CP-violating Asymmetries in $B^0 \to a_1(1260)^{\pm} \pi^{\mp}$ Decays

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Outline

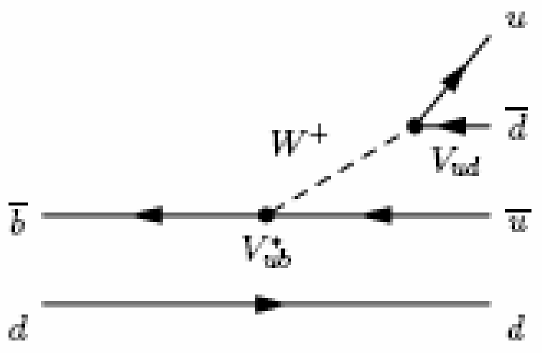
- Physics Motivation
  - CP violation in $B^0 \rightarrow a_1^{\pm} \pi^{\mp}$ $(a_1^{\pm} \rightarrow \pi^{\pm} \pi^{\mp} \pi^{\pm})$
  - α_{eff} extraction and SU(3) bounds
- Branching Fraction Measurement
- Time-Dependent CP Analysis
- Fit Results
- Analysis Improvements ? Other Decay Modes?
- Conclusions

Physics Motivation

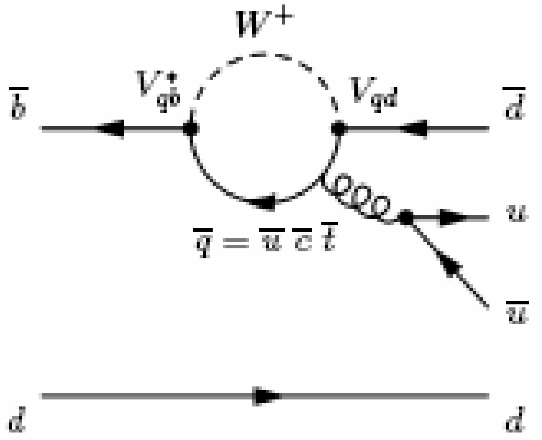
- B decays to $a_1\pi$, may be used to measure TD CP-asymmetries and extract the weak phase α in a new and independent way from $\pi\pi$, $\rho\pi$, $\rho\rho$.

R. Aleksan et al, NP B361, 141 (1991)
The BaBar Physics Book, p.404
M. Gronau, J. Zupan , PRD73, 057502 (2006)

- Penguin contributions alter the values of CP-violating parameters → we extract α_{eff} :



Tree



(Gluonic) Penguin

Decay Modes

In the present analysis we use only all-charged pions mode

- $B^0 \to a_1^+ \pi^-$
- $B^0 \to a_1^- \pi^+$

$$\left\{\begin{array}{l}\boxed{\pi^+\pi^-\pi^+\pi^-}\\ \pi^+\pi^0\pi^0\pi^-\end{array}\right.$$

Same CP asymmetries.

- $B^0 \to a_1^0 \pi^0$ $\quad \pi^+\pi^0\pi^-\pi^0$

CP eigenstate.

- $B^+ \to a_1^+ \pi^0$ $\quad \pi^+\pi^-\pi^+\pi^0$ $\quad (\pi^+\pi^0\pi^0\pi^0)$
- $B^+ \to a_1^0 \pi^+$ $\quad \pi^+\pi^0\pi^-\pi^+$

+ charge conjugate modes

Q2B vs Amplitude and Isospin Analyses

- We have 4 particles in the final state, with still problems with a_1 lineshape, limited statistics and background issues : time-dependent amplitude analysis is impractical.
- Full isospin analysis is unrealistic at available statistics : 2 pentagons in complex plane, 10 decay rates and asymmetries to be precisely measured, several ambiguities in α.
- So in our analysis we adopt a quasi-2-body approximation. Formalism is very similar to B^0 decays to $\rho^{\pm}\pi^{\mp}$ (Q2B)
- We use the cleanest decay mode with four charged pions in the final state

