Probing Strong Interactions at *BABAR*

Sepehr Saremi
University of Massachusetts (Amherst)
On behalf of the *BABAR* Collaboration

PHENO 06
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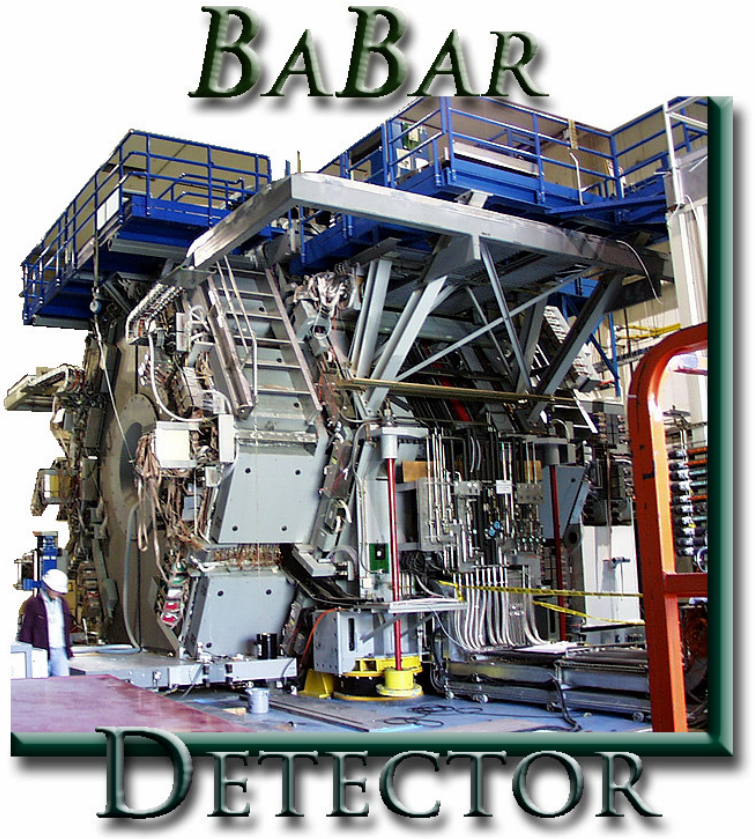
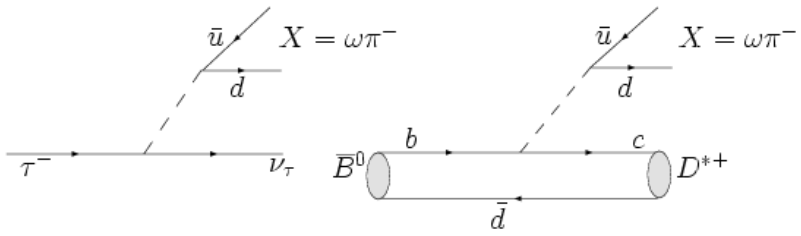


Topics in this talk

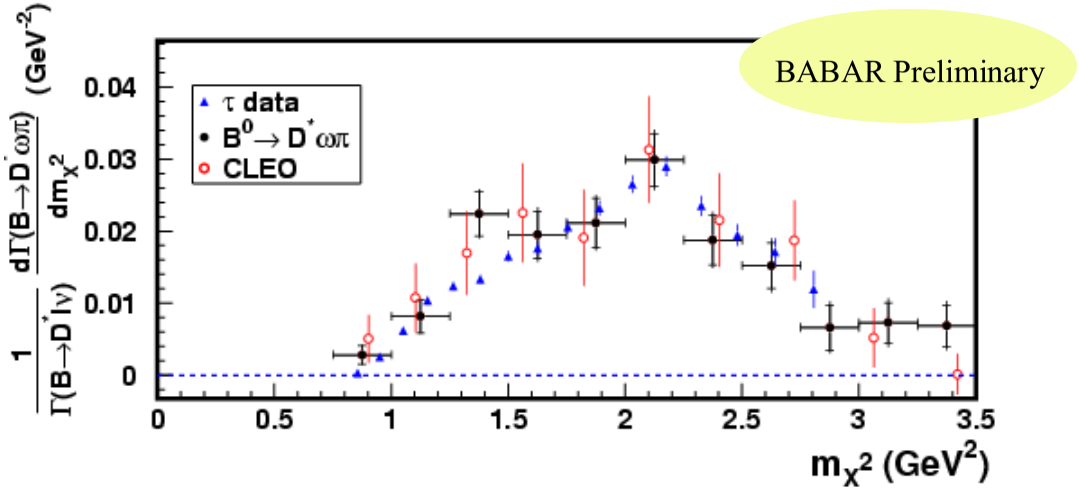
- Test of factorization in B-meson decays
- Form Factors (f_{D_s} and $D^0 \to K^- e^+ \nu_e$)
- The first observation of C=+1 hadronic final states in e^+e^- interactions
- Initial State Radiation: $e^+e^- \to \gamma_{ISR} p\bar{p}$, $\gamma_{ISR} 6\pi$
- η and η' Transition Form Factors at $q^2 = 112\ GeV^2$
- High precision angular analysis of $B \to (c\bar{c})K^*$

Test of factorization in $\overline{B}^0 \to D^{*+}\omega\pi^-$ (I)



Ligeti, Luke and Wise have proposed an elegant test of factorization based on data from $\tau \to X\nu$ decay (Phys. Lett. B507, 142 (2001)).

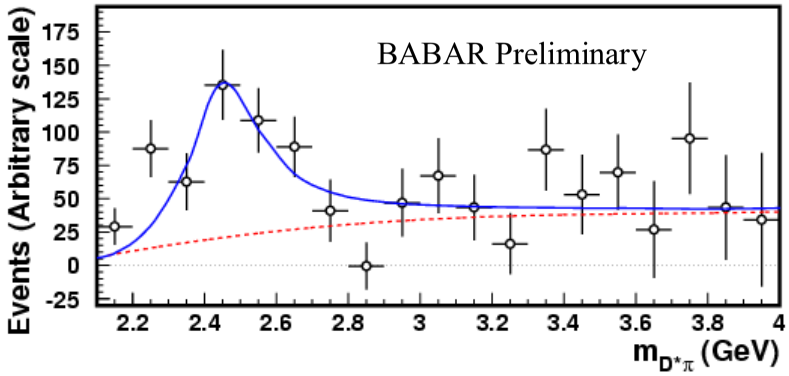
The invariant mass spectrum of the $\omega\pi$ system is found to be in agreement with expectations based on factorization and τ decay data.

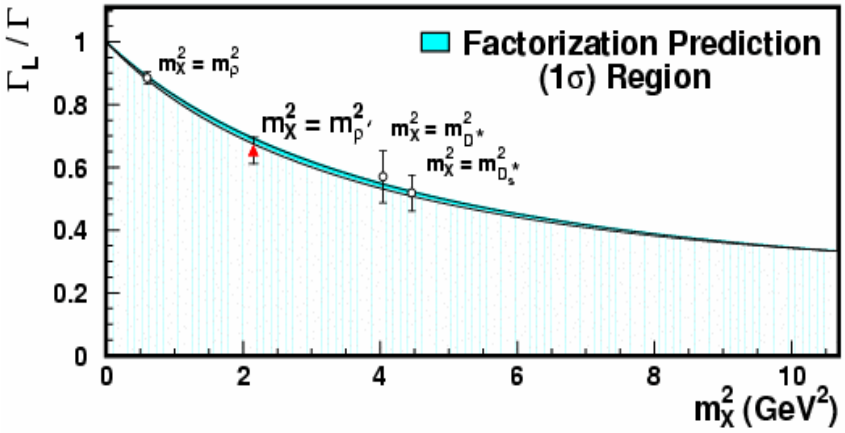


CLEO points are for $B \to D^*\omega\pi$

Test of factorization in $\bar{B}^0 \to D^{*+}\omega\pi^-$ (II)

We find an enhancement for $D^*\pi$ masses around 2.5 GeV. This could be due to color-suppressed decays into a broad D'_1 resonance followed by $D'_1 \to D^{*+}\pi^-$.





