TREDI 2023

18th Trento Workshop on Advanced Silicon Radiation Detectors

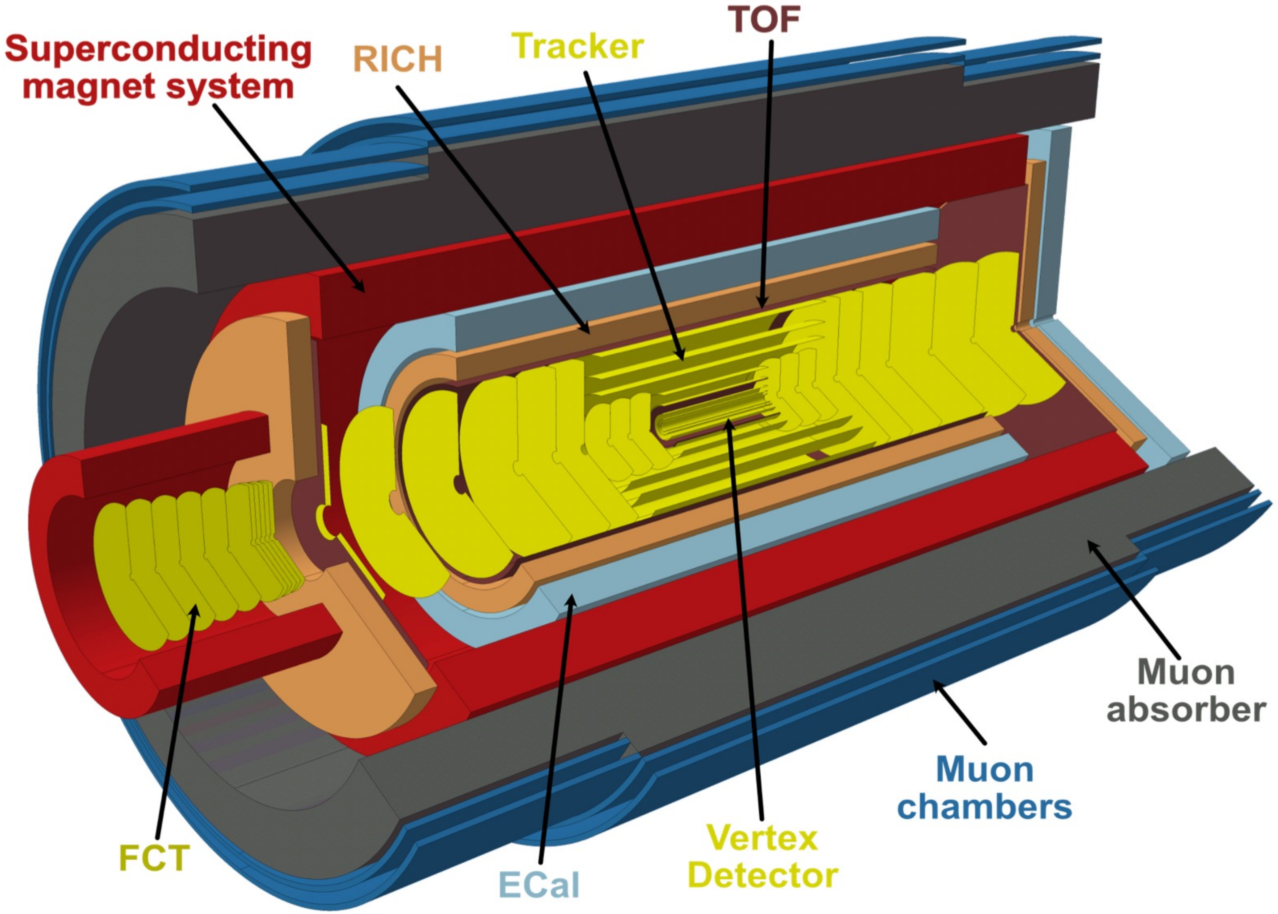
Trento
1/03/2023

Performance study of **very thin Low Gain Avalanche Detectors** (LGADs) and investigation of the **new "double LGAD"** concept

Sofia Strazzi

on behalf of the ALICE Collaboration

University and INFN, Bologna



ALICE 3: a next generation heavy-ion experiment

Nearly mass-less, based on the most advanced silicon technologies

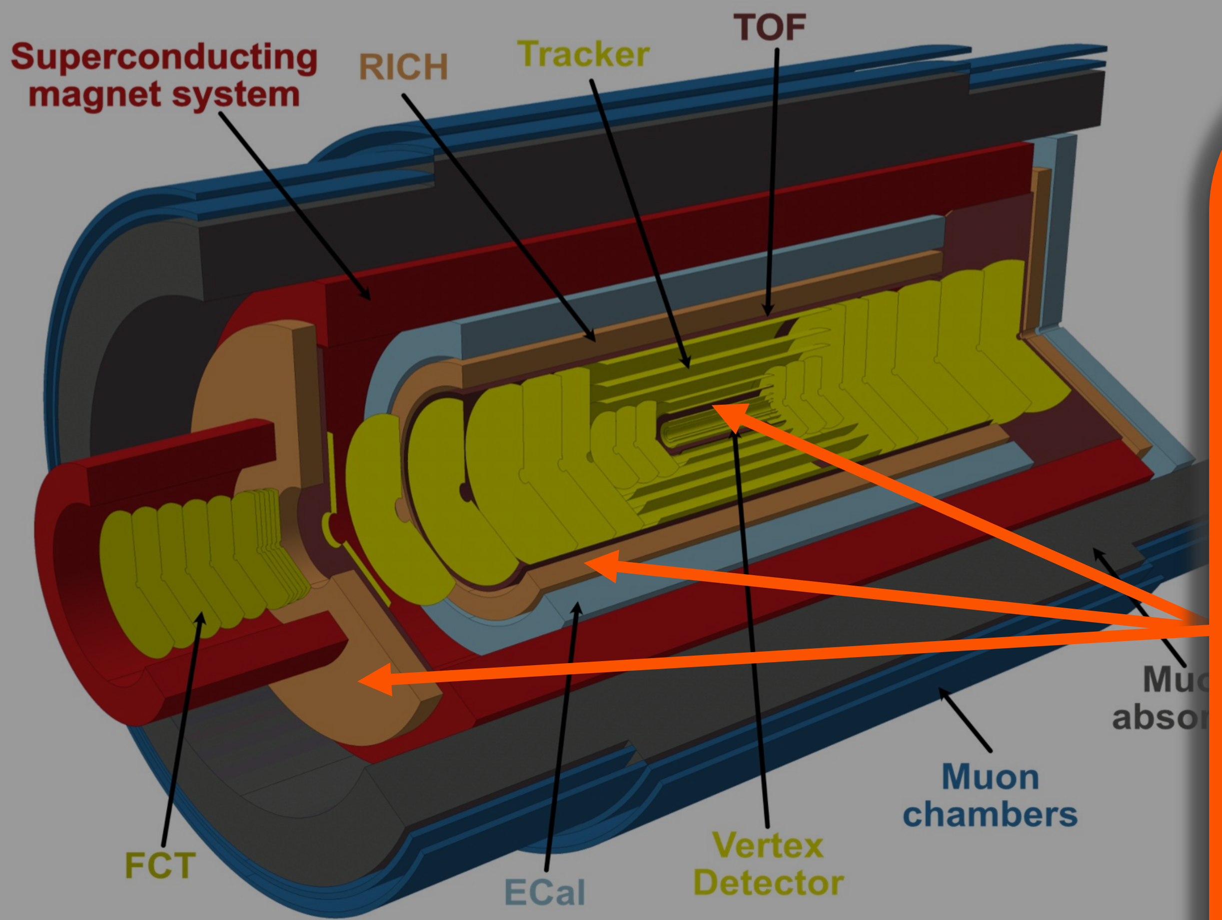
- Excellent PID
- Secondary vertex finding
- Reconstruction efficiency at very low momenta

New exciting opportunities for the study of:

✦ **Heavy flavor** hadrons

✦ electromagnetic and hadronic **probes of the QGP** at very low momenta

https://arxiv.org/abs/2211.02491



ALICE 3: a next generation heavy-ion experimen

Nearly mass-less, based

Silicon-based Time-Of-Flight (TOF)

$$\text{Separation Power} \propto \frac{L}{\sigma_{TOF}}$$

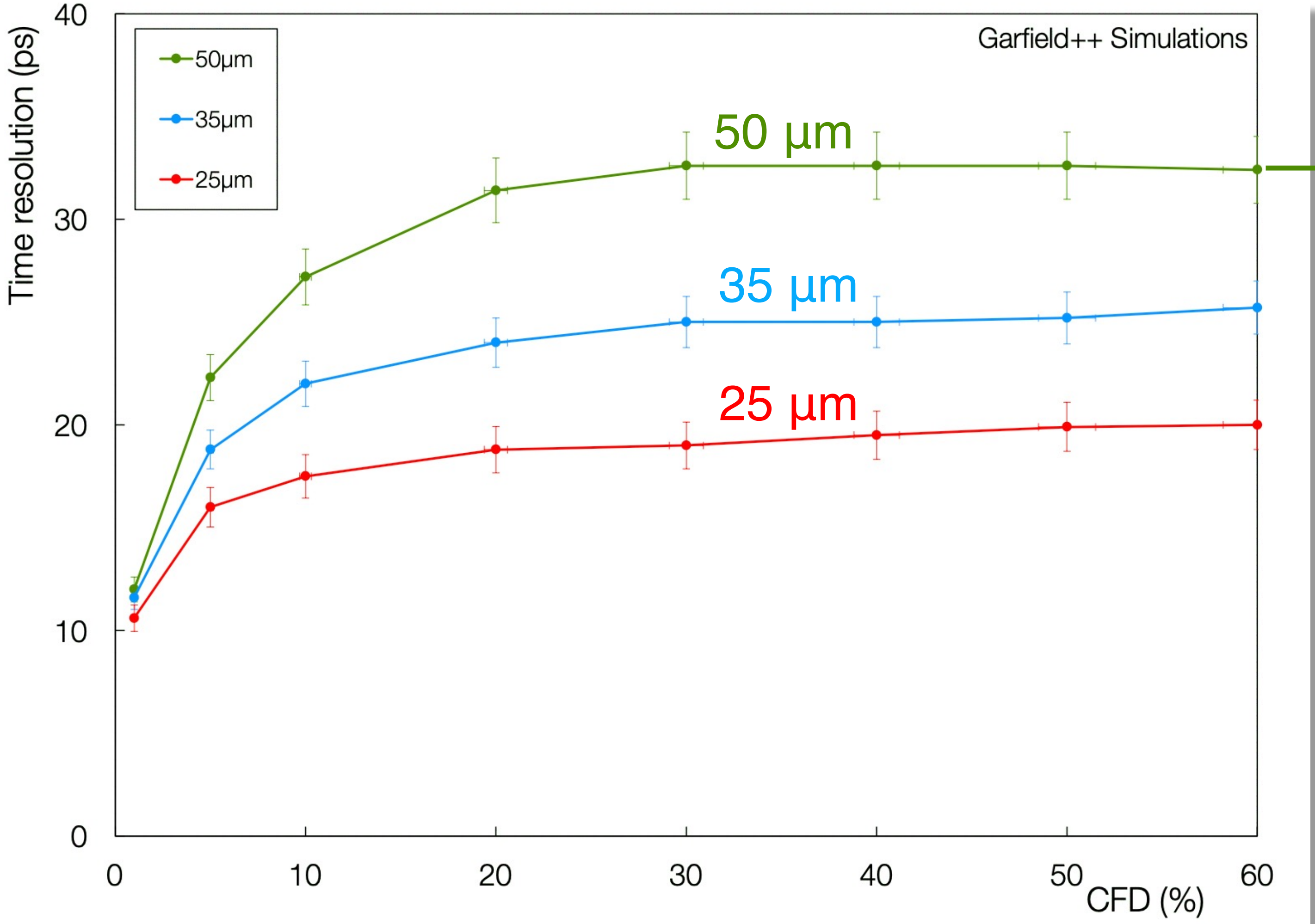
- outer TOF at $R \approx 85$ cm
- inner TOF at $R \approx 19$ cm
- forward TOF at $z \approx 405$ cm

Required time resolution → **20ps**

Several **innovative technologies** are **under evaluation**

2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
	LHC Run 3				LHC LS3			LHC Run 4			LHC LS4

https://arxiv.org/abs/2211.02491



MOTIVATION

State of the art ~30 ps

Already planned for the detector upgrades at the HL-LHC both in ATLAS and CMS for 2026

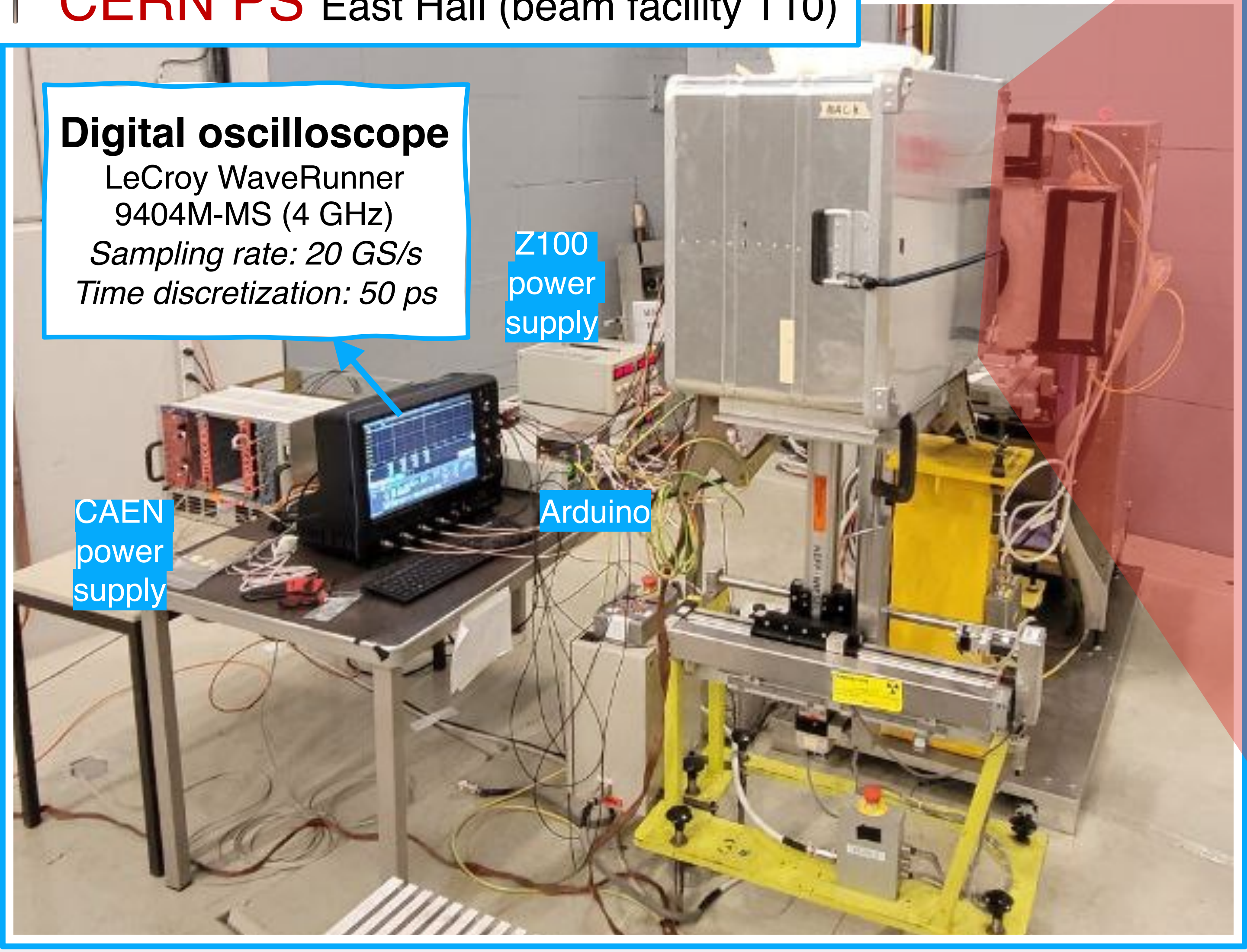
Future generation experiments need an even better time resolution ~**20 ps**

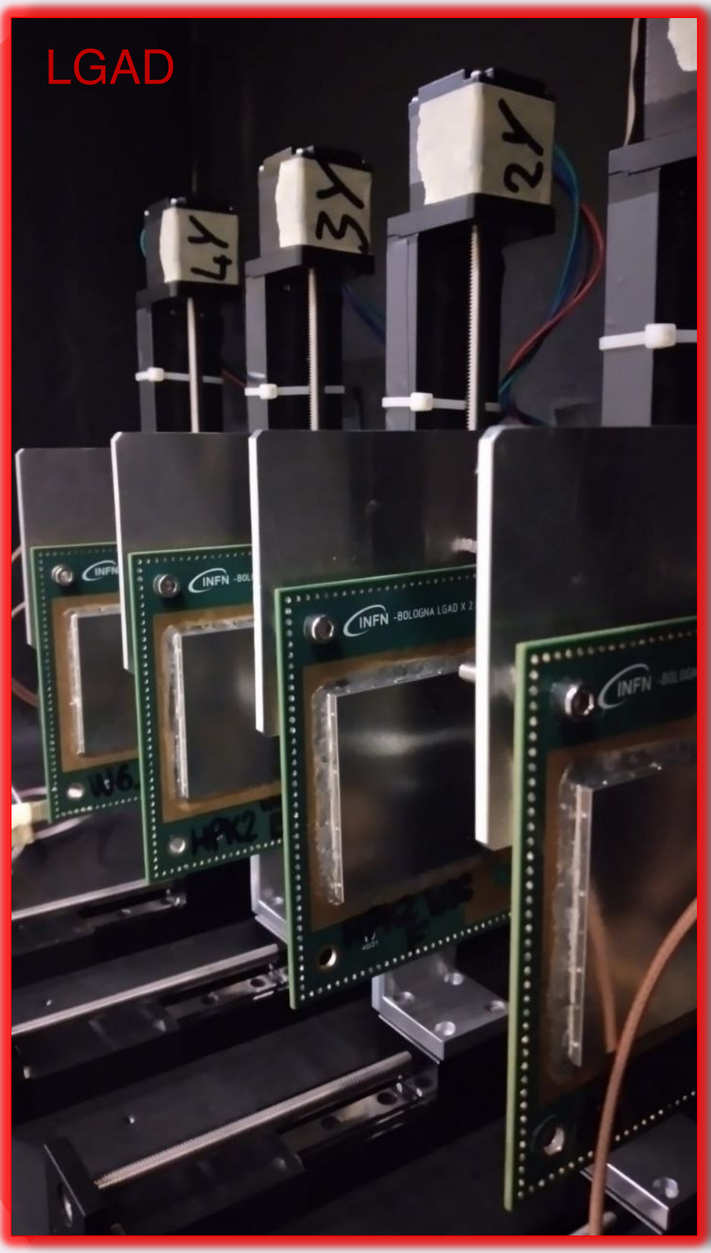
→ A **thinner** LGAD design could match the requirements

TEST BEAM SETUP

CERN PS East Hall (beam facility T10)

Digital oscilloscope
LeCroy WaveRunner
9404M-MS (4 GHz)
Sampling rate: 20 GS/s
Time discretization: 50 ps





PUBLISHED RESUTS – Beam Test of November 2021

First 25 and 35 μm thick FBK LGAD sensors were tested for the first time in a beam test with 12 GeV/c pion beam

25 µm

25 ps : Slightly worse time resolution than what foreseen from simulations (worse S/N)

35 µm

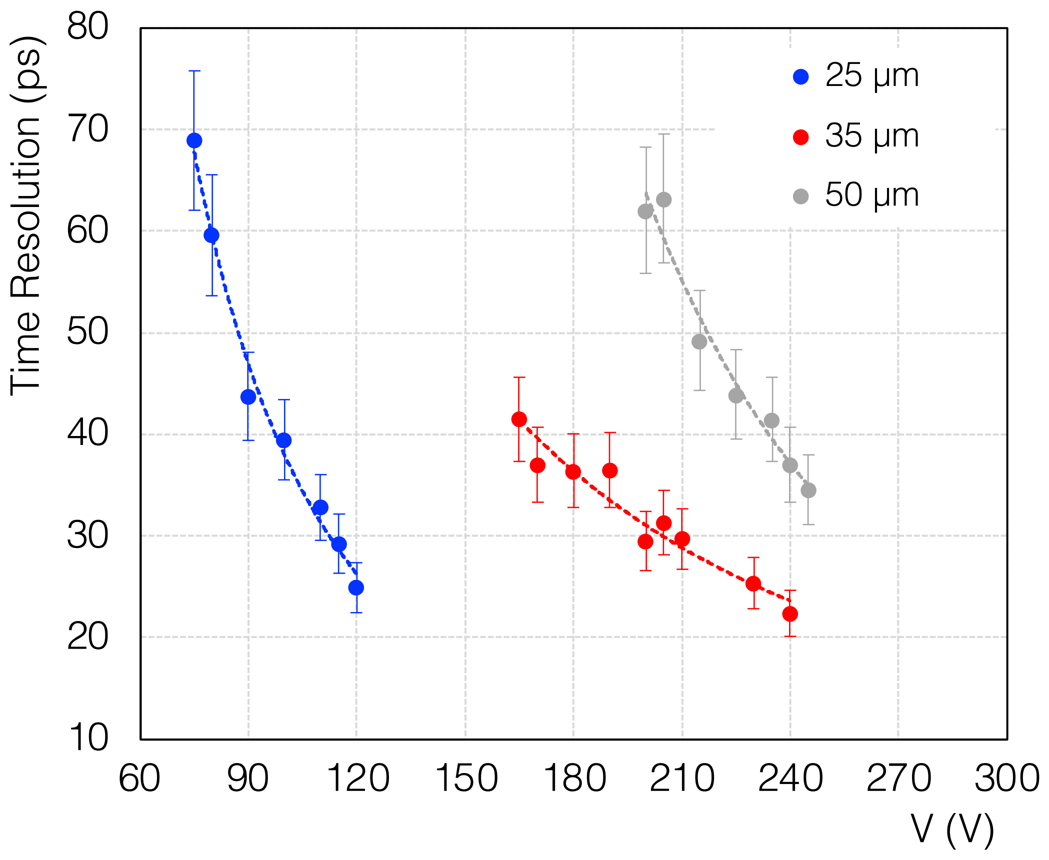
22 ps : In agreement with MC simulations

