Measurements of LGAD segmented devices

Emanuele Cavallaro – Ivan Lopez
Jörn Lange – Sebastian Grinstein

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Outline

Brief introduction on **LGAD technology**

Some words on **LGAD segmented devices**

TCT measurements on **strips devices**
- Setup description
- Results

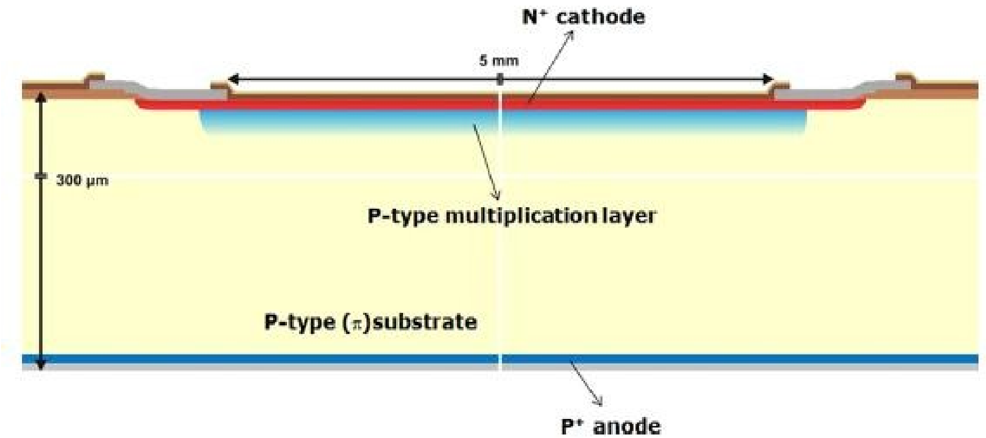
Measurements on **pixels devices**
- Setup description
- **FEI3** results
- **FEI4** results

Summary

Introduction

Low Gain Avalanche Detector concept:

- n-on-$p \rightarrow n^{+}$- p^{+}- p^{-}- p^{+}
- High electric field volume at the n^{+}- p^{+} junction
  - Avalanche region
- Gain ~10
  - Linearity preserved w/ primary charge



Advantages of LGAD devices as HEP detectors:

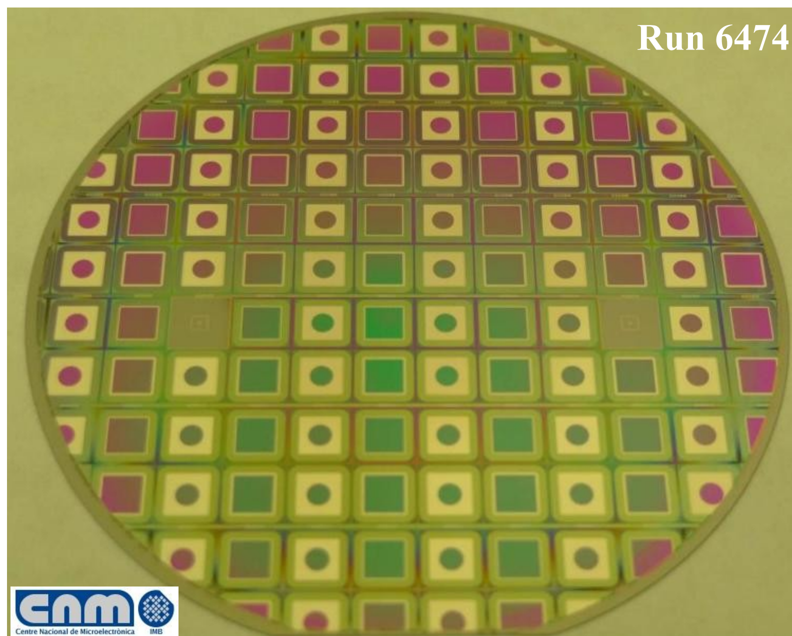
- Improved signal to noise ratio
  - Compensating radiation worsening effect
- Lower bias voltage required
- Opportunity to build thinner detectors with same charge collection
  - Reduced material budget & timing devices

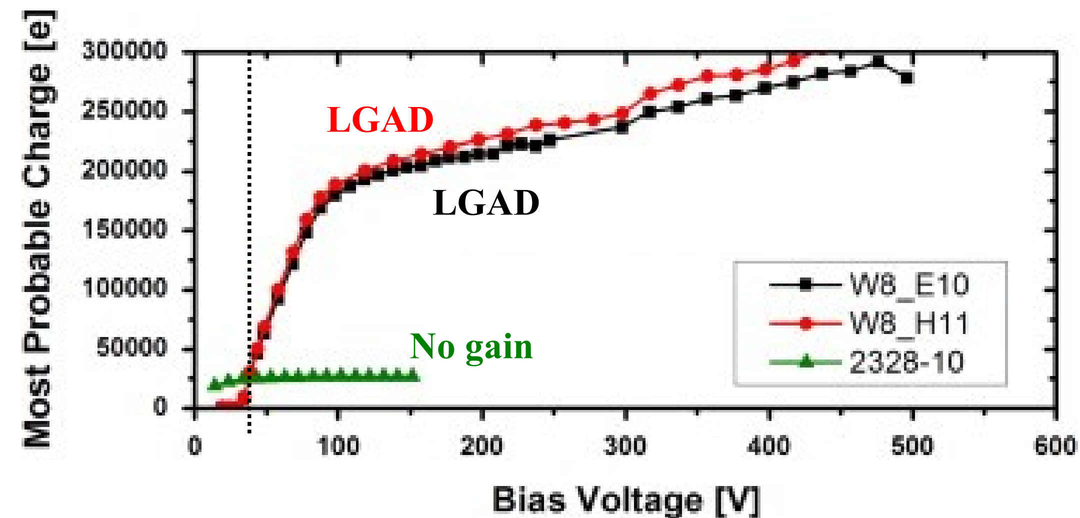
Details on the LGAD technology on Pablo Fernandez' talk

Diodes LGAD production

The Centro Nacional de Microelectrónica in Barcelona (**CNM**) is developing LGAD technology and producing LGAD devices

A production run of pure diodes successfully showed the **charge multiplication** (CM) effect even **at low voltages**





