Time Resolution of Thin LGADs

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with

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- Results from the Nov 2014 Beam Test at CERN
- Improvement in hand: Sensor Capacitance
- Measurements with α Front TCT

Time Resolution and Slew Rate

The time resolution σ_t depends on rise time τ_r ,
and τ_r depends on the collection time (i.e. the detector thickness).
The time resolution has 3 terms: **time walk** due to amplitude variation, **time jitter** due to noise, **binning** resolution:

$$\sigma_t^{\,2} = ([\tau_r \frac{V_{th}}{S}]_{RMS})^2 + (\tau_r \frac{1}{S/N})^2 + (\frac{TDC_{bin}}{\sqrt{12}})^2$$

Introducing the **slew-rate S/ τ_r = dV/dt**

$$\sigma_t^{\,2} = ([\frac{V_{th}}{dV/dt}]_{RMS})^2 + (\frac{N}{dV/dt})^2 + (\frac{TDC_{bin}}{\sqrt{12}})^2$$

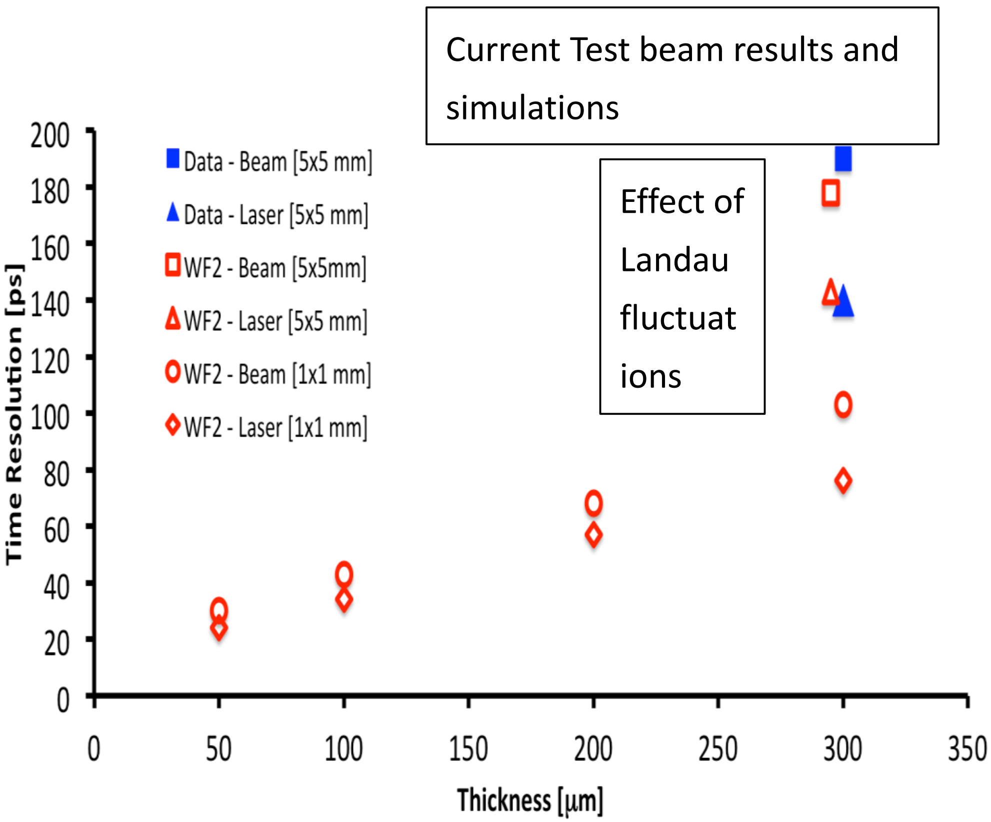
18ps (measured),
vs 14ps (expected)

(binning error is negligible at 50 ps sampling rate)
we find that for constant noise N, to minimize the time resolution, we need to maximize the slew-rate dV/dt of the signal (and threshold in the simple case)

Need both large and fast signals.

Time Resolution for thin LGAD

For the 300 µm thick large LGAD pads (C ≈ 10 pF), the time resolution measured in the beam tests (BT) at Frascati and CERN, is predicted by the **Weightfield (WF2)** simulation)



The time resolution is predicted to improve for smaller LGAD and optimized electronics. Reduced the thickness also improves the time resolution.

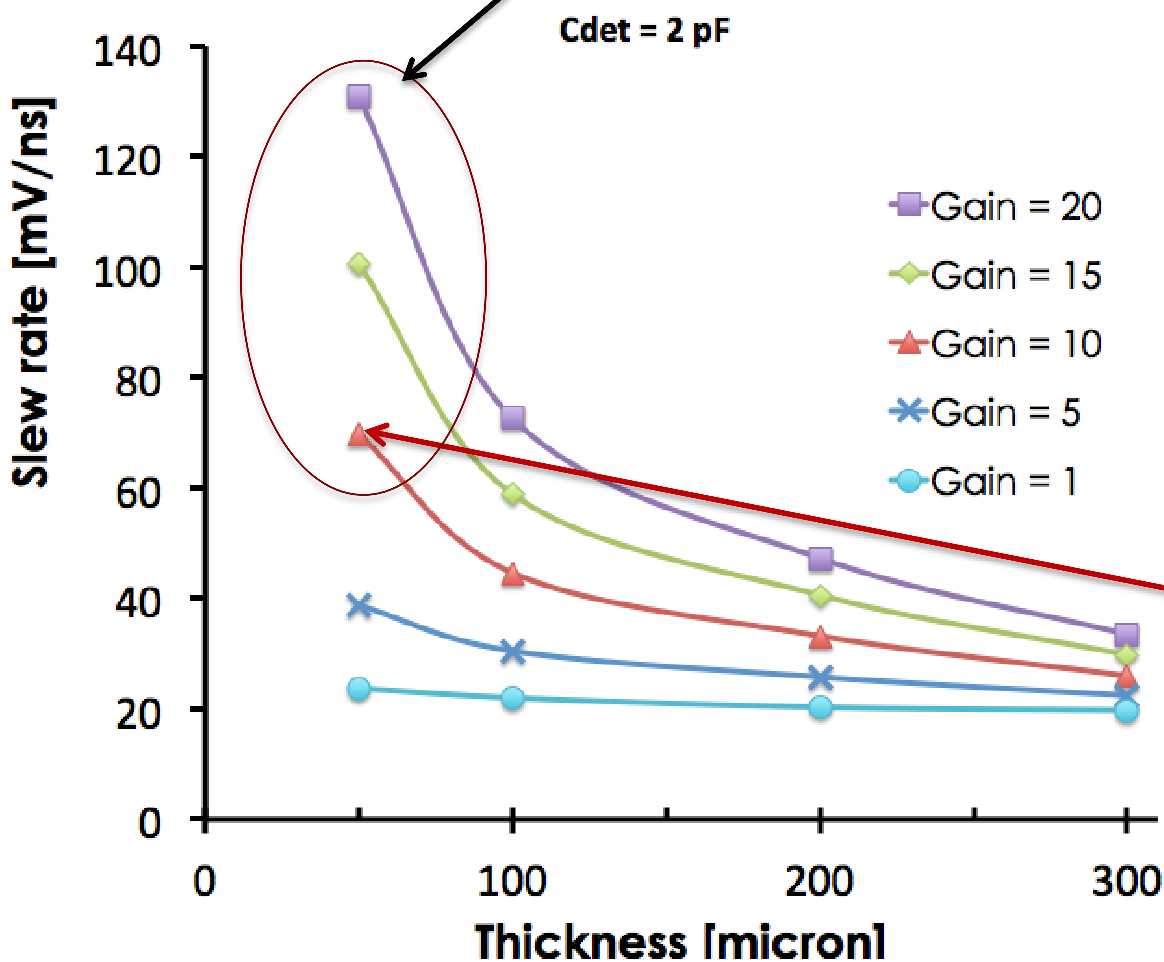
Expect for 50 µm thick LGAD (C~2pF):

