

# Measurements of $\varphi_1$ and $\varphi_2$

Tagir Aushev

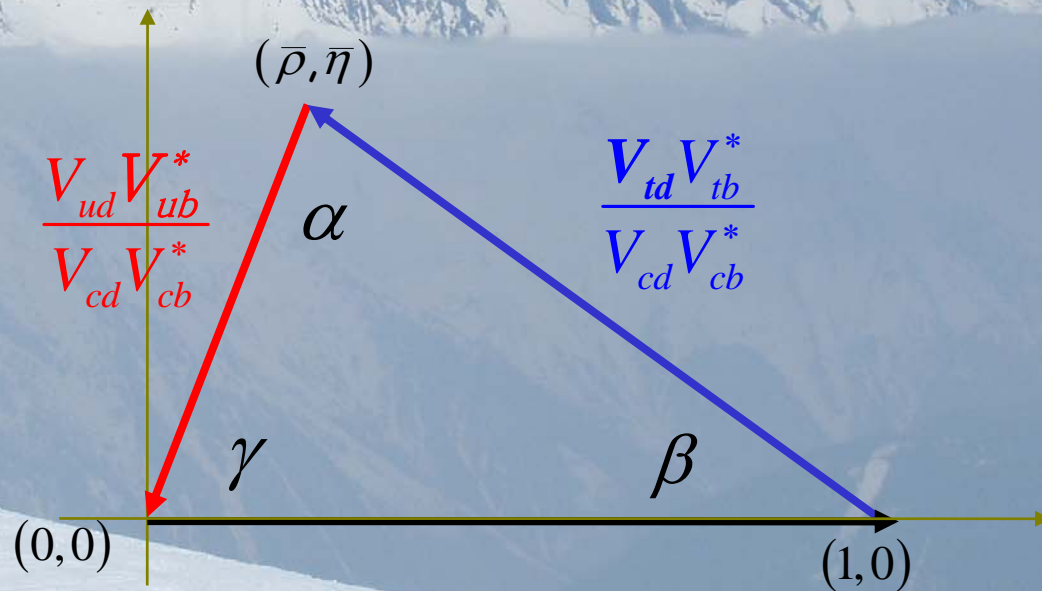
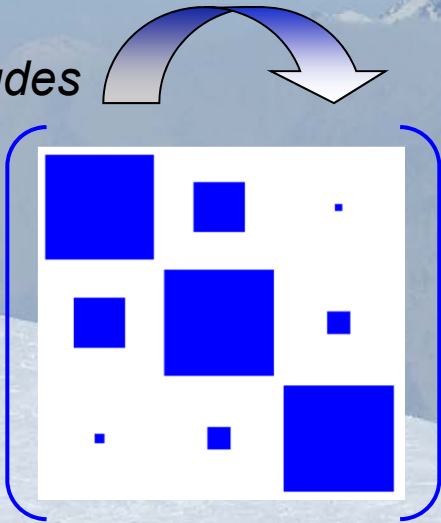
For the Belle Collaboration  
(EPFL, Lausanne  
ITEP, Moscow)

- $B \rightarrow K_S \pi^0 \pi^0$
- $B \rightarrow K_S K_S$
- $B \rightarrow K_S \pi^0$
- $B \rightarrow D^{*+} D^{*-}$
- $B \rightarrow a_1 \pi, a_1 K, b_1 \pi, b_1 K \dots$
- $Y(4S) \rightarrow B_{CP} B_{CP}$

# CKM matrix & unitary triangle

$$V^\dagger V = 1 \quad \rightarrow \quad V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$

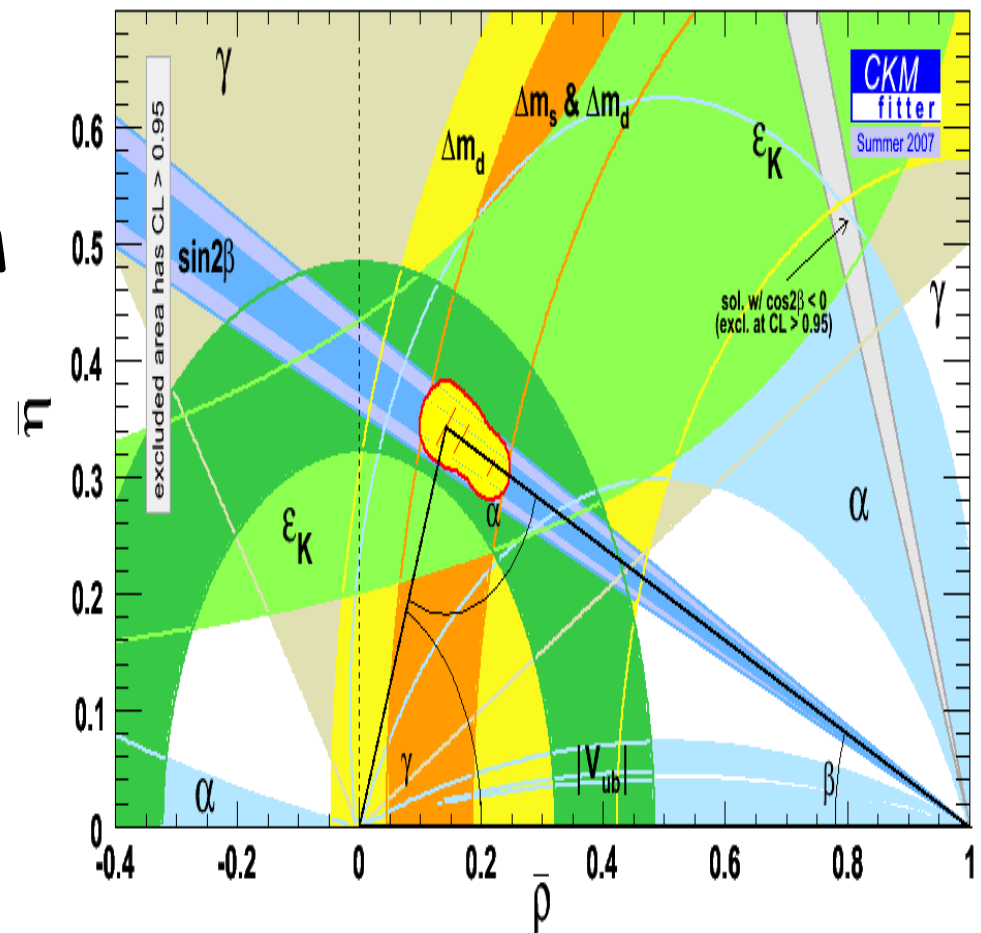
relative  
magnitudes



$$\alpha = \arg \left( -\frac{V_{td} V_{tb}^*}{V_{ud} V_{ub}^*} \right), \beta = \arg \left( -\frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*} \right), \gamma = \arg \left( -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right)$$

# CP Violation in the Standard Model

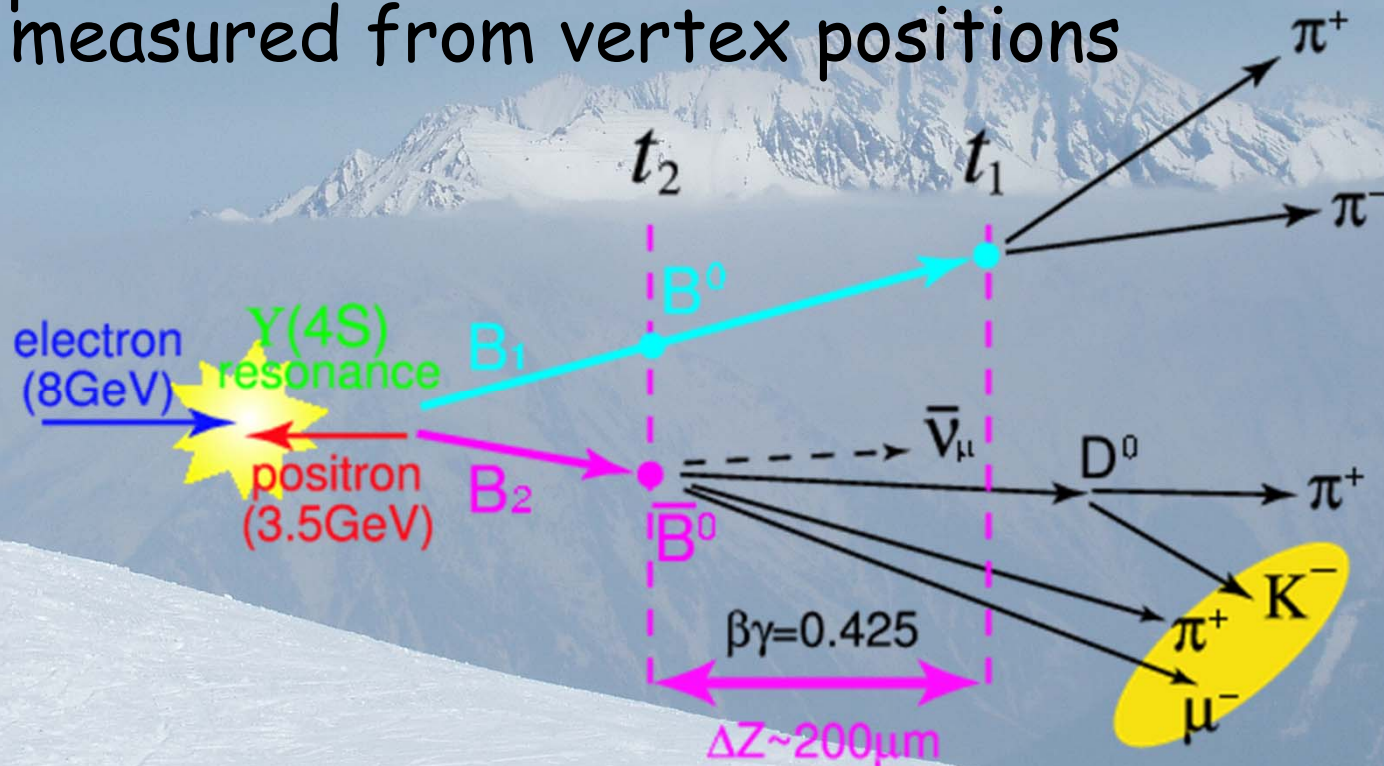
- Triangle is well measured
- $\varphi_1(\beta)$  mainly from  $B^0 \rightarrow J/\psi K_S$  "golden mode"
- Smaller and smaller room for the vertex position, but it is still in
- New decay modes are examining to find a New Physics





