Measurement of inclusive branching fraction for $\psi(3686) \rightarrow \phi X$

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Outline

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- Cross section analysis
- Systematic uncertainties
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Introduction

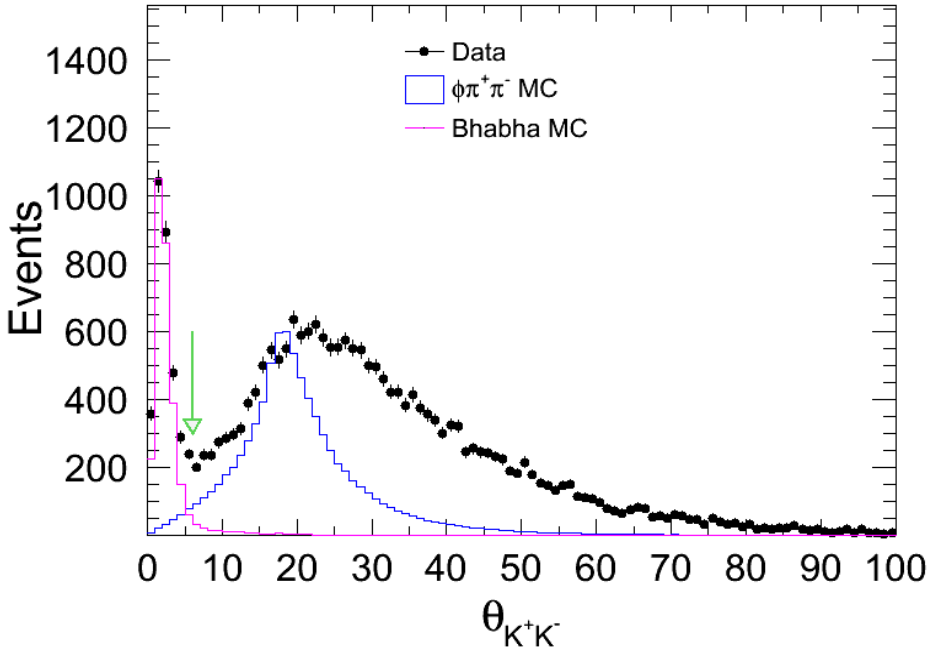
- The decay of $\psi(3686)$ provide a place to test predictions based on quantum chromodynamics (QCD). Its property has been studied for more than 40 years.
- Comparison of inclusive and exclusive branching fractions would provide us information of the unmeasured exclusive decay final states, which would guide us to study more exclusive channels and search for intermediate states in those decay channels.
- However, no inclusive branching fractions have been reported in PDG. Based on the data sample taken with BES-III, this analysis reports the first measurement of the inclusive decays of the $\psi(3686)\rightarrow\phi X$ (X=anything).

Data and Monte Carlo

- **Boss Version:**
  - 6.6.4.p01.
- **Data:**
  - Data taken in the energy range of 3.64~3.71 GeV in 2010;
- **Monte Carlo:**
  - Kinds of Monte Carlo events are generated with KKMC + BesEventGen, 500000 MC samples are generated for every process at 7 energy points (3.64, 3.65, 3.66, 3.67, 3.68, 3.69, 3.70 GeV).
    - **(1) $\gamma_{ISR}\psi'$ (2) $\gamma_{ISR}J/\psi$ (3) qqbar**
  - To estimate QED background, we use the large IncMC samples generated at 3.773 GeV.
    - **(1) Bhabha (2) Dimu (3) Ditau**

