Charm physics at B-factories

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Summary

Both experiments have extended charm physics programs :
I will present only some of the more recent results (highlighted in red for BaBar and green for Belle, common in blue).

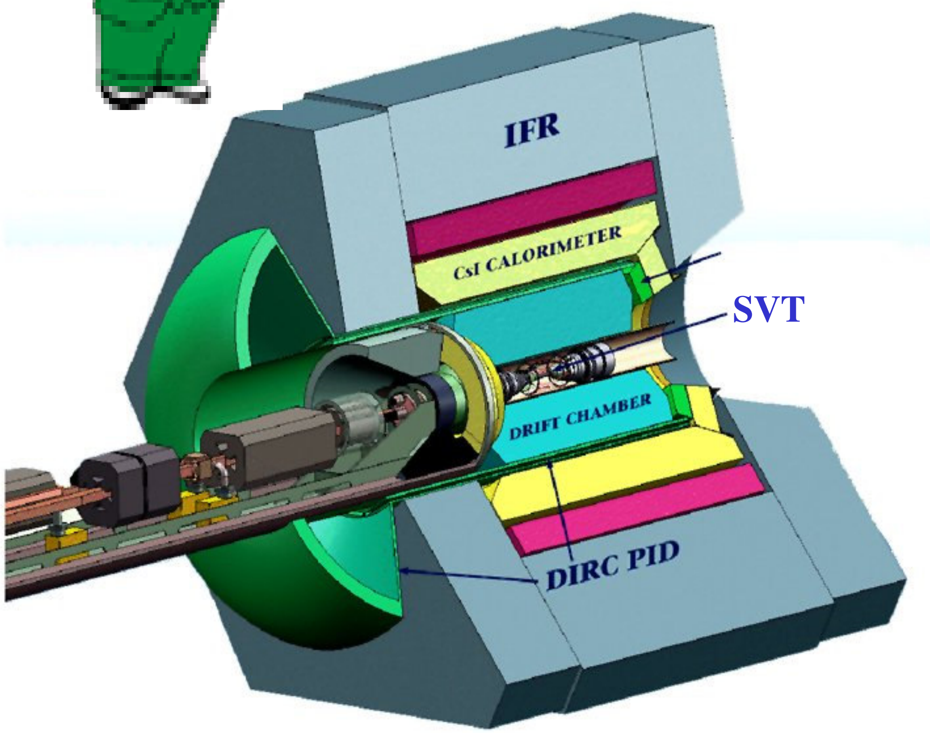
- Charm mixing : hadronic D^0 mixing, ….
- New states spectroscopy : $D_{sJ}(2317)$, $D_{sJ}(2460)$, $D_{sJ}(2632)$,…
- Production and decay BR measurements : $\Xi^0_c \rightarrow \Omega^- K^+$, $\Xi^- \pi^+$, ….
- $c\bar{c}$ recoil spectrum
- Measurement of charm hadron masses and widths : Λ_c , ….

- Semileptonic D^0 mixing, ….
- Rare and forbidden decays : $D^0 \rightarrow l^+ l^-$, …
- Dalitz plot analyses : $D^0 \rightarrow K^0_s \pi^+ \pi^-$, $K^0_s K^+ K^-$, …..

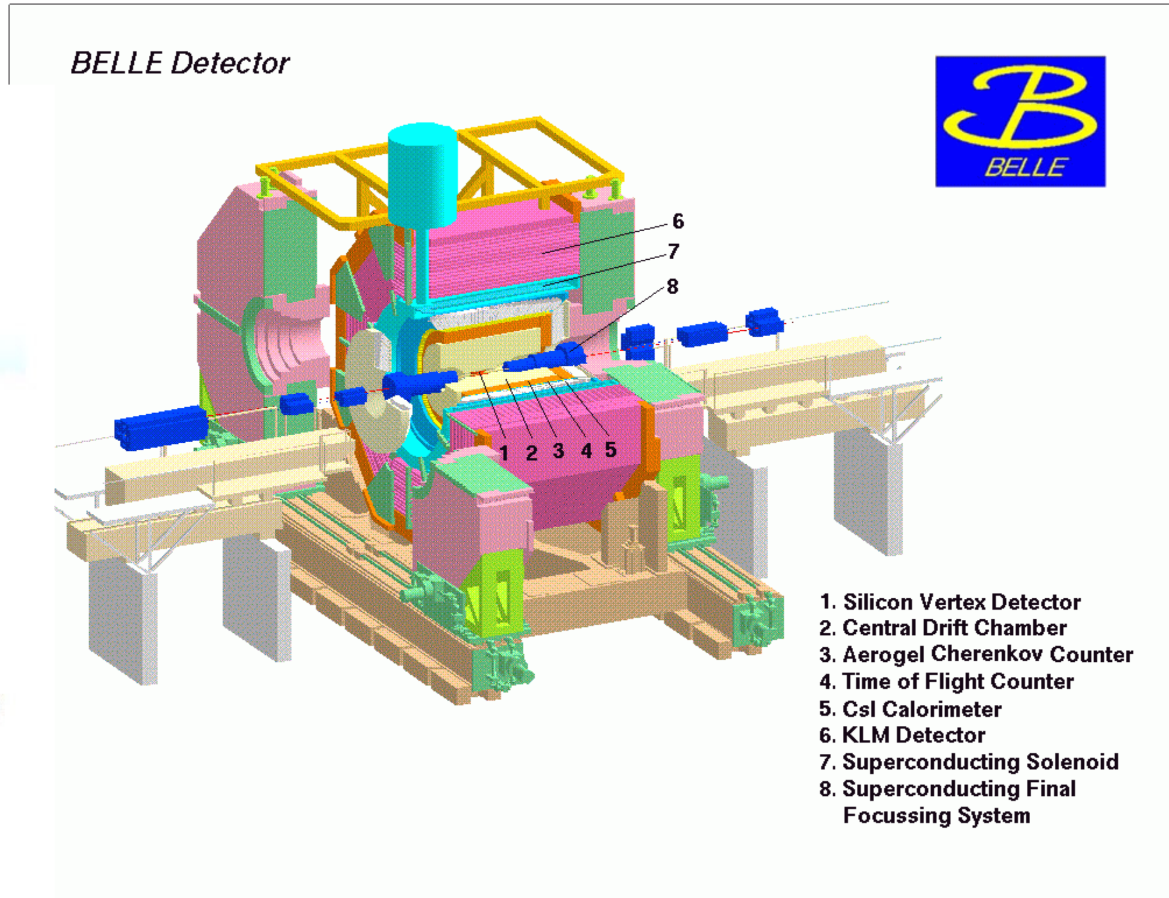
and much more

The use of charge conjugate states is implicit everywhere.

BaBar @ PEP-II



Belle @ KEK



Both detectors optimized for B physics BUT all-purpose

- Asymmetric e^+e^- collisions at $\Upsilon(4s)$ (+ off-peak for continuum)
- **Very clean environment**
- **Excellent vertexing (SVT), tracking (DCH) and PID (DIRC) essentials for all charm analyses as well as excellent π^0,γ detection**

Remind: $\sigma(b\bar{b})$ ~ 1.05 nb on resonance and $\sigma(c\bar{c})$ ~ 1.3 nb (continuum)

B-factories are also charm-factories !

~ 90 % data @ $\sqrt{s}$ = 10.58 GeV - Y(4s).
~ 10 % data @ $\sqrt{s}$ = 10.54 GeV (off resonance)

$\int L dt$ = 244 fb^{-1} (Run 1- 4 total)

L_{peak} = 9.2 • 10^{33} cm^{-2} s^{-1}

~ 260 • 10^6 $B\bar{B}$ pairs collected

BUT ALSO

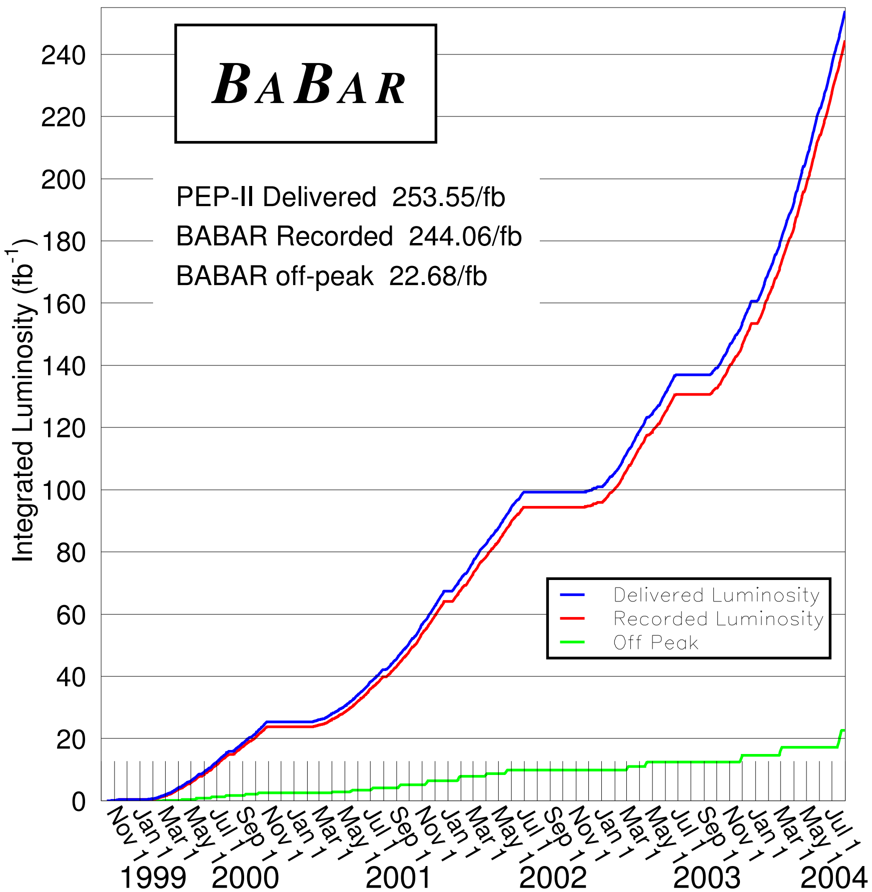
~ 310 • 10^6 $c\bar{c}$ pairs !

