# Search for Zs in $e^+e^-\to\phi\pi\pi$ at Ecm=2.125GeV

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the 12th International Workshop on Heavy Quarkonium

2017.11.6-10

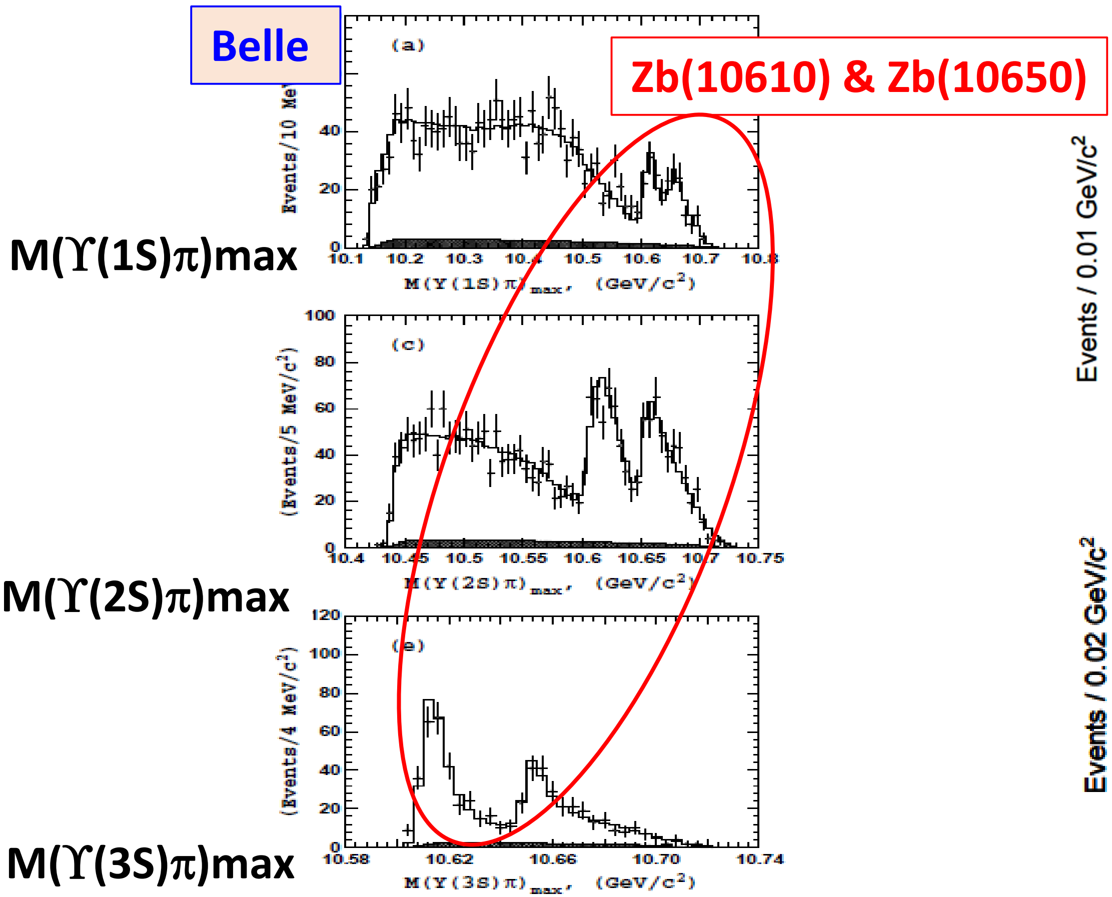
# Outline

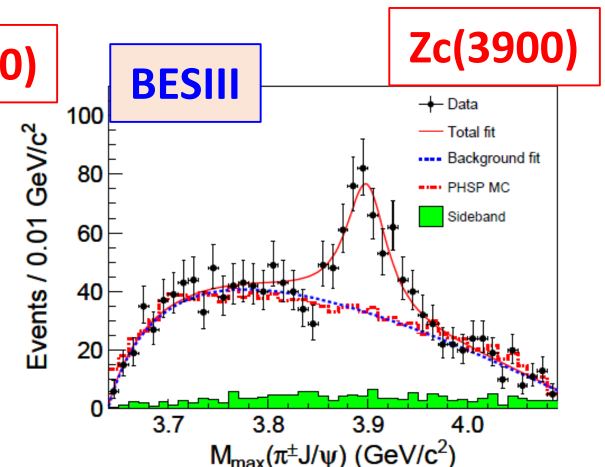
- **Introduction**
- **Search for Zs in $e^+e^-\to\phi\pi\pi$**
- **Cross section for $e^+e^-\to\phi\pi\pi$ @2.125 GeV**
- **Systematic uncertainties**
- **Summary**

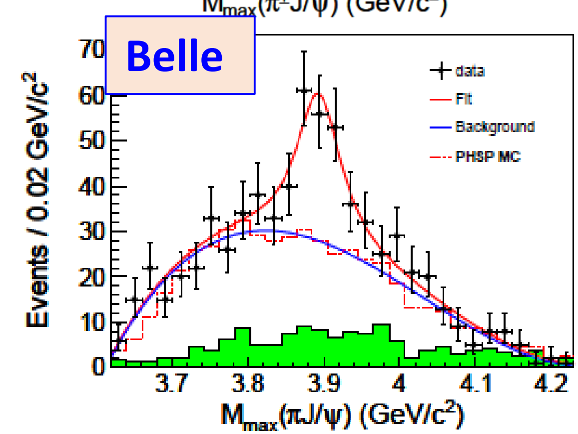
# Introduction

$$e^+e^- \Rightarrow \begin{cases} \Upsilon(5S) & \rightarrow \Upsilon(1S,2S,3S)\pi^+\pi^- & \text{bottom} \\ Y(4260) & \rightarrow J/\psi\pi^+\pi^- & \text{charm} \\ Y(2175) & \rightarrow \phi(1020)\pi^+\pi^- & \text{strange} \end{cases}$$

| |
|---|
| Phys.Rev.Lett.108.122001(2012) |
| Phys. Rev. Lett. 110,252001(2013) and Phys. Rev. Lett. 110, 252002 (2013) |
| Phys. Rev. D80,031101(2009) |



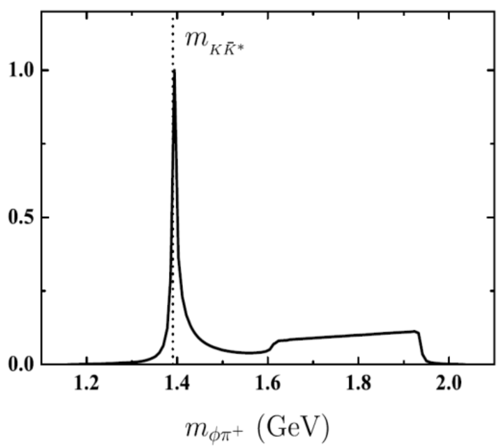



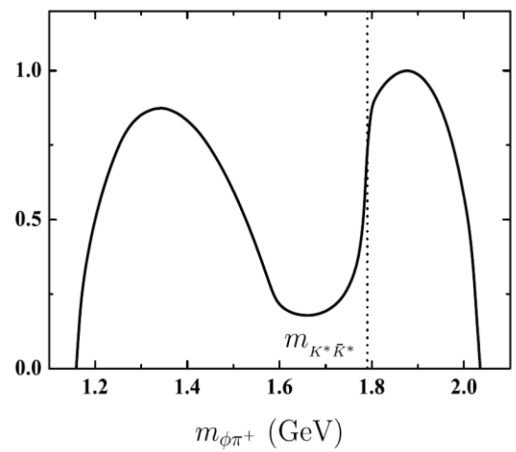



# Introduction

- The study of Y(2175)$\rightarrow\phi\pi^+\pi^-$ via the Initial Single Pion Emission (ISPE) mechanism indicates that there exist two charged strangeonium-like structures

Eur. Phys. J. C72, 2008(2012)



