B factories: present and future

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on behalf of the BABAR Collaboration

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B factories: 15 years of success

- Established CP violation in B system and measurement of the CKM parameters
- Observation of direct CPV in B decays
- Searches for new CP violation sources in B, D and τ decays
- Search for New Physics (NP) in rare decays
  - $B \to X_{s,d}\,\gamma$, $B \to X_{s,d}\,l^+l^-$, $B \to K^{(*)}\nu\nu$, $B \to \tau\nu$, $B \to D^{(*)}\,\tau\nu$, $B \to$ invisible, …
- Observation of direct Time Reversal violation

topics covered
in this talk

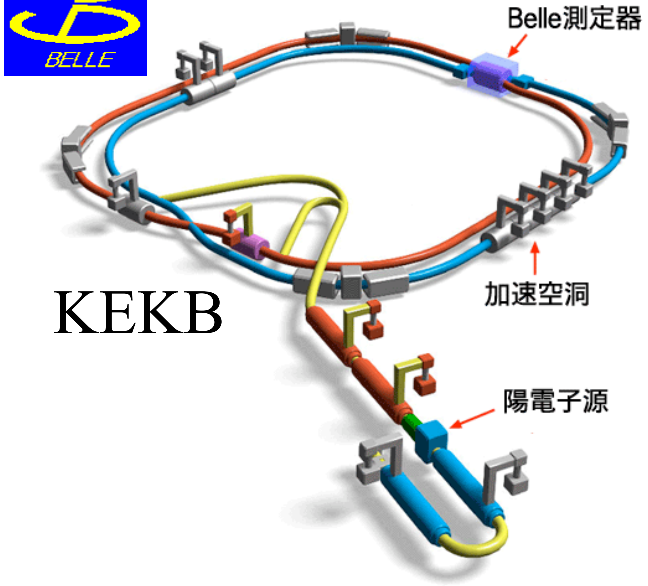
- Explore the region above the Υ(4S) and study of B_s decays at the Υ(5S)
- Discovery of several bottomonium (including η_b) and bottomonium-like states

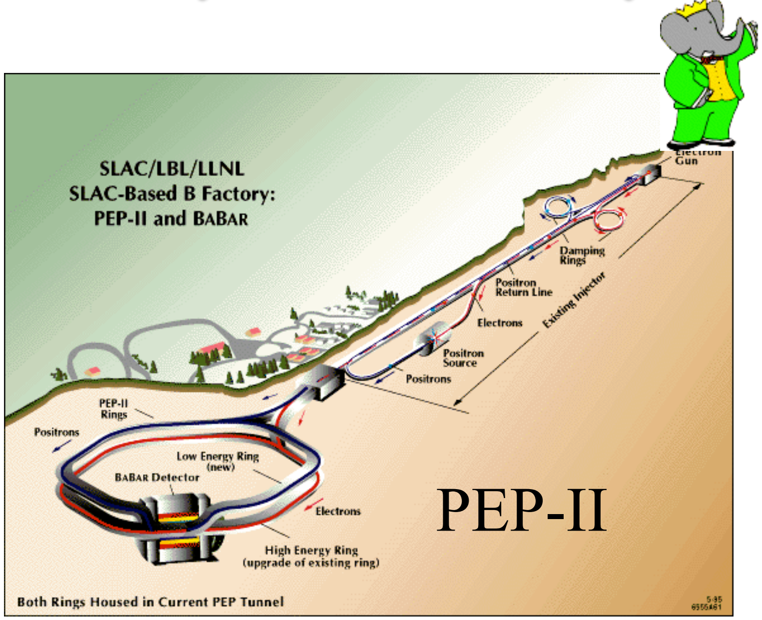
- Observation of D^0-D^0bar mixing
- Discovery of unexpected states in charmed mesons and charmonium-like spectra
- Search for Lepton Flavor Violation (LFV) in τ and B decays

- Precise measurement of the hadronic contributions to the muon (g-2)
- Searches for low mass New Physics (NP) particles (light CP-odd Higgs, dark photons)
- Searches for heavy neutrinos in B decays
- …..

The colliders

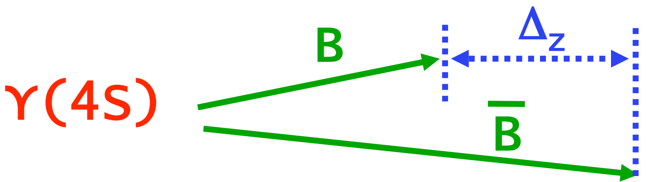
Asymmetric-energy B factories => Flavor Physics at the intensity frontier





$\sqrt{s} \cong m(\Upsilon(4S))=10.58$ GeV

PEP-II/BaBar	e^-: 9 GeV,	e^+: 3.1 GeV,	$\beta\gamma=0.56$
KEKB/Belle	e^-: 8 GeV,	e^+: 3.5 GeV,	$\beta\gamma=0.42$



$\Delta_z \sim c\beta\gamma t_B$

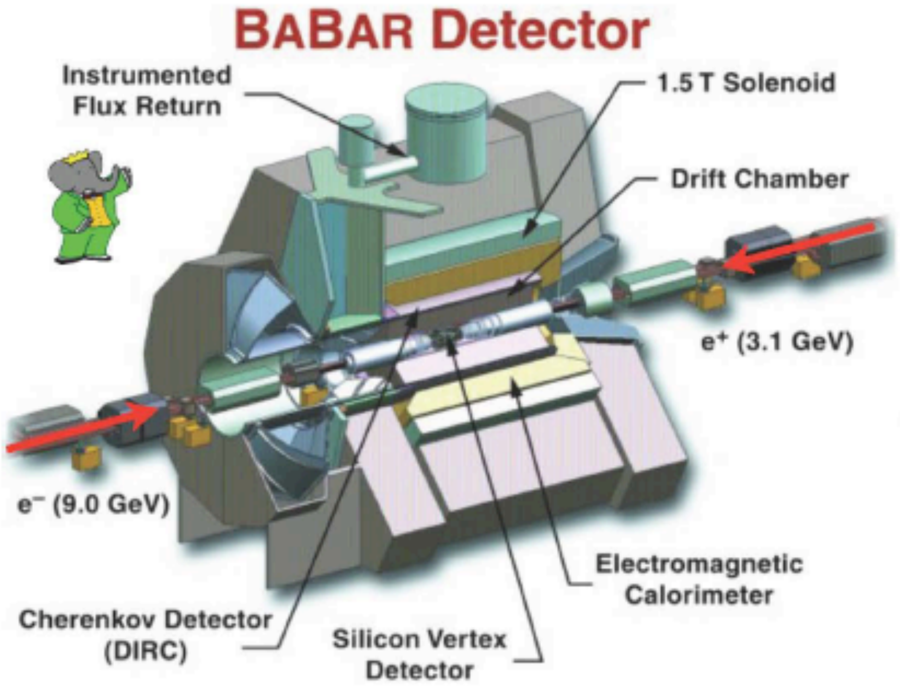
$\sim 200\mu m$

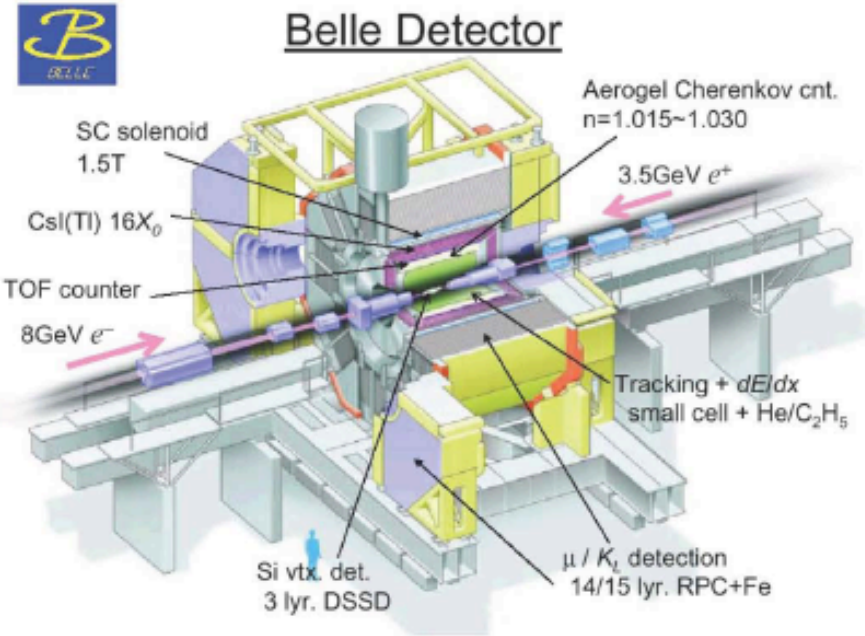
Integrated Luminosity
- Belle: >1000 fb^{-1}
- *BABAR*: ~550 fb^{-1}

mainly at the Υ(4S), but also at Υ(1,2,3,5S) and in the continuum

The detectors

- Asymmetric beam energies to measure *B*-meson decay times
- Tracking & vertexing
- Cherenkov-based particle ID
- EM calorimeter
- μ/K_L system.





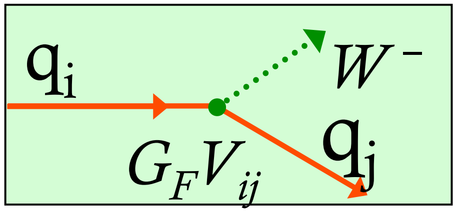
CP violation
and the
CKM Matrix

The Cabibbo-Kobayashi-Maskawa (CKM) matrix

$$V_{CKM} = \begin{array}{cc} & \begin{array}{ccc} \quad d \quad & \quad\quad s \quad\quad & \quad b \quad \end{array} \\ \begin{array}{c} u \\ c \\ t \end{array} & \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \end{array} + O(\lambda^4)$$

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2+|V_{us}|^2}; \quad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2+|V_{us}|^2}; \quad \bar{\rho}+i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

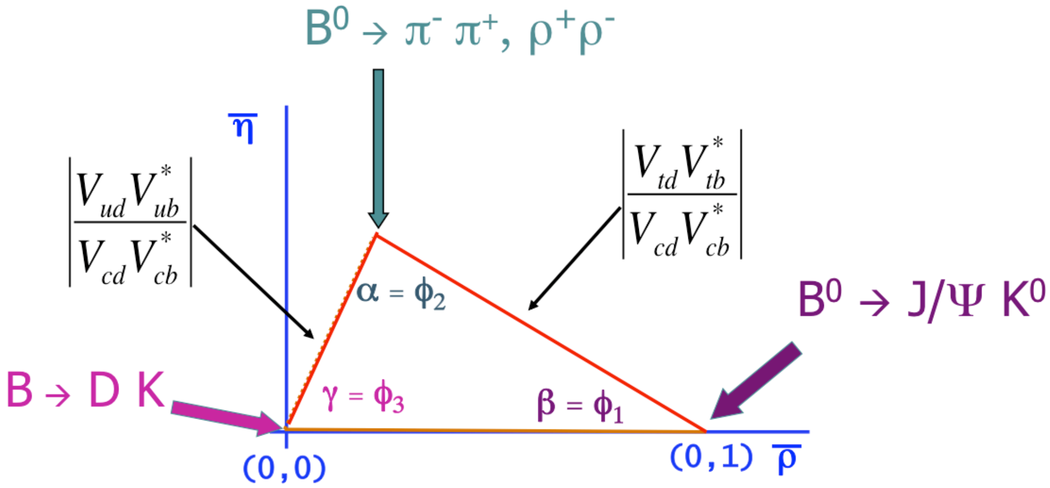
Describes the quark mixing in weak charged transitions



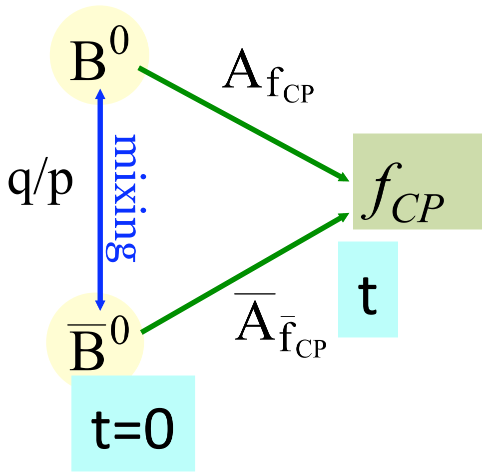
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

- The CKM is unitary
  - 4 independent parameters:
  - 3 angles and 1 phase
    - ➔ *Vij* are complex
- Interfering amplitudes can give *CP* violating asymmetries
- The CKM is the only source of *CPV* in the SM

- Measurements at *B* factories can over-constrain the Unitarity Triangle
- New Physics would be revealed in discrepancies among measurements



Time-dependent *CP* asymmetries



- *CP* violation arises from interference between the two paths (decay with and without mixing)

Independent of phase convention

$$\lambda_{f_{CP}} = \frac{q}{p} \cdot \frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}}$$

amplitude ratio

mixing

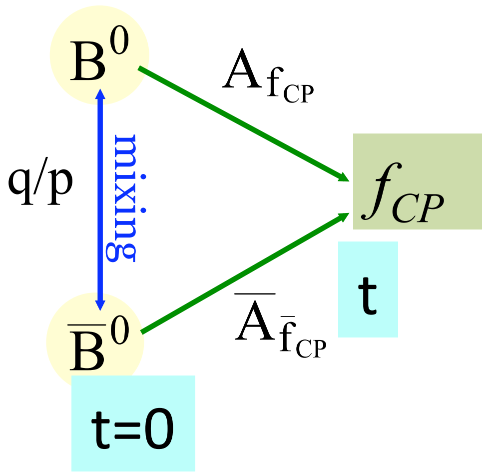
$$\boxed{\lambda_{f_{CP}} \neq \pm 1 \Longleftrightarrow \Gamma\,(\overline{B}^0_{phys}(t) \to f_{CP}) \neq \Gamma\,(B^0_{phys}(t) \to f_{CP})}$$

Time dependent *CP* asymmetry:

$$\boxed{\begin{aligned} A_{CP}(t) &= \frac{\Gamma\left(\overline{B}^0_{phys}(t) \to f_{CP}\right) - \Gamma\left(B^0_{phys}(t) \to f_{CP}\right)}{\Gamma\left(\overline{B}^0_{phys}(t) \to f_{CP}\right) + \Gamma\left(B^0_{phys}(t) \to f_{CP}\right)} \\ &= C_{f_{CP}} \cos\left(\Delta m\, t\right) + S_{f_{CP}} \sin\left(\Delta m\, t\right) \end{aligned}}$$

$$\boxed{\begin{aligned} C_{f_{CP}} &= \frac{1-\left|\lambda_{f_{CP}}\right|^2}{1+\left|\lambda_{f_{CP}}\right|^2} \\ S_{f_{CP}} &= \frac{-2\, Im\lambda_{f_{CP}}}{1+\left|\lambda_{f_{CP}}\right|^2} \end{aligned}}$$

Time-dependent *CP* asymmetries



- *CP* violation arises from interference between the two paths (decay with and without mixing)

Independent of phase convention ←
$$\lambda_{f_{CP}} = \frac{q}{p} \cdot \frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}$$
← **amplitude ratio**

mixing

$$\boxed{\lambda_{f_{CP}} \neq \pm 1 \Longleftrightarrow \Gamma\,(\bar{B}^0_{phys}(t) \to f_{CP}) \neq \Gamma\,(B^0_{phys}(t) \to f_{CP})}$$