Good agreement for the fraction of D^* longitudinal polarization in the region of $\omega\pi$ mass between 1.1 and 1.9 GeV with predictions based on factorization and HQET.

$$\Gamma_L/\Gamma = 0.654 \pm 0.042(stat) \pm 0.016(sys)$$

BABAR Preliminary

Best measurement of f_{D_s} to date

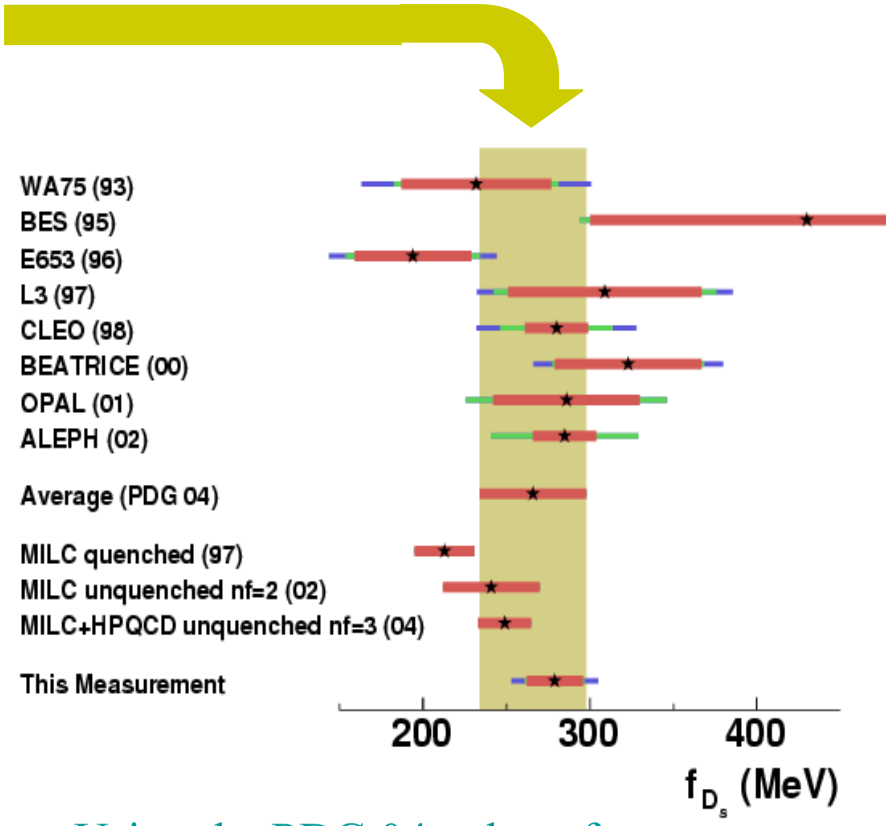
- Previous world average: (266 ± 32) MeV
- Recent results from CLEO-c:

  $f_{D^+} = (223 \pm 17)$ MeV
- BABAR measurement using 230.2 fb^{-1}:

  $f_{D_s} = (279 \pm 17 \pm 6 \pm 19)$ MeV (prelim.)

using BaBar measurement of:

$$B(D_s^+ \to \phi\pi^+) = (4.81 \pm 0.64)\%$$



These measurements yield:

$f_{D_s}/f_D = 1.25 \pm 0.14$

Consistent with lattice calculation:

$f_{D_s}/f_D = 1.24 \pm 0.07$

Using the PDG 04 value of:

$$B(D_s^+ \to \phi\pi) = (3.6 \pm 0.9)\%$$

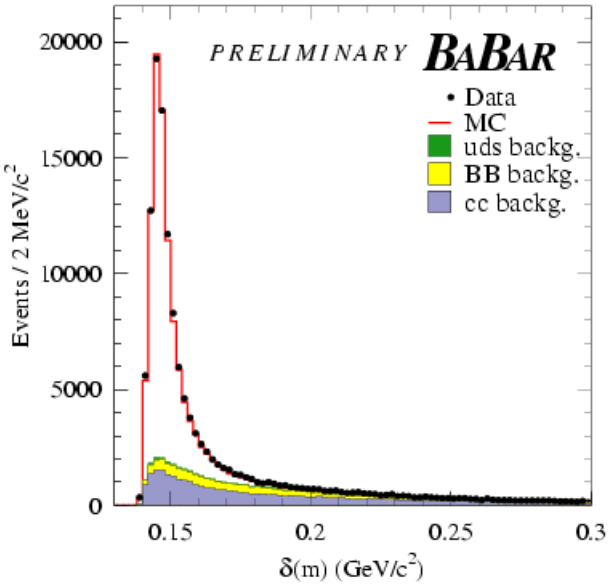
BaBar prelim. measurement would be:

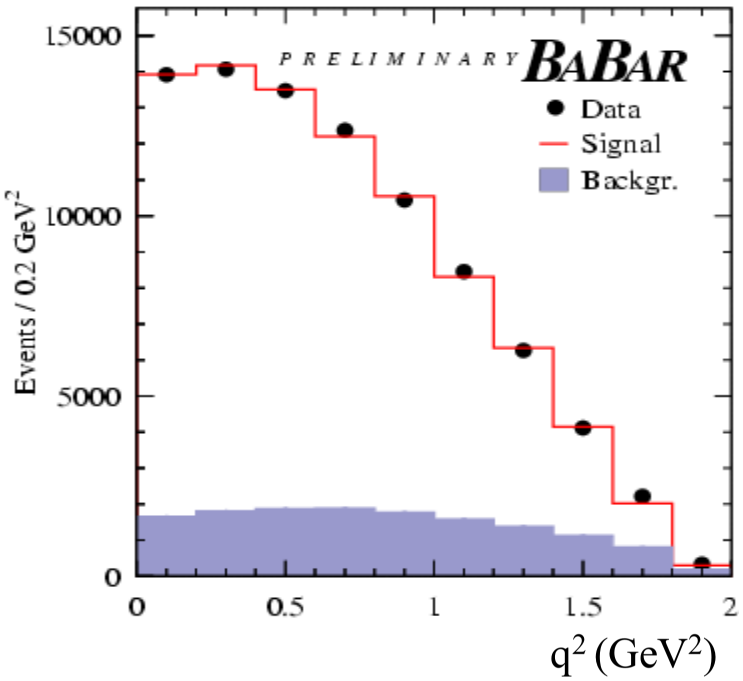
$$(f_{D_s})_{PDG} = (241 \pm 15 \pm 6 \pm 31)\ \ MeV$$

Form Factor in $D^0 \to K^- e^+ \nu_e$ (I)

This analysis is based on the reconstruction of D^{*+} mesons produced in $c\bar{c}$ events and in which the D^0 meson decays semileptonically.

$$\delta m = m(D^0 \pi^+) - m(D^0)$$

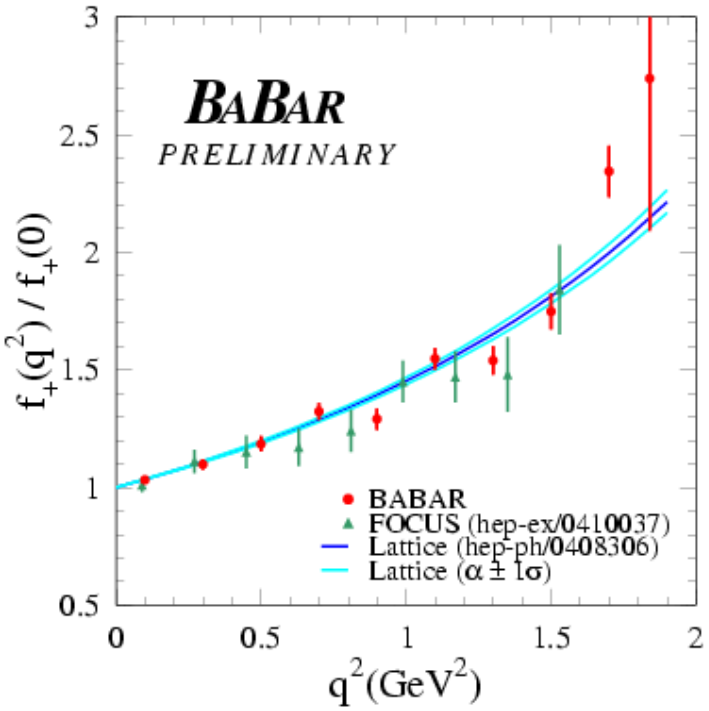




In this decay one can define a q^2 as following:

$$q^2 = (p_e + p_{\nu_e})^2 = (p_D - p_K)^2$$

Form Factor in $D^0 \to K^- e^+ \nu_e$ (II)



