Low-energy hadronic cross sections measurements at BaBar, and implication for the g-2 of the muon

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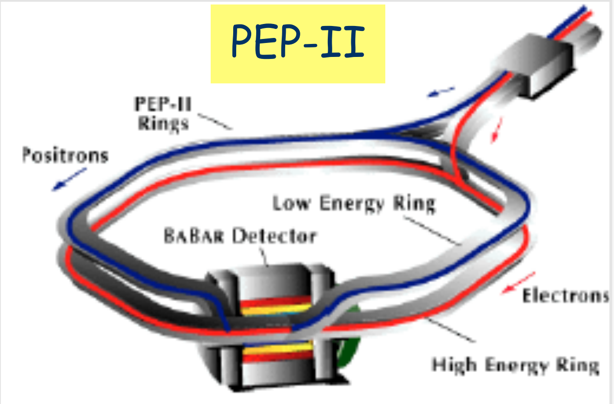
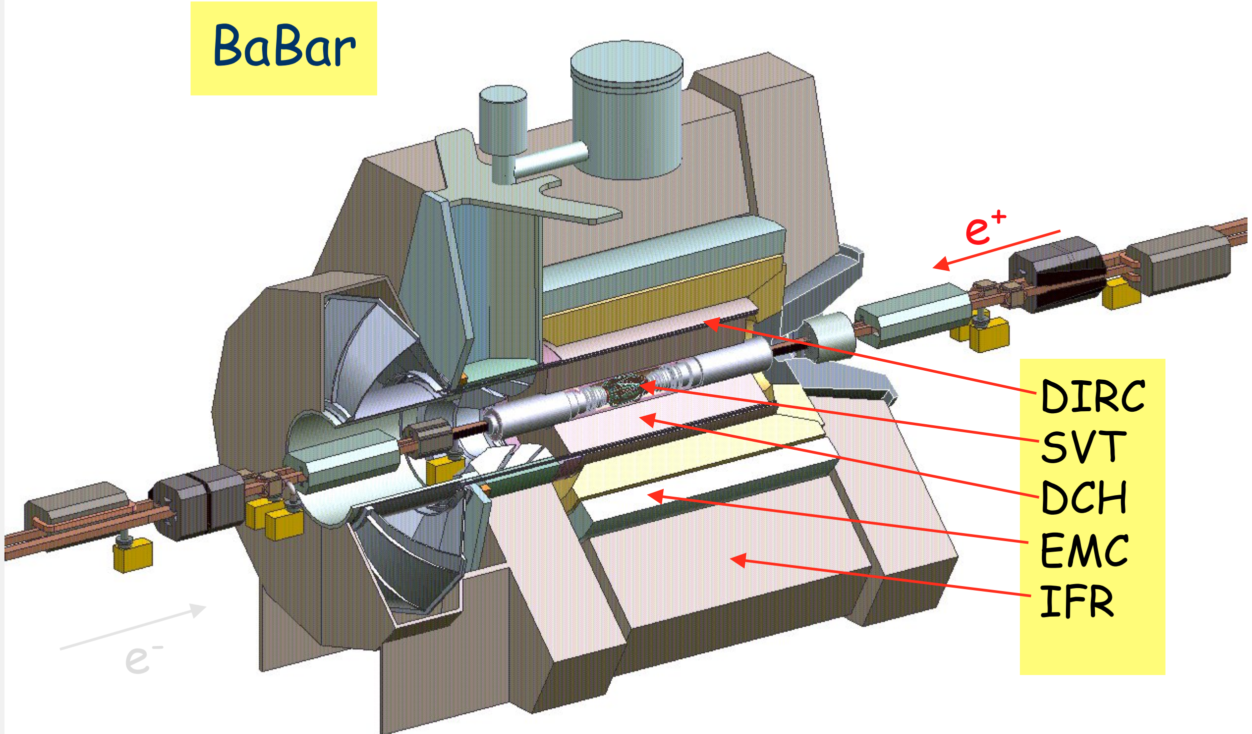
PEP-II e+e- collider, Babar detector

E_+ = 3.1 GeV, E_- = 9 GeV



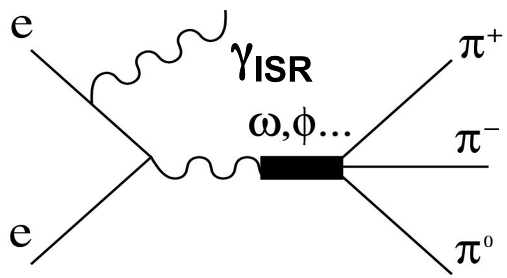
E_{CM} = M(Υ(4S))=10.6 GeV
2000 - 2008 yrs
ΔL = 500 fb^{-1}
N(B) = 10^9



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

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

θ - photon polar angle in c.m.



ISR study at BaBar

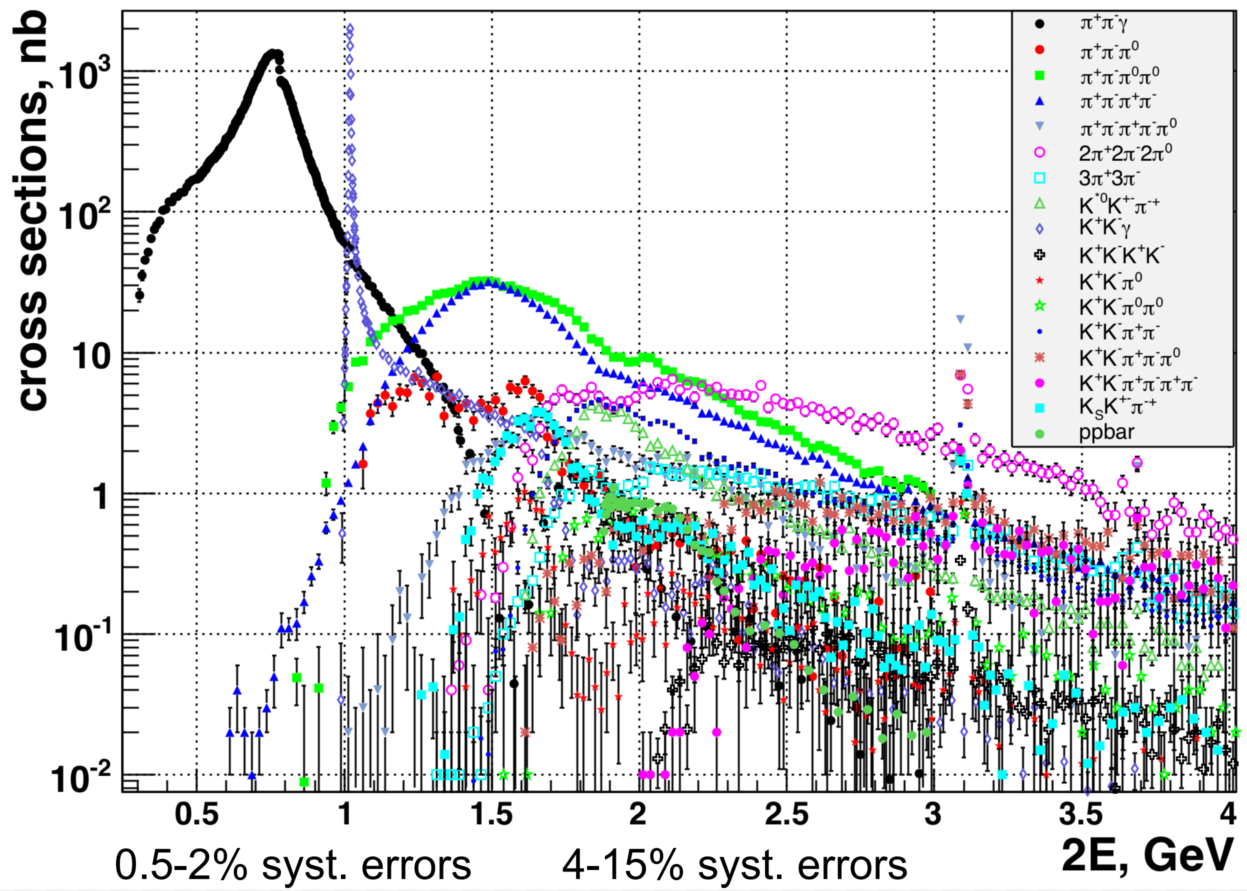
- ISR at BaBar gives competitive (even dominates!) statistics
- BaBar has excellent capability for ISR study
- Many major hadronic processes have been studied

published

$e^+e^- \to \pi^+\pi^-$	PR D 86 (2012) 032013, PR L 103 (2009) 231801
$e^+e^- \to K^+K^-$	PR D 88, (2013) 032013
$e^+e^- \to \phi f_0(980)$	PR D 74 (2006) 091103, PR D 76 (2007) 012008
$e^+e^- \to \pi^+\pi^-\pi^0$	PR D 70 (2004) 072004
$e^+e^- \to K^+K^-\eta, K^+K^-\pi^0, K^0_S K^\pm\pi^\mp$	PR D 77 (2008) 092002, PR D 71 (2005) 052001
$e^+e^- \to 2(\pi^+\pi^-)$	PR D 85 (2012) 112009, PR D 76 (2007) 012008
$e^+e^- \to K^+K^-\pi^0\pi^0, K^+K^-\pi^+\pi^-, 2(K^+K^-)$	PR D 86 (2012) 012008, PR D 76 (2007) 012008
$e^+e^- \to K^0_S K^0_L, K^0_S K^0_L\pi^+\pi^-, K^0_S K^0_S\pi^+\pi^-, K^0_S K^0_S K^+K^-$	PR D 89 (2014) 092002
$e^+e^- \to 2(\pi^+\pi^-)\pi^0, 2(\pi^+\pi^-)\eta, K^+K^-\pi^+\pi^-\pi^0, K^+K^-\pi^+\pi^-\eta$	PR D 76 (2007) 092005
$e^+e^- \to 3(\pi^+\pi^-), 2(\pi^+\pi^-\pi^0), 2(\pi^+\pi^-)K^+K^-$	PR D 73 (2006) 052003
$e^+e^- \to p\bar{p}$ (small $\sqrt{s}$)	PR D 87 (2013) 092005, PR D 73 (2006) 012005
$e^+e^- \to p\bar{p}$ (large $\sqrt{s}$)	PR D 88 (2013) 072009
$e^+e^- \to \Lambda\bar{\Lambda}, \Lambda\bar{\Sigma}^0, \Sigma^0\bar{\Sigma}^0$	PR D 76 (2007) 092006
$e^+e^- \to c\bar{c} \to \dots$	... ...

Some reactions are being updated to the full BaBar data with ~500 fb^{-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_SK_L, $K_SK_L\pi^+\pi^-$, $K_SK^+\pi^-\pi^0$ are under study: $\pi^+\pi^-2\pi^0$ will come soon. Work is in progress for $K_SK_L\pi^0\pi^0$, $K_SK_L\pi^0$

BaBar measured: $e^+e^- \rightarrow \pi^+\pi^-$

Motivation: dominance of the E<1GeV region, accessed through $\pi^+\pi^-$

Features of the cross section distribution

- Includes possible FSR
- Dominated by ρ(770) resonance
- ρ-ω interference
- Dip at 1.6GeV: interference between ρ′ and ρ″
- Dip at 2.2GeV: higher mass ρ state

