Time and Energy analysis of 2015-16 data

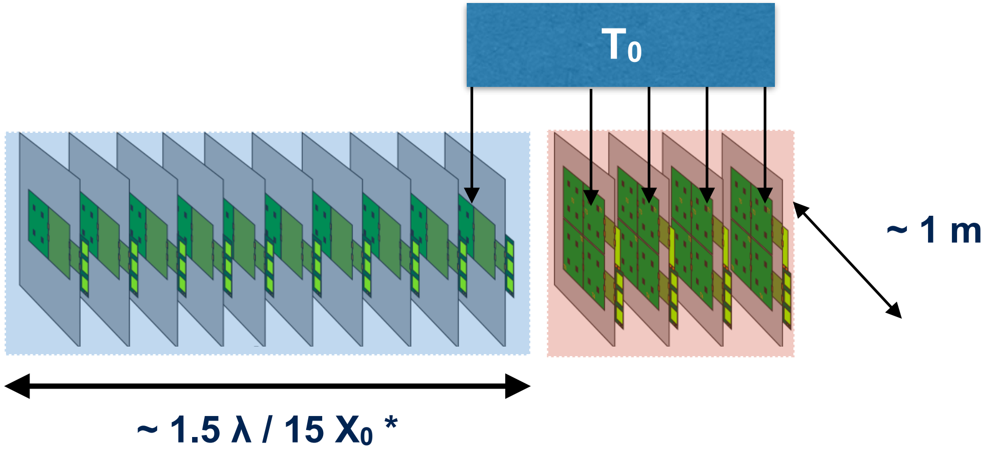
- AHCAL Setup in July 2015 at SPS
- Energy analysis
  - high gain / low gain inter-calibration
  - saturation correction
- Time analysis

Ambra Provenza (DESY),
Eldwan Brianne (DESY),
Sascha Krause (Uni Mainz),
Katja Krüger (DESY)

CALICE Meeting, UT Arlington
15 September 2016

AHCAL testbeam at SPS in July 2015

- Testbeam times:
  - 2 weeks in July 2015 in EUDET steel absorber
  - 2 weeks in August 2015 in tungsten absorber
- Data sets:
  - Muons (180 GeV),
  - Pions (10 - 90 GeV)
  - Electrons (10 - 50 GeV)



- Setup:
  - 14 Layers *(3744 channels)*: 10 layers shower start finder + 4 large layers
  - Trigger signal (T_0) directly fed to the chip as a normal channel → reference time

Energy analysis

strategy:

- muons:
  - do/check MIP calibration
  - dead channel list
- electromagnetic showers
  - **high gain / low gain inter-calibration**
  - **saturation correction**
  - study response and resolution
- hadron showers
  - study shower shapes

- for all: compare with simulation

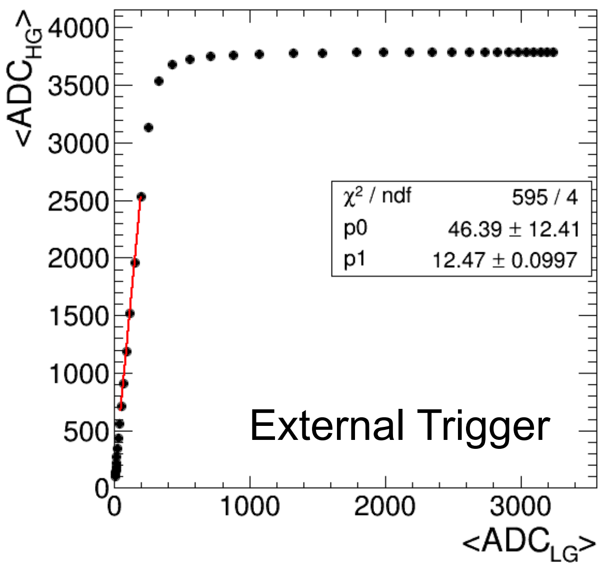
High gain / low gain inter-calibration

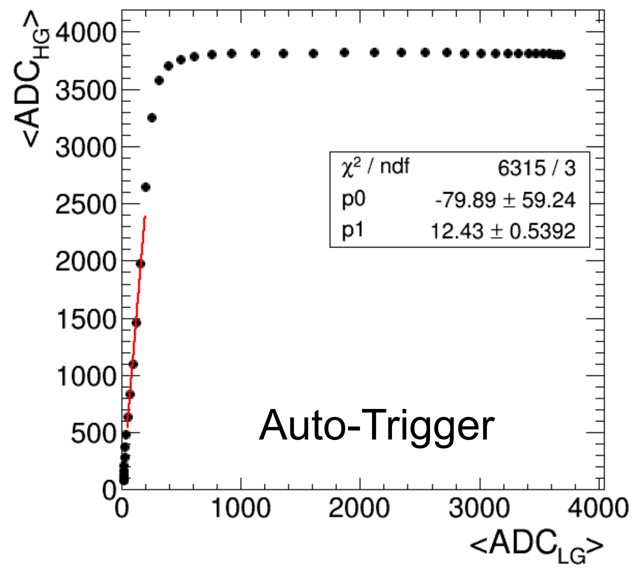
- beam data: SPIROC switches automatically from high to low gain (auto-gain), so only one information available
- LED calibration runs:
  - usually also taken in auto-gain mode
  - in 2015: some short LED runs taken in dual gain mode
    - difficulty: only very few LED voltages at very low amplitude, optimised for gain calibration (single pixel spectra)
    - non-optimal for inter-calibration, can only determine 1 inter-calibration constant per chip
- check method channel-by-channel with dedicated inter-calibration runs in July 2016
  - LED voltages 3500 mV → 8000 mV in steps of 50 mV
  - external trigger mode
    - additional pedestal run
  - auto-trigger mode
    - pedestal from MIP scan in DESY beam

High gain / low gain inter-calibration

two step procedure:

- **first estimate:**
  - for each LED voltage: study mean of high gain vs. mean of low gain ADC distribution (pedestal subtracted per memory cell)
  - fit in linear range: slope is IC factor
- refinement:
  - correct low gain measurement with IC factor, check difference to high gain for each measurement





