Correction for PMT temperature dependence of the LHCf calorimeters
LHCfカロリーメータのPMT温度依存性を考慮した補正
Ellie Matsubayashi
STEL Nagoya Univ.
• **Background**
  - Energy Scale of LHCf calorimeters
  - Energy Scale Problem

• **PMT Temperature Dependence**
  - Method of Gain Correction
  - Results

• **Summary**
1. Shower Energy deposit is measured in each layer by scintillator → PMT $Q_i$ [ADC]

2. ADC “$Q_i$” is changed to Energy deposit in each scintillators “$dE_i$”
   
   $$dE_i = A_i \cdot Q_i \text{[MeV]}$$

   Decision Energy Scale

   Conversion factors “$A_i$” obtained from $e^-$ test beam data taken below 200GeV.

3. Sum of Energy despite “$\Sigma dE_i$” is converted to injected Energy $E_{rec}$
   
   $$E_{rec} = f(\Sigma dE) \text{[GeV]}$$

   Conversion function “$f$” obtained by MC simulation.
Because LHCf calorimeters contain two towers, calorimeter can catch two γ generated by the π⁰ decay.

→ Energy scale of calorimeter is tested by using reconstructed π⁰ mass. **Inspection of energy Scale**

Measures energy and position of two γ generated by the decay of π⁰. Reconstruct the invariant mass $M_{γγ}$

$$M_{γγ} \approx \sqrt{E_{γ1}E_{γ2}\theta^2}$$

Compare with π⁰ rest mass 135 MeV

Inspection of energy Scale

Event distribution $M_{γγ}$
LHCf had an operation at the $\sqrt{s}=7$TeV p-p collision in 2010.

**Expected $\pi$ mass**

$\pi^0$ rest mass

135 MeV

**Reconstructed $\pi$ mass**

$M_{gg}$ in Fill1104 are ...

Arm1 $145.8\pm0.1$ MeV (+8.1 %)

Arm2 $139.9\pm0.1$ MeV (+3.8 %)

→Taken into account as a part of the systematic errors of the energy.

(Black line)

PMT Temperature Dependence

We suspected some points….
• Energy calibration points:
  Calculate conversion factor $A$ by more severe event selection.
  Improve Scintillator shower leak-in leak-out correction
• Inject point:
  gap limited by construction accuracy (tens $\mu$m)
  ← require offset of 1.8 mm to explain the disagreement of Arm1.

\[ M_{\gamma\gamma} \equiv \sqrt{E_{\gamma 1} E_{\gamma 2} \theta^2} \]

→ not significant problems

$M_{g\tilde{g}}$ correlates with PMT holder temperature.

Influence of PMT(R7400U) temperature dependence of PMT gains  $\sim$-0.25%/°C
Correction methods

In order to correct the PMT gains changed effect by temperature, Correction term \( G_i(T_{PMT}) \) is included in \( dE_i \) function.

\[
dE_i = G_i(T_{PMT}) \cdot A_{i,SPS} \cdot Q_i
\]

1. The temperature difference between at SPS and at LHC
2. During LHCf operation of $\sqrt{s}=7\text{TeV}$, H.V. were applied just before measurement of each Fill. So PMT temperature were changed for Joule heat from PMT divider.

\[ T_{UP}(t) = \Delta T_i (1 - \exp(-t/\tau)) \]

Include these two effect, $G_i$ are

\[ G_i = \frac{1}{1 - a \cdot \{T_{SPS-LHC} + T_{UP}(t)\}} \]

Temperature Parameters to be measured

\[ a_i \quad \Delta T_i \quad \tau \]
Temperature Inside Detectors

In order to measure $\Delta T_i [\degree C] & \tau [\text{sec}]$

1. Pt thermometer was attached on each PMT.
2. Calorimeters were assembled in Jul. and Sep. 2014.
3. Calorimeters were installed to the LHC tunnel in Nov. 2014.
4. H.V. was applied (500 or 600 V)

Because of structure $\Delta T_i$ are different between PMTs.

$\Delta T_i = 2 \sim 5.7 \degree C$

$\tau = 3428 \pm 41 \text{ sec}$

Arm2 detector

Pt thermometer

PMT (R7400U)
Temperature Coefficient $a_i$

Temperature coefficients ($a_i$) were measured after Installation in 2014.

- Visible light (405 nm) is injected on each PMT fivers through fibers from the laser.
- PMTs were heated by PMT breeders gradually.
Temperature Coefficient $a_i$

We confirm temperature dependence of each PMT.

$\rightarrow$ Calculate $a_i$ [%/°C]

$a_i$ have large individual difference between PMTs.
Energy Scale shift were improved to +1.1 %~ -1.3%
There are energy scale shift in each Fill.
Summary

• LHCf results have large systematic errors resulting from the energy scale shift.

• It was found that one of the major sources of energy shift is the temperature dependence of PMT.

• In order to correct the variation of the PMT gain by temperature, two types of temperature variation were considered.

  By correction, Arm2 energy scale shift was improved from 3.8% to +1.1~-1.3%. 
Back Up
Future Prospects

• Improve PID

• L_{90} calculation will change.
  → PID error will improved

• We can integrate each Fill which are measured different director positions.
  → Analysis large rapidity region
放射線ダメージと$M_{\text{gg}}$

Stability of $\pi$ mass peak at Arm2 (Fill 1013~Fill1122)

LHC2010 Dose Monitore

5/6以降長時間で連続したFillが固まっているため、積分線量が急激に上昇
エネルギー決定由来の系統誤差

LHCf実験のエネルギースケールはπ⁰のmassが135MeVになるようにずらしてある。その代わり、実際の測定値を含むような大きな系統誤差をつけている。

\[ M_{\gamma\gamma} \approx \sqrt{E_{\gamma1}E_{\gamma2}\theta^2} \]
のエラーは、
- \((\Delta E/E)_{\text{calib}} = 3.5\%\) (SPSで測定)
- \(\Delta\theta/\theta = 1\%\)
- \((\Delta E/E)_{\text{leak-in}} = 2\%\) (シミュの漏れ出し・漏れ込みのエラー)
これらから \(\Delta M/M = 4.2\%\)となり、エラー内に測定値を含むことができない。