Photon Energy Scale from $\pi^0$ Data

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Outline

- Introduction
- $\gamma$ energy scale, E and $\theta$ dependence run I - run IV
- $m(\pi^0)$ measurement in the EMC
- Summary
- Conclusion
Introduction

There were extensive presentations at previous meetings where the concept of extracting the photon energy scale using $\pi^0$ data had been discussed. We understand in detail the role the different photon energy distributions in Data and MC on the $\pi^0$ signal and quantified the systematic effects.

- Show the final results on the $E, \theta$ dependence of the $\gamma$ energy scale for run I - run IV.

- Compare the $E, \theta$ dependence of $\langle m (\pi^0) \rangle$ for data and MC and test the $\gamma$ energy scale.

- Change in the splitting of $EMC_{\text{forward}}$ and $EMC_{\text{barrel}}$. The binning in $I_\theta$ is now adapted to the EMC hardware.
\( \pi^0 \) Signal processing

Definition of the event samples

- Use CM2 (cache) data and generic B MC: Black Diamond sets run I - run IV

- Data Selection:
  - Reconstruction release 14.5.2
  - Data selection: require BGF multihadron and R2 < 0.8
  - Require LAT < 0.6 and \( I_0 > 3 \) for all photon candidates
  - Truth information is available in MC
  - Use beam vertex

- Use symmetric \( \pi^0 \)
  - Due to the E dependence of \( m_{\gamma\gamma} \) expect systematic mass shifts combining \( \pi^0 \)'s out of different \( \gamma \) energies.
  - To relate the \( \pi^0 \) mass to a single \( \gamma \) scale, we use symmetric \( \pi^0 \)'s.
  - 12 E bins in the range of 70 MeV - 2 GeV.
γ energy scale - E and θ dependence

 Calibration recipe

- Obtain γ energy scale parametrizations in data including errors for EMC_{barrel} and EMC_{forward}.
  - Measure in MC: $m^{\gamma\gamma}_{\text{corrected}}(E_\gamma)$ Known from MC studies:
    - γ scale exactly
    - Changes of $m^{\gamma\gamma}$ in $E_\gamma$ bins with angular resolution
    - Changes of $m^{\gamma\gamma}$ with tail and resolution of $E_\gamma$
  - Measure in data: $m^{\gamma\gamma}(E_\gamma)$ Adjust to MC and correct for in data using MC studies:
    - Data / MC differences in tail and resolution of $E_\gamma$
    - Data / MC differences in angular resolution

- Apply the E and θ dependent parametrizations obtained from the true γ energy scale in EMC_{barrel} to the MC data.
- Apply the E dependent parametrizations obtained for EMC_{barrel} to data.
- Measure $m^{\gamma\gamma}$ in bins of the θ index ($I_\theta$) for data and MC in EMC_{barrel}.
- The ratio $m^{\gamma\gamma}(MC) / m^{\gamma\gamma}(data)$ determines the γ energy scale in data in bins of $I_\theta$.
Larger calibration factors due to increasing leakage at large $E_\gamma$.

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EMC Calibration Meeting
Run 1: forward area shows an E dependence, but is flat in the barrel area.
γ energy scale in Monte Carlo - θ dependence, EMC_{barrel}

After applying E dependent MC calibration.

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E scale from symmetric $\pi^0$'s - E dependence, EMC_{barrel}

- E dependence of the $\gamma$ energy calibration for data in the energy range from 70 MeV to 2 GeV.
\( \gamma \) energy scale from symmetric \( \pi^0 \)'s for \( \text{EMC}_{\text{forward}} \)

- Photon energy calibration for data in the energy range from 130 MeV to 2 GeV.

**Run 1**

- 3.5%

**Run 2**

- 2.8%

**Run 3**

- 2.8%

**Run 4**

- 3.0%
E scale from symmetric $\pi^0$'s - $\theta$ dependence, $EMC_{barrel}$

- Photon energy calibration for data in the energy range from 70 MeV to 2 GeV for $EMC_{barrel}$.

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EMC Calibration Meeting
Comparison of the $\gamma E$ scale in $EMC_{barrel}$ and $EMC_{forward}$ (2)
Comparison of the $\gamma$ E scale in $EMC_{\text{barrel}}$ and $EMC_{\text{forward}}$ (1)
Compare $\pi^0$ response in Data and MC

**EMC response to $\pi^0$'s**

Determine $E, \theta$ dependence of $m(\pi^0)$ in data and MC after applying the corresponding $E$ and $\theta$ dependent $\gamma$ calibration parametrizations. Signal processing is similar as for the determination of the $\gamma$ calibration parametrizations. The data samples are the same!

