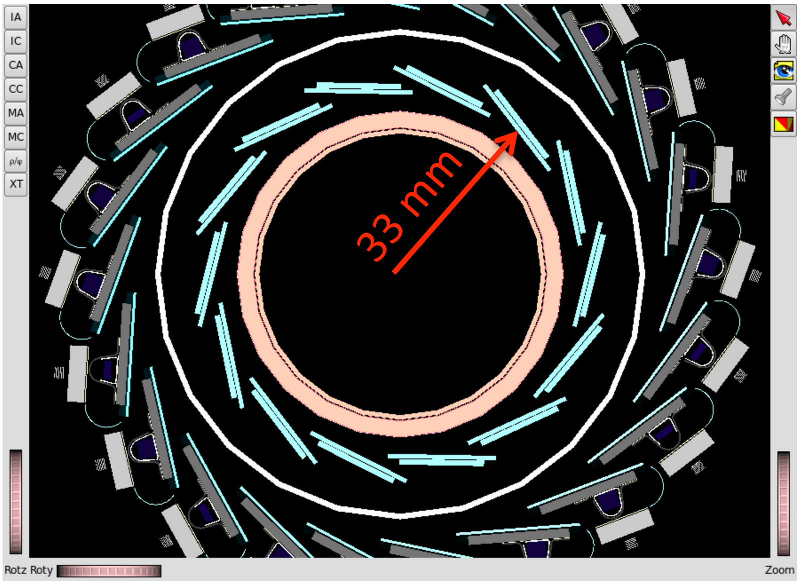
CMS Pixel System

Erika Garutti

Hamburg University

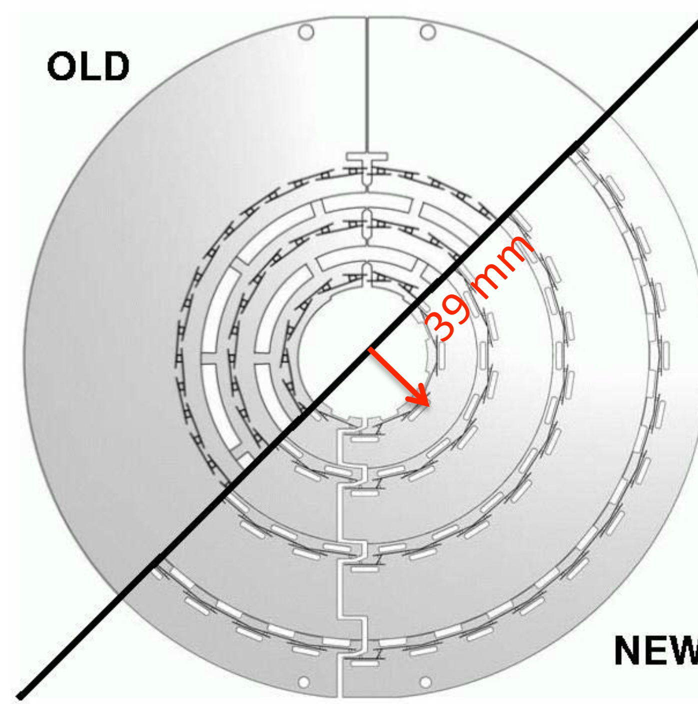
Pixel detector upgrade

ATLAS	Phase 0



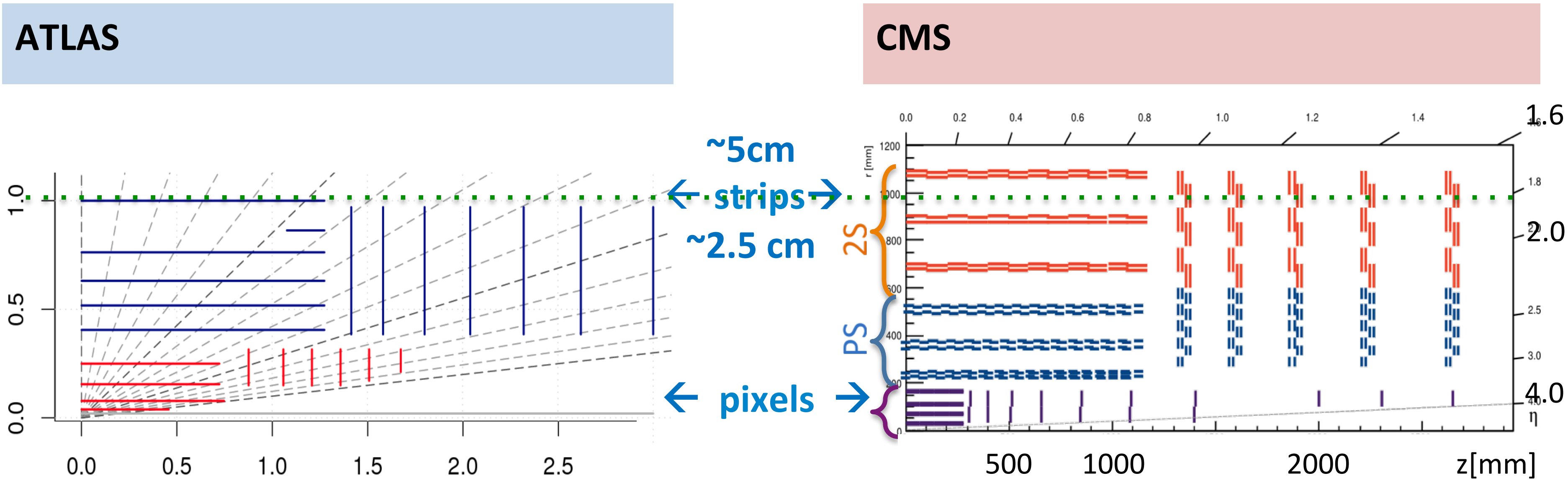
Insertable B-Layer (IBL) to be installed in 2014 inside present pixel detector

