Partial Wave Analysis of $J/\psi \to \gamma\omega\phi$ at BESIII

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Outline

1. Introduction to BEPCII and BESIII
2. Partial Wave Analysis of $J/\psi \to \gamma\omega\phi$

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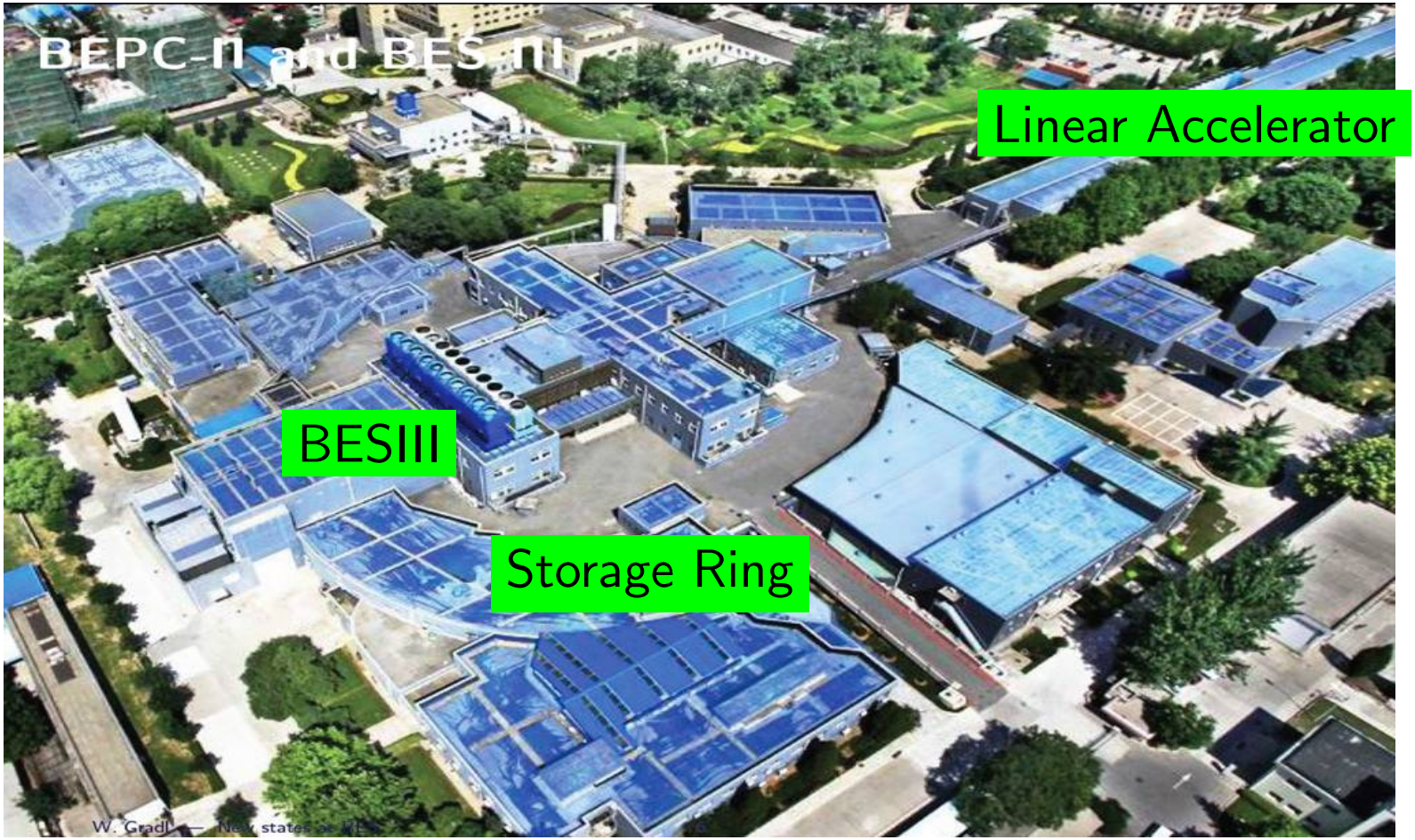
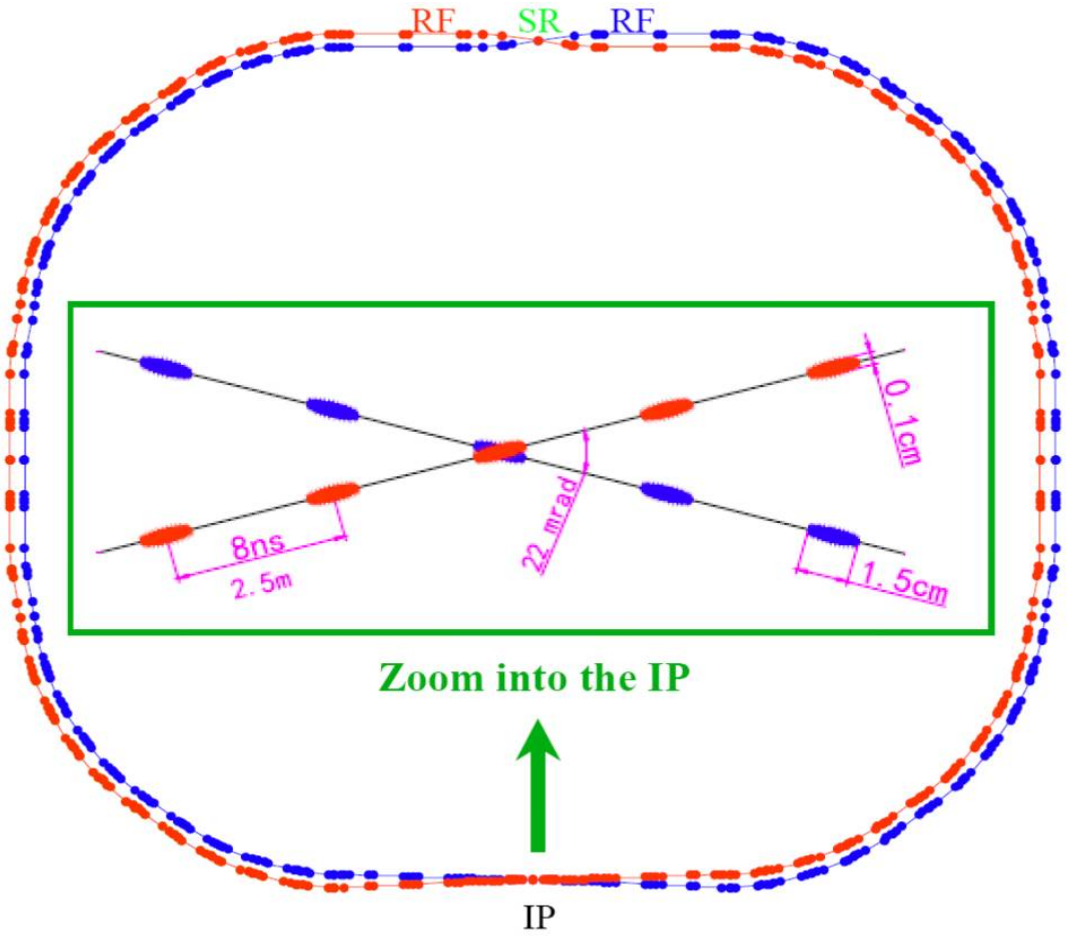
Beijing Electron Positron Collider (BEPCII)