Measuring CP Parameters

$$\begin{cases} \Gamma(B^0(t)\rightarrow a_1^{\pm}\pi^{\mp}) = (1 \pm A_{CP})e^{-|\Delta t|/\tau}/4\tau[1 + (C \pm \Delta C)\cos(\Delta m_d\,\Delta t) - (S \pm \Delta S)\sin(\Delta m_d\,\Delta t)] \\ \Gamma(\overline{B}^0(t)\rightarrow a_1^{\pm}\pi^{\mp}) = (1 \pm A_{CP})e^{-|\Delta t|/\tau}/4\tau[1 - (C \pm \Delta C)\cos(\Delta m_d\,\Delta t) + (S \pm \Delta S)\sin(\Delta m_d\,\Delta t)] \end{cases}$$

We measure A_{CP} , $\underbrace{S,\ C}$ $\underbrace{\Delta C, \Delta S}$

A_{CP} ↑ Time- and flavor-integrated charge asymmetry

$S,\ C$ ↑ Mixing-induced CP-violating parameters

$\Delta C, \Delta S$ ↑ CP-conserving parameters

Gronau-Zupan
PR D73, 057502 (2006)

SU(3) Bound on $|\alpha-\alpha_{eff}|$

Because of penguin pollution, using the measured quantities we extract α_{eff}

Upper bound to $|\alpha-\alpha_{eff}|$ calculable through the ratio of CP-averaged rates involving other SU(3) related decays (in the axial-vector nonet 1^{++}) :

