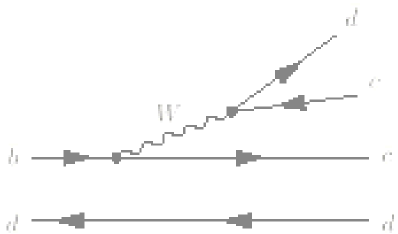
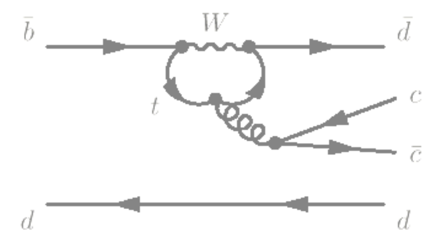
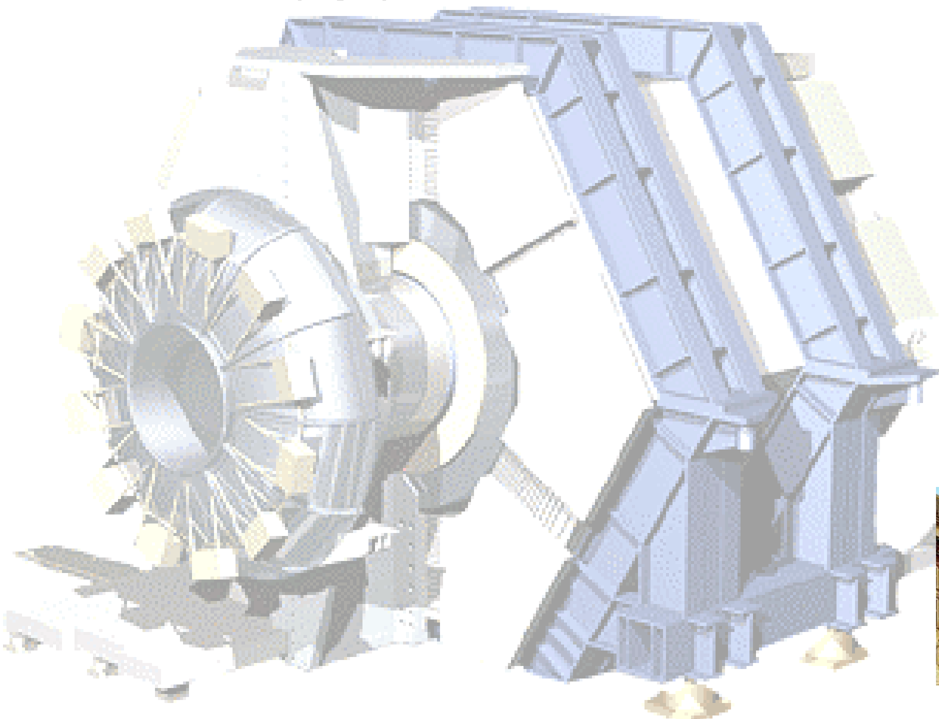
Measurement of CP Violating Time-Dependent Asymmetries in $B^0 \longrightarrow D^{*+}D^{(*)-}$ at BABAR







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XIVth Recontres de Blois

June 19, 2002

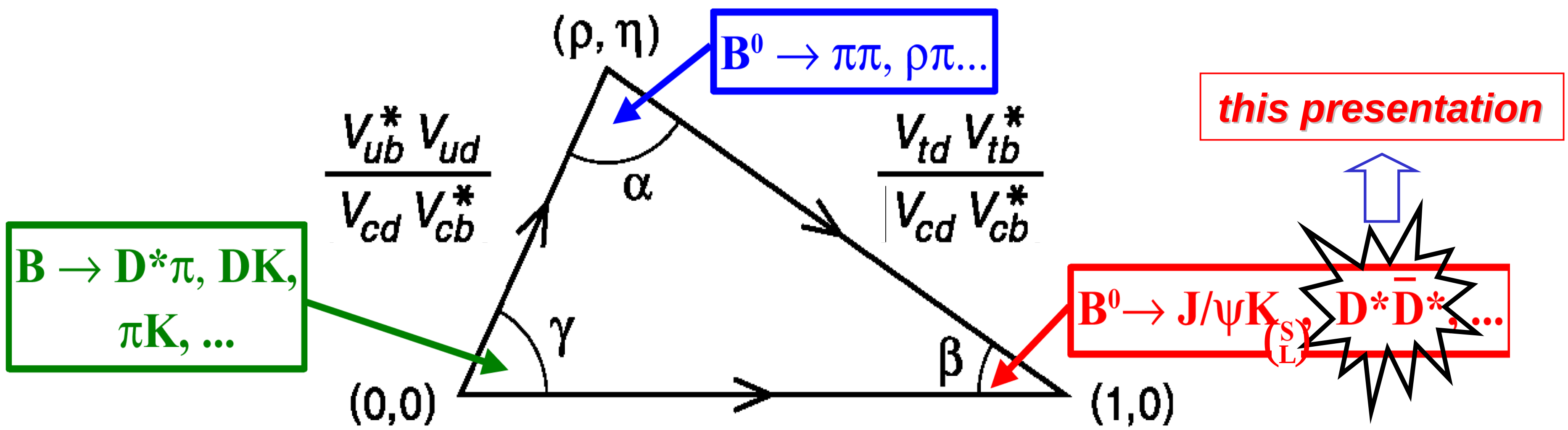
CPV and the Standard Model

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

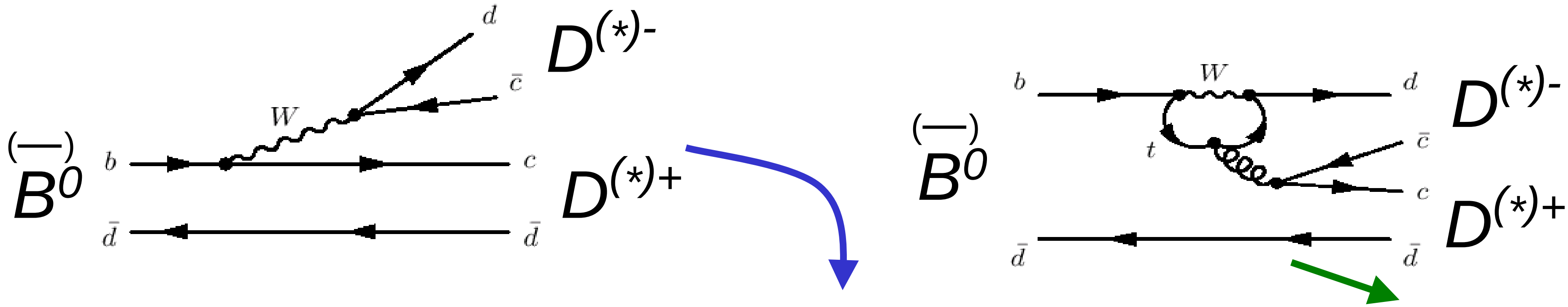
CKM Matrix

CKM matrix is unitary $\Rightarrow$

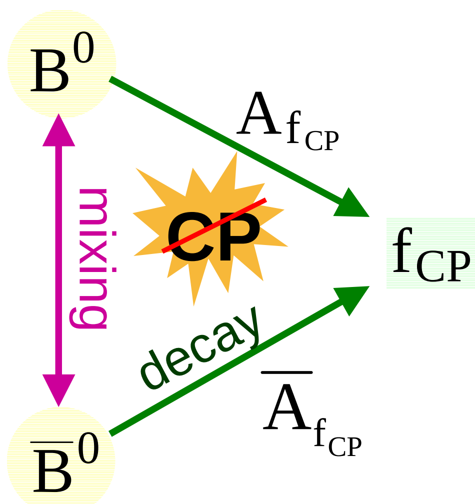
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



