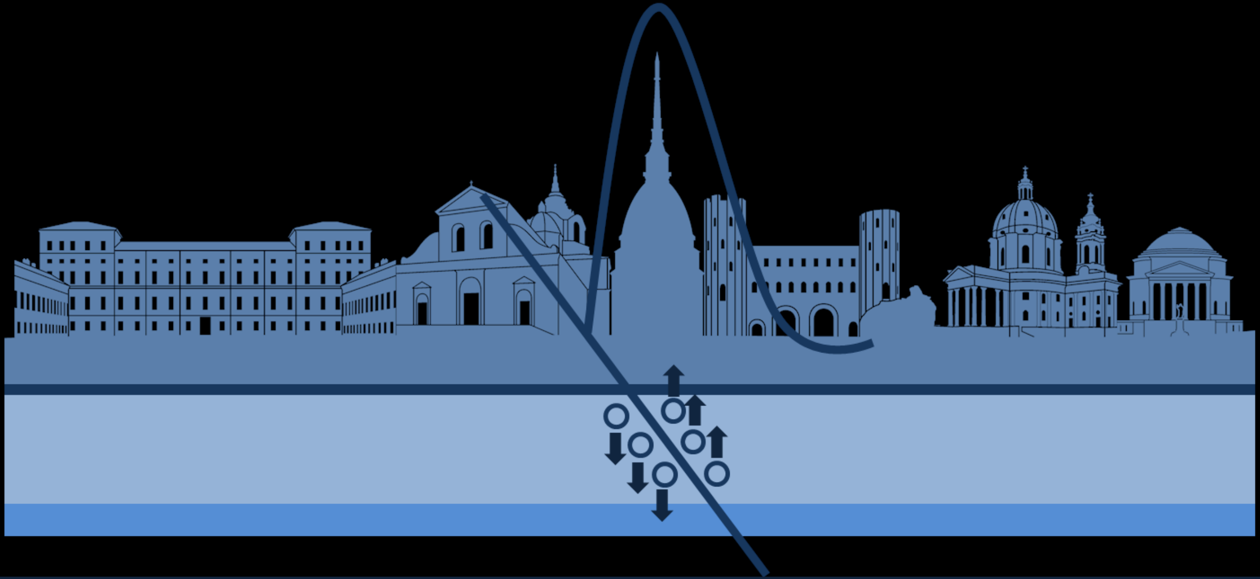


Status of the research in the TOFFEE ASIC

Workshop on pico-second timing detector for physics and medical applications

Turin
May 16th 2018

Jonhatan Olave
On behalf of the **UFSD** collaboration

Outline

- Motivation
- Time resolution
- UFSD sensors
- Chip description
- Test results
- Future plans

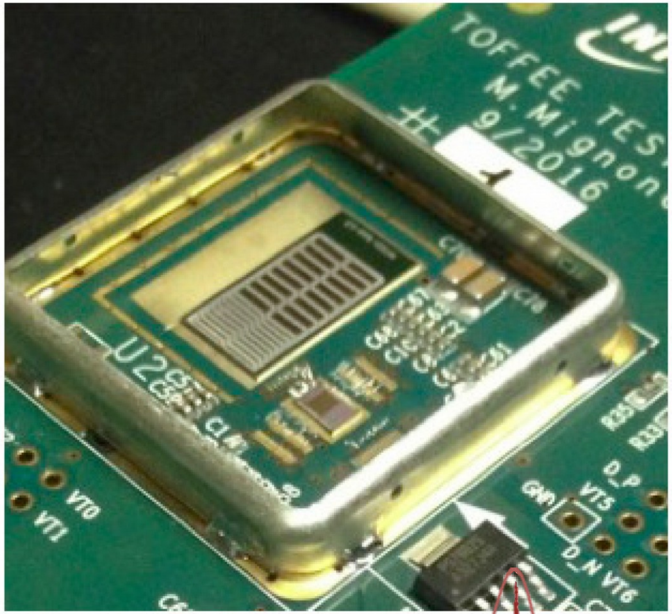
Motivation

TOFFEE = **T**ime **O**f **F**light **F**ront **E**nd **E**lectronics

First prototype developed for timing measurements with multichannel LGADs

Applications

- Testing purposes
- Usage in CT-PPS timing stations
    - Due to the high luminosity, 150 – 200 events/bunch crossing are expected
    - Time-tagging of protons is used as a pile-up mitigation tool
    - To determine the z position of the vertex with an accuracy of 4 mm, 20 ps time resolution is needed



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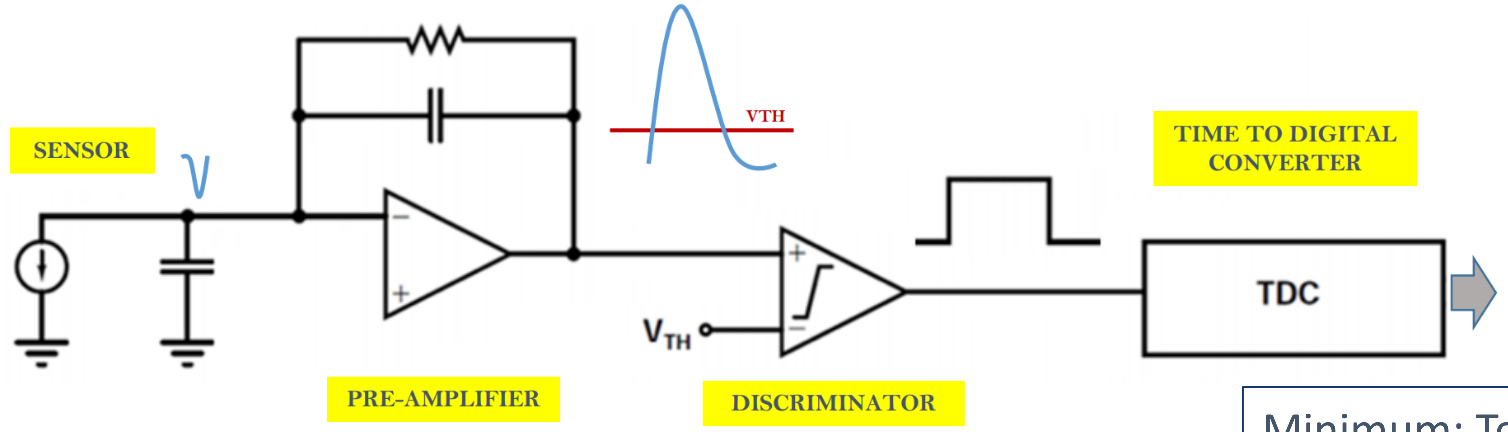
Time resolution



Minimum: Tc = Tp

$$\sigma_t \propto \sqrt{T_p + \frac{T_c^2}{T_p}}$$

$$\sigma_t^2 = \left(\frac{N}{\frac{dV}{dt}}\right)^2 + \left(\frac{\delta_{Bin}}{\sqrt{12}}\right)^2 + \sigma_{Time\ Walk}^2$$

JITTER

TDC contribution

Sensor signal shape variations due to Landau flutuations

High time resolution = Fast Sensor + Fast Electronics

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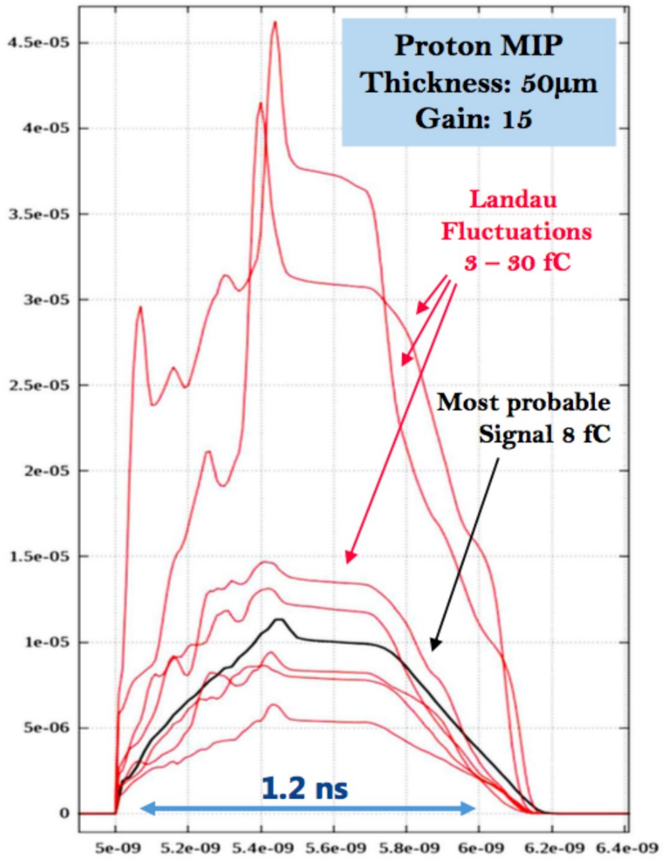
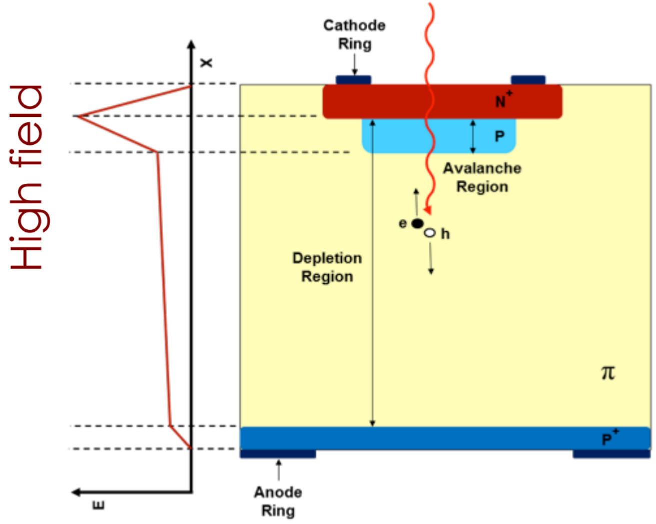
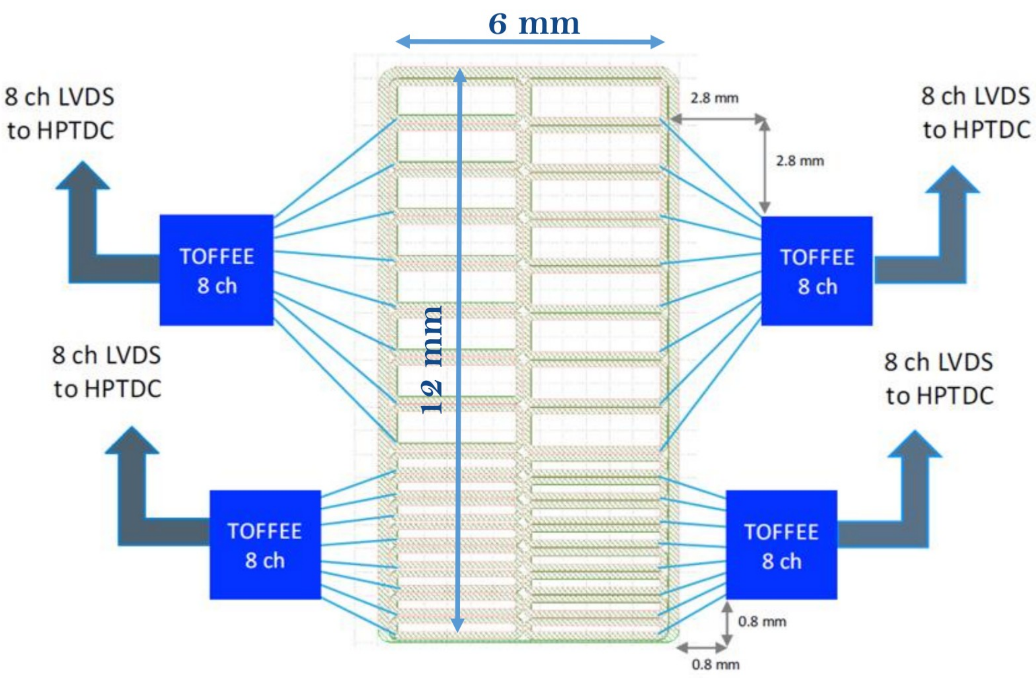
Fast sensors: Ultra Fast Silicon Detectors (UFSD)



