Energy Calibration of the EMC with Bhabha Events at BESIII

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• BESIII EM Calorimeter overview
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• Summary
The calorimeter is composed of one barrel and two endcap sections.

In the barrel, there are 44 rings of crystals, each with 120 crystals.

Each endcap consists of 6 rings.

The entire calorimeter has 6240 CsI(Tl) crystals.

Typical size of crystal:
- The front face is ~5cm × 5cm
- The rear face is ~ 6.5cm × 6.5cm
- The length of all crystals is 28cm

The crystals are suspended from the support girder, i.e. without supporting wall between crystals, in order to minimize the dead areas and gaps between the crystals.
Single crystal energy calibration (Digi-calibration)

- **Converting ADC counts into energy (MeV)**

  \[ E_i = ADC_i \times c_i \]

  Here ADC\(_i\) is subtracted Pedestal and calibrated by electronics, \(c_i\) is the calibration constants.

- **Cosmic ray calibration**
  - There are not the absolute energy calibration in the Lab. before crystals installation into the container.
  - And only there are the relative light yield data.
  - So we do the initial calibration using cosmic ray without magnetic field, the cosmic data taken during the BESIII detector joint debugging.
  - The initial calibration constants will be as input of the first bhabha calibration.

- **Bhabha calibration**
  - The crystals have different light yields and different uniformities.
  - The light yield and uniformity change with time through the radiation damage.
  - And some factors cause the change of the light output, and so on.
  - So counter-by-counter calibration is executed using Bhabha events, in order to achieve more accurate \(c_i\).
Cosmic ray calibration

- Event selection
  - EMC back-to-back (trigger condition)
  - only two crystals with energy $>10\text{MeV}$

- In BESIII detector, the cosmic data is mainly $\mu$ lepton, and its momentum is basically larger than $1\text{GeV}$, so we may suppose that the deposited energy is proportional to the depth through CsI crystal.

- Check the ADC(MeV) distribution for every crystal
  - First calibrated by the relative light yield, the calibration constant is
    \[ C^i_{LY} = \frac{LY_{\text{average}}}{LY_i} \]
    here, $LY_{\text{average}}$ is the average of the relative light yield $LY_i$ is the relative light yield of the ith crystal
  - then comparison with the MC, the MC constant is
    \[ C^i_{MC} = E_{\text{average(MC)}}/E_{\text{average(data)}} \]

- Cosmic calibration constant for every crystal
  \[ C^i_{\text{cosmic}} = C^i_{LY} \times C^i_{MC} \]
bhabha data @ 3.686GeV in Oct 2008, i.e. in the early stage of BESIII running

- The black dot is the results of the cosmic calibration.
- The blue dot is the results of the first Bhabha calibration.
- First Bhabha calibration was very successful based on the cosmic calibration constants.
Bhabha calibration

Construct the $\chi^2$:

$$\chi^2 = \sum_{k=1}^{N} \left( \frac{E^k_{\text{exp}} - \sum_i g_i E^k_i}{\sigma(\theta,\phi)} \right)^2$$

Here

$$E^k_{\text{exp}} = E_e(\theta,\phi) f(E_e,\theta,\phi)$$

$E^k_{\text{exp}}$: expected energy, $\sigma(\theta,\phi)$: energy resolution

$E_e(\theta,\phi)$: electron or positron energy from kinematics

$f(E_e,\theta,\phi)$: the fraction of energy deposited in EMC

$i$ — crystal index, $k$ — shower index, $g_i$ — calibration constant

At present, $f$ & $\sigma$ are determined from MC simulation,

By minimizing the $\chi^2$, matrix equation is extracted.

$$\sum_j g_j Q_{ij} = R_i, \quad \text{with} \quad Q_{ij} = \sum_{k=1}^{N} \frac{E_{ik} E_{jk}}{\sigma_k^2}, \quad R_i = \sum_{k=1}^{N} \frac{E_{ik} E^k_{\text{exp}}}{\sigma_k^2}$$

$Q$ is matrix with order 6240, is sparse.

All $g_i$ are decided simultaneously by inverting matrix equation.

