The Luminosity Measurement of the CEPC and ATLAS with the LGAD

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Introduction

After the upgrade of the High-Luminosity Large Hadron Collider (HL-LHC), the uncertainty of luminosity measurement needs to be controlled within 1%. The diamond detectors used in run2 suffer from the performance degradation after irradiation, and thus cannot complete accurate luminosity measurement. A low-gain avalanche detector (LGAD) developed by the Institute of High Energy Physics can maintain a good signal-to-noise ratio even after high radiation doses (2.5 x 10^{15} N_{eq}/cm^2), and has been selected by ATLAS for the luminosity measurement. LGAD sensor is also being explored for the rapid beam monitoring in the future positron-electron collider to ensure accurate luminosity measurement and the realization of their physics potential.

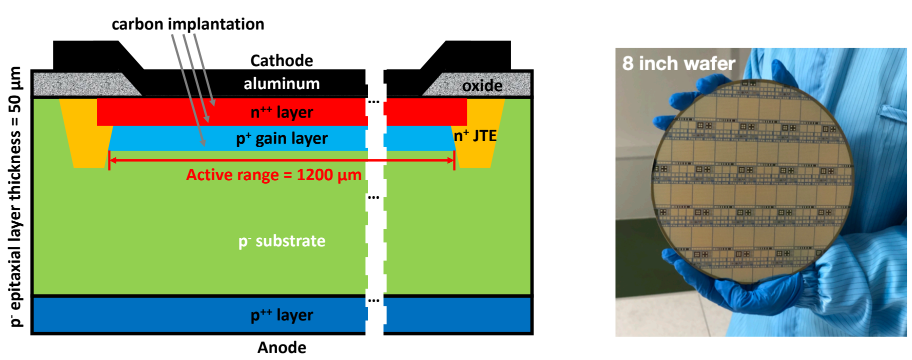

Figure 1:（left）Sketch of the LGAD structure (not to scale)，
（right）IHEP-IME LGAD sensor which could survive after 2.5 x 10^{15} N_{eq}/cm^2 irradiation .

The setup of the BMA at ATLAS

ATLAS's strategy of the luminosity measurement adopts multiple luminosity detector systems for mutual calibration to ensure the low uncertainty, good linearity and high stability. One of the systems, specifically designed for HL–LHC run4, is called the Beam Monitor for ATLAS (BMA), which was installed in 2022. Its main purpose is to address the luminosity measurement challenges of the HL–LHC brought by the increase in the number of primary collision events (mu 60 –> 200). The BMA is installed at the front–end shielding of the ATLAS experiment, JFC3, and it uses two IHEP–IME LGAD sensors (1.7mm²). The BMA with LGADs has advantages, which could be easy to replace annually and does not require additional cooling equipment. The performance of the BMA was tested during the run3 data taking process.

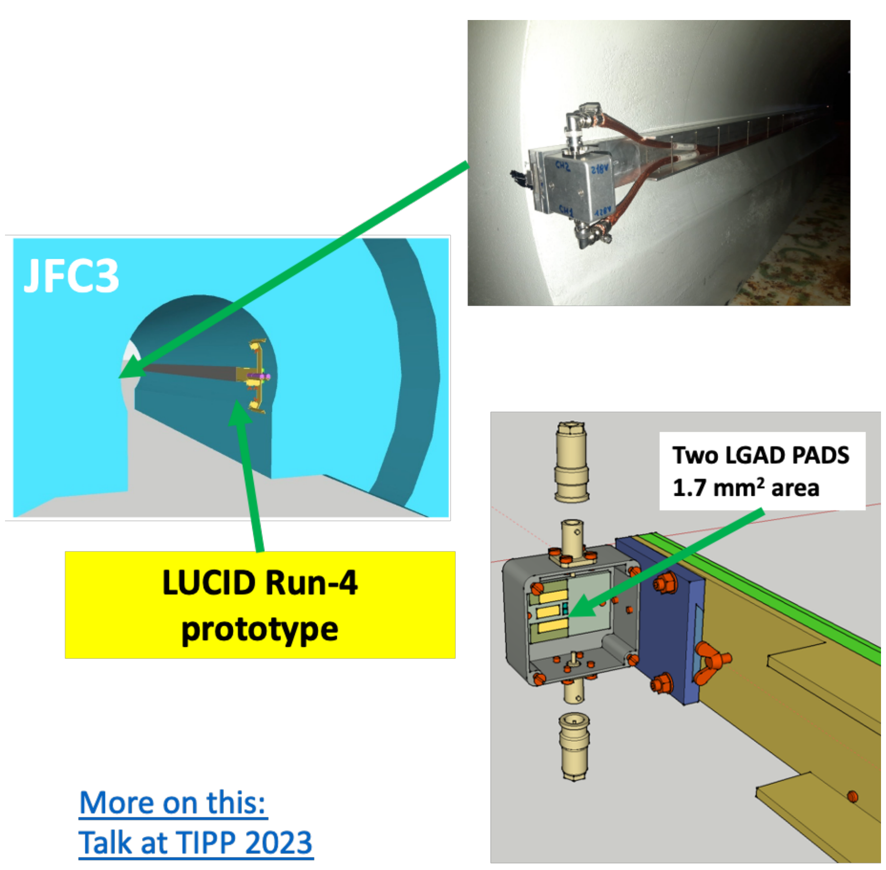

Figure 2: The setup of the BMA for the luminosity measurement of the ATLAS.