➢ A preliminary q^2 dependence of the form factor, corrected for the effects of reconstruction efficiency and resolution:

$$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{m^2_{pole}}}$$

$m_{pole} = (1.854 \pm 0.016 \pm 0.020)\ GeV/c^2$

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{m^2_{D^*_s}})(1 - \frac{\alpha_{pole} q^2}{m^2_{D^*_s}})}$$

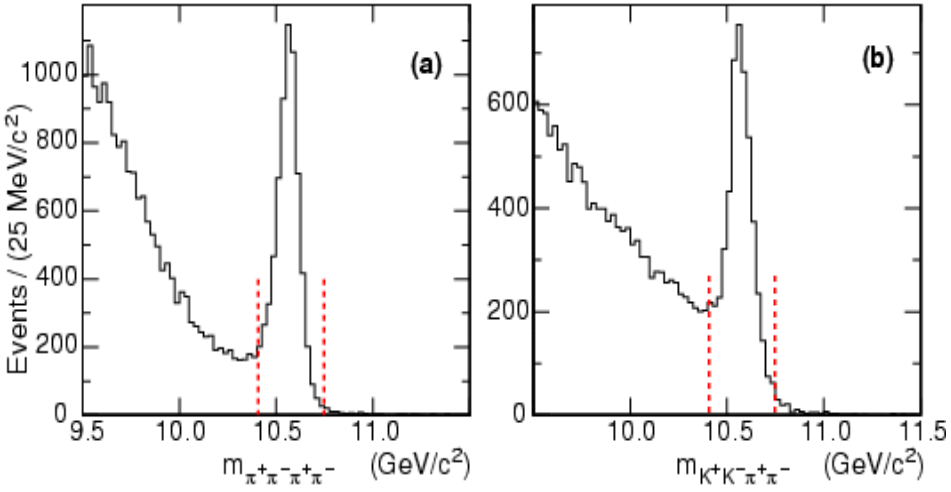
$\alpha_{pole}(lattice) = 0.50 \pm 0.04$

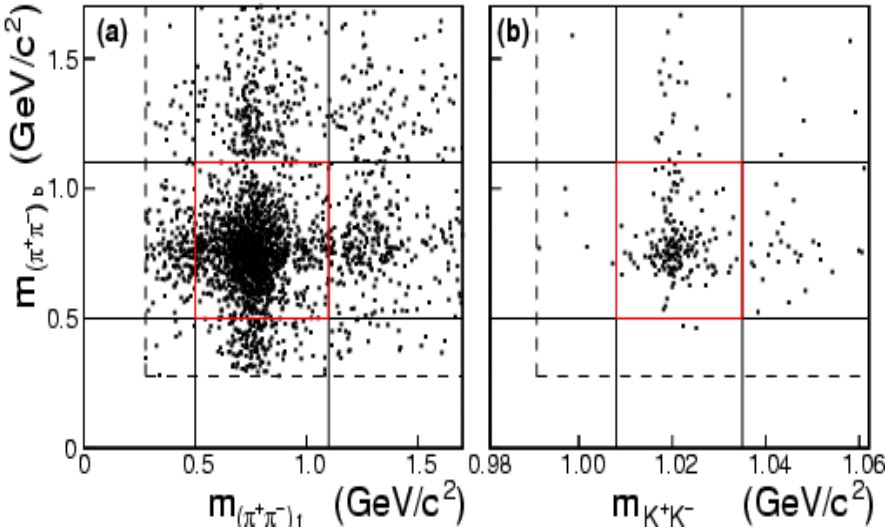
$\alpha_{pole} = 0.43 \pm 0.03 \pm 0.04$

$m(D_s^{*+}) = 2.112\ GeV/c^2$

Exclusive C=+1 Hadronic final states (I)

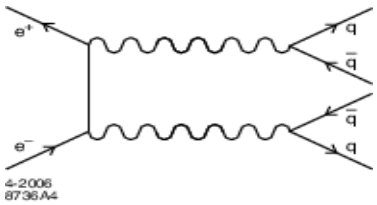
- Exclusive processes $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ and $e^+e^- \to K^+K^-\pi^+\pi^-$ observed cleanly.
- We can see clear ρ and φ signals in the exclusive 4-charged-track samples.





- Strong correlations can be seen for ρρ and ρφ which are forbidden in the usual 1 virtual photon processes.
- This is the first observation of $e^+e^- \to \rho^0\rho^0$ and $e^+e^- \to \varphi\rho^0$; the final states are even under charge conjugation.

Exclusive C=+1 final states (II)

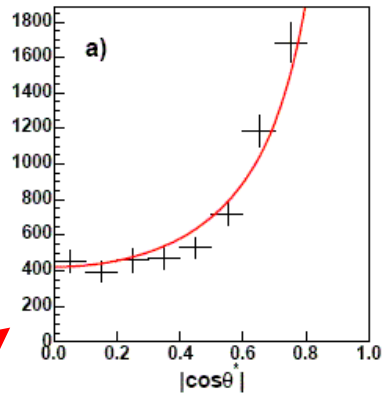


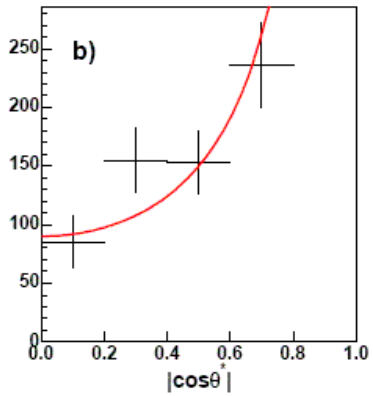
V (ρ)

V (ρ,φ)

Two-Virtual-Photon Annihilation (TVPA)

BABAR Preliminary





- The C=+1 final states are consistent with production via 2 virtual photons:
- The angular distributions of the ρ and φ in CM frame are similar to $e^+e^- \to \gamma\gamma$ as expected.

$$\frac{d\sigma_{TVPA}}{d\cos\theta^*} \propto \frac{1+\cos^2\theta^*}{k-\cos^2\theta^*}$$

- The distributions in cosine of helicity angle, $\cos\theta_H$, are $\sim\sin^2\theta_H$ as expected for quasi-real photons.
- BaBar preliminary cross section measurements (values agree with TVPA expectation):

