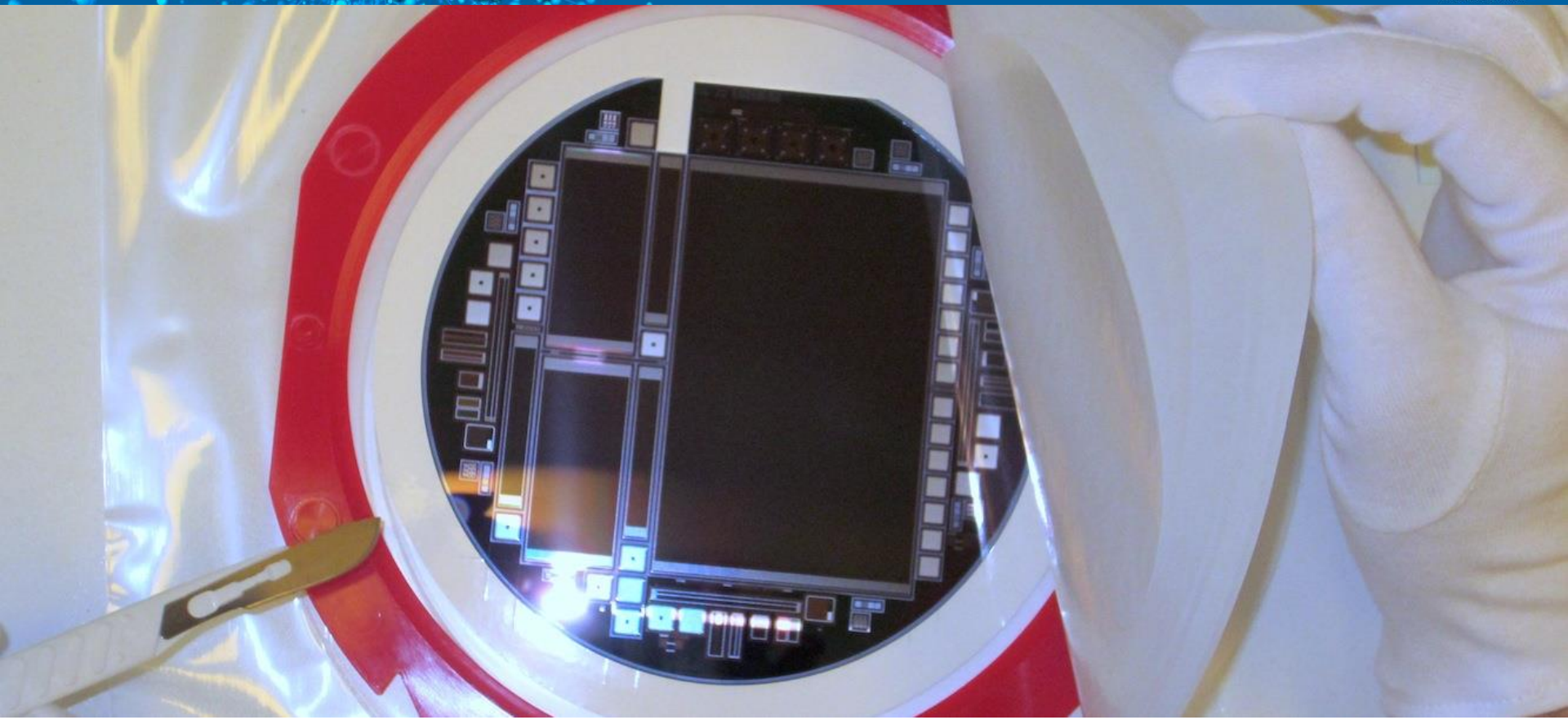
HEPHY
Institute of High Energy Physics

ÖAW
Österreichische Akademie der Wissenschaften



A new vendor for high volume production of silicon particle detectors

With results from the first prototype batch

Marko Dragicevic (HEPHY Vienna)

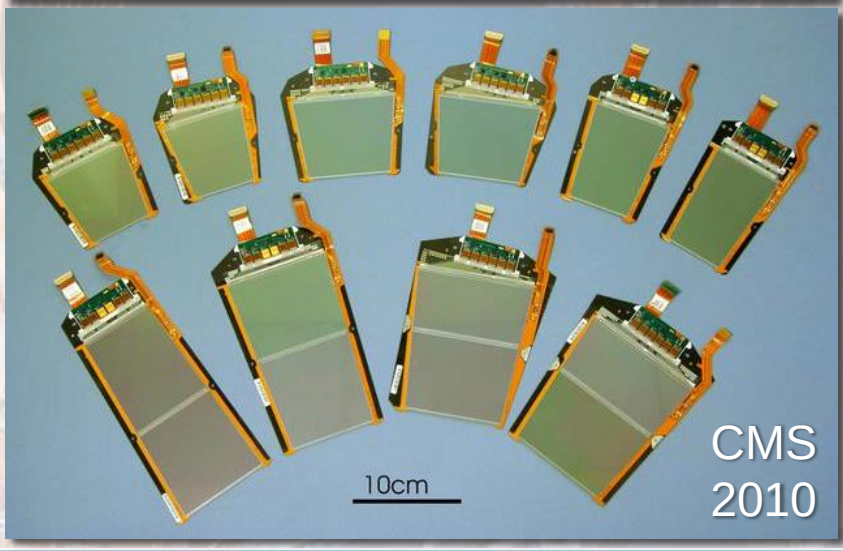
9th Hiroshima Symposium

2. September 2013

Silicon Particle Sensors: A little History

- **First use** of silicon as detectors in 50s and 60s
- **Planar process** to fabricate silicon detectors introduced in 1979 by J. Kemmer
  - First use of planar silicon strip detectors in CERN experiment NA11 the 80ies

Despite new fabrication methods like 3D sensors, the planar process is still the most important fabrication process!

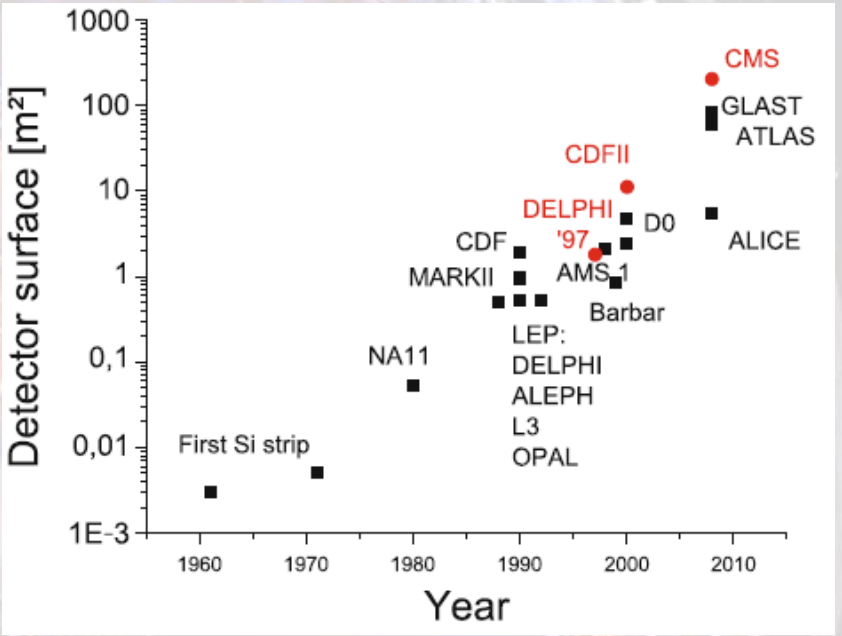


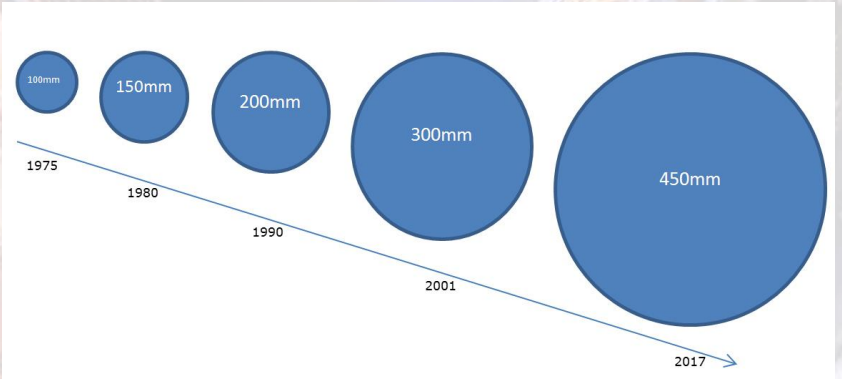
What has changed since the 80ies

What has changed since the 80ies

- Silicon surface
  - Today: Up to 200 m² (CMS)
  - Similar size for the upgrades of CMS and ATLAS
- Wafer Size
  - NA11 started with 2” and 3”
  - Today 6” (150 mm) is standard

  → **Introduced in the Industry in the 80ies!**





Wafer Size: 6” → 8”

- Diameter: 150 mm
- Clearance: ~ 5 mm
- Area: 15,394 mm^2

- Diameter: 200 mm
- Clearance: ~ 5 mm
- Area: 28,353 mm^2

Manufacturing Companies

- Small Scale Production (few 10-100 wafers per year)
  - Many institutes and companies
  - 6” available at many sites
  - Broad spectra of quality and price
- For large scale production (few 1.000 – 10.000 wafers per year)
  - Currently only one (high quality) producer
  - Dual or multi-source strategy would be preferable
- Possible new producer: Infineon
  - Wafer Output (Villach): 50.000 per week
  - Production on thinned 200 mm wafers could be possible

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HAMAMATSU
PHOTON IS OUR BUSINESS
CNM Centre Nacional de Microelectrònica IMB
VTT
Infineon

Outline

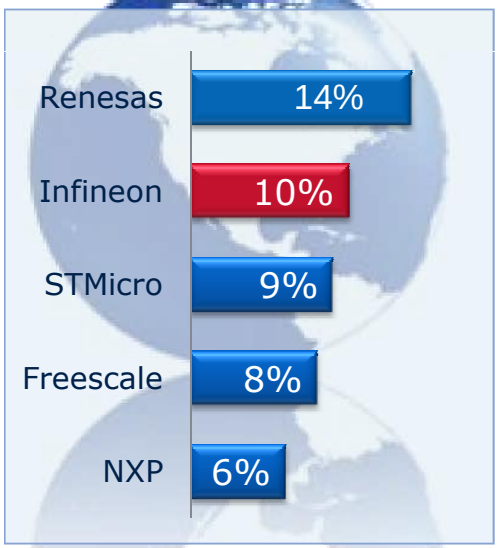
- Infineon Technologies AUSTRIA
- Overview of the Project
- Results from the Electrical Characterisation
- Results Beam Tests
- Outlook & Summary

INFINEON TECHNOLOGIES AUSTRIA AG

Infineon Technologies

Automotive

#2

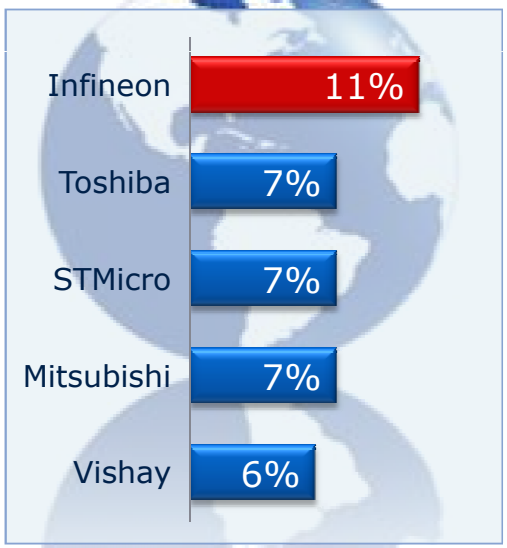


Calendar Year 2011.

