Simultaneous Measurement of $\tau(B^0)$ and Δm_d using Partially Reconstructed $\overline{B}^0 \rightarrow D^{*+} l^- \nu$ decays

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- **Systematic Errors**
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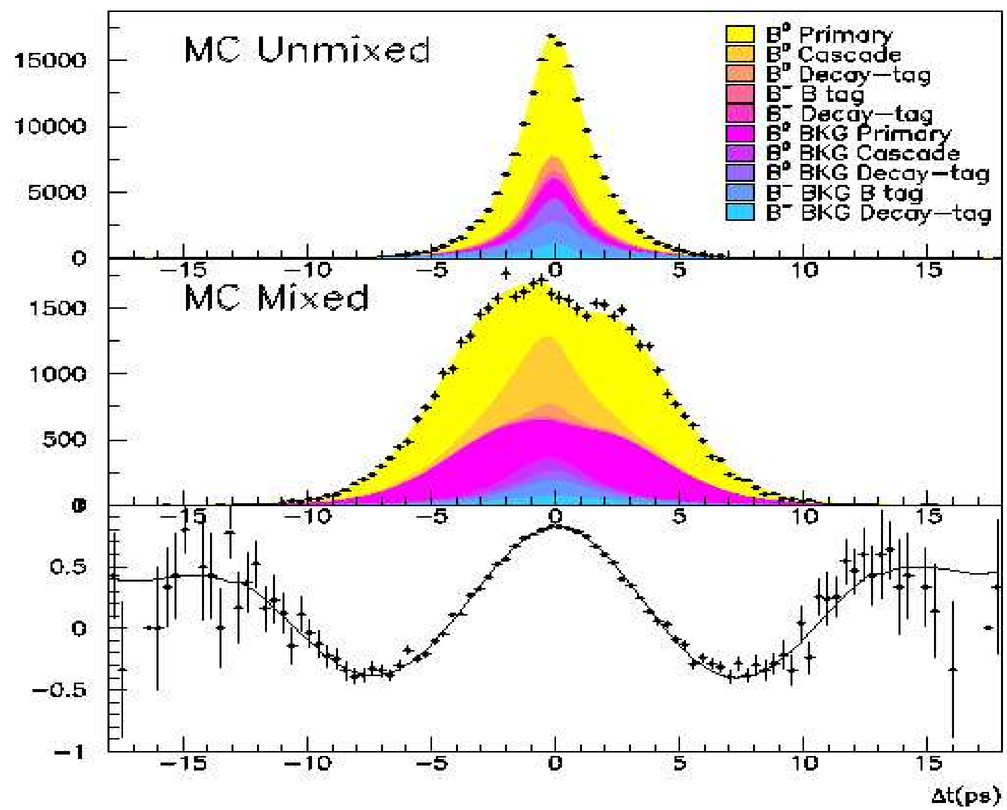
- BAD 287
- CONF−04/15 (ICHEP)



Analysis Strategy (1)

$\bar{B}^0 \rightarrow D^{*+}\, l^- \nu$

$\quad \hookrightarrow D^0\, \pi_s^+$

$l^\mp\, \pi_s^\pm$: right−charge correlation

$l^\mp\, \pi_s^\mp$: wrong−charge correlation

Partial Reconstruction:

D^* identified only from π_s

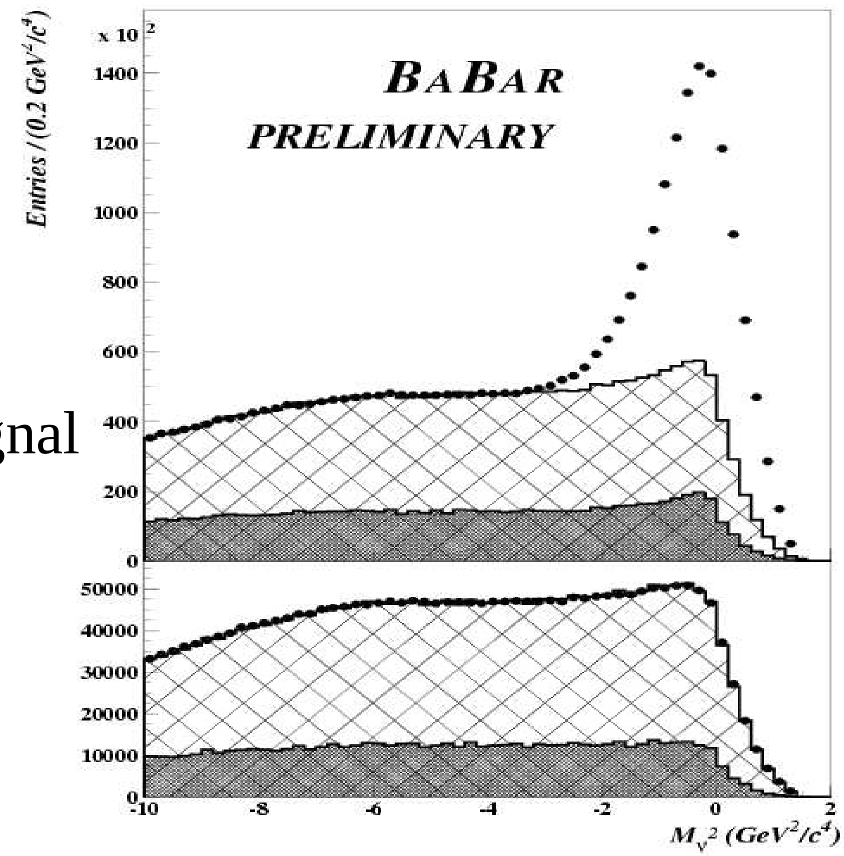
B^0 ~ at rest in Y rest frame

Selection Variable:

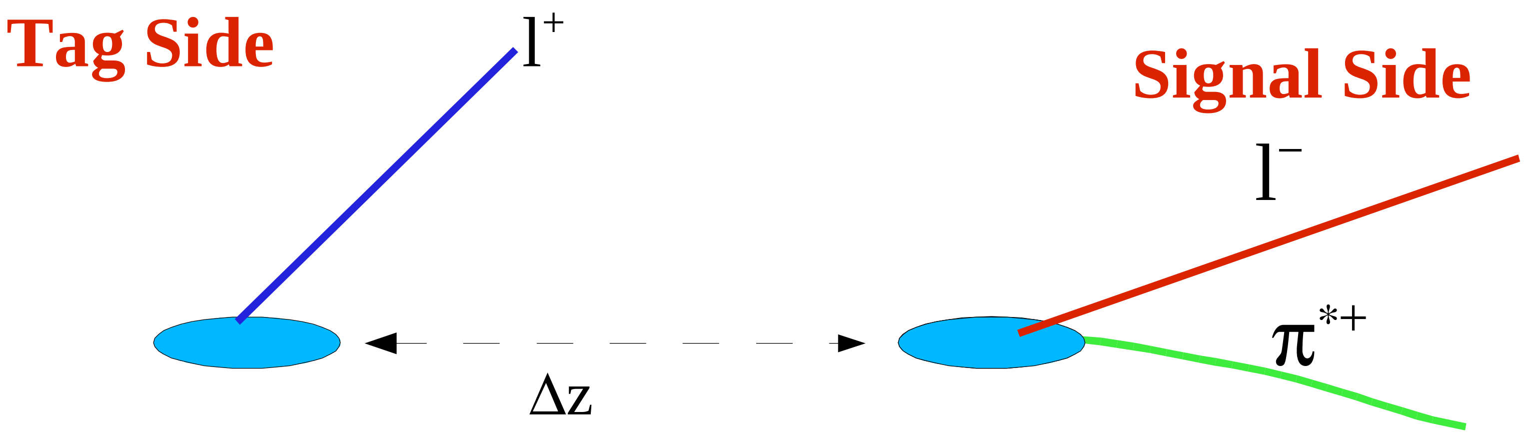
$M_\nu^2 = (M_{B0} - E_{D^*} - E_l)^2 - (\mathbf{P}_{D^*} + \mathbf{P}_l)^2 \sim 0$ for Signal

From $E_{\pi s}$, $P_{\pi s}$ parameterization

750K Peaking events (Run1+2)

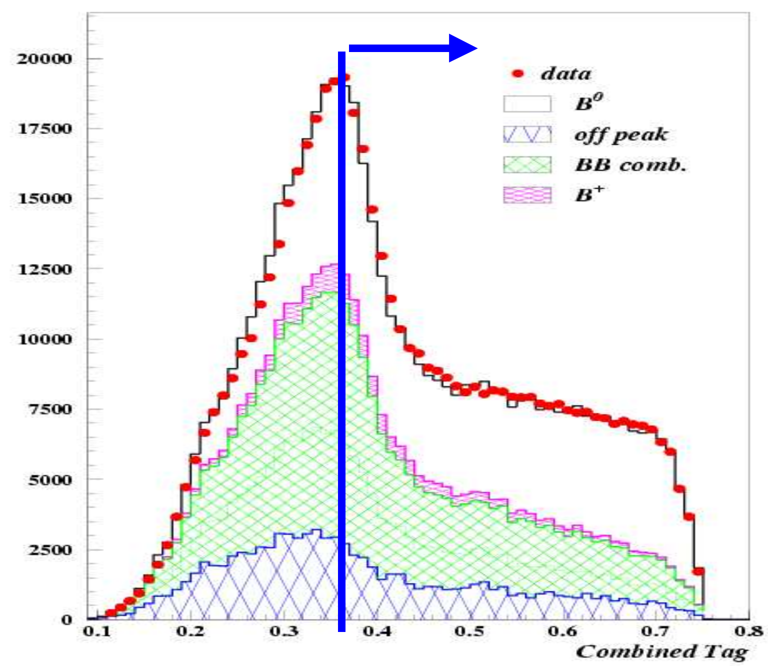


Analysis Strategy (2)



Signal Vertex: $l\pi^*$ + Beam Spot (x,y), σ_y(B.S.) inflated to 50μm (B motion)

Combine P_l, $P_{\pi s}$, Prob Vtx (l,π_s) in Likelihood Ratio χ



Tag Vertex: *l* (Elbatag) (ε~10 %) +BS (x,y)

P_l > 1 GeV/c (e) (1.1 GeV/c (μ))

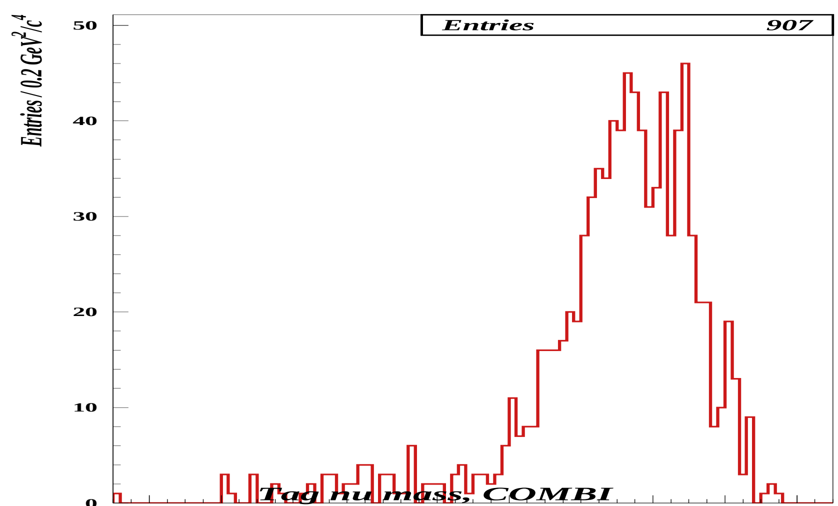
Tag Lepton alone: No D^0 bias

Compute $\Delta t = \Delta z / \beta\gamma$ (Boost Approx.)

