Timing in pixel detector

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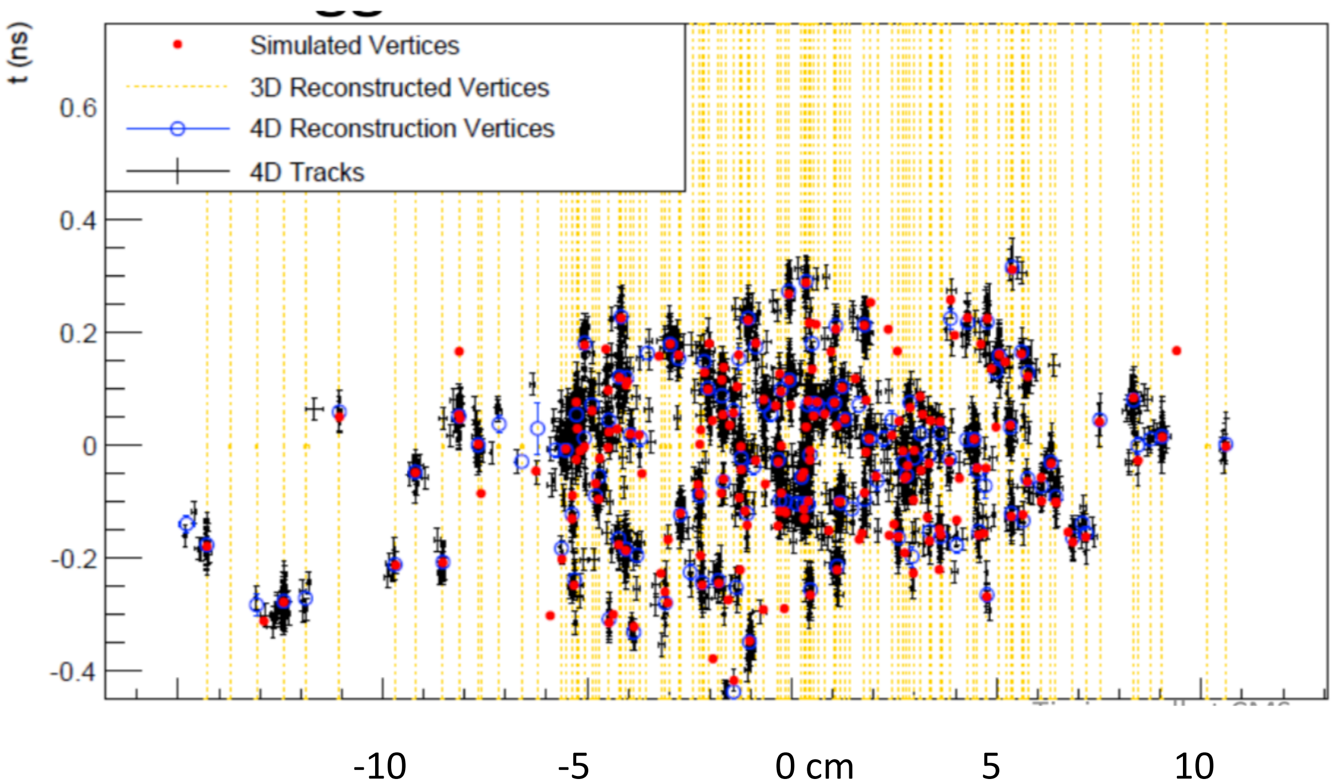
Lots of slides taken from others :
Especially Hartmut Sadrozinski
(Torino timing workshop 2018, RD50 2018)

Assuming we are really behind … punchline :

- Timing resolution most helpful for Z0 resolution in extended tracking region
  - ATLAS timing layer $2.4 < |\eta| < 4.0$, disk at z = 3.4m, 3 layers of 1.3 x 1.3 mm^2 LGADs
  - CMS has timing $|\eta| < 3.0$, LGADs for $1.5 < |\eta| < 3.0$ at 2.7m, 1 layer of 1x3 mm^2
- Possibility to extend timing into pixel detector ?
  - 4^{th} layer of EPIX could be replaced (LS 4 ?) with a small-pixel (0.1 x 0.1 $mm^{2)}$ LGAD
- Challenges -> Solutions
  - Radiation tolerance -> carbonated Boron shows improvement, R&D ongoing
  - Fill factor : Dead region in gain layer to separate pads -> AC-LGADs, I-LGADS
  - Readout chip : Will require more groups to join effort, perhaps free personpower after RD53 development
  - Power and cooling : needs more since sampling faster. Small capacitance is a plus
  - ATLAS has 3 timing hits : CMS would only have one (degrades with radiation) -> ?

