$e^+e^- \to$ hadrons via ISR: light quarks spectroscopy

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PhiPsi09, October 2009

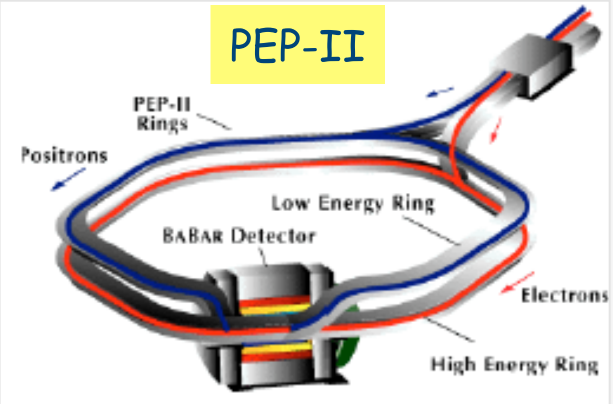
Outline

- Short introduction
- Comparison with direct e^+e^-
- Overview of results obtained up to now
- Channel-by-channel discussion
- Conclusion

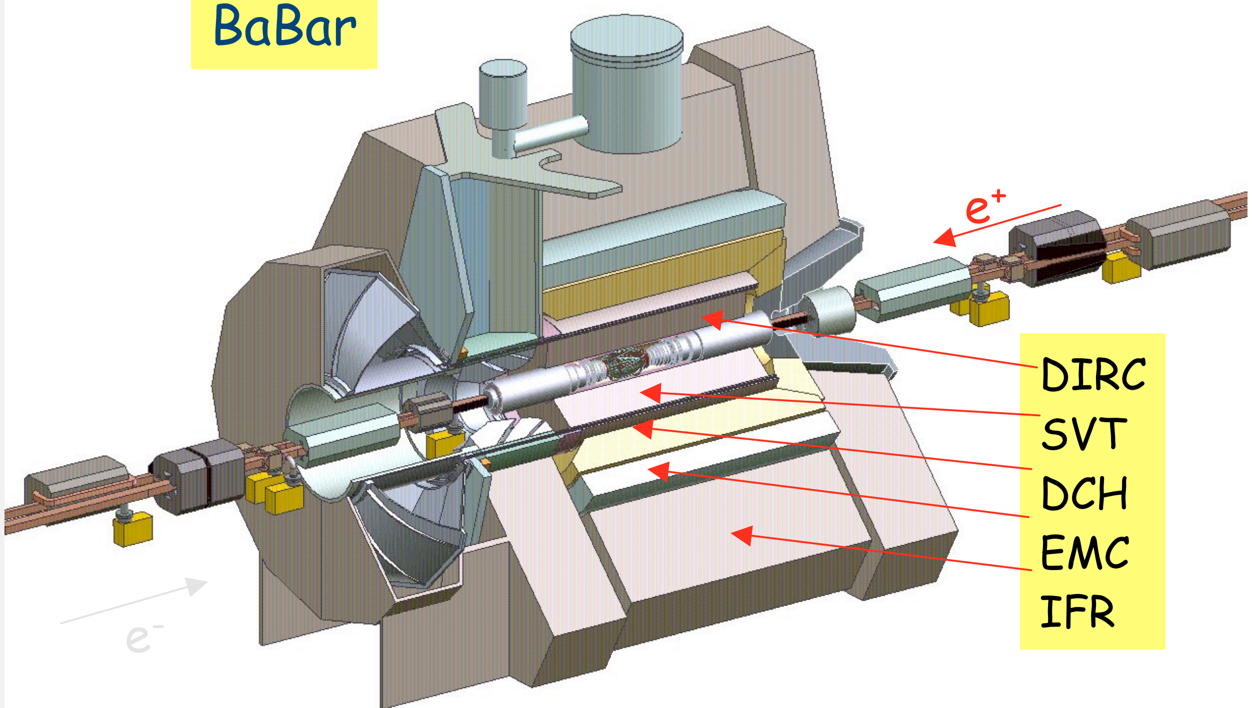
More attention to the intermediate final states and hadron spectroscopy

PEP-II e+e- collider, Babar detector

$E_+ = 3.1$ GeV, $E_- = 9$ GeV



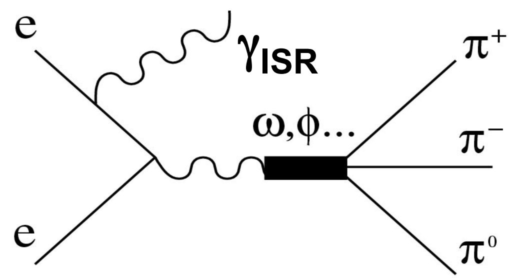
$E_{CM} = M(\Upsilon(4S))$=10.6 GeV
2000 – 2008 yrs
$\Delta L = 500\ \mathrm{fb}^{-1}$
$N(B) = 10^9$



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

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

θ - photon polar angle in c.m.



Motivation

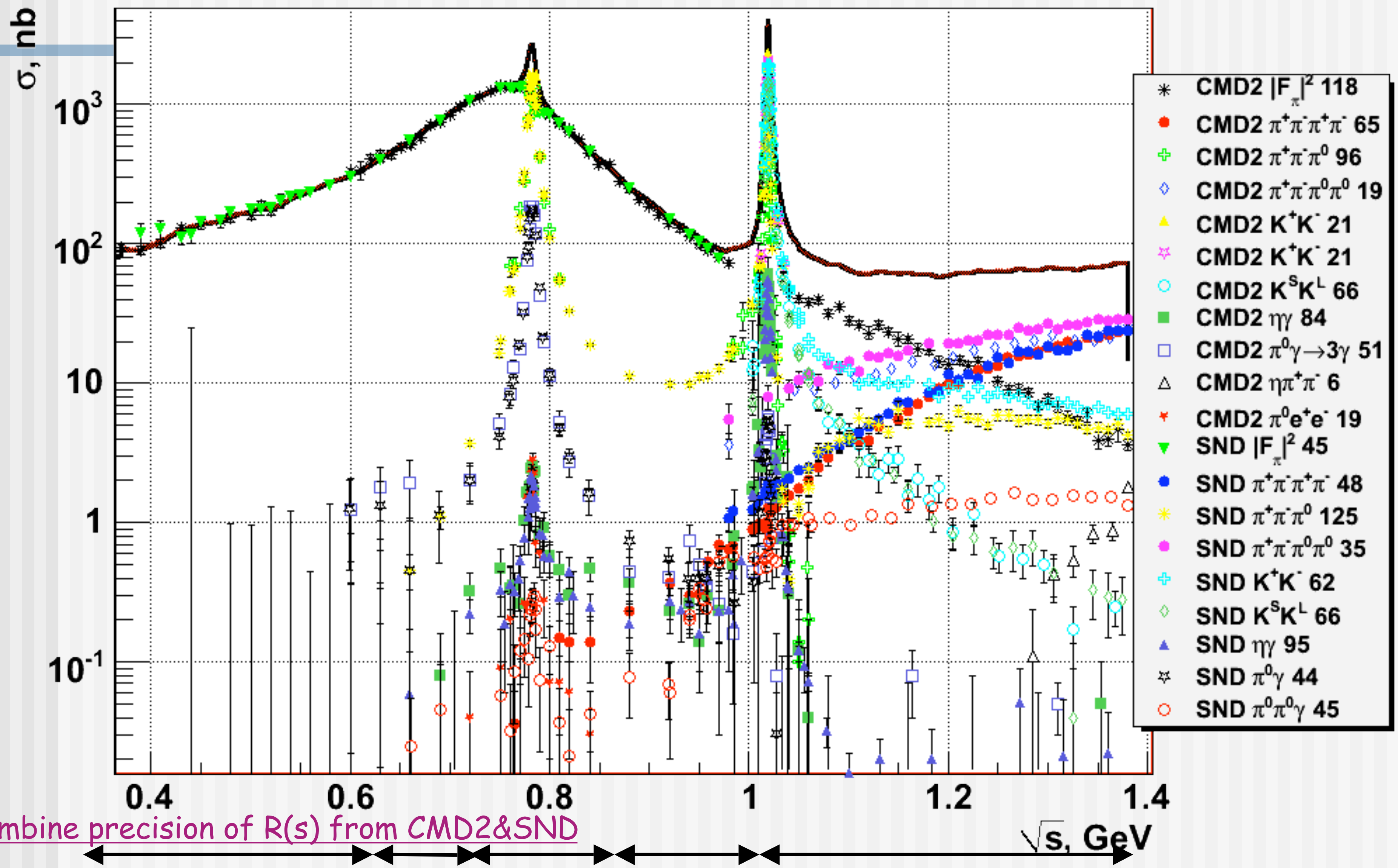
- Low energy e^+e^- cross section dominates in hadronic contribution to g-2 of muon - data from VEPP-2M were most precise
- Poor direct e^+e^- data in 1.4 - 2.5 GeV region
- Hadron spectroscopy at low masses
- Access to charmonium region (J/ψ, $\psi(2S)$ decays)

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

$e^+e^- \to 2\mu\gamma,\ 2\pi\gamma,\ 2K\gamma,\ 2p\gamma,\ 2\Lambda\gamma,\ 2\Sigma\gamma,\ \Lambda\Sigma\gamma$
$e^+e^- \to 3\pi\gamma$
$e^+e^- \to 2(\pi^+\pi^-)\gamma,\ K^+K^-\pi^+\pi^-\gamma,\ K^+K^-\pi^0\pi^0\gamma,\ 2(K^+K^-)\gamma$
$e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0\gamma,\ 3(\pi^+\pi^-)\gamma,\ K^+K^-2(\pi^+\pi^-)\gamma$
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\eta\gamma$ ...
$e^+e^- \to K^+K^-\pi^0\gamma,\ K^+K^-\eta\gamma\ \ (KK^*\gamma,\ \phi\pi^0\gamma,\ \phi\eta\gamma\ ...)$
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0/\eta\gamma,\ K^+K^-\pi^+\pi^-\pi^0/\eta\gamma$

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

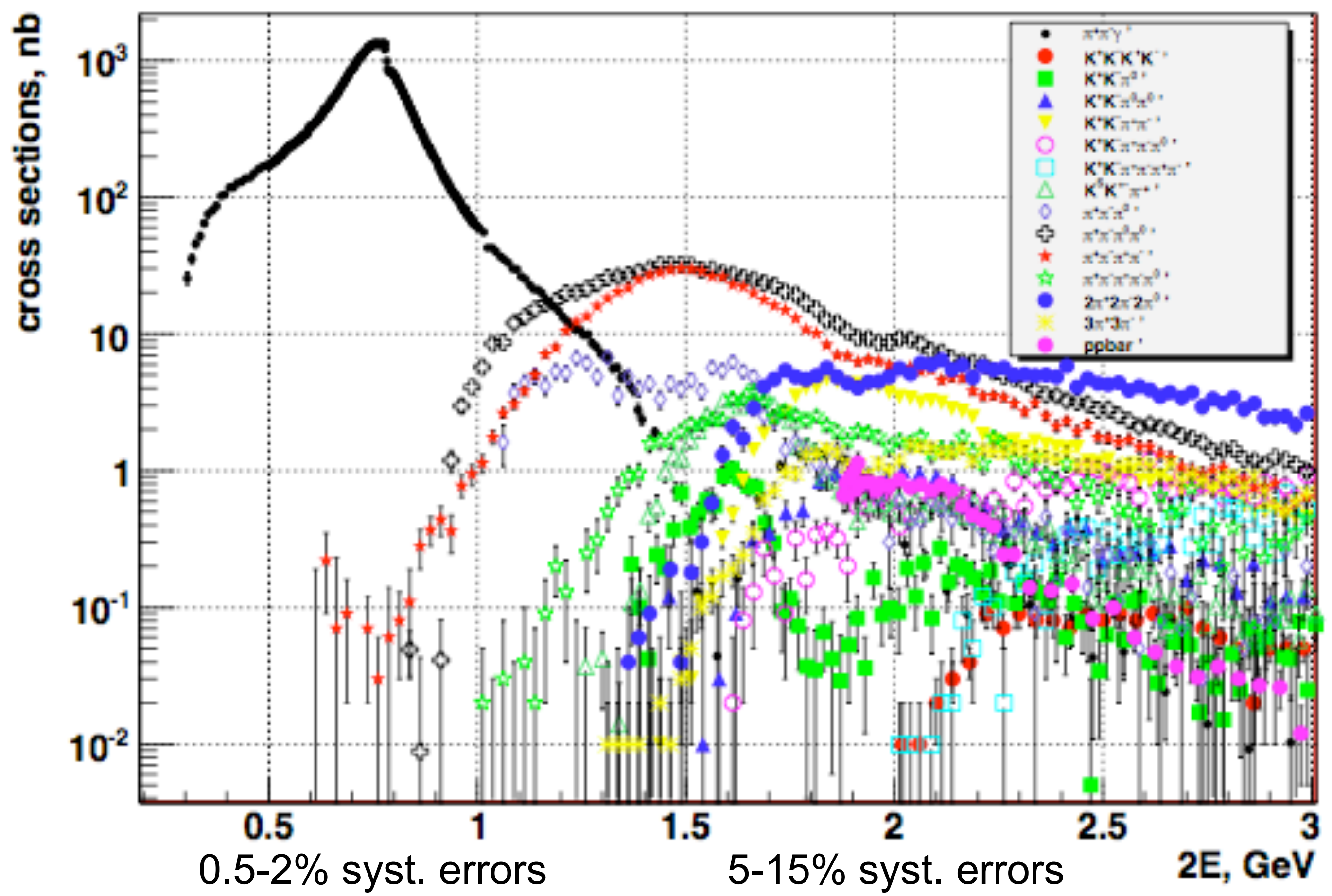
Inclusive Hadronic Cross-Sections with CMD2&SND



Combine precision of R(s) from CMD2&SND

Sys. error:	~0.6-0.7%	1.0%	0.6%	1.5%	1.5 -- 3.5 %
Total error:	~ 6 -- 1%	1.5%	1--2%	2.0%	2.5 -- 3.5 %

BaBar measurements summary

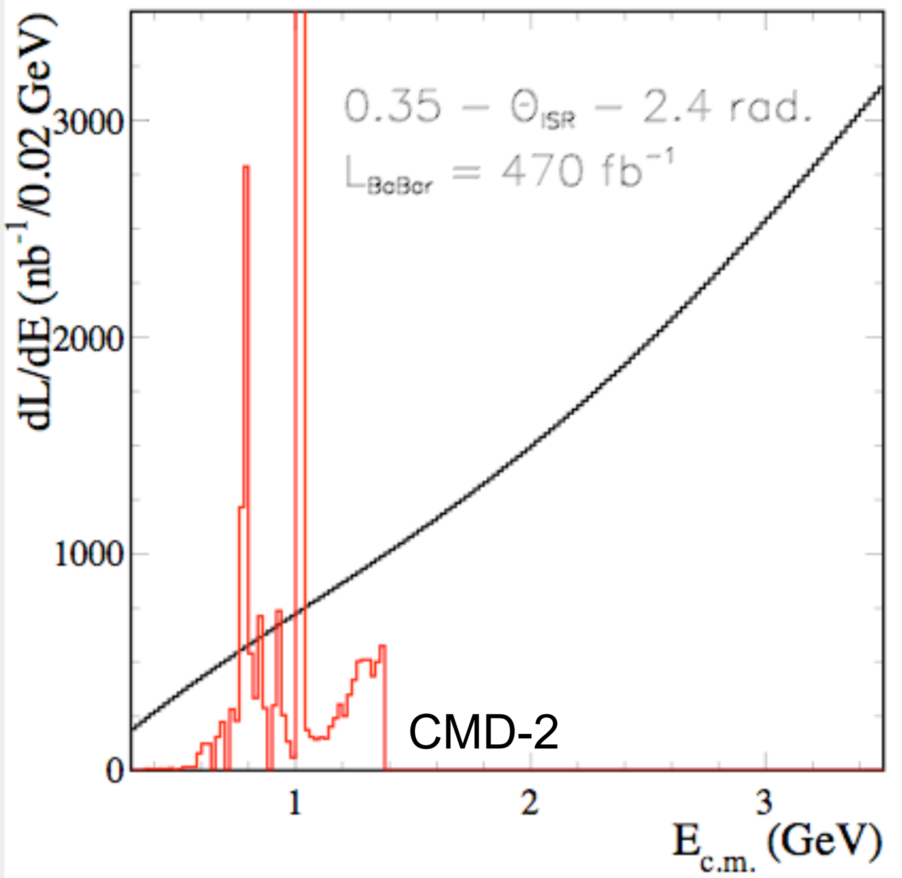


To calculate R in the energy range 1-2 GeV the processes

$\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\pi^-\pi^0$

must be measured. Work is in progress.

ISR vs. e^+e^- luminosity at low $E_{c.m.}$



1-2 GeV region:

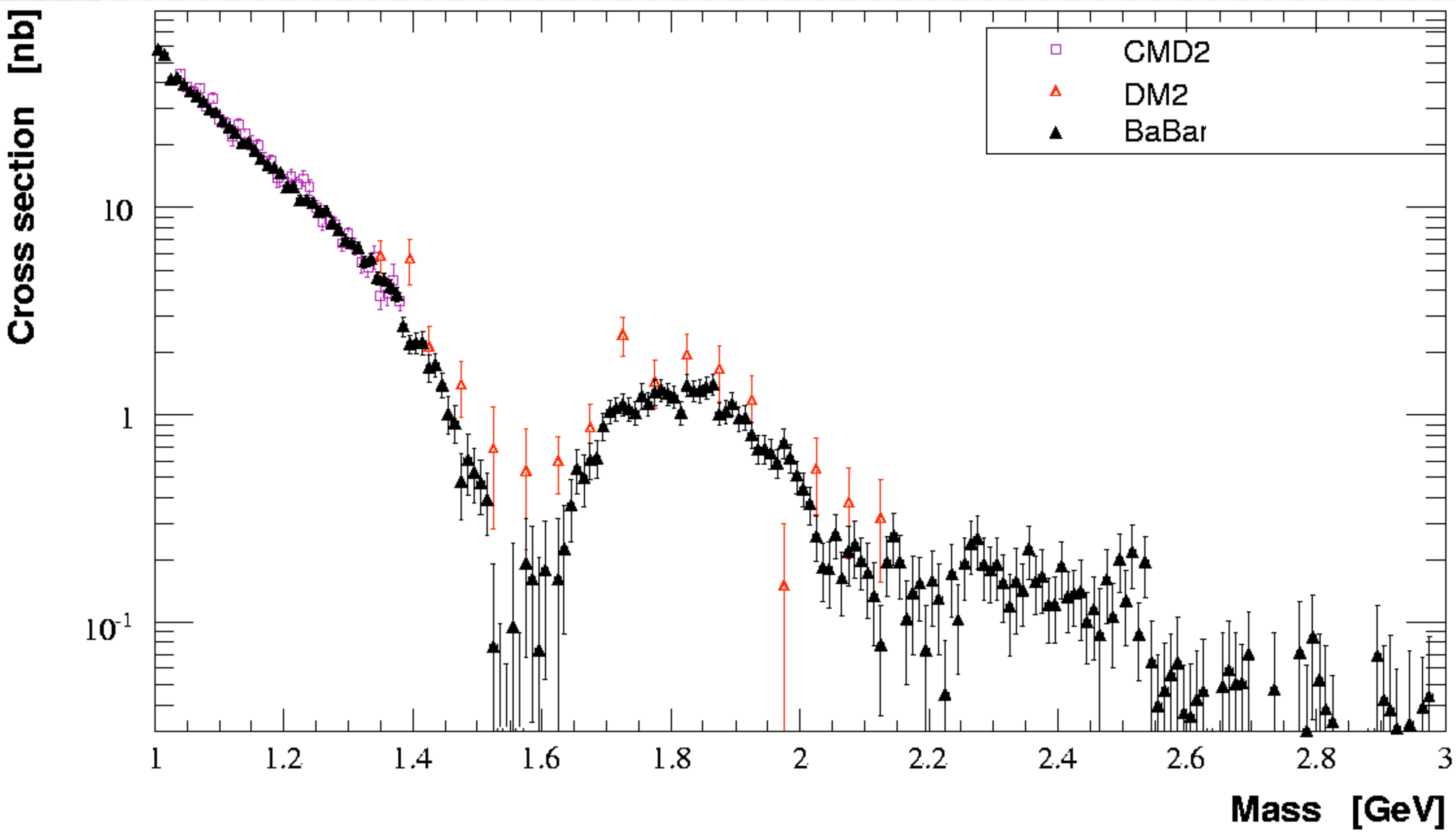
BaBar - ~50 pb^{-1}
DM2 - 1.6 pb^{-1}
(+ ~100 pb^{-1} from Belle)

For VEPP2000:
$L_{av} = 5 \times 10^{31}$ --> 500 pb^{-1}/year

ISR luminosity: $$\frac{dL}{dm} = \frac{\alpha}{\pi x}\left(\left(2-2x-2x^2\right)\log\frac{1+C}{1-C} - x^2 C\right)\frac{2m}{s}L$$

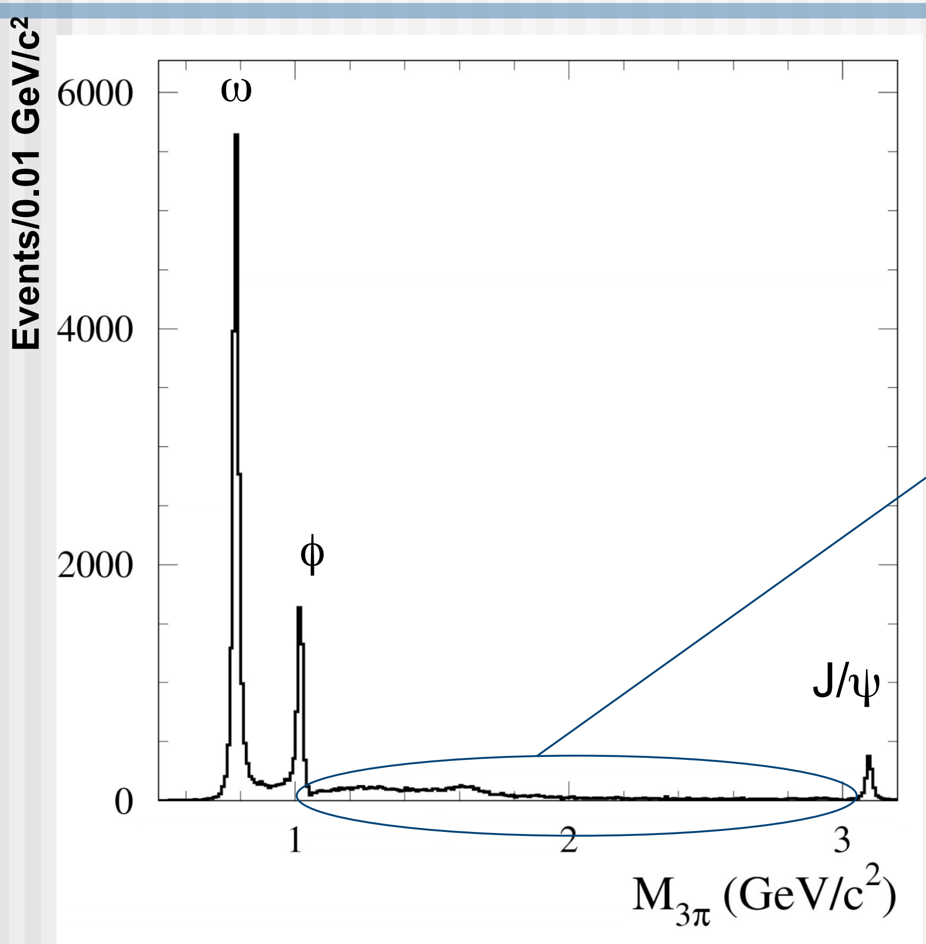
$C=\cos\theta_0$ - photon polar angle. BaBar EMC provides ~10% acceptance for ISR photon. Mass resolution ~8 MeV

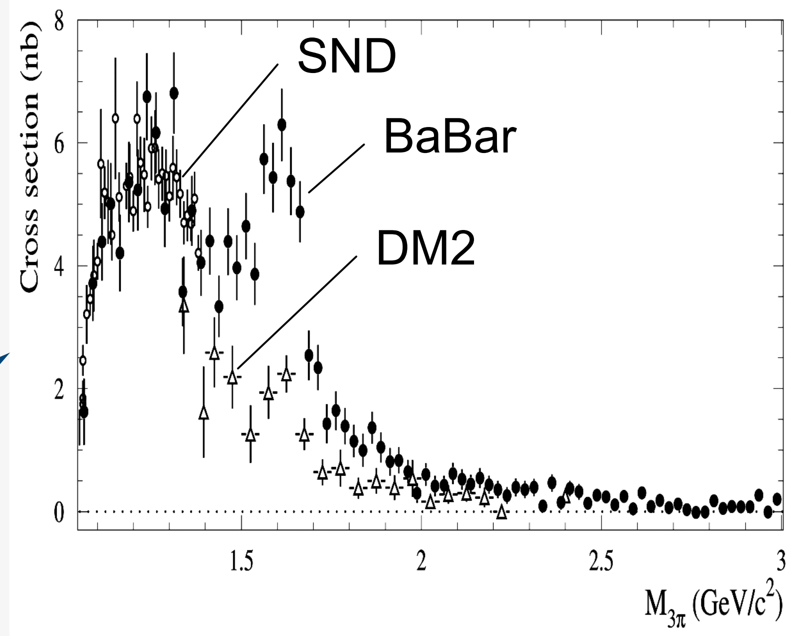
$e^+ e^- \rightarrow \pi^+ \pi^-$ cross section



Good agreement with VEPP-2M data, DM2 data have large systematic errors.
Can we understand all structures in the cross section?

