# Study of resonant-states production in $e^+e^-$ annihilation in the energy region around 2.2 GeV

- The BaBar experiment
- Resonances in $e^+e^-$ annihilation near 2.2 GeV
  Phys. Rev. D 101, 012011 (2020)
- The measurement of the cross section of $e^+e^- \rightarrow K_S K_L$
- Discussion
- Summary

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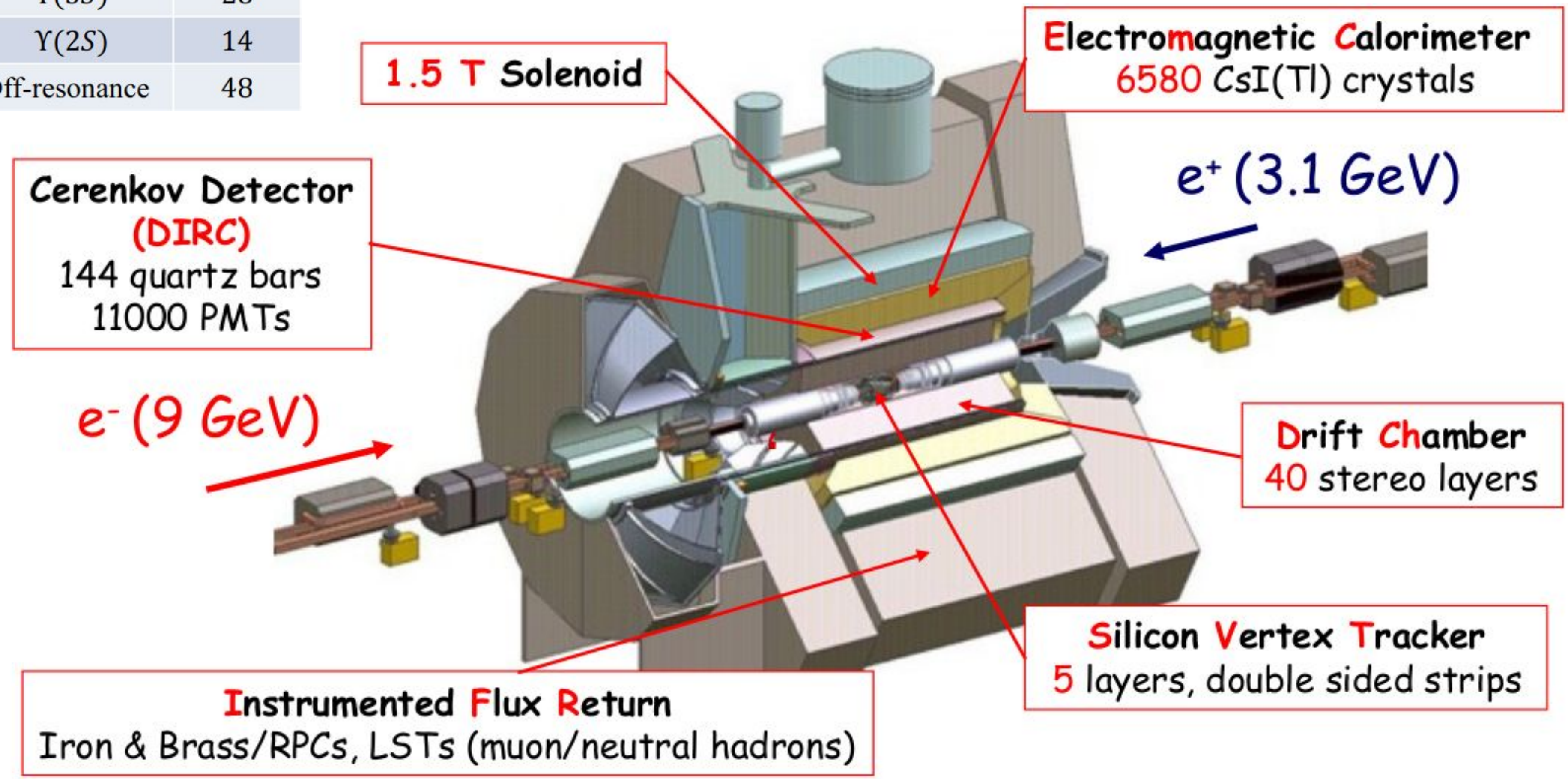
Remotetalk