CP Violation in $D^{(*)}\overline{D}^{(*)}$



- Time-dependent CP-violating asymmetry from tree amplitude is proportional to $\sin(2\beta)$, penguin amplitude can however add different phase.
- Phase correction due to penguins expected to be small in SM (< 0.1 correction to measured $\sin(2\beta)$†) however supersymmetry & other loop-enhancing models can produce large corrections.



$$a_{f_{CP}} = \frac{\Gamma(B^0_{\rm phys}(t) \to f_{CP}) - \Gamma(\overline{B}^0_{\rm phys}(t) \to f_{CP})}{\Gamma(B^0_{\rm phys}(t) \to f_{CP}) + \Gamma(\overline{B}^0_{\rm phys}(t) \to f_{CP})}$$

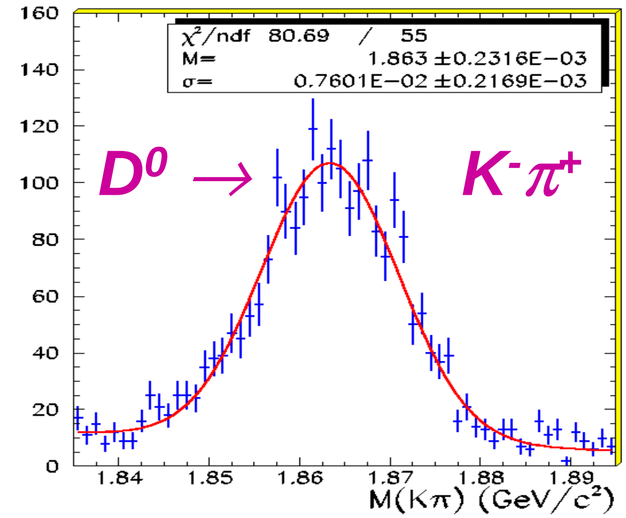
$$\approx -\eta_{\rm eff}\sin(2\beta)\sin(\Delta m \Delta t)$$

† Grossmann & Worah, Phys. Lett. **B395**, 241 (1997)

$D^{*+}D^{(*)-}$ Event Selection

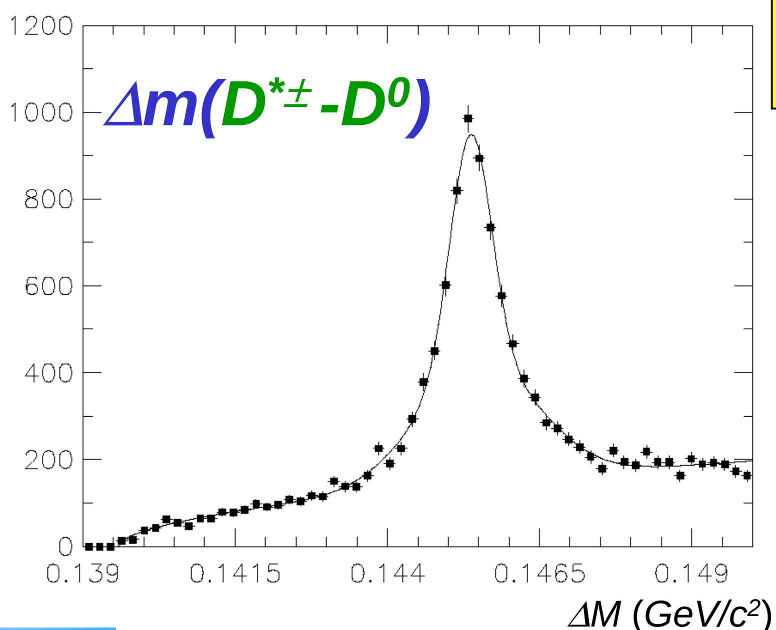
- $D^{*\pm}$ reconstructed to both $D^0\pi^\pm$ and $D^\pm\pi^0$
  - ! for $B^0 \to D^{*+}D^{*-}$: eliminate case where both D^* decay to $D^\pm\pi^0$
- $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$, $K_S\pi^+\pi^-$
- $D^+ \to K^-\pi^+\pi^+$, $K_S\pi^+$, $K^-K^+\pi^+$

➤ Form ***"mass likelihood"*** from the masses of the D candidates and Δm of D^* candidates:

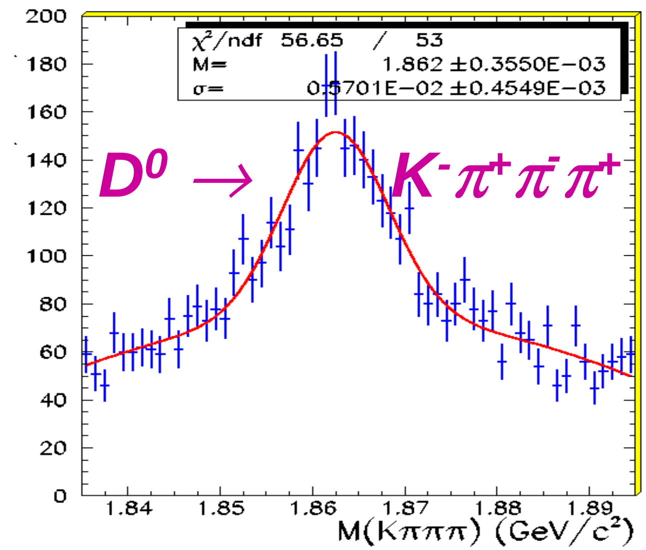


$$masslik \equiv \frac{1}{\sqrt{2\pi}\sigma_{m_{D+}}}\frac{1}{\sqrt{2\pi}\sigma_{m_{D+}}}\exp[-\frac{(m_{D+}-m_{PDG})^2}{2\sigma_{m_{D+}}{}^2}]\cdot\exp[-\frac{(m_{D-}-m_{PDG})^2}{2\sigma_{m_{D-}}{}^2}]$$

x Δm terms

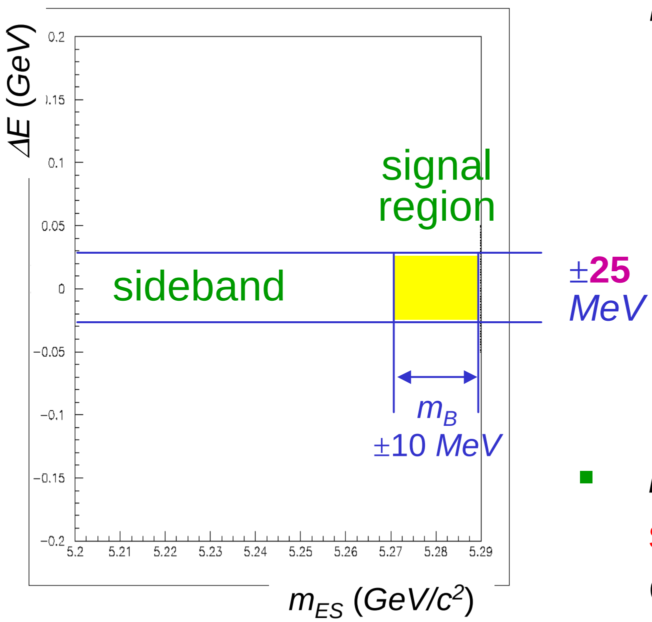


➤ Each D and D^* candidate is *vertexed* and *mass constrained* before being combined to form a B candidate.



