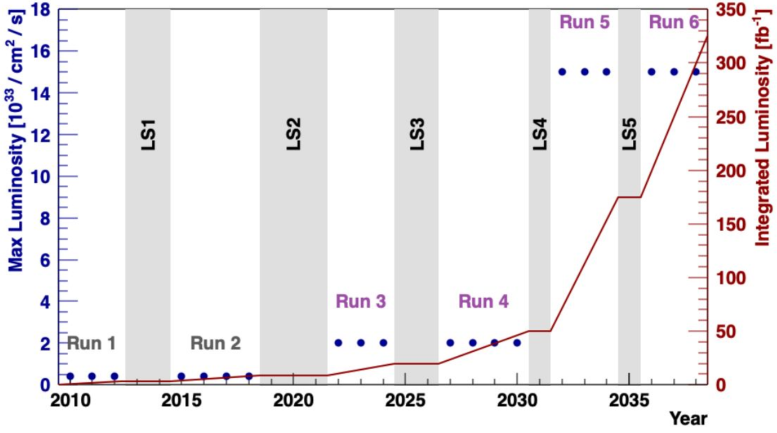
Characterisation and preliminary results on 3D trench pixel sensors irradiated up to 10^{17} 1 MeV n_{eq} cm^{-2}

19th Trento Workshop on Advanced Silicon Radiation Detectors

M. Addison, F. Borgato, A. Cardini, G.M. Cossu, G.-F. Dalla Betta, M. Garau, L. La Delfa, A. Lai, A. Lampis, A. Loi, M. Obertino, G. Simi, S. Vecchi, M. Verdoglia

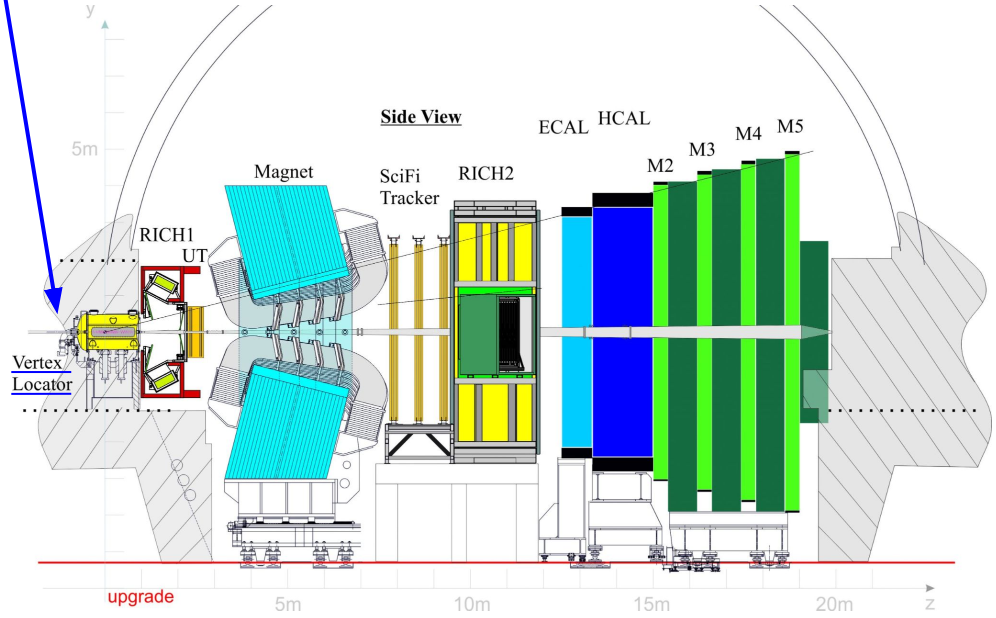
Introduction: LHCb detector Upgrade II

- One of the 4 major experiment at CERN
- Planned upgrade for the Phase II in 2035 to cope with the increase of luminosity
- Primary vertex detector **VE**rtex **LO**cator



- Single-arm **forward** spectrometer

Phase II Upgrade LHCb Detector



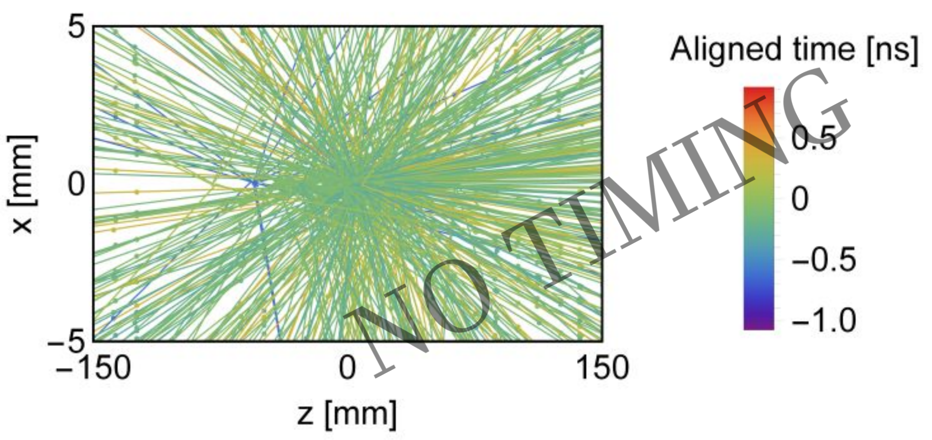
Introduction: LHCb detector Upgrade II, timing

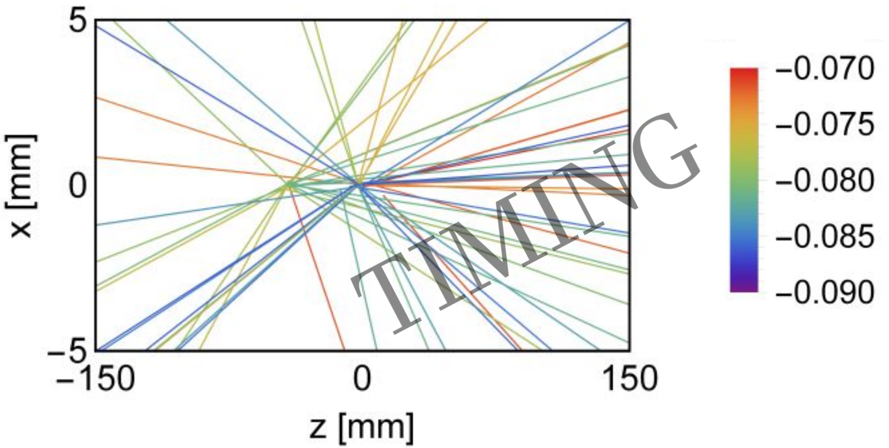
VErtex **LO**cator requirements for the Run 5 and Run 6

