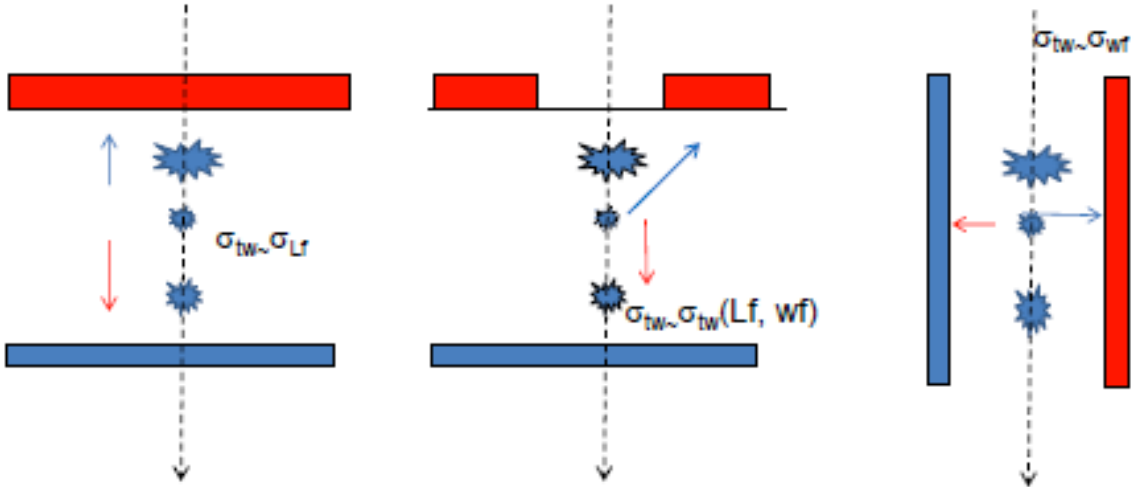
Timing in 3D detectors

Timing in different detectors

- Time walk component includes
- Weighting field contribution
- Landau fluctuations in shape of the signal (limiting 50 um LGAD time resolution to 25 ps)
- Landau fluctuations in height – correctable with ToA-ToT or CFD



$$\sigma_t^2 = \sigma_j^2 + \sigma_{tw}^2 + \sigma_{TDC}^2$$

$$\sigma_j = N/(dV/dt) \sim t_p/(S/N) \quad , \quad \sigma_{TDC} = TDC_{bin}/\sqrt{12}$$

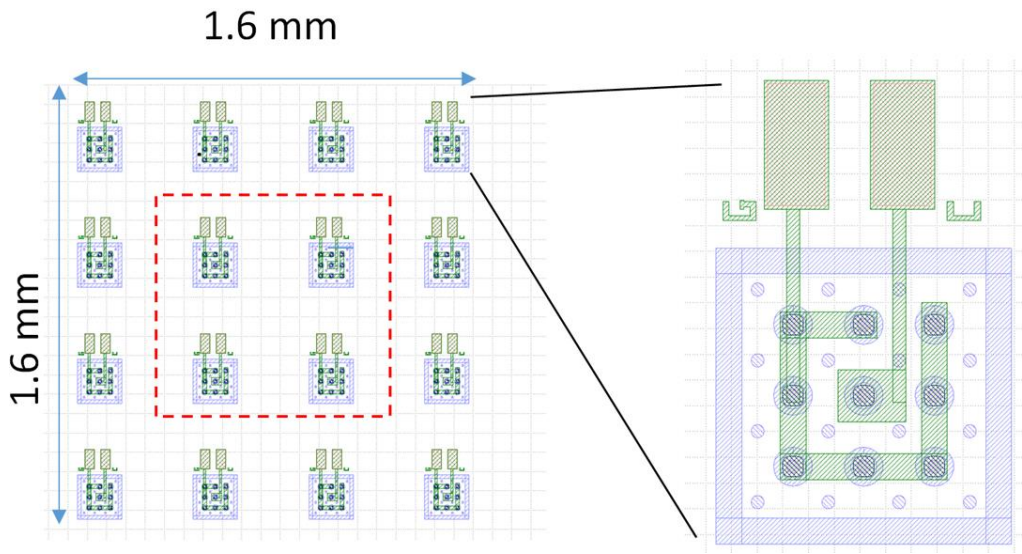
Limitations of LGAD

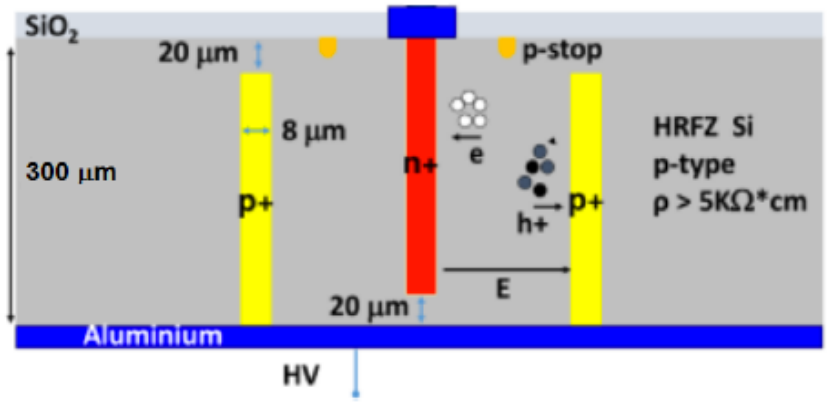
LGADs are now considered as candidates for 4D tracking, but:

- radiation hardness is a problem
- fill factor is a problem, especially when the cell size decreases (1.3 mm2 – 87% with 100 um gap between the pads)

How about 3D for timing?

