Measurement of the $e^+e^-\to\pi^+\pi^-\pi^0\pi^0\pi^0$, $\pi^+\pi^-\pi^0\pi^0\eta$ processes in ISR at *BaBaR*

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BaBaR detector

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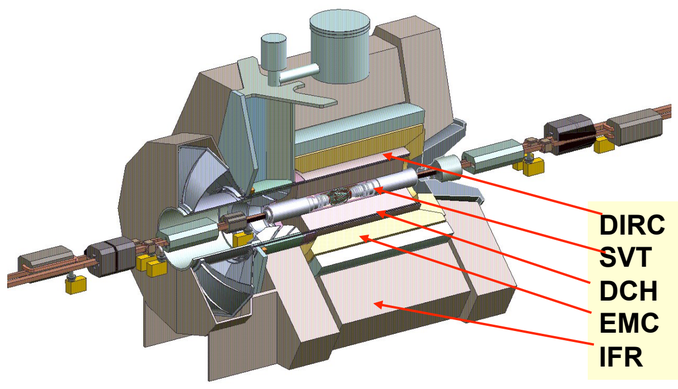
$E_+ = 3.1$ GeV, $E_- = 9$ GeV



$E_{CM} = m(\Upsilon(4S))=10.6$ GeV
2000 – 2008 yrs
L_{ins} ~10 nb^{-1}/sec
$L_{int} \approx 500$ fb^{-1}

***BaBaR* Data :** **Run1- run6 - 469 fb^{-1}**

MC-simulation : **~100 – 200 k events each**

Signal: $e^+e^-\to\omega\pi^0\pi^0\gamma$, $\eta\pi^+\pi^-\gamma$
$e^+e^-\to 2\pi2\pi^0\eta\gamma$ (PS, $\omega\pi^0\eta\gamma$)

Background: $e^+e^- \to 3\pi\gamma$, $4\pi\gamma$, $5\pi\gamma$, $6\pi\gamma$, $2\pi2\pi^0\gamma$(!)
$e^+e^- \to \tau^+\tau^-$
$e^+e^- \to qq$ (q = u,d,s,c) –
major background is from $e^+e^- \to 2\pi4\pi^0$

Abstract

We study the processes $e^+e^-\to\pi^+\pi^-\pi^0\pi^0\pi^0\gamma$ and $\pi^+\pi^-\pi^0\pi^0\eta\gamma$ with an energetic photon radiated from the initial state (ISR). About 14000 and 4700 events, respectively, have been selected. The invariant mass of the hadronic final state defines the effective e^+e^- center-of-mass energy. From the mass spectra, the first precise measurements of the $e^+e^-\to\pi^+\pi^-\pi^0\pi^0\pi^0$ cross section and the first measurement ever of the $e^+e^-\to\pi^+\pi^-\pi^0\pi^0\eta$ cross sections are performed for center-of-mass energies from threshold to 4.35 GeV. The systematic uncertainty in the cross section measurement is typically between 10 and 13%. The contributions from $\omega\pi^0\pi^0$, $\eta\pi^+\pi^-$, and other intermediate states are presented. We observe the J/ψ and $\psi(2S)$ in all these final states and measure the corresponding branching fractions, most of them for the first time.

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Motivation

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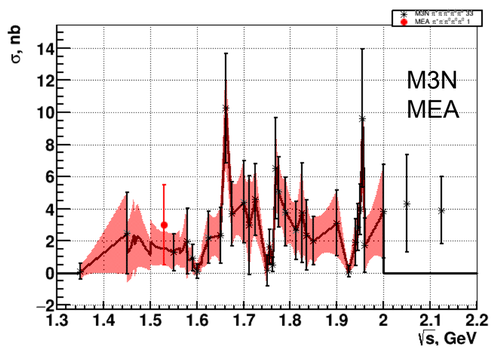
Very poor experimental information –
large uncertainty in R calculation



1989 data !

