LGADs for the HGTD ATLAS upgrade

Cross-Collserola PhD Meeting 2023

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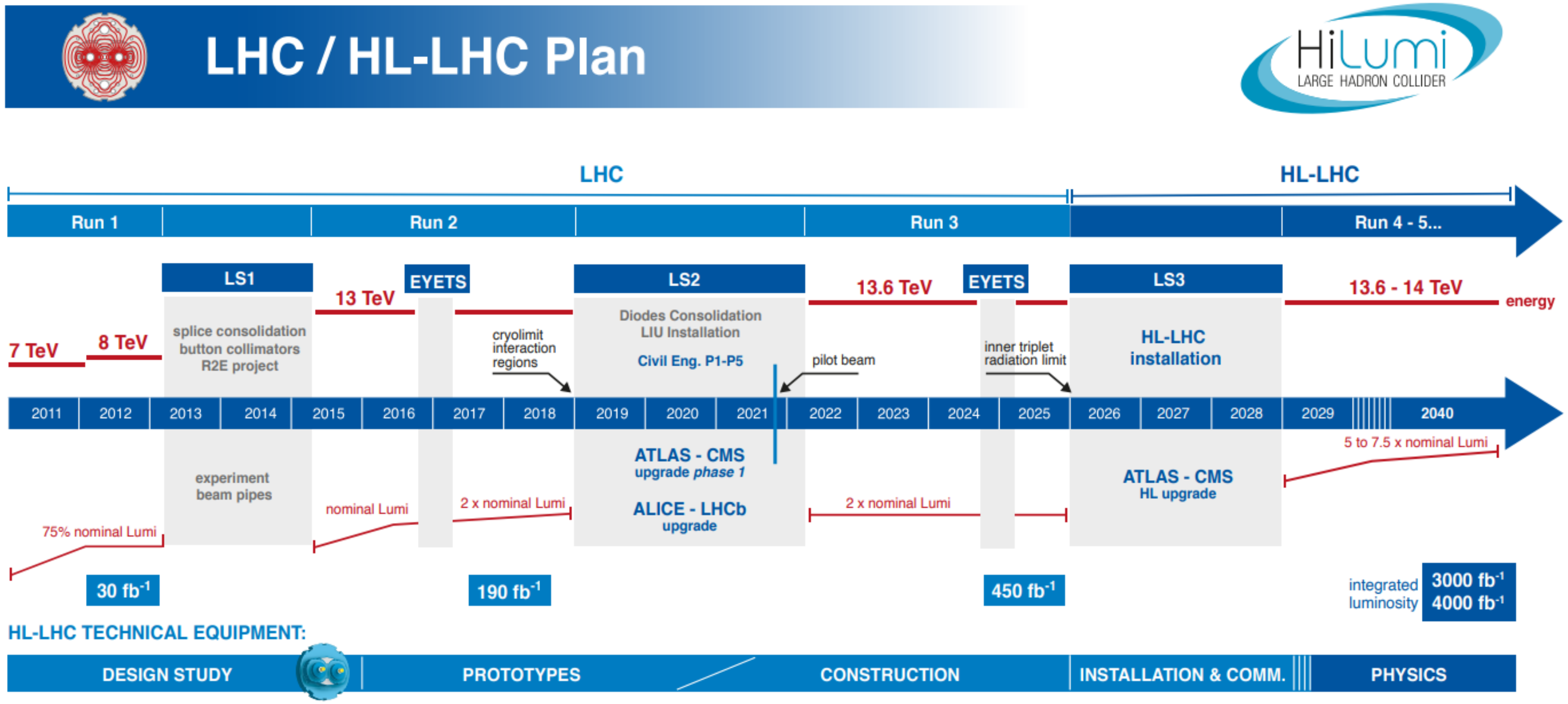
PhD- IFAE