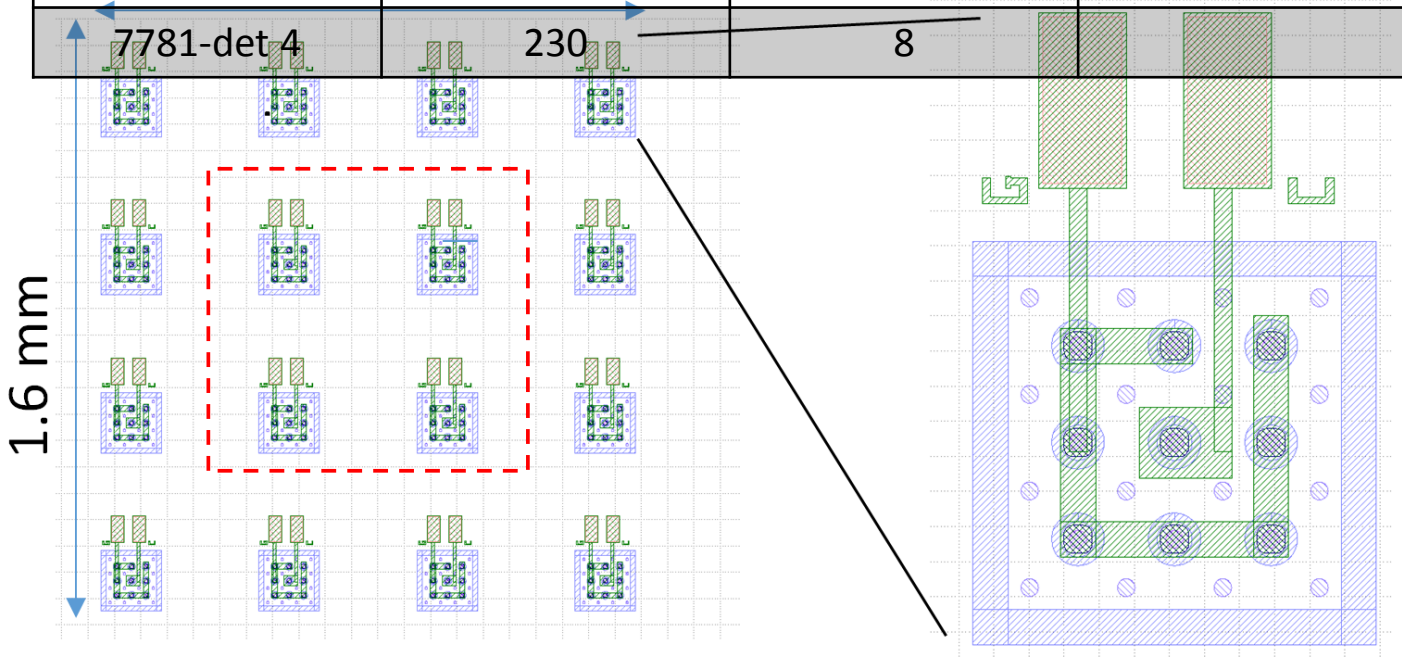
Sample	Thickness [µm]	Column diameter [µm]	
5306-det 4	300	10	tested
7945-det 6	230	10	
7781-det 4	230	8	





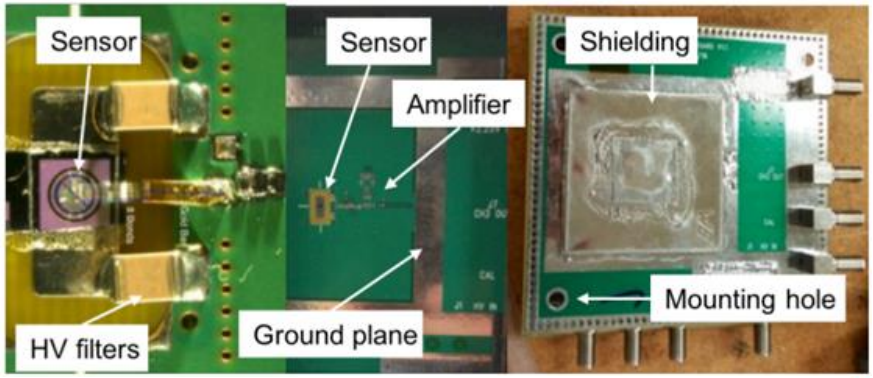
First Measurements – CNM samples

Sample	Thickness [µm]	Column diameter [µm]	
5306-det 4	300	10	tested
7945-det 6	230	10	
7781-det 4	230	8	