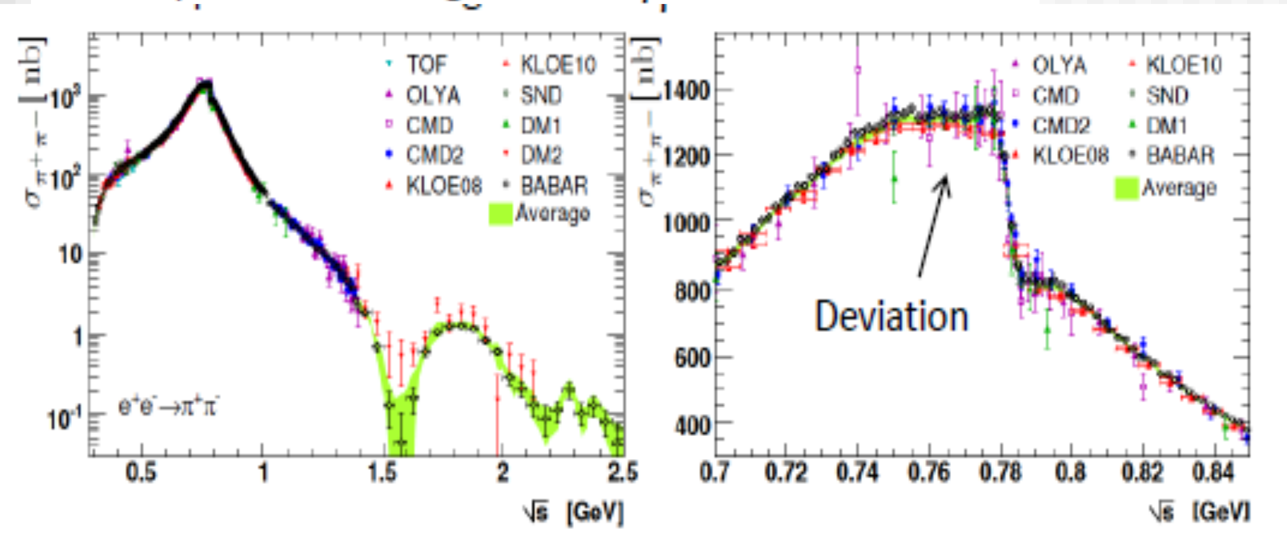
LO Hadr.,0.28-1.8 GeV

Babar

$a_\mu=(514.1\pm3.8)\ 10^{-10}$

all e^+e^-

$a_\mu=(505.8\pm3.0)\ 10^{-10}$



Systematic uncertainties at the ρ region

BaBar: 0.5%

CMD2: 0.8%

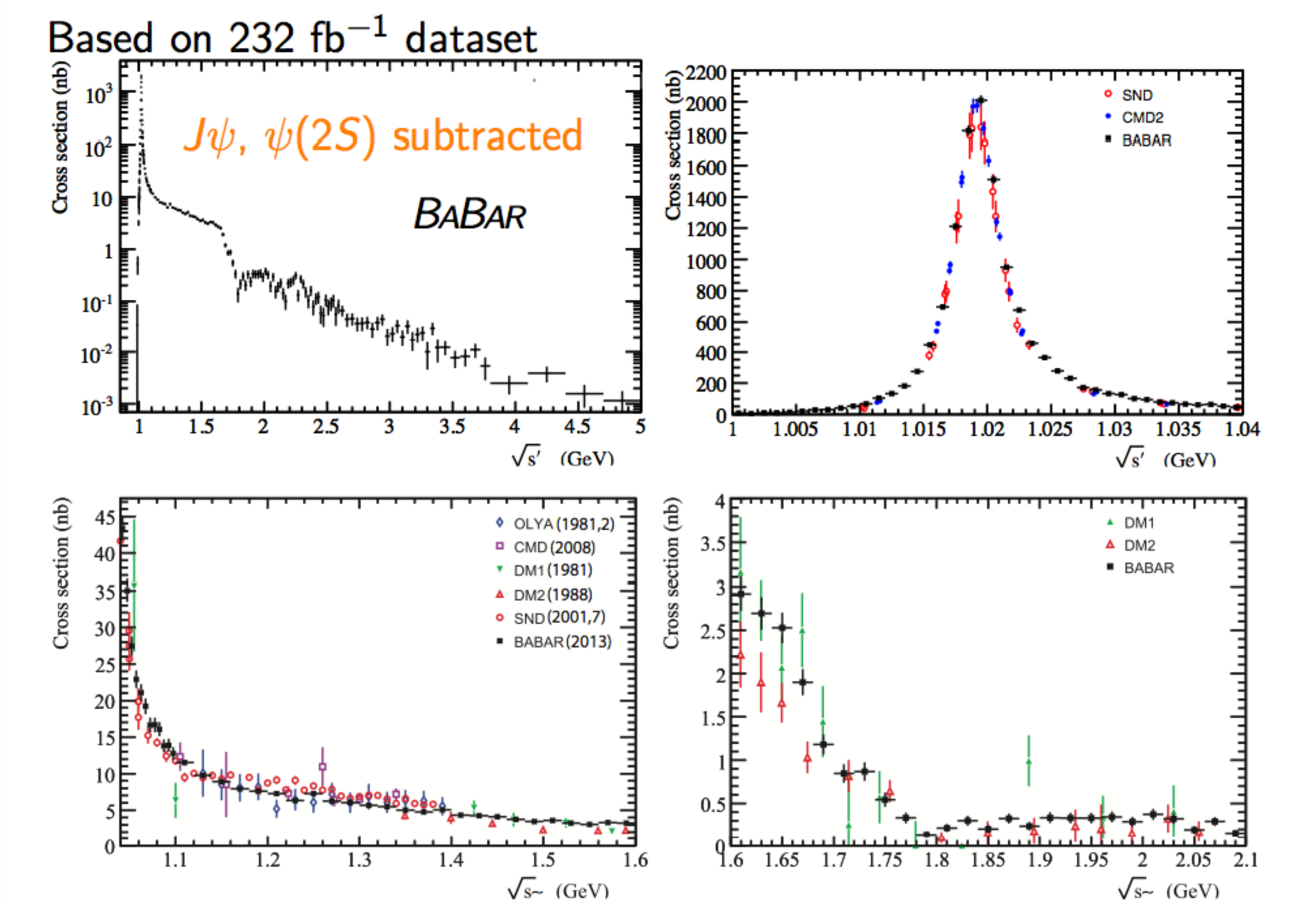
SND: 1.5%

KLOE: 0.8%

BaBar measured: $e^+e^- \rightarrow K^+K^-$

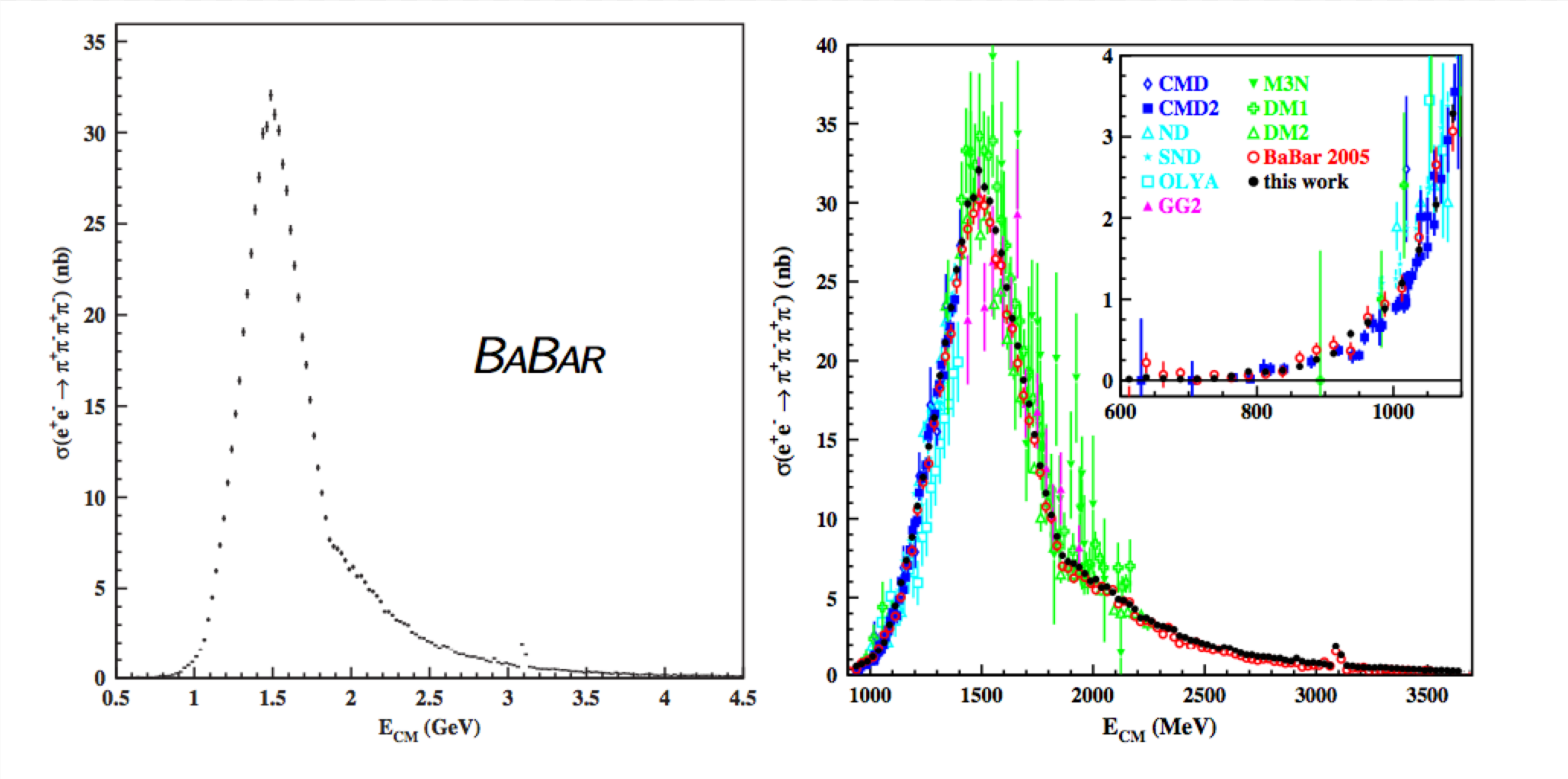
Published **Phys. Rev. D 88, 032013 (2013)**

Our result is more precise than the current world average



BaBar updated: $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$

Published PRD 85 112009 (2012)
Based on 454 fb^{-1} dataset (statistical uncertainties are shown)
Our result is more precise than the current world average (<3% systematic error)



Contribution of missing channels to a_μ

SM-to-experiment comparison [in units 10^{-10}]

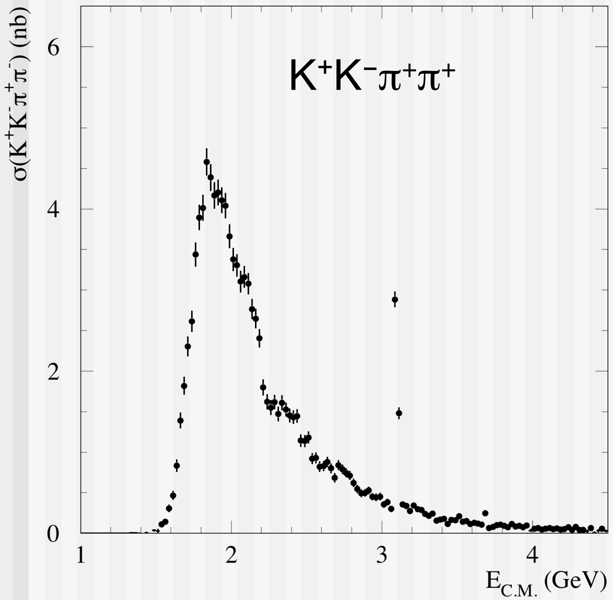
QED	116 584 71.81	$\pm$ 0.02
Leading hadronic vacuum polarization (VP)	690.30	$\pm$ 5.26
Sub-leading hadronic vacuum polarization	-10.03	$\pm$ 0.11
Hadronic light-by-light	11.60	$\pm$ 3.90
Weak (incl. 2-loops)	15.32	$\pm$ 0.18
Theory	11659179.00	$\pm$ 6.46
Experiment	11659208.00	$\pm$ 6.30
Exp − theory	29.00	$\pm$ 9.03

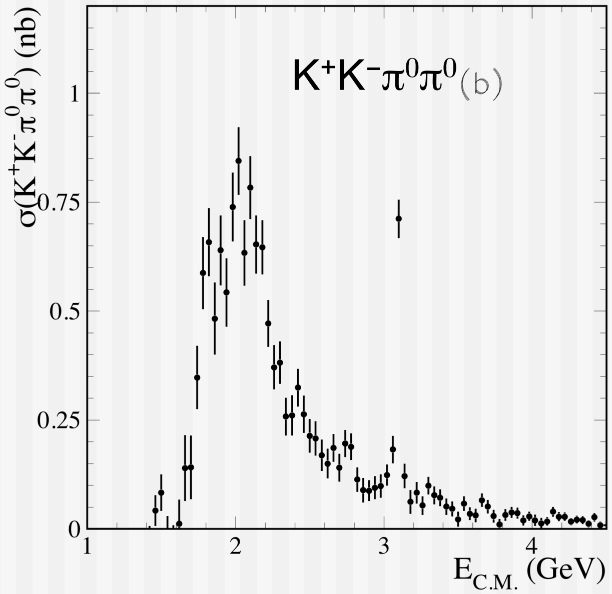
a_μ ($\sqrt{s}$ <1.8 GeV)	K^+K^-	$2(\pi^+\pi^-)$	$3(\pi^+\pi^-)$	$2(\pi^+\pi^-\pi^0)$
without BABAR	21.63 ± 0.70	13.35 ± 0.90	0.10 ± 0.10	1.42 ± 0.30
with BABAR	22.95 ± 0.26	13.64 ± 0.36	0.11 ± 0.02	0.89 ± 0.09

Missing channels contribute 5.98 ± 0.42 or 12.46 ± 0.76 if $\sqrt{s}$ <2.0 GeV

Contribution from $KK\pi$, $KK2\pi$, $2\pi3\pi^0$, $2\pi4\pi^0$, (7π, 8π)… added using iso-spin relations (in particular, using measured $K^+K^-\pi^+\pi^-$ ($\pi^0\pi^0$) channels)

The cross section comparison – BaBar data



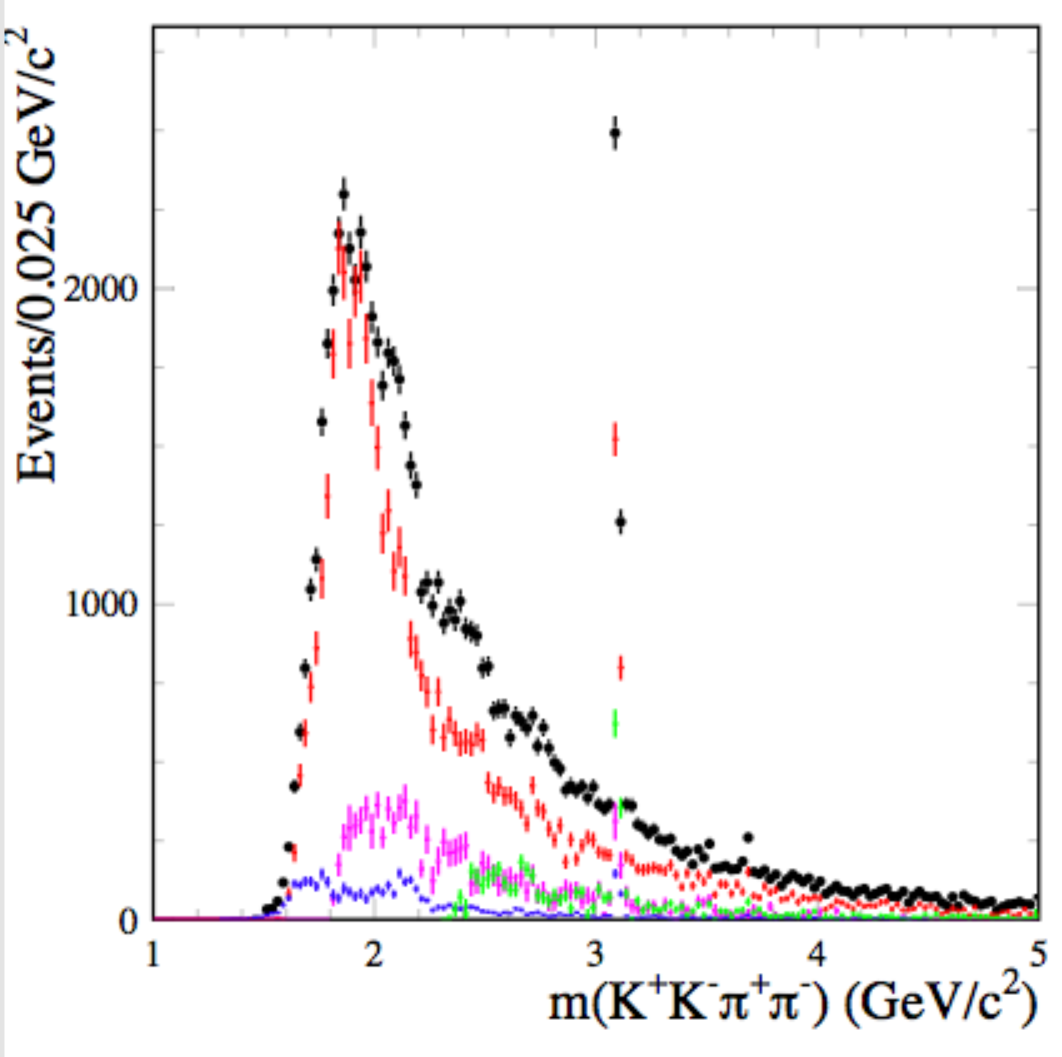


Naively expect: $N(K^+K^-\pi^+\pi^-) = 2\,N(K^+K^-\pi^0\pi^0)$

Many intermediate states break the relation.

Study of intermediate states is important!

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

Phys. Rev. D 86, 012008 (2012)

$e^+e^- \to K_S K_L, K_S K_L \pi^+\pi^-, K_S K_S \pi^+\pi^- (K^+K^-)$

We present (with more details) results on the study of the processes:

$e^+e^- \to K_S K_L$

$e^+e^- \to K_S K_L \pi^+\pi^-$

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

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

Published Phys. Rev. D 89, 092002 (2014)

And new (preliminary) results on the process

$e^+e^- \to K_S K^{-+} \pi^{+-} \pi^0$

ready for publication

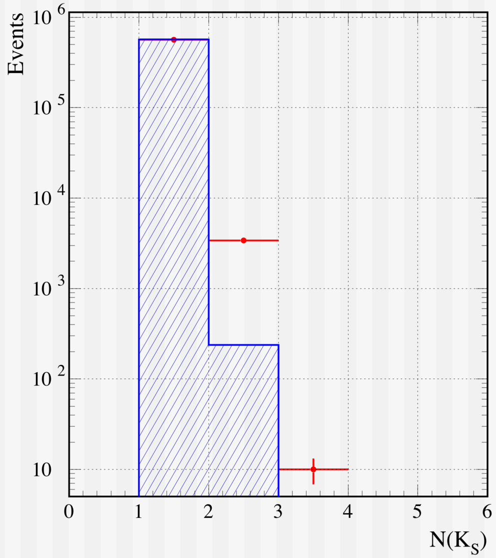
Based on 469 fb^{-1} integrated luminosity.

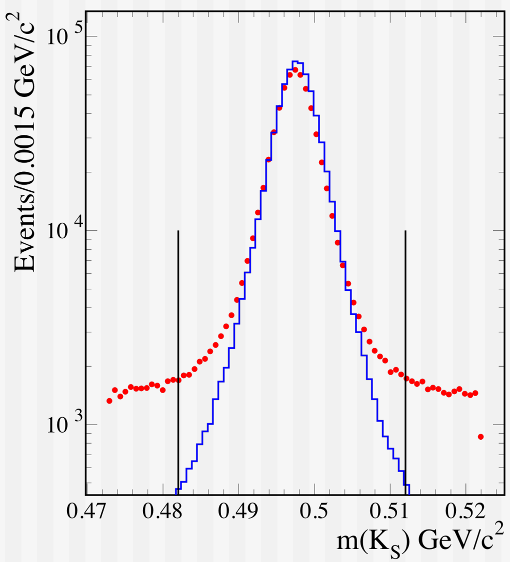
K_S selection (in $\pi^+\pi^-$ decay)

Loop over all K_S candidates with ISR photon with $E\gamma$ >3 GeV, and select events with:

- Good quality K_S coming from IP
- No electron ID for either charged track

Simulation of $\phi\gamma$ -> $K_SK_L\gamma$ compare to data





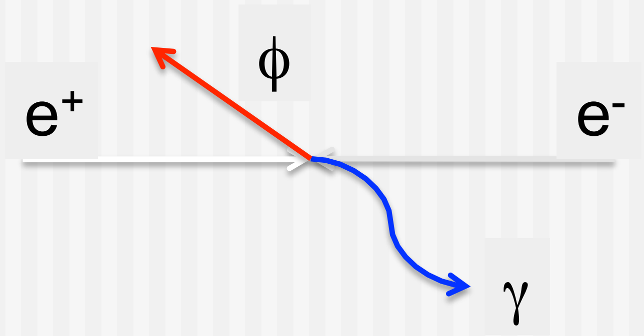
Dominated by $\phi\gamma$ -> $K_SK_L\gamma$ process if require NO additional tracks from IP

$e^+e^- \to \phi\,\gamma \to K_S K_L\,\gamma$ (without K_L detection)

$E_0 = E^+ + E^-$

$\vec{p}_0 = \vec{p}^+ + \vec{p}^-$

$\vec{p}_\gamma = \vec{n}\,E_\gamma$



Assuming $e^+e^- \to \phi\gamma$ reaction

Use ϕ mass to get $E_{\gamma ISR}$

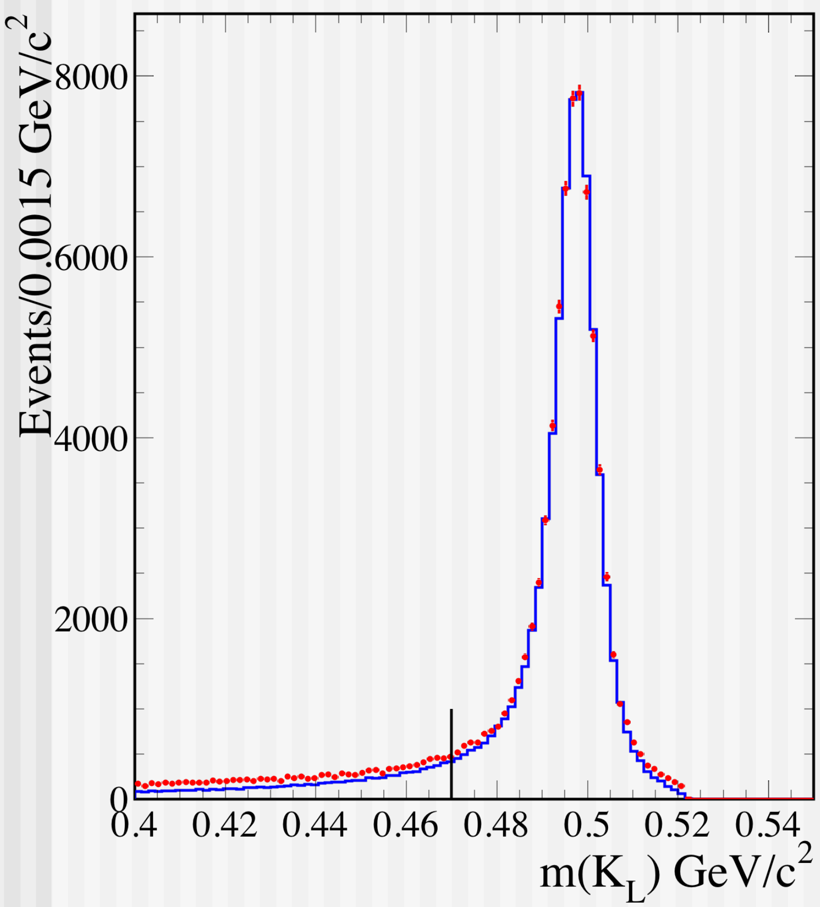
$$E^c_\gamma = \frac{E_0^2 - p_0^2 - m_\phi^2}{2\left(E_0 - \vec{p}_0 \cdot \vec{n}_\gamma\right)}$$

