H2020-MSCA-RISE-2015 – Grant Agreement N° 690835

Gain corrections

Alberto Lusiani

Scuola Normale Superiore & INFN, sezione Pisa

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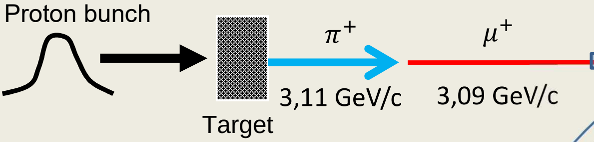
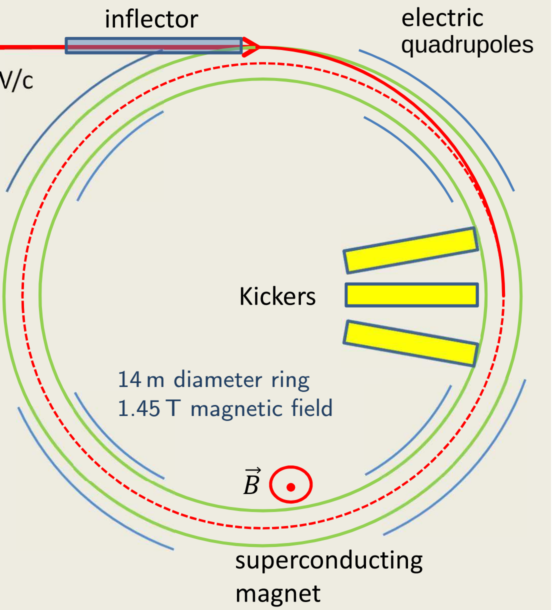
Muon $g-2$ measurement





- muon anomaly $a_\mu = (g-2)_\mu/2$ obtained by measuring muon spin precession in magnetic field
- rate of $\mu \to e\bar{\nu}_e\nu_\mu$ with $E_e > 0.6 E_e^{\text{max}}$ modulated with $\omega_a \propto (g-2)_\mu$
- $E_e^{\text{measured}} = E_e^{\text{true}} \times G^{\text{calo}}(t)$
- $G^{\text{calo}}(t)$ uncertainty $\Rightarrow$ a_μ systematics
- $G^{\text{calo}}(t)$ depends on
  - previous detector hits
  - temperature of detector, electronics

Largest ω_a measurement systematics

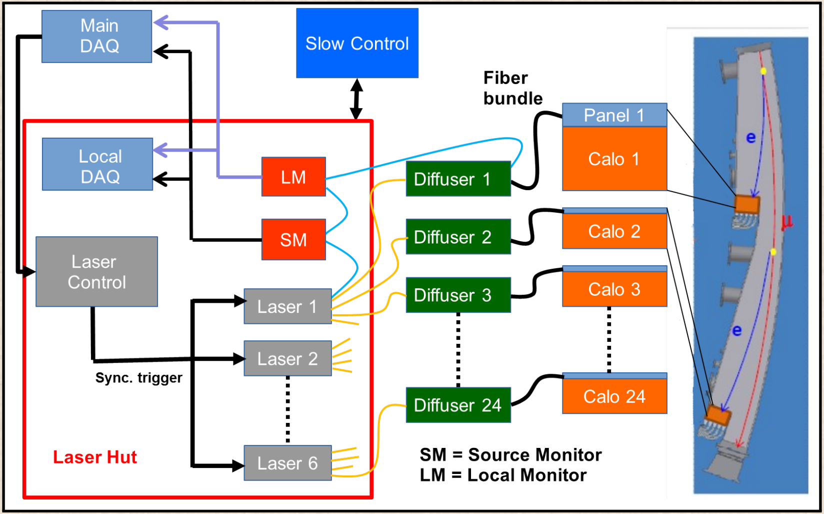
E989 TDR systematics goals

	E821 [ppb]	E989 improvement plans	E989 goal [ppb]
gain changes	120	improved laser calibration low-energy threshold	20
pileup	80	low-energy samples recorded calorimeter segmentation	40
lost muons	90	better collimation in ring	20
CBO	70	higher n value (frequency) better match of beamline to ring	$<$30
E and pitch	50	improved tracker precise storage ring simulation	30
total	180		70

Notes

CBO = coherent betatron oscillation due to quadrupole focusing
pitch = oscillating vertical inclination of muon momentum