FPCP 2020 A Toxa, Spain

# BaBar detector, the collecting of data taking ended in 2008

| Resonance | L($fb^{-1}$) |
|---|---|
| $\Upsilon(4S)$ | 424 |
| $\Upsilon(3S)$ | 28 |
| $\Upsilon(2S)$ | 14 |
| Off-resonance | 48 |




BABAR detector at center-of mass energy of 10.6 GeV at the $e^+e^-$ collider PEP-II at SLAC

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

- Recently a very precise measurement of the $e^+e^- \to K^+K^-$ cross section has been carried out in the BESIII experiment
-

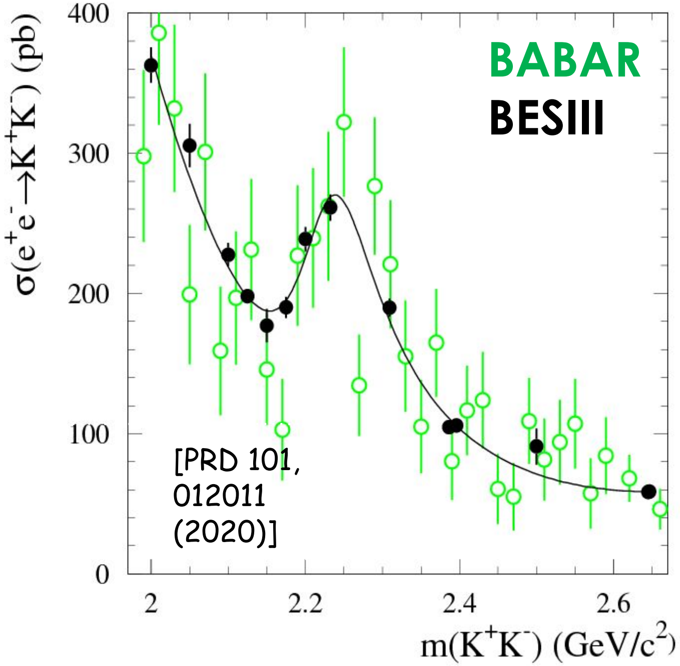
$$\sigma(E) = \frac{M_R^2 \beta(E)^3}{E^2 \beta(M_R)^3} \left| \sqrt{\sigma_R} BW(E) + e^{i\varphi} P(E) \right|^2$$

| | |
|---|---|
| $M_R$ | $2227 \pm 9 \pm 9$ MeV/$c^2$ |
| $\Gamma_R$ | $127 \pm 14 \pm 4$ MeV |
| $\sigma_R$ | $39 \pm 6 \pm 4$ pb |
| $\varphi$ | $143 \pm 8 \pm 9$ deg |

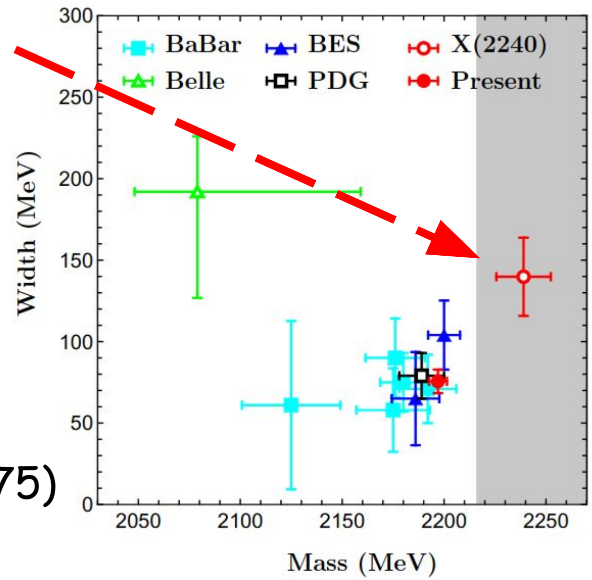
"KK-R"