chip 117 chn 8

each point corresponds to one LED voltage

High gain / low gain inter-calibration

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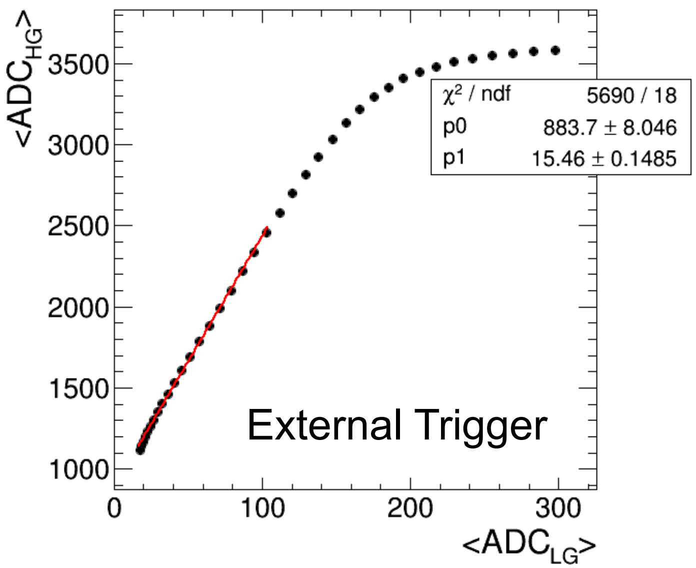
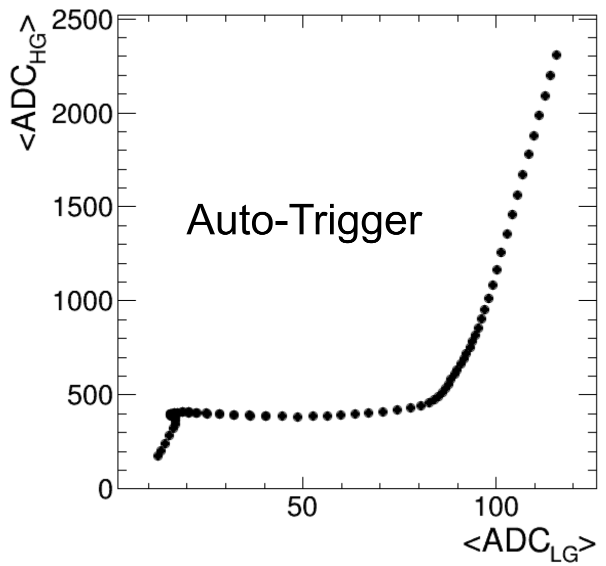




chip 211 chn 0

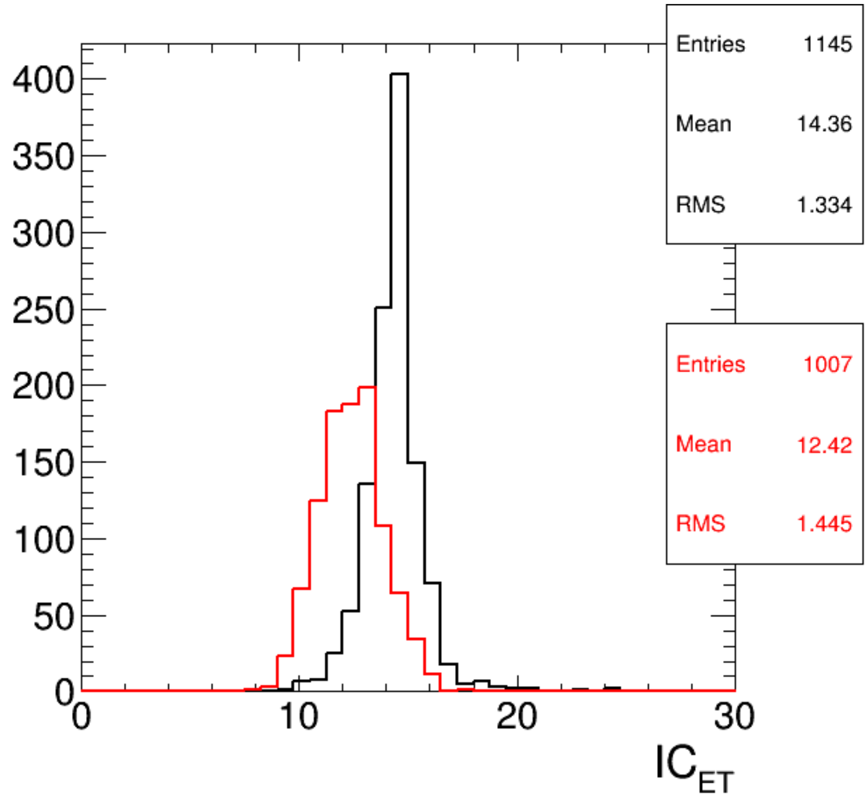
each point corresponds to one LED voltage

strange behaviour in auto-trigger (probably due to pedestal shift)
→ auto-trigger not useable!

High gain / low gain inter-calibration: result of first step

- **first estimate:** distribution of IC factors (per channel) from LED scan in July 2016 in external trigger mode

8 "old" SensL HBUs: 1152 channels (7 not fitted)
7 SMD HBUs: 1008 channels (1 not fitted)



difference between the HBUs: different preamplifiers used:

Sensl: ~200fF
SMD: 650fF

High gain / low gain inter-calibration

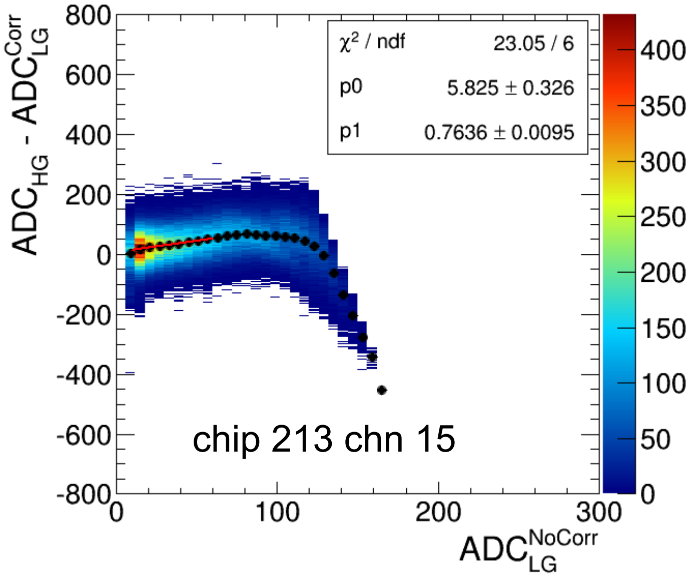
two step procedure:

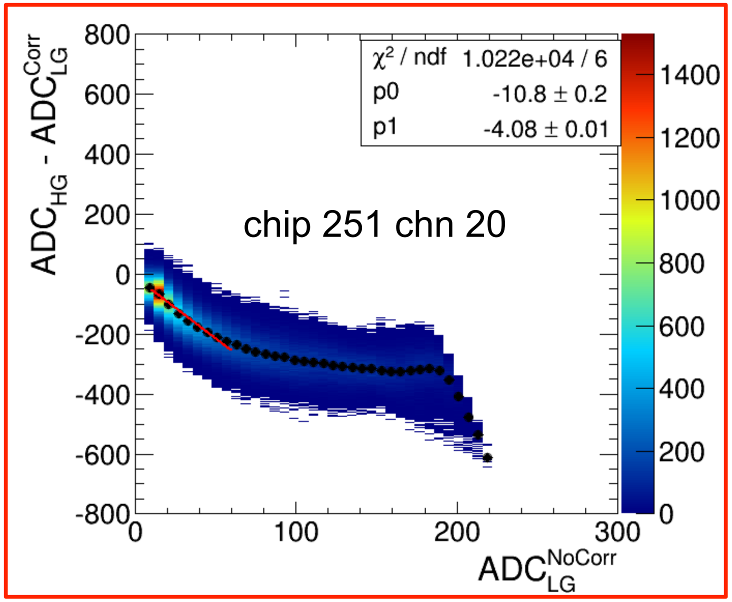
> first estimate:

- for each LED voltage: study mean of high gain vs. mean of low gain ADC distribution (pedestal subtracted per memory cell)
- fit in linear range: slope is IC factor