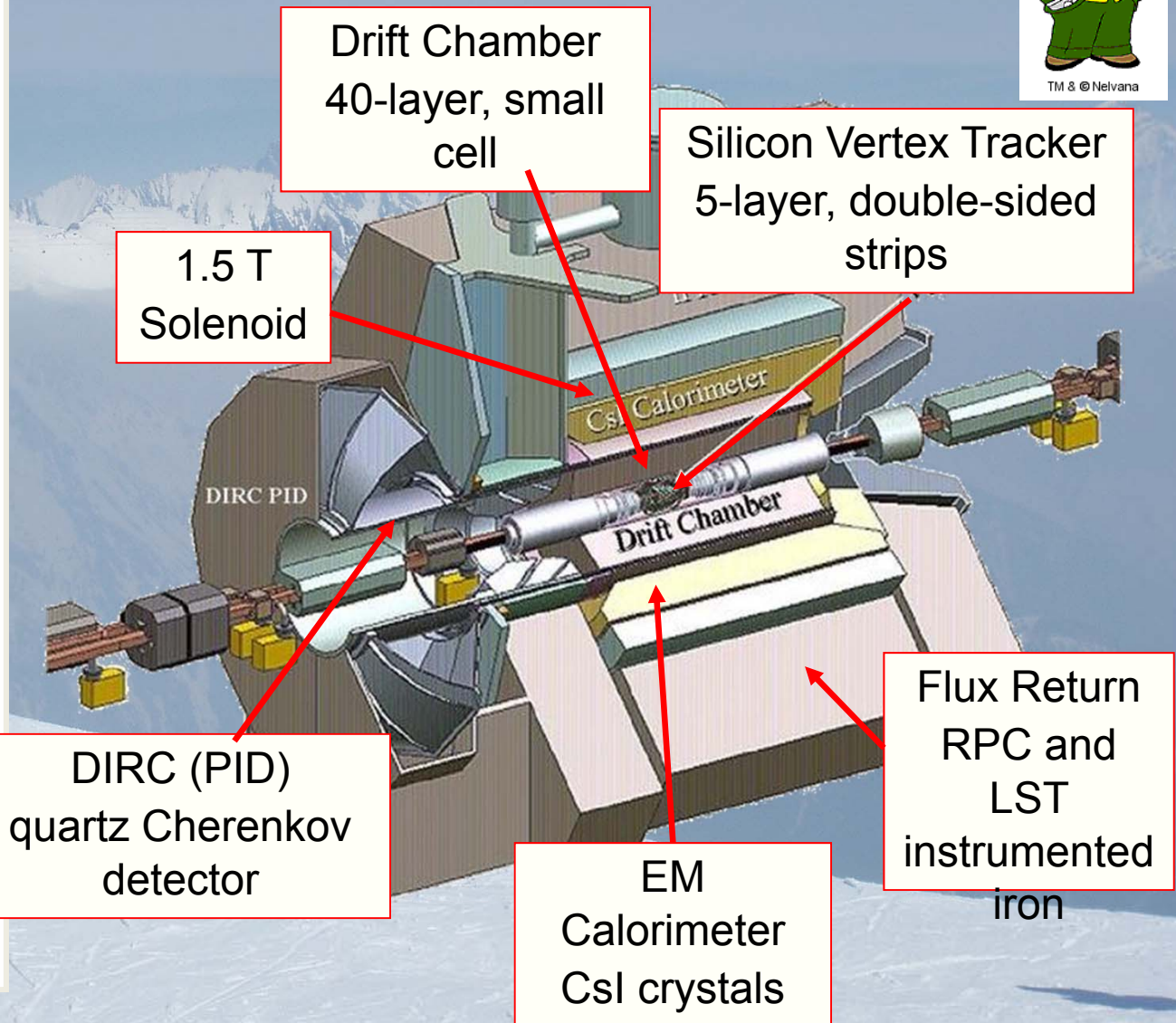
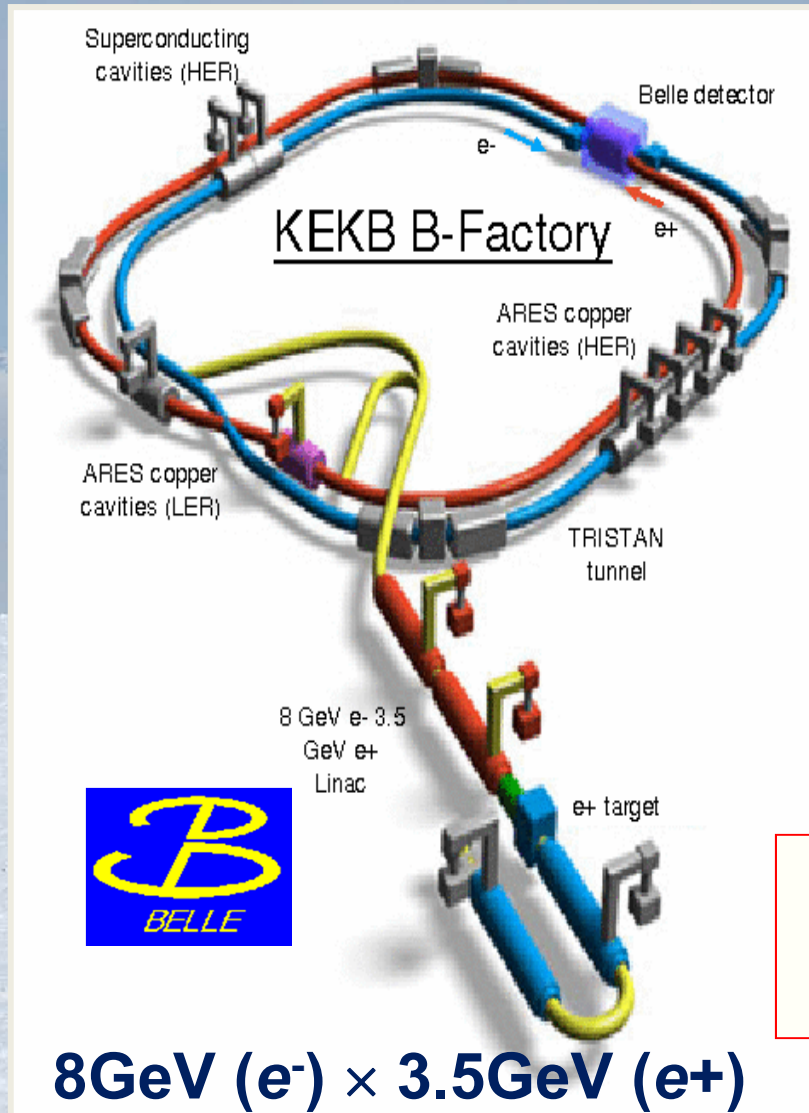
# TCPV measurement on $B$ -factory

$B$ s are produced in a boosted frame  
→  $\Delta t$  is measured from vertex positions



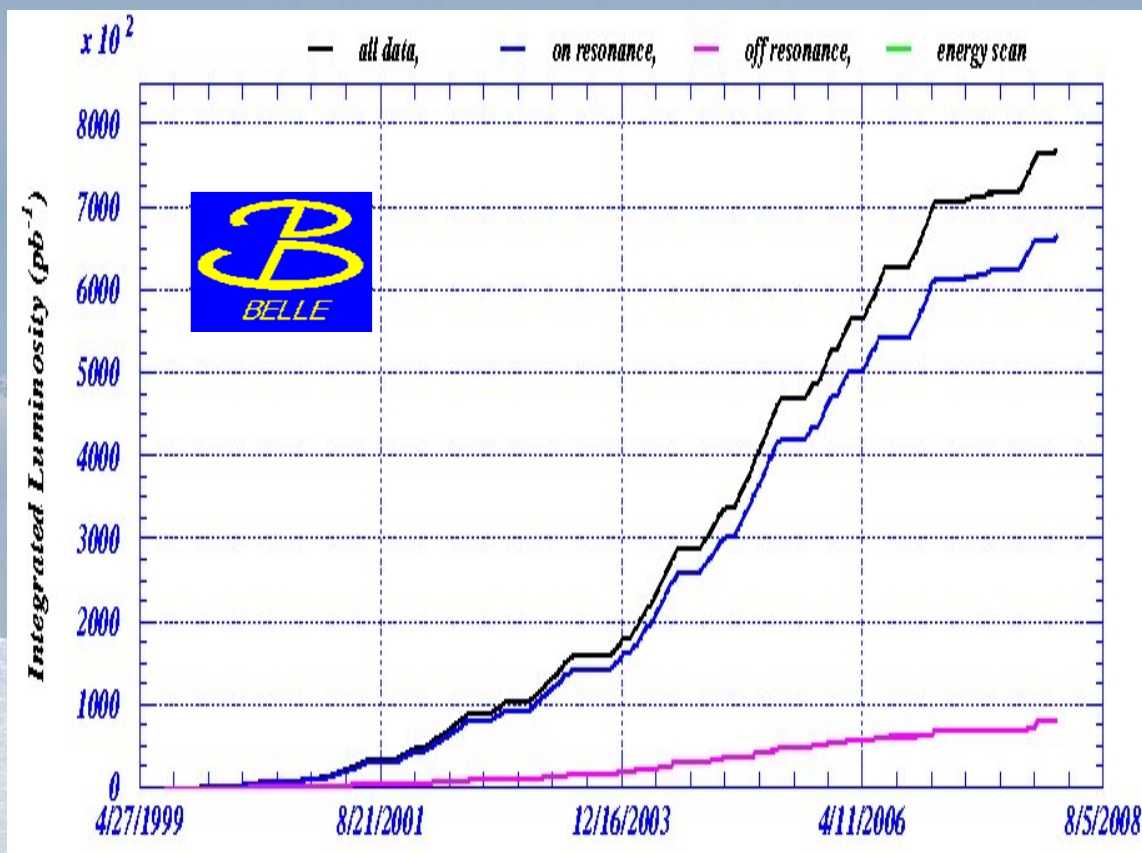
$B$ s are entangled  
→ flavor of  $B_1$  at time  $t_2$  is determined by  $B_2$  decay