Events selection and Kinematic fit

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- Consider events with two pion tracks and 7 and more photons
- Take most energetic photon as ISR
- Test each 6 photons in the event (up to 25/event sometime)
- For each 6 photons take 3 $\gamma\gamma$ pairs (15 combinations) with ±35 MeV windows around π^0 mass for two best pairs.
- Perform 6C fit in $2\pi2\pi^0\gamma\gamma\gamma_{ISR}$ hypothesis with π^0 mass constrain for these two pairs, NO constrain on mass for 3rd $\gamma\gamma$ pair.
- Look for best χ^2, trying all pairs to be 3rd (+ 3 combinations)
- If fit OK, perform 6C fit for the $2\pi2\pi^0\gamma_{ISR}$ hypothesis

Extra cuts after 6C fit:

$E_{\gamma min} > 0.035$ GeV, $\chi^2_{2\pi2\pi0\gamma\gamma} < 60$ – signal $60 < \chi^2_{2\pi2\pi0\gamma\gamma} < 120$ control region
$\chi^2_{2\pi2\pi0} > 30$ – suppressed $2\pi2\pi^0\gamma$, $\Delta\psi > 1.0$ rad. - ISR photon-track min. angle – suppressed $\tau\tau$
$E_{\gamma\ extra} < 0.7$ GeV for energy of all extra photons
NO kaon ID, NO muon ID
Fitted momenta, angles are used for all calculated parameters

Fit results. Data

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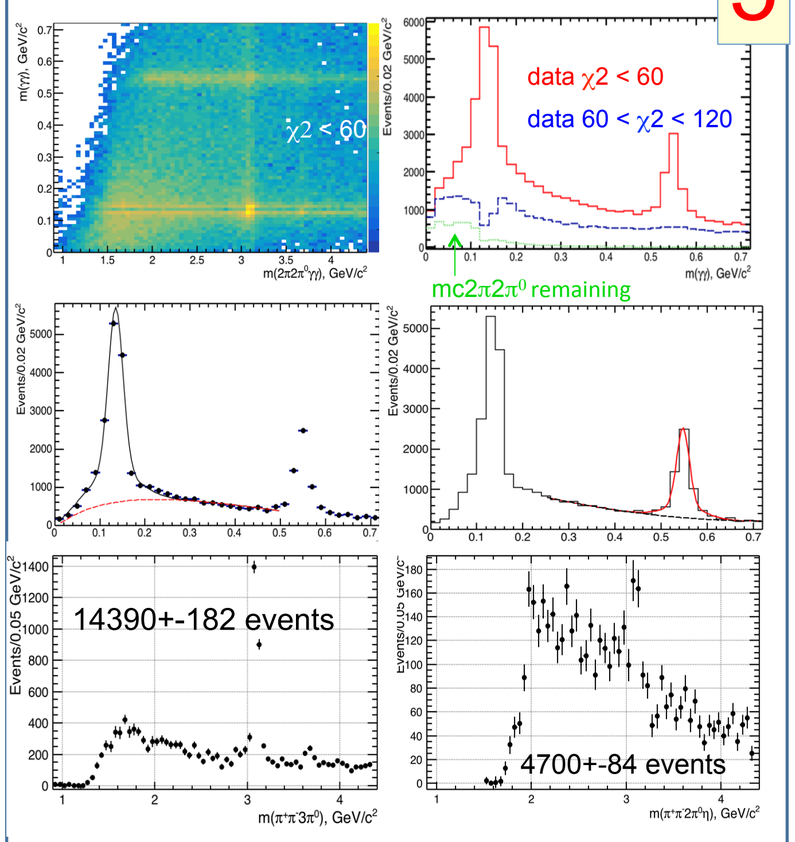

We fit 3rd photon pair mass to π^0 or to η mass after control region bckground subtraction and obtain number of events vs $\pi^+\pi^-\pi^0\pi^0\pi^0$ or $\pi^+\pi^-\pi^0\pi^0\eta$ invariant mass

