A Measurement of the $B^0\overline{B}^0$ Oscillation Frequency using Hadronic B^0 Decays

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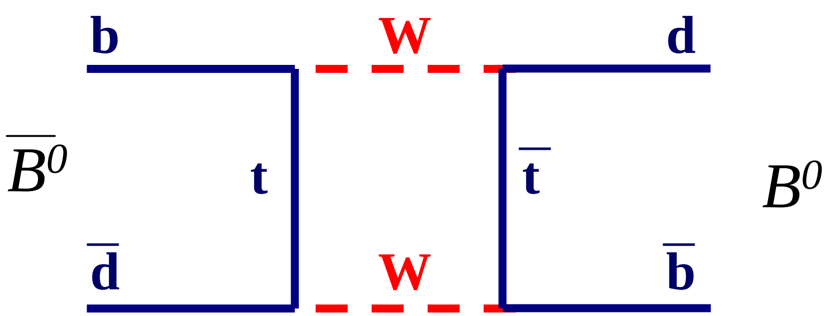
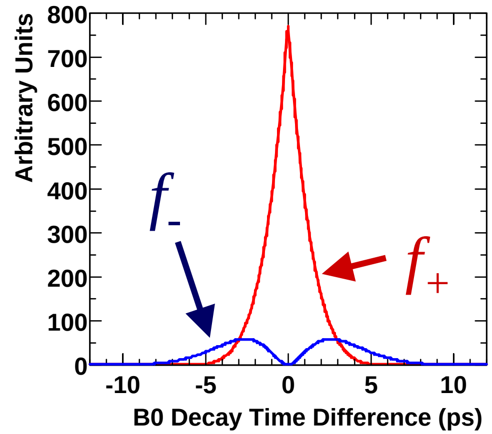
$B^0\overline{B}^0$ Oscillations

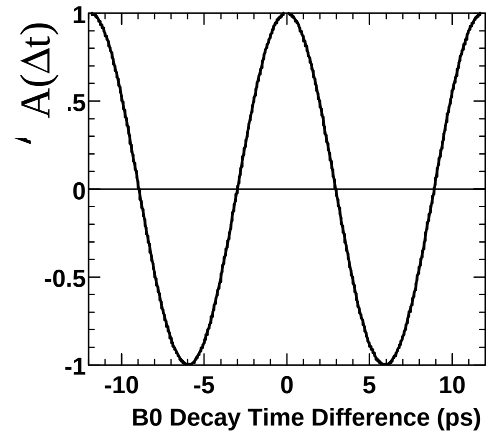
Second-Order Weak Interactions



Motivation:

- Precision measurement
- Constrain CKM parameters
- Validation for CP measurements





Time-evolution of B^0s:

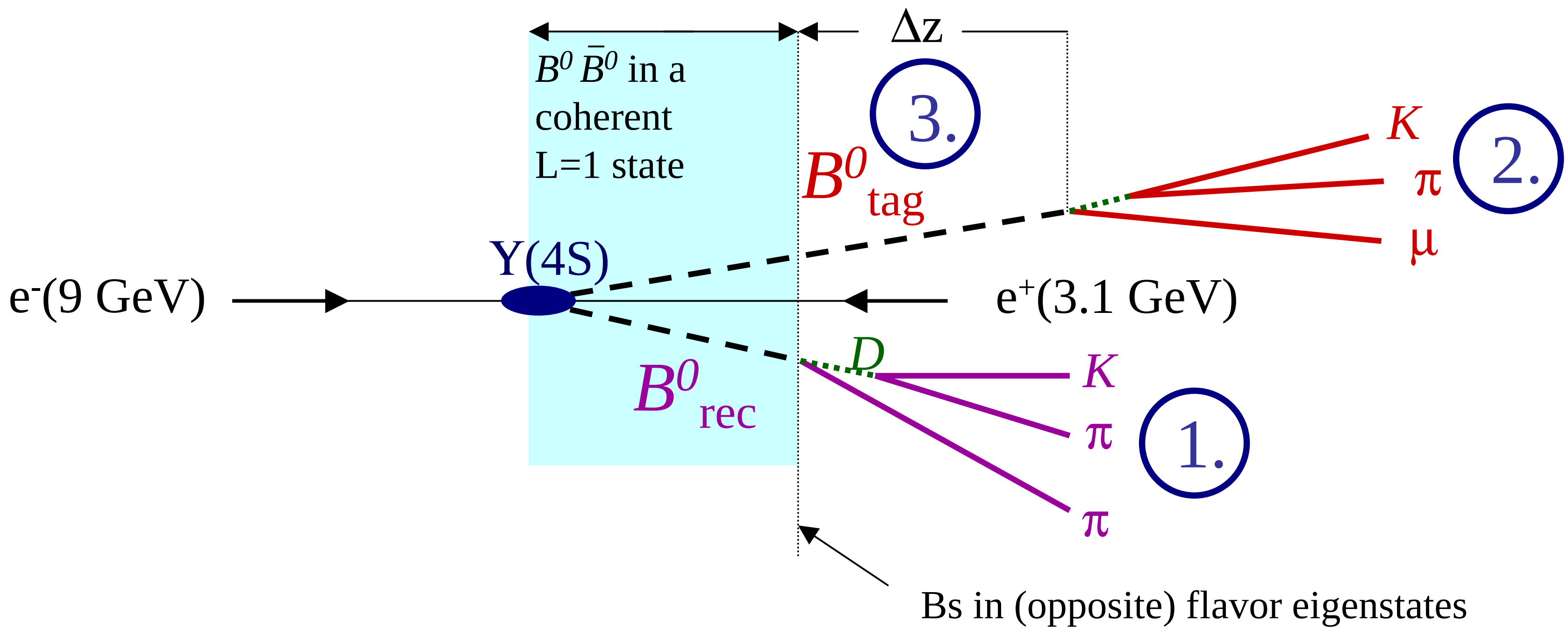
$$f_{\pm} \approx \frac{1}{2} e^{-\left(\frac{|\Delta t|}{\tau}\right)} \left[1 \pm \cos(\Delta m \Delta t)\right]$$

where f_+ is the fraction of unmixed Bs

And f_- is the fraction of mixed Bs

$$A(\Delta t) = \frac{f(\Delta t)_{unmixed} - f(\Delta t)_{mixed}}{f(\Delta t)_{unmixed} + f(\Delta t)_{mixed}}$$

Experimental Ingredients



1. **Fully Reconstruct one *B* in a flavor eigenstate ($D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, $J/\psi\ K^{*0}$)**
2. **Vertex and flavor-tag second *B***
3. **Measure decay time difference ($\Delta z \sim \beta\gamma\gamma_B c\Delta t$)**
4. **Maximum-Likelihood fit to extract Δm**

1. Fully Reconstruct B^0s in flavor eigenstates

$B^0 \to$
$D^{*-}\pi^+$, $D^{*-}\rho^+$, $D^{*-}a_1^+$, $D^-\pi^+$, $D^-\rho^+$, $D^-a_1^+$, $J/\psi K^{*0}$

Signal region defined by two kinematic variables:

$$\Delta E = E_B^* - E_{beam}^*$$

$\sigma(\Delta E) \sim$ 15-30 MeV

Mode-dependent

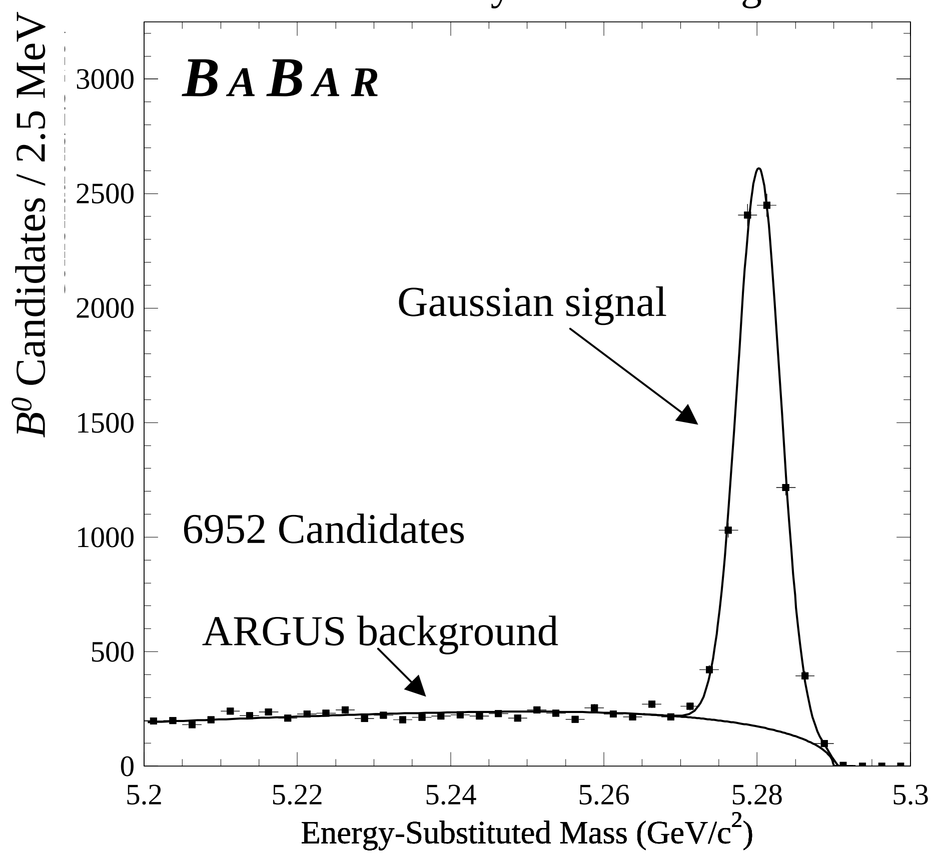
Dominated by detector resolution

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

$\sigma(m_{ES}) \sim$ 3 MeV

Dominated by the beam energy spread

B^0 Hadronic Decays to Flavor Eigenstates



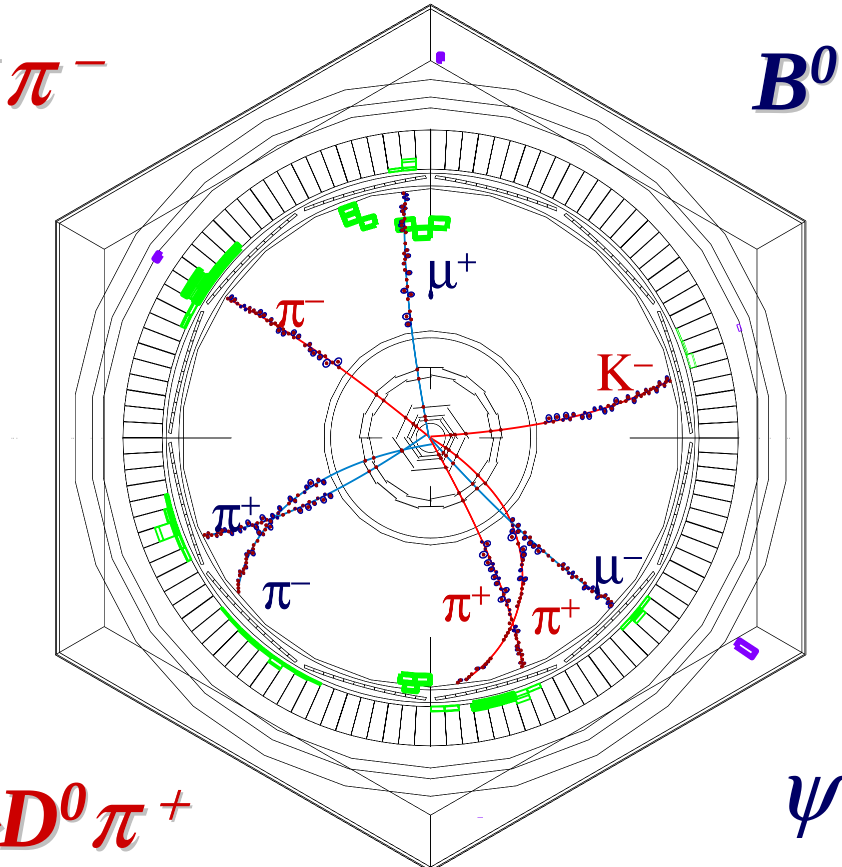
m_{ES}

20.7 fb^{-1}

A Fully Reconstructed Υ(4S) Event

$\bar{B}^0 \rightarrow D^{*+}\pi^-$

$B^0 \rightarrow \psi(2S)K^0_s$



$D^{*+} \rightarrow D^0\pi^+$
$D^0 \rightarrow K^-\pi^+$

$\psi(2S) \rightarrow \mu^+\mu^-$
$K^0_s \rightarrow \pi^+\pi^-$

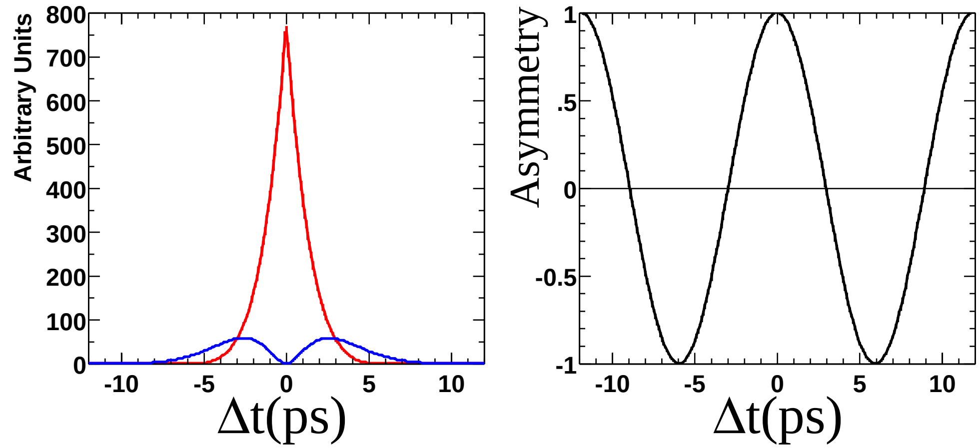
2. Flavor-tag other *B*

- **Use correlations between decay products of B_{tag} and its flavor**
