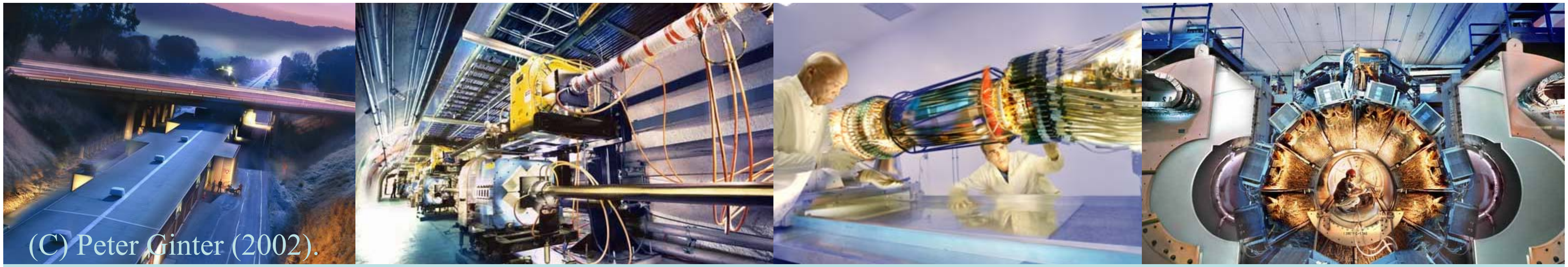


Measuring the Unitarity Triangle Angle α with BaBar

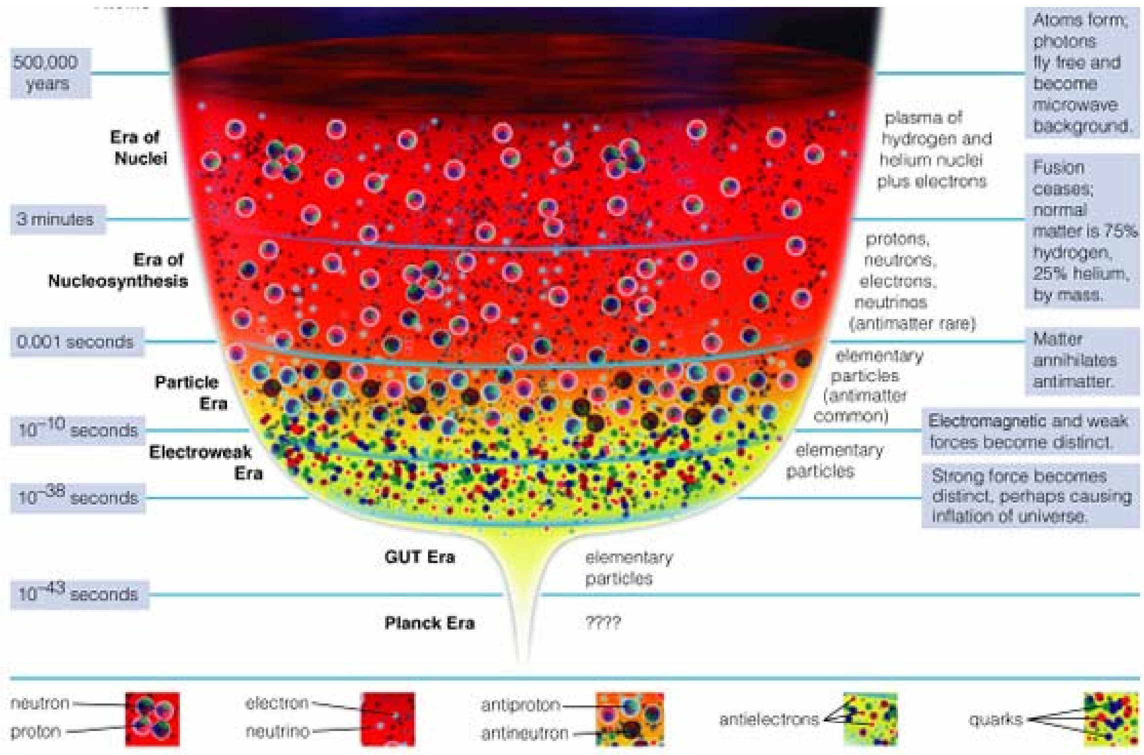
Adrian Bevan

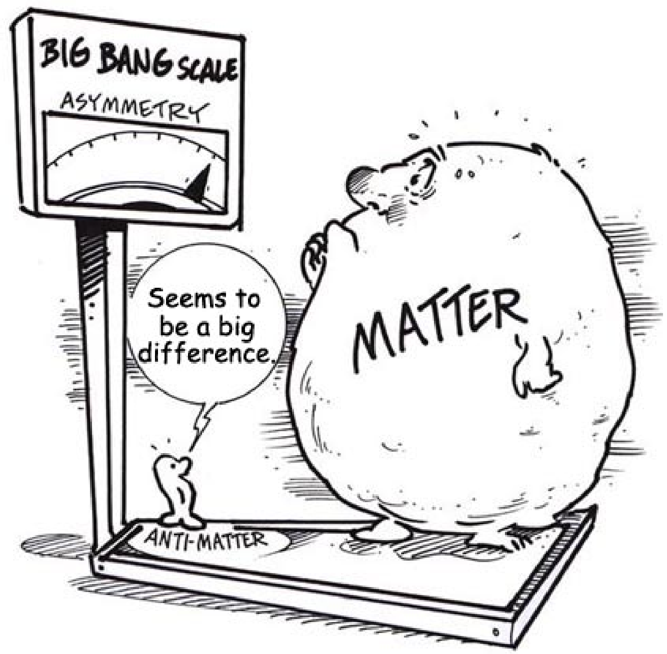
KEK, 15th September 2006

Overview

- Motivation
- PEP-II and the BaBar Detector
- CKM Matrix.
- Measuring α through understanding penguins.
- Ingredients of a time dependent analysis
- Results
  - $B \to \pi\pi$, $\rho\rho$, $\rho\pi$. New For Summer '06
  - combination of results
  - Prospects from $u\bar{u}d$ transitions with a_1 mesons.
- Summary

Motivation

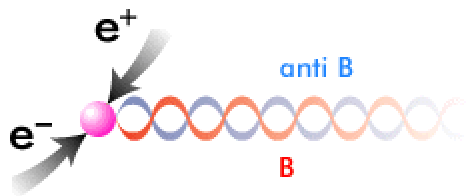




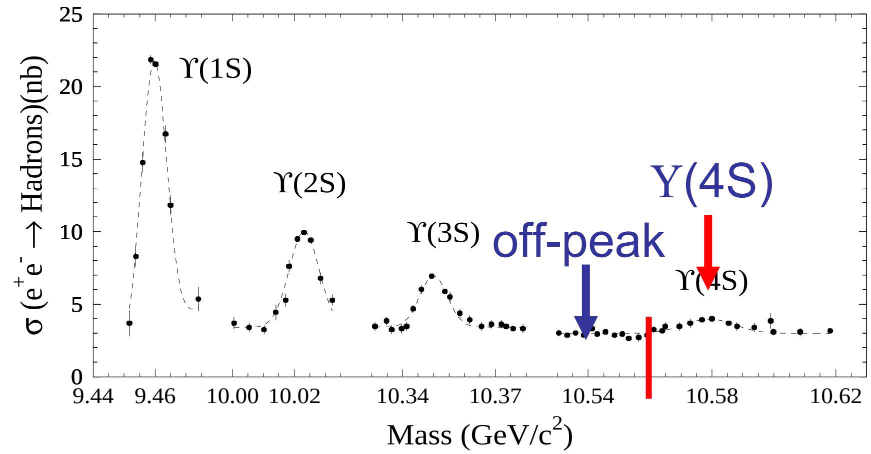
“Why is our universe matter dominated?”

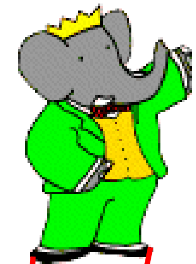
PEP-II

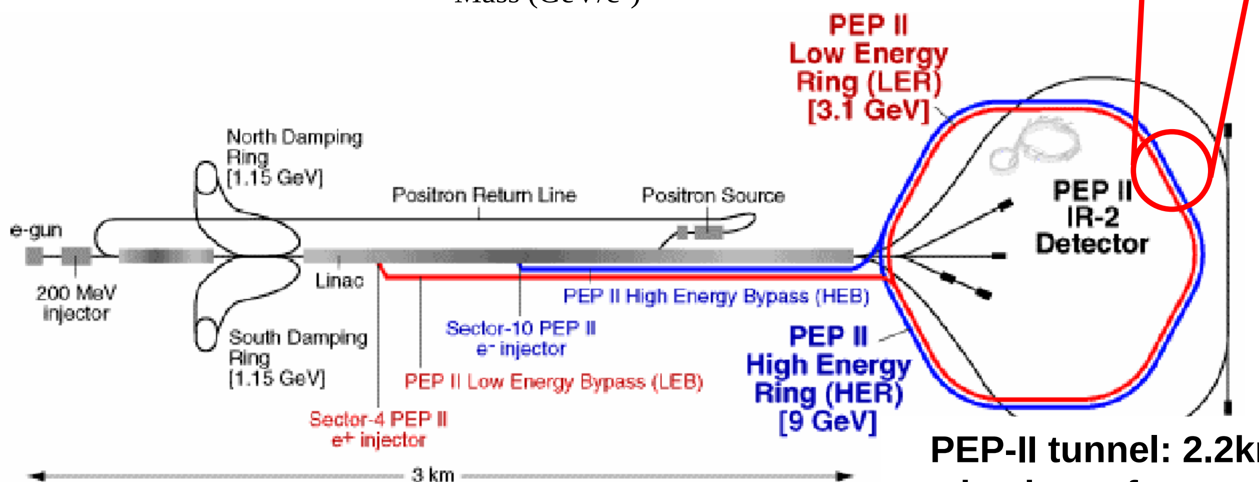
- Asymmetric energy e^+e^- collider
- Study decay of B meson pairs.



- Record data at the Υ(4S) ~90% of the time.
- Run below the $b\bar{b}$ production threshold for background studies.



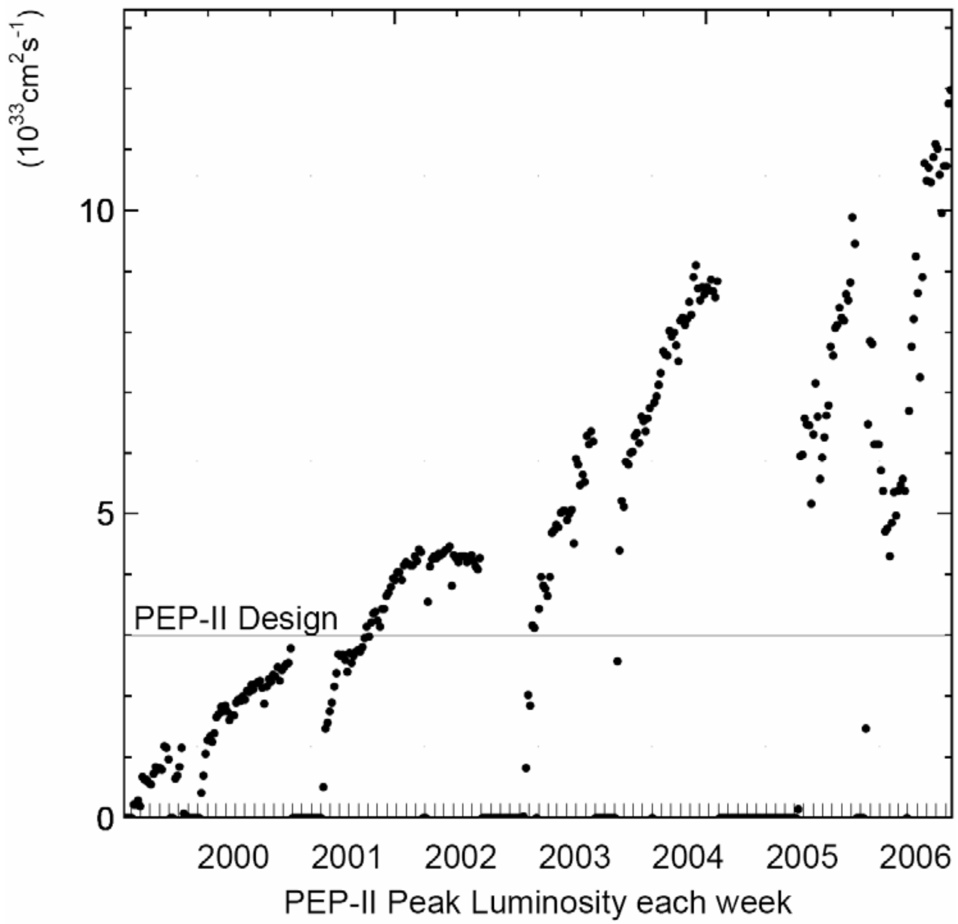




PEP-II tunnel: 2.2km in circumference

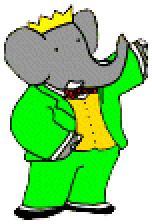
$$9\ \text{GeV}\ e^- \times\ 3.1\ \text{GeV}\ e^+$$
$$\Upsilon(4S)\ \text{boost: } \beta\gamma = 0.55$$
$$\text{Head-on collisions}$$

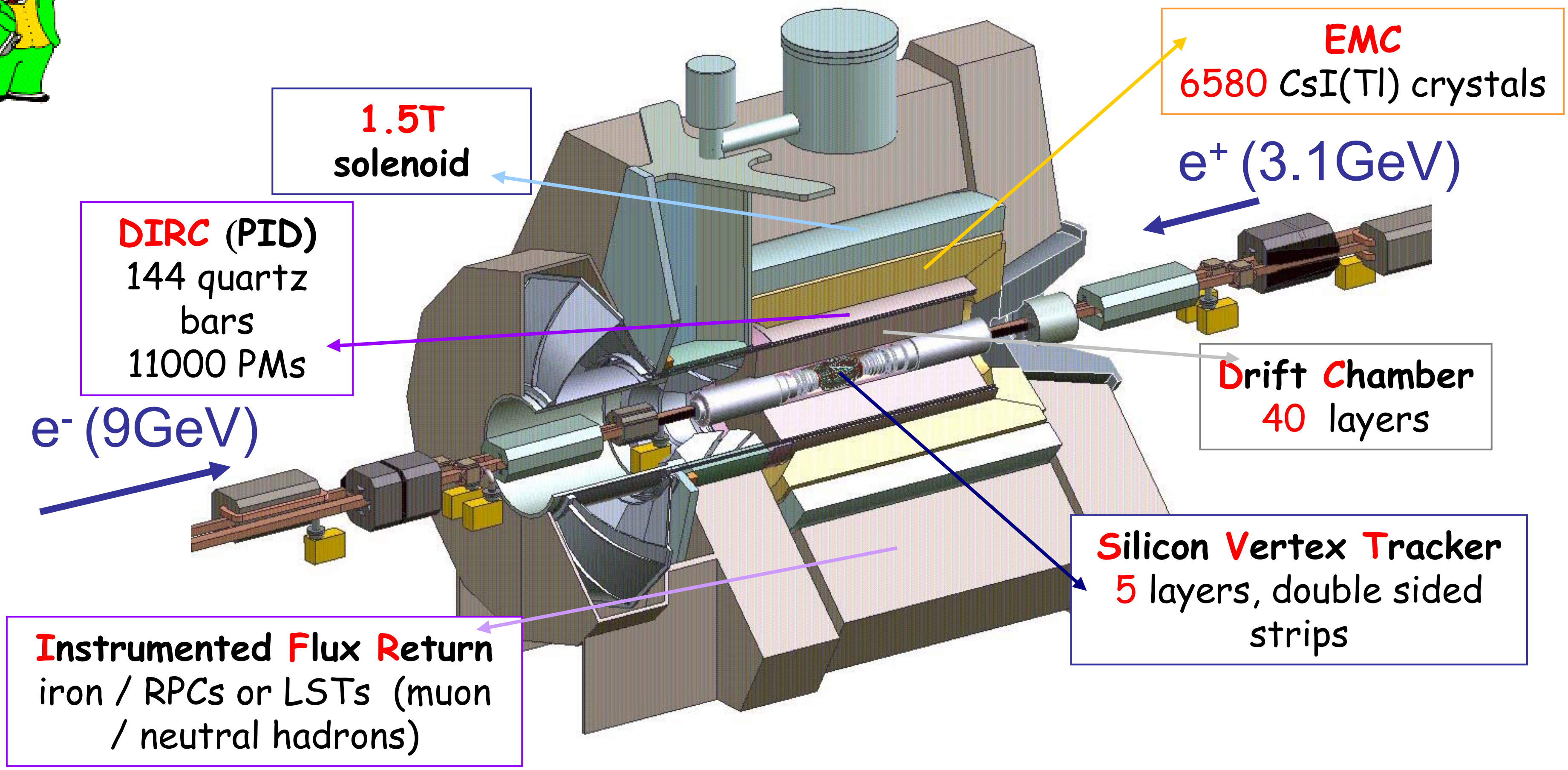
PEP-II performance



- The accelerator is performing well:
  - Maximum Luminosity of 1.207 10^{34} cm^2s^{-1}
  - I_{HER}= 1900 mA
  - I_{LER} = 2900 mA
- Reached over 4 times the design luminosity.
- Current PEP-II status:
  - Scheduled summer shutdown. Data taking will resume in January '07.

