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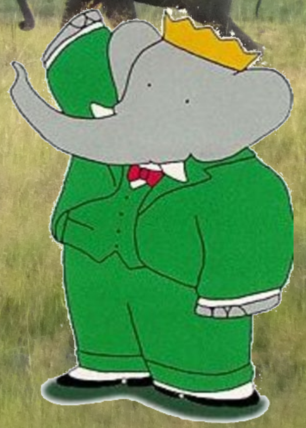
First Direct Observation of Time Reversal Violation in B System and Other CPV Measurements at BABAR



INTERNATIONAL WORKSHOP ON DISCOVERY PHYSICS AT THE LHC

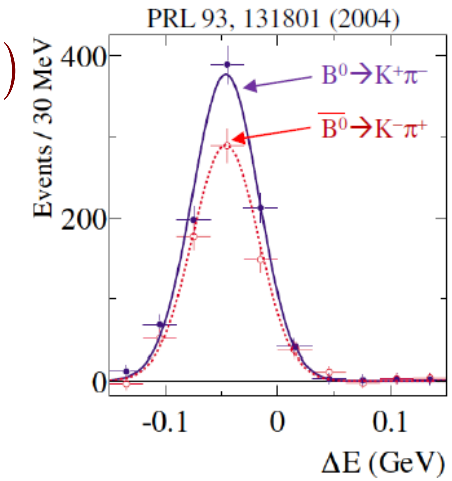
KRUGER 2012

DECEMBER 3 - 7, 2012

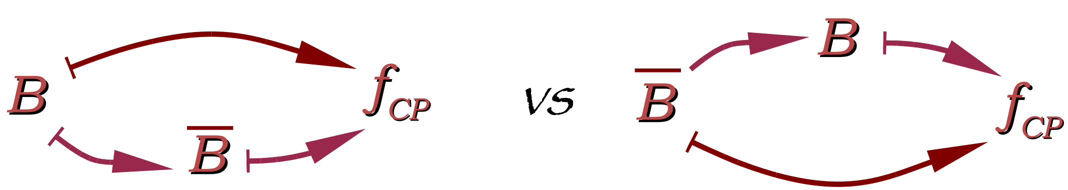
- First Observation of Direct CPV : $\Gamma(B \to f) \neq \Gamma(\bar{B} \to \bar{f})$

$$\frac{\Gamma(\overline{B^0} \to K^- \pi^+) - \Gamma(B^0 \to K^+ \pi^-)}{\Gamma(\overline{B^0} \to K^- \pi^+) + \Gamma(B^0 \to K^+ \pi^-)} = -0.133 \pm 0.030 \pm 0.009$$

PRL 93.131801

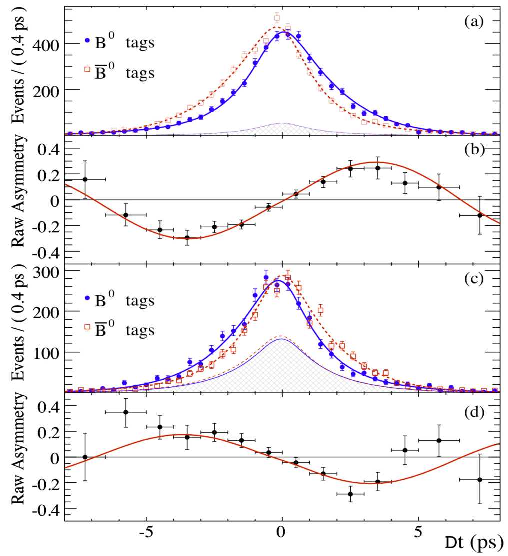


- CPV in interference of mixing and decay



$$\sin(2\beta) = 0.666 \pm 0.031 \pm 0.013$$

PRD 79 (2009) 072009



- Not yet observed in mixing alone

$$\mathcal{A}_{\ell\ell}(B^0) = \frac{N(B^0 B^0) - N(\overline{B^0}\,\overline{B^0})}{N(B^0 B^0) + N(\overline{B^0}\,\overline{B^0})} = (-0.05 \pm 0.56)\%$$

B-Factories ICHEP 2012

Questions to CPV - Outline of the Talk

- CPV is well established
- CPT + CPV ⟼ T Violation

  (1.a) Can we assert T Violation independently of CPT assumption ?

  (1.b) Can we test CPT in the B system ?
- CP in mixing has not yet been observed

  (2) Can we improve wrt existing measurements ?
- CP measurements provide precise value for the CKM parameter β

  (3) What can we say for the other CKM angles ?

PART I

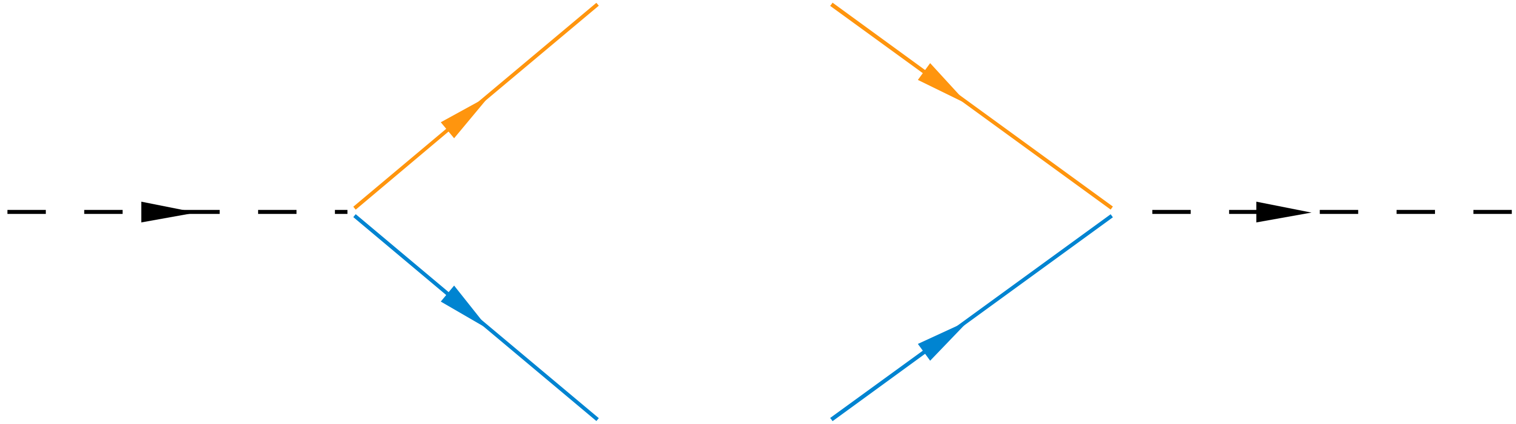
Discovering T-Violation

(and testing CPT)

Direct Measurement of T Violation

- Ideally compare two time-conjugate processes

$$\mathcal{M}(B^0 \to K^+ \pi^-) \quad \text{vs} \quad \mathcal{M}(K^+ \pi^- \to B^0)$$



- Unfeasible :
  - tiny effects
  - swamped by strong interactions

Direct Measurement of T Violation

- In practice, exploit EPR entanglement in *BB* production at Υ(4S)

$$e^+ e^- \rightarrow \Upsilon(4S) \rightarrow b\bar{b}$$

$J^{PC} = 1^{--}$

Direct Measurement of T Violation

- In practice, exploit EPR entanglement in $B\bar{B}$ production at $\Upsilon(4S)$

$$e^+ e^- \rightarrow \Upsilon(4S) \rightarrow b\bar{b}$$

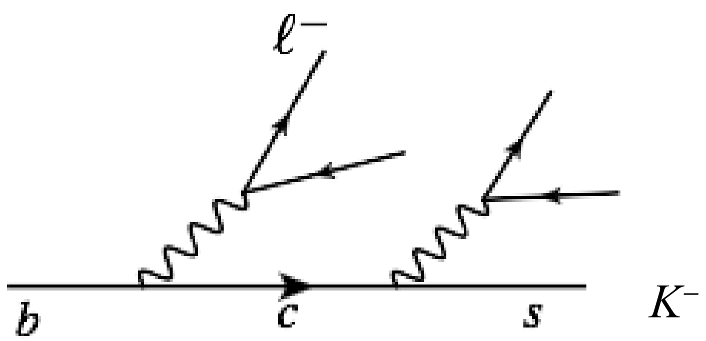
$J^{PC} = 1^{--}$

$$\rightarrow \frac{1}{\sqrt{2}}\left(|B^0(t_1)\overline{B^0}(t_2)\rangle - |B^0(t_2)\overline{B^0}(t_1)\rangle\right)$$

flavor eigenstate: $B^0 = (\bar{b}\, d)$

- Flavor tagged by same means as CP analyses :

$$\overline{B}^0 \rightarrow \ell^- X$$
$$\overline{B}^0 \rightarrow K^- X$$
$$\overline{B}^0 \rightarrow \pi^+_{soft} X, \ldots$$



- In practice, exploit EPR entanglement in $B\bar{B}$ production at $\Upsilon(4S)$

$$e^+ e^- \to \Upsilon(4S) \to b\bar{b}$$

$J^{PC} = 1^{--}$

$$\to \frac{1}{\sqrt{2}}\left(|B^0(t_1)\overline{B^0}(t_2)> - |B^0(t_2)\overline{B^0}(t_1)>\right)$$

flavor eigenstate: $B^0 = (\bar{b}\, d)$

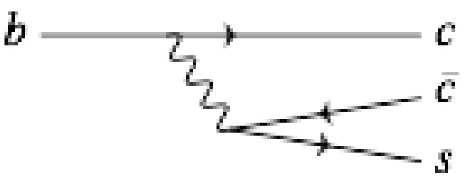
$$\to \frac{1}{\sqrt{2}}\left(|B_+(t_1)B_-(t_2)> - |B_+(t_2)B_-(t_1)>\right)$$

CP eigenstate: $CP|B_\pm> = \pm|B_\pm>$

- $B_{+,-}$ decay to CP eigenstates

$$B_+ \to J/\psi K_L$$

$$B_- \to (c\bar{c})K_S$$



Direct Measurement of T Violation

- In practice, exploit EPR entanglement in $B\bar{B}$ production at $\Upsilon(4S)$

$$e^+ e^- \to \Upsilon(4S) \to b\bar{b}$$

$J^{PC} = 1^{--}$

$$\to \frac{1}{\sqrt{2}}\left(|B^0(t_1)\overline{B^0}(t_2)> - |B^0(t_2)\overline{B^0}(t_1)>\right)$$

flavor eigenstate: $B^0 = (\bar{b}\, d)$

$$\to \frac{1}{\sqrt{2}}\left(|B_+(t_1)B_-(t_2)> - |B_+(t_2)B_-(t_1)>\right)$$

CP eigenstate: $CP|B_\pm> = \pm|B_\pm>$

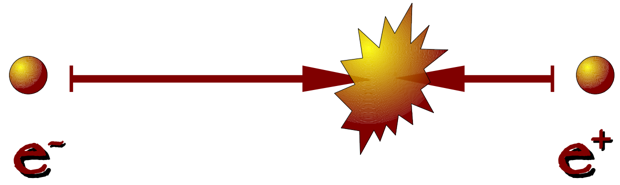
- Perform 4 complementary tests:

$$B_+ \to B^0 \quad vs \quad B^0 \to B_+$$
$$B_- \to B^0 \quad vs \quad B^0 \to B_-$$
$$B_- \to \overline{B^0} \quad vs \quad \overline{B^0} \to B_-$$
$$B_+ \to \overline{B^0} \quad vs \quad \overline{B^0} \to B_+$$

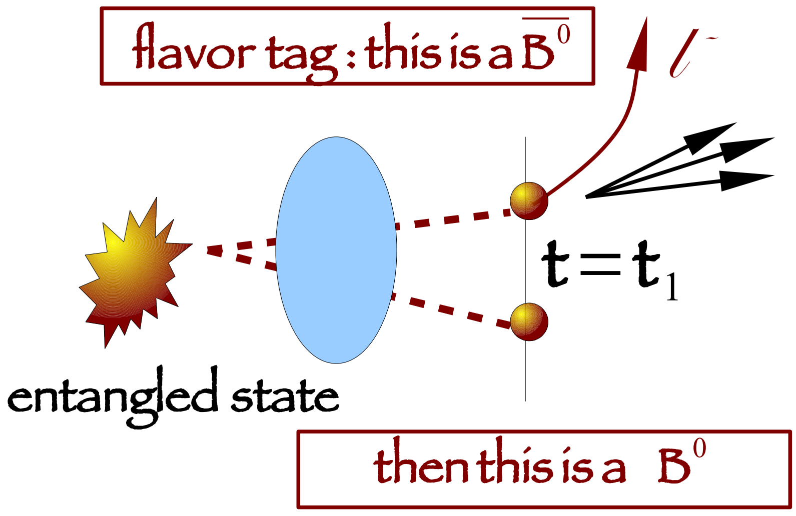
- ... plus tests of CPT and CP

τ Analysis in a nutshell

boosted Υ(4S) ($\beta\gamma = 0.56$)