$e^+ e^- \to \pi^+ \pi^- \pi^0$ cross section





coverage of wide region in this experiment -

no point-to-point normalization problems

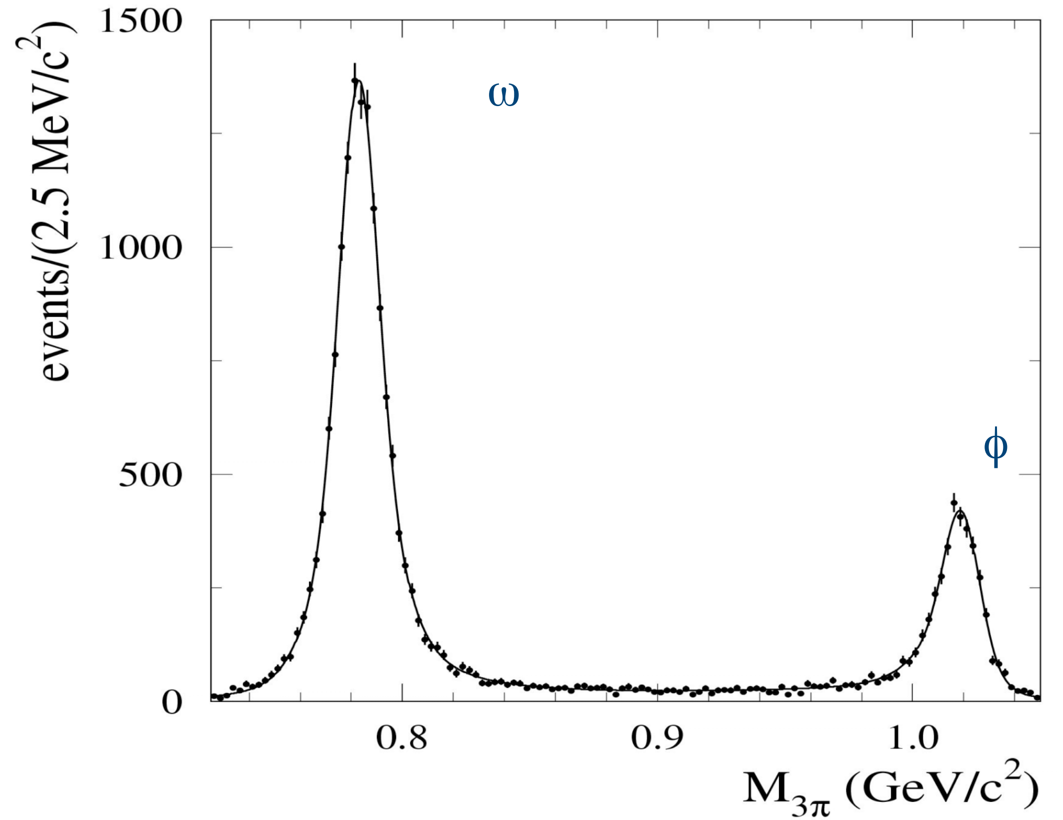
consistent with SND data $E_{C.M}$<1.4 GeV

inconsistent with DM2 results

overall normalization error ~5% up to 2.5 GeV

$$\sigma_{3\pi}(m) = \frac{(dN/dm)}{\varepsilon(m) \cdot R(m) \cdot dL/dm}$$

Fit results: ω - ϕ region



χ^2/d.f.=146/148

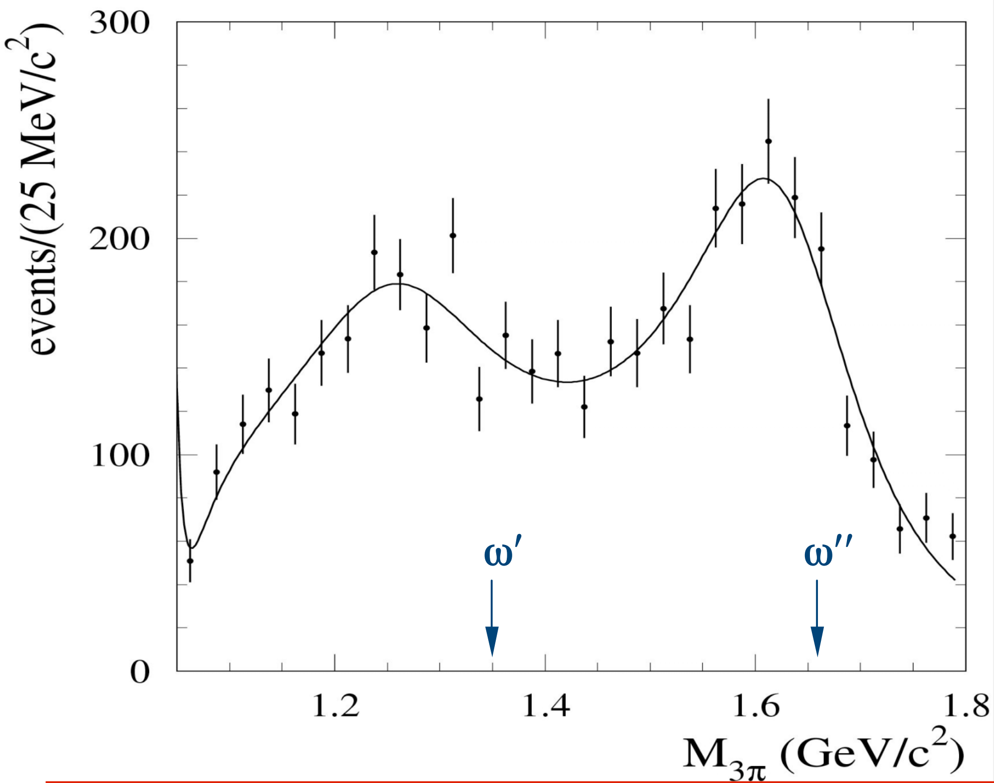
consistent with known properties of these resonances
(ω, ϕ widths fixed to PDG values)

The resolution is about 6, 7, 9 MeV/c^2 at ω, ϕ, J/ψ masses.

Fitted resolution smearing is ~1 MeV/c^2

	BaBar	PDG04
$B(\omega\to ee)B(\omega\to 3\pi)$	$=(6.70\pm0.06\pm0.27)\cdot10^{-5}$	$(6.35\pm0.11)\cdot10^{-5}$
$B(\phi\to ee)B(\phi\to 3\pi)$	$=(4.30\pm0.08\pm0.21)\cdot10^{-5}$	$(4.59\pm0.14)\cdot10^{-5}$

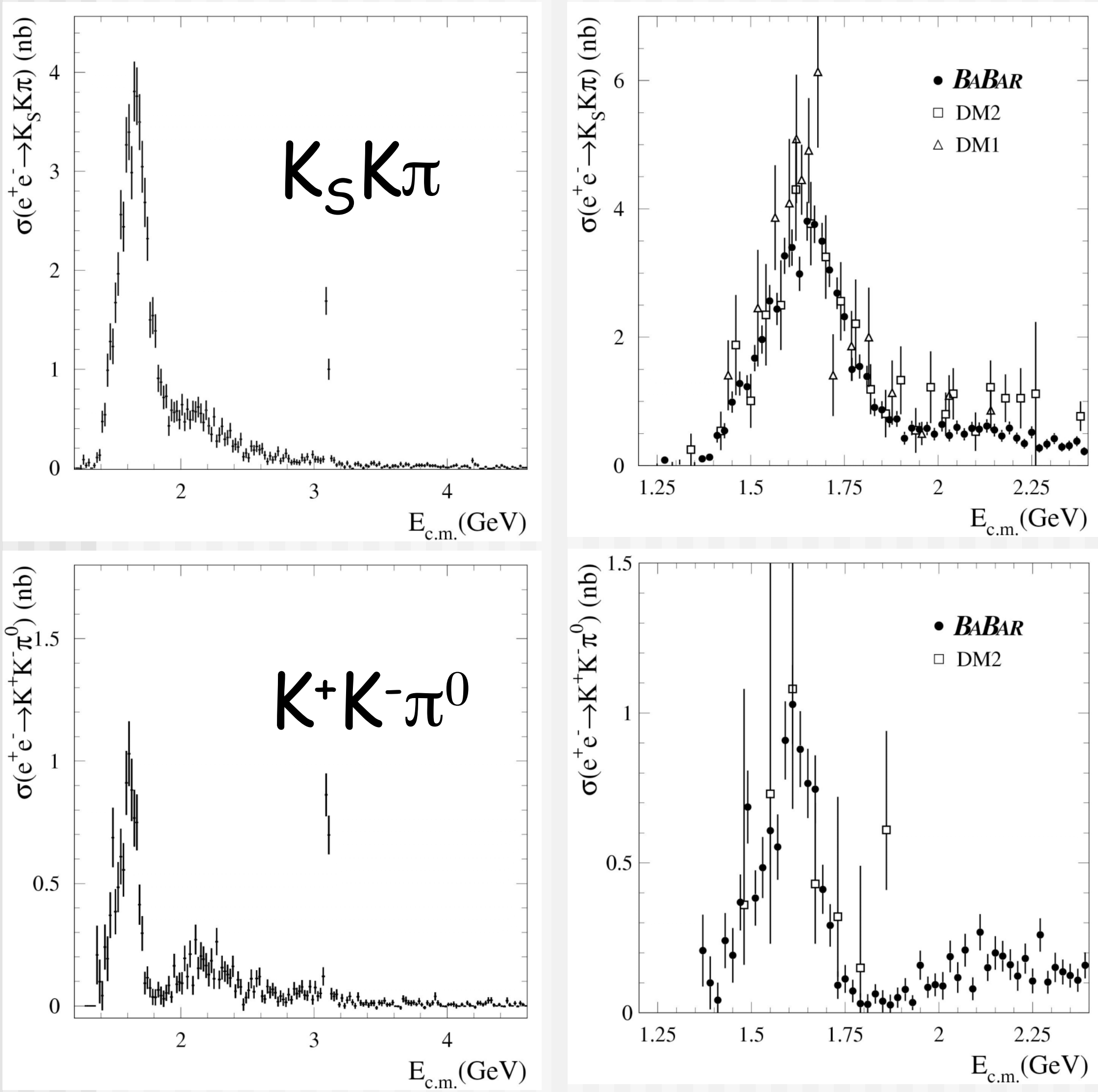
Fit results: higher mass region



- Good fit obtained for the range up to 1.8 GeV/c^2.
- Extending the fit to masses above 1.8 GeV/c^2 may require a more complicated fitting function taking into account non-resonant 3π production.
- Mass and width parameters are dependent upon our assumed phases - interference effect is strong

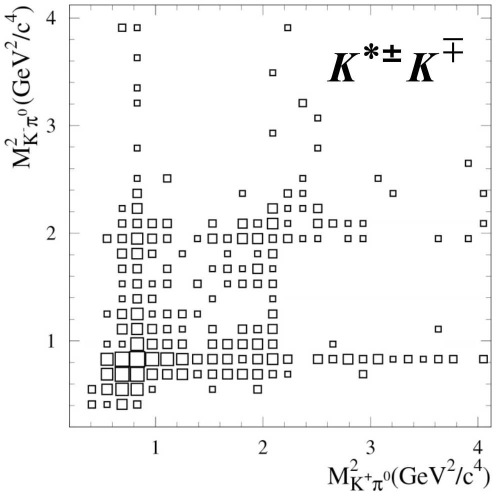
BaBar		PDG04
$B(\omega'\to ee)B(\omega'\to 3\pi)=(0.82\pm0.05\pm0.06)\cdot10^{-6}$	$M(\omega')= 1350\pm20\pm20$ MeV/c^2	1400 - 1450
	$\Gamma(\omega')= 450\pm70\pm70$ MeV	180 - 250
$B(\omega''\to ee)B(\omega''\to 3\pi)=(1.3\pm0.1\pm0.1)\cdot10^{-6}$	$M(\omega'')= 1660\pm10\pm2$ MeV/c^2	1670 ± 30
	$\Gamma(\omega'')= 230\pm30\pm20$ MeV	315 ± 35

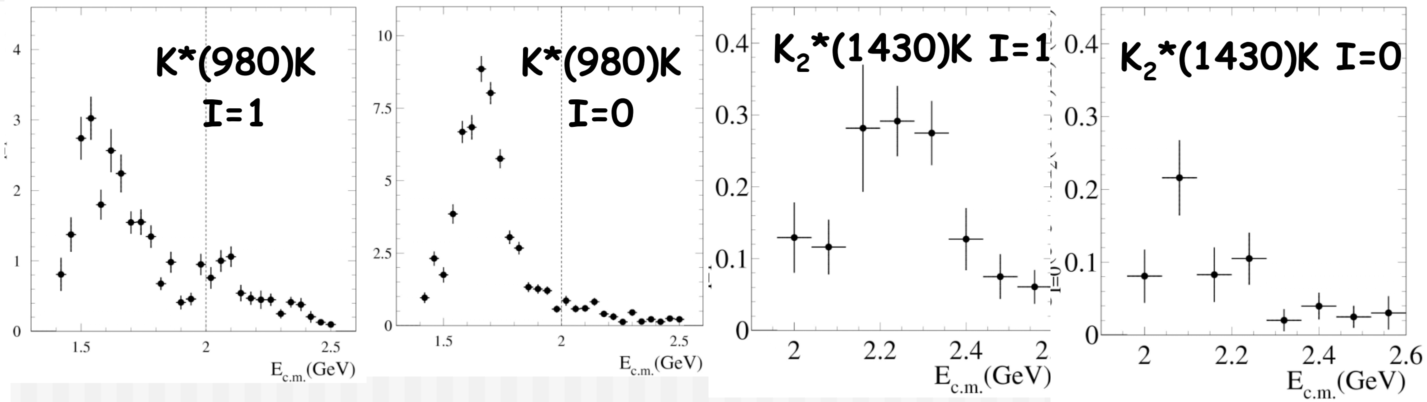
BaBar ISR: $e^+e^- \to K^+K^-\pi^0$, $K_SK\pi$

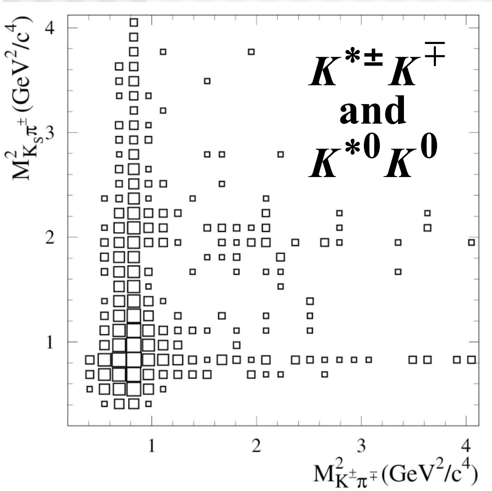


- Dominant decay mode for $\phi(1680)$
- Systematic error:
  5% for $K_SK\pi$
  6% for $K^+K^-\pi^0$
- Agreement with DM1, DM2
- Significant improvement in accuracy

BaBar ISR: $e^+e^- \to K^+K^-\pi^0$, $K_SK\pi$







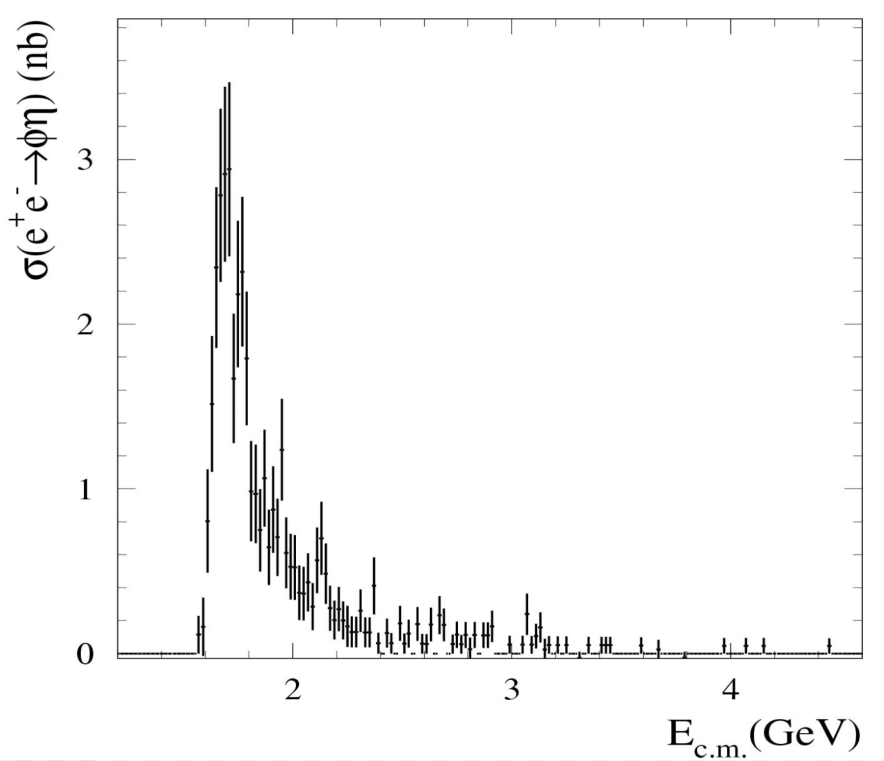
Dominant intermediate states: K*(980)K and K_2*(1430)K

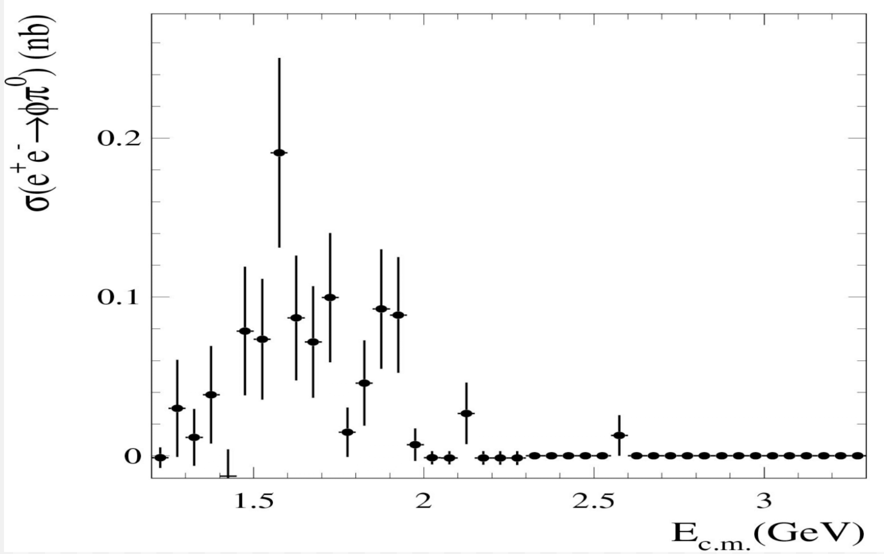
Dalitz plot population for $K_SK^-\pi^+$ final state strongly depends on relation between I=0 and I=1 amplitudes:

$$M=M^{\pm}(\alpha_{I=0} - \alpha_{I=1})+M^0(\alpha_{I=0} + \alpha_{I=1})$$

From Dalitz plot fit isovector and isoscalar cross sections can be extracted both for K*(980)K and for K_2*(1430)K

BaBar ISR: $e^+e^- \to \phi\eta, \phi\pi^0$

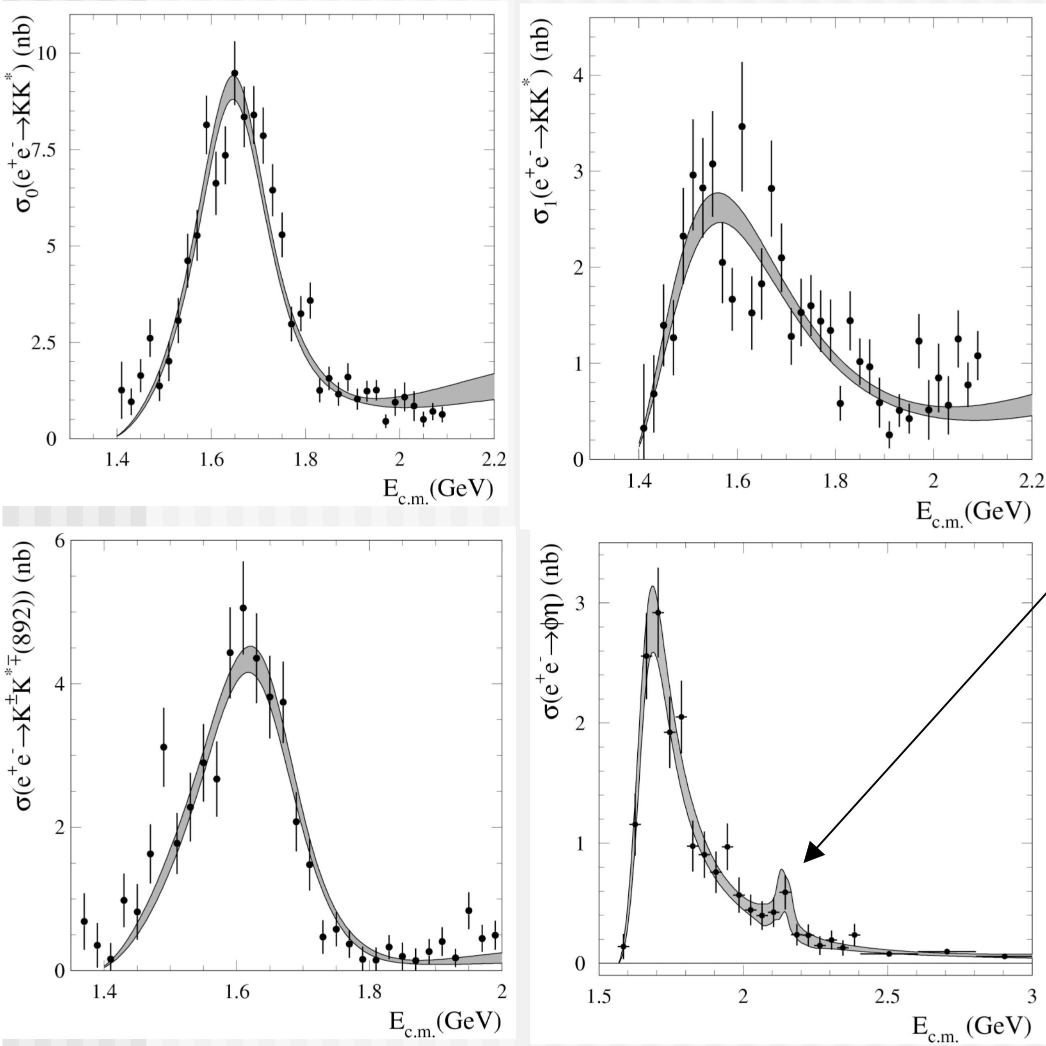




$e^+e^- \to \phi\eta$ is best channel for study of excited ϕ-state. Contribution of ω-like states is suppressed by OZI rule.

