Recent results on exclusive hadronic cross sections measurements at *BaBar*

KAON16 conference, Birmingham

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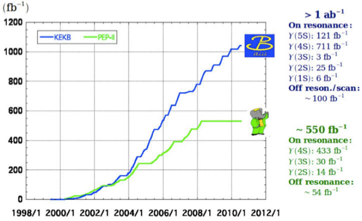
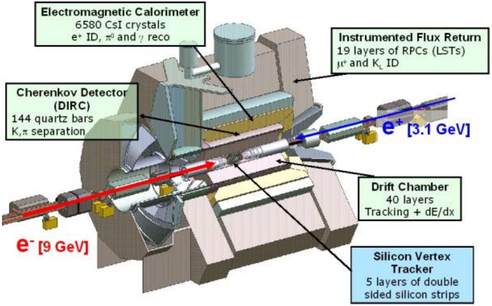
BaBar and PEP-II

More than just a B factory

0.5 ab^{-1} of data over $\sim$ 10 years
B mesons primary goal - but
also produce charm and τ
($\sigma_{B\overline{B}} = 1.05, \sigma_{\tau^+\tau^-} = 0.92, \sigma_{c\overline{c}} = 1.35nb$)
many *BABAR* τ and charm publications.
Also does interesting light quark physics
e^+e^- annihilation down to threshold





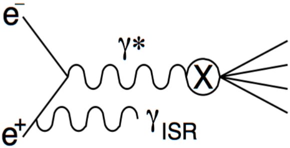
Detector features

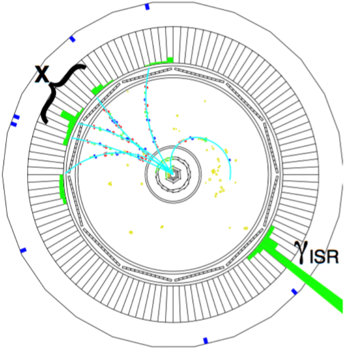
- CsI(TI) crystal ECAL
  Great EM energy resolution:
  γ energy well measured
  Good π^0&η reconstruction
- Superb K/π separation
- Vertexing

PEP-II as a low energy e^+e^- collider

Photon emitted from electron or positron as Initial State Radiation (ISR)

$$s' = s(1 - 2E_\gamma/\sqrt{s})$$





s' measured event by event - need unfolding

X is boosted - good detection even at threshold

Rates are low - but we have huge data samples

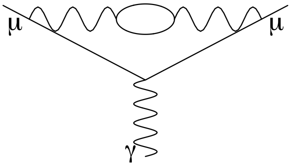
FSR small. Interference vanishes for charge symmetric detector

Why?

Here's one reason

Muon $a_\mu = \frac{g-2}{2}$ measured as $(11\ 659\ 209.1 \pm 5.4 \pm 3.3) \times 10^{-10}$
Calculated $(11\ 659\ 180.4 \pm 5.1) \times 10^{-10}$

3.4 Standard deviations! Is this the end for the standard model?



Corrections from QED (calculable), EW (small and calculable) and strong.

Hadronic correction to virtual photon propagator needs experimental input

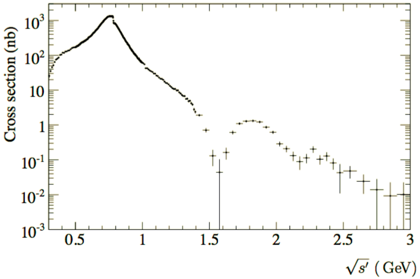
$\gamma^* \to q\bar{q} \to \gamma^*$ - or, equivalently,
$\gamma^* \to hadrons \to \gamma^*$

Linked to $\sigma(e^+e^- \to \gamma^* \to hadrons)$ by the optical theorem. Need to know $R = \sigma(hadrons)/\sigma(\mu^+\mu^-)$. Behaviour below 2 GeV most important

$\pi^+\pi^-$

Phys. Rev. Lett. 103, 231801 (2009); Phys. Rev. D 86, 032013 (2012).

Data driven techniques - uncertainties below 1%
Effective luminosity from $\mu\mu\gamma$ events
2nd photon allowed - visible or along beam pipe.
Particle identification using DIRC etc, also kinematic fit
Efficiencies from MC corrected by data using control channels



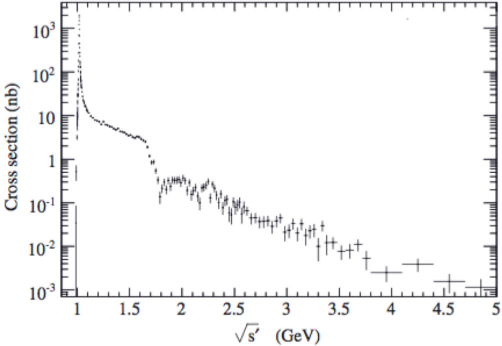
Cross section as a function of energy

Pion contribution to vacuum polarisation (from threshold up to 1.8 GeV):

$$(514.1 \pm 2.2 \pm 3.1) \times 10^{-10}$$

K^+K^-

PRD **88** 032013 (2013)



Dominated by ϕ. Fitted mass and width agree with PDG

Excellent agreement with other experiments (CMD-2, SND)

Kaon form factor also measured

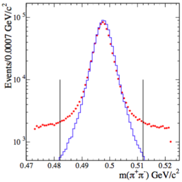
K^+K^- contribution to vacuum polarisation :

$$(22.93 \pm 0.18 \pm 0.22 \pm 0.03) \times 10^{-10}$$

(3rd error from ϕ parametrisation)

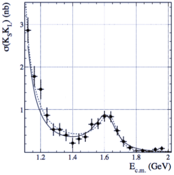
$K_S^0 K_L^0, K_S^0 K_L^0 \pi^+\pi^-, K_S^0 K_S^0 \pi^+\pi^-, K_S^0 K_S^0 K^+ K^-$

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



K_S^0 from $\pi^+\pi^-$ decays: pairs of tracks forming distinct vertex. Easy. K_L^0 harder. Cluster in EM calorimeter, similar to photon cluster. Efficiency studies from $\phi \to K_S^0 K_L^0$ decays.