UFSD are thin Low Gain Avalanche Diodes (LGAD) sensors optimized of timing measurements of MIPs.



The CT-PPS UFSD sensors



PADS	16 narrow + 16 wide
Thickness	50 µm
Module size	12 mm × 6 mm
Strip size	3 mm × 0.5 mm 3 mm × 1 mm
Gain	15
Cdet	3 pF (narrow) 6 pF (wide)
Dead space	50 µm between pads

The ASIC **size** and the **number of channels** have been chosen based on the CT-PPS sensor.
Power consumption can be **20 mW/CH** → **Power is not a constraint**

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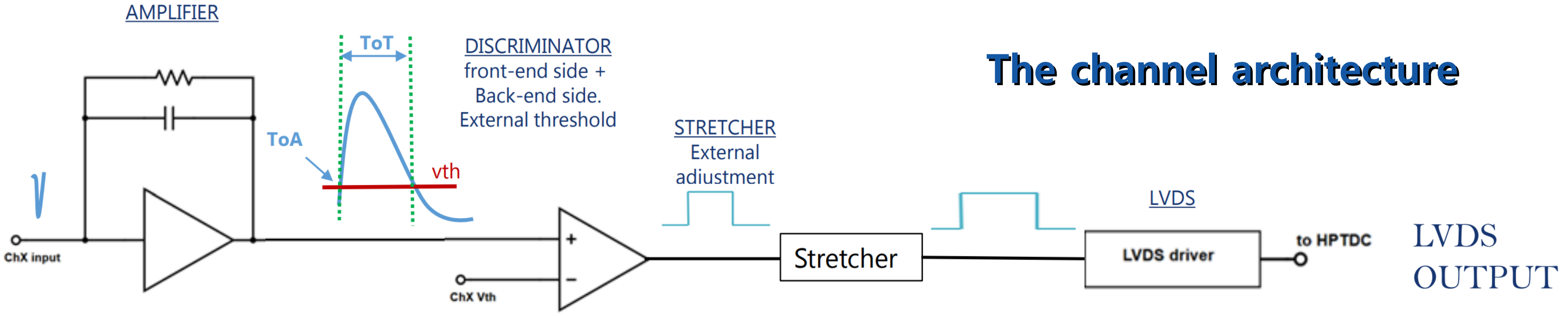
The TOFFEE ASIC

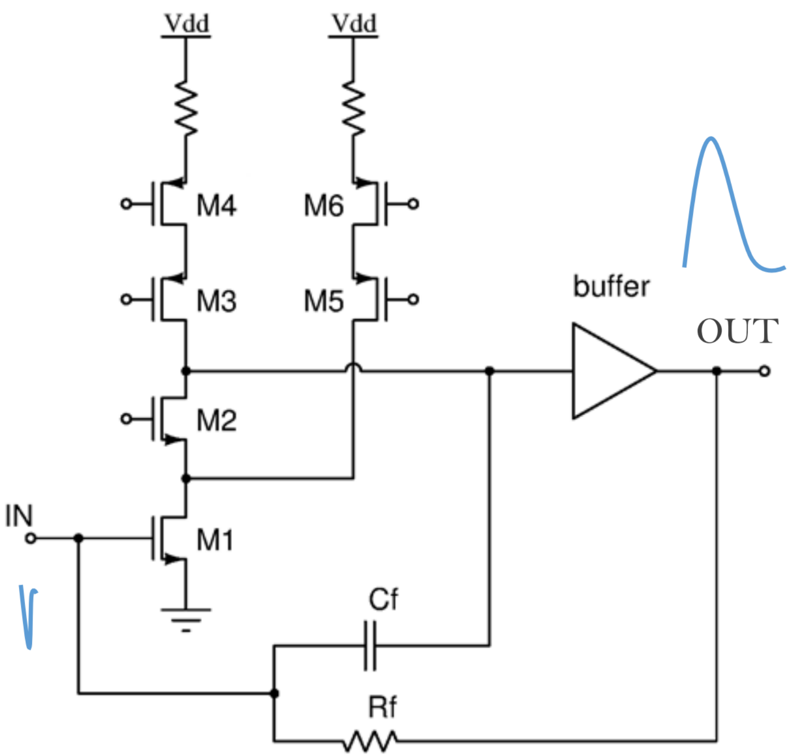
The channel architecture



Technology	CMOS 110 nm
Channels	8
Sensor capacitance	2-10 pF
Input dynamic range	3 fC – 60 fC
Analog gain	7 mV/fC
GBW	14 GHz
RMS noise (C=6pF)	800 μV
Discriminator output	2 – 14 ns
Power consumption	18 mW/ch
AVDD/DVDD	1.2 V/2.5 V

- TOFFEE is a **full custom analog chip** developed by the INFN of Turin and the LIP institute of Lisbon
- Developed for the amplification and digitalization of signals coming from UFSD sensors
- The outputs are digitalized by the external **High Precicion TDC**[1] and for this reason a stretcher line is used
- The **size 2.4 mm x 3.6 mm**
- **(1) J. Christiansen, 2004, http://cds.cern.ch/record/1067476**

The amplifier: charge sensitive amplifier



Rise time	schematic ~2 ns / post-layout < 3 ns
Analog Gain	~ 7 mV/fC
Slew Rate +	~ 25 mV/ns
Noise	~ 800 uV
Expected jitter	~ 32 ps

- Based on a **telecopic cascode common source** with split bias current
- Source degeneration resistors used for noise reduction
- Wide dynamic range
- High slew rate

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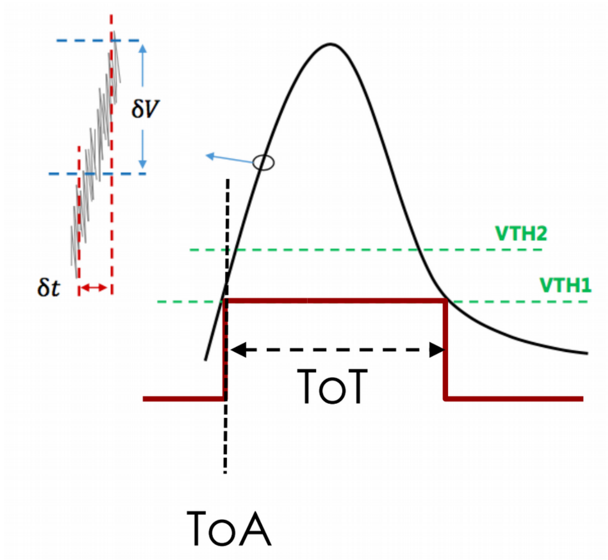
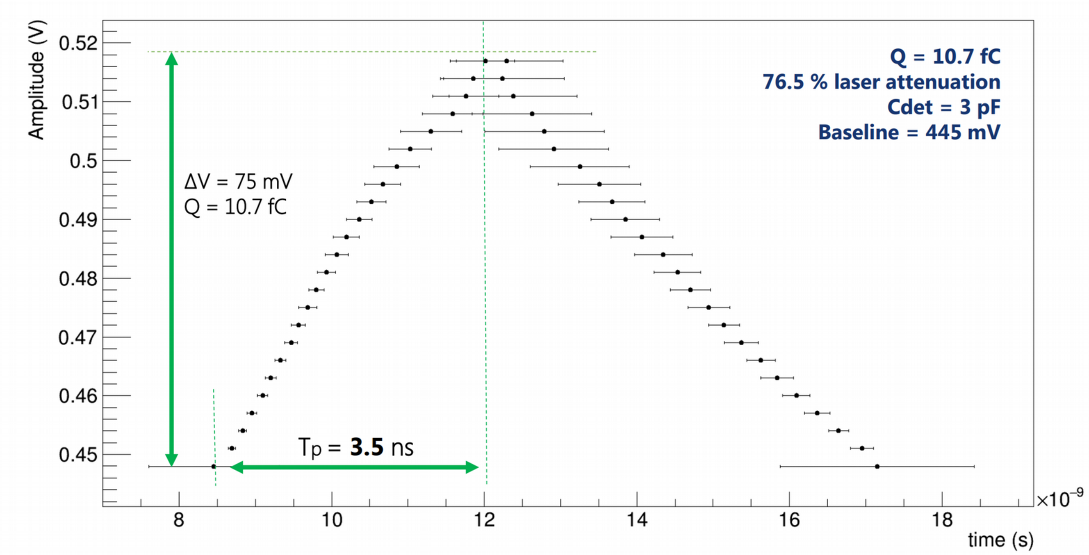
Analog signal reconstruction



$$SR^{+} = \frac{ToA_{VTH2} - ToA_{VTH1}}{VTH2 - VTH1}$$

$$Noise = SR^{+} \times Jitter$$

The reconstruction is done by means of a Vth scan

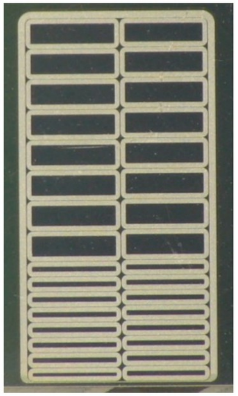


rise time: 3.5 ns (3 ns in post-layout)
slew rate: 25 mV/ns
noise: 0.8 mV

Time resolution: What is the expected final time resolution?