Improved time resolution with thinner LGAD detectors

Ref **50** µm

In line with expectations

- Validation of setup and analysis procedure

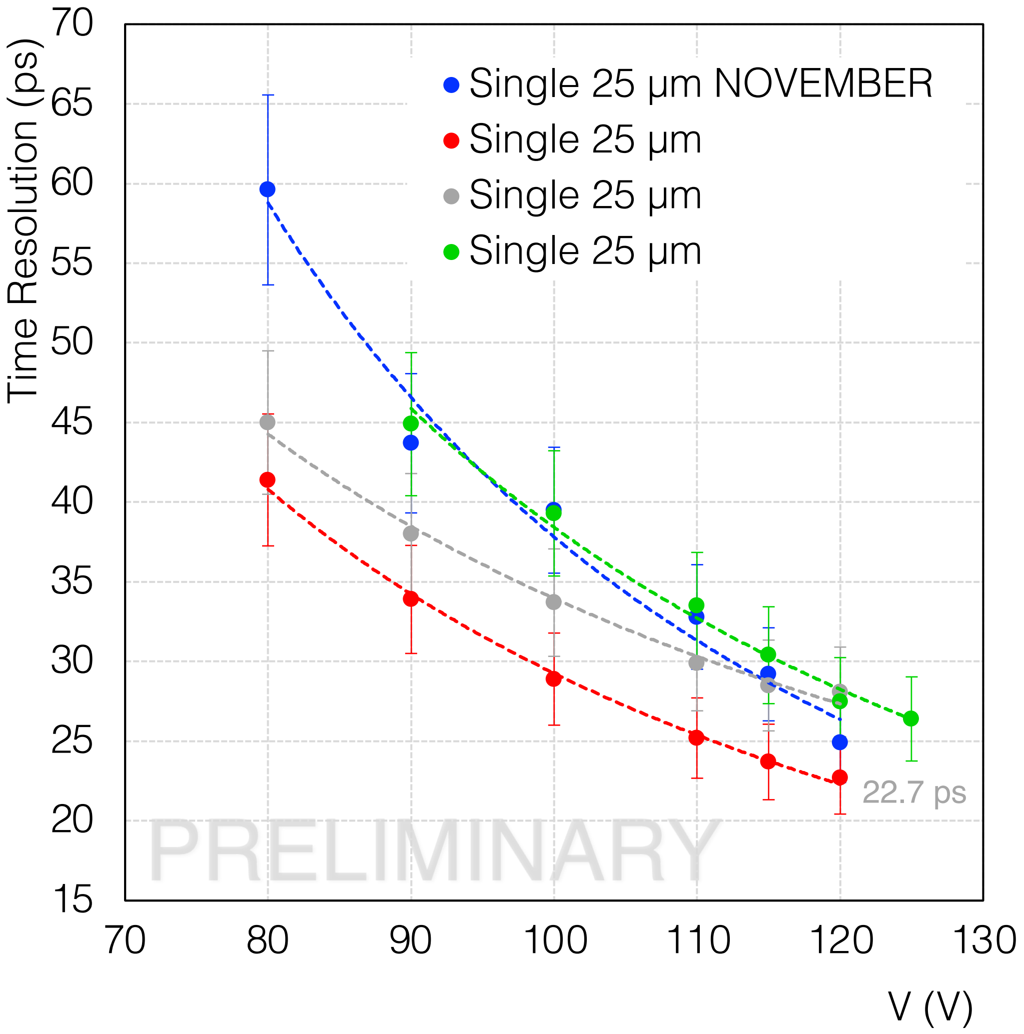


https://link.springer.com/article/10.1140/epjp/s13360-022-03619-1

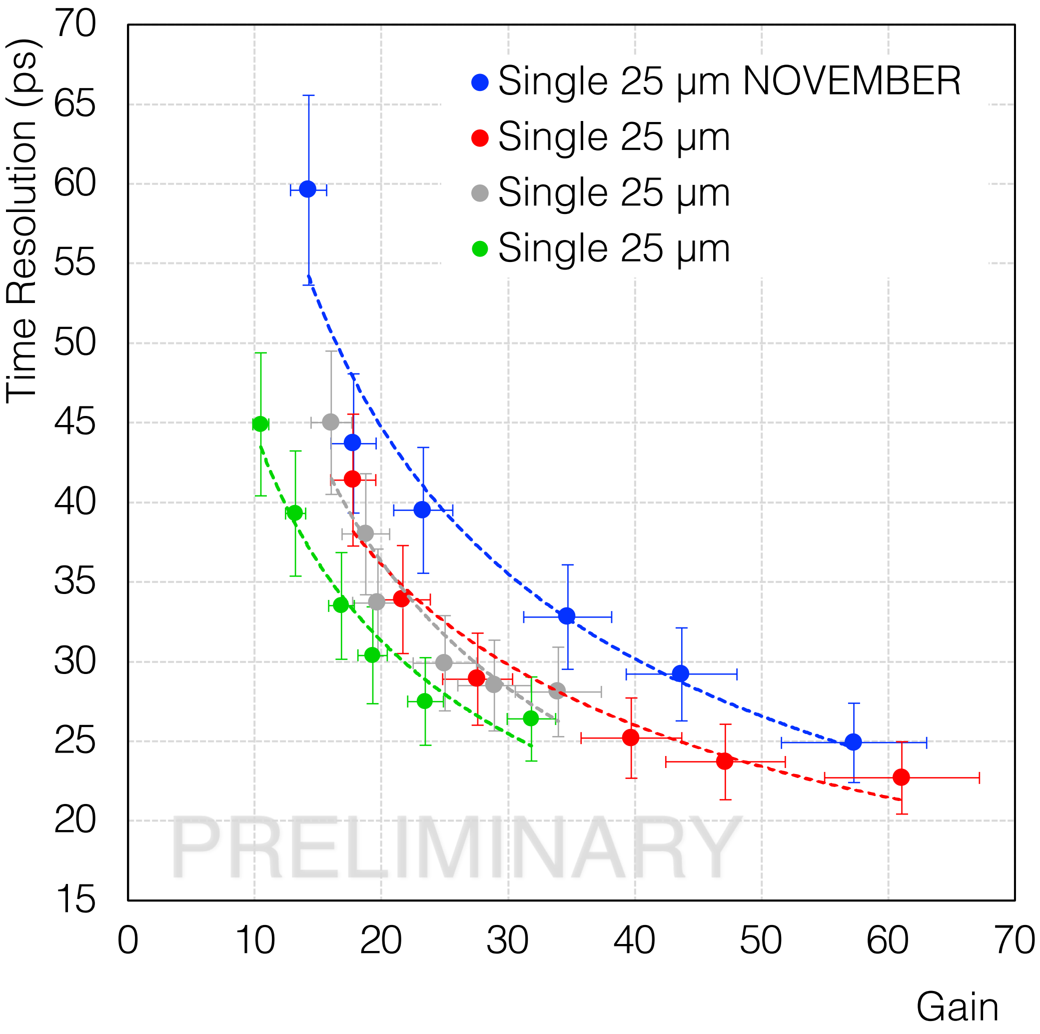
July BT
10 GeV/c pion beam

TIMING PERFORMANCE: 25 µm LGAD

VOLTAGE



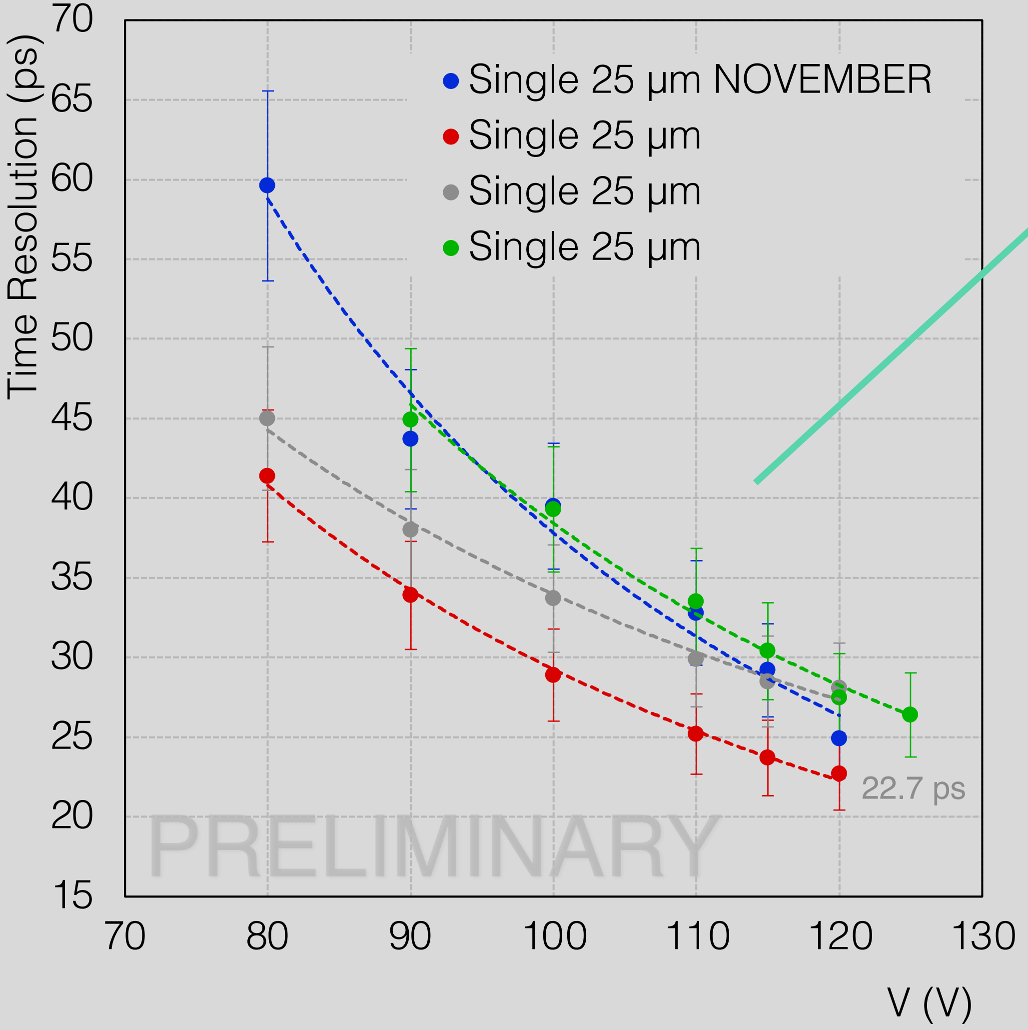
GAIN



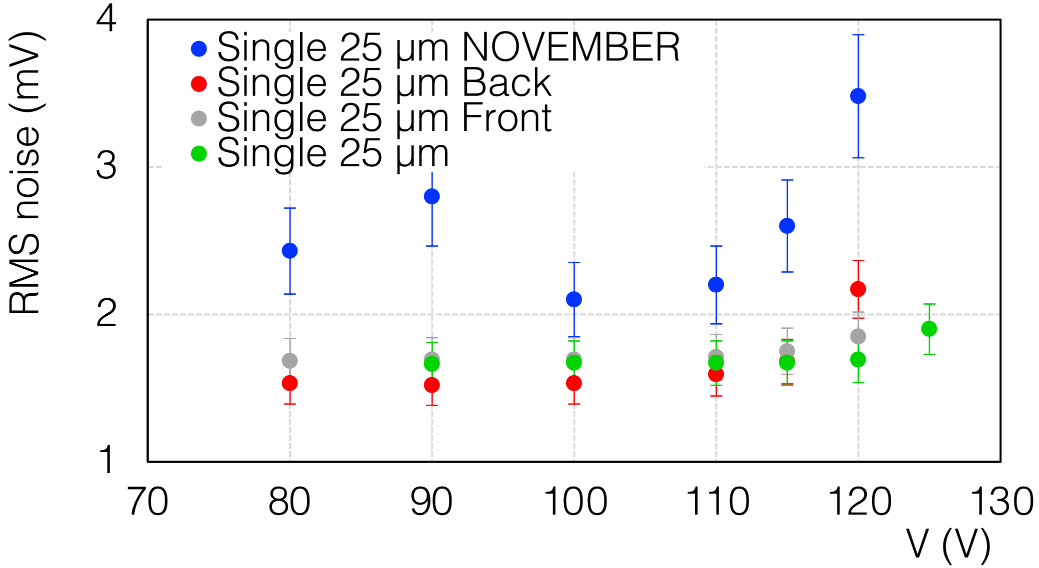
July BT
10 GeV/c pion beam

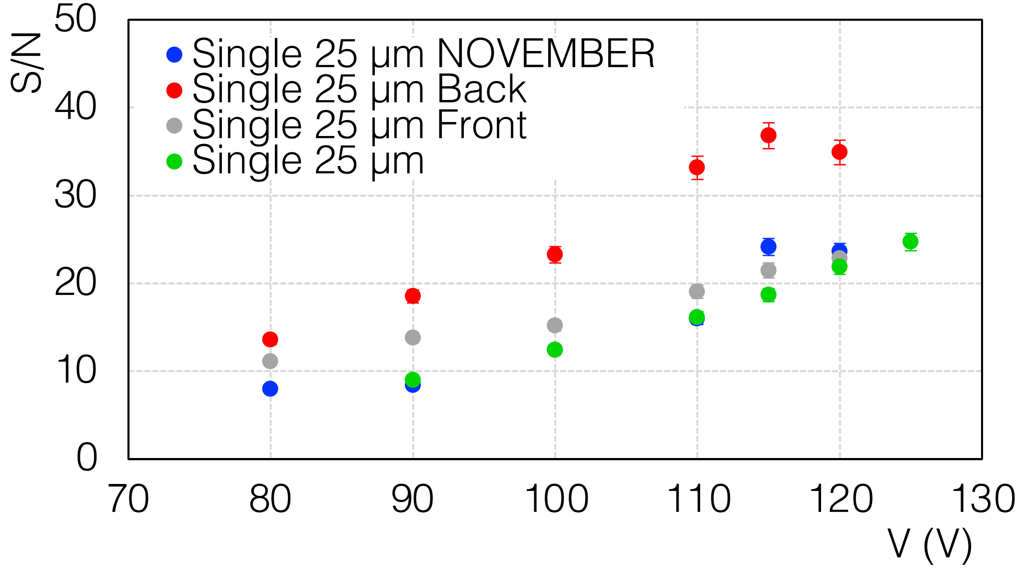
TIMING PER

VOLTAGE

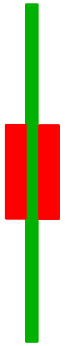


Noise RMS & S/N



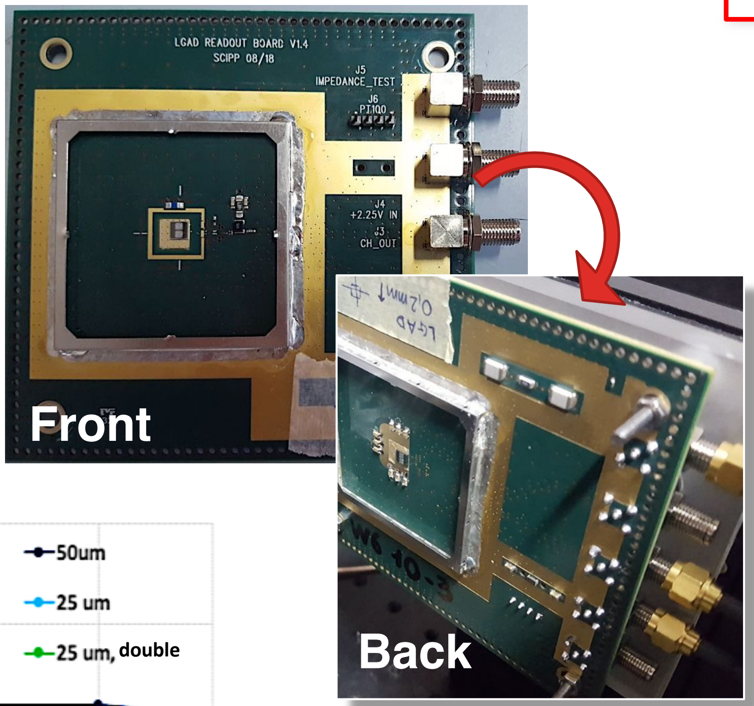


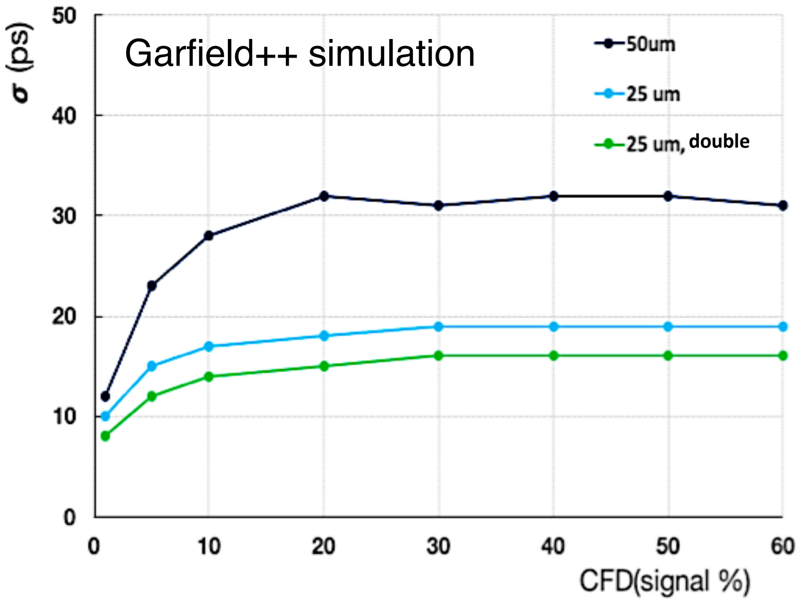
New ‘**double LGAD**’ concept



One LGAD on each side of the board, both connected to the **same amplifier**

25+25 µm





Just a proof of concept

- ➢ *talk with foundries about assembly and implementation*

PRO

- **Higher signal**
- **Less power-consuming** front-end **electronics**
- 50 µm same/similar electronics (only 1 channel of front-end & readout)
- The benefit of a slightly **better time resolution**

CONS

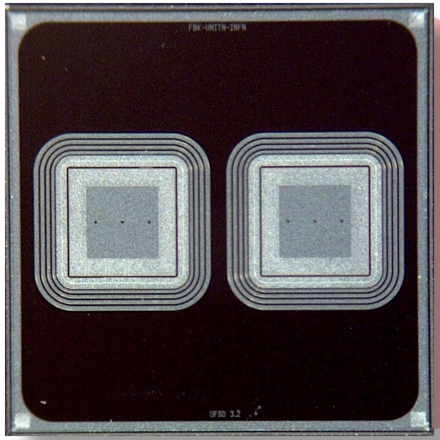
- Higher **material budget**

TESTED LGADs & ELECTRONICS

First very thin LGAD prototypes produced by FBK

25 µm and **35 µm** -thick FBK single channel

Area = **1x1 mm²**



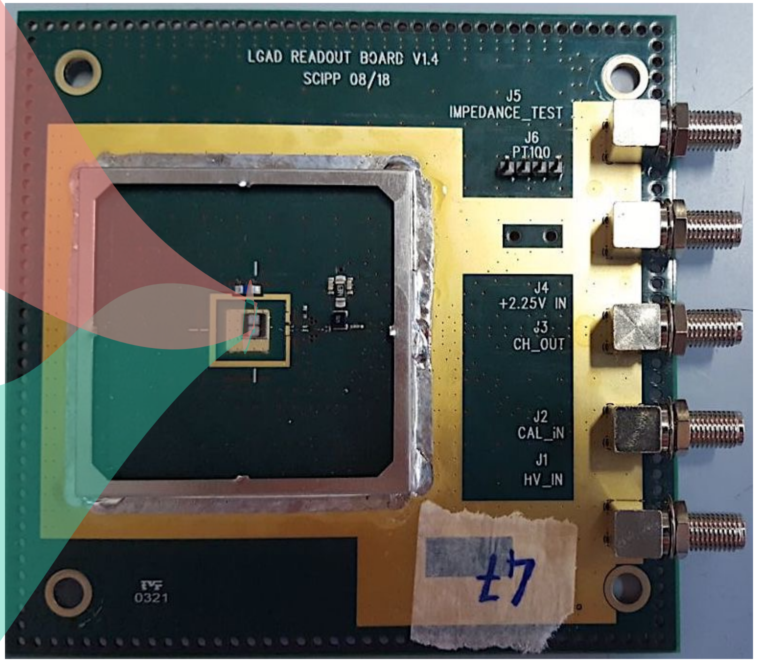
Standard sensors produced by HPK

50 µm -thick HPK single channel

(W42 & W36 with different doping concentrations)

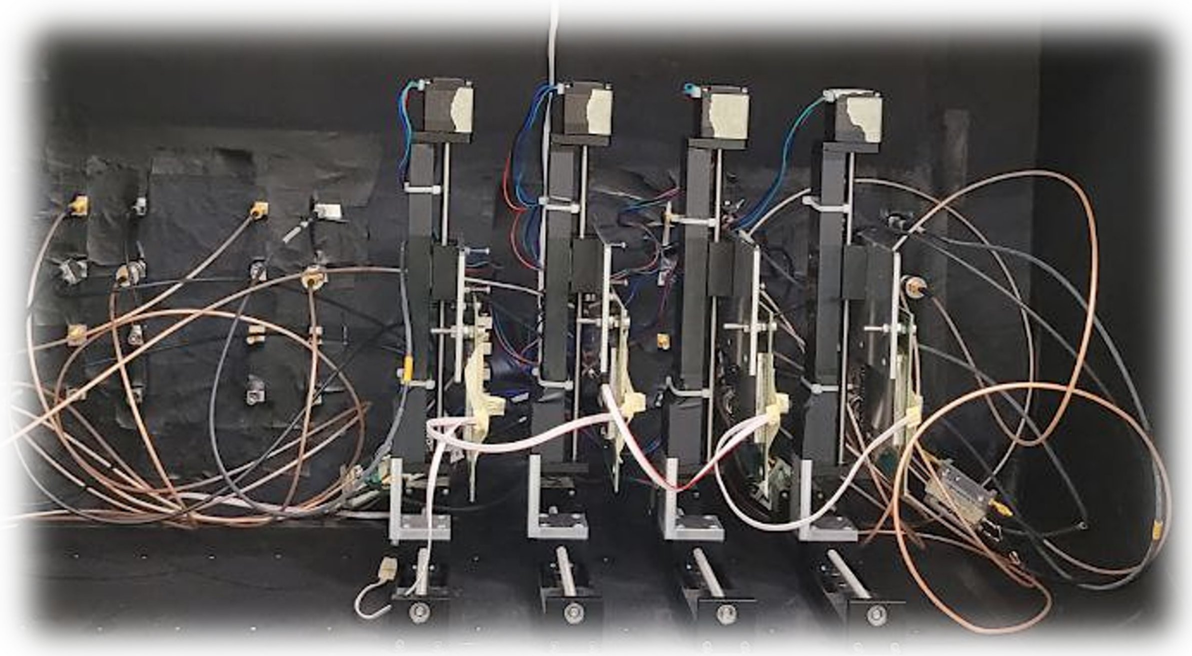
Area = **1.3x1.3 mm²**

SantaCruz single-channel LGAD read-out board *V1.4 SCIPP 08/18* ($G_{amplifier}$ ~ **6)**

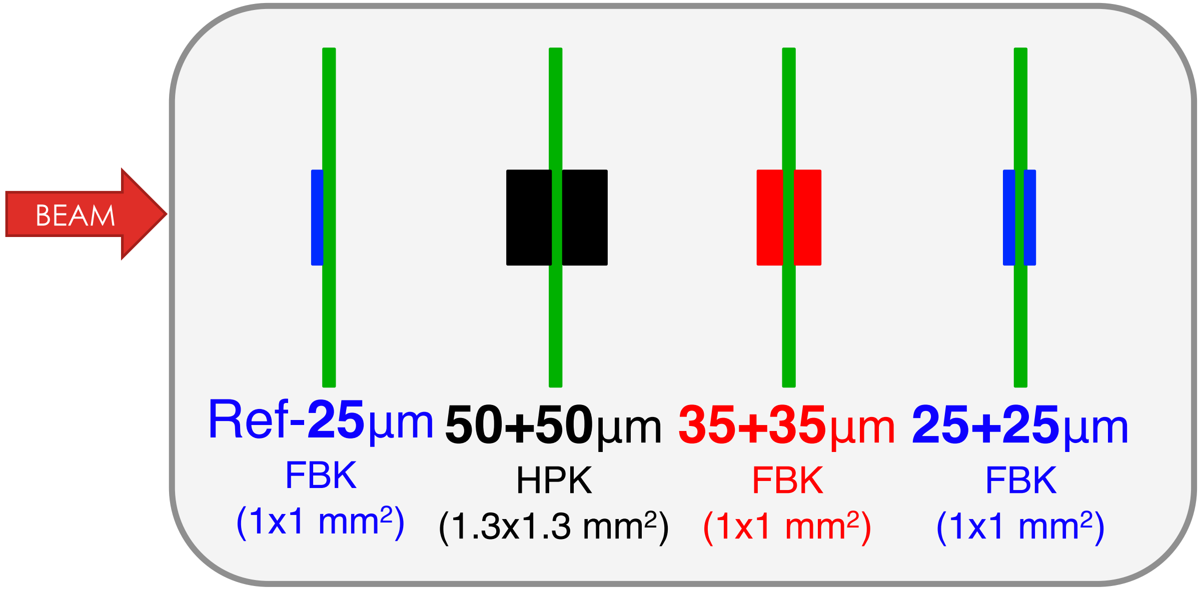


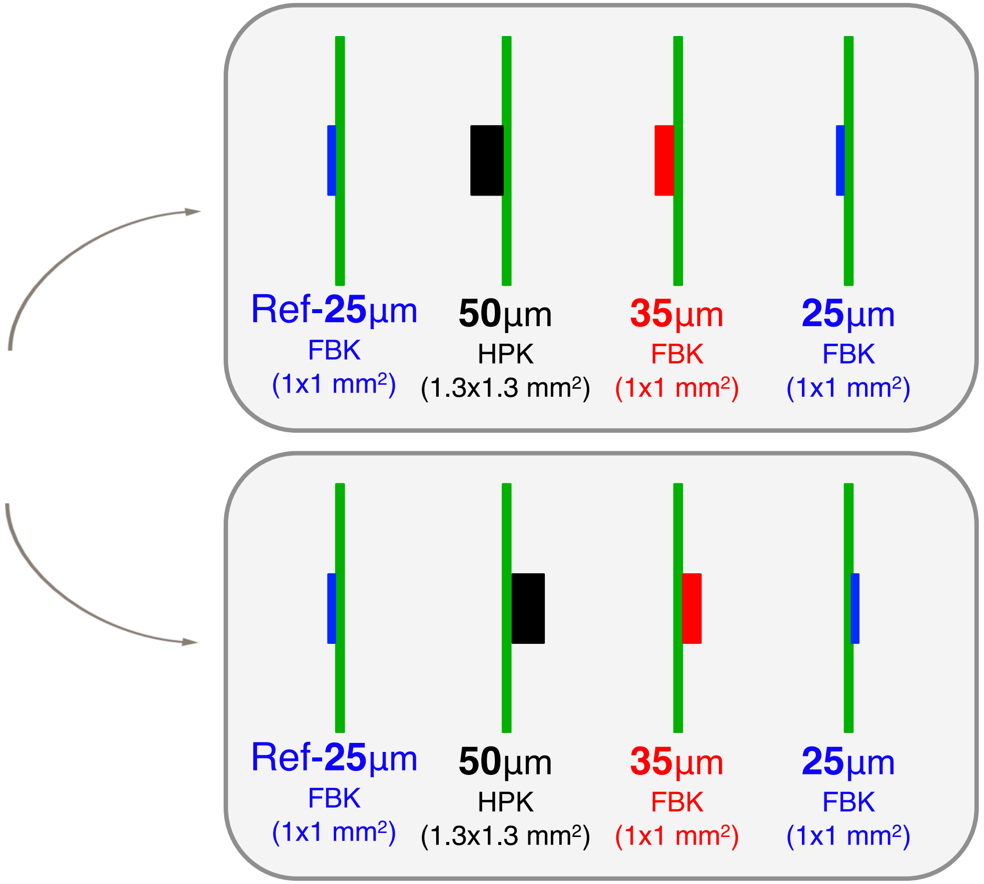
+ Second stage external amplifier ($G_{amplifier}$ ~ **11-14**)

Configuration example

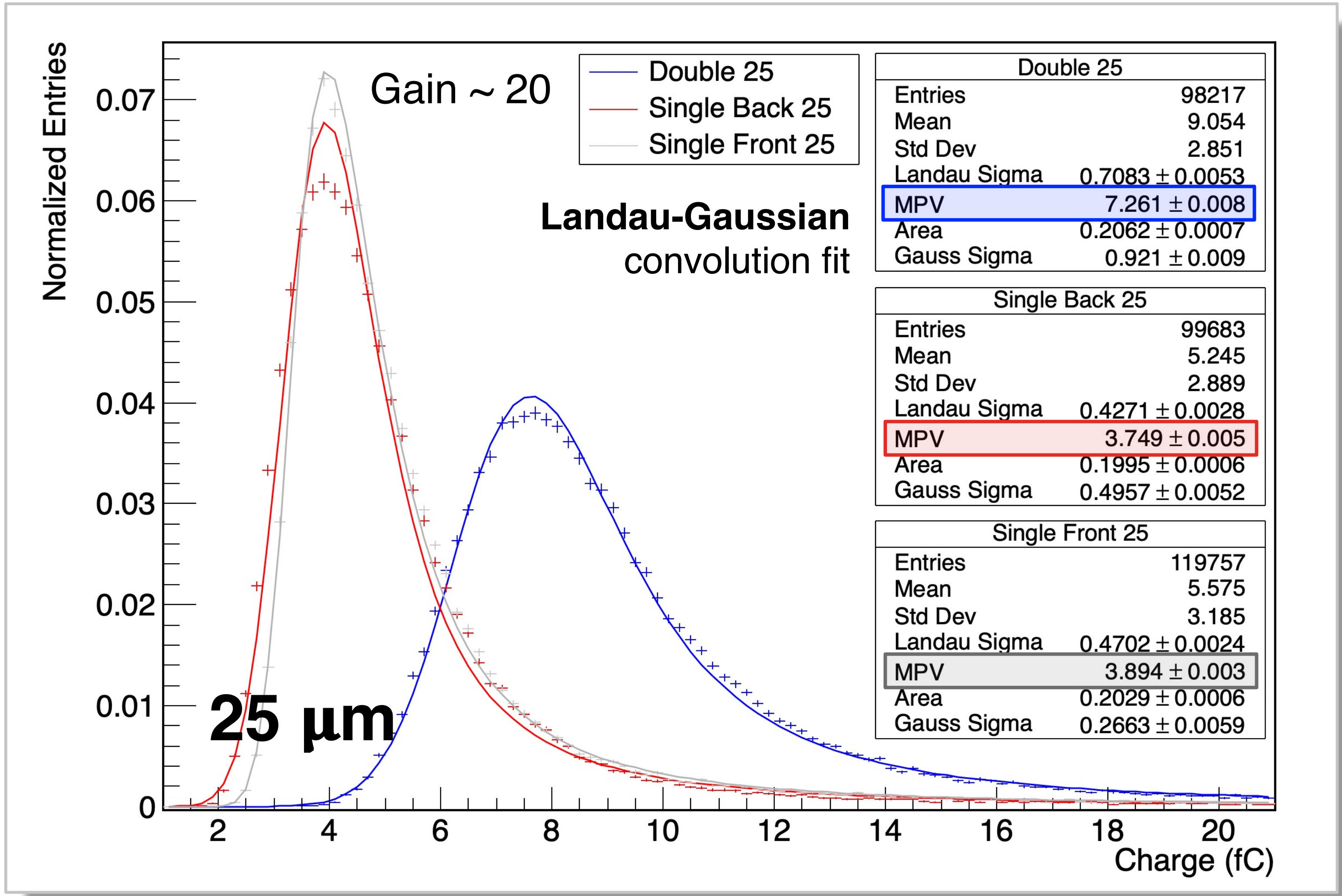


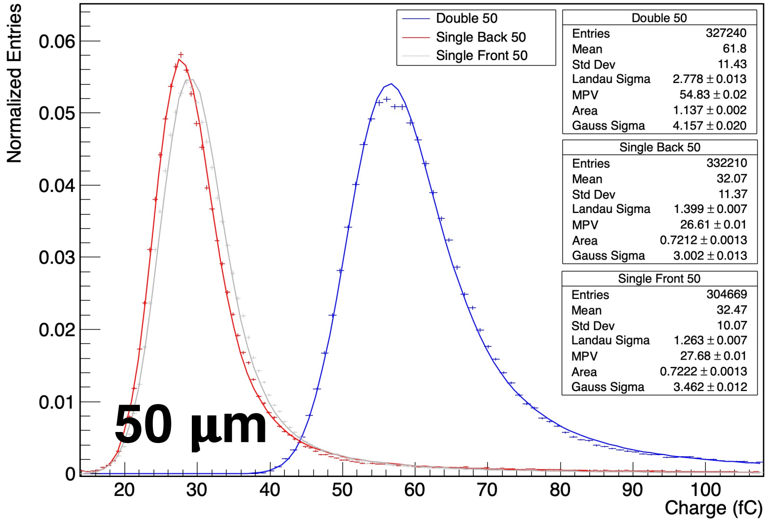
All the runs were repeated with both the single sensors of each couple using the same electronics

