Measurement of the hadronic cross sections for e^+e^- to final states with neutral kaons with the BABAR detector

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Abstract

We measure the energy-dependent cross-sections for e^+e^- annihilation to $K^0_S K^0_L \pi^0$, $K^0_S K^0_L \eta$, and $K^0_S K^0_L \pi^0\pi^0$ up to a center-of-mass energy of 4 GeV with the BABAR detector at PEP-II (SLAC). The measurements rely on studies of e^+e^- collisions at and near the $\Upsilon(4S)$ that result in the above mentioned final states plus a photon radiated from the initial state. The intermediate resonance structures are studied, and we observe J/ψ decays to all of these final states for the first time. We present measurements of their J/ψ branching fractions, and search for $\psi(2S)$ decays. The results are based on 469 fb^{-1} of data.

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Introduction and motivation

The study of e^+e^- annihilation events with initial-state radiation (ISR) allows the *B*-factories to measure $\sigma(e^+e^- \to \text{hadrons})$ at energies below the center-of-mass energy, contributing experimental inputs for the determination of the hadronic contribution to $(g-2)_\mu$. This technique relies on the precise simulation of the "radiation function" that relates the $e^+e^- \to$ hadrons cross-sections to the corresponding ISR processes $e^+e^- \to \gamma_{ISR}$hadrons. In the following processes, charge conjugation is silently implied.

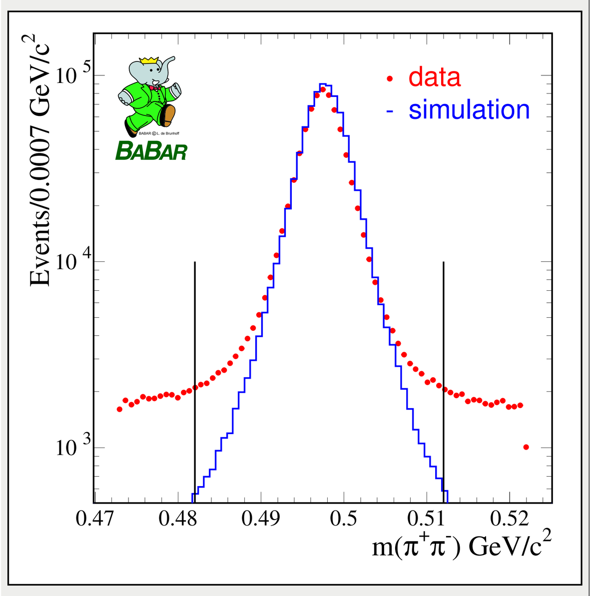
Event selection

- 2 opposite-sign tracks from interaction region, ≥ 4 clusters in electromagnetic calorimeter (EMC)
- ISR photon (γ_{ISR}) candidate: EMC cluster with $E > 3$ GeV
- K^0_S from $\pi^+\pi^-$ candidate tracks with $482 < m_{\pi\pi} < 512$ MeV, displaced from beams $0.1 < d_{xy} < 40$ cm
- K^0_L candidate direction (not energy) from one EMC cluster with $E > 200$ MeV
  - K^0_L momentum determined with constrained kinematic fit
- π^0 and η candidates from 2 EMC clusters, $|m(\gamma\gamma) - m(\pi^0)| < 30$ MeV, $|m(\gamma\gamma) - m(\eta)| < 50$ MeV
- extra EMC clusters (multi-photon ISR, spurious) must have $E_\gamma < 500$ MeV

Constrained kinematic fits are used to ...

