Test beam characterization of Hamamatsu LGADs for the CMS endcap timing layer

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Tanvi Wamorkar, *on behalf of the CMS collaboration (Northeastern University)*

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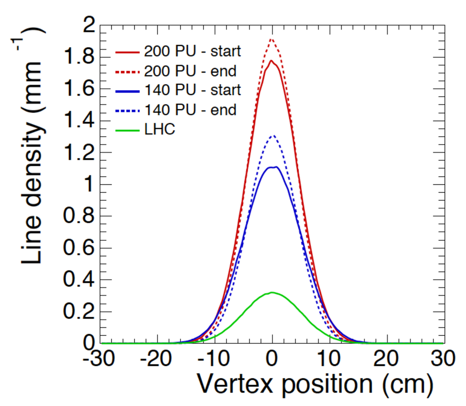
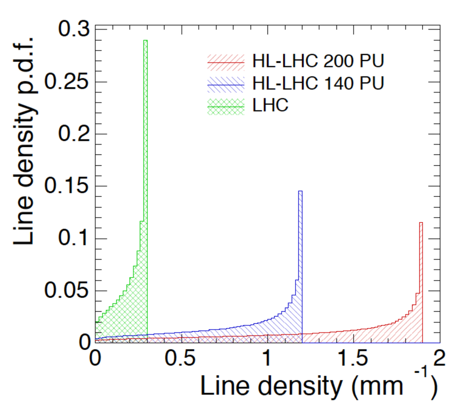
Case for a precision timing upgrade of the CMS detector

- HL-LHC will provide unprecedented instantaneous and integrated luminosity
- Higher instantaneous luminosity, higher levels of overlapping events (pile-up) and higher radiation level will create a harsh detector environment
- Maintaining high efficiencies for particle reconstruction and primary vertex identification will be main challenges at CMS
- CMS detector will be upgraded with a timing layer, MTD (MIP timing detector) capable of detecting minimum ionizing particles (MIPs) with a timing resolution of 40 ps or better

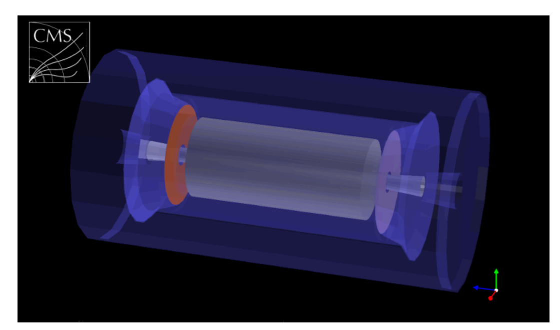




- Left: Spread of vertices along the beam direction at LHC and HL-LHC
- Right: Probability density function of the vertex density along the beam axis

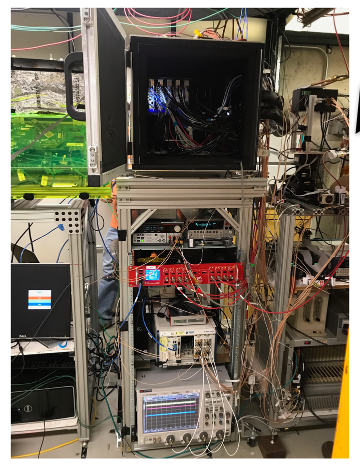
Overview of the MTD design

- MTD will be composed of barrel and endcap parts, will be hermetic with coverage upto pseudorapidity |η| < 3.0
- Endcap timing layer (ETL) will cover a pseudo rapidity region of 1.6 < |η| < 3.0 and will be based on planar silicon detectors with gain
- The internal gain helps in providing good timing precision by enhancing the MIP signal and providing good signal to noise ratio
- Ultra-fast silicon detector (UFSD) is a good candidate for ETL since it is radiation tolerant and provides optimum time resolution by means of timing-optimized low-gain avalanche detector (LGAD) technology



