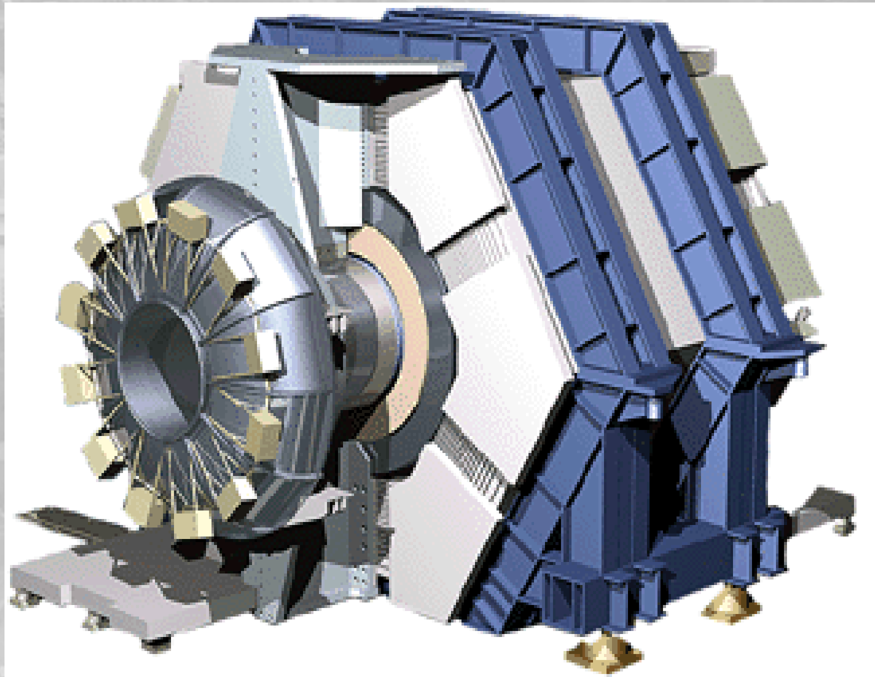
Charm Decays At BaBar

Richard Kass for the BaBar Collaboration



Outline of Talk

*Introduction

*Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$
PRD 79, 032003 (2009)

*Preliminary $D^0 \to (\omega/\varphi/K^*)\eta$ Branching Fractions

*Summary & Conclusions

Introduction

A *B*-meson factory is also a charm factory.

Cross section for $e^+e^- \to \Upsilon(4S) \to B\bar{B}$: $\sigma_{B\bar{B}}$ **=1.05 nb**

Cross section for $e^+e^- \to c\bar{c}$: $\sigma_{c\bar{c}}$**=1.3 nb**

Also get ~1 charm per *B*-meson decay

BaBar data~531 fb^{-1}; >10^9 charm particles produced

SVT, DCH: chgd particle trking

vertex & mom. resolution, K^0s, Λ

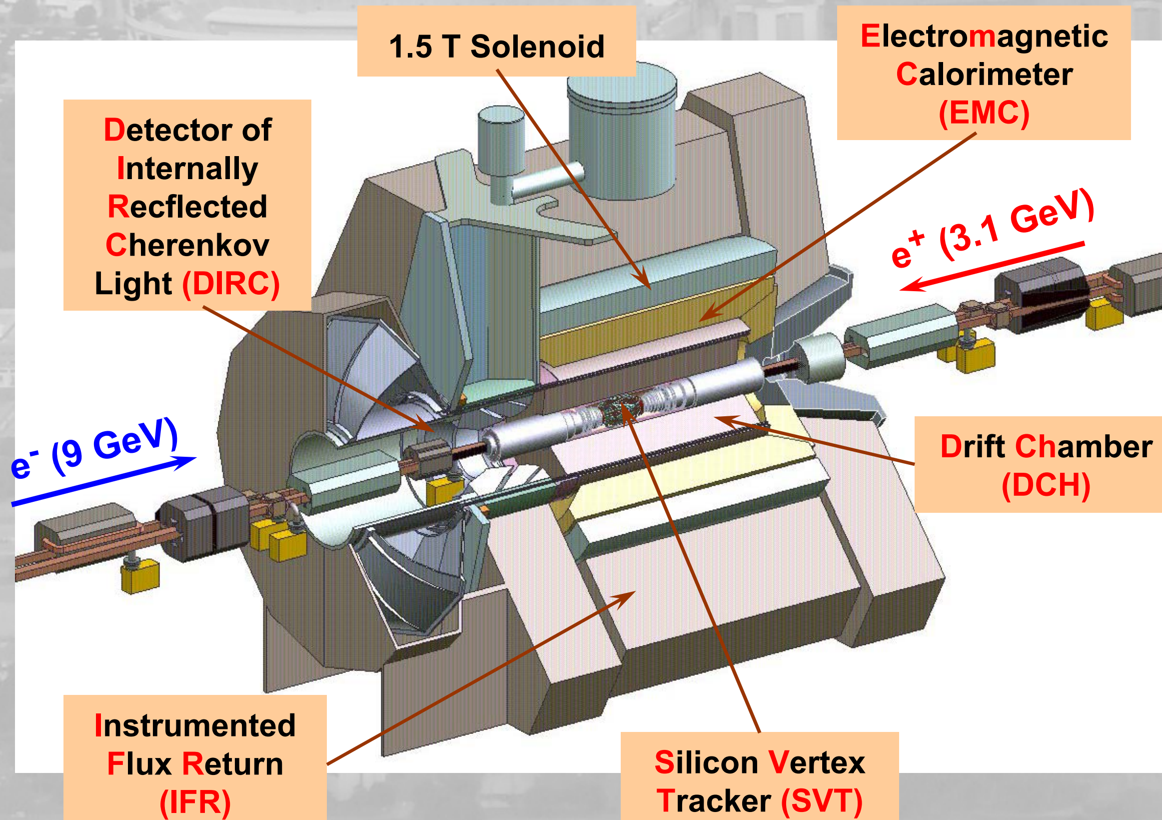
EMC: electromagnetic calorimeter

$\gamma/e/\pi^0/\eta$

DIRC,IFR,DCH:chgd particle ID

$\pi/\mu/K/p$

Highly efficient trigger for events with charmed particles



Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

A Dalitz analysis can provide useful information on the dynamics/resonant substructure of a decay.