Sparse matrix package (SLAP), solving the matrix equation.
Bhabha calibration flow chart

1. Raw data ADC (Elec. Calib. Applied)
2. DST Production Conversion
3. Bhabha Selection & Monitoring
   - Histogram
   - Intermediate Data (matrix, vector)
4. Data accumulation
   - Matrix Sum
   - Matrix inversion
5. Check the Energy Peak for each crystal

- DB gi
- DB Ci
- Check
- Check
- Ci = Ci x gi
- Bhabha calibration const.
- Matrix inversion
- Raw data
- ADC
- (Elec. Calib. Applied)

Q + Q + ... + Q
- Matrix inversion

R + R + ... + R
- Matrix Sum

Bhabha calibration const.
The shower expected energy of Bhabha calibration $E_{\text{exp}}(\theta, \phi)$ is the function of $\theta$ & $\phi$ in Lab. because of the angle (11mrad) between the electron and positron beam.

**Calculation of the expected energy $E_{\text{exp}}(\theta, \phi)$ in lab:**

- **The assumption:**
  
  the fraction of energy deposition in Lab. is the same as that in the center-of-mass system (cms), in which $f(\theta) = \frac{E_{\text{exp}}(\theta)}{E_{\text{cms, beam}}}$ is from Bhabha MC

- **In Lab. the expected energy**

  $E_{\text{exp}}(\theta, \phi) = f(\theta) \times E_{\text{lab, beam}}(\theta, \phi),$

  here $\theta, \phi$ is $\theta_{\text{seed}}, \phi_{\text{seed}}$ of the front center of the shower seed crystal.
Event selection is very important for Bhabha calibration

- offline PreSelected Bhabha or online Bhabha
  - $1 \text{ GeV} < e_1 < 4 \text{ GeV}$
  - $0.4 \text{ GeV} < e_2 < 4 \text{ GeV}$
  - $|\Delta \theta| < 3^\circ, -25^\circ < \Delta \phi < -4^\circ \parallel 2^\circ < \Delta \phi < 20^\circ$
  - $M_{dc\text{-hit}} > 20$

Select the shower for Bhabha calibration
- Because the light yield and uniformity change with time through the radiation damage, and the status of every crystal is different.
- Select the shower with the energy in the range of Peak(ixtal) $\pm 1\sigma(I\theta)$ for every crystal.
EMC Bhabha calibration Procedure can be summed up the following steps

- **Check Online Bhabha data (several days)**
  - Check the e5x5 energy vs crystal index profile, the status of every crystal can be checked
  - find the accurate energy peak for every crystal using Histogram method --- peak(ixtal)
  - Get the energy resolution for the different ThetaID index using fitting method --- $\sigma(I\theta)$

- **Select the bhabha events for EMC calibration**
  - Criteria : e5x5cms shower with the energy of $\text{peak(ixtal)} \pm 1\sigma(I\theta)$

- **Bhabha calibration: solving the matrix equation**

- **Check the EMC calibration constants**
  - E5x5cms energy peak and resolution vs. theta-index
  - E5x5cms energy peak and resolution vs. phi-index in barrel
  - E5x5cms energy vs. ixtal profile
Energy peak and resolution in center-of-mass system (Bhabha events)

Bhabha data @3.686GeV

DATA and MC consist very well for Bhabha events, after the calibration with Bhabha
In lab, calibrate to the MC expected energy.

DATA/MC consist with each other both in the Lab. and the center-of-mass system after Bhabha calibration.
Bhabha calibration (cont’)

- **Bhabha Calibration error**
  - Study of errors caused by calibration algorithm itself.
  - First calibration, get the first constants.
  - Calibrate again based on first constants, then get the second constants.

![Distribution of the second constants](image1.png)

![Second constants VS crystal number](image2.png)

Mean=1
RMS=0.7%
BESIII EM Calorimeter performance

Data @3.686GeV

- Bhabha: 2.3%
- digamma: 2.7%

Energy resolution for electrons (from $e^+e^- \rightarrow e^+e^-$) 2.3% in barrel and 4.1% in endcap, for photons (from $e^+e^- \rightarrow \gamma\gamma$) reaches 2.7% in barrel and 4.2% in endcap
Summary

- In BESIII EMC the single crystal energy calibration is very good.
- Data and MC consist very well after the calibration with Bhabha.
- BESIII EMC has very nice performance.
Thanks for your attentions