

# $B^0 \rightarrow \rho^0 K_s$ ; Branching Fraction and Time Dependent CP Analysis at BaBar

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# Introduction and Overview

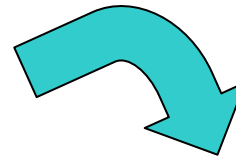
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- CKM Matrix, CP violation and the Unitarity Triangle
- Event selection
- Maximum Likelihood fit
- Branching fraction results
- CP fit validation

# CKM Matrix and Unitarity Triangle

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

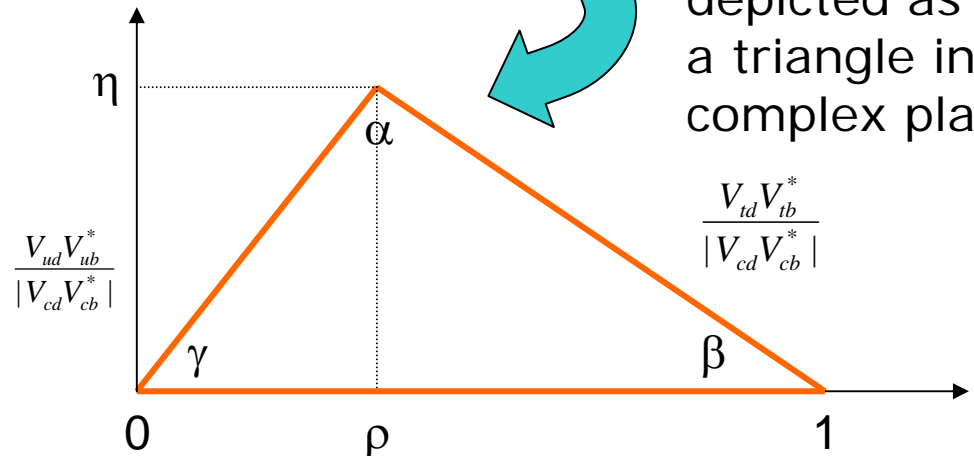
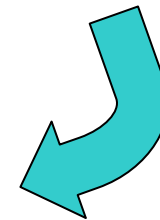
CKM matrix relates rotated quark states to physical states



Requirement of unitarity

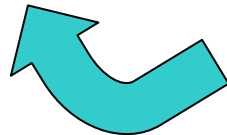
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

This relation is depicted as a triangle in the complex plane



$$\beta = -\arg \left[ \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \right]$$

Angles related to CKM matrix elements



# CP violation due to Interference between Mixing and Decay

$$A_{CP}(t) = \frac{\Gamma[\overline{B_0}(t) \rightarrow f_{CP}] - \Gamma[B^0(t) \rightarrow f_{CP}]}{\Gamma[\overline{B_0}(t) \rightarrow f_{CP}] + \Gamma[B^0(t) \rightarrow f_{CP}]}$$



