e^+e^- Annihilations into Quasi-two-body Final States at 10.58 GeV

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Jefferson Lab, May 23, 2007

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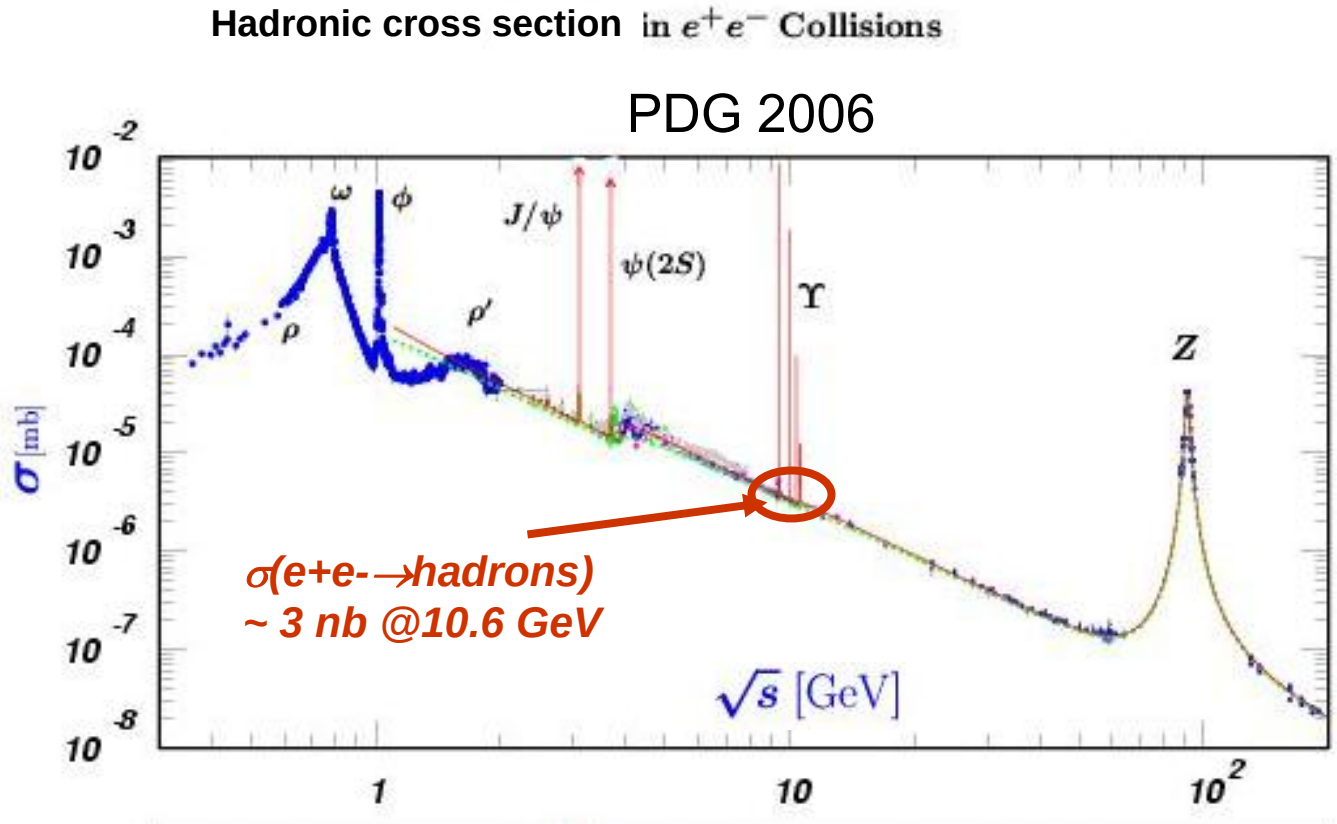
Outline

- *Introduction*
- *First Observation of positive C parity hadronic final states in the reactions* $e^+e^- \to \rho^0\rho^0, \phi\rho^0$
- *Observation of* $e^+e^- \to \phi\eta$ *(C=–1 final state)*
- *First Observation of* $e^+e^- \to \rho^+\rho^-$ *(C=–1 ?)*
- *Summary and Outlook*

Introduction—General Information



The design goal of the B factory is the study of B physics.

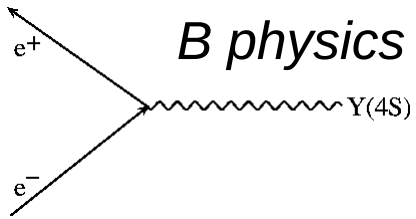
However, at $\sqrt{s}$~10.6 GeV, $\sigma(e^+e^- \rightarrow hadrons)$ ~3 nb and $\langle N_{ch} \rangle$ ~8

Large integrated luminosity (~500 fb^{-1}) $\Rightarrow$ can study low-multiplicity exclusive hadronic processes with σ values ~fb; this provides tests of QCD at the amplitude level.

Today's talk makes use of:
$\int\mathcal{L}$~343 fb^{-1} @10.58 GeV (OnPeak); $\int\mathcal{L}$~36 fb^{-1} @10.54 GeV (OffPeak)

Introduction—Possible Processes at B Factories

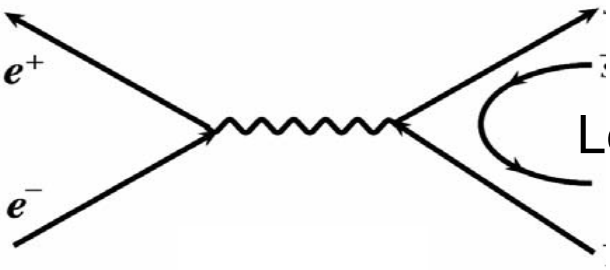
One photon processes



B physics *or* *h*

σ~nb

C=−



M_1

Low multiplicity

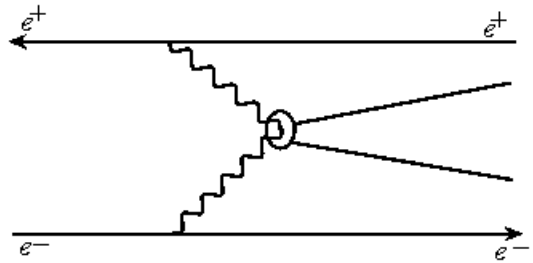
M_2

σ~fb

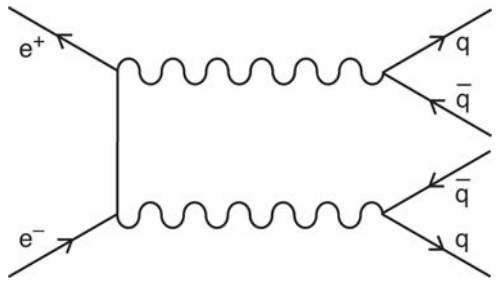
A subset of $e^+e^- \to q\bar{q}$ processes;
$e^+e^- \to M_1 M_2$ can also be studied via ISR
Excellent test ground for QCD

