# CMS Phase II Tracker Upgrade

## GRK-Workshop in Bad Liebenzell

## 8.10. – 10.10.2012

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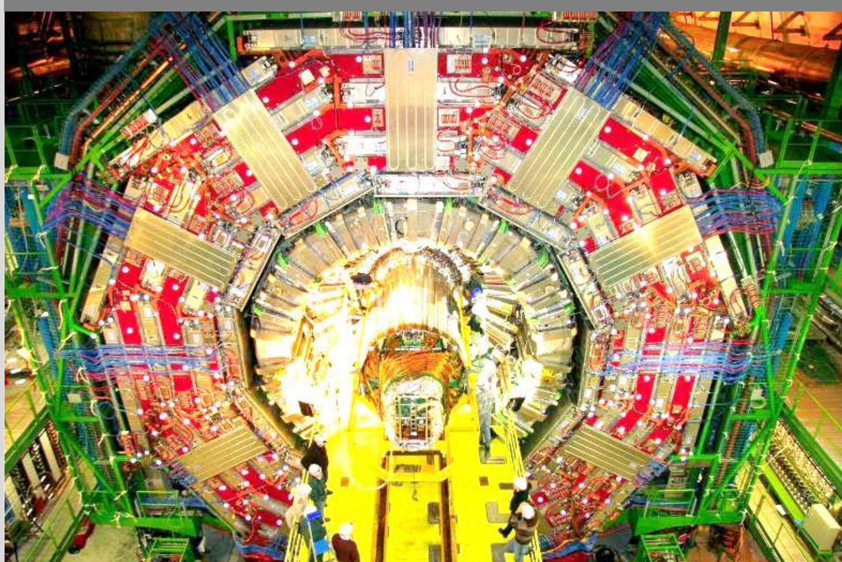
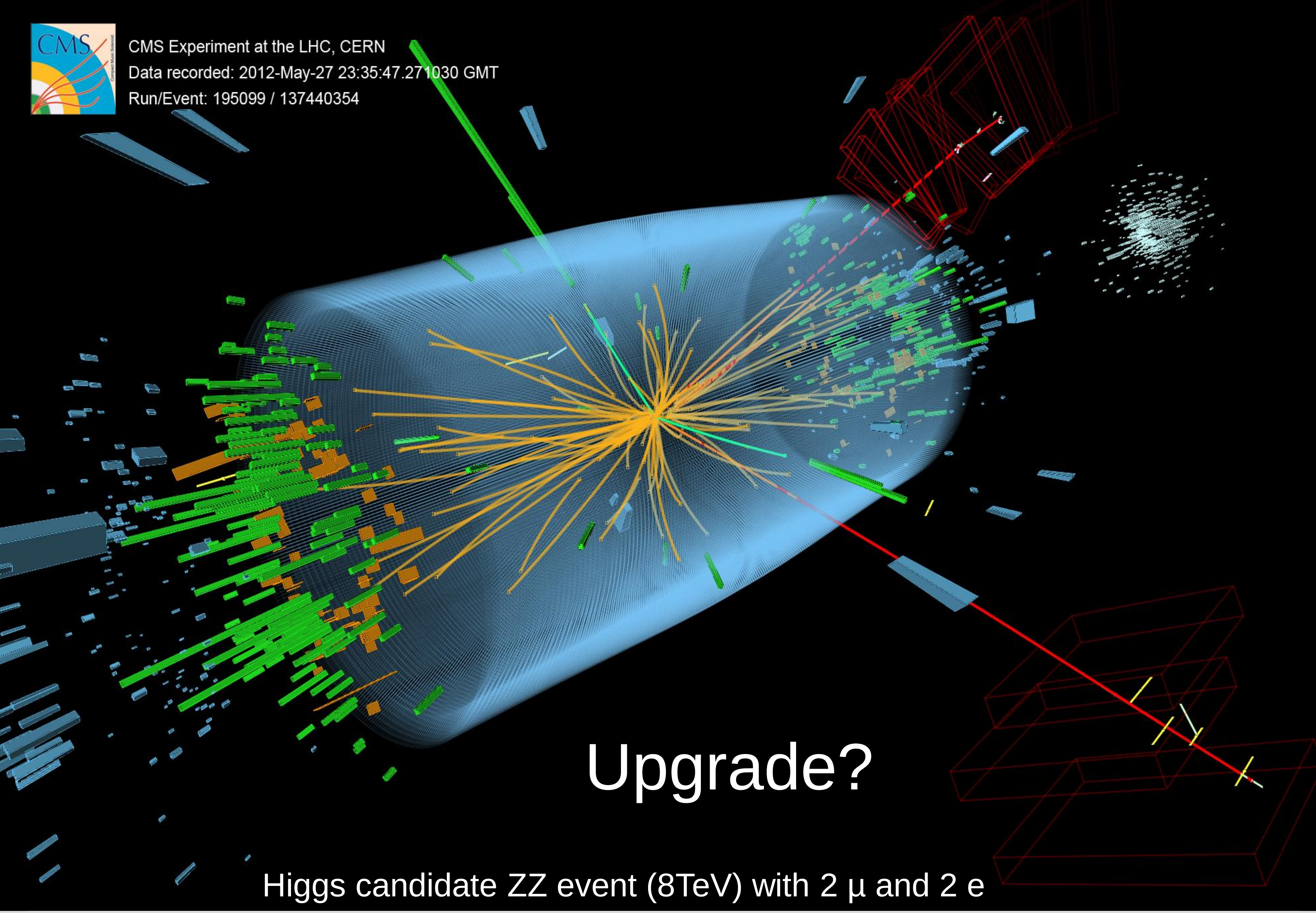
Institut für Experimentelle Kernphysik






# Upgrade?

Higgs candidate ZZ event (8TeV) with 2 μ and 2 e



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# Outline

CMS Overview

Tracker

Phase II Tracker Upgrade

HPK Campaign

- Radiation Hardness
- Sensor Qualification
- Tracker Trigger Concept

Summary


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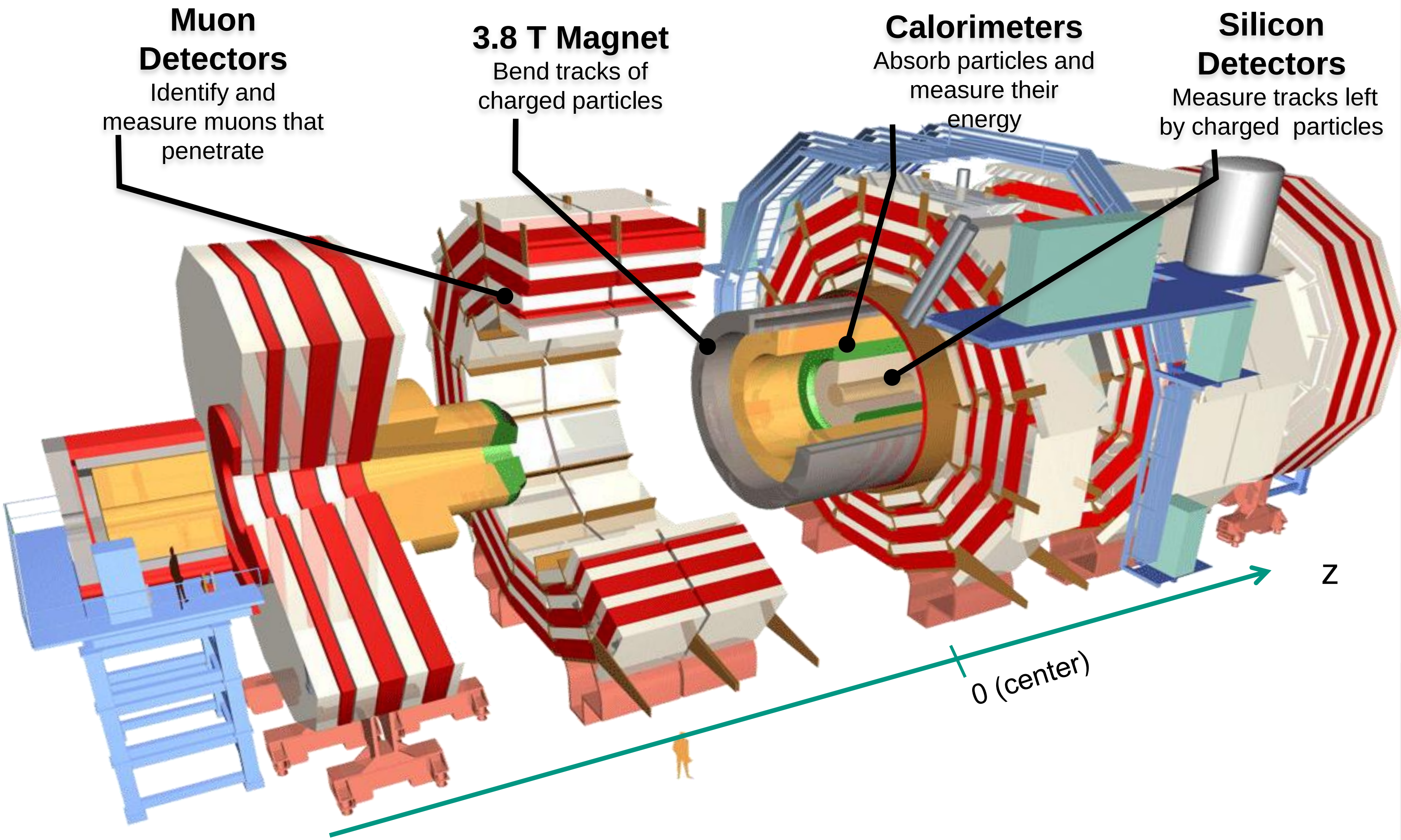
# Compact Muon Solenoid (CMS) Experiment





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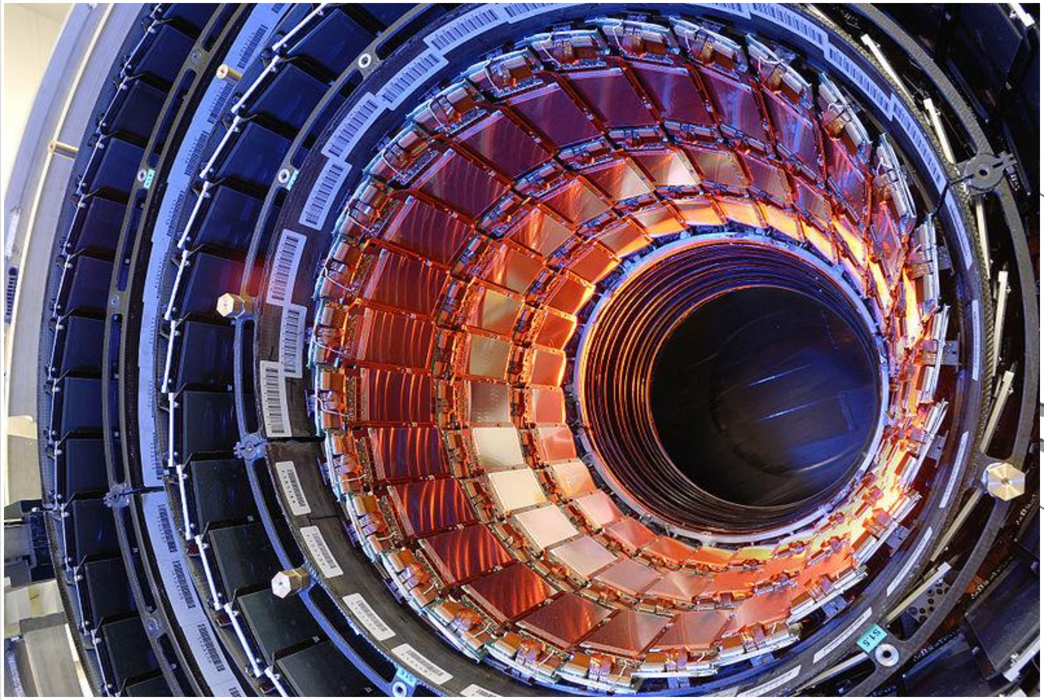
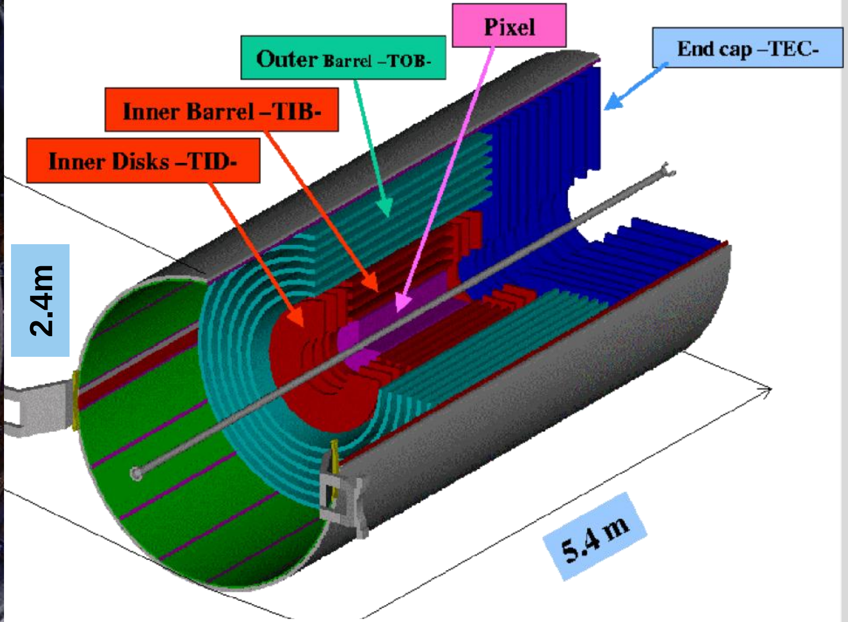
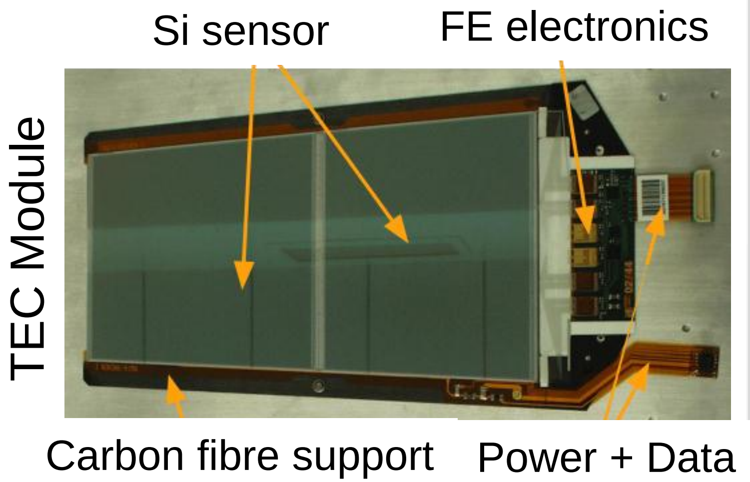
# CMS Tracker