$D^{*+}D^{(*)-}$ Event Selection (II)

$D^{*+}D^{*-}$



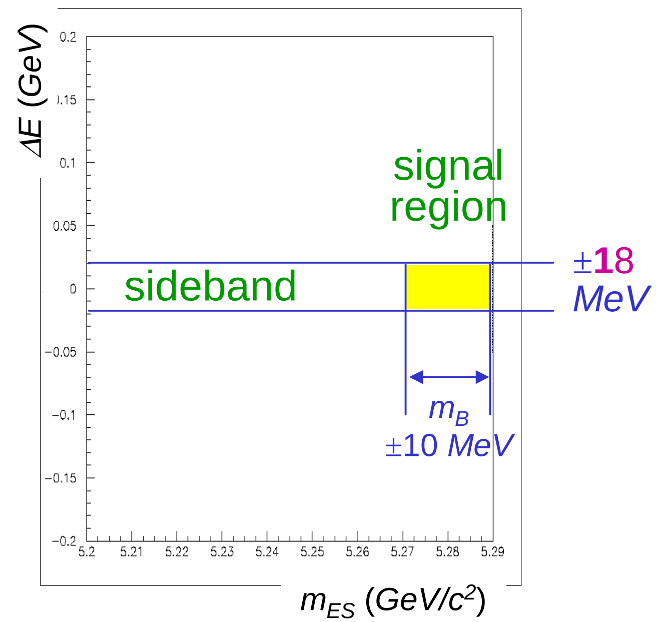
- *Beam-energy substituted* *B* mass:

$$m_{ES} = \sqrt{\left(\sqrt{s}/2\right)^2 - p_B^{*2}}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

- m_{ES} and ΔE signal region sizes tuned (using Monte Carlo simulation) to maximize Signal²/(Signal+Background).
  - ΔE: 25 *MeV* ½-width (18 *MeV* for D^*D)
  - m_{ES}: 10 *MeV* ½-width

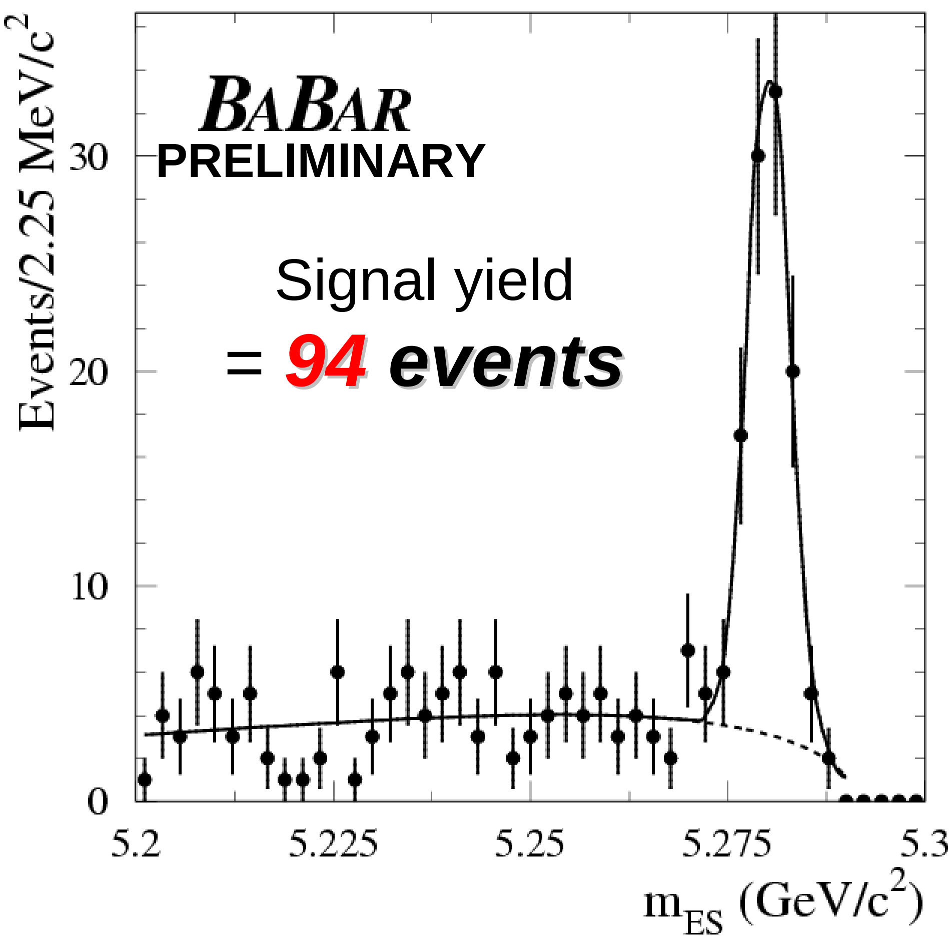
$D^{*\pm}D^{\mp}$



$D^{*+}D^{*-}$ & $D^{*\pm}D^{\mp}$ Data Samples (56 fb^{-1})

