Ultra-Fast Silicon Detectors

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for the

UFSD Group

UCSC – Torino – CNM Barcelona – IJS Ljubljana- LPNHE

- First measurements on 75 um LGAD
- Contributions to UFSD time resolution
- R&D for ATLAS HGTD by CSM

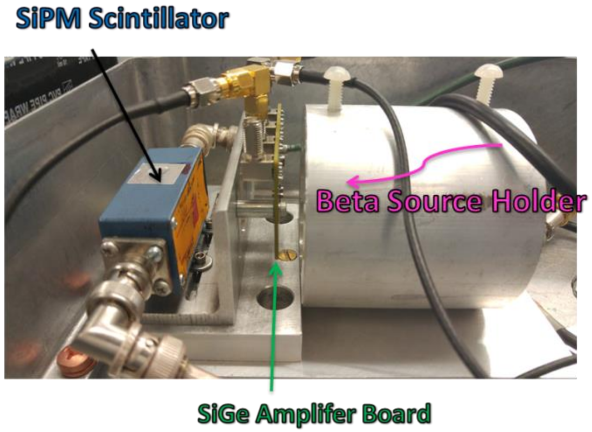
LGAD Testing with β source

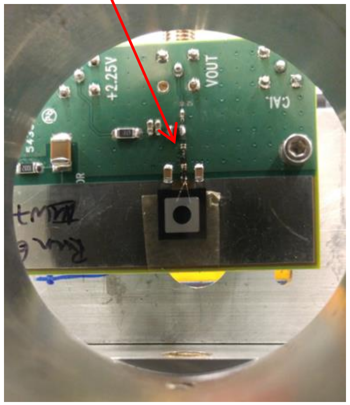
For the first beam tests we used commercial amplifiers with bias-T.

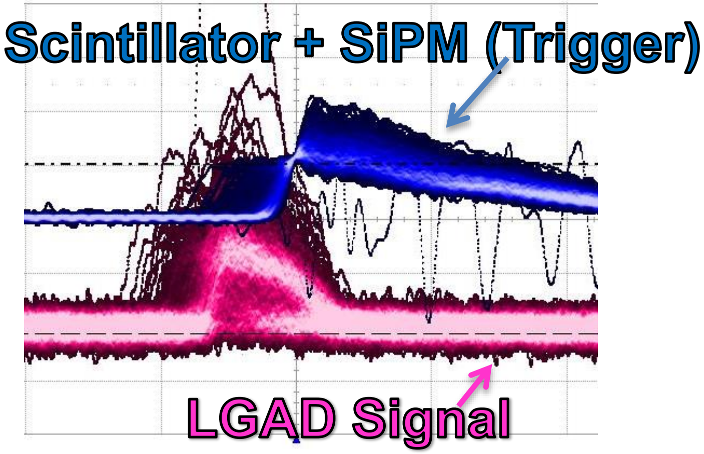
For the next tests with ^{90}Sr sources and beams, we developed a broadband amplifier
(BW > 2GHz, discrete SiGe frontend, analog readout into digital scope)

Signals in:
LGAD, power, sensor bias
Signals out:
single-ended analog signals into 50 Ω

Important: development of shielding
Use β source as test bed for signal and noise performance:
tune the details of the circuit with LGAD data!.
Precision measurements will be done in beam tests.



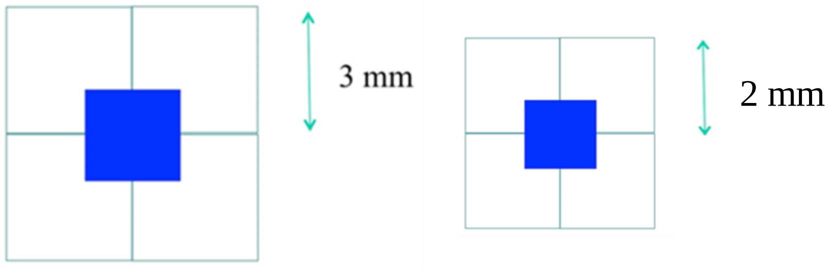




LGAD detectors for HGTD Beam Test

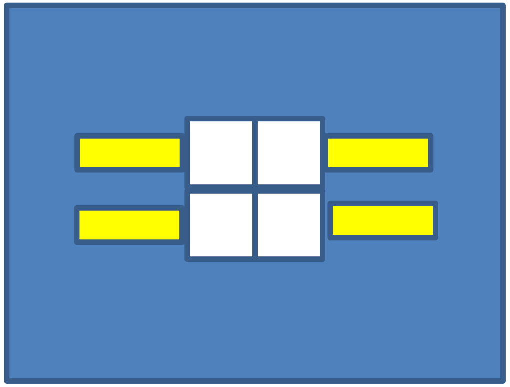
Expect by May 2016:
2x2 arrays of 3 mm and 2 mm side length
various thickness and doping concentration (see later slides)

2x2 array with 1 ASIC



Amplification and time digitization is required locally for trigger
ASIC development just starting

For the first beam tests plan to use
broadband amplifier developed by UCSC
4 amplifier channels (~ 1mm width)
wire-bonded to 2x2 array

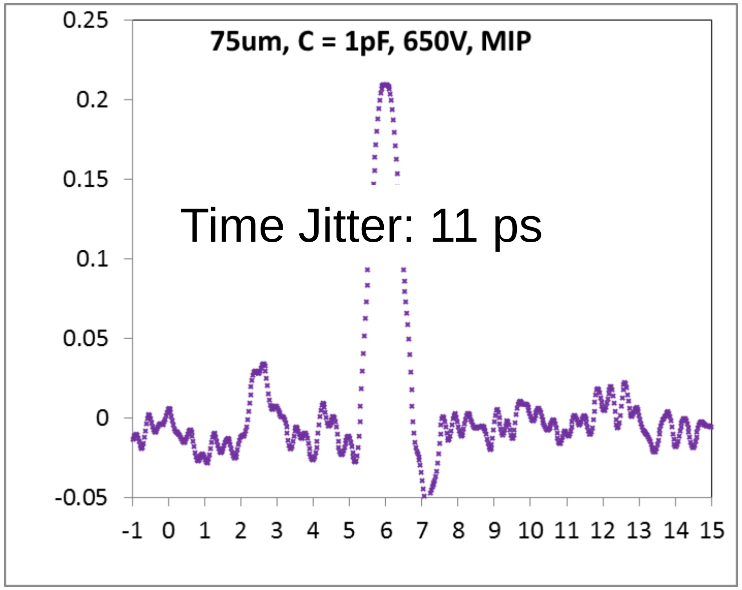


β Beam data with 75 um LGAD (G = ?)

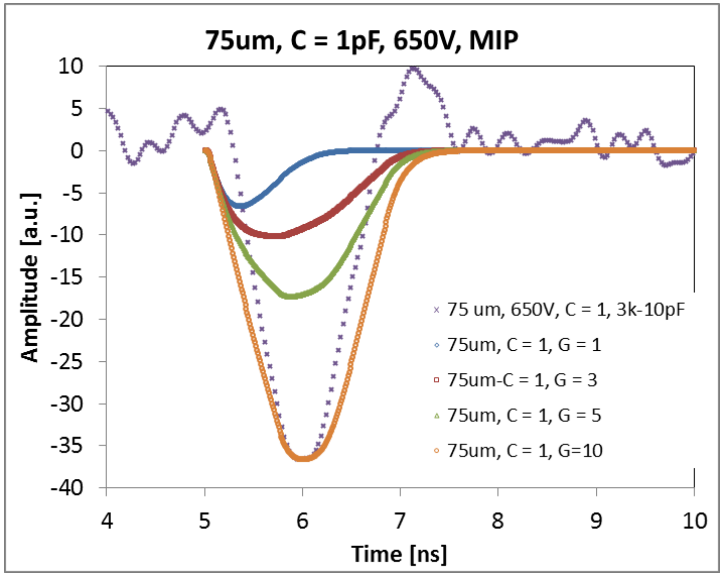
75 um, β's

Pulses shorter than simulation!?

Ave. Time Jitter < 40ps



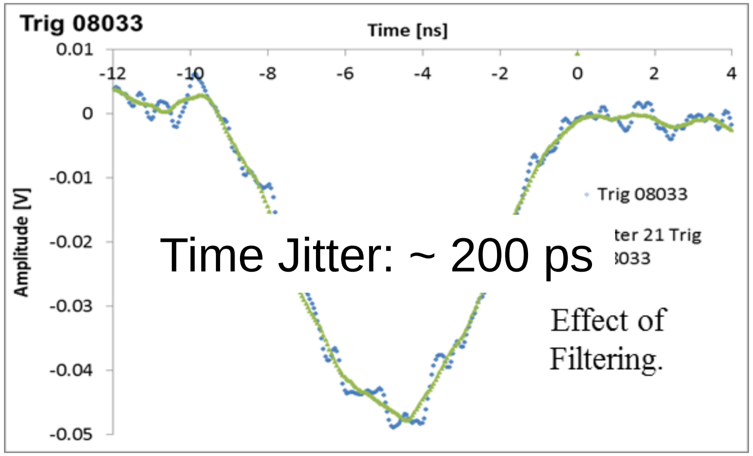
Time Jitter: 11 ps



Pulse shape suggests gain G ≈ 10!

