Calibrating the Electromagnetic Calorimeter of the STAR Forward Calorimeter System using $p+p$ collision data at $\sqrt{s} = 510$ GeV

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Supported in part by

STAR forward upgrade

- STAR: at Relativistic Heavy Ion Collider (RHIC) located in Brookhaven National Laboratory (BNL).
- STAR forward upgrade includes upgrades on tracking and calorimeters on pseudorapidity region $2.5 < \eta < 4$.
- Built to measure $h^{+/-}$, $e^{+/-}$, photons, π^0 with good e/h separation and photons, π^0 identification.
- Allows to study various of physics in cold QCD and hot QCD at forward rapidity up to $\eta \sim 4.0$

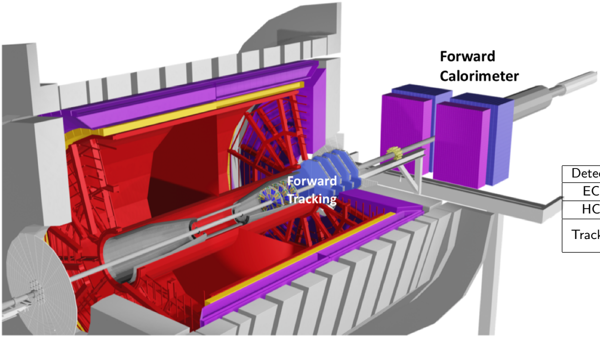


Table: Resolution requirement

Detector	pp and pA	AA
ECal	$\sim$10 % / $\sqrt{E}$	$\sim$20 % / $\sqrt{E}$
HCal	$\sim$50 % / $\sqrt{E}$ + 10%	-
Tracking	Charge separation photon suppression	$\delta p_T/p_T$ $\sim$20 - 30% for $0.2 < p_T < 2$ GeV/c

STAR Forward Calorimeter System (FCS)

- The entire FCS includes ECal, HCal and preshower.
- FCS was installed in 2020, and takes physics data in Run 22 (in 2022).

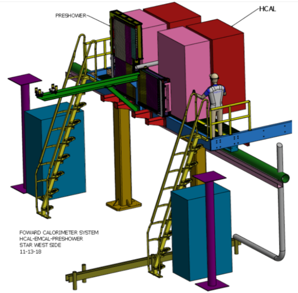
★ ECal (reuse of PHENIX Pb/Sc sampling calorimeter)

- 1496 towers: $5.52 \times 5.52 \times 33\ cm^3$
- 2 halves ECal on two sides of beam pipe (South/North), with 34 rows and 22 columns each.
- $\sim 18\ X_0$
- Use SiPM for readout.

★ HCal (Fe/Sc sandwich)

- 520 towers: $10 \times 10 \times 84 cm^3$
- $\sim$ 4.5 nuclear interaction lengths
- Same SiPM readout as ECal

★ Preshower: split signals from EPD for triggering



FCS ECal module and LED system

- 4 independent towers in each module
- Penetrating WLS fibers for light collection

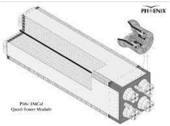


Figure: PHENIX ECal Module

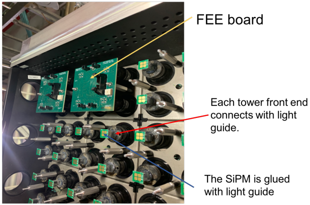


Figure: Refurbished ECal tower front end display

- There are blue LED at the back side of ECal stack, which shine light to enclose cover. Some light will be absorbed by exposed loops of Wavelength Shifting fibers at the back side.

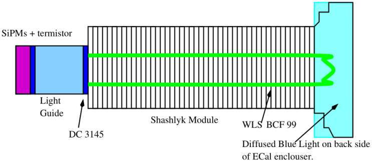


Figure: LED system

Motivation

- Gain loss due to the radiation damage to FEE boards can be observed from the LED system.
  - LED ratio: ratio of LED readout between each LED test run and the reference test run in a period (between dash line).
    - Change the attenuator and SiPM bias set voltage on FEE boards to adjust the LED readout between periods.
  - For each tower, LED ratio drops $\rightarrow$ the tower suffers radiation damage.
  - Higher LED ratio drop rate $\rightarrow$ more serious radiation damage.
- This analysis applies the π^0 reconstruction to calibrate ECal and study the ECal performance under the radiation damage.

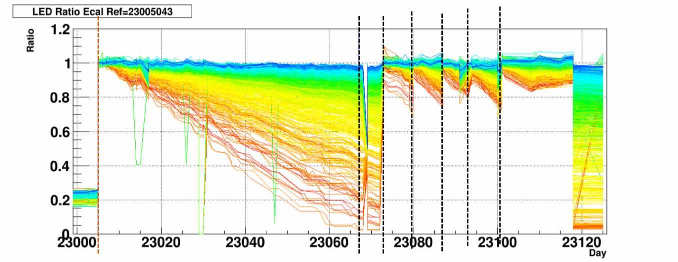


Figure: LED ratio for all the towers during RHIC run in 2022.

