DPF 2009
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Wayne State University, Detroit, MI

Branching Fraction Measurements of $D^0 \Rightarrow$ Vector Meson + η Decays

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On behalf of the BABAR Collaboration

Why Study Charm Physics?

- Dedicated Facilities
  - CLEO-c, BES-III
- Large data sample from B-Factories
  - BaBar, Belle
- Renewed theoretical interest
- …

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Ikaros Bigi
Charm 2009

Executive Summary

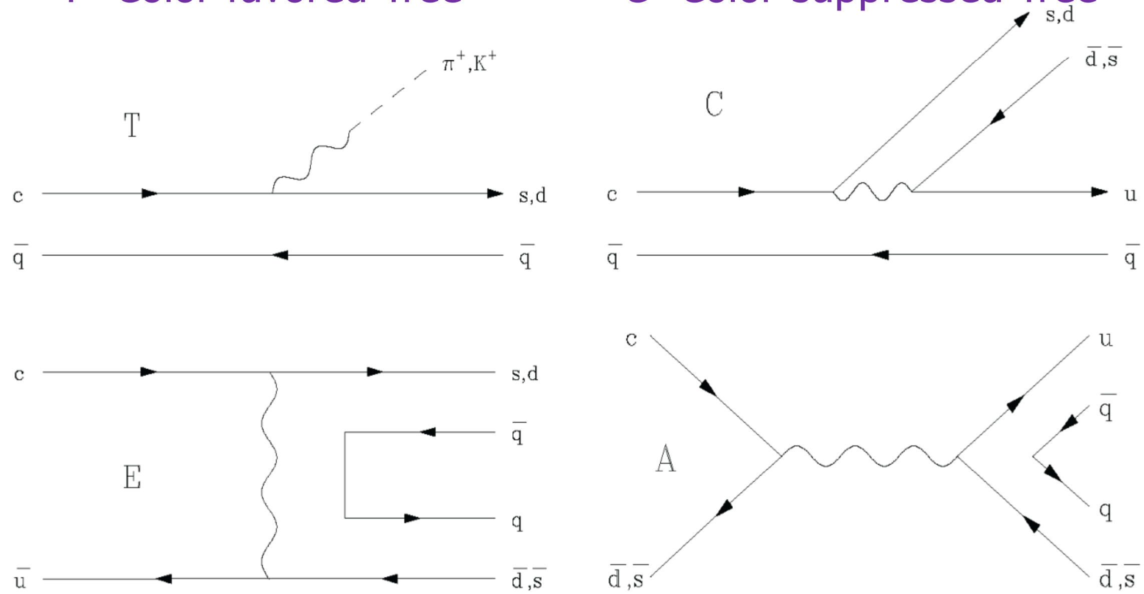
Relative `dullness' of SM on FCNC & $\not{CP}$ for charm - unique low (yet ≠ 0) background search for NP

$$\left(\frac{\text{NP signal}}{\text{theor.SM noise}}\right)_{\text{up-type}} > \left(\frac{\text{NP signal}}{\text{theor.SM noise}}\right)_{\text{down-type}}$$

Hadronic Decays of Charm Mesons

Topological Approach

T=Color-favored Tree C=Color-suppressed Tree



E=Exchange A=Annihilation

Meson	Decay mode	Representation
D^0	$\pi^+\rho^-$	$-(T_V{}' + E_P{}')$
	$\pi^-\rho^+$	$-(T_P{}' + E_V{}')$
	$\pi^0\rho^0$	$\frac{1}{2}(E_P{}' + E_V{}' - C_P{}' - C_V{}')$
	K^+K^{*-}	$T_V{}' + E_P{}'$
	K^-K^{*+}	$T_P{}' + E_V{}'$
	$K^0\overline{K}^{*0}$	$E_V{}' - E_P{}'$
	$\overline{K}^0K^{*0}$	$E_P{}' - E_V{}'$
	$\pi^0\phi$	$\frac{1}{\sqrt{2}}C_P{}'$
	$\pi^0\omega$	$\frac{1}{2}(E_P{}' + E_V{}' - C_P{}' + C_V{}')$
	$\eta\rho^0$	$\frac{1}{\sqrt{6}}(2C_V{}' - C_P{}' - E_P{}' - E_V{}')$
	$\eta\omega$	$-\frac{1}{\sqrt{6}}(2C_V{}' + C_P{}' + E_P{}' + E_V{}')$
	$\eta\phi$	$\frac{1}{\sqrt{3}}(C_P{}' - E_P{}' - E_V{}')$
	$\eta'\rho^0$	$\frac{1}{2\sqrt{3}}(E_P{}' + E_V{}' + C_P{}' + C_V{}')$
	$\eta'\omega$	$\frac{1}{2\sqrt{3}}(E_P{}' + E_V{}' + C_P{}' - C_V{}')$

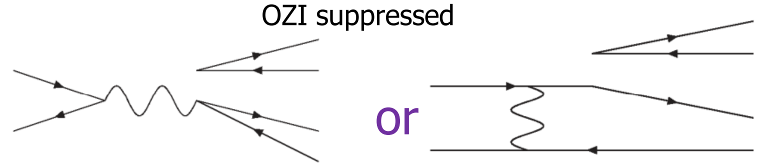
B. Bhattacharya and J. L. Rosner
Phys. Rev. D 77, 114020 (2008)

Single Cabibbo Suppressed Decays

SU(3) symmetry relates amplitudes

Decays with η's – more amplitudes?