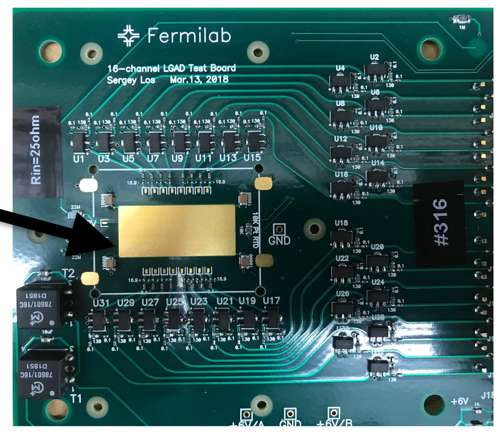
- Simplified GEANT geometry of the timing layer
- LYSO barrel (Grey cylinder)
- Two Silicon endcap timing layers (orange discs)

Test Beam Setup at FNAL



- Permanent test beam setup at FNAL
- Mobile setup
- 8-channel high voltage supply
- 20 GHz, 40 GS/s oscilloscope enables collection of up to 100k events in a single acquisition

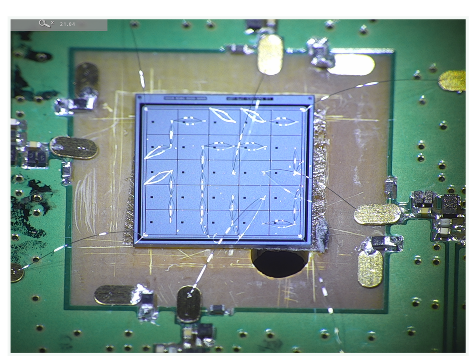
- 16 channel LGAD mounted on Fermilab board

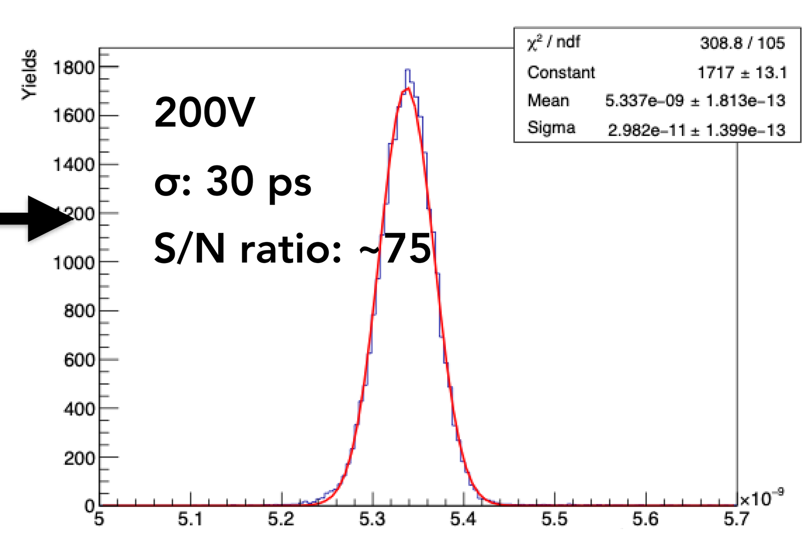


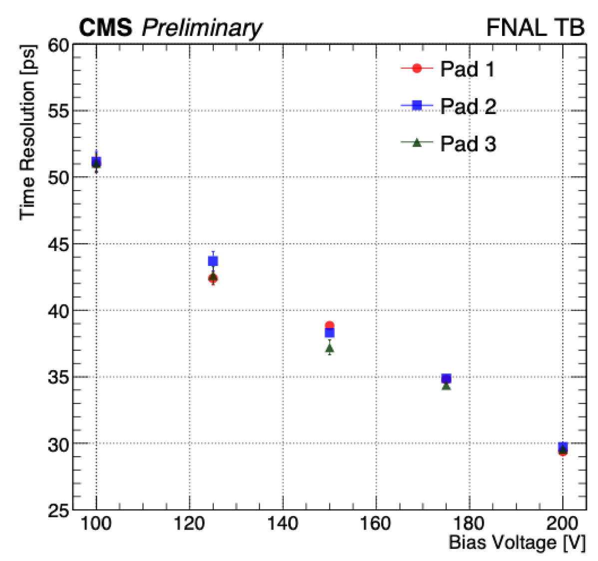
Preliminary test beam results on the characterization of Hamamatsu LGADs

- Extensive test beam campaign has been carried out at FNAL
- HPK 3.1 non-irradiated (5x5; 1.3 mm) and HPK 3.2 1.5E15 neq (single 1.3 mm) sensors studied in the test beam

