Summary of the LXe calorimeter analyses

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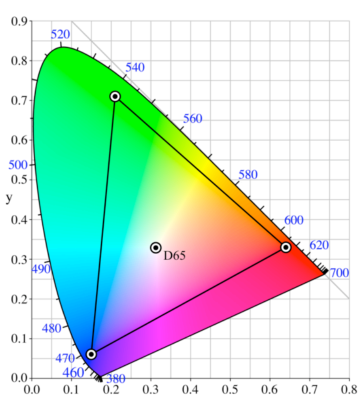
Outline

- The LXe analysis deals with the evaluation of
  - calorimeter performance
  - calorimeter stability
- For sake of simplicity I will divide the topics in two classes

  - Short term properties
    - evaluation of calorimeter resolutions/properties that deal with a limited lapse of time
    - evaluated on a (time and statistics) limited number of runs

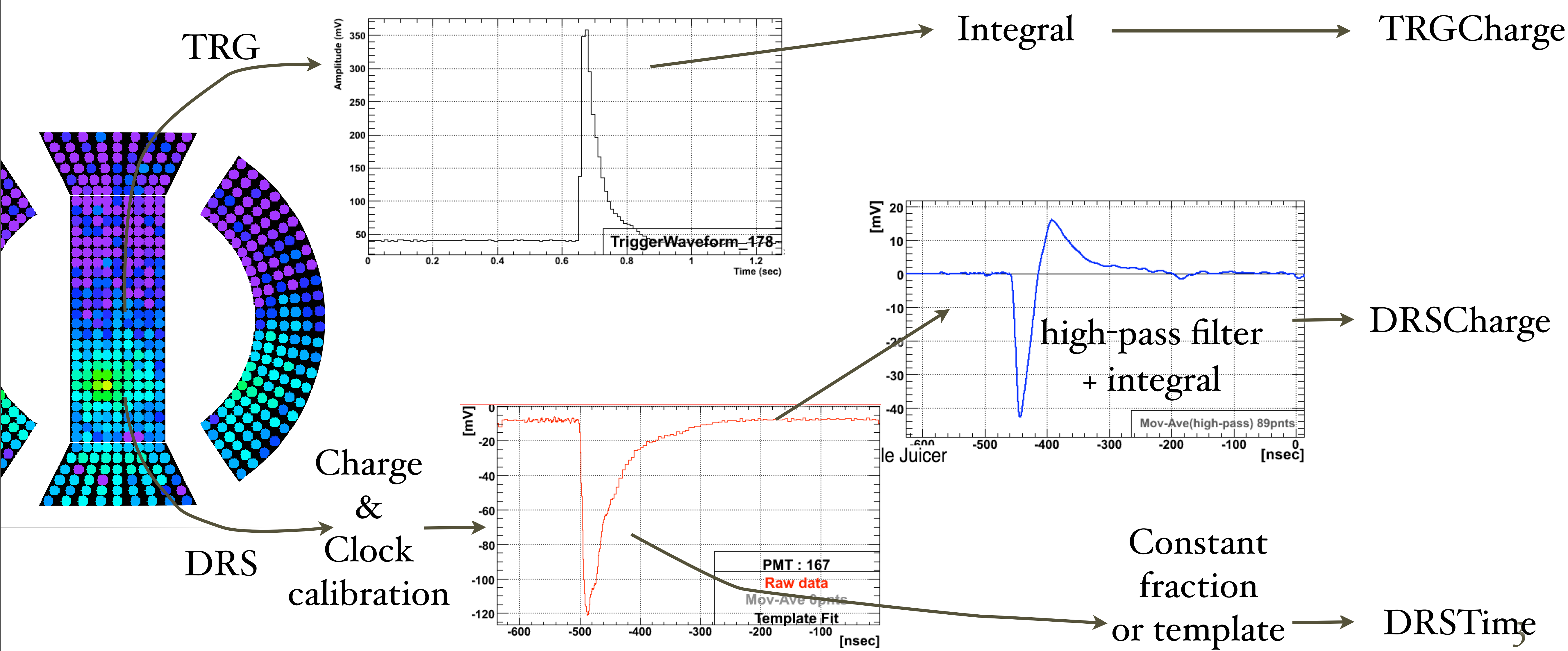
  - Long term properties
    - follow the evolution of the performance of the detector for the full duration of the physics run
    - makes use of day-to-day calibration and monitoring



- First I show some common calibrations for both
  - Waveforms
  - QEs
  - Gains

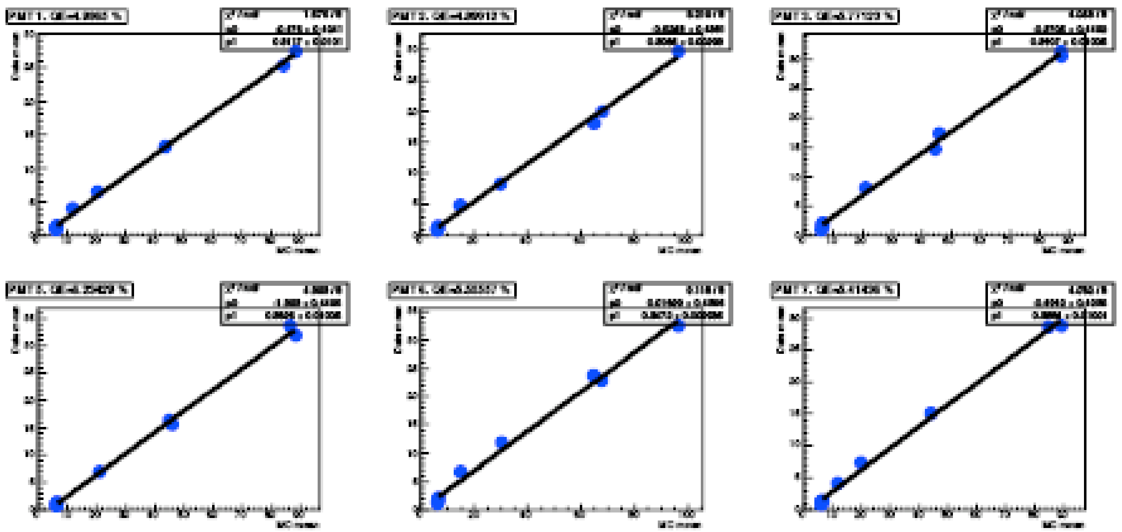
XEC Analysis

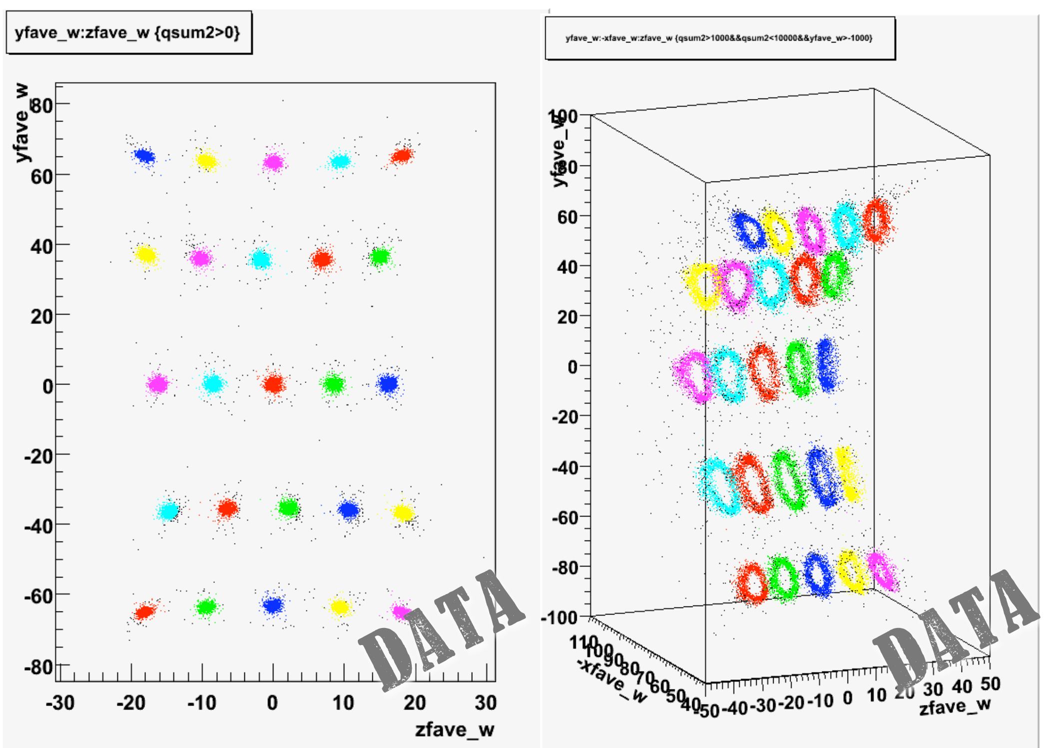
- Aims at reconstructing energy, position and timing of the photon;
- Two digitizers available
  - TRG (100 MHz, 10 ns/bin): online charge & time, offline charge
  - DRS (1.6 GHz, 62.5 ps/bin) : charge & timing



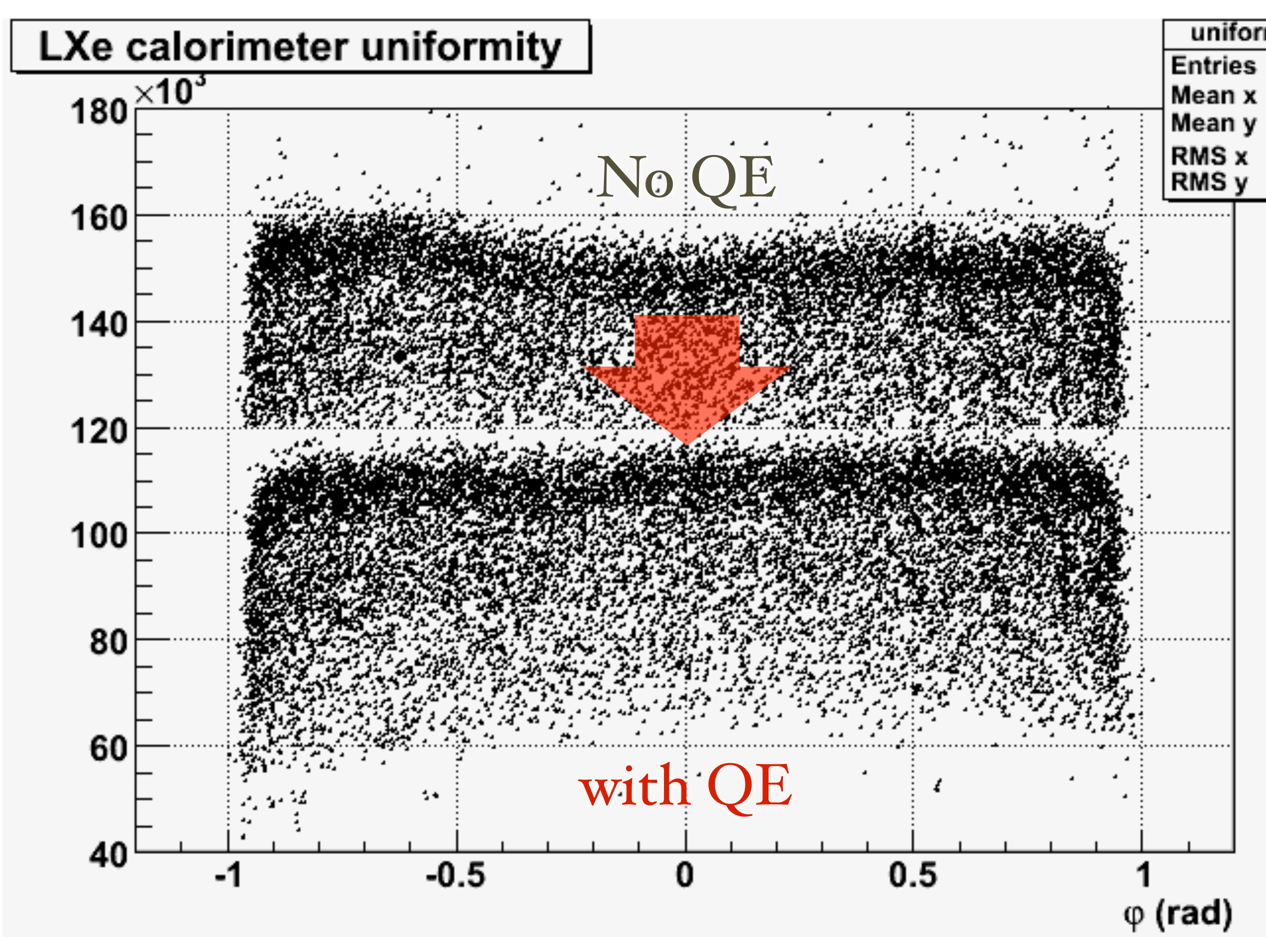
QE computation

- Comparison between data and Monte Carlo
  - QE in liquid xenon
  - QE in gas xenon