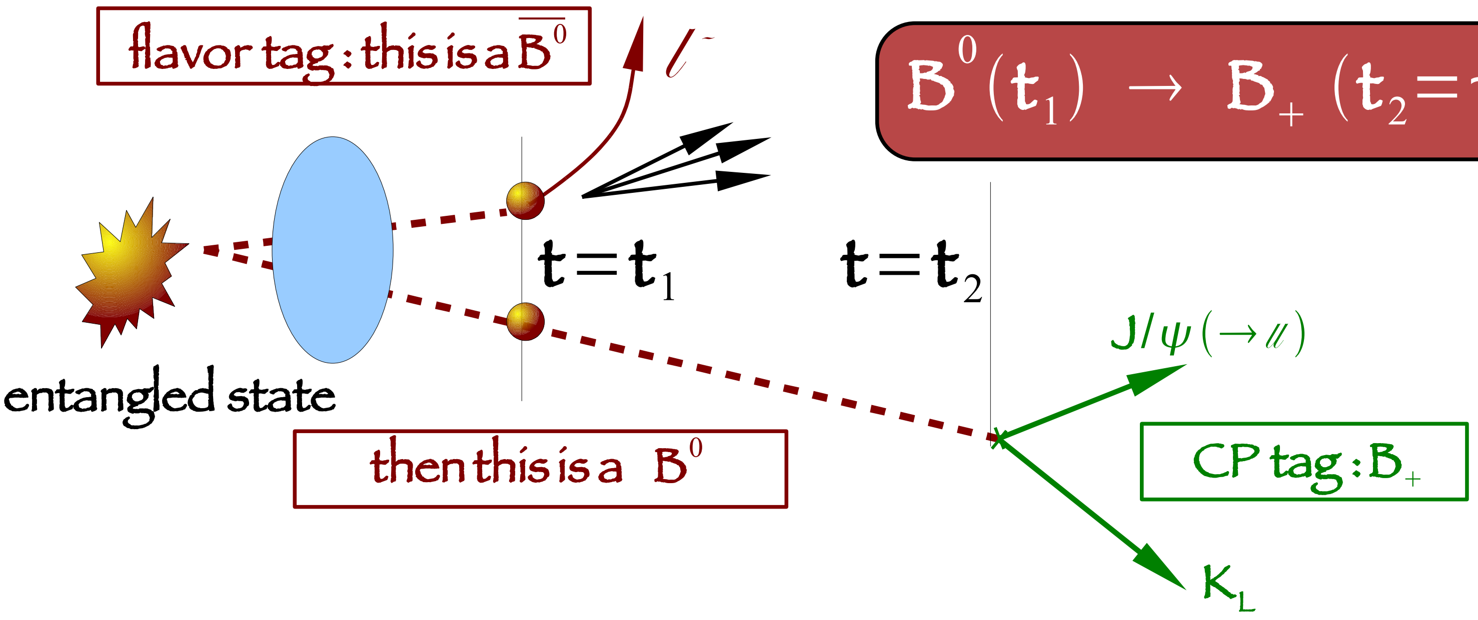


T Analysis in a nutshell

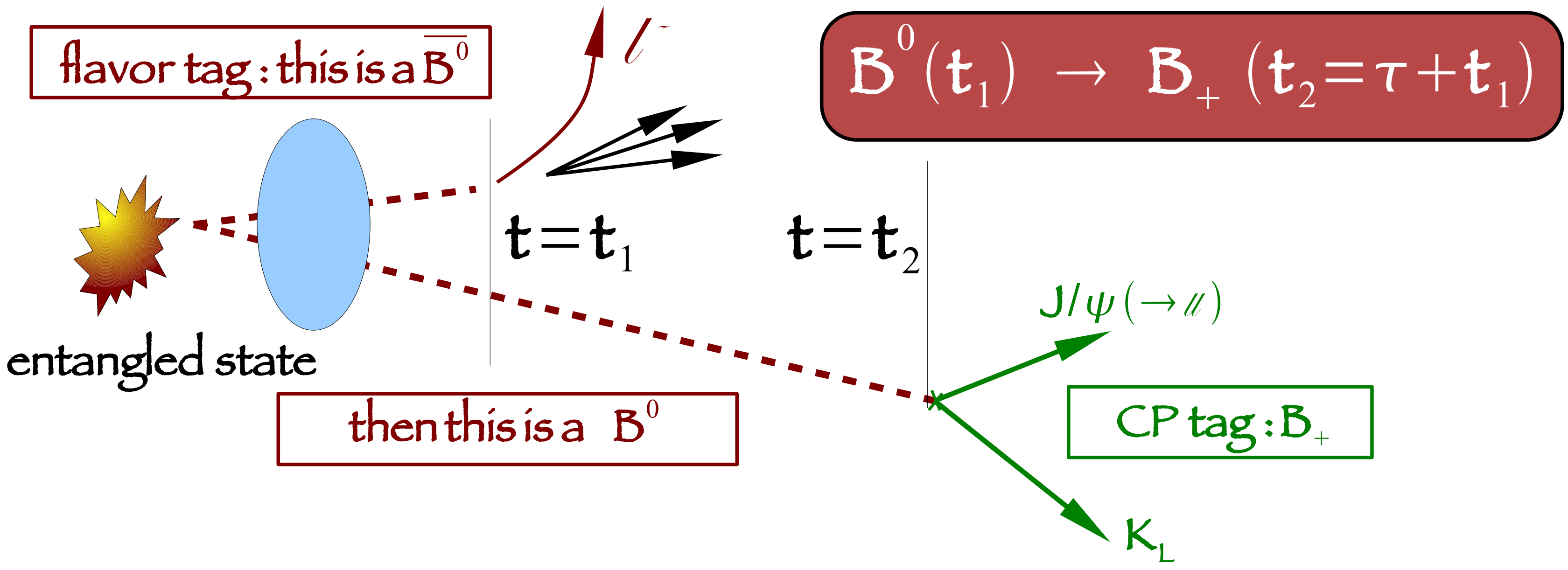


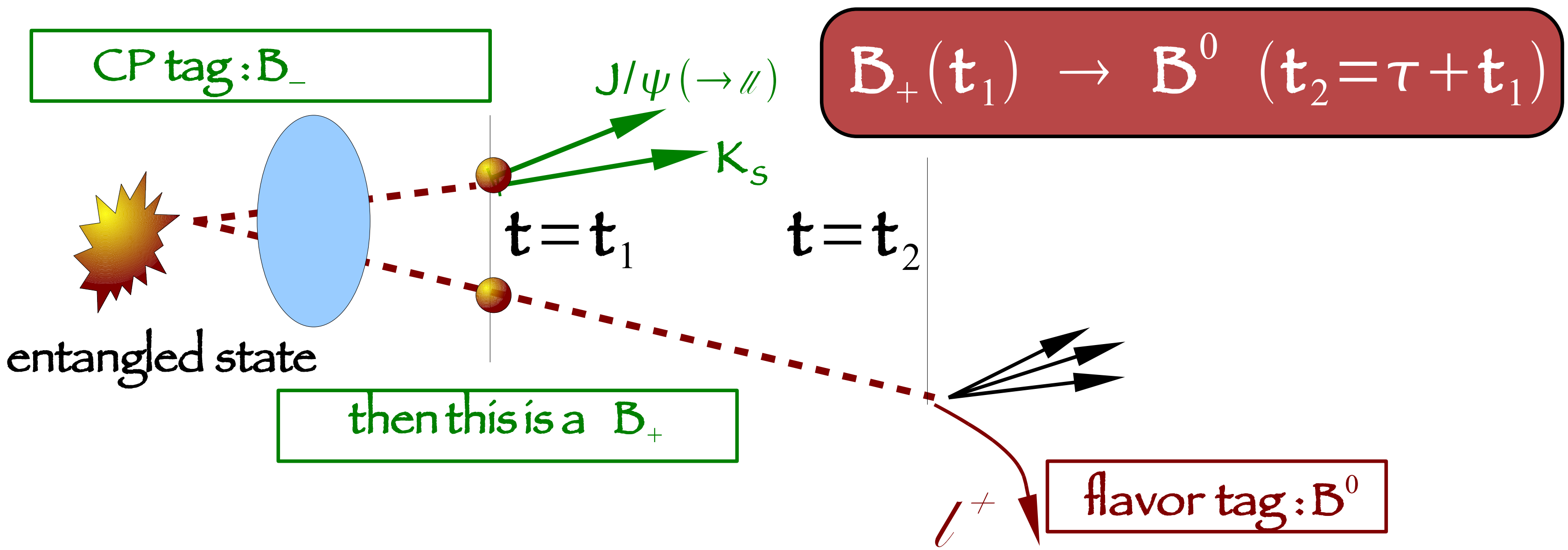
T Analysis in a nutshell

$$B^0(t_1) \rightarrow B_+(t_2=\tau+t_1)$$



T Analysis in a nutshell





TV analysis steps

- Define $\Delta\tau$ = t(flavor) - t(CP)
- Consider eight combinations (flavor x CP x sign of $\Delta\tau$)
  - $\alpha = B^0/\overline{B}^0$
  - $\beta = K_L/K_S$
- Fit each with EPR-motivated function

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma|\Delta\tau|}\,\mathcal{H}(\pm\Delta\tau)\,[1+S^{\pm}_{\alpha,\beta}\sin(\Delta m_d \Delta\tau)+C^{\pm}_{\alpha,\beta}\cos(\Delta m_d\Delta\tau)]$$

$\mathcal{H}$: Heavyside step function

- $S^{+-}_{\alpha\beta}$, $C^{+-}_{\alpha\beta}$: fit parameters
  - T-Violation : $\Delta S^{\pm}_{T} = S^{\pm}_{\overline{B}^0,K_L} - S^{\mp}_{B^0,K_S} \neq 0$
  - CP-Violation : $\Delta S^{-}_{CP} = S^{\pm}_{B^0,K_L} - S^{\mp}_{B^0,K_S} \neq 0$
  - CPT-Violation : $\Delta S^{-}_{CPT} = S^{\pm}_{B^0,K_S} - S^{\mp}_{\overline{B}^0,K_S} \neq 0$
- Assuming CPT & CP fit results, expect :

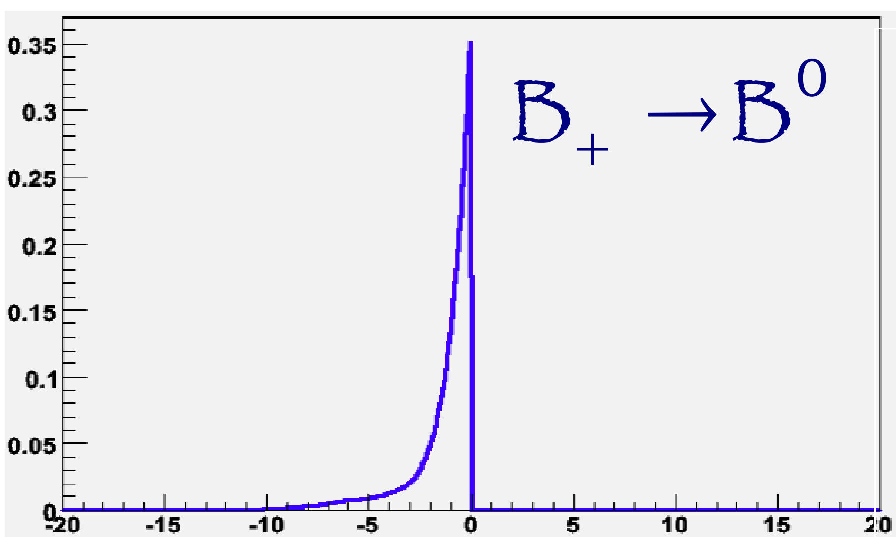
$$S^{\pm}_{T,\alpha,\beta} = \pm\sin(2\beta)$$
$$\Delta S^{\pm}_{T} = 2\sin(2\beta)$$

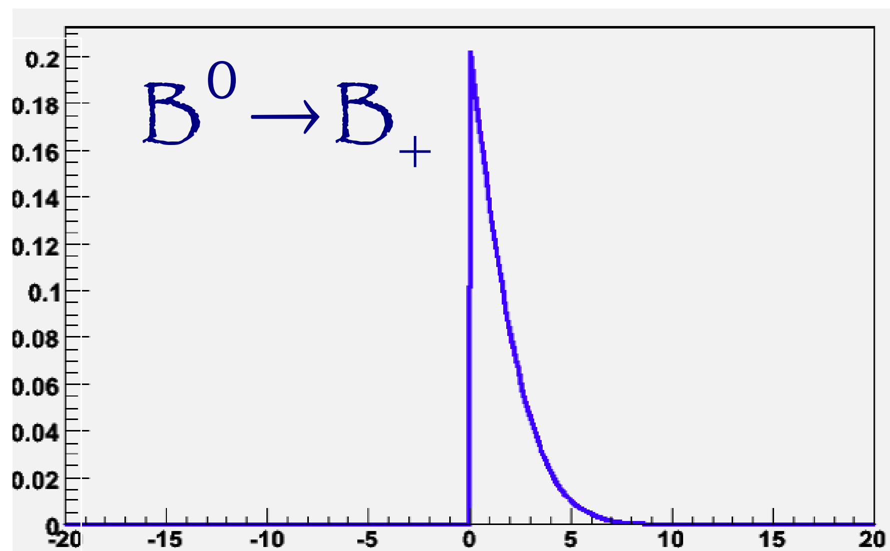
TV analysis steps

- Define $\Delta\tau = t(\text{flavor}) - t(CP)$
- Consider eight combinations (flavor (α) x CP(β) x sign of $\Delta\tau$)
- Fit each with EPR-motivated function

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma|\Delta\tau|}\,\mathcal{H}(\pm\Delta\tau)\,\left[1+S^{\pm}_{\alpha,\beta}\sin(\Delta m_d \Delta\tau)+C^{\pm}_{\alpha,\beta}\cos(\Delta m_d \Delta\tau)\right]$$