PRD 88 (2013), 032013

PRD 99 (2019), 032001



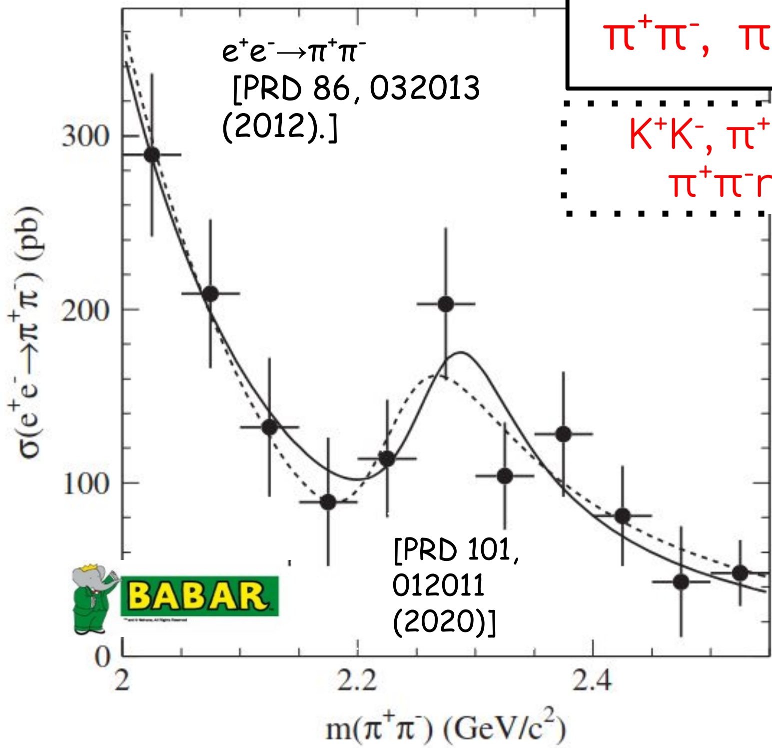

- In the PDG there are φ(2170) and ρ(2150)
- Does the resonance correspond to an isoscalar or an isovector state?
- In which processes should the resonance be seen?




The resonance parameters of Y(2175)