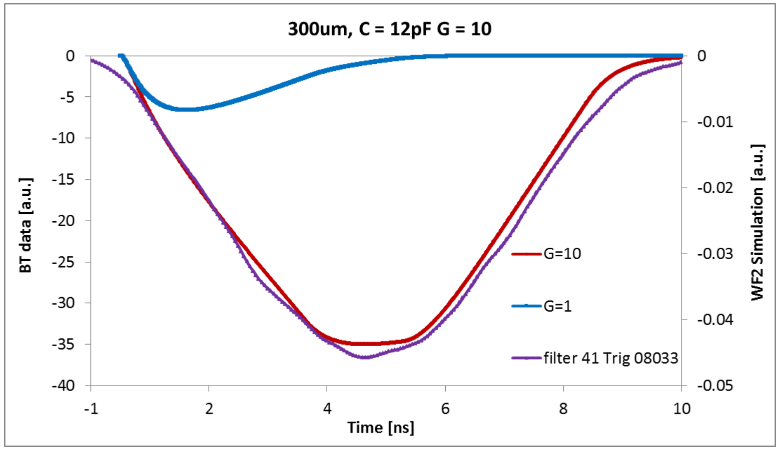
300 um, CERN BT

Filtered time resolution ~100ps

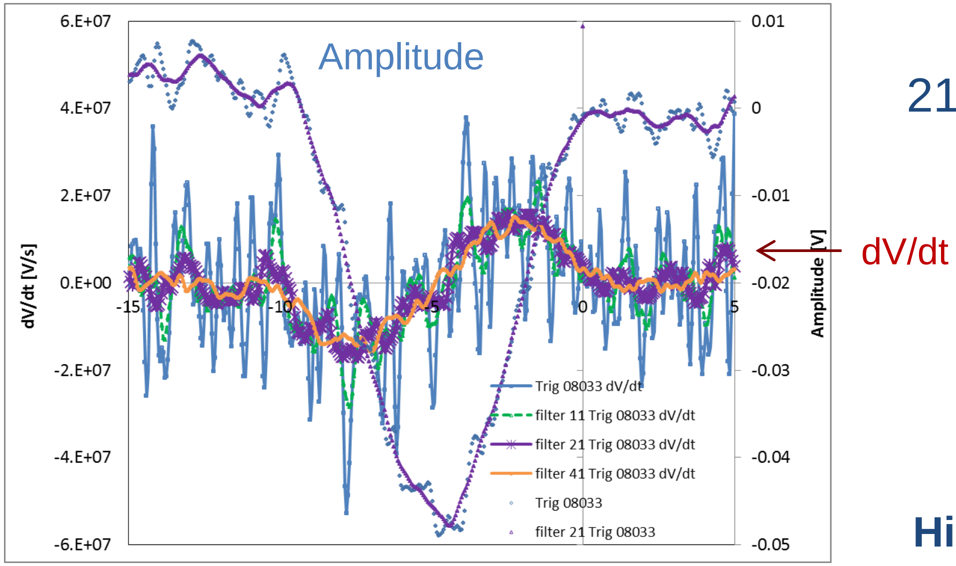


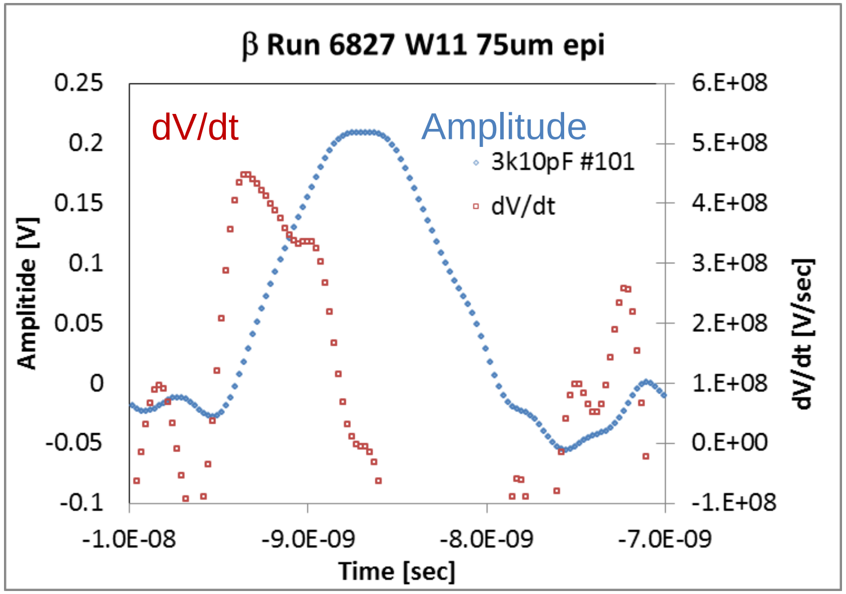
Time Jitter: ~ 200 ps

Effect of Filtering.



dV/dt Comparison of 75 um - 300um LGAD

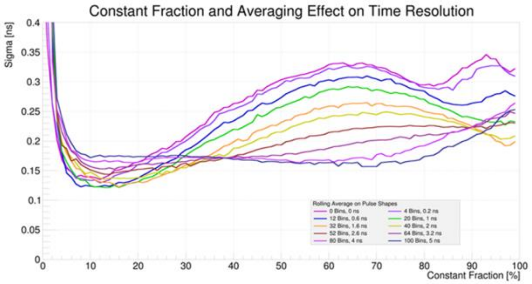




<u>300um:</u>

21 average used to reduce noise

1 ns shaping ≈ 1/3 of rise time



High frequencies not important for 300um

(Need to adjust the CFD threshold)

High frequencies very important for 75um

(only for BB)

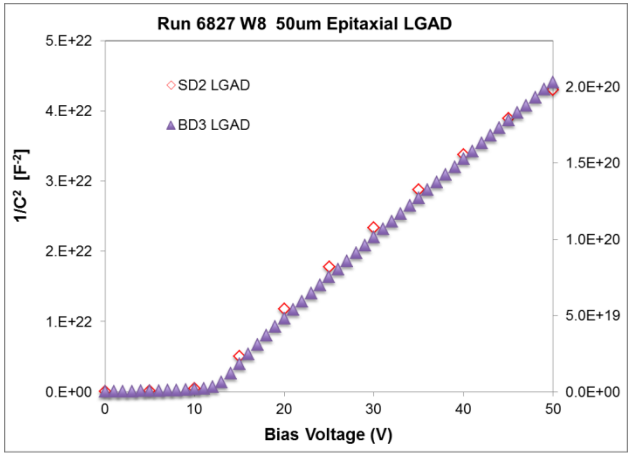
<u>75um:</u>

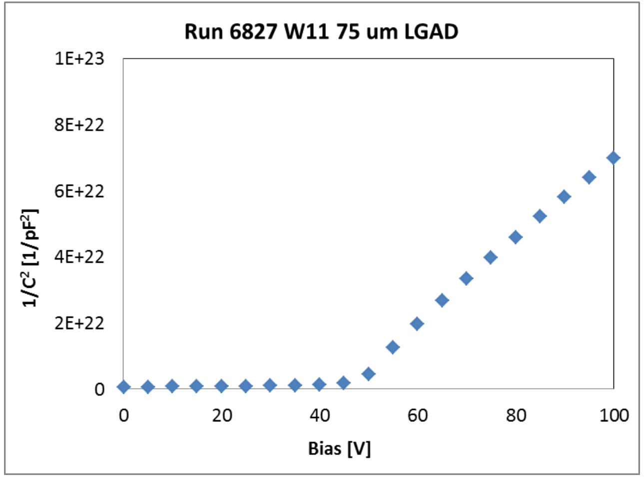
21 averages reduces dV/dt by ½

500 ps shaping ≈ rise time

Fast, low-noise amplifier a requirement

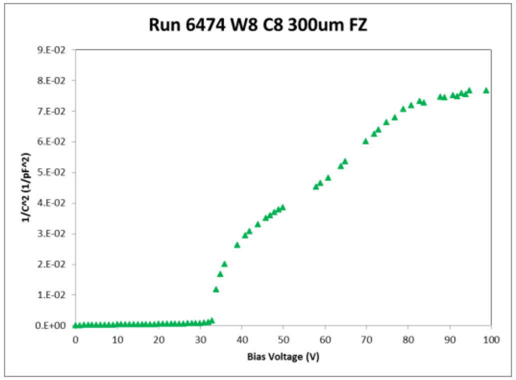
C-V 50um (W8) & 75um (W11) epi LGAD Run 6827





50um: C-V suggests gain G < 3!
also measured

75um: C-V suggests gain G > 10!



300um:
measured gain G > 10!

