High Precision Timing Measurement in the CALICE Analogue Hadronic Calorimeter.

NSS-2016

- Motivation
- The CALICE AHCAL engineering prototype
- SPS CERN Campaign
- Timing Calibration
- Results and Conclusion

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Motivation for precision timing

➤ Timing may help:

- Resolving components in hadronic showers -> $\sim ns$
- Separation of *vertices* -> 20-30 ps $\sim$ 1 cm, 1 ns $\sim$ 30 cm
- Timing based clustering/Energy reconstruction -> $\sim ns$
- Background rejection and pile-up mitigation -> $\sim ns$

➤ ILC beam structure

- ~ 300 ns bunch spacing -> $\sigma_t \ll 300$ ns
- No need to disentangle bunch crossings

➤ CLIC beam structure

- ~ 0.5 ns bunch spacing -> $\sigma_t \ll 0.5$ ns
- Timing is very important here to associate particles to correct bunch crossing

The CALICE AHCAL

- Highly granular Hadronic calorimeter concept readout with Silicon Photo-multipliers (SiPMs)
- Active material: plastic scintillator
- Designed for a future e^+e^- linear collider (ILC)
- Technological prototype: Scalability to a collider detector and mass production
 - Front-end integration/performance (see M. Reinecke poster - N24-2)
 - DAQ (see J. Kvasnicka talk - N63-1)
- Contributions to time resolution:
 - SiPM $\sim 10 - 100$ ps rise time (dependant of number of p.e)
 - Scintillator $\sim$ ps rising time
 - Light propagation to the photodetector $\sim$ ps to ns
 - Electronics $\rightarrow$ ps to ns

Scheme for ILC

HCAL Board Unit

plastic tile
3x3x0.3 cm³

SiPM

Testbeam at CERN SPS

➤ Testbeam campaign at CERN in July 2015

➤ Goals:

- Test of different tile/SiPM designs
- Check EM performance of the detector
- Study of timing of *hadronic showers* in 3D (radial, longitudinal)

➤ Setup:

- 14 layers (~ 3800 channels)
- **Trigger signal** (T_0) directly fed to the chip as a normal channel → reference time

Picture of AHCal in steel stack @ CERN

* Iron : $\lambda = 16.8 \text{ cm}$, $X_0 = 1.7 \text{ cm}$

The readout chip : SPIROC2b

- **Self-triggered** chip / 36 channels
- Only the first hit is registered in a clock period
- Energy measurement :
 - Analog measurement / 12 bits
 - 16 memory cells per channel
- Time measurement :
 - ADC sampling of 2 voltage ramps
 - 16 memory cells per channel
 - Testbeam (250 kHz BX) : $\rightarrow \sim 1.6$ ns per bin
 - Design to run synchronous to the ILC machine (5 MHz BX) $\rightarrow$ time resolution $\sim$ x20 better
- Calibration of analogue components is needed.

Conversion from TDC to nanoseconds

➤ Timing is measured via a voltage ramp and stored in a memory cell

- Assumed to be linear
- Not possible to measure directly the ramp (too many chips) -> developing a robust procedure to extract the slope of the ramp

➤ Need to use instantaneous particles -> muons for *calibration*, electrons for *validation*

➤ Procedure:

- Measuring starting point and end point of the ramp on the TDC Spectrum
- Total ramp length in TB (250 kHz) ~ 4000 ns (3920 ns due to dead-time)
- Extract slope for each chip, BXID
- Extract pedestal for each chip, channel and first memory cell

➤ In the order of expected value: ~1.6 ns/TDC

$$\text{slope}_{chip,BXID} [\text{ns/TDC}] = \frac{3920 \text{ ns}}{\text{Max}_{chip,BXID} - \text{Pedestal}_{chip,BXID}}$$

$$t [\text{ns}] = (\text{TDC} - \text{Pedestal}_{chip,chn,Mem=1}) \times \text{slope}_{chip,BXID}$$

Calibration of the time reference

- The time of the trigger is needed in order to have the relative time of a particle -> need proper calibration
- 4 channels in the AHCAL receiving the trigger signal from scintillators
- The trigger signal is coming from the exact same source
 - Time of the trigger should be the same between channels.
 - Additional offset needed due to different pedestal values per ramp BXID for each memory cells
- Trigger resolution ~ 4 ns
- Electronics contribution in final resolution

Time reference correction per ramp type (BXID **odd**/**even**)