Introduction

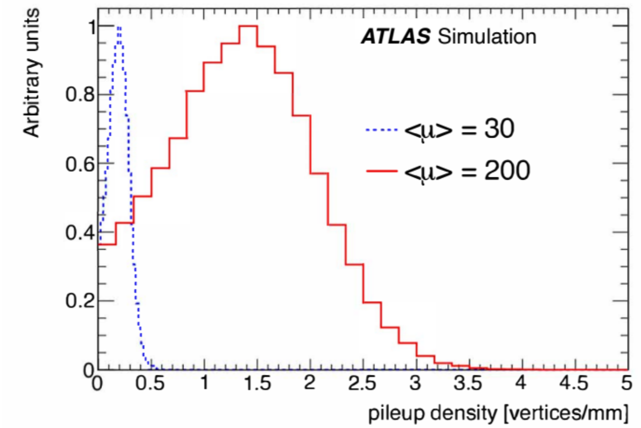


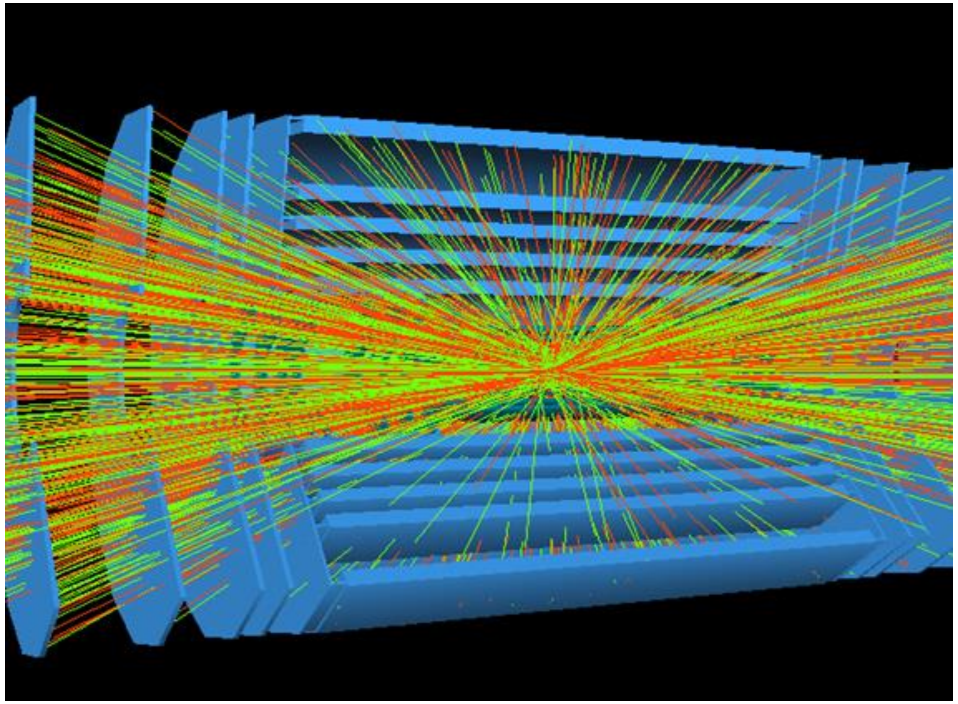
This talk will include:

1. Introduction to HGTD
2. Low Gain Avalanche Diode
3. Testbeam and lab setups
4. Performances of irradiated LGADs
5. Performance of full HGTD modules

- LHC upgrade to HL-LHC: Planned to start operating in 2029
- Instantaneous luminosity $7.5 \times 10^{34} \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (7 times present luminosity)
- Increase in luminosity results in more pile-up and radiation damage
- ATLAS experiment also needs to be upgraded to meet the new requirements

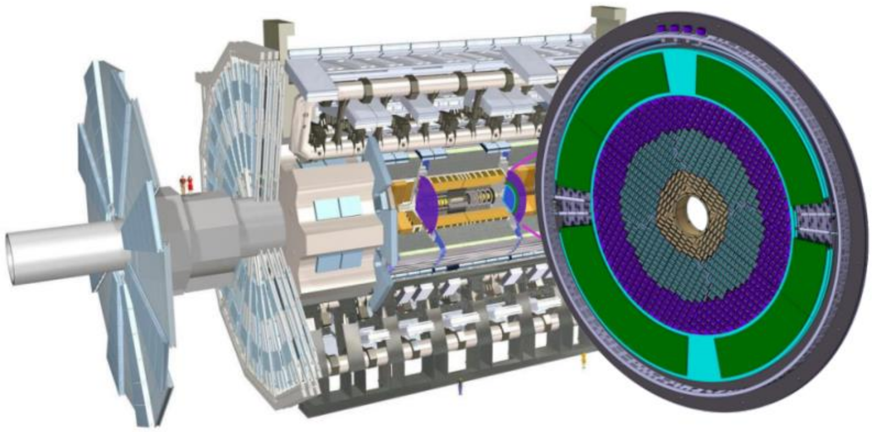
Motivation

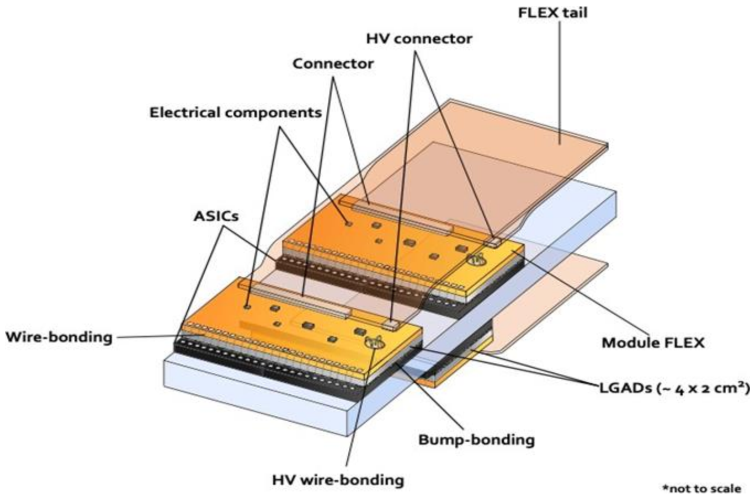




- Pile-up Challenge
  - $<\mu> = 200$ interactions/bunch crossing
  - ~ 1.8 vertices/mm
  - Current conditions (Run 3): $< \mu >$ ~ 40 interactions/bunch crossing
- High Granularity Timing Detector (HGTD) proposed in front of the end-cap calorimeter for pile-up mitigation
- Performance improved by combining HGTD timing and Inner-Tracker (Itk) position information

High Granularity Timing Detector





- Two disks located in the gap region between the barrel and the end-cap calorimeters
- Distance in z of ~ ± 3.5 m from the nominal interaction point
- 8032 HGTD modules instrumented:
  - Low Gain Avalanche Detectors (LGAD) demonstrated to provide excellent time resolution (~ 30 ps before irradiation) : next slides
  - ALTIROC readout chip