Can be particularly useful to sort out the (confusing) role of scalar mesons

I=1	I=1/2	I=0
$a_0(980)$	$\kappa(800)$ (?)	$f_0(600)$
$a_0(1450)$	$K^*_0(1430)$	$f_0(980)$
		$f_0(1370)$
		$f_0(1500)$
		$f_0(1700)$
		$X_0(1550)$ (?)

In quark model $f_0(980)$ and $a_0(980)$ are mostly $s\bar{s}$ and $u\bar{u}/d\bar{d}$ respectively.

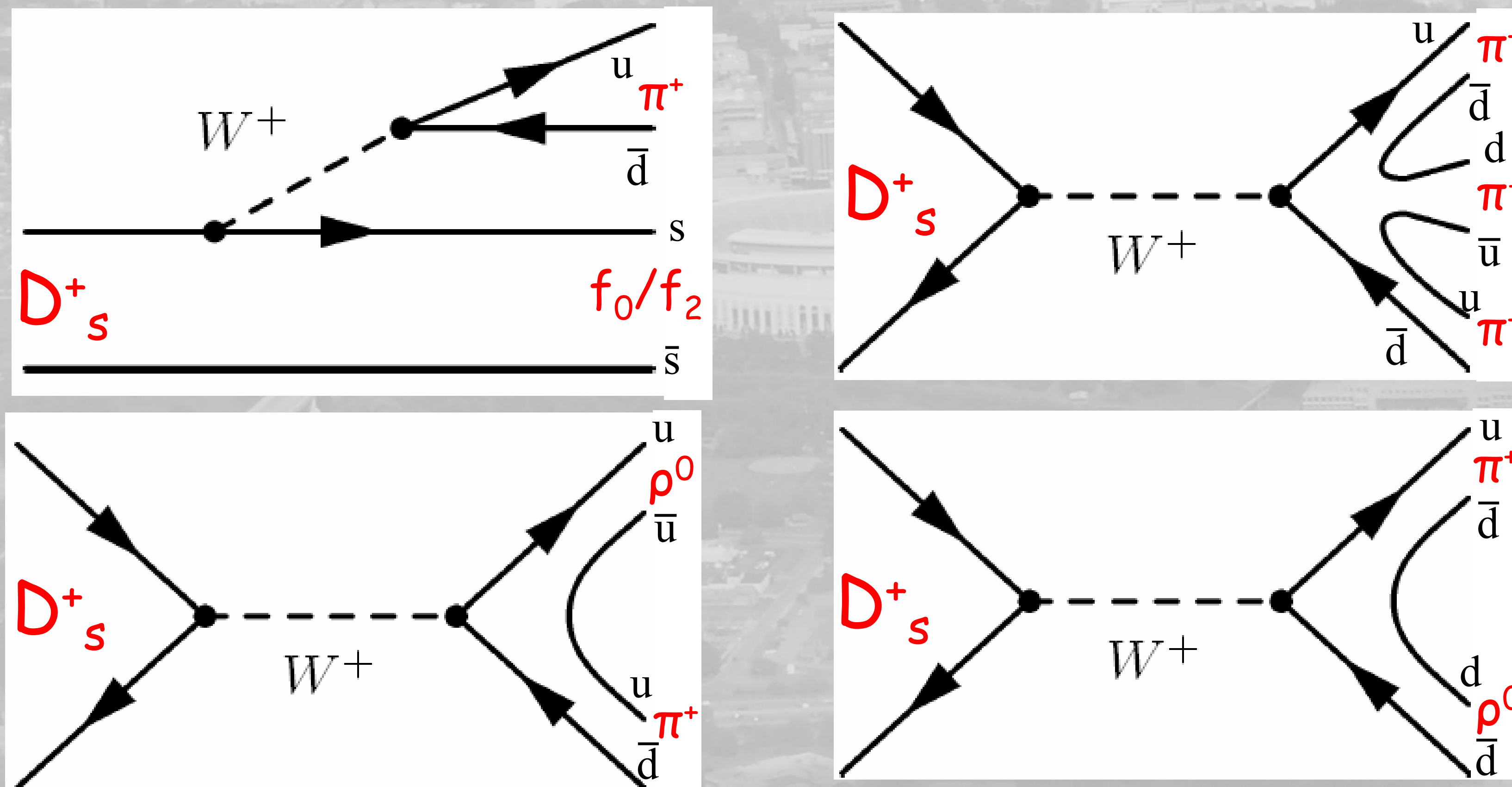
QCD: scalar meson candidates too numerous to fit in single $q\bar{q}$ nonet. May be multi-quark or meson-meson bound state.

Experiment: Difficult to resolve scalar mesons due to large decay width.