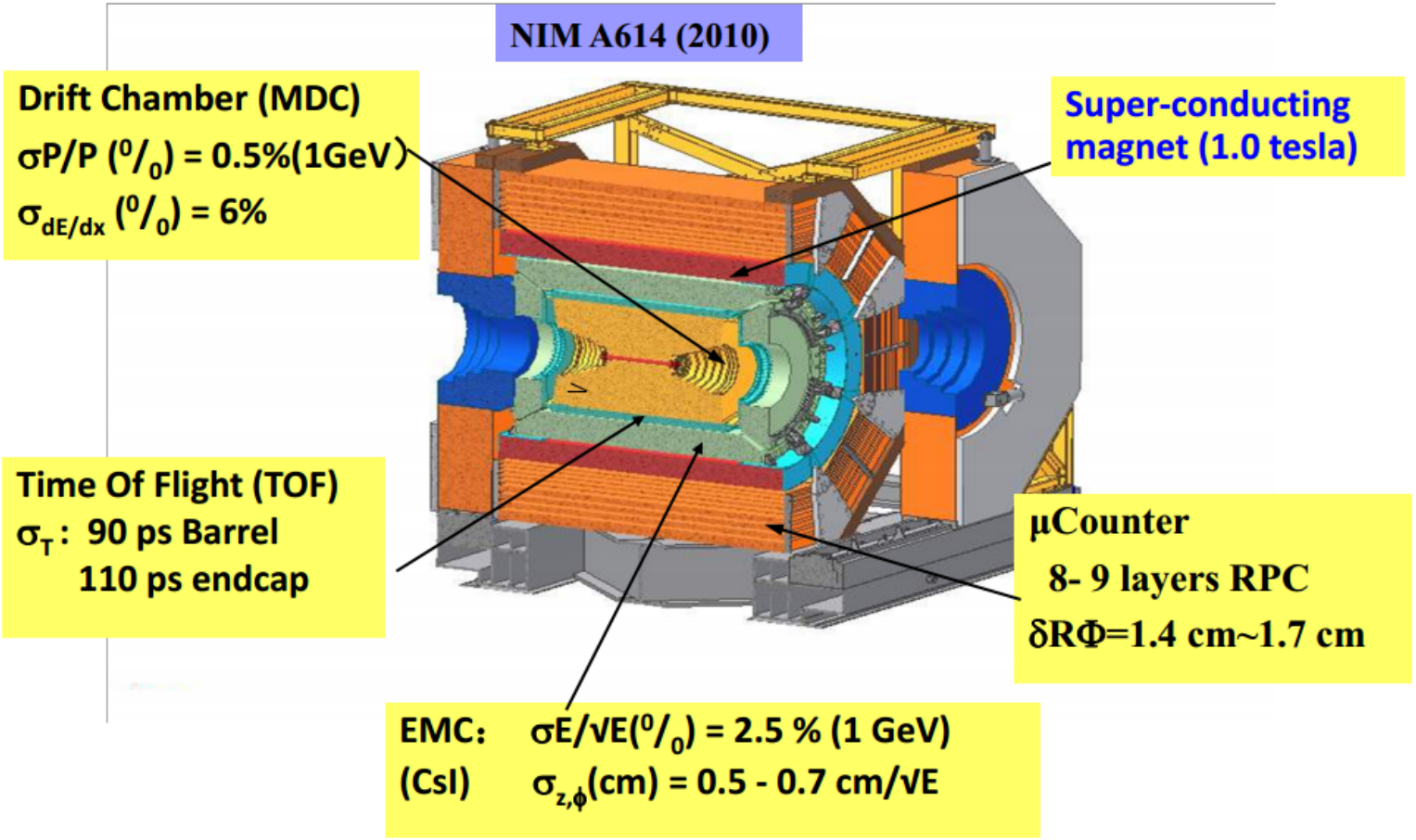
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BEPCII/BESIII data taking

