TCT measurements of HV-CMOS test structures irradiated with neutrons

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E-TCT measurements with HVCMOS structures from 3 different foundries made on different substrate resistivities:

1. **AMS**: 10 Ωcm and 20 Ωcm

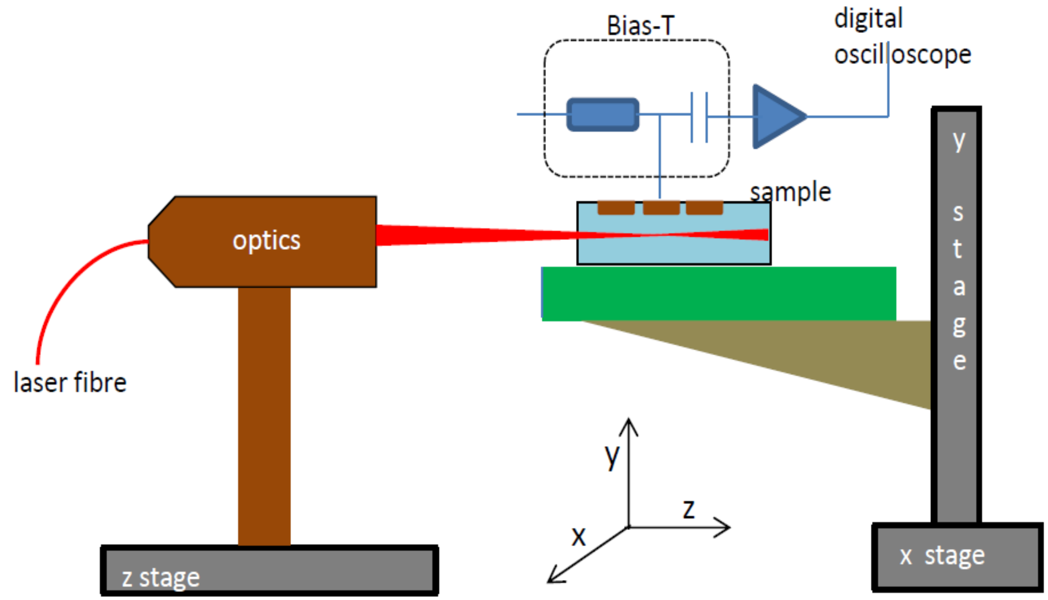
2. **X-FAB** :100 Ωcm

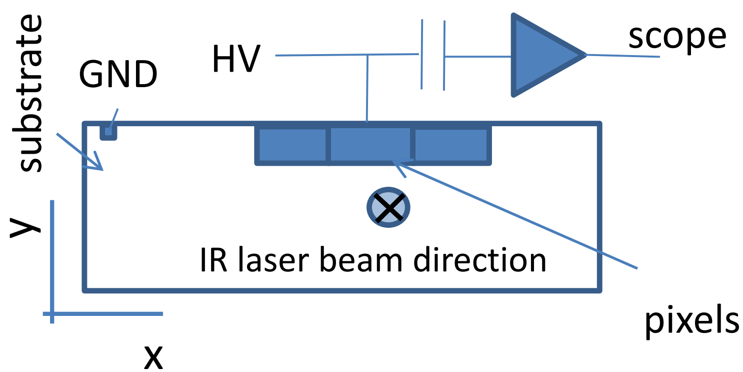
3. **LFoundry**: 2000 Ωcm

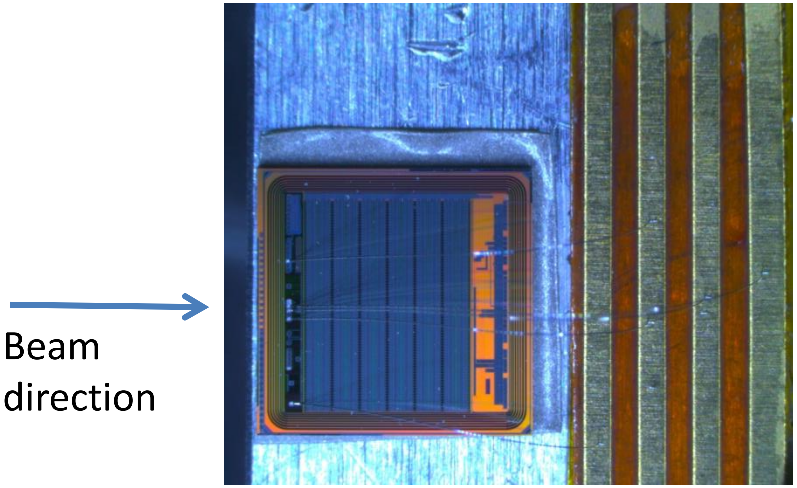
All devices are made on **p-type** substrates

These structures are investigated as candidates for tracking detectors at HL-LHC

E-TCT setup:







Passive devices (no amplifier in the pixel):

- ➔ observe induced current pulses on collecting electrode on the scope
- ➔ collected charge: integral of the pulse in 25 ns

AMS: 10 Ωcm, 20 Ωcm

CCPDv2 (HV2FEI4) chip, AMS 0.18 μm process:

→ active device: output of the amp in the n-well observed on the scope

- substrate resistivity **10 Ωcm**
- max bias 60 V

CHESS1 chip, AMS 0.35 μm process:

→ passive device

- substrate resistivity **20 Ωcm**
- max bias 120 V

Back plane not processed

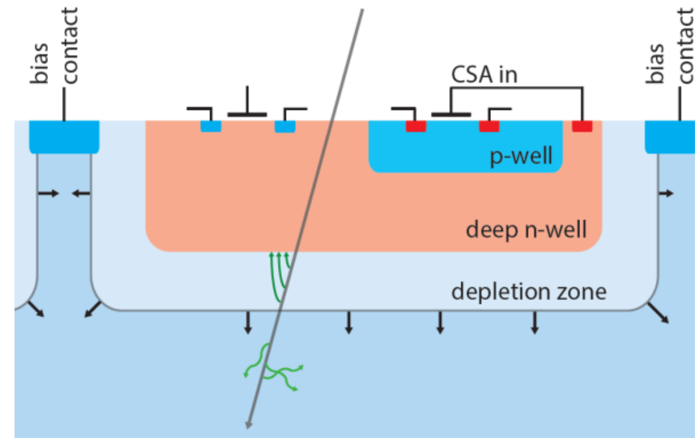
→ bias connected from the top of the chip

More detail:

I. Perić et al., NIMA582 (2007) 876-885

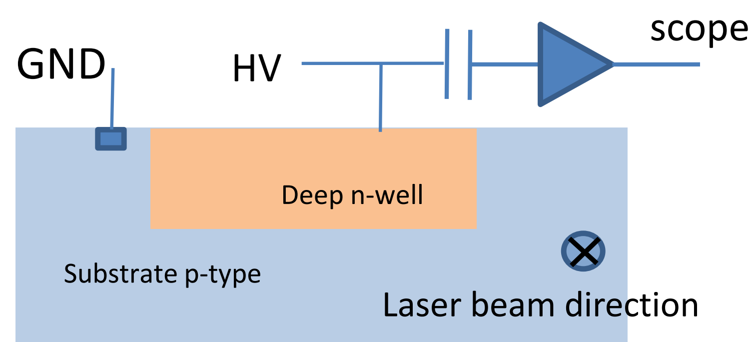
I. Perić et al., NIMA765 (2014) 172-176

I. Peric et al., 2015 JINST 10 C05021.



From: S. Fenandez-Perez, TWEPP 2015

Passive pixel: no electronic in the n-well



LFoundry: 2000 Ωcm

- 150nm CMOS
- 2 kΩcm p-type bulk
- HV process, max bias > 100 V
- Thinning and back side metallization possible