σ_t = 30 ps (requires ASIC)

N. Cartiglia, F. Cenna et al. “Weightfield”, 2014 IEEE NSS-MIC

Slew-rate as a Function of Sensor Thickness

Large slew rate, good time resolutions



Weightfield2 simulation

N. Cartiglia et al.

2014 IEEE NSS-MIC

50 micron:

~ 3x improvement with gain = 10

Significant improvements in time resolution require thin and small detectors

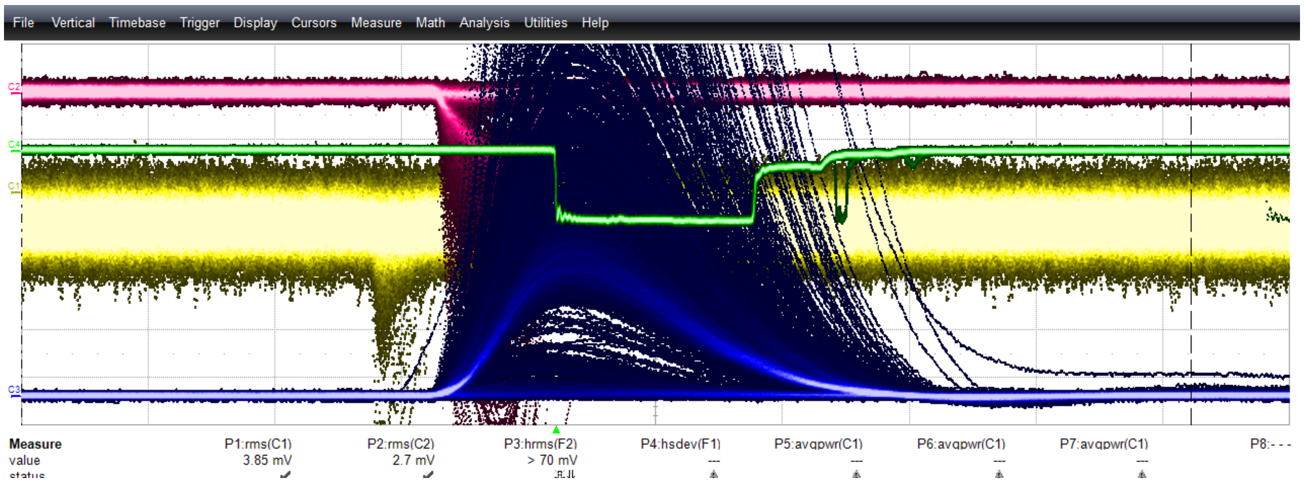
2014 November nights in the H6 Beam Line

2 300FZ LGAD (G = 10-15)

50um epi LGAD (G = 2-3).

Trigger: fast SiPM

Bias voltage scans taken with digital scope at 10 ps sample speed.



Ch 2: 300 FZ BB

Ch 4: SiPM Trigger

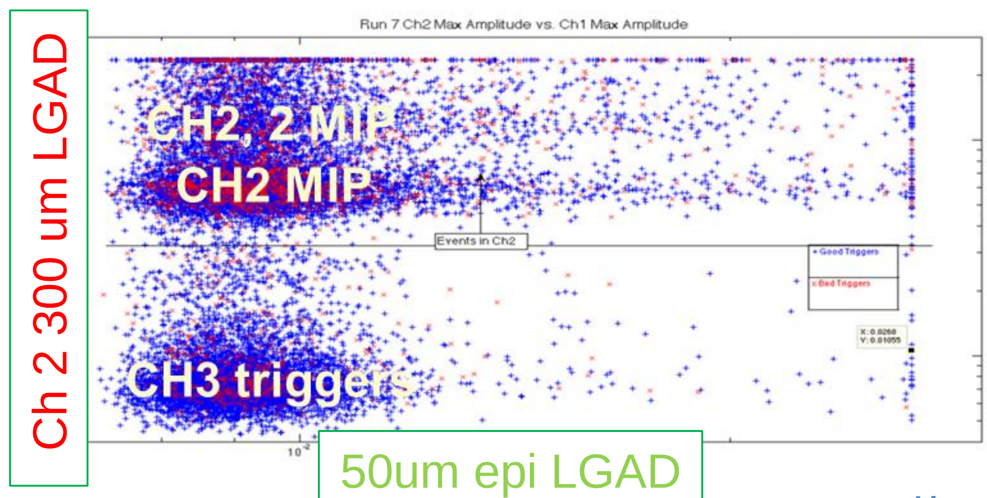
Ch 1: 50um epi

Ch 3: 300 FZ CSA

Trigger:

(OR of 300um FZ sensors). AND.SiPM

(SiPM resolution ~50 ps?).

