# Trigger threshold verification for the hadronic calorimeter prototype for the ILC

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2014/09/10

DESY summer student session

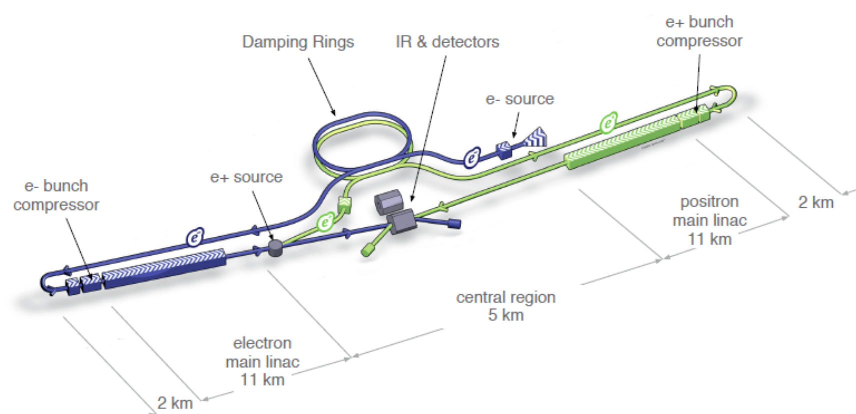
# Content

- Introduction on ILC & ILD and the hadronic calorimeter engineering prototype
- Method of measurement
- Results

# Introduction

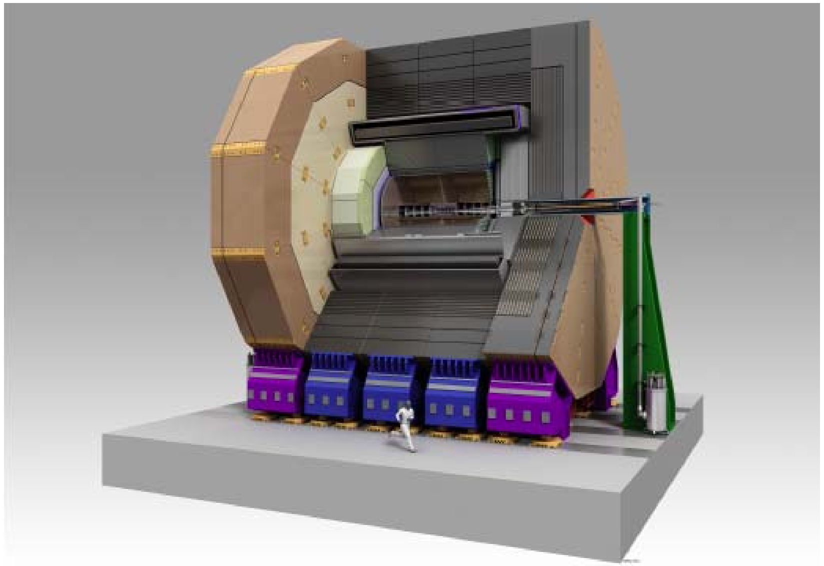
- The International Linear Collider
  - Center-of-mass energy of 500GeV $e^+e^-$ linear collider
  - To be build in Japan
  - Precision measurement mainly Higgs, "LHC successor"

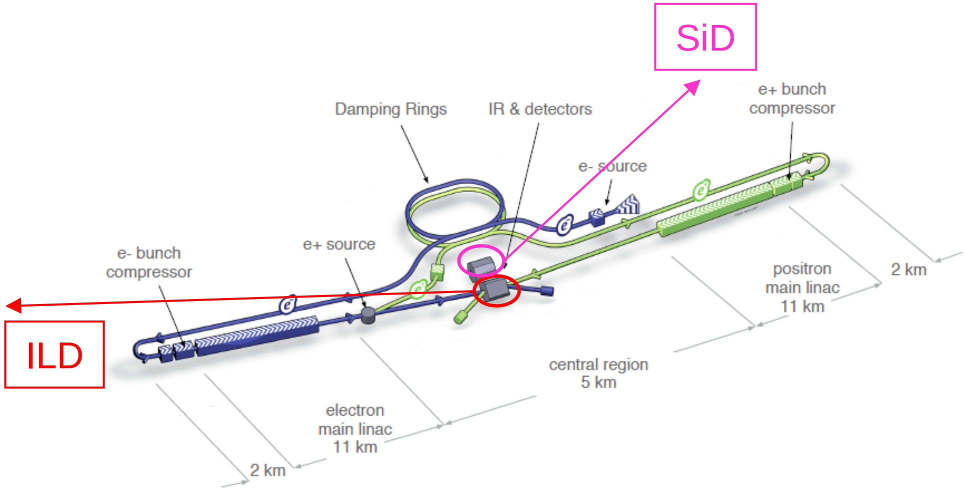


# Introduction

- The International Linear Collider
  - Center-of-mass energy of 500GeV $e^+e^-$ linear collider
  - To be build in Japan
  - Precision measurement mainly Higgs, “LHC successor”
- The Internation Large Detector (ILD):
  - Particle detector being develop for the ILC
  - Excellent tracking and high granularity calorimetry systems.(In the order of $10^6$ channels for hadron calorimeter)
  - Reconstruct the energy of individual particles using the Particle Flow approach.
- Analogue hadron calorimeter (AHCAL)
  - Scintillator tiles and silicon photomultipliers (SiPM)
  - Scintillation: light produced by the passage of particle
  - SiPM: avalanche photodiode array to generate analog signal from light

