LGAD for Luminosity Measurement

Yunyun Fan, Mei Zhao, Xuan Yang, Zhijun Liang

fanyy@ihep.ac.cn

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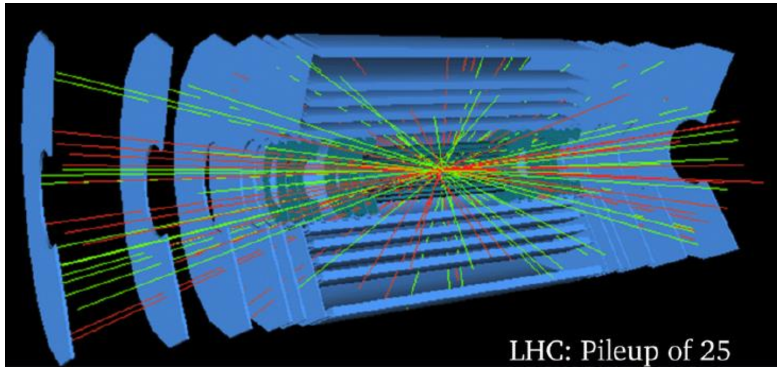
Outline

- **Motivation**
- **Luminosity of the ATLAS at HL-LHC with IHEP-IME LGAD**
- **Design for CEPC fast luminosity measurement**
- **Summary**

Motivation

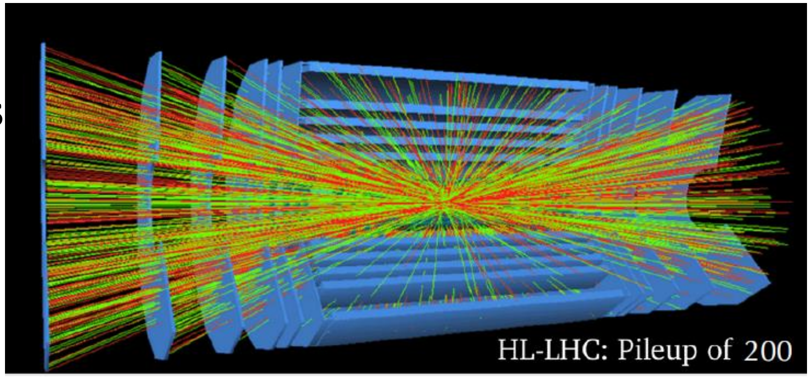
- **The importance of the luminosity measurement**
  - Affect the physics goals： precision measurement of the Higgs …
  - fast feedback for the beam adjustment: efficient beam steering, machine optimization and fast checking of running conditions
- **High luminosity Large Hadron Collider**
  - Instantaneous luminosity $7.5 \times 10^{34} cm^{-2} s^{-1}$
  - The uncertainty decrease from <2% to < 1%(off line) (LHC is 2%) very challenging！

LHC



L increase 7 times

HL-LHC



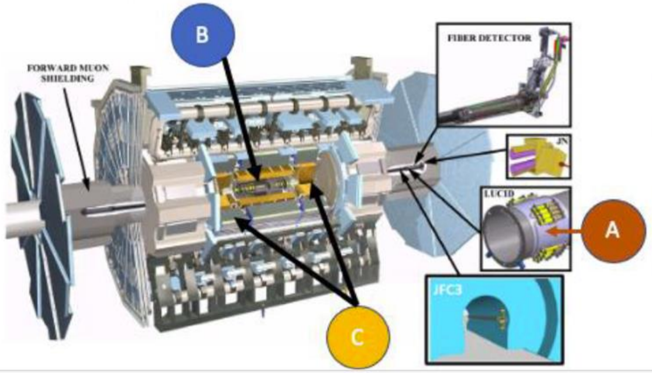
Challenges for luminosity measurement

- **Experience we got from the LHC ?**
  - **Linearity and stability is most important**
  - Several luminosity detectors work together to decrease the uncertainty to1%.
- **LGAD to do the luminosity measurement (new technology)**
  - Fast time resolution, excellent radiation hardness

Luminosity measurement detectors

A LUCID
- Cherenkov light detector with 2x16 PMT at z=±17m from IP
- Bunch-by-bunch luminosity through **hit counting** (many different algorithms in use)
- Additional three prototypes detectors, shown in the inset, are being tested in RUN 3

TRACK COUNTING (TC) B
- Counting tracks in the inner detector(ID)
- Bunch-by-bunch capabilities (although statistically limited)

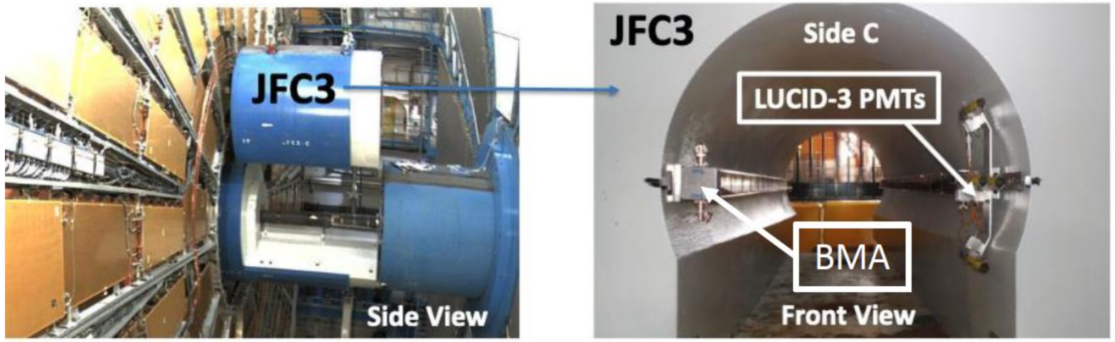


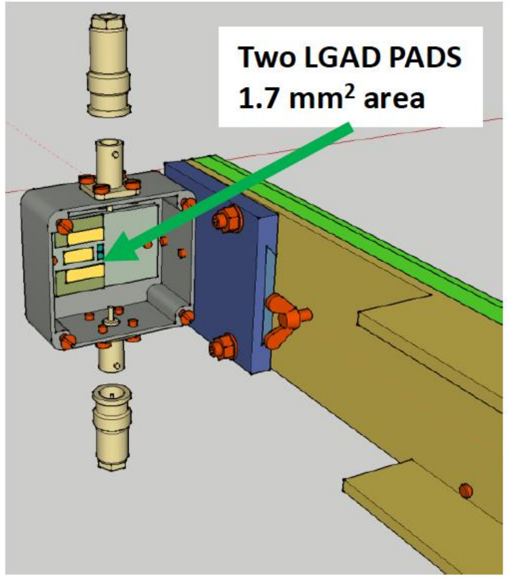
Calorimeter measurements C
- LAr (EMEC and FCAL)
  - using the total ionization current
- Tile calorimeter
  - using the current drawn by PMT
- Only bunch integrated measurement