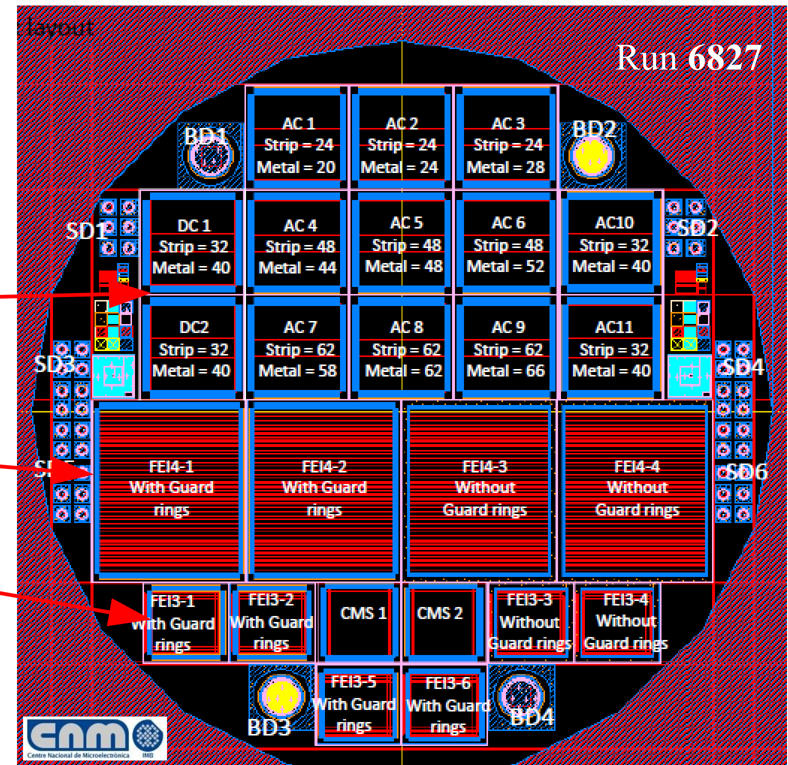
G. Pellegrini, et al., Nucl Instrum Meth A (2014)

The multiplication effect strongly depends on the electric field profile on the multiplication region
Next step is to test this technology on segmented devices

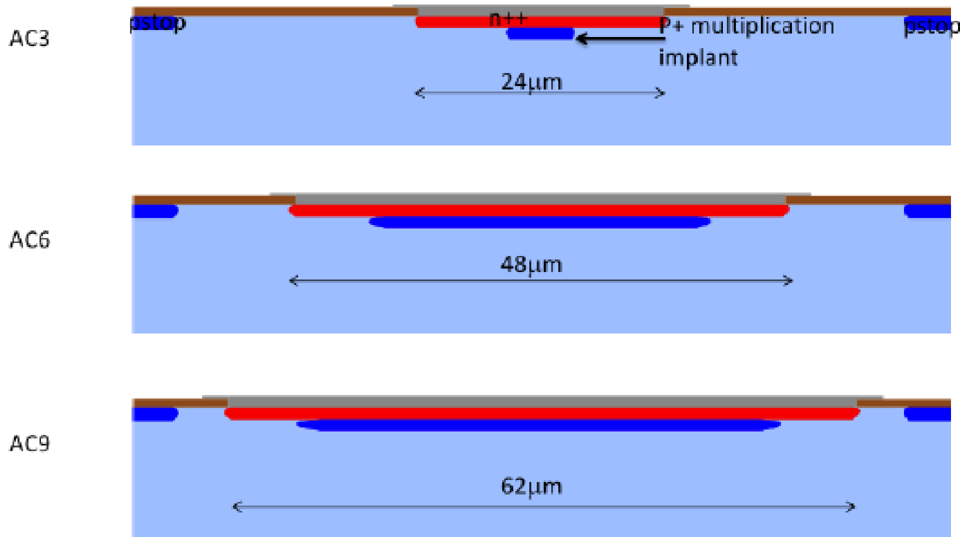
Segmented LGAD devices

A run of segmented devices has been produced by CNM
It includes:

- Strips of different sizes
  - Both AC and DC coupled
- FEI4 pixels devices
- FEI3 pixels devices
- Others pixels devices
- Big and small diodes



Different strips layout w/ 80 μm pitch:



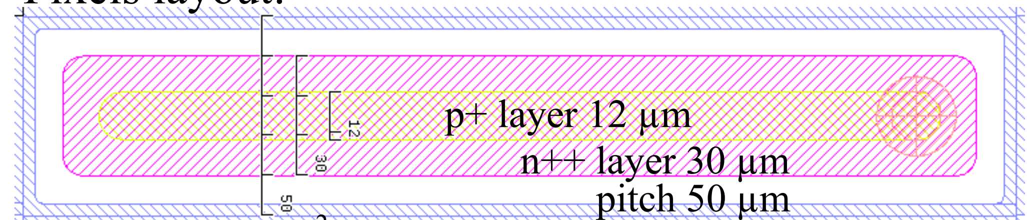
Marta Baselga 23rd RD50 workshop

Float zone 285μm thick w/ different n^+ implantation:

Shallow	**wafer 12**
Standard	wafer 13
Deep	**wafer 14**

Deeper → less CM → higher $V_{breakdown}$

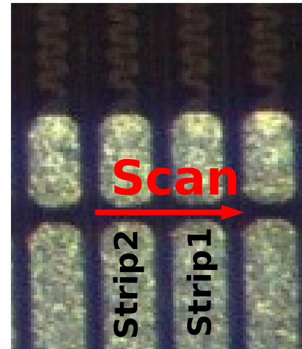
Pixels layout:

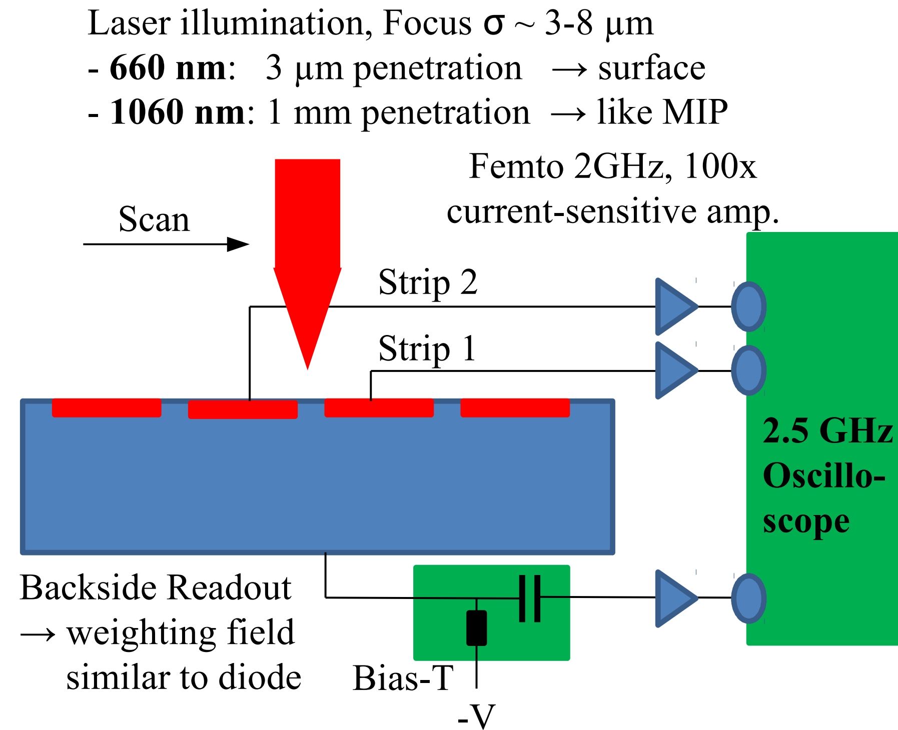


FEI3: 50 x 400 μm^2
FEI4: 50 x 250 μm^2

TCT measurements on strips

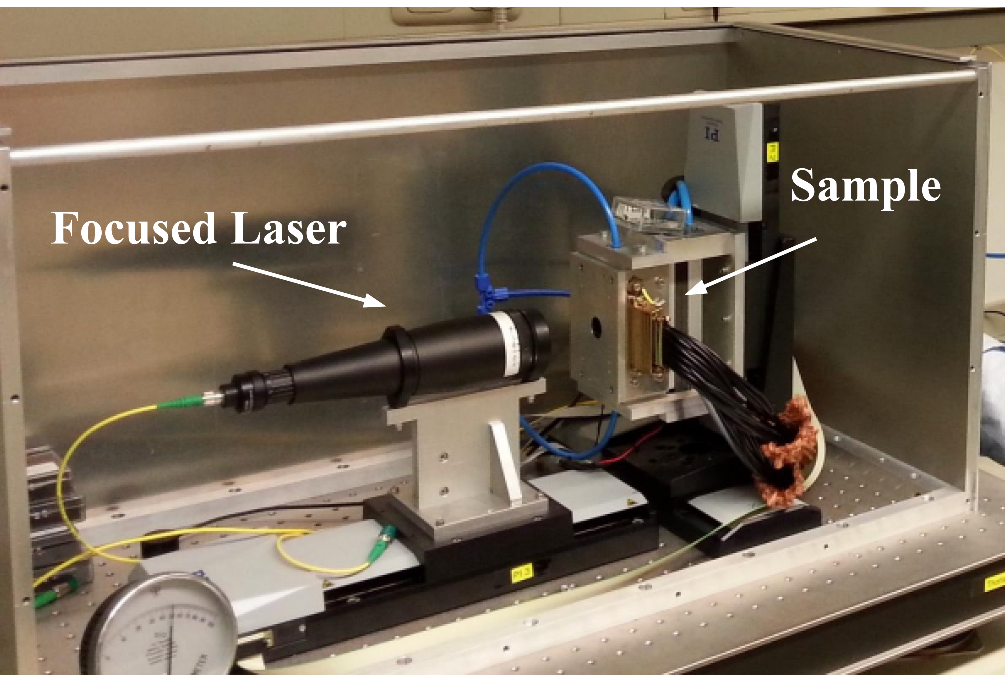
Goal:
- Verify CM by comparing LGAD with reference w/o CM
- Study uniformity with surface scan





TCT setup in Hamburg

Thanks a lot to UHH colleagues
(M. Centis, P. Buhmann, T. Pöhlsen, C. Scharf)



Measured at room temperature
2-3% charge-injection reproducibility after warm-up

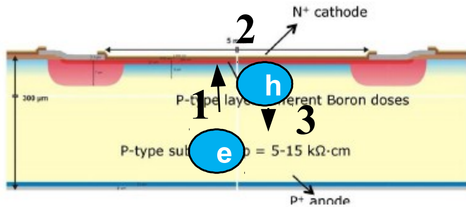
Measured Devices	n⁺ impl. width	CM p⁺ impl. width	Diffus. of N implant	Max. Volt.
6894-W14-AC7 (ref.)	62 µm	44 µm	Deep	300 V
6827-W14-AC7 (LGAD)	62 µm	44 µm	Deep	300 V
6827-W14-AC1 (LGAD)	24 µm	6 µm	Deep	150 V
6827-W14-AC2 (LGAD)	24 µm	6 µm	Deep	600 V
6827-W12-AC11 (LGAD)	32 µm	14 µm	Shallow	200 V

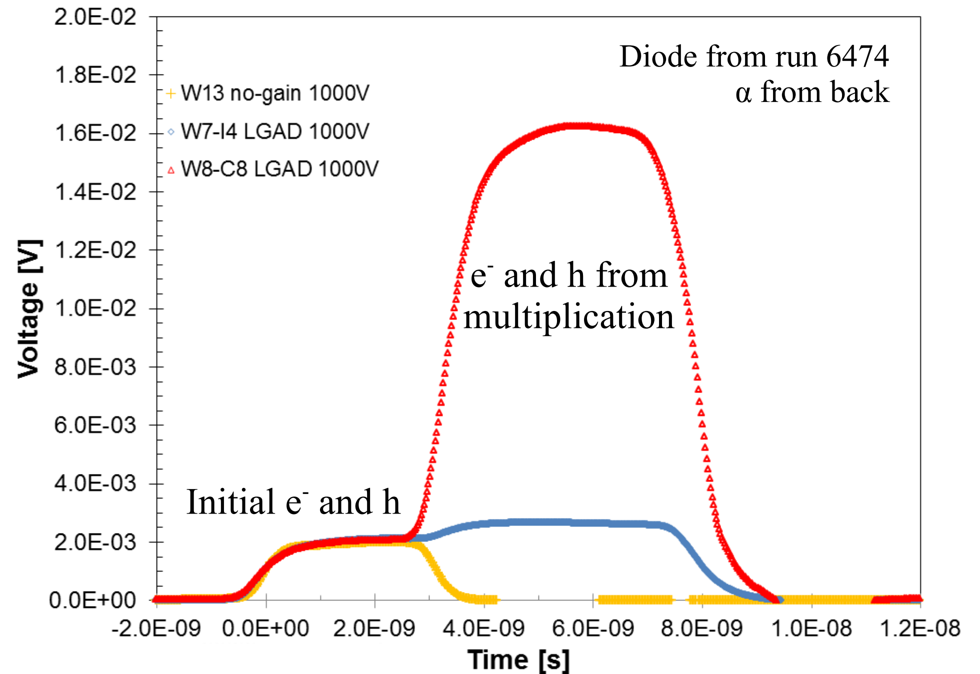
TCT Waveforms (660 nm back illumination)

Powerful tool to study creation of CM in time

0) e-h pairs created at back side, h immediately collected
1) e drift from back to front
2) e multiply in CM region
3) CM h drift back

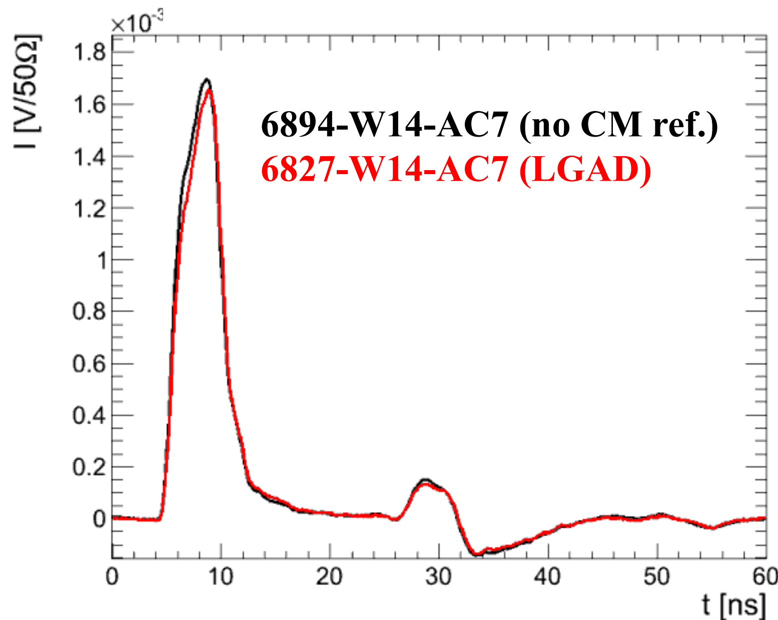
(2 and 3: Only in case of CM)





