B Mixing and Lifetimes With Exclusive and Inclusive Techniques

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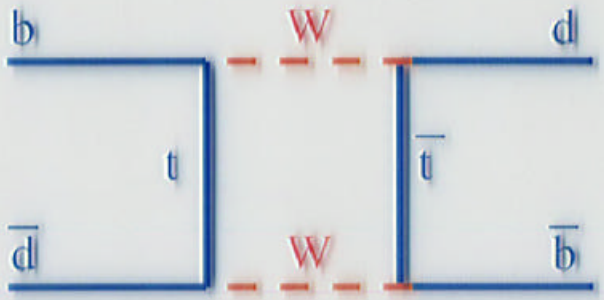
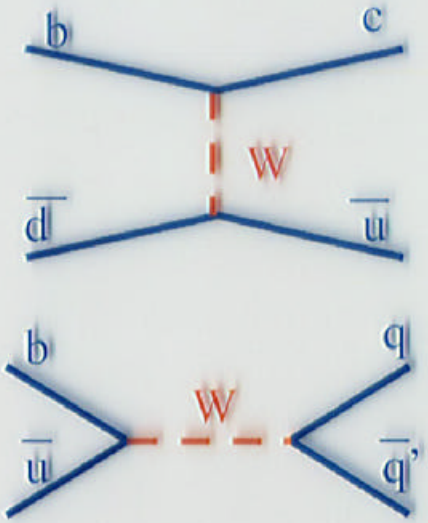
Motivations

- Mixing:
  - Constraint on the ρ–η plane
  - Precision measurement at B-factories
  - Validation for CP violation measurement



- Lifetimes:
  - Tests of theoretical models of HQ decays
  - Validation for CP violation measurement



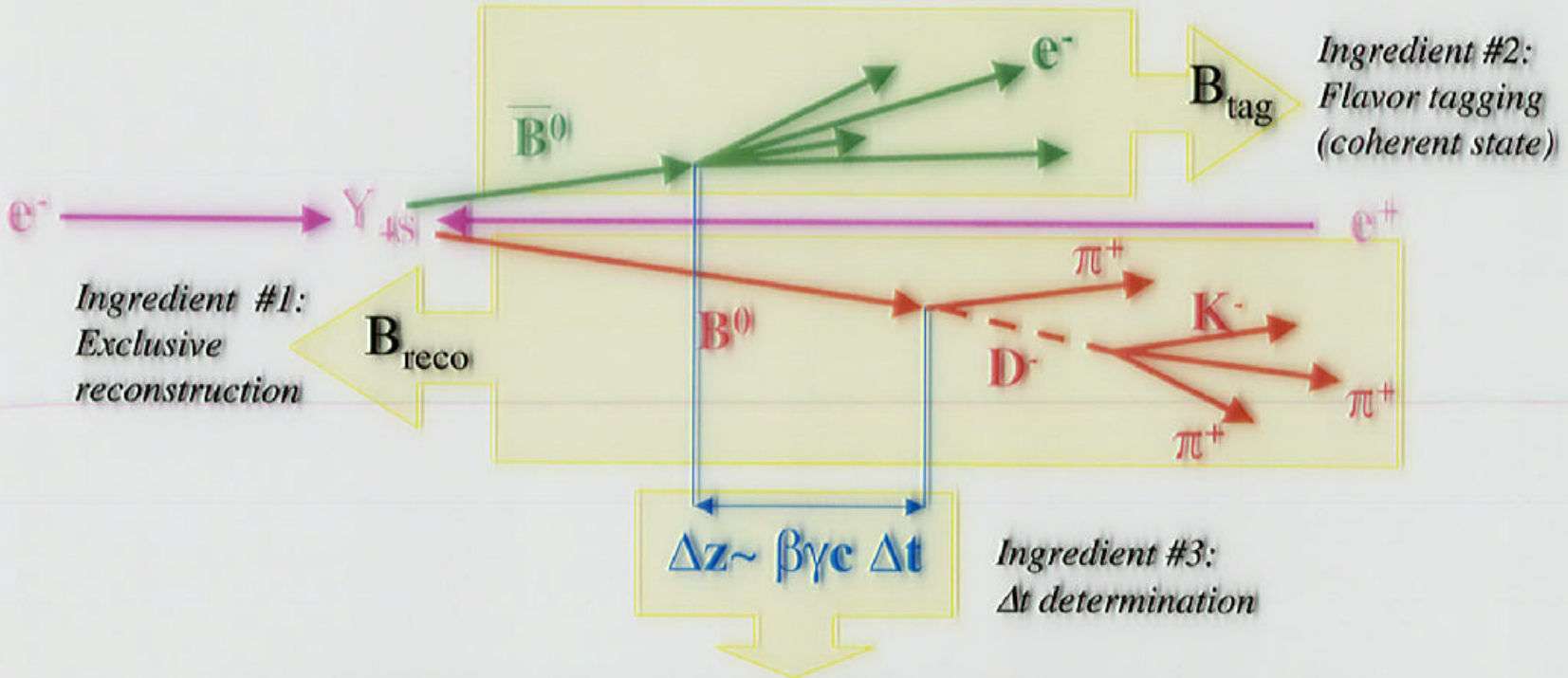
Experimental Techniques

1. Fully reconstructed hadronic B decays ($D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, $J/\psi\ K^{*0}$)
   - Limited statistics (6k in 20fb-1)
   - Small systematics
   - Most similar to sin(2β)
2. Partially reconstructed hadronic B decays
3. Fully or partially reconstructed $B \to D^* \ell \nu$
4. Dileptons
   - Large data sample (100k in 20fb-1, neutral and charged B in equal proportions)
   - Systematically limited (?)

Concentrate mostly on mixing from 1. and 4. in the following

WARNING: All results are PRELIMINARY !

Mixing With Fully Reconstructed Hadronic B Decays



$$h_{\pm}(\Delta t;\Gamma,\Delta m,\mathcal{D}) = 1/4\ \Gamma\ e^{-\Gamma|\Delta t|}(1 \pm \mathcal{D}\cos(\Delta m\ \Delta t))$$

$$\text{Asymmetry} = \sim \mathcal{D}\cos(\Delta m\ \Delta t)$$

[$\mathcal{D} = 1 - 2w$, w=mistag probability]

(also add resolution function, backgrounds...)

Ingredient #1: B_{reco}

- Investigate the decays:

  $\bar{B}^0 \to D^{(*)+}\pi^-$, $D^{(*)+}\rho^-$, $D^{(*)+}a_1^-$

  $\bar{B}^0 \to J/\psi K^{*0}$ $(K^{*0} \to K^+\pi^-)$ see Andreas' talk

- $D^{*+} \to D^0\pi^+$
  - $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^0$, $K_s^0\pi^+\pi^-$
- $D^+ \to K^-\pi^+\pi^+$, $K_s^0\pi^+$
- $\rho^- \to \pi^-\pi^0$, $K_s^0 \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$, $a_1^- \to \pi^-\pi^+\pi^-$

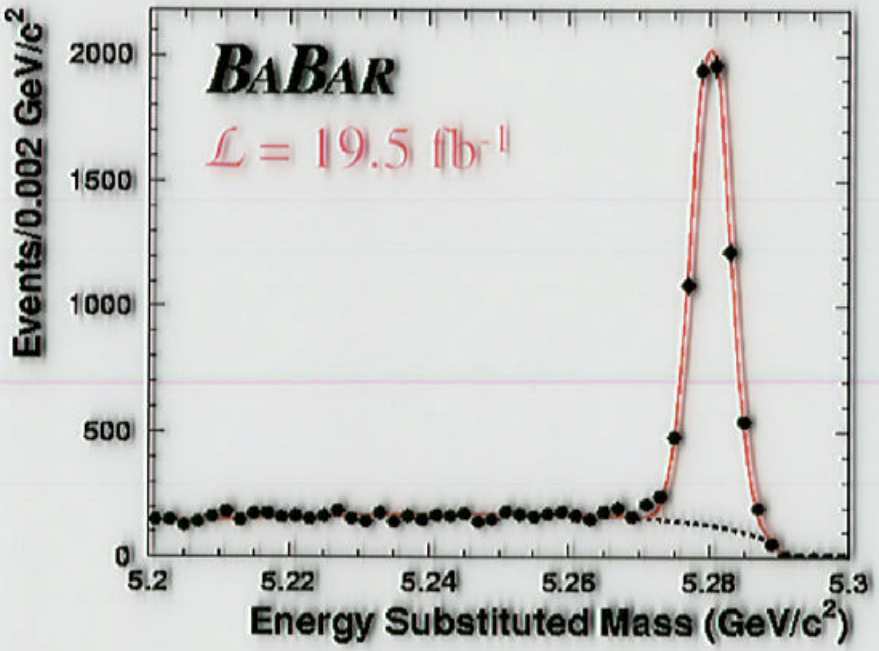
- Signal definition for B_{reco}:
  - Define a window in the m_{ES} vs. ΔE plane:

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_B} \qquad \Delta E = E^*_B - E^*_{beam}$$

$\sigma(m_{ES})$ ~ 2.6 MeV dominated by the beam energy spread

$\sigma(\Delta E)$ ~ 20-30 MeV (channel dependent)

