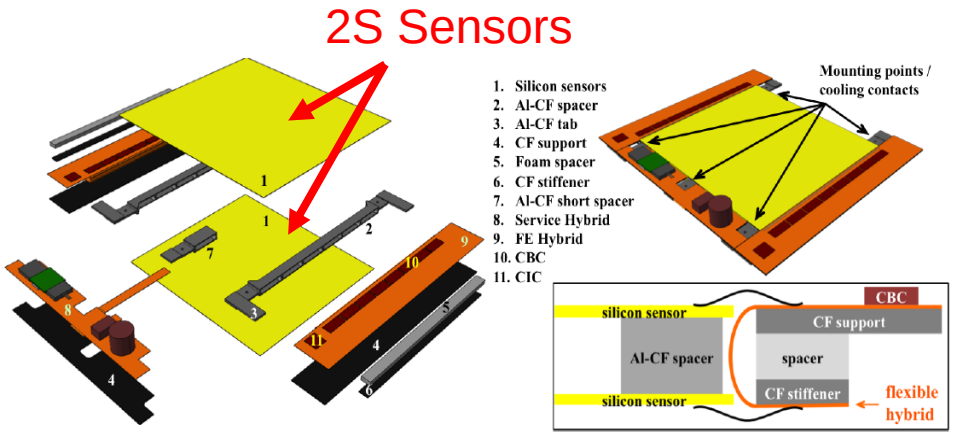
- Stubs will be processed in the back end to build L1A



CMS Tracker

2S modules:

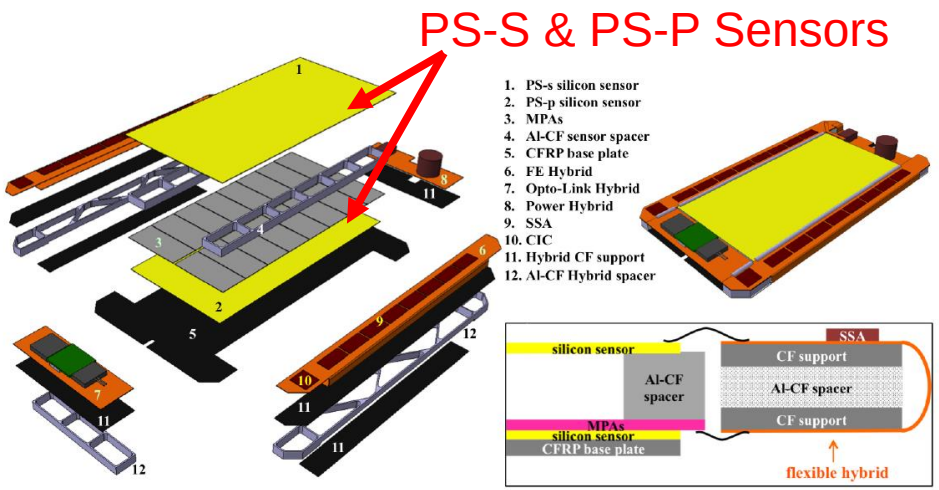
- Outer part of tracker
- Two stacked strip sensors with parallel strip orientation
- Sensor sizes 10x10 cm
- Strips wire-bonded to hybrid containing CBC chips



2S module schematics

PS modules:

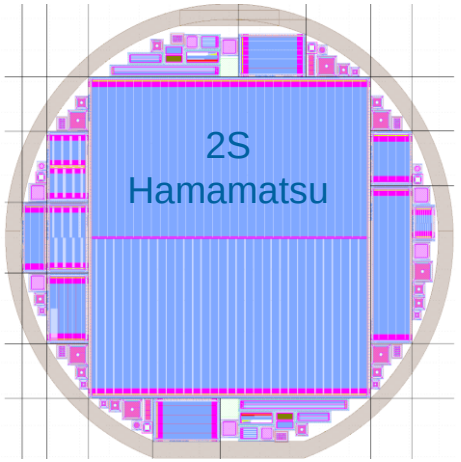
- Inner part of tracker close to pixels
- Consists of one strip sensor and one macro pixel sensor stacked
- Sensor sizes 10x5 cm