Time of first hit

- Previous calibration applied similarly to all channels
- Time of first hit is determined by looking at the time of the hit relative to the time of the trigger
 - Slightly asymmetric distribution
 - Time resolution ~ 5.7 ns RMS
- Possible improvements due to effects known from the electronics
 - Non-linearity of the voltage ramp
 - Time-walk effect due to the threshold
 - Pedestal shift with high number of hits in a chip

Ramp non-linearity correction

➤ Assumption of a linear voltage ramp would mean:

- Time of the hit versus the TDC value of hit would yield a flat distribution -> no dependency of where the hit occurred in the ramp

➤ Dependency observed

➤ Correction with a 2nd order polynomial done for each chip and ramp BXID (odd/even)

➤ Improvement in the order of 6%

Time-Walk correction

- Threshold -> dependency with hit energy
 - Low amplitude hits triggers later than high amplitude hits
- Fit with a exponential function and assumed to be global
- Corrections up to ~ 6 ns between low energy hits and high energy hits
- Improvement in the order of 4%

Number of hits correction (electrons)

- Expected offset compared to muons (different trigger setup) ~ 13 ns
- When several channels of a single chip are saturated $\rightarrow$ shift in the ADC pedestal position can be observed
 - Electronics effect $\rightarrow$ too much current flowing through the chip leading to a decrease of the power supply of the pre-amplifier
- Similar effect for the TDC is observed $\rightarrow$ increase of the time of hit with the number of hits in a chip
- Increase of the *time resolution up to 10-15 ns* for large number of hits $\rightarrow$ relevant for electrons and hadron showers

Results

➤ Muons

- Resolution ~ 5 ns RMS
- Fit with double gauss function -> take into account asymmetry
- Use parameters extracted from data for simulation
- $\sim 20\%$ max deviation over $[-20, 20]$ ns range

➤ Electrons

- Resolution ~ 7.8 ns RMS
- Single hit distribution -> very similar to muons
- MC ongoing -> introduction of number of hits effect

Conclusion and Outlook

- A procedure to calibrate timing in the CALICE AHCAL has been developed
- Timing resolution in testbeam with SPIROC2b achieved between 5 to 7.8 ns -> should be enough to study timing in hadronic showers
- Extrapolation to ILC (clock period 5 MHz) -> ~ 400 ps if electronics are the dominating effect in time resolution (if influence of scintillator and SiPM negligible)
- Outlook:
 - Look into pion data: time dependence in 3D (radial and longitudinal evolution)
 - Short/long term correlations between layers for hadronic showers
 - Study of impact of the use of timing in background rejection, pattern recognition and energy reconstruction
- New chip (Spiroc2e) with improved pedestal shift and TDC scheme -> should improve the time resolution

The International Linear Collider

- Future e⁺e⁻ linear collider
 - 32 km length
 - Energy : 250 - 500 GeV (upgrade to 1 TeV possible)
 - Luminosity :
- Planned to be build in Japan
- 2 detector concepts (ILD and SiD)
- Physics goals :
 - Precise Higgs mass / top mass measurements
 - Higgs self-coupling
 - BSM

SiPM used in CALICE AHCAL Technological prototype

Old ITEP tiles with WLS fiber
800 px

New ITEP tiles
Ketek 12k px

EBU strip
Hamamatsu MPPC 10k px - 3600 px

NIU megatile SMD
MPPC 1600 px (50 μ m)
MPPC 25 μ m

UHH + Heidelberg wrapped tiles
Ketek 2300 px
SenSL 1300 px

Layer 11 - Electronics problem

➤ Layer 11 shows significant worse time resolution

- Due to noisy TDC ramp -> double ramp present for all chips
- Difficulties to extract the ramp slope
- Worsen the time resolution significantly

Additional ramp

SPIROC Acquisition

Time-walk effect

- Time-walk effect due to the threshold in the chip
 - Low amplitude hits -> slow rise of the signal
 - High amplitude hits -> fast rise of the signal
- Low amplitude hits -> later trigger

D.S. Carman, CLAS12 CTOF Time-Walk Corrections

Correction for trigger delay

- An offset is extracted to account for the delay of the trigger
 - Trigger logic and cabling
- Offset extracted for each chip, channel, memory cell and BXID
- Offset per BXID needed!
 - Pedestal per memory cells different for each ramp BXID

Asymmetry in muons

➤ Probably due to the non-linearity from the time reference

- Non-corrected for as no external reference
- Dependence visible function of the TDC value of the time reference
- Late hits seems to explain the asymmetry observed -> time reference more off along the ramp (lever arm)

Influence of ROC Digitisation

- Checking influence of the ROC Digitiser on the timing
- As expected for muons, no change with threshold
- Electrons -> same conclusion