Study of the ISR reactions at BaBar

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Motivation

- Low energy e^+e^- cross section dominates in hadronic contribution to $a_\mu = (g-2)/2$ of muon
- Direct e^+e^- data in 1.4 - 2.5 GeV region have very low statistic
- Hadron spectroscopy at low masses and charmonium region

- ISR at BaBar gives competitive statistic
- BaBar has excellent capability for ISR study
- All major hadronic processes are under study

$e^+e^- \to 2\mu\gamma,\ 2\pi\gamma,\ 2K\gamma,\ 2p\gamma,\ 2\Lambda\gamma,\ 2\Sigma\gamma,\ \Lambda\Sigma\gamma,\ \Lambda_c\Lambda_c\gamma$

$e^+e^- \to 3\pi\gamma$

$e^+e^- \to 2(\pi^+\pi^-)\gamma,\ K^+K^-\pi^+\pi^-\gamma,\ K^+K^-\pi^0\pi^0\gamma,\ 2(K^+K^-)\gamma$

$e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0\gamma,\ 3(\pi^+\pi^-)\gamma,\ K^+K^-2(\pi^+\pi^-)\gamma$

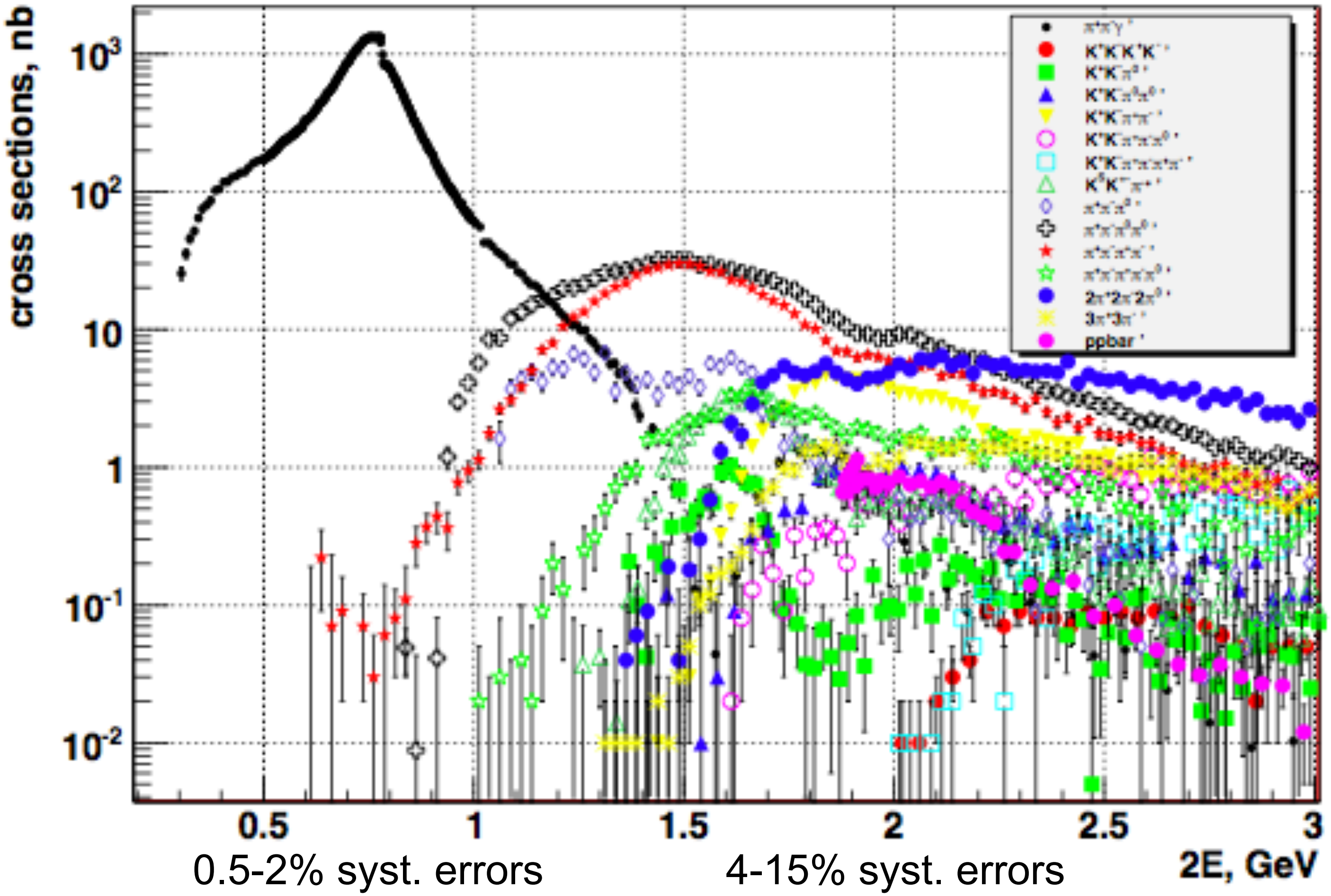
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\eta\gamma$ ...

$e^+e^- \to K^+K^-\pi^0\gamma,\ K^+K^-\eta\gamma$ $(KK^*\gamma,\ \phi\pi^0\gamma,\ \phi\eta\gamma\ ...)$

$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0/\eta\gamma,\ K^+K^-\pi^+\pi^-\pi^0/\eta\gamma$

Are being updated to full BaBar data with ~500fb^{-1}

BaBar measurements summary



To calculate R in the energy range 1-2 GeV the processes
$\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\pi^-\pi^0$
must be measured. The $\pi^+\pi^-2\pi^0$ is still preliminary. Work is in progress.

$e^+e^- \to K^+K^-\pi^+\pi^-, K^+K^-\pi^0\pi^0$

We present new preliminary results on the study of the processes:

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

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

$$e^+e^- \to K^+K^-K^+K^-$$

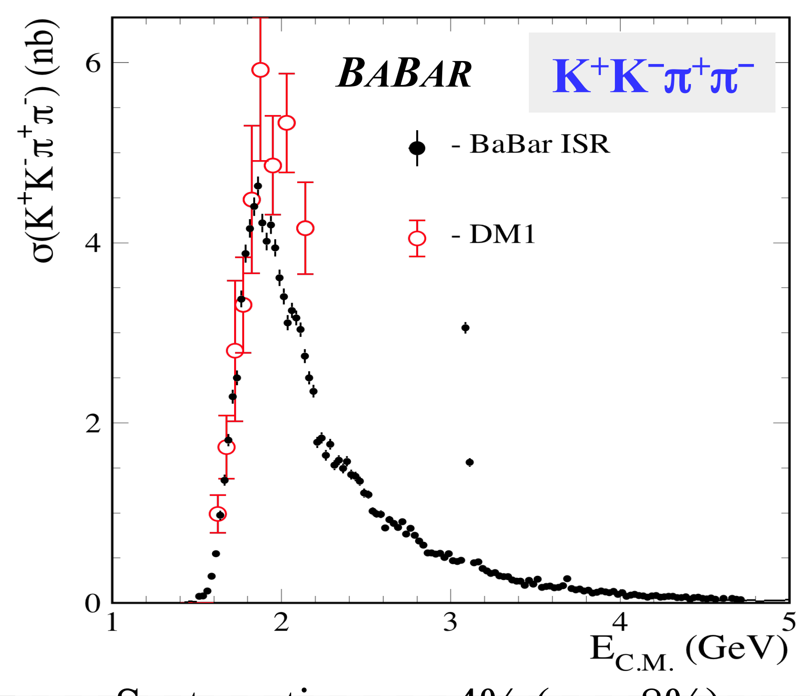
(arXiv:**1103.3001v1)**

Our previous publication, based on part of the data:
B. Aubert *et al.* (BaBar Collaboration),
Phys. Rev. D76, 012008 (2007).

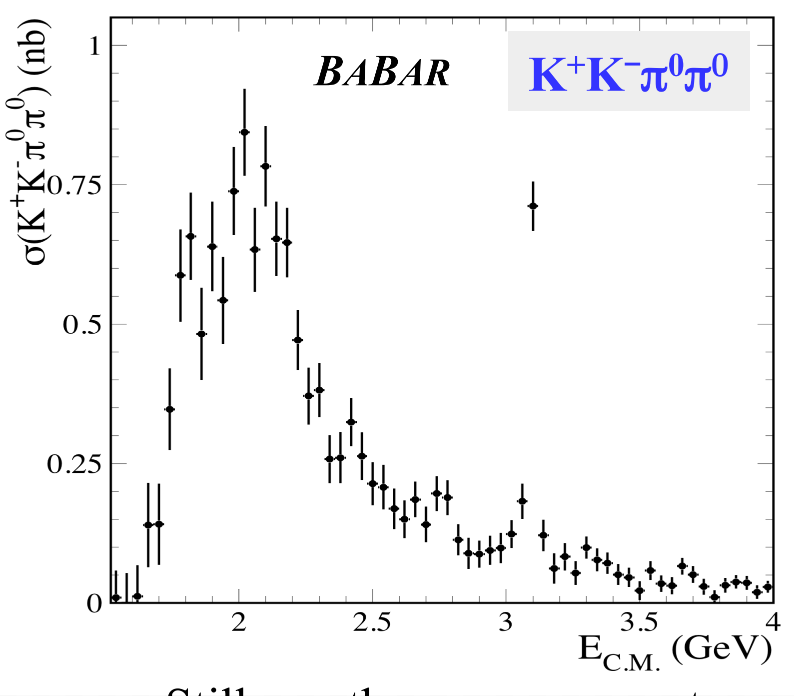
$e^+e^- \rightarrow K^+K^-\pi^+\pi^-, K^+K^-\pi^0\pi^0$

In the new study, base on full BaBar data set (454 fb^{-1}):

We know many ISR processes for better control of background
We know tracking and photon reconstruction efficiency with better accuracy.
More intermediate states are separated.
All above allows to decrease systematic uncertainties. Important for g-2



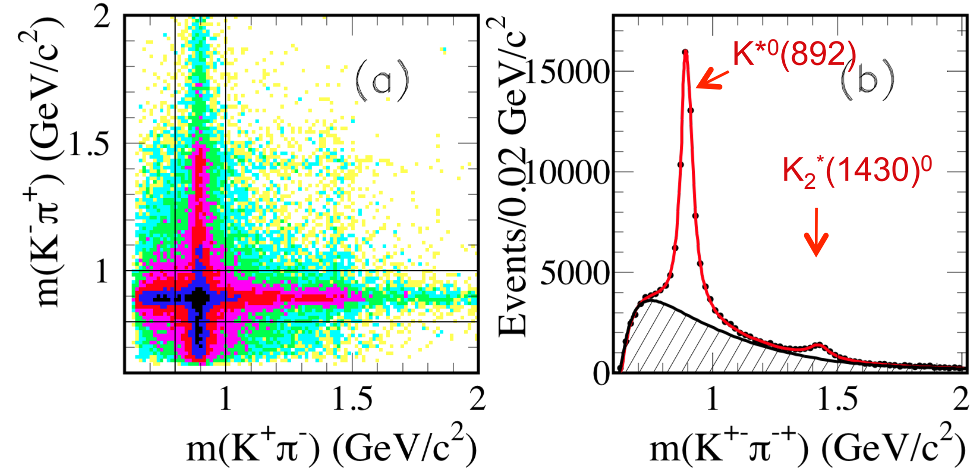
- Systematic error 4% (was 8%)
- Error dominated by acceptance