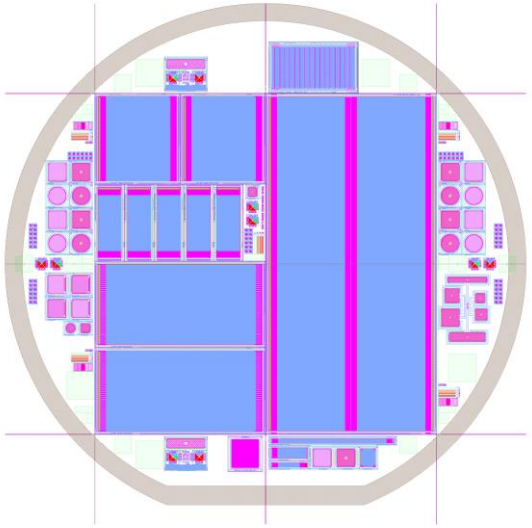
PS module schematics

CMS Tracker

- Feasibility of a production on **8'' wafers** was investigated
  - Cost advantages were expected as wafer area increases more than costs
  - Infineon produced full scale 2S long prototype sensors produced on 8" wafers in a cooperation with HEPHY
    - ➔World's first silicon strip sensors produced on 8'' wafers



- **Baseline of CMS**: production on 6'' wafers
- prototype wafers from two possible vendors already available
  - full scale 2S prototypes (HPK)
  - Full scale PS-S prototypes (IFX)



CMS High Granularity Calorimeter

Current CMS Calorimeters:

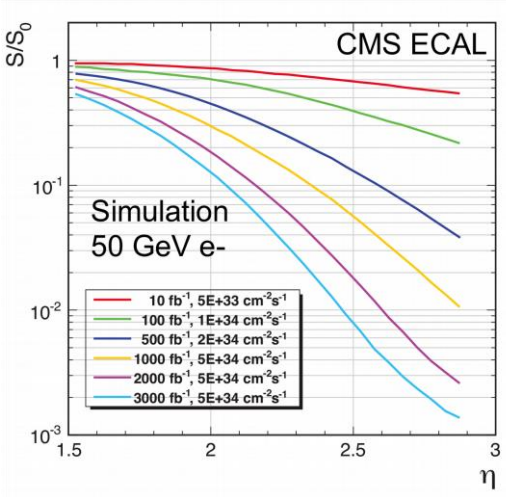
- Designed for integrated luminosity of maximal 500 fb^{-1}
- Electromagnetic: $PbWO_4$ crystals
- Hadronic: plastic scintillators

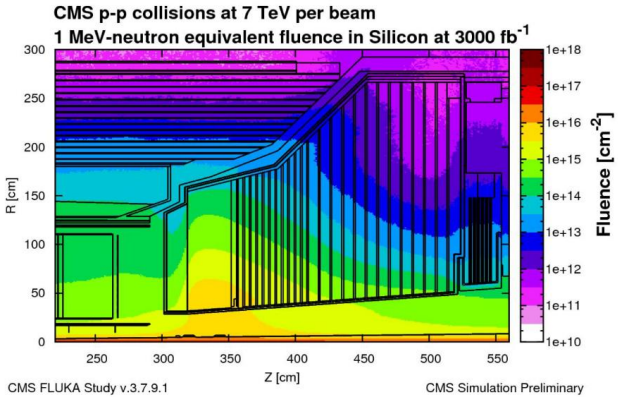
Environment of CMS Endcap at HL-LHC:

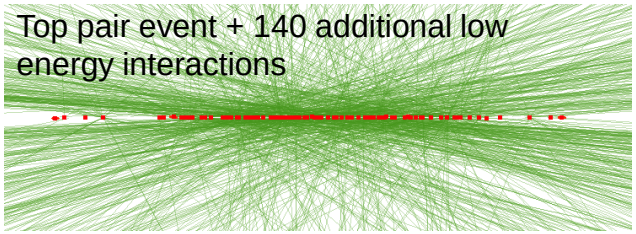
- Fluences of up to 10^{16} n_{eq}/cm^2
- doses of up to 1.5 MGy
- Pile-up of up to 200 collisions/crossing

→ Only silicon detectors are

- radiation tolerant enough
- Fast enough to mitigate pile-ups
- Fine segmented to allow high granularity
- affordable