$$A_{CP} = -C \cos(\Delta mt) + S \sin(\Delta mt)$$

Ratio of CKM elements  
In Feynman diagrams

$$S = \Im m \left( \eta_f \frac{q}{p} \frac{A_f}{A_f} \right)$$

**BB Mixing**

$$|B_L\rangle = p|B_0\rangle + q|\overline{B_0}\rangle$$

$$|B_H\rangle = p|B_0\rangle - q|\overline{B_0}\rangle$$

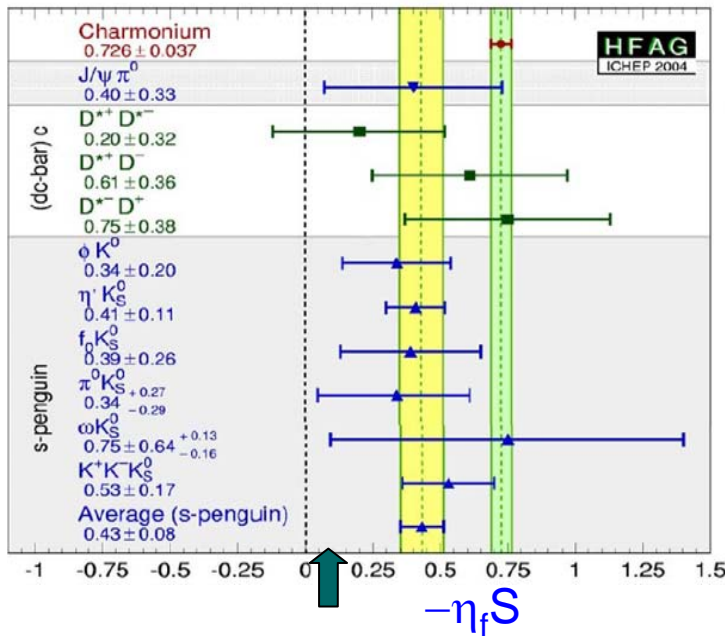
The diagram shows a box diagram for BB mixing. The top quark line starts with a  $b$  quark, emits a  $W^+$  boson (labeled  $V_{tb}$ ), and then a  $t$  quark line connects to a  $d$  quark line. The  $d$  quark line emits a  $W^-$  boson (labeled  $V_{td}$ ), which then connects to a  $\bar{b}$  quark line. The bottom quark line starts with a  $\bar{d}$  quark, emits a  $W^-$  boson (labeled  $V_{td}^*$ ), and then a  $t$  quark line connects to a  $b$  quark line. The  $b$  quark line emits a  $W^+$  boson (labeled  $V_{tb}^*$ ), which then connects to the  $t$  quark line in the top part of the box.

$$\frac{q_B}{p_B} = \frac{V_{td} V_{tb}^*}{V_{td}^* V_{tb}}$$

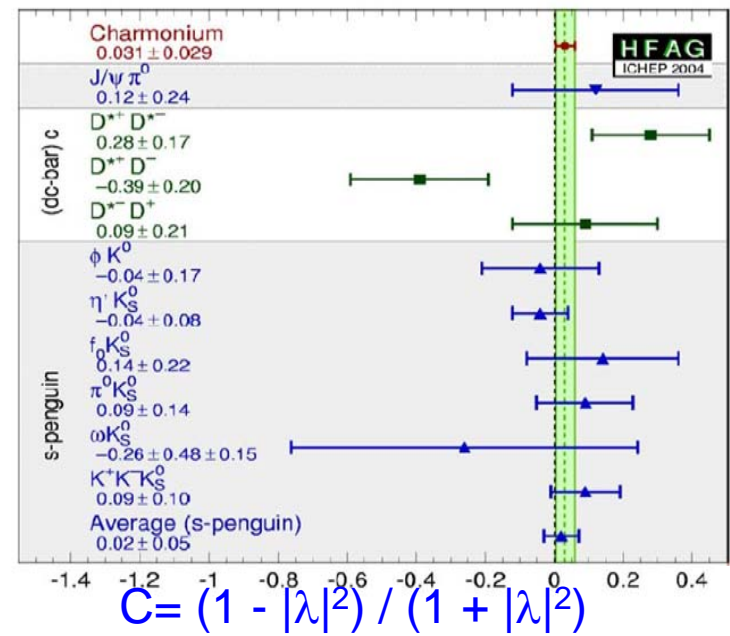
(Equivalent factor for KK mixing if decay involves  $K_S$ )

Particular B decays have physically interesting values of  $Im(\lambda)$  eg:  $B^0 \rightarrow J/\Psi K_S$  and decay modes dominated by 'b-s penguin' diagrams

# Measuring $\text{Sin}2\beta$ From b-s Penguins



3.6 $\sigma$  from s-penguin to  $\text{sin}2\beta$  (cc)