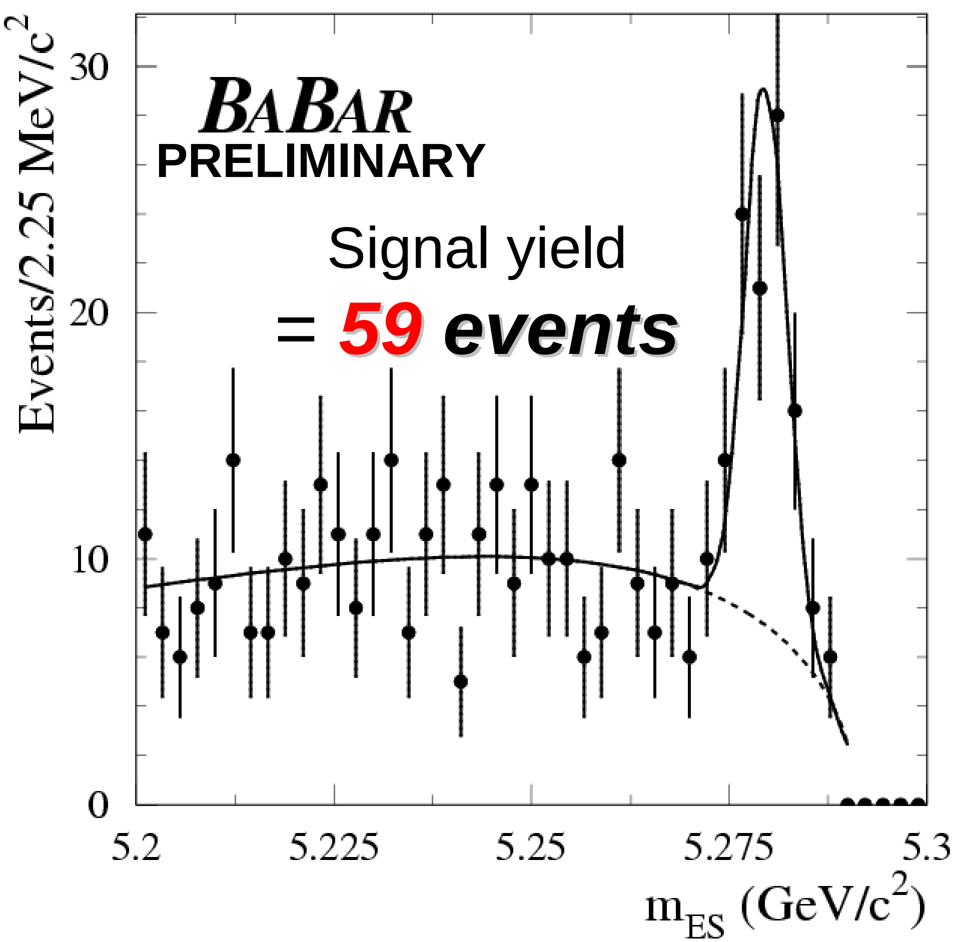
Fully Reconstructed

$B^0 \to D^{*+}D^{*-}$



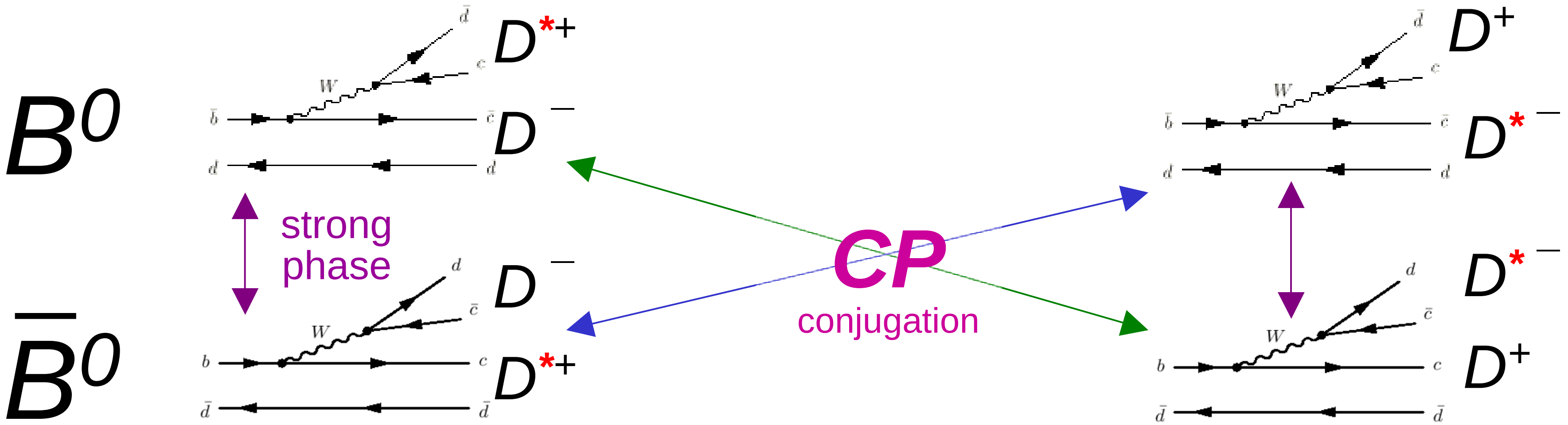
Fully Reconstructed

$B^0 \to D^{*\pm}D^{\mp}$

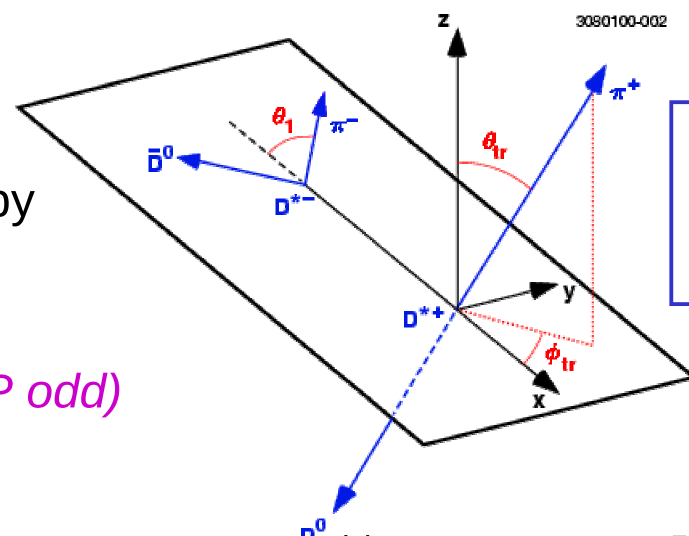


$D^{(*)}\bar{D}^{(*)}$ - specific ~~*CP*~~ issues

- *D*D* final states are not *CP* eigenstates:



- $D^{*+}D^{*-}$ isn't an eigenstate either: it is a combination of *CP*-odd and *CP*-even amplitudes.
  - We can separate out angular momentum components by looking in ***transversity basis*** *(S, P, D waves)*
  - Define the ***fraction** of P-wave (CP odd) component* of the final state as R_t



direction of soft π in D* decays gives us angular momentum info

$D^{*+}D^{*-}$ Angular Distribution

The angular distribution as a function of one angle, θ_{tr}:

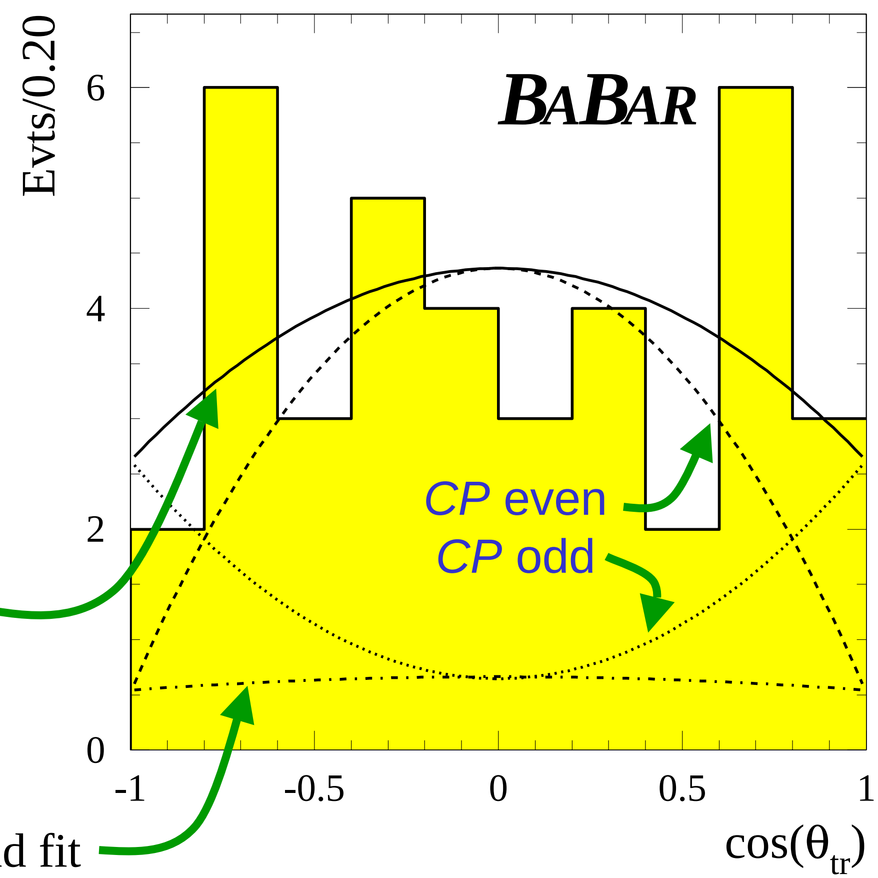
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{tr}} = \frac{3}{4}(1-R_t)\sin^2\theta_{tr} + \frac{3}{2}R_t\cos^2\theta_{tr}$$

We measure $\cos\theta_{tr}$ and we can determine R_t from the distribution by using a maximum likelihood fit method…

Perform full fit on ***38 events*** (from 20.7 fb^{-1} of data) in the signal region… (input to fit is the purity of sample and value of R_t^{bkg}).