- Silicon only Tracker (>200m² area) with pixel and strip sensors: provide track points for
  - Momentum determination
  - Charge assignment
  - Vertex reconstruction
- Excellent performance so far





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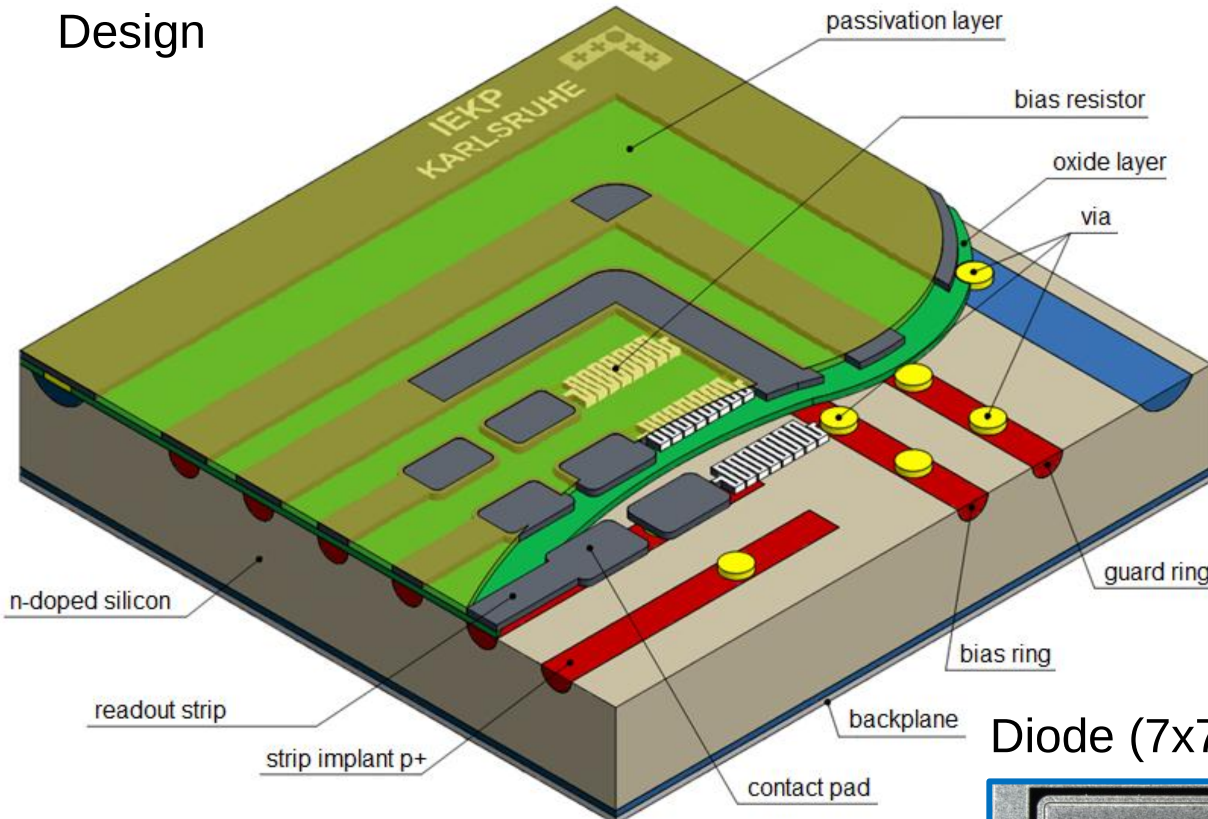
CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295
65 reconstructed vertices

Karlsruhe Institute of Technology

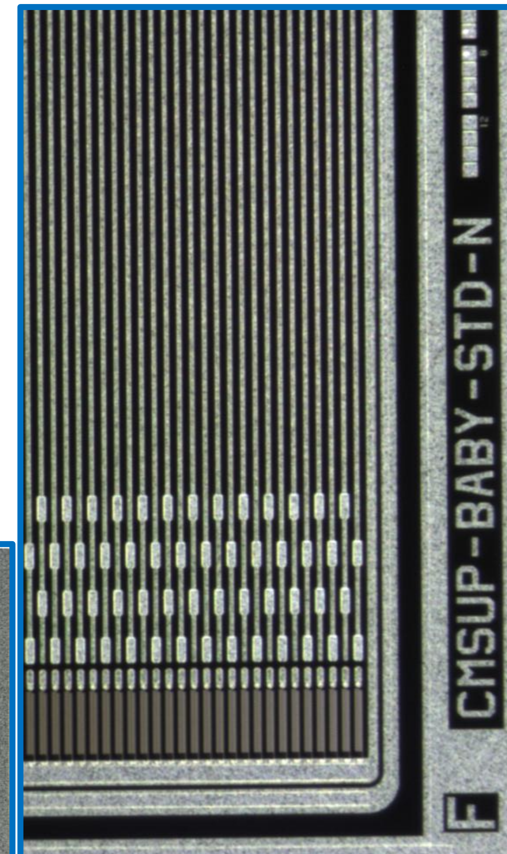
# Silicon (Strip) Sensor

## Design




F. Hartmann, Evolution of Silicon Sensor Technology in Particle Detectors, Springer 2008

## Mini strip test sensor ($2.5 \times 3.5 cm^2$)




## Diode ($7 \times 7 mm^2$)



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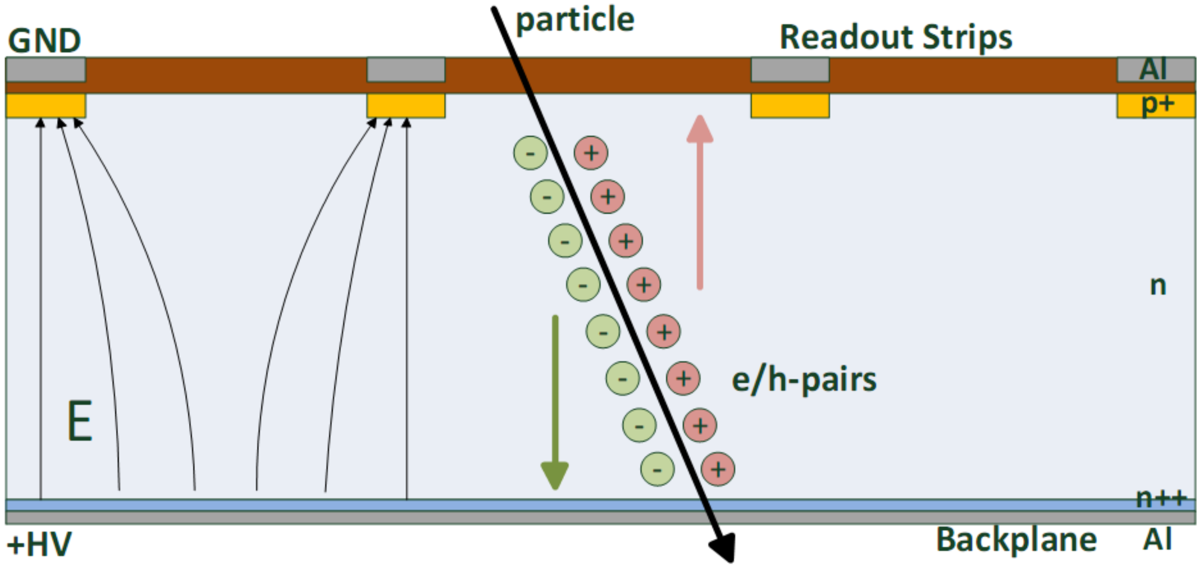
# Silicon Sensor

## Working Principle




- Create depletion zone (pn-junction) by applying reverse bias
- Charged particles create electron-hole-pairs
- e/h are seperated by electric field
- Drifting charge induces signal on AC strips
- Readout electronics wire bonded to AC strips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# UPGRADE OF THE CMS TRACKER


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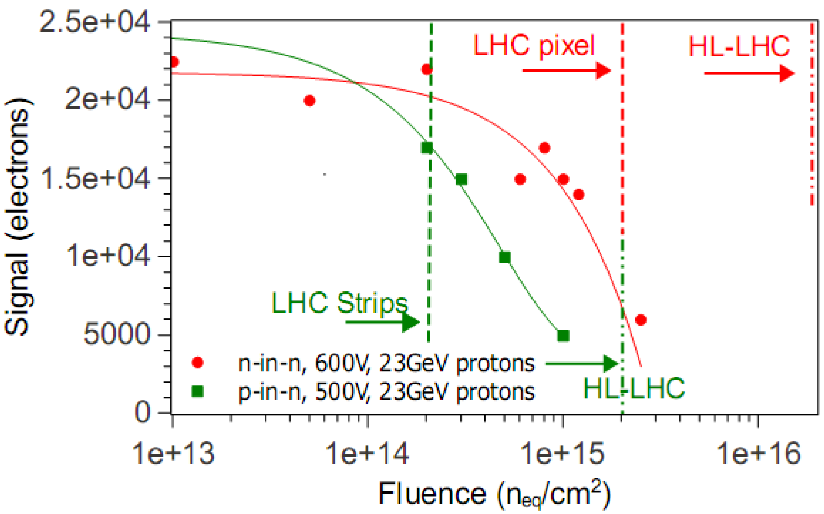
# Phase II Upgrade – Why Upgrade?

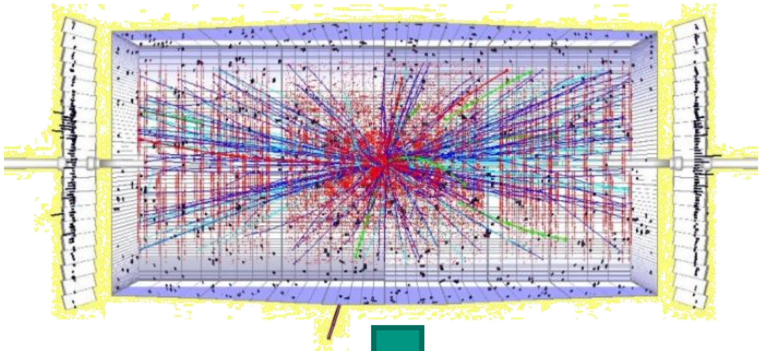
- Upgrade of the LHC: HL-LHC (> 2022)
  - $L = 5 – 10 \times 10^{34}\ cm^{-2}s^{-1}$
- Requirements:
  - **$L_{int}$ → Improve radiation hardness**
  - Pile-up → Higher granularity
  - $\sigma_{pT}$ → Save material
  - L1 Trigger contribution

FZ Silicon
Strip and Pixel Sensors

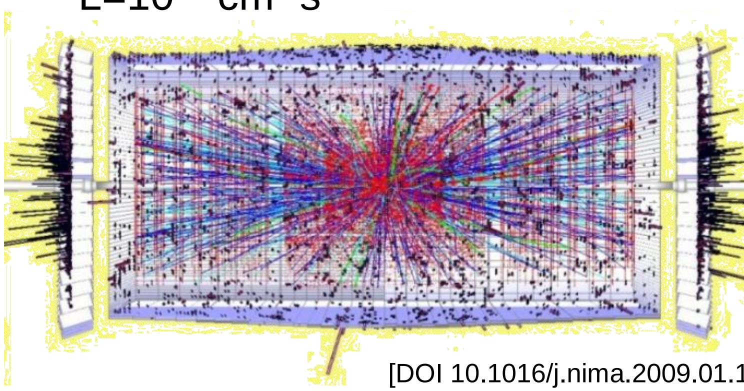



[1] Pixel: Casse et al. 2008
[2] Strips: Rohe et al. 2005

$L=10^{34}\ cm^{-2}s^{-1}$



$L=10^{35}\ cm^{-2}s^{-1}$



[DOI 10.1016/j.nima.2009.01.196]