$K_S^0 K_L^0$ dominated by ϕ, like K^+K^-. Fitted values agree with PDG. Also appearance of $\phi'(1680)$ - different behaviour from K^+K^-



First measurements of $e^+e^- \to K_S^0 K_L^0 \pi^+\pi^-$,$K_S^0 K_S^0 \pi^+\pi^-$ and $K_S^0 K_S^0 K^+ K^-$
$K_s^0 K_L^0 \pi^+\pi^-$ dominated by K^* production, some $\phi\pi\pi$

$K_S^0 K_L^0 \pi^0, K_S^0 K_L^0 \eta, K_S^0 K_L^0 \pi^0 \pi^0$
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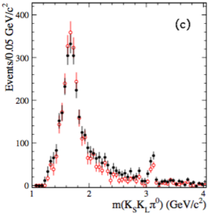
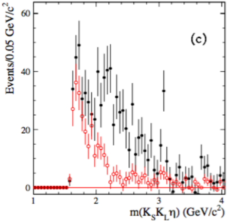
Mass of $K_S^0 K_L^0 \pi^0$ system, dominated by $KK^*(892)$ (red circles). $\phi\pi^0$ small. J/ψ appears



Mass of $K_S^0 K_L^0 \eta$ system, dominated by ϕ (red circles). Again, J/ψ appears

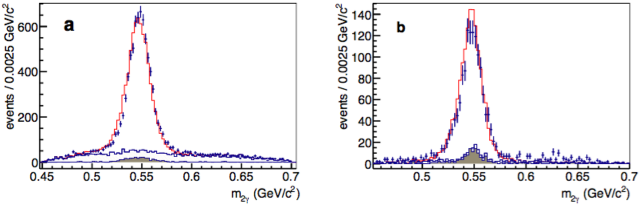


Measurement of $K_S^0 K_L^0 \pi^0 \pi^0$ gives total a_μ contribution of $KK\pi\pi$ as $(0.85 \pm 0.05) \times 10^{-10}$ - previously $(1.35 \pm 0.39) \times 10^{-10}$. Order of magnitude improvement as no reliance on isospin relations.

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

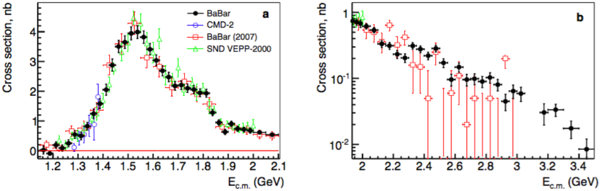
ICHEP 2016

$\eta \to \gamma\gamma$ so 3 photons+2 tracks



$m_{\gamma\gamma}$ for total energies below and above 2 GeV

$\sigma(e^+e^- \to \pi^+\pi^-\eta)$ as function of energy



Well described by models including $\rho(770)$, $\rho(1450)$ and $\rho(1700)$

Small peak at 3.1 GeV - measure $BR(J/\psi \to \pi^+\pi^-\eta) = (0.042 \pm 0.008)\%$

$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

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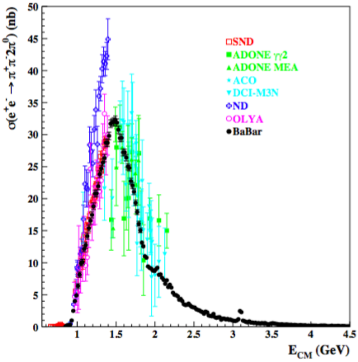
Use full 431 fb^{-1} sample of e^+e^- collisions 150,000 signal events selected

Was big contribution to a_μ theory uncertainty

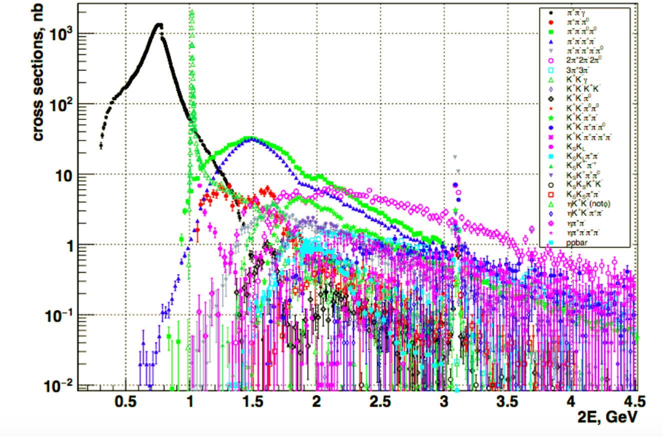


BABAR data (black) much better than previous experiments

Contribution to a_μ $(18.1 \pm 0.1 \pm 0.6) \times 10^{-10}$ in range 0.85 to 1.8 GeV

Conclusions

BABAR using the ISR technique can do precision studies of low energy e^+e^- annihilation



If the $g-2$ anomaly persists, it can't be explained by uncertainties in the hadronic vacuum polarsation