High Energy Physics in BES-III

by
Haichuan Cao
Matthew Tilley
Yangyang Yu
Yunxiao Li
Ziyan Yang
What is the BES-III?

The Beijing Spectrometer (BESIII) detector of the Beijing positron electron collider (BPECII)
Brief overview

- Up to 4.6GeV center of mass energy
- Originally designed as a charm factory

Some goals of BESIII:
- Charmonium Physics
- Exotic hadronic states
- Precision measurements
The BES-III detector

- Drift chamber
- Electromagnetic calorimeter
- Time of flight system
- Superconducting magnet
- Muon chamber
J/Ψ and Ψ(2s)

- Meson formed from C and C bar pair
- Strange name for the J/Ψ due to a near simultaneous discovery
- J/Ψ is found at a mass 3.10GeV
- Ψ(2s) or Ψ’ is a second resonance at 3.77GeV

SLAC-SPEAR: Burton Richter et al. (1974)  
BNL: Samuel Ting et al. (1974)
$Z_{c+}(4050)$ is believed to be a very short lived tetra-quark state!
Y(4260) and Z\(_c\)(3900)

- Y(4260) was found at BaBar in 2006
- Z\(_c\)(3900) was found in 2013 at BESIII and KEK
• Use these simple fits to the $\Psi(2s)$ mass on data and monte-carlo to calculate cross sections
Brief look at results
Brief look at results

$Z(4450)$ in here somewhere!
The $k^+k^-\pi^+\pi^-$ Final State

$e^+ + e^- \rightarrow \phi + \pi^+ + \pi^-$

$\phi \rightarrow k^+ + k^-$

Kate Yang
FPISC camper in High Energy Lab
What is MC?

• MC is short for Monte-Carlo methods.

• They are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results.
The original data

MC simulation

Real Data
Fit of the scatter diagram

MC data dual-Gauss fit

There is another peak

Real data dual-Gauss fit
The $k^+ k^- \pi^+ \pi^-$ Final State

$\chi^2$ Distribution with background

mass distribution
THE $K^+ K^- K^+ K^-$ FINAL STATE

Yangyang Yu
FPISC camper in High Energy Lab
THE $K^{+}K^{-}K^{+}K^{-}$ FINAL STATE

![Graph showing the $\chi^2_{4K}$ distribution for signal and control regions with events/unit $\chi^2$ on the y-axis and $\chi^2_{4K}$ on the x-axis.]
THE $K^+ K^- K^+ K^-$ FINAL STATE

Invariant-mass distribution
Preliminary study of

\[ e^-e^+ \rightarrow \phi\pi^0\pi^0 \]
\[ \phi \rightarrow K^+K^- ; \pi^0 \rightarrow 2\gamma \]

Yunxiao Li

FPISC camper in High Energy Lab
Motivation

• Confirm the decay $\phi \rightarrow K^+ K^-$
• Measure the cross section of this process $e^- e^+ \rightarrow \phi \pi^0 \pi^0$
Data sample

• **Boss version 6.6.5**

• **Date sets**
  Data of BEPCII from April.3rd to April.9th,
  1 energy point : 2.175GeV

• **Monte Carlo Data**
  \( e^-e^+ \rightarrow \phi\pi^0\pi^0 \)
Event selection criteria (I)

- **Charged Tracks:**
  - \(|V_r| < 1.0 \land |V_z| < 10.0 \land |\cos \theta| < 0.93;
  - N_{good} = 2 \lor 1;

- **Particle Identification:**
  - Kaon: \(\text{prob}_K > \text{prob}_P \land \text{prob}_K > \text{prob}_\pi\);
  - N_{good} = 2: \(N(K^+) = N(K^-) = 1\);
  - N_{good} = 1: \(N(K^+) \lor N(K^-) = 1\);

- **Good Photon:**
  - E_{barrel} > 25 \text{ MeV}; E_{endcap} > 50 \text{ MeV}; \(\theta_{min}\) (\(\gamma\),charge) > 10\(^\circ\); 0 \leq \text{TDC} \leq 14; N_\gamma \geq 4;
Event selection criteria (II)

- $\pi^0$ reconstruction
- $\chi^2 = \frac{(M\gamma_1\gamma_2 - M\pi^0)}{2} + \frac{(M\gamma_3\gamma_4 - M\pi^0)}{2}$
- 1C kinematic fit: $(4\gamma K \pm)$

![Graph showing event distribution with $\chi^2_{1C}$ on the x-axis and events on the y-axis, with a peak at 40 ev and $\sqrt{s} = 2175$ MeV.]
Event selection criteria (III)

\[ |\cos(\theta) = \frac{E_{\gamma_1} - E_{\gamma_2}}{P_{\gamma_1} P_{\gamma_2}}| < 0.95 \]

\( \sqrt{s} = 2175 \text{ MeV} \)
$\Phi\pi^0\pi^0$ cross section measurement

$\sqrt{s} = 2175\text{MeV}$
$\phi\pi^0\pi^0$ fit $\phi$ signal

Fitting function: Signal MC $\otimes$ Gauss + Argus
\( \varphi \pi^0 \pi^0 \) cross section calculation