$e^+e^- \to \phi\pi^0$ is suitable for search of exotic isovector resonances. For ordinary isovector states, $\varphi\pi^0$ decay is suppressed by OZI rule. The cross section is described by single resonance with $m=1600\pm30$ MeV, $\Gamma=200\pm100$ MeV

Fit to $e^+e^- \to \phi\eta$, K^*K



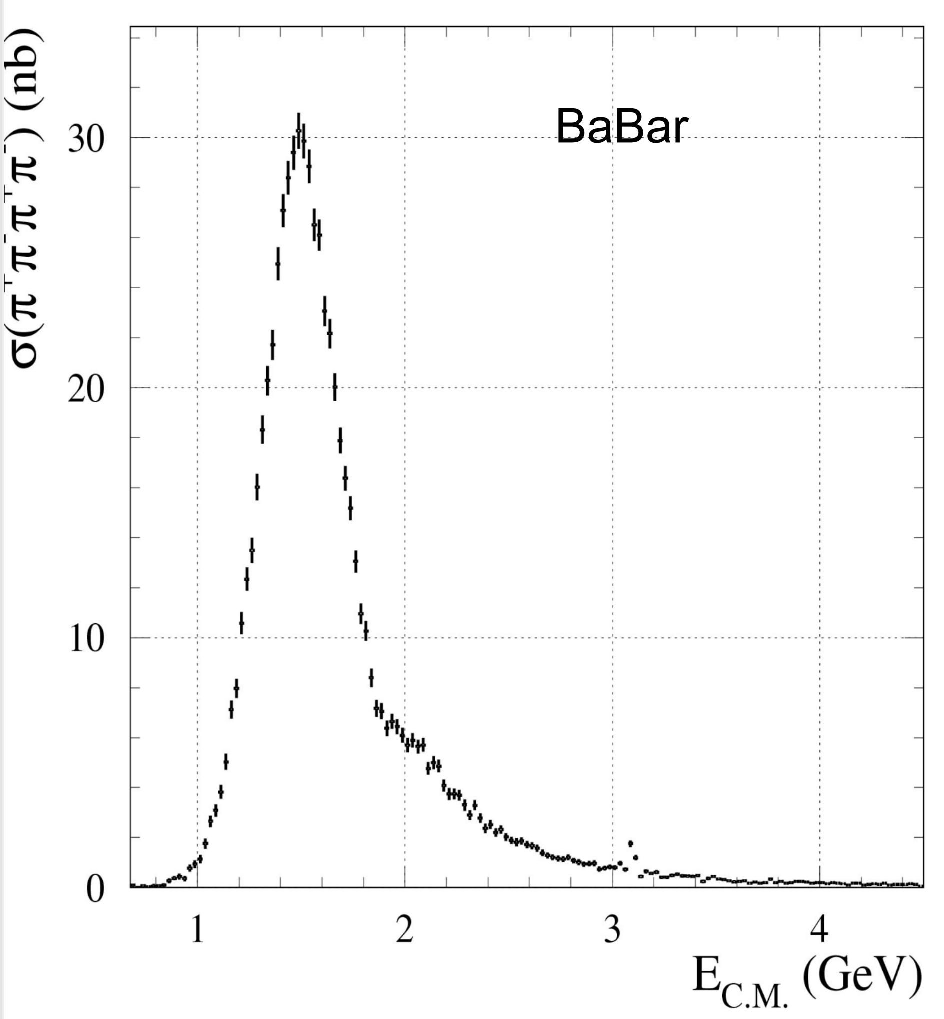
Parameters $\phi(1680)$:
$m = 1723 \pm 20$ MeV,
$\Gamma = 371 \pm 75$ MeV,
$\Gamma_{ee} = 580 \pm 60$ eV,
$B_{\phi\eta}/B_{K^*K} \sim 1/3$
(bands show uncertainties of the fit)

PDG
1680 ± 20
150 ± 50

In $\phi\eta$ channel the peak with $m=2139\pm35$ MeV, $\Gamma=76\pm62$ MeV is seen with 2 sigma significance - compare with:

From $e^+e^- \to \phi f_0(980)$
$M=2175\pm18$ MeV
$\Gamma=58\pm25$ MeV

$e^+e^- \to 2\pi^+ 2\pi^-$ cross section



Systematic errors:

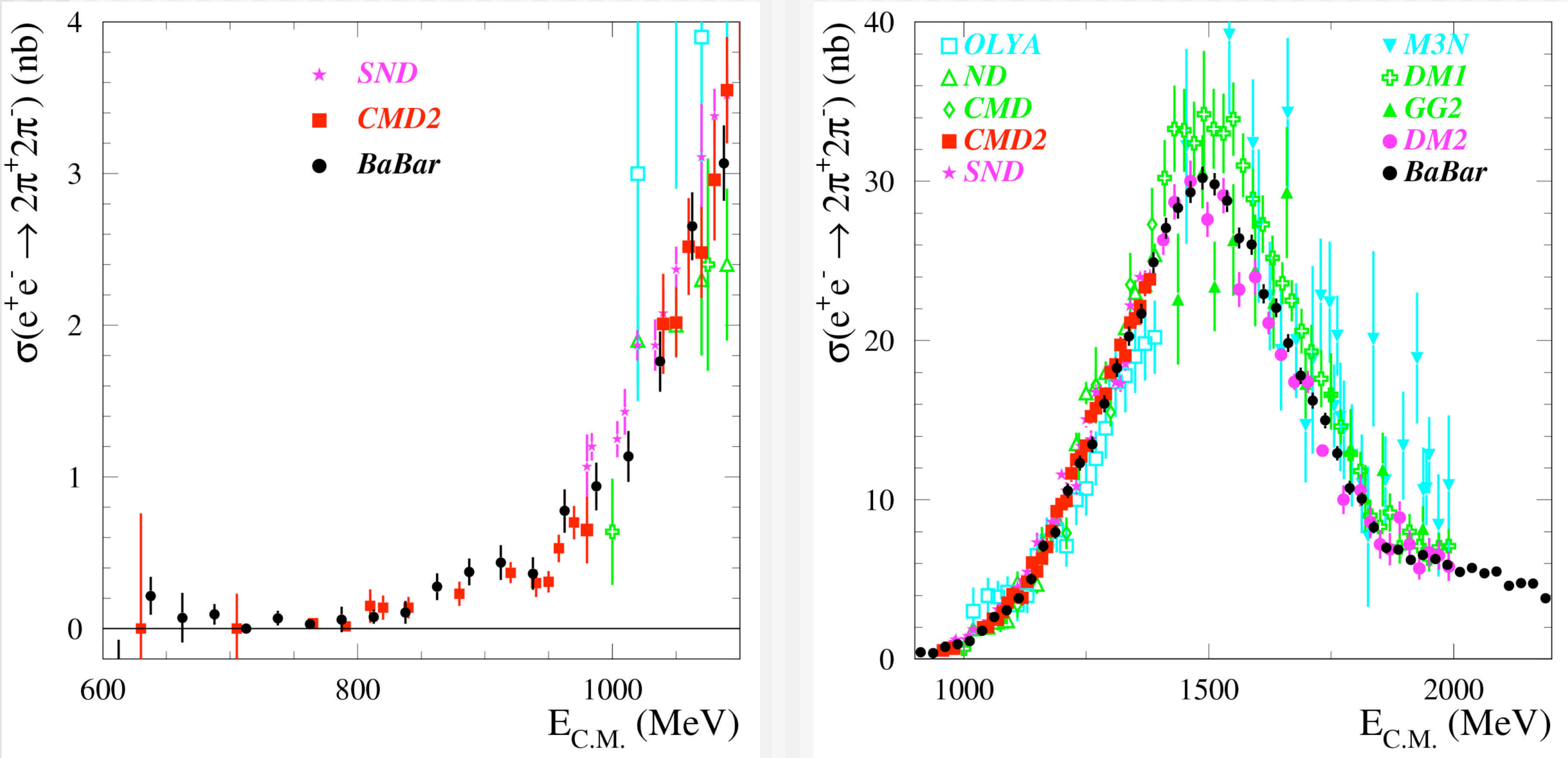
- **12% for $m_{4\pi} < 1$ GeV,**
- **5% for $1 < m_{4\pi} < 3$ GeV,**
- **16% for higher masses)**
- **best measurement above 1.4 GeV**

Coverage of wide region in one experiment
No point-to-point normalization problems

Intermediate states:

- **$a_1(1260)\pi$ - dominant, structure which may be $f_0(1370)\rho$ final state is seen.**
- **For detailed study, a simultaneous analysis of $2\pi^+2\pi^-$ and $\pi^+\pi^-2\pi^0$ final states is required.**

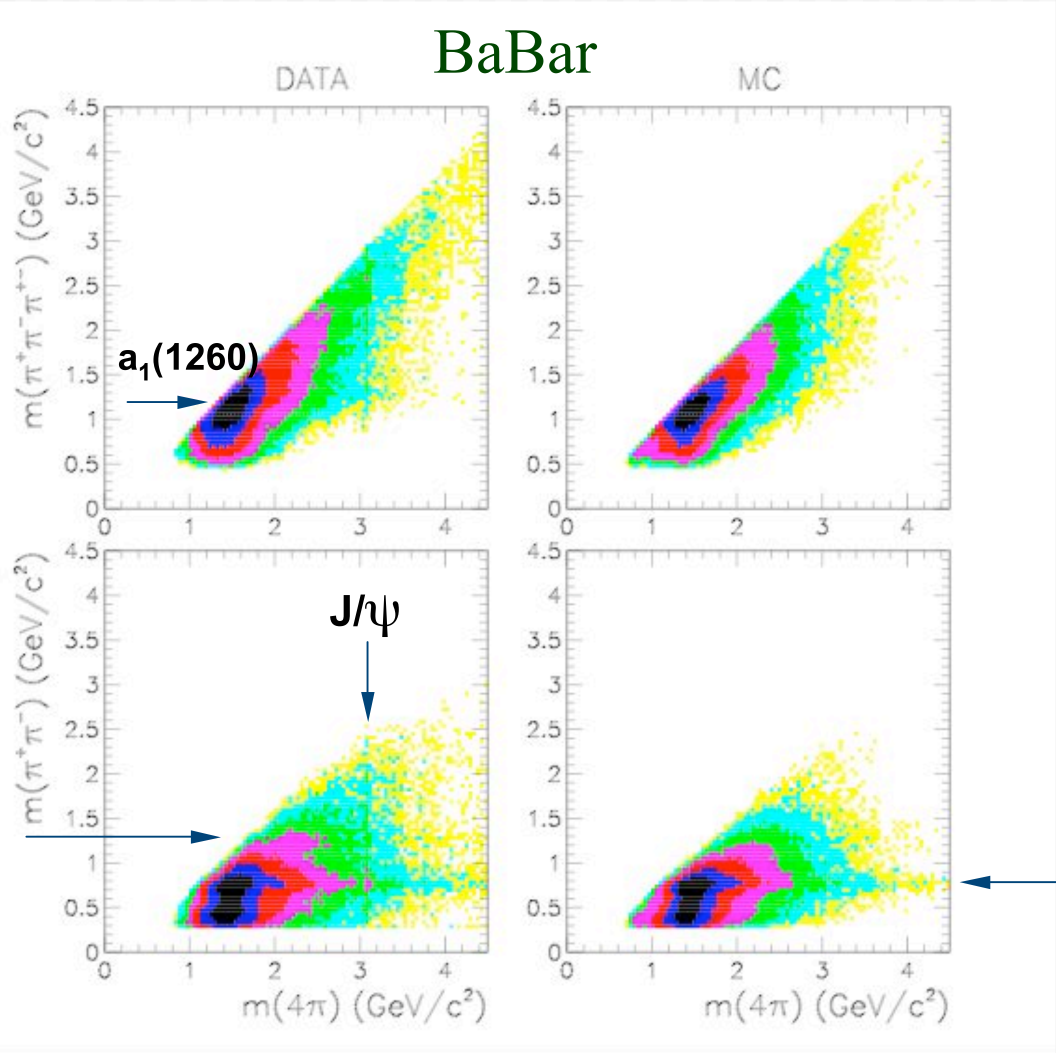
$e^+ e^- \to 2\pi^+ 2\pi^-$ cross section



Good agreement with direct $e^+ e^-$ measurements

Most precise result above 1.4 GeV

$\pi^+\pi^-\pi^+\pi^-$ substructures



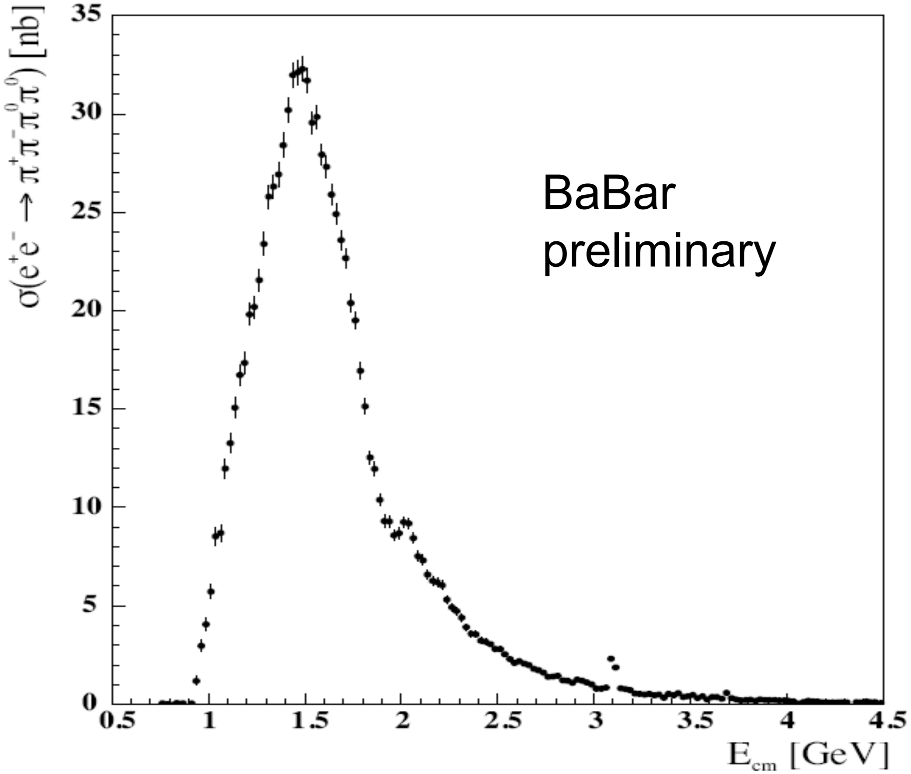
f0(1370)

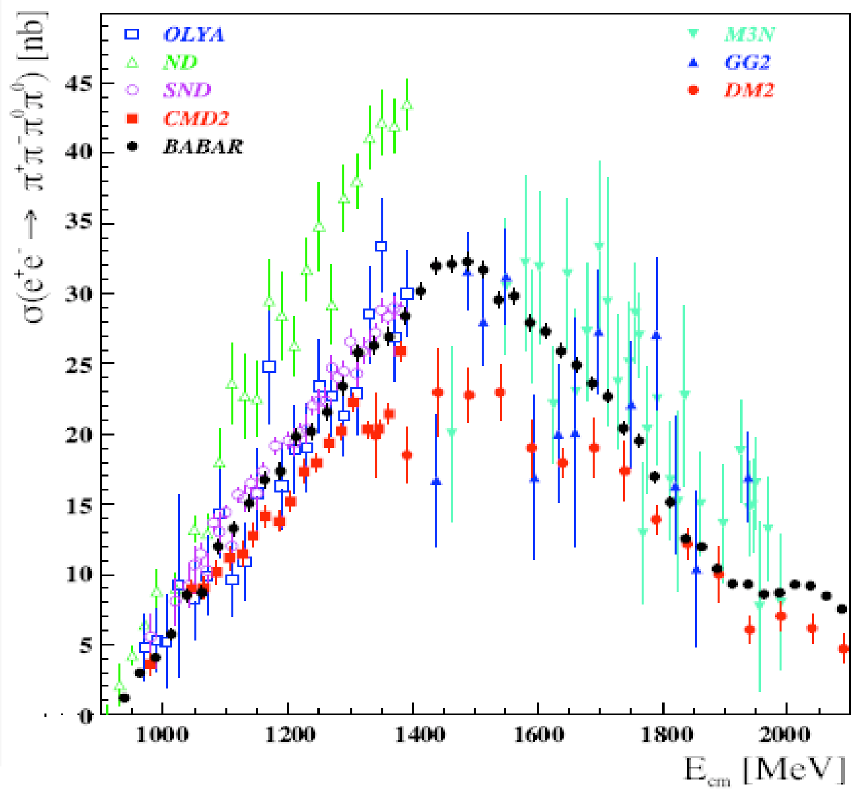
ρ(770)

MC generator:

- **H.Czyz and J.H.Kuehn, Eur.Phys.J C18(2000)497-509**
- **Includes $a_1(1260)\pi$ and $f_0(1370)\rho$**
- **Does not include J/ψ**

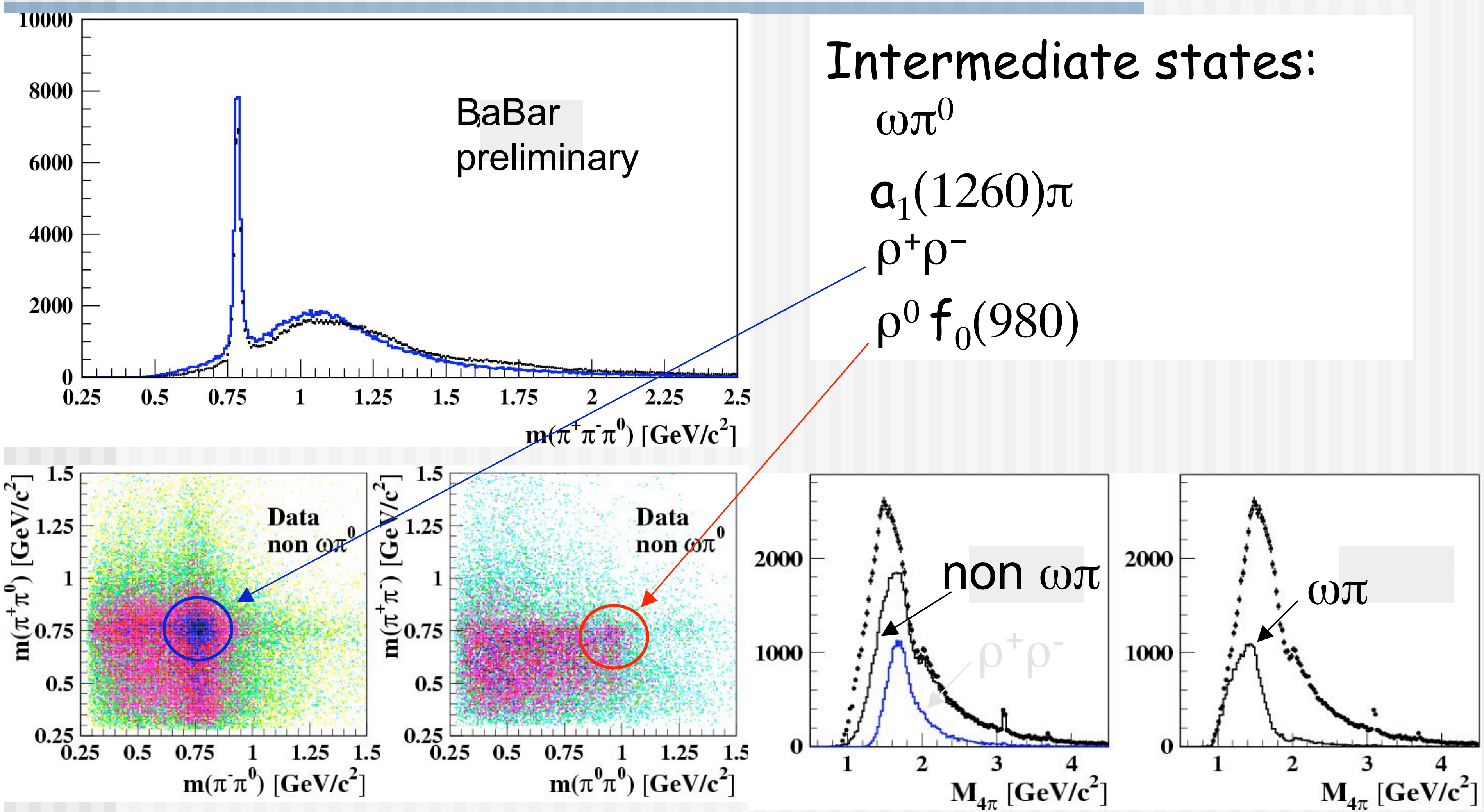
$e^+ e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ (Preliminary)





- Very important mode for a_μ and α_{QED}
- Preliminary precision: 8% in peak 5%
- Good agreement with SND and new CMD-2
- Huge improvement above 1.4 GeV
- First measurement above 2.5 GeV

$\pi^+\pi^-\pi^0\pi^0$ substructures



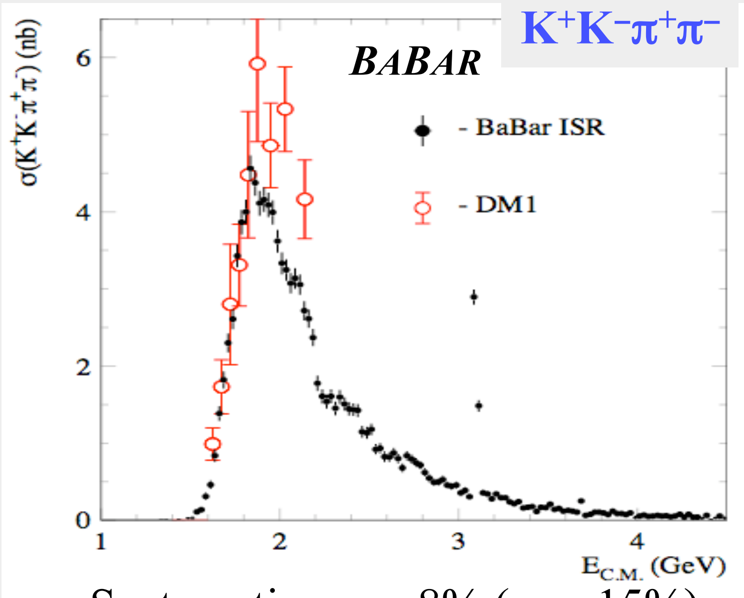
- For **first time $\rho^+\rho^-$ is seen**, it is large and even dominating the non-ω- spectrum.
- The structure at **2050 MeV is the $\rho(2050)$**?!

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

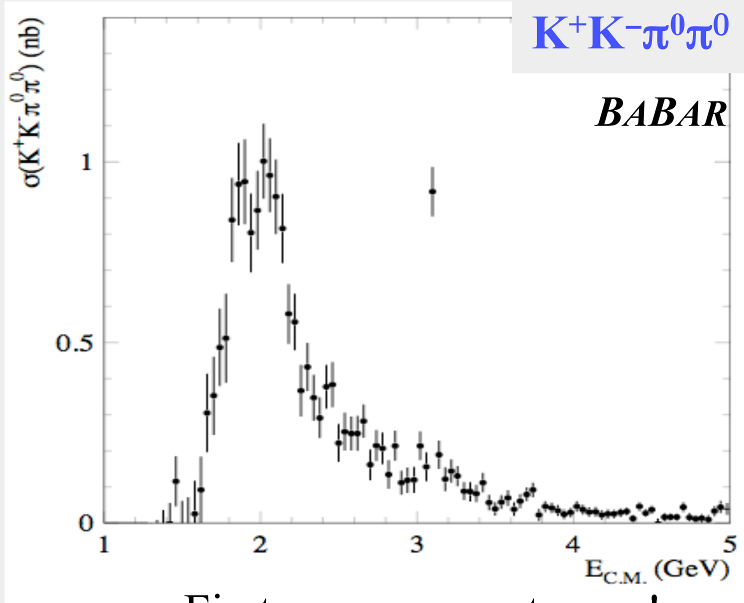
PRD-RC 74 (2006) 091103
PRD 76 (2007) 012008

Motivation:

- Factor 2.5 **more statistics** with respect to published result - x2 NOW!
- Search for **$\phi(1020)f_0(980)$ final state** and relation to $\phi(1020) \to f_0(980)\,\gamma$
- BR of **J/ψ and $\psi(2S)$ to $\phi(1020)\pi\pi$**
- Search for **new states**

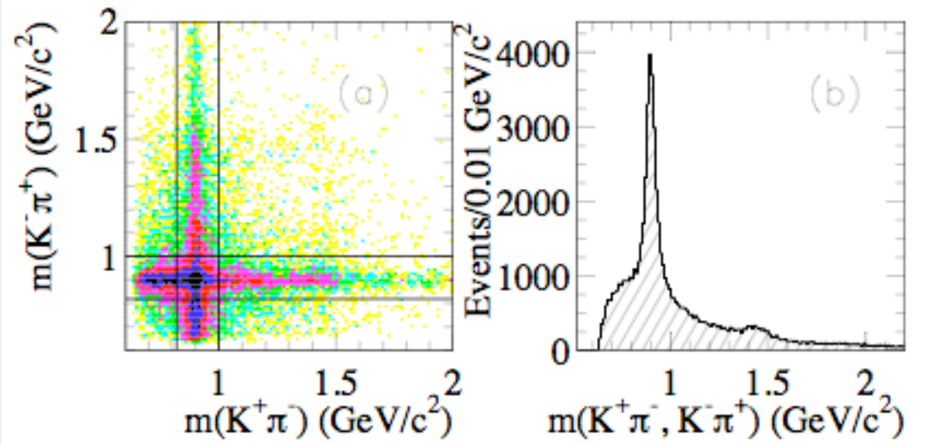


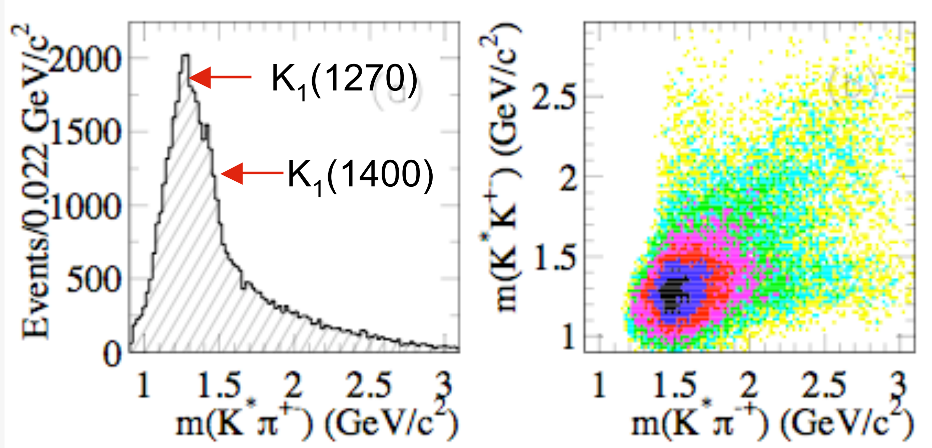
- Systematic error 8% (was 15%)
- Error dominated by acceptance



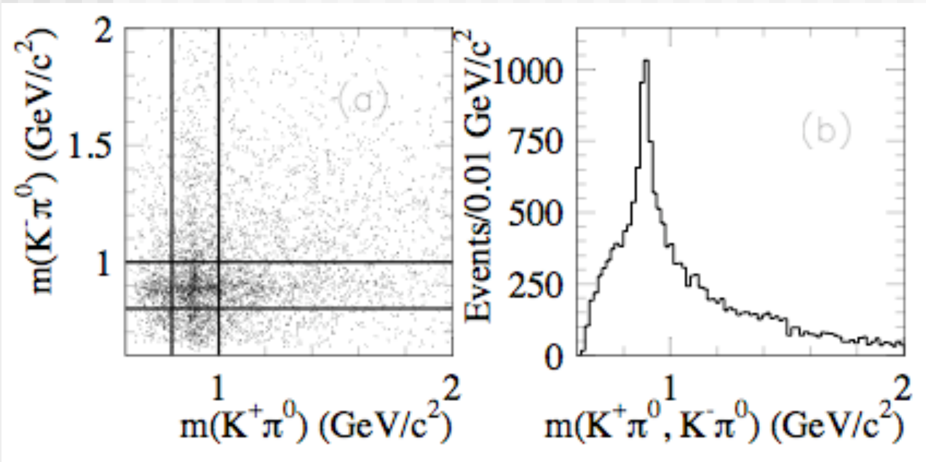
- First measurement ever !
- Systematic error 11%