Toward LGAD Specifications for HGTD

Larger cell size, higher gain, lower resistivity (?) ==> increased shot noise,
Larger cell size ==> increased electronic noise (CSA), lower dV/dt (BB)
Thicker sensors ==> increased Landau Noise
Lower input impedance ==> lower trans-impedance

Electronics and sensors are closely coupled.
Both LGAD and no-gain n-in-p are being considered

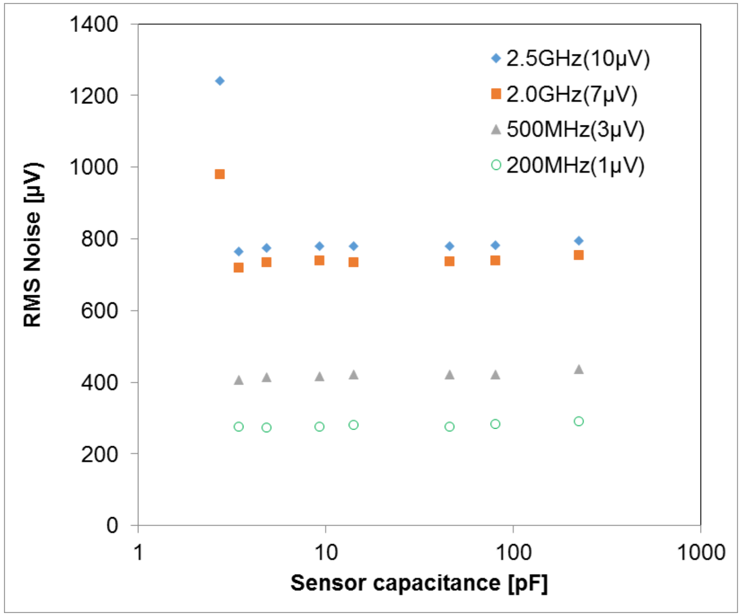
To get to 10 ps jitter:
- dV/dt at threshold > 0.5 uV/ps ?
- Noise (into 50Ohm) < 5 uV ?

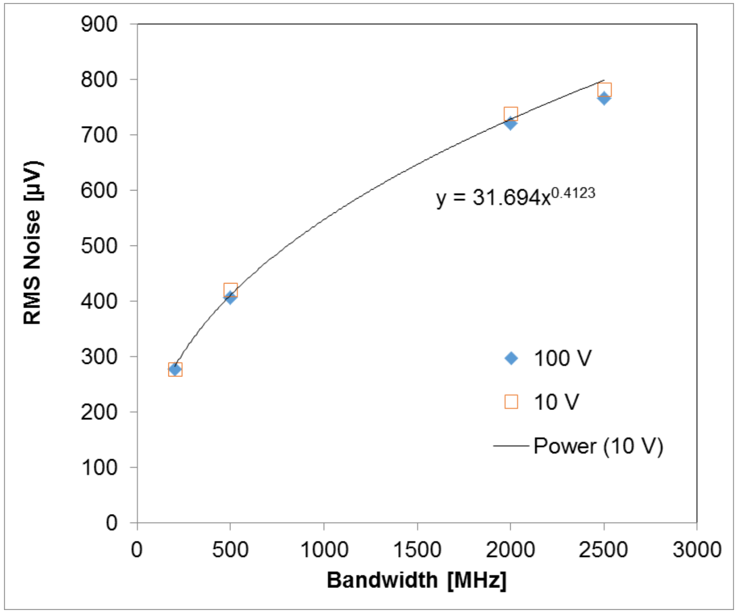
LGAD details (all numbers TBD):
- Gain 10 - 20
- Thickness <100 um
- Resistivity 0.1 - 10 kΩ-cm
- Cell size dimension 2-5 mm
- Impedance at amplifier input 20 – 50 Ω
- Radiation Hardness (Leakage current, Noise, dV/dt)
- Power per cell
- Power per cm^2

Jitter

Time Jitter = Noise/slope = Noise / (dV/dt)

Hard to predict the noise in the moment.
At least we know that for BB it is constant vs capacitance.
Need to know what it is as a function of the input impedance.
(Data taken with amplifier with gain = 130 shows 4uV at 1 GHz.)



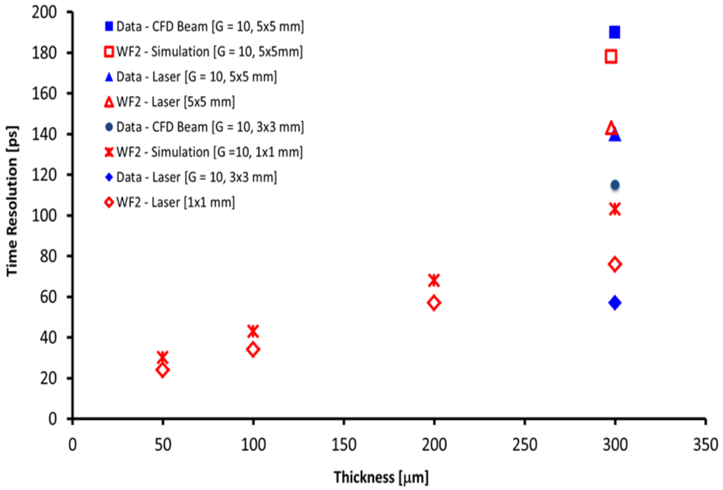


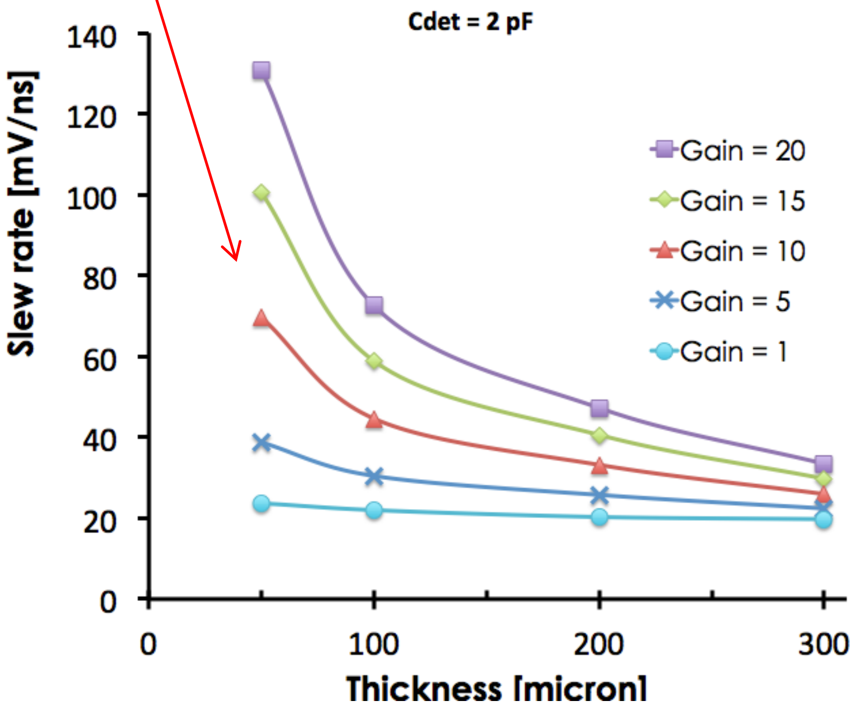
Slew-rate (Slope) dV/dt

Assume that the resolution scales with slope dV/dt.

For 50um LGAD (G=10), required dV/dt = 0.7 uV/ps (correcting for gain = 100 in WF2).

Slope dV/dt = 0.5 uV/ps would give 40ps



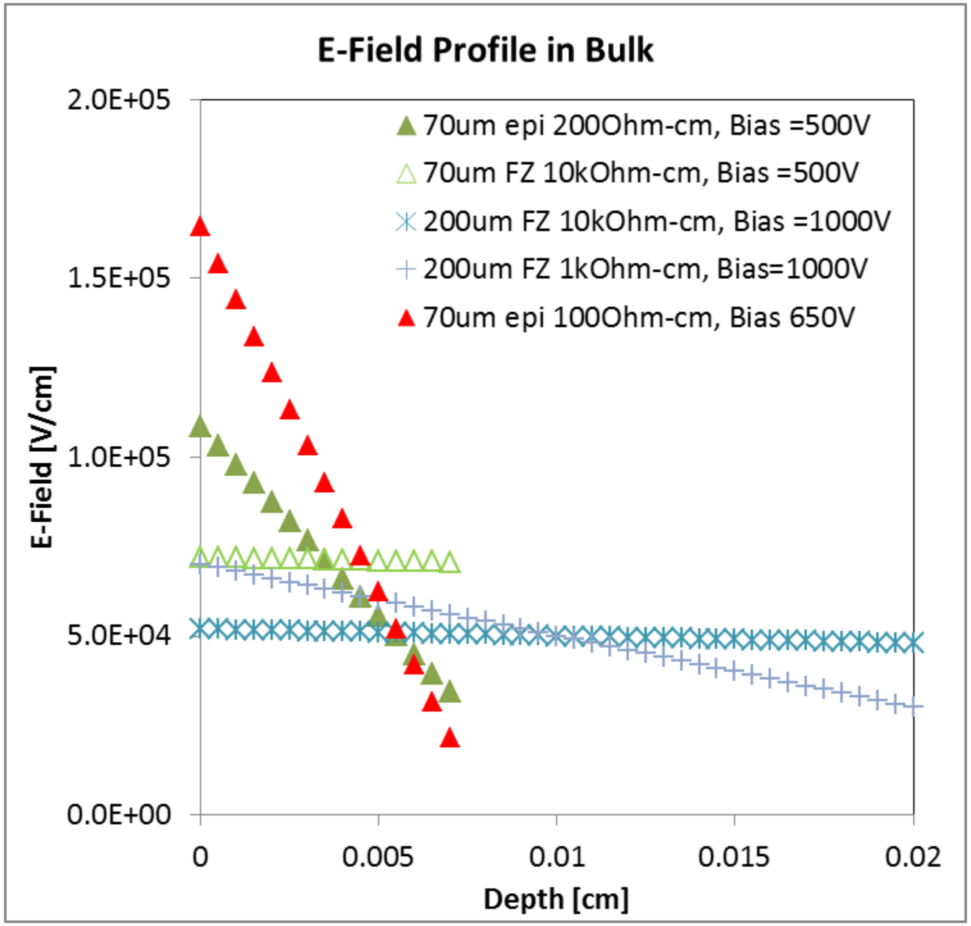


Bulk Resistivity

Resistivity 0.1 - 10 kΩ-cm

Low-resistivity bulk (100 Ω-cm) generates high field at the junction (about ½ what is needed for LGAD).