CMS	Phase 1



Complete replacement of pixel system in 2017

Pixel detector upgrade (phase 2)



CMS upgrade: Same radial envelope but extended rapidity coverage

- 4 barrel layers + 10 disks ($\eta = |4.0|$)

Same or better spatial resolution

- Higher granularity (25x100 µm² instead of 100x150 µm²)

Same (or lower) material budget as phase 1

About 5 m² of pixelated sensors

HGF-Alliance Project of ATLAS and CMS groups: "Enabling Technologies for Silicon Tracking detectors at HL-LHC" (PETTL)

Pixel phase II sensors

CMS activities on pixel phase II are getting momentum…

Working group (co. Daniela Bortoletto, US, sub-co. Alexandra Junkes, UHH)

Goal: prepare for TDR in 2016

Work Packages	Planar	3D	Diamond
Material	DESY/KIT/UHH		
Sensor Design	UHH		
Radiation hardness	DESY/KIT/UHH		
ROC-Sensor interface	UHH		
Bump bonding			
New submission	DESY/KIT/UHH		
Physics requirements	UHH		
Simulation	DESY/KIT/UHH		

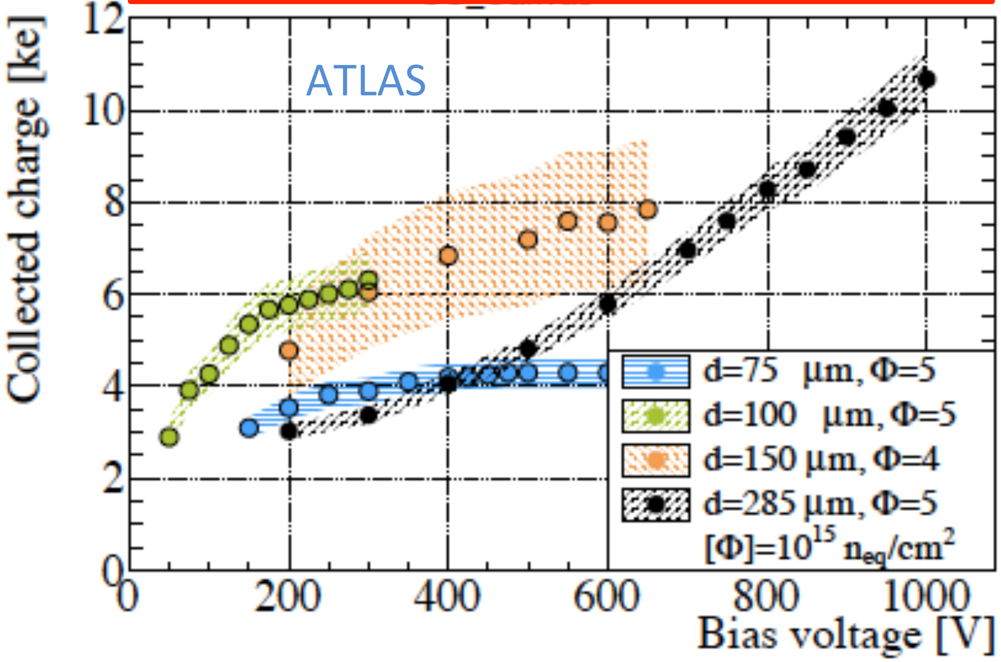
3D: Strong US / IT activity

Diamond: Strong US / CH activity

* Only German groups contributions

Material

S. Terzo et al., MPI Munich, 23rd RD50 workshop

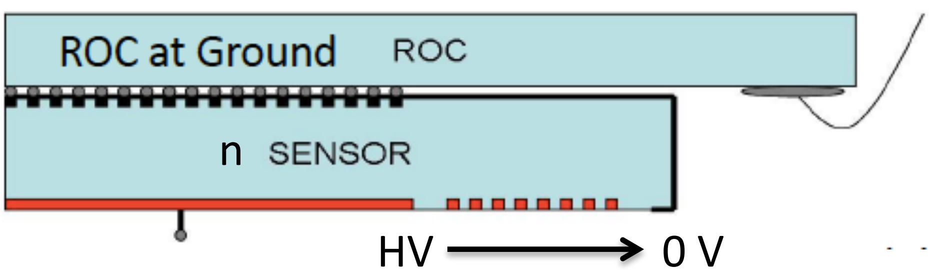


ATLAS studies on sensors from various vendors indicate:

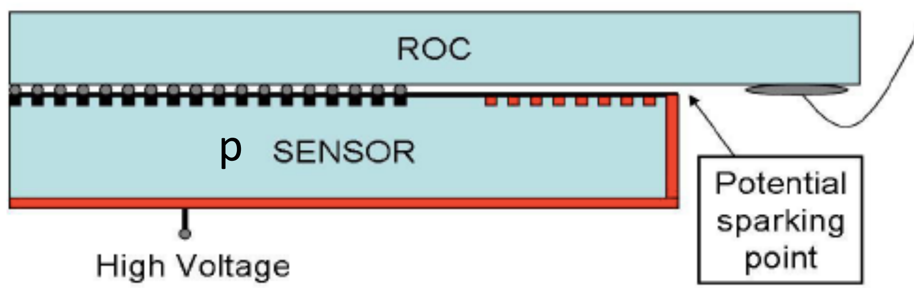
highest collected charge on 100-150 µm thick sensors at moderate voltages (200-300 V) up to a fluence of $10^{16}\ n_{eq}/cm^2$

Open questions:

- Epitaxial vs standard silicon
- n-on-p or n-on-n
- Active edges



Double-sided, n-on-n module



Single-sided, n-on-p module

Test of Epitaxial sensors at DESY Test Beam

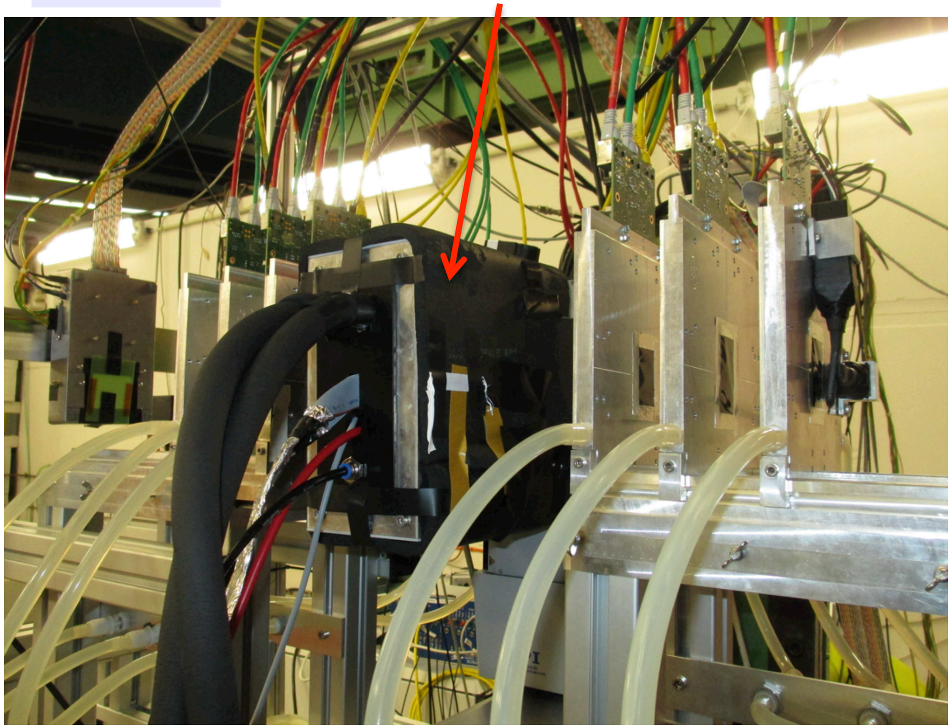
	Epi 100 P	Epi 100 Y	Epi 100 N	Epi 70 N
Φ = 0	0 & 1	3?	-	1
Φ = 1e15	3?	3?	3?	-
Φ = 1.5e15	1	2	1	-
Φ = 3e15	2	– (broken)	2	-
Φ = 1.3e16	2	2	3?	-

24 GeV/c protons from CERN

800 MeV/c protons from Los Alamos

Recently started activity on epitaxial HPK sensors measured in TB21 with DATURA telescope

