Implementing TOT Digitization in LDMX Hcal

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Overview

- The goal is to Implement TOT digitization in Hcal.
- The H2GCROC uses two primary methods for digitizing pulses: ADC and TOT.
- The charge is given by ADC in the preamplifier linear region.
- When the preamplifier saturates, TOT gives the charge.
- A threshold voltage for the TOT should be set.

Procedure

- H2GCROC has a charge dynamic range of 160 fC to 320 pC.
- Set the capacitance to $\frac{13}{5.1}$ pF (≈ 2.5 pF).
- Take 160 fC - 13 pC to be the linear range of ADC (this is an approximation based on [1]).
- This allows us to calculate the maximum voltage that the ADC can handle:

$$V_{\text{ADC Max}} = \frac{13\,\text{pC}}{\frac{13}{5.1}\,\text{pF}} = 5100\,\text{mV}$$

Procedure

- 1 MIP $\approx$ 68 PE and 1 PE $\approx$ 5 mV are used.
- So we can fit 15 MIPs within the linear ADC range.
- New gain is set to:

$$\text{gain} = \frac{5100}{1023}\,\text{mV/ADC} \approx 5\,\text{mV/ADC}$$

Procedure

- The chip uses 12 bits ($2^{12} = 4096$) to measure TOT maximum of 200 ns.
- Adjust the drain rate to drain maximum charge of 320 pC within 200 ns.

$$\text{drain rate} = \frac{320\,\text{pC}}{200\,\text{ns}}$$

- Finally, set TOT Threshold to 5100 mV.

Amended Hcal Hard-coded conditions

```
HcalHgcrocConditionsHardcode.validForAllRows([
    1. , #PEDESTAL
    0.02*5/(5100./1023.), #NOISE
    12.5, #MEAS_TIME - ns
    13/5.1, #PAD_CAPACITANCE - pF
    200., #TOT_MAX - ns
    320000./200., #DRAIN_RATE - fC/ns
    5100./1023., #GAIN
    1. + 4., #READOUT_THRESHOLD
    1.*(5100./1023.) + 1*5, #TOA_THRESHOLD - mV
    5100., #TOT_THRESHOLD
    ])
```

Results of Simulations

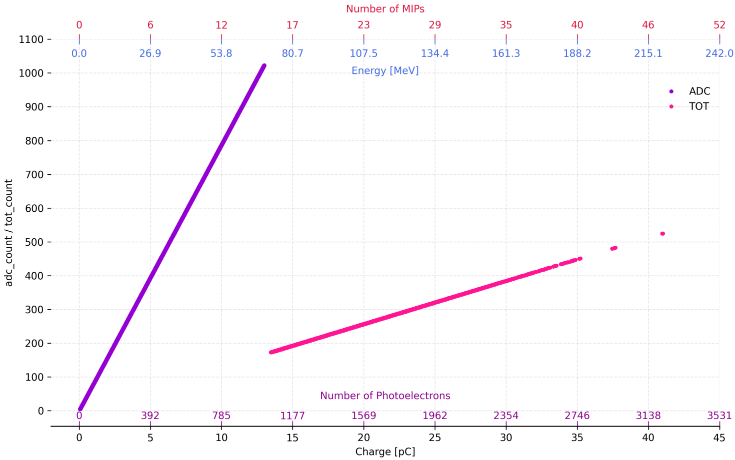


Figure: Figure 01: Electrons with 8 GeV energy for 1000 events

Discussion

- To generate the above result, HgcrocEmulator must start TOT digitization when bxvolts $>$ totThreshold.

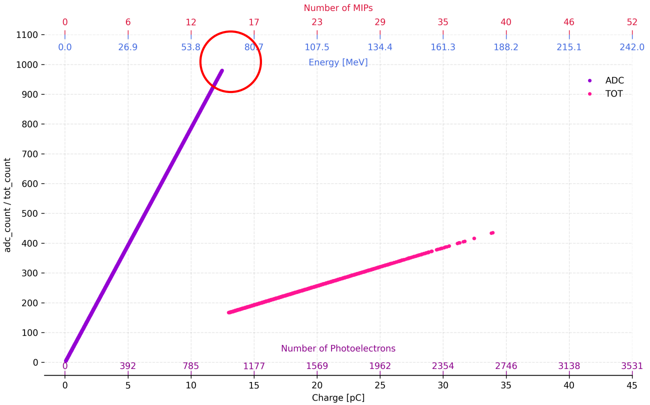
```
double vpeak = pulse(hit.second);
double bxvolts = pulse((iADC - iSOI_)*clockCycle_);

      //if (vpeak > totThreshold){
      //startTOT = true;
      //if (toverTOT < hit.second)
      //toverTOT = hit.second;
      //}

      if (bxvolts > totThreshold){
      startTOT = true;
      if (toverTOT < hit.second)
      toverTOT = hit.second;
      }
```

Discussion

- If instead we keep the original condition bxvolts > totThreshold, we obtain:



- Note that the ADC range does not extend to its maximum 1024.

- This behavior could be due to slight differences between the voltages vpeak and bxvolts.

```
DEBUG PRINT
    Voltage using pulse(hit.second): 62.2955
    Voltage using pulse((iADC - iSOI_) * clockCycle_): 60.193

DEBUG PRINT
    Voltage using pulse(hit.second): 59.5319
    Voltage using pulse((iADC - iSOI_) * clockCycle_): 56.704

DEBUG PRINT
    Voltage using pulse(hit.second): 62.2955
    Voltage using pulse((iADC - iSOI_) * clockCycle_): 60.193
```

Figure: vpeak and bxvolts calculated using different methods

Hcal TOT Reconstruction

- The following method is proposed but not yet implemented.
- The HcalDigiProducer calculates TOT using:

$$\text{TOT} = \text{Charge} \times \left(\frac{4096}{\text{TOT}_{\text{max}} \times \text{Drain Rate}} \right) + \text{Pedestal} \qquad (1)$$

- Solve for Charge and then Voltage.

$$\text{Voltage} = \underbrace{\left(\frac{\text{TOT}_{\text{max}} \times \text{Drain Rate}}{\text{Capacitance} \times 4096} \right)}_{\text{Constant 2}} \left(\text{TOT} - \underbrace{\text{Pedestal}}_{\text{Constant 1}} \right) \qquad (2)$$

Hcal TOT Reconstruction

- Constant 1 and Constant 2 can be used to reconstruct the voltage.
- Numerically, Constant 2 is given by:

$$\text{Constant 2} = \frac{(200\,\text{ns}) \times \left(\frac{320000}{200}\ \frac{\text{fc}}{\text{ns}}\right)}{\left(\frac{13}{5.1}\,\text{pF}\right) \times 4096}\ \frac{\text{mV}}{\text{TOT}} = \frac{6375}{208}\ \frac{\text{mV}}{\text{TOT}} \quad (3)$$

References

[1] G Bombardi et al. "Performance of H2GCROC3, the readout ASIC of SiPMs for the back hadronic sections of the CMS High Granularity Calorimeter.". In: ().