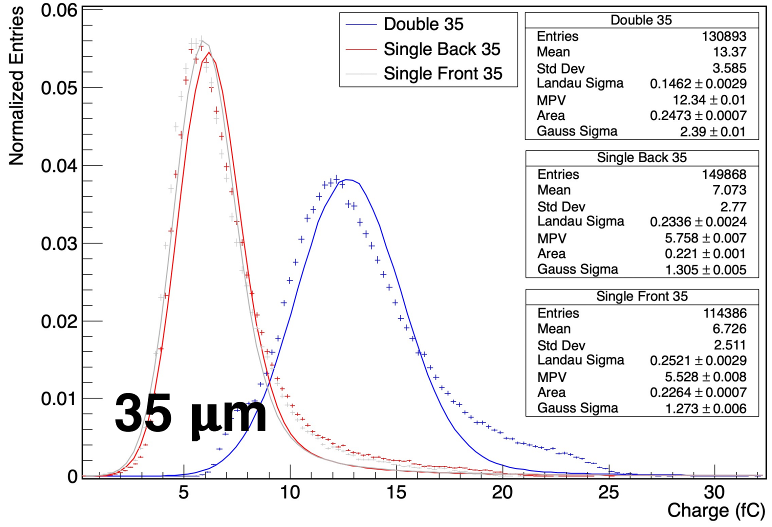




CHARGE DISTRIBUTIONS

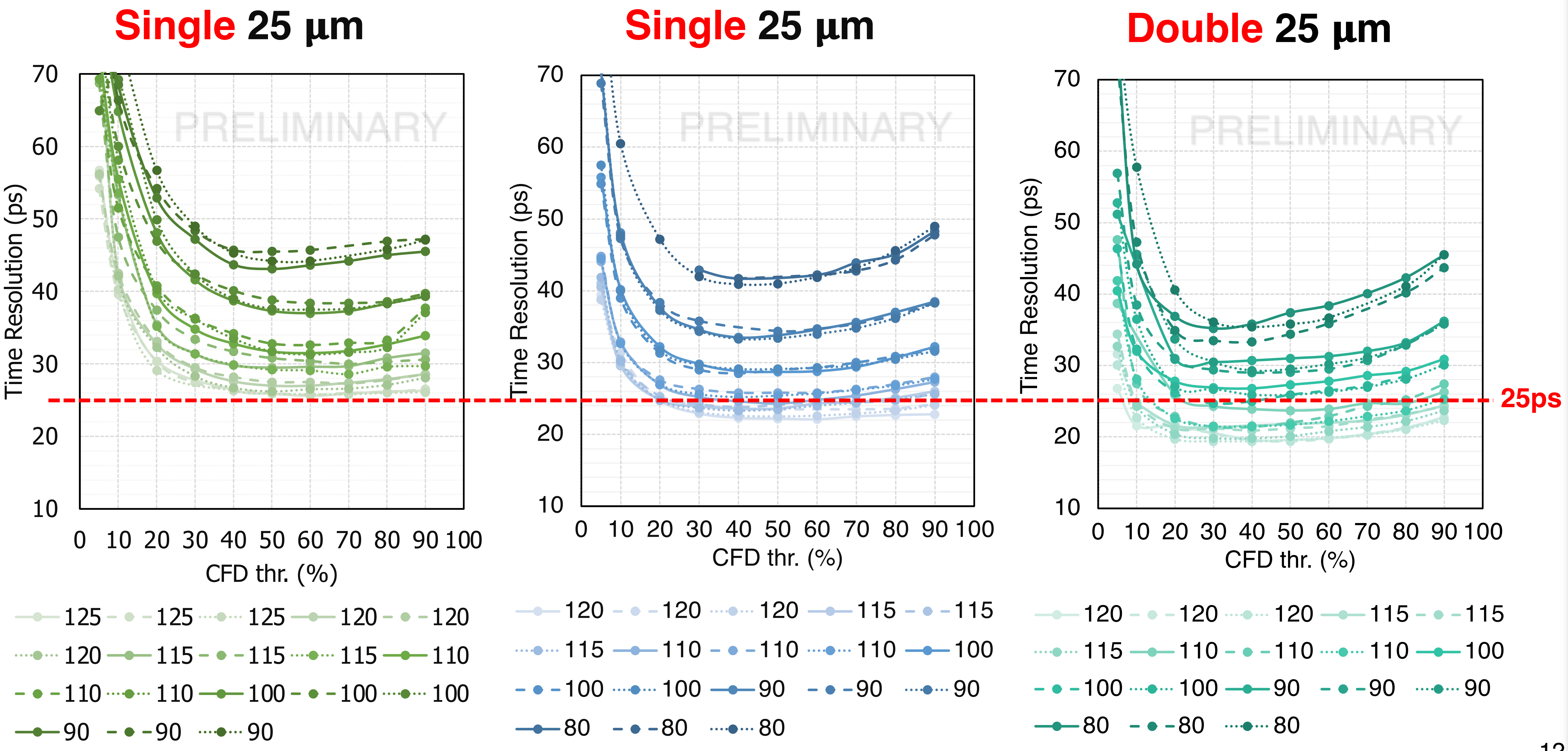






Double charge MPV for the ‘double LGAD’, as expected → advantage for the electronics

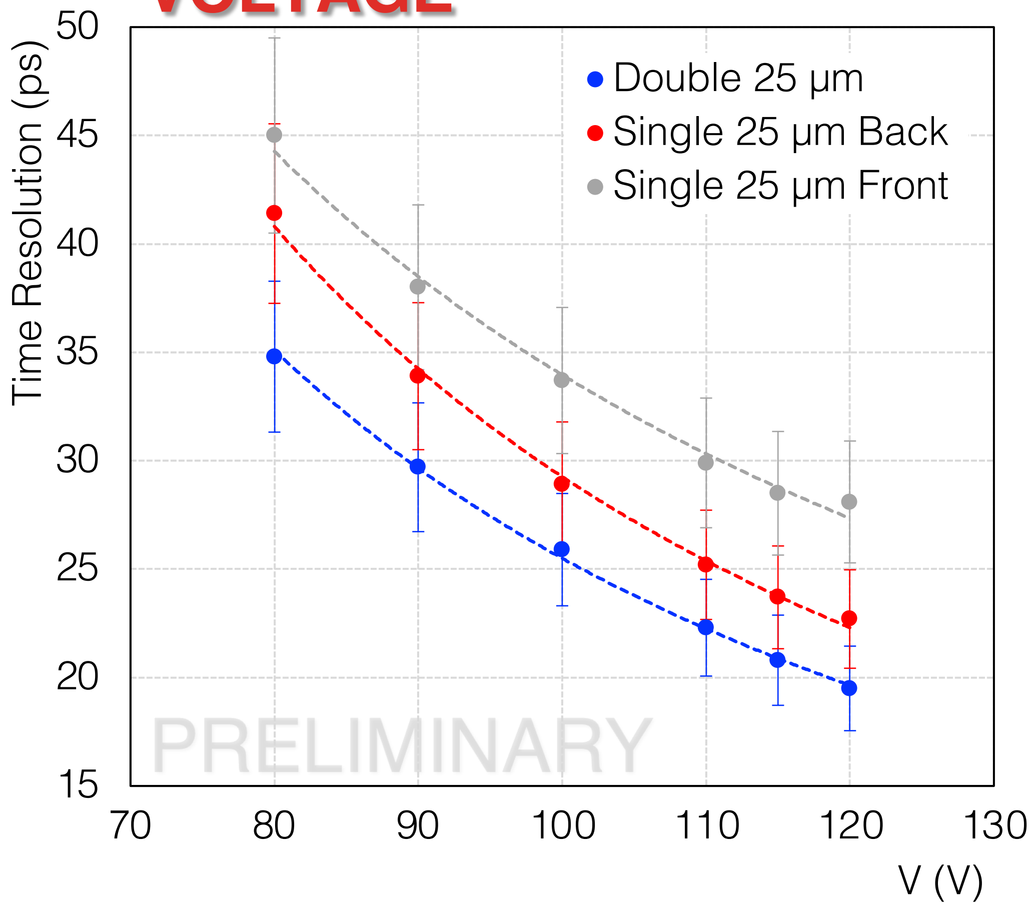
Time resolution extraction example: **CFD technique**



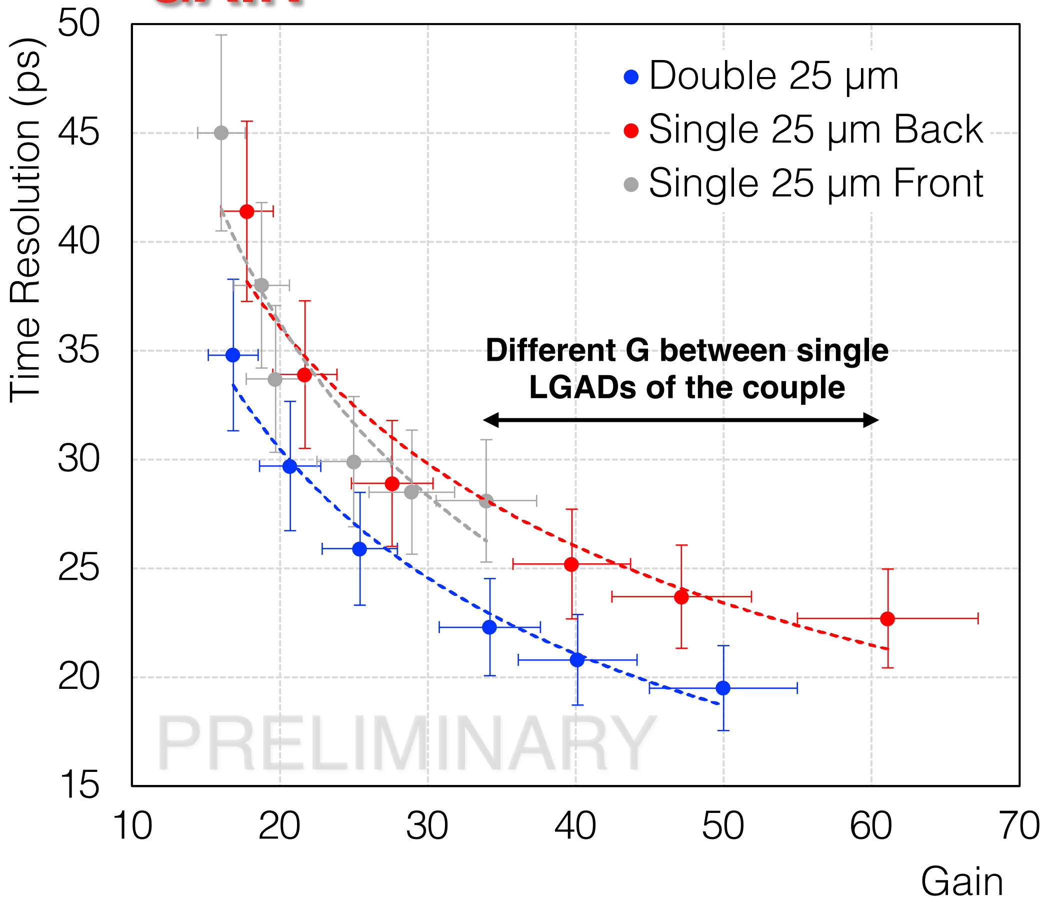
New results

TIMING PERFORMANCE:
Single VS Double 25 μm

VOLTAGE

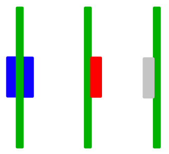


GAIN

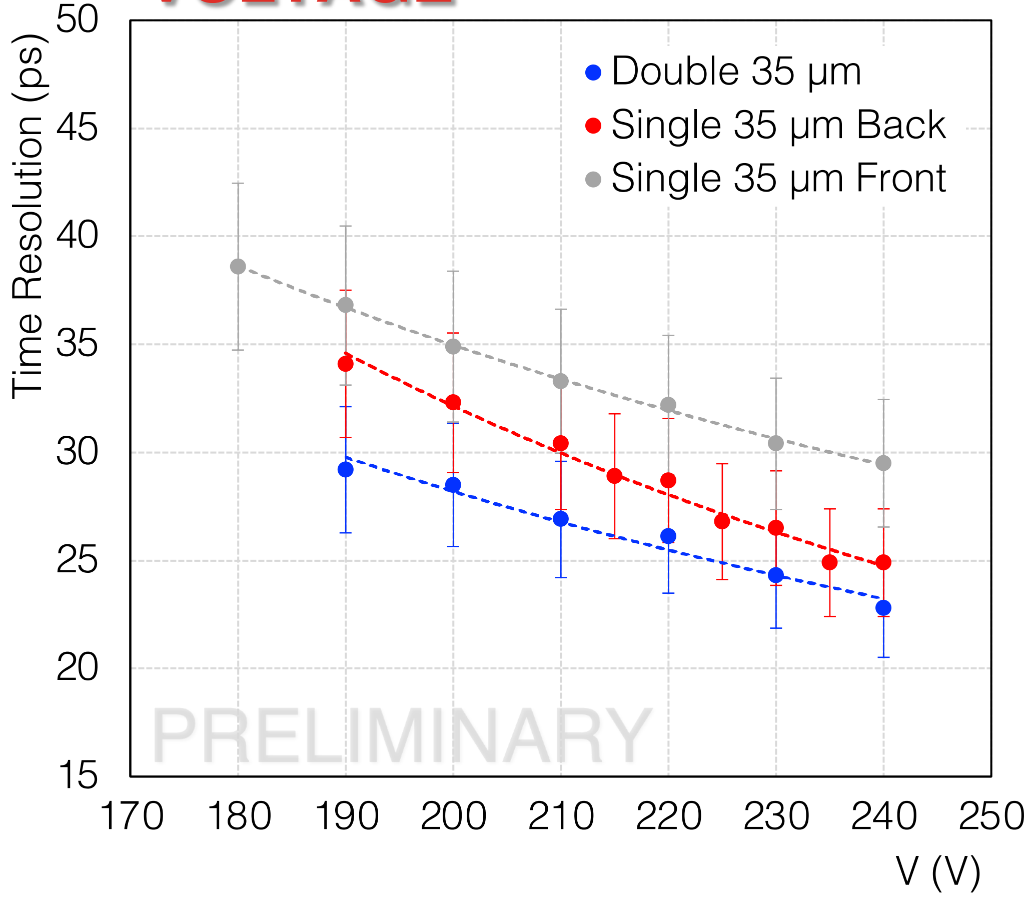


- Comparable time resolution for the two single LGAD at a same gain
- Benefit of a **slightly better time resolution for double** LGADs (~15%)

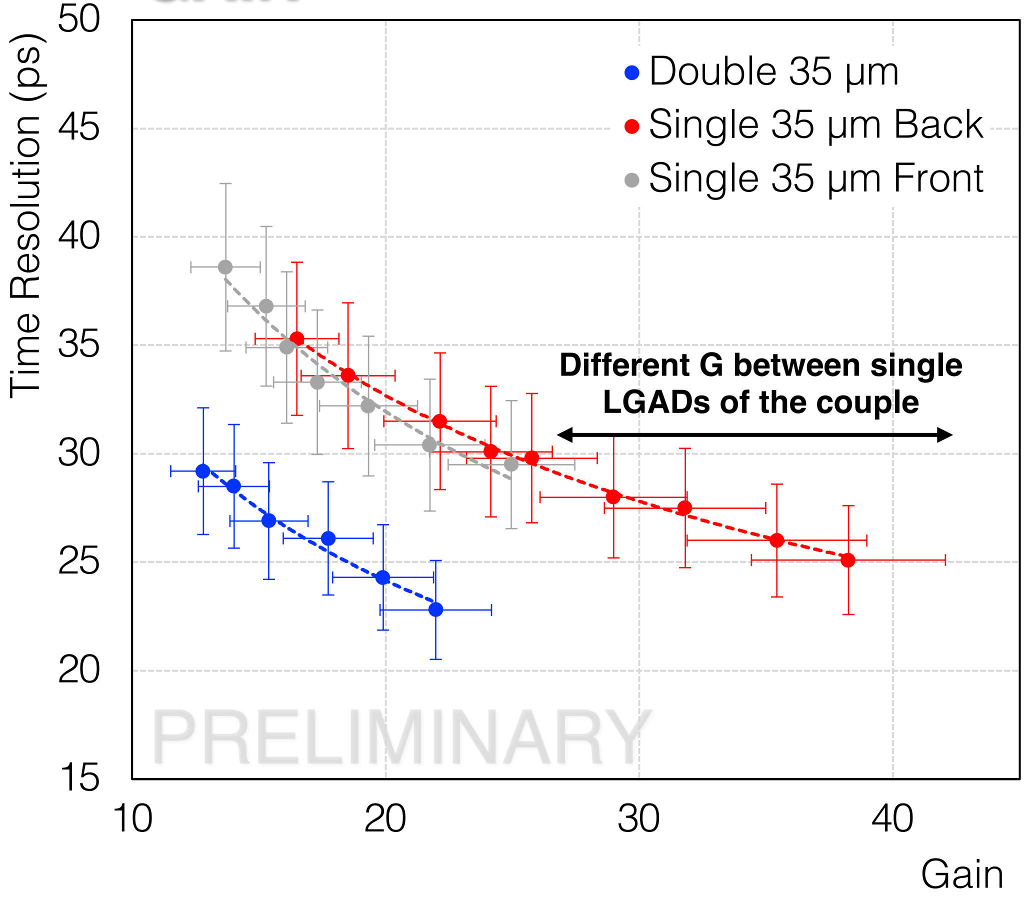
TIMING PERFORMANCE:
Single VS Double 35 µm



VOLTAGE



GAIN

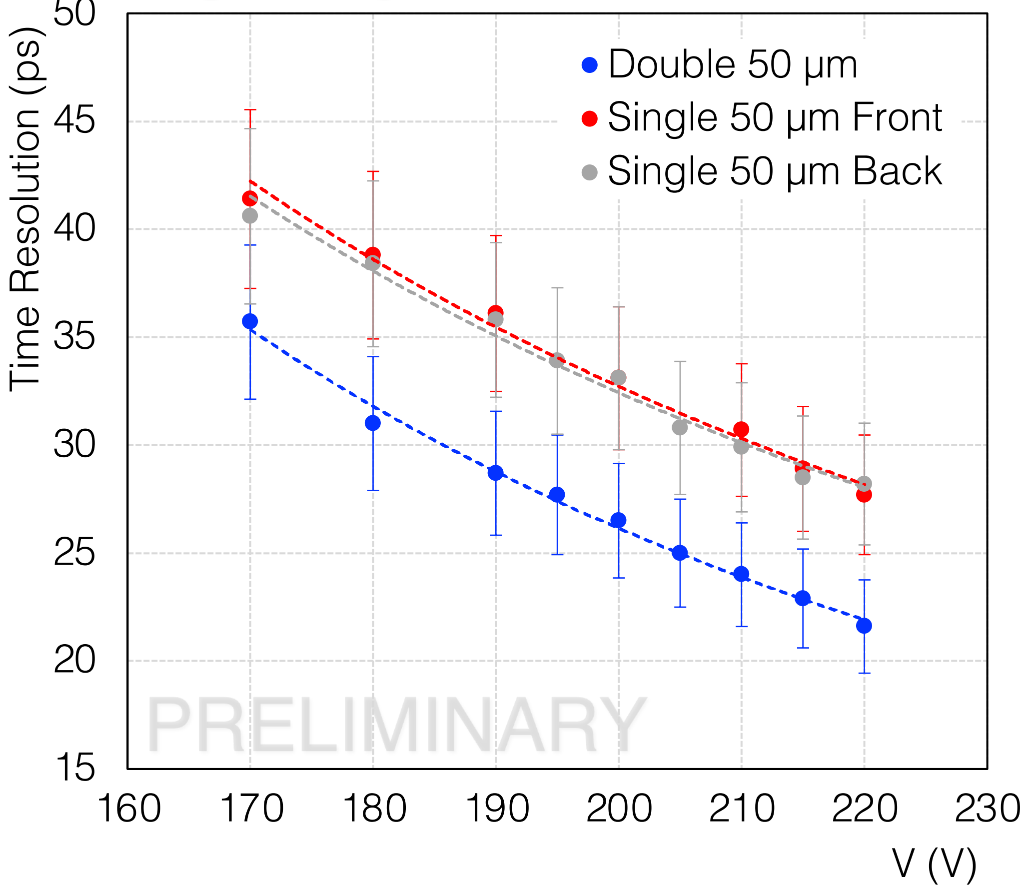


- Comparable time resolution for the two single LGAD at a same gain
- Benefit of a **slightly better time resolution for double** LGADs (~24%)

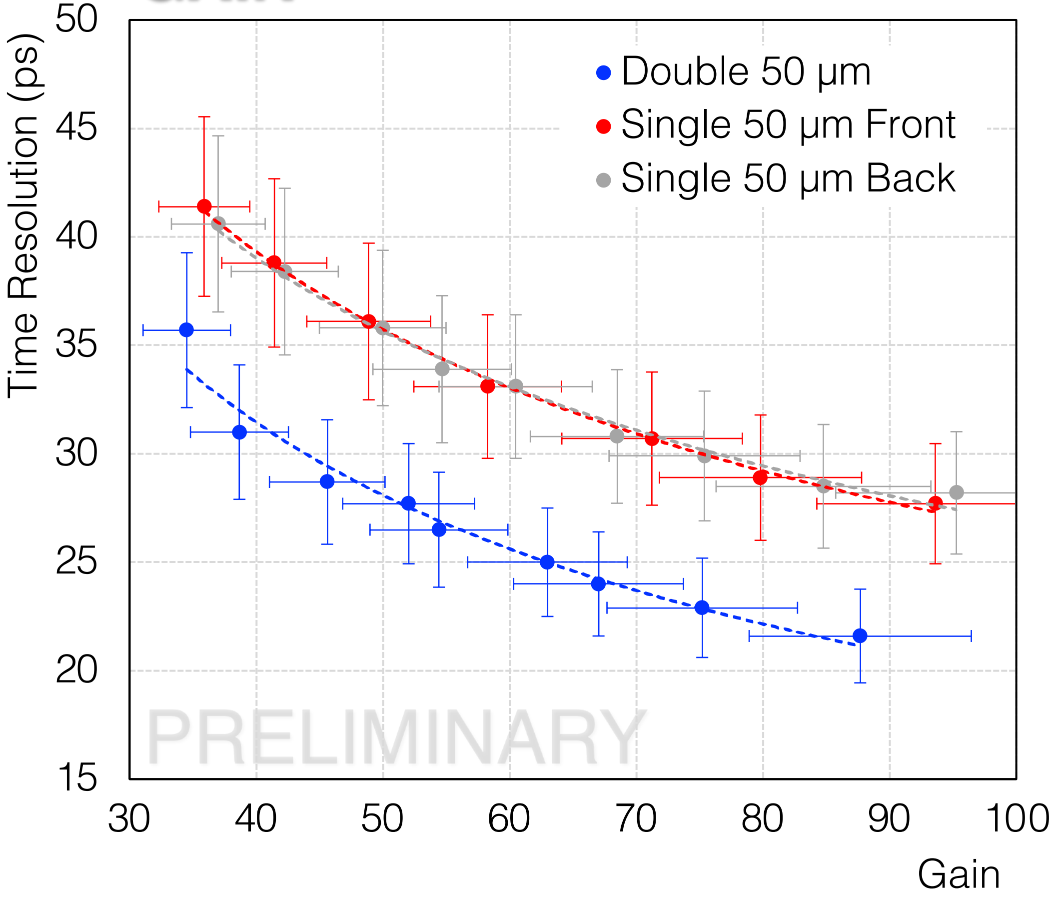
New results

TIMING PERFORMANCE:
Single VS Double 50 µm

VOLTAGE



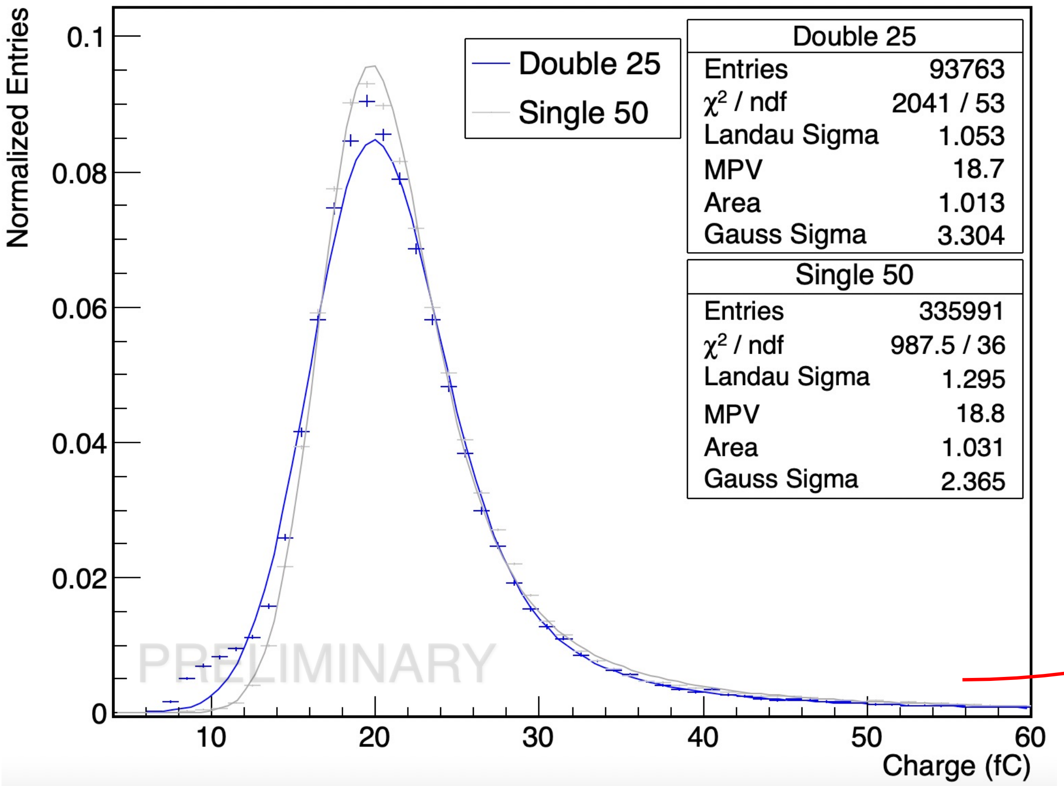
GAIN



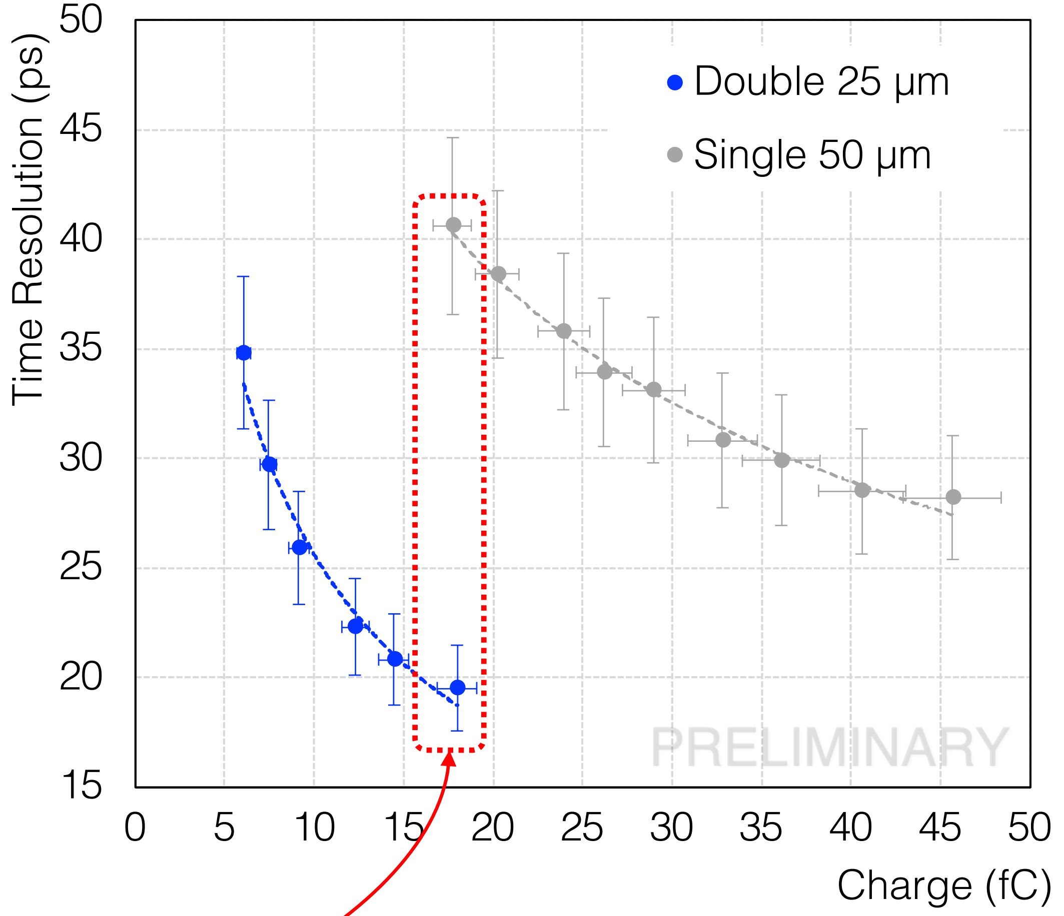
- **Very uniform LGADs** with a standard thickness of 50 µm
- Benefit of a **slightly better time resolution for double** LGADs (~23%)