Using energy-momentum conservation and detected K_S we determine K_L mass and direction:

$$m^2(K_L) = \left(E^+ + E^- - E^c_\gamma - E_{K_S}\right)^2 - \left(p^+ + p^- - p^c_\gamma - p_{K_S}\right)^2$$

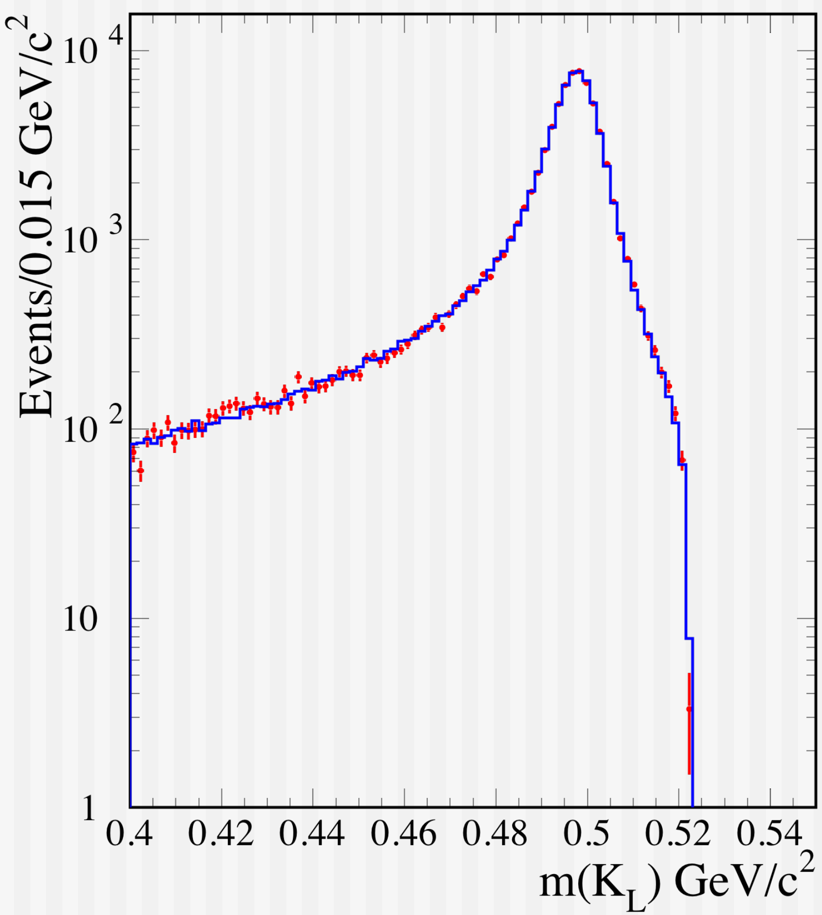
Using this events we can study K_L detection.

K_L mass using ϕ mass constraint



MC normalized to two bins at peak

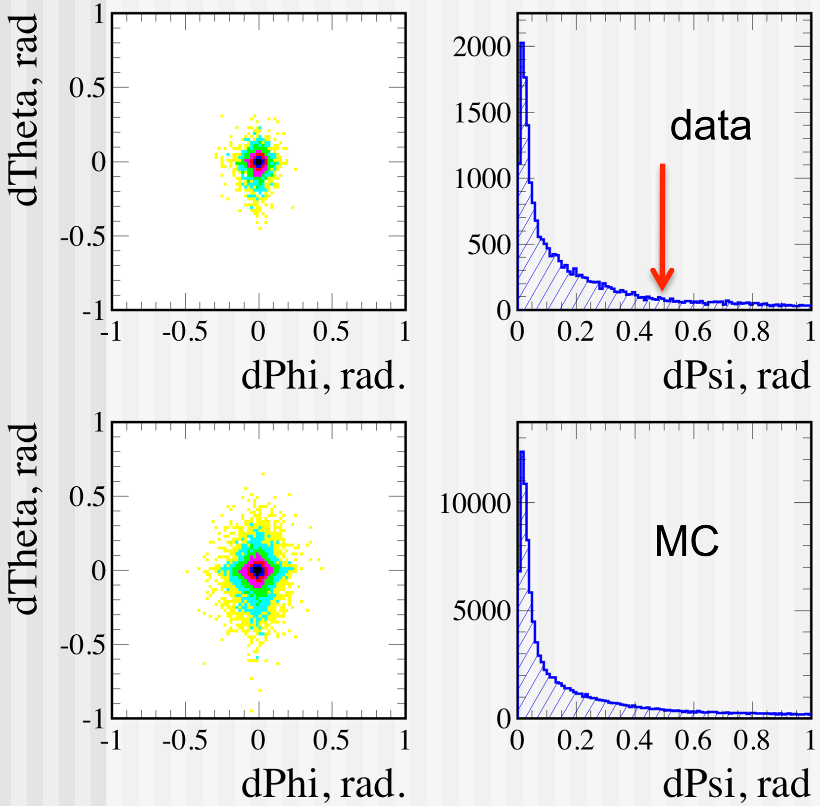
Very low background!

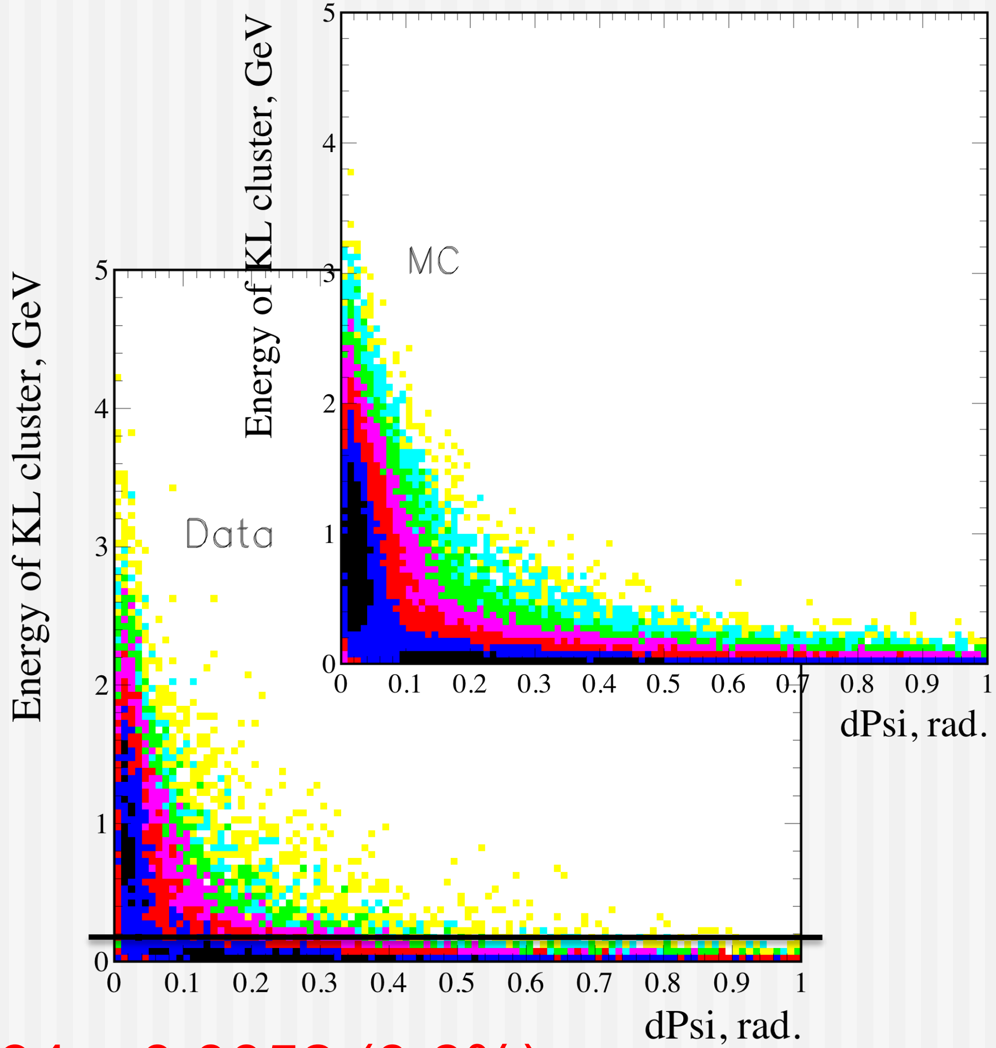


After background subtraction (5.6%) we have 81012±285 events (447434±669 MC) . We estimate ~0.5% systematic error for background subtraction uncertainty.

How K_L cluster in Calorimeter looks like?

1. Search for EMC cluster closest to K_L direction:



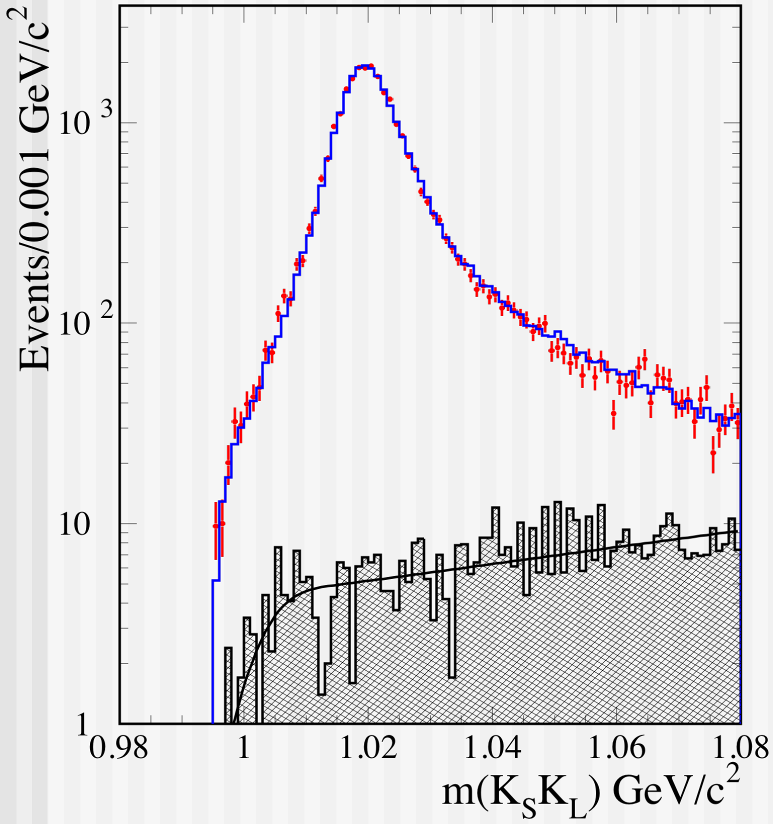


E(K_L) > 0.2 GeV cut is set
Apply loose cut dPsi<0.5

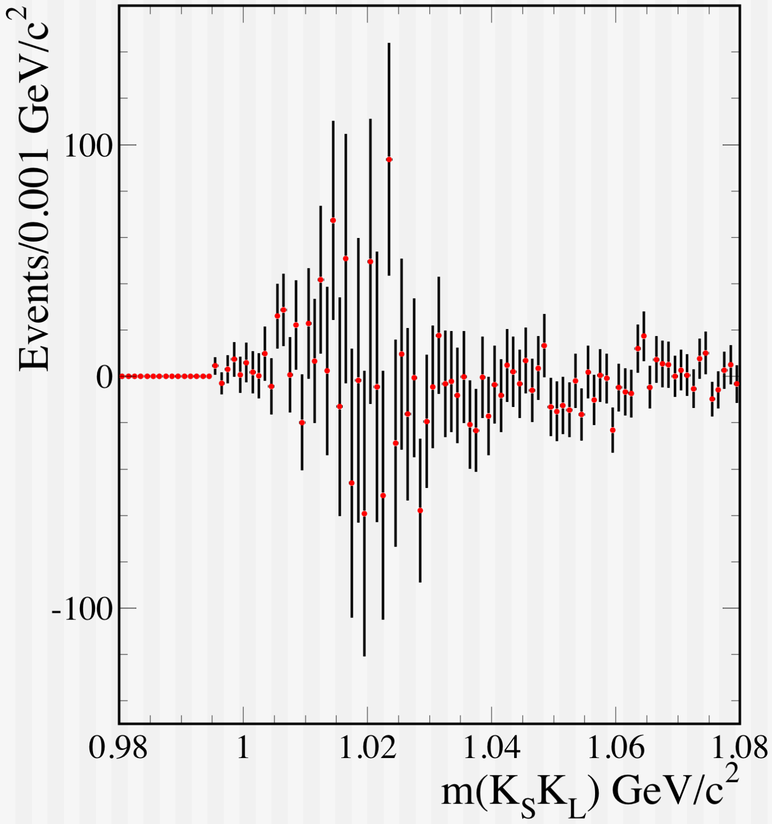
Data/MC = 0.9394 ± 0.0052 (0.6%)

ϕ signal in $e^+e^- \longrightarrow K_SK_L$ reaction

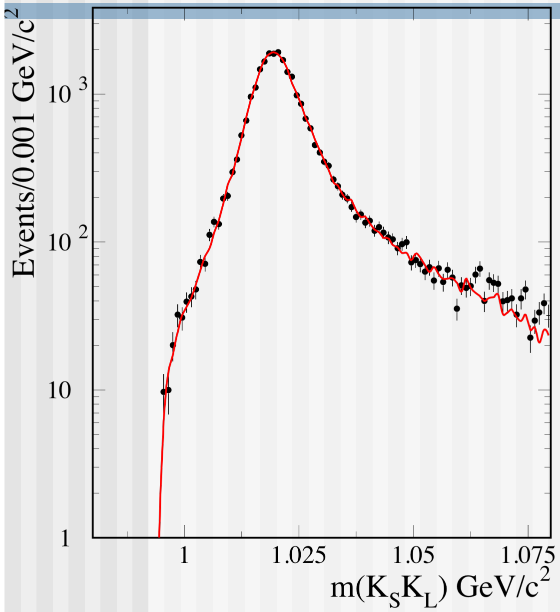
Use events with $\chi^2<15$ and reconstructed parameters of K_S and K_L to calculate $m(K_SK_L)$



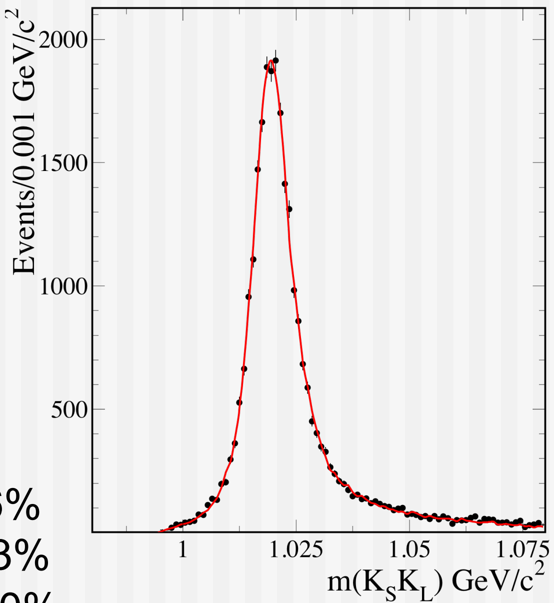
Data-MC difference



Fit to ϕ parameters



Fit:
σ_0 = 1409 ± 33 ± 42 ± 15 nb
m = 1019.462 ± 0.042 ± 0.050 ± 0.025 MeV/c^2
Γ_0 = 4.205 ± 0.103 ± 0.050 ± 0.045 MeV



BaBar

CMD-2

σ_0 = 1376 ± 6 ± 23 nb
m = 1019.483 ± 0.011 ± 0.025 MeV/c^2
Γ_0 = 4.280 ± 0.033 ± 0.025 MeV
Γ_{ee} = 1.235 ± 0.006 ± 0.022 keV

PDG2010-2012

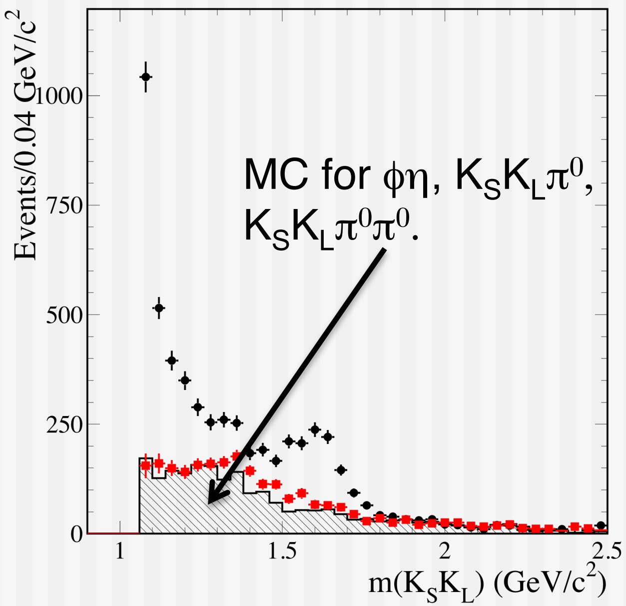
m = 1019.455 ± 0.020 MeV/c^2
Γ_0 = 4.26 ± 0.04 MeV
Γ_{ee} = 1.27 ± 0.04 keV
B_{KSKL} = 0.342 ± 0.004
$B_{ee} \cdot B_{KSKL}$ = 1.006 ± 0.016

