Hadron production in the ISR reactions at BaBar

E.Solodov for BaBar collaboration

Budker INP SB RAS, Novosibirsk, Russia

PhiPsi2013, Rome, Italy

Motivation of ISR study at BaBar

- 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
- New inputs for the 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 (green == published)

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

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

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

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

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

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

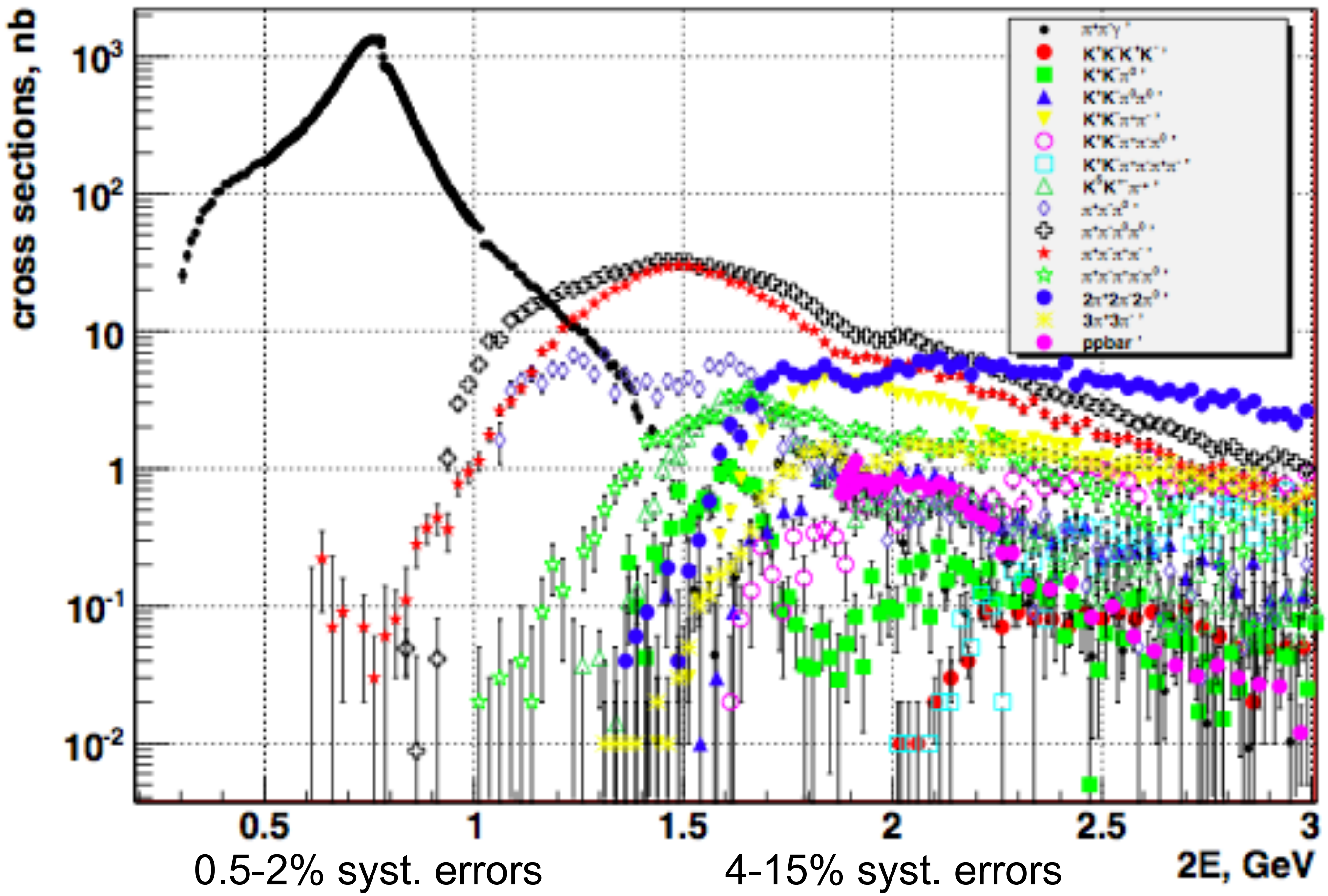
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0/\eta\gamma,\ K^+K^-\pi^+\pi^-\pi^0/\eta\gamma$

$e^+e^- \to KK_S\pi\pi^0/\eta\gamma,\ K_SK_L,\ K_SK_L\pi^+\pi^-,\ K_SK_S\pi^+\pi^-(K^+K^-)$

Some reactions are being updated to full BaBar data with ~500fb^{-1}

(talk by V. Druzhinin on $e^+e^- \to 2p\gamma$)

BaBar measurements summary

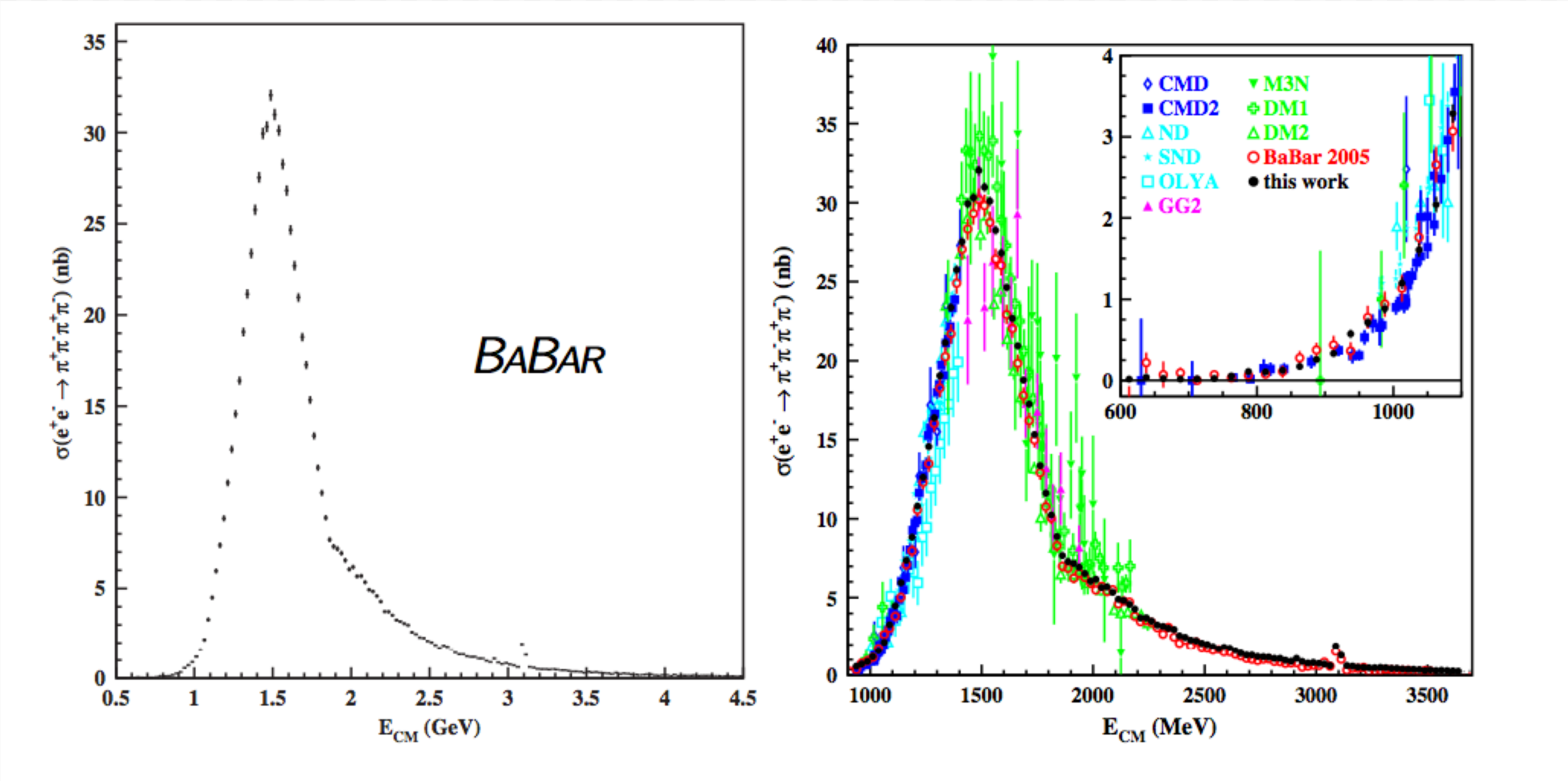


0.5-2% syst. errors 4-15% syst. errors

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.
The $\pi^+\pi^-2\pi^0$ is still preliminary. Work is in progress.

Recently published: $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$

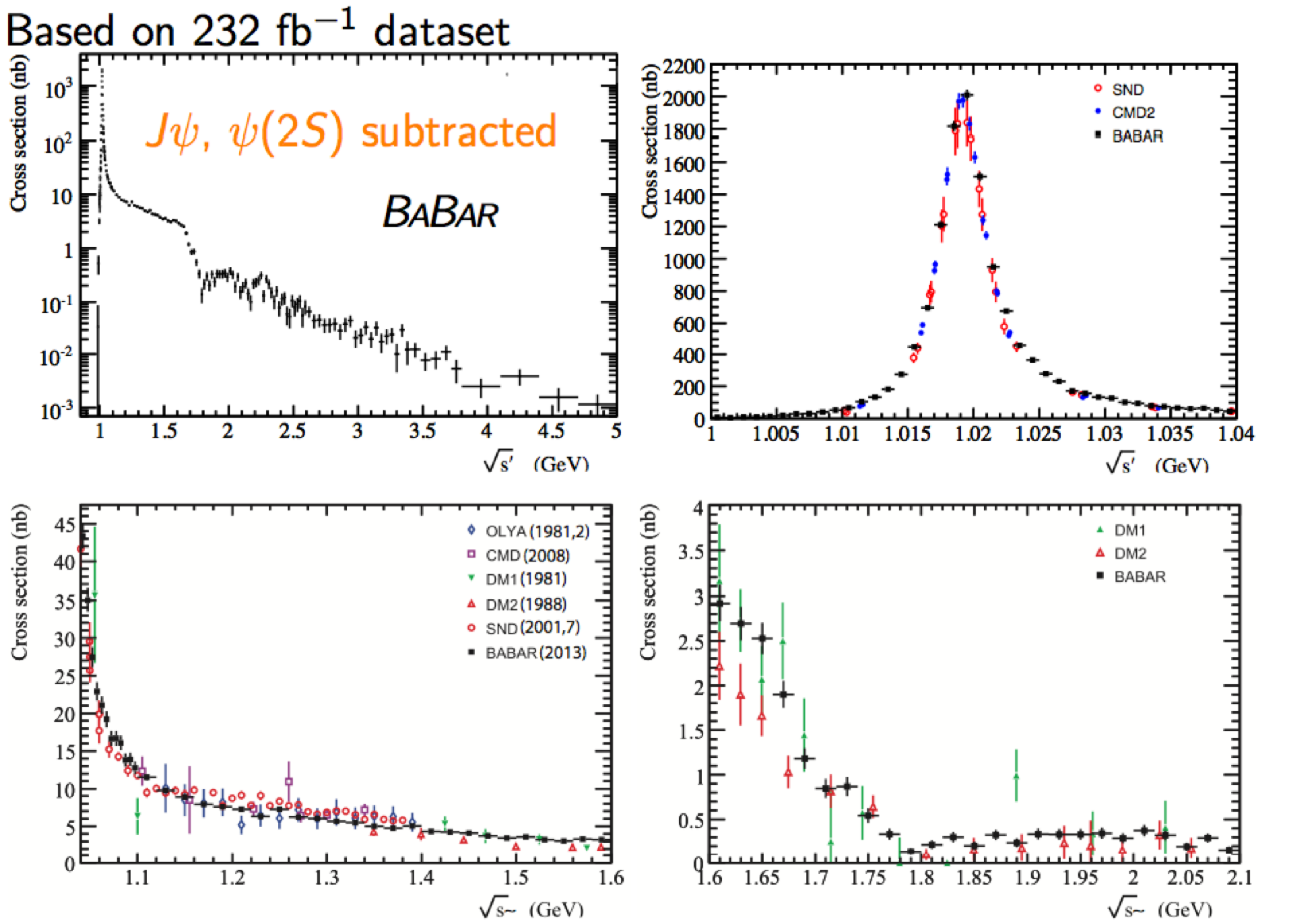
PRD 85 112009 (2012)
Based on 454 fb^{-1} dataset (statistical uncertainties are shown)
Our result is more precise than the current world average (<3% systematic error)



Recently published: $e^+e^- \to K^+K^-$

arXiv:1306.3600, **Phys. Rev. D 88, 032013 (2013)**

Our result is more precise than the current world average



SM prediction for muon g-2

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

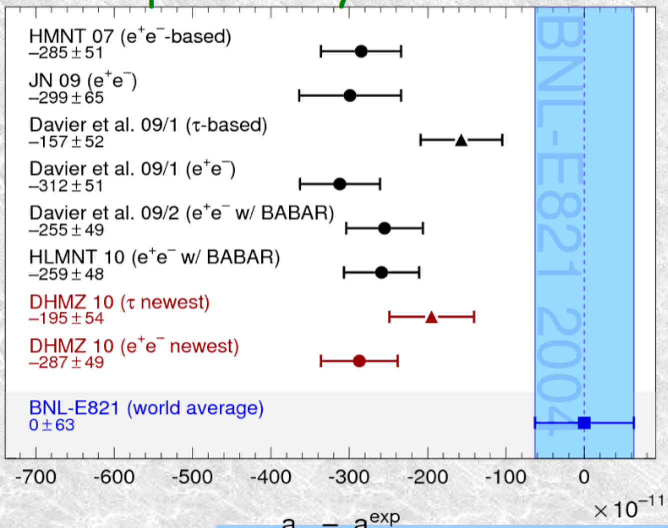
11 659 208.9 ± **6.3** × 10^{-10} world average

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

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

ArXiv:1010.4180,arXiv:1105.3149

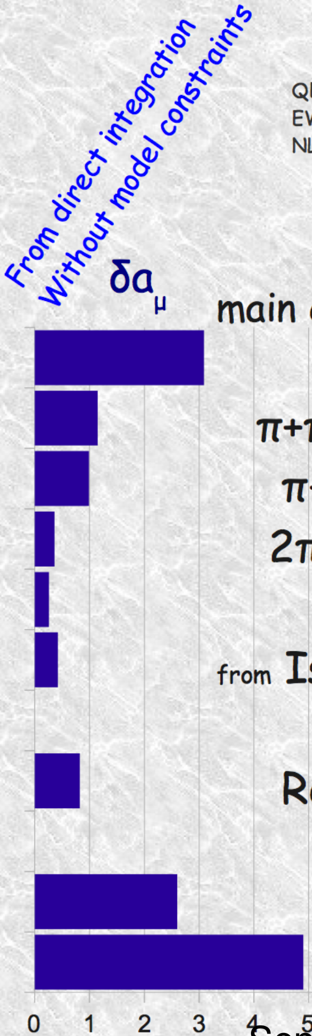
Δ Exp - Theory~ 3.3–3.6σ



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}**

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

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

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

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

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

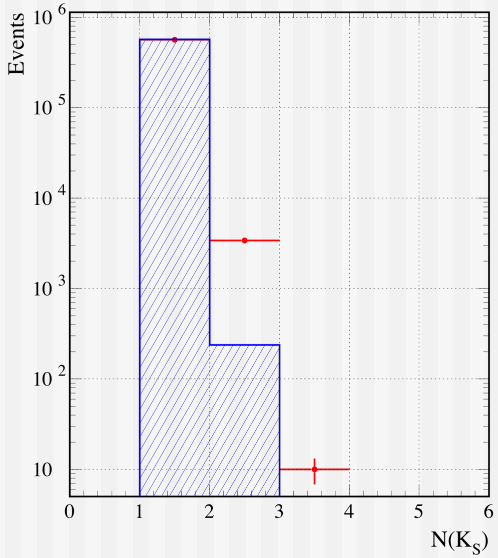
$e^+e^- \to K_S K_S K^+K^-$

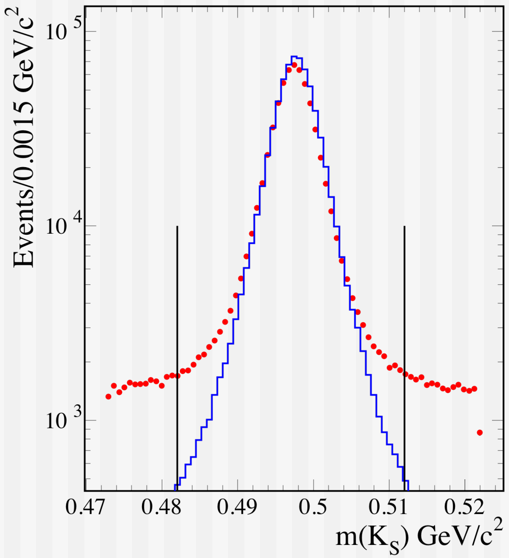
Based on 469 fb^{-1} integrated luminosity.

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

A loop over all K_S candidates with ISR photon in $0.375 < \Theta_{ISR} < 2.4$ rad., $E\gamma > 3$ GeV, and select events with:

- Good quality K_S coming from IP and decays in 0.2-40 cm range.
- No electron ID for both charged tracks
- $0.472 < m(K_L) < 0.522$ MeV/c^2
- Both pions are in $0.375 < \Theta < 2.4$ radians – good region of DCH





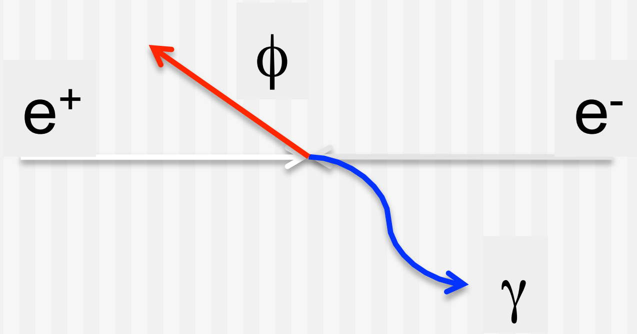
Additional requirement: 0 or 2 tracks with DocaXY < 0.2 cm

$e^+e^- \to \phi\,\gamma \to K_S K_L\,\gamma$ (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 $E_{\gamma ISR}$

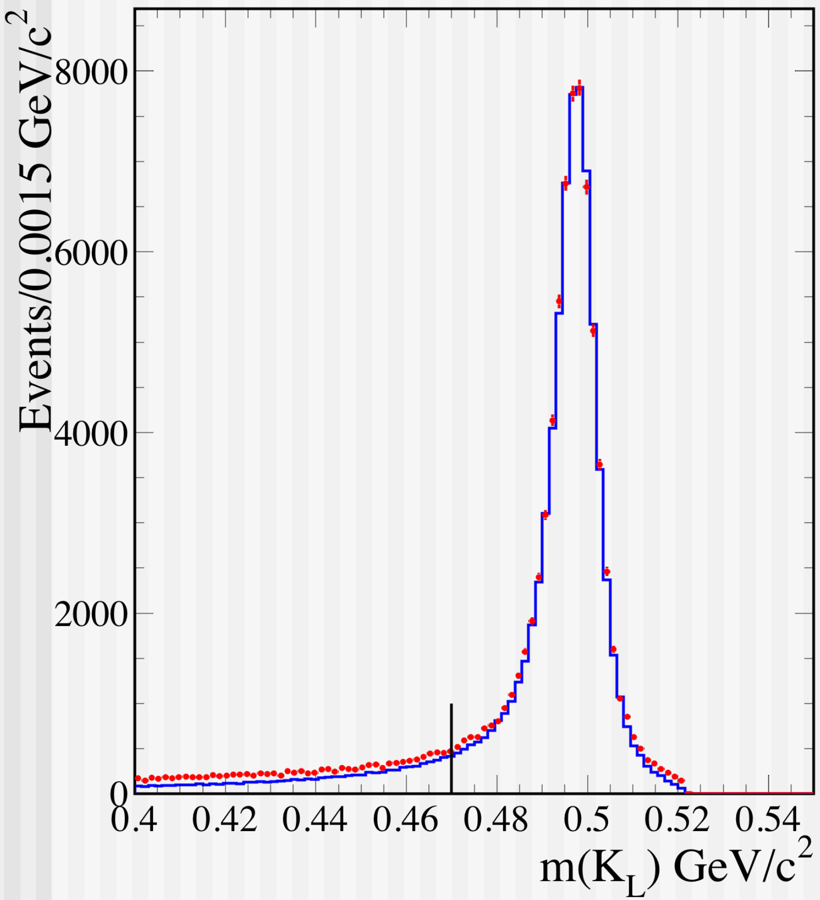
$$E^c_\gamma = \frac{E_0^2 - p_0^2 - m_\phi^2}{2\left(E_0 - \vec{p}_0 \cdot \vec{n}_\gamma\right)}$$

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

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

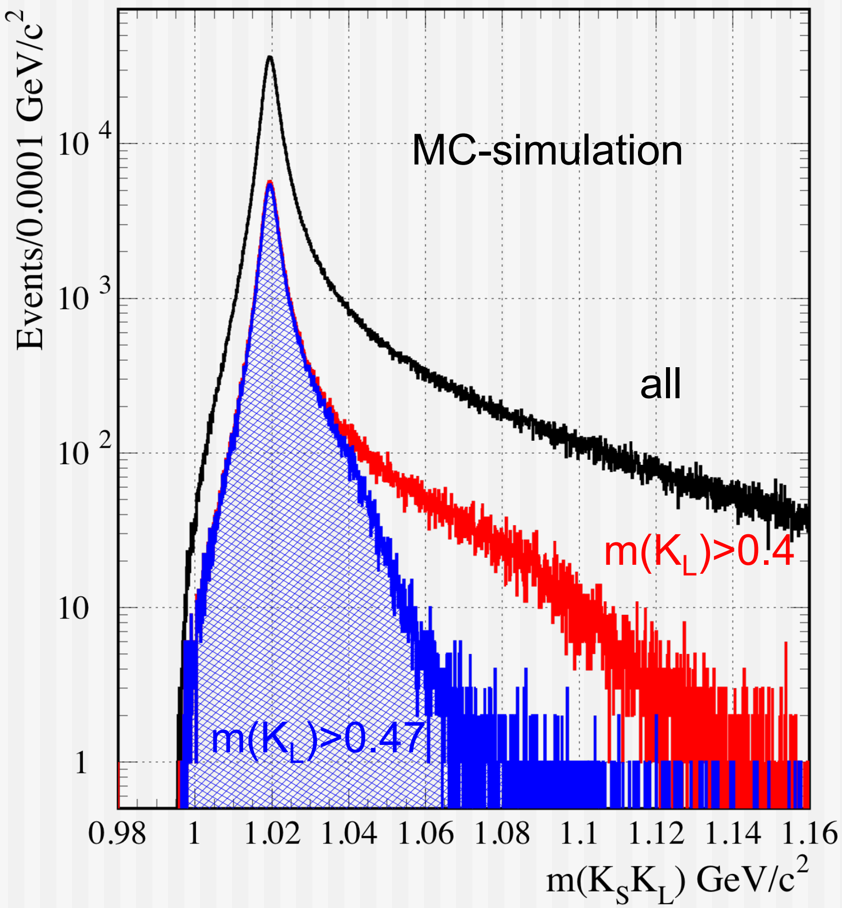
Using this events we can study K_L detection.