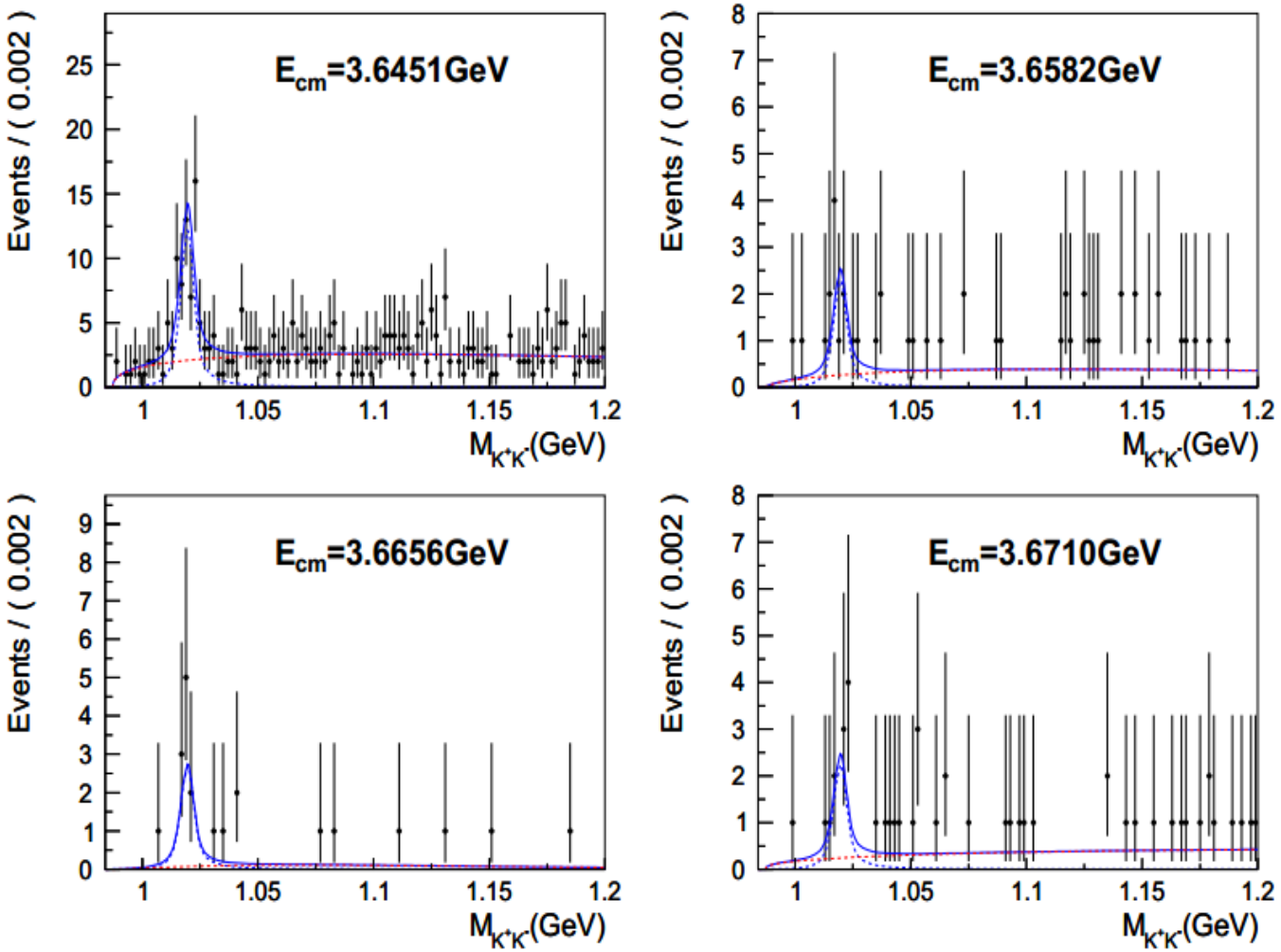
Event Selection

- **Charged track selection:**
  - $|R_{xy}| < 1.0$ cm;
  - $|R_z| < 10.0$ cm;
  - $|\cos\theta| < 0.93$;
- **Number of charged tracks satisfy:**
  - $N_{\text{good charge}} \geq 2$;
- **Particle identification:**
  - K: CL(K)>CL(π);
- **To reject Bhabha background:**
  - The angle between K^+K^- is required to be larger than 6.



K^+K^- Invariant Mass Spectrum

The invariant mass distribution of K^+K^- is fitted to obtain the number of signal events.