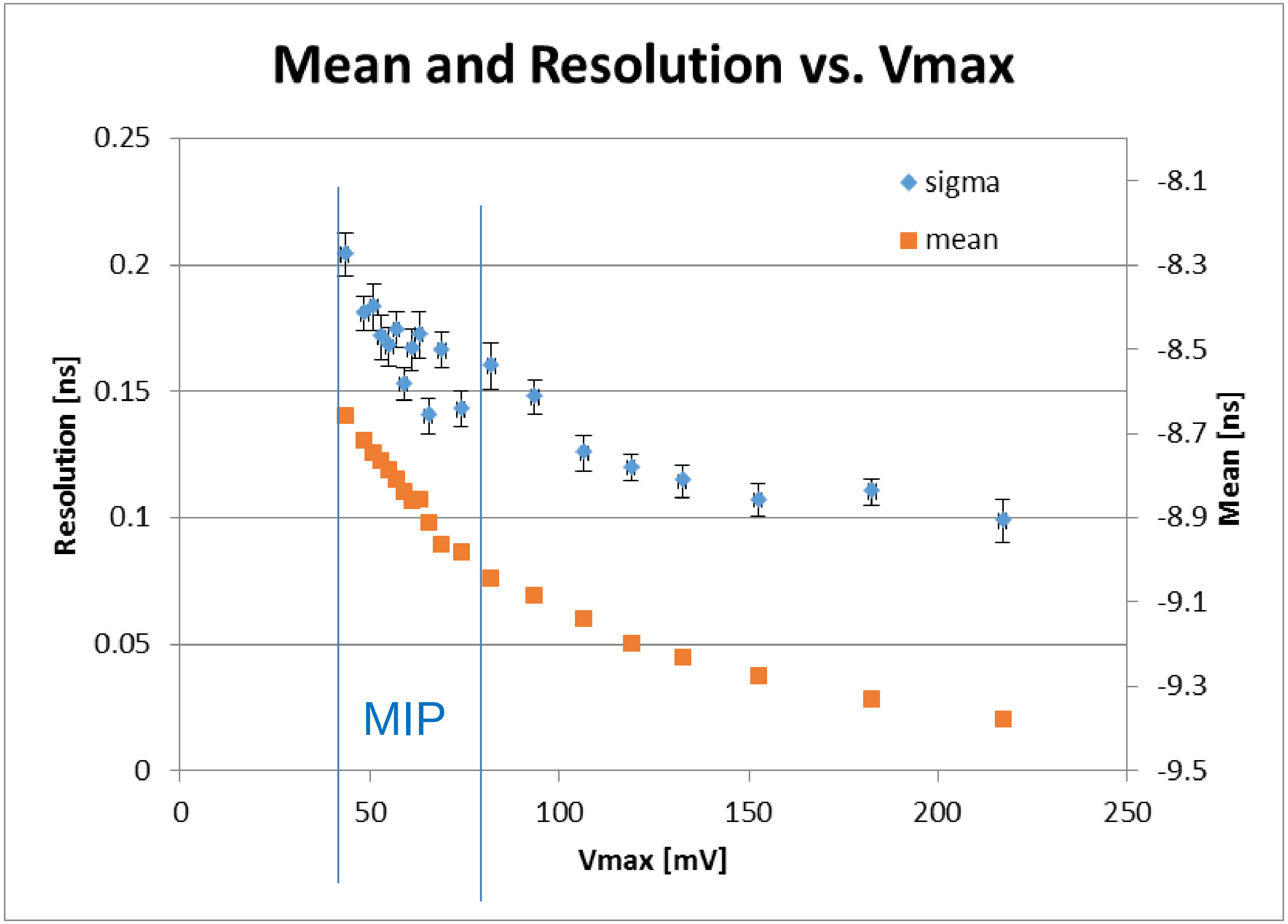


Thanks to the AFP beam test group (Joern Lange & Michael Rijssenbeek) for help and use of the trigger

Analysis of Ch 2 (300 µm FZ, BB)

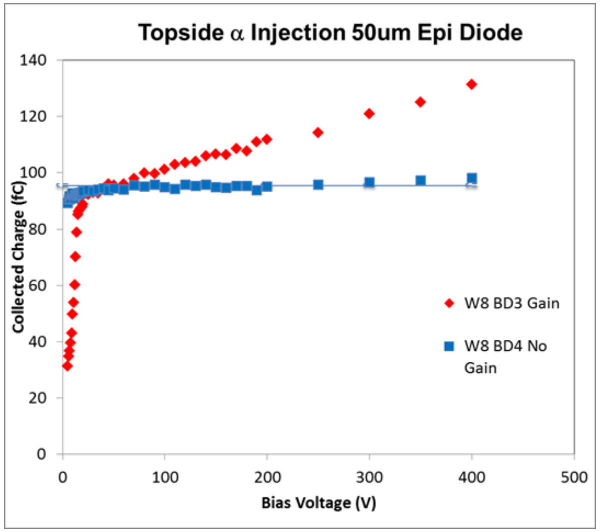
Bias 1000V
fixed threshold = 10 mV

Time walk is large (700ps)!



Gain in large (34pF) 50um epi Diode (Marta)

Top-side α injection

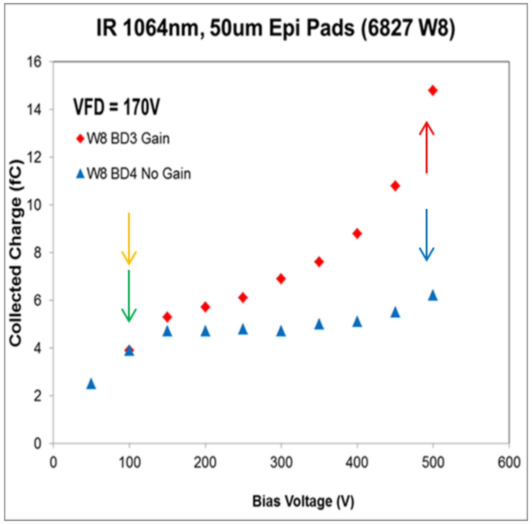


The epi structure prevents electron injection through back-side α radiation.
Using front-side α injection to compare LGAD and no-gain pads requires that the energy loss of the α's in the active region are the same (or are known well).