BaBar detector

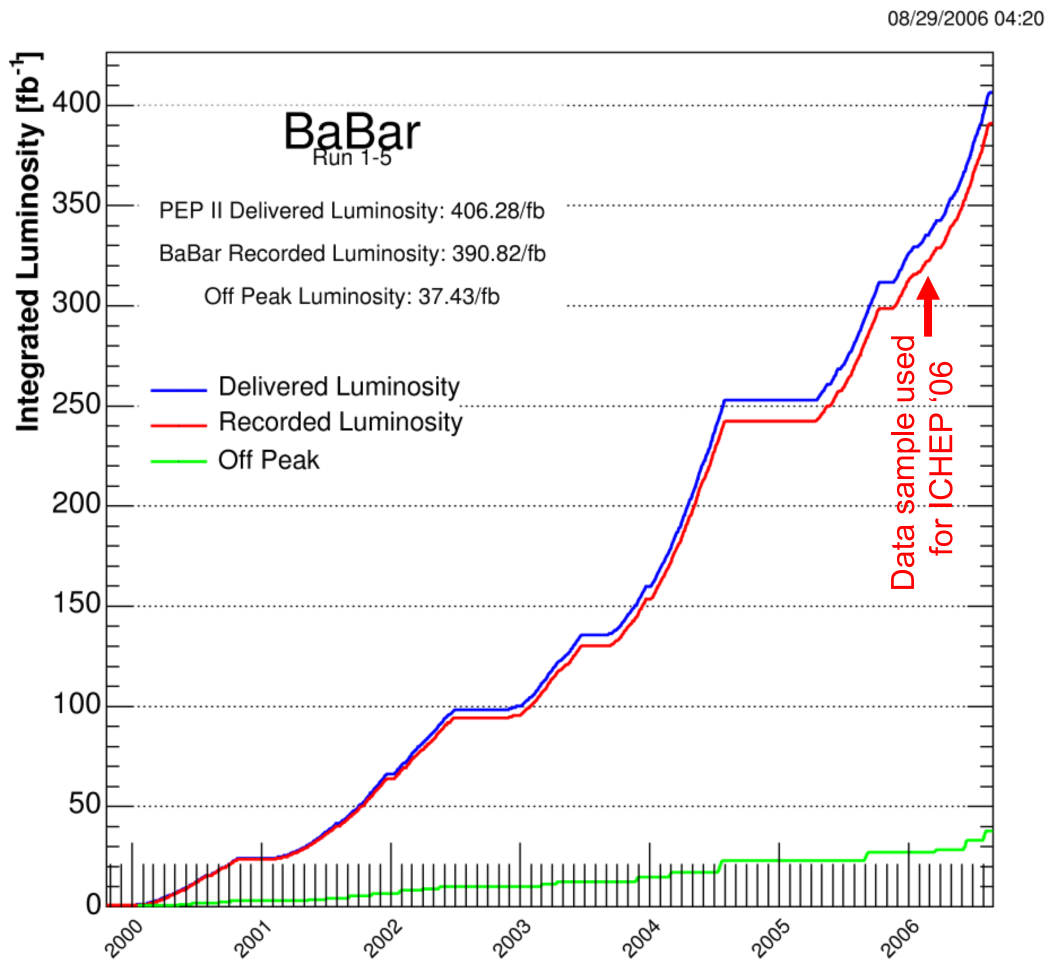




- Upgrading muon system to replace all remaining RPCs with LSTs for run 6.

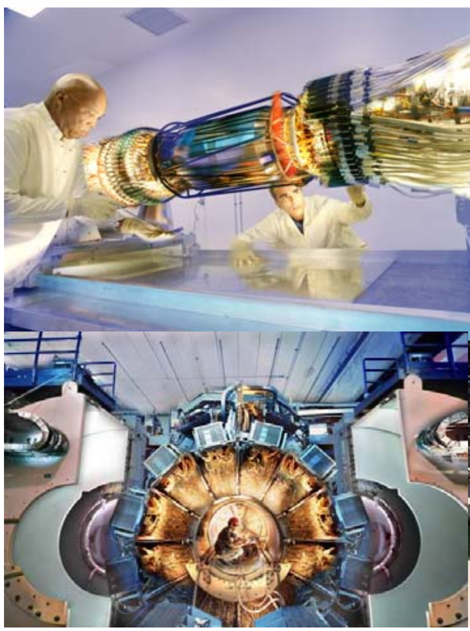
BaBar integrated luminosity

- Recorded 390/fb (~410 million B pairs).
- Expect ~1000/fb by summer 2008.
- DOE funding is approved until summer 2008.
- 114 contributed papers to ICHEP '06.
- 242 papers submitted to either PRL or PRD as of 12th September '06.



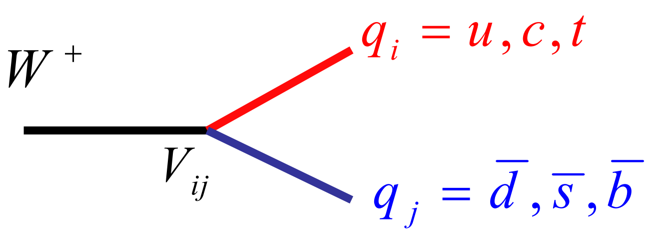
The BaBar Collaboration

- 80 institutes
- 11 countries
- 623 Physicists

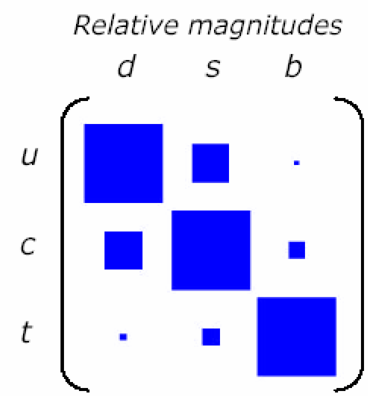


CP violation in meson decay

- Manifest in couplings between quark generations:



$V =$



- The couplings V_{ij} form the 3×3 CKM Matrix.

Wolfenstein Parameterisation:

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

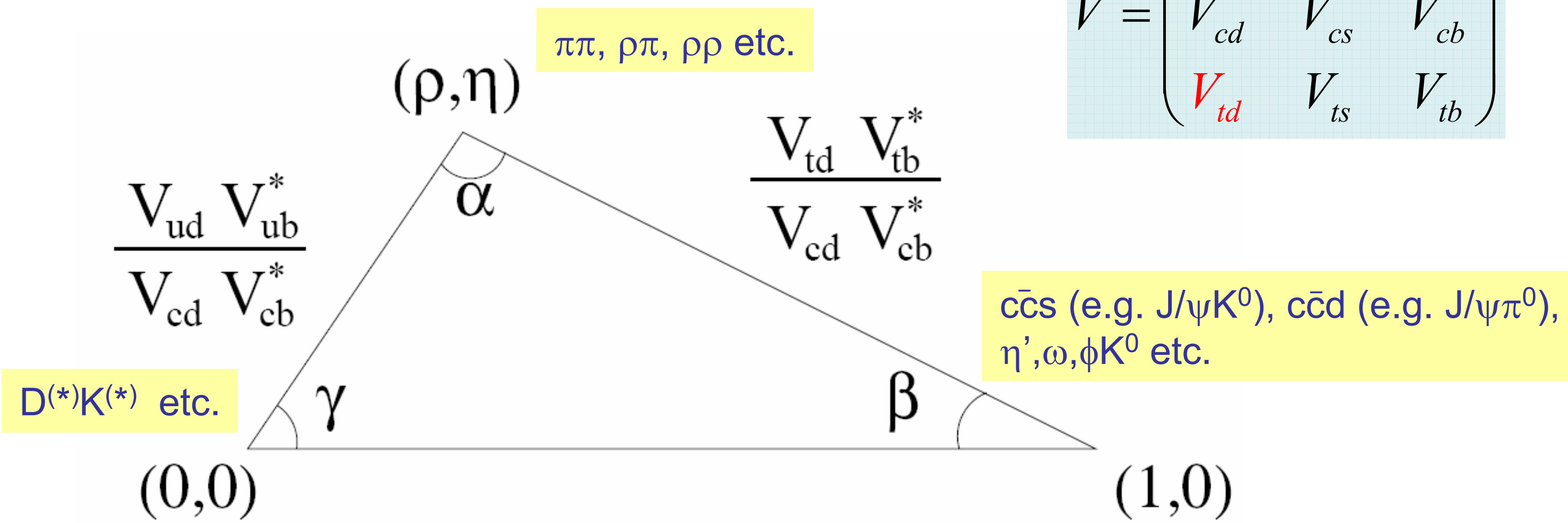
$$\lambda \sim 0.22$$
$$A \sim 0.8$$
$$\rho \sim 0.2 - 0.27$$
$$\eta \sim 0.28 - 0.37$$

Understanding Standard Model CP Violation means accurate measurements of ρ and η

Studying CP violation in B decay

- Study decays involving $b \to u$ and $b \to t$ transitions to probe the weak phase of V_{ub} and V_{td}.

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

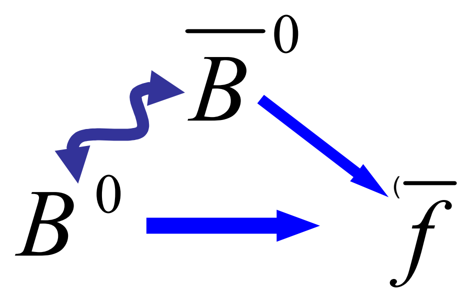


- B-factories have measured β to ~1° in cc̄s, and starting to do precision measurements in charmless $b \to s$ penguin decays.
- Now starting to constrain α and γ.

CP violation effects

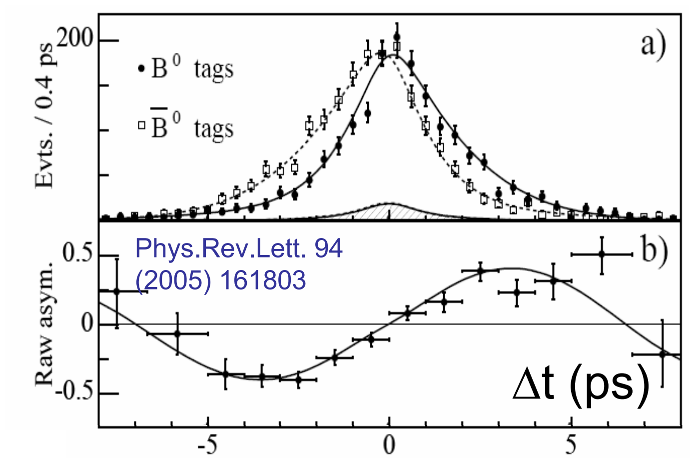
- CP violation is manifest through interference.
- Direct CP violation

$$\Pr(B^0 \to f) \neq \Pr(\overline{B}^0 \to \overline{f})$$



  – '*just*' number counting like ε'/ε: e.g. A_{CP} in B→Kπ.

- CP violation in interference of mixing and decay (Imλ ≠ 0).
  – Time-dependent effect.
  – Need asymmetric e^+ and e^- beam energies study in detectors.



Observables

- Analyse time evolution of $B^0\bar{B}^0$ system (assume $\Delta\Gamma=0$):

$$f_{+/-}(B^0/\overline{B}^0_{phys} \to f/\overline{f}, \Delta t) =$$

$$\tfrac{\Gamma}{4} e^{-\Gamma|\Delta t|}\left[1+\eta S \sin(\Delta m_d \Delta t) - \eta C \cos(\Delta m_d \Delta t)\right]$$

$$\eta = +1(-1) \text{ for } B^0(\overline{B}^0)$$

$$\lambda_{f_{CP}} = \frac{q}{p}\cdot\frac{\overline{A}_{\overline{f}_{CP}}}{A_{f_{CP}}}$$

$$S_{f_{CP}} = \frac{2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}$$

$$C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}$$

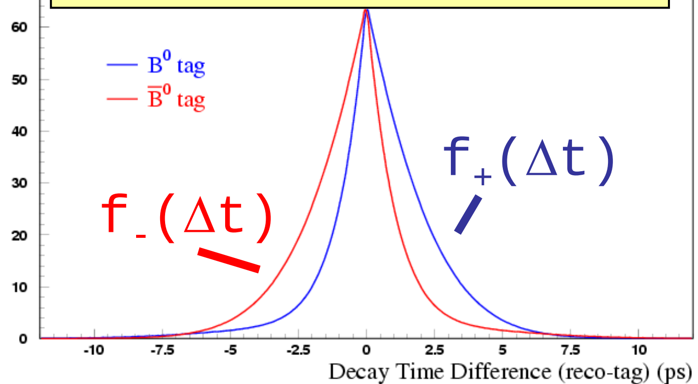
$$C = -A_{CP}$$

$$BaBar : Belle$$

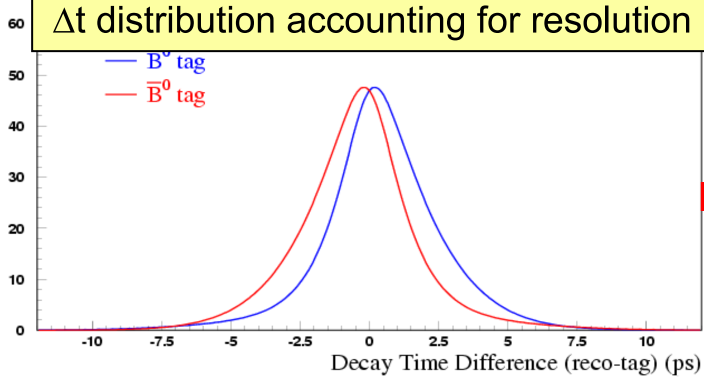
Observables

- Construct an asymmetry from the time distributions for f_+ and f_-.

Δt distribution for a perfect detector

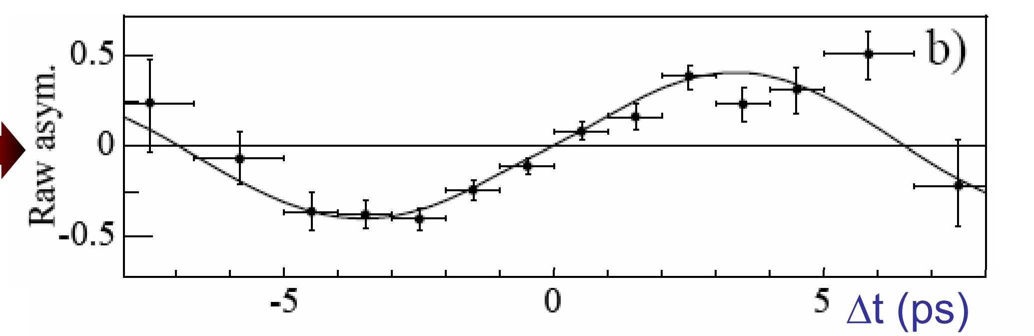


Δt distribution accounting for resolution



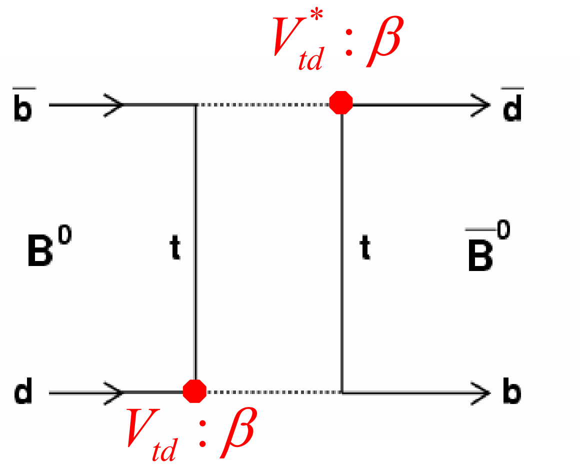
$$A_{CP}(\Delta t) = \frac{f_+(\Delta t) - f_-(\Delta t)}{f_+(\Delta t) + f_-(\Delta t)}$$

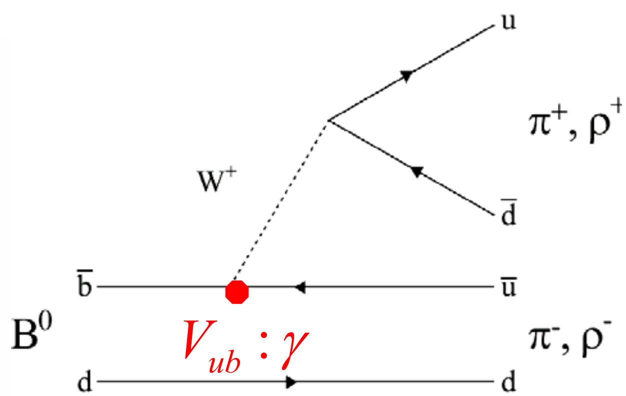
$$= S \sin(\Delta m_d \Delta t) - C \cos(\Delta m_d \Delta t)$$

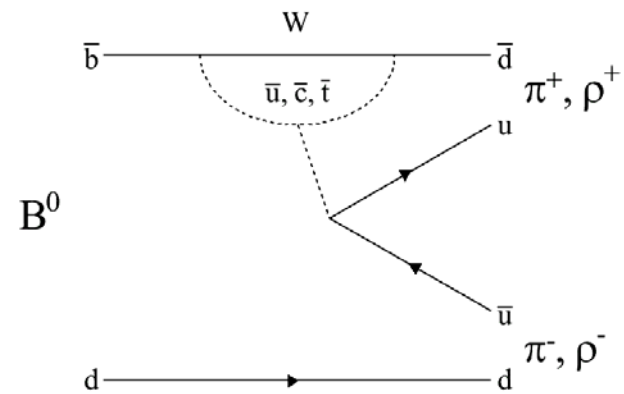


CP violation in $B \to h^+h^-$, $h=\pi,\rho$

+Loops (penguins)







$$C_{hh} = 0$$

$$S_{hh} = \sin(2\alpha)$$

$$C_{hh} \propto \sin(\delta)$$

$$S_{hh} = \sqrt{1 - C_{hh}^2}\,\sin(2\alpha_{\mathrm{eff}})$$

$$\delta = \delta_P - \delta_T$$

- Measure α_{eff}.
- Need to bound $|\alpha_{\mathrm{eff}} - \alpha|$ (shift from loops).
- Different |Penguin/Tree| for different decays.