Timing and pile-up

- CMS has timing layer coverage with goal of σ = 30 ps



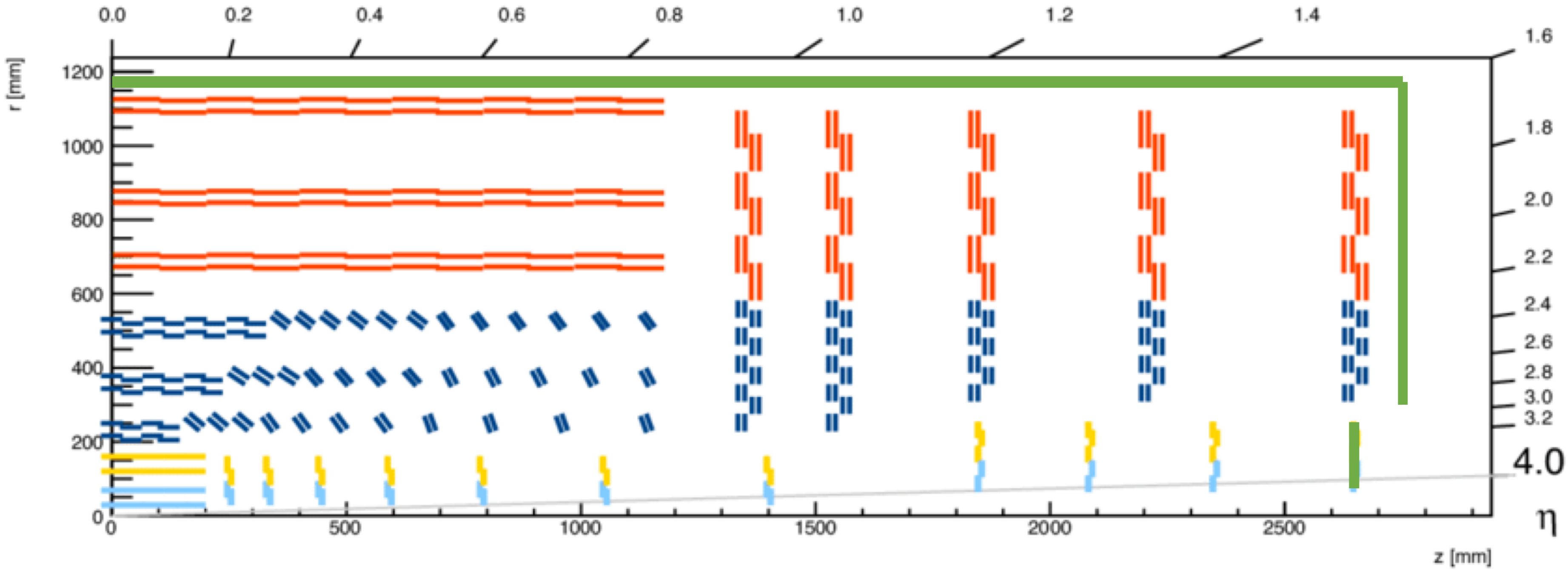
c: 30 ps ~ 1 cm

200 pile-up can be reduced by factor of ~4

<PU>	3D merged vertex fraction
50	3.3%
200	13.4%

CMS-DP-2016-008

Barrel Timing layer



Endcap Timing layer

1x3 mm^2 pads

Possible EPIX Timing layer

~0.1 x 0.1 mm^2 pixels

4D: Provides timing and position resolution

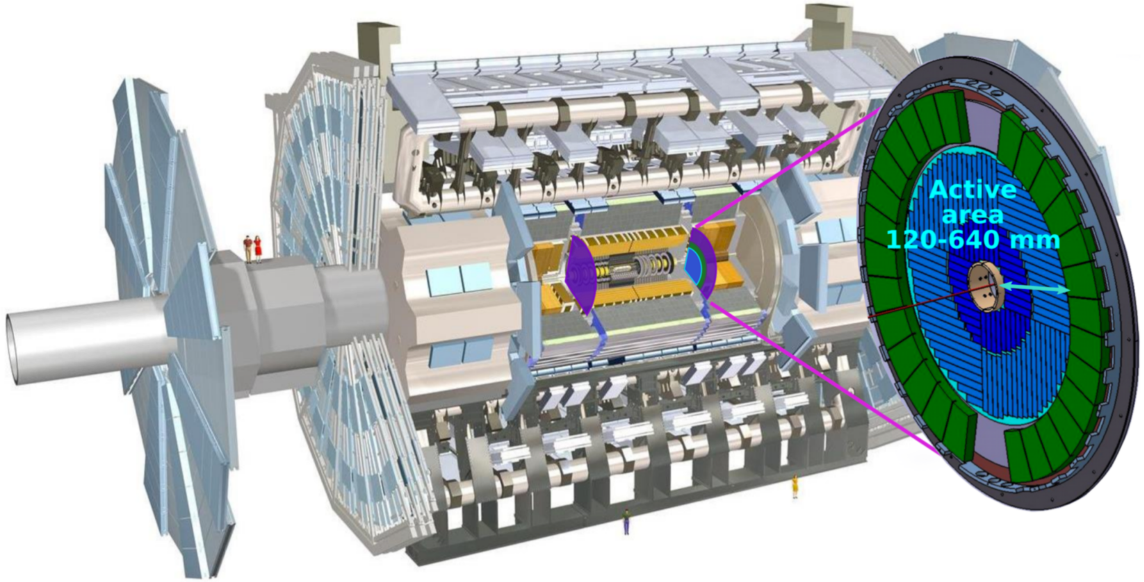
ATLAS

The HGTD: timing in ATLAS

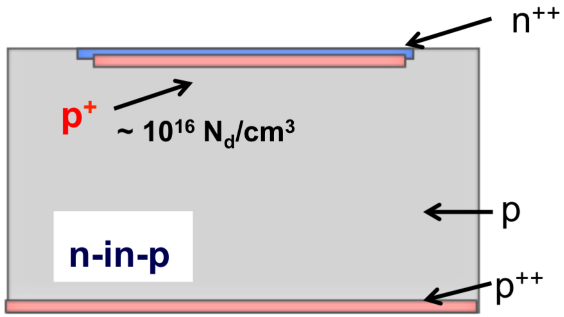
General parameters:

- $2.4 < |\eta| < 4.0$
- Active area 6.3 m^2 (total)
- Design based on $1.3 \times 1.3\,\mathrm{mm}^2$ silicon pixels ($2 \times 2\,\mathrm{cm}^2$ sensors)
- Radiation hardness up to 4.5 10^{15} n_{eq}/cm^2 and 4.5 MGy
- Number of hits per track:
  - 2 in $2.4 < |\eta| < 3.1$
  - 3 in $3.1 < |\eta| < 4.0$

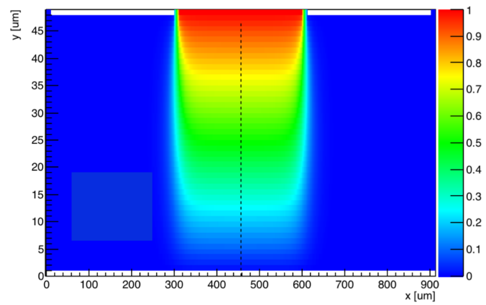
The HGTD will provide time measurements for objects in the forward regions of the ATLAS detector



The technology:
Low Gain Avalanche Diode (LGAD)



Device schematic



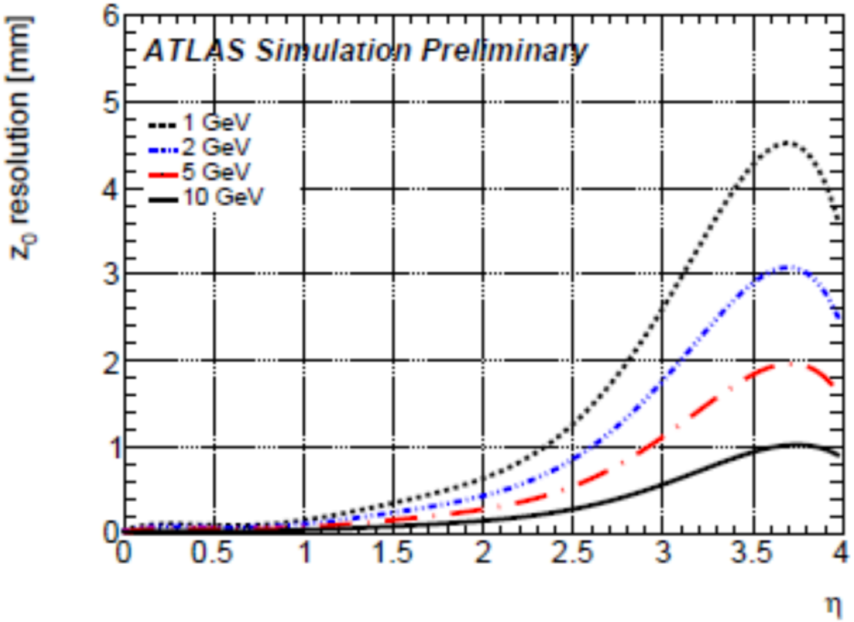
Field

To achieve a 30 ps resolution a number of expedients have been exploited:
Readout pad length >> sensor thickness
Relatively thin sensors (50 to 35 µm thickness)
large pitch (pixel size 1x1 mm^2)
for each sensor there is a dead area of about 20-30 µm around it

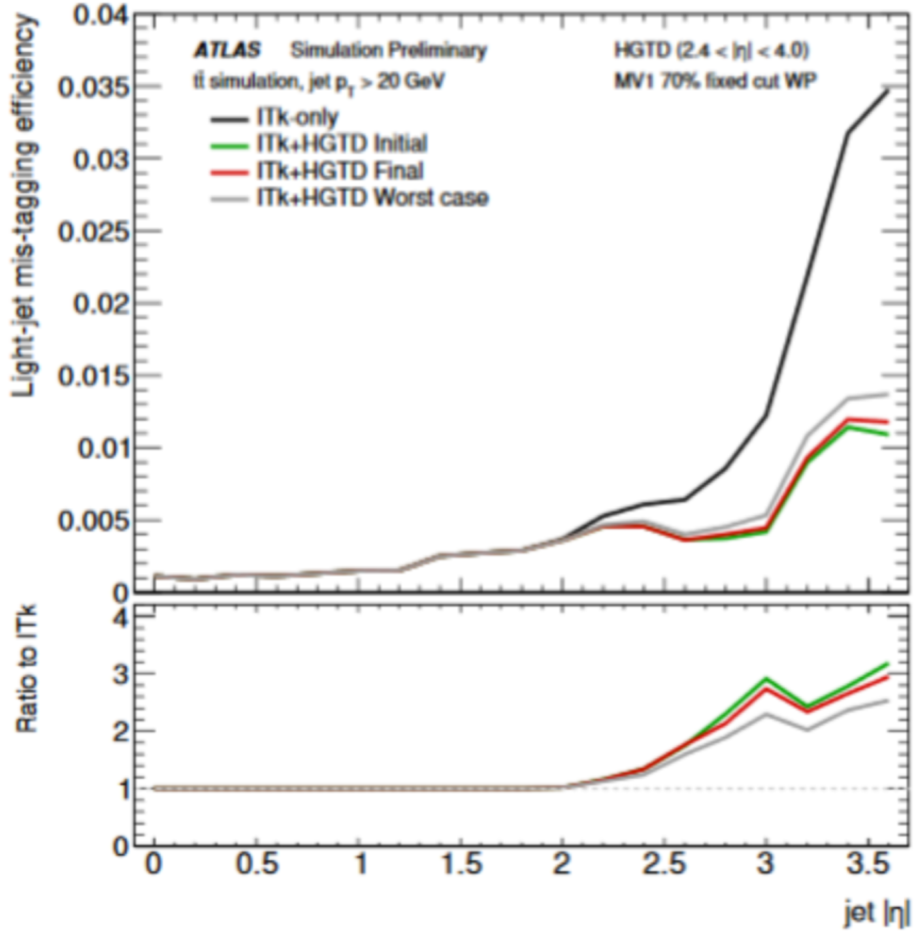
In the pixel we need a smaller cell size (resolution but most importantly occupancy)