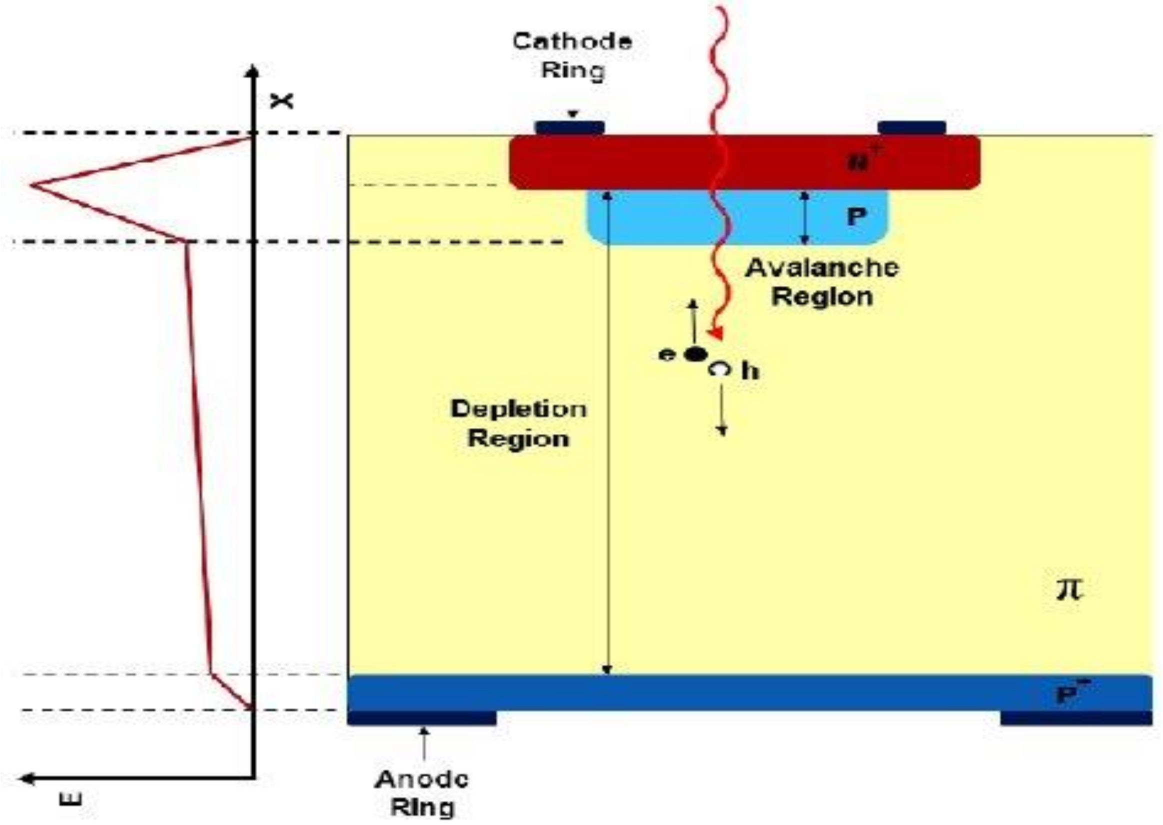
HGTD Requirements :

- Performance
  - Minimum charge of 4 fC
  - Time resolution per track of 30 ps (start) and 70 ps (after 4000 fb^{-1})

HGTD Module :

- Consits of $2 \times (15 \times 15)$ matrix of LGAD+ ALTIROC
- pads (4 cm × 2 cm). Pad size: 1.3 mm × 1.3 mm
- A module consists of two hybrids joined by a module flex printed circuit board (PCB)

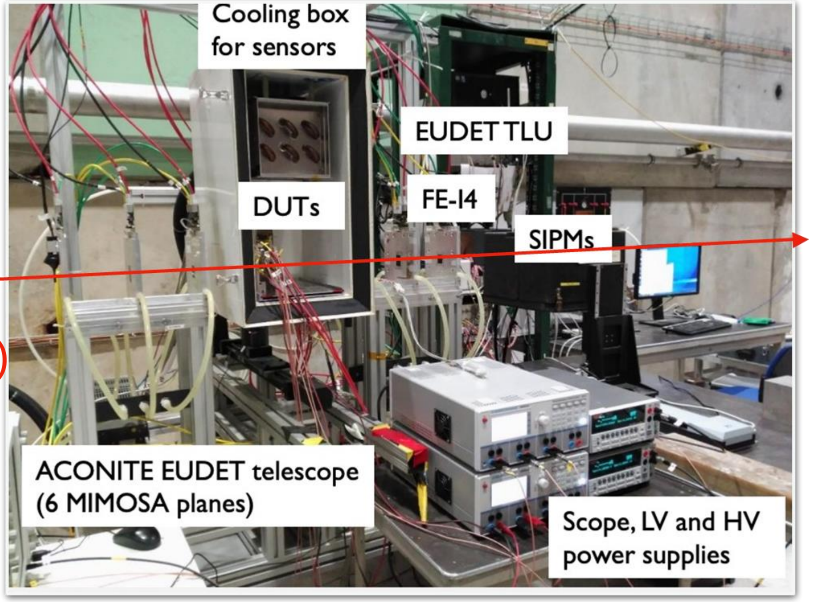
Low Gain Avalanche Detectors (LGAD)