BEPCII storage rings



Beam energy:
1.0-2.3GeV
Design Luminosity:
$1 \times 10^{33} cm^{-2} s^{-1}$
Record Luminosity:
$6.492 \times 10^{32} cm^{-2} s^{-1}$
Energy spread:
5.16×10^{-4}
Optimum energy:
$1.89 GeV$
No.of bunches:
93
Bunch length:
$1.5 cm$
Total current:
$0.91 A$
Circumference:
$237 m$

The BEijing Spectrometer (BESIII) detector



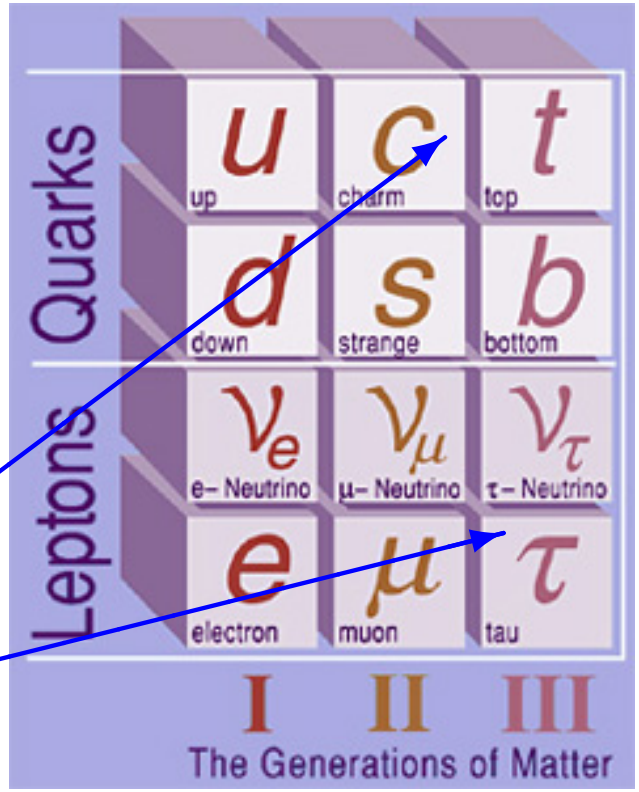
Physics topic at BESIII

"$\tau - Charm$ factory"