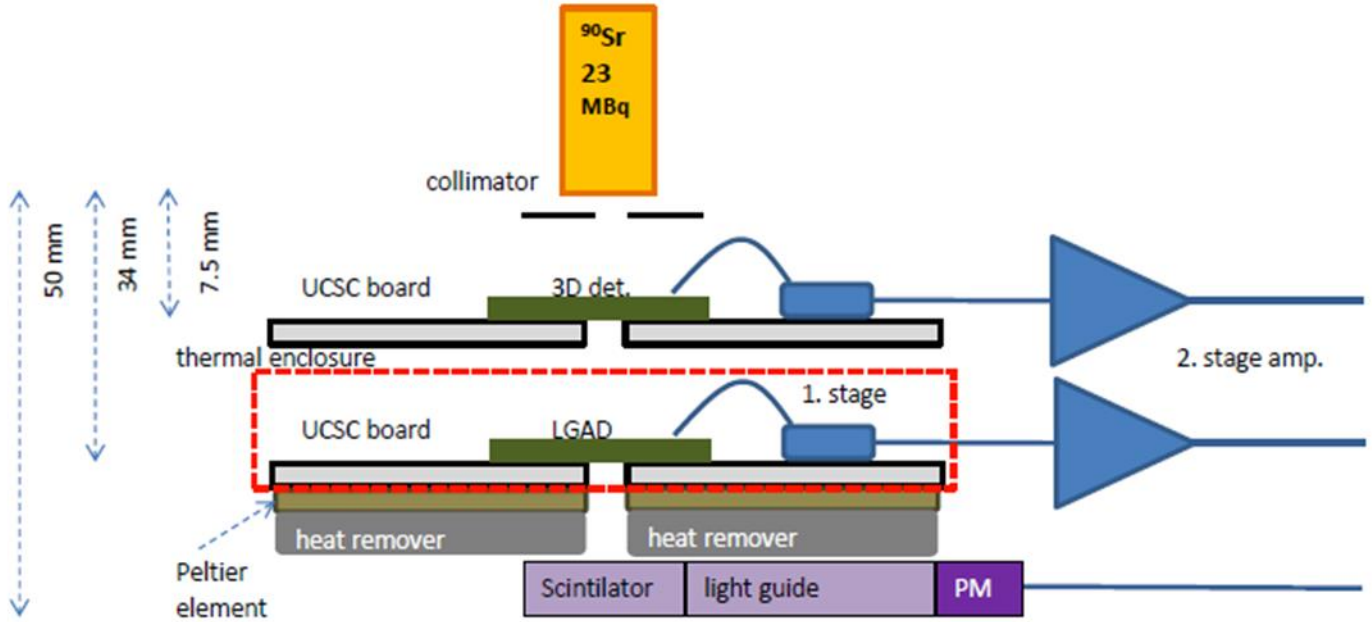


HGTD timing telescope

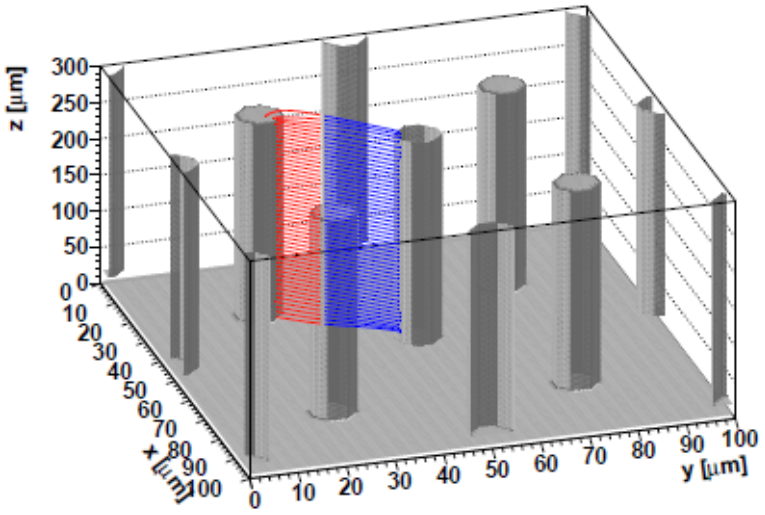
UCSC timing boards used for measuring the signal followed by 35 dB Particulars amp

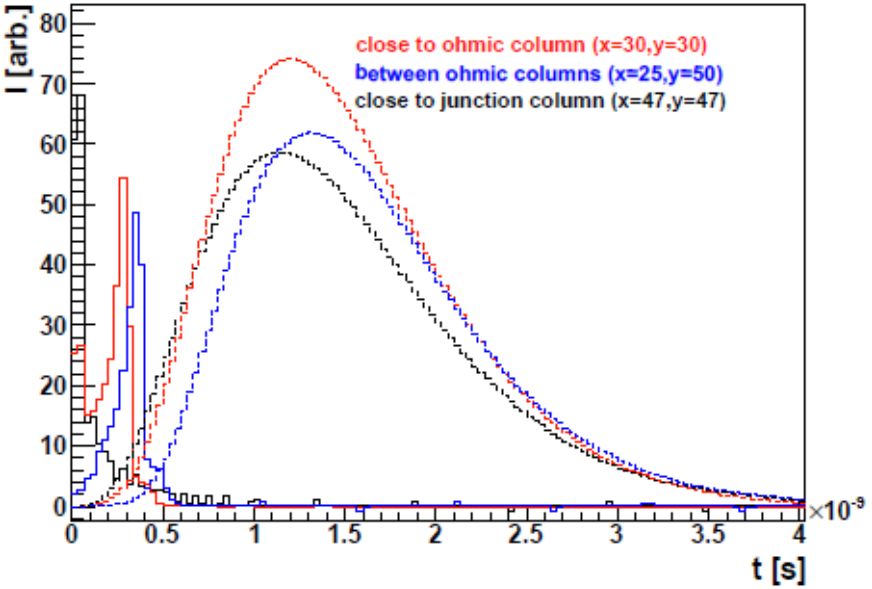


- required hits with very low threshold of 15 mV in both planes (extremely low rate ~1000 in ~20 h)
- no Scintilator+PM were used
- 3D detectors were not cooled in first tests



