Measurements of LGAD Properties & First Use in a HEP Experiment

UFSD2: new 50 µm LGAD Production at FBK

V. Sola for the UFSD Group

INFN and Università di Torino, Università del Piemonte Orientale, UCSC
FBK, TIFPA, Università di Trento (FBK production)

OUTLINE

- **LGAD from CNM**
  - Measurement of α parameter
  - Measurement of k parameter
  - Measurement on Epi LGAD
  - First installation of UFSD in HEP experiment

- **LGAD from Hamamatsu**
  - Laser scan on multi-pad sensor surface
  - Beam test results

- **LGAD from FBK**
  - First UFSD production at 50 µm

LGAD from CNM

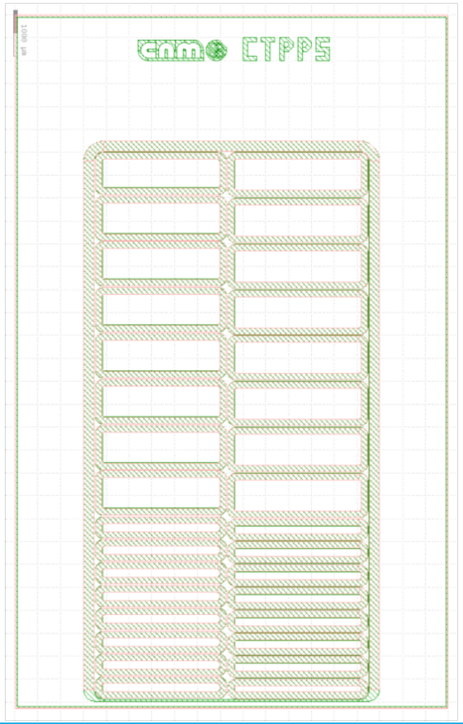
CNM - Irradiated Sensors

CNM Run 9088 50 µm [1]	
Doses:	2.0
	1.9
	1.8

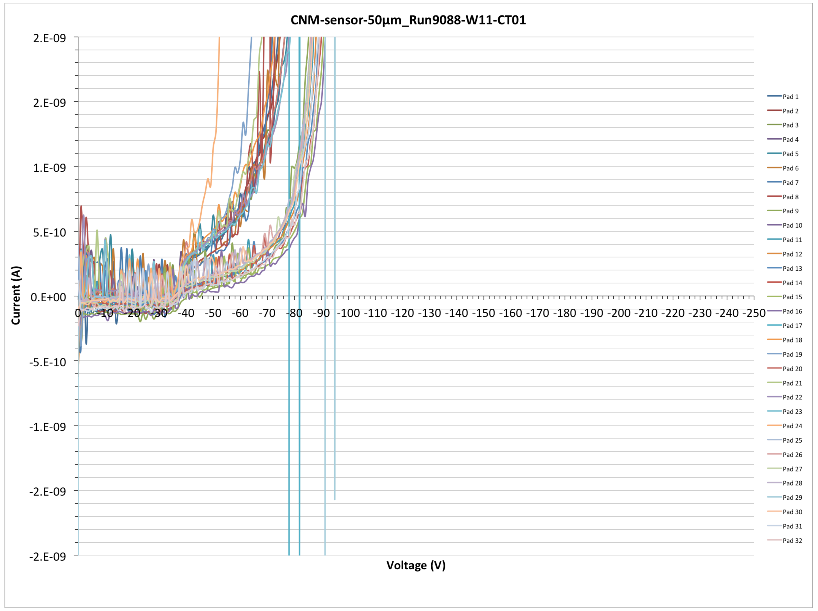
☞ **irradiated to 3x10^{14} and 5x10^{14} n/cm^2**

[1] M. Carulla, 28th RD50 Workshop, Torino, Italy, June 2016

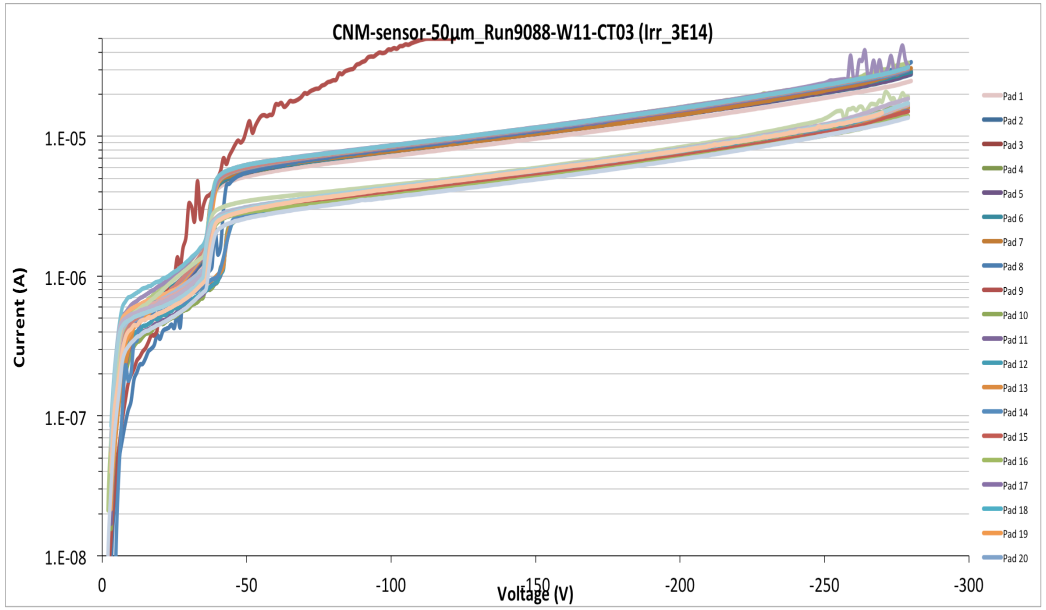
First CNM 50 µm LGAD production, released in Spring 2016



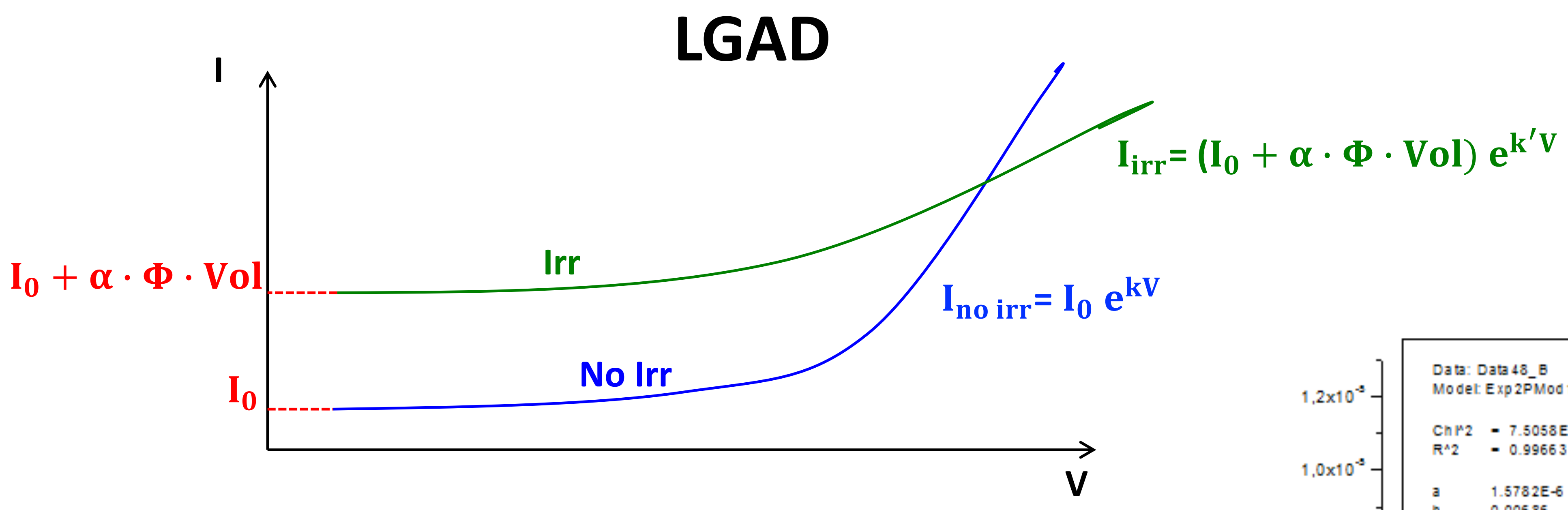
IV pre Irradiation



IV after Irradiation at 3x10^{14} n/cm^2



IV CURVE STUDIES - α and k determination



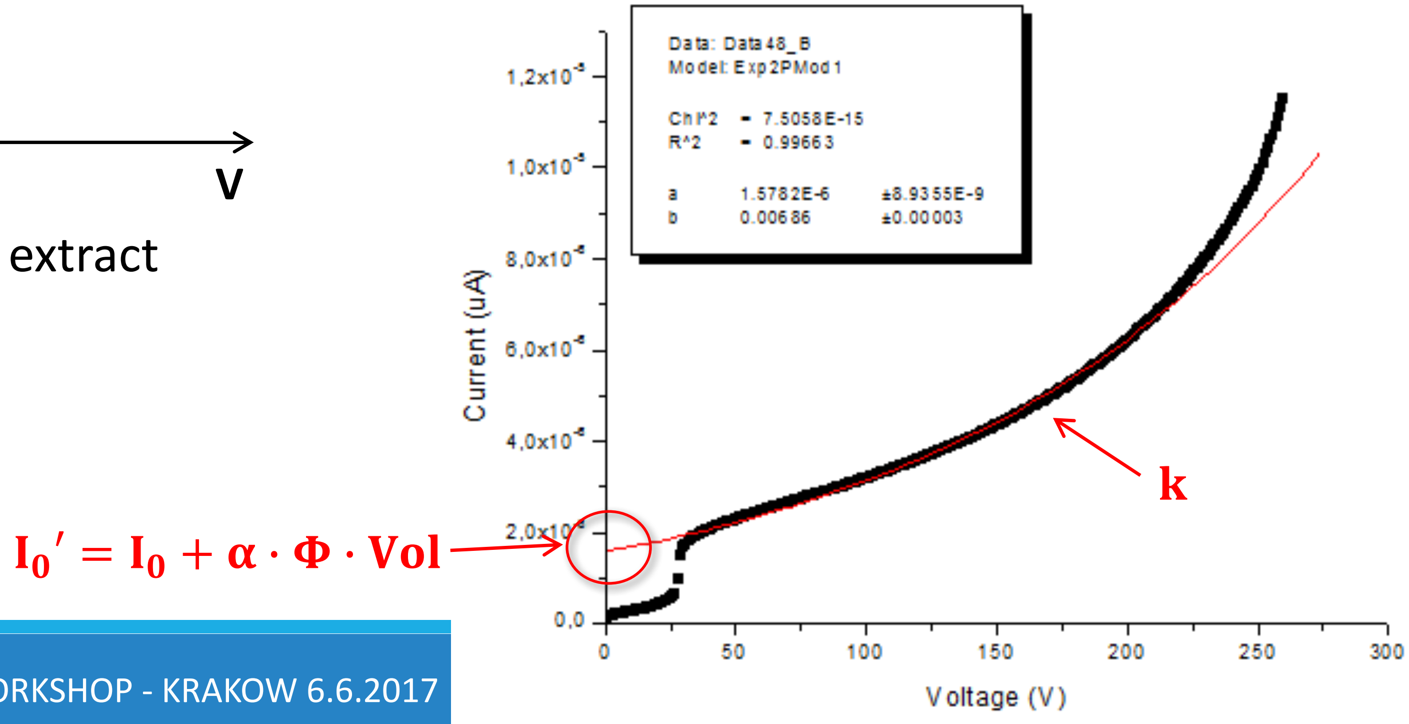
By an exponential fit to the IV curve we can extract

No irr → k

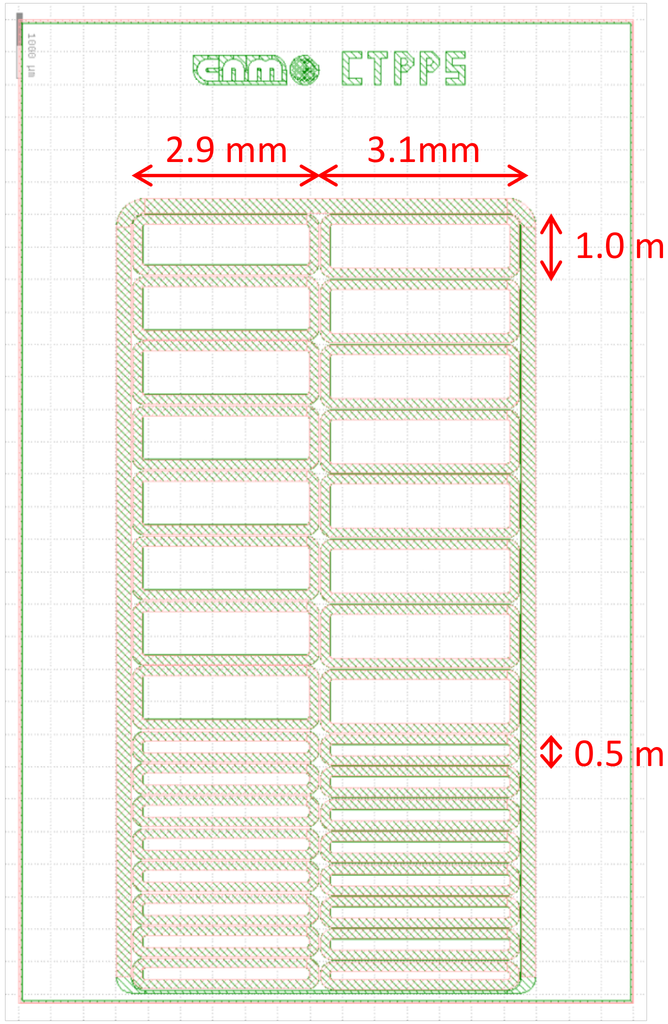
Irr → α, k'