D mesons very useful:
large coupling to scalar mesons
& well defined initial state ($J^P=0^-$)

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

$D^+_s \to \pi^+\pi^-\pi^+$ can proceed via several diagrams:



Intermediate resonances can include f_0's and ρ's

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

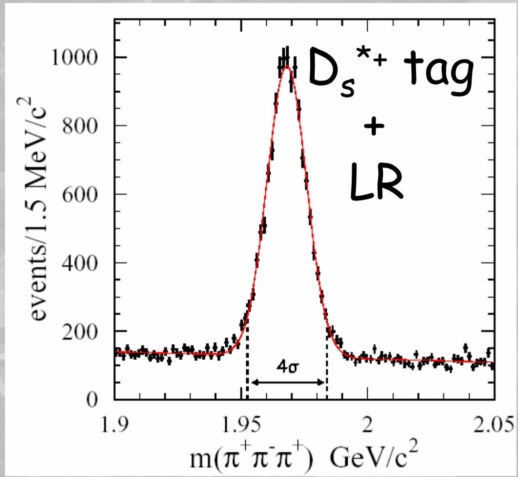
Selection Criteria

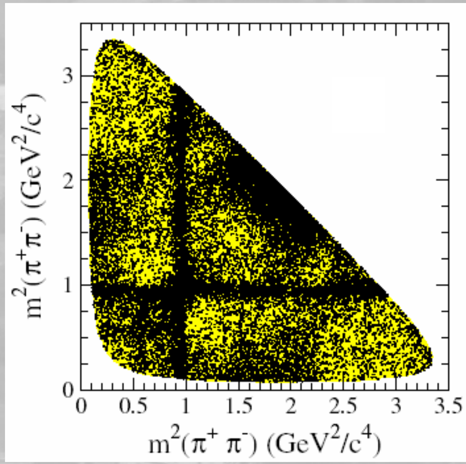
Use $D_s^{*+} \to D^+_s\gamma$ tag

Use a likelihood ratio (LR) to improve S/B

- use $D^+_s \to K^+K^-\pi^+$ to build signal PDFs
  - decay distance transverse to beam plane
  - vertex information
  - center of mass momentum of D^*_s

Eliminate reflections from $D^{*+} \to D^0\pi^+ \to (K^-\pi^+/\pi^-\pi^+)\pi^+$





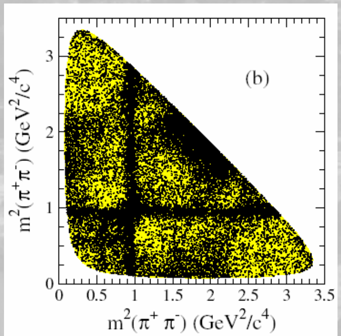
Symmetrized Dalitz Plot
(2 entries per event)

Sample uses 384 fb^{-1}, 13179 events, 80% purity

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

Lots of substructure evident in Dalitz Plot

$f_0(980)$, region ~1.4 GeV/c^2



Unravel structure with an unbinned maximum likelihood analysis

$$L = \prod_{events} \{ f(M)\varepsilon(m_1^2, m_2^2) \frac{\sum_{i,j} c_i c_j^* A_i A_j^*}{N_A} + (1 - f(M)) \frac{\sum_i k_i^2 B_i B_i^*}{N_B} \} \qquad m \equiv m_{\pi^+\pi^-}$$

f(M) =fraction of signal events as function of D_s mass (M)

ε =efficiency as a function of (m^2_1, m^2_2) in Dalitz Plot, 3rd order polynomial

A=dynamical function describing the signal (more on next slide)

B=dynamical function describing resonances in the background events

c_i=complex amplitude for i^{th} component of signal. Output of fit.

k_i=real amplitude for i^{th} component of background. Determined from sidebands.

N_A, N_B= normalization factors for signal and background (respectively).

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

Signal shapes for UBML fit:

P & D-wave: $A = BW(m_{\pi\pi}) \times T(\Omega)$

BW=relativistic Breit-Wigner with Blatt-Weisskopf form factors

$T(\Omega)$=angular factors

S-wave: avoid uncertainties in scalar meson properties:

Existence of certain states?

Unitarity issues when broad BW's overlap.

	Mass (MeV)	Γ (MeV)
$f_0(600)$	400-1200	600-1000
$f_0(980)$	980±10	40-100
$f_0(1370)$	1200-1500	200-500

Parameterize S-wave amplitude in a model independent way:

$$\mathbf{A_S(m_{\pi\pi}) = Interp\{c_k(m_{\pi\pi}) \exp[i\varphi_k(m_{\pi\pi})]\}_{k=1,,30}}$$

Divide the $m_{\pi\pi}$ spectrum in 29 slices and interpolate between endpoints

each slice has ~ same number of events

Fit for the 30 c_K's and φ_k's

Systematic errors are evaluated in the fit.

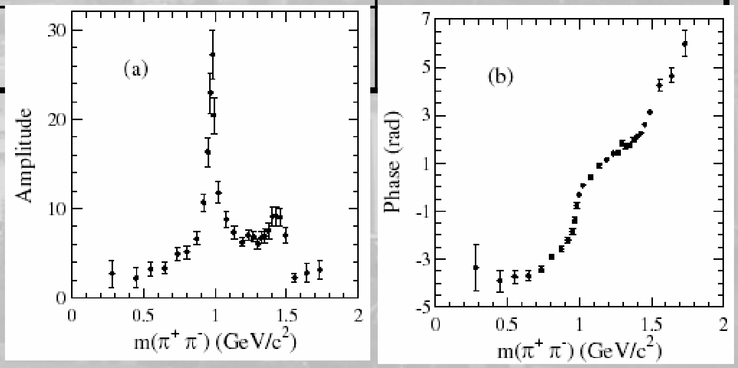
vary background models, BW barrier factors, selection criteria, # of $m_{\pi\pi}$ slices, etc.