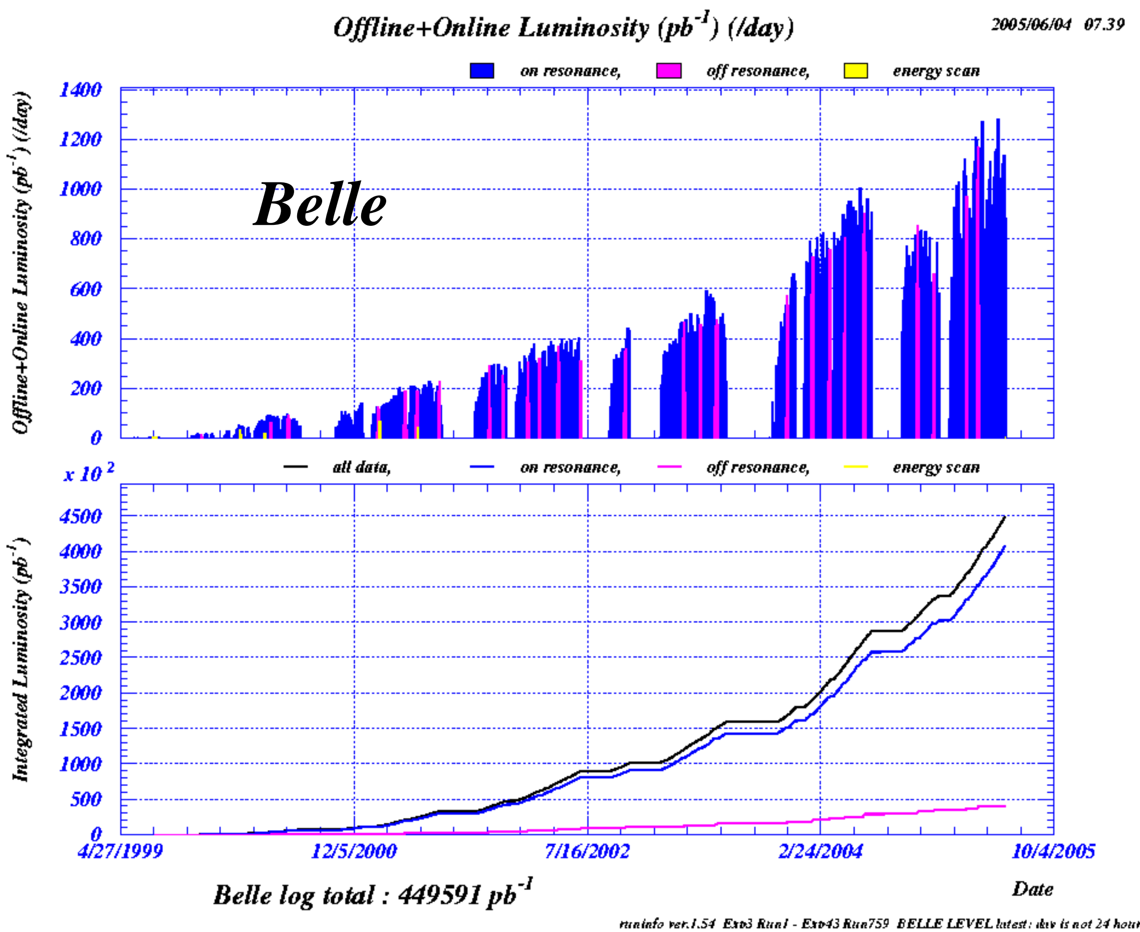
$\int L dt$ ~ 400 fb^{-1} on reson.

~ 50 fb^{-1} off reson.

L_{peak} = 21 • 10^{33} cm^{-2} s^{-1}

~ 420 M $B\bar{B}$





Fabio Ferrarotto, INFN Roma

Hadronic D^0 mixing

Belle
PRL 94,071801(2005)
90 fb^{-1}

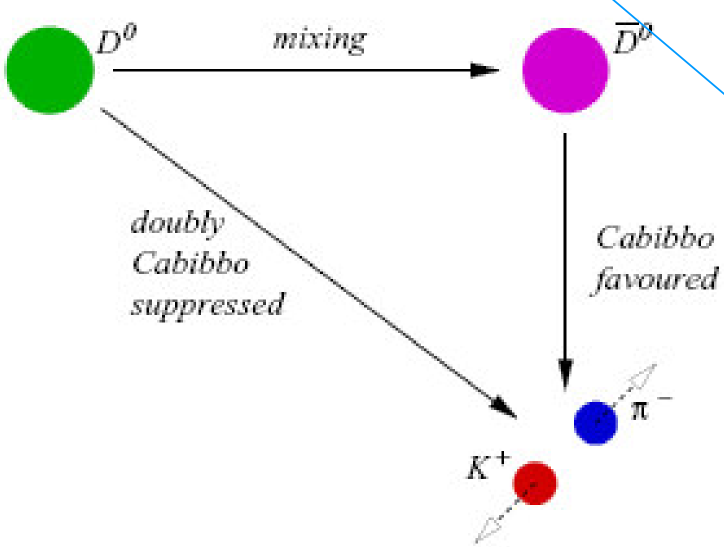
D^0 from $D^{*+} \rightarrow D^0\pi^+_{slow}$

$D^0 \rightarrow K^+\pi^-$ decay ; analysis à la Cleo

R_D = DCS/CF decay rates

$$\frac{dN}{dt} \propto e^{-\overline{\Gamma}t}\left[R_D + \sqrt{R_D}\,y'(\overline{\Gamma}t) + \frac{x'^2+y'^2}{4}(\overline{\Gamma}t)^2\right]$$

$x = \Delta m/\overline{\Gamma}$; $y = \Delta\Gamma/(2\overline{\Gamma})$



- strong phase difference $\delta_{K\pi} \longrightarrow$ we measure x and y *rotated* by $\delta_{K\pi}$

$x' = x\cos\delta + y\sin\delta$

$y' = y\cos\delta - x\sin\delta$

- time dependence disentangles

e^{-t}	DCSD
$t \cdot e^{-t}$	interference term
$t^2 \cdot e^{-t}$	mixing

$t = (l_{D0}/p_{D0}) \times m_{D0}$

$\sigma(t) \sim 200$ fs

interference term $f(t) \longrightarrow$ sensitivity to mixing

- categorize backgrounds by $f(t)$
- fix in the timing fit $\longrightarrow$ recover interference

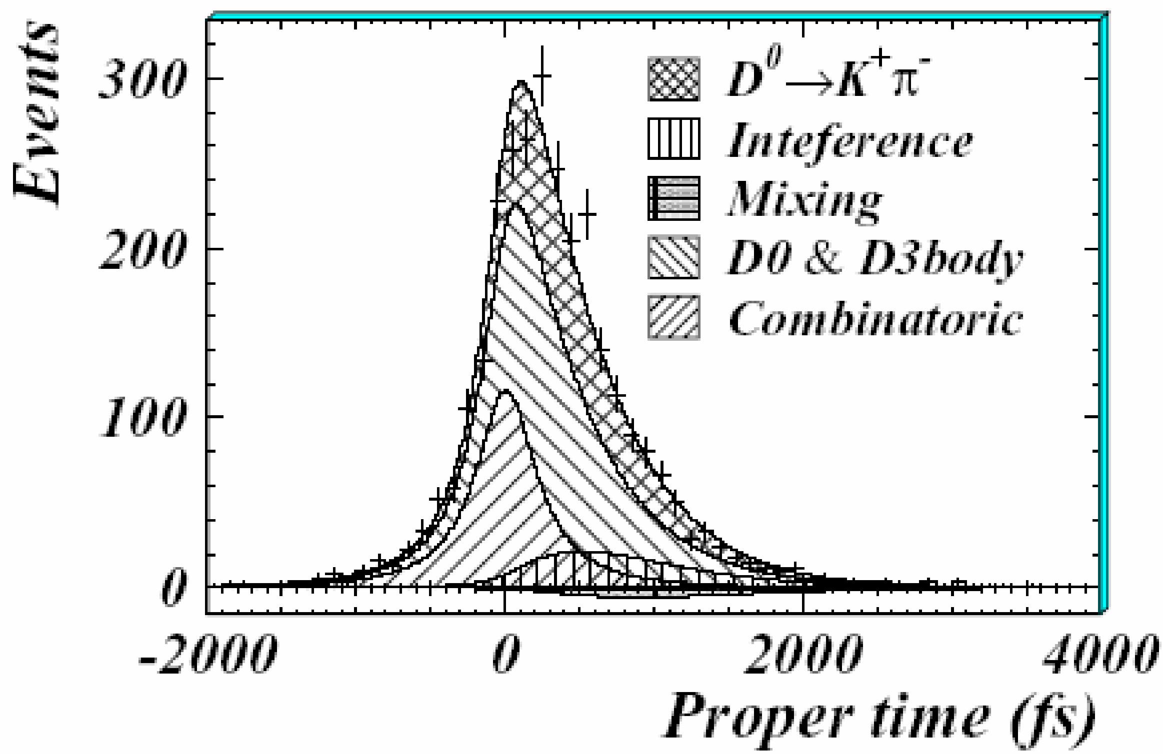
Hadronic D^0 mixing

Belle
PRL 94, 071801 (2005)
90 fb^{-1}

	timing fit results ($/10^{-3}$)		
	R_D	y'	x'^2
mixing fit, x' free:	2.87 ± 0.37	$+25.4^{+11.1}_{-10.2}$	$-1.53^{+0.80}_{-1.00}$
mixing fit, x' fixed:	3.43 ± 0.26	$+6.0 \pm 3.3$	0

project^n of full (M, Q) region:

- $\chi^2/n_{\text{bins}} = 71.9/60$
- $x' = 0$ fixed $\mapsto$ $\chi^2/n_{\text{bins}} = 73.2/60$
- toy MC at $x' = 0$: $P(x'^2 < x'^2_{\text{fit}}) = 8\%$
- CPV fits also done ($D^0, \overline{D}^0$ separately) . . .