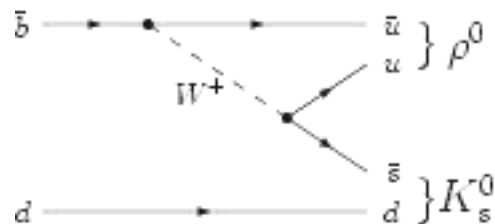


No sign of direct CP asymmetry

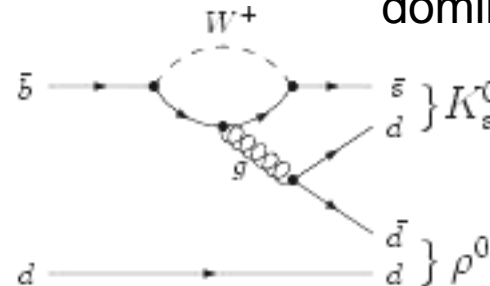
- b-s penguins showing signs of measuring a different value for b to  $c\bar{c}$  decays (eg  $B^0 \rightarrow J/\psi K_S$ )
- Interesting area of research at the moment



CKM suppressed  
Tree diagram



Gluonic penguin  
dominates



- The two leading order Feynman diagrams.
- Penguin decay has weak phase able to measure  $\beta$ , the Unitarity Triangle angle.
- We extract a measurement of  $\beta$  by performing a time dependent CP analysis using a maximum likelihood fit.

# Initial Event Selection

- $|\Delta E| < 0.3 \text{ GeV}$
- $m_{ES} > 5.18 \text{ GeV}$
- $\text{Cos}(Thrust \text{ angle}) < 0.9$
- $\Delta T < 20 \text{ ps}$ ,
- $\sigma\Delta T < 2.5 \text{ ps}$