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

Results

Decay Mode	fraction %	Amplitude	Phase (rad)
$f_2(1270)\pi^+$	10.1±1.5±1.1	1.0 (fixed)	0 (fixed)
$\rho(770)\pi^+$	1.7±0.5±1.0	0.19±0.02±0.12	1.1±0.1±0.2
$\rho(1450)\pi^+$	2.3±0.8±1.9	1.2±0.3±1.0	4.1±0.2±0.5
S-wave	83.0±0.9±1.9		
Total	97.2±3.7±3.8		

$\chi^2/dof = 437/(422-64) = 1.2$



The decay is dominated by S-wave
- S-wave has amplitude & phase expected for $f_0(980)$
- Also S-wave contributions from $f_0(1370)$ & $f_0(1500)$
- S-wave is small in $f_0(600)$ region, small coupling to $s\bar{s}$

Important contribution from $f_2(1270)$
- amplitude 2X smaller than E791, comparable to FOCUS result

Additional resonances ($\omega(780)$, $f'_2(1525)$) do not improve fit

Also measure: $$\frac{B(D_s^+ \to \pi^+\pi^-\pi^+)}{B(D_s^+ \to K^+K^-\pi^+)} = 0.199 \pm 0.004 \pm 0.009$$

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

Cabibbo-suppressed vector-pseudoscalar decays

Singly Cabibbo-suppressed $D^0 \rightarrow (\varphi, \omega)\eta$

Doubly Cabibbo-suppressed $D^0 \rightarrow K^{*0}\eta$

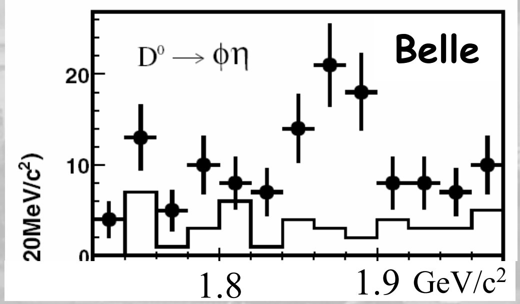
Very little information on these decays.

Only Belle measurement of $D^0 \rightarrow \varphi\eta$ [1]

D^* tagged, $\phi \rightarrow KK$, $\eta \rightarrow \gamma\gamma$

31.1 ± 9.8 events, 78 fb^{-1} data

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



Mode	Theory [2] $BF \times 10^{-3}$	Theory [3] $BF \times 10^{-3}$
$\omega\eta$	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] O. Tajima, Phys. Rev. Lett 92, 101803 (2004)
[2] Y. Wu, M. Zhong, Y. Zhou, Eur. Phys. J. **C42**, 391 (2005)
[3] B. Bhattacharya and J. Rosner, arXiv:0812.3167v1 [hep-ph]

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

Selection Criteria Summary

*Use 467 fb^{-1} of BaBar data (on and off $\Upsilon(4S)$)

About 1 billion produced D mesons in sample

*Use $D^{*+} \to D^0\pi^+$ to reduce backgrounds

*Particle ID on kaons and pions

*D^0 mass window

*Cuts on vector meson decay angles:

helicity angle + Dalitz plot helicity angle for $\omega \to \pi^+\pi^-\pi^0$ (next slide)

*Use $\eta \to \gamma\gamma$

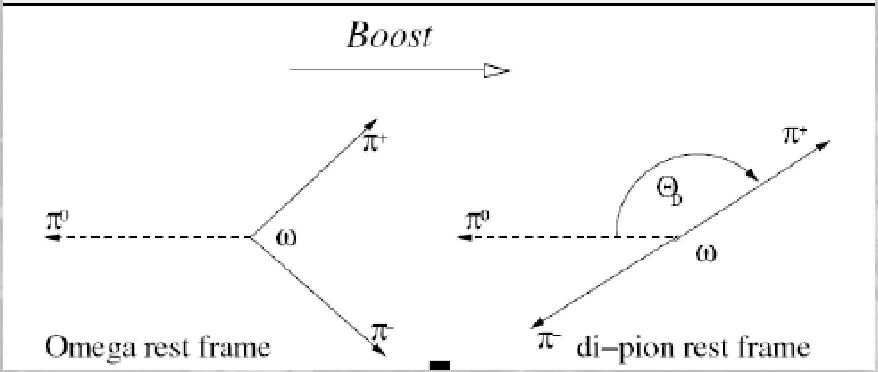
*Fit $\Delta M = M(D^{*+}) - M(D^0)$ with unbinned extended Maximum likelihood

ΔM gives better signal resolution than M(D)

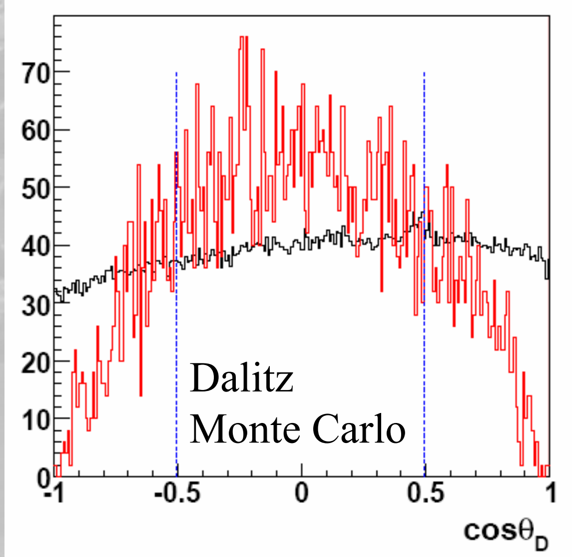
Study of $D^0 \to (\omega/\phi/K^*)\eta$