Hartmut Sadrozinski
23rd RD50 workshop

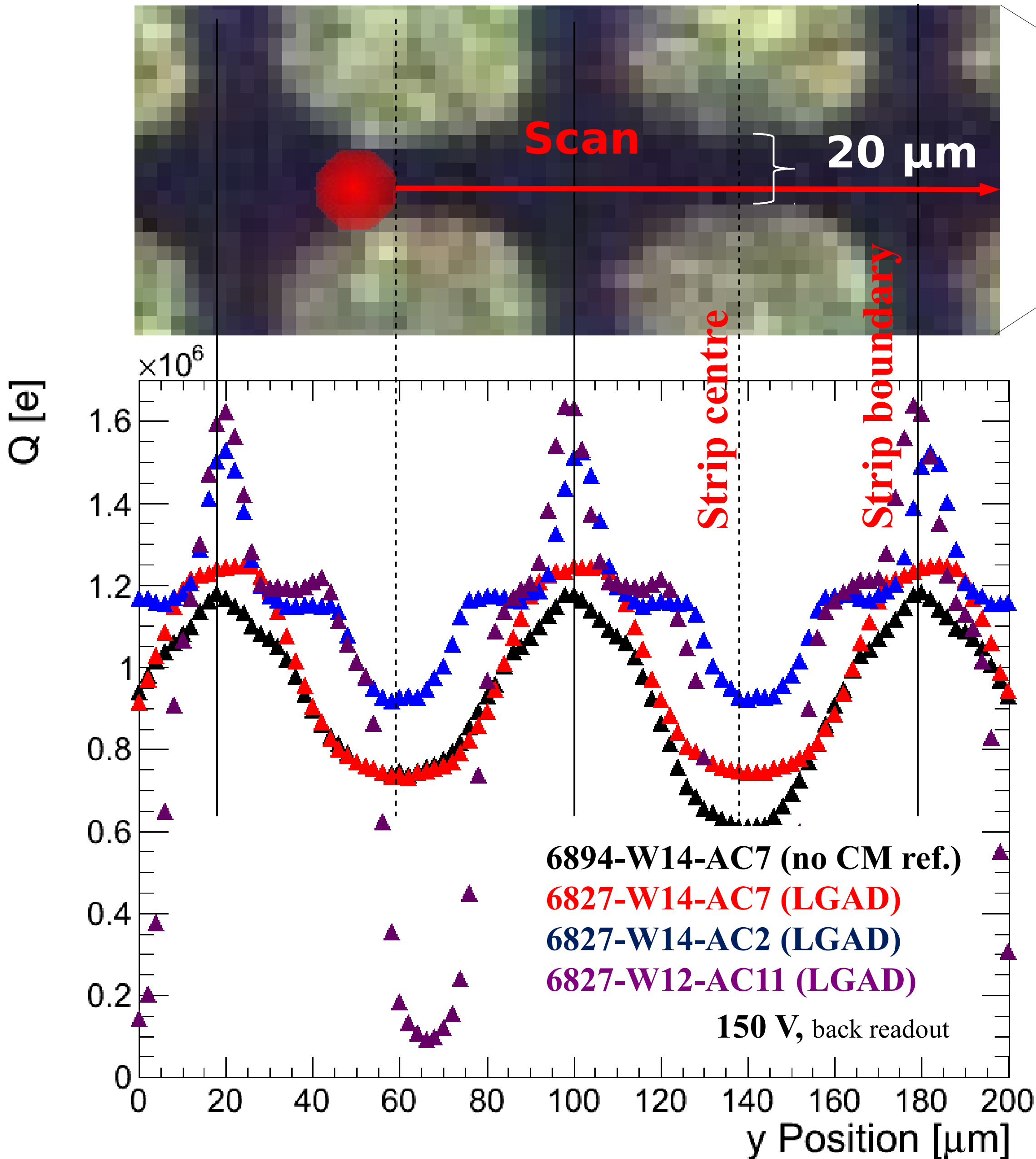
Comparison LGAD and reference
Strip centre, back readout, 300 V



- Signal from e^- drifting to high-field region at front
- No second signal part due to CM holes

No difference between LGAD and no-CM-ref. up to 300 V!

TCT: Charge Across Strips (1060 nm Front)



- Charge from waveform integral (50 ns)
- Scan through 20 μm hole in Al in strip centre
  → lower signal in centre due to residual reflections
- ***6827-W14-AC7 (LGAD)*** and ***6894-W14-AC7 (ref.)*** almost same charge
- ***6827-W14-AC2 (LGAD)*** and ***6827-W12-AC11 (LGAD)*** measured in different month than others
  → laser intensity might vary, better focus (i.e. less reflections)
  → slightly higher charge (~20%) probably due to different laser conditions

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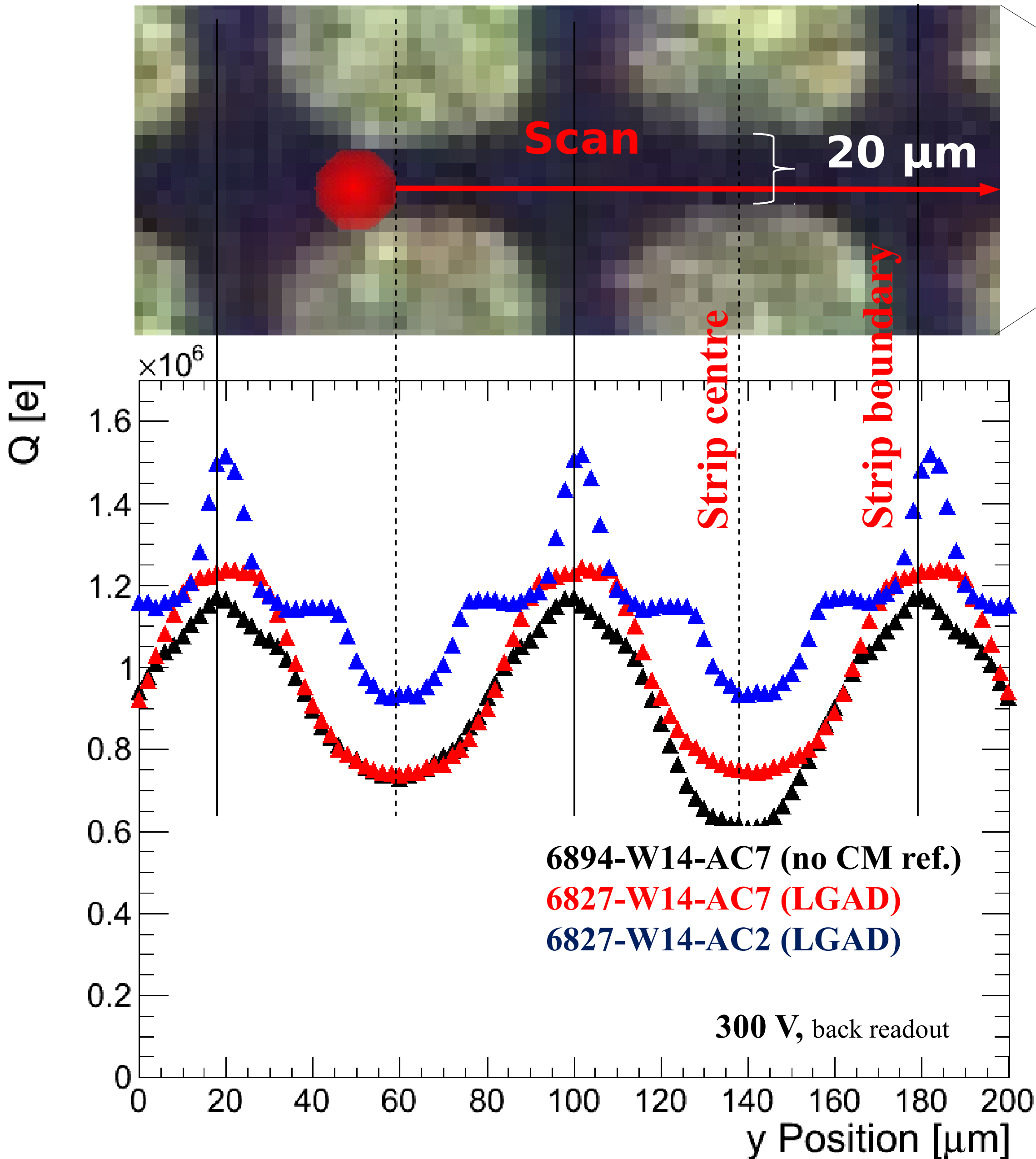

