Recent Flavor Physics results from e^+e^- Colliders

Gabriele Simi
Università di Padova

IFAE – Cagliari 3-5/4/2013

Outline

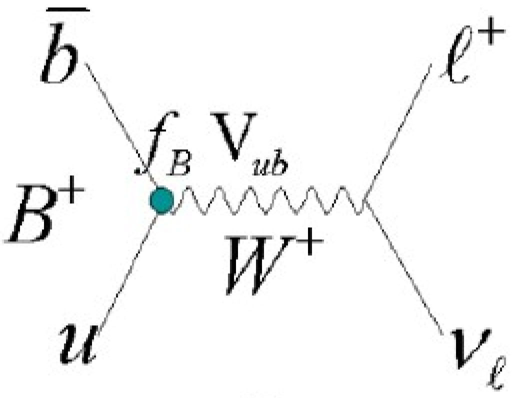
- Belle
  - $B \to \tau\nu$
- BaBar
  - CPV in mixing from $B \to D^* l\nu$ partial reconstruction
  - First observation of time reversal violation
- Perspectives

$B \to \tau\nu$

Motivation

$$\Gamma(B^+ \to \ell^+\nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- helicity-suppressed: $\Gamma(B^+ \to e^+\nu_e) \ll \Gamma(B^+ \to \mu^+\nu_\mu) \ll \Gamma(B^+ \to \tau^+\nu_\tau)$
- very clean place to measure f_B (or V_{ub}?) and/or search for new physics (e.g. H^+, LQ)
- charged boson may take the role of the W



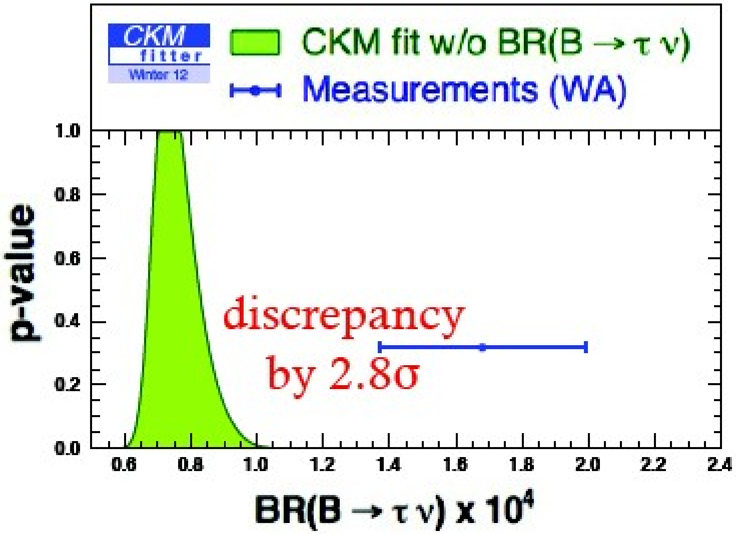
(a)

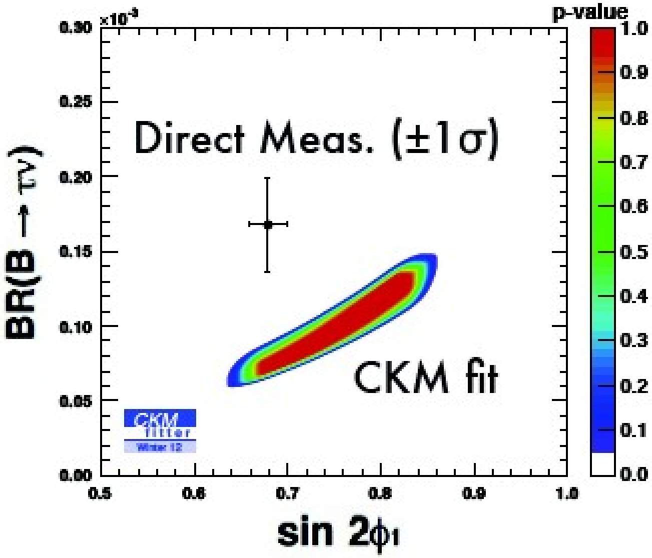
Previous measurement

- e.g. H^+ of 2-Higgs doublet model (type II)[3]:

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \mathcal{B}_{\rm SM}(B^+ \to \tau^+ \nu_\tau) \times r_H$$

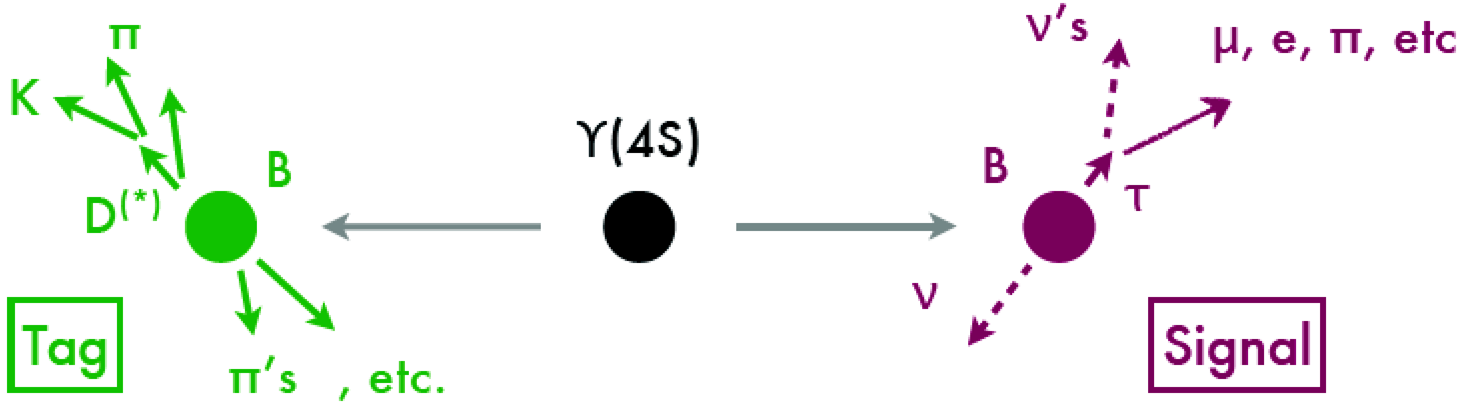
$$r_H = \left[1 - (m_B^2/m_H^2)\tan^2\beta\right]^2$$





3 W.S. Hou, PRD 48, 2342 (1993)

Reconstruction

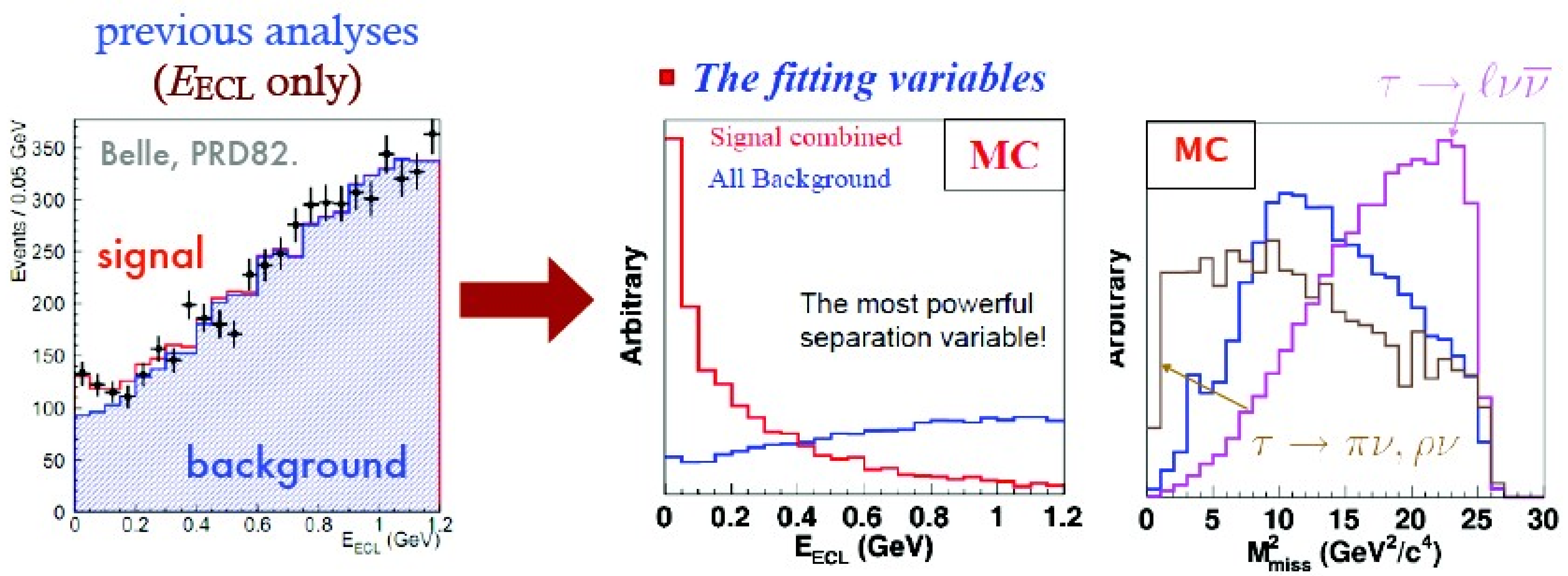


- 2-3 neutrinos in the final state
- full reconstruction tagging (hadronic)

