

Test beam data analysis



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Tokyo Test Beam Analysis Workshop
Tokyo, 7.8.2018

Plan

- Analysis strategy
- Basic hardware checks
- Electromagnetic performance
- Hadronic performance
- Algorithms and shower physics

General strategy

- For high level analysis - physics and algorithms - we must ensure that the detector is understood
- "Understood" means that we are able to model it and reproduce its characteristics by means of simulations
- And we want to propose and build a calorimeter for the ILC!
- Electromagnetic processes can be modelled with less uncertainty than hadronic showers
- 1st step: tests with noise, LEDs and muons
- 2nd step: tests with electrons
- 3rd step: hadrons
- Only then: higher level studies

of course we work on these in parallel
but publication must come in this order

Noise

- So-called pedestal data
 - from baseline of the pulse on an oscilloscope
- Method: "random" triggers
 - in new prototype: triggers by neighbouring cells in same ASIC
- Mean value of pulse height: zero point of energy scale
 - **pedestal** to be subtracted from all amplitudes from now on
 - otherwise ratios between amplitudes, e.g. signal / noise, cannot be formed and calibrations (multiplicative factors) not applied
- Width of pulse height distribution:
 - very small: **dead** channel
 - very large: **noisy** channel
 - look at distribution of widths of distributions to find out what is small and what is large
- Exclude dead and noisy channels from all subsequent steps
 - in data **and in MC**

LED data

- Low intensity LED light to observe single photo-electron spectra
 - distance between peaks is proportional to **gain** of SiPM
- Due to spread in LED light intensity, need to scan amplitudes of LED calibration pulse voltage (VCALIB) in order to have useful amplitude in each channel
- Investigate distribution of results and check for outliers
 - bad fits
 - noisy channels
 - SiPM problems
- Optimise procedures and define treatment of **outliers**
 - default values or exclusion - but do not ignore them!
- LED data with larger amplitudes provide **inter-calibration** between low gain and high gain of amplifier
 - switches automatically for each hit, according to signal amplitude
 - in special runs can read both low gain and high gain simultaneously
 - not the same as inter-calibration of physics prototype modes, which had different pulse lengths
 - procedures still under development: look out for surprises

Muon data

- Muons (minimum ionising particles) define the energy scale of each individual read-out cell
- After calibration the most probable value of the MIP pulse height distribution should be 1 by construction
- Easier said than done:
 - for cosmics the pulse height depends on the track length in the cell, i.e. on the incident angle
 - for radio-active sources, on the energy spectrum of the the beta decay and on the trigger condition
 - for beams, there are
 - contaminations by hadrons which induce showers
 - delta rays and secondary particles from the absorber
- For beam data the event selection has to be optimised for statistics versus purity
 - muon runs and muons in “mixed” beams
- Guidance from simulation can help to judge how close the situation is to idealised conditions

Simulation

- Ingredients (detector):
 - geometry
 - material description
 - modelling of electronics effects
- Cross-checks
 - the Monte Carlo should be calibrated: $MPV(MIP) = 1$
 - the geometry should be checked using event displays
- Ingredients (beam):
 - particle type
 - energy (momentum)
 - material upstream
 - transverse beam profile
 - for muons only affects distribution of hits, for electrons and hadrons also amplitudes

MIP calibration and light yield

- Obtain MIP calibration values (**ADC counts per MIP_{MPV}**)
- Optimise procedure and define treatment of outliers
 - exclude or use default
- Extract light yield = MIP / gain = **no. of pixels per MIP**
 - check for **outliers** again - there should not be any
- If MIP fits do not work, the average LY did provide a better guess than the average MIP
 - i.e. $\text{MIP}_{\text{default}} = \langle \text{LY} \rangle * \text{gain}$ better than $\text{MIP}_{\text{default}} = \langle \text{MIP} \rangle$ since spread in gain was larger than in LY
 - in technological prototype spread in gain smaller, while LY outliers must be expected
- If calibration done, re-run to check **convergence**
 - result may change due to re-calibration of thresholds and impact on track selection
 - do not forget to apply proper calibration and thresholds in event display
- Now we have a tracker. Let us make a calorimeter.

Electrons

- Unfortunately also electron beams are not 100% pure
 - and Cerenkov based particle ID is not 100% efficient
- Scan the events, look for
 - **contaminations** by hadrons and muons
 - additional particles in the beam line
 - soft garbage
- Conceive cuts to suppress unwanted contributions
 - define **fiducial volume**: do not include more cells than necessary for measuring electrons
 - reject events using all available information,
 - topology, outer and rear part
- Verify with simulations that the cuts do not bias response and resolution
 - i.e. there is no effect on pure electrons
 - indirectly select what you want

Electron observables

- All to be compared with **simulations**
- **Response** = energy in units of MIPs = sum over cells in fiducial volume
 - mean as expected? stable in time? independent of impact point?
 - use centre of gravity
 - distribution has no unexpected tails or shoulders?
- More detailed look: **longitudinal profile**
 - sensitive to dead channels and mis-calibrations
 - contaminations
- Even more details: **cell energies**
 - careful! this depends rather strongly on impact point
 - use either tight cuts on c.o.g. or MC with accurately tuned beam profile
- Reproducing cell energy spectra is hard, but on the other hand, if they match, everything else does, too
 - **radial profiles** last
- For a first pass, concentrate on shower centre
 - deviations here spoil everything else
- Apart from material, calibration, beam profile, here **saturation** corrections become relevant
 - and for the new prototype also the **inter-calibration**

Linearity and resolution

- If everything OK up to here, we can analyse performance
- **Linearity**: mean response vs beam energy
- Sensitive to
 - remaining impurities
 - imperfect saturation correction
 - noise and threshold (positive and negative offsets)
- **Resolution**: width of response distribution
- Sensitive to
 - noise (at low energies)
 - material (and electronics) description at intermediate energies
 - mis-calibrations, instabilities, and not properly modelled hardware effects (inhomogeneities) at high energies
 - parameters are inter-correlated
- Now we have a calorimeter and can do physics

Hadrons

- Hadron response depends on **particle type**
 - higher for pions than for protons
 - lower available energy for p due to baryon number conservation
 - anti-p?
- Simulated hadron response is **model-dependent**
 - 5%, locally (profiles) up to 20%
- **Leakage** introduces
 - non-linearity (negative; “saturation”)
 - asymmetric response: carefully devise fit and extraction of “the” response
- **Non-compensation** ($e/\pi > 1$) introduces (positive) non-linearity
 - effect is small for AHCAL, but not zero
- In principle: **response** is non-linear
- In principle: **resolution** does not follow $1/\sqrt{E}$ behaviour
- **Shower start** point:
 - distribution to check material and possible problems (contamination, noise)
 - profiles from start allow for more refined tests
- Be aware that cells and regions enter which were not validated with electrons
 - that is why MIPs need to be checked so carefully

Higher levels

- Software compensation
 - energy
 - topology
- Two-particle separation
 - new Pandora
 - ARBOR
- Electron-pion separation
- Timing analysis
 - shower model validation
 - shower parameters vs time cuts
 - use of timing in particle flow

Summary

- A calorimeter is not black magic
- Everything can be checked and understood
- Monte Carlo simulations are better than their reputation
 - hadrons a bit less than electrons
 - tails (delta rays, soft photons, neutrons) always tricky
- We do imaging calorimetry: use the event display and enjoy!
- There are lots of interesting physics to come

Backup