# Belle & BaBar B-factories

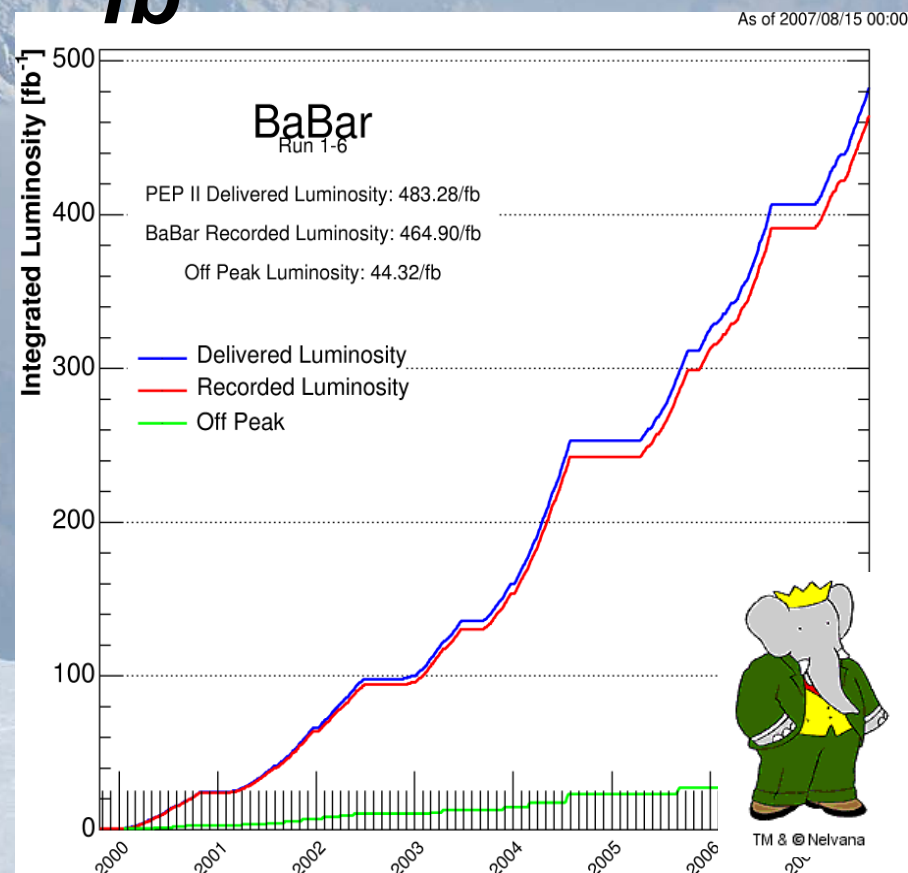




# Current luminosities



**BaBar collected 510  $\text{fb}^{-1}$**



$$L_{\text{peak}} = 1.71 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$$

$$\int L dt = 770 \text{ fb}^{-1}$$

# $B \rightarrow D^{(0,+)} D^0$



After evidence for DCPV in  $B \rightarrow D^- D^+$  recently shown by Belle *all*  $B \rightarrow DD$  decays has a special interest

*B.R. and charge asym* for  $B \rightarrow D^+ D^0$  were updated by Belle:

$$\text{B.R.} = (3.85 \pm 0.31 \pm 0.38) \cdot 10^{-4}$$

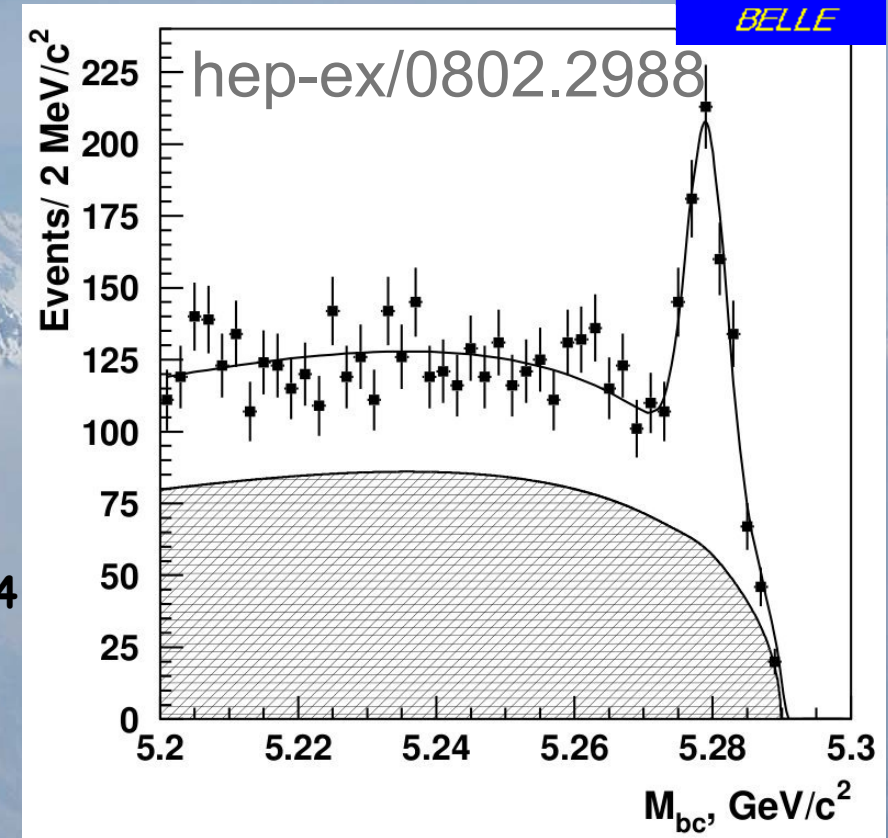
$$\text{BaBar'06: } (3.8 \pm 0.6 \pm 0.5) \cdot 10^{-4}$$

$$A = 0.00 \pm 0.08 \pm 0.02$$

$$\text{BaBar'06: } -0.13 \pm 0.14 \pm 0.02$$

Also an upper limit for  $B \rightarrow D^0 D^0$ :

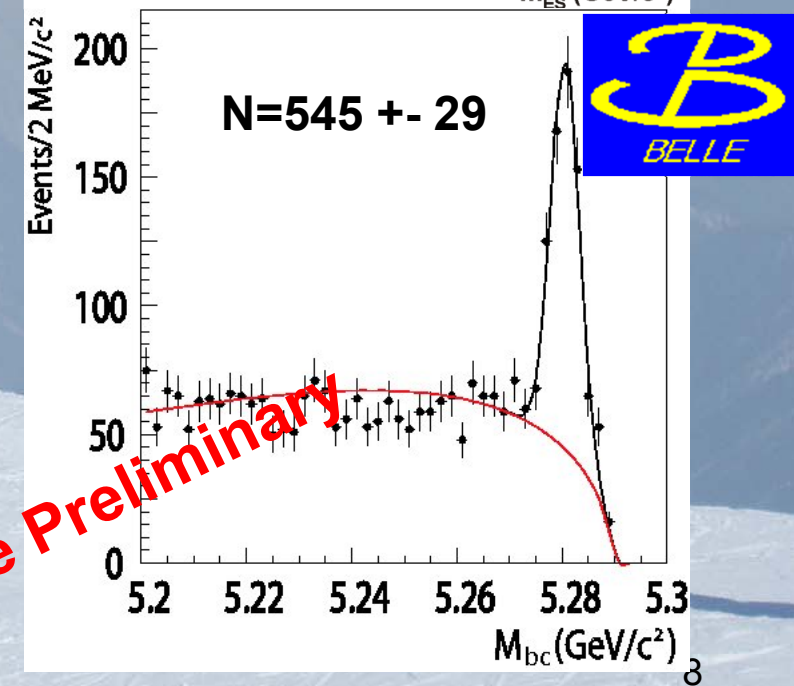
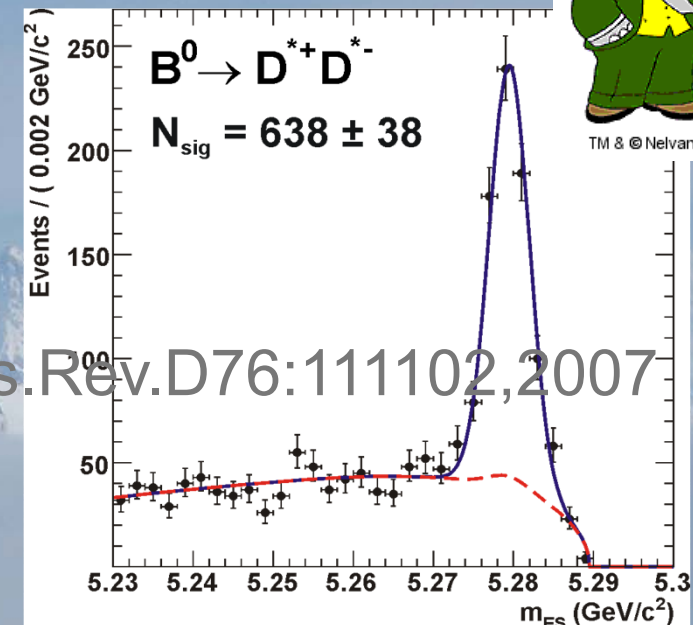
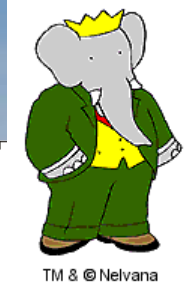
$$\text{B.R.} < 0.43 \cdot 10^{-4} @ 90\% \text{C.L.}$$





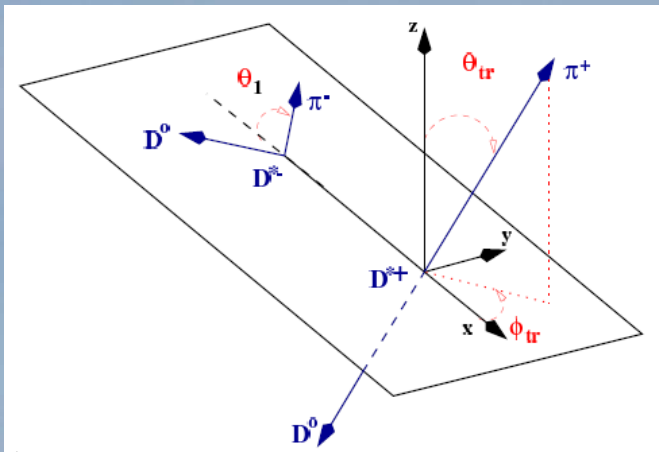
# TCPV in $B^0 \rightarrow D^{*+} D^{*-}$

- $B^0 \rightarrow D^{*+} D^{*-}$  is  $b \rightarrow ccd$  transition and so sensitive to  $\sin 2\varphi_1$  just like the "Golden"  $B^0 \rightarrow cc \bar{K}^0$  making it an important check
- Series of papers were published by Belle and BaBar
- Recently the results are updated with latest statistics
- Belle result is the first time presented