OZI suppressed



Singlet-Annihilation (S-A) Singlet-Exchange (S-E)

Study of $D^0\to(\omega/\varphi/K^*)\eta$

Cabibbo-suppressed vector-pseudoscalar decays

$D^0\to(\varphi,\omega)\eta$ Singly Cabibbo-suppressed
$D^0\to K^{*0}\eta$ Doubly Cabibbo-suppressed

Very little information on these decays:

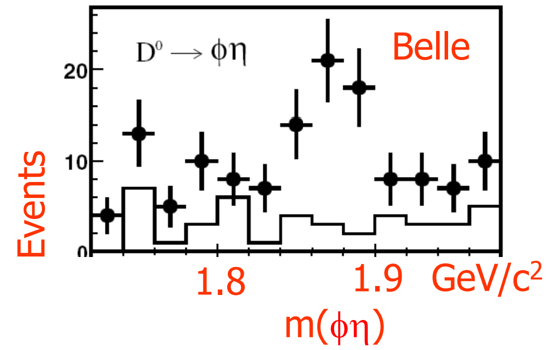
Only Belle measurement of $D^0\to\varphi\eta$

D* tagged, $\phi\to KK$, $\eta\to\gamma\gamma$

31.1 ± 9.8 events, 78 fb^{-1} data

$BF=(1.4 \pm 0.5) \times 10^{-4}$

Phys. Rev. Lett 92, 101803 (2004)

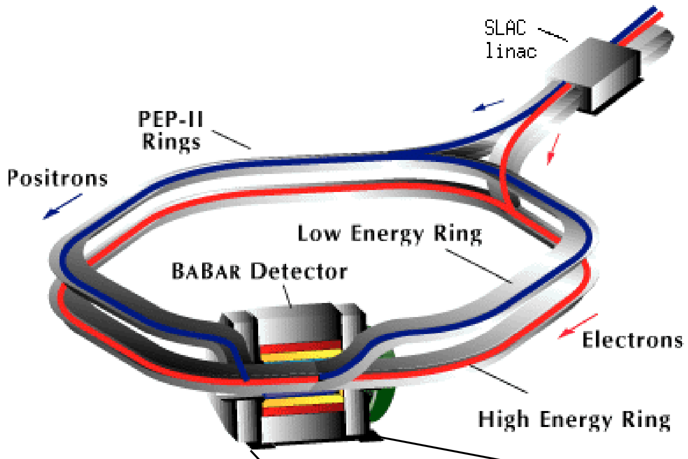


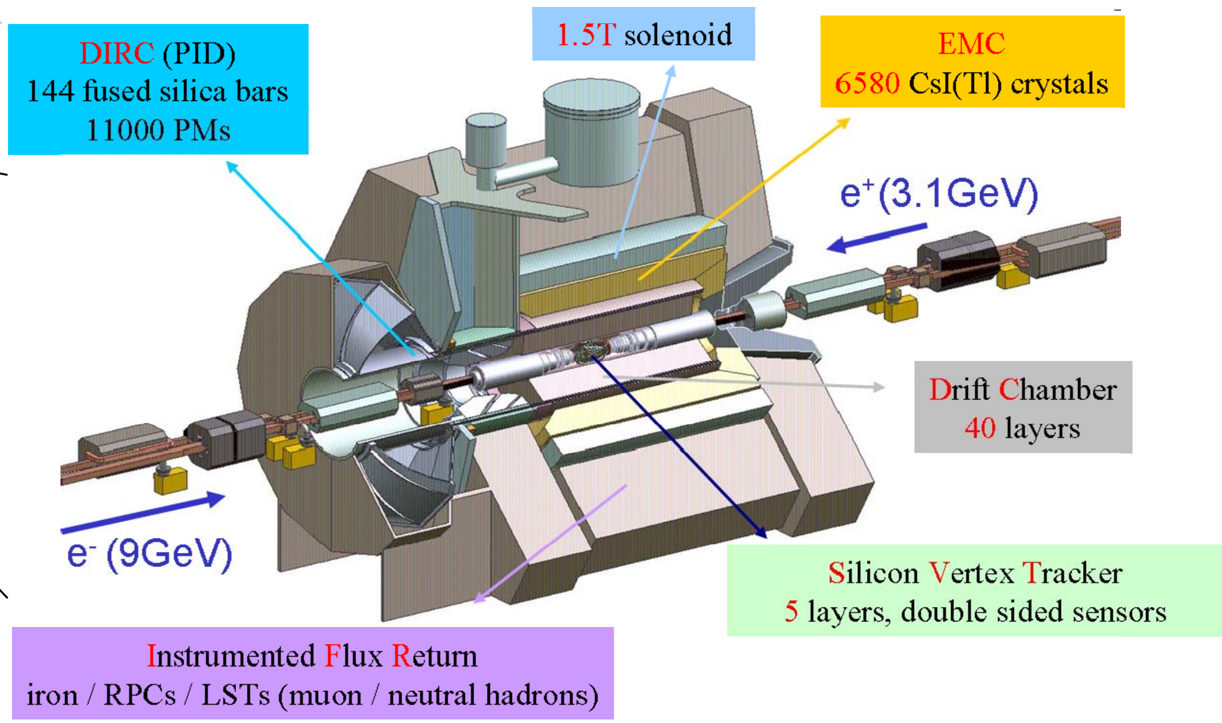
Mode	Theory [1] $BF\times10^{-3}$	Theory [2] $BF\times10^{-3}$
$\omega\eta$	1.0 & 1.3	1.4 ± 0.09 & 1.27 ± 0.09
$\varphi\eta$	0.34 & 0.35	0.93 ± 0.09 & 1.4 ± 0.1
$K^{*0}\eta$	0.030 & 0.041	0.038 ± 0.009 & 0.037 ± 0.004