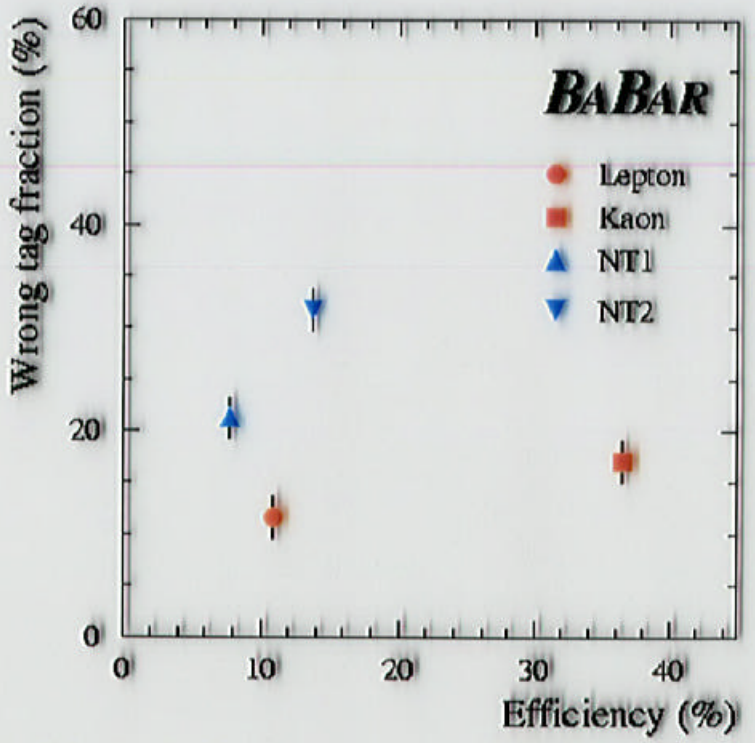
Ingredient #1 (Cont.)



- m_{ES}>5.27 GeV
  - 6643±96 signal events
  - 84% signal purity
- Combinatorial background:
  - Amount determined from m_{ES} fit
  - Time dependence: see later
- Peaking background
  - Due to pion swapping between the two B mesons
  - OK for neutral B
  - Add a background term in the fit for charged B (1-2%)

Ingredient #2: Tagging

- Analyze the remaining tracks of the event to determine the flavor of the B_{tag}
- 4 tagging categories
  - Primary lepton tag: $b \to c\, \ell^- \nu_\ell$ $p^*_\ell > 1.0$ GeV (e) or 1.1 GeV (μ)
  - Kaon tag: $b \to c\, X$; $c \to s\, X$; $s \to K^-$ (require $\Sigma Q_K \neq 0$)
  - NT1 and NT2: neural net
    using other (correlated) info
    (e.g. slow pions from D*, ...)
- Prioritized algorithm
- Lepton and Kaon ID performance is crucial!



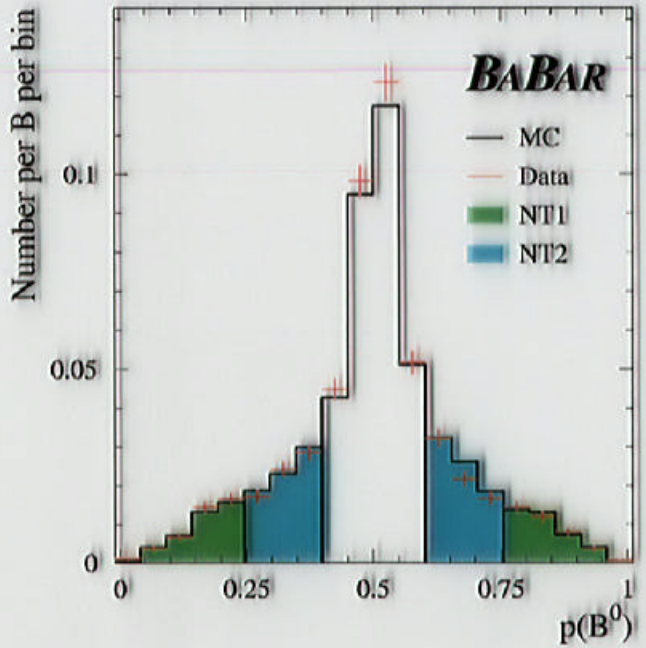
The effective tagging efficiency is

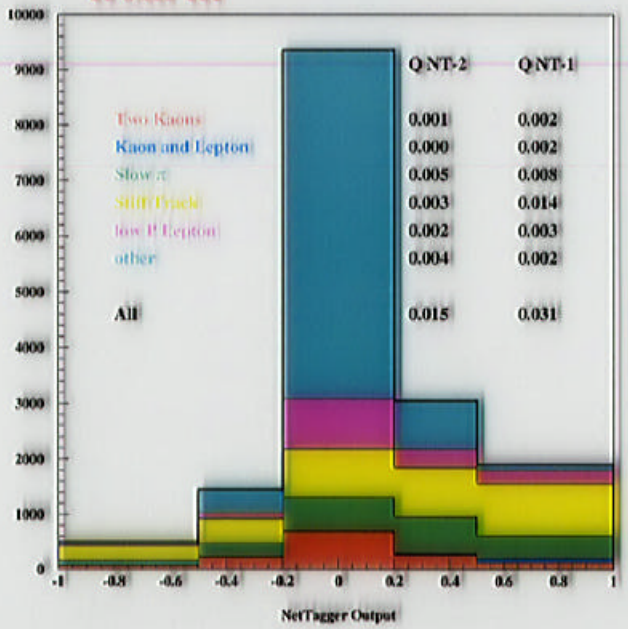
$$Q_i = e_i (1 - 2w_i)^2$$

Tagging perfomance

Category	Tagged Events	Efficiency(%)	Mistag (%)	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**

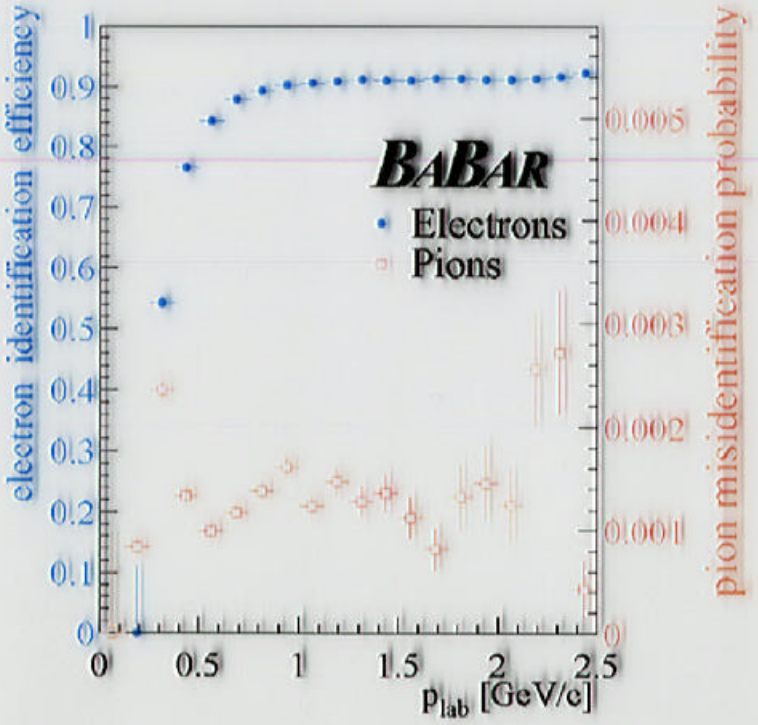
determined from fit

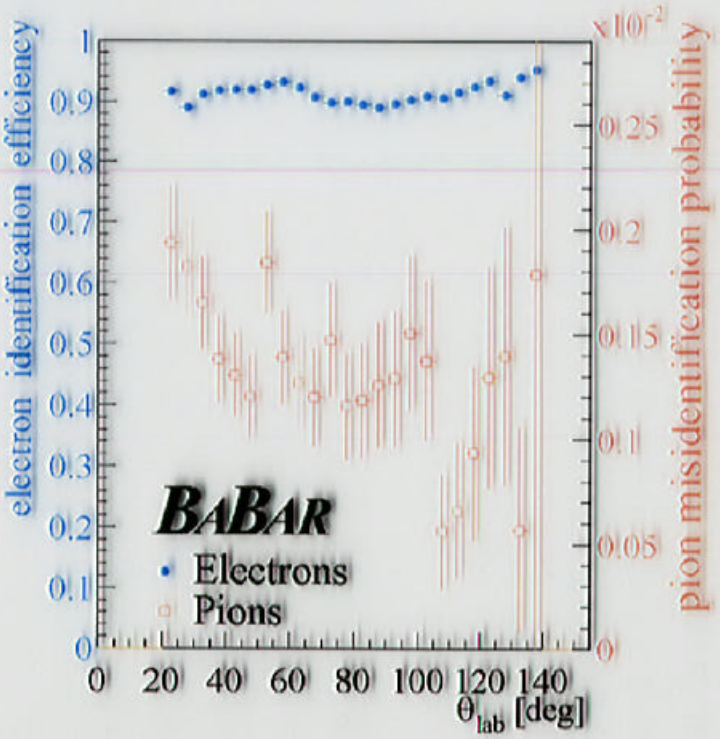




Particle ID in Babar

- **Electron ID** ε=91%, π misid=0.13%
  - Match track to EMC cluster
  - 0.89<E/p<1.2
  - EM shower shape requirements
  - dE/dx and DIRC Č angle consistent with electron hypothesis