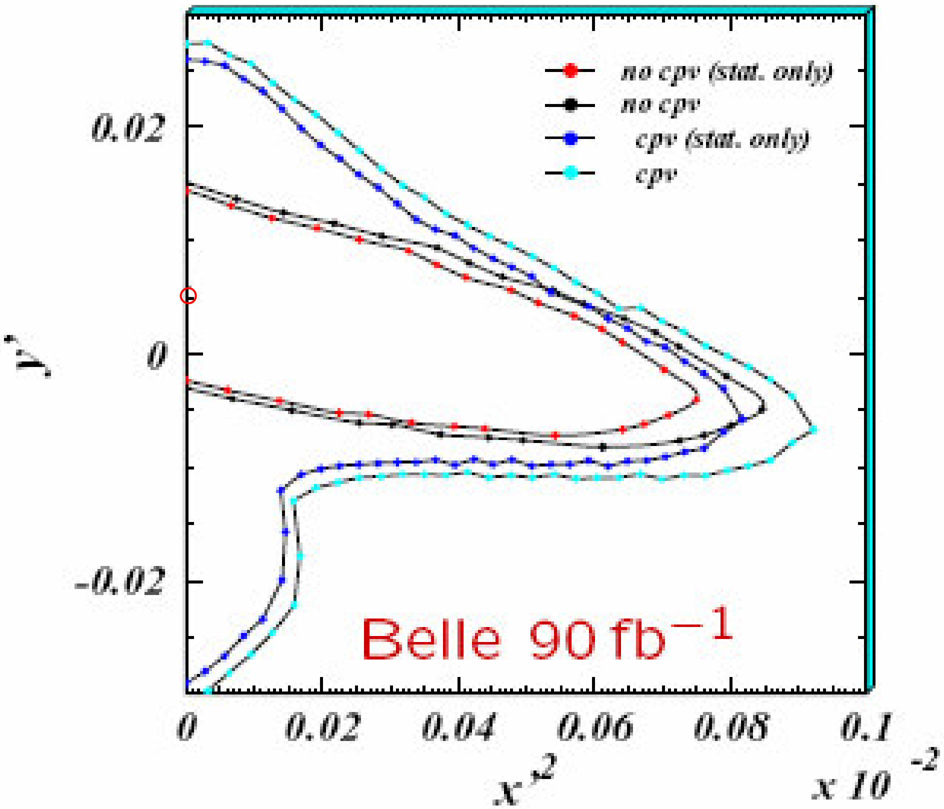


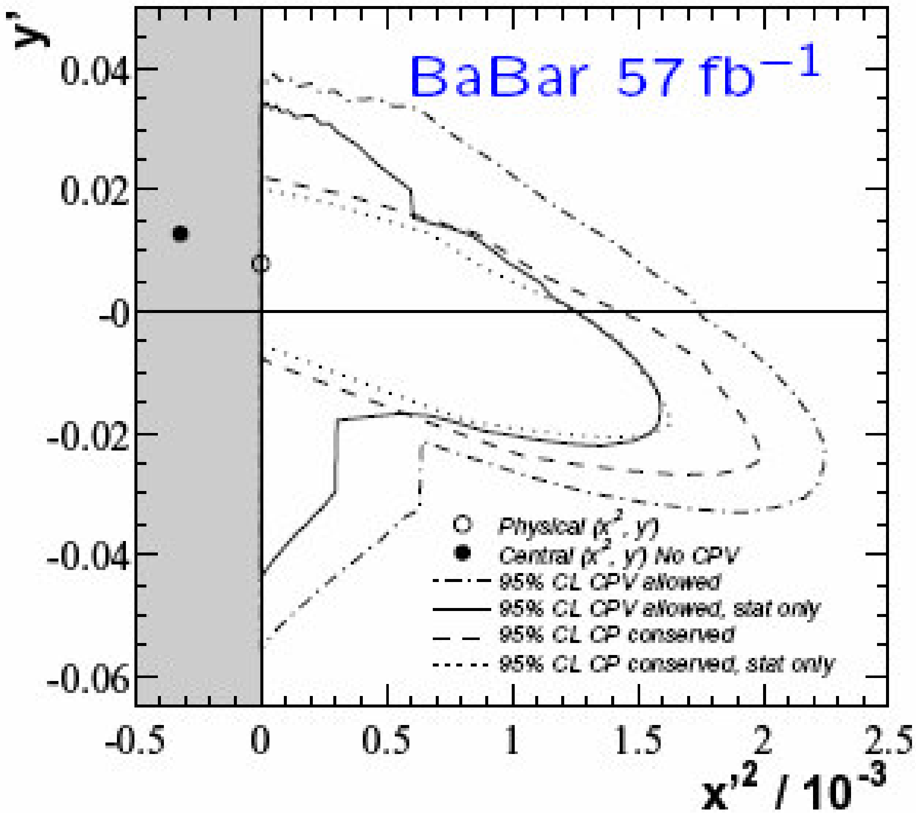
If no mixing, no CPV measure $R_D = (0.381 \pm 0.017\ ^{+0.008}_{-0.016})\ \%$

Hadronic D^0 mixing

Belle
PRL 94, 071801(2005)
90 fb^{-1}

- most restrictive single result; *cf.* BaBar *PRL* **91**, 171801 (2003)





- both favour values $y' \sim 1\%$:

  (but strong phase $\delta_{K\pi}$, between DCS and CF decays, is unknown)

- update with full statistics is underway ...

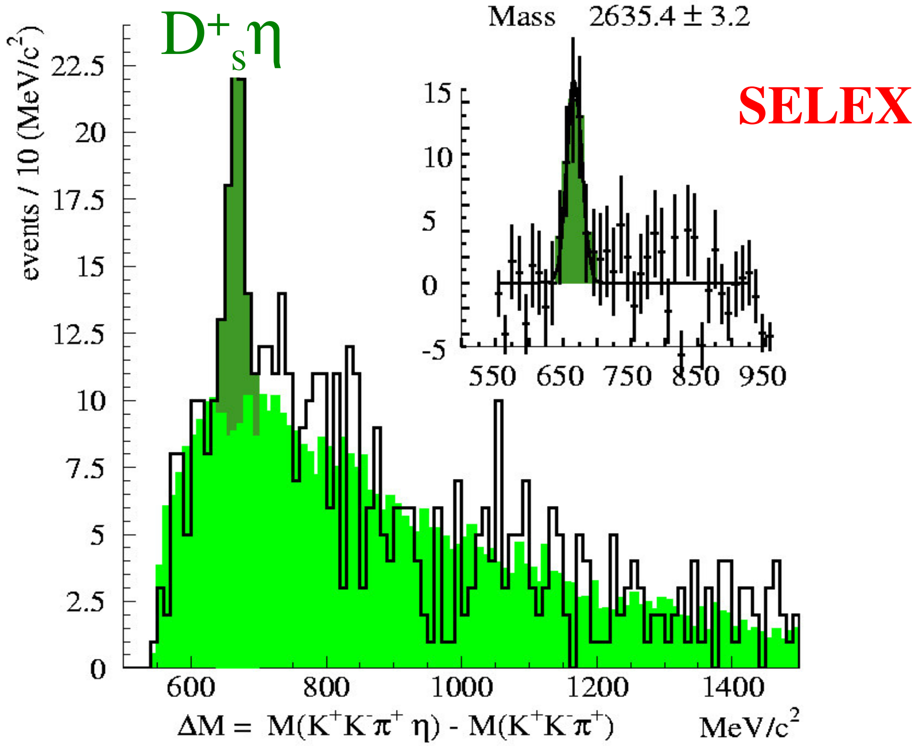
Search for $D_{sJ}(2632)$

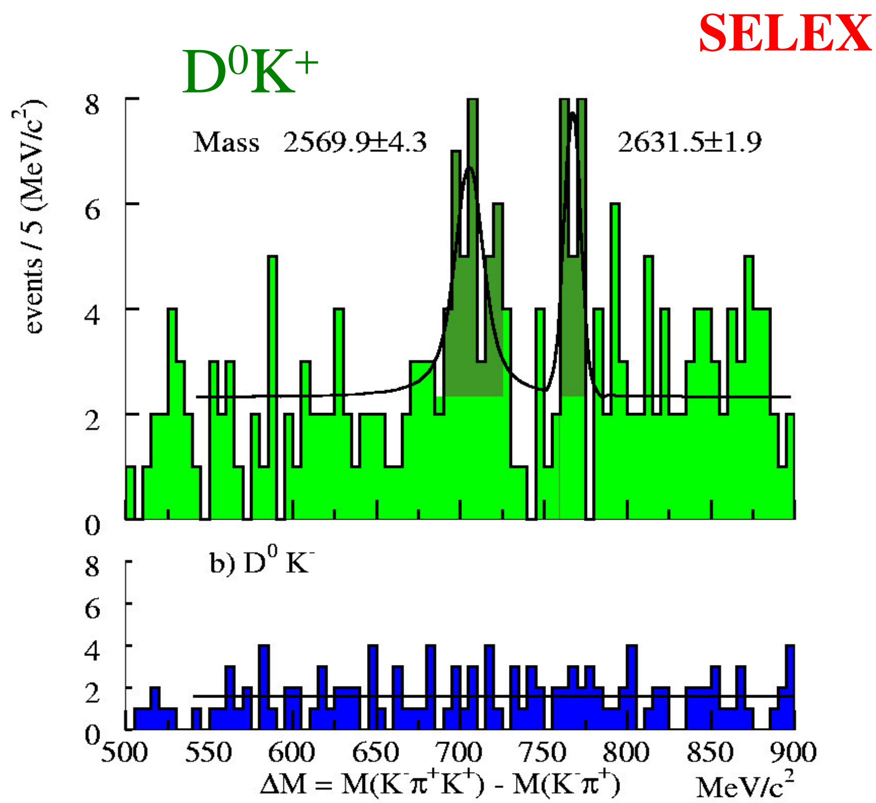
Selex reported the observation of a new narrow charm-strange meson : the $D^+_{sJ}(2632) \to D^+_s\eta$, D^0K^+

$N(D_s^+) = 544 \pm 29$

$N(\eta) = 5087 \pm 863$ uncorrelated η

SELEX: Phys. Rev. Lett. 93:242001 (2004)





Search for $D_{sJ}(2632)$

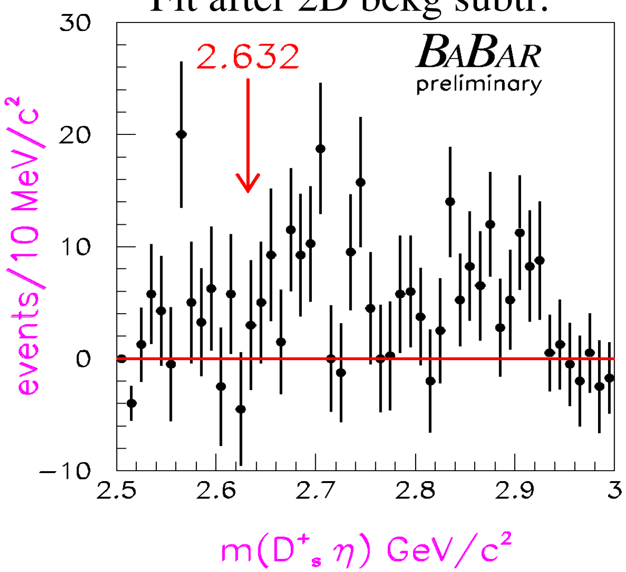
BaBar : hep-ex/0408087
126 fb^{-1}

BaBar sees no evidence for production of $D_{sJ}(2632)$ in $D^+_s\eta$, D^0K^+ and $D^{*+}K^0_s$ in 126 fb^{-1} of data

$N(D_s^+) = 196000$
$N(\eta) = 3900$ correlated η

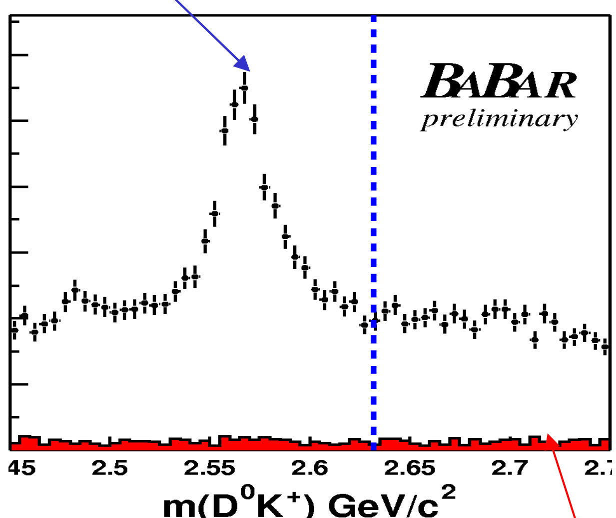
$D^+\eta$

Fit after 2D bckg subtr.