Simulation of detectors





- p-type bulk (N_{eff}=-1.4·10^{12} cm^{-3})
- n-type collection
- different geometries 1E, holes r=4 μm
- -20oC
- no trapping, no multiplication
- CR-RC3 shaping with 1.2 ns peaking time – interestingly this is not crucial

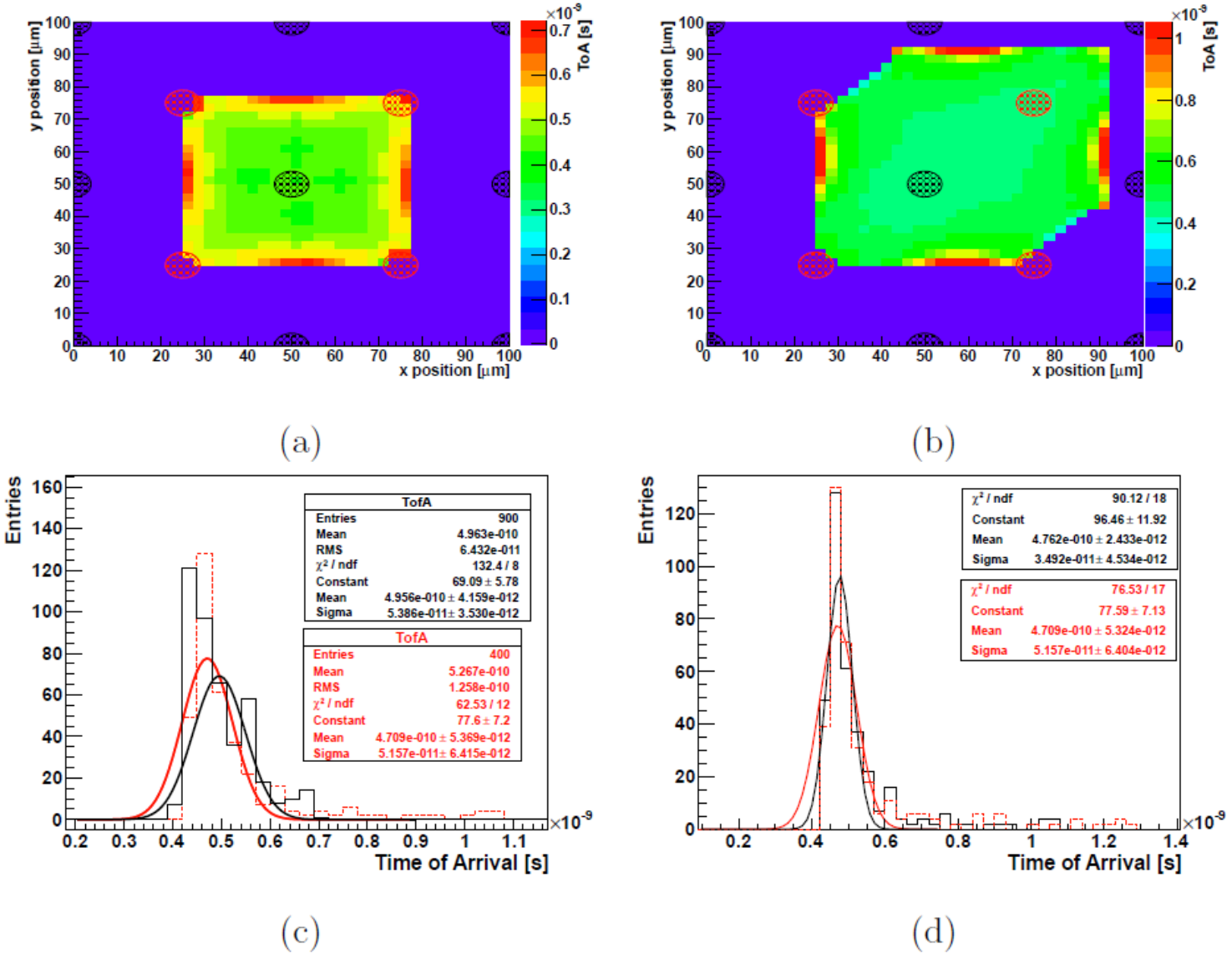
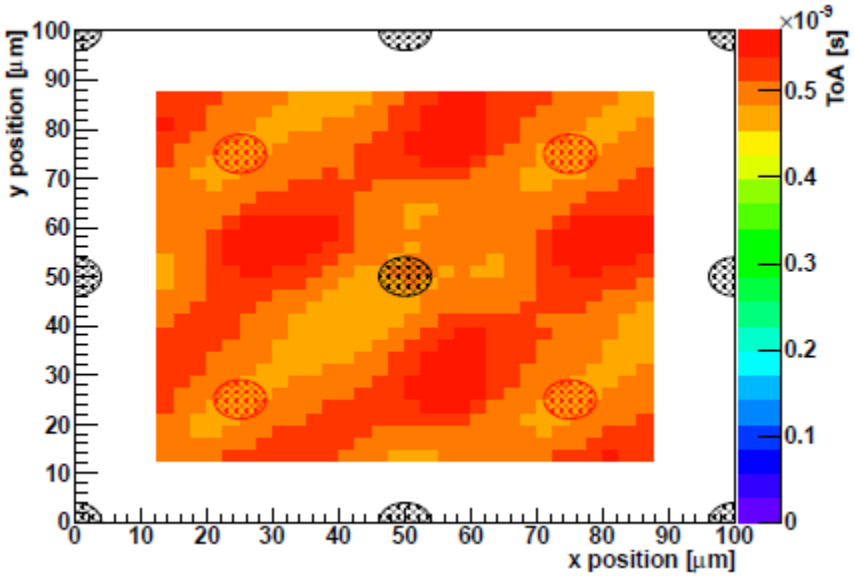
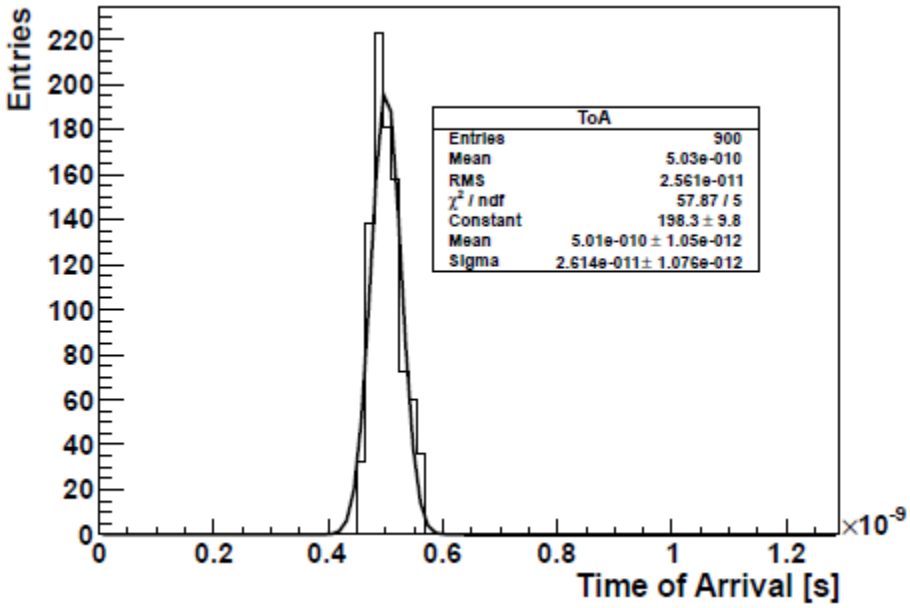
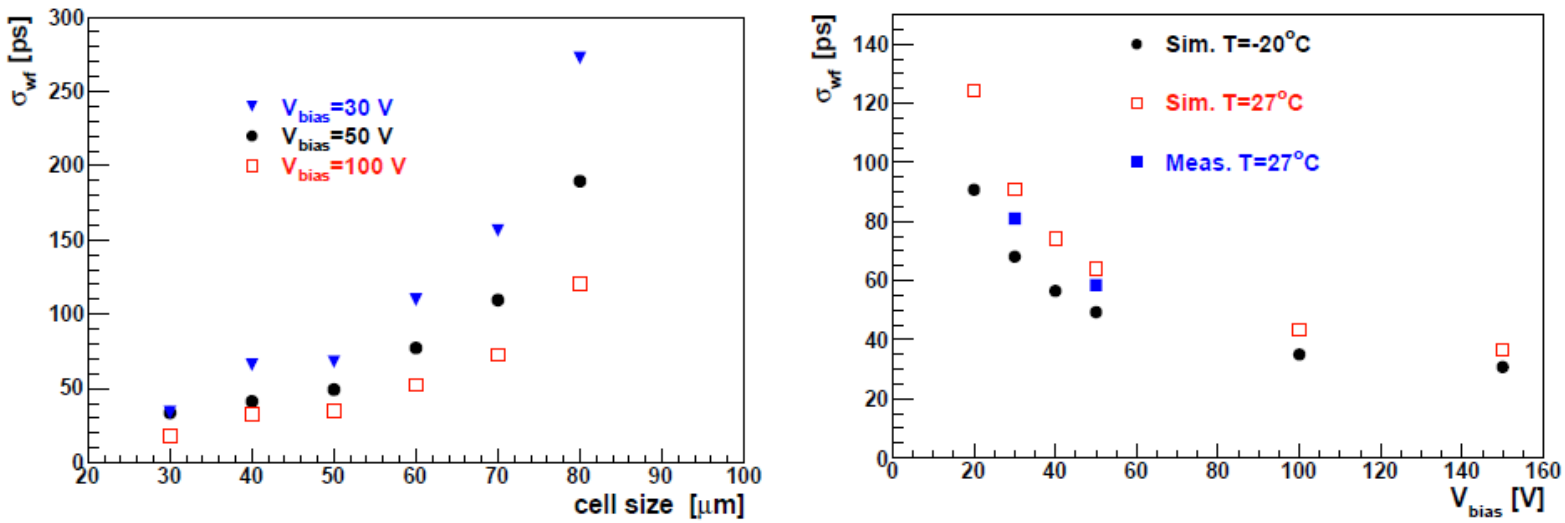


