中国科学技术大学
University of Science and Technology of China

Defense Report for PhD Candidate Qualification

2023.04.24

Longyu Qin

Outline

- Personal Introduction
- Training Plan Verification
- BEPCII and BESIII
- Introduction of my work
- Summary

Personal Introduction

- Name: Longyu Qin(秦龙宇)
- Student ID: SA21004071
- Major: Particle and Nuclear Physics
- Supervisor: Yingchun Zhu(朱莹春)
- Education
  - ✓ 2017-2021: Bachelor degree in Applied Physics in at USST (University of Shanghai for Science and Technology)
  - ✓ 2021-now: Master student in Particle and Nuclear Physics at USTC

Training Plan Verification

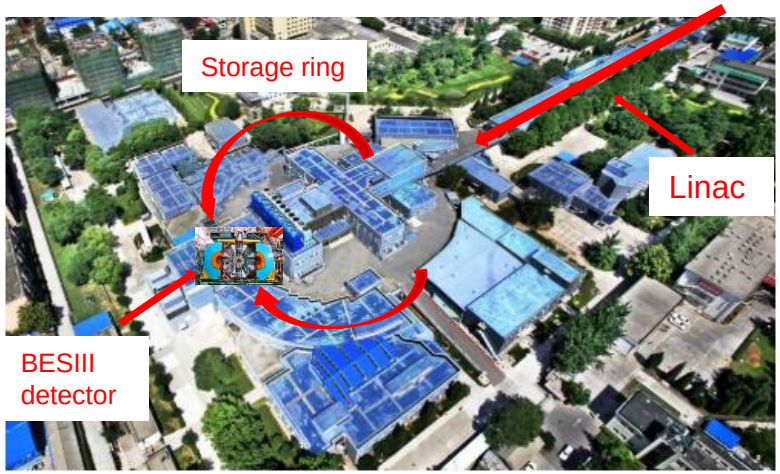
- Scores:

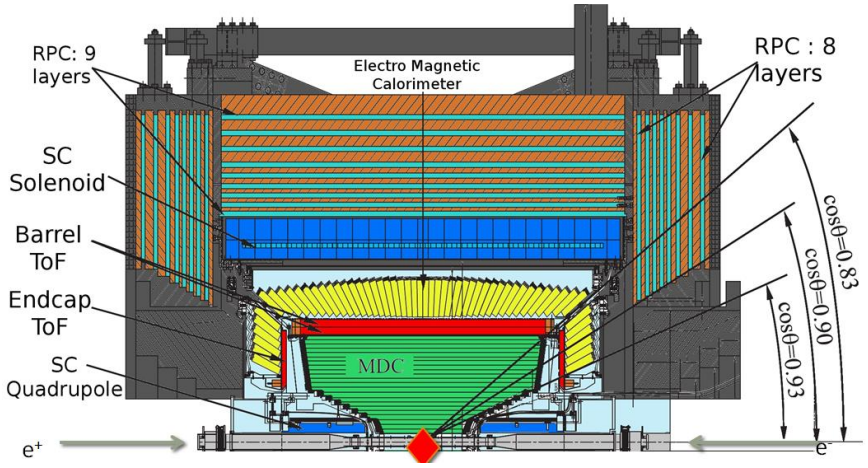
培养计划要求	已经获得学分	是否合格
总学分(带必修环节)>=35	总学分=39	合格
基础课加权平均>=75	基础课加权平均=84	合格
基础课学分>=16	基础课学分=28	合格
学科基础课学分>=8	学科基础课学分=12	合格
公共必修课学分=7	公共必修课学分=7	合格
基础英语课学分>=2	基础英语课学分=2	合格
应用英语课学分>=2	应用英语课学分=2	合格
学位论文开题报告		尚未合格

BEPCII and BESIII

Electromagnetic Calorimeter
CsI(Tl): L=28 cm
Barrel $\sigma_E = 2.5\%$
Endcap $\sigma_E = 5.0\%$