COMPARISON DOUBLE 25+25 & SINGLE 50

CHARGE



TIME RESOLUTION



For a similar charge

→ The double 25 μm thick LGAD shows a **50% better time resolution**

CONCLUSIONS

The results show that: single 25, 35 μm thick LGADs and the 'double LGAD concept'

can reach a time resolution near to the requirement of 20 ps

FUTURE PLANS

For ALICE 3 in 2023 all the maturated experience will be focused on the new CMOS LGADs we are going to receive:

Looking forward CMOS LGADs tests

Test of thinner LGADs with a more uniform doping concentration

down to 10-15 μm LGADs, single and double

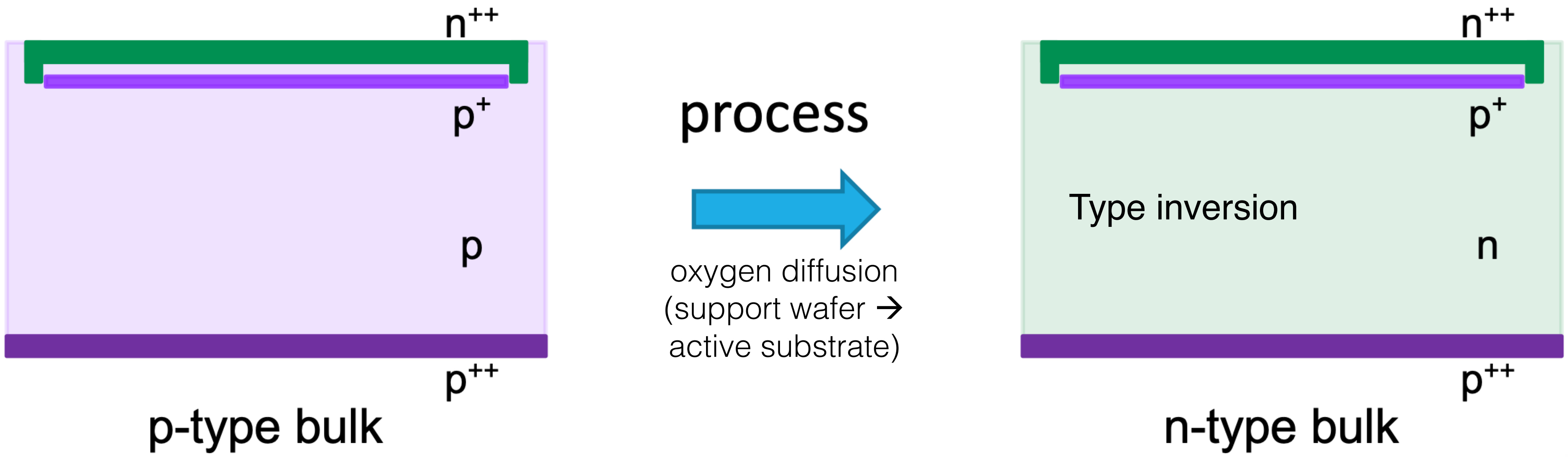
BACKUP SLIDES

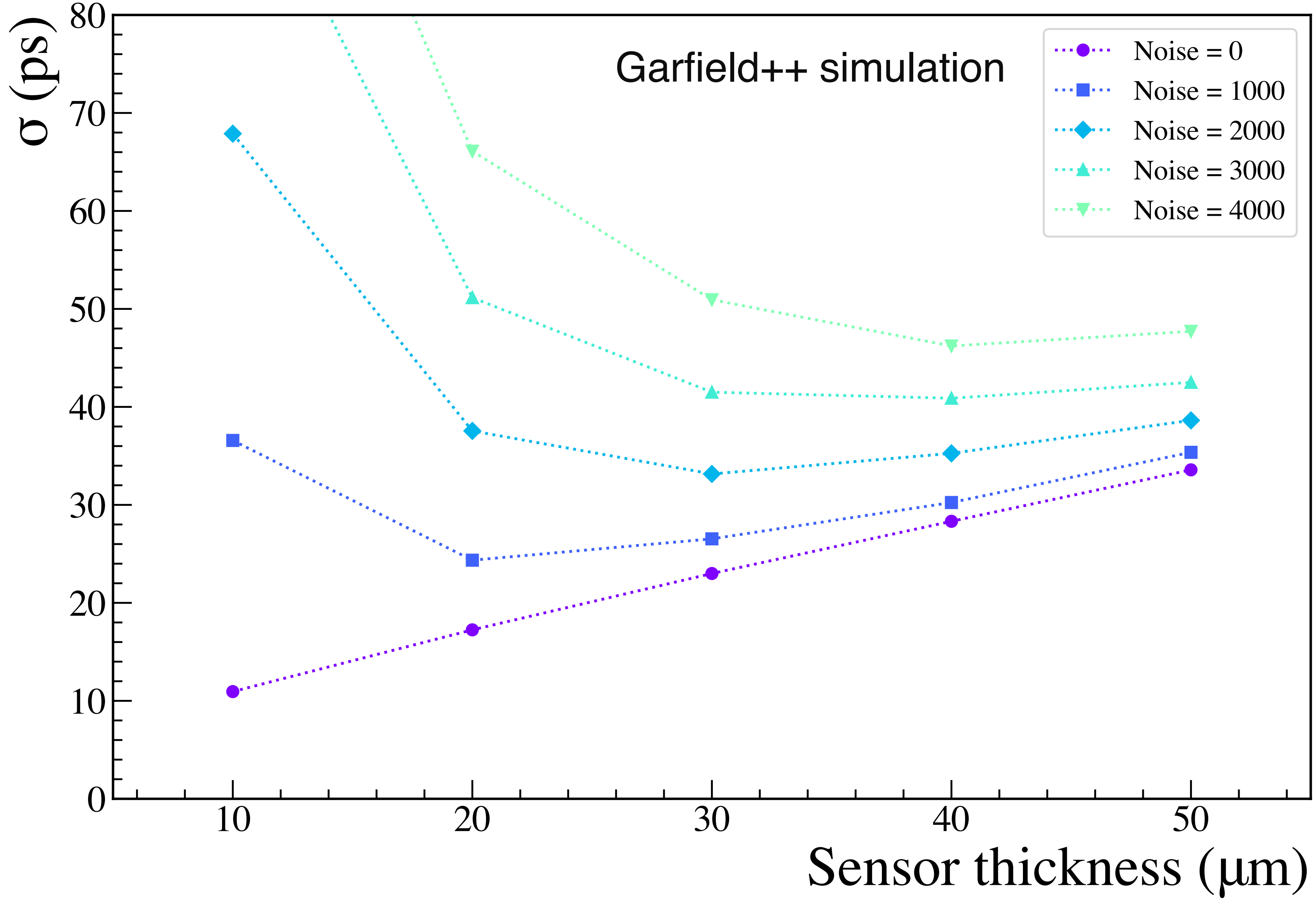
BACKUP SLIDES

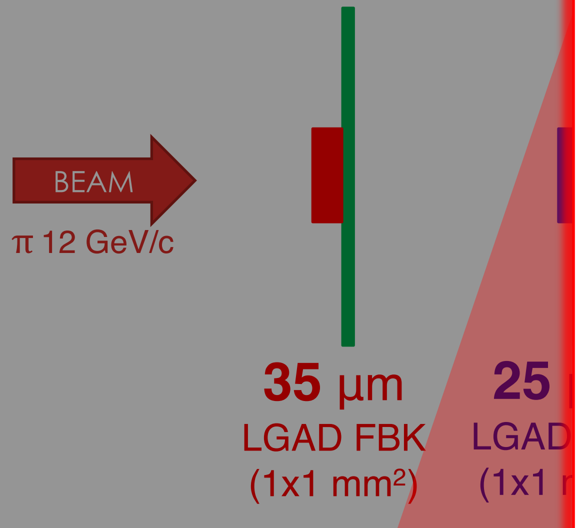
Difficulties in the production → Different doping concentrations

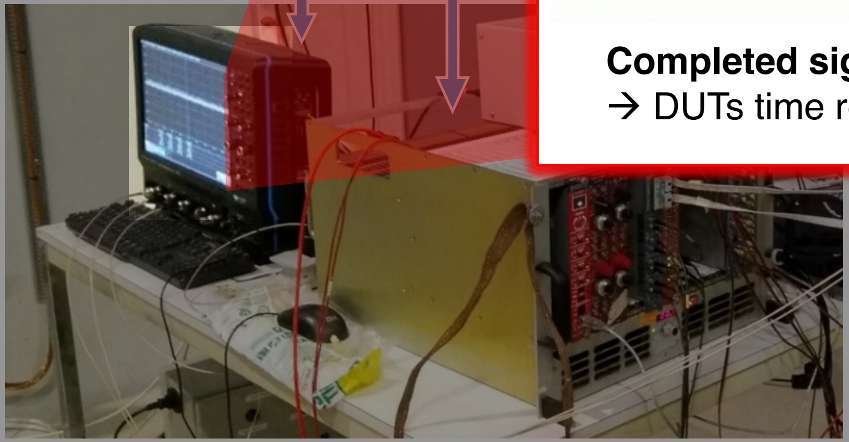
25 µm-thick LGAD

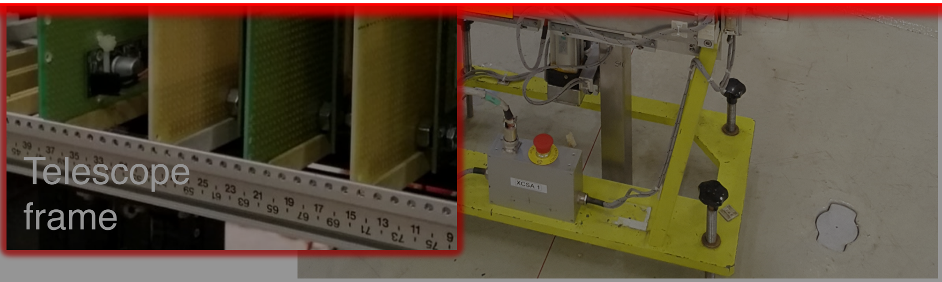
35 µm-thick LGAD

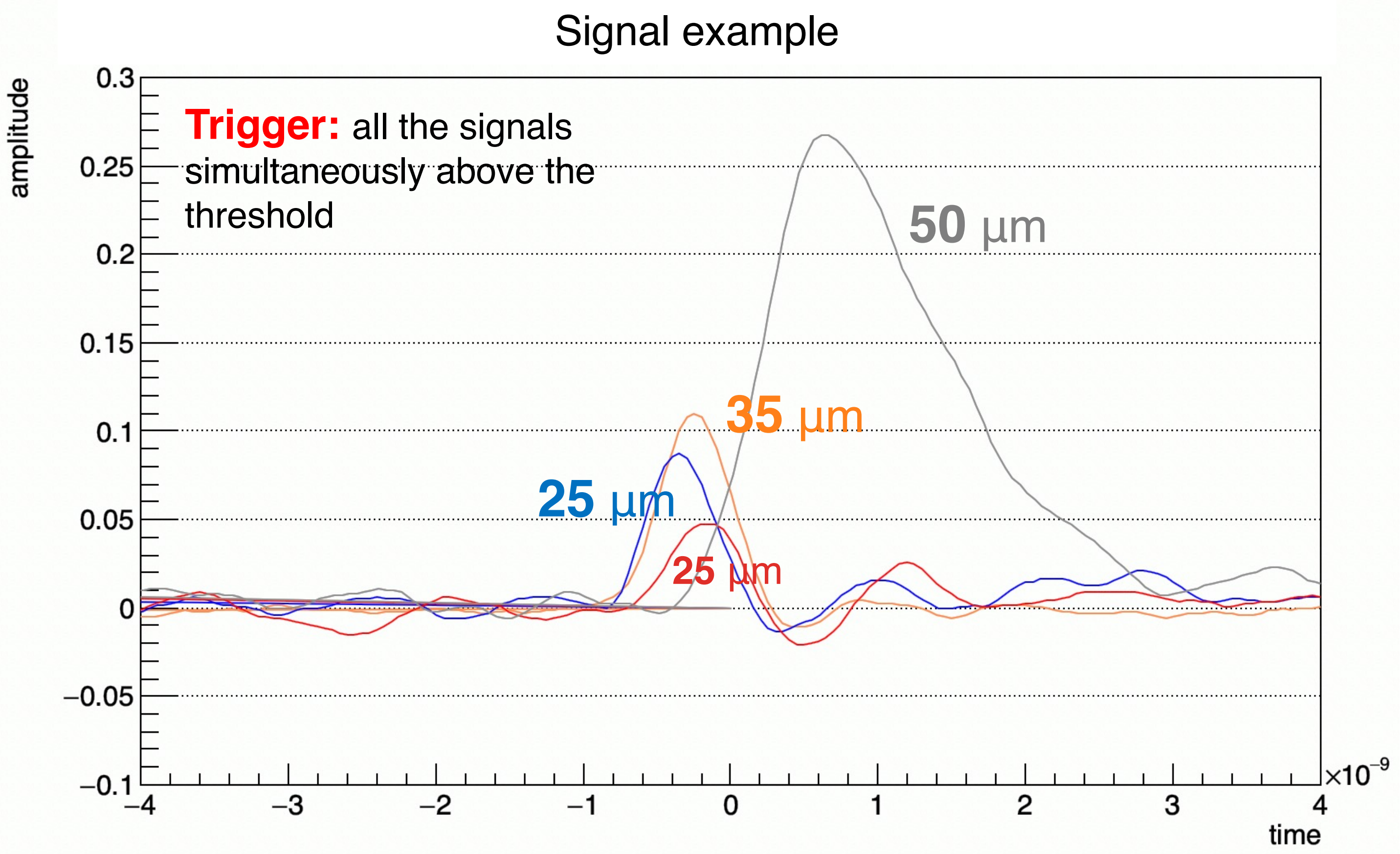



Garfield++ simulation
Noise = 0
Noise = 1000
Noise = 2000
Noise = 3000
Noise = 4000
σ (ps)
80
70
60
50
40
30
20
10
0
10
20
30
40
50
Sensor thickness (μm)









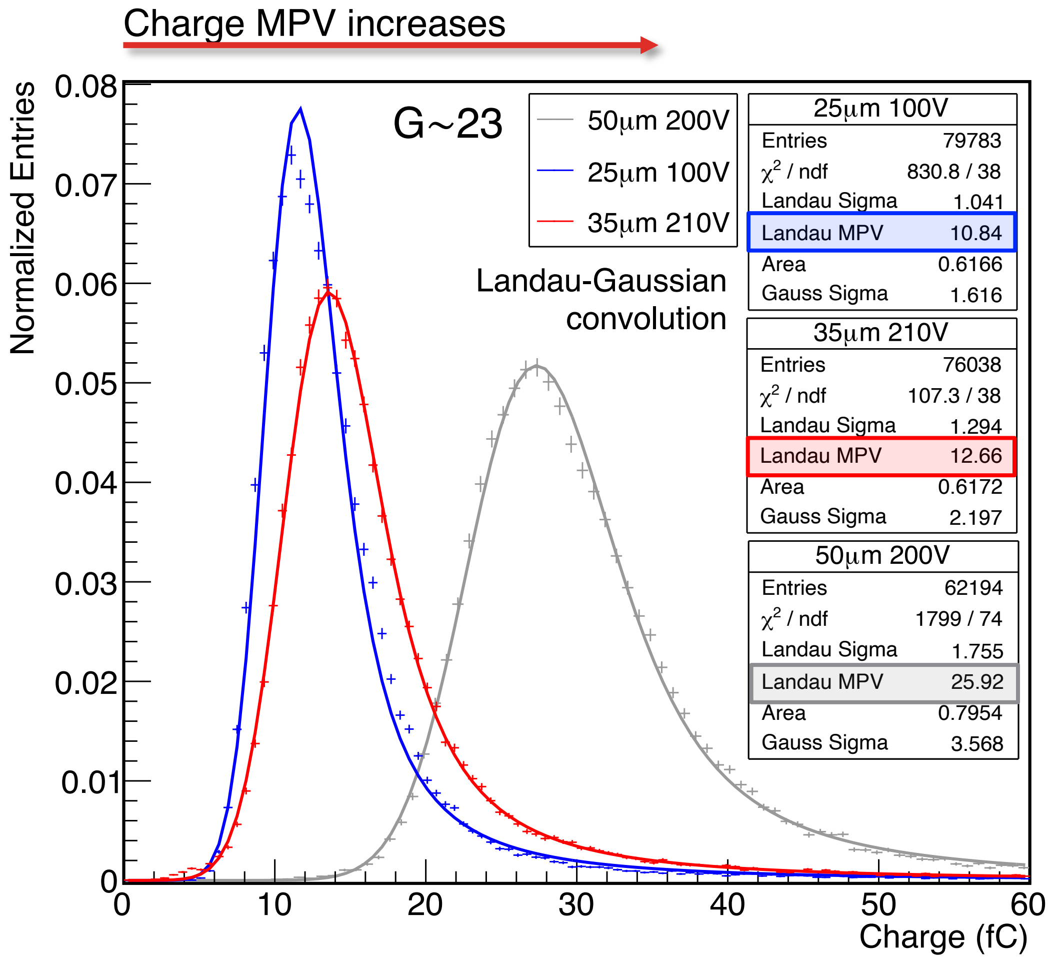
Completed signal waveforms recorded and analyzed offline

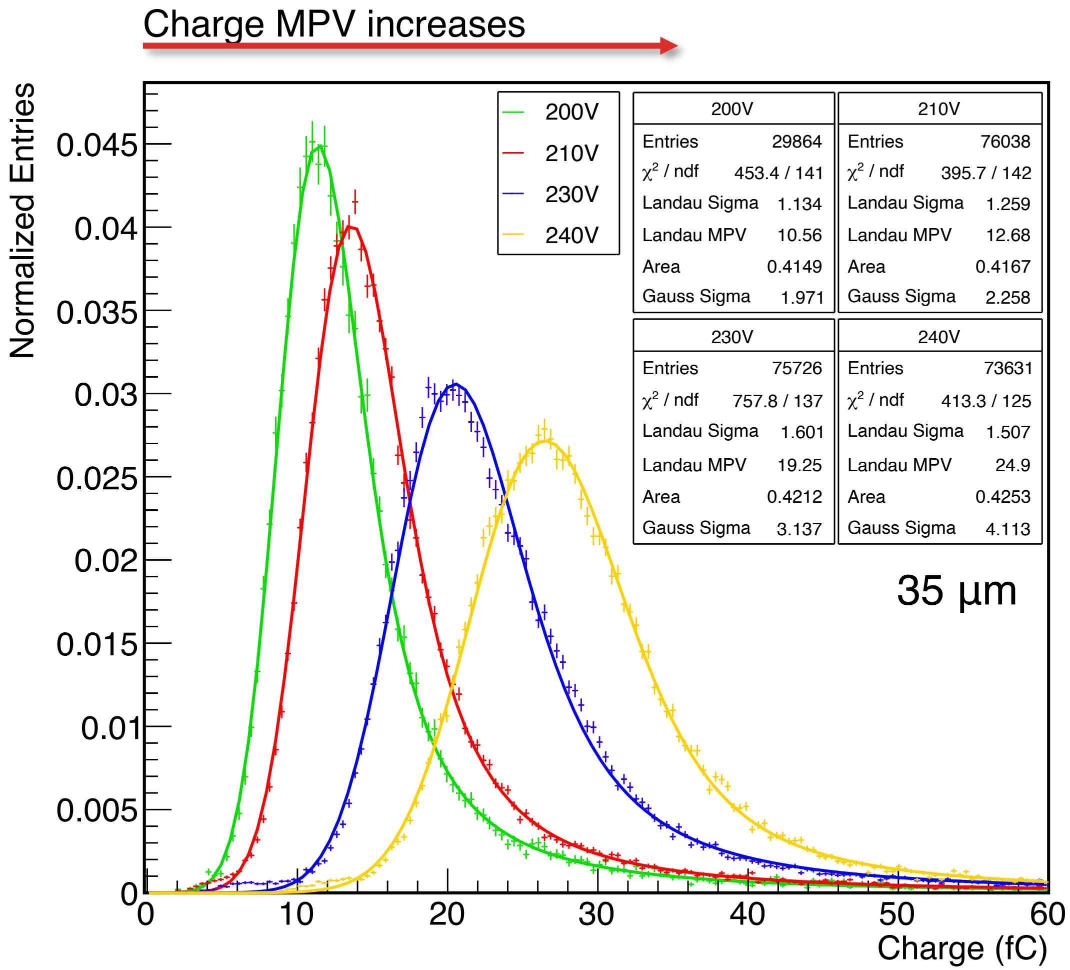
→ DUTs time resolutions without problems relates to the front-end electronics