ω Dalitz & Helicity Angles: Monte Carlo Study

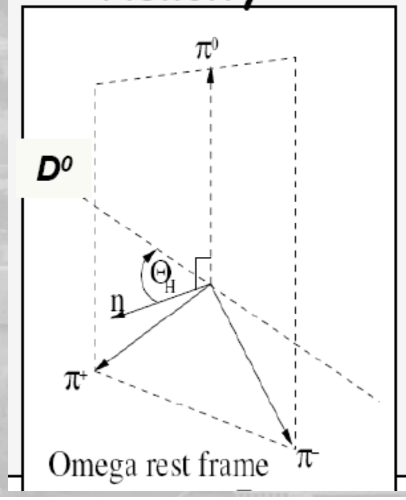
Dalitz



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

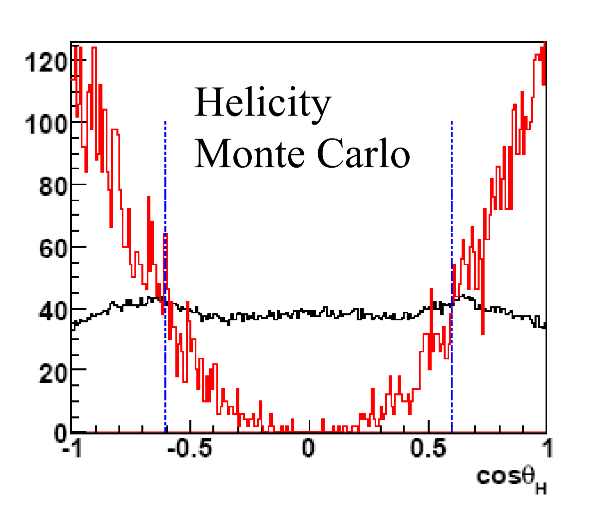


Helicity



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

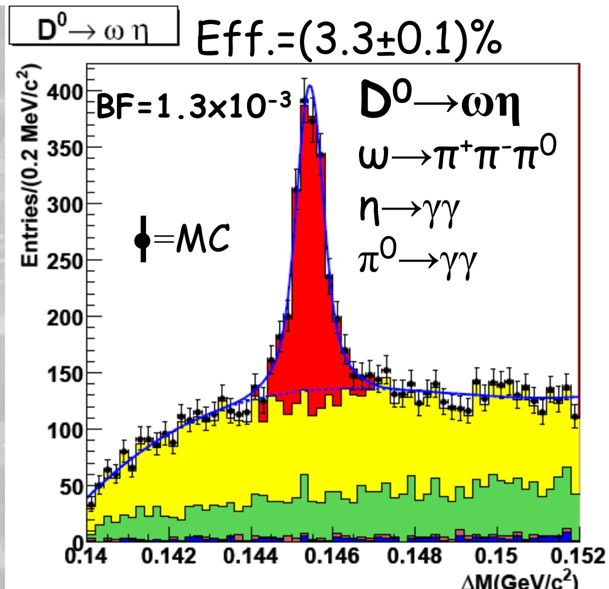
Signal MC in red
Background MC in black
Events in shaded regions are excluded

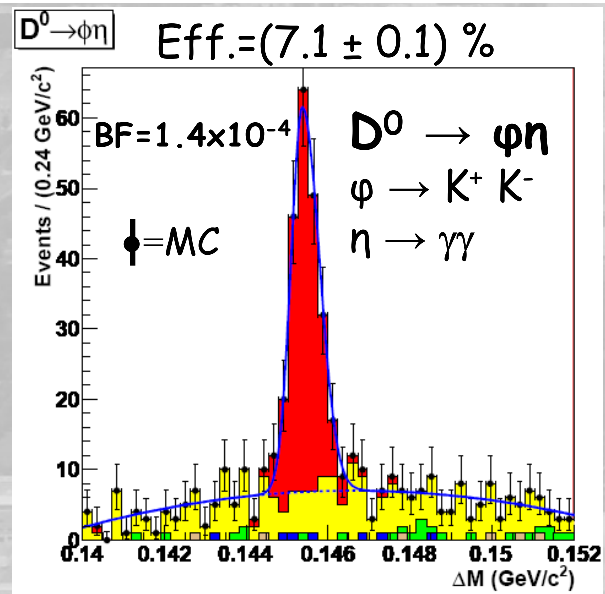


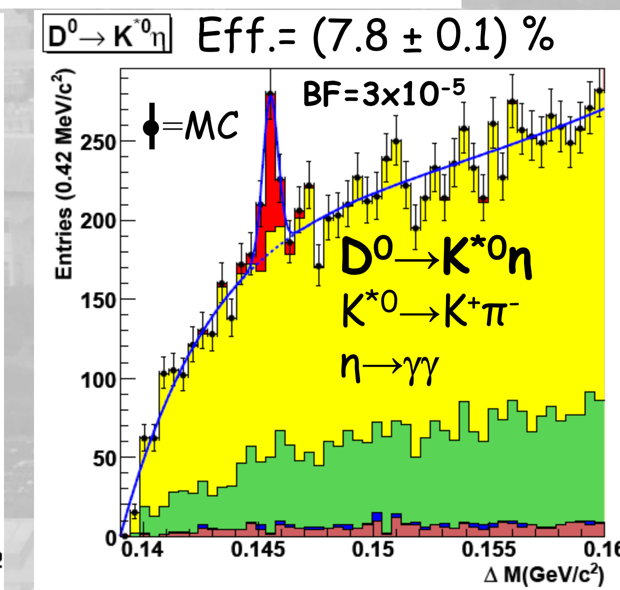
Study of $D^0 \to (\omega/\varphi/K^*)\eta$

Monte Carlo Studies

MC: red: signal MC, yellow: $c\bar{c}$, green: uds, blue/brown: B-meson
MC background normalized to data luminosity, signal uses theory estimates for BFs.
Fit $\Delta M = M_{D^*} - M_D$ with an extended maximum likelihood fit







We do not perform a Dalitz analysis so we can not isolate contributions from other final states:

$D^0 \to a_0(980)K$, $a_0(980) \to \eta\pi$ $D^0 \to f_0(980)\pi$, $f_0(980) \to KK$.