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$\left|\frac{q}{p}\right| \cong 1$ if also $\left|\frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}\right| \cong 1$ ⟹ $\lambda_{f_{CP}} = e^{2i\phi}$ ⟹

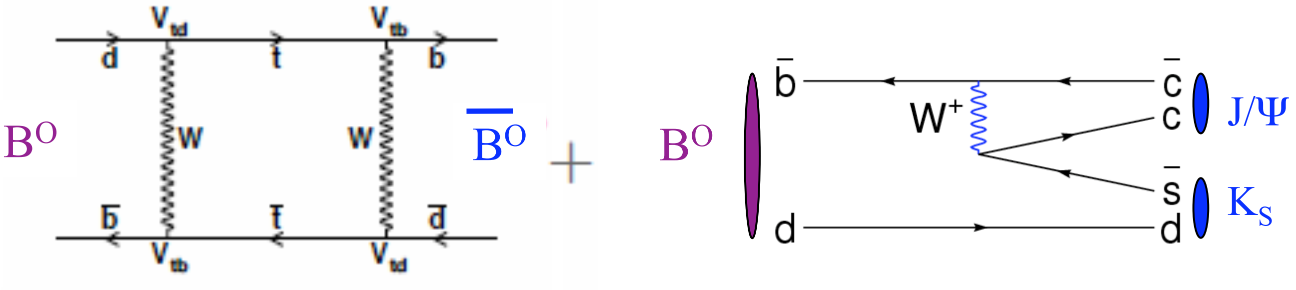
(no direct CPV)

$$\boxed{\begin{aligned} C_{f_{CP}} &= 0 \\ S_{f_{CP}} &= -\sin 2\phi \end{aligned}}$$

$B^0 \rightarrow J/\psi\ K_S^0$: the Golden Mode

quark subprocess: $b \rightarrow c\bar{c}s$

Dominated by tree decay amplitude, with a small penguin pollution $A_P / A_T \approx O(\lambda^2)$



- Single weak phase
- no direct CP violation

$$\boxed{|\lambda| \cong 1\ ; \qquad A_{CP} \cong -\mathrm{Im}(\lambda)\ \sin(\Delta m\ t)}$$

$$\lambda = -\left(\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}\right)\left(\frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}^*}\right)\left(\frac{V_{cd}^* V_{cs}}{V_{cd} V_{cs}^*}\right) = -e^{2i\beta}$$

B^0 mixing

$b \rightarrow c\bar{c}s$

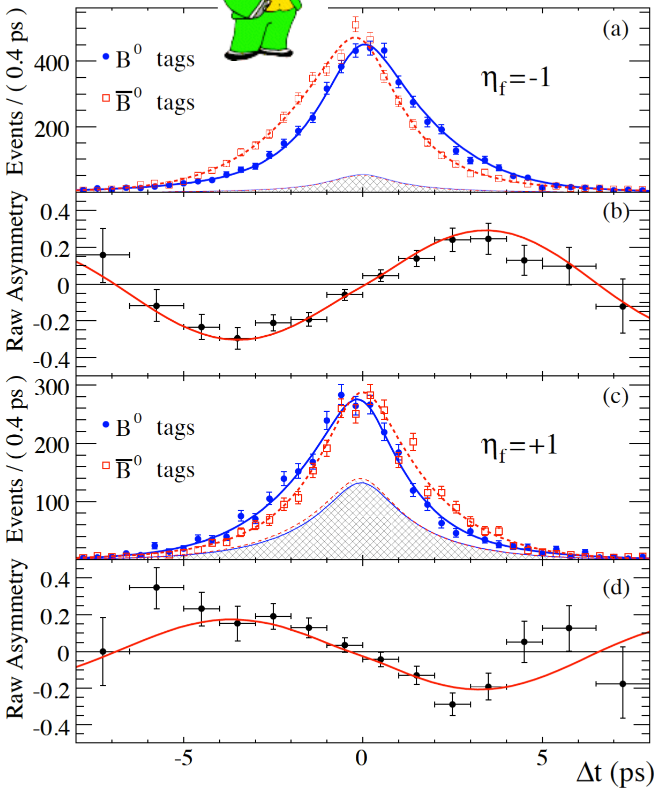
K^0 mixing

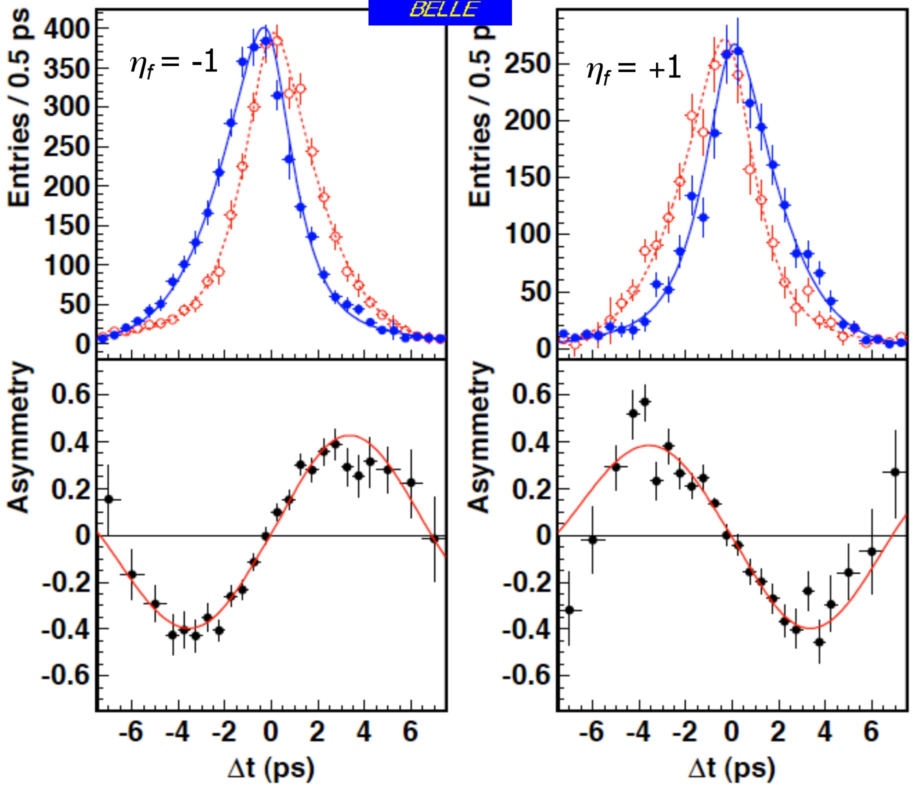
A_{CP}(t) directly measure sin2β

$$\boxed{A_{J/\psi K^0_{S,L}}(t) = -\eta_{J/\psi K^0_{S,L}} \sin 2\beta \sin(\Delta m_{B_d} t)}$$

- ✓ the asymmetry is large
- ✓ theoretically cleanest way to measure sin2β
- ✓ clear experimental signature
  $J/\Psi \rightarrow l^+l^-$, $K_S \rightarrow \pi\pi$
- ✓ relatively large branching fractions (BR ~ 4.5 x10^{-4})
- ✓ similar considerations hold for other charmonium modes
  ($\Psi(2S)K_S$, $X_{c1}K_S$…)

sin2β from b→c$\bar{c}$s





***BABAR*, PRD 79, 072009**

S = -0.687 ± 0.028 ± 0.012

C = 0.024 ± 0.020 ± 0.016

Belle, PRD 108, 171802 (2012)

S = -0.667 ± 0.023 ± 0.012

C = -0.006 ± 0.016 ± 0.012

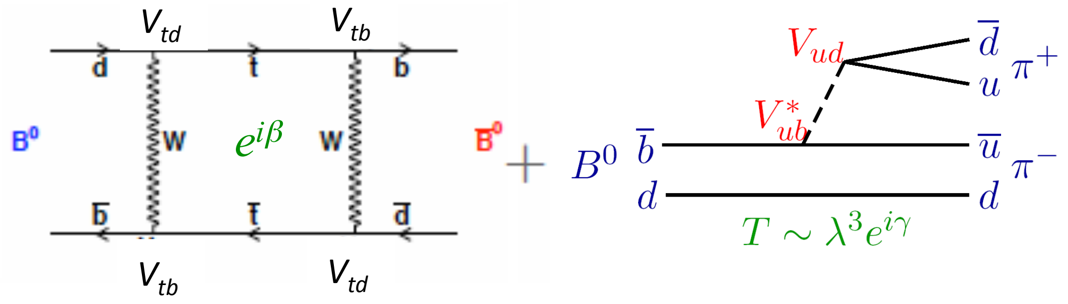
World Average:
sin2β = 0.68 ± 0.02

The angle $\alpha \equiv \phi_2$

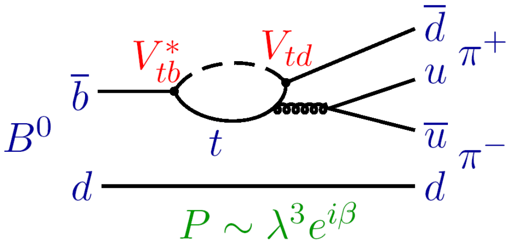
$\alpha = \varphi_2$ accessible via $b \to u$ transitions in $B \to \pi\pi, B \to \rho\rho$, or $B \to \rho\pi$

Measure Time-dependent CP asymmetries as for sin2β

e.g. $B \to \pi^+\pi^-$ and $B \to \overline{B} \to \pi^+\pi^-$ interference



Sizable penguin contribution with different weak phase



At tree level

$C = 0$

$S = \sin 2\alpha$

Because of penguin pollution

$C \neq 0$ allowed

$S = \sqrt{1 - C^2}\, \sin 2\alpha_{eff} = \sin(2\alpha + 2\Delta\alpha)$

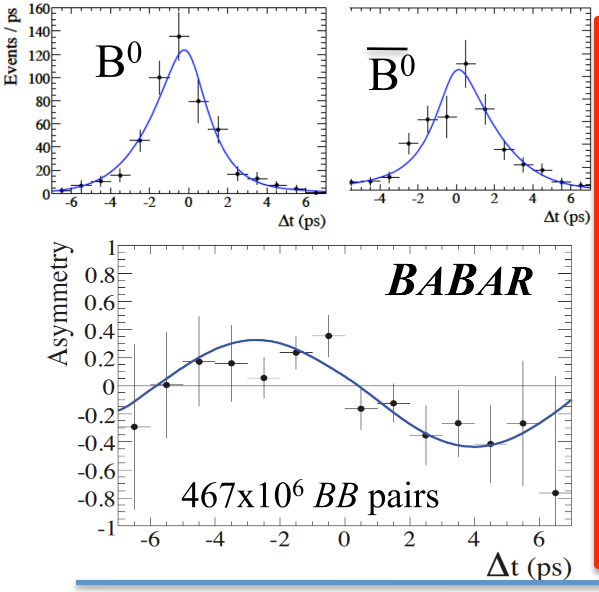
Needs measurement of $B^+ \to \pi^+\pi^0$ and $B^0 \to \pi^0\pi^0$ processes and isospin analysis to recover sin2α (see backup slides)

$B \rightarrow \pi^+\pi^-$

Recent results from both experiments on time-dependent CP asymmetry in $B \rightarrow \pi^+\pi^-$

PRD **87**, 052009 (2013)

PRD **88**, 092003 (2013)

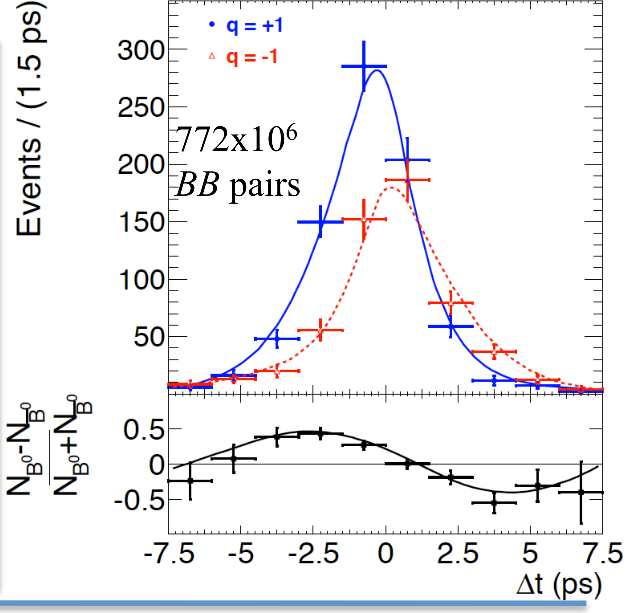


$S^{\pi\pi}$

BABAR	-0.68 ± 0.10 ± 0.03
Belle	-0.64 ± 0.08 ± 0.03

$C^{\pi\pi}$

BABAR	−0.25 ± 0.08 ± 0.02
Belle	−0.33 ± 0.06 ± 0.03



Global fits to extract α

- Overall fit using B →ππ , B →ρρ, B →ρπ
- Tightest constraint from B →ρρ
- B →ρπ is very promising but needs much more statistics => key channel for Belle-2
- LHCb just entered the game

CKMFitter

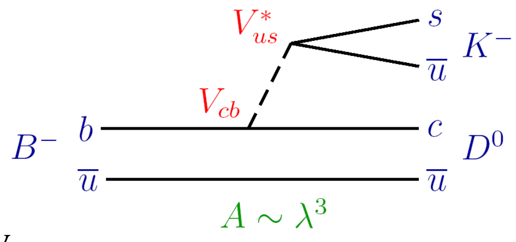
$$\alpha\ or\ \phi_2 = \left(88.5\ ^{+4.7}_{-4.4}\right)^{o}$$

UTfit

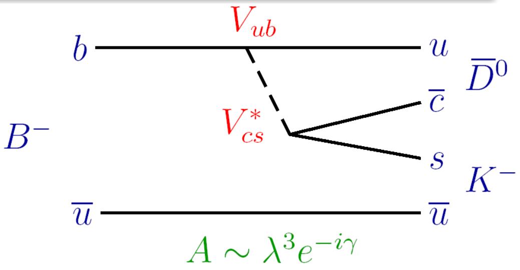
$$\alpha\ or\ \phi_2 = \left(88.7 \pm 3.1\right)^{o}$$

Angle $\gamma=\phi_3$

- No time-dependent analysis
- Interference between tree amplitudes $b \rightarrow c$ (V_{cb},real) and $b \rightarrow u$ (V_{ub}, $\propto e^{-i\gamma}$)
- Unknown strong phases and hadronic parameters to be determined experimentally



dominant $b \rightarrow c$ amplitude

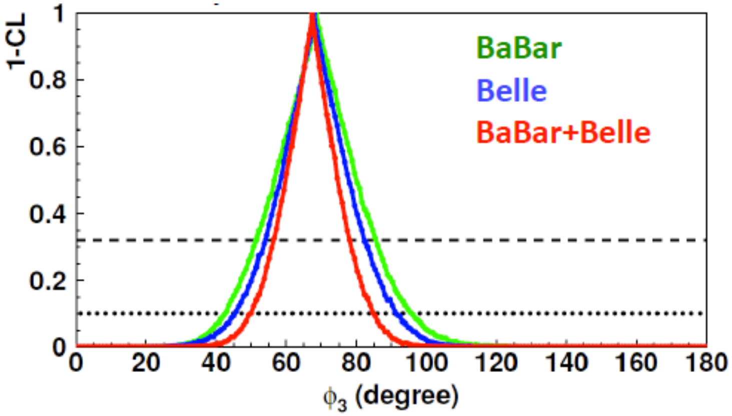


Color suppressed $b \rightarrow u$ amplitude

$$B^{\pm} \rightarrow D^{(*)0} K^{(*)\pm} \text{ decays dominate } \gamma = \phi_3 \text{ measurements}$$