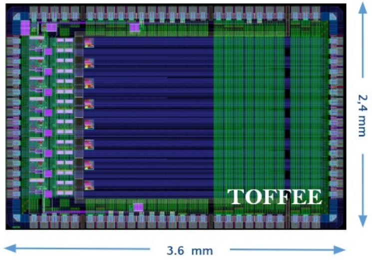
Complete system:

SENSOR



+

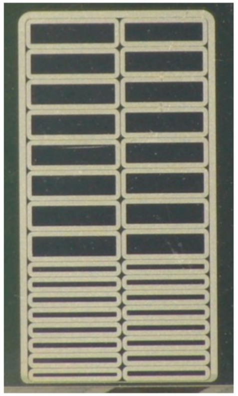
ELECTRONICS



Time resolution: What is the expected final time resolution?

Complete system:

SENSOR



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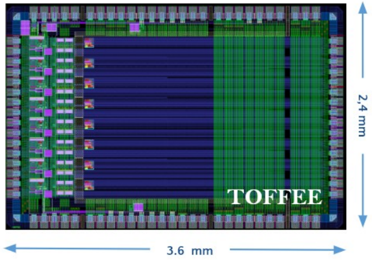
ELECTRONICS

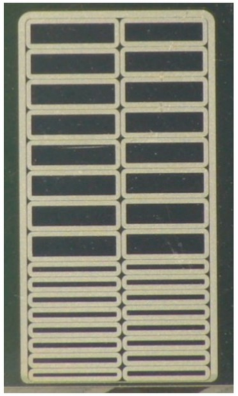


$$\sigma_t^2 = \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2 + \sigma_{TimeWalk}^2$$

Time resolution: What is the expected final time resolution?

Complete system:

SENSOR



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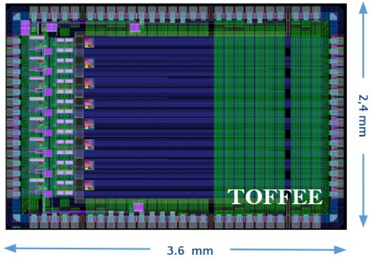
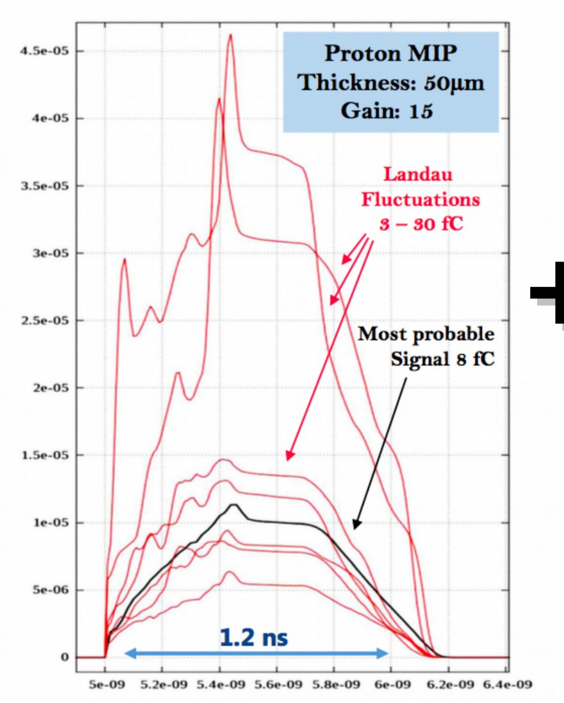
ELECTRONICS



$$\sigma_t^2 = \boxed{\sigma^2_{LandauNoise}+\sigma^2_{Distortion}} + \boxed{\sigma^2_{Jitter}+\sigma^2_{TDC}+\sigma^2_{TimeWalk}}$$

Time resolution: What is the expected final time resolution?

The effect of the non-uniform charge deposition can be studied with WF2 (1)



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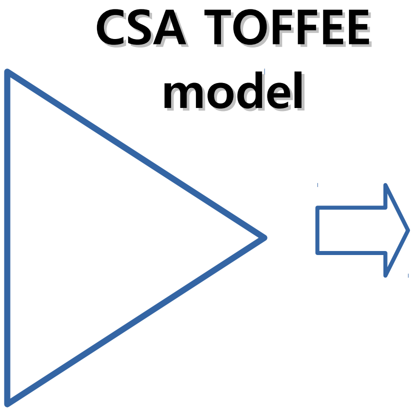
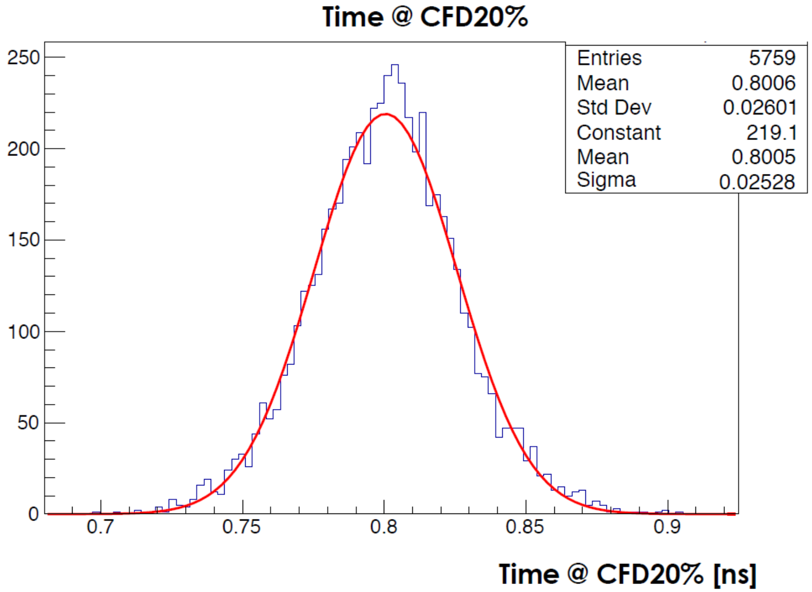
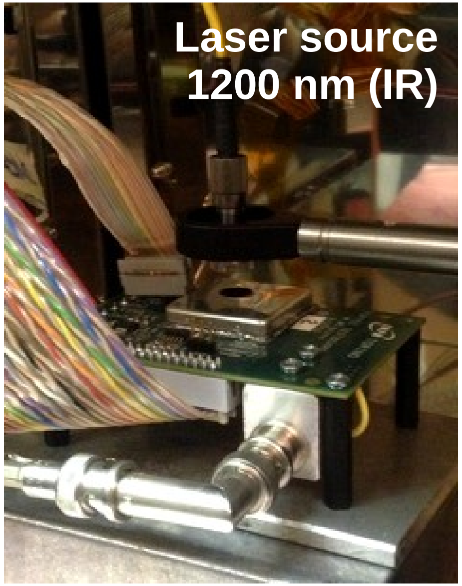


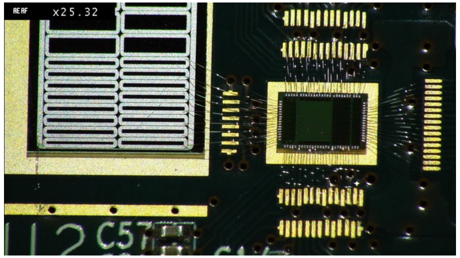


The sensor contribution is 25 – 30 ps

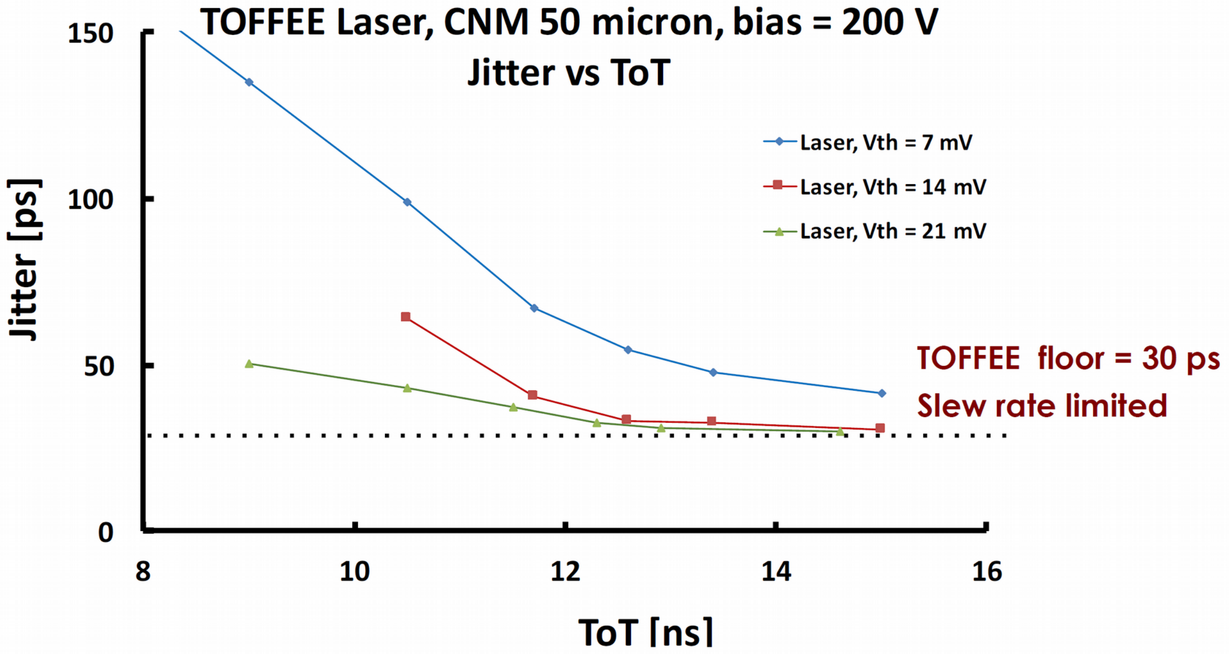
(1) Nicolo's talk on Friday

Time resolution: What is the expected final time resolution?