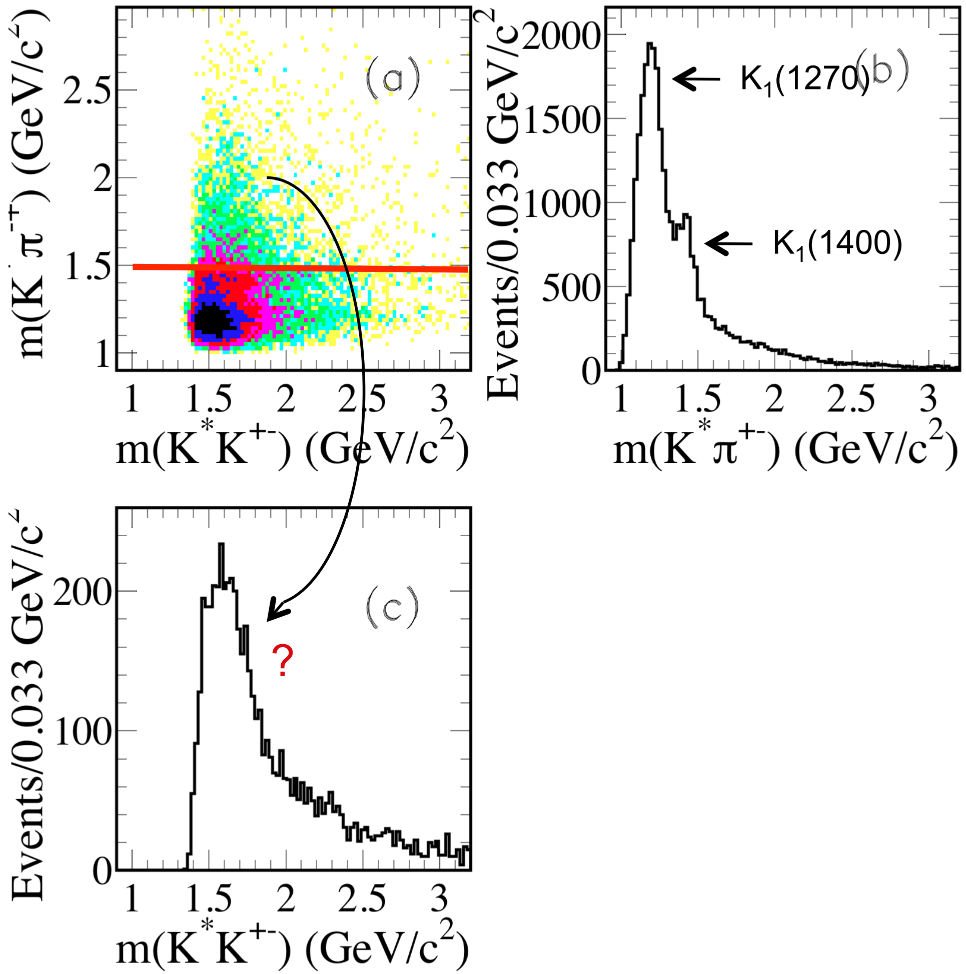


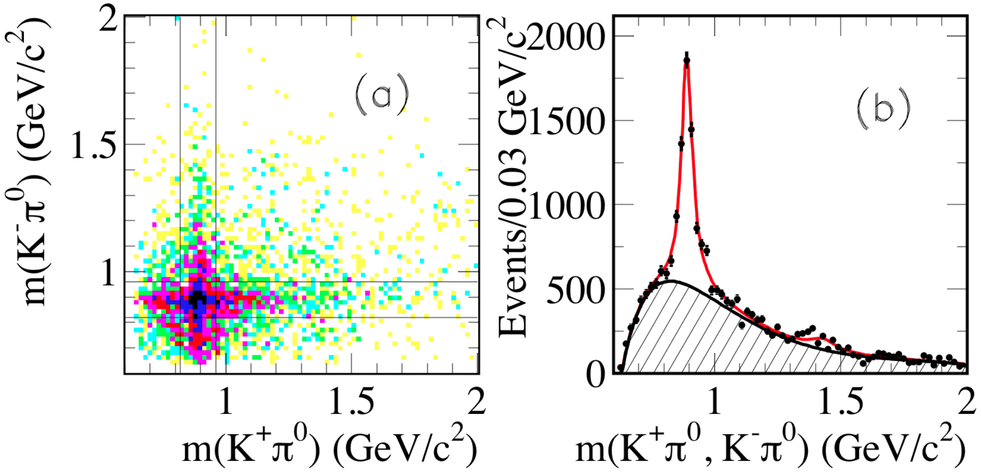
- Still no other measurements
- Systematic error 7% (was 11%)

Kaon substructures for $K^+K^-\pi^+\pi^-$, $\pi^0\pi^0$

Charged combinations from $K^*(892)^0$ bands



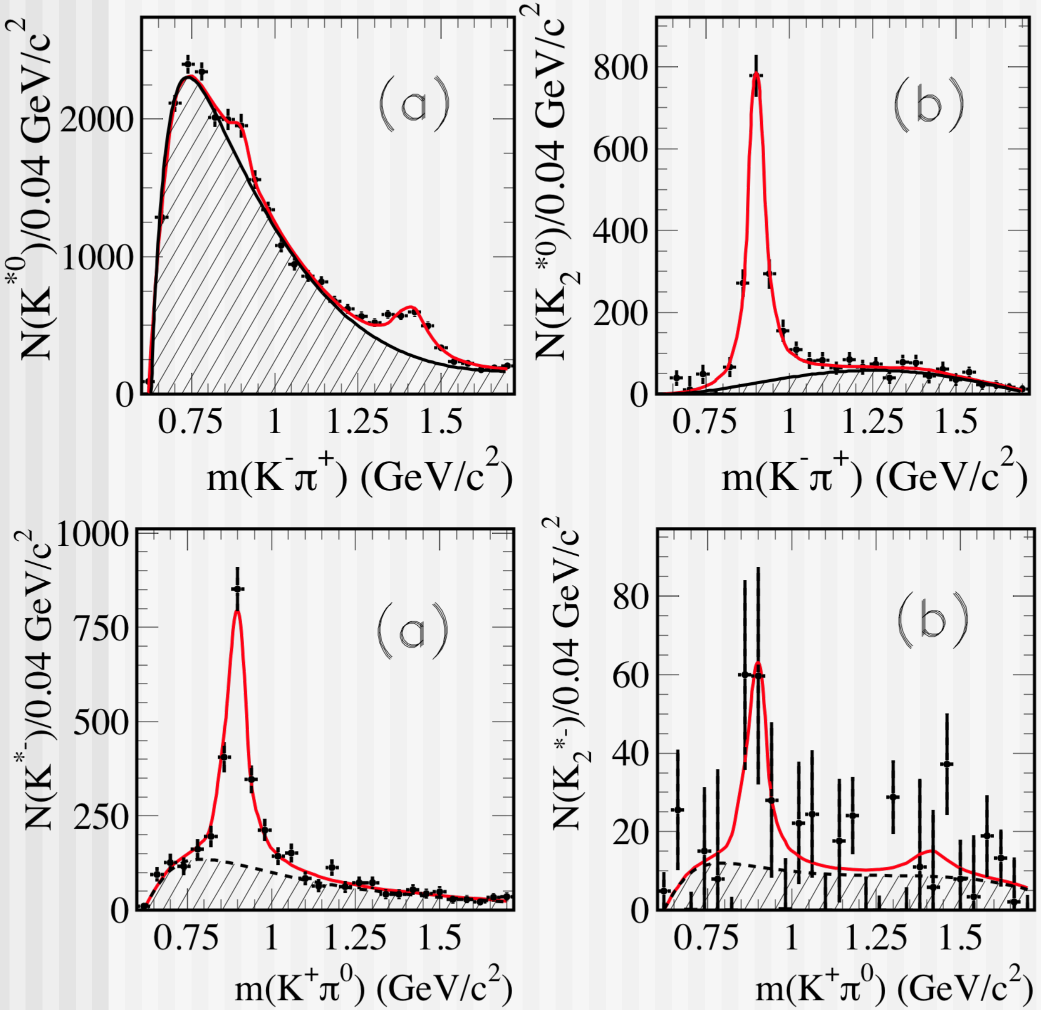




Cross section dominates by $K^{*0}(892)K\pi$ final state.
BUT…..

$K_1(1270,1400) \rightarrow K^*(892)K$, $K^*(892)\pi$, and
$K_1(1270,1400) \rightarrow K\rho(770)$ are seen.

Kaon substructures (2)



Count number of $K^*(892)^0$ and $K_2^*(1430)^0$ by fitting $K^+\pi^-$ mass in every 40 MeV bin of $K^-\pi^+$ mass.

Less than 1% of $2K2\pi$ events are from $K^{*0}(892)\,\underline{K}^{*0}(892)$

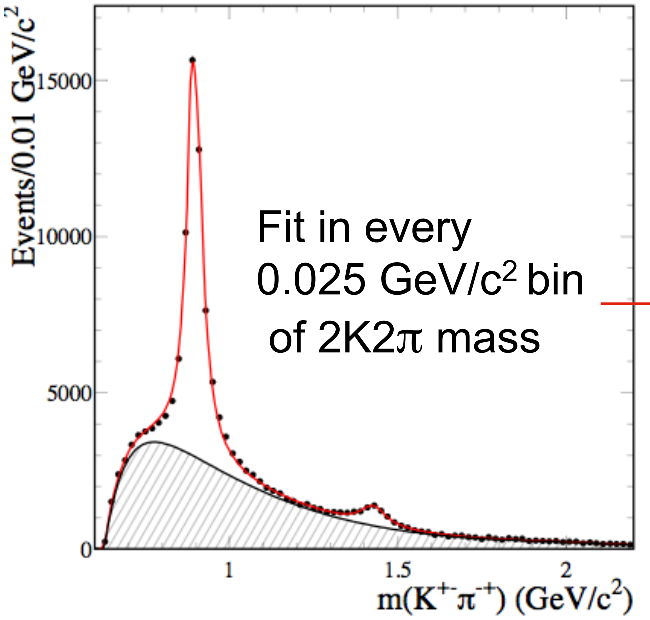
$K^{*0}(892)\underline{K}_2^*(1430)^0$ + c.c. is seen, mostly from J/ψ decay

$Br = (6.7 \pm 2.6) \times 10^{-3}$ (PDG)

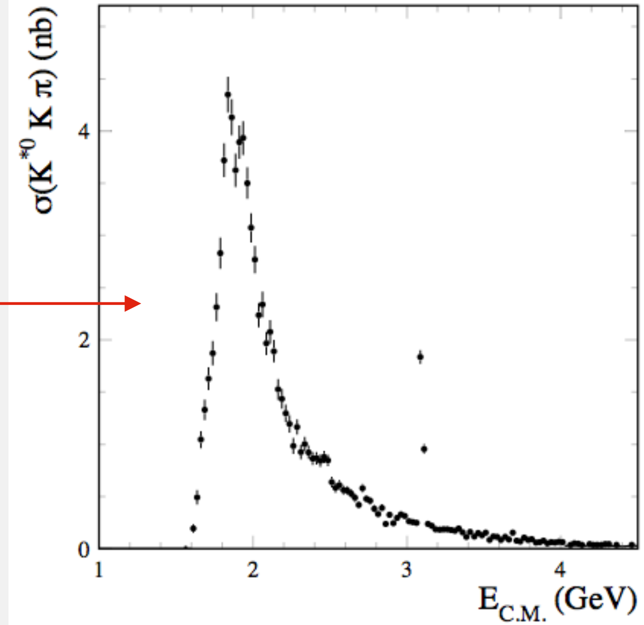
Count number of $K^*(892)^+$ events fitting 40 MeV mass slice in $K^-\pi^0$ mass

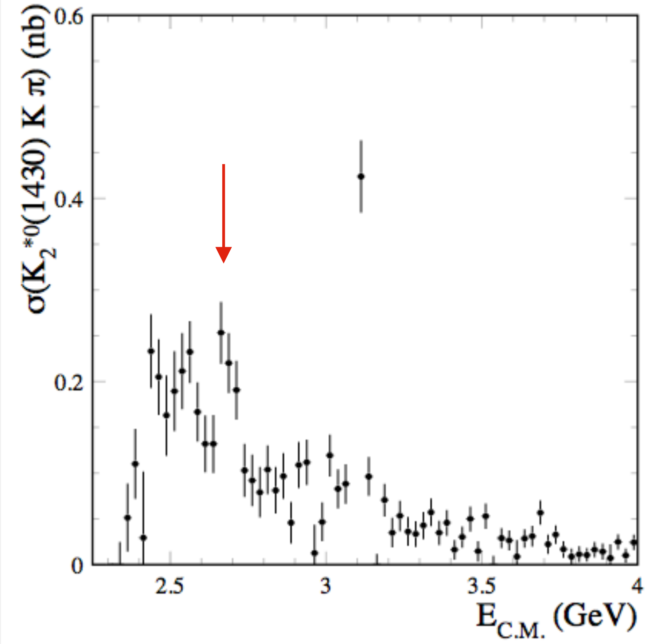
Cross section dominates by $K^{*\pm}(892)K\pi^0$ final state, the same as for $K^+K^-\pi^+\pi^-$ final state, but ~30% (1750 ± 60) events are from $K^*(892)^+K^*(892)^-$ - compare to <1% $K^*(892)^0\underline{K}^*(892)^0$ from $K^+K^-\pi+\pi-$ study (548 ± 263). No other structures are seen in $K\pi^0\pi^0$ or $K^+K^-\pi^0$.