K_L mass using ϕ mass constraint



MC normalized to two bins at peak
83247 (413401) events for data (MC)

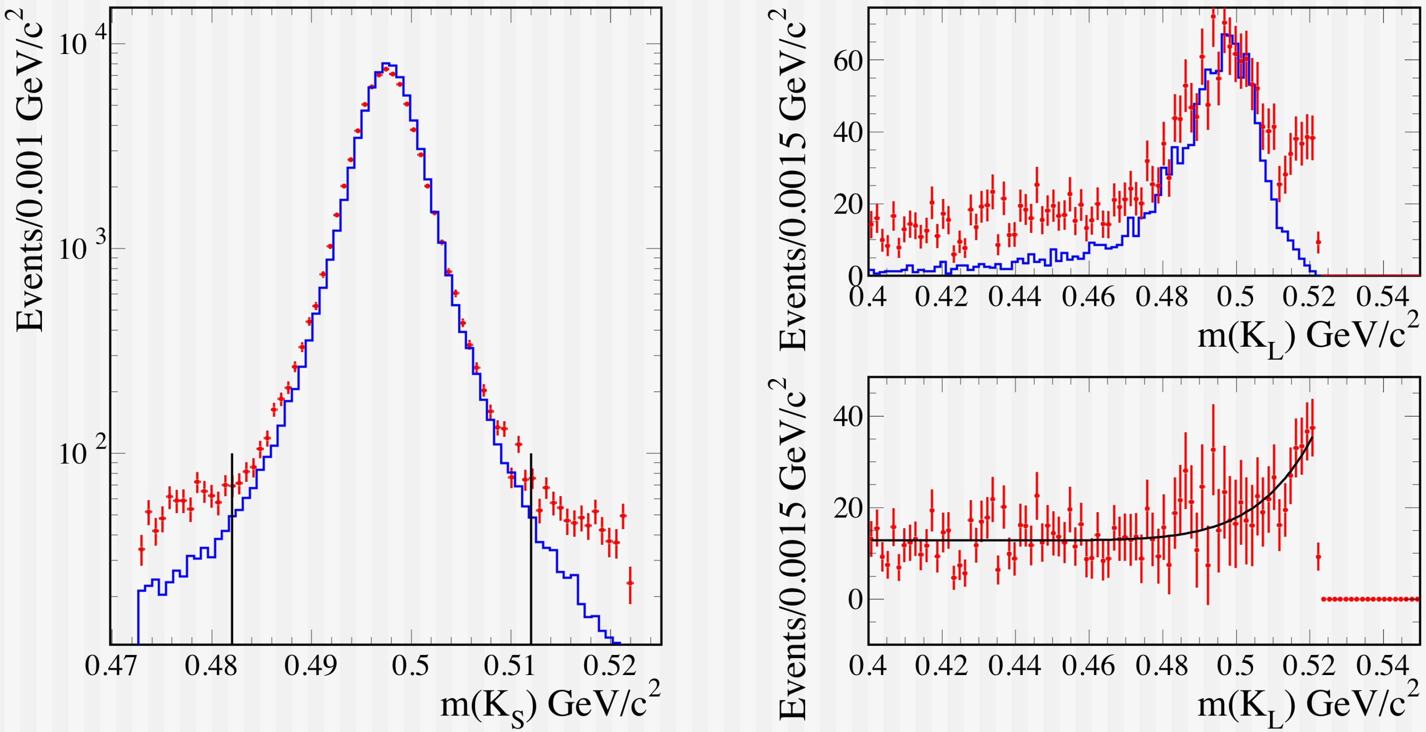
Very low background!



True K_SK_L mass corresponding to $m(K_L)>0.4$ and $m(K_L)>0.47$ GeV/c^2

Background subtraction (1)

We apply additional cuts to the K_S mass and use side band events to estimate background (non-K_S) to calculated K_L mass.

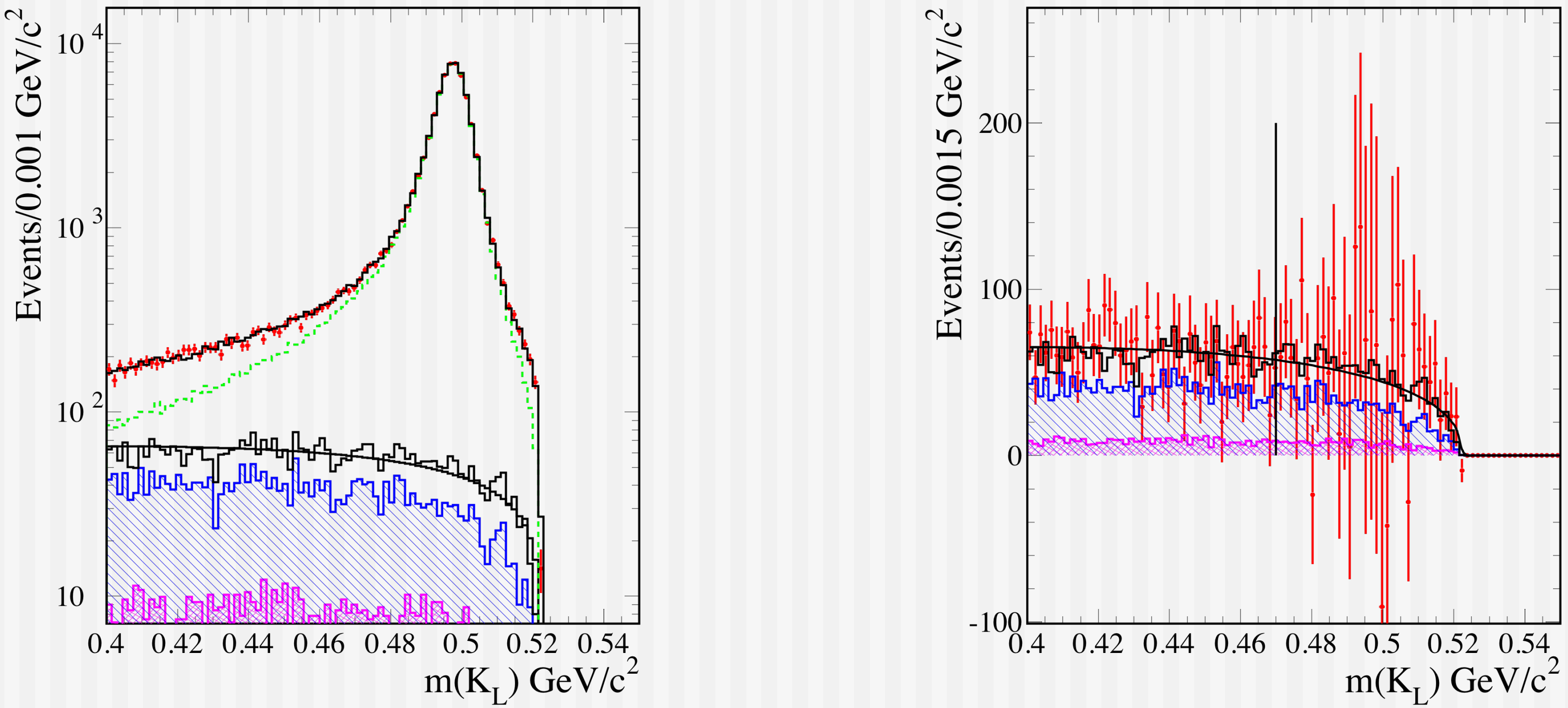


We subtract (normalized) simulated signal events from K_S side band to obtain background distribution and fit it with $p_0+p_1*x^8$. It counts only 0.8% of all selected events.

This background comes from the $\gamma\gamma$ events with conversion and mis-identified electrons

Background subtraction (2)

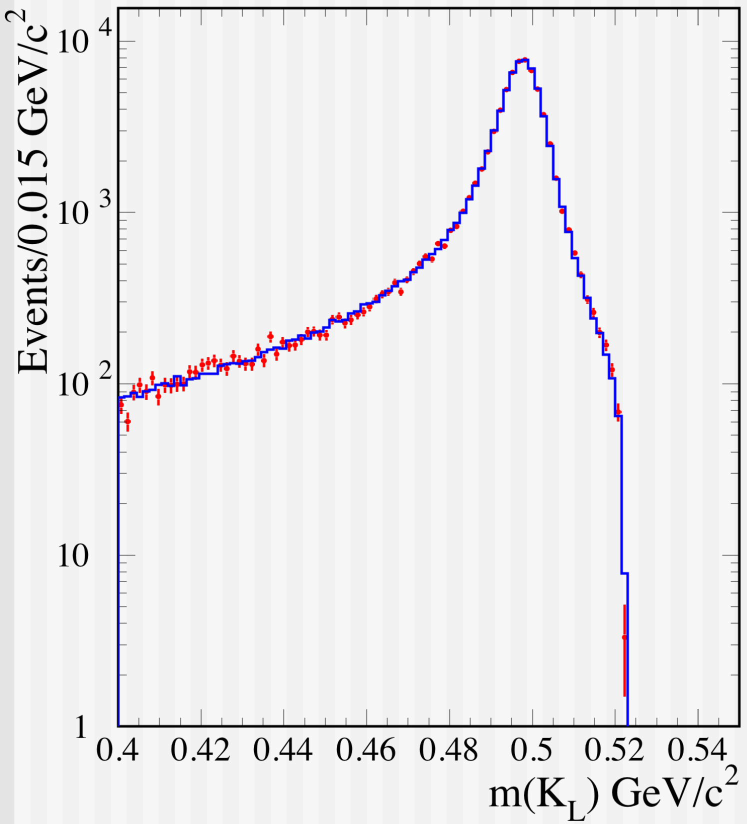
Major background comes from events with real K_S. We found negligible contribution from uds continuum background ($e+e- \to K_S K_L \pi^0(\eta)$ is very small if any, nothing is seen in $\gamma_{ISR}\gamma$ combinations).

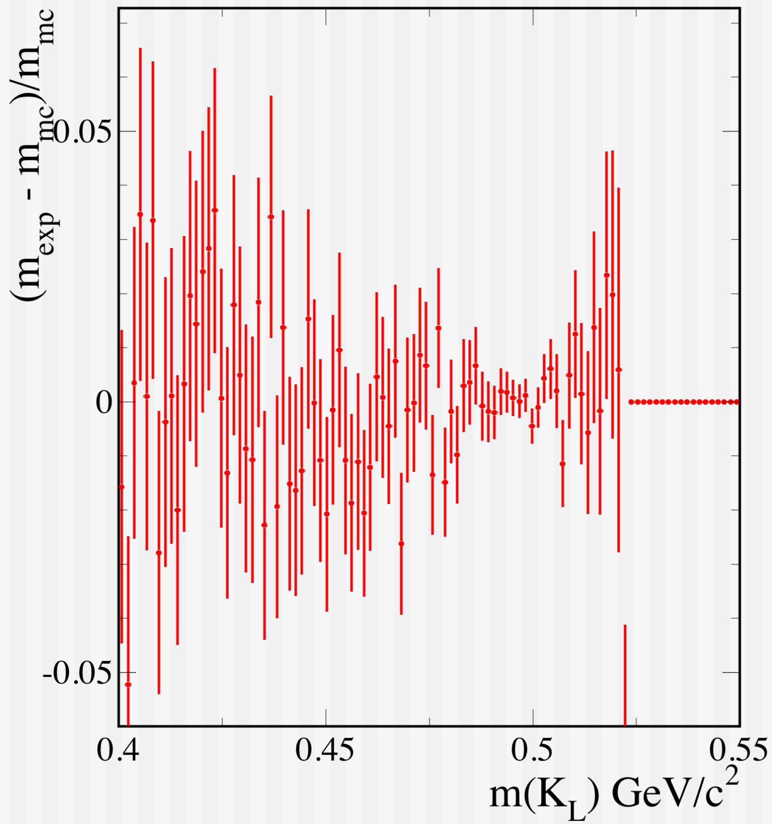


Major contributions come from (cumulatively shown) $e+e- \to K_S K_L 2\pi^0\gamma$, $K_S K_L \pi^0\gamma$ and $\phi\eta\gamma$ ISR processes. We subtract (normalized) MC from data and fit the difference with "ARGUS" function. 4572 (5.6%) and 1586 (2.4%) for $m_{KL}>0.47$.

We estimate ~0.5% systematic error to total number of events for background uncertainty.

$K_S K_L \gamma$ events at ϕ

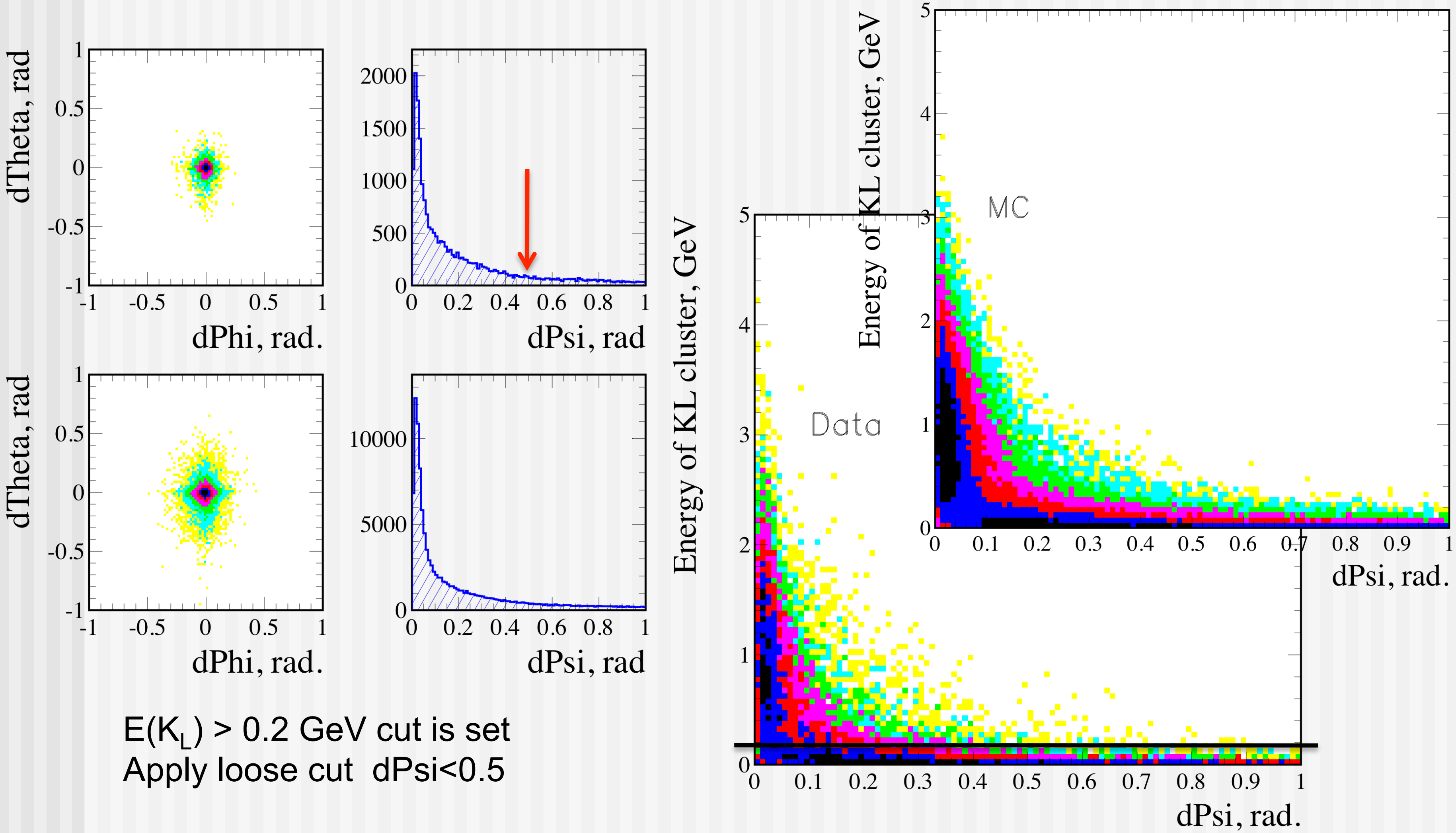




We have very clean 81012±285 events for data (447434±669 MC) .
Calculated K_L mass strongly depends on ϕ mass used and K_S momentum.

How K_L cluster in Calorimeter looks like?

1. Search for EMC cluster closest to K_L direction:

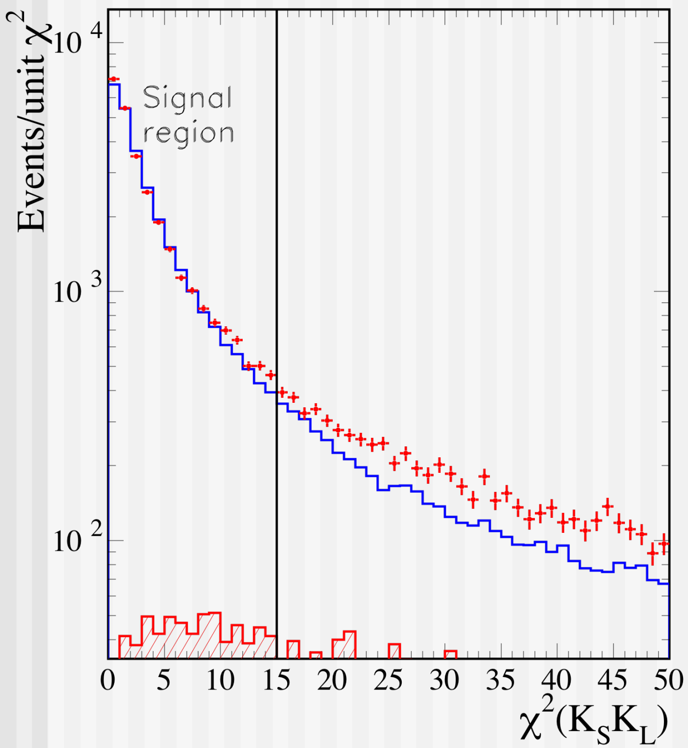


$E(K_L) > 0.2$ GeV cut is set
Apply loose cut dPsi<0.5

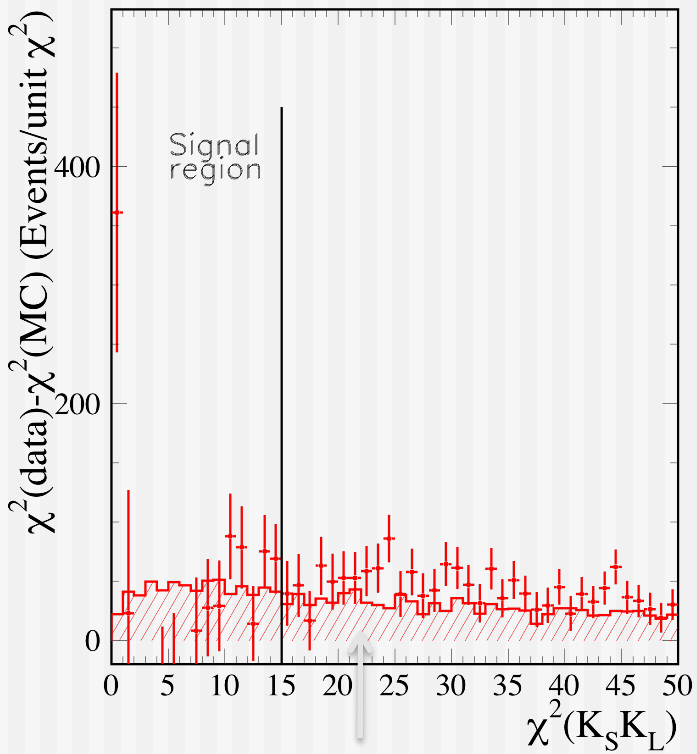
K_L detection probability in EMC ~ 48% (~6% data-MC difference)

2. Search for K_L cluster using kinematic fit :

- Select (best) K_S (and cov. matrix)
- Select ISR photon (use alignment and resolution corrections)
- Loop over remaining clusters with E > 0.2 GeV to look for K_L candidate
- Use angular resolutions from Method 1
- Select event with best χ^2 for 3C fit in $K_S K_L \gamma$ hypothesis ($P(K_L)$ float)



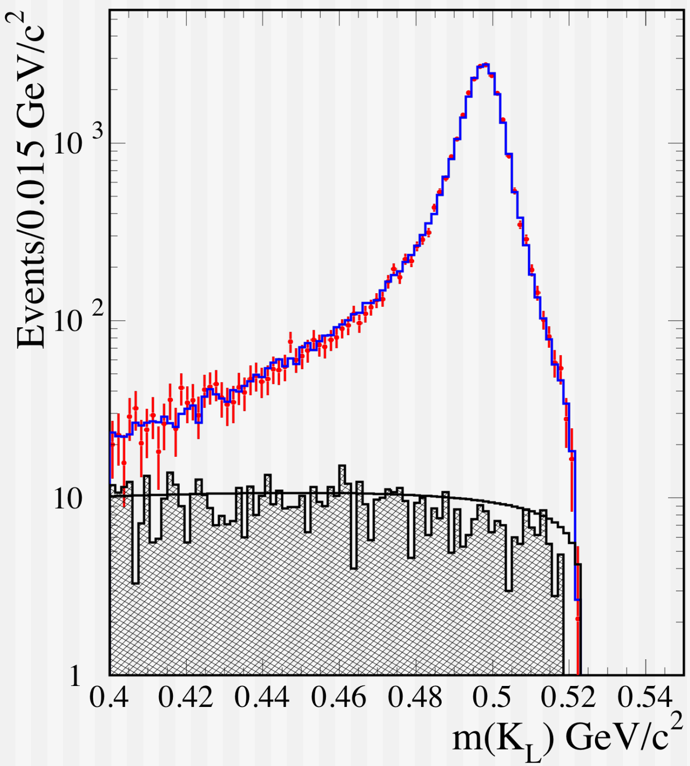
Low bkg. with χ2<15.