Heavyside step function

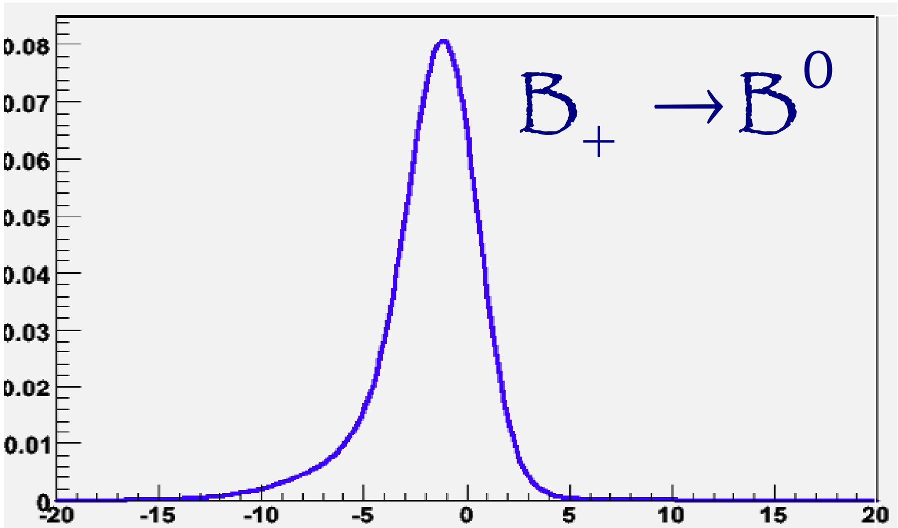


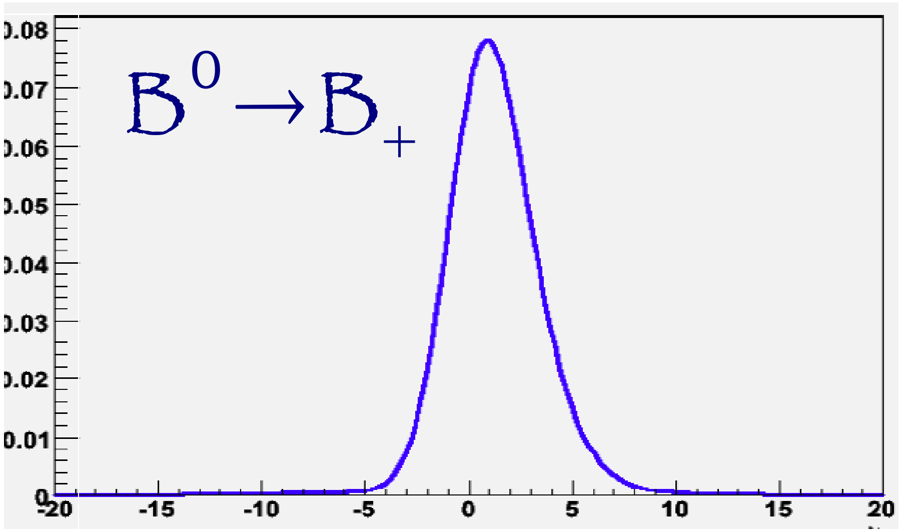


TV analysis steps : real data

- Need to account for finite Δτ resolution

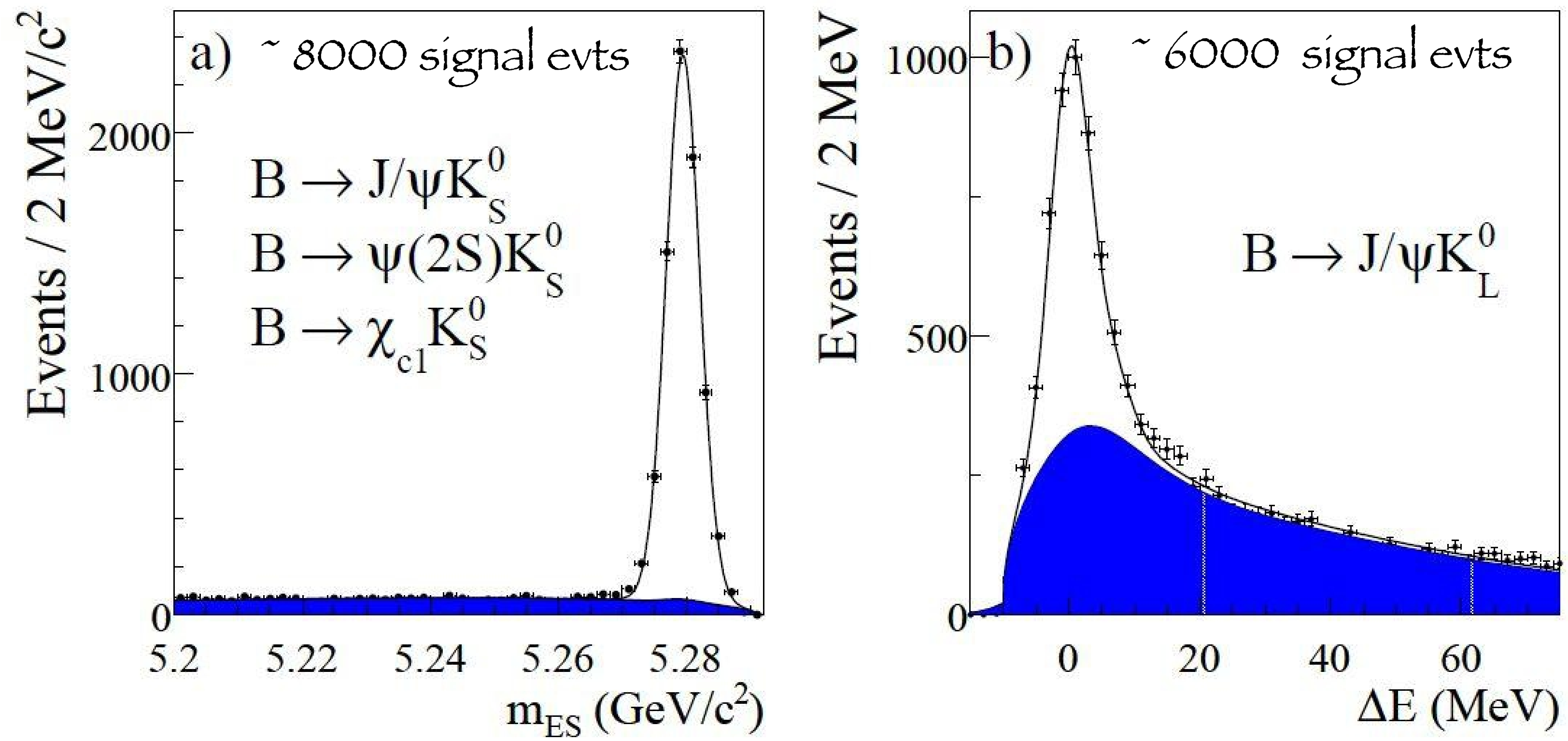
$$\mathcal{F}^{\pm}_{\alpha,\beta}(\Delta\tau) \propto g^{\pm}_{\alpha,\beta}(\Delta\tau')\times\mathcal{R}(\Delta\tau,\Delta\tau')$$





TV analysis steps : real data

- Need to account for finite $\Delta\tau$ resolution
- Need to account for background (mostly for $J/\psi K_L$)

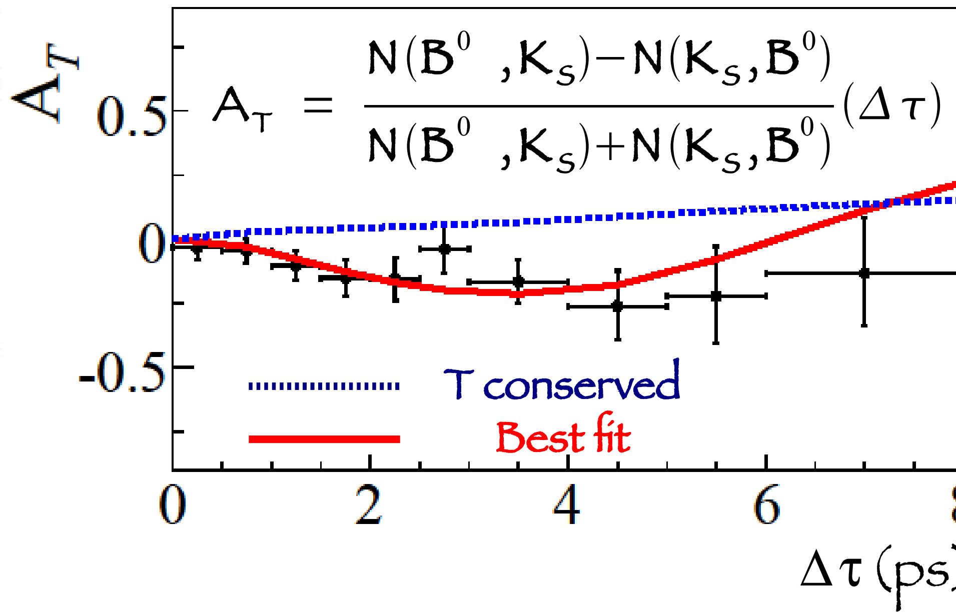


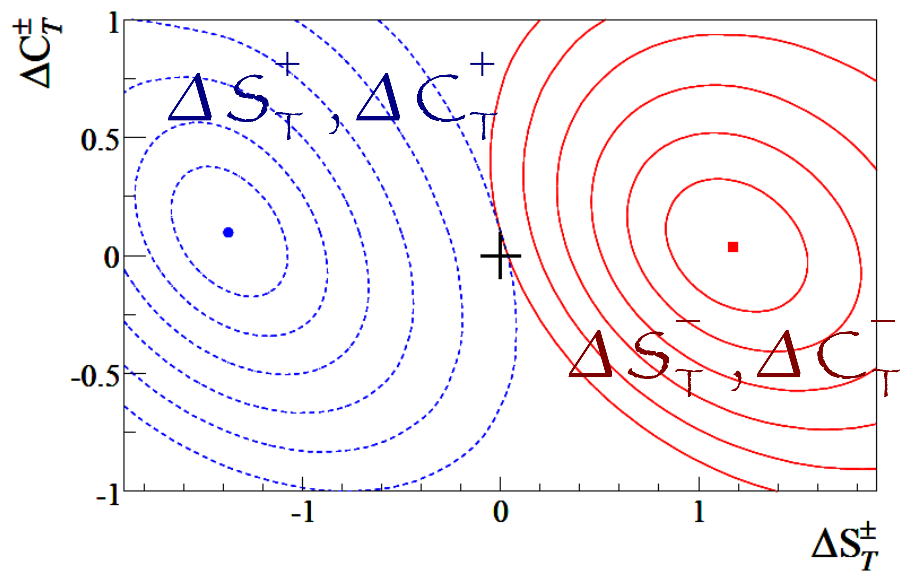
TV analysis steps : real data

- Need to account for finite $\Delta\tau$ resolution
- Need to account for background (mostly for $J/\psi\, K_L$)
- Need to account for dilution from wrong flavor tags
  - Tag-category dependent
  - Use samples of fully reconstructed flavor eigenstates ($D^{(*)}\pi, D^{(*)}K, J/\psi K^{(*)+}$, etc.)

T-V : RESULTS

Parameter	Final result
$\Delta S_{\mathrm{T}}^{+}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_{\mathrm{T}}^{-}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C_{\mathrm{T}}^{+}$	$0.10 \pm 0.16 \pm 0.08$
$\Delta C_{\mathrm{T}}^{-}$	$0.04 \pm 0.16 \pm 0.08$
$\Delta S_{\mathrm{CP}}^{+}$	$-1.30 \pm 0.10 \pm 0.07$
$\Delta S_{\mathrm{CP}}^{-}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C_{\mathrm{CP}}^{+}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C_{\mathrm{CP}}^{-}$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S_{\mathrm{CPT}}^{+}$	$0.16 \pm 0.20 \pm 0.09$
$\Delta S_{\mathrm{CPT}}^{-}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C_{\mathrm{CPT}}^{+}$	$0.15 \pm 0.17 \pm 0.07$
$\Delta C_{\mathrm{CPT}}^{-}$	$0.03 \pm 0.14 \pm 0.08$
$S_{\mathrm{B^0,K^0_S}}^{+}$	$0.545 \pm 0.084 \pm 0.06$
$S_{\mathrm{B^0,K^0_S}}^{-}$	$-0.660 \pm 0.059 \pm 0.04$
$C_{\mathrm{B^0,K^0_S}}^{+}$	$0.011 \pm 0.064 \pm 0.05$
$C_{\mathrm{B^0,K^0_S}}^{-}$	$-0.049 \pm 0.056 \pm 0.03$





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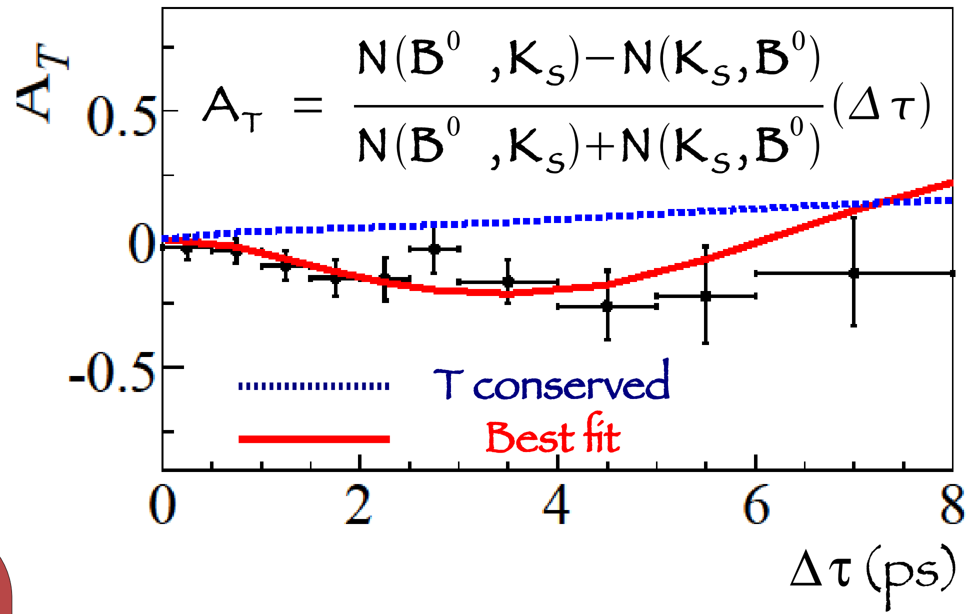
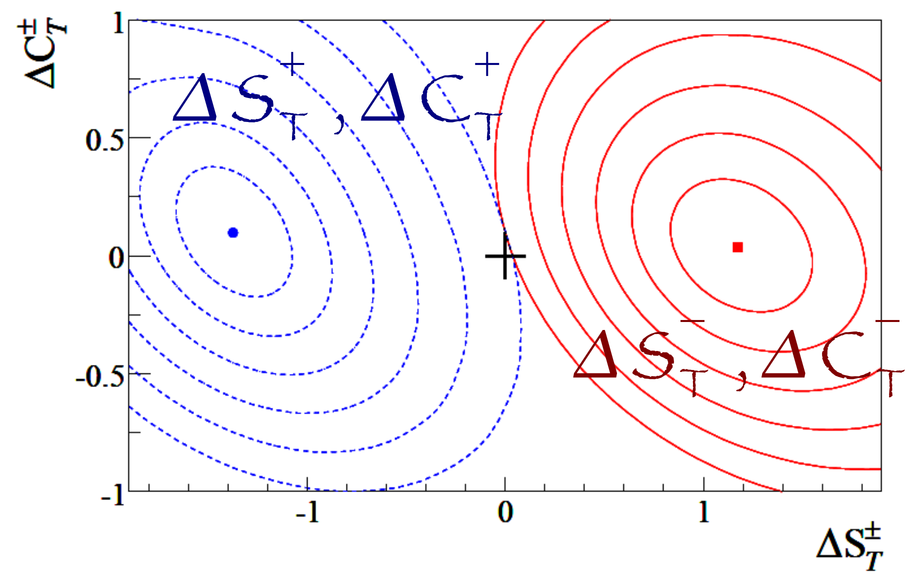
T-V : RESULTS

Parameter	Final result
ΔS_T^+	$-1.37 \pm 0.14 \pm 0.06$
ΔS_T^-	$1.17 \pm 0.18 \pm 0.11$
ΔC_T^+	$0.10 \pm 0.16 \pm 0.08$
ΔC_T^-	$0.04 \pm 0.16 \pm 0.08$
ΔS_{CP}^+	$-1.30 \pm 0.10 \pm 0.07$
ΔS_{CP}^-	$1.33 \pm 0.12 \pm 0.06$
ΔC^+	$0.07 \pm 0.09 \pm 0.03$