Two photon processes

Two Photon TP



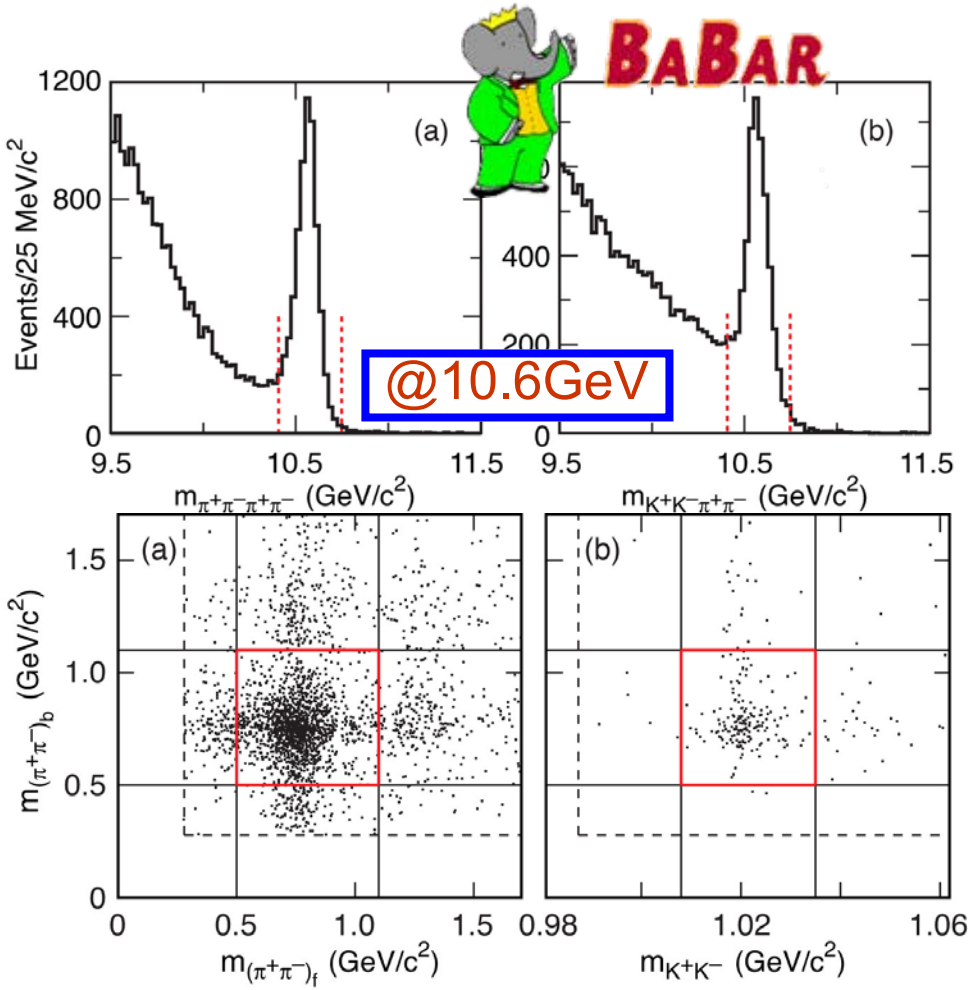
C=+



Two-Virtual-Photon-Annihilation, TVPA; new observation at BaBar

Observation of $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ (C=+1)

PRL 97, 112002 (2006)



Select events with invariant mass of ($K^+K^-\pi^+\pi^-/\pi^+\pi^-\pi^+\pi^-$) within 170 MeV of c.m. energy.

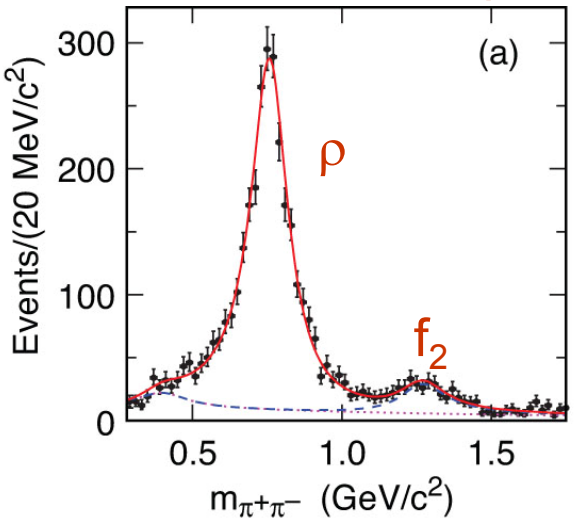
Only one entry in the $\pi^+\pi^-\pi^+\pi^-$ region of interest out of two possible combinations (no ambiguity)

Use binned log-likelihood fit over 9 tiles to extract signal

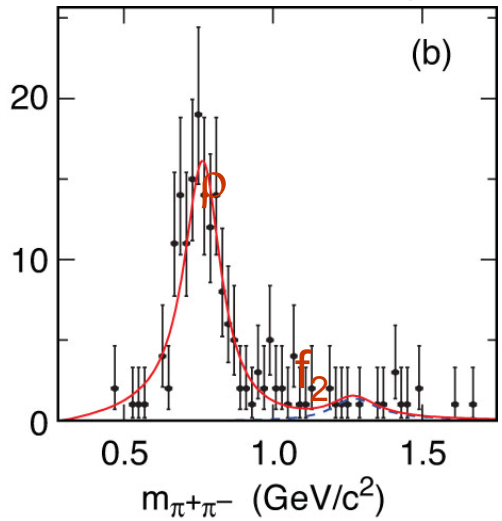
signal tiles:
$0.5<m_{\pi\pi}<1.1$ GeV/c² (ρ)
$1.008<m_{KK}<1.035$ GeV/c² (ϕ)