E989 laser calibration system



- 6 lasers, each divided in four beams, illuminate 24 modules with 54 PbF_2 crystals each
- laser intensity measured by source and local monitors before and after distributions

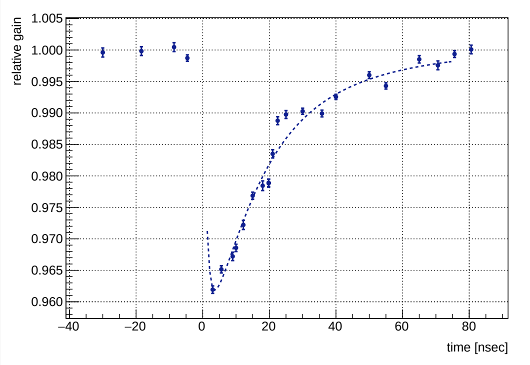
E989 laser calibration system

- 6 source monitors, each consisting of
  - 2 large-area (1 cm^2) PIN diodes (stable)
  - 1 PMT
  - ^{241}Am source + NaI converter illumitating PMT cathode
  - monitor laser power variation
- 2x24 local monitors, each consisting of 1 PMT
  - get light
    - back from distribution to calo modules
    - from laser sources
  - detected signals are distinct in time
  - 24 using silica fiber, 24 using plastic fiber
  - monitor laser power & laser distribution variations
- injects and reads laser light in 1296 calorimeter crystals with SIPM readout

Gain variation due to previous detector hits

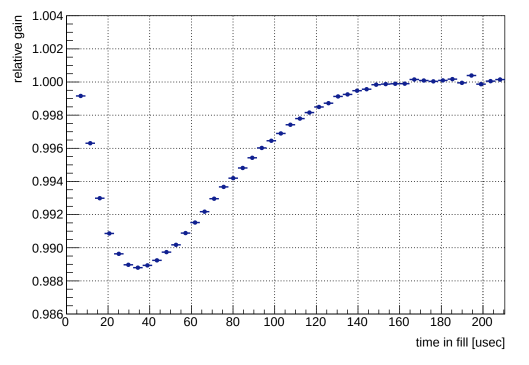
short-term gain variation

- gain drops because SIPM pixels need some ns to recover from the previous hit (SIPM pixel recovery time ∼10 ns)



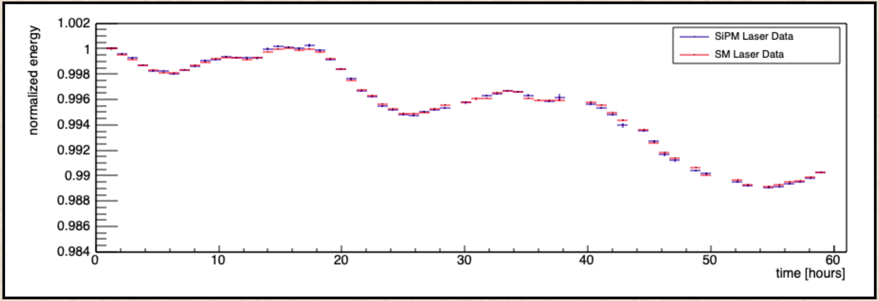
in-fill gain variation

- gain drops because SIPM power supply voltage drops because of previous absoption caused by hits integrated over a perion of about 10 μs (SIPM power supply recovery time)



Long-term gain variation

- temperature affects laser source intensity, laser distribution attenuation, detectors' gain
- variations are significant on time scales $> 700\,\mu s$