$B^0 \rightarrow a_1^+ K^-$

$B^0 \rightarrow K_1^+(1270)\, \pi^-$, $B^0 \rightarrow K_1^+(1400)\, \pi^-$

See previous talk by Jure

and/or

$B^+ \rightarrow a_1^+ K^0$

$B^+ \rightarrow K_1^0(1270)\, \pi^+$ and $B^+ \rightarrow K_1^0(1400)\, \pi^+$

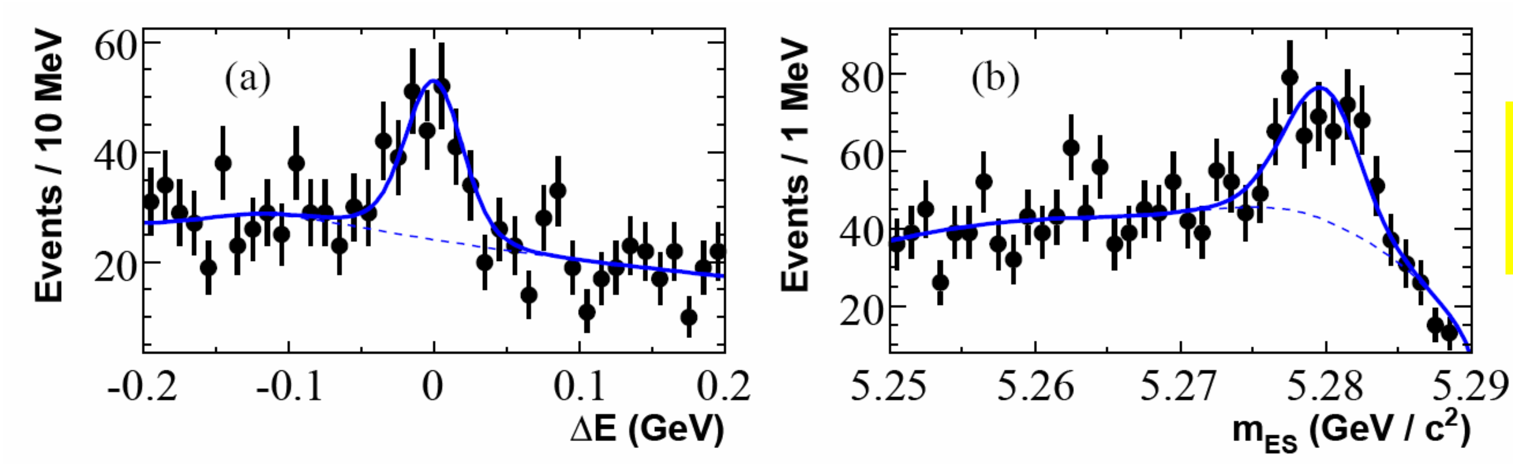
Such measurements are in progress

BF $B^0 \rightarrow a_1^{\pm} \pi^{\mp}$

BaBar already measured this BF with 218 million $B\overline{B}$ pairs

$$\mathcal{B}(B^0 \rightarrow a_1^{\pm}(1260)\,\pi^{\mp})\mathcal{B}(a_1^{\pm}(1260) \rightarrow \pi^{\mp}\pi^{\pm}\pi^{\pm}) = (16.6 \pm 1.9 \pm 1.5) \times 10^{-6}$$

PRL97, 051802 (2006)



9.2 σ significance

Belle preliminary result : BF($B^0 \rightarrow a_1^{\pm}\ \pi^{\mp}$) = (48.6 ± 4.1 (stat) ± 3.9 (syst)) 10^{-6}

TD CP Violation Analysis

Analysis done with 384 million $B\bar{B}$ pairs

Unbinned extended maximum likelihood fit with 6 discriminating variables :

M_{ES}	B meson mass
ΔE	B energy difference
F	Fisher discriminant (4 variables)
M_{a1}	a_1 meson invariant mass
H	angular variable (cosine of angle between normal to plane of 3π resonance and direction of bachelor pion in 3π resonance rest frame)
Δt	proper time difference

Δt Resolution Models

Δt distributions convolved with resolution function
(a sum of 3 Gaussians) determined

- ☐ from data for signal
- ☐ from off-resonance for continuum background
- ☐ from Monte Carlo simulations for $b \to c$
- ☐ $a_2(1320)\,\pi$, $\rho\pi\pi$ and charmless have the same model as signal but S, C, ΔS, $\Delta C = 0$ in nominal fit and varied for systematic uncertainty

Fit Model

- Six components in the likelihood: signal, charmless, charm, continuum background , $a_2(1320)^{\pm}\,\pi^{\mp}$, $\rho^0\pi^+\pi^-$

- Linear correlation among observables <10%. Factored form of PDF. Residual correlation accounted using MC pseudo-experiments.

- Flavor tagging with 6 mutually exclusive categories

- Total likelihood:

$$\mathcal{L} = \prod_c \exp\left(-n_c\right) \prod_i^{N_c} \left[\sum_j n_j f_{j,c} \mathcal{P}^i_{j,c} \right]$$

- $f_{j,c}$ fraction of events of fit component j in category c

Fit Parameters and Checks

- 35 free parameters in the fit :

  S, C, ΔS, ΔC, A_{CP}^{sig}, $A_{CP}^{q\bar{q}}$, 5 yields,
  the width Γ of signal a_1,
  11 parameters of combinatorial background,
  12 tag efficiencies for the continuum $q\bar{q}$.

- Fit procedure validated with MC $q\bar{q}$ pseudo-experiments drawn from PDF into which we embed expected numbers of signal, charm, charmless, $a_2(1320)\ \pi$, and $\rho\pi\pi$

