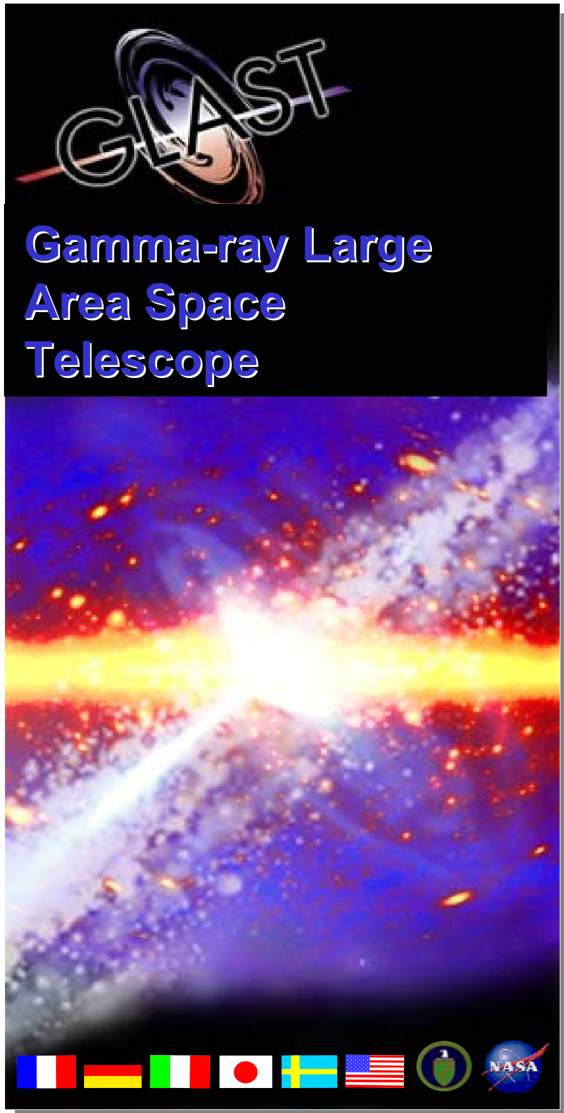

Lessons learned for CAL calibration.

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Calibration Unit Calorimeter structure

- 3 towers
- 8 layers per tower
- 12 crystals per layer
- 2 ends: positive and negative
- At each crystal end – two photodiodes:
  - Big diode (Low Energy diode):
    - LEX8 range: max energy ~100 MeV
    - LEX1 range: max energy ~1 GeV
  - Small diode (High Energy diode):
    - HEX8 range: max energy ~8 GeV
    - HEX1 range: max energy ~70 GeV
- The electronics chain for each diode:
  - Preamplifier + shaper (common for both x1 and x8 ranges)
  - Track & hold – individual for each range

Crystal energy reconstruction

- Input: ADC values (0-4095) for positive and negative end of crystal
- Output: energy in MeV
- Algorithm:
  - Pedestal subtraction:
    - ADC_PED = ADC – PED
  - Conversion to the units of charge injection DAC:
    - DAC = adc2dac(ADC_PED)
  - calculation of geometric mean of two ends of crystal:
    - DAC_mean = sqrt(DAC_pos*DAC_neg)
  - Conversion to MeV:
    - Ene = MeVperDAC*DAC_mean
- Calibration data needed:
  - Pedestal – one constant for each range
  - Adc2dac – spline function for each range
  - MeVperDAC – one constant for crystal and diode size(big/small)

Meaning of calibration constants

- adc2dac (integral nonlinearity) – relationship between measured signal (in ADC units) and the charge injected to the preamplifier input
  - Should take care of different preamplifier gain
- MeVPerDAC – relationship between deposited energy in a crystal and the charge (in DAC units) injected to the preamplifier input
  - Should NOT depend on preamplifier gain

Measurement of calibration constants

- Pedestals:
  - From CPT pedestal runs
  - From periodic trigger events during normal data taking
- Adc2dac:
  - calibGen charge injection script - measures adc2dac for different combinations of configuration parameters:
    - In each run only one diode pulsed at each crystal end
      - Both diodes are read out – allows the crosstalk measurement
    - Two different gain settings for small diode: flight gain and muon gain (used for muon calibration of small diode)
    - Two values of charge injection capacitor
      - Allows to find the crosstalk for realistic signal ratio between big and small diodes
- MeVperDAC:
  - For big diode – from calibration with cosmic muons
  - For small diode – from small/big diode ratio

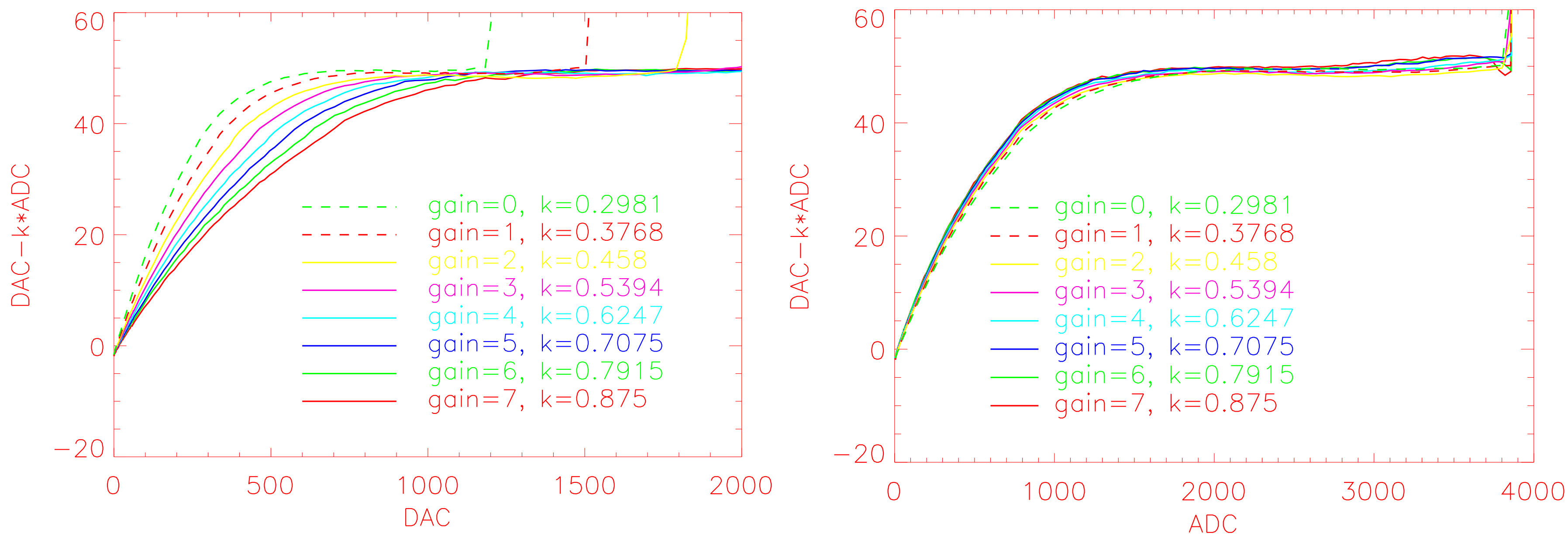
Calibration process for high energy diode