•Muon ID

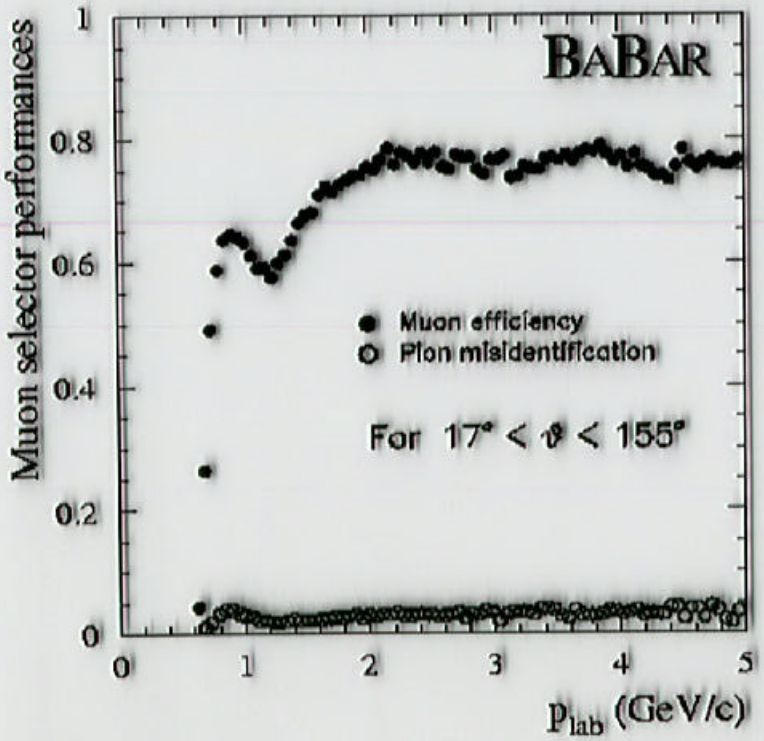
ε=75%, π misid=2.5%

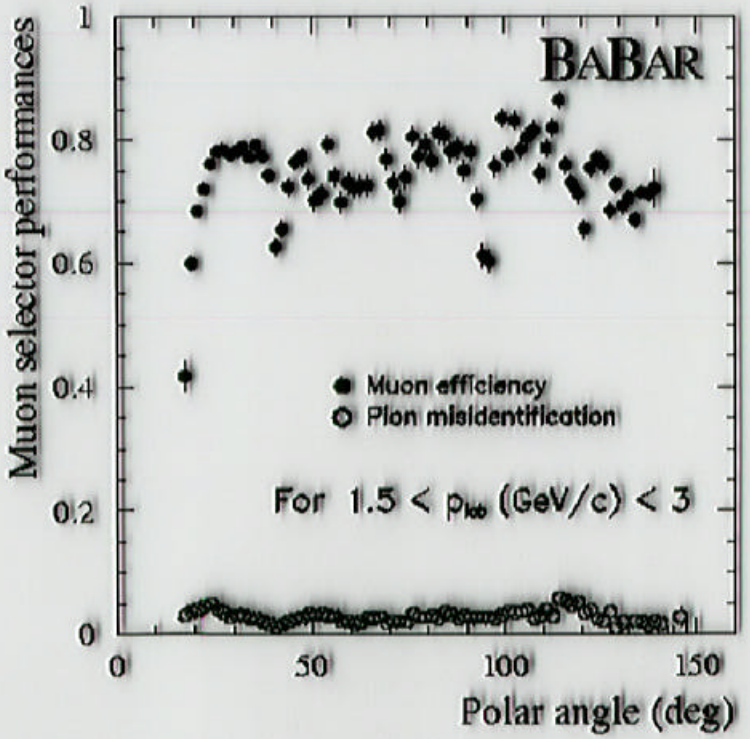
–# interaction lenghts in IFR >2.2

–Difference in measured and expected int. Length <1

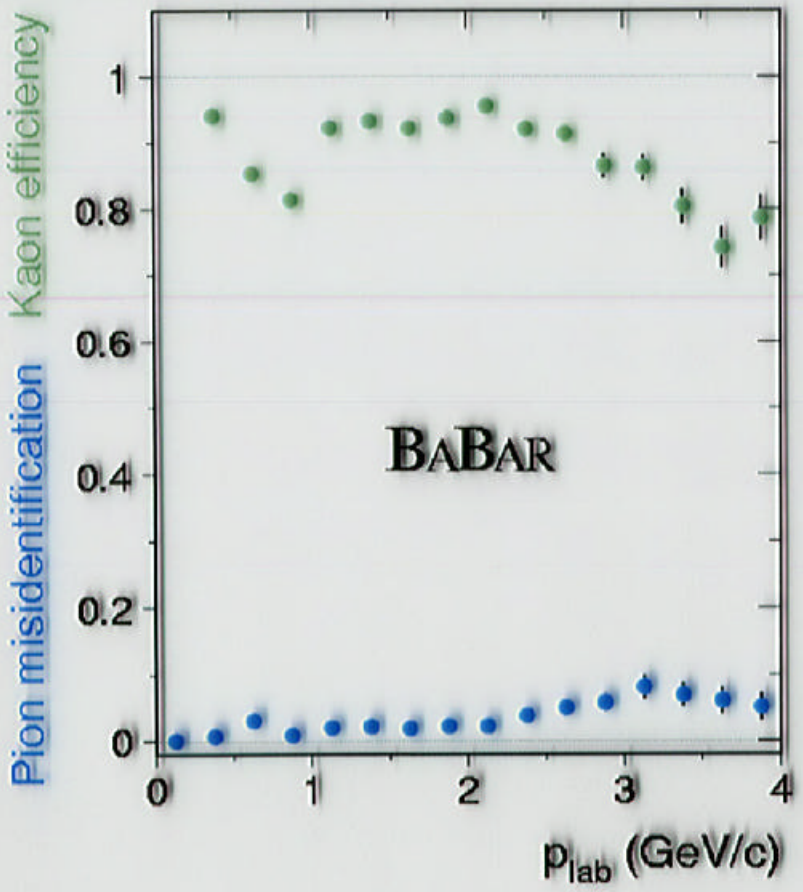
–Match between extrapolated track and IFR hits

–Requirements on average and spread of # of IFR hits per layer

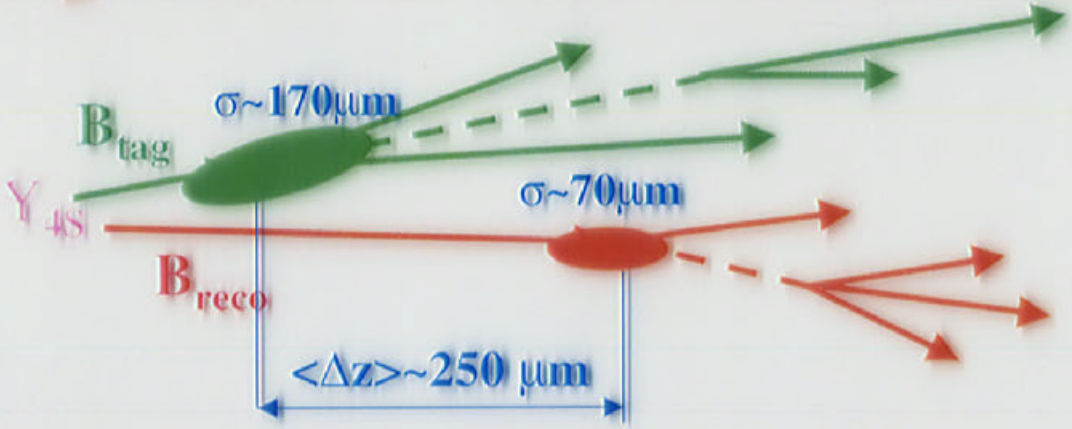




- **Kaon ID** ε=85%, π misid=5%
  - NN based on likelihood ratios in DCH and SVT (dE/dx), and in DIRC (compare single hits with expected pattern of Č light)
  - $>3\sigma$ K/π separation @ $0.25<p<3$GeV



Ingredient #3: Time Measurement



- B boosted along z axis: $\Delta t \sim \Delta z / (\beta\gamma c)$
- B_{reco} vertex explicitly reconstructed
- B_{tag} vertex inclusively reconstructed with all other tracks except B_{reco}
  - Kinematic constraint from B_{reco} momentum and decay vertex, beam spot and boost
  - Exclude tracks from charm ($\Delta\chi^2$ cut)
- Resolution function $\mathcal{R}$: 3 gaussians (core, taill, 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 tagging categories
  - Fit parameters: scale factors, biases, relative core/tail/outlier amounts

Fitting Procedure

- Unbinned maximum likelihood fit to mixed-unmixed distributions
- Signal:

$$\mathcal{H}_{\pm,\mathrm{sig}}(\Delta t;\Gamma,\Delta m,\mathcal{D}) = 1/4\ \Gamma\ e^{-\Gamma|\Delta t|}(1 \pm \mathcal{D}\cos(\Delta m\ \Delta t)) \otimes \mathcal{R}(3\mathrm{Gauss})$$