Observation of $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ (C=+1)

$\pi^+\pi^-$ against "ρ"



$\pi^+\pi^-$ against "ϕ"

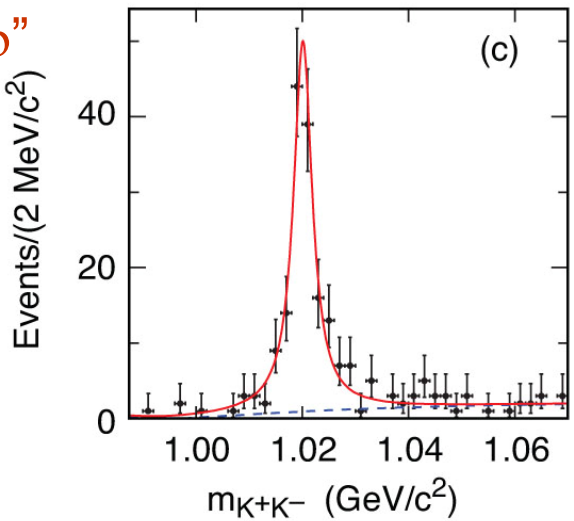


total

$\mu\mu$ background+f_2

$\mu\mu$ background

K^+K^- against "ρ"



total

background

Correlated ϕ and ρ^0 signals

Relativistic Breit-Wigner lineshapes used in the fit

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Observation of $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ (C=+1)

The extracted signals:

	All Events		*Yield @ 10.58 GeV*	*Yield @ 10.54 GeV*	*Expected continuum @ 10.56 GeV (from $\int\mathcal{L}$ ratio)*
	Yield	significance			
$\rho^0\rho^0$	*1243±43*	*>> 5σ*	*1138± 42*	*104± 14*	*112 ±4*
$\phi\rho^0$	*147±13*	*>> 5σ*	*135± 13*	*14± 4*	*13± 1*

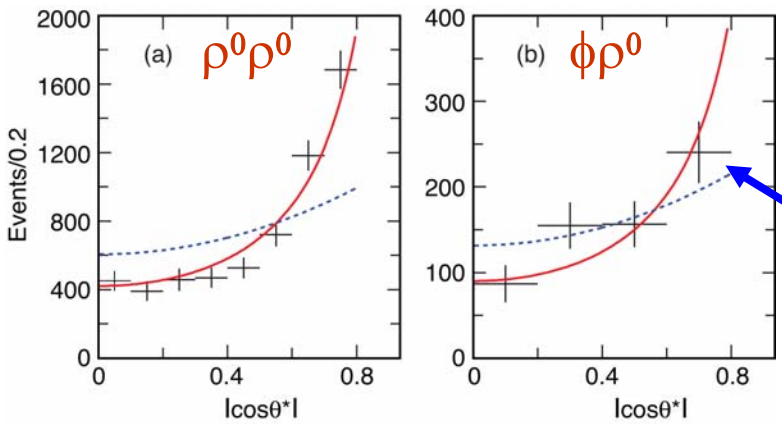
consistent

Y(4S) production cannot contribute because of C parity conservation.
The yields are consistent with continuum production

Signals large enough to analyze the angular distributions and investigate the production mechanism of these events.

Observation of $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ (C=+1)

Efficiency-corrected projections



Production angle θ^*–polar angle of ϕ or $\rho_{forward}$ in CM consistent with expectation for TVPA

$1+\cos^2\theta^*$ for comparison

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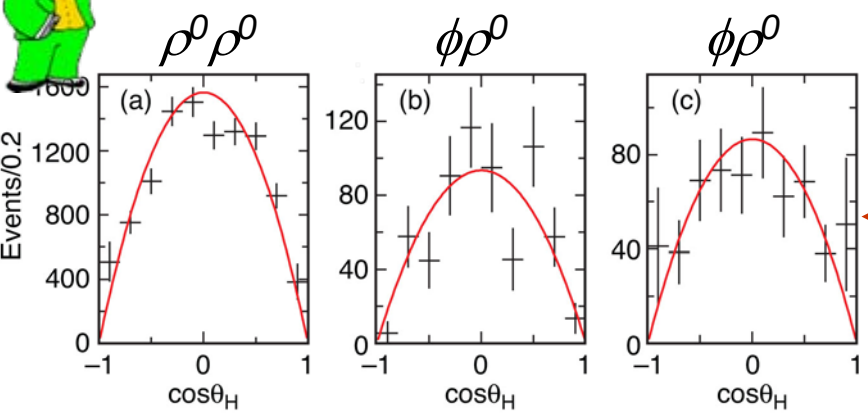

θ_H for π^+ θ_H for K^+ θ_H for π^+

Helicity angle θ_H—the angle between daughter and recoil in the mother rest frame

$\sin^2\theta_H$ distributions

All angular distributions are consistent with TVPA expectation for quasi-real photons

Observation of $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ (C=+1)

We observe $e^+e^- \to C=+1$ exclusive hadronic final states and angular analyses support TVPA production

For $1.008<m_\phi<1.035$ GeV and $0.5<m_\rho<1.1$ GeV ($|\cos\theta^*|<0.8$); the cross sections are:

$\sigma(\rho^0\rho^0)=20.7\pm0.7(stat)\ \pm2.7(syst)$ fb

$\sigma(\phi\rho^0)=5.7\pm0.5(stat)\ \pm0.8(syst)$ fb

reminder:

$\sigma(e^+e^- \to hadrons\ @10\ GeV) \sim 3$ nb

Theory calculations (after the measurement) consistent with our results:

	hep-ph/0606155	PRD 74 074012,2006	
$\sigma(\rho^0\rho^0)=$	21.4 ± 0.7	17.7 ± 0.6	fb
$\sigma(\phi\rho^0)=$	6.0 ± 0.1	5.6 ± 0.2	fb