- When high energy diode is being calibrated with muons, preamplifier gain is set to the value 10 times bigger, than normal ("muon" gain)
- In this simplified model to take into account the different preamplifier gain setting we just have to use the appropriate adc2dac calibration (for flight gain or for muon gain)
- Real situation is more confusing: we also can change the charge corresponding to one DAC unit by switching charge injection capacitor (controlled by CALIBGAIN bit in the configuration word)
  - We use CALIBGAIN=OFF setting when doing charge injection calibration with muon gain, otherwise the step of charge injection calibration would be too big, compare to muon signal
    - This setting decrease the value of one DAC unit by factor ~9.3 (CALIBGAIN factor).
    - to take this into account, we have to multiply MeVPerDAC values by this CALIBGAIN factor, when reconstructing data collected with flight gain
    - CALIBGAIN factor is defined individually for each channel, by comparing charge injection calibrations done with CALIBGAIN=ON and CALIBGAIN=OFF

Intercalibration of ranges with the beam

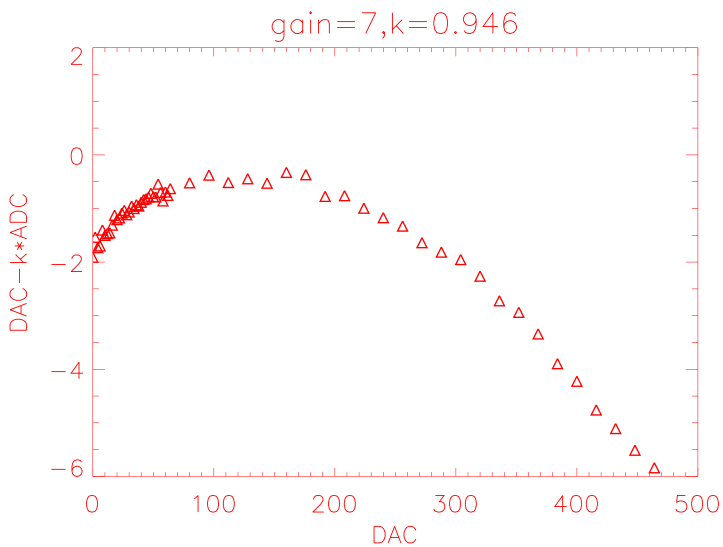
- We can verify the quality of CAL calibration by collecting beam test data in 4-range readout mode and comparing energies measured by two different ranges
- Comparing LEX1 and HEX8 energies in the overlap region (200-800 MeV) allows to confirm the nonlinearity measurements, used to propagate the calibration from MIP energy depositions ~10 MeV
- If measured HEX8/LEX1 ratio is not equal to 1, we then corrected HEX8 MeVperDAC coefficient in calibration database , to make HEX8/LEX1=1
- The analysis of the range intercalibration data (see Philippe Bruel's talk) showed that HEX8 energy is systematically smaller than LEX1 by 5-10%
  - This discrepancy stimulated us to search for the effects which could explain it
  - Two effects were found and corrected:
    - DAC nonlinearity at small signals
    - Crosstalk from low energy diode to high energy diode

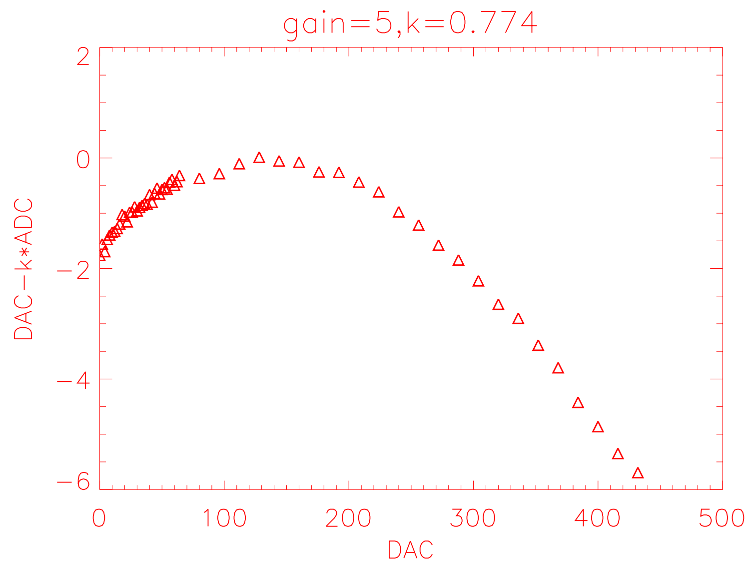
LEX1 nonlinearity for different gain settings

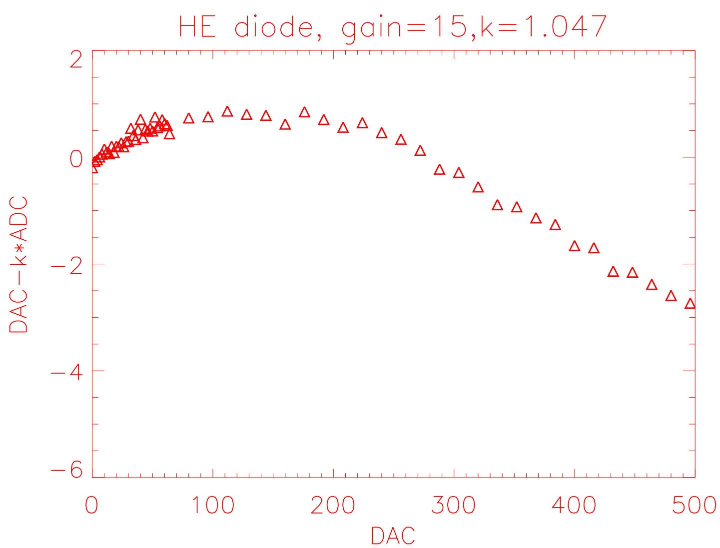


- Nonlinearity curve as a function of DAC changes with gain setting
- Nonlinearity curve as a function of ADC almost independent of gain setting
  - *Consistent with a model containing some small parasitic feedback capacitance changing with output signal*