$$\Delta E = E_B - E_{BEAM}$$

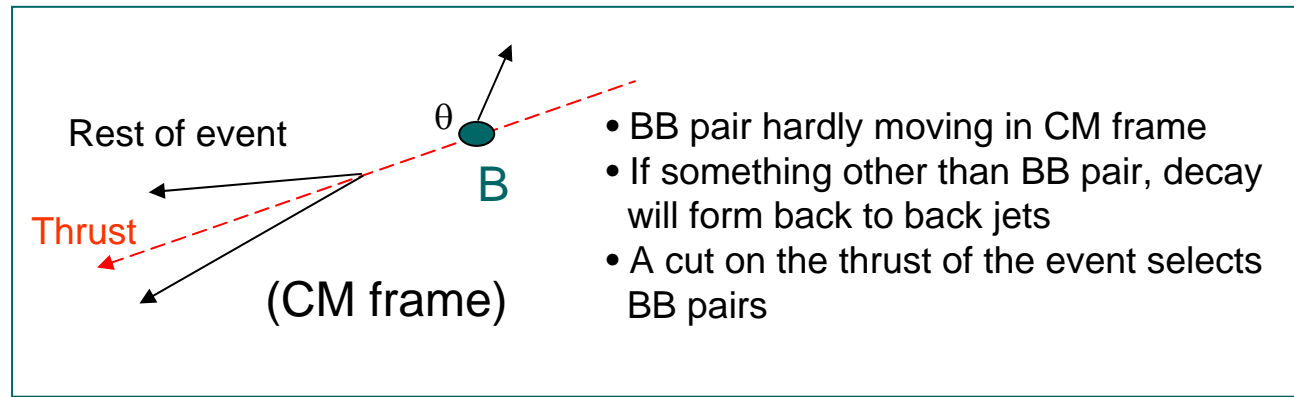
Energy of the B

Energy of the beam

$$m_{ES} = \sqrt{E_{BEAM}^2 - p_B^{*2}}$$

Center of mass  
Momentum of B

$\Delta T$  is the time  
between the decay  
of the B's



# Ntuple Level Selection

- The 2 tracks from the  $\rho^0$  are required to fail tight PID selections for e, p and K.
- Invariant mass of these two tracks must be within 0.375GeV of the PDG  $\rho^0$  mass (0.776GeV)
- $m_{ES} > 5.23\text{GeV}$  (on peak data),  $m_{ES} > 5.21\text{GeV}$  (off peak data)
- Cosine of pointing angle  $< 0.997$
- $K_s$  vertex must be displaced from the  $\rho^0$  vertex by more than 3x the error on the distance.
- Mass of  $K_s$  must be within 0.13GeV of the PDG value for the  $K^0_s$  (0.498GeV)
- Veto against  $D^+\pi^-$  and  $K^{*+}\pi^-$  by ensuring mass of  $K_s\pi$  combination are more than 0.055GeV and 0.04GeV away from the PDG masses of  $D^+$  and  $K^{*+}$ .
- Efficiency  $\sim 25\%$

Pointing angle is the Angle between the Displacement vector Between the  $\rho^0$  and The  $K_s$  and the  $K_s$  Momentum vector

# Backgrounds

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## Continuum Background

- Almost all of the events in our selection are continuum ~99%!!

## B Backgrounds

- Split into two fundamental categories; Charmed and Charmless.
- Charmed Backgrounds
  - Identified with MC.
  - Split up into B<sup>+</sup> and B<sup>0</sup> with all sub-modes collected together into two non-parametric PDF's
  - Charmless modes contributing < 1 event included in the PDF's
- Charmless Backgrounds
  - Identified with Generic MC all modes contributing > 1 event.
  - Modeled with non-parametric PDF.

# Maximum Likelihood Fit

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## Discriminating Variables

- mES
- $\Delta E$
- Neural Net  
Output (NNO)
- $\text{Cos}(q\text{HELICITY})$
- $\Delta T$
- $\pi\pi$  Mass

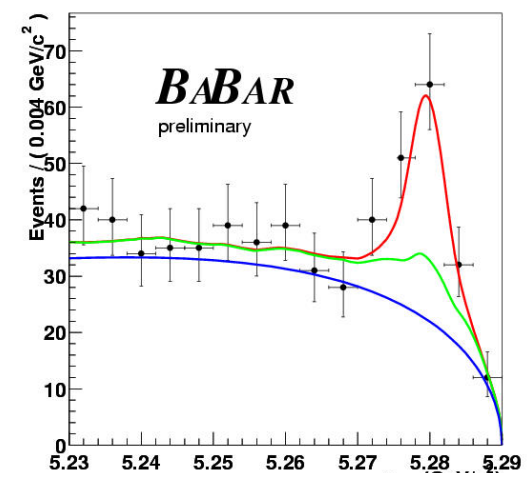
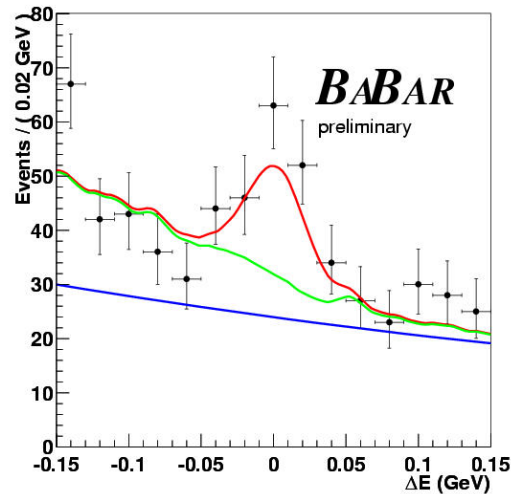
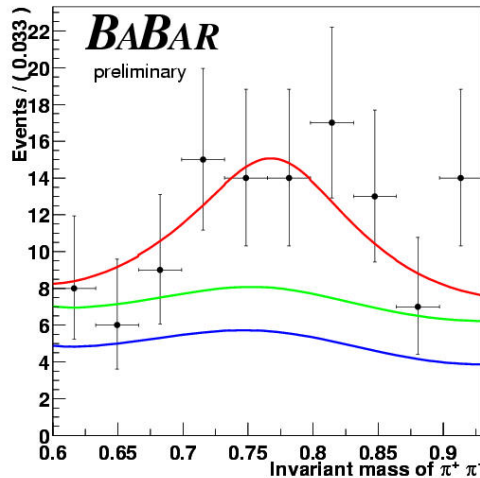