Source: Strategy Analytics, April 2012.

Power

#1

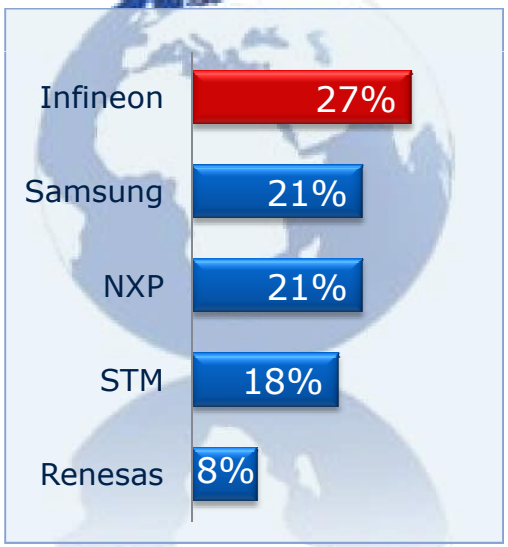


Calendar Year 2010.

Source: IMS Research, August 2011.

Chip Card

#1



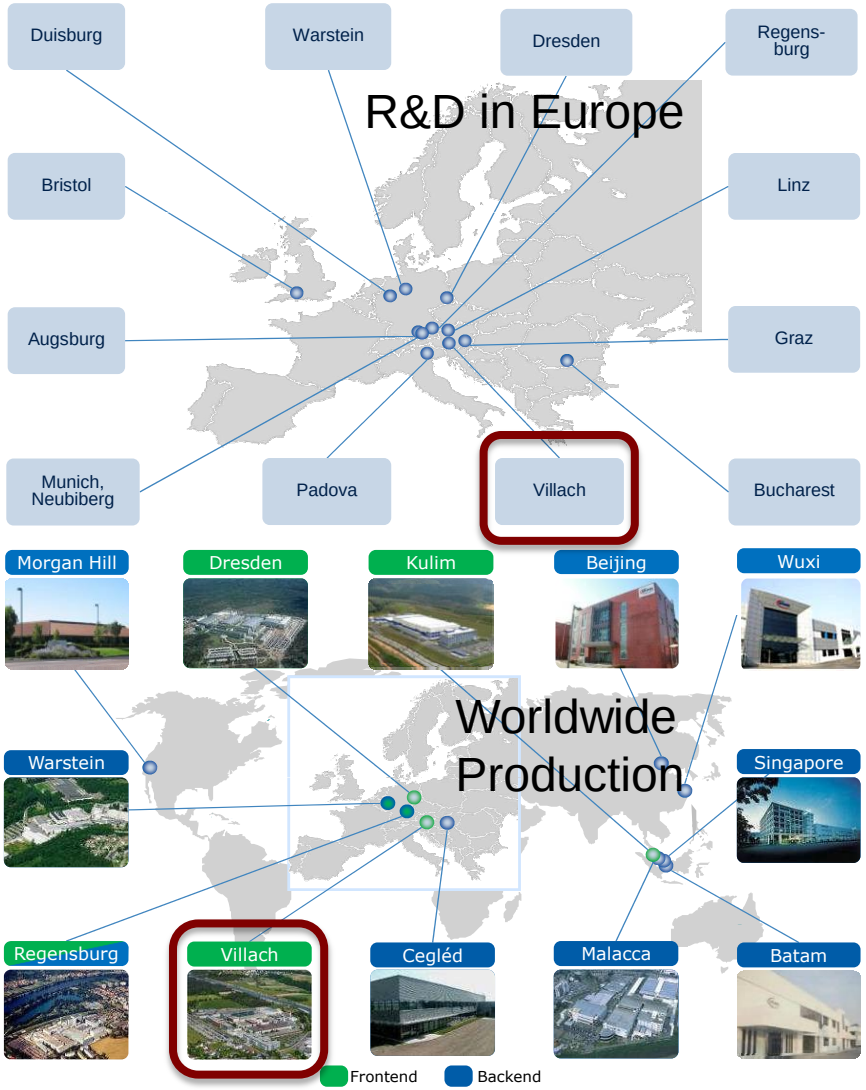
Calendar Year 2010.

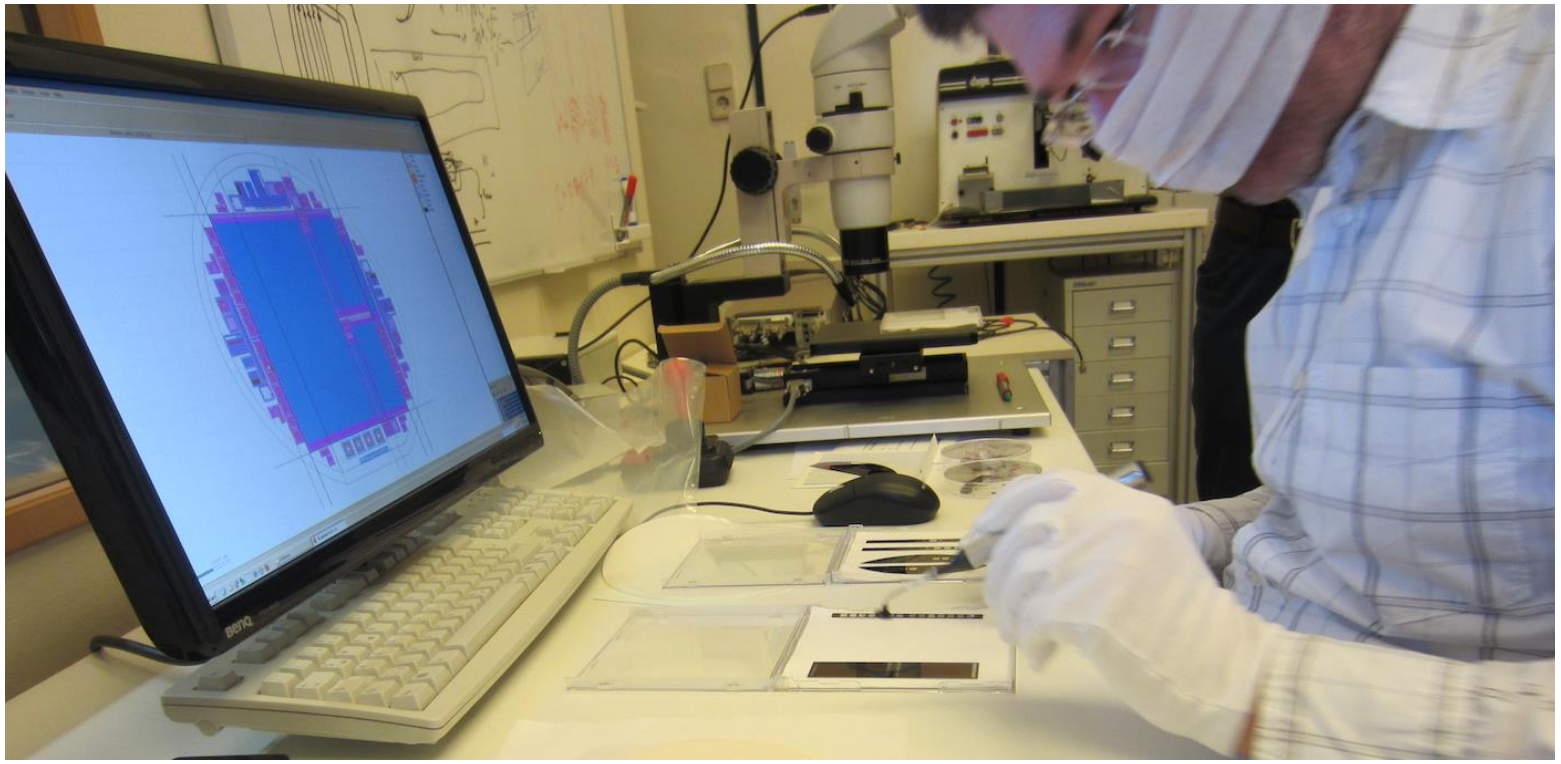
Source: IMS Research, August 2011.

Infineon Technologies AUSTRIA (Villach)

Frontend **Production** and **R&D**:

- **Pilot production lines are developed at Villach**
  - Eg.: Worlds first power devices on 300 mm thinned wafers (Oct. 2011)
- Cleanroom facilities extended to over 10.000 m^2

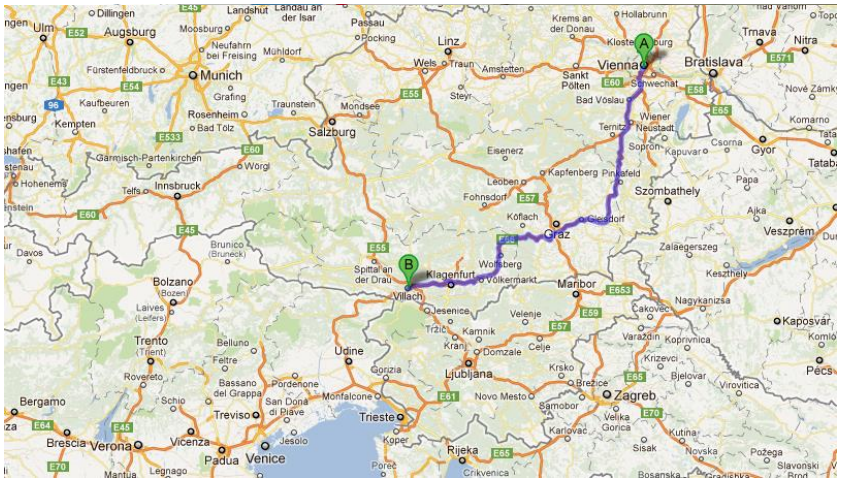




OVERVIEW OF THE PROJECT

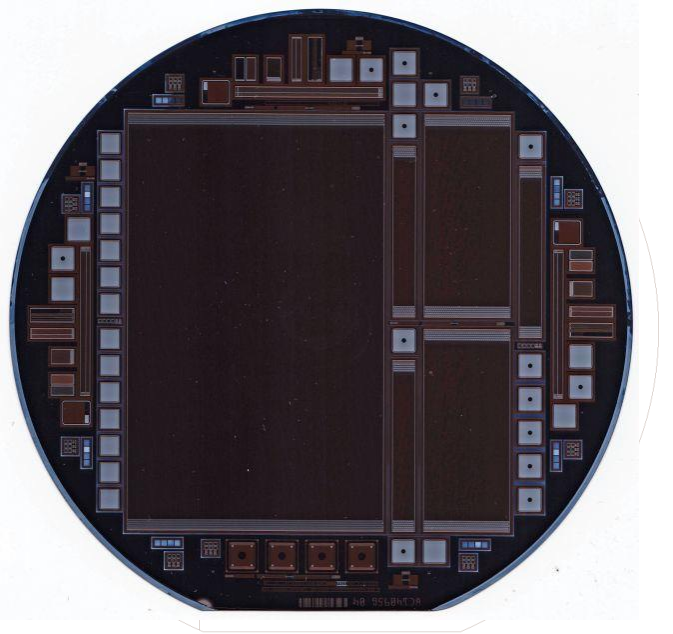
Infineon and HEPHY

- In **April 2009** a small delegation from HEPHY visited Infineon Villach
- We enjoyed a **tour of the production facilities**!
- We discussed the possibilities for a **joint development**
- Later we decided that the **production of silicon strip sensors** at Infineon Villach is feasible