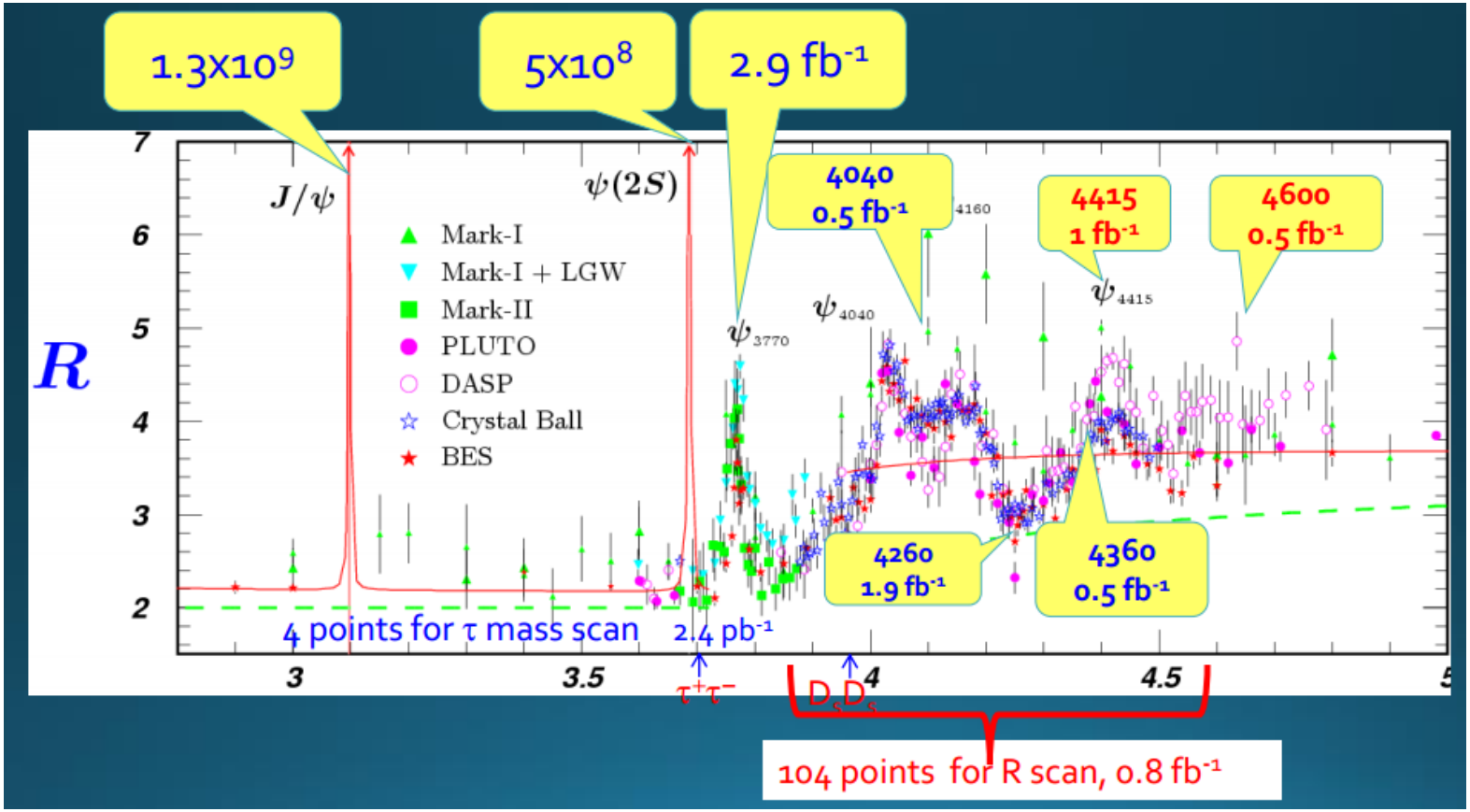
beam energy 1∼2.3GeV

$e^+ + e^-$

charmonium states:
$J/\psi, \psi(2S), \psi(3770)$
...
charm mesons and τ lepton



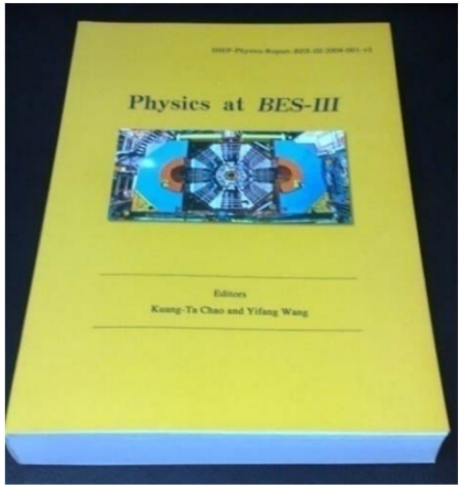
Data sample



This analysis is based on 225M J/ψ event sample collected at 2009.

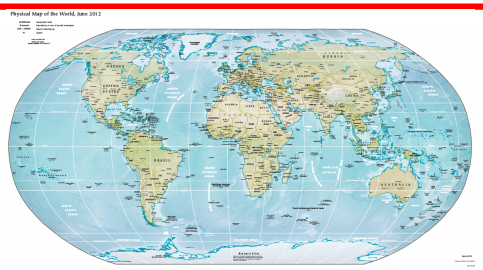
What can we do at BESIII

- Study of Light hadron spectroscopy
  - search for non qq or non qqq states
  - meson spectroscopy
  - baryon spectroscopy
- Study of the production and decay mechanisms of charmonium states: $J/\psi, \psi(2S), \psi(3770)$ etc.
- New Charmonium states above open charm threshold.
  - Precise measurement of R values, τ mass, ...
  - Precise measurement of CKM matrix
  - Search for DDbar mixing, CP violation, etc.



arXiv:0809.1869

BESIII Collaboration



11 countries, 53 institutions, ∼350 people

US(5)
Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Pakistan (2)
Univ. of Punjab
COMSAT CIIT
Korea (1)
Seoul Nat. Univ.
Japan (1)
Tokyo Univ.

Europe(13)
Germany:
Univ. of Bochum
Univ. of Giessen
GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia:
JINR Dubna
BINP Novosibirsk
Italy:
Univ. of Torino
Frascati Lab
Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

China(31)
IHEP, CCAST, GUCAS, Shandong Univ., Univ. of Sci. and Tech. of China Zhejiang Univ., Huangshan Coll. Huazhong Normal Univ., Wuhan Univ. Zhengzhou Univ., Henan Normal Univ. Peking Univ., Tsinghua Univ. , Zhongshan Univ.,Nankai Univ. Shanxi Univ., Sichuan Univ., Univ. of South China Hunan Univ., Liaoning Univ. Nanjing Univ., Nanjing Normal Univ. Guangxi Normal Univ., Guangxi Univ. Suzhou Univ., Hangzhou Normal Univ. Lanzhou Univ., Henan Sci. and Tech. Univ. Hong Kong Univ., Hong Kong Chinese Univ.