- Combinatorial background:
  - Zero-lifetime component

$$\mathcal{B}_{\pm,1} = (1 \pm \mathcal{D}_1) \otimes \mathcal{R}_{\mathrm{bck}}(2\mathrm{Gauss})$$

  - Non-oscillatory, non-zero lifetime component

$$\mathcal{B}_{\pm,2} = (1 \pm \mathcal{D}_2)\ \Gamma_2/2\ e^{-\Gamma_2|\Delta t|} \otimes \mathcal{R}_{\mathrm{bck}}(2\mathrm{Gauss})$$

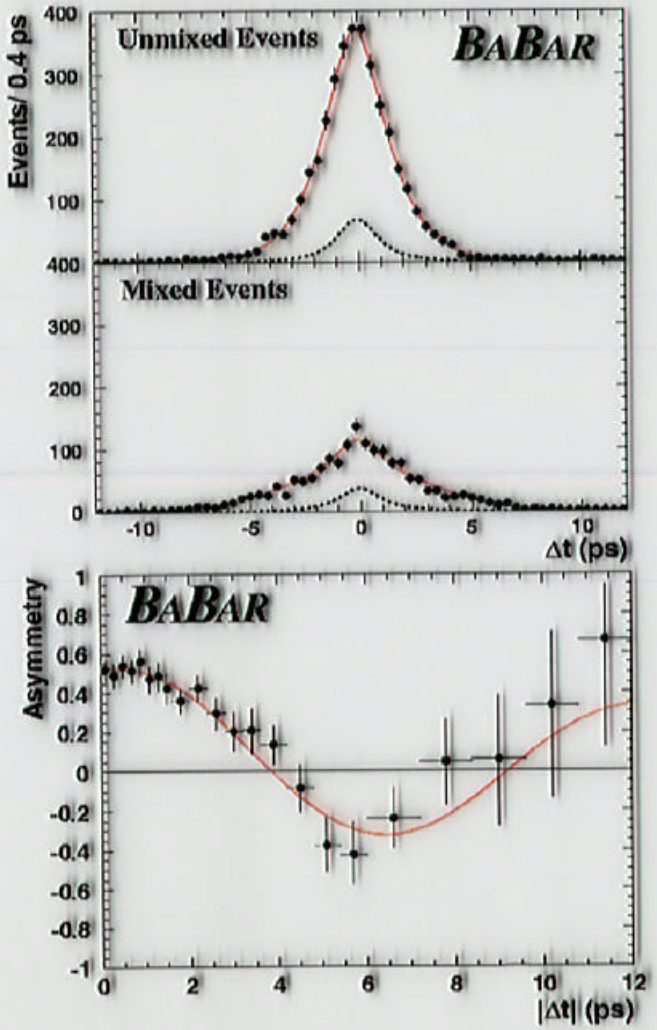
- Peaking background

$$\mathcal{B}_{\pm,\mathrm{charged}} = (1 \pm \mathcal{D}_+)\ \Gamma_+/2\ e^{-\Gamma_+|\Delta t|} \otimes \mathcal{R}_{\mathrm{sig}}(3\mathrm{Gauss})$$

- $\mathcal{D}, \mathcal{D}_1, \mathcal{D}_2, \mathcal{D}_+$ split according to tagging categories
- 34 fit parameters

Fit Results

$\mathcal{L} = 19.5\ \text{fb}^{-1}$



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

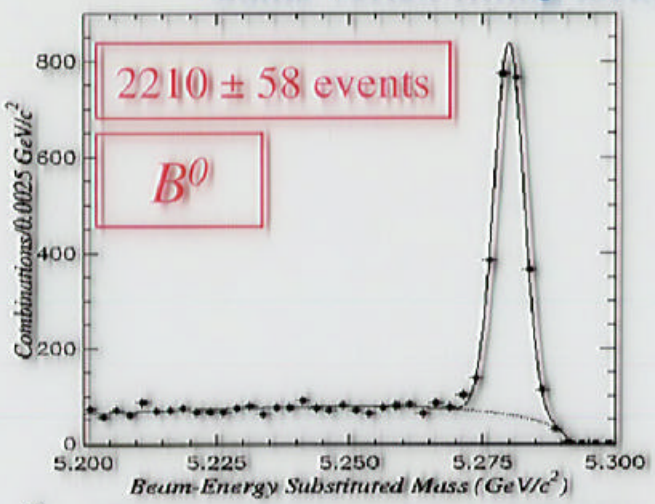
w_{lepton}	=	0.085 ± 0.018
w_{kaon}	=	0.167 ± 0.014
w_{NT1}	=	0.195 ± 0.026
w_{NT2}	=	0.326 ± 0.024

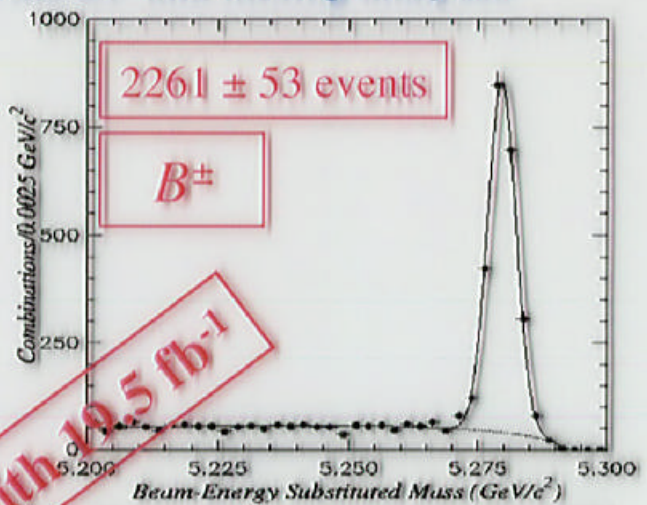
Source	Δm [$\hbar ps^{-1}$]
MC stats	0.004
MC correction	0.009
Δt outliers	0.002
Likelihood norm.	0.003
Background	0.005
B^0 lifetime	0.006
Z scale	<0.005
Z boost	0.005
SVT alignment	0.004
Beamspot postn/size	0.001
Total	**0.016**

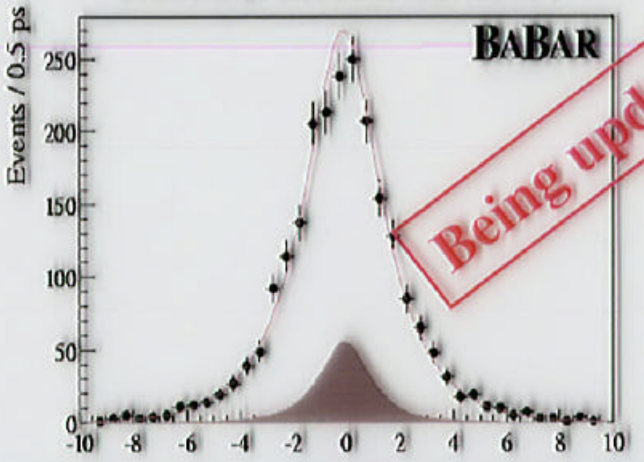
Lifetimes with fully reco hadronic decays

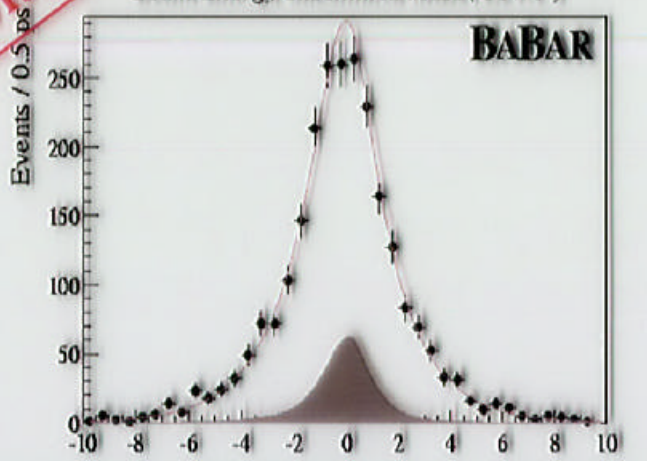
Same vertex fitting technique as the *CP* and mixing analyses