Only half needs to be supplied by p+ multiplication layer



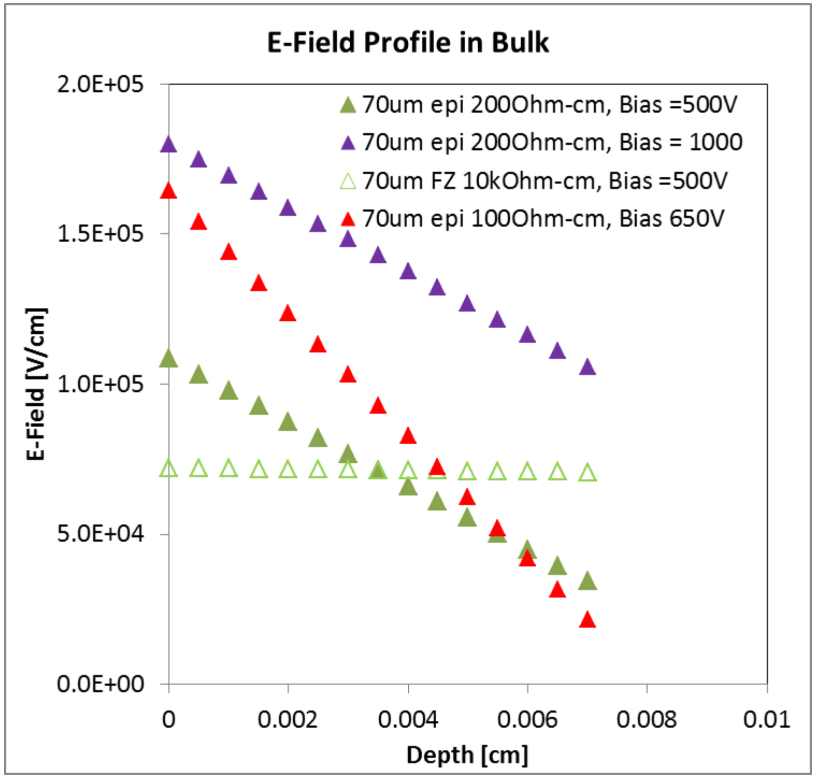
Observe remarkable bias reach in low-resistivity LGAD

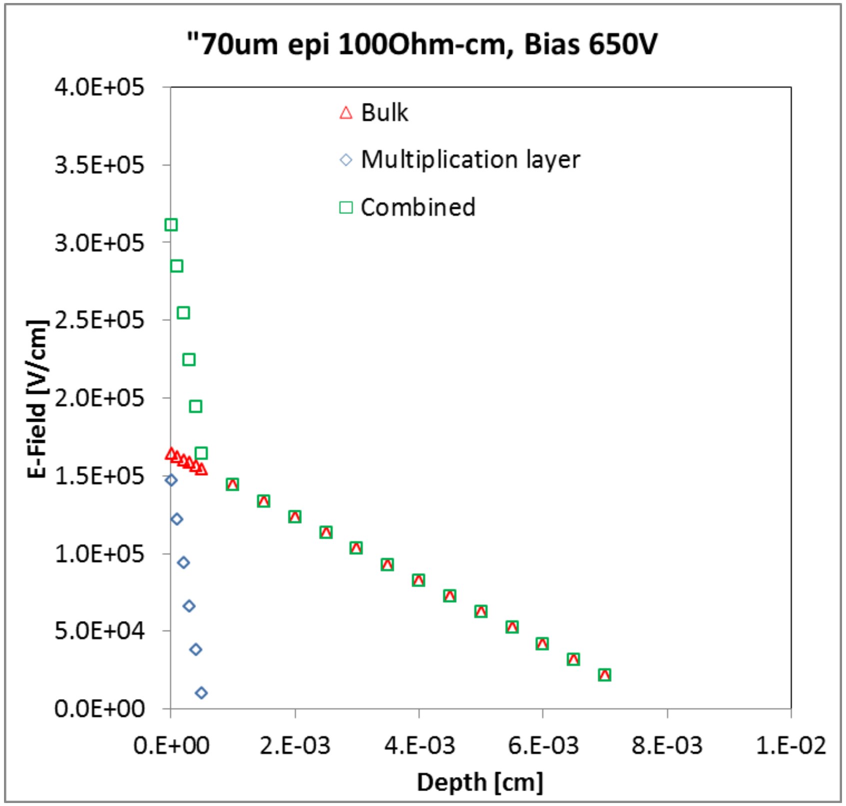
We are operating 50um & 70um epi sensors with 100 Ω-cm bulk at 650 V bias.

E-field in LGAD bulk adds to the “gain field”

Hartmut F.-W. Sadrozinski, 75 um LGAD, "Trento" 2016

Low-resistivity bulk (100 Ω-cm) generates high field at the junction (about ½ what is needed for LGAD).
Only 1/2 is supplied by p+ multiplication layer





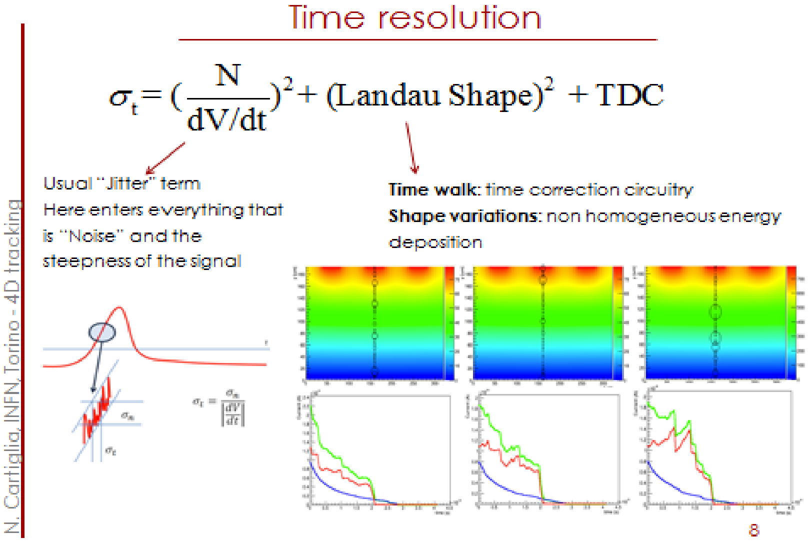
Near-term: thin 4” wafers at CNM

SOI 100um & 150um > 5kΩ-cm

Epi 50um 100Ω-cm; 75um 100Ω-cm; 110um 600Ω-cm

Hartmut F.-W. Sadrozinski, 75 um LGAD, "Trento" 2016

Landau Fluctuations



Time resolution

$$\sigma_t = \left(\frac{N}{dV/dt}\right)^2 + (\text{Landau Shape})^2 + \text{TDC}$$

Usual "Jitter" term
Here enters everything that is "Noise" and the steepness of the signal

Time walk: time correction circuitry
Shape variations: non homogeneous energy deposition

N. Cartiglia, INFN, Torino - 4D tracking

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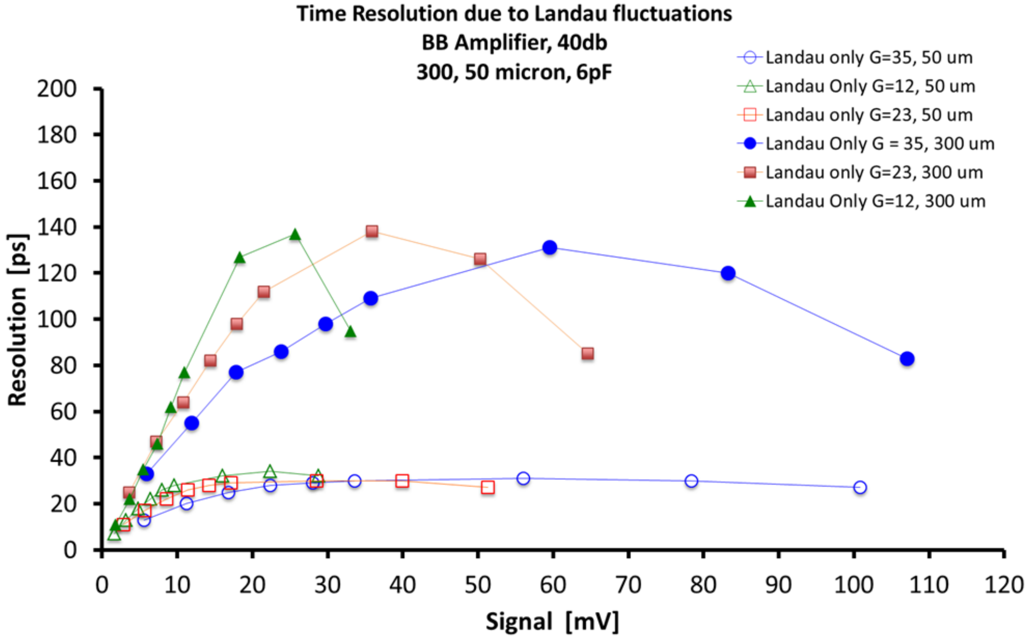


Time Resolution due to Landau fluctuations
BB Amplifier, 40db
300, 50 micron, 6pF

Beam Tests show that we can correct for time walk.