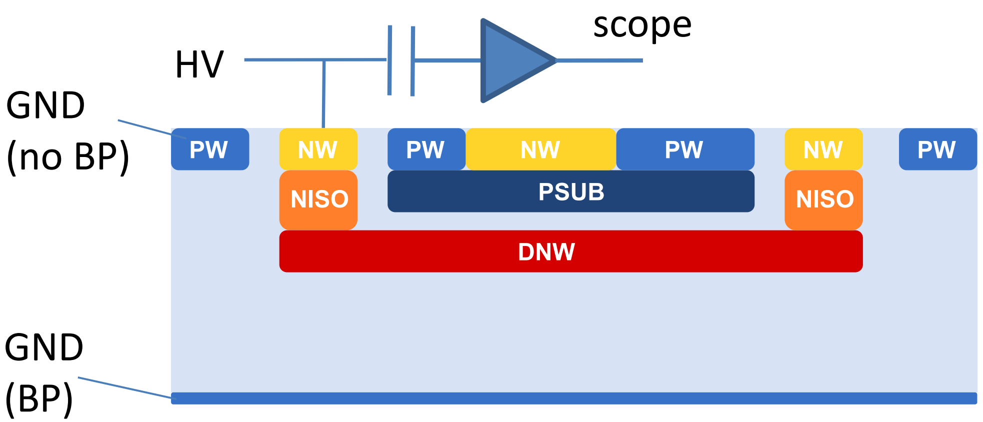
More detail:
- Piotr RYMASZEWSKI et al., *Prototype active silicon sensor in LFoundry 150nm HV/HR-CMOS technology for ATLAS Inner Detector Upgrade* (TWEPP 2015), **2016 *JINST* 11 C02045**

https://indico.cern.ch/event/357738/session/9/contribution/200

CCPDLF_VB chip
two versions:

- without back side (BP) metallization
  → substrate bias from top
- with BP
  → substrate bias from the back plane

Measurements done with structures **A** and **F** on **CCPDLF_VB** chip
→ see slides from F. Hügging from this morning



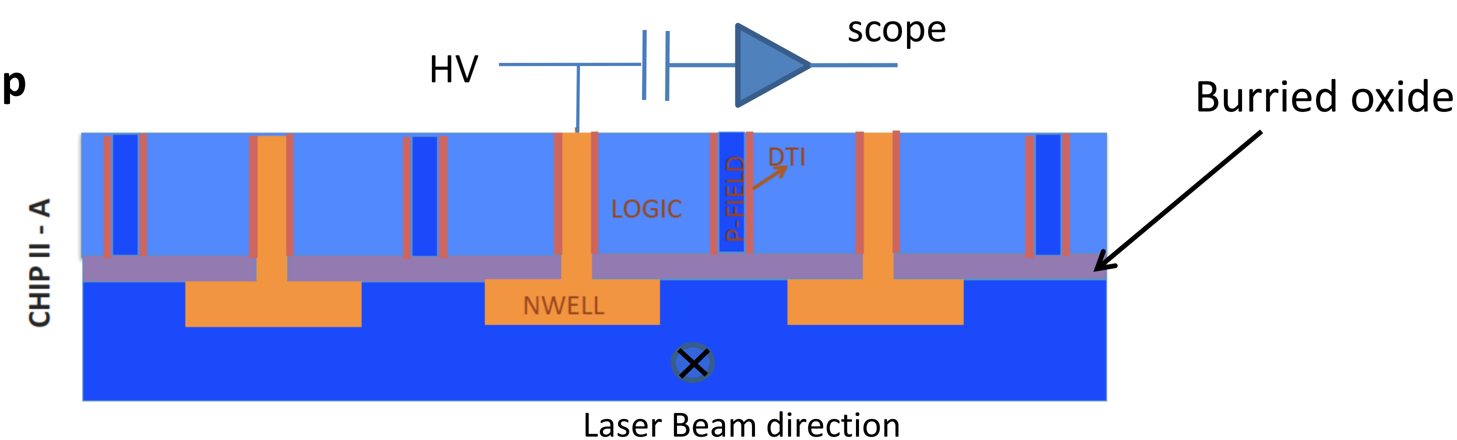
X-FAB: 100 Ωcm

- X-FAB Trench SOI 0.18 um
- p-type bulk, 100 Ωcm
- max bias 300 V
- no back side processing (bias from TOP)

More detail:

- S. Fernandez et al., *Charge Collection Properties of a Depleted Monolithic Active Pixel Sensor using a HV-SOI process* (TWEPP 2015), **2016 *JINST* 11 C0106**
https://indico.cern.ch/event/357738/session/9/contribution/3
- S. Fernandez-Perez et al., *Radiation hardness of a 180nm SOI monolithic active pixel sensor*, NIMA 796 (2015) 13.
- T. Hemperek et al., *A Monolithic Active Pixel Sensor for ionizing radiation using a 180 nm HV-SOI process,* NIMA 796(2015)8-12
- slides of M. Backhaus from this morning session

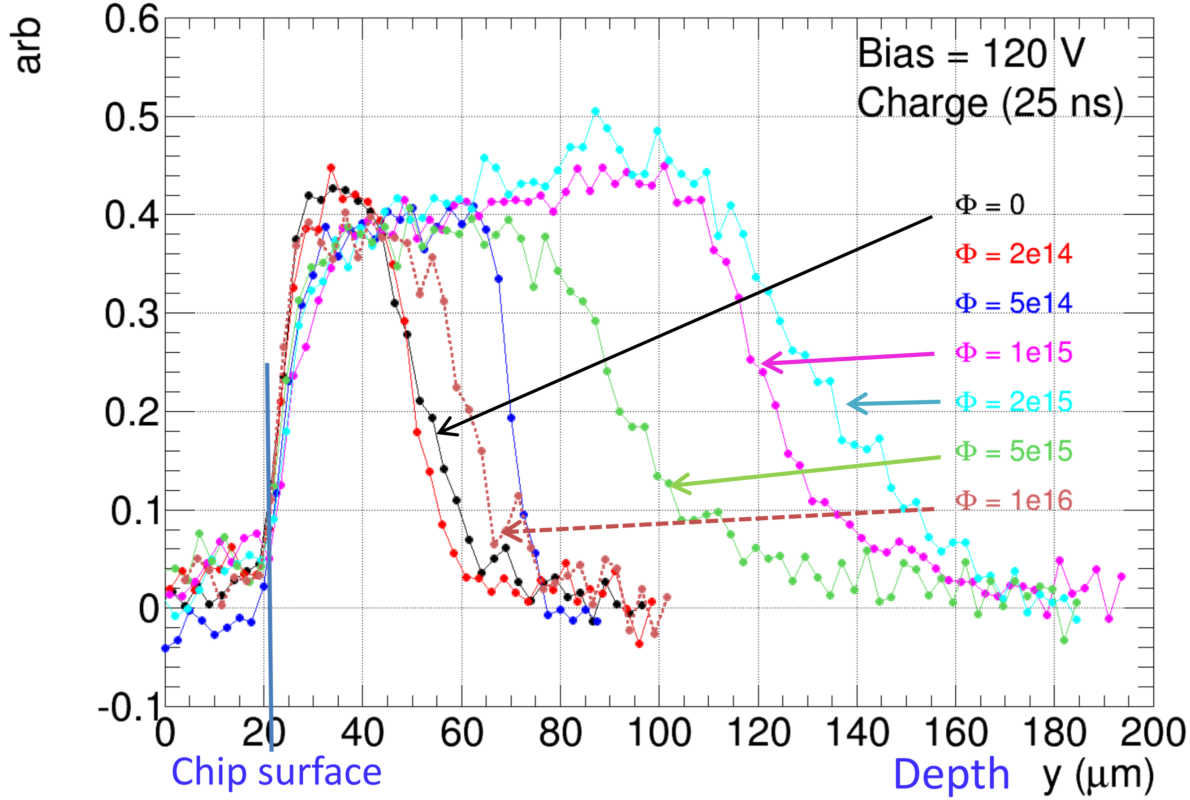
XTB02 chip

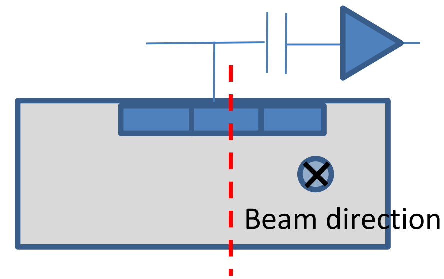


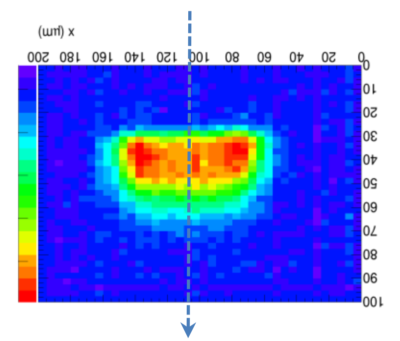
E-TCT, charge collection profile, AMS (20 Ωcm)