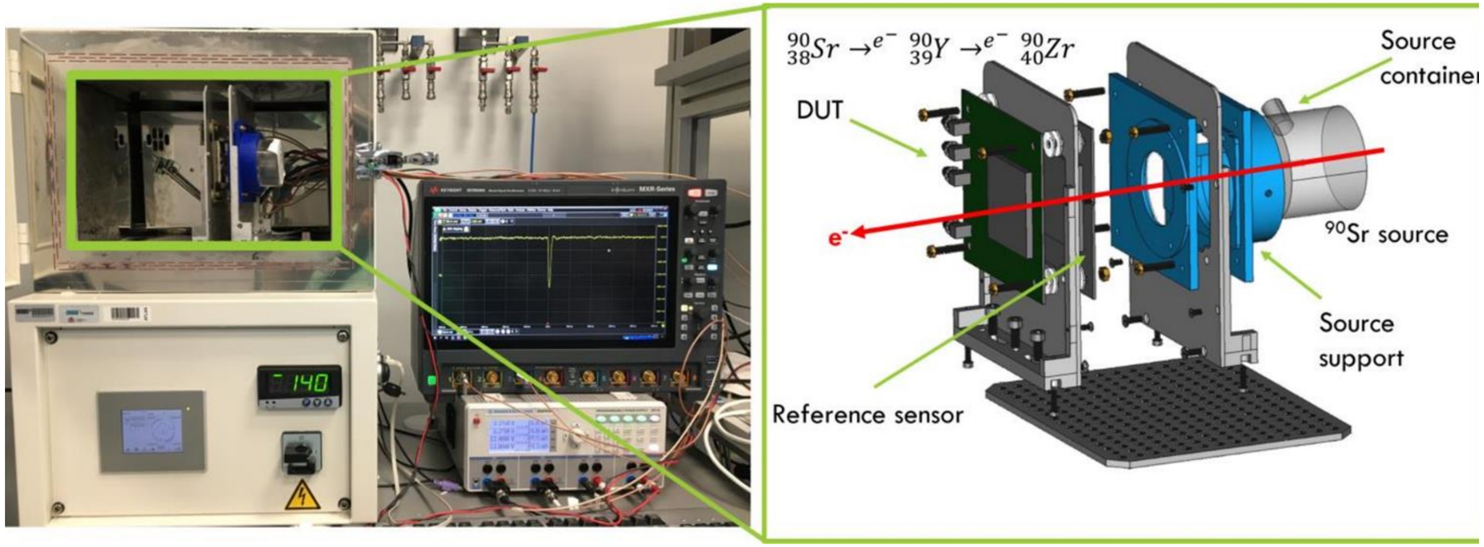


- p-n junction based n on p silicon detector
- Low gain multiplication layer:
  - gain~10-20
  - To reduce sensor noise
- Radiation hard detector for tracking
- For timing purpose the intrinsic gain of LGADs enhance the slew rate resulting in beneficial effect on time resolution
- Thin sensors for fast rising edge

Testbeam and Lab tests

pions
(120 GeV)