Some physics

- Z0 resolution degrades at high Eta



Z0 resolution of the reconstructed vertices



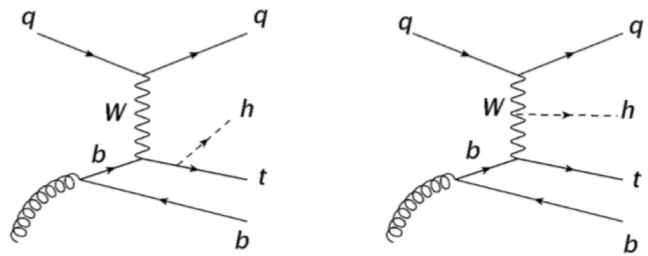
More physics

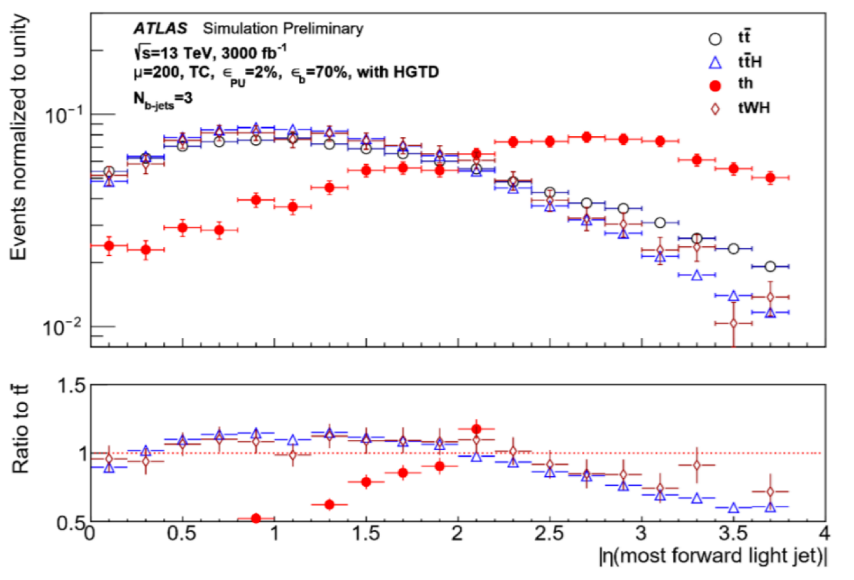
Signals with forward jets benefit more since timing improves pile-up jet rejection

tH(→bb)