×3 B_{tag} sample size

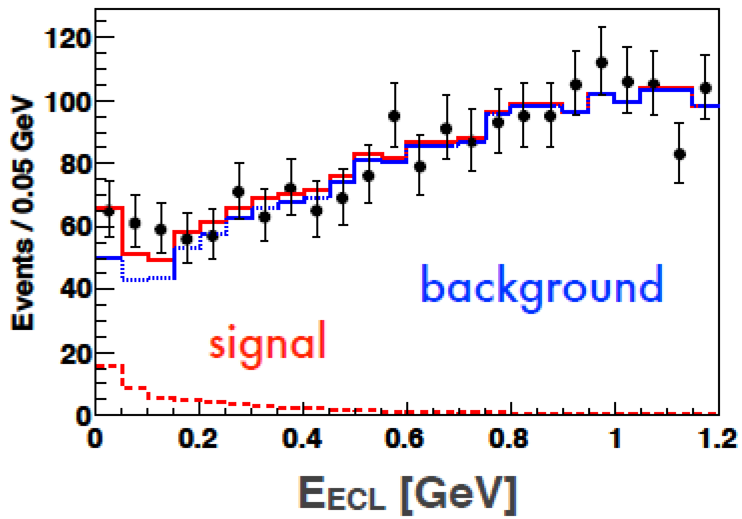
Signal Extraction

- Signal τ modes: $\tau^+ \to e^+\nu_e\overline{\nu}_\tau,\ \mu^+\nu_\mu\overline{\nu}_\tau,\ \pi^+\overline{\nu}_\tau,\ \rho^+\overline{\nu}_\tau$
- 2D fitting to E_{ECL} & M^2_{miss}
  - improve sensitivity by $\sim 20\%$
  - more robust against peaking backgrounds in E_{ECL}

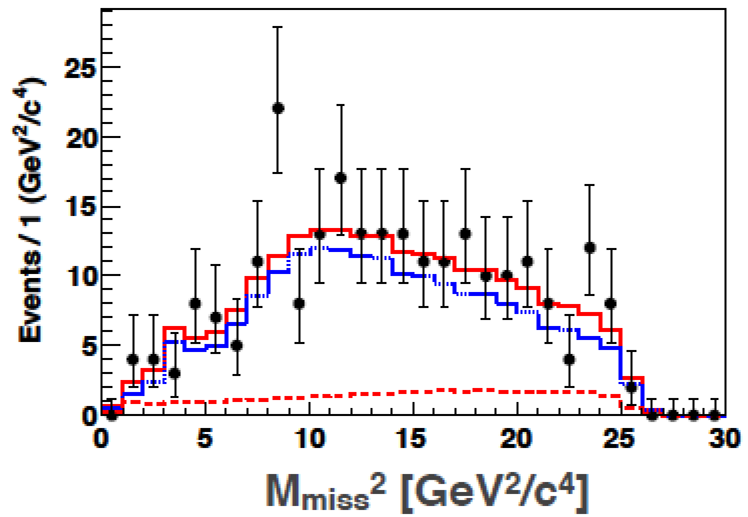


Results

- Simultaneous fit to different τ decay modes
  Figures below shown for the sum of different τ decay modes



(Projection for all M_{miss}^2 region.)

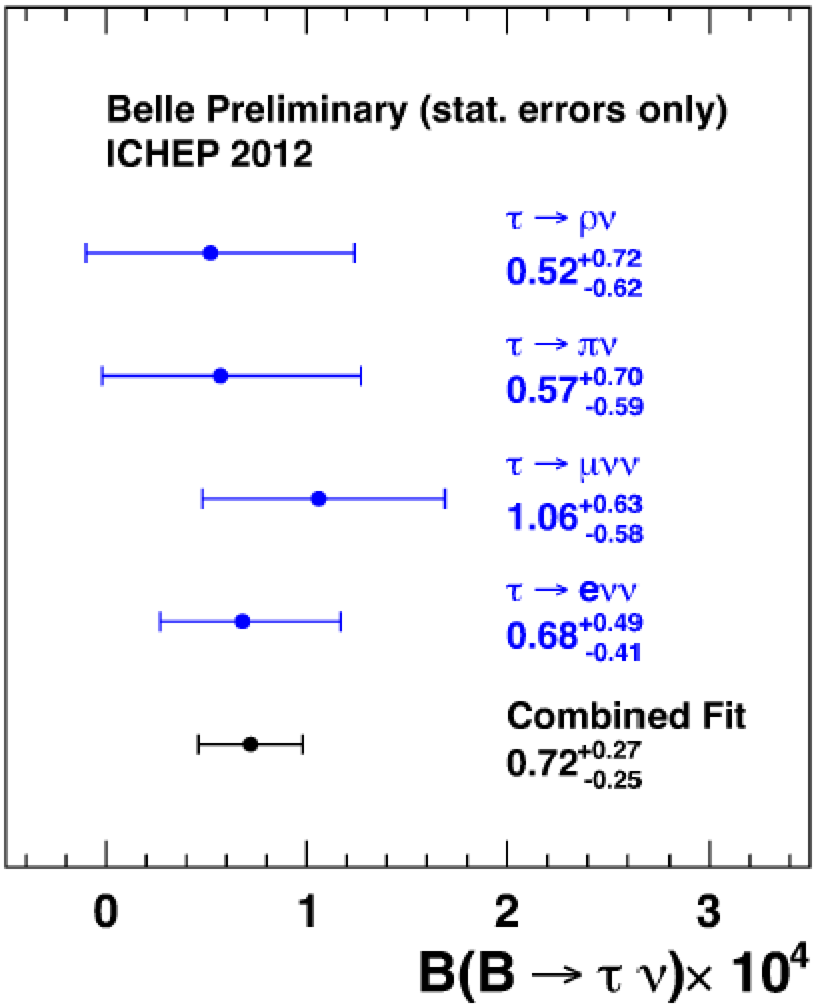


(Projection for E_{ECL} < 0.2 GeV)

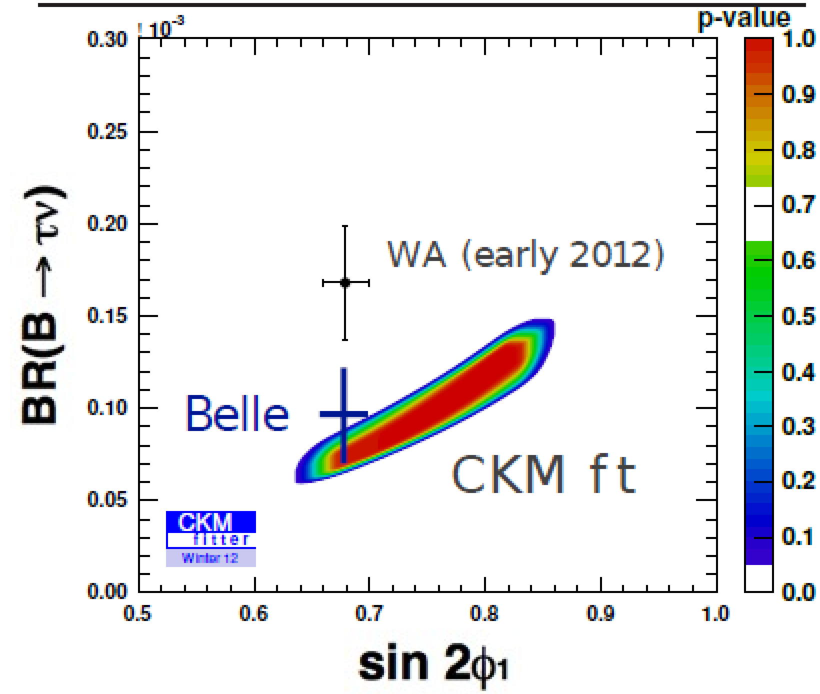
- Signal yield: $62^{+23}_{-22} \pm 6$ significance = 3.0σ incl. systematic error
- $\mathcal{B}(B^+ \to \tau^+\nu_\tau) = \left(0.72^{+0.27}_{-0.25} \pm 0.11\right) \times 10^{-4}$ arXiv:1208.4678, *to appear in PRL*

Results

- consistency over all τ decay modes



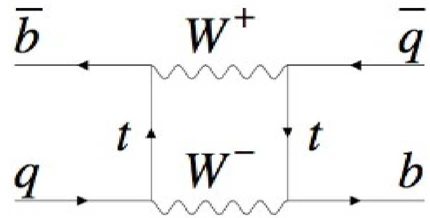
Sub-mode	N_{sig}	(10^{-4})	$B\ (10^{-4})$
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$	16^{+11}_{-9}	3.0	$0.68^{+0.49}_{-0.41}$
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$	26^{+15}_{-14}	3.1	$1.06^{+0.63}_{-0.58}$
$\tau^- \rightarrow \pi^- \nu_\tau$	8^{+10}_{-8}	1.8	$0.57^{+0.70}_{-0.59}$
$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$	14^{+19}_{-16}	3.4	$0.52^{+0.72}_{-0.62}$
Combined	62^{+23}_{-22}	11.2	$0.72^{+0.27}_{-0.25}$

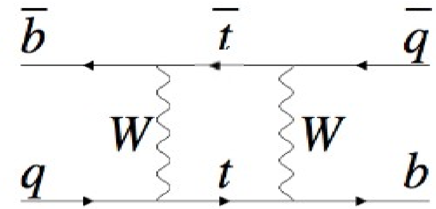


CPV in mixing from $B \rightarrow D^* l \nu$

CPV in B^0 Mixing

- Mixing $B^0\bar{B}^0$ originates from box diagram





$$A_{CP}=\frac{Prob(\bar{B}^0\to B^0,t)-Prob(B^0\to\bar{B}^0,t)}{Prob(\bar{B}^0\to B^0,t)+Prob(B^0\to\bar{B}^0,t)}$$

- In Y4S decays B produced in entangled state ($B^0\bar{B}^0$-$\bar{B}^0B^0$)
- A_{CP} measured experimentally as