OTHER RESULTS

OTHER RESULTS

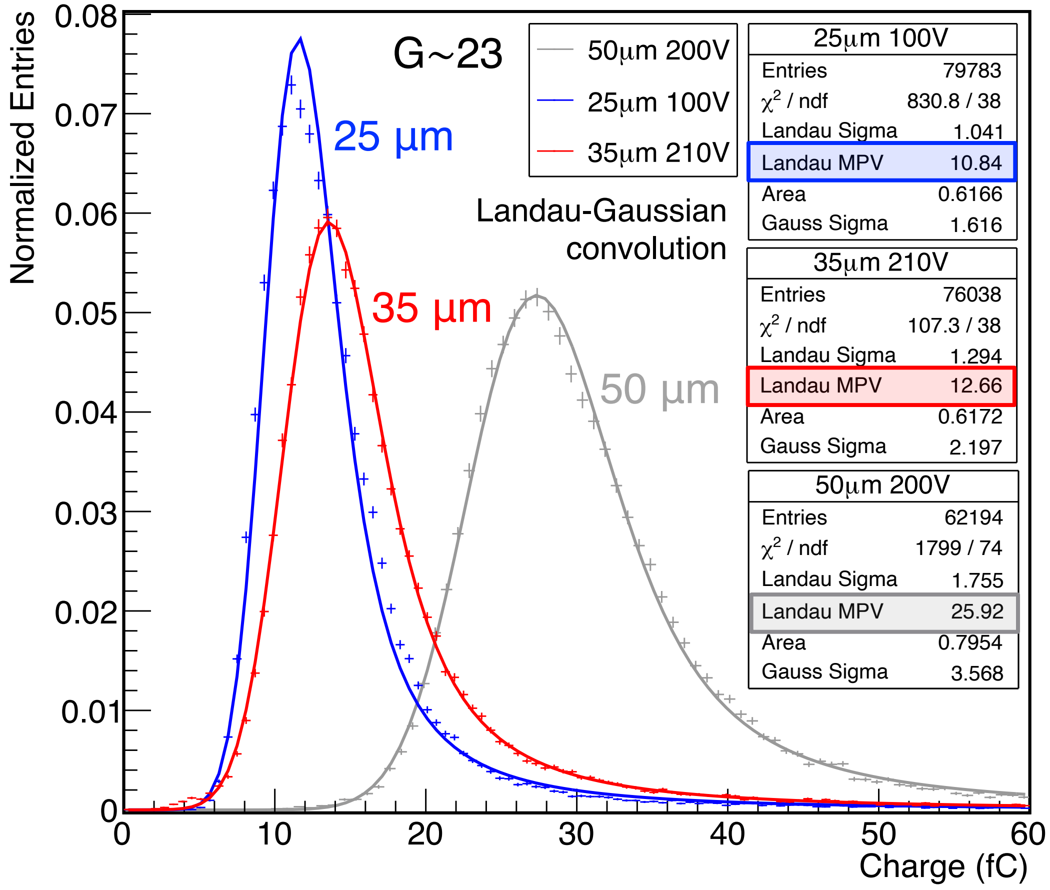
CHARGE DISTRIBUTIONS



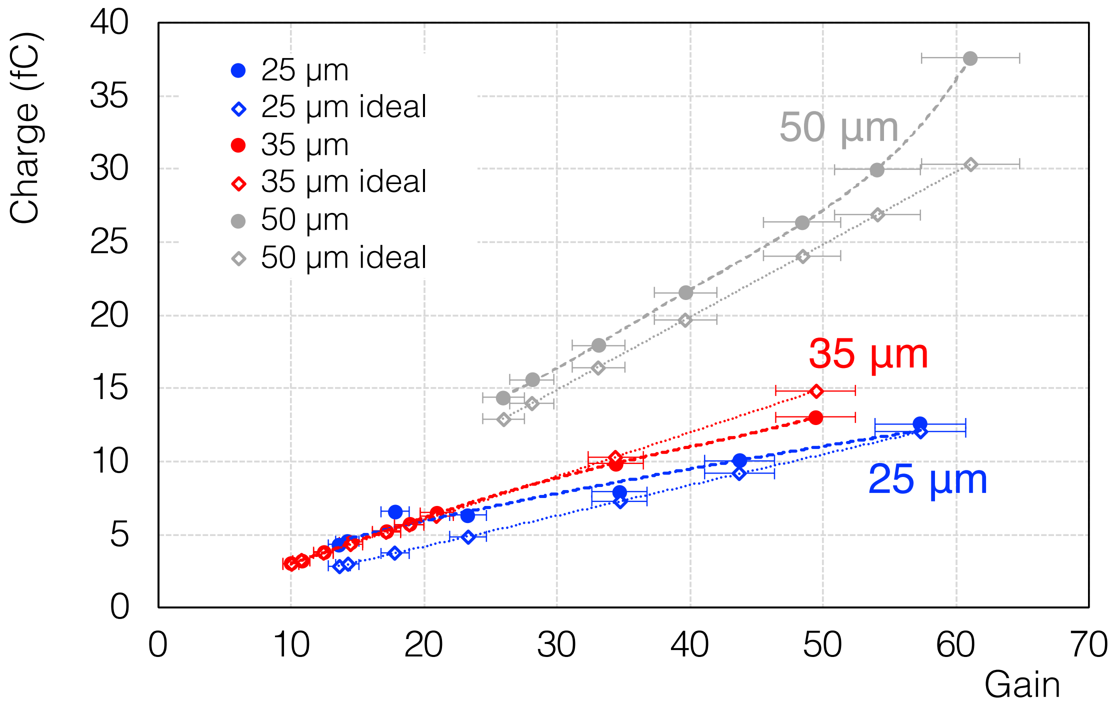


CHARGE DISTRIBUTIONS

Charge MPV increases with the thickness

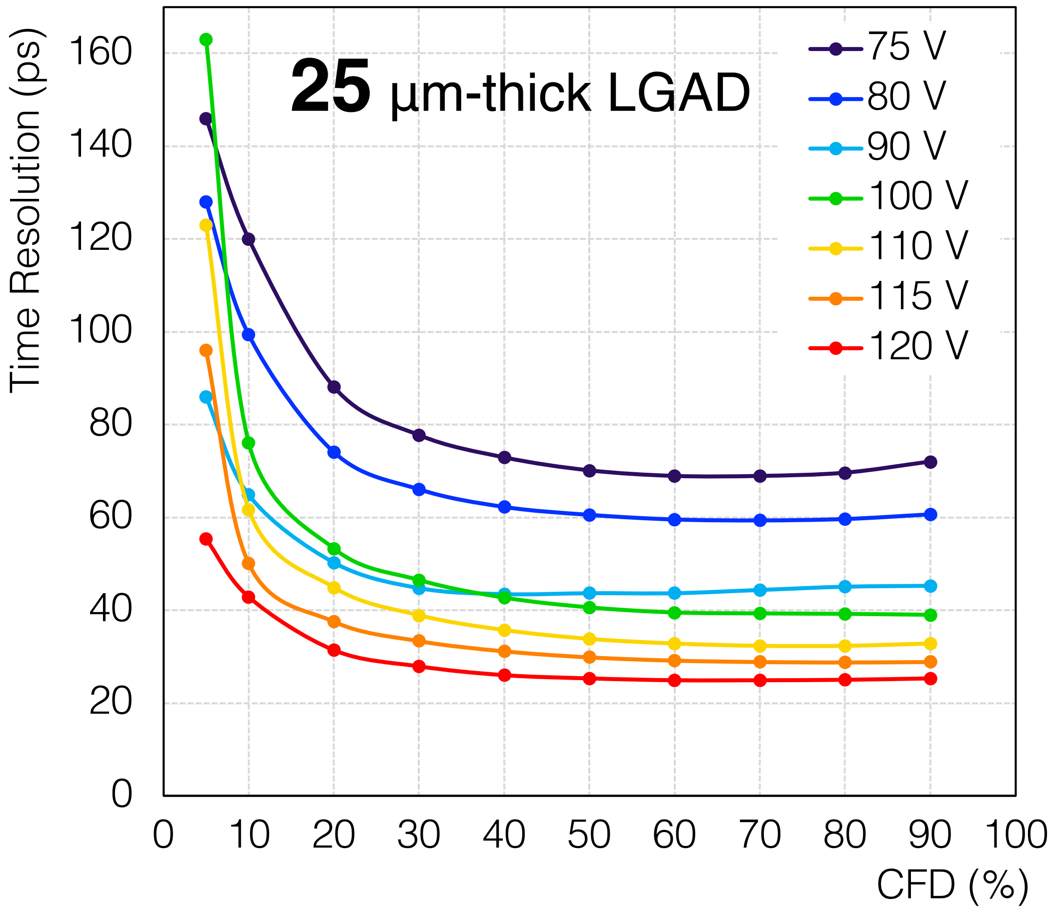


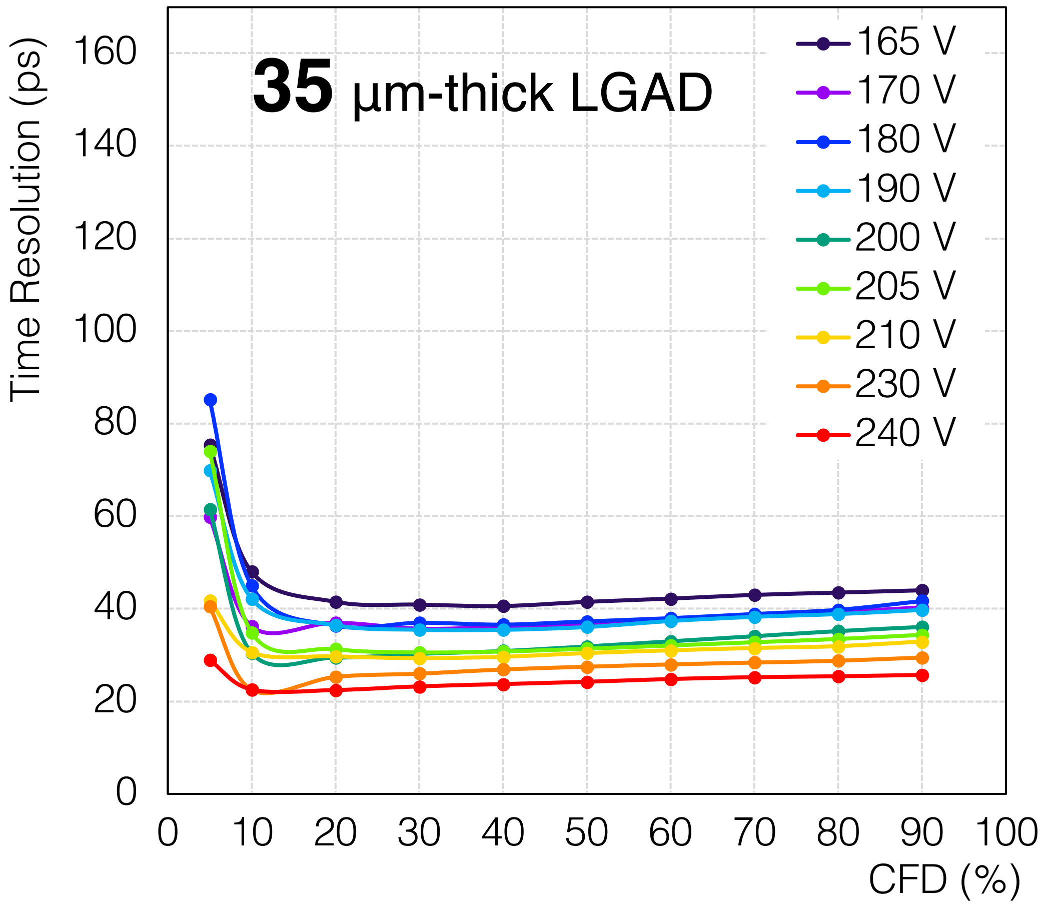
Measured Charge MPV vs Ideal



Ideal Charge = $Charge_{PIN}$ x $Gain_{meas}$
→ results are in good agreement with the expected values

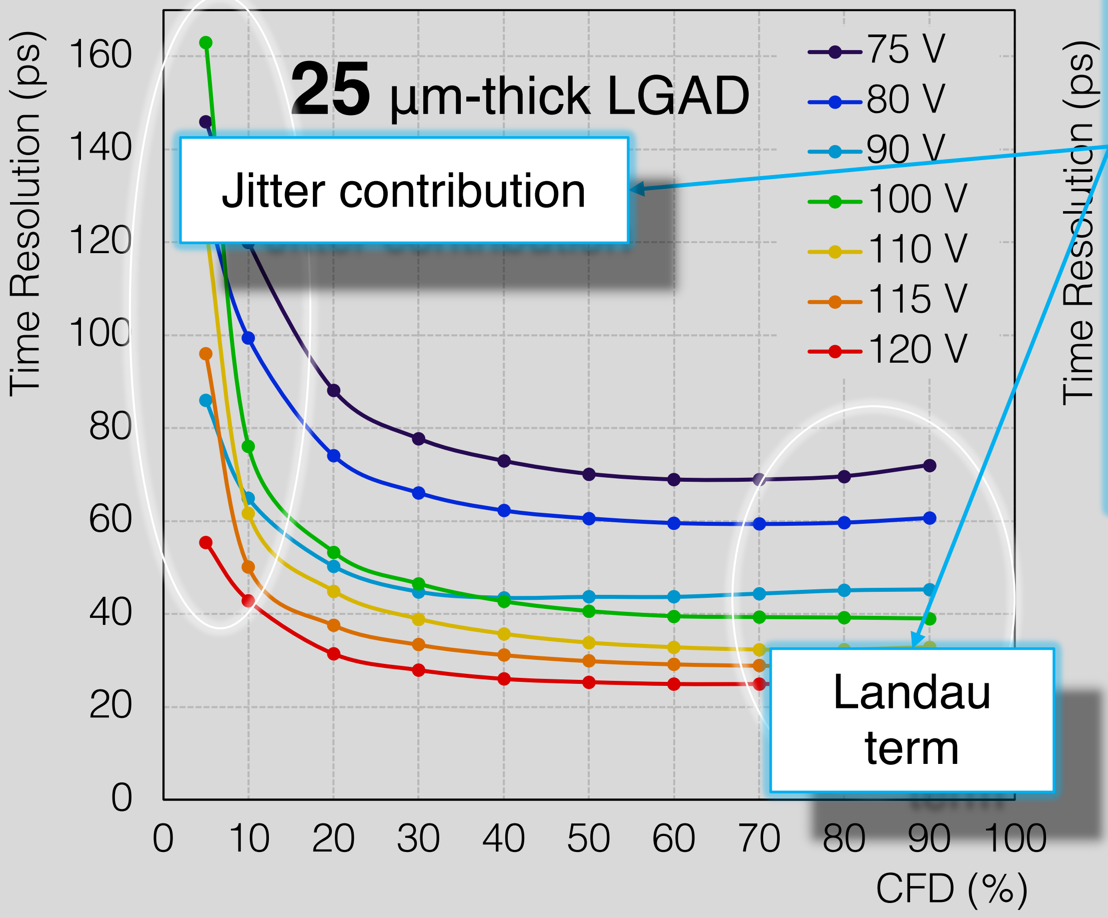
TIMING PERFORMANCES

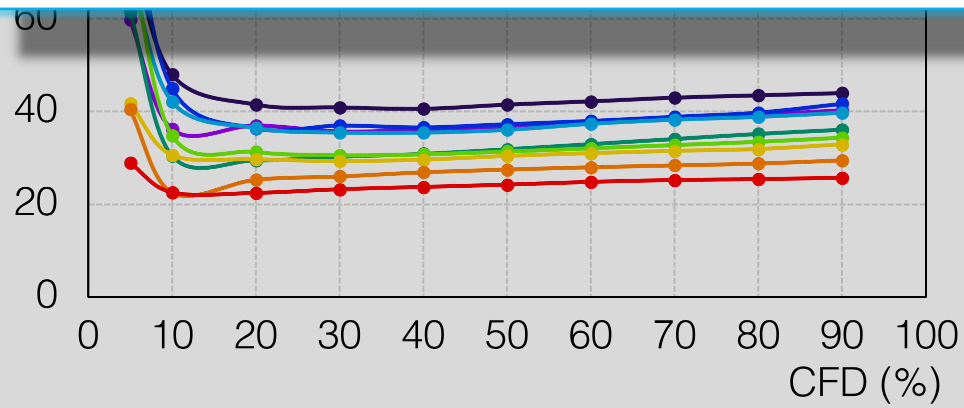




Trend and values of **50 µm** LGAD **totally in agreement** with previous results

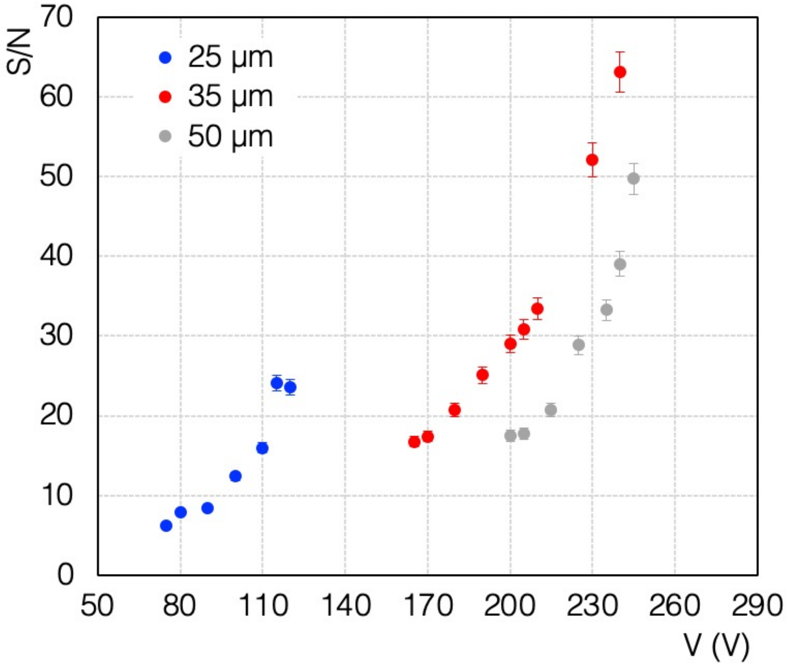
TIMING PERF





- Thickness
- S/N
  - Electronics
  - Detectors
  - Shielding

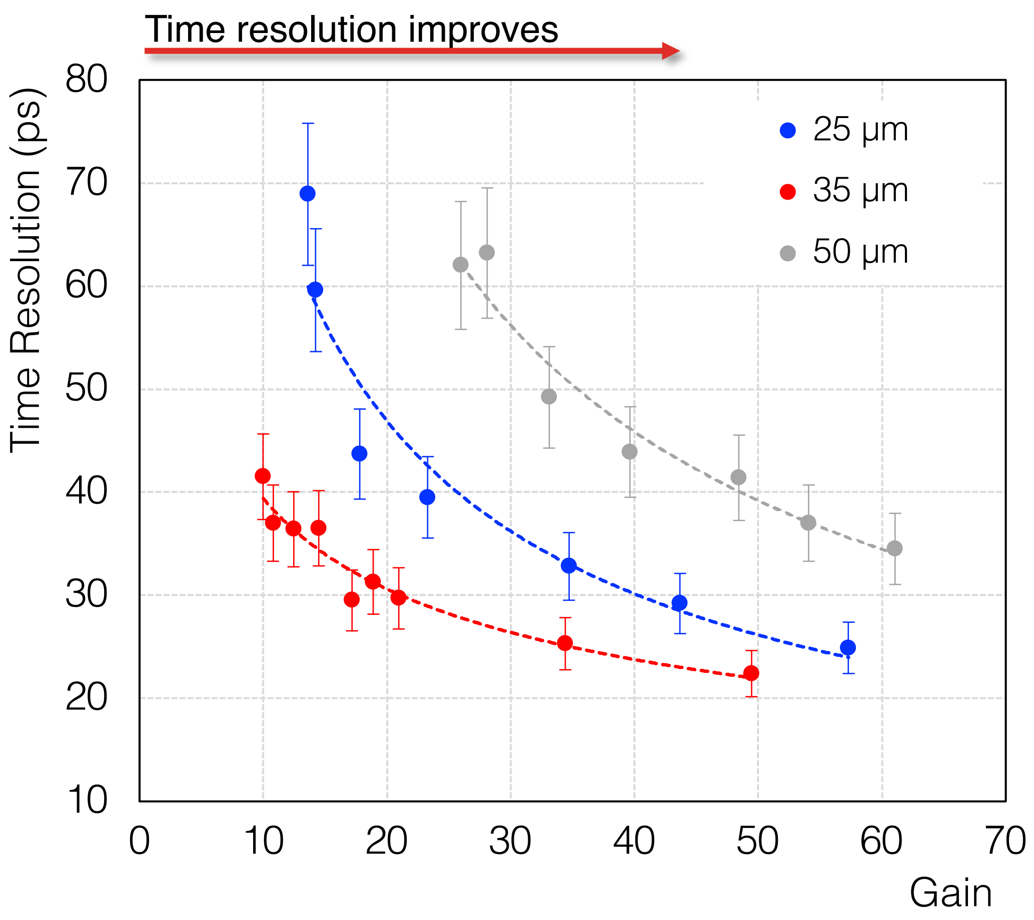
25 µm: 6-24
35 µm: 16-63

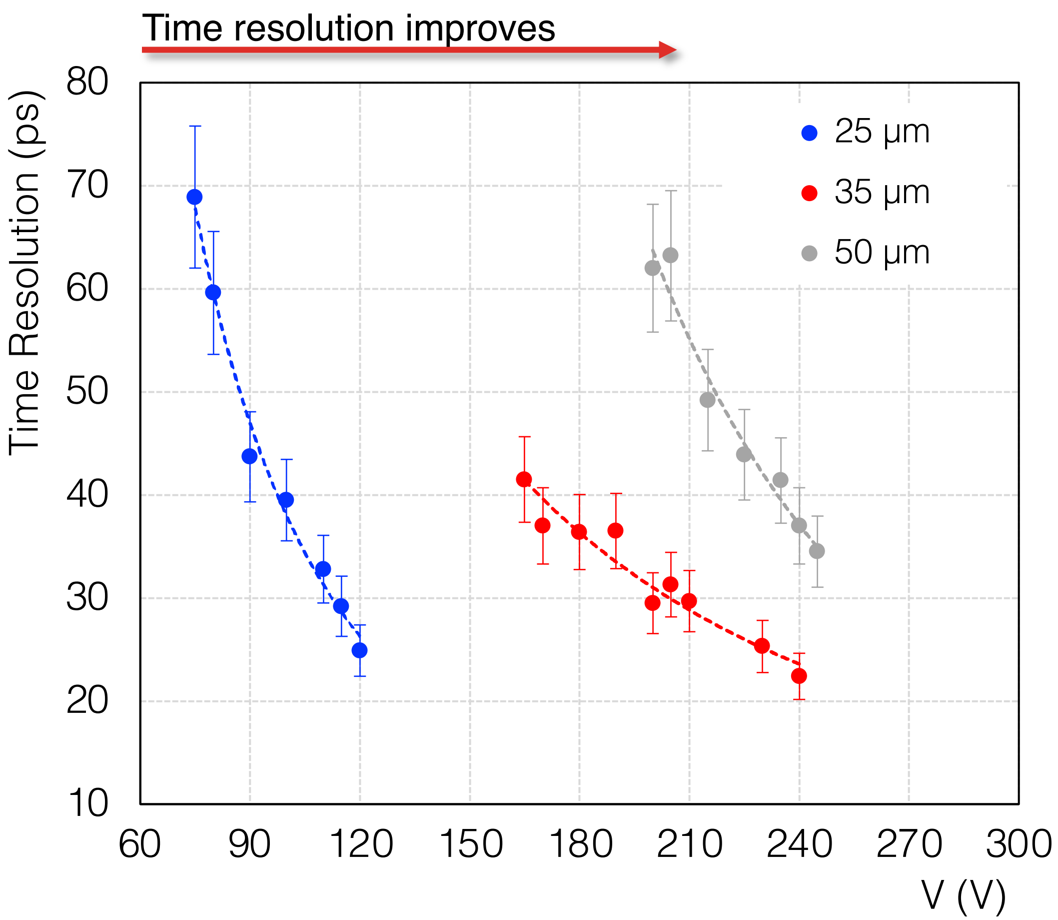


Trend and values of **50 µm** LGAD **totally in agreement** with previous results

TIMING PERFORMANCES

- 50 µm LGAD → ~34 ps confirms previous results
- Better values for thinner detectors (↘ Landau term)
- 25 & 35 µm are compatible within the uncertainties ~25 ps & 22 ps
  - ↳ worse S/N, not optimized wafer production





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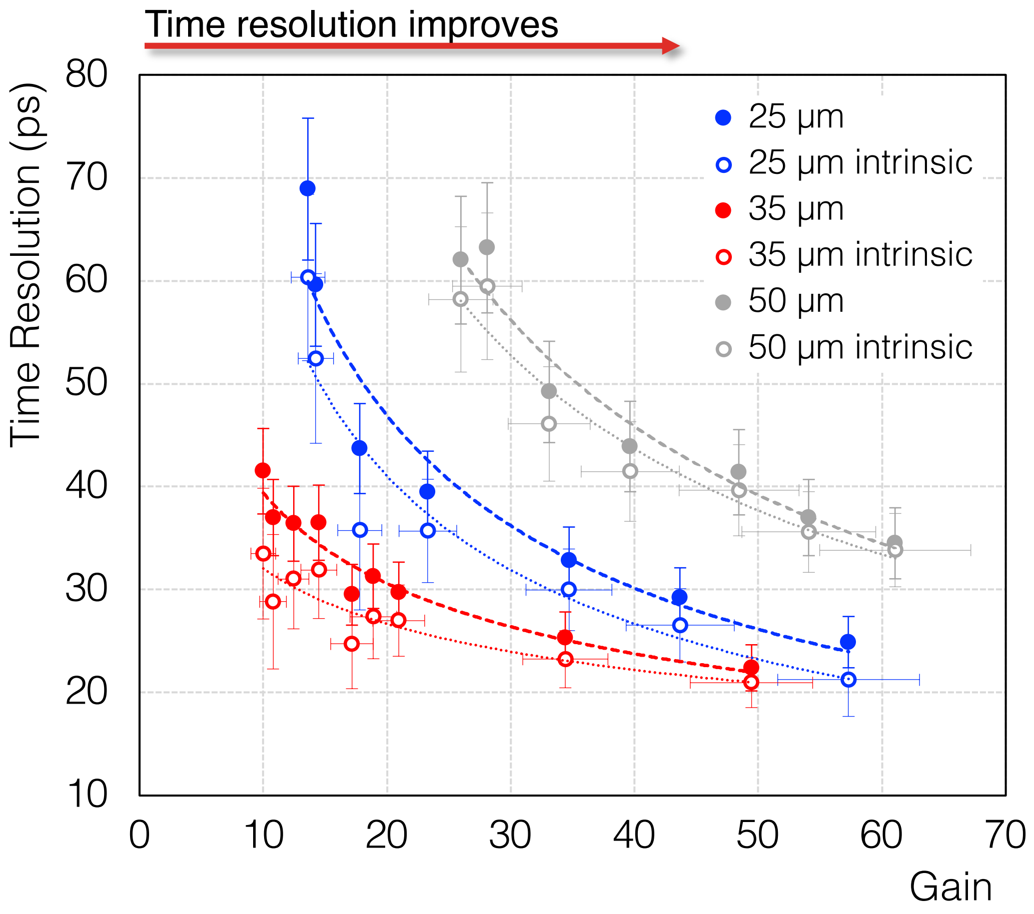
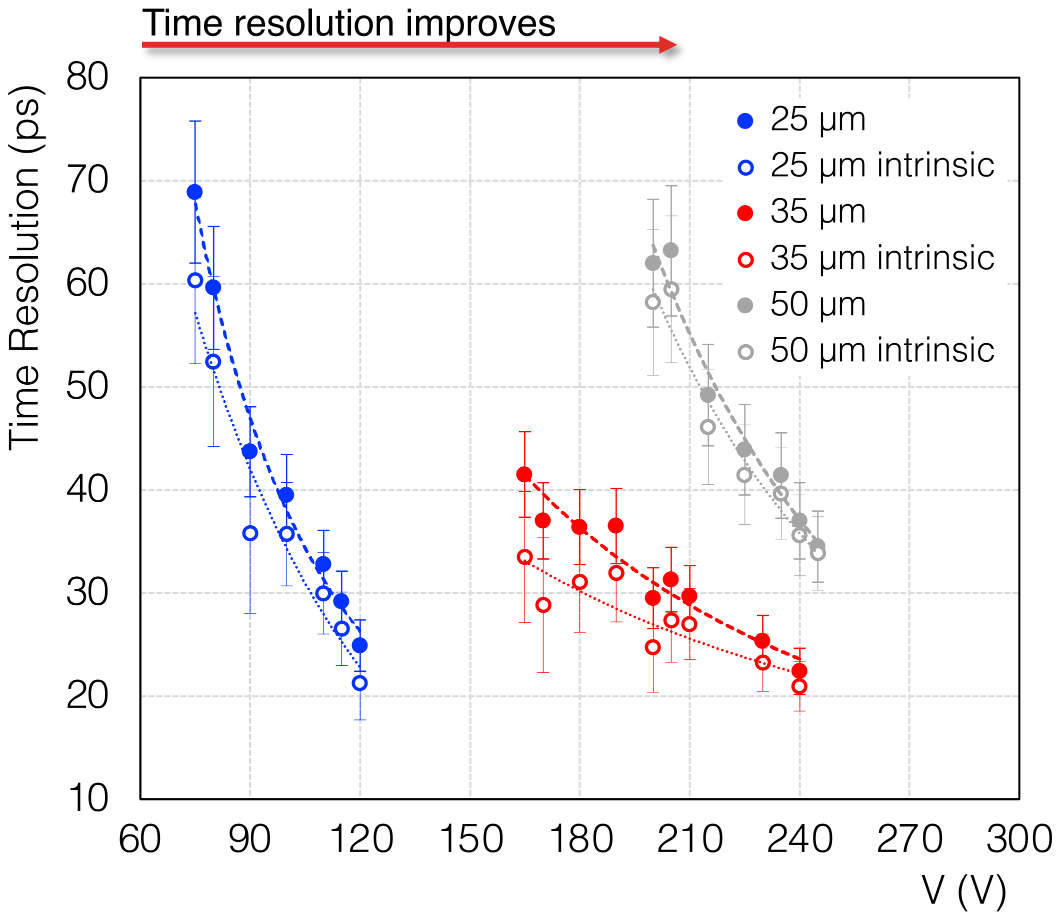