- suppress / control backgrounds
  - signal final states cross-feed: $\gamma_{ISR}K^0_S K^0_L\pi^0$, $\gamma_{ISR}K^0_S K^0_L\eta$, $\gamma_{ISR}K^0_S K^0_L\pi^0\pi^0$
  - important backgrounds: $\gamma_{ISR}K^0_S K^0_L$, $\gamma_{ISR}K^0_S K^\pm\pi^\mp$, $\gamma_{ISR}K^0_S K^\pm\pi^\mp\pi^0$
- remove large $\gamma_{ISR}\phi$, $\phi \to K^0_S K^0_L$ background by requiring inconsistent $\gamma_{ISR}K^0_S K^0_L$ fit ($\chi^2 > 15$) when $m(K^0_S K^0_L) < 1040$ MeV

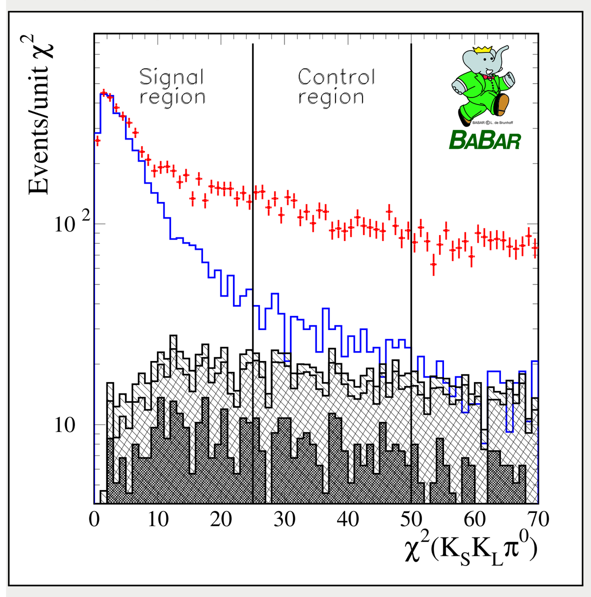
K^0_S mass distribution



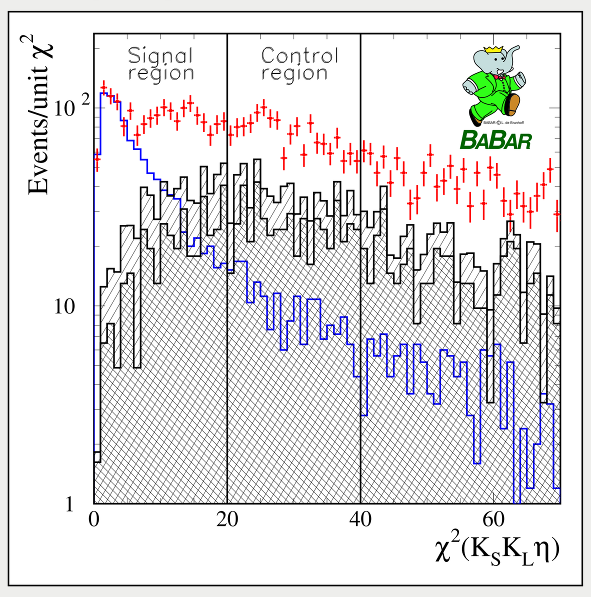
- background estimated on sidebands

Use data to calibrate backgrounds and cross-feeds

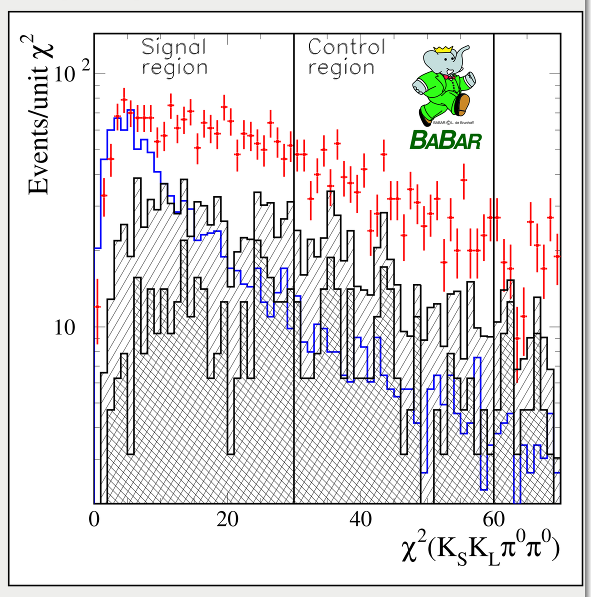
$\gamma_{ISR}K^0_S K^0_L\pi^0$ kinematic fit χ^2