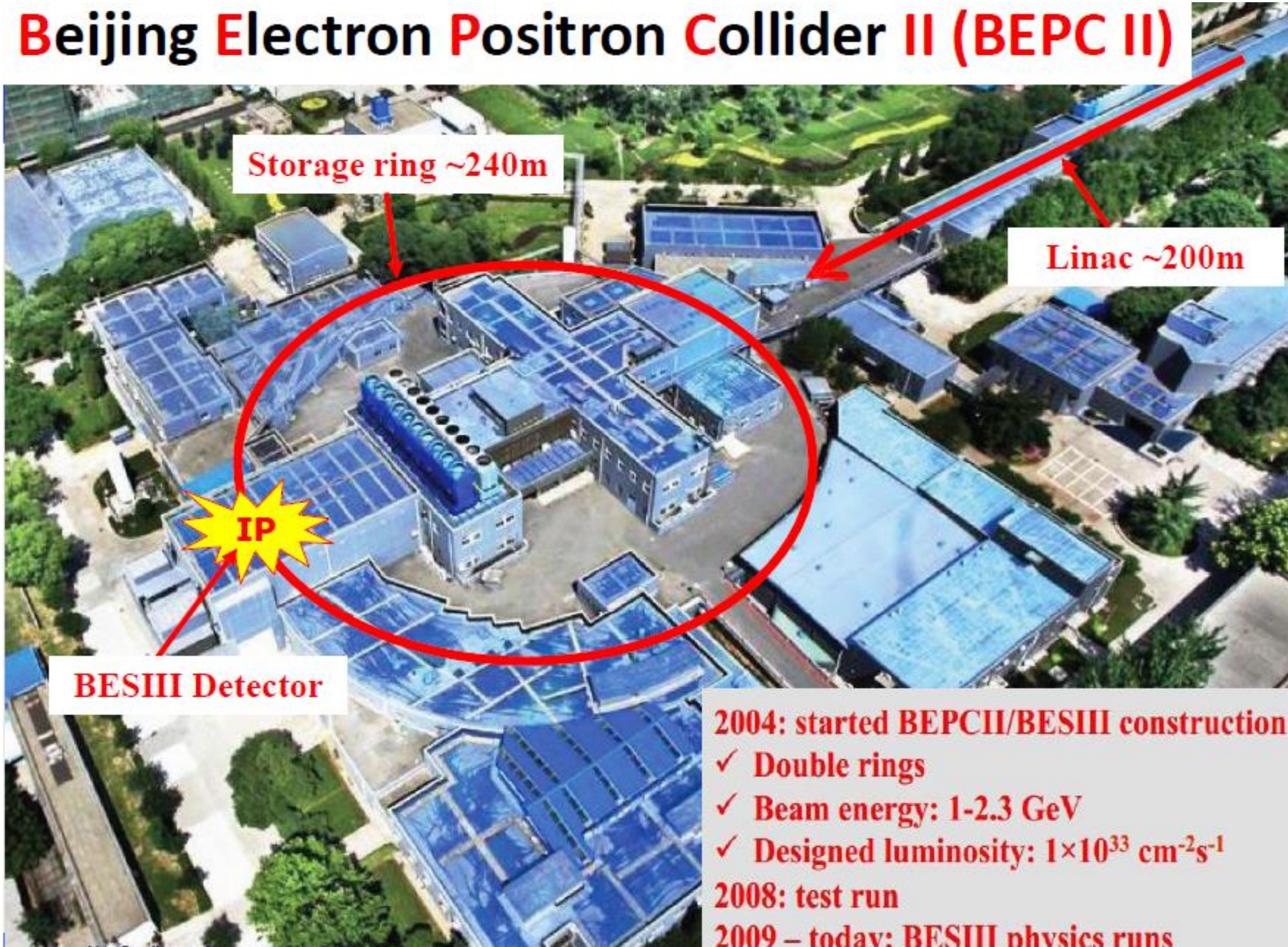




**a sharp peak structure $Z_{s1}^{\pm}$ close to KK* threshold**

**a broad structure $Z_{s2}^{\pm}$ near K*K* threshold**

- Search for the strangeonium-like structure ($Z_{s1}$) in $e^+e^-\rightarrow\phi\pi\pi$ @2.125 GeV, provides more experimental information for Y(2175)

# Beijing Electron Positron Collider II (BEPC II)

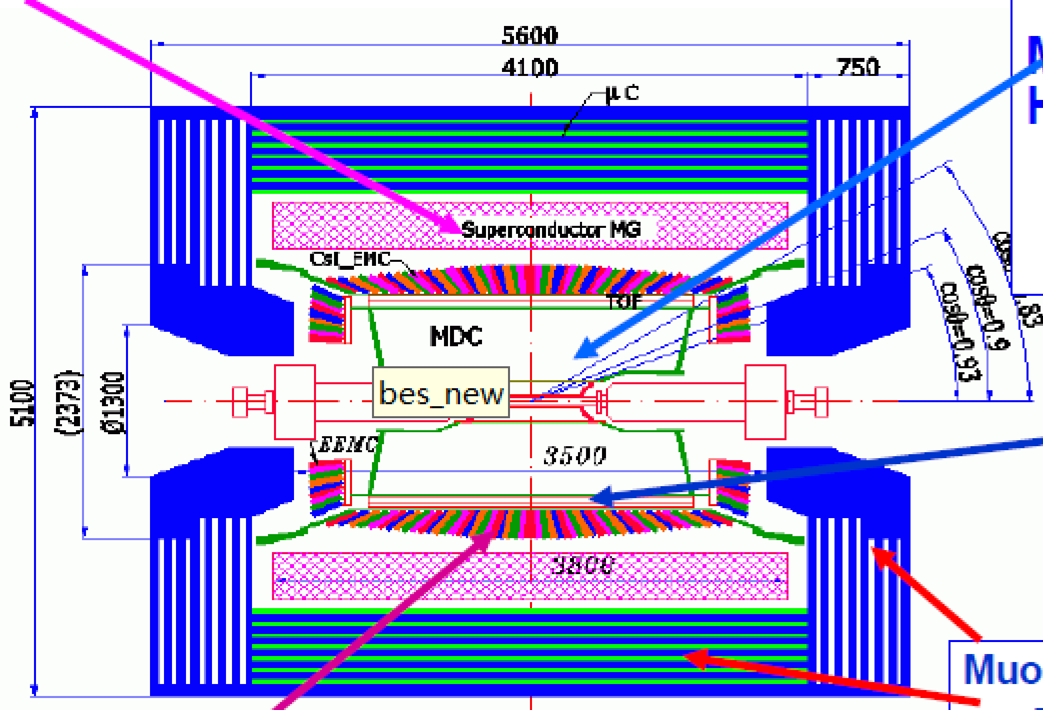



**2004: started BEPCII/BESIII construction**
- ✓ **Double rings**
- ✓ **Beam energy: 1-2.3 GeV**
- ✓ **Designed luminosity: $1\times10^{33}$ cm$^{-2}$s$^{-1}$**