First unambiguous observation of T-violation in B-Physics with 14 σ significance





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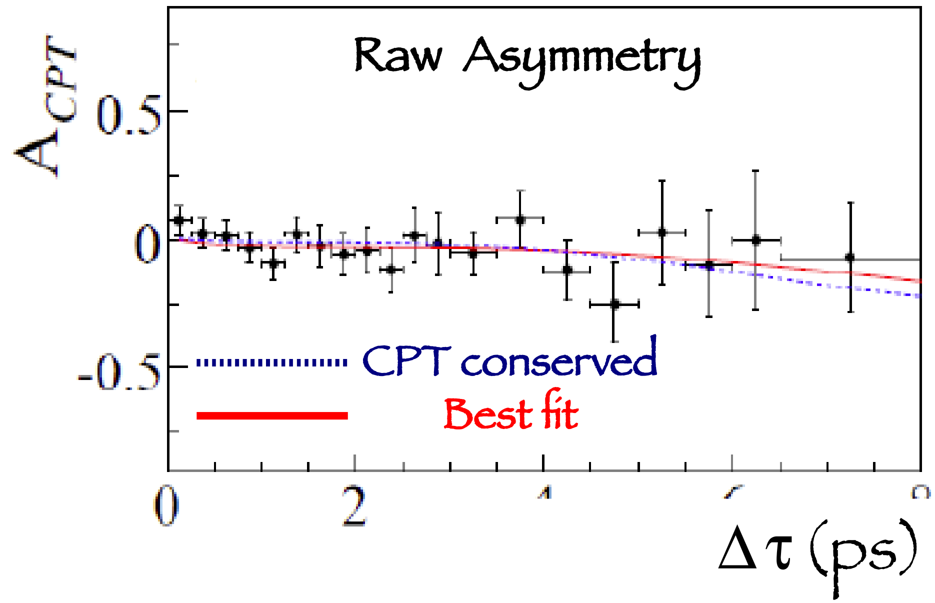
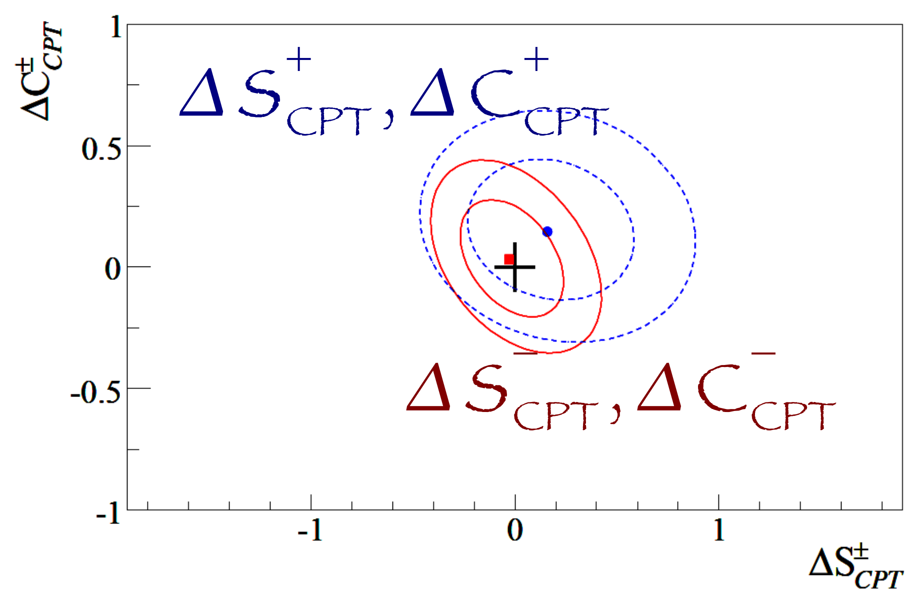
CPT-V : RESULTS

Parameter	Final result
$\Delta S^+_{\rm T}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S^-_{\rm T}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C^+_{\rm T}$	$0.10 \pm 0.16 \pm 0.08$
$\Delta C^-_{\rm T}$	$0.04 \pm 0.16 \pm 0.08$
$\Delta S^+_{\rm CP}$	$-1.30 \pm 0.10 \pm 0.07$
$\Delta S^-_{\rm CP}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C^+_{\rm CP}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C^-_{\rm CP}$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S^+_{\rm CPT}$	$0.16 \pm 0.20 \pm 0.09$
$\Delta S^-_{\rm CPT}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C^+_{\rm CPT}$	$0.15 \pm 0.17 \pm 0.07$
$\Delta C^-_{\rm CPT}$	$0.03 \pm 0.14 \pm 0.08$
$S^+_{\rm B^0,K^0_S}$	$0.545 \pm 0.084 \pm 0.06$
[illegible] $_{\rm B^0,K^0_S}$	[illegible]
$C^-_{\rm B^0,K^0_S}$	$-0.049 \pm 0.056 \pm 0.03$

CPT is Conserved





BABAR PRL 109, 211801 (2012)

PART II

MIXING – INDUCED CPV

MIXING-INDUCED CPV

- CPV in mixing if : $\mathcal{P}(B^0 \to \overline{B}^0) \neq \mathcal{P}(\overline{B}^0 \to B^0)$
- CP asymmetry is usually measured through B semileptonic decays :

$$\mathcal{A}_{ll} = \frac{N(B^0B^0) - N(\overline{B}^0\overline{B}^0)}{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)} = \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)}$$

- Very tiny effects in the SM:

$$\mathcal{A}_{ll}(B^0) = (-4.1 \pm 0.6) \cdot 10^{-4}$$

$$\mathcal{A}_{ll}(B_s) = (1.9 \pm 0.3) \cdot 10^{-5}$$

(Lenz, Nierste, arXiv:1102.4274 (2011)):

- Positive observation : DISCOVERY OF NEW PHYSICS

MIXING-INDUCED CPV

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- CP asymmetry is usually measured through B semileptonic decays :

$$\mathcal{A}_{ll} = \frac{N(B^0B^0) - N(\overline{B}^0\overline{B}^0)}{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)} = \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)}$$

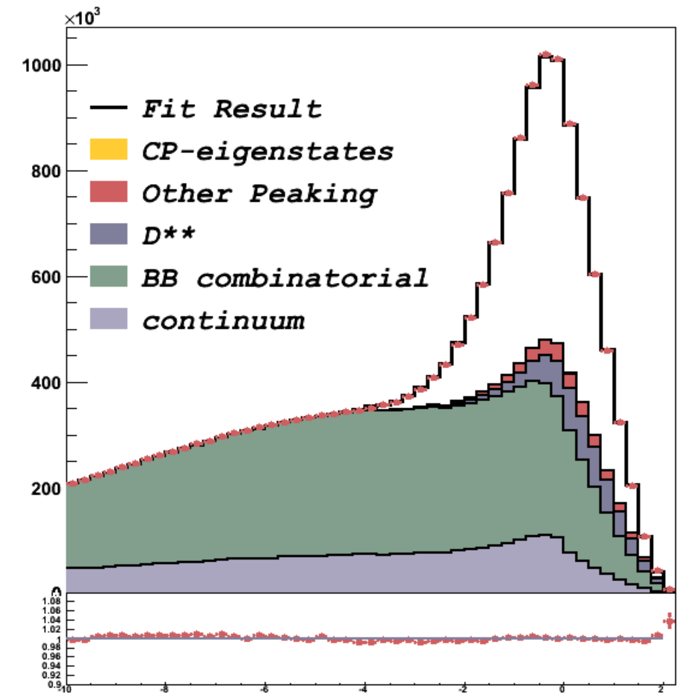
- A new approach, pionereed by BABAR is here presented:
  - "Reco" 1st B : partial reconstruction of $B^0 \to \ell^+ \nu_\ell D^{*-}$
  - "Tag" 2nd B : use charged Kaons

$$\mathcal{A}_{ll} = \frac{N(B^0B^0) - N(\overline{B}^0\overline{B}^0)}{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)} = \frac{N(\ell^+K^+) - N(\ell^-K^-)}{N(\ell^+K^+) + N(\ell^-K^-)}$$

B -> D*ℓν Partial Reconstruction

- Use only ℓ and low momentum π_s from the decay $D^{*-} \to \pi_s^- \overline{D}^0$
- Assume B^0 at rest in $\Upsilon(4S)$ frame $\vec{P}_B \sim 0$
- Get D^* from π_s: $\vec{P}_{D*} = \vec{f}(\vec{P}_{\pi_s})$
- Compute missing mass from four momenta difference:

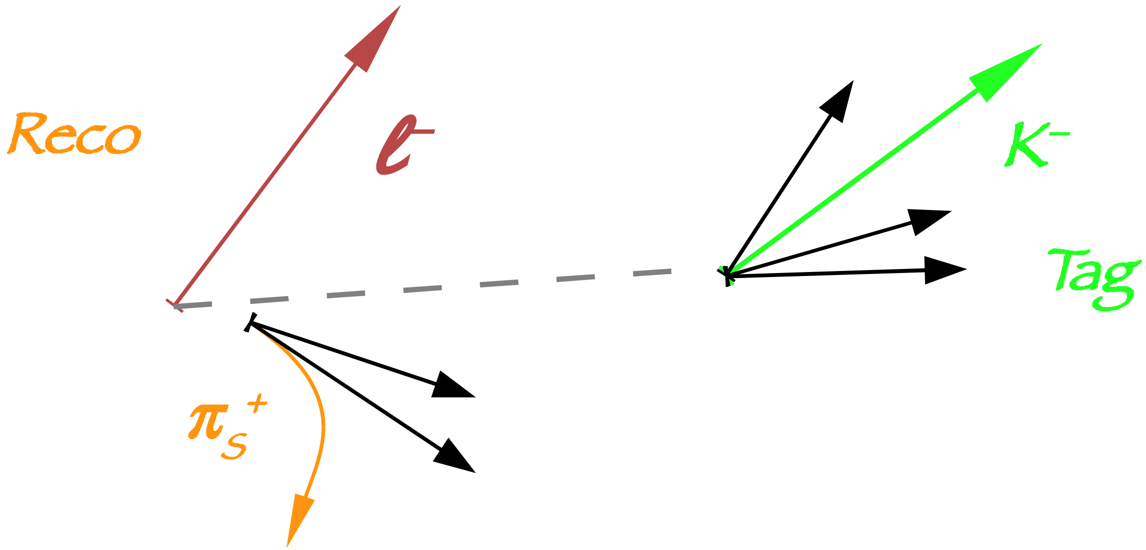
$$M_\nu^2 = (\mathcal{P}_B - \mathcal{P}_{D*} - \mathcal{P}_\ell)^2$$



- Large event yield

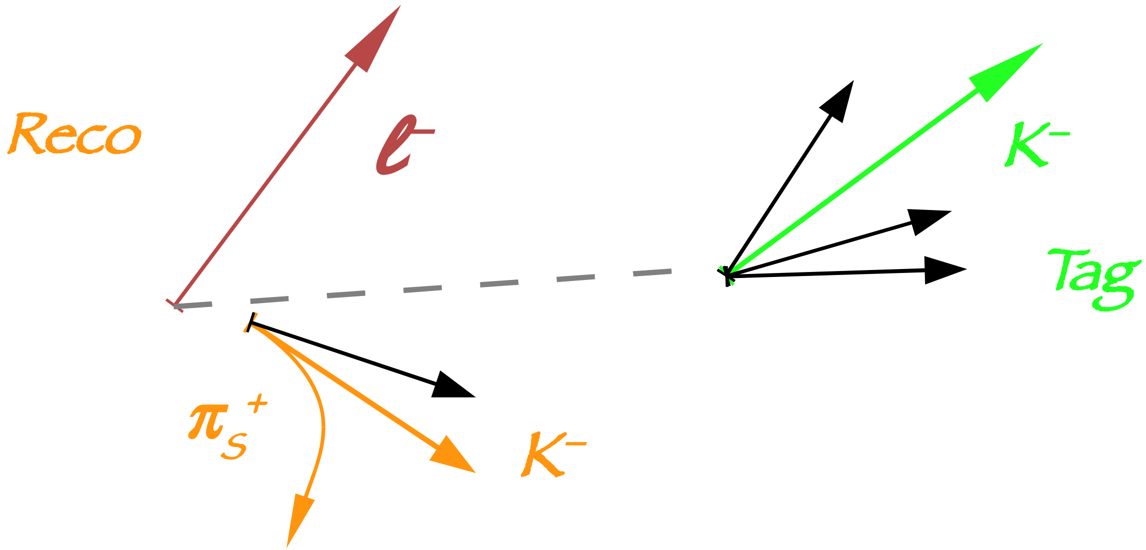
$(5370 \pm 6) \cdot 10^3$ Peaking Events

The Kaon Tag



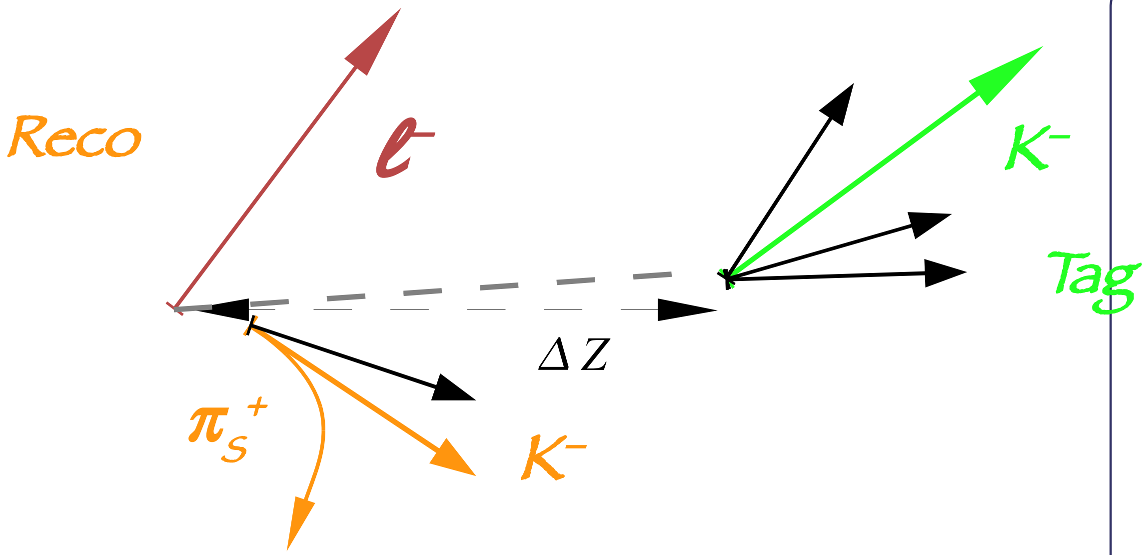
- K identified using dE/dX & Cherenkov with high purity