RUN 3 Lumi detectors

+ HGTD, BCM', (PLR?) in RUN 4

Beam Monitor of ATLAS with LGAD





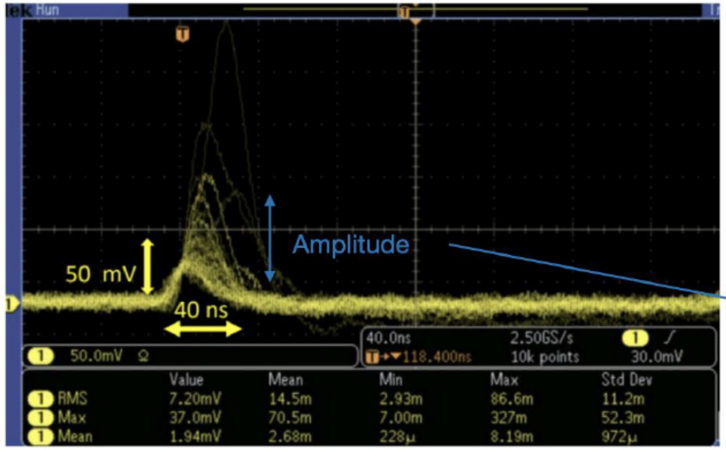
- BMA is a prototype for an additional ATLAS monitor for the HL-LHC
- Installed in 2022
- Main characteristics (to cope with μ_b~60 → ~200)
  - Low geometrical acceptance
    - Smaller systematics effects (non linearities with pile-up)
    - Potentially less μ dependence → good performances at high lumi
    - In the present prototype version can not be absolutely calibrated during van der Meer scans
  - Placed in the ATLAS Forward shielding
    - can be replaced at the end of every year → limited radiation damage
    - easy to install and uninstall
    - No cooling needed (good thermal contact with the forward shielding, an ideal heat reservoir)

[More on this: Talk at TIPP 2023]

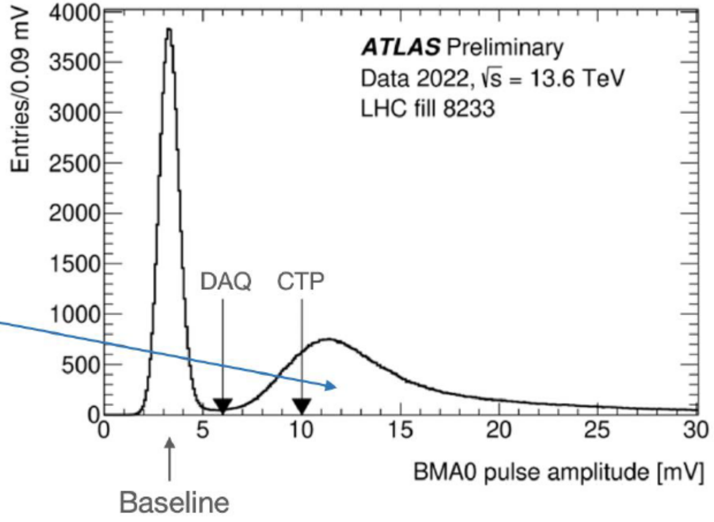
The signal of the BMA with LGAD

- 2022
  - CTP: standard NIM trigger with threshold at 10 mV
- 2023
  - using BMA LUCROD integrated in the OLC
    - DAQ: with a lower threshold at 7.3 mV
    - DAQ (gain-corrected): same as DAQ but increasing the LUCROD amplification to compensate for detector gain losses

BMA signal waveforms



BMA pulse amplitude spectra

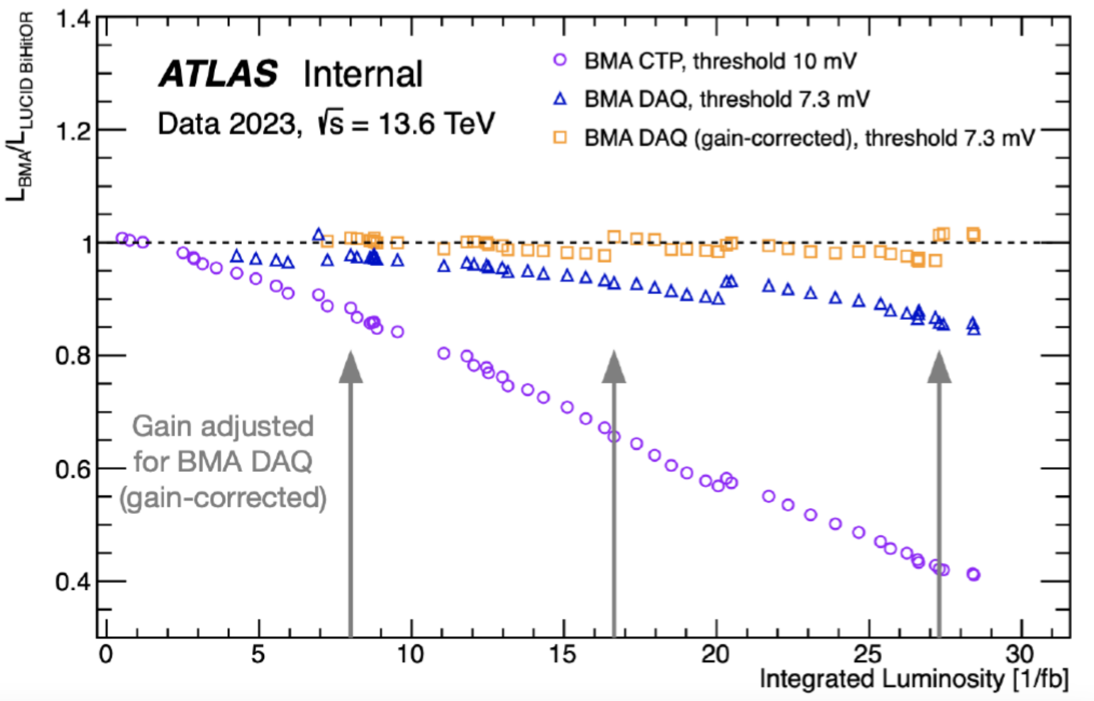


- S/N ~ 24!
- Very low acceptance: σ_{vis}~80 μbarn
- BMA pulse amplitude spectra can be considered as **SINGLE MIP** spectra (~ independent from μ value)
- Calibration technique is very promising: under study