- **Algorithm uses 4 categories:**
  - **Lepton tag: $b \rightarrow c\ \ell^- \nu_\ell$**
  - **Kaon tag: $b \rightarrow c\ X$; $c \rightarrow s\ X$; $s \rightarrow K^-$**
  - **NT1 and NT2: Single neural net using other (correlated) information (e.g. slow pions from D*, kinematics), two "goodness of tag" categories**

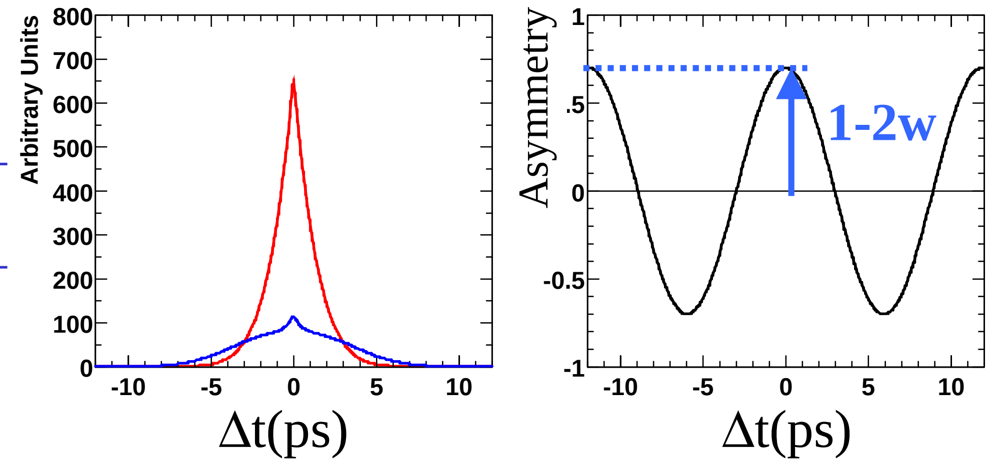
Needs accurate and efficient Particle Identification

Category	Tagged Events	Efficiency (%)	Mistag (%) (Measured in fit)	Purity (%)
Lepton	**754 ± 28**	**11.3 ± 0.4**	**8.5 ± 1.8**	**97.1 ± 0.6**
Kaon	**2317 ± 54**	**34.8 ± 0.6**	**16.7 ± 1.4**	**85.2 ± 0.8**
NT1	**556 ± 26**	**8.3 ± 0.3**	**19.5 ± 2.6**	**88.7 ± 1.5**
NT2	**910 ± 36**	**13.7 ± 0.4**	**32.6 ± 2.4**	**83.0 ± 1.3**
Total	4538 ± 75	68.1 ± 0.9		86.7 ± 0.5