$\gamma_{ISR}K^0_S K^0_L\eta$ kinematic fit χ^2

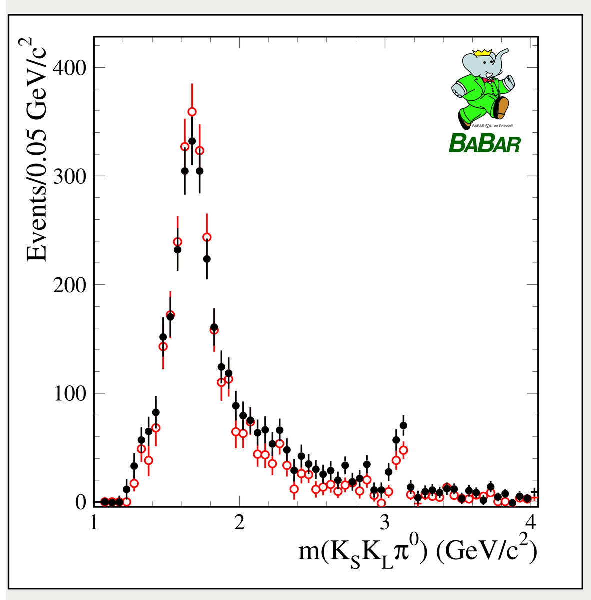


$\gamma_{ISR}K^0_S K^0_L\pi^0\pi^0$ kinematic fit χ^2

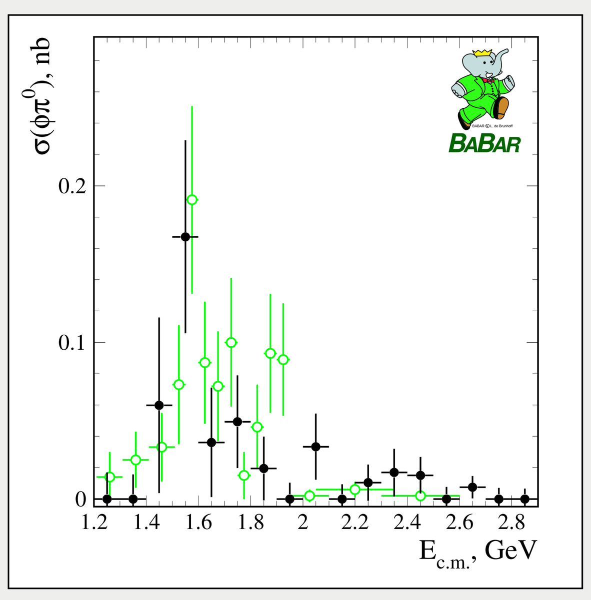


- data: red points with errors
- simulated signal: blue line
- simulated backgrounds (cumulated): non-ISR $(q\bar{q})$ shaded; ISR ϕ cross-hatched; ISR $\phi\eta$ hatched
- use background-dominated control region to calibrate MC simulated backgrounds normalization (in doing that, normalize MC signal in small χ^2 region where signal dominates)