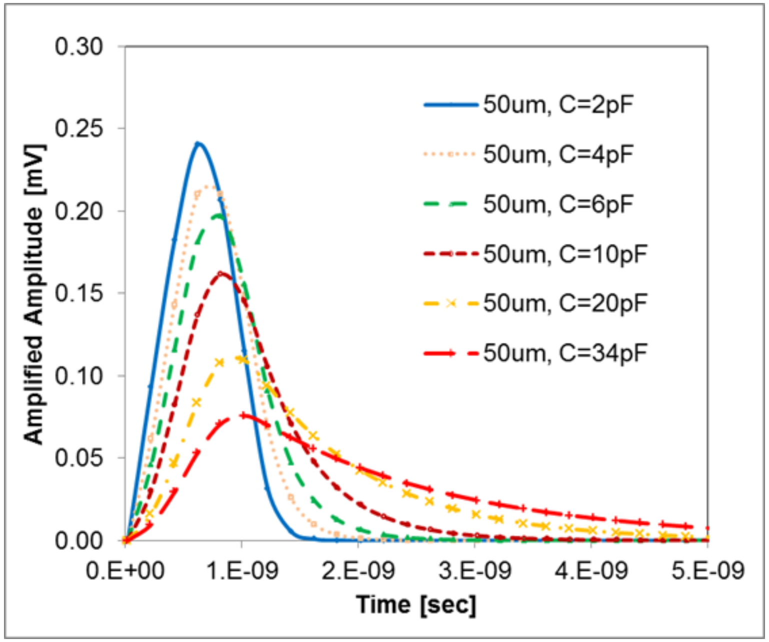
So assuming we can beat the time jitter with lower noise and higher gain, Landau fluctuations become the time resolution floor which we can't go below.
They depend on the sensors thickness, independent of the gain.

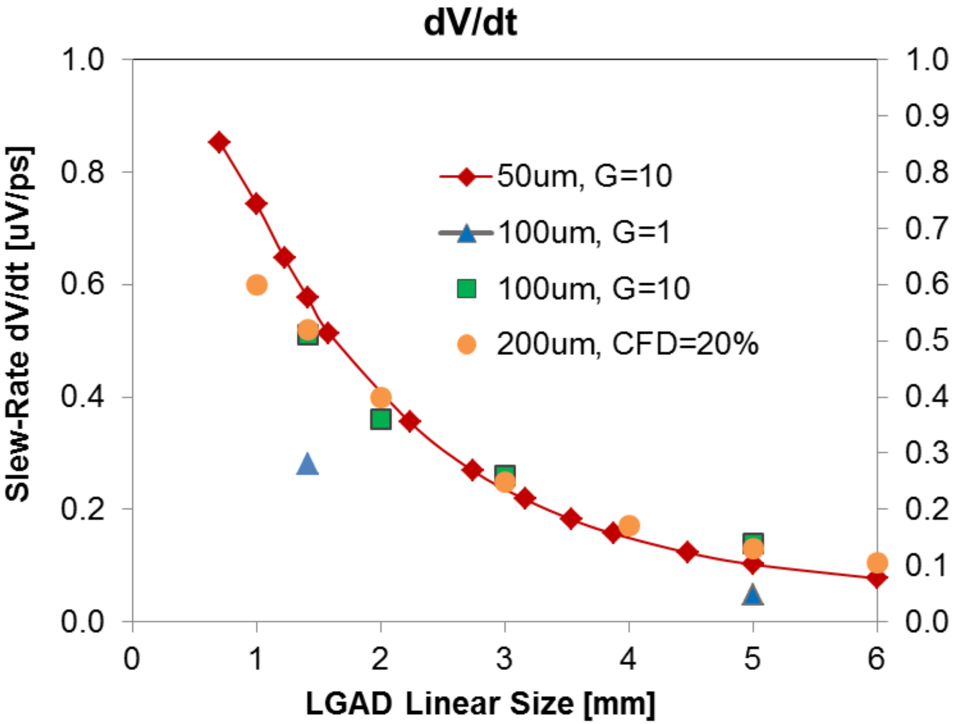
Both thin sensors, and low threshold are required for good timing resolution:

Another reason to develop low-noise amplifiers

Cell Size

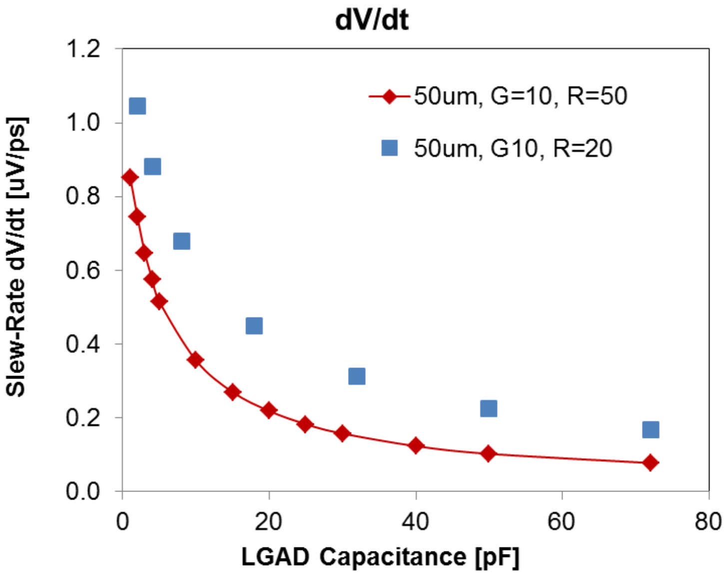
Cell size dimension 2-5 mm
Need gain, need small detector sizes to get to sufficient dV/dt Into 50Ω

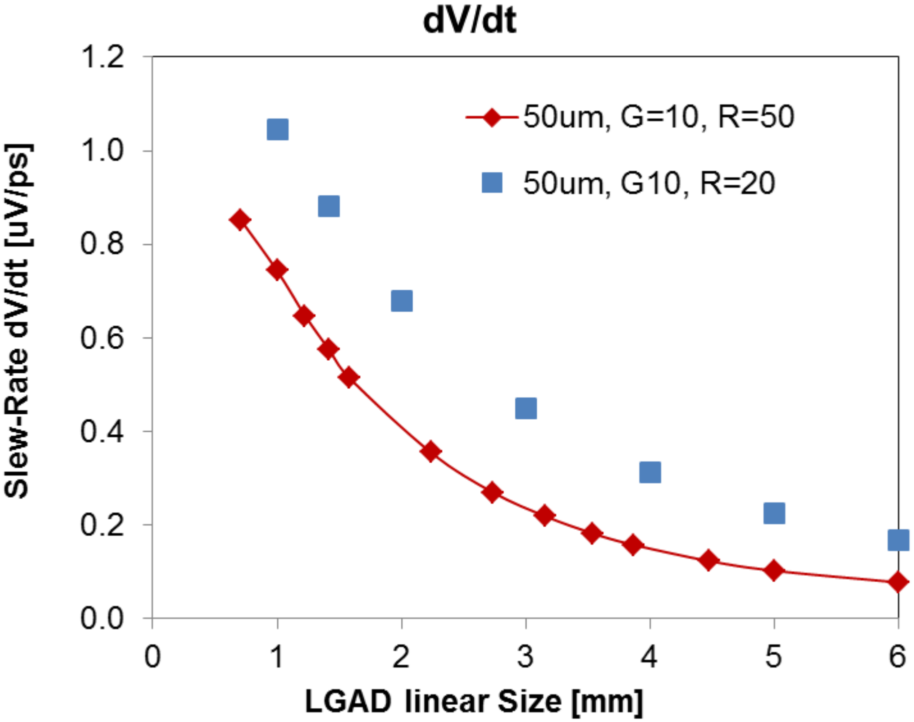




Impedance at Amplifier Input 20 – 50Ω

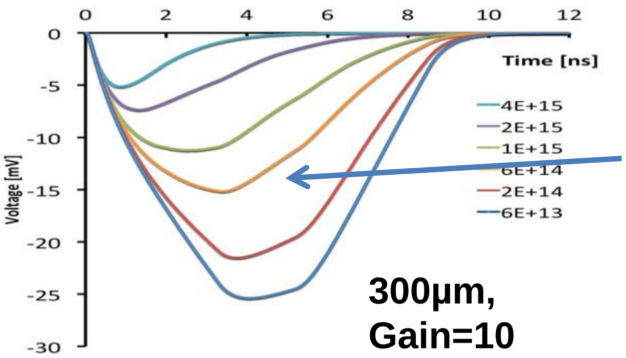
Lowering the amplifier input impedance allows higher slope dV/dt.
We need to assertain that the noise scales exactly, too.



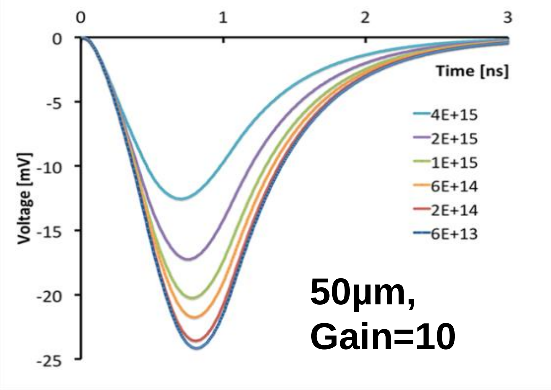


WF2 Simulation: Radiation Damage (Trapping)

Effect of trapping in thick and thin detectors at large fluences is different since the trapping distance is ~ 50 µm.