Extending our results to low energy, the TVPA contribution to muon (g-2) is small; this removes a possible uncertainty source in the g-2 calculation (hep-ph/0606155)

Observation of $e^+e^- \to \phi\eta$ at ~10.6 GeV

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PRD (RC) 74, 111103(2006)

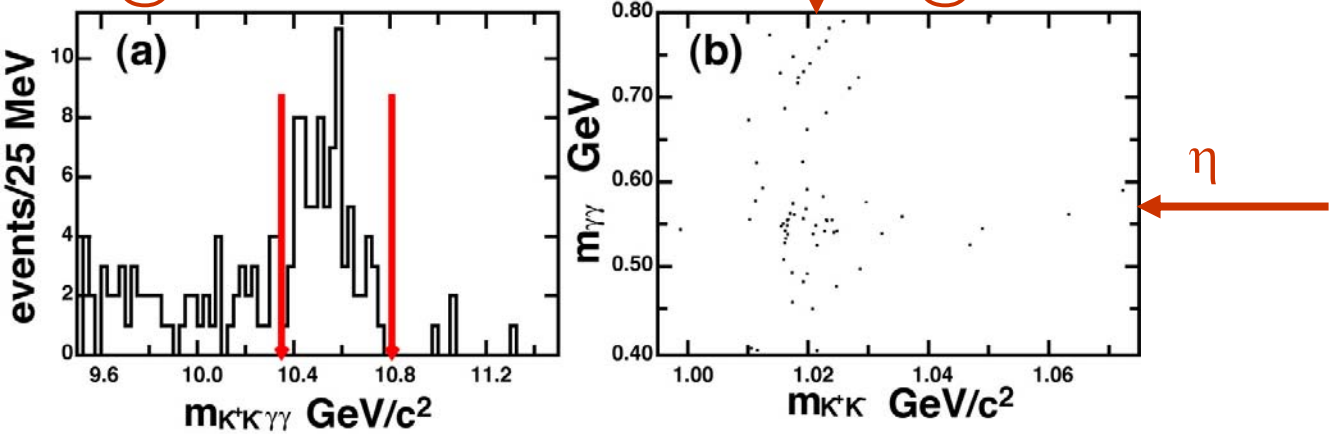
$e^+e^- \to \phi\eta$ is analogous to $e^+e^- \to J/\psi\eta_c$ (η has s-sbar content)
Interesting because observed $\sigma(e^+e^- \to J/\psi\eta_c)$ 10X higher than QCD predictions

- *Provides information on s-dependence by combining with a CLEO measurement at lower energy*

- Selection procedures similar to those for $e^+e^- \to \rho^0\rho^0/\phi\rho^0$ final states

@ 10.58 GeV

ϕ @10.58+10.54 GeV



We see $\phi\eta$ correlation.
Use a two-dimensional log-likelihood fit to extract signal:
P-wave relativistic Breit-Wigner for ϕ; Gaussian resolution function for η

Observation of $e^+e^- \to \phi\eta$ at ~10.6 GeV

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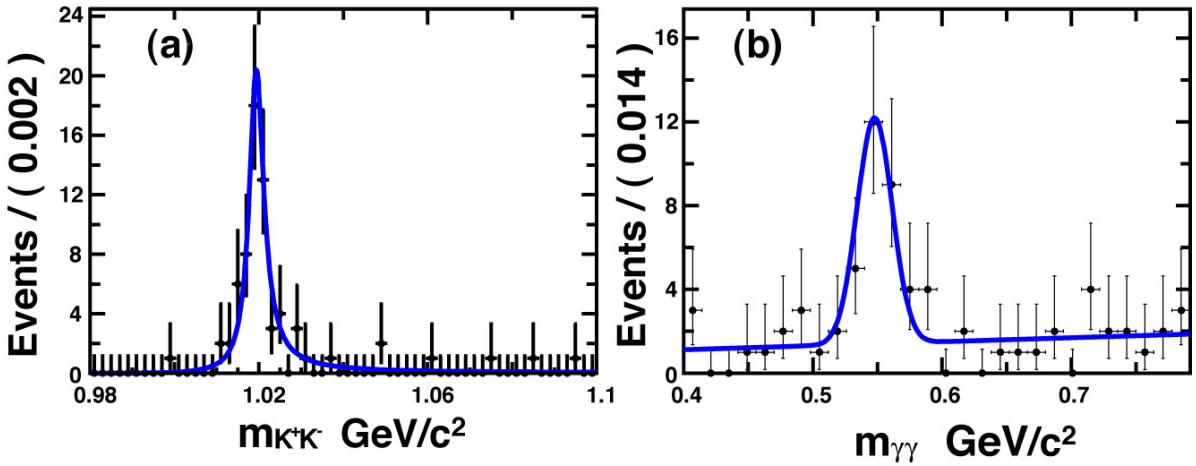
Mass projections



Yield for $1.008<m_{\phi}<1.035$ GeV/c², and $0.4<m_{\gamma\gamma}<0.8$ GeV/c² :

All data: 24 ± 5 events @10.58 GeV: 20 ± 5 @10.54 GeV: 3 ± 2

Significance: $6.5\ \sigma$

U.L. for BF of Y(4S) decay @90% CL based on -10 ± 21 events: 2.5×10^{-6}

Observation of $e^+e^- \to \phi\eta$ at ~10.6 GeV

The full angular distribution, assuming one-virtual-photon production, is given by:

$$\frac{dN}{d\cos\theta^* d\cos\theta_\phi d\varphi_\phi} \propto \sin^2\theta_\phi(1+\cos^2\theta^* + \cos 2\varphi_\phi \sin^2\theta^*)$$

Projections:

$$\frac{dN}{d\cos\theta^*} \propto (1+\cos^2\theta^*)$$

$$\frac{dN}{d\cos\theta_\phi} \propto \sin^2\theta_\phi$$

$$\frac{dN}{d\varphi_\phi} \propto (2+\cos 2\varphi_\phi)$$

θ^*: polar angle in c.m.

θ_ϕ: ϕ helicity angle

φ_ϕ: azimuthal angle of the decay plane ϕ w.r.t. production plane normal in the c.m. frame

Distributions in data are consistent with predictions within limited statistics

We weight isotropic MC angular distributions as above for efficiency estimation.