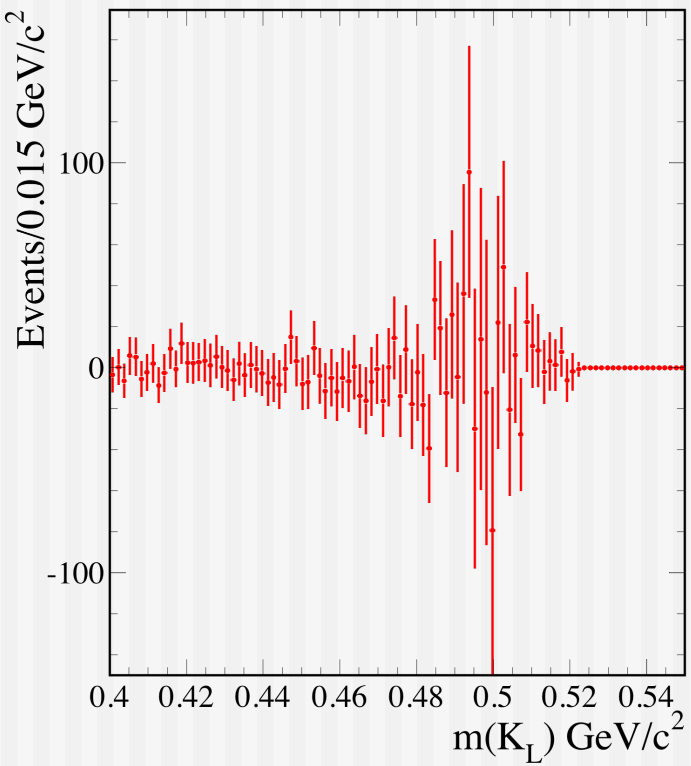


$K_S K_L \pi^0$, $\phi\eta$, $K_S K_L 2\pi^0$

K_L EMC detection probability (2)

For events, selected by χ^2<15 we calculate m(K_L) using ϕ mass (~36% efficiency).



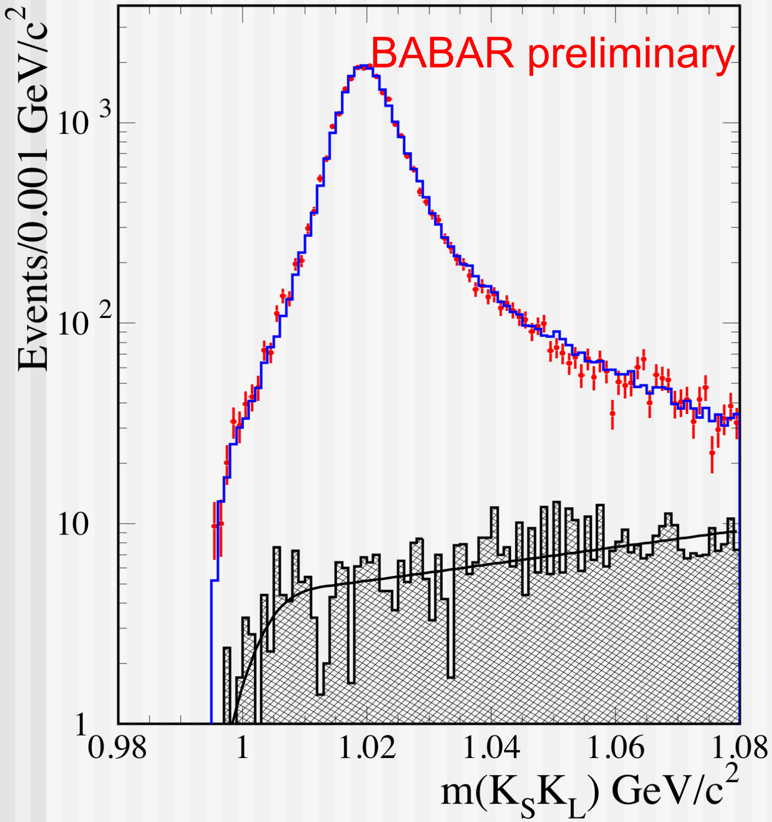


After 814 background events subtraction we obtain 27925±176 events for data and 164179±405 events for MC. By comparing with numbers without K_L detection:

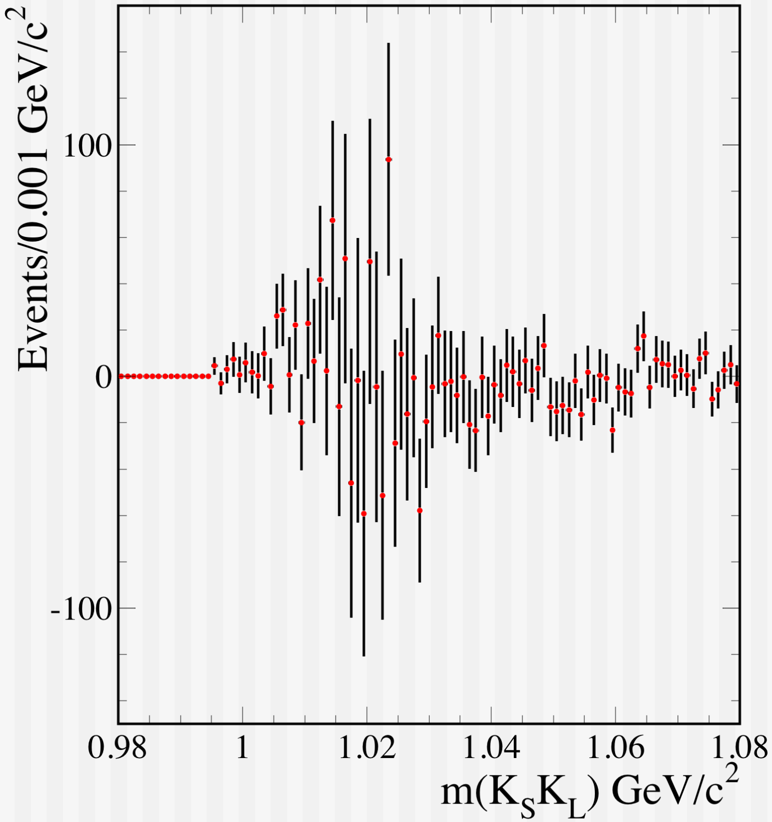
Data/MC = 0.9394 ± 0.0052 (0.6%) (includes also χ^2 cut efficiency)
Used in all other analyses.

ϕ signal in $e^+e^- \longrightarrow K_S K_L$ reaction

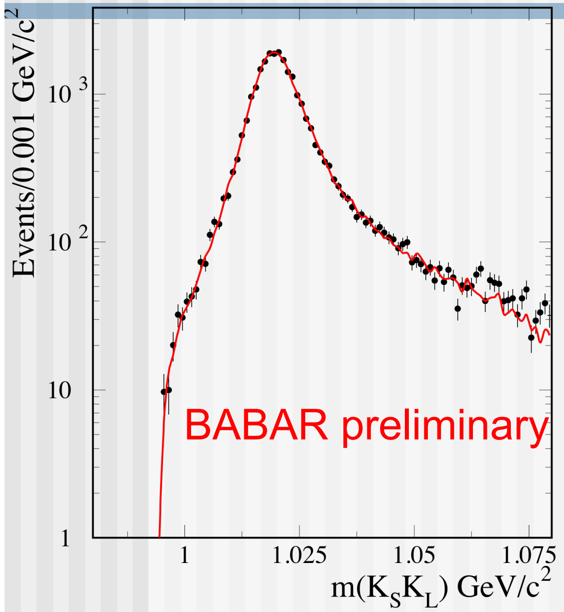
Use events with $\chi 2<15$ and reconstructed parameters of K_S and K_L to calculate $m(K_S K_L)$



Data-MC difference



Fit to ϕ parameters (preliminary)

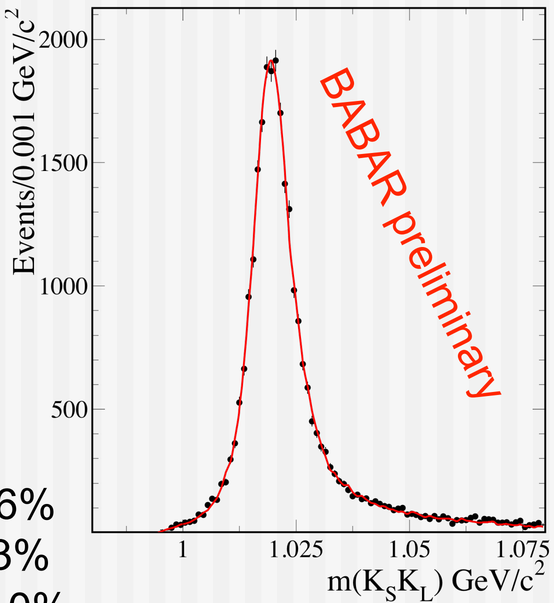


Fit:

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 errors count:

KL efficiency (+ χ2)	0.6%
BGFilter efficiency	2.3%
KS efficiency	1.0%
ISR photon	0.5%
Luminosity	0.5%
Rad.corr.	1.0%
Track overlap	0.6%
Background sub.	0.5%
	2.9%

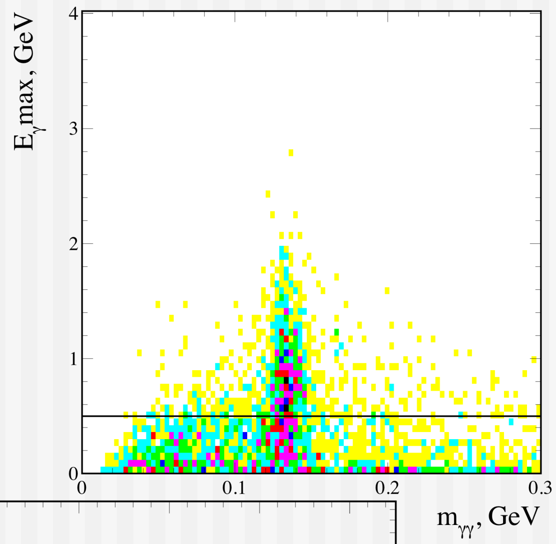
$\Gamma_{ee} \cdot B_{KSKL}$ = 0.4200 ± 0.0033 ± 0.0122 ± 0.0019 keV

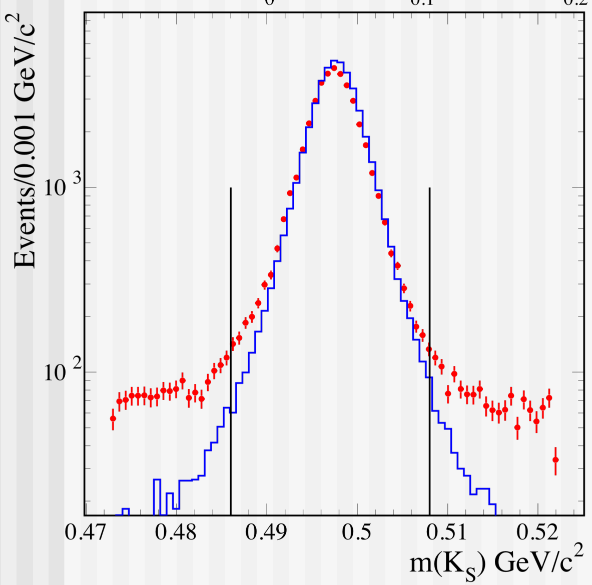
Γ_{ee} = 1.228 ± 0.037 ± $0.014_{(PDG\ BKSKL)}$ keV

$B_{ee} \cdot B_{KSKL}$ = 0.986 ± 0.030 ± $0.009_{(PDG\ \Gamma KSKL)}$

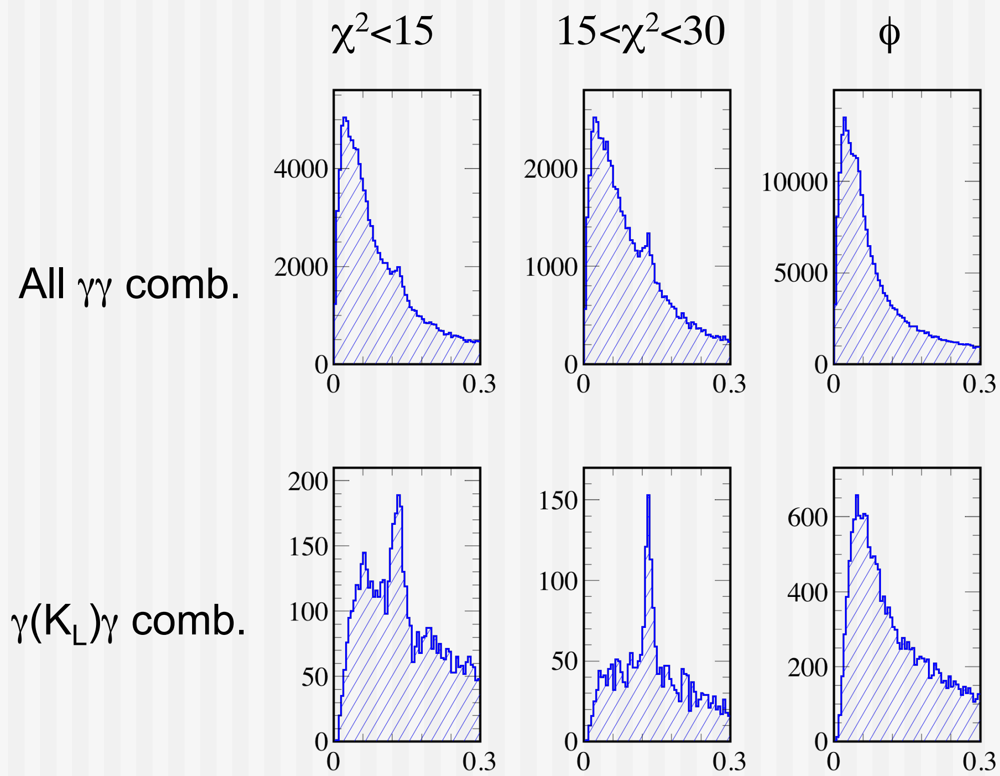
Region above ϕ: $m(K_S K_L)>1.06$ GeV

Huge background from processes with π^0. This background is reduced by a requirement $E\gamma(max) < 0.5$ GeV (gives ~3% data-MC difference in ϕ region).