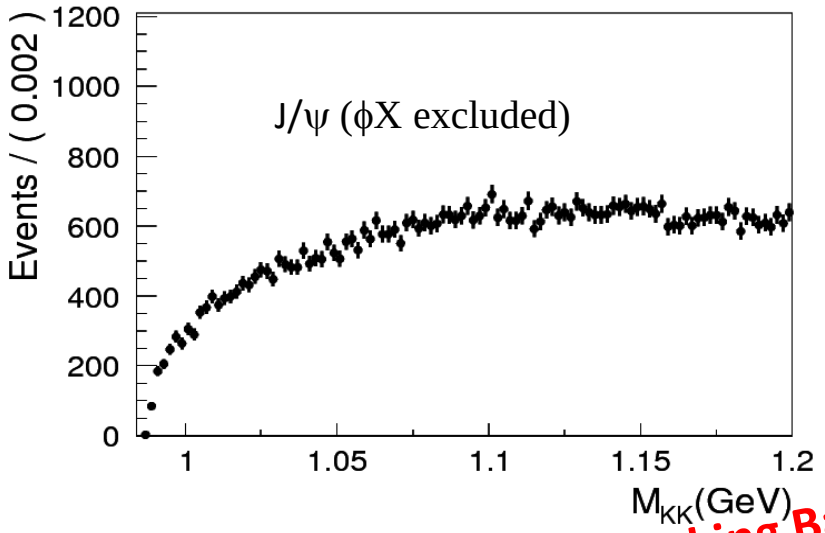


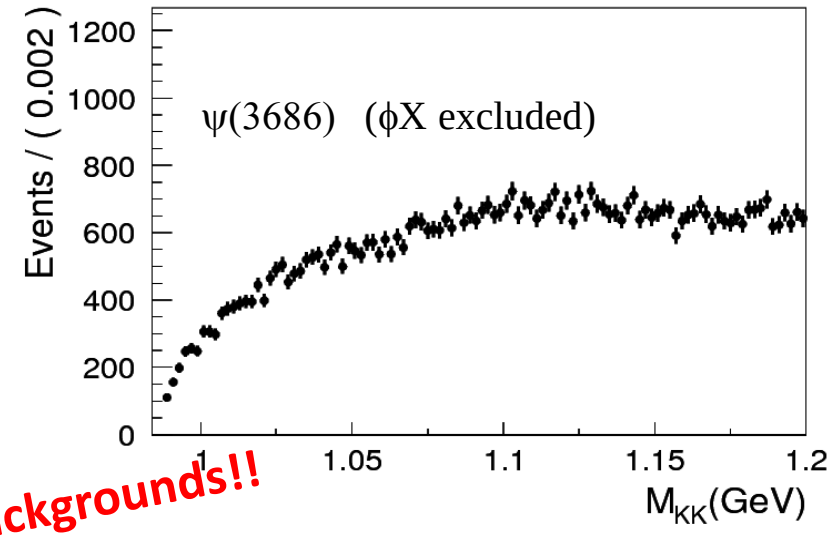
Signal shape:
Monte Carlo Shape convolved by a Gaussian

Background shape:
Argus function

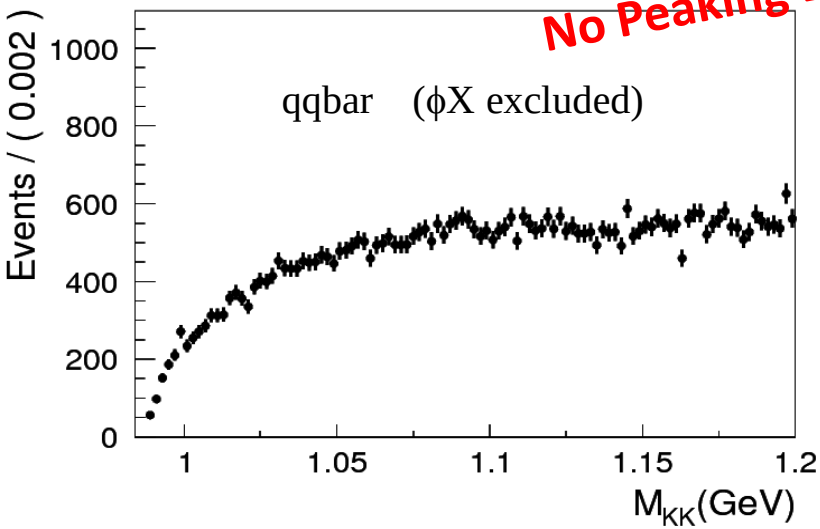
Backgrounds

When analyzing backgrounds, the signal events are excluded.