New Tracker necessary for upgrade!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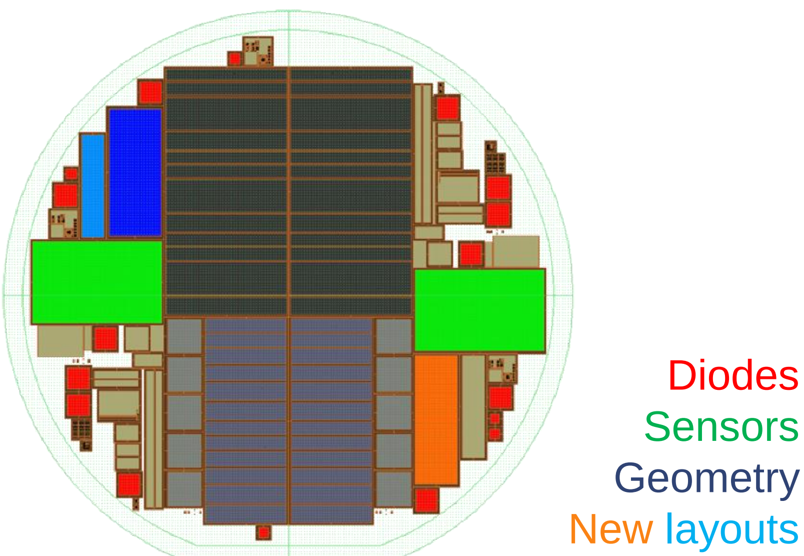
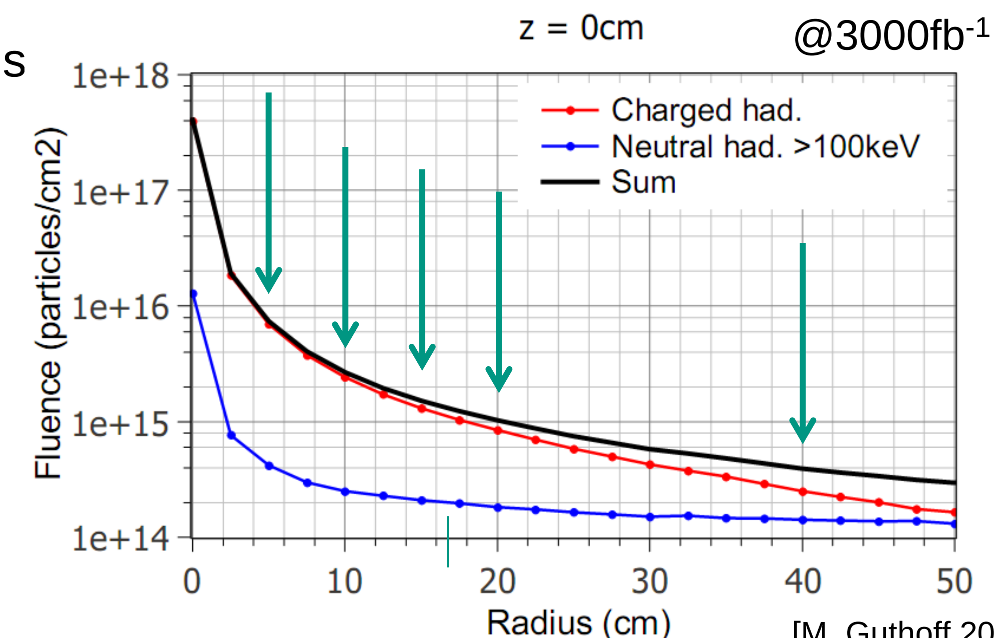
# Upgrade Activities – Radiation Hard Silicon Sensors

- Campagne in the scope of the CMS Tracker Collaboration (17 Institutes)
- 162 6"-wafers with several *sensors* and test structures from **one** manufacturer
  - Floatzone (**FZ**), Magnetic Czochralski (**MCz**) and Epitaxial (**Epi**) Silicon
  - Different thicknesses from 320µm (current inner tracker) down to 50µm; *current baseline*: **200µm** to reduce radiation length
  - N-bulk and p-bulk silicon
  - Choose 5 radii for irradiations

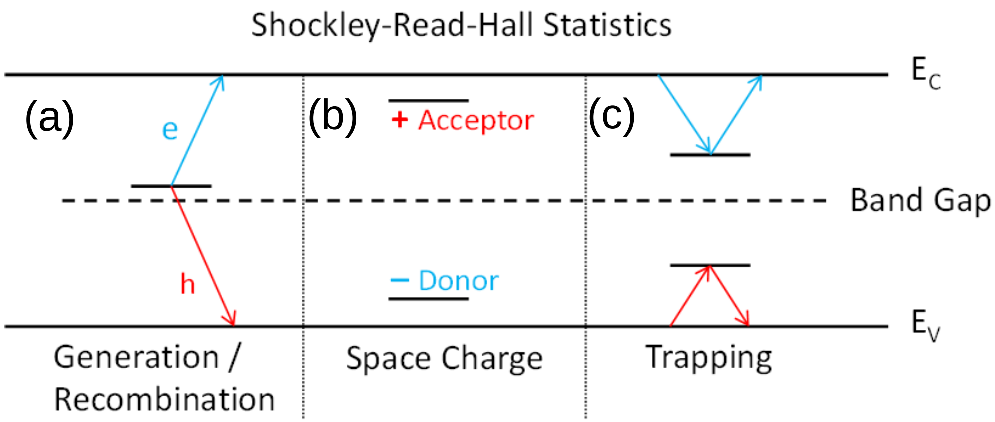


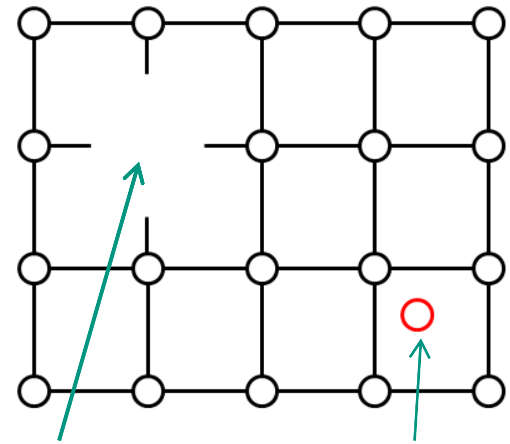




[M. Guthoff,2012]

# Defects

- The reason for sensor degradation: **Defects**



Vacancy and interstitial atom

- Radiation damage introduces defects in the silicon crystal: forming of energy levels in the bandgap
- Effects
  - Increase of leakage current (a)
  - Generation of space charge (b) – Increase of depletion voltage
  - Trapping of charge carriers (c) – Reduction of signal and collected charge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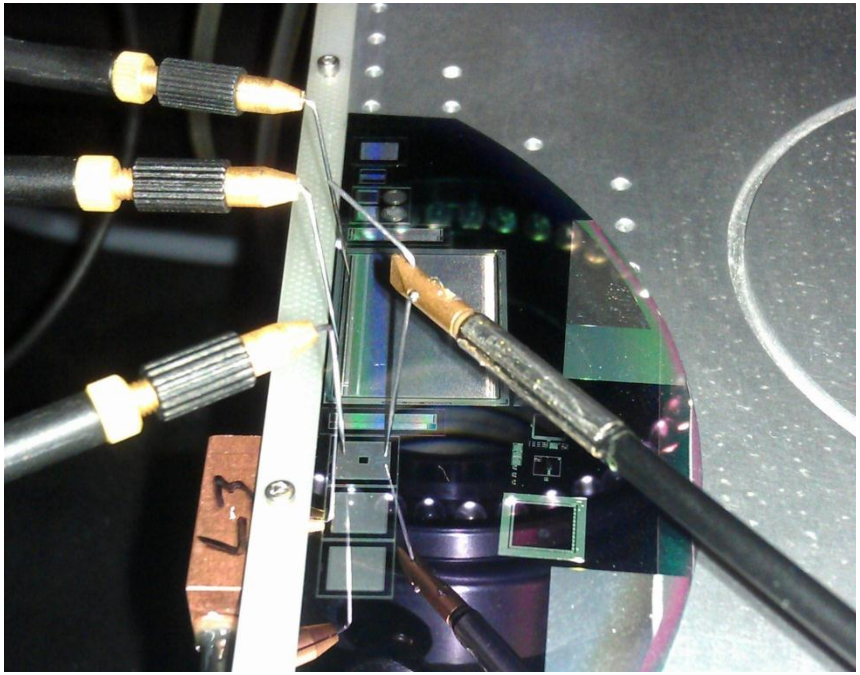
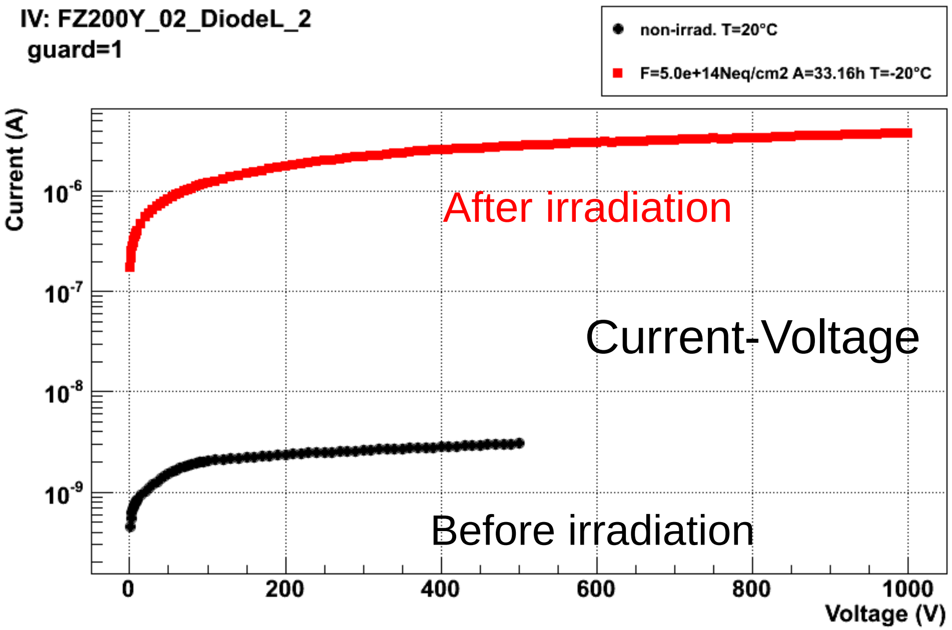
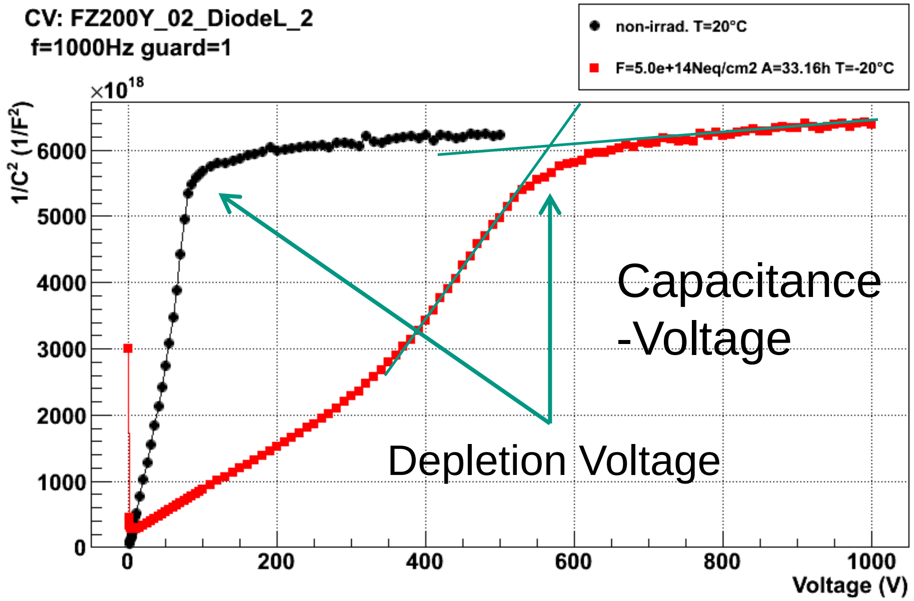
# Sensor Qualification

## Karlsruhe Probe Station






- Measure Characteristics
- Strip measurements
  - Rbias, RStrip, Ccouple, IStrip, Idiel
  - Interstrip Capacitance (electronics noise for chip)