> **refinement:**

- correct low gain measurement with IC factor, check difference to high gain for each measurement

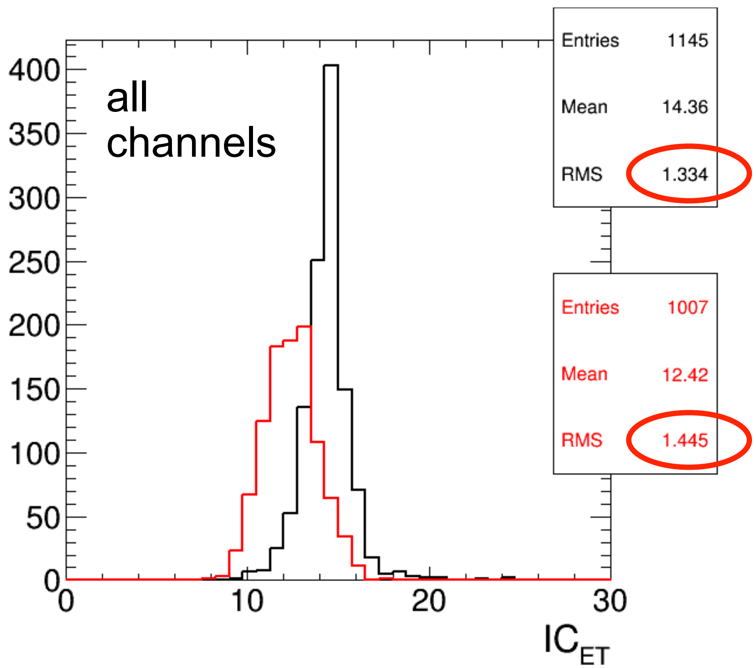


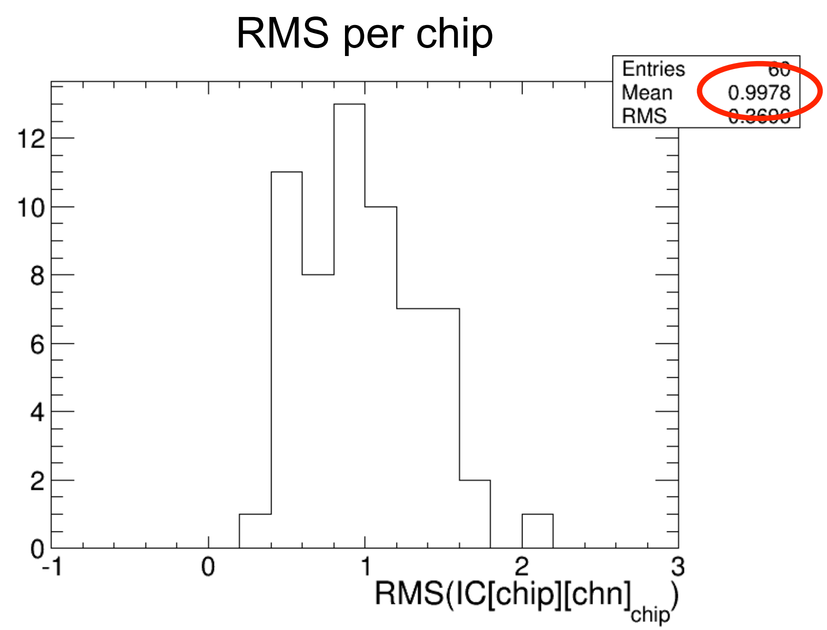


~20% of channels show clearly not flat behaviour (probably due to pedestal shift)
→ for those take average IC

High gain / low gain inter-calibration

- channel-wise IC calibration needed?
- if chip-wise is good enough, RMS of the channels on a chip should be significantly smaller than RMS of all channels





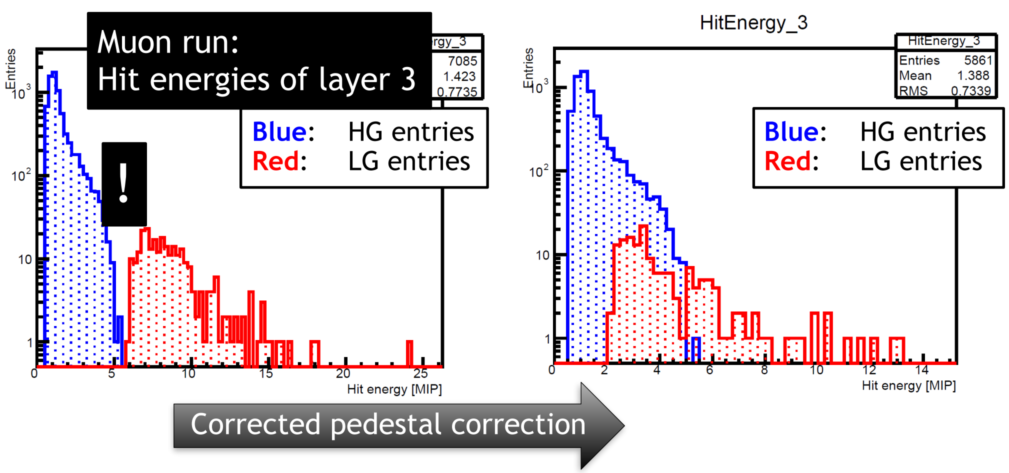
- RMS are comparable, so in future will use channel-wise inter-calibration

CERN TB 2015: Ongoing analysis at Mainz

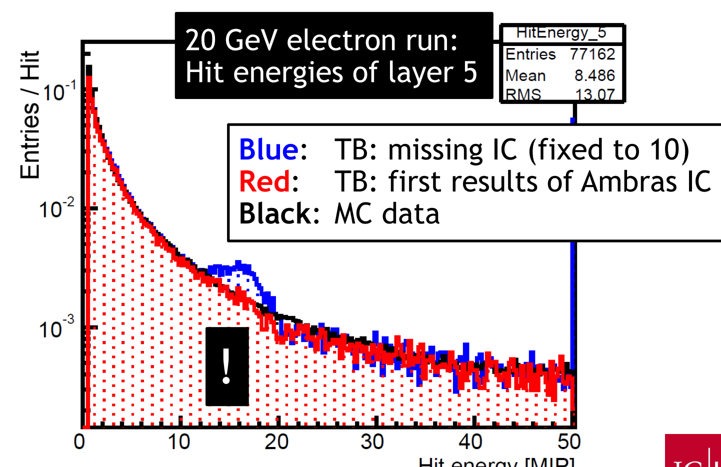
Comparison of data & MC for muons, electrons and pions.

- Applying and testing different event selections:
  - T0, Cherenkov, track finder, #hits per event/layer/..
- Testing and controlling calibration parameters:
  - Gain & LY
- Focus on discrepancies between MC & data allowed to find and correct for bugs & missing calibration:
  1. Wrong **pedestal subtraction** in reconstruction software for LG entries.
  2. Missing **HG/LG intercalibration**.
  3. Missing calibration of SiPM **saturation effects**.