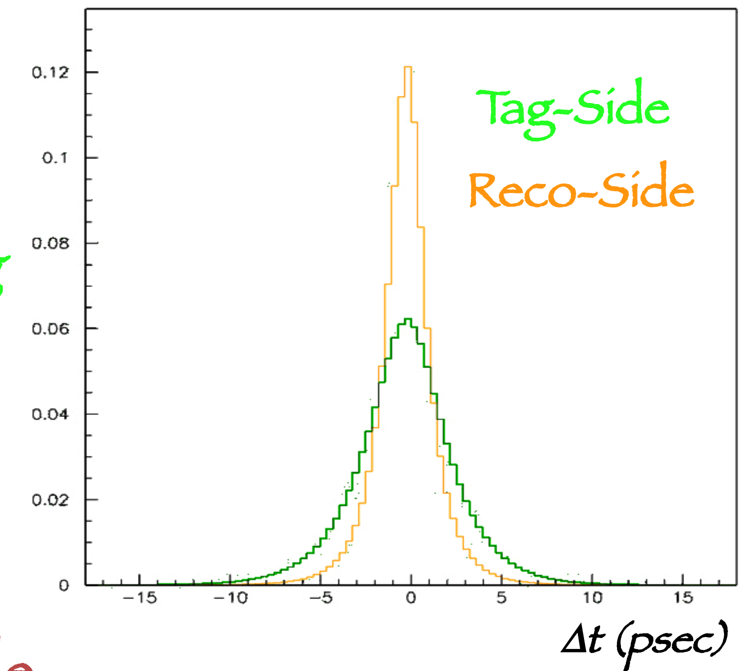
The Kaon Tag

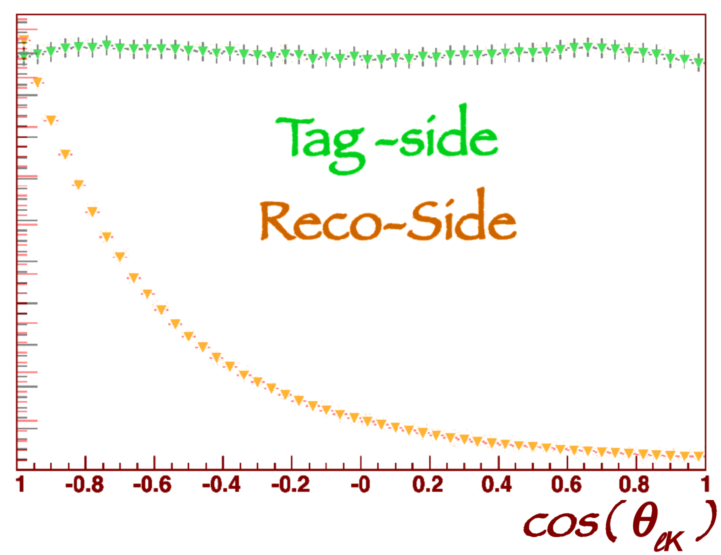


- Equal charge Kaons also from the reco side, mimick a mixed event .

The Kaon Tag



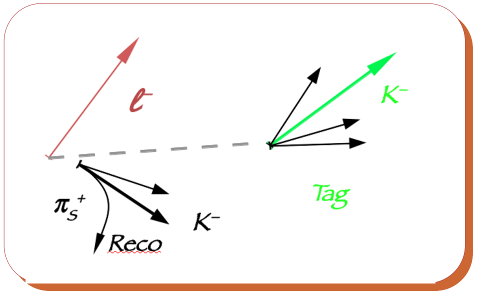




- Equal charge Kaons also from the reco side, mimick a mixed event .
- Separated by:
  - $\Delta t = (Z_\ell - Z_K) / (c\beta\gamma)$ (in the Lab)
  - $\cos(\theta_{\ell K})$ (in $\Upsilon(4S)$ rest frame)

Asymmetry

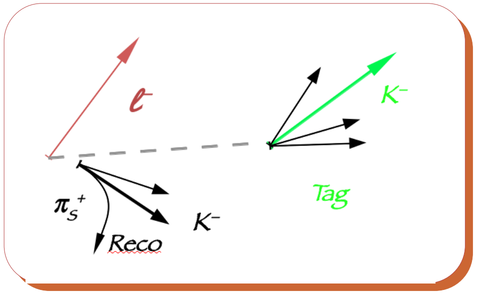
- Observed asymmetries for mixed reflect RECO-side charge asymmetry, K-id charge asymmetry and Physical asymmetry:



$$\mathcal{A}_{obs,K\text{-}Tag} \simeq \mathcal{A}_{Rec} + \mathcal{A}_{K} + \mathcal{A}_{\ell\ell}$$

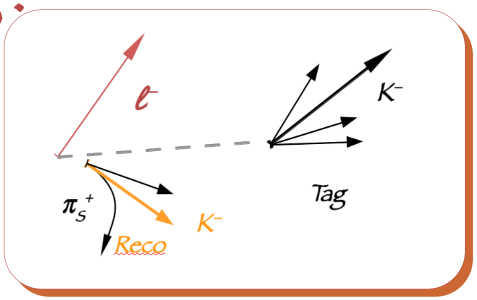
Asymmetry

- Observed asymmetries for mixed reflect *RECO-side* charge asymmetry, *K*-id charge asymmetry and Physical asymmetry:



$$\mathcal{A}_{obs,K\text{-}Tag} \simeq \mathcal{A}_{Rec} + \mathcal{A}_{K} + \mathcal{A}_{\ell\ell}$$

- Kaons from reco side have tiny contribution from mixing :



$$\mathcal{A}_{obs,K\text{-}Rec} \simeq \mathcal{A}_{Rec} + \mathcal{A}_{K} + \chi_d \mathcal{A}_{\ell\ell}$$

Asymmetry

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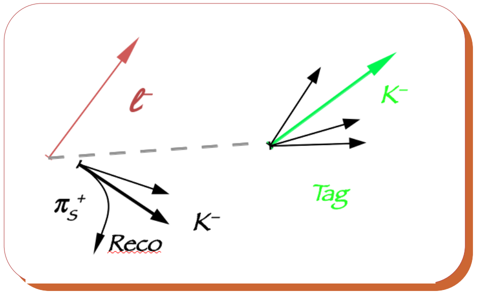
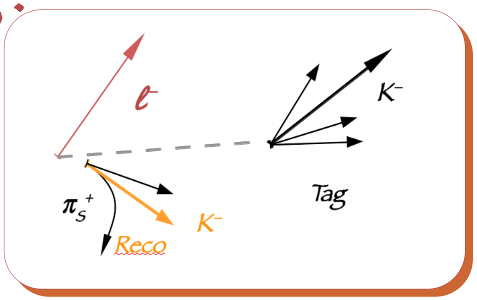


$$\mathcal{A}_{obs,K\text{-}Tag} \simeq \mathcal{A}_{Rec} + \mathcal{A}_{K} + \mathcal{A}_{\ell\ell}$$

- Kaons from reco side have tiny contribution from mixing :



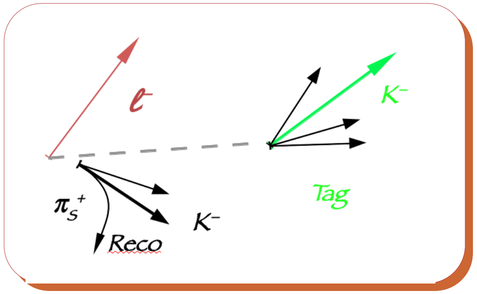
$$\mathcal{A}_{obs,K\text{-}Rec} \simeq \mathcal{A}_{Rec} + \mathcal{A}_{K} + \chi_d \mathcal{A}_{\ell\ell}$$

- Measure also single lepton asymmetry (before tagging) :

$$\mathcal{A}_{obs,Rec} \simeq \mathcal{A}_{Rec} + \chi_d \mathcal{A}_{\ell\ell}$$

Asymmetry

- Observed asymmetries for mixed reflect RECO-side charge asymmetry, K-id charge asymmetry and Physical asymmetry:



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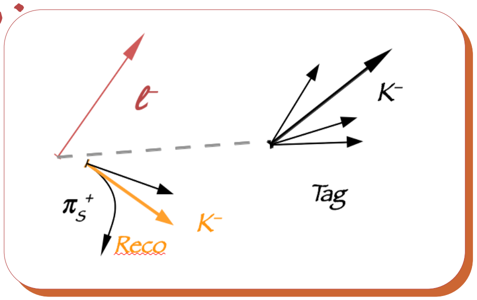

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- Measure also single lepton asymmetry (before tagging) :

$$\mathcal{A}_{obs,Rec} \simeq \mathcal{A}_{Rec} + \chi_d \mathcal{A}_{\ell\ell}$$

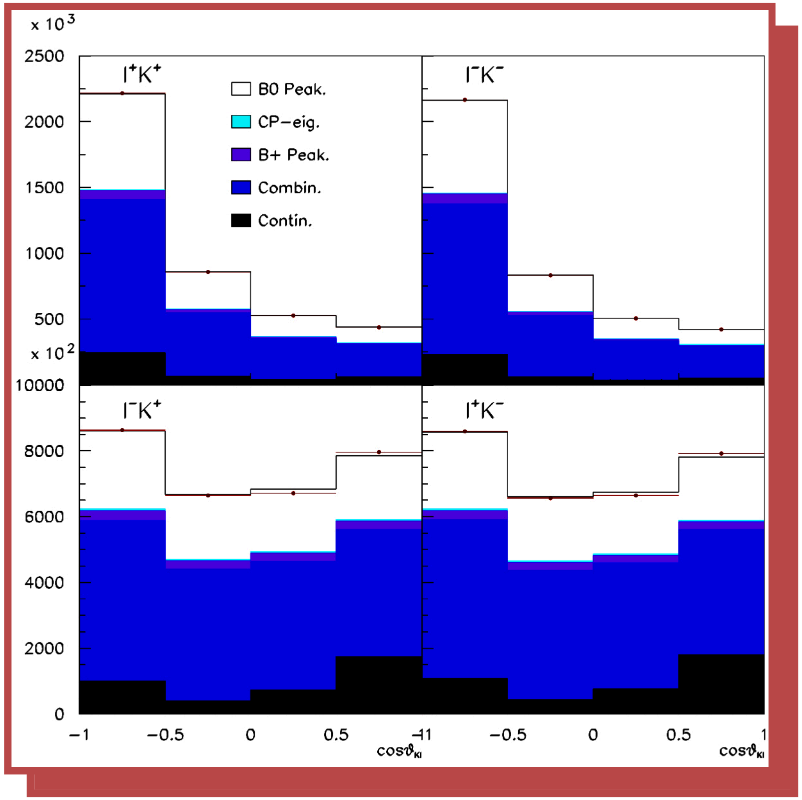
- Constrained system:

determine $\mathcal{A}_{\ell\ell}$ and main sources of systematic uncertainty from the data

MEASUREMENT

- 4D binned fit to (ΔZ, $\cos\theta_{\ell K}$, M_ν^2, p_K) space
- Use also opposite sign ℓ^+K^- / ℓ^-K^+ to improve precision
- More than 100 free parameters:
  - $\mathcal{A}_{\omega}$, $\mathcal{A}_{REC}$, $\mathcal{A}_{K}$, K-Rec fraction, fraction of wrong tags (charge dependent), fraction of DCSC Kaons, ΔZ resolution parameters, …

BABAR Preliminary



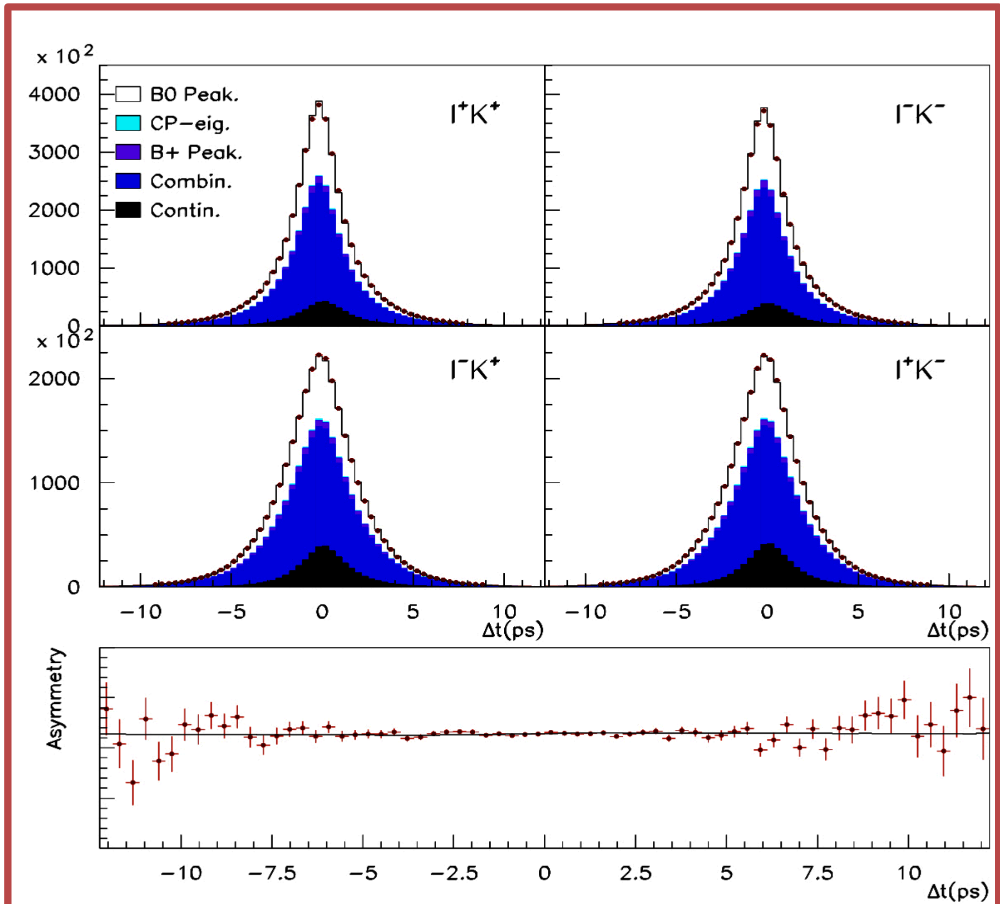
$\cos\theta_{\ell K}$

Results

$$\mathcal{A}_{ll} = (0.06 \pm 0.16^{+0.36}_{-0.32})\,\%$$

BABAR Preliminary

- No positive observation



$$\frac{1}{2}\sigma(\mathcal{A}_{ll})$$

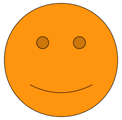
Source	$\Delta\lvert q/p\rvert$
Peaking Sample Composition	$^{+1.17}_{-1.50} \times 10^{-3}$
Combinatoric Sample Composition	$\pm 0.39 \times 10^{-3}$
ΔT Resolution Model	$+0.60 \times 10^{-3}$
Dtag fraction	$\pm 0.11 \times 10^{-3}$
Dtag ΔT distribution	$\pm 0.65 \times 10^{-3}$
Fit Bias	$^{+0.46}_{-0.58} \times 10^{-3}$
CP-eigenstate description	—
Physical Parameters	$+0.28 \times 10^{-3}$
Total	$^{+1.61}_{-1.78} \times 10^{-3}$