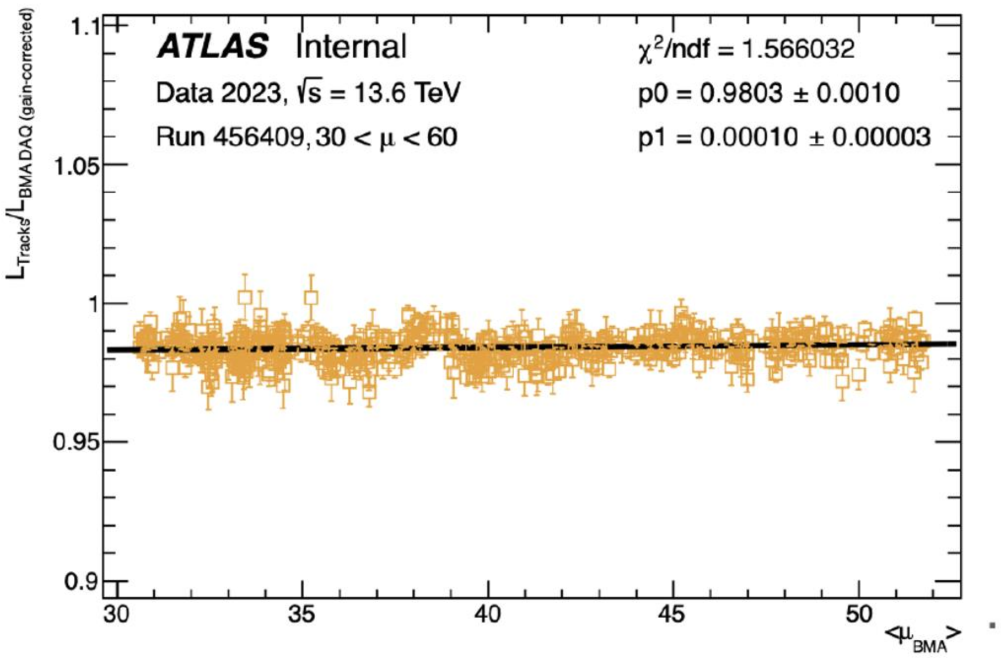
Efficiency vs integrated luminosity

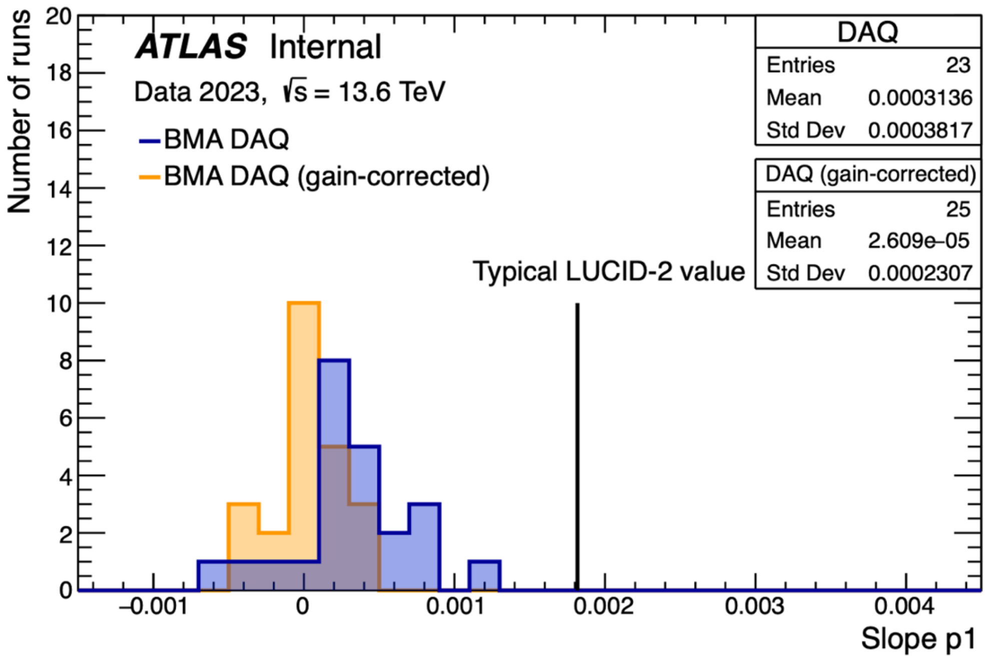
- BMA CTP has a linear decrease with around 2.5% per /fb
  The first channel of BMA DAQ has a linear decrease with around 0.7% per /fb (between 10-20 /fb)
  and 1.25% per /fb (between 20-28 /fb)
- For the second channel, BMA DAQ (gain-corrected), the gain was adjusted three times: May 17th (around 8 /fb), June 8th (around 16 /fb) and
  July 12th (around 28 /fb)
- BMA DAQ (gain-corrected) follows LUCID somewhat closely with a total difference less than 2%
- The efficiency loss is dominated by gain loss
- The efficiency and stability can be improved by adjusting the gain regularly!