Cold box with sensor

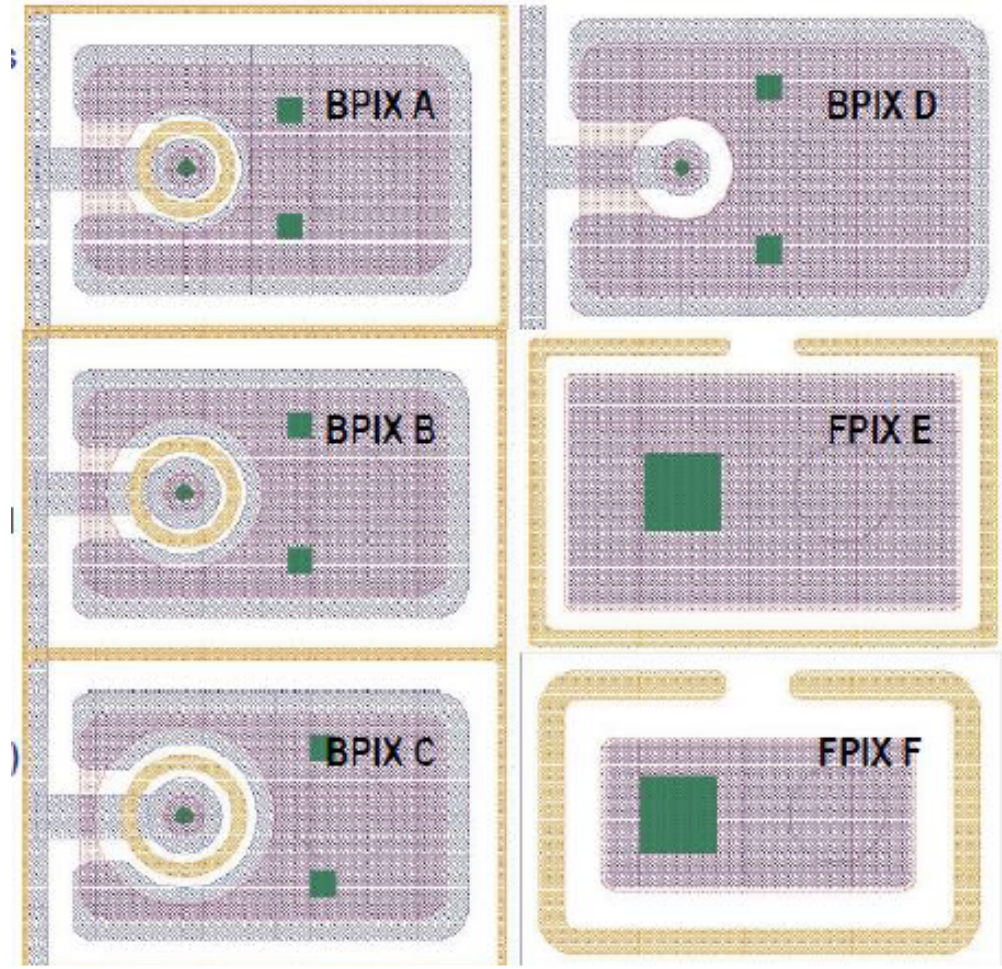


Pixel design

Impact on performance:

- High efficiency (>99%)
  minimize bias dot
  maximize implant size
- High breakdown voltage
  minimize oxide thickness
  optimize depth of junction
- Avoid micro-discharges
  avoid field “spikes”
  optimize metal overhang
- …

p-stop No p-stop



Open p-stop

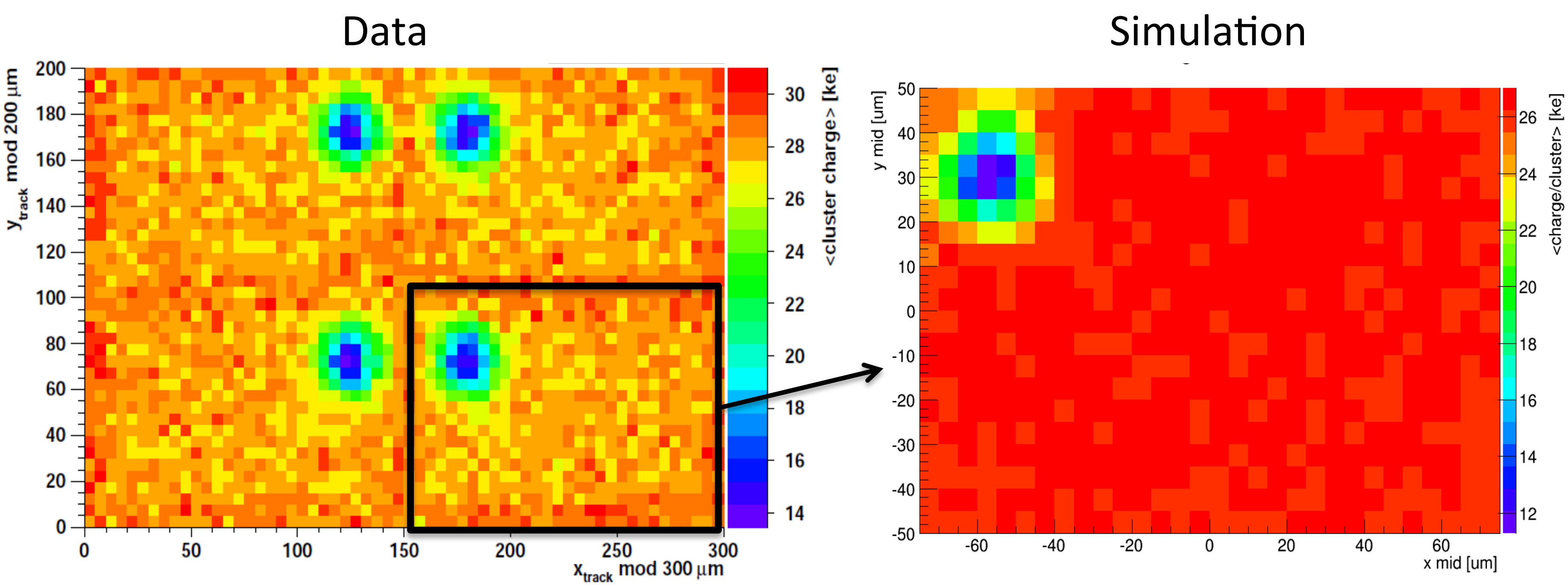
* Pixel designs produced in the HPK-campaign