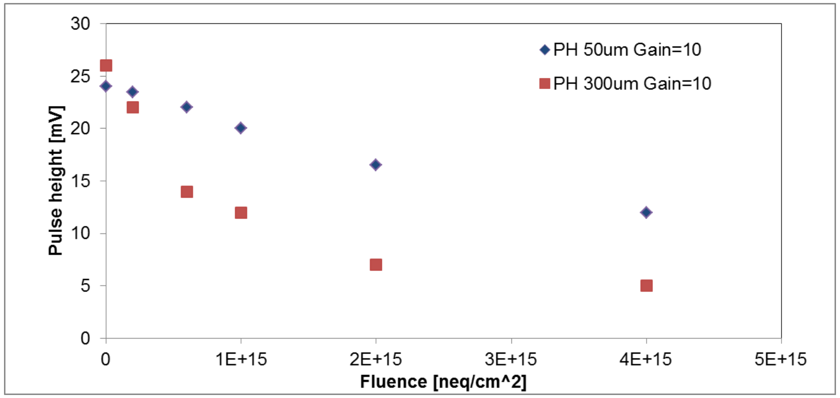


Effect of trapping: gain holes disappear, looks like a change in gain



The rising edge of thin sensors is essentially insensitive to trapping: good for timing!

Trapping:
Degradation of pulse height in 4*10^{15} neq/cm^2
down to ~ 20% for 300 µm LGAD
down to ~ 50% for 50 µm LGAD

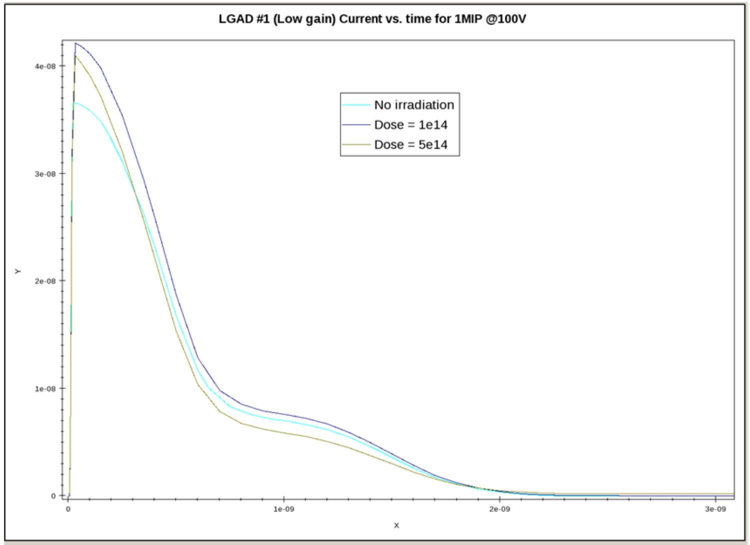


An additional effect resulting in a decrease in gain beyond trapping has been reported in 300 µm LGADs and is being investigated on 50 µm LGAD.
Investigate restoring gain loss after irradiation with increasing the bias voltage.
Pursue program to improve radiation tolerance by replacing Boron with Gallium.

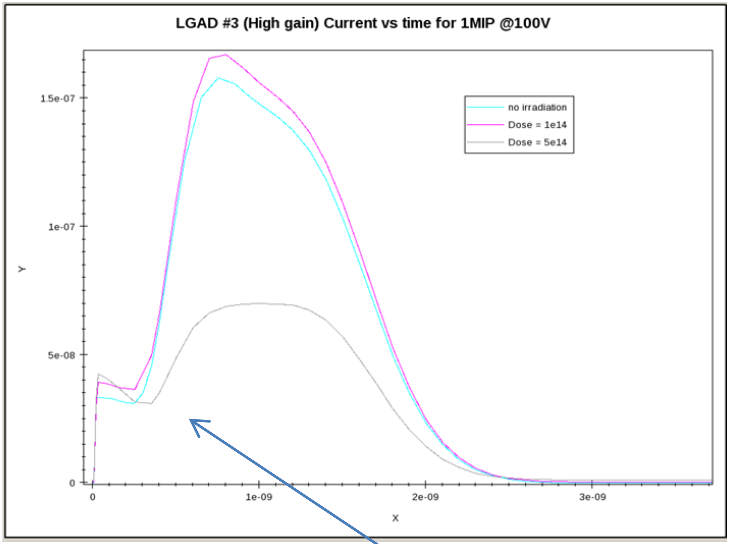
Weightfield 2 (WF2) Implementation and Simulation: Bianca Baldassari

Sentaurus Simulations (Julie Segal, SLAC)

LGAD #1 (low gain) 50um thick
Current vs. Time for 1MIP @100V Bias
No radiation, 1e14, 5e14



LGAD #3 (high gain) 50um thick
Current vs. Time for 1MIP @100V Bias
no radiation, 1e14, 5e14



N.B. “1MIP” relates to the amount of charge is injected into the backside of the LGAD: maximum .

Similar results are reported by many groups: TCAD works “right out of the box”

We are now measuring LGAD which were irradiated with protons at Los Alamos and neutrons at Llubljana.

HGTD Simulation, Design and fabrication.

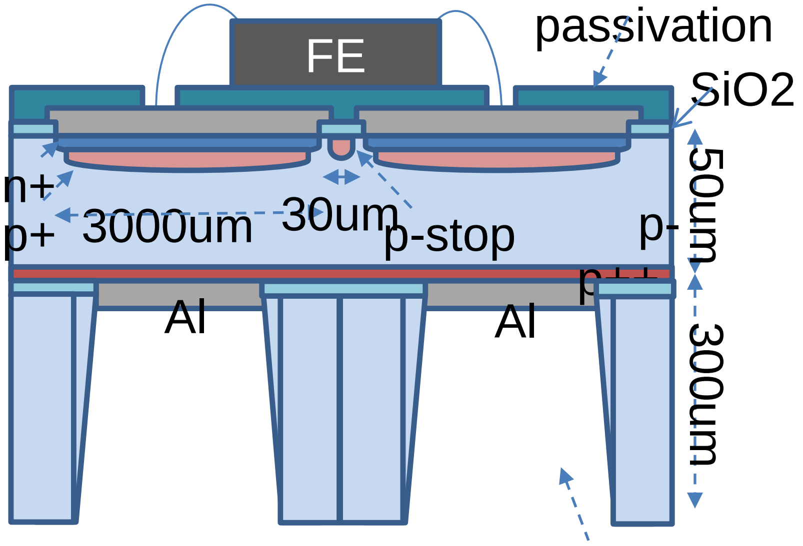
G. Pellegrini, M. Carulla, S. Hidalgo, D. Flores, D. Quirion

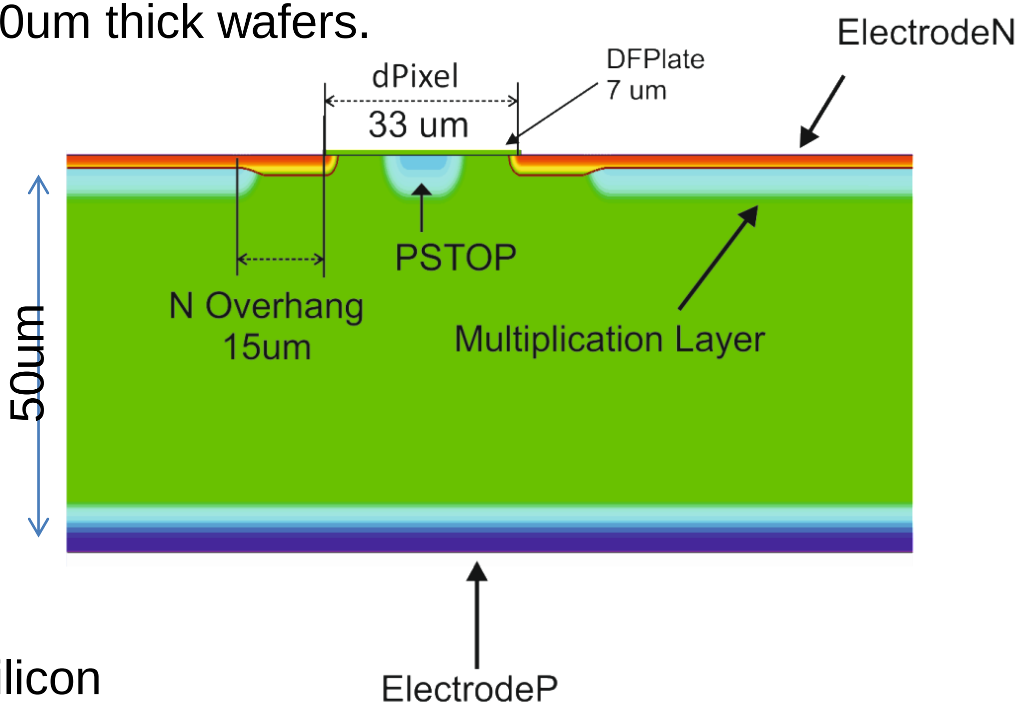
Design of HGTD ATLAS LGAD

- 3x3 mm^2 and 2x2mm^2 pads separated by 33um (optimized by simulation).
- P-stop isolation.
- 50um thick active area. Support wafer can be etched away leaving a mechanical structure for mounting the read out chip and wire bonding.
- Each chip reads out 4 channels.
- Gain is set by the thickness of the substrate (max bias expected 200V due to the planar junction breakdown), a complete (technological and electrical) simulation has been performed using Sentaurus and Silvaco to find the parameter necessary for the fabrication. Expected gain 6-10
- Fabrication steps are the same than standards LGAD (with the thermal steps and implant energy and dose to be optimized by simulation).
- First fabrication in 4” SOI wafers. Fabrication started in February 2016, wafers should be ready by May 2016.
- Then fabrication should be optimized in 6” wafers. At the moment CNM is already doing a run of LGAD detectors in 6” wafers, 200um thick. The run is due in 2016.
- Open question: are they radiation hard? Fluences expected up to 5x10E15neq/cm2.