Zoom of small DAC region





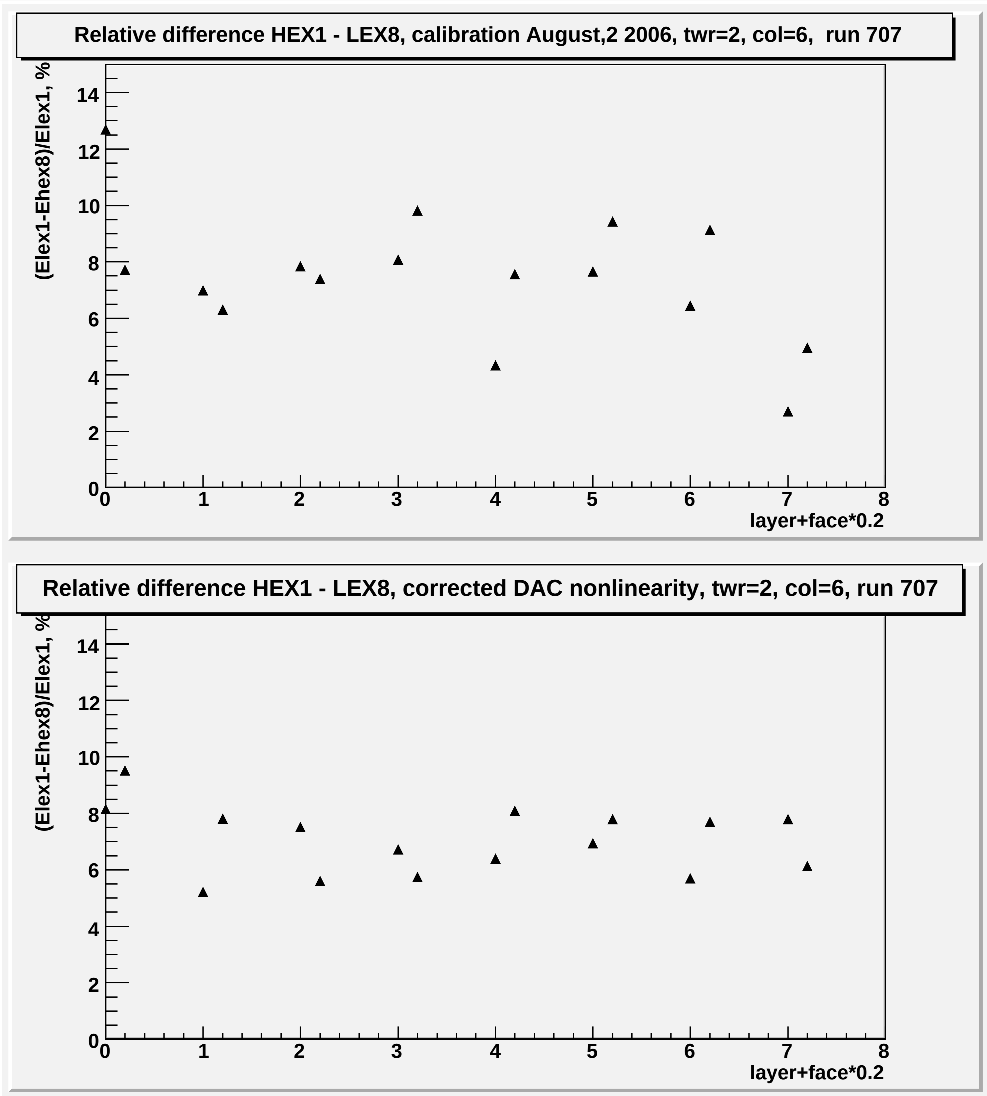


- The part of nonlinearity curve at low DAC values contains significant changes of DAC/ADC slope happening at the same DAC value independently of gain (top left and top righ plots)
- Similar pattern could be seen for high energy diode (bottom left plot)
- This could be interpreted as DAC nonlinearity
- Difference in slope between region 0<DAC<32 and 64<DAC<200 is ~2%