The α signal in the no-gain diode is constant as a function of the bias voltage.
While the α signal in the LGAD reaches the same level only after sufficient depth of the p+ implant is depleted (we estimate ~ 7 um) at a bias of ~ 25V. .

At higher bias, gain of about g = 1.4 is observed.

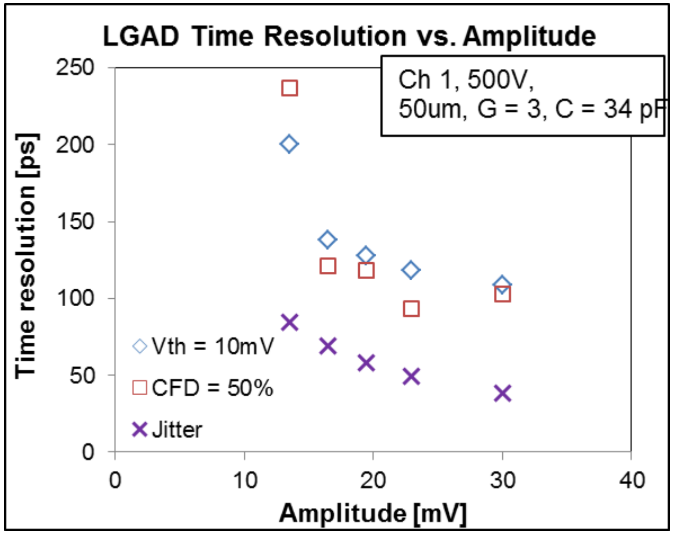
IR Laser Injection



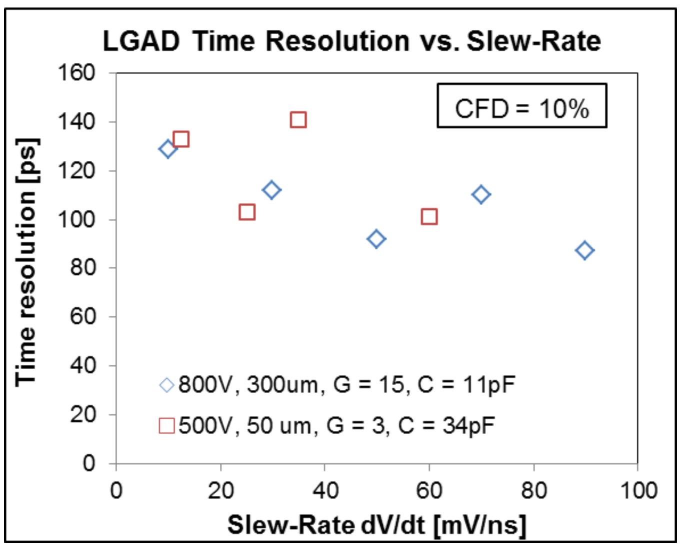
IR (1064nm) laser injection from front shows characteristic LGAD voltage dependence of signal, while no-gain diode is ~ constant above full-depletion voltage VFD = 140 V.
Gain of about 3 is observed.

The observed difference of the gain factor for top-side α injection (1.4) wrt laser (g=3) is predicted by the "Weightfield2" program.

Preliminary Beam Test Time resolution



Expected strong dependence on amplitude

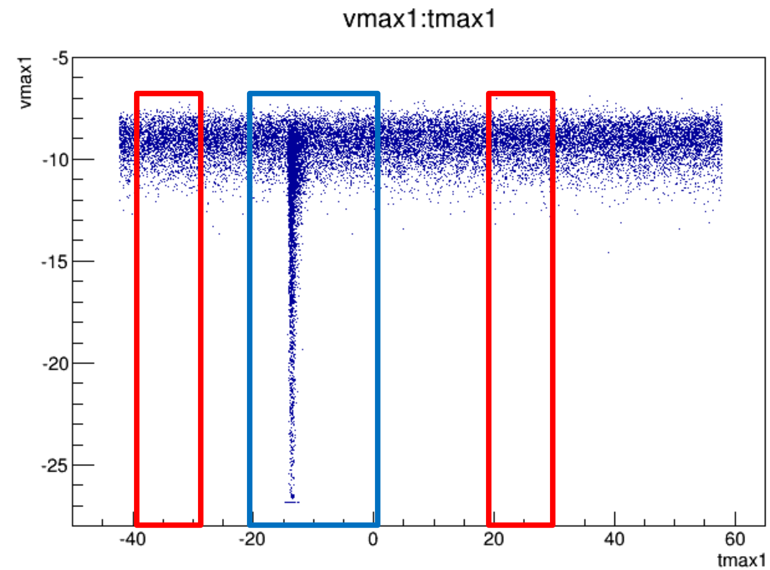


Using the slew-rate dV/dt yields unified description of both thin and thick sensor! (amplitudes of 50um epi and 300 FZ LGADs differ by factor 5!)

Surprisingly weak dependence on slew rate: trigger resolution??

Time Stamp of Pulse Maximum

Introduce the time stamp tmax1 of the maximum pulse amplitude vmax1



Beam Data is in a very narrow band:

→ To get amplitude spectrum:

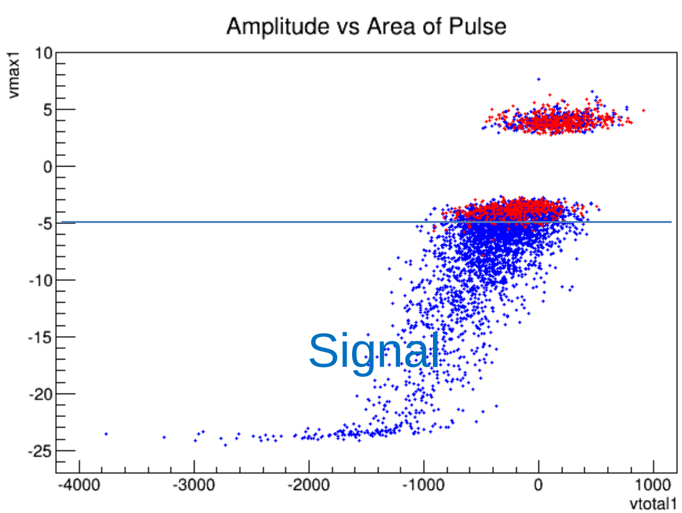
Select signal window -20 < tmax1 < 0 ns

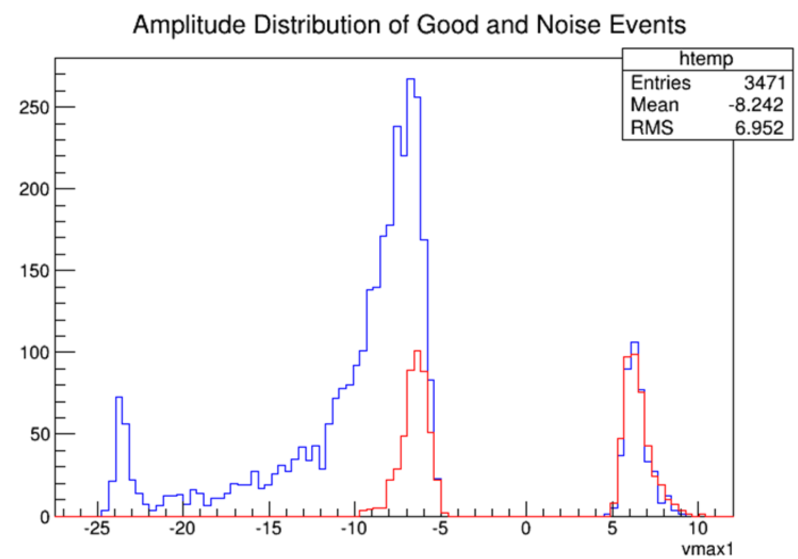
Subtract noise from siide bands

-40 < tmax1 < -30 ns + 20 < tmax1 < 30 ns

Introduce pulse area vtotal1 of the pulse.

Pulse amplitude vs. Pulse area for signal window and side bands.





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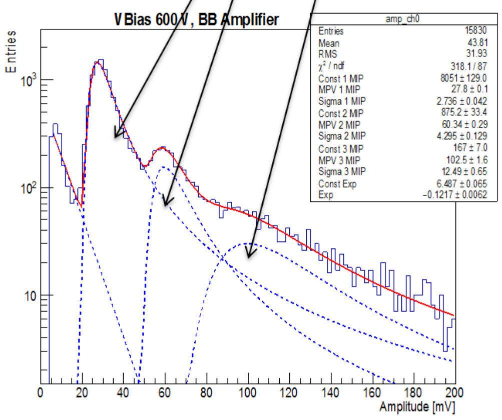
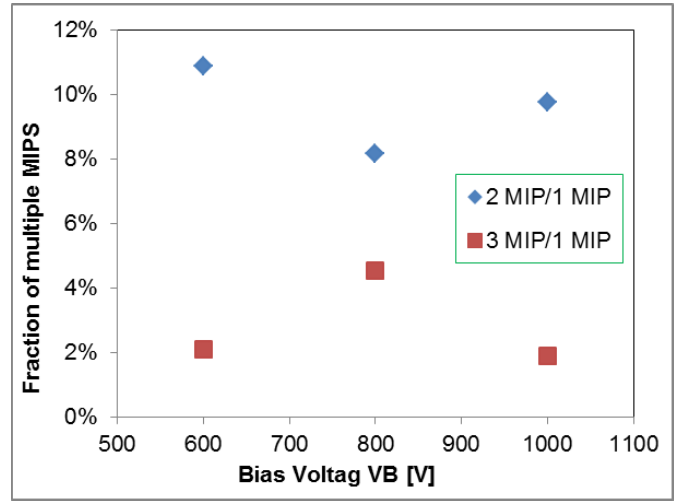
Signal Analysis in terms of MIPs

Extraction of Beam Composition from 300µm FZ sample

The 300um FZ data are well explained as a sum of 3 Landau distributions: 1, 2 and 3 MIPS

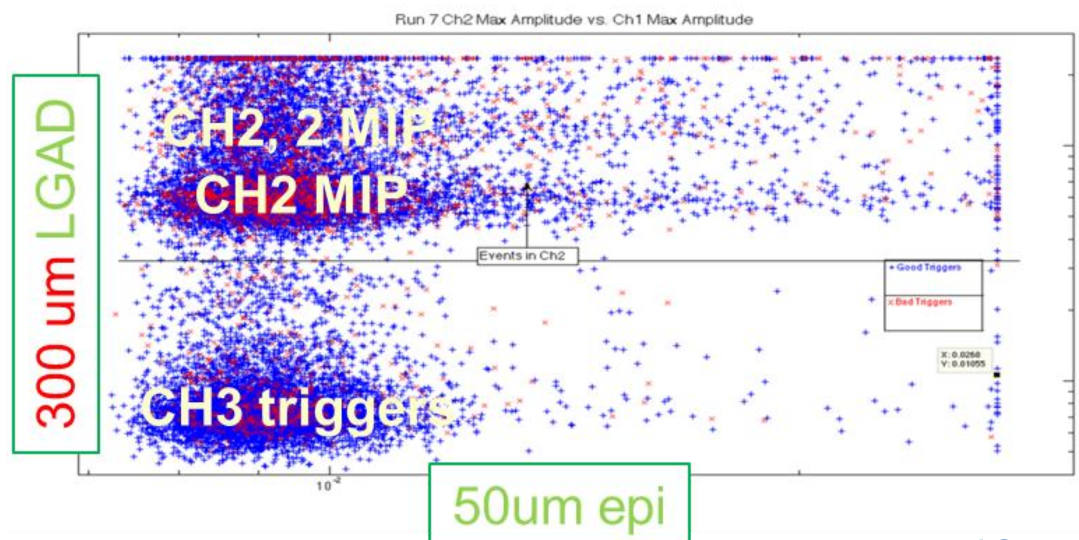




Beam Composition: 88% single MIP

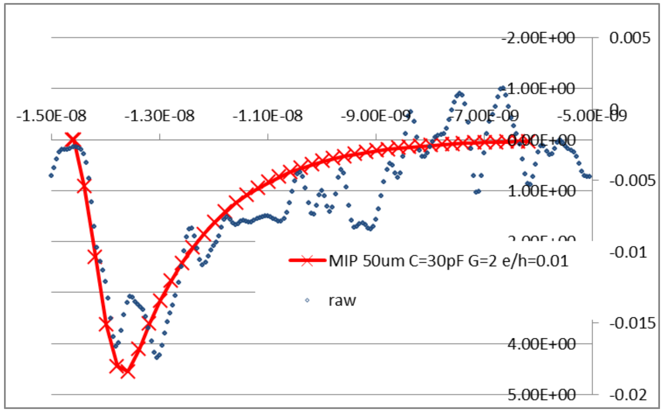
Estimate > 50% of events in 50µm sample above threshold of 5 mV are single MIPs