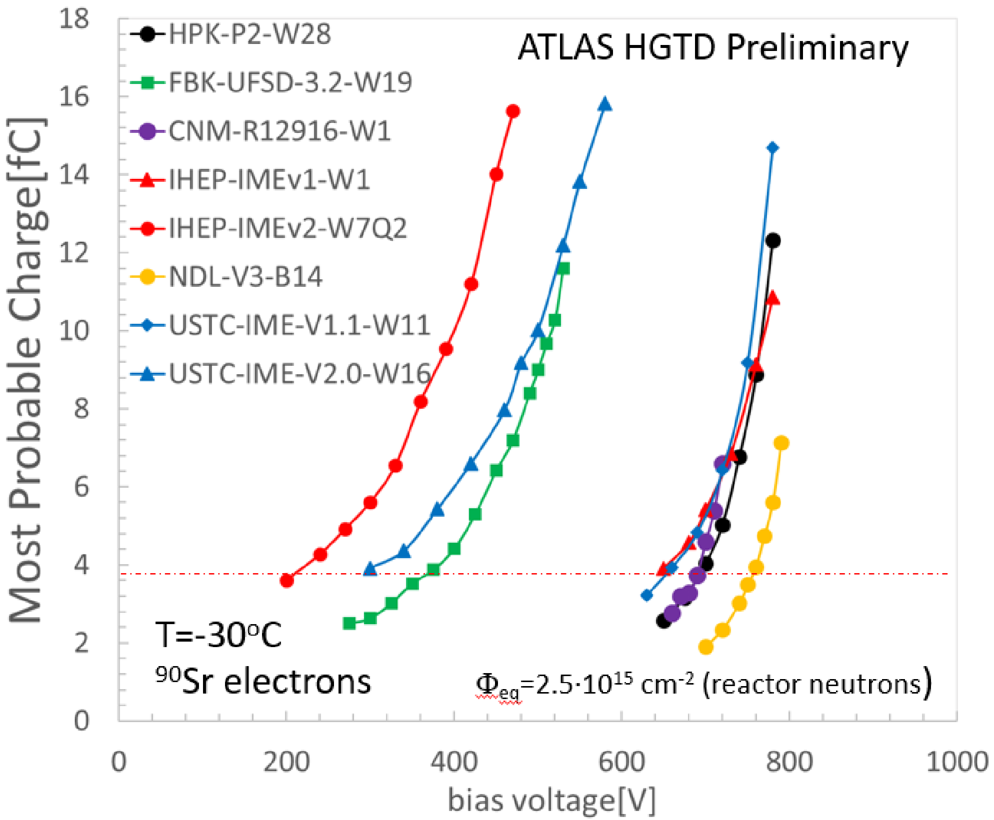


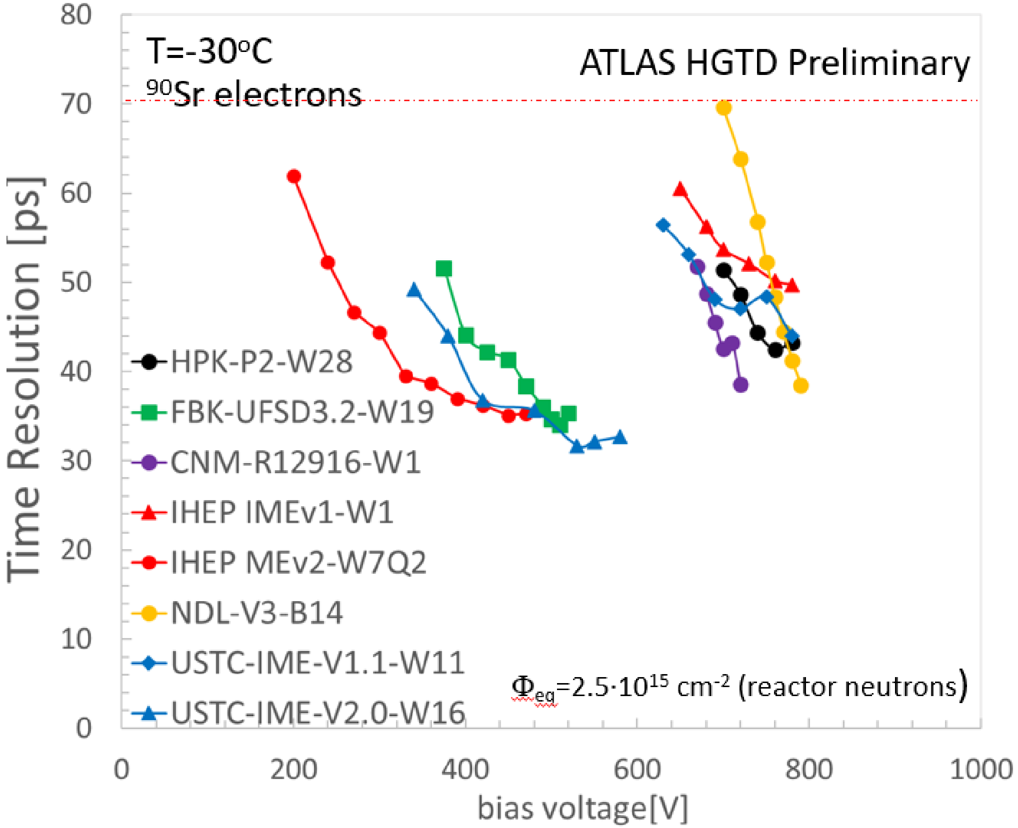
Testbeam setup CERN SPS

Sr-90 setup at IFAE, Barcelona

- LGAD performance studied in several testbeam campaigns as well as in lab tests with Sr-90
- Performed at CERN SPS H6A and DESY.