E989 laser calibration system, principles of operation

- muon decays are measured in 700 μs-long fills

short-term gain variation

- minor systematics effects
- measured in dedicated laser runs

in-fill gain variation

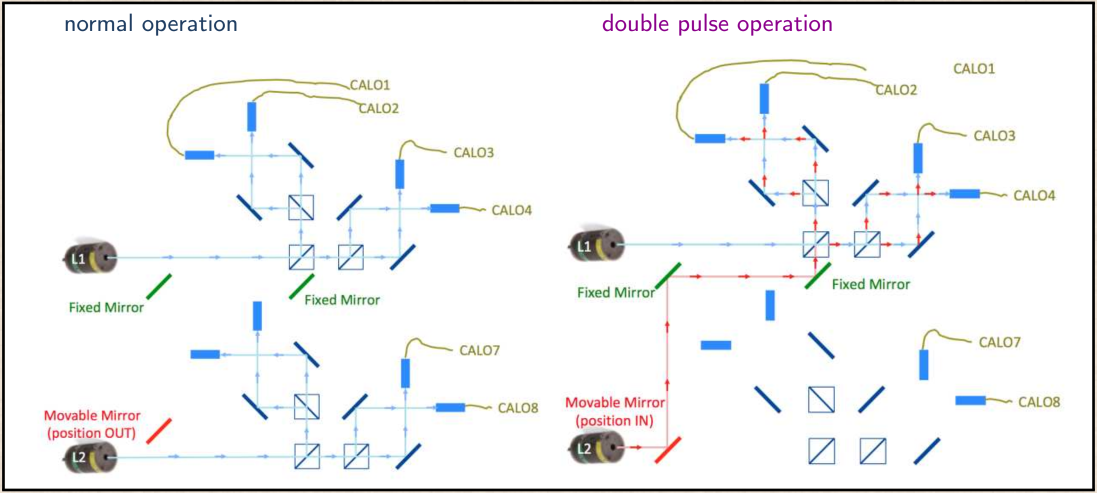
- this corresponds by far the largest systematic contribution
- measured in two ways
  - injecting / measuring laser light pulses in $\sim$1/10 of recorded muon fills
  - on laser-dedicated runs

long-term gain variation

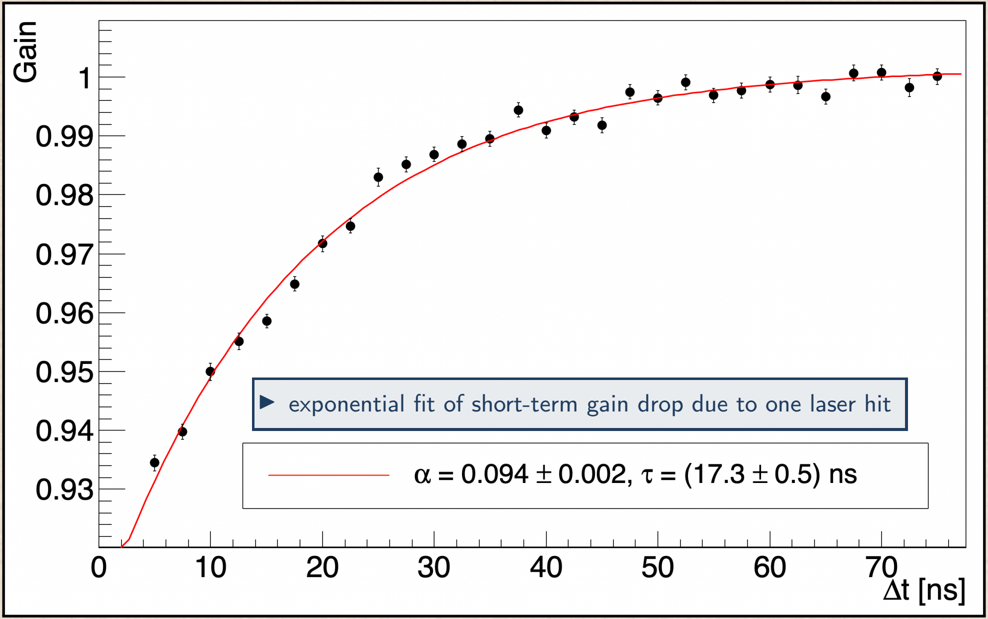
- negligible systematic contribution
- but measure to calibrate the calorimeter measurements energy scale
- measure SM, LM, laser light response on crystals during data-takin but out-of-fill
- also monitor temperature in several places of experimental apparatus for further studies

Short-term (ns) gain variation measurent

- cannot fire two laser pulses few ns apart
  ⇒ use two laser sources to shoot two close laser pulses on same crystals