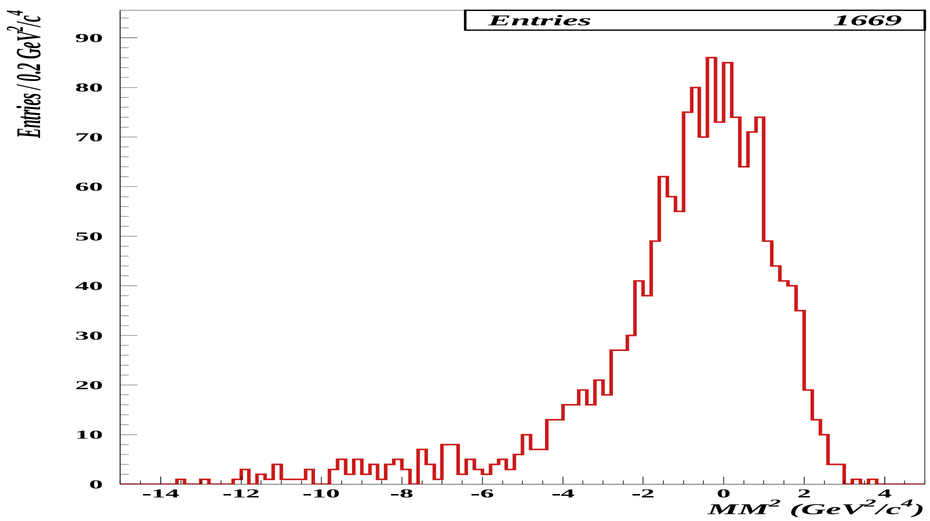
Analysis Strategy (3) (After ICHEP)

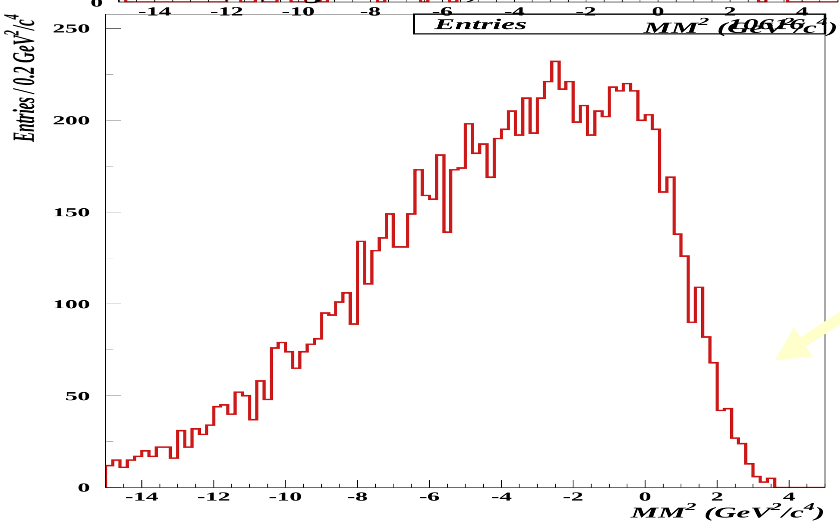
●Multiple candidates events with additional π* from the Tag−B^0 decay chain originate a Selection Bias: look at ***M^2_ν on Tag−Side:***

π* from D*, Decay−Side Signal



π* from D*, Decay−Side BKG





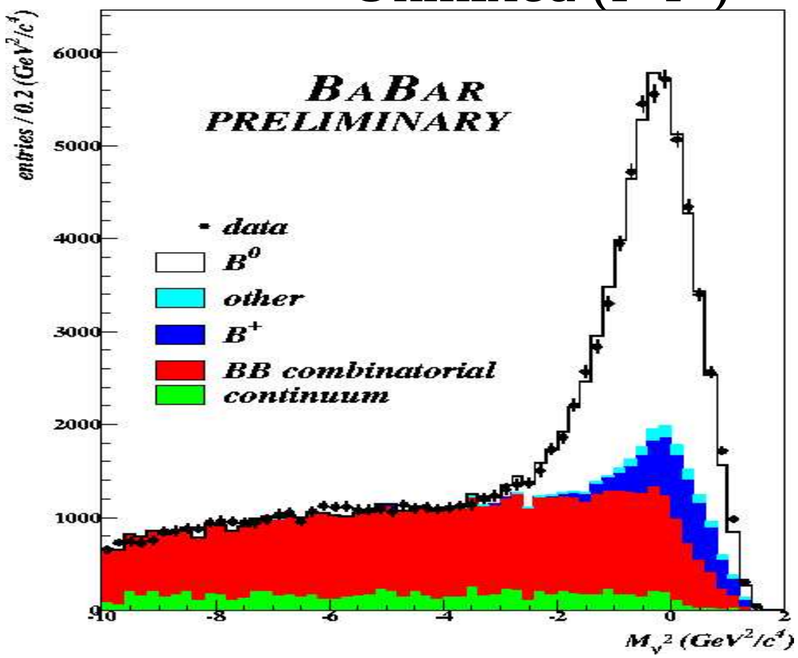
π* not from D*

●Event removed if :
M^2_ν(tag−side)>−3 GeV^2

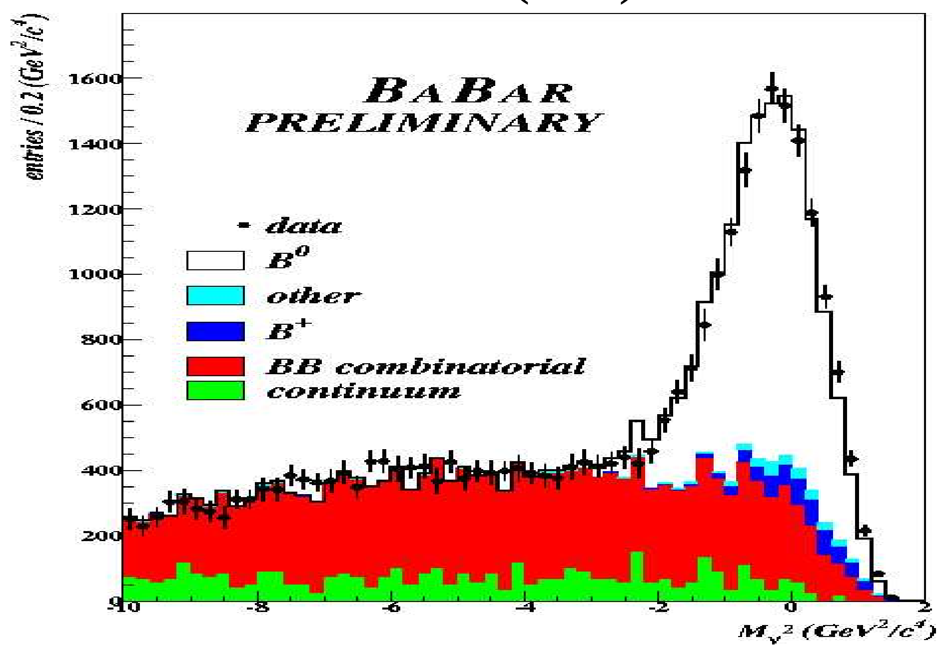
Sample Composition (I)

- Run 1+2 Analysis 10 (~88 MBB); MC~2 X DATA
- Select events with $|\Delta t|<18$ ps, $\sigma\Delta t<3$ ps

Unmixed ($l^{\mp}\, l^{\pm}$)



Mixed ($l^{\mp} l^{\mp}$)



- M^2_{ν} (for unmixed and mixed subsamples) fitted as a sum of:

✗ Continuum (off−peak)

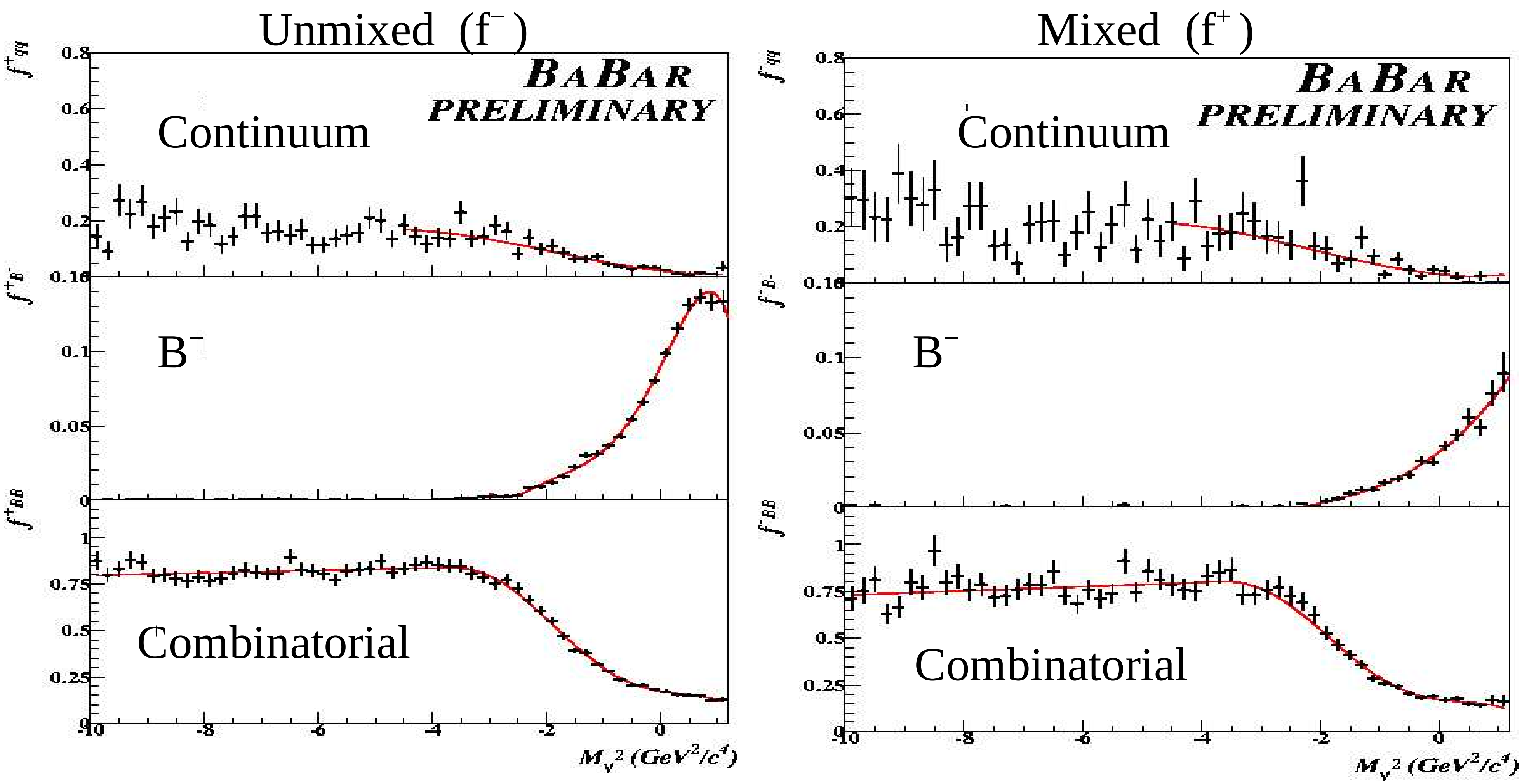
✗ BB Combinatorial (MC)