HL-LHC → 1.5 x 10^{34} cm^{-2} s^{-1} → Radiation Hardness ~5 x 10^{16} 1 MeV n_{eq} cm^{-2}

→ Timing capabilities σ_t ~ 50 ps

(for the entire duration of the experiment)



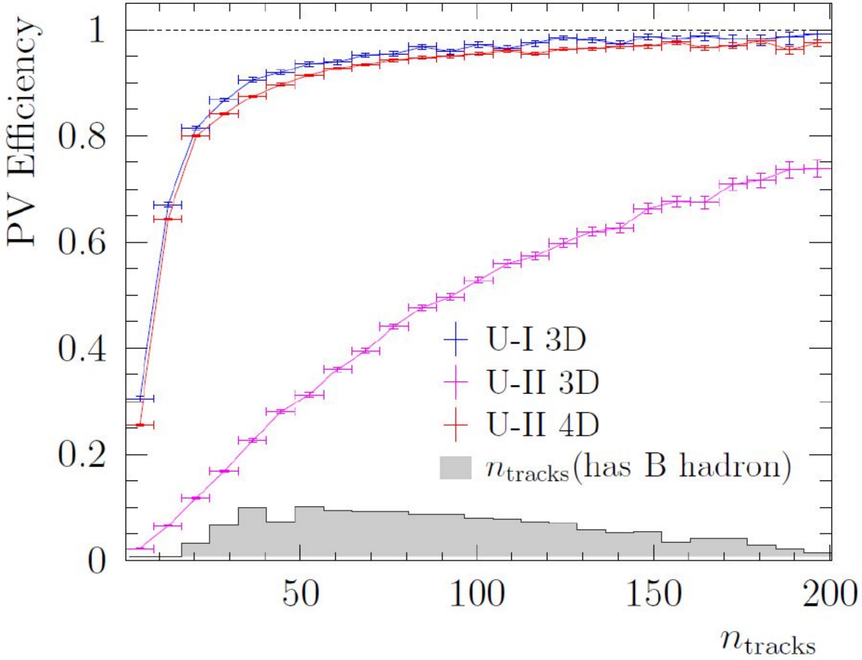


Introduction: LHCb & **UII Detector**

VErtex **LO**cator, new technologies are needed in order to *maintain* the current primary vertices reconstruction efficiency also at high luminosity:

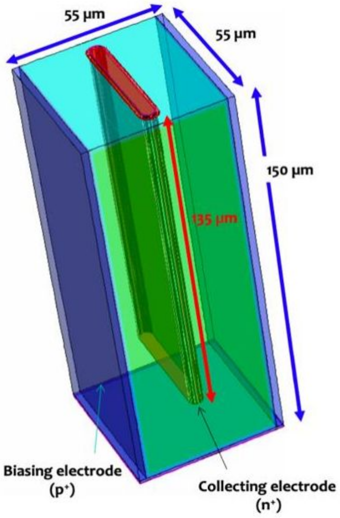
3D silicon pixel with timing capabilities

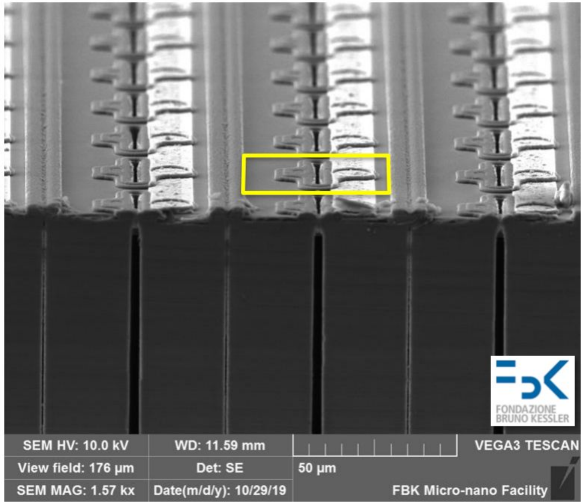
- Spatial resolution (pitch~50μm)
- Timing resolution (~50ps)
- Radiation hardness (~5x10^{16} fluence)

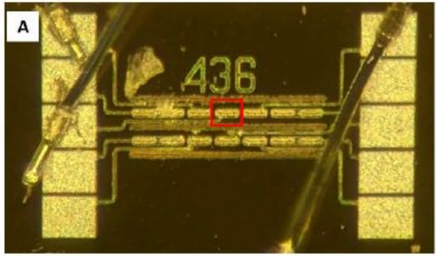


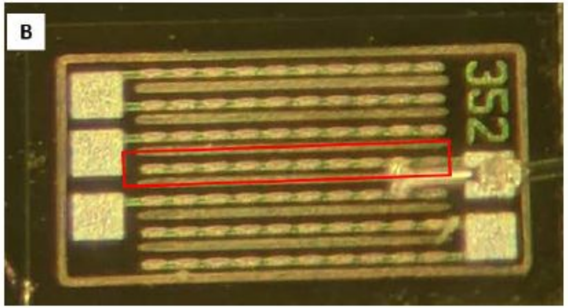
TimeSPOT project

- 3D silicon pixel technology is suitable for its *radiation hardness*
- Geometry optimisation lead to excellent *timing performance*
- TimeSPOT 3D Trench silicon pixel