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

Use notation $(K^+\pi^-)_{K^{*0}}$ to indicate mass region ($0.841 < M(K^+\pi^-) < 0.946$) GeV/c^2

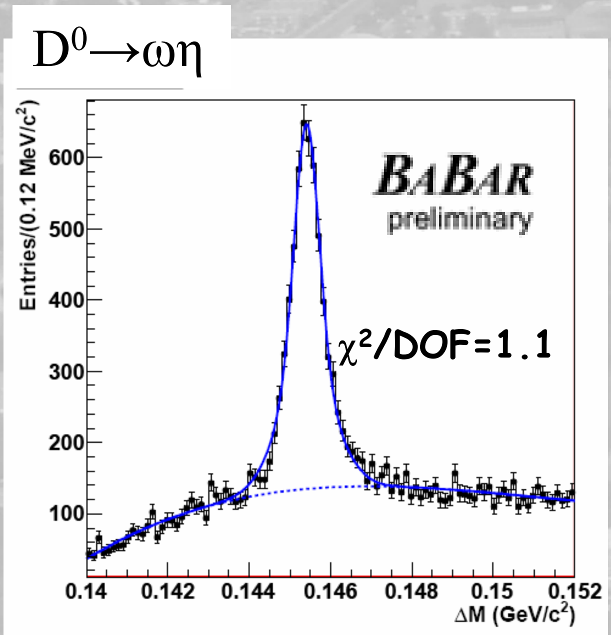
Mis-ID studies show that swapped K-π ID is a very small background

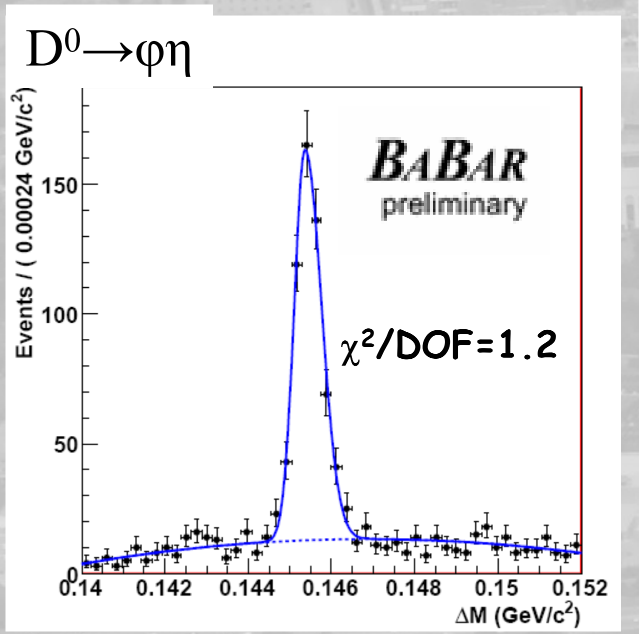
Study of $D^0 \to (\omega/\varphi/K^*)\eta$

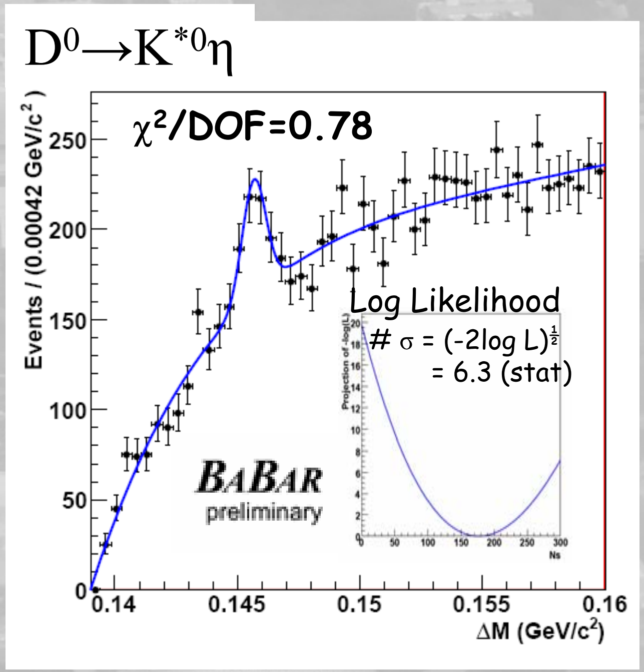
Fits to Data

ΔM fits use unbinned extended maximum likelihood function

Data + MC studies: no peaking backgrounds from other D's







Large signals in each mode

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

Preliminary Branching Fractions

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

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

M. Artuso et al, "Charm Meson Spectra in e+e- Annihilation at 10.5 GeV CME," Phys. Rev. D70, 112001 (2004)

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

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

~4% correction in efficiency

$L = 467.1\ fb^{-1}$

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

stat syst

Summary & Conclusions-I

Dalitz study of $D^+_s \to \pi^+\pi^-\pi^+$

Mostly S-wave from quasi-model independent analysis

FOCUS: K-matrix
E791: isobar model

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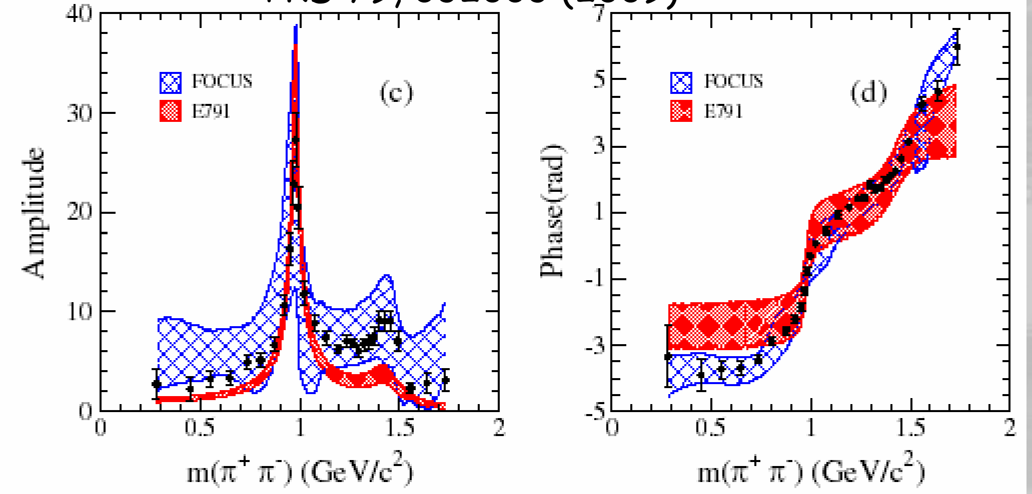