α → current-related damage rate

k → proportional to the sensor gain

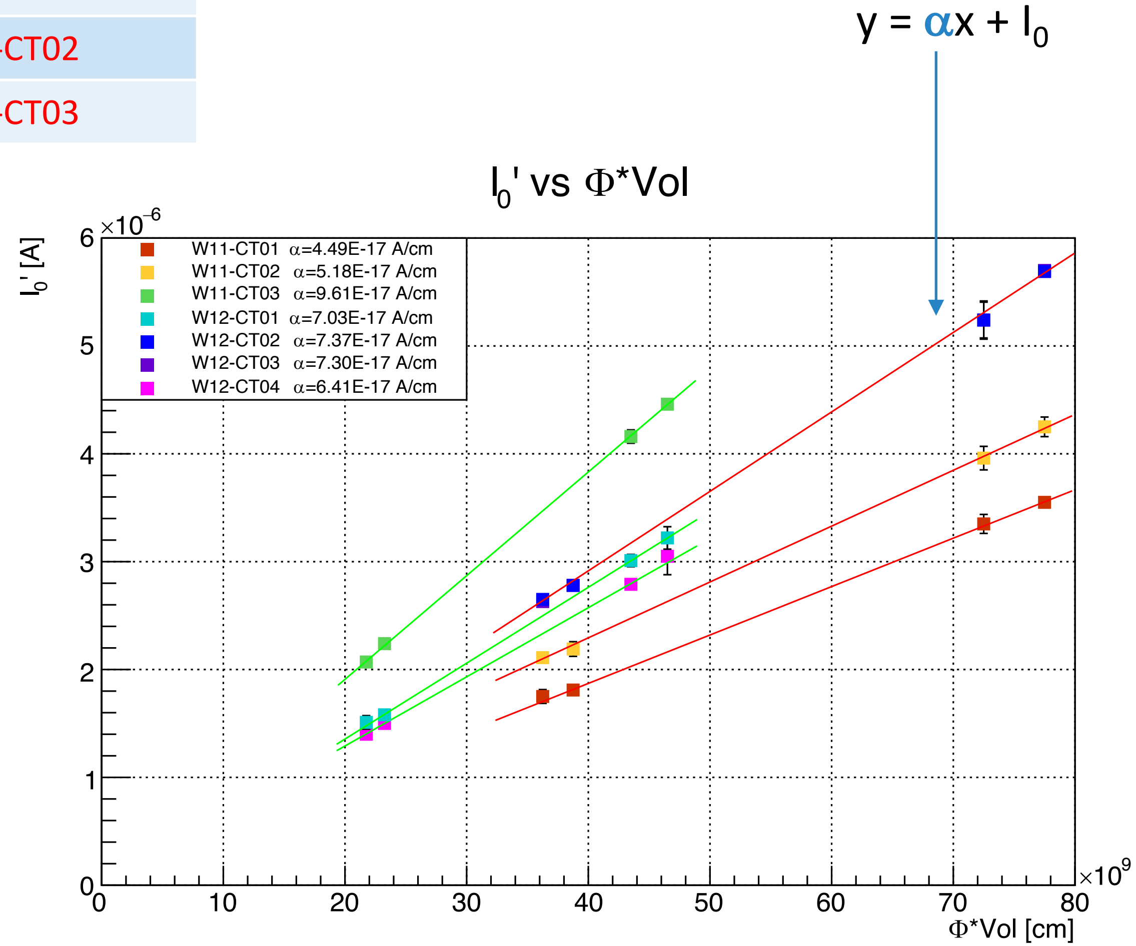


CNM - α Parameter

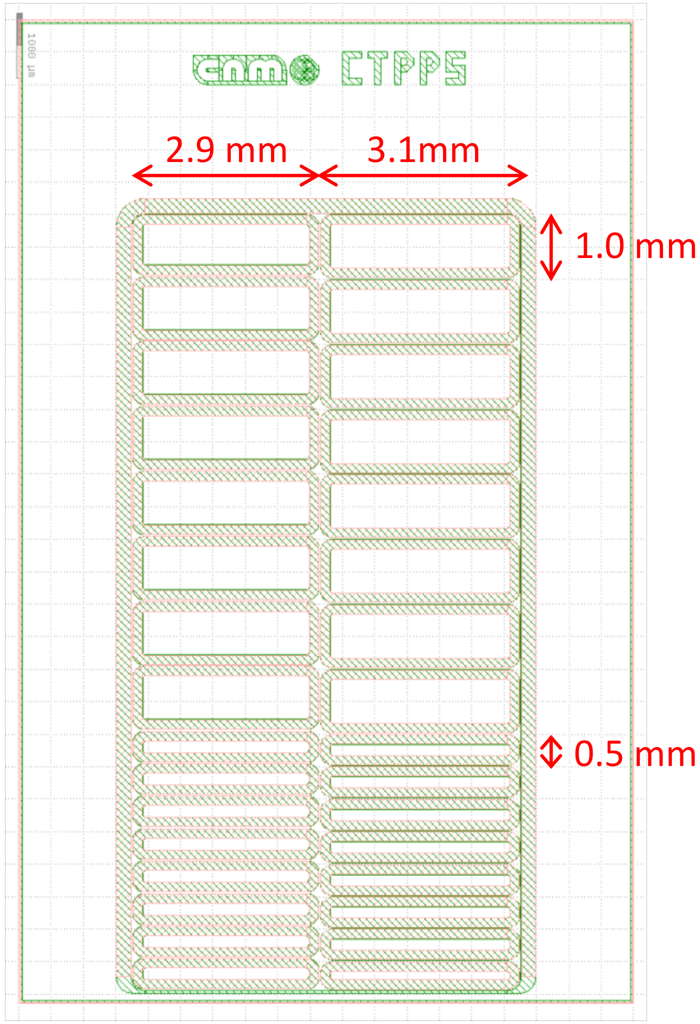


$\Phi = 3x10^{14}\ n/cm^2$	$\Phi = 5x10^{14}\ n/cm^2$
W11-CT03	W11-CT01
W12-CT01	W11-CT02
W12-CT04	W12-CT02
	W12-CT03

To extract α we have
- 4 values of Vol
- 2 values of Φ



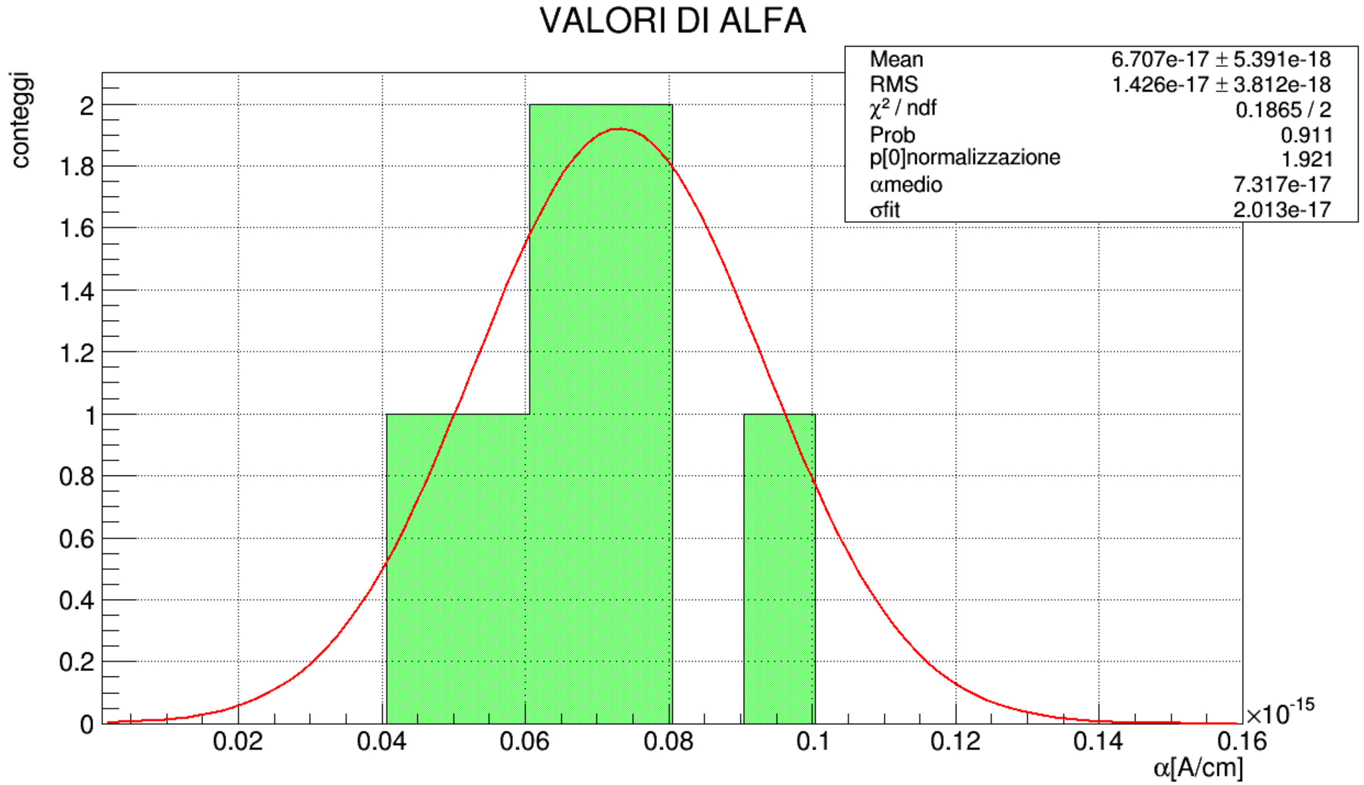
CNM - α Parameter



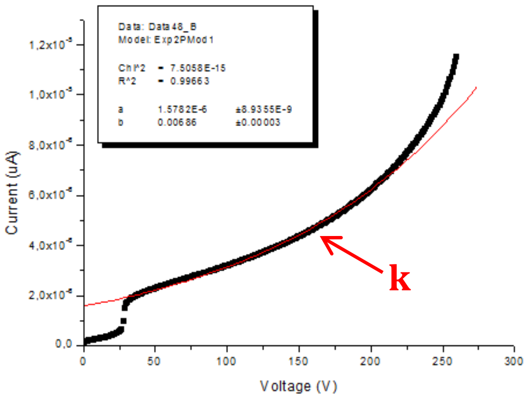
Φ = 3x10^{14} n/cm^2	Φ = 5x10^{14} n/cm^2
W11-CT03	W11-CT01
W12-CT01	W11-CT02
W12-CT04	W12-CT02
	W12-CT03