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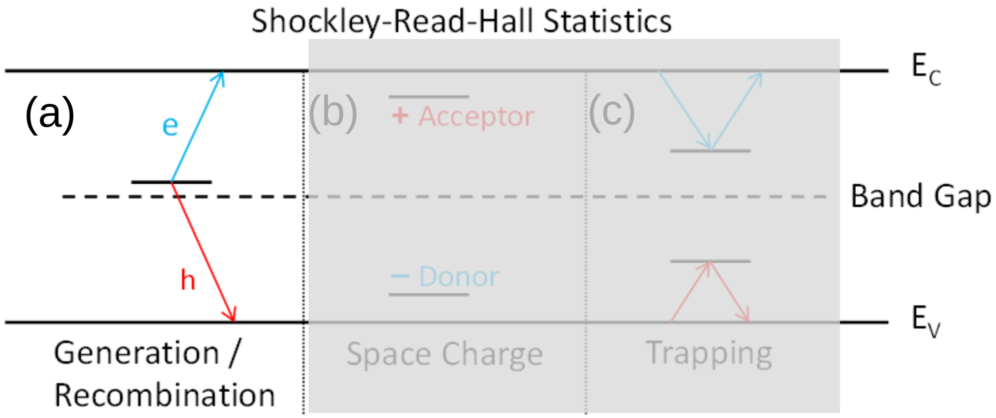
# Radiation Hardness I

- The reason for sensor degradation: **Defects**

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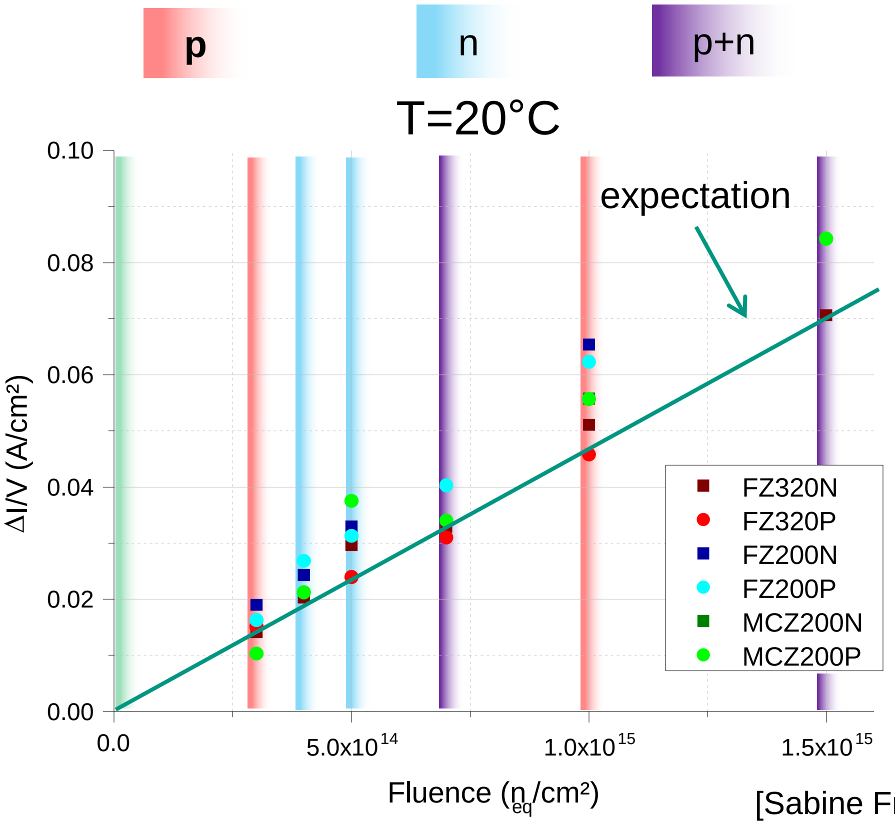
# Radiation Hardness I – Alpha Factor




[Sabine Frech]

Increase of leakage current proportional to fluence: radiation damage factor α

$$\frac{\Delta I}{V} = \alpha \cdot \mathrm{F}_{eq}$$

- Current in both n- and p-type material scale the same
- Cooling power estimation at 0°C and F=1e15$n_{eq}$/$cm^2$

$$\Delta I = 0.008 \frac{A}{cm^3} \times 200\mu m \times 200m^2$$
$$= 3.2A$$
$$U = 600V$$
$$\Delta P = U \times \Delta I = 1.9kW$$

- $CO_2$ cooling at -20°C foreseen in phase II upgrade
  - Cool additional thermal power
  - At lower T → lower ΔI
  - Prevent / control annealing



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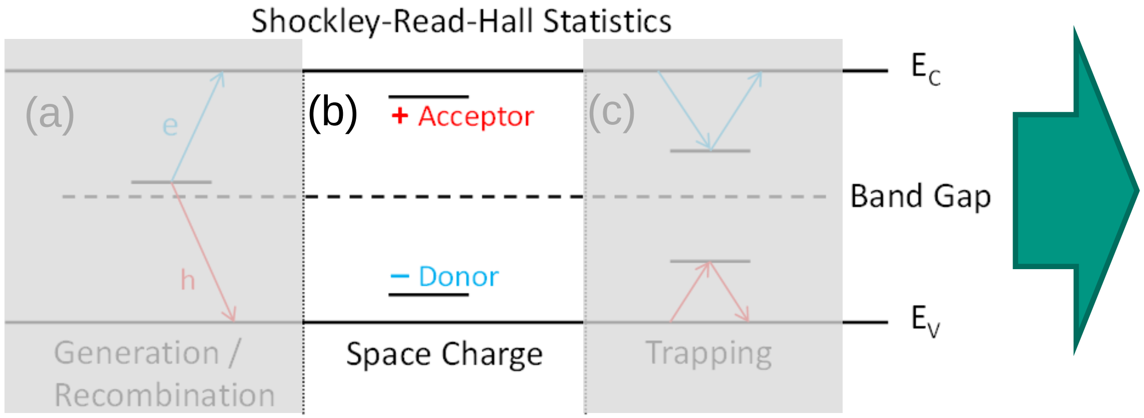
# Radiation Hardness II

- The reason for sensor degradation: **Defects**




Irradiation creates more **acceptor like** defects

- Radiation damage introduces defects in the silicon crystal: forming of energy levels in the bandgap
- Effects
  - Increase of leakage current (a)
  - Generation of space charge (b) – Increase of depletion voltage
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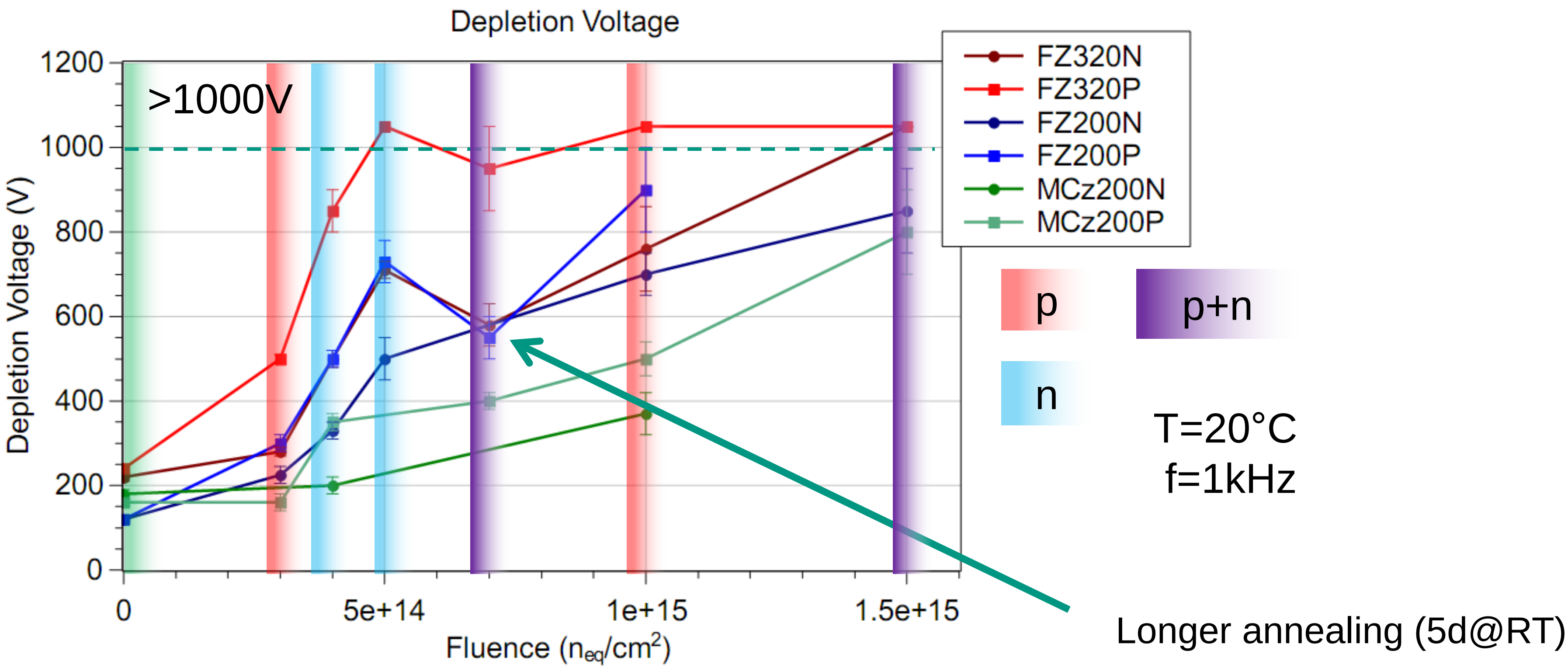
# Radiation Hardness II – Depletion Voltage

- Depletion Voltage increases after (high) irradiation
- $V_{dep}$ in p-bulk sensors increases faster due to acceptor like defects
- Short annealing reduces depletion voltage, long annealing increases $V_{dep}$
- Sensors above 1000V could not be depleted any more





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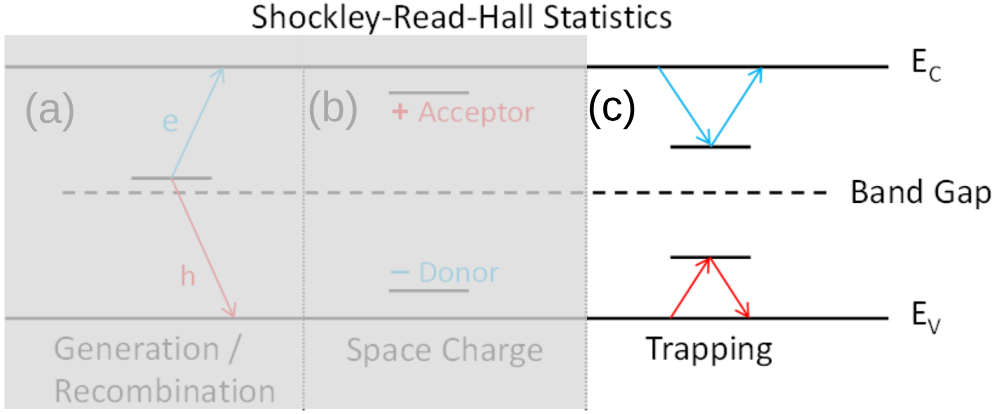
# Radiation Hardness III

- The reason for sensor degradation: **Defects**

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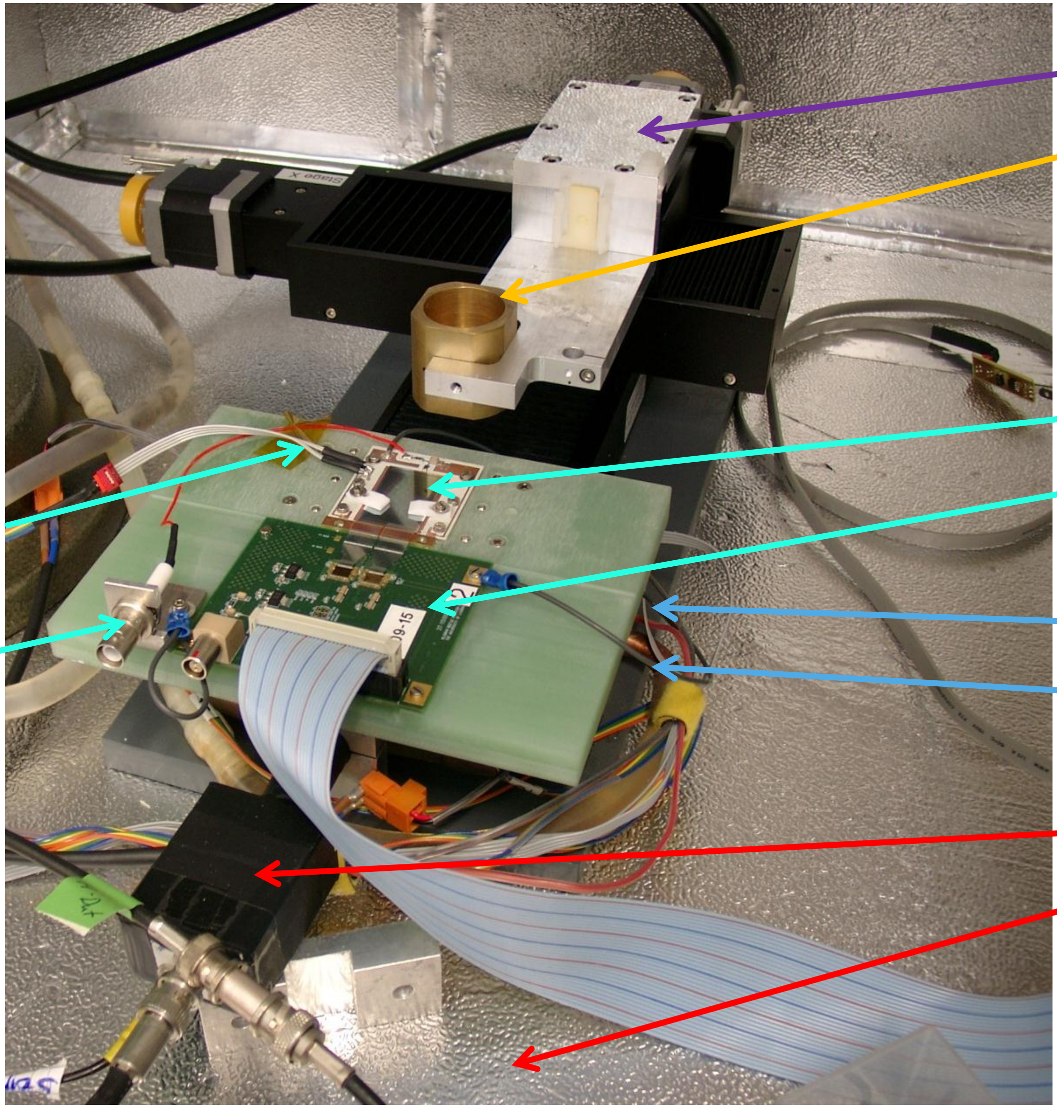
# Strip Readout Sytem (Signal) – ALiBaVa