1. Corrected pedestal subtraction for LG entries:
→ gaps in energy spectra.



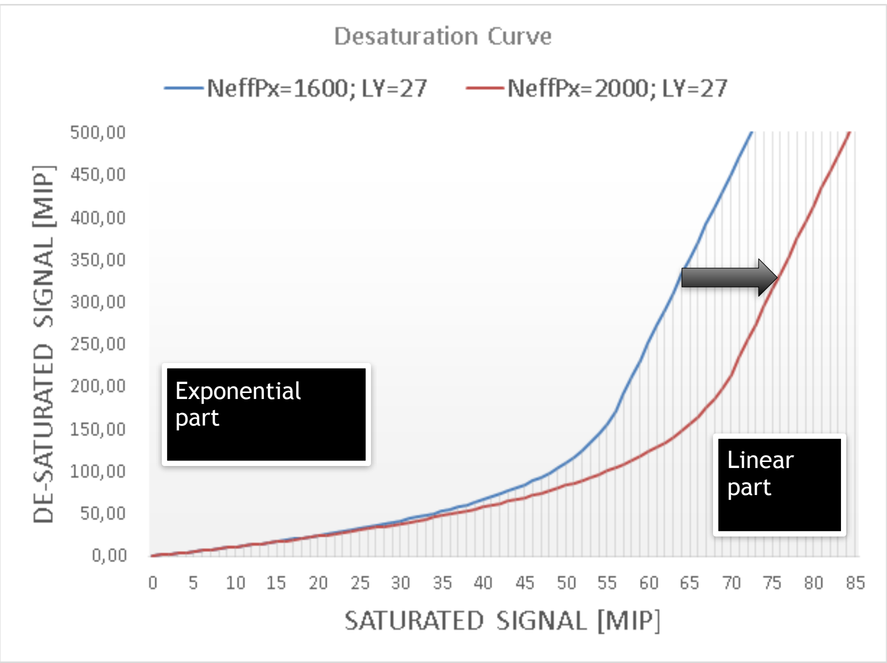
2. Missing HG/LG intercalibration:
→ **overlap peak** between HG and LG entries.



CERN TB 2015: Ongoing analysis at Mainz

3. Missing calibration of SiPM saturation effects:

Number of effective pixels (*NeffPx*) has a large impact on saturation correction in high energy region.



Reason for new saturation calibration:

- SiPM saturation function does not only depend on real number of pixels, it also depends on the recovery of pixels in a few ns after fired, which can be taken into account by a number of effective pixels.

First step:

- Try to match raw TB data (intrinsic SiPM saturation) with MC data including saturation in digitization by adapting NeffPx.

Second step:

- Compare effect on new saturation corrected data to MC data.

CERN TB 2015: Ongoing analysis at Mainz

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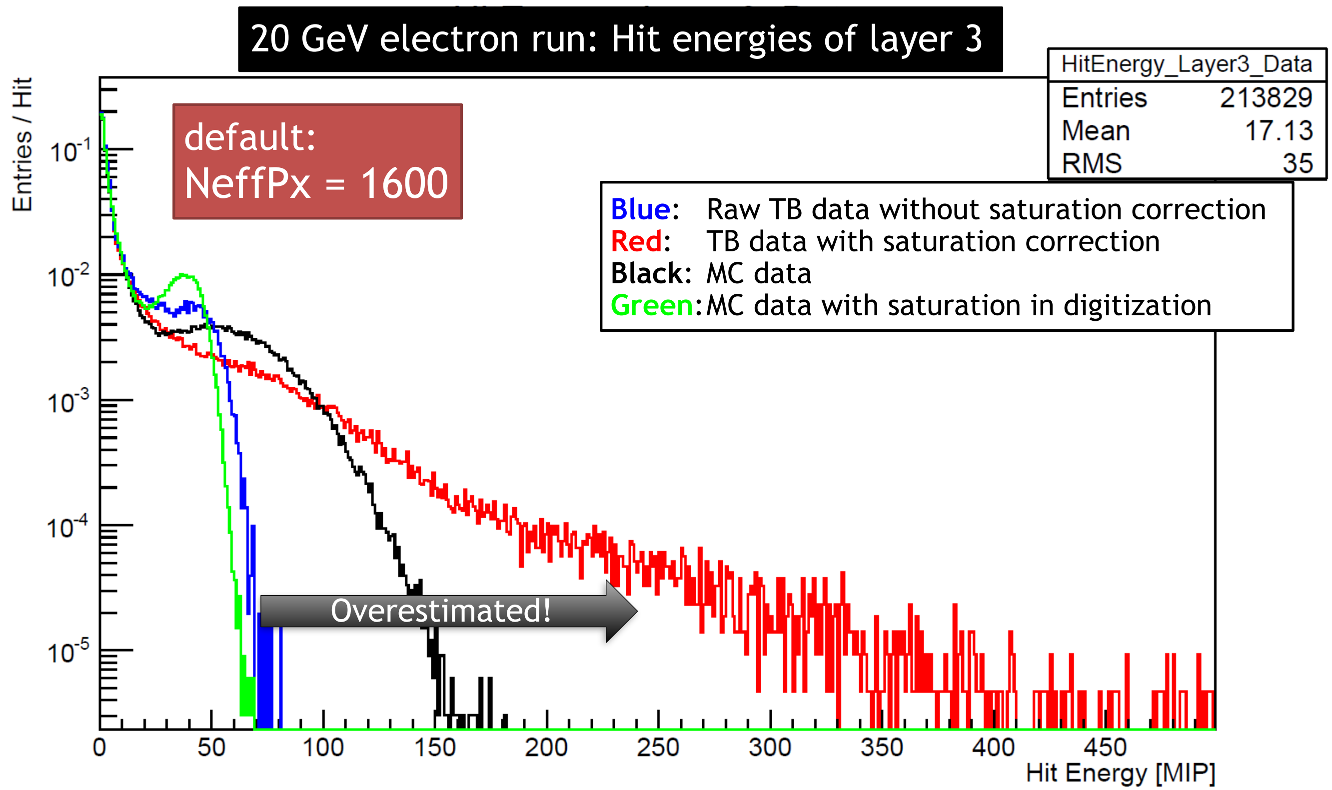