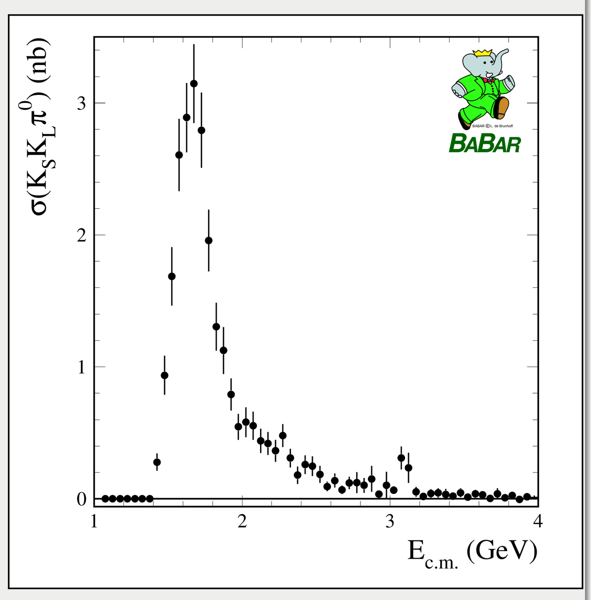
$K^0_S K^0_L \pi^0$ channel



- $K^0_S K^0_L\pi^0$ mass distribution
- $K^0_S K^0_L\pi^0$ channel dominated by $e^+e^- \to K^*(892)^0\bar{K}^0 \to K^0_S K^0_L\pi^0$ (red open circles)
- other contributions: $K^*_2(1430)\bar{K}^0$, $\phi\pi^0$

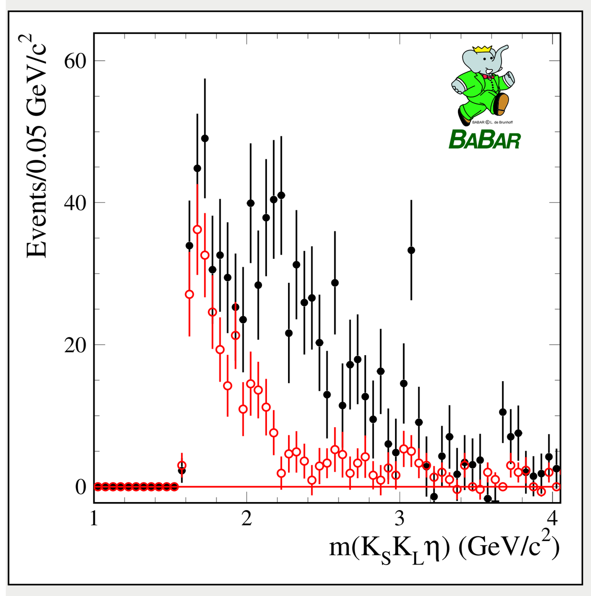


- measured $e^+e^- \to \phi(K^0_S K^0_L)\pi^0$ cross section (dots) compared with that obtained in the $K^+K^-\pi^0$ channel [1] (circles).
- error bars are statistical only

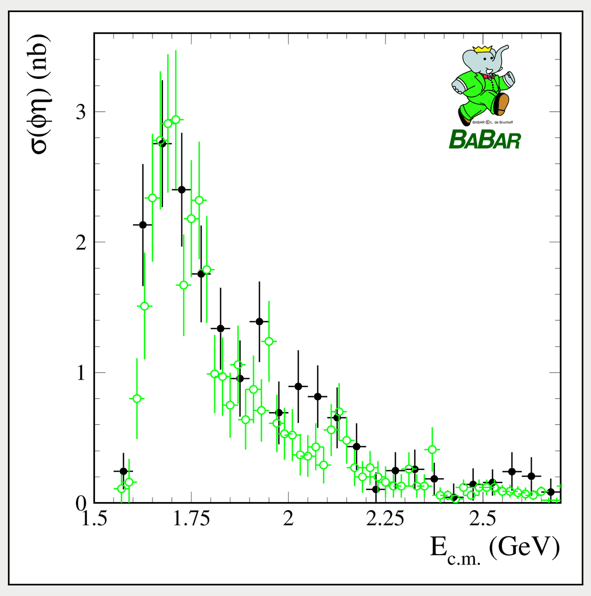


- background-subtracted cross-section of $e^+e^- \to K^0_S K^0_L\pi^0$ as function of energy