Muon Counter
RPC
Barrel: 9 layers
Endcap: 8 layers
$\sigma_{spatial} = 1.48$ cm





double ring: $e^+\ e^-$
$Ecm\ =\ 2.0 - 4.95$GeV
Peak Luminosity:
$1.1 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}@\psi(3770)$
Cross angle: 22 mrad
Circumference: 237.53m

Main Drift Chamber
small cell, 43 layer
$\sigma_{xy} = 130\ \mu$m
$dE/dx \sim 6\%$
$\sigma_p/p = 0.5\%$ @ 1GeV

Time Of Flight
Plastic scintillator
σ_T(barrel): 68 ps
σ_T(endcap): 60 ps

Physics in BESIII

Charm

CKM matrix elements related to charm weak decays
D mesons
CP violation in the charmed-quark sector
Λ_c decays

Charmonium

charmonium spectroscopy
XYZ states
Hadronic transitions

Light Hadron

Meson Spectroscopy
Baryon Spectroscopy
Light Hadron Dynamics
Hyperons Physics

Tau-QCD

τ Mass Scan
J/ψ Line Shape
Inclusive and Exclusive Hadronic Cross Sections
Baryon Form Factors
Transition Form Factors

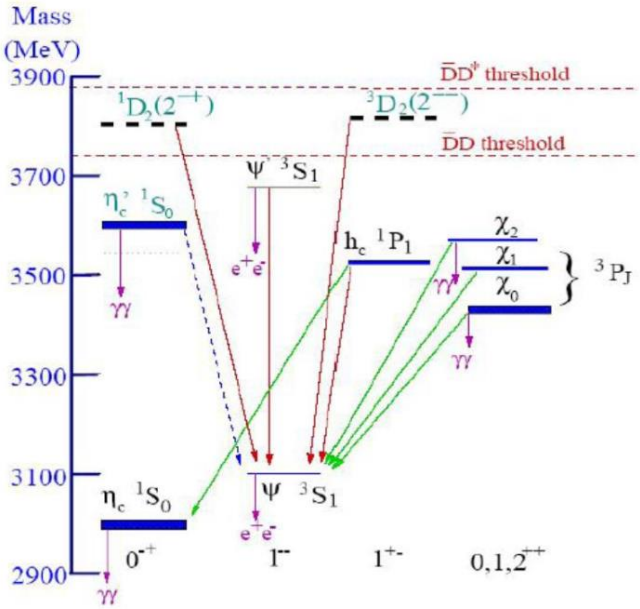
New Physics

Forbidden or symmetry violation processes
Invisible decays
Other exotic phenomena searches

Measurement of Branching Fraction of $\eta_c \to \omega\phi$ in $J/\psi \to \gamma\eta_c$ decay.

Motivation

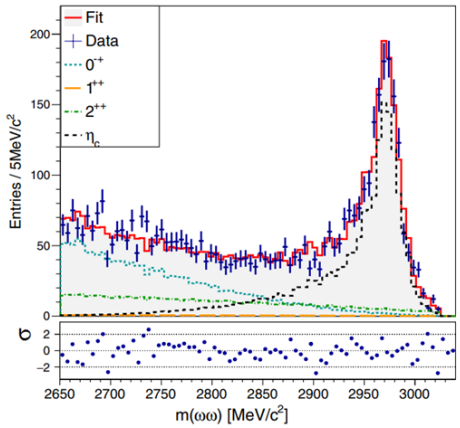
- As the lightest charmonium, also the 1^1S_0 partner of the 1^3S_1 J/ψ, $\eta_c(1S)$ is a basic state in study of charmonium. But $\eta_c(1S)$ is still under investigation. Branching fractions (BFs) yet of different decay modes of the $\eta_c(1S)$ are only measured roughly or with large uncertainties. And the observed BFs sum up to only about 60%.