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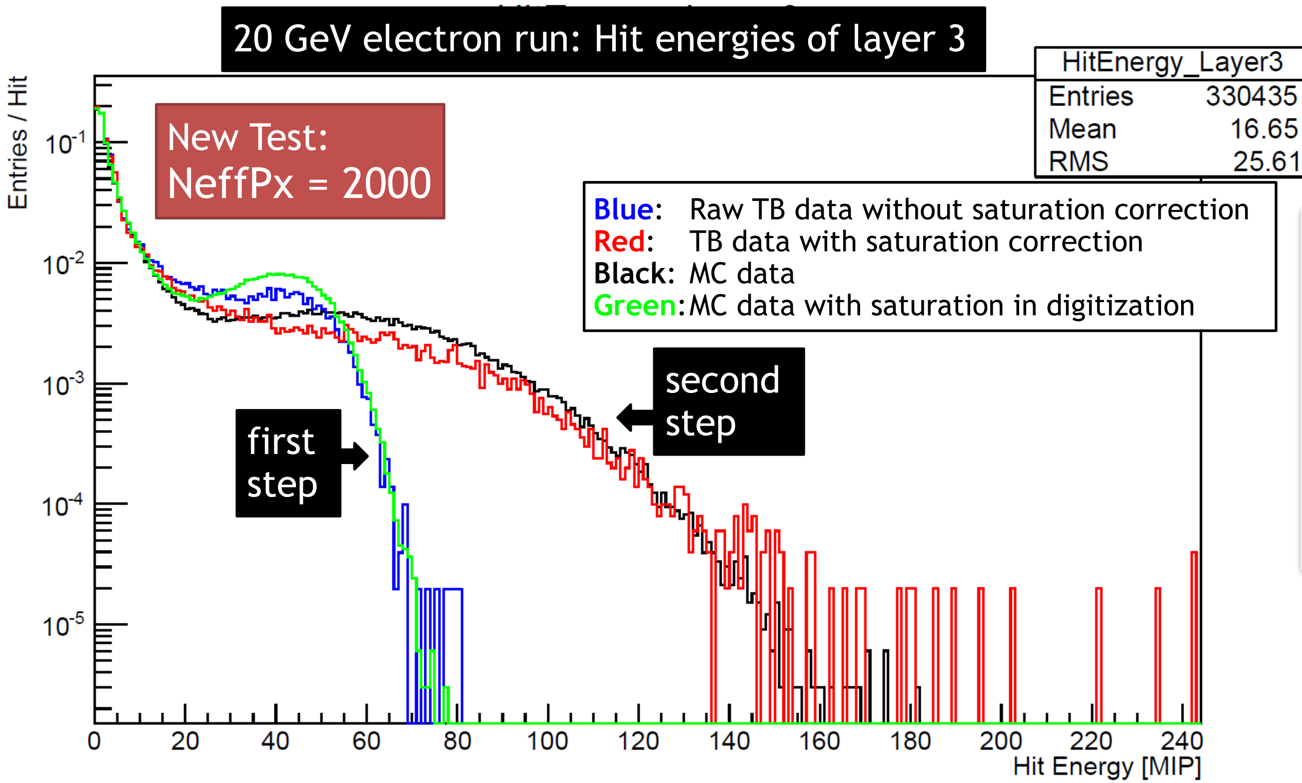


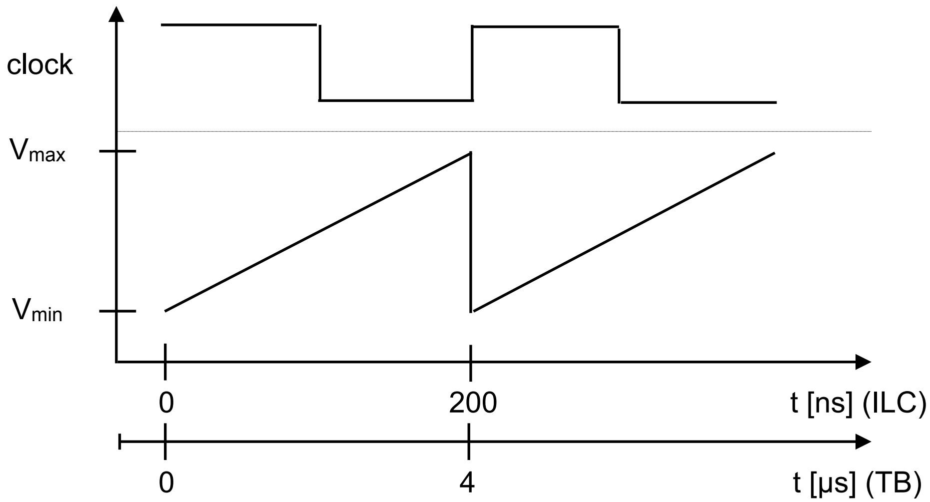
- First result looks promising and is in reasonable region.
- Has to be confirmed.

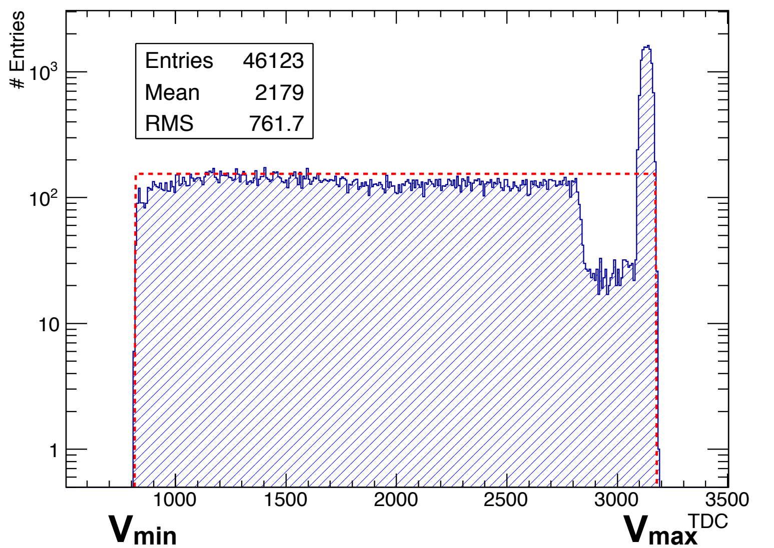
Time analysis: Calibration

- strategy
  - use only t0 signals as reference, no additional measurements
  - use muons for calibration
  - use electrons to cross-check calibration
  - study pions
- measurement principle:
  - SPIROC2b ramp: 3920 ns ramp length (testbeam mode)
  - TDC: ~1.6 ns/bin
- slope calibration (edge extraction):
  - Pedestal and Maximum of the ramp extracted using edges of the TDC Spectrum

$$slope_{Chip,BXID} = \frac{3920\ ns}{(V_{max}[TDC] - V_{min}[TDC])}$$

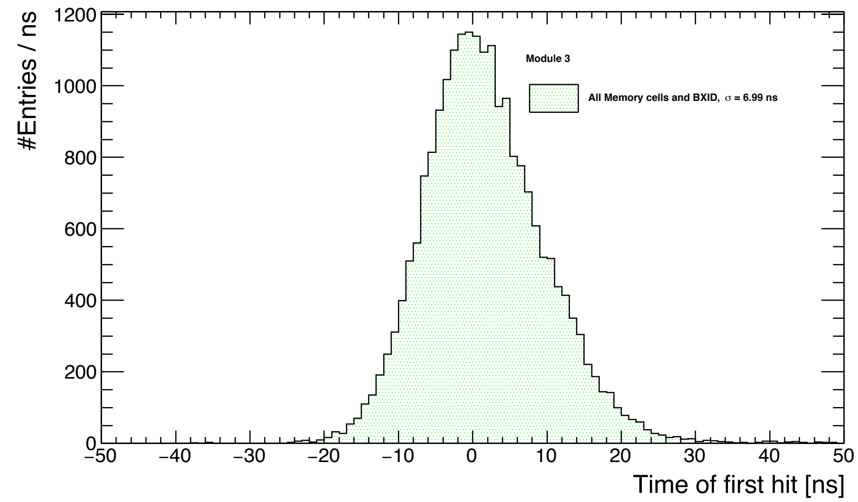
  - many calibration constants needed
    - 2 ramps per chip
    - offsets per channel and per memory cell