Calibration method: π^0 reconstruction

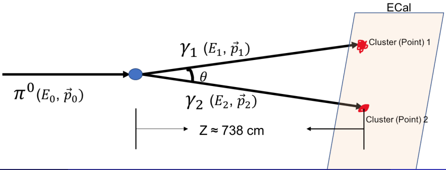
π^0 reconstruction

- π^0 reconstruction using 2 photons (clusters).
- Cluster: a group of towers fired on ECal from EM shower of photon.
- Data set sample used: 8.5 M events from $p + p$ collision data at $\sqrt{s} = 510$ GeV.

Energy $=$ ADC $\times$ gain $\times$ gain correction

Cluster pair selection:

- Each cluster energy E_1 $(E_2) > 1$ GeV
- Energy asymmetry $Z_{\gamma\gamma} = \frac{|E_1 - E_2|}{E_1 + E_2} < 0.7$
- For each event, only keep the pair with highest sum energy $(E_1 + E_2)$



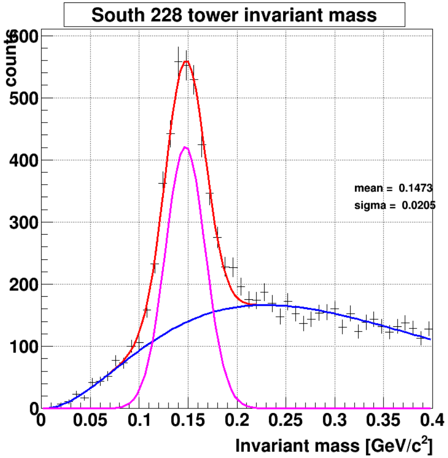
Invariant mass peak extraction

Goal

Develop various gain correction factor for each tower due to various radiation damage.

Extract invariant mass peak for each tower invariant mass plot:

1. For each best pair of clusters, find out the tower with the highest energy inside each cluster (highest energy tower) and fill the 2 highest energy towers with invariant mass of this pair.
2. For each tower invariant mass plot, use Gaussian to fit for the signal and use power $\times$ exponential to fit for the background.
3. Obtain the invariant mass peak from Gaussian mean for each tower.



Gain correction calculation and π^0 reconstruction iteration

- Based on the invariant mass peak for each tower, the corrected gain correction can be calculated by:

$$gain\ correction_{corrected} = gain\ correction_{original} \times \frac{\pi^0\ invariant\ mass}{invariant\ mass\ peak}$$

- Apply the corrected gain correction values again for the π^0 reconstruction as another iteration.
- After several iterations, most of the tower invariant mass peaks are converged at π^0 invariant mass.

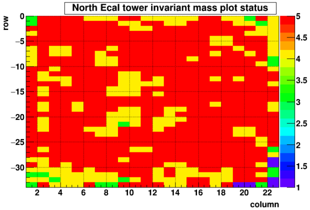


Figure: Invariant mass peak status plot before iterations.

- Invariant mass peak status for every tower.
- Red color: the invariant mass peak is less than 10% difference to π^0 invariant mass.
- Other color: the invariant mass peak away from π^0 invariant mass and need iterations to fix.

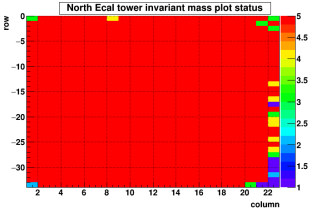


Figure: Invariant mass peak status plot after 2 iterations.

Successful π^0 reconstruction for FCS ECal after 2 iterations

- The invariant plot for after 2 iterations shows an obvious peak right at π^0 invariant mass and with smaller width.

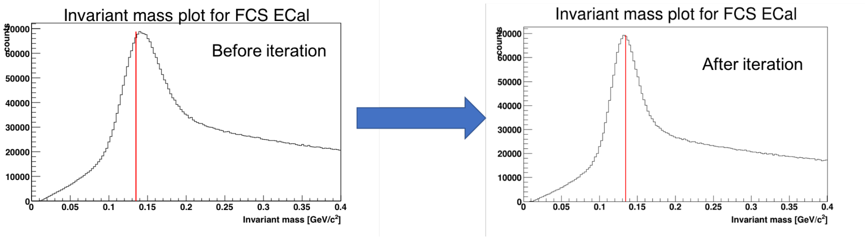


Figure: Invariant mass plot before and after iterations.

Conclusion

- Radiation damage is observed and varied by every tower. Gain correction for each tower is developed to deal with such various radiation damage effect.
- π^0 reconstruction can be a good approach to calibrate for the FCS ECal (tower). The iterations based on gain correction calculated from each tower invariant mass peak are successfully applied for calibration.
- Next step for π^0 reconstruction and radiation damage:
    - Calibrate the physics data in other periods for the whole Run 22.
    - Based on the LED ratio drop rate of every tower, study the relation between LED ratio and gain correction within each period.

Back up

LED ratio and gain correction study

- Plot the LED ratio as a function of RHIC ZDC rate (related to the integrated luminosity) for each period, and use linear fit to estimate the LED ratio change.
- Predict the LED ratio of each tower for every run.

* Calibrate the ECal tower and obtain the corrected gain correction from π^0 reconstruction iteration.
* Investigate the possible relation between LED ratio difference and gain correction difference between 2 different runs in the same period.
    - Possible relation: Gain correction $\times$ LED ratio $=$ Constant