# Helicity of $B^0 \rightarrow D^{*+} D^{*-}$

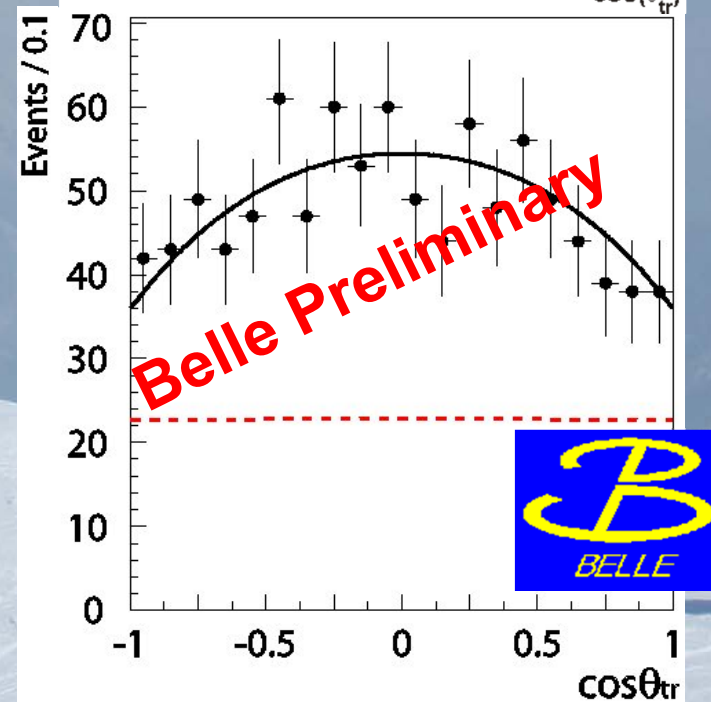
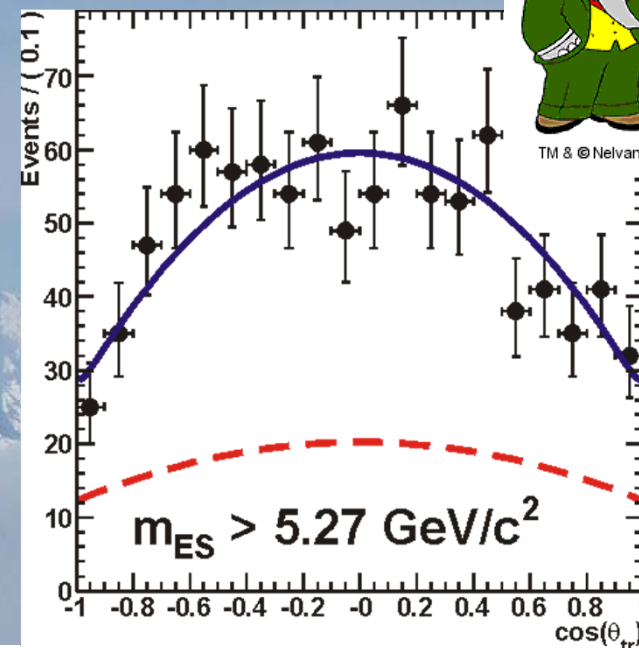


Since it is a decay of  $S \rightarrow VV$  CP-eigenstate depends on angular momentum of the  $VV$  system:

- Separating the CP-odd fraction,  $R_{\perp}$ , is done via a 1D angular analysis

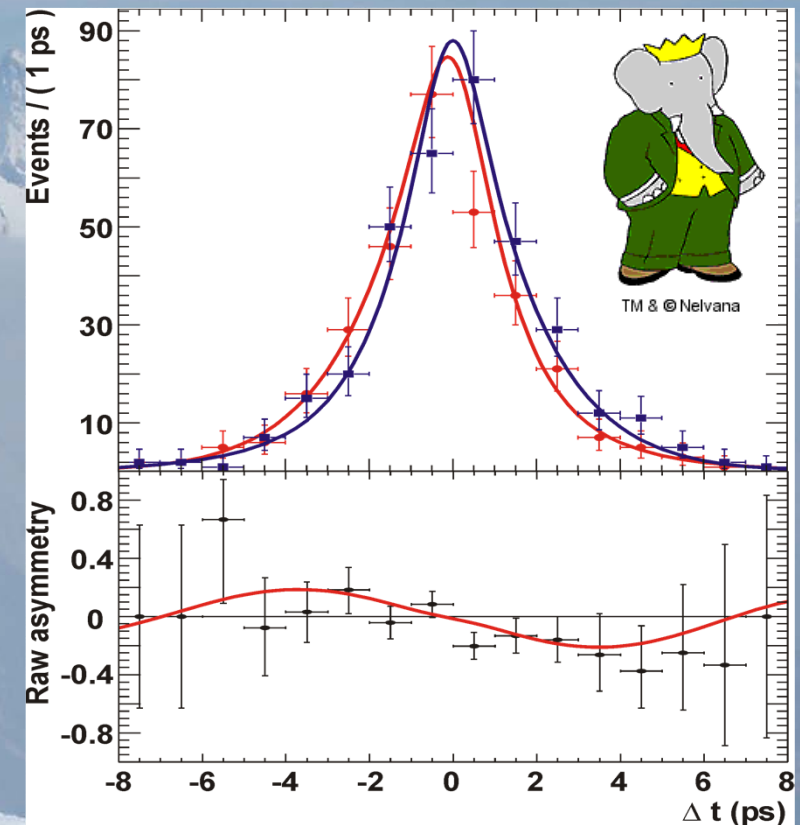
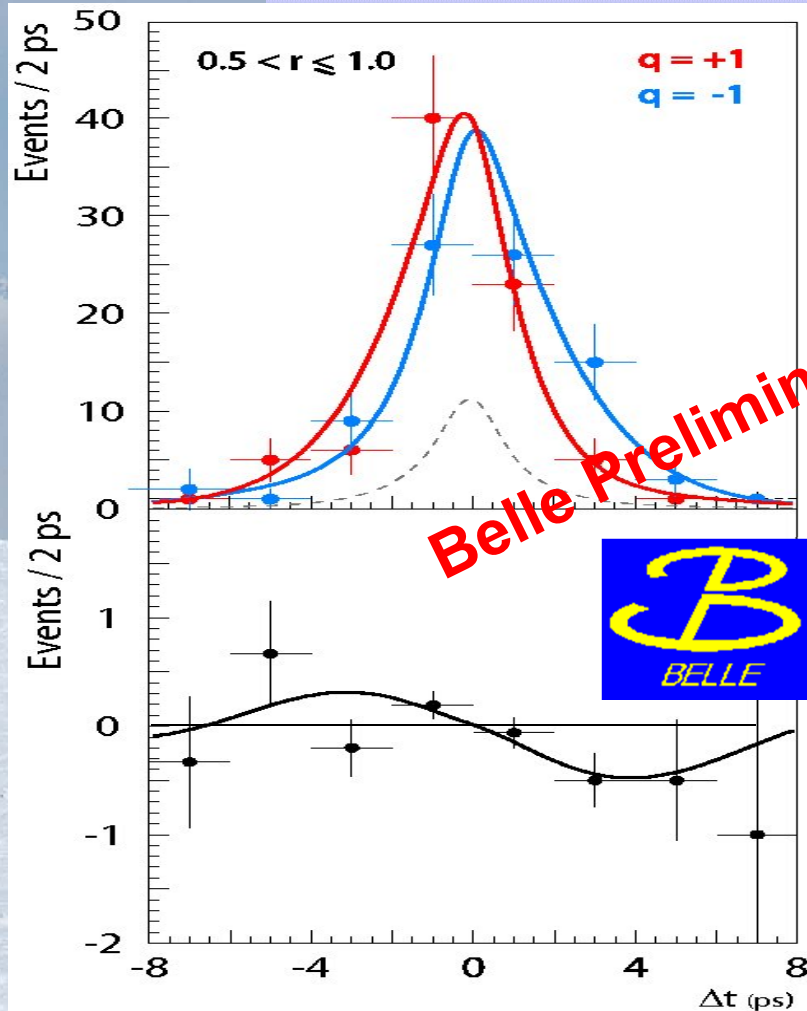
**BaBar:**  $R_{\perp} = 0.143 \pm 0.034 \pm 0.008$

**Belle:**  $R_{\perp} = 0.116 \pm 0.042 \pm 0.004$



# TCPV in $B^0 \rightarrow D^{*+} D^{*-}$

$$A_{CP}(t) \equiv \frac{\Gamma_{\bar{B}^0 \rightarrow f_{CP}}(t) - \Gamma_{B^0 \rightarrow f_{CP}}(t)}{\Gamma_{\bar{B}^0 \rightarrow f_{CP}}(t) + \Gamma_{B^0 \rightarrow f_{CP}}(t)} = \mathcal{S} \sin \Delta m_d t + \mathcal{A} \cos \Delta m_d t$$



$$\mathcal{S} = -\sin 2\phi_1$$

$$\mathcal{A} = -C$$

BaBar

$-0.66 \pm 0.19 \pm 0.04$   $+0.02 \pm 0.11 \pm 0.02$

Moriond EW, 3 Mar 2008

Tagir Aushev (EPFL, ITEP)

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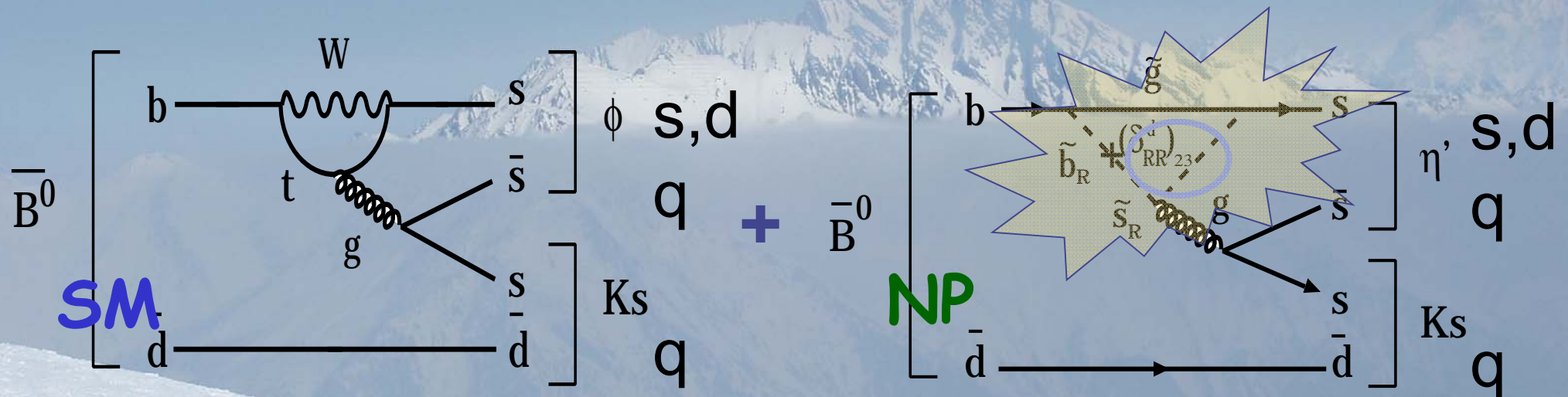
Belle

$-0.93 \pm 0.24 \pm 0.15$   $+0.16 \pm 0.13 \pm 0.02$



# Searches for a New Physics

- Penguin dominated B decays are sensitive to NP

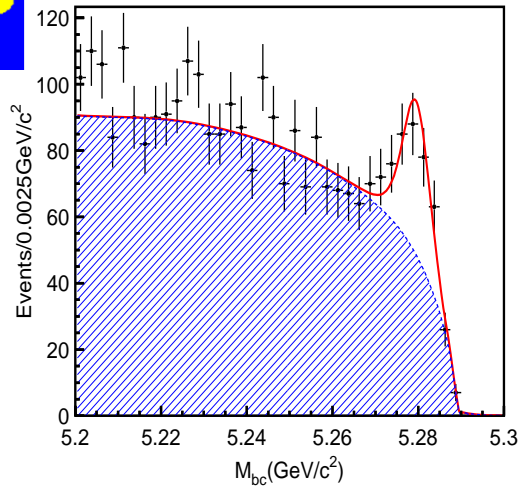


- New Physics may introduces **extra CP phase** in the decay
- Deviation of Time-dependent CP violation parameters from the SM expectation  $\rightarrow$  **Hint of New Physics**