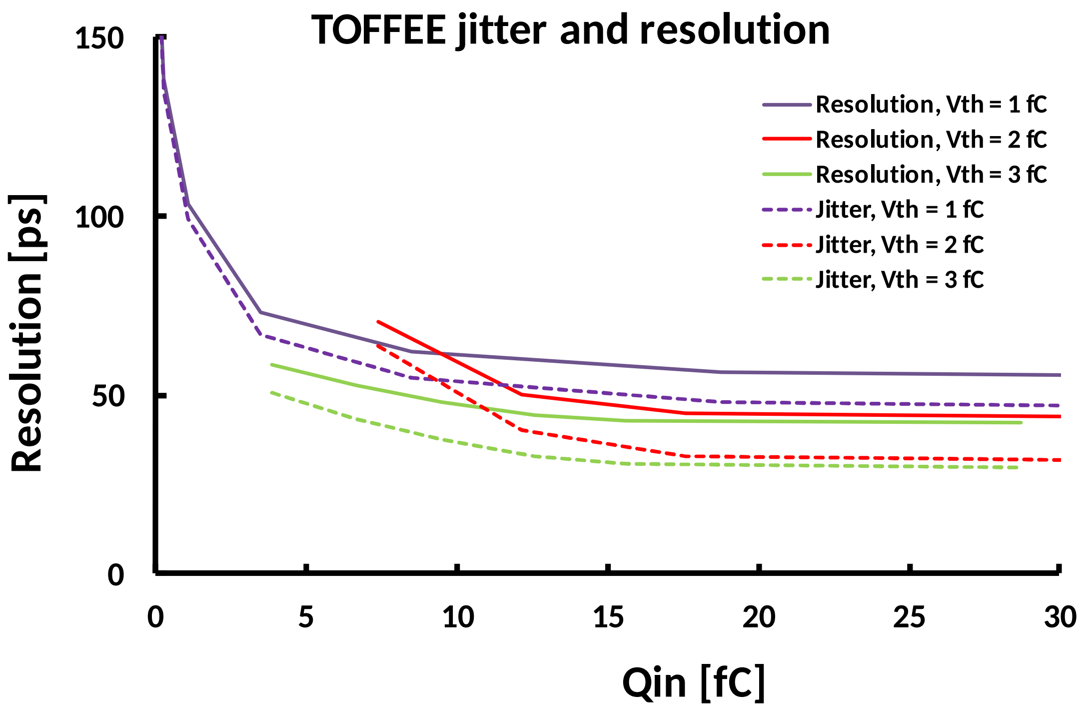


The contribution from the electronics can be measured with a laser



The electronics contribution is 35 ps

Time resolution: What is the expected final time resolution?



Jitter (35 ps) and non-uniform distribution (30 ps) determine the final expected time resolution (45 – 50 ps)

Outline

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Beam tests

Four beam tests at CERN SPS - H8

In H8: 120 GeV/c pion beam

May:

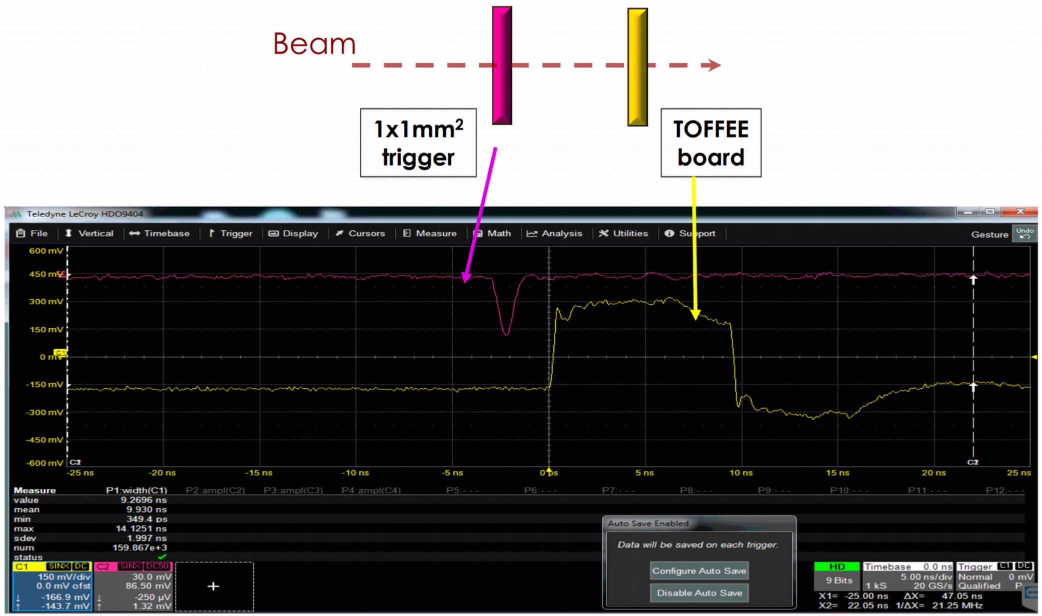
- Telescope 3 TOFFEE boards + HPTDC
- Scan in sensor Vbias – fixed Vth

July and End of August:

- TOFFEE board, read-out with differential probe
- UFSD CNM 1x1 mm^2 + USCS preAmp board (time resolution ~ 35 ps)
- Both recorded by a 4 GHz scope (LeCroy HDO9404)
- Several studies done

October

- Telescope of 2 TOFFEE boards read-out with the differential probe
- HPK pad 1x1mm^2 (50 um)

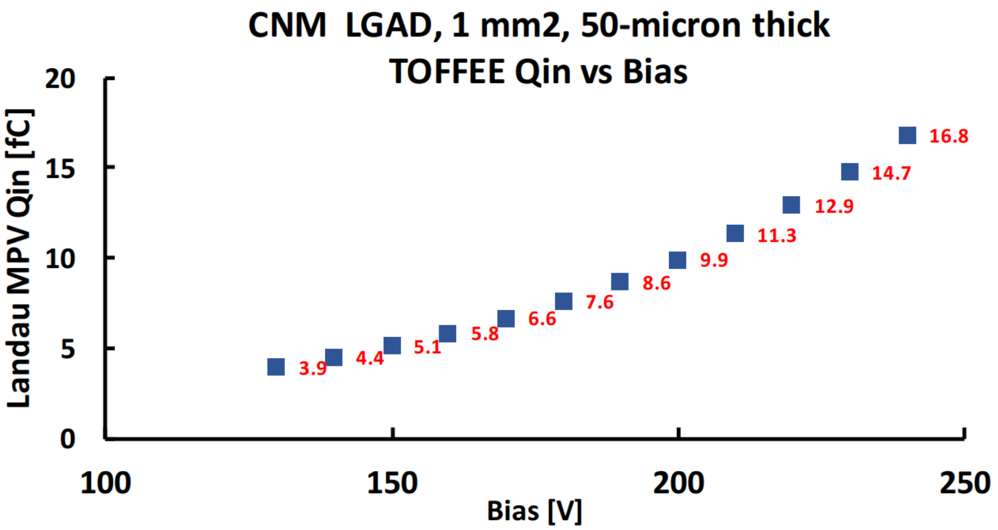


From R. Arcidiacono TWEPP 2017

Analog gain

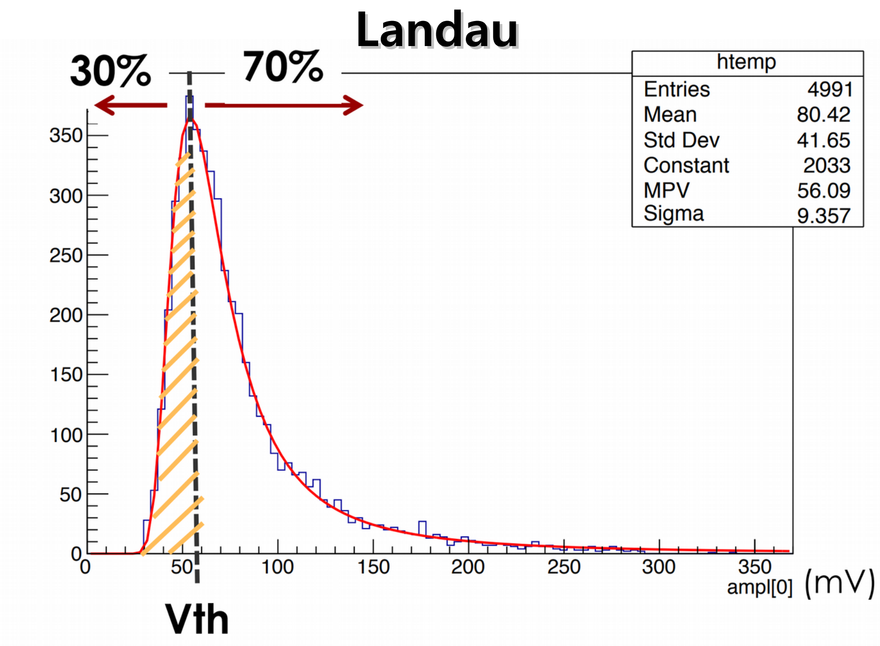
The analog gain is determined by measuring the signal amplitude generated by different input charges.