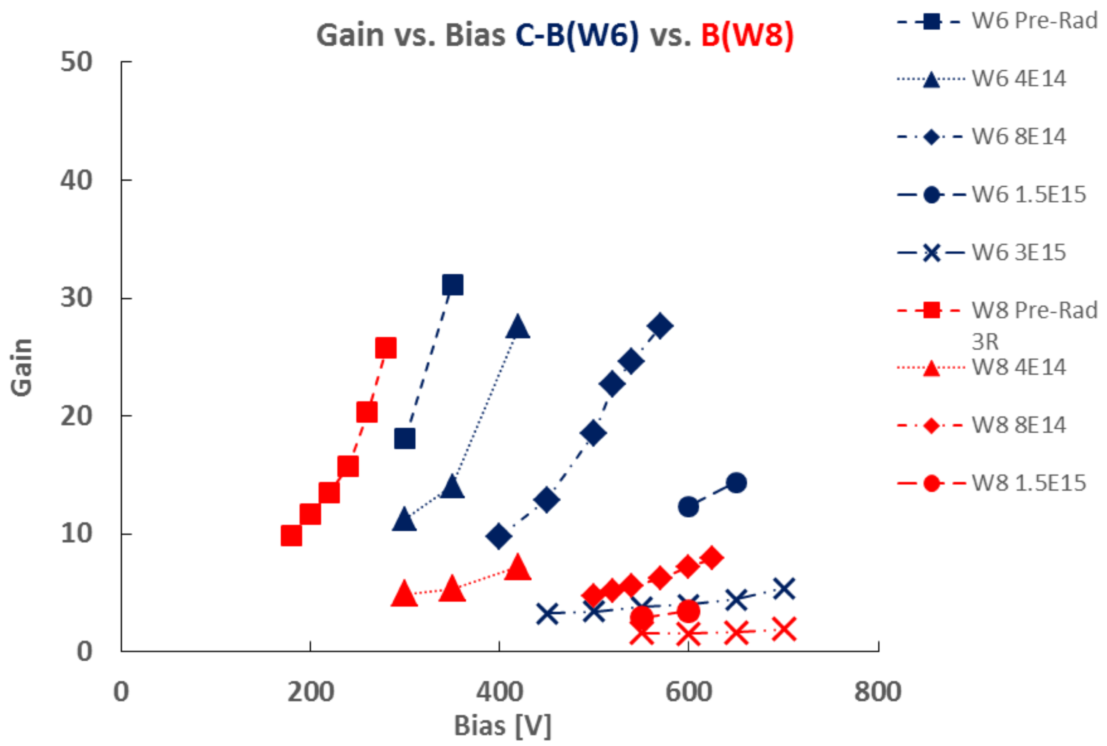
- **11% relative improvement**

starting





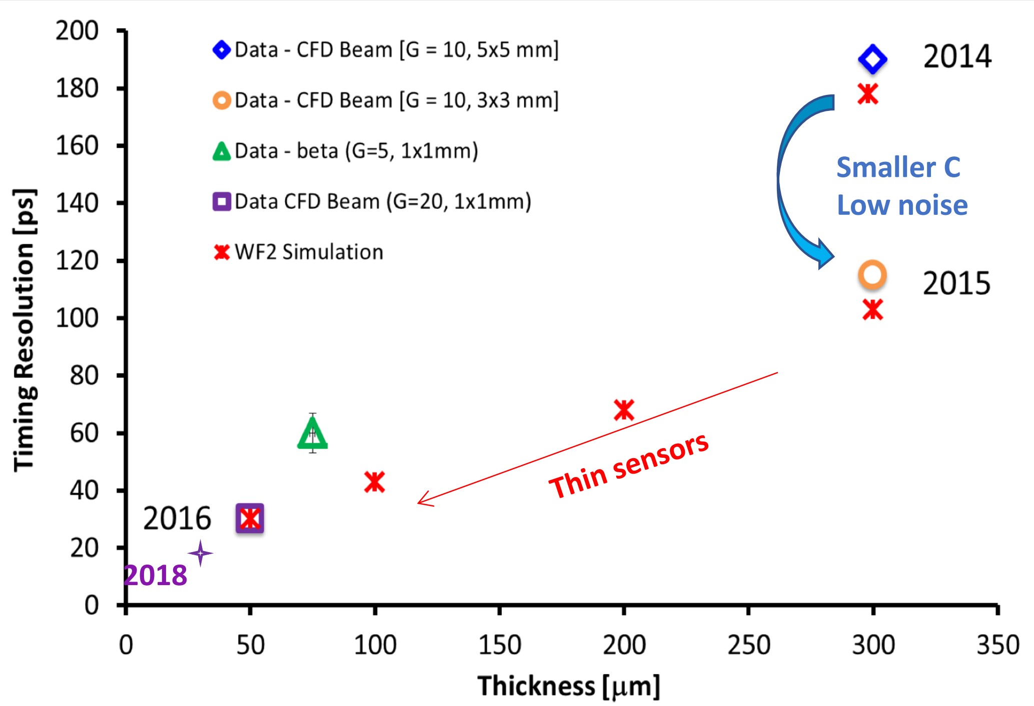
Improving radiation tolerance



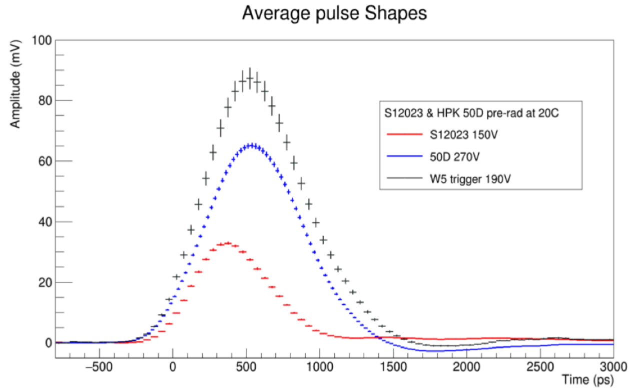
Carbonated Boron vs. Boron
Large mitigation of gain loss with Carbon

LGADs : some improving timing resolution

- Thinner is better

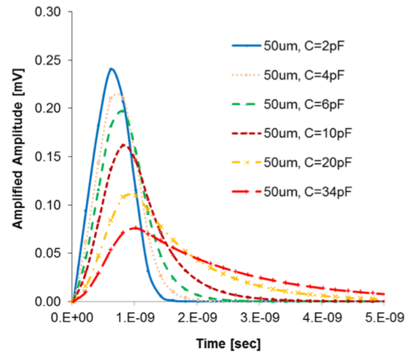


35 um thickness currently being produced
20 um thickness being tested



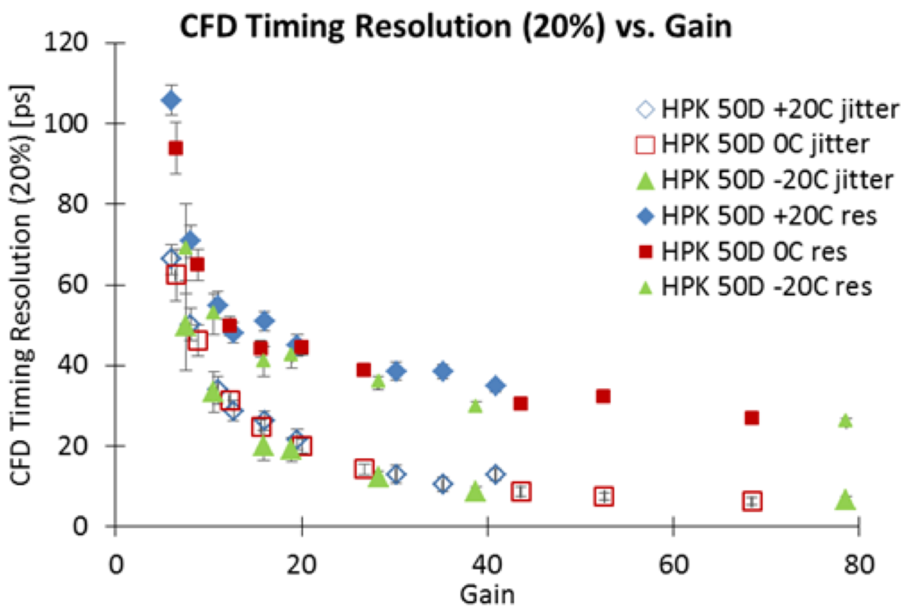
Thickness : thinner sensor better but less signal : Worse S/N