[1] Y. Wu, M. Zhong, Y. Zhou, Eur. Phys. J. C42, 391 (2005)
[2] B. Bhattacharya and J. Rosner, Phys. Rev. D 77, 114020 (2008)

PEP-II and the BaBar Detector

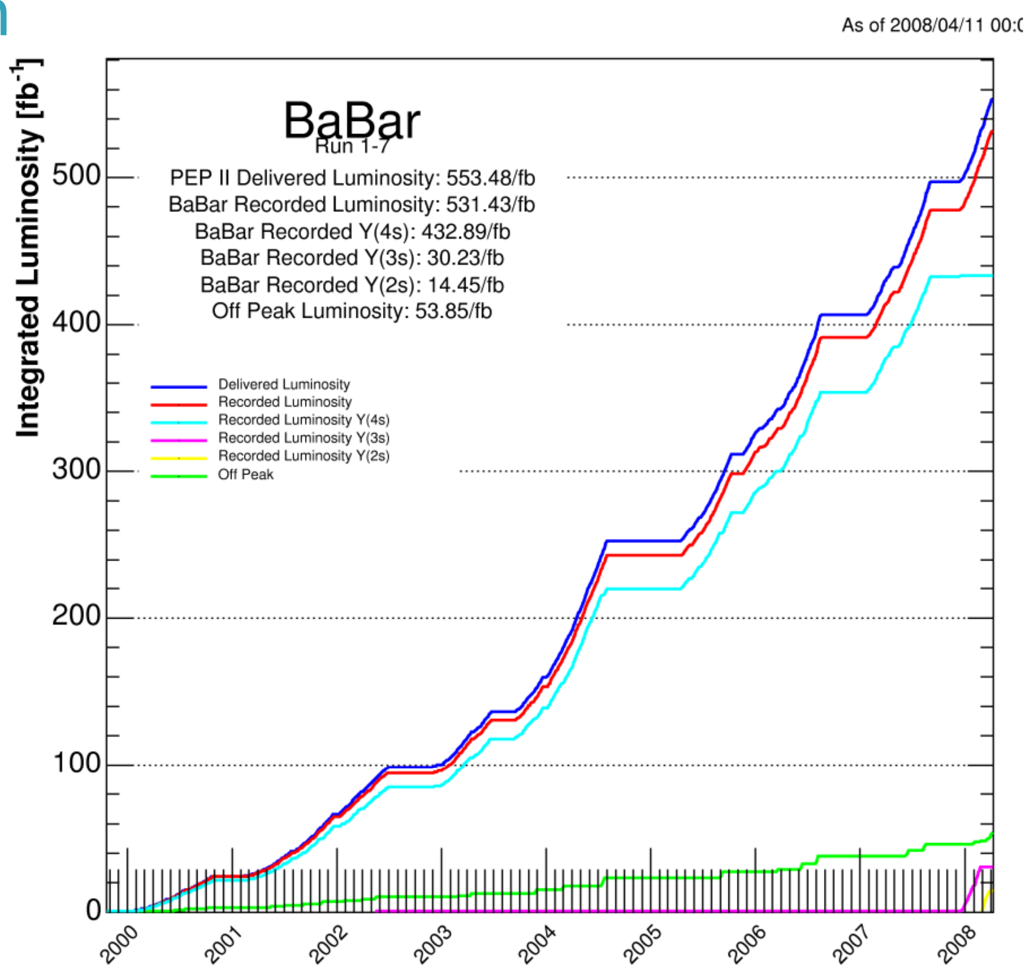
- PEP II/BaBar *B*-Factory located at SLAC National Accelerator Center
- Colliding beams of electrons and positrons with asymmetric energies





Dataset

- BaBar data-taking ended on April 7, 2008
- Total recorded luminosity
  - 531 fb^{-1}
- On the Y(4S)
  - 432 fb^{-1}
- Off Peak (40 MeV below)
  - 54 fb^{-1}
- Given $\sigma_{c\bar{c}}$ ≈1.3 nb we have > 1.2 x 10^9 charm decays