# TCPV in $B^0 \rightarrow K_S \pi^0 \pi^0 : b \rightarrow s \bar{q} q$



$N_{\text{sig}} = 307 \pm 32$



$$M_{bc} = \sqrt{E_b^2 - p_b^2}$$

$$S = -\sin 2\phi_1$$

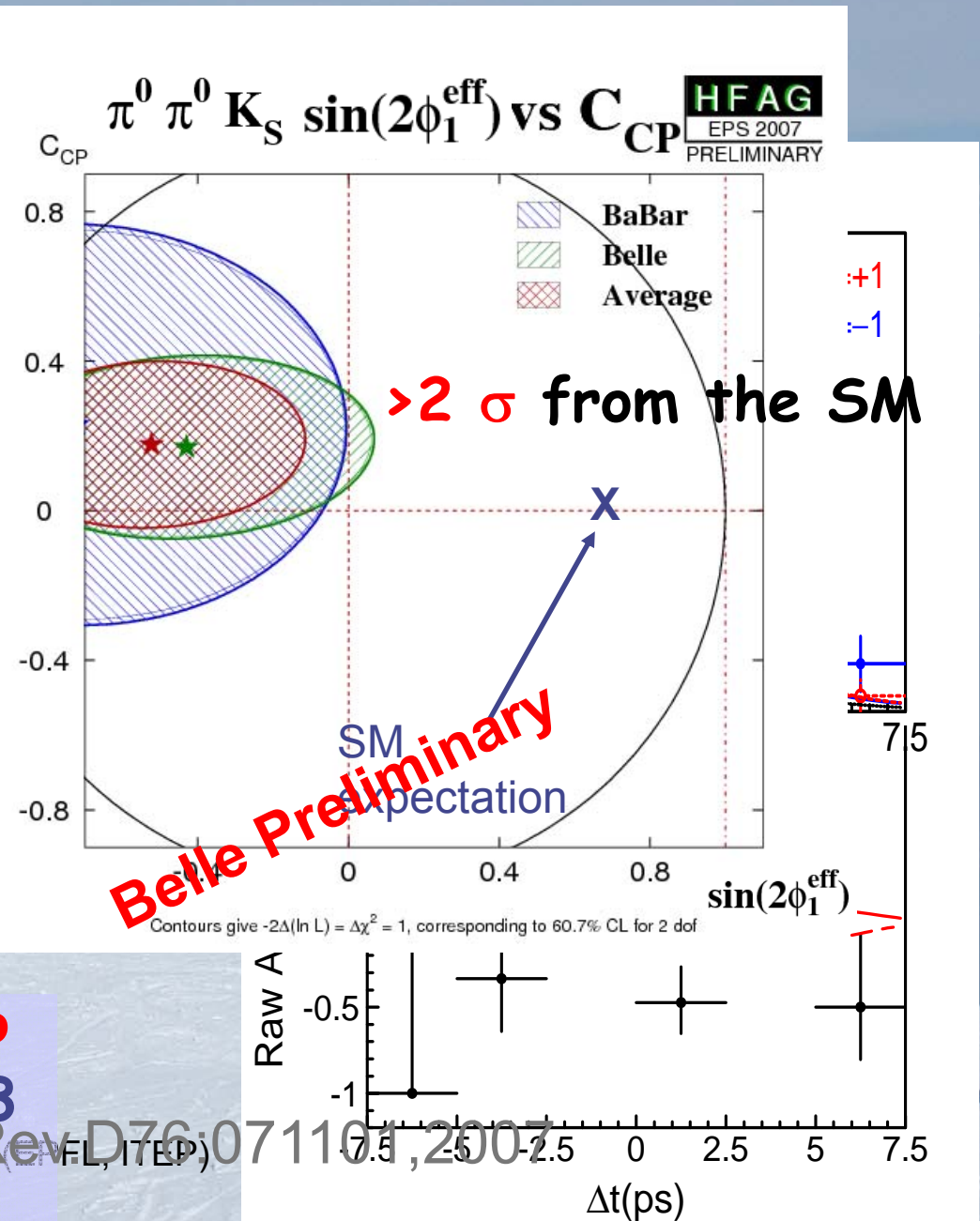
Belle	$+0.43 \pm 0.49 \pm 0.09$
BaBar	$+0.72 \pm 0.71 \pm 0.08$
Average	$+0.52 \pm 0.41$

$$A = -C$$

Belle	$-0.17 \pm 0.24 \pm 0.06$
BaBar	$-0.23 \pm 0.52 \pm 0.13$
Average	$-0.18 \pm 0.22$

Moriond EW, 3 Mar 2008

Tagir A. Aghajani (CERN, ITEP)

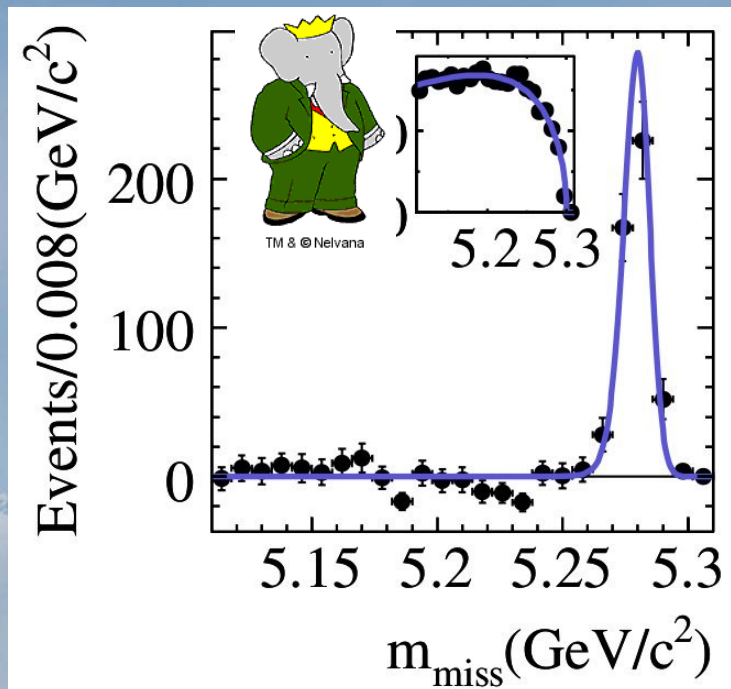




# TCPV in $B^0 \rightarrow K_S \pi^0$

$$N_{\text{sig}} = 459 \pm 29$$

$$\text{B.R.} = (10.3 \pm 0.7 \pm 0.6) \cdot 10^{-6}$$



$$S = \sin 2\phi_1$$

$$\text{Belle} \quad +0.33 \pm 0.35 \pm 0.08$$

$$\text{BaBar} \quad +0.40 \pm 0.23 \pm 0.03$$

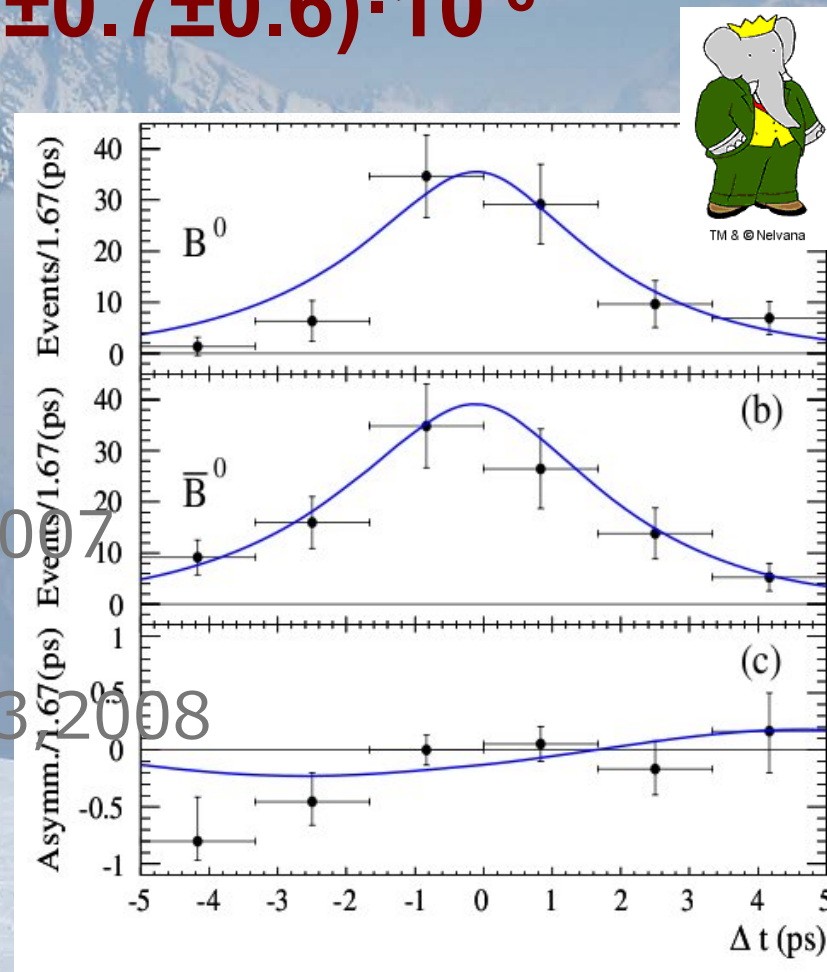
$$A = -C$$

$$\text{Belle} \quad -0.05 \pm 0.14 \pm 0.05$$

$$\text{BaBar} \quad -0.24 \pm 0.15 \pm 0.03$$

Moriond EW, 3 Mar 2008

Tagir Aushev (EPFL, ITEP)