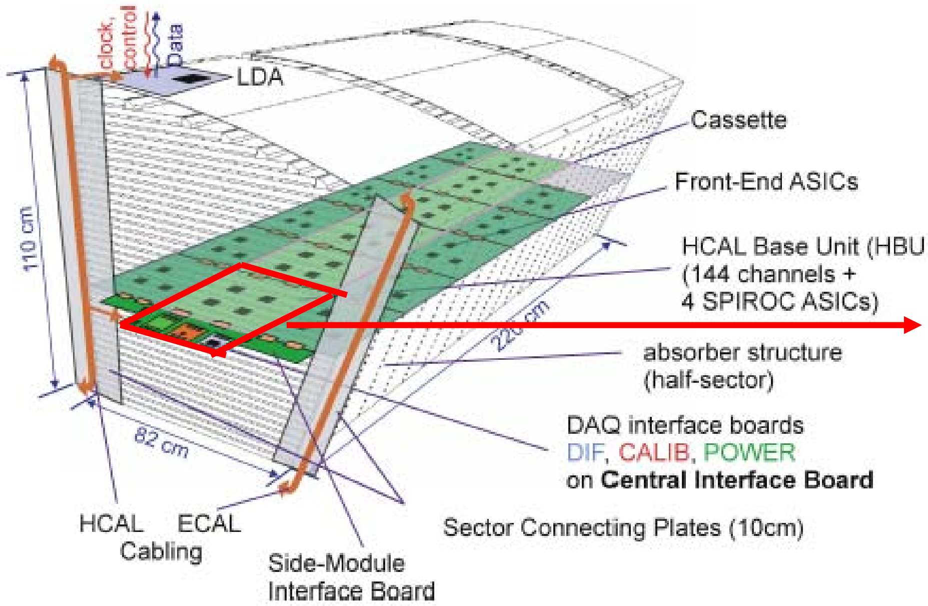




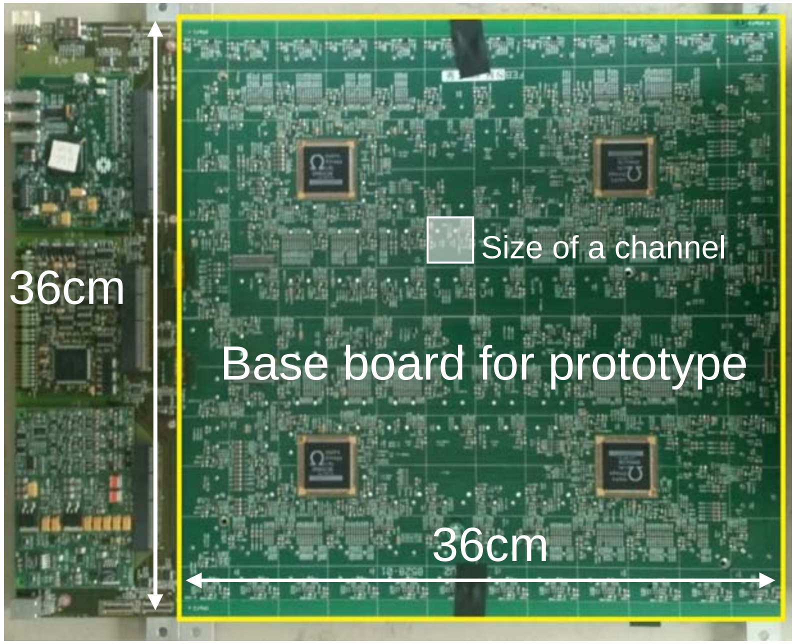

*From ILC Technical Design Report*

# Introduction

- The AHCAL engineering prototype:
  - Base board: 36 channels x 4 ASIC (Application specific integrated circuit)

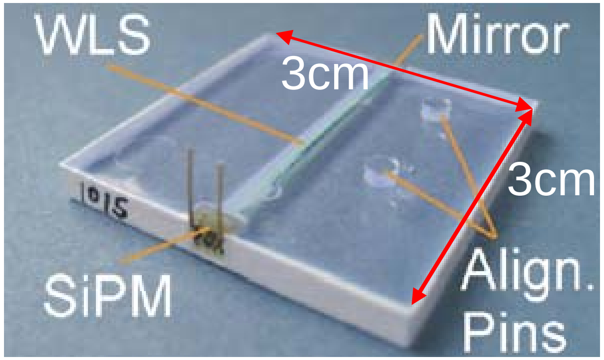


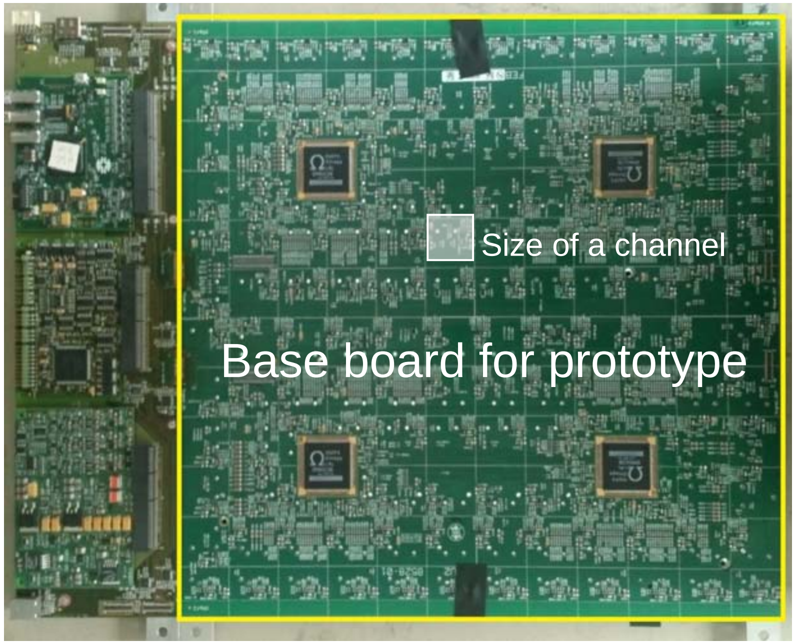

*Part of the barrel in the ILC HCAL*



# Introduction

- The AHCAL engineering prototype:
  - Base board: 36 channels x 4 ASIC (Application specific integrated circuit)
  - The LED system:
    - Direct inject light into scintillator tile
    - Every channel has an LED
    - LED light amplitude can be controlled via voltage setting.