Correlation mainly with Ch 2



Effect of Detector Capacitance (50µm epi)

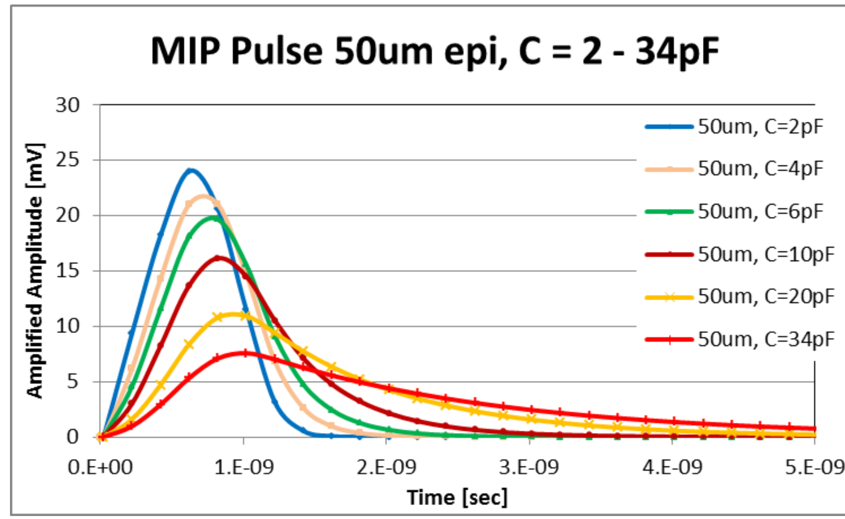
Good match of pulse shape data-WF2

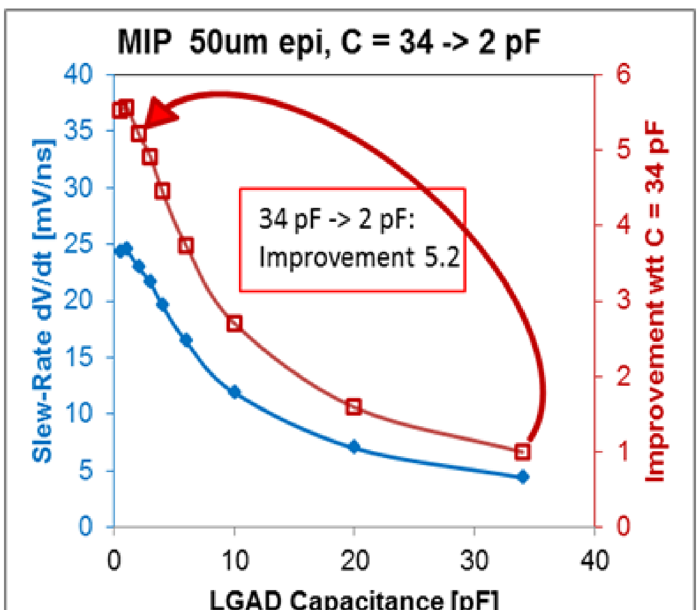


Lower capacitance will improve rise time

Risetime vs. C