Inclusive $e^+e^- \to K^* K\pi$, $K^+K^-\rho$ cross sections



Fit in every 0.025 GeV/c² bin of 2K2π mass

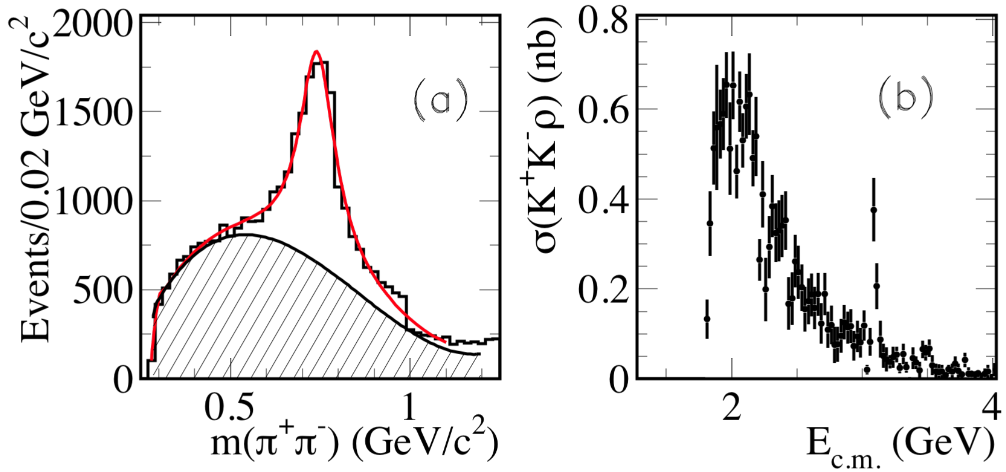




$N_{K^*(892)}$ = 53997 ± 526
$m_{K^*(892)}$ = 893.2 ± 0.2 MeV/c^2
Γ = 52.1 ± 0.7 MeV

$N_{K2^*(1430)}$ = 4361 ± 235
m_{K2} = 1427.4 ± 1.9 MeV/c^2
Γ= 90.2 ± 5.6 MeV

In agreement with PDG

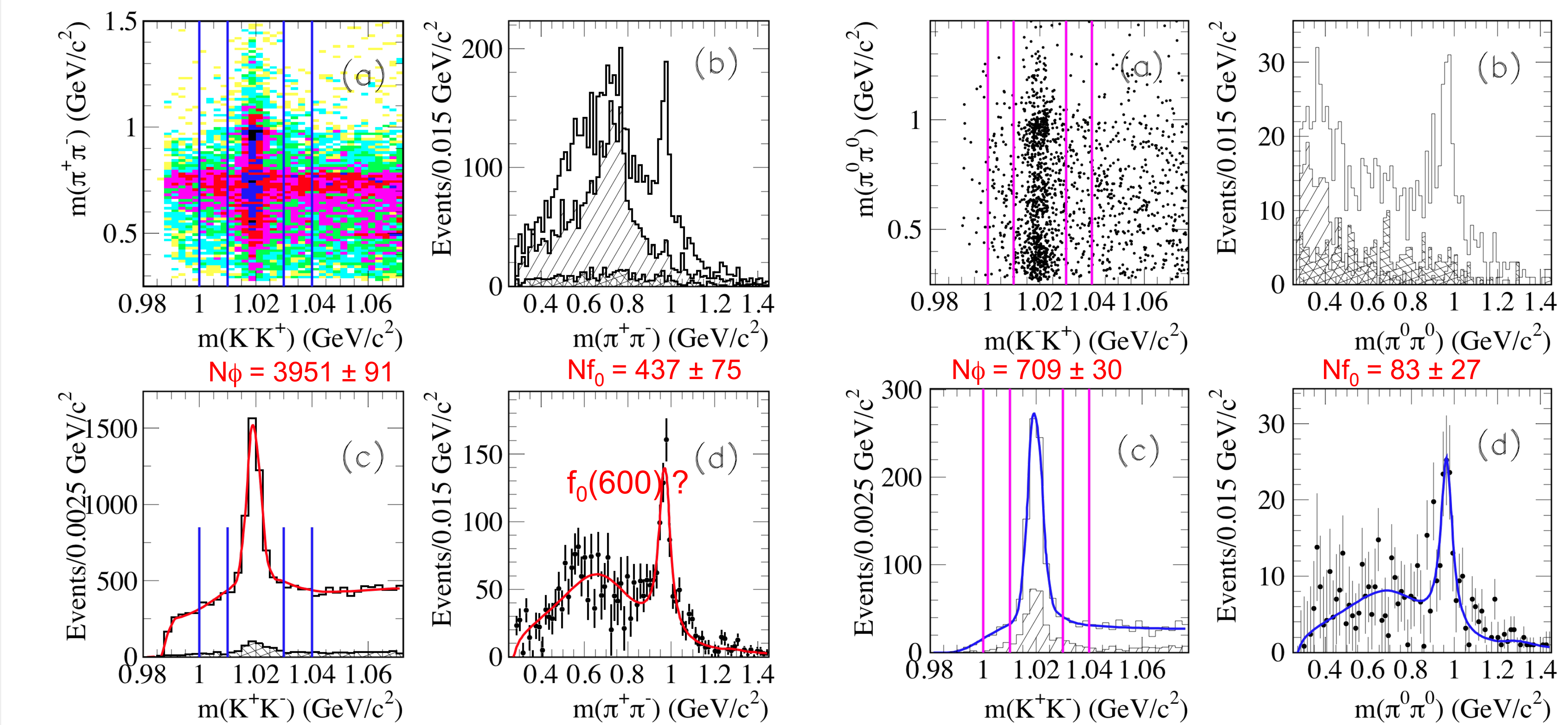


Mass and width of ρ are fixed

Fit in every 0.025 GeV/c² bin of 2K2π mass

Selection of $\phi(1020)\pi^+\pi^-$, $\pi^0\pi^0$

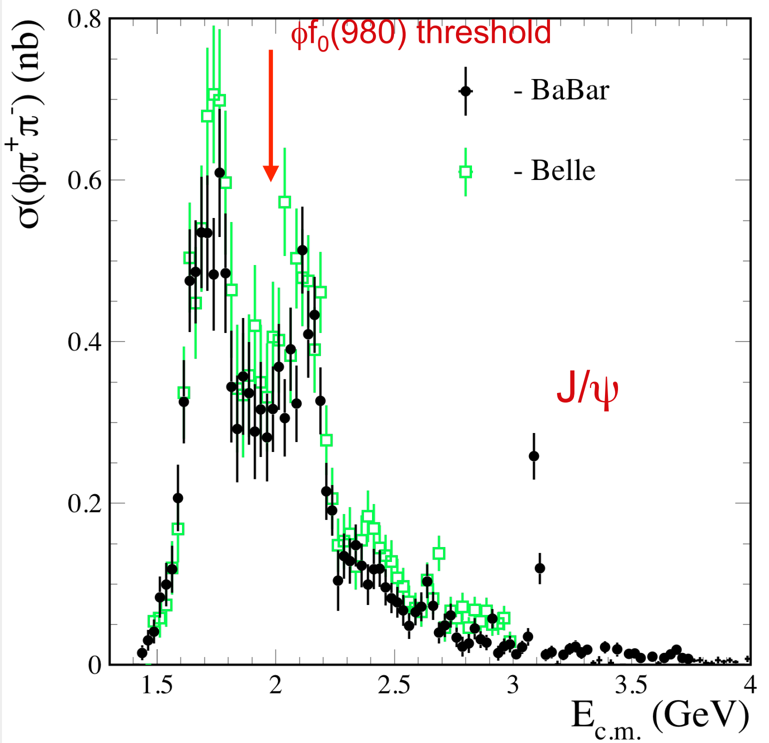
$K^+K^-\pi^+\pi^-$ **$K^+K^-\pi^0\pi^0$**

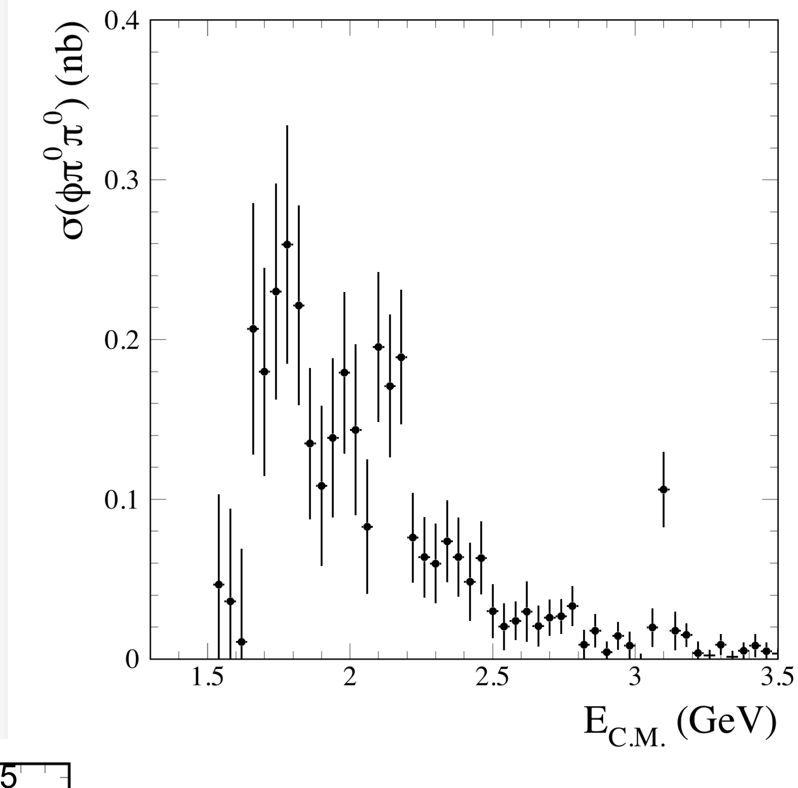


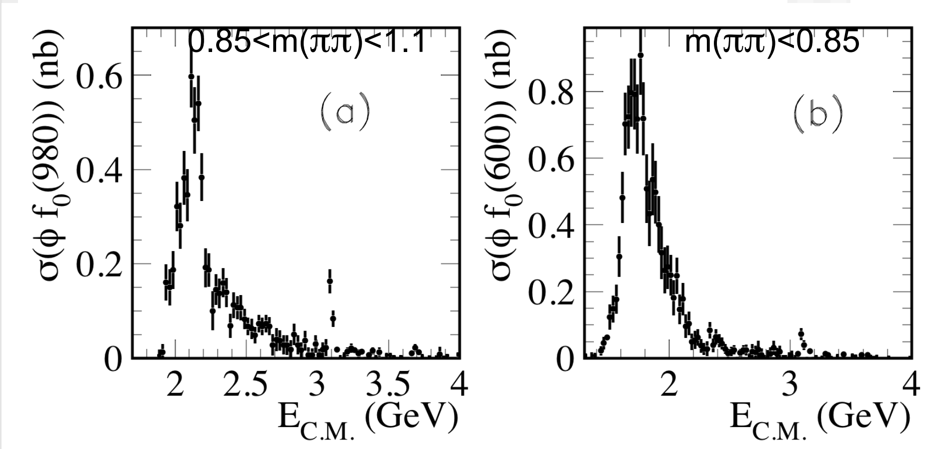
Number of $\phi\pi\pi$ events are selected by fitting of ϕ signal in 0.025 (0.04) GeV/c2 bin of 2K2π mass

The $f_0(980)$ parameters are not shifted from PDG values – f_0-$\pi\pi$ interference is small because of kinematics.

Cross sections for $e^+e^- \to \phi\pi^+\pi^-, \phi\pi^0\pi^0$

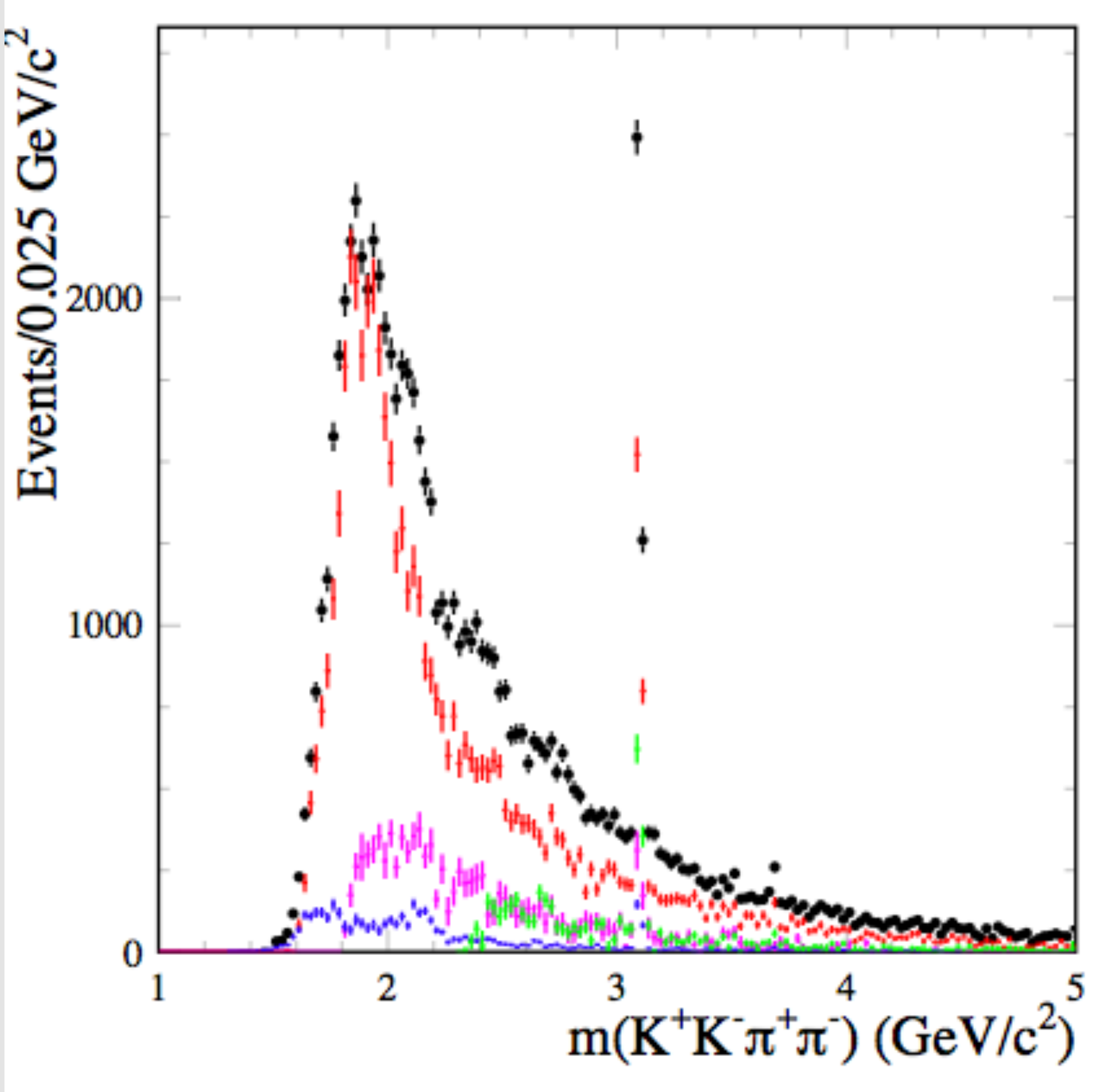






Cut $m(\pi\pi)<0.85$ completely removes structures above E_{cm} = 2 GeV !!
And confirms Y(2175) structure if $0.85<m(\pi\pi)<1.1$ GeV/c2 (next slides)