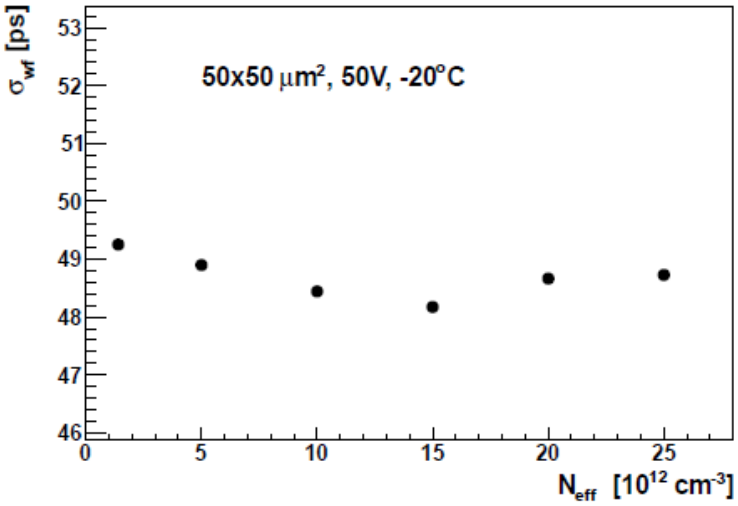
Fig. 4. (a) Time of arival for differnt hit positions at 50 V, 27°C and constant fraction of 25% for a tracks under small angle. (b). Distribution of time of arival for the tracks crossing the detector cell with a Gaussian fit to the peak of the distribution.