NNO: Inputs to the neural net are:

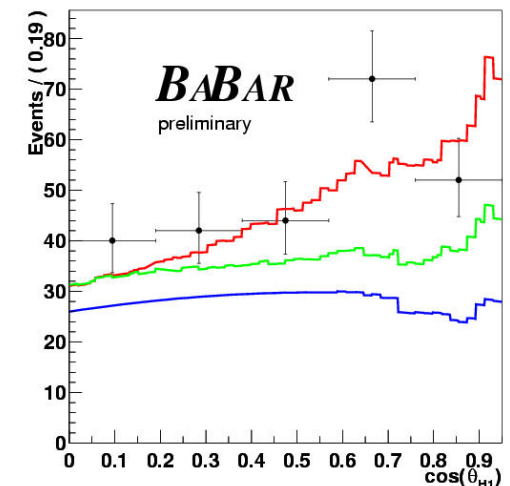
- Fisher: combines neutral and charged, 0<sup>th</sup> and 2<sup>nd</sup> order Legendre monomials
- Sum of the transverse momentum
- Cosine of angle between direction of B and the thrust axis
- Cosine of angle between direction of B and the z axis
- Cosine of angle between thrust axis of B and the z axis

# Results of BF Fit

(Dataset – 227 million BB pairs corresponding to 205 fb<sup>-1</sup> int. luminosity)

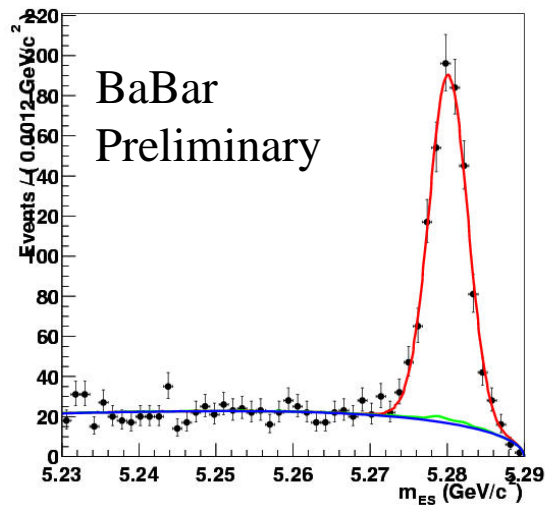


- $BF(B^0 \rightarrow \rho^0 K_S) = (5.1 \pm 1.0 \pm 1.2) \times 10^{-6}$
- Float a non-resonant  $B^0 \rightarrow K_S \pi \pi$  component with flat helicity distribution
- Evidence for  $B^0 \rightarrow \rho^0 K_S$  at the 3.6 $\sigma$  level
- Presented at ICHEP 2004



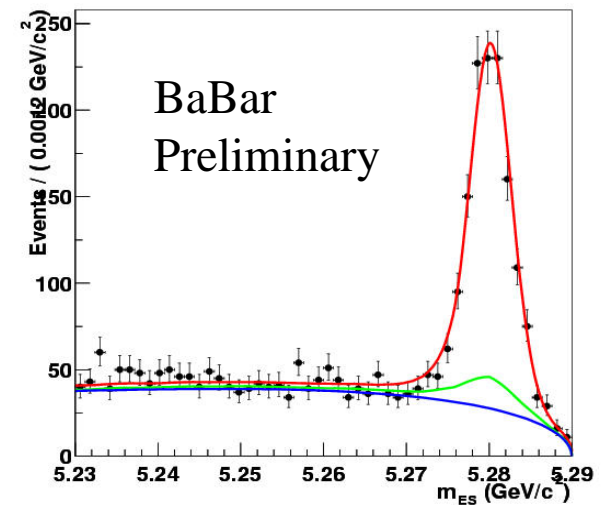
# CP Fit Validations

Validation fits use the nominal fit but selecting the mass of The  $J/\psi$  or  $D^+$  instead of the  $\rho^0$