Rapid luminosity measurement detector for the CEPC

The luminosity measurement of the CEPC requires the rapid provision of luminosity information for quickly assessing the beam collision quality and providing adjustment information. According to simulations, the main signal for CEPC luminosity comes from the Barbar reaction, with GeV electrons distributed asymmetrically on both sides of the beam pipe and escaping from the beam pipe at a 1 mrad angle at a position 10 m away the IP point. The signal intensity is more than two orders of magnitude higher than background electrons. Therefore, in order to perform rapid monitoring of luminosity, it is planned to install LGAD at the 10m position of the beam pipe, with a 1 mrad angle with respect to the beam direction, and symmetrically placed on both sides, as shown in Figure 5. With the picosecond resolution, LGAD could monitor the real–time beam density by counting the electrons from the Barbar reaction.

Test results of the BMA at ATLAS

After the beam tests in 2022 and 2023, as shown in Figures 3 and 4, the BMA with IHEP-IME LGAD demonstrated excellent linearity and stability. With the gain degradation correction, the BMA using IHEP-IME LGAD showed good stability. It has a stability level of less than 2% compared to one of ATLAS's main luminosity detectors, LUCID, and has no dependence on mu. There is potential for the LGAD with even higher precision in measuring luminosity after further gain degradation correction in the future.