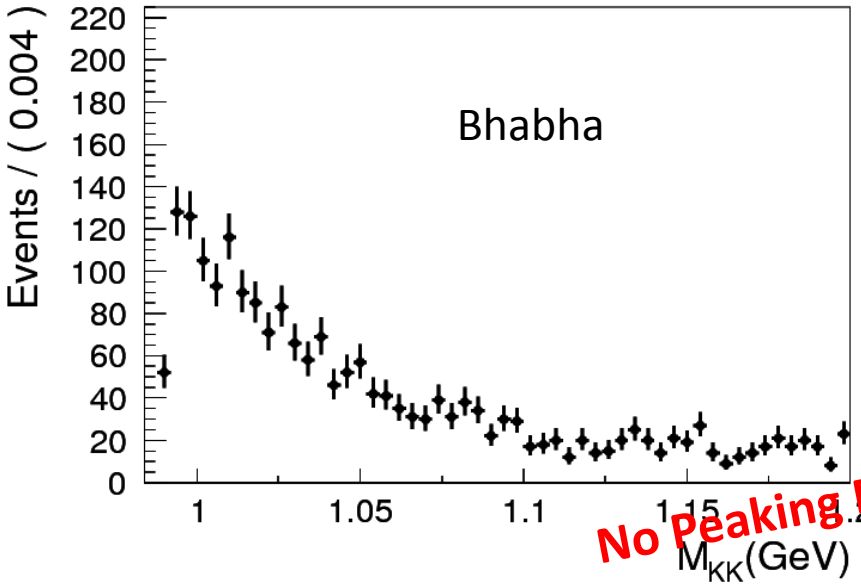


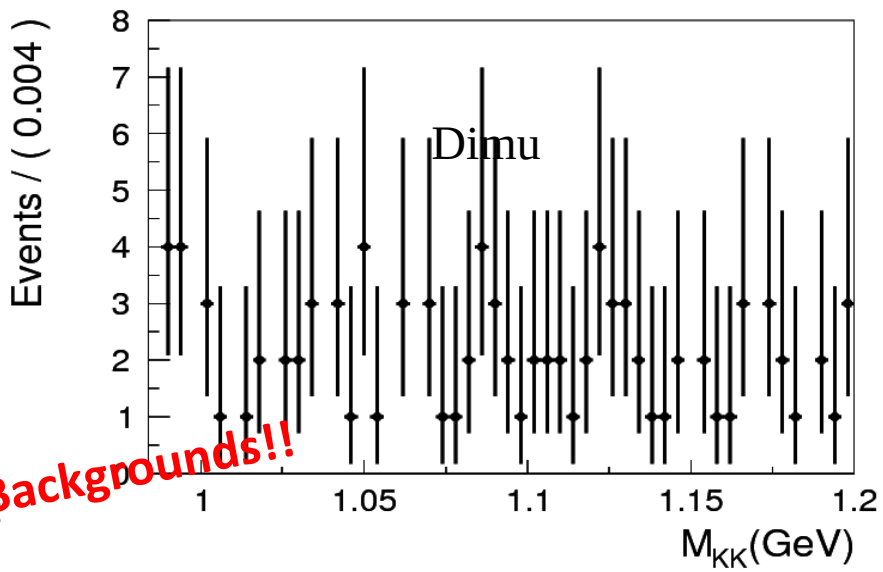
No Peaking Backgrounds!!