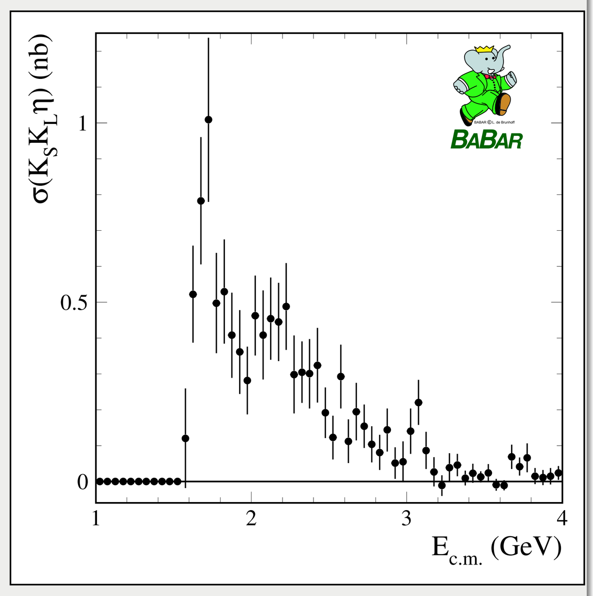
$K^0_S K^0_L \eta$ channel



- $K^0_S K^0_L\eta$ mass distribution
- $K^0_S K^0_L\eta$ channel dominated at low energies by $e^+e^- \to \phi\eta$, $\phi \to K^0_S K^0_L$ (red open circles)

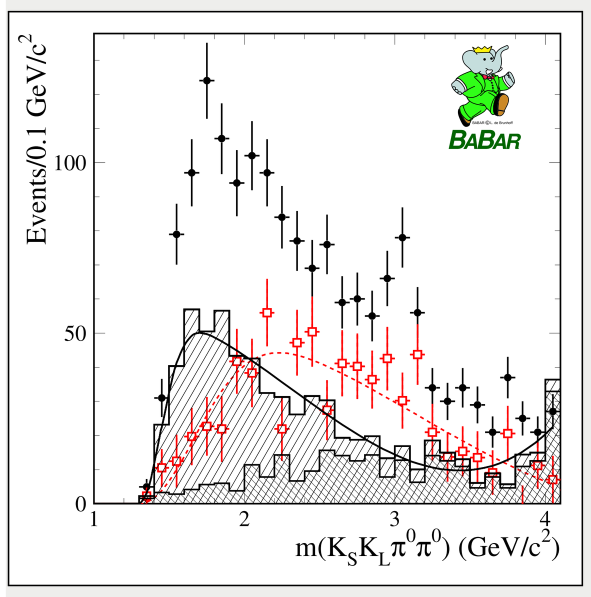


- measured $e^+e^- \to \phi(K^0_S K^0_L)\eta$ cross section (dots) compared with that obtained in the $K^+K^-\eta$ channel [1] (green open circles).
- error bars are statistical only

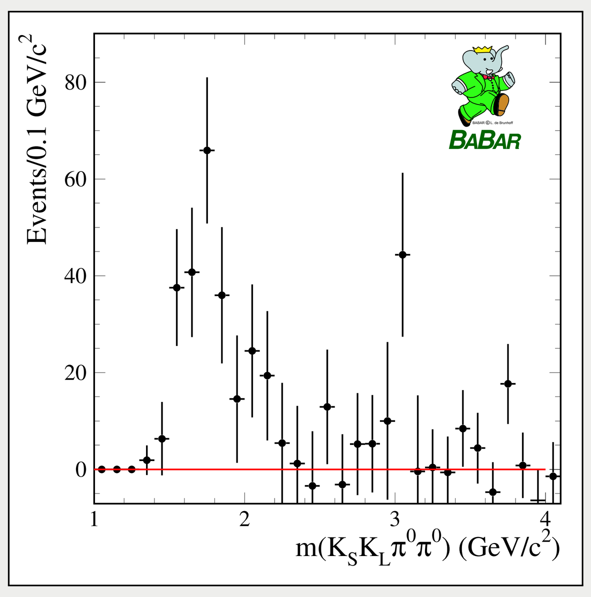


- background-subtracted cross-section of $e^+e^- \to K^0_S K^0_L\eta$ as function of energy