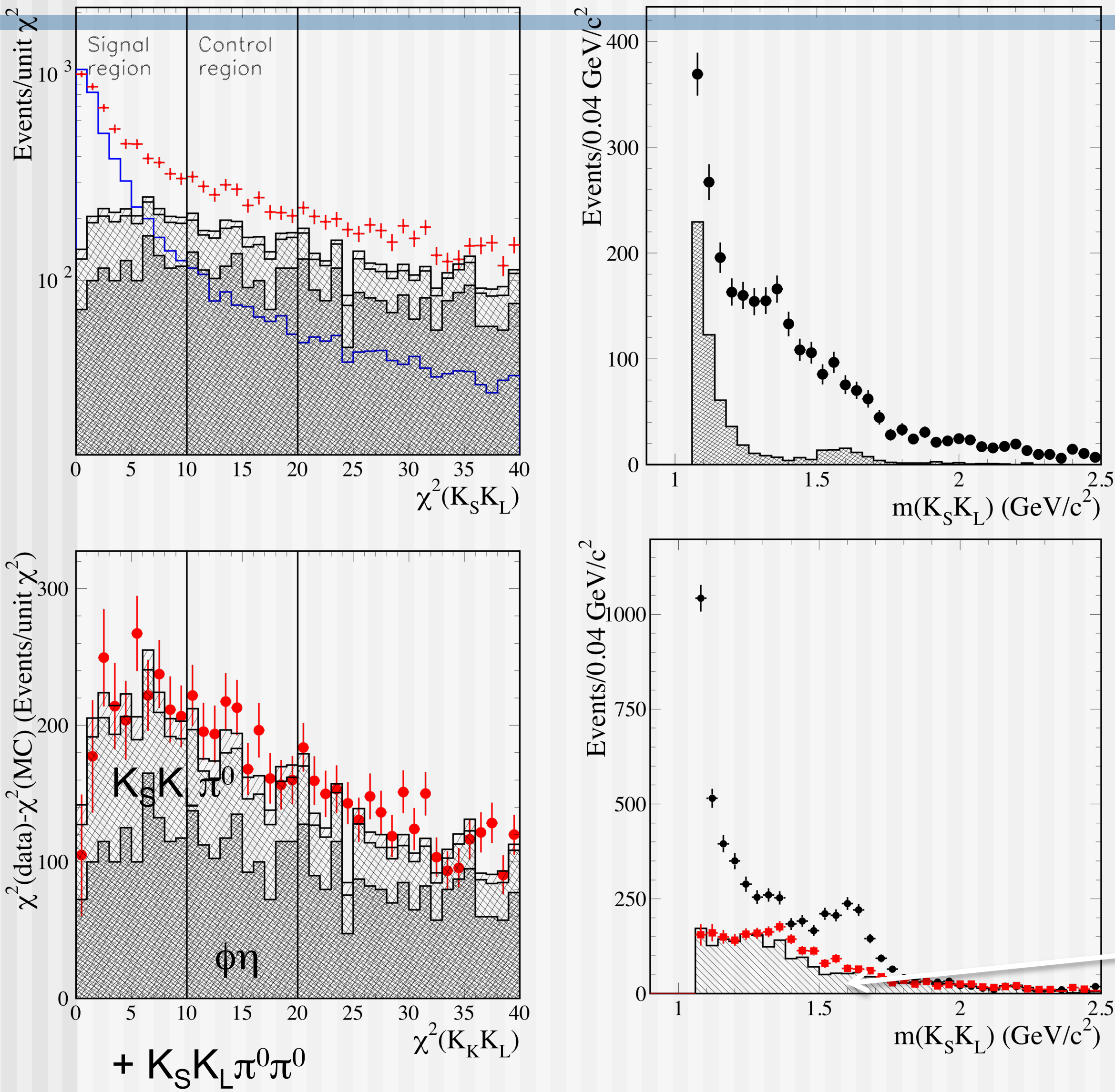


Tighter cut on K_S mass, use side bands to estimate background



After $E_\gamma$max cut still a lot π^0

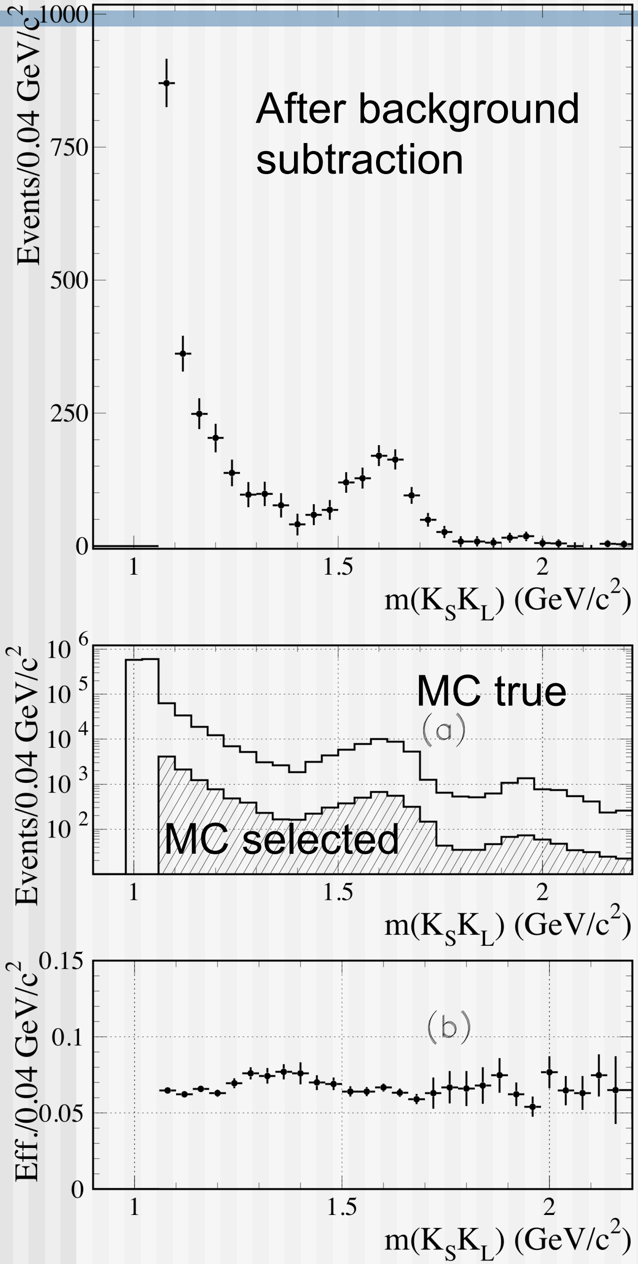
Use χ^2 control region subtraction

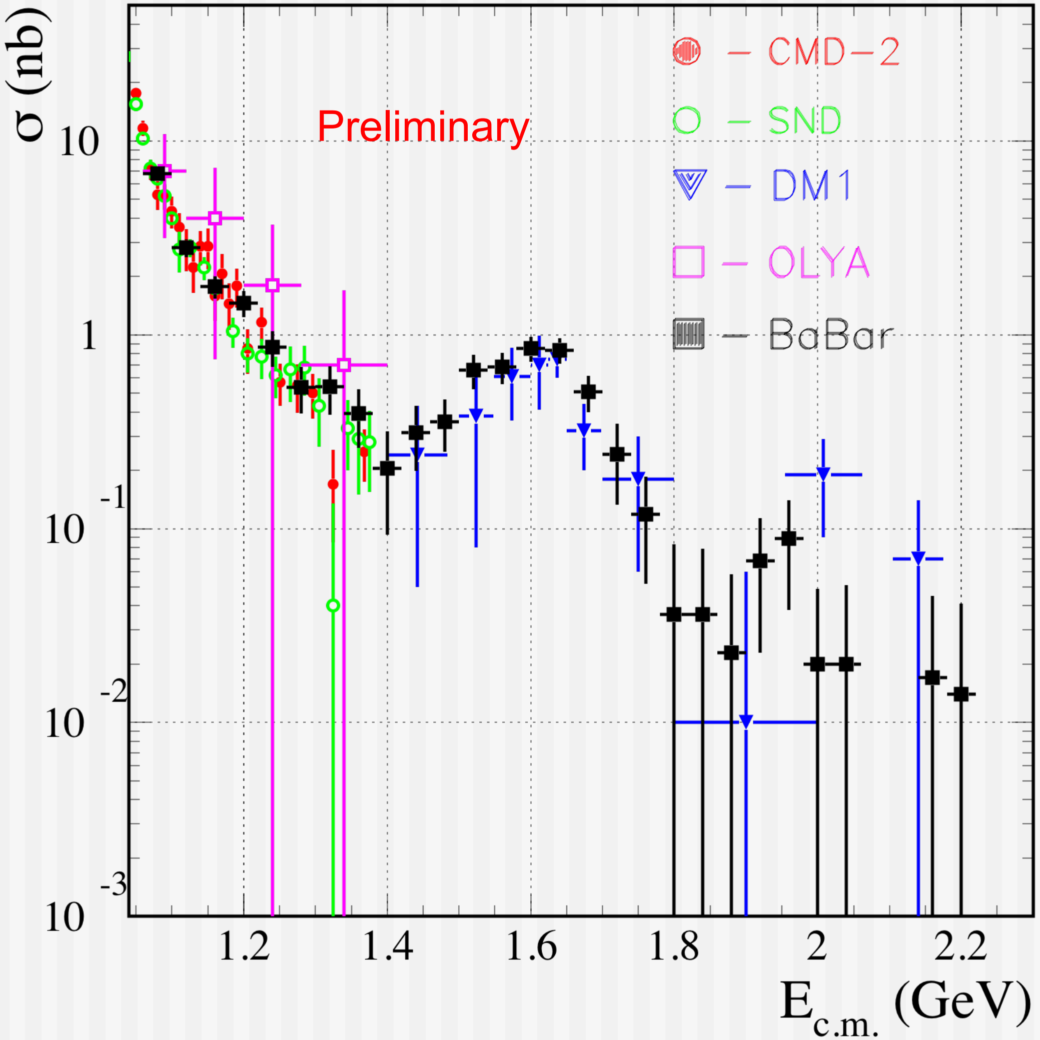


Control region data events and signal contribution from MC (normalized by first bin and shape corrected by Data-MC difference – iteration procedure).

Signal region events with a background estimated from control region events after normalization.
Shaded is MC background estimate from $\phi\eta$, $K_SK_L\pi^0$, $K_SK_L\pi^0\pi^0$.

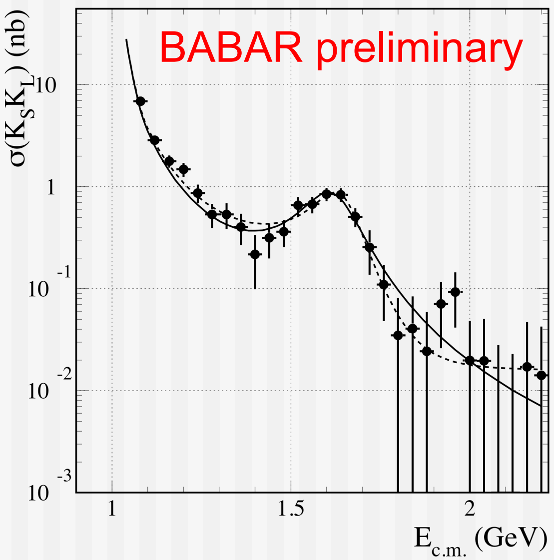
$e^+e^- \longrightarrow K_S K_L$ cross section

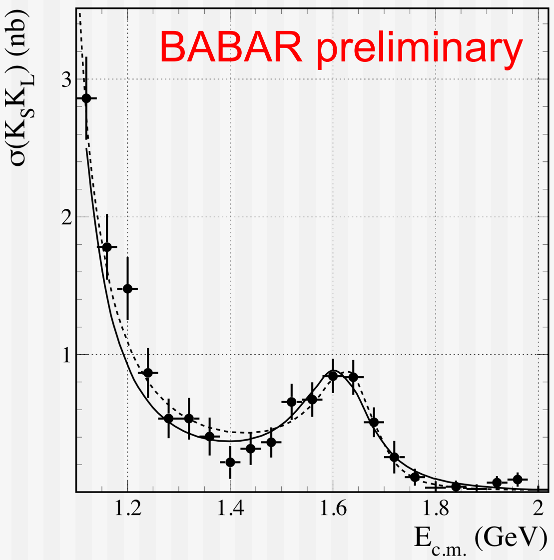




Systematic error ~10% (~30% for σ<0.3 nb), dominated by background subtraction procedure.

Is it $\phi(1680)$?





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

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

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

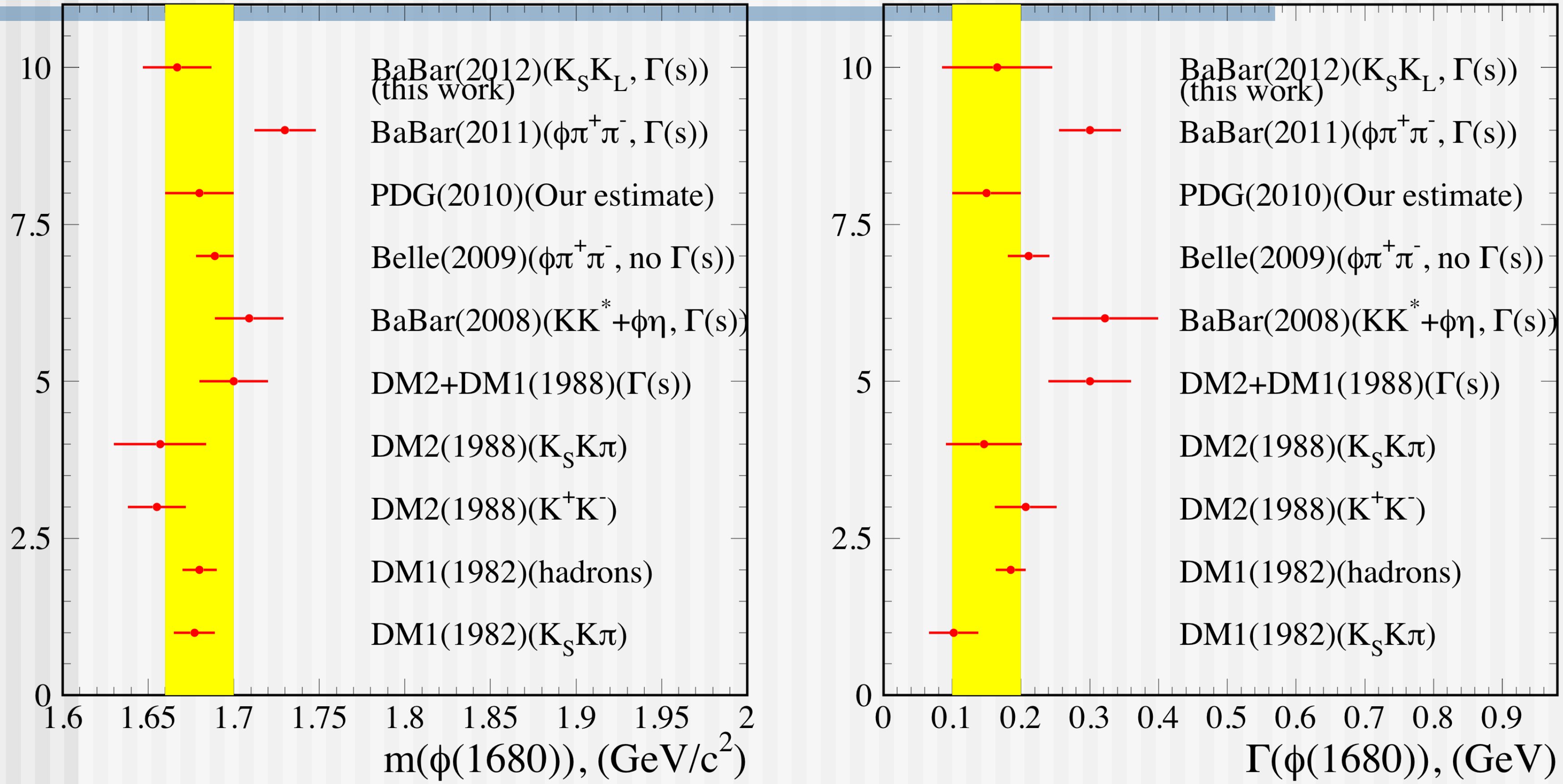
$$\Gamma(s) = \Gamma \cdot \sum_f B_f \cdot \frac{P_f(s)}{P_f(m_f^2)}$$

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

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

What we know about $\phi(1680)$



Energy dependence significantly increase width.

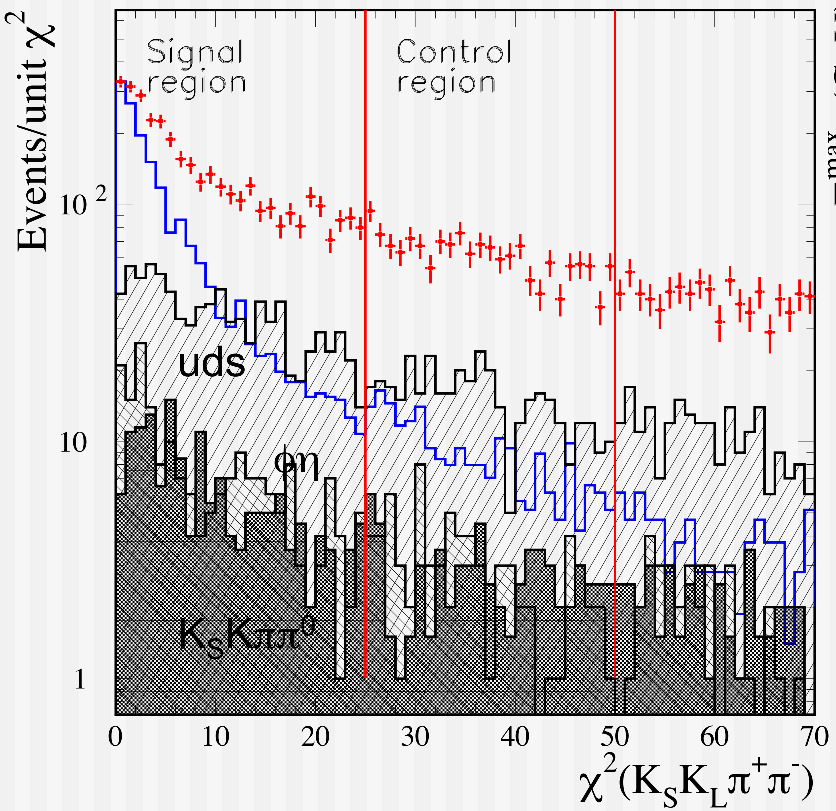
BaBar has measured $\phi(1680)$ parameters in major decay modes:

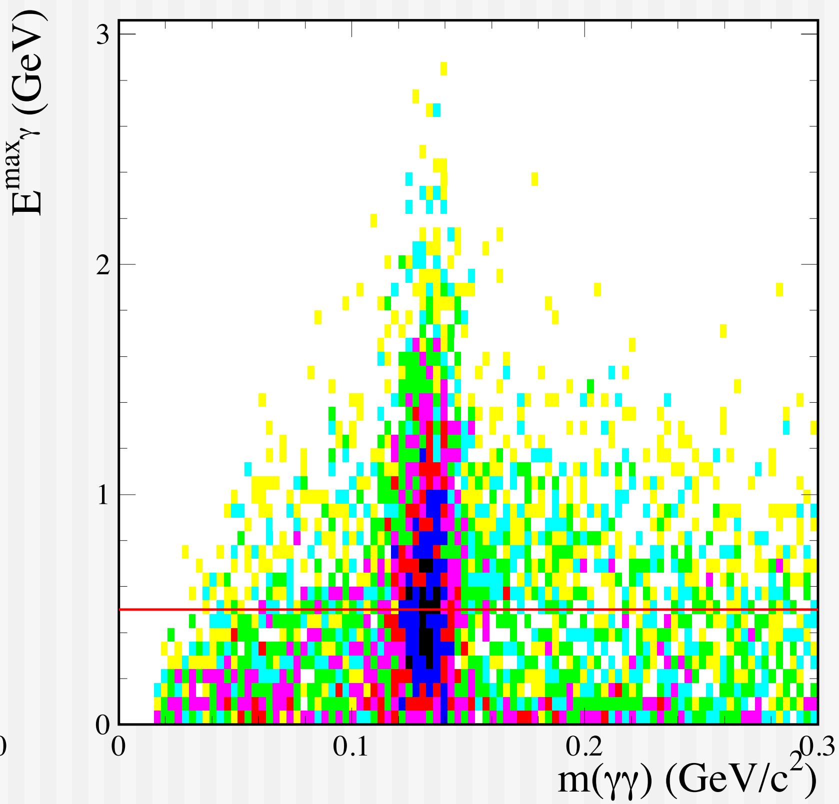
$\phi(1680) \rightarrow K_S K\pi$, $KK\pi^0$ (K^*K), $\phi\eta$, $\phi\pi\pi$, $K_S K_L$ (preliminary) - still no info in PDG

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

- Select (best) K_S (use cov. matrix)
- Select ISR photon (use align. corrections and res.)
- Two tracks (only) with DocaXY<0.2 cm (not from K_S, no K ID)
- No more tracks inside (1cm in R x 3 cm in Z) cylinder.
- Cycle over remaining photons with $E\gamma$>0.2 GeV
- 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

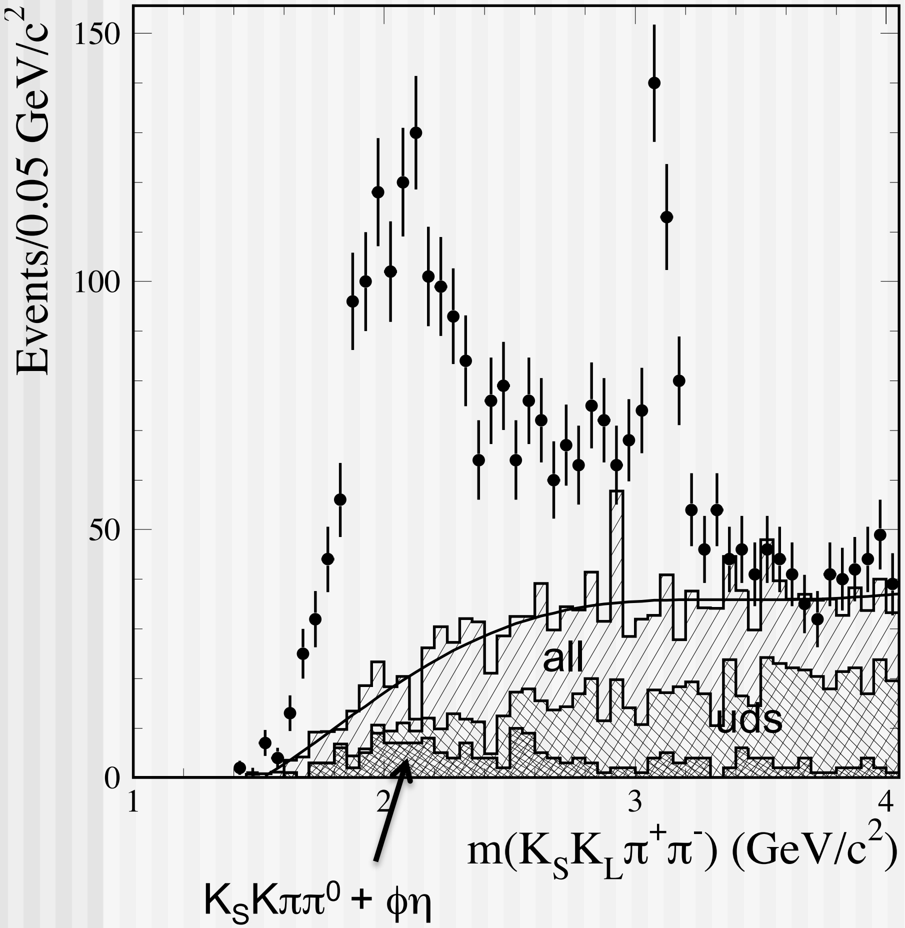
$K_S K_L \pi^+ \pi^- \gamma$ selection

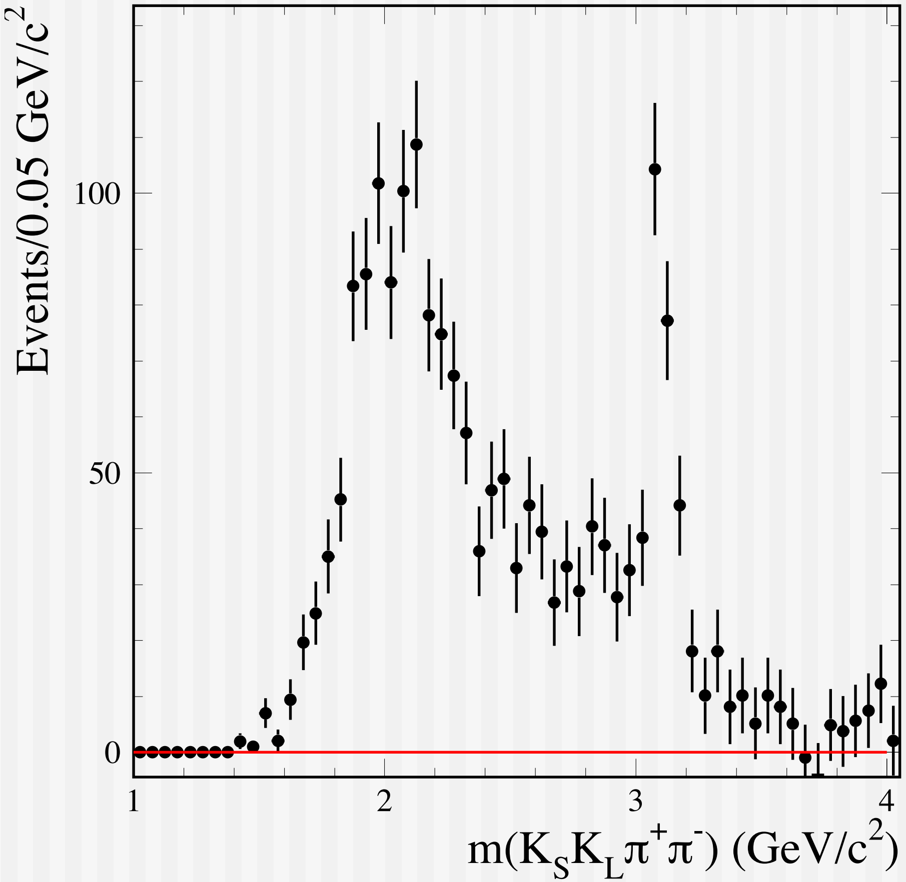




Huge background from events with π^0. Cut $E_\gamma max<0.5$ GeV does not help much. Known background does not explain what we see – use observed side band for the background estimate.