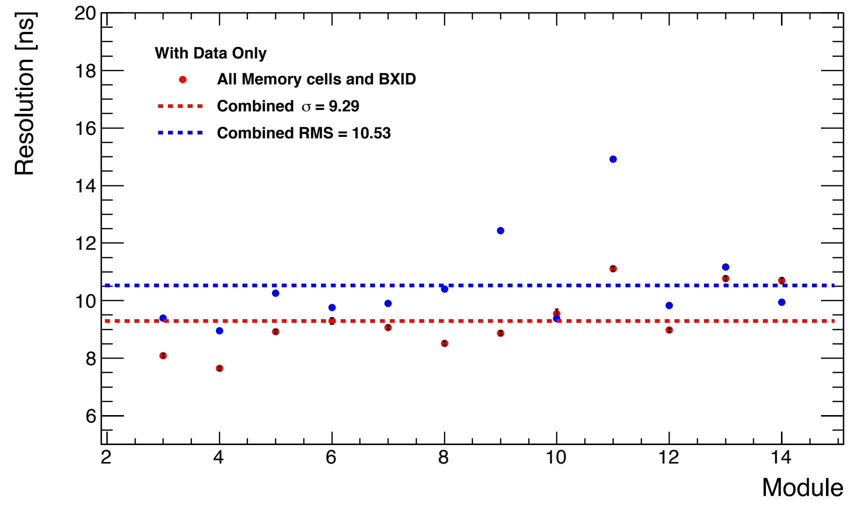




Time resolution: muons before corrections

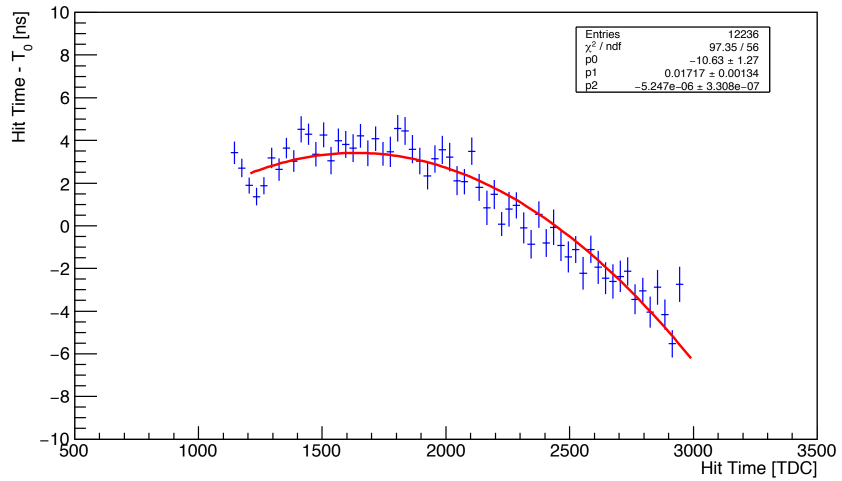
- correct for memory-cell wise pedestal
- time delay between reference hit time and the real event
  → offset corrected chip by chip
- no other corrections
- clearly asymmetric
- resolution around 8-11 ns
  - RMS of whole distribution significantly wider than Gaussian sigma
  - big layers slightly worse
  - need to check layers 9 & 11
- known effects deteriorating the resolution:
  - non-linearity of the TDC ramp
  - time-walk effect

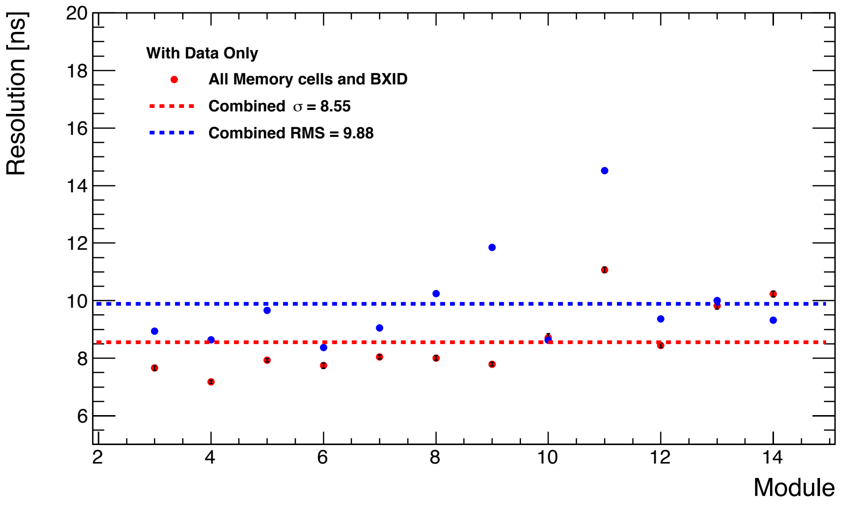




Linearity Correction

- calibration assumes linear ramp
- non-linearity can be checked by plotting the mean of the hit time distribution versus the TDC value of the hit
  → would be flat for linear ramp
- clearly not flat
- fit with polynomial function and correct
- one correction function per TDC ramp (2 per chip)
- small improvement in timing resolution: ~7%
  corresponds to ~3.6 ns effect





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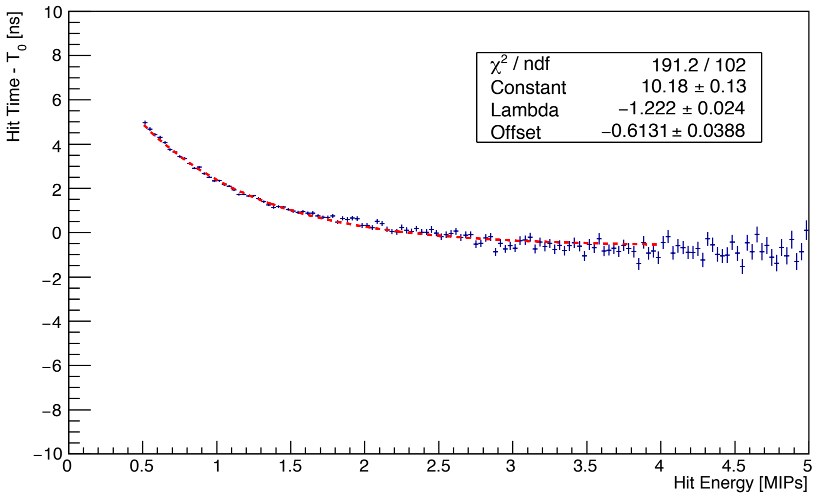
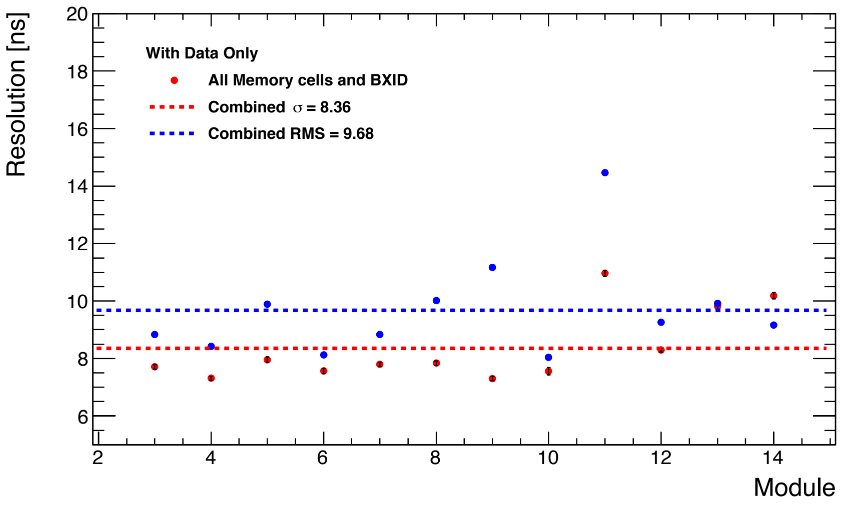
Time-Walk Correction