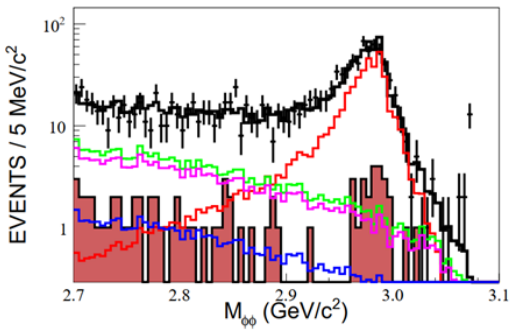


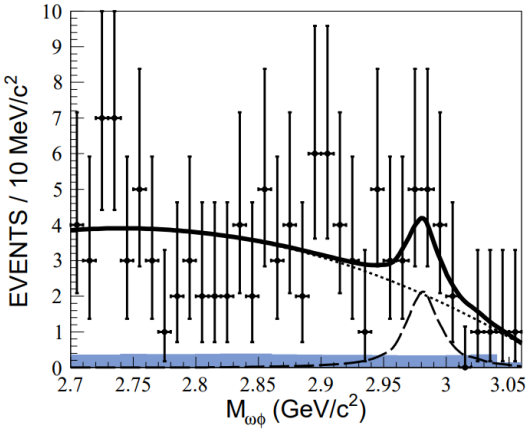
- $\eta_c(1S) \to VV$ should be suppressed by helicity selection rule, but the observed results experimentally are much larger than published predictions of BFs for those decay modes.

Motivation

- $\eta_c(1S) \to VV$ modes such as $\eta_c(1S) \to \omega\omega$ and $\eta_c(1S) \to \phi\phi$ has been well measured by BESIII.





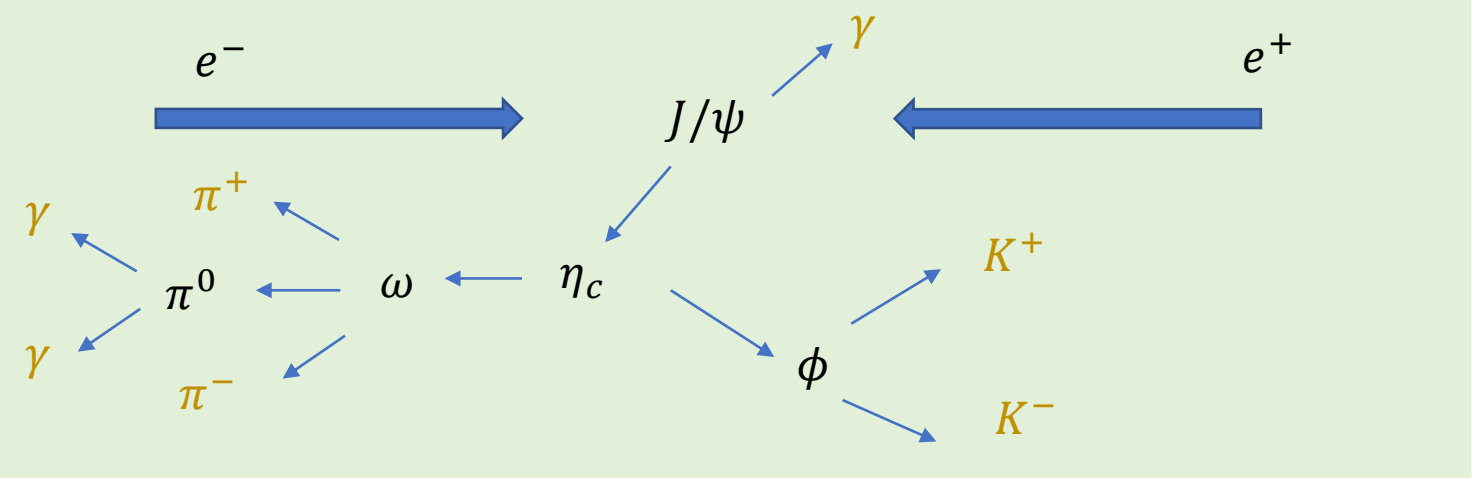


but due to doubly OZI suppress, there is only an upper limit for $\eta_c(1s) \to \omega\phi$ which is 2.5×10^{-4}.