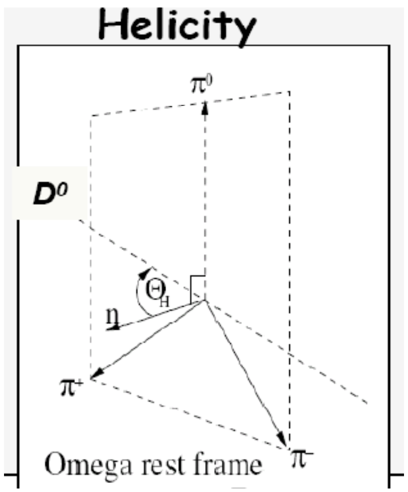


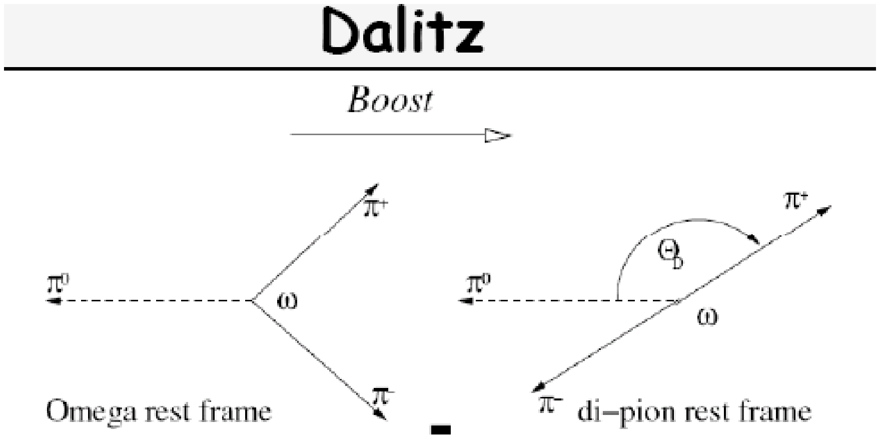
- This analysis is based on 467 fb^{-1}

Analysis Procedure and Selection Criteria

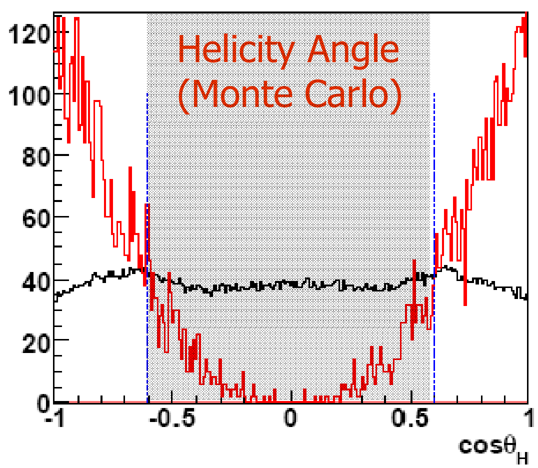
- Use 467 fb^{-1} of BaBar data (on and off Υ(4S))
  - About 1 billion produced D mesons in sample
- Use $D^{*+} \rightarrow D^0 \pi^+$ to reduce backgrounds
  - D* momentum cut removes (most) background from B decays
  - Constraint Fit to beam spot
- Particle ID on kaons and pions
- Select candidates in D^0 mass window
- Cuts on vector meson decay angles:
  - helicity angle + Dalitz plot helicity angle for $\omega \rightarrow \pi^+ \pi^- \pi^0$ (next slides)
- Use the $\eta \rightarrow \gamma\gamma$ decay mode
  - Photon, η momentum cut
- Extract yield from $\Delta M = M(D^{*+}) - M(D^0)$ with an unbinned extended maximum likelihood fit
  - ΔM gives better signal resolution than M(D)

ω Dalitz & Helicity Angles: Monte Carlo Study



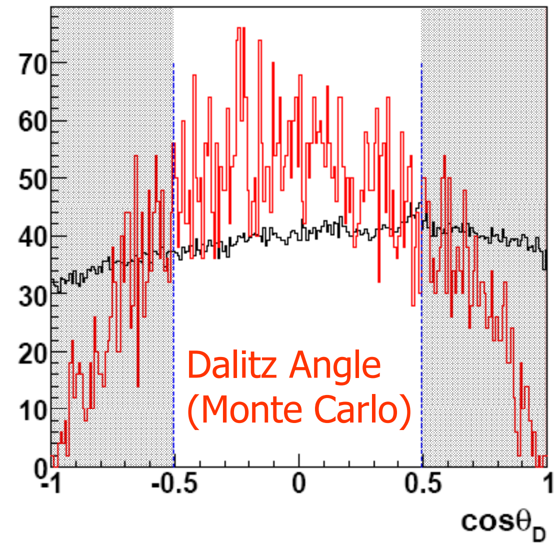


Cosine of helicity angle for signal:
$\cos^2\Theta$ distribution



Signal MC in red
Background MC in black
Events in shaded regions are excluded

Cosine of Dalitz angle for signal:
$\sin^2\Theta$ distribution



$D^0 \to \omega\eta$ Mode: Monte Carlo Study

$D^0 \to \omega\eta$: $\omega \to \pi^+ \pi^- \pi^0$, $\eta \to \gamma\gamma$, $\pi^0 \to \gamma\gamma$