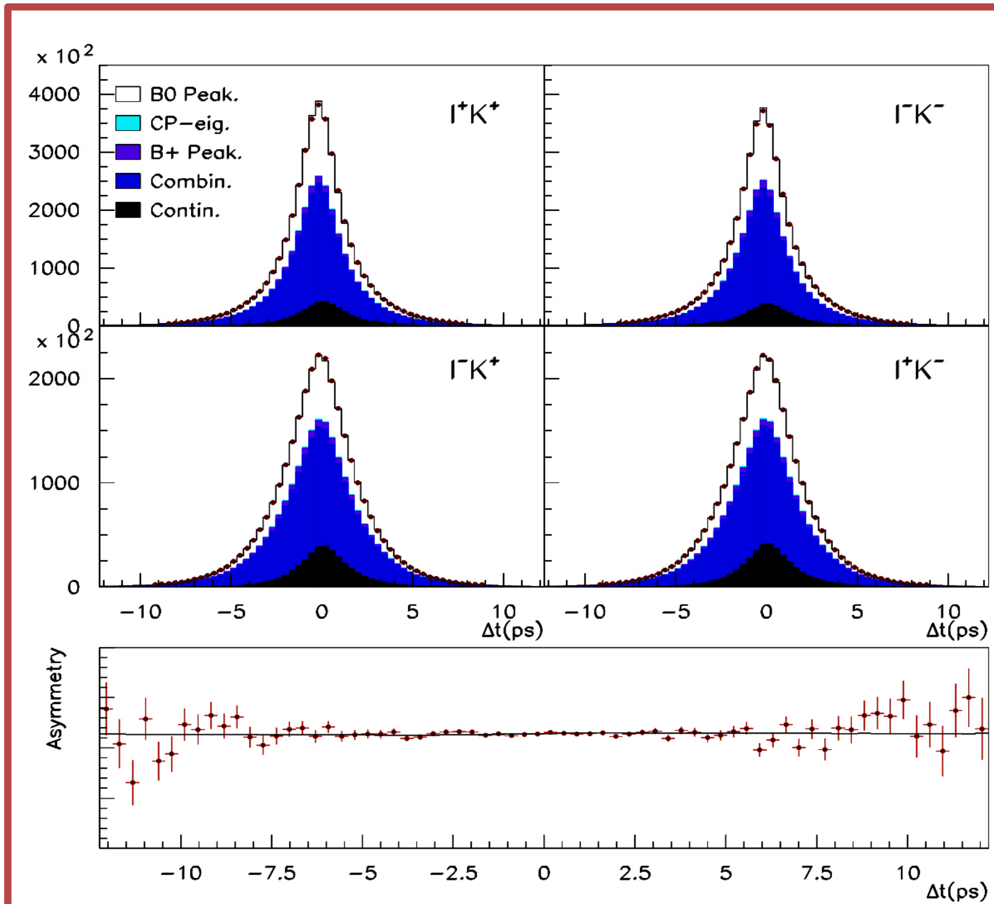
Results

BABAR Preliminary

$$\mathcal{A}_{\ell\ell} = (0.06 \pm 0.16^{+0.36}_{-0.32})\%$$

- More precise than previous B-Factories average:





$$\mathcal{A}_{\ell\ell} = (-0.05 \pm 0.56)\%$$

Source	$\Delta\lvert q/p\rvert$
Peaking Sample Composition	$^{+1.17}_{-1.50} \times 10^{-3}$
Combinatoric Sample Composition	$\pm 0.39 \times 10^{-3}$
ΔT Resolution Model	$+0.60 \times 10^{-3}$
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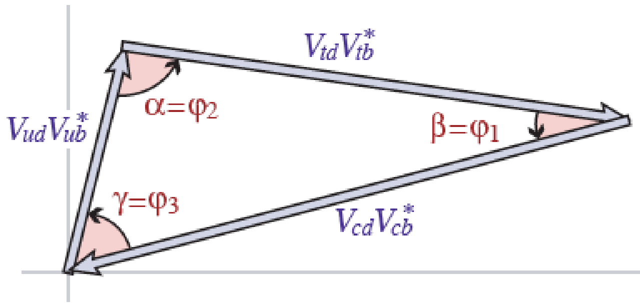
$$\frac{1}{2}\sigma(\mathcal{A}_{\ell\ell})$$

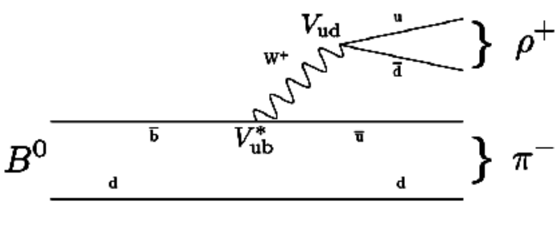
PART III

Measurement of α from B –> $\pi^+\pi^-\pi^0$

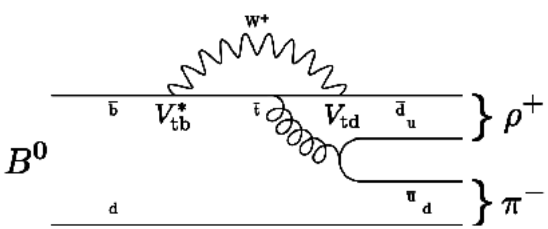
Measurement of α

- Interference between mixing and decay would allow to compute sin 2α a-la sin2β
- Tree & penguin diagram have comparable size. Their interference:
  - introduces a strong phase difficult to compute
  - may induce a sizable amount of direct CP violation
- Time dependent tagged analysis across the $\rho\pi$ Dalitz plot permits – in principle – an unambiguous measurement of α





Tree Diagram



Penguin Diagram

Snyder- Quinn Phys.Rev. D 48,2139 (1993)

A NEW measurement of α

BABAR has recently updated its 2007 measurement:

- to the full dataset (431 fb^{-1}, + 25%)
- improved tracking + PID
- re-optimized selection requirements
- performed a robustness study to assess the reliability with which the true value of α can be extracted

Time-Dependent PDF

Direct CPV

$$|\mathcal{A}^{\pm}_{3\pi}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[|A_{3\pi}|^2 + |\overline{A}_{3\pi}|^2 \mp \left(|A_{3\pi}|^2 - |\overline{A}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) \pm 2\mathrm{Im}\left[\frac{q}{p}\overline{A}_{3\pi}A^*_{3\pi}\right]\sin(\Delta m_d \Delta t)\right]$$

$\sin(2\alpha_{\mathrm{eff}})$

$$A_{3\pi} = f_+A^+ + f_-A^- + f_0A^0 \quad \text{for} \quad B^0 \to \pi^+\pi^-\pi^0$$

$$\overline{A}_{3\pi} = f_+\overline{A}^+ + f_-\overline{A}^- + f_0\overline{A}^0 \quad \text{for} \quad \overline{B}^0 \to \pi^+\pi^-\pi^0$$

$\rho^+ \quad \rho^- \quad \rho^0$

$$f_\kappa(m,\theta_\kappa) \propto F_{\rho(770)}(m,\theta_\kappa) + a_{\rho'}e^{i\phi_{\rho'}}F_{\rho(1450)}(m,\theta_\kappa)$$

ρ(1700) is neglected

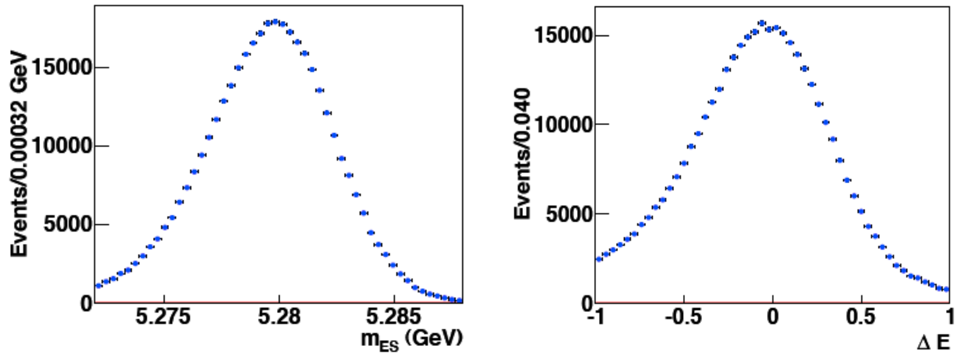
Event selection

- Usual tags from B(πππ) invariant mass and energy

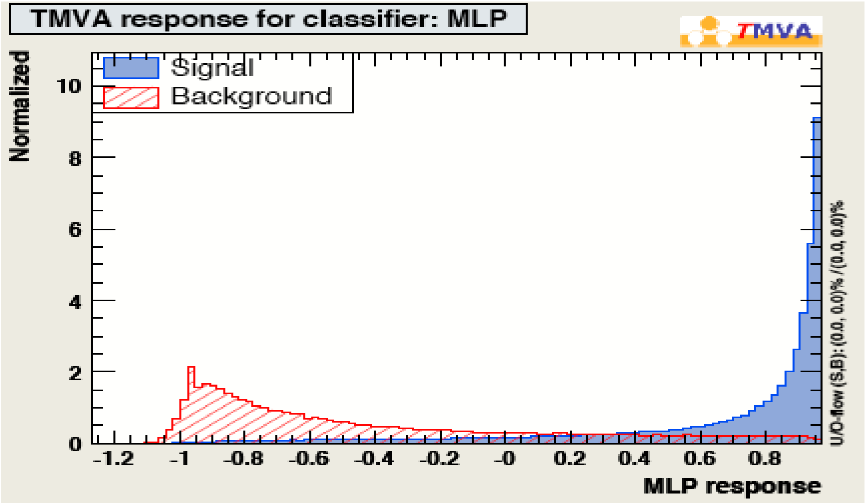
$$m_{ES} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - (p_B^*)^2}$$

$$\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$$

BABAR signal simulation



- NN to reject jet-like *(udsc)* continuum background



- Still large amount of residual background
- Fit (see below) estimates :

2900 ± 100 signal events

46700 ± 200 continuum background events

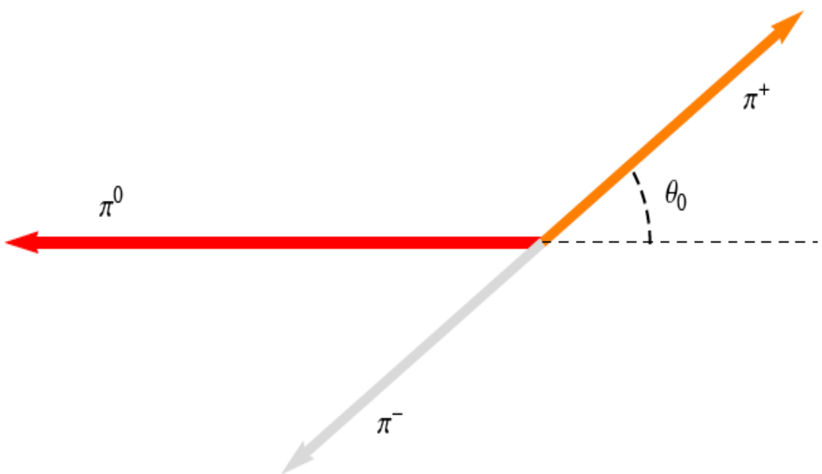
Dalitz Model

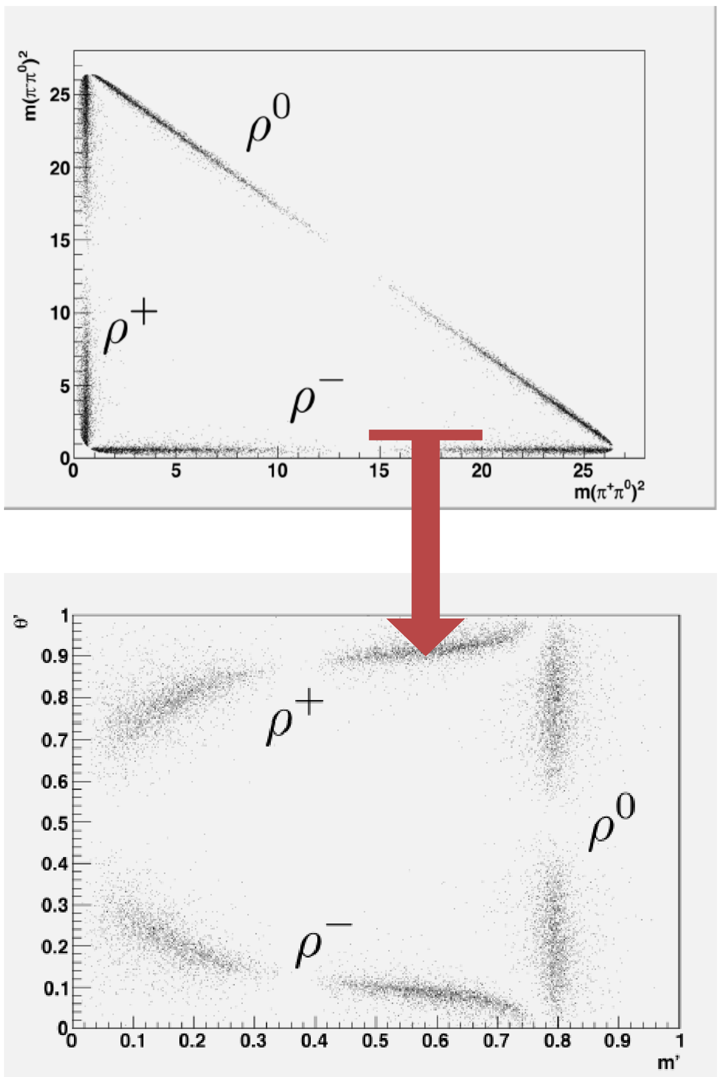
- Dalitz variables mapped to a square domain :