- Measured quantities have been corrected for small fit biases

Fit Results

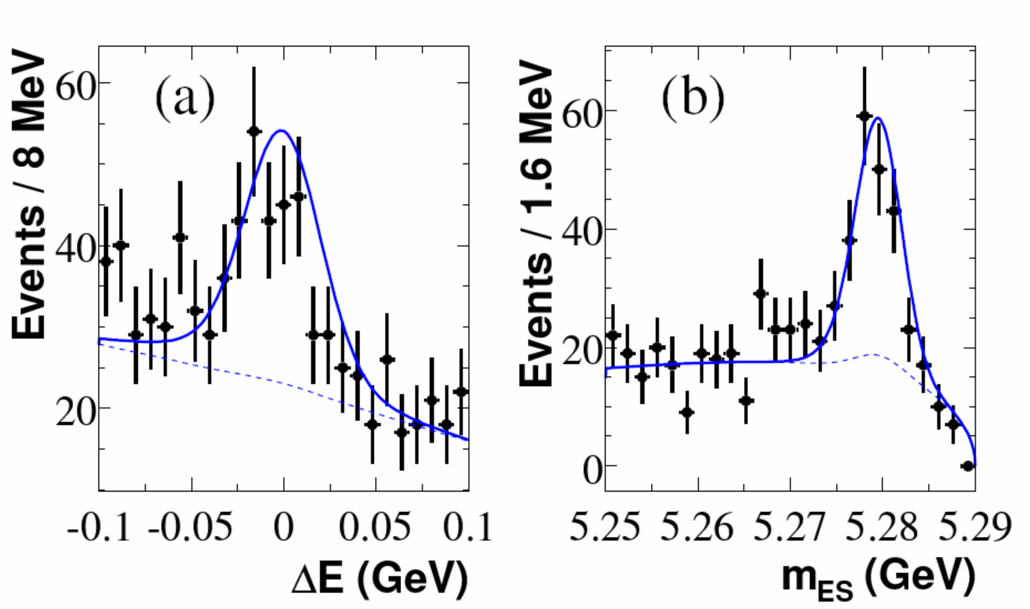
With an input to ML of 29300 events, we obtain the following results :

$S= 0.37 \pm 0.21$ $C= -0.10 \pm 0.15$

$\Delta S= -0.14\pm 0.21$ $\Delta C= 0.26 \pm 0.15$

$A_{CP} = -0.07 \pm 0.07$

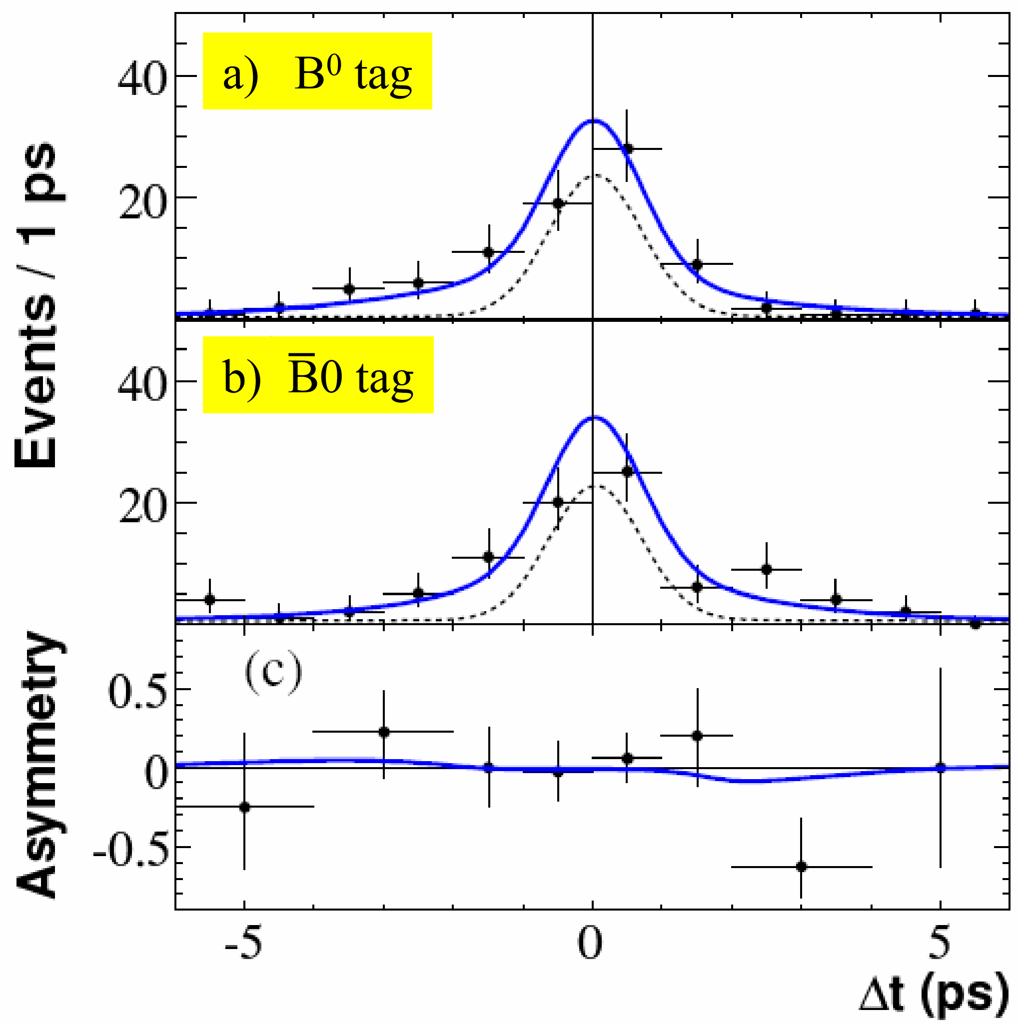
Projections with a cut on the likelihood ratio (to enhance the signal) . 28% of signal survives this cut