Backgrounds

Based on 3773 IncMC





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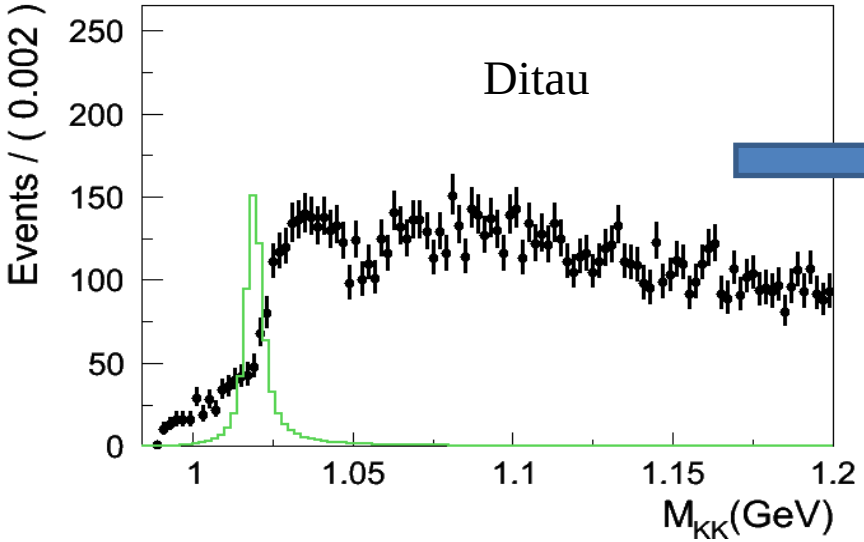
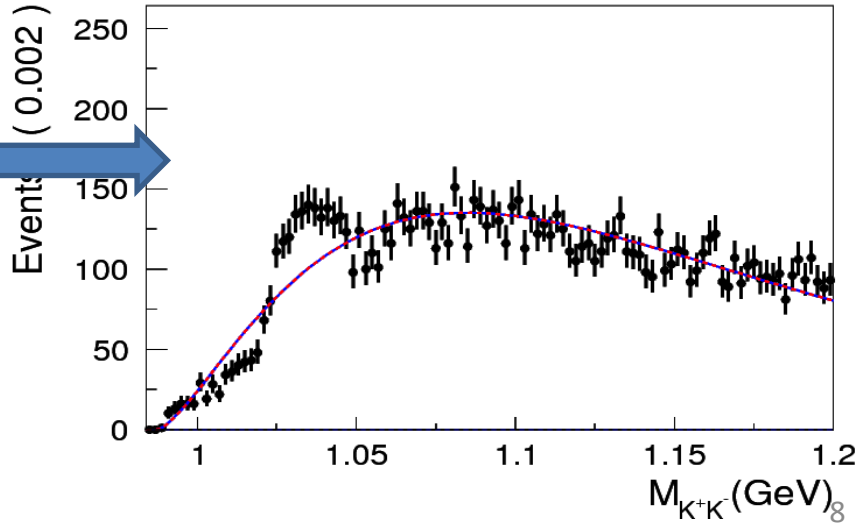
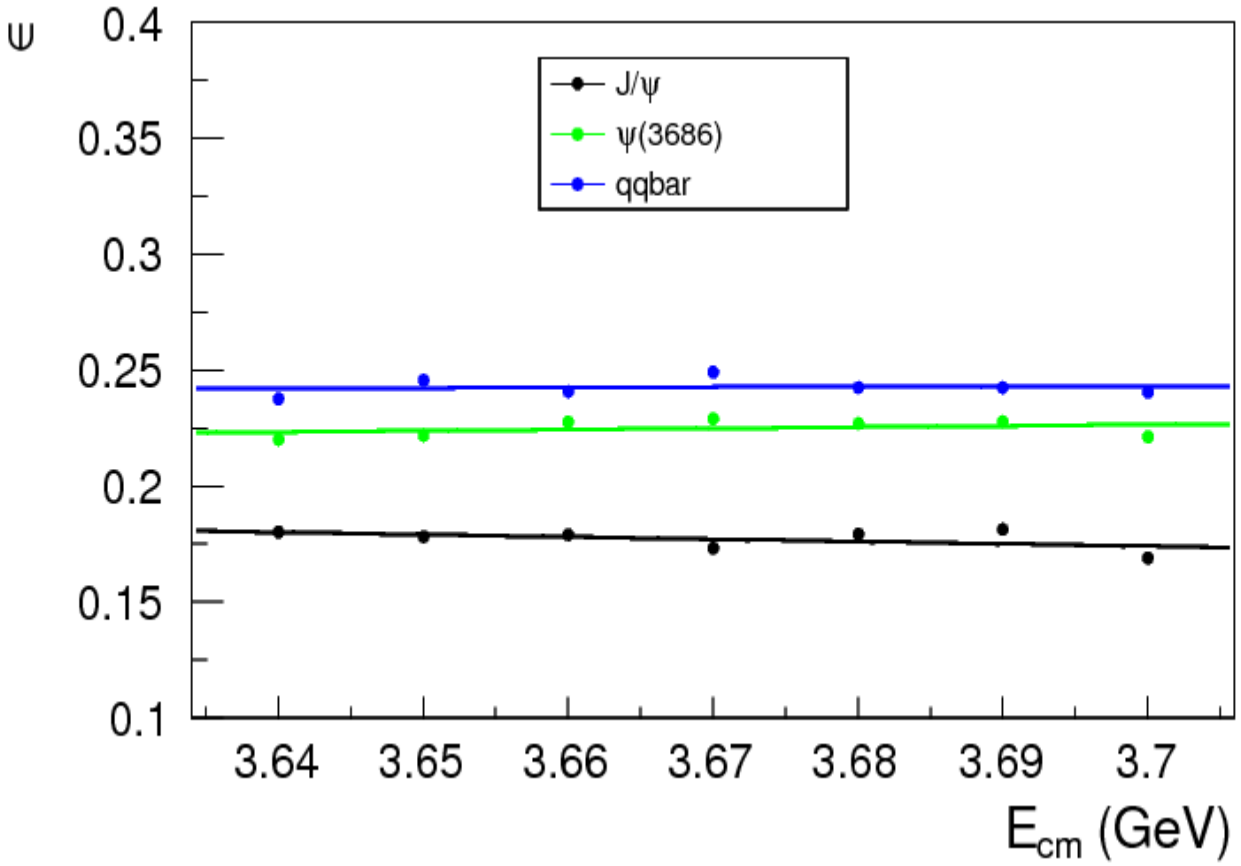




Detection Efficiency

Efficiencies of every components are considered separately before obtaining the average efficiency.