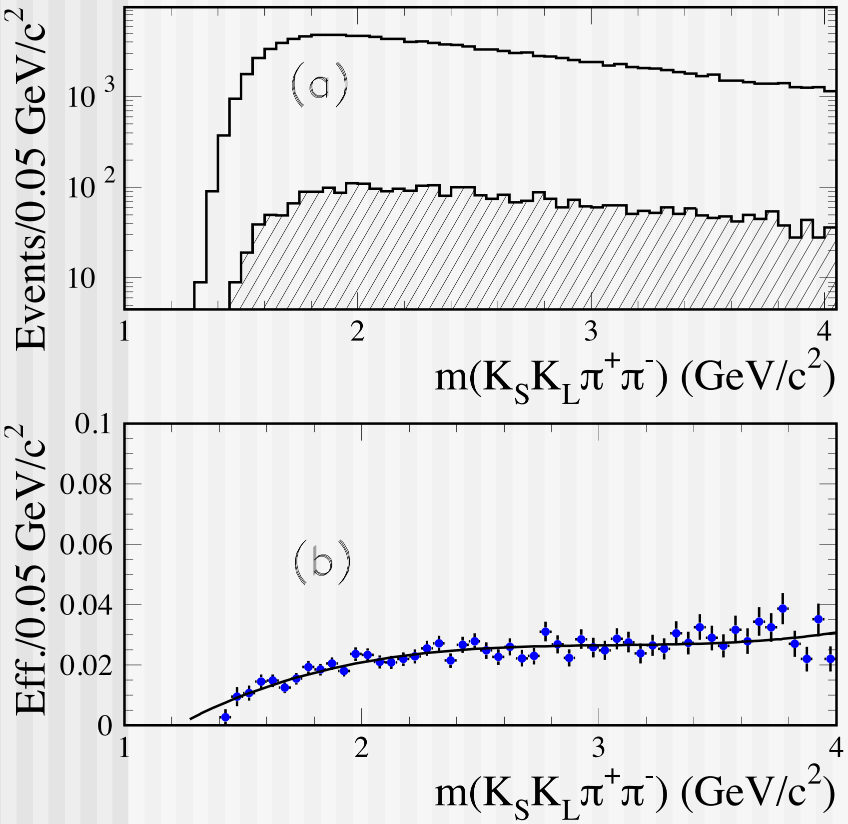
$K_S K_L \pi^+ \pi^-$ mass distribution

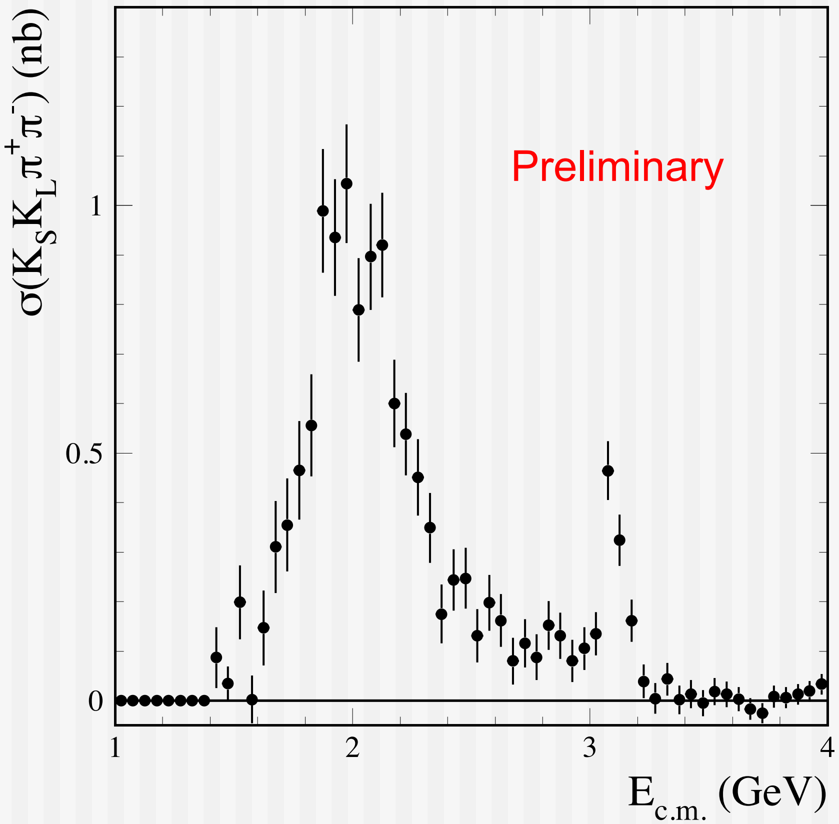




1580 events after background subtraction

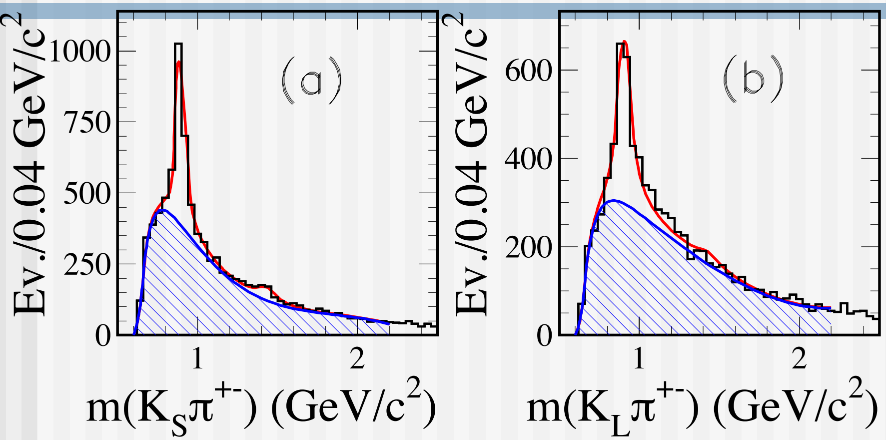
$e^+e^- \rightarrow K_S K_L \pi^+\pi^-$ cross section

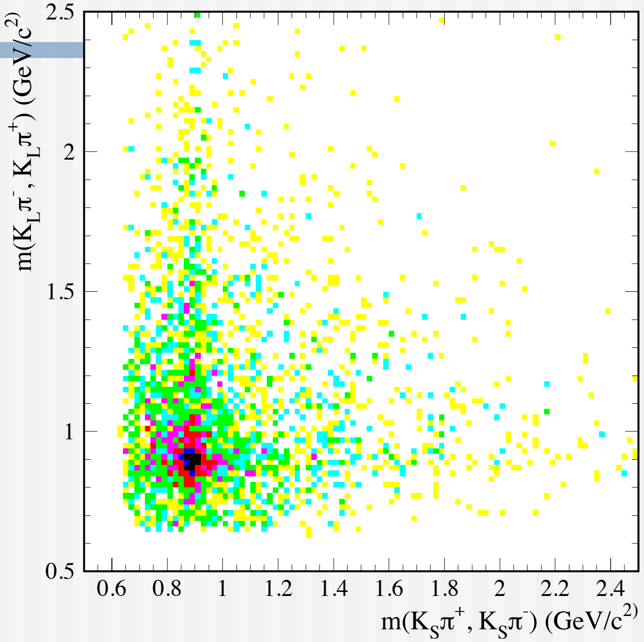




No other measurements are available

Some mass distributions



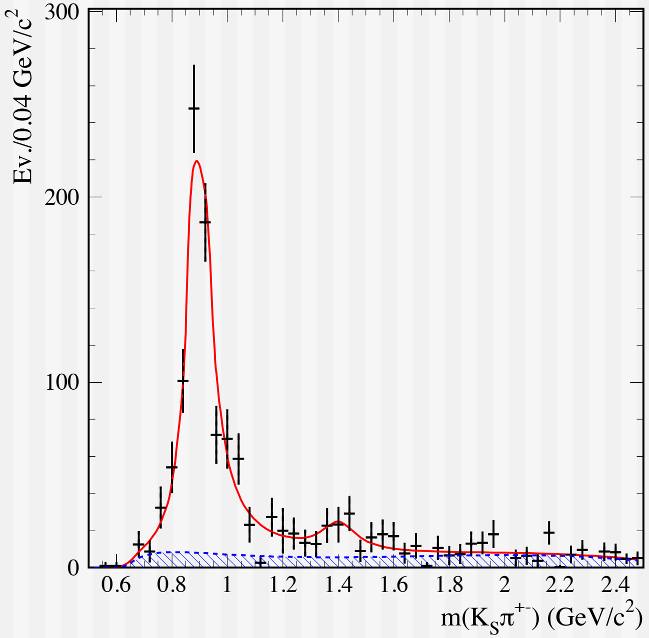


Very clear $K^*(892)^{\pm}$ signals with
1322 ± 70 for $K^{*\pm}$ ($K_S\pi$) and 1362 ± 78 for $K^{*\pm}$ ($K_L\pi$)
Plus 183 ± 48 events for $K_2(1430)^{\pm}$

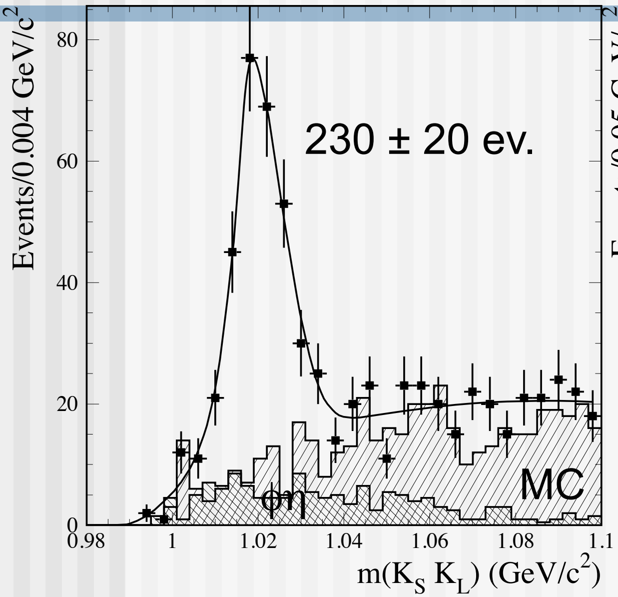
How large is $K^*(892)^+K^*(892)^-$?
Fit slice in m($K_L\pi^{+-}$) for number of $K_S\pi^{-+}$

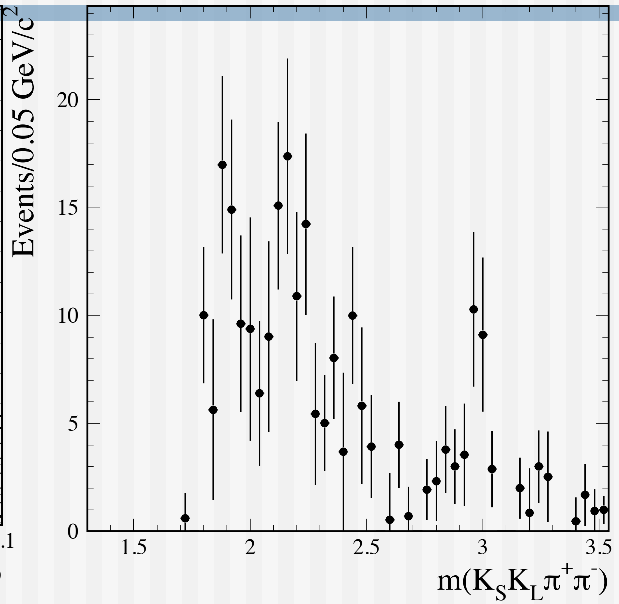
Very clear signal with 913 ± 37 events (70%)
of $K^*(892)^+K^*(892)^-$ correlated production!
And 90 ± 16 for $K^*(892)^{+-}K_2^*(1430)^{-+}$.

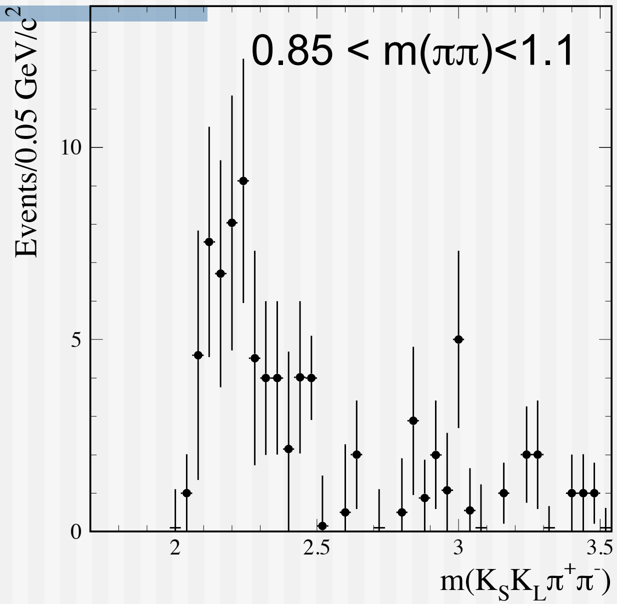
We have negligible contribution from $K^*(892)^0\underline{K}^*(892)^0$ from our $K^+K^-\pi^+\pi^-$ analysis! And relatively large for $K^*(892)^+K^*(892)^-$ from our $K^+K^-\pi^0\pi^0$ analysis.

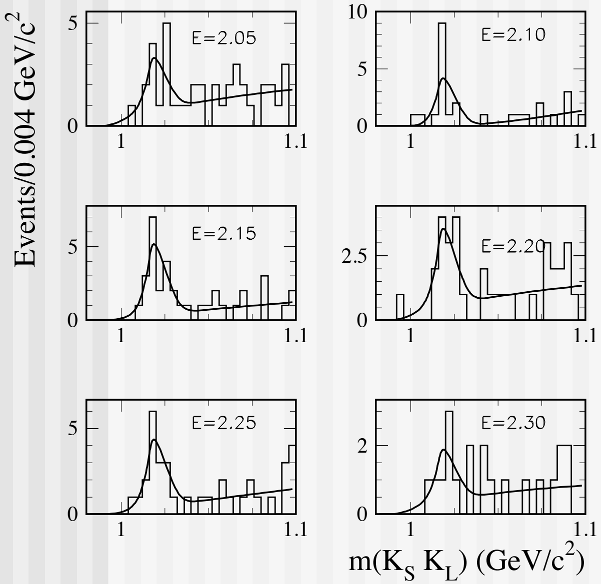


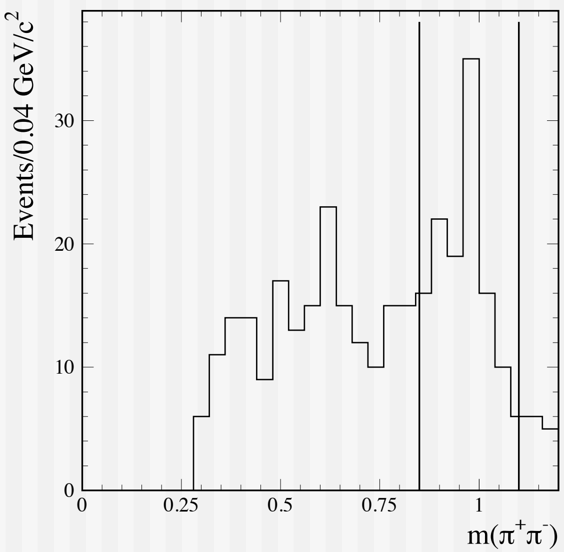
$\phi(1020)\pi^+\pi^-$ contribution











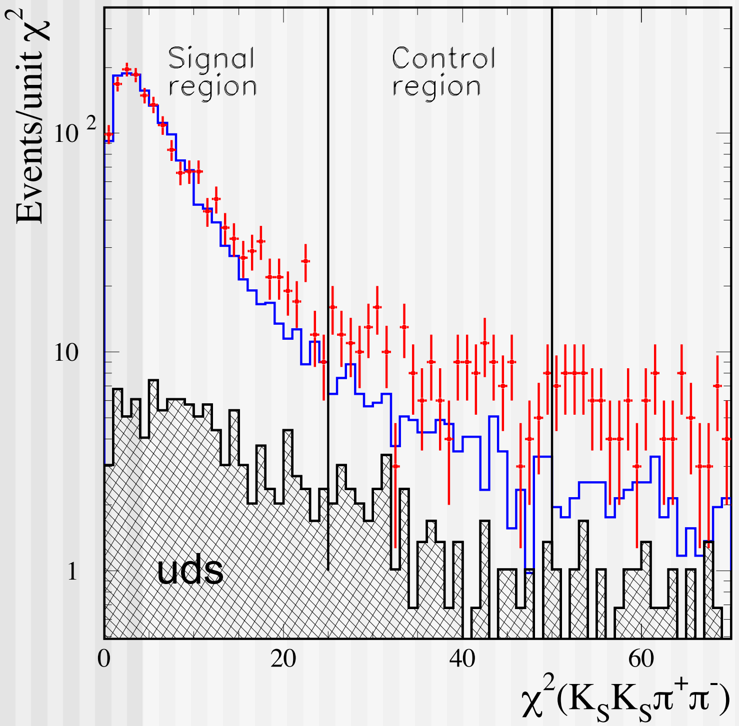
$\phi\pi^+\pi^-$ (ϕ $f_0(980)$)
seen as expected

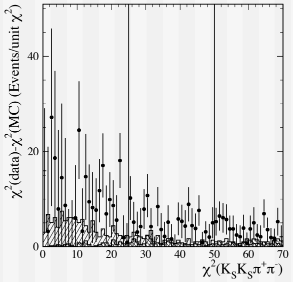
$K_S K_S(2\pi, 2K)$ in ISR study

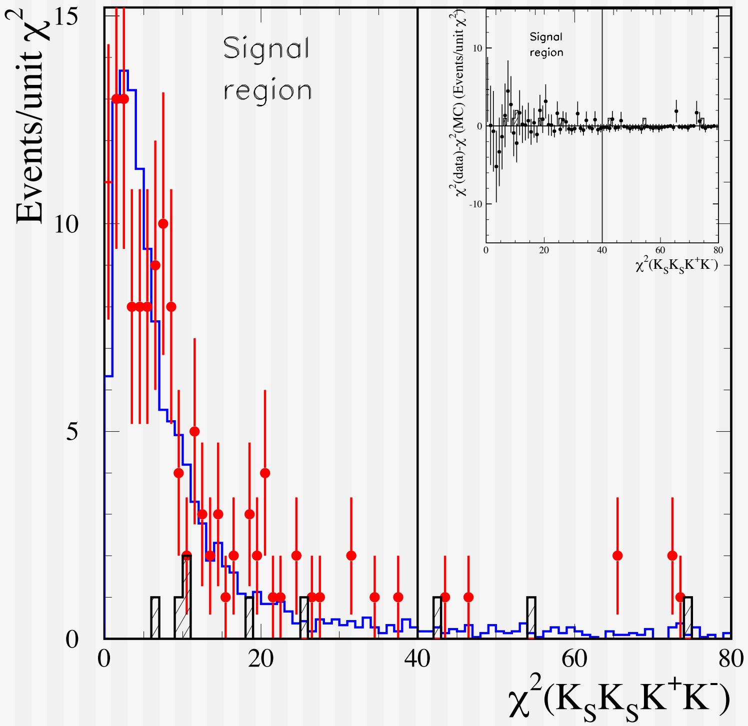
$K_S K_S \pi^+\pi^-(K^+K^-)\gamma$ event selection

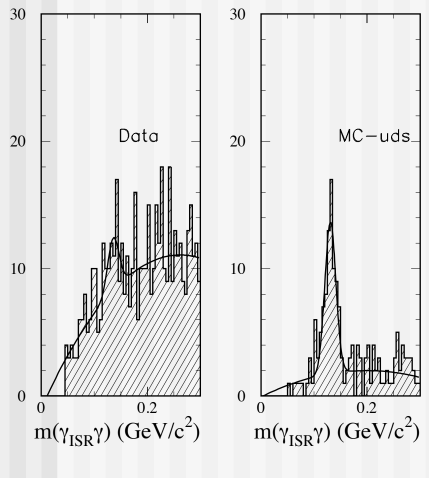
- Select 2 (best) K_S (use cov. matrix)
- Select ISR photon (use align. corrections and res.)
- Two tracks with DocaXY<0.1 cm (not from $K_{S,}$ 0-1 K ID for $\pi\pi$ or 2 K ID)
- No more tracks inside (1cm in R x 3 cm in Z) cylinder.
- Best χ^2 for 4C fit assuming $K_S K_S \pi^+\pi^-(K^+K^-)\gamma$ hypotheses