Isospin analysis

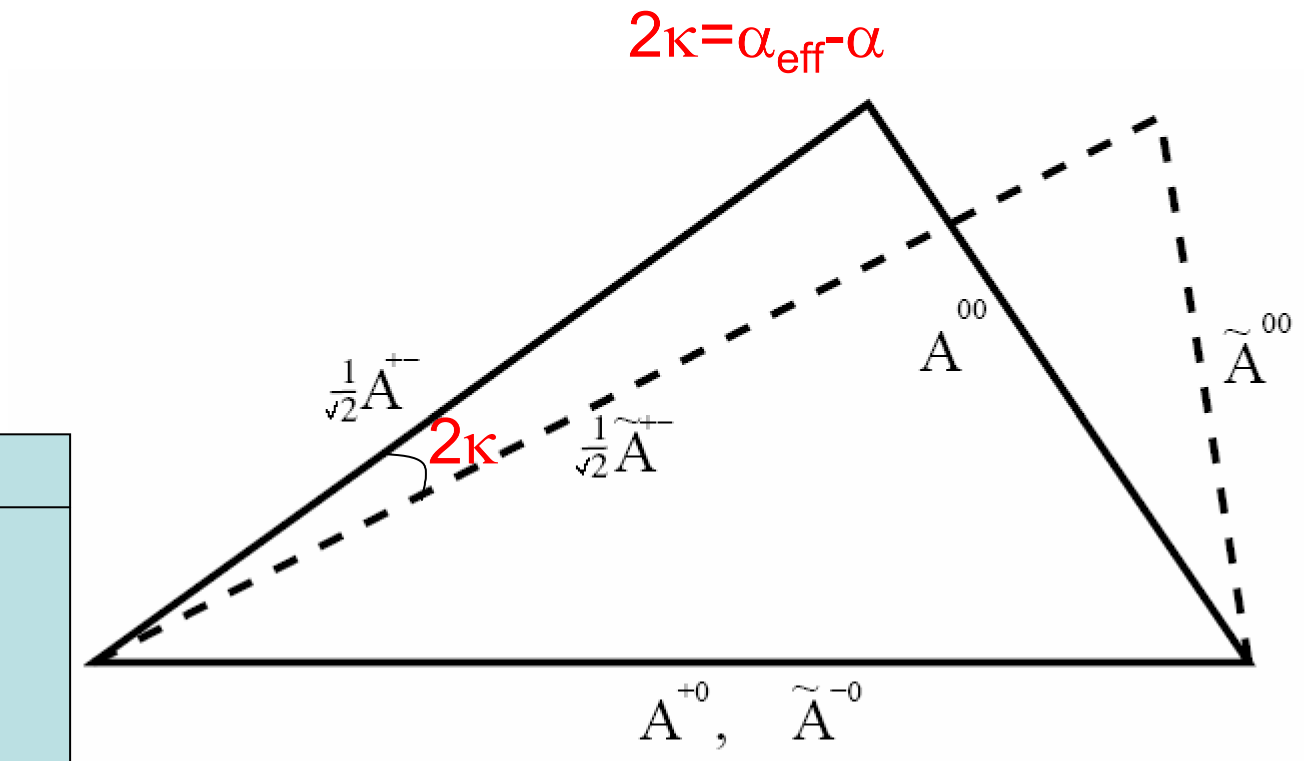
$\pi\pi$: Gronau & London PRL**65**, 3381 (1990) etc.
$\rho\pi$ Snyder-Quinn: PRD**48**, 2139 (1993) etc.
($\rho\rho$ 3 x $\pi\pi$)

- SU(2) isospin symmetry relates u and d quarks: $m_u \sim m_d$
- Different $B \to \pi\pi$, $\rho\pi$ and $\rho\rho$ final states can be related to each other through isospin amplitudes.
- These amplitude relations can be used to constrain the penguin shift in the time dependent measurement:
  - Bounds α_{eff}-α.
  - Relations are triangles for $\pi\pi$ and $\rho\rho$, and pentagons for $\rho\pi$.

Isospin analysis

$$\frac{1}{\sqrt{2}}A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}}\overline{A}^{+-} + \overline{A}^{00} = \overline{A}^{+0}$$



For ππ & ρρ require:

$$B^0 \to h^+h^- + C.C.$$

$$B^0 \to h^0h^0 + C.C.$$

$$B^+ \to h^+h^0 + C.C.$$

$$S_{h^+h^-}$$

- There are SU(2) violating corrections to consider, for example electroweak penguins, but these are much smaller than current experimental accuracy and can be incorporated into the isospin analysis.

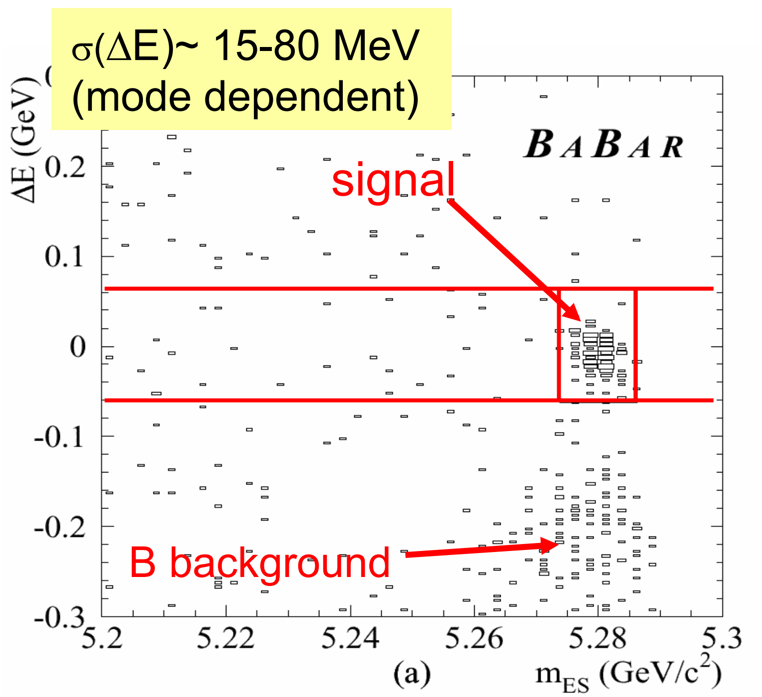
Ingredients of a time dependent analysis

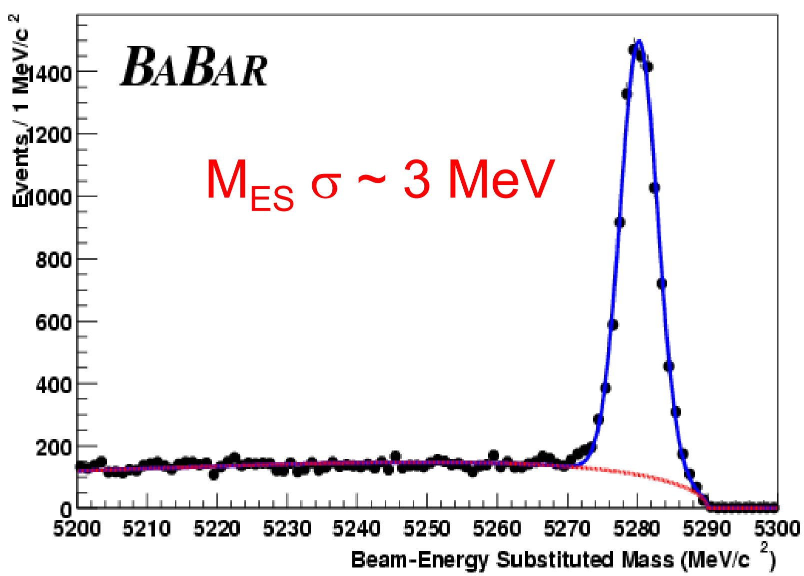
- In order to measure S and C we need to be able to
  - Isolate the signal from large samples dominated by background.
  - Measure the proper time difference between the decay vertices of the two B mesons in the event [vertexing].
  - Determine the flavor of the other B meson in the event [tagging].

Isolating signal events

- Beam energy is known very well at an e^+e^- collider like PEP-II / KEK-B
  - use an energy difference and effective mass to select events:

$$\Delta E = E_B - E^*_{beam} \qquad m_{ES} = \sqrt{(E^*_{beam})^2 - P_B^2}$$

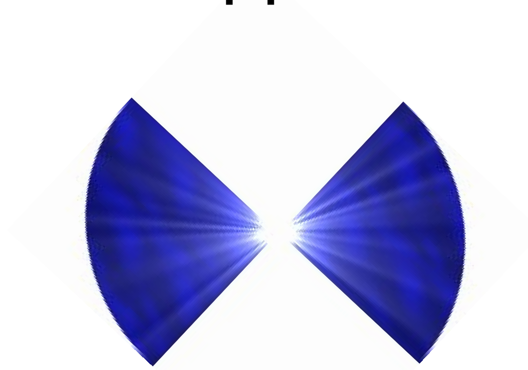




More background suppression

- Use the shape of an event to distinguish between $\Upsilon(4S) \rightarrow B\bar{B}$ and $e^+e^- \rightarrow q\bar{q}$

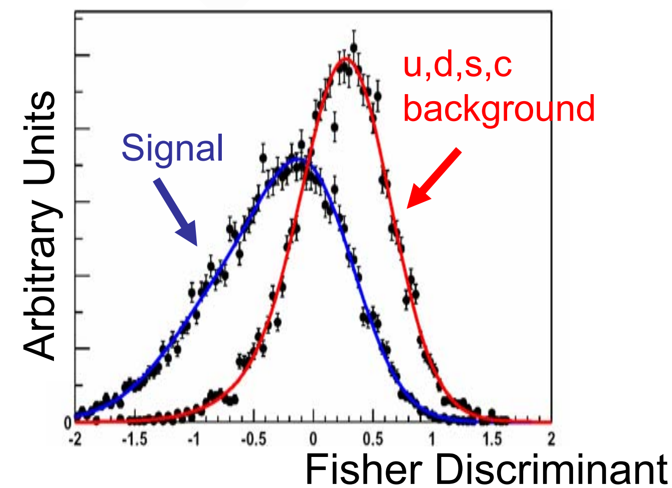
B events tend to be spherical



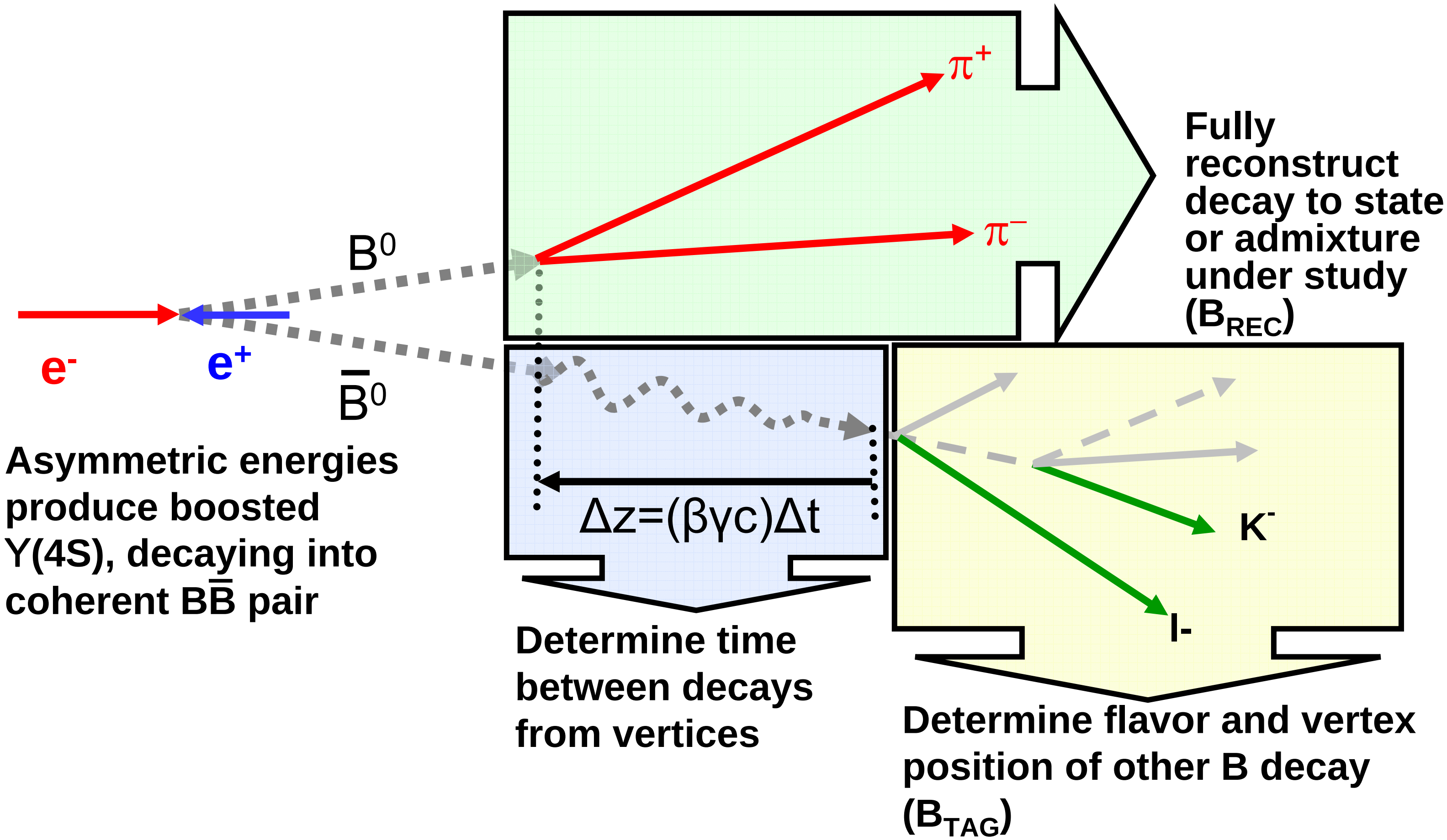
continuum ($ee \rightarrow q\bar{q}$) events are 'jetty'

Analyses combine several event shape variables in a single discriminating variable: either Fisher or artificial Neural Network.

This allows for some discrimination between B and continuum events



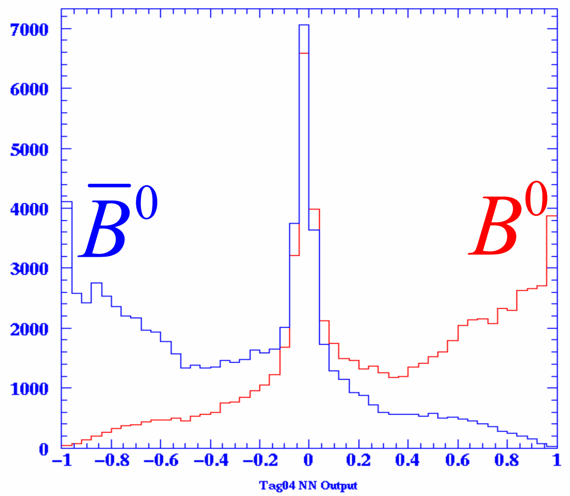
Vertexing



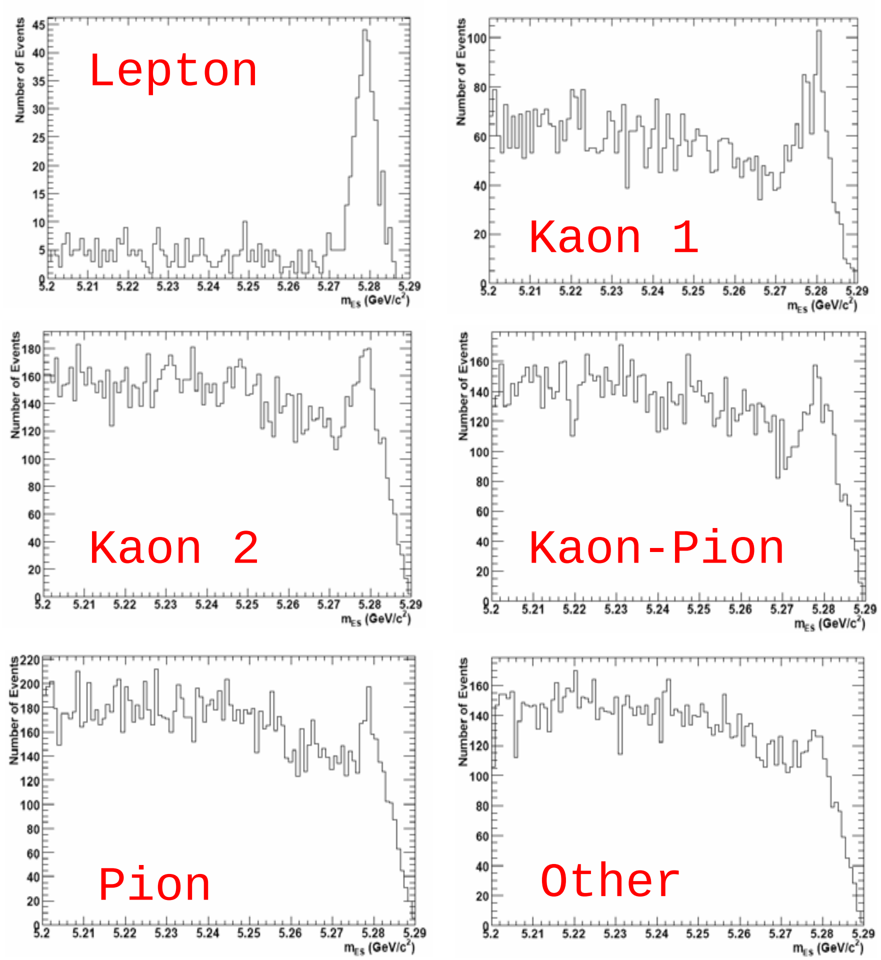
- Then fit the Δt distribution to determine the amplitude of sine and cosine terms.

Flavor tagging

- Decay products of B_{TAG} are used to determine its flavor.
- At $\Delta t=0$, the flavor of B_{REC} is opposite to that of other B_{TAG}.
- B_{REC} continues to mix until it decays.
- Different B_{TAG} final states have different *purities* and different *mis-tag probabilities*.



BaBar's flavor tagging algorithm splits events into mutually exclusive categories ranked by signal purity and mis-tag probability. These plots are for the 316fb^{-1} h^+h^- data sample.

