IHEP-NDL Prototype LGAD sensors for the HGTD

Yunyun Fan on behalf of IHEP HGDT group
2019.12.18
Outline

- Physics motivation
- Introduction to HGTD and LGAD
- IHEP-NDL LGAD sensor production
- IHEP-NDL LGAD performance
  - Beta test
  - Laser test
- Irradiation study
  - Proton irradiation
  - X ray irradiation
- Summary
Outline

- **Physics motivation**
  - Introduction to HGTD and LGAD
  - IHEP-NDL LGAD sensor production
  - IHEP-NDL LGAD performance
    - Beta test
    - Laser test
- **Irradiation study**
  - Proton irradiation
  - X ray irradiation
- **Summary**
Physics Motivation

- Pileup is the major challenges at HL-LHC
  - Track from different vertexes close in space, but well-separated in time.
  - Explore the spread of the collision to reduce pileup background by timing
  - Need **30ps timing resolution** to reduce the pileup background by a factor of 6

- Significant impact on some physics case
  - VBF Higgs, Weak mixing angle measurement

Higgs signal and pileup are separated in time!
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High-Granularity Timing Detector (HGTD) is proposed for ATLAS phase II upgrade:

- Timing resolution per track: better than 50ps
- Reduce pileup contribution by a factor of 5
- 6.4m² area silicon detector and ~ $5 \times 10^6$ channels
- Radiation hardness requirement: $2.5 \times 10^{15}$ Neq/cm² and 2MGy
Low Gain Avalanche Detector (LGAD)

- Low-Gain-Avalanche-detector (LGAD)
  - Compared to APD and SiPM, LGAD has lower gain (~10)
  - high drift velocity, thin active layer (fast timing)
  - High S/B, no self-triggering

LGAD Foundry:
- HPK (Japan)
- CNM (Spain)
- FBK (Italy)...
- IHEP-NDL (China)
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IHEP NDL Sensor R&D

- IHEP cooperated with NDL in 2019
- LGAD sensor with Epitaxial layer
  - **Epitaxial layer:**
    - thickness is **33um**
    - resistivity: **100 Ohm.cm** or **300 Ohm.cm**
- Three batches LGAD sensor fabricated in 2019.

**1st Batches:**
- 2x2
- BV170 & BV60

**2nd Batches:**
- 2x2
- 9# & 10#

**3rd Batches:**
- 5x5
- 6# & 12#
## IHEP NDL Sensor

### Detailed parameters for 3 bathes

<table>
<thead>
<tr>
<th>Bathes</th>
<th>Sensor Type</th>
<th>VBD (V)</th>
<th>V_Depleted (V)</th>
<th>Layout</th>
<th>Wafer (Ω.cm)</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>13# (BV170)</td>
<td>~165</td>
<td>~100</td>
<td>6GR</td>
<td>100</td>
<td>40</td>
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<tr>
<td></td>
<td>12# (BV60)</td>
<td>~95</td>
<td>~40</td>
<td>6GR</td>
<td>300</td>
<td>40</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>10#</td>
<td>~300</td>
<td>~40</td>
<td>2GR</td>
<td>300</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>9#</td>
<td>~250</td>
<td>~40</td>
<td>2GR</td>
<td>300</td>
<td>80</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>NDL 5x5 6#</td>
<td>~400</td>
<td>~120</td>
<td>2GR</td>
<td>100</td>
<td>10~20</td>
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<tr>
<td></td>
<td>NDL 5x5 12#</td>
<td>~390</td>
<td>~35</td>
<td>2GR</td>
<td>300</td>
<td>10~20</td>
</tr>
</tbody>
</table>
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  - X ray irradiation
- Summary
Time Resolution from Beta Test

- Beta test (time resolution, collected charge)
  - Electrons by Sr90 Beta source
  - Single channel board developed by UCSC
  - Fast amplifier with bandwidth >1GHz

Time resolution is about 30ps!
Collected Charge from Beta Test

- Beta test (time resolution, collected charge)

Charge collection: 3~30 fC
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Laser test: timing resolution study

- Preliminary results
  - The time resolution of NDL is from 3~50 ps
  - Better than HPK W18 SE5
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Irradiation campaign