Δt Projections

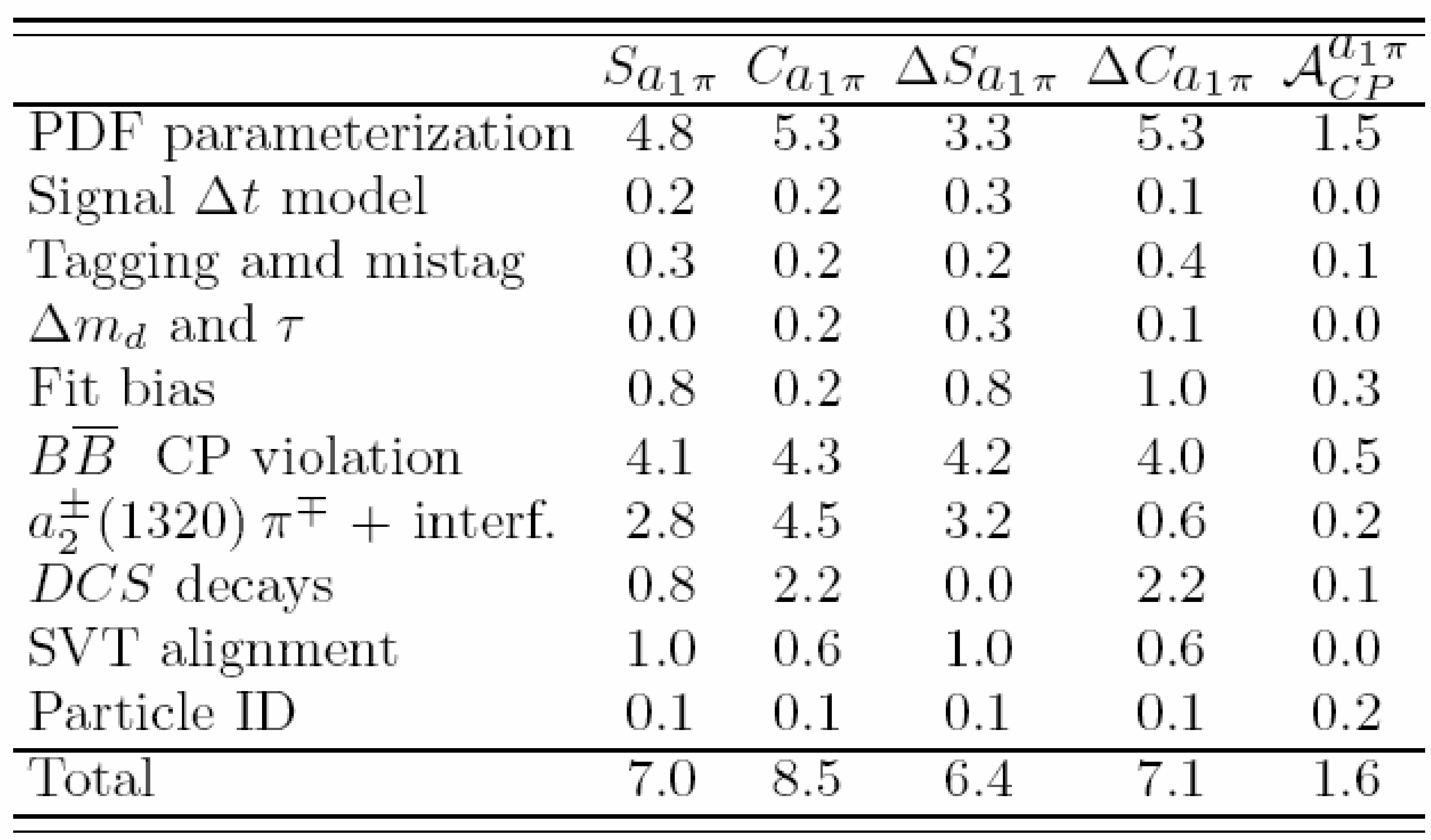
Events selected with a cut on the likelihood ratio