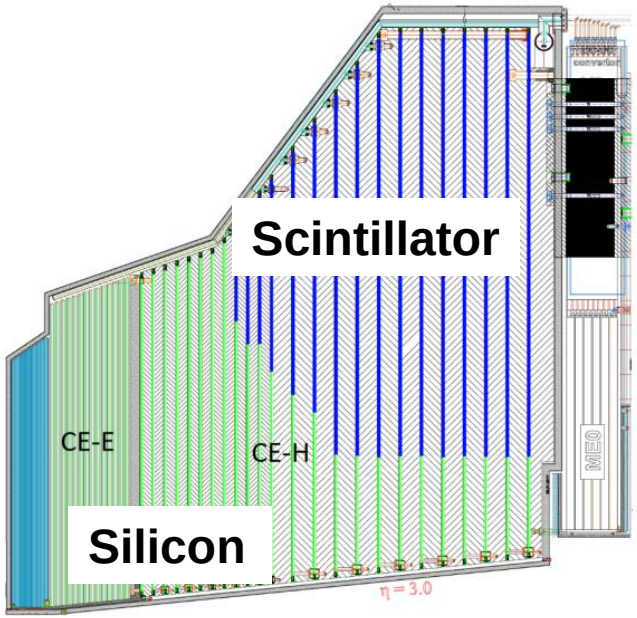




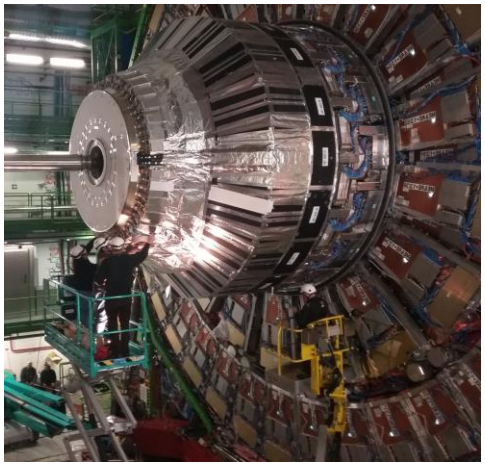


CMS High Granularity Calorimeter

	CE-E	CE-H (Si)	CE-H (Si + Scint)
Active	Silicon sensors		Scintillators
Absorber	Lead	Stainless steel	
Depth	$26X_0$ / 1.7λ	9λ	
Layers	28	8	16
Weight	23t	205t	

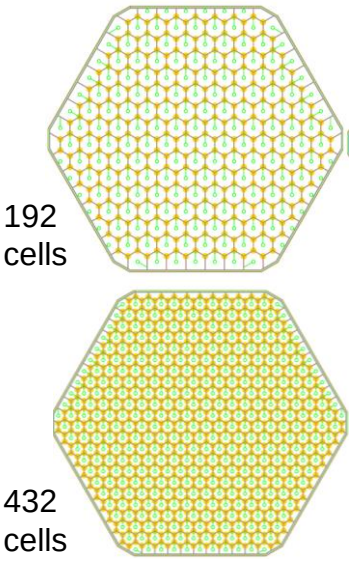


	Silicon sensors	Scintillators
Area	**600 m²**	500 m²
# Modules	25,000	2500
Channels Size	0.5-1 cm²	4-30 cm²
# Channels	6 Mio	400k
Op. temperature	-30° C	-30° C