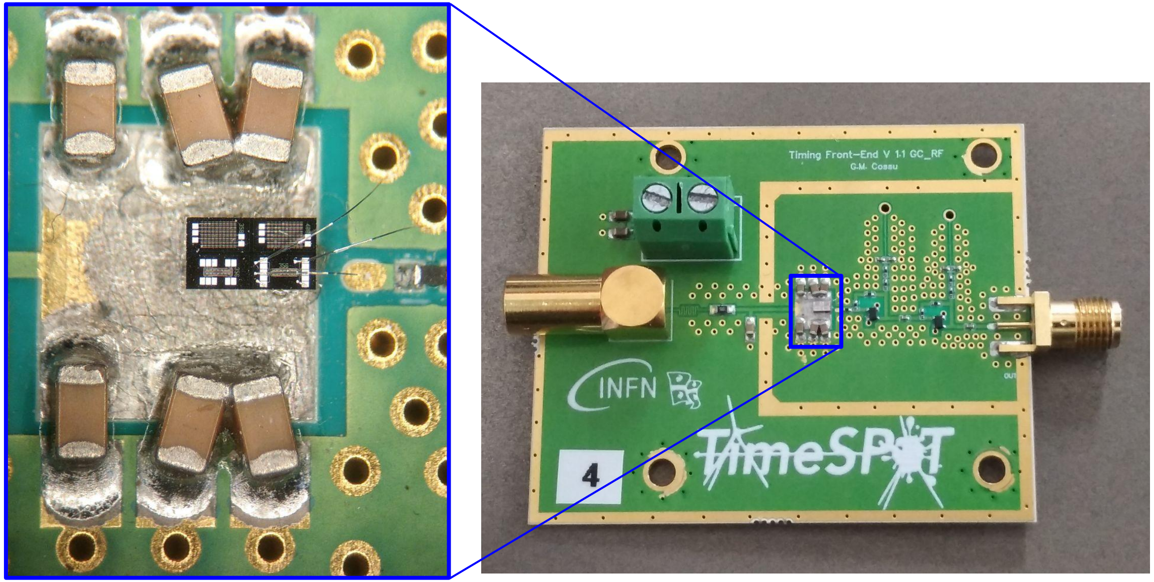






TimeSPOT: sensor characterisation

Two batches produced by *Fondazione Bruno Kessler* (Trento, Italy), of which non-irradiated and irradiated up to $2.5\mathrm{x}10^{16}$ 1 MeV n_{eq} cm^{-2} sensors were characterised (Irradiation of TimeSPOT sensors with neutrons has been done by the *TRIGA Mark II reactor* of the *Jožef Stefan Institute* in Ljubljana, Slovenia)

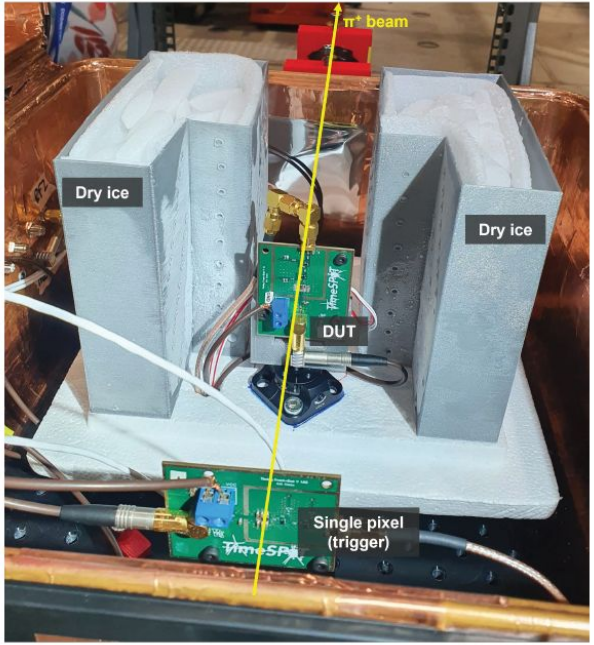


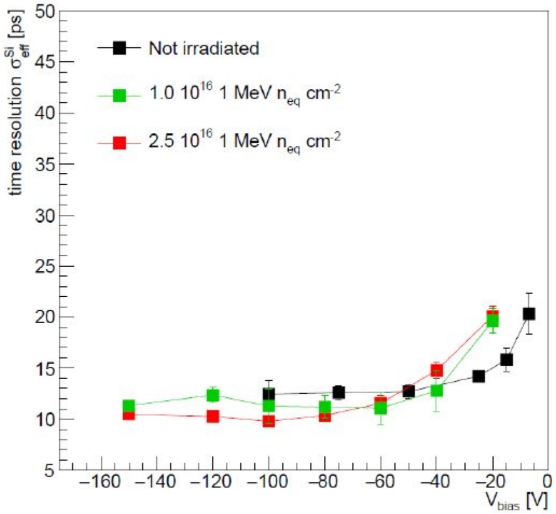
Custom-made front-end electronics boards featuring a two-stage transimpedence amplifier made with fast SiGe BJTs, designed and produced to test TimeSPOT 3D trench sensors timing performance

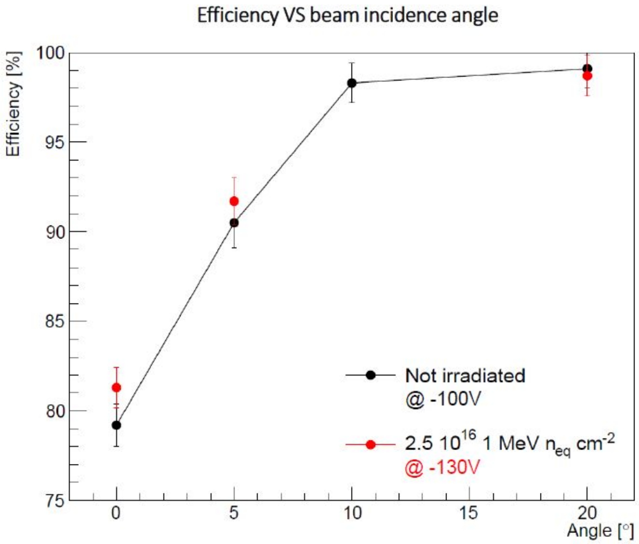
https://iopscience.iop.org/article/10.1088/1748-0221/18/01/P01039/meta

TimeSPOT: sensor characterisation @ test beam

Previous irradiating campaign up to $2.5x10^{16}$ of fluence at test beam (2022) shown excellent timing resolution and efficiency:







SETUP at 2022 test beam

Characterisation of 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel: setup

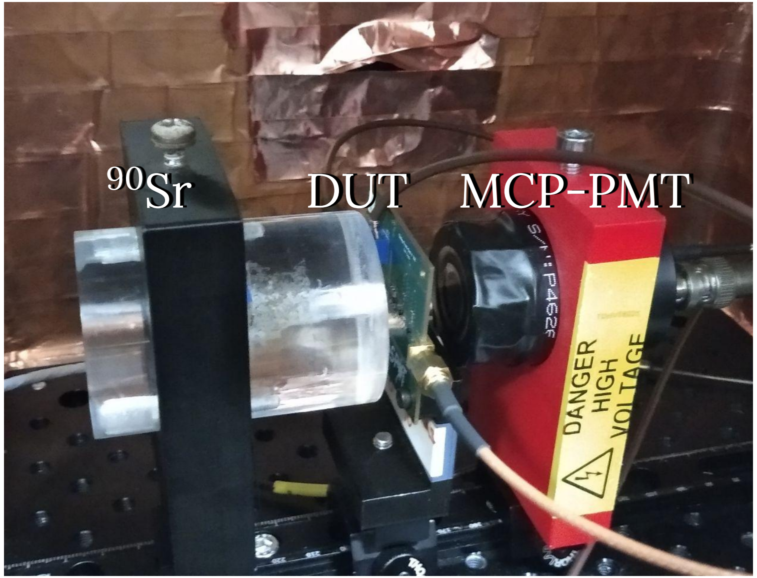
^{90}***Sr*** radioactive source measurements in laboratory in order to validate performances of highly irradiated sensors:

Setup:

- DUT
- ^{90}Sr radioactive source
- Climatic chamber at **T = -20°C**
- MCP-PMT as time reference (ref)
- Oscilloscope

Measurements:

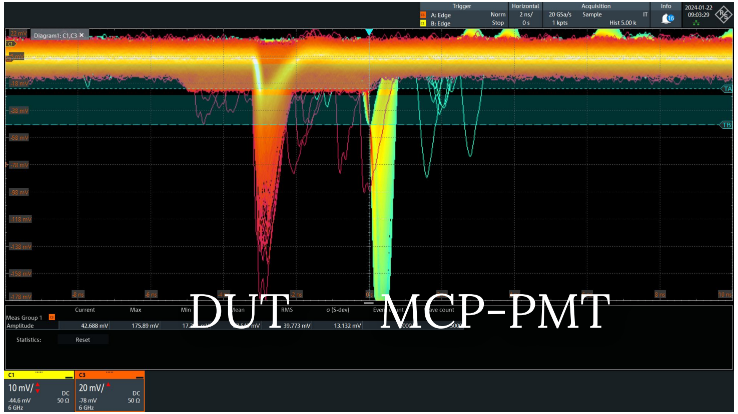
- Signal amplitude
- Time resolution

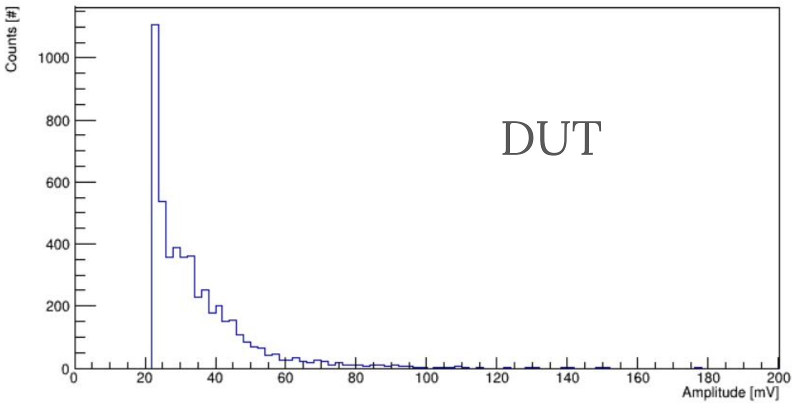


Amplitude distribution of 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel

Characteristic events @ V_{BIAS} = -140 V

- Trigger in coincidence DUT/MCP-PMT
- Threshold selected to eliminate noise contributions

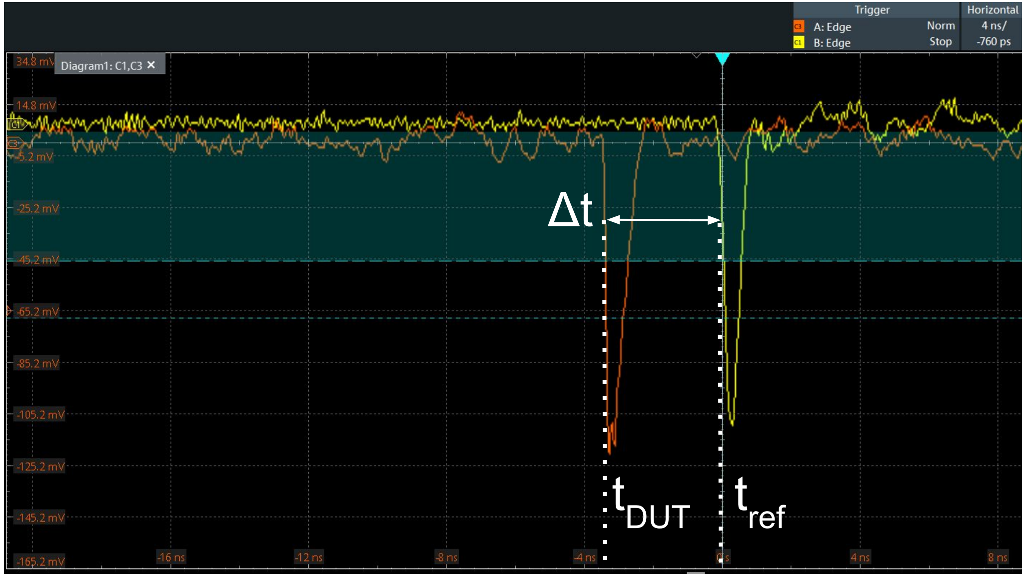


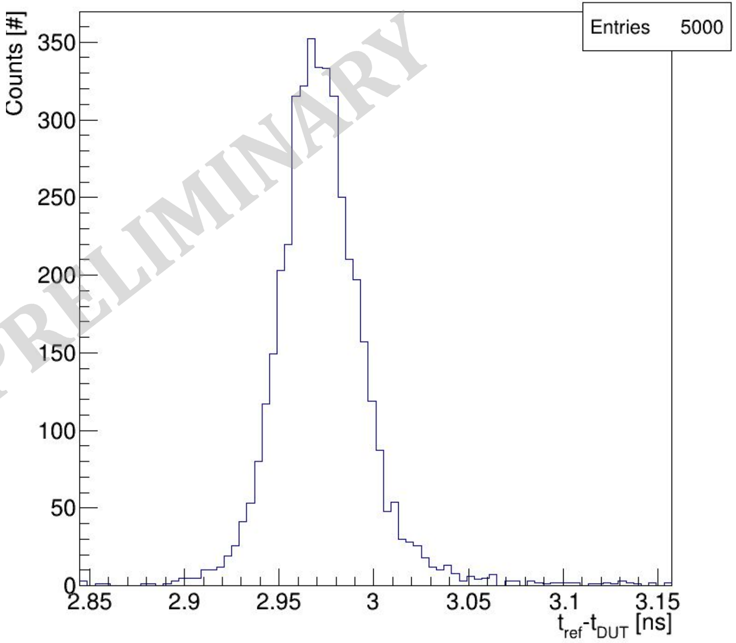


Highly irradiated TimeSPOT sensors can be used as particle detector

Timing of 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel

$\Delta t = t_{ref} - t_{DUT}$, t = Time of Arrival (ToA) calculated via Software Constant-Fraction-Discrimination (CFD) method:





Time resolution of 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel

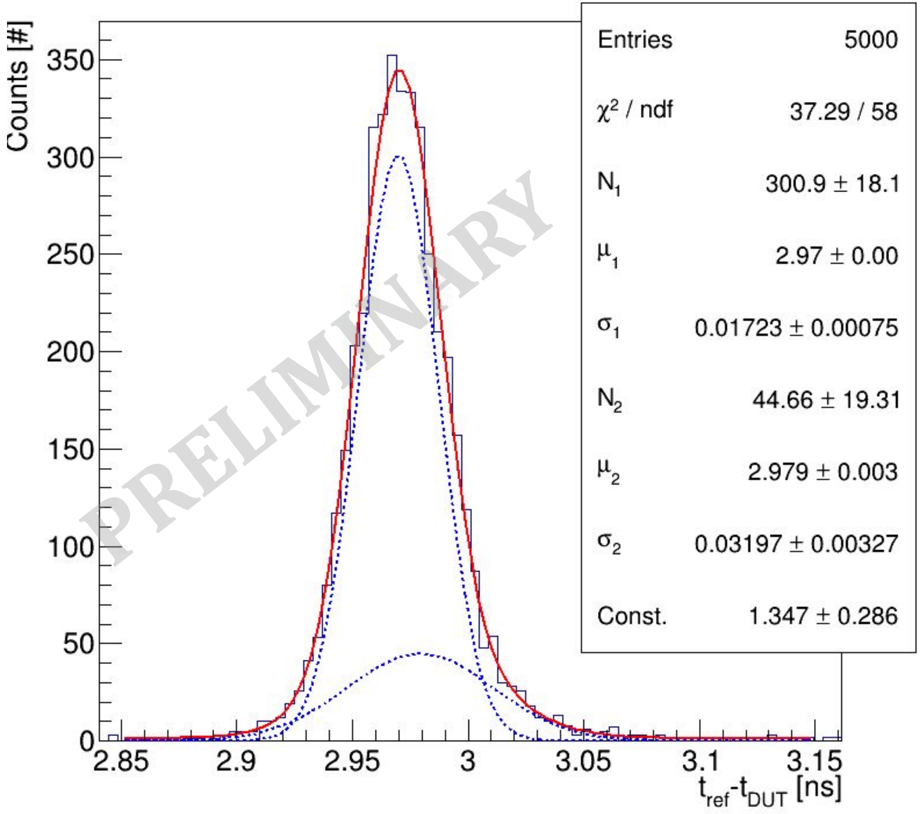
Time resolution:

Characteristic time distribution of 3D trench silicon pixels presents an asymmetric shape:

Sum of two gaussian fit function

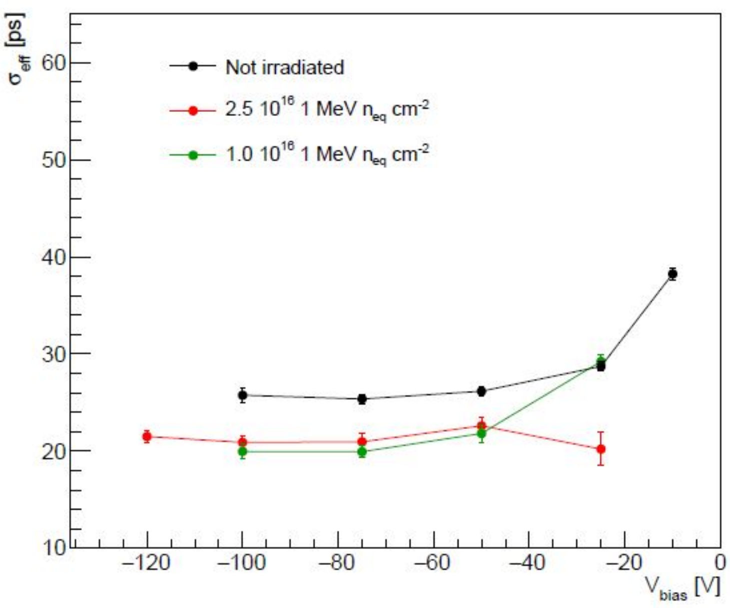
single pixel
@ V_{BIAS} = -140 V

σ_{eff} = 20 ± 1.3 ps

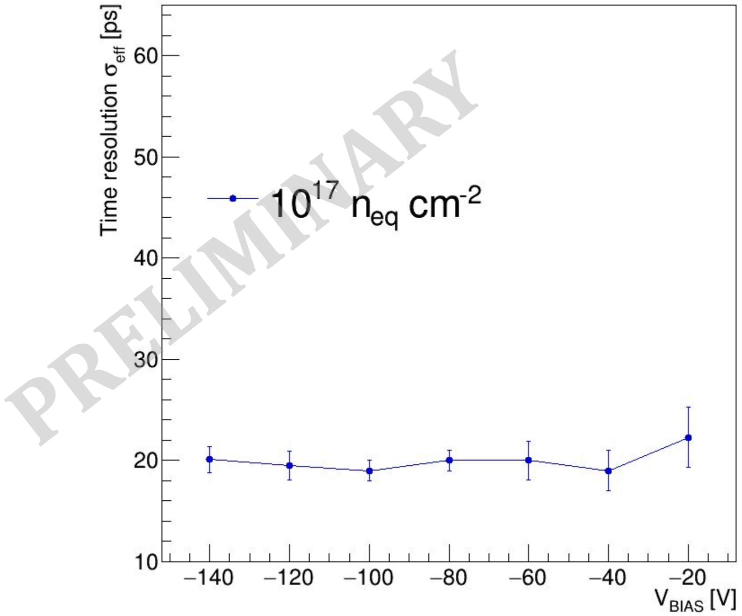


Time resolution Vs V_{BIAS} in laboratory

Time resolution σ_{eff} as a function of V_{BIAS} single pixel using ^{90}Sr source in Lab