Uppsala University joined in at 2012.

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1. Introduction to BEPCII and BESIII

2. Partial Wave Analysis of $J/\psi \to \gamma\omega\phi$

Motivation

J/ψ radiative decay

- An ideal laboratory to search for glueball

$J/\psi \to \gamma VV, (V = \omega, \phi, \rho)$

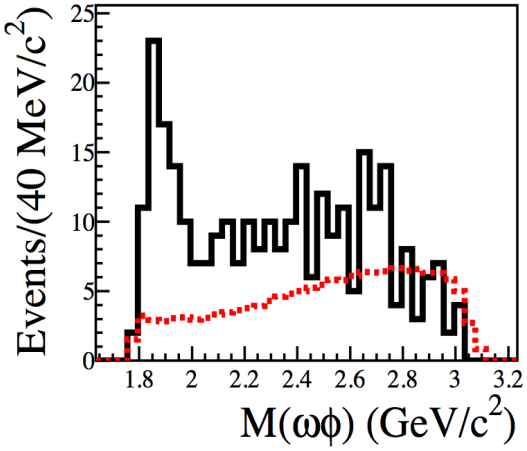
- Signatures of gluonic bound states
- Pseudoscalar enhancements in $\omega\omega$, $\phi\phi$ and $\rho\rho$ observed

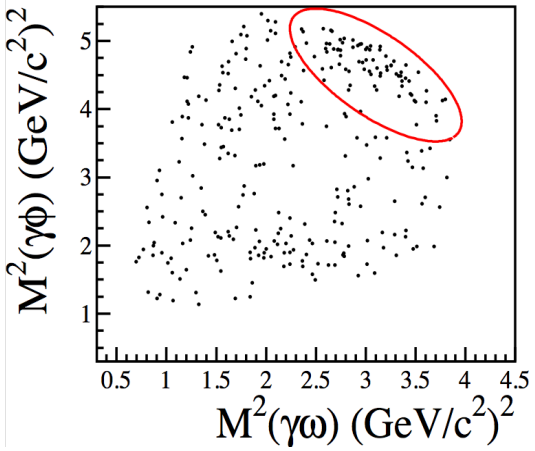
$J/\psi \to \gamma\omega\phi$

- Doubly OZI suppressed decay
  - Production rate should be suppressed relative to $J/\psi \to \gamma\omega\omega$ or $J/\psi \to \gamma\phi\phi$ by at least one order of magnitude.
- An anomalous enhancement, $X(1810)$ observed by BESII

First observation of $X(1810)$ at BESII

2006: BESII observed an anomalous enhancement near the $\omega\phi$ threshold. Phys. Rev. Lett. 96(2006)162002





$X(1810)$:

$J^{PC} = 0^{++}$

$M = 1812^{+19}_{-26} \pm 18 \mathrm{MeV}/c^2$

$\Gamma = 105 \pm 20 \pm 28 \mathrm{MeV}/c^2$

$Br. = (2.61 \pm 0.27(stat) \pm 0.65(syst)) \times 10^{-4}$

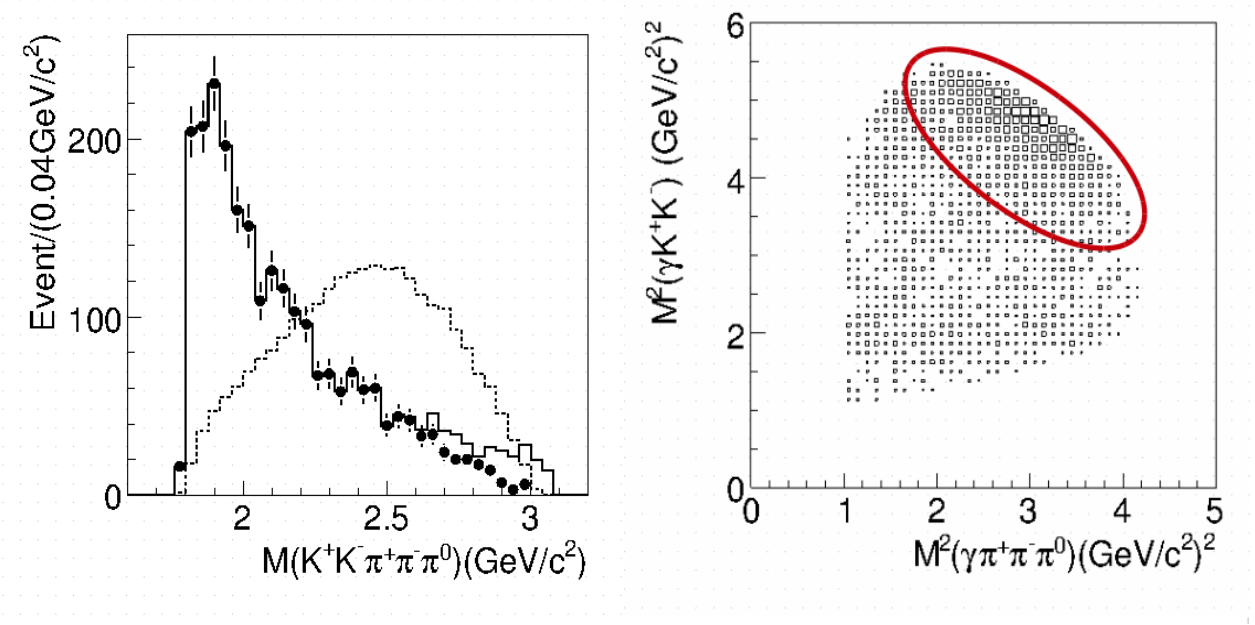
$X(1810)$'s mass different from e.g. $f_0(1710), f_0(1790)$.