$\alpha = (7.3 \pm 2.0)\ 10^{-17}$ **A/cm**

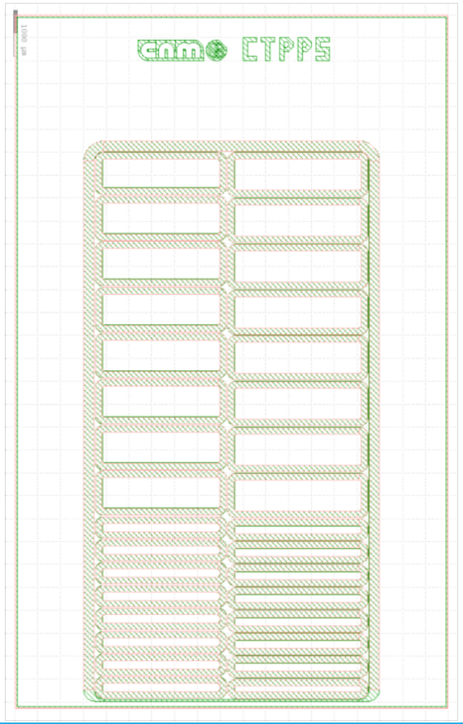
α value in line with expectation



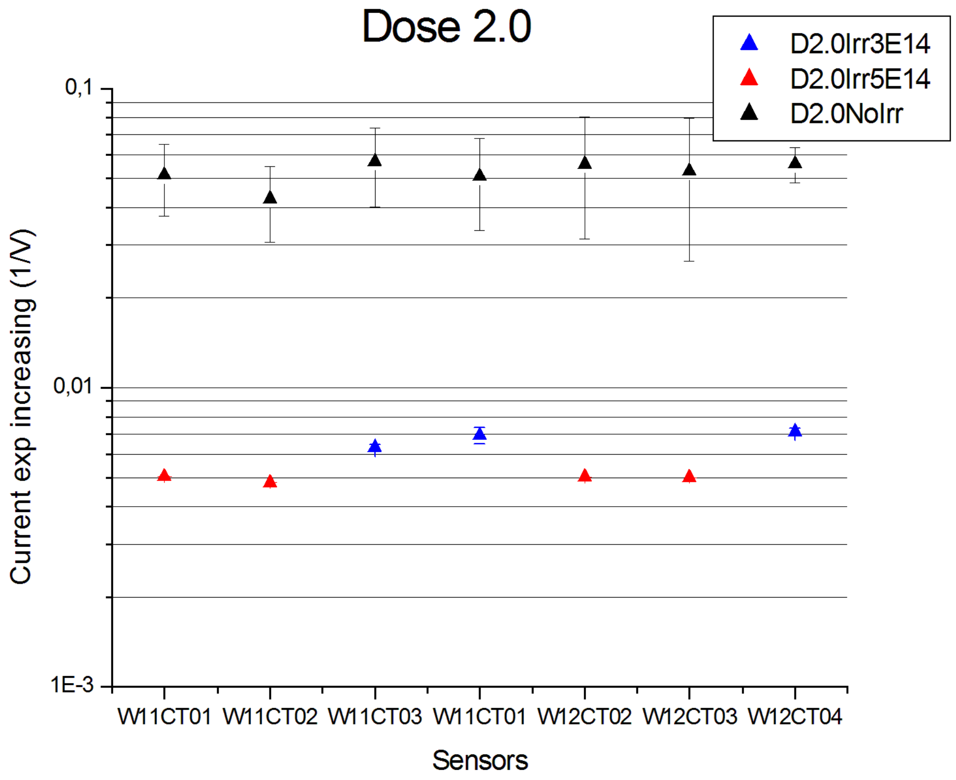
CNM - k Parameter



CNM Run 9088 50 µm [1]	
Doses:	**2.0**
	1.9
	1.8



☞ **irradiated to 3x10^{14} and 5x10^{14} n/cm^2**

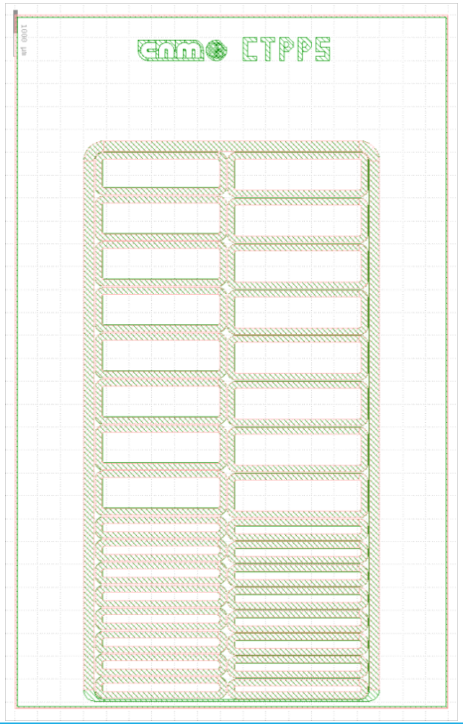


k is proportional to LGAD internal gain

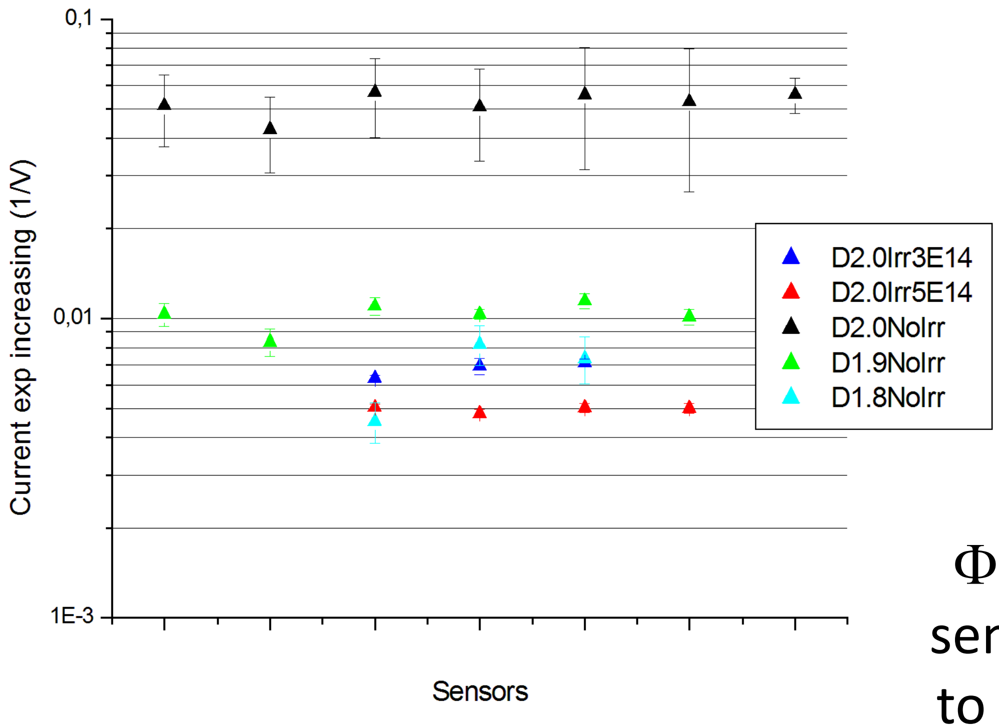
k = k(V) but for small intervals of V k is ~ constant

CNM - k Parameter

CNM Run 9088 50 µm [1]	
Doses:	**2.0**
	1.9
	1.8



☞ **irradiated to $3x10^{14}$ and $5x10^{14}$ n/cm^2**

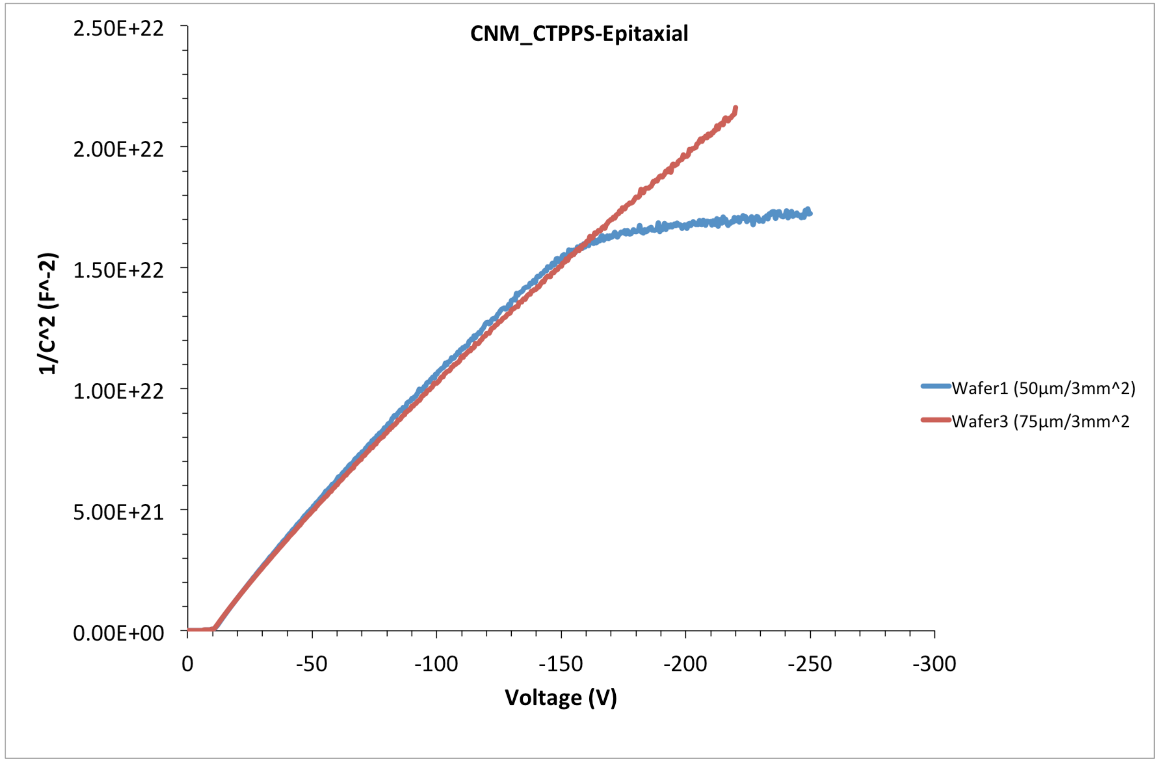


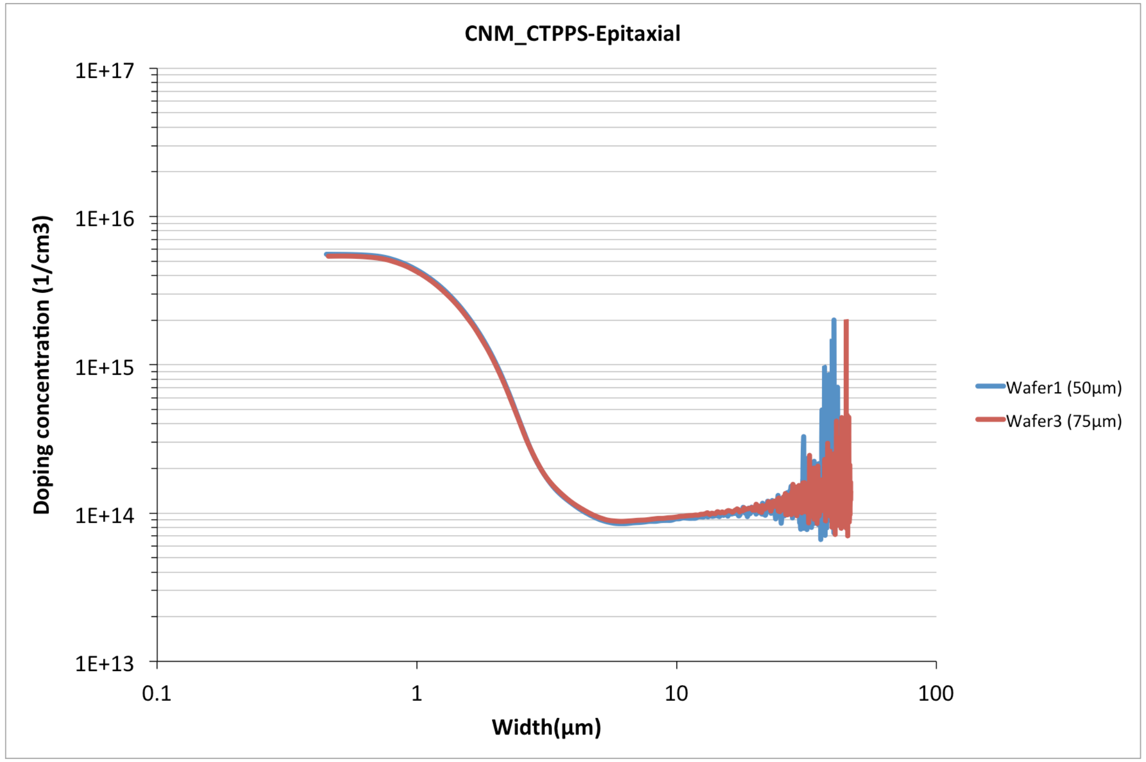
After irradiation at Φ = $3x10^{14}$ n/cm^2 LGAD sensors have gain similar to dose 1.8 un-irradiated

CNM - LGAD on Epitaxial Wafers[2]

EPI 50 µm - ρ = 96.7 Ωcm
EPI 75 µm - ρ = 104.6 Ωcm

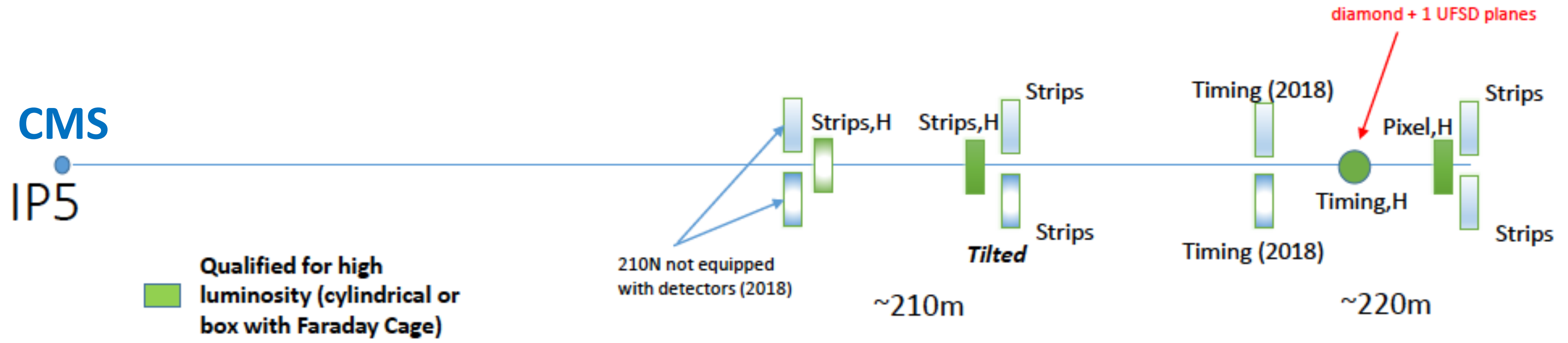
Due to early breakdown, not possible to fully deplete 75 µm sensor
CV measurement confirm resistivity values of Epi wafers

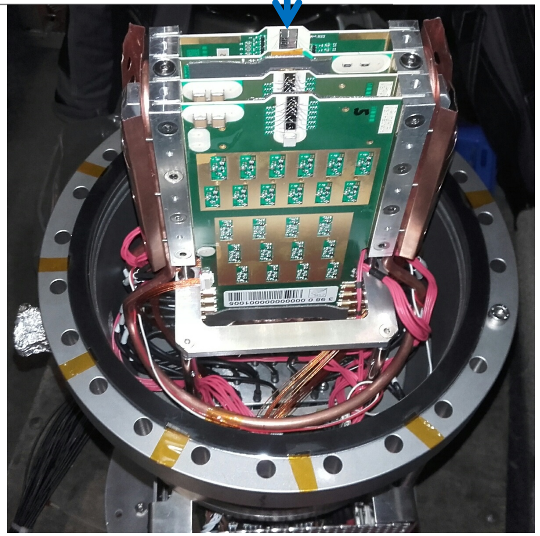


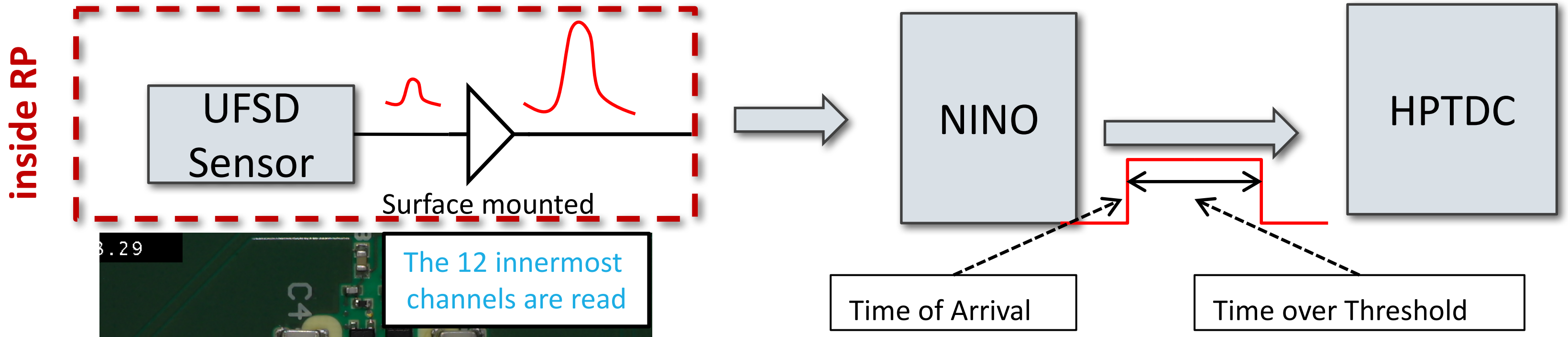


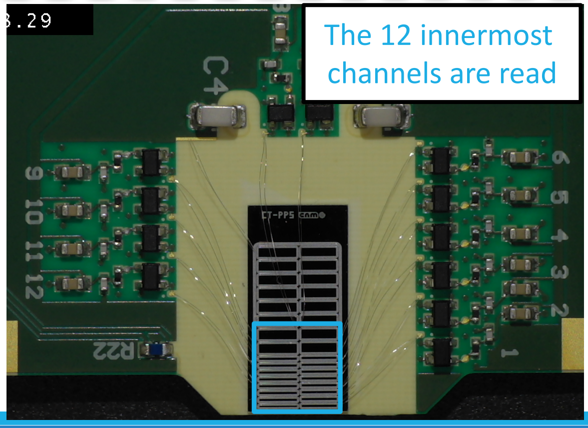
[2] M. Carulla, 12th TREDI Workshop, Trento, Italy, February 2017