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

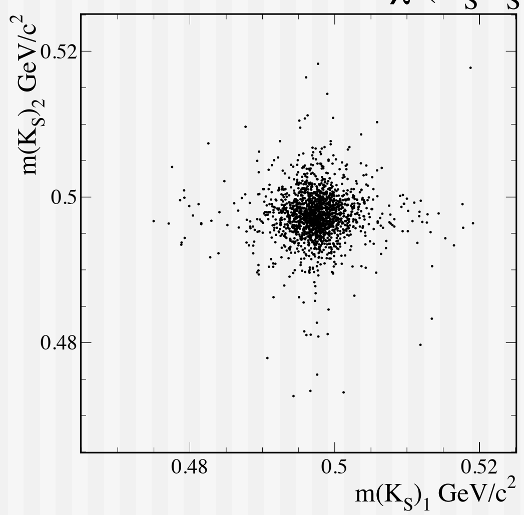




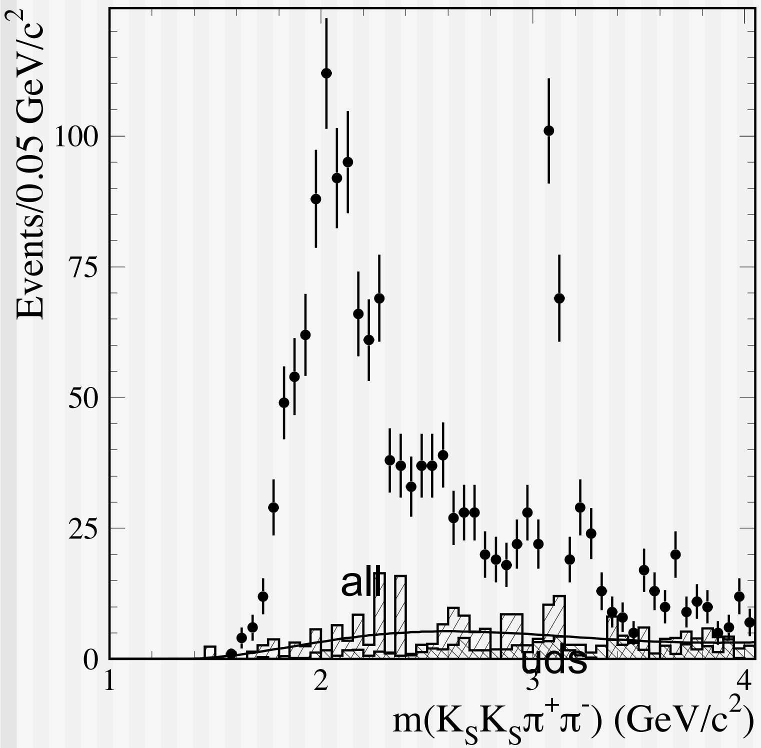


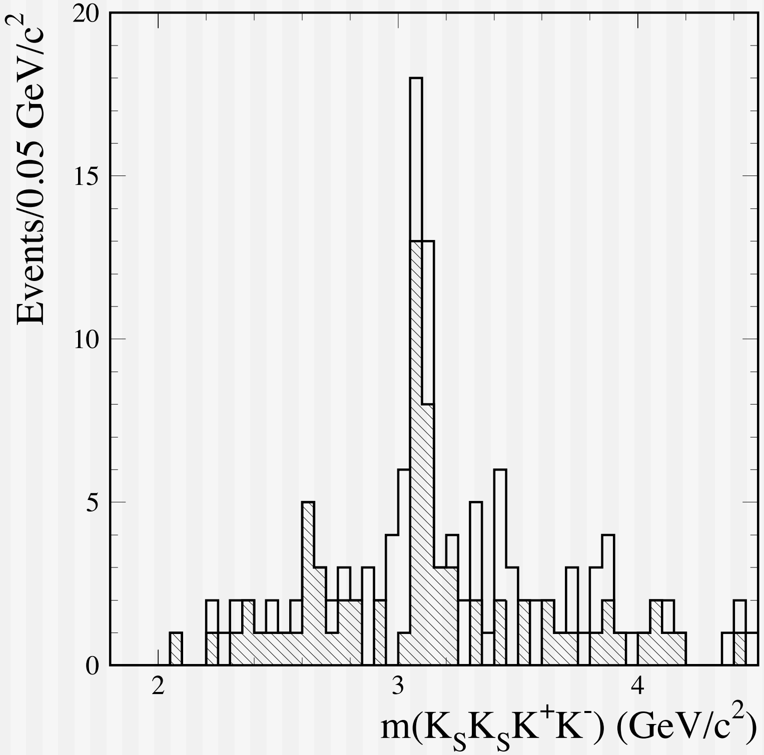


Very low background,
21/61 data-MC uds normalization



$K_S K_S \pi^+\pi^-(K^+K^-)$ mass distribution

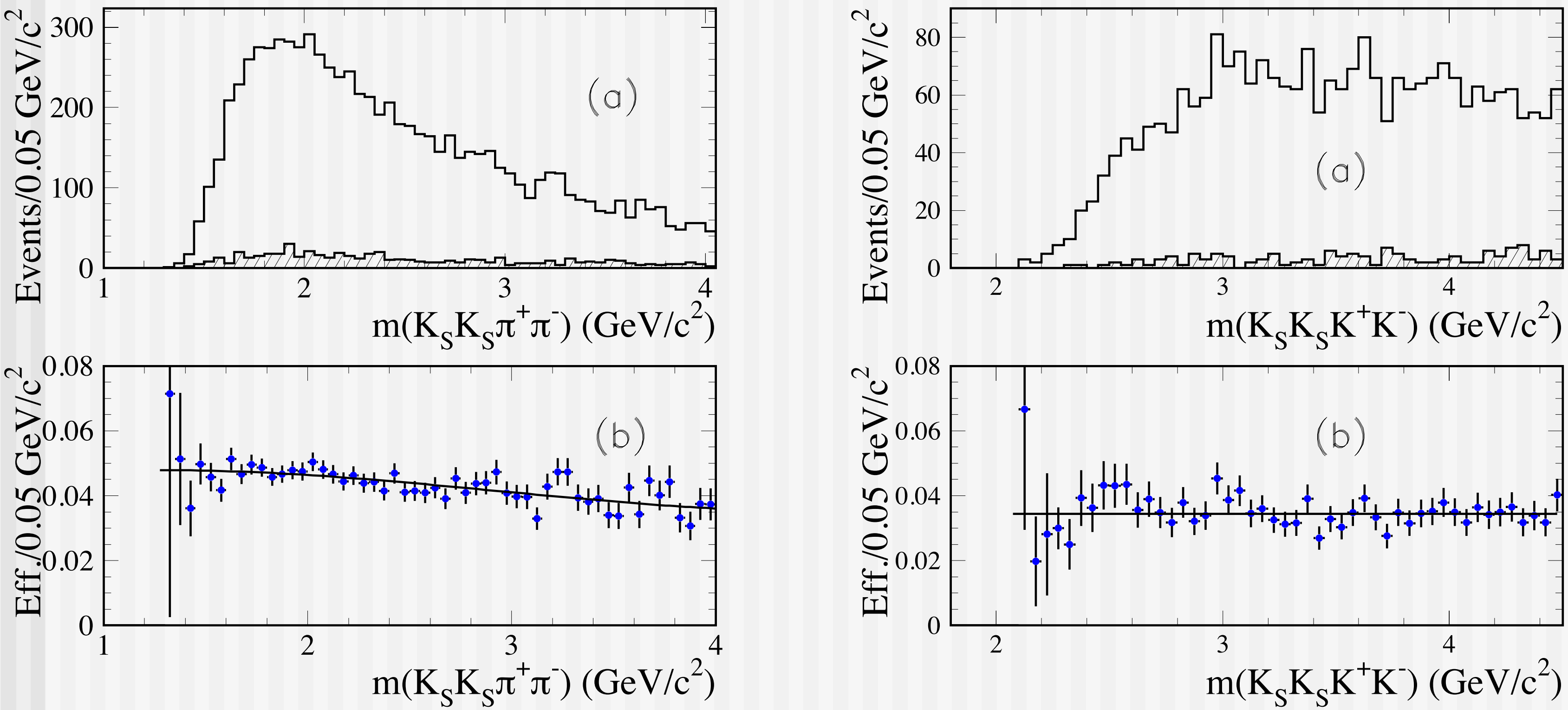




1479 events after background subtraction

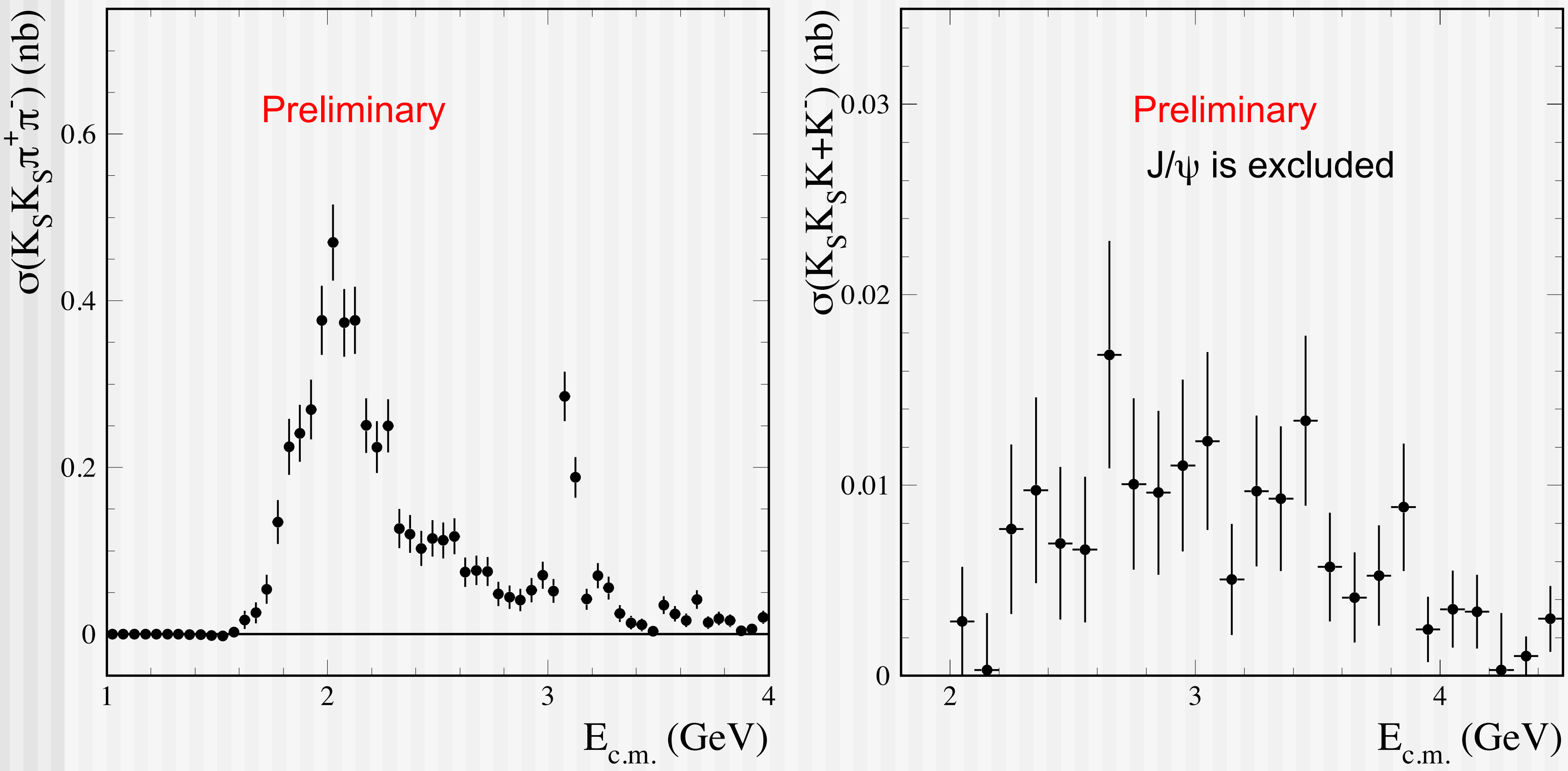
129 events – assume no background
(shaded: $\phi(1020)K_S K_S$)

$e^+e^- \rightarrow K_S K_S \pi^+\pi^-(K^+K^-)\gamma$ efficiency



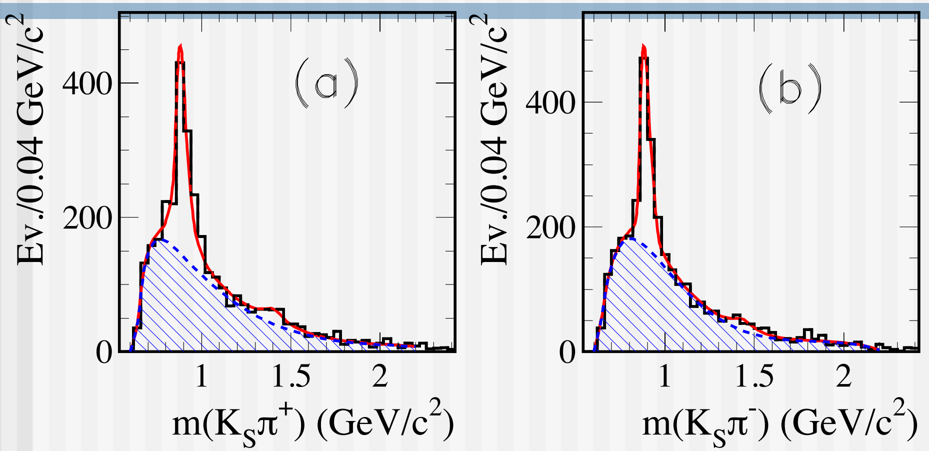
Corrections: -6% (1%/track), -1.5% for ISR gamma

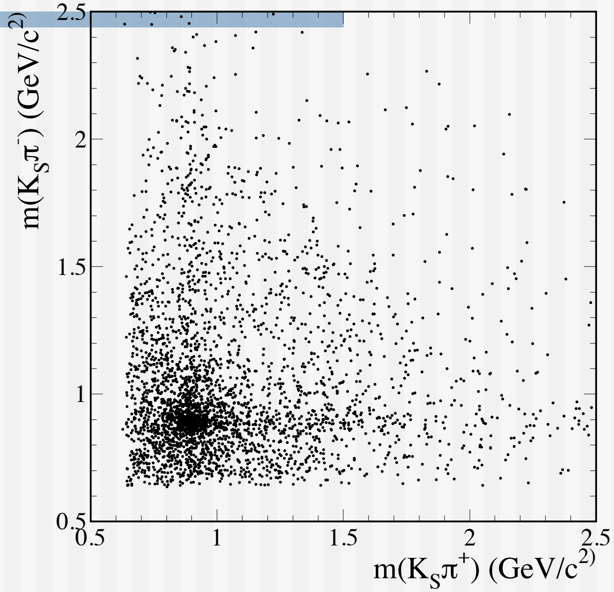
$e^+e^- \rightarrow K_S K_S \pi^+\pi^-(K^+K^-)$ cross sections



No other measurements are available

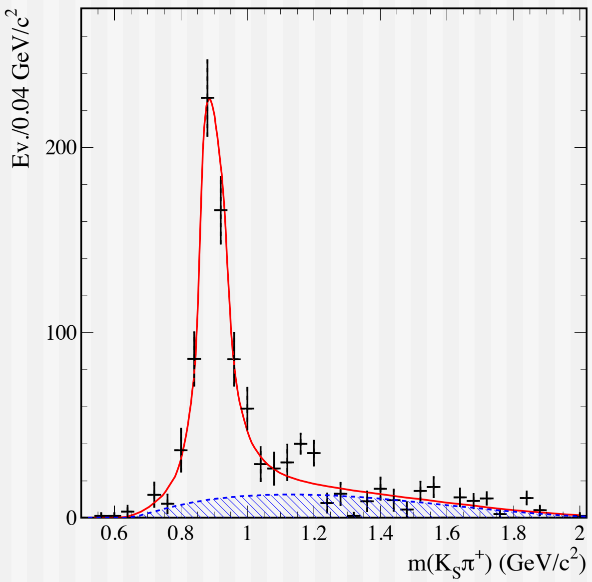
Some mass distributions (1)





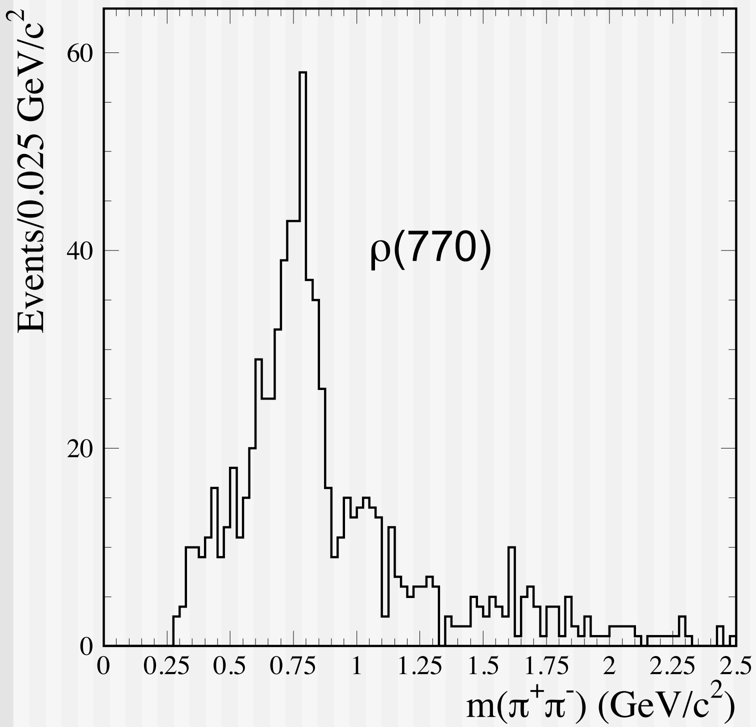
Very clear $K^*(892)^{\pm}$ signals with
829 ± 49 for K^{*+} ($K_S\pi^+$) and 856 ± 50 for K^{*-} ($K_S\pi^-$)
Plus   116 ± 40 (70±34) events for $K_2(1430)^{\pm}$

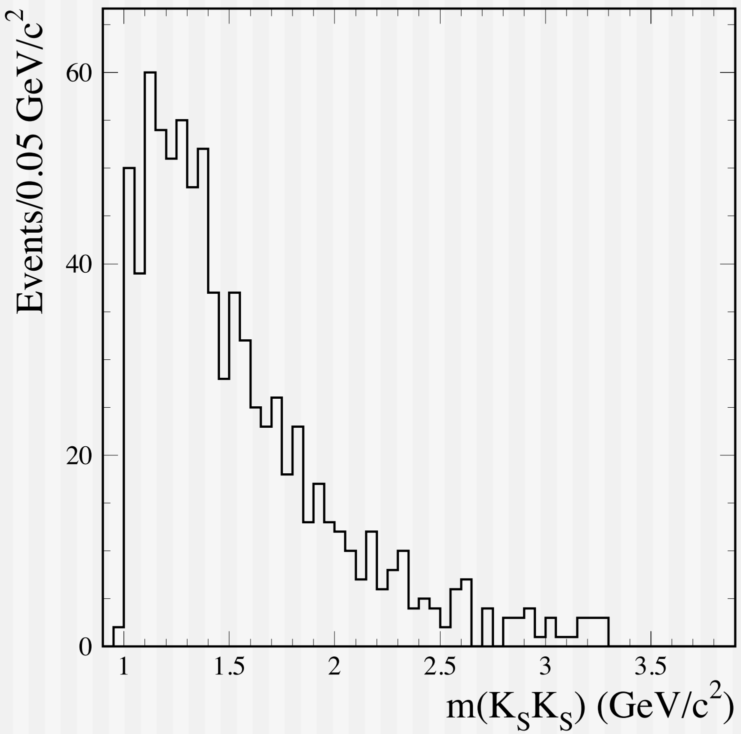
How large is $K^*(892)^+K^*(892)^-$?
Fit slice in $m(K_S\pi^-)$ for number of $K_S\pi^+$
Very clear signal with 742 ± 30 ± 100 events (50%)
of $K^*(892)^+K^*(892)^-$ correlated production!
No $K^*(892)^{+-}K_2^*(1430)^{-+}$ seen.



Some mass distributions (2)

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

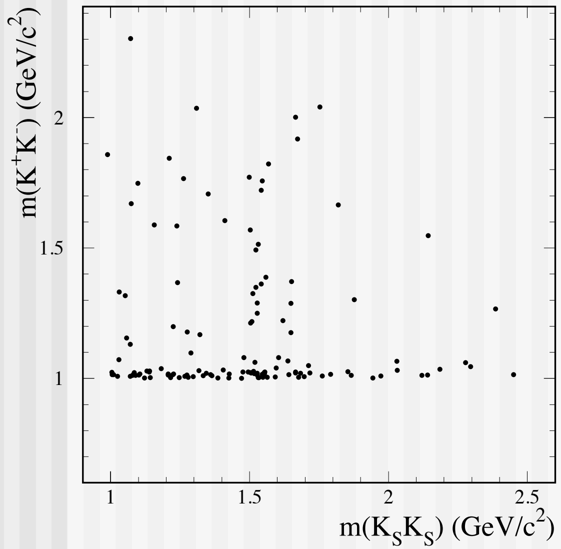


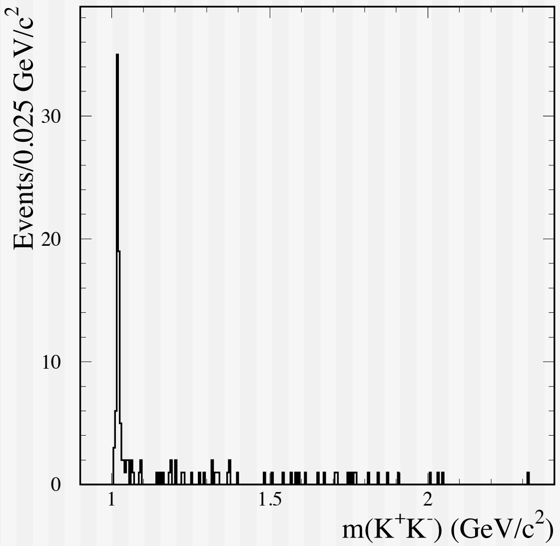


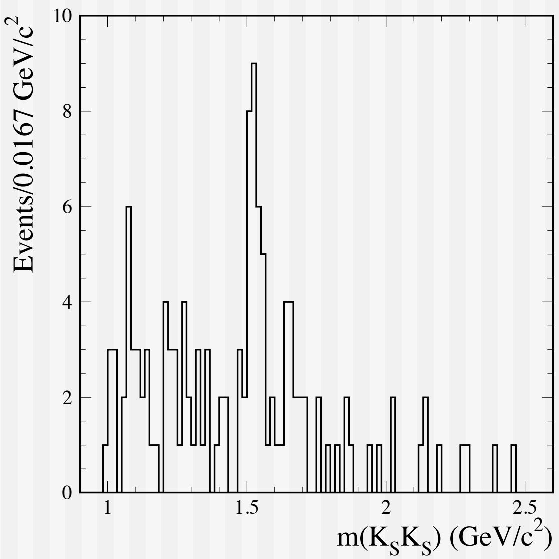
Plus some number of $K^*(892)K_S\pi$ events

Some mass distributions (3)

For the $K_S K_S K^+ K^-$ channel:



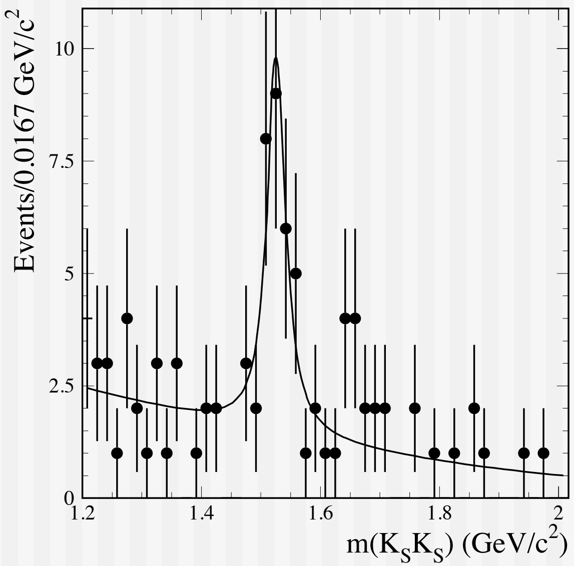




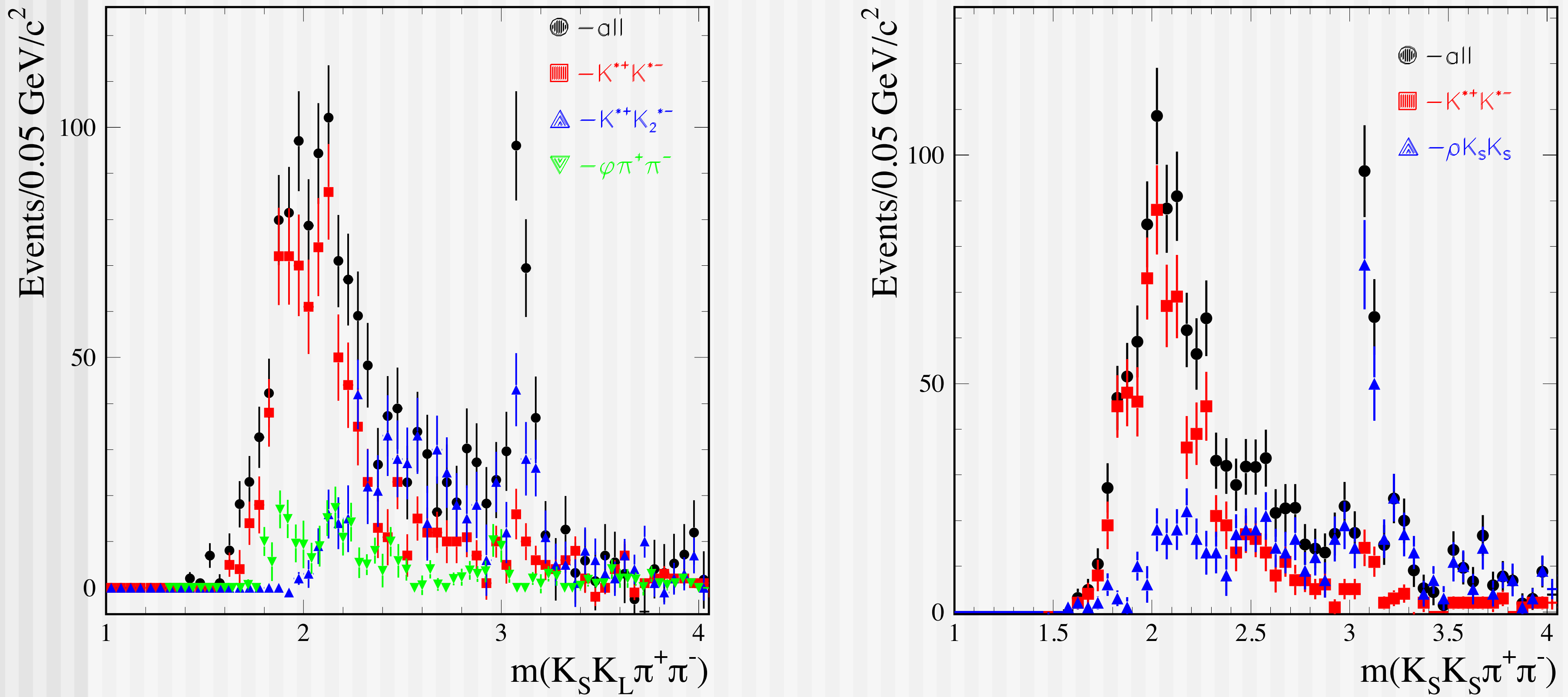
N (K^+K^- f2')= 29 ± 7 events

$m(K_S K_S)$ = 1.526 ± 0.007 GeV/c2
Γ = 0.037 ± 0.013 GeV

PDG:
$m(f_2')$ = 1.525 ± 0.005 GeV/c2
Γ = 0.073 ± 0.006 GeV

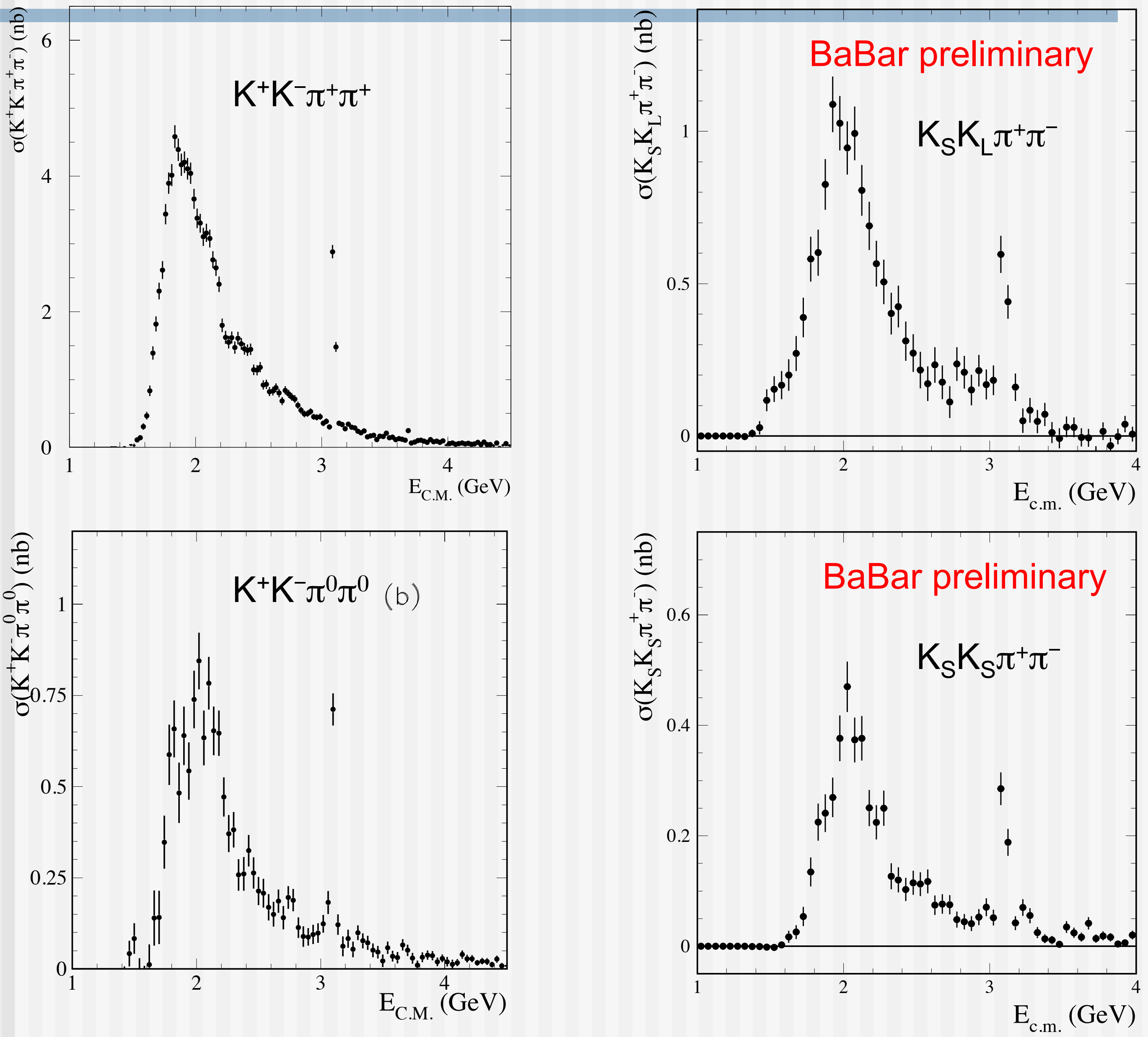


$K_S K_L \pi^+\pi^-$, $K_S K_S \pi^+\pi^-$ signal decomposition



Preliminary

The cross sections comparison



$K^+K^-\pi^+\pi^+$ 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:

$N(K^+K^-\pi^+\pi^-) = 548 \pm 263$ eff= 22% ($K^*(892)^0K^*(892)^0$)

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

Iso-spin relations: ArXiv:1010.4180 (Davier)

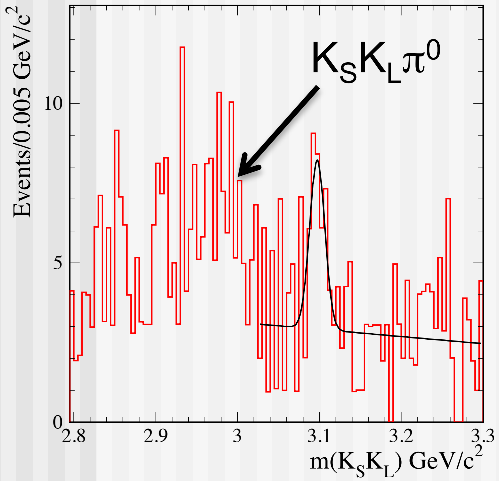
$N(K^+K^-\pi^0\pi^0) = \frac{1}{4} N(K^0\underline{K}^0\ \pi^+\pi^-)$
$N(K_SK_L\pi^+\pi^-) = \frac{1}{2} N(K^0\underline{K}^0\ \pi^+\pi^-)$
$N(K_SK_S\pi^+\pi^-) = N(K_LK_L\pi^+\pi^-) = \frac{1}{4} N(K^0\underline{K}^0\ \pi^+\pi^-)$

Should be (after efficiency correction) :

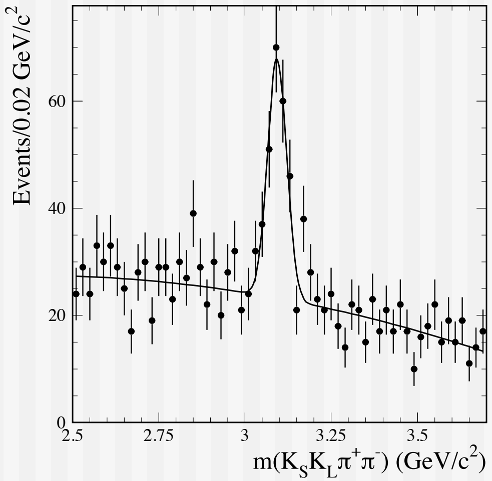
2188 ± 76 ~ 2098 ± 209 ~ 1648 ± 232 Some tension (~2 sigma)

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

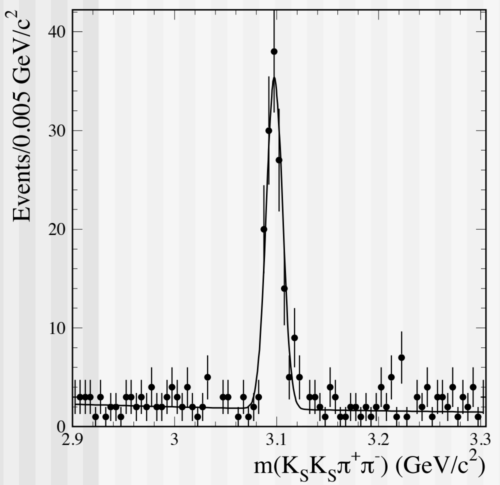
J/ψ region



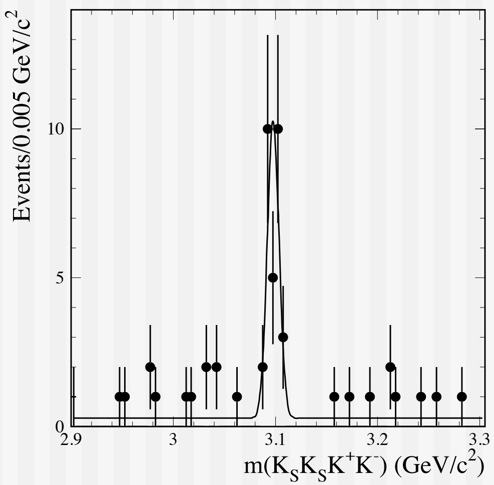
N = 24.6 ± 7.5



N = 154 ± 19



N = 248 ± 27



N = 28.5 ± 5.1

We observe J/ψ signal in all studied channels (Preliminary)

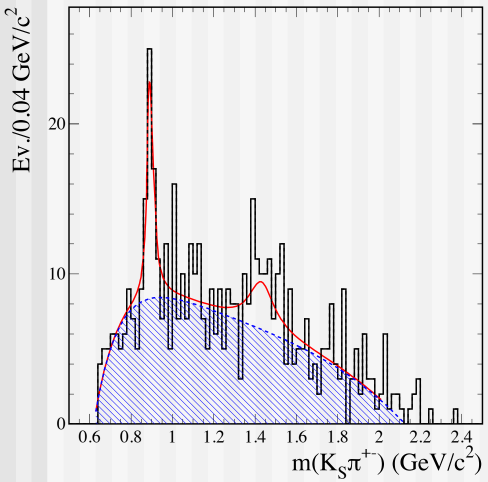
We measure:

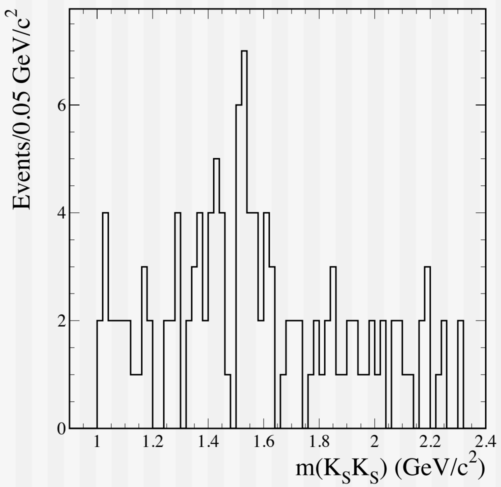
$$\mathcal{B}_{J/\psi \to f} \cdot \Gamma_{ee}^{J/\psi} = \frac{N_{J/\psi \to f} \cdot m^2_{J/\psi}}{6\pi^2 \cdot d\mathcal{L}/dE \cdot \epsilon_f(m_{J/\psi}) \cdot C}$$

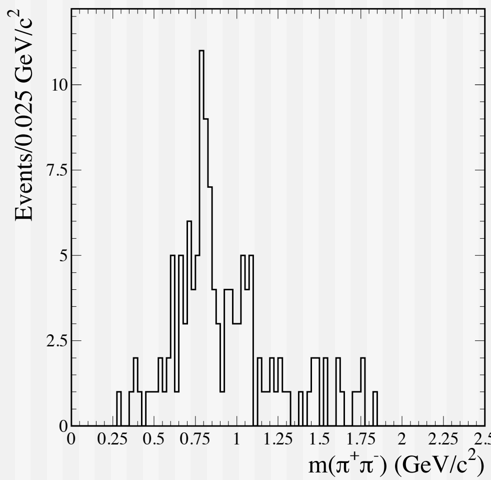
J/ψ intermediate states (Preliminary)

For $K_S K_S \pi^+ \pi^-$

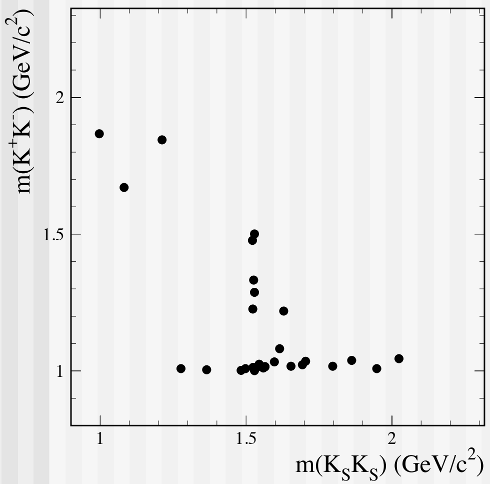
If $K^*(892)^+$ $K^*(892)^-$ are excluded:



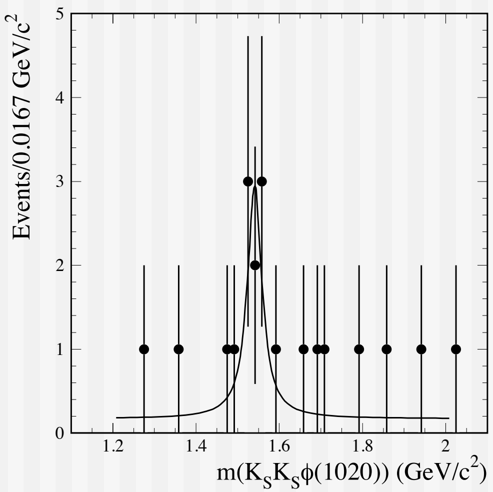




For $K_S K_S K^+ K^-$



N (ϕ $K_S K_S$)= 20 ± 5



N (ϕ f2') = 11 ± 4

J/ψ decay results (Preliminary)

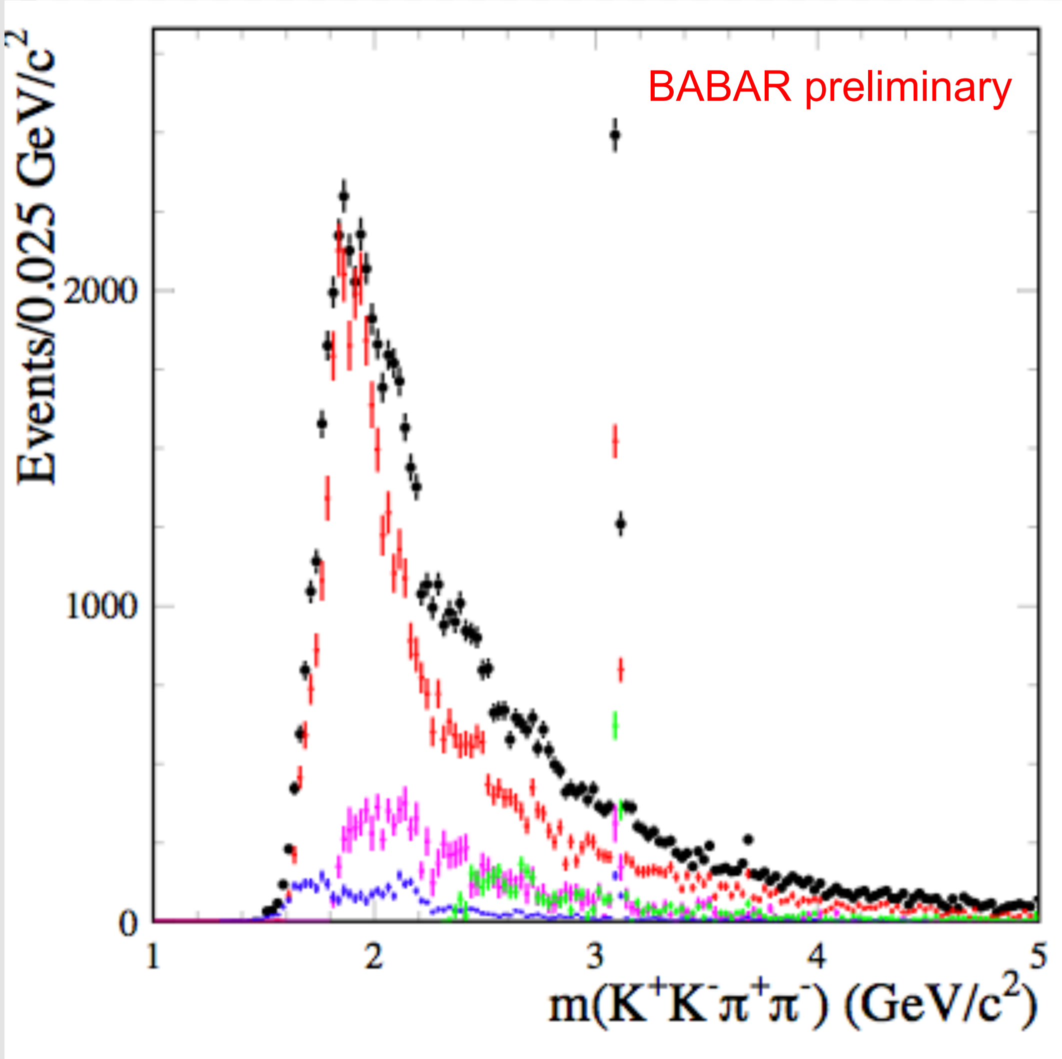
Measured Quantity	Measured value (eV)	This work Br (10^{-3}) Γ_{ee} = 5.55 ± 0.14 keV	PDG 2012
Γ_{ee}•Br(J/ψ -> $K_S K_L$)	1.13±0.34±0.11	0.20 ± 0.06± 0.02	0.146 ± 0.026 S=2.7
Γ_{ee}•Br(J/ψ -> $K_S K_L \pi^+\pi^-$)	20.9±2.7±2.1	3.7 ± 0.6 ± 0.4	no entry
Γ_{ee}• Br(J/ψ -> $K_S K_S \pi^+\pi^-$)	9.3±0.9±0.5	1.68 ± 0.16 ± 0.08	no entry
Γ_{ee}• Br(J/ψ -> $K_S K_S K^+K^-$)	2.3±0.4±0.1	0.42 ± 0.08 ± 0.02	no entry
Γ_{ee}• Br(J/ψ->$K_S K_S$φ)•Br(φ ->K+K-)	1.6±0.4±0.1	0.58 ± 0.14 ± 0.03	no entry
Γ_{ee}• Br(J/ψ->f2'φ)•Br(φ->K+K-) •B(f2'->$K_S K_S$)	0.88±0.34±0.04	0.45±0.17 ± 0.02	0.8 ± 0.4 S=2.7

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)

Summary

- BaBar continues analysis of collected data and ISR study in particular
- Recently published results for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, K^+K^- reactions have the best to date accuracy.
- New analysis of K_SK_L, $K_SK_L\pi^+\pi^-$, $K_SK_S\pi^+\pi^-$, $K_SK_SK^+K^-$ has been performed using 469 fb^{-1}
- The $e^+e^- \to K_SK_L\pi^+\pi^-$, $K_SK_S\pi^+\pi^-$, $K_SK_SK^+K^-$ cross section were never studied before
- Using these cross sections we can reduce uncertainty in the muon g-2 calculation.
- J/ψ decays to $K_SK_L\pi^+\pi^-$, $K_SK_S\pi^+\pi^-$, $K_SK_SK^+K^-$ have been measured for the first time.
- PRD paper is in preparation.