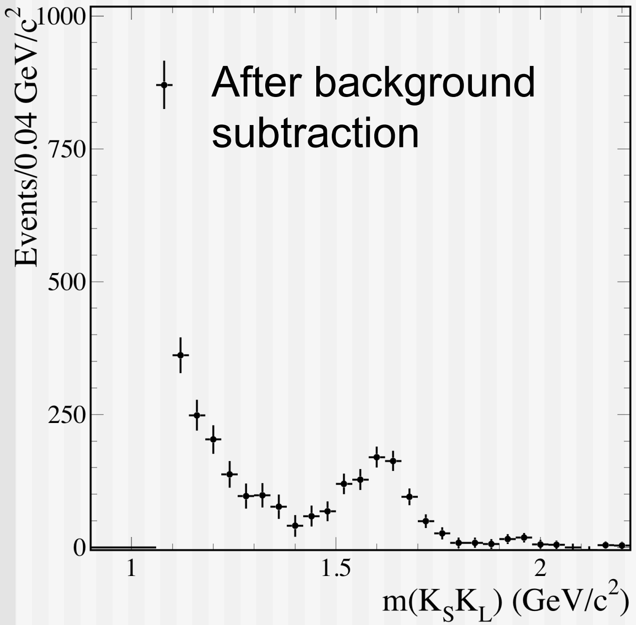
Systematic uncertainty:

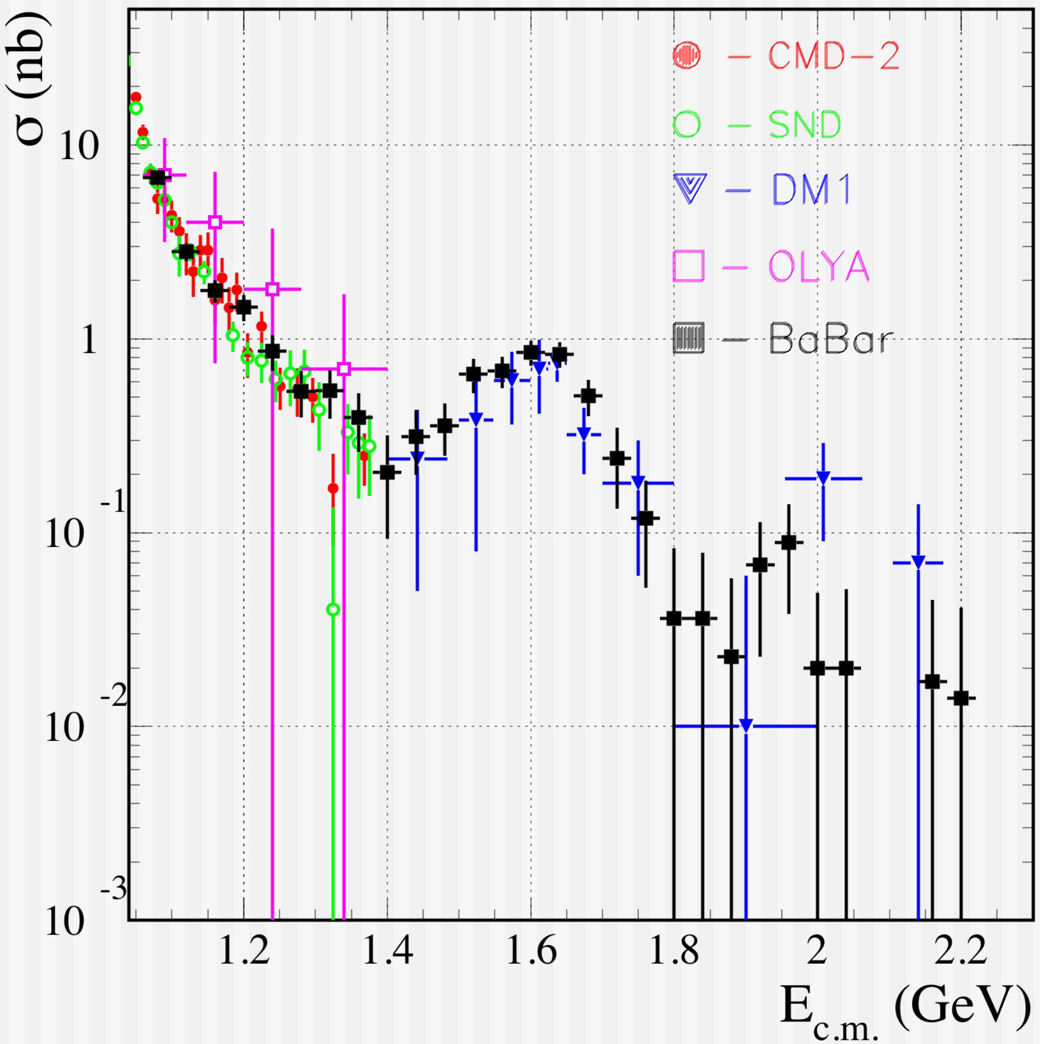
K_L efficiency (+ χ^2)	0.6%
BGFilter efficiency	2.3%
K_S efficiency	1.0%
ISR photon	0.5%
Luminosity	0.5%
Rad.corr.	1.0%
Track overlap	0.6%
Background sub.	0.5%
	2.9%

$\Gamma_{ee} \cdot B_{KSKL}$ = 0.4200 ± 0.0033 ± 0.0122 ± 0.0019 keV
Γ_{ee} = 1.228 ± 0.037 ± $0.014_{(PDG\ BKSKL)}$ keV
$B_{ee} \cdot B_{KSKL}$ = 0.986 ± 0.030 ± $0.009_{(PDG\ \Gamma KSKL)}$

$e^+e^- \to K_SK_L$ cross section for $m(K_SK_L)>1.06$ GeV

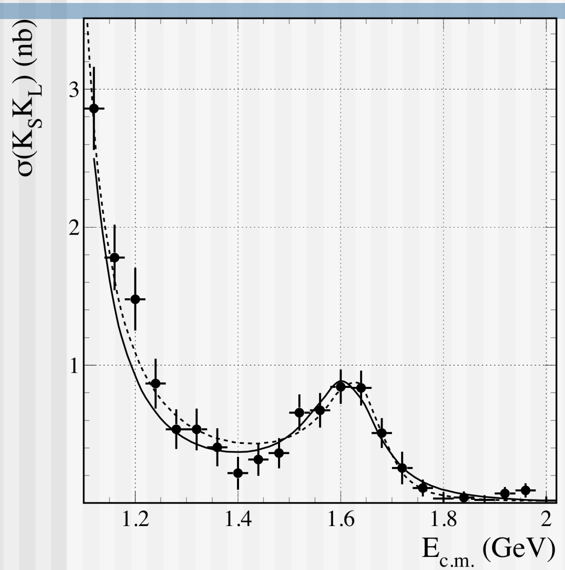


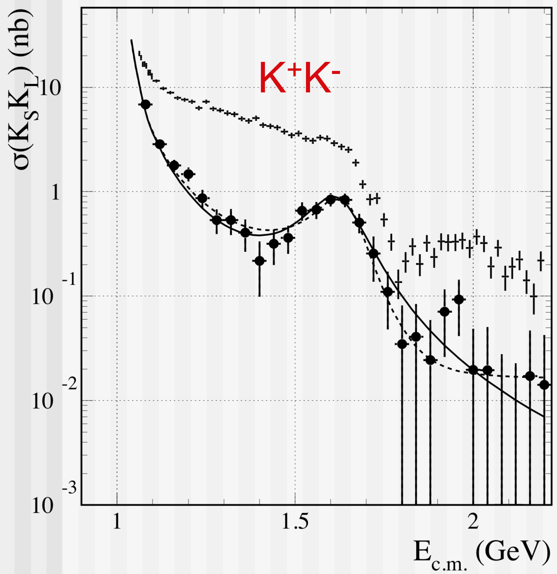




Systematic error ~10% (~30% for σ<0.3 nb), dominated by background subtraction procedure.

Is it ϕ(1680) ? Fit with single BW





$$\sigma(s) = \frac{P(s)}{s^{5/2}} \left| \frac{A_{\phi(1020)}}{\sqrt{P(m_\phi)}} + \frac{A_X}{\sqrt{P(m_X)}} \cdot e^{i\varphi} + A_{bkg} \right|^2$$

$$P(s) = \left((s/2)^2 - m_{K^0}^2 \right)^{3/2}$$

$$A(s) = \frac{\Gamma(m^2) \cdot m^3 \sqrt{\sigma_0 \cdot m}}{s - m^2 + i\sqrt{s}\Gamma(s)}$$

$$\Gamma(s) = \Gamma \cdot \sum_f B_f \cdot \frac{P_f(s)}{P_f(m_f^2)}$$

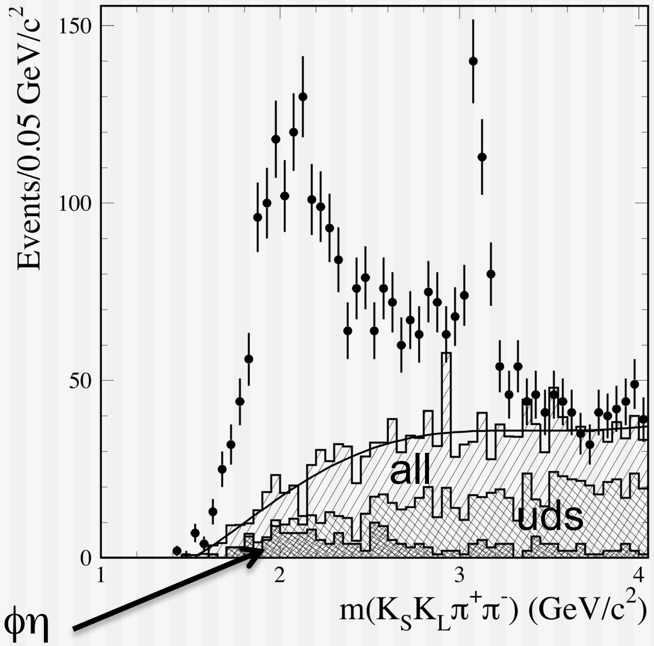
$$A_{\phi(1020)} = A_\phi + A_\omega - A_\rho, \qquad f = K^* K, \phi\eta, \phi\pi\pi, K_S K_L$$

σ_0 = 0.46 ± 0.10 ± 0.04 nb
m = 1674 ± 12 ± 6 MeV/c^2
Γ_0 = 165 ± 38 ± 70 MeV
φ = 3.01 ± 0.38 – fixed to π
σ_{bkg} = 0.36 ± 0.18 nb
$\Gamma_{ee} \bullet B_{KSKL}$ = 14.3 ± 2.4 ± 1.5 ± 6.0 eV

Simultaneous $K_S K_L$ and K^+K^- (and $\pi\pi$) fit is needed to separate I=0,1 states and ω(1420, 1650), ρ(1450,1700) contribution

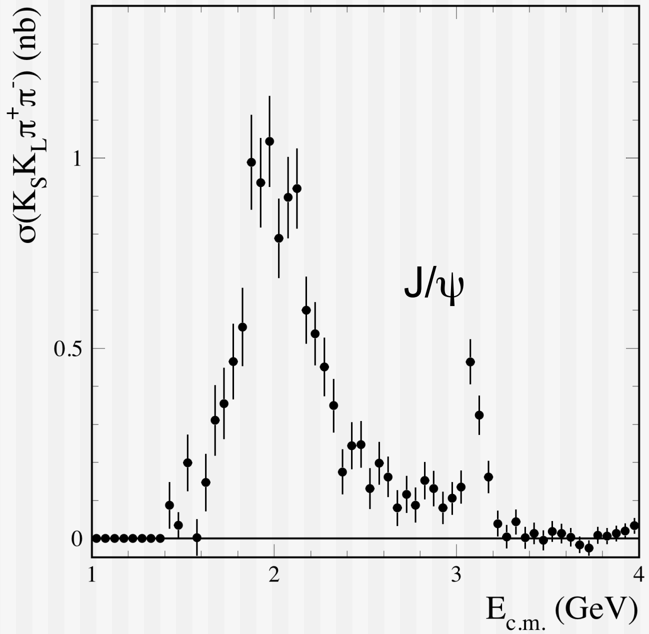
$K_S K_L \pi^+\pi^-\gamma$ event selection

- Select (best) K_S
- Select ISR photon with E > 3 GeV
- Two additional tracks from IP (no kaon ID)
- Cycle over remaining clusters with E > 0.2 GeV – K_L candidates
- Best χ^2 for 3C fit (K_L momentum float)
- $\chi^2 > 100$ and $|m_{\gamma\gamma L}-0.135|>0.03$ for the $K_S K\pi\pi^0\gamma$ hypothesis



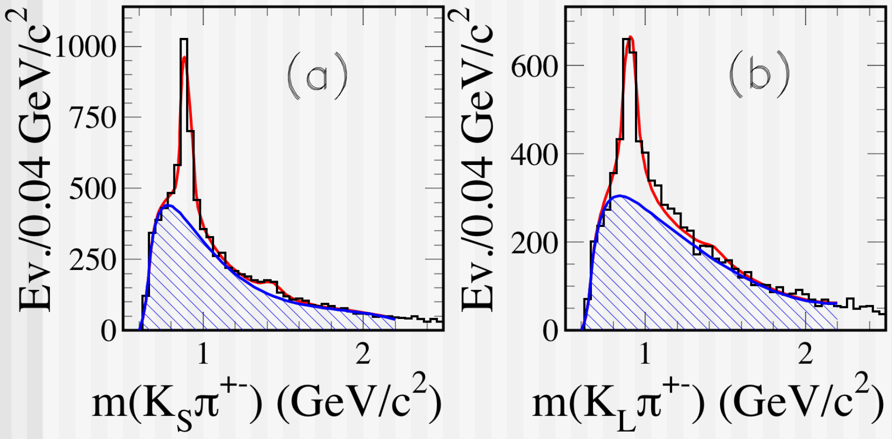
$K_S K\pi\pi^0 + \phi\eta$

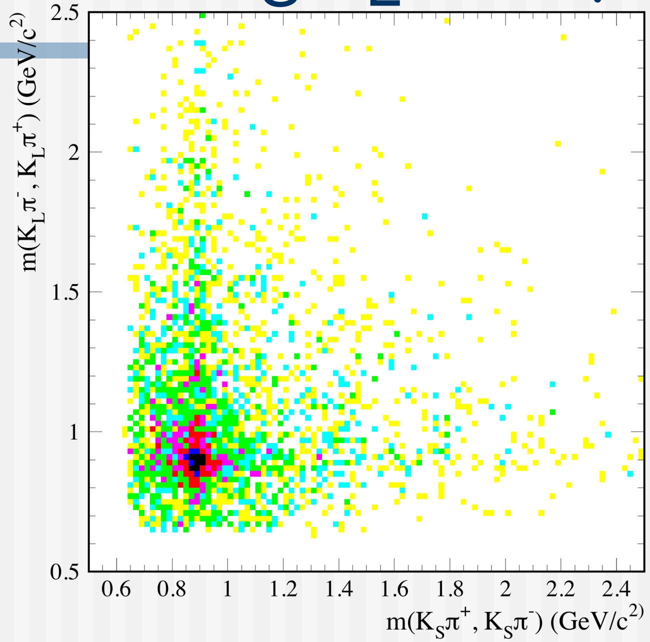
1580 events after background subtraction



No other measurements exist

Some mass distributions in $K_S K_L \pi^+\pi^-\gamma$



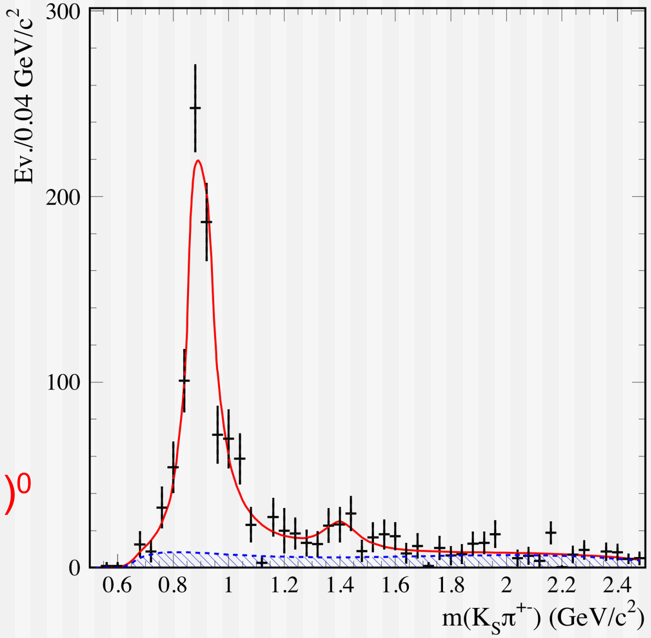


Very clear $K^*(892)^{\pm}$ signals with
1322 ± 70 for $K^{*\pm}$ ($K_S\pi$) and 1362 ± 78 for $K^{*\pm}$ ($K_L\pi$)
Plus 183 ± 48 events for $K_2(1430)^{\pm}$

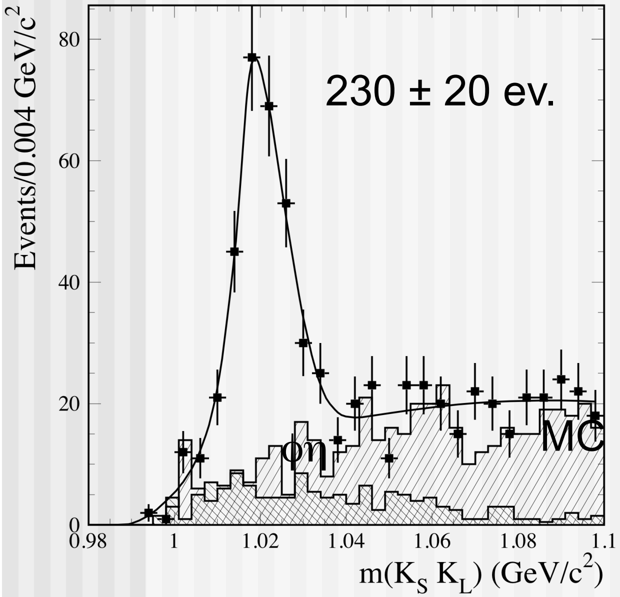
How large is $K^*(892)^+K^*(892)^-$?
Fit slice in m($K_L\pi^{+-}$) for number of $K_S\pi^{-+}$

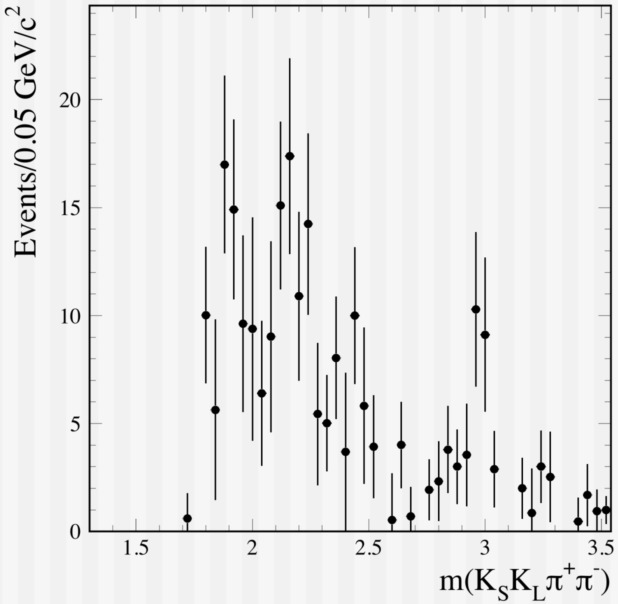
Very clear signal with 913 ± 37 events (70%)
of $K^*(892)^+K^*(892)^-$ correlated production!
And 90 ± 16 for $K^*(892)^{+-}K_2^*(1430)^{-+}$.