$D_{s2}(2573)^+$

D^0K^+

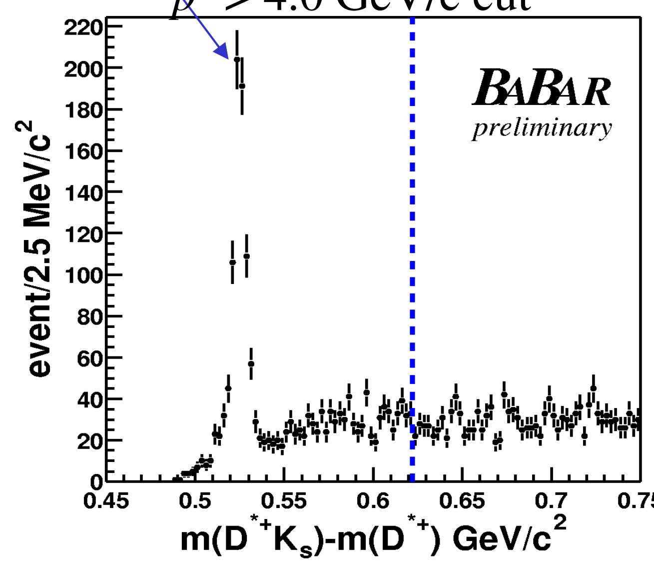


D^0K^-

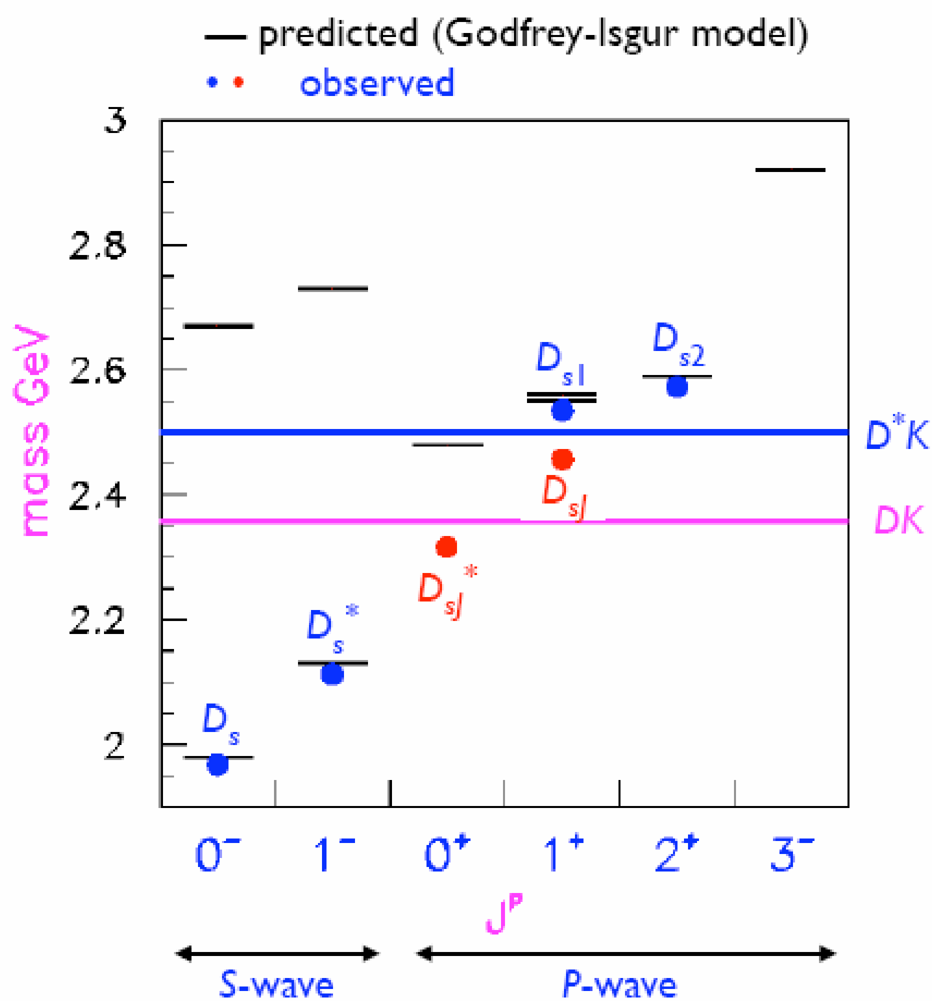
$D_{s1}(2536)^+$

D^*K^0

$p^* > 4.0$ GeV/c cut



$D_{sJ}^*(2317)$ and $D_{sJ}(2460)$



Two new $c\bar{s}$ states observed :

D_{sJ}*(2317) and D_{sJ}(2460)

Lot of excitement by theorists

- Well established
- Observed both in continuum and B decays
- J^P consistent with P-wave

To be understood:

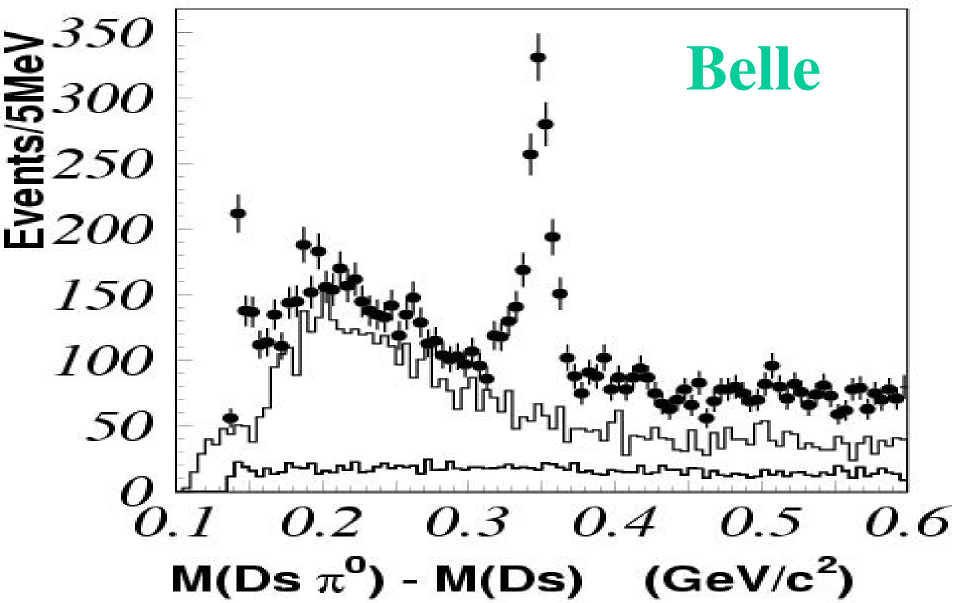
- Masses lower than predicted in potential models
- Very small widths (Γ < 10 MeV exp.)
- Isospin-violating decays