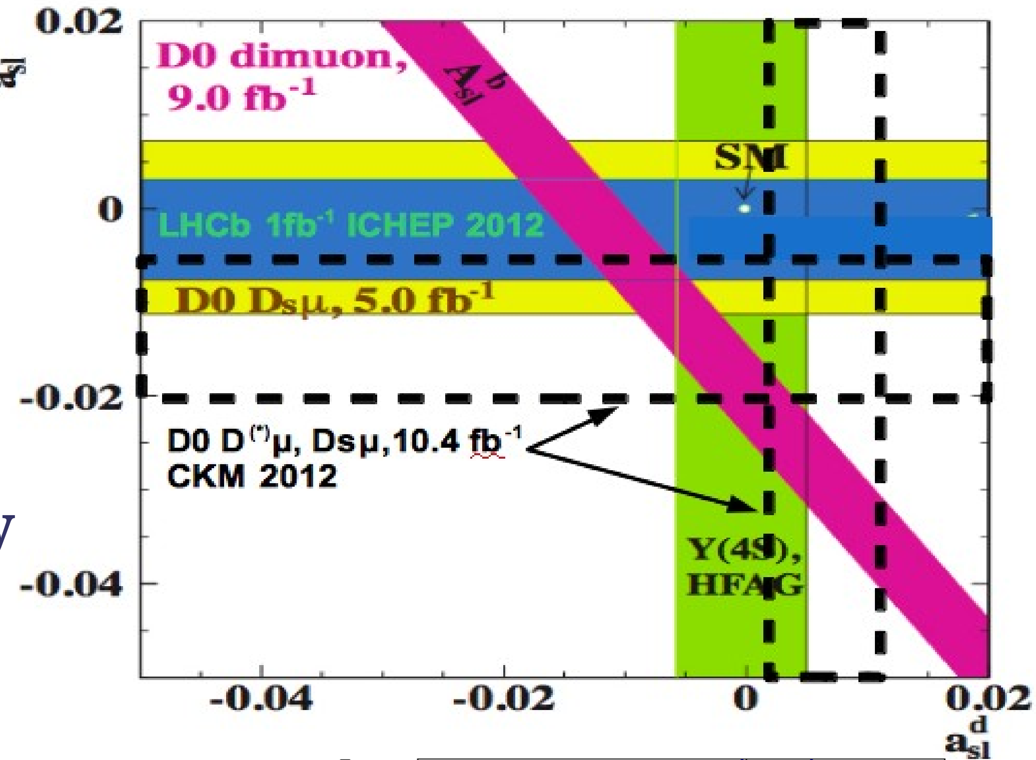
$$A_{SL}=\frac{N(l^+l^+)-N(l^-l^-)}{N(l^+l^+)+N(l^-l^-)}=\frac{1-|q/p|^4}{1+|q/p|^4}=\frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\Phi\simeq 2(1-|q/p|)$$

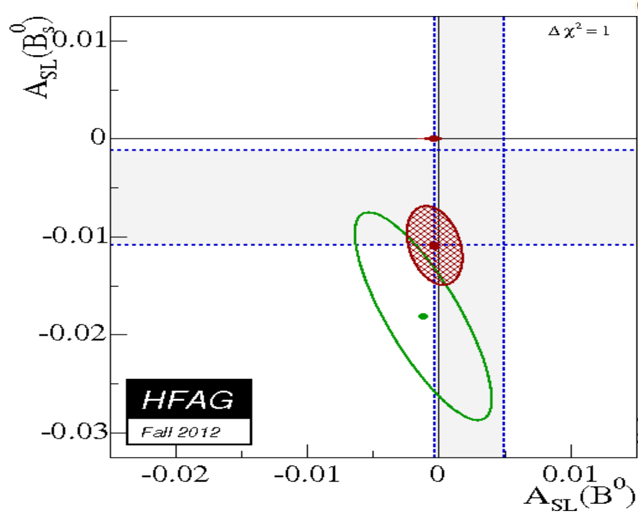
- SM prediction very small (Lenz, Nierste, arXiv:1102.4274 (2011))
  - B_d: A^d_{SL}= (-4.1±0.6)10^{-4} Φ_d=-4.3º±1.4º; B_s: A^s_{SL}=(1.9±0.3)10^{-5} Φ_s=0.22º±0.06º
- Hadron colliders measure a combination of B^0_d and B^0_s predicted to be
  - $A^b_{SL}=C_dA^d_{SL}+C^sA^s_{SL}=A^b_{SL}$=(-0.028+/-0.006)%

CPV in B^0 mixing

- HFAG average of Υ(4S) results (arXiv:1207.1158v1 (2011)):
  - $|q/p|_d$=1.0002±0.0028
  - A^d_{SL} = (-0.05±0.56)%
  - **In agreement with SM**
- **D0 result on charge Asymmetry of like-sign dimuons differs by 3.9 σ from SM expectation (Phys. Rev. D 84, 052007 (2011)):**

A^b_{SL}=(-0.787±0.172±0.093)%





Analysis Method

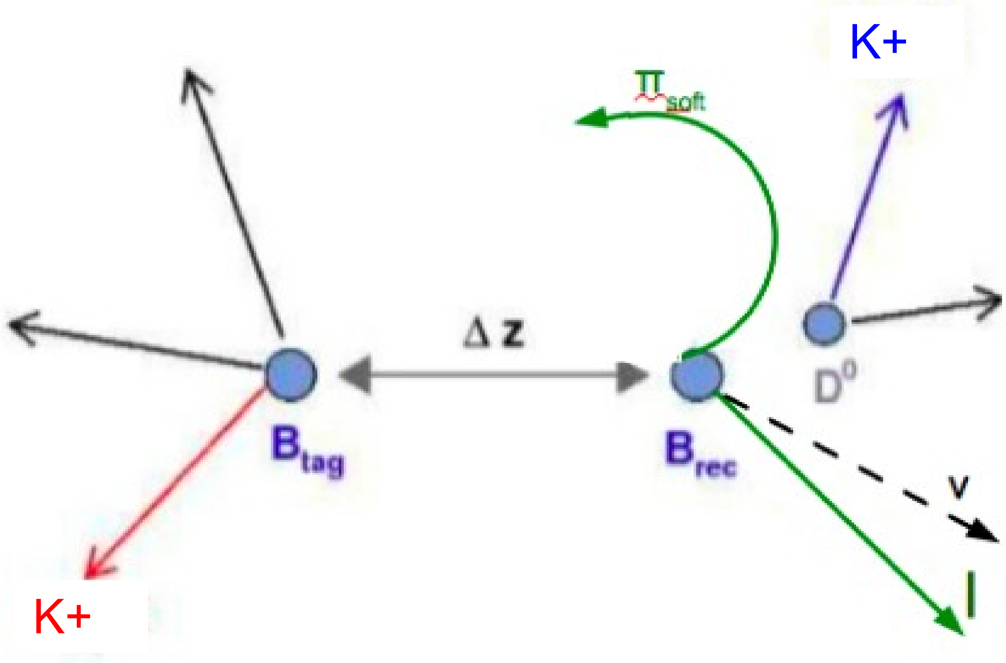
- Partial reconstruction of B→D*lν + new approach
  - Tag the flavor using Kaon
  - b->K- + b->c->K-
  - $\bar{b}$->$\bar{D}$->K+

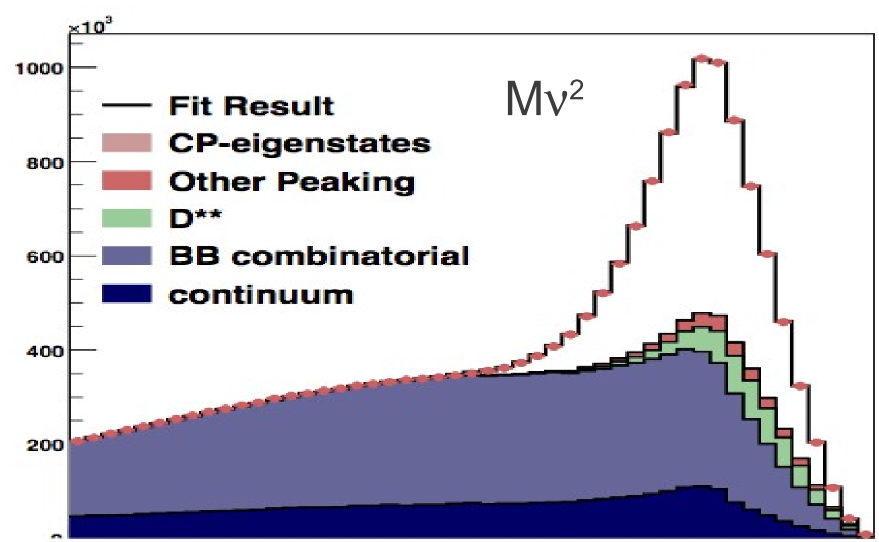
$$A_{SL}=\frac{N(l^+K^+)-N(l^-K^-)}{N(l^+K^+)+N(l^-K^-)}$$