**2008: test run**
**2009 – today: BESIII physics runs**

# The BESIII detector

**Solenoid Magnet: 1 T Super conducting**




**MDC: small cell & He gas**

$\sigma_{xy}$=130 μm

$\delta p/p$ = 0.5% @1GeV

dE/dx=6%

**TOF:**

$\sigma_T$ = 90 ps Barrel

110 ps Endcap

**Muon ID: 8~9 layer RPC**

$\sigma_{R\Phi}$=1.4 cm~1.7 cm

**EMCAL: CsI crystal**

$\Delta E/E$ = 2.5% @1 GeV

$\sigma_{\varphi,z}$ = 0.5~0.7 cm/$\sqrt{E}$

**Data Acquisition:**

Event rate = 3 kHz

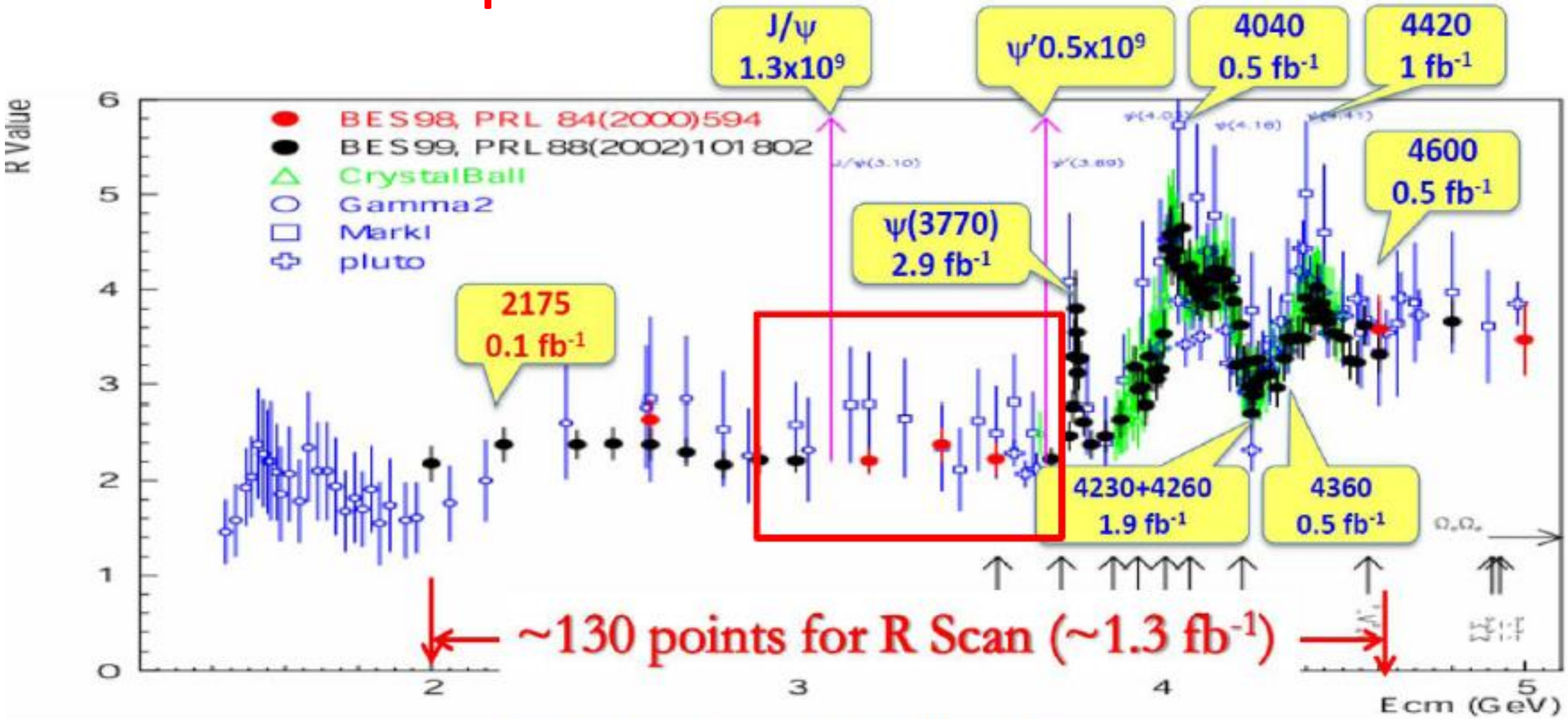
Throughput ~ 50 MB/s

**Trigger: Tracks & Showers**

Pipelined; Latency = 6.4 μs

**The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.**

# Data Sample




3.1 $fb^{-1}$ data at 4.18 GeV, 2016

World largest J/ψ, ψ(3686), ψ(3770), … produced directly from $e^+e^-$ collision:
an ideal factory to study light meson spectroscopy

# Event selection

- Data sets @ 2.125 GeV
  $L_{int} = (108.49 \pm 0.75)\ pb^{-1}$ (**arXiv:1705.09722**)

**$e^+e^- \to \phi\pi^+\pi^-$** with $\phi \to K^+K^-$

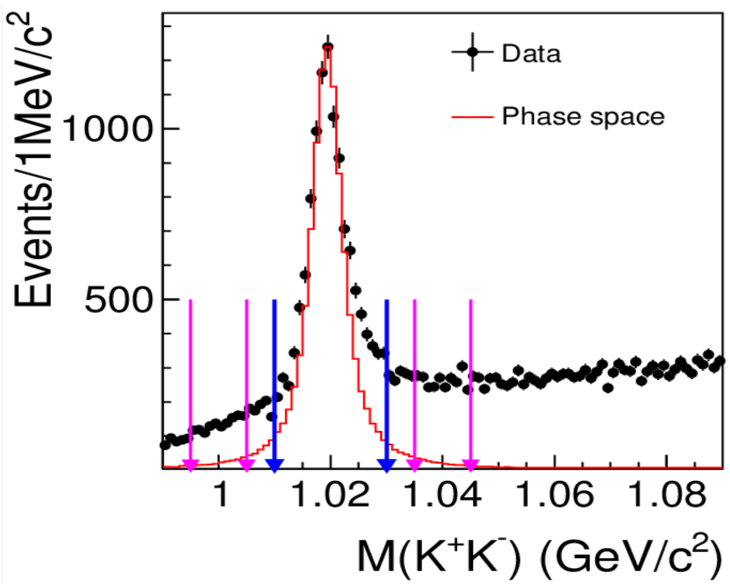
- Charged tracks
  - ✓ Ngood = 3 || 4
- PID:
  - ✓ two pions are identified
  - ✓ at least one K is identified
- 1C kinematic fit (missing one K)
  - ✓ $\chi^2_{1C}<10$

**$e^+e^- \to \phi\pi^0\pi^0$** with $\phi \to K^+K^-$& $\pi^0 \to \gamma\gamma$

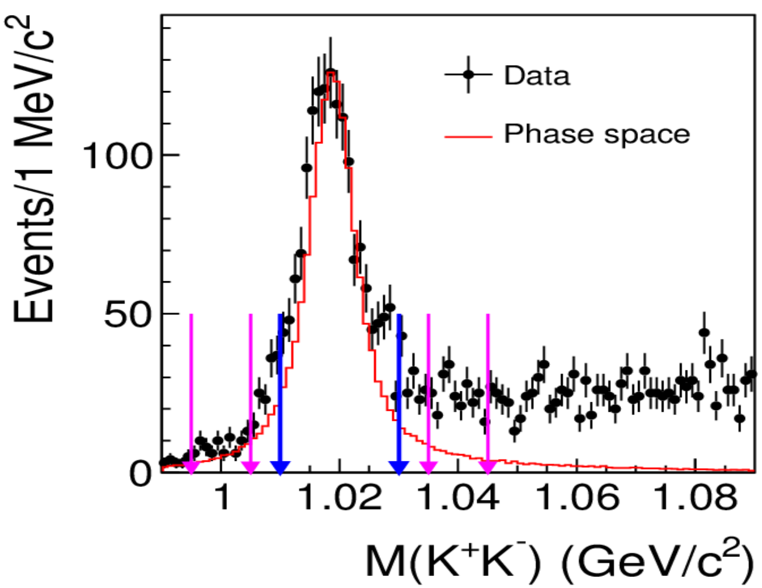
- Charged tracks
  - ✓ Ngood = 1 || 2
- PID: identify at least one K
- At least 4 good photons
- 1C kinematic fit
  - ✓ $\chi^2_{1C}<20$
- $\pi^0$ reconstruction
  - ✓ $\chi^2_{min} = \sqrt{|M(\gamma_1\gamma_2) - M(\pi^0)|^2 + |M(\gamma_3\gamma_4) - M(\pi^0)|^2}$