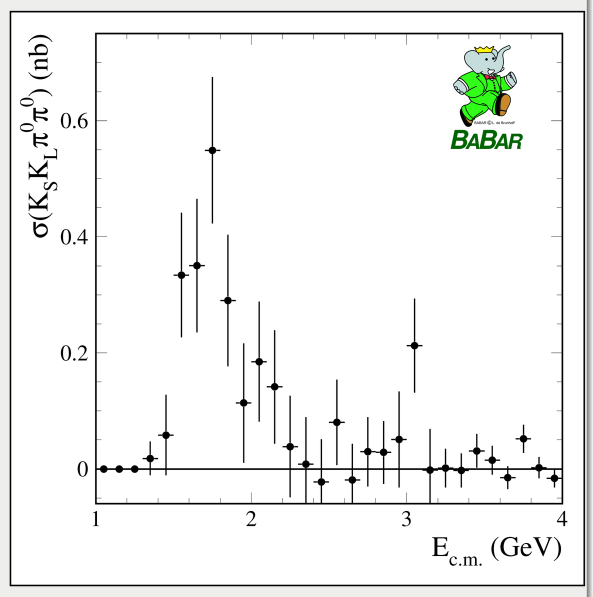
$K^0_S K^0_L \pi^0\pi^0$ channel



- $K^0_S K^0_L\pi^0\pi^0$ mass distribution
- additional background estimated from control region (red open circles)



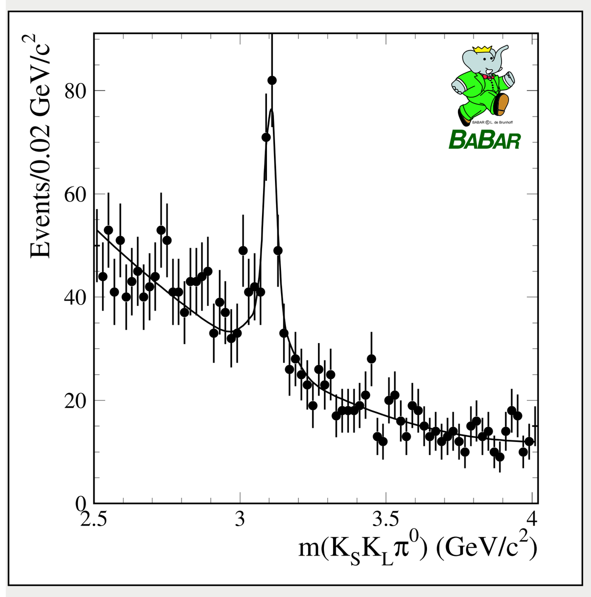
- $K^0_S K^0_L\pi^0\pi^0$ bkg-subtracted mass distribution



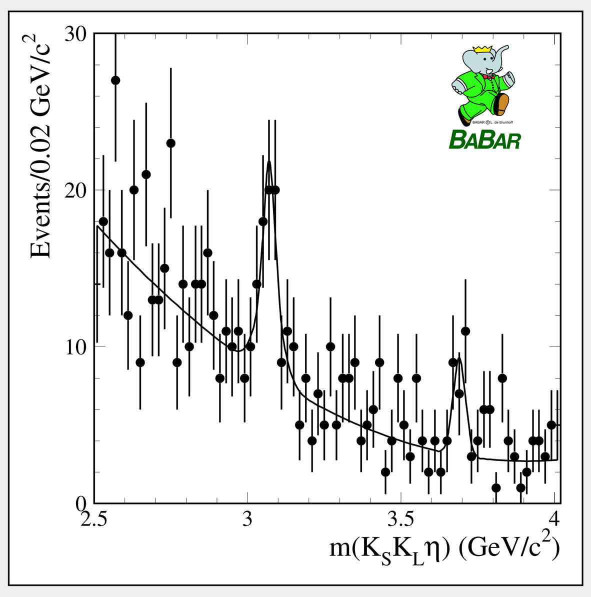
- background-subtracted cross-section of $e^+e^- \to K^0_S K^0_L\pi^0\pi^0$ as function of energy