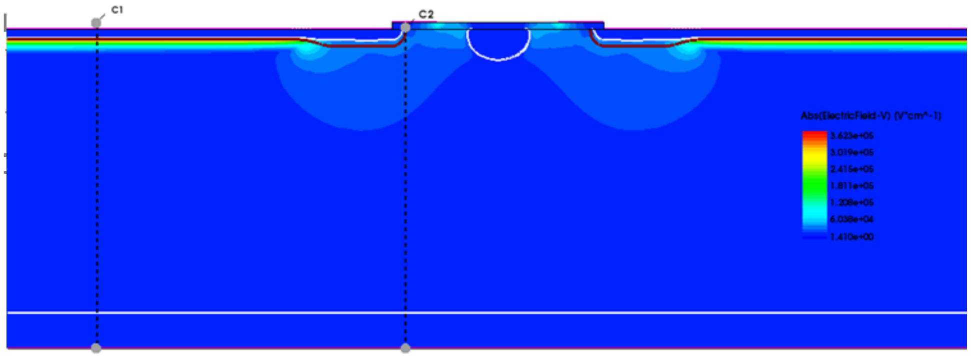
Core Structure

Multiplication dopant implant as measured by SIMS. The fabrication process is the same as for the standard 300um thick wafers.

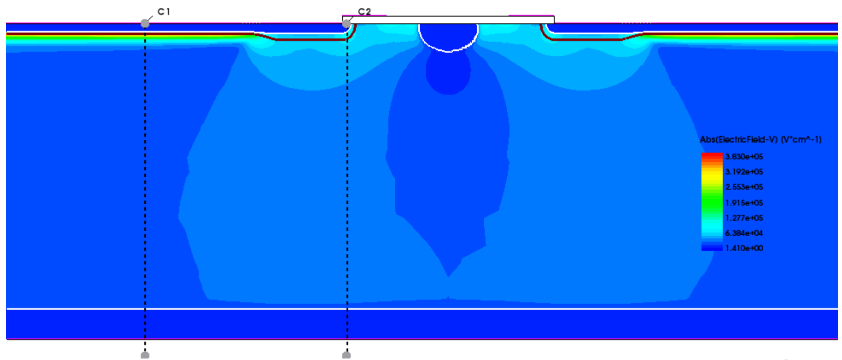




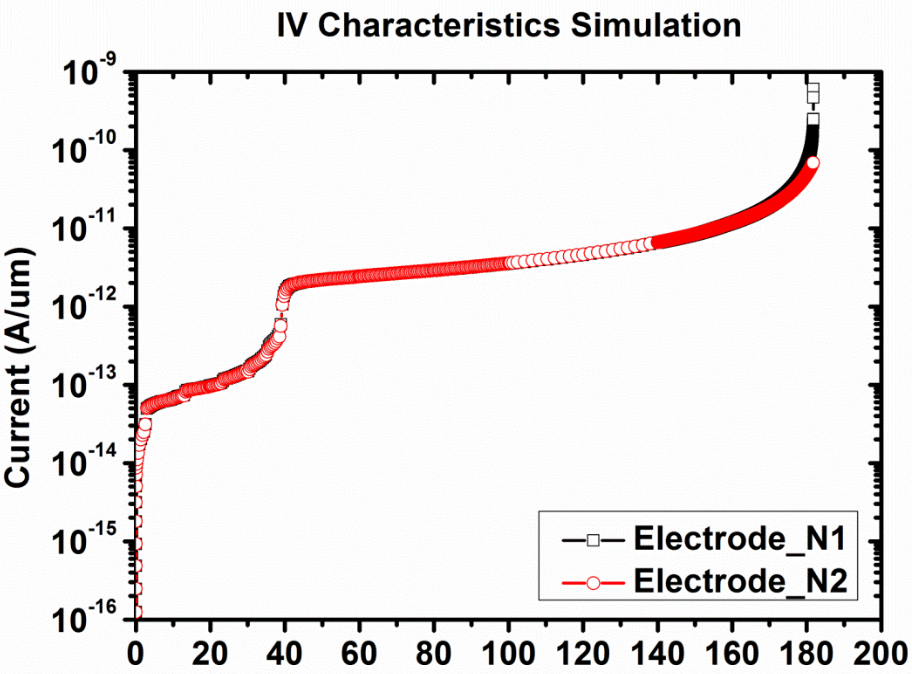
Electric Field @ 50V



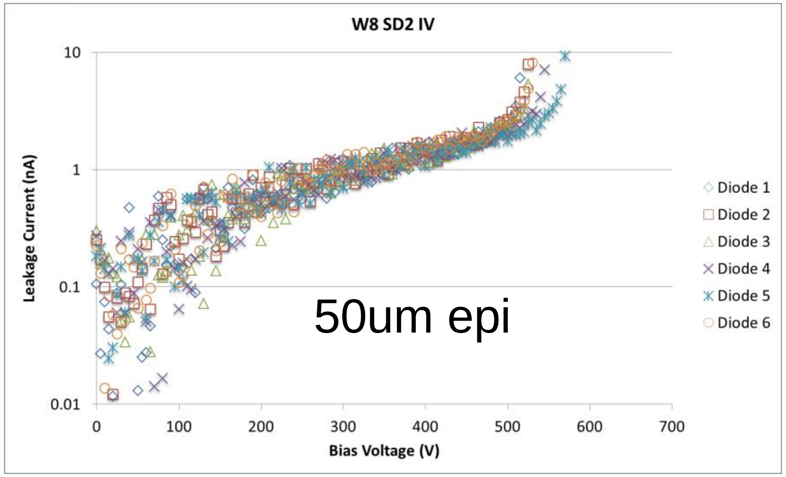
Electric Field @ 140V



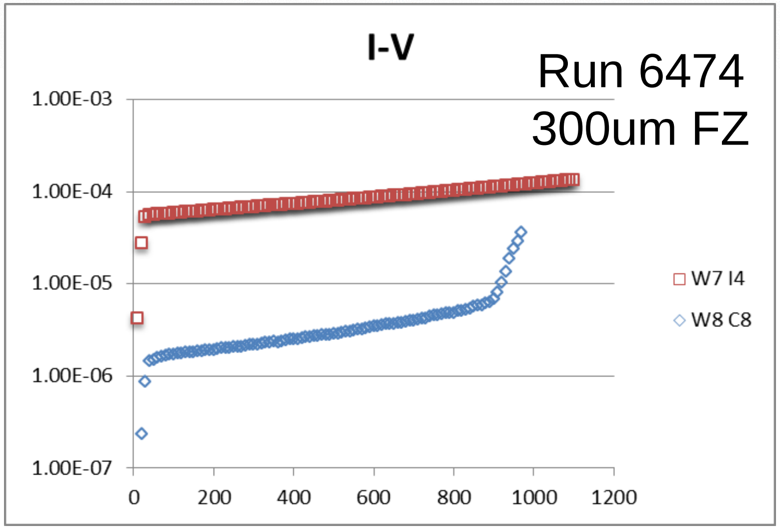
I-V Characteristics of thin detectors



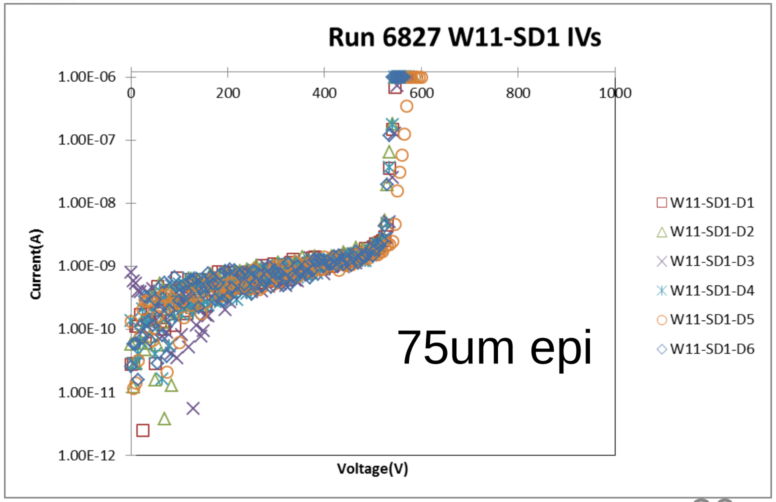
Beware of the dimensions of the active volume