34pF	710 ps
2 pF	390 ps

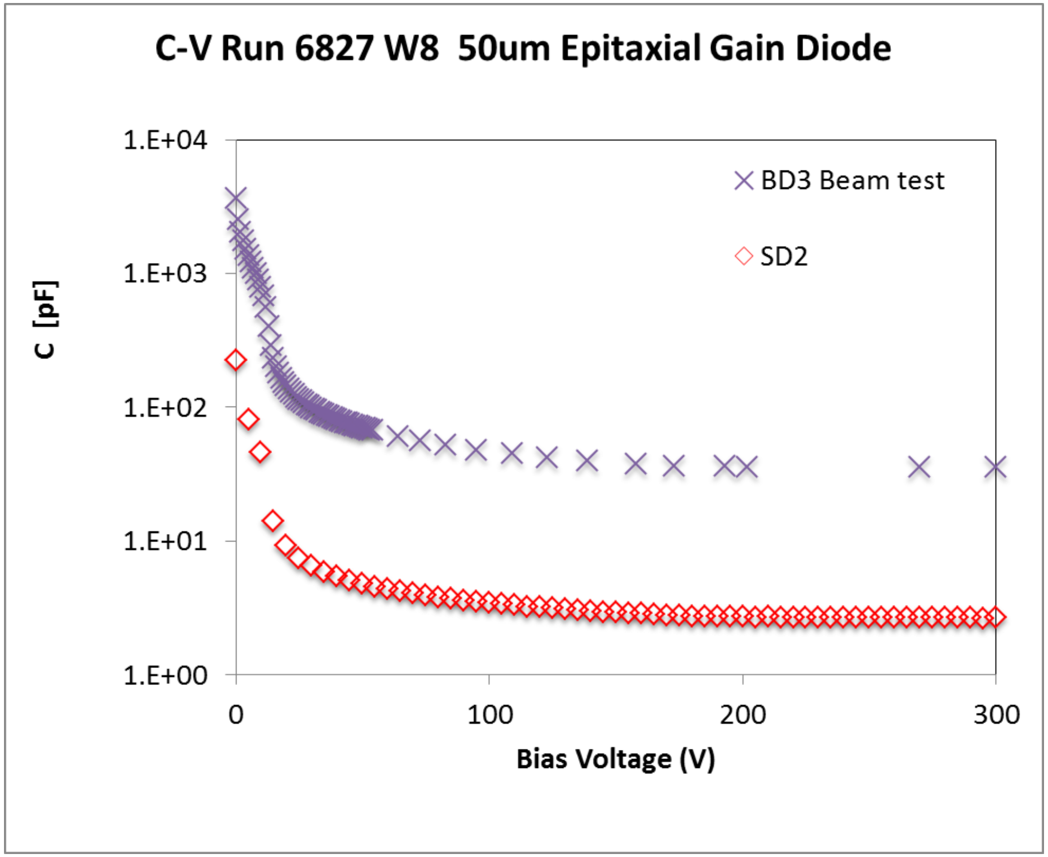




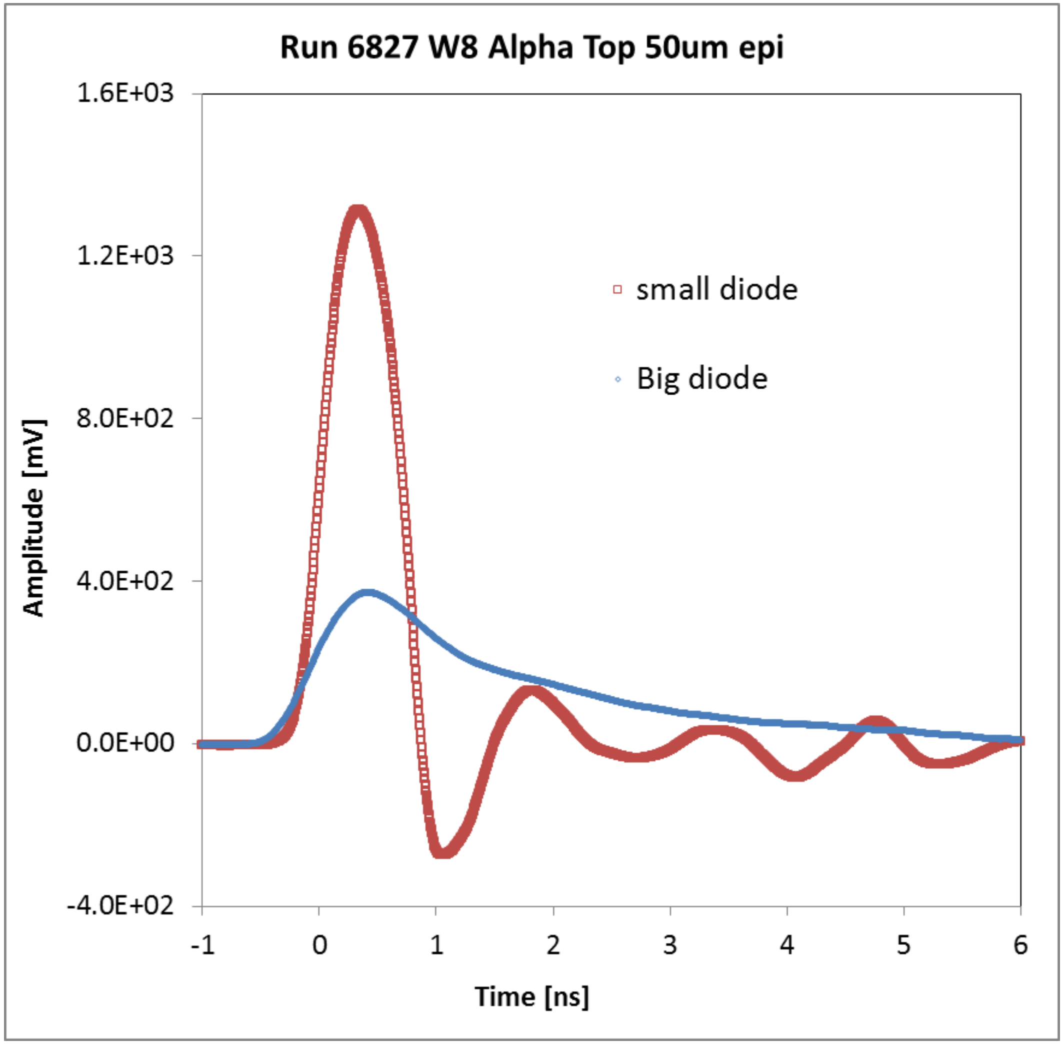
The LGAD diodes with C = 2.5 pF will increase the amplitude by a factor 3 and the slew rate by factor 5.2 wrt beam test diode.