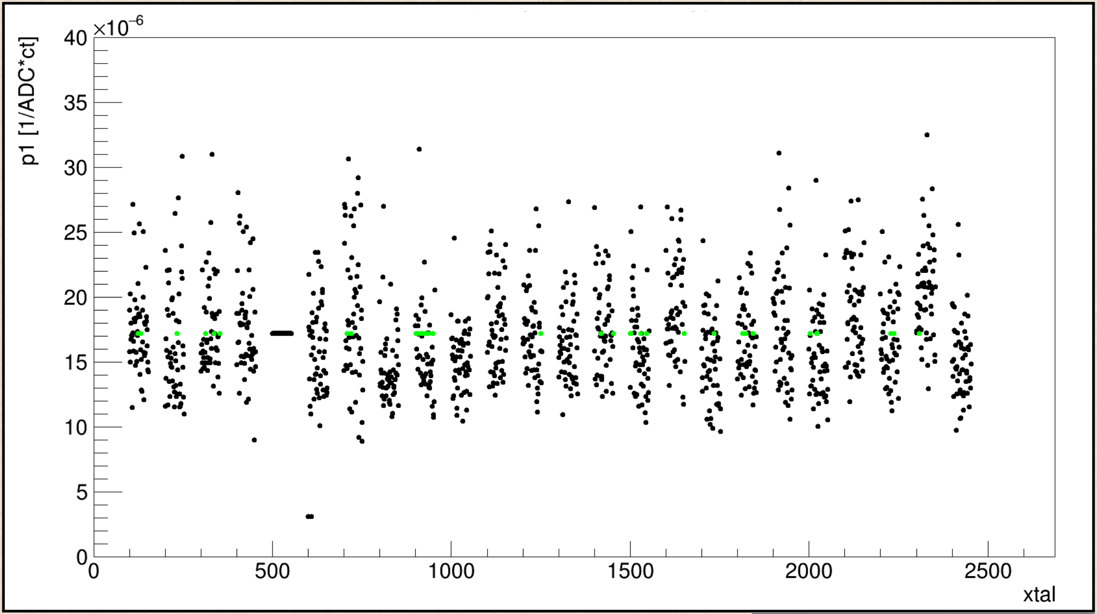


Short term average gain variation, example fit



- exponential fit of short-term gain drop due to one laser hit

Short term average gain variation, exponential amplitude



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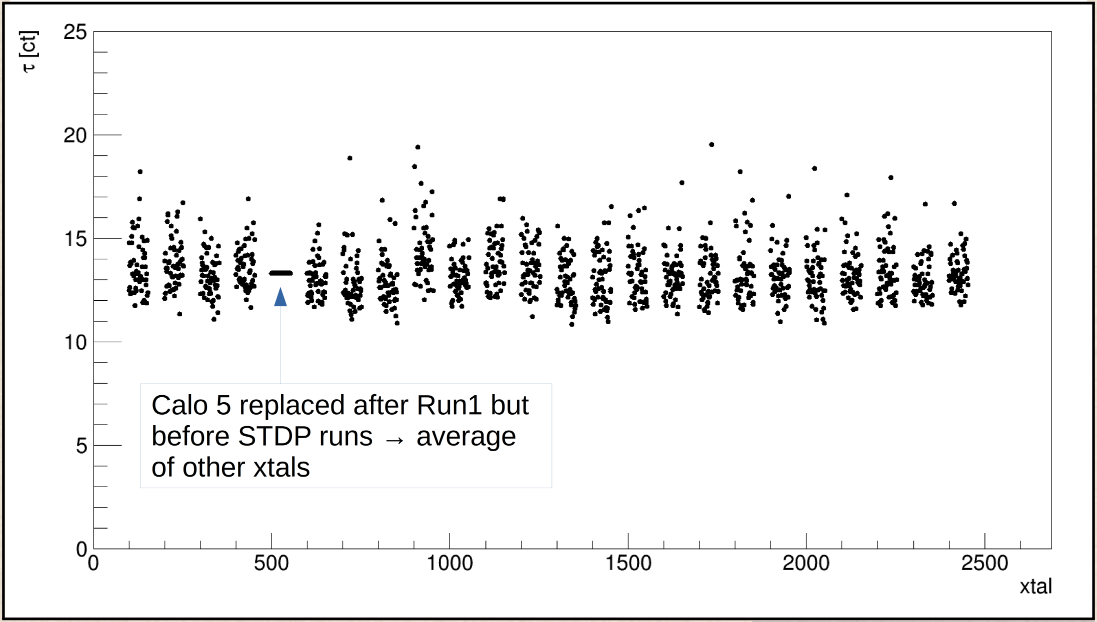
Short-term average gain variation, exponential time constant