Silicon Sensor Geometry

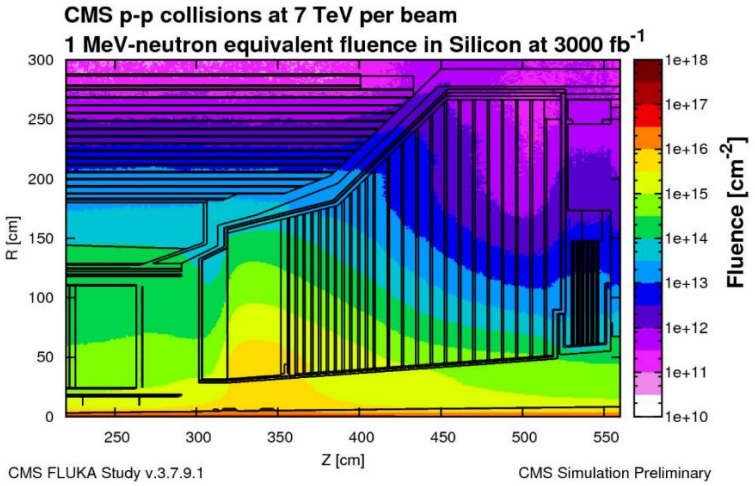
- Hexagonal sensor geometry as largest tile-able polygon
  - maximize use of circular wafer
  - Minimize ratio of periphery to surface area
  - Truncated tips ("mouse-bites") used for module mounting → Further increase use of wafer surface
- Each sensor consists of 192/432 individual diodes (called "cells" or "pads")

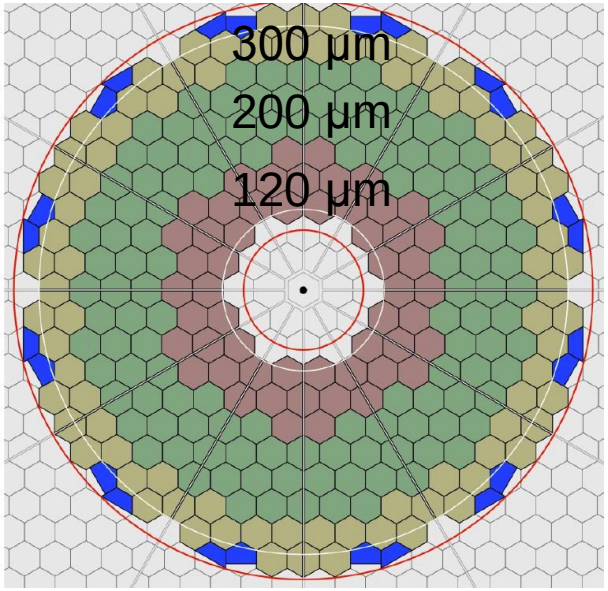


Thickness [µm]	# cells	Cell size [cm^2]	Cell C [pF]	Bulk polarity	Expected Fluence [E15 n cm^{-2}]	# wafers (8 inch)	# partial 8 inch wafers
300	192	1.18	45	p	0.1-0.5	13164	1284
200	192	1.18	65	p	0.5-2.5	8712	144
120	432	0.52	50	p	2-7	3000	324
					Total:	**24876**	**1752**

Radiation Levels

- Fluence is n-dominated w.r.t. charged hadrons (90%/10%)
- Deployment of thinner sensors in the higher fluence regions of the calorimeter
  - improved charge collection
  - reduced leakage current
- Typical signals in calorimeter much higher than MIPs
  - MIP sensitivity needed for energy calibration (e.g. isolated muons)



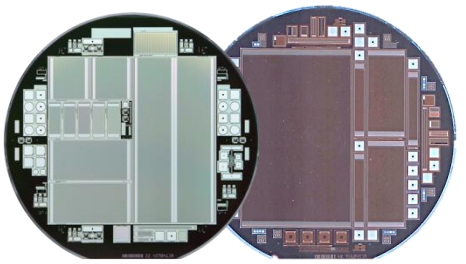


Detector Development with Infineon

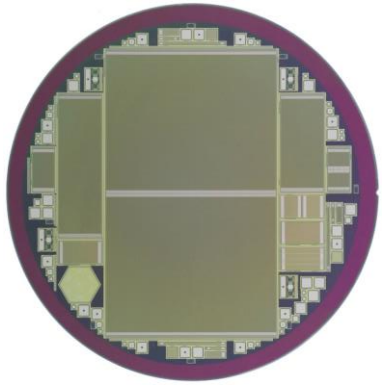
History of the Project

- We were collaborating with them since a couple of years to develop Si sensors for HEP
  - 2012-2014: production of 6” p-on-n sensors
  - 2015-2017: production of first Si strip sensors on 8-inch FZ p-type wafers
  - 2016/17 onwards: production of Si pad sensors for HGCal
- Quality constantly improving
  - One remaining problem: premature IV breakdowns, scaling with sensor size
  - Addressed by different mitigation measures