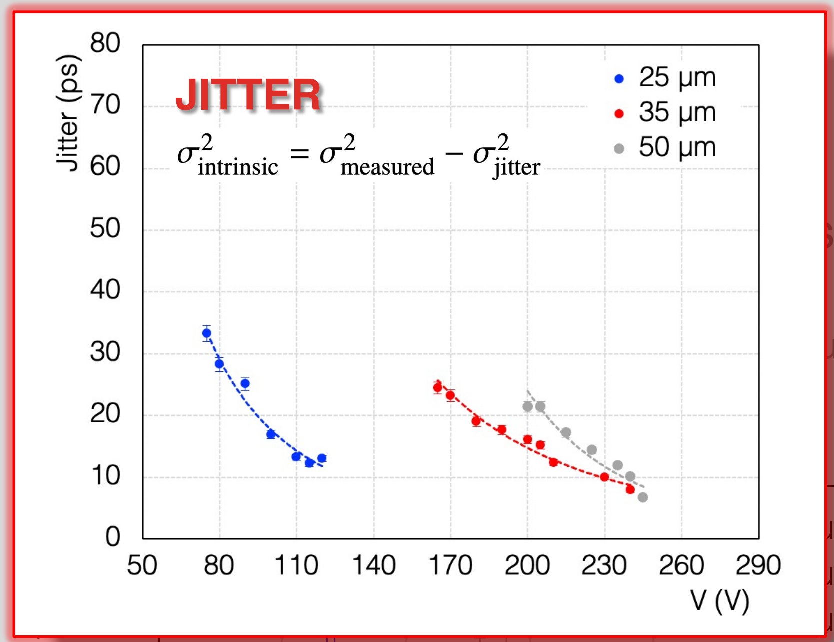
PERFORMANCES

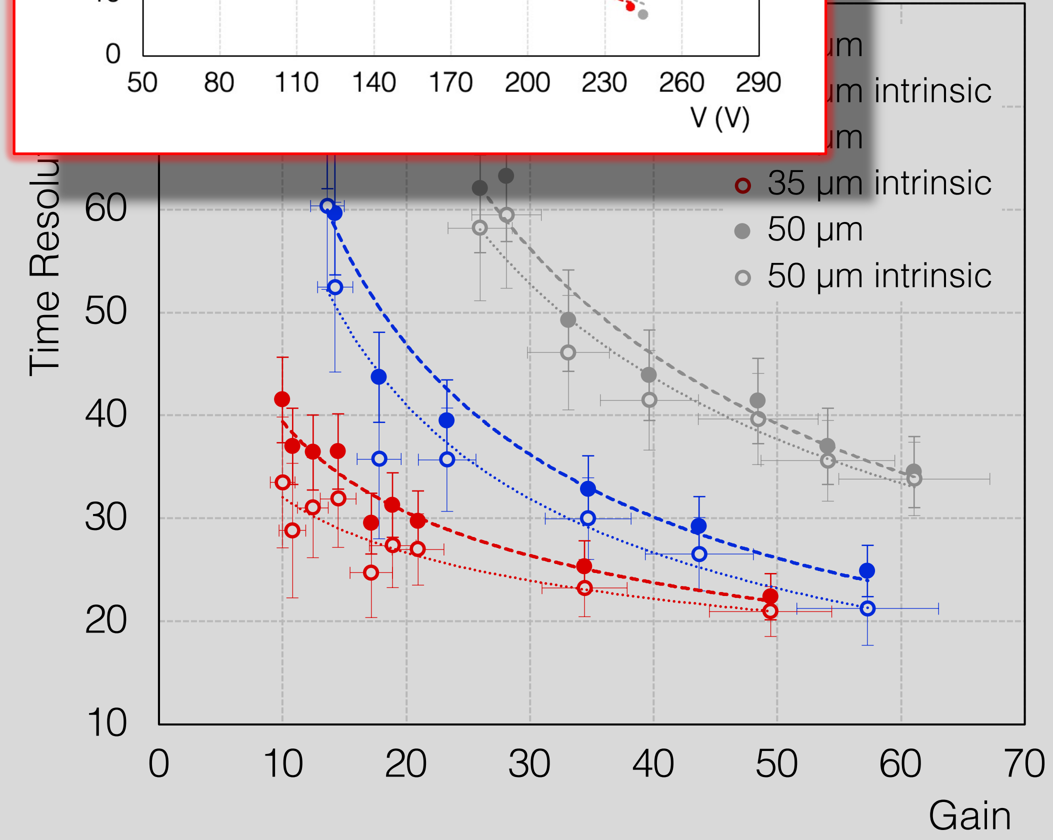
previous results

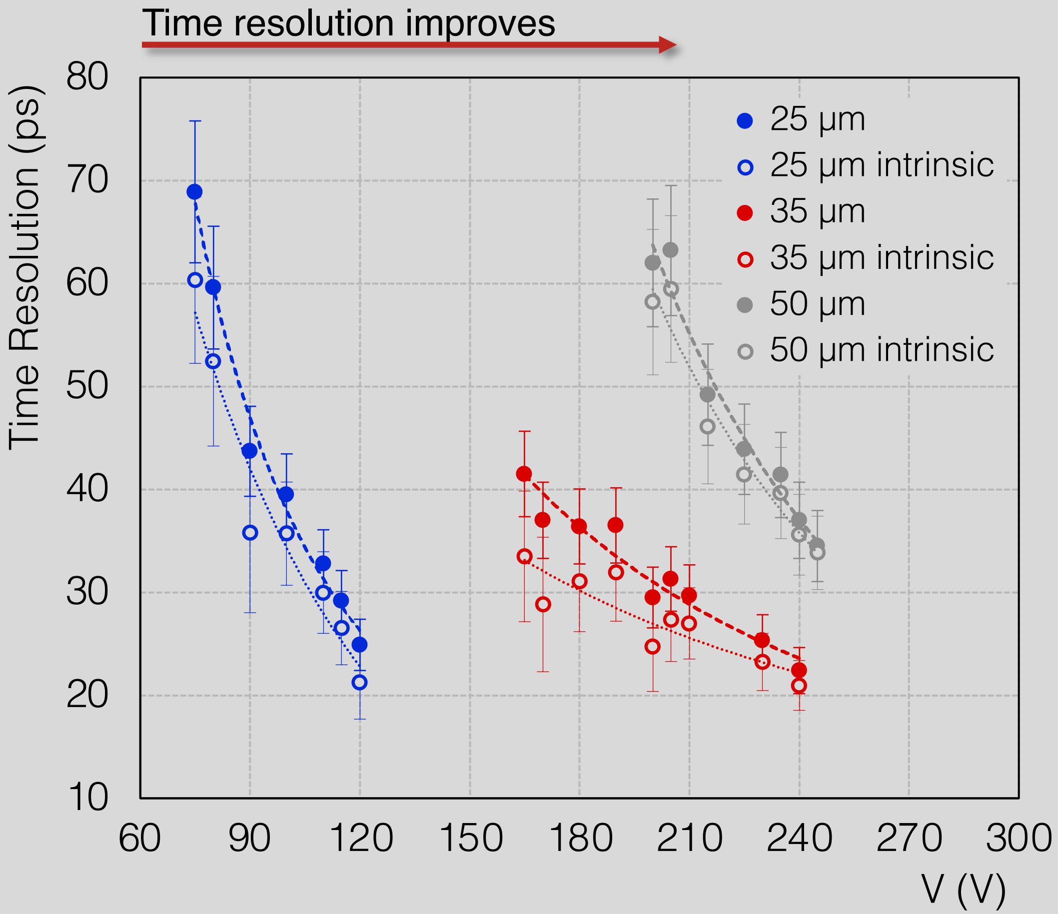
s (↘ Landau term)

the uncertainties ~25 ps & 22 ps

uction

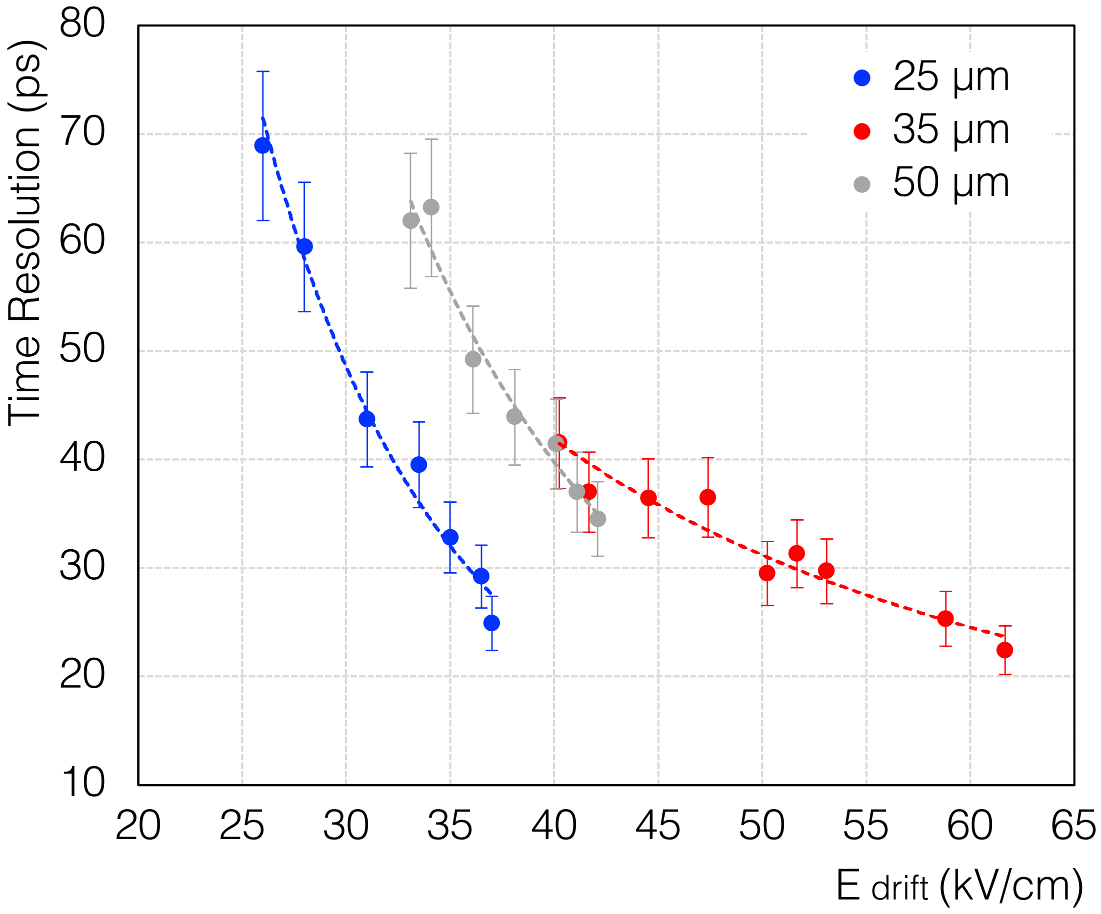




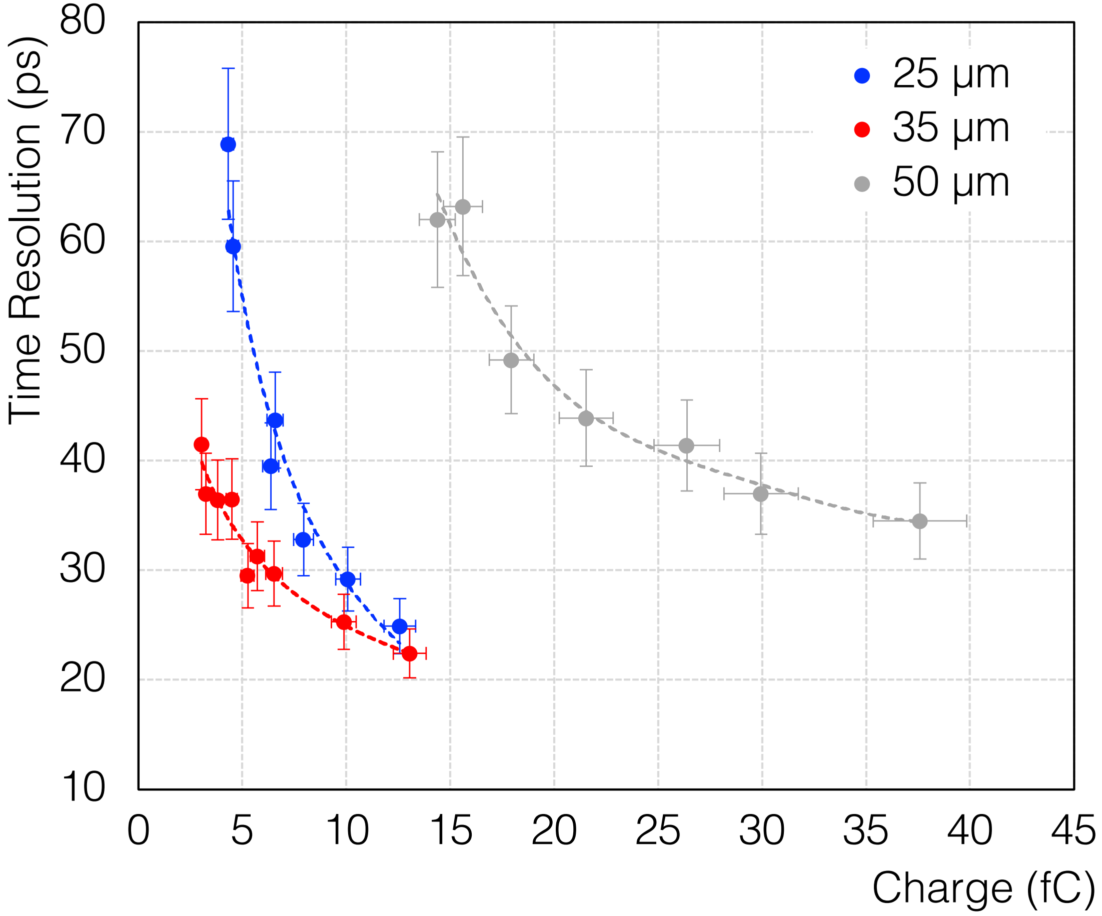


TIMING PERFORMANCES

DRIFT ELECTRIC FIELD



CHARGE

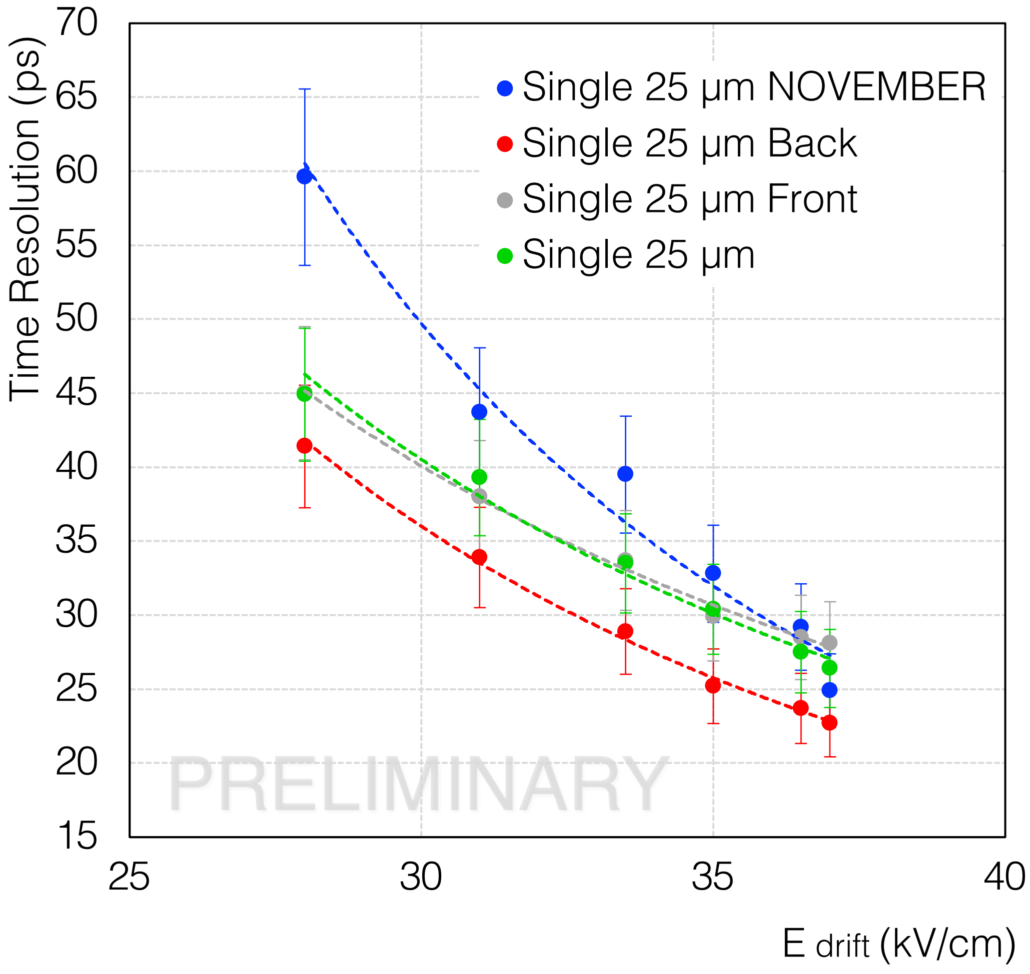


*E_{drift} → Electric field inside the silicon bulk (drift region)

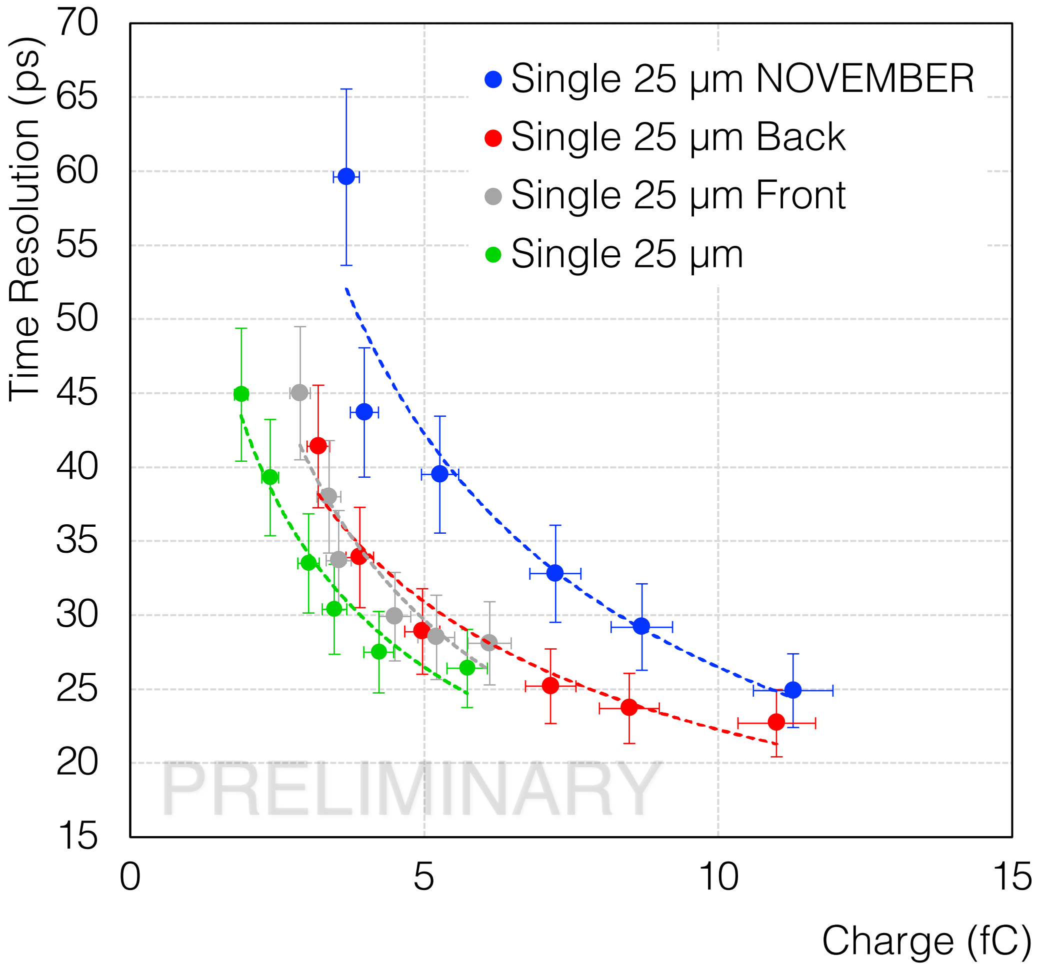
→ extracted from the data considering V and Thickness (*Weightfield simulation for the 25 µm*)

TIMING PERFORMANCE: 25 µm LGAD

ELECTRIC FIELD

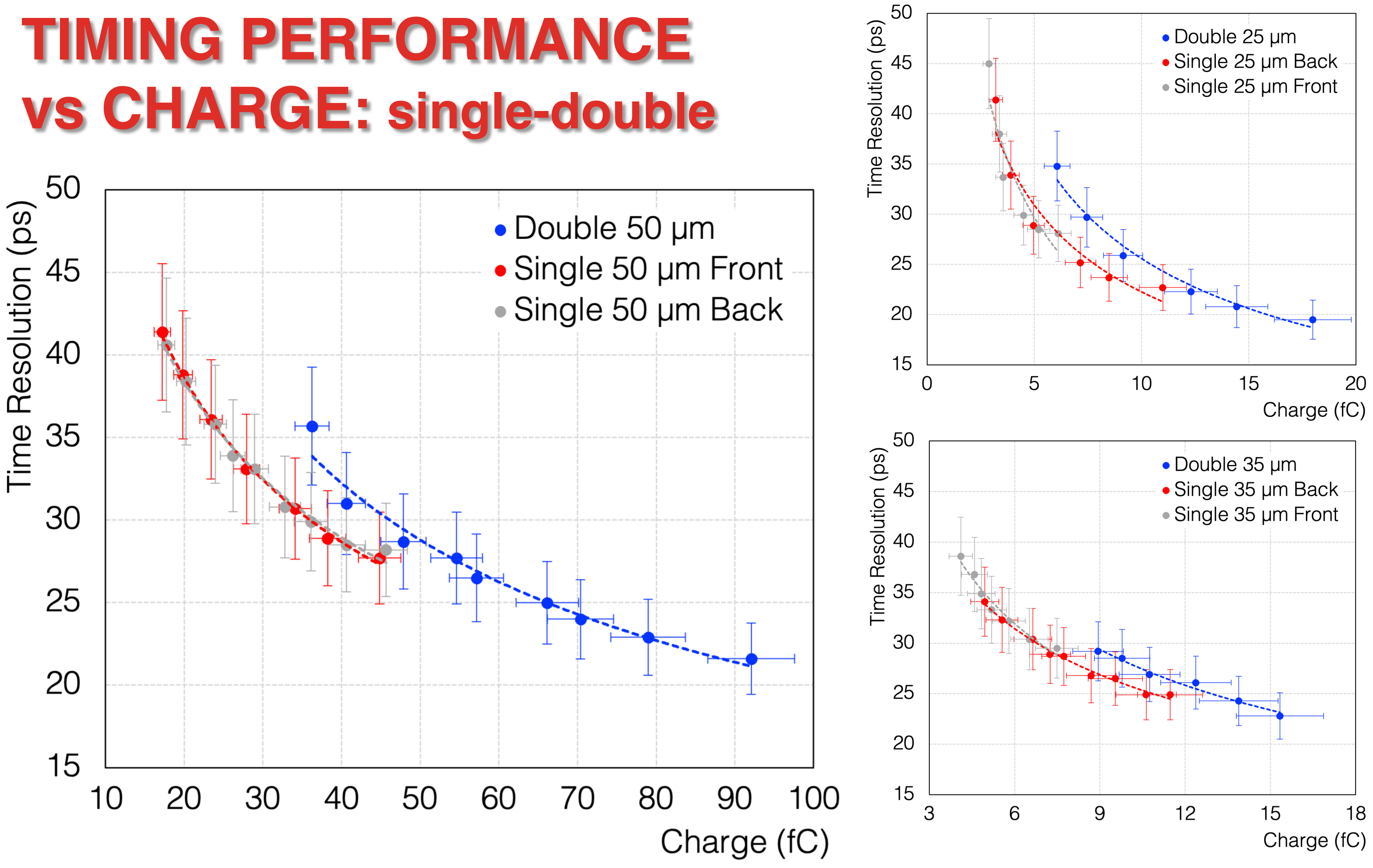


CHARGE



*E_{drift} extracted from the data considering V and Thickness

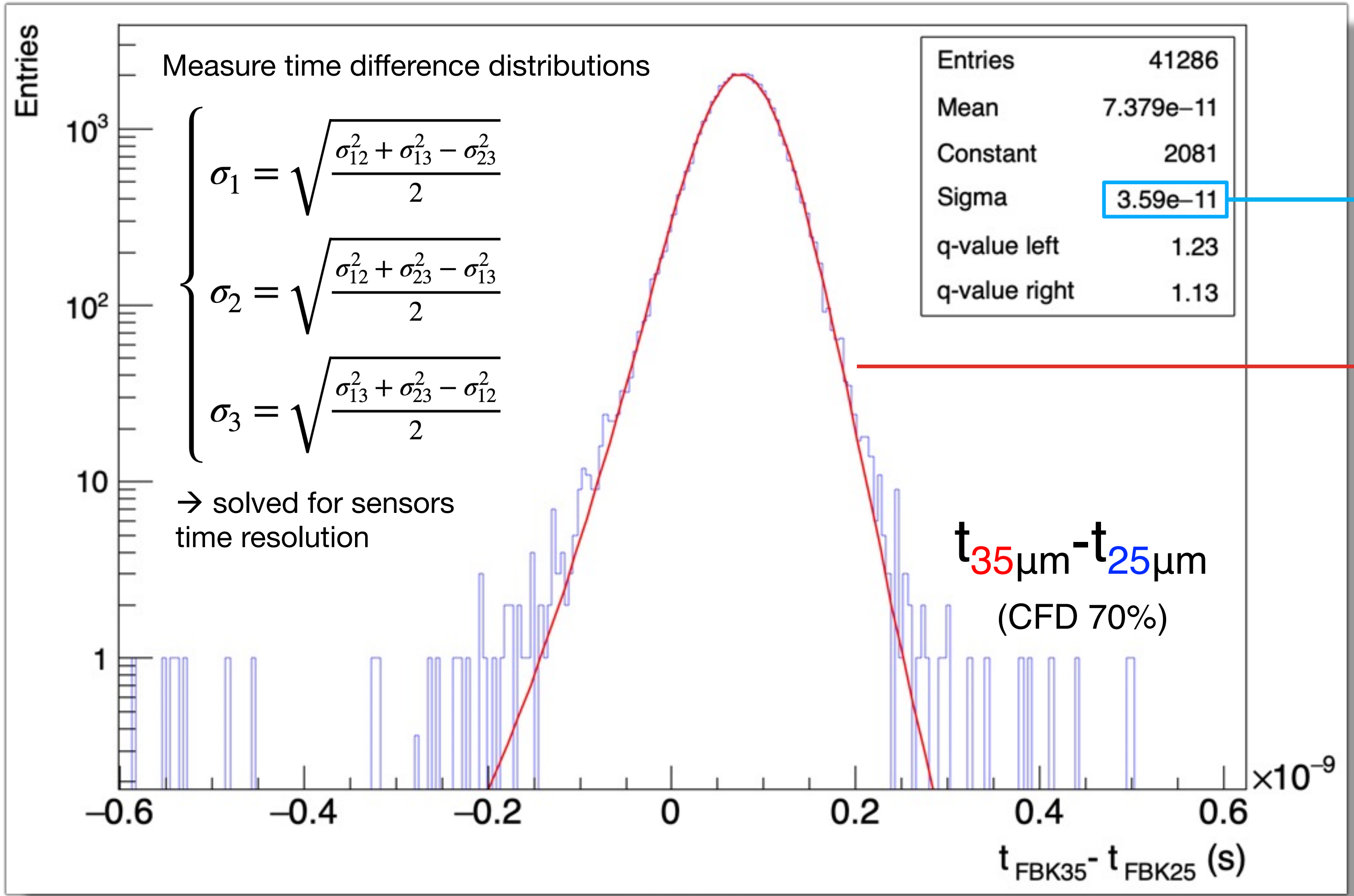
TIMING PERFORMANCE vs CHARGE: single-double



DATA ANALYSIS

DATA ANALYSIS FOR THE TIMING PERFORMANCE

Constant fraction discrimination (CFD) technique



$$\sigma_1 = \sqrt{\frac{\sigma_{12}^2 + \sigma_{13}^2 - \sigma_{23}^2}{2}}$$

$$\sigma_2 = \sqrt{\frac{\sigma_{12}^2 + \sigma_{23}^2 - \sigma_{13}^2}{2}}$$

$$\sigma_3 = \sqrt{\frac{\sigma_{13}^2 + \sigma_{23}^2 - \sigma_{12}^2}{2}}$$

Measurements in full bandwidth (4 GHz) → Smoothing to remove high frequency noise → 1 GHz

Self-trigger from the DUTs:

Difference between the threshold crossing time of each couple

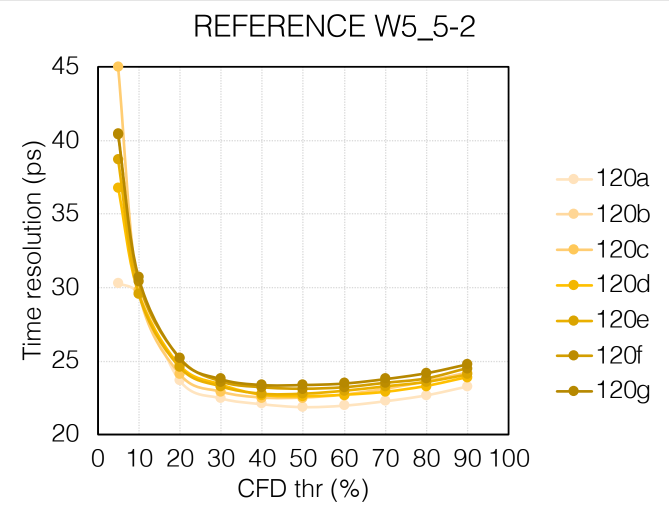
Asymmetric q-Gaussian fit

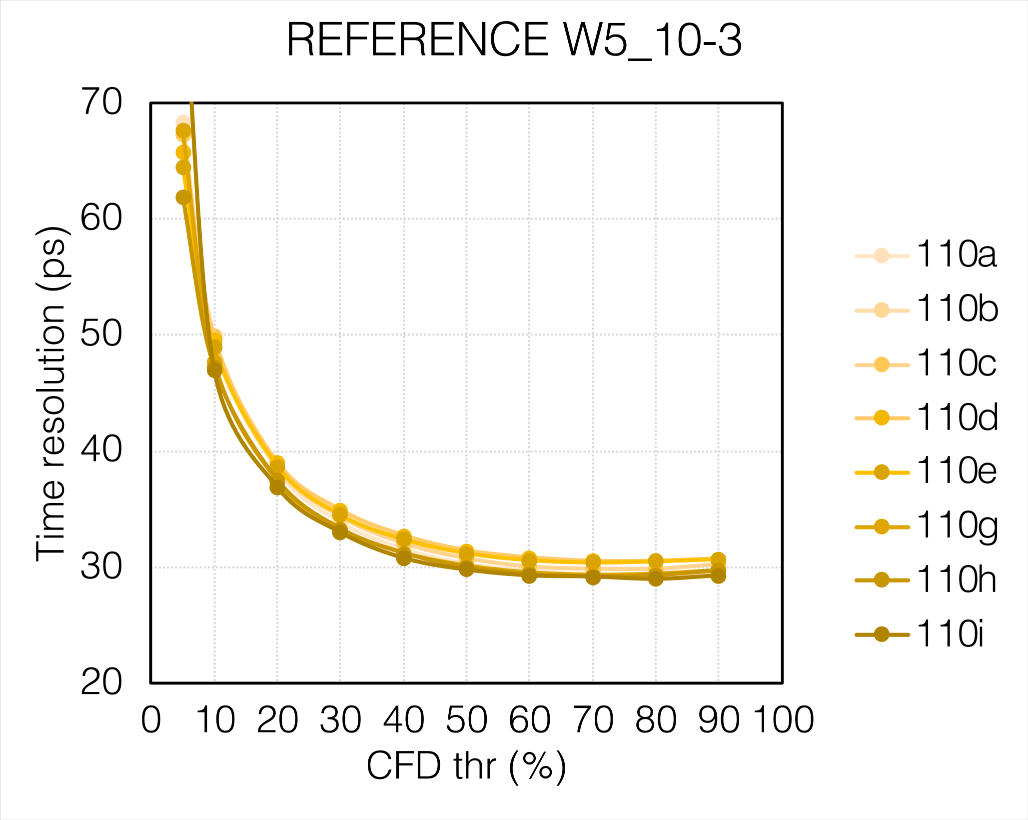
- Gaussian shape of the arrival times
- small tails (2.5% of the measures)