y position [μm]
x position [μm]
ToA [s]
×10⁻⁹
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5


Entries
Time of Arrival [s]
×10⁻⁹
ToA
Entries 900
Mean 5.03e-010
RMS 2.561e-011
χ² / ndf 57.87 / 5
Constant 198.3 ± 9.8
Mean 5.01e-010 ± 1.05e-012
Sigma 2.614e-011 ± 1.076e-012

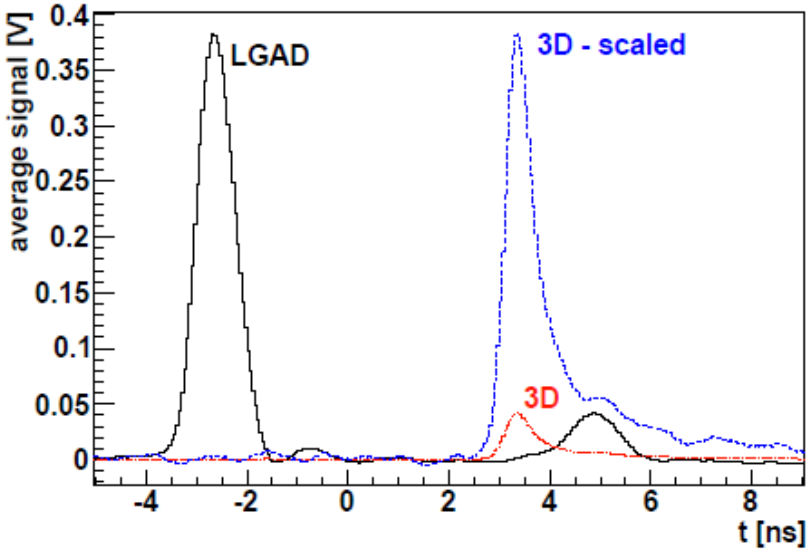


(a) (b)

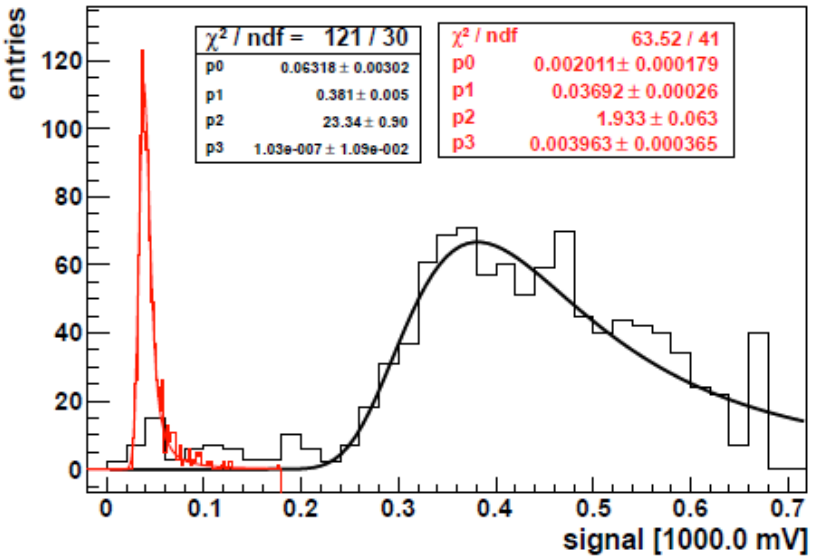


(c)

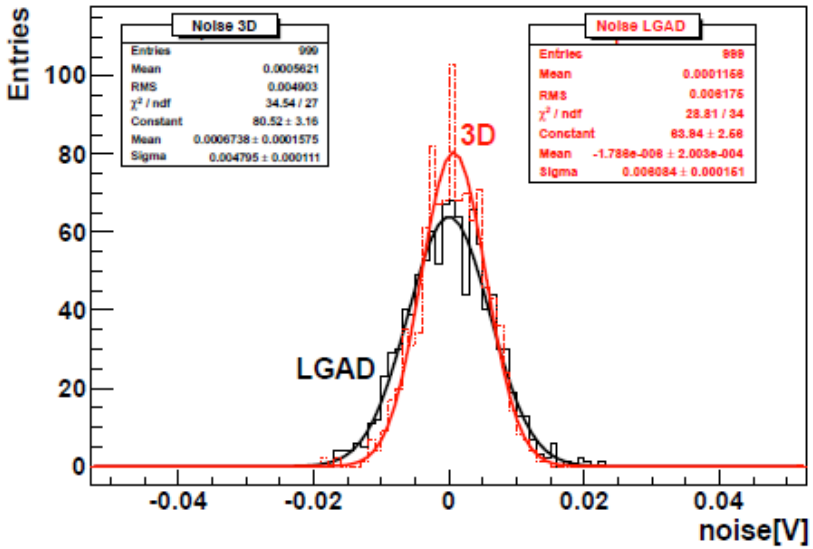
Fig. 6. (a) Time resolution dependence on a cell length of a square cell for different bias voltages at -20C. (b) Time resolution dependence on bias voltage for a 50×50 μm^2 cell at different temperatures.