Decomposition of $K^+K^-\pi^+\pi^-$ mass spectrum



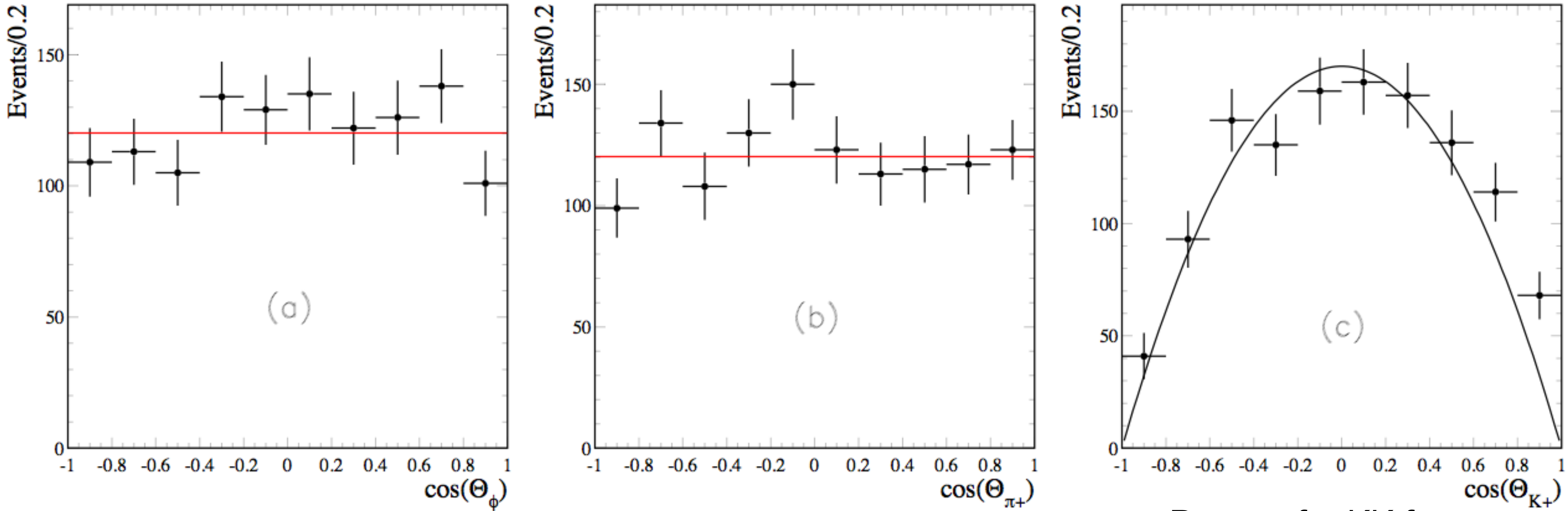
$K^+K^-\pi^+\pi^-$
$K^{*0}(892)K\pi$
$K^+K^-\rho(770)$
$\phi\pi^+\pi^-$
$K_2^{*0}(1430)K\pi$

Tables with cross sections (corrected for BF) are provided

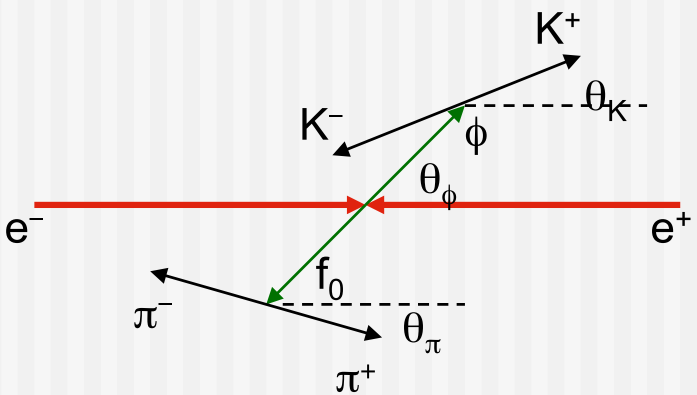
Cross section for $e^+e^- \to \phi\ \pi^+\pi^-\ (\pi^0\pi^0)$

VMD model description

Angles for $e^+e^- \to \phi\pi^+\pi^-$ events



S-wave for ϕ ($\pi\pi$) | S-wave for $\pi\pi$ from $f_0(\sigma)$ | P-wave for KK from ϕ



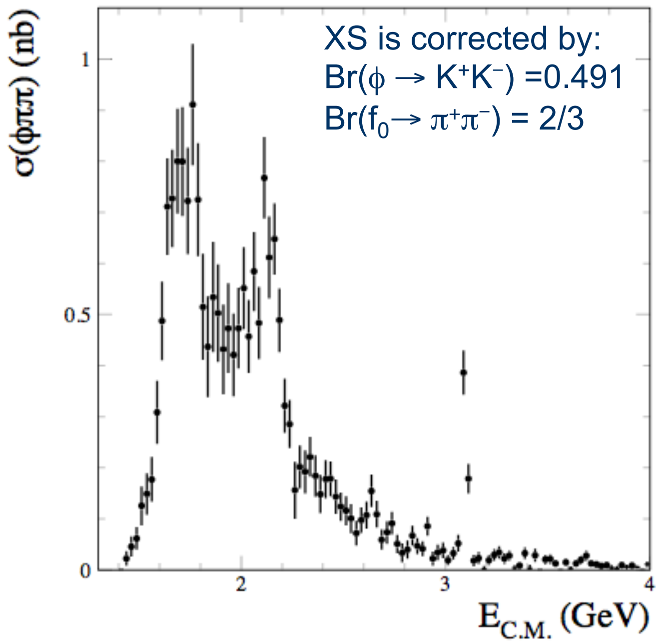
ϕ and $\pi\pi$ system are in S-wave

Pions in $\pi\pi$ system are in S-wave

Kaons from ϕ are in P-wave (as expected)

Cross section for $e^+e^- \to \phi\, \pi^+\pi^-(\pi^0\pi^0)$

Consider $\phi\pi\pi$ as quazi-two-body reaction with two particles in S-wave.
Two possible resonances below 3 GeV can be described as:



$$\sigma(s) = \frac{P_{\phi\pi\pi}(s)}{s^{3/2}} \bullet \left| \frac{A_{r1}(s,m_1)e^{i\varphi}}{\sqrt{P_{\phi\pi\pi}(m_1)}} + \frac{A_{r2}(s,m_2)}{\sqrt{P_{\phi\pi\pi}(m_2)}} \right|^2$$

$$A_{rx}(s,m_x) = \frac{\sqrt{\sigma_x^0}\, m_x^{3/2} m_x \Gamma_x^0}{m_x^2 - s - i\sqrt{s}\,\Gamma_x(s)}$$

Phase space in S-wave ~ momentum for two particles:

$$q(s,m_i,m_j) = \frac{1}{2\sqrt{s}} \sqrt{(s-(m_i-m_j)^2(s-(m_i+m_j)^2}$$

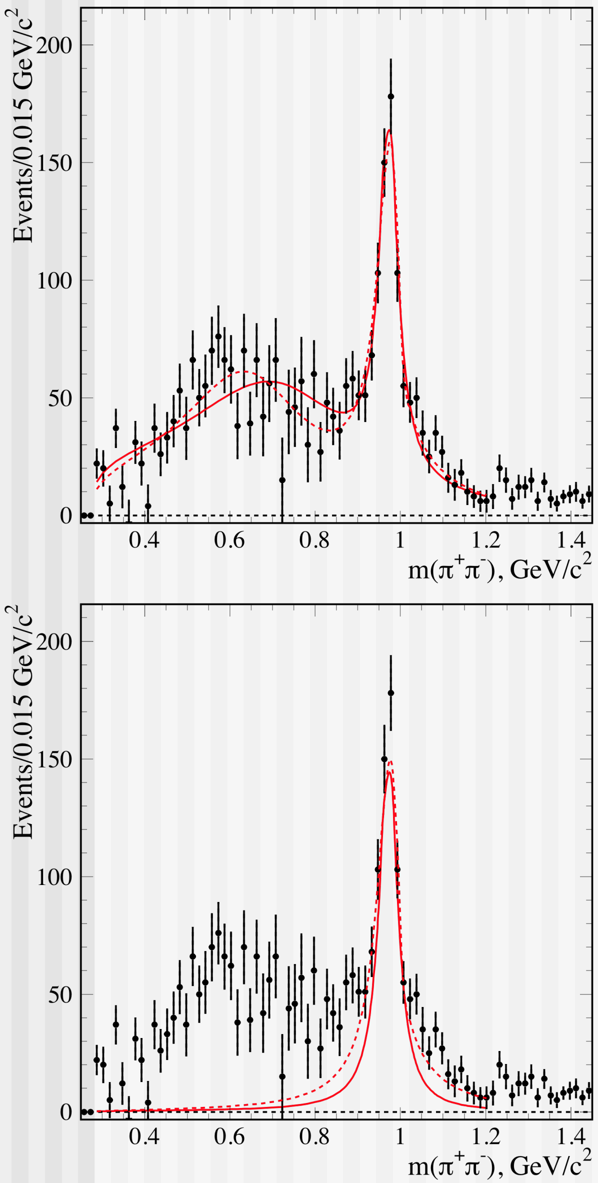
m_i = mϕ - narrow

m_j = m(ππ) - not narrow - use integral over ππ mass:

$$P_{\phi\pi\pi}(s) = \int_{2m_\pi}^{\sqrt{s}-m_\phi} 2m\,dm\,BW_{\pi\pi}(s)\,q(s,m,m_\phi)$$

$BW_{\pi\pi}(s)$ - describes ππ mass distribution

$\pi\pi$ mass distribution



Describe m($\pi\pi$) as a sum of two Breit-Wigner functions normalized to unit (interference is small due to kinematics)

$$BW_{\pi\pi}(m) = \frac{N^0 p(m)}{\pi}\left(\frac{(1-r)bw_1(m,m_1)}{p(m_1)} + \frac{rbw_2(m,m_2)}{p(m_2)}\right)$$

$$p(m) = \sqrt{m^2 - 4m_\pi^2}$$

$$bw_x(m,m_x) = \frac{m\Gamma_x}{(m^2 - m_x^2)^2 - (m\Gamma_x)^2}$$

$m_1 = 0.972 \pm 0.002$ GeV/c^2 $m_2 = 0.692 \pm 0.015$ GeV/c^2
$\Gamma_1 = 0.056 \pm 0.011$ GeV $\Gamma_2 = 0.538 \pm 0.038$ GeV
$r = 0.32 \pm 0.03$ - fraction of $f_0(980)$

Flatte approximation for $f_0(980)$ gives better fit with a little wider width:

(and leave less room for $f_0(600)$)

$$A_{f_0}(s) = \frac{\Gamma_\pi \Gamma_{f_0}}{m_{f_0}^2 - s - i\Gamma_{f_0}(\Gamma_\pi + R\Gamma_K)}$$

$$\Gamma_\pi = \sqrt{s - 4m_\pi^2}, \Gamma_K = \sqrt{s - 4m_K^2},$$

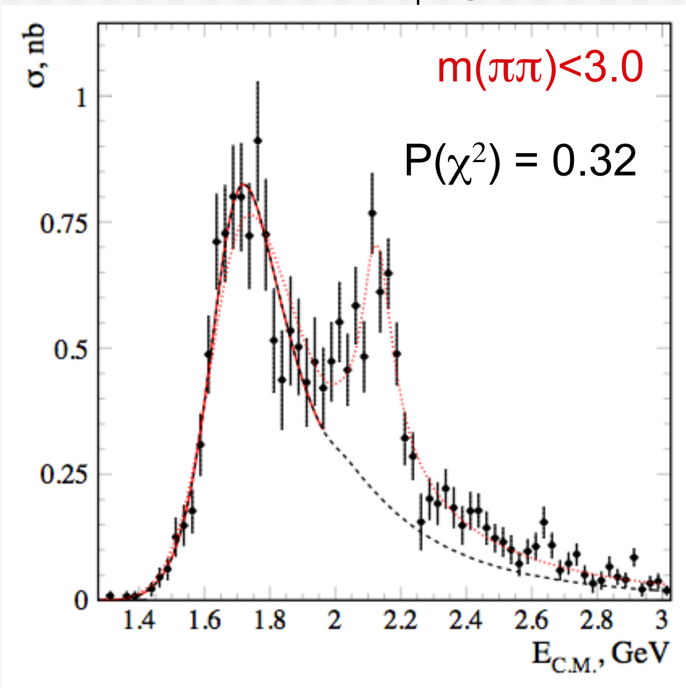
$$R = \frac{g_{KK}^2}{g_{\pi\pi}^2} = 1.74 \pm 0.62$$