# $K^+K^-$ mass spectra

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




$e^+e^- \to \phi\pi^0\pi^0$



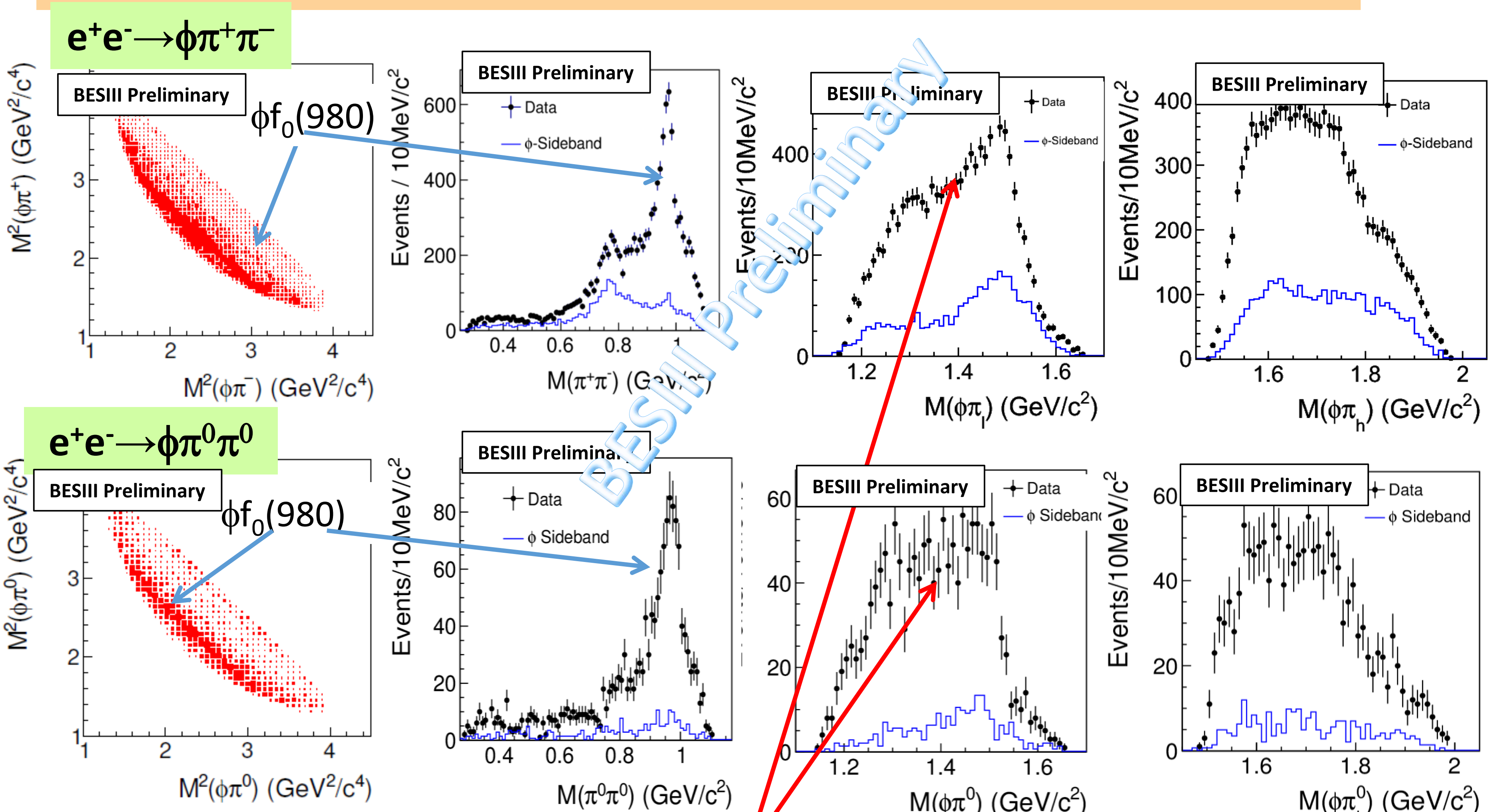

**Signal region:**

$|M(K^+K^-)-M(\phi)|<0.01 GeV/c^2$

**Sideband region:**

$(0.995,1.005)\&\&(1.035,1.045)\ GeV/c^2$

# Dalitz plot for $e^+e^-\to\phi\pi\pi$ and mass spectra with $|M(K^+K^-)-M(\phi)|<0.01\mathrm{GeV}/c^2$




**No obvious $Z_S$ signal around 1.4GeV in $M(\phi\pi_l)$**

# Background study with $\phi$ signal

- **To describe data without Zs contribution (with $\phi$ signal), such as $\phi f_0(980)$, $\phi\sigma$…, PWA for the $\phi\pi\pi$ is performed.**

- Partial waves: $\phi\sigma$, $\phi f_0(980)$, $\phi f_0(1370)$, $\phi f_2(1270)$
  - For $f_0(980)$, Flatte formula is used[1] $f = \frac{1}{M^2 - s - i(g_1\rho_{\pi\pi} + g_2\rho_{K\bar{K}})}$
  - For $f_0(1370)$, simple BW is used[1]
  - For $\sigma$[2] $f = \frac{G_\sigma}{M^2 - s - iM\Gamma_{\rm tot}(s)}$,

$$\Gamma_{\rm tot}(s) = g_1\frac{\rho_{\pi\pi}(s)}{\rho_{\pi\pi}(M^2)} + g_2\frac{\rho_{4\pi}(s)}{\rho_{4\pi}(M^2)}, \quad g_1 = f(s)\frac{s - m_\pi^2/2}{M^2 - m_\pi^2/2}\exp[-(s - M^2)/a].$$

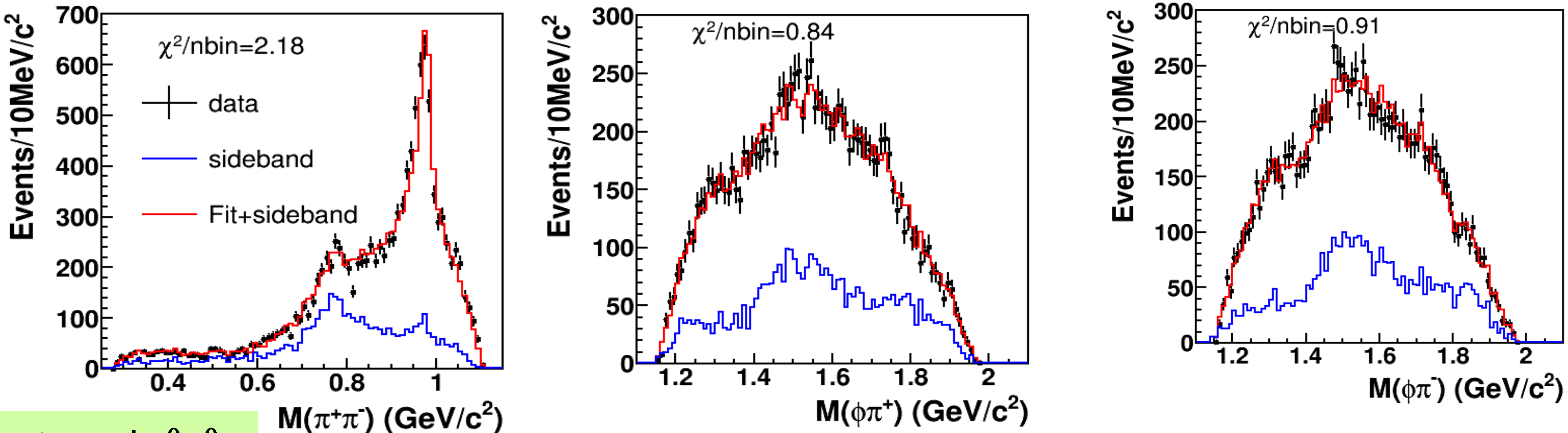
  - For $f_2(1270)$, energy-dependent BW is used [1]
- The parameters are all fixed accordingly
- Backgrounds from $\phi$ sideband is subtracted in Log-Likelihood

[1] Phys. Lett. B 607 (2005), 243
[2] Phys. Lett. B 598 (2004), 149

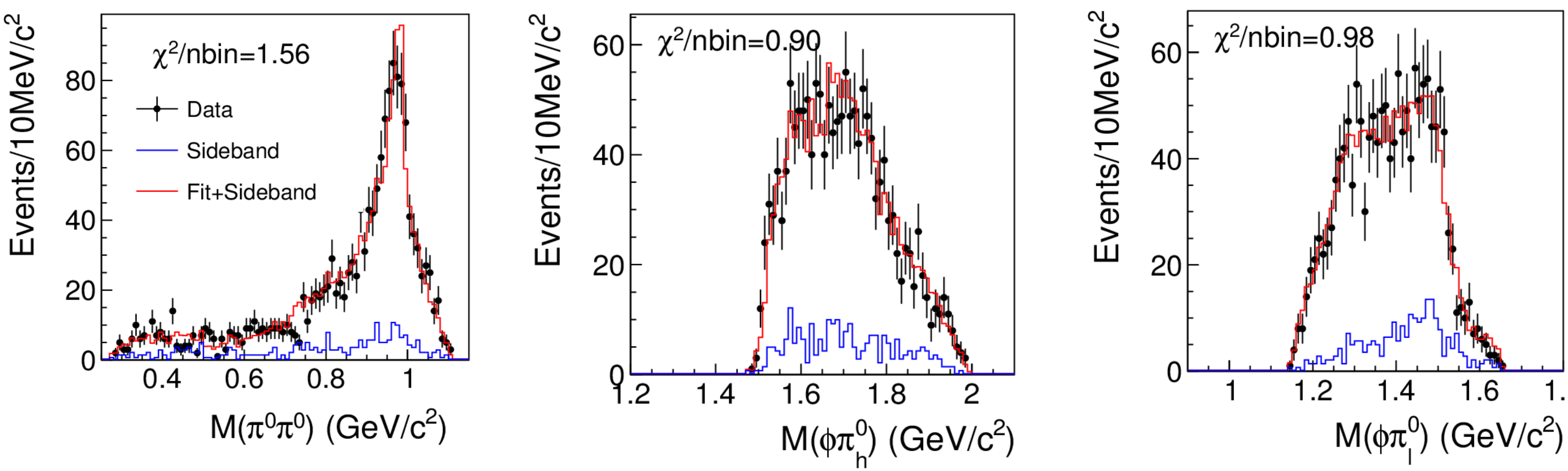
- **Based on the PWA results, a dedicated MC sample (mDIY)** modeled with decay amplitudes **is generated to determine the background contribution with $\phi$ signal and the reconstruction efficiency for $\sigma(e^+e^-\to\phi\pi\pi)$ @2.125 GeV.**