CP-odd fraction

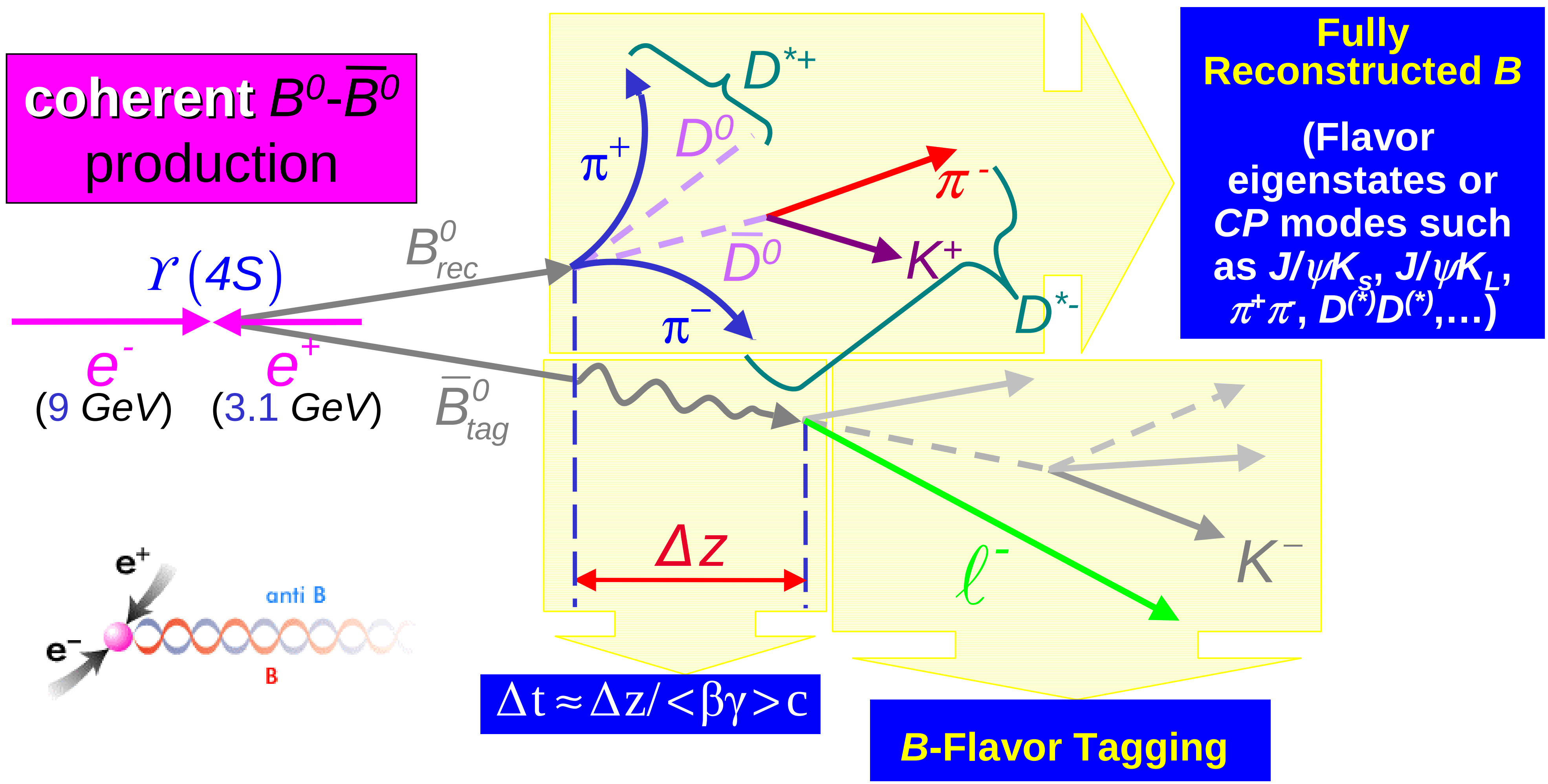
$$R_t = 0.22 \pm 0.18 \pm 0.03$$



signal fit

background fit

~~*CP*~~ Measurement at the $\Upsilon(4S)$

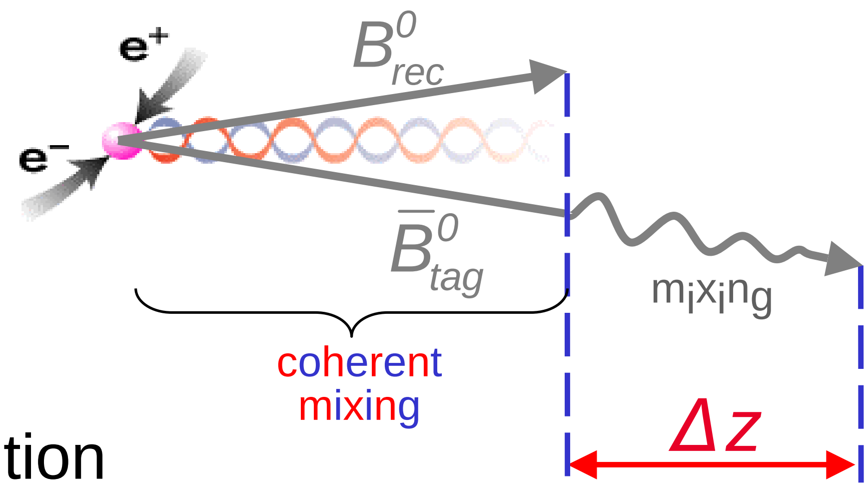


Δt Measurement and Resolution

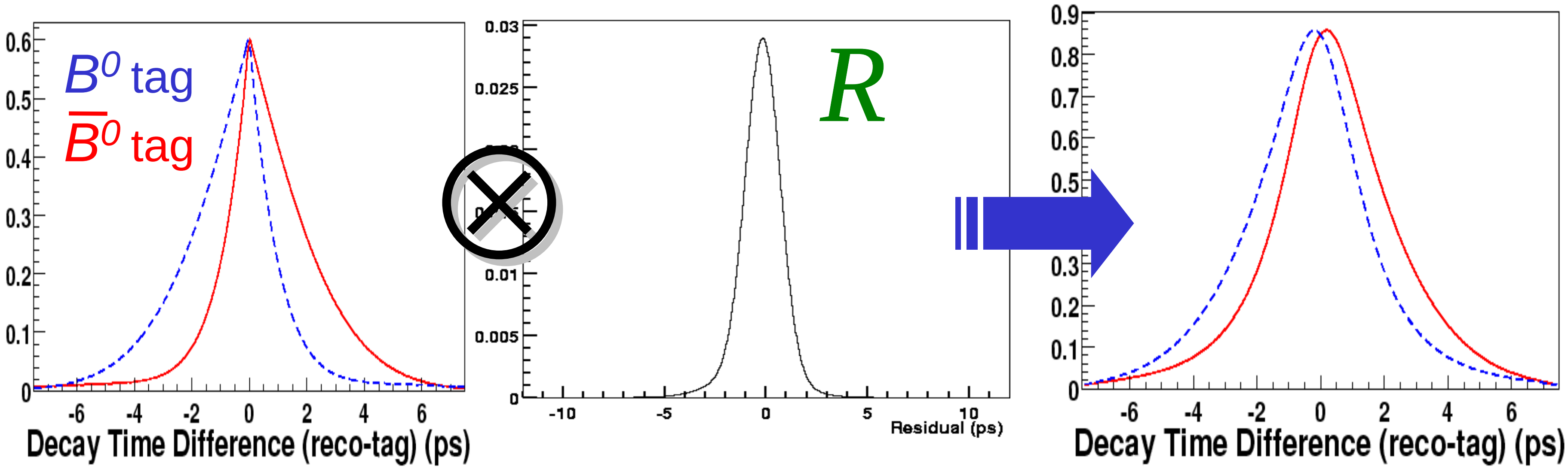
- Obtain vertices for reconstructed *B* and tag *B* to find Δz.

- Then use:

$$\Delta t \approx \Delta z / \langle \beta\gamma \rangle c$$



resolution
function



Likelihood Fit Method

Signal PDFs:

□ = asymmetries

○ = tagging dilutions ($\omega \equiv$ mistag frac.)

$$\Gamma\left(\overset{(-)}{B^0} \to D^{*+}D^{*-}\right) = e^{-\Gamma t}A^2\left\{1 \overset{(+)}{-} (1-2\omega)\, C_{D^{*+}D^{*-}} \cos(\Delta m_d t) \overset{(+)}{-} (1-2\omega)\, S_{D^{*+}D^{*-}} \sin(\Delta m_d t)\right\} \otimes R$$

$$\Gamma\left(\overset{(-)}{B^0} \to D^{*-}D^{+}\right) = e^{-\Gamma t}\overline{A}^2\left\{1 \overset{(+)}{-} (1-2\omega)\, C_{D^{*-}D^{+}} \cos(\Delta m_d t) \overset{(+)}{-} (1-2\omega)\, S_{D^{*-}D^{+}} \sin(\Delta m_d t)\right\} \otimes R$$