Different methods for extracting γ depending on the D - meson decay mode

- *BABAR* and Belle have reconstructed the most sensitive decay modes using all or nearly all of their datasets
- Recently published results on combination of all analysis methods from both Collaborations



Belle	CKM2012 arXiv:1301.2033	$\gamma=\left(68^{+15}_{-14}\right)^o$	(mod 180^o)
BABAR	PRD87 052015 (2013)	$\gamma=\left(69^{+17}_{-16}\right)^o$	(mod 180^o)

BABAR and Belle

Physics of the B Factories to be submitted EPJC

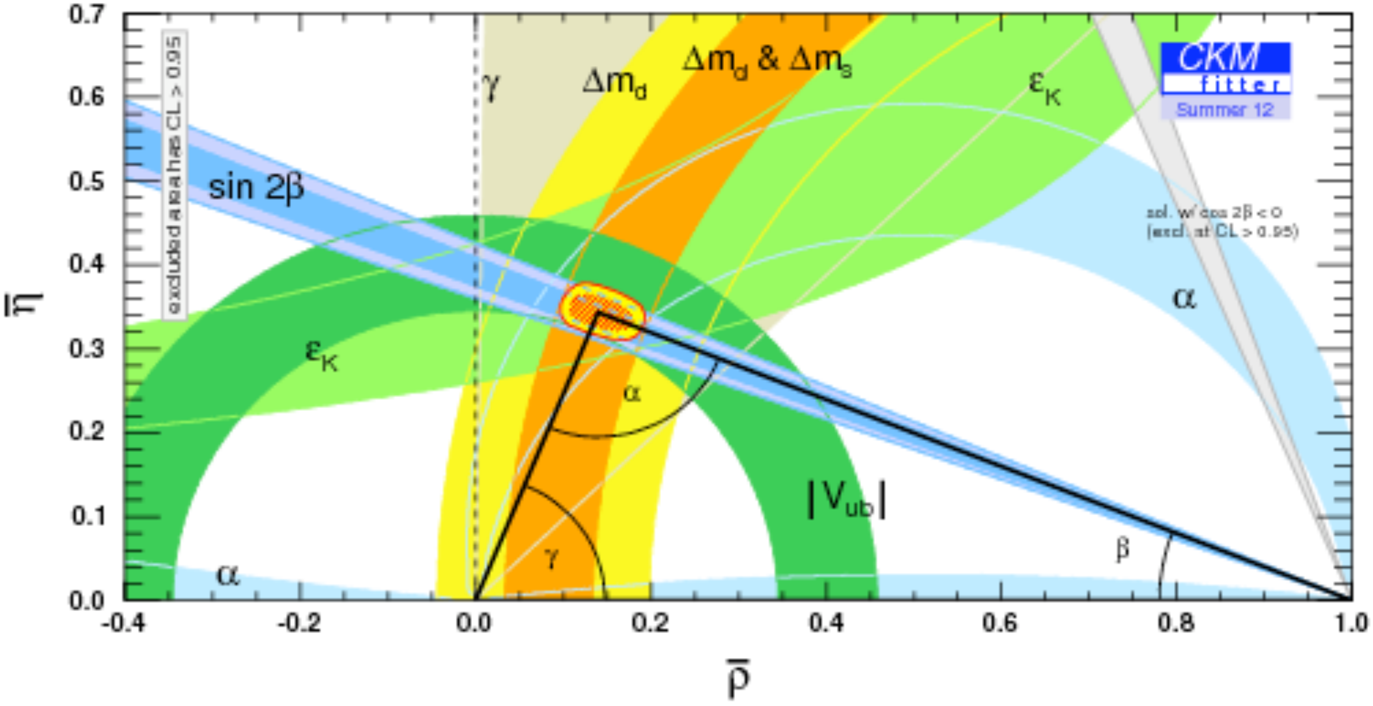
$\gamma=\left(67\pm11\right)^o$ (mod 180^o)

LHCb with 3fb^{-1}

$\gamma=\left(67\pm12\right)^o$ (mod 180^o)

CKM summary

- All measurements of CKM parameters (not only from *B* factories) are used for global fits to constrain the apex of the UT.
- Fits performed by several groups. Most common CKMfitter and UTfit



Consistent results between CKMFitter and UTfit

Parameter	Output Value	
	CKMfitter	UTfit
$\bar{\rho}$	$0.129^{+0.027}_{-0.022}$	0.132 ± 0.020
$\bar{\eta}$	0.345 ± 0.014	0.348 ± 0.013

CKM summary

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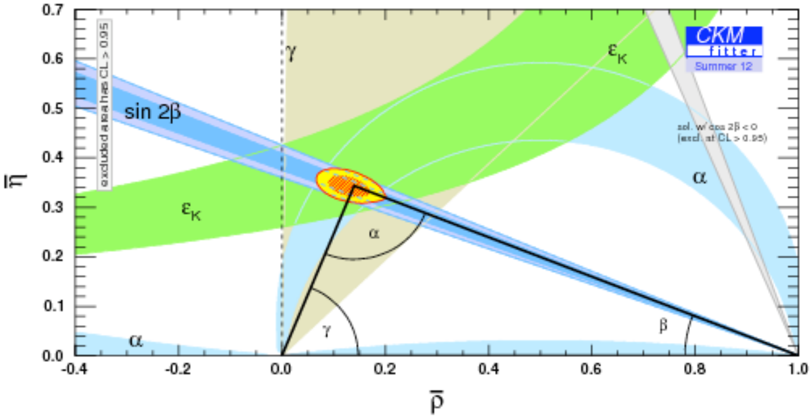
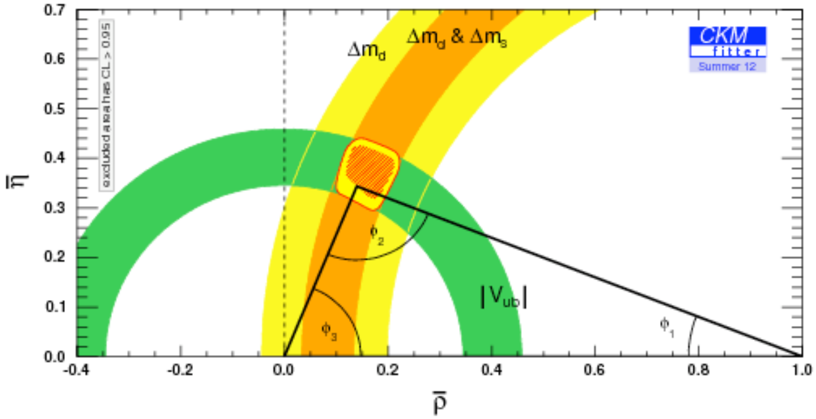
Fit including only CP-violating parameters



Fit including only CP-conserving parameters



- Subset of measurements allow to check consistencies of specific parameters
- Generally good consistency, with some tension in few cases:
  - Inclusive *vs* Exclusive V_{ub}
  - for B → τν "case" see later

- Consistency between:

- CP violating and CP conserving parameters
- *B*-factories results (*b* → *d* transitions), Bs oscillations (*b* → *s*), and CPV in kaon system (*s* → *d*)

- There is no significant evidence for a departure from the KM picture of CP violation and from the CKM matrix descritption of quark mixing
- However, there is still room for New Physics…

Direct observation of Time Reversal Violation

Phys. Rev. Lett. **102**, 211801 (2013)

T, CP and CPT

- T, C, and P discrete symmetries related to each other via the CPT theorem:
  - A QFT with local Lorentz invariant and a Hermitian Hamiltonian conserves CPT
- As a consequence, CP violation ==> T violation
- CPV well established in the SM framework of weak decays

- Can TV be directly observed, independently of CPT?

- In unstable systems, one needs to exchange |in> and |out> states and measure the asymmetry

$$A_T = \frac{P(|i\rangle \to |f\rangle) - P(|f\rangle \to |i\rangle)}{P(|i\rangle \to |f\rangle) + P(|f\rangle \to |i\rangle)}$$

- What about using weak decays of B mesons?
- Large CP violation measured in many B decays (e.g. direct CPV in B→Kπ) , but it is essentially impossible to observe the time-reverse process Kπ→B.
  - unfeasable to prepare a Kπ initial state
  - in any case hadronic interactions will wash out any asimmetry from the rare weak Kπ→B processes

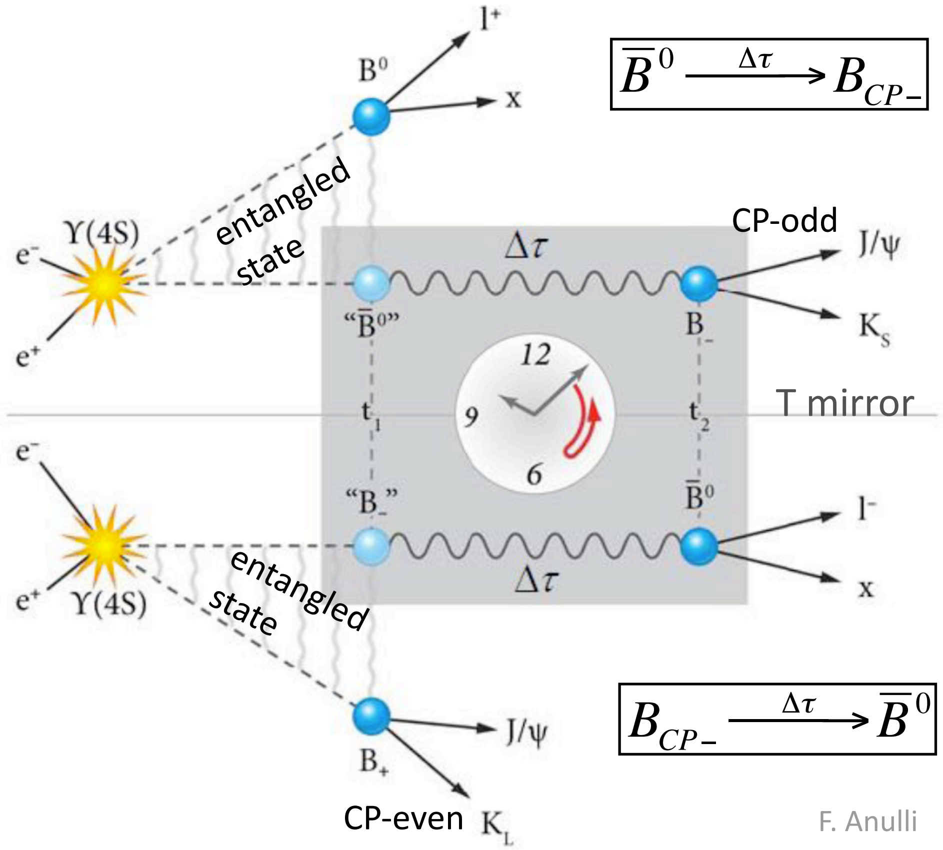
Measuring Time-Reversal Violation at the *B* factories

Solution: exploit the EPR entanglement of the B^0-$\overline{B}^0$ pair produced at the $\Upsilon(4S)$

Bernabeu & Bañuls,
PLB464, 117 (1999)

$$|i\rangle = \frac{1}{\sqrt{2}}\left[B^0(t_1)\bar{B}^0(t_2) - \bar{B}^0(t_1)B^0(t_2)\right] = \frac{1}{\sqrt{2}}\left[B_{CP+}(t_1)B_{CP-}(t_2) - B_{CP-}(t_1)B_{CP+}(t_2)\right]$$

- Because of EPR the state of the 1st B decay at t_1 dictates the state of the other B at the same time t_1, which will decay after a time $\Delta t = t_2 - t_1$
- This is the way CPV in the interference between decays with and without mixing is measured



$$\boxed{\bar{B}^0 \xrightarrow{\Delta\tau} B_{CP-}}$$

$$\boxed{B_{CP-} \xrightarrow{\Delta\tau} \bar{B}^0}$$

Method described in
J. Bernabeu et al. JHEP08 (2012) 064

Semileptonic decays project a B-flavor state:

$$l^+ \to B^0 \quad and \quad l^- \to \bar{B}^0$$

Decays to $J/\psi\, K_{L,S}$ project a CP eigenstate:

$$J/\psi K_L \to B_{CP+} \quad and \quad J/\psi K_S \to B_{CP-}$$

- Test TV comparing the decay time distributions of the two processes
- 4 different T comparisons, plus 4 CP, and 4 CPT

Time-Reversal Violation: Results

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

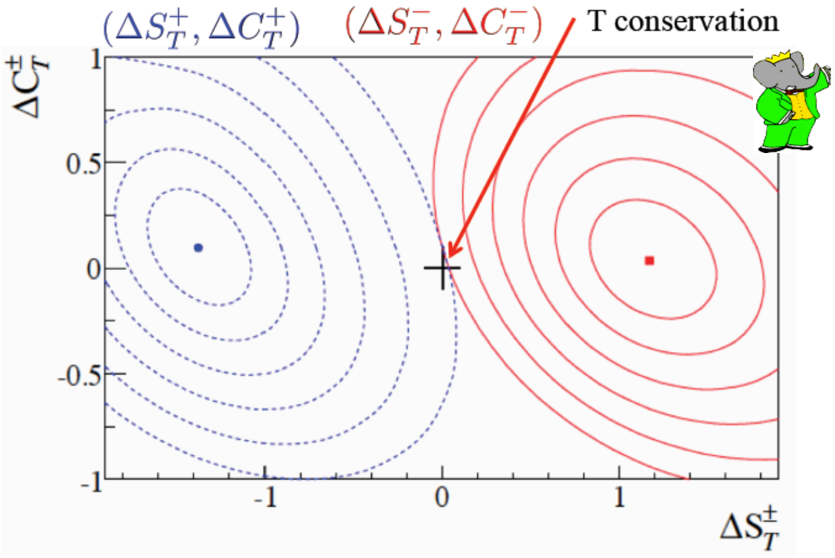
$$C^{\pm}_{\alpha,\beta} = \frac{1-|\lambda|^2}{1+|\lambda|^2} \qquad S^{\pm}_{\alpha,\beta} = \frac{2Im\lambda}{1+|\lambda|^2}$$

$\alpha = B^0$, $\overline{B}^0$

$\beta = J/\psi\, K_s$, $J/\psi\, K_L$

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

Simultaneous ML fit to all flavor- and CP-eigenstates samples for Δt>0 and Δt<0 events. Obtain 8 sets of *S, C* parameters, define from these the T-violating parameters Δ*S*, Δ*C*



PRL **102**, 211801 (2013)

$$\begin{aligned}
\Delta S_T^+ &= S^-_{\ell^-,K_L^0} - S^+_{\ell^+,K_S^0} && -1.37 \pm 0.14 \pm 0.06\\
\Delta S_T^- &= S^+_{\ell^-,K_L^0} - S^-_{\ell^+,K_S^0} && 1.17 \pm 0.18 \pm 0.11\\
\Delta C_T^+ &= C^-_{\ell^-,K_L^0} - C^+_{\ell^+,K_S^0} && 0.10 \pm 0.14 \pm 0.08\\
\Delta C_T^- &= C^+_{\ell^-,K_L^0} - C^-_{\ell^+,K_S^0} && 0.04 \pm 0.14 \pm 0.08
\end{aligned}$$

Large T violation observed

T-violation observed at >14σ !