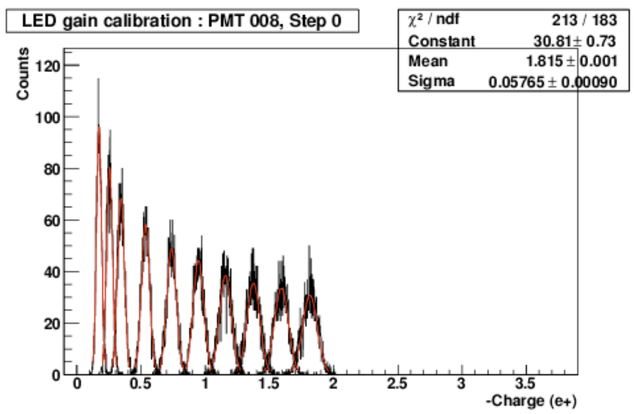


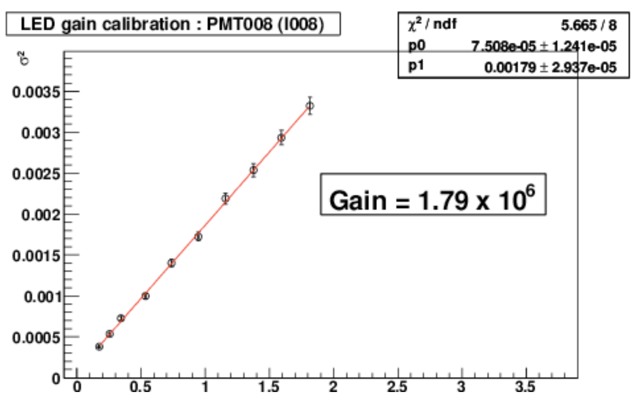
- Improves the uniformity of the calorimeter response
  - ever-improving procedure
  - tuning of the MC by comparing w/data
    - wire positions
    - Xe optical properties

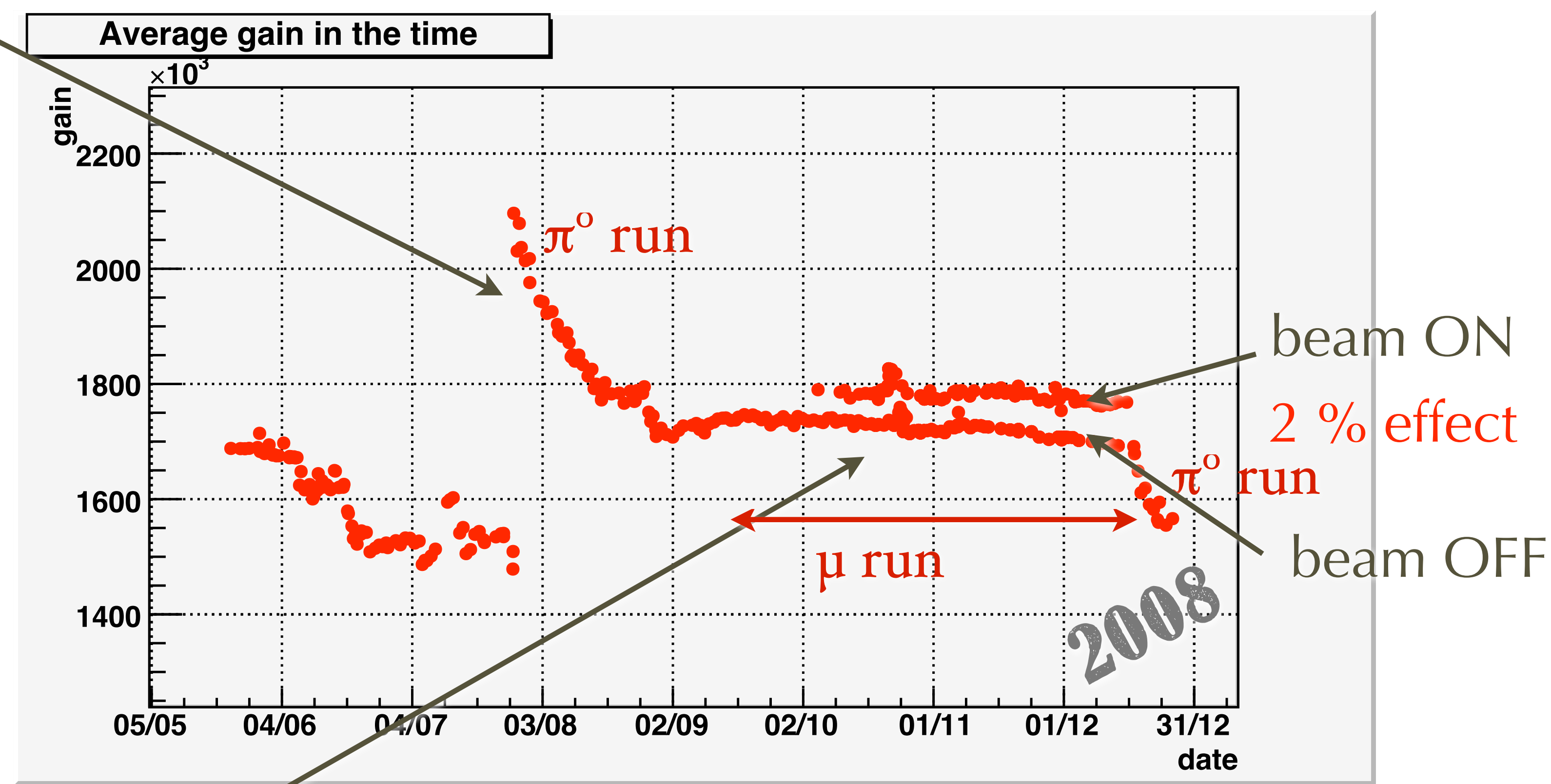


Gain determination

- Unforeseen gain variation requires some “new” treatment this year
- Long term drift (→*see Mihara-san presentation)*
  - taken under control w/daily calibrations



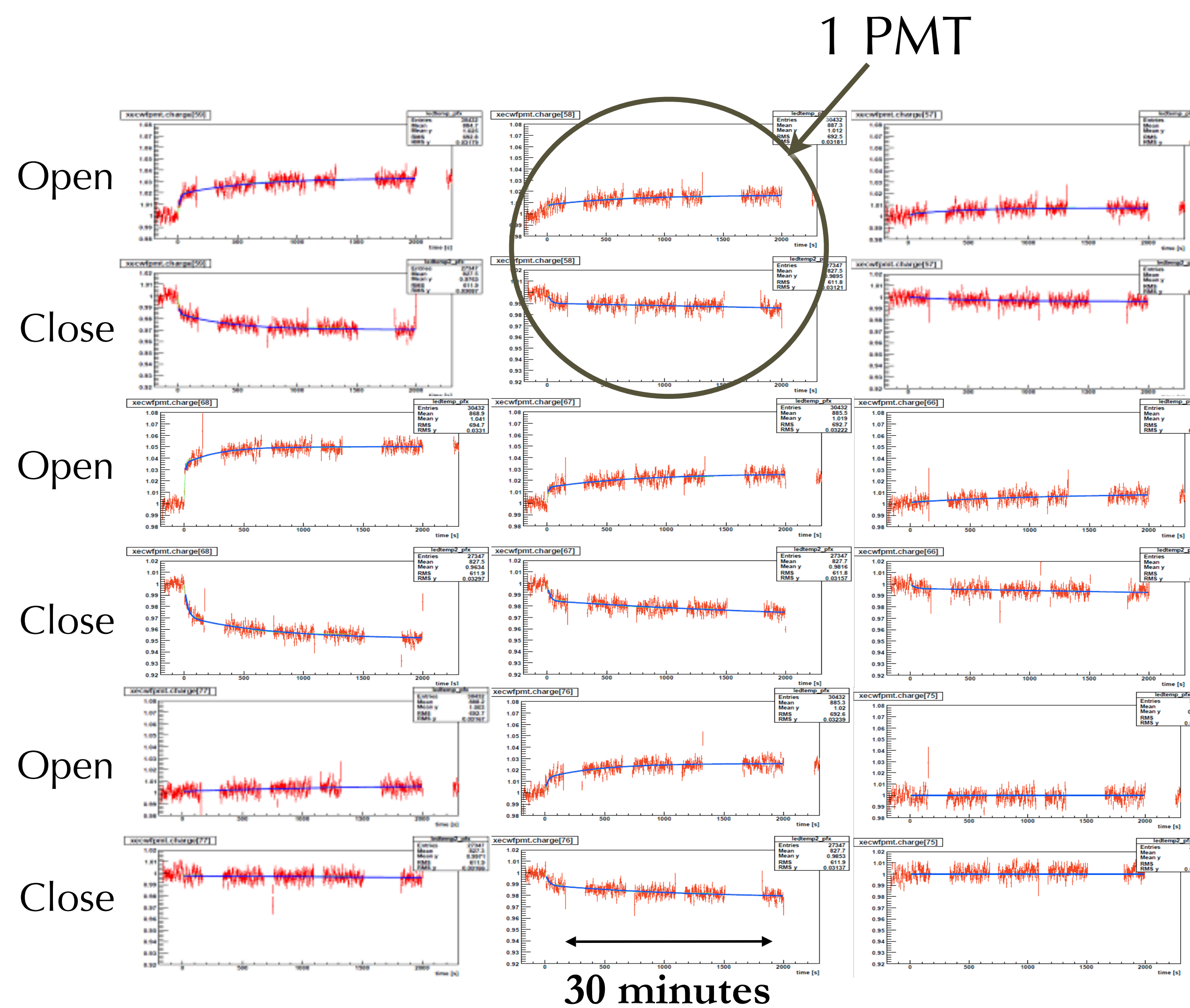


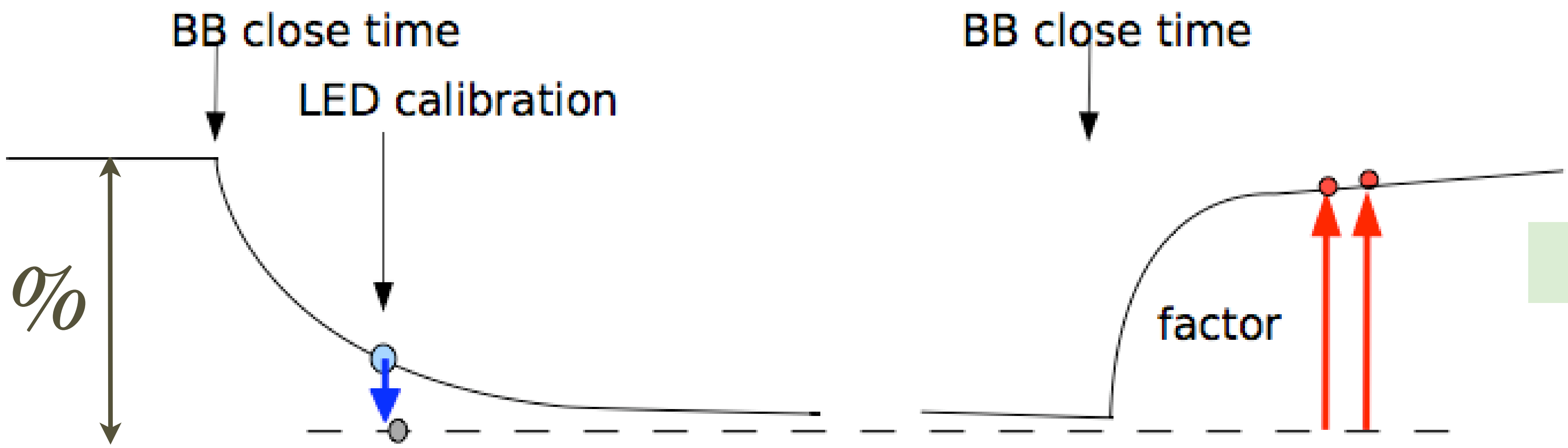


- Beam ON/beam OFF variation
  - It was discovered because of a shift in the cosmic ray peak in the calorimeter
  - rate dependent

Gain shift correction

- the correction has been measured for each PMT taking special runs
  - fitted with 3-ple exponential
    - $1 + a_1(1-e^{-t/T_1}) + a_2(1-e^{-t/T_2}) + a_3(1-e^{-t/T_3})$
    - beam ON→OFF ≠ beam OFF→ON
    - different PMT by PMT
- rate dependence of the shift
  - necessary to take into account the difference between μ-runs and π^o runs
- corrected through database





n generator!

Once calculate the gain with out beam (infinite time after BB closed) = g_0.
Apply correction factor to the g_0 according to the duration from BB opened.