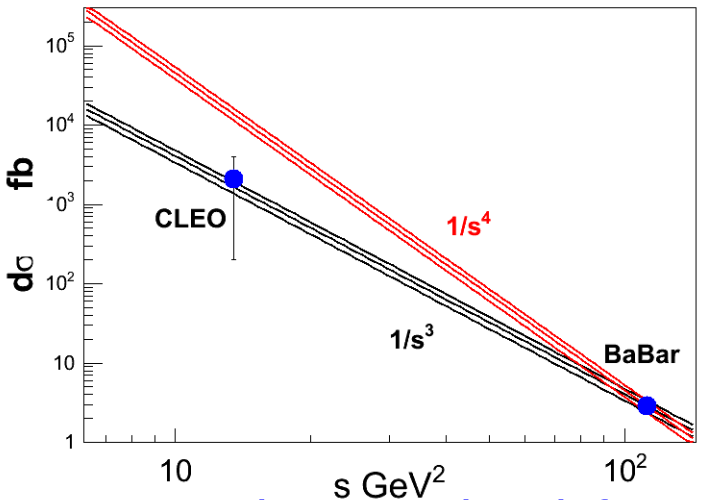
Observation of $e^+e^- \to \phi\eta$ at ~10.6 GeV

For $1.008 < m_\phi < 1.035$ GeV/c^2 and $|\cos\theta^*| < 0.8$, the cross section after radiative corrections is measured as:

$$\sigma(\phi\eta) = 2.1 \pm 0.4(\text{stat}) \pm 0.1(\text{syst})\ \text{fb}$$

Extending to ($|\cos\theta^*| <= 1$) by assuming a $1 + \cos^2\theta^*$ distribution, this becomes:

$$\sigma(\phi\eta) = 2.9 \pm 0.5(\text{stat}) \pm 0.1(\text{syst})\ \text{fb}$$



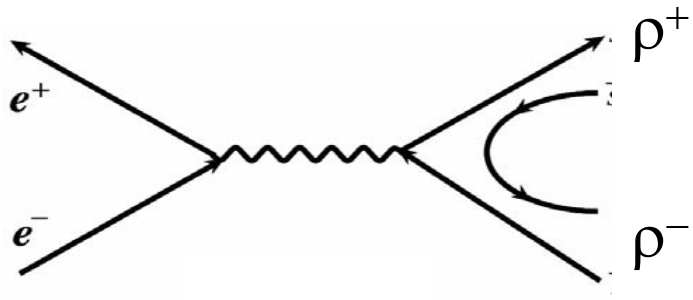
Combine with CLEO measurement at lower energy; $1/s^3$ energy dependence favored over $1/s^4$ (pQCD prediction), assuming continuum production. Another QCD puzzle?

Analysis of BaBar ISR data is ongoing; will provide improved measurement of the s dependence

Recent theory value (after the measurement) (hep-ph/0702065): σ~3.1~4.3 fb, and $1/s^3$ dependence favored.

Observation of $e^+e^- \to \rho^+\rho^-$

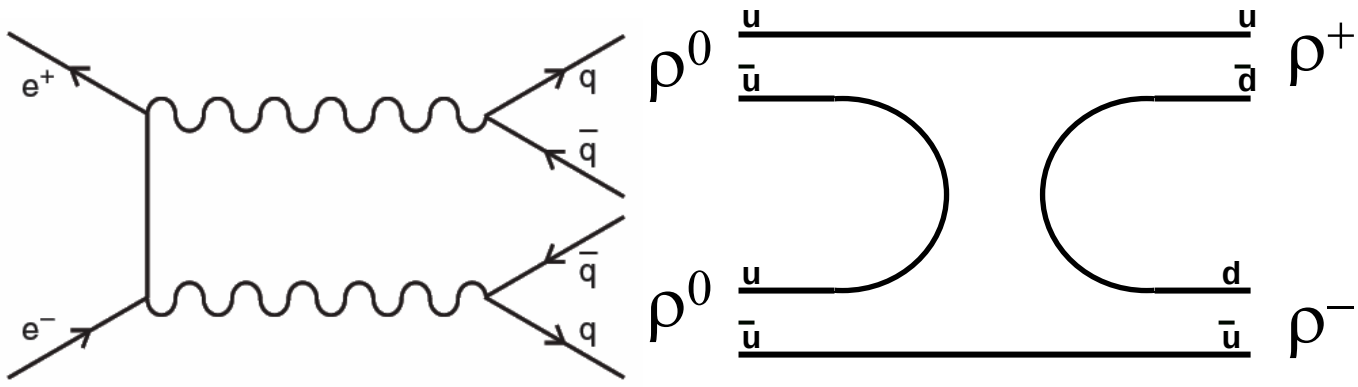
Single photon ($J^{PC} = 1^{--}$)



- In general:
- $C(\rho^+\rho^-)=(-1)^{L+S}$, + or -;
- $P(\rho^+\rho^-)= (-1)^L$;

Single photon production$\Rightarrow$
L odd, S even, $I(\rho^+\rho^-)=1$(Bose Statistics).

Other possibility: Two-Virtual Photon Annihilation (C = +1) followed by FSI $\to$ unlikely?



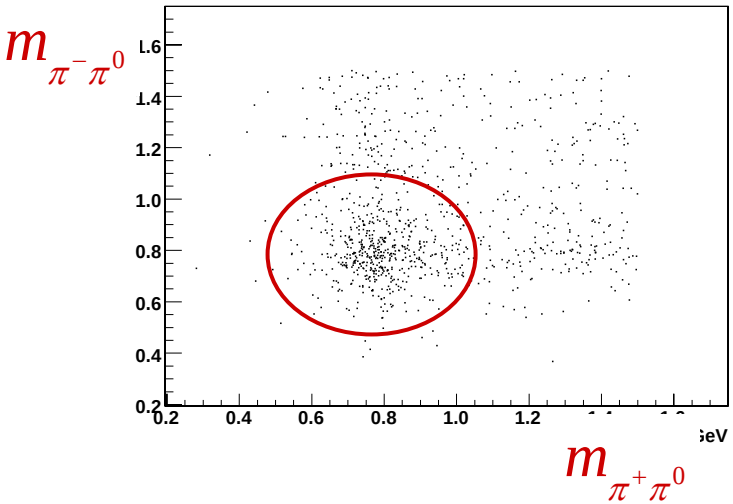
No angular correlation predictions

Observation of $e^+e^- \to \rho^+\rho^-$

Selection procedures similar to other final states

Likelihood Fit in ($m_{\pi^-\pi^0}$, $m_{\pi^+\pi^0}$) plane:

- Signal function= product of P-wave relativistic BWs
- $\rho\pi\pi$ = threshold function
- Linear combinatorial background

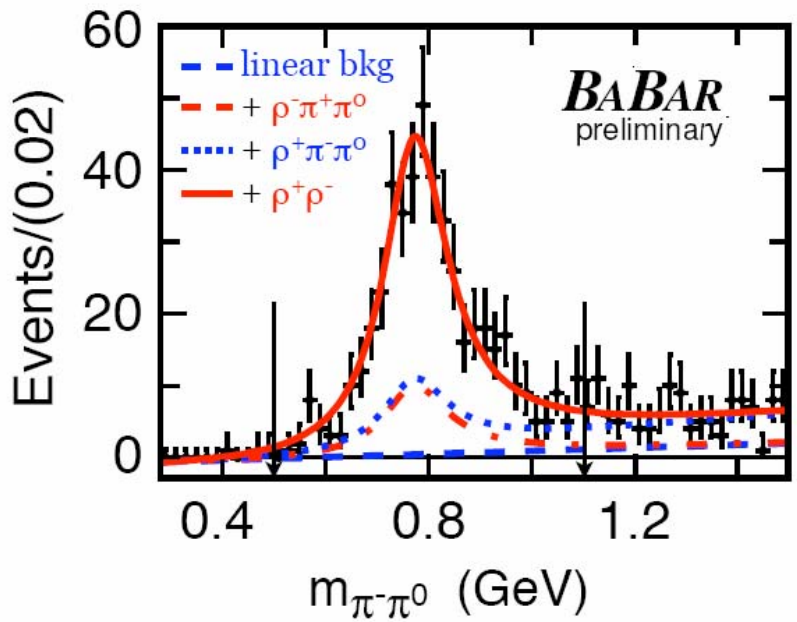


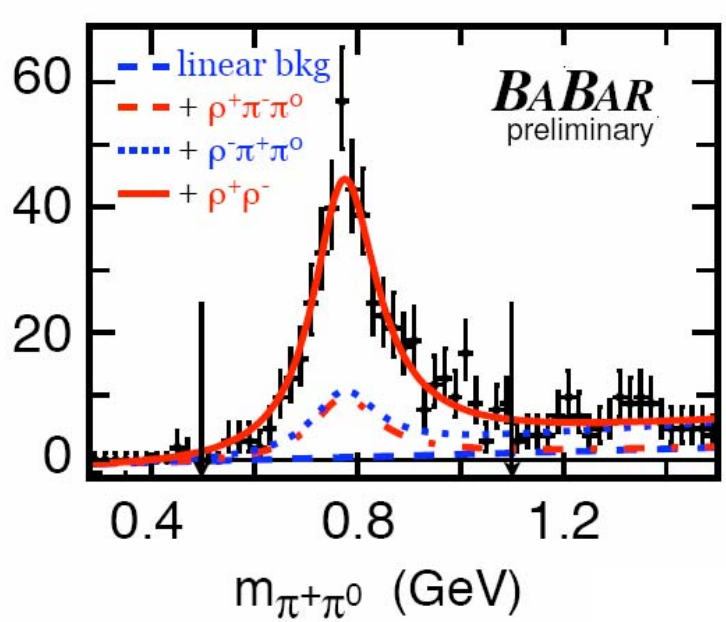
N = 308 ± 25 signal events (> 5σ)

$\sigma(e^+e^- \to \rho^+\rho^-)$ = (20.0 ± 1.6 ± 3.6 ± 1.7) fb

extending to full angular range (stat) (syst) (ampl)

preliminary





Observation of $e^+e^- \to \rho^+\rho^-$

Assuming one-virtual-photon production, the angular distribution projections are:

$$\frac{dN}{d\cos\theta^*} \propto \frac{3}{4}(\sin^2\theta^*|F_{00}|^2+2(1+\cos^2\theta^*)|F_{10}|^2+2\sin^2\theta^*|F_{11}|^2)$$
$$\frac{dN}{d\cos\theta_\pm} \propto \frac{3}{2}(\cos^2\theta_\pm|F_{00}|^2+(1+\cos^2\theta_\pm)|F_{10}|^2+\sin^2\theta_\pm|F_{11}|^2)$$
$$\frac{dN}{d\varphi_\pm} \propto \frac{1}{2\pi}(|F_{00}|^2+(4-\cos 2\varphi_\pm)|F_{10}|^2+2|F_{11}|^2)$$

$\theta^\pm = \rho^\pm$ helicity angle

$\phi^\pm$ = azimuthal angle of π in ρ frame

$\theta^* =$ scattering angle in the CM frame

pQCD prediction (single γ^*):

Brodsky and Lepage, PRD 24, 2848 (1981)

$$|F_{10}|^2 \sim |F_{11}|^2 < 0.01|F_{00}|^2$$

Observation of $e^+e^- \to \rho^+\rho^-$

Fit normalization constraint:

$$|F_{00}|^2 + 4|F_{10}|^2 + 2|F_{11}|^2 = 1$$

Results:

$$|F_{00}|^2 = 0.51 \pm 0.14(\text{stat}) \pm 0.02(\text{syst})$$
$$|F_{10}|^2 = 0.10 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$$
$$|F_{11}|^2 = 0.04 \pm 0.03(\text{stat}) \pm 0.00(\text{syst})$$