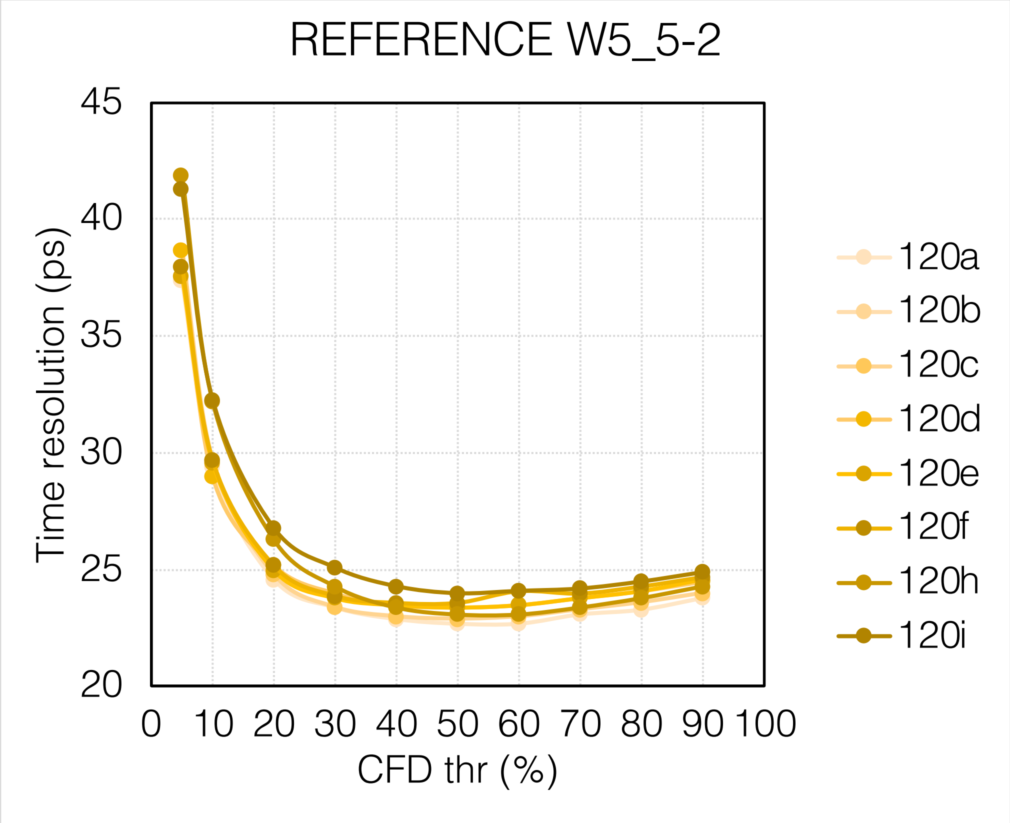
Time resolution extraction

25 µm REFERENCE

→ **Results compatible with the July beam test**

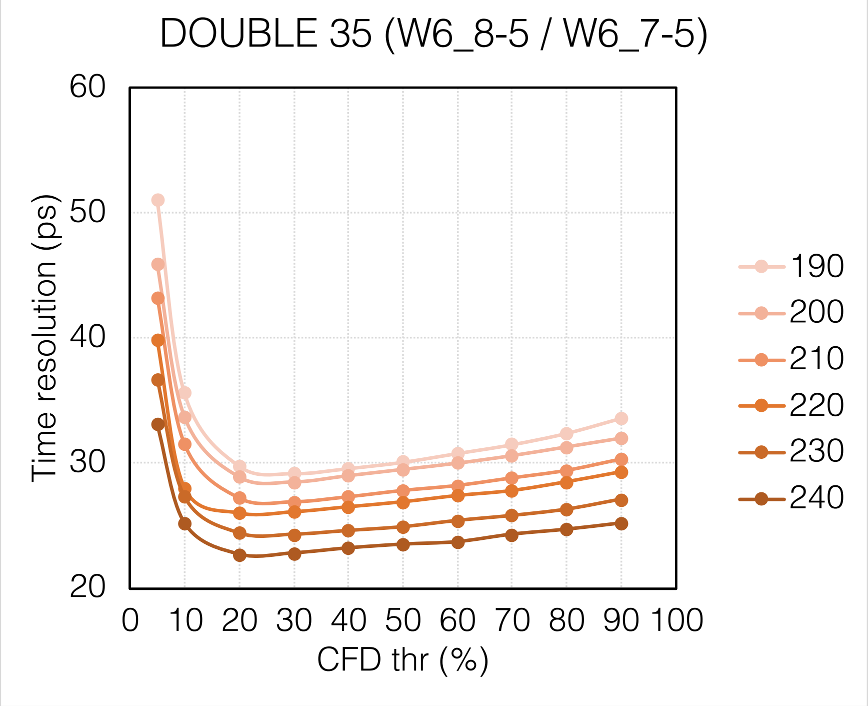


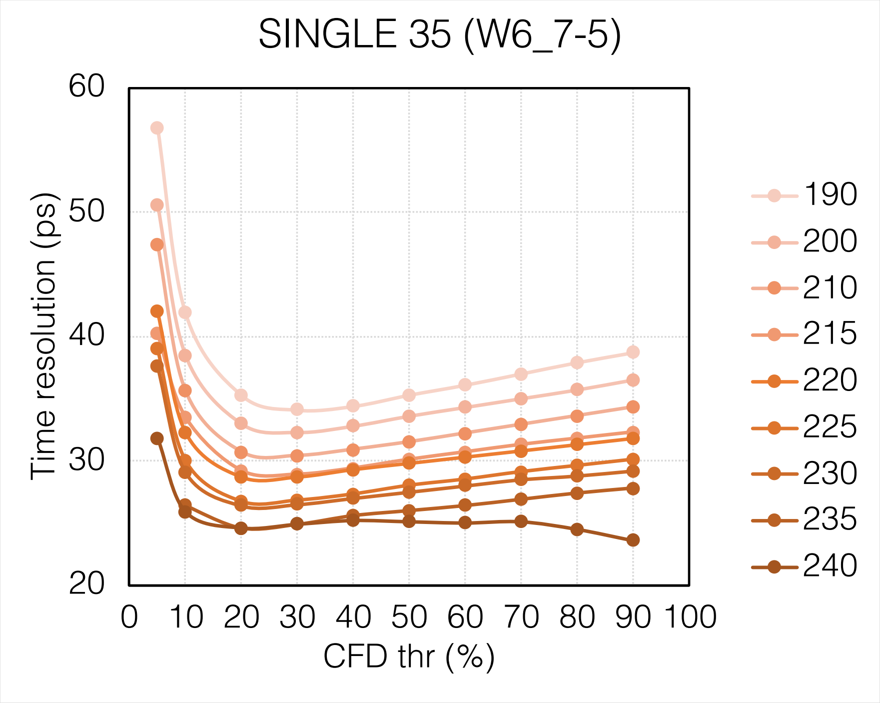


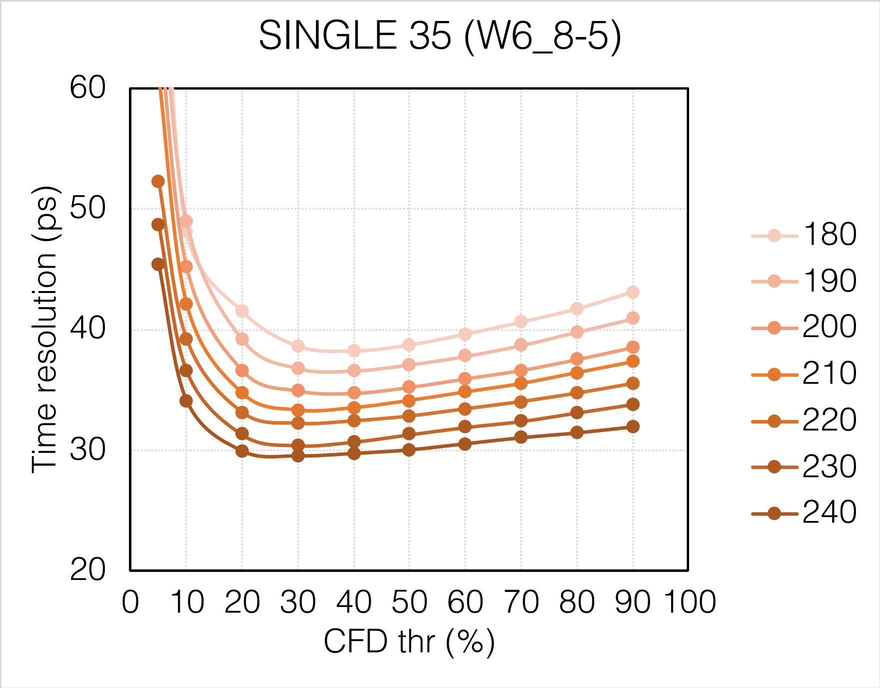


TIME RESOLUTION VS CFD FOR DIFFERENT VOLTAGES

35 µm W6

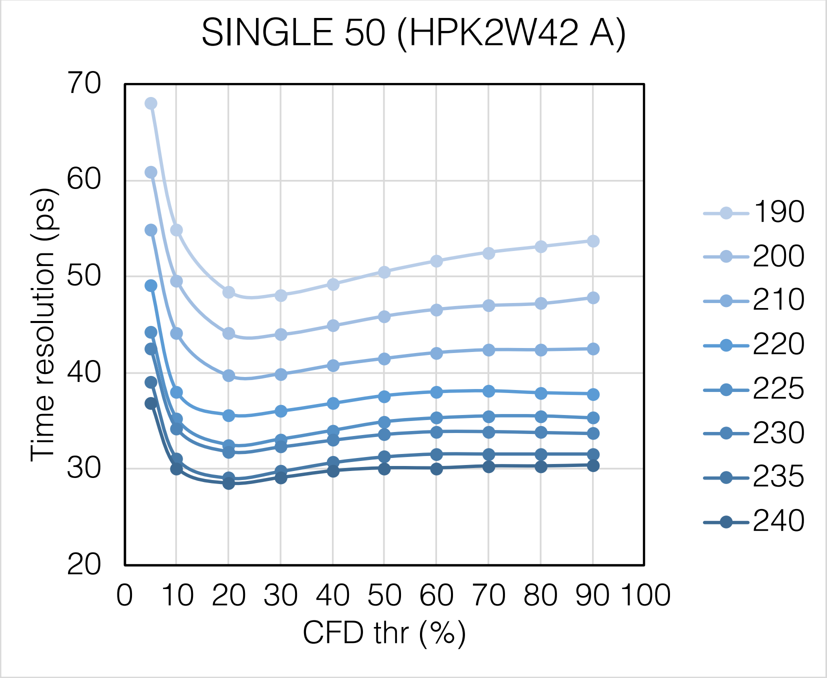


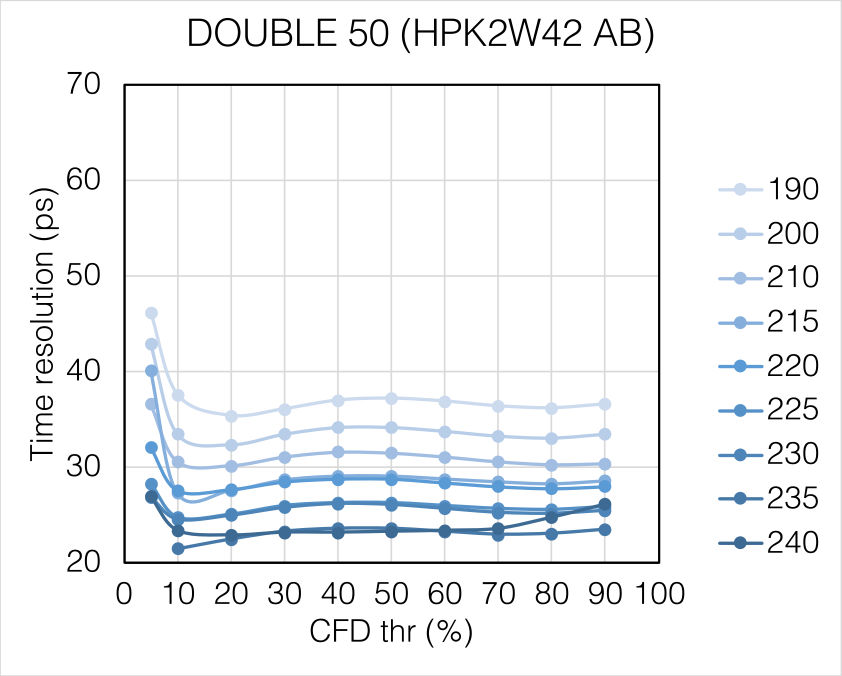


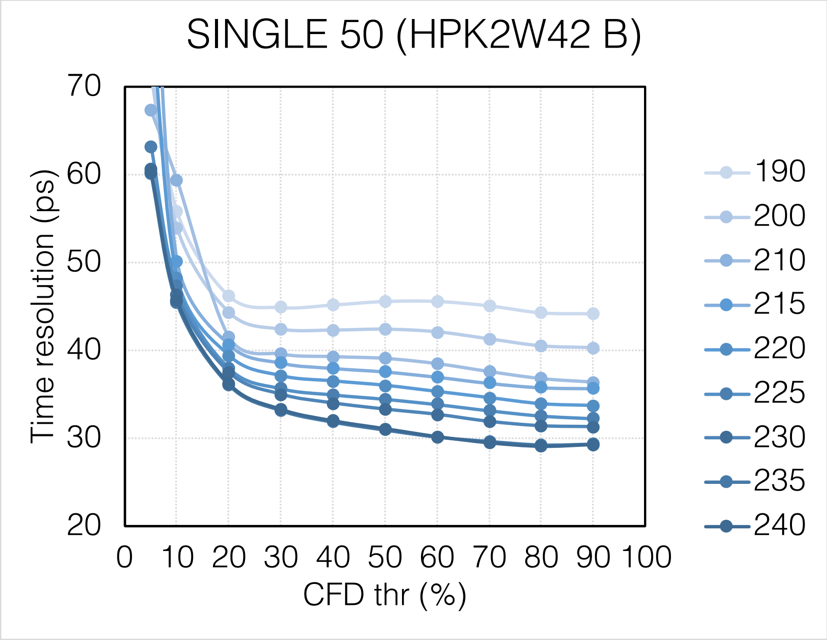


TIME RESOLUTION VS CFD FOR DIFFERENT VOLTAGES

50 µm W42

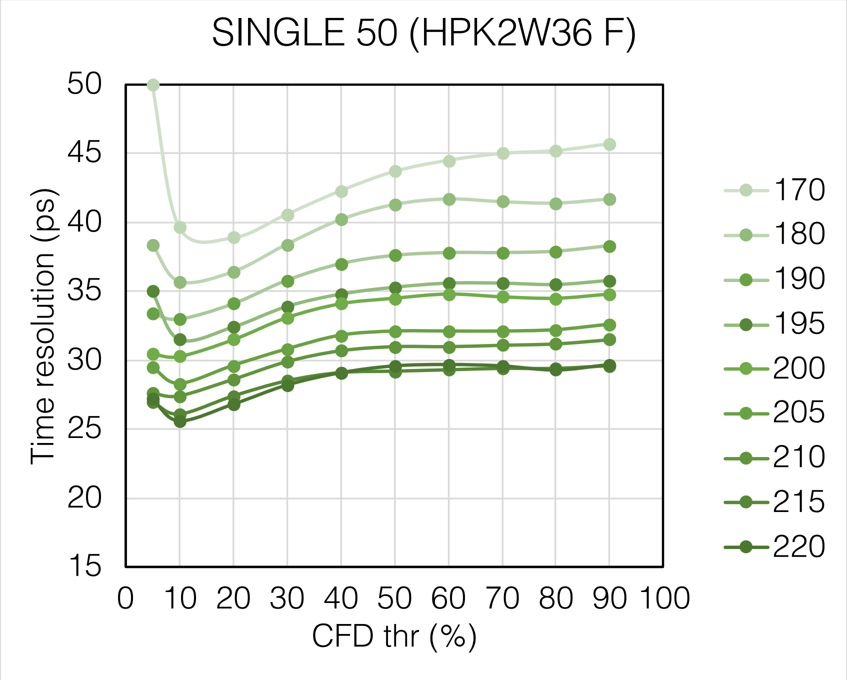


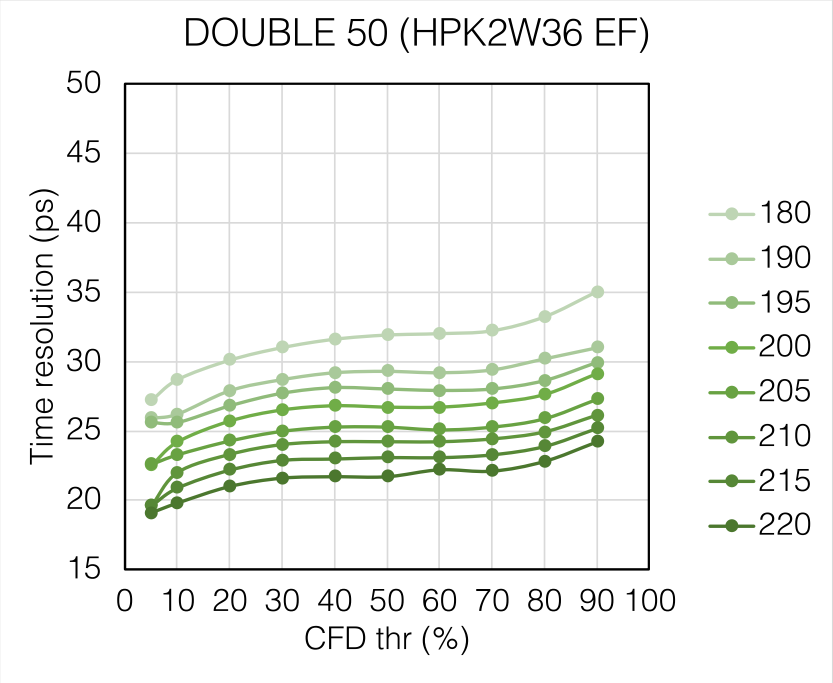


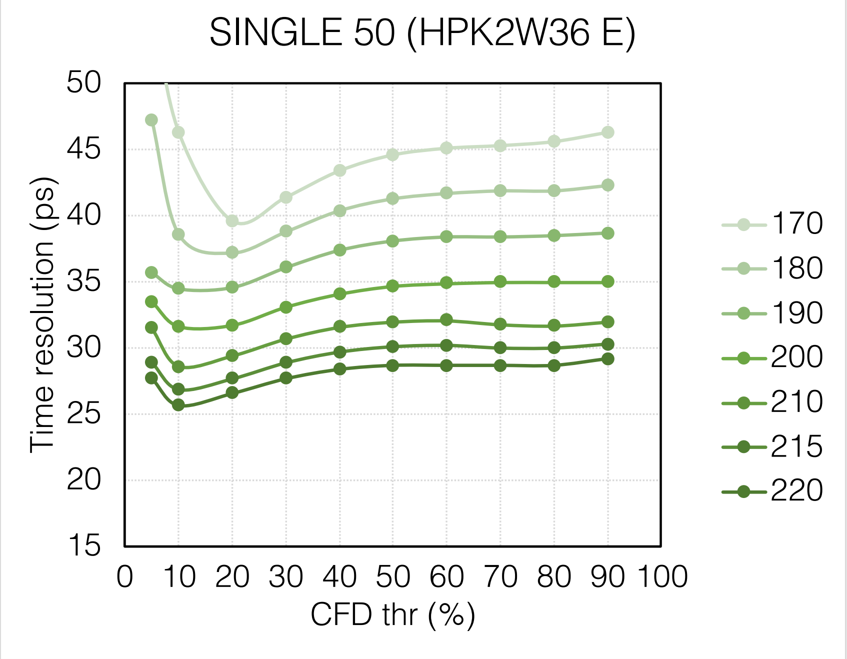


TIME RESOLUTION VS CFD FOR DIFFERENT VOLTAGES

50 µm W36



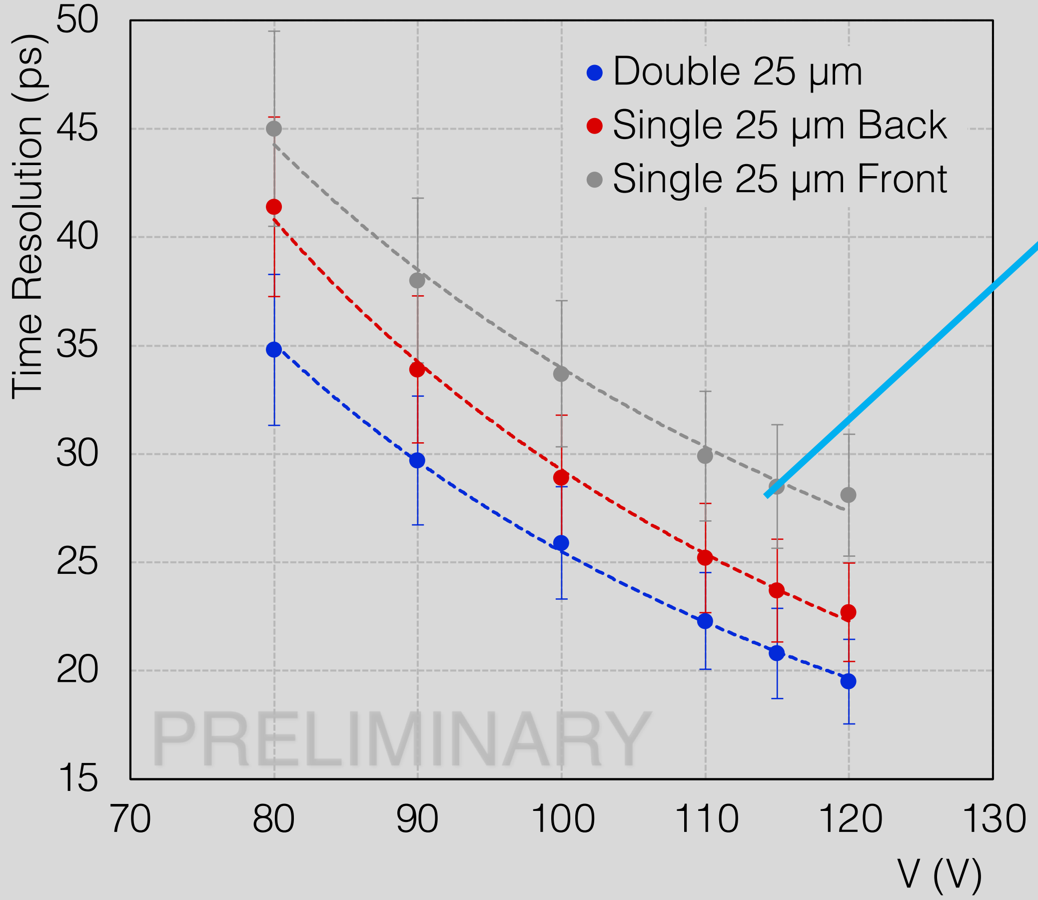




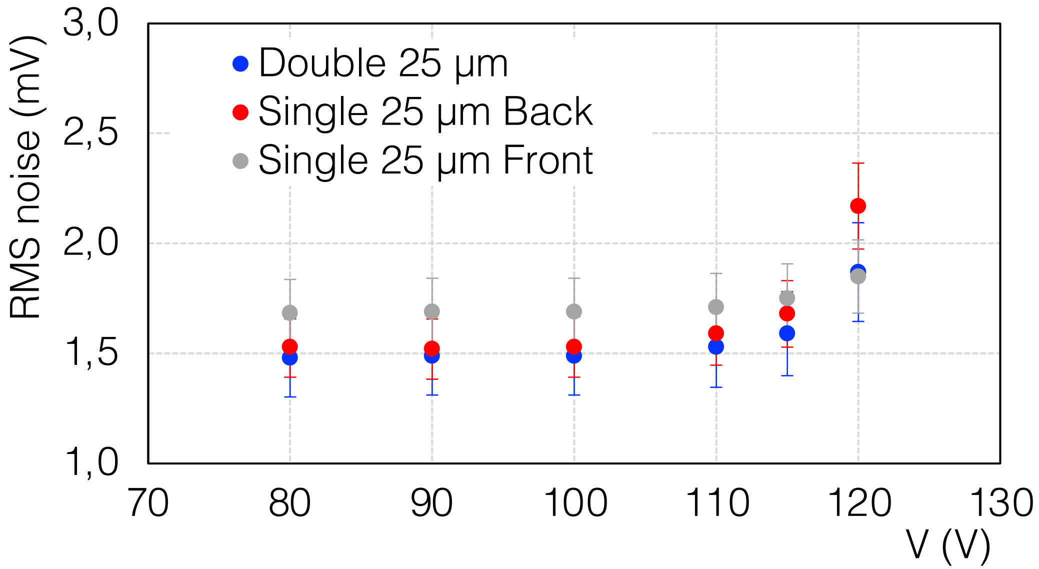
NOISE AND S/N RATIO

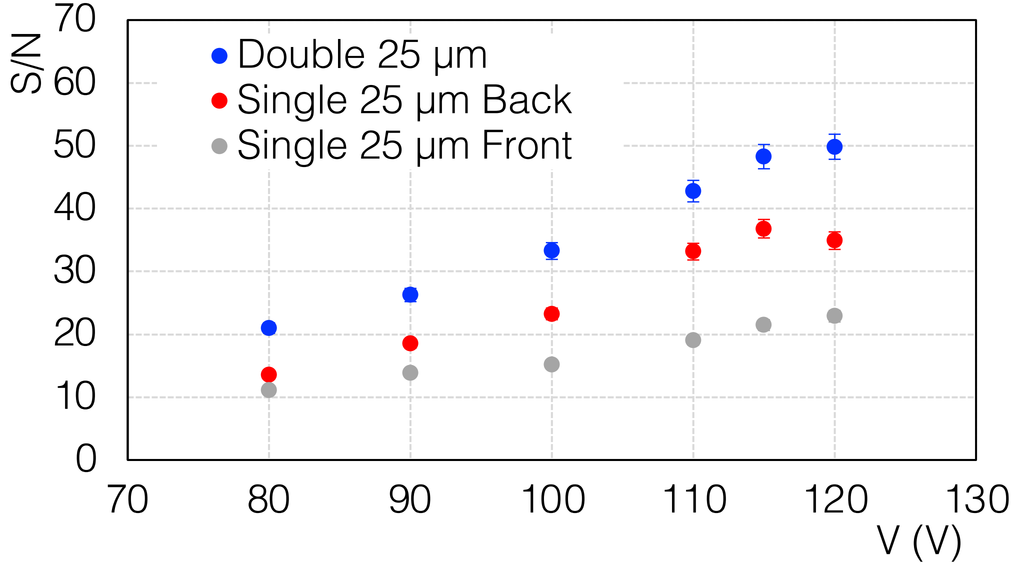
TIMING PERFORMANCE: S

VOLTAGE



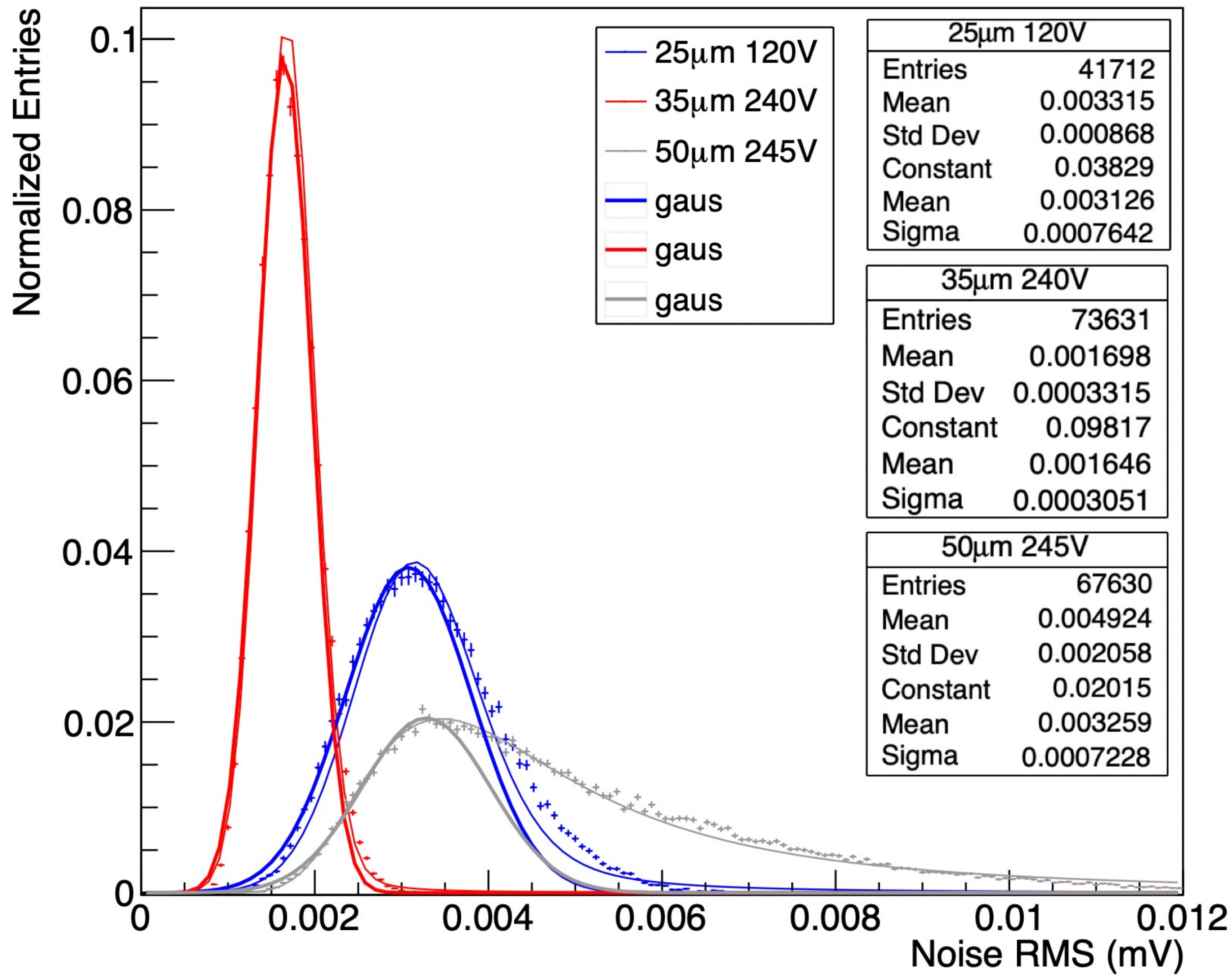
Noise RMS & S/N





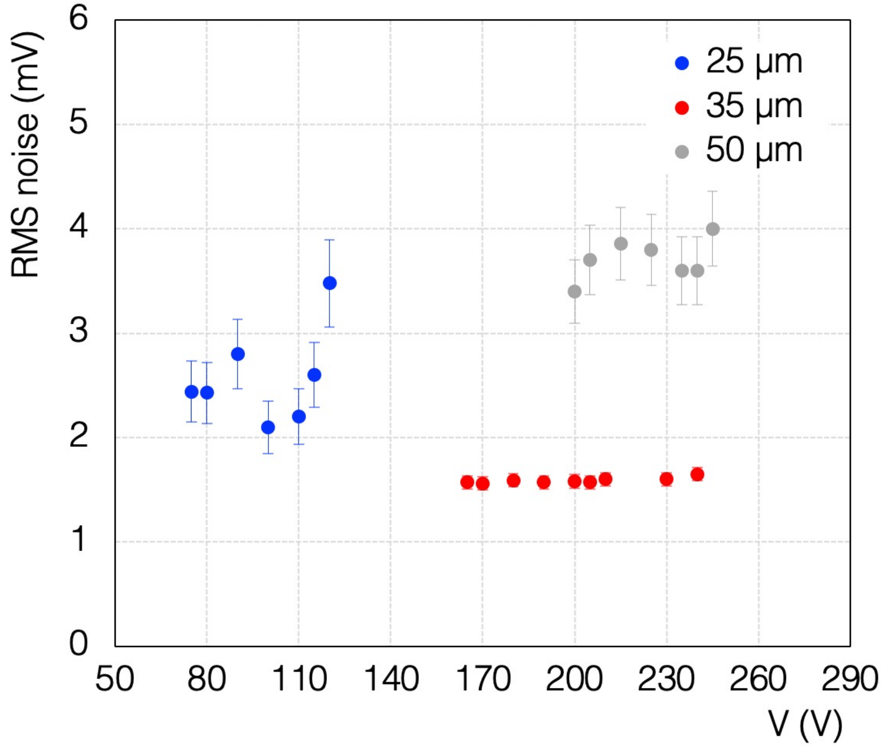
- **Same trend**
- The ‘**double** LGAD’ shows a **slightly better ti**

NOISE RMS



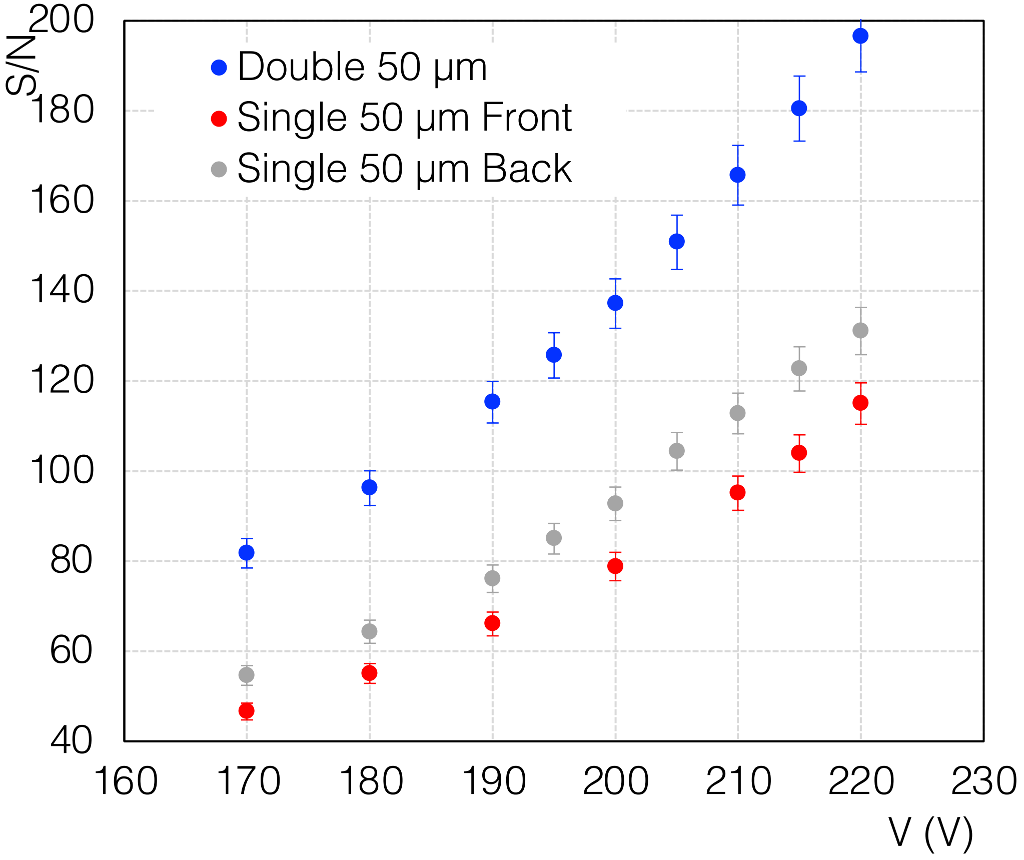
Extracted considering a time window before the signals

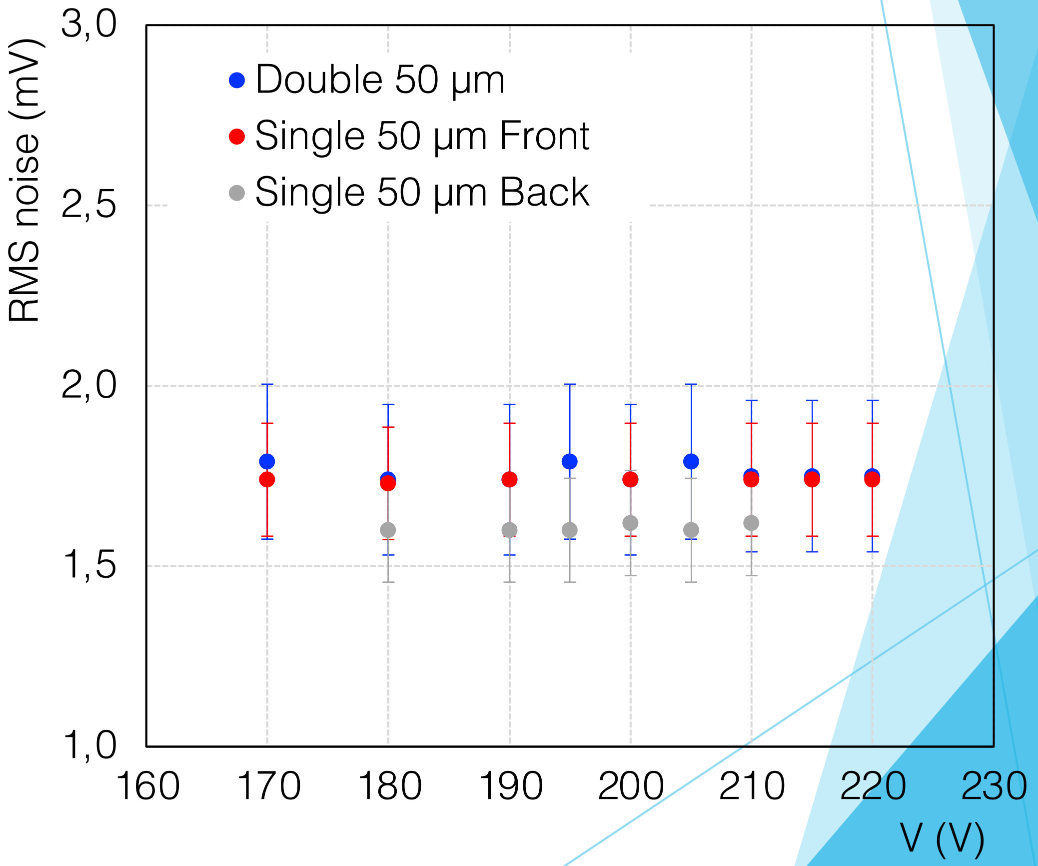
- More Gaussian distribution for the thinner sensors