- Signal extraction from fit to

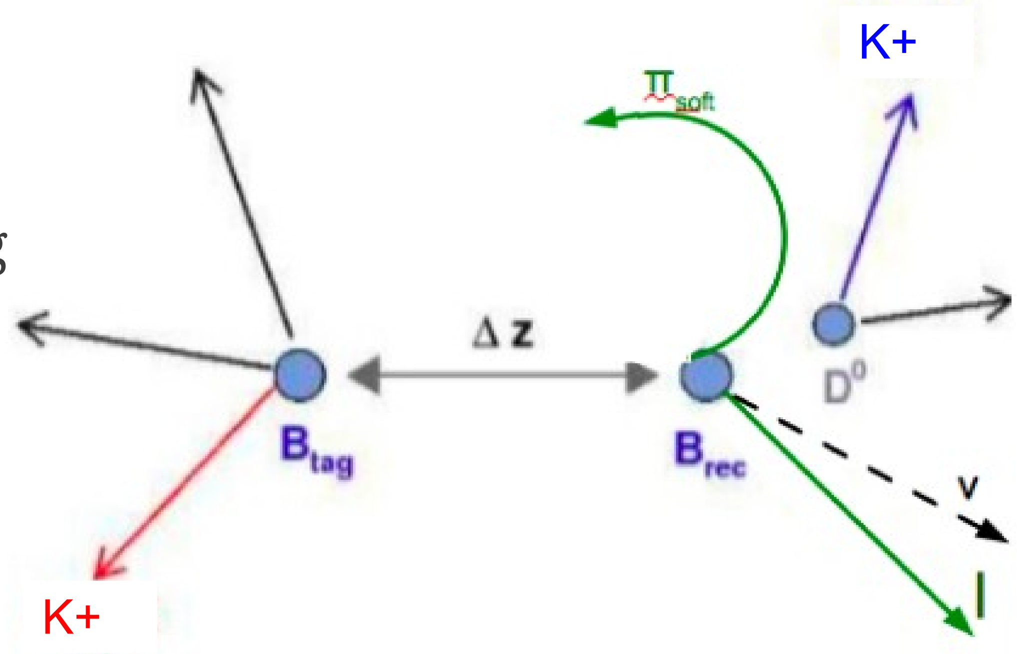
$$\mathcal{M}_\nu{}^2 \equiv (E_{beam} - E_{D^*} - E_\ell)^2 - (\vec{p}_{D^*} + \vec{p}_\ell)^2$$

- D* 4-momentum from π_{soft} kinematics





- Equal charge kaons from the reco side mimicking a mixed event can be distinguished using Δz and the angle θ_{lk} between the lepton and the kaon
- Information exploited to disentangle detector asymmetry from physical asymmetry without relying on different control samples
- Arec=lπ reco asymm
- Atag=K reco asymm



	B0	B+
Single lepton	Arec + Asl*χ_d	Arec
Kaon from tag side	Arec + Atag(P_K) +Asl	Arec + Atag(P_K)
Kaon from rec side	Arec + Atag(P_K) +Asl*χ_d	Arec + Atag(P_K)

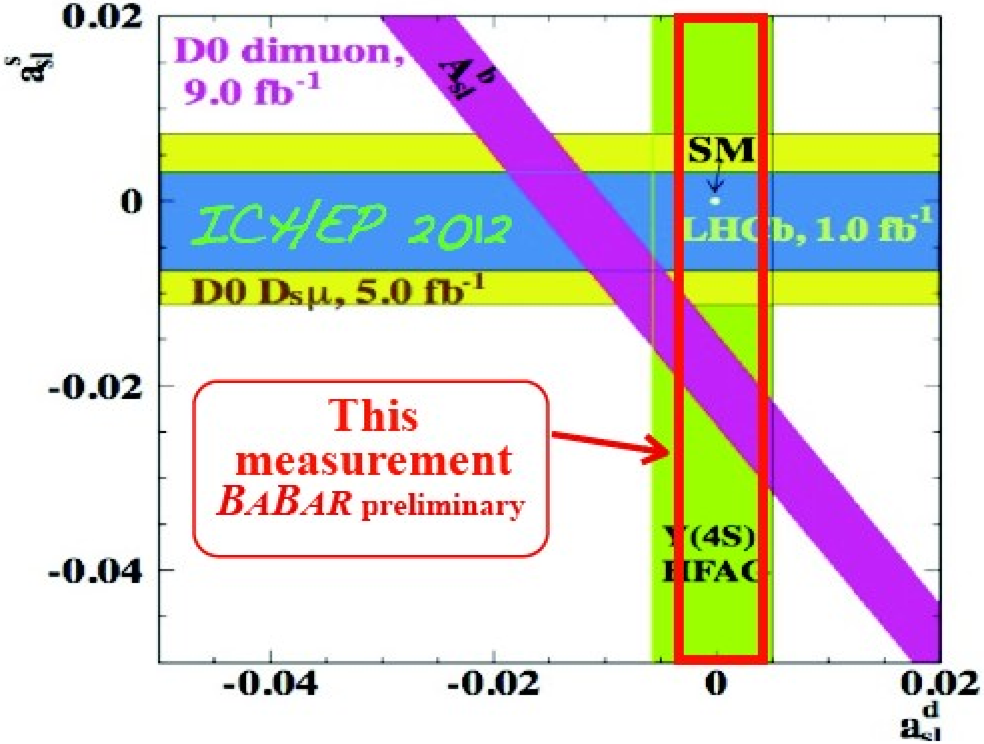
Results

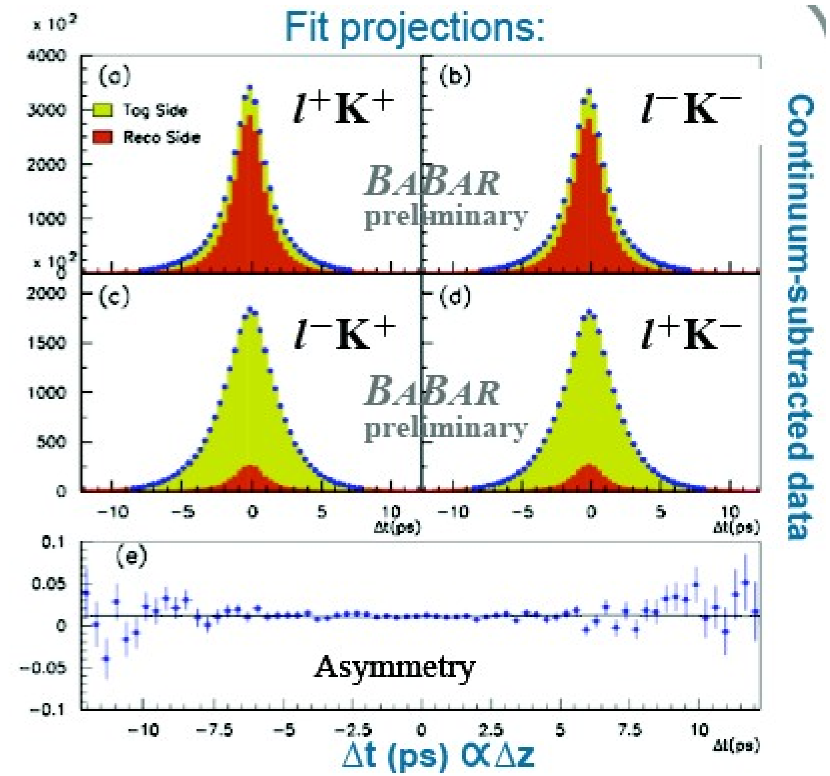
- **Asymmetry parameters:**

BABAR preliminary

$$\mathcal{A}_{CP} = (0.06 \pm 0.17^{+0.36}_{-0.32})\%$$

$$1 - |q/p| = (0.29 \pm 0.84^{+1.78}_{-1.61}) \times 10^{-3}$$





- **Consistent with HFAG average**
- **Consistent with SM expectations**
- **Single most precise measurement**
- **Expect more results from Belle & LHCb**