This will improve the time resolution by a factor 5.2

Improvement: Reduce Capacitance



C = 2.5 & 34 pF 50 um epi Sensors: Front α TCT



Collected energy E

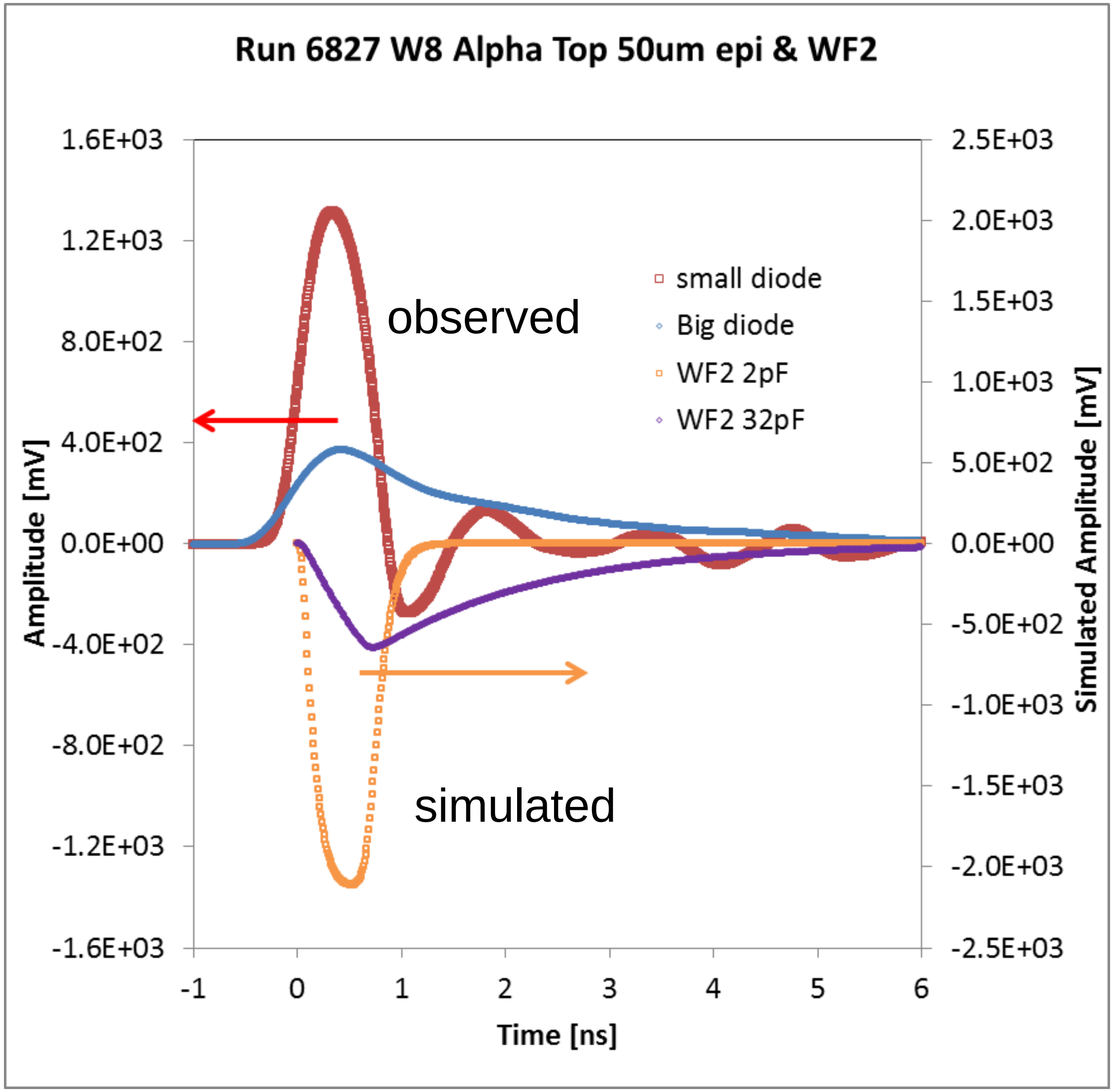
(out of 5.5 MeV):

Small diode: E=3.66 MeV

Big Diode: E=3.69 MeV

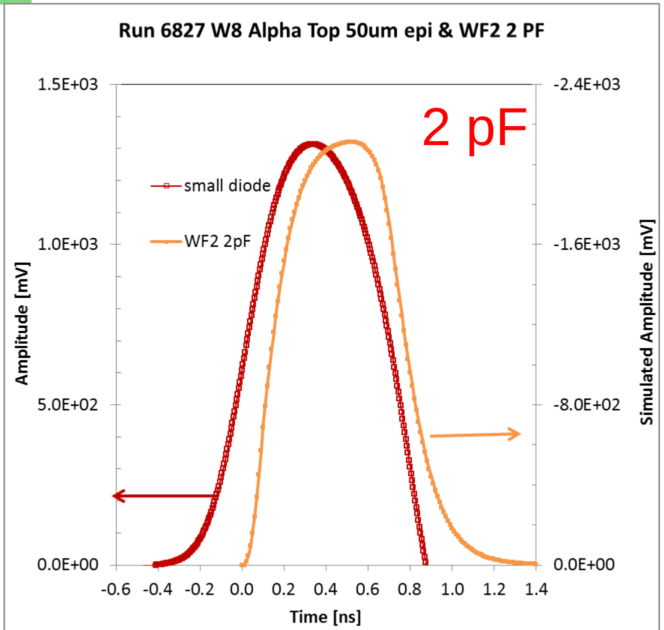
(This is the usual observed α energy fraction ≈ 0.66)

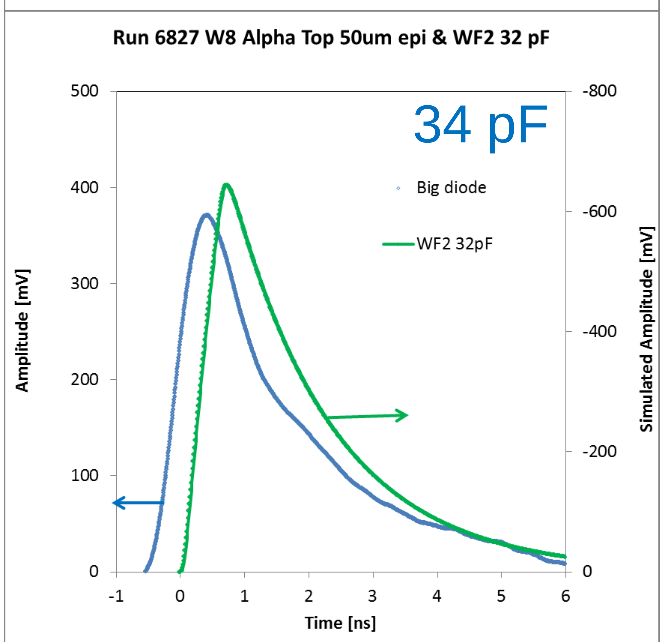
Front α 50 um epi Sensors: Comparison with WF2



Excellent predictive power of Weightfield2 simulator

Front α 50 um epi Sensors: Comparison with WF2





Measured Pulse shapes for the small diode (C = 2.5 pF) and big diode (C= 34pF) compared to WF2 simulation.

Comparisons with Weightfield2 (WF2) are excellent:

(The WF2 simulation is scaled down in both plots by 1.5/2.4 = 0.63, close to the observed α energy fraction)

Conclusion

Thin LGAD promise excellent time resolution.

A 50 µm epi sample in the Nov 2015 beam test was missing two needed ingredients:

- **large gain (gain = 3 instead of 10)**
- **small capacitance (C = 34 instead of 2.5 pF)**

A comparison of the time resolution with a 300 µm FZ LGAD shows the expected scaling with the slew rate dV/dt.

A small diode (C=2.5pF) is under preparation and we expect improvement of

- **about 3 in S/N which will improve the trigger efficiency**
- **about 5 in dV/dt which will improve the time resolution**