- time-walk effect:
  - low hit amplitudes induce a time slew due to the threshold
  - assumed to be the same for all chips
    → one parametrisation needed
- check mean hit time as function of hit energy
- fit with

$$f(t) = A * e^{-\lambda t}$$

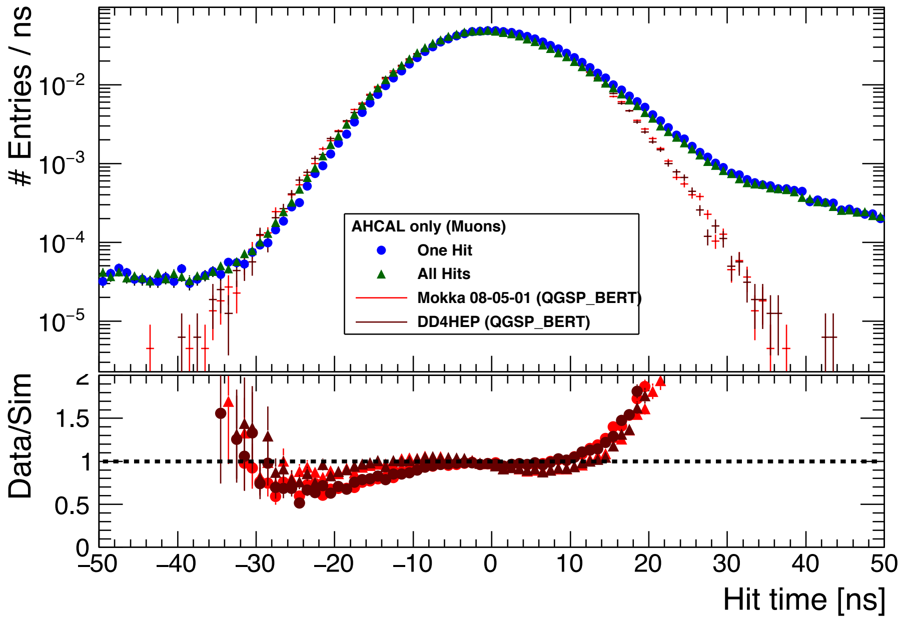
- up to 5 ns correction for small hits
- ~2.4% improvement in resolution (~ 2 ns effect)





Time analysis: resolution for muons

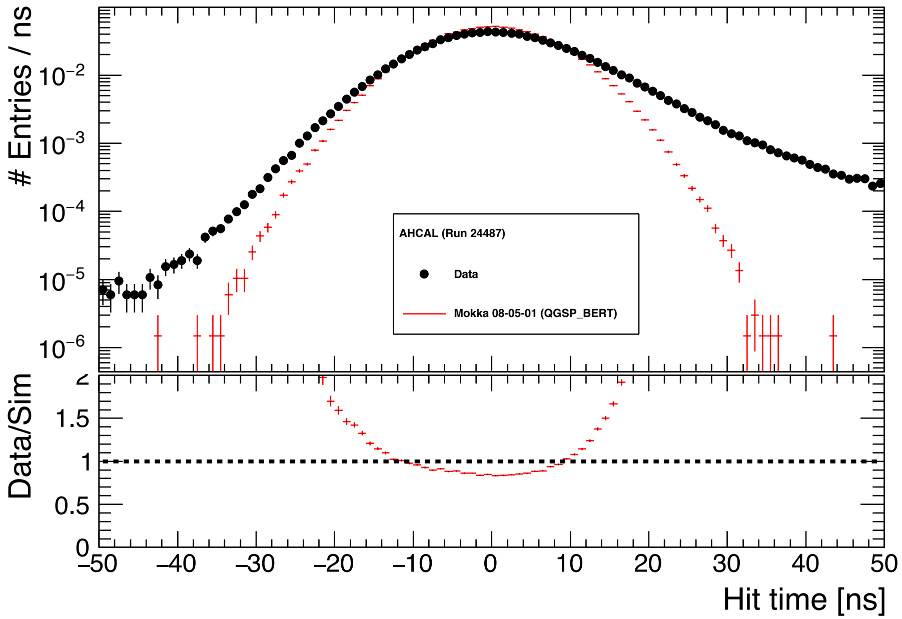
- hit time distribution for a single channel after corrections (non-linearity, timewalk)
- resolution obtained ~8 ns
  - still asymmetric tail to the right
    - biased cut?
    - propagation time in scintillator?
  - comparison with Mokka and DD4hep simulation
    - Gaussian smearing of hit times
    - no noise added
  - good agreement in [-10, 10] ns range
  - same Gaussian resolution used in Mokka and DD4hep, needs more checks in DD4hep



- ILC mode has ~200ns TDC ramps instead of ~4ms
- if resolution is dominated by TDC: expect factor ~20 better resolution, corresponding to ~0.4 ns

Time analysis: check with electrons

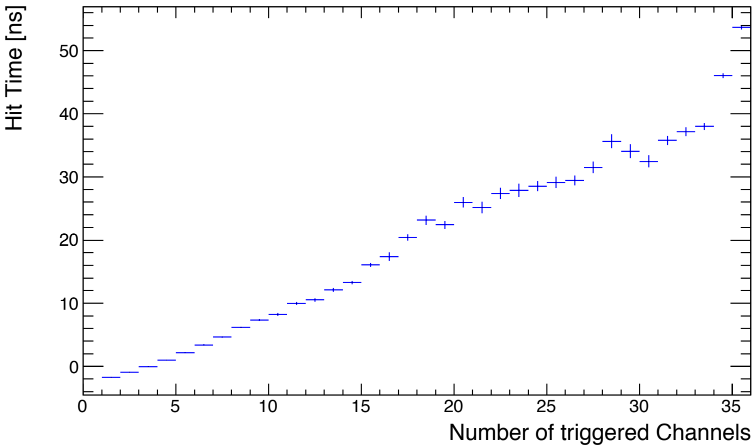
- apply the calibration constants determined from muons to electron data
- allow only for an offset in the time reference because of a different trigger setup
- width similar to muons, but tail to the right even larger
- pedestal shift for events with many triggered channels on the same chip? → check