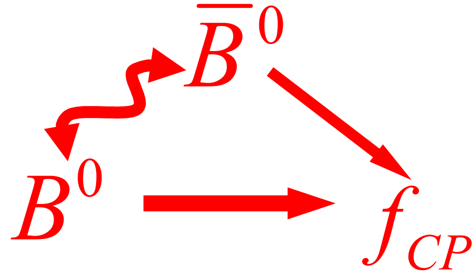


Search for a needle in a haystack

Study the decay
of several channels
to constrain α:

$B \to \pi\pi$

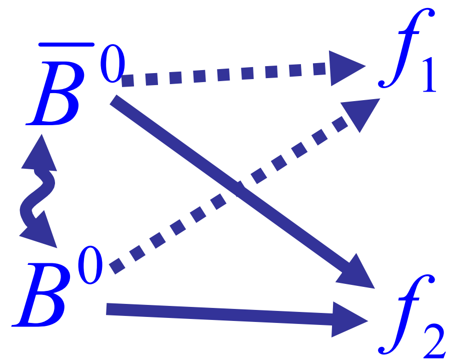
$B \to \rho\rho$

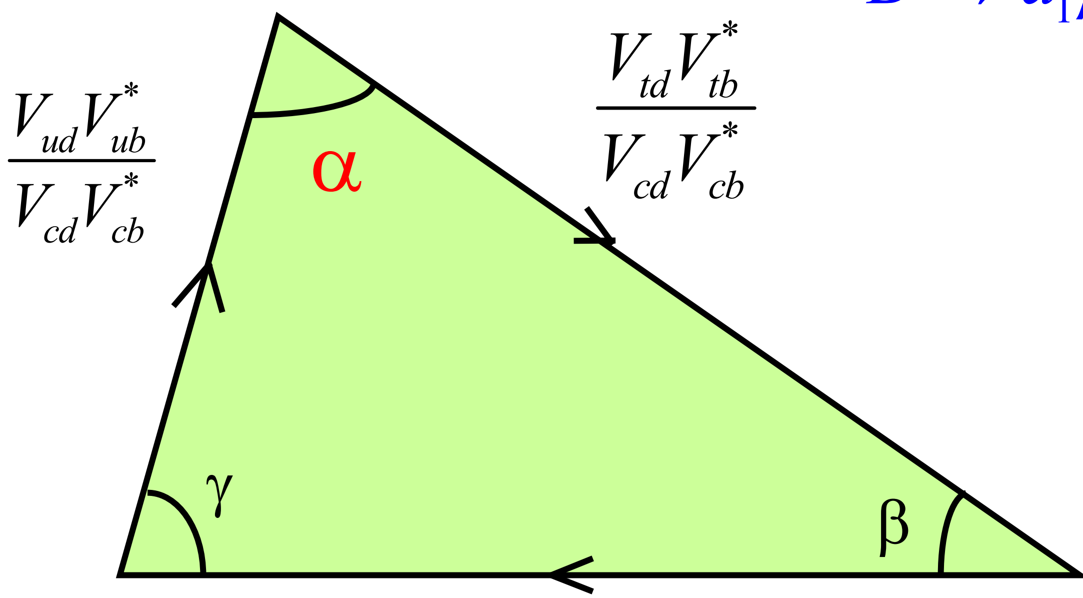


$B \to \rho\pi$

$B \to a_1\pi$

$B \to a_1\rho$

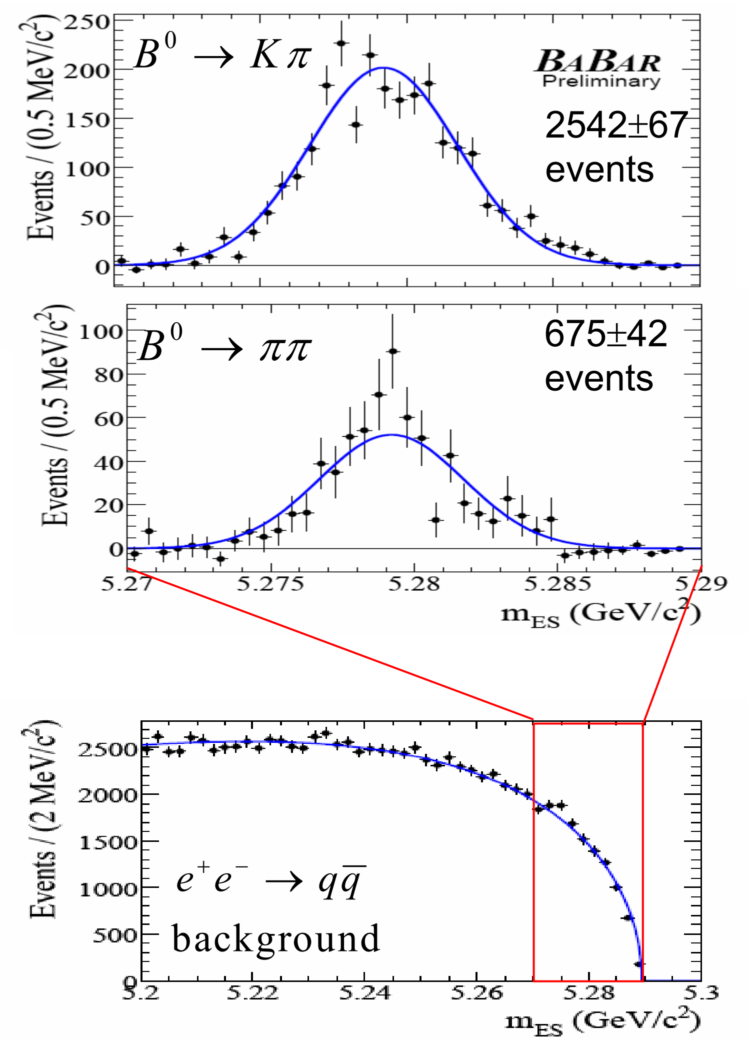


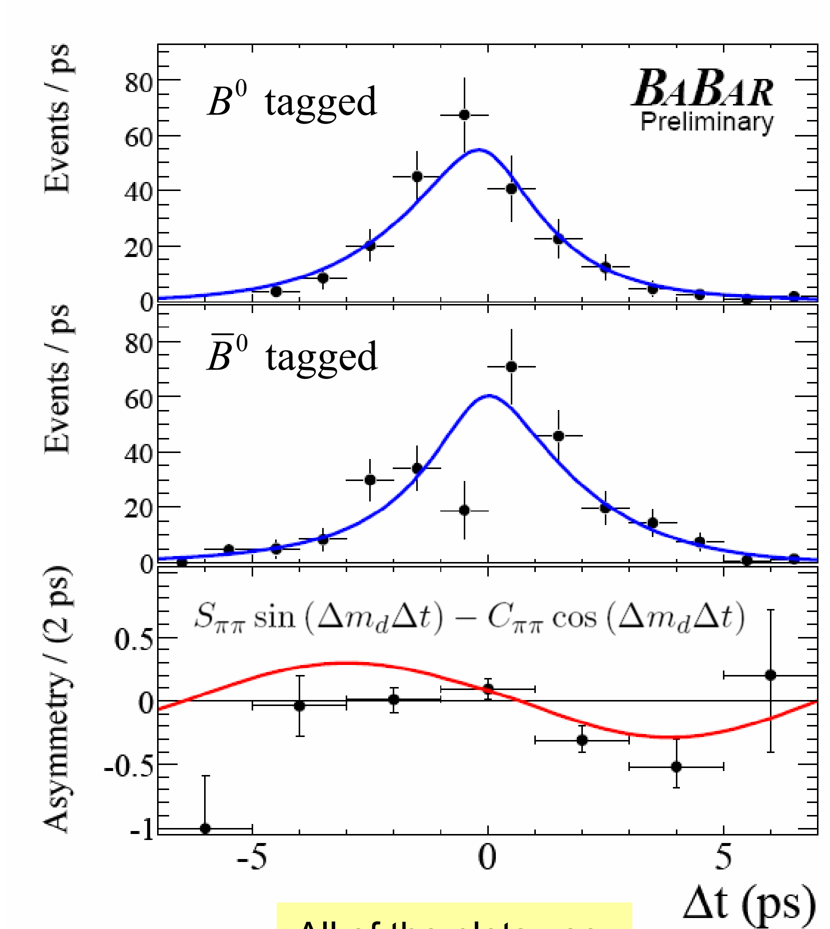


B→$\pi^+\pi^-$

hep-ex/0607106

- Updated measurement using 347×10^6 B pairs.





All of the plots use the sPlot technique

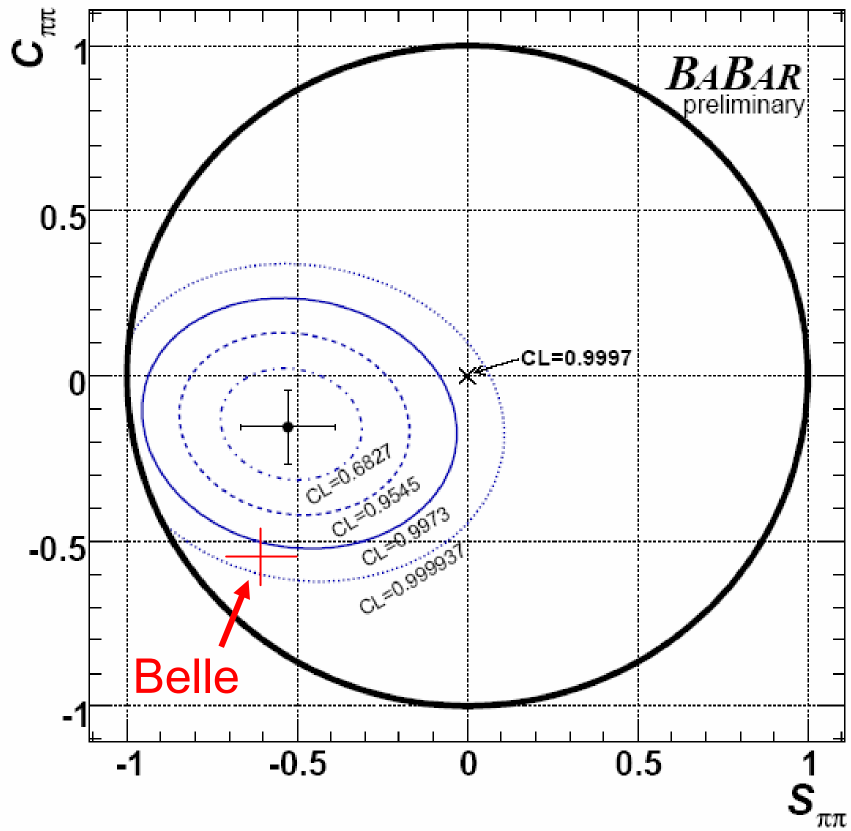
NIM A555 (2005) 356-369
(physics/0402083)

Evidence for CP Violation in B→ππ

hep-ex/0607106

- BaBar data shows evidence for CP violation at 3.6σ using the S and C measurement in $B\to\pi^+\pi^-$.

$$S_{\pi\pi} = -0.53 \pm 0.14 \pm 0.02$$
$$C_{\pi\pi} = -0.16 \pm 0.11 \pm 0.03$$



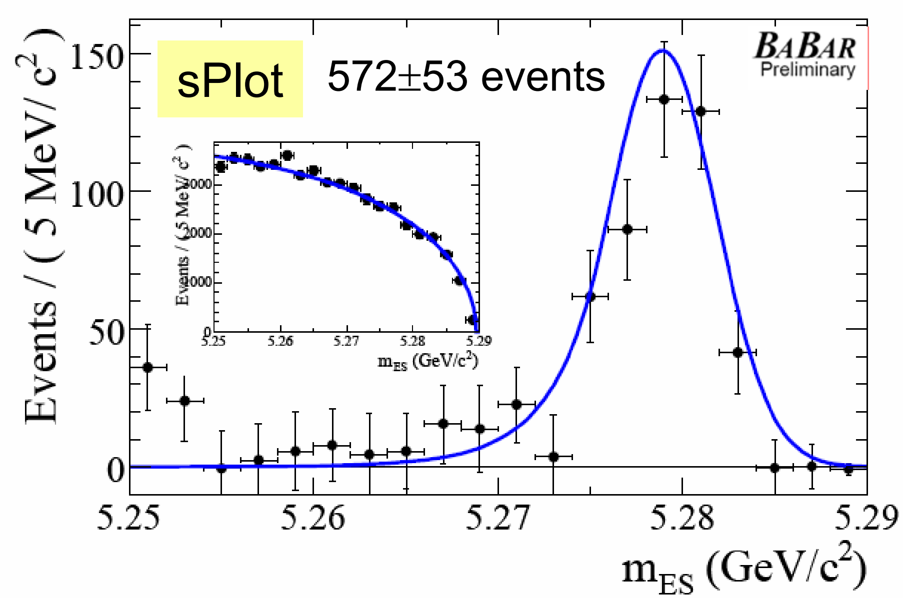
- (S,C)=(0,0) is excluded at a confidence level of 0.9997.
- Still a mild discrepancy with Belle's result ⇒ need more data to resolve this.

Updated sides of the ππ triangle

hep-ex/0607106

- Using 347x10^6 B pairs.
- $\pi^0\pi^0$ selection improved use $\gamma\rightarrow e^+e^-$ conversions, and ‘merged’ π^0 mesons.

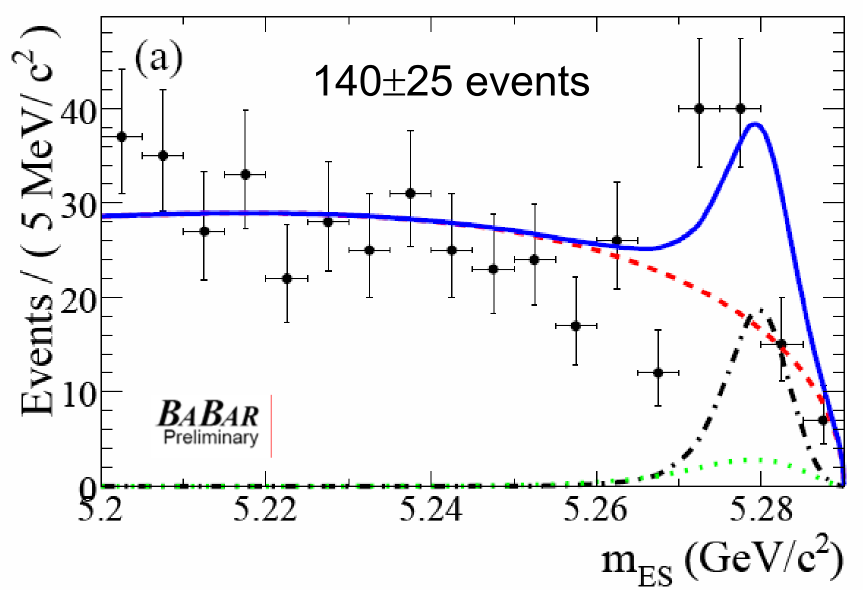
$$B^+ \rightarrow \pi^+\pi^0$$



$$\mathcal{B}(B^\pm \rightarrow \pi^\pm\pi^0) = (5.12 \pm 0.47 \pm 0.29) \times 10^{-6}$$

$$\mathcal{A}_{\pi\pi^0} = -0.019 \pm 0.088 \pm 0.014$$

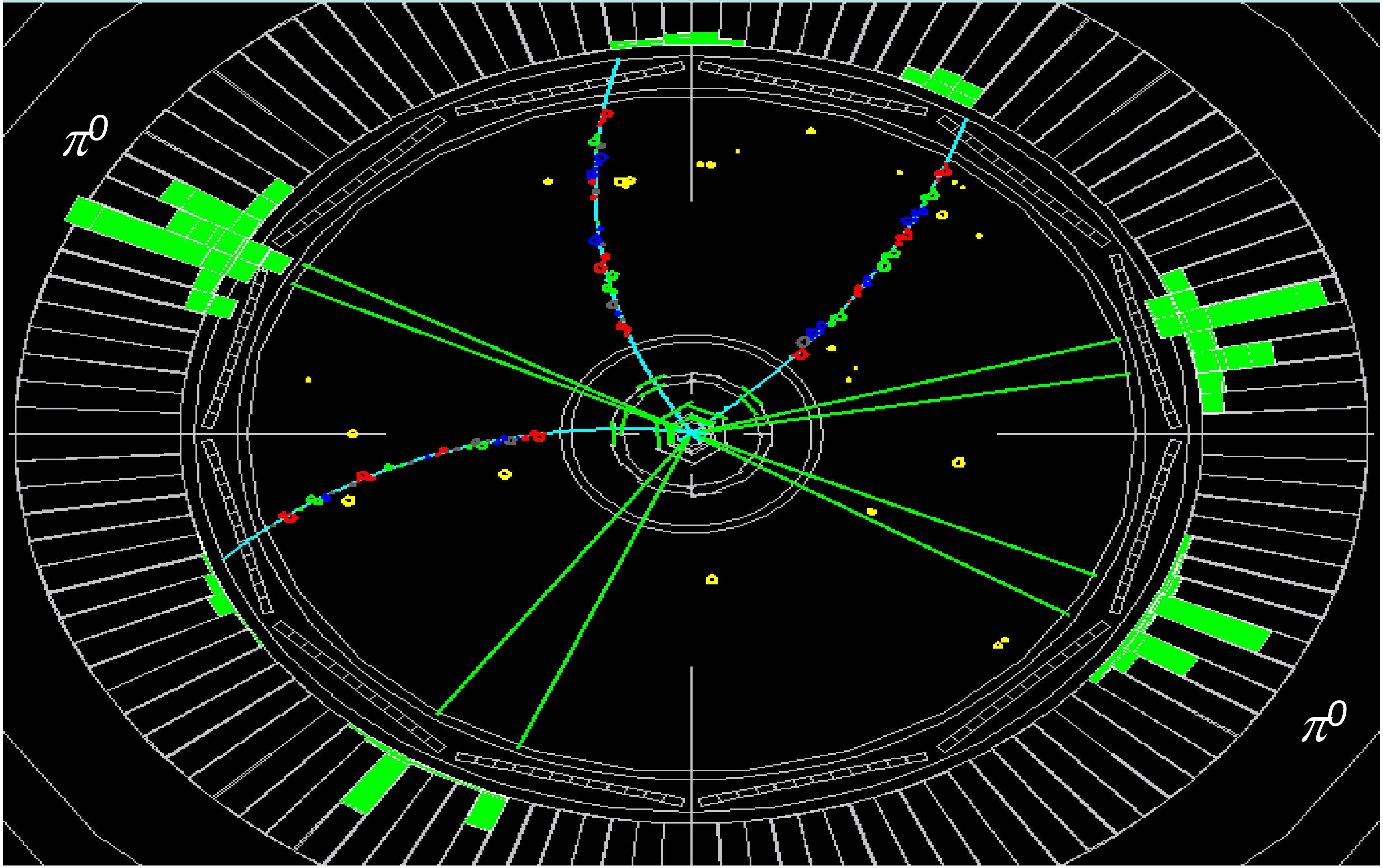
$$B^0 \rightarrow \pi^0\pi^0$$



$$\mathcal{B}(B^0 \rightarrow \pi^0\pi^0) = (1.48 \pm 0.26 \pm 0.12) \times 10^{-6}$$