J/ψ and $\psi(2S)$ region signals, first observation

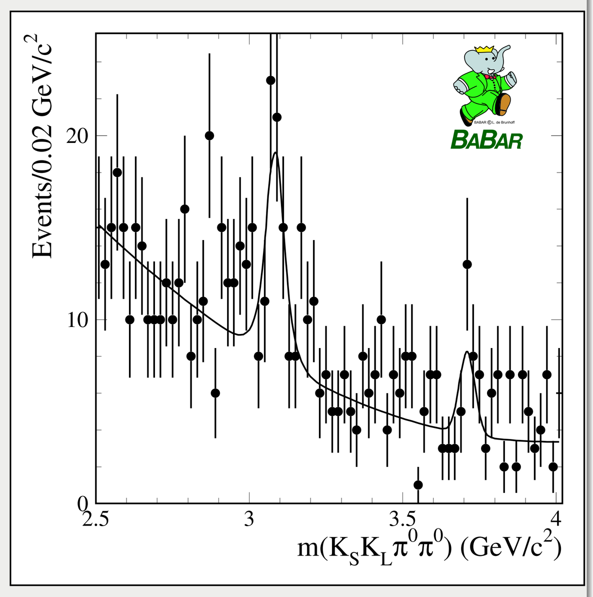
$K^0_S K^0_L\pi^0$ mass distribution



$K^0_S K^0_L\eta$ mass distribution



$K^0_S K^0_L\pi^0\pi^0$ mass distribution



- J/ψ signal in all channels, data on points with errors, fit on continuous line
- $\psi(2S)$ signal hints in $e^+e^- \to K^0_S K^0_L\eta$ and $e^+e^- \to K^0_S K^0_L\pi^0\pi^0$

Quantity	Value (10^{-3})
$\mathcal{B}(J/\psi \to K^0_S K^0_L\pi^0)$	2.06 $\pm$0.24 $\pm$0.10
$\mathcal{B}(J/\psi \to K^0_S K^0_L\eta)$	1.45 $\pm$0.32 $\pm$0.08
$\mathcal{B}(J/\psi \to K^0_S K^0_L\pi^0\pi^0)$	1.86 $\pm$0.43 $\pm$0.10
$\mathcal{B}(J/\psi \to K^*(892)^0\bar{K}^0) \cdot \mathcal{B}(K^*(892)^0 \to K^0\pi^0)$	1.20 $\pm$0.15 $\pm$0.06
$\mathcal{B}(J/\psi \to K^*_2(1430)^0\bar{K}^0) \cdot \mathcal{B}(K^*_2(1430) \to K^0\pi^0)$	0.43 $\pm$0.12 $\pm$0.02
$\mathcal{B}(\psi(2S) \to K^0_S K^0_L\pi^0)$	< 0.3
$\mathcal{B}(\psi(2S) \to K^0_S K^0_L\eta)$	1.33 $\pm$0.46 $\pm$0.07
$\mathcal{B}(\psi(2S) \to K^0_S K^0_L\pi^0\pi^0)$	1.24 $\pm$0.54 $\pm$0.06

Paper

BABAR collaboration, Cross sections for the reactions $e^+e^- \to K^0_S K^0_L\pi^0$, $K^0_S K^0_L\eta$, and $K^0_S K^0_L\pi^0\pi^0$ from events with initial-state radiation, Phys. Rev. D 95, 052001 (2017), arXiv:1701.08297 [hep-ex]

References

[1] BaBar, B. Aubert *et al.*, Phys. Rev. **D77** (2008) 092002, arXiv:0710.4451.

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