Fit results. MC. Efficiency

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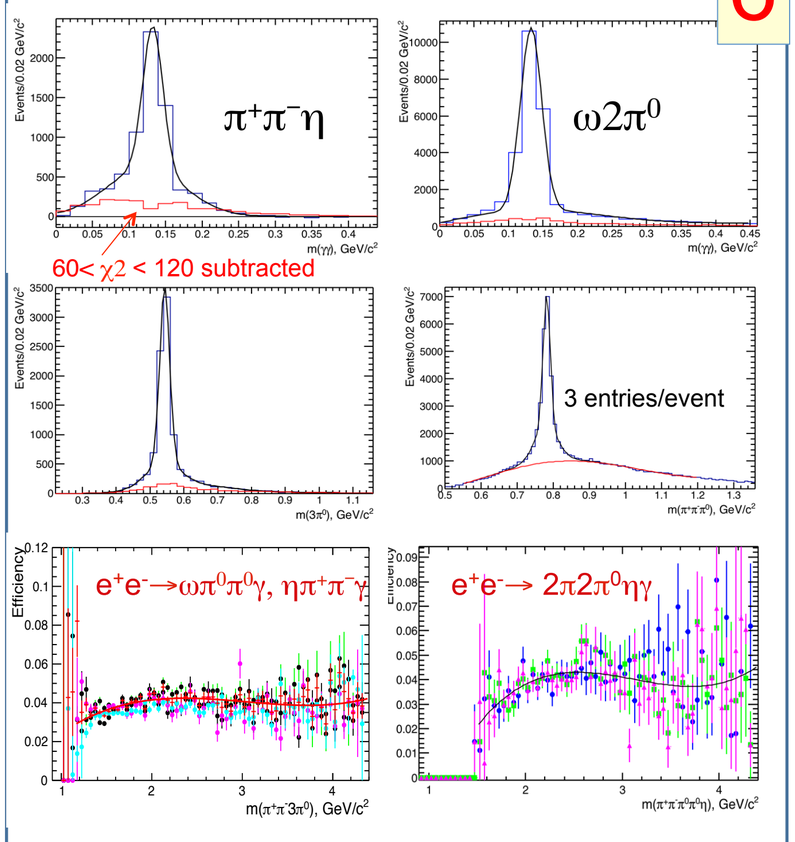

We fit 3rd photon pair mass to π^0 or to η mass or $3\pi^0$ mass to η, or $\pi^+\pi^-\pi^0$ mass to ω to obtain efficiency vs five-pion mass: four methods

Cross sections

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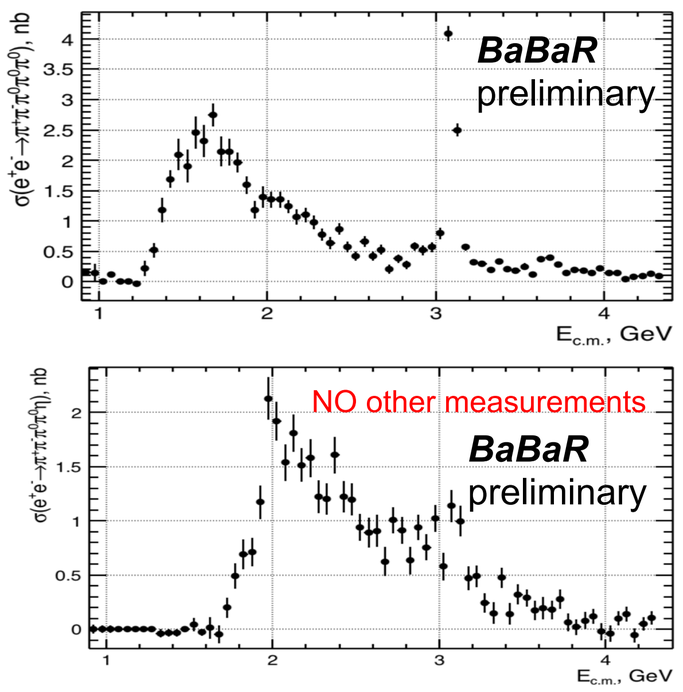
$$\sigma(2\pi3\pi^0)(E_{\rm c.m.}) = \frac{dN_{5\pi\gamma}(E_{\rm c.m.})}{d\mathcal{L}(E_{\rm c.m.})\cdot\epsilon^{\rm corr}_{5\pi}\cdot\epsilon^{\rm MC}_{5\pi}(E_{\rm c.m.})(1+\delta_R)}$$