Fluence steps: 2e14, 5e14, 1e15, 2e15, 5e15, 1e16

G. Kramberger et al., submitted to JINST
I. Mandić et al., 27th RD50 workshop







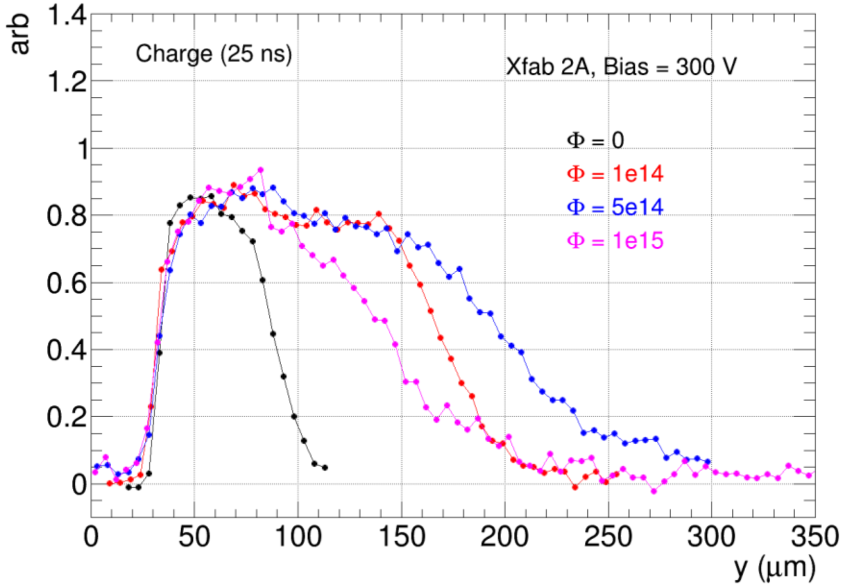
- charge collection width increases with fluence up to ~ 2e15 n/cm^2
  - ➔ concentration of initial acceptors falls with irradiation faster than new acceptors are introduced → space charge concentration falls
- charge collection width falls with fluences above ~ 2e15 n/cm^2
  - ➔ initial acceptor removal finished, space charge concentration increases with irradiation
- **at 1e16 charge collection region still larger than before irradiation**

→ similar behaviour also in CCPDv2 chip (10 Ohm-cm)

E-TCT, charge collection profiles, Lfoundry, X-FAB

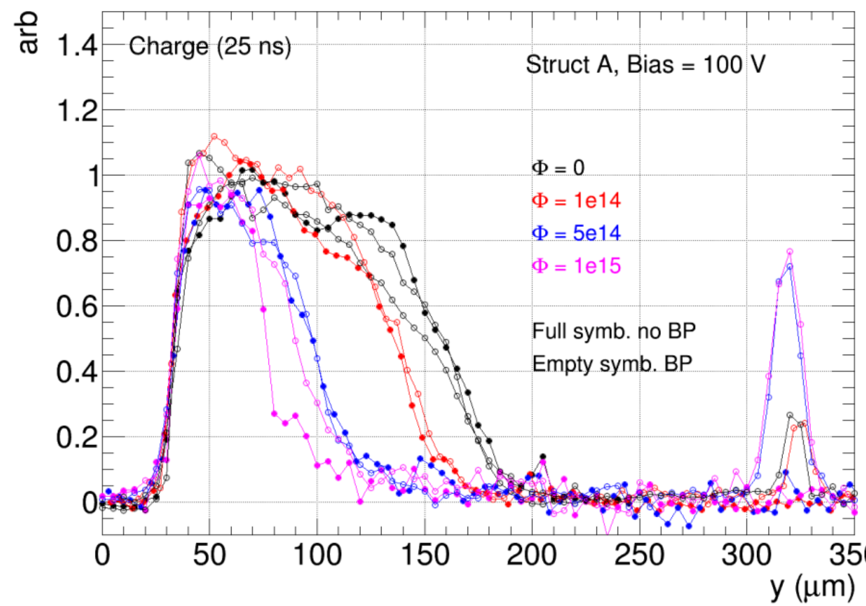
Irradiated up to 1e15 n/cm^2

X-FAB (100 Ohm-cm)



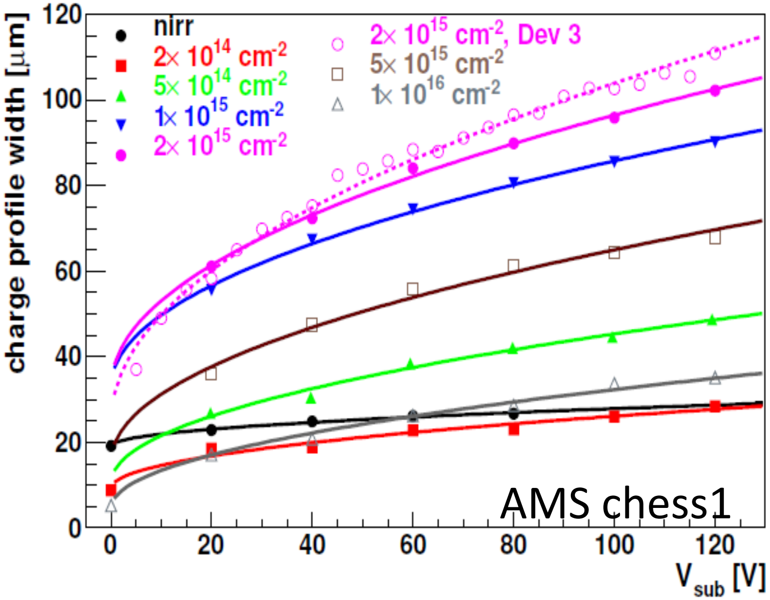
Large increase of charge collection width after 1e14 and 5e14
→ effective acceptor removal in X-FAB

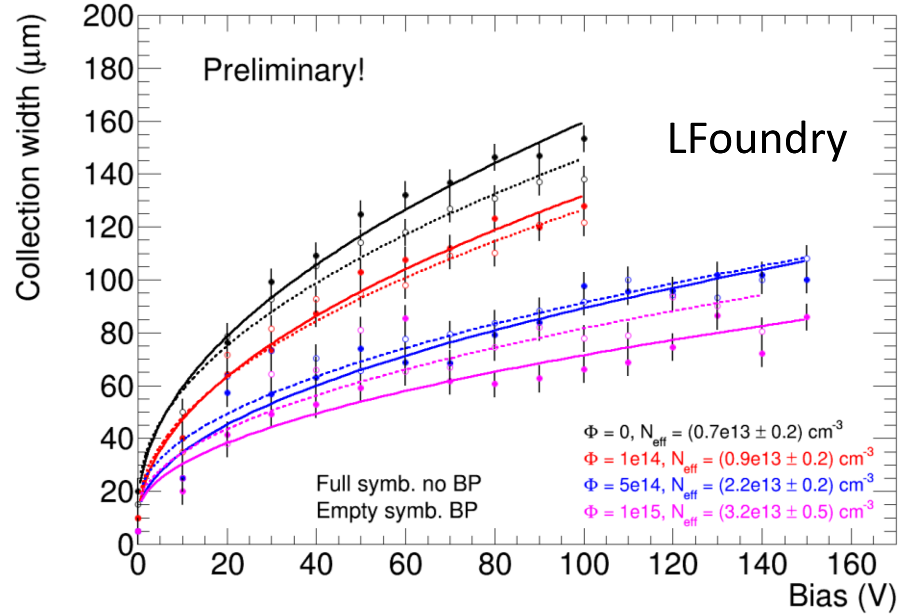
LFoundry (2000 Ohm-cm)
Structure A



Charge collection width doesn't increase with irradiation
→these measurements show no effective acceptor removal effect in LFoundry
→some difference between Back Plane and no Back Plane samples at highest fluence