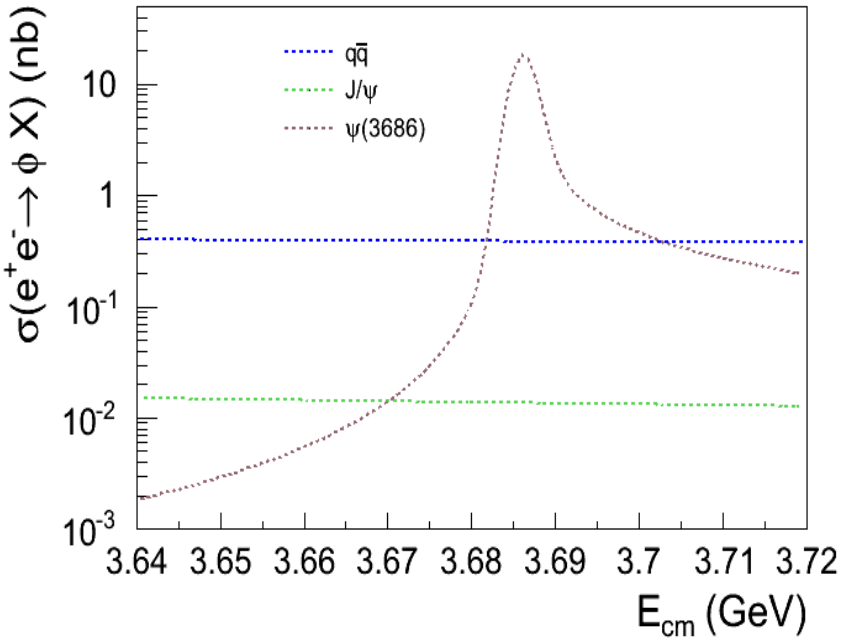


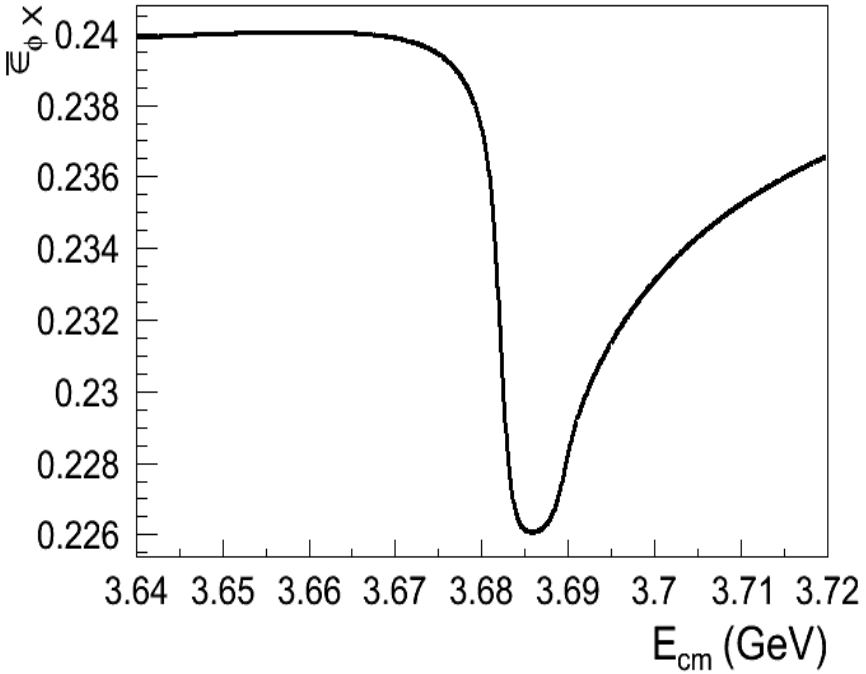
500000 J/ψ, ψ(3686) and qqbar Monte Carlo are generated at 7 points. From those samples, we selected the ϕX events and calculated efficiencies.

Detection Efficiency

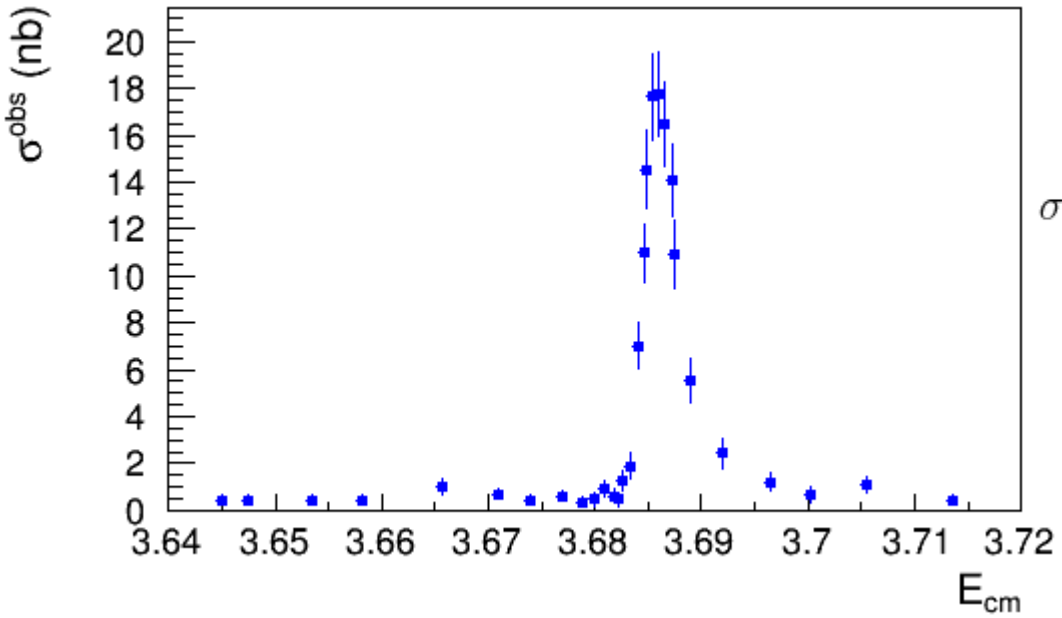
The average efficiency is obtained using the cross sections of those components .