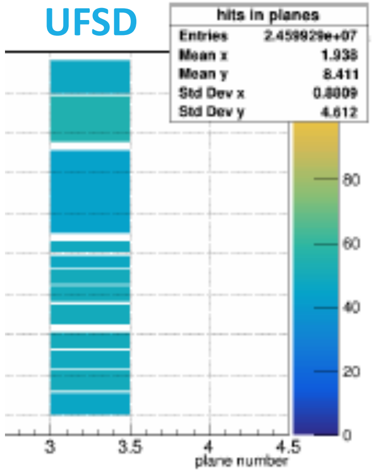
CNM - First UFSD Installation at CT-PPS











Run 294737
Sun 21, 21:36

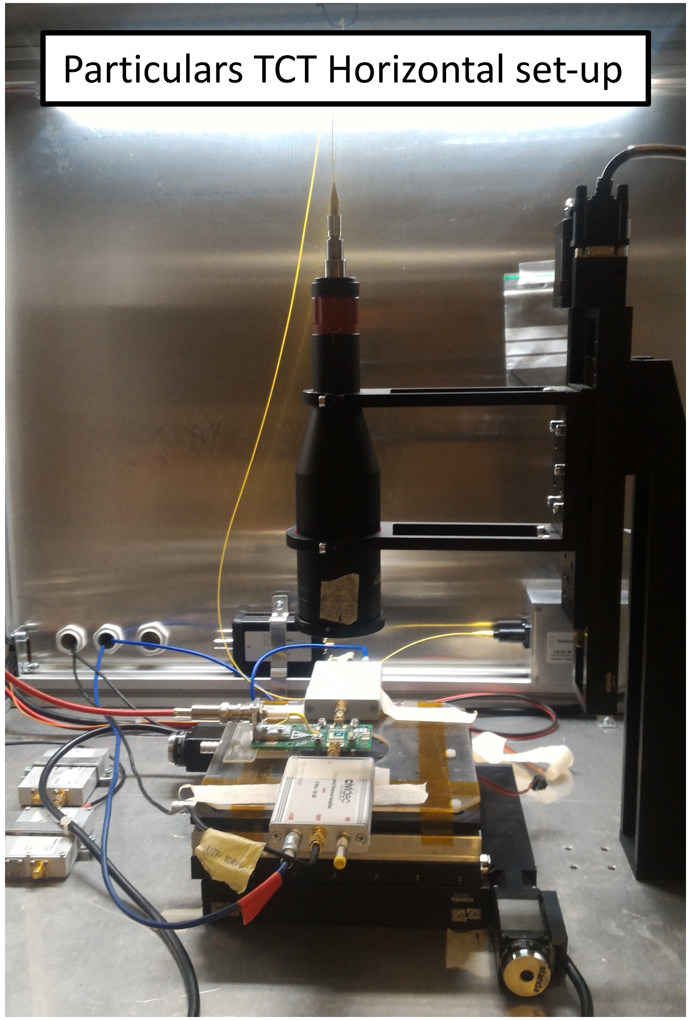
DQM Plot from UFSD plane in RP Sector 56

UFSD are working properly

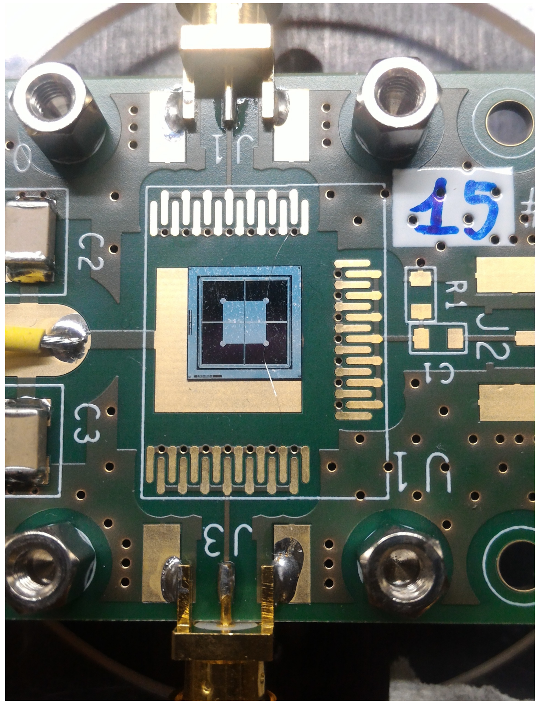
Time resolution analysis ongoing

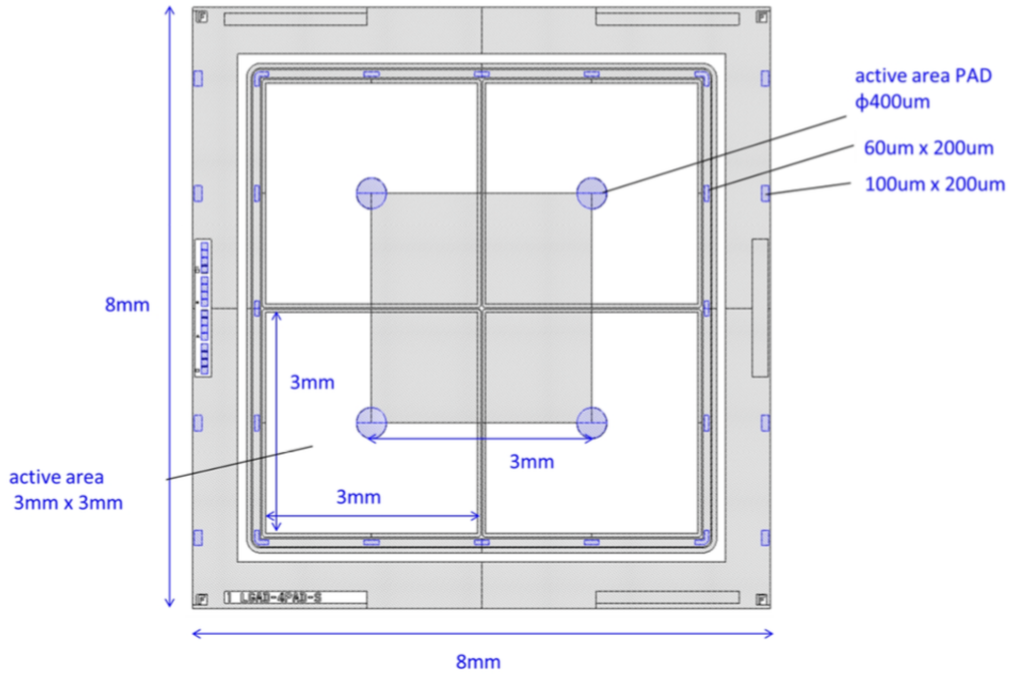
LGAD from Hamamatsu

HAMAMATSU - Laser scan

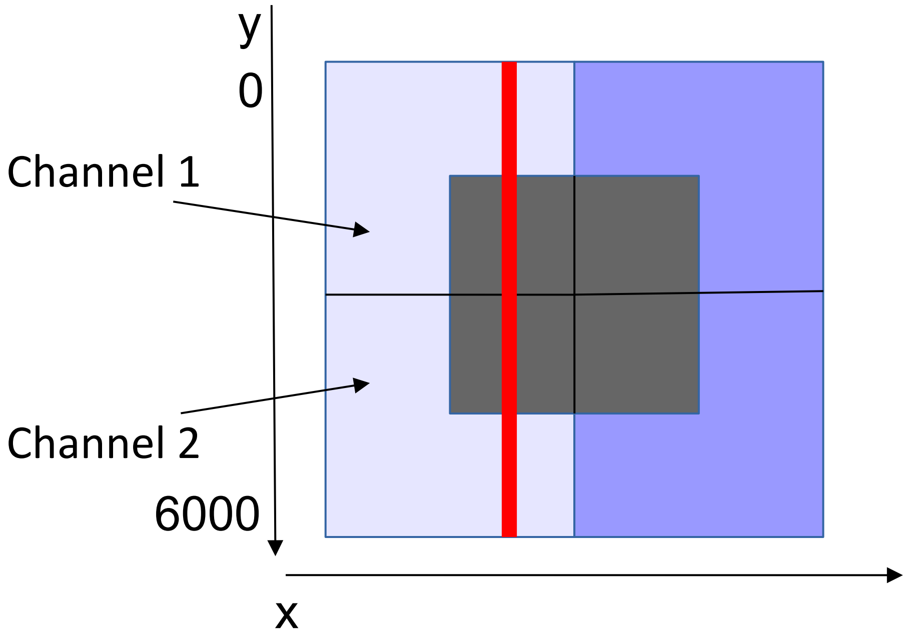


A laser scan on the sensor surface and in the region between pads has been performed

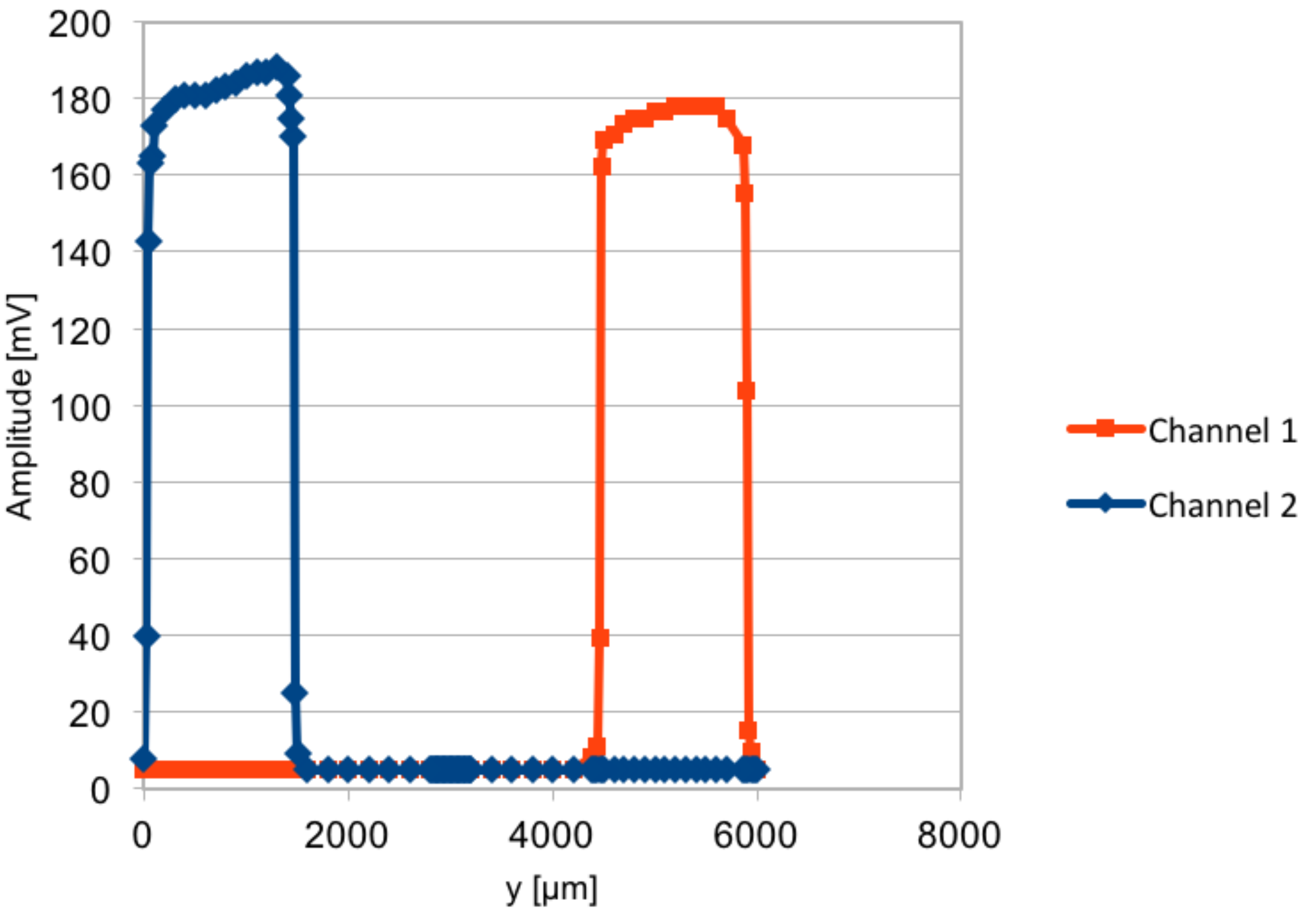




HAMAMATSU - Laser scan

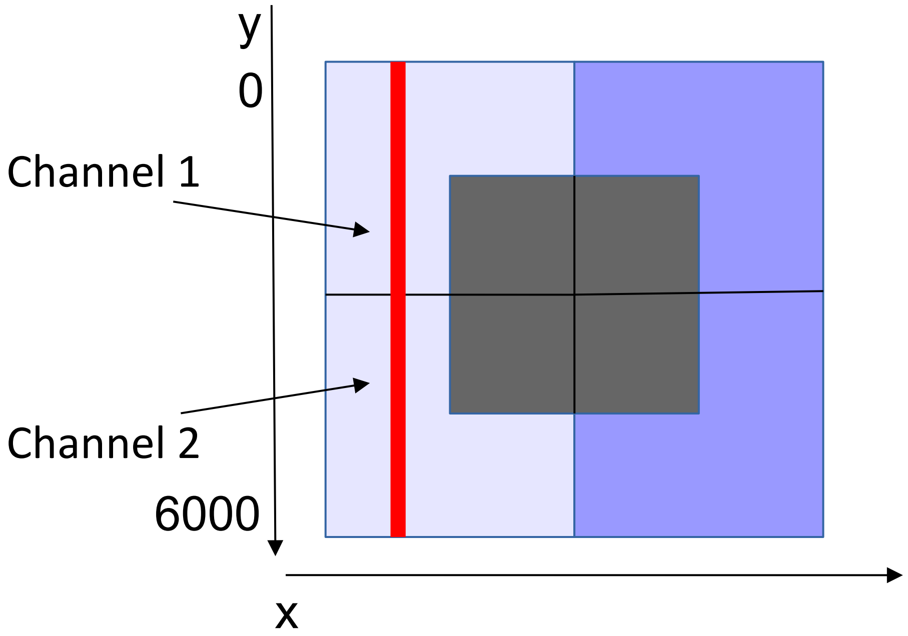


4 pad 3x3 mm^2
only 2 pad bonded
signal produced by TCT laser
(λ=1060 nm, 1 kHz, 1 MIP intensity, 20 μm spot)