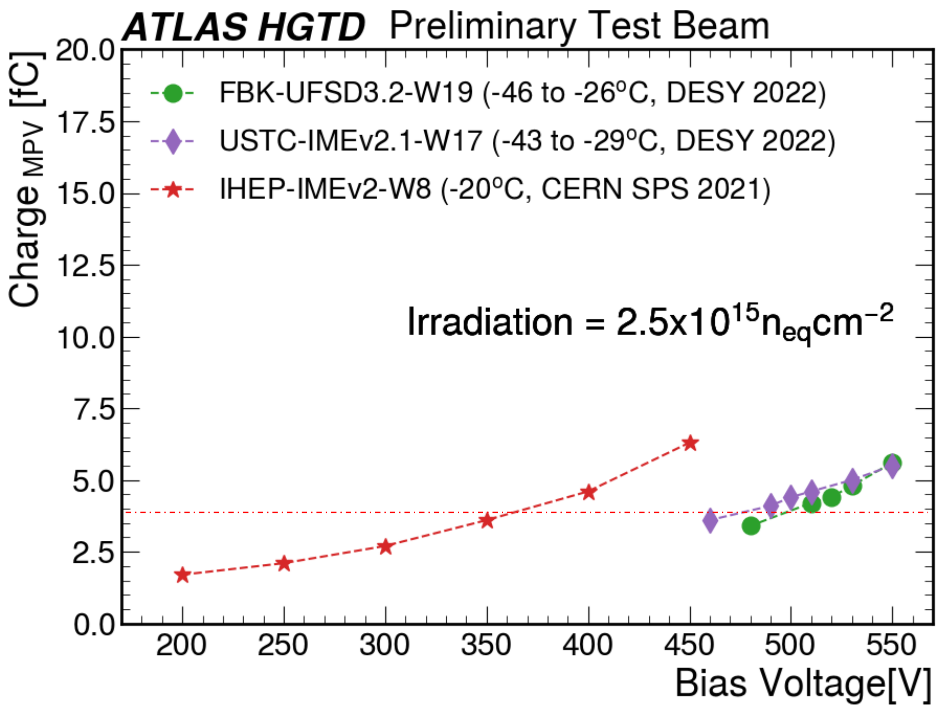
LGAD Performance with Sr-90 tests

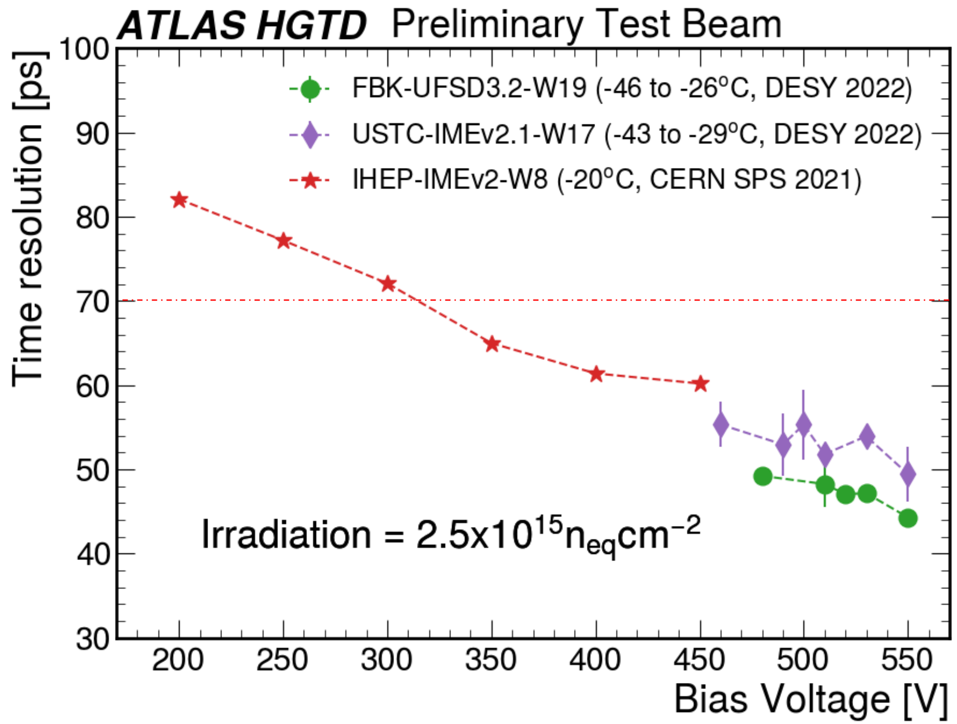




- Results from Sr90 tests in lab measurements are shown
- LGADs from different vendors meet the charge requirement of 4 fC and time resolution below 70 ps in irradiated devices

LGAD Performance at tesbeam

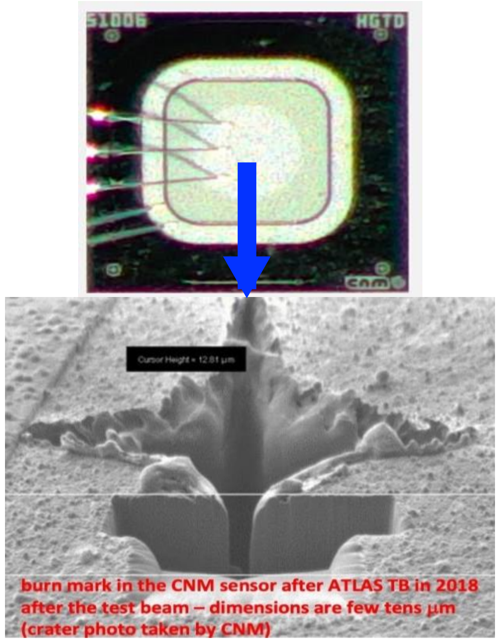


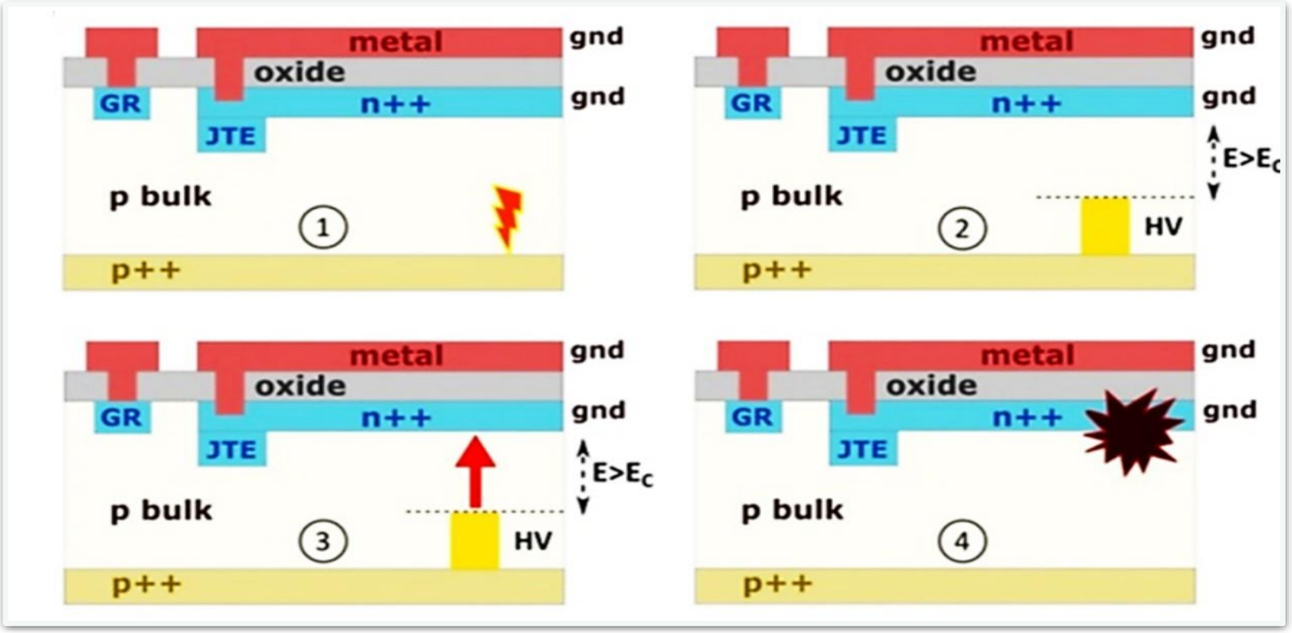


- Results from different testbeams are shown
- LGADs from FBK, USTC and IHEP-IME meet the charge requirement of 4 fC and time resolution below 70 ps in irradiated devices. CNM under investigation

Single event Burnout for LGAD

- Single Event Burnout (SEB) has been observed in several test beam campaigns
- Irreversible breakdown triggered by a large charge deposition while operating at high voltage.
- Observed by CMS/ATLAS/RD50 teams.
- Systematically studied by the HGTD group in beam tests. Safe limit E < 11 V/um