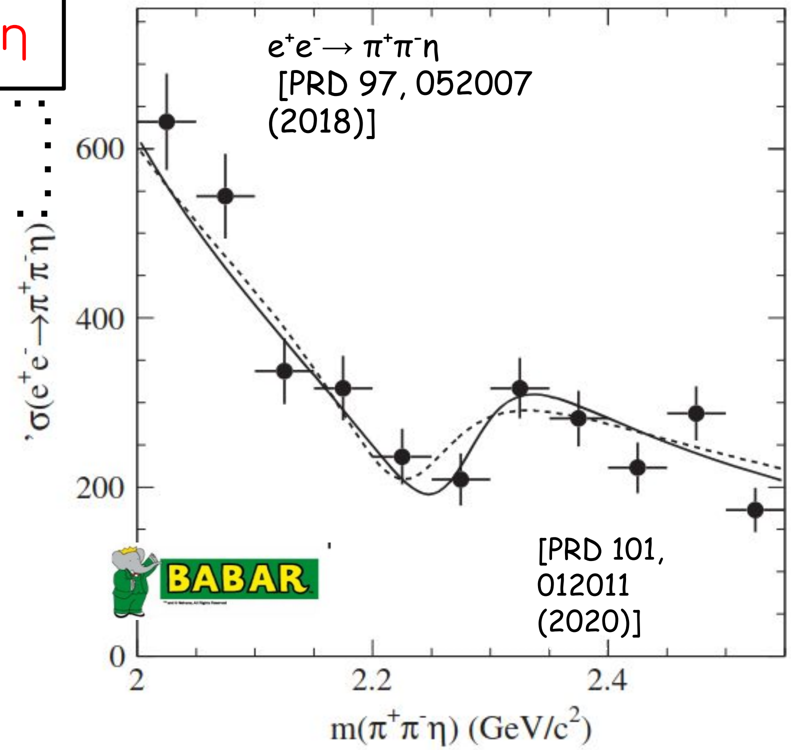
https://arxiv.org/pdf/2004.09701.pdf

# Simultaneous study of $e^+e^- \to K^+K^-$, $\pi^+\pi^-$, $\pi^+\pi^-\eta$




$\pi^+\pi^-$, $\pi^+\pi^-\eta$

$K^+K^-$, $\pi^+\pi^-$, $\pi^+\pi^-\eta$

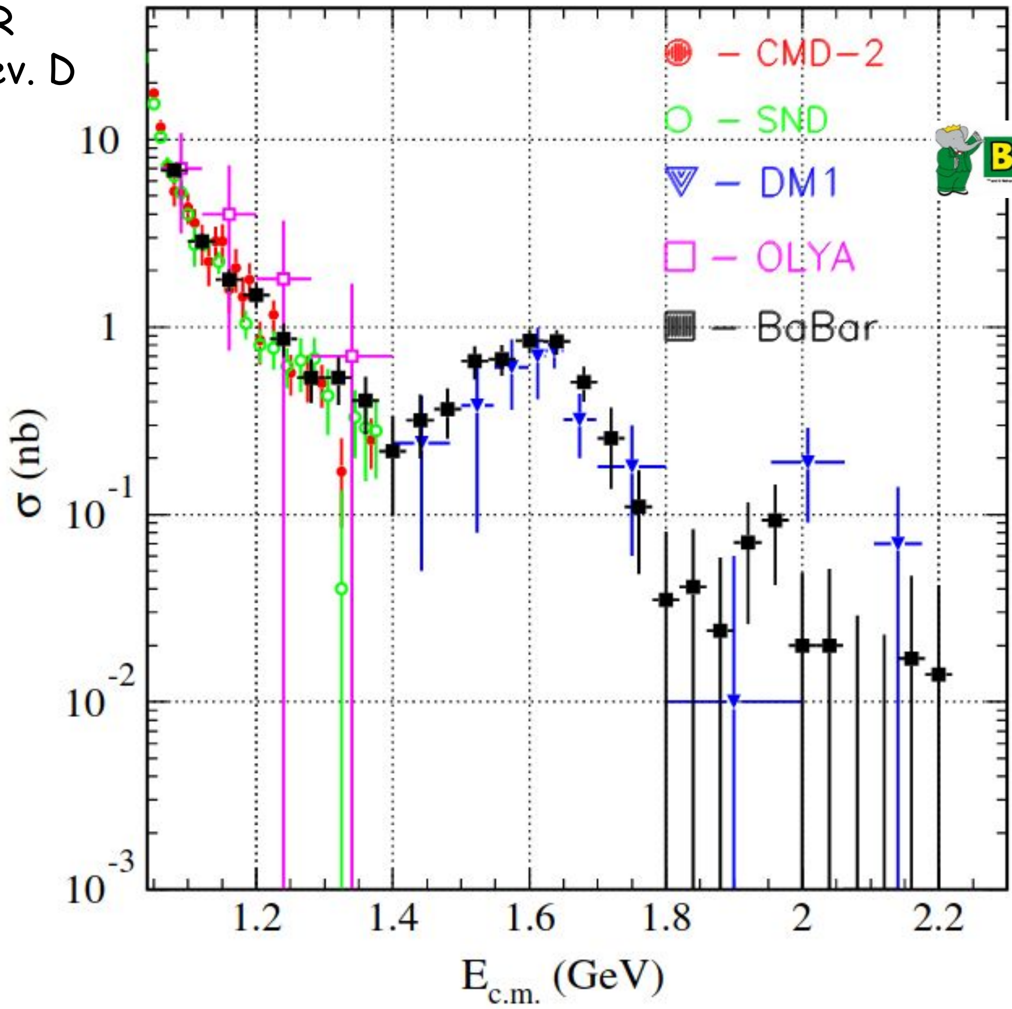



| | $\pi^+\pi^-$ and $\pi^+\pi^-\eta$ | $K^+K^-$, $\pi^+\pi^-$, and $\pi^+\pi^-\eta$ |
|---|---|---|
| $M_R$ (MeV/$c^2$) | $2270 \pm 20 \pm 9$ | $2232 \pm 8 \pm 9$ |
| $\Gamma_R$ (MeV) | $116^{+90}_{-60} \pm 50$ | $133 \pm 14 \pm 4$ |
| $\sigma(e^+e^- \to R \to K^+K^-)$ (pb) | ... | $41 \pm 6 \pm 4$ |
| $\sigma(e^+e^- \to R \to \pi^+\pi^-)$ (pb) | $34^{+26}_{-19} \pm 4$ | $36^{+27}_{-20} \pm 4$ |
| $\sigma(e^+e^- \to R \to \pi^+\pi^-\eta)$ (pb) | $33^{+34}_{-13} \pm 4$ | $27^{+14}_{-11} \pm 4$ |
| $\varphi(e^+e^- \to K^+K^-)$ (deg) | ... | $140 \pm 8 \pm 9$ |
| $\varphi(e^+e^- \to \pi^+\pi^-)$ (deg) | $147 \pm 30 \pm 10$ | $188 \pm 19 \pm 9$ |
| $\varphi(e^+e^- \to \pi^+\pi^-\eta)$ (deg) | $217 \pm 24 \pm 9$ | $251 \pm 15 \pm 9$ |
| $\chi^2/\nu$ | 13.96/12 | 17.2/14 |