Progress of the Project

- End of 2009: Started intense **discussion on technical details**
- Beginning of 2011: **First milestone**
  - Reached a general **understanding of the production process**
  - HEPHY started **design of the masks**
  - Infineon started the generation of the **detailed production plan**
- 24 August 2011: **Final mask design finished!**
- October 2011: **Production start!**
  - Full production at Infineon was accompanied by HEPHY diploma student Edwin Frühwirth
- 29 February 2012: **Production finished!**
- 2 April 2012: **Wafers arrive in Vienna** (via CERN)
- October 2012: **Beam tests and Irradiation**
  - **Beam tests** at the SPS accelerator at CERN
  - Gamma Irradiation at SCK-CEN Mol, Belgium



HEPHY Institute of High Energy Physics

Infineon

Comments on the Collaboration

- Since the beginning of 2010 we held **weekly telephone conferences**
- We were discussing all technical details **directly with the engineers**
- The design of the masks was entirely **made by HEPHY**
- The production in the clean room was **accompanied by our diploma student** *(Edwin Frühwirth)*
- We finally received **every wafer from the production** batch *(except for one wafer, damage due mishandling)*

  → **no hidden losses**

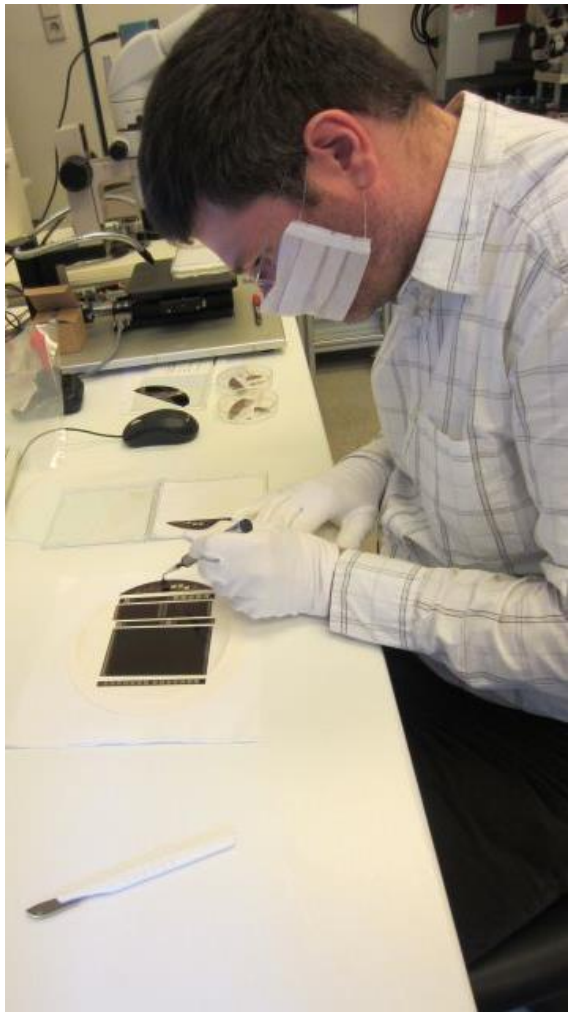
Baseline for the first prototype batch

Wafer Material
- 6” n-type
- 300 micron thickness
- Approx. 1.2 kΩcm resistivity

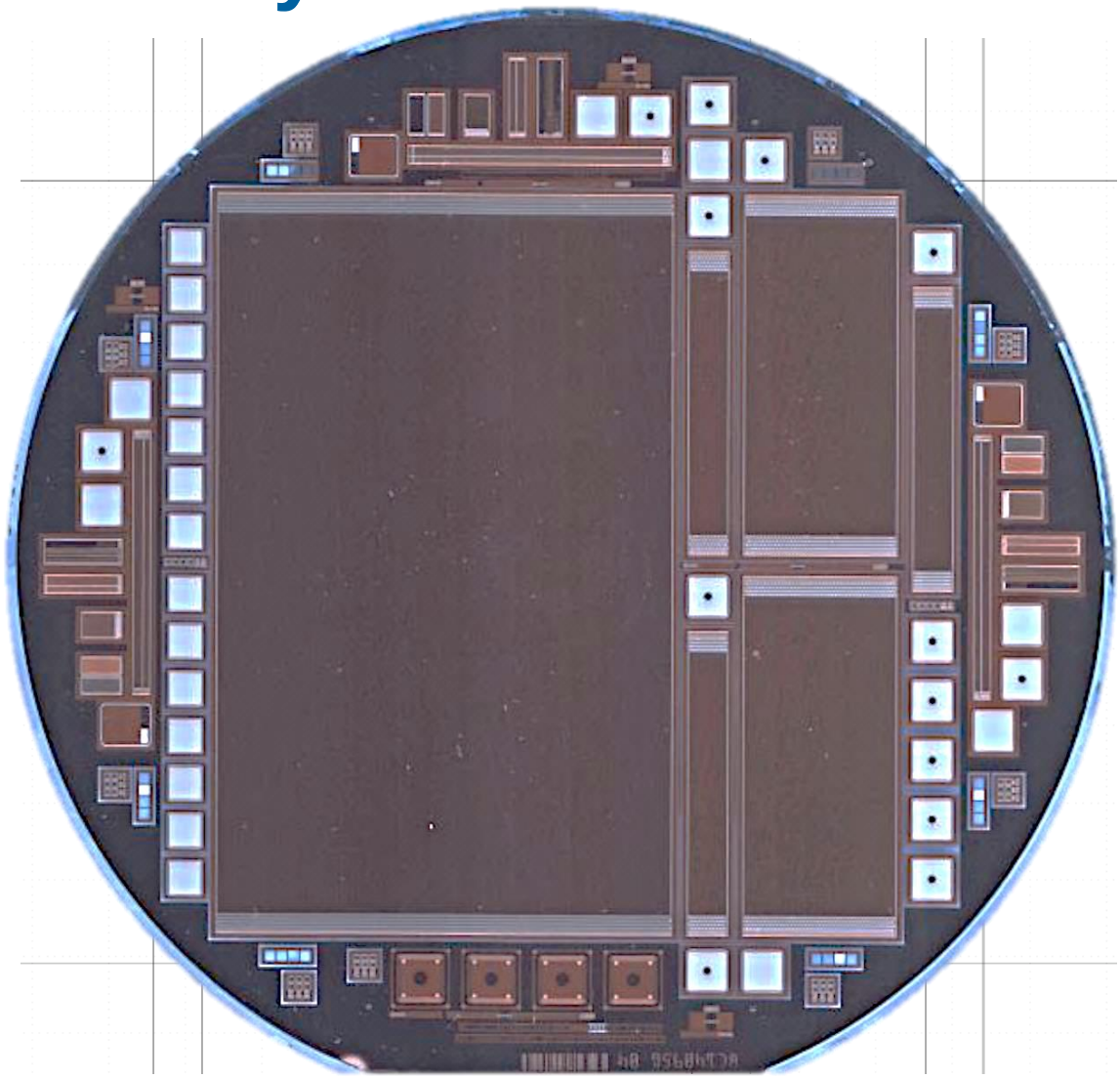
Process Specifications
- Standard p-on-n technology
- AC coupled strips
- SiO_2/Si_3N_4 sandwich dielectric
- PolySi resistor biasing

→ 8 photomasks (one for patterning of Si_3N_4)

Design Considerations
- Large sensor similar to current CMS Tracker Sensors
- Smaller sensors for testbeams
- Standard + extended test structures