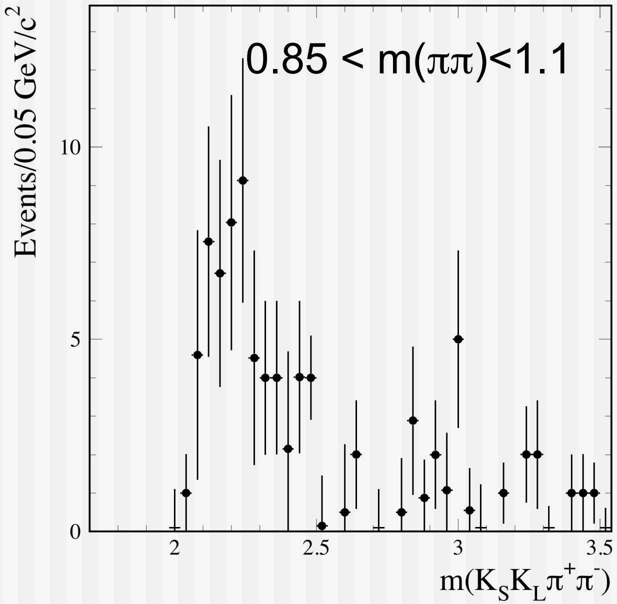
We have negligible contribution from $K^*(892)^0\underline{K}^*(892)^0$
from our $K^+K^-\pi^+\pi^-$ analysis!

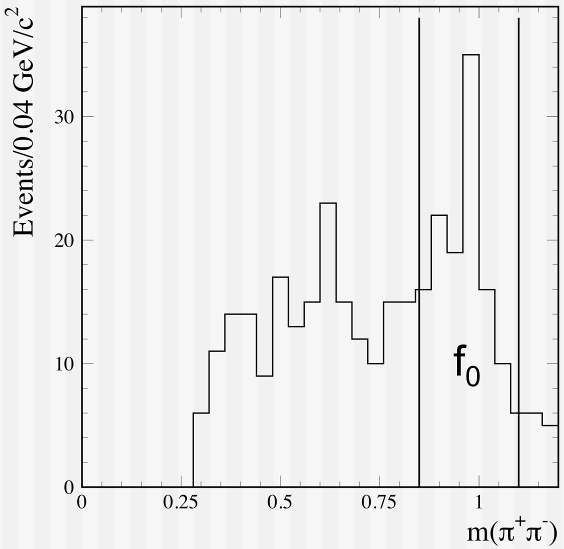


$\phi(1020)\pi^+\pi^-$ contribution in $K_S K_L \pi^+\pi^-\gamma$







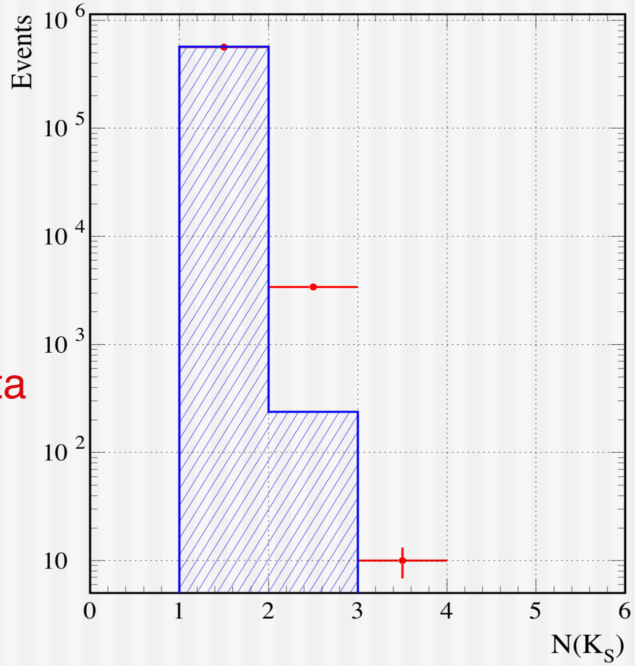


$\phi\pi^+\pi^-$ ($\phi f_0(980)$) seen as expected in agreement with our $K^+K^-\pi^+\pi^-$ study

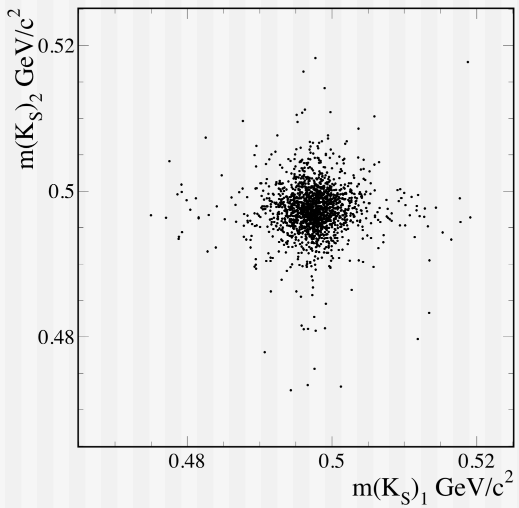
$K_S K_S \pi^+\pi^-(K^+K^-)\gamma$ event selection

- Select 2 (best) K_S
- Select ISR photon with E > 3 GeV
- Two additional tracks from IP with pion or kaon ID
- Best χ^2 for 4C fit assuming $K_S K_S \pi^+\pi^-(K^+K^-)\gamma$ hypotheses

Simulation
of $\phi\gamma$ -> $K_S K_L \gamma$
compare to data

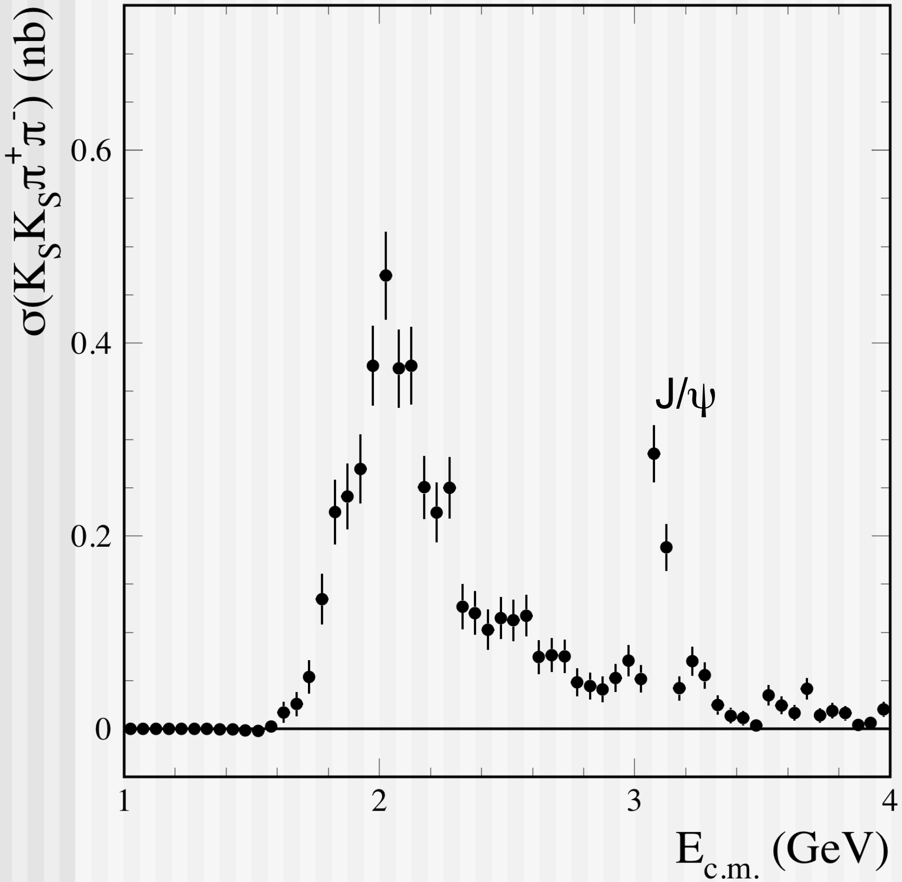


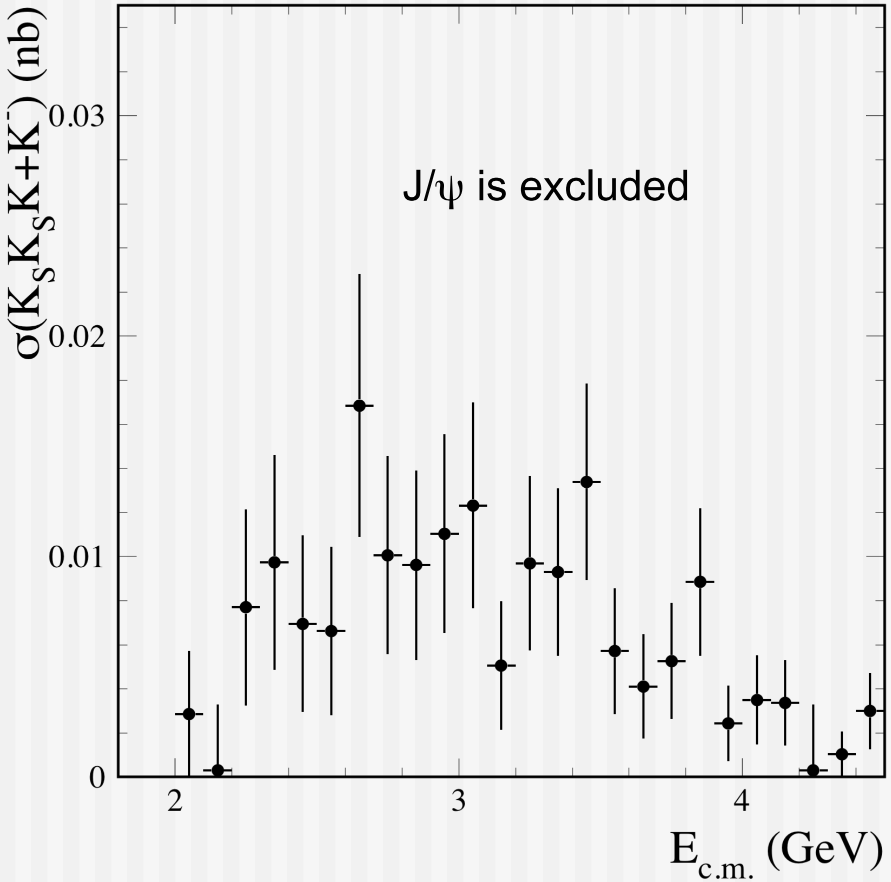
About 3000 ISR events with 2 good K_S



Six tracks with ISR photon – very low background!

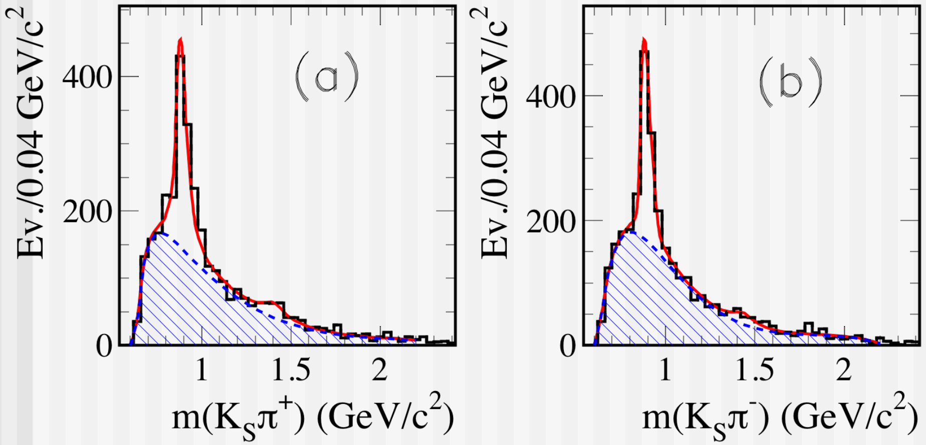
$e^+e^- \rightarrow K_S K_S \pi^+\pi^-(K^+K^-)$ cross sections



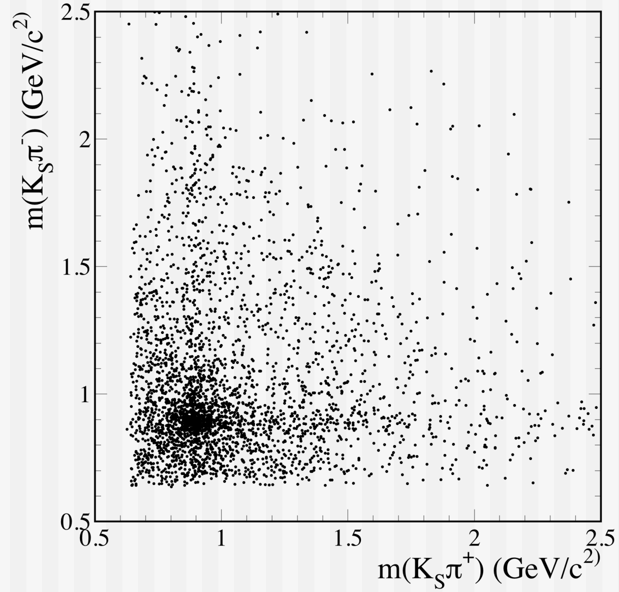


No other measurements exist

Some mass distributions in $K_S K_S \pi^+ \pi^-$



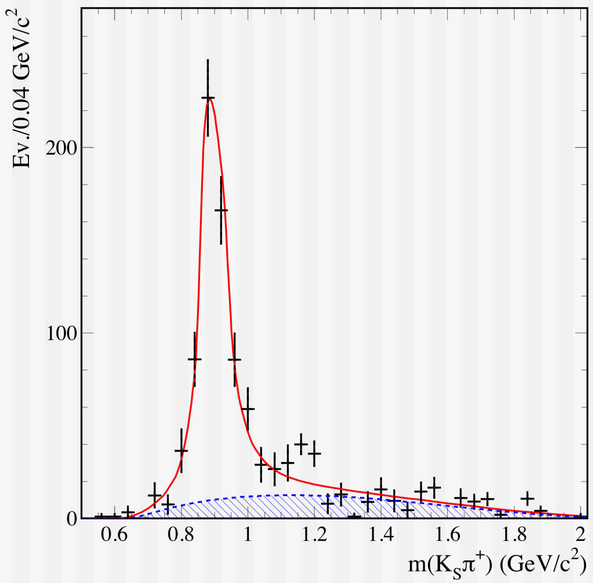
Very clear $K^*(892)^\pm$ signals with
829 ± 49 for K^{*+} ($K_S\pi^+$) and 856 ± 50 for K^{*-} ($K_S\pi^-$)
Plus 116 ± 40 (70±34) events for $K_2(1430)^\pm$



How large is $K^*(892)^+K^*(892)^-$?
Fit slice in $m(K_S\pi^-)$ for number of $K_S\pi^+$

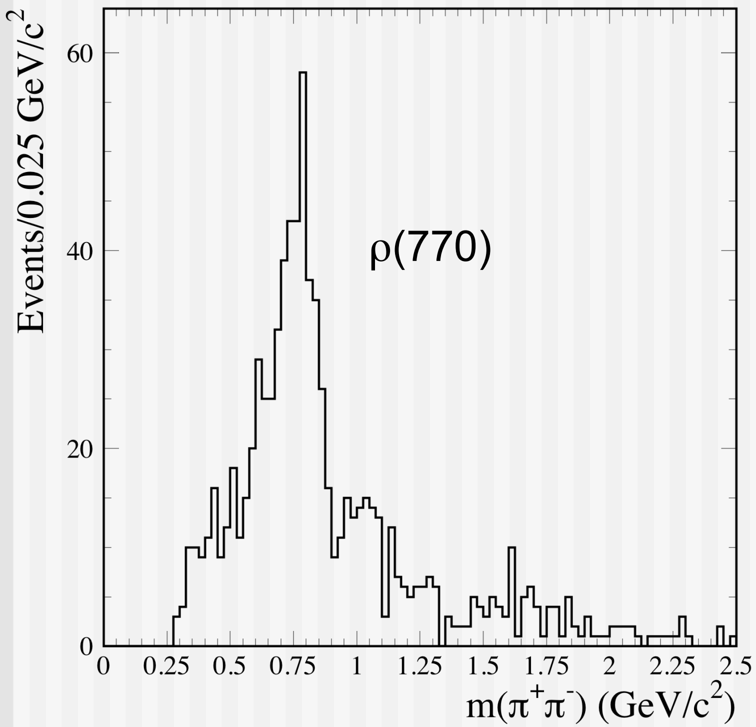
Very clear signal with 742 ± 30 ± 100 events (50%) of $K^*(892)^+K^*(892)^-$ correlated production!