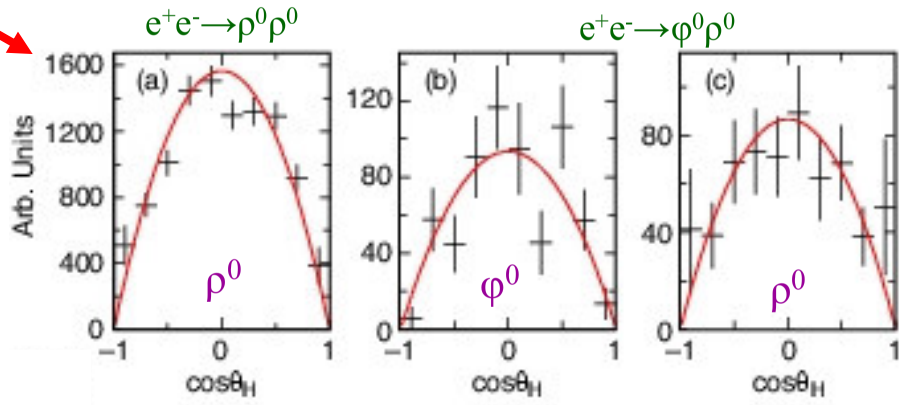
$$\sigma_{fid}(e^+e^- \to \rho^0\rho^0) = 20.7 \pm 0.7(\text{stat}) \pm 2.7(\text{sys})\ \text{fb}$$

$$\sigma_{fid}(e^+e^- \to \phi\rho^0) = 5.7 \pm 0.5(\text{stat}) \pm 0.8(\text{sys})\ \text{fb}$$

fid = $|\cos\theta^*|<0.8$

$0.5<m(\rho)<1.1$ GeV/c^2

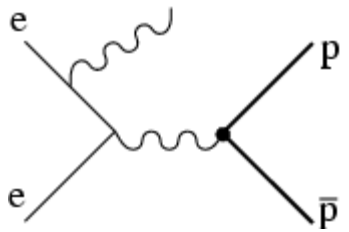
$1.008<m(\varphi)<1.035$ GeV/c^2



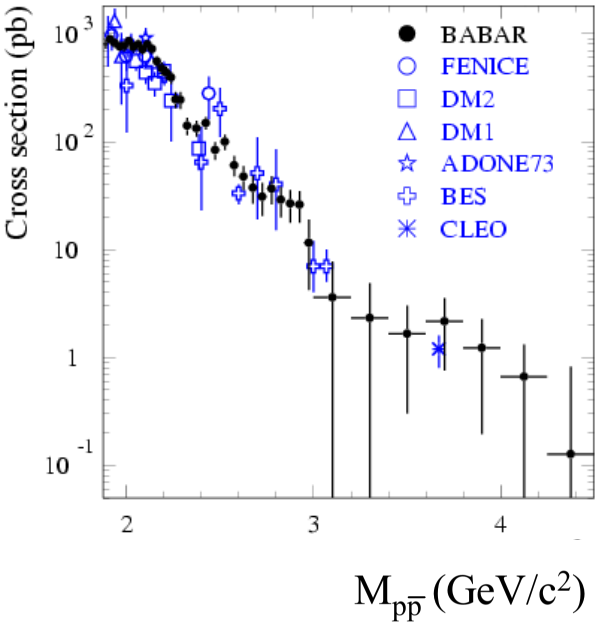
ISR production of $p\bar{p}$ (I)

- The cross section for $e^+e^- \to p\bar{p}$ is parametrized by Electric (G_E) and Magnetic (G_M) form factors:

$$\sigma(m) = \frac{2\pi\alpha^2\beta C}{3m^2}\left(2|G_M(m)|^2 + \tau\,|G_E(m)|^2\right) \qquad \tau = \frac{4m_p^2}{m^2}$$

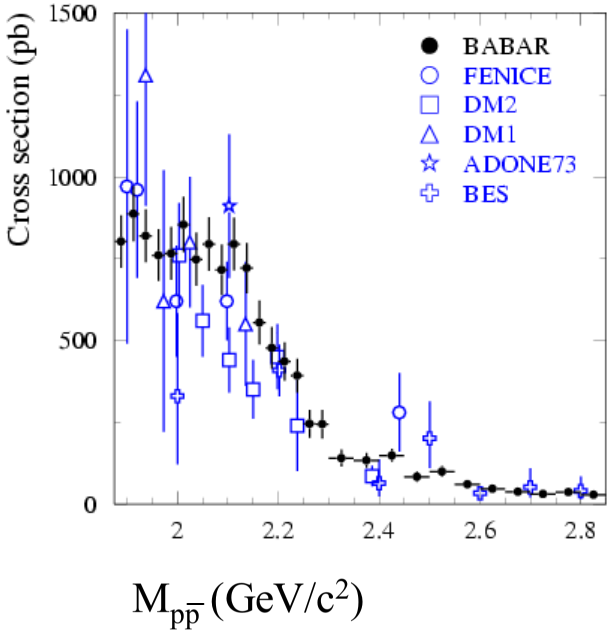


- Only BABAR has measurements in the entire range 1.875-4.5 GeV/c^2



PRD 73, 012005 (2006)

There is no simple theoretical interpretation of the sharp drops at ~2.15 and ~3.0 GeV/c^2



ISR production of $p\bar{p}$ (II)

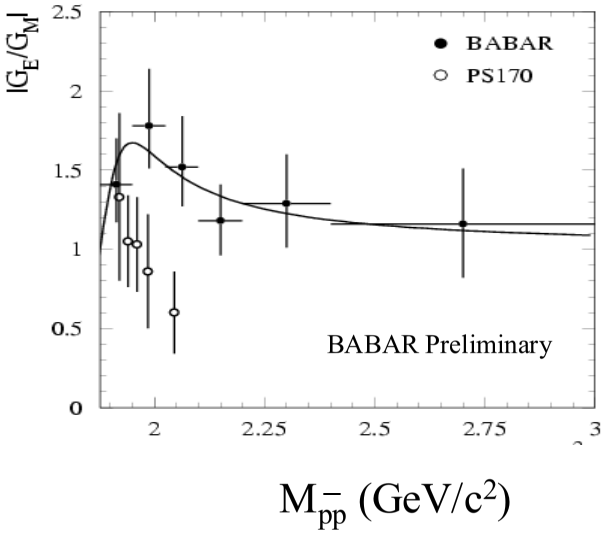
- The angular distributions associated with the electric and magnetic form factors are:

$$\frac{d\sigma(G_M)}{d\cos\theta_p} \sim 1 + \cos^2\theta_p$$

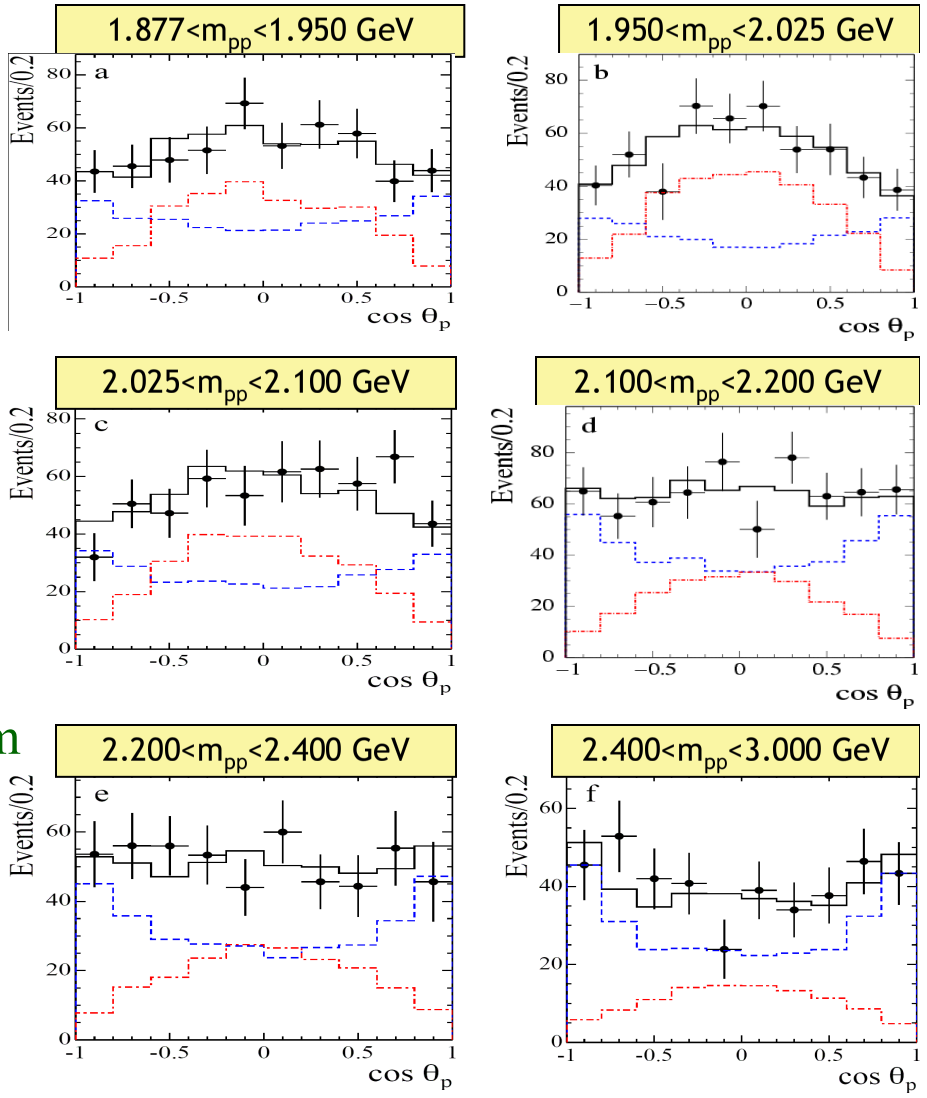
$$\frac{d\sigma(G_E)}{d\cos\theta_p} \sim \sin^2\theta_p$$