7.4 fb^{-1} on peak









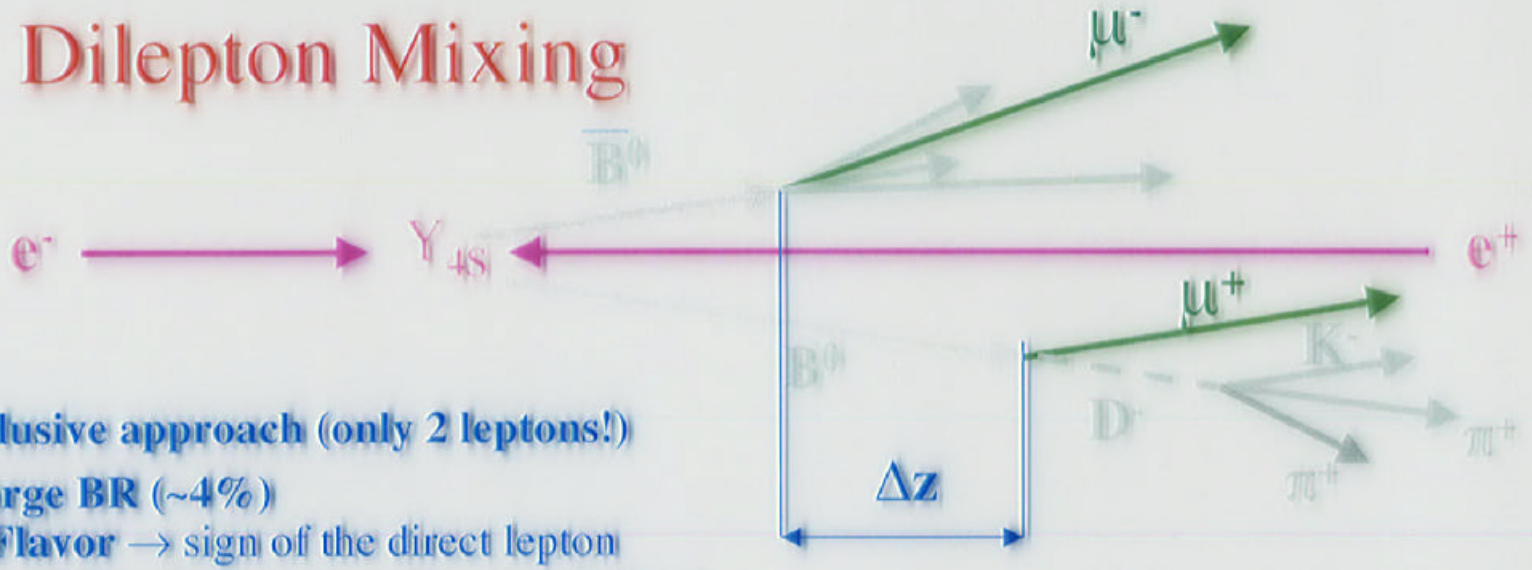
Being updated with 19.5 fb^{-1}

$\tau_{B^0} = 1.506 \pm 0.052$ (stat) ± 0.029 (syst) ps

$\tau_{B^+} = 1.602 \pm 0.049$ (stat) ± 0.035 (syst) ps

$\tau_{B^+} / \tau_{B^0} = 1.065 \pm 0.044$ (stat) ± 0.021 (syst)

Dilepton Mixing



- **Inclusive approach (only 2 leptons!)**
- **Large BR (~4%)**
- **B Flavor** → sign of the direct lepton
- **B^0 and $B^\pm$ admixture** → Fraction R fitted
- Δz → **points of closest approach of the leptons to the beam spot in transverse plane**

$$A(\Delta t) = \frac{N(\ell^+\ell^-)(\Delta t) - N(\ell^\pm\ell^\pm)(\Delta t)}{N(\ell^+\ell^-)(\Delta t) + N(\ell^\pm\ell^\pm)(\Delta t)}$$

2 additionall parameters in the fit to take into account the fraction of mistagged events (cascade leptons).

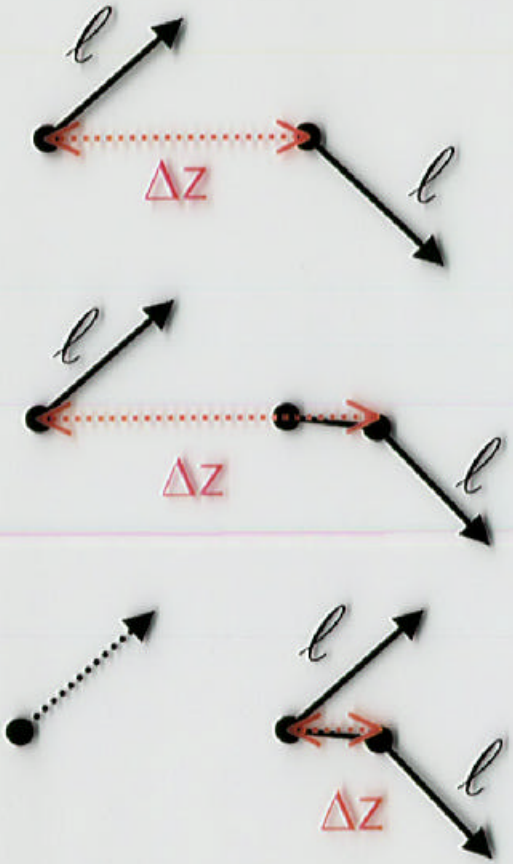
Fit of Δm and the fraction R

$$A(\Delta t) = \frac{e^{-\Gamma^0|\Delta t|}\cos(\Delta m_B \Delta t) + R \cdot e^{-\Gamma^+|\Delta t|}}{e^{-\Gamma^0|\Delta t|} + R \cdot e^{-\Gamma^+|\Delta t|}}$$

Dilepton Mixing: Event selection

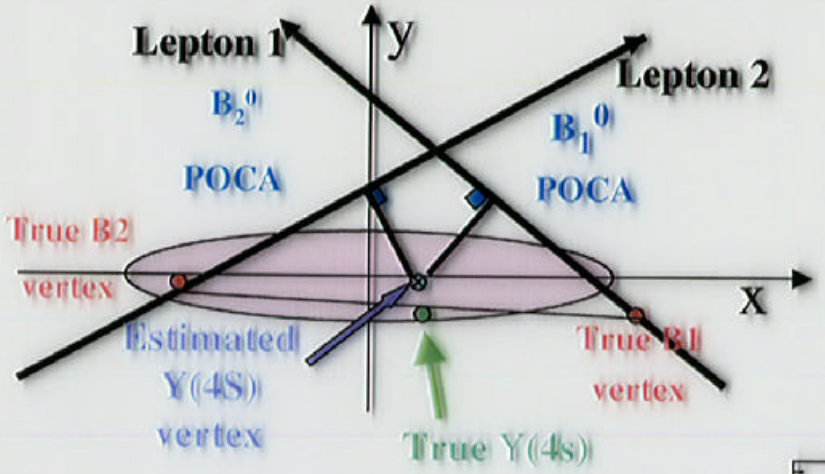
- Continuum background rejection: event shape variables
- Rejection of J/ψ and conversions with invariant mass cut
- cuts on track quality (SVT z hits, polar angle, Δz error)
- NN to select signal events (lepton p* and opening angle, total energy and missing momentum of the event)
- sample composition: 78% signal, 12% direct-cascade, 5% with one or more fake leptons, 5% continuum + other
- Eventuallly increase neutral B purity by inclusively reconstructing the $B \rightarrow D^* \ell \nu$ decay with a soft pion from D*

Signal and (main) backgrounds



- Direct leptons (78%)
  - sensitive to mixing (!)
  - B-lifetime component
- Opposite-B cascade (OBC) leptons (~7%)
  - sensitive to mixing, but
  - source of mistag (~100%)
  - extra-lifetime due to charm decay
    (B-lifetime + effective lifetime from charm)
- Same-B cascade (SBC) leptons (~5%)
  - not sensitive to mixing
  - source of opposite-sign leptons only
  - effective lifetime from charm
- Misidentified leptons (~5%):
  - same topologies (and resolution function) as above
  - extra mistag to be taken into account
- Continuum (~5%): fit off-resonance data

Dilepton Mixing: Δt measurement



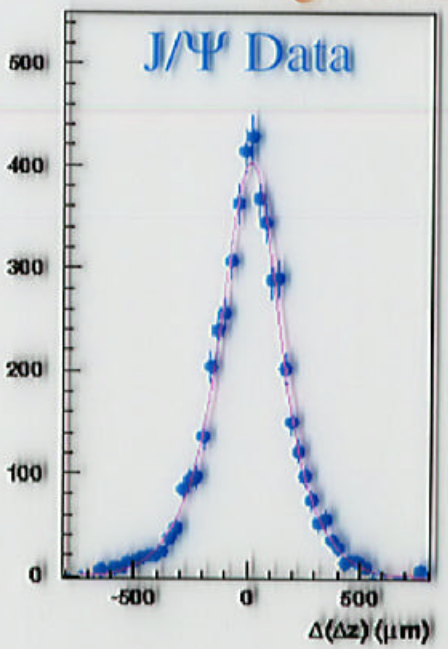
Δz = z difference of the point of closest approach (POCA) of the tracks to a Y(4S) vertex, estimated with the 2 leptons and a beam spot constraint

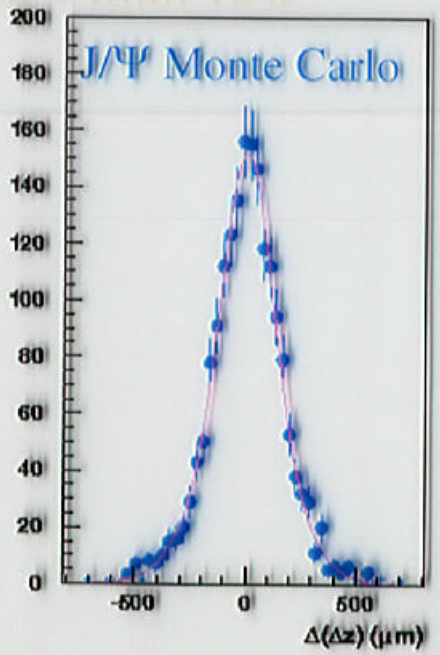
- Δz resolution function determined with MC and cross-checked with J/Ψ.
  - Narrow Gaussian : 87μm (76%)
  - Wide Gaussian : 195μm (24%)

- Boost approximation:

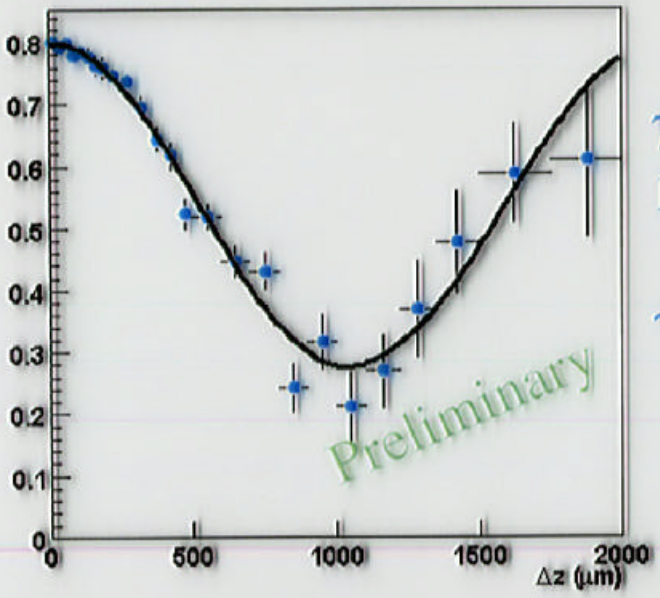
$$\Delta t = \Delta z / (c < \beta\gamma >)$$

Agreement within 10%



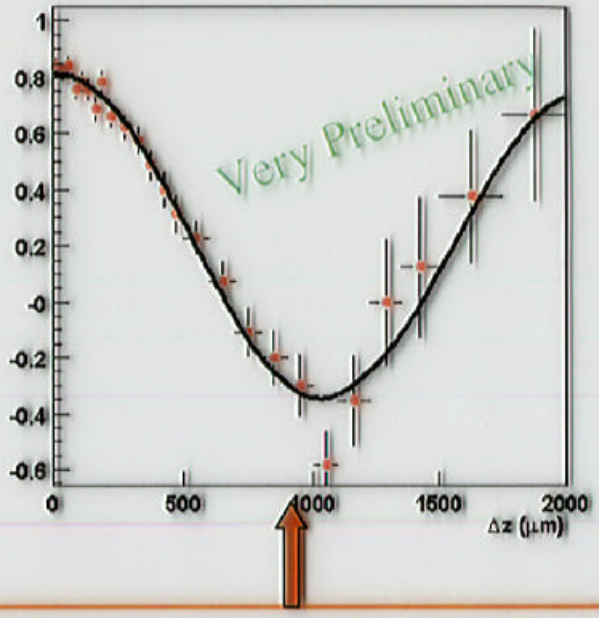


Dilepton Mixing: Results



7.7 fb^{-1} on-resonance
1.1 fb^{-1} off-resonance

~35000 events



Dilepton sub-sample enriched in B^0 with partial reconstruction of $B^0 \to D^{*}l\,\nu$ (soft pion tag)

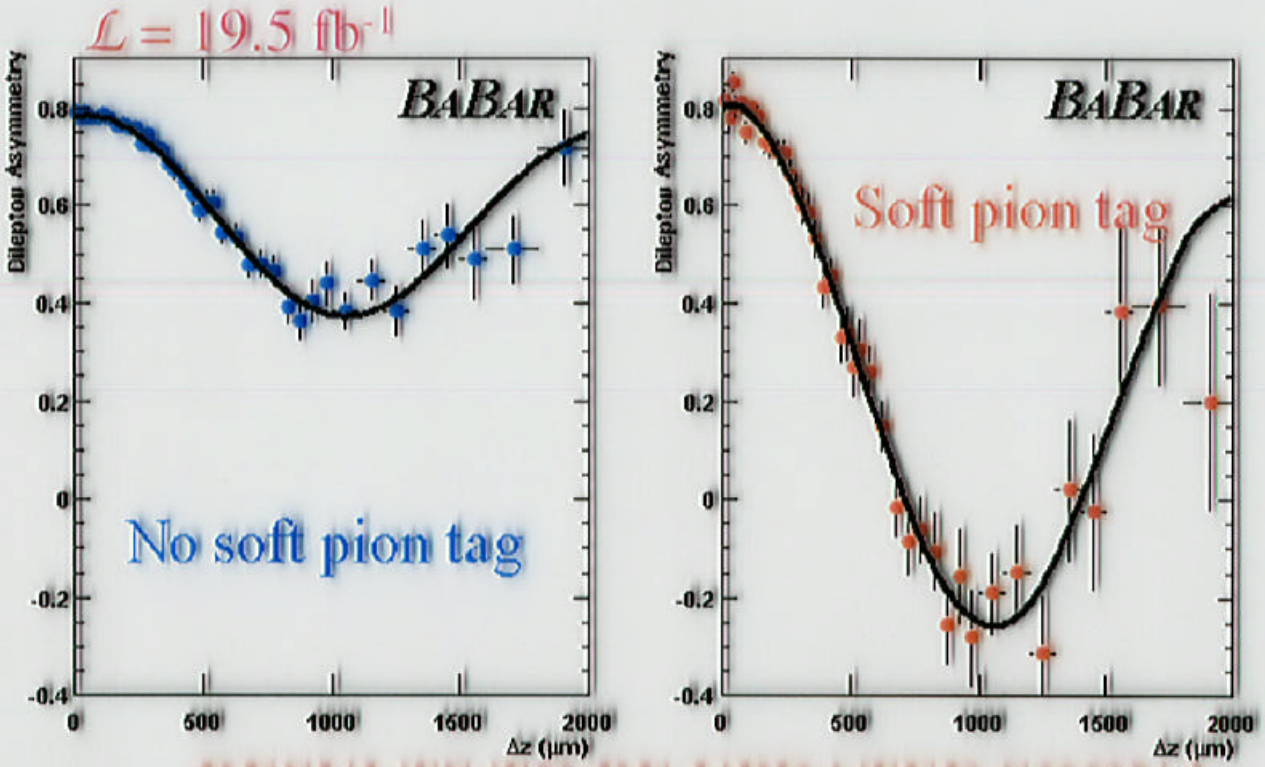
$$\Delta m_d = (0.507 \pm 0.015(\text{stat}) \pm 0.022\ (\text{syst}))\ \hbar\ ps^{-1}$$

Systematic uncertainties dominated by

- lepton misID
- cascades parametrization
- Δz resolution function
- B meson lifetimes

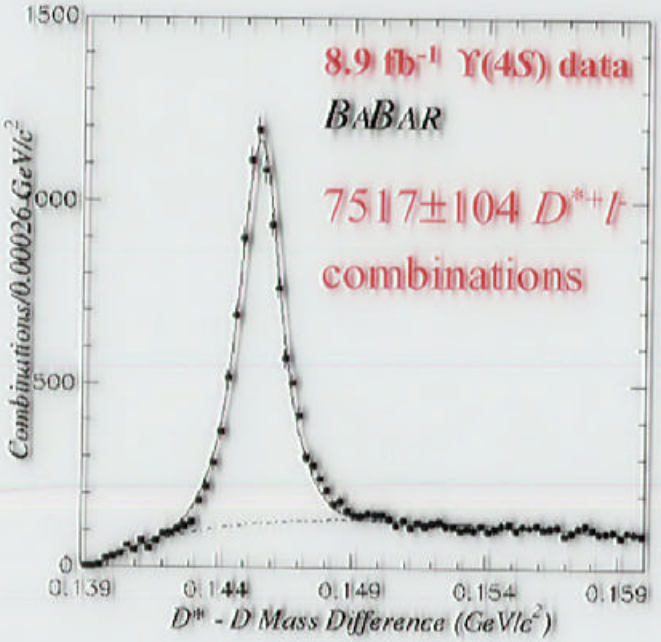
Dilepton Mixing Prospects With Run1 Data

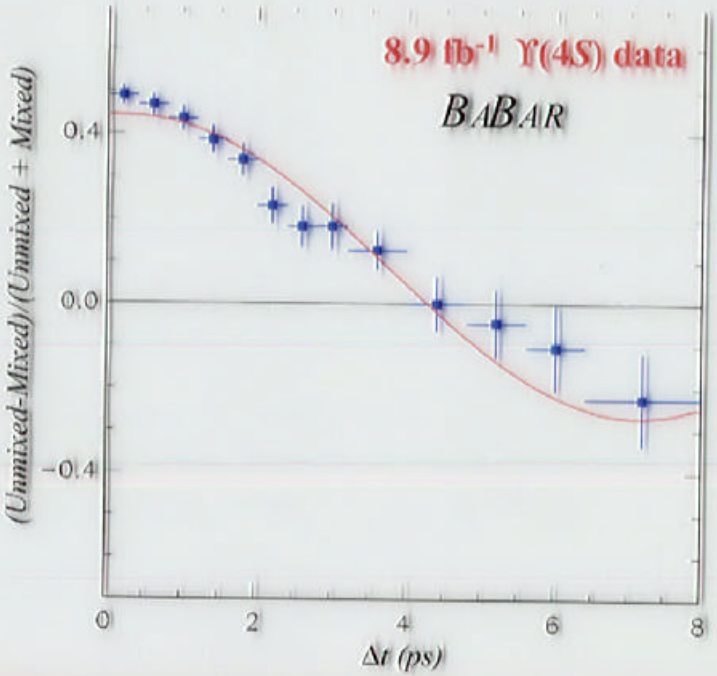
- From 7 to 20 fb-1 (~100K events): *statistical error* 0.015 → 0.010 $\hbar$ *ps*$^{-1}$
- Improve background description and fitting technique and strategy to reduce *systematic error*: 0.022 → <0.010 $\hbar$ *ps*$^{-1}$



RESULTS TO BE UPDATED SOON !