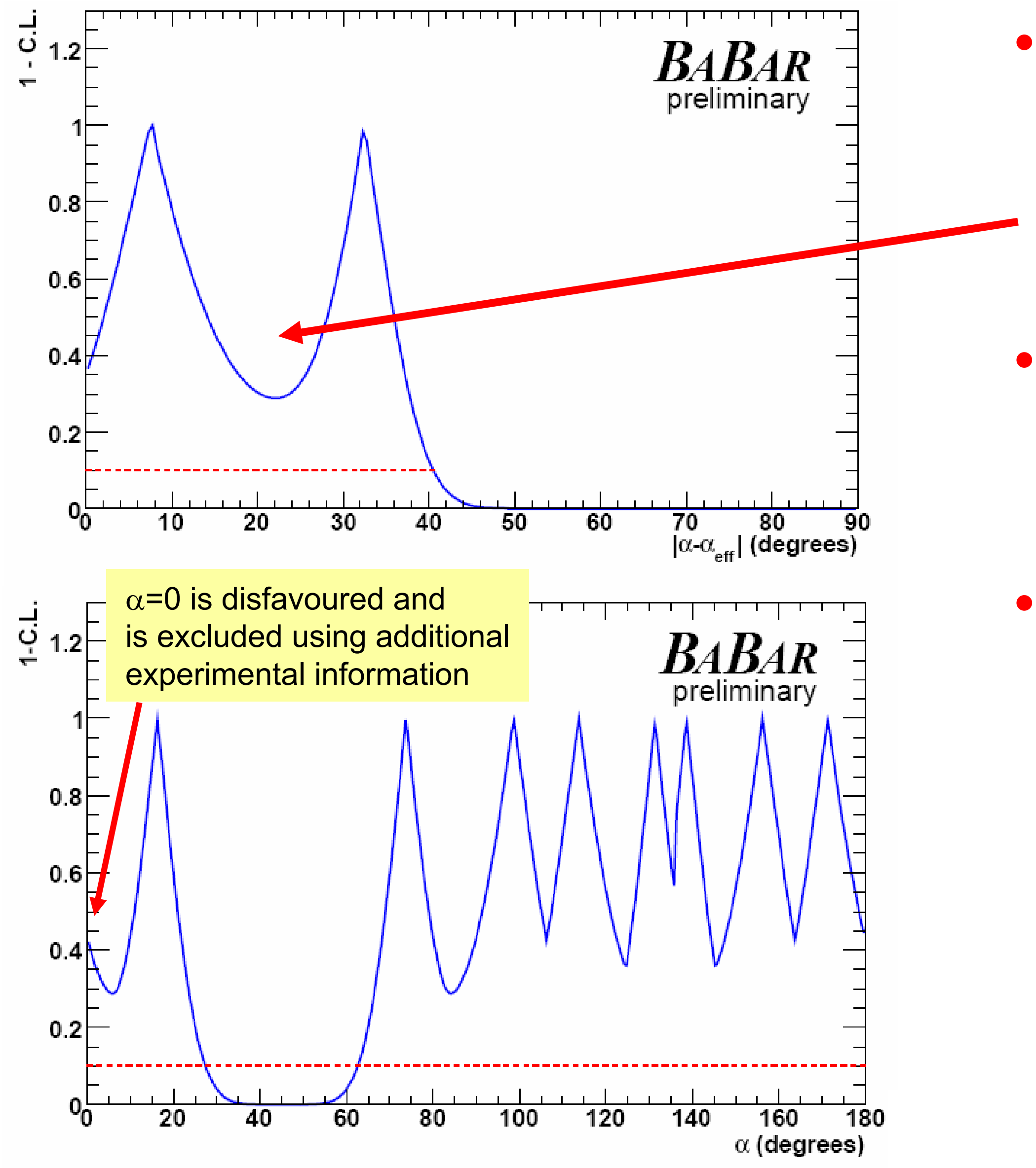
$$C_{\pi^0\pi^0} = -0.33 \pm 0.36 \pm 0.08$$

A $B^0 \rightarrow \pi^0\pi^0$ candidate



$B \to \pi\pi$ Isospin analysis

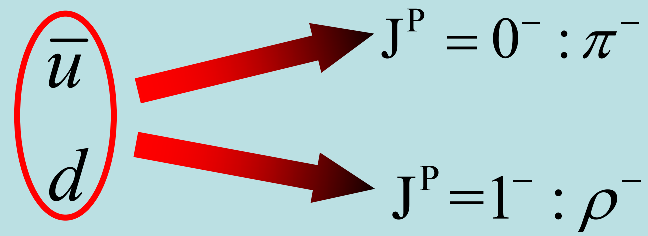
hep-ex/0607106



- The measurement of C^{00} is starting to distinguish between possible solutions for $\delta\alpha$.
- Need more data before the dip starts to become significant.
- The precision of the $\pi\pi$ isospin analysis will be something to watch as the B-factories approach $1ab^{-1}$.

B→ρρ

- Use B→ρρ decays to measure α.
- Theory is slightly more complicated than ππ.
- Experimentally challenging.
- But loop contributions are better constrained than ππ.



Spin 0 → Spin 1
narrow particle → broad resonance

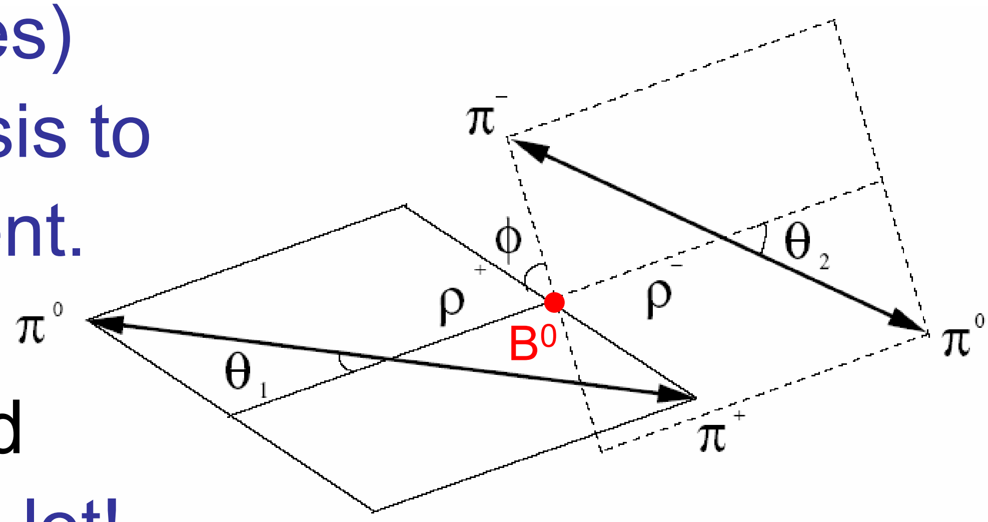
$$\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi} \propto \left| \sum_{m=-1,0,1} A_m Y_{1,m}(\theta_1,\Phi) Y_{1,-m}(\theta_2,\Phi) \right|^2$$

$$\propto \left\{ \begin{array}{l} \frac{1}{4}\sin^2\theta_1 \sin^2\theta_2 (|A_{+1}|^2 + |A_{-1}|^2) + \cos^2\theta_1 \cos^2\theta_2 |A_0|^2 \\ + \frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 [\cos 2\Phi \Re(A_{+1}A_{-1}^*) - \sin 2\Phi \Im(A_{+1}A_{-1}^*)] \\ + \frac{1}{4}\sin 2\theta_1 \sin 2\theta_2 [\cos\Phi \Re(A_{+1}A_0^* + A_{-1}A_0^*) - \sin\Phi \Im(A_{+1}A_0^* - A_{-1}A_0^*)] \end{array} \right\}$$

$$f_L = \frac{|A_0|^2}{\sum_{m=-1,0,1} |A_m|^2}$$

Measuring α with $B\to\rho\rho$ decays

- $B\to VV$ decay;
  - Angular correlation has 11 observables (6 amplitudes, 5 phases)
  - need angular analysis to determine CP content.
- $\rho^+\rho^-$ is almost 100% longitudinally polarized
  - simplifies analysis a lot!
  - CP even helicity zero state dominates:



$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left(f_L \cos^2\theta_1 \cos^2\theta_2 + \frac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2\right)$$

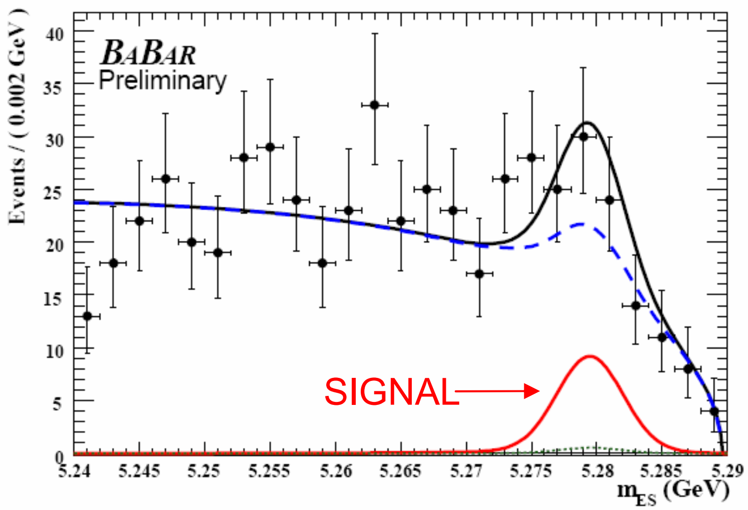
Longitudinal (CP even)

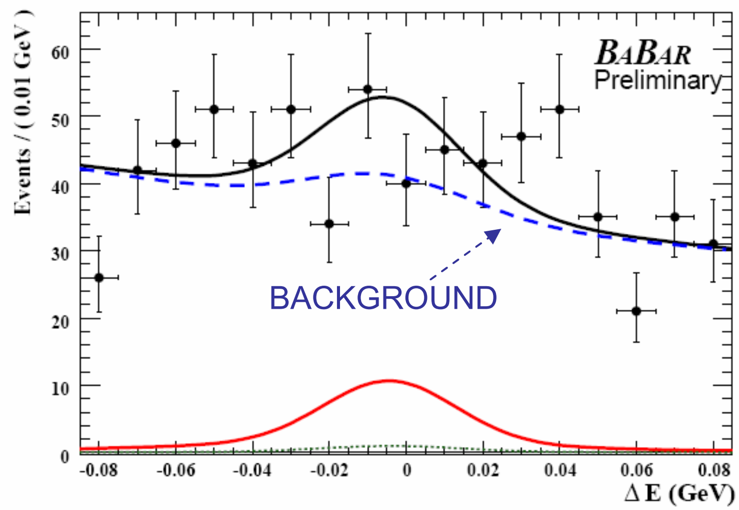
Transverse (Mixed CP state)

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

hep-ex/0607097

- Updated measurement using 347×10^6 B pairs.





Previous result UL < 1.1×10^{-6} (central value was 0.54×10^{-6})

$$\mathcal{B}(B^0 \rightarrow \rho^0\rho^0) = [1.16^{+0.37}_{-0.36}\ (\mathrm{stat.}) \pm 0.27\ (\mathrm{syst.})]\times10^{-6}$$

$$f_L = 0.86^{+0.11}_{-0.13}\ (\mathrm{stat.}) \pm 0.05\ (\mathrm{syst.})$$

$$N(\rho^0\rho^0) = 98^{+32}_{-31} \pm 22$$

$$N(\rho^0 f^0) = 12^{+18}_{-17} \pm 13$$

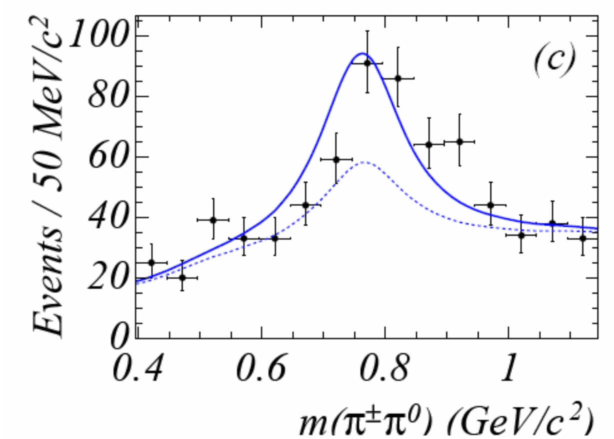
$$N(f^0 f^0) = -5^{+7}_{-6} \pm 12$$

- 3σ Evidence for $\rho^0\rho^0$ with systematic errors.
  - Leads to a weaker constraint on penguin pollution.

$B^+ \to \rho^+ \rho^0$

Submitted to PRL hep-ex/0607092

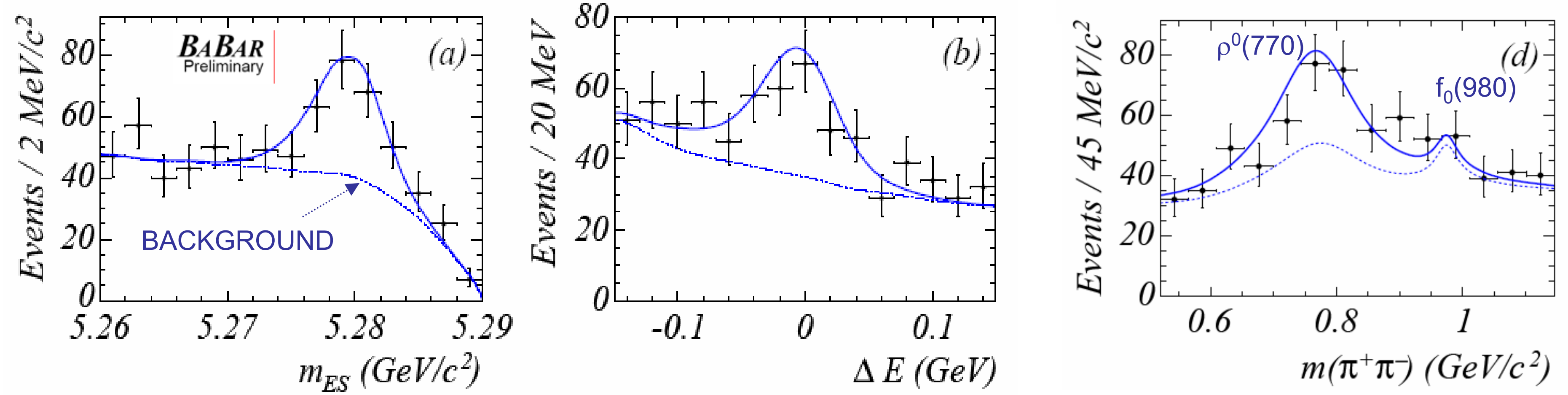
- Updated measurement using 232×10^6 B pairs.
- Simultaneous fit for $B^+ \to \rho^+ f_0(980)$.
- Smaller Branching Fraction measured.
  - Leads to a weaker constraint on penguin pollution.



$$390 \pm 49 \text{ events}$$

$$\mathcal{B} = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$$

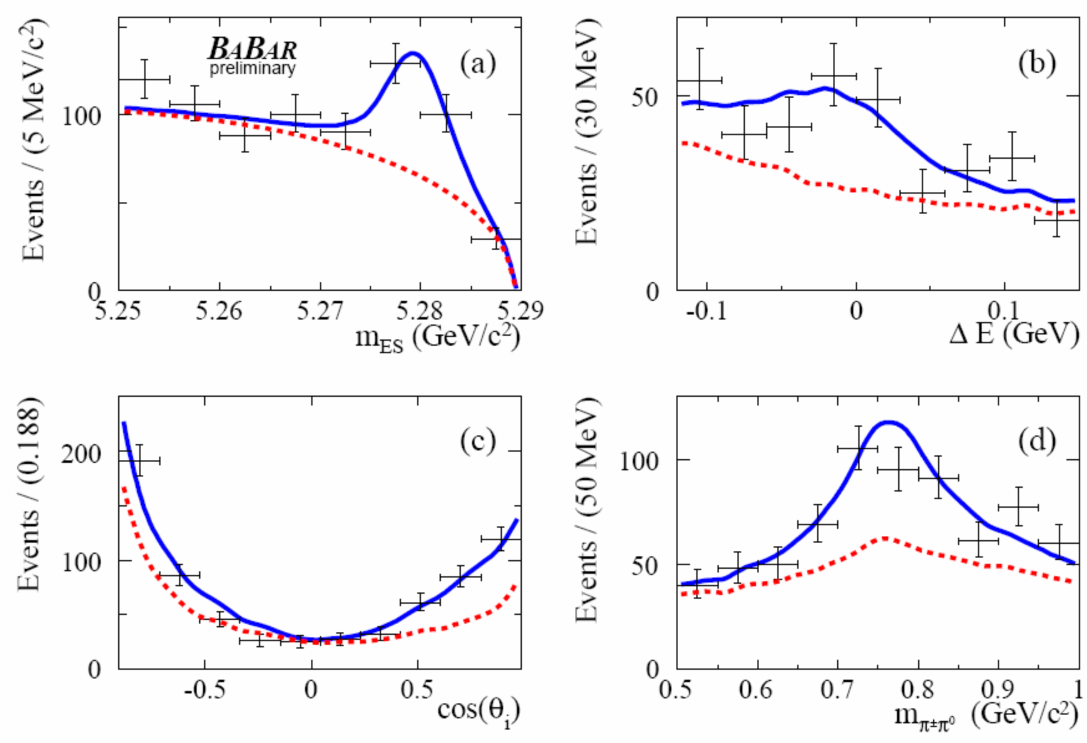
$$f_L = 0.905 \pm 0.042^{+0.023}_{-0.027}$$



$B^0 \to \rho^+\rho^-$

hep-ex/0607098

- Updated for ICHEP '06.
- Using 347x10^6 B pairs.
- Reduced systematic uncertainty by improving treatment of correlations.
- Use only the tagged events for all results.