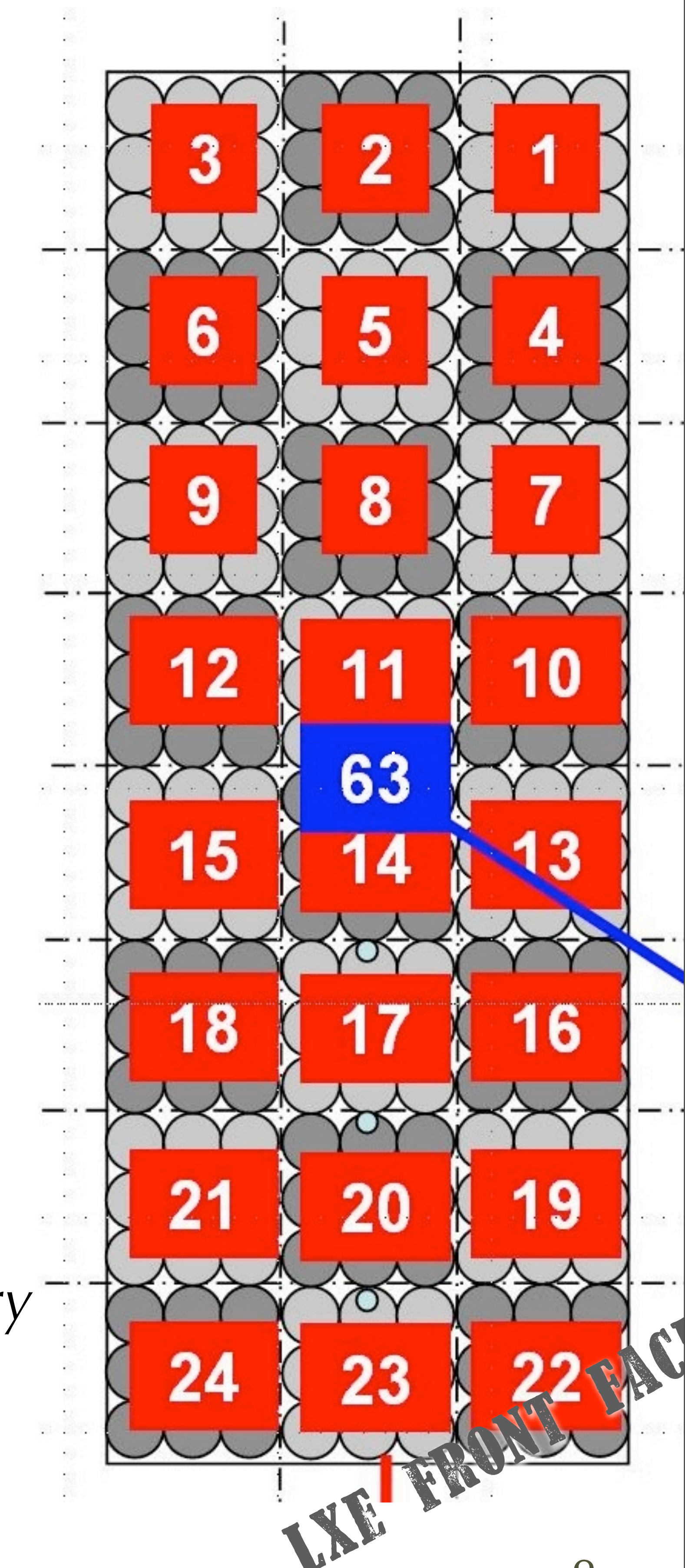
Short-term properties

- Snapshot of our detector at a fixed moment in time
- Resolutions
  - Position — γ from π^o
  - Time
    - intrinsic time resolution (neglect conversion point, positron side...) — γ from π^o
    - absolute time resolution — RD Dalitz CW B γ from π^o
  - Energy
    - @ different energies — CW Li & B γ from π^o
- Part of the information needed a dedicated π^o run
- Part of the information was checked on an almost-daily basis
  - Provides the link between the various snapshots
  - see second part: long term stability

The π^o runs

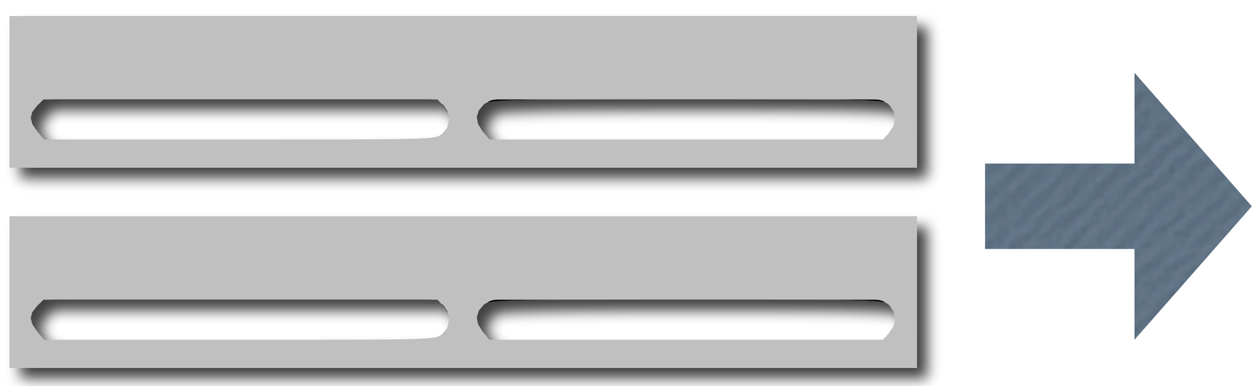
- Summer run:
  - 55 MeV photon all over the calorimeter surface
    - uniformity of the calorimeter to extract the *pdf*
    - energy resolution
    - time resolution
  - lead collimators with slits
    - position resolution
  - unknown gain correction due to the rate
- Winter run:
  - one week of data taking
    - estimate the rate-dependence of the gain shift
  - 55 MeV photon in significant places

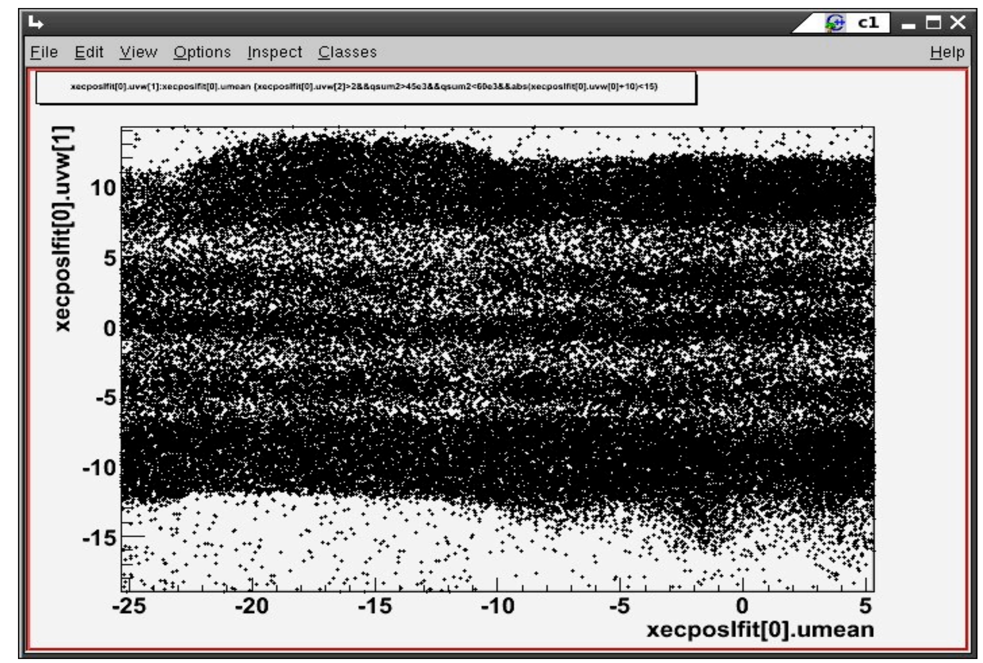
- NOTE: from a single rate point of view the π^o runs are *very* different from the μ-runs because of the much larger pile-up



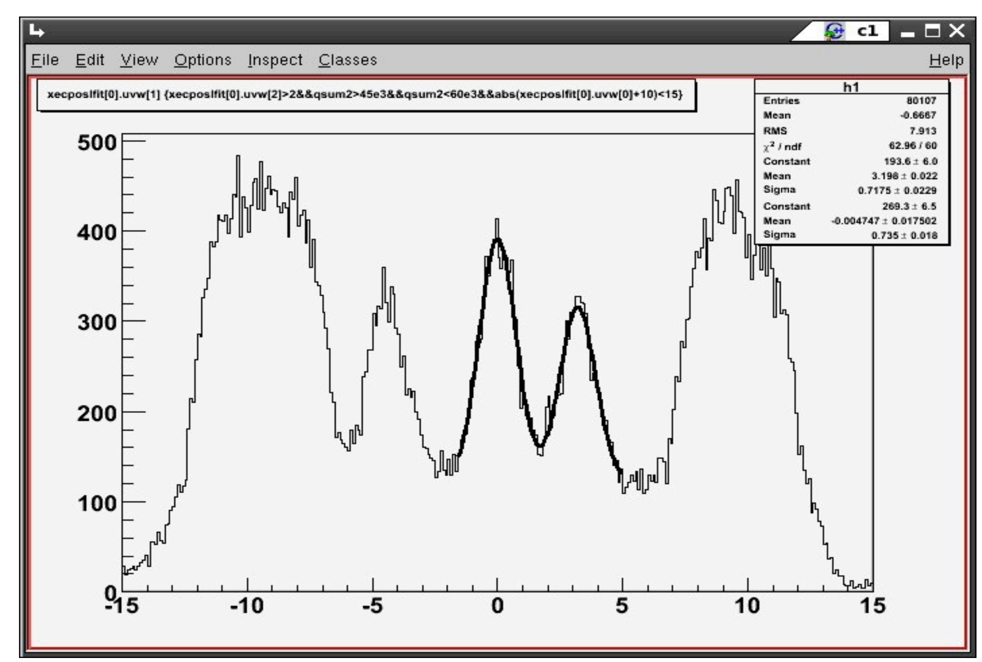
Position resolution

- A lead collimator is placed in the central calorimeter region
- The "shadow" of the collimator is reconstructed. The resolution is extracted from the deconvolution of the edge of the collimator



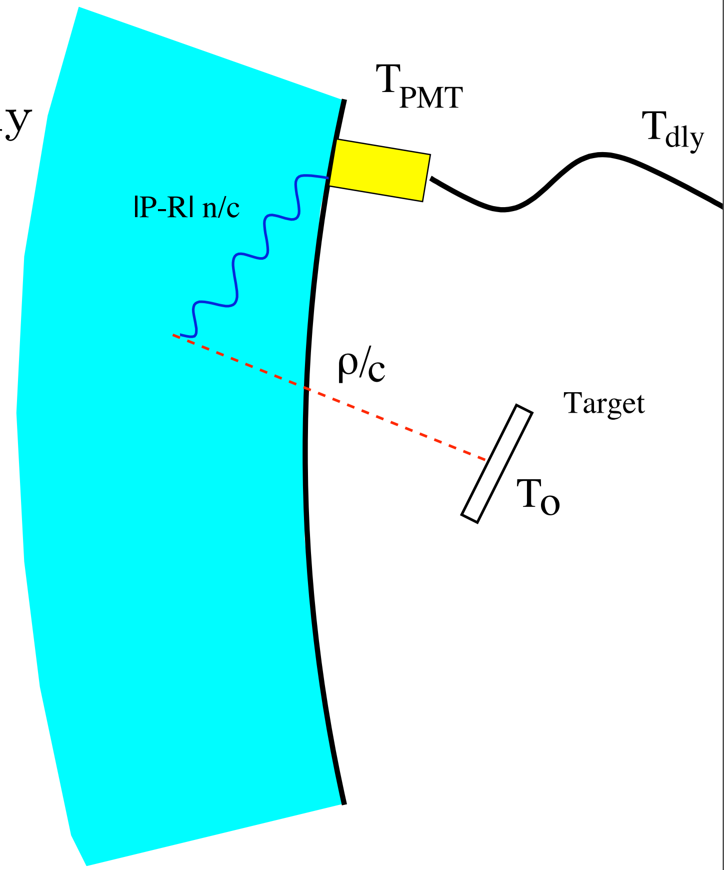


- Present result:
  - Edge: resolution ~ 0.51, 0.52 cm
  - Slit: resolution ~ 0.65 – 0.70 cm
- Effect of the finite size of the target
  - under evaluation
- Analysis with refined QEs in progress