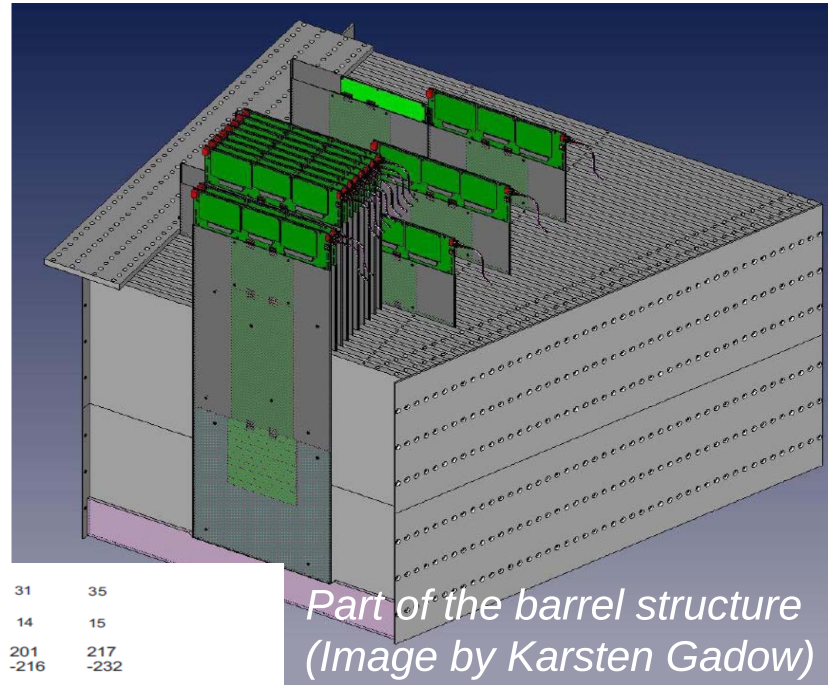





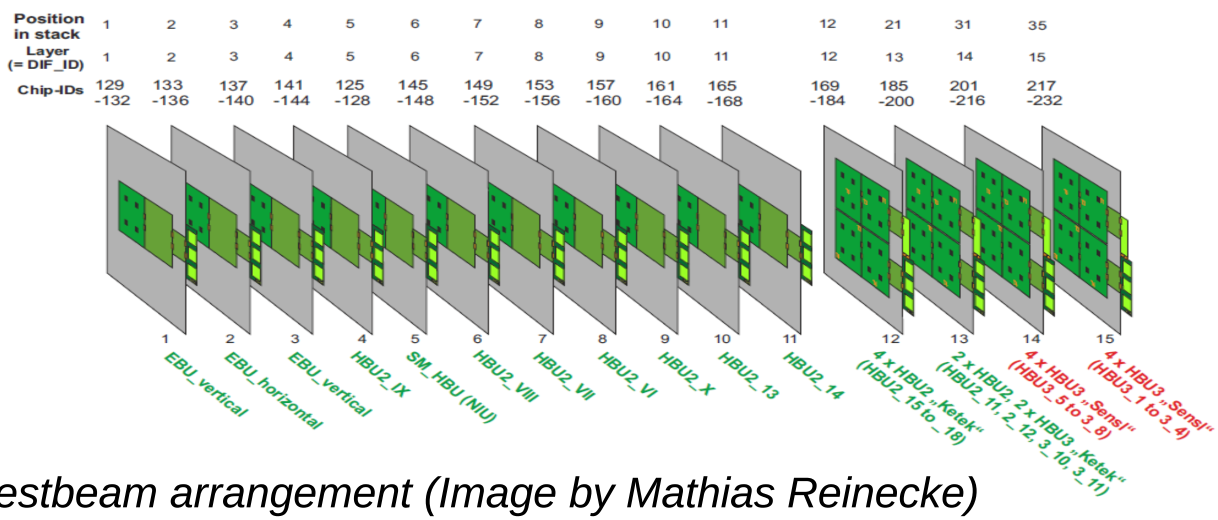

*Bottom view (channels are wrapped in reflector foil)*

# Introduction

- The AHCAL engineering prototype:
  - next testbeam at CERN in October till December:
  - 24 layers, ~3450 channels
  - Trigger thresholds are everything!



*Part of the barrel structure (Image by Karsten Gadow)*




*Testbeam arrangement (Image by Mathias Reinecke)*

# Introduction

- The AHCAL engineering prototype:
  - next testbeam at CERN in October till December:
  - 24 layers, ~3450 channels
  - Trigger thresholds are everything!

No trigger threshold

“Good” trigger threshold

# Introduction

- Triggering system (2 modes):
  - Auto trigger (AT) :
    - Triggers when the signal pulse exceeds a threshold value automatically.
    - The threshold values are set in the configuration files of the readout system.
  - Reference system :
    - Triggers everything regardless of the signal pulse strength, we call it the external trigger (**ET**).
- Set thresholds with acceptable noise rates
- Goal: Verify threshold.

No trigger threshold

“Good” trigger threshold

# Introduction

- Current status:
  - Trigger threshold behavior varies for each channel.
  - Previously, these measurement can only be done for 1 channel at 1 time
  - Need a relatively fast method to measure trigger threshold for each channel. (ILC HCAL: millions of channel).

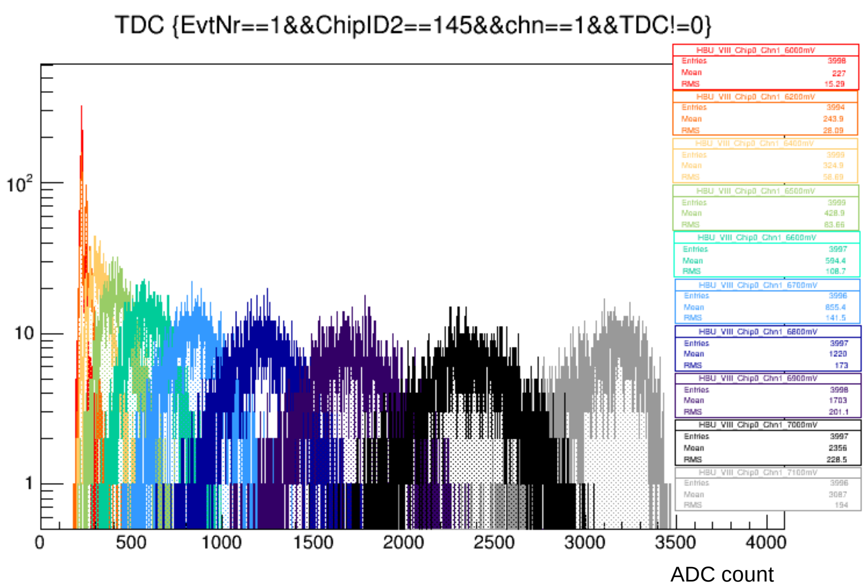
# Introduction

- Current status:
  - Trigger threshold behavior varies for each channel.
  - Previously, these measurement can only be done for 1 channel at 1 time
  - Need a relatively fast method to measure trigger threshold for each channel. (ILC HCAL: millions of channel).

**Solution: LED System + Trigger in two modes + Oskar (my acting supervisor)**

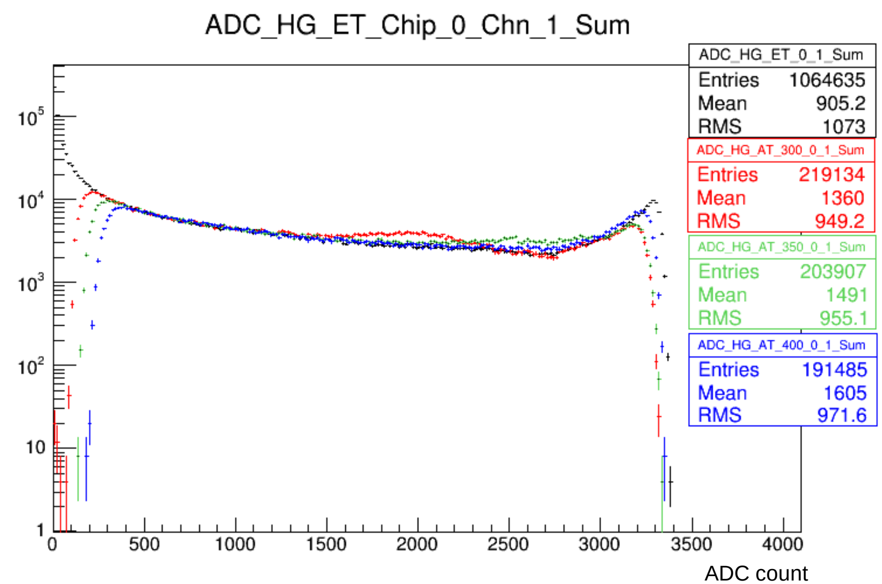
# Method of measurement

- Take runs using LED with a wide range of LED amplitude .
- The runs are added together to produce a spectra for each channel.
- Runs are taken with external trigger(ET) and auto trigger(AT) mode.




Runs in for different LED amplitude

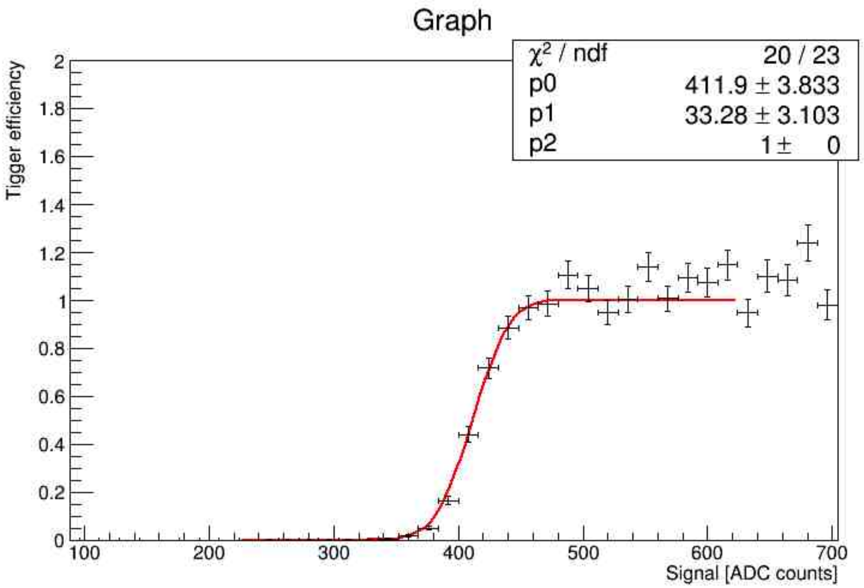
*Before subtracting noise offsets




Spectra of a typical channel for AT & ET(sum of all LED amp.)