Possible interpretations:

- a tetraquark, a hybrid, a glueball,
- a dynamical effect arising from intermediate meson rescattering,
- a manifestation of the $f_0(1710)$ below threshold,
- a cusp of an attracting resonance.

Neither of these interpretations were confirmed nor ruled out by experiment.

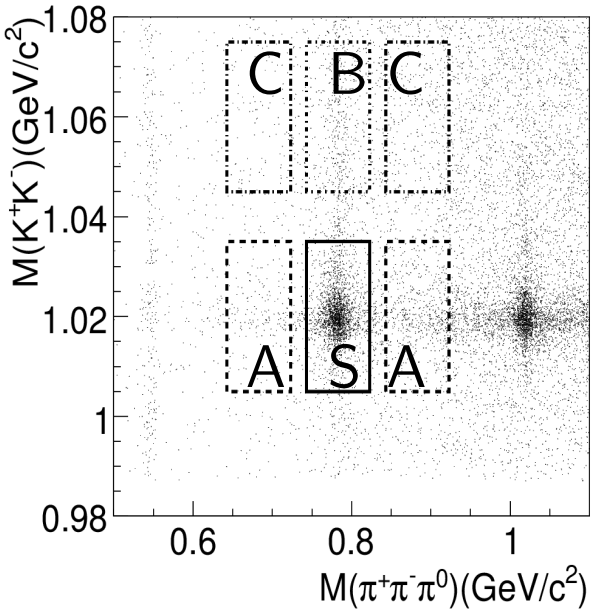
A similar enhancement at BESIII

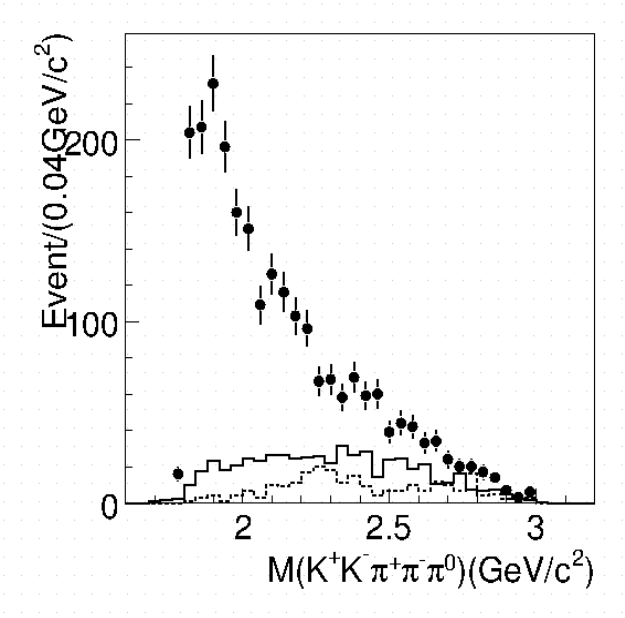


$X(1810)$:

- $J/\psi \to \gamma\omega\phi$ revisited
- 4 times more data
- Similar enhancement observed
- Invariant mass distribution very different from phase space
- Threshold structure visible in the Dalitz plot

Background study





- S: $\omega\phi$ signal region
- A: ω sideband region
- B: ϕ sideband region
- C: corner region

- Solid line: background sideband
- Dashed line: inclusive J/ψ decays.

No enhancement near $\omega\phi$ threshold from background.

Partial Wave Analysis(PWA)

Here, decay processes:
$J/\psi \to \gamma X$, $X \to \omega\phi$, $\omega \to \pi^+\pi^-\pi^0$, $\phi \to K^+K^-$

- X: J^{PC} unknown, maybe $0^{++}, 1^{++}, 2^{++}, 1^{-+}$.....
- Theoretically, each possible partial wave amplitude:

$$A^i = A_{prod} BW^X_{\omega\phi} A_{decay}, \tag{1}$$

  i: different J^{PC}
  A_{prod}: how does X come
  A_{decay}: how does X decay
  $BW^X_{\omega\phi} = 1/(M^2 - s - iM\Gamma)$, M: X's mass, Γ: X's width

- A^i is unobservable
- But, total differential cross section is observable

$$\frac{d\sigma}{d\Phi} = |\sum A(J^{PC})|^2, \tag{2}$$

  We can extract magnitudes and phases, M and Γ by an unbinned Maximum likelihood fit of $\frac{d\sigma}{d\Phi}$.