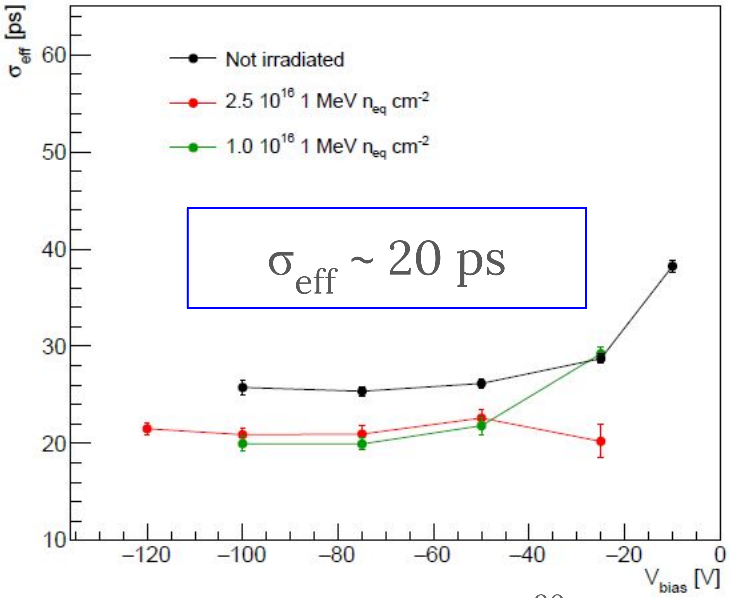
Previous irradiated sensors



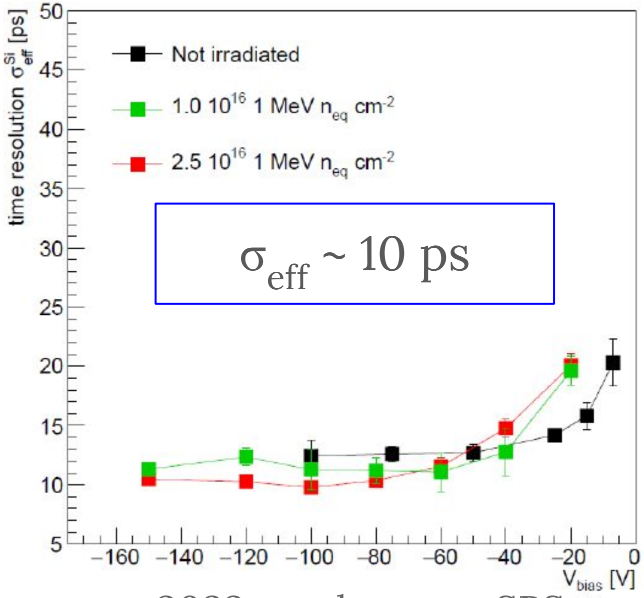
New irradiated sensor

Time resolution Vs V_{BIAS} , laboratory Vs test beam

Time resolution σ_{eff} as a function of V_{BIAS} single pixel comparison between Lab and test beam, *expected similar results* for 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel



Previous results using ^{90}Sr
(Landau + MCS, particles not collimated)

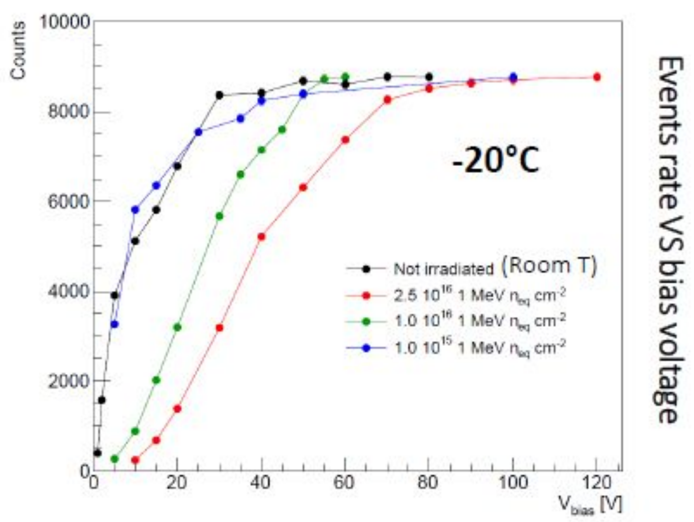


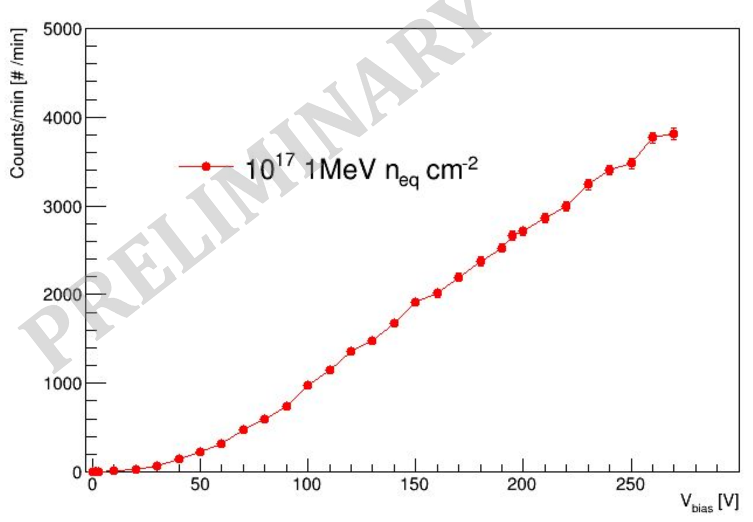
2022 test beam at SPS
(Landau MIP, Beam is collimated)

Efficiency estimate of 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel

Efficiency estimate:

- Previous measurements shown correlation between counting rate per time unit as a function of V_{BIAS} using ^{90}Sr source and *efficiency* at test beam "plateau"
- New results shows that 10^{17} 1 MeV n_{eq} cm^{-2} irradiated pixel do not reach the "plateau", in-pixel spatial charge collection studies are ongoing





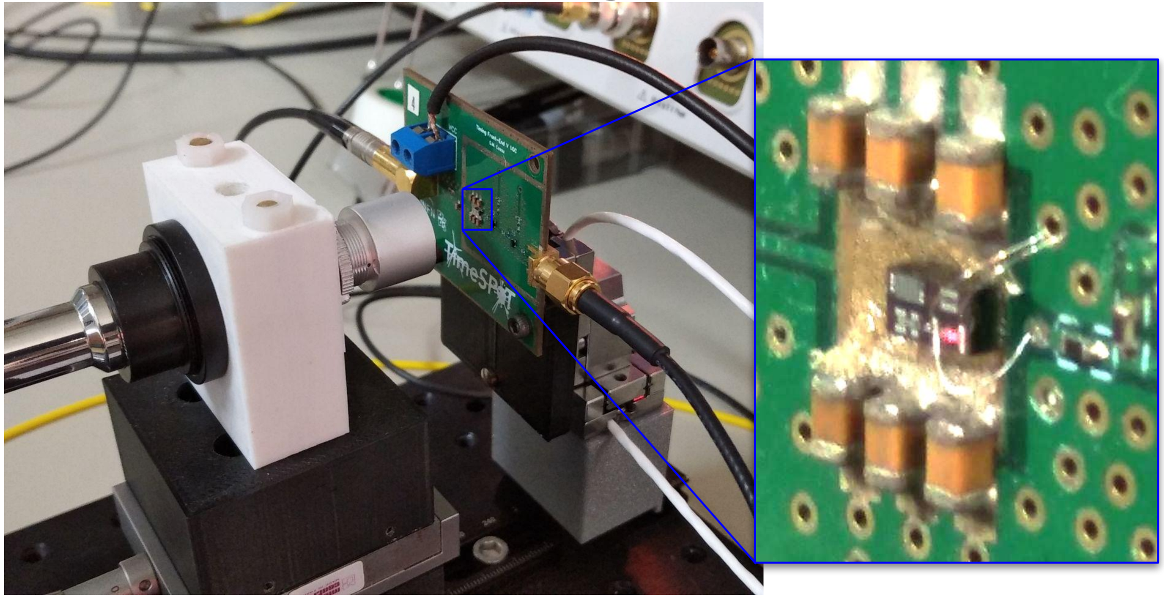
Ongoing Activities

In-pixel laser measurements in laboratory in order to compare performances between highly irradiated sensor and not irradiated :