- The inclusion of φ(2170) does not almost change results

# The previous measurement of $e^+e^- \to K_S K_L$ cross section with BaBar detector

J. P. Lees et al. (BABAR Collaboration), Phys. Rev. D 89, 092002 (2014).

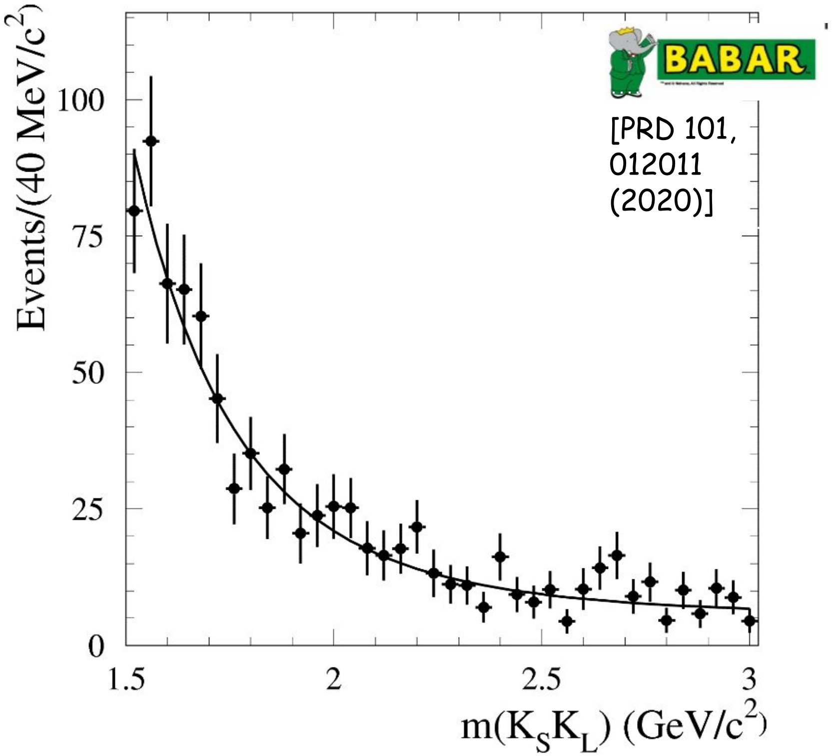



The $e^+e^- \to K_S K_L$ cross section compared with all available data

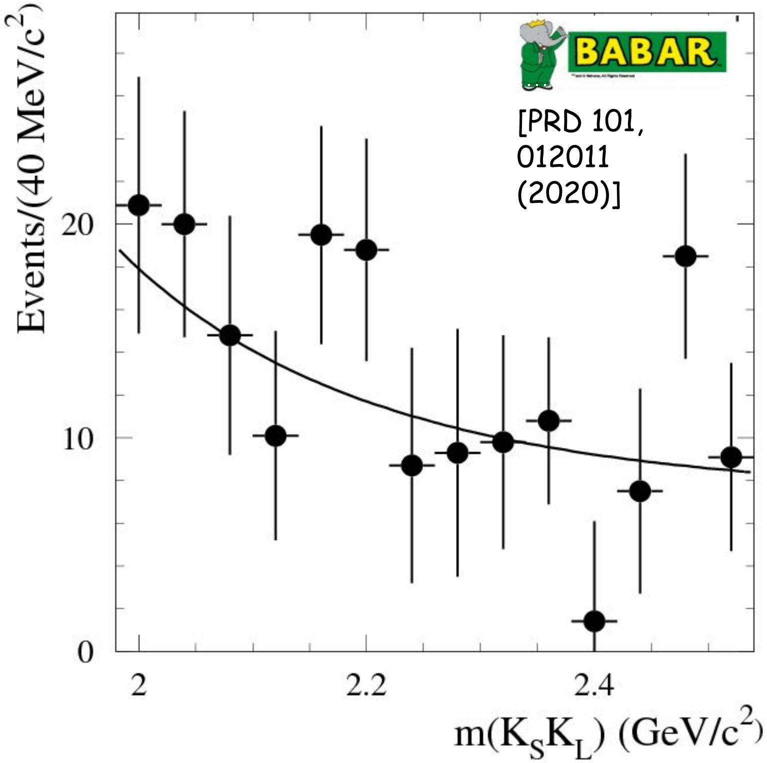
The new measurement of $e^+e^- \to K_S K_L$ cross section. Phys. Rev. D 101, 012011 (2020)