"Correction" of DAC nonlinearity at low signals

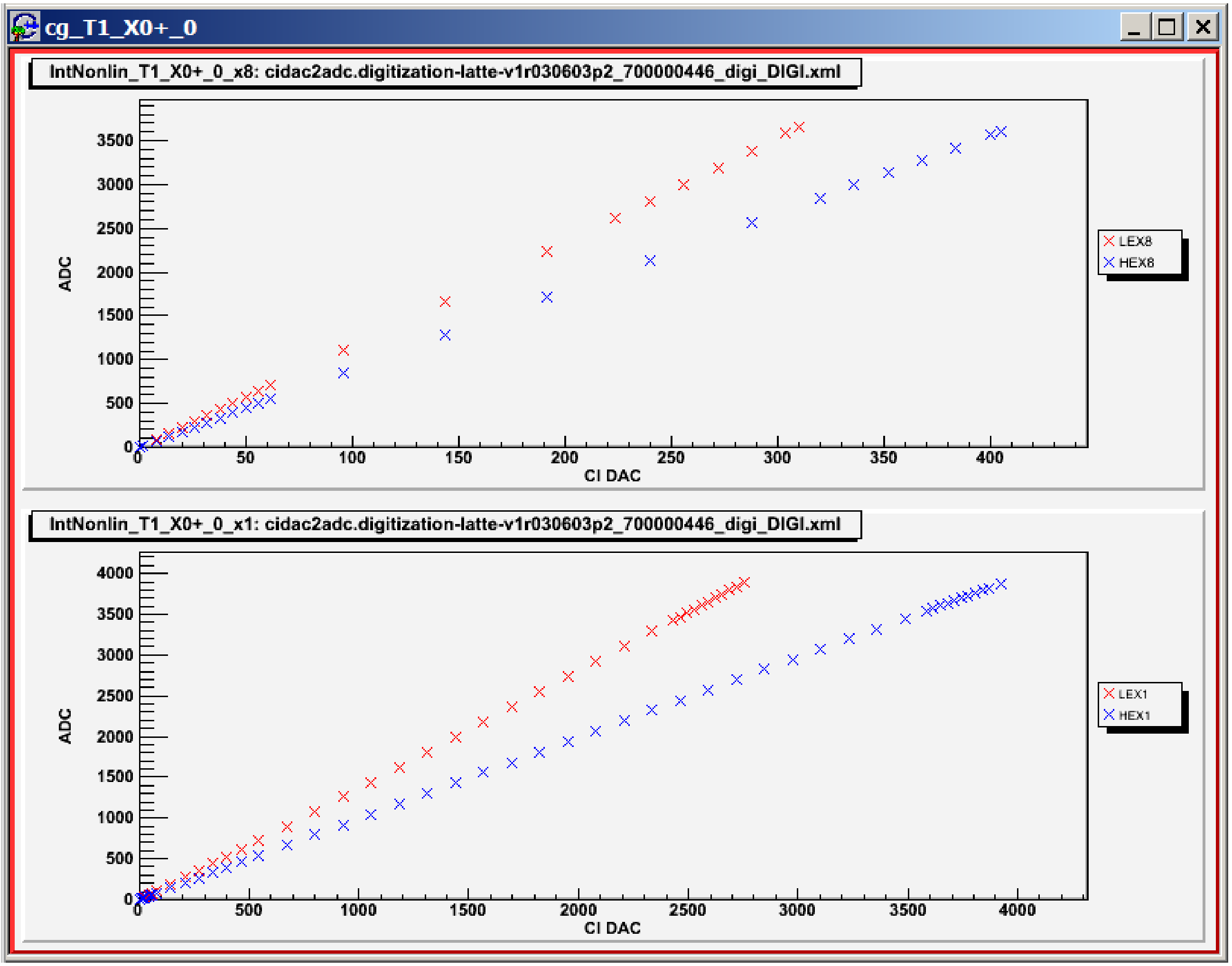
- We suspected that nonlinearity measurement is wrong at low signals
  - We decided to try what happens if we consider electronics linear for low signals
- We suppose that charge injection DAC is not linear below DAC=64, while the ADC is linear in this region
  - so we fit linear function to the ADC vs DAC nonlinearity measurement in the region 64<DAC<192 and replace measured DAC values below 192 by the values calculated from ADC values using this linear function
  - The extrapolated DAC value at ADC=pedestal we call "DAC pedestal" and subtract it from all DAC values

Intercalibration of LEX1 and HEX8 ranges after DAC nonlinearity correction



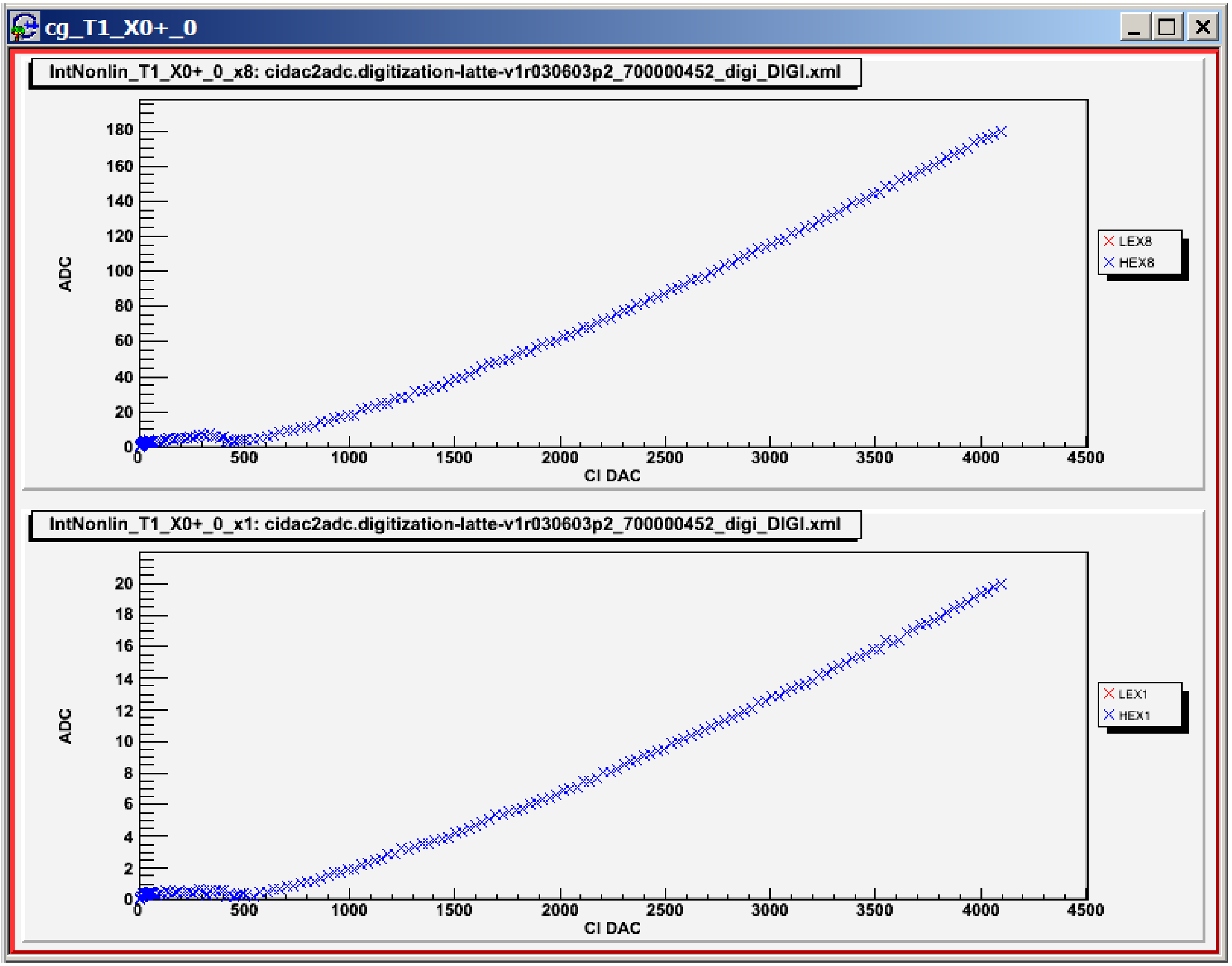
- Relative difference in energy scale between LEX1 and HEX8 ranges in %
  - Top plot: using old calibration
  - Bottom plot: using new calibration
- There is some improvement:
  - the fluctuations from layer to layer became smaller
- The main problem is still not solved:
  - All channels have in average ~7 % smaller energy in HEX8 range than in LEX1