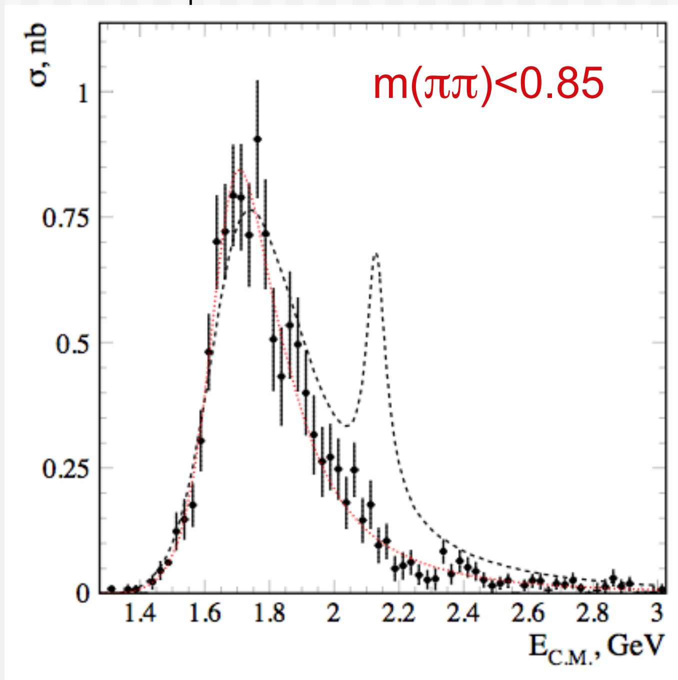
Cross section for $e^+e^- \to \phi\pi\pi$ (1)

Option #1 - both resonances decay to $\phi(f_0(600) + f_0(980))$

$$\sigma(s) = \frac{P_{\phi\pi\pi}(s)}{s^{3/2}} \bullet \left| \frac{A_{r1}(s,m_1)e^{i\varphi}}{\sqrt{P_{\phi\pi\pi}(m_1)}} + \frac{A_{r2}(s,m_2)}{\sqrt{P_{\phi\pi\pi}(m_2)}} \right|^2$$

$P_{\phi\pi\pi}(s)$ integral has sum of $bw_{f0} + bw_{\sigma}$





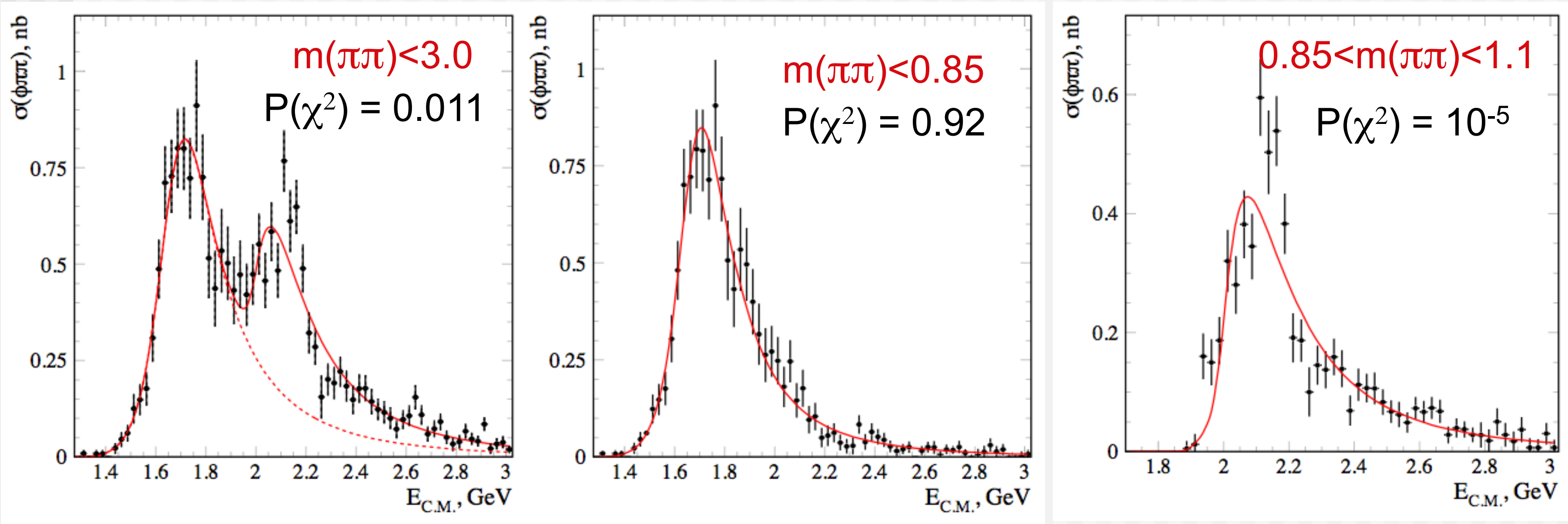
The m(ππ)<0.85 selection completely removes second resonance! Model is wrong.
Not a surprise - $f_0(600)$ has only *u,d* quarks, but $f_0(980)$ is $s\bar{s}$ or $s\bar{s}s\bar{s}$

Cross section for $e^+e^- \to \phi\pi\pi$ (2)

Option #2 - first resonance decays to $f_0(600)$, second to $f_0(980)$ - Belle paper.

- Have two phase spaces: $P_{\phi\sigma}(s)$ and $P_{\phi f0}(s)$ - integral uses one BW for each mode.

$$\sigma(s)=\frac{P_{\phi\sigma}(s)}{s^{3/2}}\bullet\left|\frac{A_{r1}(s,m_1)}{\sqrt{P_{\phi\sigma}(m_1)}}\right|^2+\frac{P_{\phi f_0}(s)}{s^{3/2}}\bullet\left|\frac{A_{r2}(s,m_2)}{\sqrt{P_{\phi f_0}(m_2)}}\right|^2$$

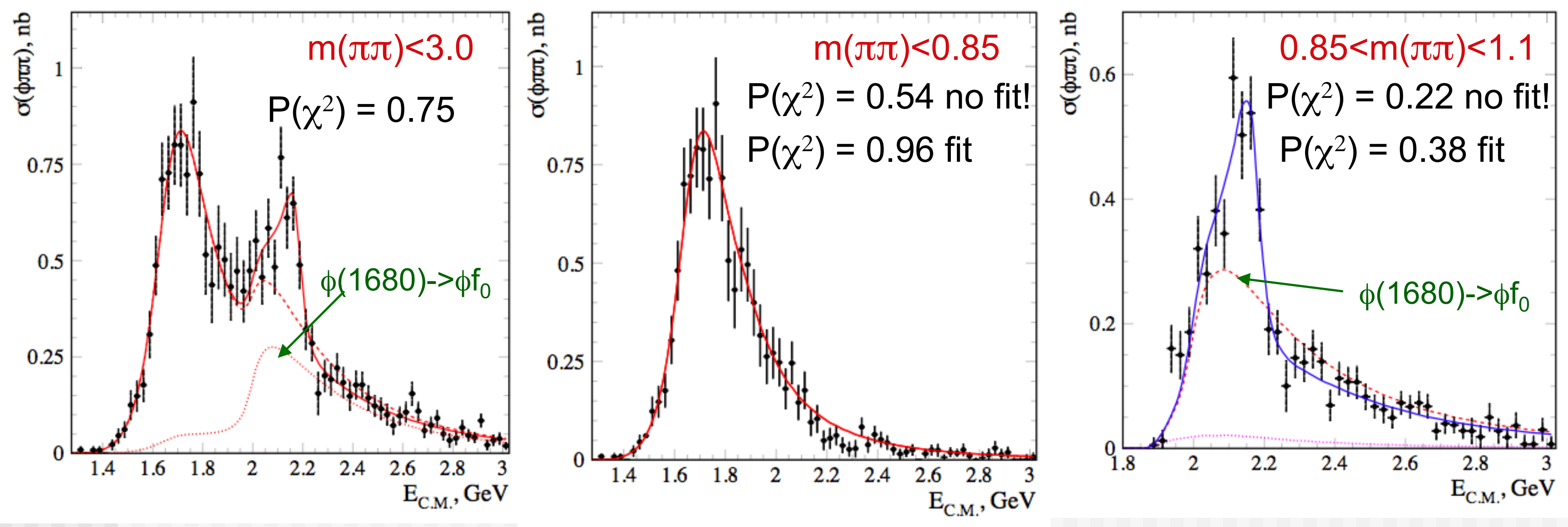


This approach cannot explain our data for the 0.85<m(ππ)<1.1 selection

Cross section for $e^+e^- \to \phi\pi\pi$ (3)

Option #3 - first resonance decays to $\phi f_0(600)$ (A1) and $\phi f_0(980)$ (A2), second only to $\phi f_0(980)$.

$$\sigma(s) = \frac{P_{\phi\sigma}(s)}{s^{3/2}} \bullet \left| \frac{A1_{r1}(s,m_1)}{\sqrt{P_{\phi\sigma}(m_1)}} \right|^2 + \frac{P_{\phi f_0}(s)}{s^{3/2}} \bullet \left| \frac{A2_{r1}(s,m_1)e^{i\varphi}}{\sqrt{P_{\phi f_0}(m_1)}} + \frac{A_{r2}(s,m_2)}{\sqrt{P_{\phi f_0}(m_2)}} \right|^2$$



Fit of total XS automatically describes all $m(\pi\pi)$ selections.

There is no physical reasons for $\phi(1680)$ not to decay to $\phi f_0(980)$ and have large coupling…

But no evidence for Y(2175) decay to $\phi f_0(600)$.

Our results for $\phi(1680)$

TABLE XII: Summary of parameter values obtained from the fits with Eq. (6) described in the text. An asterisk denotes a value that was fixed in that fit.

Fit	All $m(\pi\pi)$	$m(\pi\pi) < 0.85$ GeV/c^2	$0.85 < m(\pi\pi) < 1.1$ GeV/c^2
σ_{11} (nb)	0.655±0.039±0.040	0.678±0.047±0.040	0.655*
m_1(GeV/c^2)	1.742±0.013±0.012	1.733±0.010±0.010	1.742*
Γ_1(GeV)	0.337±0.043±0.061	0.300±0.015±0.037	0.337*
σ_{22} (nb)	0.082±0.024±0.010	0.082*	0.094±0.023±0.010
m_2(GeV/c^2)	2.176±0.014±0.004	2.176*	2.172±0.010±0.008
Γ_2(GeV)	0.090±0.022±0.010	0.090*	0.096±0.019±0.012
σ_{12}(nb)	0.152±0.034±0.040	0.152*	0.132±0.010±0.010
ψ (rad)	-1.94±0.34±0.10	-1.94*	-1.92±0.24±0.12
χ^2/n.d.f.	48/(67-9)	46/(66-4)	38/(46-6)
P(χ^2)	0.74	0.96	0.40

For $e^+e^- \rightarrow \phi(1680) \rightarrow \phi\pi\pi$ we get:

σ_0 = 0.678 ± 0.062 nb
m = 1.733 ± 0.015 GeV/c^2
Γ = 0.300 ± 0.040 GeV

$\Gamma_{ee} \bullet B_{\phi\pi\pi}$ = (42 ± 2 ± 3) eV

(369 eV for KK* and 138 eV for $\phi\eta$)

For $e^+e^- \rightarrow \phi(1680) \rightarrow \phi\, f_0(980)$ we cannot use expression

$$\Gamma_{ee} B_f = \frac{\sigma_0 \Gamma_f m^2}{12\pi C}$$

Not clear how to present result

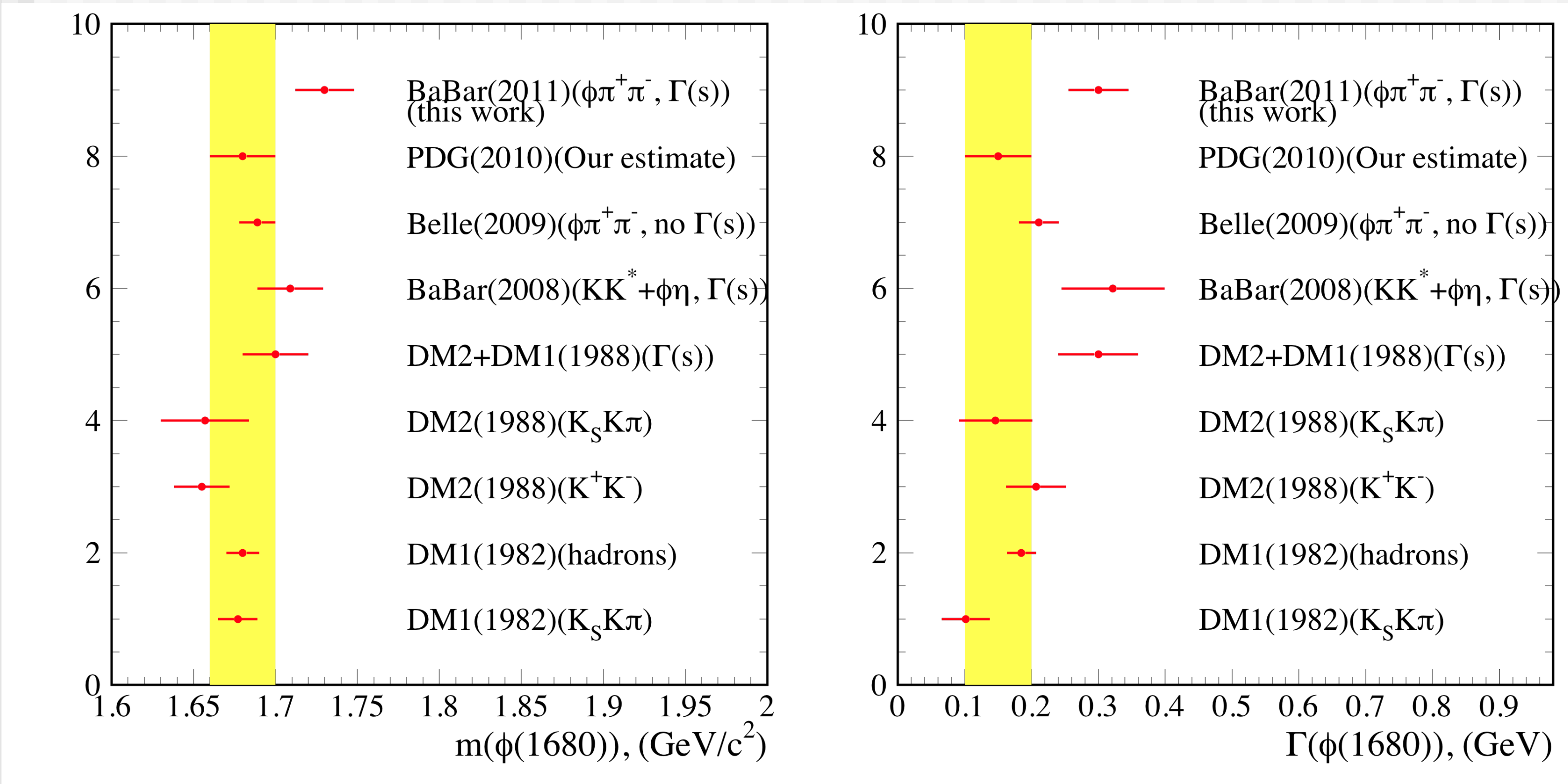
To use $g^2_{\phi\, f0(980)} / g^2_{\phi\pi\pi}$? How to calculate?