Mixing with fully reco B→D*ℓν





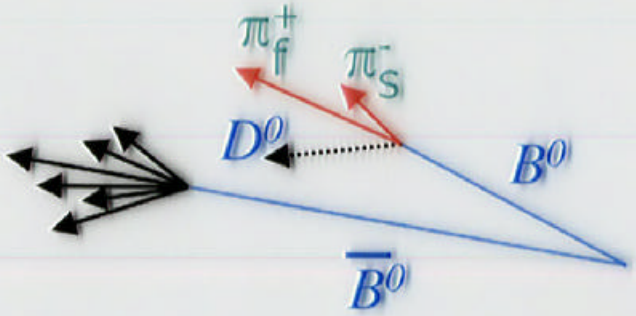
$B^0 \to D^{*-} l^+ \nu_l$
$D^{*-} \to D^0 \pi$
$D^0 \to K^- \pi^+$,
$D^0 \to K^- \pi^+ \pi^0$,
$D^0 \to K^- \pi^+ \pi^- \pi^+$

$\Delta m_d = (0.508 \pm 0.020(\text{stat}) \pm 0.022 (\text{syst})) \hbar\, ps^{-1}$

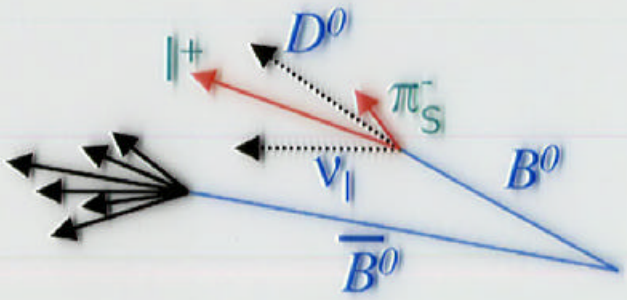
(Being updated with 19.5 fb^{-1})

Lifetimes and mixing with partial reco methods

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



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



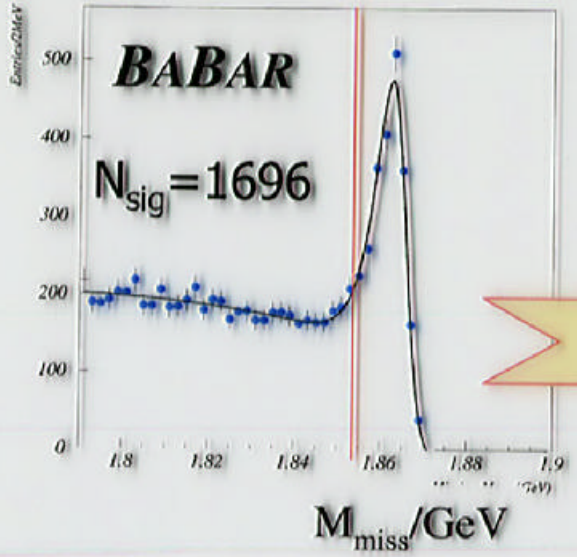
High statistics

- Reconstruct M_{miss} from π^+ and π^- only.
- Use beam constraints

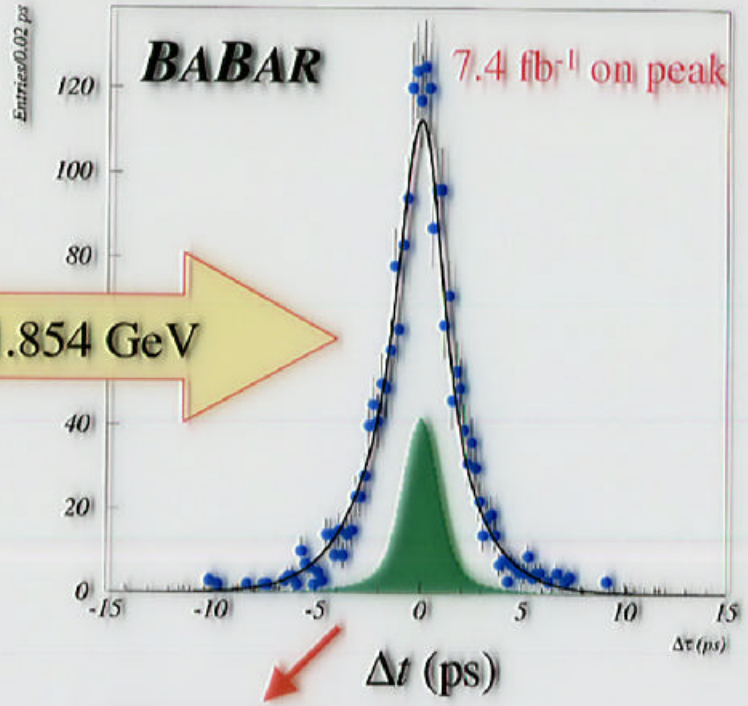
- π_s direction ≈ D^* direction.
- Reconstruct m_ν^2 from l^+ and π only .

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

Unbinned maximum likelihood fit.



$M_{miss} > 1.854$ GeV



27% background

Selection:

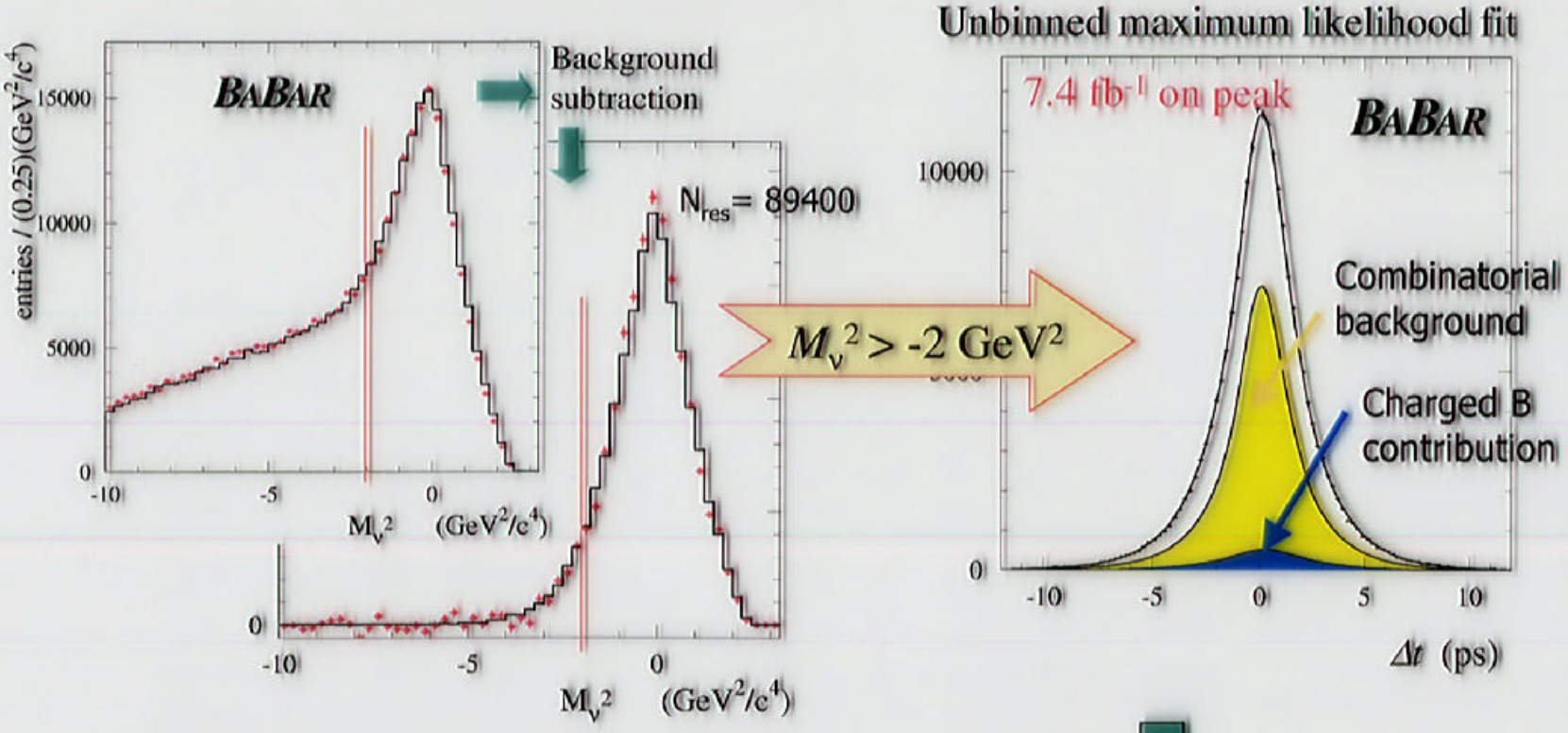
- Kinematics: $2.114 < p_{\pi_f} < 2.404$ GeV
- Event shape $R_2 < 0.35$
  - π_f isolation (0.4 rad)
  - Fisher discriminant
- Helicity angle $|\cos\psi| > 0.4$