Ratio of the run-integrated-luminosity of BMA wrt to LUCID



Linearity ： μ dependence





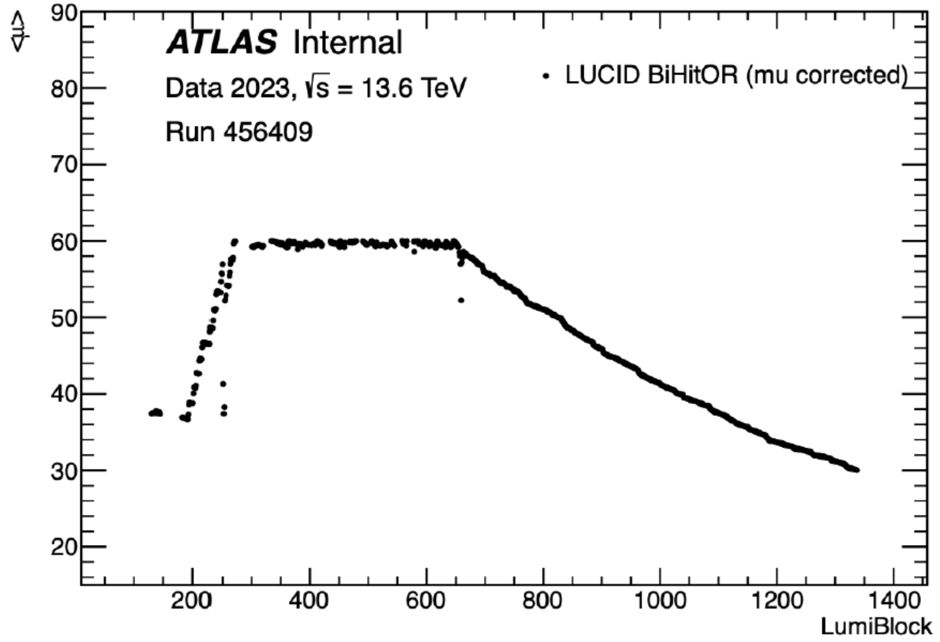
- ✓ μ dependence: Any detector response systematic effect which will affect the linearity of the luminosity measurement
- ✓ The data points were fitted with straight line. (P1 is the slope)

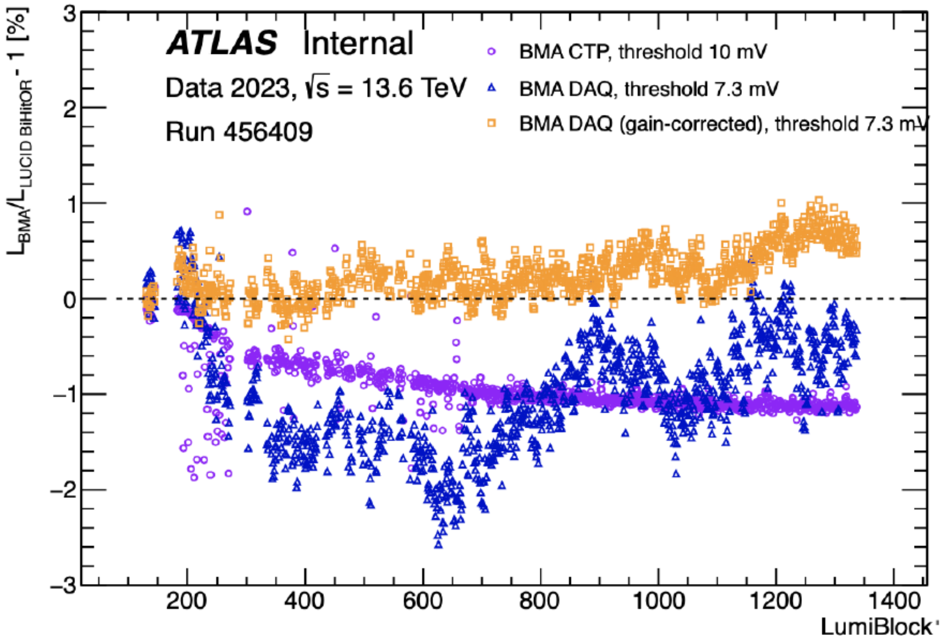
✓ The BMA DAQ (gain-corrected) has the lowest P1
Which means the highest linearity

- One order better than the LUCID

Physics performance

- Study of BMA performance for run 456409 the 12-13th of July, with an integrated luminosity of 0.9616 /fb
- The upper plot shows the bunch-averaged mu as a function of LumiBlock for LUCID BiHitOR (the current best luminosity algorithm)
- The lower plot shows the ratio between the integrated luminosity measured in each LumiBlock by LUCID BiHitOR and each BMA configuration as a function of LumiBlock. The ratios are normalized to 1 for each BMA configuration in the first LumiBlock
  - The maximum deviation for BMA CTP is around 1.2%
  - The maximum deviation for BMA DAQ is around 2.7%
  - The maximum deviation for BMA DAQ (gain- correction) is around 1%



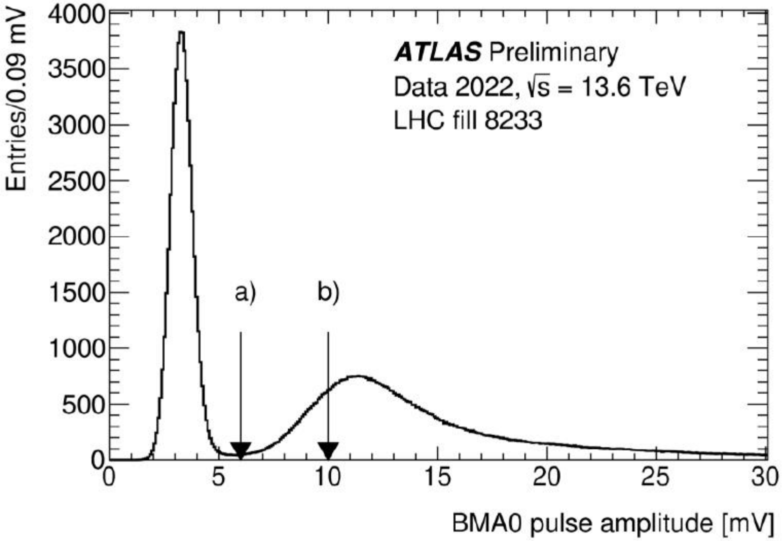


Calibration Strategy

It is of utmost importance to monitor the detector response and gain stability

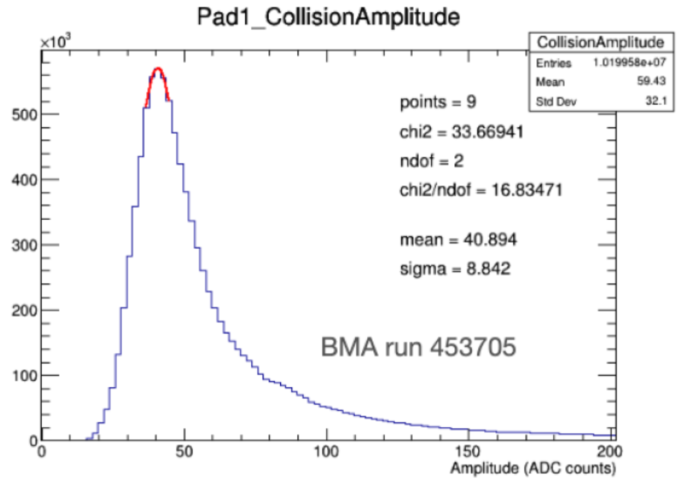
1. **Calibration using a standard RP ^{90}Sr**
    - The present BMA box foresees already the possibility to place a source to regularly calibrate the detector
    - This method has been used during the installation phase of the detector
    - A final RP validation is needed for the installed detector
    - **This solution will conflict with the plan to place BMA close to LUCID**