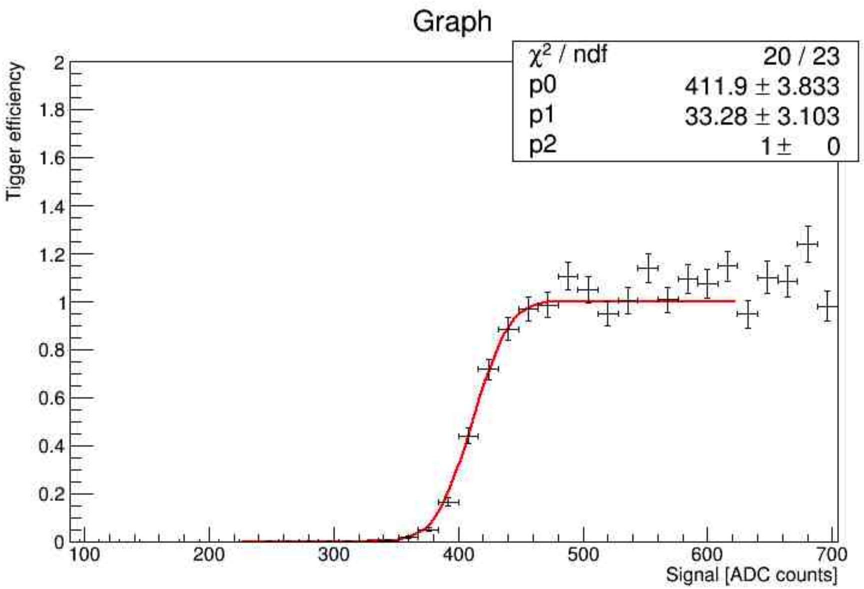
# Method of measurement

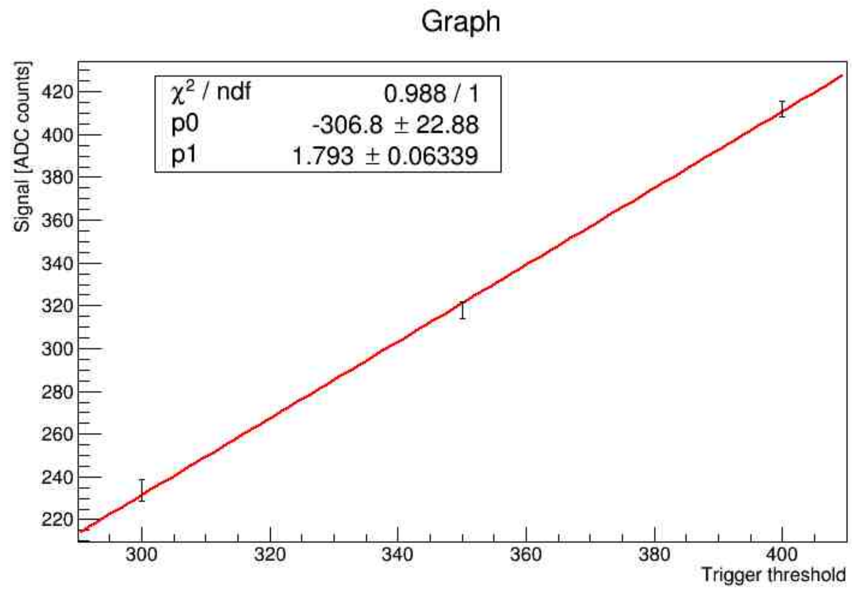
- Take the division of AT/ET plots for each threshold values to see the trigger efficiency.
- From this ratio plot, extract the trigger position where trigger efficiency 50%.



# Method of measurement

- Take the division of AT/ET plots for each threshold values to see the trigger efficiency.
- From this ratio plot, extract the trigger position where trigger efficiency 50%.
- For each AT trigger setting, the trigger positions are plotted into a signal vs threshold graph.
- From this graph, we can calculated the values of signal from different threshold values.



# Results and discussion

- The prototype used for the CERN testbeam was studied.

- The method works, as boards with 100% channels of good data was achieved.

- The time taken to do this measurement is roughly ~2 hours.

# Summary

- A new method to define the trigger threshold using LED system has been established. (by my acting supervisor, Oskar Hartbrich)

- Safe and fast method, developed by using existing systems which was not originally designed for it.

- This method works well. More improvements can be achieved (eg. faster measurement time)



Thank you for your attention.

Join the ILC group to work in many countries especially Japan!