- XYZ stage
- Collimator for $^{90}Sr$ source
- Sensor
- Daughterboard
- Peltier cooling
- Primary cooling
- Scintillator (trigger)
- Isolation and shielding
- Pt100
- HV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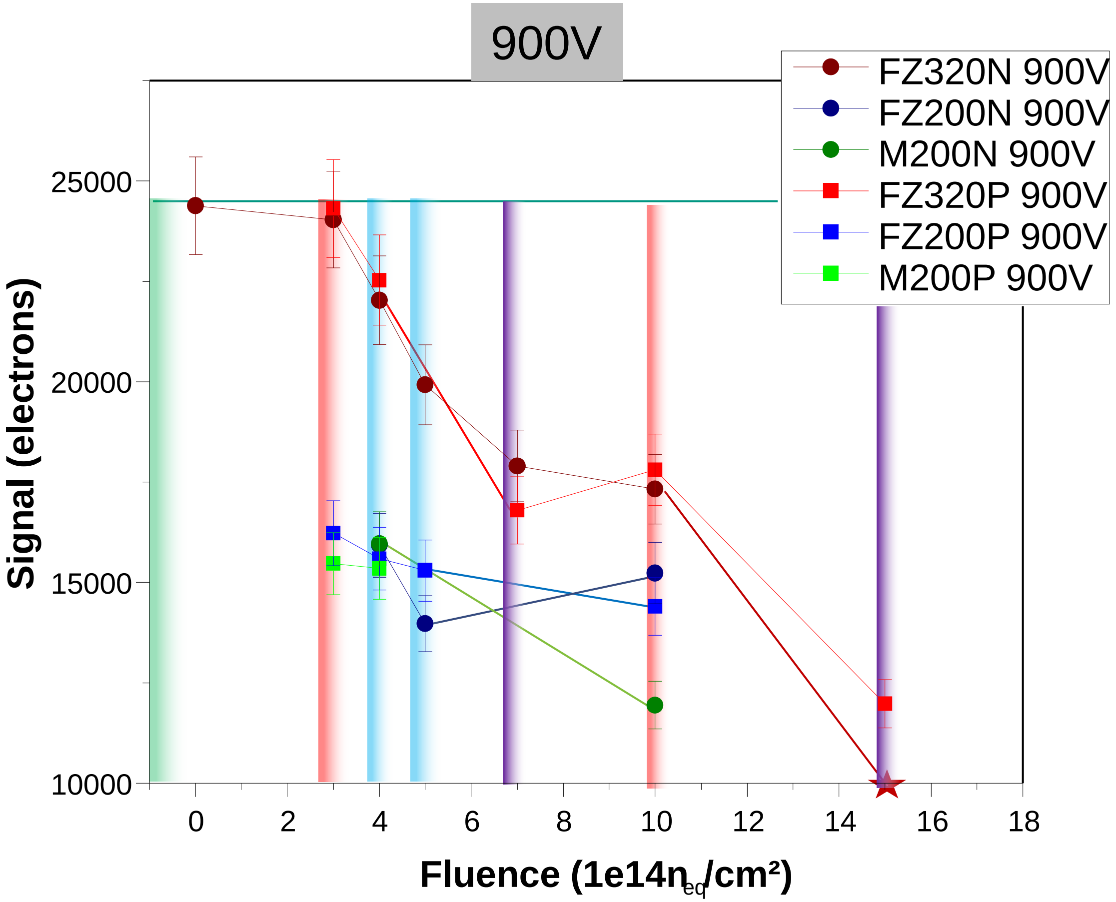
# Radiation Hardness III – Electron Signal




- MIP creates ~80 e/h pairs per µm silicon
- Thinner materials → lower signals
- 320µm recover more signal at 900V → Signal lower at 600V
- FZ320N doesn't work at 1.5e15$n_{eq}$/cm$^2$

- S/N is important for final readout chip
  - Noise is better in thinner sensors (less leakage current)
  - Noise of ALiBaVa comparable to CBC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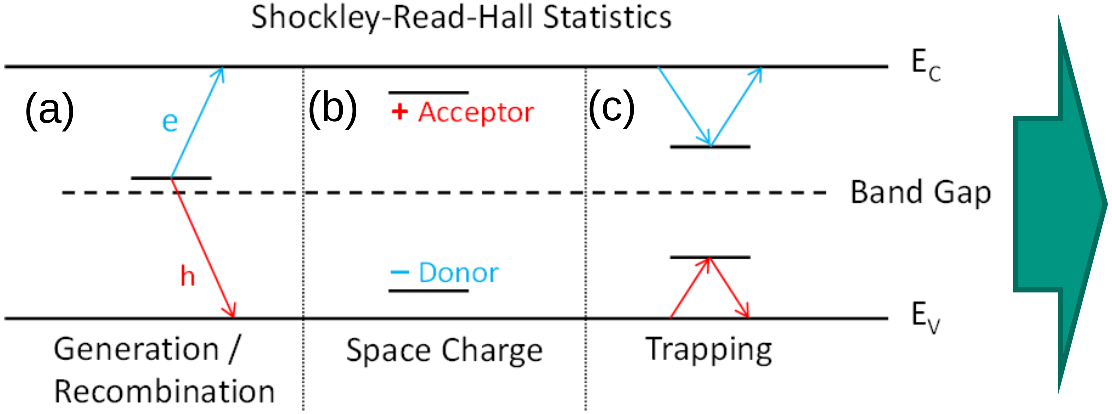
# Radiation Hardness III

- The reason for sensor degradation: **Defects**




Influence on the **electric field** in the silicon bulk

Important for readout

- Radiation damage introduces defects in the silicon crystal: forming of energy levels in the bandgap
- Effects
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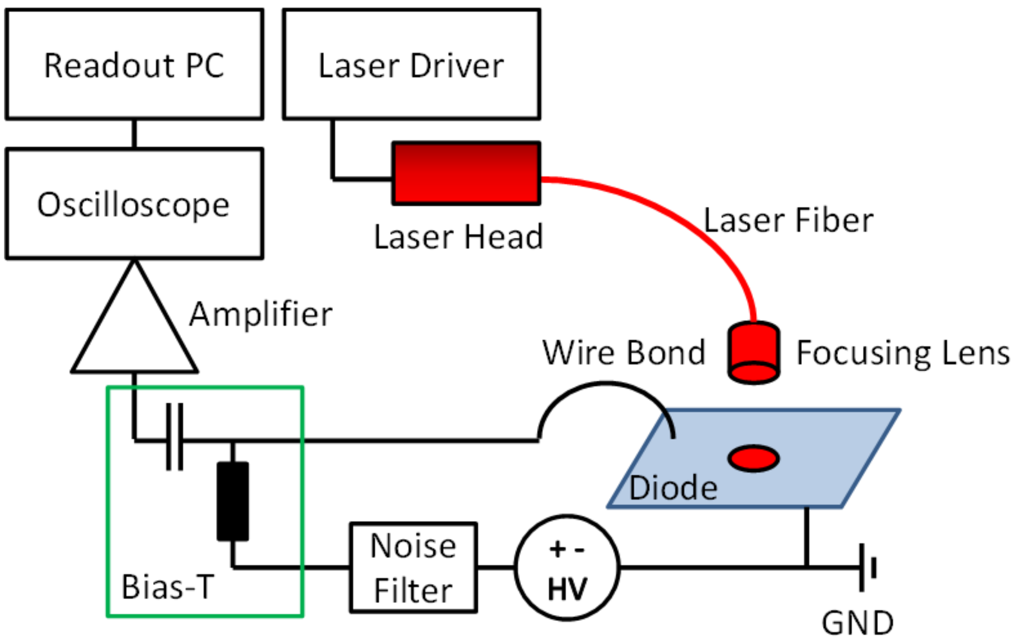
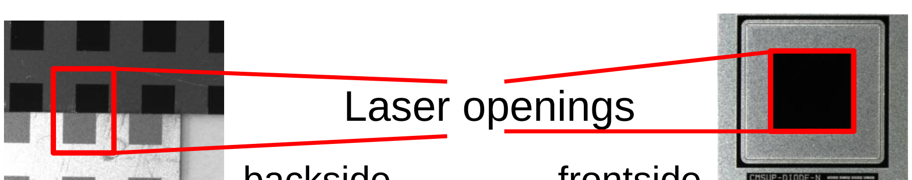
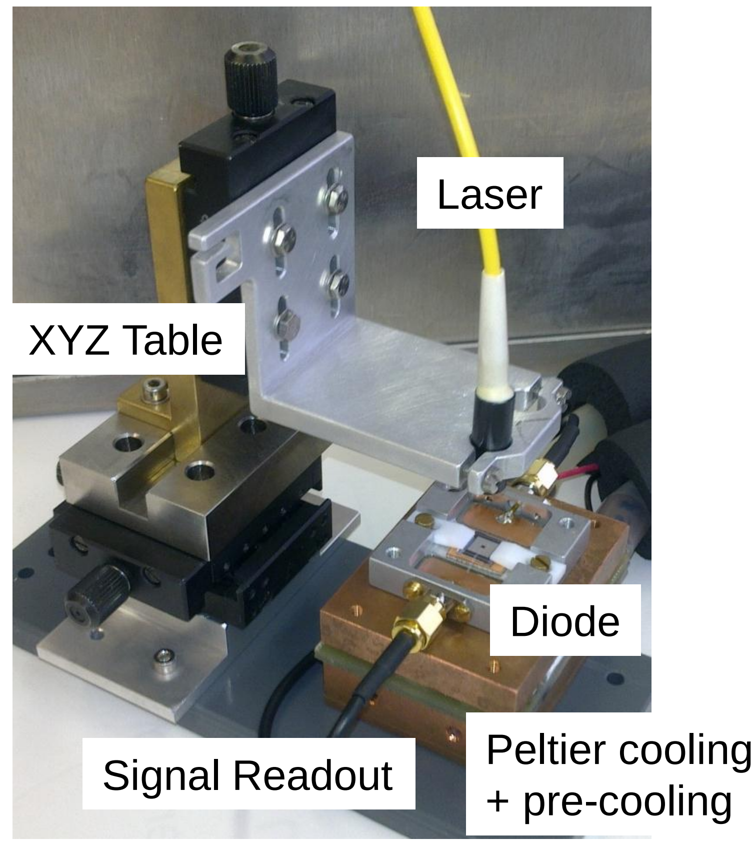
# Basic Material Characterization

## Picolaser Setup (TCT)

- Measure current created by particle tracks in the device (diodes)
- Charge created by Laser





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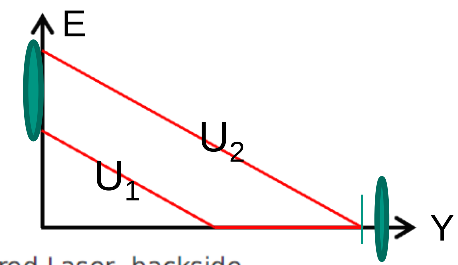
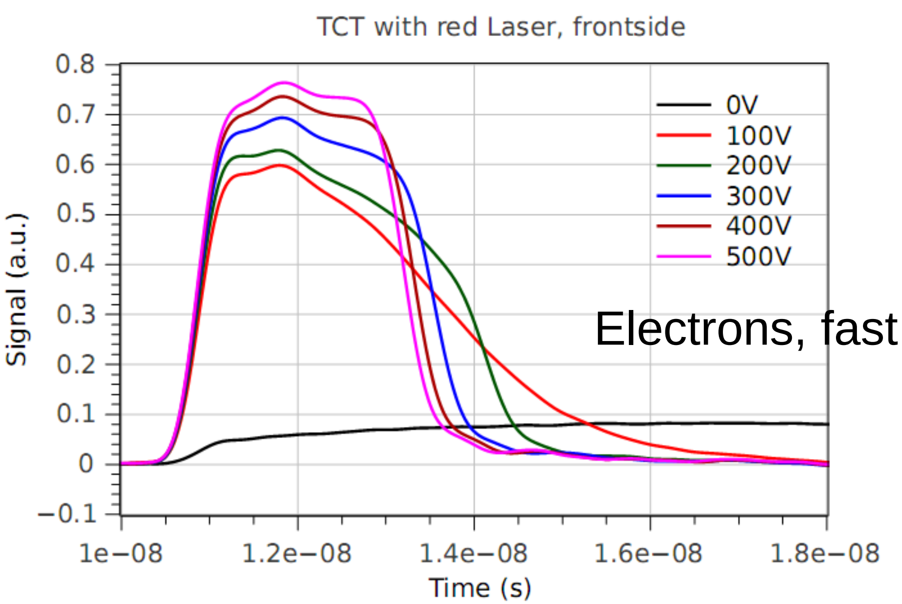
# Transient Current Technique (TCT)