G_M in Blue
G_E in Red

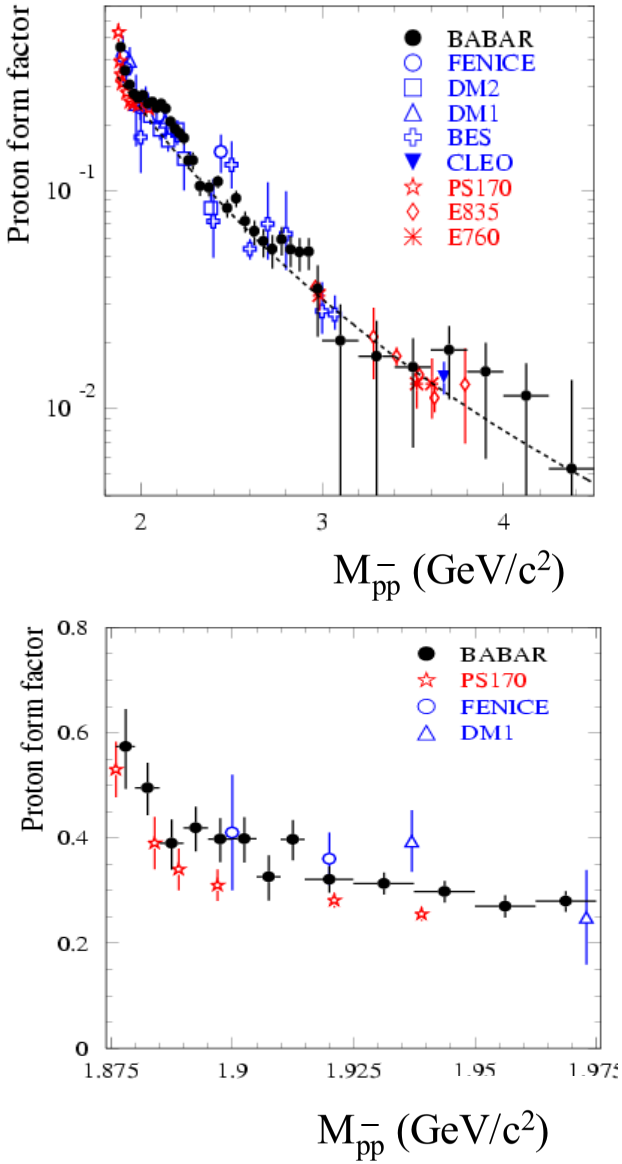
- There seems to be G_E dominance just above threshold ($m \approx 2$ GeV/c^2);



- Our result does not confirm the PS170 measurements.

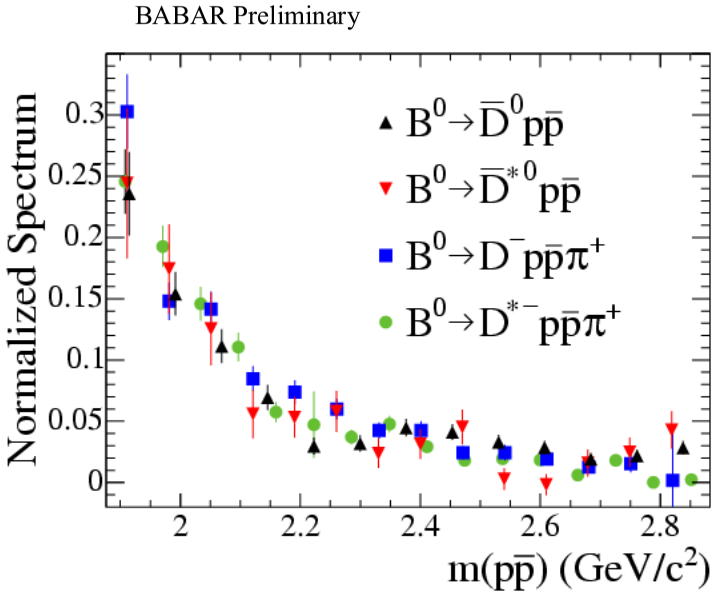


ISR production of $p\bar{p}$ (III)



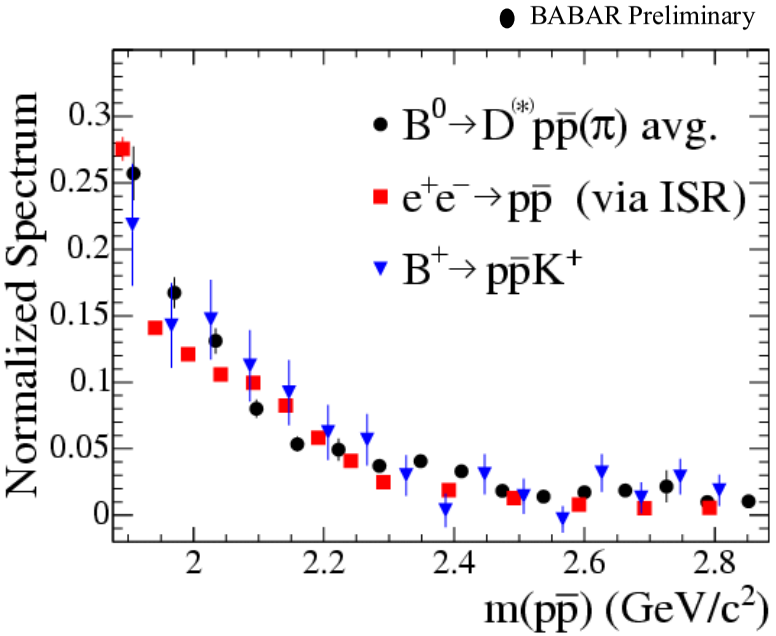
- The BABAR results are obtained from ISR production and so do not suffer from the typical point-to-point uncertainties which affect other measurements obtained from e^+e^- colliders operating at individual c.m. energy values.
- The significant increase in form factor as the $p\bar{p}$ threshold is approached may be a manifestation of a $p\bar{p}$ subthreshold resonance with negative C parity.
- Similar behavior in $J/\psi \rightarrow \gamma p\bar{p}$ (BES), but $p\bar{p}$ has positive C parity.
- The dashed line in the top plot corresponds to the asymptotic QCD fit [PRL 43, 545, (1979)].