Considerations on pixel design

Bias dot

Simulate effect on overall/local charge collection efficiency

➔ Data from DESY Test Beam (pixel phase 1 sensor)

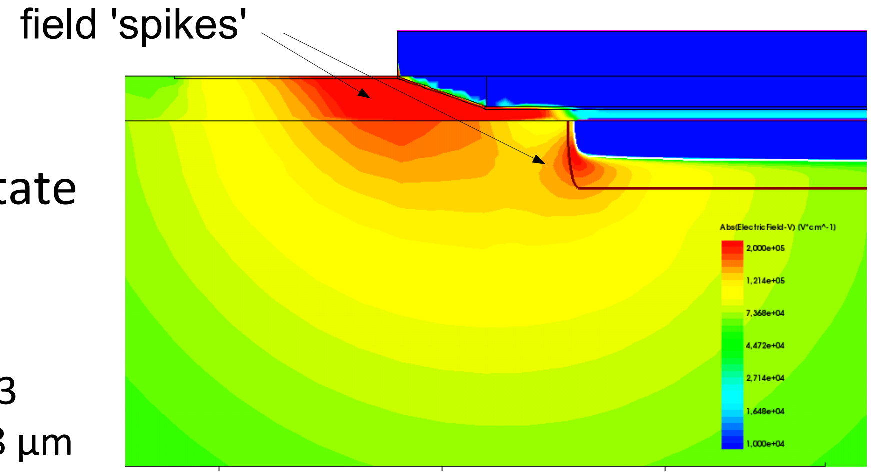


Similar studies already performed by PSI during the pixel design phase

Considerations on pixel design

High field region at strip edges leads

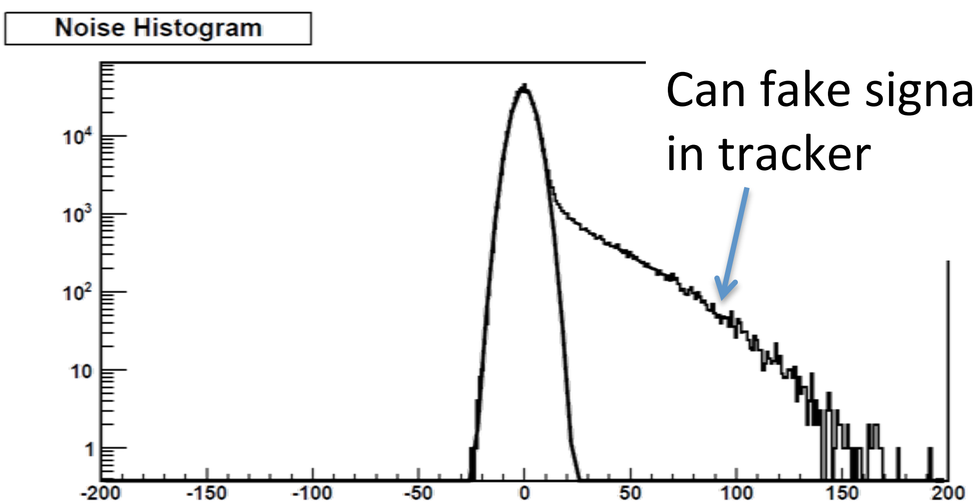
- More noise (mostly in n-type)
- Charge multiplication in non-defined state



E-field in p-in-n sensor (Synopsys T-CAD)

Simulations from HPK-campaign studies:

Sensor thickness: 200µm   Bias: 400V
Bulk doping: 3.5e12 cm-3 Implant doping: 5e18 cm-3
Oxide thickness: 1µm Oxide thickness under Al: 0.68 µm
Si3N4 thickness: 0.05 µm Oxide charge: 2e11cm-3



Can fake signals in tracker

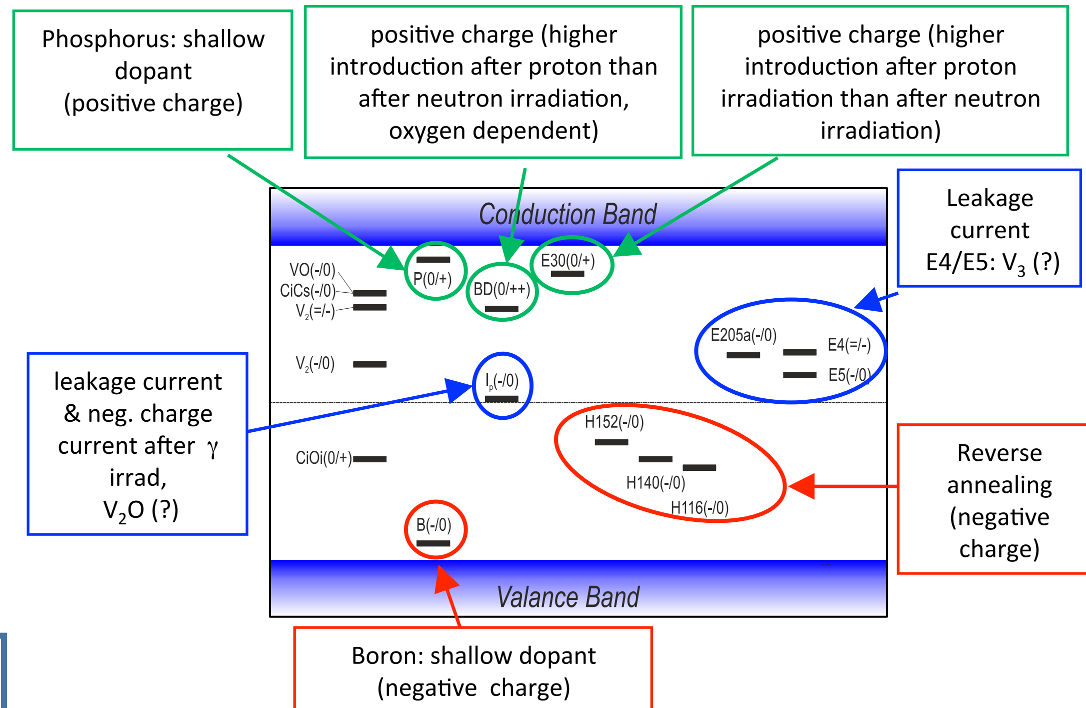
Non-Gaussian noise seen in most irradiated p-in-n sensors by several groups and using different readout systems throughout CMS HPK campaign