# Projection on M(ππ) and M(ϕπ) from PWA

**$e^+e^-\to\phi\pi^+\pi^-$**




**$e^+e^-\to\phi\pi^0\pi^0$**



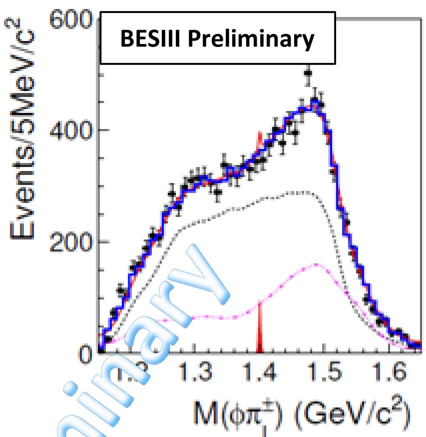
# Upper limit on $\sigma(e^+e^- \to Z_s\pi, Z_s \to \phi\pi)$

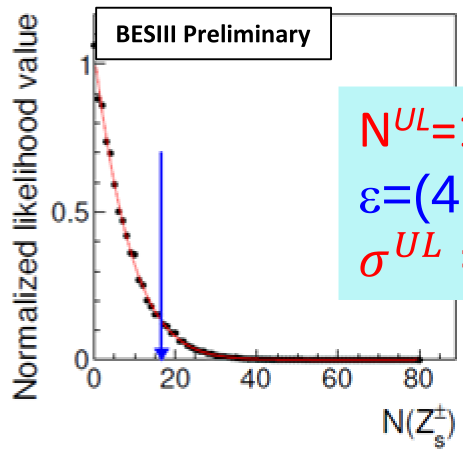
- Assume M=1.4GeV, $\Gamma$=0 for $Z_S$ in Ref. **Eur. Phys. J. C72, 2008(2012).**
- Phase space MC sample of $e^+e^- \to Z_s\pi@2.125GeV(Z_s \to \phi\pi)$ is used for $Z_S$ signal shape and to estimate the selection efficiency
- Fit $M(\phi\pi_l)$ with Zs signal + background shape with $\phi$ events from mDIY MC sample (modeled with decay amplitudes based on PWA ) + background with non-$\phi$ events (from $\phi$ sideband)
- By changing the fit range and background shape, the maximum number of Zs events is taken as the upper limit
- The uncorrelated systematic uncertainties (described in detail later) are taken into account by smearing the likelihood curves

# Upper limit on $\sigma(e^+e^- \to Z_s\pi, Z_s \to \phi\pi)$

$$\sigma^{UL}_{Z_s}(e^+e^- \to Z_s\pi, Z_s \to \phi\pi) = \frac{N^{UL}}{\mathscr{L}\boxed{(1+\delta)}\varepsilon\mathscr{B}}$$

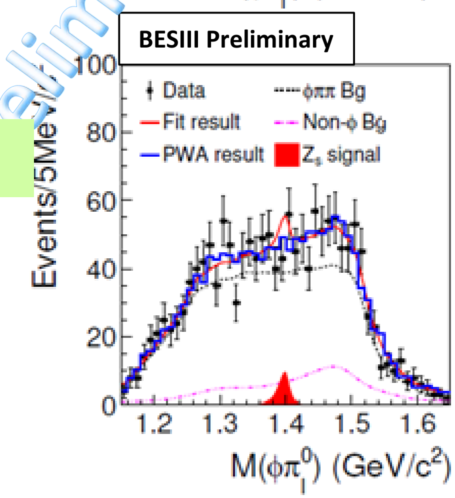
$e^+e^- \to \phi\pi^+\pi^-$

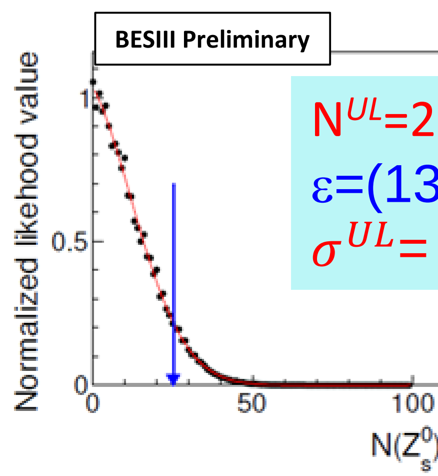



$N^{UL}$=16.6@90%C.L.
ε=(46.9±0.07)%
$\sigma^{UL}$ = 0.68 pb

$e^+e^- \to \phi\pi^0\pi^0$




$N^{UL}$=25.2@90%C.L.
ε=(13.7±0.05)%
$\sigma^{UL}$= 3.72 pb



- (1+δ) is the radiative correction, which is calculated to second-order in QED by assuming that the line-shape follows the measured cross section of the BaBar experiments[Phys. Rev. D86, 012008(2012)].

# Upper limit on Zs cross section

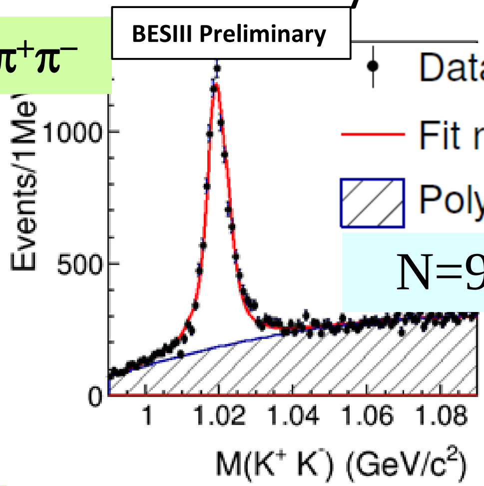
We also determine the upper limit by assuming its width to be 5 MeV or 10 MeV and its mass to be 1.38GeV or 1.42GeV, respectively.

| | Mass (GeV/$c^2$) | 1.380 | | | 1.400 | | | 1.420 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Width (MeV/$c^2$) | $N^{UL}$ | $\varepsilon$(%) | $\sigma^{UL}_{Z_s}$(pb) | $N^{UL}$ | $\varepsilon$(%) | $\sigma^{UL}_{Z_s}$(pb) | $N^{UL}$ | $\varepsilon$(%) | $\sigma^{UL}_{Z_s}$(pb) |
| $\phi\pi^+\pi^-$ | 0 | 22.2 | 47.3 | 0.90 | 16.6 | 46.9 | 0.68 | 44.4 | 46.8 | 1.82 |
| | 5 | 37.8 | 47.5 | 1.53 | 29.8 | 46.9 | 1.22 | 54.6 | 47.2 | 2.22 |
| | 10 | 49.6 | 47.5 | 2.01 | 40.2 | 47.4 | 1.63 | 60.8 | 47.3 | 2.47 |
| $\phi\pi^0\pi^0$ | 0 | 25.6 | 13.8 | 3.75 | 25.2 | 13.7 | 3.72 | 27.2 | 13.5 | 4.07 |
| | 5 | 28.0 | 13.8 | 4.10 | 28.6 | 13.7 | 4.22 | 30.2 | 13.5 | 4.52 |
| | 10 | 31.2 | 13.8 | 4.57 | 32.4 | 13.7 | 4.78 | 33.6 | 13.6 | 4.99 |

# Cross section for $e^+e^-\to\phi\pi\pi$ @2.125 GeV

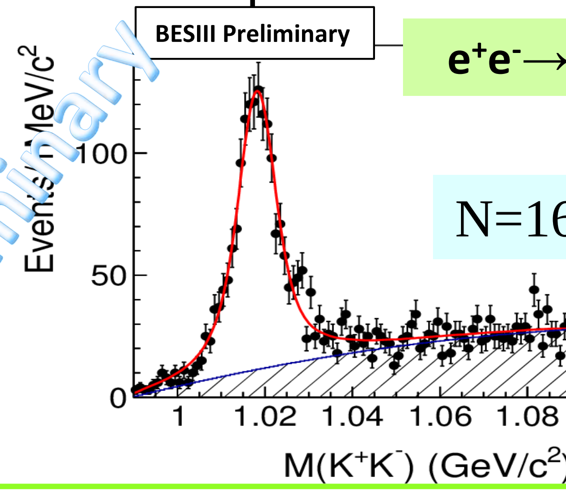
- Fit M(KK) with MC-shape ⊗ Gaussian + 2nd-order Chebychev polynomial background function
- Selection efficiency is estimated by mDIY MC sample

**$e^+e^-\to\phi\pi^+\pi^-$**




N=9421±138

**$e^+e^-\to\phi\pi^0\pi^0$**




N=1649±60



$\varepsilon=(52.7\pm0.1)\%$

the radiative correction factor:

$(1+\delta)=0.9823$

$$\sigma=\frac{N_{sig}}{L_{int}\cdot(1+\delta)\cdot\varepsilon\cdot Br(\phi\to K^+K^-)}=(343.0\pm5.1\pm22.3)\ \mathrm{pb}$$

$\varepsilon=(16.0\pm0.1)\%$

the radiative correction factor:

$(1+\delta)=0.955$

$$\sigma=\frac{N_{sig}}{L_{int}(1+\delta)\varepsilon Br(\phi\to K^+K^-)Br^2(\pi^0\to\gamma\gamma)}=(208.3\pm7.6\pm12.7)\ \mathrm{pb}$$

| | $\phi\pi^+\pi^-$ | |
|---|---|---|
| $E_{c.m.}$(GeV) | BaBar | Belle |
| 2.1125 | $510\pm50\pm21$ | $480\pm60\pm42$ |

Phys. Rev. D86,012008[Belle]
Phys. Rev. D80,031101[BaBar]

| | $\phi\pi^0\pi^0$ |
|---|---|
| $E_{c.m.}$(GeV) | BaBar |
| 2.10 | $195\pm50\pm14$ |

# Systematic Uncertainties

| Source | $Z_s^{\pm}$ | $\phi\pi^+\pi^-$ | $Z_s^0$ | $\phi\pi^0\pi^0$ |
|---|---|---|---|---|
| MDC tracking | 4.5 | 4.5 | 1.5 | 1.5 |
| Photon detection | – | – | 4 | 4 |
| K PID | 3 | 3 | 3 | 3 |
| $\pi$ PID | 2 | 2 | – | – |
| Kinematic fit | 2.1 | 2.1 | 0.1 | 0.1 |
| $\pi^0$ mass window | – | – | 0.1 | 0.1 |
| Fitting range | – | 0.1 | – | 1.4 |
| Background shape | – | 1.3 | – | 2.0 |
| Branching fractions | 1.1 | 1.1 | 1.1 | 1.1 |
| Integrated luminosity | 0.7 | 0.7 | 0.7 | 0.7 |
| Model uncertainty | – | 0.8 | – | 1.3 |
| Total | 6.3 | 6.5 | 5.4 | 6.1 |

# Summary

- No Zs signal around 1.4GeV is observed in e+e-→$\phi\pi\pi$@2.125GeV.
- The upper limits of Zs cross sections (at 90%C.L.) are obtained



| | Mass (GeV/$c^2$) | 1.380 | | | 1.400 | | | 1.420 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Width (MeV/$c^2$) | $N^{UL}$ | $\varepsilon(\%)$ | $\sigma^{UL}_{Z_s}$(pb) | $N^{UL}$ | $\varepsilon(\%)$ | $\sigma^{UL}_{Z_s}$(pb) | $N^{UL}$ | $\varepsilon(\%)$ | $\sigma^{UL}_{Z_s}$(pb) |
| $\phi\pi^+\pi^-$ | 0 | 22.2 | 47.3 | 0.90 | 16.6 | 46.9 | 0.68 | 44.4 | 46.8 | 1.82 |
| | 5 | 37.8 | 47.5 | 1.53 | 29.8 | 46.9 | 1.22 | 54.6 | 47.2 | 2.22 |
| | 10 | 49.6 | 47.5 | 2.01 | 40.2 | [illegible] | 1.63 | 60.8 | 47.3 | 2.47 |
| $\phi\pi^0\pi^0$ | 0 | 25.6 | 13.8 | 3.75 | [illegible] | 13.7 | 3.72 | 27.2 | 13.5 | 4.07 |
| | 5 | 28.0 | 13.8 | 4.10 | [illegible] | 13.7 | 4.22 | 30.2 | 13.5 | 4.52 |
| | 10 | 31.2 | 13.8 | 4.57 | [illegible] | 13.7 | 4.78 | 33.6 | 13.6 | 4.99 |

- The cross sections for $e^+e^-\to\phi\pi\pi$@2.125GeV are measured

| $\phi\pi^+\pi^-$ | | | |
|---|---|---|---|
| $E_{c.m.}$(GeV) | BaBar | Belle | BESIII |
| 2.1125 | $510 \pm 50 \pm 21$ | $480 \pm 60 \pm 42$ | - |
| 2.125 | - | - | $343.0 \pm 5.1 \pm 22.3$ |
| $\phi\pi^0\pi^0$ | | | |
| 2.10 | $195 \pm 50 \pm 14$ | - | - |
| 2.125 | - | - | $208.3 \pm 7.6 \pm 12.7$ |

Thank you for your attention!

# Introduction

$$\Upsilon(5S) \to h_b(mP)\pi^+\pi^- \quad (m = 1, 2)$$

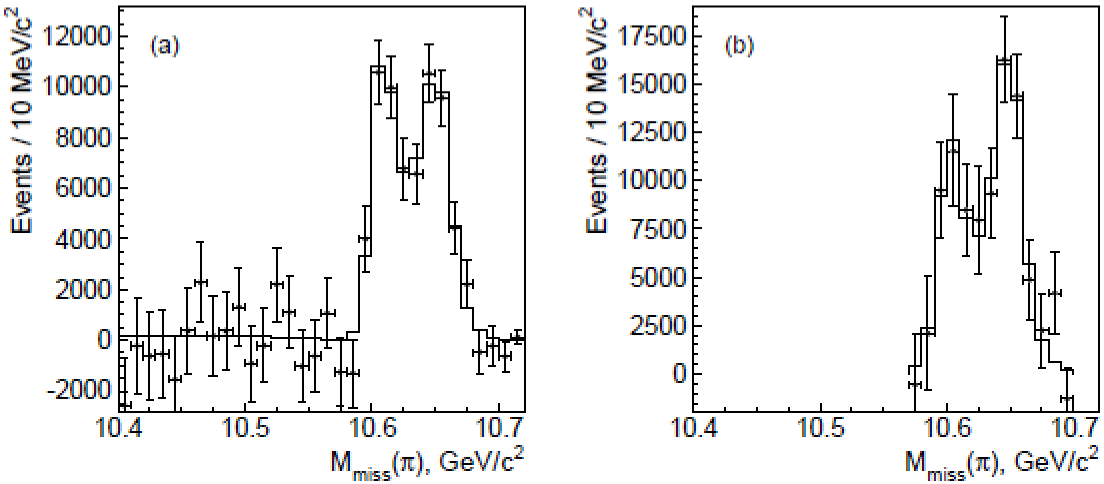
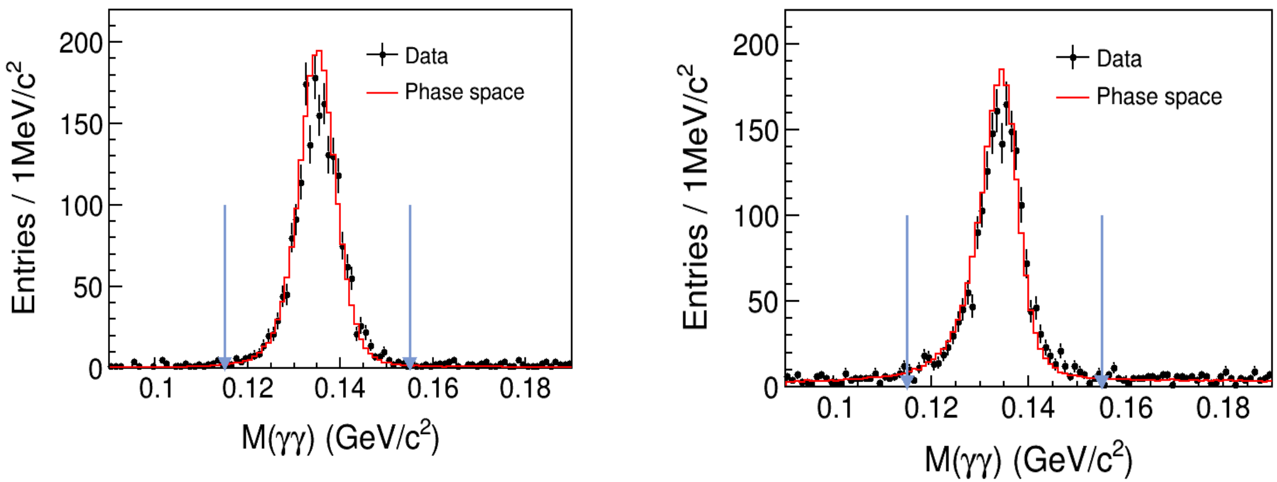



FIG. 3: The (a) $h_b(1P)$ and (b) $h_b(2P)$ yields as a function of $M_{\rm miss}(\pi)$ (points with error bars) and results of the fit (histogram).