✗ B^- Peaking BKG (MC); Isospin Conservation: 2/3 of $B \to D^*\pi l\nu$ from B^- decays

✗ B^0 Signal (MC)

- $M^2\nu > -2.5\,GeV^2/c^4$: Nevts ~ 70000 lepton tagged; f(B^0 Signal)~65%

Sample Composition (2)



- Background Fractions to be used in the Δt fit:

  $f^{\pm}_{qq}(M^2_{\nu})$, $f^{\pm}_{BB}(M^2_{\nu})$, $f^{\pm}_{B-}(M^2_{\nu})$
- $M^2_{\nu} < -4.5$ GeV²/c⁴: $f^{\pm}_{qq}(M^2_{\nu}) = 1 - f^{\pm}_{BB}(M^2_{\nu})$

PDF Description

- $\mathcal{F}^{\pm}(\Delta t, \sigma\Delta t, M^2_\nu \mid \tau, \Delta m) =$

$$f^{\pm}_{qq}(M^2_\nu)\,\mathcal{F}^{\pm}_{qq}(\Delta t, \sigma\Delta t) \otimes \mathcal{R}(\delta\Delta t, \sigma\Delta t)$$ Continuum

$$+\ f^{\pm}_{BB}(M^2_\nu)\,\mathcal{F}^{\pm}_{BB}(\Delta t, \sigma\Delta t) \otimes \mathcal{R}(\delta\Delta t, \sigma\Delta t)$$ Combinatorial

$$+\ S_{B-}\,f^{\pm}_{B-}(M^2_\nu)\,\mathcal{F}^{\pm}_{B-}(\Delta t, \sigma\Delta t) \otimes \mathcal{R}(\delta\Delta t, \sigma\Delta t)$$ Peaking B^-

$$+\ [1 - S_{B-}\,f^{\pm}_{B-}(M^2_\nu) - f^{\pm}_{BB}(M^2_\nu) - f^{\pm}_{qq}(M^2_\nu)]$$

$$*\ \mathcal{F}^{\pm}_{B0}(\Delta t, \sigma\Delta t \mid \tau, \Delta m) \otimes \mathcal{R}(\delta\Delta t, \sigma\Delta t)$$ B^0 Signal

$f^{\pm}_i(M^2_\nu)$: fractions, $\mathcal{F}^{\pm}_{qq}(\Delta t, \sigma\Delta t)$: PDF, S_{B-} : scale factor constr. to 1±50% (Isospin Assumption)

- Resolution Function:

$$\mathcal{R}(\delta\Delta t, \sigma\Delta t) \sim (1-f_w-f_o)\ \exp(-(\delta\Delta t - o_n)^2/2(S_n\sigma\Delta t)^2)$$ Narrow

$$+\ f_w\ \exp(-(\delta\Delta t - o_w)^2/2(S_w\sigma\Delta t)^2)$$ Wide

$$+\ f_o\ \exp(-\delta\Delta t/2S^2_o)$$ Outlier

- $\delta\Delta t = \Delta t(\text{measured}) - \Delta t(\text{true})$
- Offset o_n, o_w adjusted for each sample; f_o, S_o, S_n (Comb.) $\neq f_o$, S_o, S_n (Signal)
- Other Resolution Function parameters common to all samples

Fit Method (I)

- Fit to Δt to determine simultaneously τ, Δm and dilution $\mathcal{D}$, constrained to the fraction of mixed events:

$$N_{mix}/N_{tot} = \chi_d \mathcal{D} + (1-\mathcal{D})/2; \quad \chi_d = x^2/(1+x^2)2; \quad x = \Delta m\, \tau$$

- Binned (100/250 Δt X 25/50 $\sigma\Delta t$) Maximum−likelihood fit to mixed and unmixed subsamples

- Likelihood value computed at the bin center / average in the bin

- Use all the events in the range $-10\ \mathrm{GeV}^2/c^4 < M^2_\nu < 2\ \mathrm{GeV}^2/c^4$
(Assumption: Same PDFs in BKG/Signal regions for BB Combinatorial and Continuum)

- Float all the Signal/Bkg parameters in the same fit

Fit Method (2)

- Validate in the simulation the resolution model and the measured tagging dilution comparing the generated τ, Δm values with the results of the fits using:
  - true Δt and tagging (Selection Bias check)
  - true Δz and tagging (Boost Approximation check)
  - true Δz and experimental tagging (realistic dilution)
  - experimental Δz and true tagging (resolution function)
  - experimental Δz and tagging (realistic fit)

- Validate in the simulation every term in the PDF (B^0, B^-, Combinatorial) :
  - Add terms (one a time) and repeat the fit
  - Perform complete (B^0+B^-+BB) MC test
  - Check Continuum using off−peak events

- Fit the Real Data events

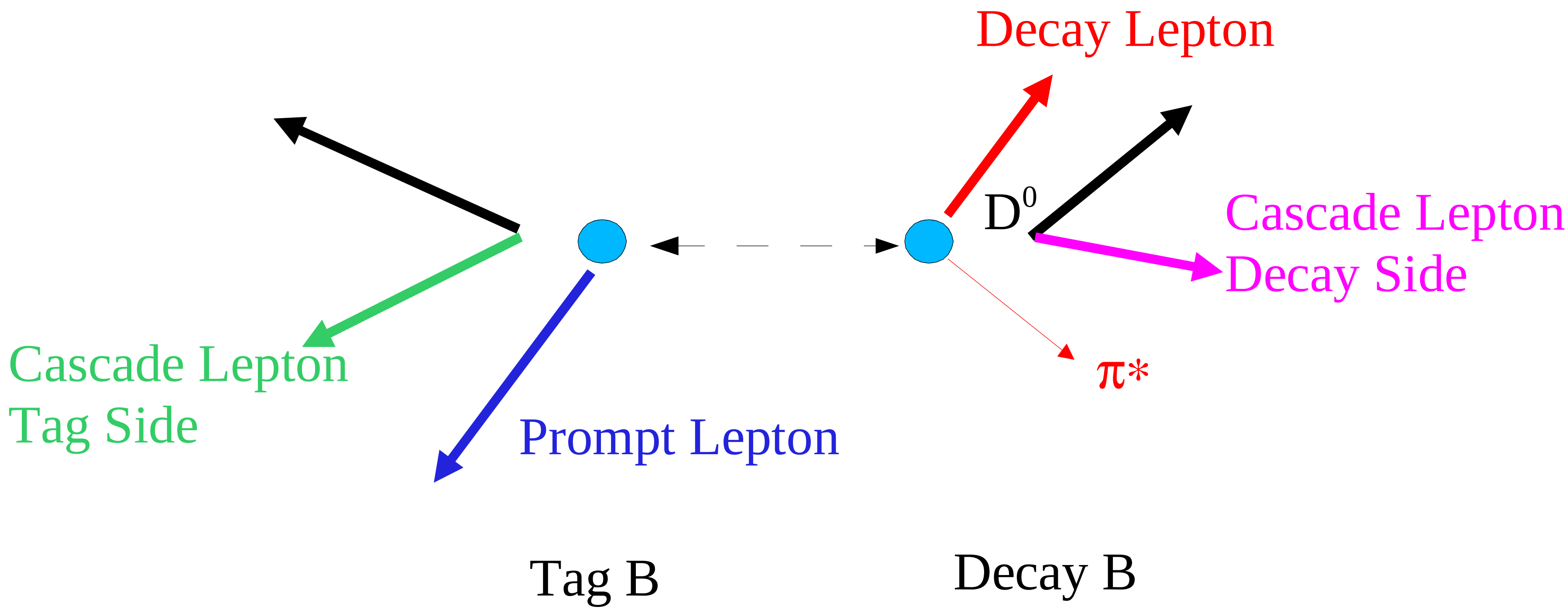
➔Total of 14 tests

Fit Method (4): B^0 Signal PDF

Tagging Lepton Sample: { b−> l / b−>c−>l / D^0 −> l

From tag B

From decay B

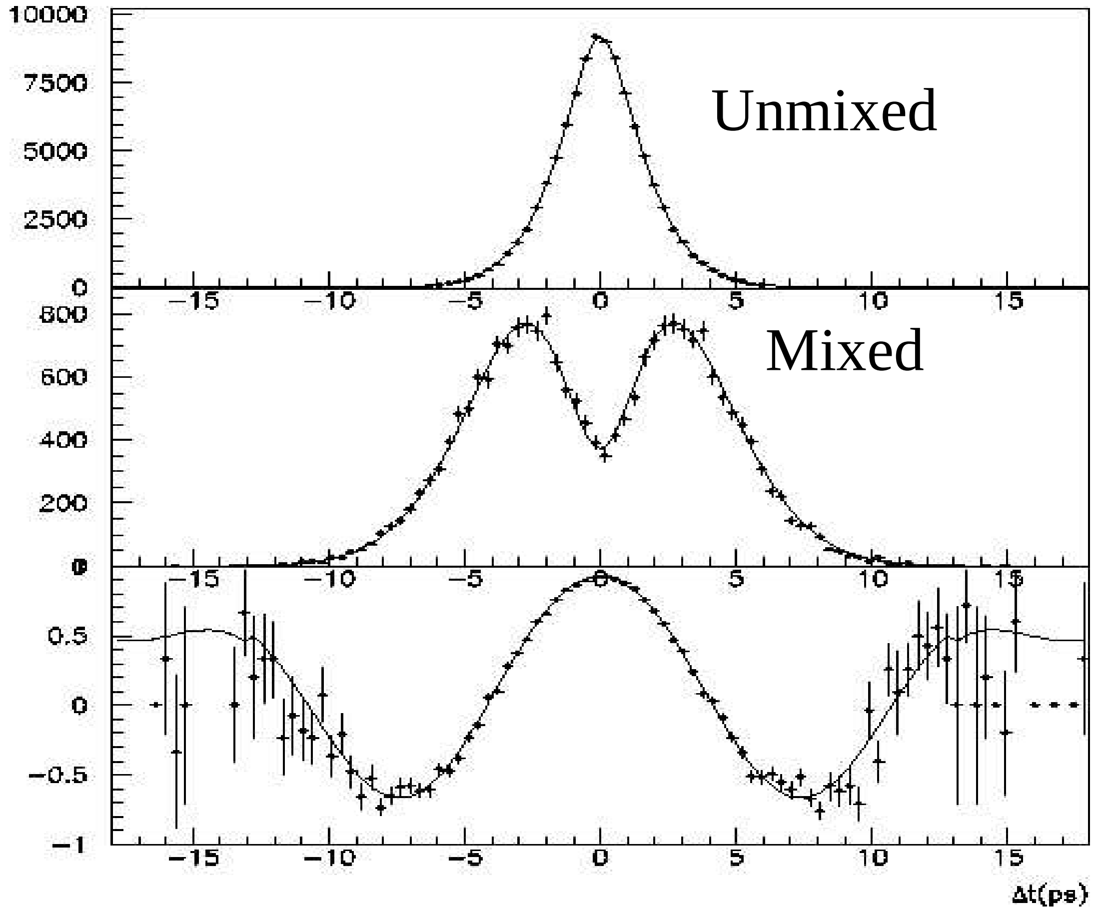


MC Results (I): Prompt

- MC: $\mathcal{D}_P \sim 0.97$

  Floated in the fit;
- DT: $\mathcal{D}_P \sim 0.99$
- o_N, o_W compatible with zero

$$\mathcal{F}^{+-}_{P} = e^{-|\Delta t|/\tau}(1 \pm \mathcal{D}_P \cos(\Delta m \Delta t))$$