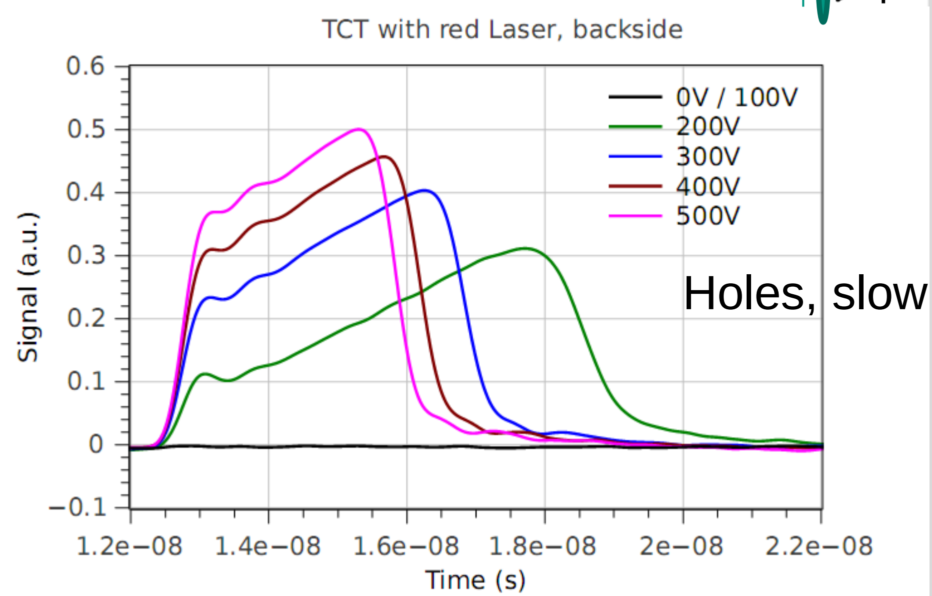
- Red Laser (680nm) generates charge carriers just beneath the surface absorption length ~4µm
- Observe drift of charge carriers (current) of only one type through the diode

$$v_{dr} \propto E \qquad , v_{dr} < v_{max}$$

- Measurements in unirradiated diodes show expected electric fields





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# TCT in Irradiated Diodes

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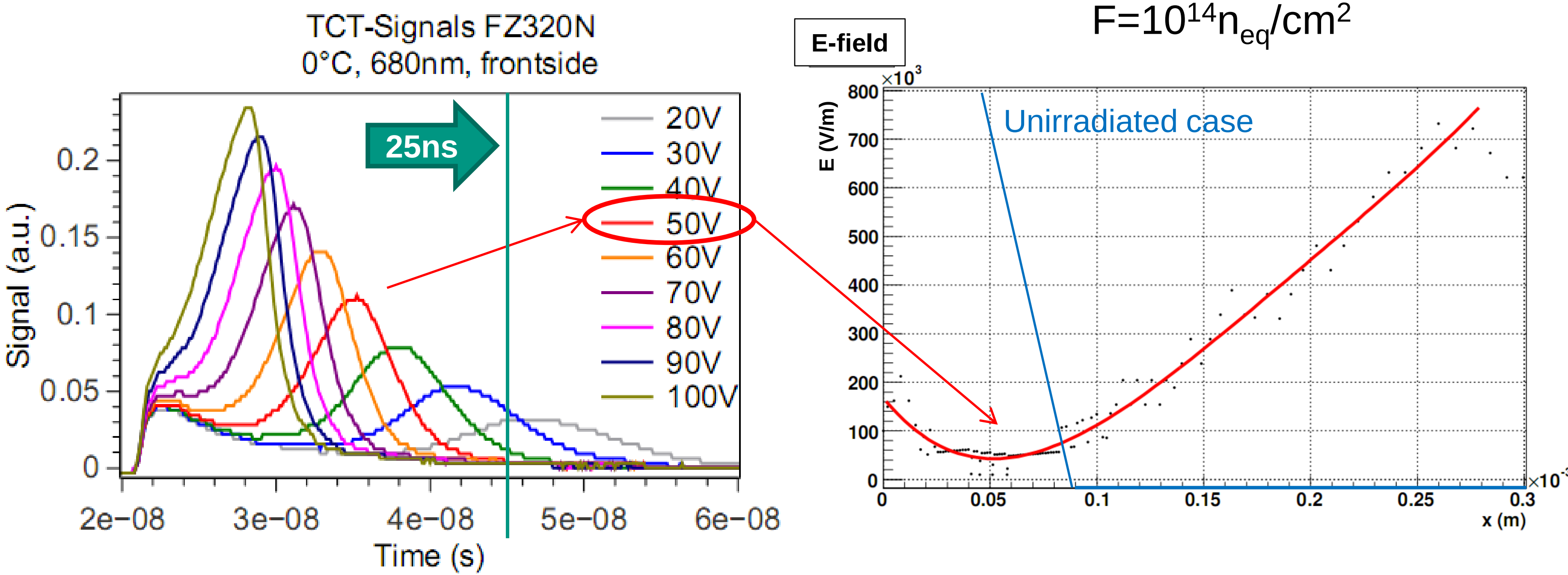
- After irradiation: electric field in the bulk changes




- Stepwise reconstruction of the electric field in a diode
- E-field is pulled towards the backside
- Strips at frontside won't see full charge
- At higher voltages, low field region vanishes

Higher fluences: double peak visible at higher voltages

# UPGRADE – TRIGGER CONCEPT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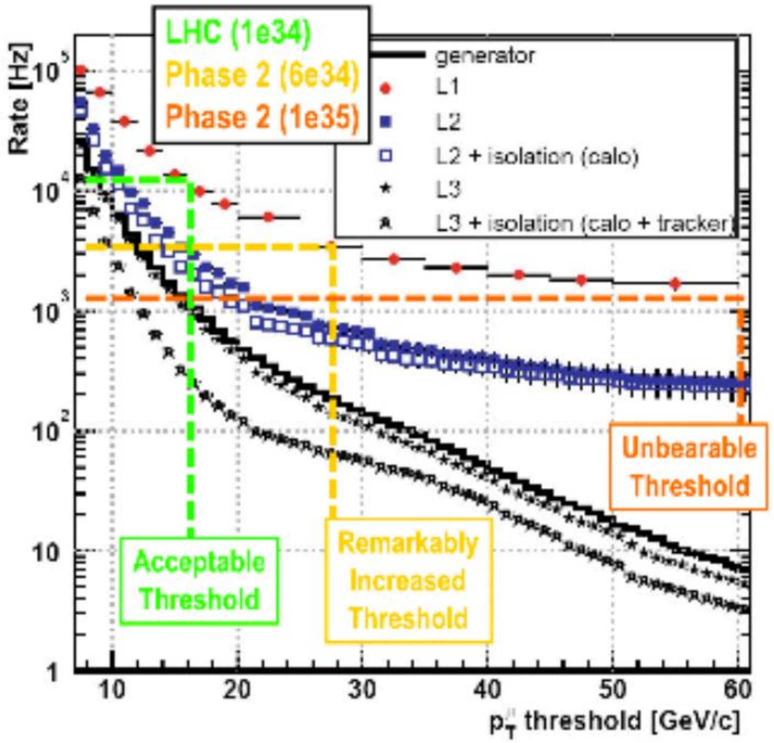
# Tracker Trigger – L1 Contribution

- Trigger needs to maintain 100kHz output rate (with 5 – 10 times increased luminosity and pile-up)
  - Not possible with contribution from calorimeters and muon detectors
  - Flattening of L1 rate as function of pT → Increasing threshold doesn't work
- Tracker will have to provide information for L1 trigger
  - Precise transverse momentum threshold

Muon triggers only




[Gaelle Boudoul, Vertex2012]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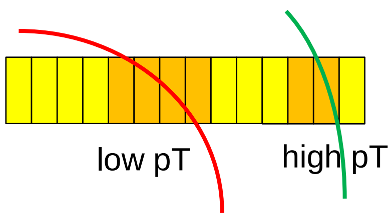
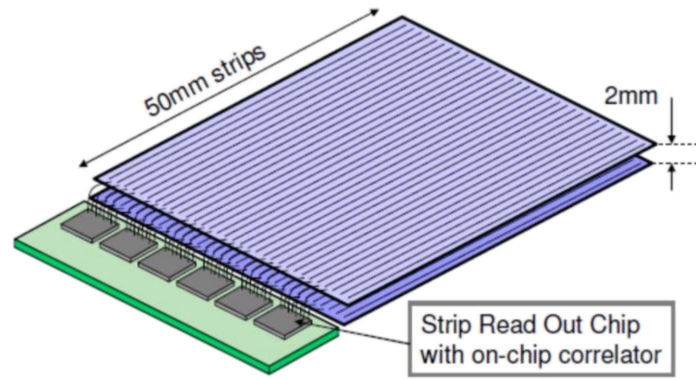
# Tracker Trigger

Reduction of data volume

- 90% of tracks have pT<1GeV, 97% pT<2GeV

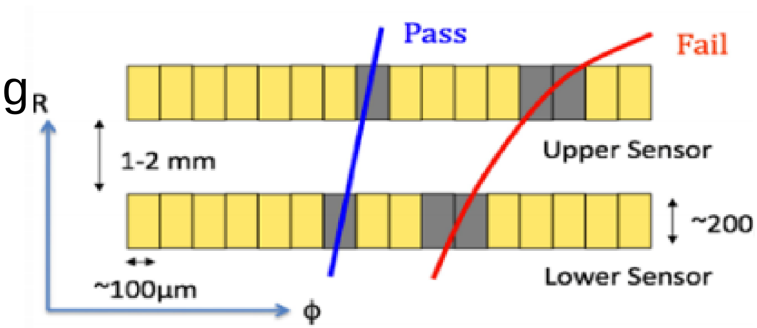
- Preselection of cluster widths
  - Low momentum tracks are bent in the magnetic field



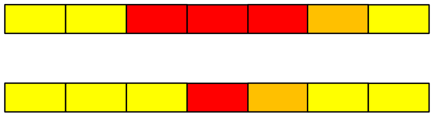




Working principle of Tracker Trigger

- Hits in 2 sensors close together provide geometrical cut on pT
- Measuring Δ(Rφ) over ΔR (sensor spacing)
- Optimize selection window and sensor spacing




e.g. search window = 3 strips





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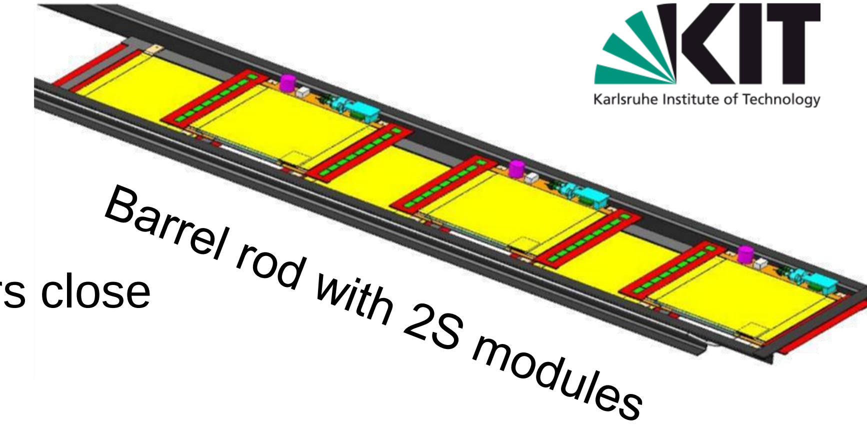
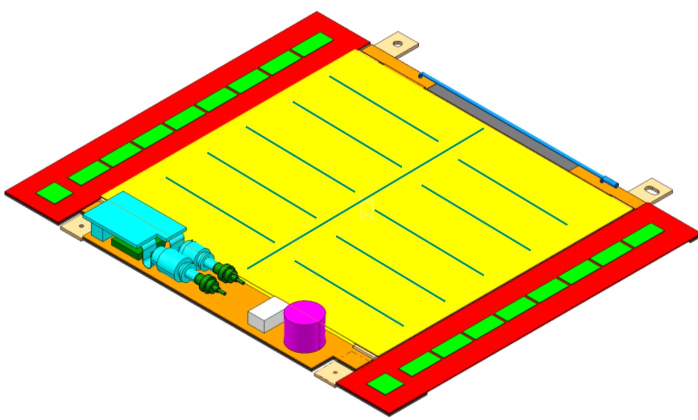
# Track Trigger Modules