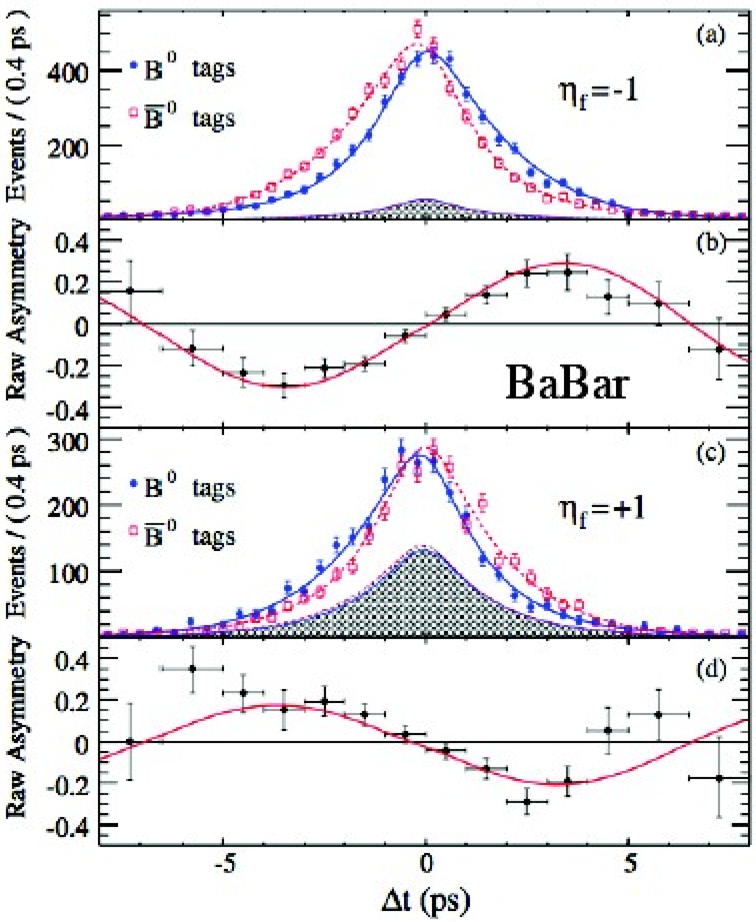
Time Reversal Violation

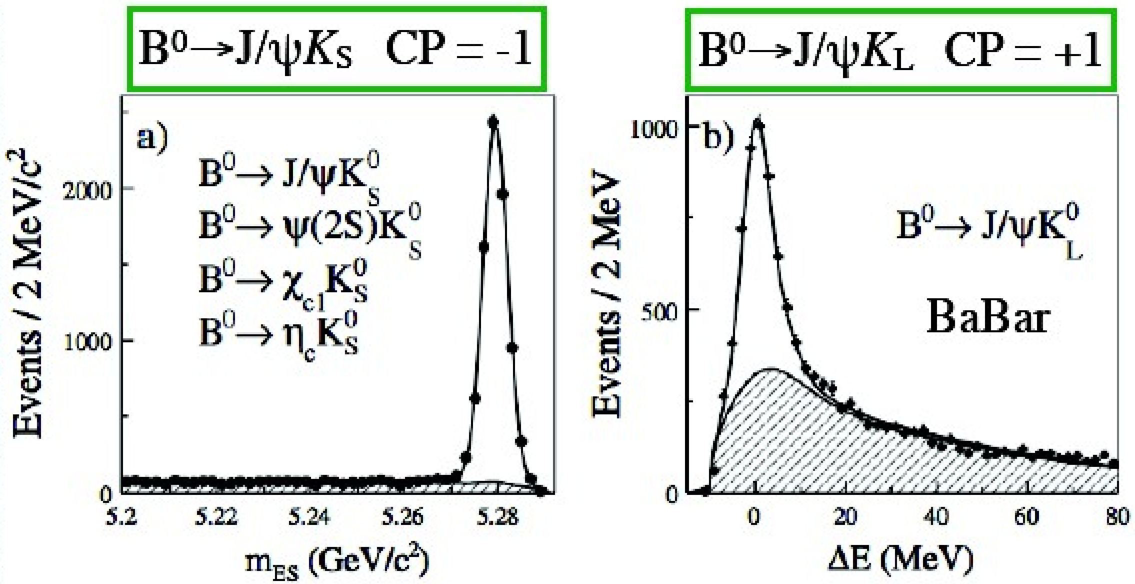
Time reversal violation and CPT

- CP violation is observed in B and K mesons decays
- No violation of CPT is observed
- CPT is also a fundamental requirement of quantum field theories
- To conserve CPT, CP violation requires T violation
- In B decays CP violation is large, can we measure a large T violation?

CP Violation

- CP violation was measured precisely using b->ccs transitions





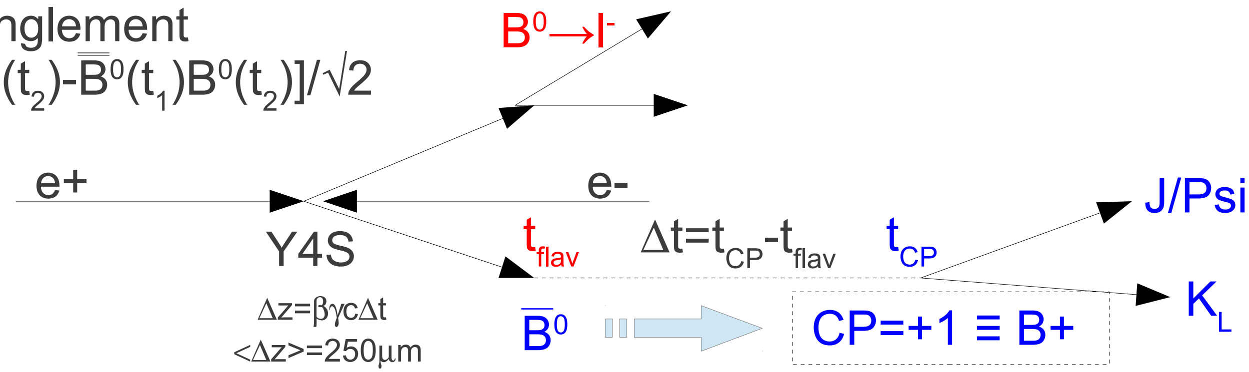
$$g_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{(1 \mp \Delta w) \pm (1-2w)$$
$$\times [S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)]\}$$

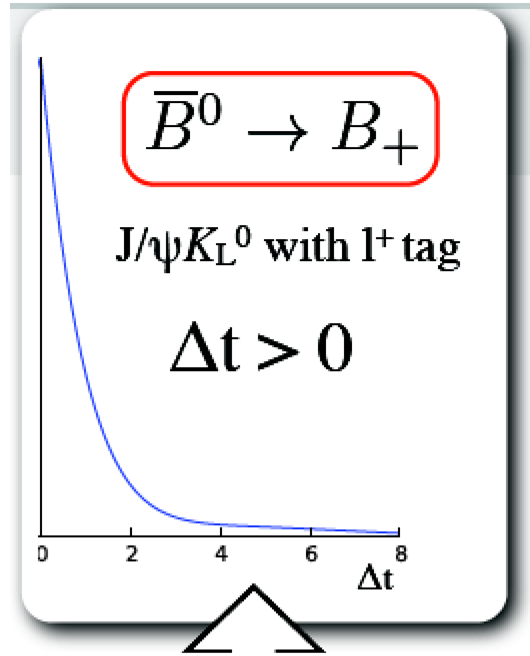
M.C.Bañuls, J. Bernabéu, Phys. Lett. B 464, 117 (1999)

Time reversal

Flavor entanglement

$|i\rangle=[B^0(t_1)\overline{B}^0(t_2)-\overline{B}^0(t_1)B^0(t_2)]/\sqrt{2}$

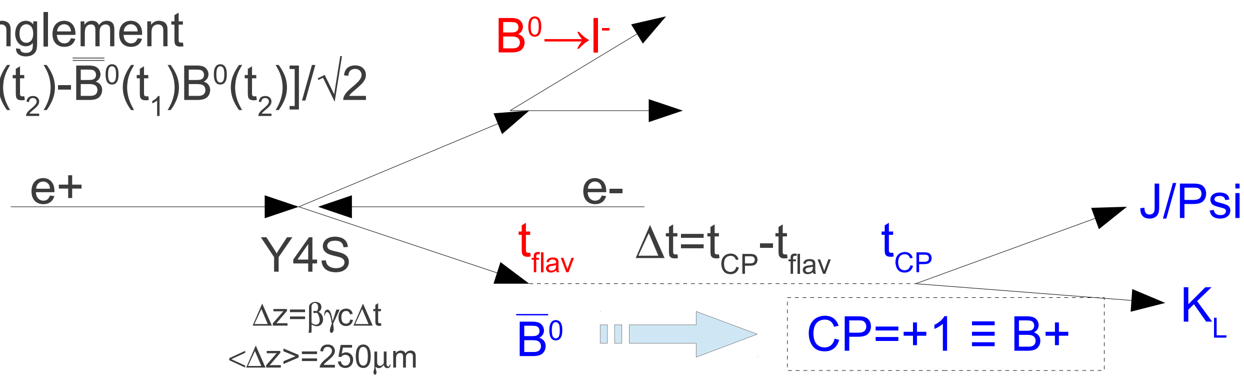




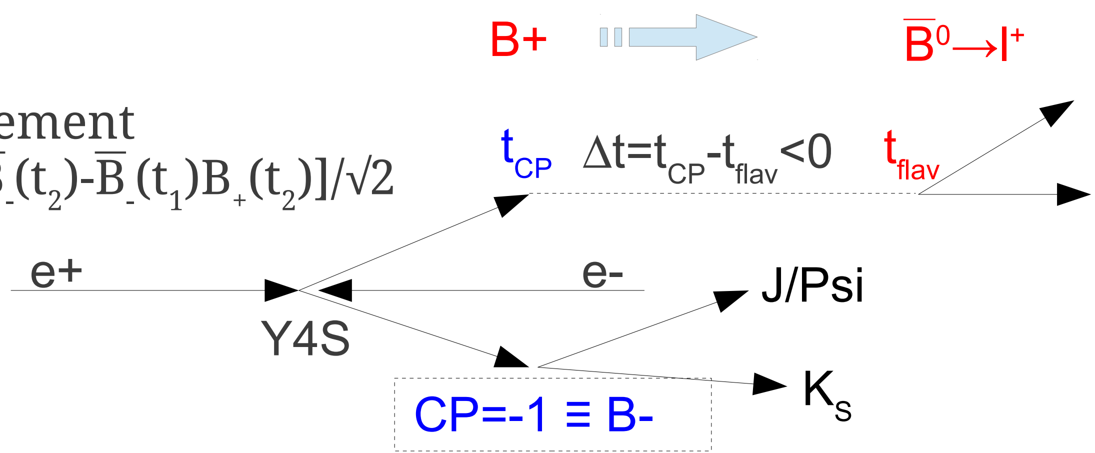
M.C.Bañuls, J. Bernabéu, Phys. Lett. B 464, 117 (1999)