2. **Self-calibration using P.H. spectra**
    - The pad acceptance is very small, BMA is recording **single track spectra (MIP)**
    - The efficiency variation can be hence be evaluated by the LUCROD amplitude spectra
    - A promising method based on keeping the MIP peak position fixed by adjusting the LUCROD amplification factor is under study

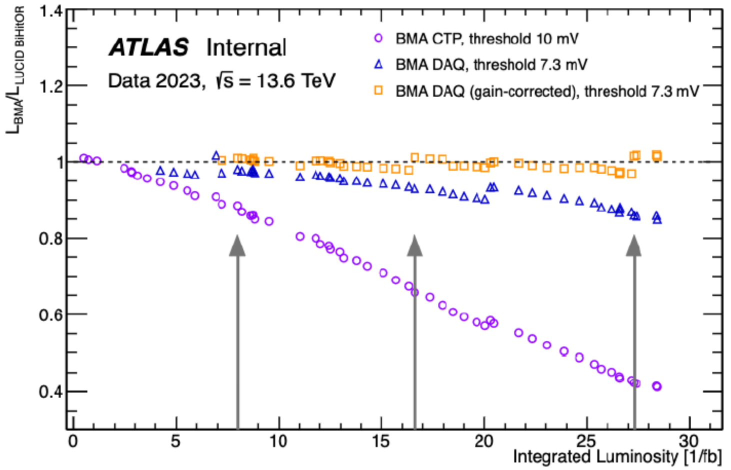


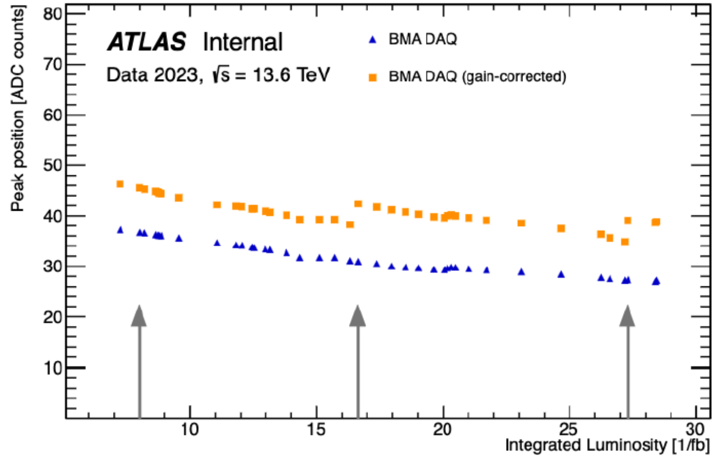
Self calibration using the pulse height spectra

- The pulse height spectra peak is fitted with a parabola (upper plot) and the peak position is plotted as a function of the integrated luminosity (lower right plot) for the BMA DAQ and DAQ (G.C.) channels
- The peak positions trends are very similar to the ones reported in the Efficiency plot (lower left plot) already shown in slide 5
- It looks like the peak position can be used as a monitor of the detector efficiency
- **Next (crucial) step**
  - Prove that the peak position does not depend on the μ-value
  - Work in progress