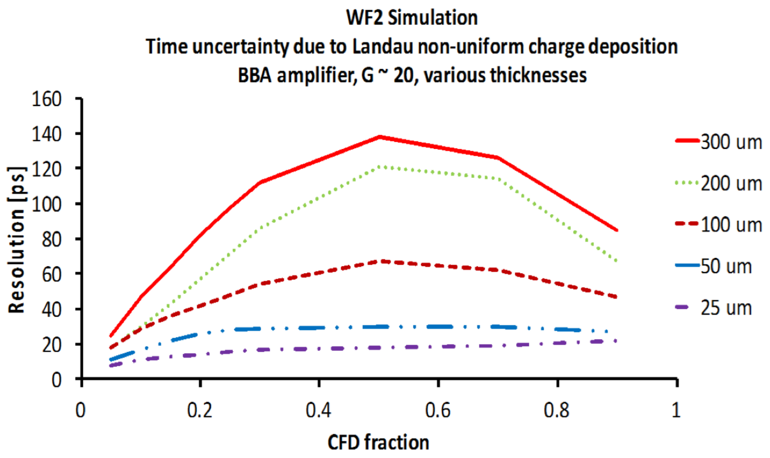
Detector capacitance dependence – smaller pixels better



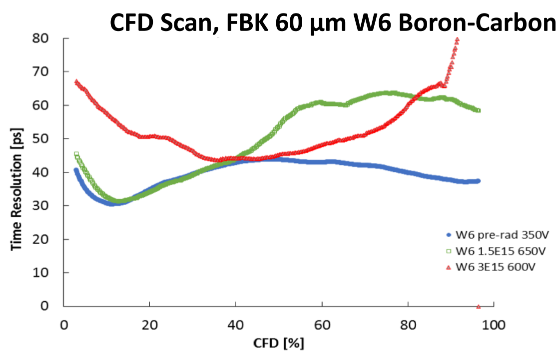
Improving timing resolution

- CFD is best to avoid timewalk:
- low CFD better

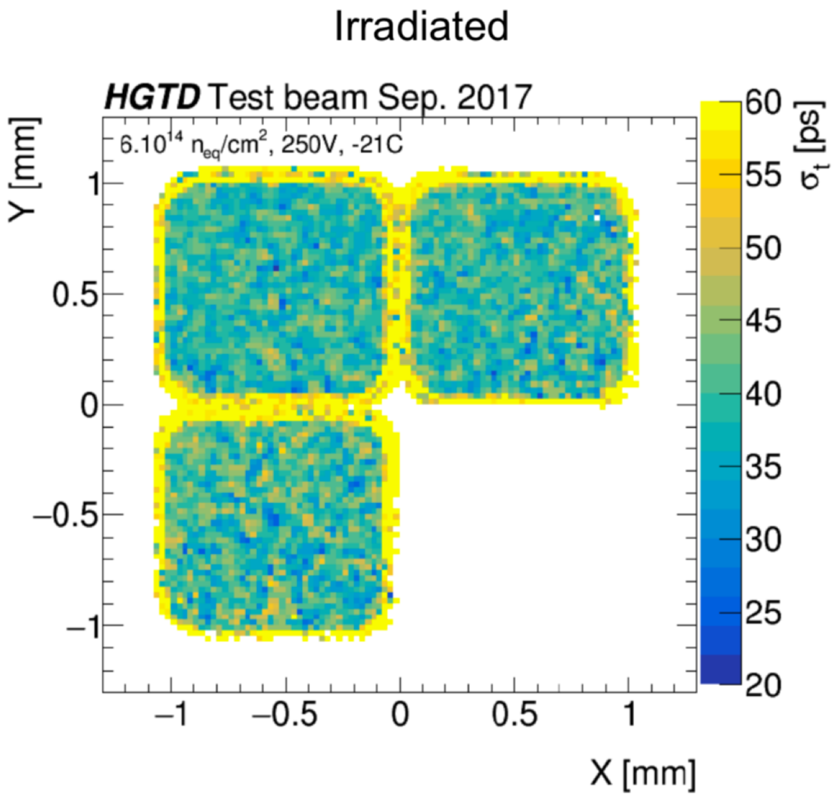




Contributions of Landau fluctuations to the time resolution as a function of the Constant Fraction Discriminator value for different detector thicknesses. Based on simulations.