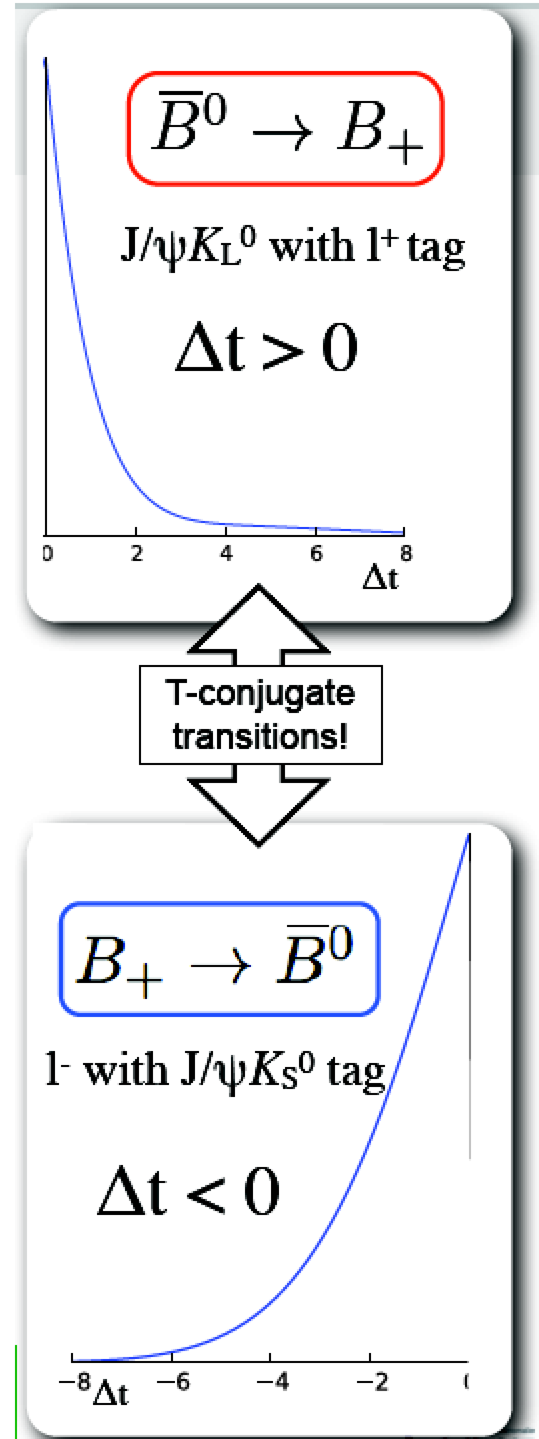
Time reversal

Flavor entanglement
$|i\rangle=[B^0(t_1)\overline{B}^0(t_2)-\overline{B}^0(t_1)B^0(t_2)]/\sqrt{2}$



CP entanglement
$|i\rangle=[B_+(t_1)\overline{B}_-(t_2)-\overline{B}_-(t_1)B_+(t_2)]/\sqrt{2}$





Reference (X,Y)		T-Transformed	
$B^0 \to B_+$	$(\ell^-, J/\psi K^0_L)$	$B_+ \to B^0$	$(J/\psi K^0_S, \ell^+)$
$B^0 \to B_-$	$(\ell^-, J/\psi K^0_S)$	$B_- \to B^0$	$(J/\psi K^0_L, \ell^+)$
$\overline{B}^0 \to B_+$	$(\ell^+, J/\psi K^0_L)$	$B_+ \to \overline{B}^0$	$(J/\psi K^0_S, \ell^-)$
$\overline{B}^0 \to B_-$	$(\ell^+, J/\psi K^0_S)$	$B_- \to \overline{B}^0$	$(J/\psi K^0_L, \ell^-)$

(X,Y) is the reconstructed final states (tag, reco.)

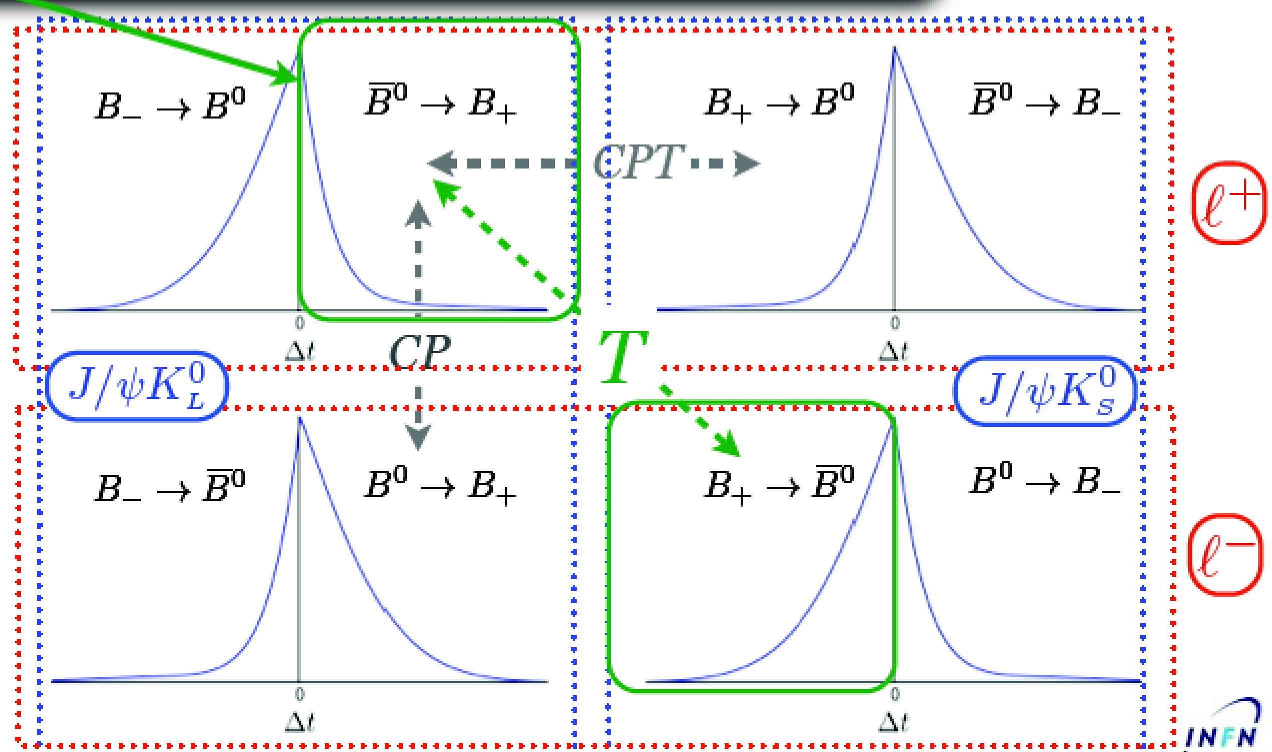
...and similar for CP, CPT

In total we can build:

- 4 independent T comparisons
- 4 independent CP comparisons
- 4 independent CPT comparisons

T implies comparison of:

1) Opposite Δt sign
2) Different reco states (ψK_S v. ψK_L)
3) Opposite flavor states (B^0 v. $\overline{B}^0$)



Fit Parameters

8 Signal PDFs (assuming ΔΓ=0):

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

Mistag dilutes the S, C parameters by a factor of (1-2w)