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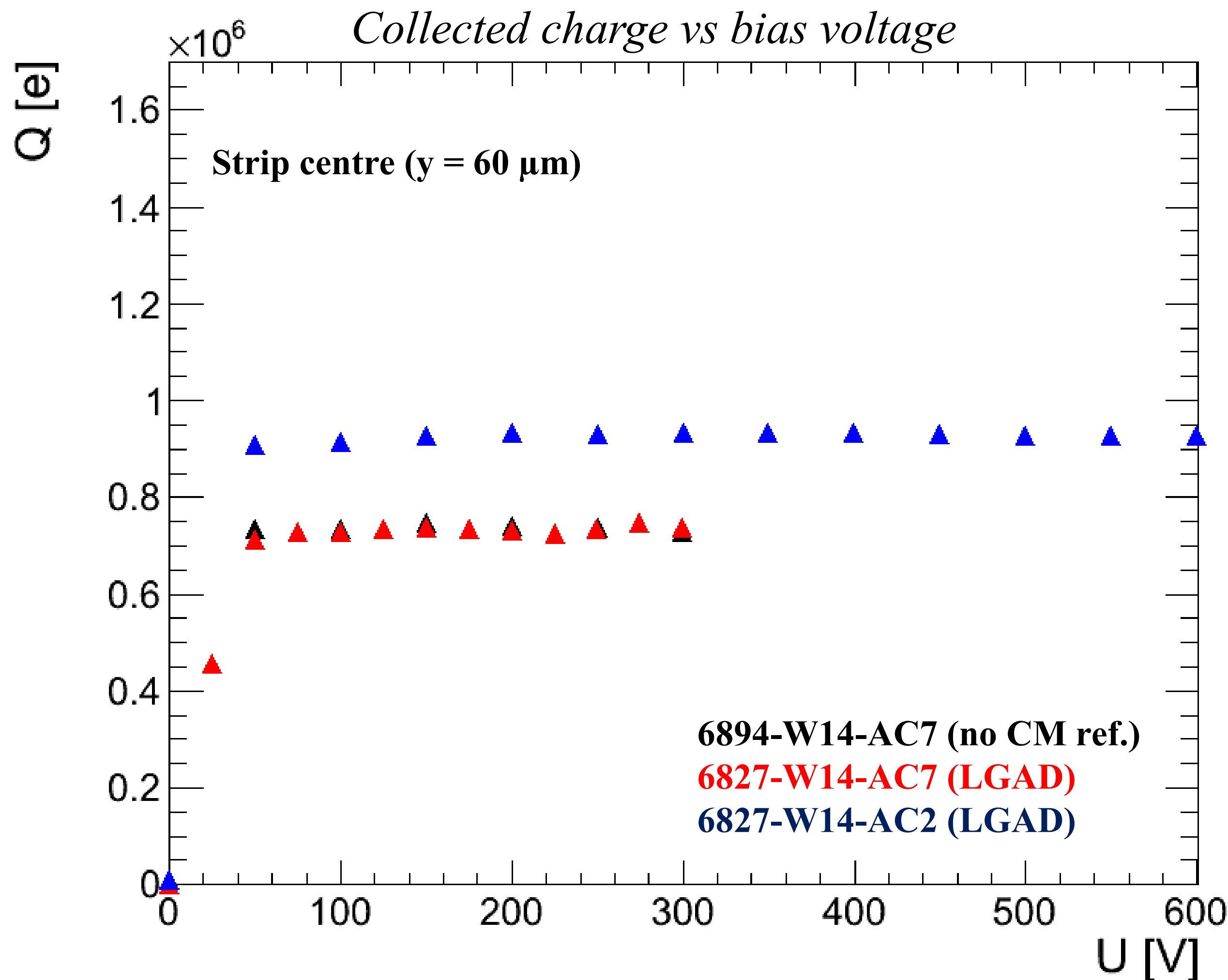
TCT: Charge vs. Voltage (1060 nm front)

No change of charge with voltage above 50 V



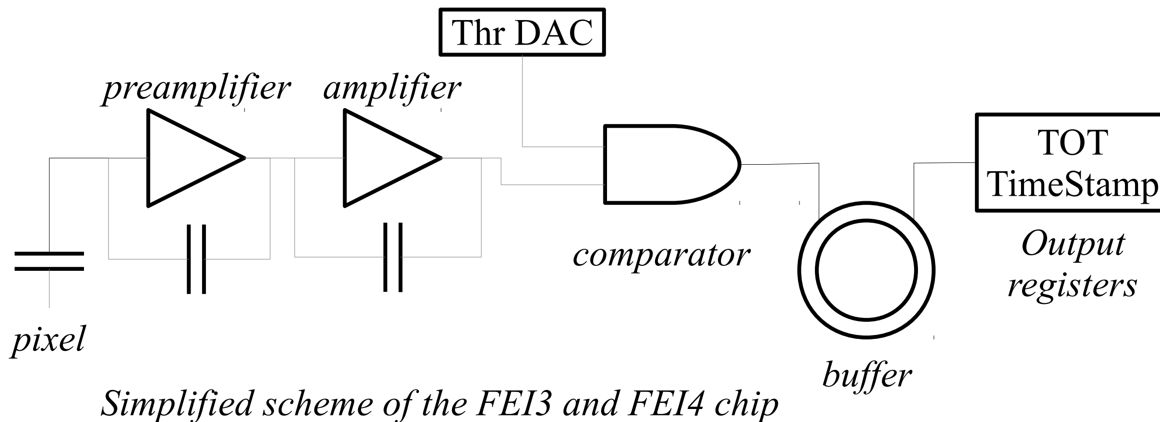
Conclusions for all measured LGAD strips
run 6827 - W12/14