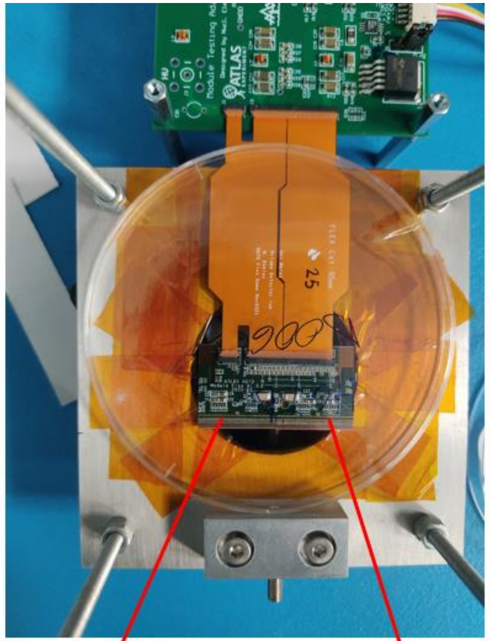


Conclusions and Outlook

- The LGAD sensor technology has reached a mature state in recent years and moving from R&D towards production.
- Carbon-enriched LGADs from different vendors (FBK, IHEP-IME, USTC-IME and CNM) have shown sufficient radiation hardness.
- >4 fC and <70 ps @ 2.5×1015 neq/cm2
- Results confirmed the feasibility of an LGAD-based timing detector for HL-LHC
- Tests with first prototyes full hybrid also shows good communication.
- Futher tests with full hybrids are to be done for final timing performance