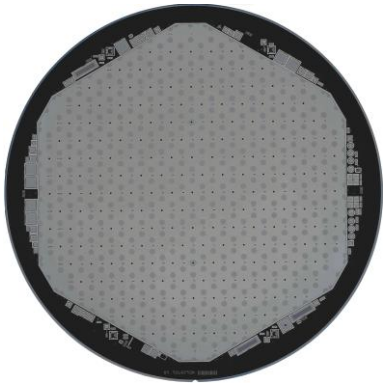
6” strips



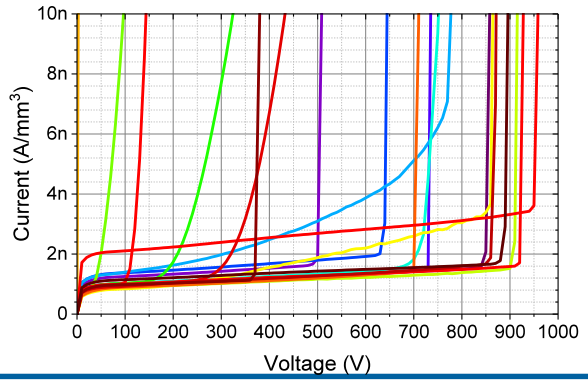
8” p-type strips

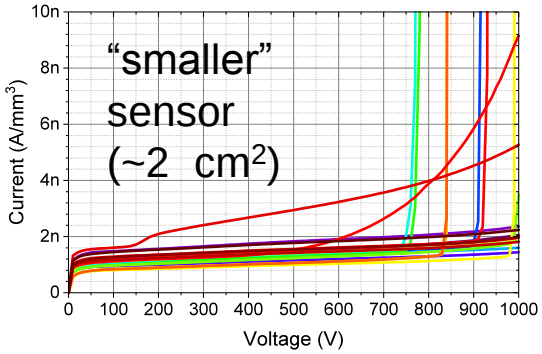


8” p-type pads



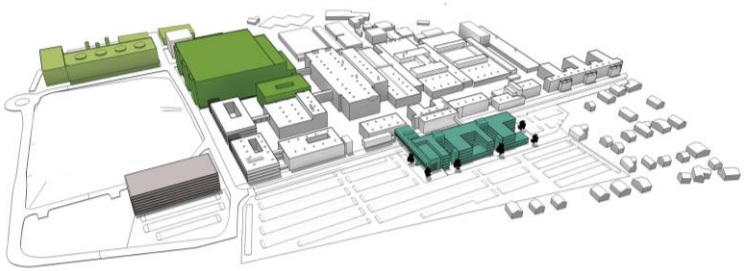
Baby sensor (11.6cm^2)





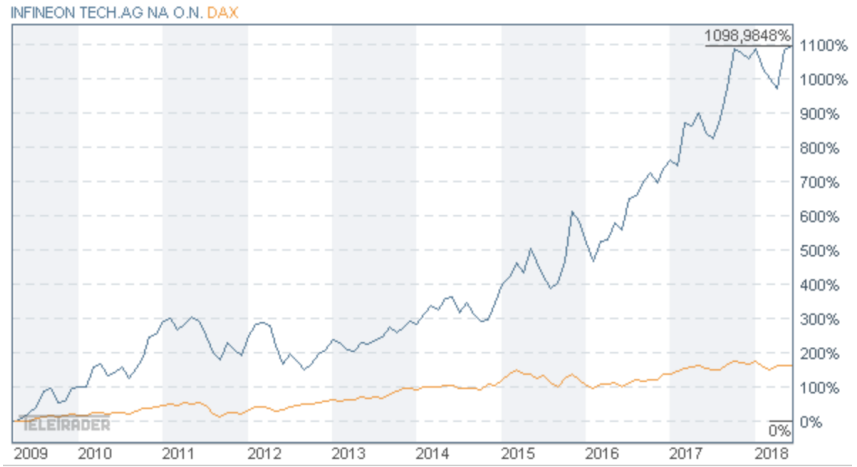
Sensor development with Infineon

- Meanwhile, Infineon became an even larger player in the semiconductor business
  - Acquired US competitor in 2015 for 3 Billion $
  - Investment of 1.6 Billion € to expand research & production site in Villach (Austria) with automated 12-inch wafer fab