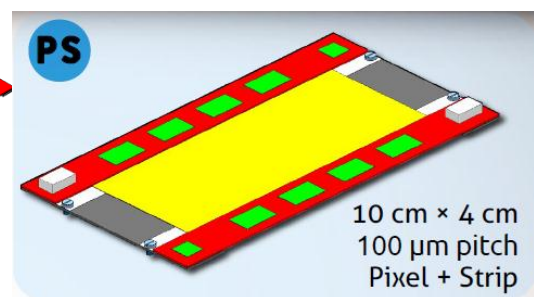


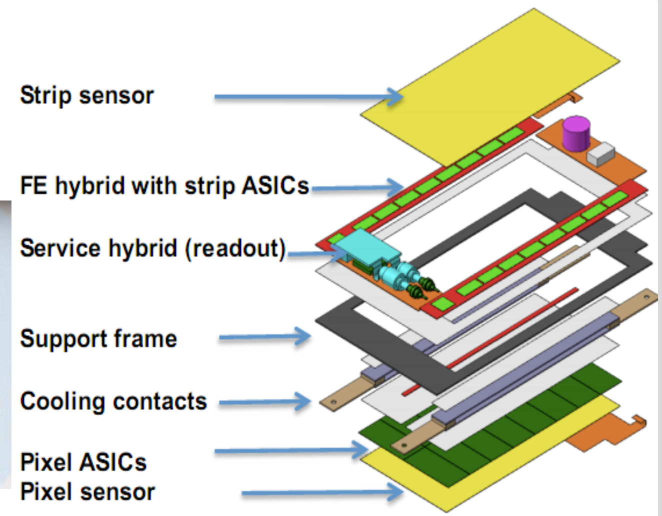

- Stacked sensor modules
  - Correlation between hits in 2 sensors close together
  - Strips read out at the edge
  - Correlation done on the chips
  - Cut in X-Y plane allows to select pT treshold
- 2 Modules foreseen for the Tracker



2 Strip Sensors pT module

Pixel + Strip pT module



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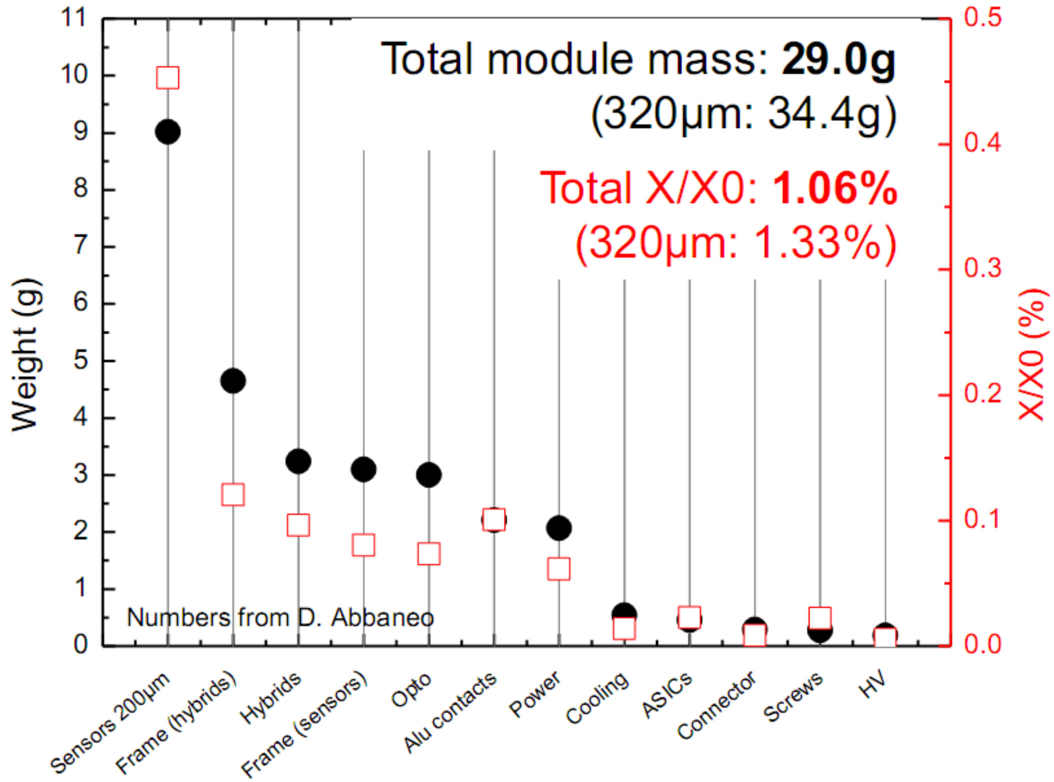
# Light Modules




- Light modules
  - Thin silicon sensors (main contribution to material budget)
- New sensor designs
  - Integrated pitch adapters on the sensors

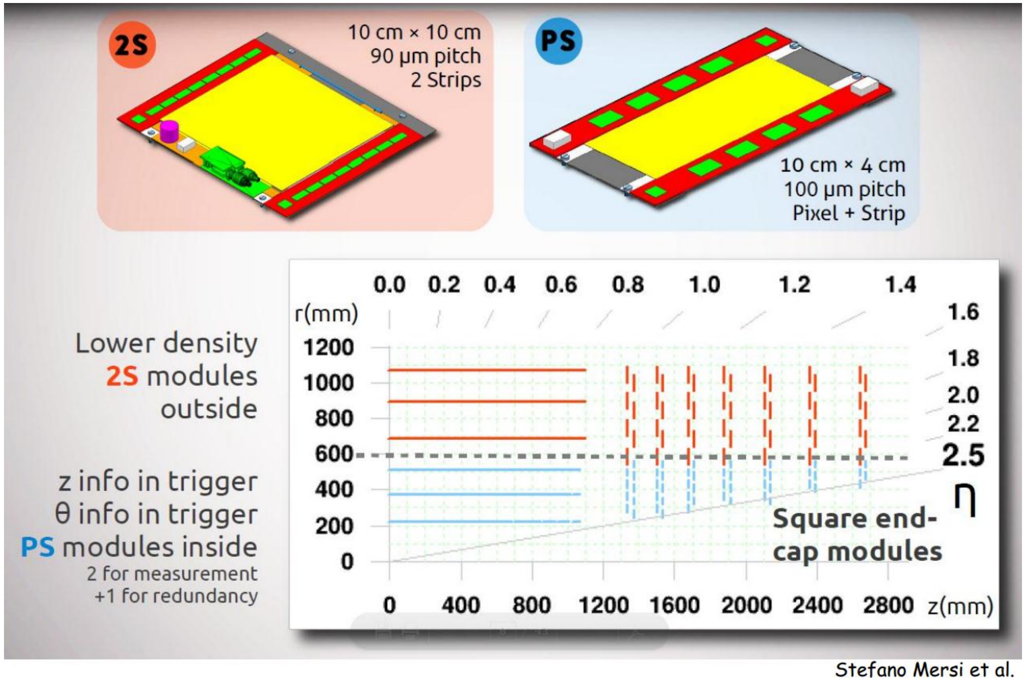
# CMS Tracker Layout

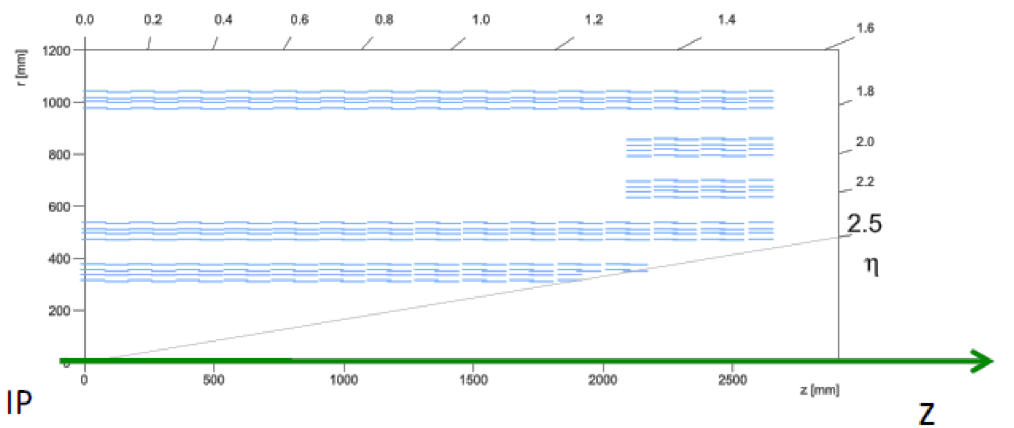
- 2 Designs for the CMS Tracker

1. Built of trigger modules only
   - Inner radii: PS module
   - Outer radii: 2S module

2. Long barrel geometry (no end caps)

   VPS modules only: like PS modules with vertical interconnector



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# SUMMARY



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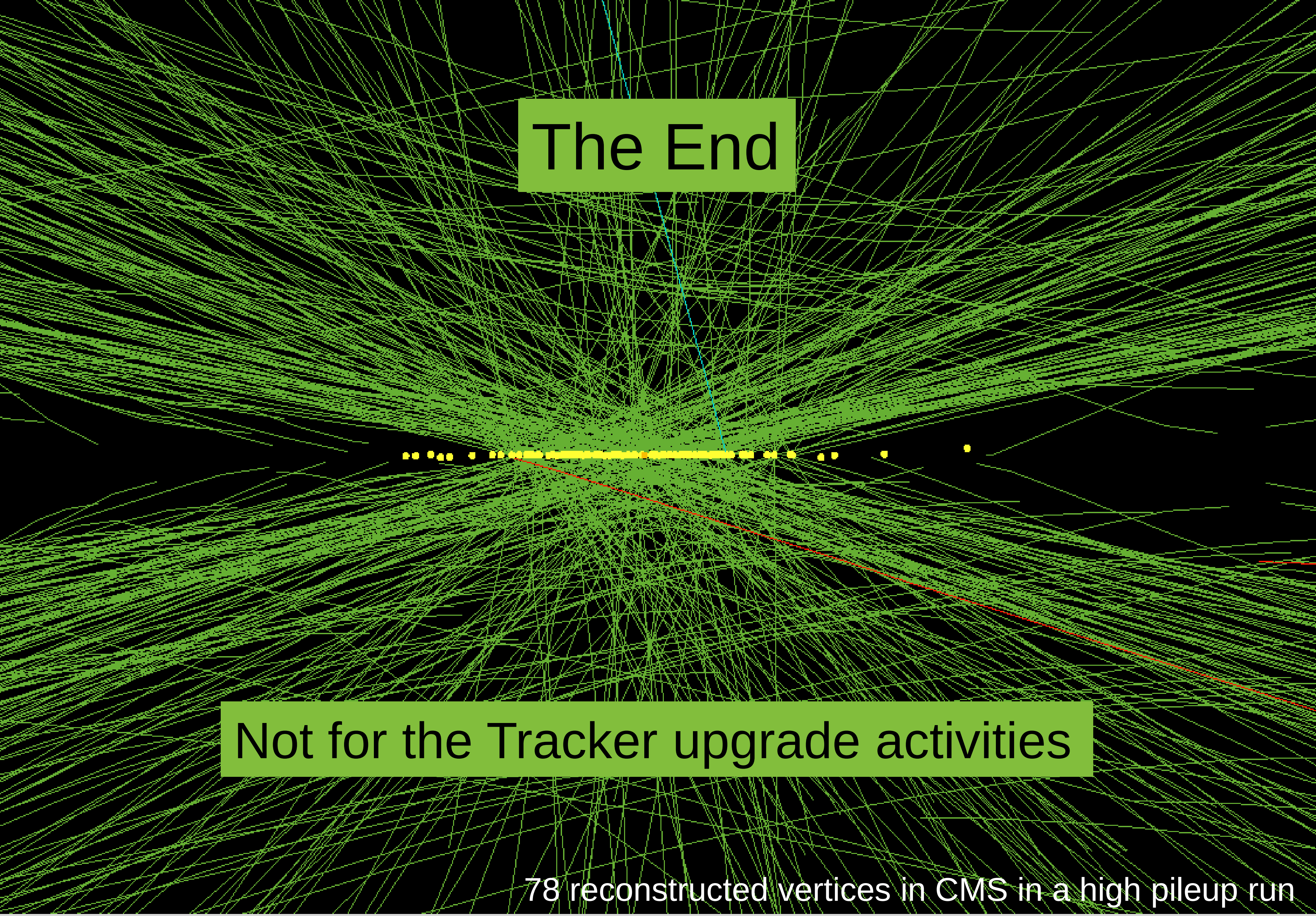
# Summary

- The CMS Tracker will be upgraded during the Phase II upgrade beyond 2022
- CMS Tracker Collaboration has to decide within the Campagne on a sensor material till end of March 2013
  - Next step module building and testing
- Contributions at IEKP to
  - Sensor characterization (probe station)
  - Material characterization and electric field (TCT)
  - Signal, S/N measurements (ALiBaVa)
  - Sensor layout studies for 2S module
- Huge campaign in full progress, a lot of irradiations, measurements to be done; annealing studies to come
  - So far p-bulk material and a thickness of 200µm is considered baseline (material budget)
- Radiation hard sensors, higher granularity, less material budget and a trigger contribution will make the CMS Tracker ready for HL-LHC