Category (c)	ϵ_c	ω_c	$\Delta\omega_c$
Lepton	0.080 ± 0.001	0.032 ± 0.004	0.002 ± 0.008
Kaon 1	0.114 ± 0.001	0.053 ± 0.005	-0.012 ± 0.009
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Pion	0.137 ± 0.002	0.327 ± 0.007	0.059 ± 0.010
Other	0.095 ± 0.001	0.412 ± 0.008	0.042 ± 0.001
Untagged	0.266 ± 0.002	0.500 ± 0.000	0.000 ± 0.000

$B^0 \to \rho^+\rho^-$

hep-ex/0607098

Conservative uncertainty on mis-reconstructed signal fraction which can be reduced.

Table 4: Summary of additive systematic uncertainty contributions.

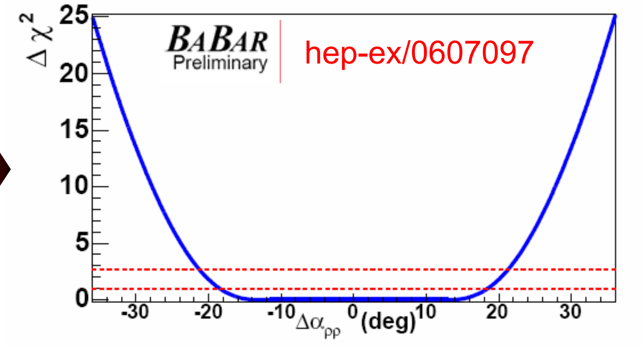
Contribution	$\sigma(N_{signal})$	$\sigma(f_L)$	$\sigma(S_{\rm long})$	$\sigma(C_{\rm long})$
PDF parameterisation	$^{+16.7}_{-30.2}$	$^{+0.0082}_{-0.0064}$	$^{+0.0149}_{-0.0425}$	$^{+0.0300}_{-0.0306}$
SCF fraction	84.0	$^{+0.0007}_{-0.0011}$	$^{+0.00235}_{-0.00355}$	$^{+0.0070}_{-0.00683}$
m_{ES} and ΔE width	22.9	0.005	0.011	0.012
B background normalisation	$^{+16.0}_{-17.2}$	$^{+0.0033}_{-0.0038}$	$^{+0.0096}_{-0.0115}$	$^{+0.0024}_{-0.0015}$
floating B backgrounds	33.6	0.004	0.033	0.006
CPV in B background	$^{+3.3}_{-2.0}$	$^{+0.0006}_{-0.0016}$	$^{+0.0059}_{-0.0214}$	$^{+0.0118}_{-0.0115}$
τ	$^{+0.1}_{-0.4}$	$^{+0.0000}_{-0.0002}$	$^{+0.0002}_{-0.0008}$	0.0007
Δm	$^{+0.0}_{-0.2}$	$^{+0.0000}_{-0.0002}$	$^{+0.0014}_{-0.0020}$	$^{+0.0018}_{-0.0012}$
tagging and dilution	$^{+2.6}_{-8.1}$	$^{+0.0029}_{-0.0021}$	$^{+0.0016}_{-0.0053}$	$^{+0.0068}_{-0.0054}$
transverse polarisation CPV	$^{+0.0}_{-8.3}$	$^{+0.0057}_{-0.0000}$	$^{+0.0125}_{-0.0152}$	$^{+0.0095}_{-0.0110}$
WT SCF CPV	$^{+0.2}_{-1.1}$	$^{+0.0000}_{-0.0003}$	$^{+0.0051}_{-0.0065}$	$^{+0.0116}_{-0.0113}$
DCSD decays	–	–	0.012	0.037
Interference	14.8	0.0036	0.023	0.022
Fit Bias	28	0.007	0.002	0.022
SVT Alignment	–	–	0.0100	0.0055
Total	$^{+97}_{-101}$	$^{+0.015}_{-0.013}$	$^{+0.05}_{-0.07}$	± 0.06

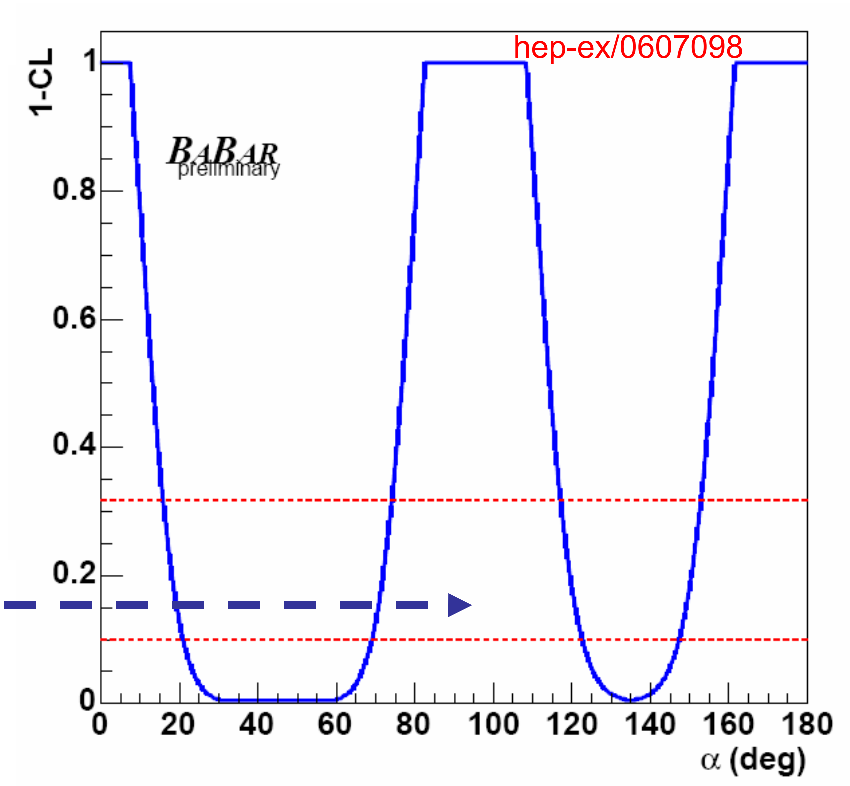
- Improvements in modelling correlations and backgrounds result in a reduced systematic uncertainty on S and C.
- Improved upper limit for $B \to a_1\rho$ also helps to reduce systematic uncertainty.

$$\begin{aligned}
\mathcal{B}(B^0 \to \rho^+\rho^-) &= (23.5 \pm 2.2(\text{stat}) \pm 4.1(\text{syst}))\times 10^{-6},\\
f_L &= 0.977 \pm 0.024(\text{stat})^{+0.015}_{-0.013}(\text{syst}),\\
S_{\rm long} &= -0.19 \pm 0.21(\text{stat})^{+0.05}_{-0.07}(\text{syst}),\\
C_{\rm long} &= -0.07 \pm 0.15(\text{stat}) \pm 0.06(\text{syst}).
\end{aligned}$$

Updated α from $B \rightarrow \rho\rho$ decays

- Penguin pollution is constrained to be <18° (68% CL).
- Evidence for $\rho^0\rho^0$ and a lower branching fraction for $\rho^+\rho^0$ result in a weakened constraint on α.





$$\alpha_{\text{eff}} = (95.5^{+6.9}_{-6.2})^\circ$$

$$\alpha = [74, 117]^\circ \text{ at } 68\% \text{ CL}$$

Can use a different approach

Beneke et al., Phys.Lett. B638 (2006) 68-73

- Relate the penguin contribution in $\rho^+\rho^-$ to $K^{*0}\rho^+$ using SU(3) symmetry:

$$C_{\rm long} = \frac{2r\sin\delta\sin(\beta+\alpha)}{1-2r\cos\delta\cos(\beta+\alpha)+r^2},$$

$$S_{\rm long} = \frac{\sin 2\alpha + 2r\cos\delta\sin(\beta-\alpha) - r^2\sin 2\beta}{1-2r\cos\delta\cos(\beta+\alpha)+r^2},$$

$$R = \left(\frac{|V_{cd}|f_\rho}{|V_{cs}|f_{K^*}}\right)^2 \cdot \frac{\Gamma_{L,CP-averaged}(B^\pm \to K^{*0}\rho^+)}{\Gamma_{L,CP-averaged}(B^0 \to \rho^+\rho^-)},$$

$$= \frac{Fr^2}{1-2r\cos\delta\cos(\beta+\alpha)+r^2}.$$

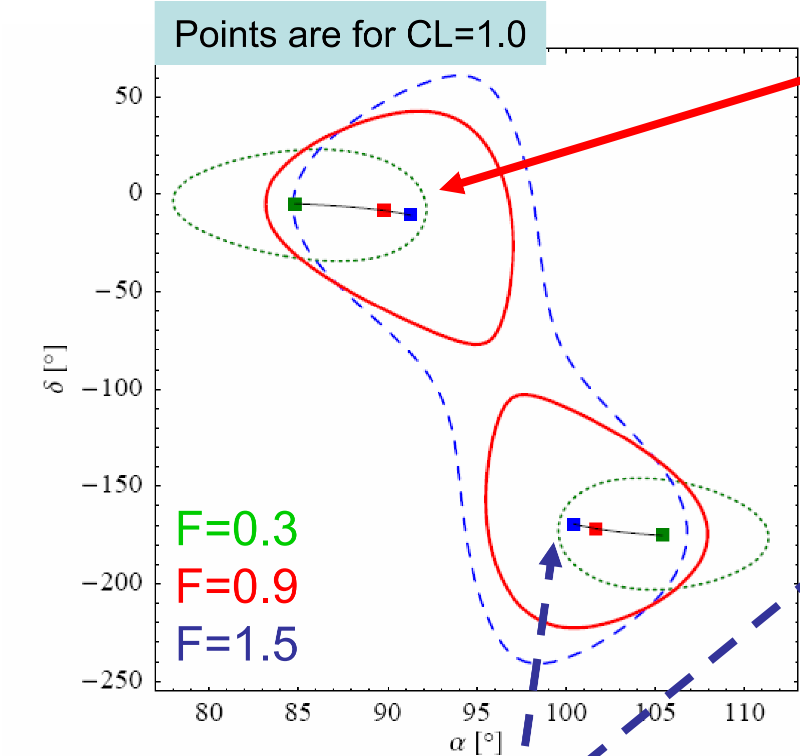
r=|P/T|
δ=strong phase difference between P and T
F=Correction for SU(3) breaking effects not included in the decay constants

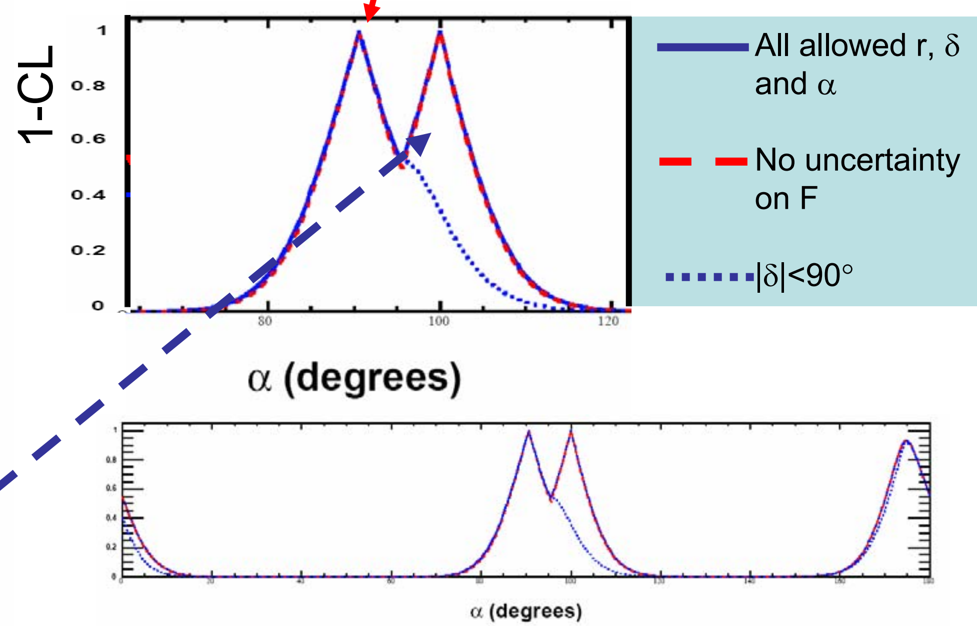
- It turns out that the error on α and δ don't depend strongly on F and σ(F).

Constraints using the Beneke et al. model

- Several solutions in 0-180°
- For the standard model solution of α, these two are overlapping

α~90° is preferred for |δ|<90°





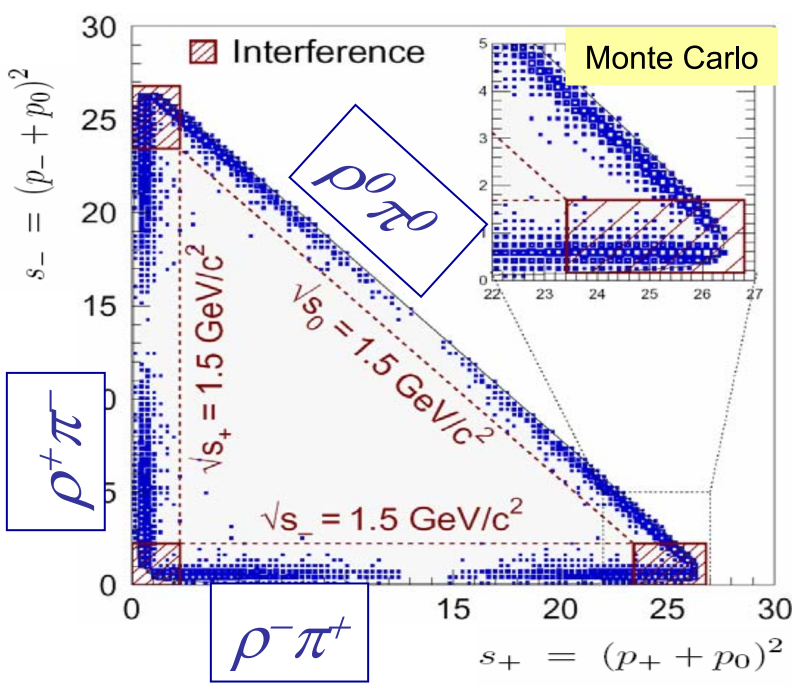
α~100° is preferred for |δ|>90°

$\sigma(\alpha)$~7°(expt.)±1.5 °(th.)

B→ρπ

Snyder-Quinn method: PRD **48** 2139 (1993)

- Extract α and strong phases using interference between amplitudes in the $\pi^+\pi^-\pi^0$ Dalitz plot.
- Amplitude $A_{3\pi}$ dominated by $\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$ and radial excitations



- The differential decay rate across the Dalitz plot is given by

$$d\Gamma(B^0 \to \pi^+\pi^-\pi^0) = \frac{1}{(2\pi)^3}\frac{|A_{3\pi}|^2}{8m_{B^0}^3} ds_+ ds_-$$

- where

$$\begin{aligned} A_{3\pi} &= f_+ A^+ + f_- A^- + f_0 A^0 \\ \overline{A}_{3\pi} &= f_+ \overline{A}^+ + f_- \overline{A}^- + f_0 \overline{A}^0 \end{aligned}$$

- A^κ and f^κ are the amplitudes and kinematic functions of the Dalitz variables for a ρ meson of charge κ.

Fitting the time dependence

hep-ex/0608002

- Fit 26 coefficients of the time dependence of $B\to\pi^+\pi^-\pi^0$ decays

$$|\mathcal{A}_{3\pi}^{\pm}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big[|\mathcal{A}_{3\pi}|^2 + |\overline{\mathcal{A}}_{3\pi}|^2 \mp \left(|\mathcal{A}_{3\pi}|^2 - |\overline{\mathcal{A}}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) \pm 2\mathrm{Im}\left[\overline{\mathcal{A}}_{3\pi}\mathcal{A}_{3\pi}^*\right]\sin(\Delta m_d \Delta t)\Big],$$

- Where the amplitudes are written in terms of *U* and *I.*

$$\left|A_{3\pi}\right|^2 \pm \left|\overline{A}_{3\pi}\right|^2 = \sum_{\kappa\in\{+,0,-\}} \left|f_\kappa\right|^2 U_\kappa^{\pm} + 2\sum_{\sigma<\kappa\in\{+,0,-\}}\left(\mathrm{Re}\left[f_\kappa f_\sigma^*\right]U_\kappa^{\pm} - \mathrm{Im}\left[f_\kappa f_\sigma^*\right]U_{\kappa\sigma}^{\pm,\mathrm{Im}}\right)$$

$$\mathrm{Im}\left(\overline{A}_{3\pi}A_{3\pi}^*\right) = \sum_{\kappa\in\{+,0,-\}} \left|f_\kappa\right|^2 I_\kappa + \sum_{\sigma<\kappa\in\{+,0,-\}}\left(\mathrm{Re}\left[f_\kappa f_\sigma^*\right]I_{\kappa\sigma}^{\mathrm{Im}} + \mathrm{Im}\left[f_\kappa f_\sigma^*\right]I_{\kappa\sigma}^{\mathrm{Re}}\right)$$

- The information on α and CP violation is hidden in these variables:

$$C = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} + \frac{U_-^-}{U_-^+}\right) \qquad S = \frac{I_+}{U_+^+} + \frac{I_-}{U_-^+} \qquad A_{CP} = \frac{U_+^+ - U_-^+}{U_+^+ + U_-^+}$$