Charge profile width vs bias voltage





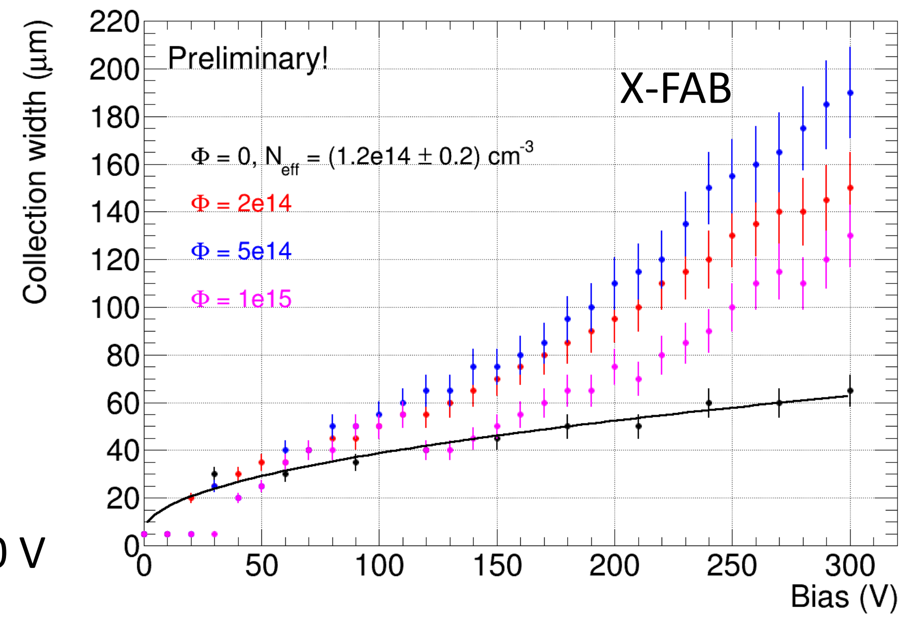
Fit: $$Width(V_{bias}) = w_0 + \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$$

w_0 and ***N_{eff}*** free parameters

→works for AMS and LFoundry

→X-FAB: can't fit with sqrt(V_{bias})

- estimate N_{eff} from width at ~100 V



N_{ef} vs fluence

AMS and X-FAB:

acceptor removal

Radiation introduced deep acceptors: $g \sim 0.02\ \mathrm{cm}^{-1}$

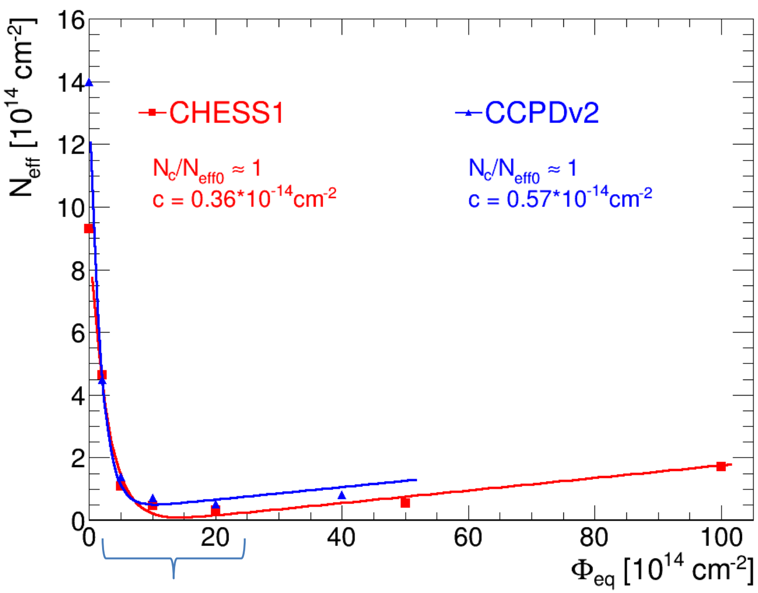
Fit: $N_{eff} = N_{eff\,0} - N_c \cdot (1 - \exp(-c \cdot \Phi_{eq})) + g \cdot \Phi_{eq}$

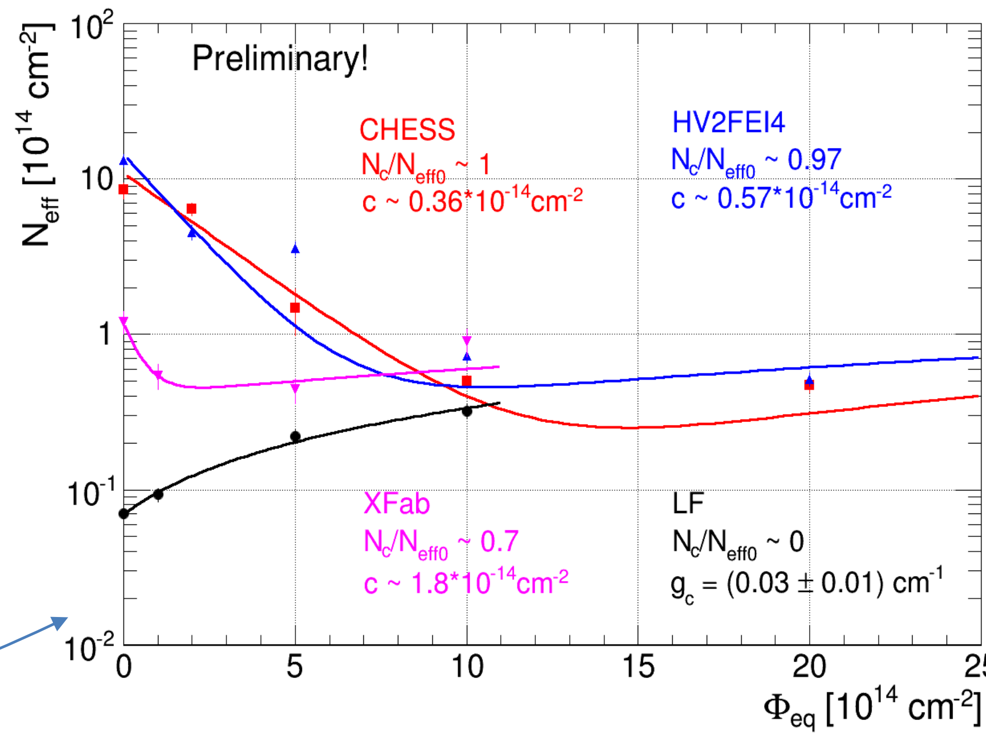
N_c, N_{eff0} and c free parameters, g fixed to 0.02

LFoundry: no removal ($N_c \sim 0$), fit: $N_{eff} = N_{eff\,0} + g \cdot \Phi_{eq}$ N_{eff0} and g free