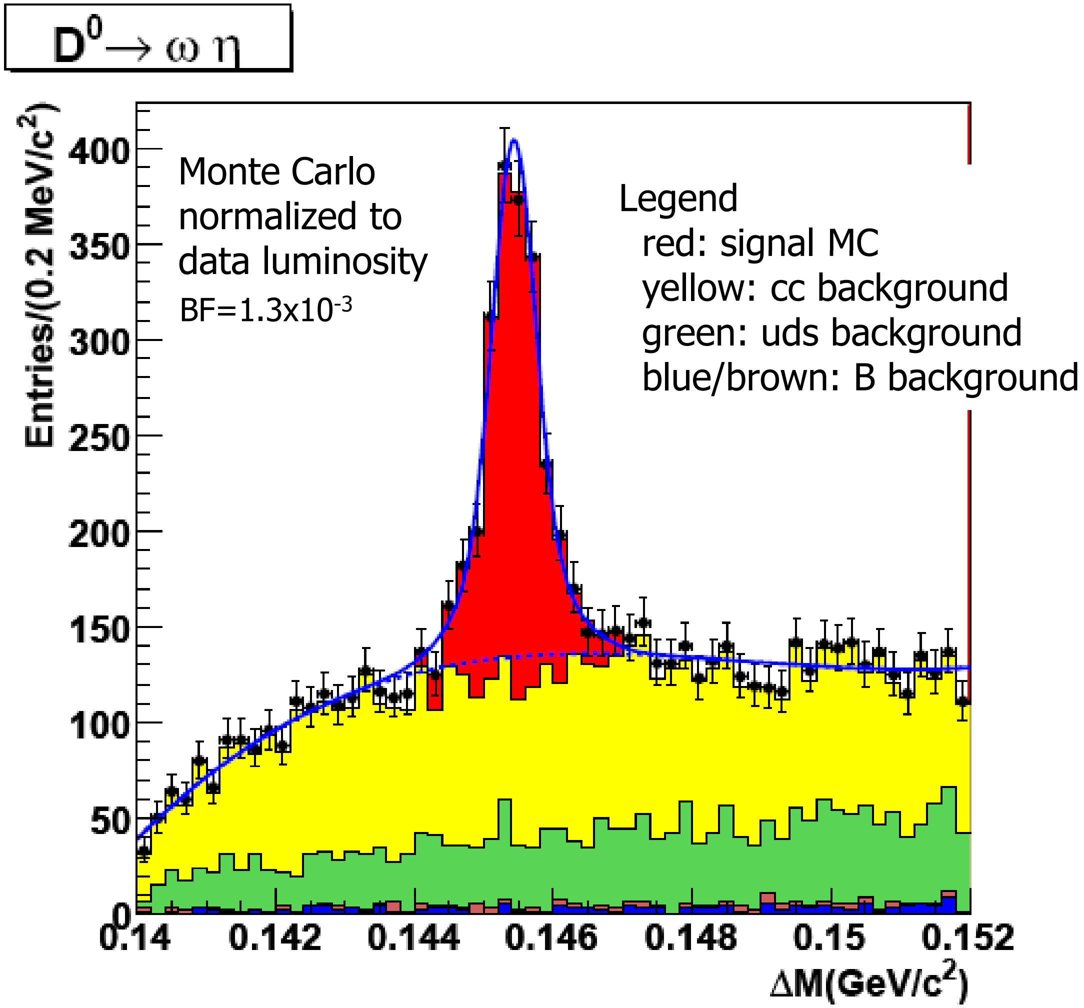
Signal PDF:

2 Gaussians

Background:

3rd order polynomial

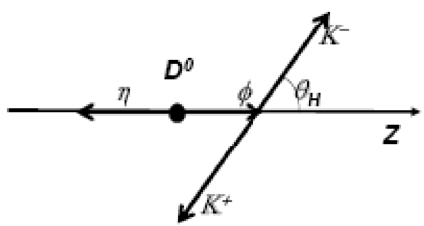
Efficiency: (3.3±0.1)%

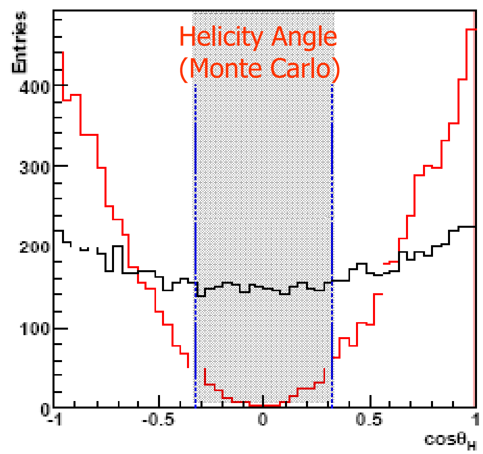


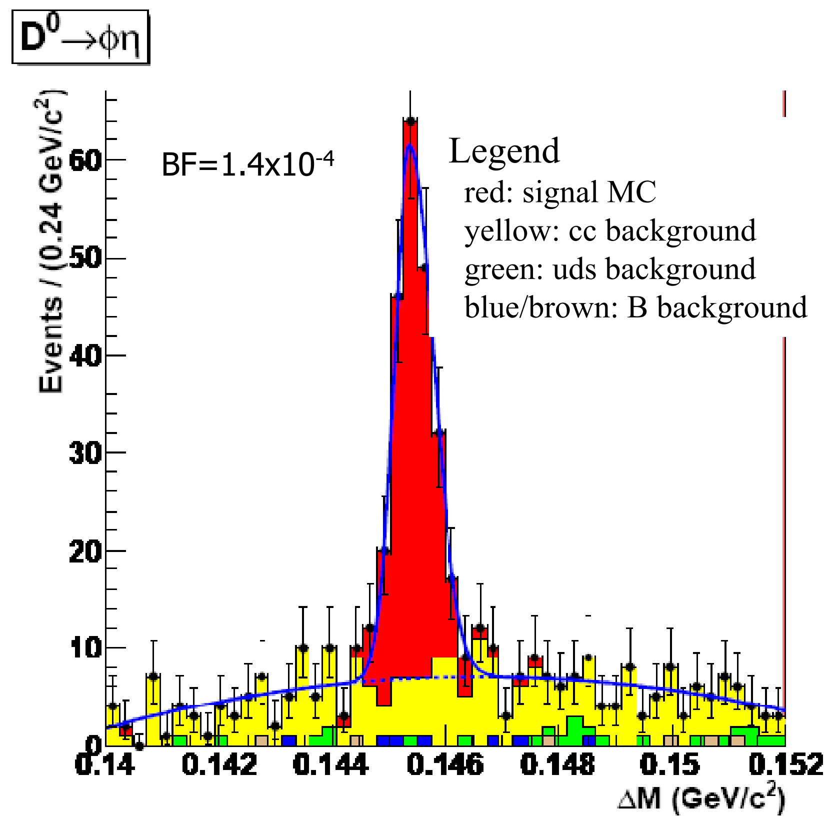
$D^0 \rightarrow (K^+K^-)_\varphi \eta$ Mode: Monte Carlo Study