Using obtained number of events, ISR luminosity, efficiency from MC, radiative correction (~1%), and correction for the data-MC efficiency difference we calculate the cross sections vs $E_{c.m.}$ up to 4.35 GeV. Systematic uncertainties 10-13%

Intermediate states for $2\pi3\pi^0$

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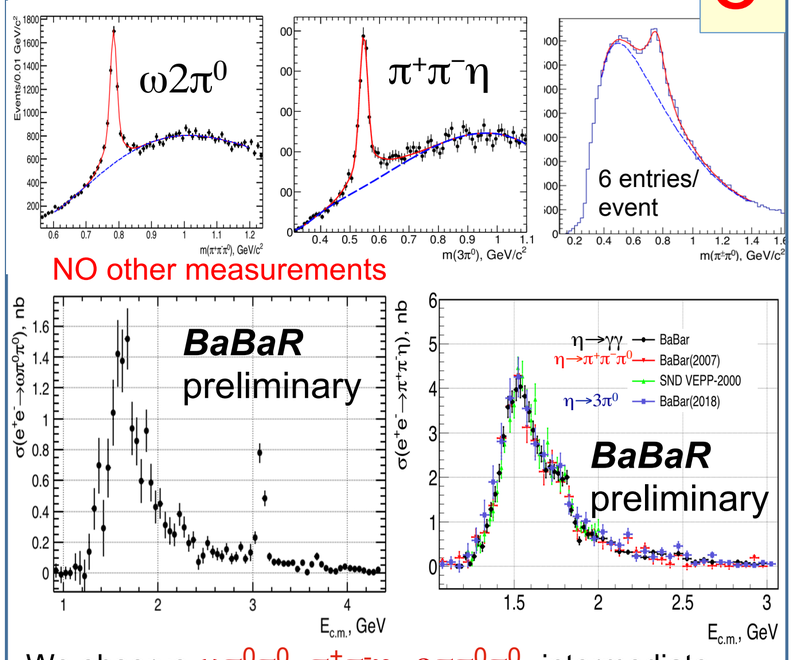

We observe $\omega\pi^0\pi^0$, $\pi^+\pi^-\eta$, $\rho\pi\pi^0\pi^0$ intermediate states and determine cross sections

Intermediate states for $2\pi2\pi^0\eta$

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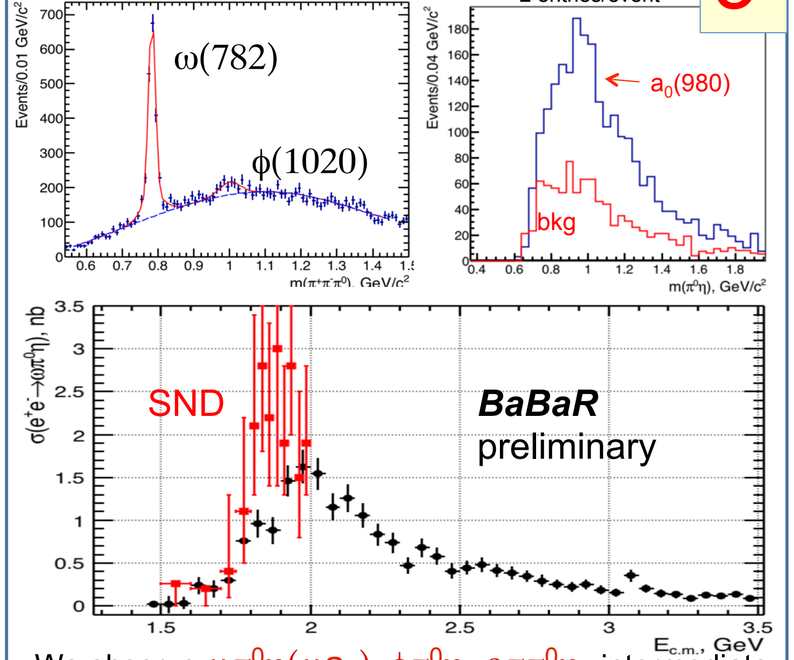