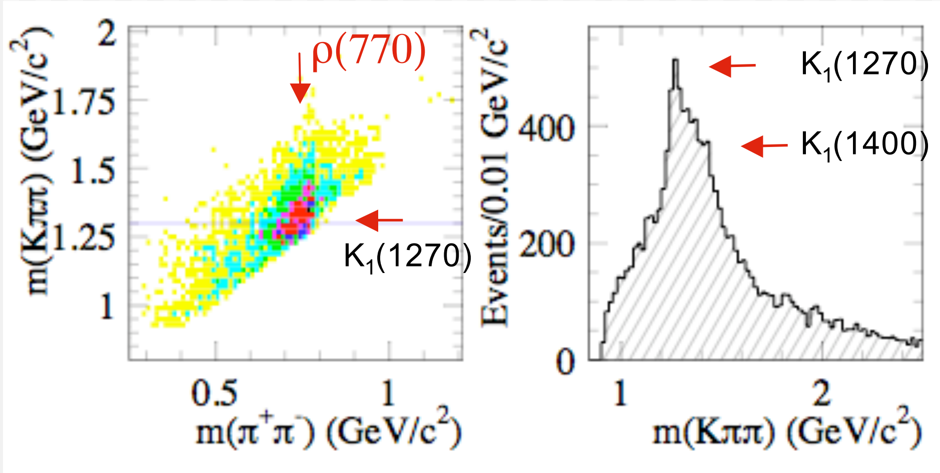
Kaon substructures for $K^+K^-\pi^+\pi^-$, $\pi^0\pi^0$





Also $K_1(1270,1400) \rightarrow K^*(892)K$, $K^*(892)\pi$ are seen



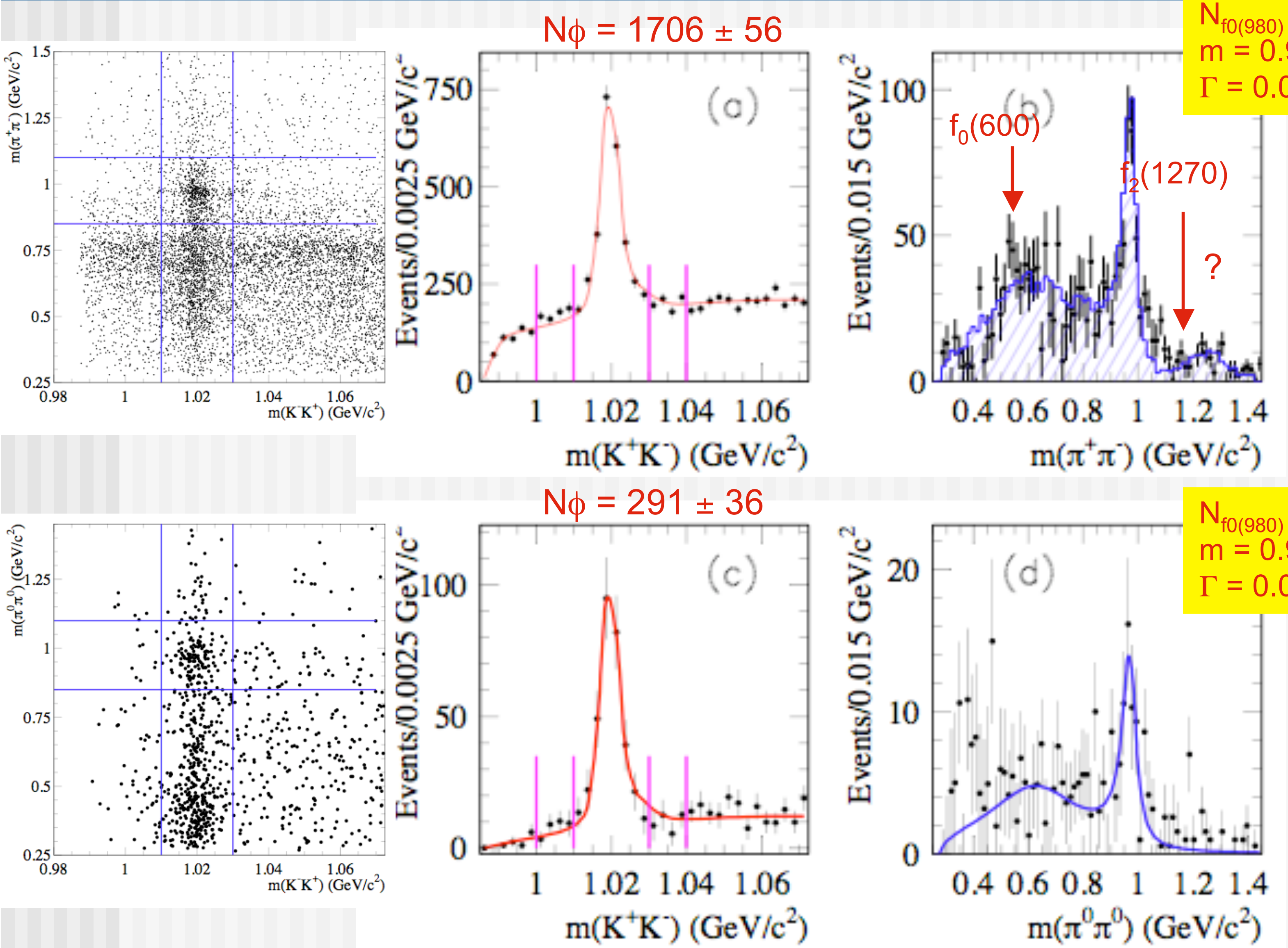


Cross section dominates by $K^{*0}(892)K\pi$ final state.
NO evidence of $K^{*0}\,K^{*0}$!!

ρ's are from $K_1(1270)$, $K_1(1400)$ $\rightarrow$ $K\rho$ decay

But $K^{*0}(892)K_2^*(1430)^0$ + c.c. is seen.

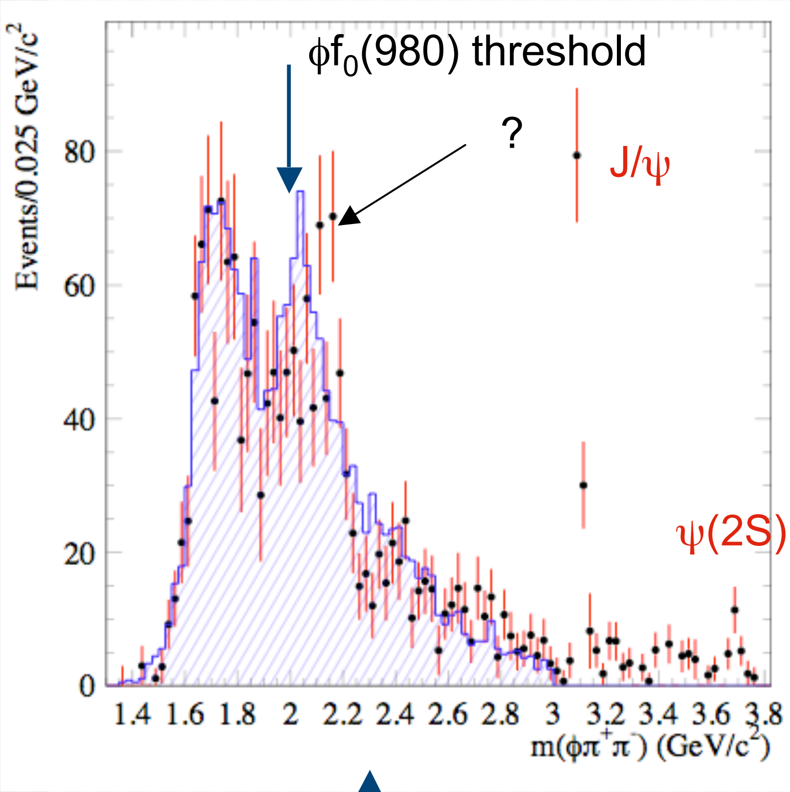
Selection of $\phi(1020)\pi^+\pi^-$, $\pi^0\pi^0$



$N_{f0(980)} = 262 \pm 30$
$m = 0.973 \pm 0.003$ GeV/c^2
$\Gamma = 0.065 \pm 0.013$ GeV

$N_{f0(980)} = 54 \pm 9$
$m = 0.970 \pm 0.007$ GeV/c^2
$\Gamma = 0.081 \pm 0.021$ GeV

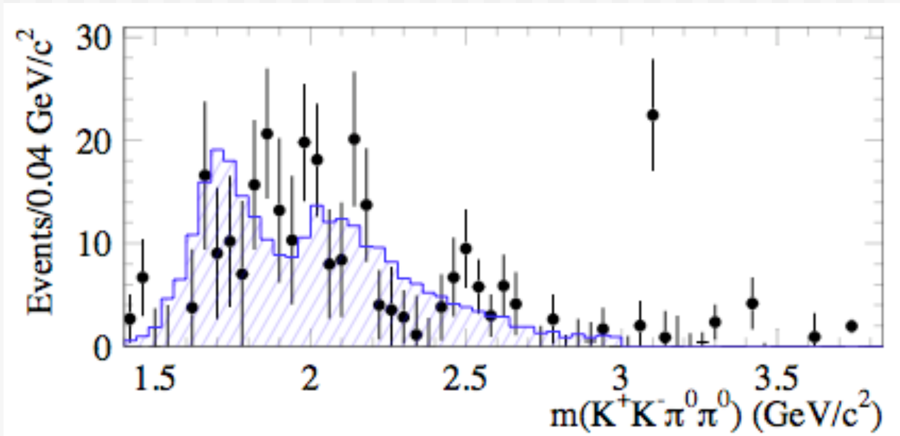
Mass spectrum for $e^+e^- \to \phi\,\pi^+\pi^-,\ \phi\,\pi^0\pi^0$



$\phi f_2(1270)$ threshold

Mass specrum is obtained by fitting of ϕ peak by BW with a continuum to extract number of $\phi\pi\pi$ events

J/ψ

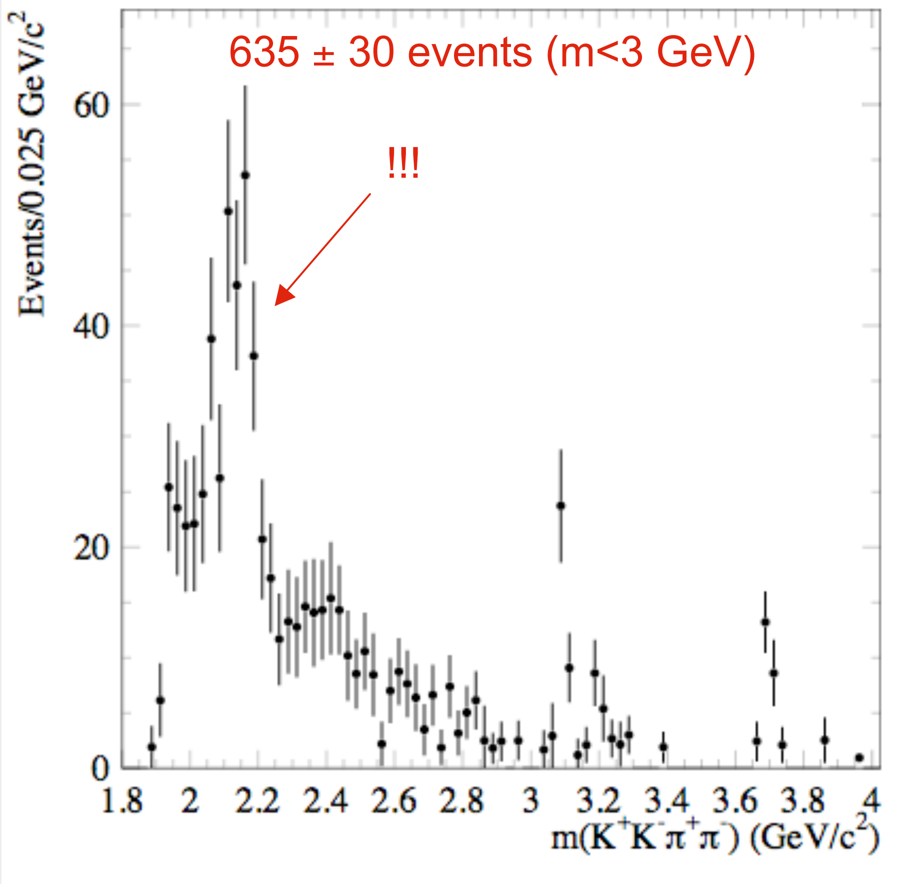


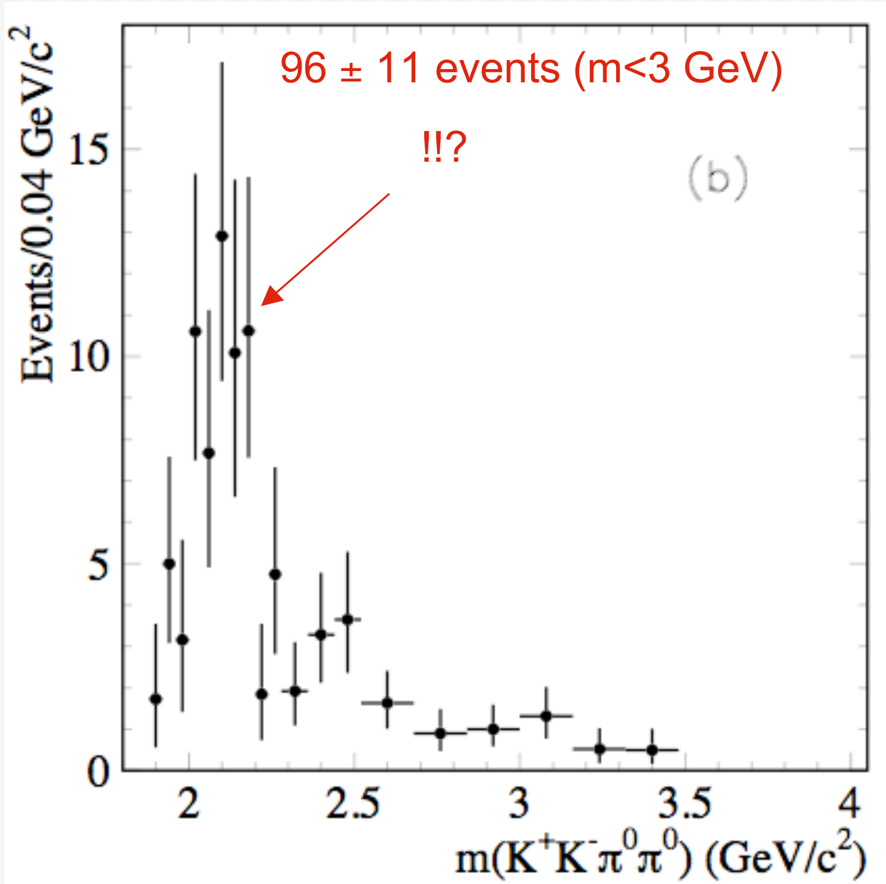
MC for $\phi\pi\pi$ mode with $\pi\pi$ in S-wave

Mass spectrum described by a ~1.68 GeV resonance (ϕ(1680), 0.2 GeV width)

$e^+e^- \to \phi(1680) \to \phi(1020)\ (Af_0(600)+e^{i\varphi 1} \bullet Af_0(980)\ )+e^{i\varphi 2} \bullet Af_2(1270)\ )$

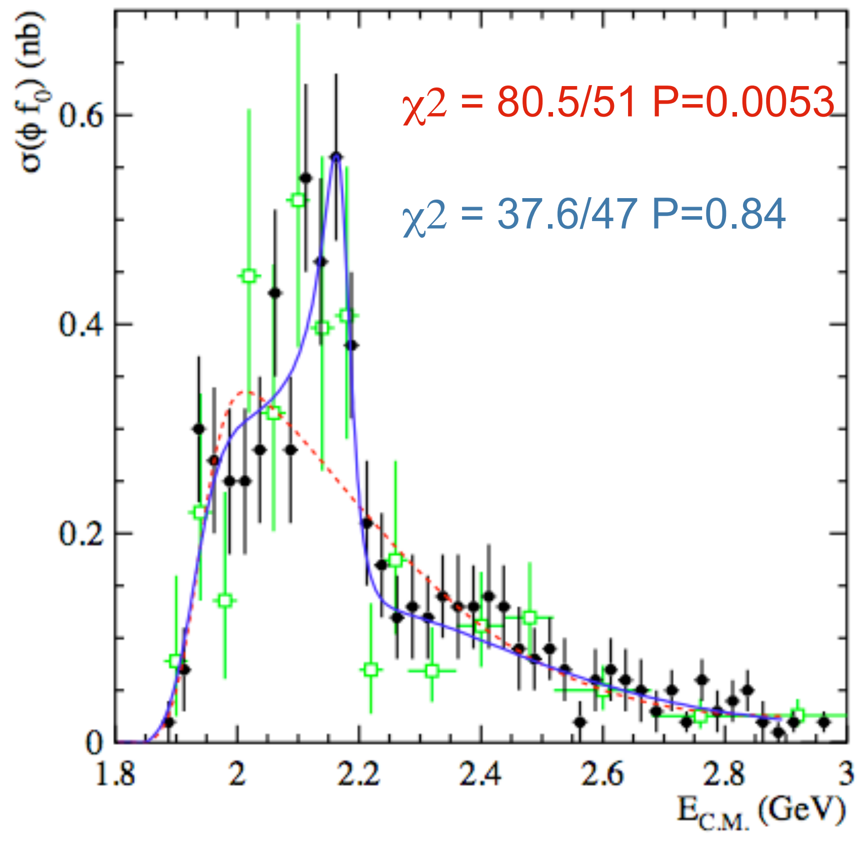
$e^+e^- \rightarrow \phi\, f_0(980) \rightarrow K^+K^-\pi^+\pi^-(\pi^0\pi^0)$





Select $f_0(980)$ by $0.85< m(\pi^+\pi^-)<1.1$ and fit $m(K^+K^-)$
for every 0.025 GeV/c^2 bin
in $m(2K2\pi)$ to determine number of ϕ

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



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

σ_0^x = 0.236 ± 0.075 ± 0.040 nb
m_x = 2.175 ± 0.010 ± 0.015 GeV/c^2
Γ_x = 0.058 ± 0.016 ± 0.020 GeV
φ = 0.56 ± 0.30 ± 0.20 rad.

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

$\Gamma_{ee} \cdot B_{\phi\, f0}$ = (2.5 ± 0.5 ± 0.3) eV

$$\sigma(E_{c.m.} = \sqrt{s}) \sim \sqrt{1 - \frac{4m^2_{f_0,\phi}}{s}} \bullet \left| \frac{\sqrt{\sigma_0}\, m_x \Gamma_x e^{i\varphi}}{m_x^2 - s - i m_x \Gamma_x} + A_{bkg.} \right|^2$$

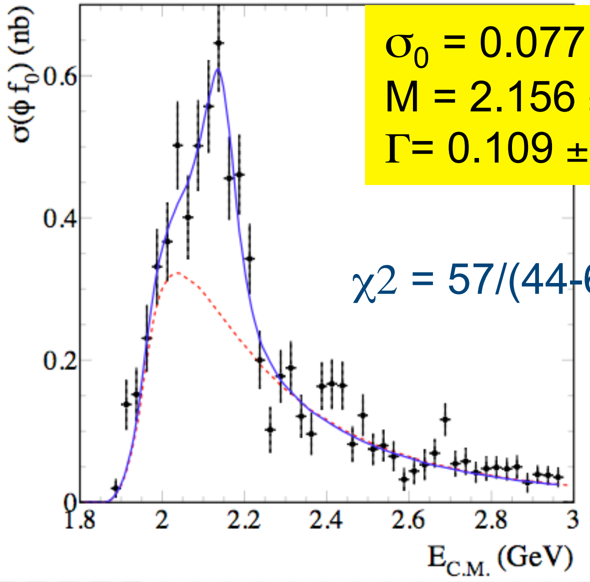
XS is corrected by:
$Br(\phi \to K^+K^-)$ =0.491
$Br(f_0 \to \pi^+\pi^-)$ = 2/3
$Br(f_0 \to \pi^0\pi^0)$ = 1/3

A fit with free interference phase with continuum - $A_{bkg.}$ = Thr*P2

2 ln (L_0/L_x) = sqrt (80.5 - 37.6) ~ 6.5 σ

Evidence of Y (2175) state

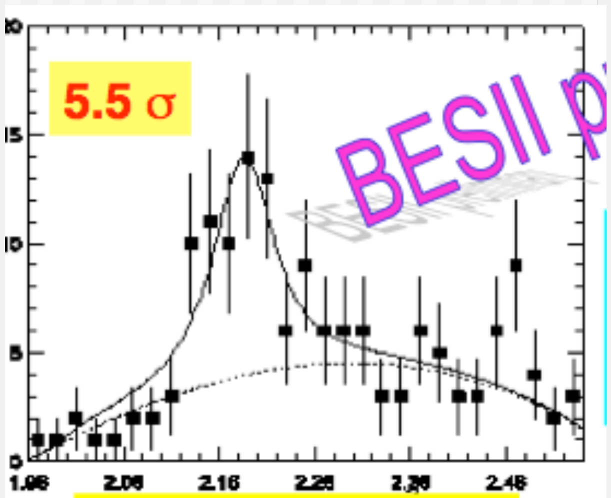
~ 670 fb^{-1} Belle data



σ_0 = 0.077 ± 0.018 nb
M = 2.156 ± 0.011 GeV/c^2
Γ= 0.109 ± 0.022 GeV

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

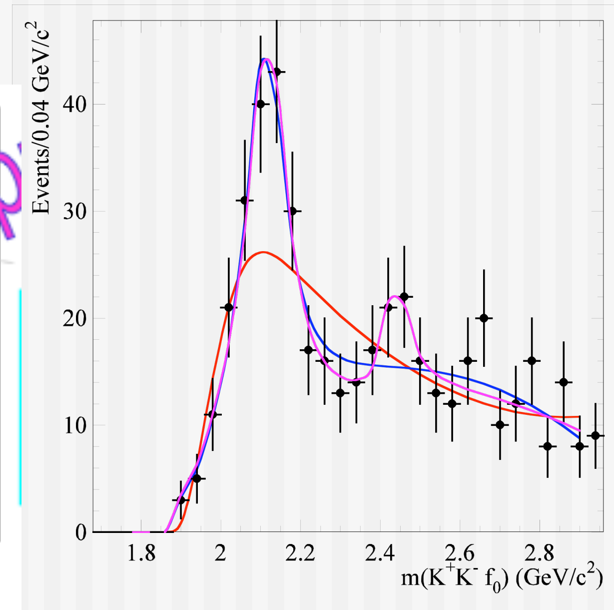
Significance is ~ 6.7 σ



M(ϕf_0(980)) GeV/c^2

M = 2.186 ± 0.011 GeV/c^2
Γ= 0.065 ± 0.025 GeV

e+e-> $K^+K^-f_0$ f^0 -> $\pi^0\pi^0$



Possible nature of Y(2175):

1 – ssss,   2 – φ'',

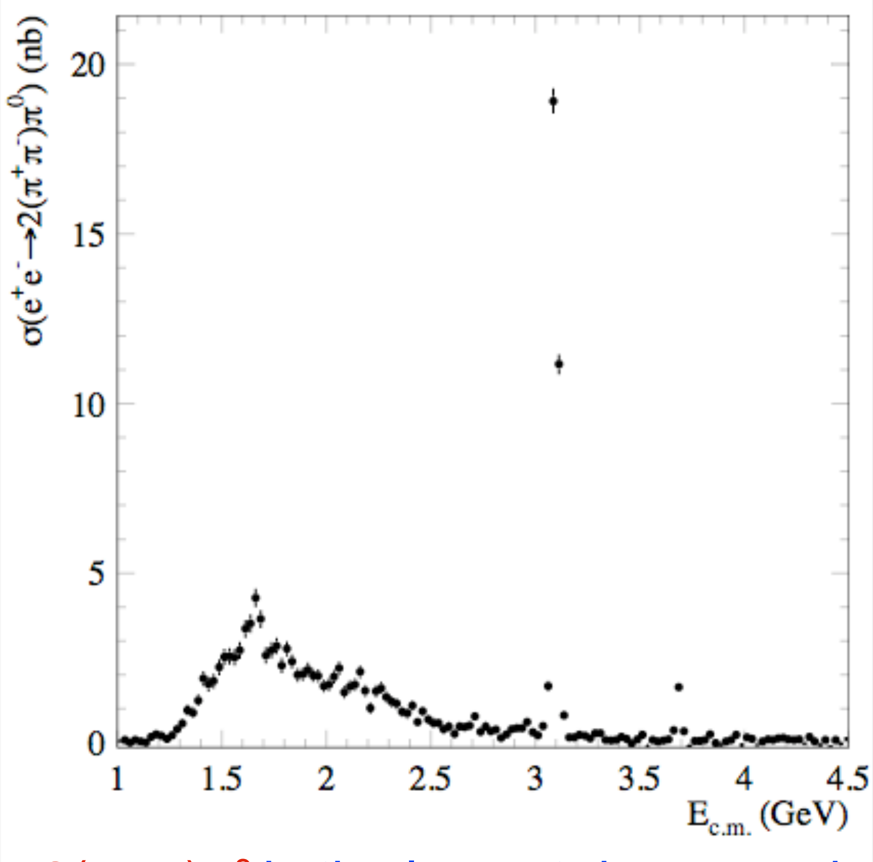
3- Y(2175) is similar to Y(4260):

Y(4260) = J/Ψ f_0, Γ_{ee}=5.5 eV

Y(2175)= φf_0, Γ_{ee}=2.5 eV

Y(2175) is confirmed by Belle and BES.
Babar update is coming soon.