What we know about $\phi(1680)$

From 2010 PDG (only e^+e^- experiments):

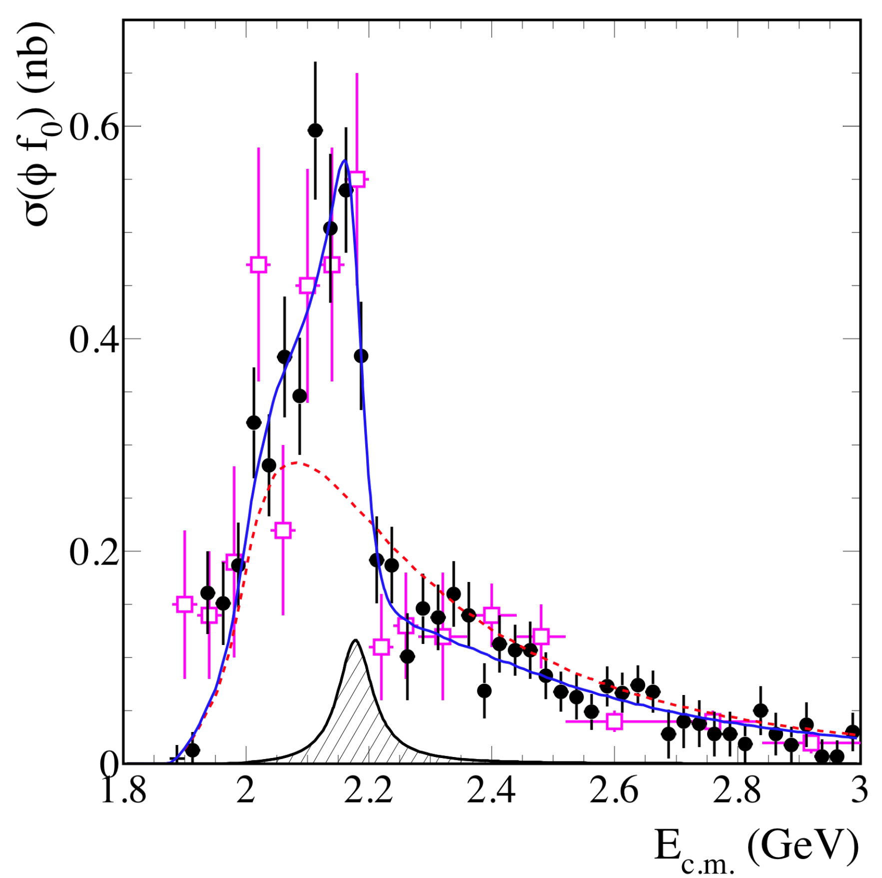
There is NO BF table – only "seen".
BaBar provides $\Gamma_{ee} \bullet B$ for KK^* and $\phi\eta$ and $\phi\pi\pi$

There are 4 photo-production (K^+K^- channel) and one $p\bar{p}$ ($K_S K\pi$) experiments giving mass ~1740, and width ~0.1 GeV (but could be $\rho(1700)$ as stated in PDG)



Taking into account energy dependent width ("standard" for recent low mass spectroscopy) makes mass ~50 MeV higher and 100-150 MeV wider width

Cross section for $e^+e^- \to \phi f_0(980)$, Y(2175)



$K^+K^-\pi^0\pi^0$ + $K^+K^-\pi^+\pi^-$

σ_0^x = 0.093 ± 0.023 ± 0.010 nb
m_x = 2.180 ± 0.008 ± 0.008 GeV/c^2
Γ_x= 0.077 ± 0.015 ± 0.010 GeV

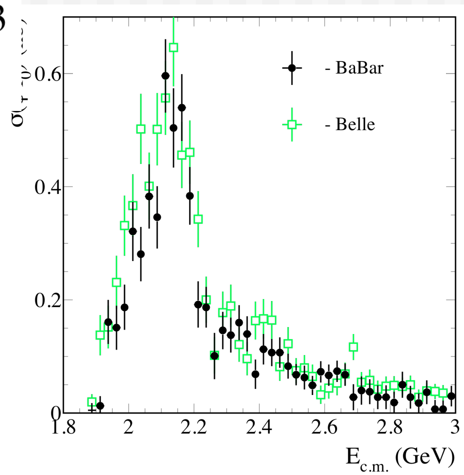
$$\Gamma_{ee}B_x = \frac{\sigma_0 \Gamma_x m^2}{12\pi C}$$

$\Gamma_{ee} \cdot B_{\phi\ f0}$ = (2.3 ± 0.3 ± 0.3) eV

2 ln (L_0/L_x) = sqrt (150 – 64) ~ 9.3 σ

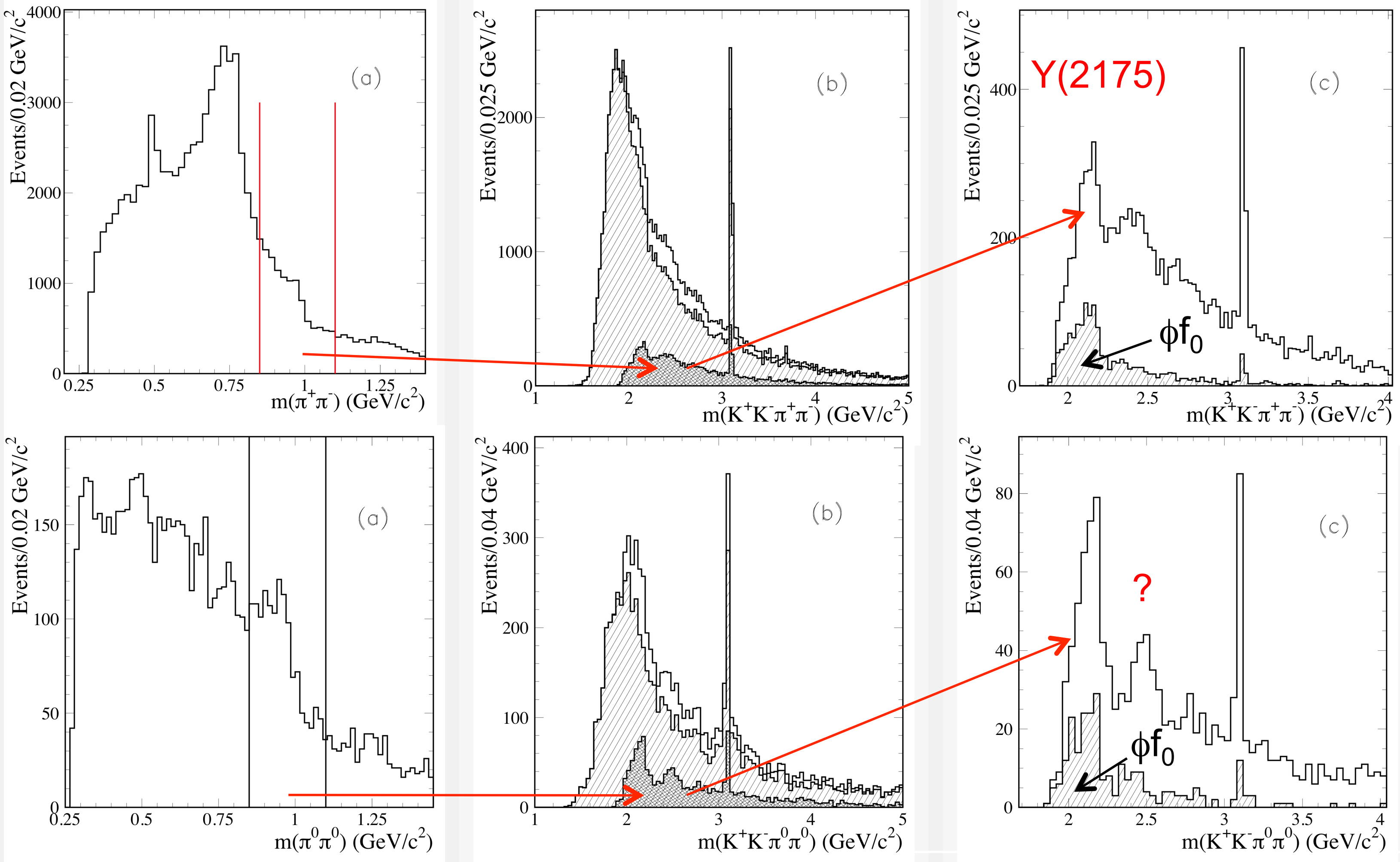
XS is corrected by:
Br($\phi \to K^+K^-$) =0.491
Br($f_0 \to \pi^+\pi^-$) = 2/3
Br($f_0 \to \pi^0\pi^0$) = 1/3

A fit with free interference phase with continuum



Good overall agreement with 670 fb^{-1} Belle data for $K^+K^-\pi^+\pi^-$ channel
C.P.Shen *et al.* (Belle Collaboration), Phys. Rev. D80, 031101(R) (2009).

Evidence of Y (2175) in K+K-f_0 final state



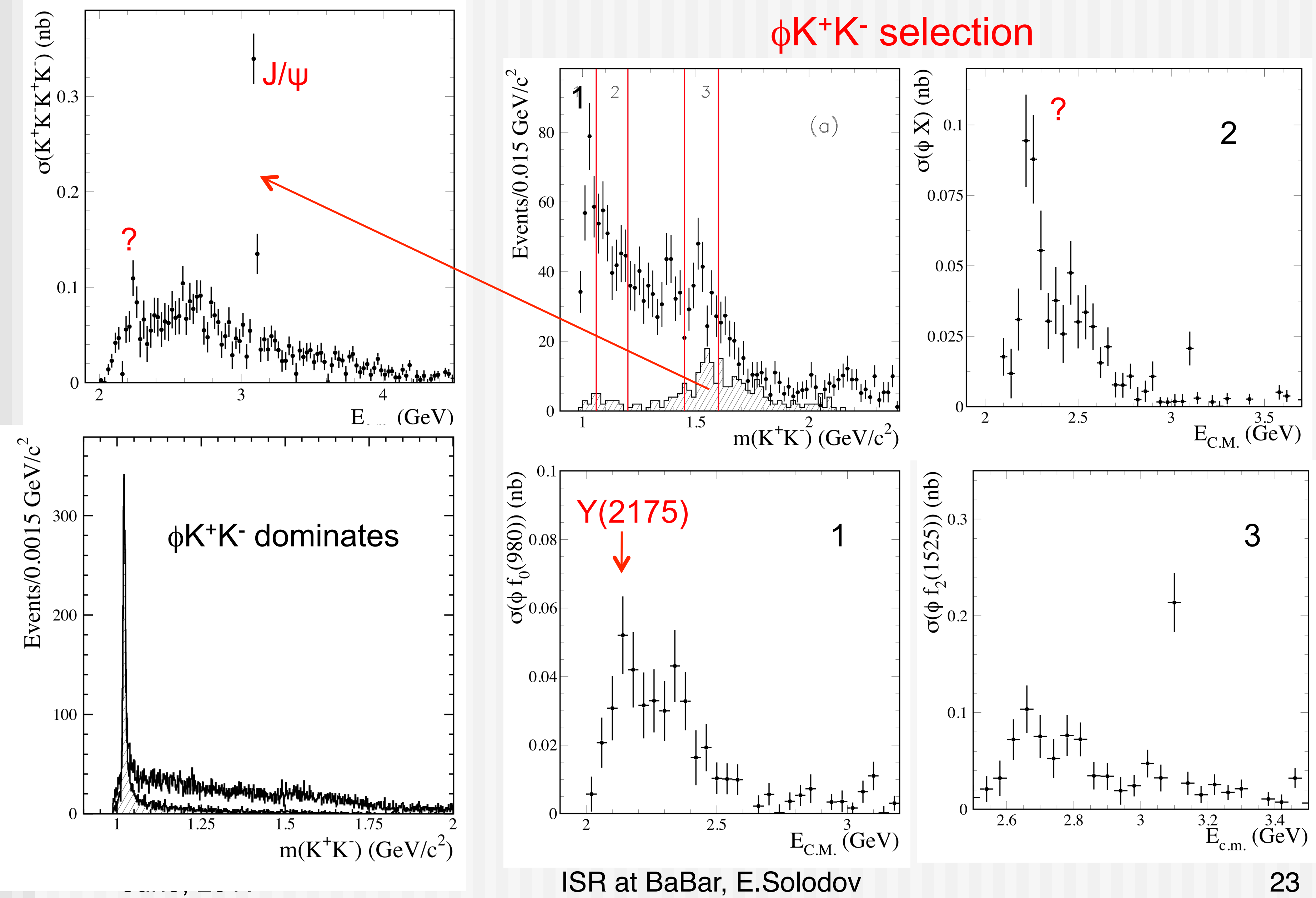
Raw $\pi\pi$ mass
No background subtraction