50um epi



Run 6474
300um FZ



75um epi

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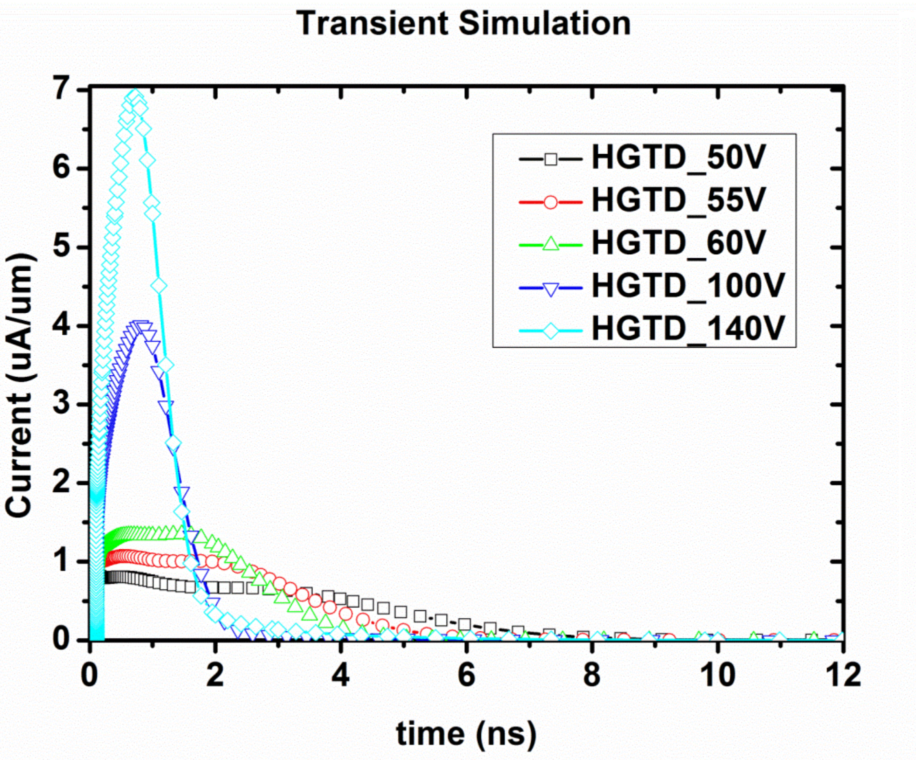
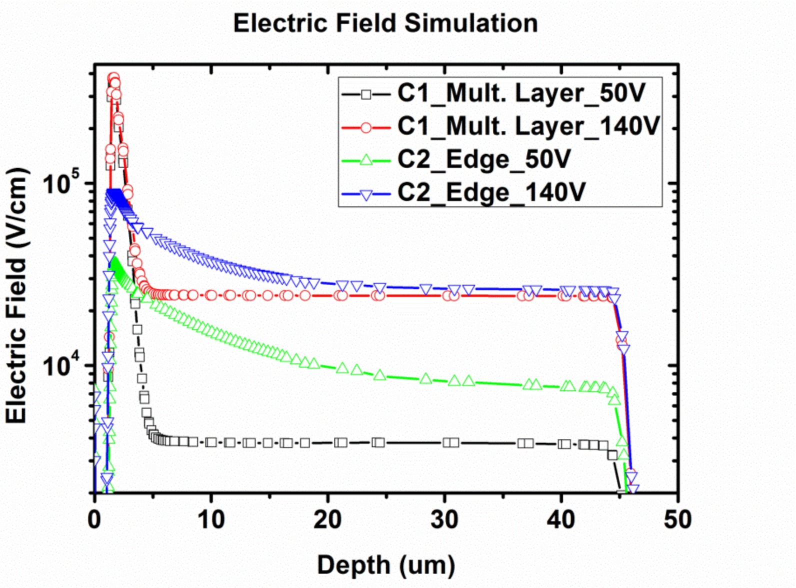
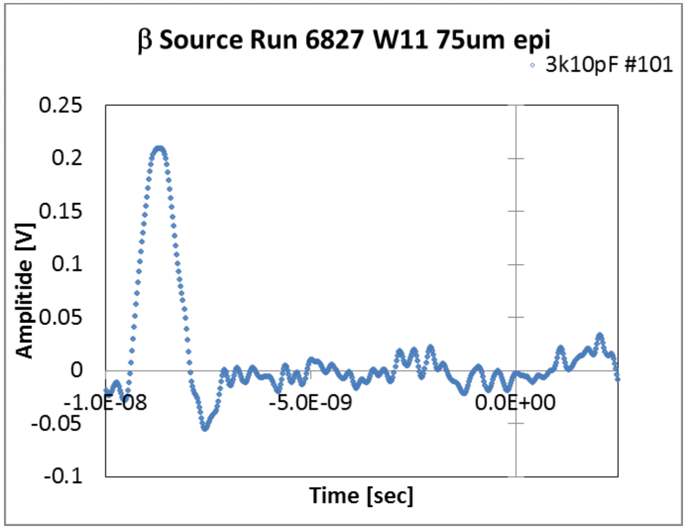
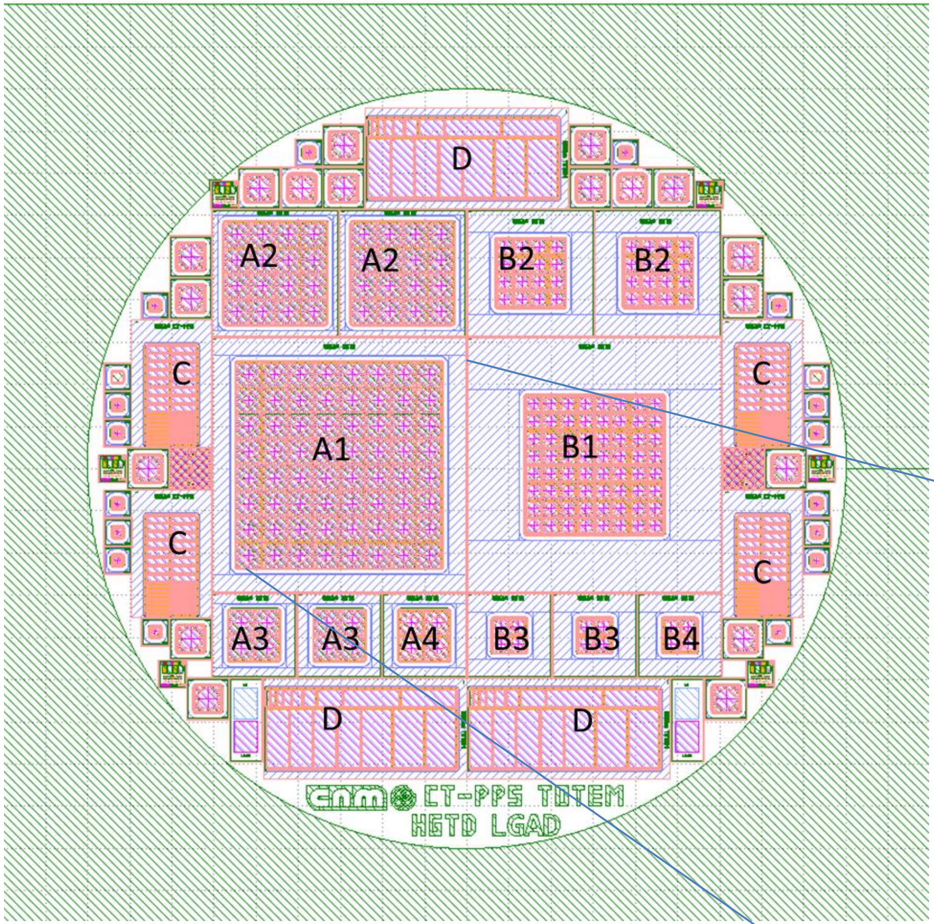
Transient Simulations and Measurements



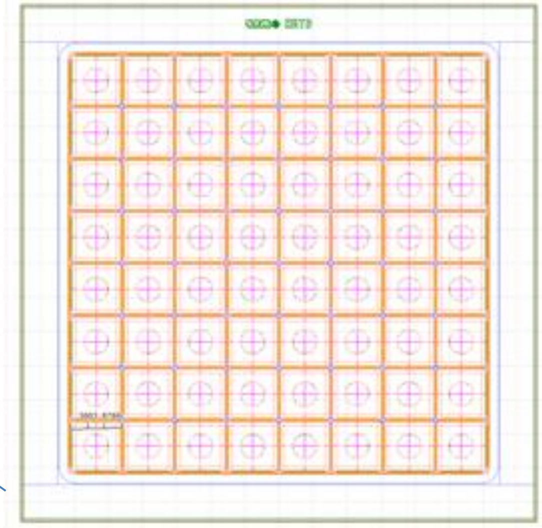




CNM Wafer Layout



A1=8x8 matrix, 3mm pad
B1=8x8 matrix, 2mm pad
A2=4x4 matrix, 3mm pad
B2=4x4 matrix, 2mm pad
A3=2x2 matrix, 3mm pad
B3=2x2 matrix, 2mm pad
A4=2x2 matrix, 3mm pad, PIN
B4=2x2 matrix, 2mm pad, PIN
C=CT-PPS
D=TOTEM detector
Different diodes and test structures.



3x3mm2 pixels.
Hole in the metallization
JTE only in the guard ring.
P-stop isolation.

Contributors

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Conclusions

- We took data in a triggered β source with 75um thick epi LGAD with gain G ≈ 10 and measured a jitter of less than 40 ps.
- The timing resolution in beam and laser tests are confirmed by the Weightfield 2 simulations.
- We are developing specifications for LGAD to be used in the ATLAS HGTD.
- We are looking forward to the next production run of UFSD at CNM available in May 2016.
- **Thanks to the organizers for arranging this year's "Trento" meeting in Paris!**