Very good signal uniformity along the pads

HAMAMATSU - Laser scan



4 pad 3x3 mm^2
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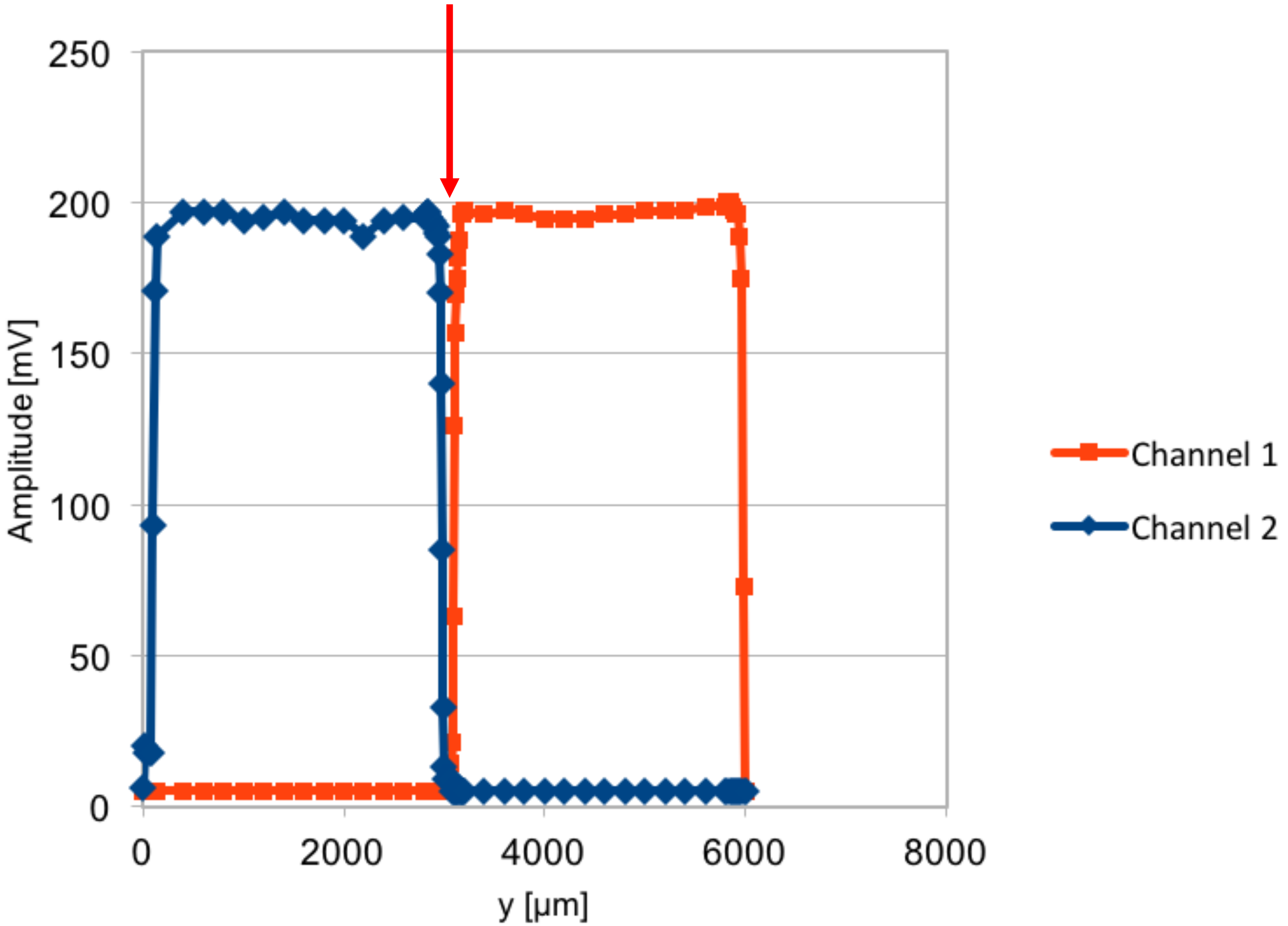
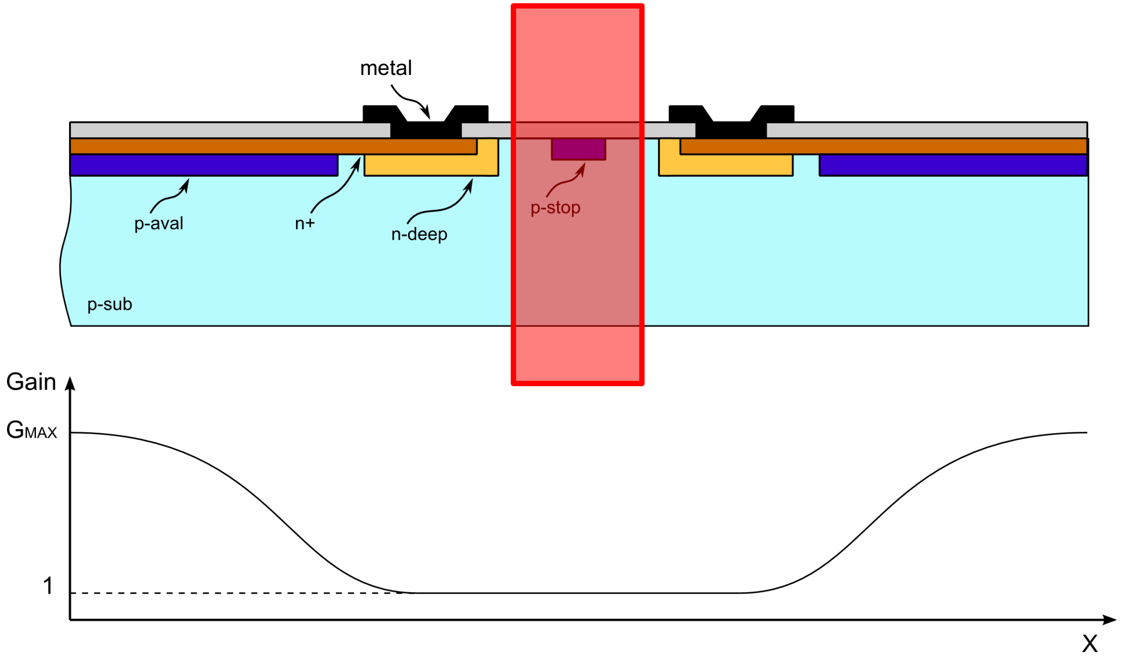
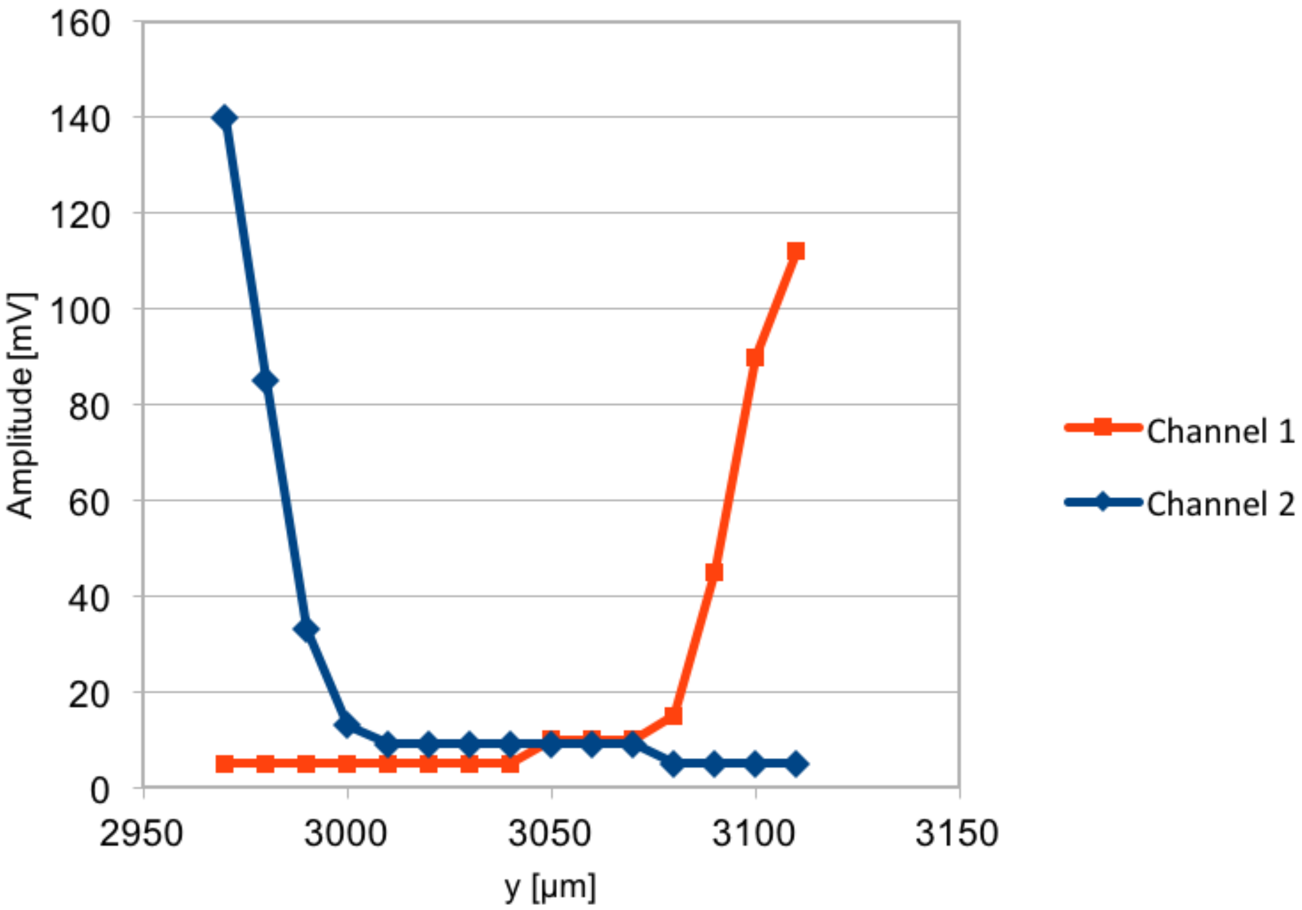


Very good signal uniformity along the pads

HAMAMATSU - Laser scan

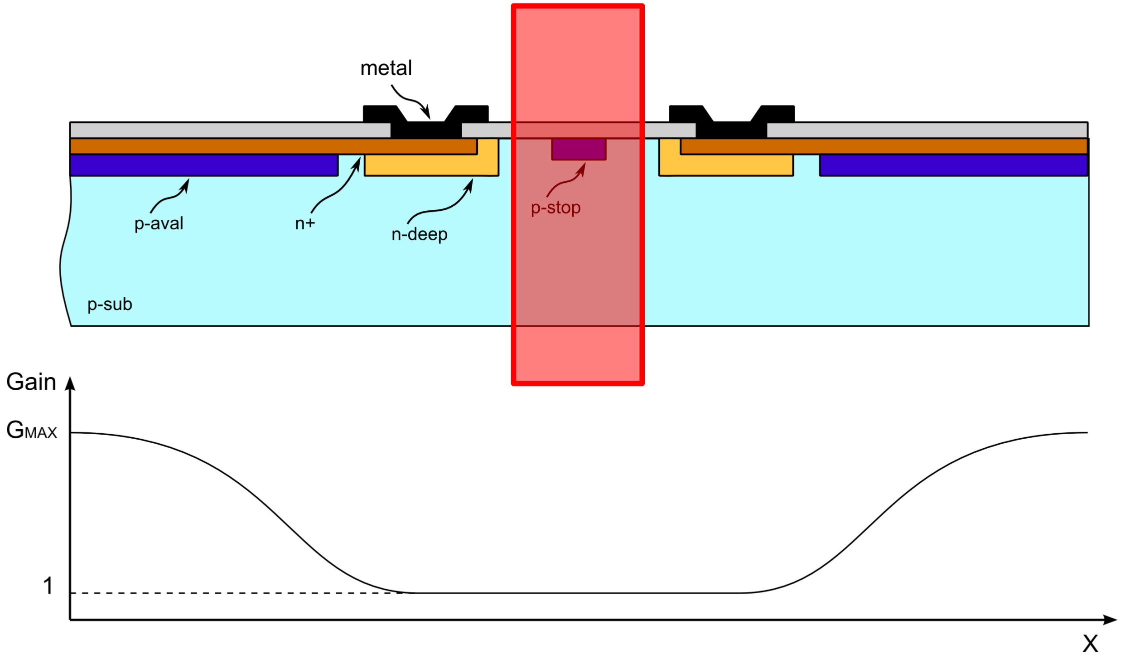


signal produced by TCT laser
(λ=1060 nm, 1 kHz, 1 MIP intensity, 20 µm spot)