$$\Gamma\left(\overset{(-)}{B^0} \to D^{*+}D^{-}\right) = e^{-\Gamma t}\overline{\overline{A}}^2\left\{1 \overset{(-)}{+} (1-2\omega)\, C_{D^{*+}D^{-}} \cos(\Delta m_d t) \overset{(+)}{-} (1-2\omega)\, S_{D^{*+}D^{-}} \sin(\Delta m_d t)\right\} \otimes R$$

$$\Gamma\left(\overset{(-)}{B^0} \to D^{*}\pi, etc.\right) = e^{-\Gamma t}\overline{\overline{\overline{A}}}^2\left\{1 \overset{(+)}{-} (1-2\omega) \cos(\Delta m_d t)\right\} \otimes R$$

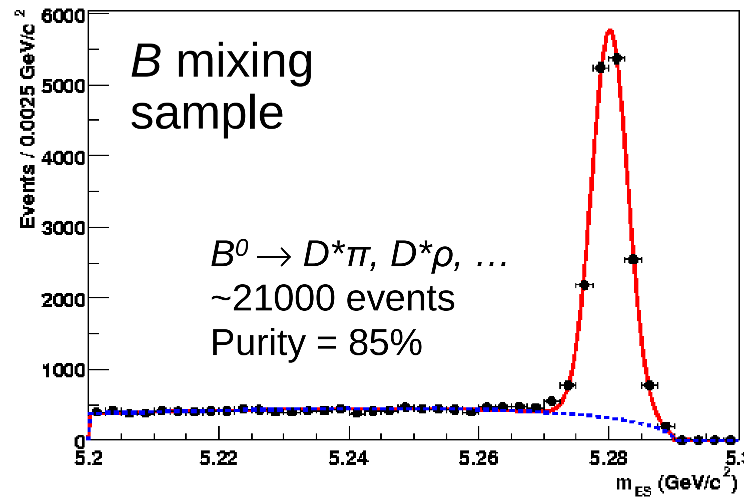
same R (and $(1-2\omega)$)

Likelihood Fit Method (II)

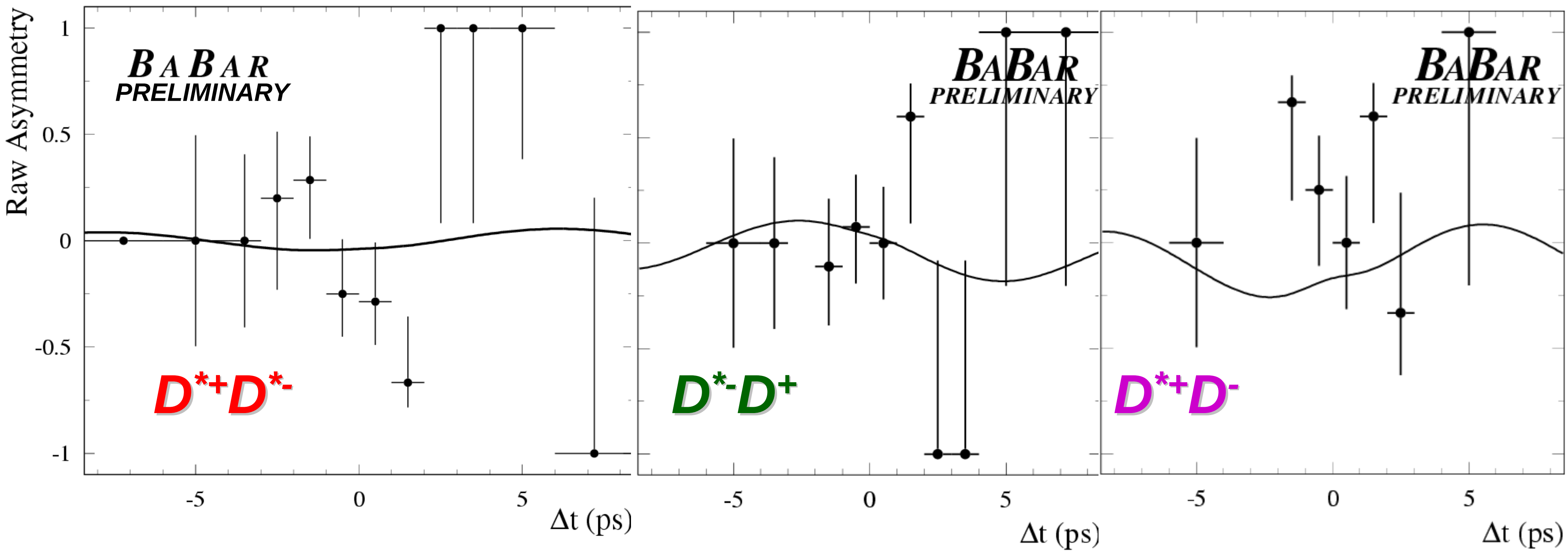
- Combined maximum likelihood fit to $D^{*+}D^{*-}$ and $D^{*}D$ events as well as *B* mixing events of definite flavor in order to extract the following parameters:

CP **violating asymmetries**	**2** (***D*D****), **4** (***D*D***)	
Mistag fractions	8	
Signal resolution function	8	
Empirical description of bkgd. Δt	17	
B lifetime fixed (PDG2000 value)	τ_B = 1.548 ps	
Mixing freq. fixed (PDG2000 value)	$\Delta m_d = 0.472\ ps^{-1}$	

includes also:



Fit Results (56 fb^{-1} of data)



Note: statistics are limited.