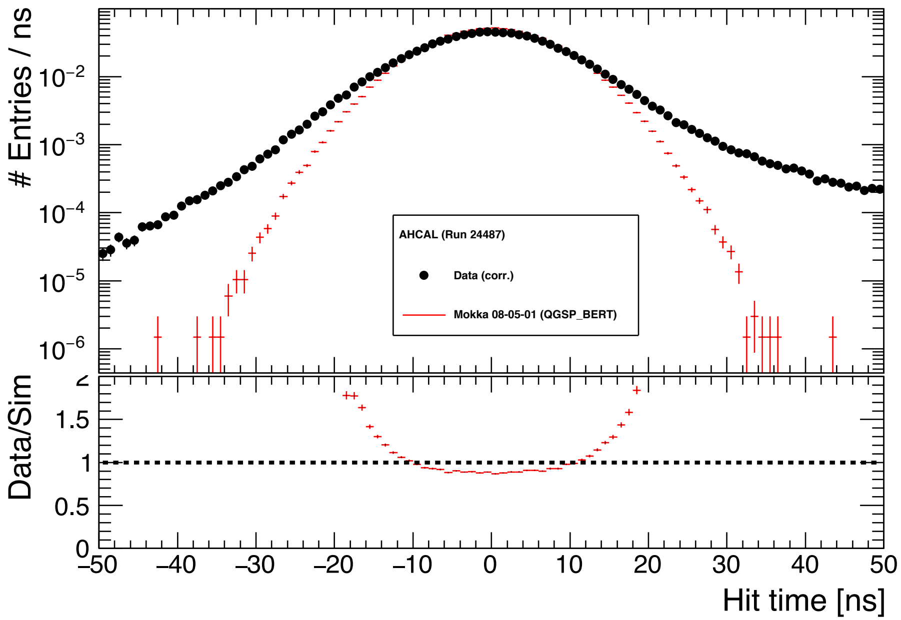


Time analysis: check with electrons

- check mean hit time as function of number of triggered channels on the chip
- clear effect observed
- correct with a linear function
  - at the moment the same for all chips, need to check
- distribution more symmetric, but still larger tail to the right
- improves resolution for electrons by ~2% (1.6 ns effect)
- effect for muons negligible

- **next steps:**
  - understand origin of asymmetry
  - check influence of noise
  - estimate resolution of time reference from t0 channels
  - look into pion data





Summary

- distributed analysis of 2015 data progressing
- energy measurement
  - MIP calibration done
  - dead channel map done
  - high gain / low gain inter-calibration
    - can probably only do chip-wise values for 2015 data
    - in future need channel-wise calibration procedure
  - saturation correction: started
  - next steps: response, shower shapes
- time measurement
  - calibration procedure developed for muons
  - cross check with electrons look reasonable
  - next steps
    - understand asymmetry
    - look into hadrons

Backup

Intercalibration constant applied to LED

- Intercalibration constant used to correct ADC_LG:

$$ADC_{LG}^{corr} = \mathcal{C} * ADC_{LG} + p0$$
$$pedestal_{LG}^{corr} = \mathcal{C} * pedestal_{LG} + p0$$

$$ADC_{LG}^{corr} = \mathcal{C} * (ADC_{LG} - pedestal_{LG})$$

p0 doesn't play any role

- IC obtained using mean ADC value per channel. ADC_{HG} - ADC_{LG}^{corr} vs ADC_{LG}^{Nocorr} plotted to verify if the IC is well done and estimate the corrections **C** to apply to the IC, due to the fact that the mean ADC value has been used

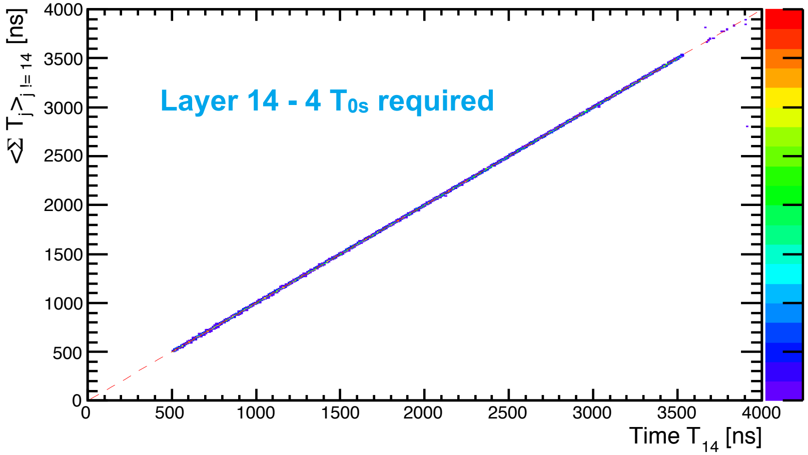
- How to apply the correction

$$ADC_{LG}^{final} = (\mathcal{C} + C) * ADC_{LG} + \cancel{p0}$$

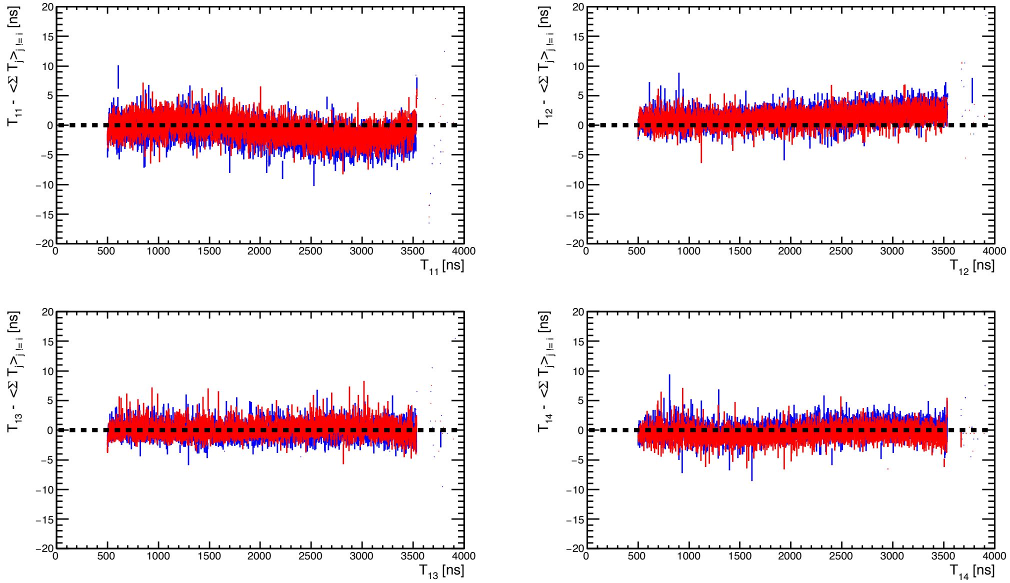
Again p0 has no role because same correction applied also to the pedestal

T0 Calibration Check (Time reference)

- T_0 are the reference time to the trigger. 6 available in the AHCAL, only 4 working (Layers 11 to 14)
- Control of the time reference
    - Cross-Check : T_{0s} against one another and T_{0s} against sum of the others
    - Good calibration → line at 45 degrees
- Deviation ~ < 5 ns
- Averaging of the T0s :
    - Reducing the uncertainty on the reference time.



Residuals for each T_0 (Blue - BXID even / Red - BXID odd)



Time analysis: resolution for muons

- hit time distribution for a single channel after corrections (non-linearity, timewalk)
- resolution obtained ~7.5 ns
  - still asymmetric tail to the right
    - biased cut?
    - propagation time in scintillator?
  - comparison with Mokka and DD4hep simulation
    - gaussian smearing of hit times
    - no noise added
  - good agreement in [-10, 10] ns range
  - same gaussian resolution used in Mokka and DD4hep, needs more checks in DD4hep

with N_triggered correction