Cross section for $e^+e^-\to 2(\pi^+\pi^-)\pi^0$

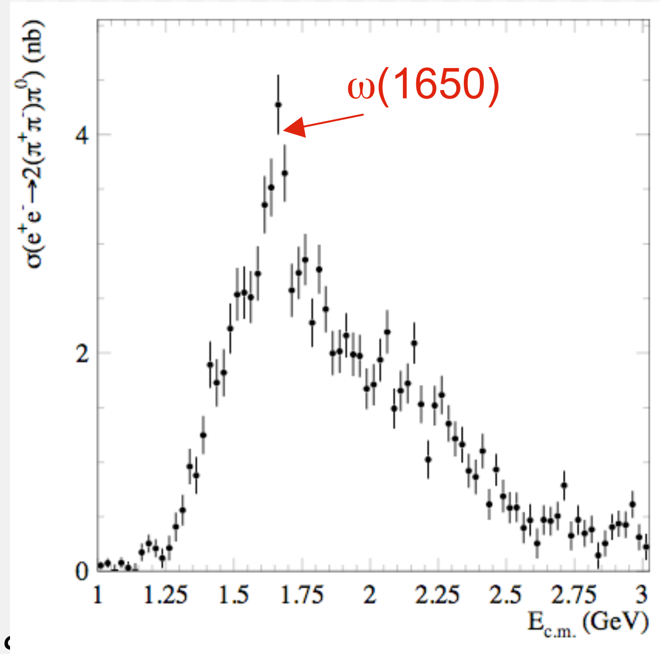


$J/\psi\to 2(\pi^+\pi^-)\pi^0$ is the largest decay mode

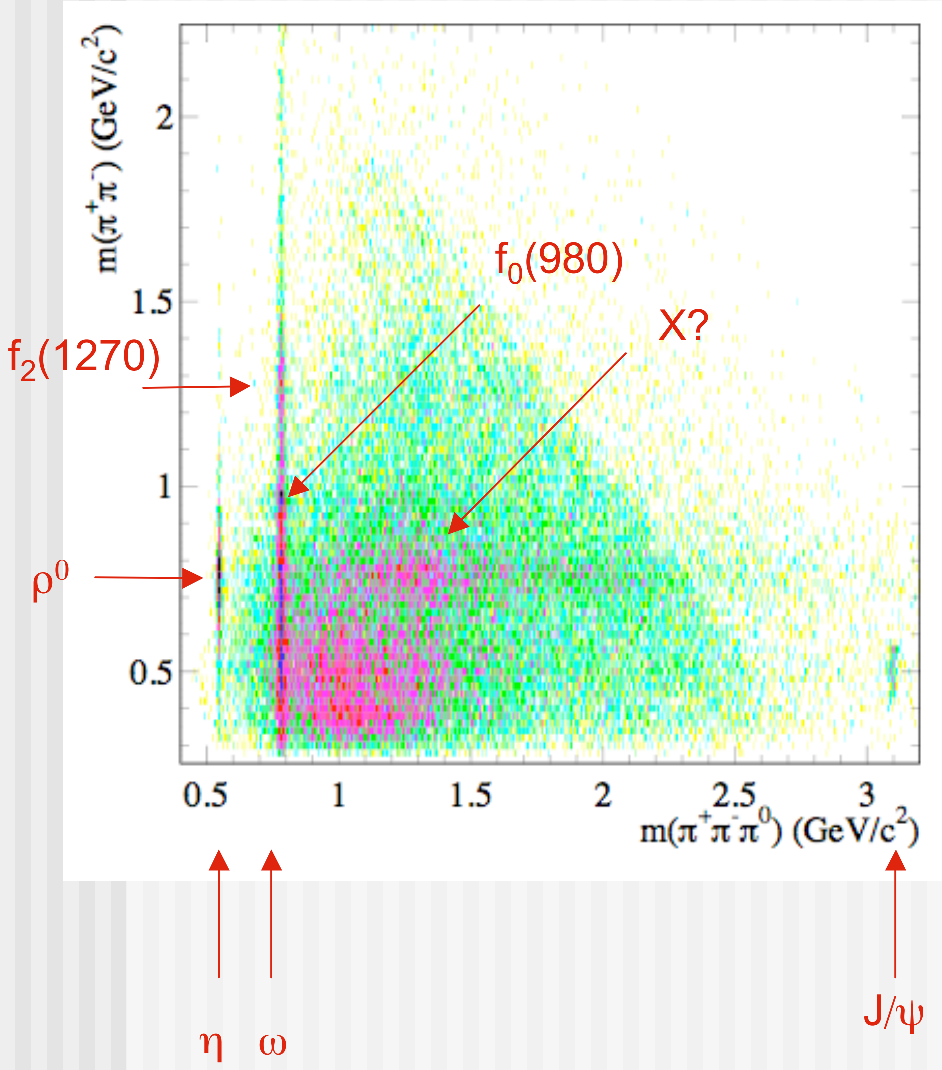
$$\sigma_{5\pi}(m \equiv E_{c.m.}) = \frac{(dN/dm)}{\varepsilon(m)\cdot d\varepsilon(m)\cdot dL/dm}$$

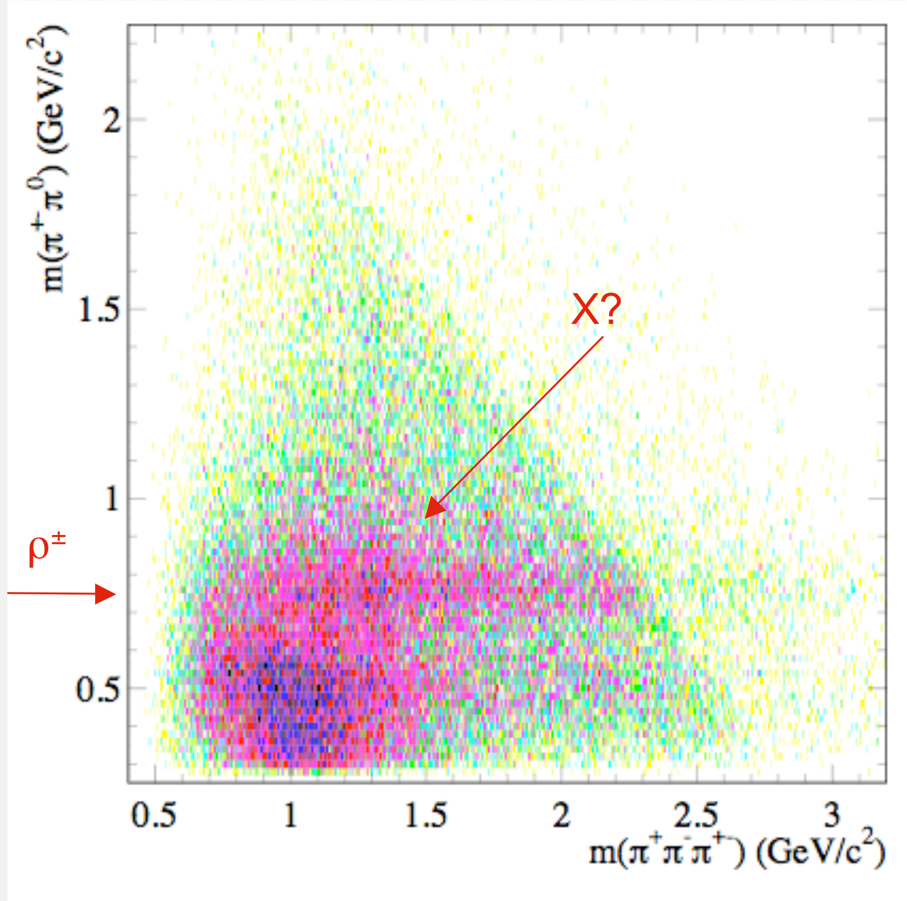
Systematic errors:

Background subtraction	--	5% (50)
Tracking efficiency	--	2%
Luminosity	--	3%
Acceptance(model + cuts)	--	3-5%
χ^2 cut uncertainty	--	3%
π^0 efficiency	--	2%
Radiative corr.	--	1%
Total	--	~8-9%



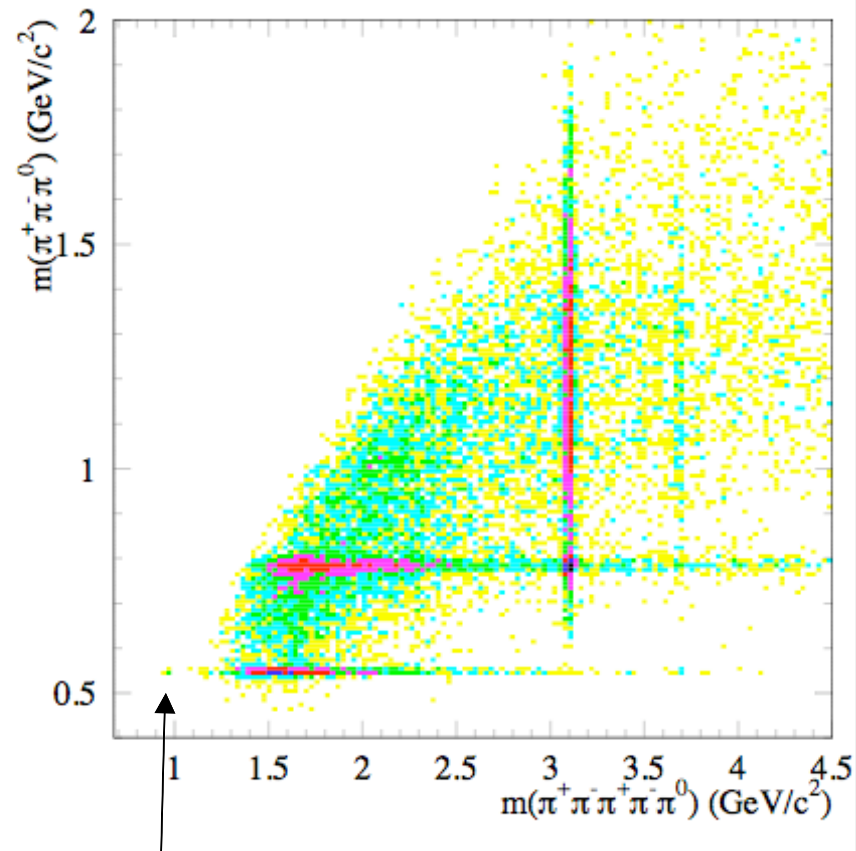
What we have inside of 5π?

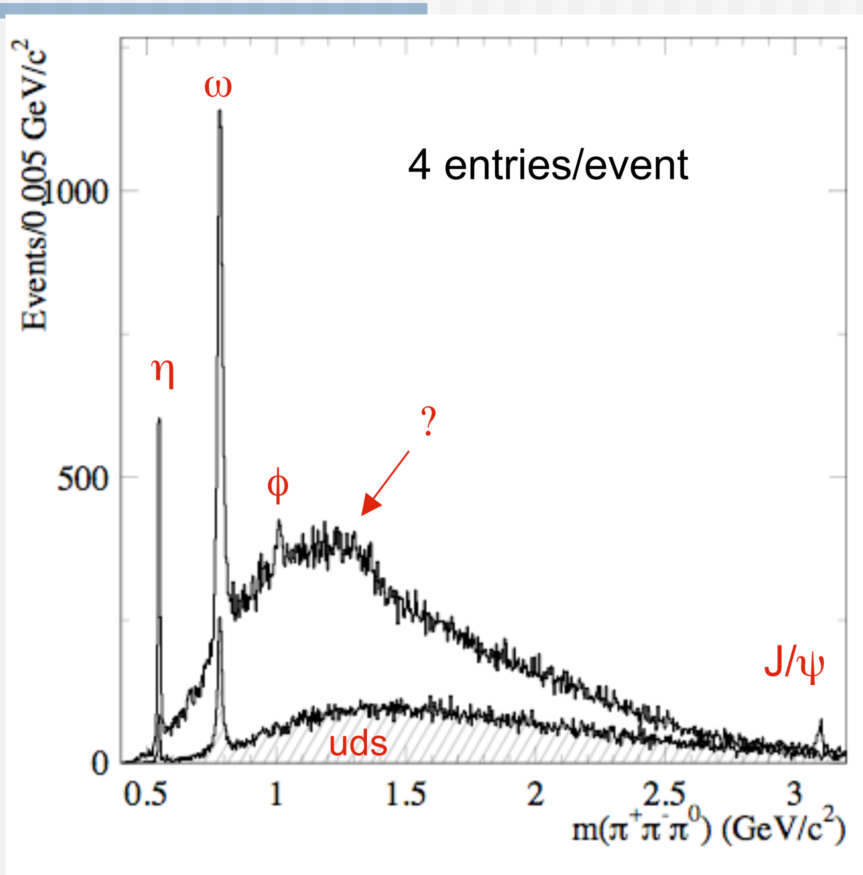




$e^+e^- \to \rho X$, X ~ $a_1(1260)$, $\pi(1300)$, $a_2(1320)$?

What we have inside of 5π?



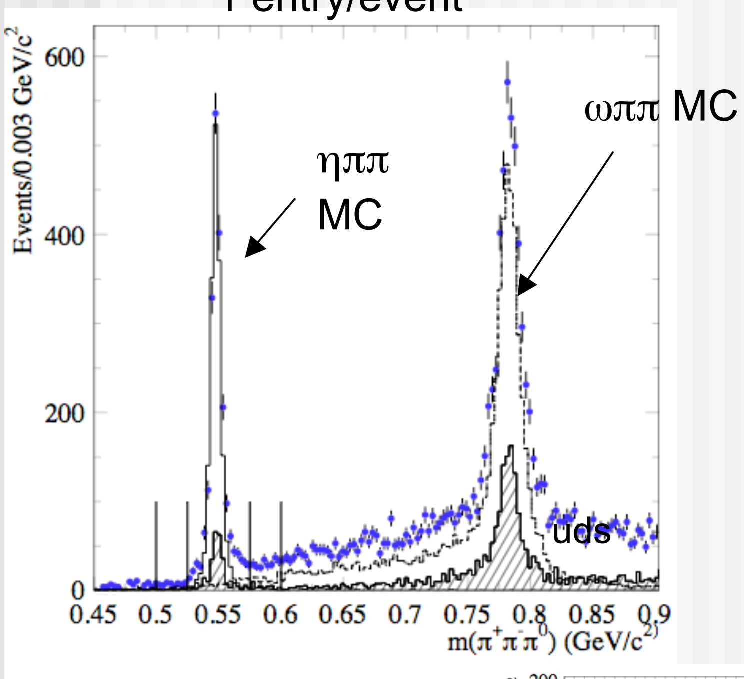


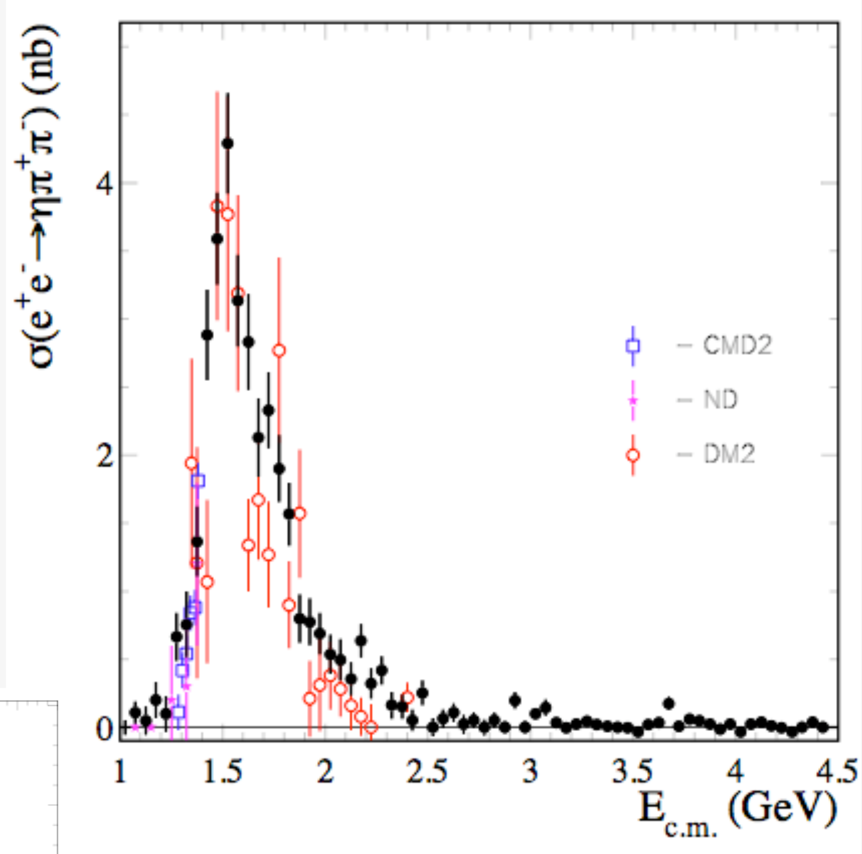
$e^+e^- \to \eta'\gamma$
Published in PRD

Dominates by $\eta\pi\pi$, $\omega\pi\pi$, $\phi\pi\pi$ and $J/\psi\pi\pi$ production

Cross section for $e^+e^- \to \eta\pi^+\pi^-$

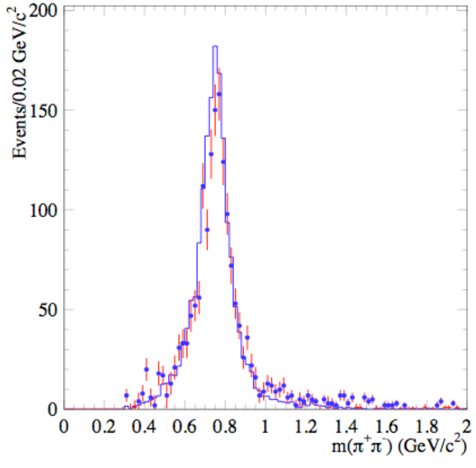
1 entry/event





Select 3π with nearest to η mass

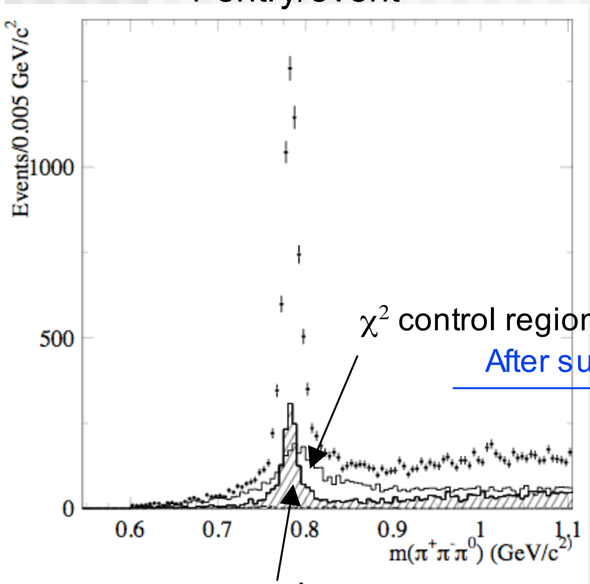
Combinatorial side bands used for background estimate.



The process practically dominates by the $e^+e^- \to \eta\rho(770)$ reaction (used in MC simulation).

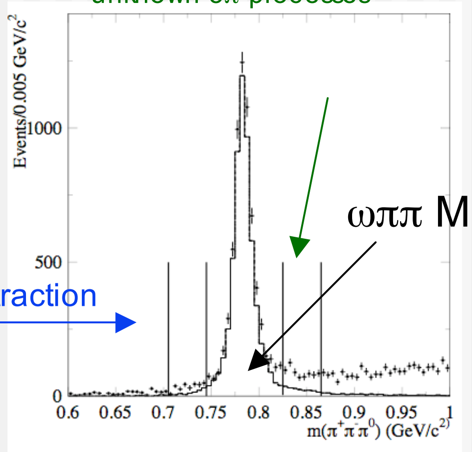
Cross section for $e^+e^- \to \omega\pi^+\pi^-$

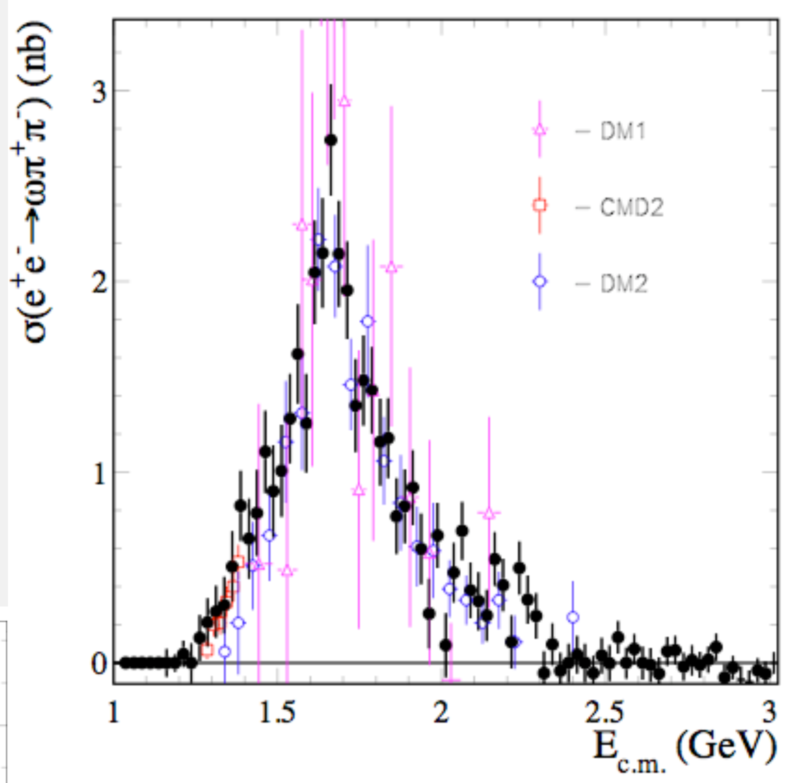
1 entry/event



After subtraction

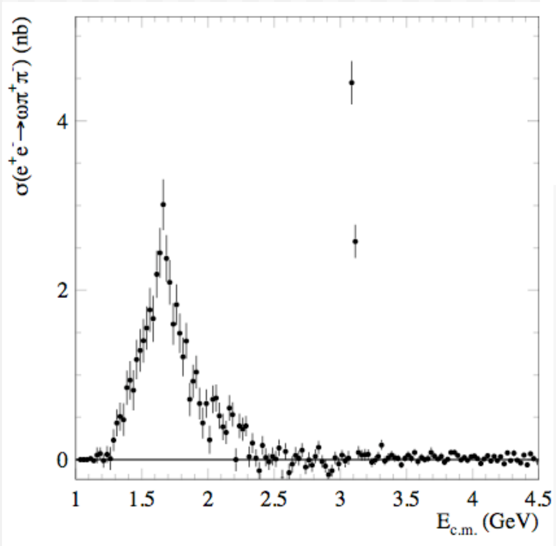
Combinatorial side bands is used for background subtraction from unknown 5π processes





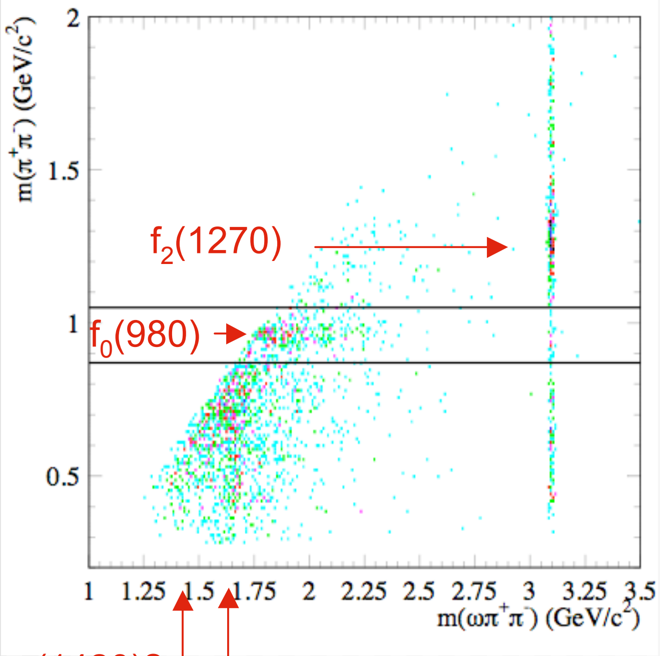
Select 3π with nearest to ω mass.