Asymmetry consistent with expectation from CPT theorem and measured sin2β.

Measurement independent from any assumption on CP or CPT

Time-Reversal Violation: Results

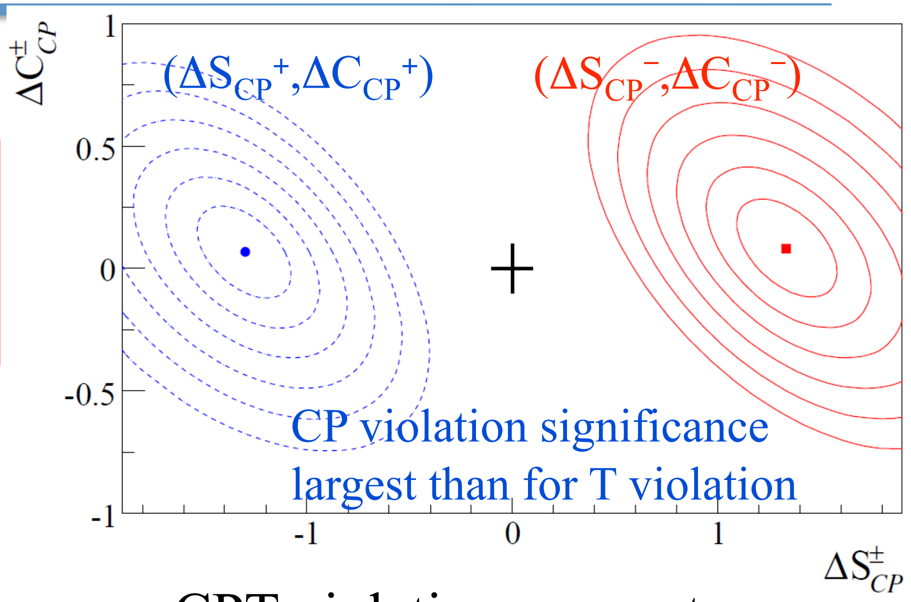
CP-violating parameters

$$\Delta S^{+}_{CP} = S^{+}_{\ell^{-},K^{0}_{S}} - S^{+}_{\ell^{+},K^{0}_{S}} \qquad -1.30 \pm 0.11 \pm 0.07$$

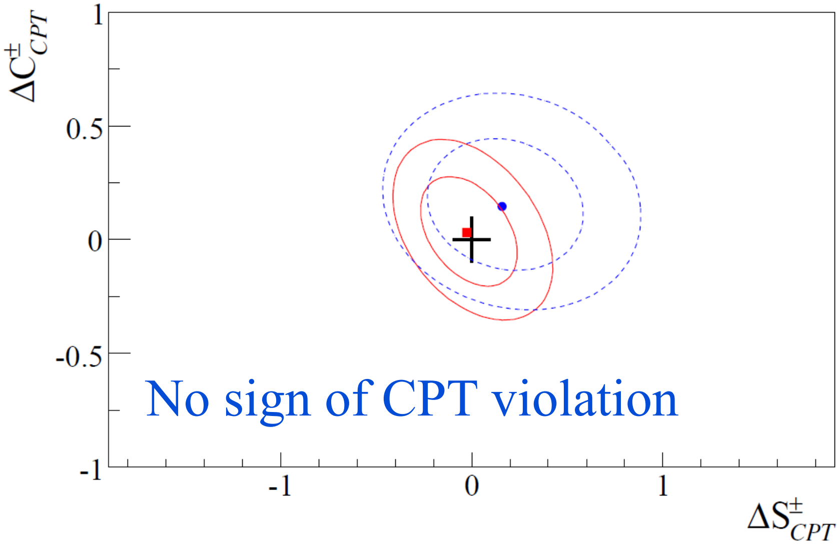
$$\Delta S^{-}_{CP} = S^{-}_{\ell^{-},K^{0}_{S}} - S^{-}_{\ell^{+},K^{0}_{S}} \qquad 1.33 \pm 0.12 \pm 0.06$$

$$\Delta C^{+}_{CP} = C^{+}_{\ell^{-},K^{0}_{S}} - C^{+}_{\ell^{+},K^{0}_{S}} \qquad 0.07 \pm 0.09 \pm 0.03$$

$$\Delta C^{-}_{CP} = C^{-}_{\ell^{-},K^{0}_{S}} - C^{-}_{\ell^{+},K^{0}_{S}} \qquad 0.08 \pm 0.10 \pm 0.04$$



CP violation significance largest than for T violation



No sign of CPT violation

CPT-violating parameters

$$\Delta S^{+}_{CPT} = S^{-}_{\ell^{+},K^{0}_{L}} - S^{+}_{\ell^{+},K^{0}_{S}} \qquad 0.16 \pm 0.21 \pm 0.09$$

$$\Delta S^{-}_{CPT} = S^{+}_{\ell^{+},K^{0}_{L}} - S^{-}_{\ell^{+},K^{0}_{S}} \qquad -0.03 \pm 0.13 \pm 0.06$$

$$\Delta C^{+}_{CPT} = C^{-}_{\ell^{+},K^{0}_{L}} - C^{+}_{\ell^{+},K^{0}_{S}} \qquad 0.14 \pm 0.15 \pm 0.07$$

$$\Delta C^{-}_{CPT} = C^{+}_{\ell^{+},K^{0}_{L}} - C^{-}_{\ell^{+},K^{0}_{S}} \qquad 0.03 \pm 0.12 \pm 0.08$$

Simultaneous and independent test of T, CP, CPT.

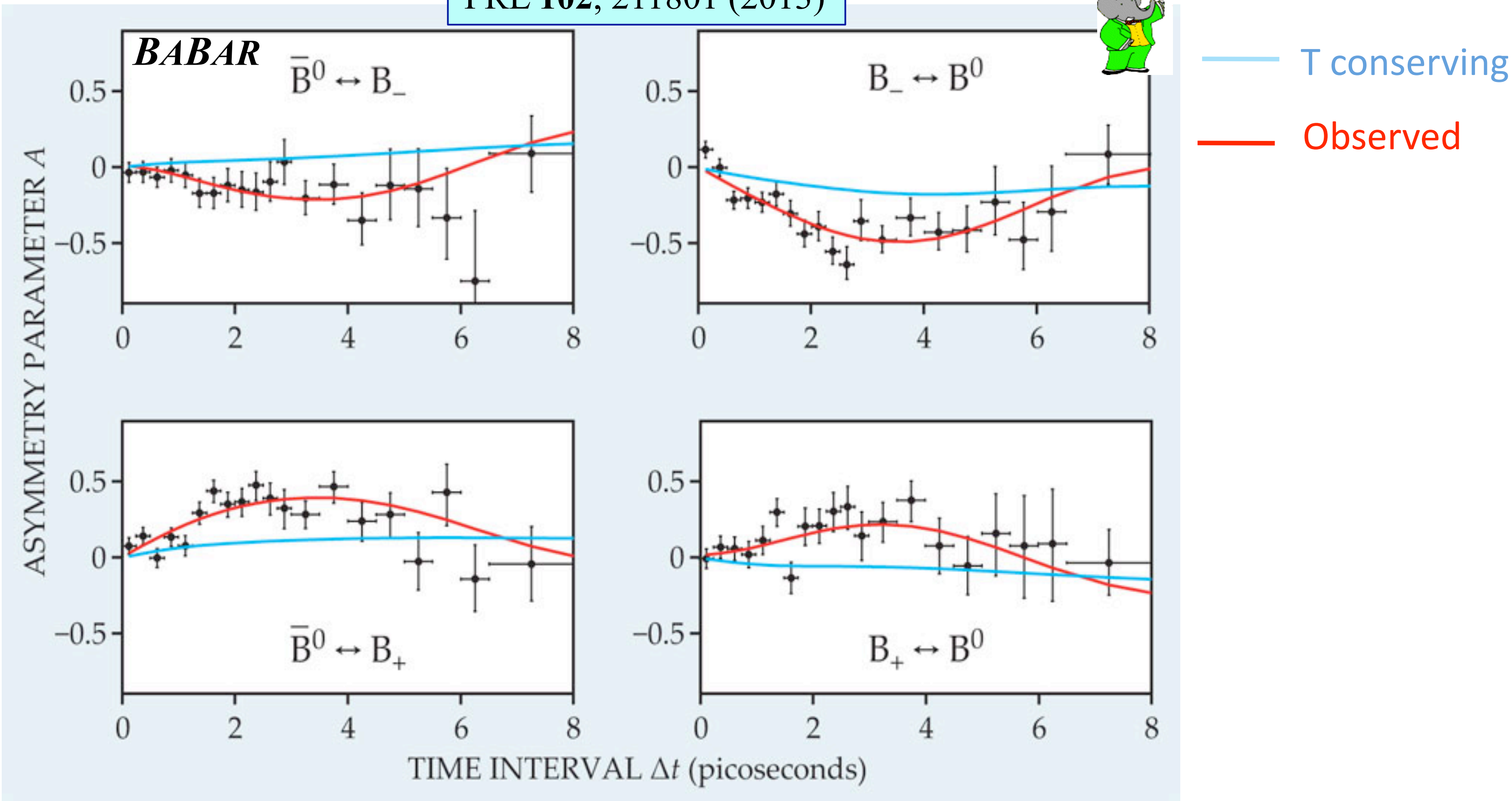
T and CP show compensating violation effects, while CPT is consistent with no violation

Visualizing the time asymmetries

The T violation effects can be visualized defining the time asymmetries as:

$$A_T = \frac{P(|i\rangle \to |f\rangle) - P(|f\rangle \to |i\rangle)}{P(|i\rangle \to |f\rangle) + P(|f\rangle \to |i\rangle)} \simeq \frac{\Delta C_T^{\pm}}{2} \cos \Delta m \Delta t + \frac{\Delta S_T^{\pm}}{2} \sin \Delta m \Delta t$$

PRL **102**, 211801 (2013)



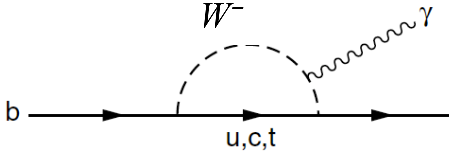
New Physics in “rare” *B* decays

Search for indirect New Physics effects

- Different experimental and theoretical uncertainties among the various modes
- Some channel impossible or very challenging at hadronic colliders

Rare decays via radiative and electroweak penguins

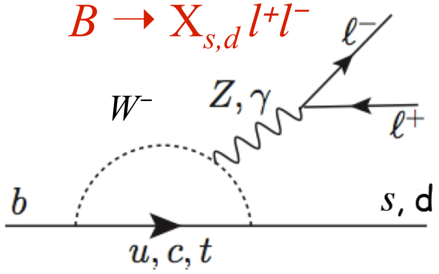
$B \to X_s\,\gamma$



$\mathcal{B}(s\gamma) \sim 10^{-4}$

$\delta_{th} < 10\%$

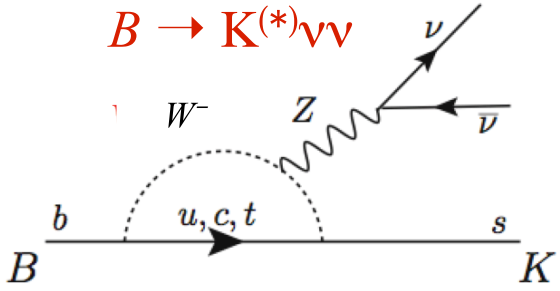
$B \to X_{s,d}\, l^+ l^-$



$\mathcal{B}(sll) \sim 10^{-6}$, δ_{th} ~ 12-20%

$\mathcal{B}(dll) \sim 10^{-8}$, δ_{th} ~ 24%

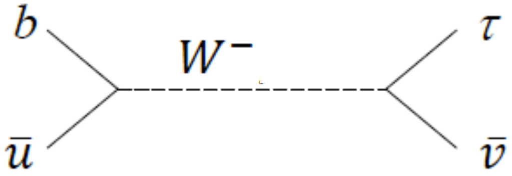
$B \to K^{(*)}\nu\nu$



$\mathcal{B}(s\nu\nu) \sim 10^{-6}$, δ_{th} ~ 15%

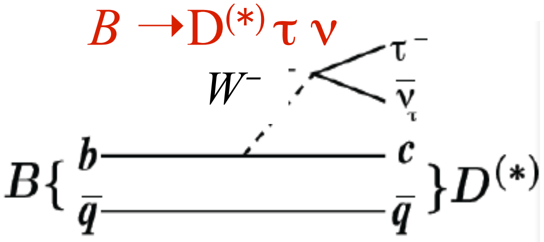
$B \to \tau\,\nu$

Search for NP in tree processes



$\mathcal{B}(\tau\nu) \sim 10^{-4}$, δ_{th} ~ 25%

$B \to D^{(*)}\tau\,\nu$



$\mathcal{B}(D^{(*)}\tau\nu) \sim 0.02$, δ_{th} ~ 5%

- Large New Physics effects predicted for H⁺, Z′, SUSY particles
- Indirect studies complementary to direct searches at the LHC

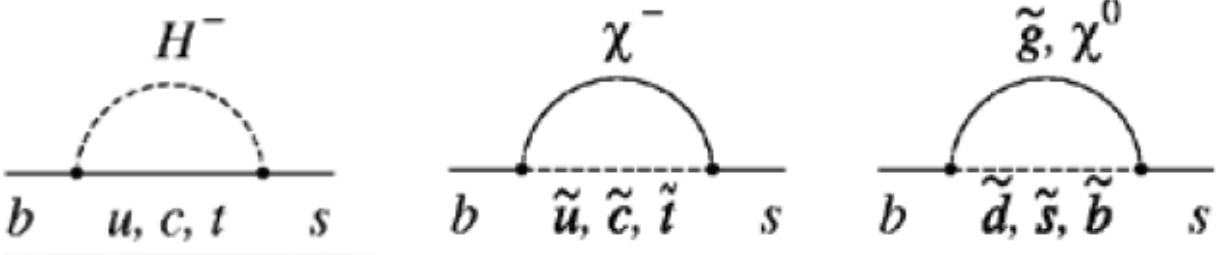
Inclusive B $\rightarrow X_s\gamma$

$B \to X_s\,\gamma$

- $B \to X\gamma$ and $B \to Xl^+l^-$ are FCNC processes forbidden at three level in the SM, but happen at loop level.
- OPE factorize short-distance from long-distance effects

$$H_{eff} = \frac{4G_F}{\sqrt{2}} \sum_q V_{qb} V_{qs(d)} \sum_i C_i(\mu) O_i \qquad q = u, c, t$$

- For radiative b→sγ decays, theory uncertainty on *BF* is at 7% level with calculations at NNLO (Misiak et. al, PRL 98, 0222002 (2007))
- Contributions from two effective Wilson coefficients, C_7^{eff}, and C_8^{eff}
- New Physics can contribute at the same level as SM (more loops with new particles)
  - modify the SM values of Wilson coefficients
  - Measurable changes in BF and CP asymmetry expected from NP
- Can add constraints on several NP models, in particular on the Two-Higgs Doublet Model (2HDM)



$B \rightarrow X_s \gamma$

- Three different analysis approaches performed:

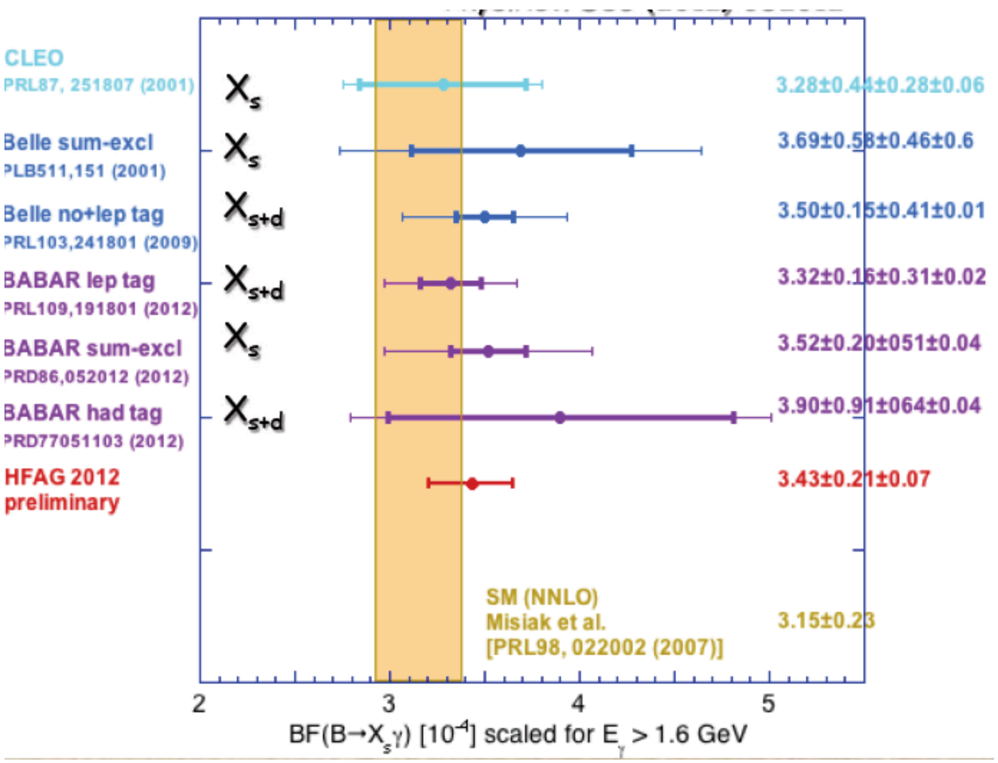
Fully inclusive (with lepton tag)	Inclusive with hadronic tag (full reco of the other B)	Sum of exclusive modes
• Advantage: - Insensitive to final state fragmentation, theoretically clean	• Advantage: - theoretically clean - low non-B background - identify B charge and flavor - E_γ is measured in the B-decay frame	• Advantage: - low background - good photon resolution - E_γ is measured in the B-decay frame
• Disadvantage: - huge background - E_γ is measured in Υ(4S) frame - does not distinguish between b →sγ and b→dγ	• Disadvantage: - low efficiency on the tag side	• Disadvantage: - sensitive to details of X_s fragmentation - Missing X_s modes

$B\to X_s\,\gamma$: Branching Fractions

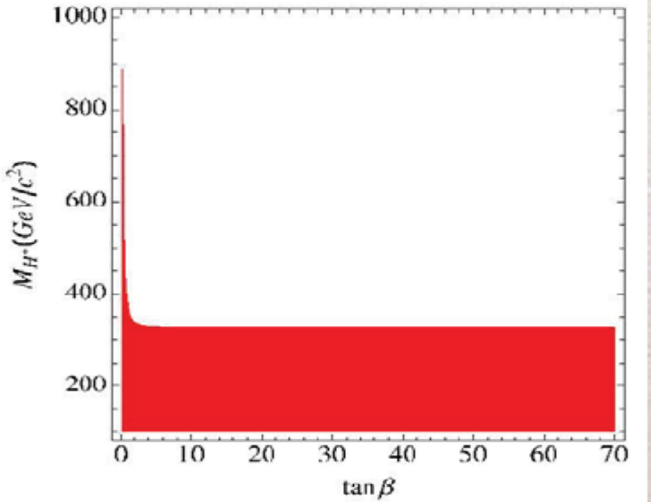
- *BF*s measured in bins of photon energy
- Different minimum energy reached by single measurements
- Results extrapolated to E_γ>1.6 GeV, and averaged

HFAG average:
$\mathcal{B}(B\to X_s\gamma) = (343 \pm 21 \pm 7)\mathrm{x}10^{-6}$

SM prediction @NNLO:
$\mathcal{B}(B\to X_s\gamma)_{SM} = (315 \pm 23)\mathrm{x}10^{-6}$



- Use extrapolated results to constrain $m(H^\pm)$ in the type-II 2HDM
- Exclude at 95% CL charged Higgs for $m(H^\pm)$ <327 GeV, independent of tanβ

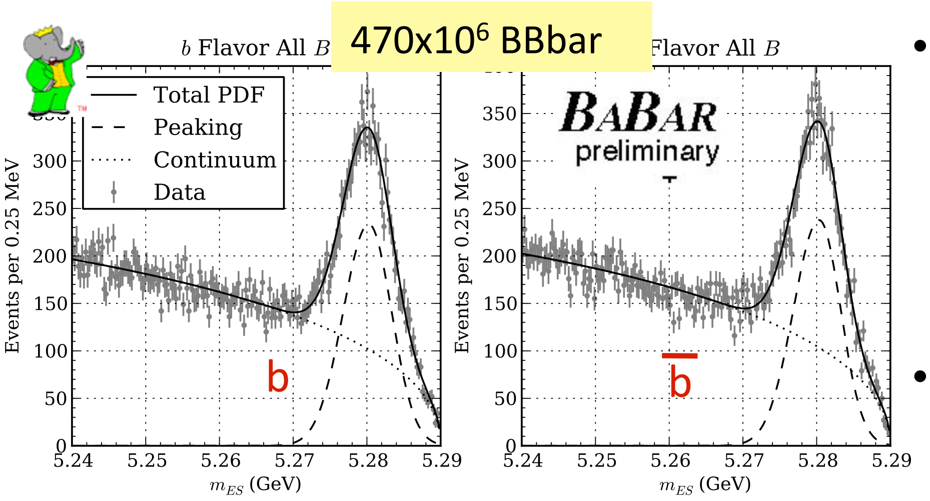


$B \rightarrow X_s\gamma$: Semi-inclusive $\mathcal{A}_{CP}$ results

- SM predictions yield -0.6% < $\mathcal{A}_{CP}(X_s\gamma)$ < 2.8%
- Present world average $\mathcal{A}_{CP}(X_s\gamma) = -0.8 \pm 2.9\%$

$$\mathcal{A}_{CP}(X_s\gamma) \equiv \frac{\Gamma(\bar{B} \to \bar{X}_s\gamma) - \Gamma(B \to X_s\gamma)}{\Gamma(\bar{B} \to \bar{X}_s\gamma) + \Gamma(B \to X_s\gamma)}$$

- Recent *BABAR* analysis using 470 million Bbbar events, and a sum of exclusive decay modes
- Extract $\mathcal{A}_{CP}$ from simultaneous fit to reconstructed masses of B and $\overline{\mathrm{B}}$ samples
- Correct raw asymmetries for detector effects



- In full X_s mass region the corrected $\mathcal{A}_{CP}$ is measured to be:

  $\mathcal{A}_{CP}(X_s\gamma) = (1.73 \pm 1.93_{stat} \pm 1.02_{syst})\%$

  - Good agreement with SM prediction

- These new results have significantly lower uncertanties than previous measurements

$B \rightarrow X_s\,\gamma$: ΔA_{CP}

- The difference for charged and neutral B decays depends on C_7 and C_8 Wilson coeff.

(Benzke et *al*., PRL106.141801.2011)

$$\Delta A_{CP}(X_s\gamma) = A_{CP}\left(B^+ \rightarrow X_s^+\gamma\right) - A_{CP}\left(B^0 \rightarrow X_s^0\gamma\right) \approx 0.12\,\frac{\tilde{\Lambda}_{78}}{m_b}\,\mathcal{Im}\,\frac{C_8^{eff}}{C_7^{eff}}$$

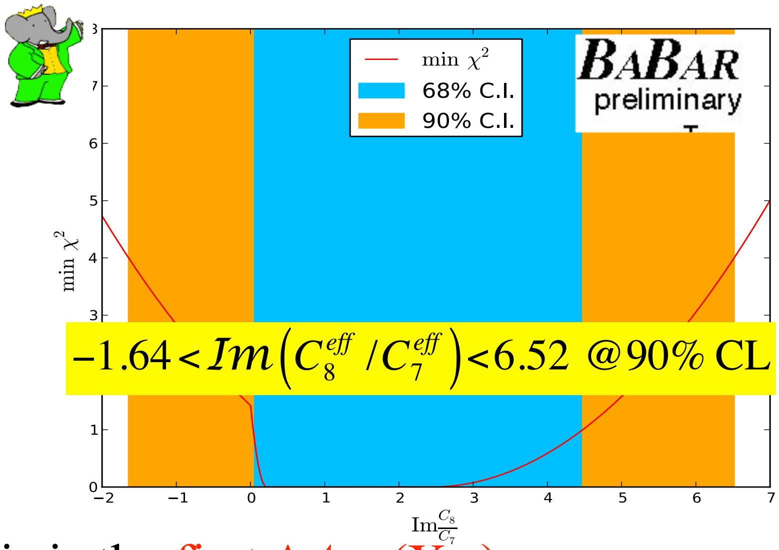
$$17\text{ MeV} < \tilde{\Lambda}_{78} < 190\text{ MeV}$$

- In the SM, C_8 and C_7 are real ==> ΔA_{CP}=0

- From the simultaneous fits to charged and neutral B samples *BABAR* measures

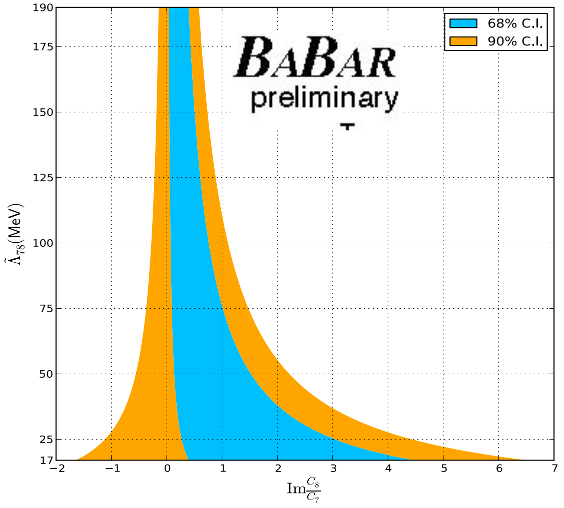
$$\boxed{\Delta A_{CP}(X_s\gamma) = \left(5.0 \pm 3.9_{stat} \pm 1.5_{syst}\right)\%}$$

- Set 90% CL on $\mathcal{Im}(C_8/C_7)$ for any value of Λ_{78} in the allowed range



$$-1.64 < \mathcal{Im}\left(C_8^{eff}/C_7^{eff}\right) < 6.52 \text{ @90\% CL}$$

68% and 90% CL for Λ_{78} vs $\mathcal{Im}(C_8/C_7)$

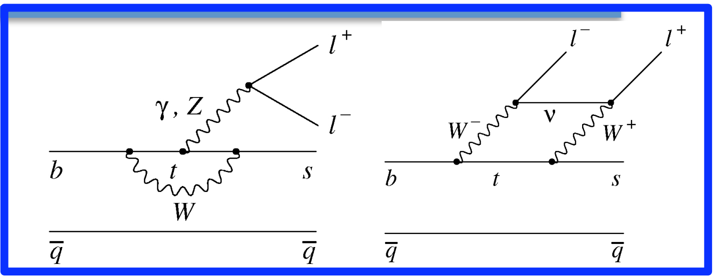


This is the first ΔA_{CP} ($X_s\gamma$) measurement and the first constraint on the ratio of Wilson coefficients C_8/C_7 for new physics in this process

Inclusive B $\rightarrow X_s l^+ l^-$
and
Exclusive B $\rightarrow X_d l^+ l^-$

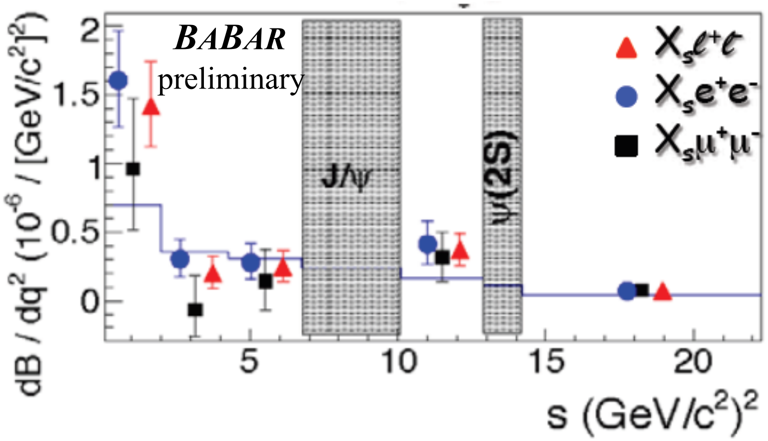
$B \rightarrow X_s l^+ l^-$

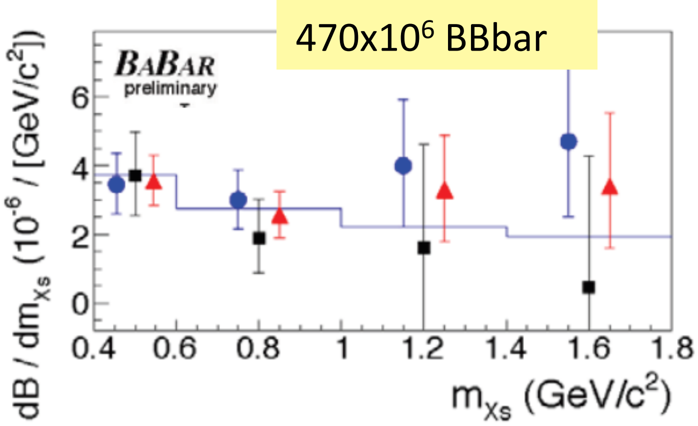
- Within the SM, it proceeds via electroweak penguin and box diagram
- 3 effective Wilson coefficients: C_7^{eff}, C_9^{eff}, C_{10}^{eff}
- Expect BF in SM: $\mathcal{B}(X_s l^+ l^-) = (4.6 \pm 0.8) \times 10^{-6}$



- Recent BABAR analysis uses a sum of exclusive modes $B \rightarrow X_s e^+e^-$ and $B \rightarrow X_s \mu^+\mu^-$
- Reconstruct 10 X_s final states, with 1 kaon, and up to 2 charged and 1 neutral pion
  - It represents ~70% of the inclusive rate with $m(X_s)<1.8$ GeV/c^2, accounting for K^0_L modes
  - Unseen modes estimated with MC (inclusive generator model and JETSET fragmentation)

- Measure the total *BF* and partial *BF*s in 5 bins of $q^2=m_{ll}^2$ and 4 bins of m_{Xs}
- General consistency with the SM predictions