G. Kramberger et al., submitted to JINST

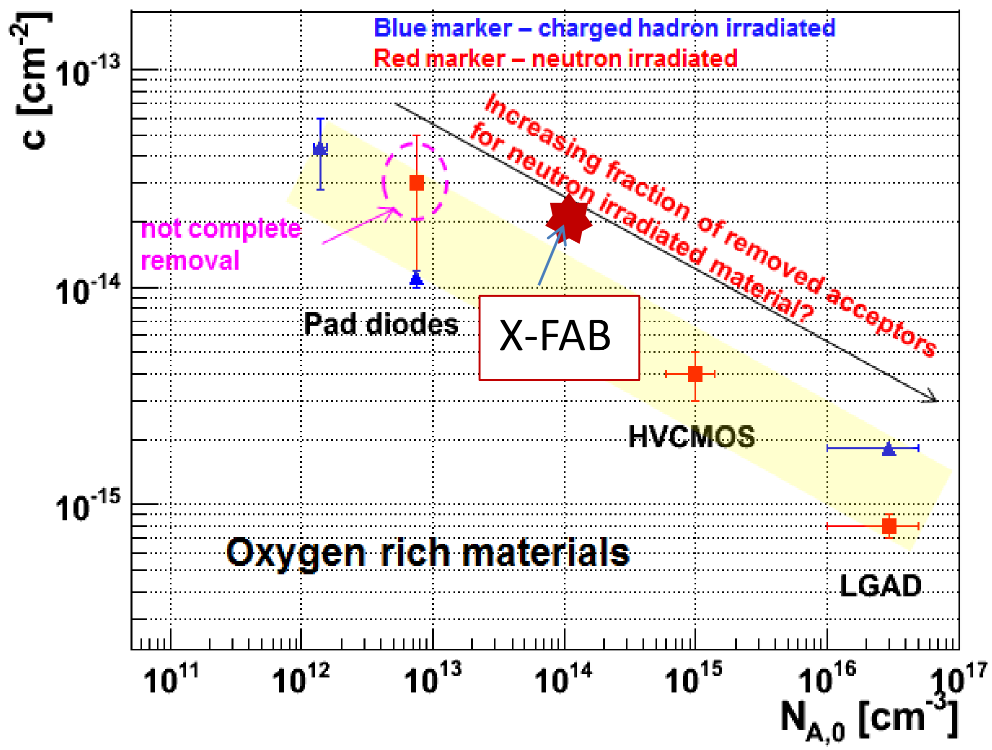
I. Mandić et al., 27th RD50 workshop





Effective acceptor removal

G. Kramberger et al, 10th Trento Meeting, Feb. 17-19, 2015

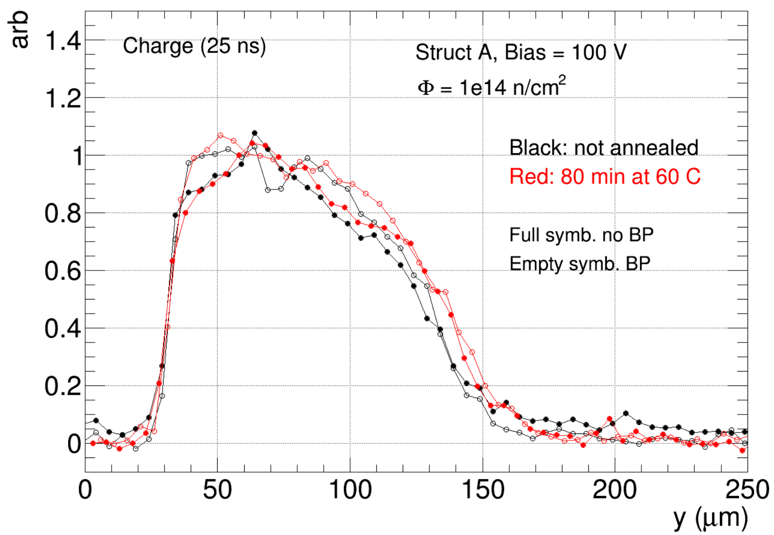


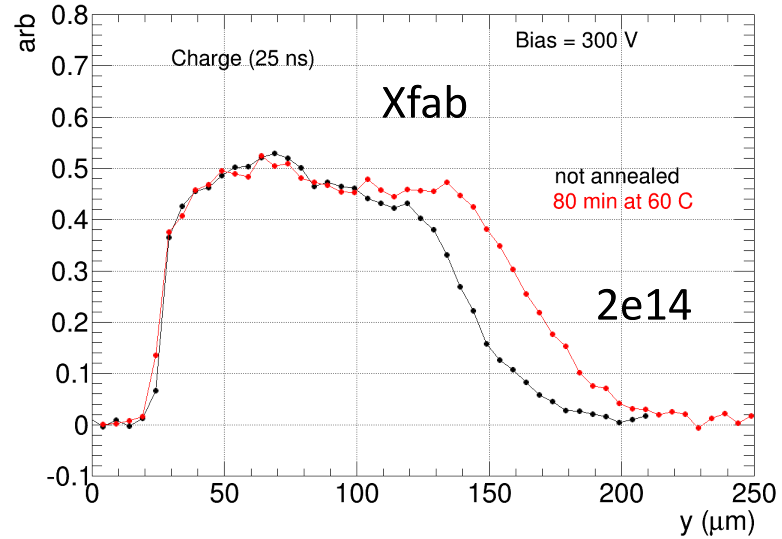
- AMS (20 Ωcm, $N_{A0} \sim 10^{15}$ cm^{-3}): $c \sim 4\cdot10^{-15}$ cm^{-2}, $N_c/N_{eff0} \sim 1$
- X-FAB (100 Ωcm, $N_{A0} \sim 10^{14}$ cm^{-3}): $c \sim 2\cdot10^{-14}$ cm^{-2}, $N_c/N_{eff0} < 1$
- LFoundry (2000 Ωcm, $N_{A0} \sim 6\cdot10^{12}$ cm^{-3}), no effective acceptor removal observed in this study
  ➔ probably because $N_c/N_{eff0} << 1$

Charge collection profile - annealing

Measurement before and after 80 minutes at 60 C

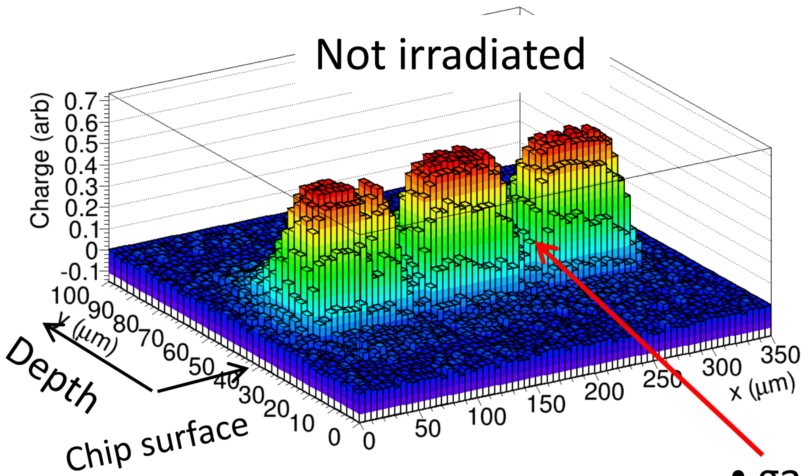
→ 10% to 20 % increase of charge collection width after annealing

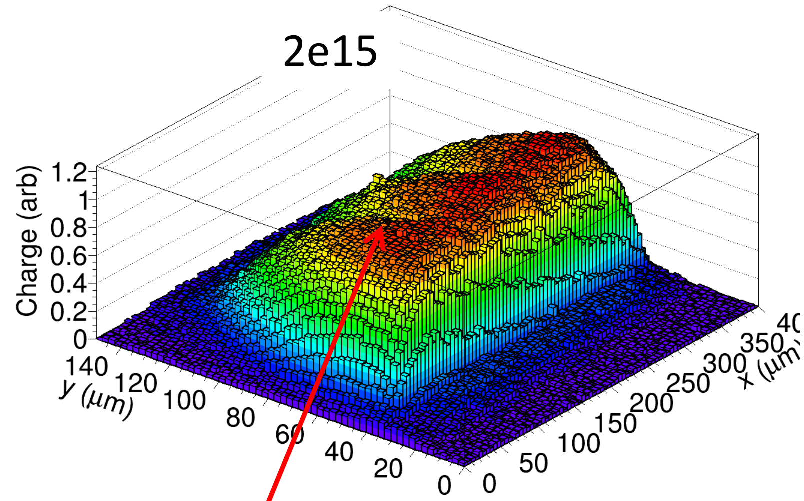




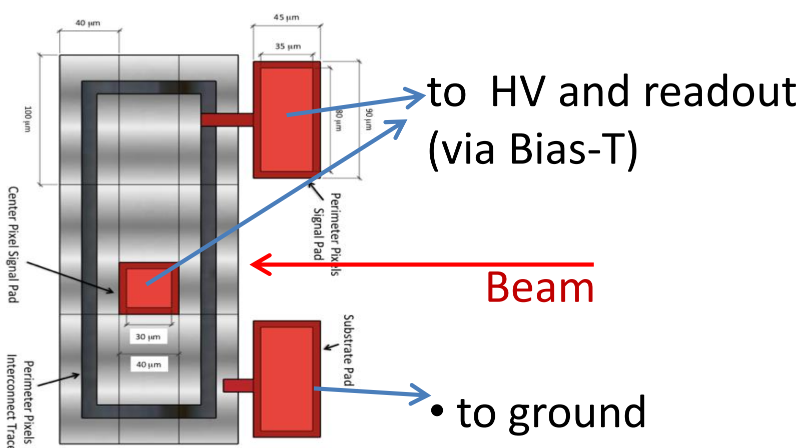
Measurenents with pixel array: AMS (20 Ωcm)