We observe $\omega\pi^0\eta(\omega a_0)$, $\phi\pi^0\eta$, $\rho\pi\pi^0\eta$ intermediate states and determine cross sections

J/ψ region (preliminary)

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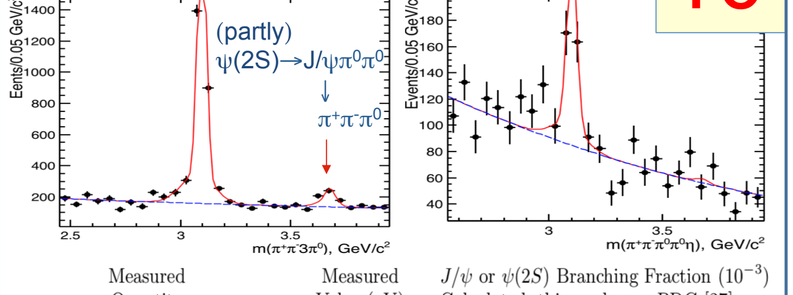

Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) Calculated, this work	PDG [27]
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\pi^+\pi^-\pi^0\pi^0\pi^0}$	150.0 ±4.0±15.0	27.0 ±0.7 ±2.7	no entry
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\omega\pi^0\pi^0}\cdot\mathcal{B}_{\omega\to3\pi}$	24.8 ±1.8±2.5	5.04±0.37±0.50	3.4±0.8
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\rho^\pm\pi^\mp\pi^0\pi^0}$	78.0 ±9.0±8.0	14.0 ±1.2 ±1.4	no entry
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\rho^+\rho^-\pi^0}$	33.0 ±5.0±3.3	6.0 ±1.1 ±0.6	no entry
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\pi^+\pi^-\pi^0\pi^0\eta}$	12.8 ±1.8±2.0	2.30±0.33±0.35	no entry
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\omega\pi^0\eta}\cdot\mathcal{B}_{\omega\to3\pi}$	1.7 ±0.8±0.3	0.34±0.16±0.06	no entry
$\Gamma^{J/\psi}_{ee}\cdot\mathcal{B}_{J/\psi\to\rho^\pm\pi^\mp\pi^0\eta}$	10.5 ±4.1±1.6	1.7 ±0.7 ±0.3	no entry
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\pi^+\pi^-\pi^0\pi^0\pi^0}$	12.4 ±1.8±1.2	5.2 ±0.8 ±0.5	no entry
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to J/\psi\pi^0\pi^0}\cdot\mathcal{B}_{J/\psi\to3\pi}$	10.1 ±1.5±1.1	22.9 ±2.8 ±2.3	21.1±0.7
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\omega\pi^0\pi^0}\cdot\mathcal{B}_{\omega\to3\pi}$	2.3 ±0.7±0.3	1.10±0.30±0.11	no entry
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\rho^\pm\pi^\mp\pi^0\pi^0}$	<6.2 ± 90% C.L.	<2.6 ± 90% C.L.	no entry
$\Gamma^{\psi(2S)}_{ee}\cdot\mathcal{B}_{\psi(2S)\to\pi^+\pi^-\pi^0\pi^0\eta}$	<0.85± 90% C.L.	<0.35± 90% C.L.	no entry

We observe J/ψ, $\psi(2S)$ signals and determine BFs

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