input charge



- The gain of UFSD changes with Vbias.
- This curve is well known from lab and beams test

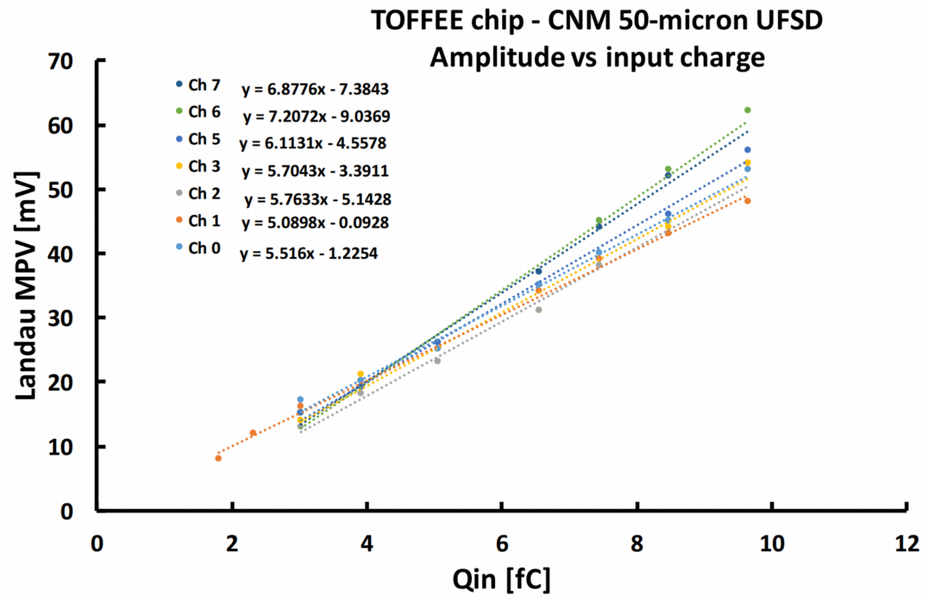
Analog gain

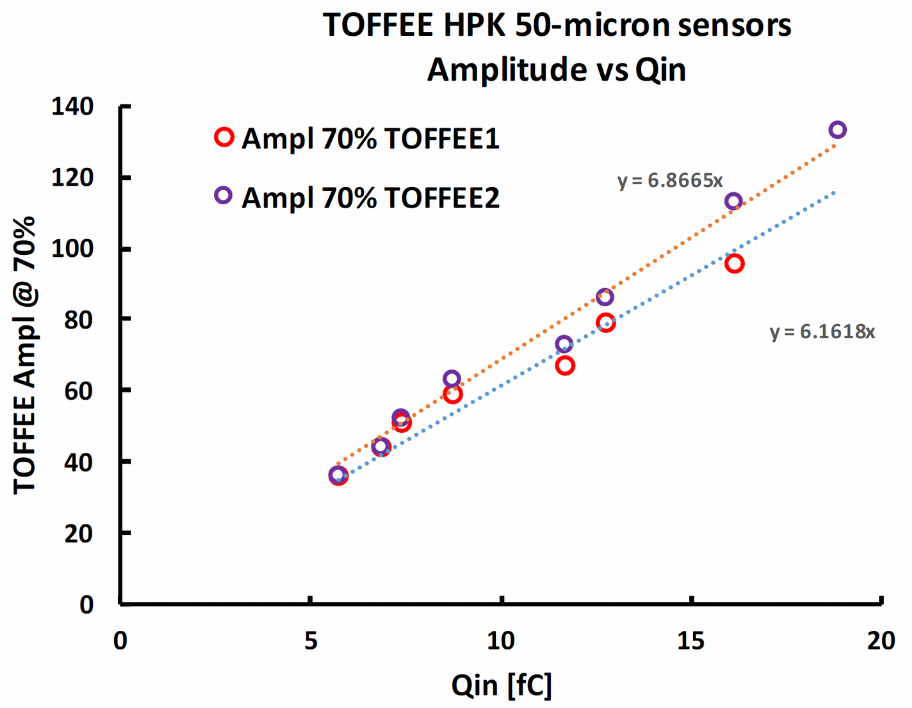


- The amplitude is determined exploiting the **bunched structure of particles** and the **properties of the Landau distribution**
- The number of particle per spill is fixed (300 – 400 particles/spill)

The Vth value which keeps **70%** of the events/spill corresponds to the Landau MPV

Analog gain

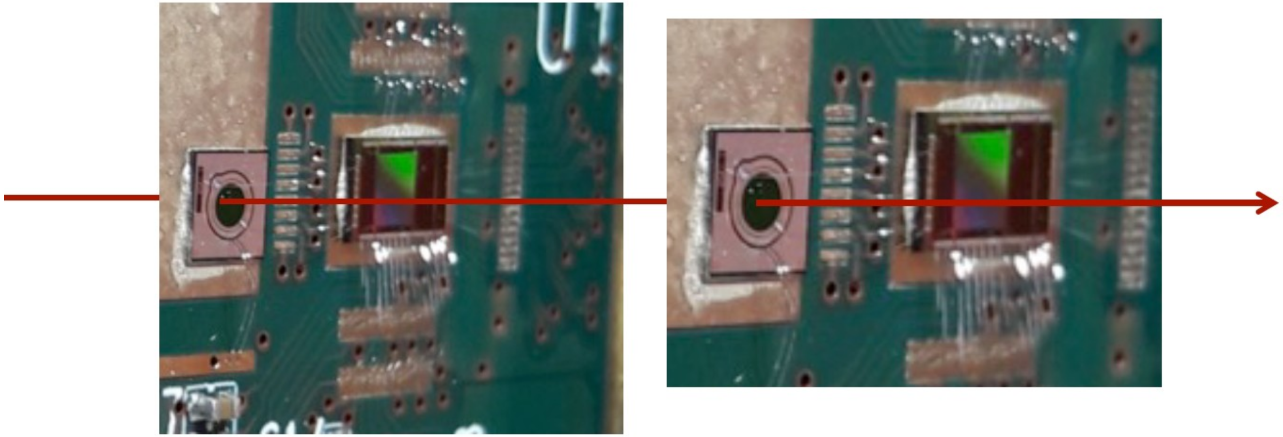




Good agreement with the expected value (6.5 mV/fC)

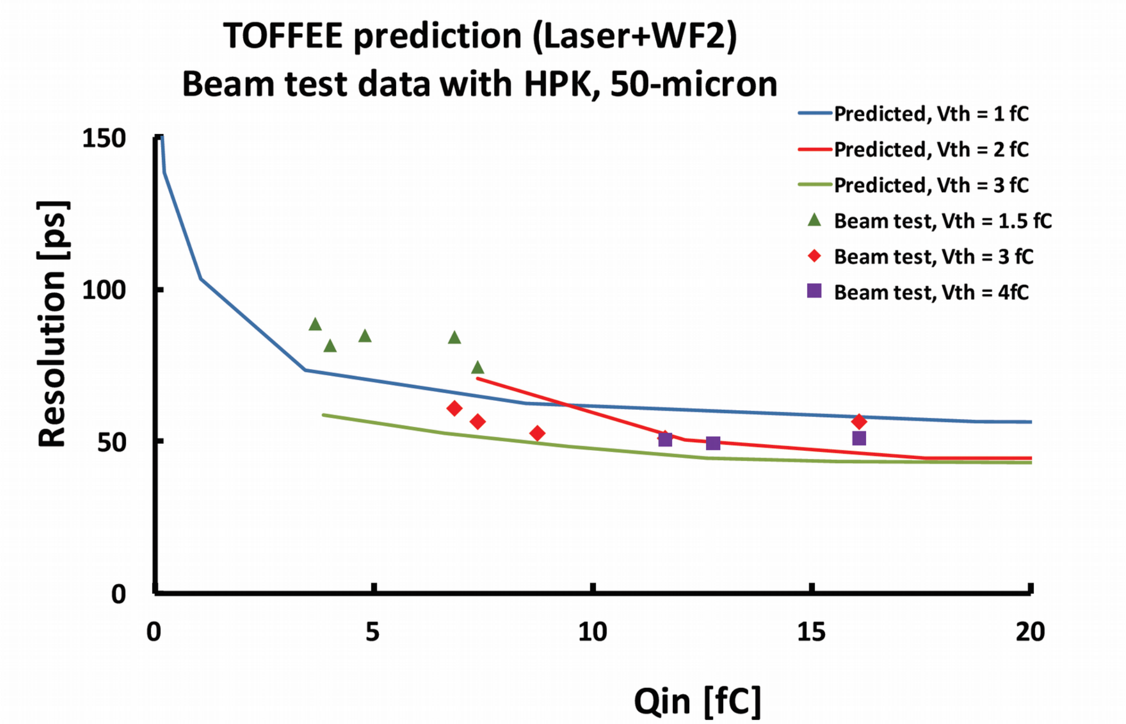
Beam test: TOFFEE + HPK

Two layers of TOFFEE + Hamamatsu Photonics (HPK) pad 1 mm (50 um)