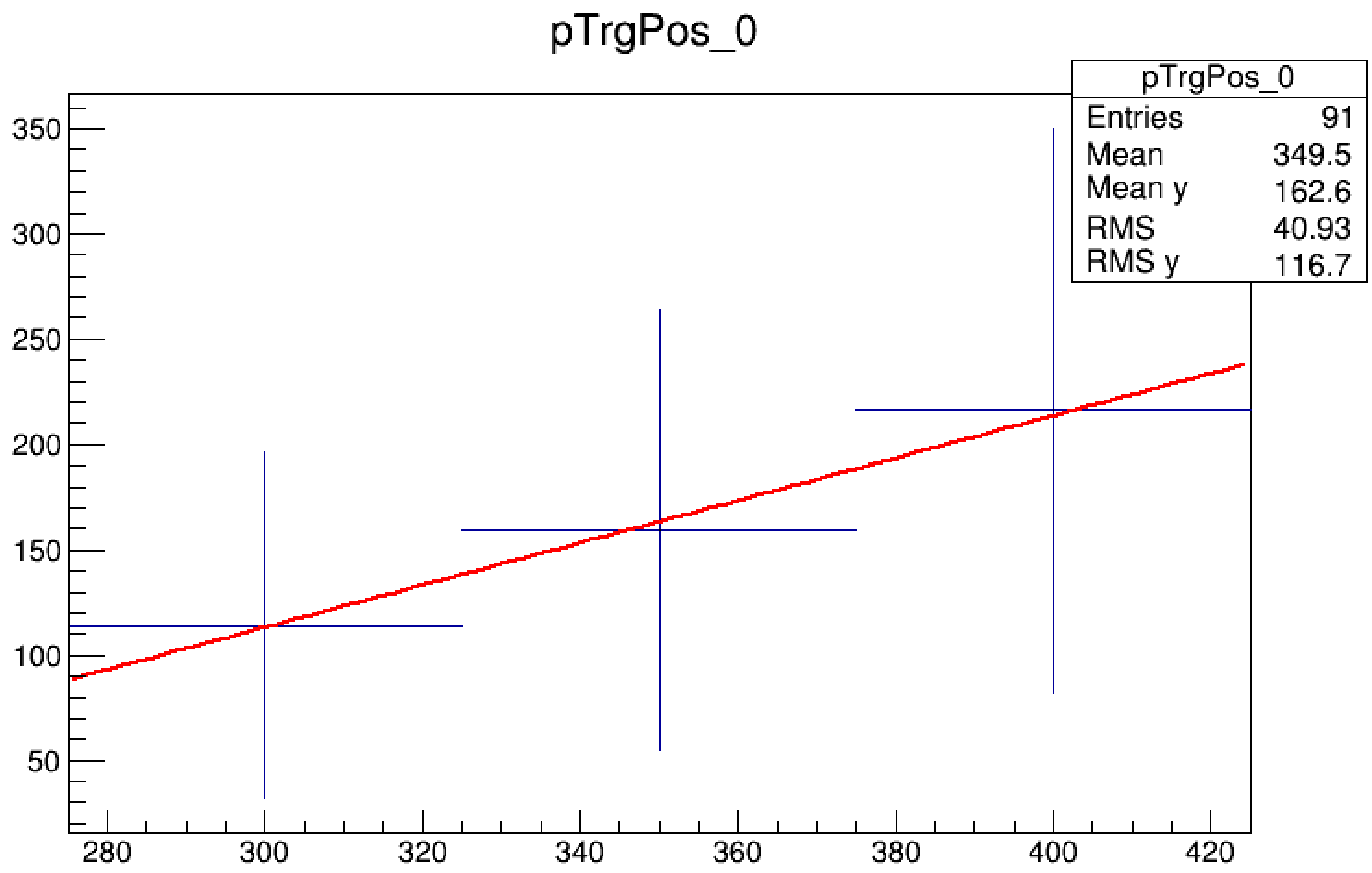
# Backup slides

**Table 3.1.** Summary table of the 250–500 GeV baseline and luminosity and energy upgrade parameters. Also included is a possible 1st stage 250 GeV parameter set (half the original main linac length)

| | | | Baseline 500 GeV Machine | | | 1st Stage | L Upgrade | $E_{CM}$ Upgrade | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A | B |
| Centre-of-mass energy | $E_{CM}$ | GeV | 250 | 350 | 500 | 250 | 500 | 1000 | 1000 |
| Collision rate | $f_{rep}$ | Hz | 5 | 5 | 5 | 5 | 5 | 4 | 4 |
| Electron linac rate | $f_{linac}$ | Hz | 10 | 5 | 5 | 10 | 5 | 4 | 4 |
| Number of bunches | $n_b$ | | 1312 | 1312 | 1312 | 1312 | 2625 | 2450 | 2450 |
| Bunch population | $N$ | $\times 10^{10}$ | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.74 | 1.74 |
| Bunch separation | $\Delta t_b$ | ns | 554 | 554 | 554 | 554 | 366 | 366 | 366 |
| Pulse current | $I_{beam}$ | mA | 5.8 | 5.8 | 5.8 | 5.8 | 8.8 | 7.6 | 7.6 |
| Main linac average gradient | $G_a$ | MV m$^{-1}$ | 14.7 | 21.4 | 31.5 | 31.5 | 31.5 | 38.2 | 39.2 |
| Average total beam power | $P_{beam}$ | MW | 5.9 | 7.3 | 10.5 | 5.9 | 21.0 | 27.2 | 27.2 |
| Estimated AC power | $P_{AC}$ | MW | 122 | 121 | 163 | 129 | 204 | 300 | 300 |
| RMS bunch length | $\sigma_z$ | mm | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.250 | 0.225 |
| Electron RMS energy spread | $\Delta p/p$ | % | 0.190 | 0.158 | 0.124 | 0.190 | 0.124 | 0.083 | 0.085 |
| Positron RMS energy spread | $\Delta p/p$ | % | 0.152 | 0.100 | 0.070 | 0.152 | 0.070 | 0.043 | 0.047 |
| Electron polarisation | $P_-$ | % | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Positron polarisation | $P_+$ | % | 30 | 30 | 30 | 30 | 30 | 20 | 20 |
| Horizontal emittance | $\gamma\epsilon_x$ | μm | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Vertical emittance | $\gamma\epsilon_y$ | nm | 35 | 35 | 35 | 35 | 35 | 30 | 30 |
| IP horizontal beta function | $\beta_x^*$ | mm | 13.0 | 16.0 | 11.0 | 13.0 | 11.0 | 22.6 | 11.0 |
| IP vertical beta function | $\beta_y^*$ | mm | 0.41 | 0.34 | 0.48 | 0.41 | 0.48 | 0.25 | 0.23 |
| IP RMS horizontal beam size | $\sigma_x^*$ | nm | 729.0 | 683.5 | 474 | 729 | 474 | 481 | 335 |
| IP RMS veritcal beam size | $\sigma_y^*$ | nm | 7.7 | 5.9 | 5.9 | 7.7 | 5.9 | 2.8 | 2.7 |
| Luminosity | $L$ | $\times 10^{34}$ cm$^{-2}$s$^{-1}$ | 0.75 | 1.0 | 1.8 | 0.75 | 3.6 | 3.6 | 4.9 |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | | 87.1% | 77.4% | 58.3% | 87.1% | 58.3% | 59.2% | 44.5% |
| Average energy loss | $\delta_{BS}$ | | 0.97% | 1.9% | 4.5% | 0.97% | 4.5% | 5.6% | 10.5% |
| Number of pairs per bunch crossing | $N_{pairs}$ | $\times 10^3$ | 62.4 | 93.6 | 139.0 | 62.4 | 139.0 | 200.5 | 382.6 |
| Total pair energy per bunch crossing | $E_{pairs}$ | TeV | 46.5 | 115.0 | 344.1 | 46.5 | 344.1 | 1338.0 | 3441.0 |

| Energy | Reaction | Physics Goal |
|---|---|---|
| 91 GeV | $e^+e^- \to Z$ | ultra-precision electroweak |
| 160 GeV | $e^+e^- \to WW$ | ultra-precision $W$ mass |
| 250 GeV | $e^+e^- \to Zh$ | precision Higgs couplings |
| 350–400 GeV | $e^+e^- \to t\bar{t}$ | top quark mass and couplings |
| | $e^+e^- \to WW$ | precision $W$ couplings |
| | $e^+e^- \to \nu\bar{\nu}h$ | precision Higgs couplings |
| 500 GeV | $e^+e^- \to f\bar{f}$ | precision search for $Z'$ |
| | $e^+e^- \to t\bar{t}h$ | Higgs coupling to top |
| | $e^+e^- \to Zhh$ | Higgs self-coupling |
| | $e^+e^- \to \tilde{\chi}\tilde{\chi}$ | search for supersymmetry |
| | $e^+e^- \to AH, H^+H^-$ | search for extended Higgs states |
| 700–1000 GeV | $e^+e^- \to \nu\bar{\nu}hh$ | Higgs self-coupling |
| | $e^+e^- \to \nu\bar{\nu}VV$ | composite Higgs sector |
| | $e^+e^- \to \nu\bar{\nu}t\bar{t}$ | composite Higgs and top |
| | $e^+e^- \to \tilde{t}\tilde{t}^*$ | search for supersymmetry |