$$D_{sJ}^*(2317)^+ \to D_s^+\pi^0,$$
$$D_{sJ}(2460)^+ \to D_s^*(2112)^+\pi^0,$$

D_{sJ} states

Production in continuum

$D_{sJ}^*(2317)^+ \to D_s^+ \pi^0$

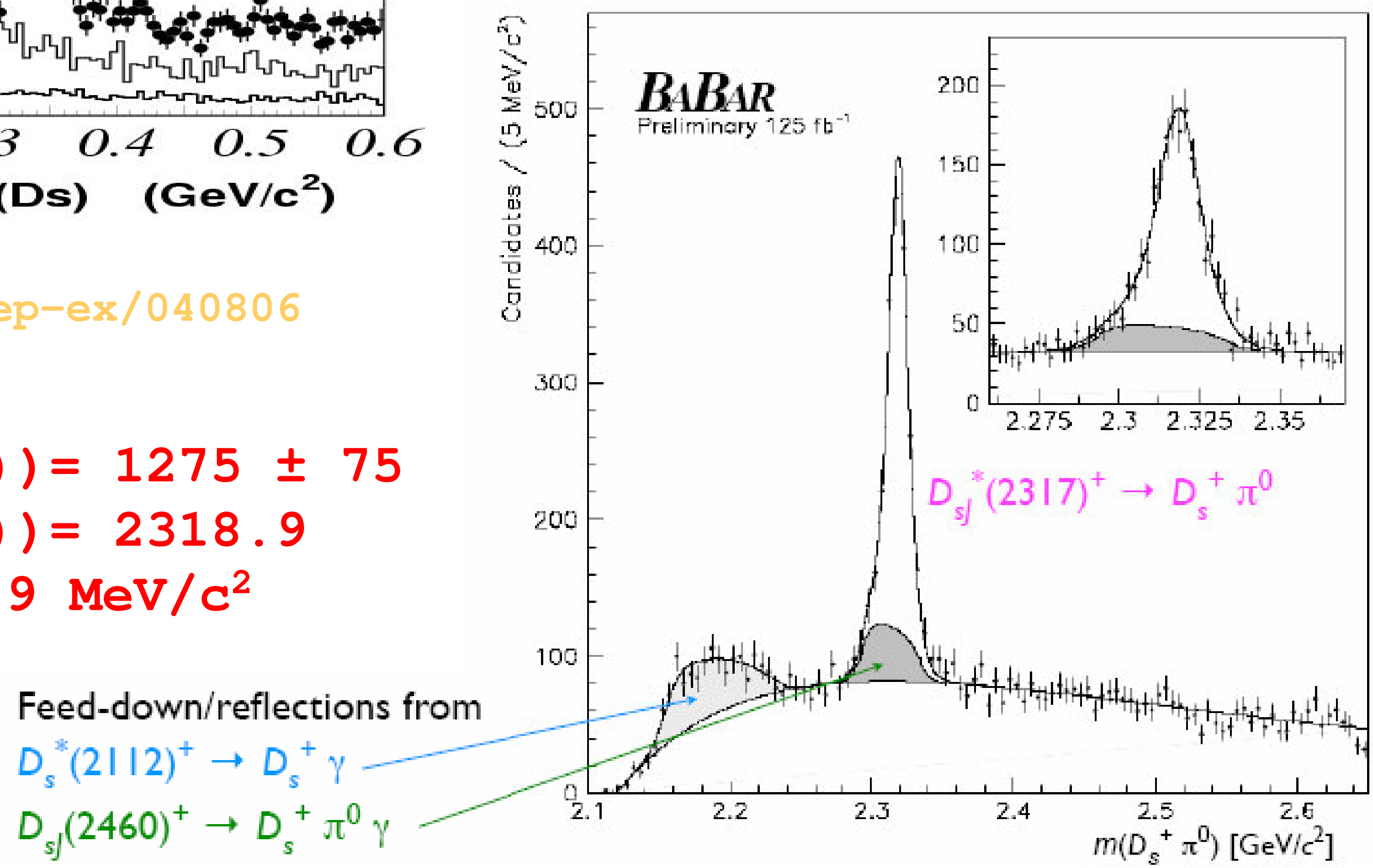


Belle : PRL92,012002(2004)
86.9 fb-1

$M(D_{sJ}(2317)) = 2317.2 \pm 0.5 \pm 0.9\ MeV/c^2$

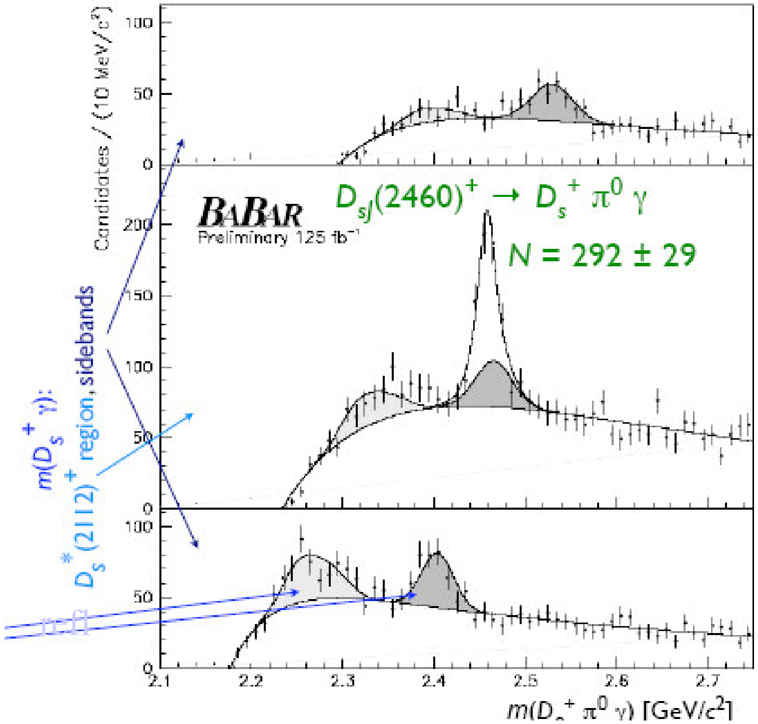
BaBar : hep-ex/040806
125 fb-1

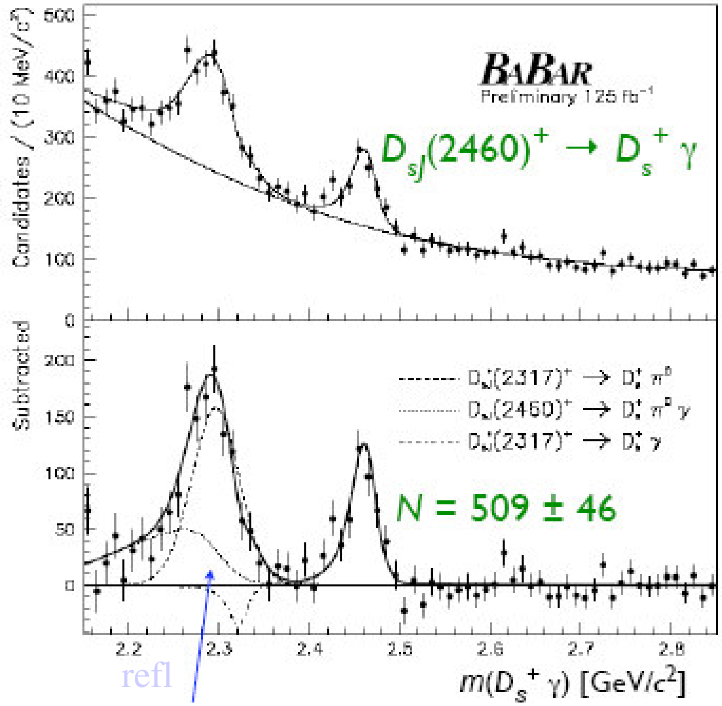
$N(D_{sJ}(2317)) = 1275 \pm 75$
$M(D_{sJ}(2317)) = 2318.9 \pm 0.3 \pm 0.9\ MeV/c^2$



D_{sJ} states

Production in continuum

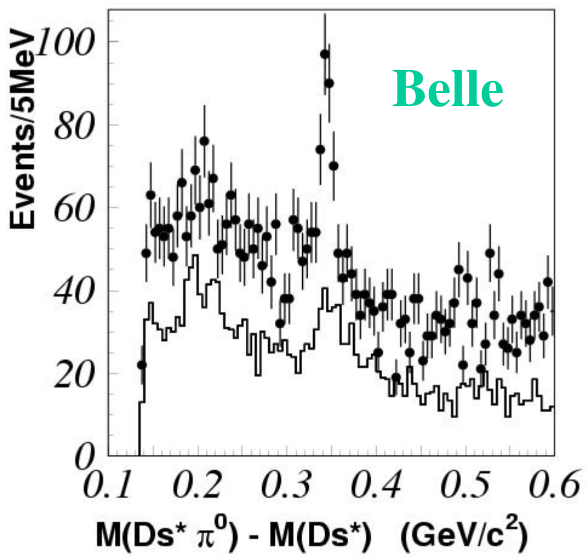


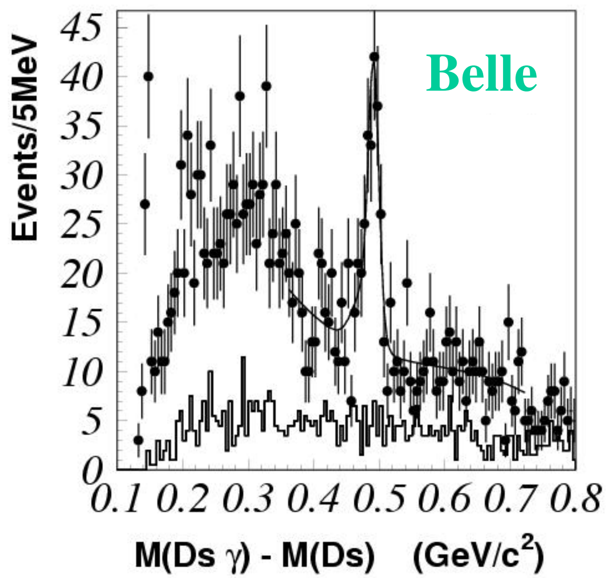


BaBar
hep-ex/0408067
125 fb-1

$D_{sJ}^+(2460) \to D_s^{*+} \pi^0$

$D_{sJ}^+(2460) \to D_s^+ \gamma$



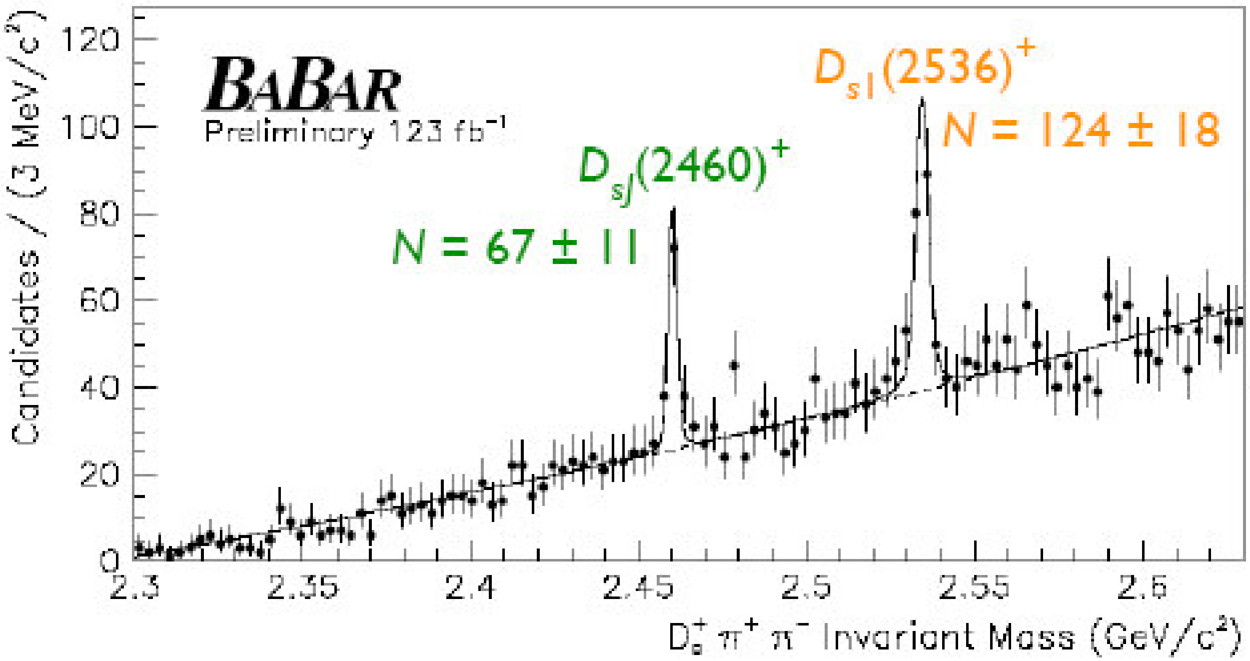


BELLE
PRL92,012002(2004)
86.9 fb-1

$M(D_{sJ}(2460)) = 2456.5 \pm 1.3 \pm 1.3$ MeV/c^2

D_{sJ} states

Production in continuum



BaBar
hep-ex/0408067
125 fb^{-1}

BaBar : all 3 modes combined fit

$$\frac{\mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\gamma)}{\mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\pi^0\gamma)} = 0.375 \pm 0.054 \pm 0.057$$

$$\frac{\mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\pi^+\pi^-)}{\mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\pi^0\gamma)} = 0.082 \pm 0.018 \pm 0.011$$