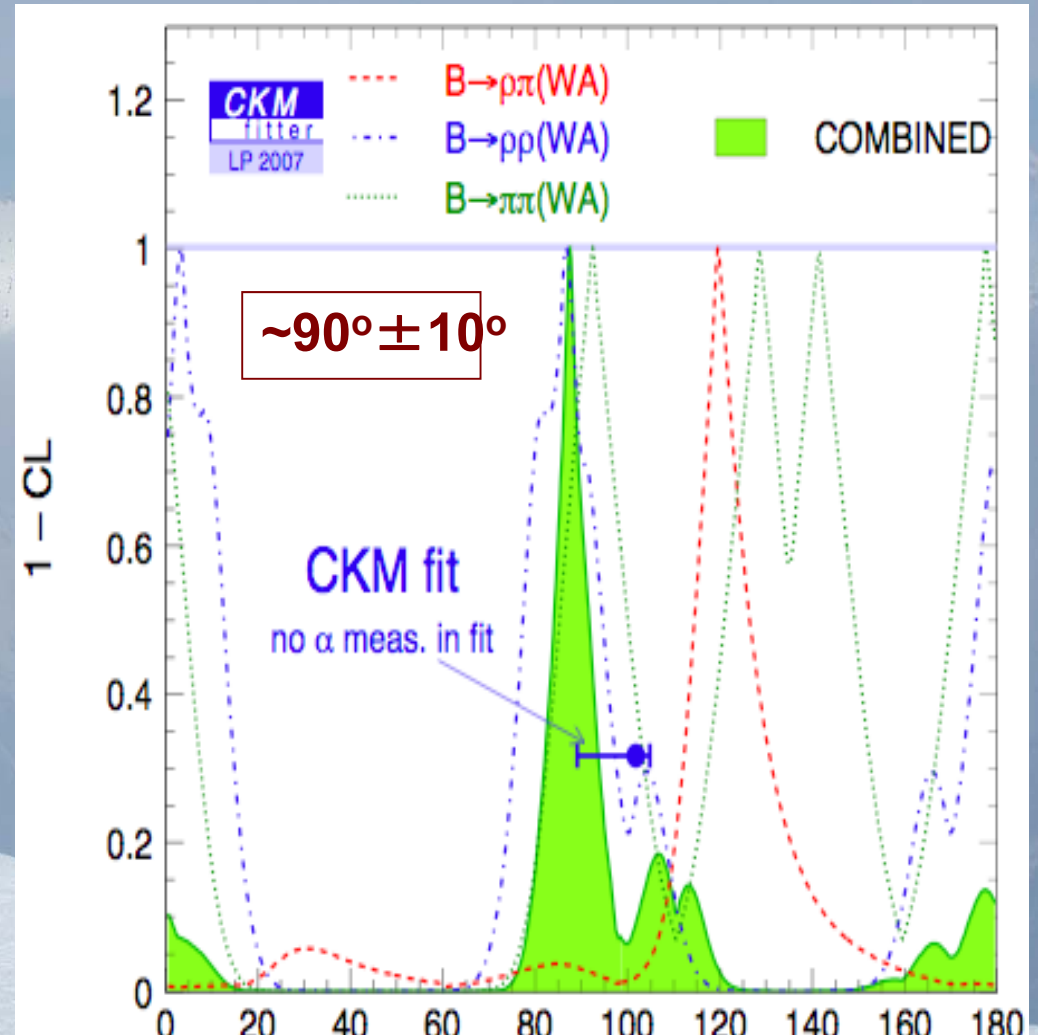


# Measurements of $\varphi_2$

$\varphi_2(\alpha)$  was measured in  $\pi\pi$ ,  $\rho\pi$  and  $\rho\rho$  systems

The same matrix elements are also involved to the B decays to axial vectors  $a_1$ ,  $b_1$  ...

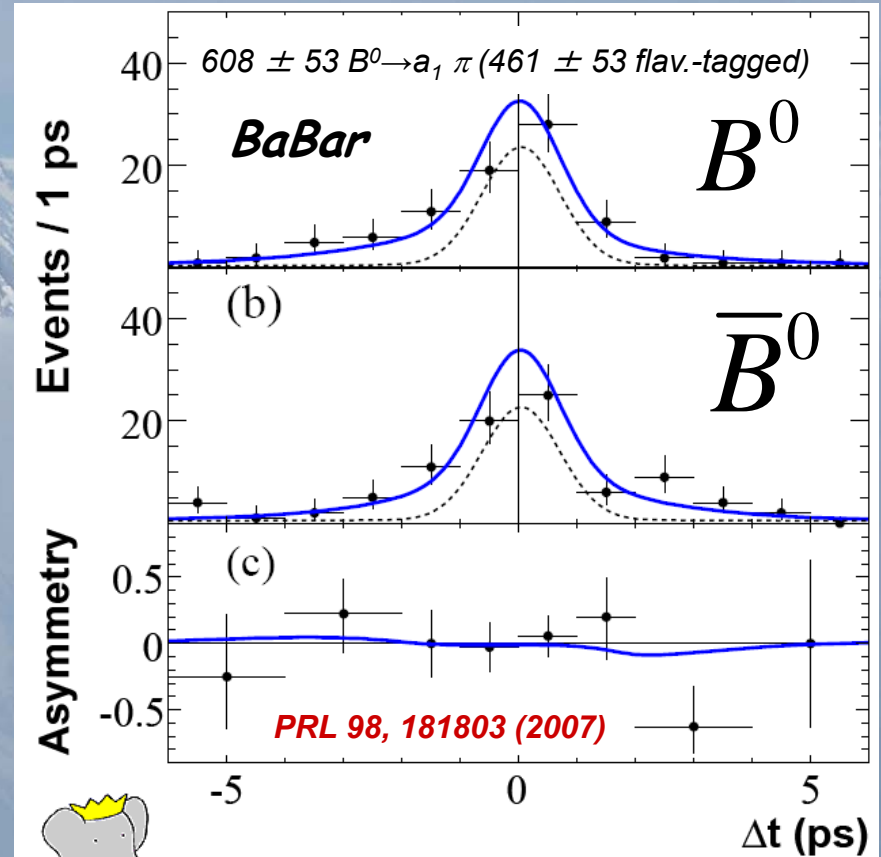
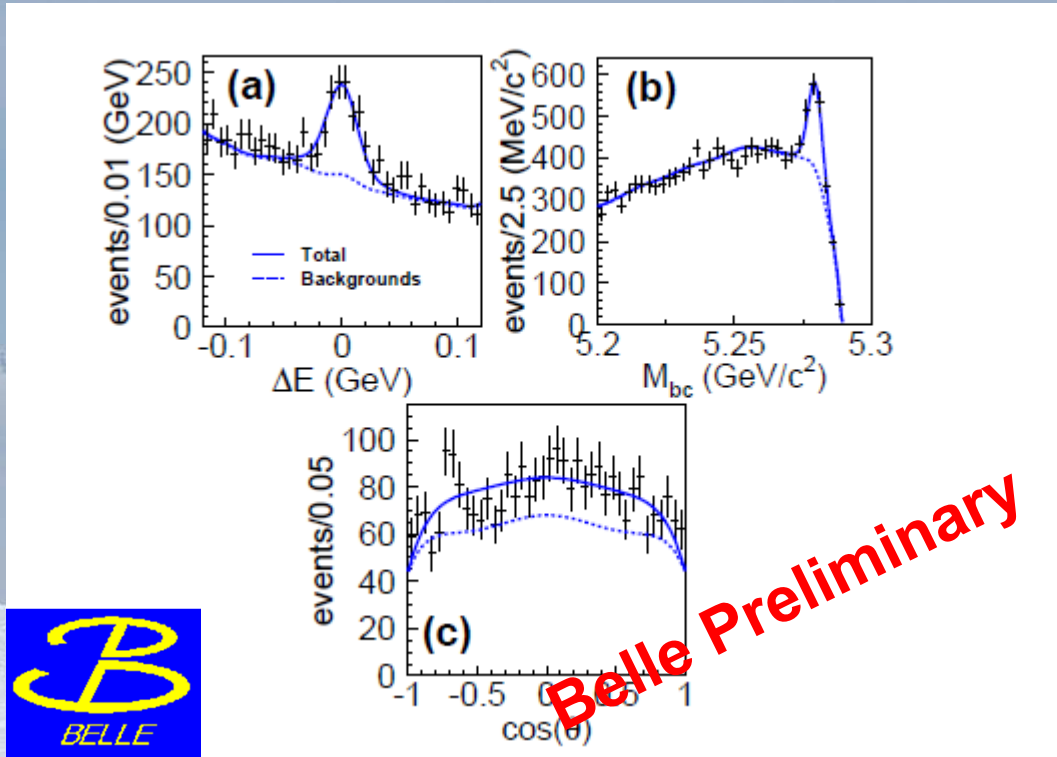
Some of them can be used only with much larger statistics





# Measurement $B \rightarrow a_1 \pi$

First time-dep CP asymmetry in  $B \rightarrow a_1 \pi$



$$B.R.(B^0 \rightarrow a_1^\pm \pi^\mp) B.R.(a_1 \rightarrow \pi^\pm \pi^\pm \pi^\mp) = (14.9 \pm 1.6 \pm 2.3) \times 10^{-6}$$

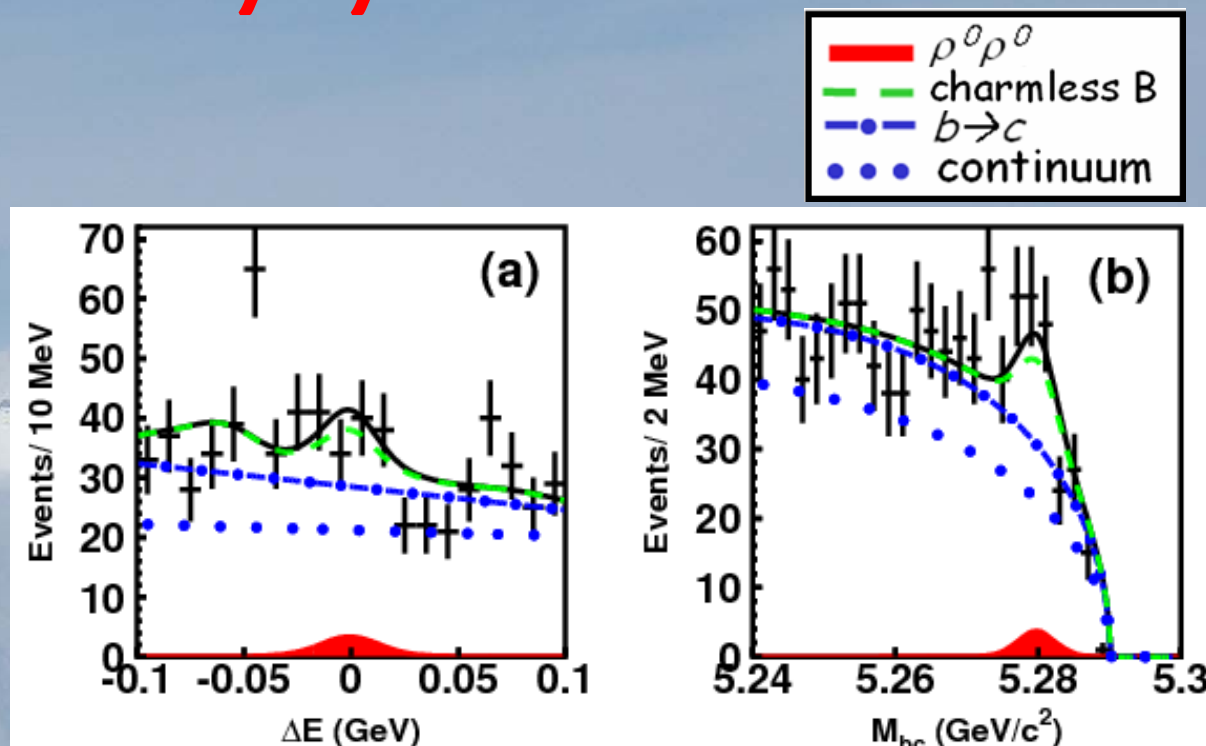


$$\alpha_{\text{eff}} = (79 \pm 7)^\circ, \alpha = ?$$

# $B \rightarrow \rho^0 \rho^0$

Latest result from Belle:

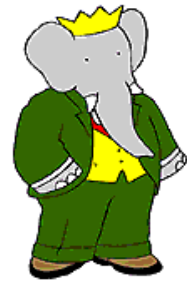
$$\mathcal{B}(B^0 \rightarrow \rho^0 \rho^0) < 1.0 \times 10^{-6}$$



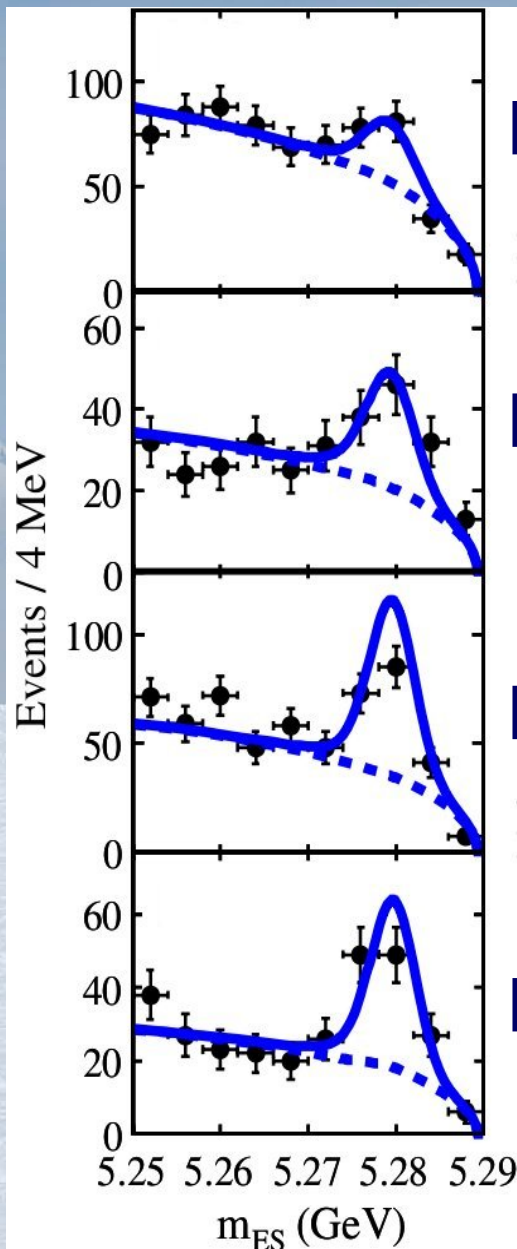
Mode	Yield	Eff.(%)	$\mathcal{S}$	$\mathcal{B}(\times 10^{-6})$	UL( $\times 10^{-6}$ )
$\rho^0 \rho^0$	$24.5^{+23.6+9.7}_{-22.1-9.9}$	9.16	1.0	$0.4 \pm 0.4 \pm 0.2$	$< 1.0$
$\rho^0 \pi \pi$	$112.5^{+67.4+51.5}_{-65.6-53.7}$	2.90	1.3	$5.9^{+3.5+2.7}_{-3.4-2.8}$	$< 11.9$
$4\pi$	$161.2^{+61.2+26.0}_{-59.4-28.5}$	1.98	2.5	$12.4^{+4.7+2.0}_{-4.6-2.2}$	$< 19.0$
$\rho^0 f_0$	$-11.8^{+14.5+4.9}_{-12.9-3.6}$	5.10	0.0	0.0	$< 0.6$
$f_0 f_0$	$-7.7^{+4.7+3.0}_{-3.5-2.9}$	2.75	0.0	0.0	$< 0.4$
$f_0 \pi \pi$	$6.3^{+37.0+18.0}_{-34.7-18.1}$	1.55	0.0	$0.6^{+3.6}_{-3.4} \pm 1.8$	$< 7.3$