# $\pi^0$ reconstruction in $e^+e^-\to\phi\pi^0\pi^0$

$$\chi^2_{min}=\sqrt{|M(\gamma_1\gamma_2)-M(\pi^0)|^2+|M(\gamma_3\gamma_4)-M(\pi^0)|^2}$$

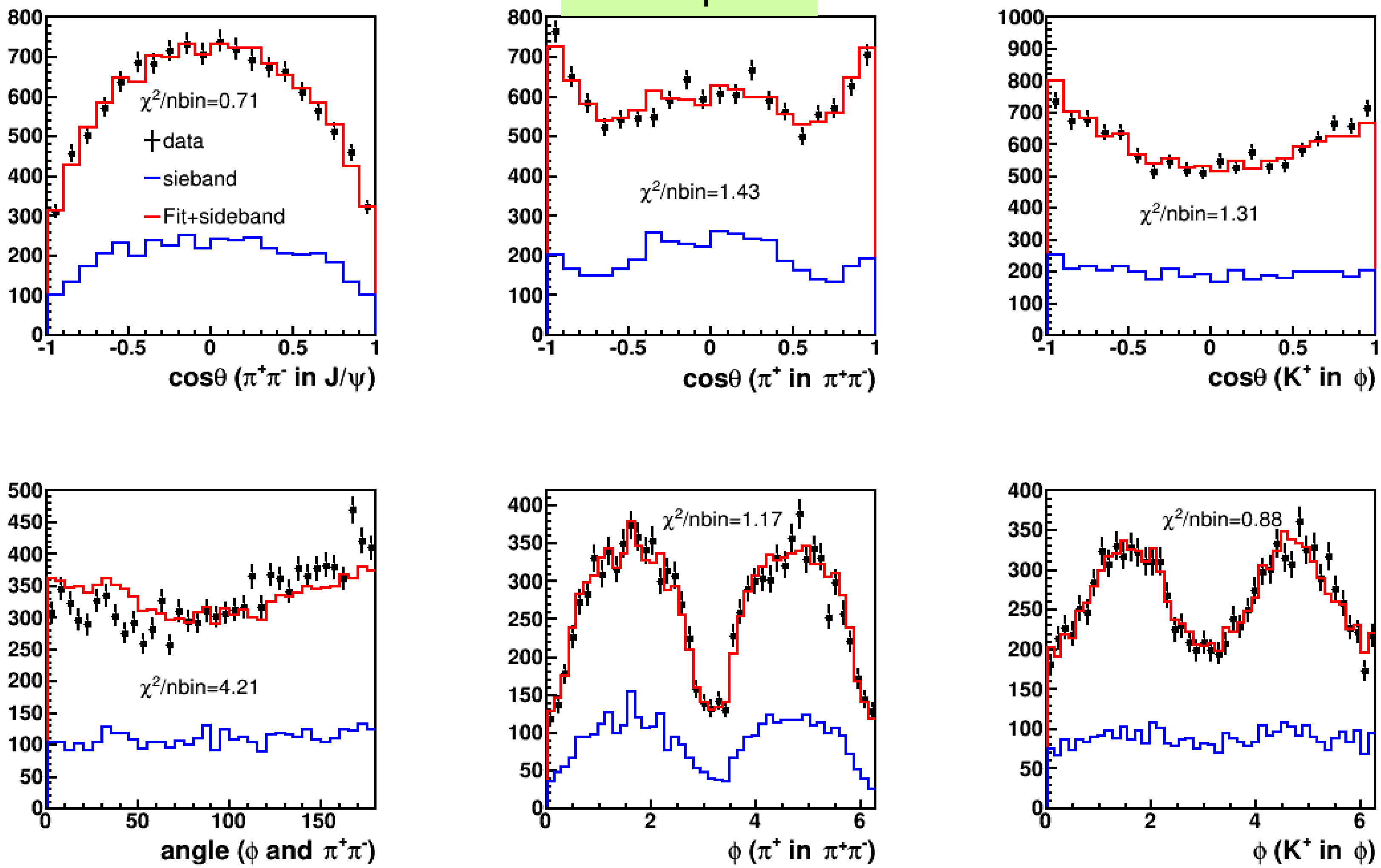



$$|\mathrm{M}(\gamma\gamma)-0.135|<0.02\mathrm{GeV/c^2}$$

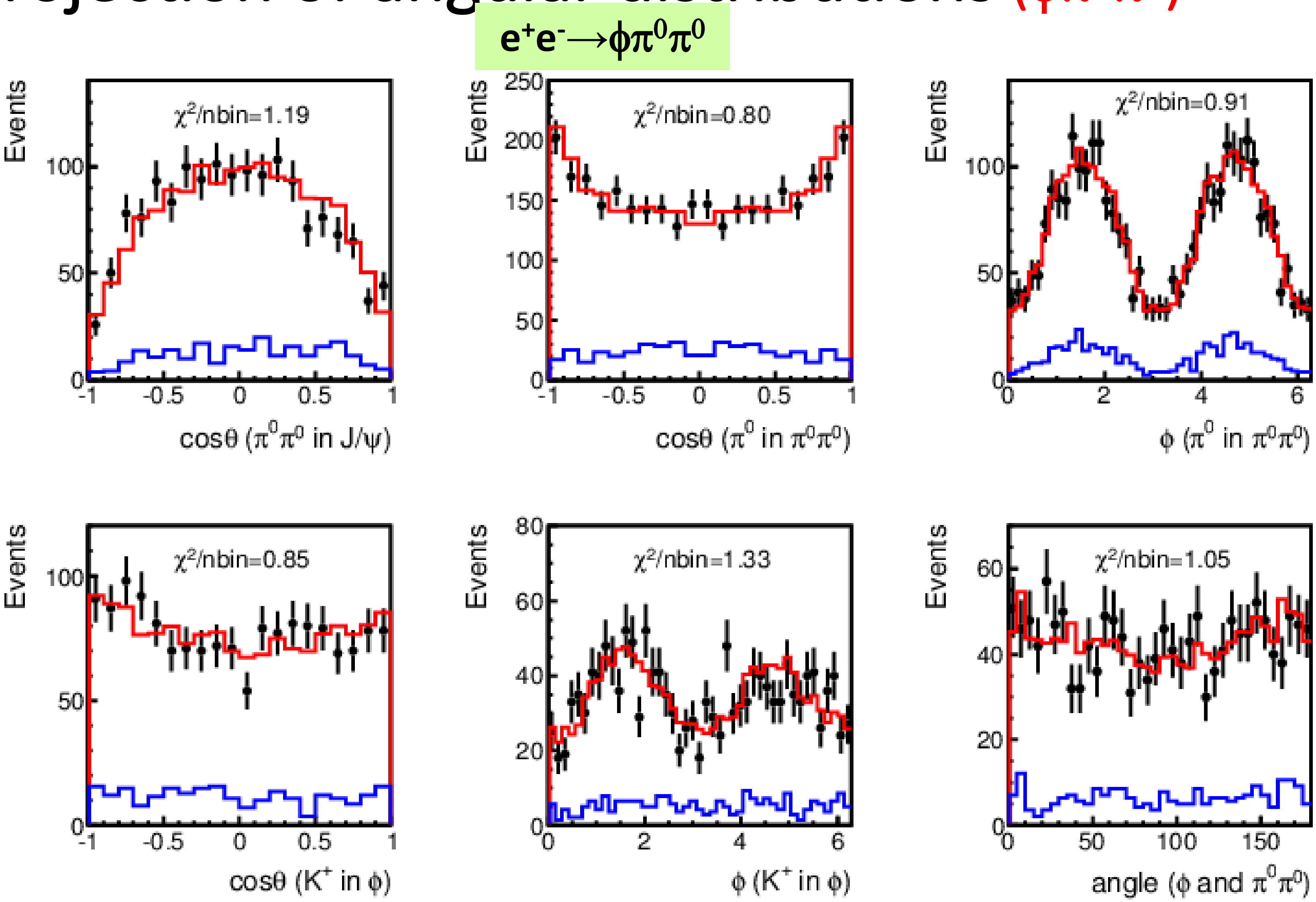
The two $\pi^0$ are ordered as $\pi^0_l$ and $\pi^0_h$ according to their energy in Lab-S.