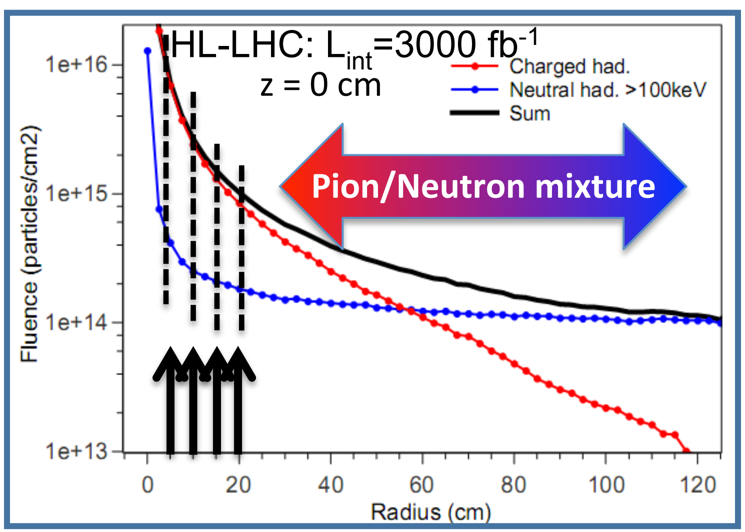
Radiation Hardness

Detailed understanding of bulk defects in past years

➔ Led to the decision in CMS to use n-in-p material for tracker

➔ Pixel will also use n-readout





Pixel: fluence dominated by charged particles

➔ surface damage cannot be neglected, may be a relevant issue also for strip tracker

Radiation Hardness

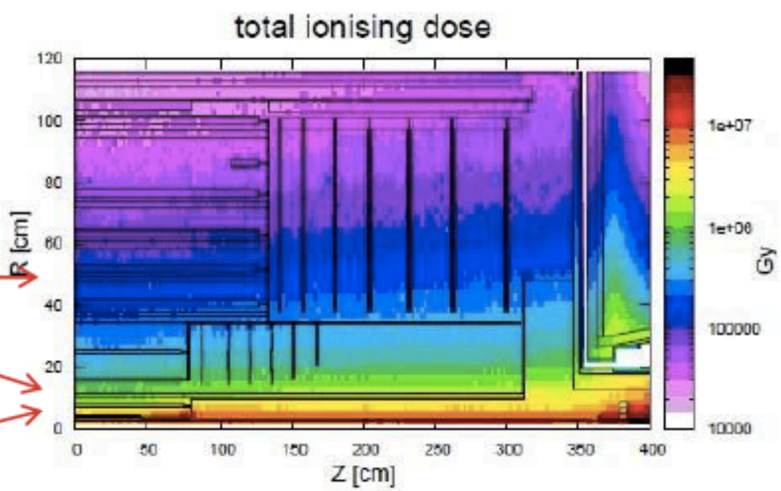
Surface damage (studies performed for AGIPD detector, XFEL)

ATLAS expected dose:

~100 kGy

~1 MGy

~4 MGy



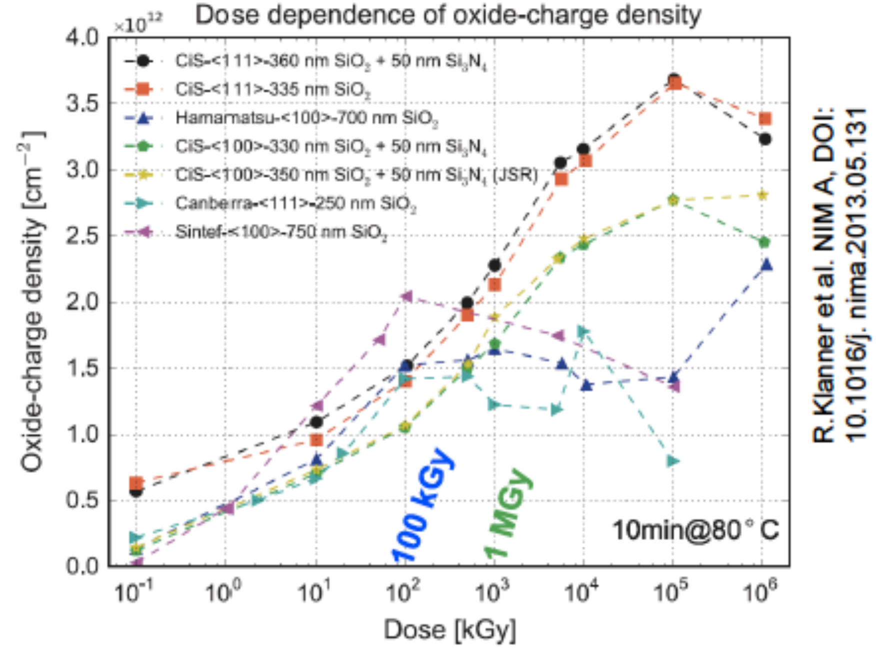


Fig. 1. Dependence of the surface-charge density, N_{ox}, on X-ray dose obtained from measurements on MOS capacitors from four different vendors after annealing for 10 min at 80 °C.

R.Klanner et al. NIM A, DOI: 10.1016/j. nima.2013.05.131

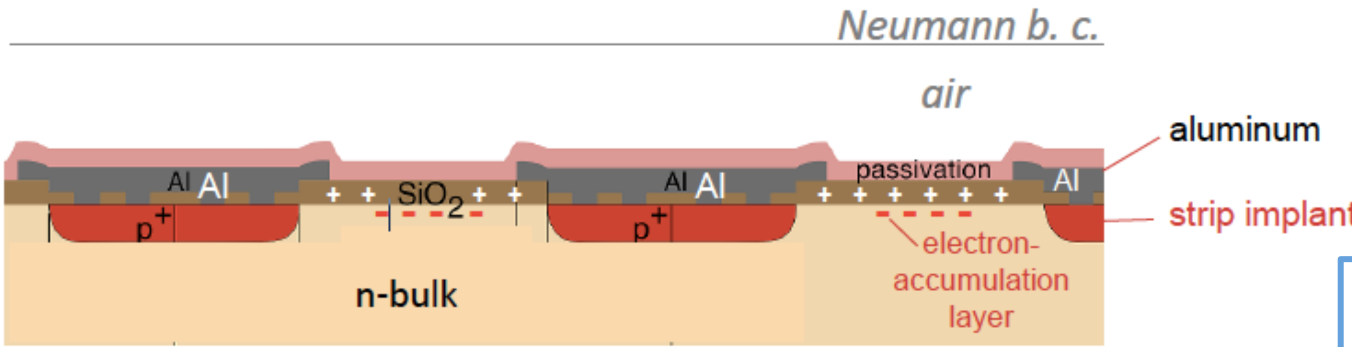
⇒ Oxide charge densities of 1 to 2·10^{12} cm^{-2} are expected at the HL-LHC (for R<60 cm)

➔ Need to study effect of surface damage in n-on-p sensors @ HL-LHC conditions

➔ Minimize surface effects by design

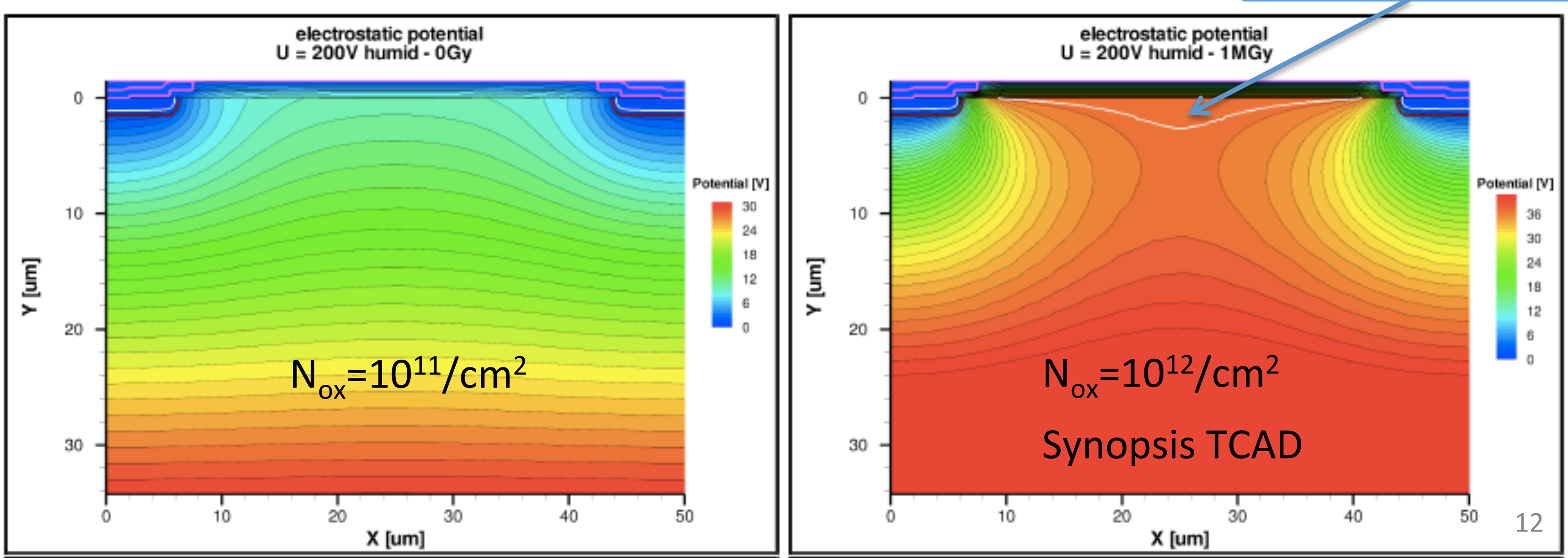
Radiation Hardness

Surface damage (studies performed for AGIPD detector, XFEL)