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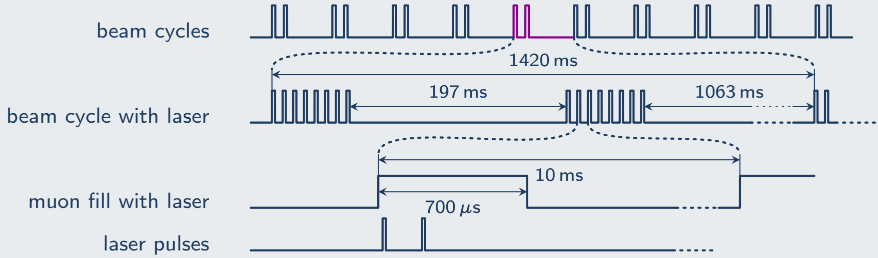
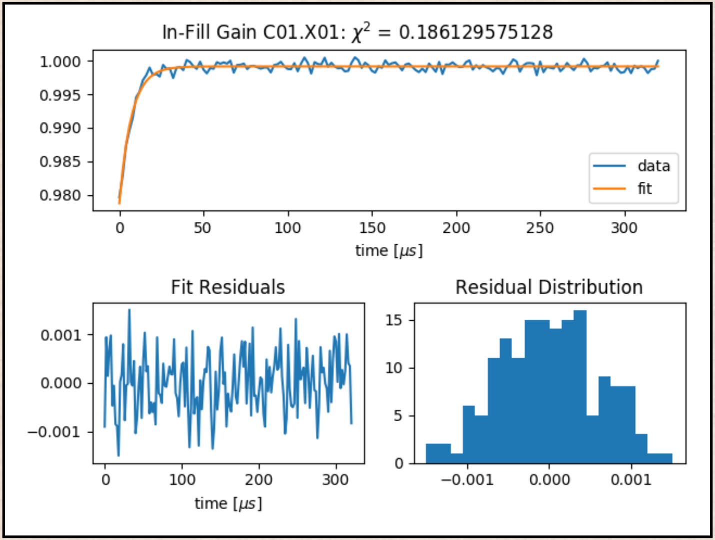
In-fill gain variation monitoring



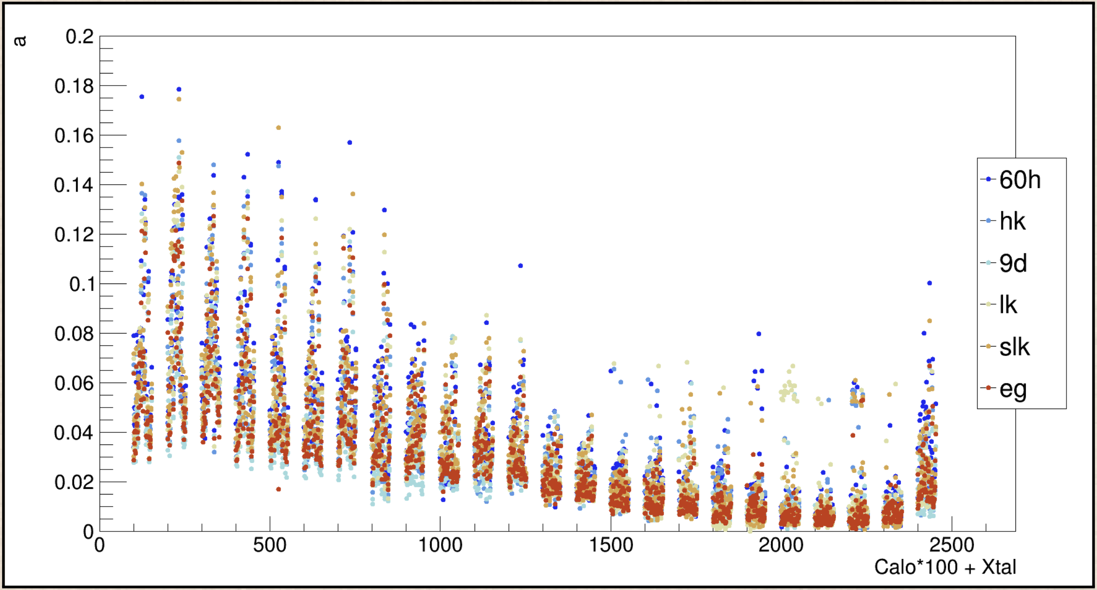
- 1 beam cycle every ~10 beam cycles has in-fill laser pulses
- firing time of laser pulses scans the fill time in subsequent events

Fit in-fill average gain variation, per crystal

- gain drop dominated by muon-injection-related "splash" at beginning of fill
- fit as an exponential