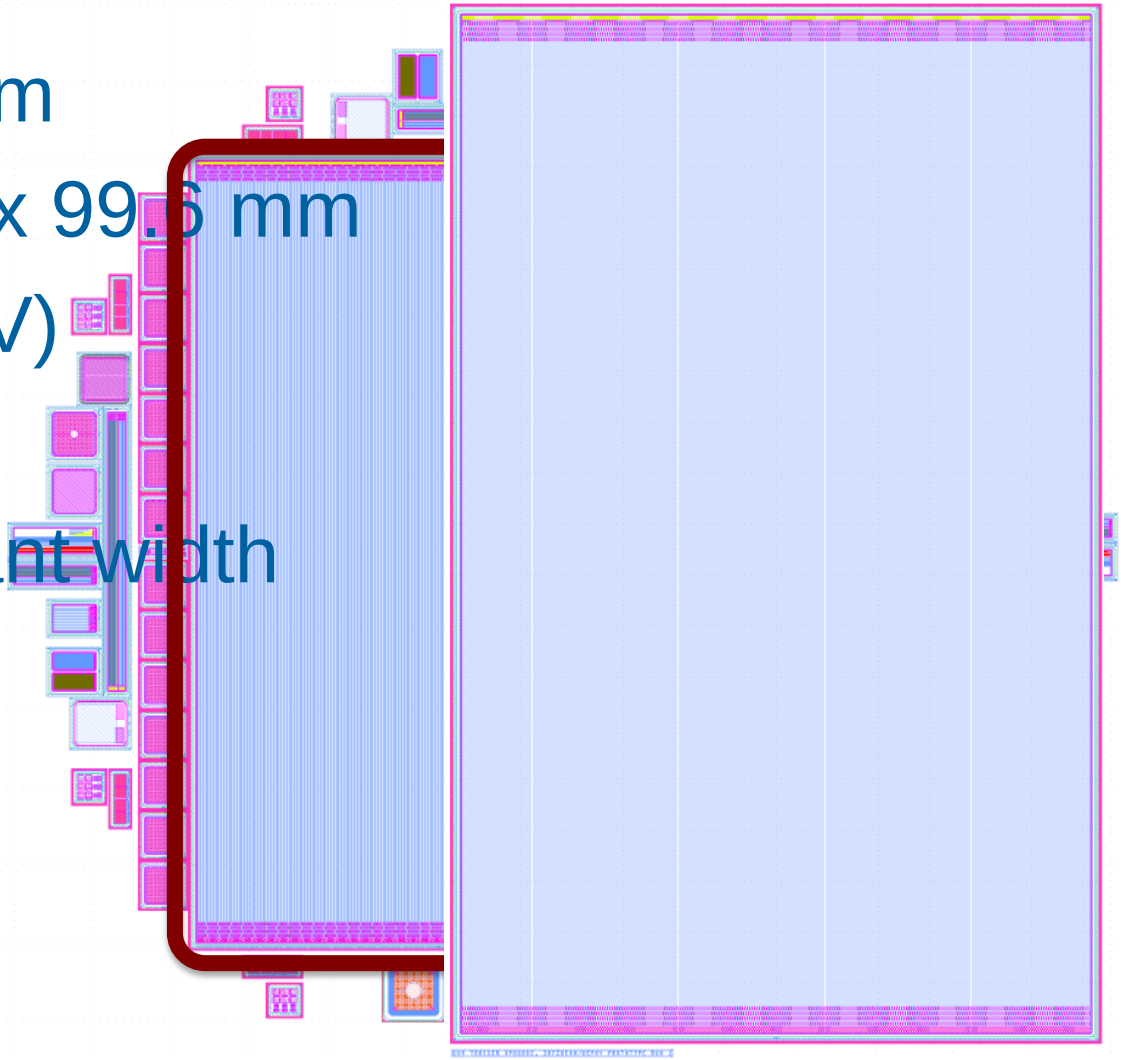


Wafer Layout



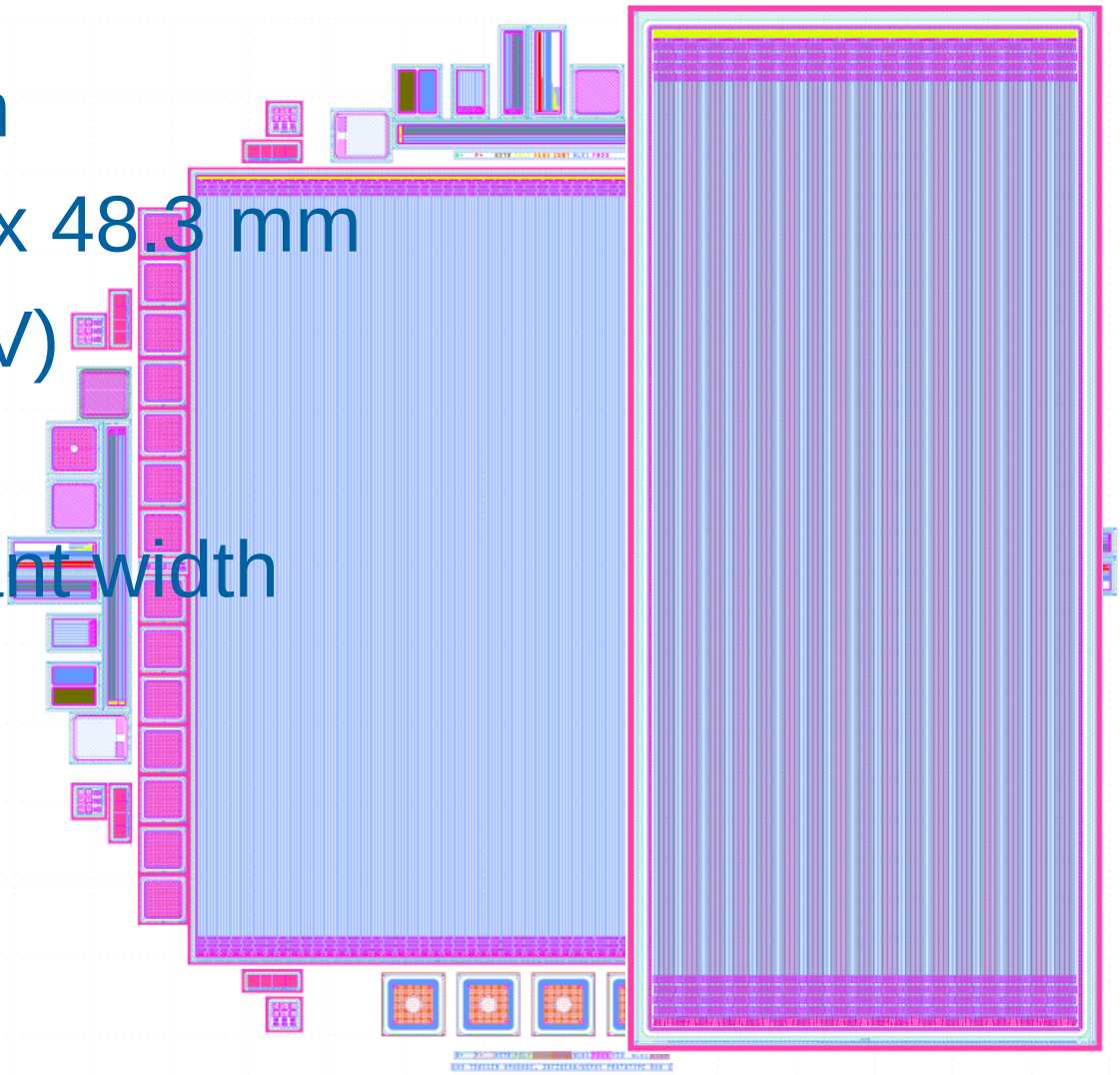
Large Sensor

- Size: 64 x 102 mm
- Active Size 61.5 x 99.6 mm
- 512 strips (4xAPV)
- 120 µm pitch
- 20 µm strip implant width



Baby Sensor

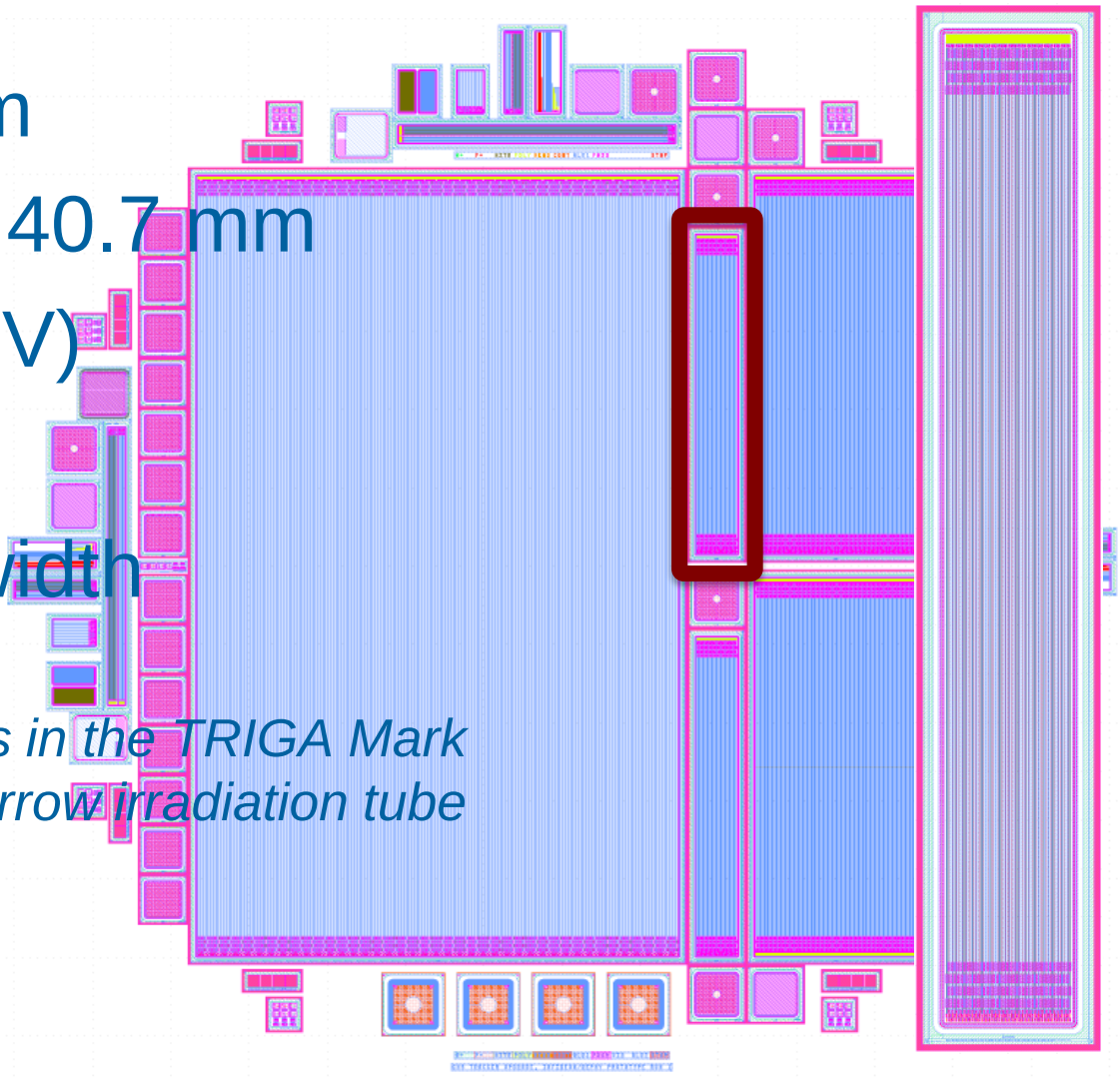
- Size: 23 x 50 mm
- Active Size 20.6 x 48.3 mm
- 256 strips (2xAPV)
- 80 µm pitch
- 20 µm strip implant width



Narrow Sensor

- Size: 7 x 42.5 mm
- Active Size 5.3 x 40.7 mm
- 64 strips (0.5xAPV)
- 80 micron pitch
- 20 strip implant width

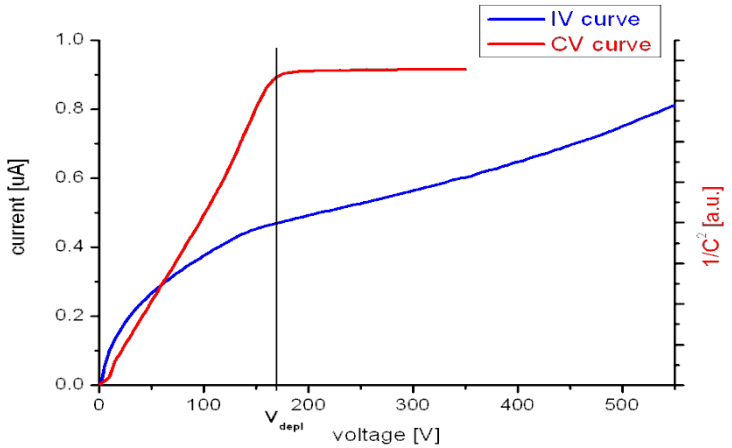
Was designed for irradiations in the TRIGA Mark II reactor in Vienna with a narrow irradiation tube



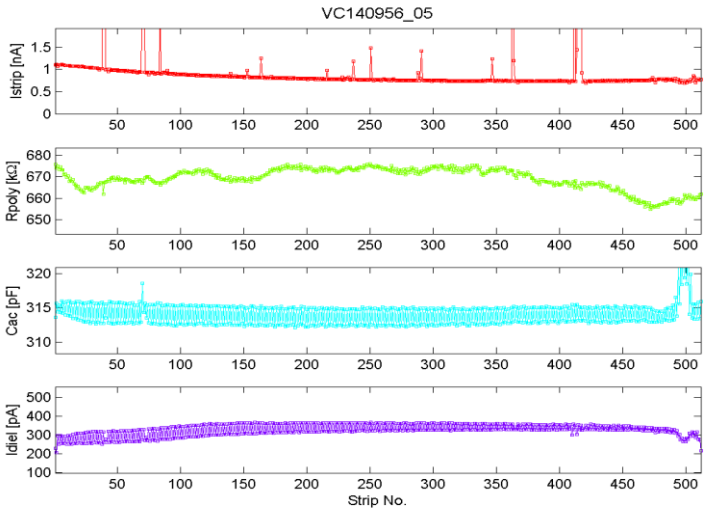
RESULTS FROM THE ELECTRICAL CHARACTERISATION

Measurements performed on all Sensors

- Global parameters:
  - **IV-Curve:** Dark Current, Breakdown Voltage
  - **CV-Curve:** Depletion Voltage, Total Capacitance



- Strip Parameters
  - strip leakage current I_{strip}
  - poly-silicon resistor R_{poly}
  - coupling capacitance C_{ac}
  - dielectric current I_{diel}

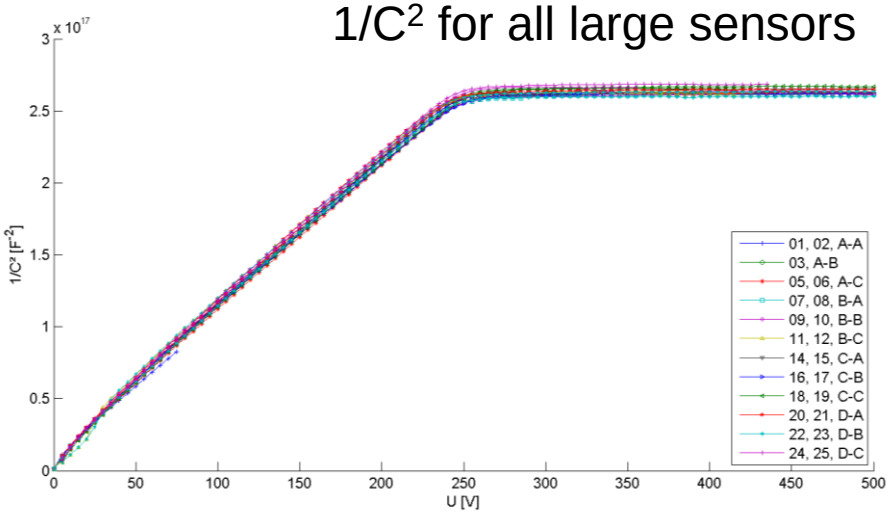


Global Parameters

CV-Curves

- Uniform for all sensors on all wafers
- Depletion voltage well defined ≈ 240 V
  - Corresponds to 1.2 kΩcm and matches specs of bulk material