$\pi^+\pi^-$ invariant mass

$$m' \equiv \frac{1}{\pi} \arccos\left(2\frac{m_0 - m_0^{\min}}{m_0^{\max} - m_0^{\min}} - 1\right)$$

$$\theta' \equiv \frac{1}{\pi}\theta_0$$ helicity angle





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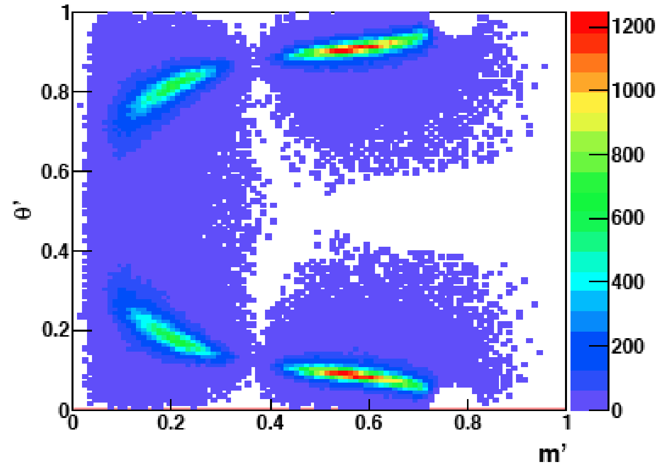
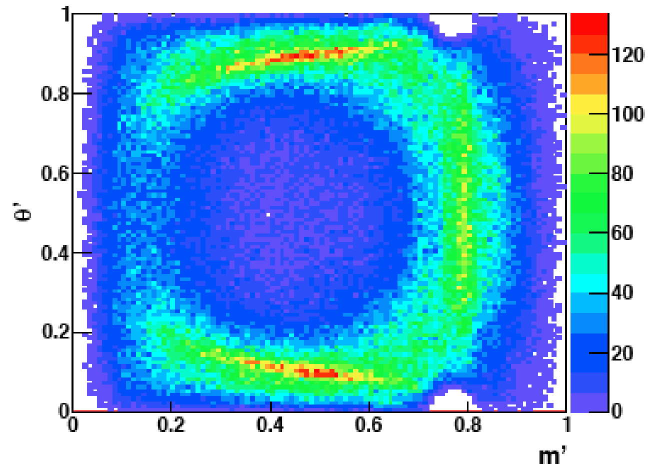
$$\theta' \equiv \frac{1}{\pi}\theta_0$$ helicity angle

Correctly Reconstructed Signal MC



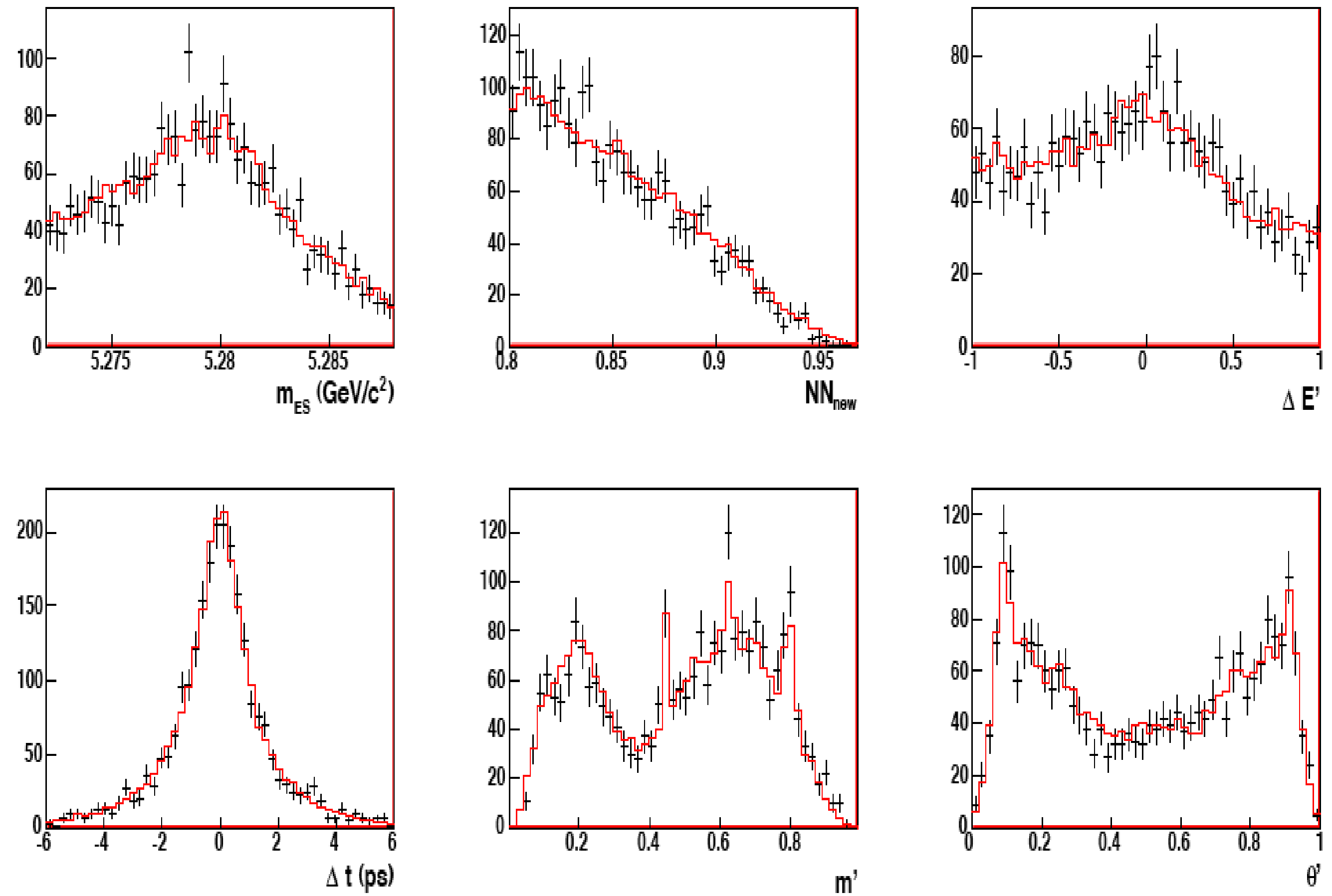
M_{ES} Sideband Data



- Data model:
  - Signal , BB background (MC)
  - Continuum (sidebands, data collected below Υ(4S) threshold)

Fit

- 6-D fit (m_{ES},ΔE,NN,Δt,m',θ') performed in the U,I formalism (26 param.) and then mapped into the physical quantities .
- Good overall agreement:

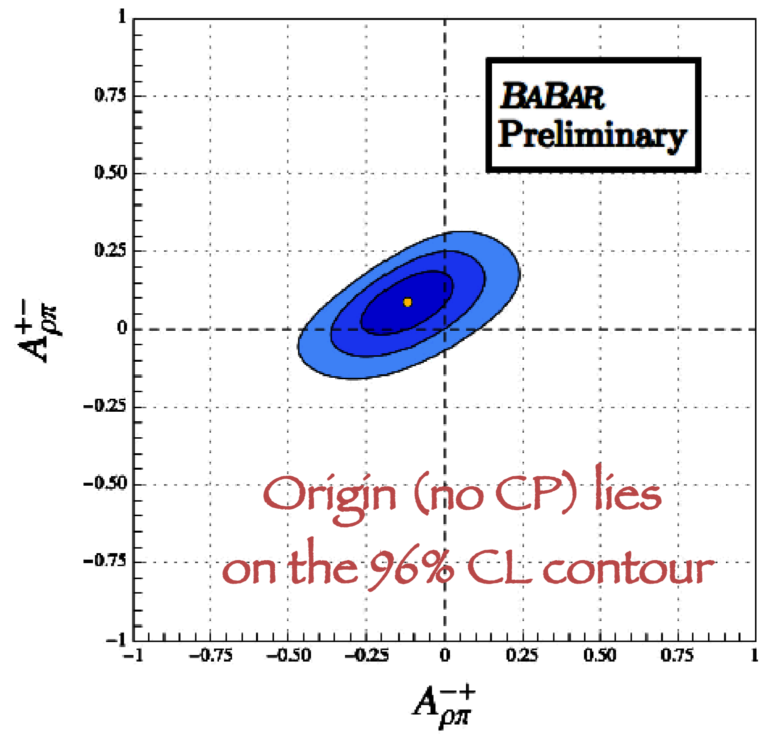


Results (1) : direct CP

- Observe direct CP violation from the asymmetries:

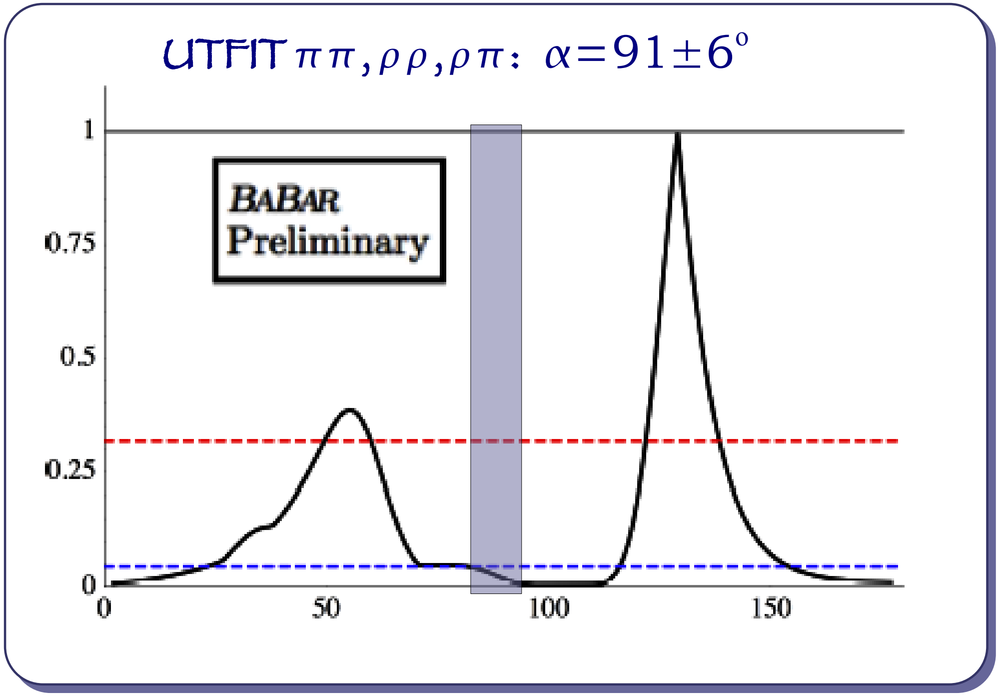
$$\mathcal{A}_{\rho\pi}^{+-} \equiv \frac{\Gamma(\overline{B}^0 \to \rho^-\pi^+) - \Gamma(B^0 \to \rho^+\pi^-)}{\Gamma(\overline{B}^0 \to \rho^-\pi^+) + \Gamma(B^0 \to \rho^+\pi^-)} = 0.09^{+0.05}_{-0.06} \pm 0.04$$

$$\mathcal{A}_{\rho\pi}^{-+} \equiv \frac{\Gamma(\overline{B}^0 \to \rho^+\pi^-) - \Gamma(B^0 \to \rho^-\pi^+)}{\Gamma(\overline{B}^0 \to \rho^+\pi^-) + \Gamma(B^0 \to \rho^-\pi^+)} = -0.12 \pm 0.08^{+0.04}_{-0.05}$$



Results (2) : α

- parameter scan to get $\Delta\chi^2$ profile and 1-CL plot



- result disagree with World Average (B–>ππ , B–>ρρ)

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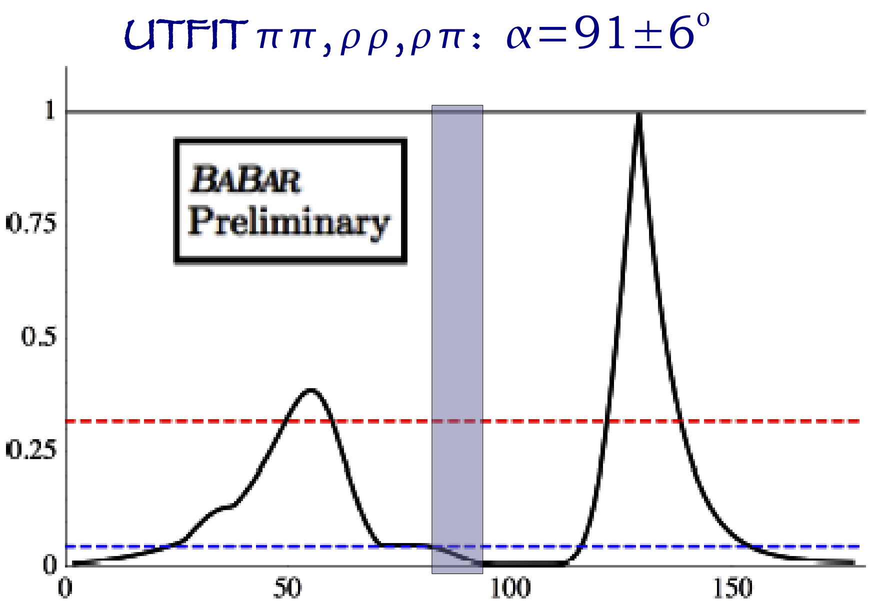
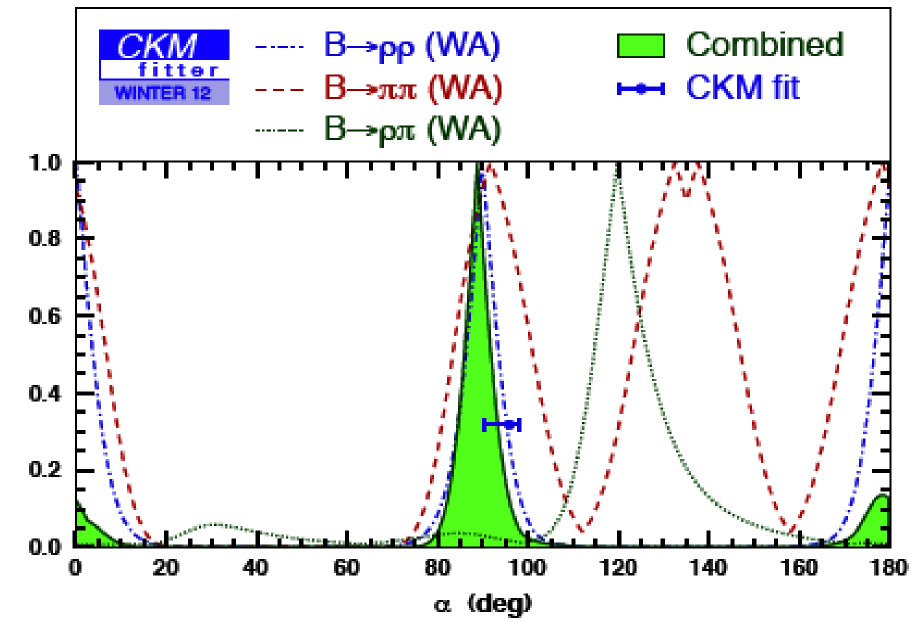
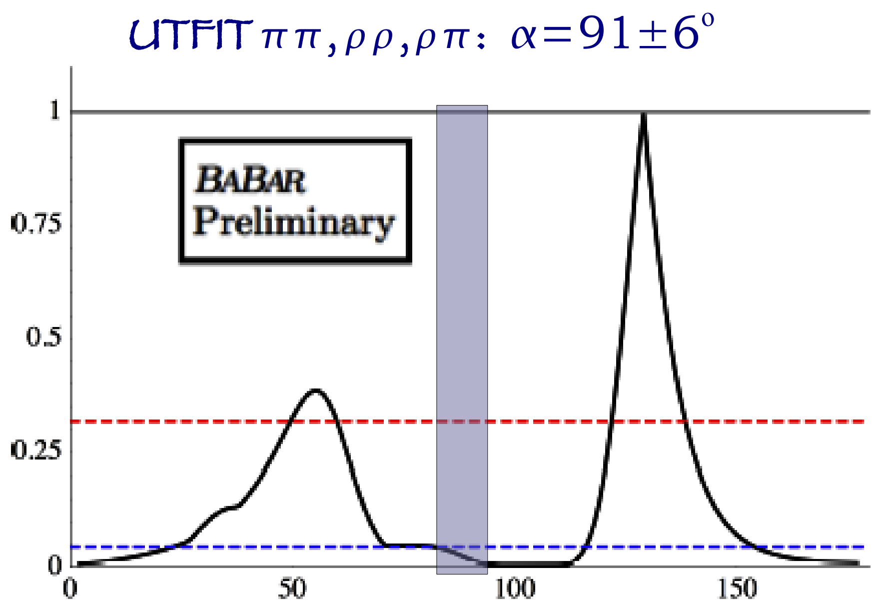


