Summary of the LXe calorimeter analyses

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MEG Review meeting    18 Feb. 2008
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 \(\mu\)-runs and \(\pi^0\) runs
- corrected through database

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
  • Time
    – intrinsic time resolution (neglect conversion point, positron side...)
    – absolute time resolution
  • Energy
    – @ different energies

• Part of the information needed a dedicated $\pi^0$ 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 $\pi^0$ 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 $\pi^0$ runs are very different from the $\mu$-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

\[ T_0 = T_{i}^{tw} - \frac{\rho_{\text{int}}}{c} - \frac{|\vec{R}_{\text{int}} - \vec{P}_i| n_Xe}{c} - T_{\text{PMT}} - T_{\text{dly}} \]

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

\[
\begin{align*}
T_{\text{PMT}} & \quad \text{shower fluctuations cancel out} \\
\text{Target} & \quad \text{2007 data and extrapolation} \\
\text{Top} & \quad \text{2008 different cuts} \\
\text{Bottom} & \quad \text{52.8 MeV}
\end{align*}
\]
Absolute time resolution

\[ T_{\text{Abs}} = \frac{1}{2} (T_L + T_R) - T_{\text{ref}} \]

- Use a lead-plastic scintillator converter placed in front of the NaI detector as a reference counter
- The \( \gamma \) conversion point in LXe contributes to this resolution
- This resolution includes contribution from
  - spread of \( \pi^0 \) decay point (~60ps)
  - resolution of reference counter (~93ps)
- \( \sigma_t(\text{Abs}) \sim 150 \Theta (93 \pm 60) \sim 100 \) ps
- systematics under study

Dec.

![Diagram of detector setup with converter and scintillator](image)
Energy resolution

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

\[ \langle \sigma_R \rangle = 2.3\%, \quad \langle \text{FWHM} \rangle = 6.4\% \]

- Worse than expected
- Effect of the high rate during \( \pi^0 \) run
  - necessary to make a mini-CEX at the end of the year
  - gain correction are being improved following the new information available
\[ \sigma_E \text{ from CW runs} \]

- 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

\[
\text{FWHM @ 52.8 MeV} = (4.7 \pm 1.2)\%
\]
CW – $\pi^0$ mismatch

- There is still some inconsistency between the CW and the $\pi^0$ calibration
  - energy scale
  - resolutions
- During the $\pi^0$ 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
Long-term analysis

- Stability
- Performance
- As a function of the time
- ...

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. ⇒ $\sigma_{E}(t)$
  • $\tau$ ⇒ $\sigma_{t}(t)$

• 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)

17.6 MeV peak as a function the date

40% purification & stability test
µ data taking

purification & stability test
µ data taking
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
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 $\mu$-beam.
- Both the spectrum **shape** and the absolute **rate** are correctly reproduced
  - $3 \times 10^7 \mu^+/s$ stopping rate
- We **can use MC evaluation of efficiency** for the detection of a photon from the calorimeter:
  - $\varepsilon(\text{MC}, E\gamma > 27 \text{ MeV}) = 0.51$ compatible w/MC+reco efficiency on signal $\gamma$.
  - (Read: probability that a $\gamma$ with $E>27$ MeV is detected with $E>27$ 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 $\Rightarrow$ the corresponding 55 MeV $\gamma$-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
  - \( \sigma_{\text{pos}} \sim 0.6 \text{ cm} \)
  - \( \sigma_{\text{time}} \sim 55 \text{ ps} \) (intrinsic) \( \sim 100 \text{ ps} \) (including photon conversion in XEC)
  - \( \text{FWHM}(E) \sim 6.4\% \) @ 55 MeV
- Algorithm tuning and computation of calibration constants are still under way
  - PMT charge inter-calibration, \( t_0 \) drift, ...
  - FWHM of \( \pi^0 \) is an upper limit \( \rightarrow \) pile-up \( \neq \mu \)-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
- $\pi^0$ pile-up
- Li peak summed on all runs
- Pile-up rejection algorithms
- XEC uniformity after QE correction