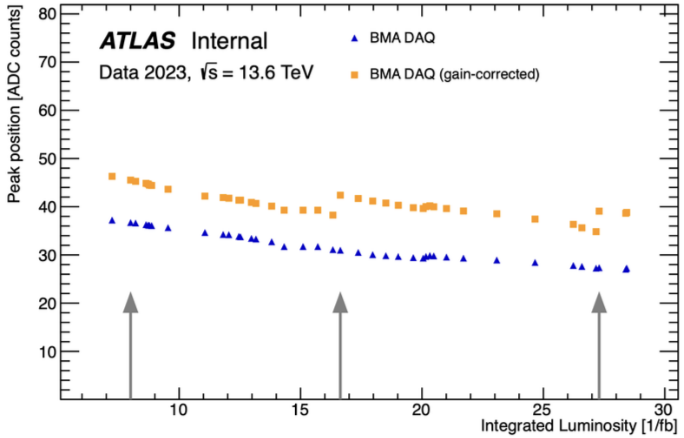


Efficiency plot

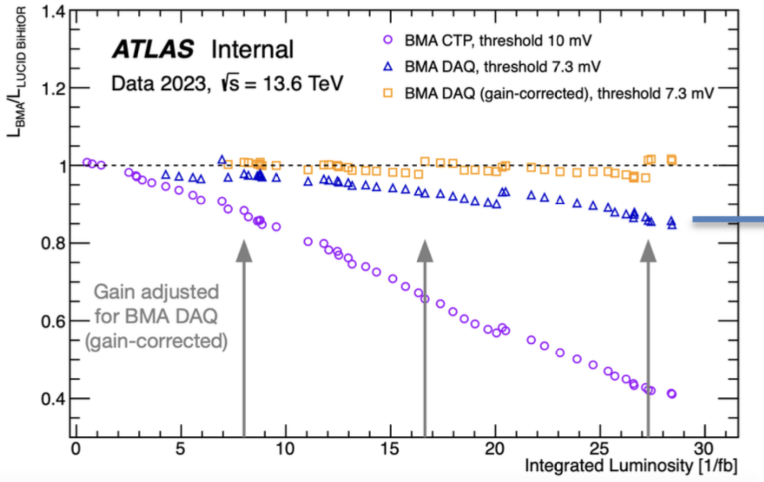


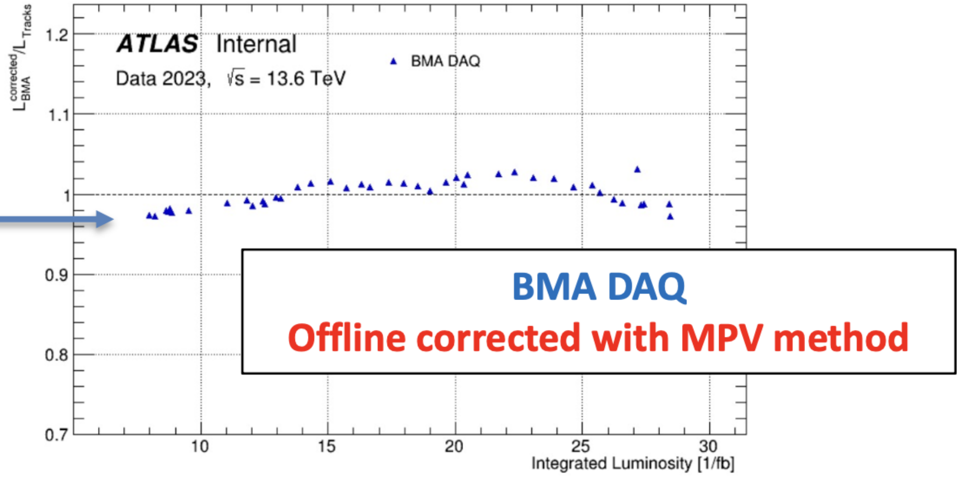


Detector calibration based on MPV



- **The change of electronic gain during 2023 data-taking was done to bring back the Most Probable Value (MPV) back to the value measured at the start of data-taking.**
- **Based on the MPV, it is possible to apply offline corrections on data (as one would do online).**





Promising results with BMA DAQ. Analysis on-going with BMA DAQ gain-corrected.

Carbonated LGAD Performance at room temperature

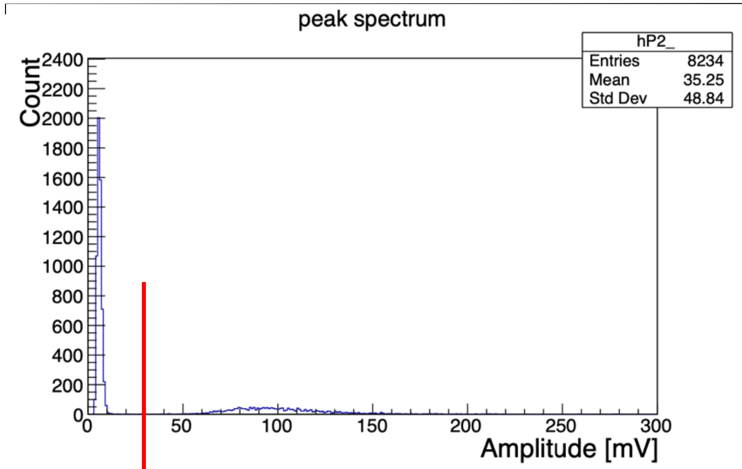


Fig. 1: Running time 0-2h

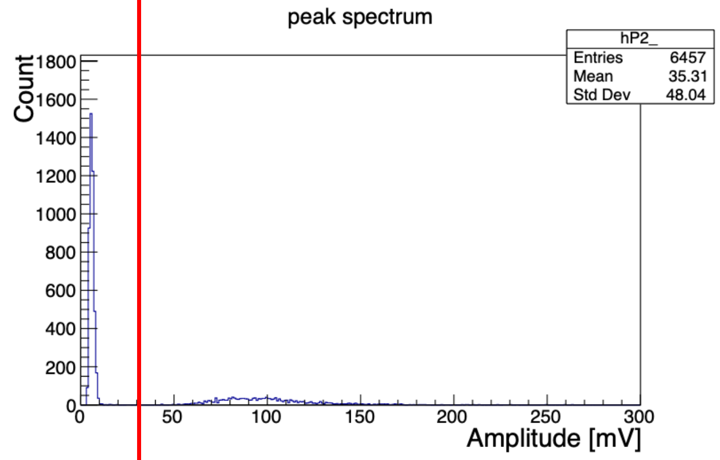
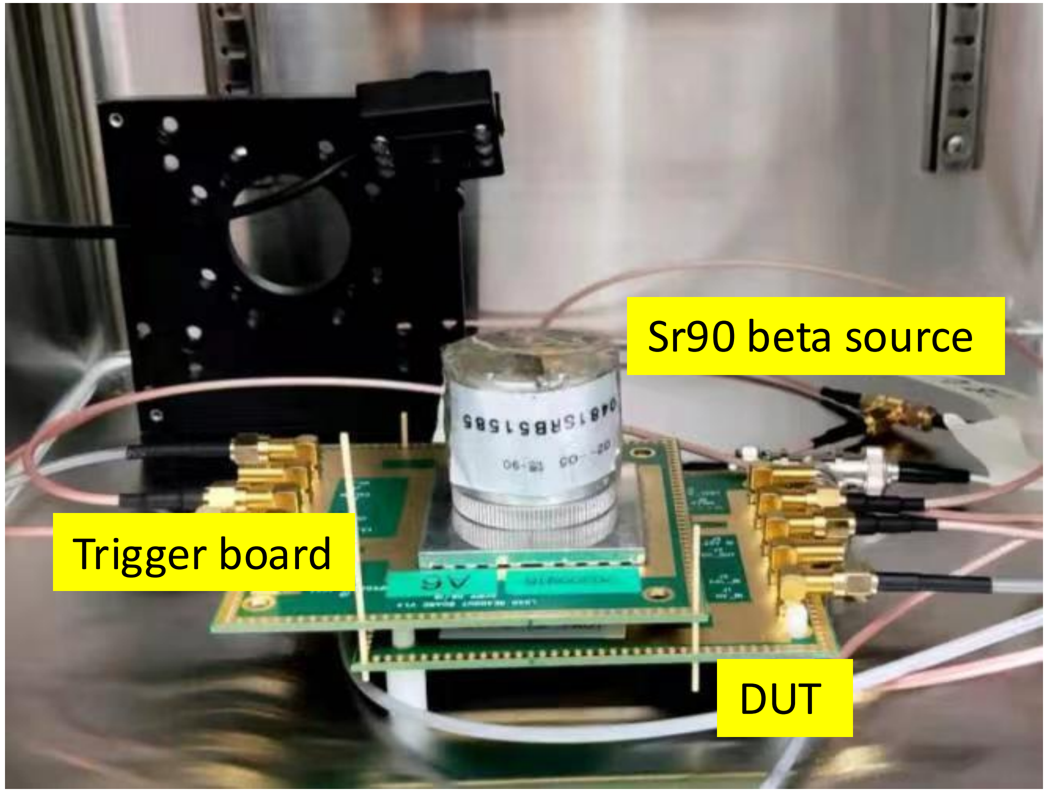
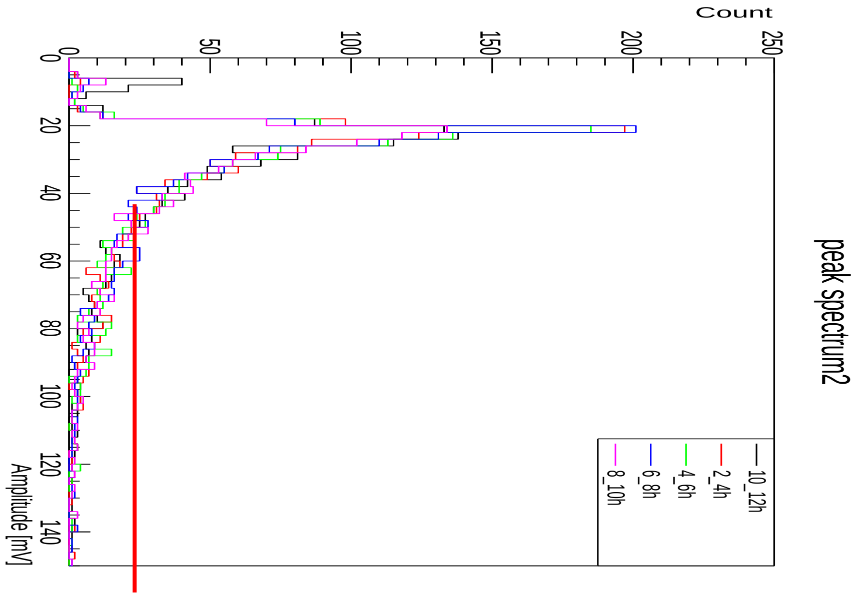