# Background subtraction.

The background mass distribution estimated from the $\chi^2$ sideband



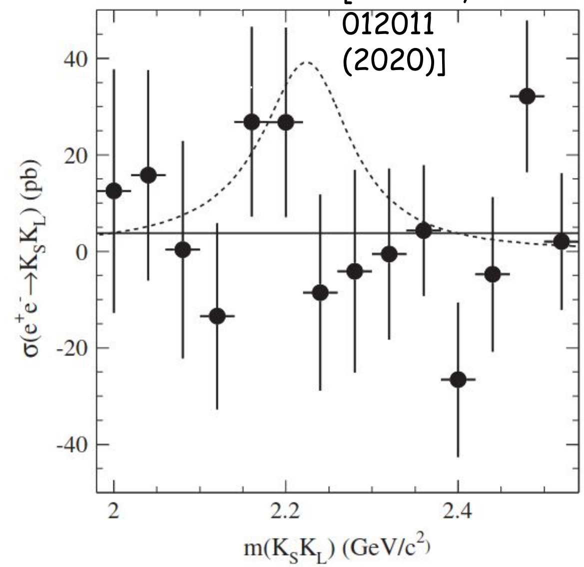

The mass distribution in the signal region and fitted background




- The systematic uncertainty of fitted background above 2 GeV is 12%
- We do not see a significant signal of $K_S K_L$ events over background.

# The new measurement of $e^+e^- \to K_S K_L$ cross section

[PRD 101, 012011 (2020)]




## 1. Fit with constant

The **average** value of the cross section between 1.98 and 2.54 GeV/$c^2$ is found to be **(4±5±5) pb**, which is **consistent with zero**.

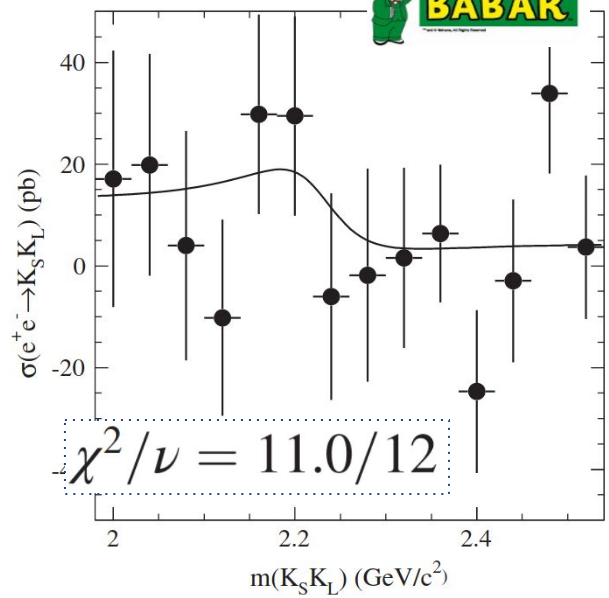
**2. The dashed curve** represents the cross section for the resonance observed in $e^+e^- \to K^+K^-$ . Formally, from the $\chi^2$ difference between the resonance and non-resonance hypotheses the resonance interpretation can be excluded at 2.3σ.

## 3. Fit with interference term

$$\sigma(E) = \frac{M_R^2 \beta(E)^3}{E^2 \beta(M_R)^3} \left| \sqrt{\sigma_R} BW(E) + e^{i\varphi} \sqrt{\sigma_{NR}} \right|^2$$

$\sqrt{\sigma_R} BW(E)$ fixed from the fit of $e^+e^- \to K^+K^-$

$$\sigma_{NR} = 7.3^{+7.4}_{-5.3} \text{ pb} \qquad \varphi = (-69 \pm 23)^\circ$$