Perfect Tagging



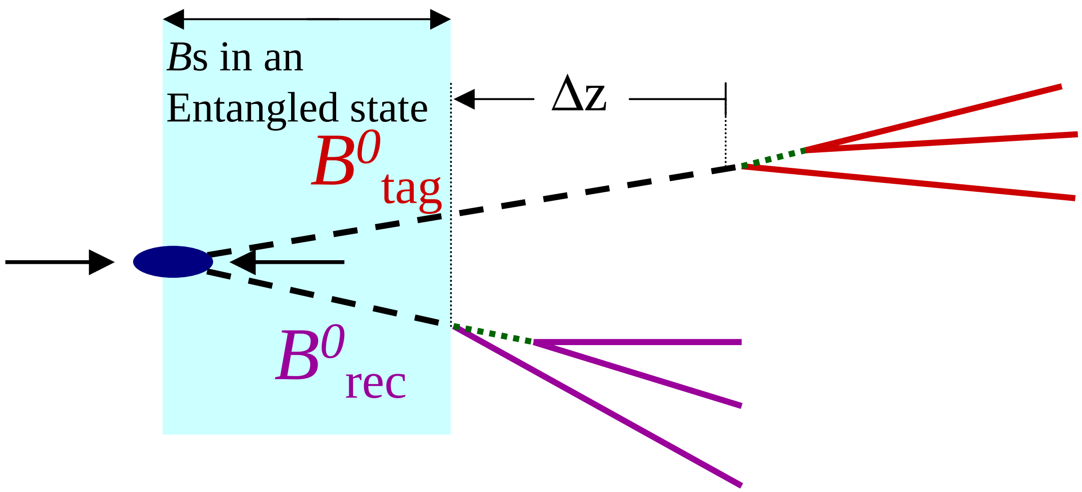
Imperfect Tagging

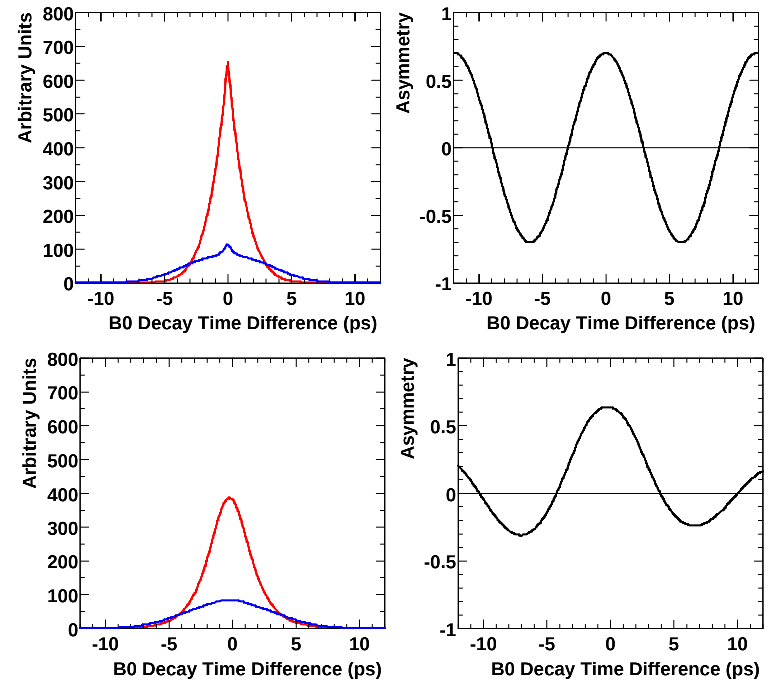


The effective tagging efficiency is

$$Q_i = e_i\,(1-\ 2\,w_i)^2$$

3. Measure decay time difference: Δt





- **CMS boosted along z axis: $\Delta t \sim \Delta z / (\beta\gamma\gamma_B c)$**
- **B_{reco} vertex completely reconstructed**
- **B_{tag} vertex partially reconstructed using remaining tracks**
  - Exclude tracks from charm decays (vertex $\Delta\chi^2$)
- **Resolution function $\mathcal{R}$: 3 Gaussians (core, tail, outlier)**
  - Scale core/tail widths with event-by-event errors derived from vertex fits
  - Outlier (<1%): fixed width σ~8ps
  - Allow different core biases depending on 4 tagging categories
  - Fit parameters: scale factors, biases, relative core/tail/outlier amounts

4. Fit decay-time distribution to extract Δm

Unbinned maximum likelihood fit to decay-time distributions

Signal:

$$f_{\pm} = \frac{1}{2\tau} e^{-(\frac{|\Delta t|}{\tau})} [1 \pm D \cos(\Delta m \Delta t)] \otimes R(3Gaussian)$$