S-wave amplitude & phase as expected for $f_0(980)$

S-wave contributions from $f_0(1370)$ & $f_0(1500)$

S-wave is small in $f_0(600)$ region $\to$ small coupling to $s\bar{s}$

Important contribution from $f_2(1270)$

Precision measurement of BR relative to $D^+_s \to K^+K^-\pi^+$

$$\frac{B(D_s^+ \to \pi^+\pi^-\pi^+)}{B(D_s^+ \to K^+K^-\pi^+)} = 0.199 \pm 0.004 \pm 0.009$$

CLEO_c: 0.202 ± 0.011 ± 0.009 (PRL 100 161804 (2008))
PDG08 : 0.265 ± 0.041 ± 0.031

Summary & Conclusions-II

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

Mode	Ref [2]x10^{-3}	Ref [3] x 10^{-3}	N_{obs}	preliminary BaBar BFx 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 result

This will reduce systematic errors

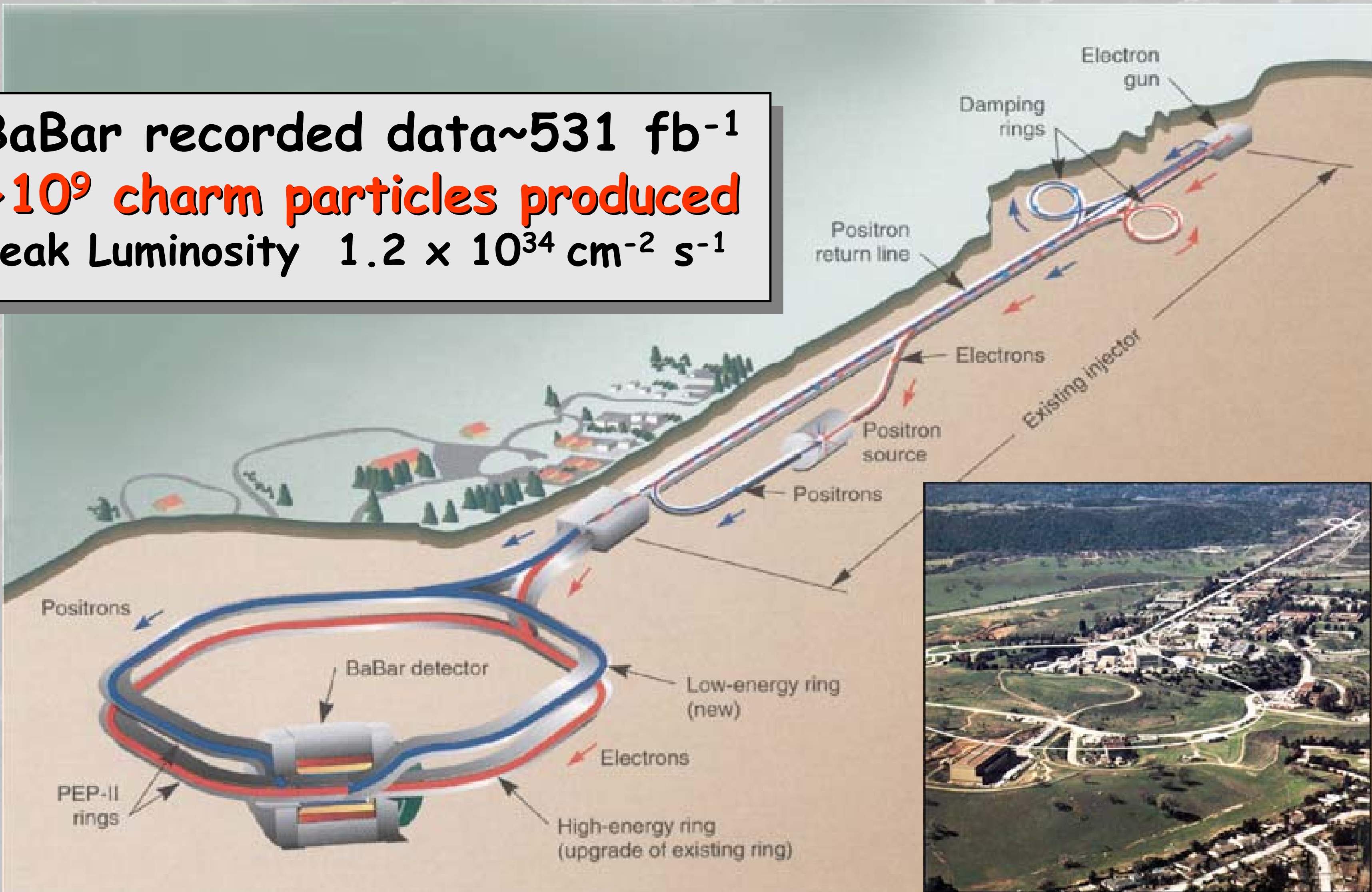
Extra slides

PEP-II was a great accelerator

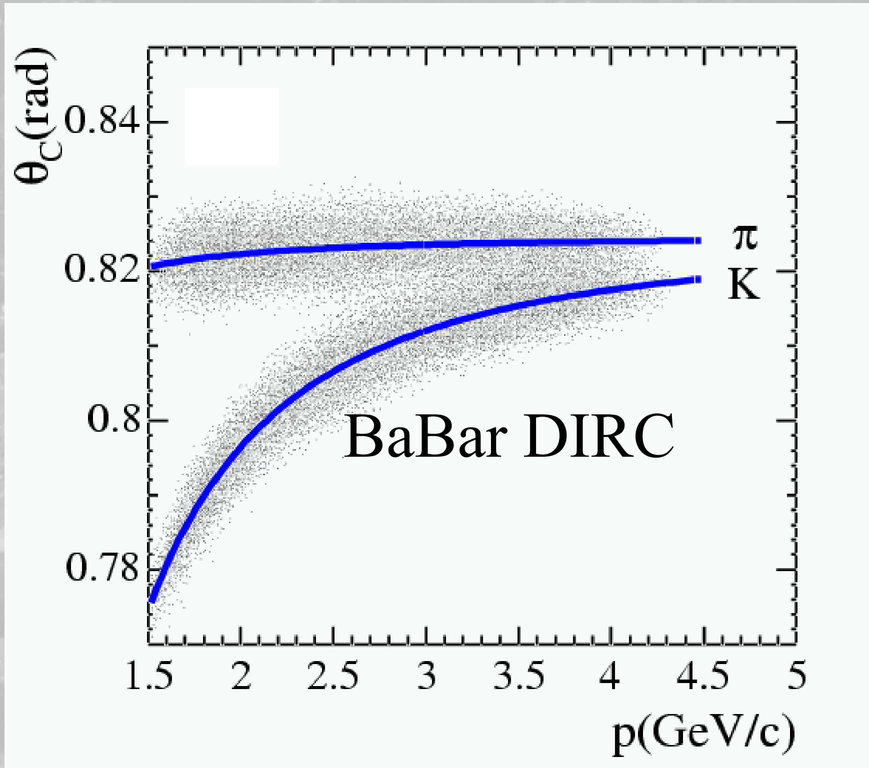
BaBar recorded data~531 fb^{-1}

>10^9 charm particles produced

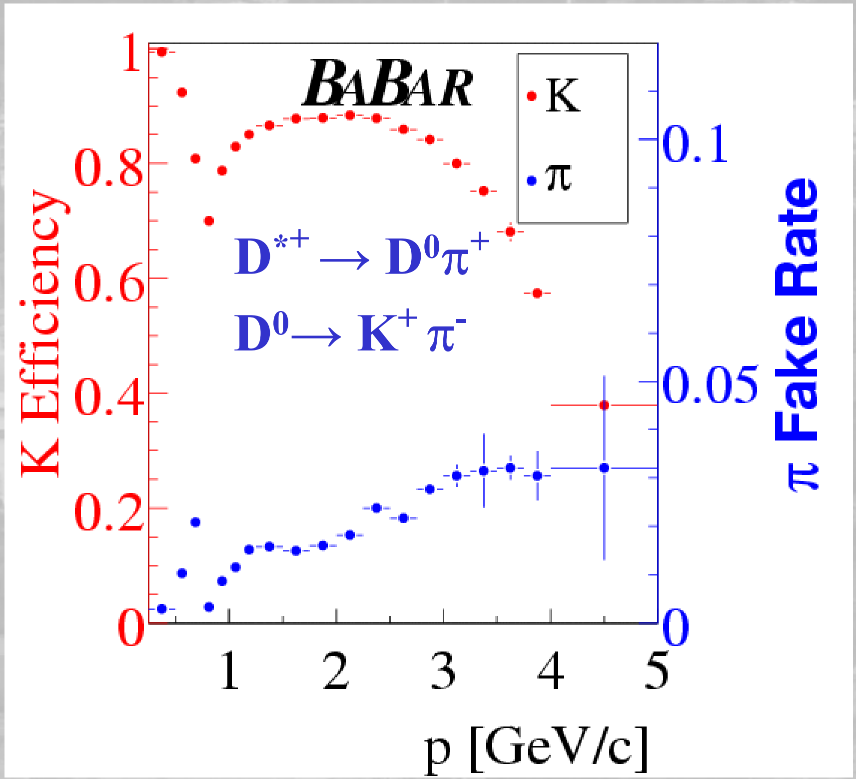
Peak Luminosity 1.2 x 10^{34} cm^{-2} s^{-1}



BaBar K/π ID



θC(rad)
0.84
0.82
0.8
0.78
π
K
BaBar DIRC
1.5
2
2.5
3
3.5
4
4.5
5
p(GeV/c)



BABAR
K
π
D*+ → D0π+
D0→ K+ π-
K Efficiency
π Fake Rate
1
0.8
0.6
0.4
0.2
0
0.1
0.05
0
1
2
3
4
5
p [GeV/c]

Selection Criteria Summary

Use 467 fb^{-1} of BaBar data (on and off $\Upsilon(4S)$)

About 1 billion D mesons in sample

Use $D^{*+} \to D^0\pi^+$ to reduce backgrounds