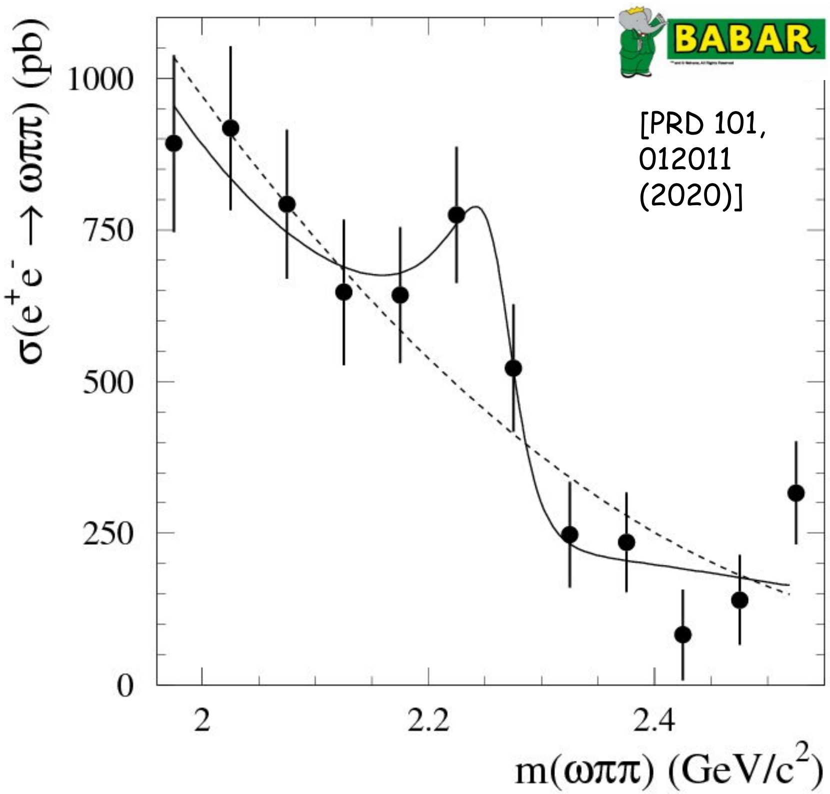



BABAR $e^+e^- \to K_S K_L$ data does not exclude the resonance observed in $e^+e^- \to K^+K^-$, but restricts the possible range of allowed values of the relative phase between the resonant and nonresonant amplitudes.

# ω-like resonance near 2250 MeV

The indication of ω-like resonance near 2250 MeV is seen in the BABAR data on the reactions $e^+e^- \to \omega\pi^+\pi^-$ and $\omega\pi^0\pi^0$.
B.Aubert et al., Phys. Rev. D76, 092005 (2007), J.P.Lees et al., Phys. Rev. D98, 112015 (2018)

- The fit results are
  M = 2265 ± 20 MeV
  $\Gamma = 75^{+125}_{-27}$ MeV
- The obtained values of the resonance mass and width are close to those for the isovector resonance.
- The dashed curve represents the fit without resonance by a second-order polynomial.
- The significance of the resonance estimated from the difference of $\chi^2$ for the two hypotheses is 2.6σ.



# Two-resonance fit: with ρ(2230) and ω near 2250 MeV/$c^2$

The isovector and isoscalar amplitudes enter to the $e^+e^- \to K_S K_L$ amplitude (in contrast to the $e^+e^- \to K^+K^-$ case) with opposite signs [1]

$$A(e^+e^- \to K^+K^-) = A_{I=0} + A_{I=1},$$
$$A(e^+e^- \to K_S K_L) = A_{I=0} - A_{I=1}$$

- The quark model predicts that $A_{I=0} = 1/3\ A_{I=1}$.
- The resonance amplitude in $e^+e^- \to K_S K_L$ is about two times smaller than that in the $e^+e^- \to K^+K^-$ reaction.
- Repeating this fit of $e^+e^- \to K_S K_L$ with the resonance amplitude smaller by a factor of two we obtained weakened parameters:

$$\sigma_{NR} = 5.0^{+8.2}_{-4.8}\ \text{pb},\ \ \varphi = \left(-51^{+56}_{-41}\right)^{\circ}$$

1. C.Bruch, A.Khodjamirian and J.H.Kuhn, Eur. Phys. J. C 39, 41 (2005)

# Summary

- The $e^+e^- \to K_S K_L$ cross section has been measured in the energy region (2--2.5) GeV.
- We do not see a significant signal of $K_S K_L$ events over background in this region and the average cross section is consistent with zero
- The interference patterns seen in the $e^+e^- \to \pi^+\pi^-$ and $e^+e^- \to \pi^+\pi^-\eta$ data near 2.25 GeV provide 4.6σ evidence for the existence of the isovector resonance ρ(2230). Its mass and width are consistent with the parameters of the resonance observed in the $e^+e^- \to K^+K^-$ channel.
- All the three cross sections are well described by the model with the isovector resonance ρ(2230) with $M = 2232 \pm 8 \pm 9$ MeV/$c^2$ and $\Gamma = 133 \pm 14 \pm 4$ MeV.
- Further study of the resonance structures near 2.25 GeV can be performed at the BESIII experiment.