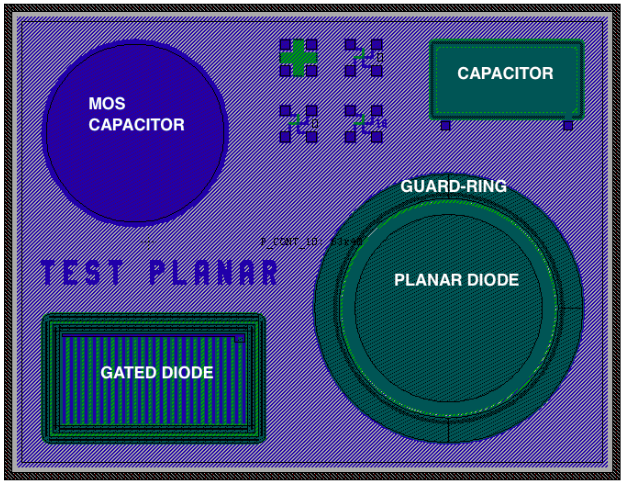
Study charge losses at the Si-SiO² interface and correlate them to the electric-field distribution and the boundary conditions.

Zero point of E field
95% e⁻ losses at ~3.5 um
(40% at 13 um)



R. Klanner, T. Poehlsen et al.
NIM A 700 (2013) 22-39

Simulation

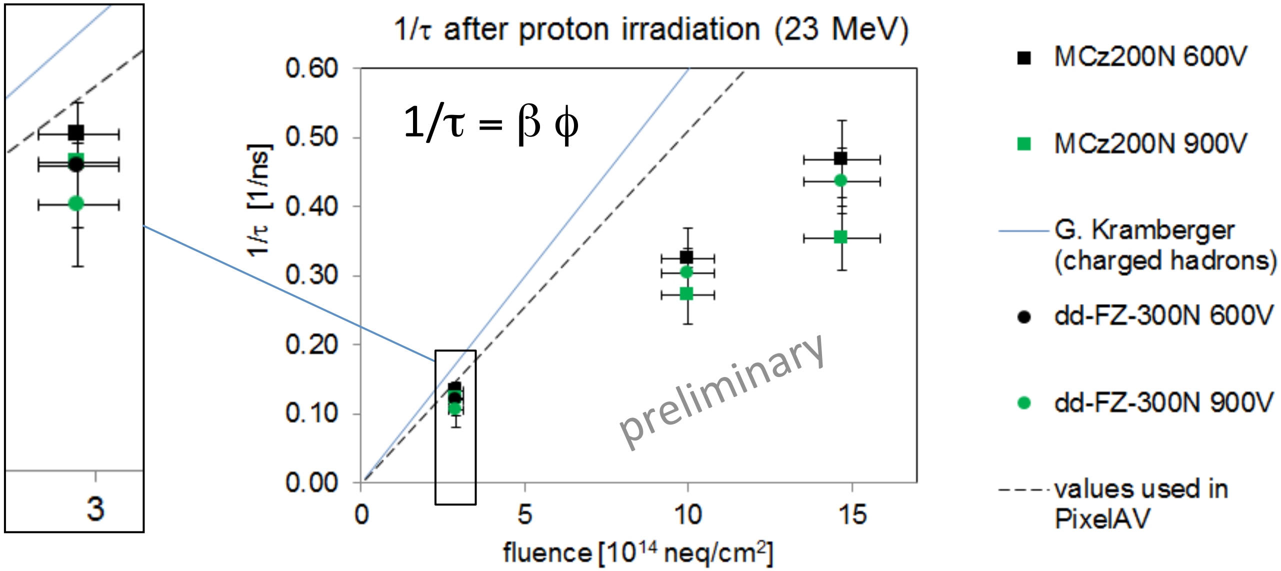


Validate T-CAD simulation for

- surface boundary conditions
- surface and bulk radiation damage
- exact pixel geometry (bias dot, field "spikes")

using measurements on dedicated structures

Validate trapping time (τ) model in simulation



TCT measurements on sensors from HPK-campaign at $\Phi \geq 10^{15}$ neq/cm^2 indicate that charge losses are overestimated in simulation (pixelAV)

Conclusion

- Pixel phase 2 activities in CMS have started
- In Germany contributions from DESY, KIT, UHH
  - Conclude studies initiated within the HPK-campaign (tracker phase 2)
  - thin planar silicon irradiated up to fluences ~3e16 n_{eq}/cm^2
- Coordinated effort with ATLAS (within RD50, RD53 and HGF-Alliance)