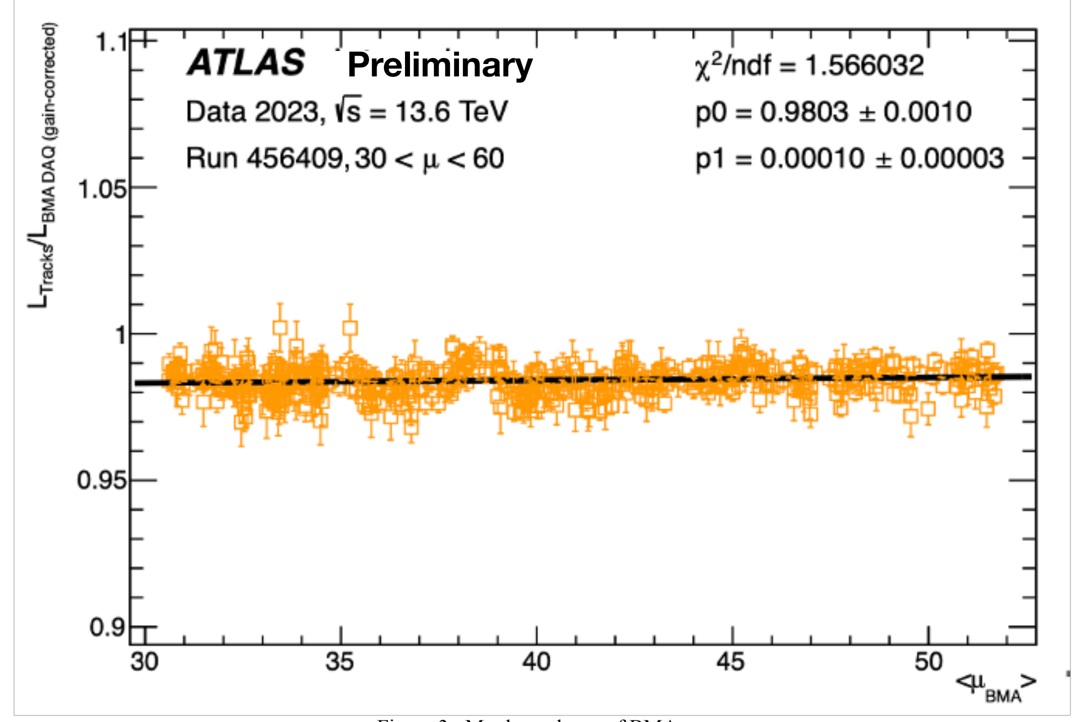

Figure 3: Mu dependence of BMA

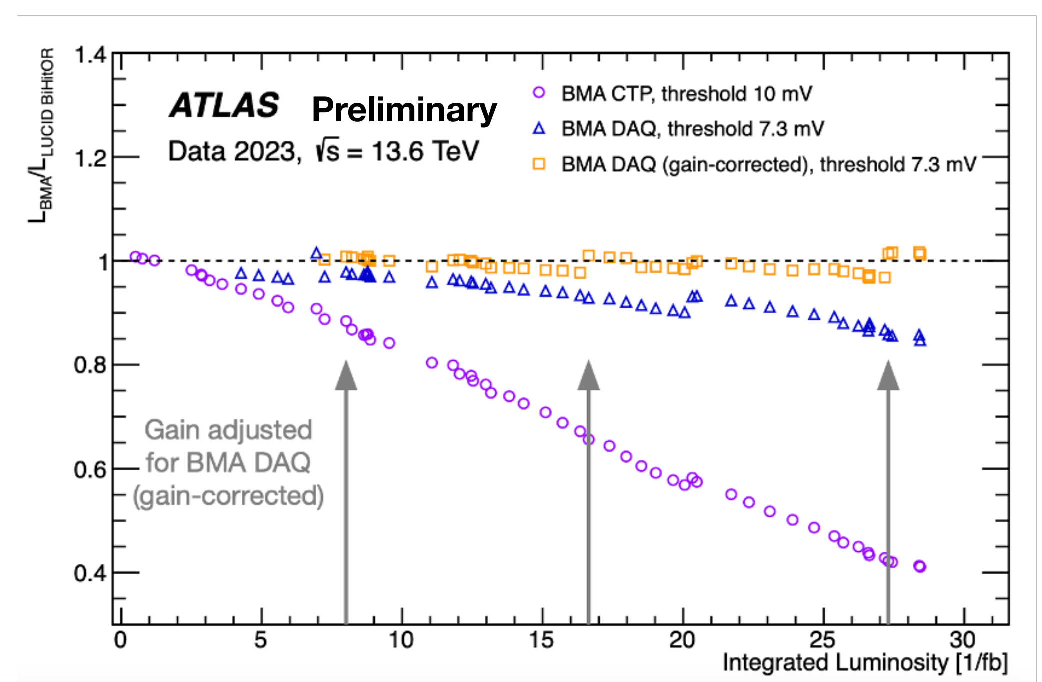

Figure 4: Ratio of the run-integrated-luminosity of BMA wrt to LUCID

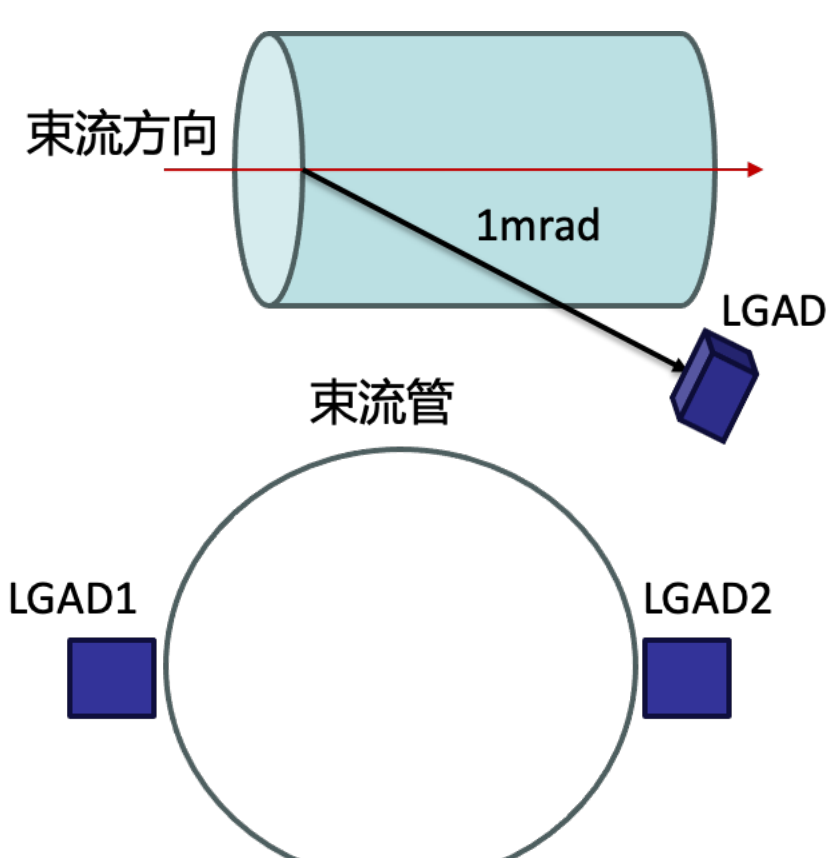

Figure 5: Diagram of LGAD luminosity detector placement，（up）LGAD is positioned 1mrad from the CEPC beam direction，（down））two LGADs are symmetrically placed on both sides of the beam pipe。