- BESIII has the largest 10 billion J/ψ data sample in the world, which is a suitable factory for our research. With a larger data sample we are hoping to observe $\eta_c(1S) \to \omega\phi$ mode.

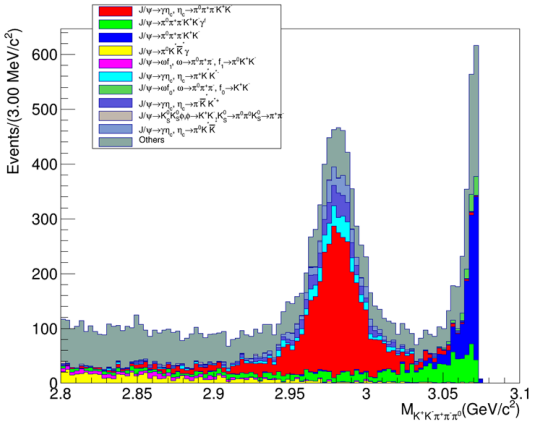
Analysis Strategy

- Data sets:
  - ✓ $1.009 \times 10^{10} J/\psi$ events accumulated in 2009, 2012, 2018 and 2019 with BESIII detector
- After event selection criteria, exactly $\pi^+\pi^-K^+K^-$ and more than three photons are required.
- ω is reconstructed with $\pi^0\pi^+\pi^-$, and ϕ is reconstructed with K^+K^-.
- Fit on $M_{\pi^0\pi^+\pi^-K^+K^-}$ distribution is performed to extract η_c signal events using reasonable model for etac line shape.
- Background estimation especially the peaking background is the difficulty in this work.

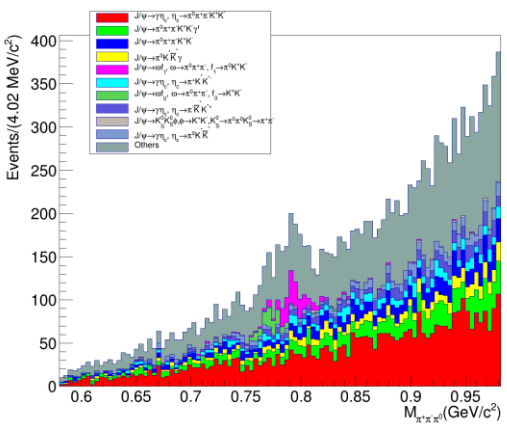


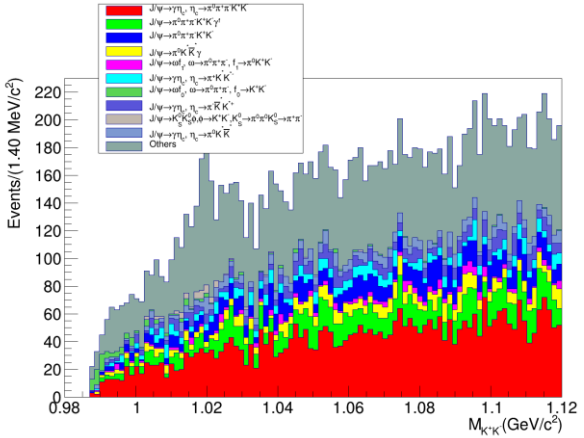
Background Analysis

- Background Analysis is based on inclusive MC.
  - ✓ There are non-peaking background, J/ψ peaking background and η_c peaking background in $M_{\pi^+\pi^-\pi^0 K^+ K^-}$ distribution.



  - ✓ There are peaking background and non-peaking background in $M_{\pi^+\pi^-\pi^0}$ and $M_{K^+K^-}$ distributions.