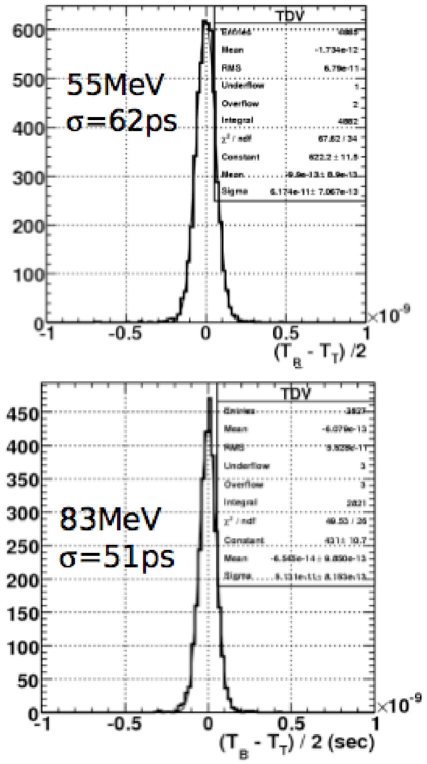
Intrinsic time resolution

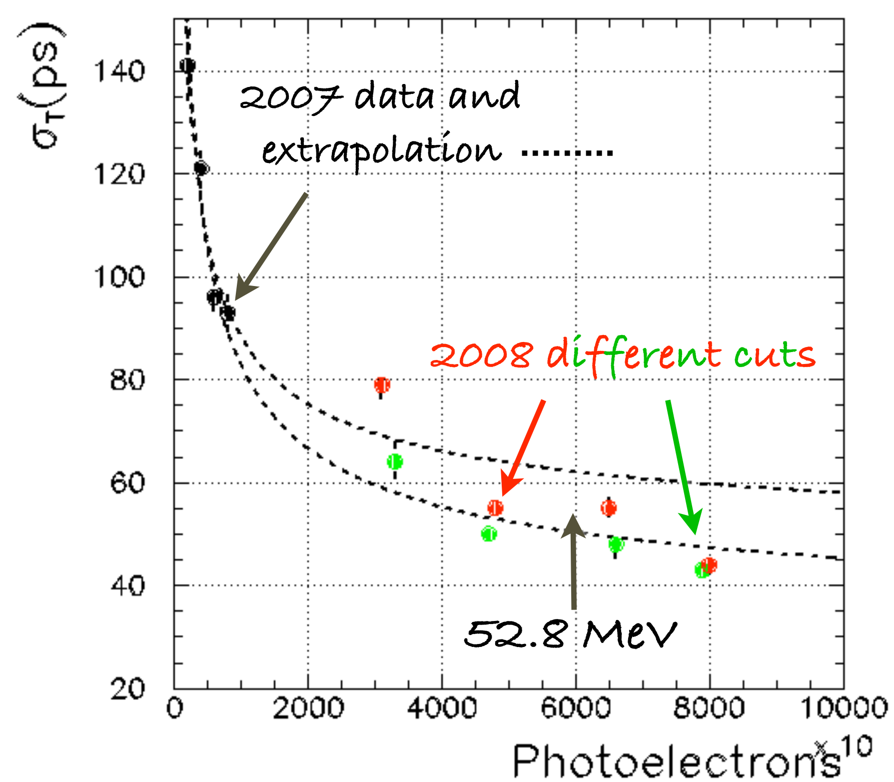
$$T_0 = T_i^{tw} - \frac{\rho_{\rm int}}{c} - \frac{|\vec{R}_{\rm int} - \vec{P}_i| n_{\rm Xe}}{c} - T_{\rm PMT} - T_{\rm dly}$$

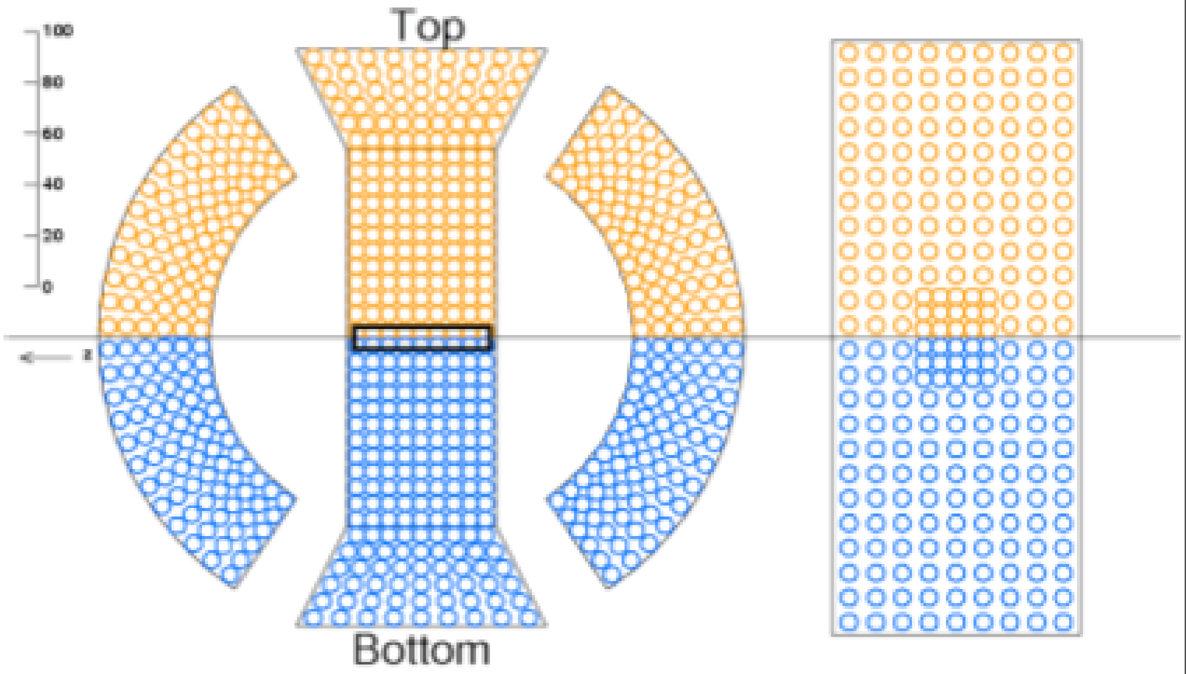


- Divide the PMTs in two groups
  - Odd / Even
  - Top / Bottom
- $t_a = \Sigma\, t_{2k}\, Q_{2k} / \Sigma Q \quad t_b = \Sigma t_{2k+1} Q_{2k+1} / \Sigma Q$
  - $\sigma_t = \mathrm{VAR}(\frac{1}{2}(t_a - t_b))$
- The two analyses agree well
  - σ_t(intrinsic) ~ 50 – 60 ps @ 52.8 MeV
  - still some dependence on cuts, geometry...

⇨ shower fluctuations cancel out



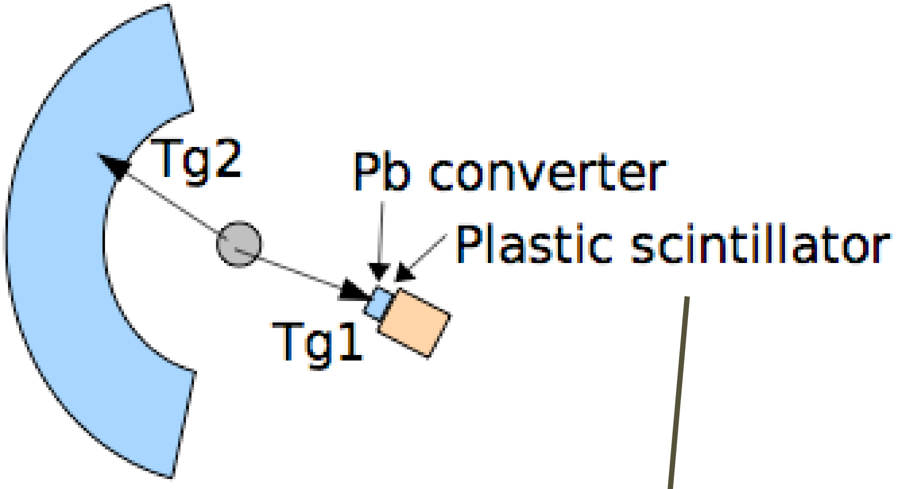




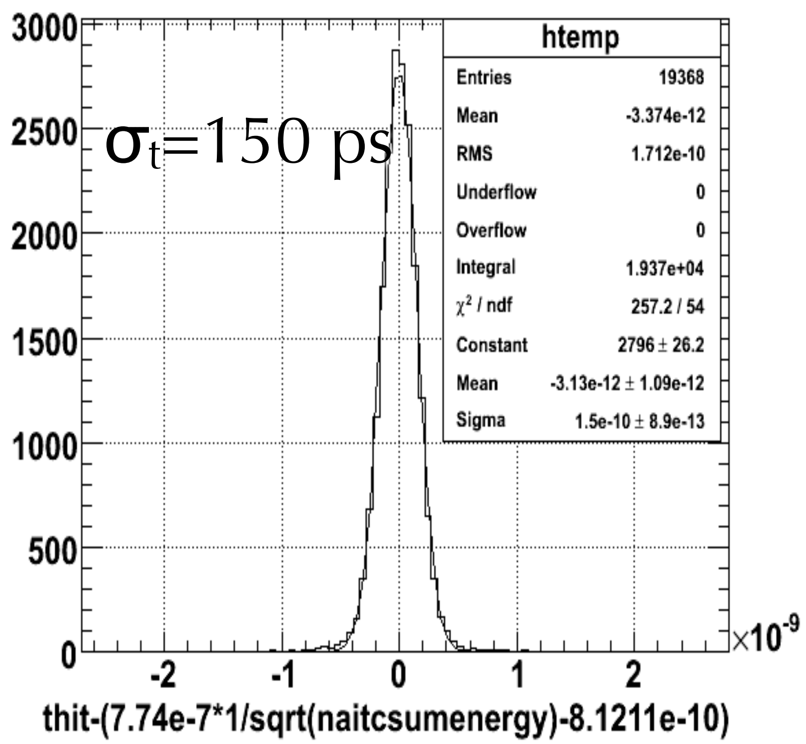
Absolute time resolution

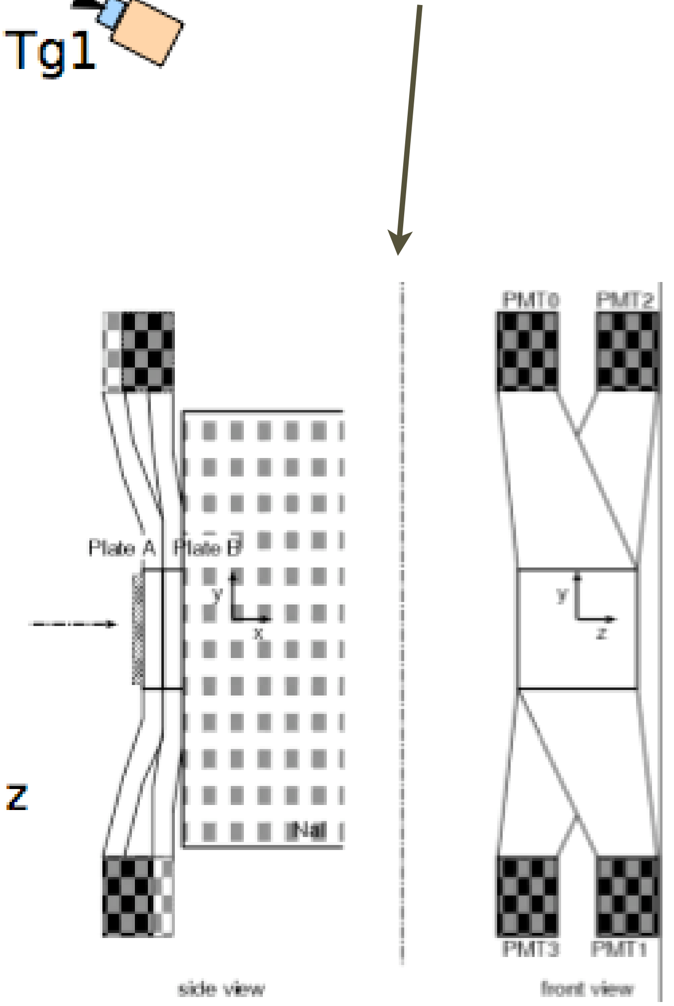
$$T_{\mathrm{Abs}} = \frac{1}{2}(T_L + T_R) - T_{\mathrm{ref}}$$

- Use a lead-plastic scintillator converter placed in front of the NaI detector as a reference counter
- The γ conversion point in LXe contributes to this resolution
- This resolution includes contribution from
  - spread of π^o dacay point (~60ps)
  - resolution of reference counter (~93ps)
- σ_t(Abs) ~ 150 ⊖ (93⊕60) ~ 100 ps
- systematics under study



Dec.