$M(D_{sJ}(2460))=2459.4 \pm 0.3 \pm 1.0\ MeV/c^2$

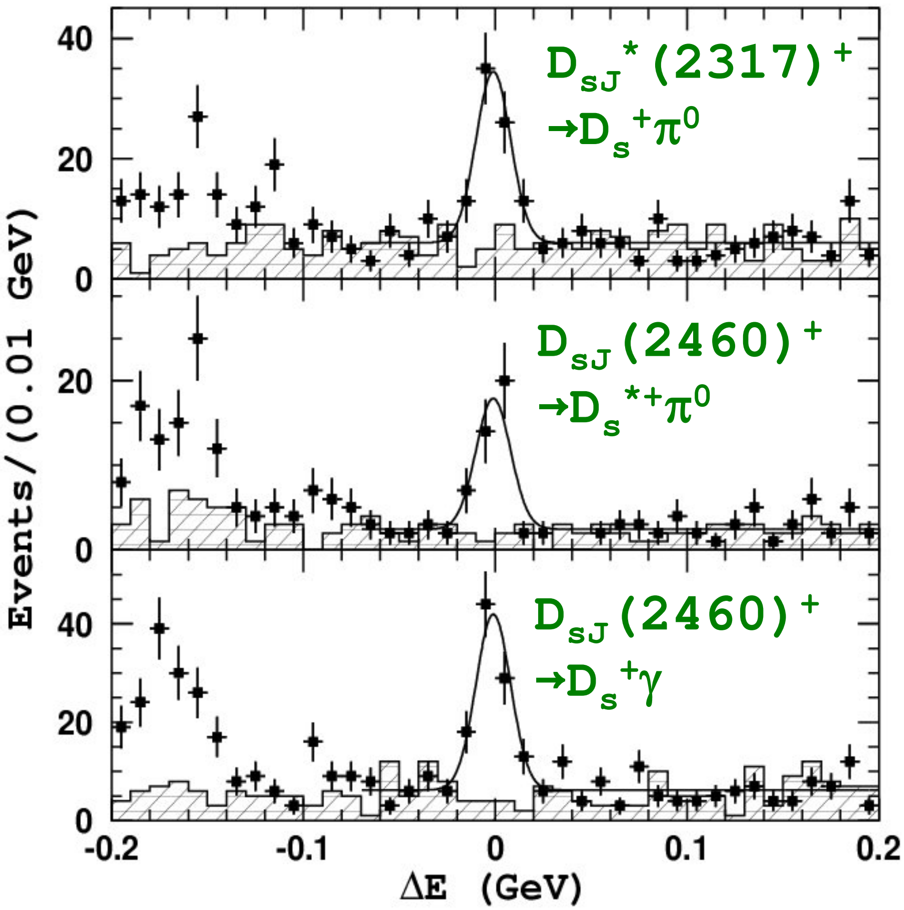
$M(D_{s1}(2536))=2534.3 \pm 0.4 \pm 1.2\ MeV/c^2$

Belle

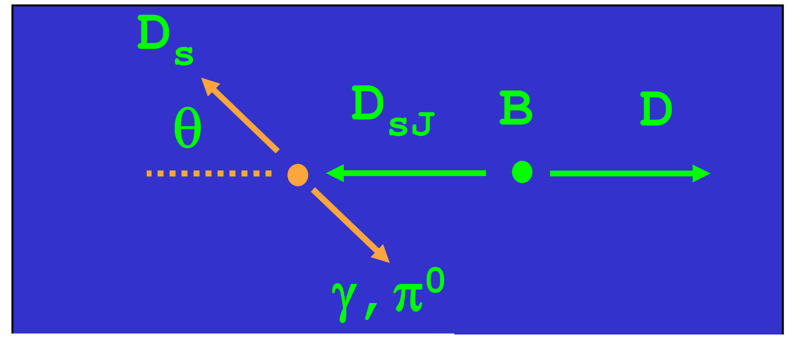
D_{sJ} states

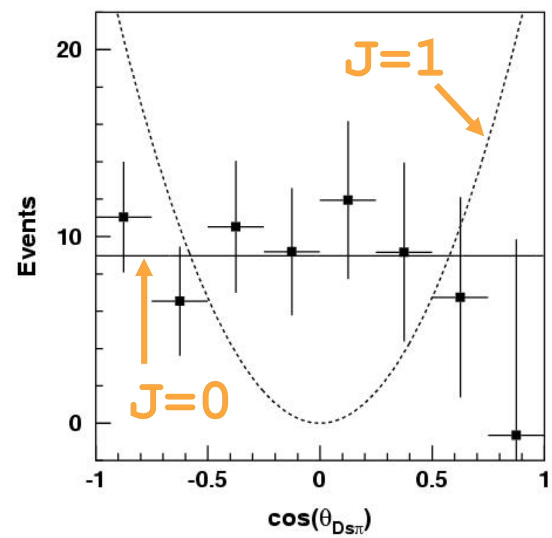
Production in B decays

$B \rightarrow \bar{D}\ D_{sJ}$

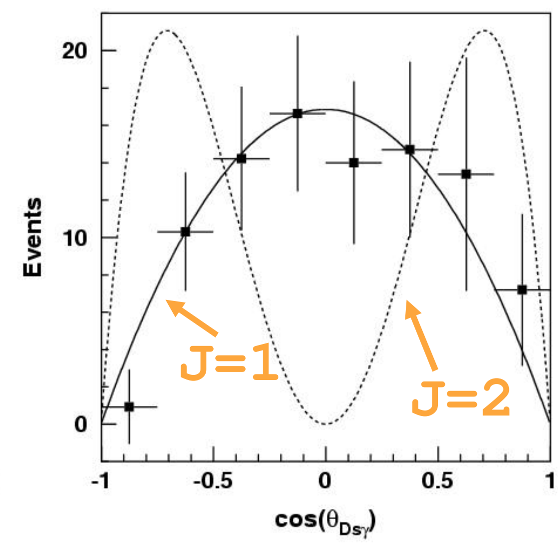


Helicity angle:





$D_{sJ}^*(2317)^+ \rightarrow D_s^+\pi^0$



$D_{sJ}(2460)^+ \rightarrow D_s^+\gamma$

275M $B\bar{B}$, BELLE-CONF-0461
PRL 91,262002

Data agree with $J^P=0^+$ ($D_{sJ}(2317)$) and 1^+ ($D_{sJ}(2460)$)

$Br(B^0 \rightarrow D^- D_{sJ}^*(2317)^+) = (10.3 \pm 2.2 \pm 3.1) \times 10^{-4}$

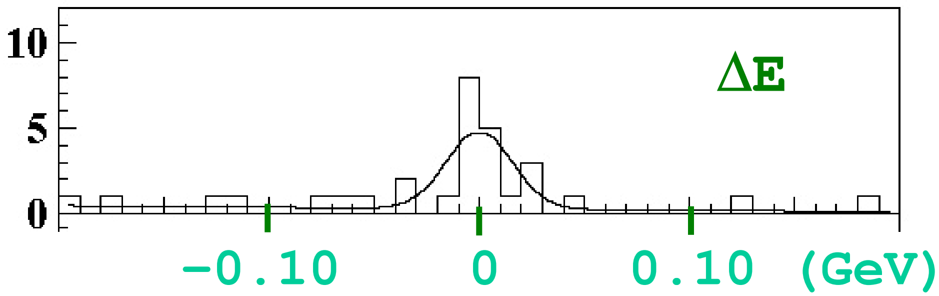
D_{sJ} states

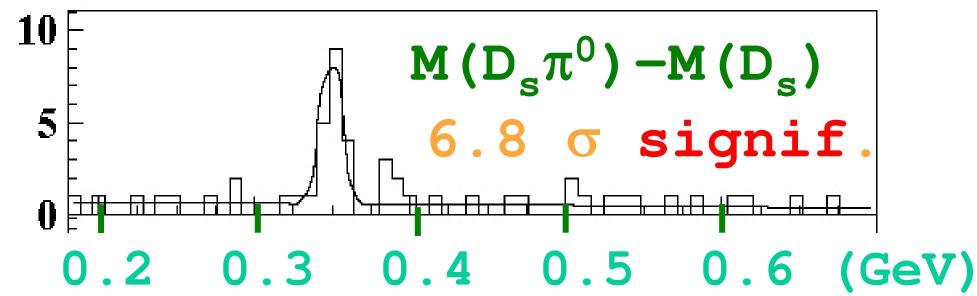
First observation of $B^0 \to D_{sJ}^{*-} K^+$

BELLE

152M $B\bar{B}$, PRL 94, 061802

$D_{sJ}^*(2317)^- \to D_s^- \pi^0$ ($D_s \to \phi\pi, K^*K, K_SK$)