In-fill average gain variation, exponential amplitude



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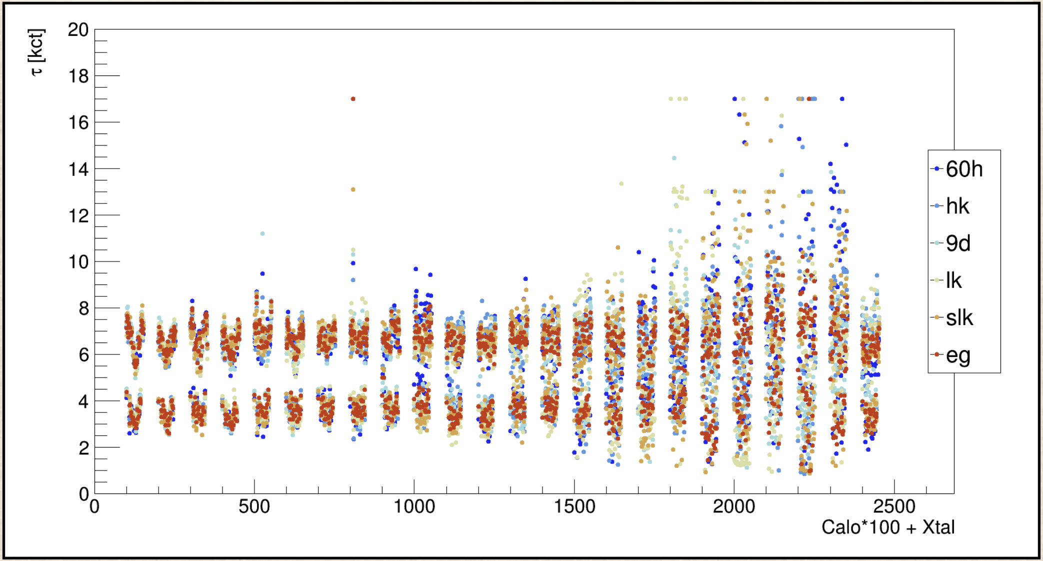
In-fill average gain variation, exponential time constant



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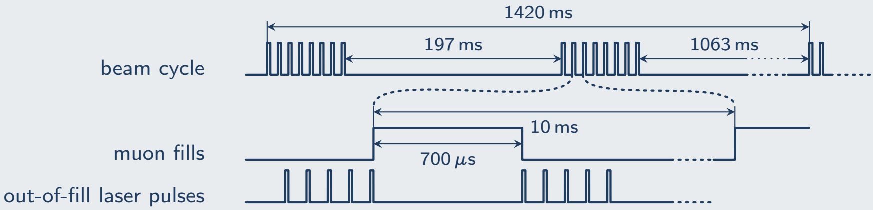
Long-term gain variation measurement

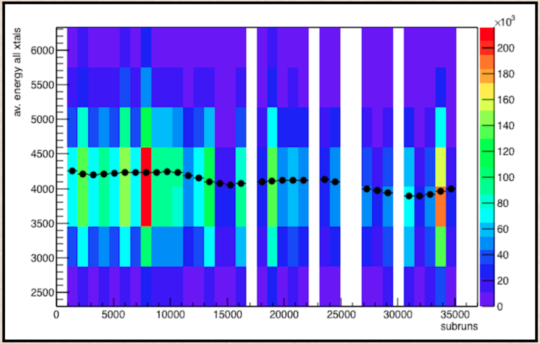
- out-of-fill laser pulses are used to measure long-term gain variation per crystal (averaged every ~5 s)



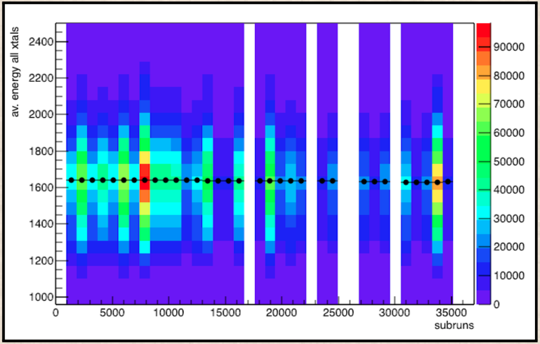
Long-term gain variation

profile of synch pulse energy distribution

before correcting for long-term gain variations



after correcting for long-term gain variations



Conclusions

- gain variations must be taken into account to limit induced systematic uncertainties on $(g-2)_\mu$
- dedicated laser calibration system measures three types of gain variations
- gain corrections are being finalized for first E989 $(g-2)_\mu$ measurement