Peaking background from B^+ (1.3% of signal)

$$F_{\pm charged} = (1 \pm D_+)\ G_+/2\ e^{-G_+|Dt|} \otimes R_{sig}(3Gaussian)$$

Combinatorial background:

Zero-lifetime component

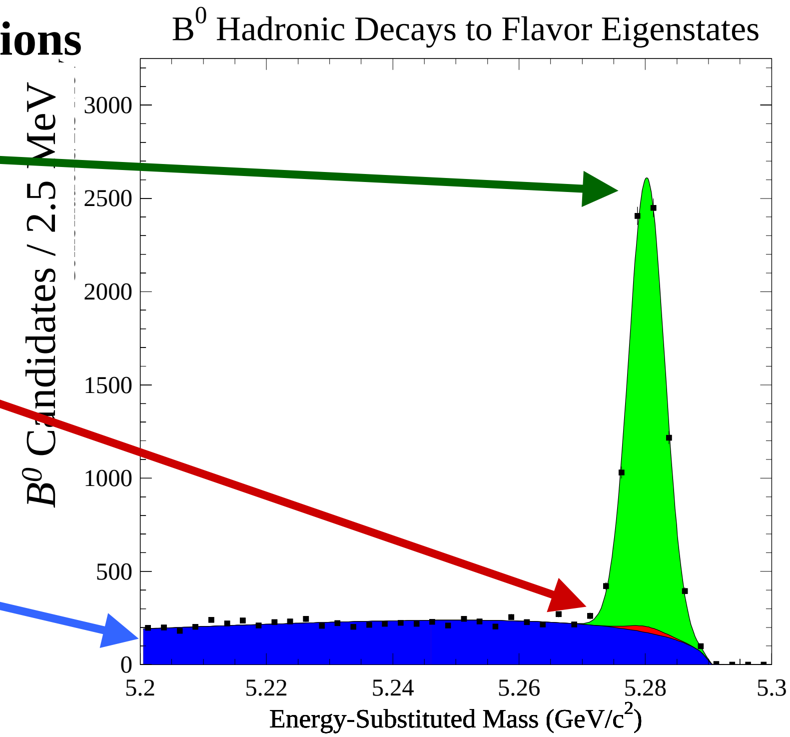
$$F_{\pm 1} = (1 \pm D_1) \otimes R_{bck}(2Gaussian)$$

Non-oscillatory, non-zero lifetime component

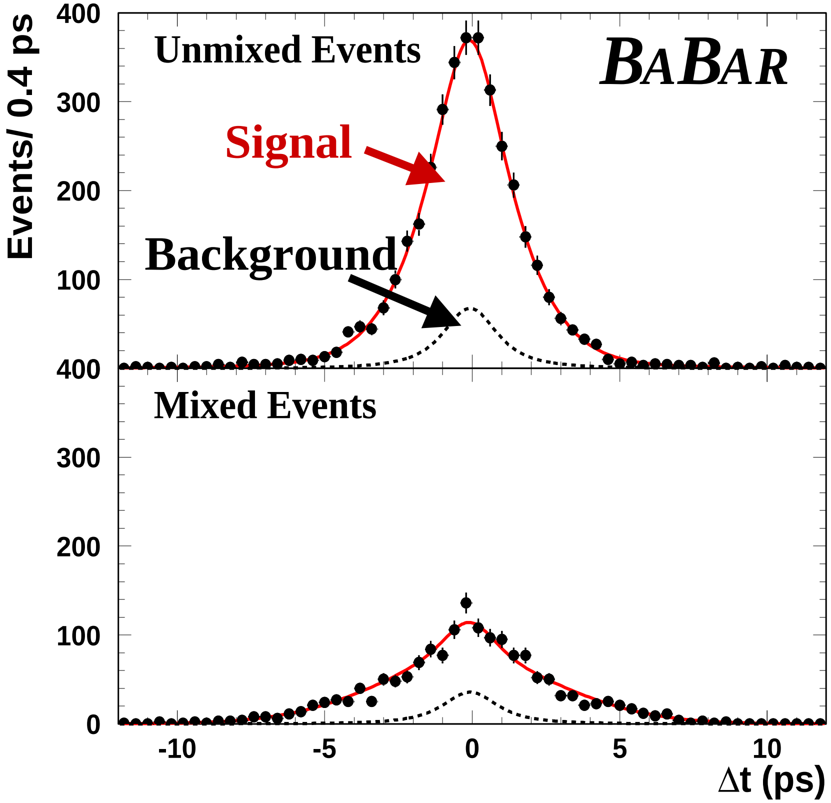
$$F_{\pm 2} = (1 \pm D_2)\ G_2/2\ e^{-G_2|Dt|} \otimes R_{bck}(2Gaussian)$$