(An update with ~85 fb^{-1} will be done this summer.)

Fit Results (56 fb^{-1} of data) (II)

- $C_{D^{*+}D^{*-}}$ = 0.12 ± 0.30(stat.) ± 0.05(syst.)
- $S_{D^{*+}D^{*-}}$ = -0.05 ± 0.45(stat.) ± 0.05(syst.)

- $C_{D^{*-}D^{+}}$ = -0.30 ± 0.50(stat.) ± 0.13(syst.)
- $S_{D^{*-}D^{+}}$ = 0.38 ± 0.88(stat.) ± 0.12(syst.)
- $C_{D^{*+}D^{-}}$ = 0.53 ± 0.74(stat.) ± 0.15(syst.)
- $S_{D^{*+}D^{-}}$ = -0.43 ± 1.41(stat.) ± 0.23(syst.)

Systematic Errors

- Although systematics are small compared with statistical errors, they are fully evaluated (both $D^{*+}D^{*-}$ and $D^{*\pm}D^{\mp}$):

$D^{*+}D^{*-}$

(List of systematics is similar for $D^{*\pm}D^{\mp}$)

Systematics source	δS	δC
signal Δt resolution function	0.008	0.003
tagging dilution	0.005	0.005
peaking background	0.003	0.009
CP background content	0.022	0.038
lifetime of background	0.034	0.005
B^0 lifetime variation	0.001	0.001
Δm_d variation	0.030	0.022
SVT misalignment	0.011	0.008
Boost uncertainty	0.002	0.001
Fit bias	0.001	0.004
TOTAL	0.053	0.046

Conclusion

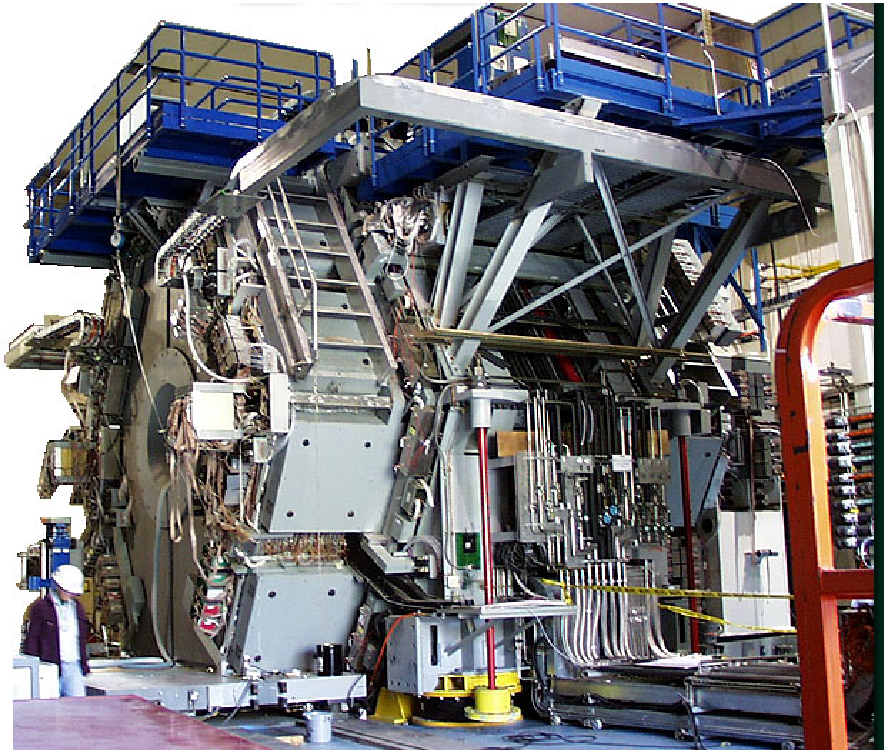
CP-violating asymmetries in $B^0 \rightarrow D^{*+}D^{(*)-}$:

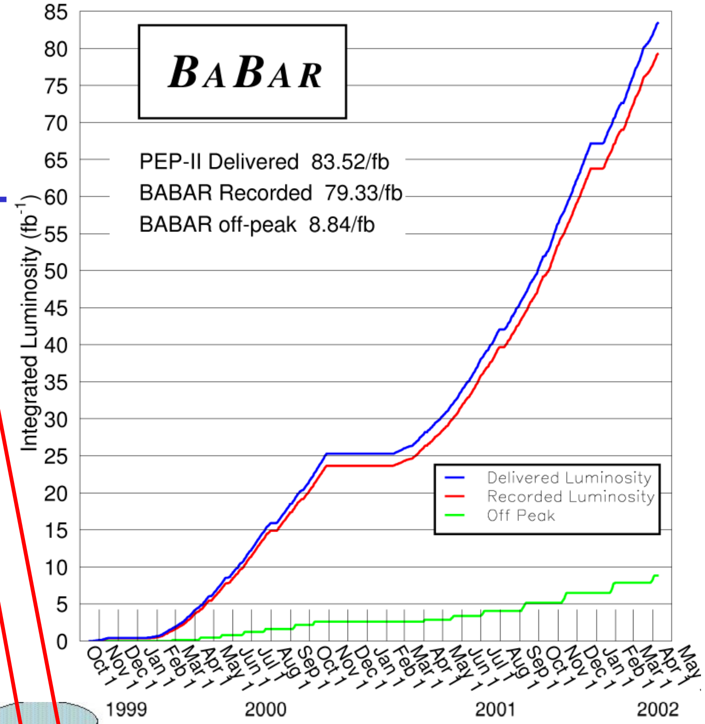
- $C_{D^{*+}D^{*-}} = \ 0.12 \pm 0.30$(stat.) $\pm\ 0.05$(syst.)
- $S_{D^{*+}D^{*-}} = -0.05 \pm 0.45$(stat.) $\pm\ 0.05$(syst.)
- $C_{D^{*-}D^{+}} = -0.30 \pm 0.50$(stat.) $\pm\ 0.13$(syst.)
- $S_{D^{*-}D^{+}} = \ 0.38 \pm 0.88$(stat.) $\pm\ 0.12$(syst.)
- $C_{D^{*+}D^{-}} = \ 0.53 \pm 0.74$(stat.) $\pm\ 0.15$(syst.)
- $S_{D^{*+}D^{-}} = -0.43 \pm 1.41$(stat.) $\pm\ 0.23$(syst.)