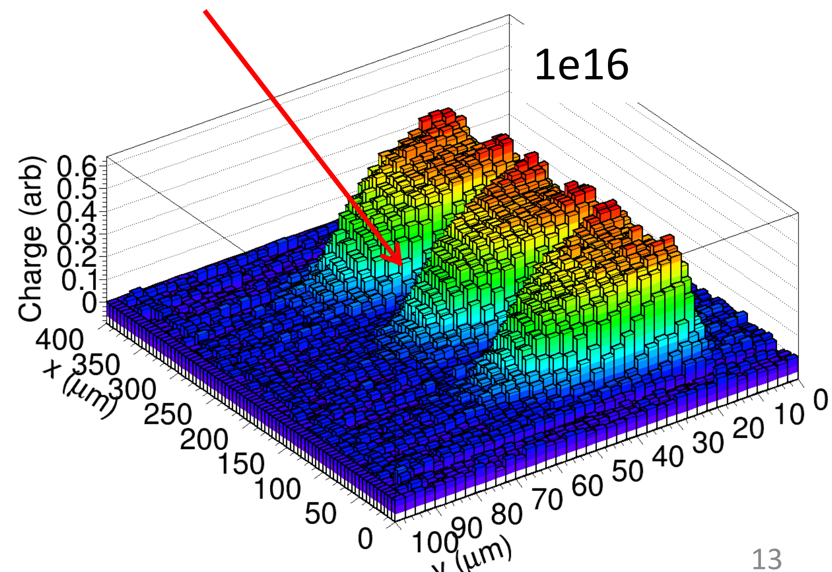
Bias = 120 V, all 9 pixels connected to readout, charge (25 ns)





- gaps before irradiation
- guard smaller after 2e15 (larger depleted region)
- gaps better seen again after 1e16

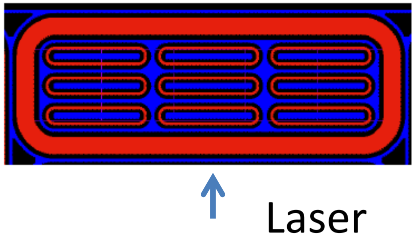




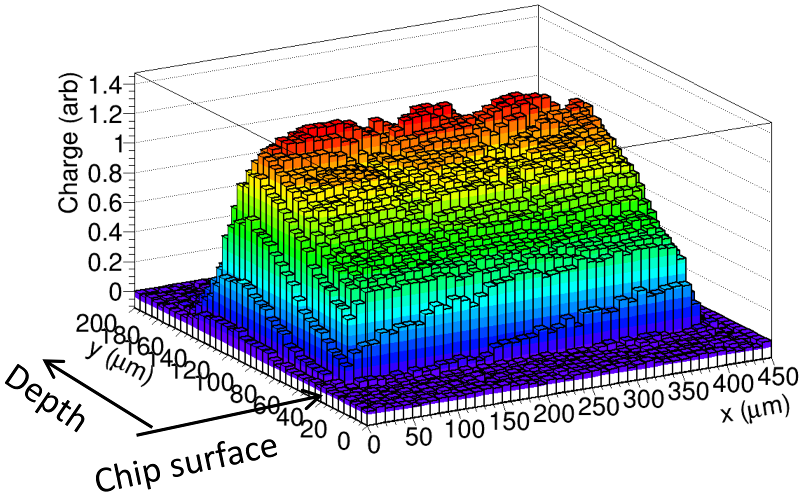
LFoundry, Structure F, all pixels read out