$$\frac{N_{B0} - N_{\overline{B}0}}{N_{B0} + N_{\overline{B}0}}$$



Systematic Uncertainties

(in units of 10^{-2})



	$S_{a_1\pi}$	$C_{a_1\pi}$	$\Delta S_{a_1\pi}$	$\Delta C_{a_1\pi}$	$\mathcal{A}_{CP}^{a_1\pi}$
PDF parameterization	4.8	5.3	3.3	5.3	1.5
Signal Δt model	0.2	0.2	0.3	0.1	0.0
Tagging amd mistag	0.3	0.2	0.2	0.4	0.1
Δm_d and τ	0.0	0.2	0.3	0.1	0.0
Fit bias	0.8	0.2	0.8	1.0	0.3
$B\overline{B}$ CP violation	4.1	4.3	4.2	4.0	0.5
$a_2^{\pm}(1320)\,\pi^{\mp}$ + interf.	2.8	4.5	3.2	0.6	0.2
DCS decays	0.8	2.2	0.0	2.2	0.1
SVT alignment	1.0	0.6	1.0	0.6	0.0
Particle ID	0.1	0.1	0.1	0.1	0.2
Total	7.0	8.5	6.4	7.1	1.6

Extracting α_{eff}

α_{eff} can be extracted using the formula :

$$\alpha_{eff} = \frac{1}{4}\left[\arcsin\left(\frac{S+\Delta S}{\sqrt{1-(C-\Delta C)^2}}\right) + \arcsin\left(\frac{S-\Delta S}{\sqrt{1-(C+\Delta C)^2}}\right)\right]$$

Gronau-Zupan
PR D73, 057502 (2006)

- In absence of penguin contribution → $\boldsymbol{\alpha_{\mathrm{eff}} = \alpha}$
- 4-fold ambiguity in α_{eff}

α_{eff}

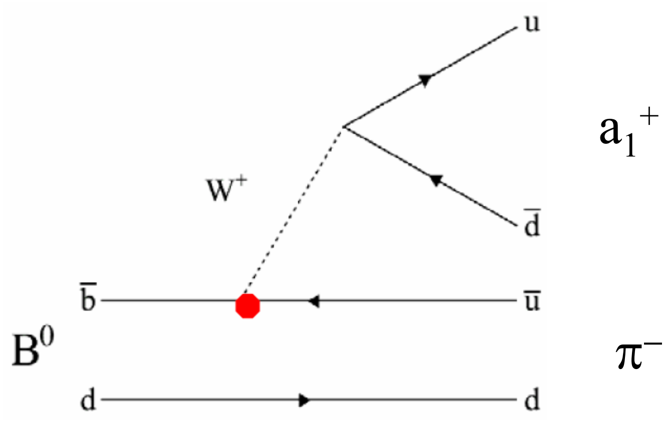
Using the measured quantities S, C, ΔS, ΔC we determine :