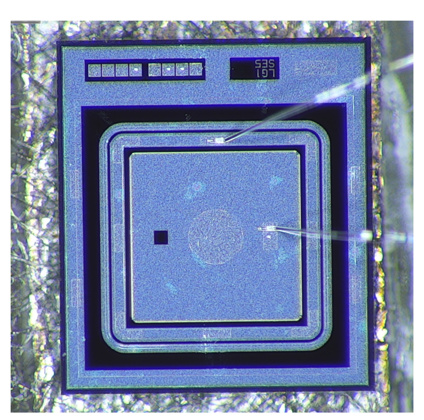
Non-irradiated sensor, 5x5; 1.3mm

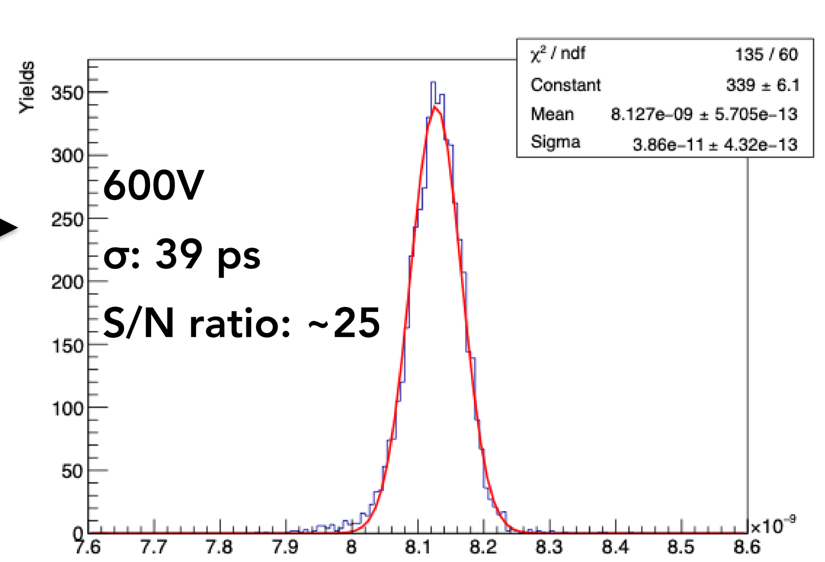




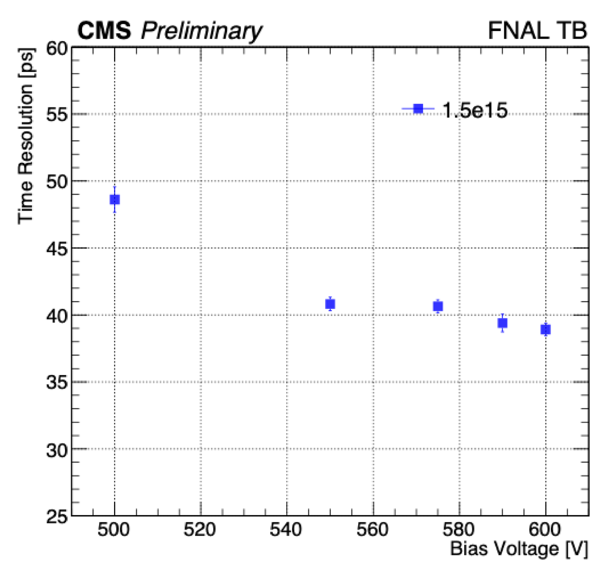


1.5e15 neq, Single sensor 1.3mm



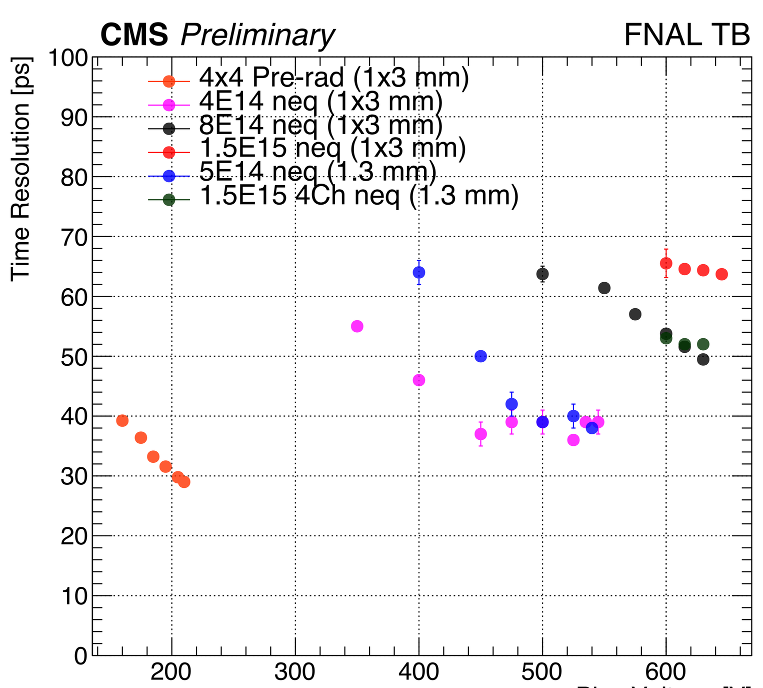


deltaT w.r.t MCP [s]

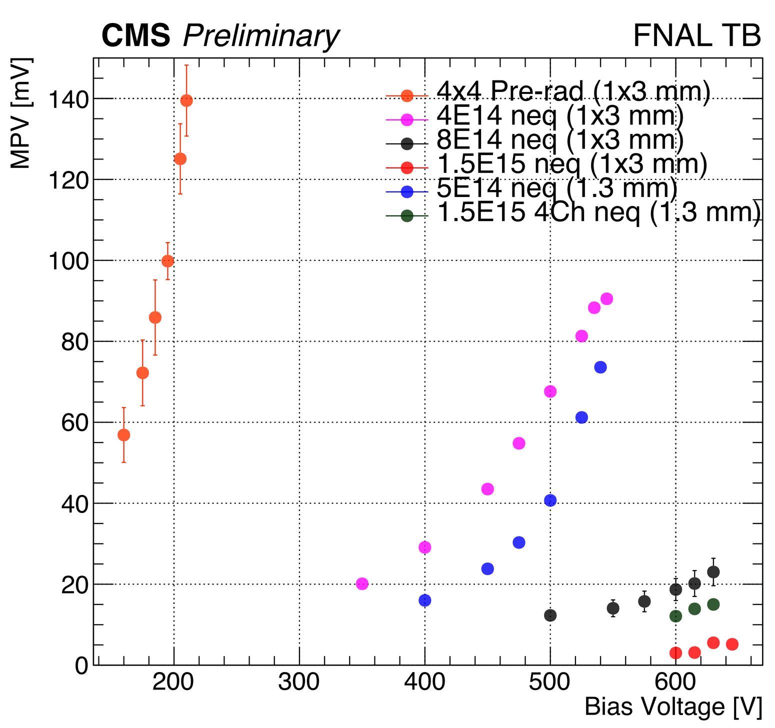


Time resolution vs Bias Voltage

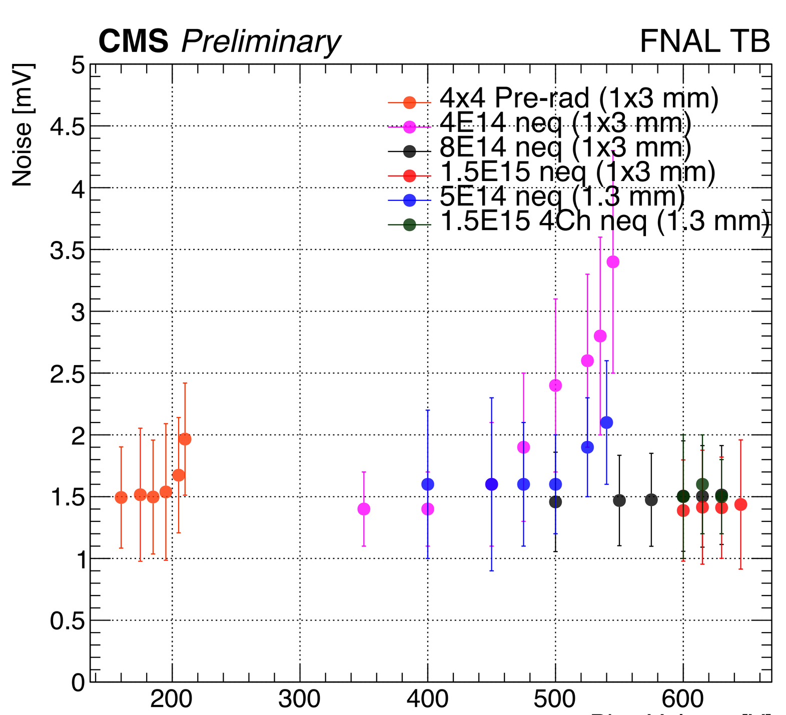
- Results from study of radiation hardness of the sensors
- Hamamatsu sensors with different irradiation levels were operated at different bias voltage points
- Two designs of sensors studied: 1x3 mm and single 1.3 mm
- Time resolution, MPV and noise measured versus applied bias voltage
- Maintained sub-40 ps resolution even with 5E14 neq
- High gain observed for the pre-radiated sensor
- High signal crucial for good time resolution