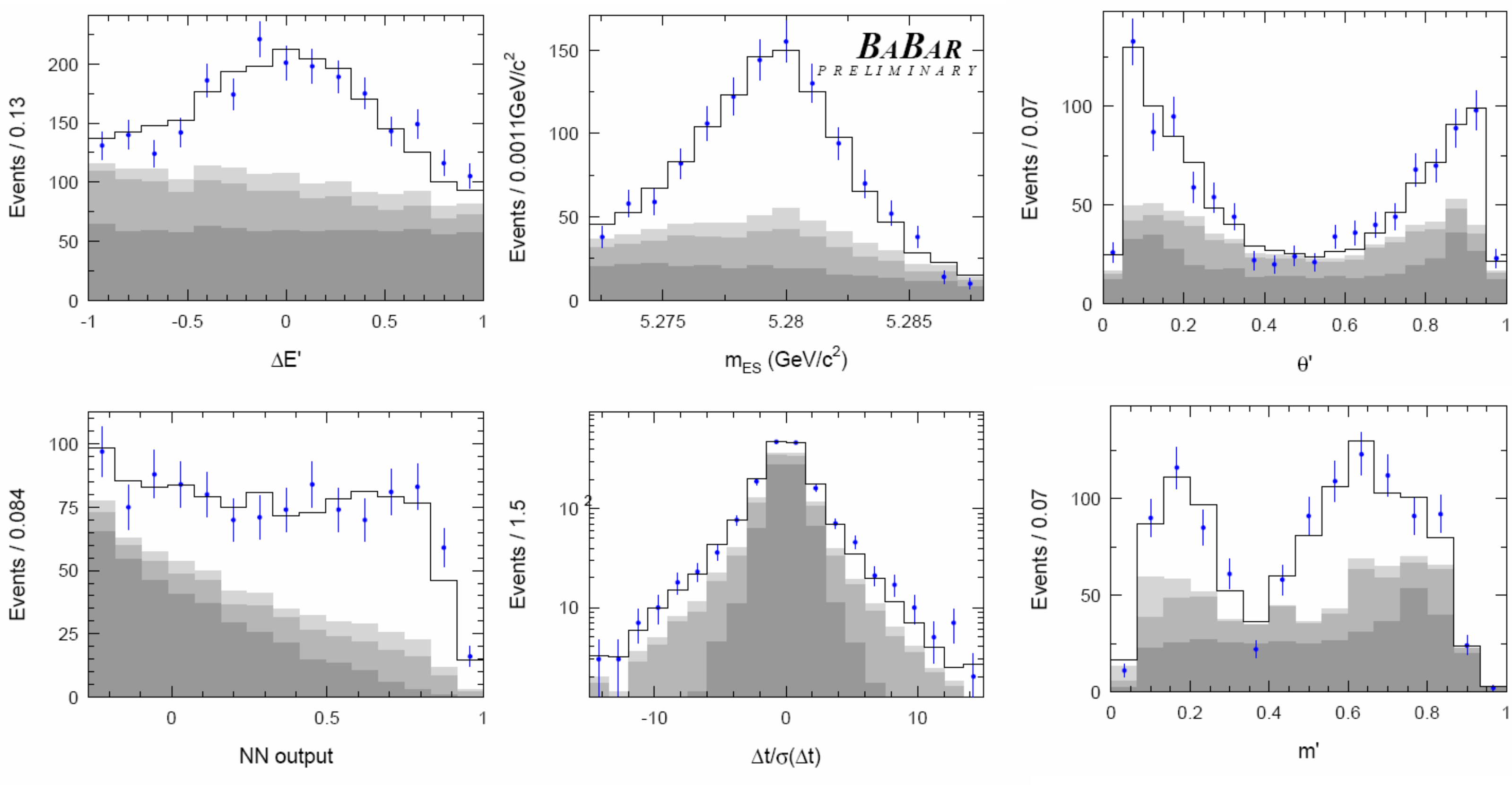
$$\Delta C = \frac{1}{2}\left(\frac{U_+^-}{U_+^+} - \frac{U_-^-}{U_-^+}\right) \qquad \Delta S = \frac{I_+}{U_+^+} - \frac{I_-}{U_-^+}$$

ΔS and ΔC are not CP observables

B→ρπ

hep-ex/0608002

- Updated result using 347×10^6 B pairs



TM signal	← Correctly reconstructed signal
SCF signal	← Mis-reconstructed signal
B-background	
Continuum	

$1847 \pm 69 \; B \rightarrow \pi^+\pi^-\pi^0$ signal

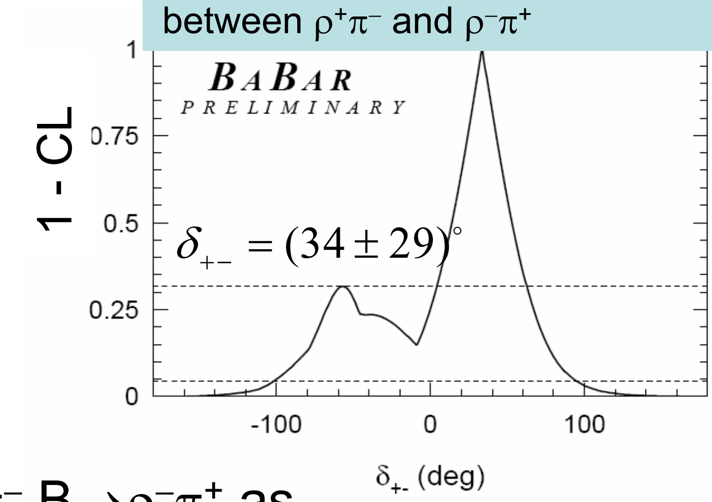
Results

- Convert the 27 fitted coefficients into observables used in the Q2B analysis (where one analyses the narrow ρ bands in the Dalitz plot)

$$\mathcal{A}_{\rho\pi} = -0.142 \pm 0.041 \pm 0.015 ,$$
$$C = 0.154 \pm 0.090 \pm 0.037 ,$$
$$S = 0.01 \pm 0.12 \pm 0.028 ,$$

$$\Delta C = 0.377 \pm 0.091 \pm 0.021 ,$$
$$\Delta S = 0.06 \pm 0.13 \pm 0.029 .$$

δ_{+-} is the strong phase difference between $\rho^+\pi^-$ and $\rho^-\pi^+$

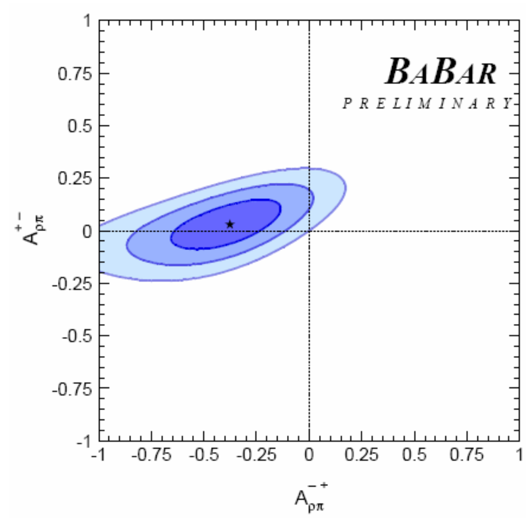


- We can also study A_{CP} for $B \to \rho^+\pi^-$ $B \to \rho^-\pi^+$ as

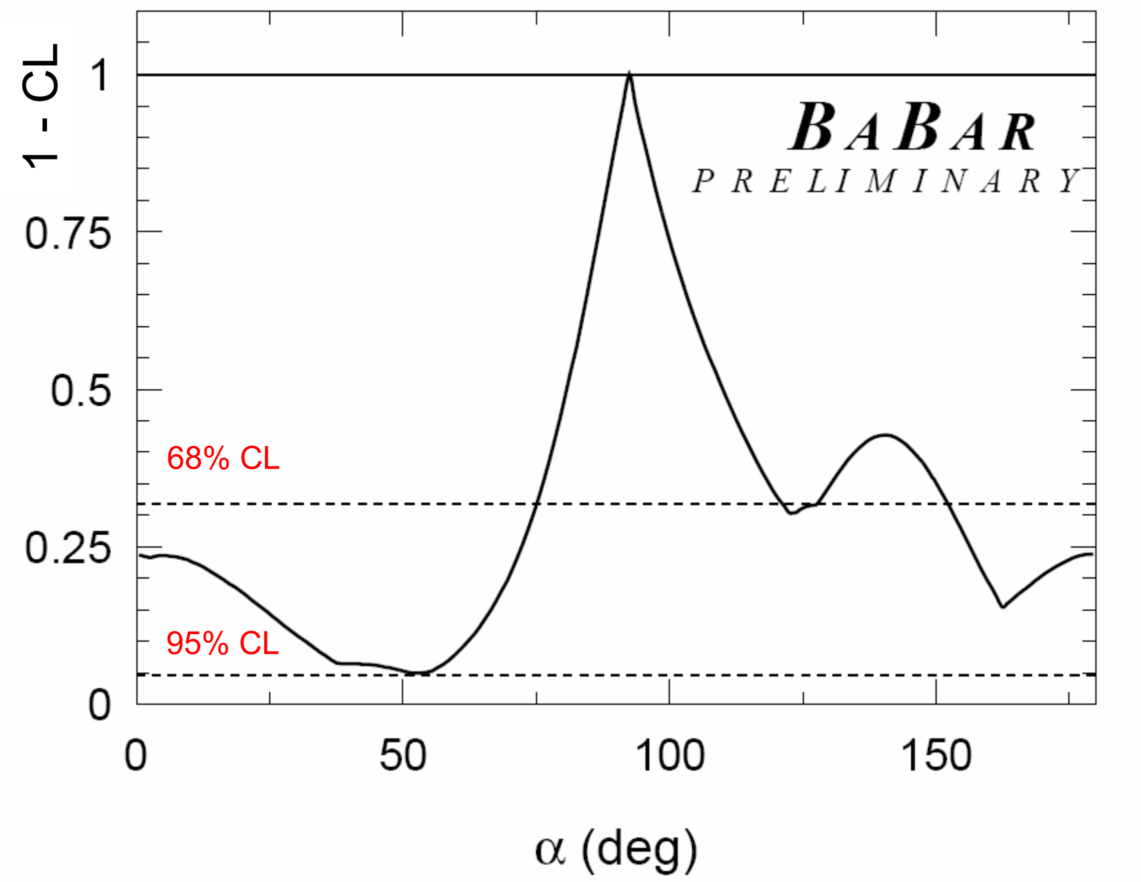
$$A_{\rho\pi}^{-+} = \frac{A_{\rho\pi} - C - A_{\rho\pi}\Delta C}{1 - C - A_{\rho\pi}\Delta C}$$

$$A_{\rho\pi}^{+-} = \frac{A_{\rho\pi} + C + A_{\rho\pi}\Delta C}{1 + C + A_{\rho\pi}\Delta C}$$

$$\mathcal{A}_{\rho\pi}^{+-} = 0.03 \pm 0.07 \pm 0.03 ,$$
$$\mathcal{A}_{\rho\pi}^{-+} = -0.38\,^{+0.15}_{-0.16} \pm 0.07 ,$$

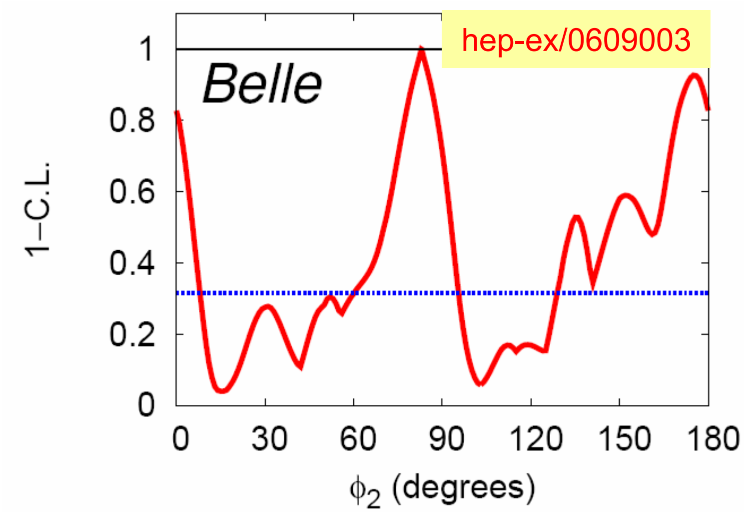


Constraint on α



hep-ex/0608002

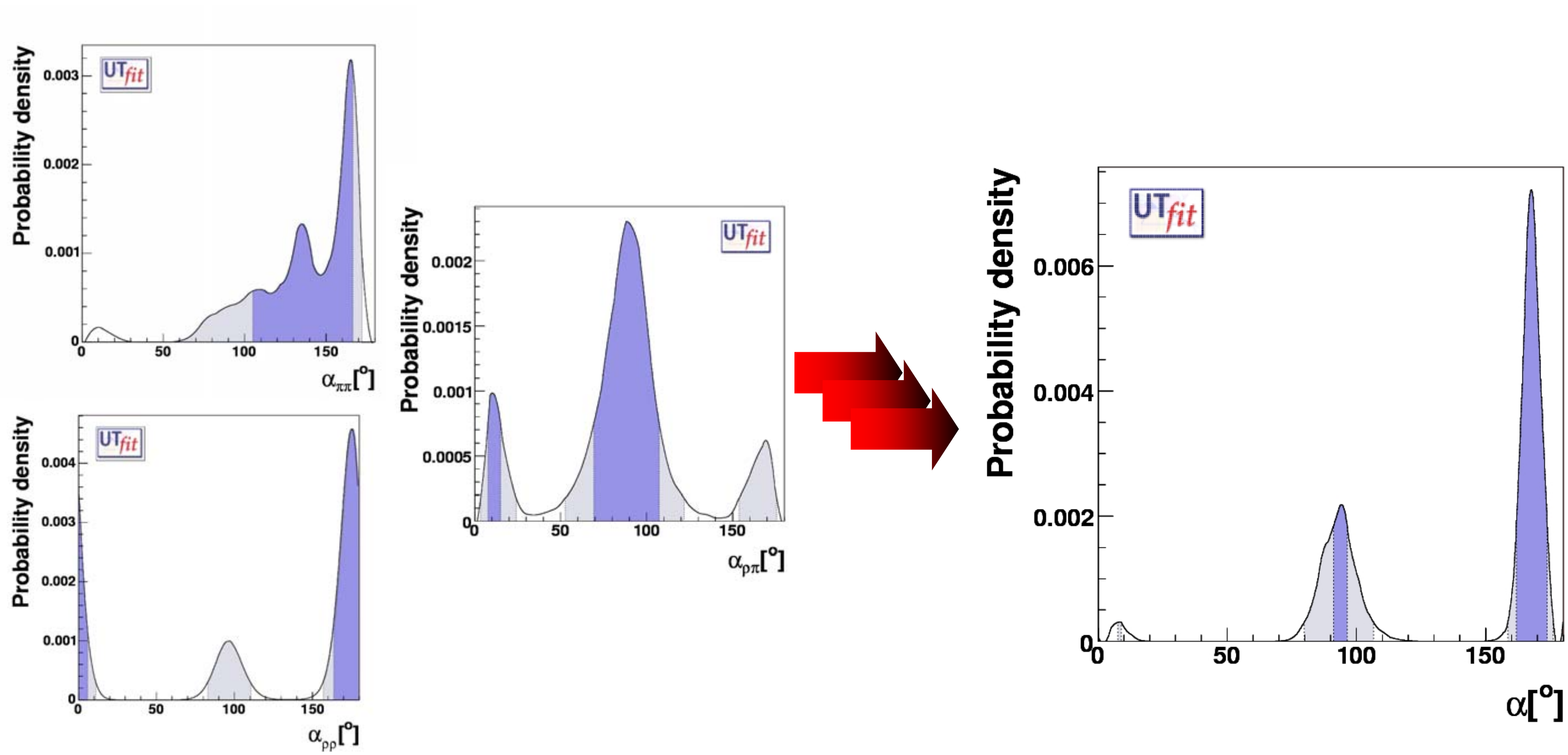
- Data prefer $\alpha \sim 90°$
- No constraint at 95% CL
- Need more data for a precision measurement.



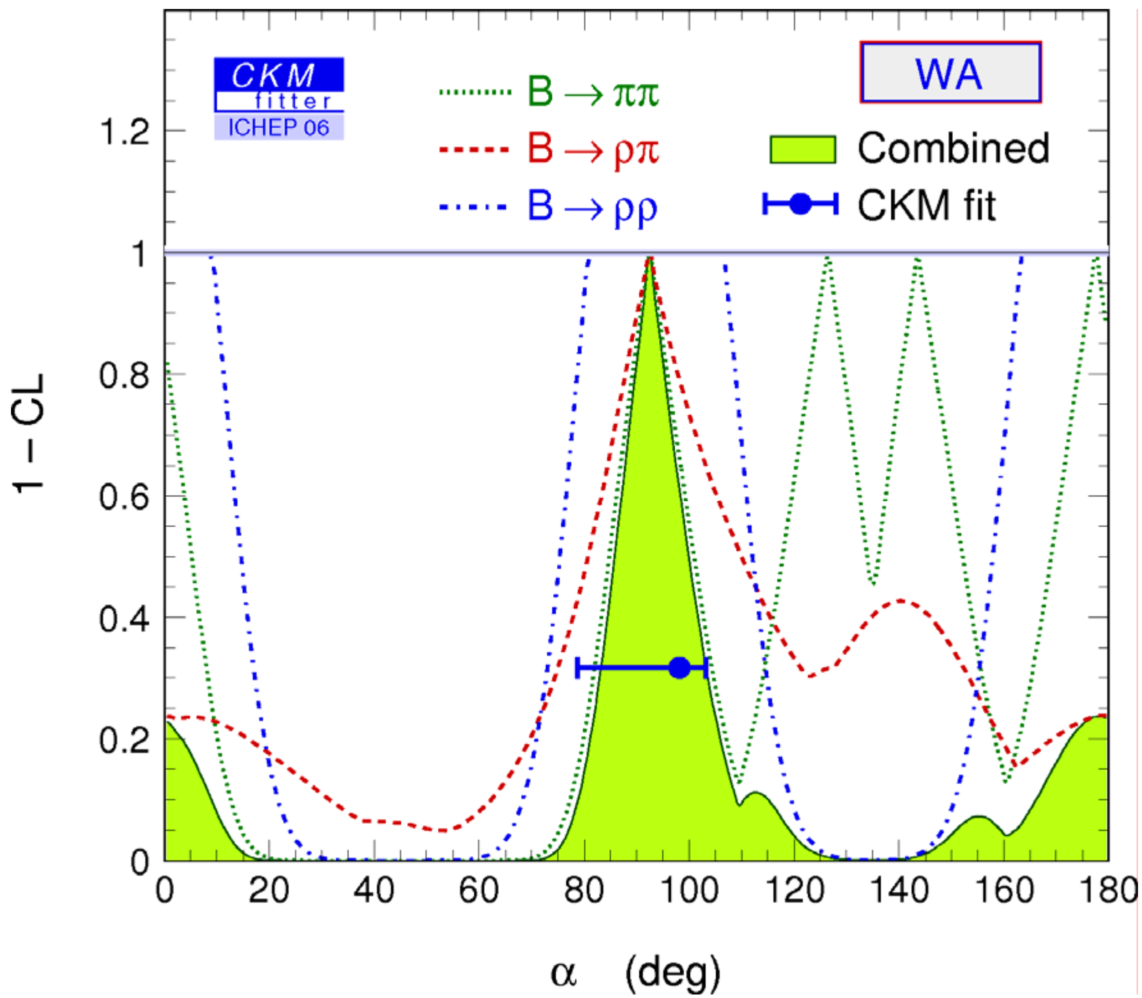
- An alternative would be to use SU(3) to obtain a model dependent result with better precision and 15° theory uncertainty [see M. Gronau and J. Zupan PRD**70** (2004) 074031].