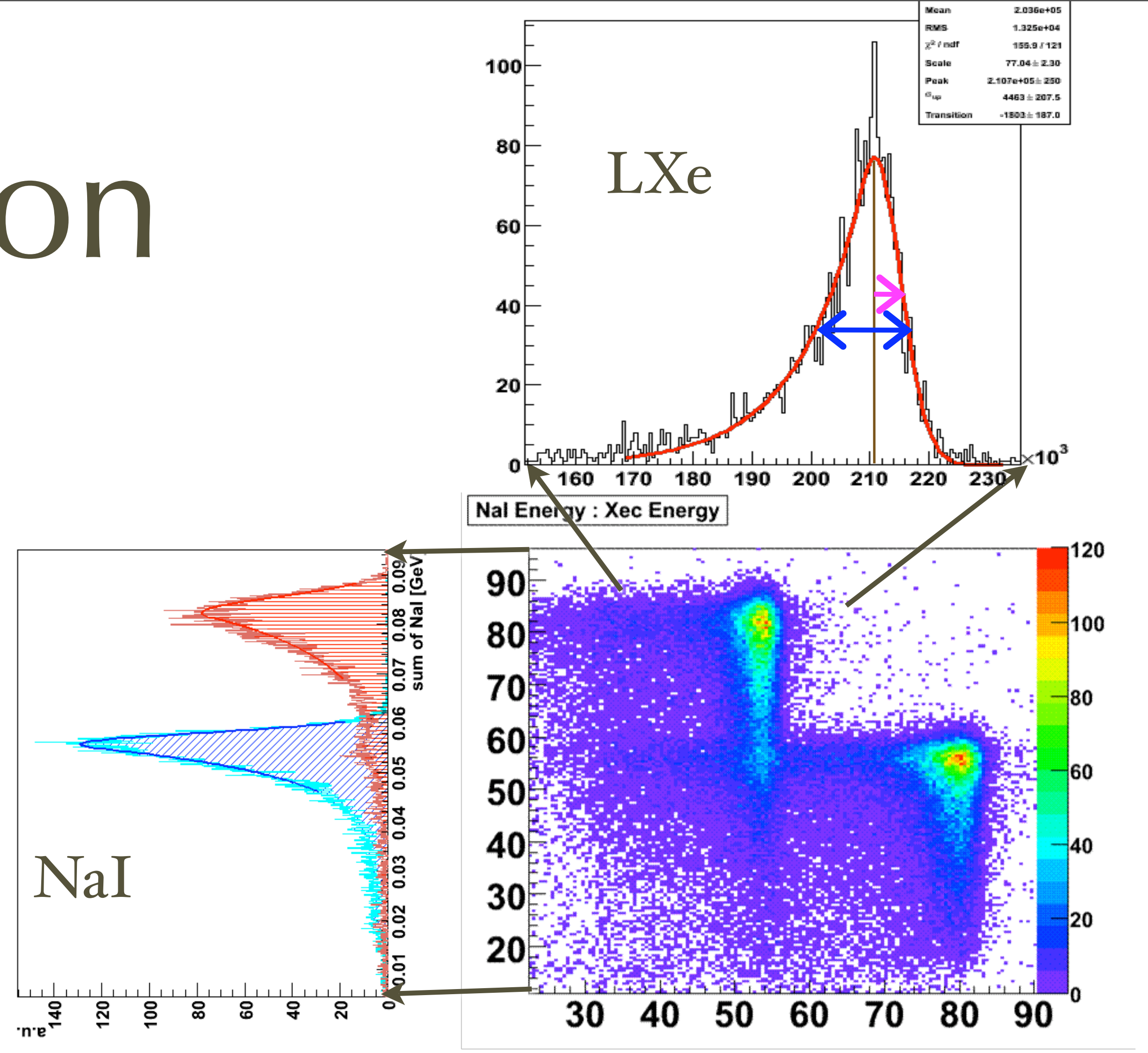


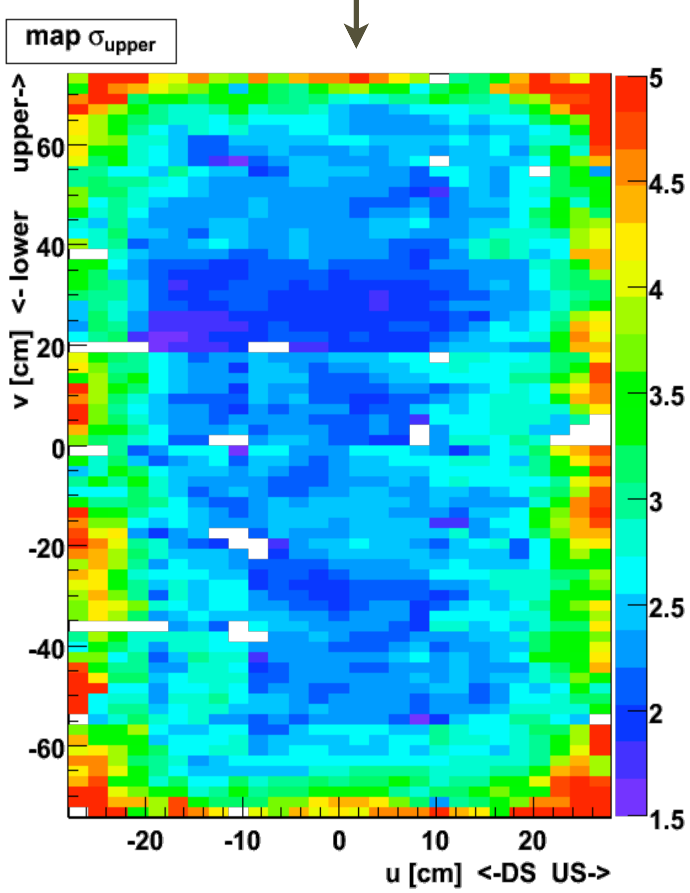


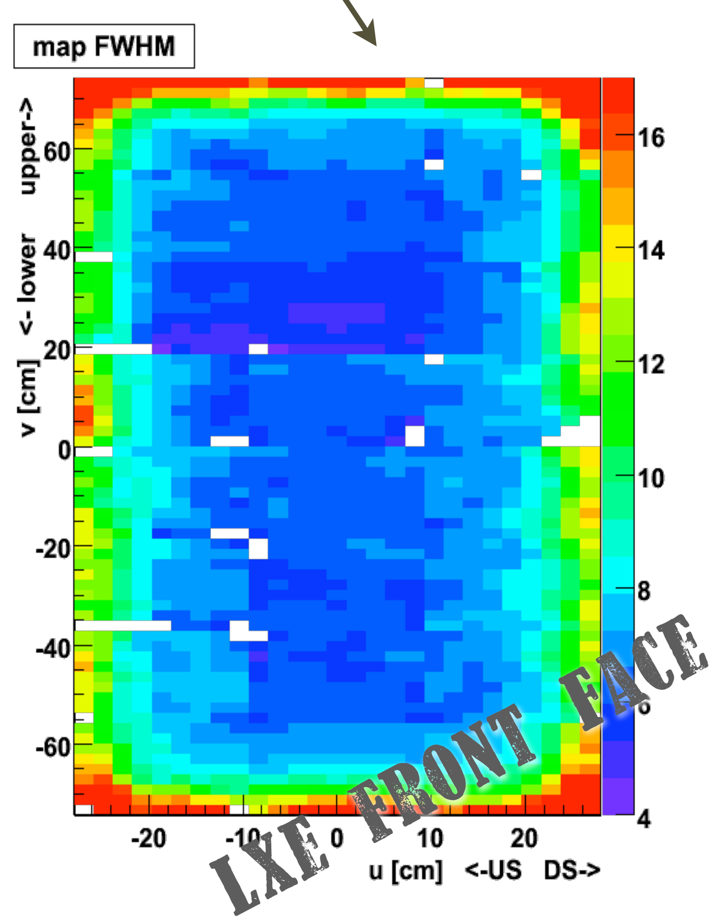
Energy resolution

- 180º coincidence selects 55 MeV and 83 MeV in LXe and NaI
- Resolution evaluated on all calorimeter surface

$\langle \sigma_R \rangle$ = 2.3%, $\langle \mathrm{FWHM} \rangle$ = 6.4%



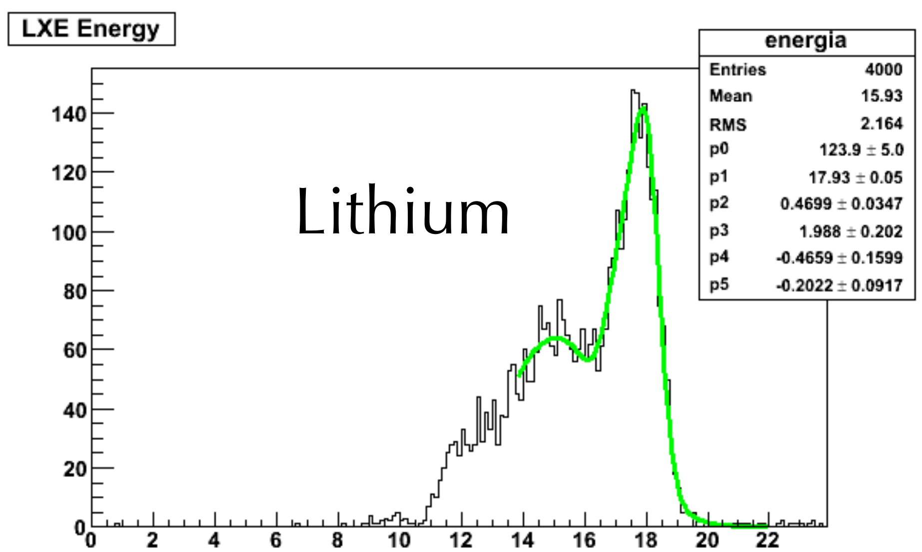


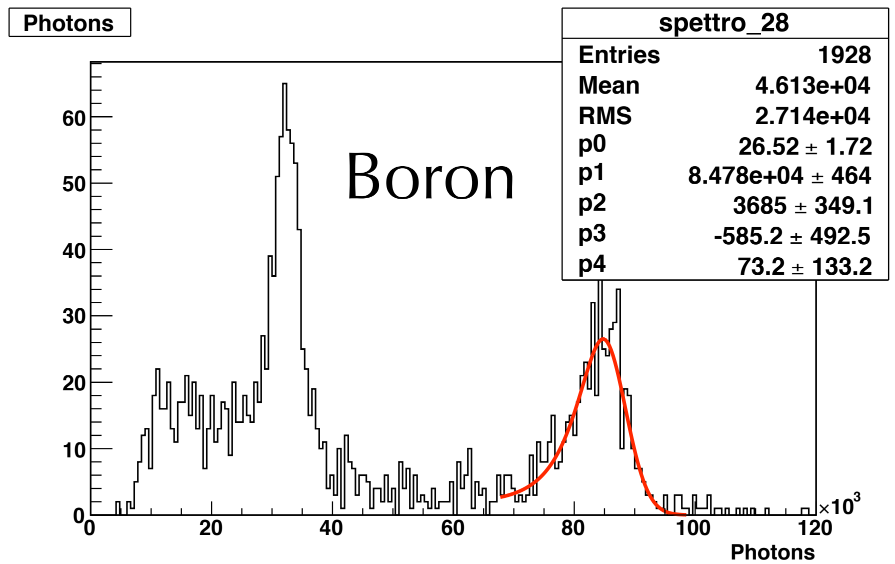


- Worse than expected
- Effect of the high rate during π^0 run
  - necessary to make a mini-CEX at the end of the year
  - gain correction are being improved following the new information available

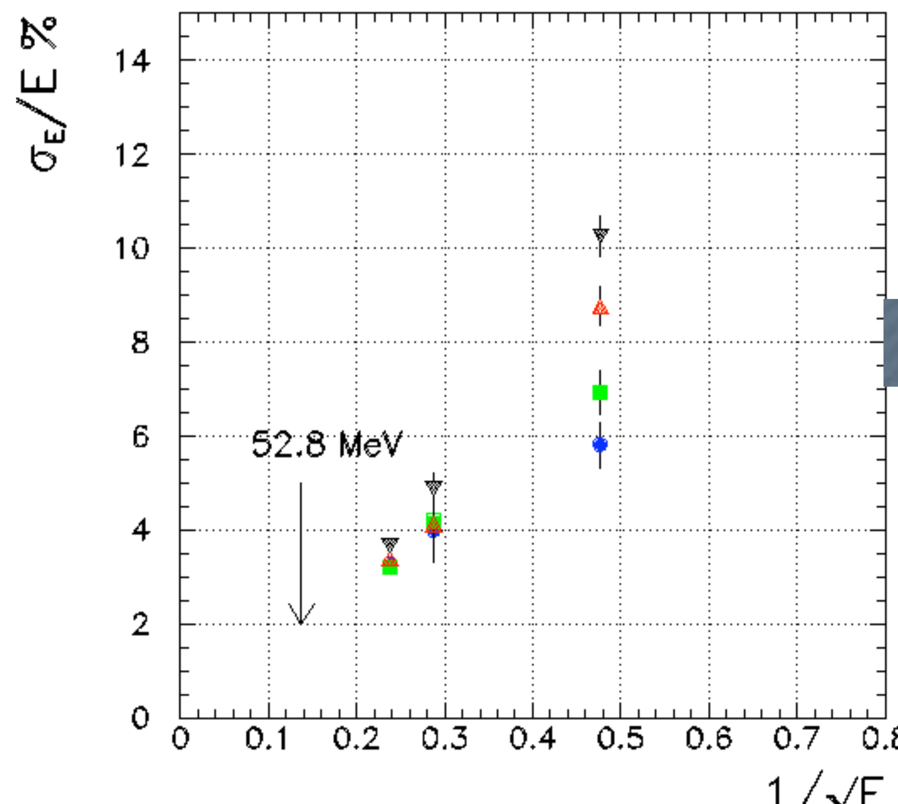
σ_E from CW runs

- Three times per week we take (p,Li) and (p,B) reactions
  - 17.6 MeV line
  - 4.4 MeV & 11.6 MeV coincidence with TC
- Extract the resolutions