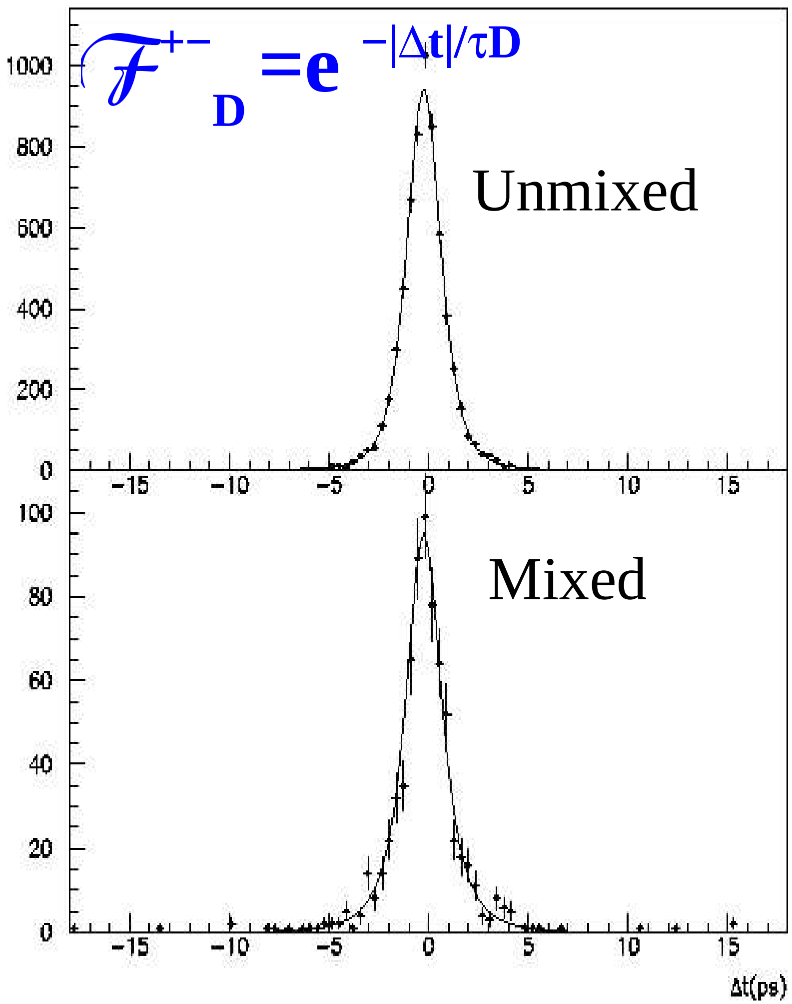
$\tau_B = 1.547 \pm 0.006$ ps

$\Delta m = 0.466 \pm 0.002\ \text{ps}^{-1}$

MC Results (2): Decay−Side Cascade

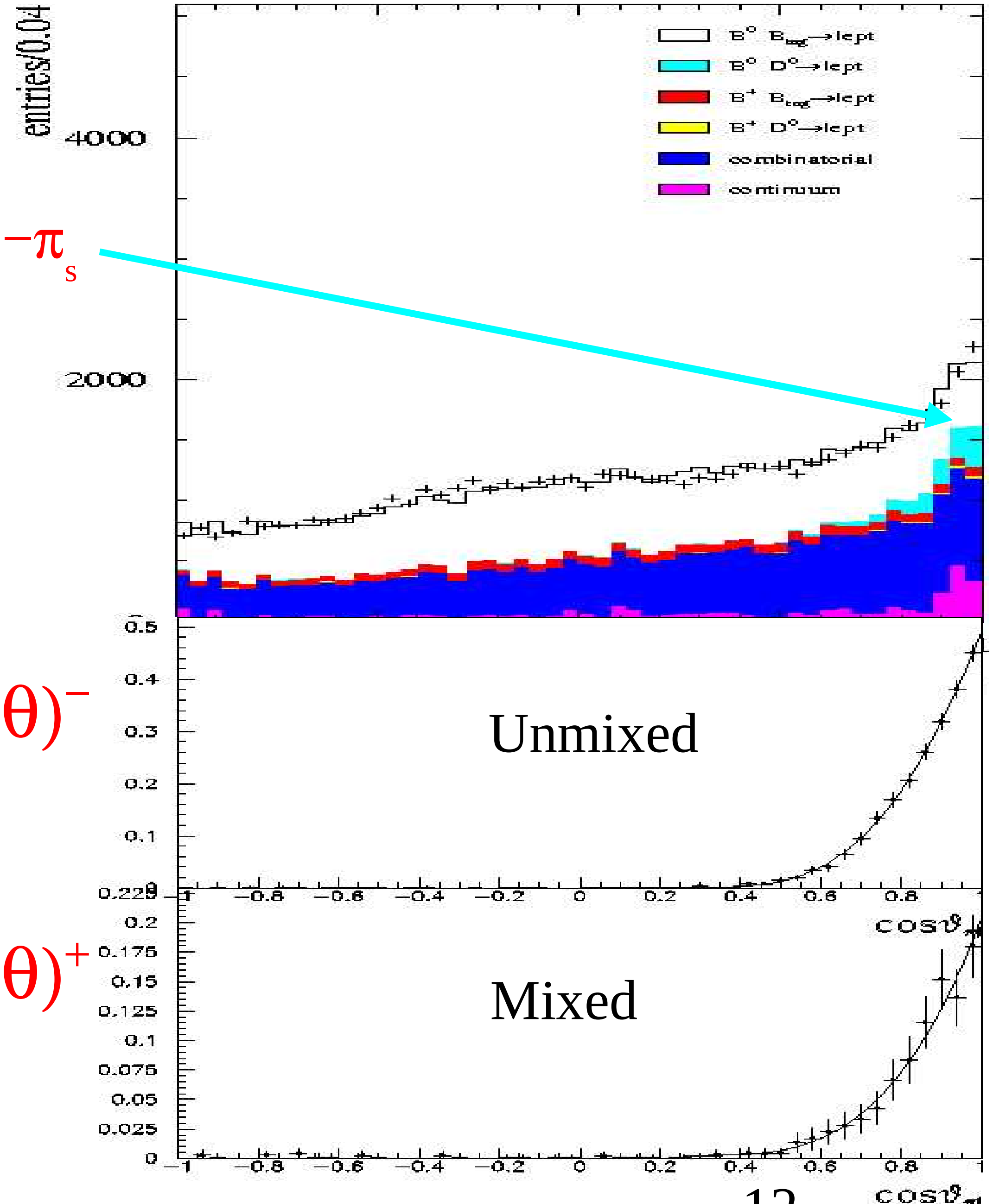
- No information on mixing
- Effective D Lifetime τ_D floated
- Fraction $\alpha(\theta)^{\pm}$ from angle l(tag)−π_s

$$\mathcal{F}^{+-}_{D} = e^{-|\Delta t|/\tau D}$$



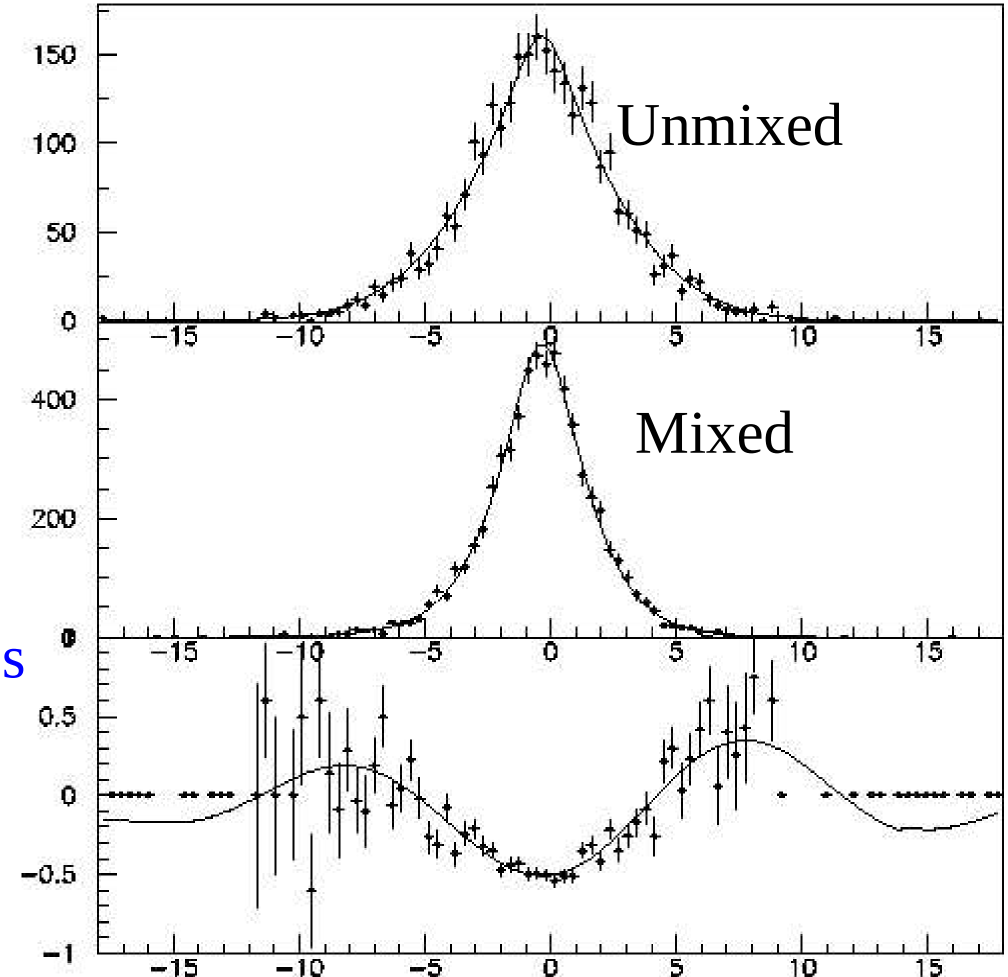
$\alpha(\theta)^{-}$

$\alpha(\theta)^{+}$



MC Results (3): Tag−Side Cascade

$\mathcal{F}^{+-}_{c} = e^{-|\Delta t|/\tau} (1 \mp \mathcal{D}_{c} \cos(\Delta m \Delta t))$