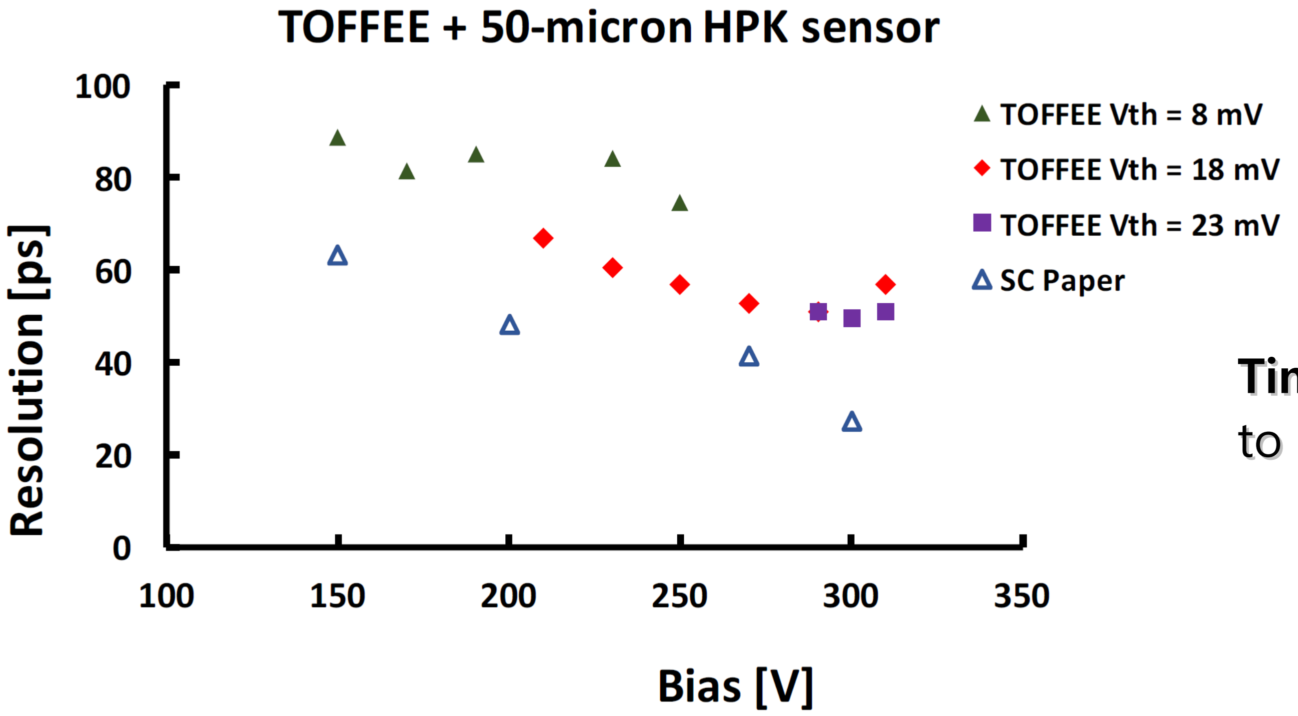
Only one channel is used while the others are grounded

Test beam: time resolution



Best resolution (~50 ps) is in **good agreement** with the expected (45 ps)
Low thresholds degrade the time resolution