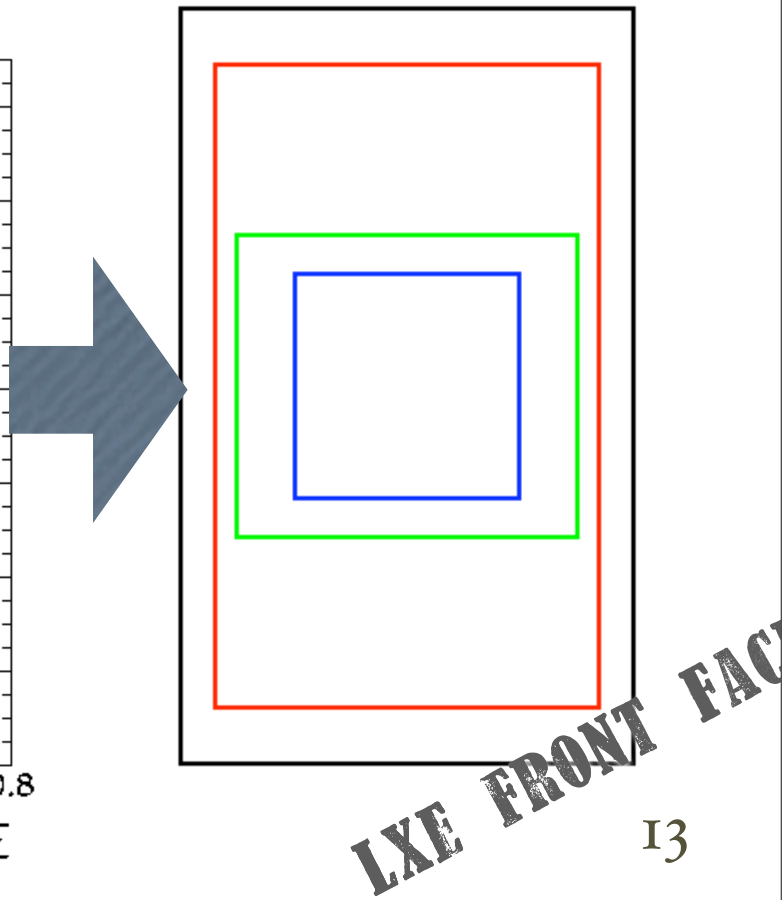




FWHM @ 52.8 MeV = (4.7 ± 1.2)%

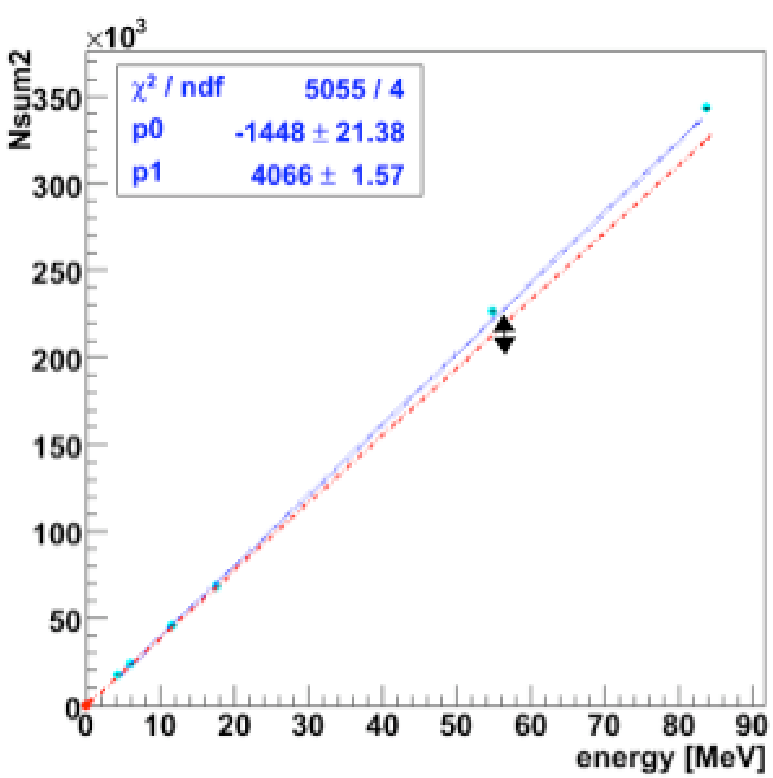


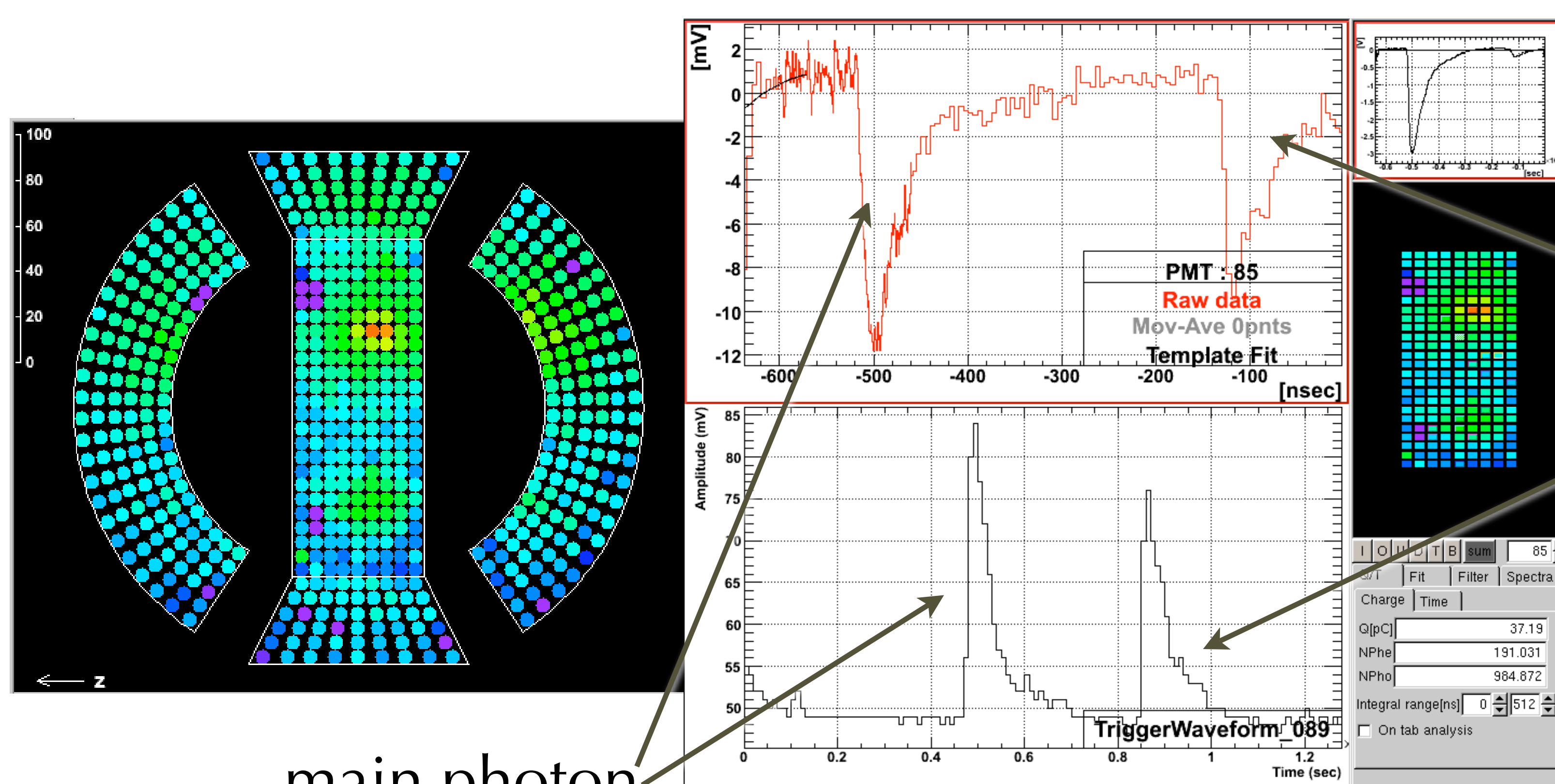
LXe calorimeter



CW – π^o mismatch

- There is still some inconsistency between the CW and the π^o calibration
  - energy scale
  - resolutions
- During the π^o run the background in the calorimeter is different from the normal muon run
  - different working point of the PMTs (gain shift)
  - much higher pile-up
- To be understood as it represents a huge systematics for our analysis





pile-up photon

main photon

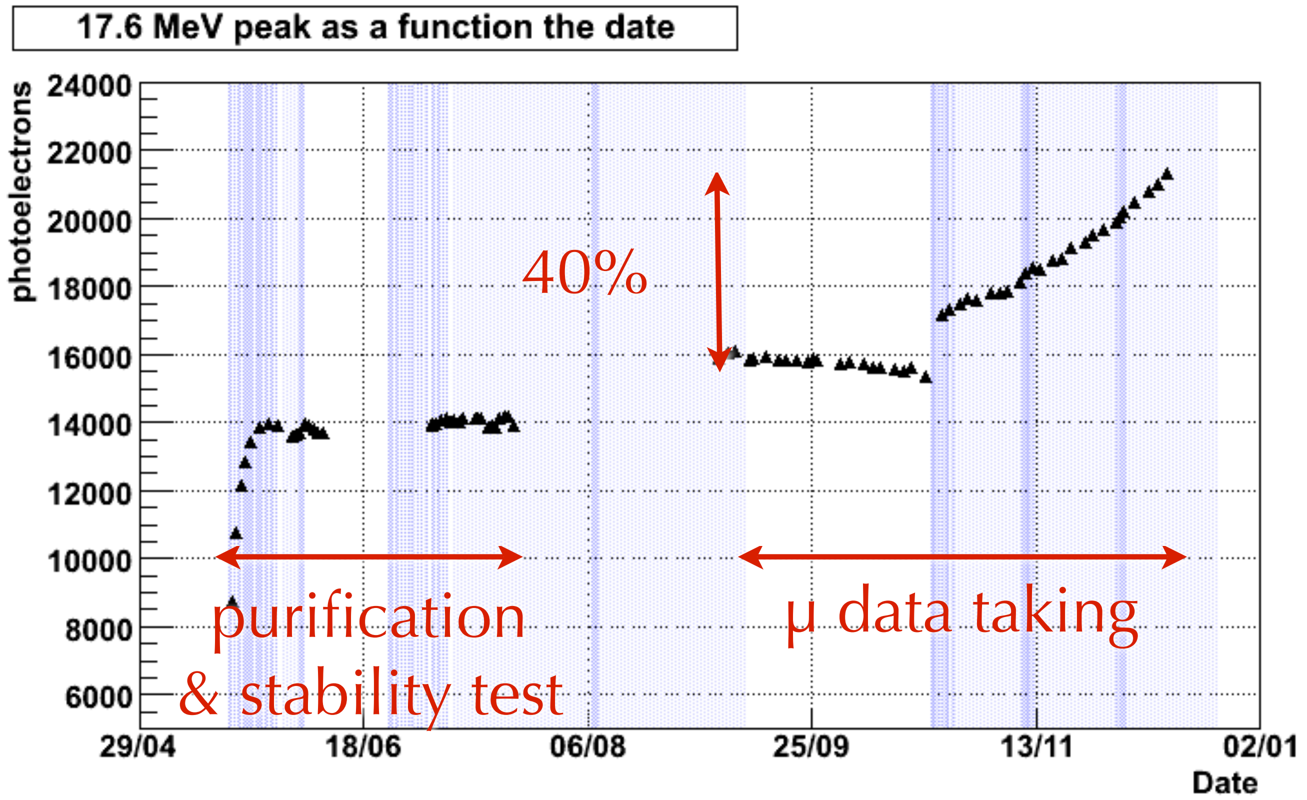
Long-term analysis

- Stability
- Performance
- ...

As a function of the time

Variation of Xe properties

- Xe was getting cleaner and cleaner with time (→*see Mihara-san presentation*).
  - change no in absorption but in emission yield
- have time-dependent resolutions, *e.g.*:
  - L.Y. ⇒ σ_E (t)
  - τ ⇒ σ_t (t)
  - Need to implement this in the
    - signal “box”
    - likelihood analysis
    - systematic uncertainty on the limit



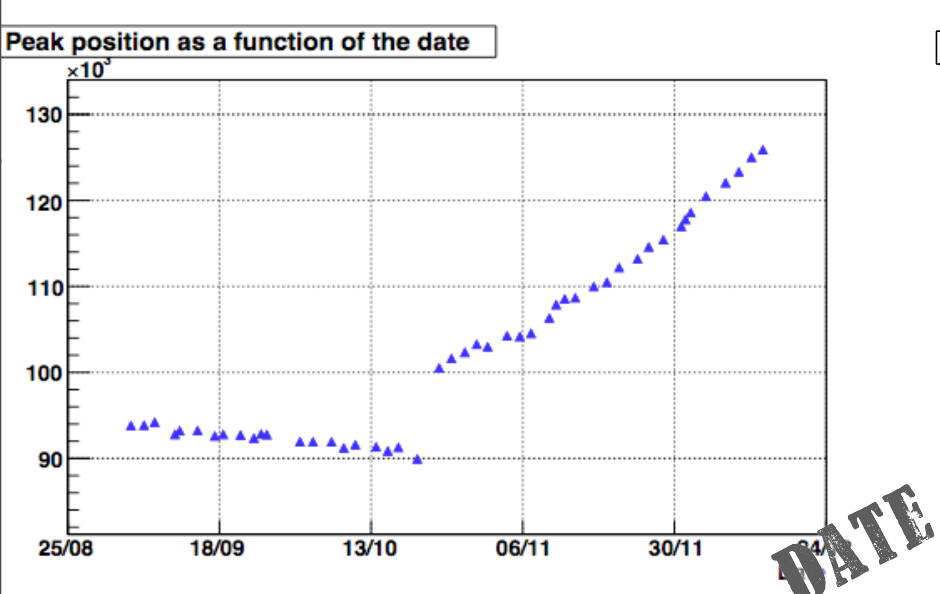
- We use the CW data to “calibrate” our knowledge of the instability
  - Li peak (17.6 MeV)
    - correct the time-dependent energy scale & follow the resolution
  - B coincidence between LXe and TC (4.4 MeV & 11.6 MeV)
    - check the energy correction and the time drift (→ *see G. Cavoto’s presentation*)