average signal [V]
LGAD
3D - scaled
3D
t [ns]

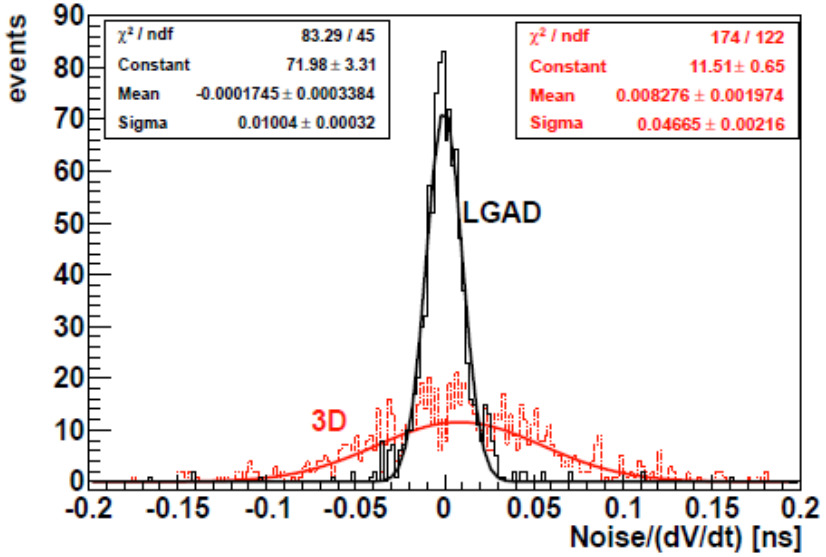
(a)


entries
χ² / ndf = 121 / 30
p0 0.06318 ± 0.00302
p1 0.381 ± 0.005
p2 23.34 ± 0.30
p3 1.03e-007 ± 1.09e-002
χ² / ndf 63.52 / 41
p0 0.002011 ± 0.000179
p1 0.03692 ± 0.00026
p2 1.933 ± 0.063
p3 0.003963 ± 0.000365
signal [1000.0 mV]

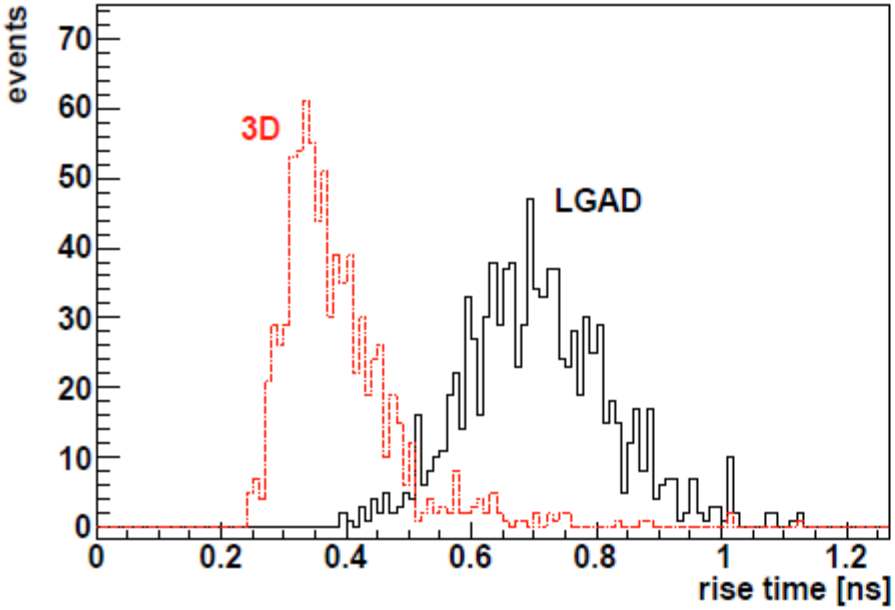
(b)