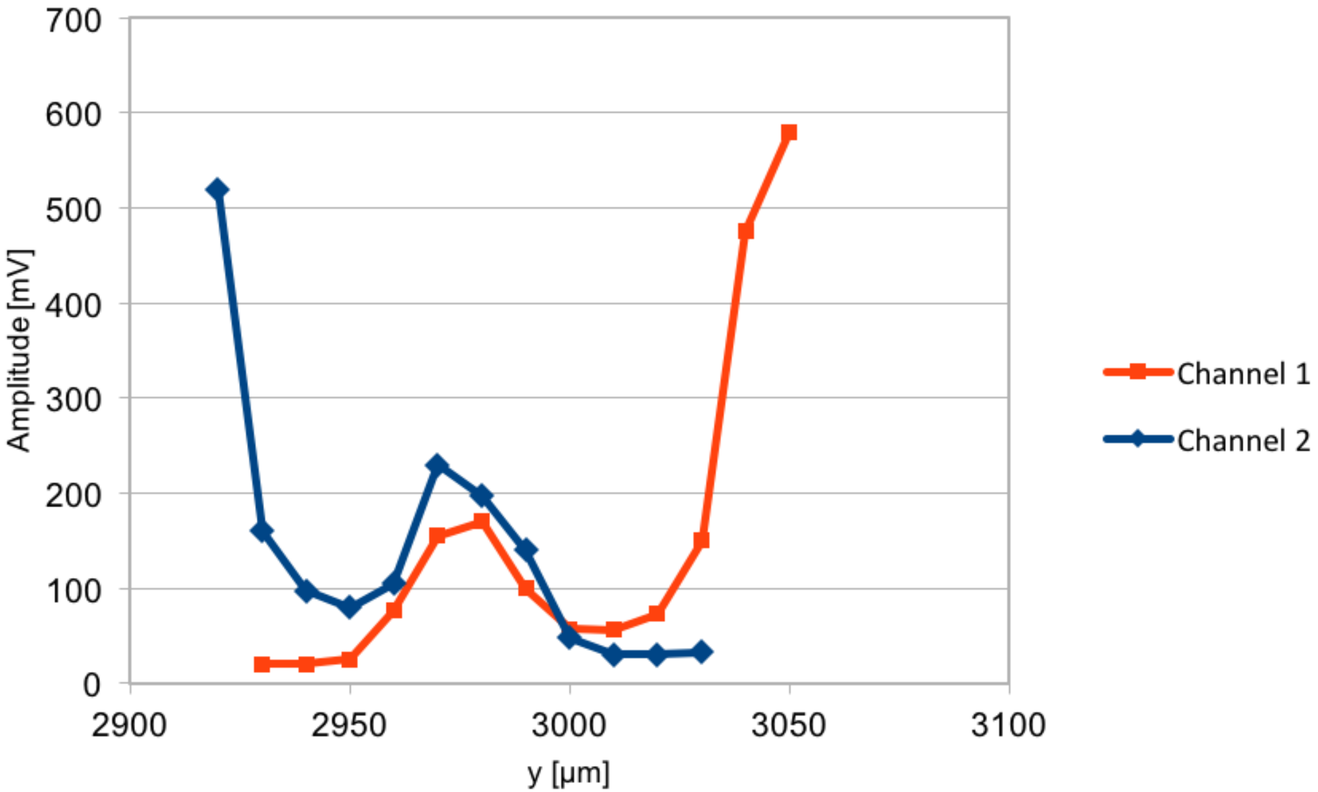


No signal from the region with metal nor on the p-stop with 1 MIP-equivalent signal

HAMAMATSU - Laser scan



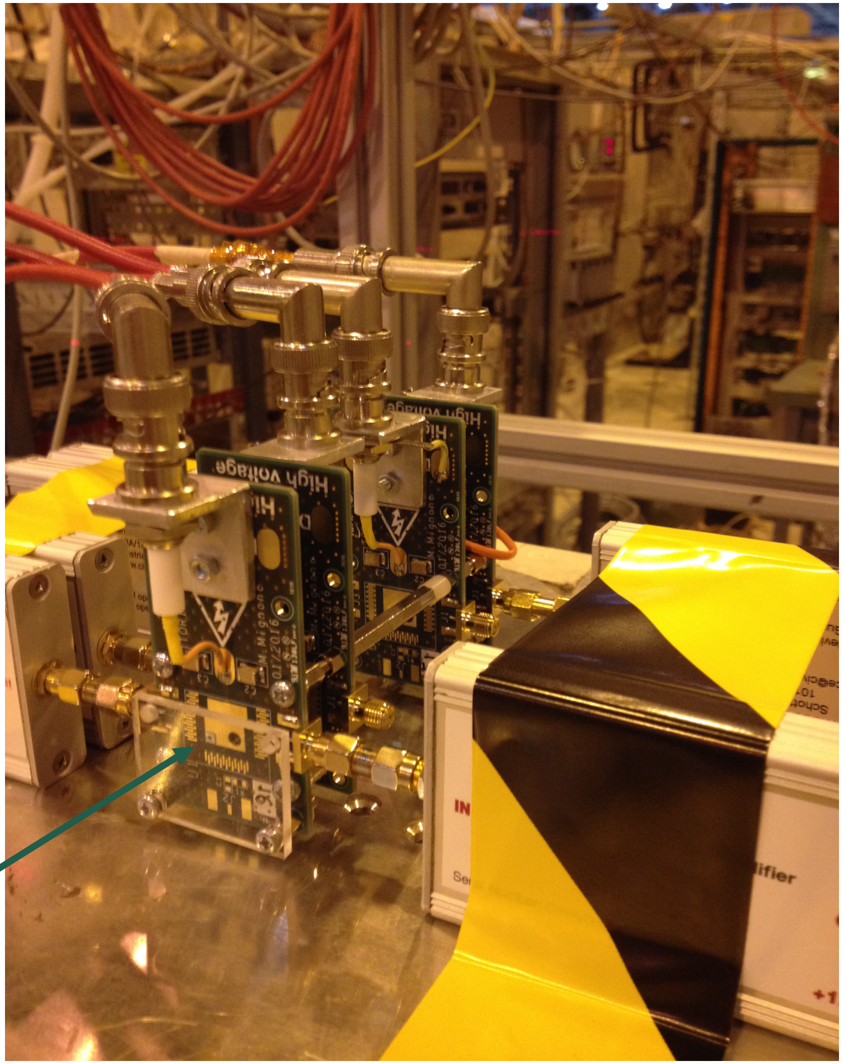
signal produced by TCT laser
(λ=1060 nm, 1 kHz, VERY HIGH intensity, 20 µm spot)



Signal generated under p-stop is collected by both pads

In collaboration with Bologna University and INFN,
F. Carnesecchi

HAMAMATSU - Beam Test



180 GeV
π beam

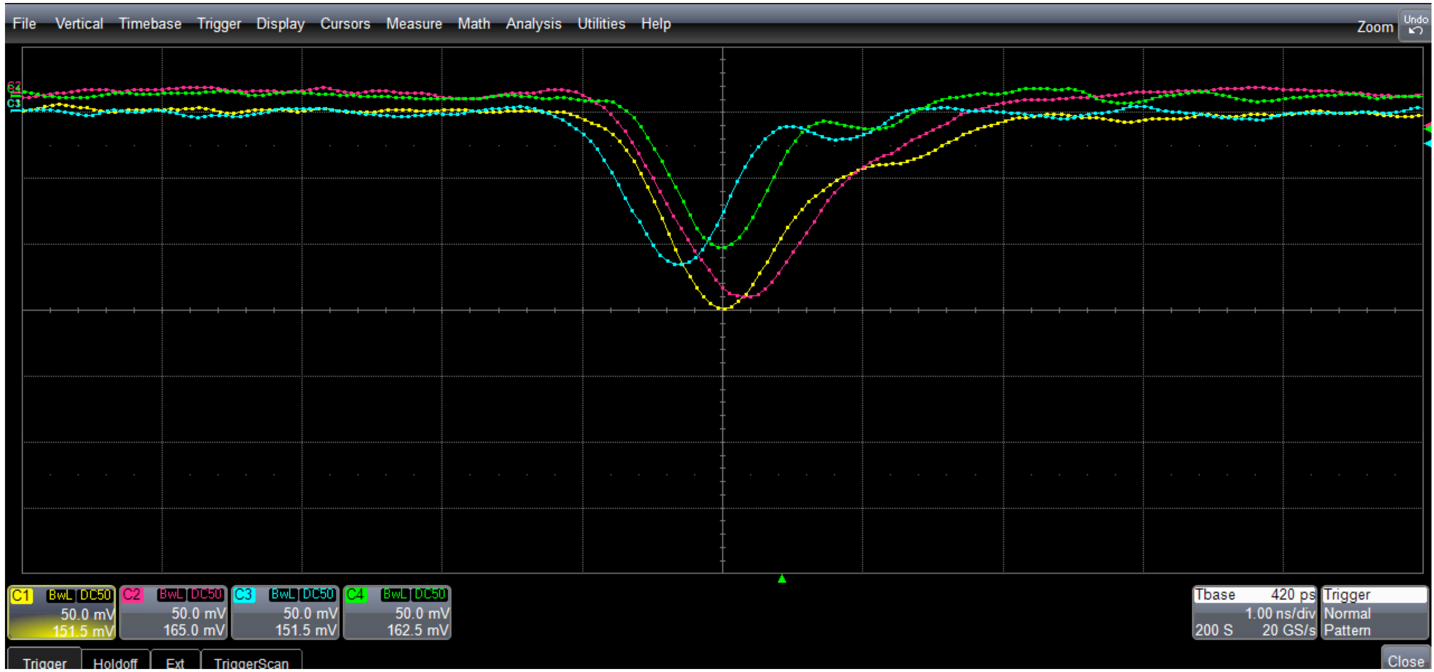
Beam test at CERN SPS on first Hamamatsu LGAD production

ϕ = 1 mm^2 sensors, 4 planes

50C - GBGR 80C - GBGR

50D - GBGR 80D - GBGR

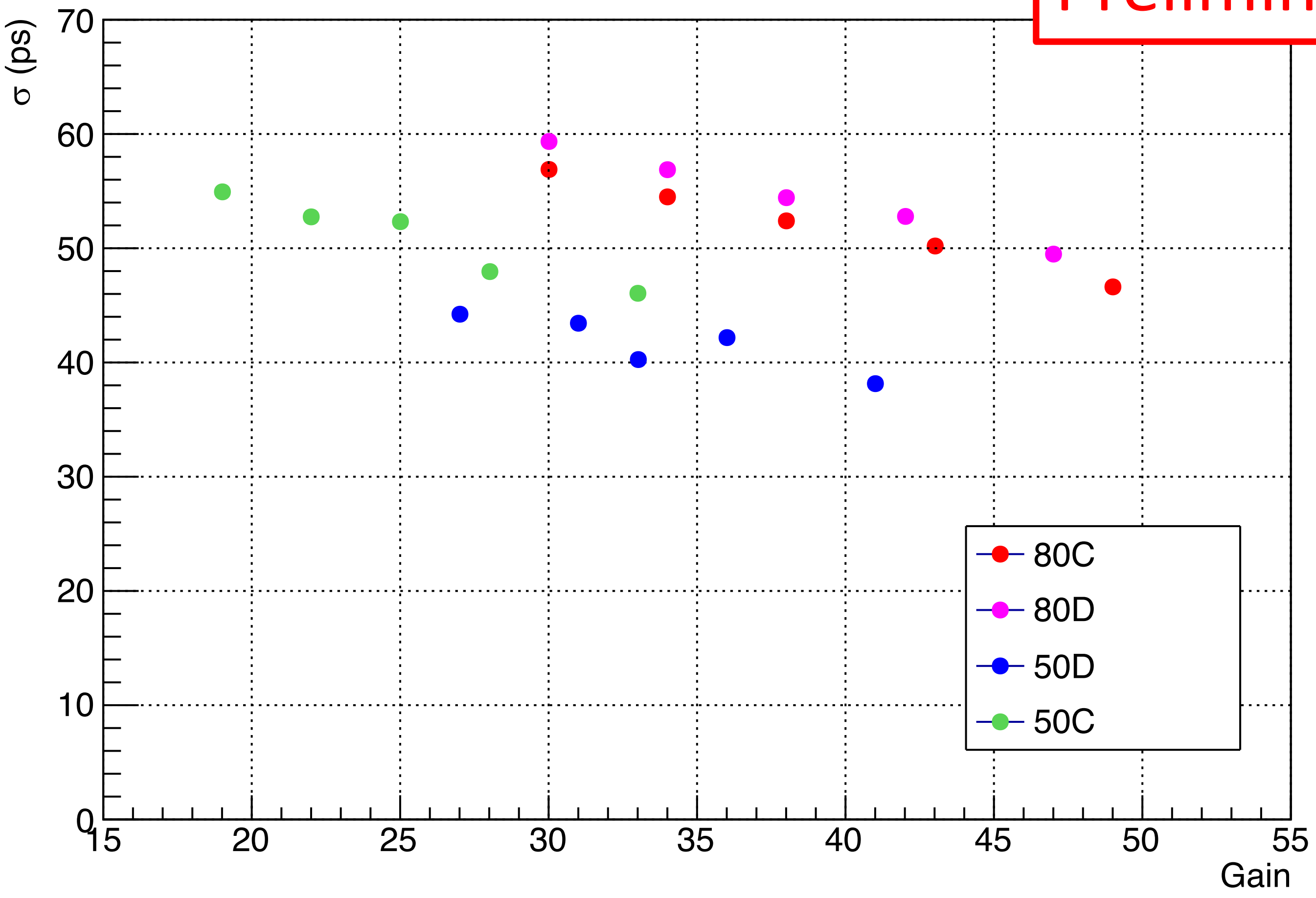
Setup: sensors read by Cividec broadband current amplifiers