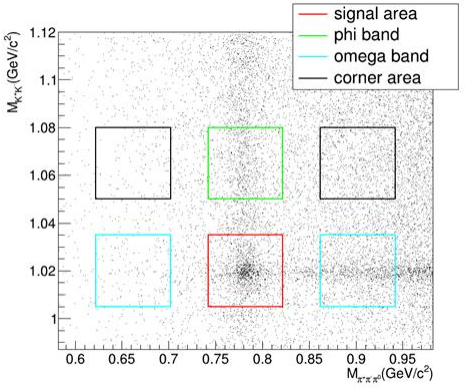
  - ✓ So 2D sideband method based on $\omega - \phi$ 2D invariant mass distribution will be used to estimate background.

Background Estimation

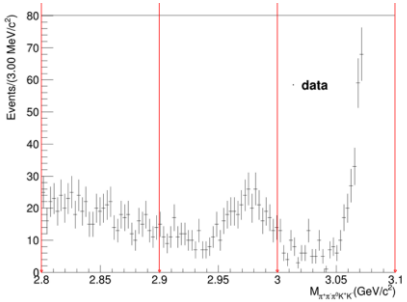
- 2D Sideband method is an effective method to estimate background.
- The number of estimated background in signal area which comes from sideband contribution is calculated by:
  - ✓ $N_{bkg} = f_\omega \times N(cyanbox) + f_\phi \times N(greenbox) - f_{corner} \times N(blackbox)$

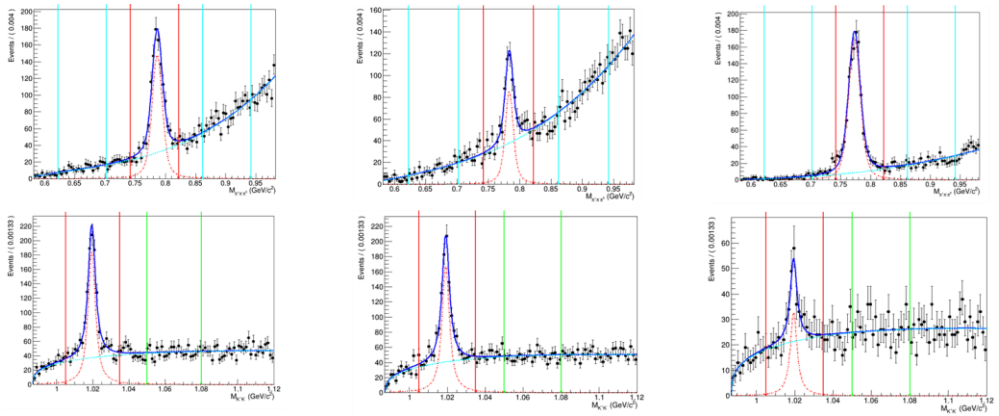
    The $N(cyanbox)$, $N(greenbox)$ and $N(blackbox)$ is the event number in the corresponding box. And scale factor is calculated with:

    $f_{\omega(\phi)} = N_{bkg}(signal\ region)/N_{bkg}(sideband\ region)$, $f_{corner} = f_\omega \times f_\phi$



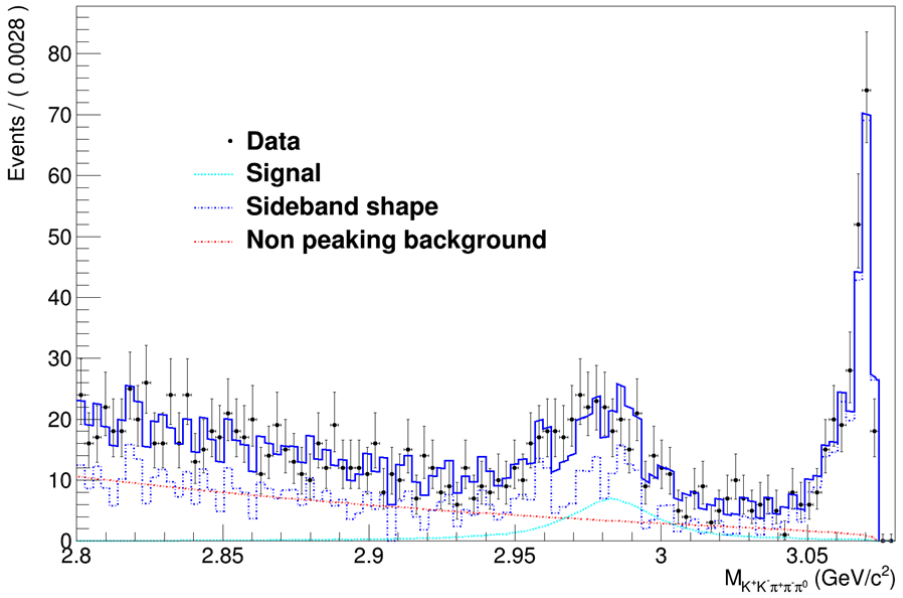
- To reduce the influence of sharing one scale factor, events are divided into three parts to perform 2D sideband method separately.