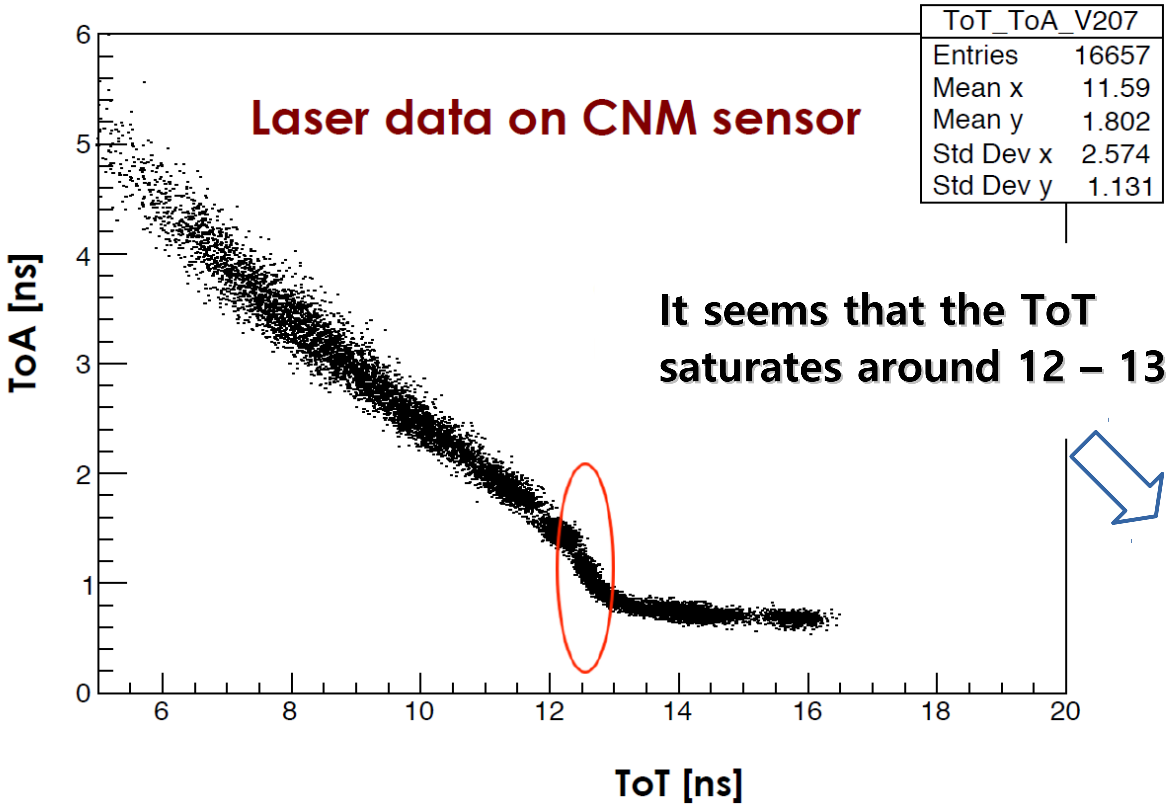
Comparison with an old test beam



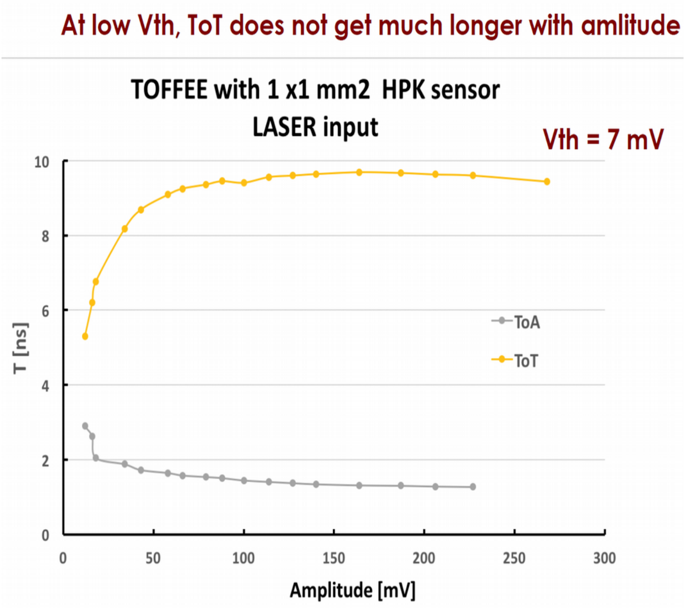
Time resolution limited to **50 ps**

Good agreement also with the old test beam results

Low thresholds effects

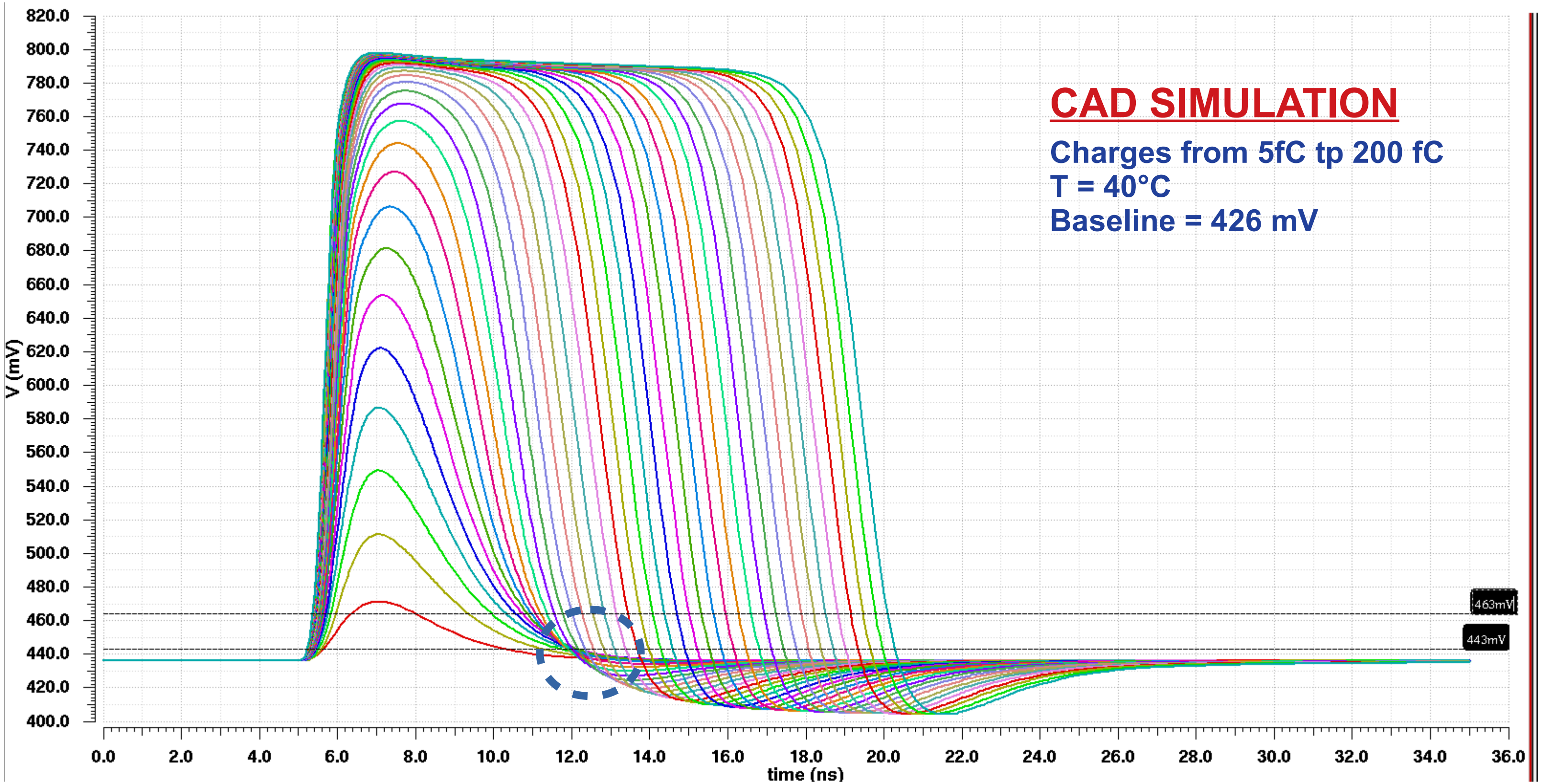


It seems that the ToT saturates around 12 – 13 ns

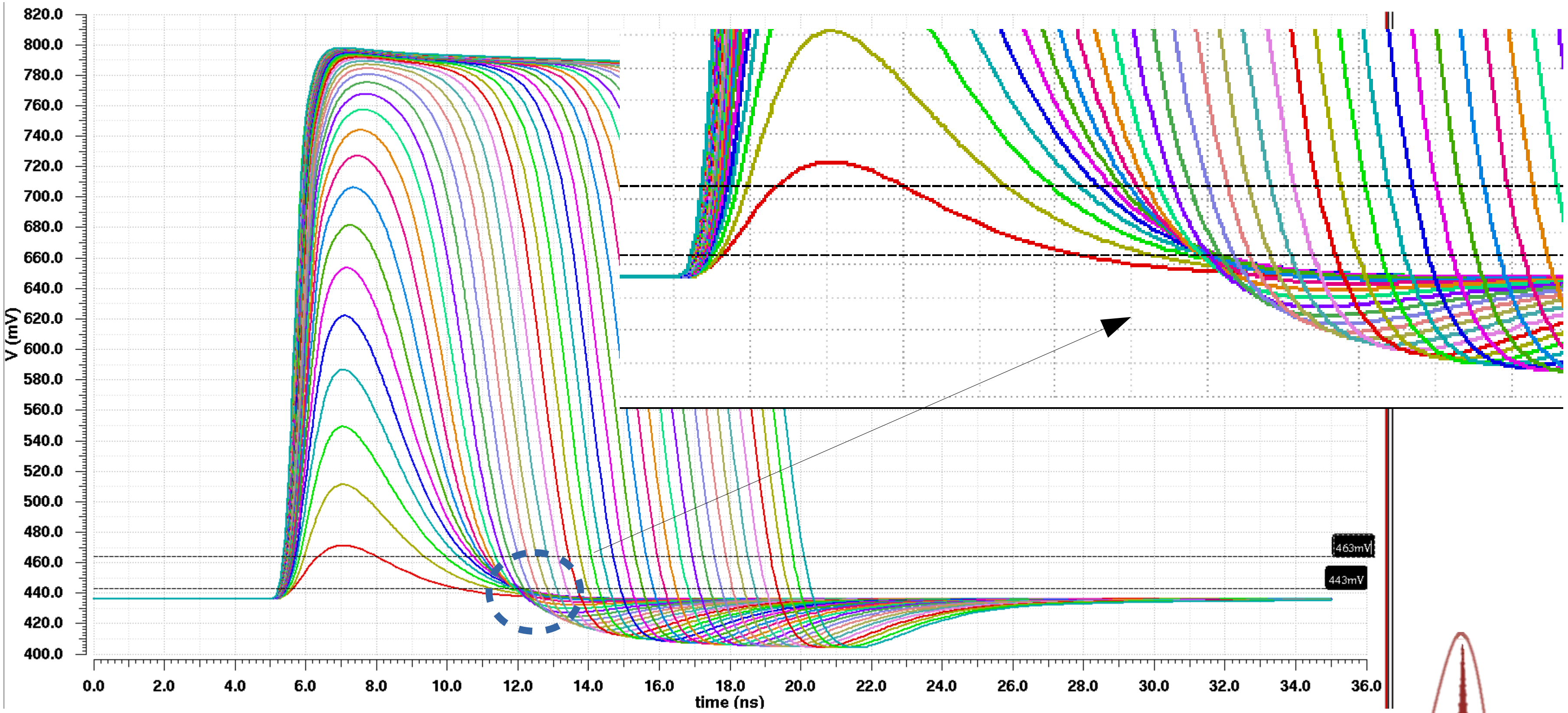


Time walk correction in this region is not possible in this region

Low thresholds effects

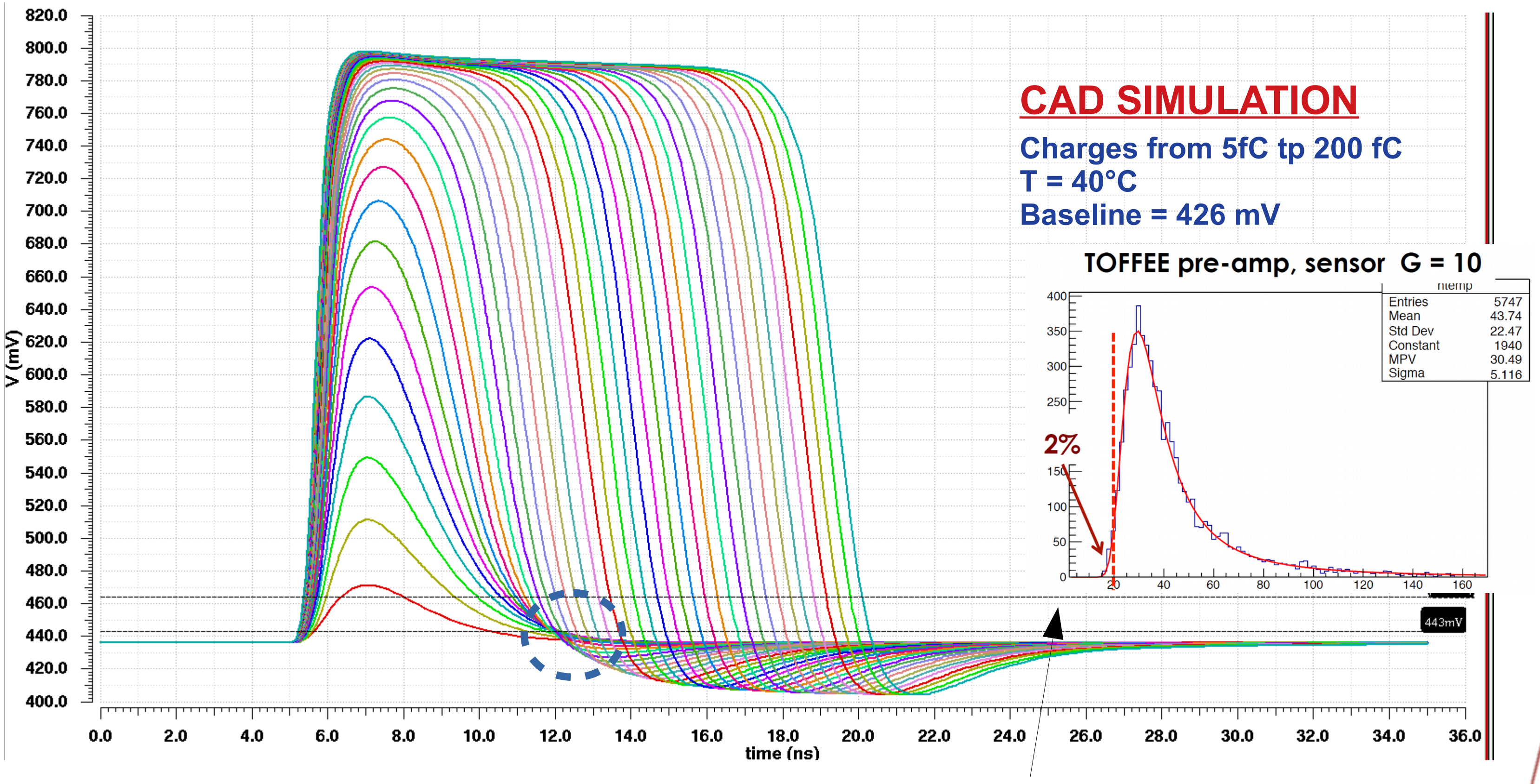


Low thresholds effects



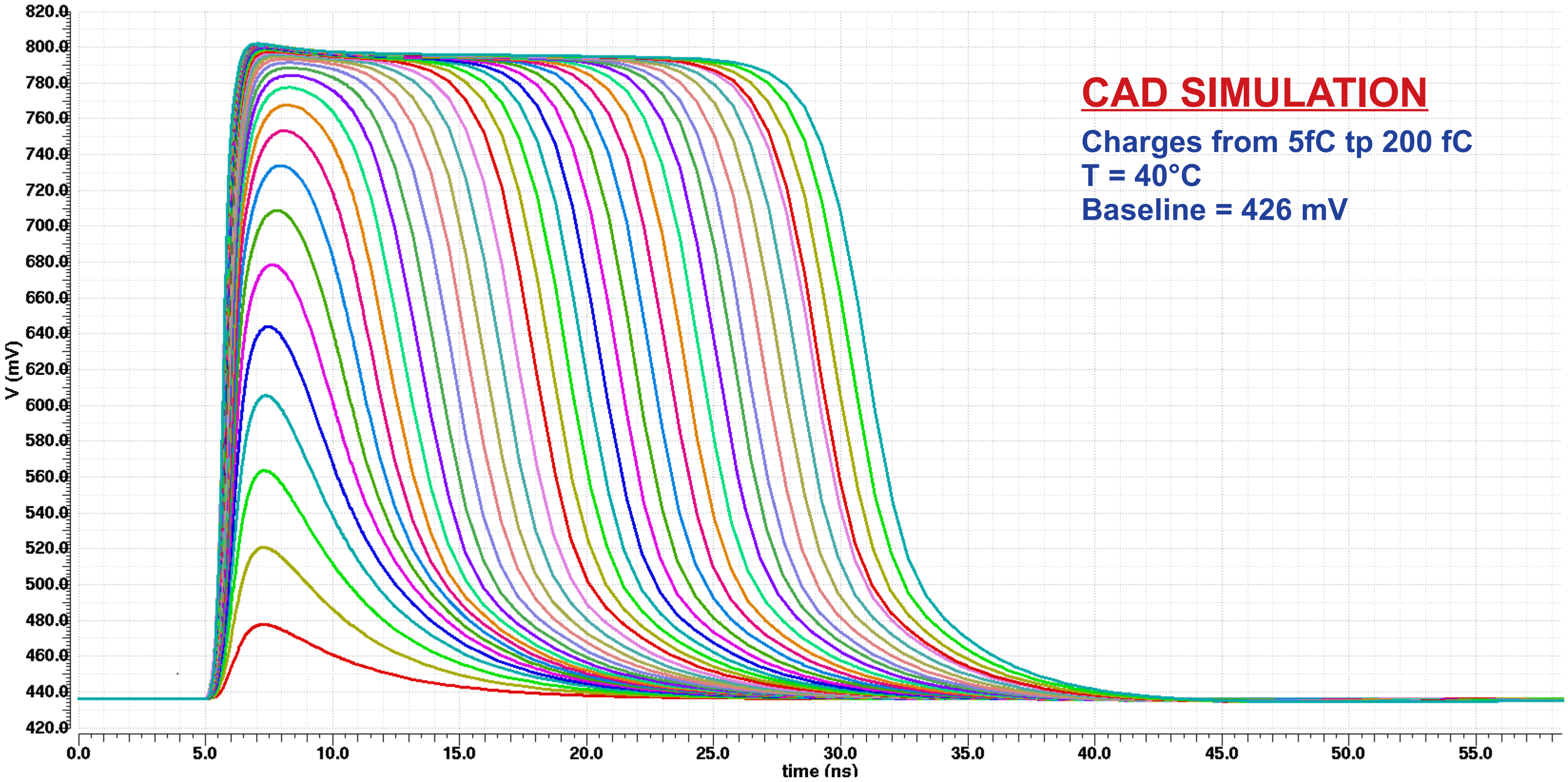
The saturation can be avoided by using thresholds higher than 21 mV (~3 fC)

Low thresholds effects



The saturation can be avoided by using thresholds higher than 21 mV (~3 fC)

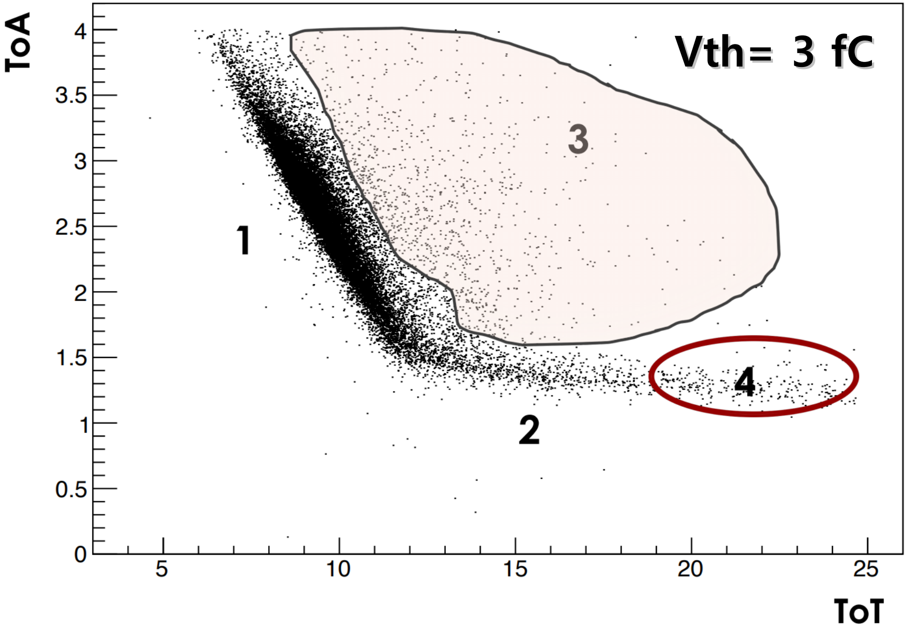
Low thresholds effects: Example of solution

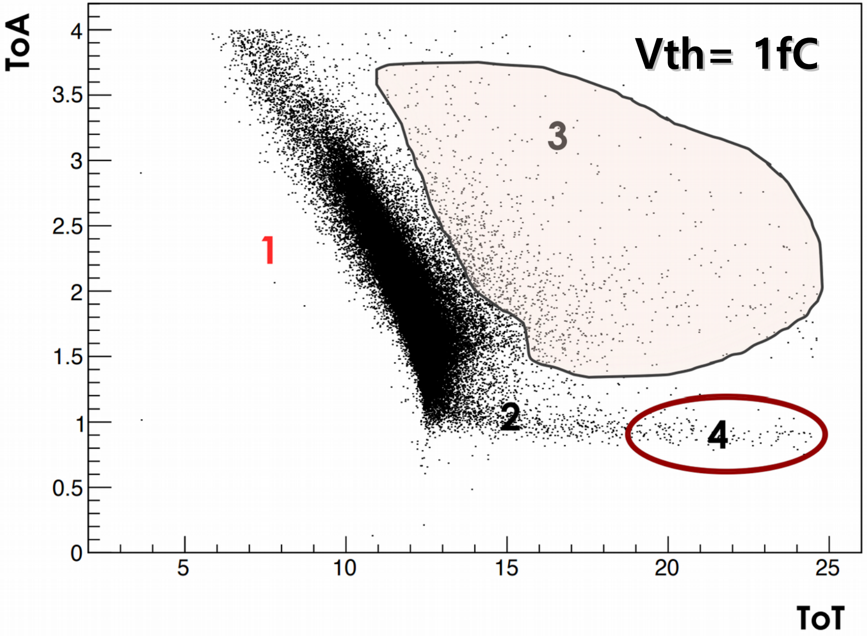


CAD SIMULATION

Charges from 5fC tp 200 fC
T = 40°C
Baseline = 426 mV

ToA vs ToT

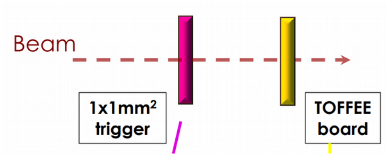




1) expected ToA/ToT correlation
2) expected slew rate saturation for high signals
3) events with incompatible ToA/ToT (not present in Laser data)
4) Very long tail, possible re-triggering

WORK IN PROGRESS