ADC vs DAC without crosstalk



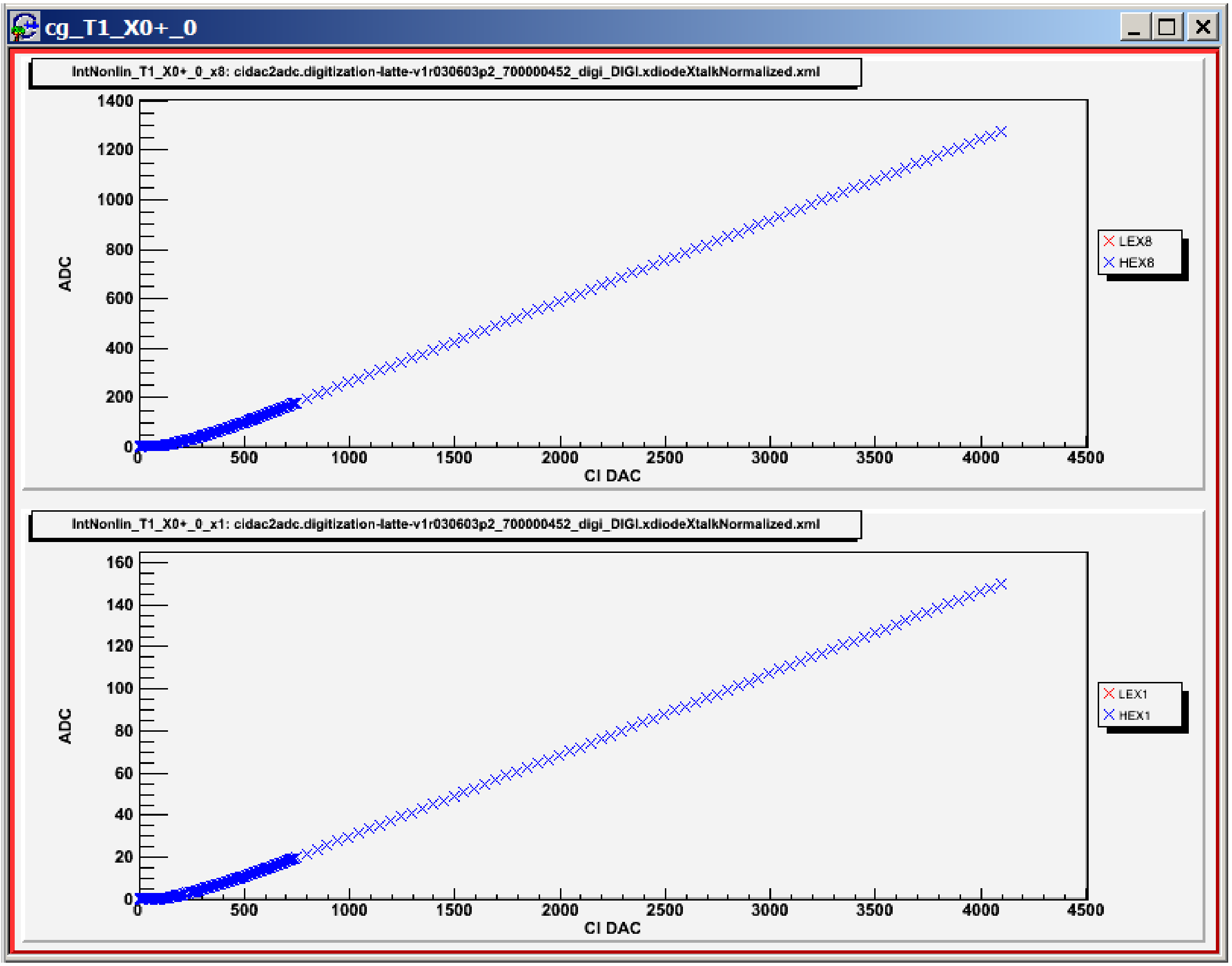
- Charge injection calibration for all 4 ranges of one crystal end
- Only one diode was pulsed in each run:
  - No crosstalk effect taken into account on this plot

Measurement of the crosstalk from big to small diode



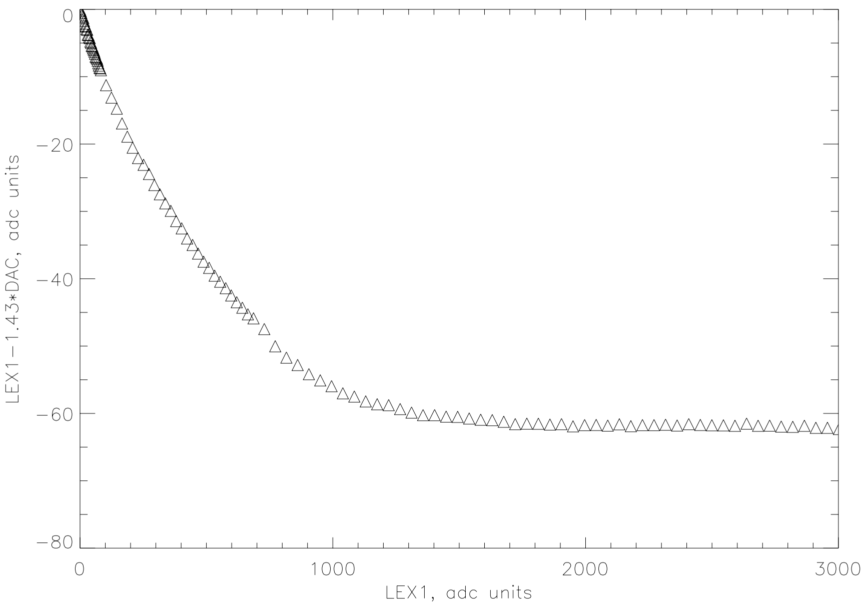
- Signal measured by HEX8 and HEX1 channels, when only LE diode was pulsed
- CALIBGAIN=OFF setting was used, to provide big signal on LE diode, (~10 times bigger than the saturation level)