In-run changes

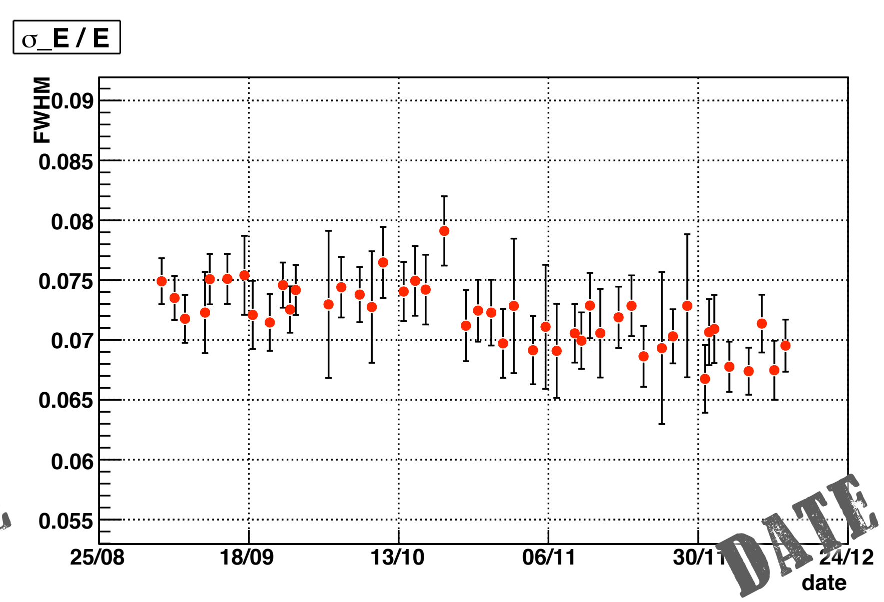
- How the performance changes during the run
- The estimated improvement in energy resolution due to the increasing number of photoelectrons is ~18%
- From the CW peaks as a function of the time we find
  - (11±6)% on Li
  - (13±8)% on B

- Refinements in progress
  - Signal & background *pdf* evaluation

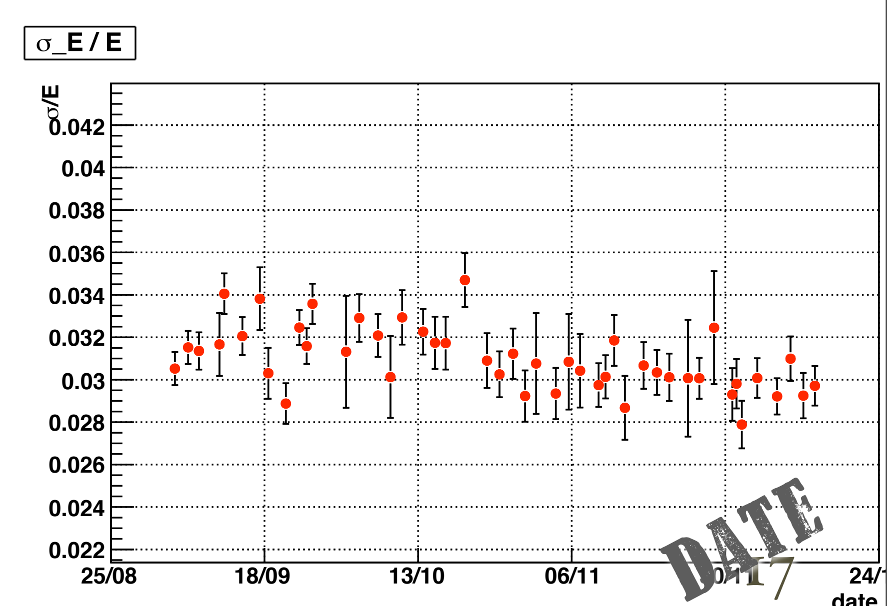
Li peak position



FWHM ~ 7%

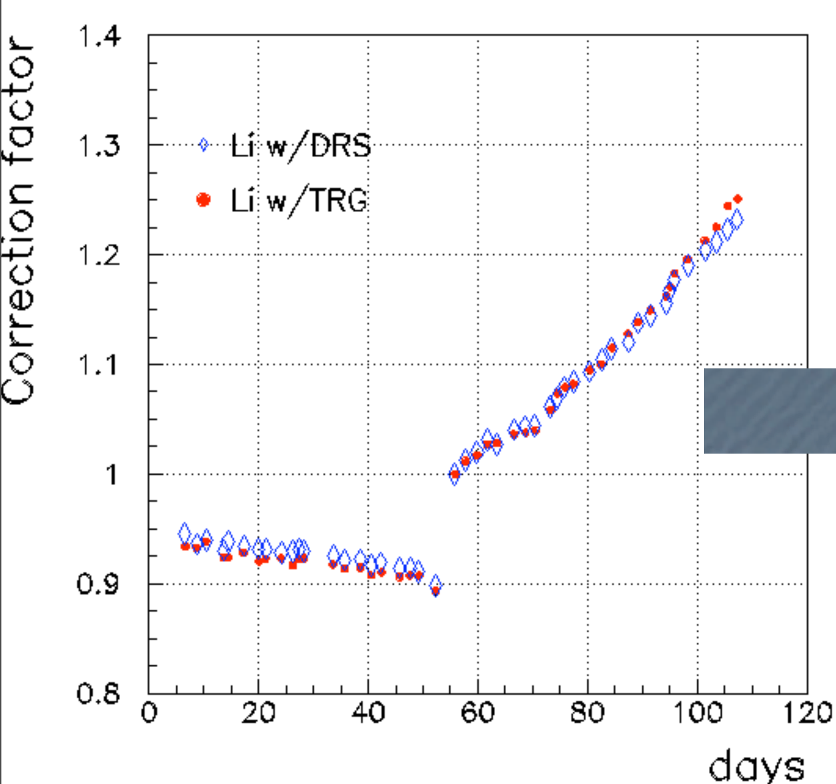


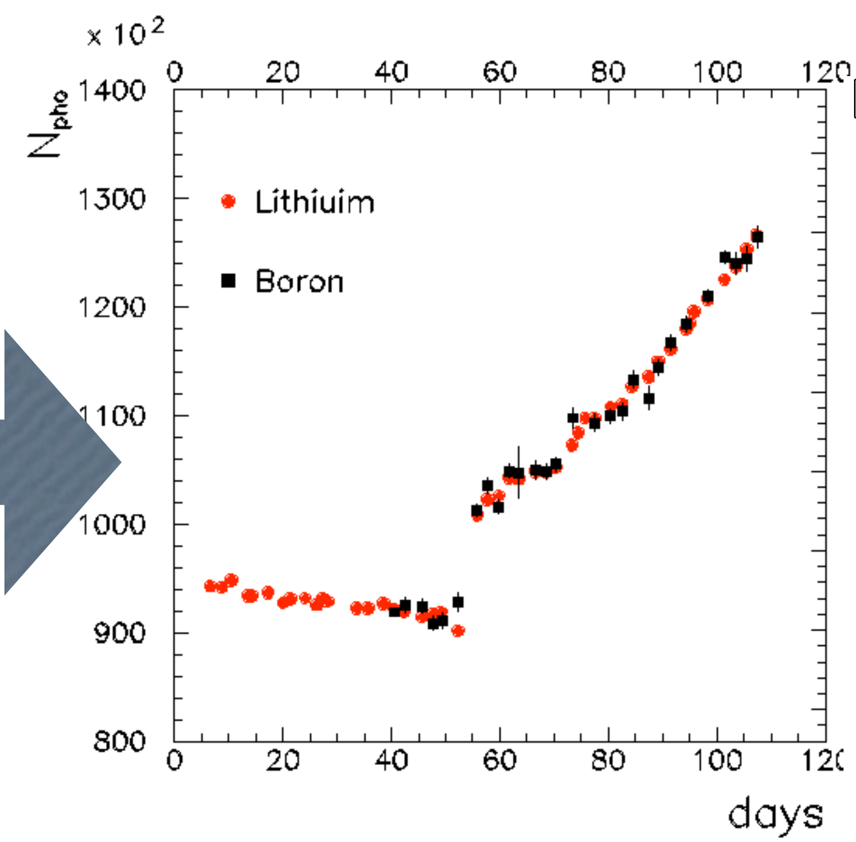
σ_R~ 3%

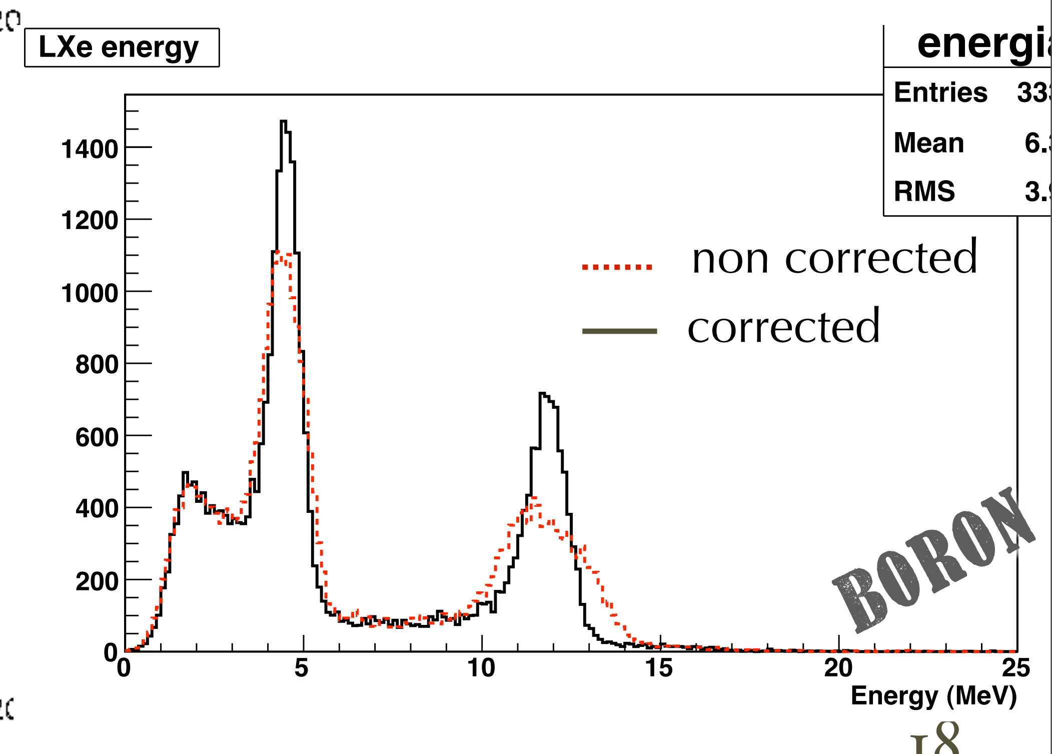


Energy scale correction

- The position of the 17.6 MeV peak is used to correct for the energy scale
  - smooth correction as a function of the time of the event
  - it is necessary to “put alls runs together”
    - Correction checked with Boron lines
    - some small discrepancy between DRS and TRG charge t.b.i.
    - influence on the *pdf* determination systematics under way