$D^0 \rightarrow \varphi\eta$: $\eta \rightarrow \gamma\gamma$, $\varphi \rightarrow K^+ K^-$

Helicity Cut







Signal PDF

Bifurcated Gaussian

Background PDF

2^{nd} order polynomial

Efficiency: $(7.1\pm0.1)\%$

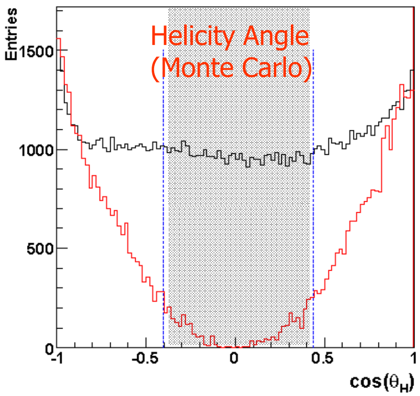
We do not perform a Dalitz analysis so we can not isolate contributions from other final states such as $D^0 \rightarrow f_0(980)\pi$, $f_0(980) \rightarrow KK$.

Use notation $(K^+K^-)_\varphi$ to indicate mass region $(1.011 < M(K^+K^-) < 1.030)$ GeV/c^2

$D^0 \to (K^+\pi^-)_{K*}\eta$ Mode: Monte Carlo Study

$D^0 \to K^{*0}\eta$: $\eta \to \gamma\gamma$, $K^{*0} \to K^+\pi^-$

Helicity Cut



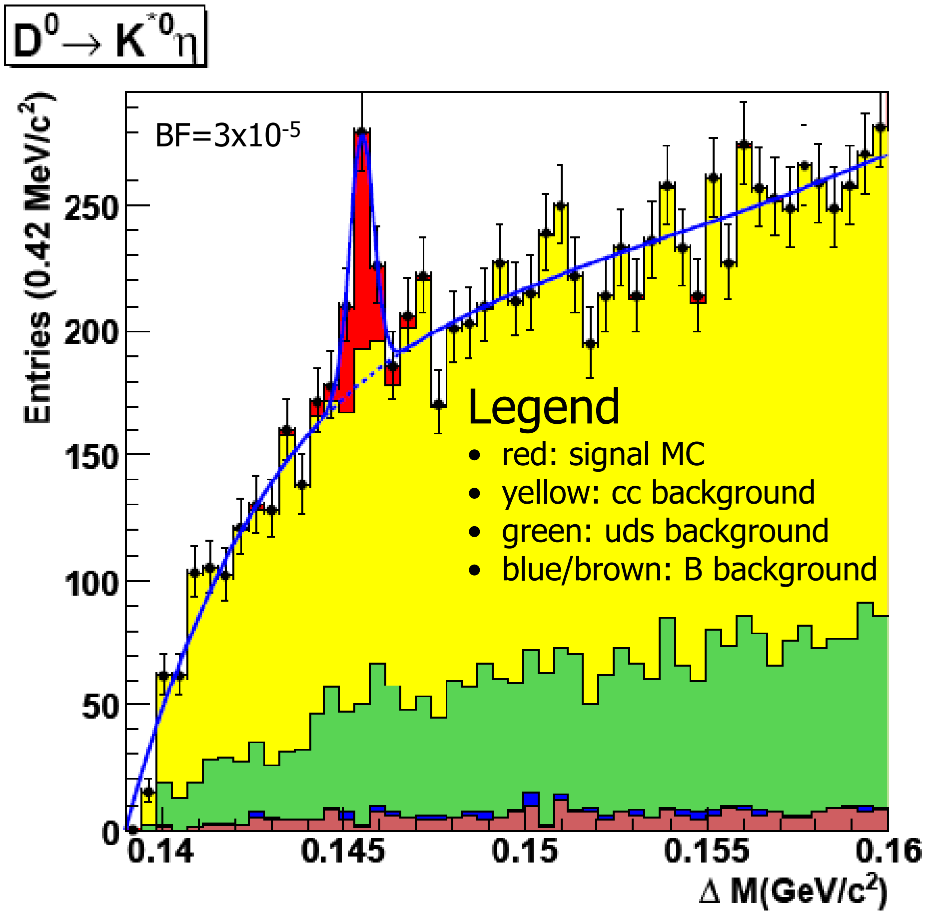
Signal PDF

Gaussian

Background PDF

Exponential with cut-off

Efficiency: $(7.8\pm0.1)\%$



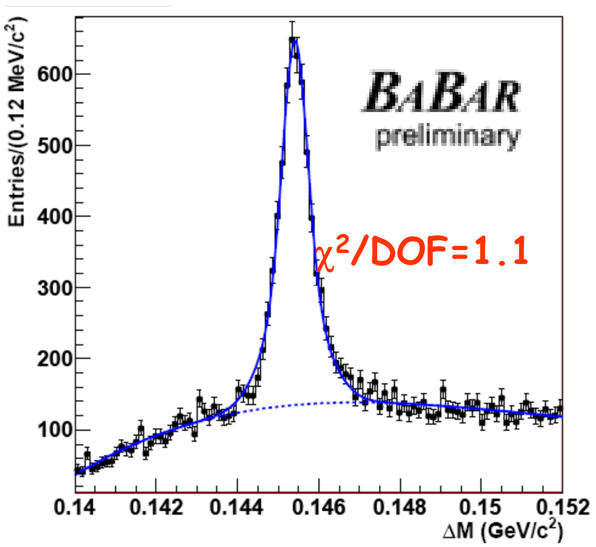
We do not perform a Dalitz analysis so we can not isolate contributions from other final states such as as $D^0 \to a_0(980)K$, $a_0(980) \to \eta\pi$.

Use notation $(K^+\pi^-)_{K*}$ to indicate mass region $(0.841 < M(K^+\pi^-) < 0.946)$ GeV/c^2

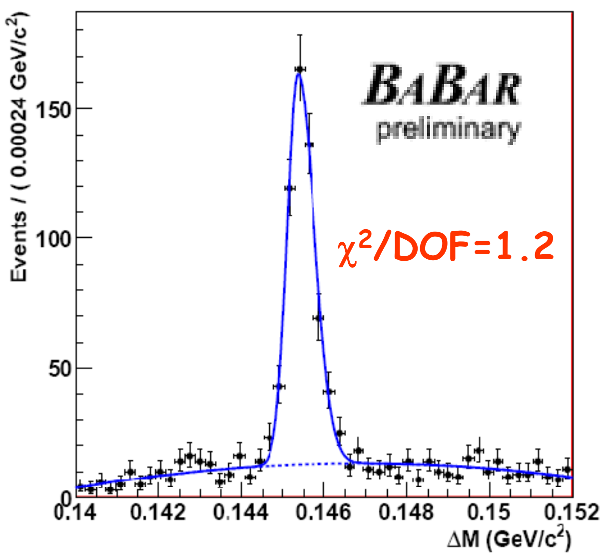
Data Fits

ΔM fits use unbinned extended maximum likelihood function