| Topic | Parameter | Accuracy $\Delta X/X$ | |
|---|---|---|---|
| Higgs | $m_h$ | 0.03% | $\Delta m_h = 35$ MeV, 250 GeV |
| | $\Gamma_h$ | 1.6% | 250 GeV and 500 GeV |
| | $g(hWW)$ | 0.24% | |
| | $g(hZZ)$ | 0.30% | |
| | $g(hb\bar{b})$ | 0.94% | |
| | $g(hc\bar{c})$ | 2.5% | |
| | $g(hgg)$ | 2.0% | |
| | $g(h\tau^+\tau^-)$ | 1.9% | |
| | $BR(h \to \text{invis.})$ | < 0.30% (95% conf.) | |
| | $g(ht\bar{t})$ | 3.7% | 1000 GeV |
| | $g(hhh)$ | 26% | |
| | $g(h\mu^+\mu^-)$ | 16% | |
| Top | $m_t$ | 0.02% | $\Delta m_t = 34$ MeV, threshold scan |
| | $\Gamma_t$ | 2.4% | |
| | $\tilde{F}^{\gamma}_{1V}$ | 0.2% | 500 GeV |
| | $\tilde{F}^{Z}_{1V}$ | 0.3% | |
| | $\tilde{F}^{Z}_{1A}$ | 0.5% | |
| | $\tilde{F}^{\gamma}_{2V}$ | 0.3% | |
| | $\tilde{F}^{Z}_{2V}$ | 0.6% | |
| $W$ | $m_W$ | 0.004% | $\Delta m_W = 3$ MeV, threshold scan |
| | $g_1$ | 0.16% | 500 GeV |
| | $\kappa_\gamma$ | 0.03% | |
| | $\kappa_Z$ | 0.03% | |
| | $\lambda_\gamma$ | 0.06% | |
| | $\lambda_Z$ | 0.07% | |
| $H^0$, $A^0$ | $m_H$, $m_A$ | 1.5% | |
| | $\tan\beta$ | 20% | |
| $\widetilde{\chi}^+$ | $m(\widetilde{\chi}^+)$ | 1% | |
| | $m(\widetilde{\chi}^0)$ | 1% | |
| $\widetilde{t}$ | $m(\widetilde{t})$ | 1% | |
| | $\cos\theta_t$ | 0.4% | |


pTrgPos_0
pTrgPos_0
Entries 91
Mean 349.5
Mean y 162.6
RMS 40.93
RMS y 116.7
350
300
250
200
150
100
50
280
300
320
340
360
380
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420

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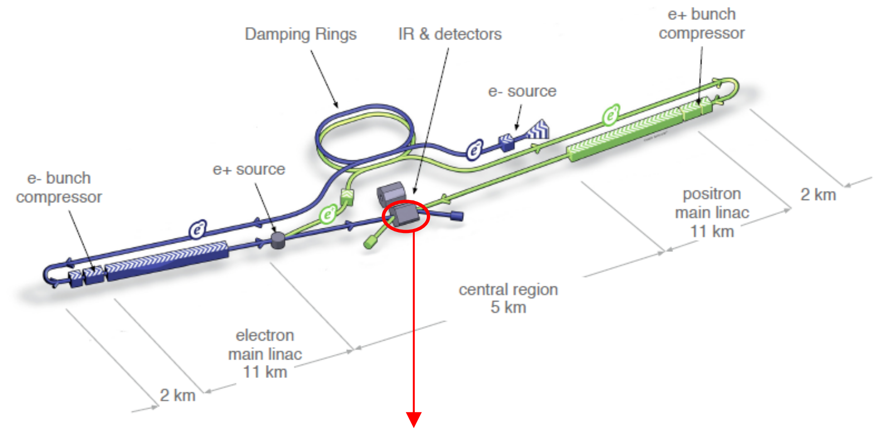
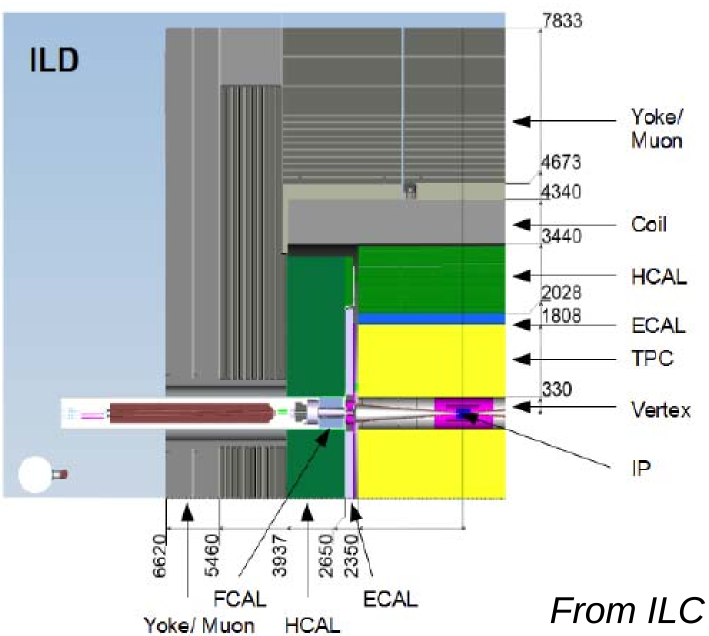
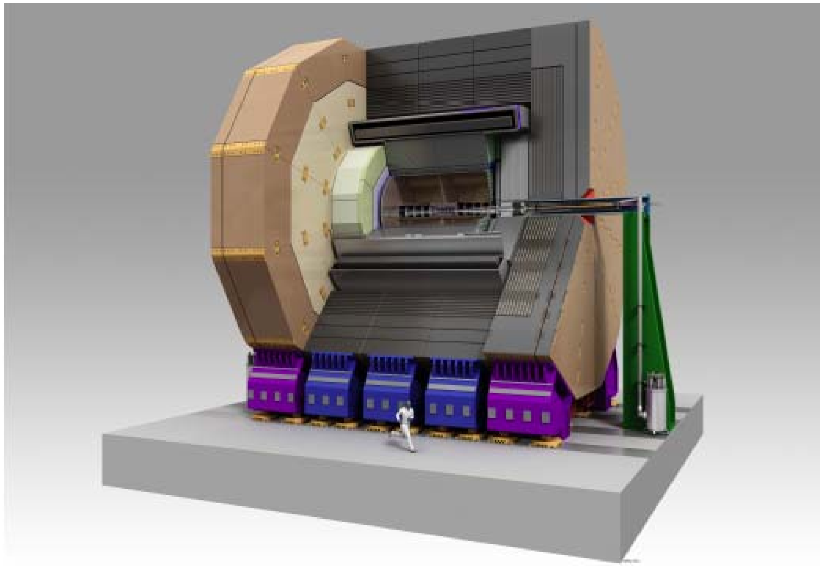
  - Onion-like structure
- Analogue hadron calorimeter (AHCAL)
  - Sampling calorimeter with sandwich structure of absorbing and detecting layers for the ILD.
  - Scintillator tiles and silicon photomultipliers (SiPM)