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

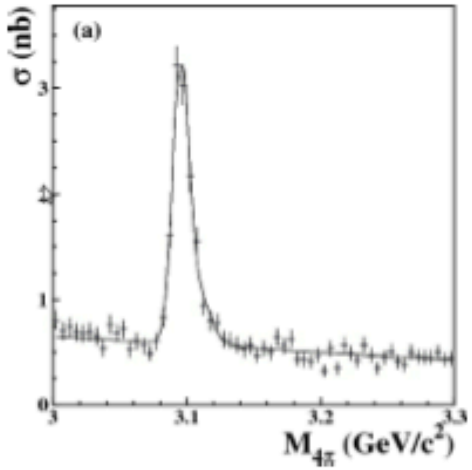
J/ψ, $\psi(2S) \rightarrow 2(\pi^+\pi^-)$, $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-$, $2(K^+K^-)$

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!)

charmonium branching ratios **PRELIMINARY**

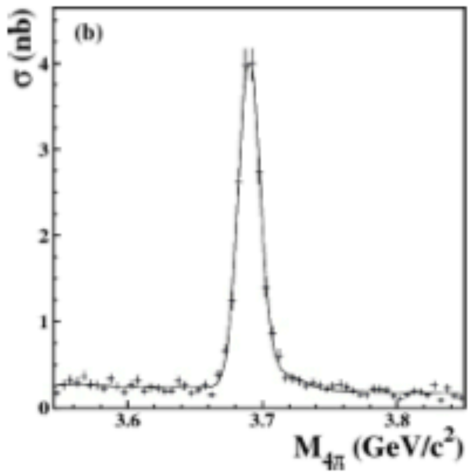


$$\mathcal{B}_{J/\psi\to 2(\pi^+\pi^-)} \cdot \sigma_{int}^{J/\psi} = \frac{N(J/\psi \to 2(\pi^+\pi^-))}{d\mathcal{L}/dE \cdot \epsilon_{MC}} = (48.9 \pm 2.1_{stat} \pm 1.0_{syst})\ \mathrm{MeV}/c^2\ \mathrm{nb}$$

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

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

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

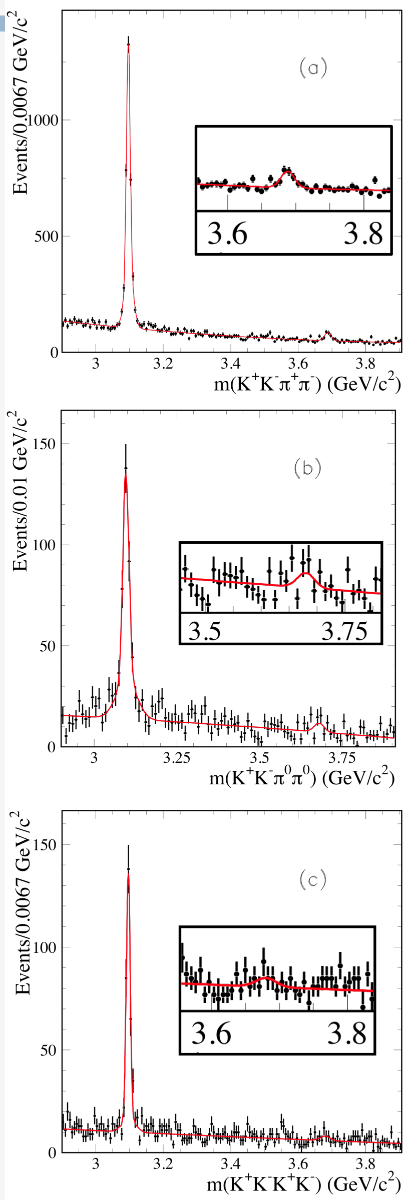


TABLE XIII: Summary of the J/ψ and $\psi(2S)$ branching fraction values obtained in this analysis.

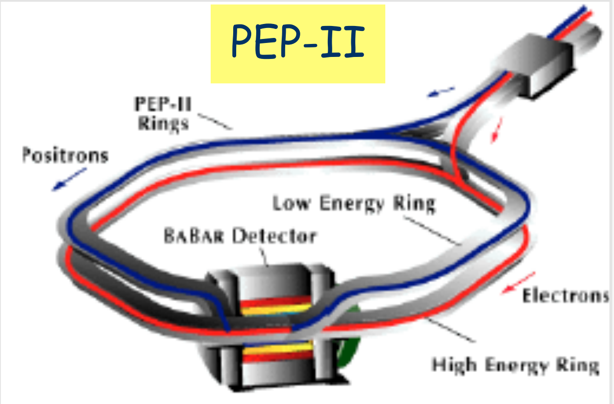
Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) This work	PDG2010
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^+\pi^-}$	37.94±0.81±1.10	6.84±0.15±0.27	6.6 ±0.5
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^0\pi^0}$	11.75±0.81±0.90	2.12±0.15±0.18	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] $\mathcal{B}_{\psi(2S)\to\phi f_0}$, $f_0\to\pi^+\pi^-$

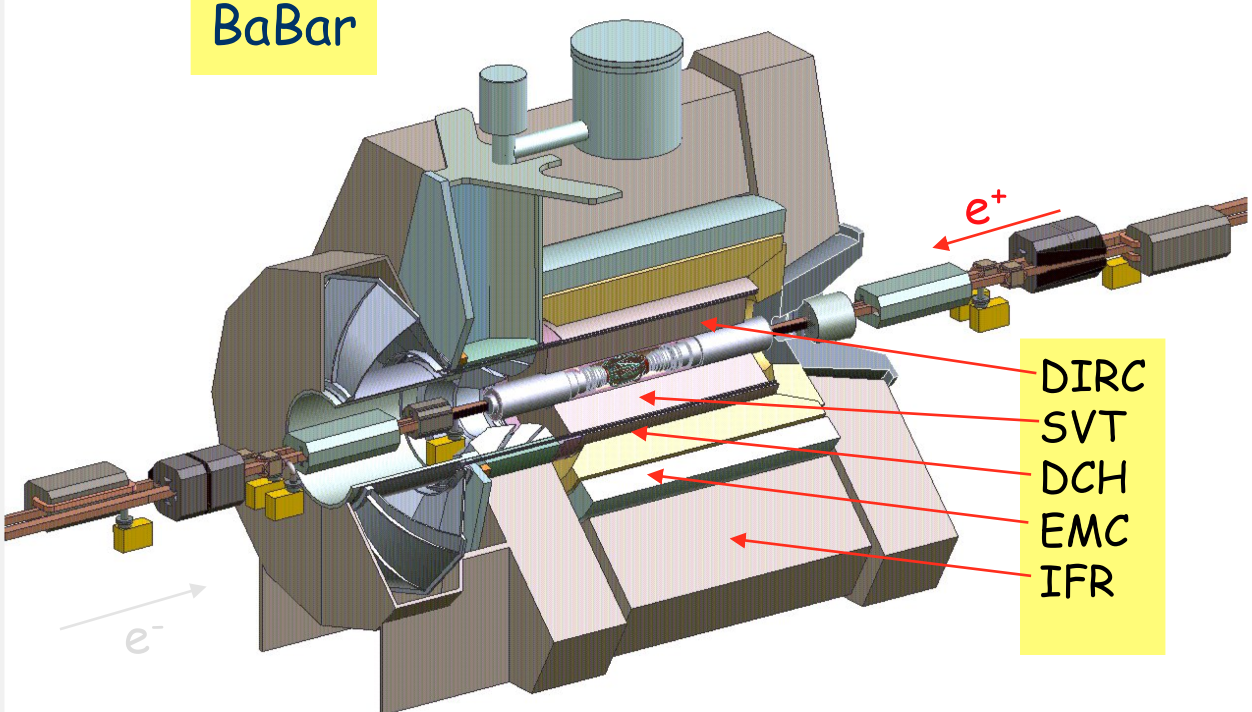
Small systematic errors allow BaBar to improve BF for major decay modes.

PEP-II e+e- collider, Babar detector

E_+ = 3.1 GeV, E_- = 9 GeV



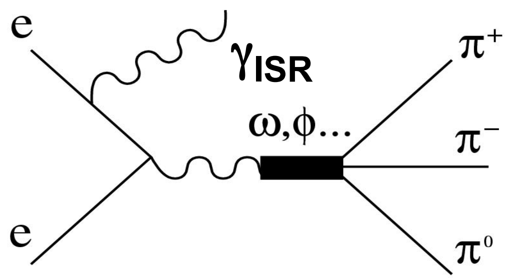
$E_{CM} = M(\Upsilon(4S))$=10.6 GeV
2000 - 2008 yrs
ΔL = 500 fb^{-1}
N(B) = 10^9



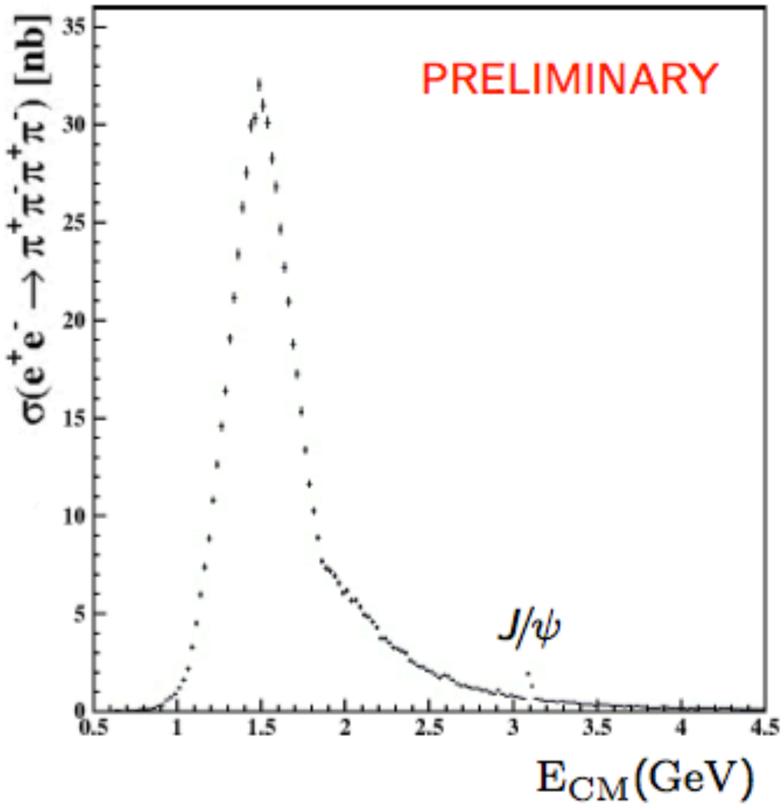
$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = W(s,x,\theta)\cdot\sigma_0(s(1-x)),$$

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

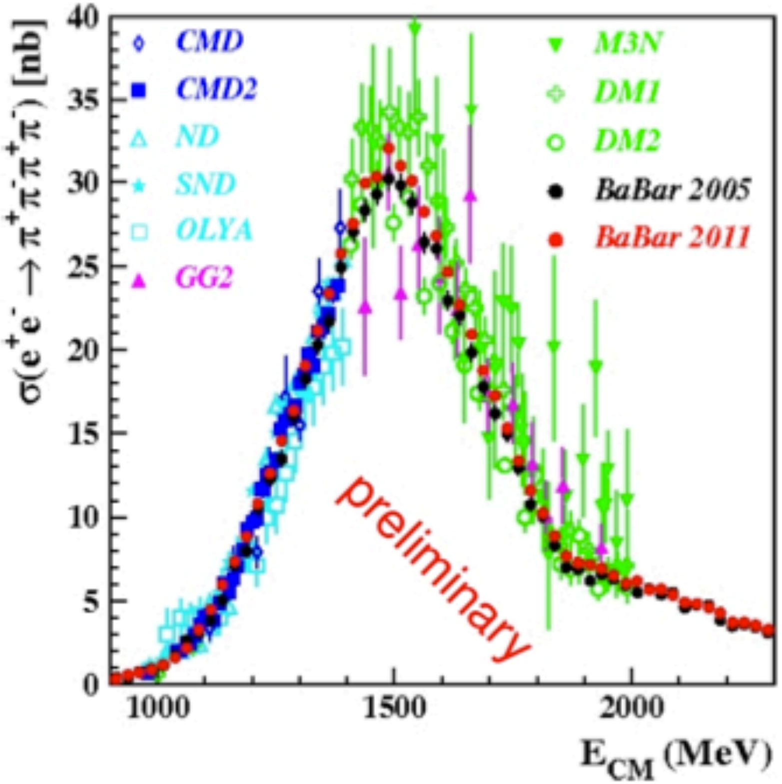
θ - photon polar angle in c.m.



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

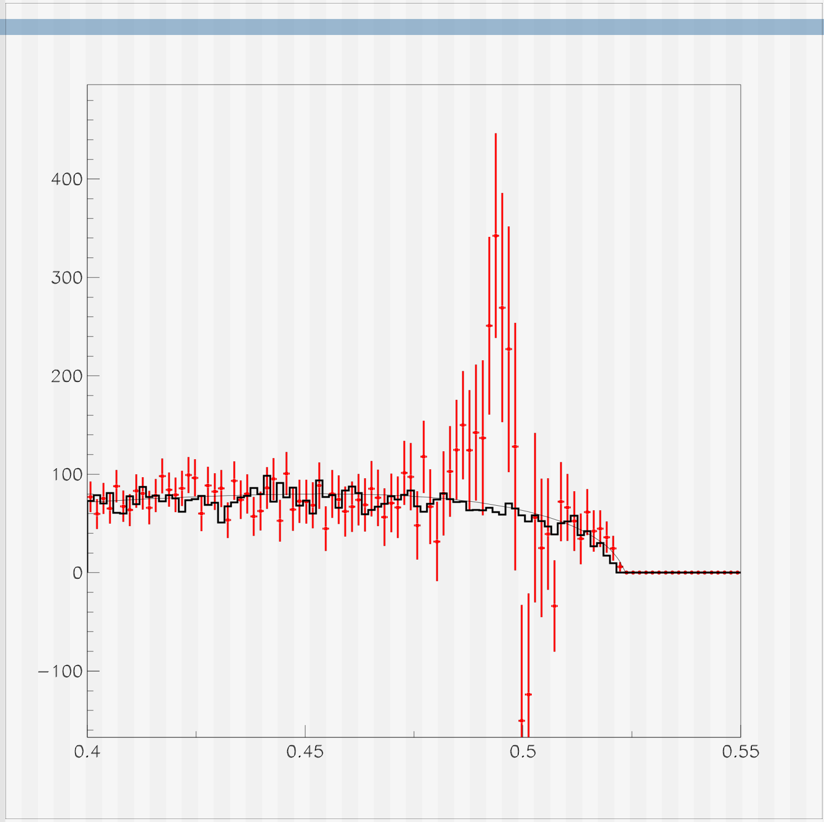


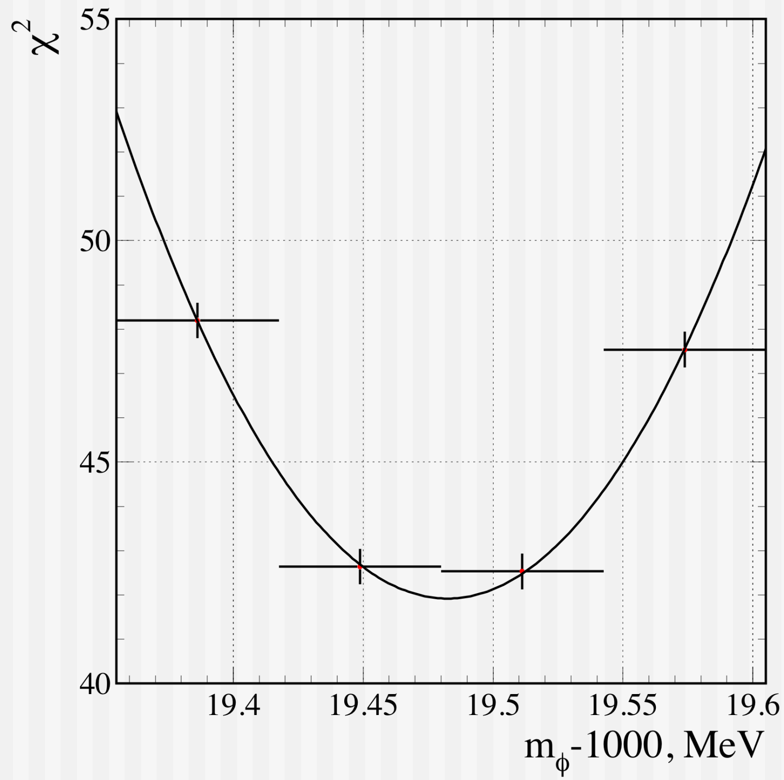
- systematic uncertainties
  2.4% in peak region (1.1-2.8 GeV)
  11% (0.6-1.1 GeV)
  4% (2.8-4.0 GeV)
- hint for J/ψ
- $a_\mu^{had}(4\pi) = (13.64 \pm 0.03 \pm 0.36) \cdot 10^{-10}$



- < 1.4 GeV: agreement with previous *BABAR* results, SND and CMD-2 data
- > 1.4 GeV: highest precision (DM2, 20%)
- $a_\mu^{had}(4\pi) = (13.35 \pm 0.10 \pm 0.52) \cdot 10^{-10}$ (EPJ C66, 1 (2011))

$\phi(1020)$ mass

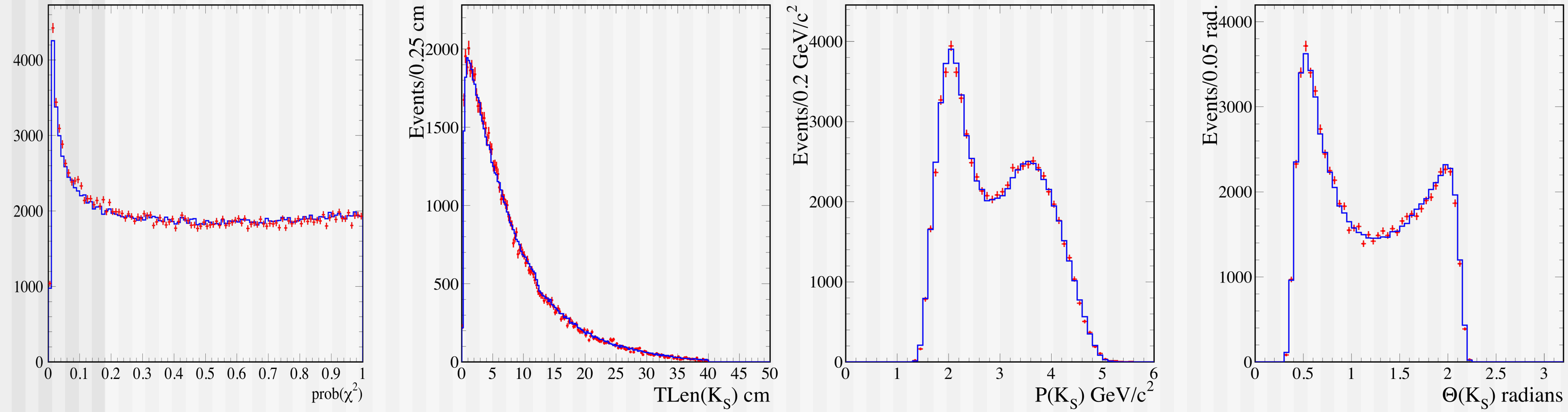


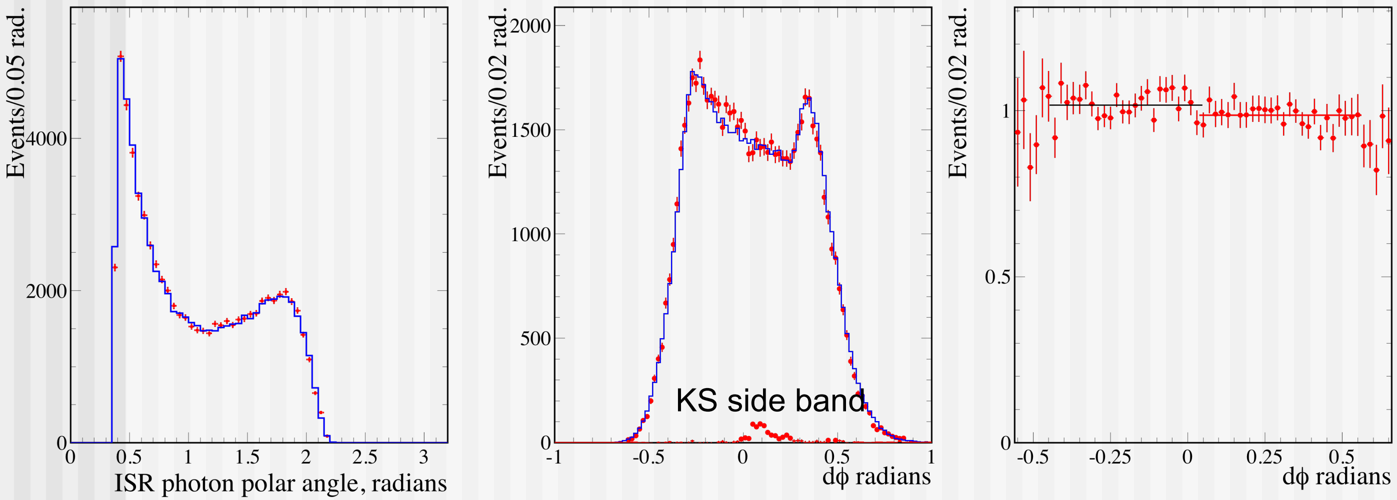


In MC we know all inputs and can create a "test" $m(K_L)$ distribution and compare with data. And the only free parameter is $\phi(1020)$ mass. By varying f mass we calculate $\chi2$ value by fitting data-MC difference with "ARGUS" function. We obtain:

$m_\phi = 1019.483 \pm 0.040 \pm 0.036$ 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.