Possible nature of Y(2175):

1 – ssss, 2 – ϕ'' but no BR $\phi\pi\pi$,

3- Y(2175) is similar to Y(4260): Y(4260) = J/Ψ f_0, Γ_{ee}=5.5 eV
Y(2175)= ϕf_0, Γ_{ee}=2.3 eV

$e^+e^- \rightarrow K^+K^-K^+K^-$



J/ψ, $\psi(2S) \rightarrow K^+K^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-$, $K^+K^-K^+K^-$

We measure

$$\mathcal{B}_{J/\psi\to f}\cdot\Gamma_{ee}^{J/\psi} = \frac{N_{J/\psi\to f}\cdot m_{J/\psi}^2}{6\pi^2\cdot d\mathcal{L}/dE\cdot\epsilon_f(m_{J/\psi})\cdot C}$$

Because of small systematic uncertainties in L (~1%) and efficiency (~3%) BaBar is competitive for measurements, where systematic errors dominate.
(Plus new, never studied states!)

J/ψ region for $K^+K^-\pi^+\pi^-, K^+K^-\pi^0\pi^0, K^+K^-K^+K^-$

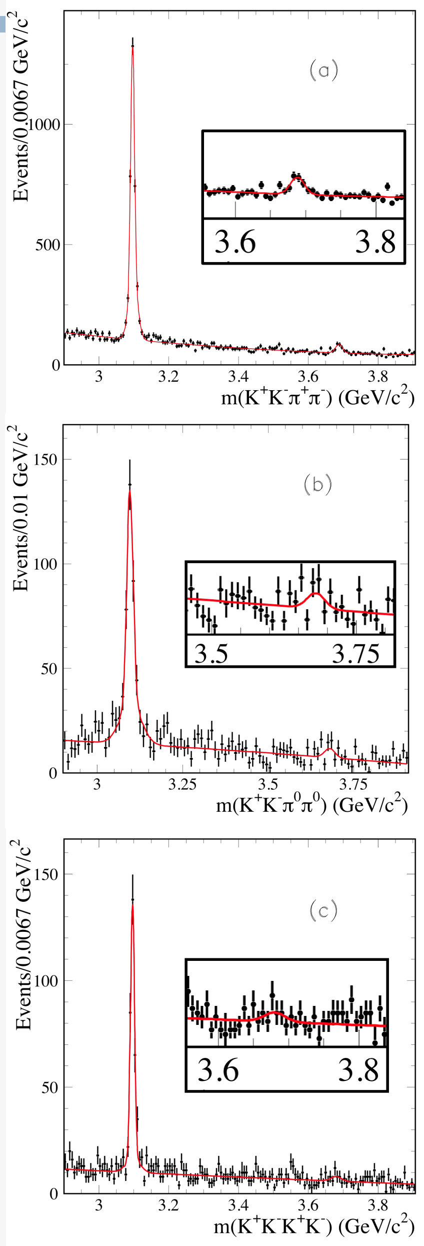


TABLE XIII: Summary of the J/ψ and $\psi(2S)$ branching fraction values obtained in this analysis.

Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) This work	PDG2010
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^+\pi^-}$	37.94±0.81±1.10	6.84±0.15±0.27	6.6 ±0.5
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^0\pi^0}$	11.75±0.81±0.90	2.12±0.15±0.18	2.45 ±0.31
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to K^+K^-K^+K^-}$	4.00±0.33±0.29	0.72±0.06±0.05	0.76 ±0.09
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to K^{*0}\overline{K}^{*0}_2}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\overline{K}^{*0}_2\to K^-\pi^+}$	8.59±0.36±0.27	6.98±0.29±0.21	6.0 ±0.6
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to K^{*0}\overline{K}^{*0}}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\overline{K}^{*0}\to K^-\pi^+}$	0.57±0.15±0.03	0.23±0.06±0.01	0.23 ±0.07
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi\pi^+\pi^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	2.19±0.23±0.07	0.81±0.08±0.03	0.94 ±0.09
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi\pi^0\pi^0}\cdot\mathcal{B}_{\phi\to K^+K^-}$	1.36±0.27±0.07	0.50±0.10±0.03	0.56 ±0.16
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi K^+K^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	2.26±0.26±0.16	1.66±0.19±0.12	1.83 ±0.24 [a]
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^+\pi^-}$	0.69±0.11±0.05	0.25±0.04±0.02	0.18 ±0.04 [b]
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^0\pi^0}$	0.48±0.12±0.05	0.18±0.04±0.02	0.17 ±0.07 [c]
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\phi f_x}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_x\to\pi^+\pi^-}$	0.74±0.12±0.05	0.27±0.04±0.02	0.72 ±0.13 [d]
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-\pi^+\pi^-}$	1.92±0.30±0.06	0.81±0.13±0.03	0.75 ±0.09
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-\pi^0\pi^0}$	0.60±0.31±0.03	0.25±0.13±0.02	no entry
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-K^+K^-}$	0.22±0.10±0.02	0.09±0.04±0.01	0.060±0.014
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\phi\pi^+\pi^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	0.27±0.09±0.02	0.23±0.08±0.01	0.117±0.029
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^+\pi^-}$	0.17±0.06±0.02	0.15±0.05±0.01	0.068±0.024 [e]

[a] $\mathcal{B}_{J/\psi\to\phi\overline{K}K}$ obtained as $2\cdot\mathcal{B}_{J/\psi\to\phi K^+K^-}$.
[b] Not corrected for the $f_0\to\pi^0\pi^0$ mode.
[c] Not corrected for the $f_0\to\pi^+\pi^-$ mode.
[d] We compare our ϕf_x, $f_x\to\pi^+\pi^-$ mode with $\phi f_2(1270)$.
[e] $\mathcal{B}_{\psi(2S)\to\phi f_0}$, $f_0\to\pi^+\pi^-$

Small systematic errors allow BaBar to improve BF for major decay modes.

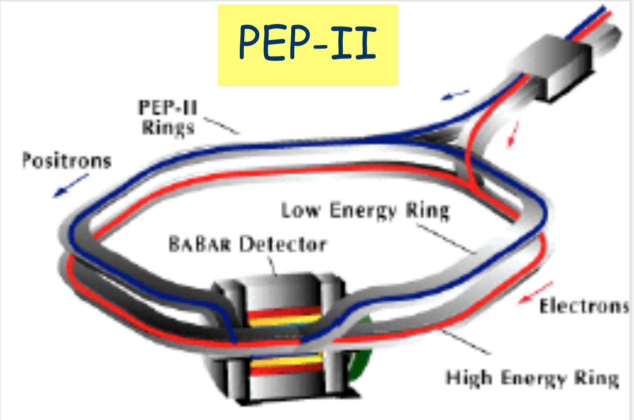
Summary

- Analysis of $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$ and $K^+K^-K^+K^-$ has been performed using ISR and 454 fb^{-1}
- The $K^+K^-\pi^+\pi^-$ cross section has been measured with ~4% syst. errors
- The $K^+K^-\pi^0\pi^0$ cross section has been measured with ~8% syst. errors
- Inclusive cross sections for $K^*(892)^0$, $K_2(1430)^0$, and $\rho(770)^0$ are provided
- It is shown, that $K^{*0}\underline{K}^{*0}$ production is suppressed, but $K^{*+}K^{*-}$ is not.
- Final states $\phi\pi^+\pi^-$, $\phi\pi^0\pi^0$ and ϕ $f_0(980)$ ($f_0 \rightarrow \pi^+\pi^-, \pi^0\pi^0$) are selected
- A structure with $m \sim 2.18$ GeV/c^2 and $\Gamma \sim 0.08$ GeV has been confirmed

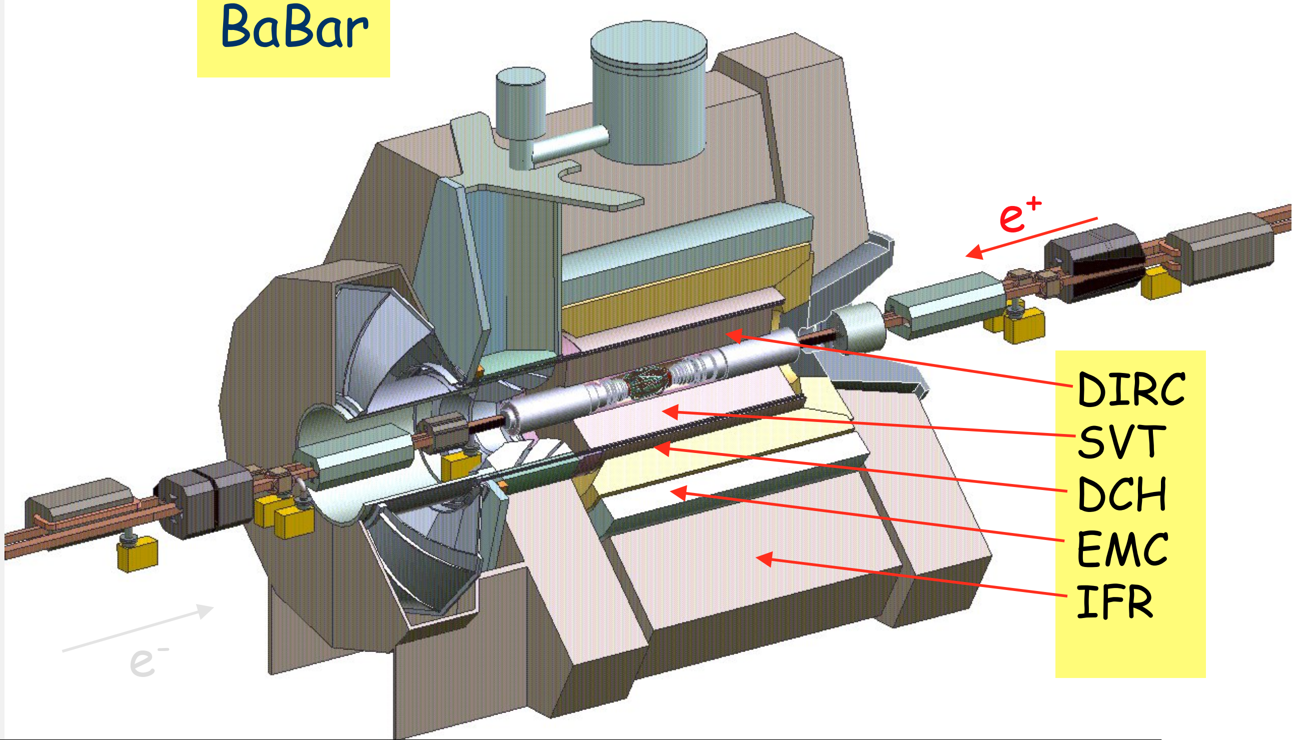
  in $e^+e^- \rightarrow K^+K^-$ $f_0(980)$ ($f_0 \rightarrow \pi^+\pi^-, \pi^0\pi^0$) reactions with ~9 σ significance
- The confirmation comes from BES and Belle.
- Y(2175) state decays to ϕ $f_0(980)$ but does not decay to ϕ $f_0(600)$.
- New final states ($\phi\pi\pi$ and ϕ $f_0(980)$) have been observed for $\phi(1680)$ and parameters measured
- J/ψ decays to $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $\phi\pi^+\pi^-$, $\phi\pi^0\pi^0$ and ϕ $f_0(980)$ have been measured.
- PRD paper is submitted.