D^* momentum cut gets rid of D mesons from B decays

Slow pion and D^*_{CMS} momenta cuts

Slow pion beam spot fit probability > 0.01

Particle ID on kaons and pions

D^0 mass window

Cuts on vector meson:

helicity angle + Dalitz plot helicity angle for $\omega \to \pi^+\pi^-\pi^0$ (next slide)

mass window

minimum momentum

Use $\eta \to \gamma\gamma$

Photons from η have a minimum momentum requirement

Fit $\Delta M = M(D^{*+}) - M(D^0)$ with unbinned extended Max likelihood

ΔM gives better signal resolution than M(D)

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

Complete Selection Criteria

Variable	$D^0 \rightarrow (K^+K^-)_\phi \eta$	$D^0 \rightarrow \omega\eta$	$D^0 \rightarrow (K^+\pi^-)_{K^{*0}}\eta$
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	$0.322 < \|cos\theta_H\|$	$0.6 < \|cos\theta_H\|$	$cos\theta_H < -0.4$ or $cos\theta_H > 0.44$
Dalitz	-	$-0.5 < cos\theta_D < 0.5$	-
kaon PID	-	-	Stringent PID selection criteria

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

Systematic Errors

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 [10]	5.7	5.7	5.7
P_{D^*} correction	2.0	2.0	2.0
Total	8.1	9.8	8.4

Systematic errors are added in quadrature

Mode	BFx10^{-3}
$D^0 \to \omega\eta$	$2.21 \pm 0.08 \pm 0.22$
$D^0 \to (K^+\pi^-)_{K^*}\eta$	$0.048 \pm 0.01 \pm 0.004$
$D^0 \to (K^+K^-)_\varphi\eta$	$0.21 \pm 0.01 \pm 0.02$