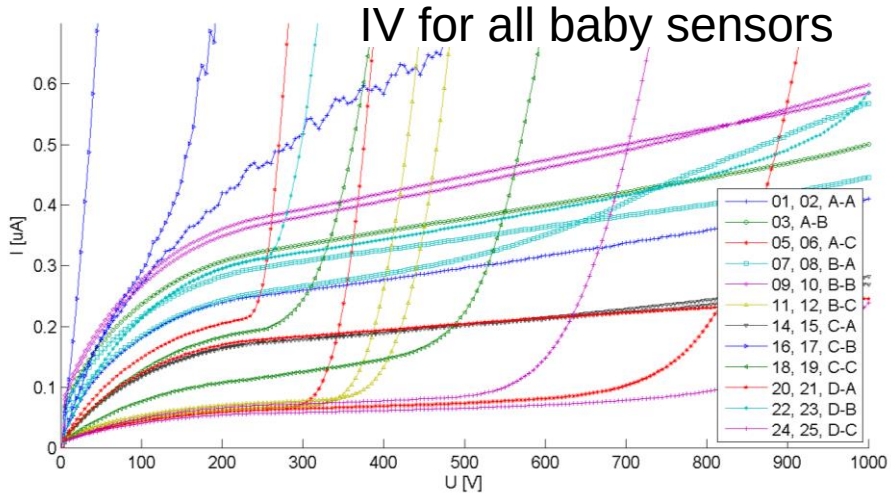
1/C² for all large sensors



IV-Curves

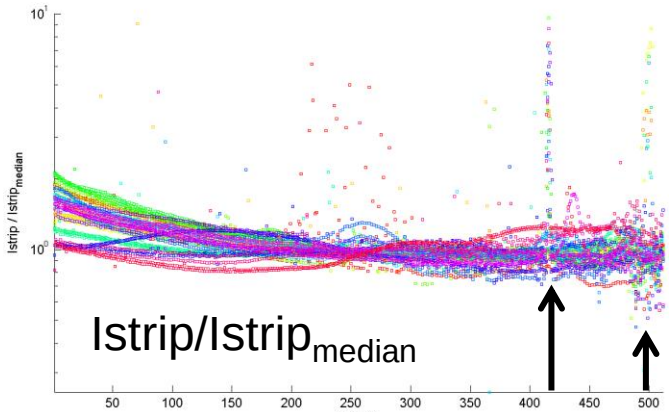
- Many sensors are stable up to 1000 V
- Some sensors with very low leakage current but early breakdown
  - Different treatment of the backside n+ implant

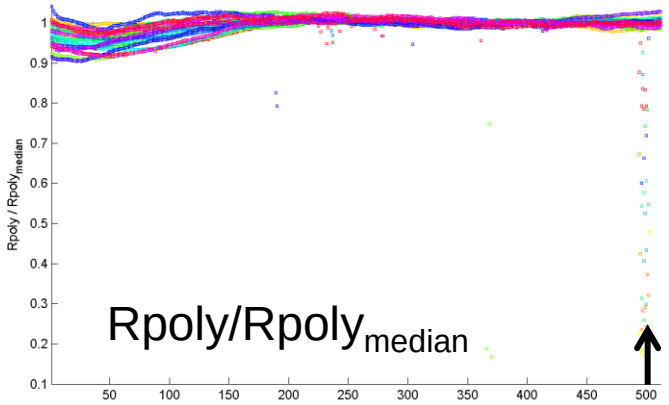
IV for all baby sensors

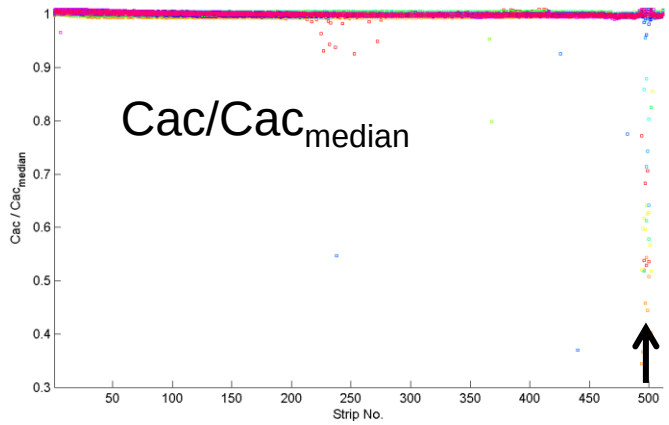


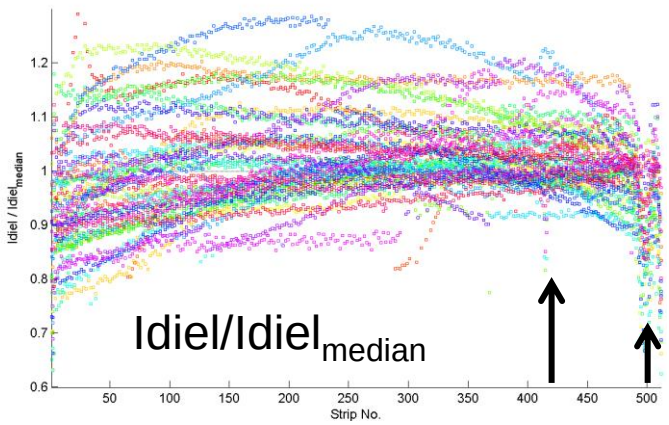
Accumulation of „*Bad Strips*“ (Large)

- Accumulation of anomalous strips around strip no. *416* and *500*



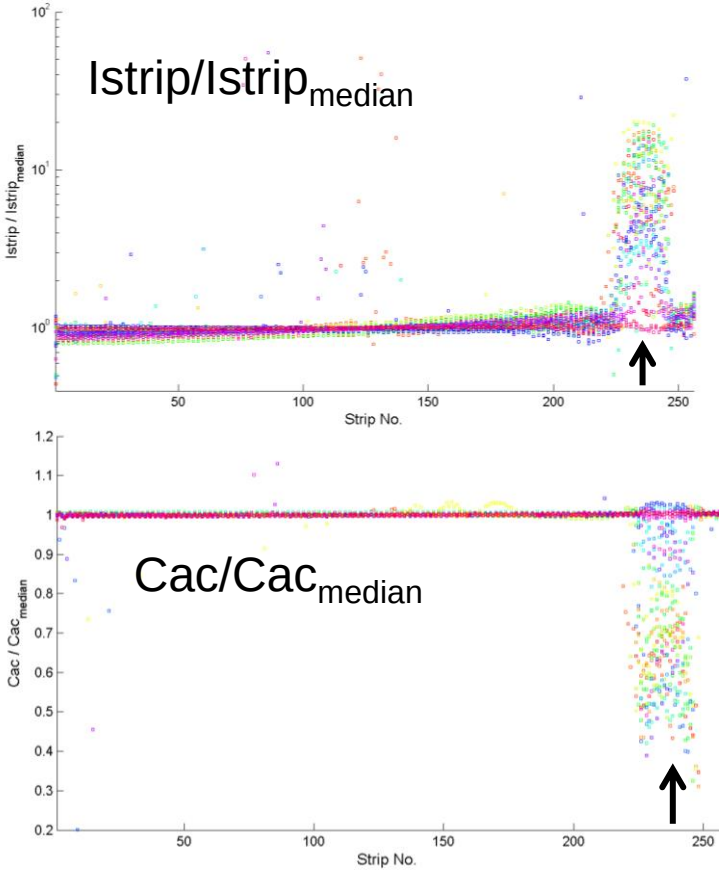


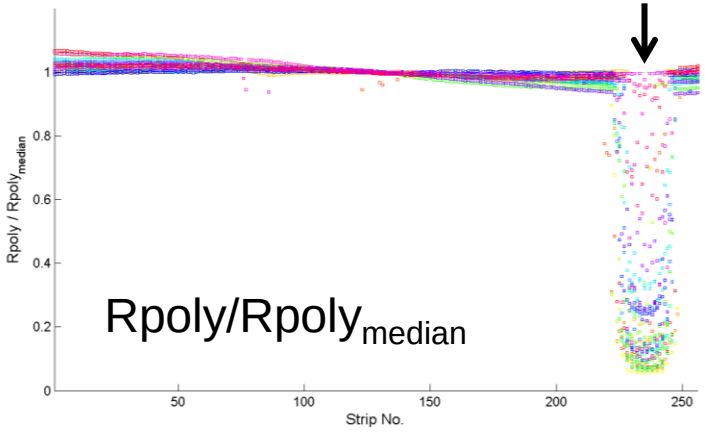


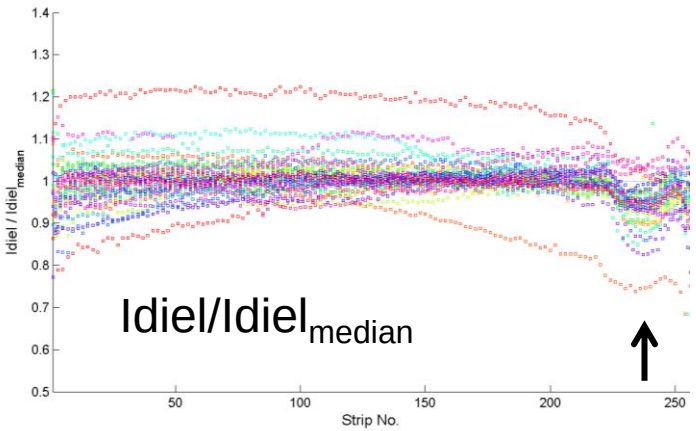


Accumulation of „*Bad Strips*“ (Baby)