Setup:

- Piezoelectric stages for micrometric movements
- Triplet Fiber Optic Collimator and focussing lens, spot FWHM~3μm
- Laser FWHM~50ps (time reference) λ = 650nm
- Oscilloscope
- Climatic Chamber

setup validation using *not irradiated pixel*



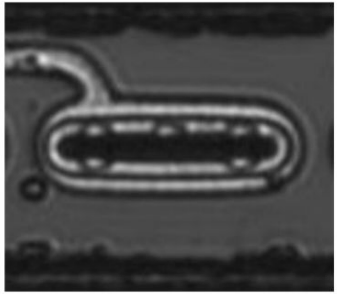
Measurements:

- Amplitude map
- Timing map
- Efficiency map

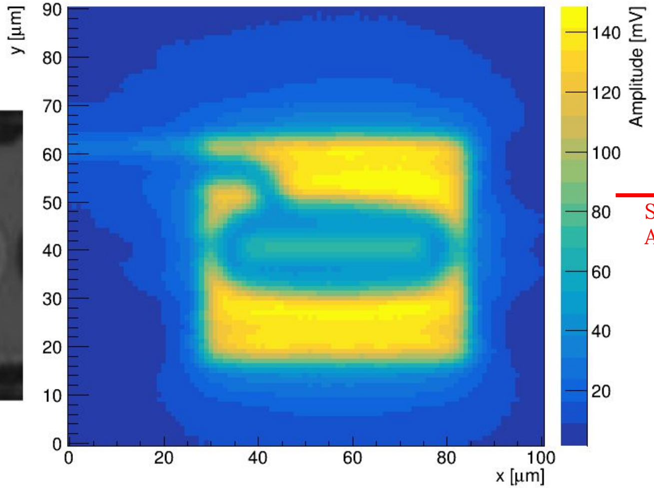
Ongoing Activities

Study in-pixel **signal amplitude** and timing distributions using *laser*

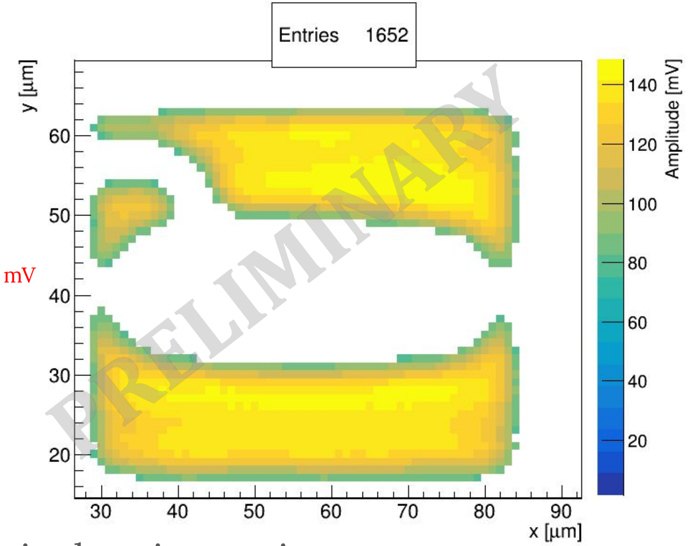
Preliminary Amplitude and ToA distributions using a *not irradiated pixel*



Pixel under the microscope



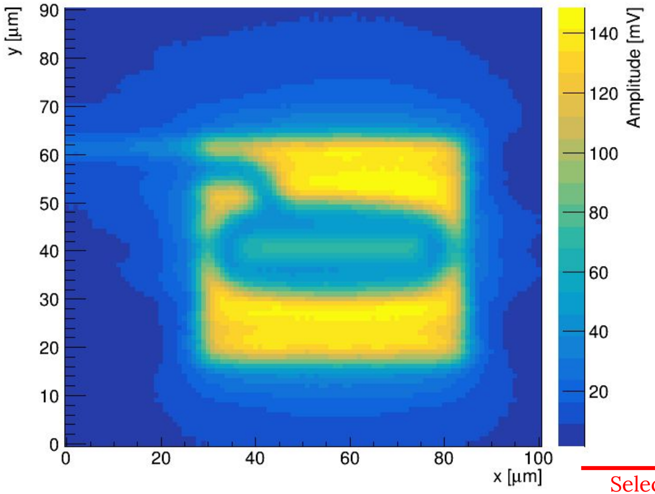
Selection
Amplitude > 80 mV



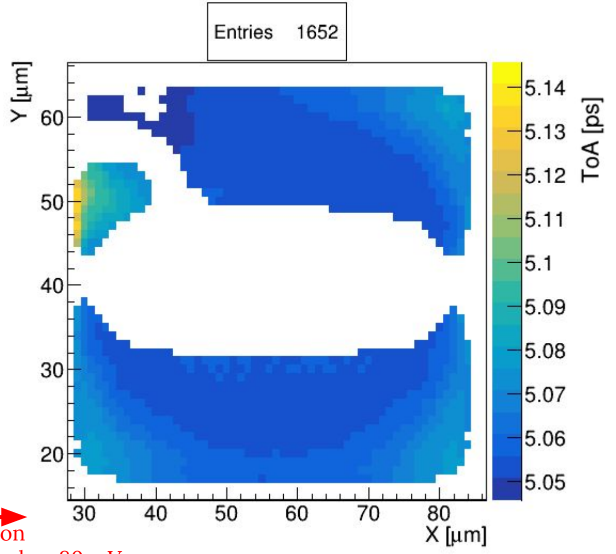
Unifor amplitudes in the pixel active region