Infineon Villach (Austria) with planned new 12-fab (green)

- Specialization of Infineon in power devices, automotive, chip cards
  - all impressing growing markets: electric cars, LED lights, smartphones ensure full order books
  - Stocks development +1100% in last 10 years (compare to +49.2% Global Index)



Sensor development with Infineon

- Infineon re-calculated the business case for the production of HEP sensors taking these developments into account

- Since they treat our project as “one-time order” all development costs needs to be taken into account for calculating the revenue
  - Development costs increased significantly last year to address the IV breakdown problems
  - The costs of the sensors increased by an factor of 4 w.r.t original CMS planning

Infineon decided to quit the development program of HEP sensors for economic reasons in summer 2018

- Unfortunate decision after 9 years of fruitful collaboration
  - understandable economic reasons for Infineon
- Nevertheless the project has to be treated as success
  - Project was very visible within local funding agencies and academic environment
  - Very educative collaboration
    - We learned a lot about commercial production of silicon devices
    - Infineon gained insights in HEP community, device irradiations and received highly trained manpower

Consequences on Infineon's decision

- **HPK is the only qualified vendor of sensors for CMS Tracker, CMS HGCal and ATLAS ITk**
  - More than 46.000 x 6" and 30.000 x 8" wafers over ~3 years

- To ensure that HPK can prepare for this large production:
  - A committee was formed with participation from all projects and CERN procurement
  - HPK was informed of the situation
  - A high-level management meeting at Hamamatsu was held (including CERN DR and ATLAS/CMS SPs)
  - A timeline was defined for the Invitation to Tender which will lead to the contracts for the series production

From Market Survey to Invitation to Tender

Common CMS/ATLAS Market survey for Tracker Sensors

Enabling factors:

- Strip sensors for ATLAS and CMS are very similar
- Different specifications are not so significant for the production

Advantages:

- Shows the combined demand of the largest projects of the coming years to interested companies
- We can share qualification work among the two collaborations
- BUT: A very large fraction of sensor production is not reflected in this MS: CMS High Granularity Calorimeter (HGCal)
  - HGCal is also participating in the results of the first step(s) of this MS

CMS/ATLAS Market Survey Procedure

Each interested company has to successfully pass a three step qualification procedure to be eligible to receive the Invitation to Tender!

- **Step 1:** Companies need to return the ***"Technical Questionnaire"*** document where the responses need to fulfil the requirements set in the "*Qualification Criteria"* document → **ADIA-2020 Milestone MS30 (2016)**

- **Step 2:** Companies need to provide samples free of charge of functional devices of e.g. previous project → **2nd annual meeting (2017)**
  - **ATLAS and CMS qualified samples produced by Infineon as 8" proof-of-principle**

- **Step 3**: CMS/ATLAS orders (and remunerates) a batch of prototype sensors according to CMS layout and specs → **2018**
  - **ATLAS and CMS ordered close-to-final prototypes as described in the TDRs**

- **Step 4:** Invitation to Tender for procurement of series production → **2019**

Market Survey to Tender

- ATLAS and CMS worked hard last weeks to define the technical specifications of the sensors they need for the series production
  - Underwent different review processes (similar to Production readiness review)
  - All information were collected in three different documents (ATLAS Itk, CMS OT, CMS HGCal)
  - Sensor procurement committee met regularly to homogenize common items (wording, definitions,…)

- Invitation to Tender sent to all companies qualified through all steps of Market Survey by CERN procurement service yesterday
  - Companies have one month to respond and fill tables with costs/options

Summary

- Phase-II Upgrades will need more than 46.000 x 6-inch and 30.000 x 8-inch wafers for strip and pad detectors
- ATLAS/CMS Market Survey was started in 2016 to identify interested companies
- European vendor Infineon was interested
  - Prototype sensors for CMS tracker, HGCal and ATLAS Itk produced through year-long collaboration
  - Infineon stopped that project in summer 2018 because of economic reasons
- Market Survey closed with only one qualified company
  - Experiments defined technical specifications for procurement
  - Invitation to Tender sent out yesterday
  - HPK has time to answer until 24 April