$$\bar{\epsilon}_{\phi X} = \frac{1}{\sigma_{\phi X}^{J/\psi} + \sigma_{\phi X}^{\psi(3686)} + \sigma_{\phi X}^{qqbar}} (\sigma_{\phi X}^{J/\psi} \times \epsilon_{J/\psi} + \sigma_{\phi X}^{\psi(3686)} \times \epsilon_{\psi(3686)} + \sigma_{\phi X}^{qqbar} \times \epsilon_{qqbar})$$





Observed Cross Section



Observed cross section :

$$\sigma^{obs}_{e^+e^-\to\phi X} = \frac{N^{obs}_{e^+e^-\to\phi X}(E_{cm,i})}{L(E_{cm,i}) \times \epsilon_{e^+e^-\to\phi X}(E_{cm,i})}$$

- N^{obs}: Number of signal events;
- L : Luminosity;
- ε : Efficiency;

Analysis of Observed Cross Section

- A maximum likelihood fit is performed to the observed cross sections.
- **Expected number of signal events:**

$$N_i^{expected} = Lum_i \times \sigma_i^{exp} \times \bar{\epsilon}$$

$$\sigma_{\phi X}^{exp} = \int_0^{\infty} ds' G(s, s') \int_0^1 dx \cdot \sigma_{\phi X}^{Dress}(s(1-x)) F(x, s)$$

Sampling function
Yad. Fiz. 41 (1985) 733.

Gaussian function

$$\sigma_{\phi X}^{Dress} = |A_{J/\psi}|^2 + |A_{\psi(3686)}|^2 + |A_{\text{continuum}}|^2$$