D , D_1 , D_2 , D_+ fit separately by tagging category

Total: 34 fit parameters including Δm

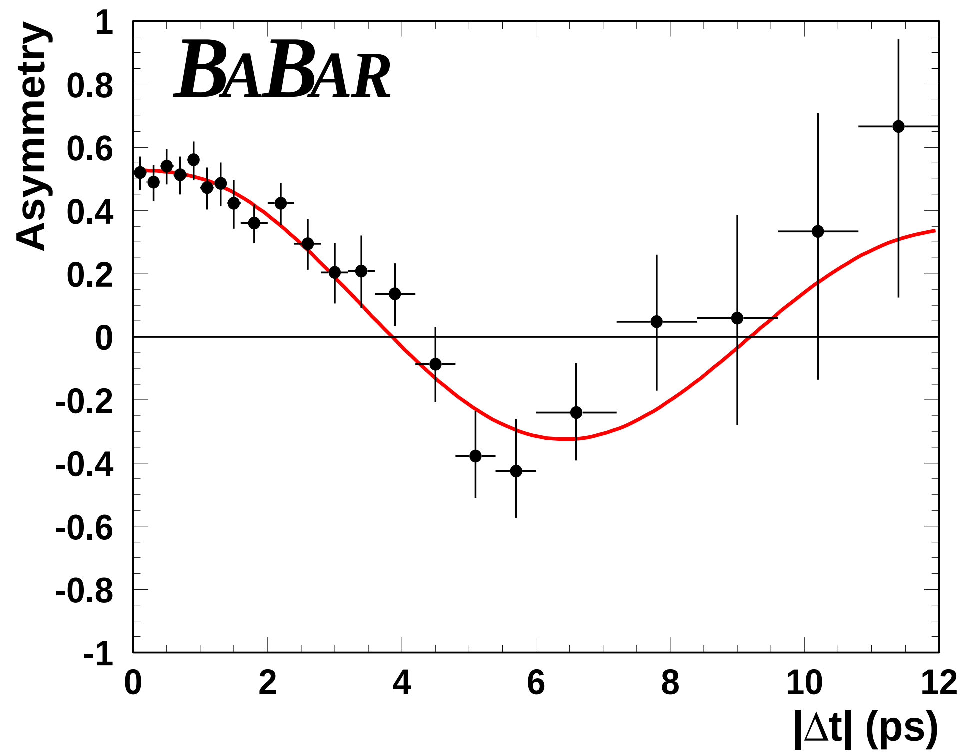


Data and Results



Data, m_{ES} > 5.27 GeV, with projection of fit result superimposed

$$A(\Delta t) = \frac{N(\Delta t)_{unmixed} - N(\Delta t)_{mixed}}{N(\Delta t)_{unmixed} + N(\Delta t)_{mixed}}$$



$\Delta m = (0.519 \pm 0.020 \pm 0.016)\ \hbar\ ps^{-1}$

PRELIMINARY

Systematic Errors and Consistency Checks

- **High purity sample, well-understood systematics.**
- **Cross-Checks:**
  - Split data sample in time
  - Split data sample by mode
  - Split data sample by tagging category
  - Float B lifetime in full fit
  - Float charged B background fraction
  - Check mistag fraction using charged B sample
  - Split MC sample, float B lifetime
  - Include charged B sample in fit for resolution function parameters
  - Fit just to lifetime

Source	Δm [$\hbar ps^{-1}$]
MC stats	**0.004**
MC correction	**0.009**
Δt outliers	**0.002**
Likelihood norm.	**0.003**
Background	**0.005**
B^0 lifetime	**0.006**
Z scale	**<0.005**
Z boost	**0.005**
SVT alignment	**0.004**
Beamspot postn/size	**0.001**
Total	0.016

Comparison of results; Conclusion

This Measurement →

$0.519 \pm 0.020 \pm 0.016\ ps^{-1}$

PDG 2000 World Average
0.472 ± 0.017

BaBar already competitive with most precise current measurements