No charge multiplication observed up to 600 V

No CM observed either on W13 strips
Riccardo Mori, Universität Freiburg

Pixel assembly and setup

An FEI3 and an FEI4 from w14 run 6827 tested
FEI3 and FEI4 are front-end chips for pixel devices
Devices bump-bonded and assembled @ IFAE
Collected charge information in Time Over Threshold units



Simplified scheme of the FEI3 and FEI4 chip

Preamplifier, amplifier and threshold are tunable, typical values are:

- FEI3 TOT = 30 for a MIP with Thr=3200e$^-$
- FEI4 TOT = 8 for a MIP with Thr=3200e$^-$

TOT to charge conversion possible

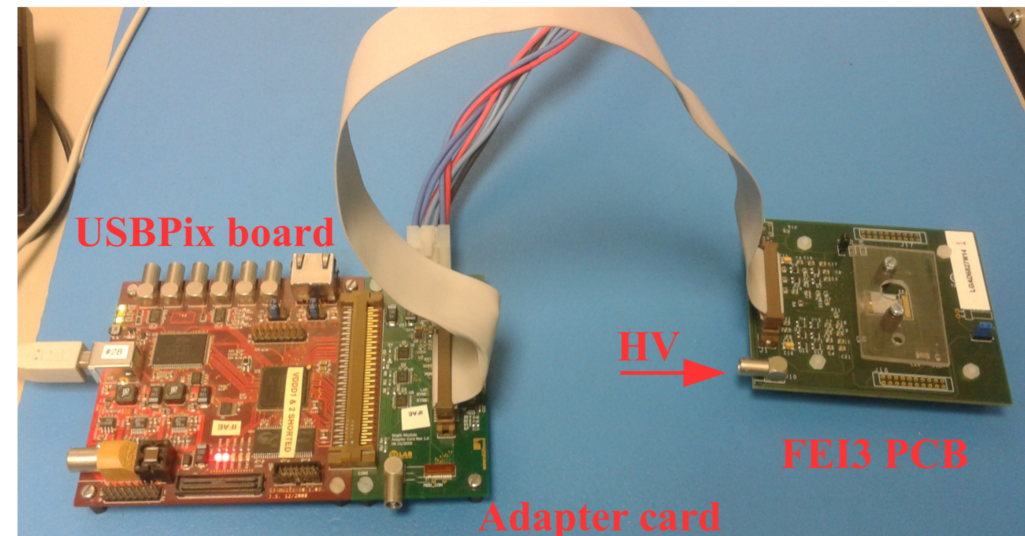
Readout chain:

FEI3/FEI4 on PCB ↔ USBPix board ↔ PC

MIP Setup:

Source → β from ^{90}Sr

Trigger → plastic scintillator + photomultiplier



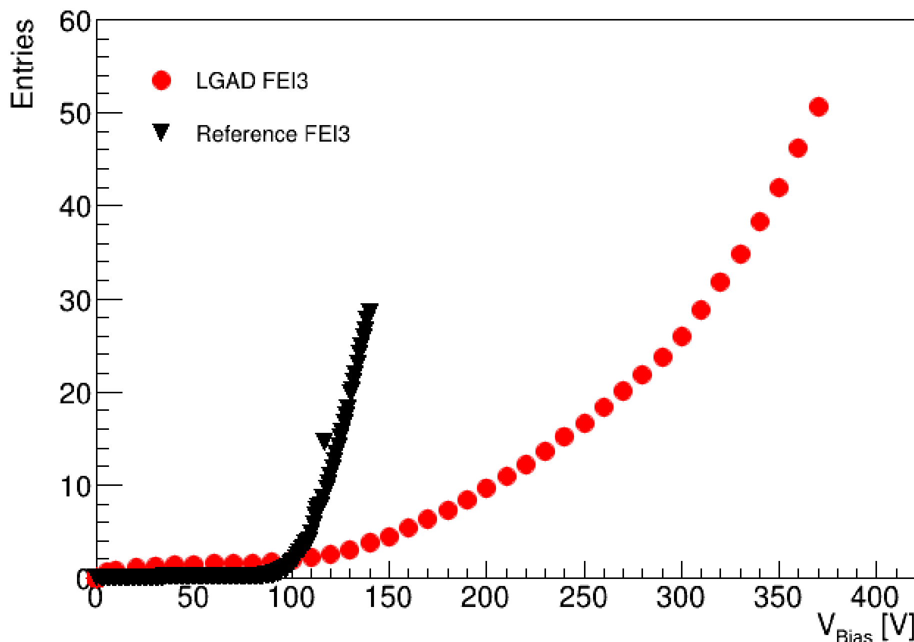
FEI3 measurements

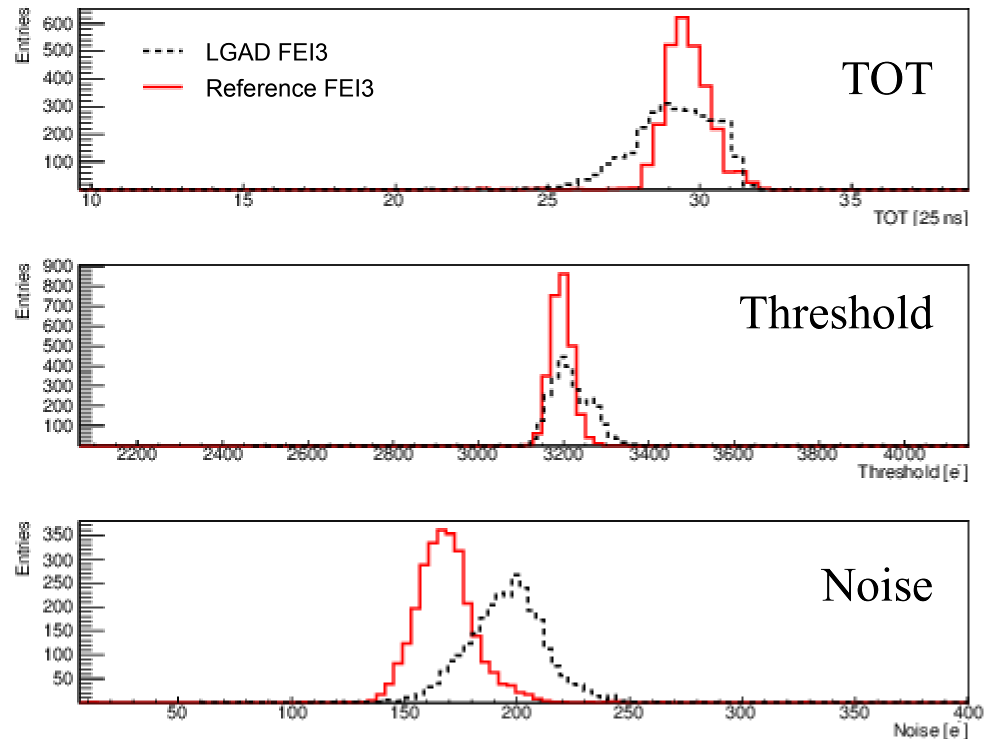
Charge collection measurements
Direct comparison of an LGAD device and a reference one
- only difference is the p^+ multiplication layer