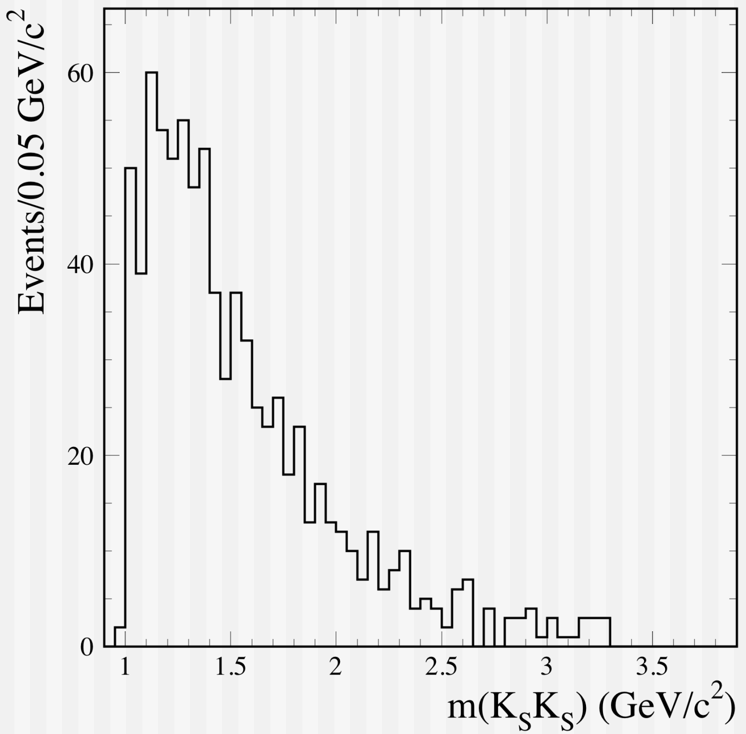
No $K^*(892)^{+-}K_2^*(1430)^{-+}$ seen.



Some mass distributions in $K_S K_S \pi^+ \pi^-$

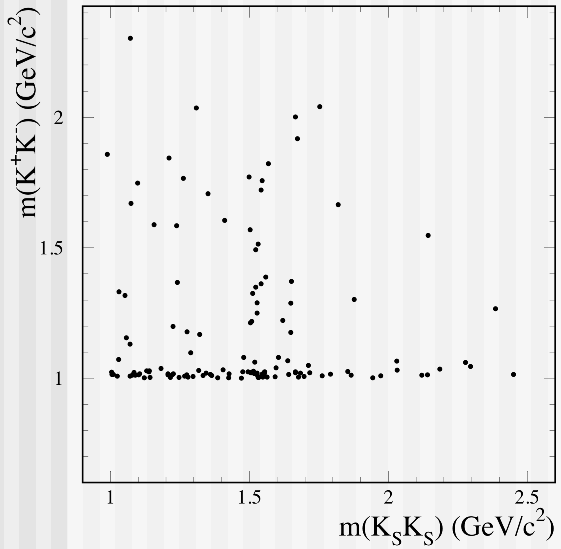
If we exclude $K^*(892)^+K^*(892)^-$ by $|m(K_S\pi) - m(K^*)| < 0.15$ GeV/c^2 in both combinations:

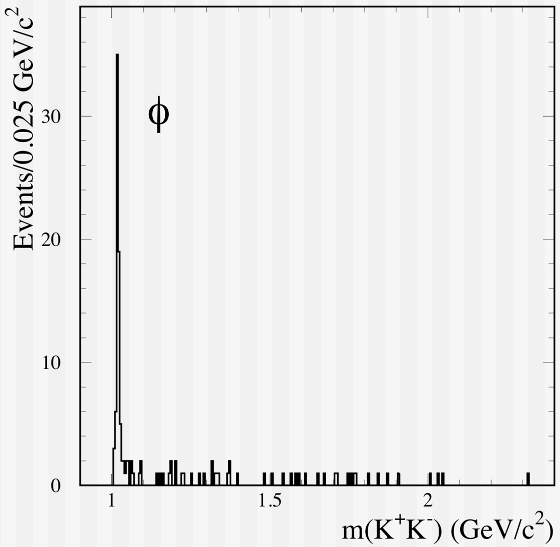


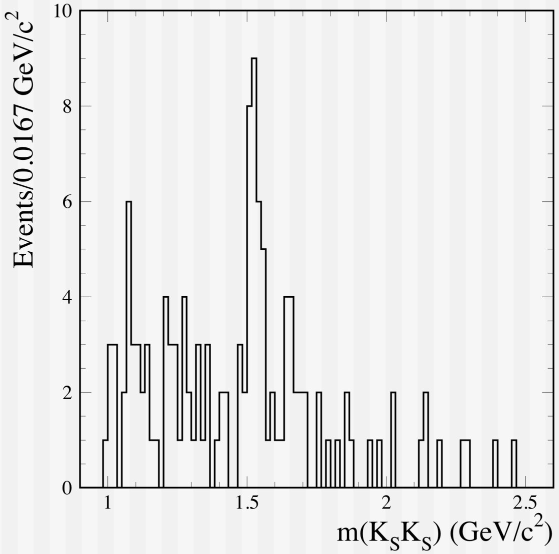


Plus some number of $K^*(892)K_S\pi$ events

Some mass distributions in $K_S K_S K^+ K^-$



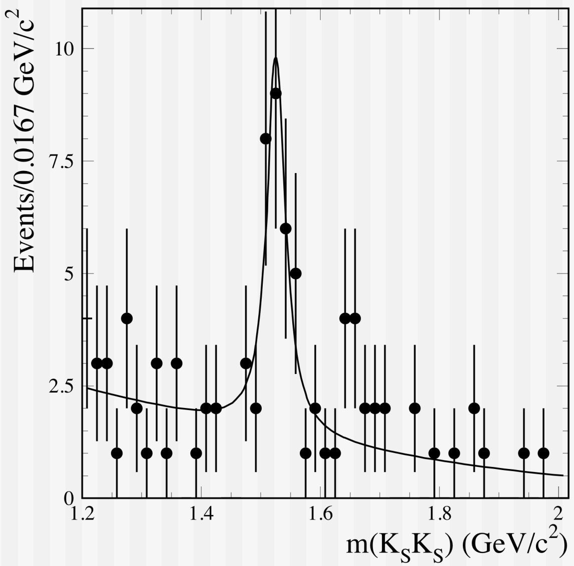




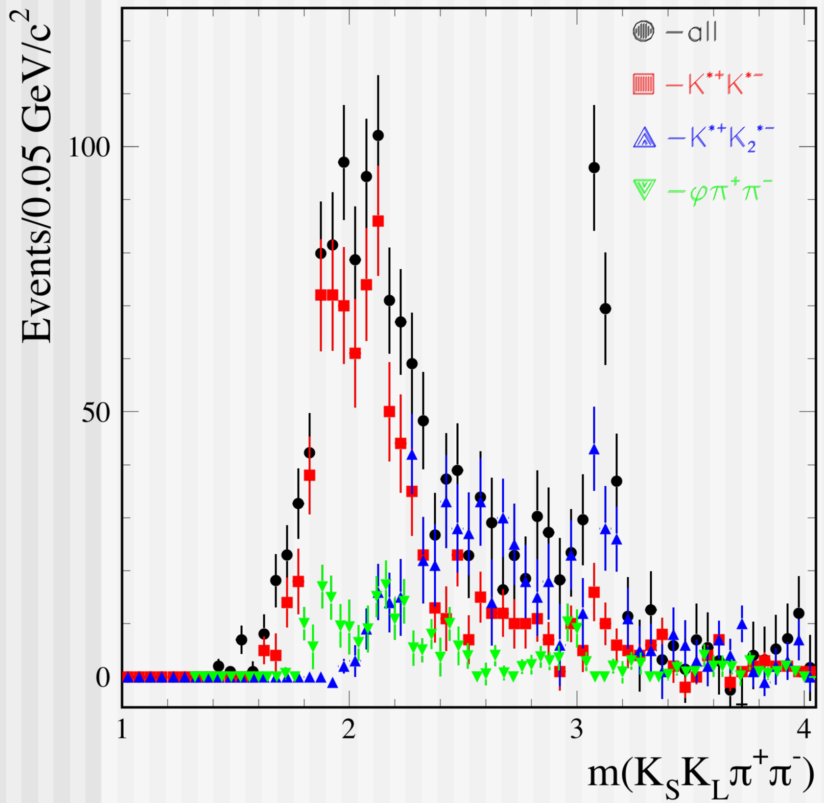
N $(K^+K^-\ f_2')$= 29 ± 7 events

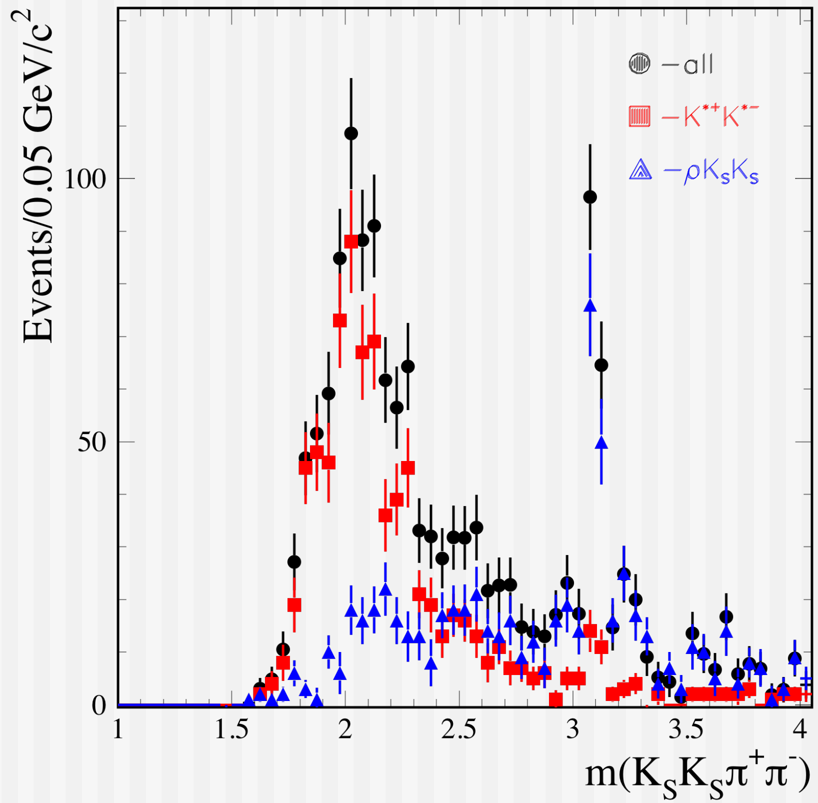
$m(K_S K_S)$ = 1.526 ± 0.007 GeV/c^2
Γ = 0.037 ± 0.013 GeV

PDG:
$m(f_2')$ = 1.525 ± 0.005 GeV/c^2
Γ = 0.073 ± 0.006 GeV

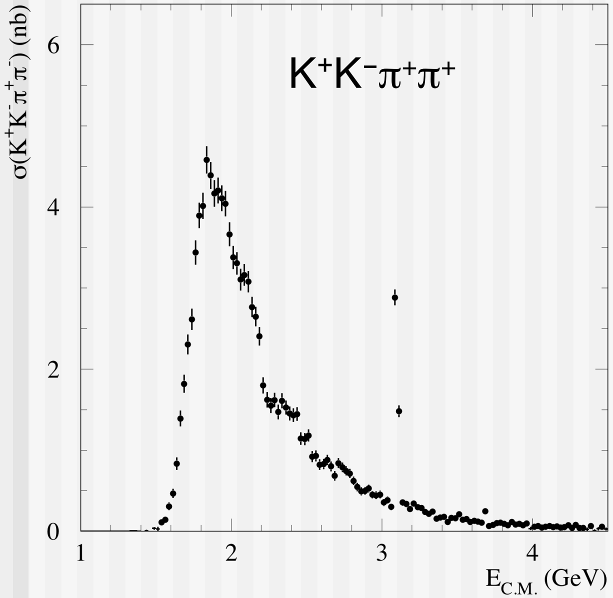


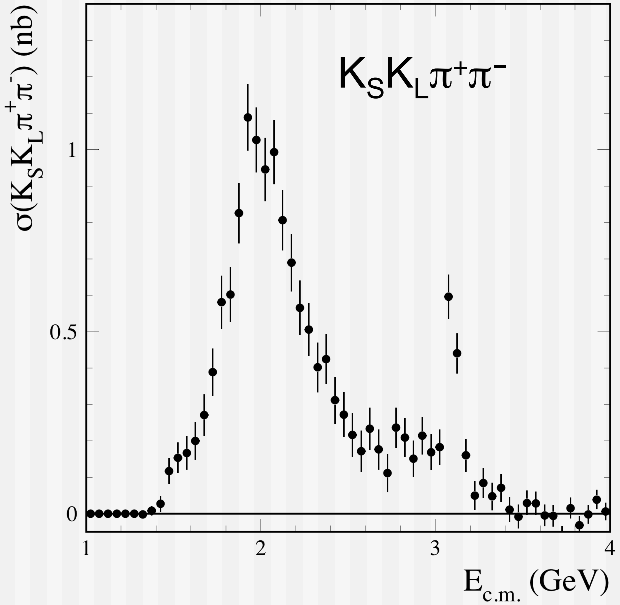
$K_SK_L\pi^+\pi^-$, $K_SK_S\pi^+\pi^-$ signal decomposition

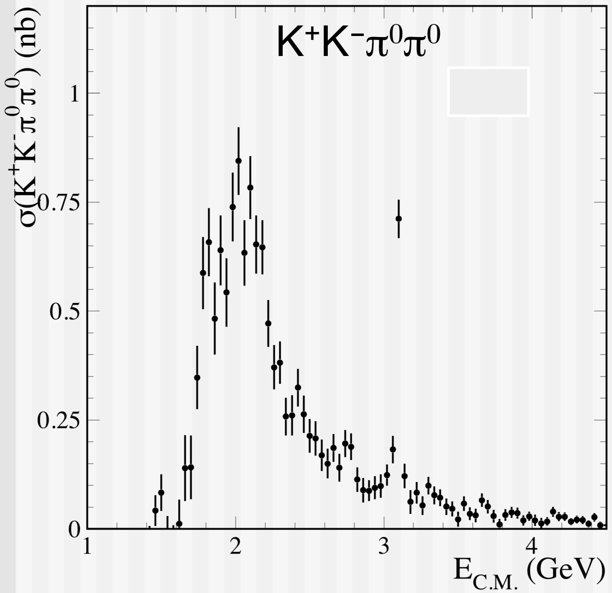


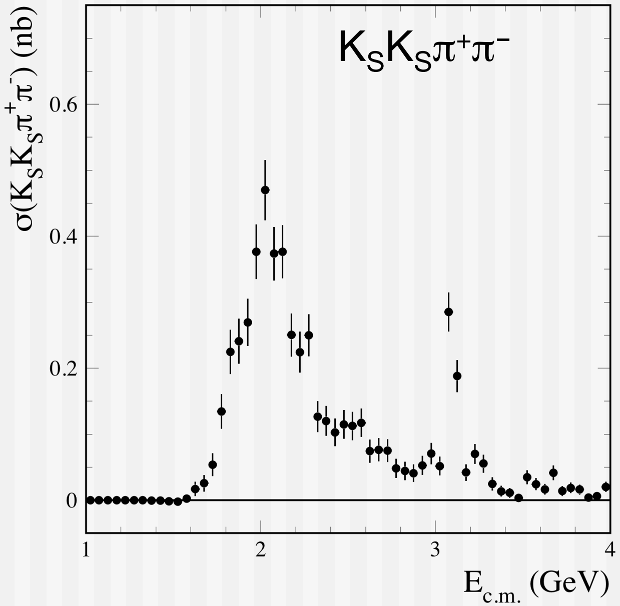


The cross section comparison – BaBar data









Naively expect:
$N(K^+K^-\pi^+\pi^-) =$
$2\,N(K^+K^-\pi^0\pi^0)$

Iso-spin relations for $K^+K^-\pi^+\pi^+$ vs. $K^+K^-\pi^0\pi^0$ vs. $K_SK_L\pi^+\pi^-$ vs. $K_SK_S\pi^+\pi^-$