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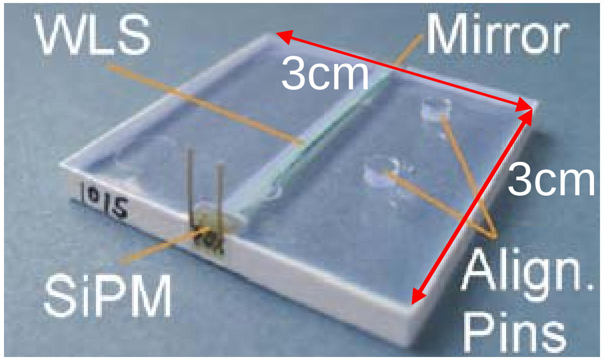
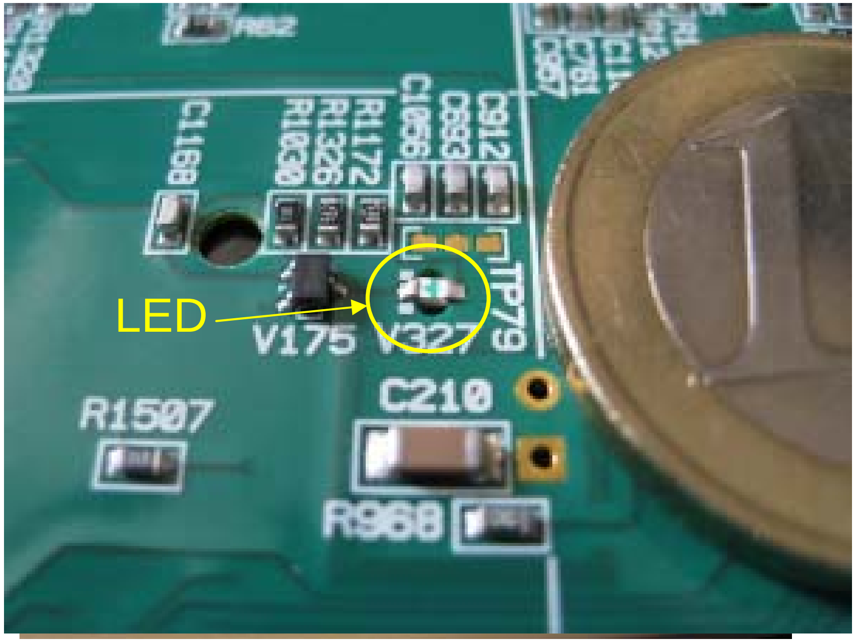
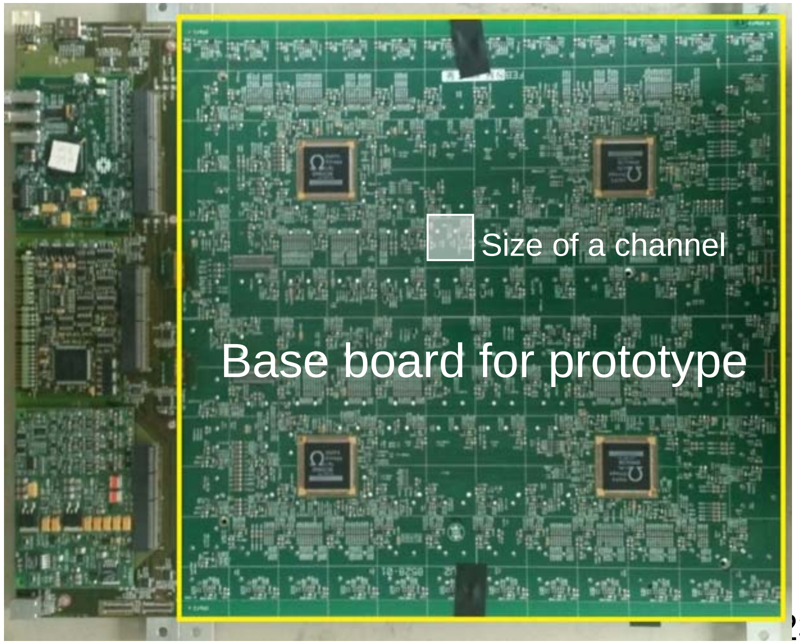
- The AHCAL engineering prototype:
  - Base board: 36 channels x 4 ASIC (Application specific integrated circuit)
  - The LED system:
    - Direct inject light into scintillator tile
    - Every channel has an LED
    - LED light amplitude can be controlled via voltage setting.
    - LED pulses are synchronize for all channels.



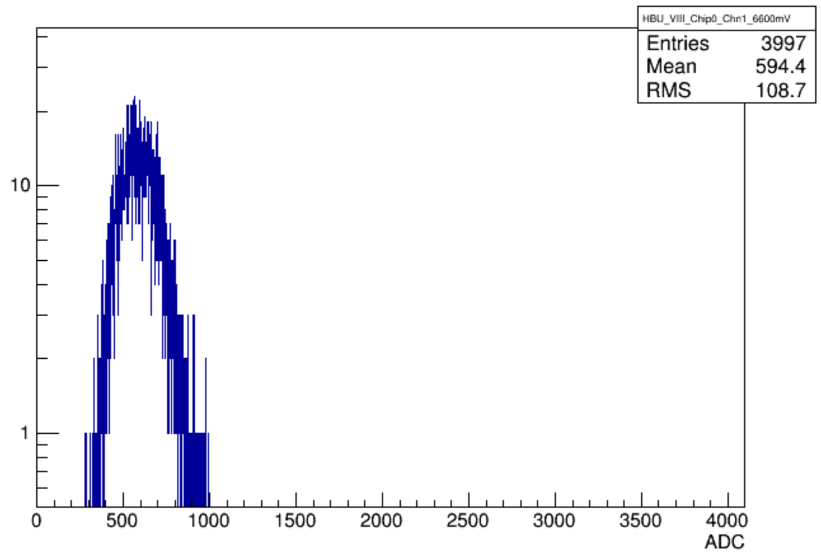





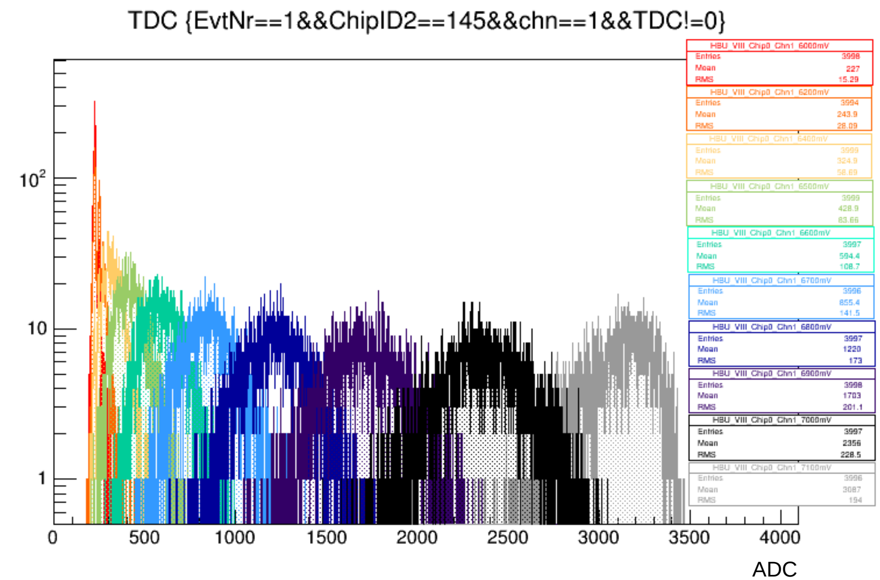

*LED system (Taken from Oskar Hartbrich master thesis)*

# Method of measurement

- Take runs using LED with a wide range of LED amplitude.
- Runs are taken with auto trigger and the reference mode.