Fit result

- Fit on $M_{\pi^+\pi^-\pi^0K^+K^-}$ distribution is performed to extract signal.
- Fit method:
  - ✓ Signal MC shape + sideband shape + Argus distribution
- $Br(\eta_c \to \omega\phi) = \frac{N_{obs}}{\epsilon \times N_{total} \times Br(J/\psi \to \gamma\eta_c) \times Br(\omega \to \pi^+\pi^-\pi^0) \times Br(\phi \to K^+K^-) \times Br(\pi^0 \to \gamma\gamma)} = \left(3.27 \pm 0.80_{stat} \pm 0.98_{syst}\right) \times 10^{-5}$
  - ✓ $\epsilon = 5.02\%$
  - ✓ $N_{total} = 1.009 \times 10^{10}$
- Significance : 4.0σ
- (PDG upper limit: 2.5×10^{-4} @ 90% C.L.)



η_c line shape

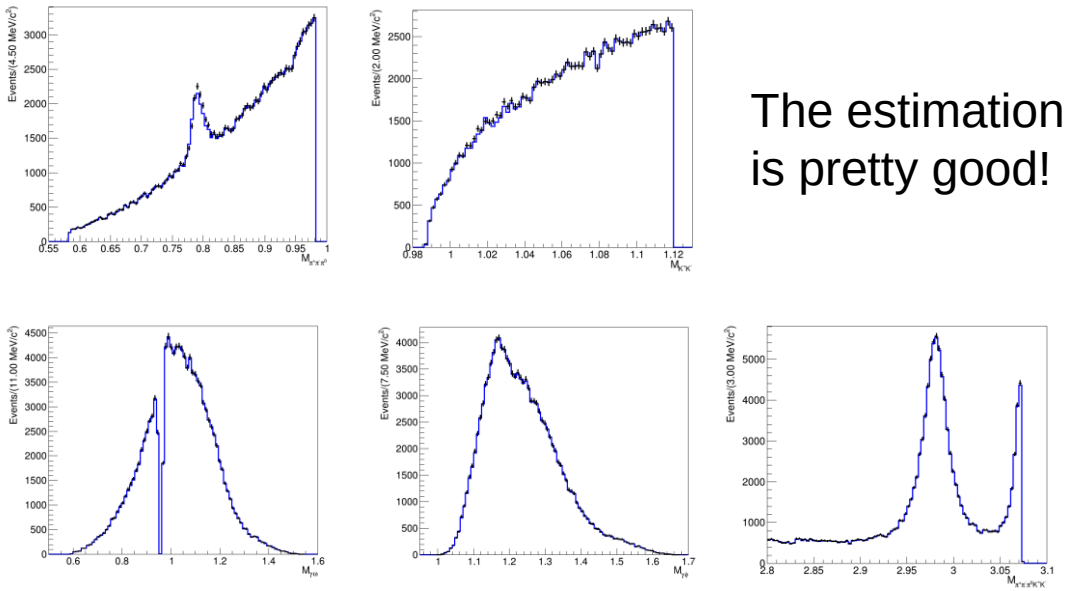
- Magnetic dipole (M1) transitions $J/\psi \to \gamma\eta_C$ is among the most poorly measured transitions in the charmonium system. It's also a key for lattice QCD calculation and effective field theory.
- Theory calculation:

$$\Gamma_{J/\psi\to\gamma\eta_c} = \frac{16}{3}\alpha e_c^2 \frac{k_\gamma^3}{M_{J\psi}^2}\left[1 + C_F\frac{\alpha_s\left(M_{J/\psi}2\right)}{\pi} - \frac{2}{3}\left(C_F\alpha_s\left(p_{J/\psi}\right)^2\right)\right]$$

- In CLEO result (PRL 102 011801) ,the distortion of the η_c line shape in the photon-energy spectrum due to phase space and energy-dependent terms in the M1 transition matrix element is observed.
  - ✓ A factor $\exp(-k_\gamma^2/\beta)$ is added to damp k_γ^3 , which is included in our signal MC for my η_c line shape.

Q-weight method

- An improved method to estimate background better is in progress.
- First, a space spanned by the ξ coordinates is defined and normalized as in this table.
- Then each event and its 200 nearest neighbors in this space are selected to form a dataset which is to be performed a 2D fit, a Q-value for this event is determined by this fit.
- Here shows the pre-known background (black dot), and the identified background (blue line) in my generated data-like MC sample.



The estimation is pretty good!

coordinate	Normalization
$m^2_{\omega\phi}$	0.3937
$m^2_{\gamma\phi}$	0.272
$m^2_{\gamma\omega}$	0.297
$\cos(\theta_\omega)$	2
$\cos(\theta_\phi)$	2
$\cos(\theta_\gamma)$	2
$\lambda_\omega/\lambda_{max}$	1

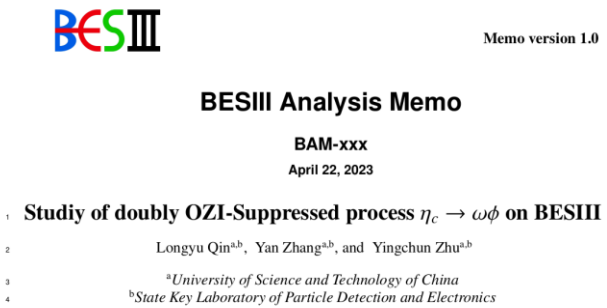
Systematic Uncertainty

Sources	Uncertainty(%)
Number of J/ψ event	0.5
Intermediate branching ratio	23.6
Tracking efficiency	4.0
Photon detection	3.0
Particle identification	4.0
Kinematic Fit	4.0
Mass window for ω	0.4
Mass window for ϕ	0.01
Decay angle cut of π^0	2.5
Veto η'	0.1
Signal MC shape of η_c	1.5
Fit range	1.0
Background estimation and fitting method	15.6
Total	30.0

Summary

- The measurement of Branching Fraction is almost completed.
  - ✓ Nominal result:
    - $Br(\eta_c \to \omega\phi) = (3.27 \pm 0.80_{stat} \pm 0.98_{syst}) \times 10^{-5}$
    - Significance : 4.0σ
    - (PDG upper limit: 2.5×10^{-4} @ 90% C.L.)
  - ✓ Q-weight method estimation is under tuning. (A preliminary result of applying Q-weight method is in agreement with my nominal result.)
  - ✓ memo is prepared
- This work has been reported in
  - ✓ Parallel contribution in BESIII Collaboration meeting in Dec.01 2022
  - ✓ Plenary contribution in BESIII P&S Workshop in Mar.15 2023
  - ✓ Light Hadron group meeting
- Next to do:
  - ✓ finish the first work
  - ✓ The next work is under discussion

Thanks!


BESIII

Memo version 1.0

BESIII Analysis Memo

BAM-xxx

April 22, 2023

Studiy of doubly OZI-Suppressed process $\eta_c \to \omega\phi$ on BESIII

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