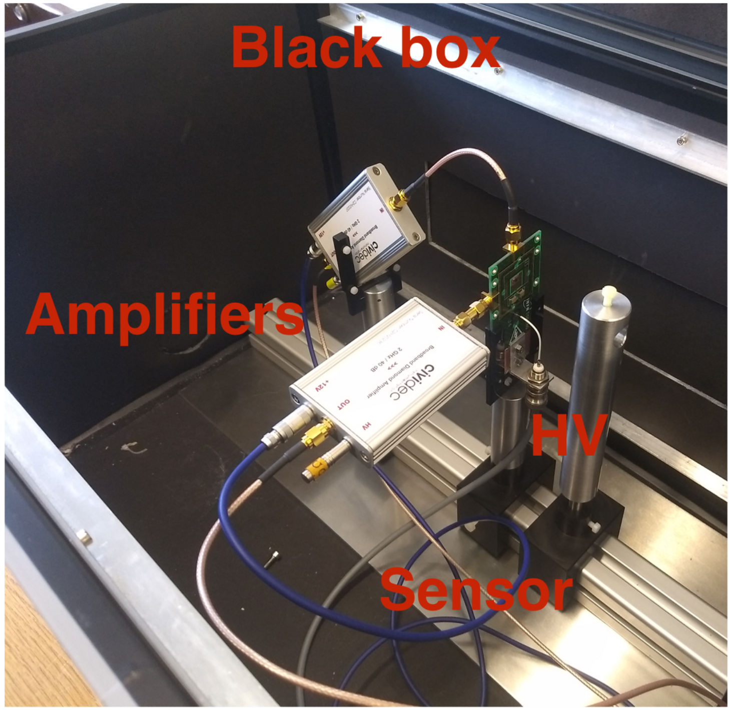


Efficiency of LGAD currently limited



- $1x1\ mm^2$ sensor pads
- Yellow - due to inefficiency of charge collection near guard ring
  - Fill factor problem
- Much bigger problem for $0.1 \times 0.1\ mm^2$