- Accumulation of anomalous strips around strip no. *222-248*



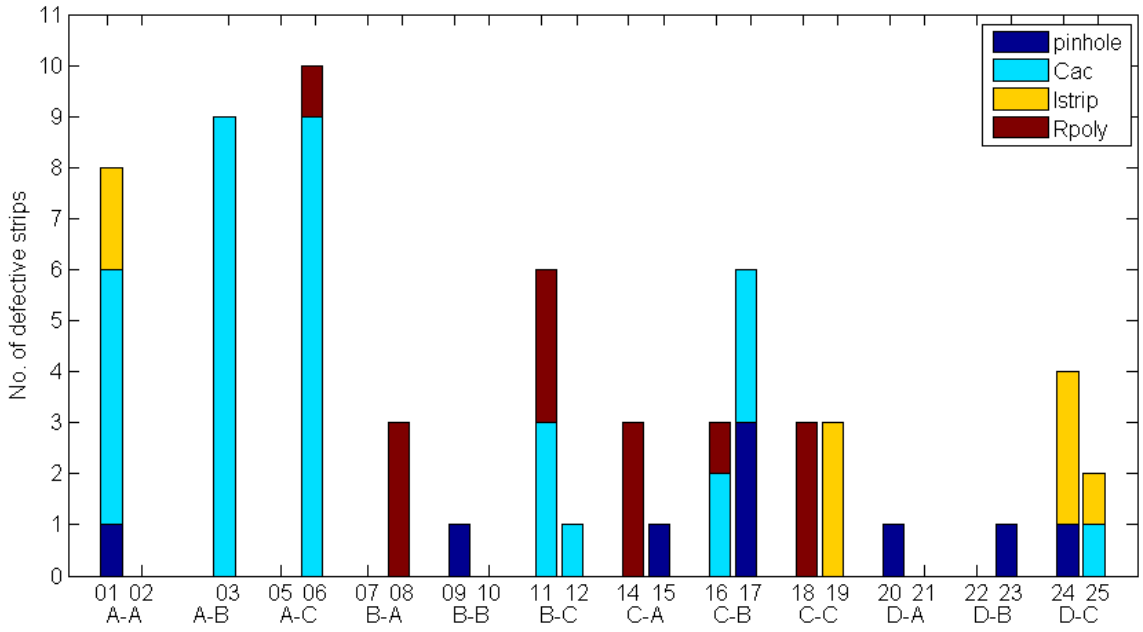




Strip Scan – No. of faulty strips (Large)

Criteria:

- Pinhole: short between dielectric and metal strip (I_{diel} **> 1nA**)
- Coupling capacitance: C_{ac} **< 1.2pF**
- Single strip current: I_{strip} **> 50nA**
- Polysilicon resistor: more than 20% deviation from the median

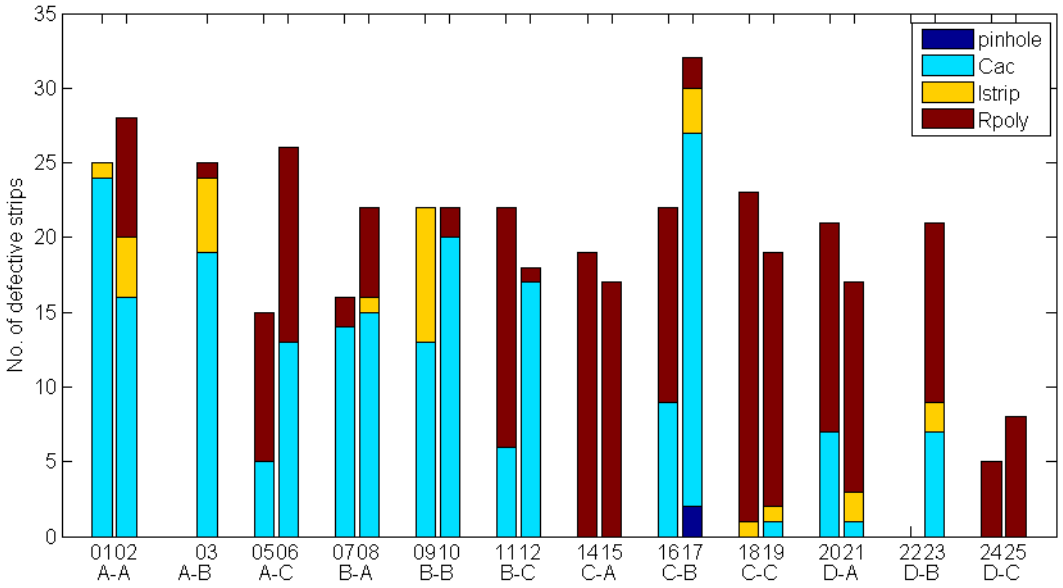


- 10 pinholes
- **5 sensor without any defective strip**
- 65 faulty strips from a total of 11776 → 5.5‰
- accumulation of *"bad strips"* at strip no. 416 and 500:
  68% of the faulty strips from that area

Strip Scan – No. of faulty strips (Baby)

Criteria:

- Pinhole: short between dielectric and metal strip ($\mathbf{I_{diel} > 1nA}$)
- Coupling capacitance: $\mathbf{C_{ac} < 1.2pF}$
- Single strip current: $\mathbf{I_{strip} > 25nA}$
- Polysilicon resistor: more than 20% deviation from the median

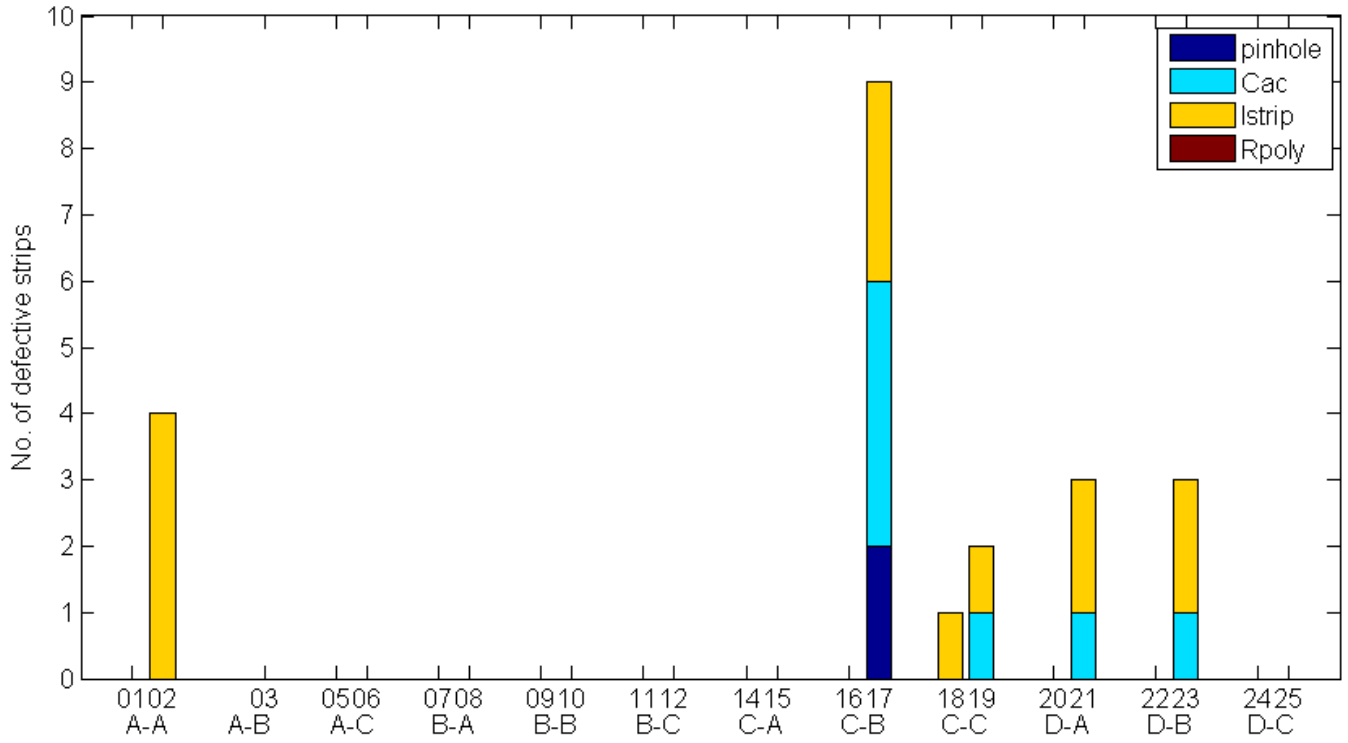


- accumulation of *"bad strips"* around strip no. 230:
  95.3% of the faulty strips from that area

Strip Scan (Baby)

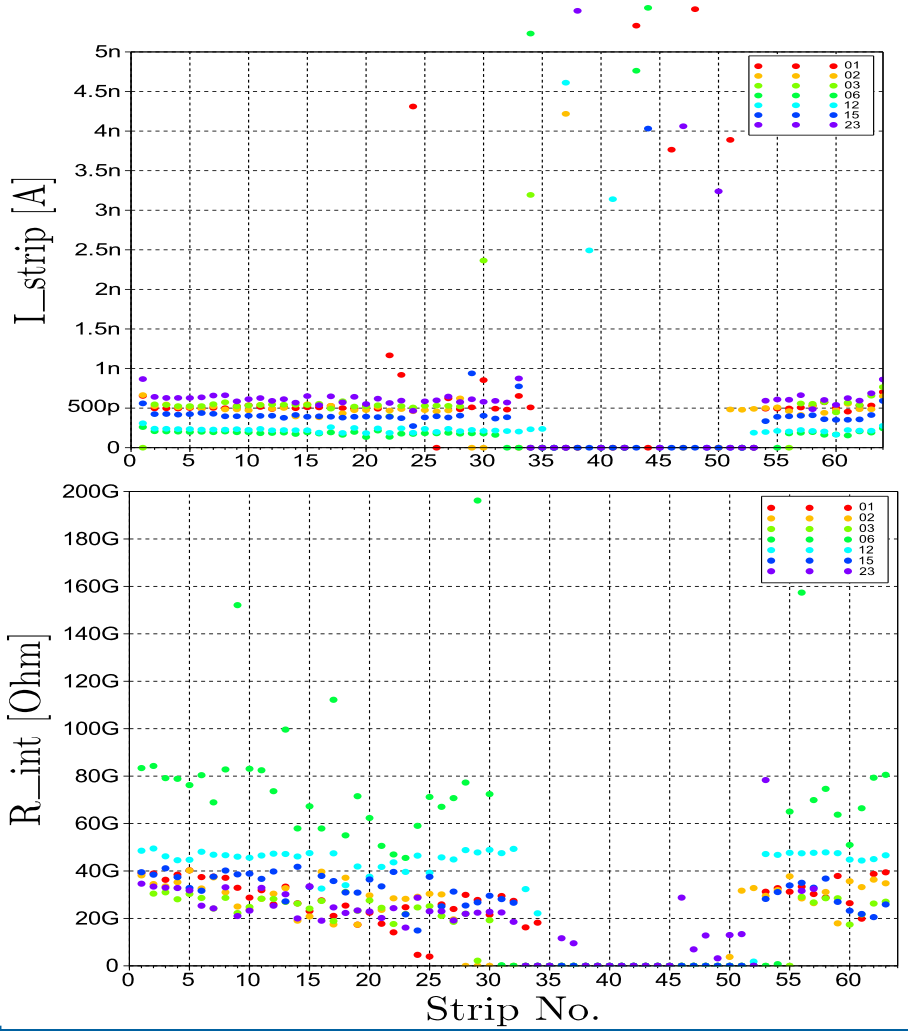
No. of faulty strips ignoring strips from *"bad strip area" 222-248*:

- Overall only 22 faulty strips remain



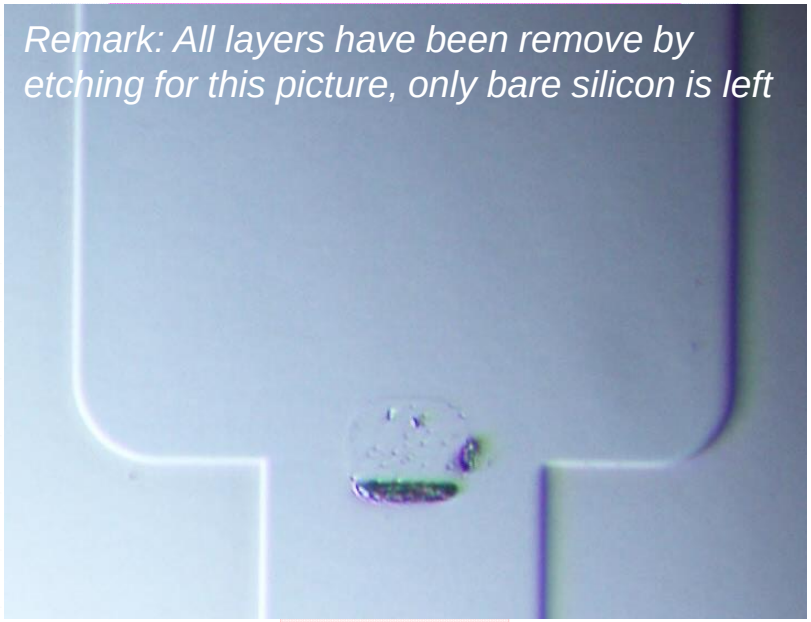
Interstrip Resistance (Narrow Sensor)

- **Interstrip Resistance**
  - Measurement shown for narrow sensor with only 64 strips
  - Good outside of “Bad Strip Area” (> 10 GΩ)
  - “Bad Strip Area” from strip 30 – 50 shows very low strip isolation (< 1MΩ)
- **Seen on all sensors**



Cause of Evil?