➔ no efficiency gaps between pixels

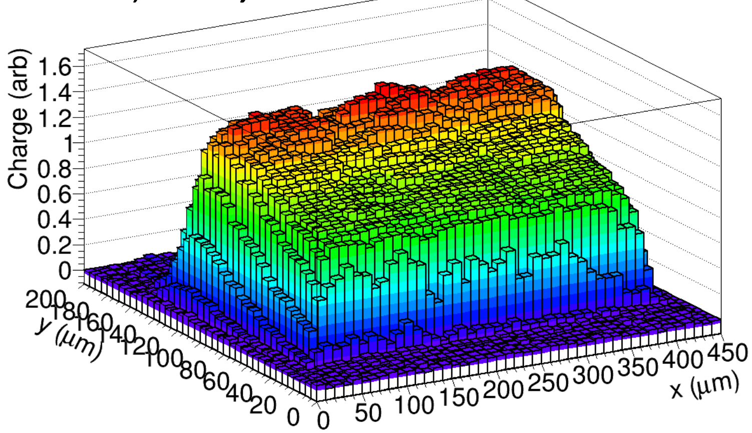
Structure F, 3x3 pixels,
125 µm x 33 µm



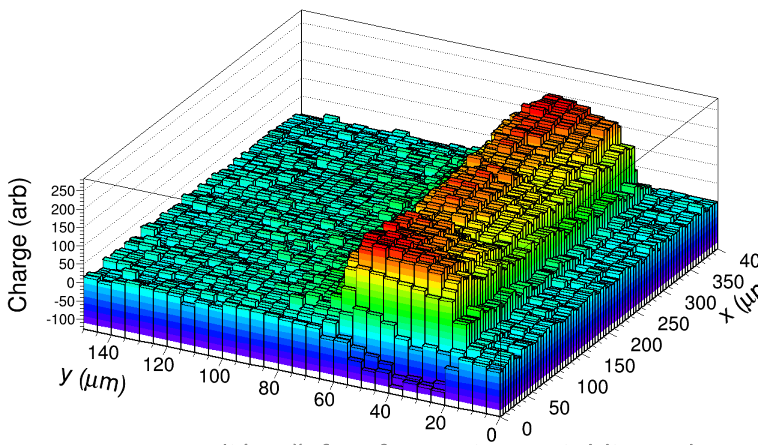
No BP, 40 V, **Φ = 0**



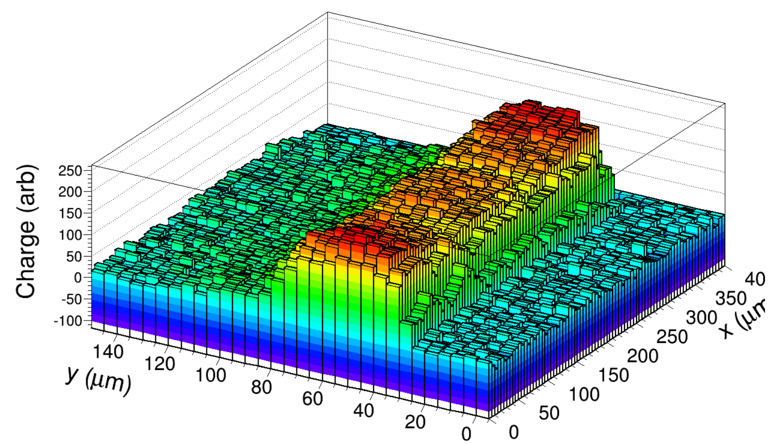
BP, 40 V**, Φ = 0**



No BP, 50 V, **Φ = 1e15**

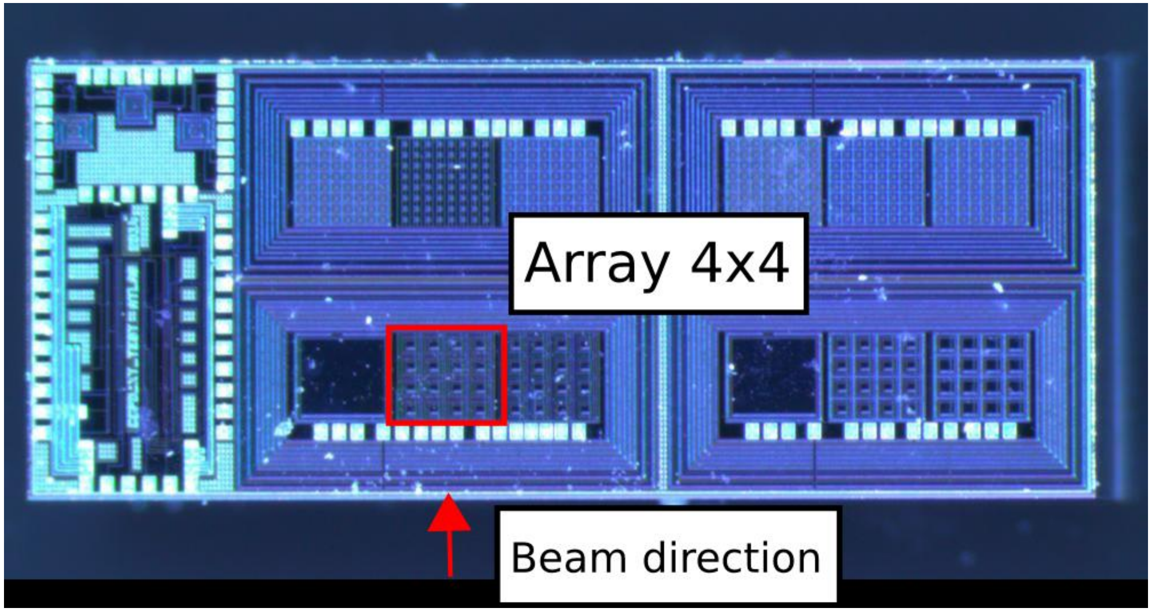


BP, 50 V, **Φ = 1e15**

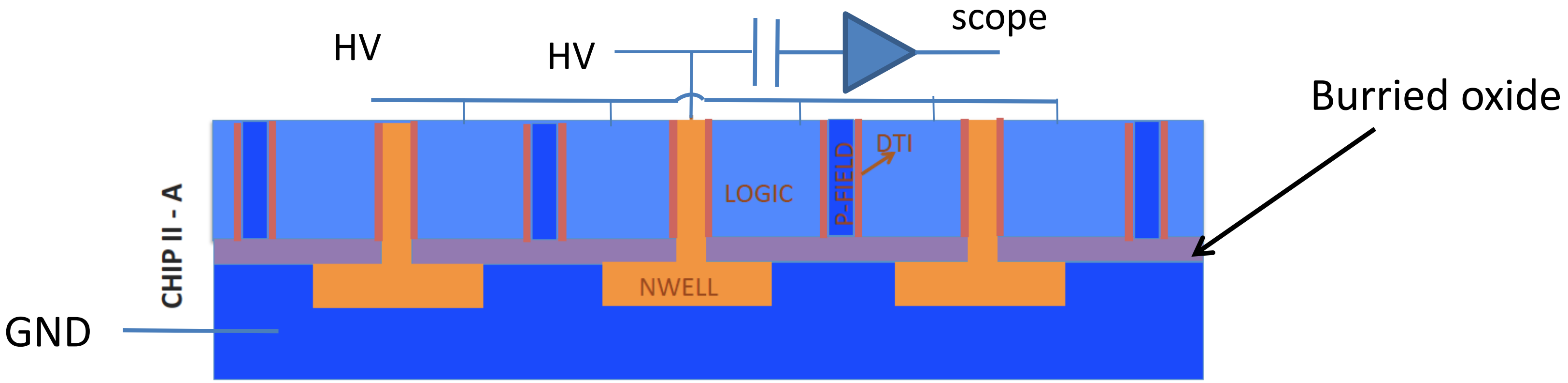


X-FAB: 100 Ωcm

XTB02 chip



- pitch 100 µm
- n-well: 40 µm x 50 µm

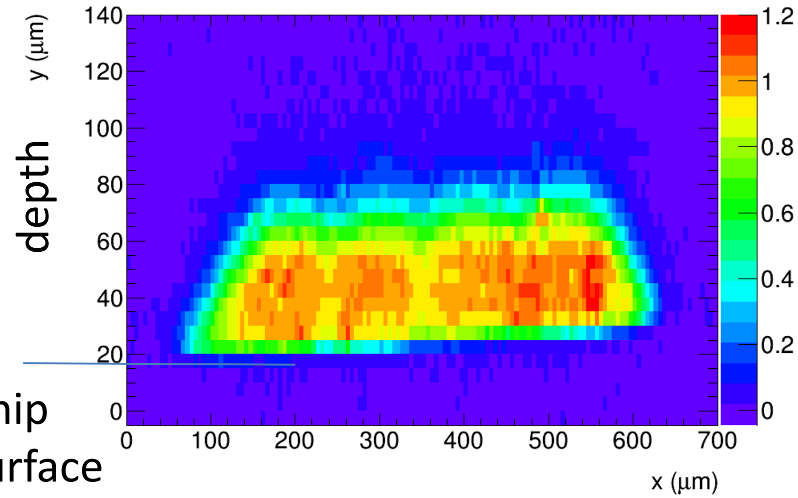


→ "logic" (space for CMOS circuits for active device) and n-well should be at same potential

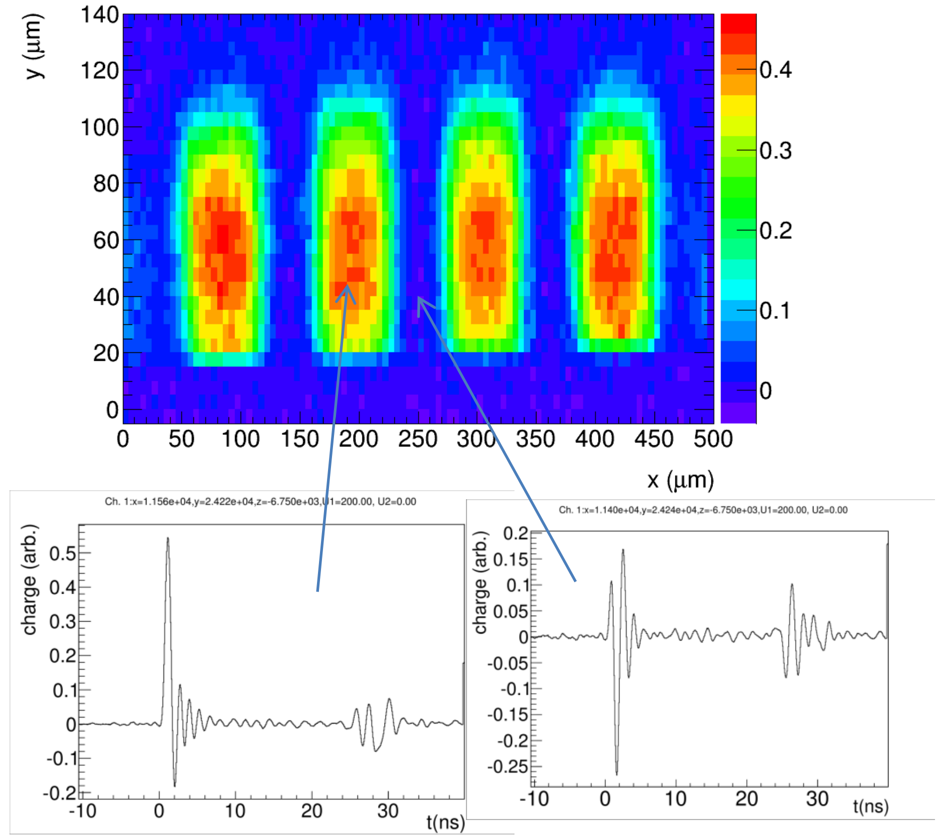
X-FAB: 100 Ωcm

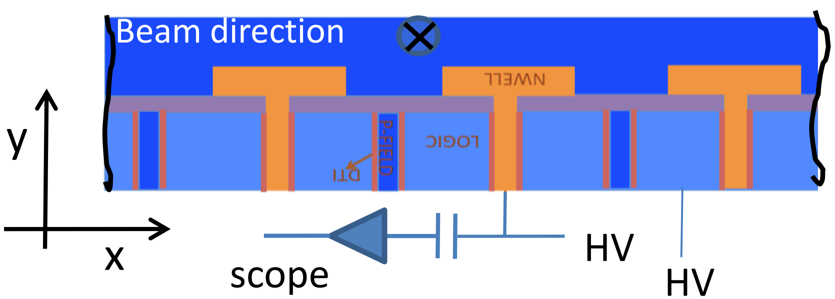
• 4x4 pixel array, all n-wells connected to readout