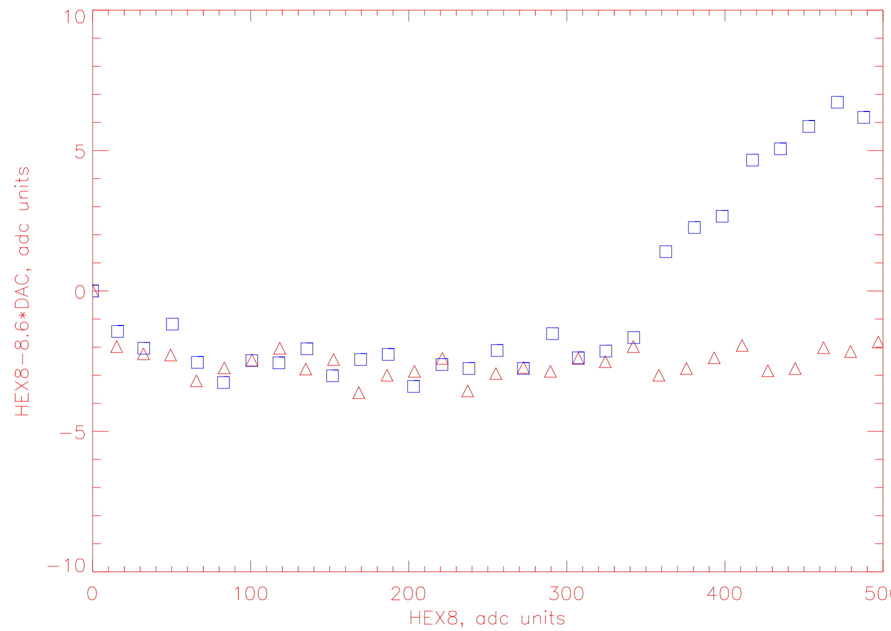
Crosstalk vs signal at HE diode



- Horizontal axis value divided by factor 5.5 to convert to HE DAC scale
  - 5.5 - the ratio between big and small diode signals for real scintillation
- All measured points are below DAC~750
  - We do linear extrapolation of crosstalk for bigger signal
- From bottom plot the crosstalk is ~3% of HEX1 signal
- no real measurement for very big signals (DAC>750 or ene>15 GeV)

Nonlinearity measured with charge injection

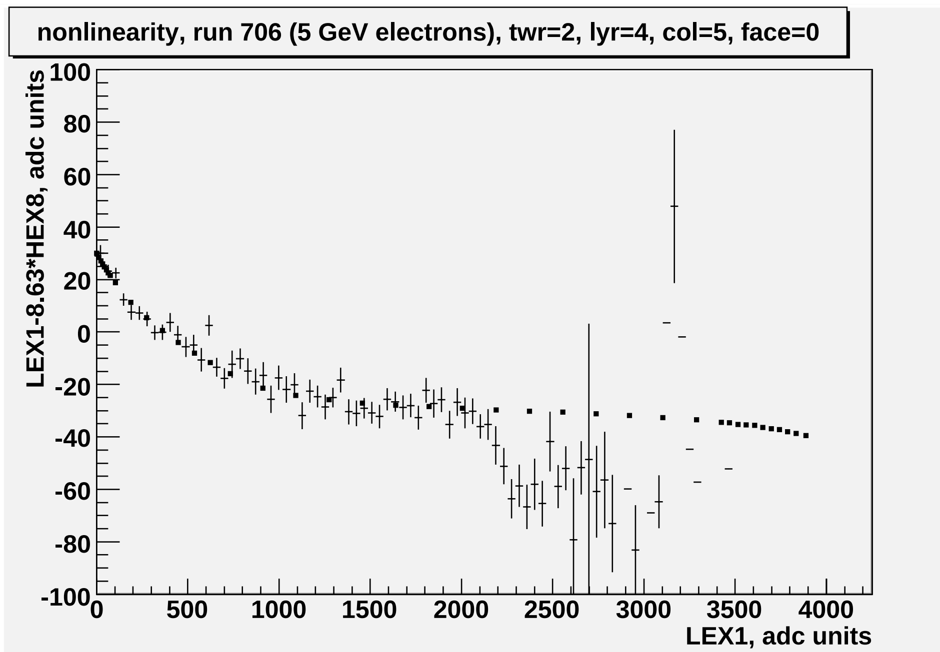


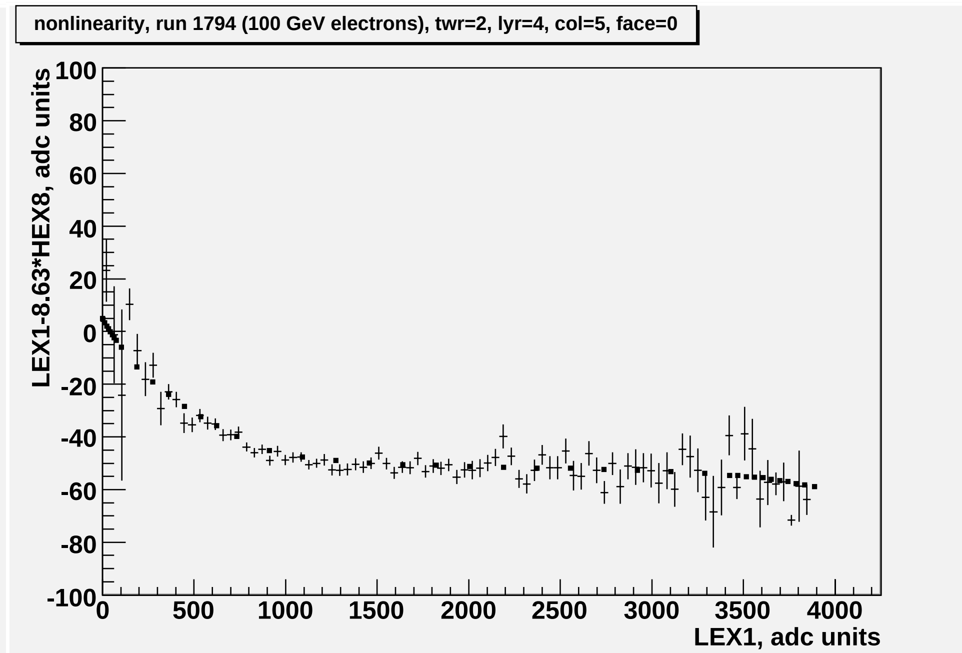


- Nonlinearity for LEX1

- Nonlinearity for HEX8
  - Red triangles – with FHE=127
  - Blue squares – with FHE=nominal
- In the region of overlap with LEX1 (HEX8<400) nonlinearity is small compare to LEX1
- For this study I will avoid the end of the region.