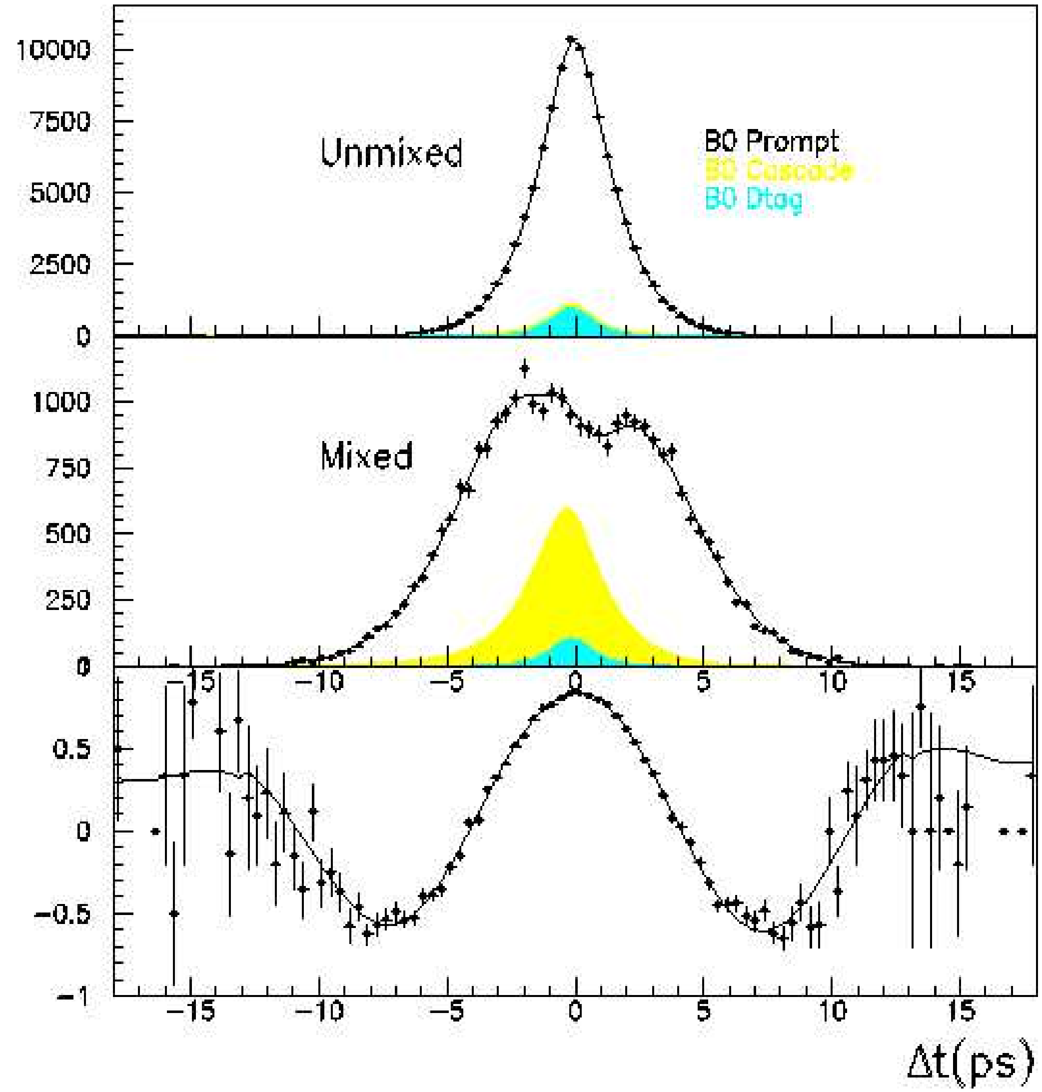
- $\mathcal{D}_c$ = 0.65 ± 0.08 from PDG
$B(b \to \bar{c} \to l^-)/(B(b \to c \to l^+)+B(b \to \bar{c} \to l^-))$
fixed in the fit;
(MC: $\mathcal{D}_c$ = 0.545)

- o_n = −0.32±0.03 ps; o_w=−2.7±0.4 ps
due to D lifetime

- τ_B = 1.54 ± 0.02; Δm=0.441±0.014 ps^{-1}

MC Results (4): Full B^0 Signal

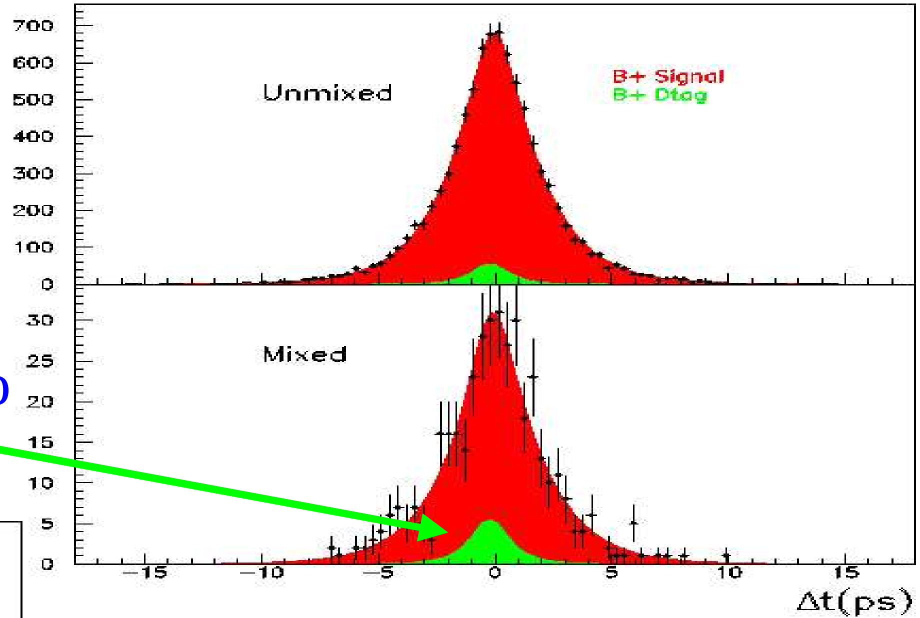
- Float ratio cascade to prompt f_{bcl}
- $\mathcal{F}^{-}_{B0} =$
  $(1-\alpha(\theta)^{-})\ \{(1-f_{bcl})\mathcal{F}^{-}_{P}(\Delta t, \tau, \Delta m)$
  $+ f_{bcl}\,\mathcal{F}^{-}_{C}(\Delta t, \tau, \Delta m)\ \}$
  $+ \alpha(\theta)^{-}\mathcal{F}_{D}(\Delta t, \tau_{D})$
- $\mathcal{F}^{+}_{B0} =$
  $(1-\alpha(\theta)^{+})\ \{(1-f_{bcl})\mathcal{F}^{+}_{P}(\Delta t, \tau, \Delta m)$
  $+ f_{bcl}\,\mathcal{F}^{+}_{C}(\Delta t, \tau, \Delta m)\ \}$
  $+ \alpha(\theta)^{+}\mathcal{F}_{D}(\Delta t, \tau_{D})$



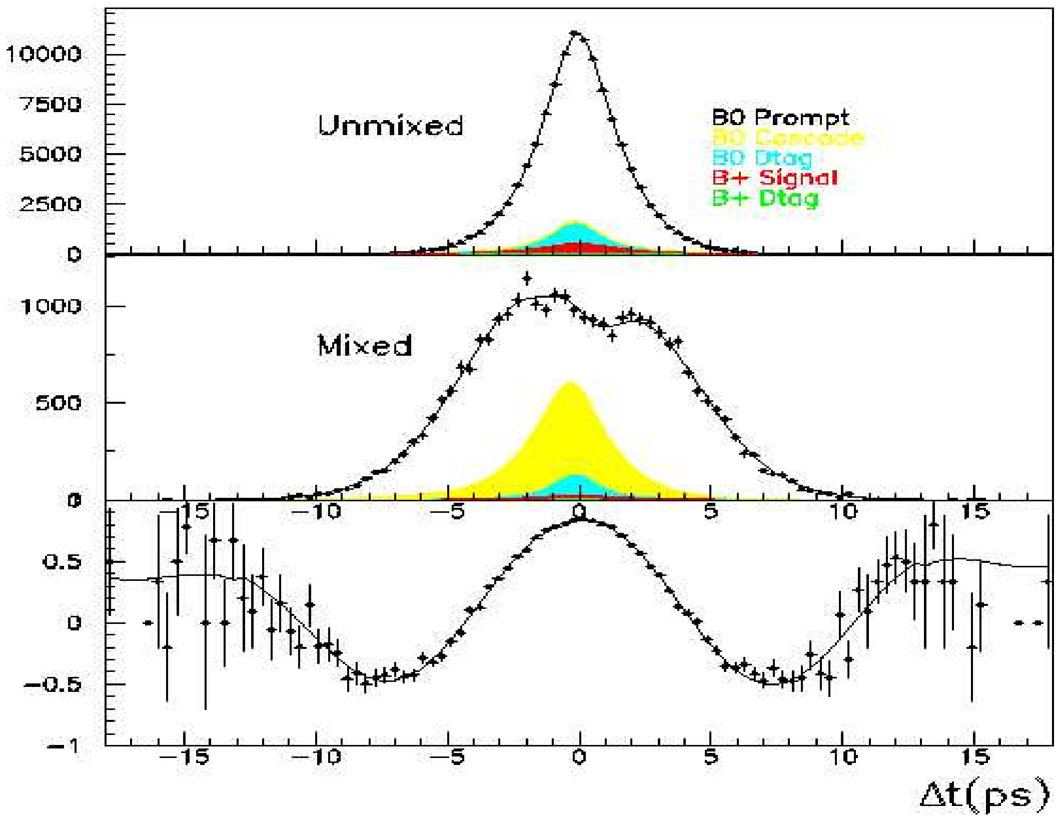
$\tau_B = 1.548 \pm 0.006$ ps; $\Delta m = 0.470 \pm 0.002$ ps^{-1}

MC Results (5): Peaking B^{-}

- Exponential term:
fixed τ_{B-}=1.671±0.018 ps (MC: 1.65 ps)
- Overall fraction constrained to 1±0.5 (Isospin Conservation Assumption)



- Decay−Side Cascade treatment similar to B^0 Signal by means of $\alpha_{B-}(\theta)^{\pm}$



B^0+B^- Resonant Fit:

- τ_B = 1.540 ± 0.006 ps;
- Δm=0.469±0.003 ps^{-1}
- S_{B-}=0.8±0.1

MC Results (6): $B\bar{B}$ Combinatorial (After ICHEP)

Strategy similar to Signal Treatment:

Fit independently each Combinatorial BKG Component and then add together all the terms, according to their relative fractions:

- B^0 BKG: prompt leptons, cascade decay−side, cascade tag−side
- B^+ BKG: prompt leptons, cascade decay−side, cascade tag−side

- Same PDF for B^0/B^+ cascade decay−side
- Same PDF for B^+ prompt leptons/cascade tag−side

Advantages:

➔All the parameters have a clear physical meaning;