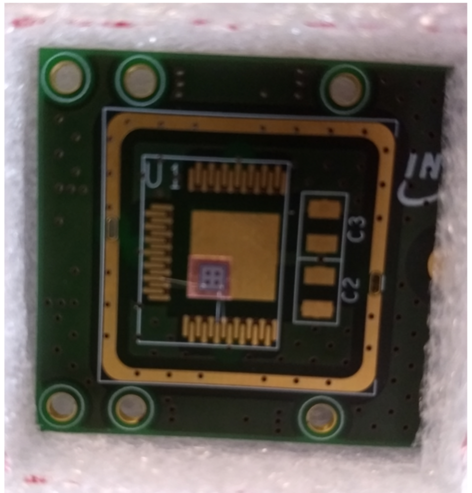
Test setup



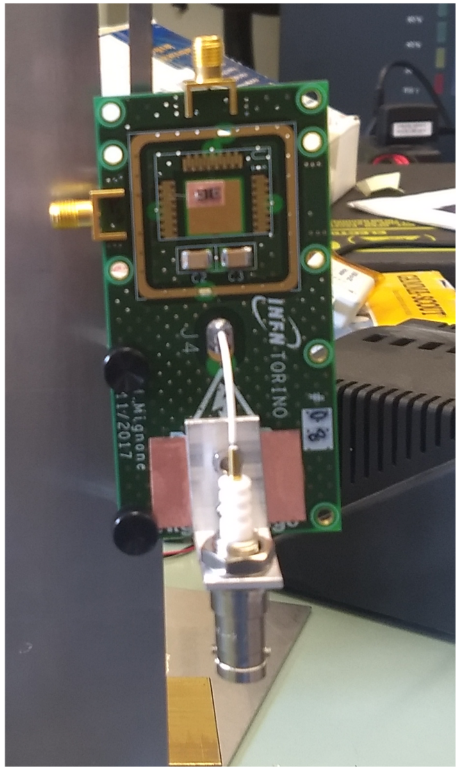
Black box - LV - scope - HV

Sr90 source, one sensor, 2 pads, gallium doping

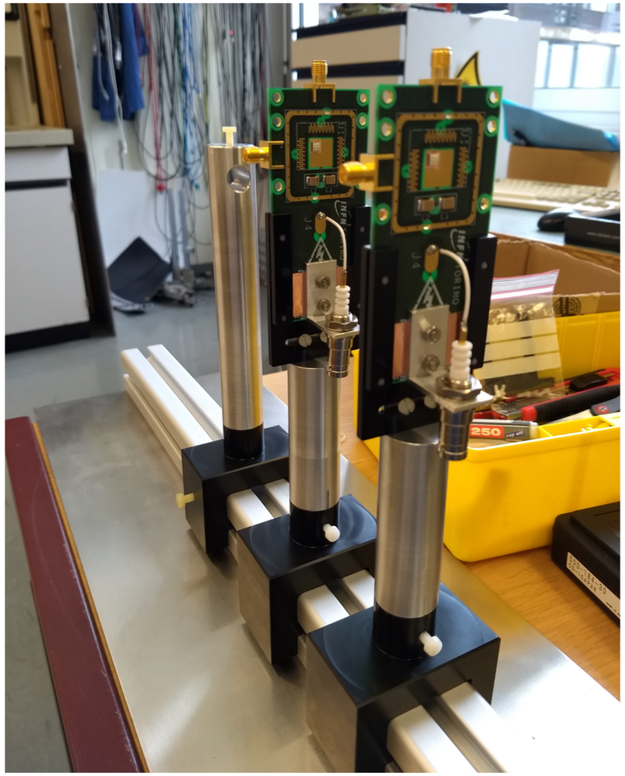
Old setup



Sensor



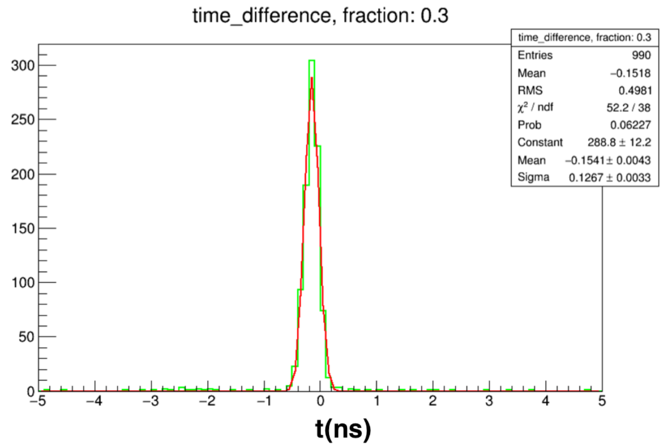
Board



Telescope

We are still working on improving this with different sensors

Signal from the boards (250 V bias) and Constant Fraction Method



$\sigma^2 = \sigma_{DET}^2 + 2\sigma_{Jitter}^2 + 2\sigma_{Time\ Walk}^2$

σ=127 ps

$\sigma_{Jitter} = t_{rise}/(S/N)$

ch1 790/24 =33 ps

ch2 720/14 =51 ps

$\sigma_{Time\ Walk} = t_{rise} * (V_{th}/S)$

ch1 24 ps

ch2 25 ps

σ_{DET}= 107/sqrt(2) =71 ps

problem is that the two sensors are different, so at the same voltage they behave differently:

- **new sensor coming (triplets)**
- **boards available**
- **new power supply with multiple channels incoming**
- **depending on the delivery time possibility to be included in the test beam (parasitically)**

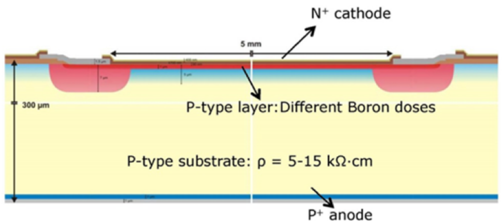
fin

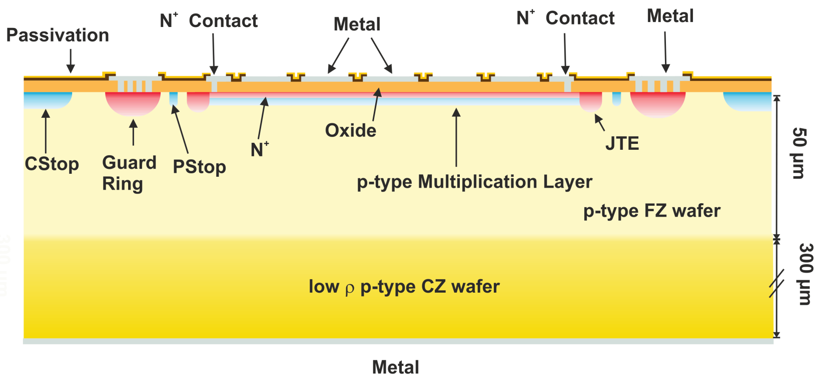
Riccardo Del Burgo

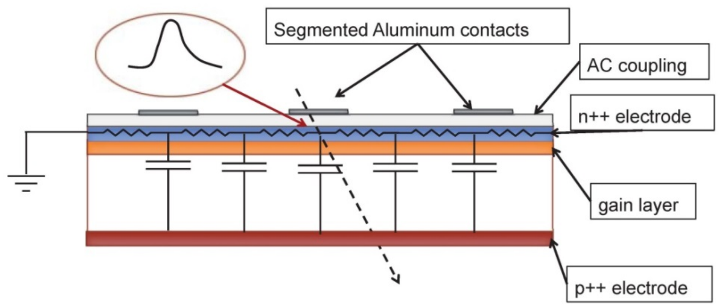
Status

- We are/will be testing a variety of RD50 sensor pixel sizes
  - 1x1 mm^2, 50x50 um^2, 100x100 um^2, 100x150 um^2
- We are expecting to test in the next 6 months :
  - Inverse-LGADs : solves problems of fill factor since charge is collected as holes on the opposite side as gain layer
  - AC-coupled LGADs
- Working on simulation studies of physics gain of timing up to $|\eta| < 4$

Less complex: AC-LGAD



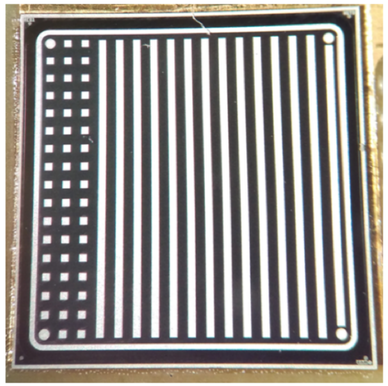




Could change the silicon sensor paradigm.

Segmented pad LGAD

Un-segmented LGAD:
sheets of p-gain layer, resistive n++ implant,
oxide,
only metal contact is pixelated and AC-coupled



First tests on-going with CNM AC-LGAD: IR laser and x-rays

Summary

- Too early to propose small LGADs as solution to timing for $3 < |\eta| < 4$ for Phase 2
  - Possibly in LS4 or some long shutdown as an upgrade to Phase 2 pixel detector
- Current lines of research :
  - Radiation hardness
  - Fill factor improvement (hit efficiency)
  - Physics simulation studies (we can guess from ATLAS’s physics studies)
- Not really covered
  - Need a group to consider readout ASICs (some are working on this in Torino)
  - Haven’t thought about how this would work for services and powering
- Other questions
  - If we had such 4-D capabilities, could we use it in other layers EPIX or FPIX ?