LEX1 nonlinearity for electrons

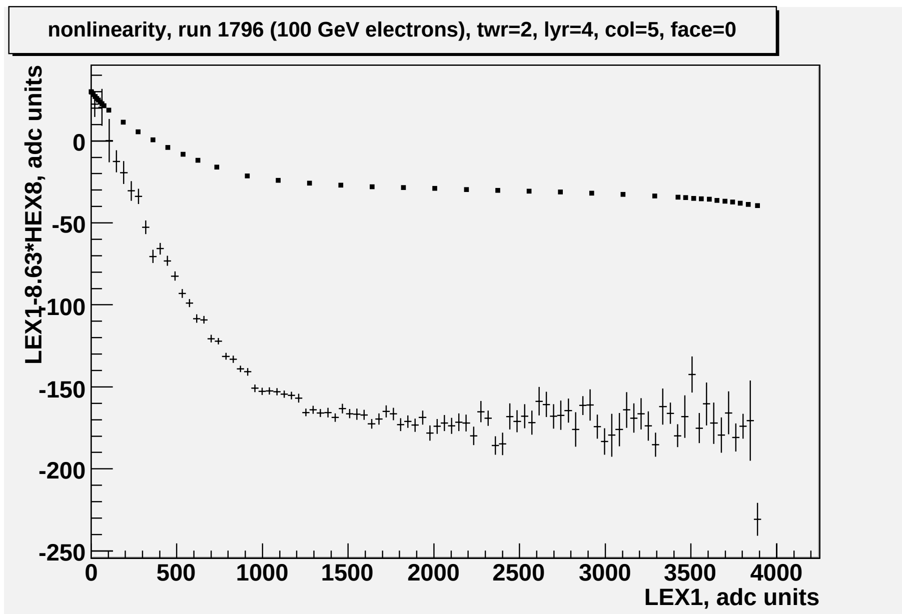


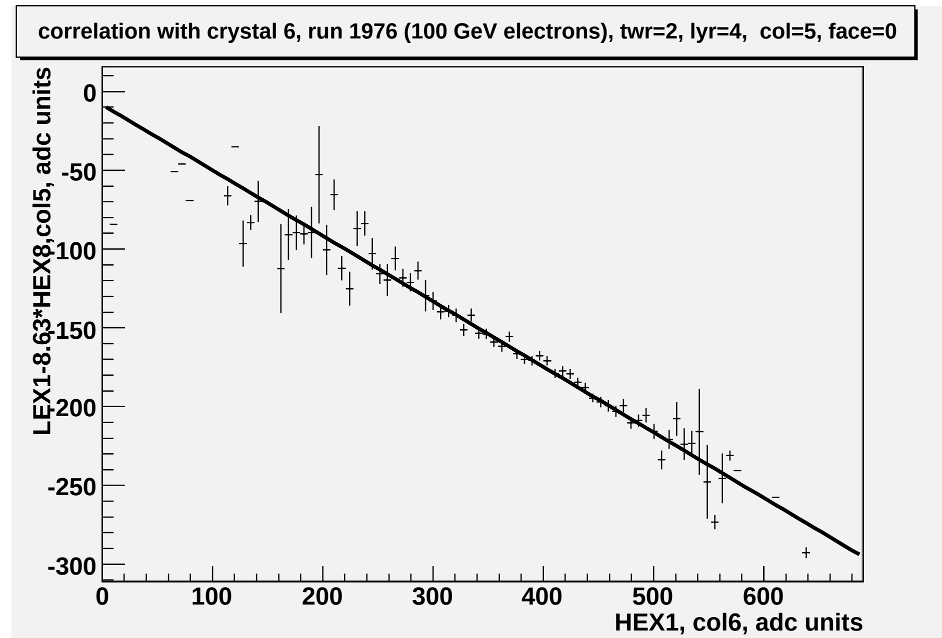


- LEX1 nonlinearity on the axis of 5 GeV electron beam
  - Squares – charge injection measurement
  - Deviation at lex1>2500 due to FHE crosstalk in HEX8 (see previous slide)

- LEX1 nonlinearity in crystal 5 when 100 GeV electron beam hits the crystal 4
  - Good agreement with charge injection