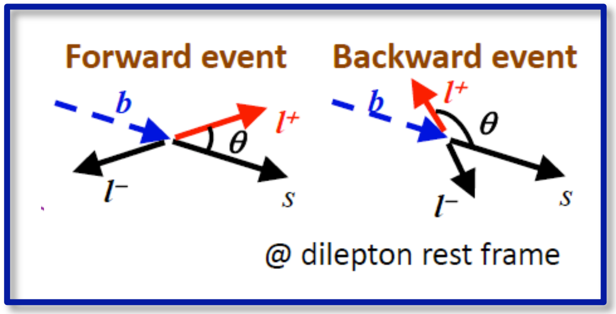
470×10^6 BBbar

$B \rightarrow X_s l^+ l^-$: Forward-Backward Asymmetry

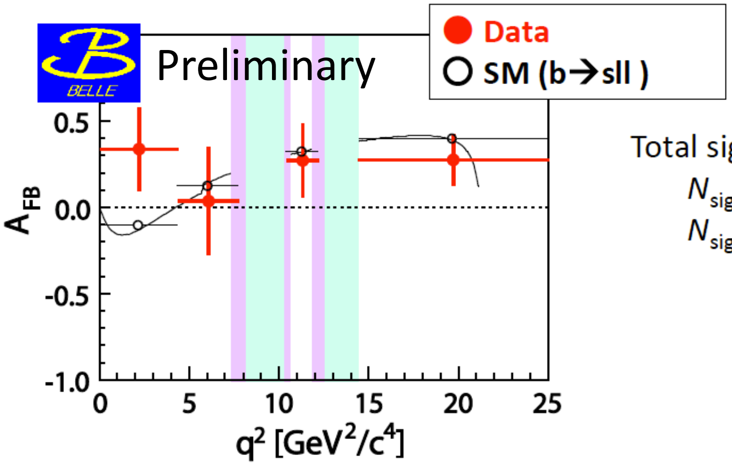
- Preliminary measurement of A_{FB} in inclusive $B \rightarrow X_s l+l-$ decays presented by Belle at the EPS-HEP Conference (Yutaro Sato)
- Uses a sum-of-exclusive analysis based on 10 X_s exclusive modes

$$A_{FB} = -\mathrm{Re}\left[\left(2C_7^{eff} + \frac{q^2}{m_b^2} C_9^{eff}\right) \bullet C_{10}^{eff}\right]$$

- Sensitive to 3 effective Wilson Coefficients
- Can constrain New Physics model



- Inclusive measurements have smaller theoretical and similar experimental uncertainties than exclusive $B \rightarrow K^{(*)} l^+ l^-$



Total signal yields

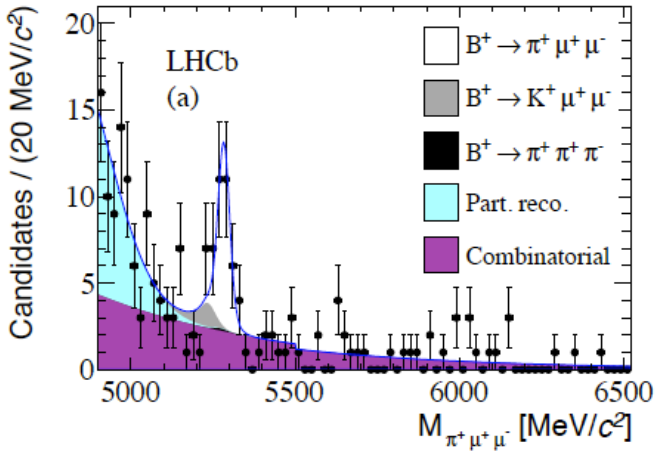
$N_{sig}^{ee} = 139.9 \pm 18.6$ (stat)

$N_{sig}^{\mu\mu} = 160.8 \pm 20.0$ (stat)

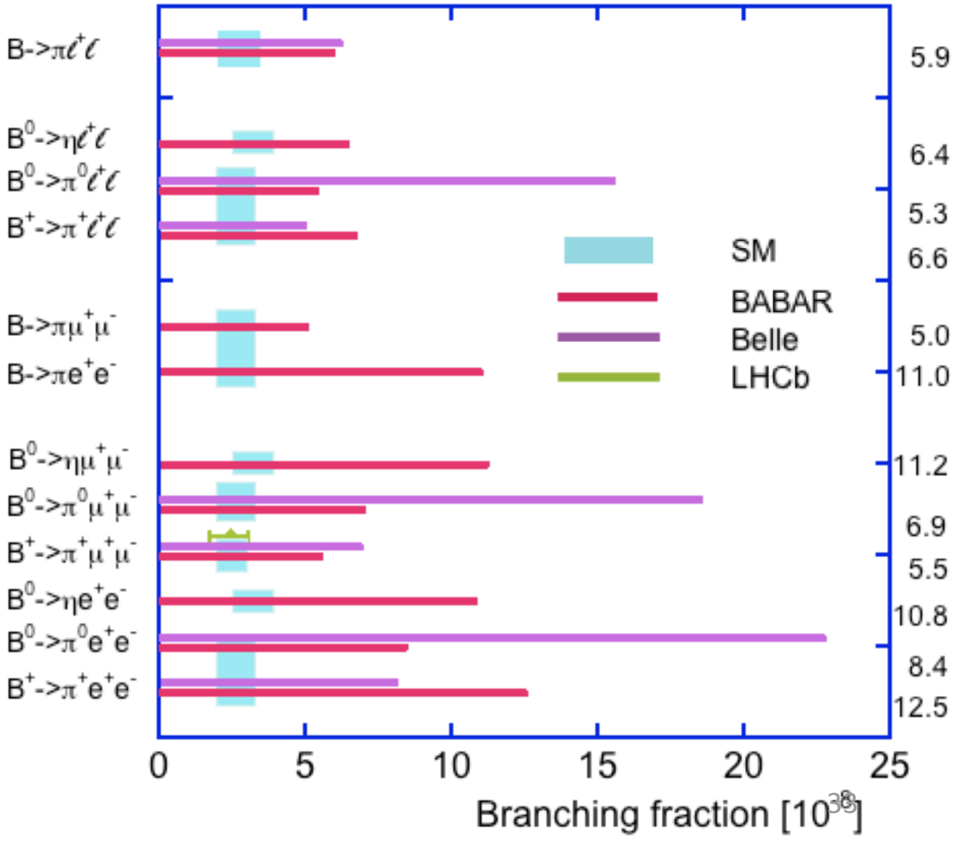
- Results consistent with SM
- Promising channel for Belle II

$B \to \pi^{\pm,0} l^+l^-$ and $B \to \eta l^+l^-$

- SM prediction of the order of ~10^{-8}
- The only observed channel (by LHCb) is $B^+ \to \pi^+\mu^+\mu^-$
  - $\mathcal{B}(B \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6 \pm 0.2) \times 10^{-8}$ JHEP 12, 125 (2012)



- B factories searched for both electron and muon modes, and for π^+, π^0, and η (only *BABAR*)
  - see no signal in any mode
  - set UL at 90% CL, for individual, isospin averaged, and lepton flavor averaged BF
- All UL within a factor ~2-3 of the SM predictions
- All modes will be observed at Belle II



$B \to \tau \nu$ and $B \to D^{(*)} \tau \nu$

Common reconstruction methodology

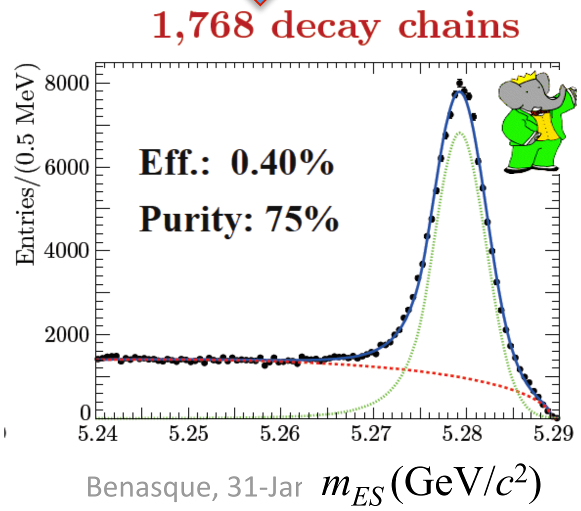
- Take advantage of the clean $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$ environment
  - perform a tagged analysis reconstructing both B mesons

- Fully reconstruct one B (B_{tag}) in hadronic modes

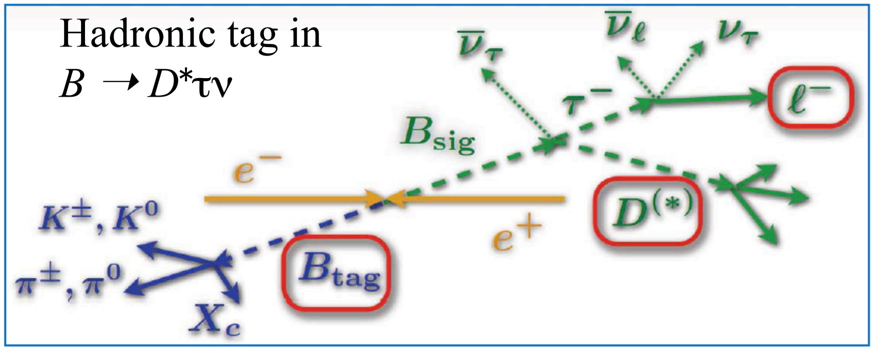
==> The direction of the B in the signal side is fully determined

- Select events by:

$$\Delta E = \frac{\sqrt{s}}{2} - E_B^* \,; \quad m_{ES} = \sqrt{\frac{s}{4} - p_B^{*2}}$$



- Look for signal decays in the rest of event



Btag hadronic reconstruction:

- High purity B-sample but low efficiency (ε <1%)
- New BABAR analyses 3x more efficient than previous

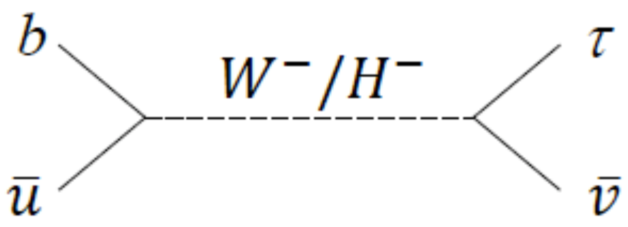
Alternative tag method uses semileptonic B decays

- Higher efficiency but lower purity
- In general similar sensitivity

B → $D^{(*)}$ τ ν and B → τ ν : motivations

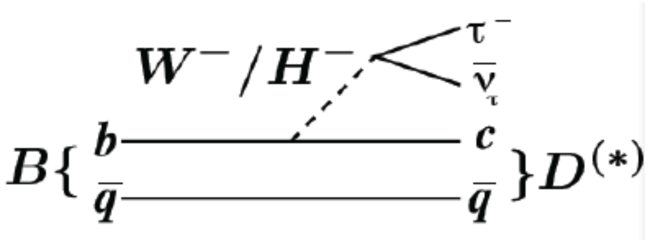
- Tree-level decays mediated in the SM by a $W^{\pm}$
- *BF* and kinematic distributions (for $D^{(*)}\tau\nu$) sensitive to a charged Higgs H^{+}
- Can probe extensions of the SM with an enlarged Higgs sector
  - e.g. Type-II Two Higgs Doublet Model (2HDM) of MSSM

B → τ ν



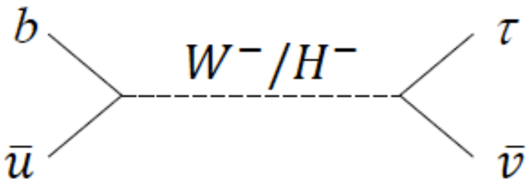
- Small *BF* ~ 0.01%
  - Helicity suppression
- Theoretical uncertainties ~25% (V_{ub}, f_B)

B → $D^{(*)}$ τ ν



- Large *BF* (O(1%))
- 3-body decay, additional observables available to test models

$B \rightarrow \tau \nu$



- Tree-level leptonic decays
  - No QCD uncertainties from hadrons in the final state
  - *BF* depends on f_B and V_{ub}

$$\boxed{\mathcal{B}(B \rightarrow \ell\nu)_{SM} = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 |V_{ub}|^2 f_B^2 \tau_B}$$

V_{ub} from global CKM fit

B decay constant from Lattice calculations

- Standard Model prediction:
  - $\mathcal{B}_{SM}(B \rightarrow \tau\, \nu) = (1.10 \pm [0.17_{stat} \pm 0.21_{th}]_{Vub} \pm [0.043_{stat} \pm 0.034_{th}]_{fb})$ x 10^{-4}

  - $|V_{ub}| = (4.15 \pm 0.50)\text{x}10^{-3}$ (PDG 2012)

  - $f_B = (190.6 \pm 3.7 \pm 2.9)$ MeV (Laiho, Lunghi and van de Water, 2012)

- Branching fraction theoretical expression depends on the NP model
  - For the 2HDM:

$$\mathcal{B}(B \rightarrow l\nu)_{2HDM} = \mathcal{B}(B \rightarrow l\nu)_{SM} \times (1 - tan^2\beta\frac{m_B^2}{m_H^2})^2$$

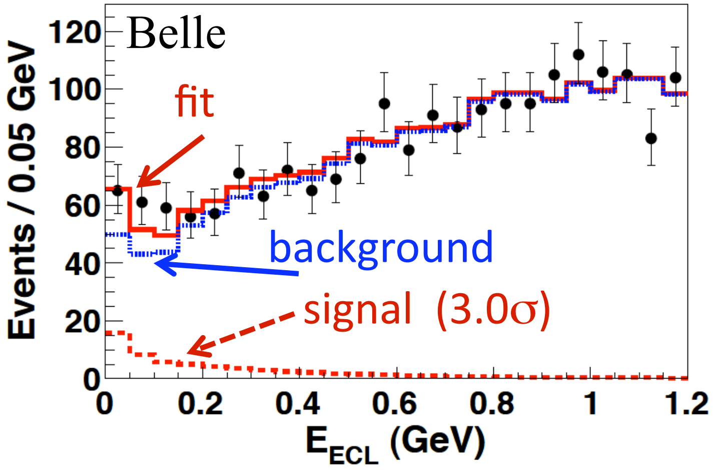
- Previous analyses used both hadronic and semileptonic tag