# The End



Not for the Tracker upgrade activities

78 reconstructed vertices in CMS in a high pileup run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# BACKUP


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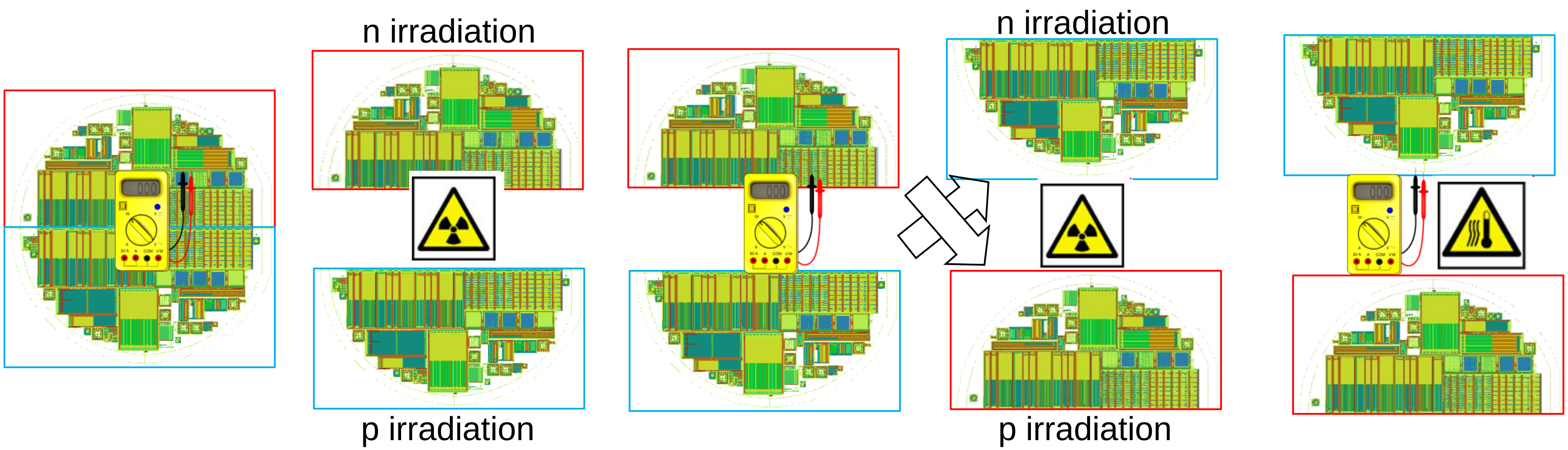
# Mixed Irradiation Study

- Degradation of silicon sensors due to radiation in the tracker
- Different contributions from protons and neutrons
- Fluence: Normalise to 1MeV neutron damage (NIEL scaling; k: hardness factor)

$$F = \frac{n}{A} \qquad F_{eq} = \frac{n\,(E) \times k(E)}{A}$$

- Goal of **mixed** irradiation: imitate real radiation environment
  Study effect of possible NIEL violation





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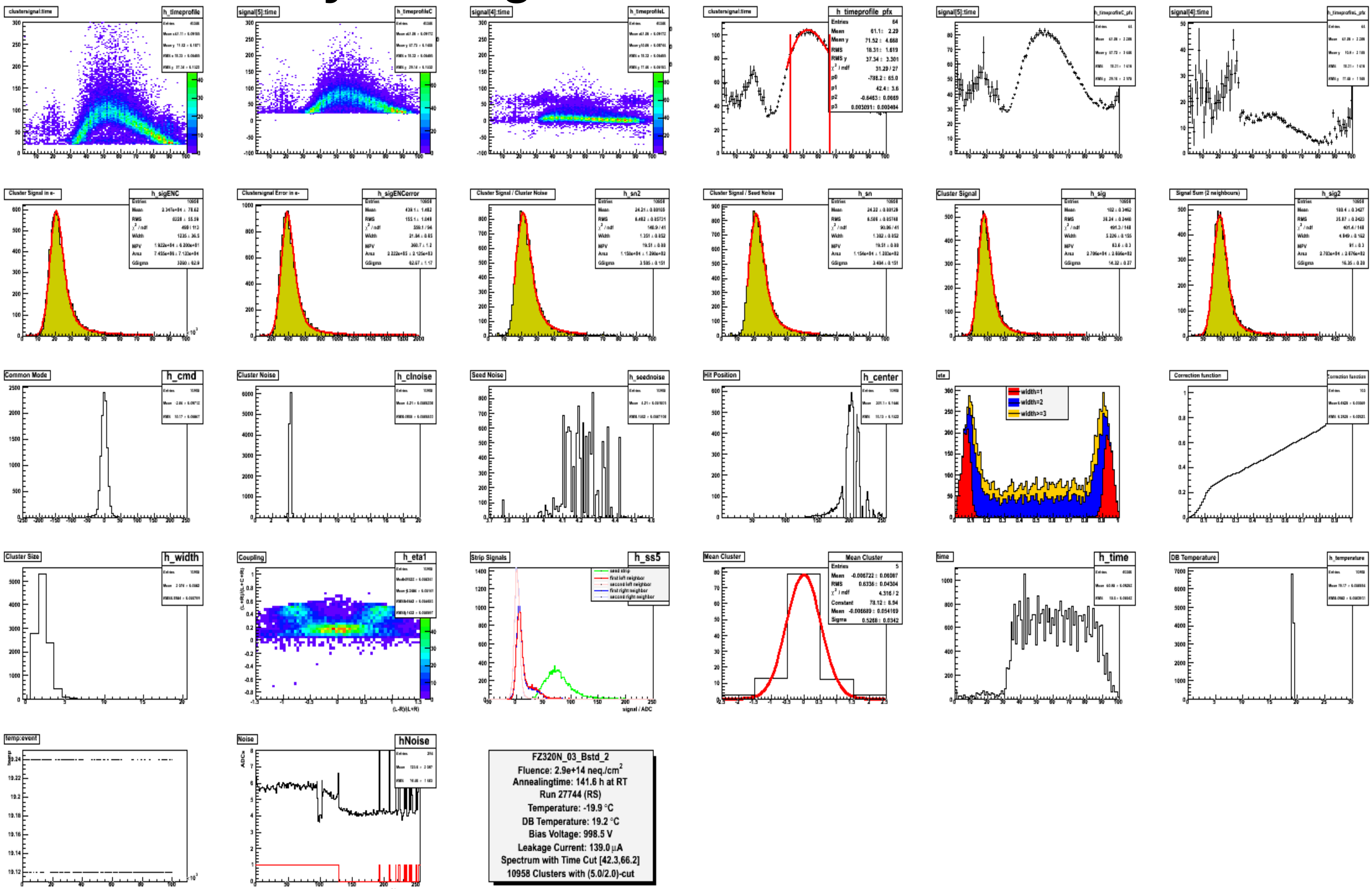
# Alibava Analysis Page



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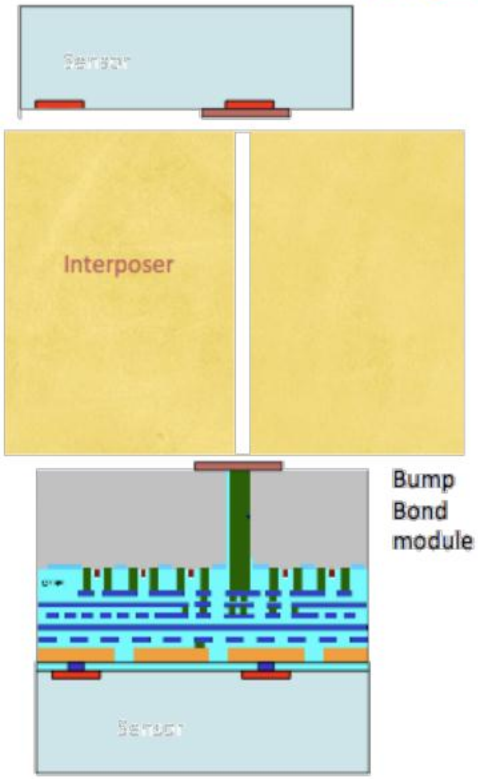
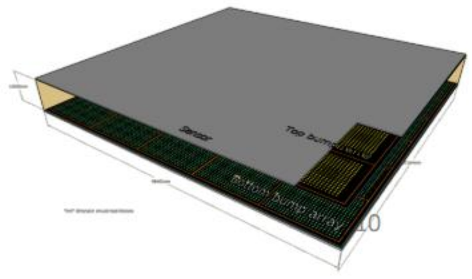
# Pt Modules types (2/3): VPS Modules

- Strip / Pixel module with Vertical interconnections

- Single chip connected to top and bottom sensors
- Analogue paths through interposer from top sensor, segmented in ~ cm long strips
- Bottom sensor gives z info (~ mm long pixels)

- Electronics and connectivity (interposer) are technological challenges (yield, robustness, mass, large–size module)
  - Several developments ongoing in parallel
- Technology for interposer still an open problem
- Data processing simulation started
- Option to use active edge sensors

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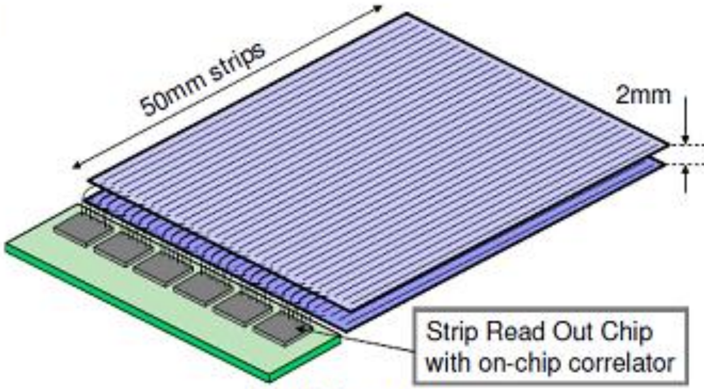
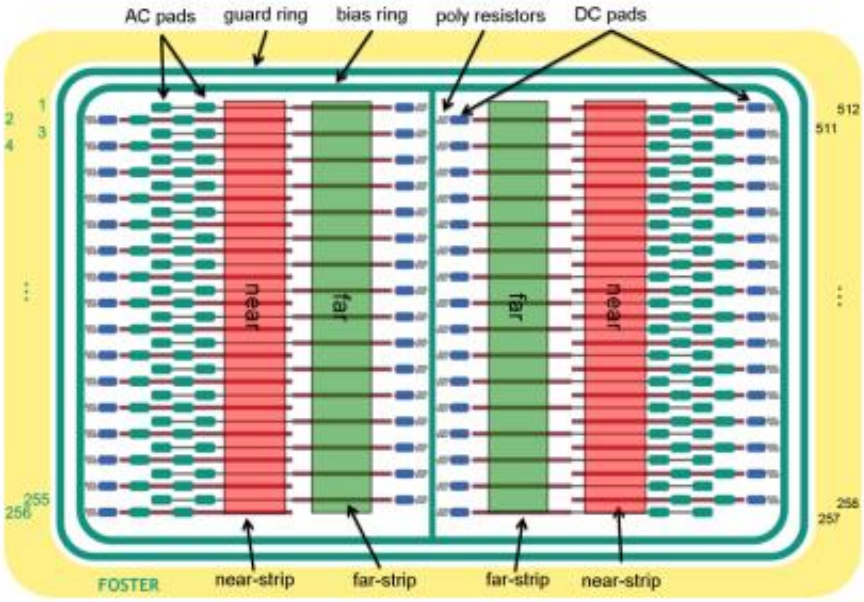
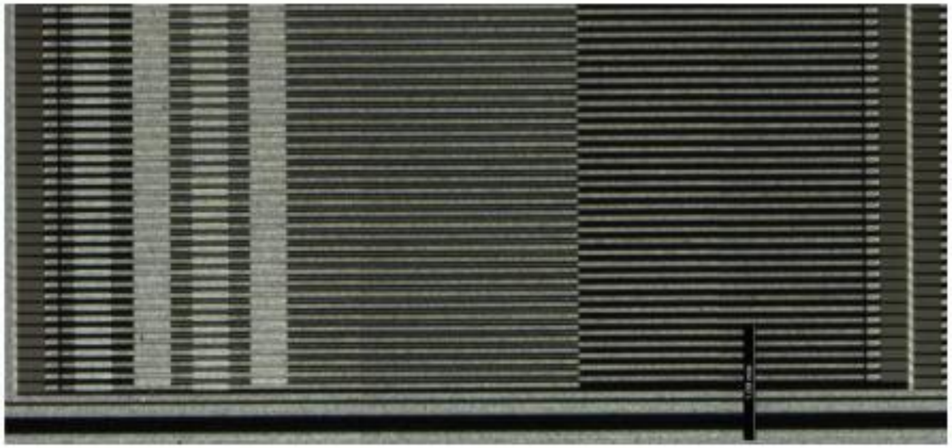
# FOSTER – Intro

- New design: **FO**ur-fold segmented **ST**rip sensor with **E**dge **R**eadout
  - increase granularity
  - keep sensor size of ~10cm x 10cm
  - allow correlation of two sensor planes on hybrid at the edge




$p_T$ module concept,
M. Raymond, TWEPP2008

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