Fig. 8: Running time 14-16h

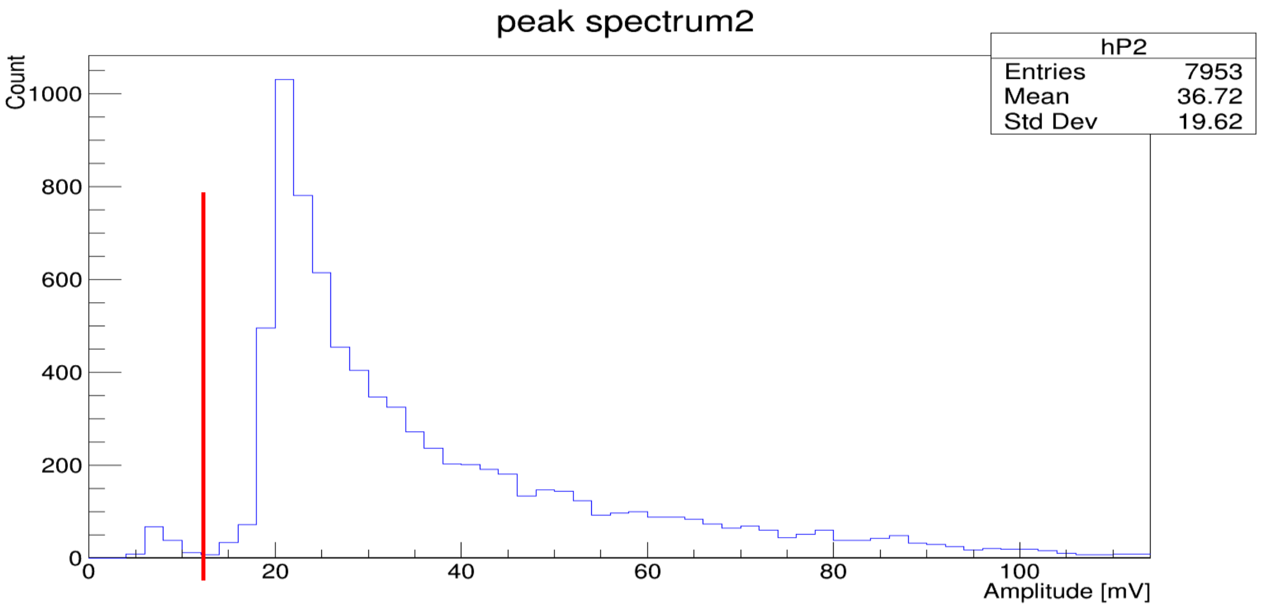
- **Carbonated LGAD before irradiation**
- **Trigger only on both trigger boar**
- **No significant performance decrease after long time operation**

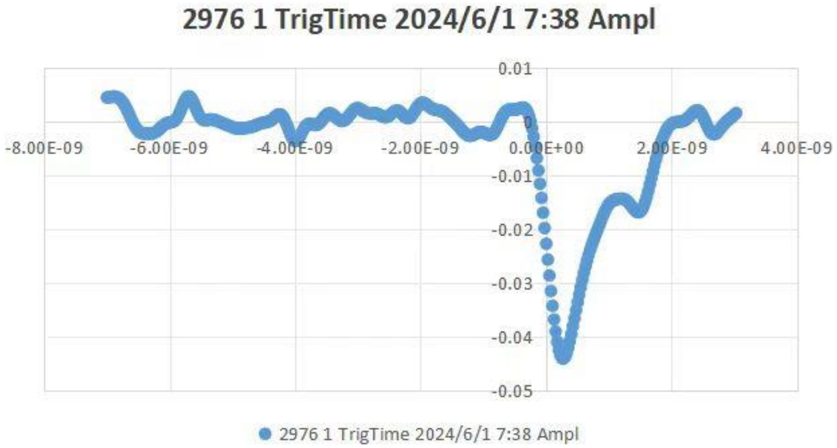


Carbonated LGAD Performance



- Carbonated LGAD after irradiation
  - 8e14 neq/cm2
- Tested at room temperature (according to BMA requirement)
- Trigger on both trigger board and DUT
  - Baseline noise reduced
  - Still can see a separation between baseline and MIP
- No significant performance decrease after long time operation