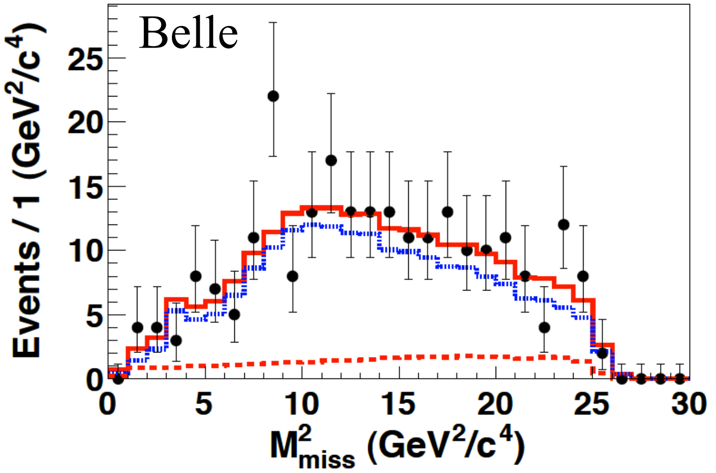
B → τ ν: results from Belle

- Full event reconstruction with Hadronic tag
  - $B_{sig} \to \tau\,\nu_{\tau};\;\; \tau \to e\nu_\tau\nu_e,\;\; \mu\nu_\tau\nu_\mu,\;\; \pi\nu,\;\; \rho(\pi^+\pi^0)\nu_\tau$
    - i.e.only 1-prong τ decays are used (~70% of all τ decays)
- Main discriminating variable : E_{ECL}
  - sum of the energy of the calorimeter clusters not associated with the reconstructed B's
  - peak at zero for correctly reconstructed events
- 2 dimensional fit to:
  - Extra neutral energy E_{ECL}
  - $m^2_{miss} = \left(p_{e^+e^-} - p_{tag} - p_{sig}\right)^2$
- PDFs obtained from MC, validated with control sampless:
  - Signal: $B \to D^{*0} l \nu$
  - Background: M_{bc} and E_{ECL} sidebands

$$Br(B \to \tau\nu) = [0.72\,^{+0.27}_{-0.25} \pm 0.11] \times 10^{-4}$$

Belle, PRL **110**, 131801 (2013)

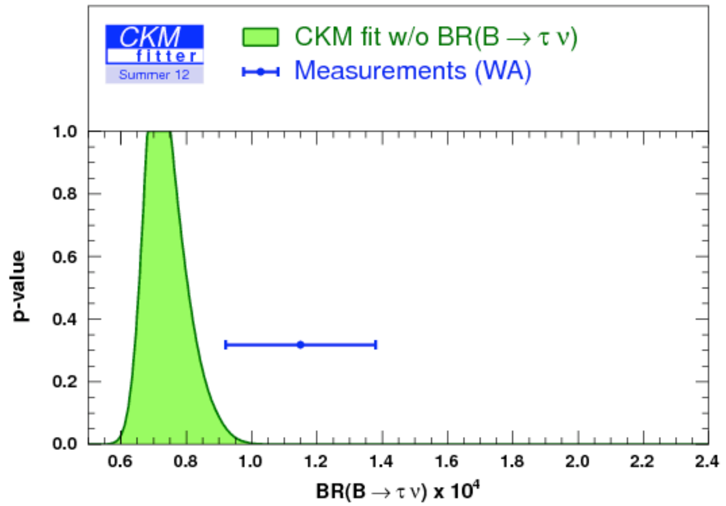




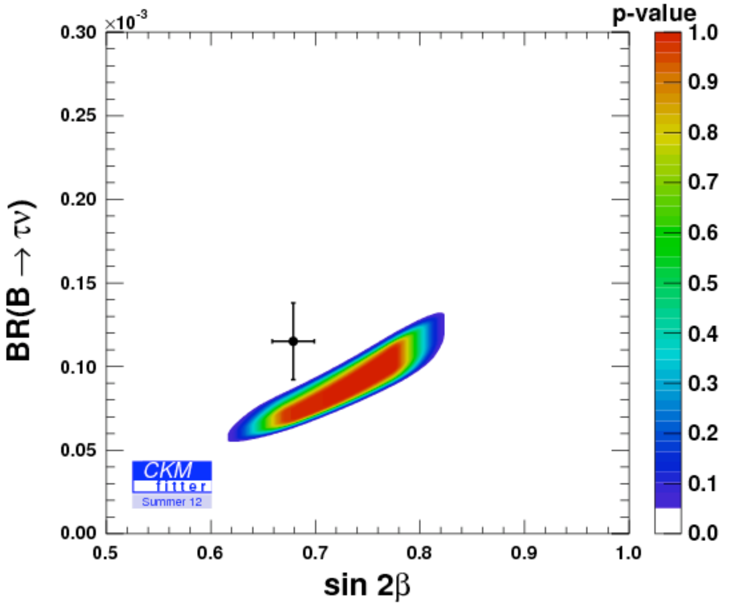
B → τ ν: Results *vs* SM

Experiment	Tag	Branching Fraction ($\times 10^{-4}$)
BABAR	hadronic	$1.83^{+0.53}_{-0.49} \pm 0.24$
BABAR	semileptonic [9]	$1.7 \pm 0.8 \pm 0.2$
Belle	hadronic	$0.72^{+0.27}_{-0.25} \pm 0.11$
Belle	semileptonic [11]	$1.54^{+0.38+0.29}_{-0.37-0.31}$

New average (HFAG) $\mathcal{B}(B \to \tau\nu) = \left(1.15 \pm 0.23\right) \times 10^{-4}$

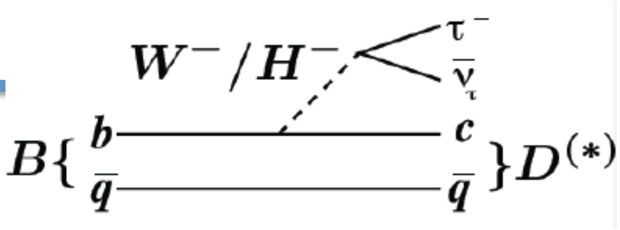


Fit to CKM parameters without $\mathcal{B}$(B→τν)



Fit to CKM parameters without $\mathcal{B}$(B→τν) and sin2β

$B \rightarrow D^{(*)} \tau \nu$



- Sensitivity to New Physics through the ratio

$$R(D^{(*)}) = \frac{\Gamma(\overline{B} \rightarrow D^{(*)}\tau\nu)}{\Gamma(\overline{B} \rightarrow D^{(*)}\ell\nu)} \qquad \frac{\text{signal mode}}{\text{normalization modes } \ \ell = e,\mu}$$

- Assume e, μ modes unaffected by H^-
- NP contributions expected to change both rates and kinematic distributions of the signal τ mode

Scalar helicity amplitude
$$H_S^{2HDM} \approx H_S^{SM} \times \left(1 - \frac{\tan^2\beta}{m^2_{H^\pm}} \frac{q^2}{1 \mp m_c/m_b}\right)$$
$-$ for $B \rightarrow D\tau\upsilon$
$+$ for $B \rightarrow D^*\tau\upsilon$

- Several theoretical (V_{cb}, FF) and experimental uncertainties cancel in the ratio
  - SM theoretical uncertainties: $\sigma^{th}(R(D)) < 6\%$, $\sigma^{th}(R(D^*)) < 2\%$
- Use leptonic τ decays to further reduce systematic uncertainties
  - same reconstructed final state for signal and normalizations channels
  - but 3 neutrinos in the final state of the signal mode

B → $D^{(*)}$ τ ν: fits and results

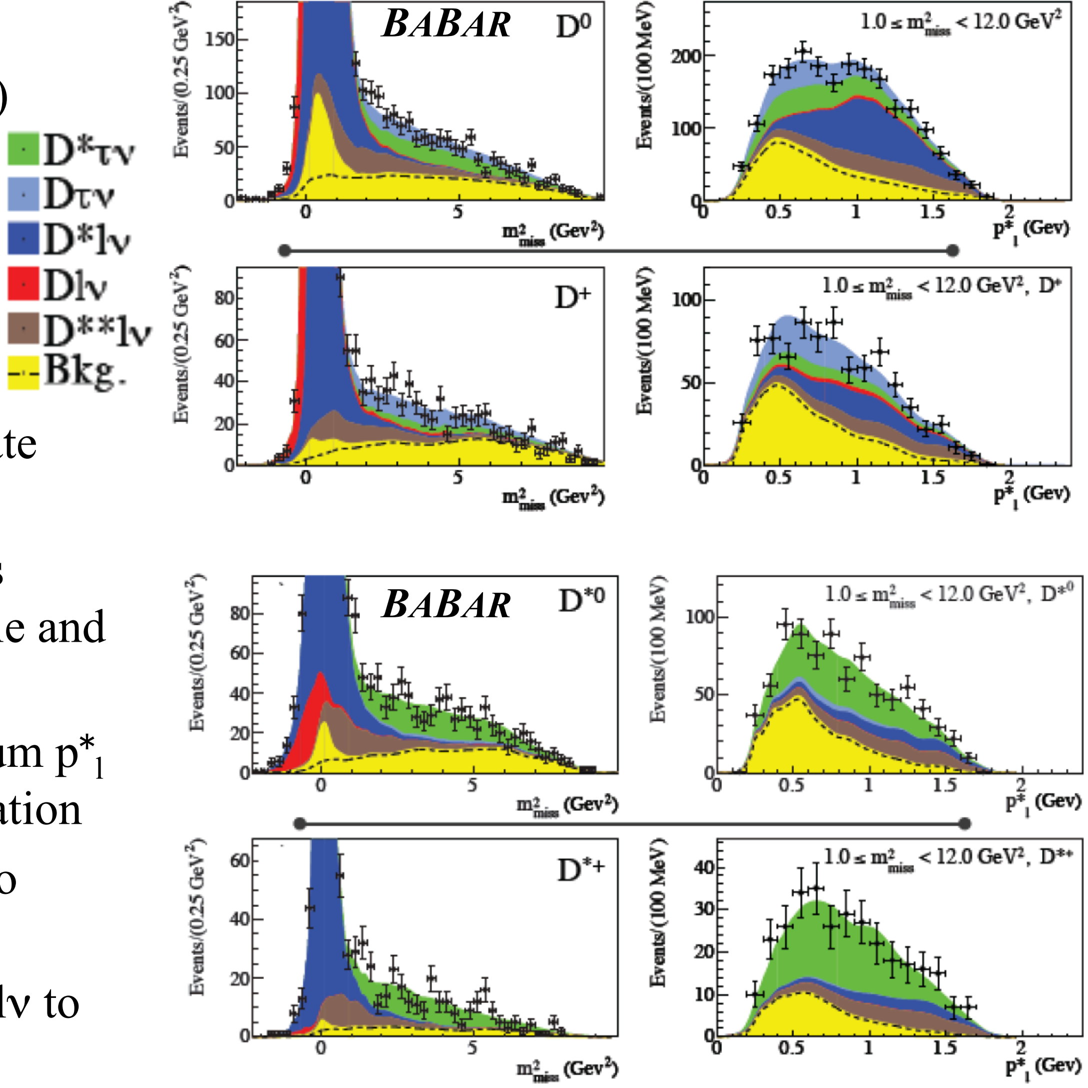
New analysis:

- x2 luminosity
- x3 higher efficiency (mainly ε_{tag})

Event selection:

- Reconstruct $D^{(*)}$ candidate
- Exactly one extra lepton candidate (τ→eνν,μνν)
- Multivariate analysis to suppress backgrounds (uses control sample and off-peak data)
- m_{miss} higher and lepton momentum p^*_l smaller for signal than normalization
- 2D Extended Maximum LH fit to m^2_{miss} and p^*_l to extract yields
- Simultaneous fit with $B \to D^{(*)}\pi^0 l\nu$ to account for D** contribution

BABAR, PRL **109**, 101802 (2012)



$B \to D^{(*)} \tau \nu$: results *vs* SM

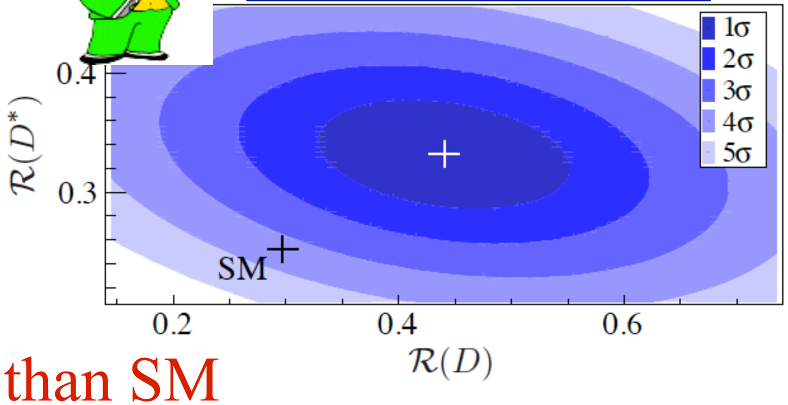
PRL **109**, 101802 (2012)

$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$

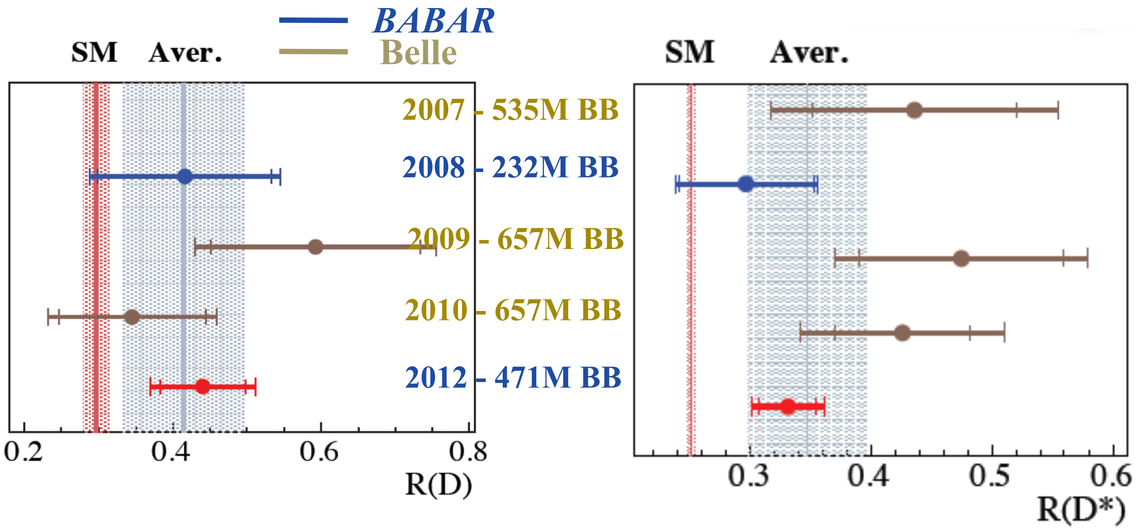
$\updownarrow$ 2.0σ $\qquad \updownarrow$ 2.7σ

$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$

SM expectations in S. Fajfer, J. Kamenik, I. Nisandzic, PRD 85, 094025 (2012).