Maximum likelihood

- Likelihood function:
  - Probability P of the ith event:

$$P(\xi_i) = \frac{\omega(\xi_i)\epsilon(\xi_i)}{\int d\xi \omega(\xi)\epsilon(\xi)} \tag{3}$$

ξ_i: four-momentum of γ, K^+, K^-, π^+, π^- and π^0
$\omega(\xi_i) \equiv (\frac{d\sigma}{d\Phi})_i$: probability density
$\epsilon(\xi_i)$: detection efficiency

  - For N events, the likelihood is:

$$\mathcal{L} = \prod_{i=1}^{N} P(\xi_i) = \prod_{i=1}^{N} \frac{\omega(\xi_i)\epsilon(\xi_i)}{\int d\xi \omega(\xi)\epsilon(\xi)}. \tag{4}$$

- Log-likelihood: Minimize $\mathcal{S}$ = -ln$\mathcal{L}$
- Minimization package FUMILI
- Background from sidebands have opposite sign correspond to data of log likelihood

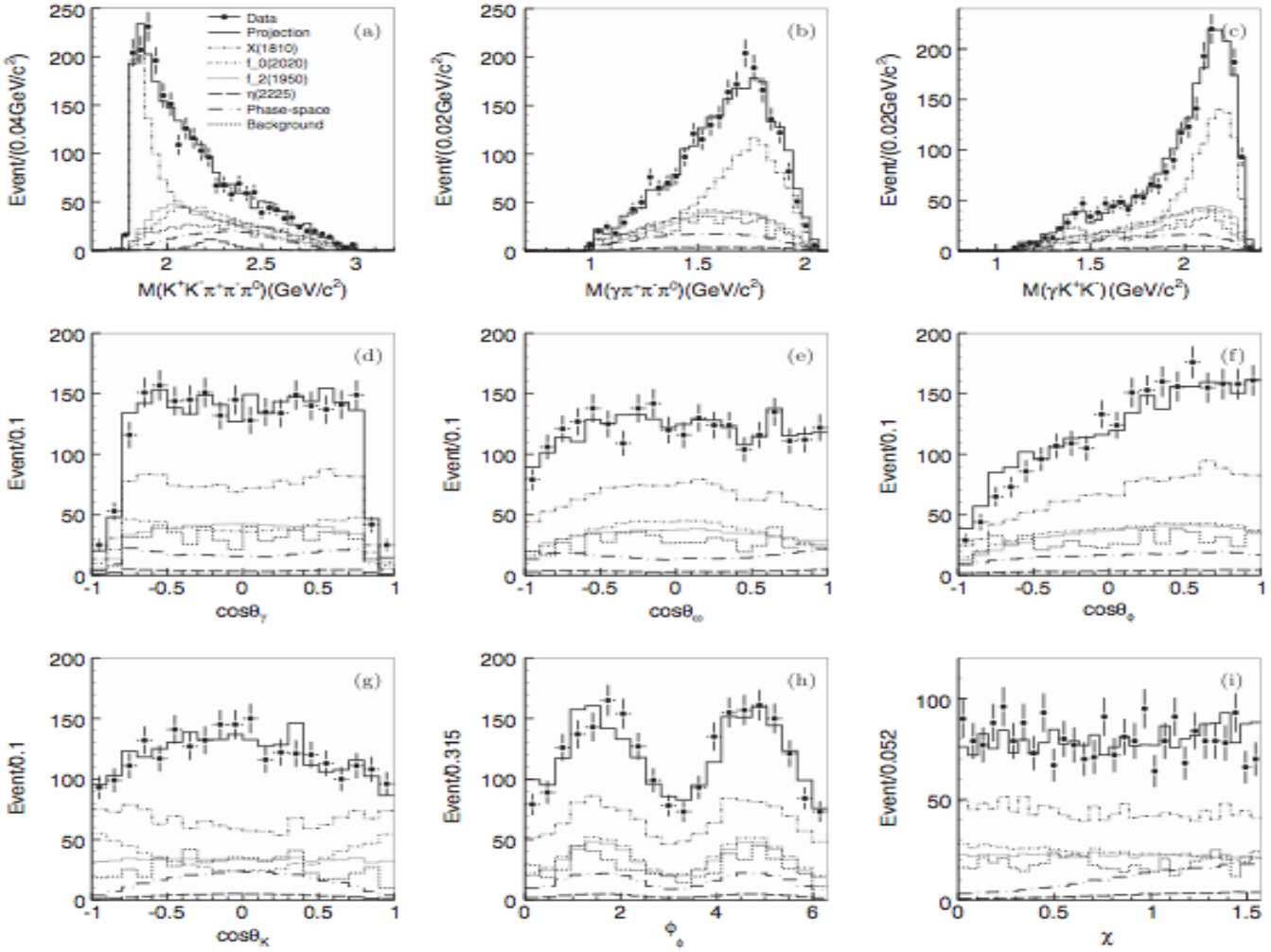
The best solution of the PWA fit

Table : Results from the best PWA fit solution.