$|F_{00}|^2 \neq 1$

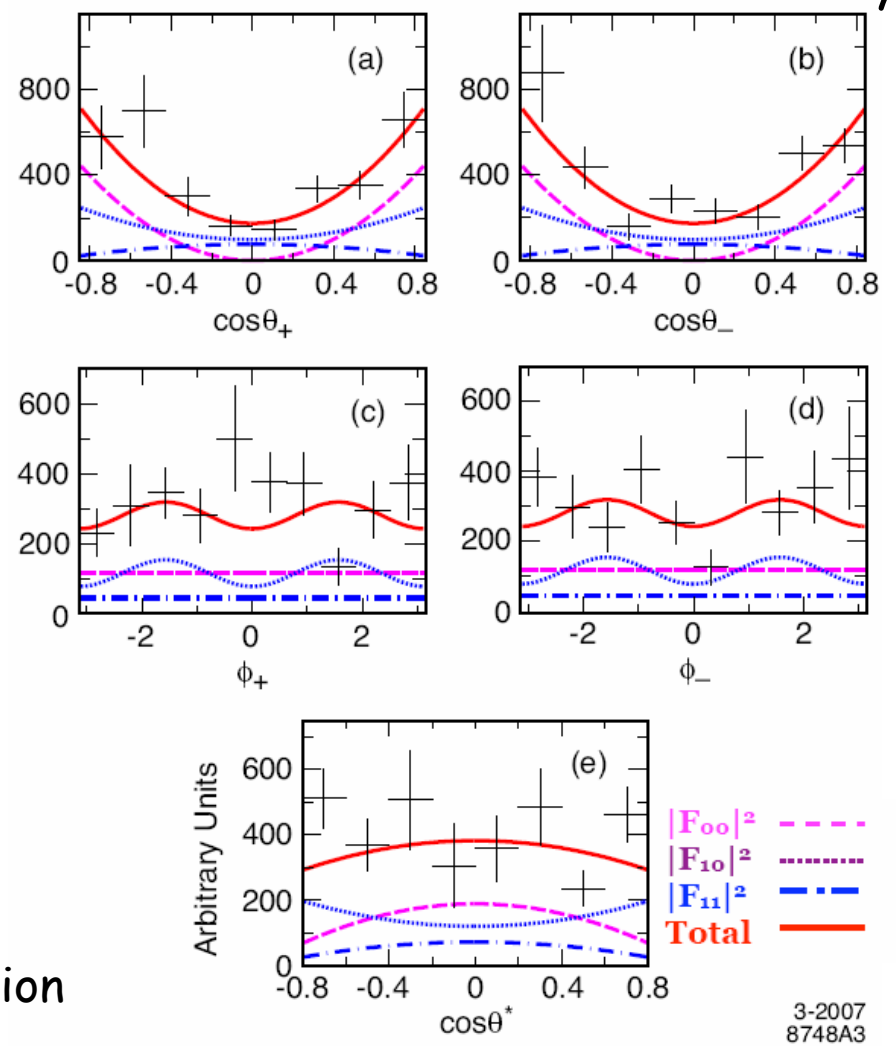
$\sigma(e^+e^- \to \rho^0\rho^0) > \sigma(e^+e^- \to \rho^+\rho^-)$

No evidence for $\Upsilon(4S) \to \rho\rho$

Are we seeing TVPA + FSI?

Combine with ongoing ISR analysis to measure s dependence of the cross section of the individual amplitudes.

BaBar Preliminary



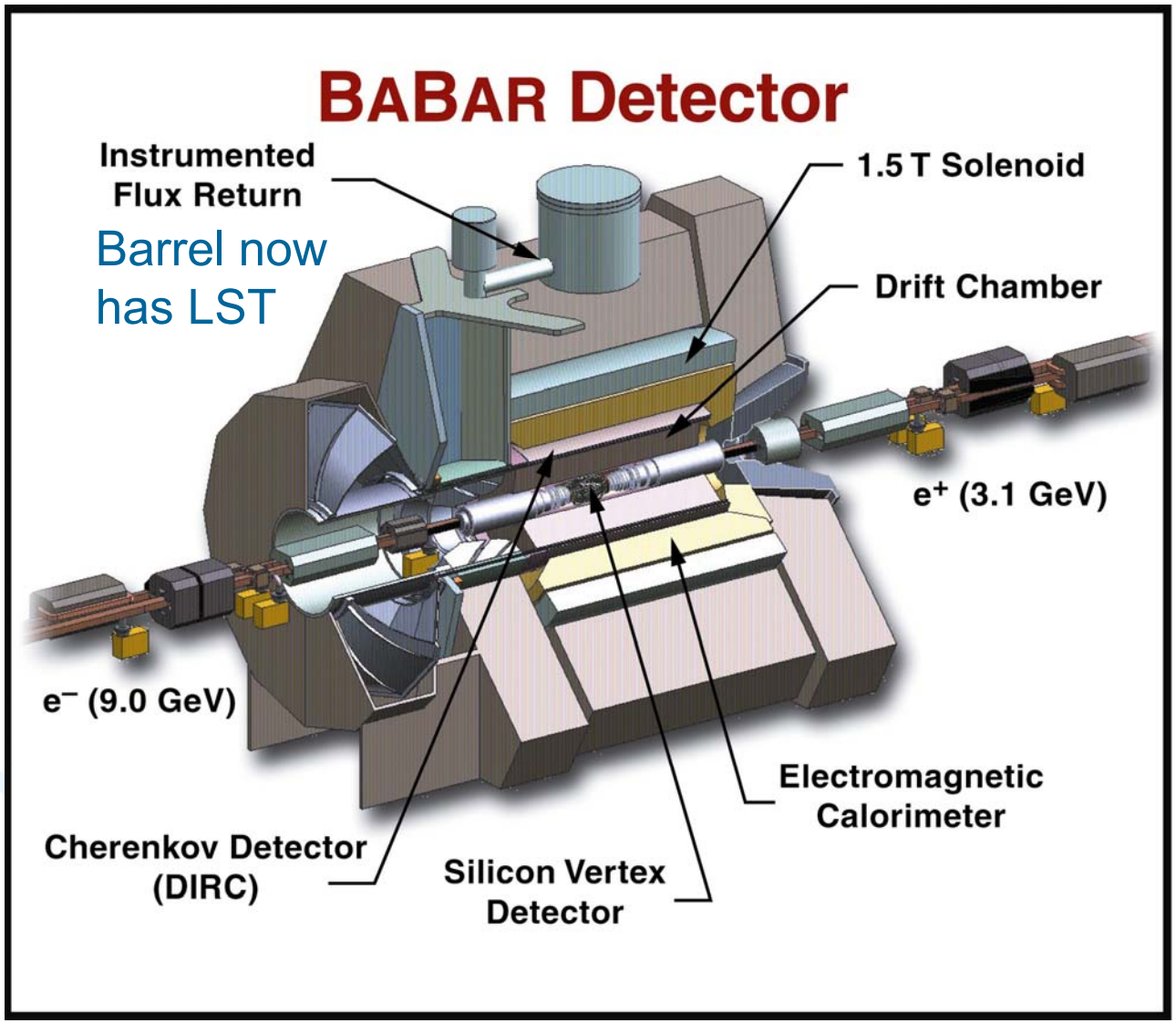
Summary and Outlook

At BaBar we have:

- *Made the first observations of the TVPA hadronic processes:*
  $e^+e^- \to \rho^0\rho^0$ *and* $e^+e^- \to \phi\rho^0$
  and measure their cross sections and angular distributions
- *Observed the process* $e^+e^- \to \phi\eta$ *and measured the cross section; this provides an interesting test of the QCD prediction of the energy dependence, assuming continuum production.*

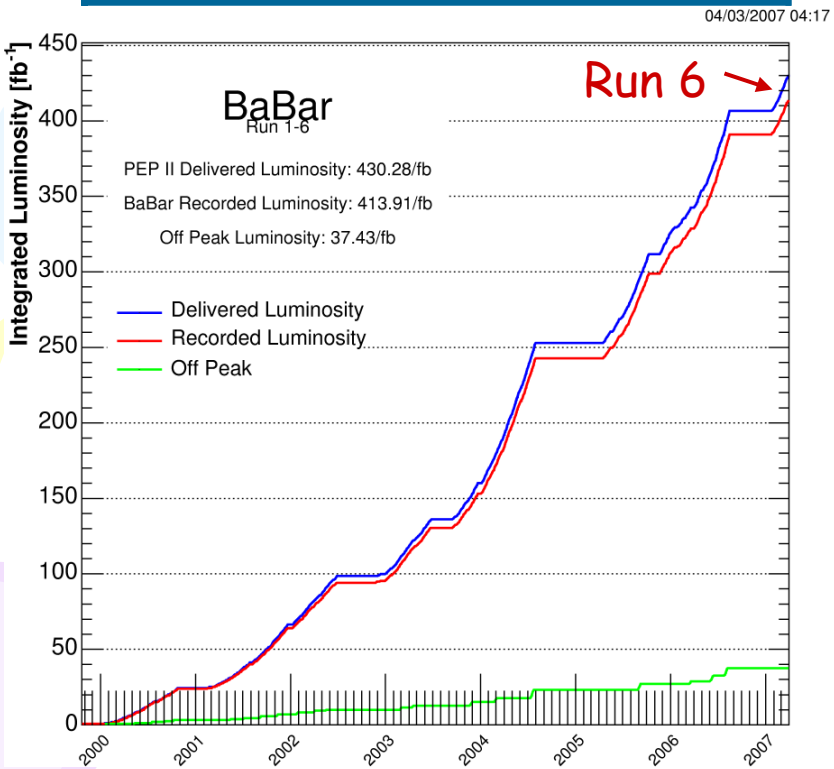
- *Observed the process* $e^+e^- \to \rho^+\rho^-$ *and measured the cross section; the measured amplitudes contradict the pQCD expectation at 3.5* σ*, assuming single photon production.*

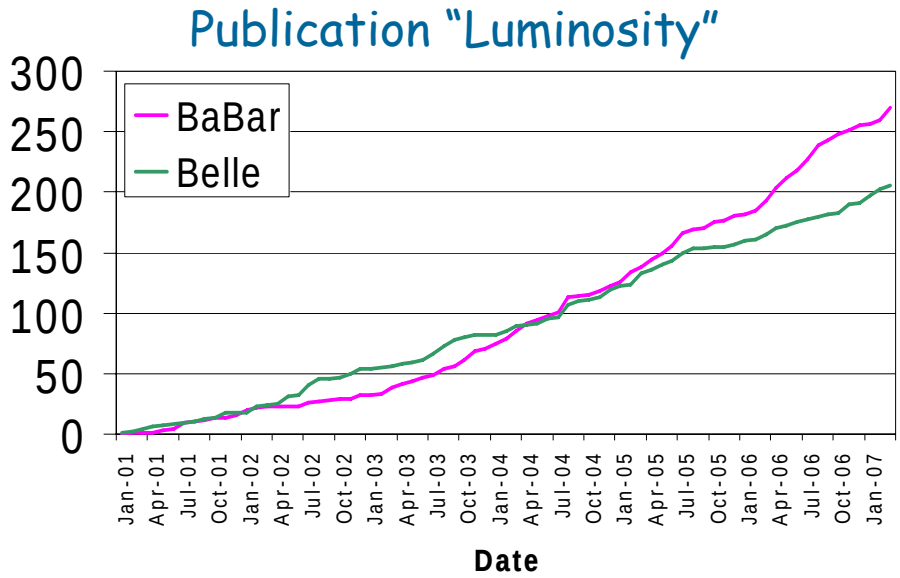
We plan to use the high integrated luminosity at BaBar to investigate other interesting low-multiplicity exclusive final states in the near future! The corresponding ISR data will enable us to measure s-dependence and compare to QCD predictions.


BABAR Detector
Instrumented Flux Return
Barrel now has LST
1.5 T Solenoid
Drift Chamber
e+ (3.1 GeV)
e− (9.0 GeV)
Electromagnetic Calorimeter
Cherenkov Detector (DIRC)
Silicon Vertex Detector

Data input and physics output

	BABAR	Belle
Luminosity	413fb^{-1}	710fb^{-1}
Journal Papers	270	206





Peak luminosity (cm^{-2}s^{-1})	1.201 x 10^{34}
Best shift	329.7 pb^{-1}
Best day	891.2 pb^{-1}
Best week	5.25 fb^{-1}
Best month	18.84 fb^{-1}
BABAR logged	414 fb^{-1}