Pre-measurement preparation:
IV curve
- Check breakdown voltage and current level

Tuning – Threshold = $3200e^-$ and TOT = 30 @ $20ke^-$
- Set the two devices in the same working condition

IV curve

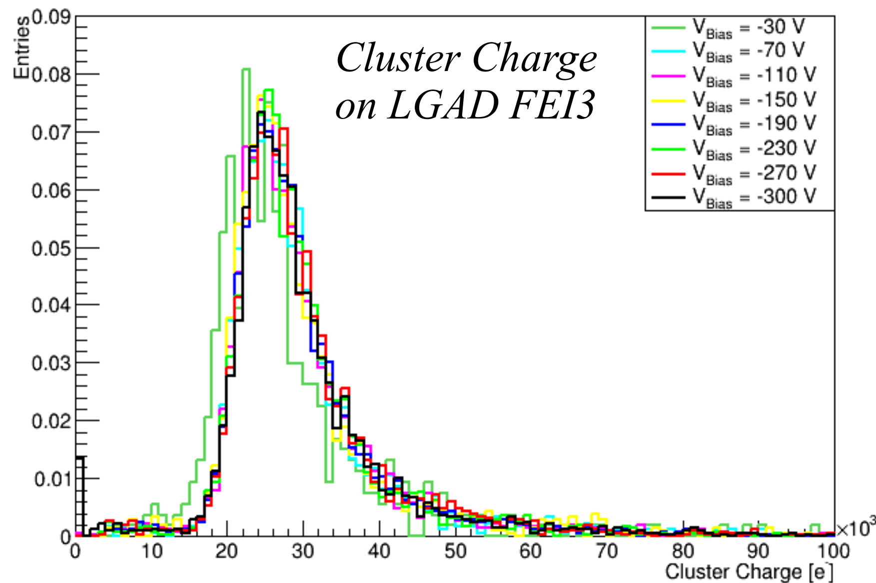




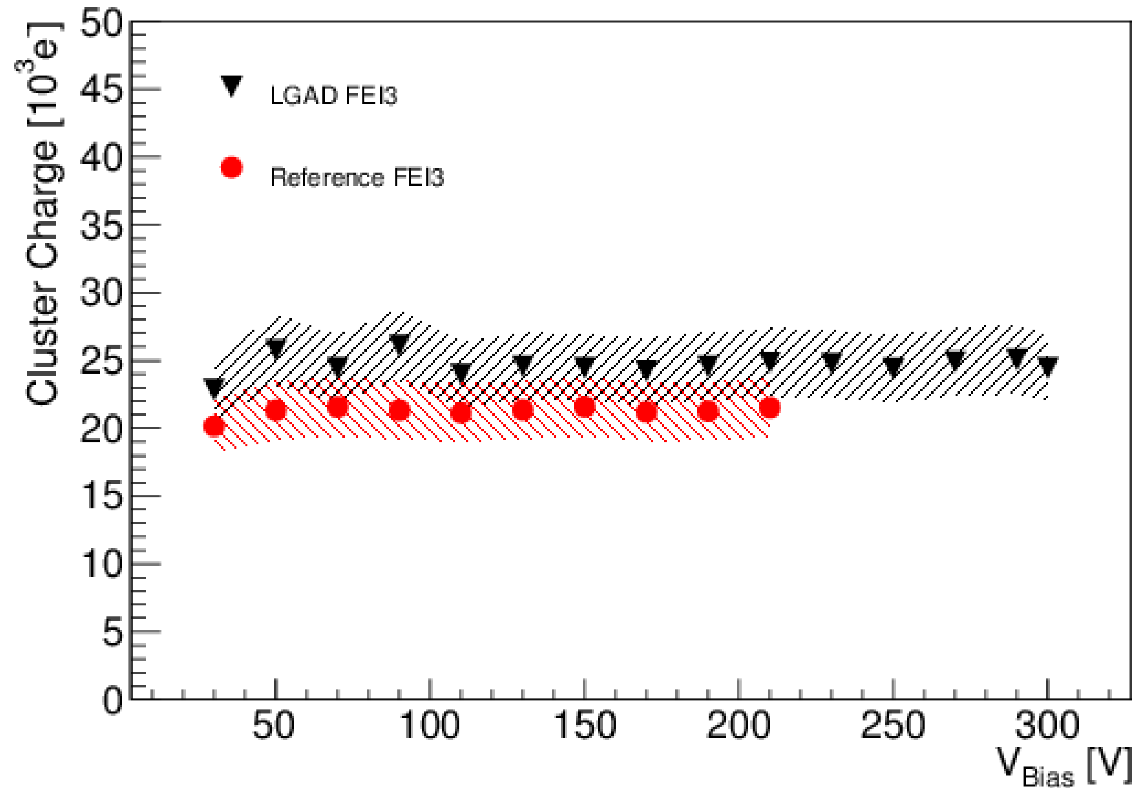
FEI3 measurements

The measurement and analysis procedure:

- Performing ^{90}**Sr source scan**
- Convert from **TOT to** electric **charge**
- Merge the hits into **clusters**
- Fit the cluster charge distribution with a **Landau function**



Cluster Charge MPV *vs* - V_{bias}



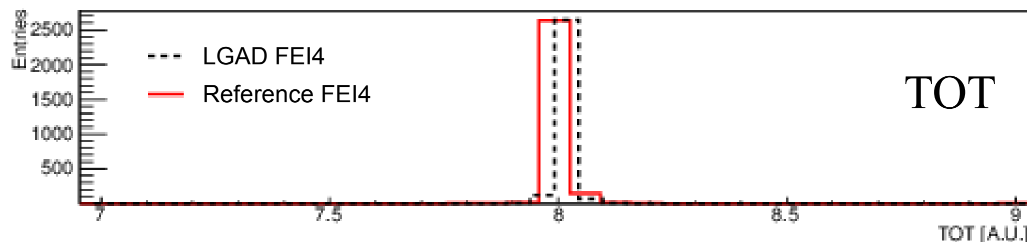
Charge on the LGAD compatible with the reference within the charge calibration uncertainty

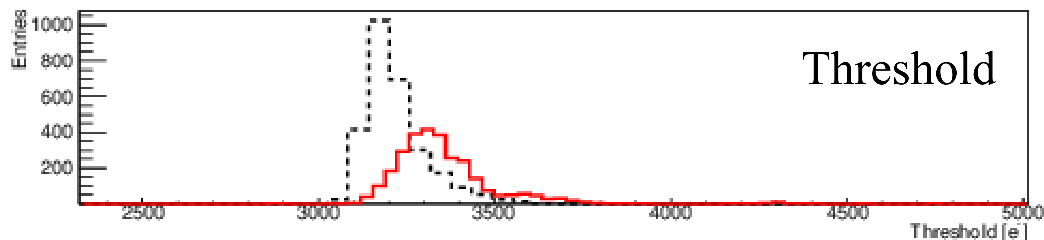
No charge multiplication observed on the FEI3 device