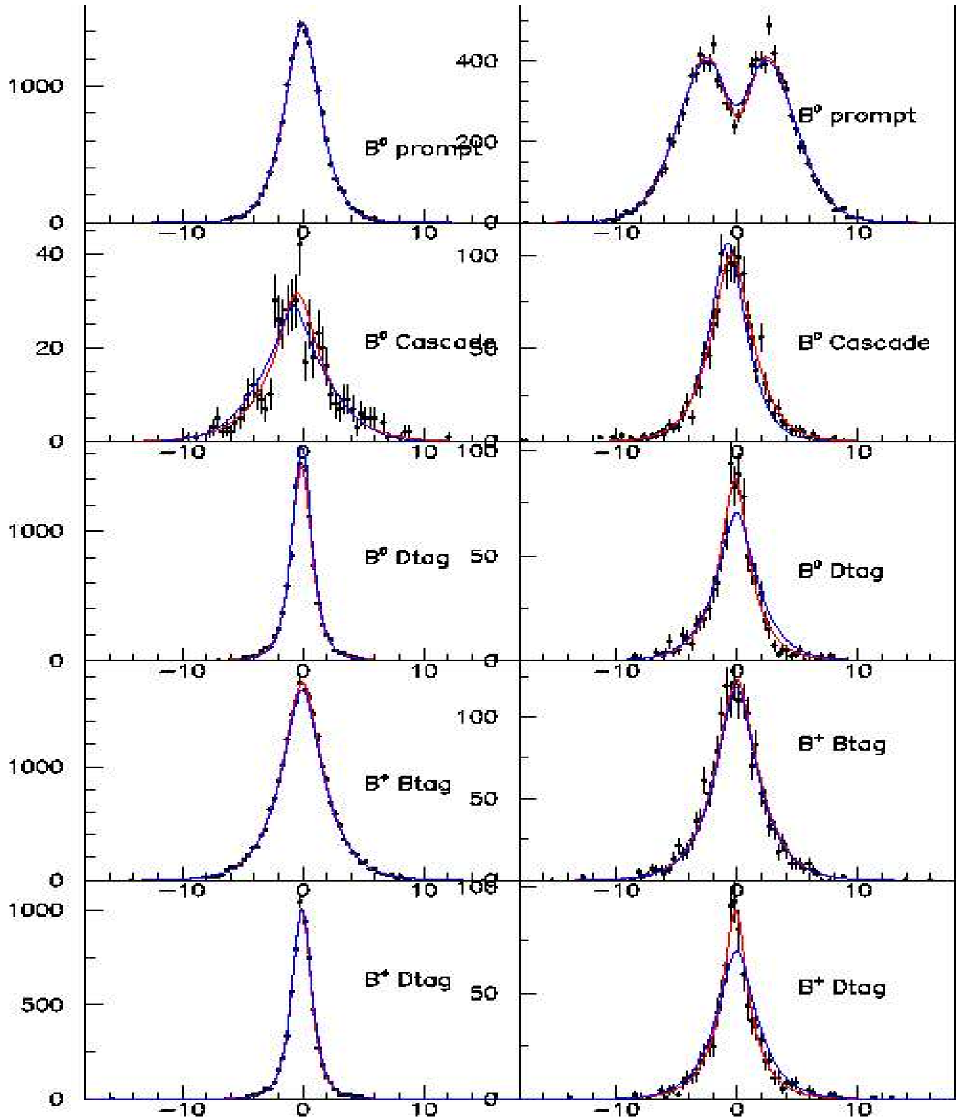
➔Check the stability of the results adding one component after another;

➔Comparison between the fitted values and the MC predictions (eventual discrepancies can be used in the systematics evaluation)

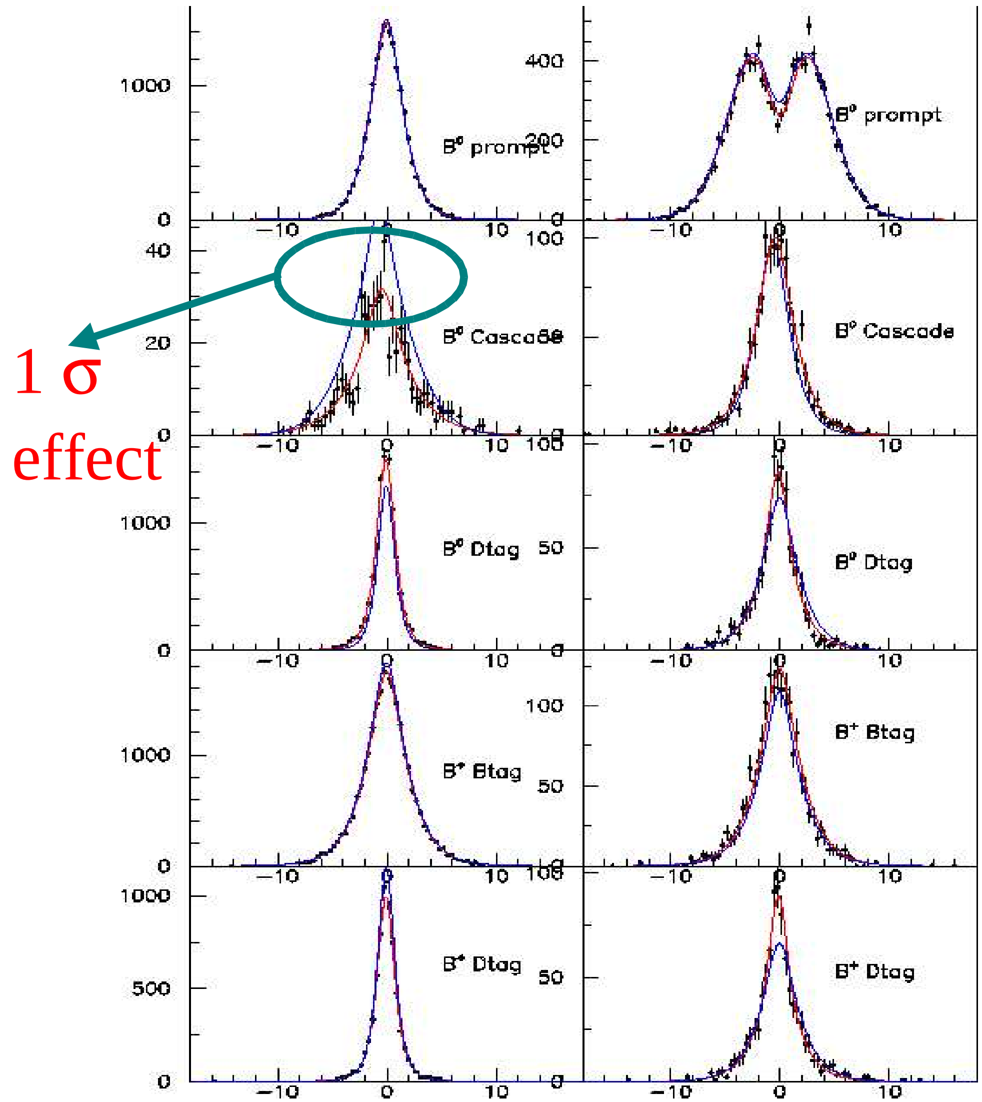
MC Results (7): $B\bar{B}$ Combinatorial

➔Compare the fitted component in the BKG global fit (blue) with the corresponding subsample result (red)

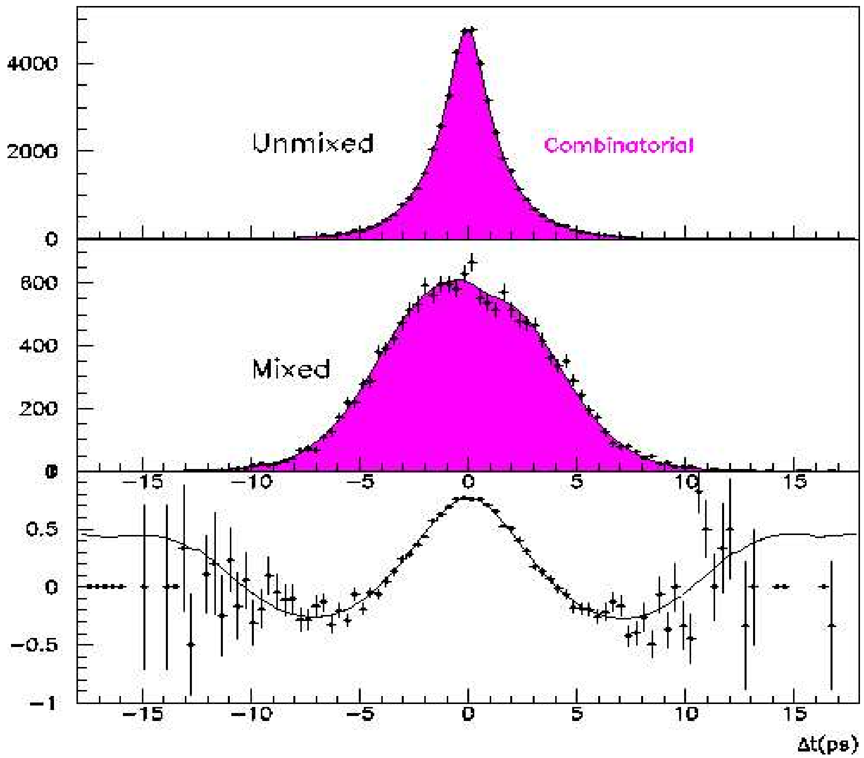
Fractions assumed from MC

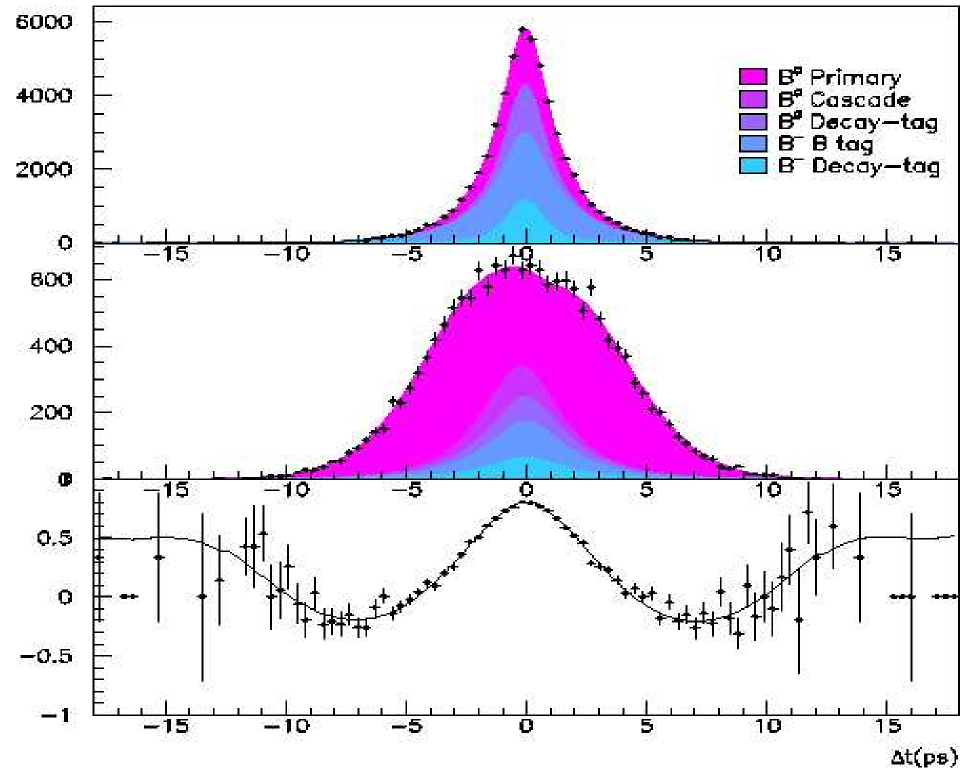


Free Fractions (apart α^{+}_{BKG})