# B decays to light mesons



TM & © Nelvana



$$B \rightarrow b_1^0 \pi^+: (6.7 \pm 1.7 \pm 1.0) \cdot 10^{-6}$$

$$B \rightarrow a_1^0 \pi^+: (20.4 \pm 4.7 \pm 3.4) \cdot 10^{-6}$$

$$B \rightarrow b_1^0 K^+: (9.1 \pm 1.7 \pm 1.0) \cdot 10^{-6}$$

$$B \rightarrow a_1^+ K^0: (34.9 \pm 5.0 \pm 4.4) \cdot 10^{-6}$$

$$B \rightarrow b_1^- \pi^+: (10.9 \pm 1.2 \pm 0.9) \cdot 10^{-6}$$

$$B \rightarrow a_1^- \pi^0: (13.2 \pm 2.7 \pm 2.1) \cdot 10^{-6}$$

$$B \rightarrow b_1^- K^+: (7.4 \pm 1.0 \pm 1.0) \cdot 10^{-6}$$

$$B \rightarrow a_1^- K^+: (16.3 \pm 2.9 \pm 2.3) \cdot 10^{-6}$$

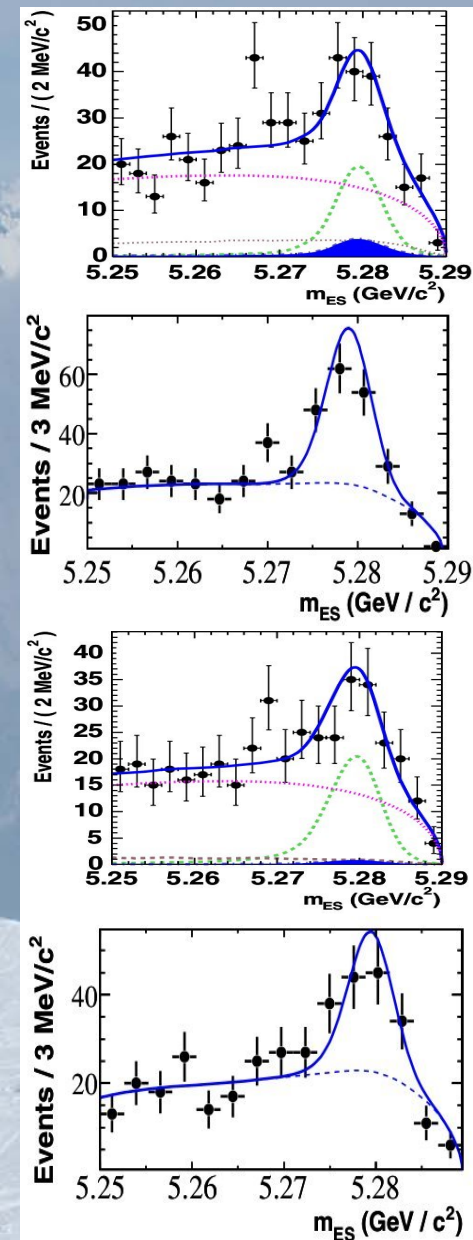
No charge asym's found

Mori and FW, 3 Mar 2008

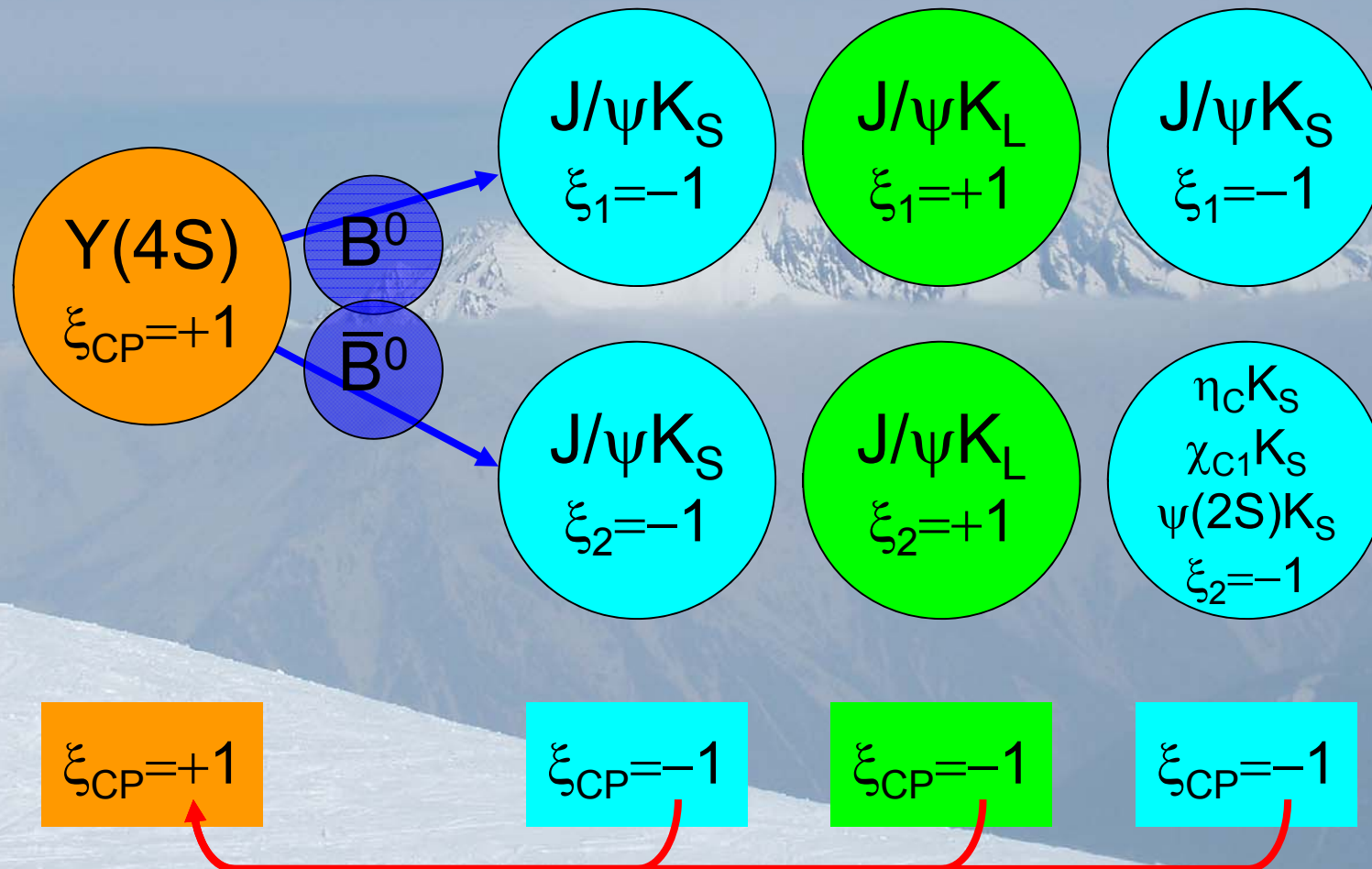
PRL 99:261801, 2007

Tagir A. Aishev (EPFL, IHEP), 2008

PRL 99:241803, 2007



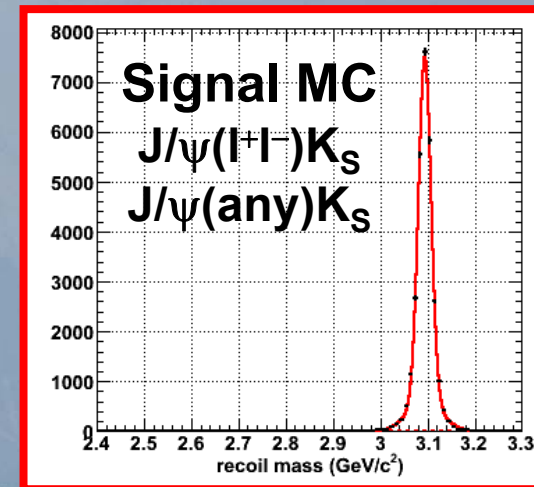
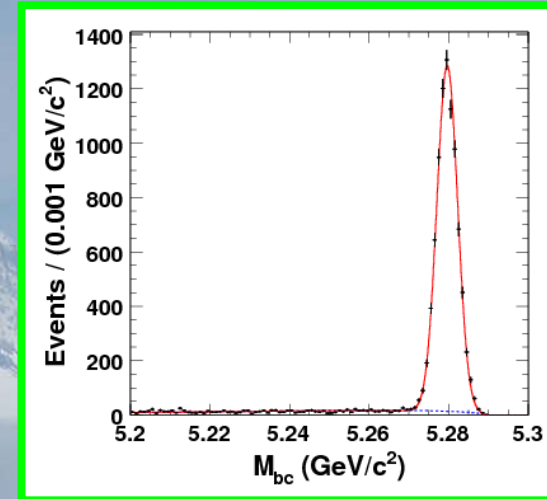
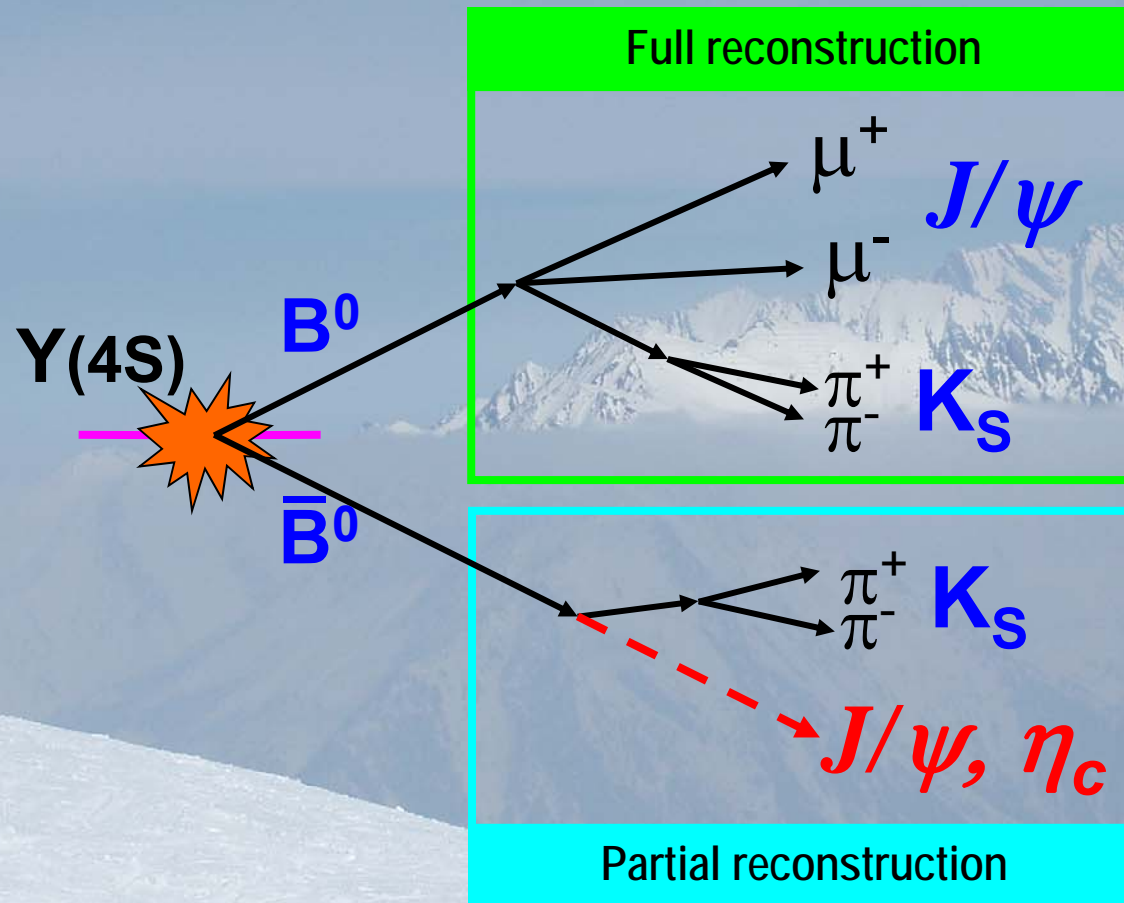
# *CP* Violating Decays of the $Y(4S)$



***CP* violation !!**



# Partial reconstruction



About 40 times higher eff. than full reconstruction method

1.1(0.6) inclusive- $J/\psi(\eta_c)$  events in 535 million  $Y(4S)$  decays

# Results with 535M $\Upsilon(4S)$ decays

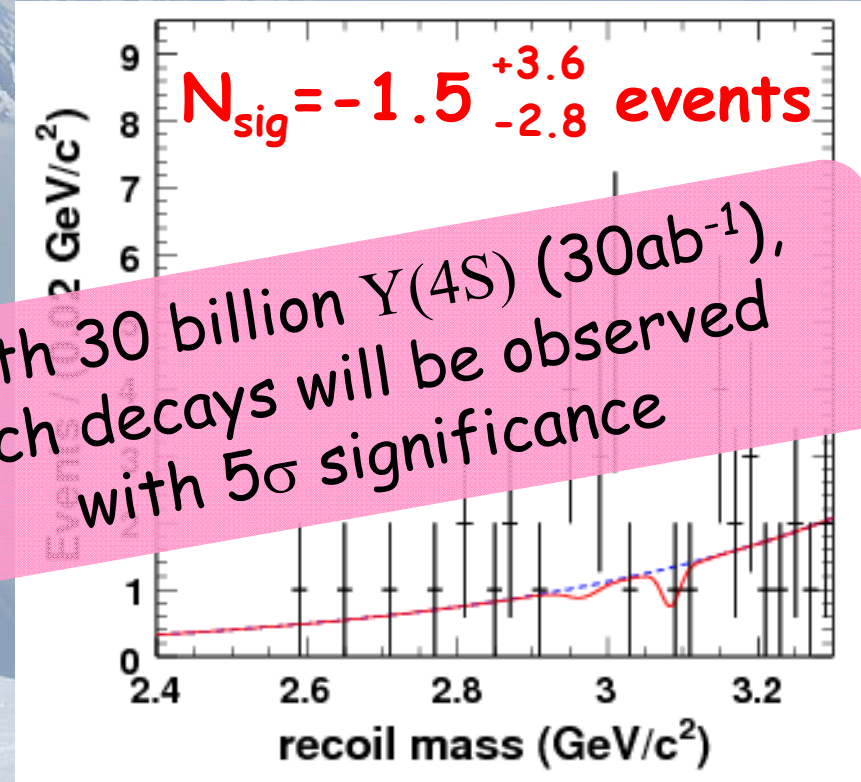
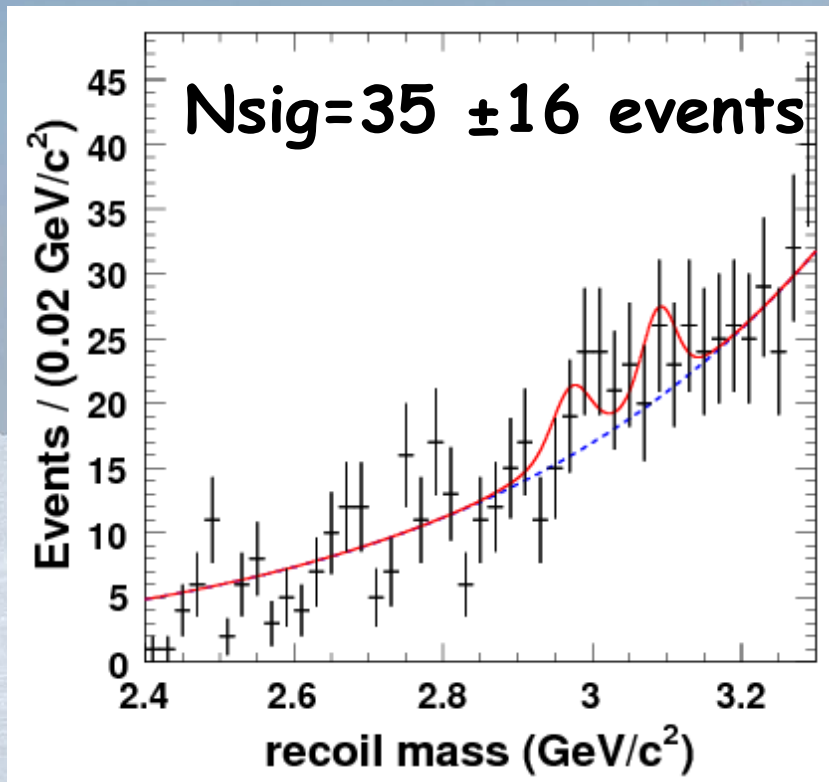
Control sample

$$B^0 \rightarrow D^{(*)-} \pi^+ \text{ and } D^{*-} \rho^+$$

$$B^0 \rightarrow \eta_c K_S \text{ and } J/\psi K_S$$

$$B^0 \rightarrow J/\psi K_S$$

$$B^0 \rightarrow J/\psi(\eta_c) K_S$$



With 30 billion  $\Upsilon(4S)$  ( $30\text{ab}^{-1}$ ),  
such decays will be observed  
with  $5\sigma$  significance

$$\text{Br}(\Upsilon(4S) \rightarrow B^0 B^0 \rightarrow J/\psi K_S + J/\psi(\eta_c) K_S) < 4 \times 10^{-7} \text{ (90\% C.L.)}$$



# Summary

- CP violations was measured in various B decays
  - Both mixing-induced & direct CPV observed
- Excellent agreement with Standard Model
  - Small room for New Physics remains in flavour sector
- Next order of the statistics is needed to give an answer for the New Physics existence