- Irradiation hardness is important for HGTD project
- IHEP is responsible for irradiation tests
  - Leading total ionization dose (TID) study for sensor and module
    - X ray irradiator in IHEP, TID up to 100kGy
  - Carried out one irradiation campaign for non-ionization damage
    - Collaboration with China atom energy institute (CIAE) for 100MeV proton irradiation
    - Fluence up to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$

**100MeV Proton irradiation campaign in CIAE**

**X ray irradiation in IHEP**
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First Results of CIAE irradiation: NDL sensors

- Depleted voltage and foot voltage Vs fluence
  - Much easier to depleted the LGAD sensor after $1 \times 10^{15} N_{eq}/cm^2$
  - Need more study for LHC application
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**I-V after X ray irradiation**

<table>
<thead>
<tr>
<th>Type</th>
<th>VBD</th>
<th>V_Depleted</th>
<th>Layout</th>
<th>Wafer</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>13# (BV170)</td>
<td>~165V</td>
<td>~100V</td>
<td>6GR</td>
<td>100Ω.cm</td>
<td>40</td>
</tr>
<tr>
<td>12# (BV60)</td>
<td>~95V</td>
<td>~40V</td>
<td>6GR</td>
<td>300Ω.cm</td>
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<tr>
<td>10#</td>
<td>~300V</td>
<td>~40V</td>
<td>2GR</td>
<td>300Ω.cm</td>
<td>40</td>
</tr>
<tr>
<td>9#</td>
<td>~250V</td>
<td>~40V</td>
<td>2GR</td>
<td>300Ω.cm</td>
<td>80</td>
</tr>
</tbody>
</table>

- **I_leak is lower** after irradiation
- **~ 0.1 nA**
- **I_leak is large** at low V_bias
  - can improve by adjusting GR

Due to Metal pad in Guard ring?

From Yunyun
I-V after X ray irradiation: comparisons

- Short summary of leakage current on working point before VBD
Inter Pad Resistance Summary

- BV170 and BV60 are better than the NDL 9# and NDL 10# sensors.
- HPK sensor is the better than NDL
Summary

- New foundry of ultra-fast LGAD sensor in China
  - Novel device lab (NDL) in Beijing Normal university
  - 30ps time resolution in beam test and beta tests
    - ~10ps in jitter term, Landau term dominated
- Irradiation hardness of NDL has been tested
Thank you for your attention!
- Back up
# IHEP HGTD team