B decay to final states containing $p\bar{p}$



The phase-space-corrected $p\bar{p}$ invariant mass for $B^0 \to \bar{D}^0 p\bar{p}$, $B^0 \to \bar{D}^{*0} p\bar{p}$, $B^0 \to D^- p\bar{p}\pi^+$ and $B^0 \to D^{*-} p\bar{p}\pi^+$

Comparing the average of the four decay modes with $e^+e^- \to p\bar{p}$ and $B^+ \to p\bar{p}K^+$

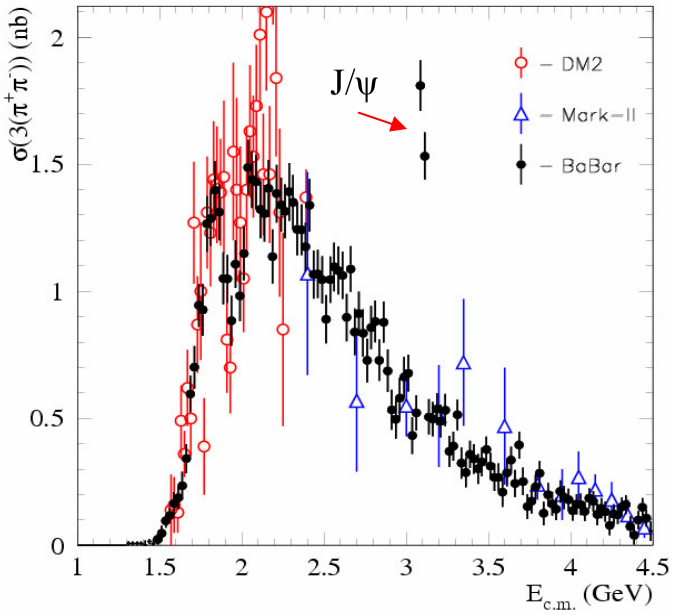


May be due to a broad gluonic resonance or short range correlations between p and $\bar{p}$

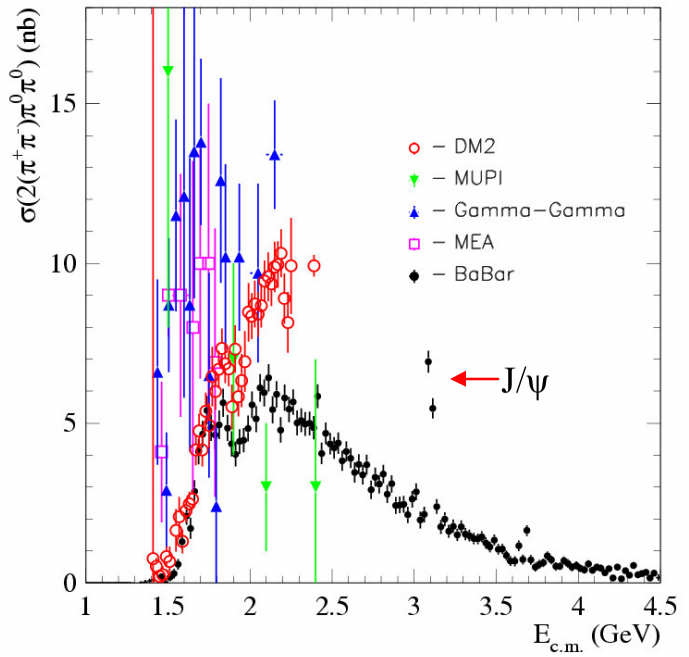
ISR study with 6π final state

PRD 73, 052003 (2006)

- ISR photon + 6 charged hadrons
- 1C fit in 6π hypothesis. Cut at χ^2<20



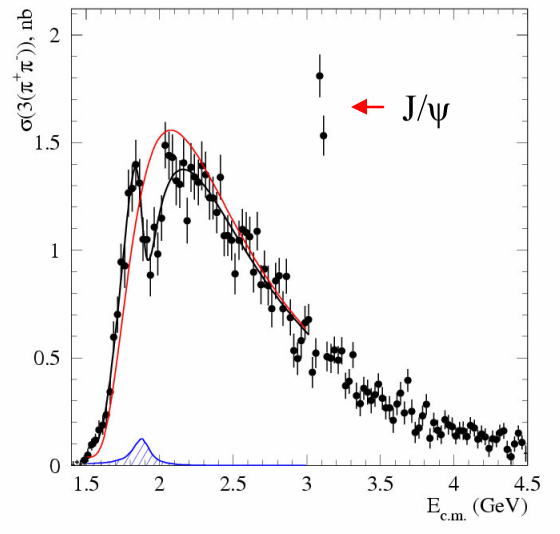
- ISR photon + 4 $h^{\pm}$ + 5γ (Eγ(ISR)>3GeV)
- Kaon veto applied to all charged tracks
- 5C fit (constrain π^0 masses)



- Structure around 1.9 GeV, already seen by DM2 and FOCUS experiments
- The BABAR measurements are much more precise than those from other e^+e^- experiments.

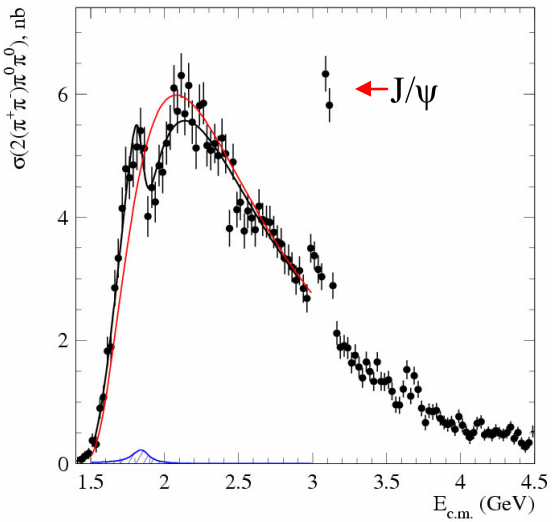
Fit to $e^+e^- \to 6\pi$ cross section data

$e^+e^- \to 3(\pi^+\pi^-)$



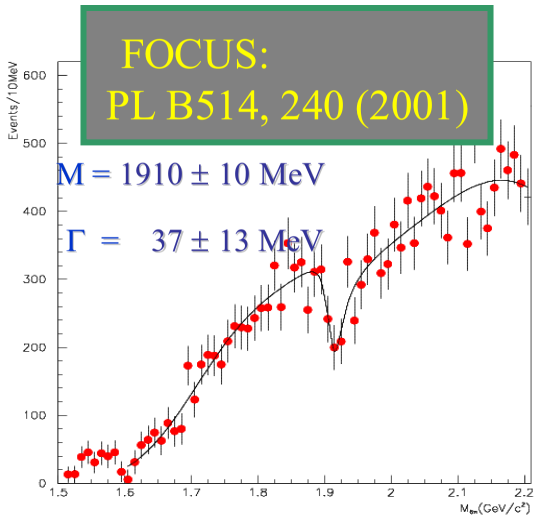
Peak cross section 4 times that for $3(\pi^+\pi^-)$

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



Fit cross section to ad hoc model:

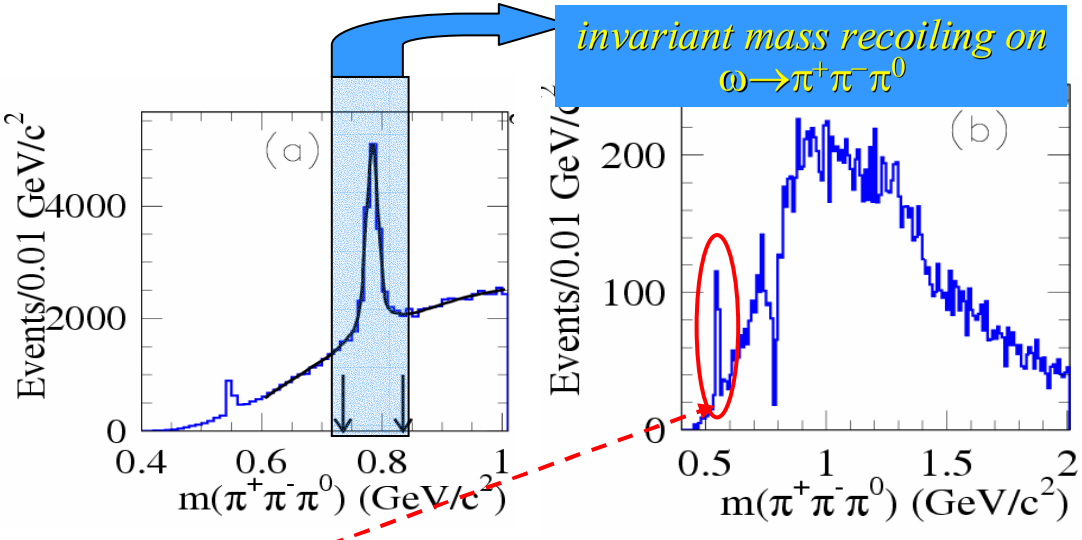
$$\sigma = \frac{4\pi\alpha^2}{s^{3/2}}\left|\frac{gm^2 e^{i\phi}}{s - m^2 + i\sqrt{s}\Gamma} + A_{cont}\right|^2$$