$\Rightarrow$ Efficiency = 16 %

$\tau = 1.55 \pm 0.05$ (stat) ± 0.07 (syst) ps

(Being updated with 19.5 fb^{-1})

B^0 lifetime with $B^0 \to D^{*-} l^+ \nu_l$



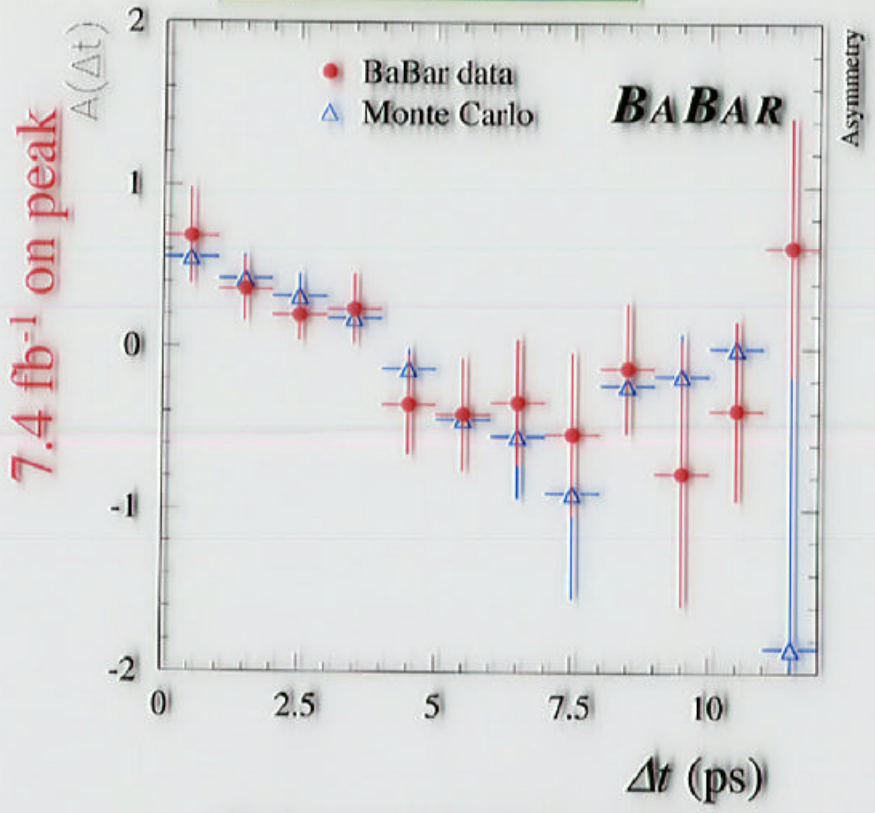
- Background determined by same sign events ($l^+\pi_s^+$, $l^-\pi_s^-$)
- Charged B contamination: 5 %
- Combinatorial background: 40.7 %

$\tau = 1.63 \pm 0.02$ (stat) ± 0.09 (syst) ps

(Being updated with 19.5 fb^{-1})

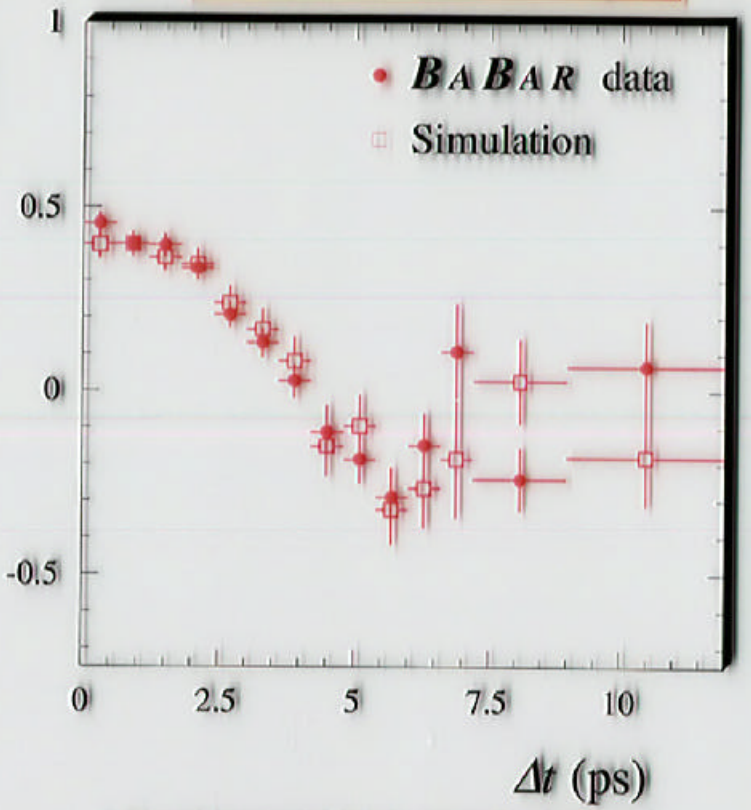
B^0 mixing with partial reco methods

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



• Background subtraction applied

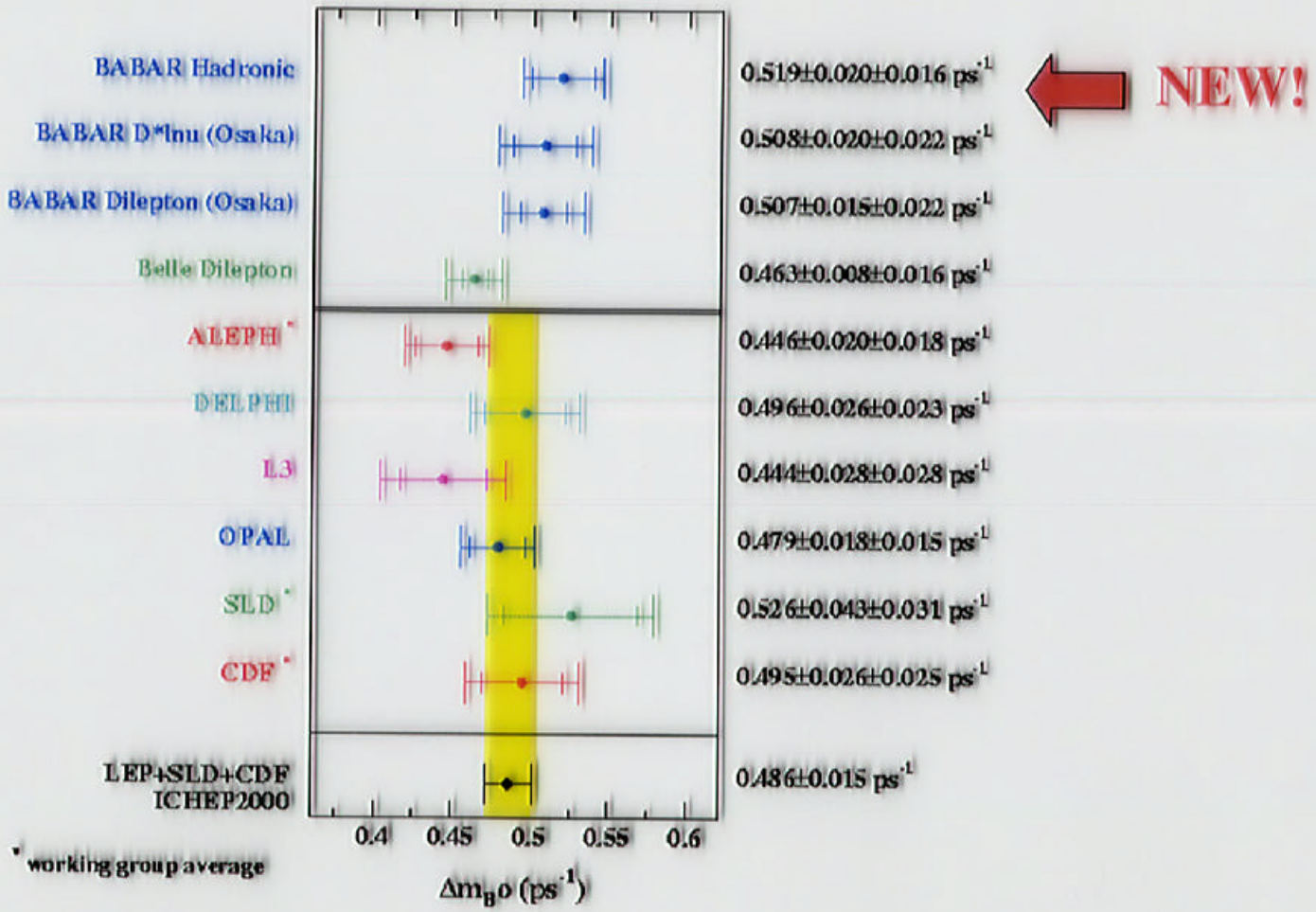
$B^0 \to D^{*-} l^+ \nu_l$



• Combinatorial background subtracted

➡ Mixing signal is seen

Mixing measurements



Conclusion

- Precise measurements of lifetimes and mixing with 4 different techniques!
  - Any single measurement as accurate as the pre-B-factory-era world average
- New result on hadronic mixing

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

  - Validates detector performance for sin(2β) measurement
- Other results to be updated/published in a short time