Unexpected effects

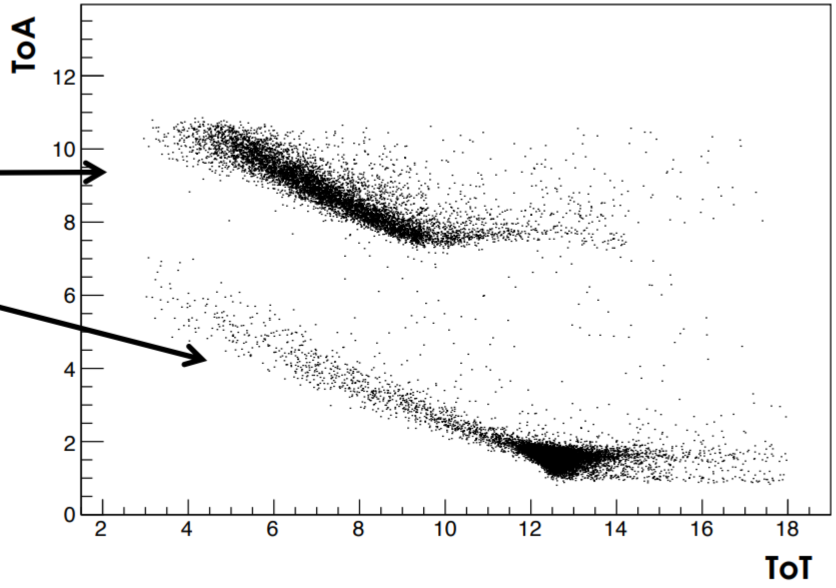


Unexpected effects

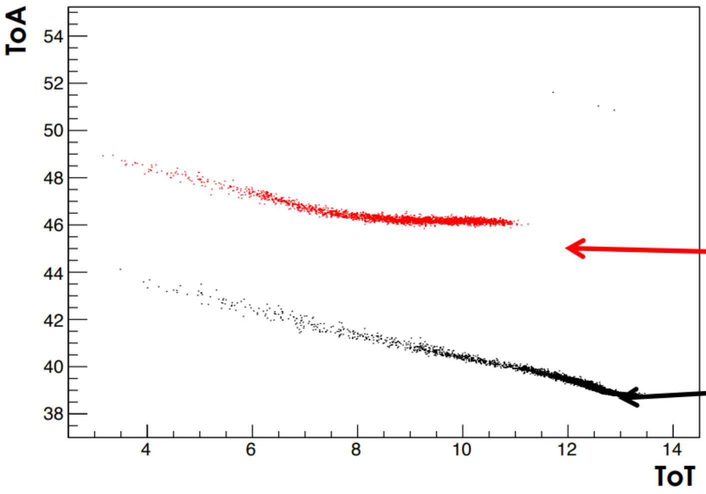
Two families of events observed

Short ToT at 5-6 ns from the trigger

Long ToT with a timing close to the trigger timing



STUDY WITH LASER SYSTEM in the LAB



Laser on neighboring strip

Laser on read-out strip

Crosstalk??

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Outlook and future plans

- The signal reconstruction with threshold scans shows that the rise time (3.5 ns) is in good agreement with what expected (3 ns). Parasitics play an important role in this value.

- The prediction of the TOFFEE performance with WF2:
  - jitter slew rate limited to ~35 ps
  - non-uniform charge deposition is ~30 ps

- The measured gain is 6 mV/fC and is in good agreement with simulations

- The time resolution of TOFFEE is 50 ps for gain > 20

Future plans

- Extensive lab measurements to investigate about possible crosstalk
- Investigate on possible crosstalk

Acknowledgements

We kindly acknowledge the UFSD group for the support and the following funding agencies:

- INFN – GruppoV
- Horizon 2020 Grant URC 669529
- Ministero degli Affari Esteri, Italy, MAE

Thank you for your attention