	M(GeV/c^2)	Γ(GeV)	phase
BABAR $3(\pi^+\pi^-)$	**1.88 ± 0.03**	**0.13 ± 0.03**	**21 ± 40**
BABAR $2(\pi^+\pi^-)\pi^0\pi^0$	**1.86 ± 0.02**	**0.16 ± 0.02**	**−3 ± 15**
FOCUS $3(\pi^+\pi^-)$	**1.91 ± 0.01**	**0.037 ± 0.013**	**10 ± 30**

Structure in $e^+e^- \to \gamma_{ISR} + 2(\pi^+\pi^-\pi^0)$

Quasi-two-body mode $e^+e^- \to \omega\eta$ observed; prominent structure seen in its cross section



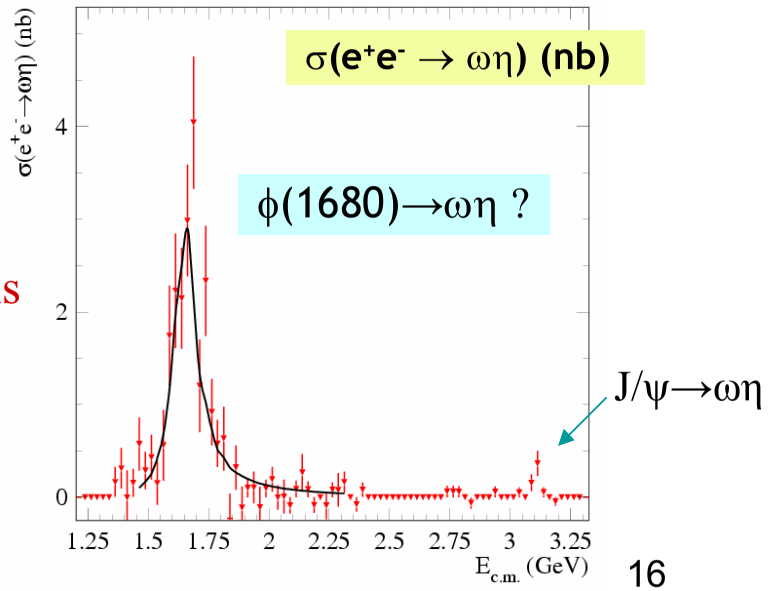
$$\sigma = \sigma_0 \left(\frac{m^2}{s}\right)^{3/2} \frac{F(s)}{F(m^2)} \left| \frac{m\Gamma_0}{s - m^2 + i\sqrt{s}\Gamma_0} \right|^2$$

$\sigma_0 = 3.08 \pm 0.33$ nb
$m = 1645 \pm 8$ MeV
$\Gamma_0 = 114 \pm 14$ MeV

Might be associated with ω(1650) but the width here is much smaller (~3σ).

BABAR: PRD 70, 072004 (2004)
m = 1660 ± 10
Γ = 230 ± 36 ($e^+e^- \to \pi^+\pi^-\pi^0$)

could it be PDG φ(1680)?
m = 1680 ± 20 MeV
Γ_0 = 150 ± 50 MeV



η and η′ Transition Form Factors (I)

- Previous measurements of $e^+e^- \to \eta\gamma$ and $e^+e^- \to \eta'\gamma$ were only up to $q^2 = 4$ GeV^2; this analysis is performed at $q^2 = 112$ GeV^2.

- These measurements are in the asymptotic region; cross sections of a few fb expected.

Sub. to PRD

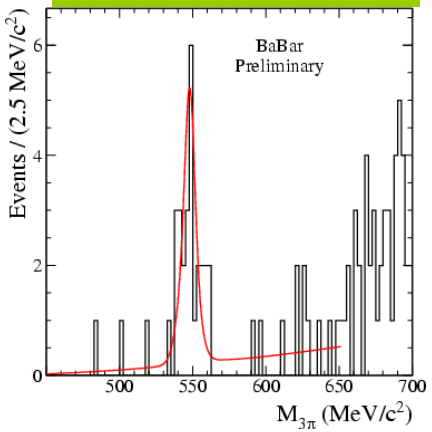
$$\sigma(e^+e^- \to \eta\gamma) = 4.48^{+1.25}_{-1.09} \pm 0.31 \quad fb$$

$$\sigma(e^+e^- \to \eta'\gamma) = 5.40^{+0.84}_{-0.77} \pm 0.32 \quad fb$$

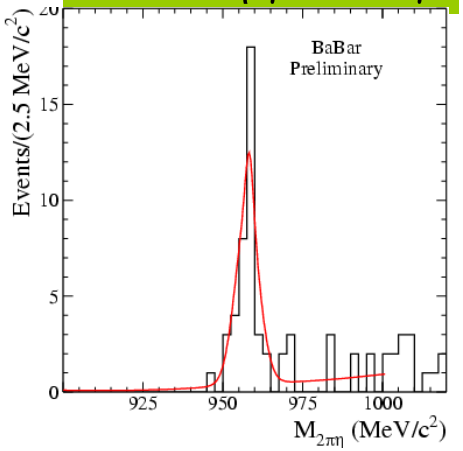
$$N(\eta\gamma) = 20^{+6}_{-5}$$

$$N(\eta'\gamma) = 50^{+8}_{-7}$$

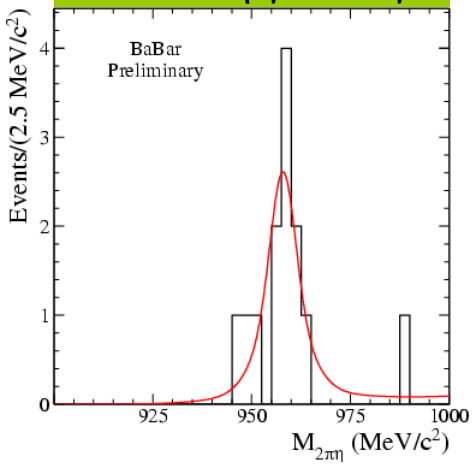
$e^+e^- \to \eta\gamma \to 3\pi\gamma$



$e^+e^- \to \eta'\gamma \to 2\pi 3\gamma$



$e^+e^- \to \eta'\gamma \to 5\pi\gamma$



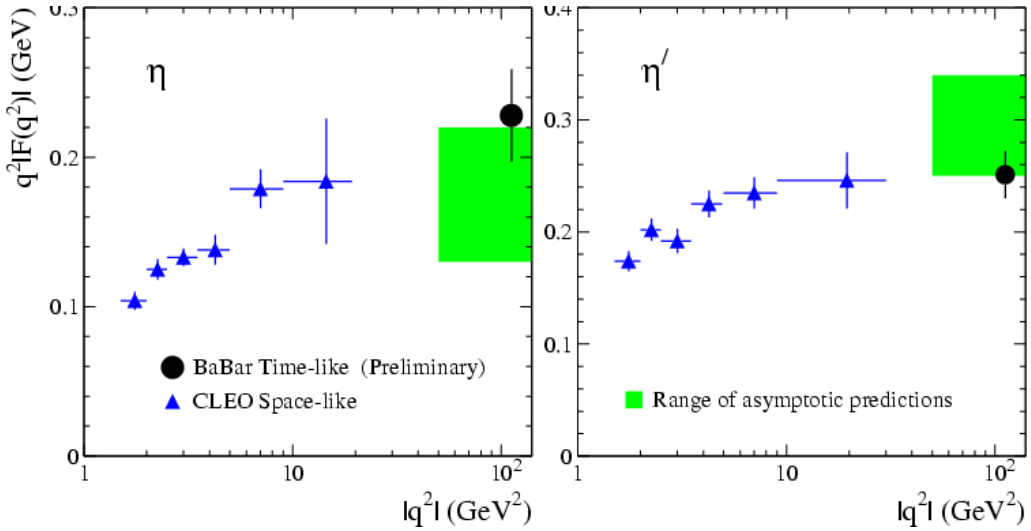
η and η' Transition Form Factors (II)

- Problem with precise prediction due to some different uncertainties like the gluon content of η and η'.
- Our data are at the upper and lower limits of the predicted ranges for η and η' respectively.