Data + MC studies: no peaking backgrounds from other D's

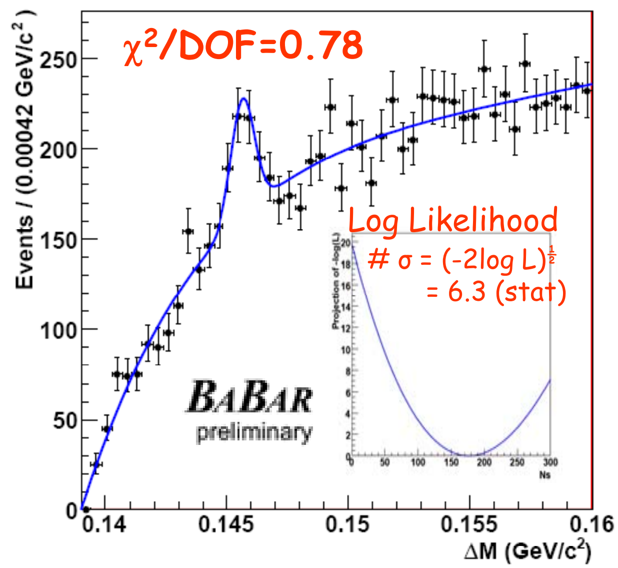
$D^0 \to \omega\eta$



$D^0 \to \phi\eta$



$D^0 \to K^{*0}\eta$



Significant signals in each mode

Preliminary Results

$$BF = \frac{N_{obs}}{L \times \sigma_{c\bar{c}} \rightarrow D^{*+} X \times BF_{D^{*+} \rightarrow D^0 \pi^+} \times BF_{V \rightarrow X} \times BF_{\eta \rightarrow \gamma\gamma} \times \varepsilon}$$

Branching fractions calculated using CLEO's D^* cross section:

M. Artuso et al, Phys. Rev. D70, 112001 (2004)

Correct for differences between CLEO's measured D^* momentum spectrum & the BaBar's Monte Carlo

~4% correction in efficiency

input parameter	value
$\sigma_{c\bar{c} \rightarrow D^{*+} X}$	$583 \pm 8 \pm 33 \pm 14$ (pb)
$BF_{D^{*+} \rightarrow D^0 \pi^+}$	$67.7 \pm 0.5\%$
$BF_{\eta \rightarrow \gamma\gamma}$	$39.38 \pm 0.26\%$
$BF_{\eta \rightarrow \pi^+ \pi^- \pi^0}$	$22.7 \pm 0.4\%$
$BF_{\phi \rightarrow K^+ K^-}$	$49.2 \pm 0.6\%$
$BF_{\omega \rightarrow \pi^+ \pi^- \pi^0}$	$89.1 \pm 0.7\%$
$BF_{K^* \rightarrow K^+ \pi^-}$	$2/3$
$BF_{\pi^0 \rightarrow \gamma\gamma}$	$98.798 \pm 0.032\%$