- **Bare silicon exposed during later steps of the fabrication**
  - At contact holes in the DC pads
  - Metal overetch was larger than expected
- **Bare silicon prone to contamination**
  - Si/SiO_2 interface
  - accumulation layer which shortens strips
  - Temperature and irradiation removes effects
- **Solution**
  - Redesign with corrected overlap of contact holes
  - New batch is in production



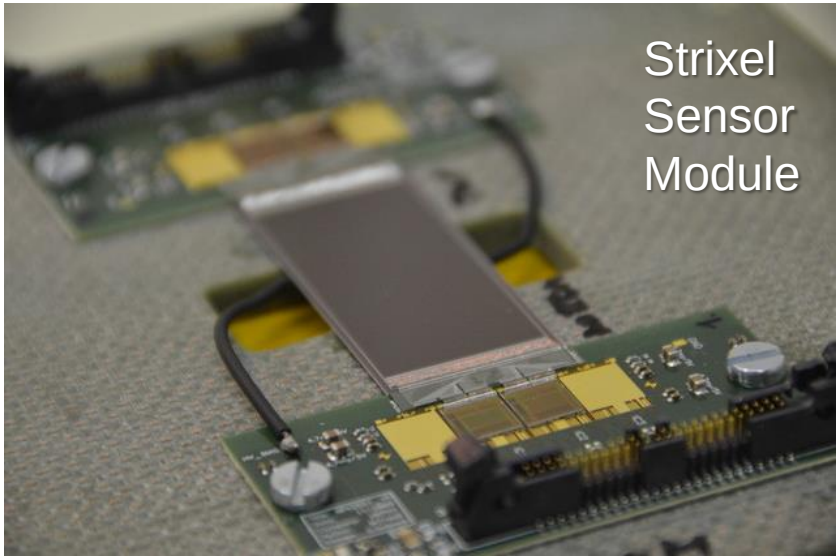
BEAM TESTS WITH BABY SENSORS

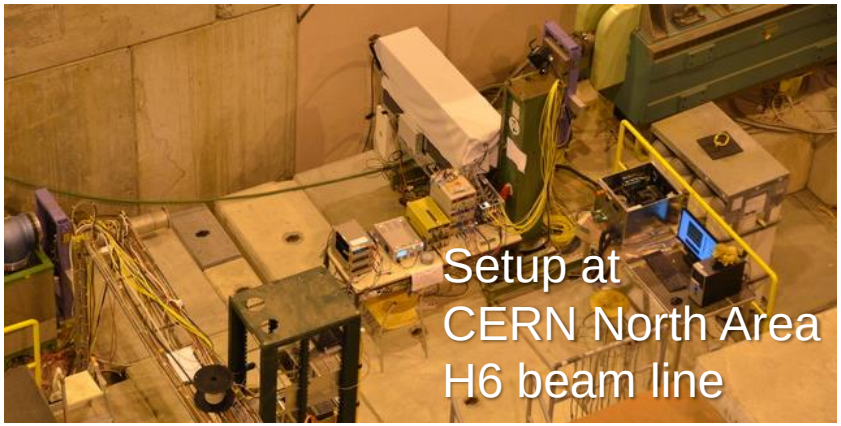
The HEPHY testbeam and irradiation team

12 October – 1. November 2012

Setup at CERN‘s SPS

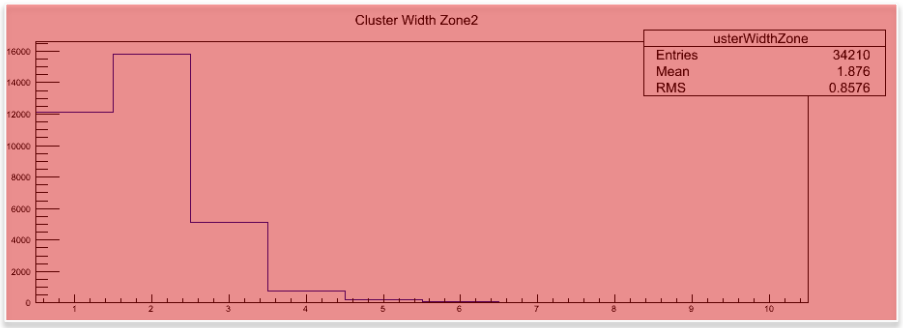
- 2 detector modules built with baby sensors
- 2 detector modules built with strixel sensors
- Readout chips (APV25) same as in the CMS Tracker
- Readout system is a prototype for the Belle II Experiment
- Detector modules were
  - Tested at CERN
  - Gamma irradiated at CNK-CEN Mol
  - Tested again at CERN

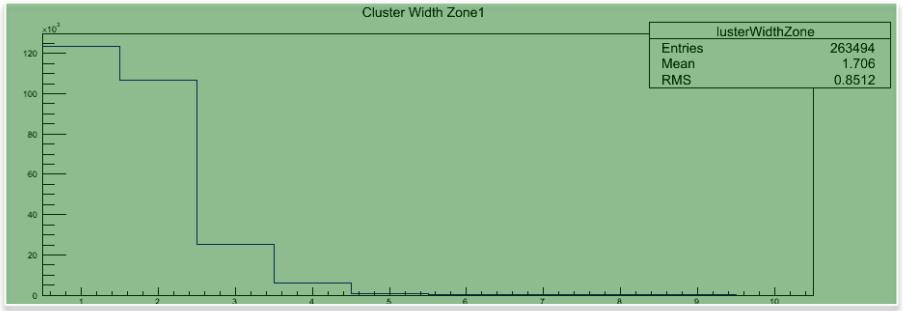




Selected results: Cluster Widths

- *"Bad Strip Area"* does not stand out clearly in beam profile
  - Area seems to be fully efficient
- But clusters are wider in "bad strip area"
  - Would be expected for bad strip isolation