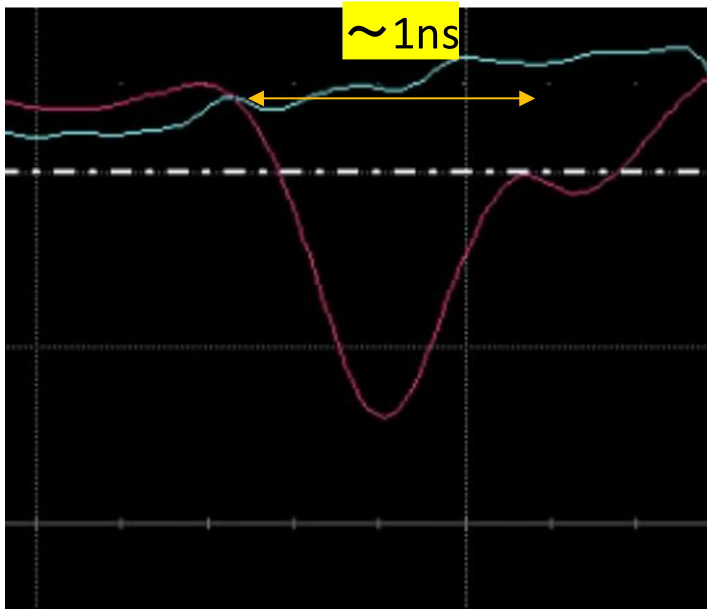




Design for CEPC fast luminosity measurement

- **Fast luminosity measurement requirement**
  - ~ns signal shape （LGAD OK）
  - 100 μs feedback time for the accelerator control （same as ATLAS L1 ）
  - More to discuss…

50 μm LGAD signal



Methods to distinguish the signals for CEPC

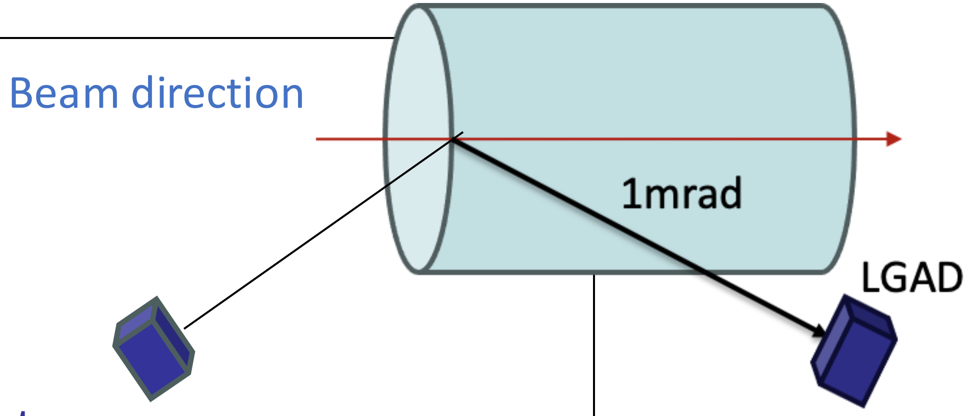
- **Signal features（According to Haoyu）：**
  - signal and background are all GeV electrons (all larger than MIP), one side has some keV photon.
  - the numbers of the signal is two orders of magnitude higher than that of the background。
  - uniform distribution of the signal electron and the background electron along the circle of the beam tubes = we can put our detector on random location and 1 location could satisfy
  - Signal has an special angle : 1mRad along the beam pipe

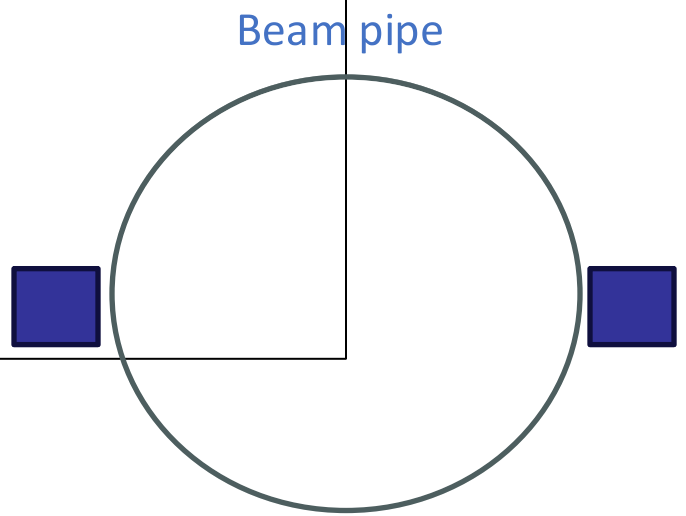
- **Method： Using counts of the signal accorded by the LGAD to distinguish the signal and background**

LGAD for fast luminosity measurement

- **Requirement of the LGAD sensor**
  - Time resolution 30 ps
  - Radiation hardness：TID 2MGy，NIEL 2.5e15？
  - Linearity ： counts vs luminosity
  - LGAD is blind to the 30KeV background， no need to worry
  - Occupancy ？ （the number of the signal electron/cm*2/s）

    Area：easy to adjust due to application of the IHEP designed LGAD
- **Requirement of the fast electronics**
  - Fast readout electronics, on line precision
  - Precision clock system
  - for CEPC 23 ns gap per bunch (at Z pole)





Summary

- **BMA with LGAD shows promising ability of the luminosity measurement at ATLAS**
  - Almost no μ dependence (**good linearity**)
  - High S/N ratio
  - Promising self calibration with the bias voltage adjustment
- **Run-3 showed that BMA with LGAD is a good candidate as an online and offline luminosity monitor @ HL-LHC, in addition to LUCID-3.**
- **CEPC fast luminosity measurement**
  - Count to separate the signal and the noise
  - Fast time resolution (30 ps), fast readout electronics, feedback within 100us
  - Radiaiton hardness and low signal decrease for signal long distance transfer

Thank you for your attention！

- **Back up**

Luminosity test System with the LGAD

- **Fast electronics**
- **Long distance of the signal transfer**
  - Radiation hardness and low signal loss cable
- **Detector HV power supply et al.**