$Br(B^0 \to D_{sJ}(2317)^- K^+) \cdot Br(D_{sJ}(2317)^- \to D_s^- \pi^0) =$

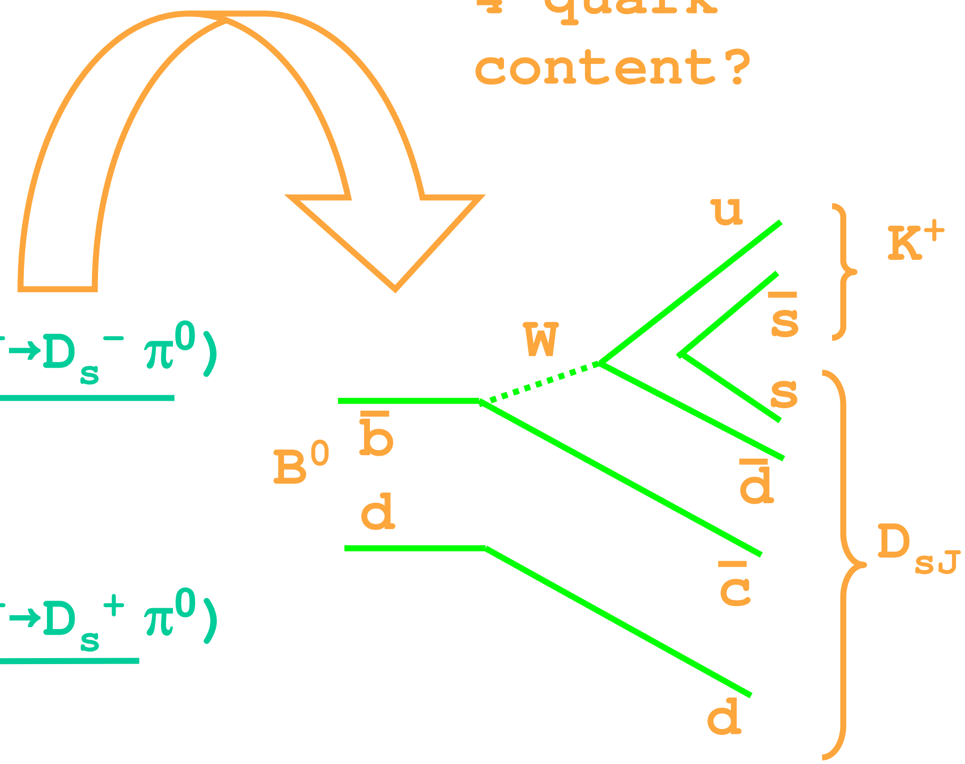
$(5.3 \pm 1.4 \pm 0.7 \pm 1.4) \times 10^{-5}$

$B \to D_{sJ}(2317)\pi^-$ $< 2.5 \times 10^{-5}$ @90% CL

$B \to D_{sJ}(2460)K^+$ $< 0.94 \times 10^{-5}$

$B \to D_{sJ}(2460)\pi^-$ $< 0.40 \times 10^{-5}$

4-quark content?



$$\frac{Br(B^0 \to D_{sJ}^*(2317)^- K^+) \cdot Br(D_{sJ}^*(2317)^- \to D_s^- \pi^0)}{Br(B^0 \to D_s^- K^+)}$$

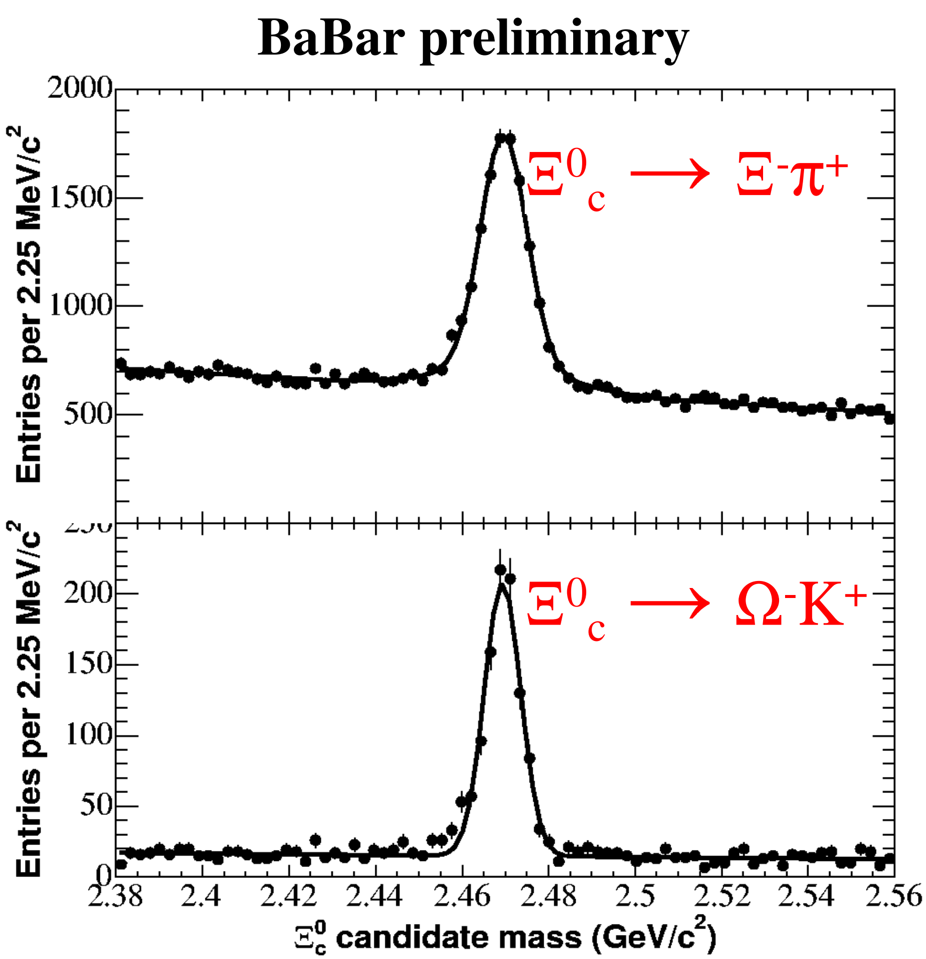
$$\frac{Br(B^0 \to D^- D_{sJ}^*(2317)^+) \cdot Br(D_{sJ}^*(2317)^+ \to D_s^+ \pi^0)}{Br(B^0 \to D^- D_s^+)}$$

Measurement of Ξ^0_c BR

BaBar : hep-ex/0504014
116 fb^{-1}

Decay chain :

$\Omega^- (\Xi^-) \to \Lambda \; K^- (\pi^-) \to p \; \pi^- \; K^- (\pi^-)$



$$\frac{\mathcal{B}(\Xi^0_c \to \Omega^- K^+)}{\mathcal{B}(\Xi^0_c \to \Xi^- \pi^+)} = 0.294 \pm 0.018 \pm 0.016$$

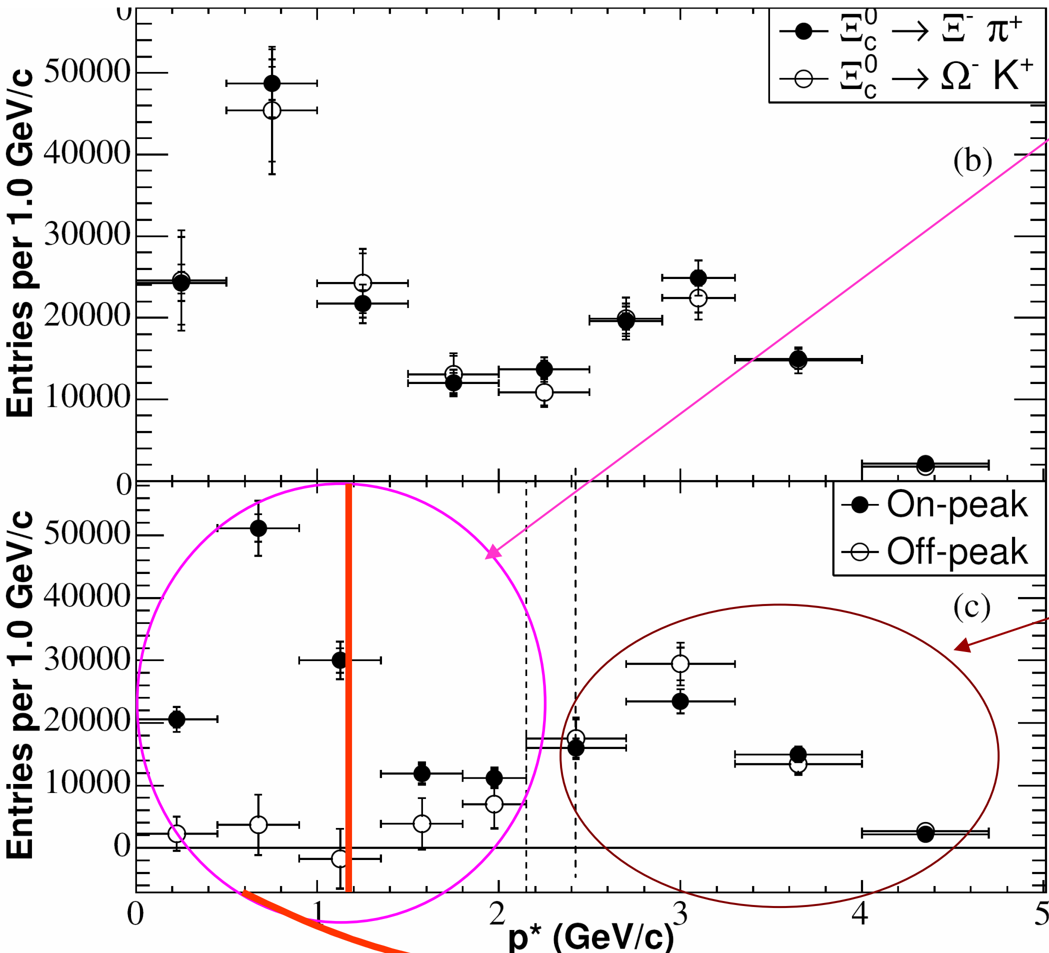
Consistent with spectator QM prediction = 0.32
Z.Phys.C55, 659

Previous CLEO result:
PRL 79,3599 (1997)

$$\frac{\mathcal{B}(\Xi^0_c \to \Omega^- K^+)}{\mathcal{B}(\Xi^0_c \to \Xi^- \pi^+)} = 0.50 \pm 0.21 \pm 0.05$$

Measurement of Ξ^0_c BR

Ξ^0_c are produced both in B decays and in continuum production.
Study the production using efficiency corrected p^* in the CMS frame.