Typical single run with ET at a single LED amplitude




Runs in ET for different LED amplitude

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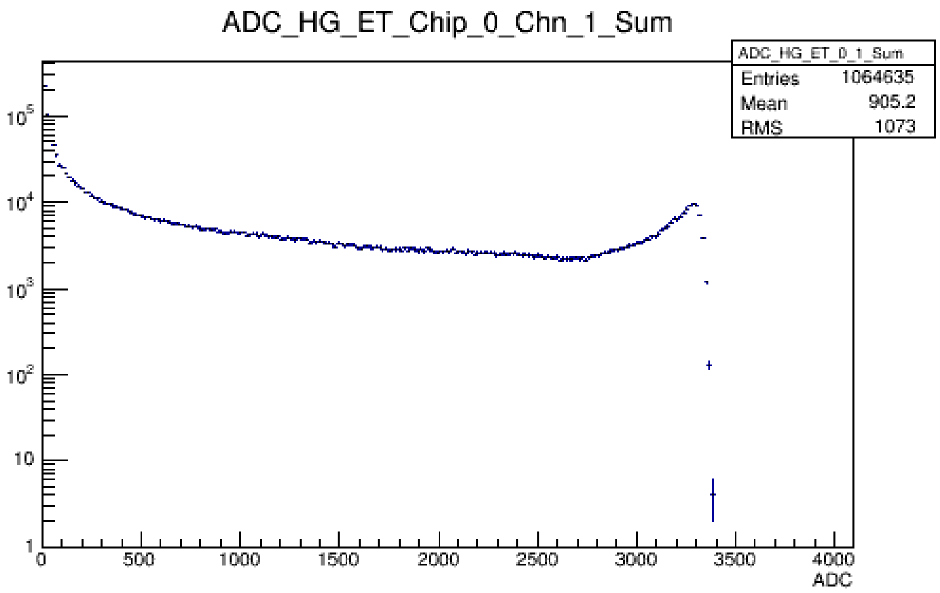
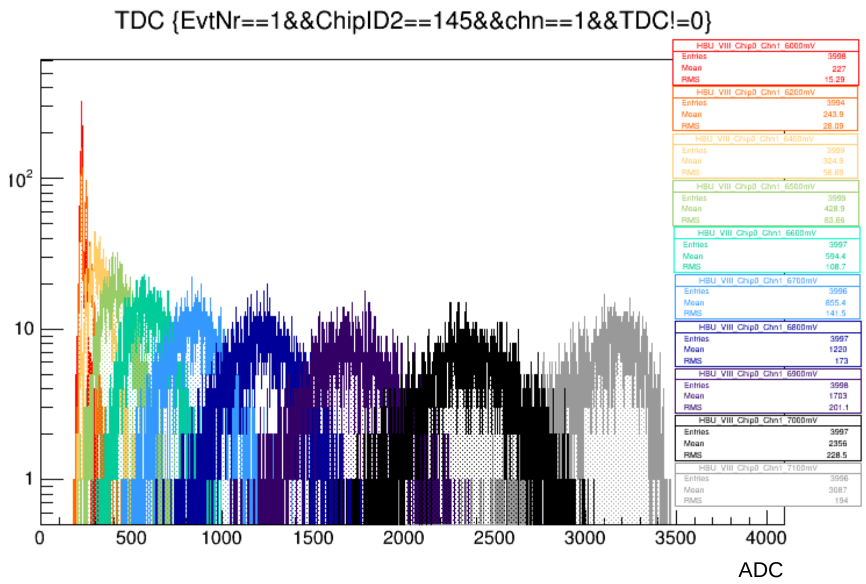


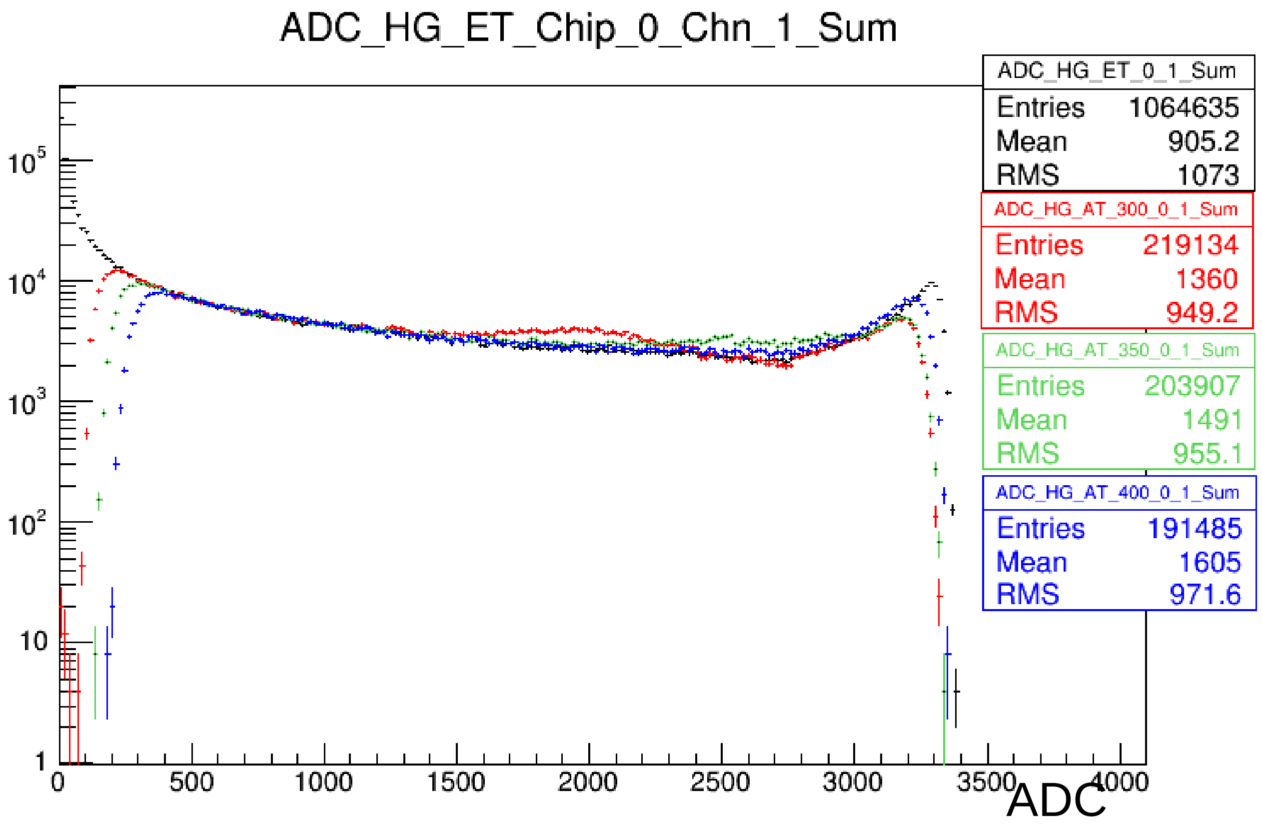

ET spectra of a typical channel (sum of all LED amp.)




Runs in ET for different LED amplitude

# Method of measurement

- In auto trigger mode, trigger threshold values are set to 300, 350 and 400 DAC counts.
- Need to get the position in ADC count where the trigger threshold starts.



# Method of measurement

- From the ADC counts for 0.5MIP data, the corresponding trigger threshold in DAC can be calculated.