Plots of variable  $M_{ES}$

— Total  
— Continuum  
— Continuum + BBkg



$B^0 \rightarrow J/\psi K_s$  study  
Fit CP parameters to values consistent with theory

$B^0 \rightarrow D^+ \pi^-$  study  
Also fit CP parameters to values consistent with theory

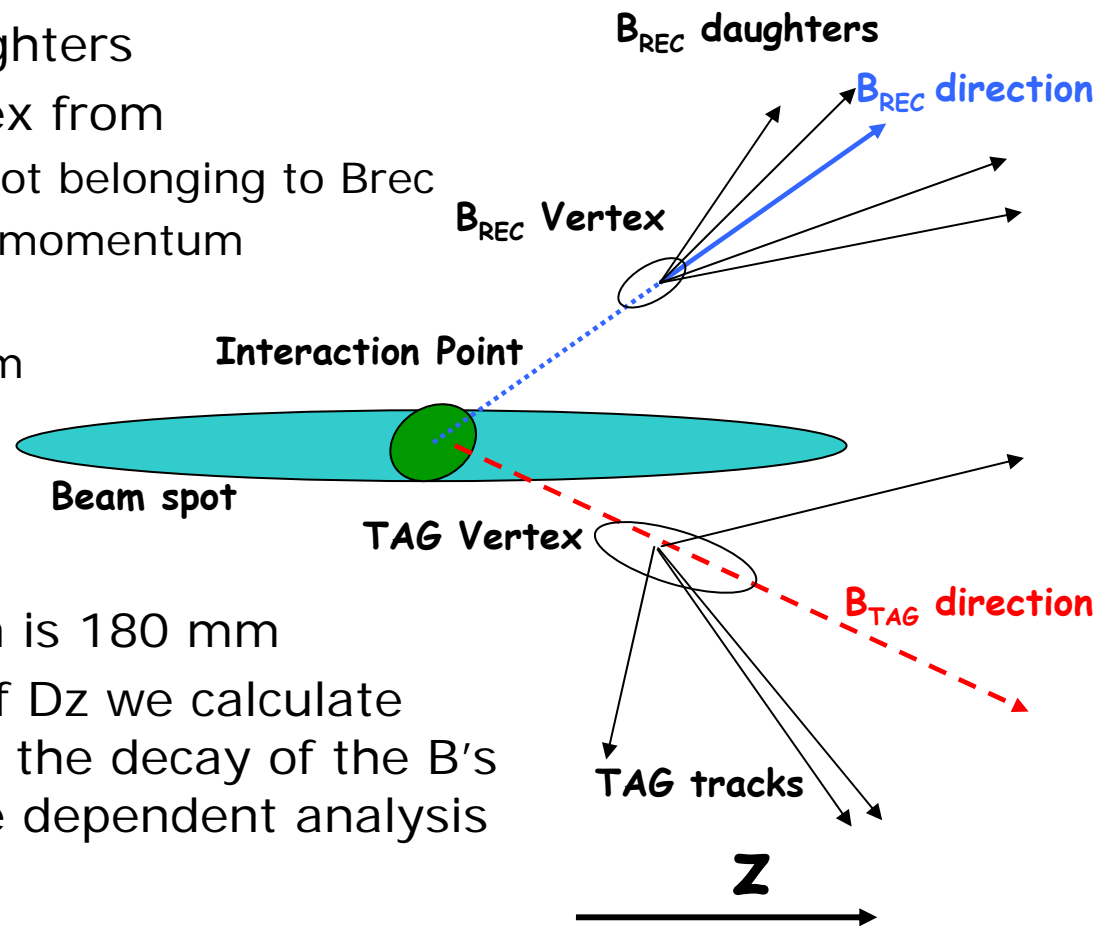
# Summary

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- Have measured evidence for the decay  $B^0 \rightarrow \rho^0 K_s$ 
  - Result went to ICHEP in the summer
  - PRL in pipeline
- Time dependent CP analysis
  - Fit two control samples and appear to get expected CP result
- CP analysis will be finished for summer