B decays

$$\mathcal{B}(B \to \Xi_c^0 X) \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (2.11 \pm 0.19 \pm 0.25) \times 10^{-4}$$

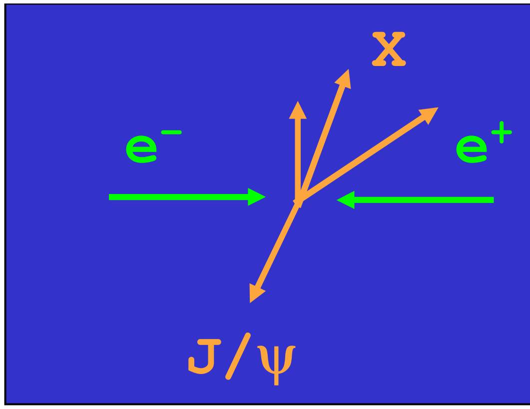
Continuum ($c\bar{c}$)

$$\sigma(e^+e^- \to \Xi_c^0 X) \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (388 \pm 39 \pm 41)\ \mathrm{fb},$$

$p^*(\Xi_c^{\,0}) < 1.2$ GeV implies production with a high mass particle (mass > 2.0 GeV/c²) probably in $b \to c\bar{c}s$ decays. (see also BaBar PRD70, 091106(RC), indirect observation)

Belle

$c\bar{c}$ recoil spectrum



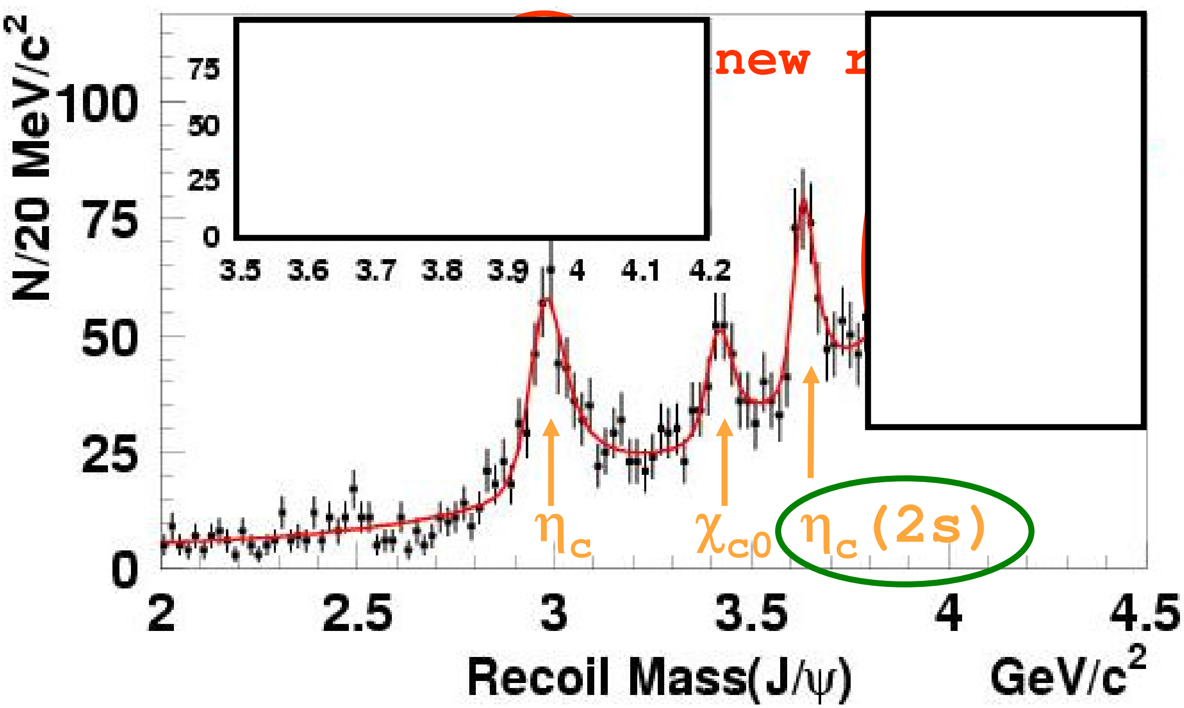
well established method (e.g. double $c\bar{c}$ production)

Calculate recoil mass (mass of X):

$$M_{rec} = \sqrt{(E_{cms} - E^*_{J/\psi})^2 - p^{*\,2}_{J/\psi}}$$

Reconstruct $J/\psi \rightarrow l^+l^-$

BELLE 285 fb^{-1}
PRD 70, 071102
hep-ex/0412041



N=148 ± 33 (4.5 σ)
M=3940 ± 11 MeV

Reconstruction of additional D or D* beside $J/\psi \rightarrow$
- new resonance decays to DD^*;
- not seen in $J/\psi\,\omega$

probably not Y(3940)

confirmation of $\eta_c(2s)$ after 1st observation by Belle

Measurement of Λ_c mass

New!

BaBar : FCP 05

~ 230 fb^{-1}

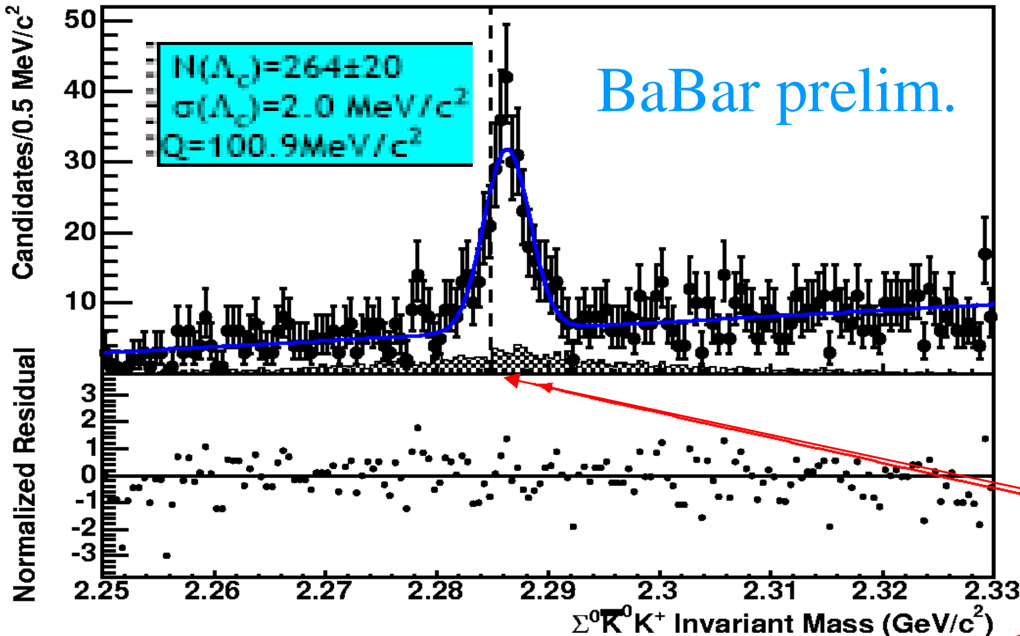
BaBar has great potential to improve on existing charm hadron mass measurements.

Charm hadron mass measurements on PDG 2004 known with a precision ~ 0.5 – 1.5 MeV/c^2 .
Done mostly 15-20 years ago with samples of $O(10^2 – 10^3)$ events.

BaBar has a VERY large sample of reconstructed charm hadrons.

Very good detector performances and resolutions ; good control over systematics .

Measurement of Λ_c mass

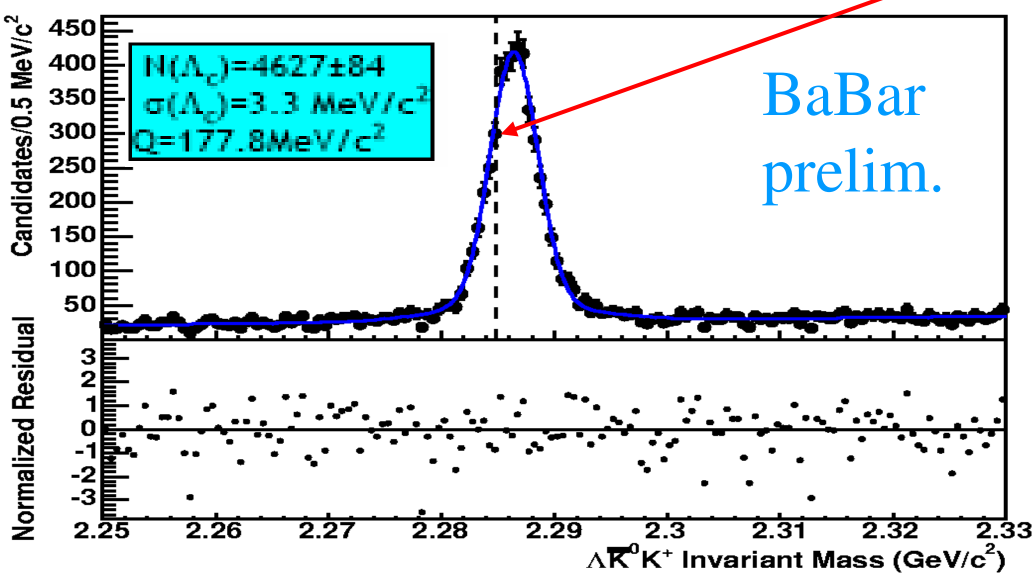


$$\Lambda_c \rightarrow \Sigma^0 \bar{K}^0 K^+, \Sigma^0 \rightarrow \Lambda\gamma$$

$$\Lambda_c \rightarrow \Lambda \bar{K}^0 K^+, \Lambda \rightarrow p\pi^-, \bar{K}^0 \rightarrow \pi^+\pi^-$$

Small Q value to minimize systematics (limiting factor for this measurement)

PDG 2004 value



Much larger control samples :

$\Lambda_c \rightarrow pK^-\pi^+$ ~ 1.5×10^6 evts

$\Lambda_c \rightarrow pK_s$ ~ 2.4×10^5 evts

(higher Q)

Measurement of Λ_c mass

$\Lambda_c \rightarrow \Sigma^0 \bar{K}^0 K^+$	$m(\Lambda_c)=2286.303 \pm 0.181$ (stat.) $\pm$ 0.126 (syst.) MeV/c^2
$\Lambda_c \rightarrow \Lambda \bar{K}^0 K^+$	$m(\Lambda_c)=2286.501 \pm 0.042$ (stat.) $\pm$ 0.144 (syst.) MeV/c^2

Control sample

$\Lambda_c \rightarrow pK^-\pi^+$	$m(\Lambda_c)=2286.393 \pm 0.018$ (stat.) $\pm$ 0.447 (syst.) MeV/c^2
$\Lambda_c \rightarrow pK_S$	$m(\Lambda_c)=2286.361 \pm 0.034$ (stat.) $\pm$ 0.428 (syst.) MeV/c^2

Larger Q !

Combined measurement :

$$m(\Lambda_c) = 2286.46 \pm 0.14 \text{ MeV}/c^2$$

About 4 times more precise than PDG (2284.9 ± 0.6 MeV/c^2) and 2.5 σ higher

Most precise measurement of open charm hadron mass to date !

Conclusion

B-factories have proven very successful also as charm-factories and BaBar and BELLE have both very rich charm physics programs.

Charm physics is very much alive :

- New spectroscopy
- High precision mass (and width) measurements
- Search for rare processes (and new physics ?)
- …

Some expected, other unexpected/puzzling observations/discoveries

Lots of questions addressed with more stat. collected

More results will be shown in summer conferences.