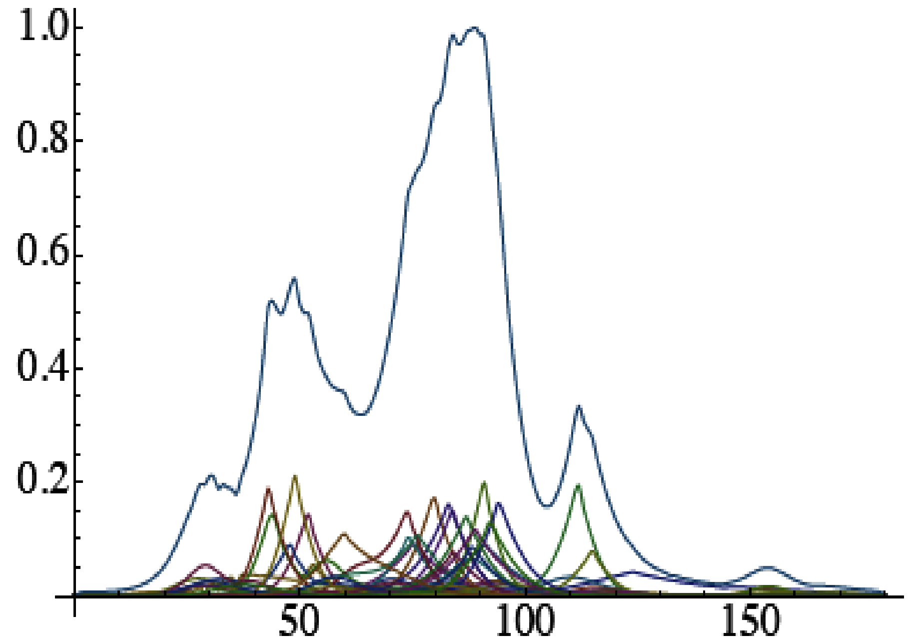


- result disagree with WA (B–>ππ , B–>ρρ)
- confirms bias observed in previous analysis by BABAR & Belle

Results (2) : α

- parameter scan to get $\Delta\chi^2$ profile and 1-CL plot





- result disagree with WA (B–>ππ , B–>ρρ)
- confirms bias observed in previous analysis by *BaBar* & *Belle*
- toy MC : due to small S/N, secondary minima are often favored

Conclusions

Four years after end running, BABAR has still glamour results on CP/T-Violation:

http://www.economist.com/node/21561111

- First uncontroversial evidence of T-Violation in the *B*-meson system
- Most precise measurement of mixing-induced CP-Violation
- Direct CP-Violation on $B \to \rho\pi$ assessed at 96% CL

Backup

Dalitz Analysis: Parameter Results

$$f_{Q_{\rm tag}}^{\rho^\pm\pi^\mp}(\Delta t) = (1 \pm \mathcal{A}_{\rho\pi})\frac{e^{-|\Delta t|/\tau}}{4\tau} \times \left[1 + Q_{\rm tag}(\mathcal{S} \pm \Delta\mathcal{S})\sin(\Delta m_d \Delta t) - Q_{\rm tag}(\mathcal{C} \pm \Delta\mathcal{C})\cos(\Delta m_d \Delta t)\right].$$

$$\mathcal{C} = (\mathcal{C}^+ + \mathcal{C}^-)/2,$$
$$\Delta\mathcal{C} = (\mathcal{C}^+ - \mathcal{C}^-)/2,$$
$$\mathcal{S} = (\mathcal{S}^+ + \mathcal{S}^-)/2,$$
$$\Delta\mathcal{S} = (\mathcal{S}^+ - \mathcal{S}^-)/2.$$

Param	Value	$\sigma_{\rm stat}$	$\sigma_{\rm syst}$
$\mathcal{A}_{\rho\pi}$	−0.100	0.029	0.021
$\mathcal{C}$	0.016	0.059	0.036
$\Delta\mathcal{C}$	0.234	0.061	0.048
$\mathcal{S}$	0.053	0.081	0.034
$\Delta\mathcal{S}$	0.054	0.082	0.039
$\mathcal{C}_{00}$	0.19	0.23	0.15
$\mathcal{S}_{00}$	−0.37	0.34	0.20
f_{00}	0.092	0.011	0.008

Dalitz Analysis : scan for α

- Information about the unitarity triangle angle α is extracted in a likelihood scan based on our final U/I fit results and full stat+syst covariance matrix
- Perform a χ^2 minimization at each value of α from $(0-180)$ degrees using

$$\chi^2_{\alpha\ \mathrm{scan}} = \left[V^{\mathrm{data}} - V^{\mathrm{scan}}\right]^T (C^{\mathrm{data}})^{-1} \left[V^{\mathrm{data}} - V^{\mathrm{scan}}\right]$$

- The variables that float in these fits are actually the tree and penguin amplitudes which are related to the ρ amplitudes by:

$$\begin{aligned}
A^+ &= T^+ e^{-i\alpha} + P^+ \\
A^- &= T^- e^{-i\alpha} + P^- \\
A^0 &= T^0 e^{-i\alpha} + P^0 \\
\overline{A}^+ &= T^- e^{+i\alpha} + P^- \\
\overline{A}^- &= T^+ e^{+i\alpha} + P^+ \\
\overline{A}^0 &= T^0 e^{+i\alpha} + P^0
\end{aligned}$$

The CP-Lear case

CPLEAR observes $K_0 \Leftrightarrow \bar{K}_0$ asymmetry

PLB444 43,1998

$$A_K = (6.6 \pm 1.6) \cdot 10^{-3}$$

- Time-integrated asymmetry
- requires ~ $\Delta\Gamma(K) \neq 0$
- Not unambiguous interpretation as T-violation (could also be mixing-induced CPV):

Wolfenstein [PRL83,911,(1999); Int.Journ.Mod.Phys.E8,501,(1999)]

Gerber, and references therein, Eur. Phys. Jour. C 35, 195 (2004)

T-V in the PDG

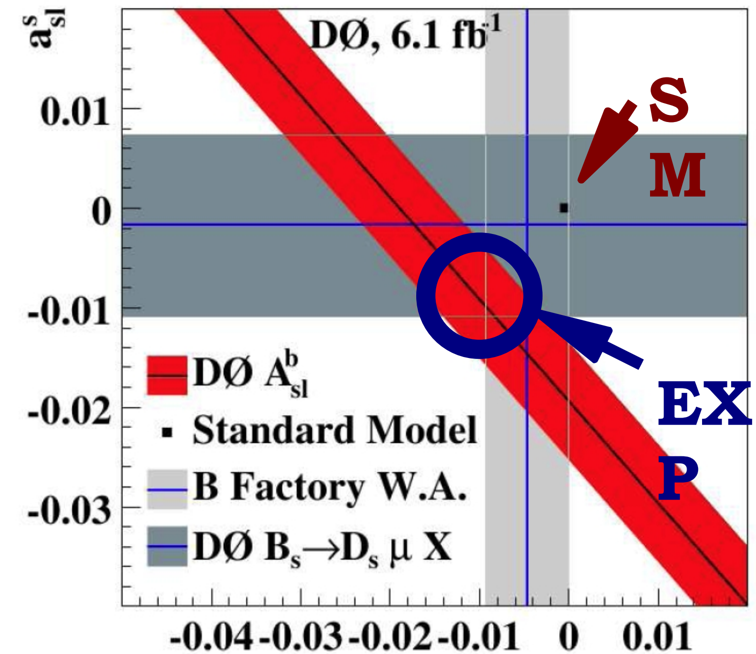
e electric dipole moment		$<10.5 \times 10^{-28}$ ecm, CL = 90%
μ electric dipole moment		$(-0.1 \pm 0.9) \times 10^{-19}$ ecm
μ decay parameters		
transverse e^+ polarization normal to plane of μ spin, e^+ momentum		$(-2 \pm 8) \times 10^{-3}$
α'/A		$(-10 \pm 20) \times 10^{-3}$
β'/A		$(2 \pm 7) \times 10^{-3}$
Re(d_τ = τ electric dipole moment)		-0.220 to 0.45×10^{-16} ecm, CL = 95%
P_T in $K^+ \to \pi^0 \mu^+ \nu_\mu$		$(-1.7 \pm 2.5) \times 10^{-3}$
P_T in $K^+ \to \mu^+ \nu_\mu \gamma$		$(-0.6 \pm 1.9) \times 10^{-2}$
Im(ξ) in $K^+ \to \pi^0 \mu^+ \nu_\mu$ decay (from transverse μ pol.)		-0.006 ± 0.008
asymmetry A_T in K^0-$\overline{K}^0$ mixing		$(6.6 \pm 1.6) \times 10^{-3}$
Im(ξ) in $K^0_{\mu 3}$ decay (from transverse μ pol.)		-0.007 ± 0.026
$A_T(D^\pm \to K^0_S K^\pm \pi^+ \pi^-)$	[b]	$(-12 \pm 11) \times 10^{-3}$
$A_T(D^0 \to K^+ K^- \pi^+ \pi^-)$	[b]	$(1 \pm 7) \times 10^{-3}$
$A_T(D^\pm_s \to K^0_S K^\pm \pi^+ \pi^-)$	[b]	$(-14 \pm 8) \times 10^{-3}$
p electric dipole moment		$<0.54 \times 10^{-23}$ ecm
n electric dipole moment		$<0.29 \times 10^{-25}$ ecm, CL = 90%
$n \to p e^- \overline{\nu}_e$ decay parameters		
ϕ_{AV}, phase of g_A relative to g_V	[c]	$(180.018 \pm 0.026)^\circ$
triple correlation coefficient D	[d]	$(-1.2 \pm 2.0) \times 10^{-4}$
triple correlation coefficient R	[d]	0.008 ± 0.016
Λ electric dipole moment		$<1.5 \times 10^{-16}$ ecm, CL = 95%
triple correlation coefficient D for $\Sigma^- \to n e^- \overline{\nu}_e$		0.11 ± 0.10

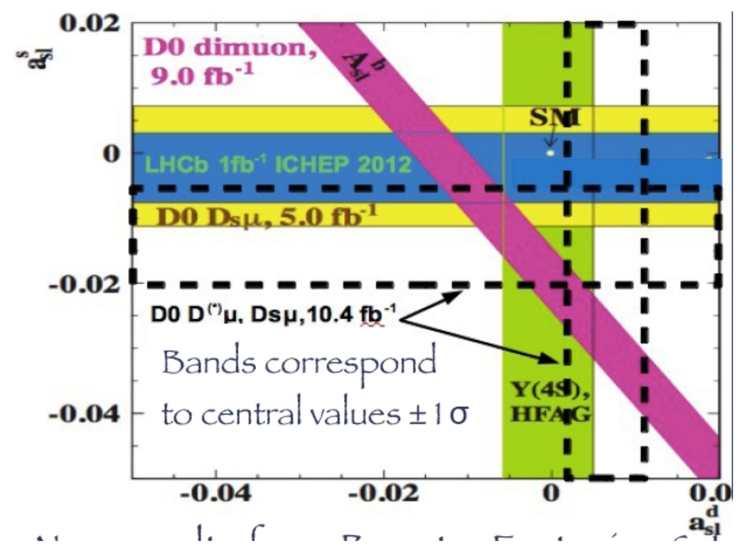
CPLEAR: PLB 444, 43 (1998)
Compares $K^0 \to \overline{K}^0$ with $\overline{K}^0 \to K^0$
Mixing rate.
- Related by T *and* CP.
- Not time-dependent.
- Various criticisms.

BABAR:
PRD(RC)81, 111103 (2010)
PRD(RC) 84, 031103 (2011)
Triple products

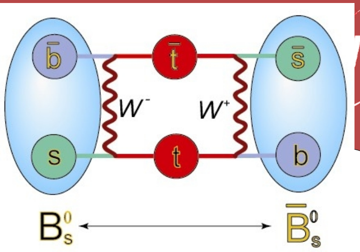
Dilepton Asymmetry @ colliders

- D0 claims large unexpected asymmetry in equal charge dilepton B decays at ICHEP 2010
- Lifetime analysis : effect connected to B_s mixing
- D0 and LHCb then measure asymmetry in the rates of $B_s \to D^{(*)}_s \mu \nu$ decays
- These measurements are consistent both with the SM and with D0 dilepton results





B^0 Mixing parameters



- Two-levels system evolution:

$$i\frac{d}{dt}\begin{pmatrix} B_q \\ \overline{B}_q \end{pmatrix} = \left[\begin{pmatrix} M_{11}^q & M_{21}^{q\,*} \\ M_{21}^q & M_{11}^q \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11}^q & \Gamma_{21}^{q\,*} \\ \Gamma_{21}^q & \Gamma_{11}^q \end{pmatrix}\right]\begin{pmatrix} B_q \\ \overline{B}_q \end{pmatrix}$$

- Mass eigenstates are related to flavor eigenstates by the relation:

$$|B_{L,H}> = \frac{1}{\sqrt{p^2+q^2}}\left(|B^0> \pm \frac{q}{p}|\overline{B}^0>\right)$$

- Where

$$\mathcal{A}_{ll} = \frac{1-|q/p|^4}{1+|q/p|^4} = \frac{\Gamma_{12}}{M_{12}}\sin\phi \qquad \left(\phi = -\mathrm{Arg}\frac{M_{12}}{\Gamma_{12}}\right)$$

- We have:

$$|q/p| = 1-(0.3^{+1.8}_{-2.0})\cdot 10^{-3} \quad \textit{This Measurement}$$

$$|q/p| = 1+(0.2\pm 2.8)\cdot 10^{-3} \quad \textit{Previous W.A.}$$