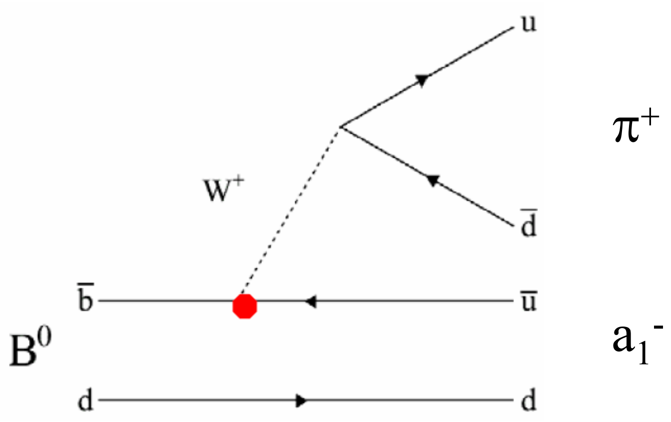
- the four values of α_{eff} : 78.6^0, 49.3°, 40.7°, 11.5°
- and we take the one consisting with the SM:

$$\alpha_{eff} = 78.6° \pm 7.3°$$

stat + syst error

Flavor and Charge Specific BFs





Flavor-charge Branching Fractions :

$$BF(\overline{B}^0 \rightarrow a_1^- \pi^+) = (11.3 \pm 2.9)\ 10^{-6}$$

$$BF(B^0 \rightarrow a_1^+ \pi^-) = (9.6 \pm 2.4)\ 10^{-6}$$

$$BF(\overline{B}^0 \rightarrow a_1^+ \pi^-) = (7.0 \pm 2.2)\ 10^{-6}$$

$$BF(B^0 \rightarrow a_1^- \pi^+) = (5.3 \pm 2.3)\ 10^{-6}$$

Analysis Improvements ?

- Possible a Dalitz analysis for a_1 to 3 π. But small signal sample in a huge background, uncertainties in a_1 lineshape.

- We can add $B^0 \rightarrow a_1^{\pm} \pi^{\mp}$ with $a_1^{\pm} \rightarrow \rho^{\pm} \pi^0$ and $\rho^{\pm} \rightarrow \pi^{\pm} \pi^0$ to all-charged final state to enhance statistics. Same asymmetries. But 2 π^0 , large background.

Other Decay Modes ?

- $a_1{}^0\,\pi^0$ is a CP eigenstate. In this case the TD CP violating parameter S is simply S= sin(2α) (if no penguin and only one amplitude dominating the decay). But one measures infact $\sin 2\alpha_{eff}$ because of penguins.

- BF is expected suppressed (factorization model with no rescattering effect) M. Bauer et al Z. Phys. C31, 103 (1987). May be enhanced by FSI ?

- $B^0 \rightarrow a_1^{\pm}\,\rho^{\mp}$ only an upper limit exists : $30 \bullet 10^{-6}$ (90% CL) It could be used for TD if signal is observed.

Conclusions

With a total sample of 29300 in input in the ML fit, we measure for the first time in the B^0 decay to $a_1^{\pm}\pi^{\mp}$:

The mixing-induced CP violation parameter $S = 0.37 \pm 0.21 \pm 0.07$

The direct-CP violation parameter $C = -0.10 \pm 0.15 \pm 0.09$

The dilution parameters $\Delta S = -0.14 \pm 0.21 \pm 0.06$

$\Delta C = 0.26 \pm 0.15 \pm 0.07$

Time- and flavor-integrated charge asymmetry

$A_{CP} = -0.07 \pm 0.07 \pm 0.02$

And we extract $\alpha_{eff} = 78.6° \pm 7.3°$

Determination of SU(3) bound on $\Delta\alpha=|\alpha-\alpha_{eff}|$ is in progress