Nonlinearity for electrons: beam in column 6

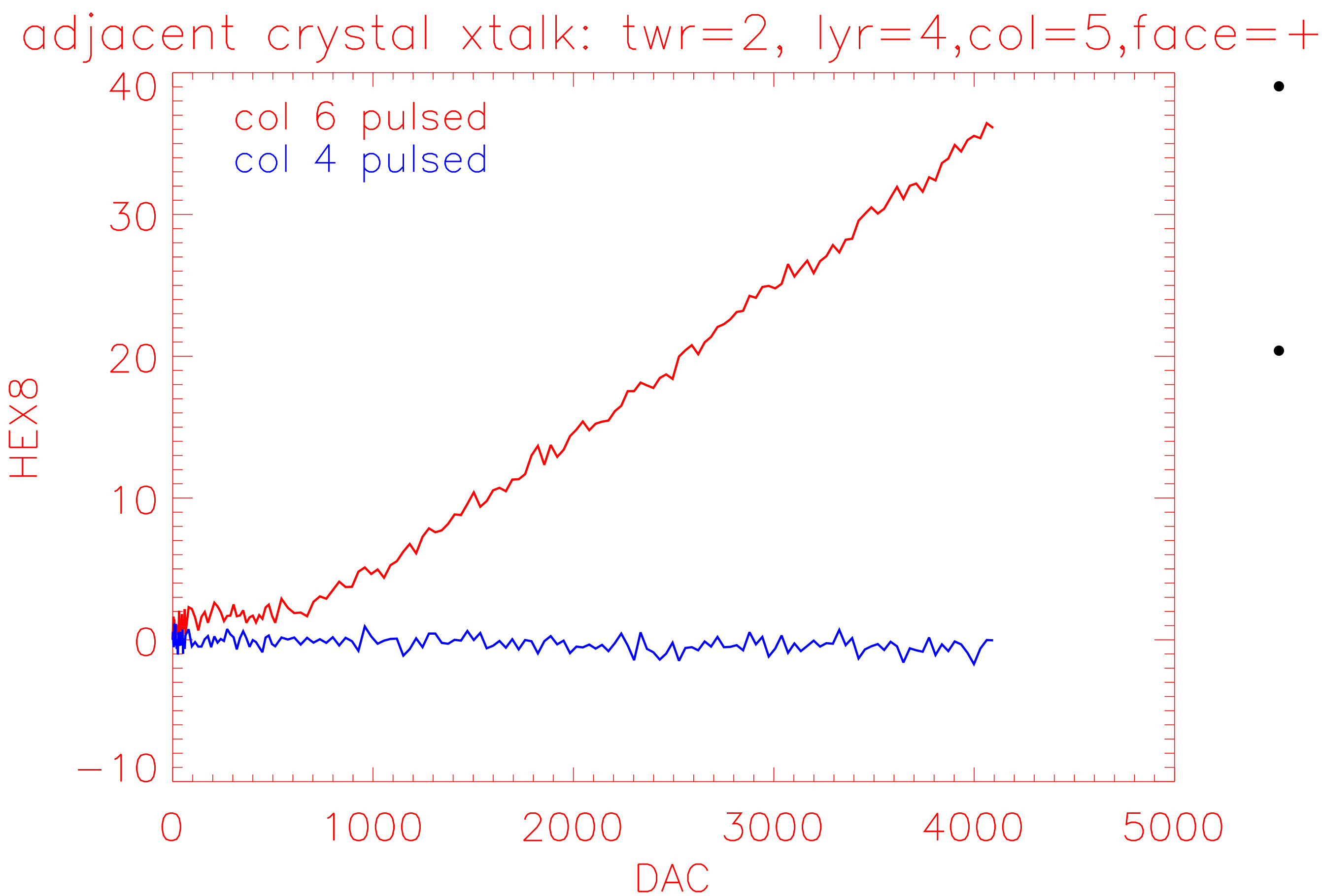




- When 100 GeV electron beam hits crystal 6 – nonlinearity curve for crystal 5 becomes very different from charge injection

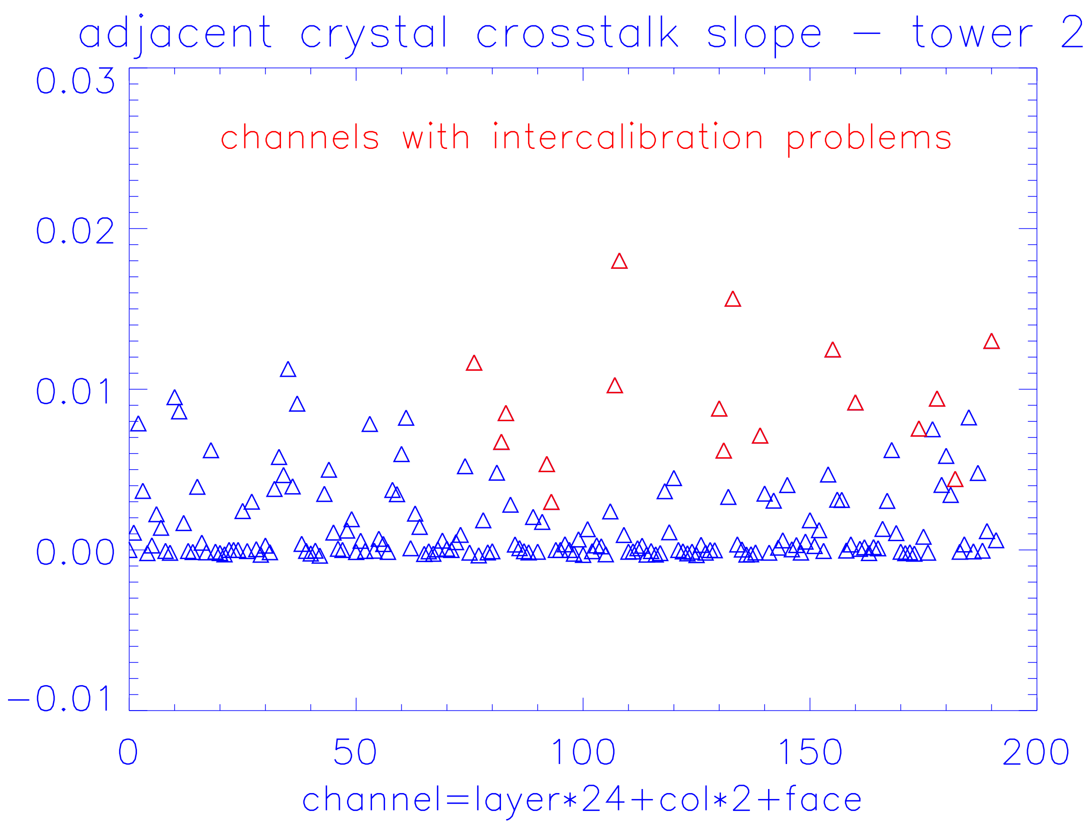
- Correlation of flat part (LEX1>1500) of the left plot versus HEX1 signal in the beam center (crystal 6)
  - Could be explained as a crosstalk from crystal 6 to crystal 5 with 0.5% amplitude

Crosstalk between adjacent crystals



- Crosstalk of ~1% from column 6, but no crosstalk from column 4
- This measurement could be used for correction during reconstruction

Crosstalk slopes for all channels of tower 2



- Red triangles – channels with intercalibration problems in Philippe's analysis
- Only layers >2 affected, because significant energy deposition is needed
-

- To correct the crosstalk, the following function was proposed:

  if(FaceSignal[col±1]>2100)FaceSignal[col]-= xtalk_slope* (FaceSignal[col±1]-2100)

- The average MeVperDAC coefficient used to convert threshold to energy scale (2100 MeV)