- Lower for the 35 µm LGAD
- Stable MPV between 1-4 mV



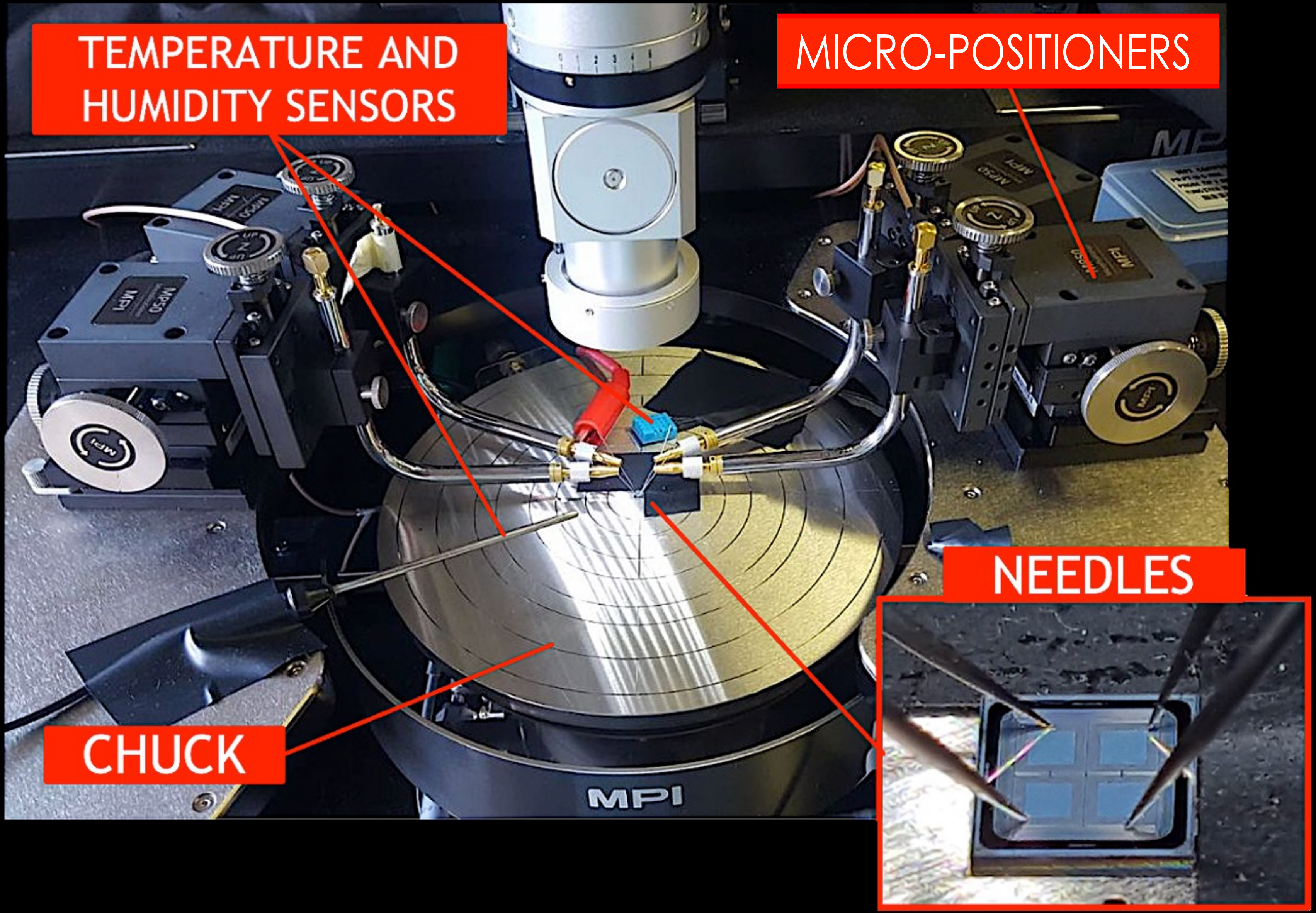
RMS BACKGROUND & S/N RATIO

50 µm
W36





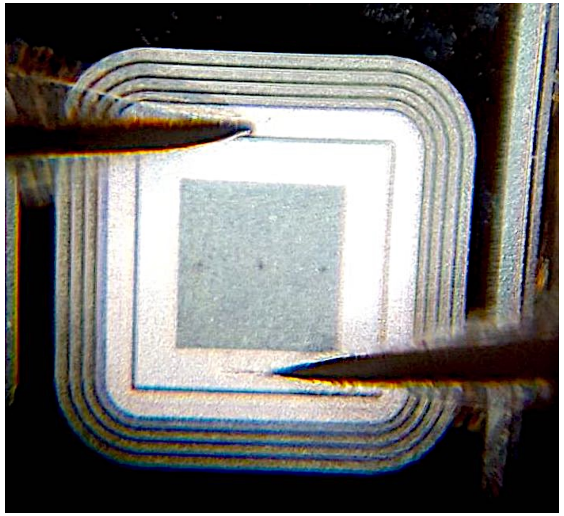
CHARACTERIZATION

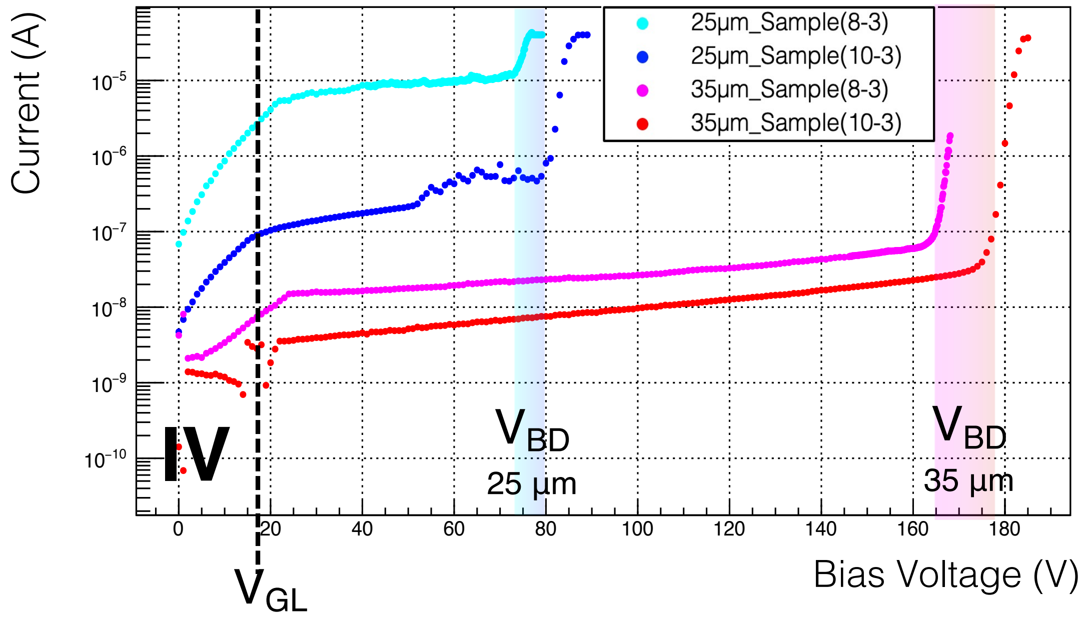


IV

ELECTRICAL CHARACTERIZATION

CV

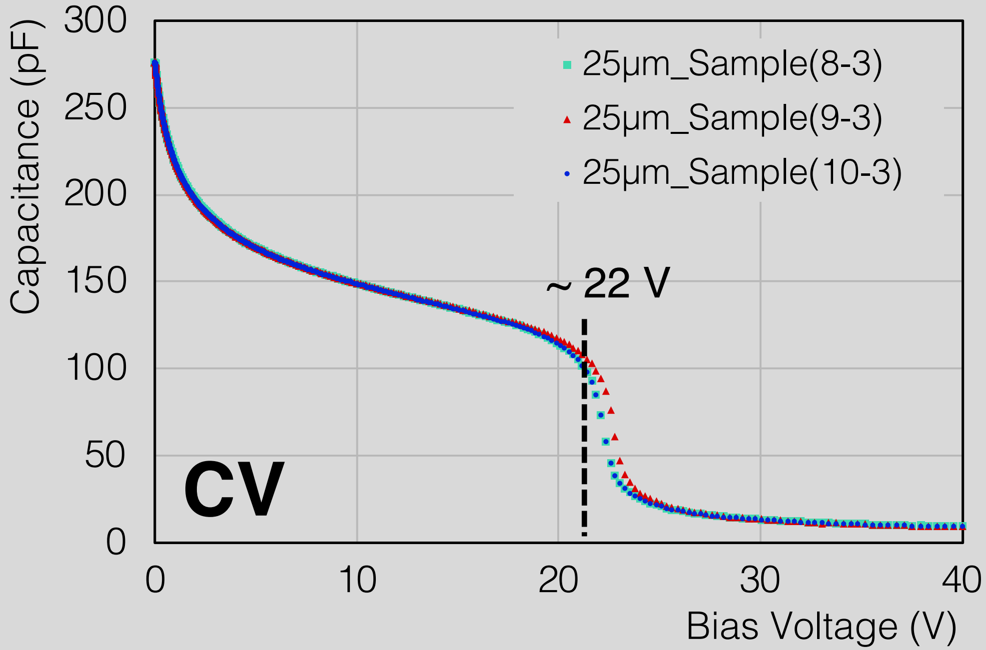




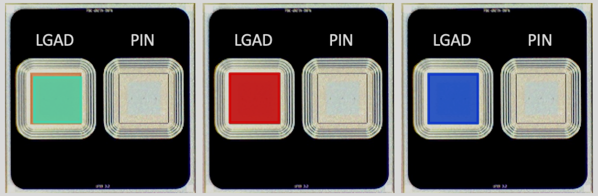
IV

- Breakdown V
- Voltage interval of operation
- Layout of the LGADs

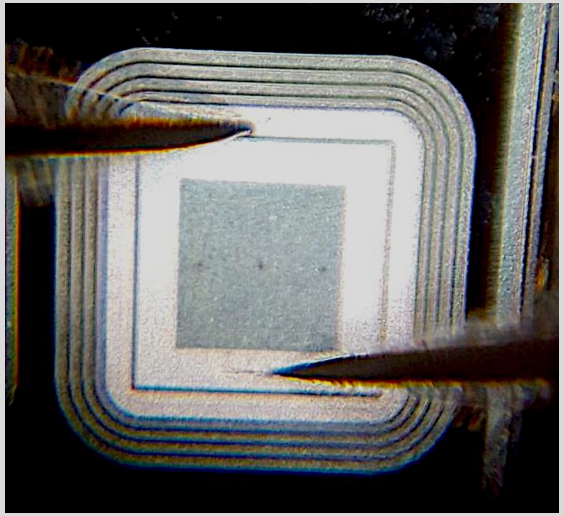
CV

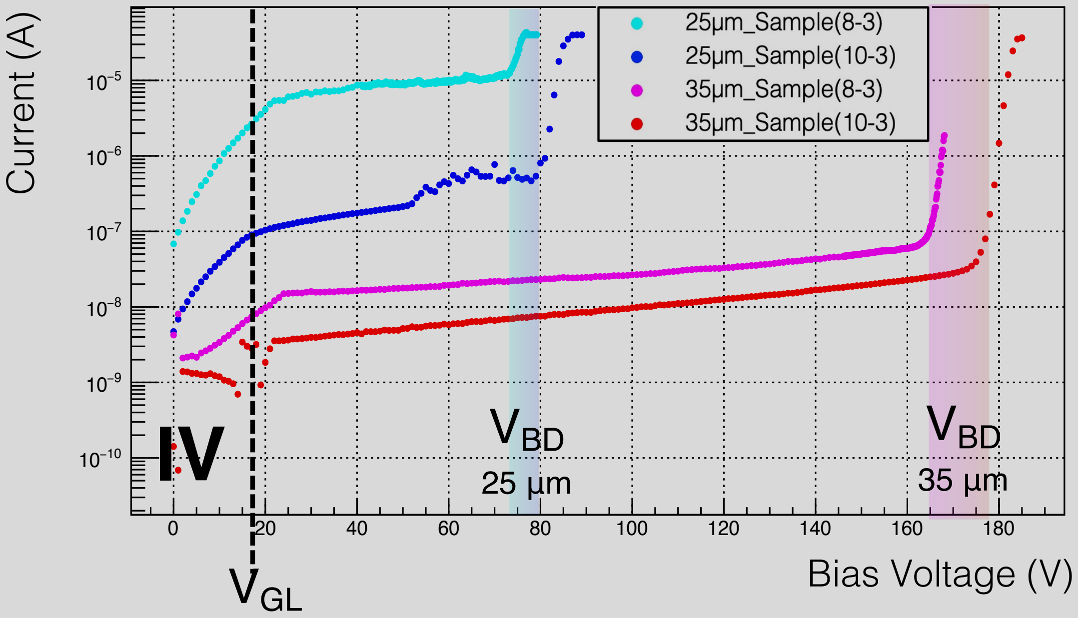


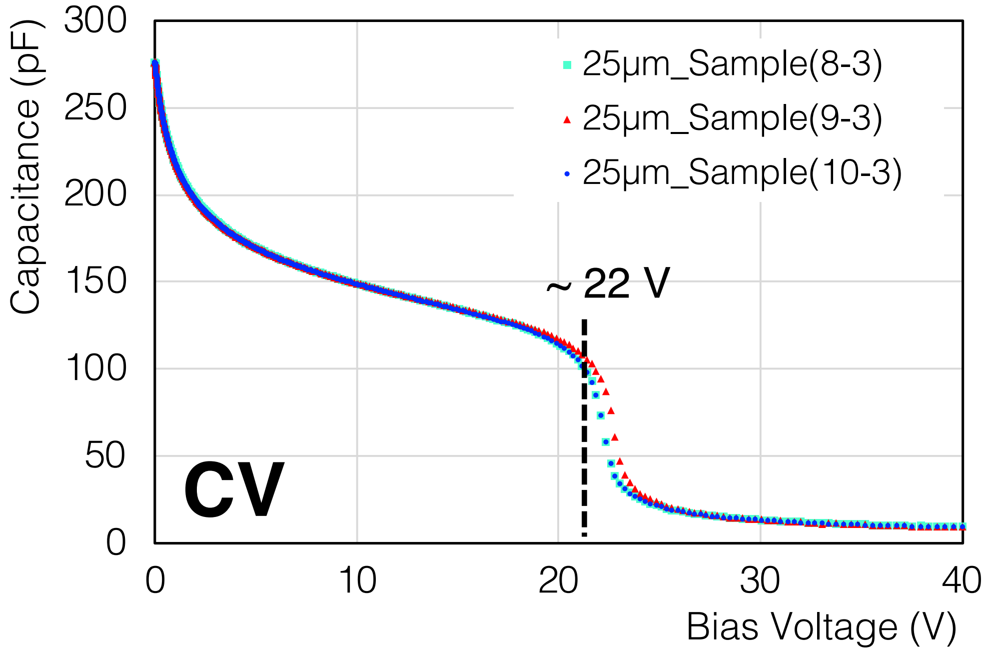
Sensors with the same wafer (25 µm)



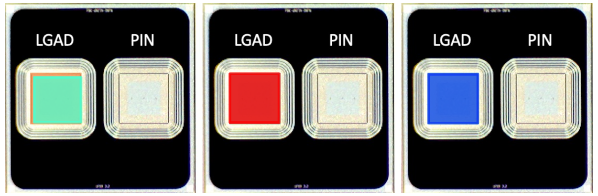
IV







Sensors with the same wafer (25 µm)



CV

- Gain layer depletion V
- Full depletion V
- Connected to the doping profile

ALICE 3 EXPERIMENT

TOF SPECIFICATIONS

	Inner TOF	Outer TOF	Forward TOF
Radius (m)	0.19	0.85	0.15–1.5
z range (m)	–0.62–0.62	–2.79–2.79	4.05
Surface (m^2)	1.5	30	14
Granularity (mm^2)	1×1	5×5	1×1 to 5×5
Hit rate (kHz/cm^2)	74	4	122
NIEL (1 MeV n_{eq}/cm^2) / month	$1.3 \cdot 10^{11}$	$6.2 \cdot 10^{9}$	$2.1 \cdot 10^{11}$
TID (rad) / month	$4 \cdot 10^{3}$	$2 \cdot 10^{2}$	$6.6 \cdot 10^{3}$
Material budget ($\%X_0$)	1–3	1–3	1–3
Power density (mW/cm^2)	50	50	50
Time resolution (ps)	20	20	20