- This is the first measurement of *CP* violation in the quark process $b \rightarrow c\bar{c}d$.
- These modes provide an alternative physics process for determining sin(2β).
- Furthermore, the difference between sin(2β) in $D^{(*)}\overline{D}^{(*)}$ and sin(2β) in $J/\psi K_{S/L}$ is sensitive to *CP* violation beyond the Standard Model (notably *CP* violation in supersymmetry).
- Statistics are low at present, but *BaBar* expects to collect 10 times these statistics in the next 4 years
  - $\Rightarrow$ > 3-fold reduction in errors by 2006
  - $\Rightarrow$ constraints on *CP* violation in SUSY.

Backup Slides

The BABAR Detector

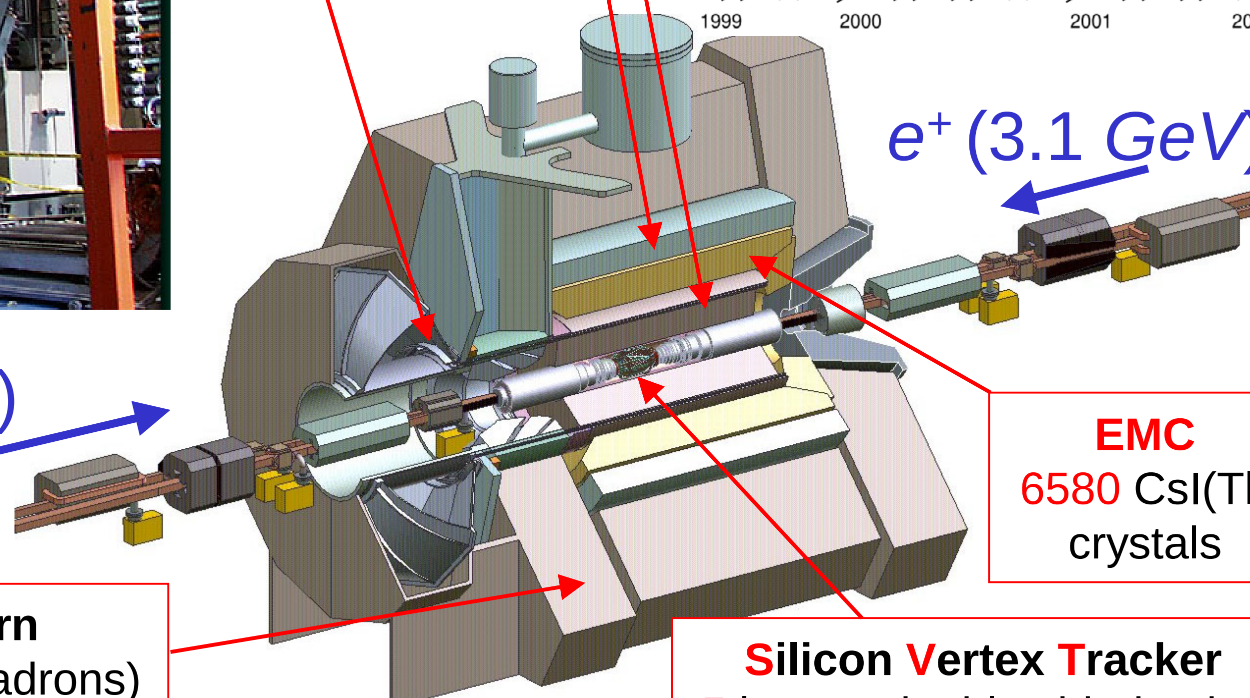




Drift CHamber
40 layers

1.5 T solenoid

DIRC (PID)
144 quartz bars
11000 PMs



EMC
6580 CsI(Tl) crystals

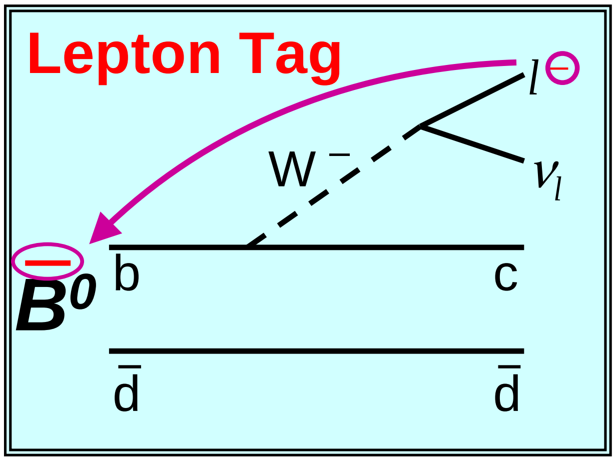
Instrumented Flux Return
iron / RPCs (muon / neutral hadrons)

Silicon Vertex Tracker
5 layers, double sided strips

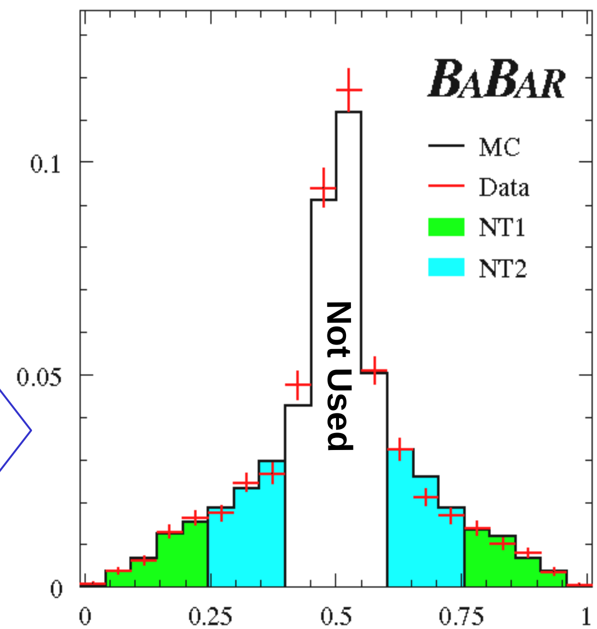
B Flavor Tagging

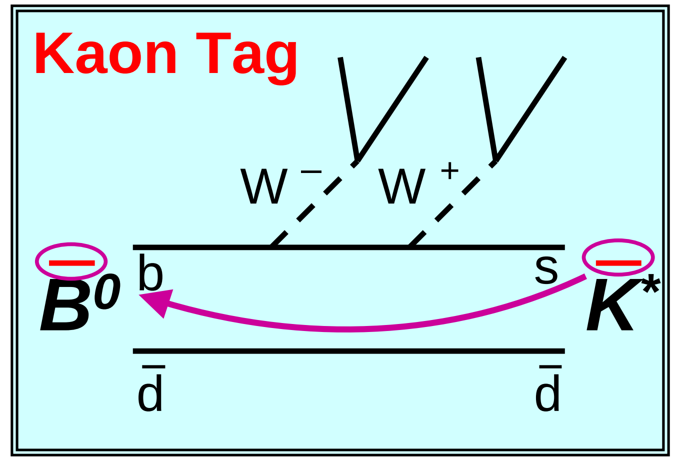
The **charge** of electrons, muons, and kaons (that are not part of the reconstructed *B*) is correlated with whether the second *B* in the event was a B^0 or $\bar{B}^0$ at the time of decay.

This is needed for determining the time-dependent *CP* asymmetry.



Neural Net





- Slow π from D^*
- Momenta of charged particles
- "Unidentified" leptons and kaons

- "Quality" of tagging $= \text{efficiency}*(1-2w)^2$ (w is wrong tag fraction)
- Total ε = 67.5%
- Overall Q = 25.1%