- **Calculation Function:** \( \sigma = \frac{N}{L_{int}(1 + \delta)\epsilon Br} \)
  - \( \epsilon \): efficiency of mc data 22.16%
  - \( L_{int}; (1 + \delta) \): constants depending on energy (2.175GeV in this analysis)
  - \( N \): number of events selected in the end (197 \( \pm \) 3)
  - \( Br \): 0.489\*0.988\*0.988
  - \( \sigma = 179.62 \pm 2.74 \) pb
Introduction

$e^+e^- \rightarrow \text{hadrons cross sections}$

and the $R_{\text{had}}$ Value

Haichuan Cao
FPISC camper in High Energy Lab
What is the R value?

• $R_{\text{had}}$, by proper definition, is the ratio of the total cross sections according to following equation,

\[
R_{\text{had}} = \frac{\sigma(e^+e^\to \text{hadrons})}{\sigma(e^+e^\to \mu^+\mu^-)} = \frac{\sum_q \sigma(e^+e^\to q\bar{q})}{\sigma(e^+e^\to \mu^+\mu^-)} = \sum Q_f^2
\]
How to measure the R value in experiment?

\[ R_{\text{had}} \equiv \frac{\sigma(e^+e^-\rightarrow\text{hadrons})}{\sigma(e^+e^-\rightarrow\mu^+\mu^-)} = \frac{1}{\sigma_{\mu\mu}^0 (e^+e^-\rightarrow\mu^+\mu^-)} \times \frac{N_{\text{had}}-N_{\text{bkg}}}{L\epsilon_{\text{had}}\epsilon_{\text{trigger}}(1+\delta)} \]

- \( \sigma_{\mu\mu}^0 \): born-level cross section for \( e^+e^- \rightarrow \mu^+\mu^- \)
- \( N_{\text{had}} \): number of hardonic events
  (It’s what I need to measure in this experiment)
- \( N_{\text{bkg}} \): number of background hadronic events (noises)
- L: integrated luminosity
- \( \epsilon_{\text{had}} \): detection efficiency for hadrons
- \( \epsilon_{\text{trig}} \): trigger efficiency (100% in this experiment)
- \( 1 + \delta \): radiative correction factor
Why need I measure the R value?

- One of the most fundamental quantities in particle physics that directly reflect the flavor and the color of the quarks.
- A necessary input for other physical quantities. Such as:

  \[ \Delta \alpha^{(5)}_{had}(s) = -\frac{\alpha s}{3\pi} \text{Re} \int_{4m^2_\pi}^{\infty} ds' \frac{R(s')}{s' - s - i\varepsilon} \]

  \[ a_\mu \text{- anomalous magnetic moment of the muon} \]

  \[ a^{\text{had}}_\mu = \left( \frac{\alpha m_\mu}{3\pi} \right)^2 \int_{4m^2_\pi}^{\infty} ds' \frac{K(s')}{s'^2} R(s') \]
Potential backgrounds (noises)

- QED(*Quantum* Electrodynamics) process:
- Bhabha($e^+e^- \rightarrow e^+e^-$), $\gamma\gamma$, $\mu^+\mu^-,\tau^+\tau^-$
- $e^+e^- \rightarrow e^+e^-+$hadrons
- Cosmic ray
- Beam-associated backgrounds; beam-wall; beam gas
Event Selection I (To exclude the noises)

Veto Bhabha and $e^+e^- \rightarrow \gamma\gamma$

Two showers with maximum deposited energy

$|\theta_1 + \theta_2 - 180^\circ| < 10^\circ$ & $E > 0.65 \times E_{beam}$

Good hadronic tracks (track level)

$|Vr| < 1.0$ cm, $|\cos \theta| < 0.93$

Momentum $< 1.1 \times E_{beam} \times (1+5\sigma)$

$$\left( \frac{dE}{dx_{mea}} - \frac{dE}{dx_{proton}} \right)/\sigma_{proton} < 10$$

Veto large momentum electrons, if $E/p > 0.8$ & $p > 0.65 \times E_{beam}$

Veto gamma conversion, if Momentum$(e^+e^-) < 0.1$ and angle$(e^+e^-) < 15^\circ$
Event Selection II

• Hadronic event candidates
  
  $N_{good} \geq 2; \text{Visible energy} > 0.4 \times E_{beam}$
  
  • If $N_{good} = 2$:
    • Veto: $|\theta_1 + \theta_2 - 180^\circ| < 15^\circ \& |\Phi_1 - \Phi_2 - 180| < 10^\circ$
    • Number of isolated photon $\geq 2$
    • If $N_{good} \geq 3$:
      • Vote: Angle of two largest energetic tracks,
        • $|\theta_{1st} + \theta_{2nd} - 180^\circ| < 15^\circ \& |\Phi_{1st} - \Phi_{2nd} - 180| < 10^\circ$
So, if the energy of $e^+ e^-$ is between 2.2-3.6 Gev, the R value will be a constant!
FPISC

THANK YOU