Only $K^*(892)^+K^*(892)^-$ contribution can be compared using iso-spin relations, and we expect:

$$N(K^+K^-\pi^0\pi^0) = \frac{1}{4} N(K^0\underline{K}^0 \pi^+\pi^-)$$
$$N(K_SK_L\pi^+\pi^-) = \frac{1}{2} N(K^0\underline{K}^0 \pi^+\pi^-)$$
$$N(K_SK_S\pi^+\pi^-) = N(K_LK_L\pi^+\pi^-) = \frac{1}{4} N(K^0\underline{K}^0 \pi^+\pi^-)$$

We detect correlated pairs:

$N(K^+K^-\pi^0\pi^0) = 1750 \pm 60$ eff= 8%

$N(K_SK_L\pi^+\pi^-) = 2098 \pm 209$ eff= 5%

$N(K_SK_S\pi^+\pi^-) = 742 \pm 104$ eff= 4.5%

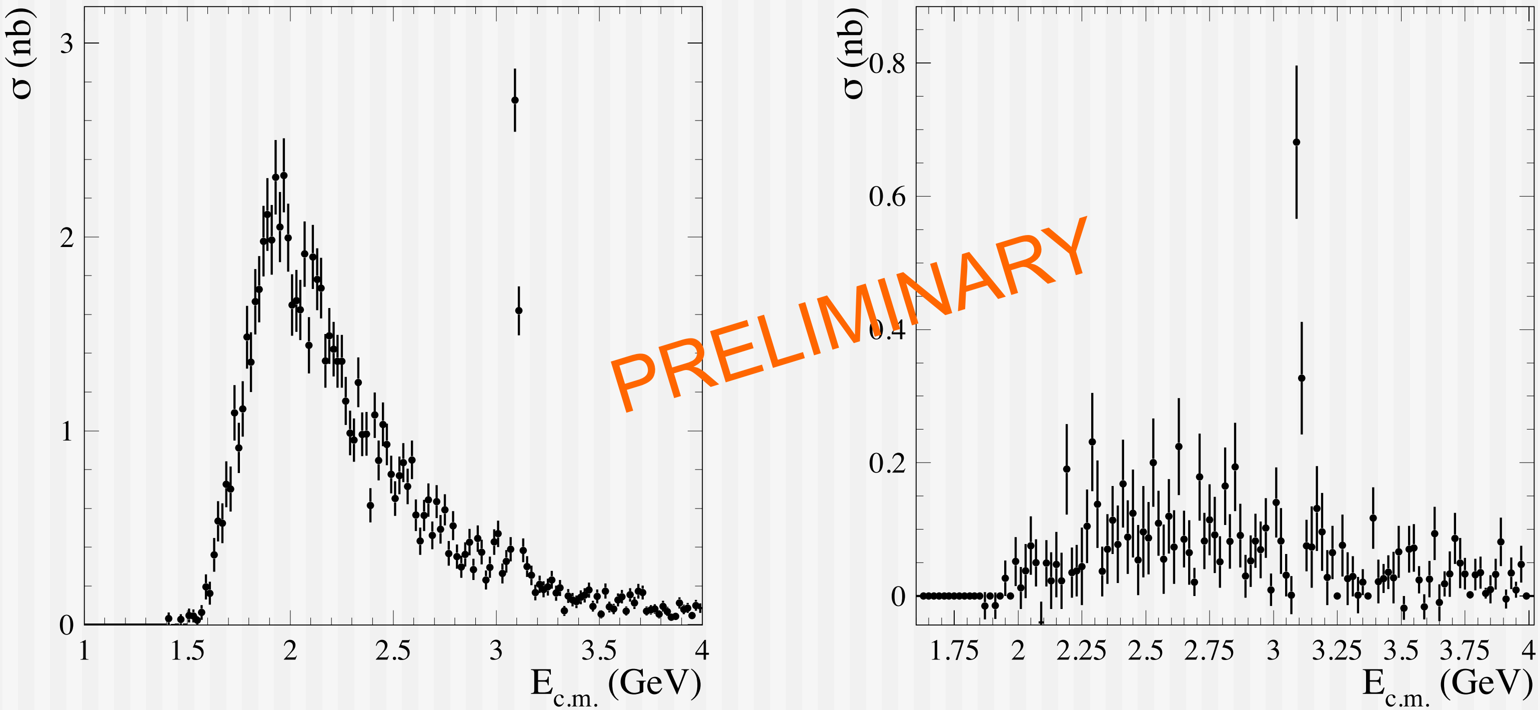
Should be equal numbers after efficiency normalized to 5% and iso-spin correction:

2188 ± 76 ~ 2098 ± 209 ~ 1648 ± 232 Some tension (~2 sigma)

30% 63% 50% of all events – how the rest are added to the g-2 calculation?

$K_S K^{-+} \pi^{+-} \pi^0 (\eta) \gamma$ event selection

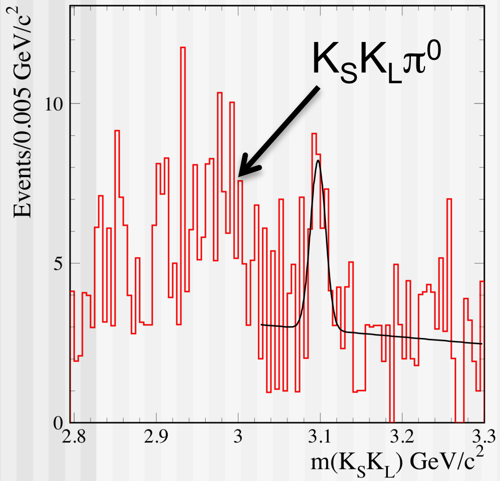
- Select 1 (best) K_S
- Select ISR photon with E > 3 GeV
- Two additional tracks from IP with pion or kaon ID
- Loop over remaining photons in π^0 or η mass windows
- Best χ^2 for 5C fit assuming $K_S K^{-+} \pi^{+-} \pi^0 (\eta) \gamma$ hypotheses



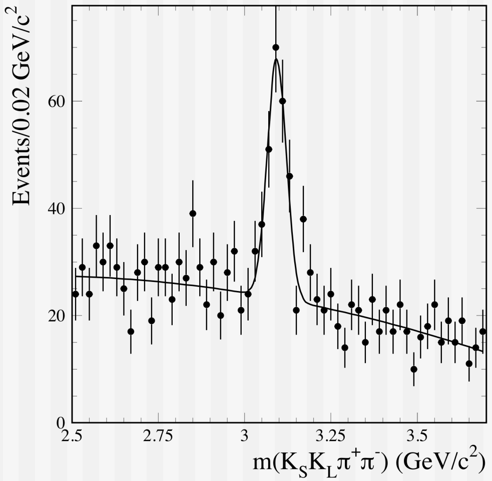
No other measurements exist

J/ψ region

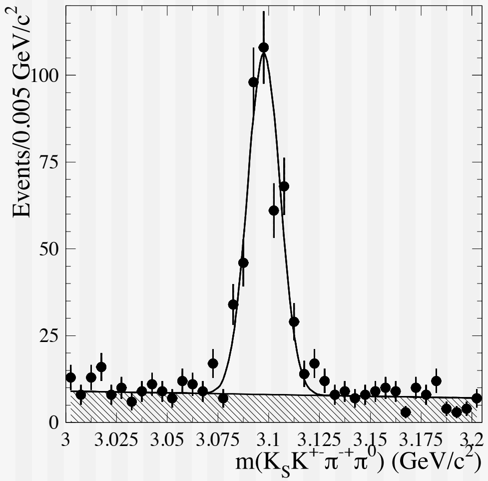
We observe a J/ψ signal in all studied channels



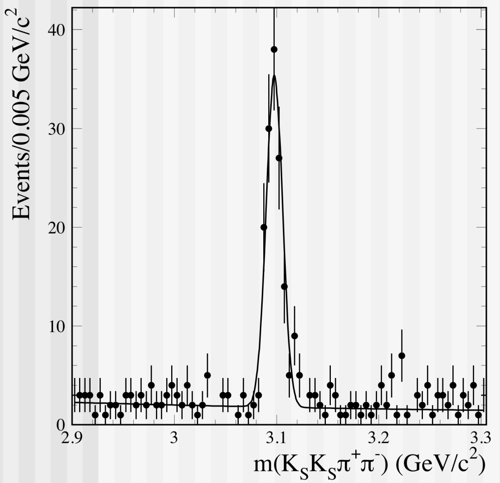
N = 24.6 ± 7.5



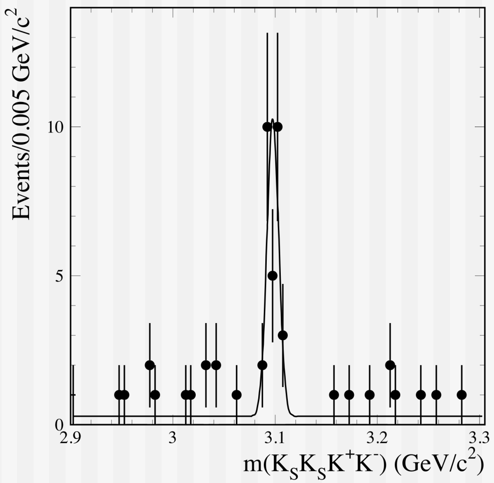
N = 154 ± 19



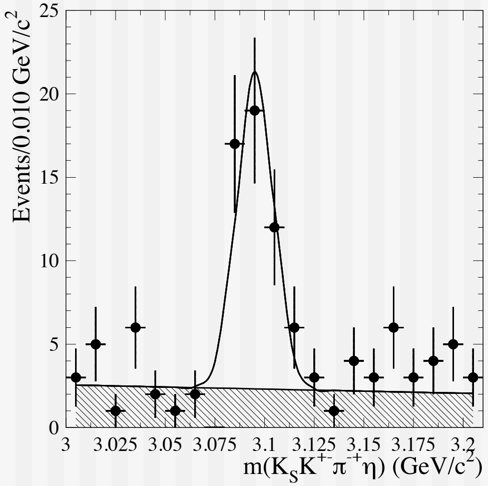
N = 393 ± 23



N = 248 ± 27



N = 28.5 ± 5.1



N = 44 ± 7

J/ψ decay results

Measured Quantity	Measured value (eV)	This work Br (10^{-3}) Γ_{ee} = 5.55 ± 0.14 keV	PDG 2014 Br (10^{-3})
Γ_{ee}•Br(J/ψ -> K_SK_L)	1.13±0.34±0.11	0.20 ± 0.06± 0.02	0.146 ± 0.026 S=2.7
Γ_{ee}•Br(J/ψ -> $K_SK_L \pi^+\pi^-$)	20.9±2.7±2.1	3.7 ± 0.6 ± 0.4	no entry
Γ_{ee}• Br(J/ψ -> $K_SK_S\pi^+\pi^-$)	9.3±0.9±0.5	1.68 ± 0.16 ± 0.08	no entry
Γ_{ee}• Br(J/ψ -> $K_SK_SK^+K^-$)	2.3±0.4±0.1	0.42 ± 0.08 ± 0.02	no entry
Γ_{ee}• Br(J/ψ->$K_SK_S\phi$)•Br(ϕ ->K^+K^-)	1.6±0.4±0.1	0.58 ± 0.14 ± 0.03	no entry
Γ_{ee}• Br(J/ψ->f_2'ϕ)•Br(ϕ->K^+K^-) •B(f_2'->K_SK_S)	0.88±0.34±0.04	0.45±0.17 ± 0.02	0.8 ± 0.4 S=2.7
Γ_{ee}• Br(J/ψ -> $K_SK^{-+}\pi^{+-}\pi^0$)	31.7±1.9±1.8	5.7 ± 0.3 ± 0.4	no entry
Γ_{ee}• Br(J/ψ -> $K_SK^{-+}\pi^{+-}\eta$)	7.3±1.4±0.4	1.30 ± 0.25 ± 0.07	2.2 ± 0.4

Preliminary

B(J/ψ -> ϕ f_2') = (0.48 ± 0.18)•10^{-3} (MarkII)
B(J/ψ -> ϕ f_2') = (1.23 ± 0.026 ± 0.20)•10^{-3} (DM2)

We measure:

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

Summary

- BaBar continues analysis of collected data and ISR studies in particular
- Most published results for $e^+e^- \to$ hadrons reactions have the best to date accuracy.
- Recently obtained $e^+e^- \to K_S K_L \pi^+\pi^-$, $K_S K_S \pi^+\pi^-$, $K_S K_S K^+K^-$, $K_S K^- \pi^+\pi^0(\eta)$ cross sections were never studied before. Intermediate states study is performed.
- Using these cross sections we can reduce uncertainty in the muon g-2 calculation.
- J/ψ decays to above modes have been measured for the first time.
- Results for $K_S K_L \pi^0(\pi^0)$ final state should come out soon – it will completely close iso-spin relations problem in the g-2 calculation for the $KK\pi\pi$ modes.

SM prediction for muon g-2

ArXiv:1010.4180,arXiv:1105.3149

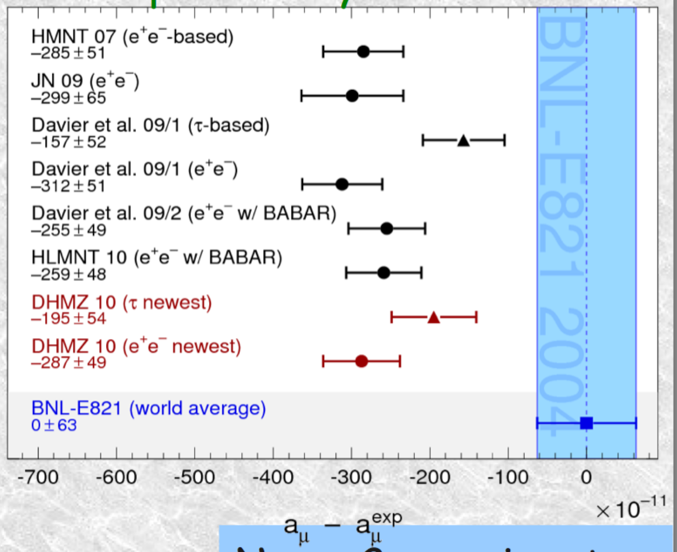
$a_\mu^{experimental} = (g-2)_\mu/2$

11 659 208.9 **± 6.3** × 10^{-10} world average

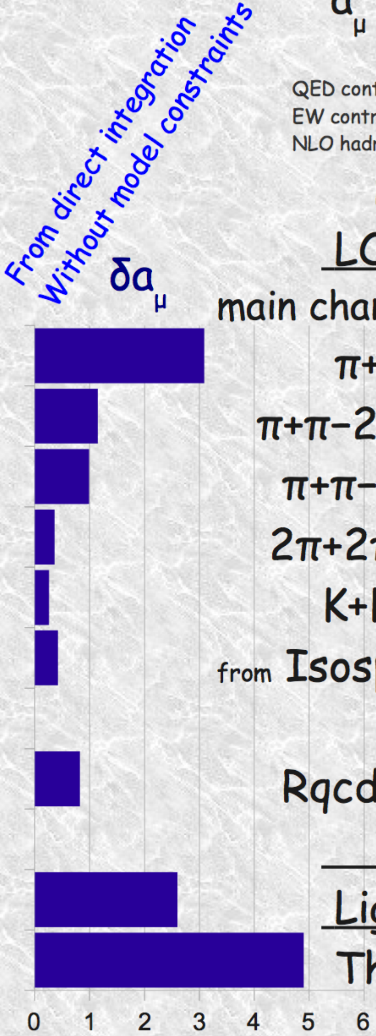
$a_\mu^{theory} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{hadron}$

QED contribution	11 658 471.808 ±0.015	Kinoshita & Nio, Aoyama et al
EW contribution	15.4 ±0.2	Czarnecki et al
NLO hadronic	-9.8 ± 0.1	HLMNT11

Δ Exp - Theory~ 3.3–3.6σ



Hadronic contributions



LO hadronic 694.1 **±4.3** x 10^{-10} HLMNT 11

main channels contribution to precision at √s<1.8 GeV

π+π−	505.65 ± 3.09	
π+π−2π0	18.62 ± 1.15	
π+π−π0	47.38 ± 0.99	(mostly from omega region)
2π+2π−	13.64 ± 0.36	(BaBar)
K+K-	22.95 ± 0.26	(BaBar)

from Isospin relations 5.98 ± 0.42 for not measured KKpi,KK2π,2π4π0,2π3π0

(or 12.46 ± 0.76 for √s<2 GeV) (1.5-3σ of total error - crucial in case of isospin violation)

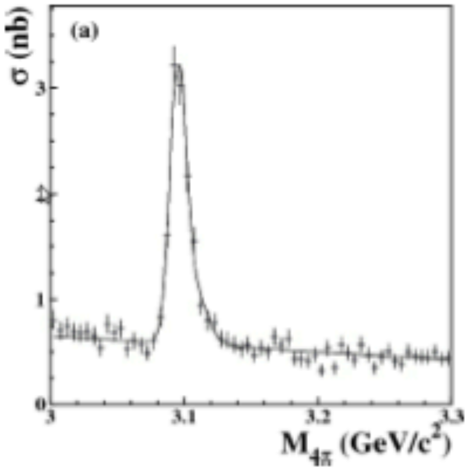
Rqcd[2-11.09GeV] 41.19 ± 0.82

Light-by-light 10.5 **± 2.6** Prades, de Rafael & Vainshtein need more theory, probably with help of experimental Transition FormFactors