Before irradiation



After 2e14 n/cm2





• high collection under n-wells

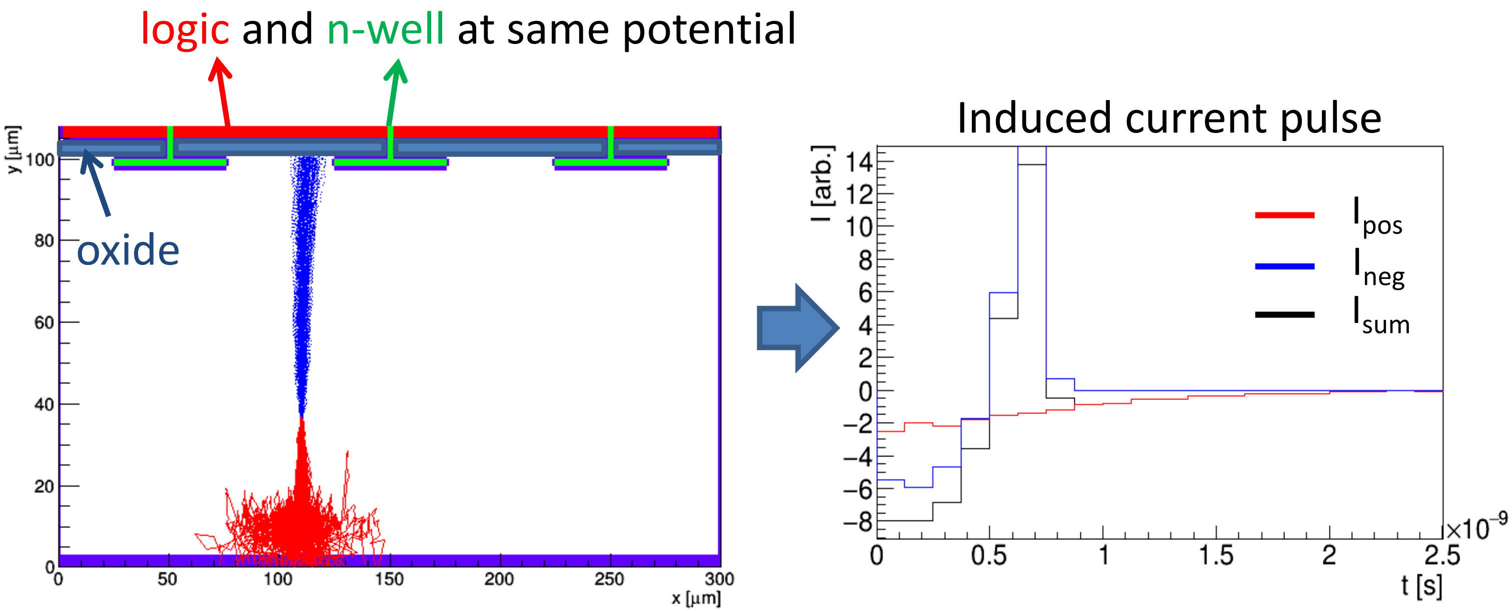
• low charge between ➔ but E-field not zero

➔ large pulses with small integral

➔ looks like "logic" acts as collecting electrode (AC coupled)

KDetSim simulation

- KDetSim - a ROOT based detector simulation package by G. Kramberger (link) (presented at 27th RD 50 Workshop)
- link to the software: http://www-f9.ijs.si/~gregor/KDetSim/



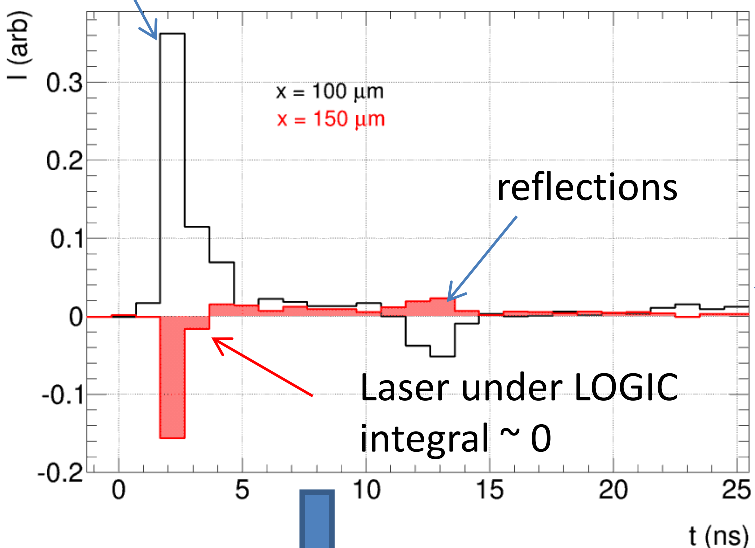
Bipolar pulse on n-well electrode:
Integral = 0

- drift of electrons stops on the oxide surface
- bipolar pulse induced on the readout electrode → integral in 25 ns = 0

Efficiency gaps smaller at longer integration times

Laser under n-well

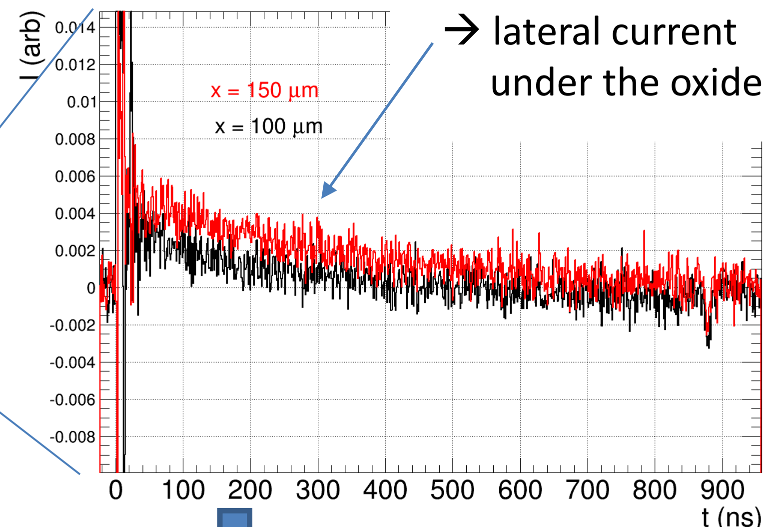
25 ns time scale:



reflections

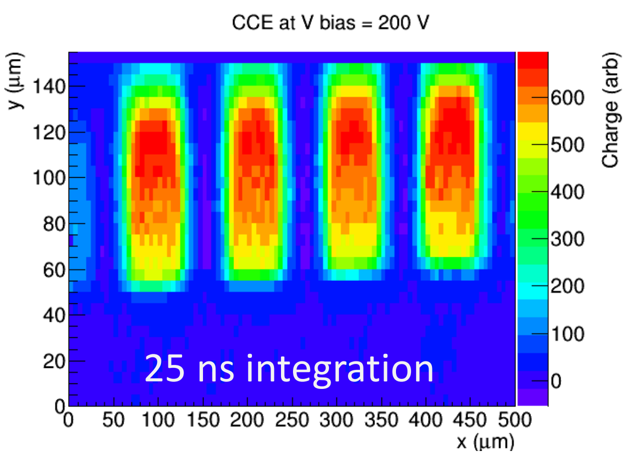
Laser under LOGIC
integral ~ 0

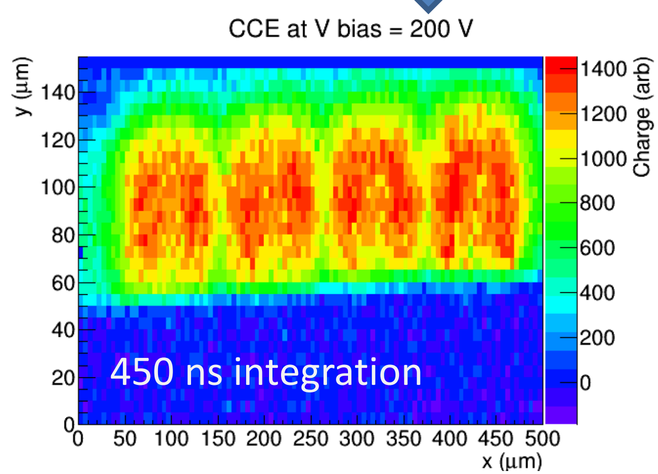
1 μs time scale:

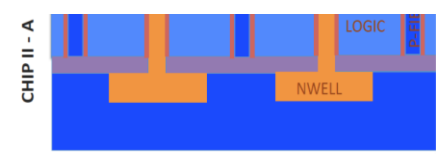


- tail larger when laser under logic (red curve)
- slow electrical discharge → lateral current under the oxide layer

$\Phi = 5e14$







Summary

- Edge-TCT measurements with test structures made on 3 different substrate resistivities:
    - AMS : 10 and 20 Ωcm
    - X-FAB: 100 Ωcm
    - LFoundry: 2000 Ωcm

- large increase of charge collection width after irradiation with neutrons observed in AMS and X-FAB
    - dependence of charge collection width with fluence consistent with effective acceptor removal
    - indication that acceptor removal in X-FAB less complete than in AMS

- X-FAB:
    - increase of charge collection width with bias voltage after irradiation faster than sqrt(V)
    - efficiency gaps between pixels after irradiation (at short (25 ns) integration times)
      → parasitic (temporary) charge collection by the "logic" electrode

- LFoundry: charge collection width decreases with increasing fluence
      → effective acceptor removal not observed
      → N_{eff} introduction rate on high side
    - no significant charge collection gaps between pixels in the array
    - indication of effect of back plane contact at highest fluence (1e15 n/cm^2)