Mode	N_{obs}	BF x 10^{-3}
$D^0 \rightarrow \omega\eta$	4450 ± 103	2.21 ± 0.08 ± 0.22
$D^0 \rightarrow (K^+K^-)_\varphi \eta$	513 ± 26	0.21 ± 0.01 ± 0.02
$D^0 \rightarrow (K^+\pi^-)_{K^*} \eta$	177 ± 37	0.048 ± 0.010 ± 0.004

stat syst

Systematic Uncertainties

Systematic	$D^0 \to (K^+K^-)_\phi \eta$ (%)	$D^0 \to \omega\eta$ (%)	$D^0 \to (K^+\pi^-)_{K^{*0}}\eta$ (%)
Tracking	0.40	0.40	0.40
Particle ID	2.1	0.87	1.6
$\pi^0 + \eta$	3.2	6.2	3.2
Background PDF	0.7	0.5	1.4
Signal PDF	2.0	3.0	3.0
Selection Criteria	3.0	3.0	3.0
Integrated luminosity	1.0	1.0	1.0
Subtotal	5.4	7.7	5.8
$e^+e^- \to D^*$ X-section	5.7	5.7	5.7
P_{D^*} correction	2.0	2.0	2.0
Total	8.1	9.8	8.4

Summary and Conclusions

Mode	Ref [1]x10^{-3}	Ref [2] x 10^{-3}	N_{obs}	preliminary BaBar BF x 10^{-3}
$D^0 \to \omega\eta$	1.3 & 1.0	1.4 ± 0.09 & 1.27±0.09	4450±103	2.21 ± 0.08 ± 0.22
$D^0 \to (K^+K)_\varphi \eta$	0.35 & 0.34	0.93±0.09 & 1.4±0.1	513 ± 26	0.21 ± 0.01 ± 0.02
$D^0 \to (K^+\pi^-)_{K*}\eta$	0.03& 0.041	0.038±0.004 & 0.037±0.004	177 ± 37	0.048 ±0.010± 0.004

1st observation of $D^0 \to \omega\eta$ & $D^0 \to (K^+\pi^-)_{K*}\eta$

- BF($\omega\eta$) larger than predicted
- BF($\varphi\eta$) higher than Belle ((1.4 ± 0.5) x 10^{-4}) but within 2σ
- *both measurements inconsistent (smaller) with predictions*
- BF($K^{*0}\eta$) within 1σ of theoretical predictions
- Future work for publication
  - Isolating K^{*0} and φ within signal region
  - Using $D^0 \to K^- \pi^+$ as the normalization mode instead of CLEO absolute cross section result
    - This will reduce systematic errors

Extra Slides

Complete List of Selection Criteria

Variable	$D^0 \to (K^+K^-)_\phi \eta$	$D^0 \to \omega\eta$	$D^0 \to (K^+\pi^-)_{K^{*0}}\eta$
signal Region (GeV/c^2)	$0.1442 < \Delta M < 0.1467$	$0.1438 < \Delta M < 0.1470$	$0.1444 < \Delta M < 0.1465$
m(D^0) (GeV/c^2)	$1.851 < m_{D^0} < 1.877$	$1.826 < m_{D^0} < 1.895$	$1.845 < m_{D^0} < 1.885$
D^{*+} CMS momentum (GeV/c)	$2.6 < P^*_{D^{*+}}$	$2.76 < P^*_{D^{*+}}$	$2.6 < P^*_{D^{*+}}$
π_{slow} I.P. χ^2fit prob	$0.01 < P(\chi^2)$	$0.01 < P(\chi^2)$	$0.01 < P(\chi^2)$
Resonance Mass (GeV/c^2)	$1.011 < m_\phi < 1.030$	$0.758 < m_\omega < 0.798$	$0.841 < m_{K^*} < 0.946$
η CMS momentum (GeV/c)	$0.7 < P^*_\eta$	$0.45 < P^*_\eta$	$0.455 < P^*_\eta$
γ_1 CMS momentum(GeV/c)	$0.184 < P^*_{\gamma_1}$	$0.15 < P^*_{\gamma_1}$	$0.16 < P^*_{\gamma_1}$
γ_2 CMS momentum(GeV/c)	$0.138 < P^*_{\gamma_2}$	$0.15 < P^*_{\gamma_2}$	$0.16 < P^*_{\gamma_2}$
D^{*+} fit χ^2 prob	$0.0005 < P(\chi^2)$	$0.0005 < P(\chi^2)$	$0.0005 < P(\chi^2)$
D^0 CMS momentum (GeV/c)	$2.5 < P^*_{D^0}$	-	-
helicity	$0.322 < \lvert cos\theta_H \rvert$	$0.6 < \lvert cos\theta_H \rvert$	$cos\theta_H < -0.4$ or $cos\theta_H > 0.44$
Dalitz	-	$-0.5 < cos\theta_D < 0.5$	-
kaon PID	-	-	Stringent PID selection criteria