## Current IHEP Cluster HGTD Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Activity</th>
<th>Position</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joao Guimaraes da Costa</td>
<td>Management + sensor + modules</td>
<td>Physics Faculty</td>
<td>50%</td>
</tr>
<tr>
<td>Zhaoru Zhang</td>
<td>Management</td>
<td>Physics Faculty</td>
<td>10%</td>
</tr>
<tr>
<td>Ming Qi (Nanjing Univ)</td>
<td>Electronics</td>
<td>Physics Faculty</td>
<td>50%</td>
</tr>
<tr>
<td>Lei Zhang (Nanjing Univ)</td>
<td>Electronics</td>
<td>Physics Faculty</td>
<td>50%</td>
</tr>
<tr>
<td>Juan Antonio Garcia</td>
<td>TDAQ + Demonstrator</td>
<td>Postdoc</td>
<td>30%</td>
</tr>
<tr>
<td>Jie Zhang</td>
<td>ASIC + module + electronics</td>
<td>Engineer</td>
<td>35%</td>
</tr>
<tr>
<td>Wei Wei</td>
<td>ASIC</td>
<td>Engineer</td>
<td>10%</td>
</tr>
<tr>
<td>Jinnyu Fu</td>
<td>Mechanics</td>
<td>Engineer</td>
<td>30%</td>
</tr>
<tr>
<td>Lianyou Shan</td>
<td>Module</td>
<td>Physics Faculty</td>
<td>70%</td>
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<tr>
<td>Feng Lv</td>
<td>Module</td>
<td>Physics Faculty</td>
<td>30%</td>
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<tr>
<td>Pellan Liu</td>
<td>Module</td>
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<tr>
<td>Ming Yi Dong</td>
<td>Module</td>
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<tr>
<td>Xin Shi</td>
<td>Sensor</td>
<td>Physics Faculty</td>
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<tr>
<td>Mei Zhao</td>
<td>Sensor</td>
<td>Engineer</td>
<td>50%</td>
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<tr>
<td>Ryuta Kikuchi</td>
<td>Sensor</td>
<td>Postdoc</td>
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<tr>
<td>Yunyun Fan</td>
<td>Sensor</td>
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<td>Kewei Wu</td>
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<td>Yuhang Tan</td>
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<td>Baohua Qi</td>
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<tr>
<td>Tao Yang</td>
<td>Sensor</td>
<td>Student</td>
<td>80%</td>
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<tr>
<td>Zhijun Liang</td>
<td>Sensor + module</td>
<td>Physics Faculty</td>
<td>50%</td>
</tr>
<tr>
<td>Suyu Xiao</td>
<td>Sensor + test beam</td>
<td>Student</td>
<td>80%</td>
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<tr>
<td>Bo Liu</td>
<td>Sensor + test beam</td>
<td>Postdoc</td>
<td>30%</td>
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<tr>
<td>Mohamad Kassem Ayoub</td>
<td>Test beam</td>
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<td>Jingyi Liu</td>
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<td>Kunlin Ran</td>
<td>Test beam</td>
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<tr>
<td>Xuai Zhuang</td>
<td>Test beam + HGTD Physics</td>
<td>Physics Faculty</td>
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<td>Yanping Huang</td>
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<td>Ludovica Aperio Bella</td>
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<tr>
<td>Huajie Cheng</td>
<td>HGTD Physics</td>
<td>Postdoc</td>
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</tr>
<tr>
<td>Yang Liu</td>
<td>HGTD Physics</td>
<td>Student</td>
<td>30%</td>
</tr>
</tbody>
</table>

- **Total: 32**
  - **Physics Faculty: 12**
  - **Engineers: 3**
  - **Postdocs: 9**
  - **Students: 8**
  - **Electronics: 5**
  - **Module/Mechanics: 8**
  - **Sensors: 14**
  - **Testbeam + Physics: 8**
Physics Motivation

- **Pileup is the major challenges at HL-LHC**
  - Track from different vertexes close in space, but well-separated in time.
  - Explore the spread of the collision to reduce pileup background by timing.
  - Need **30ps timing resolution** to reduce the pileup background by a factor of 6.

- **Significant impact on some physics case**
  - VBF Higgs, Weak mixing angle measurement.

---

Higgs signal and pileup are separated in time!
Laser setup

**Testing timing response for NDL LGAD sensor with TCT laser system**
- Replace the TCT laser with pico-second pulse laser
- pico-second Laser Pulse width: 7ps; wavelength: 1064nm, Frequency: 20MHz

**Evaluate the jitter contribution**
- Less than 10ps
- Laser power is larger than MIP

\[
\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2
\]

Wirebond one pixel to UCSC single channel board

By Yuzhen, Yunyun, Suyu, Liaoshan
Laser for Timing Measurement

\[ \sigma_{\text{TDC}}^2 + \sigma_{\text{Time walk}}^2 + \sigma_{\text{Jitter}}^2 + \sigma_{\text{Landau noise}}^2 + \sigma_{\text{Signal}}^2 \]

- light pulse
- LGAD sensor
- signal pulse
- bias trigger
- oscilloscope

Preliminary result

Time Resolution/ps vs Bias Voltage/V

- HPK W18-SE5 before irradiation
- NDL BV170 before irradiation (different)
- NDL BV170 after 100kGy x-ray irradiation
- BV 60 before irradiation

co-second laser: 7.5 ps width pulse, 1064 nm wavelength
Charge Collection

- Beta test (collected charge, gain, time resolution)
  - Electrons by Sr90 Beta source
  - Single channel board developed by UCSC
  - Fast amplifier with bandwidth >1GHz

![Graph 1: Collected Charge of BV170](image1)

![Graph 2: Collected Charge of NDL1810-2-10](image2)