$\eta\pi\pi$ events are excluded (>0.6)



Good agreement and better accuracy

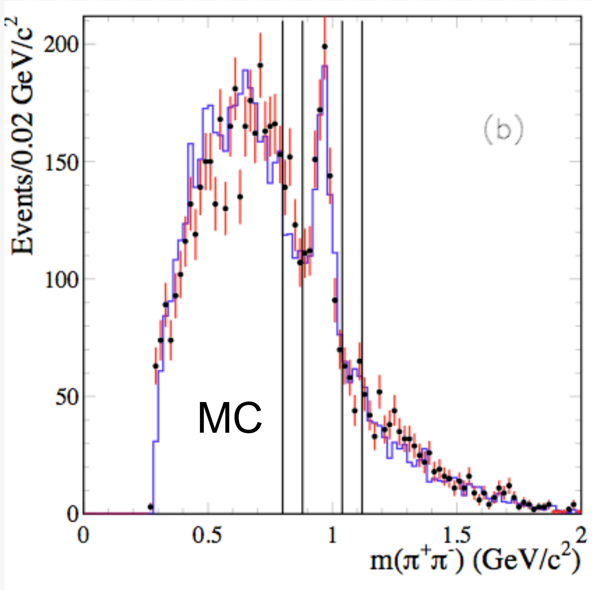
Cross section for $e^+e^- \to \omega f_0(980)$



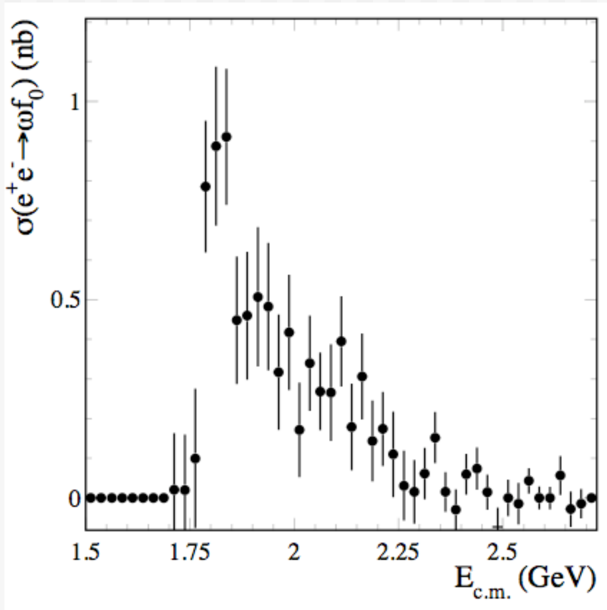
ω(1420)?

ω(1650)

m(ωππ)<3 GeV/c²



First measurement

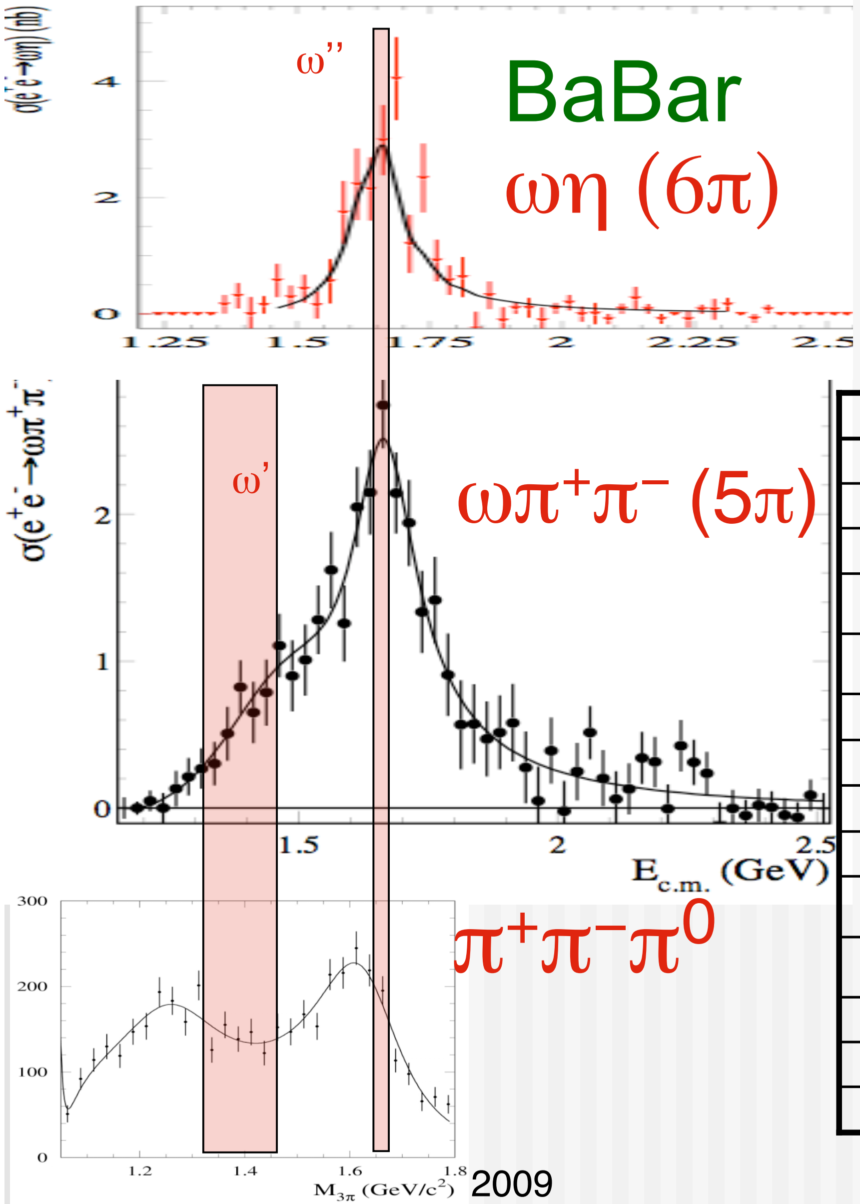


363 ± 36 events in $f_0(980)$ peak

In MC simulation we use $\omega\pi\pi$ (FS) + $\omega f_0(980)$.
There is an indication, that it should be $b_1(1235)\pi$ + ωf_0

$BR(\omega \to 3\pi)=0.891$ and $BR(f_0 \to \pi^+\pi^-)=0.67$ is taken into account

Cross section for $e^+e^- \to (\omega\pi^+\pi^- - \omega f_0(980))$



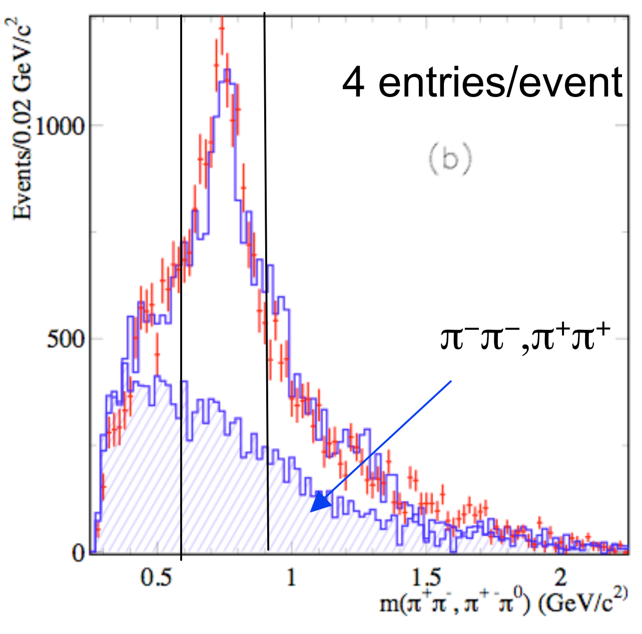
$$\sigma(s) = \frac{12\pi C P(s)}{s}\left|\sum_v \frac{\Gamma_v m_v \sqrt{B_{ee}B_{vf}}}{m_v^2 - s - i\sqrt{s}\Gamma_v}\frac{e^{i\phi_v}}{\sqrt{P(m_v)}}\right|^2$$

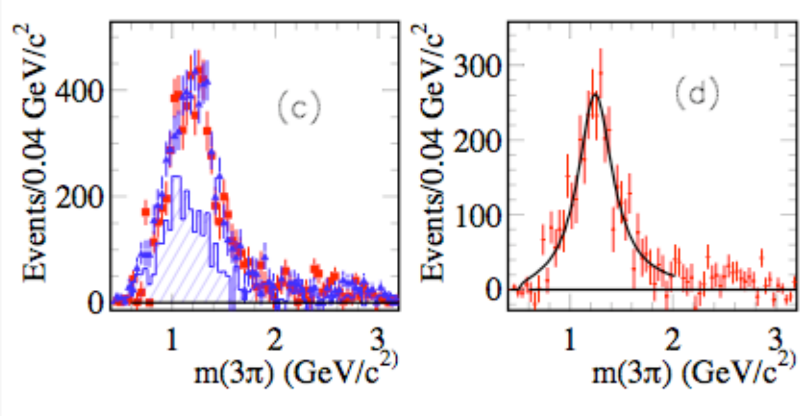
In the fit we assume ω(1420), ω(1650)
and ω(782) as 'non-resonant coherent background'

Fit	ωππ	3π	6π(ωη)	PDG
$\sigma_{0\omega'}$(nb)	1.01±0.29	-	-	-
$B_{ee}B_{\omega' f}\ 10^6$	0.13 ± 0.04	0.82 ± 0.08	-	-
$\Gamma_{ee}B_{\omega' f}$ (eV)	17.5 ± 5.4	369	-	-
$m_{\omega'}$ (GeV/c²)	1.382 ± 0.070	1.350 ± 0.030	-	1.400 - 1.450
$\Gamma_{\omega'}$ (GeV)	0.13 ± 0.08	0.450 ± 0.140	-	0.180 - 0.250
$\phi_{\omega'}$ (rad.)	π*	π*	–	-
$\sigma_{0\omega''}$(nb)	2.47±0.18	-	3.08±0.33	-
$B_{ee}B_{\omega'' f}\ 10^6$	0.47 ± 0.04	1.3 ± 0.2		-
$\Gamma_{ee}B_{\omega'' f}$ (eV)	103.5 ± 8.3	286		-
$m_{\omega''}$(GeV/c²)	**1.667 ± 0.013**	**1.660 ± 0.011**	**1.645 ± 0.015**	**1.670 ± 0.030**
$\Gamma_{\omega''}$ (GeV)	**0.222 ± 0.025**	**0.220 ± 0.040**	**0.114 ± 0.030**	**0.315 ± 0.035**
$\phi_{\omega''}$ (rad.)	0*	0*	0*	-
$\sigma_{0\omega}$(nb)	102 ± 67	PDG*	-	-
χ^2/n.d.f	35/48	-	-	-

Some distributions with $\rho(770)$

$\omega\pi\pi$, $\eta\pi\pi$, J/ψ are excluded





BW fit: $m(X)$ = **1.243 ± 0.012 ± 0.020** GeV/c^2;
$\Gamma(X^0)$ = **0.410 ± 0.031 ± 0.031** GeV

$a_2(1320)$ is excluded: m= 1.3183±0.0006 GeV/c^2; Γ=0.107±0.005 GeV

But $\pi(1300)$ is good: m = 1.300 ± 0.100 GeV/c^2; Γ = 0.200 - 0.600 GeV

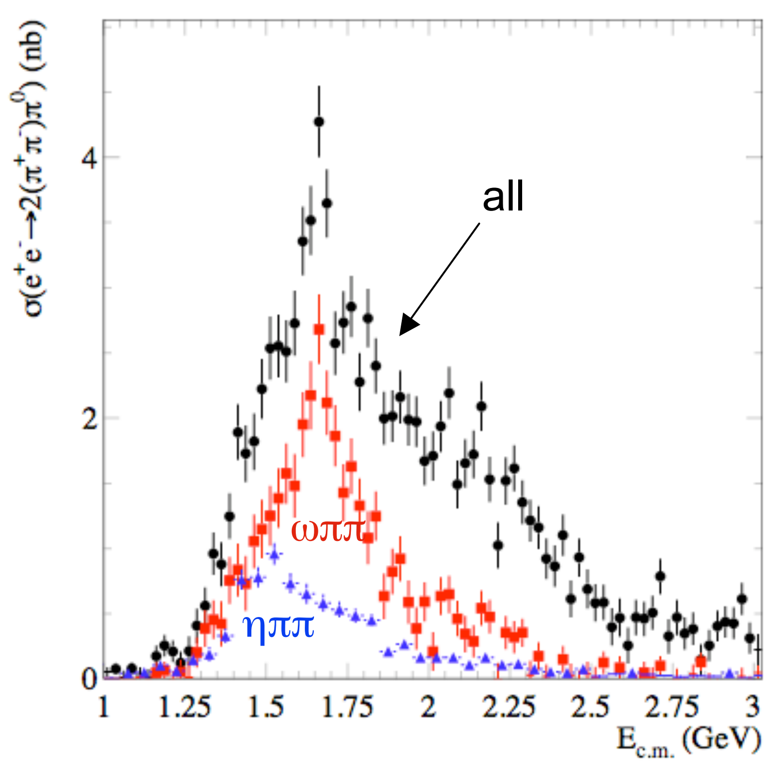
a1(1260) is good: m = 1.230 ± 0.040 GeV/c^2; Γ = 0.250 - 0.600 GeV

$N(\rho^0) = N(\rho^\pm)$ - it can be if X has I=1 and
$e^+e^- \to \rho^\pm X^\pm(1300)$, $X^\pm \to \rho^0\pi^\pm$
and
$e^+e^- \to \rho^0 X^0(1300)$, $X^0 \to \rho^\pm\pi^\pm$
$(\rho^0\rho^0\pi^0)$ combination is not allowed (C-parity)

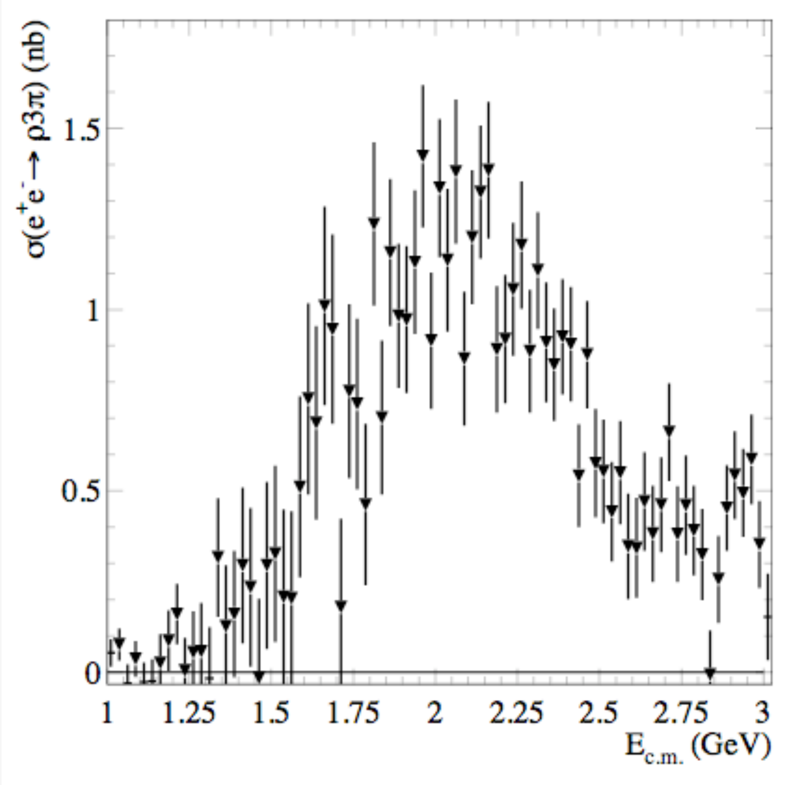
X(1300) candidates with I=1:
$a_1(1260)$
$\pi(1300)$ - best candidate
$a_2(1320)$
Helicity angle is needed - more data !

Cross section for $e^+e^- \to \rho X(1243)$

Determine $\sigma(e^+e^- \to \rho X(1300))$ as $\sigma(4\pi\pi^0)$ - $\sigma(\omega\pi\pi)$ - $\sigma(\eta\pi\pi)$



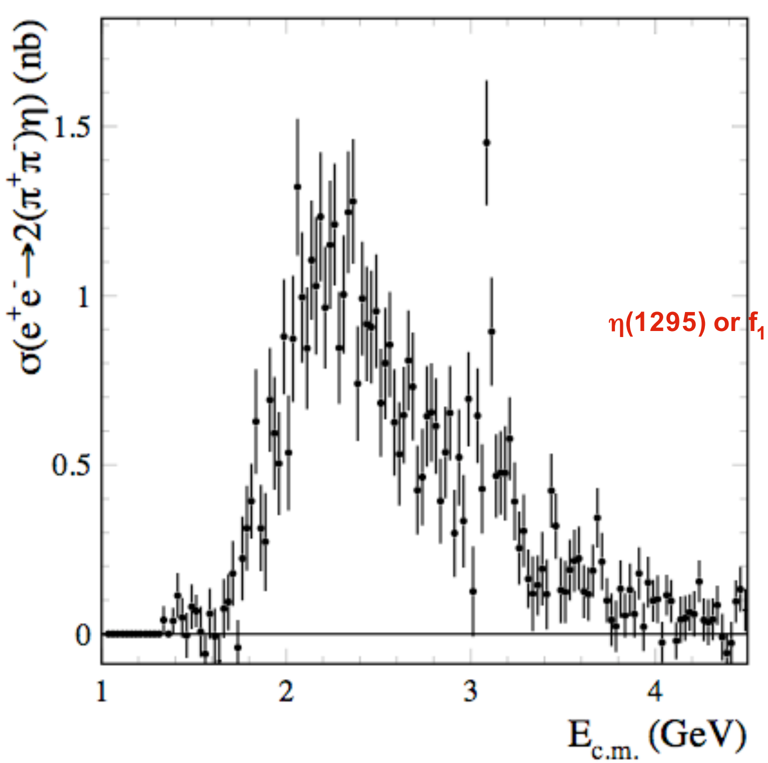
$\omega\pi\pi$, $\eta\pi\pi$ are excluded

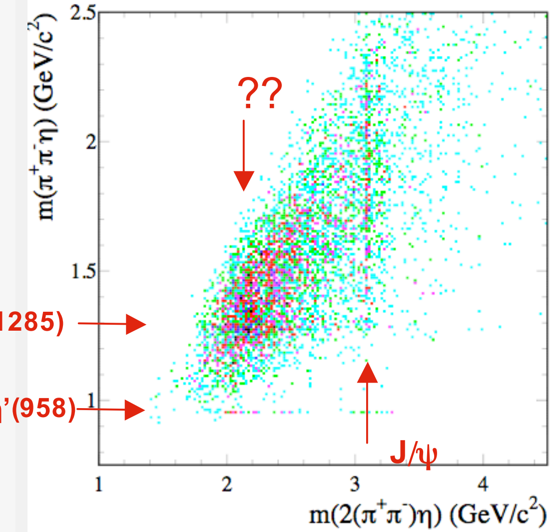


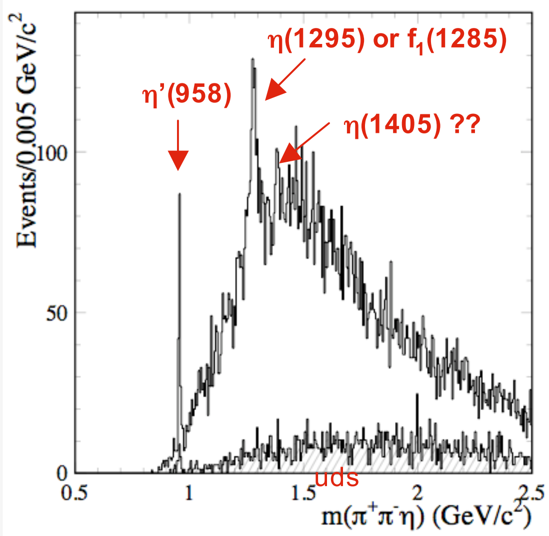
First measurement

The $e^+e^- \to 2(\pi^+\pi^-)\eta$ cross section

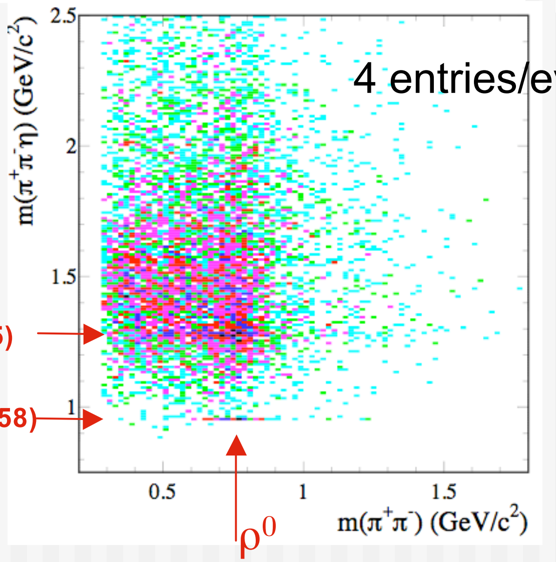
The $\eta(547)$ mass used as a constrain in the 5C fit.

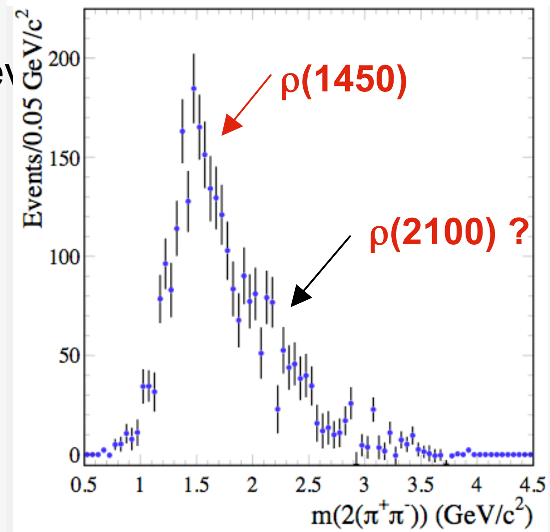






Corrected for the $\eta \to \gamma\gamma$ BF (0.445)





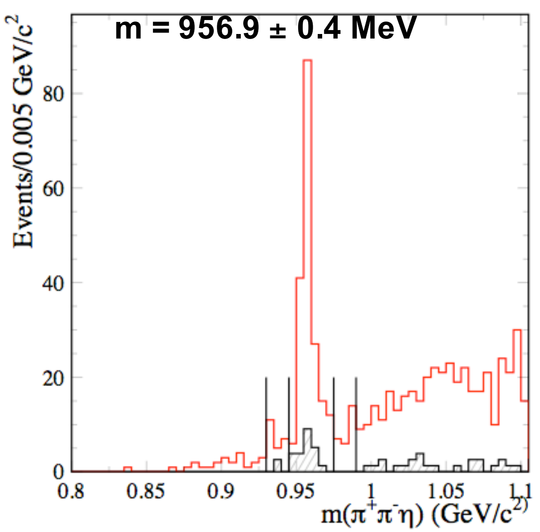
No other measurements !

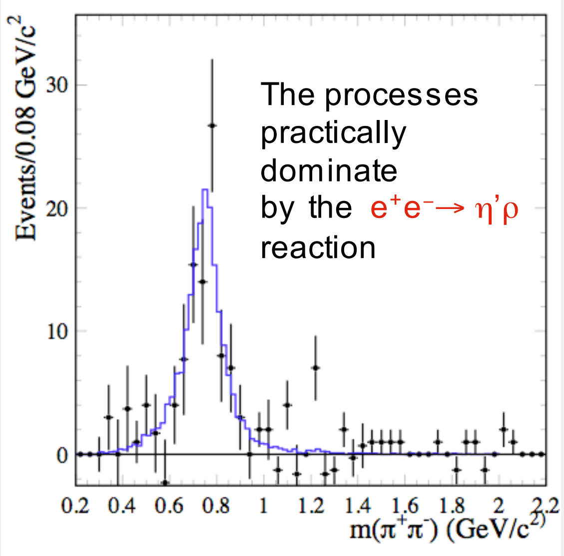
Dominates by $\eta\rho(1450)$ production

Cross section $e^+e^- \to \eta'(958)\pi^+\pi^-$, $f_1(1281)\pi^+\pi^-$

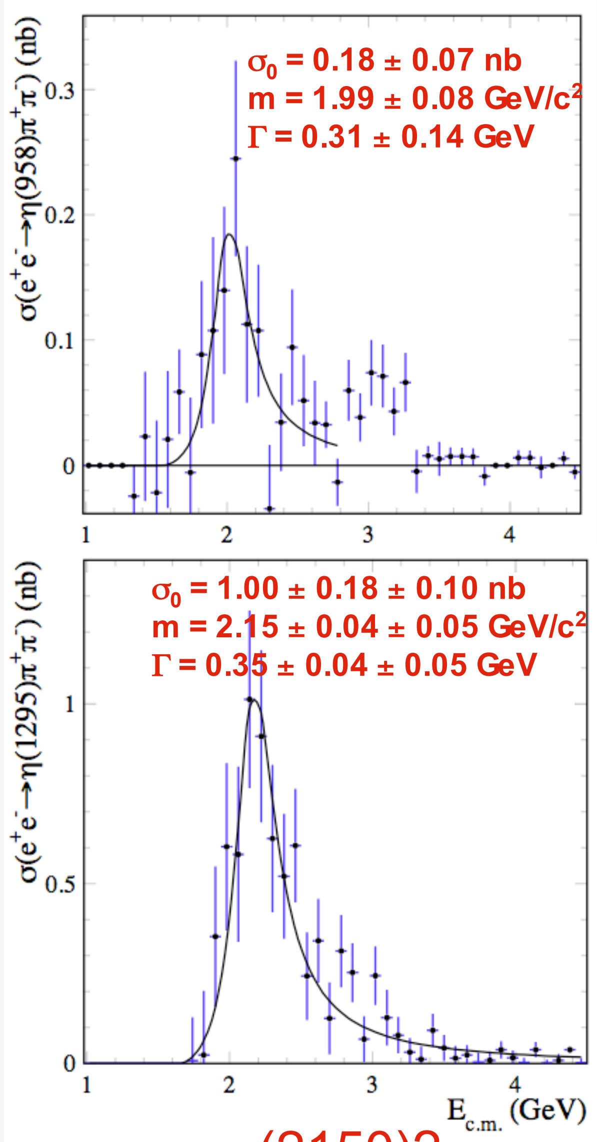
Δ_{PDG} = - 0.9 ± 0.4 MeV

m = 956.9 ± 0.4 MeV





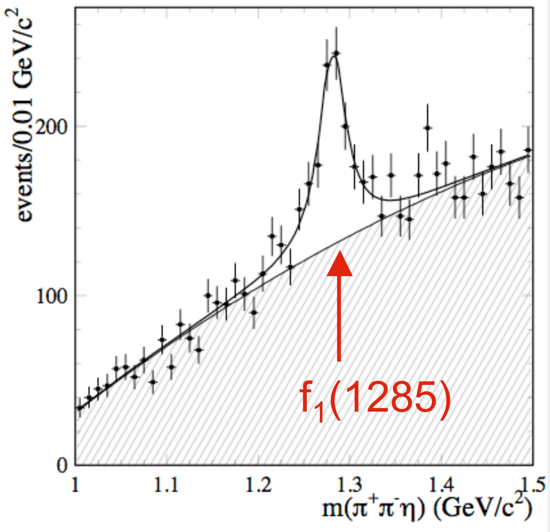
The processes practically dominate by the $e^+e^- \to \eta'\rho$ reaction



σ_0 = 0.18 ± 0.07 nb
m = 1.99 ± 0.08 GeV/c²
Γ = 0.31 ± 0.14 GeV

σ_0 = 1.00 ± 0.18 ± 0.10 nb
m = 2.15 ± 0.04 ± 0.05 GeV/c²
Γ = 0.35 ± 0.04 ± 0.05 GeV

ρ(2150)?