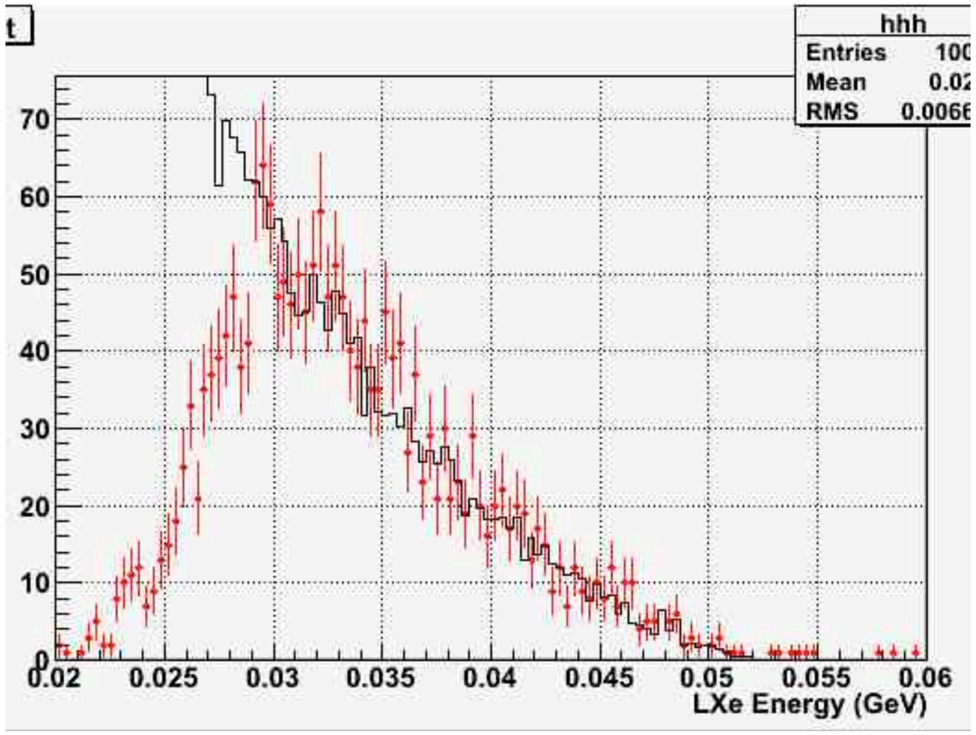


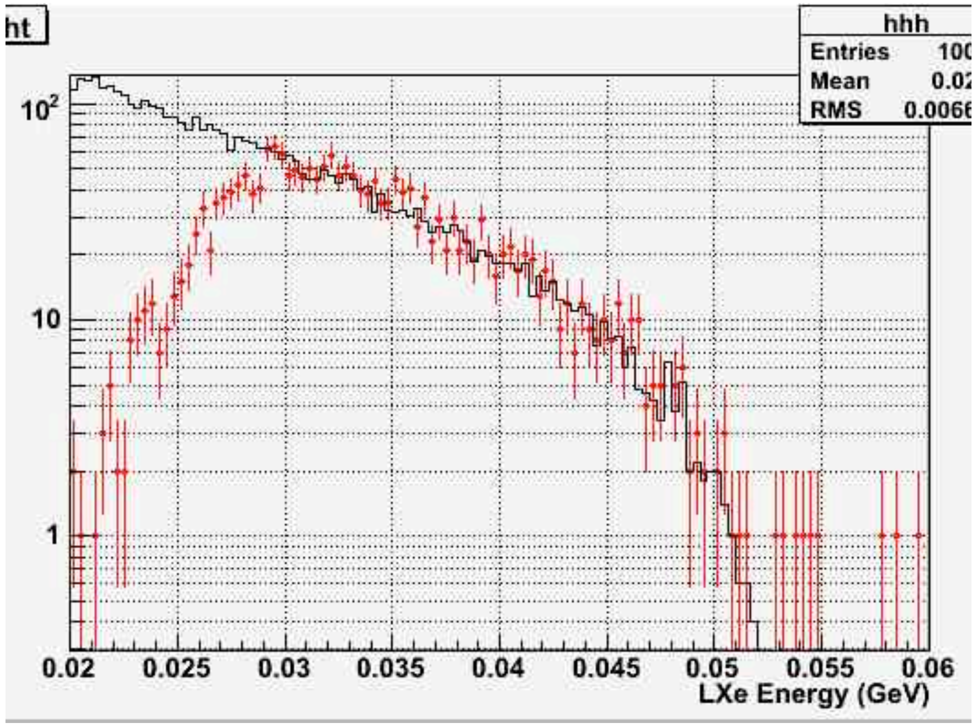




RD photon spectrum

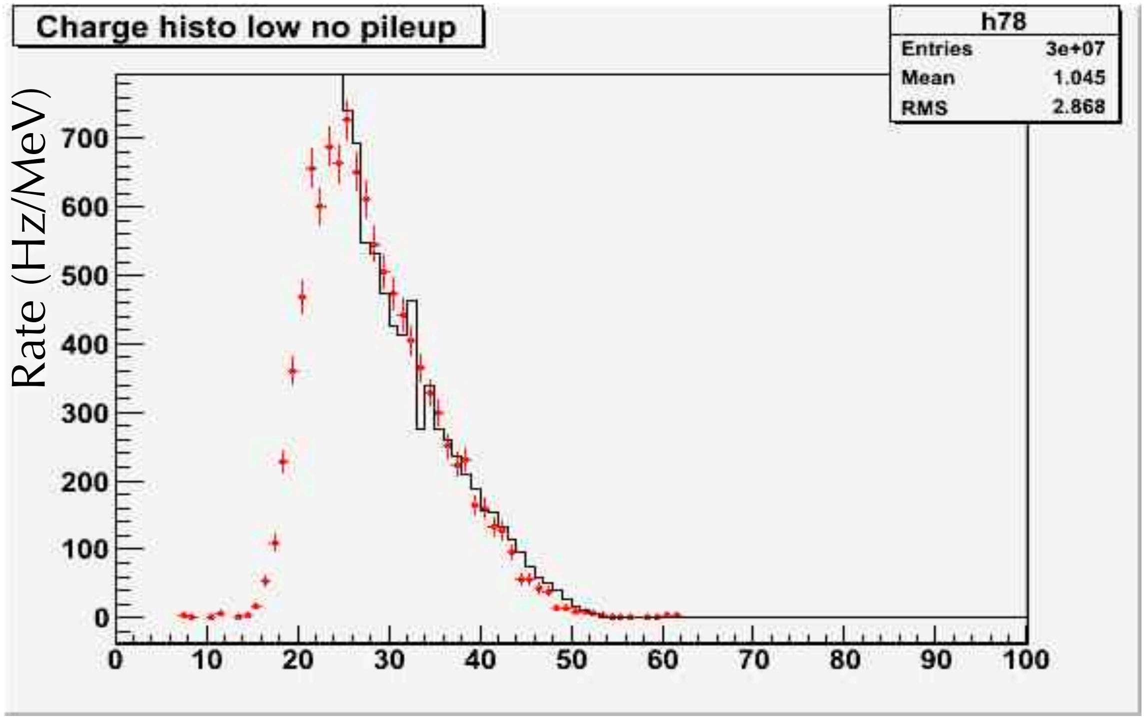
- Now that we know how to sum spectra from different runs we can try to evaluate global properties
- Events in the radiative decay set (±6σ from Δt peak → *see Ootani-san presentation*)
- The shape of the spectrum is well reproduced
- The Monte Carlo simulation is scaled to be superimposed to the measured spectrum
  - the estimate of the absolute rate is under way
    - efficiency of the selection cuts
    - efficiencies on the "positron-side"



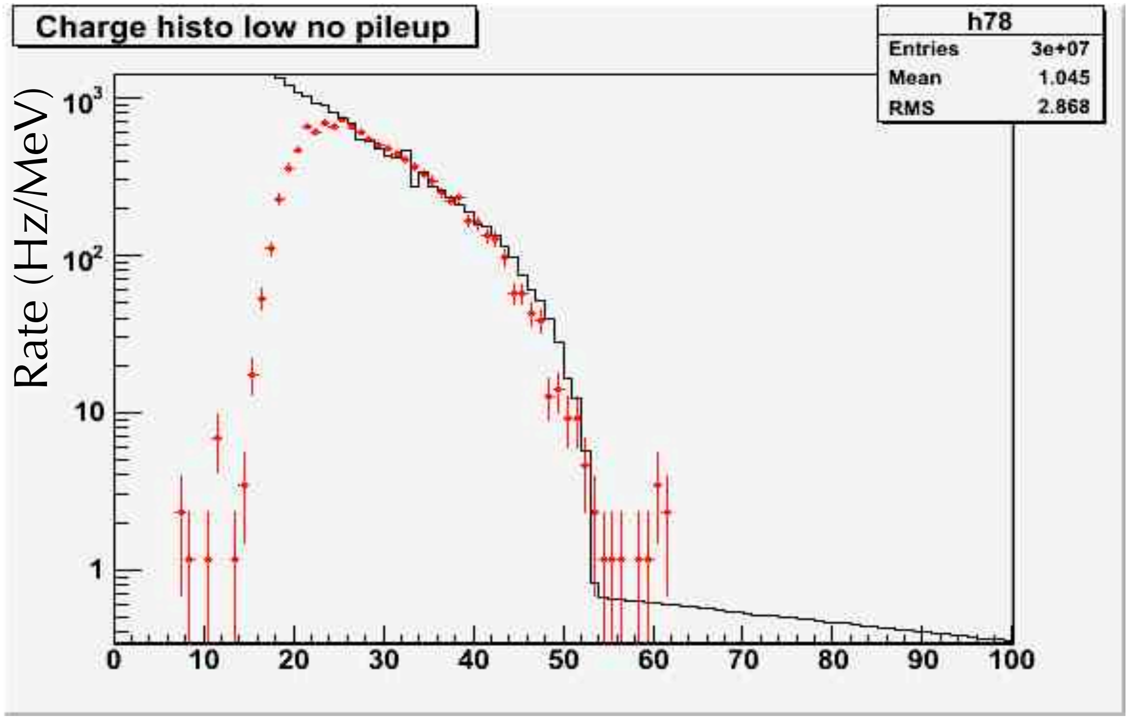


LXe single spectrum

- From the LXe single event trigger we do not observe any unforeseen background in the μ-beam.
- Both the spectrum shape and the absolute rate are correctly reproduced
  - 3 x 10^7 μ^+/s stopping rate
- We can use MC evaluation of efficiency for the detection of a photon from the calorimeter:
  - ε(MC, Eγ > 27 MeV) = 0.51 compatible w/MC+reco efficiency on signal γ.
  - (Read: probability that a γ with E>27 MeV is detected with E>27 MeV)



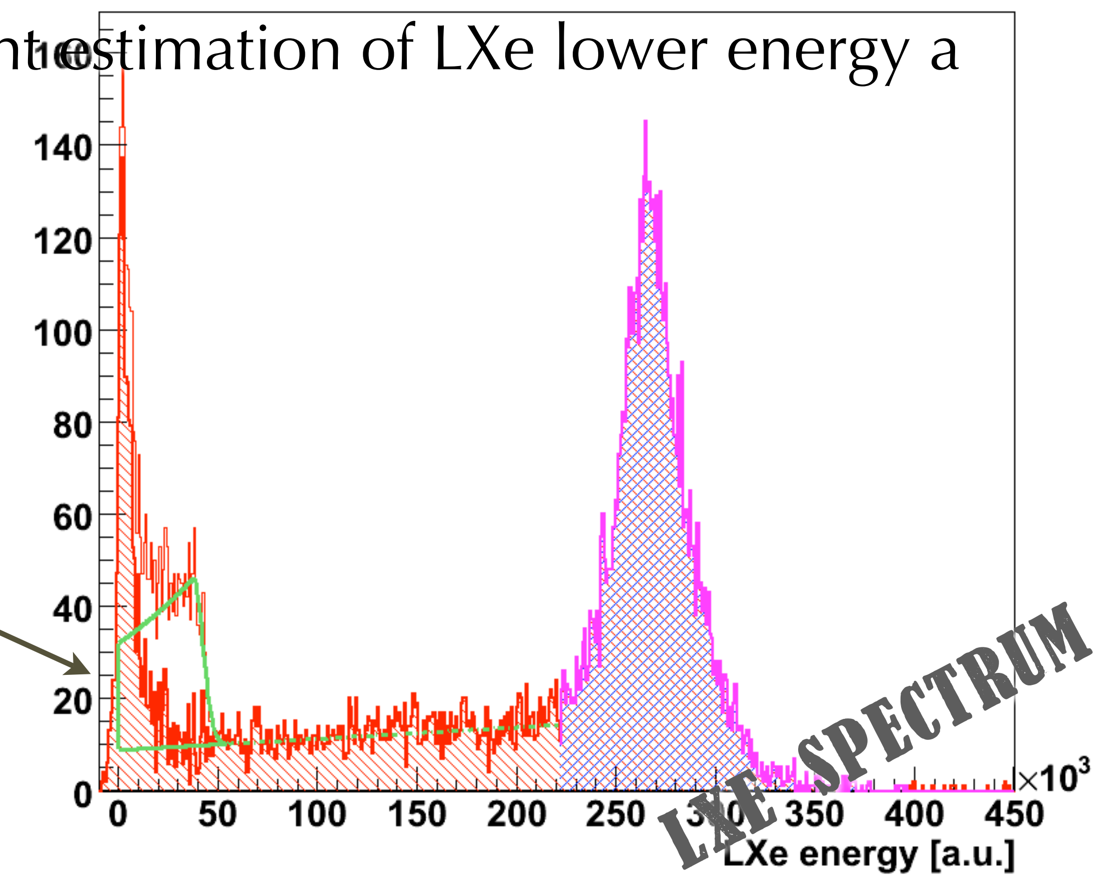
γ energy (MeV)



γ energy (MeV)

Xe detection efficiency

- Another method to estimate the LXe calorimeter detection efficiency is using events by NaI self trigger in CEX Dec/2008
- select events by NaI energy around 83MeV
  - if a photon in this energy range reaches NaI ⇒ the corresponding 55 MeV γ-ray is in the LXe calorimeter acceptance
- XEC efficiency
  - Count the number of photons detected by the calorimeter above a certain threshold
  - to avoid neutron background for event estimation of LXe lower energy a correction is applied
- In progress
  - low energy part of the spectrum



Conclusion

- The LXe calorimeter analysis is ongoing at a great speed
  - the calorimeter shows good performance, though there are variations in light yield;
  - We had our "weapons" and "tools" to follow carefully the situation
- Our measured resolutions @52.8 MeV up to-day
  - σ_{pos} ~ 0.6 cm
  - σ_{time} ~ 55 ps (intrinsic) ~ 100 ps (including photon conversion in XEC)
  - $FWHM_{(E)}$ ~ 6.4% @ 55 MeV
- Algorithm tuning and computation of calibration constants are still under way
  - PMT charge inter-calibration, t_0 drift, ...
  - FWHM of π^o is an upper limit → pile-up ≠ μ-runs
- A careful treatment of the systematics is mandatory and under way to evaluate the effect of the summing runs with
  - different resolutions
  - different energy scale...
- See the combined analysis for the "physics" performance

Back-up slides

- Time/Rate dependence of the gain
- Position correction instead of QE application
- Waveform change with purity
- π^0 pile-up
- Li peak summed on all runs
- Pile-up rejection algorithms
- XEC uniformity after QE correction