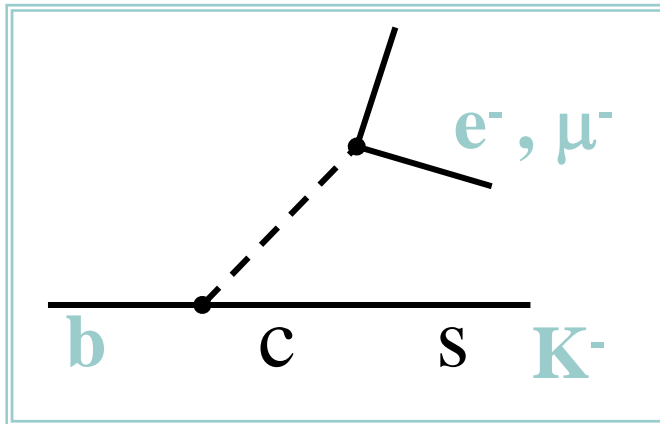
# Vertexing

- Reconstruct Brec vertex from
  - charged Brec daughters
- Determine BTag vertex from
  - charged tracks not belonging to Brec
  - Brec vertex and momentum
  - beam spot
  - $Y(4S)$  momentum
- Average  $D_z$  resolution is 180 mm
- From measurement of  $D_z$  we calculate  $DT$ , the time between the decay of the B's  
This gives us the time dependent analysis



# B Flavour Tagging

- Lepton: Charge of fastest electron (muon) with  $p^* > 1.0$  (1.1) GeV/c
- Kaon : Net charge of identified kaons  $\neq 0$
- (Also non-identified leptons and kaons, soft pions from  $D^*$ 's, etc)



Overall 67.5 +/- 0.5 % efficient

# B Background modes

Background Mode	Efficiency (%)	Branching Fraction ( $10^{-6}$ )	Number of Expected Events
$B^0 \rightarrow \eta' K_s^0$	$6.29 \pm 0.10$	$6.60 \pm 0.90$	$93.97 \pm 12.94$
$B^0 \rightarrow K_0^*(1680)^- \pi^+$	$0.04 \pm 0.01$	$14.00 \pm 14.00$	$1.79 \pm 1.79$
$B^0 \rightarrow f^0 K_s^0$	$0.40 \pm 0.02$	$2.00 \pm 2.00$	$1.79 \pm 1.79$
$B^0 \rightarrow K_2^*(1430)^+ \pi^-$	$0.20 \pm 0.02$	$14.00 \pm 14.00$	$6.35 \pm 6.35$
$B^0 \rightarrow f_2(1270) K_s^0$	$1.68 \pm 0.04$	$1.70 \pm 1.70$	$6.46 \pm 6.46$
$B^0 \rightarrow K_s^0 \pi^+ \pi^-$	$1.11 \pm 0.1$	$2.76 \pm 1.72$	$6.91 \pm 4.31$
$B^0 \rightarrow K_0^*(1430)^+ \pi^-$	$0.13 \pm 0.01$	$1.40 \pm 14.00$	$1.79 \pm 1.79$
$B^0 \rightarrow \rho^0 K^{*0}(\text{long})$	$0.64 \pm 0.03$	$7.10 \pm 7.10^*$	$10.35 \pm 10.35$
$B^0 \rightarrow D^- \pi^+$	$0.34 \pm 0.02$	$41.60 \pm 6.20$	$32.3 \pm 7.7$
$B^0 \rightarrow \omega K_s^0$	$0.09 \pm 0.00$	$8.38 \pm 0.94$	$0.92 \pm 0.10$
Charmed $B^0$			$171.34 \pm 85.67$
Charmed $B^+$			$106.10 \pm 58.05$