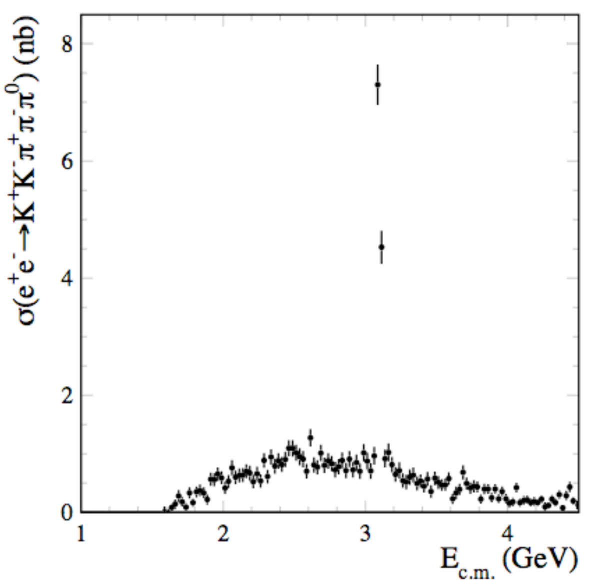


$f_1(1285)$

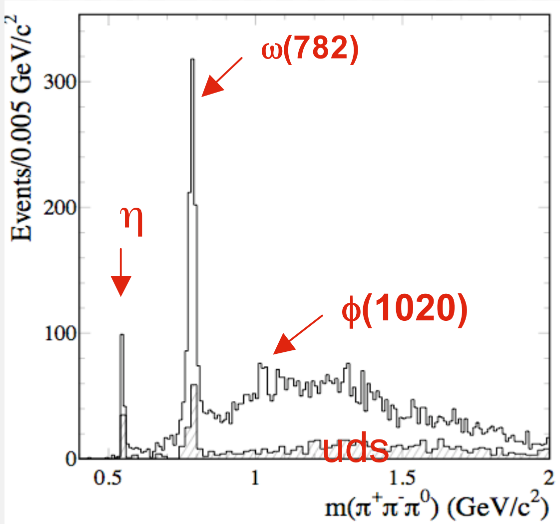
m = 1.281 ± 0.002 ± 0.001 GeV/c²
Γ = 0.035 ± 0.006 ± 0.004 GeV
Not consistent with PDG η(1295),
but in agreement with f_1(1285):
m = 1.283 ± 0.004 GeV/c²
Γ = 0.028 ± 0.005 GeV

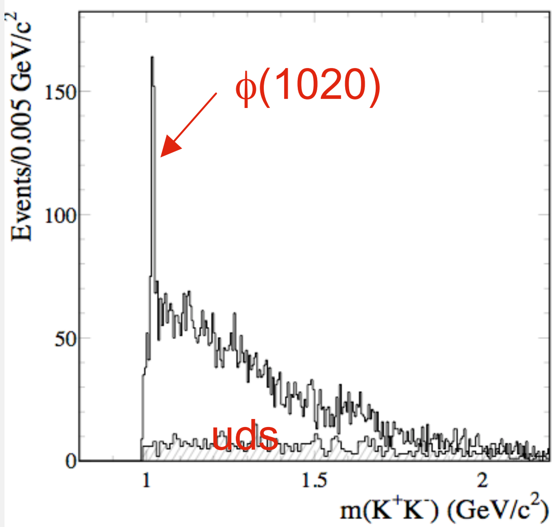
The $e^+e^- \to K^+K^-\pi^+\pi^-\pi^0$ cross sections

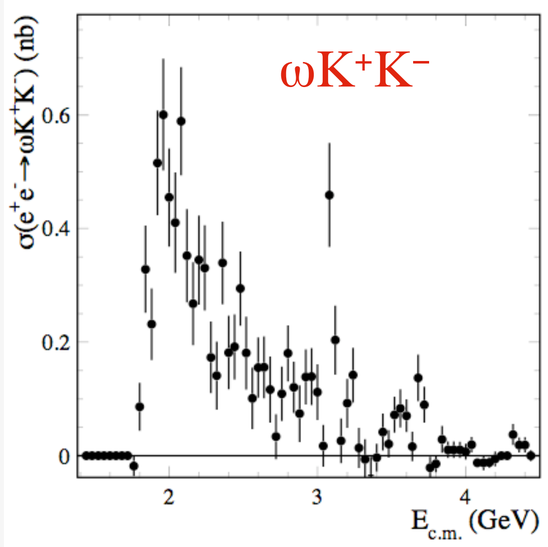
The kaon masses used as the constrains in the 5C fit.

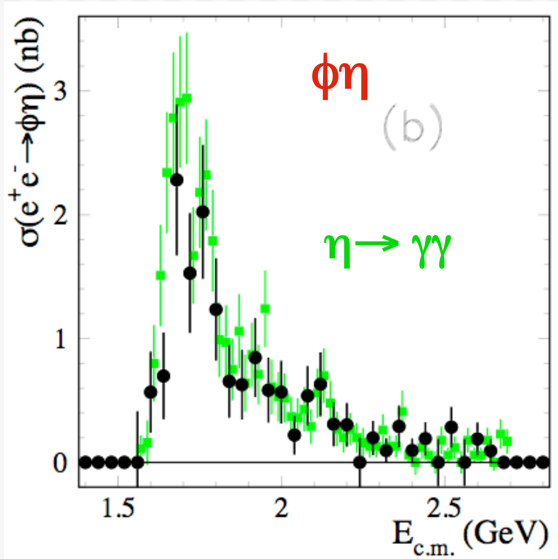


No other measurements !



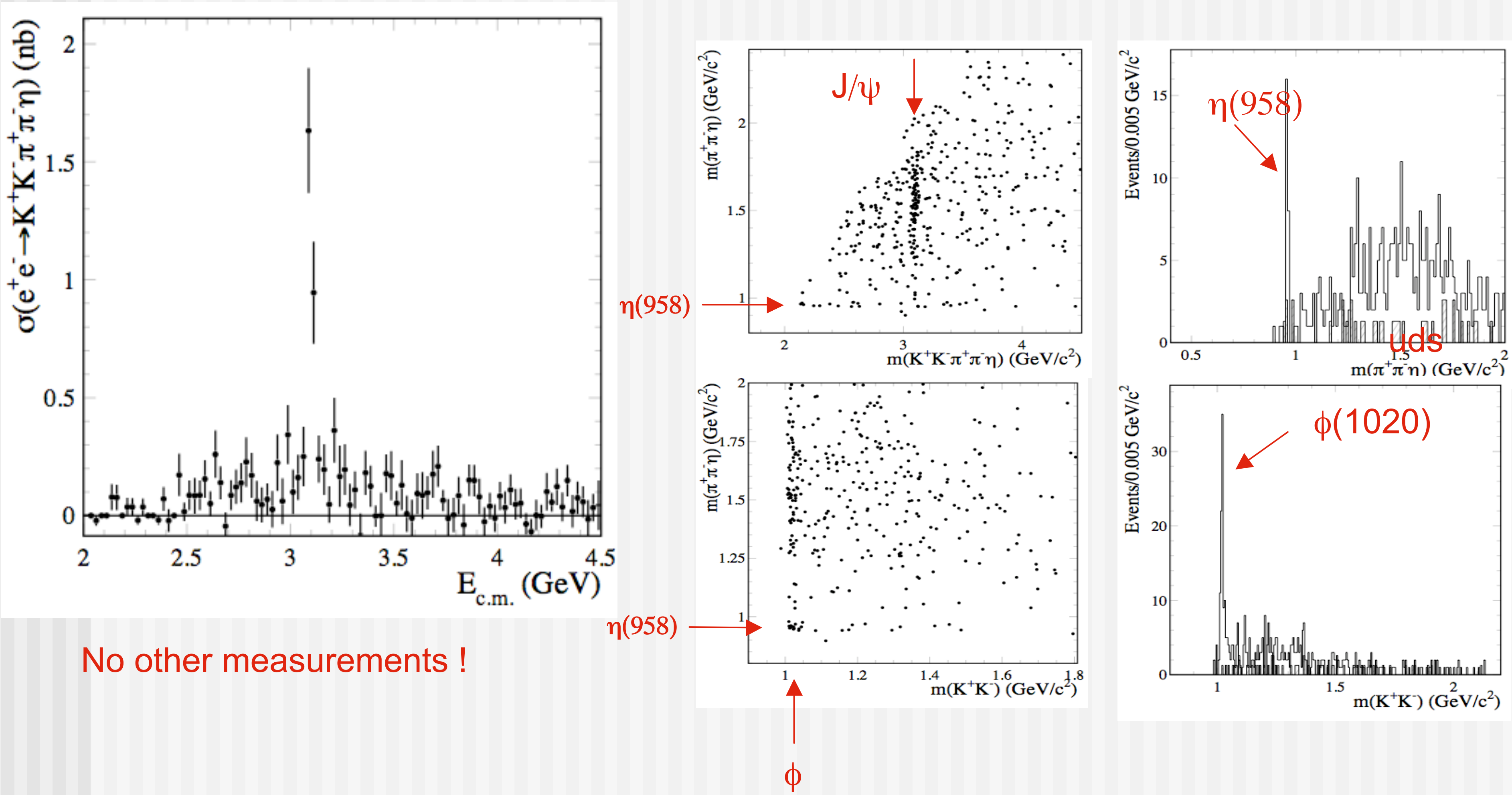






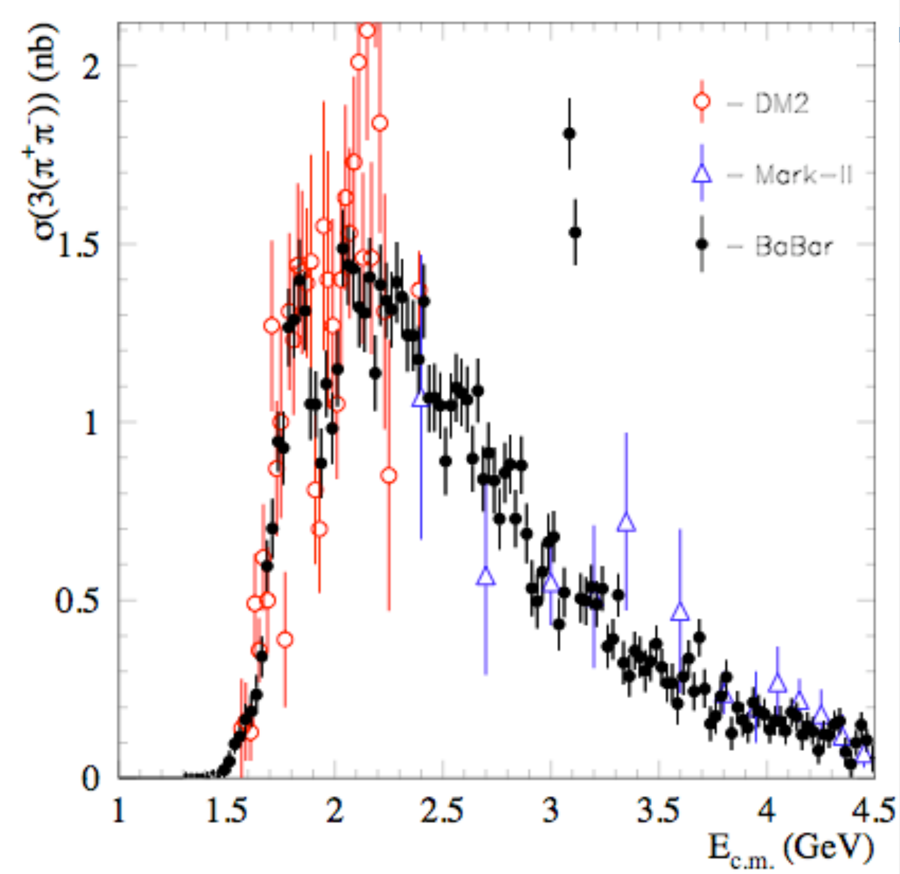
The $e^+e^- \to K^+K^-\pi^+\pi^-\eta$ cross section

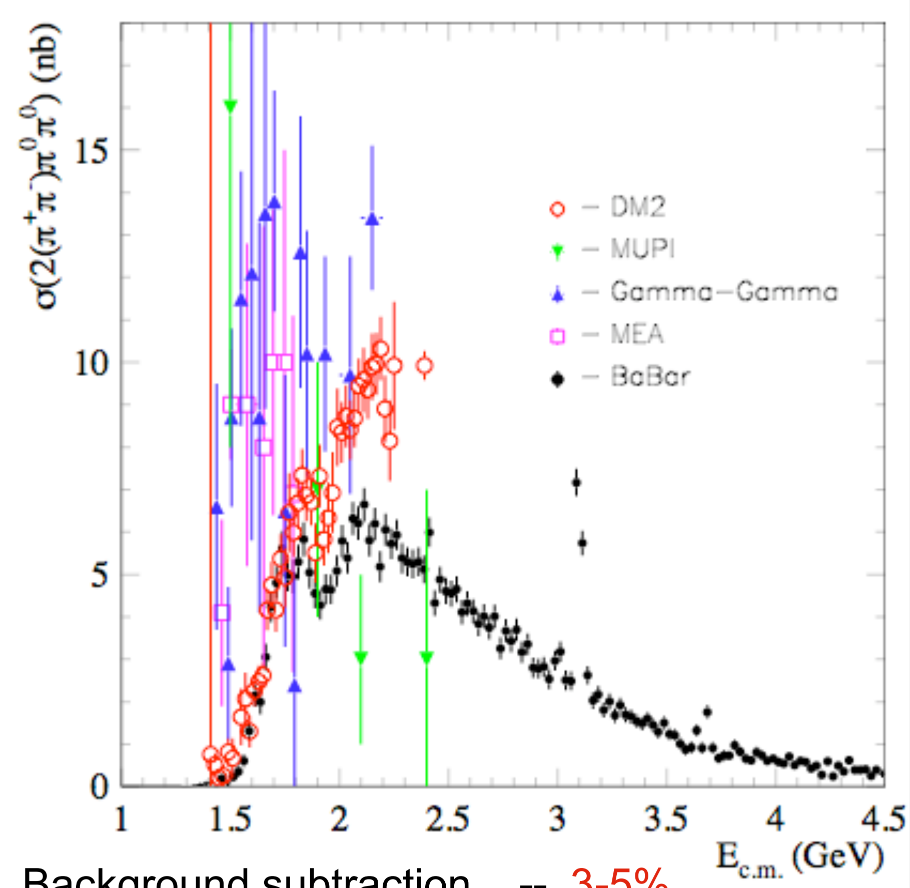
The kaon and η masses used as the constrains in the 5C fit.



No other measurements !

Cross section $e^+e^- \to 3(\pi^+\pi^-), 2(\pi^+\pi^-)\pi^0\pi^0$

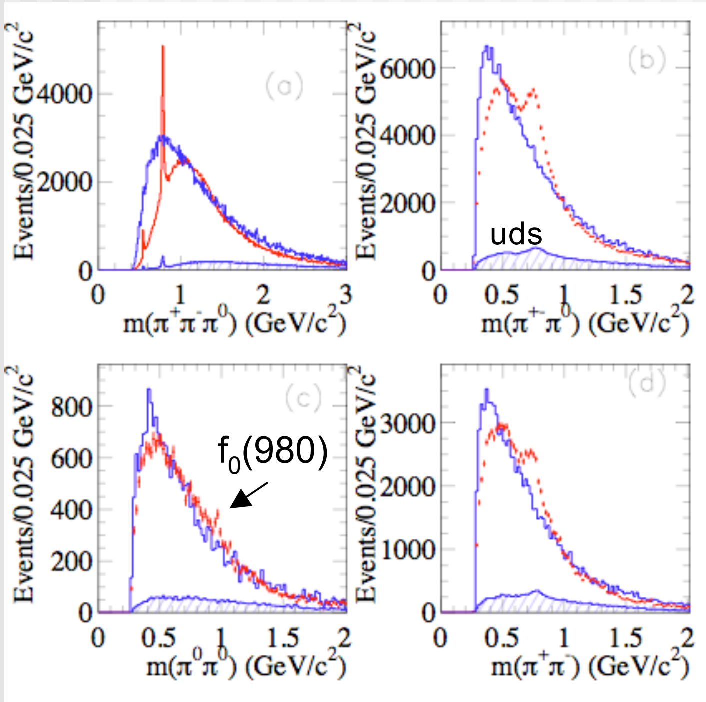


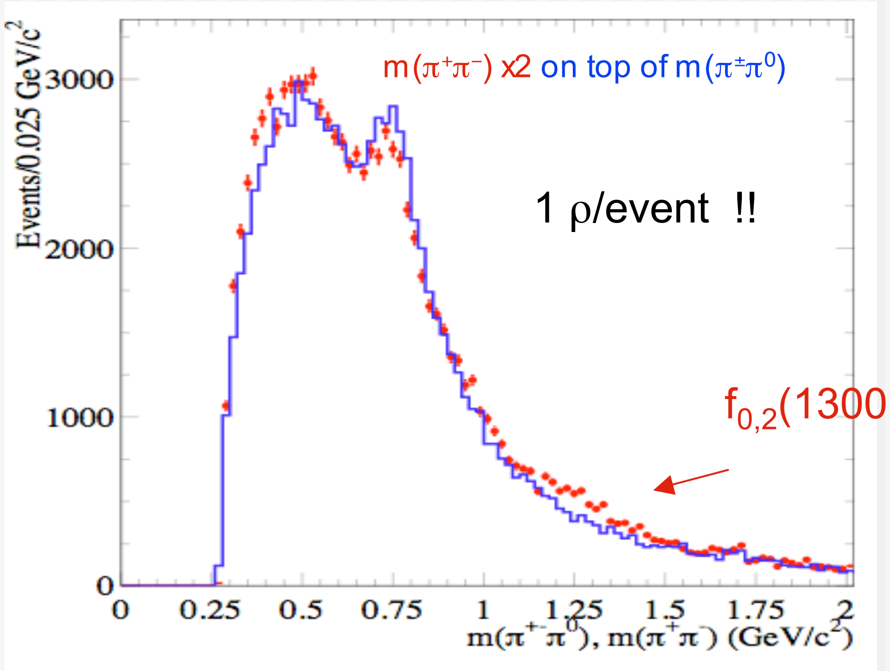


Background subtraction -- 3-5%
Tracking efficiency -- 3%
ISR luminosity -- 3%
Acceptance -- 3-5%
χ^2 cut uncertainty -- 3%
Total -- 6-8%

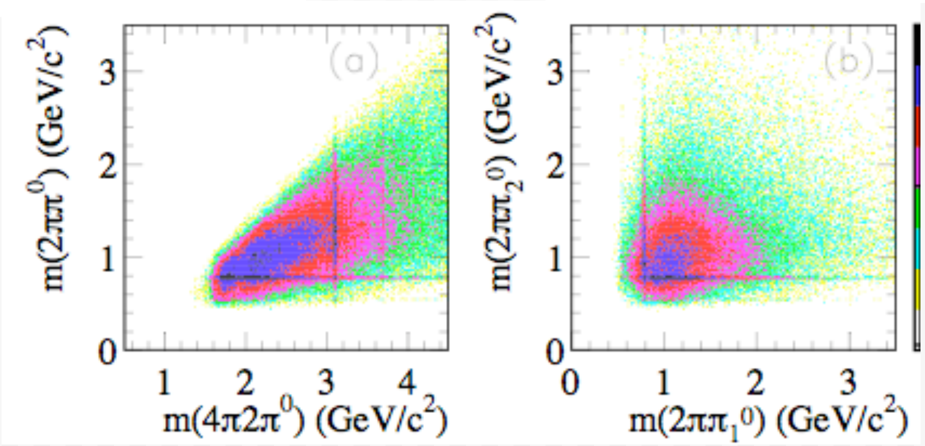
Background subtraction -- 3-5%
Tracking efficiency -- 3%
Luminosity -- 3%
Acceptance -- 3-5%
χ^2 cut uncertainty -- 6%
π^0 efficiency -- 3%
Total -- 11%

Comparison with MC simulation





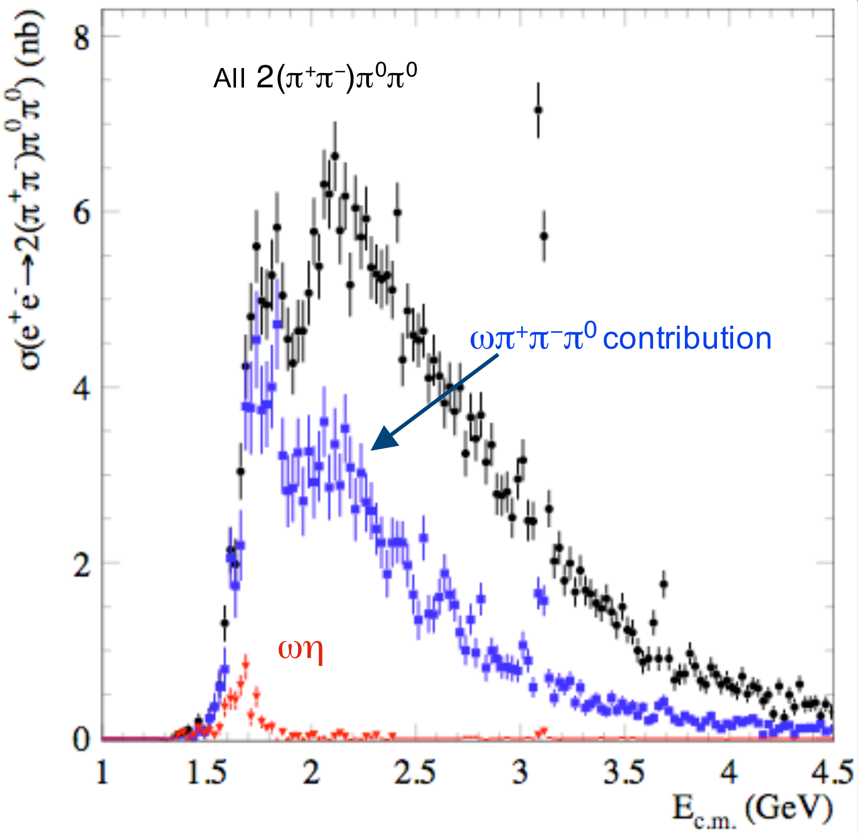
MC - phase space

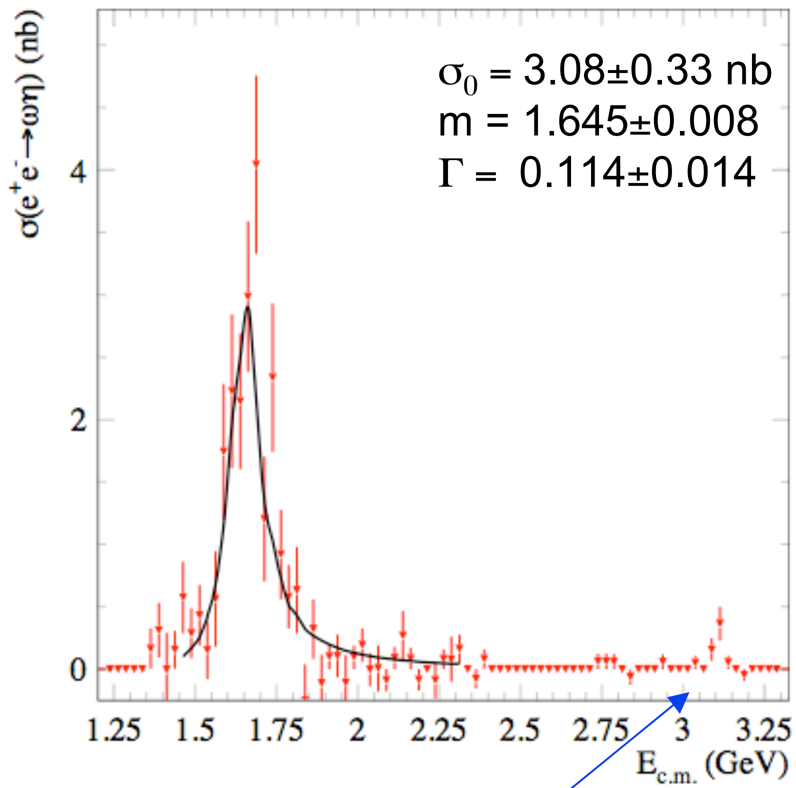


Data are in agreement with MC with 1 ρ/event, i.e. $e^+e^-\rightarrow\rho 4\pi$ reaction

How big is $\omega(782)$ contribution?