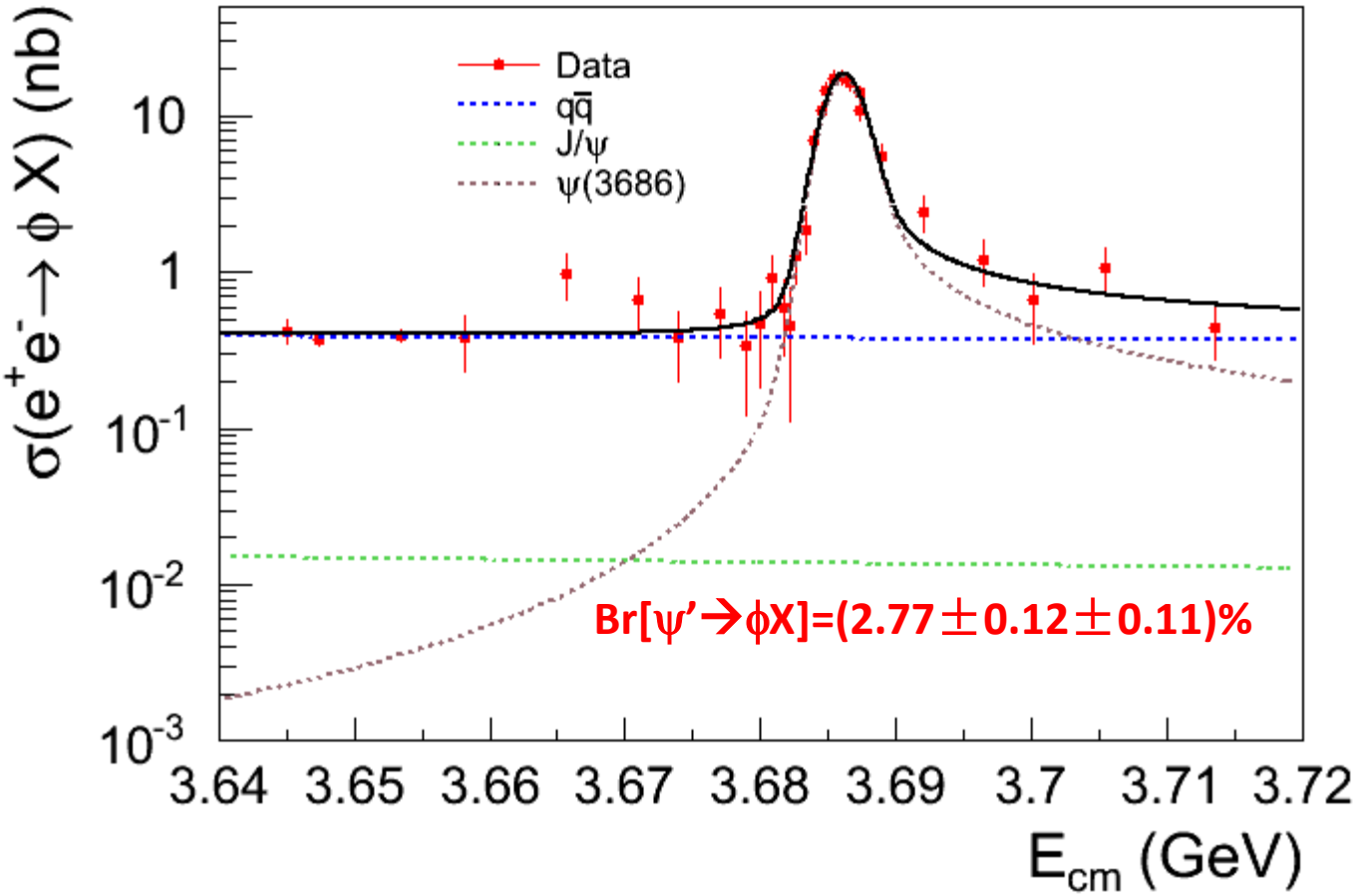
Breit-Wigner function

$$A_{\text{continuum}} = \sqrt{\frac{f}{E_{\text{cm}}^n}}$$

- **Likelihood:**

$$\mathcal{L} = \prod P_i \qquad P_i = \begin{cases} \text{Gaussian function, if } n \geq 12 \\ \text{Poisson function, if } n < 12 \end{cases}$$

Analysis of Observed Cross Section



The branching fraction in PDG(including $\psi(3686)\to\phi\pi^+\pi^-$, ϕK^+K^-, $\phi\eta$, $\phi\eta'$, $\phi f'_2(1525)$, $\psi(3686)\to J/\psi X\to\phi X$, and $\psi(3686)\to J/\psi X\to\phi X$):

$$Br[\psi'\to\phi X]=(9.89\pm0.39)\times10^{-3}$$

Systematic Uncertainties – Cross Section

Sources

- Uncertainty in angle θ_{K+K-} cut;
- Uncertainty in fitting mass spectrum;
- Uncertainty in MDC tracking for the kaons;
- Uncertainty in PID for the kaons;
- Uncertainty in branching fraction for $\phi \rightarrow K^+K^-$;
- Uncertainty in the luminosity.

Systematic Uncertainties – Cross Section

$\theta_{K^+K^-}$ cut

- The cross section is also determined with the $\theta_{K^+K^-}$ selection requirements ranging from $\theta_{K^+K^-} > 4^\circ$ to $\theta_{K^+K^-} > 8^\circ$;
- The differences from the standard selection of $\theta_{K^+K^-} > 6^\circ$ are all less than 0.15%;
- To be conservative, we take **0.2%** as the systematic error due to the $\theta_{K^+K^-}$ selection in this work.

Systematic Uncertainties – Cross Section

Fitting mass spectrum

- To estimate the uncertainties due to fits to the M_{KK} distributions, we refit the distribution by varying:
  - **Background shape**
    - 4^{th} order polynomial — 0.29%
  - **Fit region** — 1.31%
  - **Bin width** — 1.37%
- Total systematic uncertainty from fit to mass spectrum:

$$\sqrt{0.29^2 + 1.31^2 + 1.37^2}\% = 1.92\%$$

Systematic Uncertainties – Cross Section

Quoted systematic uncertainties

- **MDC tracking**
  - 1.0% per kaon; (PLB 753 (2016) 103-109)
- **K PID**
  - 1.0% per kaon; (PLB 753 (2016) 103-109)
- **Branching Fraction**
  - Br[$\phi \rightarrow K^+K^-$]=(48.9$\pm$0.5)%(PDG2016)
  - 1.0%.
- **Luminosity**
  - 1.0%. (Chin. Phys. C 37,123001 (2013))

Systematic Uncertainties – Cross Section

Summary

Source	Systematic uncertainty(%)
$\theta_{K^+K^-} > 6^\circ$	0.20
Fit to $M_{K^+K^-}$ spectrum	1.92
MDC tracking	2.00
K PID	2.00
Br[$\phi \rightarrow K^+K^-$]	1.00
Luminosity	1.00
Total	**3.70**

Systematic Uncertainties – Br[ψ(3686)→ ϕX]

- To obtain the systematic uncertainty of branching fraction, we change the values of the observed cross sections by $\pm 1\sigma$ of systematic uncertainty and refit the cross sections. The absolute differences in branching fraction is less than 0.11%, which is taken as the systematic uncertainty of Br[ψ(3686)→ ϕX].

Summary

- The observed cross section of $e^+e^- \rightarrow \phi X$ in the energy range from 3.64 to 3.71 GeV have been measured.
- By analyzing the observed cross section measured at those energy points, the branching fraction of $Br[\psi(3686) \rightarrow \phi X]$ is determined to be:

$$\mathbf{Br[\psi(3686) \rightarrow \phi X] = (2.77 \pm 0.12 \pm 0.11)\%}$$

- The branching fraction of $Br[\psi(3686) \rightarrow \phi X]$ measured in this work is much larger than that in PDG, which means many exclusive channels should be searched for.

Thank You!