Theory TOTAL **± 4.9**

New g-2 experiments at FNAL and J-PARC have plans to reduce precision to **1.5x10^{-10}**

charmonium branching ratios **PRELIMINARY**

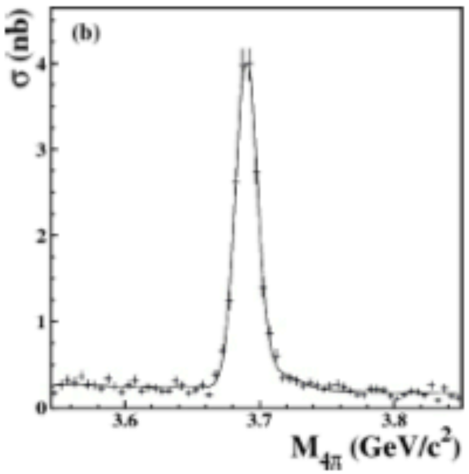


$$\mathcal{B}_{J/\psi\to 2(\pi^+\pi^-)} \cdot \sigma_{int}^{J/\psi} = \frac{N(J/\psi \to 2(\pi^+\pi^-))}{d\mathcal{L}/dE \cdot \epsilon_{MC}} = (48.9 \pm 2.1_{stat} \pm 1.0_{syst})\ \mathrm{MeV}/c^2\ \mathrm{nb}$$

$$\mathcal{B}_{J/\psi\to 2(\pi^+\pi^-)} = (3.67 \pm 0.16_{stat} \pm 0.08_{syst} \pm 0.09_{ext}) \cdot 10^{-3}$$

$$\mathcal{B}^{PDG}_{J/\psi\to 2(\pi^+\pi^-)} = (3.55 \pm 0.23) \cdot 10^{-3}$$

→ agrees with PDG, higher in precision



$$\mathcal{B}_{\psi(2S)\to J/\psi\,\pi^+\pi^-} \cdot \mathcal{B}_{J/\psi\to\mu^+\mu^-} \cdot \sigma_{int}^{\psi(2S)} = \frac{N(\psi(2S) \to \pi^+\pi^-\mu^+\mu^-)}{d\mathcal{L}/dE \cdot \epsilon_{MC}}$$

$$= (84.7 \pm 2.2_{stat} \pm 1.8_{syst})\ \mathrm{MeV}/c^2\ \mathrm{nb}$$

$$\mathcal{B}_{\psi(2S)\to J/\psi\,\pi^+\pi^-} = 0.354 \pm 0.009_{stat} \pm 0.007_{syst} \pm 0.007_{ext}$$

$$\mathcal{B}^{PDG}_{\psi(2S)\to J/\psi\,\pi^+\pi^-} = 0.336 \pm 0.005$$

$$\mathcal{B}^{CLEO}_{\psi(2S)\to J/\psi\,\pi^+\pi^-} = 0.3504 \pm 0.009_{stat} \pm 0.0007_{syst} \pm 0.0077_{ext}$$

→ agrees with recent CLEO result (PRD 78, 011102 (2008))

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

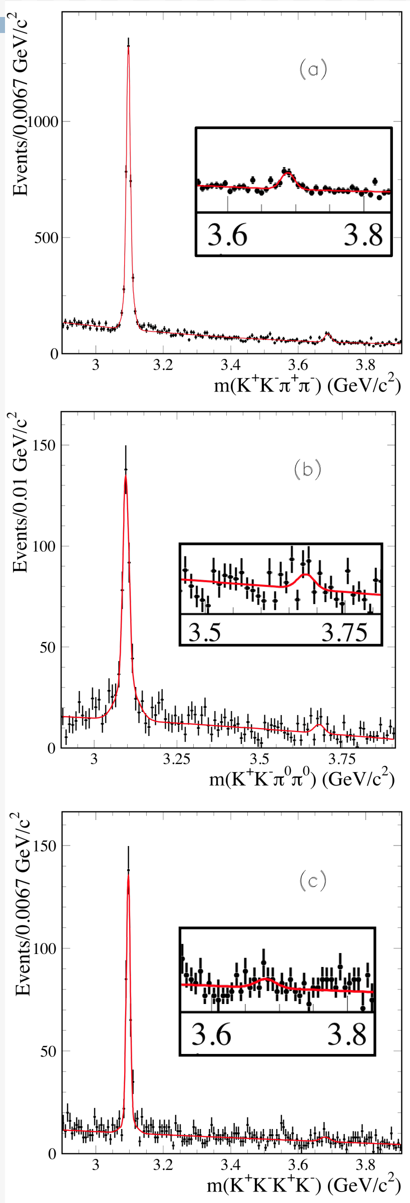


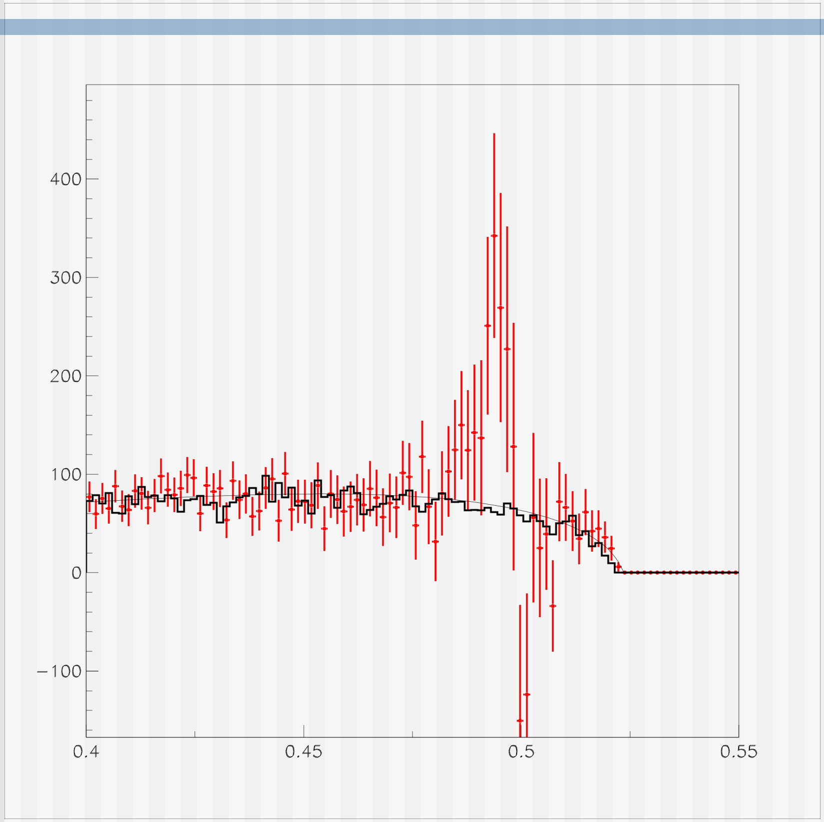
TABLE XIII: Summary of the J/ψ and $\psi(2S)$ branching fraction values obtained in this analysis.

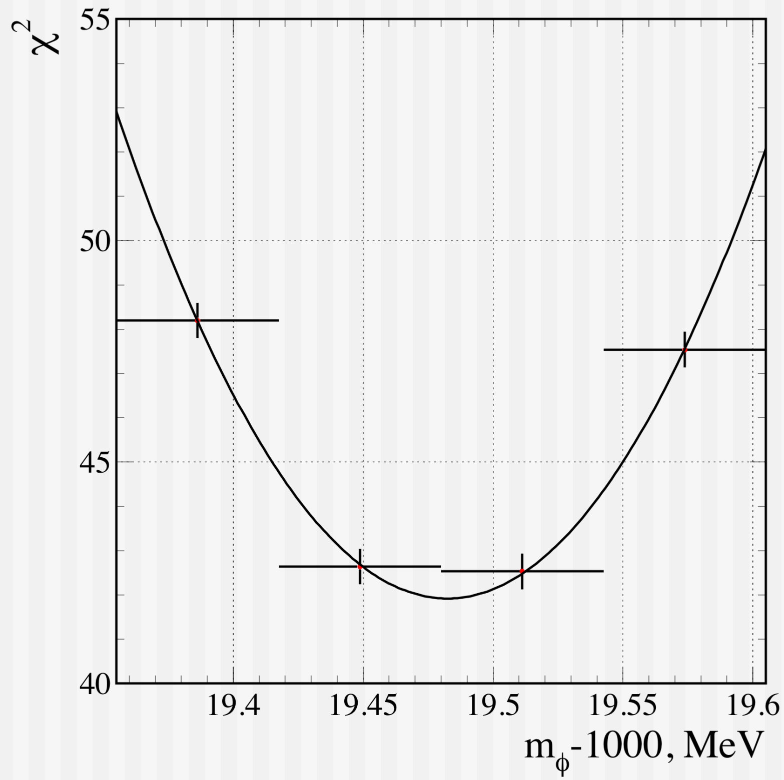
Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) This work	PDG2010
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^+\pi^-}$	37.94±0.81±1.10	6.84±0.15±0.27	6.6 ±0.5
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^0\pi^0}$	11.75±0.81±0.90	2.12±0.15±0.18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

ϕ(1020) mass

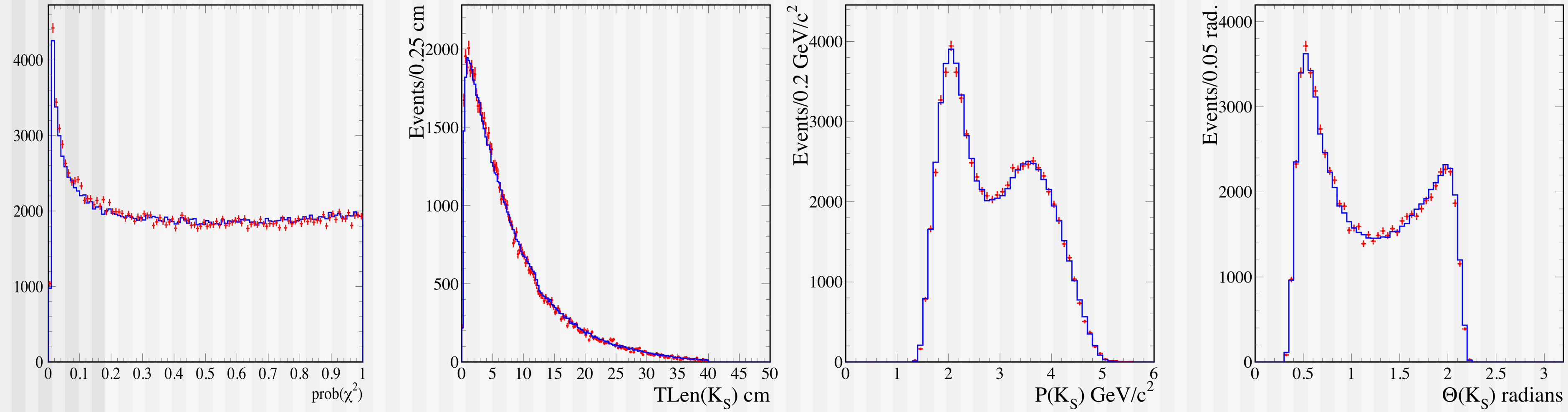


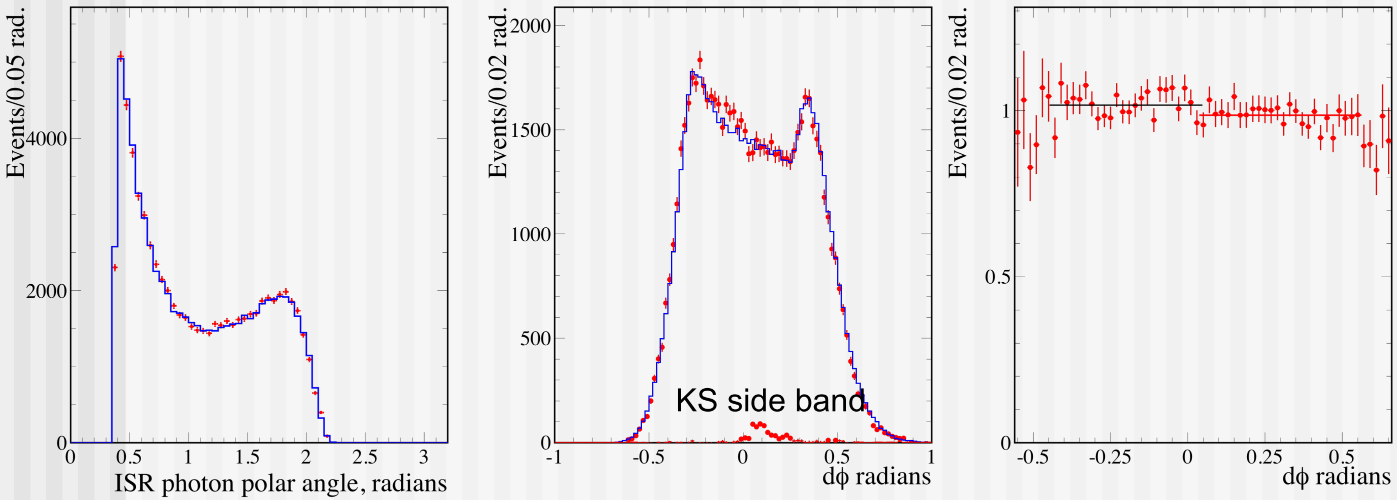


In MC we know all inputs and can create a "test" $m(K_L)$ distribution and compare with data. And the only free parameter is ϕ(1020) mass. By varying f mass we calculate χ2 value by fitting data-MC difference with "ARGUS" function. We obtain:

m_ϕ = 1019.483 ± 0.040 ± 0.036 MeV/c^2 : 24 keV – K^0 mass uncertainty, 20 keV – K_S momentum, 18 keV – DCH-EMC mis-alignment.

How other distributions look like

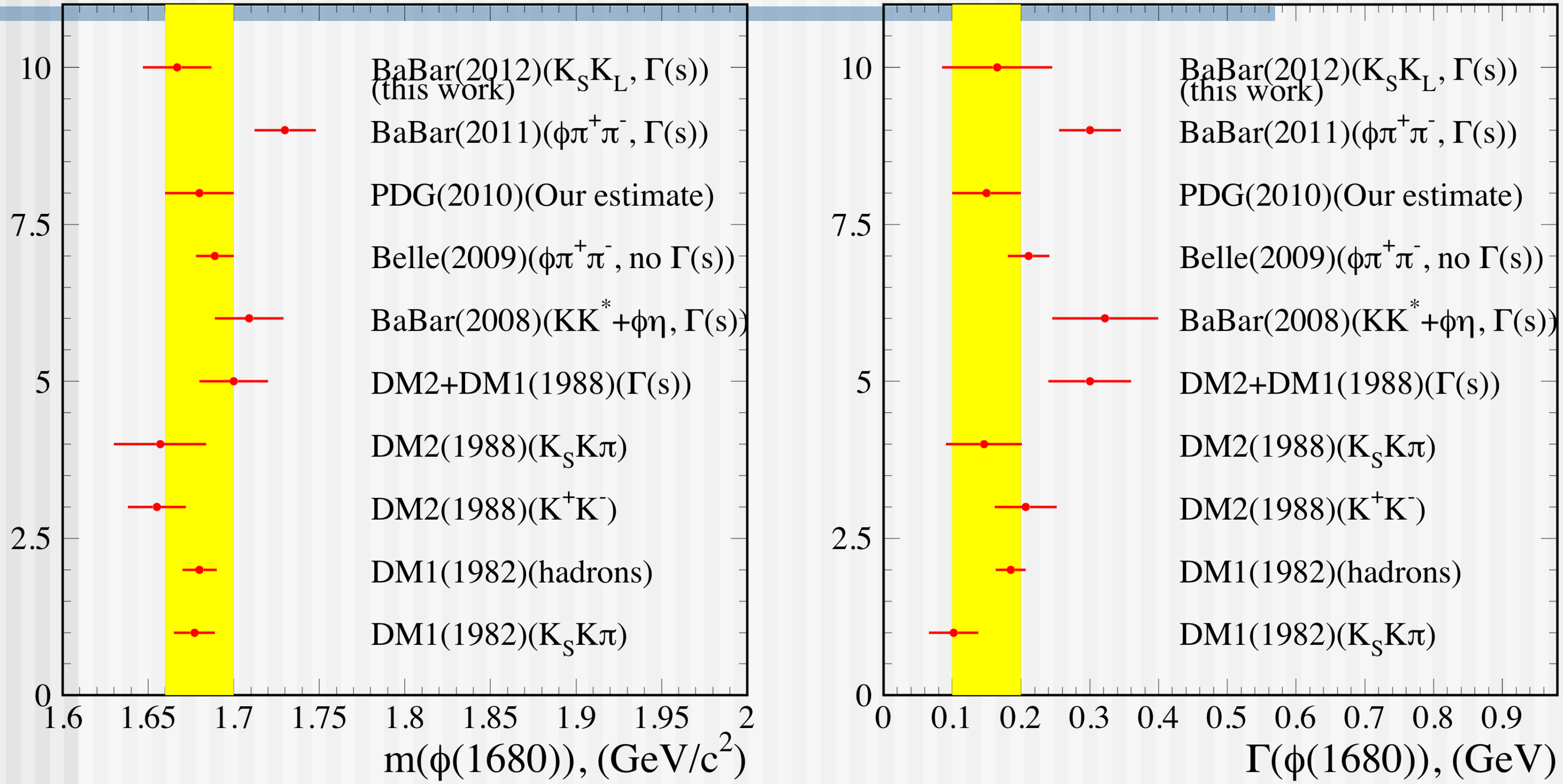




Additional +1.5±0.6% correction due to not fully compensated overlap effect

Clean events with small systematic errors - 1% from KS, 0.5% ISR photon, 0.5% background, 0.6% from overlap effect.

What we know about $\phi(1680)$



Energy dependence significantly increase width.

BaBar has measured $\phi(1680)$ parameters in major decay modes:

$\phi(1680) \rightarrow K_S K\pi$, $KK\pi^0$ (K^*K), $\phi\eta$, $\phi\pi\pi$, $K_S K_L$ - still no info in PDG