# sparks

# Two-resonance fit: with ρ(2230) and φ(2170)

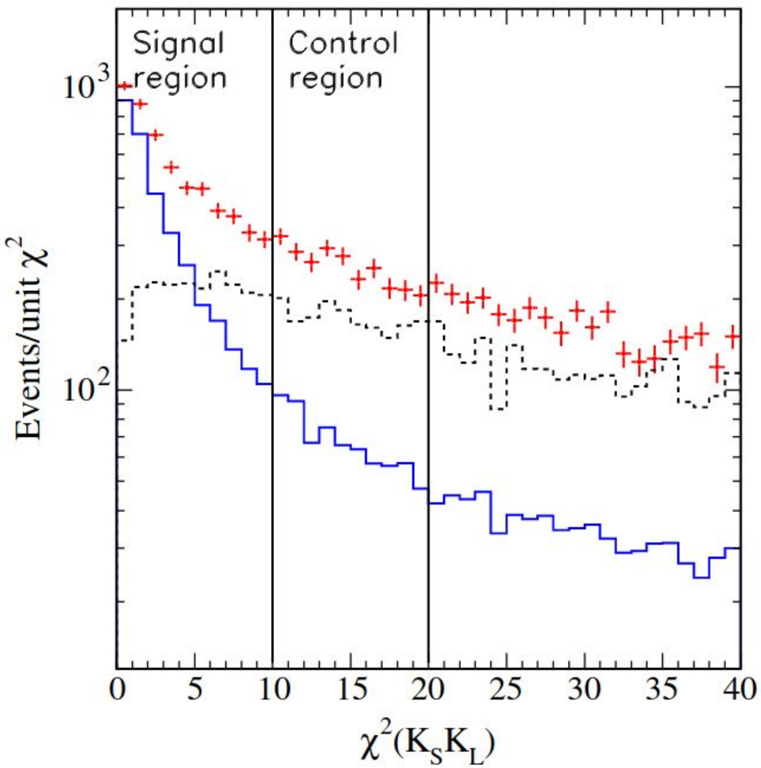
The $e^+e^- \to K^+K^-$, $\pi^+\pi^-$ and $\eta\pi^+\pi^-$ cross sections are fitted simultaneously.

$$\sigma(e^+e^- \to K^+K^-) = \frac{m_\phi^2 \beta(s)^3}{s\beta(m_\phi^2)^3}\left|\sqrt{\sigma_\phi}BW_\phi + \sqrt{\sigma_\rho}BW_\rho + e^{i\varphi}P(s)\right|^2$$

The inclusion of the ϕ(2170) improves the fit quality insignificantly. The fitted value of the ϕ(2170) peak cross section is found to be consistent with zero, $0.8^{+2.9}_{-0.8}$ pb.

# The new measurement of $e^+e^- \to K_S K_L$ cross section

- The used technique is the same as in a previous BaBar paper [PRD89, 092002 (2014)], where the cross section of $e^+e^- \to K_S K_L$ was measured from threshold up to 2.2 GeV in c.m.f.
- The cross section is measured by using ISR technique
- The candidates for $K_S, K_L, \gamma_{ISR}$ are subjected to kinematic fit with the requirement of energy and momentum balance




*The kinematic-fit $\chi^2$ distribution for selected data events with $1.06 < m_{KSKL} < 2.5\ GeV/c^2$*

- We require the absence of extra charged tracks originating from the interaction region or extra photons with energy larger than 0.5 GeV
- The background is dominated by the ISR processes $e^+e^- \to K_S K_L \pi^0 \gamma$, $K_S K_L \eta \gamma$, and $K_S K_L \pi^0 \pi^0 \gamma$.

https://www.slac.stanford.edu/BFROOT/www/Organization/CollabMtgs/2019/PJ_Mar19/agenda_items/Solodov.pdf

https://www.slac.stanford.edu/BFROOT/www/Organization/CollabMtgs/2019/detJun19/agenda_items/Tue/Solodov.pdf

http://moriond.in2p3.fr/QCD/2019/WednesdayMorning/Soffer.pdf

https://docs.google.com/presentation/d/1aMOIiLl9jIAFp_w6Txmf5Lcw3J-bZmQR5z_zNRJBJ0Y/edit#slide=id.p2

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.101.012011