MC Results (8): BB Combinatorial



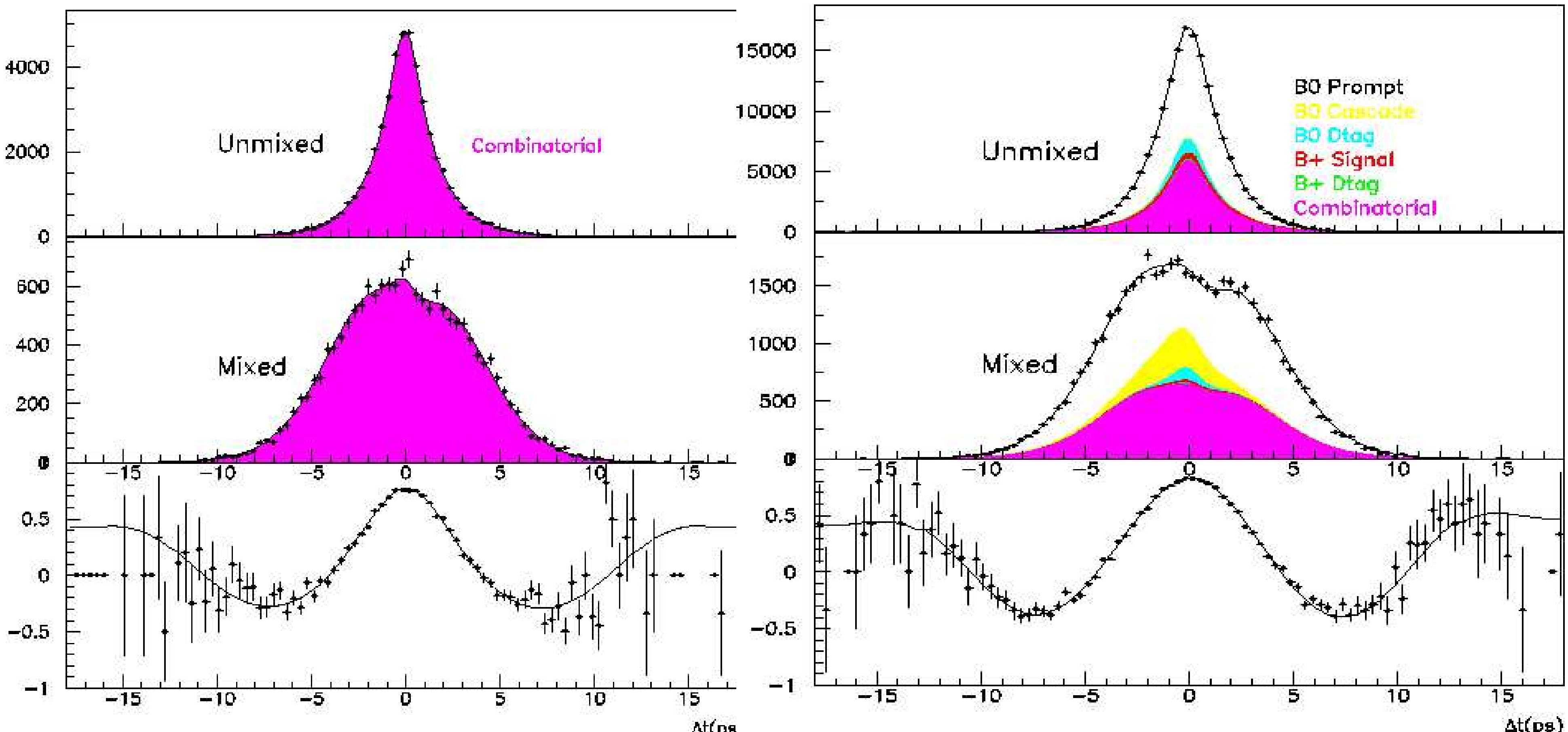


$M^2_\nu < -4.5$ GeV^2/c^4 :BKG Region $\quad$ $M^2_\nu > -4.5$ GeV^2/c^4 : Signal Region

- Parameters: 13 floated (apart resolution); 5 fixed ($\mathcal{D}_C$, τ_{B-}, $\alpha^+_{BKG,B-}$, $\alpha^+_{BKG,B0}$, $f_{w,Dtag}$)
- Assumption of same PDF in the BKG/Signal regions succesfully checked by:
  - Compatibility of the fitted parameters values in the two regions
  - Kolmogorov test
  - Compatibility of MC global fit results using fixed BKG/Signal region combinatorial parameters
  - Different BKG region definitions in MC global fit

MC Results (7): Global Fit

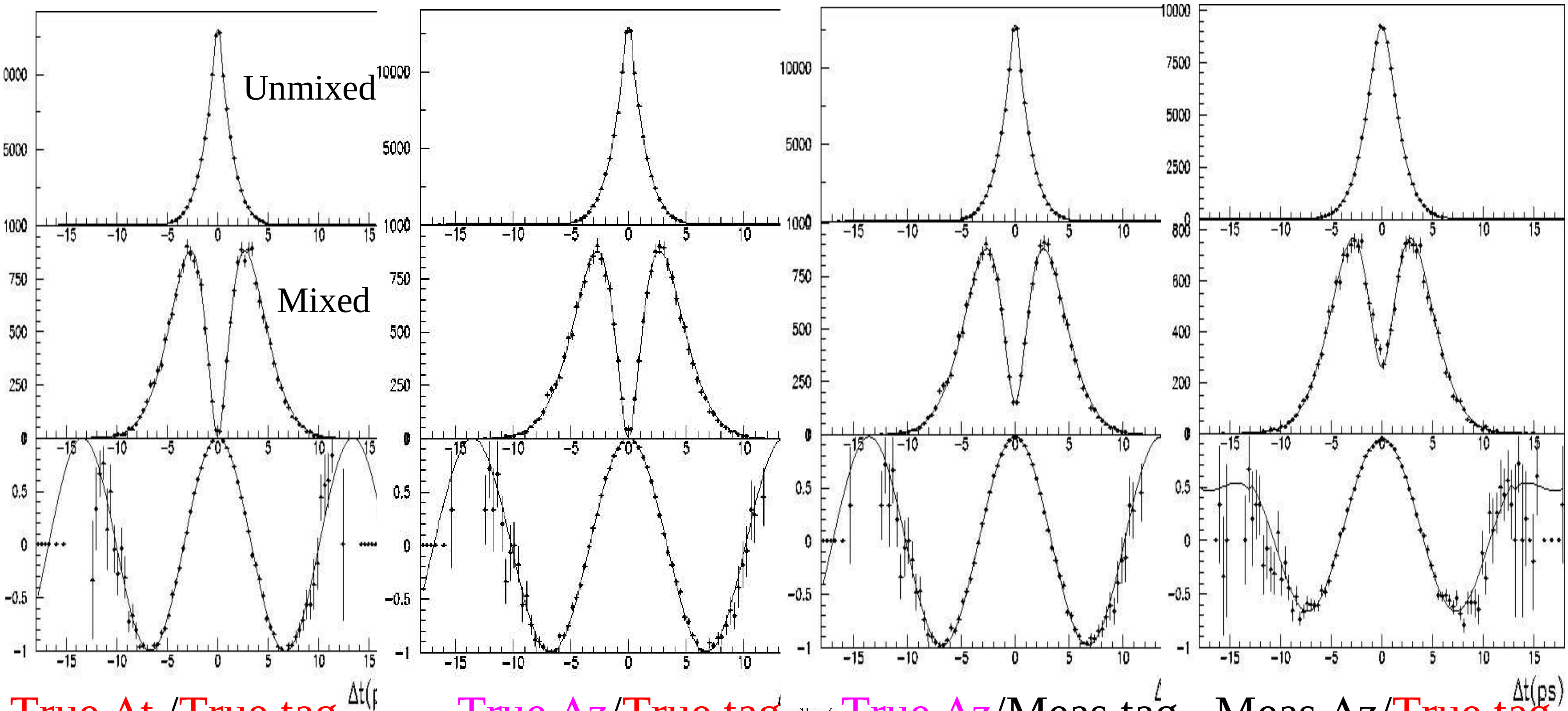
B^0+B^-+BB with 30 floated parameters (including resolution)



$M^2_\nu < -4.5\ GeV^2/c^4$:BKG Region $\quad$ $M^2_\nu > -4.5\ GeV^2/c^4$: Signal Region

$\tau_B = 1.554 \pm 0.007$ ps; $\Delta m = 0.464 \pm 0.004\ ps^{-1}$; $\rho = -1.4\%$

Analysis Bias (I)



	True Δt /True tag	True Δz/True tag	True Δz/Meas tag	Meas Δz/True tag
τ=	1.550±0.004	1.555±0.004	1.555±0.004	1.542±0.005
Δm=	0.4691±0.0010	0.4657±0.0011	0.4648±0.0013	0.4711±0.0017
CHECK:	Selection	Boost Appr.	Dilution	Resolution

Generated: τ=1.548 ps; Δm=0.472 ps^{-1}

Analysis Bias (2)

B^0 Signal Sample:

- Event Selection/Fit Procedure (True Δt, True tag vs Generated Values):

  $\delta\tau = +0.0017 \pm 0.0043$ ps; (ICHEP: $+0.016 \pm 0.005$)

  $\delta\Delta m = -0.0029 \pm 0.0010\ \mathrm{ps}^{-1}$ (fit effect, $\delta\chi_d = 0.0007 \pm 0.0011$)

- Boost Approximation (True Δz, True tag vs True Δt, True tag):

  $\delta\tau = +0.0054$ ps;

  $\delta\Delta m = -0.0034\ \mathrm{ps}^{-1}$

- Full B^0 Signal Sample with realistic resolution and tagging (Meas. Δz, Meas. tag vs True Δt, True tag):

  $\delta\tau = -0.0014 \pm 0.0036$ ps;

  $\delta\Delta m = +0.0009 \pm 0.0015\ \mathrm{ps}^{-1}$

Analysis Bias (3)

Adding Background:

- B^- Peaking (Total Resonant Sample vs B^0 Signal Sample):

  $\delta\tau = -0.0082 \pm 0.0031$ ps;

  $\delta\Delta m = -0.0014 \pm 0.0021$ ps^{-1}
- Combinatorial BKG Parameterization (Global Sample vs Resonant Sample):

  $\delta\tau = +0.014 \pm 0.0033$ ps;

  $\delta\Delta m = -0.0042 \pm 0.0024$ ps^{-1}

➔Total (Global MC Fit vs Generated Values):

$\delta\tau = +0.0065 \pm 0.0072$ ps;