Corrected on $B(\omega,\eta \to 3\pi)$



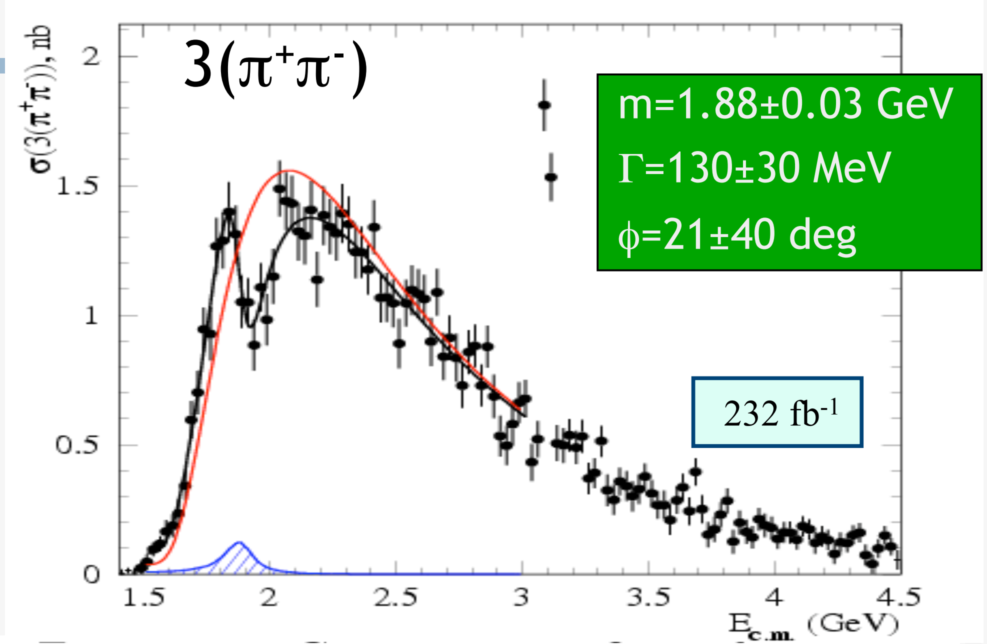


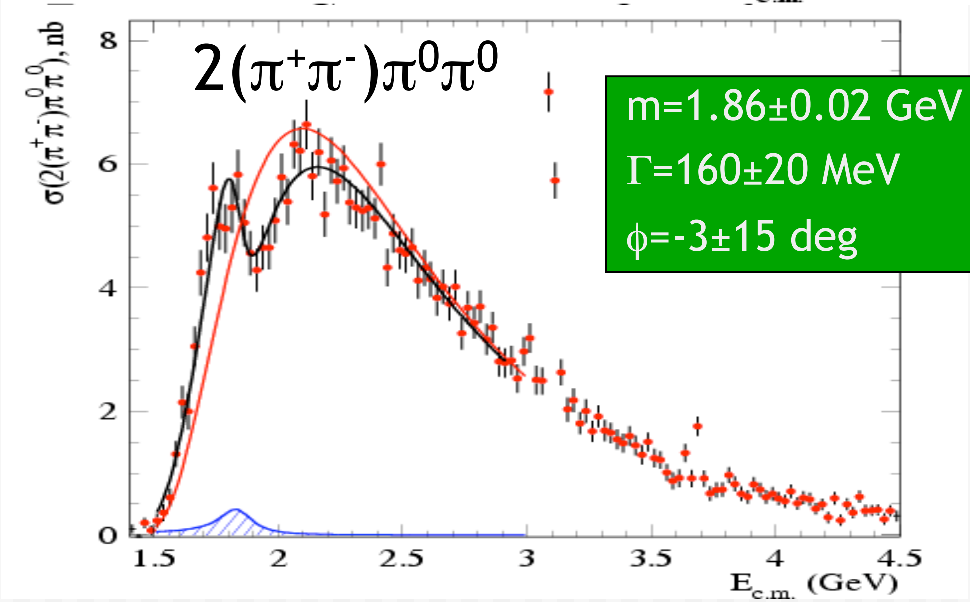
PDG2004 $\phi(1680)$
m = 1.680±0.020
Γ = 0.150±0.050

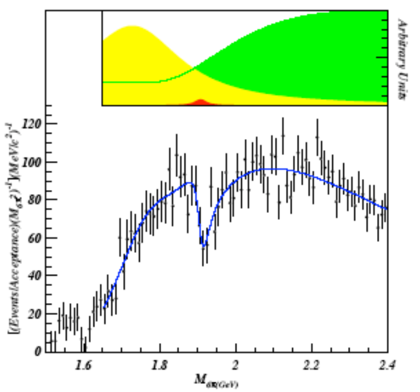
13 events are from $J/\psi \to \omega\eta$ with less than 0.5 events of background

Structure in $e^+e^- \to 6\pi$ cross section

- Under-threshold $p\bar{p}$-resonance should be seen in multihadron cross sections
- Structure at 1.9 GeV was observed in photoproduction (FOCUS) and e^+e^--annihilation (DM2, FENICE)
- BABAR confirms the structure, but width is wider than FOCUS observed.

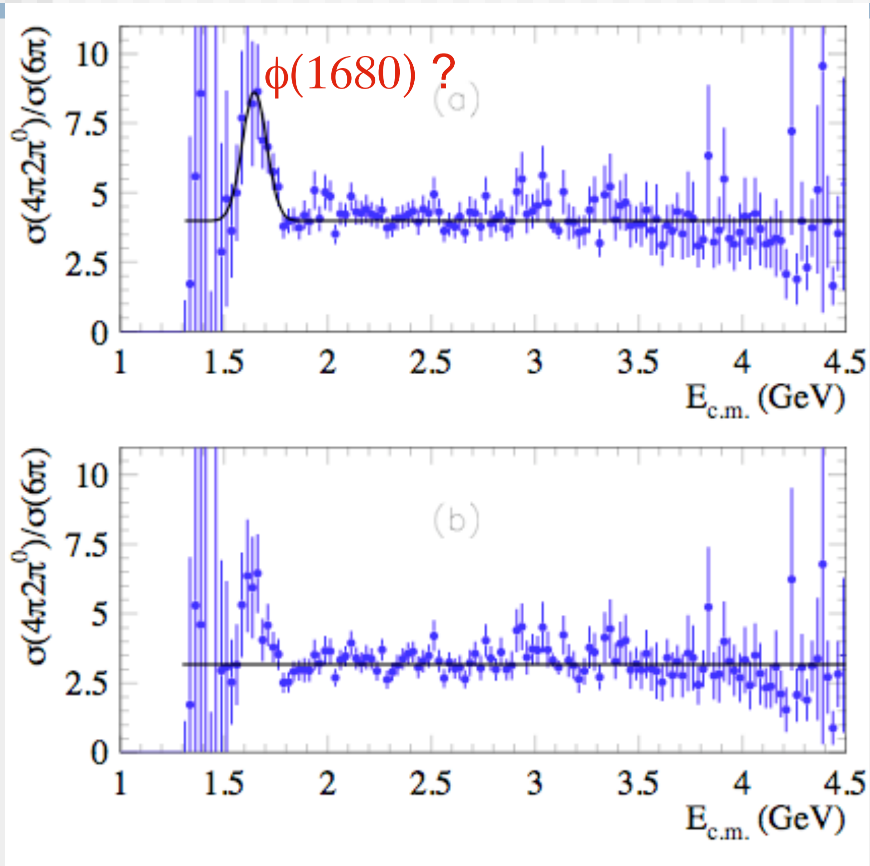






$m_1 = 1.91 \pm 0.01$ GeV/c^2
$\Gamma_1 = 0.037 \pm 0.013$ GeV
$\varphi_1 = 10 \pm 30$ deg.

Cross section ratio



Gaussian fits give:

m1 = 1.63 ± 0.02 GeV/c2

σ1 = 0.12 ± 0.02 GeV/c2

$\phi(1680)$?

R = 3.98 ± 0.06

If ω contribution is excluded:

R = 3.18 ± 0.05

R ≈ 3 if $\omega\, \pi^+\pi^-\pi^0$ events are excluded.
Can somebody calculate what this ratio should be according to isospin?

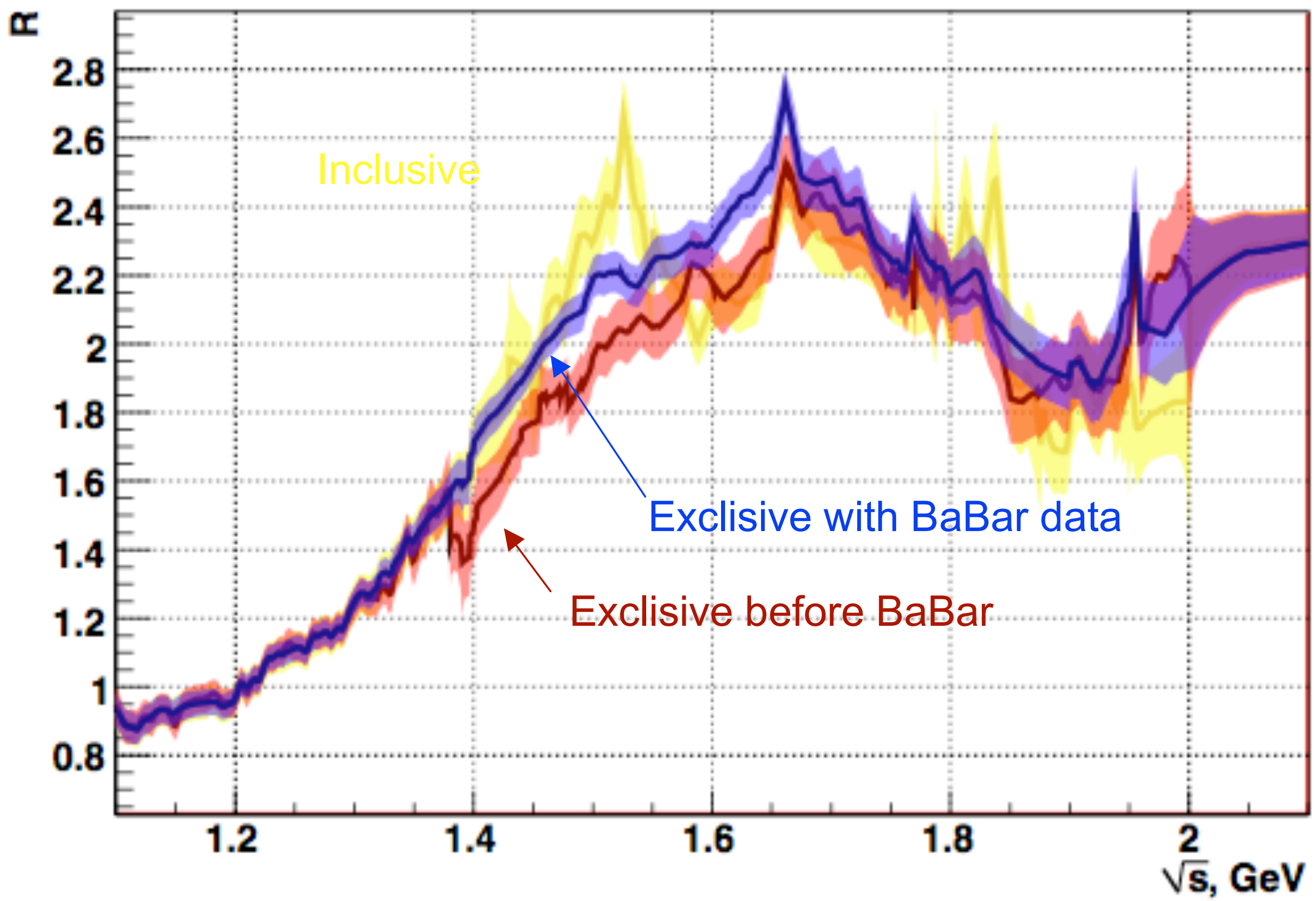
Conclusions

1. ISR method is developed at Babar as a practical tool to study e+e- annihilation in wide CM energy range from $2m_\pi$ up to 7 GeV/c^2 with competitive accuracy.
2. Numerous number of e+e→ hadrons process are studied at Babar including productions of pions, kaons, baryons, D-mesons, …
3. Decay parameters of many vector mesons are improved ρ_S, ω_S, ϕ_S, J/ψ, $\psi(2S)$, …
4. Some of the measured resonances still have no proper theoretical explanation… PWA is needed to learn more..
5. New states are discovered using ISR technique incl Y(4260), Y(2175), …
6. New low energy e+e- colliders (VEPP2000, BEPC) as well as ISR from BaBar and Belle will give improved measurements of XS and much better parameters of discovered structures.
   … new surprises are expected…

What is NOT discussed in this talk.

1. e+e- -> π+π-, analysis is going on, final result should come out in few weeks, the results will allow a new test of SM with muon magnetic moment a_μ=(g-2)/2.
2. Measurements of quantity R(s) is important to calculate fine structure constant at Z-mass $\alpha_{em}(s=M_Z^2)$
3. Isovector cross sections e+e->H(T=1) and corresponding τ-lepton decays τ->Hν are used to test CVC hypothesis.
4. Most of reactions used only half of available statistics. Many processes are still not considered. This is the perspective field for future work.
5. Super BF with 2 orders higher luminosity promise a great future for ISR

BaBar contribution to R



J/ψ – ψ(2S) region

We measure:

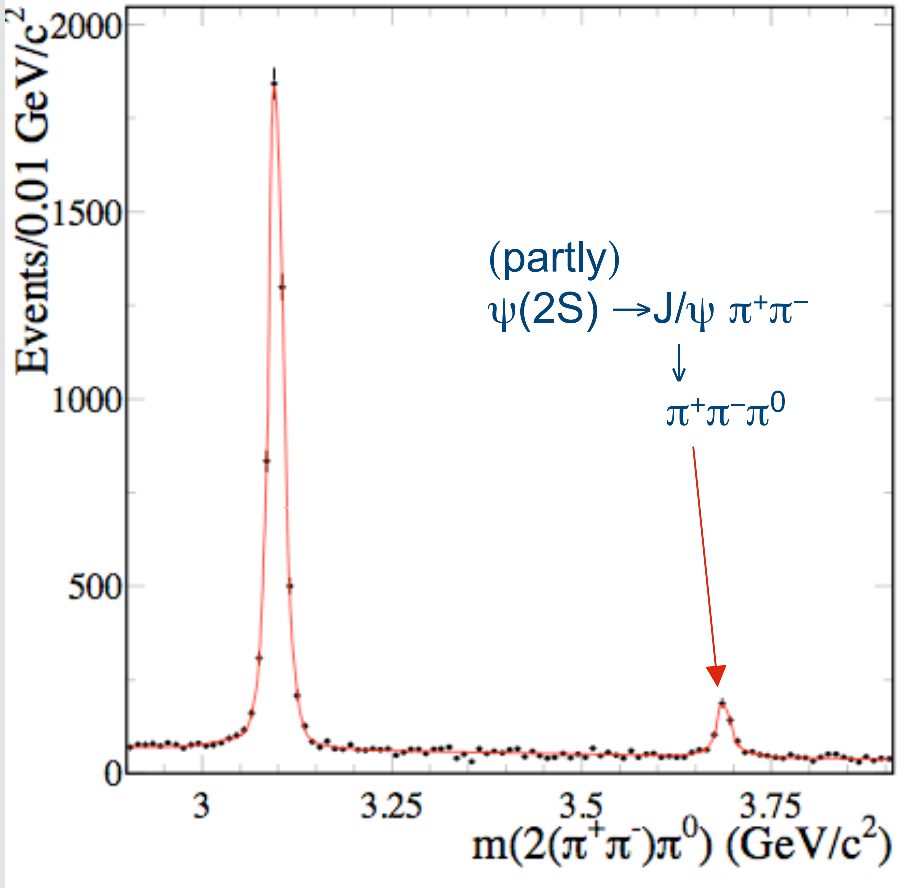
$$\Gamma_{ee}^{J/\psi} \cdot B_f^{J/\psi} = \frac{N_{J/\psi \to f} m_{J/\psi}^2}{6\pi \cdot dL/dE \cdot \varepsilon(m_{J/\psi}) \cdot C}$$

About 6% systematic error from efficiency (5%) and luminosity (3%)

(~3%) with new x2 data (1%)

If statistical error < 6(3) % BaBar is competitive with other experiments !

J/ψ region for $2(\pi^+\pi^-)\,\pi^0$



$N_{J/\psi}$ = 4990 ± 79, ε = 0.1045 dL/dE = 65.6

$\Gamma_{ee} \cdot B_{5\pi} = (3.03 \pm 0.05 \pm 0.18) \times 10^{-1}$ keV
$B_{J/\psi \to 5\pi} = (5.46 \pm 0.09 \pm 0.34) \times 10^{-2}$

$B_{J/\psi \to 5\pi} = (3.37 \pm 0.26) \times 10^{-2}$ PDG2006

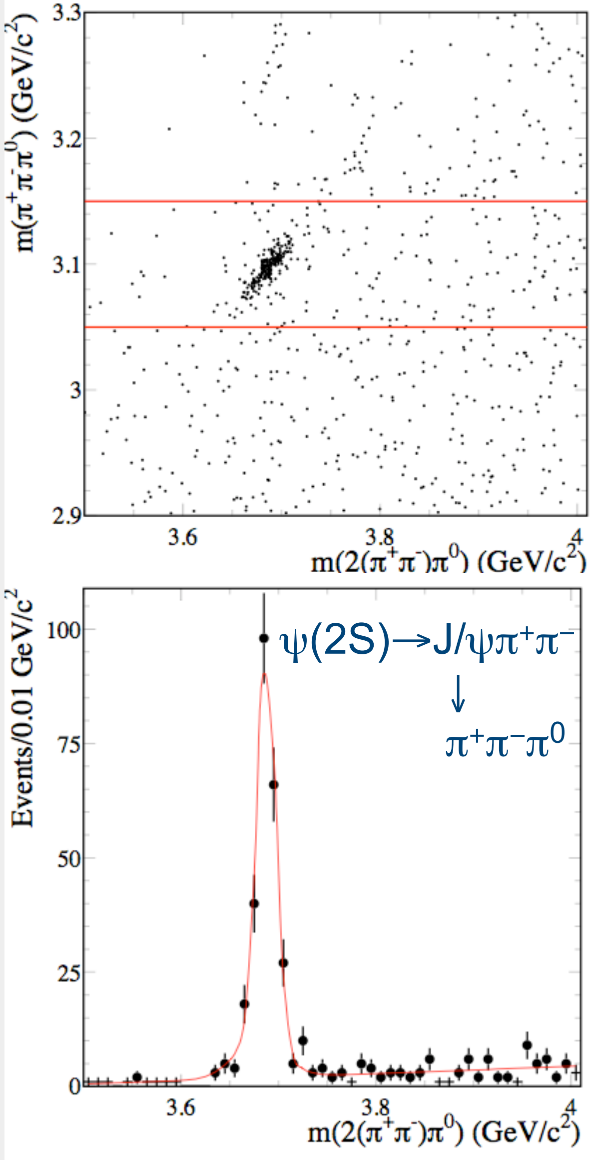
$N_{\psi(2S)}$ = 410 ± 30, ε = 0.0965 dL/dE = 84.0

$\Gamma_{ee} \cdot B_{5\pi} = (2.97 \pm 0.22 \pm 0.18) \times 10^{-2}$ keV
$B_{\psi(2S) \to 5\pi} = (1.20 \pm 0.09 \pm 0.07) \times 10^{-2}$

$B_{\psi(2S) \to 5\pi} = (0.266 \pm 0.029) \times 10^{-2}$ PDG2006

Huge discrepancy ! ?

The $\psi(2S) \to J/\psi\, \pi^+\pi^- \to 2(\pi^+\pi^-)\pi^0$



$N_{\psi(2S)}$ = 256 ± 17, ε = 0.0965 dL/dE = 84.0

$\boxed{\Gamma_{ee} \bullet B_{J/\psi\pi\pi} \bullet B_{J/\psi\to3\pi} = (1.86 \pm 0.12 \pm 0.11) \times 10^{-2} \text{ keV}}$

$\Gamma_{ee} = 2.48 \pm 0.06$ keV, $B_{J/\psi\pi\pi} = 0.318 \pm 0.006$ PDG2006

$\boxed{B_{J/\psi\to3\pi} = (2.36 \pm 0.16 \pm 0.16) \times 10^{-2}}$

$B_{J/\psi\to3\pi} = (2.02 \pm 0.14)\times10^{-2}$ S=1.7 PDG2006

$B_{J/\psi\to3\pi} = (2.18 \pm 0.19)\times10^{-2}$ BaBar 2004

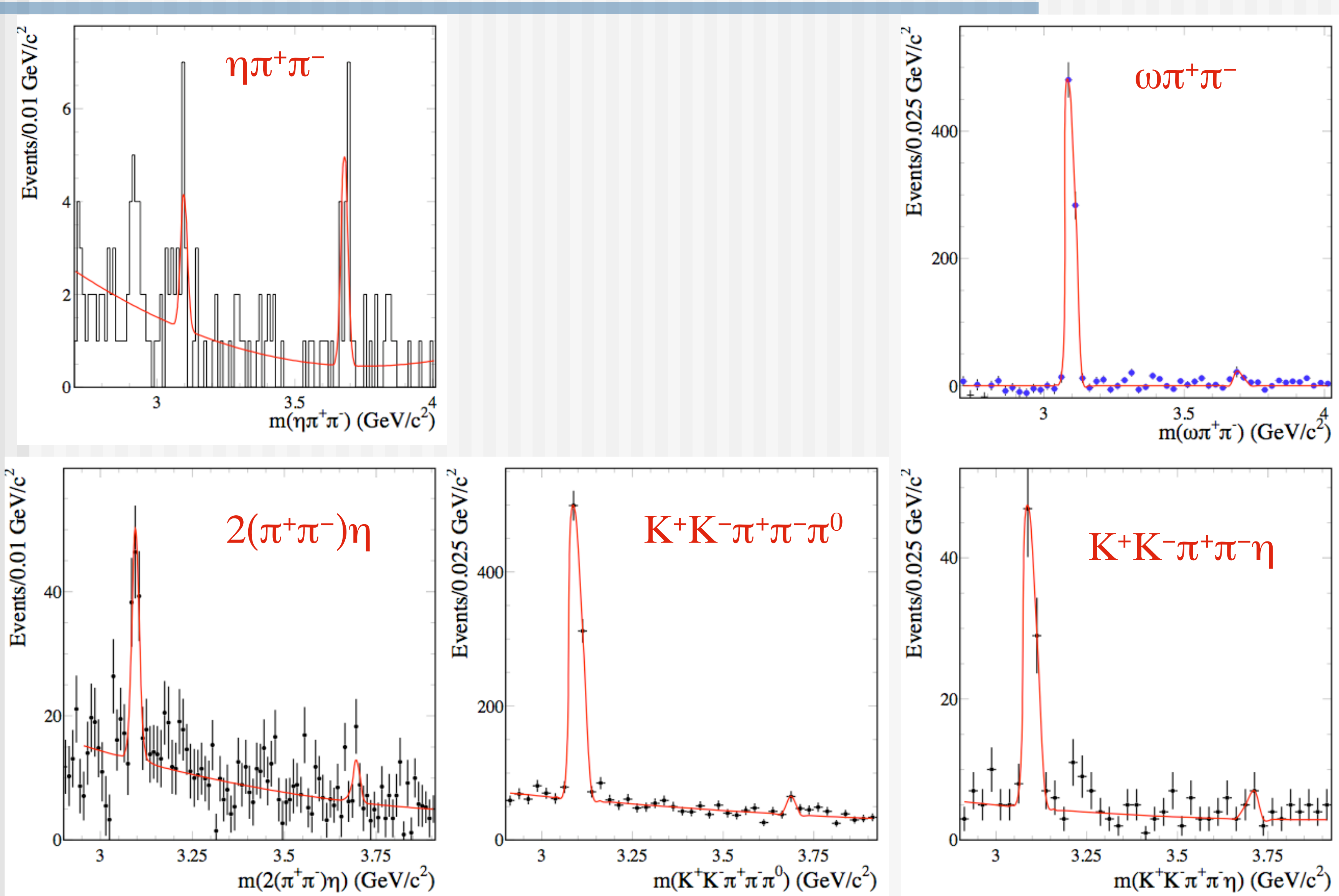
$B_{J/\psi\to3\pi} = (2.18 \pm 0.20)\times10^{-2}$ BES 2004

$B_{J/\psi\to3\pi} = (2.09 \pm 0.12)\times10^{-2}$ BES 2004

$B_{J/\psi\to3\pi} = (1.42 \pm 0.19)\times10^{-2}$ MARK3 1988

We are in agreement with BaBar and BES !

$J/\psi - \psi(2S)$ region for other selections



J/Ψ and $\Psi(2s)$ decay in ISR

With ΔL=454 1/fb $N_{J/\Psi} = 1.6\ 10^7$, $N_{\Psi(2S)} = 0.6\ 10^6$ ev. in full solid angle

More than 10 decays are observed for the first time:

$J/\psi \to K^+K^-\pi^+\pi^-\eta$

$J/\psi \to K^+K^-\rho^0\rho^0$

$J/\psi \to K^{*0}K^{*0}$

$J/\psi \to K^*K_2(1770)$

$J/\psi \to \phi\pi^0\pi^0$

$J/\psi \to \phi f_2$

$J/\psi \to \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$

$J/\psi \to \omega\pi^+\pi^-\pi^0$

$\Psi(2S) \to \pi^+\pi^-\pi^+\pi^-\eta$

$\Psi(2S) \to K^+K^-\pi^+\pi^-\eta$

$\Psi(2S) \to K^+K^-\pi^+\pi^-\pi^+\pi^-$

$\Psi(2S) \to \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$

BF ~ 10^{-3}