Time resolution vs Bias voltage

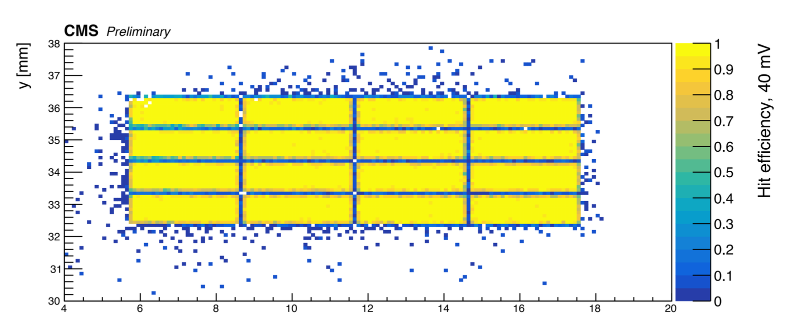


MPV vs Bias voltage

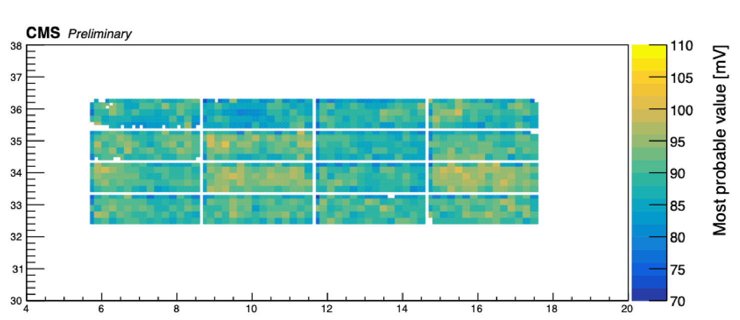


Noise vs Bias voltage

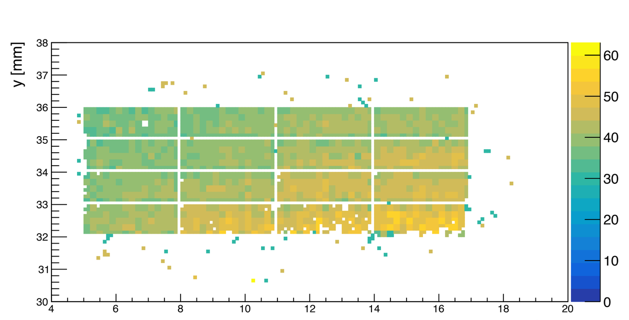
- Sensor hit efficiency and mean amplitude also studied
- Results shown for HPK 3.1 pre-radiated sensor and HPK 3.1 sensor with 4E14 neq radiation level



Sensor hit efficiency; HPK 3.1 pre-radiated



MPV of amplitude; HPK 3.1 pre-radiated



MPV of amplitude; HPK 3.1 4E14 neq

- High efficiency (~100% measured in the pre-radiated sensor)
- Most probable value (MPV) of amplitude is extracted from the landau+gaussian fit to the signal shape
- Non-uniform and low MPV values suggest a non-uniform gain layer deposition on the sensor

Conclusions and Outlook

- Test beam results of the Hamamatsu sensors show very promising results
- We are able to achieve a timing resolution of less than 40 ps even with high radiation level (5E14 neq)
- Excellent sensor hit efficiency measured for Hamamatsu sensors
- Permanent end cap timing layer (ETL) test beam setup at Fermilab allows for further R&D to be done with the Hamamatsu LGADs