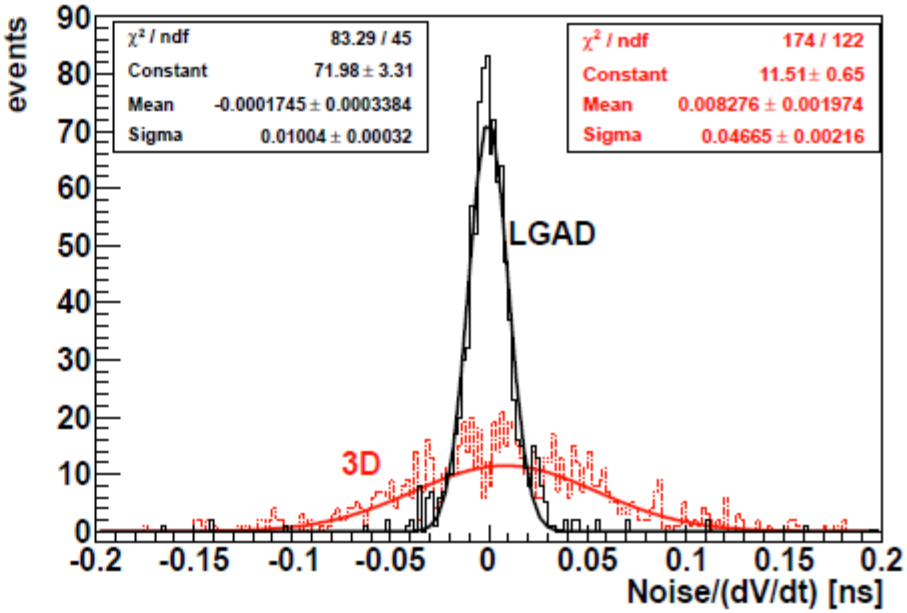

Entries
Noise 3D
Entries 999
Mean 0.0005621
RMS 0.004903
χ² / ndf 34.54 / 27
Constant 80.52 ± 3.16
Mean 0.0006738 ± 0.0001575
Sigma 0.004795 ± 0.000111
Noise LGAD
Entries 999
Mean 0.0001168
RMS 0.008175
χ² / ndf 28.81 / 34
Constant 83.84 ± 2.68
Mean -1.788e-008 ± 2.003e-004
Sigma 0.008084 ± 0.000161
3D
LGAD
noise[V]

(c)


events
χ² / ndf 83.29 / 45
Constant 71.98 ± 3.31
Mean -0.0001745 ± 0.0003384
Sigma 0.01004 ± 0.00032
χ² / ndf 174 / 122
Constant 11.51 ± 0.65
Mean 0.008276 ± 0.001974
Sigma 0.04665 ± 0.00216
LGAD
3D
Noise/(dV/dt) [ns]

(d)


events
3D
LGAD
rise time [ns]


events
χ² / ndf 83.29 / 45
Constant 71.98 ± 3.31
Mean -0.0001745 ± 0.0003384
Sigma 0.01004 ± 0.00032
χ² / ndf 174 / 122
Constant 11.51 ± 0.65
Mean 0.008276 ± 0.001974
Sigma 0.04665 ± 0.00216
LGAD
3D
Noise/(dV/dt) [ns]

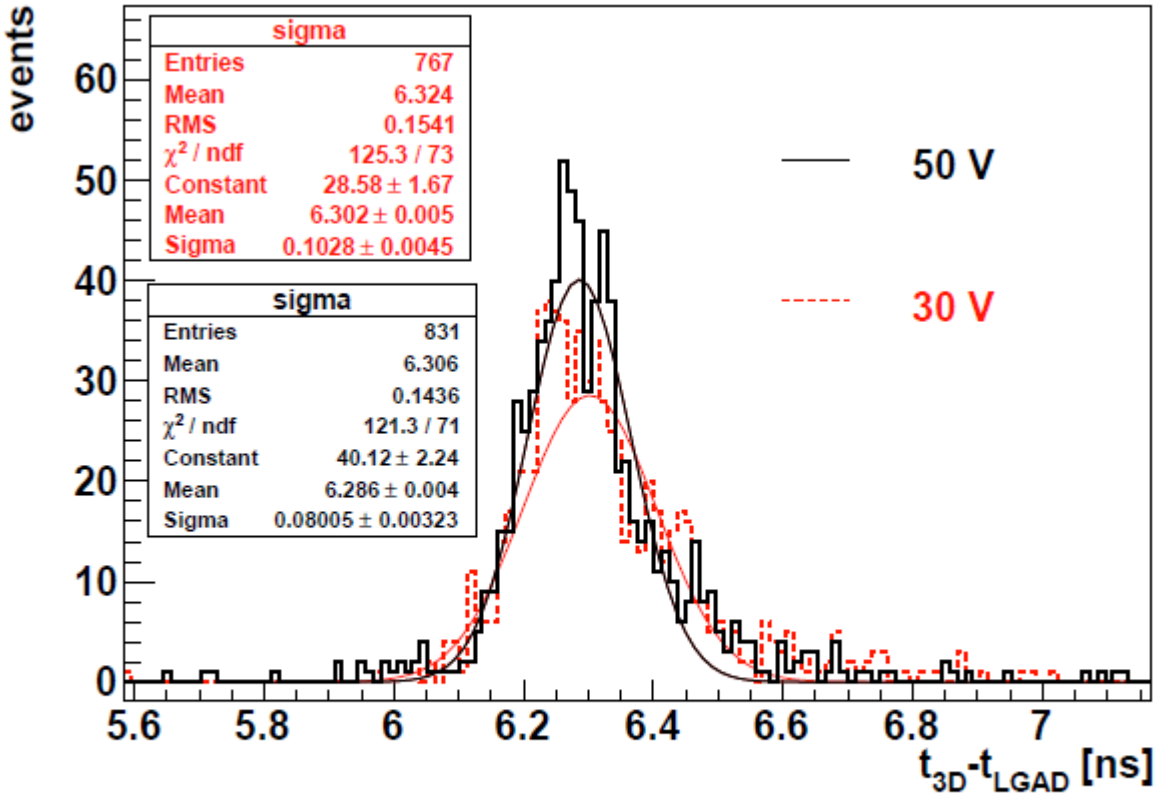


Fig. 10. Time resolution

$$\sigma_t^2 = \sigma_{LGAD}^2 + \sigma_{3D}^2 \rightarrow \sigma_{3D} = \sqrt{80^2\text{ps}^2 - 26^2\text{ps}^2} = 75 \text{ ps}$$

$$\sigma_{wf}^2 \approx \sigma_{3D}^2 - \sigma_{3D,j}^2 \rightarrow \sigma_{wf} \approx \sqrt{75^2\text{ps}^2 - 47^2\text{ps}^2} \approx 58 \text{ ps}$$