$\alpha \in \{B^0,\ \overline{B}^0\};$

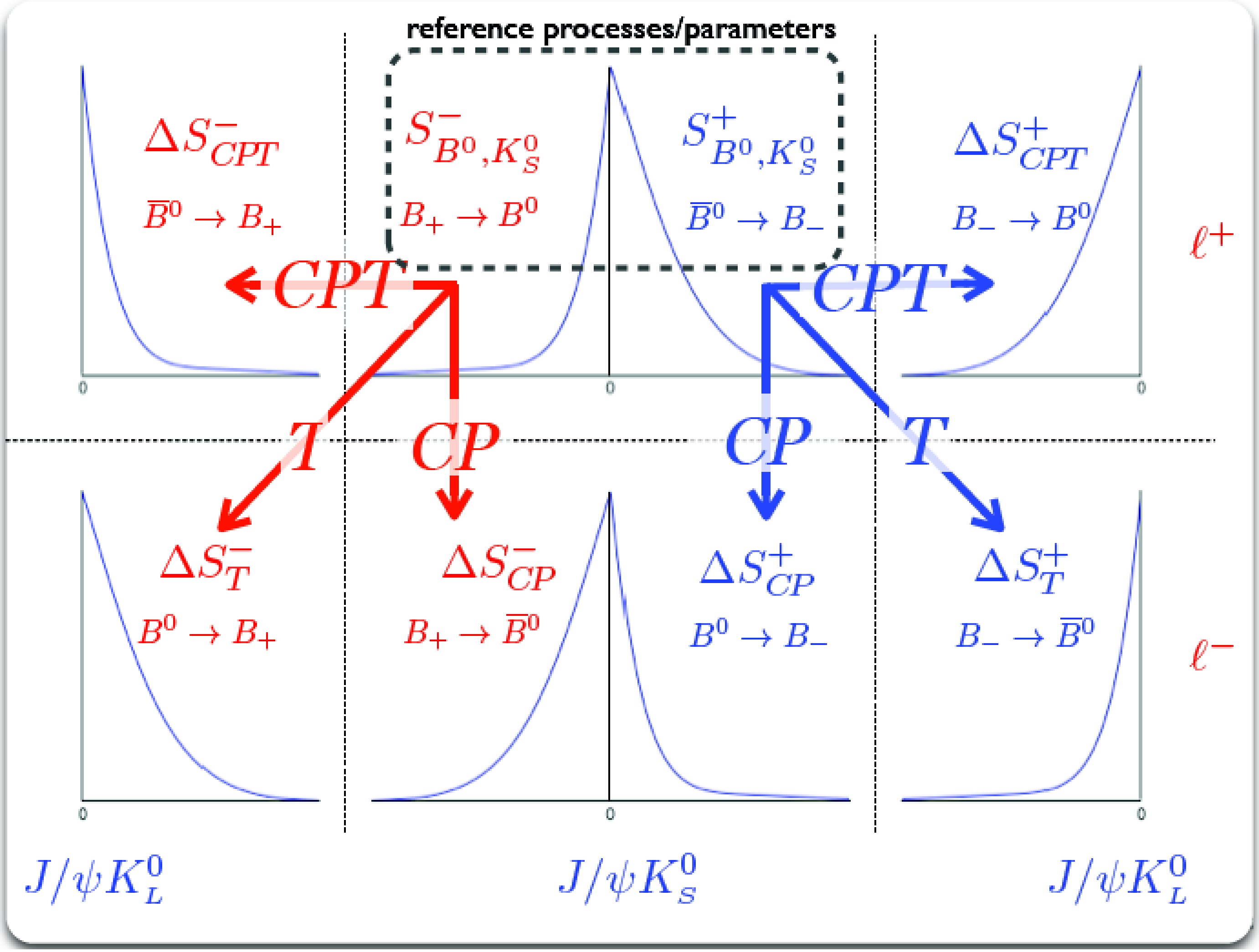
$\beta \in \{K^0_S,\ K^0_L\}$

$\tau = \pm\Delta t > 0$

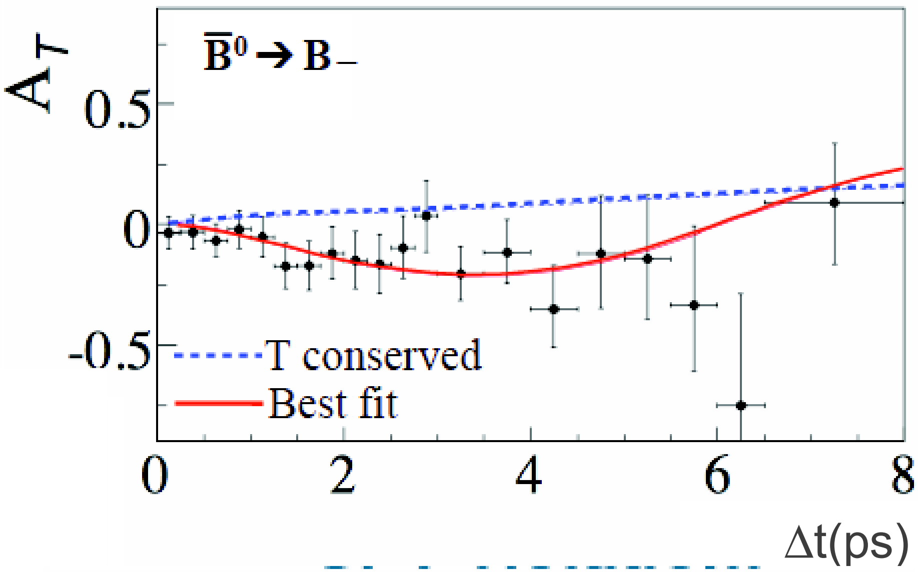
For T Violation

in the interference $\Delta S^+_T \neq 0$, $\Delta S^-_T \neq 0$

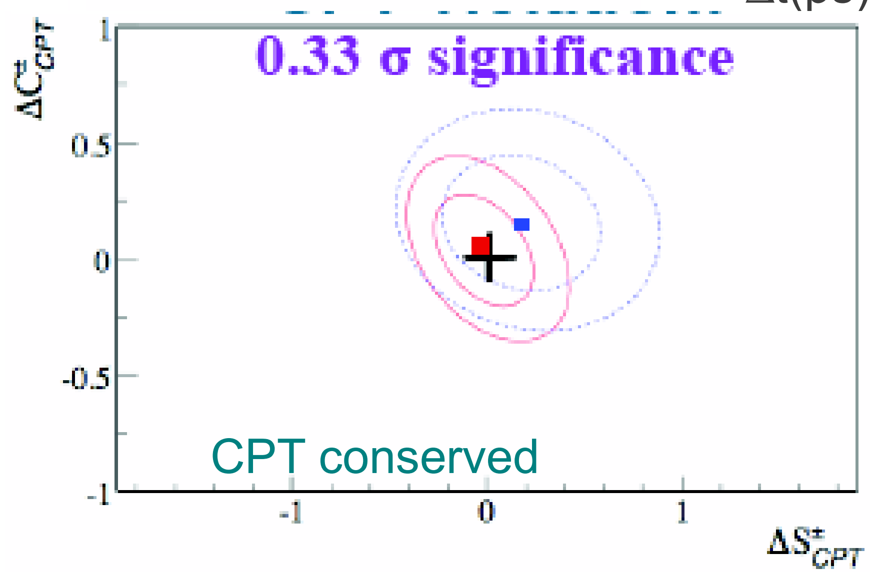
in the decay $\Delta C^+_T \neq 0$, $\Delta C^-_T \neq 0$



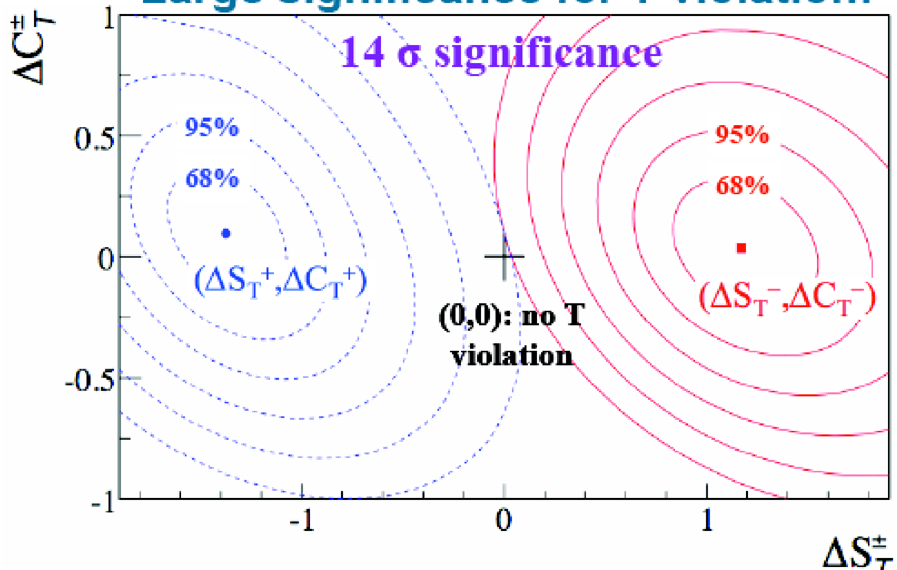
Time Reversal Results



	SM Expected
$\Delta S_T^+ = S^-_{\ell-,K_L^0} - S^+_{\ell+,K_S^0} = -1.37 \pm 0.14 \pm 0.06$	-2sin(2β)
$\Delta S_T^- = S^+_{\ell-,K_L^0} - S^-_{\ell+,K_S^0} = 1.17 \pm 0.18 \pm 0.11$	2sin(2β)
$\Delta C_T^+ = C^-_{\ell-,K_L^0} - C^+_{\ell+,K_S^0} = 0.10 \pm 0.14 \pm 0.08$	0
$\Delta C_T^- = C^+_{\ell-,K_L^0} - C^-_{\ell+,K_S^0} = 0.04 \pm 0.14 \pm 0.08$	0



Large significance for T violation:



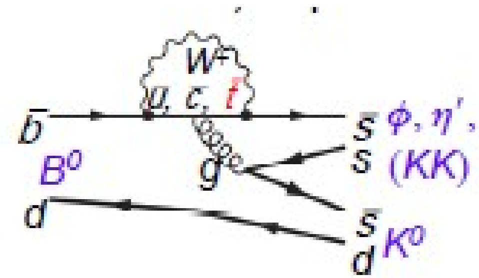
Perspective

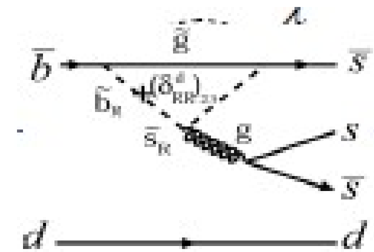
Taking BaBar and Belle one step further

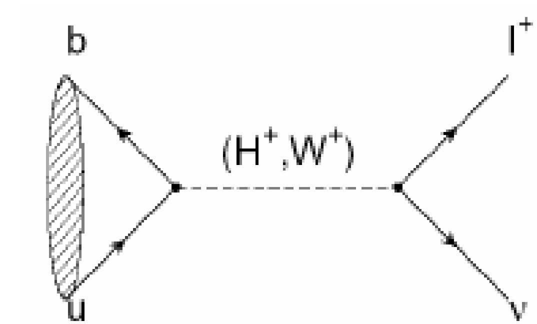
- Why is the weak scale and the Higgs mass so different from the Planck mass ?
- Quantum stabilization of the EW scale suggests that new physics (new particles) is expected at a scale of 1TeV
- One approach is to increase the energy frontier and produce directly the new particles
- A complementary approach is to study the flavor sector with increased precision to measure “virtual” effects

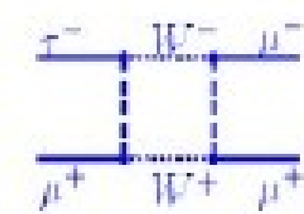
NP sensitive processes

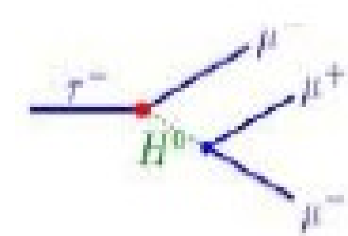
- CP violation in b->s penguin
- B->sγ
- B->τν
- τ-> μγ, lll
- D decays: CP Violation in charm sector