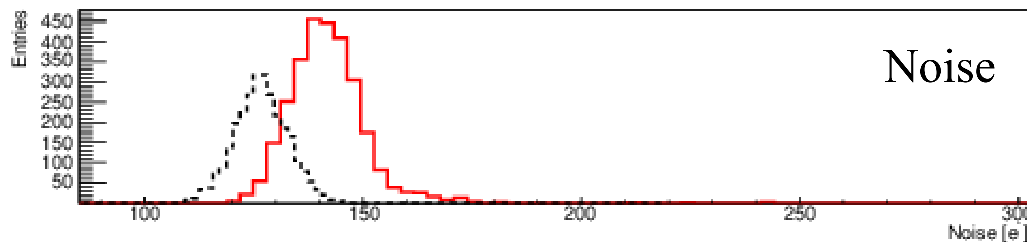
FEI4 measurements

Same measurement protocol as the FEI3

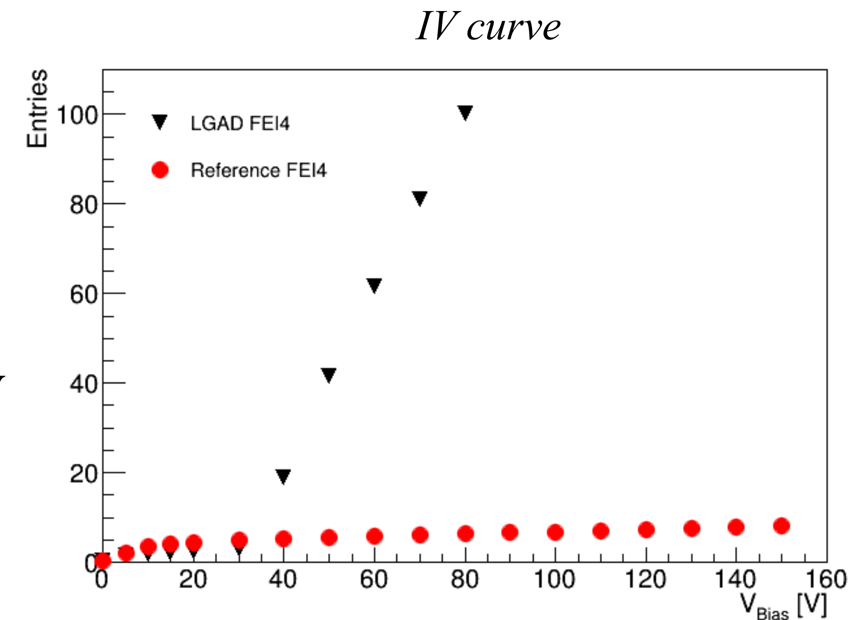
Unfortunately **very low breakdown voltage ~ 30V**







IV curve



Tuning:
Threshold = 3200e$^-$
TOT = 8 @ 20ke$^-$

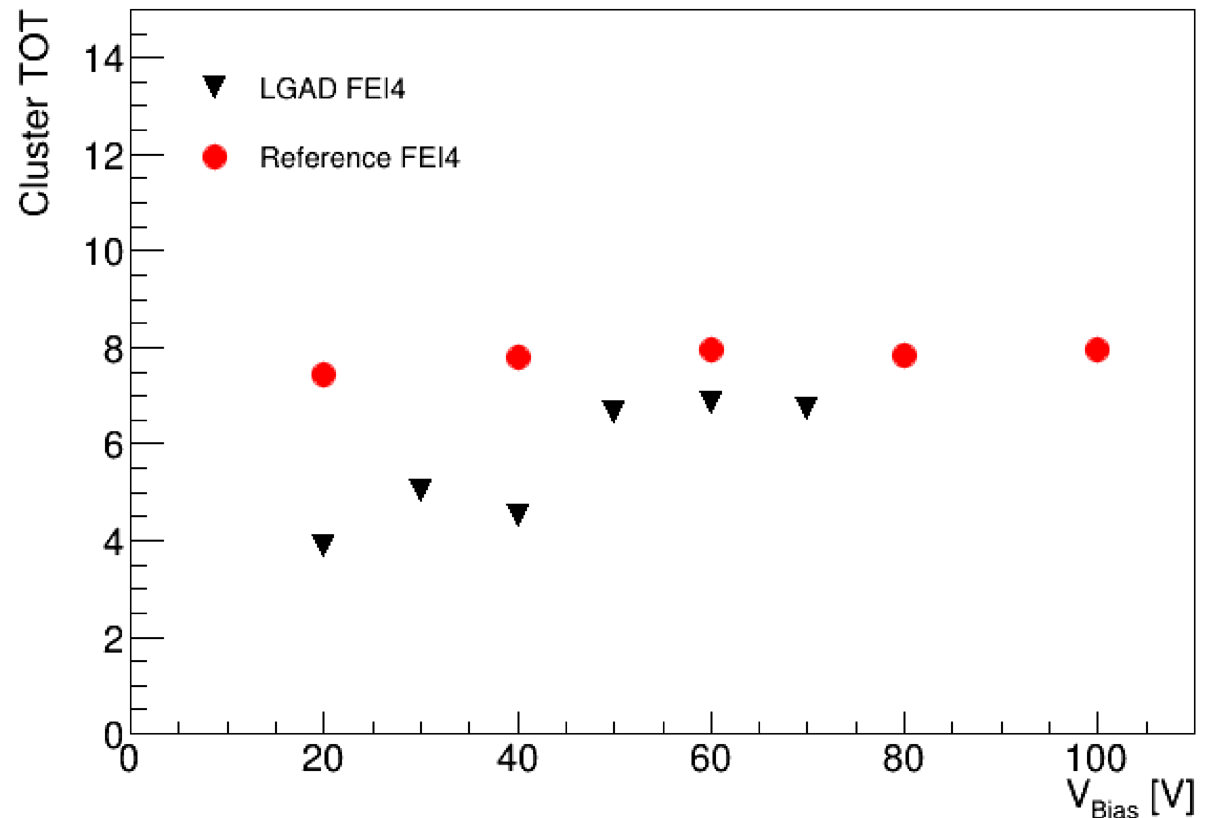
FEI4 measurements

No charge multiplication observed on the FEI4 device

Charge collection measurements not possible at higher voltages

But on diodes from run 6474
Gain >1 @ - V_{bias} ~ 50V

Cluster TOT MPV *vs* -V_{bias}



Summary

Neither the pixel nor the strip devices of run 6827 – W12/14 showed any charge multiplication

Also other groups observed no or minimal charge multiplication for this run

- W8 (50µm epitaxial) diodes - *Hartmut Sadrozinski, University of California Santa Cruz*
- W13 (FZ Standard n+ impl.) strips - *Riccardo Mori, Universität Freiburg*

The promising results obtained on the diodes from run 6474, a charge multiplication of a factor 10 at bias voltages greater than 100V, have not been confirmed on any of these devices

Many differences between run 6474 and run 6827 production

→ The lack of CM may be unrelated with segmentation

Outlook

- Investigate the differences between segmented run 6827 and diodes run 6474
- New production already ongoing
  - W/ segmented devices
  - More similar to run 6474 - *see Pablo Fernandez' talk*

Thanks for your attention