In collaboration with Bologna University and INFN,
F. Carnesecchi

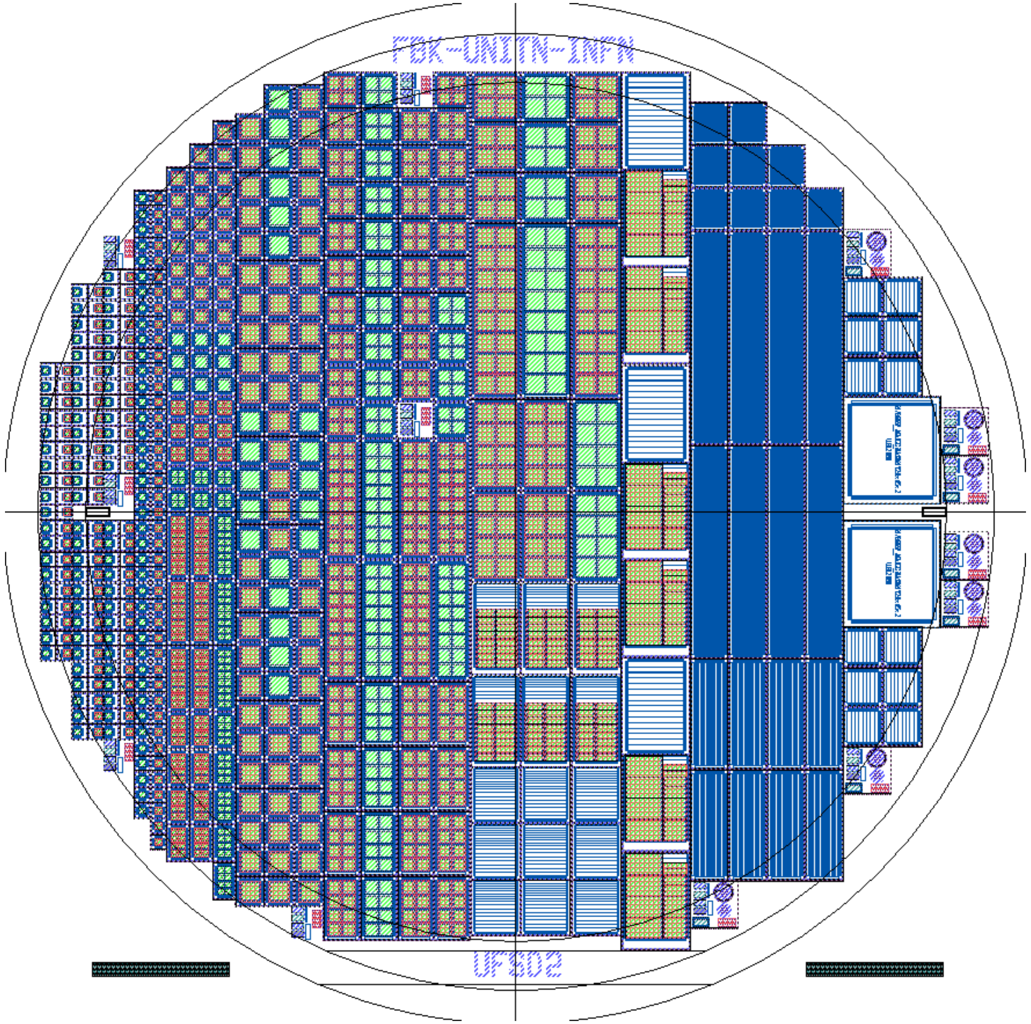
HAMAMATSU - Beam Test

Preliminary



LGAD from FBK

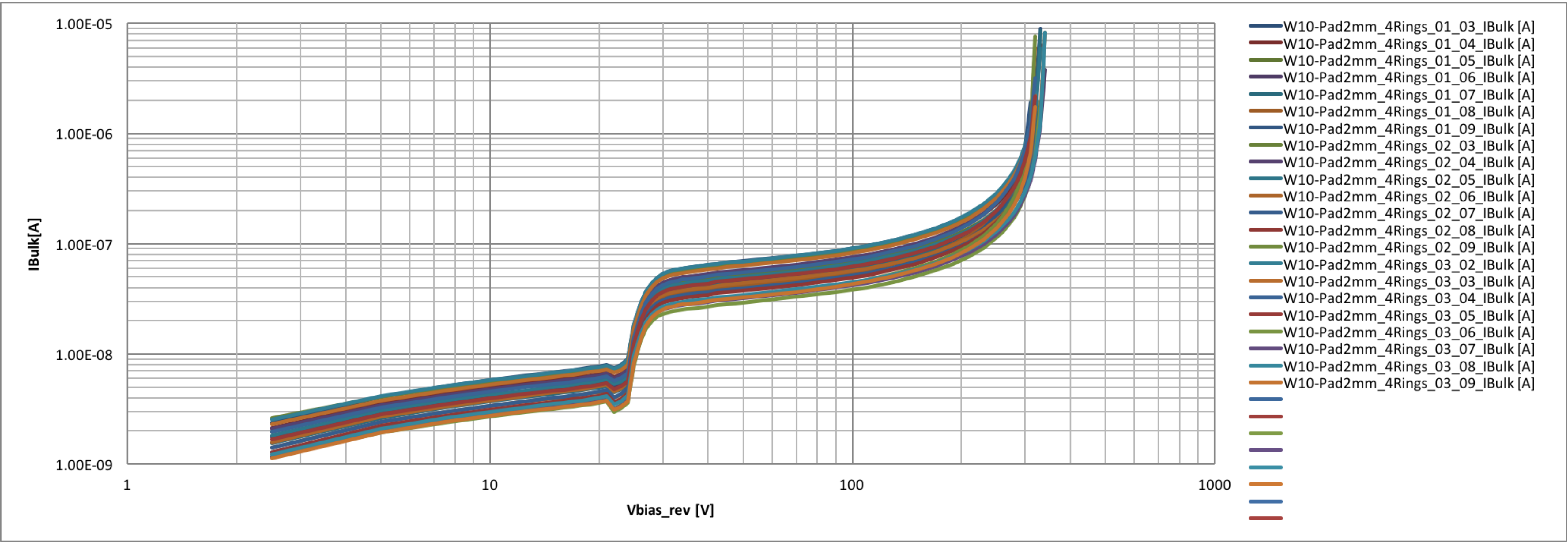
UFSD2 - First 50 µm thick, 6" wafer LGAD FBK Production



Wafer #	Dopant	Gain dose	Diffusion
1	Boron	0.98	Low
2	Boron	1.00	Low
3	Boron	1.00	HIGH
8	Boron	1.02	HIGH
9	Boron	1.02	HIGH
10	Boron	1.04	HIGH

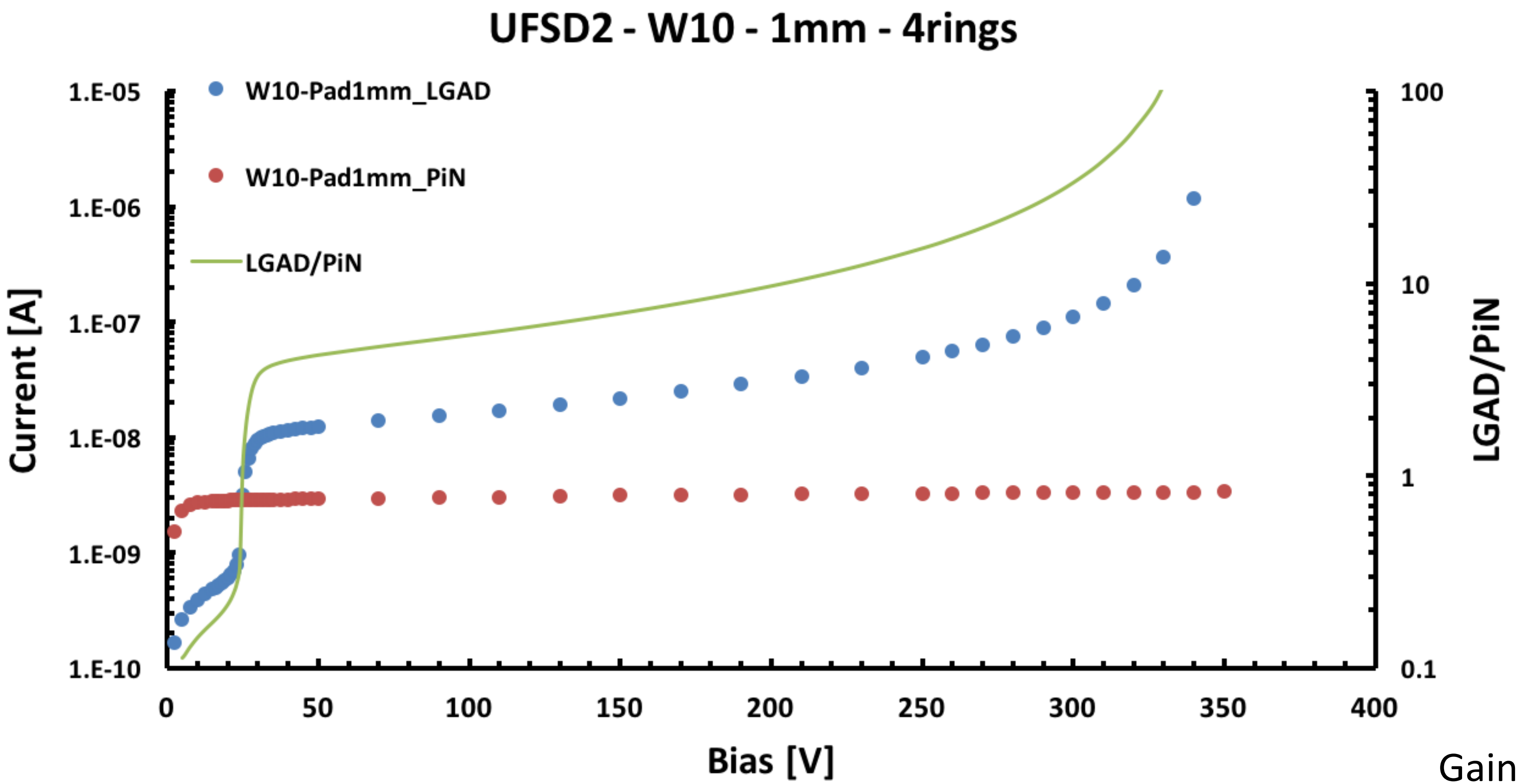
First 50 µm UFSD production by FBK released last week
Ga, C-B, C-Ga wafers expected very soon

UFSD2 from FBK - First IV Curves



Very good uniformity and reproducibility of IV curves along the wafer

UFSD2 from FBK - Gain Determination from IV Curves



Gain = I_{LGAD} / I_{Pin}

SUMMARY

➢ LGAD from CNM

- $\alpha = (7.3 \pm 2.0)\ 10^{-17}$ A/cm
- gain of dose 2.0 sensors irradiated at $3x10^{14}$ n/cm^2 similar at gain of dose 1.8 un-irradiated sensors
- CV measurements on Epi wafers confirm high bulk resistivity
- first UFSD installation in a HEP experiment (CT-PPS)

➢ LGAD from Hamamatsu

- good uniformity of signal along pads
- detailed laser scan on the intra-pad region
- beam test on 50 and 80 µm LGAD $\rightarrow \sigma_t$ =38 ps for high gain values of 50 µm sensor (Prel.)

➢ LGAD from FBK

- first 50 µm UFSD production with Boron just finished
- wafers with Gallium, carbonated Boron and carbonated Gallium expected very soon

ACKNOWLEDGEMENTS

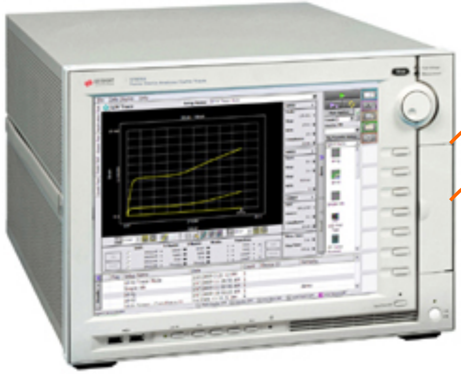
We kindly acknowledge the following funding agencies, collaborations:

- INFN - Gruppo V
- Horizon 2020, grant UFSD669529
- Horizon 2020, grant INFRAIA
- Ministero degli Affari Esteri, Italy, MAE, “Progetti di Grande Rilevanza Scientifica”
- U.S. Department of Energy grant number DE-SC0010107
- RD50, CERN

BACKUP

IV Measurement Setup

Keysight
B1505A Power Device Analyzer / Curve Tracer

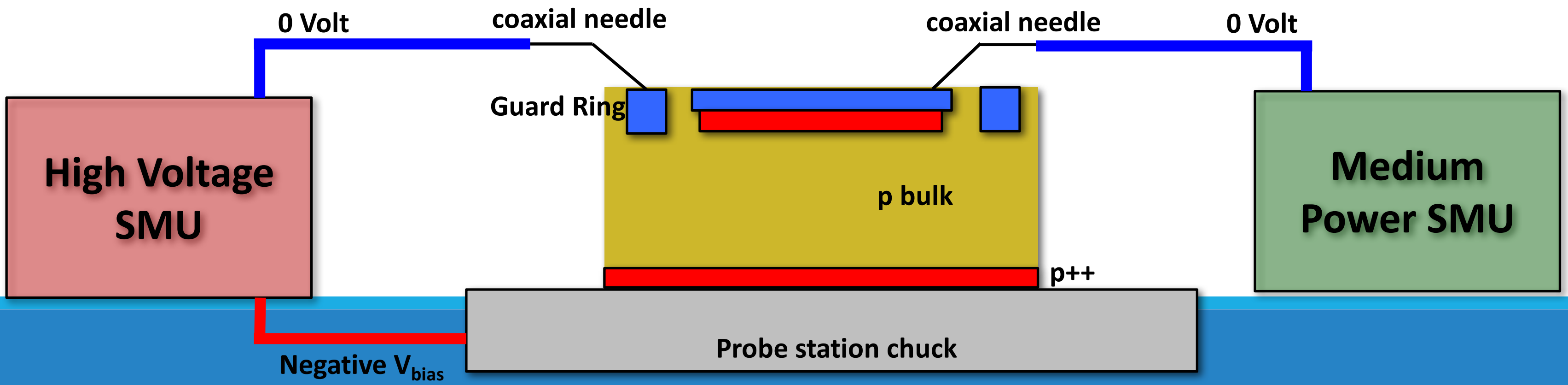


Probe station

The electric contacts was made with coaxial needles

Modules

- High Voltage SMU: Max Range (±3000V, ±4mA);
  Min Range (200V, 1nA);
- Medium Power SMU: Max Range (±100V, ±100mA);
  Min Range (0,5V, 1nA);



FAST TIMING - THE INGREDIENTS (I)

$$\sigma_t^2 = \sigma_{Jitter}^2 + \sigma^2_{\substack{Landau \\ Time\,Walk}} + \sigma^2_{\substack{Landau \\ Noise}} + \sigma_{Distortion}^2 + \sigma_{TDC}^2$$

$\sigma_{TDC} = \frac{25\text{ps}}{\sqrt{12}} \sim 7\text{ ps}$ considering 25 ps binning of the HPTDC

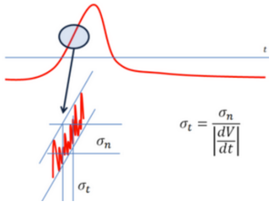
☞ **Negligible**

$\sigma_{\substack{Landau \\ Time\,Walk}}$: the effect can be compensated by an appropriate electronic circuit (using CDF or ToT)