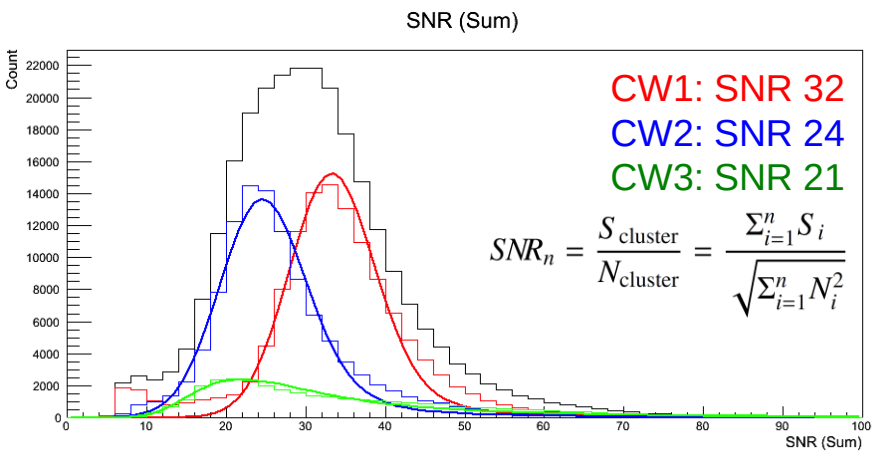


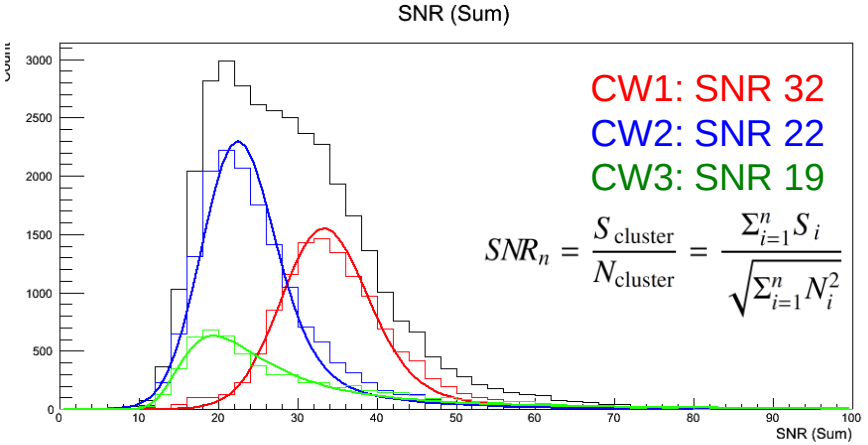
Selected results: Signal and S/N

Results from „good“ strip area

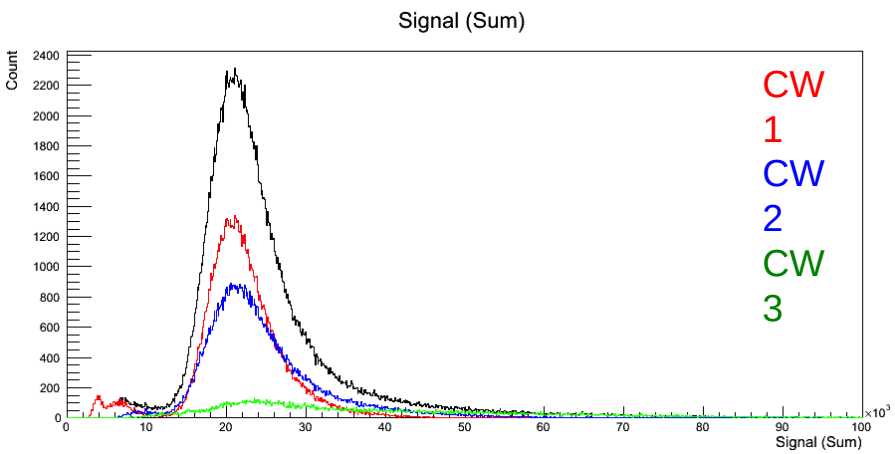
Results from „bad“ strip area

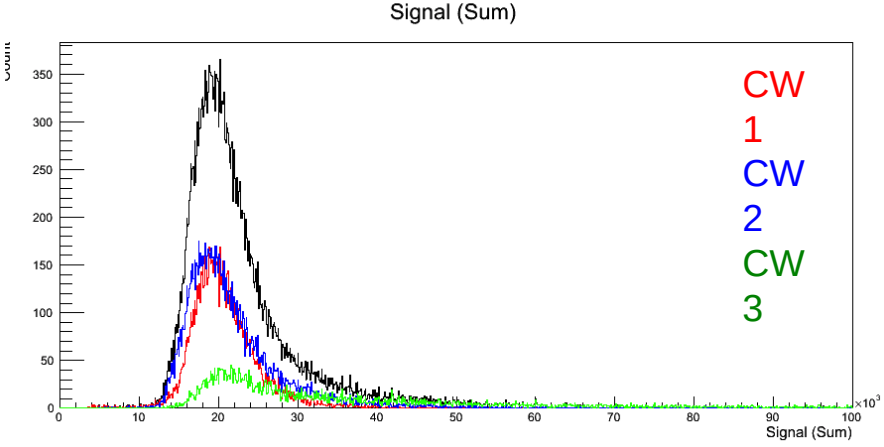
Signal-to-Noise

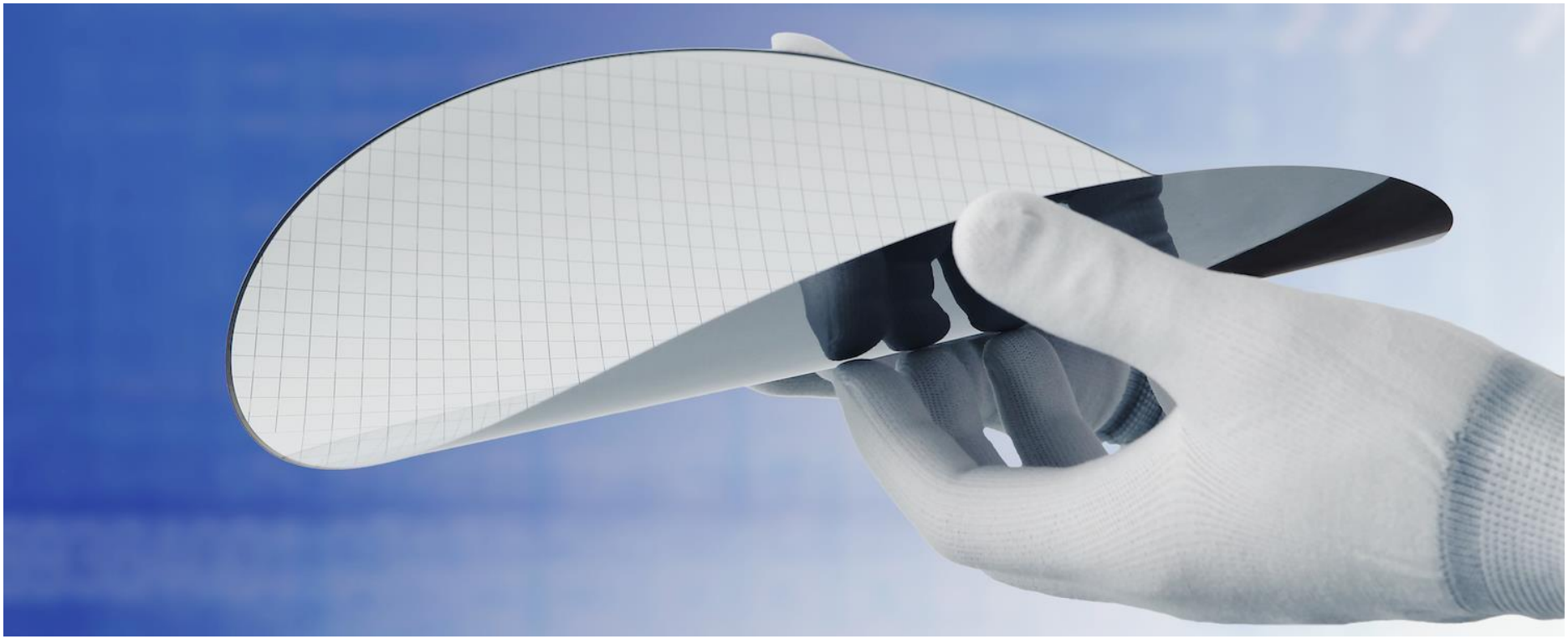




Cluster Signal







OUTLOOK & SUMMARY

Next Steps

- Irradiation tests (neutron and proton)
  - Reactor in Vienna (n) became operational again after exchanging the fuel rods
  - Irradiations at Karlsruhe (p) are in progress
- New batch of wafers
  - Small corrections in the design to prevent *“bad strip area”*
  - 3 redesigned masks
  - Production in progress
  - Delivery in fall 2013
- New run planned with CMS in 2014
  - Process and material according to CMS
    - n-on-p process on 200 µm FZ material (TBD!)
  - Production on 8” wafers is considered

CMS Track Trigger Prototype Module with 2 Infineon Baby Sensors

Summary

- Infineon could be a future supplier of high quality silicon sensors for large scale applications
- A very first prototype batch of planar p-on-n sensors was produced at Infineon Villach
  - Electrical characterisation show promising quality
  - Nevertheless, we found areas of strips which behave abnormal
  - A possible reason and a remedy was suggested and will be tested with a new batch of sensors
- ATLAS and CMS already show an interest in the possibilities offered by Infineon

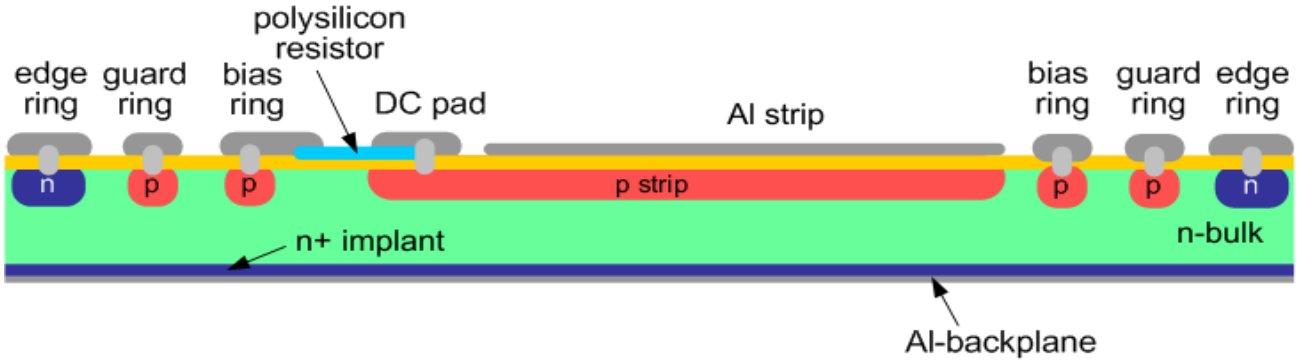

THANKS FOR
YOUR ATTENTION!

BACKUP

Strip Parameters

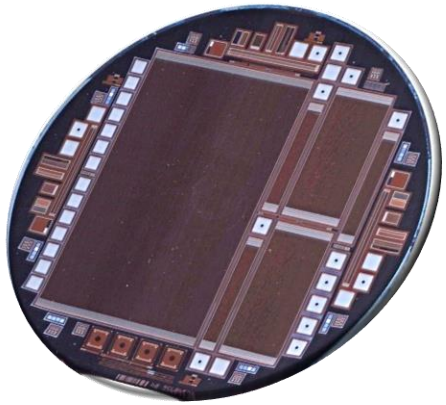
Detector at a reverse bias of 300V

- **Strip Leakage Current I_{strip}**
  - Electrometer connected to DC pad measures strip current for each strip
- **Poly-silicon Resistor R_{poly}**
  - Resistance measurement between bias-ring and DC pad
- **Coupling Capacitance C_{ac}**
  - Capacitance of dielectric between Al strip and strip implant
- **Dielectric Current I_{diel}**
  - Current through dielectric at 10V between Al strip and implant



Overview

- **First 25 wafers produced with photomasks designed by HEPHY**
  - Wafer *13* not delivered because of mechanical damage
  - Wafer *04* not diced
    → used for presentation
- **23 wafers split into 12 *split groups* to test different process parameters**
- **First split:** gate oxide
  (4 groups A to D)
- **Second split:**
  backside n+ implant diffusion
  (3 groups A to C)

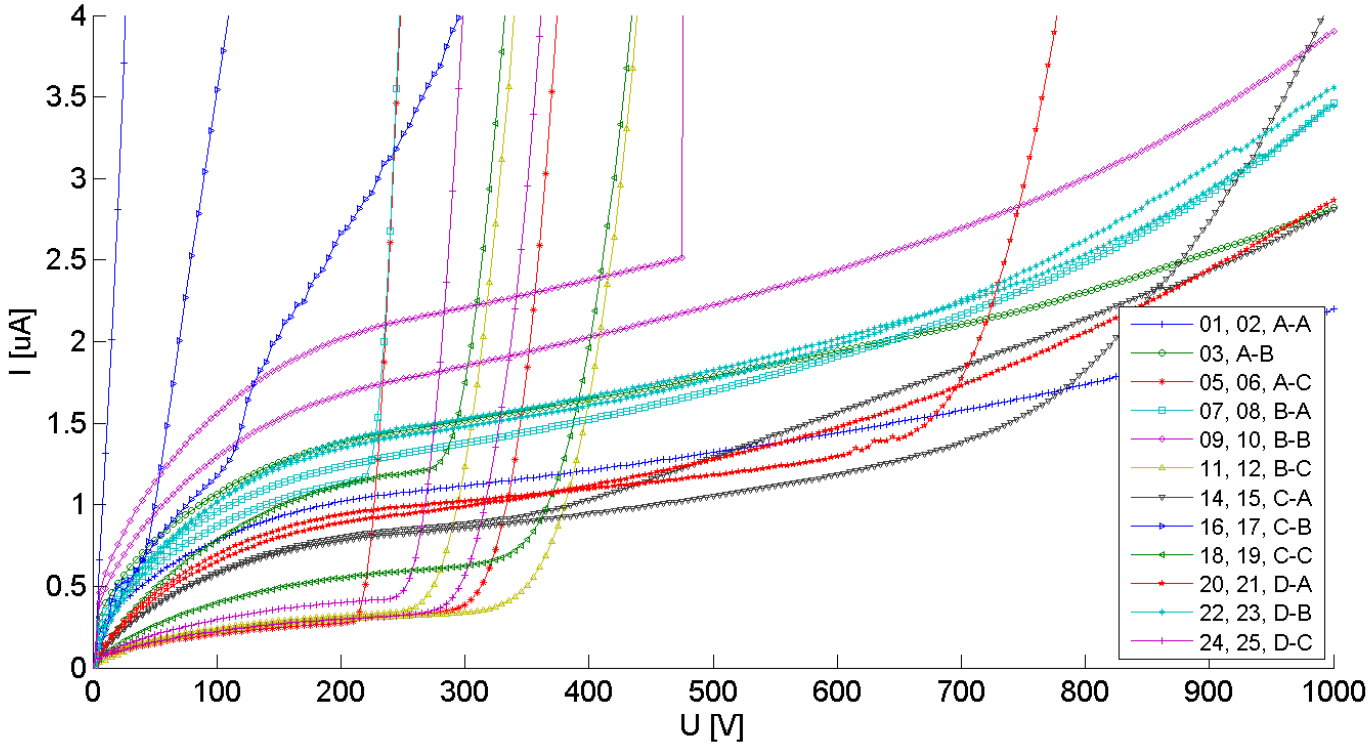


Wafer No.	Split1-Split2	Wafer No.	Split1-Split2
01	A-A	14	C-A
02	A-A	15	C-A
03	A-B	16	C-B
04	A-B	17	C-B
05	A-C	18	C-C
06	A-C	19	C-C
07	B-A	20	D-A
08	B-A	21	D-A
09	B-B	22	D-B
10	B-B	23	D-B
11	B-C	24	D-C
12	B-C	25	D-C

Large Sensors – IV

Leakage Current of sensors

- Split group *X-C* shows very low leakage currents before breakdown ~500nA



CMS Spec.:
< 5 uA@300V

Baby Sensors – IV

Leakage Current of sensors

- Split group *X-C* shows very low leakage currents before breakdown
- Sensors *16* and *17* show ohmic behavior