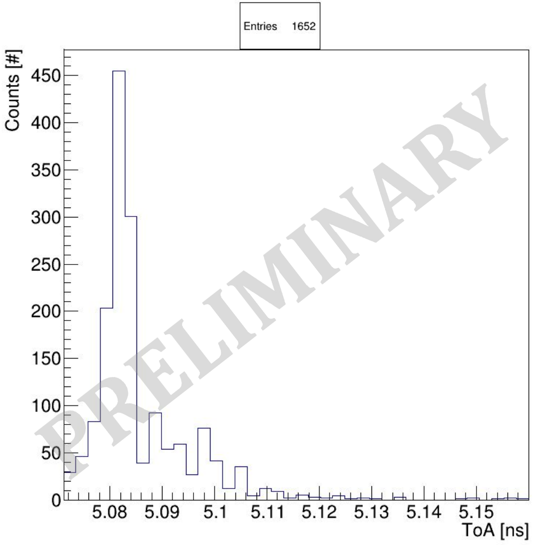
Ongoing Activities

Study in-pixel signal amplitude and **timing** distributions using *laser*
Preliminary Amplitude and ToA distributions using a *not irradiated pixel*



Selection
Amplitude > 80 mV





Excellent spatial resolution

Excellent time resolution

Summary

Preliminary results on highly irradiated (10^{17} 1 MeV n_{eq} cm^{-2}) TimeSPOT 3D trench silicon sensors in the laboratory using ^{90}Sr radioactive source

- Highly irradiated sensors still work as particle detector
- Excellent timing performance in laboratory σ_{eff}~ 20 ps, in line with previous results

Next steps:

- Measure timing, signal amplitude and efficiency maps using laser
- Characterisation at *test beam* foreseen in May 2024 at SPS

Thank you !

Backup Slides

Timing resolution fit function

Time resolution:

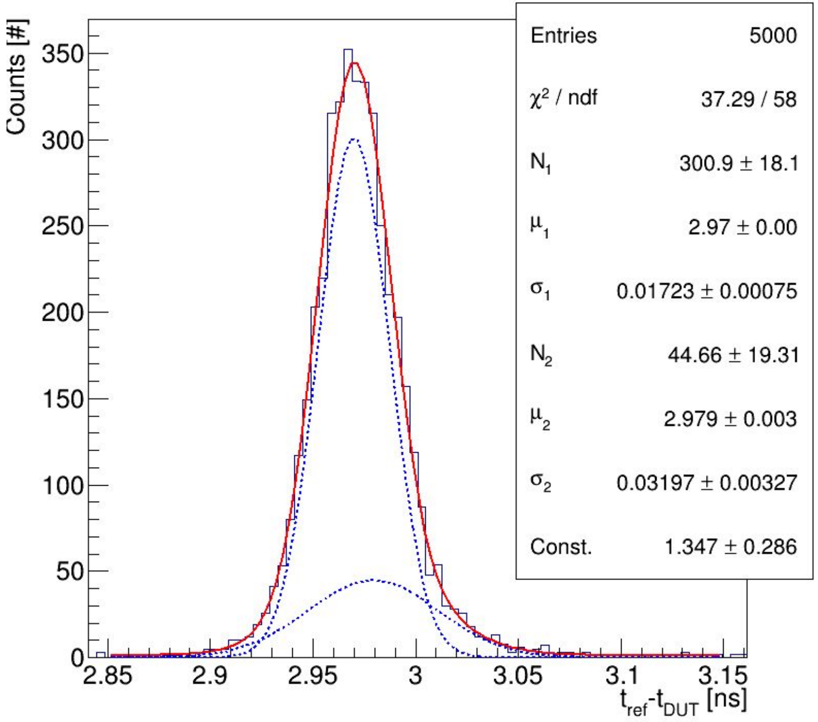
Characteristic time distribution of 3D trench silicon pixels presents an asymmetric shape:
Sum of two gaussian fit function

$$\sigma_{\mathrm{eff}}^2 = f_1(\sigma_1^2 + \mu_1^2) + (1 - f_1)\cdot(\sigma_2^2 + \mu_2^2) - \mu^2$$

$$\mu = f_1\mu_1 + (1 - f_1)\cdot\mu_2$$

single pixel
@ V_{BIAS} = -140 V

σ_{eff} = 20 ± 1.3 ps

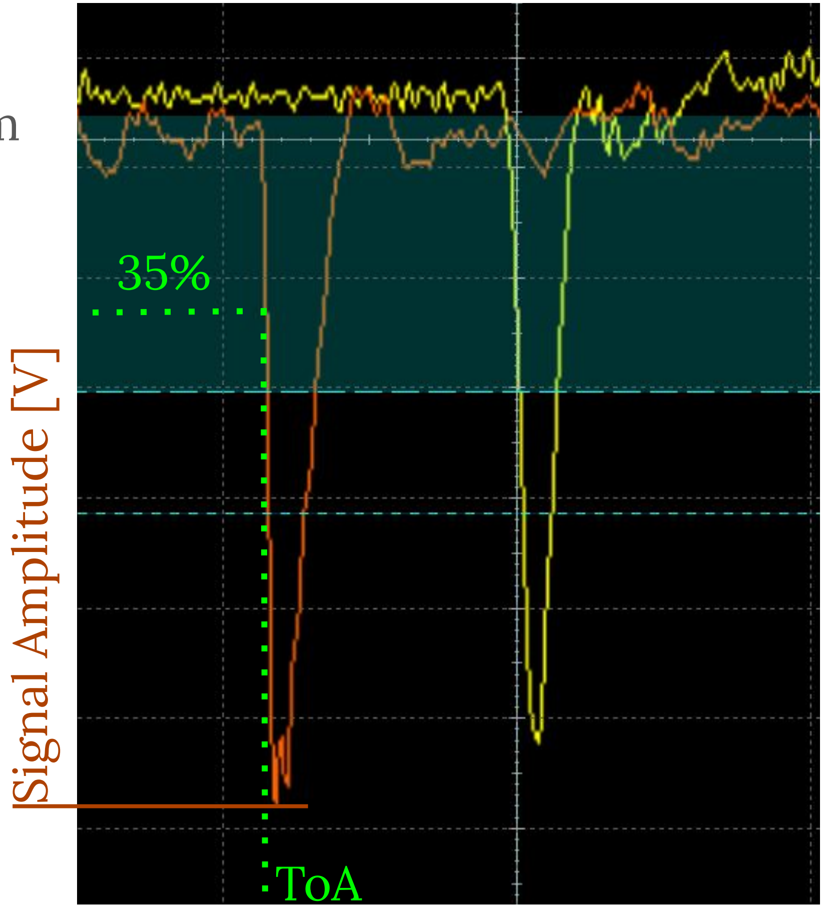


CFD

Constant Fraction Discrimination method:

- The algorithm interpolate the waveform in order to add more points
- ToA is the time the signal reaches 35% of maximum amplitude

This method allow to minimise the errors caused by the *time walk*



Previous studies on time resolution estimation have shown which algorithms to use