☞ **Negligible**

FAST TIMING - THE INGREDIENTS (II)

$$\sigma_{Jitter} = \frac{N}{dV/dt} = \frac{t_{rise}}{S/N}$$

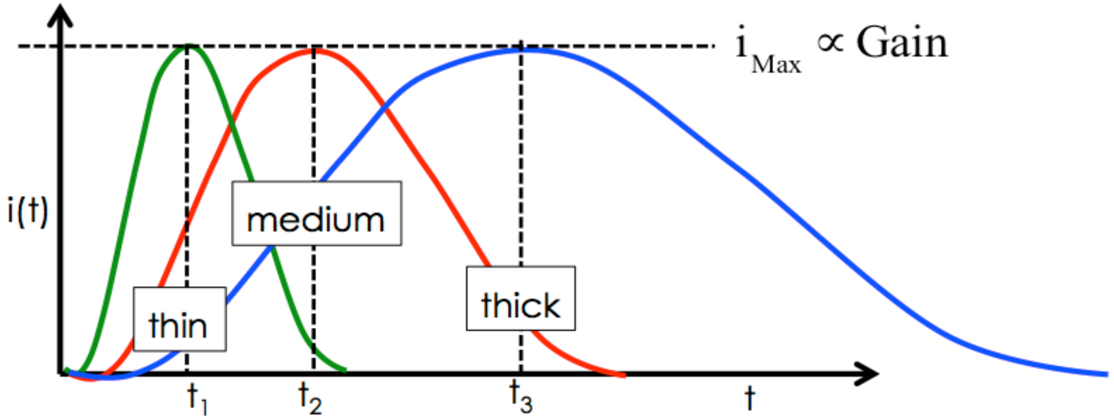


From Ramo's theorem: $\boldsymbol{i \propto q \cdot v_{drift} \cdot E_w}$

and doing some easy algebra

$S \propto I_{MAX} \propto$ Gain ☞ **Use Gain (G = 10 -20)**

$t_{rise} \propto \frac{1}{d}$ ☞ **Go thin (d = 50 µm)**

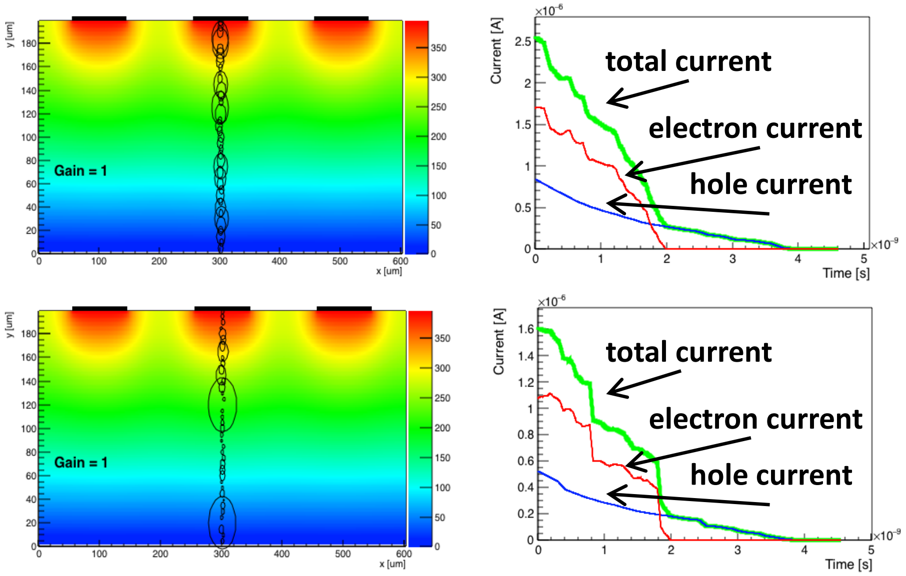


$\sigma_{Landau\ Noise}$: due to the physics governing energy deposition

The charge distribution created by an ionizing particle crossing a sensor varies on an event-by-event basis and produce an irregular current signal

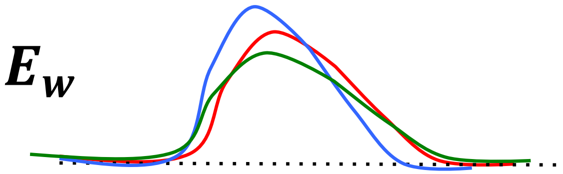
To minimize the effect ☞ **Go thin (d = 50 µm)**

Intrinsic limit: $\sigma_{Landau\ Noise} \sim$ 20 ps



Simulation done with **Weightfield2** (WF2)
[F. Cenna, 9th Trento Workshop, Genova, 2014]

FAST TIMING - THE INGREDIENTS (III)

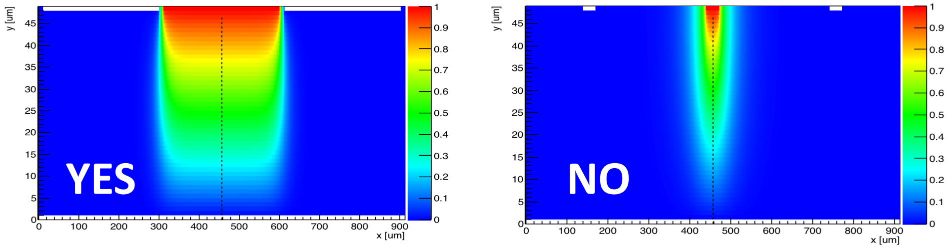


$\sigma_{Distortion}$: signal shape is determined by Ramo's theorem $i \propto q \cdot v_{drift} \cdot E_w$

Drift velocity and weighting field need to be **as uniform as possible**

Basic rule: **parallel plate geometry**

☞ **strip implant ~ strip pitch >> thickness**



Shot Noise: $ENC = \sqrt{\int i_{Shot}^2 df} = \sqrt{\frac{I \cdot (Gain)^{2+x}}{2e} \cdot \tau_{Int}}$

Shot noise increases faster than the signal

-> the ratio S/N becomes worse at high gain

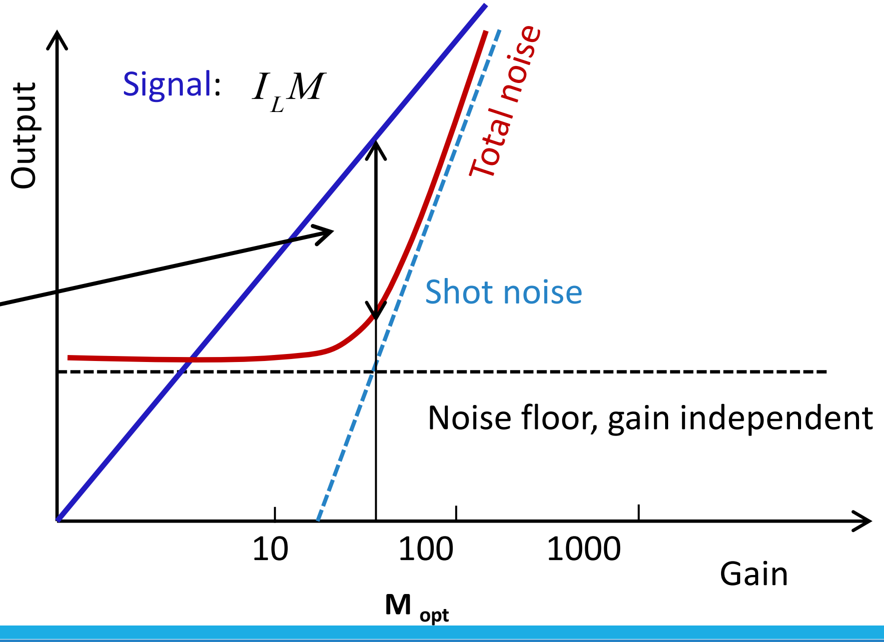
To minimize the shot noise

☞ **Low gain (G = 10-20)**

☞ **Cool the detector**

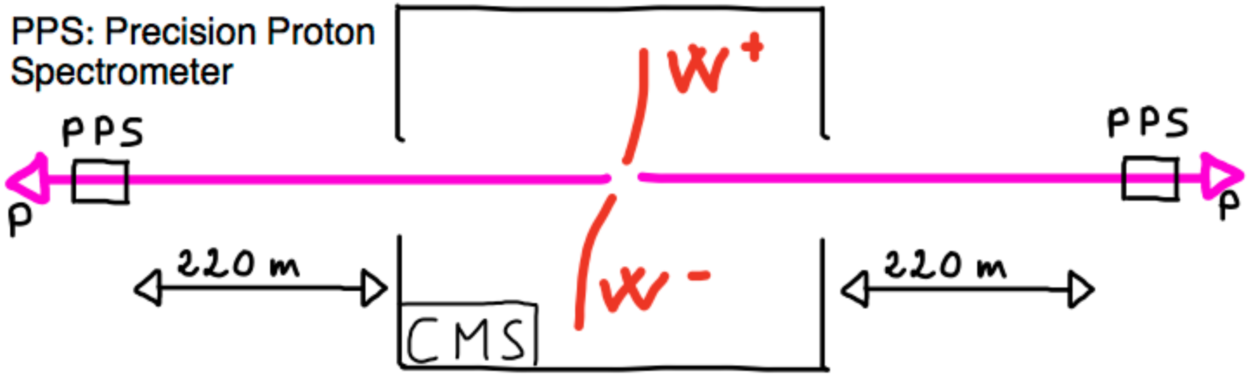
☞ **Use small pads to have less leakage current**

Best S/N ratio

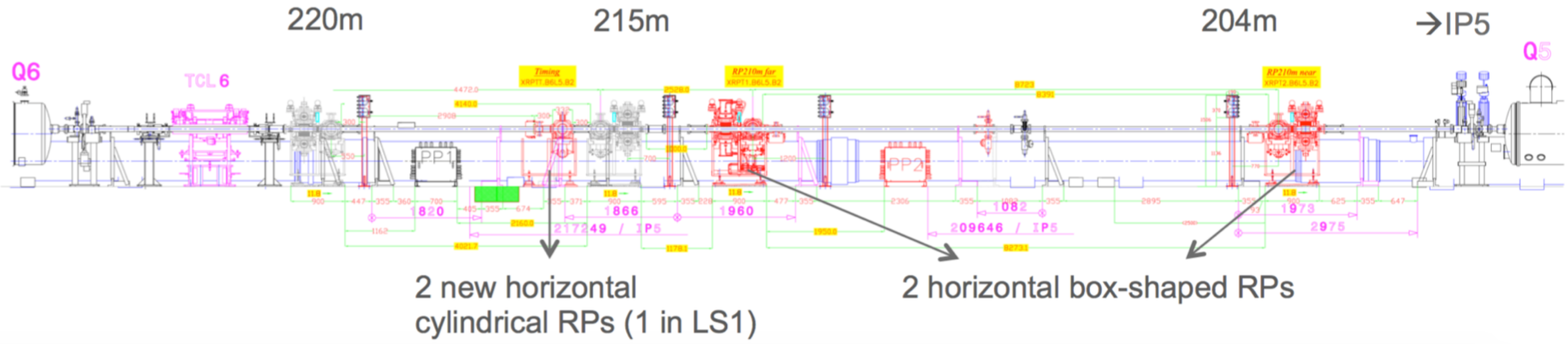


CT-PPS: CMS-TOTEM PRECISION PROTON SPECTROMETER

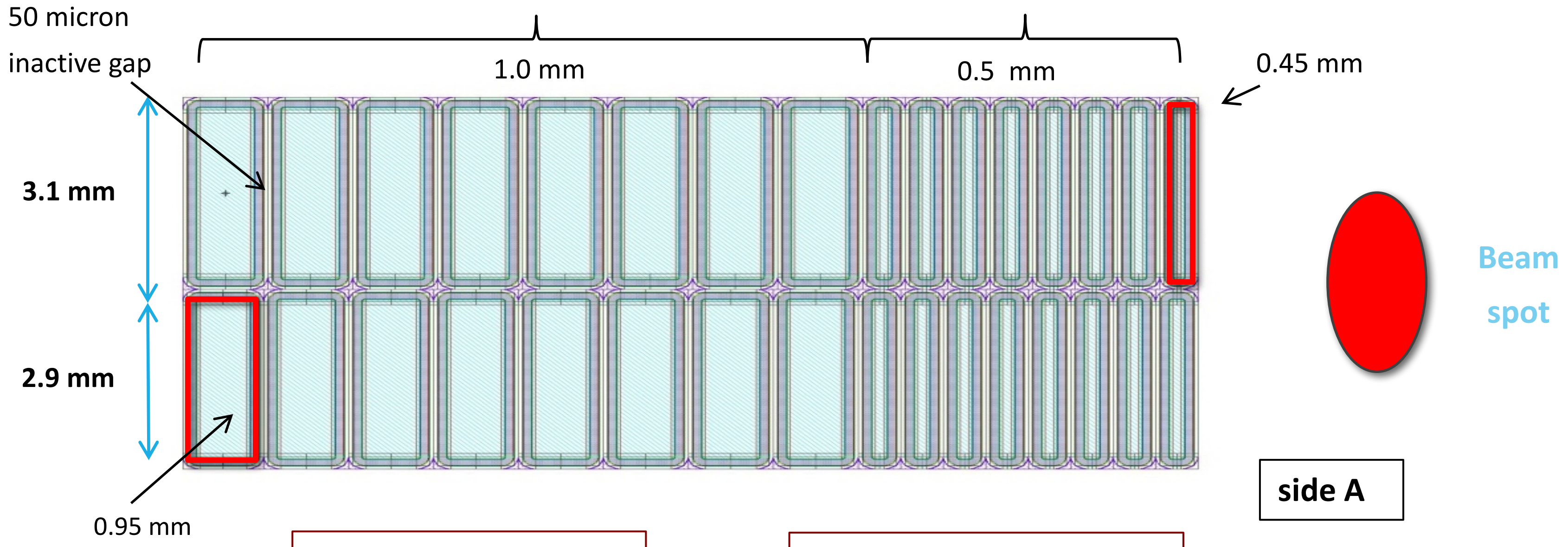
A proton spectrometer to study central exclusive production at the LHC



CT-PPS consists a silicon tracking system to measure the position and direction of the protons, and a set of timing counters to measure their arrival time



SENSOR GEOMETRY FOR CT-PPS



16 Pixel ~ 3 mm^2
Cap. Pixel ~ 6 pF

16 Pixel ~ 2 mm^2
Cap. Pixel ~ 4 pF

Asymmetric design
Area = 12mm x 6mm
Thickness = 50 um
# of channels = 32 Gain ~ 15
Slim edge of ~200 µm on side A

Expected time resolution: ~30 ps per plane