$\delta\Delta m = -0.0076 \pm 0.0037$ ps^{-1}

➔**Results on Real Data to be Corrected by:**

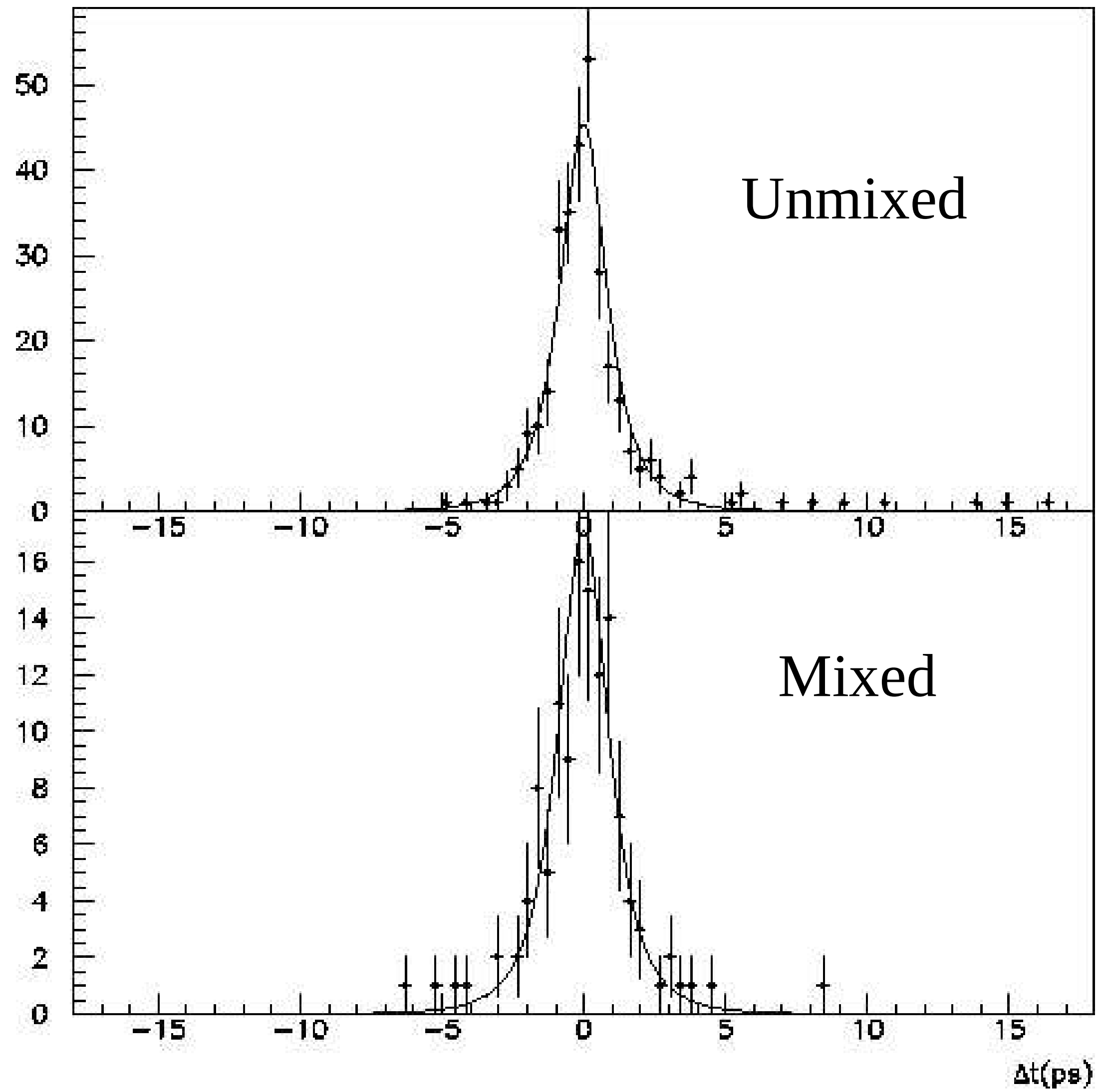
$$\tau = \tau_{meas.} - (0.0065 \pm 0.0072)\ \text{ps}$$

$$\Delta m = \Delta m_{meas.} + (0.0076 \pm 0.0037)\ \text{ps}^{-1}$$

DT Results (1): Continuum

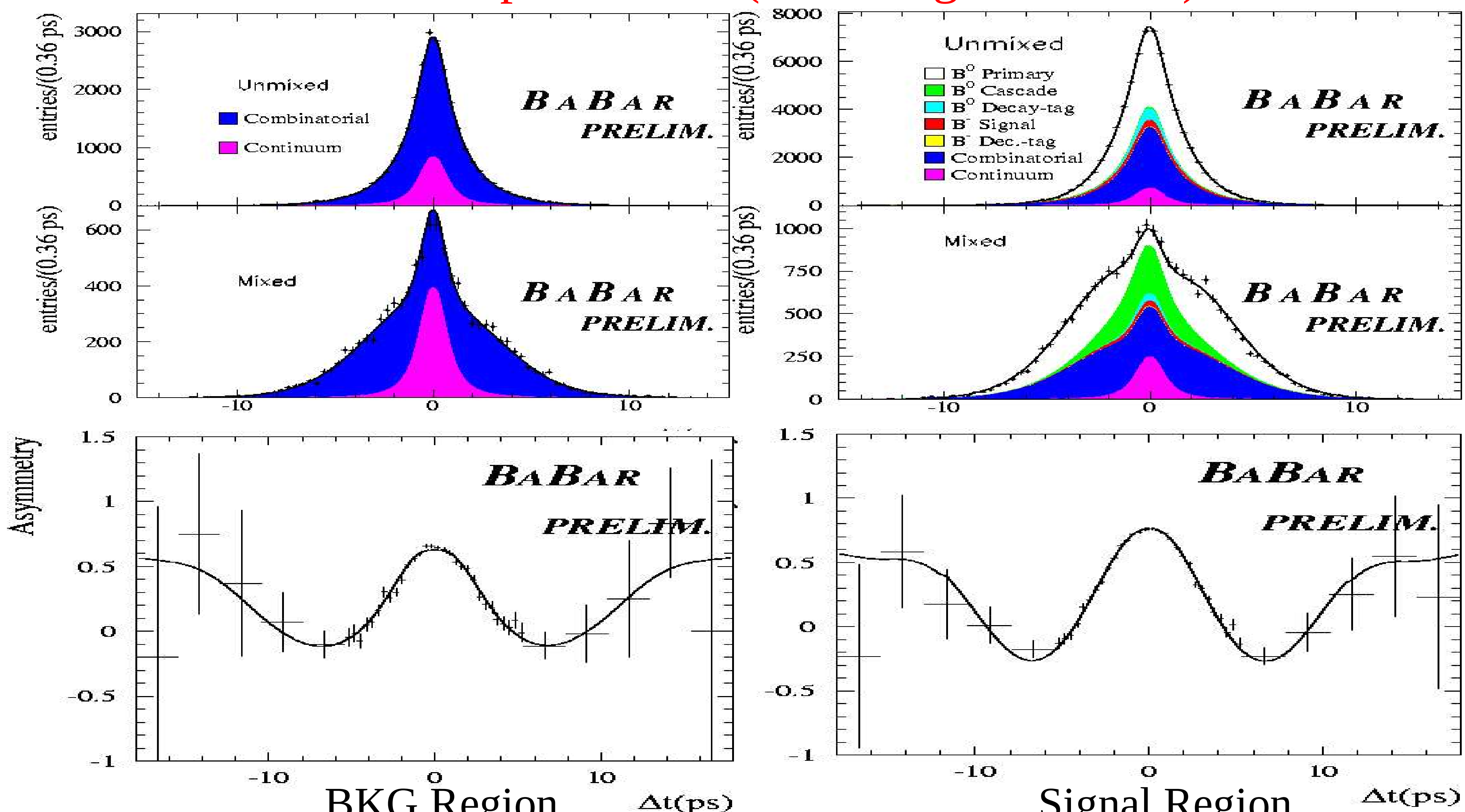
- Test on off−peak events
- Pure lifetime term with non zero offset

$\tau_{qq} = 0.36 \pm 0.06$ ps
$o_n = o_w = -0.01 \pm 0.05$ ps



DT Results (2): Global Fit

32 floated parameters (including resolution)



BKG Region

Signal Region

τ_B = XXX ± 0.0098 ps; Δm=XXX±0.0049 ps^{-1} ; ρ=+4.9%

Systematic Errors (I)

- Sample Composition: Vary BB below the peak by ± 2.3%
- Analysis Bias: Statistical error of the Full Monte Carlo Fit Result
- Vary PDF fixed parameters (τ_{B-}=1.671±0.018 ps , $\mathcal{D}_c$=0.65±0.08)
- Vary offset of outlier PDF; adopt flat PDF
- Vary fraction of decay−side cascade by its statistical error
- Vary bin size, use average value of the Likelihood in the bin
- Vary Δt, $\sigma\Delta t$ cut
- Alignment, z−scale, boost: *at present* from fully reco $D^{*+} l^- \nu$ analysis

Systematic Errors (2) (ICHEP)

Table 2: Systematic uncertainties.

Source	Variation	$\delta\tau_{B^0}$	$\delta\Delta m_d$
(a) $B\overline{B}$ fraction	±2.3%	±0.0010	±0.0010
(b) Analysis bias	-	±0.0072	±0.0037
(c) τ_{B^-}	1.671±0.018	±0.0019	±0.0010
(d) $\mathcal{D}_{\mathcal{C}\ell}$	0.65±0.08	±0.0053	±0.0005
(e) z scale	-	±0.0060	±0.0020
(f) PEP-II boost	-	±0.0015	±0.0005
(g) Alignment	-	±0.0056	±0.0030
(h) Beam spot position	-	±0.0050	±0.0010
(i) Decay-side tags	-	±0.0025	±0.0015
(j) Binning	-	±0.0017	±0.0021
(k) Outlier	-	±0.0013	±0.0021
(l) Δt and $\sigma_{\Delta t}$ cut	-	±0.0076	±0.0032
Total Preliminary		±0.0157	±0.0072

New

$$\tau_B = (XXX \pm 0.0098 \pm 0.016)\ \text{ps};$$

$$\Delta m = (XXX \pm 0.0049 \pm 0.0072)\ \text{ps}^{-1}$$

To do before Publication

- Re−Evaluation of the Systematic Errors using the new Event Selection and the new Combinatorial BKG Parameterization;
- Re−Validation of the Fit by Toy Monte Carlo;

- Cross Checks & further Systematic Errors evaluation:
  - Vary PDF Combinatorial BKG fixed parameters;
  - Alignment, z−scale, beam spot *with our analysis setup;*
  - Cut on selection variable χ;
  - Use GEXP model for the Tag−Side Cascade sample

Conclusions

A very competitive preliminary result:

	Δm	τ_{B0}
BaBar Hadronic	0.516±0.016±0.010	1.546±0.032±0.022
BaBar Dilepton	0.493±0.012±0.009	–
BaBar D*lν (P.R.)	–	1.529±0.012±0.029
BaBar D*π (P.R.)	–	1.533±0.034±0.033
BaBar D*lν	0.492±0.018±0.013	1.523±0.024±0.022
World Average	**0.502±0.007**	**1.536±0.014**
This Analysis	**xxx±0.0049±0.0072**	**xxx±0.010±0.016**