BaBar Preliminary

$$q^2\left|F_{\eta}(q^2)\right| = 0.229 \pm 0.030 \pm 0.008 \ \ GeV$$

$$q^2\left|F_{\eta'}(q^2)\right| = 0.251 \pm 0.019 \pm 0.008 \ \ GeV$$



Our measurement of the ratio of the form factors is:

1.10 ± 0.17

The prediction is 1.6 - 2.3 for the η' to η ratio.

Angular analysis of $B \to (c\bar{c})K^*$ (I)

$$B \to (c\bar{c})K^*; (c\bar{c}) = J/\psi, \psi(2S), \chi_{c1}$$

- Of interest for the precise measurement of sin2β; get cos2β from time-dependence of J/ψ ($K_S\pi^0$) [BaBar PRD 71, 032005 (2005)]
- When heavy quarks are present in final state factorization can be questioned
- More precise measurements needed to understand non-factorizable contributions (Chen and Li, PRD 71(2005) 114008)

Angular analysis of $B \to (c\bar{c})K^*$ (II)

BABAR has measured the decay amplitudes and phases for each charmonium state;

BaBar Preliminary

Channel	$J/\psi\ K^*$	$\psi(2S)\ K^*$	$\chi_{c1}\ K^*$
$\lvert A_0\rvert^2$	0.556±0.009±0.010	0.48±0.05±0.02	0.77±0.07±0.04
$\lvert A_\parallel\rvert^2$	0.211±0.010±0.006	0.22±0.06±0.02	0.20±0.07±0.04
$\lvert A_\perp\rvert^2$	0.233±0.010±0.005	0.30±0.06±0.02	0.03±0.04±0.02
$\delta_\parallel - \delta_0$ (*) (rad)	-2.93±0.08±0.04	-2.8±0.4±0.1	0.0±0.3±0.1
$\delta_\perp - \delta_0$ (*) (rad)	2.91±0.05±0.03	2.8±0.3±0.1	-----

(*) Relative phase ambiguity resolved as in PRD 71, 032005 (2005) [BaBar]

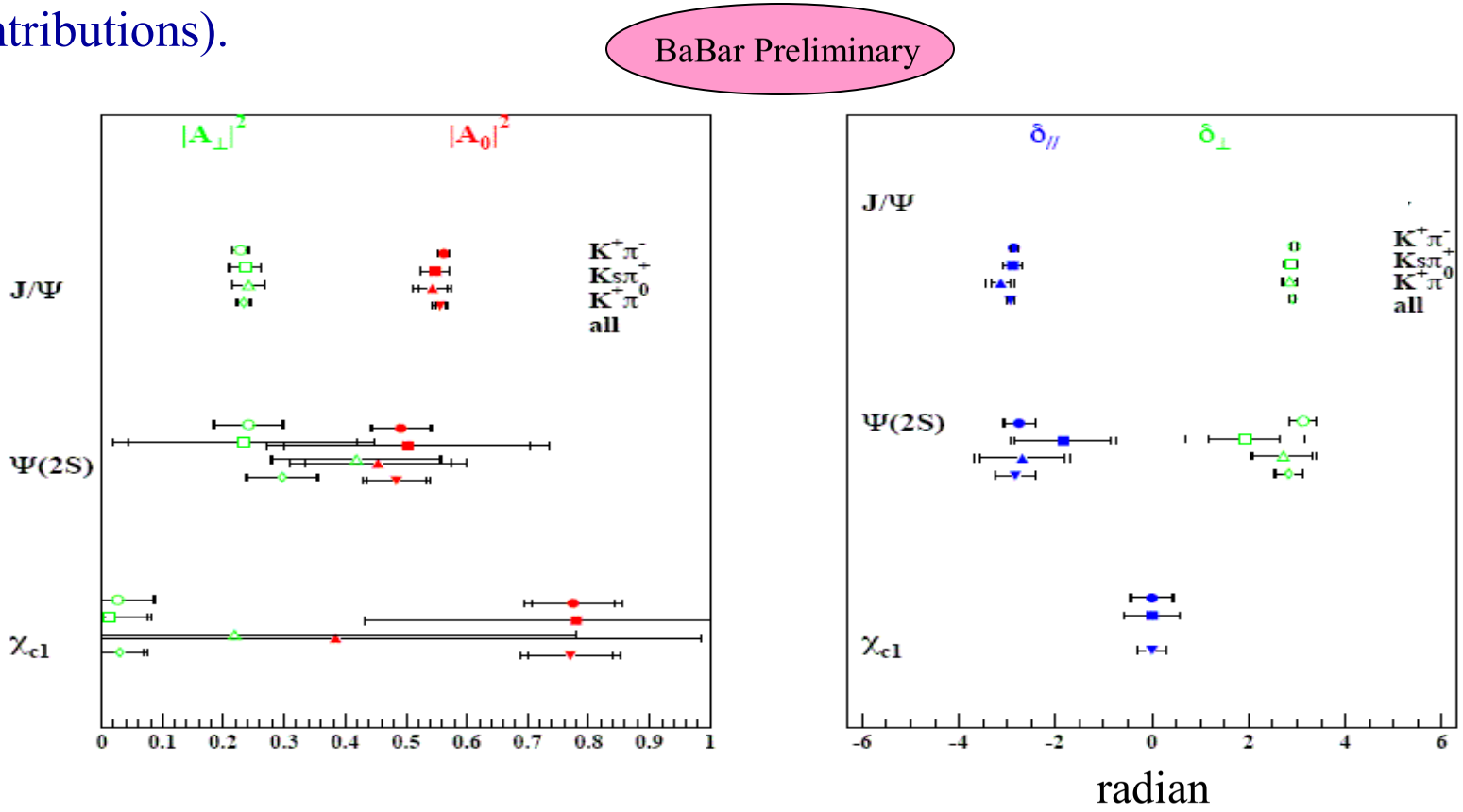
- First full angular analysis of $\psi(2S)\ K^*$ and $\chi_{c1}\ K^*$
- Measurements for J/ψ are compatible with, and more precise than, previous ones
- For $J/\psi\ K^*$ we confirm that the strong phase difference is significantly different from 0, in contrast to the factorization prediction (an 8σ effect).

Factorization predicts 0 or π.

$$\delta_\parallel - \delta_\perp = (0.45 \pm 0.05 \pm 0.02)\ \ radian$$

Angular analysis of $B \to (c\bar{c})K^*$ (III)

- The longitudinal polarization of the decay to $\psi(2S)$ is smaller than that of J/ψ ($<2\sigma$)
- The longitudinal polarization of the decay to χ_{c1} is found to be larger than that to J/ψ ($\sim 3\sigma$) in contrast with the prediction of Chen and Li (that includes non-factorizable contributions).



Conclusion

- ✓ New test of factorization using a new channel $\bar{B}^0 \to D^{*+}\omega\pi^-$
- ✓ More precise studies on form factors
- ✓ First measurement of e^+e^- producing C=+1 hadronic final states
- ✓ Best measurements of $e^+e^- \to p\bar{p}$ with insights onto G_E and G_M
- ✓ Confirmation of $p\bar{p}$ threshold enhancement in exclusive B decays
- ✓ Confirmation of a dip in $e^+e^- \to 6\pi$ channels at ~1.9 GeV
- ✓ Observation of a structure in $e^+e^- \to \omega\eta$ at ~1645 MeV
- ✓ Measurements of η and η' Transition Form Factors at q^2=112 GeV^2
- ✓ Complete angular analysis of $B \to (c\bar{c})K^*$ where $c\bar{c}$ = J/ψ, ψ(2S) and χ_{c1}