# Projection of angular distributions ($\phi\pi^+\pi^-$)

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

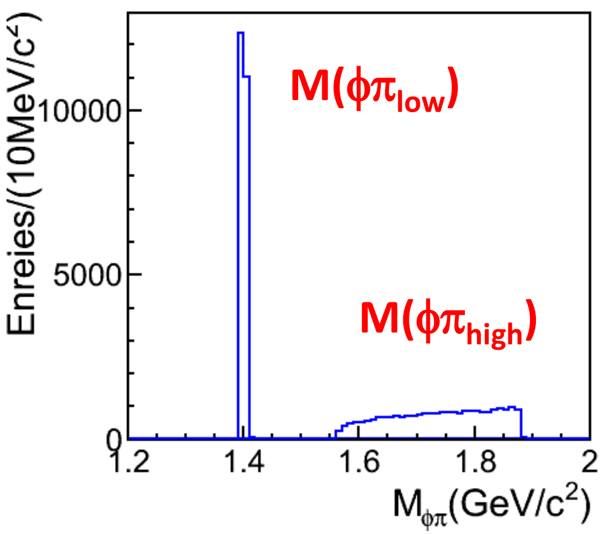


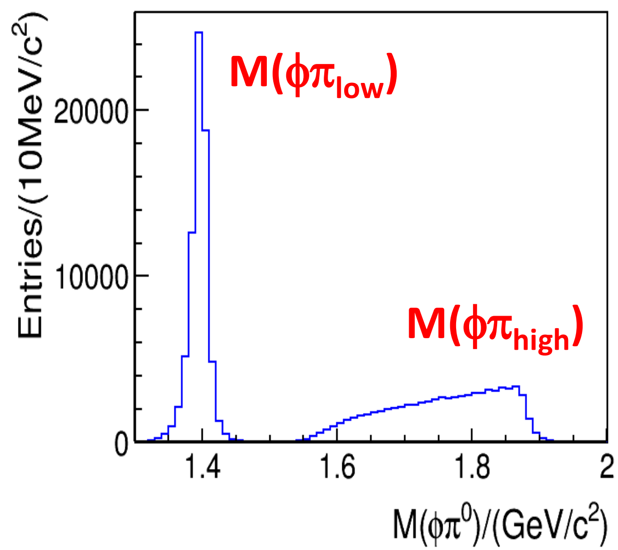
# Projection of angular distributions ($\phi\pi^0\pi^0$)



# $Z_S$ Signal shape

- Phase space MC sample of $e^+e^- \rightarrow Z_s\pi@2.125GeV(Z_s \rightarrow \phi\pi)$ will be used for $Z_S$ signal shape and to estimate the selection efficiency
- Assuming M=1.4GeV, $\Gamma$=0 for $Z_S$ in Ref. **Eur. Phys. J. C72, 2008(2012).**



# Systematic Uncertainties(1)

- Tracking and Photon
  - ✓ 1.5% and 1.5% for each charged kaon and pion, and 1.0% per photon
- Kinematic fit
  - ✓ Correct the helix parameters for the charged track (used in kinematic fit), the difference before and after the correction are taken as the systematic error **(Phys. Rev. D 87, 012002 (2013))**
- $\pi^0$ mass window
  - ✓ Estimated as the difference on selection efficiency between data and MC simulation associated with $\pi^0$ cut
- Fitting range
  - ✓ Estimated as the maximum changes on the calculated cross section in alternative fits with different fitting range

# Systematic Uncertainties(2)

- Background shape
  - ✓ Estimated as the changes on the calculated cross section in alternative fits by changing the background function (2-order /3 order polynomial)
- Intermediate state
  - ✓ The branching fractions of the intermediate process are quoted from PDG. So 1.1% is taken as the uncertainty associated with the intermediate decays
- Luminosity
  - ✓ The luminosity is determined to be (108.49$\pm$0.75) $pb^{-1}$ with the wide angle Bhabha events. So the uncertainty from this source is estimated to be 0.7%
- Efficiency from PWA
  - ✓ By changing $f_0(1370)$ to $0^{++}$ PHSP, the differences on the calculated cross section are taken as the systematic uncertainty

# Systematic Uncertainty for PID efficiency

## Control sample of $\phi\pi^+\pi^-$

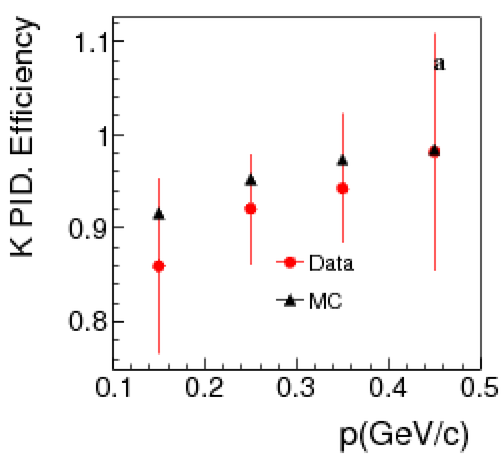
- Good charged track:
  - Ngood=3 or Ngood=4 with Q=0
- PID: one kaon is identified, the other track is assumed to be kaon or pion.
- 1C-fit to $K\pi\pi$(missing K) or $KK\pi$ (missing $\pi$) hypotheses for three and four good charged tracks, and the minimum $\chi^2_{1C}$ is selected.

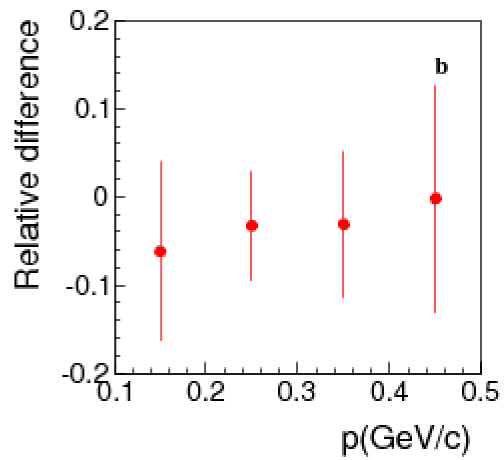
# Uncertainty from Kaon PID Efficiency

- ✓ $\chi^2_{1C}(KK\pi\pi_{missing})<10$.
- ✓ Another track assuming to be pion from 1C-fit is identified as pion.
- ✓ PID eff.(K)=$N_\Phi$(with K identified)/$N_\Phi$ by fitting KK mass

PID Eff.

Relative difference of PID Eff. Between data and MC



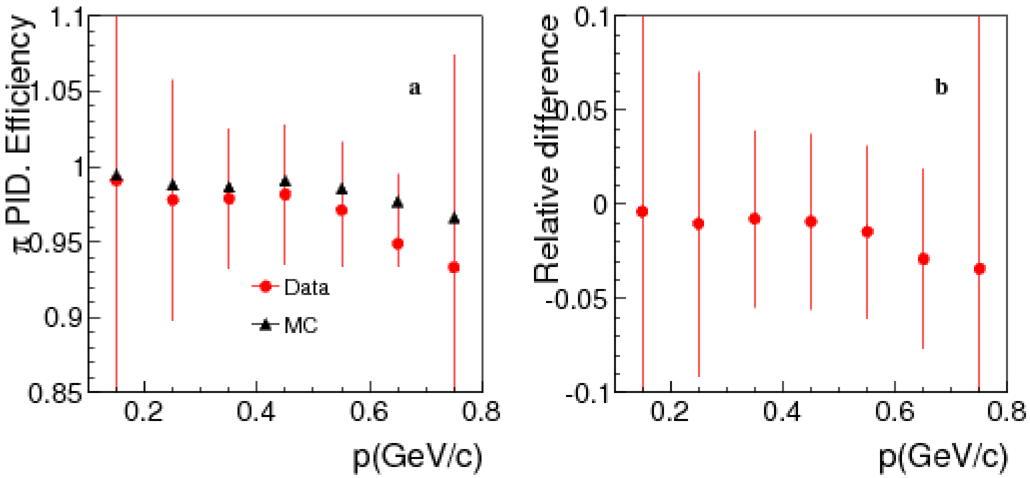

- The difference of K PID is ~3%

# Uncertainty from pion PID Efficiency

- ✓ $\chi^2_{1C}(K\,K_{missing}\,\pi^+\pi^-)<10.$
- ✓ Addition criterion:$|M(KK_{missing})-M_{\Phi}|<0.015GeV/C^2$
- ✓ Negative $\pi$ is identified as pion
- ✓ PID eff.($\pi^+$)=N($\pi^+$ is identified)/$N_{tot}$

$\pi$+ PID Eff.

Relative difference of PID Eff. Between data and MC




- The difference of $\pi$ PID is ~1%