Resonance	J^{PC}	M(MeV/c^2)	Γ(MeV/c^2)	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	20.4σ
$f_0(2020)$	0^{++}	1992	442	13.9σ
$\eta(2225)$	0^{-+}	2226	185	6.4σ
non-resonant	0^{-+}	—	—	9.1σ

- Five components in the best PWA fit.
- The spin parity of the $X(1810)$ is 0^{++}.
- The statistical significance of the $X(1810)$ is more than 30σ.
- The masses and widths for the $f_2(1950)$, $f_0(2020)$ and $\eta(2225)$ are fixed to their PDG values.

Comparisons between data and PWA fit



Variable	$M(K^+K^-\pi^+\pi^-\pi^0)$	$M(\gamma\pi^+\pi^-\pi^0)$	$M(\gamma K^+K^-)$	θ_γ	θ_ω	θ_ϕ	θ_K	ϕ_ϕ	χ
χ^2	44.4	36.4	42.4	24.2	12.4	28.2	18.2	26.4	51.0
ndf	40	35	40	20	20	20	20	20	30
χ^2/ndf	1.11	1.04	1.06	1.21	0.62	1.41	0.91	1.32	1.70

Additional fits with different assumptions

- Components in the best fit
  - Different J^{PC} of the $X(1810)$, the nonresonant component.
  - Different 0^{++}, 2^{++} and 0^{-+} components.
  - Different combinations of additional states.
- Resonance parametrization: Flatté formula describe the structure $X(1810)$. Test two cases:
  - With $g_{\omega\phi} = 1$, $g_{KK} = 0$
  - with $g_{\omega\phi} = 0.5$, $g_{KK} = 0.5$

- First systematic error: Difference between the best and worst solution
- Second systematic error: Difference between resonance resonance parametrization

Summary of the $X(1810)$

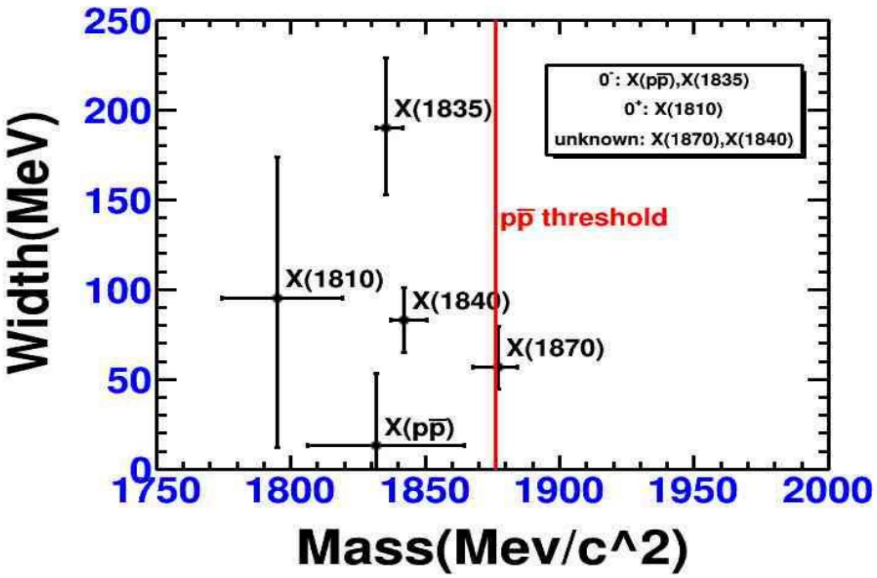
The $X(1810)$:

- $M = 1795 \pm 7(\text{stat})^{+13}_{-5}(\text{syst}) \pm 19(\text{mod})$ MeV$/c^2$
- $\Gamma = 95 \pm 10(\text{stat})^{+21}_{-34}(\text{syst}) \pm 75(\text{mod})$ MeV$/c^2$
- $\mathcal{B}(J/\psi \to \gamma X(1810)) \times \mathcal{B}(X(1810) \to \omega\phi) =$ $(2.00 \pm 0.08(\text{stat})^{+0.45}_{-1.00}(\text{syst}) \pm 1.30(\text{mod})) \times 10^{-4}$

★ Our results are consistent within errors with those from the BESII experiment.

★ The large measured branching fractions ($\sim$1/2 of $\mathcal{B}(J/\psi \to \gamma\phi\phi)$ is surprising and interesting.

Comparison of BESIII observation



- Based on 225M J/ψ event sample.
- Are they the same particle?
- It is crucial to identify them.

$X(18??)$ at BESIII

- $X(1860)$ in $J/\psi \to \gamma p\bar{p}$ (PRL 108, 112003 (2012))
- $X(1835)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$ (PRL 106, 072002 (2011))
- $X(1870)$ in $J/\psi \to \omega\eta\pi\pi$ (PRL 107, 182001 (2011))
- $X(1840)$ in $J/\psi \to \gamma 3(\pi^+\pi^-)$ (PRD 88, 091502 (2013))
- $X(1810)$ in $J/\psi \to \gamma\omega\phi$ (PRD 87, 032008 (2013))

Thank you very much for your attention!