Combination of results

- Two statistical methods:
  – UT Fit: http://www.utfit.org
  – CKM Fitter: http://www.slac.stanford.edu/xorg/ckmfitter/ckm_welcome.html



Combination of results

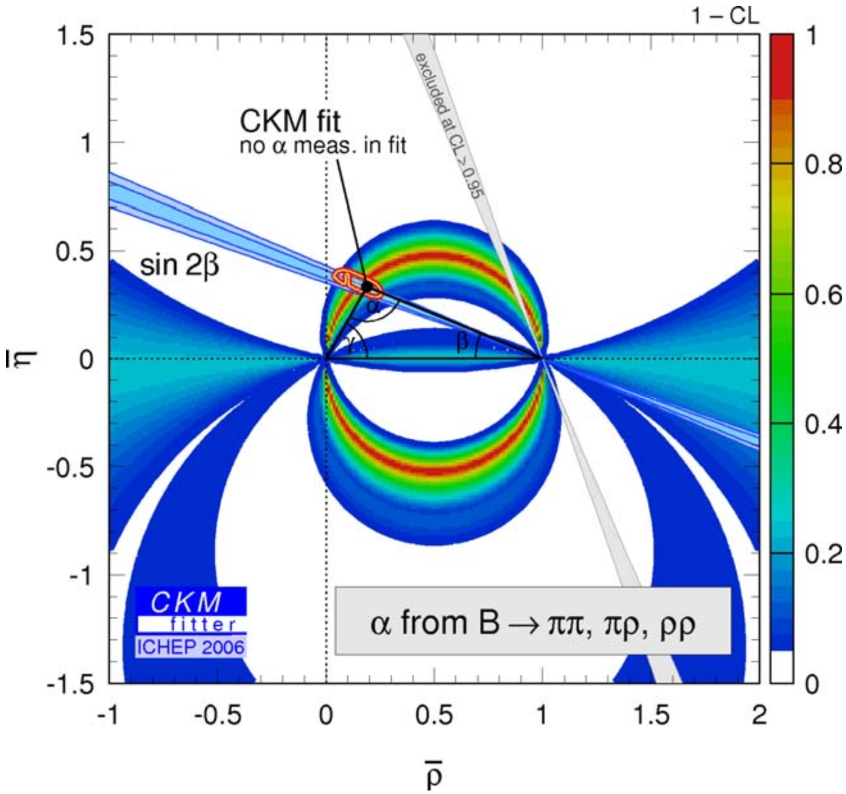


$\alpha_{\text{B-Factories}} = [\, 93^{+11}_{-9}\,]^{\circ}$

- The constraint on α obtained is dependent on the statistical treatment used.
- This is a reflection of the fact that we need more data to perform a precision measurement of α.
- Excluded regions are common to both methods.

This constraint does not include the latest result from Belle's $\rho\pi$ analysis

Finding the apex of the triangle...



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

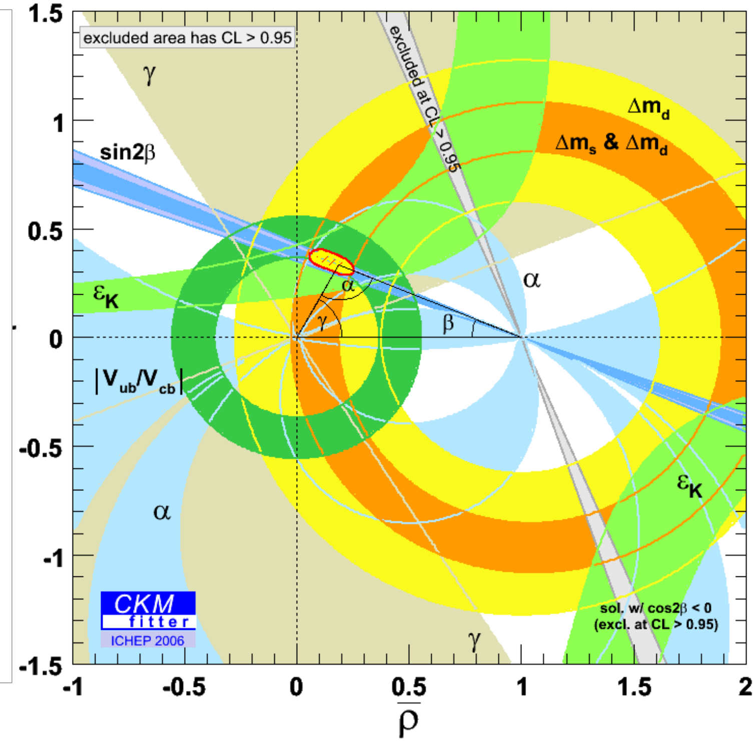
$B \to \tau\nu$

$|\varepsilon_K|$

$\sin 2\beta$

~~α~~

γ



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$B \to \tau\nu$

$|\varepsilon_K|$

$\sin 2\beta$

α

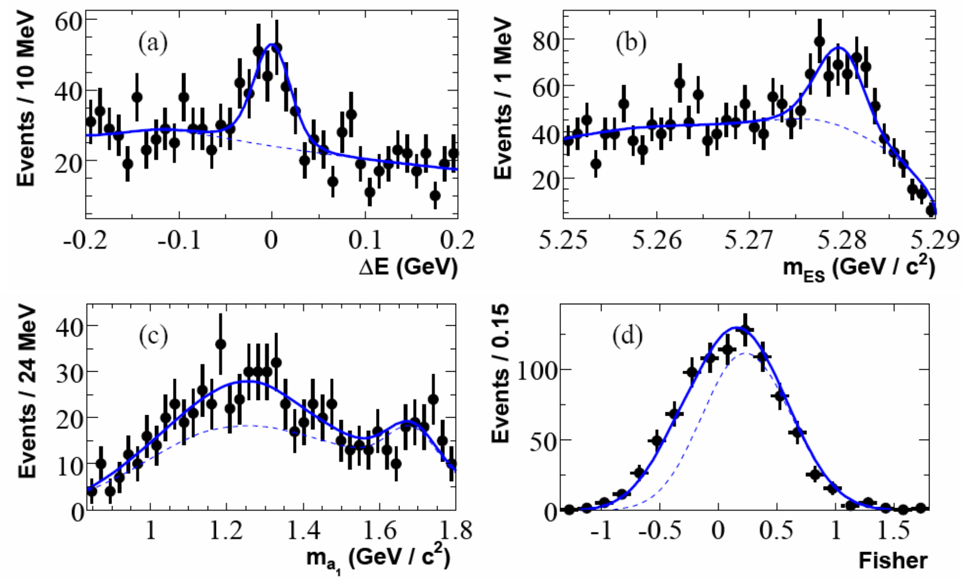
γ

This constraint does not include the latest result from Belle's $\rho\pi$ analysis

$B \to a_1\pi$ something for the future?

PRL **97** (2006) 051802

- Not a CP eigenstate like $B \to \rho\pi$.
- First observation of this channel (9.2σ).
- First step towards extracting α.



$$\mathcal{B}(B^0 \rightarrow a_1^{\pm}(1260)\pi^{\mp}) = (33.2 \pm 3.8 \pm 3.0) \times 10^{-6}$$

- To complete the puzzle we need a time dependent analysis, and to study related decays

[$K_1\pi$ etc. see Gronau and Zupan PRD **73** (2006) 057502].

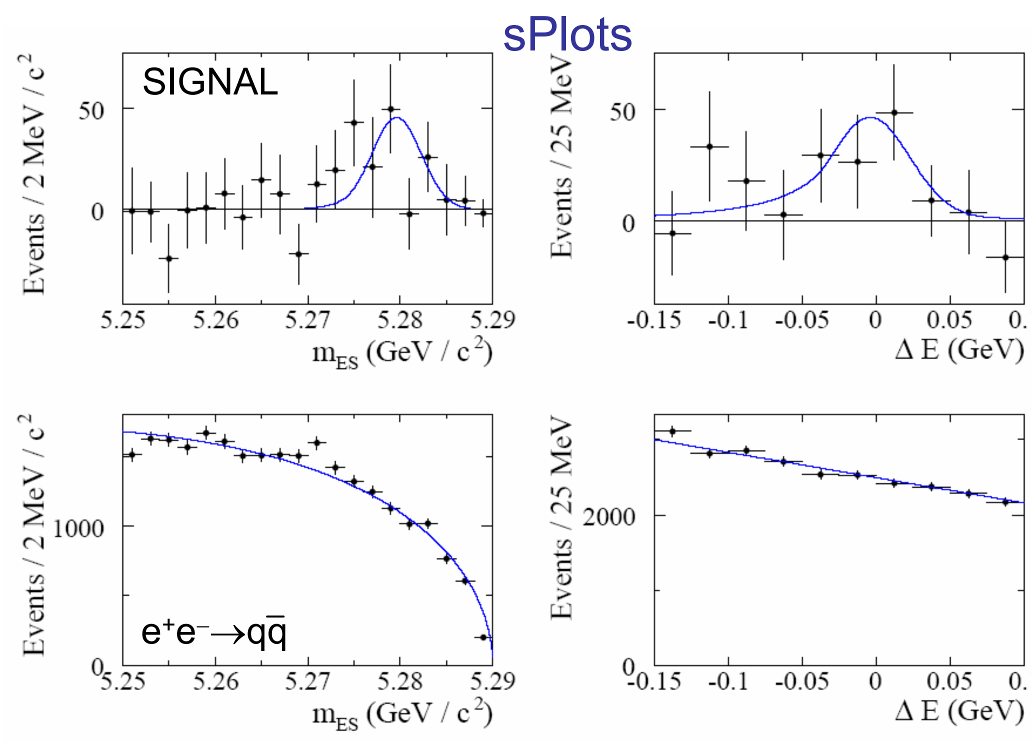
$B \to a_1 \rho$

PRD **74** (2006) 031104(R)

- Motivation analogous to $\rho\rho$ and $a_1\pi$ (this is an AV final state).
- Also a background to other charmless decays
- Using a data sample of 110x10^6 B pairs:

$$BR(B^0 \to a_1^{\pm}\rho^{\mp}) < 61\times10^{-6}\,(90\%\ \mathrm{CL})$$

- Little prospect to measure α with this decay channel.
- Improved upon the previous upper limit by more than a factor of 50.



Conclusions

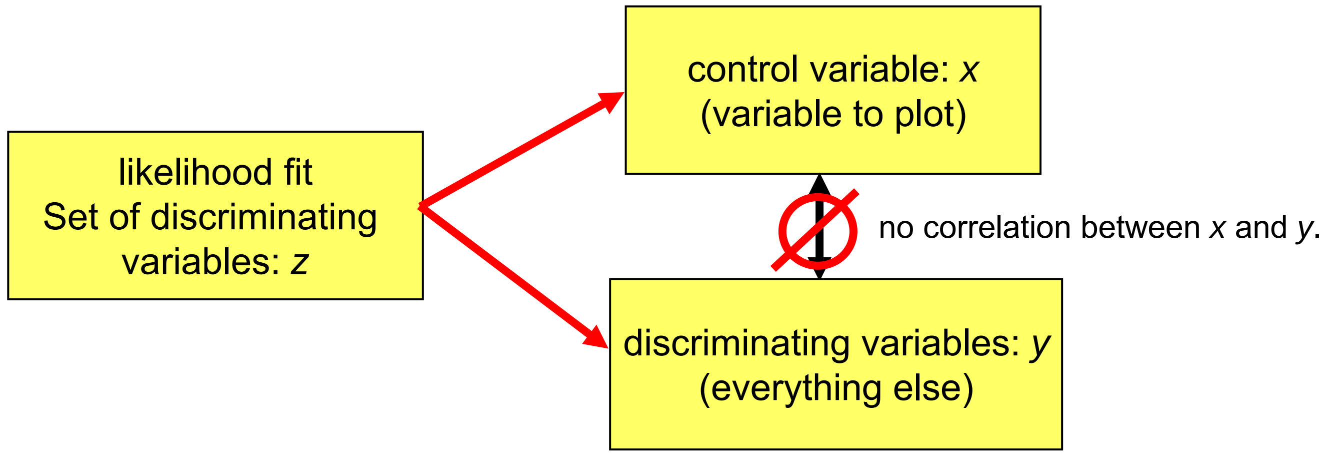
- Evidence for CP violation in $B \rightarrow \pi^{+}\pi^{-}$.
- Updated measurements of the inputs to the $\rho\rho$ isospin analysis weaken the constraint on α from $\rho\rho$.
- 1-2σ constraint on α from $\pi^{+}\pi^{-}\pi^{0}$ Dalitz analysis
  - very useful when combining the result with other measurements.
- SU(3) approach is more precise than isospin analysis for both of these.
- $a_1\pi$ may be able to provide an additional check
- Null result from search for $a_1\rho$ not encouraging.
- Combining $\pi\pi$, $\rho\pi$ and $\rho\rho$ gives a measurement of α with precision ~10°.

Additional Material

sPlots

NIM A555 (2005) 356-369
(physics/0402083)

- Technique for visually representing fit species in a maximum likelihood fit.



- Calculate an sWeight for each event
  - based on PDFs for variables, *y*
  - summed over set of species, *k*

$$ {}_s\mathcal{P}_{\mathrm{n}}(y_e) = \frac{\sum_{j=1}^{\mathrm{N_s}} \mathbf{V}_{\mathrm{n}j} \mathrm{f}_j(y_e)}{\sum_{k=1}^{\mathrm{N_s}} N_k \mathrm{f}_k(y_e)} $$

sWeight

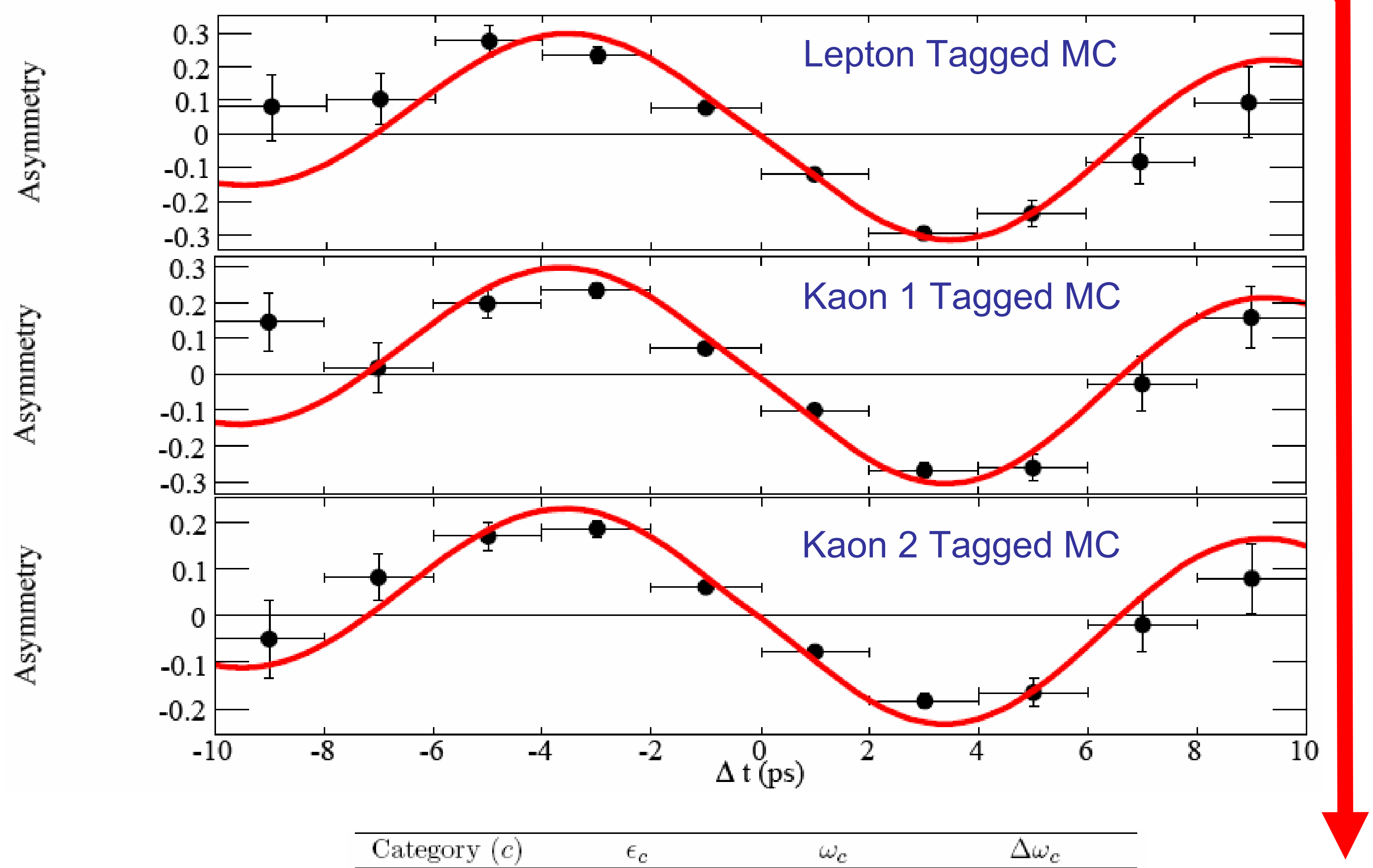
covariance matrix

PDF for variables, *y*

Number of species, k

- An sPlot for a variable is made without using that variable in the likelihood.

Flavor Tagging



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Pion	0.137 ± 0.002	0.327 ± 0.007	0.059 ± 0.010
Other	0.095 ± 0.001	0.412 ± 0.008	0.042 ± 0.001
Untagged	0.266 ± 0.002	0.500 ± 0.000	0.000 ± 0.000

Amplitude of oscillation decreases for a given S and C as the mistag probability ω_c increases.

The effective tagging efficiency decreases with increasing ω_c

$Q=\varepsilon_c(1-2\omega_c)^2$