- **Symmetric $\pi^0$'s with $\gamma$'s in $EMC_{All}$**
  - Use i) the same binning and ii) a changed binning

- **All $\pi^0$'s with $\gamma$'s in $EMC_{All}$**
  - Use i) the same binning and ii) a changed binning

- **Resolution of $m(\pi^0)$**
No calibration, symmetric $\pi^0$'s in $EMC_{\text{barrel}}$ - $E$ dependence

Run 1

$\frac{m_{\gamma\gamma}(\text{data})}{m_{\gamma\gamma}(\text{MC})}$ vs $E_\gamma$ (GeV)

Run 2

$\frac{m_{\gamma\gamma}(\text{data})}{m_{\gamma\gamma}(\text{MC})}$ vs $E_\gamma$ (GeV)

Run 3

$\frac{m_{\gamma\gamma}(\text{data})}{m_{\gamma\gamma}(\text{MC})}$ vs $E_\gamma$ (GeV)

Run 4

$\frac{m_{\gamma\gamma}(\text{data})}{m_{\gamma\gamma}(\text{MC})}$ vs $E_\gamma$ (GeV)
No calibration, all $\pi^0$'s in $EMC_{\text{All}} - E$ dependence

1 $\gamma$ is required to be within the $E$ bin, the other is out of the energy range 70 MeV to 2 GeV.

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EMC Calibration Meeting
Calibrated symmetric $\pi^0$'s in $EMC_{ALL}$ - $E$ dependence

Run 1

Run 2

Run 3

Run 4

$Jörg$ $Marks$  
$EMC$ $Calibration$ $Meeting$
Calibrated symmetric $\pi^0$'s in $EMC_{\text{barrel}} - E$ dependence

Run 1

Run 2

Run 3

Run 4

$E_{\gamma}/\text{GeV}$

$m_{\gamma\gamma}$ data, E, $\theta$ dep. calib.

$m_{\gamma\gamma}$ MC, true $\gamma$ scale calib.
Calibrated symmetric $\pi^0$'s in $EMC_{\text{barrel}}$ - $\theta$ dependence

Run 1

Run 2

Run 3

Run 4

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EMC Calibration Meeting
Calibrated all $\pi^0$'s in $EMC_{ALL} - E$ dependence
Calibrated all $\pi^0$'s in $\text{EMC}_{\text{ALL}}$ - $E$ dependence

1 $\gamma$ is required to be within the $E$ bin, the other is out of the energy range 70 MeV to 2 GeV.

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EMC Calibration Meeting
Calibrated all $\pi^0$'s in EMC$_{\text{barrel}}$ - $\theta$ dependence
π⁰ mass resolution in the EMC

Determination of the resolution

100 MeV < Eᵢ < 300 MeV

π⁰ signal treatment

Subtract combinatorial background

Measure FWHM, obtained from fitted Nov. Function to mγγ

Remaining correlated background is extrapolated to signal region and subtracted

\[ \Delta_{\text{peak}} = 0.4 \text{ MeV} \]

Depending on the fit method shifts of the peak positions in the order of 0.1 to 0.3 MeV are easily obtained!
Resolution, symmetric $\pi^0$'s in $\text{EMC}_{\text{barrel}}$ - $E$ dependence

- **Run 1**
- **Run 2**
- **Run 3**
- **Run 4**

![Graphs showing data for Runs 1 to 4](image)

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**EMC Calibration Meeting**
Resolution, all $\pi^0$'s in $EMC_{All}$ - E dependence

Run 1

Run 2

Run 3

Run 4

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EMC Calibration Meeting
Resolution, all $\pi^0$'s in $EMC_{\text{All}} - E$ dependence
Resolution, symmetric $\pi^0$'s in $EMC_{\text{barrel}}$ - $E$ dependence

Run 1

Run 2

Run 3

Run 4

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EMC Calibration Meeting
Resolution, all $\pi^0$'s in $EMC_{ALL}$ - $E$ dependence

1 $\gamma$ is required to be within the $E$ bin, the other is out of the energy range 70 MeV to 2 GeV.

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EMC Calibration Meeting
Summary

- Established a method to extract the $\gamma$ energy scale from $\pi^0$ data.
- Determined a parametrization of the $\gamma$ energy scale in $E$ and $\theta$ ($\theta$ Index) for all runs in the energy range from 70 MeV to 2 GeV.
- While the $\gamma$ energy scale in $EMC_{barrel}$ and $EMC_{forward}$ is the same in $MC$, a different $E$ dependence is observed for data. This effect decreased after introducing the hardware adapted binning.
- Very good description of $m(\pi^0)$ in data and $MC$ for $\pi^0$’s after $\gamma$ energy calibration.
- Considering all $\pi^0$’s the reconstructed $m(\pi^0)$ after $\gamma$ energy calibration has the same constant value in data and $MC$ and is independent of $E$ and $\theta$.
- Symmetric $\pi^0$’s show energy dependent $m(\pi^0)$ values at low energies.
- The $\pi^0$ mass resolution is not improving after $\gamma$ energy calibration.
- A deviation in the $\pi^0$ mass resolution between data and $MC$ of 17% at low $E_\gamma$ for symmetric $\pi^0$’s in $EMC_{barrel}$ was measured!
Conclusions

- We can release this part of the $\gamma$ energy calibration.
  
  Next week we will have a talk by Johannes on our work of the energy scale from $\mu\mu\gamma$ data.

- Since the reconstructed $m(\pi^0)$ after $\gamma$ energy calibration has the same constant value in data and MC and is independent of $E$ and $\theta$ we do not need in most cases an energy dependent calibration of $m(\pi^0)$.

  We just need to scale $m(\pi^0)$ and $E(\pi^0)$ with the same constant value.

  But in principle $m(\pi^0)$ is a complicated function of $E_{\gamma_1}$ and $E_{\gamma_2}$

- We need to do something about the data/MC deviation in $m(\pi^0)$!