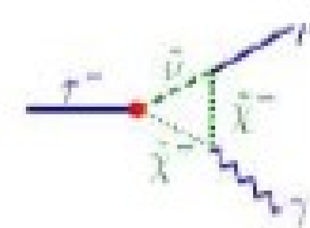






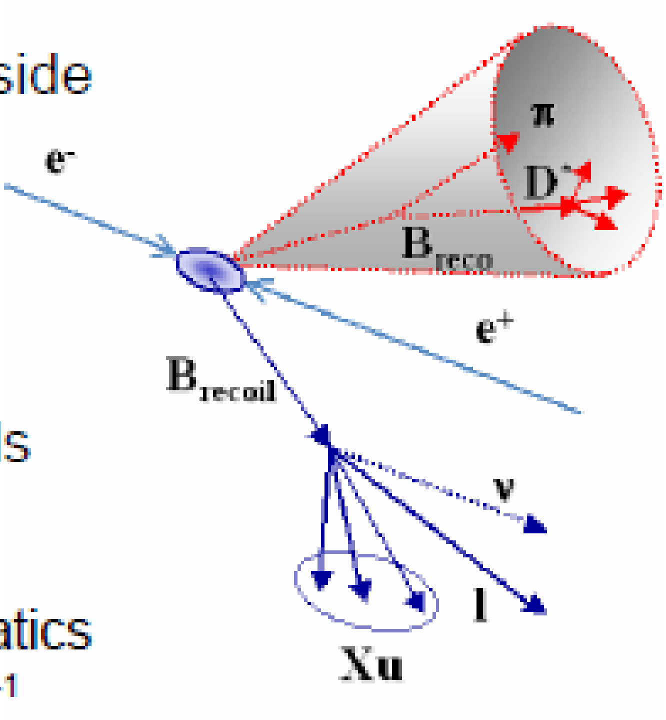






The B-recoil method

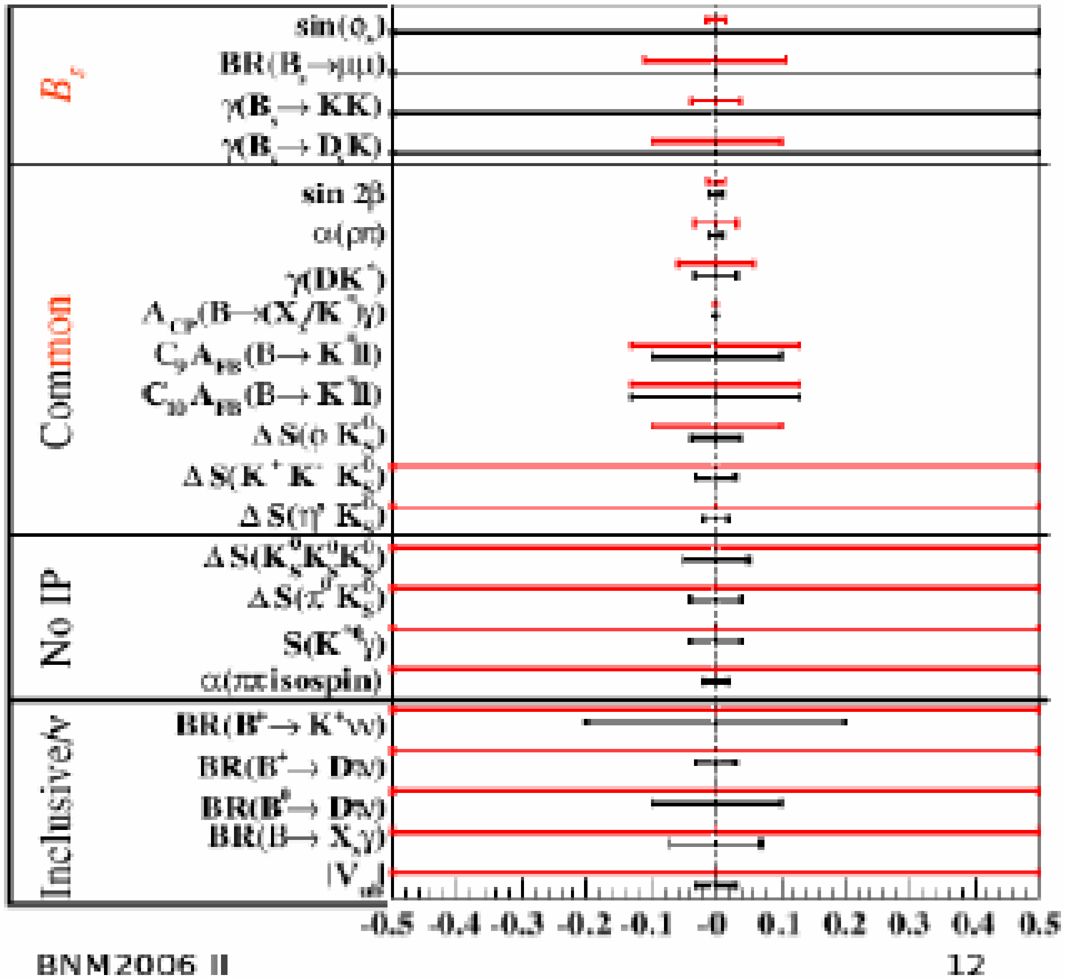
- A technique already used at the *B* factories
  - exploit clean environment at e^+e^- collider and quantum correlation of $\Upsilon(4S) \to B\bar{B}$
- Fully reconstruct one the two *B*'s in hadronic modes
- Obtain a high purity *B* beam on the opposite side
  - (almost) completely eliminate continuum background
  - *B* tracks already assigned
    - much reduced combinatorics in recoil
  - known kinematics, charge and flavour
- *Unique tool* to study rare decays and channels with missing energy
  - few per mille efficiency
  - trade loss in statistics with reduction in systematics
  - perfect tool for SuperB: > 10^7 recoil Bs in $10 ab^{-1}$
  - V_{ub}, $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$, $b \to s\gamma$ ...



Belle II vs LHCb

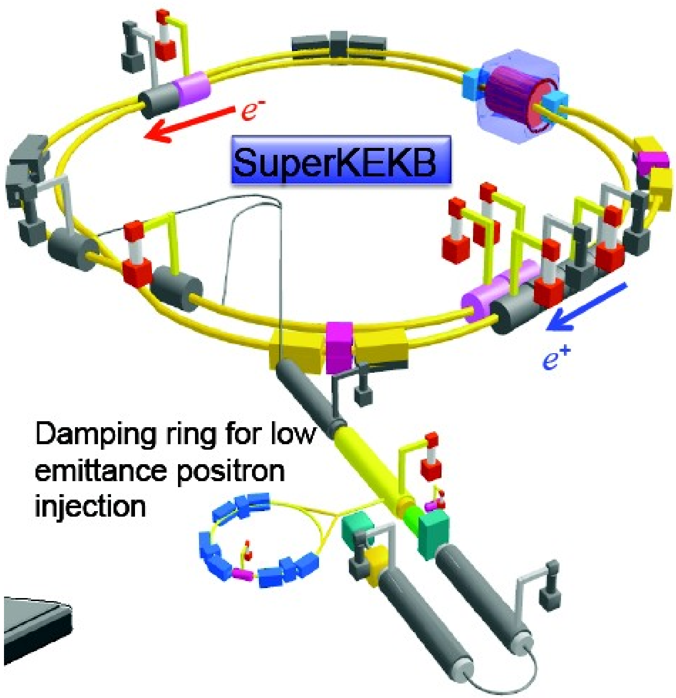
SuperB (3 years, 50 ab^{-1}) and LHCb (5 year, 10 fb^{-1})

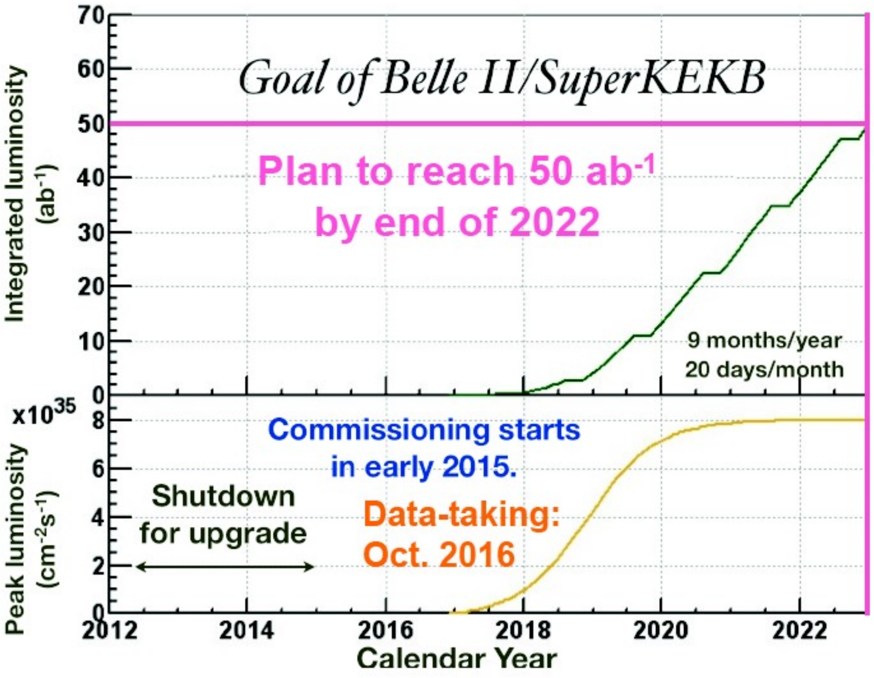
- SuperB
  - has no handle on B_s time-dependent measurements
  - is much better in modes with neutrals
  - has no competition in channels with missing energy
- Programs are largely complementary



Accelerator

- After cancellation of the SuperB project the future for an e+e- accelerator in Italy is not well defined. A workshop on a tau-charm factory will be held in May
- The Belle II project is going forward according to the schedule





Conclusions

- New approach to measure CP Violation in mixing. Most precise measurement of $|q/p|$ consistent with SM
- First direct observation of Time Reversal violation. Results are consistent with expectation from CP violation and CPT conservation
- New $B \rightarrow \tau\nu$ result consistent with the CKM fit
- Perspective for high precision measurements complementary to high energy frontier and to LHCb