PEP-II e+e- collider, Babar detector

E_+ = 3.1 GeV, E_- = 9 GeV



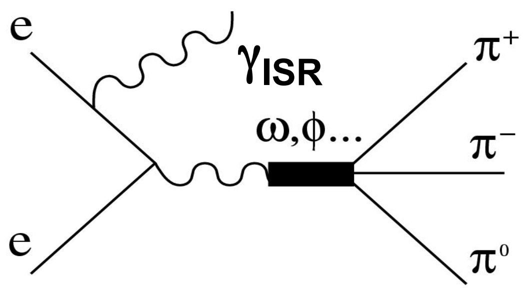
E_{CM} = M(Υ(4S))=10.6 GeV
2000 – 2008 yrs
ΔL = 500 fb^{-1}
N(B) = 10^9



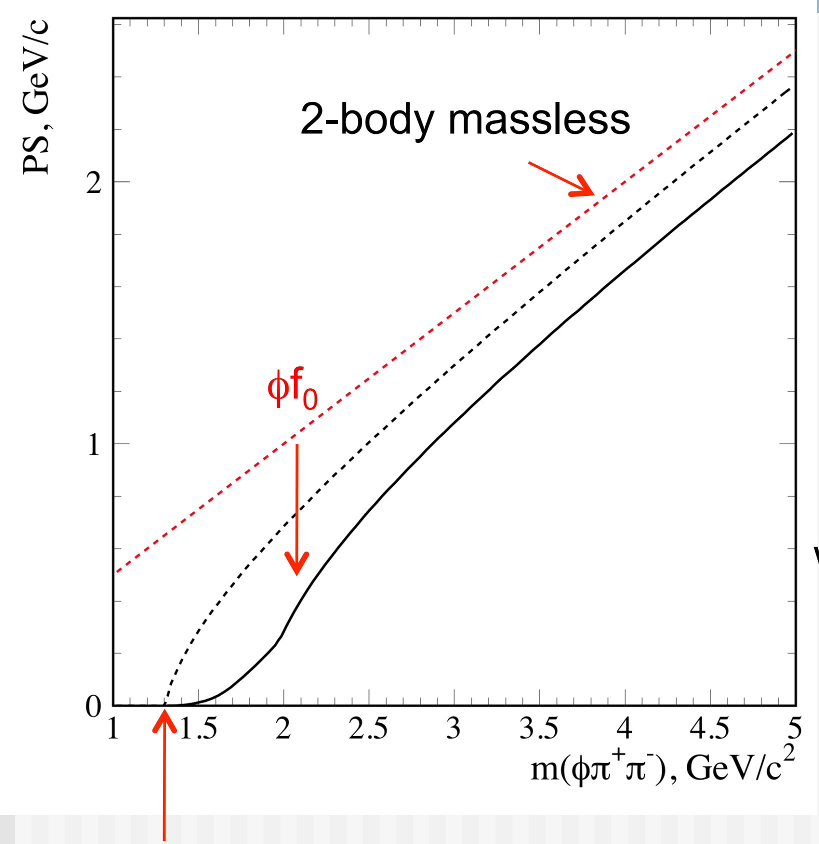
$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = W(s,x,\theta)\cdot\sigma_0(s(1-x)),$$

$$W(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right),\quad x = \frac{2E_\gamma}{\sqrt{s}}$$

θ - photon polar angle in c.m.



ππ phase space



The observed ππ mass distribution used to calculated a phase space according to:

$$P_{\phi\pi\pi}(s) = \int_{2m_\pi}^{\sqrt{s}-m_\phi} 2m\,dm\,BW_{\pi\pi}(s)\,q(s,m,m_\phi)$$

where $BW_{\pi\pi}(s)$ - describes ππ mass distribution

φππ quazi-two-body phase space with no resonant structure.

The observed ππ mass shape significantly differ from pure φππ three-body phase space and has ~150 MeV shifted threshold and fast rise, when ϕf_0 channel is opening.

The ππ mass shape contribute only to phase space!

Width energy dependence

First resonance is presumably φ(1680) with dominant decay to KK* + φη and we see ~5-10% in φ(1020)f_0(600) mode - "standard" way for Γ(s):

$$\Gamma_1(s) = \Gamma_1^0\left[0.7\frac{m_1^3 P_{2K}(s)}{s^{3/2}P_{2K}(m_1^2)} + 0.1\frac{m_1 P_{\phi\pi\pi}(s)}{s^{1/2}P_{\phi\pi\pi}(m_1)} + 0.2\frac{m_1 P_{\phi\eta}(s)}{s^{1/2}P_{\phi\eta}(m_1)}\right]$$

$$P_{2K}(s) = q^3(s, m_K, m_{K^*})$$ - P-wave for K*K

$$P_{\phi\eta}(s) = q(s, m_\phi, m_\eta)$$

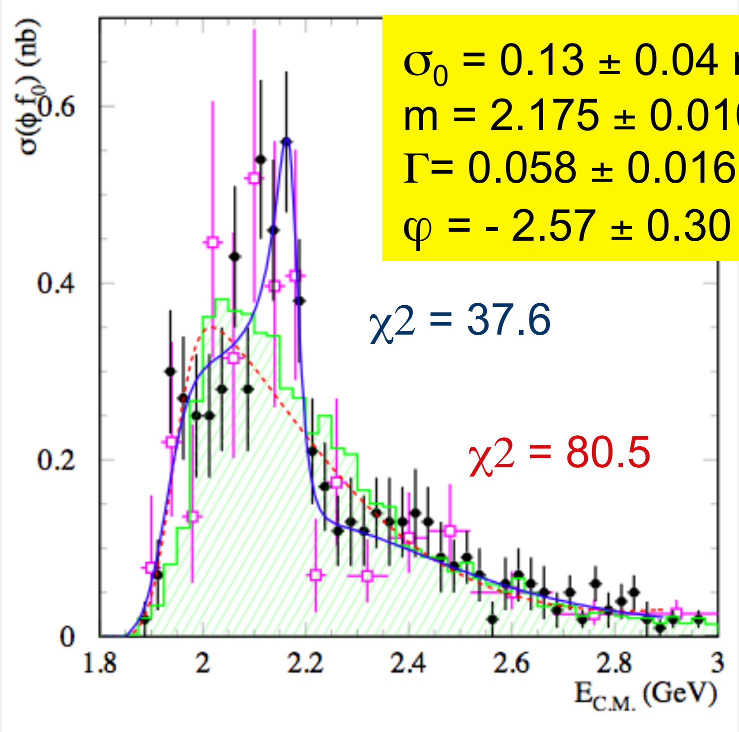
For second resonance we use:

$$\Gamma_2(s) = \Gamma_2^0 \frac{m_2 P_{\phi\pi\pi}(s)}{s^{1/2}P_{\phi\pi\pi}(m_2)}$$

Using width depending on energy significantly changes the resonance parameters for wide resonances and has small influence to narrow resonances.

Cross section for $e^+e^- \to \phi\, f_0(980)$

232 fb^{-1}

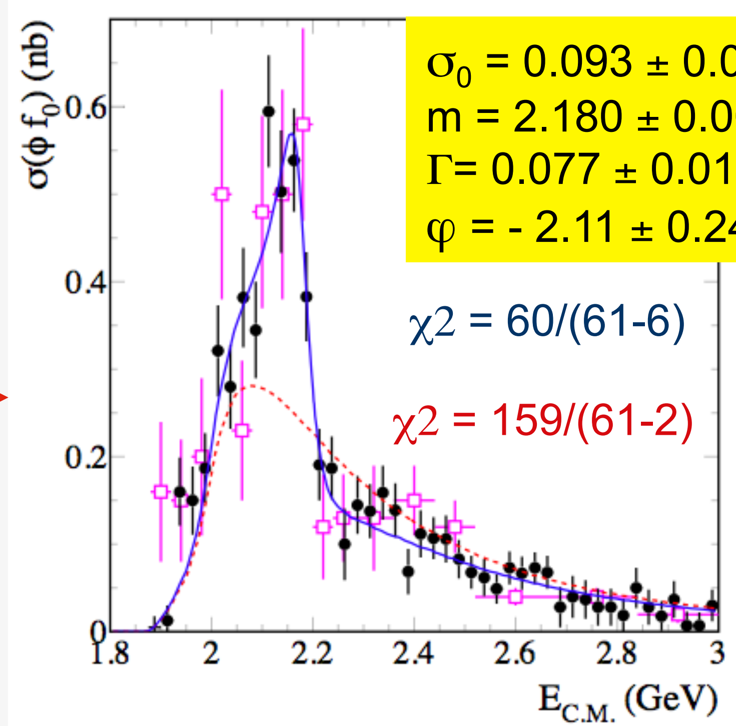


σ_0 = 0.13 ± 0.04 nb
m = 2.175 ± 0.010 GeV/c^2
Γ= 0.058 ± 0.016 GeV
φ = - 2.57 ± 0.30 rad.

$\chi2$ = 37.6

$\chi2$ = 80.5

454 fb^{-1}



σ_0 = 0.093 ± 0.021 nb
m = 2.180 ± 0.008 GeV/c^2
Γ= 0.077 ± 0.015 GeV
φ = - 2.11 ± 0.24 rad.

$\chi2$ = 60/(61-6) P($\chi2$)=0.3

$\chi2$ = 159/(61-2)

Significance is sqrt(80.5 - 37.6) ~ 6.5 σ

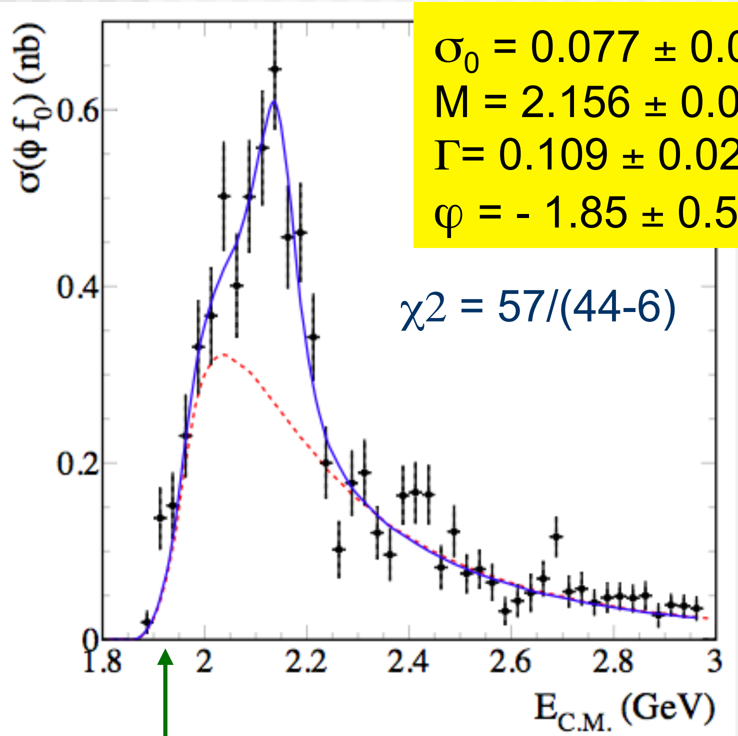
Significance is sqrt(150 - 64) ~ 9.2 σ

XS is corrected by:
Br($\phi \to K^+K^-$) =0.491
Br($f_0 \to \pi^+\pi^-$) = 2/3
Br($f_0 \to \pi^0\pi^0$) = 1/3

$$B_{\phi f_0}\Gamma_{ee} = \frac{\Gamma \sigma m^2}{12\pi C} = (2.3 \pm 0.3 \pm 0.3)eV$$

Cross section for $e^+e^- \to \phi\, f_0(980)$

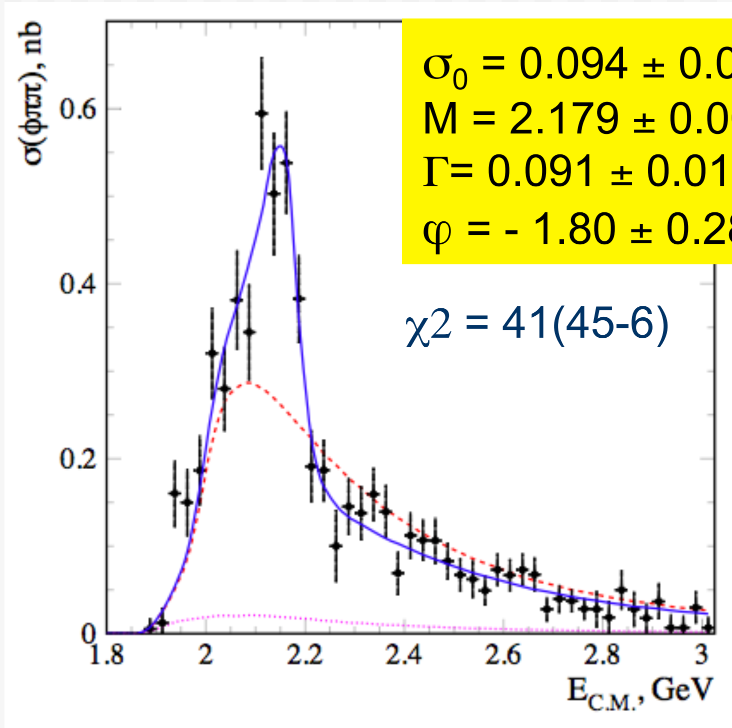
~ 670 fb^{-1} Belle data



σ_0 = 0.077 ± 0.018 nb
M = 2.156 ± 0.011 GeV/c^2
Γ= 0.109 ± 0.022 GeV
φ = - 1.85 ± 0.54 rad.

$\chi 2$ = 57/(44-6)

454 fb^{-1} BaBar data



σ_0 = 0.094 ± 0.023 nb
M = 2.179 ± 0.008 GeV/c^2
Γ= 0.091 ± 0.019 GeV
φ = - 1.80 ± 0.28 rad.

$\chi 2$ = 41(45-6)

Threshold shifted by 40 MeV! - worse resolution? Error in scale?
$f_0(980)$ mass is shifted to adjust.

XS is corrected by:
$Br(\phi \to K^+K^-)$ =0.491
$Br(f_0 \to \pi^+\pi^-)$ = 2/3