Backup Slides

Bump-bond connectivity verification of full HGTD modules at IFAE

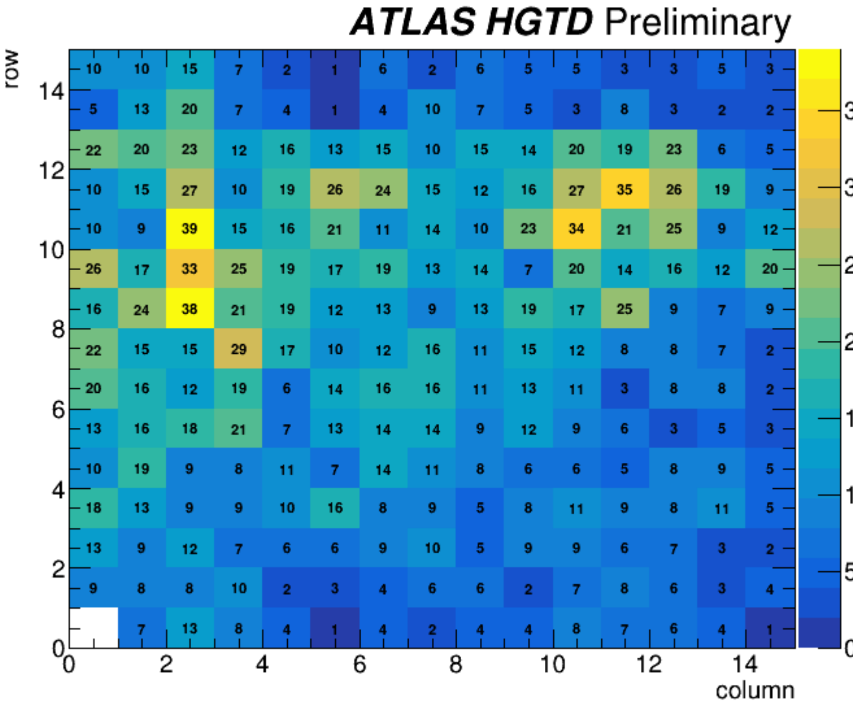


Chip 0

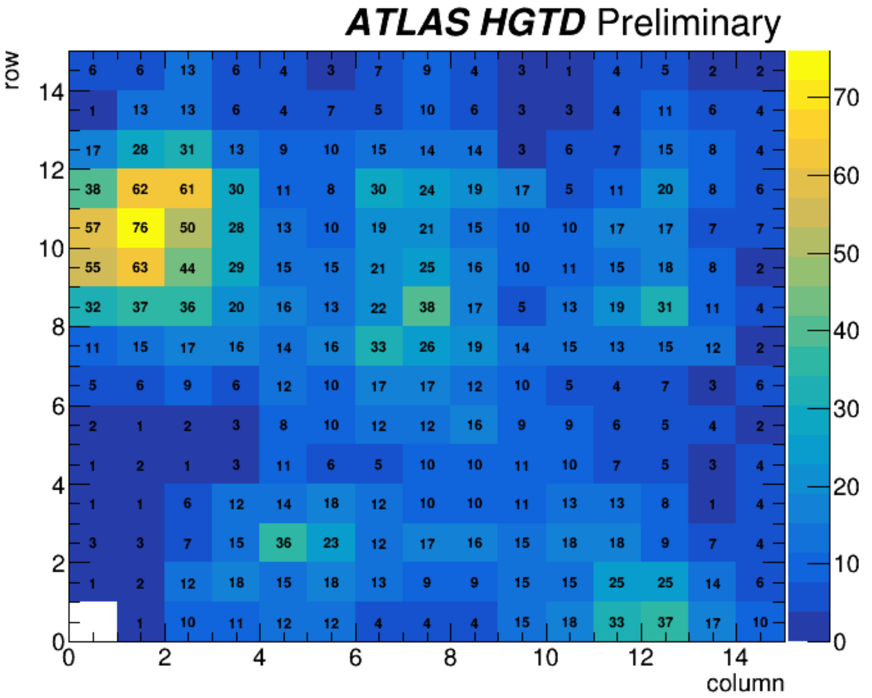
Chip 1

HV = 150 V

Threshold = 10 fC



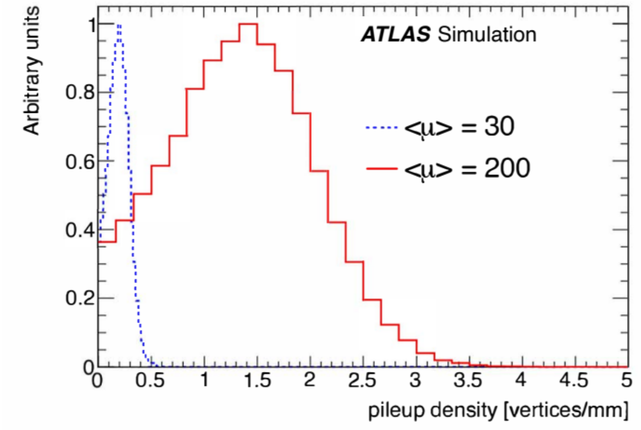
Chip 0

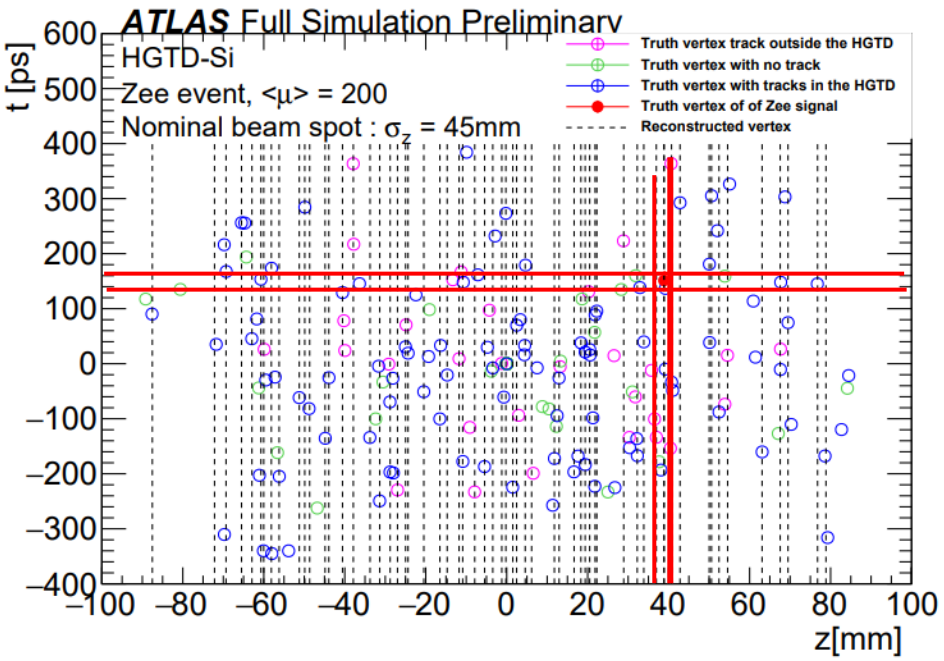


Chip 1

- Full HGTD modules with the flex assembled for demonstrator tests
- Sr-90 source scan shows 100% bump connectivity

Motivation





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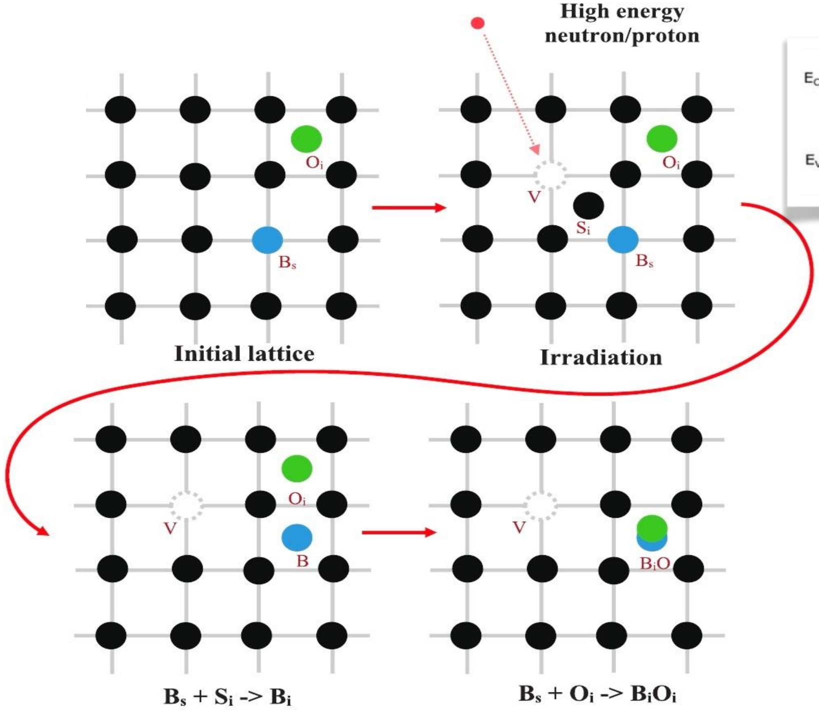
- High Granularity Timing Detector (HGTD) proposed in front of the end-cap calorimeter for pile-up mitigation
- Performance improved by combining HGTD timing and Inner-Tracker (Itk) position information
- Blue points in z vs t plot show vertices with tracks in HGTD
- Red point represents the single interaction.
  - There are also other pile-up interaction at almost the same position
  - But, timing information separates them from the primary vertex

Radiation hardness for LGAD

- The reduction of effective doping in the gain layer is caused by the “acceptor removal” process
- →LGAD gain reduction after non-ionizing radiation damage.
- Explored use of different gain layer designs, doping materials and C-enriched substrates
- → B + C shows largest gain after irradiation (Ci + Oi → CiOi competes with Bi + Oi → BiOi)



Acceptor (B_s) removal in the gain layer after irradiation