- -27% correlation between *R(D)* and *R(D*)*
- combined *BABAR* results 3.4σ higher than SM

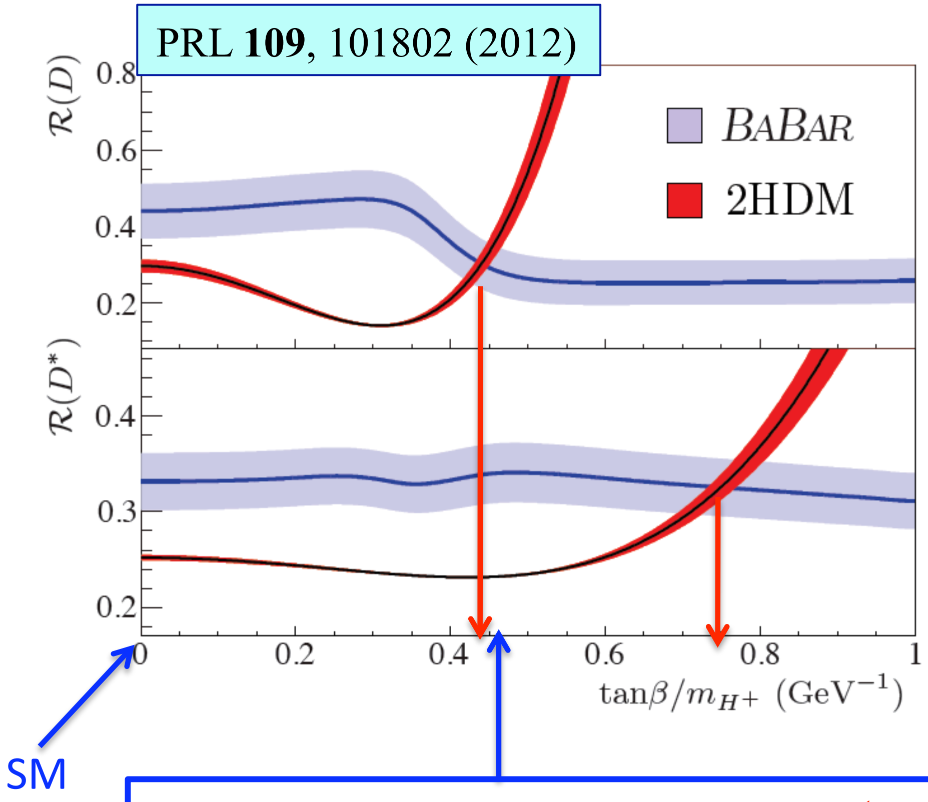


- Unpublished deviations from SM of Belle results presented at FPCP 2013 (A. Bozek)
  - *R(D*)* : 3.0σ ; *R(D)* : 1.4σ
  - Combined Belle+*BABAR*: *R*($D^{(*)}$) : 4.8σ

Averages do not include the new BABAR results

B → $D^{(*)}$ τ ν: Type II 2HDM scan

2HDM affects fit variables distributions and hence the efficiency.
==> measured $R(D^{(*)})$ are not uniform in $\tan\beta/m_{H+}$



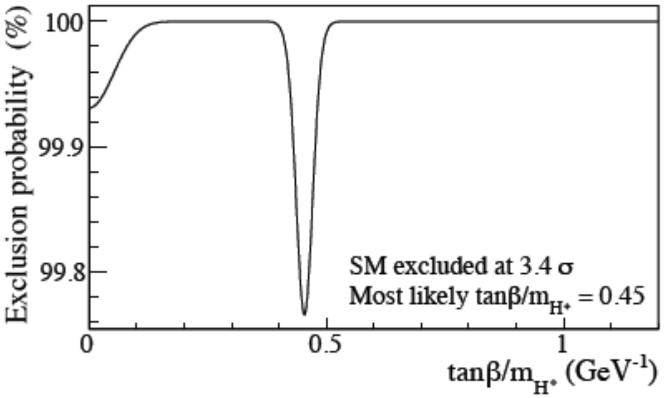
PRL **109**, 101802 (2012)

R(D):
$\tan\beta/m_{H+} = 0.44 \pm 0.02\ \mathrm{GeV}^{-1}$

R(D*):
$\tan\beta/m_{H+} = 0.75 \pm 0.04\ \mathrm{GeV}^{-1}$

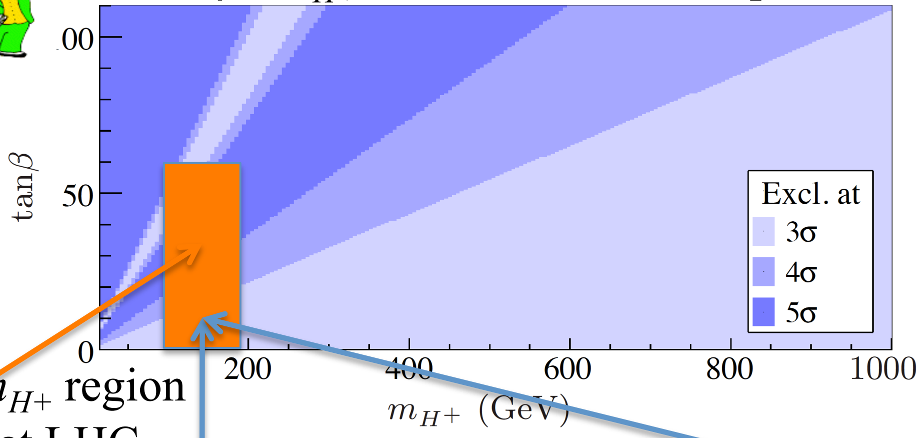
- Best point is $\tan\beta/m_{H+} \simeq 0.45\ \mathrm{GeV}^{-1}$, and it is excluded at 99.8% C.L. (3.1σ)
- All other points (with m_{H+}>15 GeV/c^2) are worse (B → $X_s\gamma$ excludes m_{H+}< 300 GeV/c^2)

Exclusion probability from combined $R(D^{(*)})$ measurements



Type-II 2HDM - connection with LHC

$\tan\beta - m_{H+}$ BABAR exclusion plot

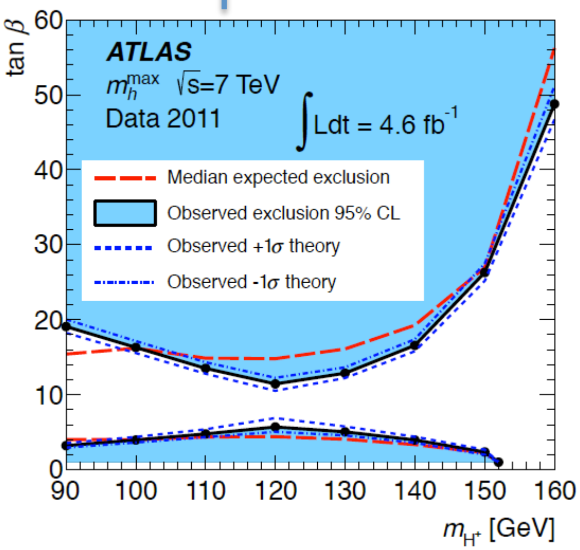


$\tan\beta - m_{H+}$ region probed at LHC

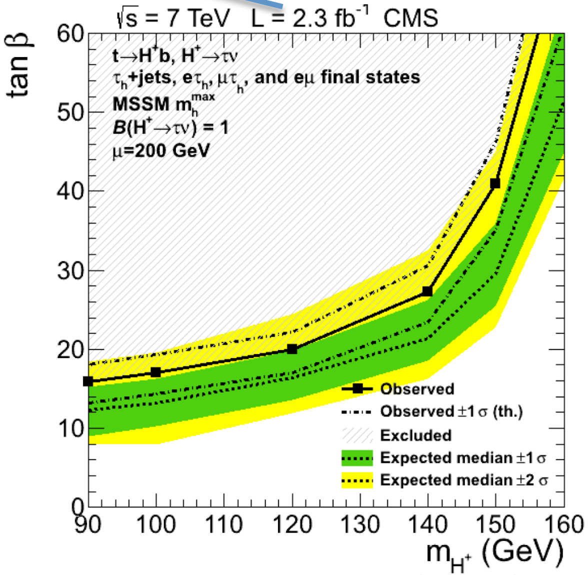
B → $D^{(*)}$ τ ν and B → τ ν searches at *B* factories are complementary to searches at LHC in

t → b H^+

→ τν



ATLAS: JHEP 1206, 039 (2012)



CMS: JHEP 07, 143 (2012)

$B \to D^{(*)} \tau \nu$: limits on Type-III 2HDM

General spin-0 interactions
$$\mathcal{H}_{\rm eff} = \frac{4G_F V_{cb}}{\sqrt{2}} \left[(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) + S_R(\bar{c}P_R b)(\bar{\tau}P_L\nu_\tau) + S_L(\bar{c}P_L b)(\bar{\tau}P_L\nu_\tau) \right]$$

Impact on $R(D^{(*)})$:
$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D {\rm Re}(S_R + S_L) + B'_D |S_R + S_L|^2$$
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} {\rm Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2$$

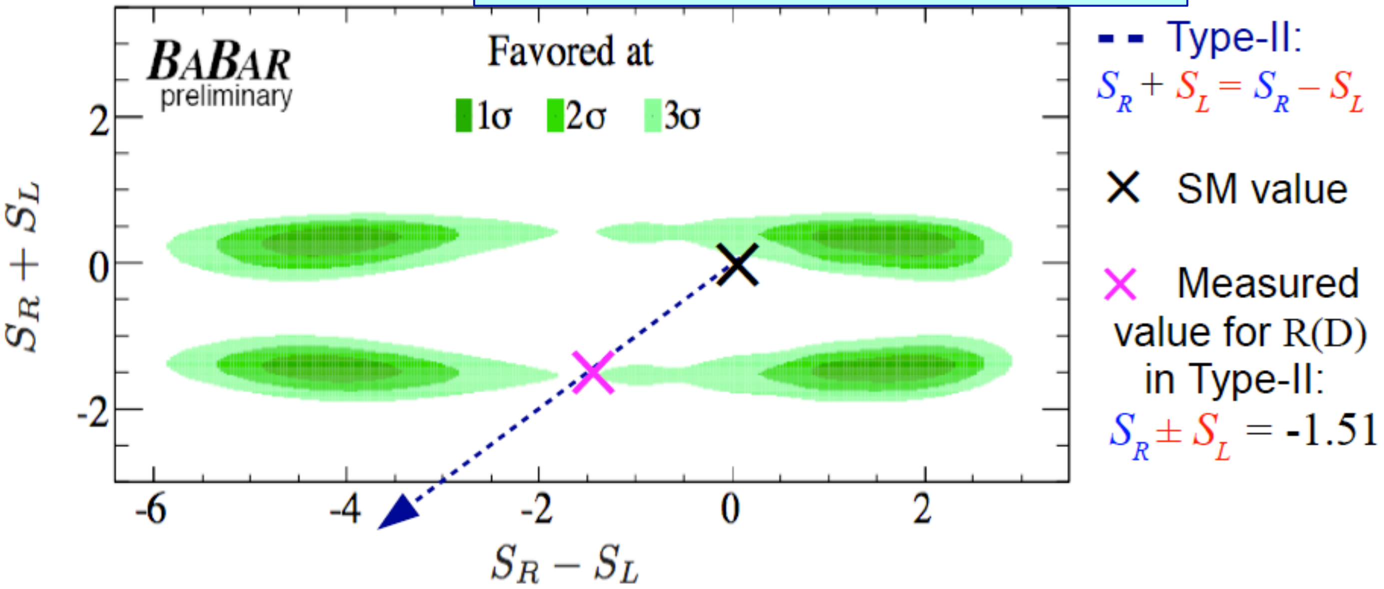
Corresponds to Type-II 2HDM case for S_L=0

Crivellin, Greub, & Kokulu, arXiv:1206.2634 (2012); Datta et al, PRD 86, 034027 (2012)

Type III
- 4 solutions for real S_R+S_L values.
- Complex values also allowed

- Type II has no solutions

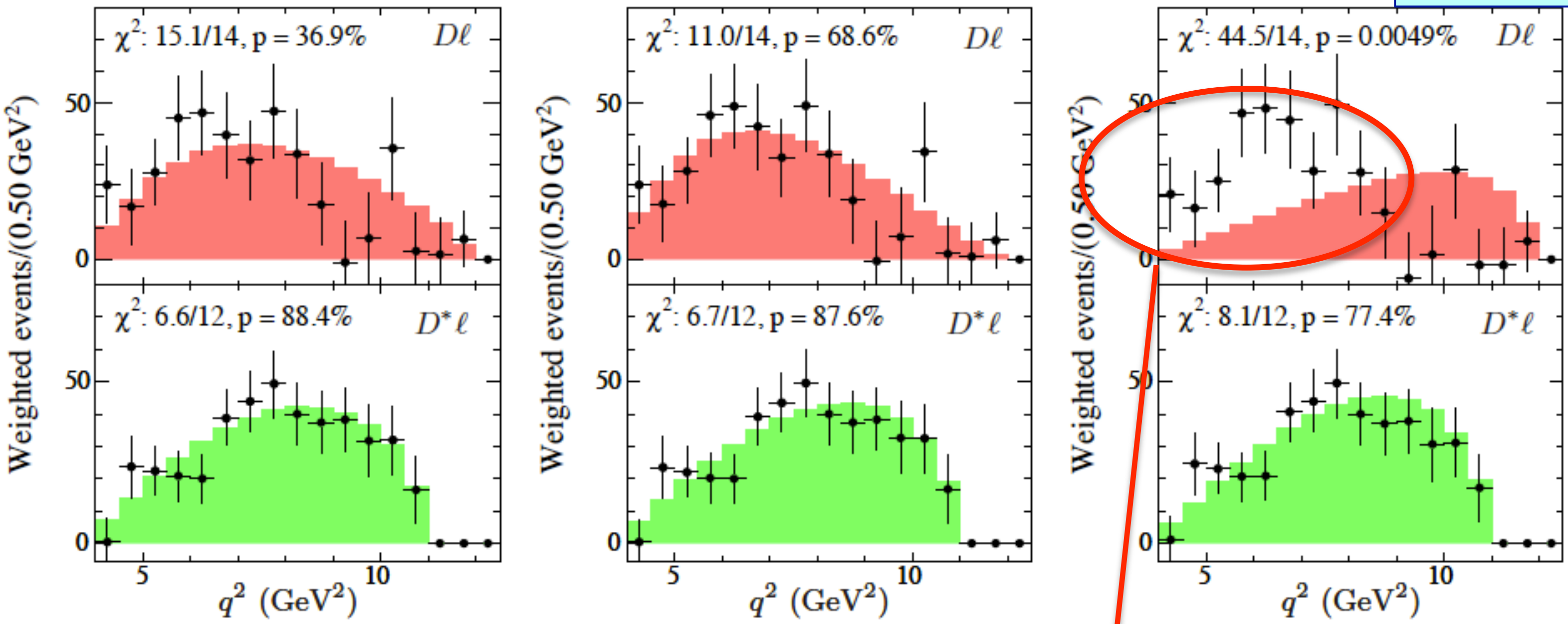
BABAR, Phys. Rev D88, 072012 (2013)



$B \to D^{(*)} \tau \nu$: information from q^2 distributions

- Background subtracted q^2 spectra compared with Model prediction
- q^2 is the momentum transferred to the leptonic system

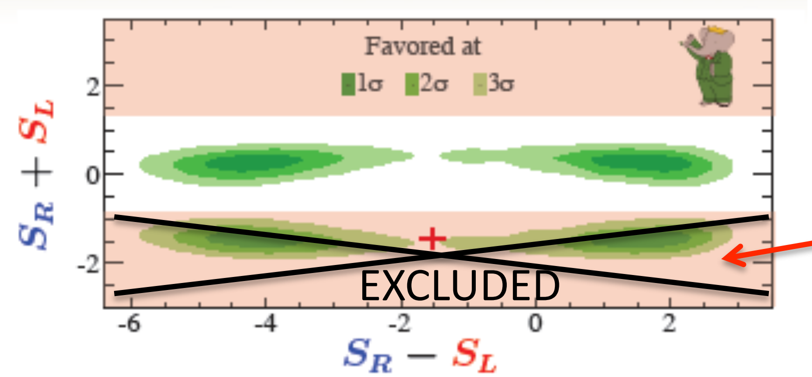
BABAR, Phys. Rev D88, 072012 (2013)



$S_R \pm S_L$=0

$S_R \pm S_L$=-0.67

$S_R \pm S_L$=-1.51



p-value for R(D) is 0.4%, excluding solutions around S_R+S_L=-1.5 with >2.9σ

Belle II
and the
SuperKEKB

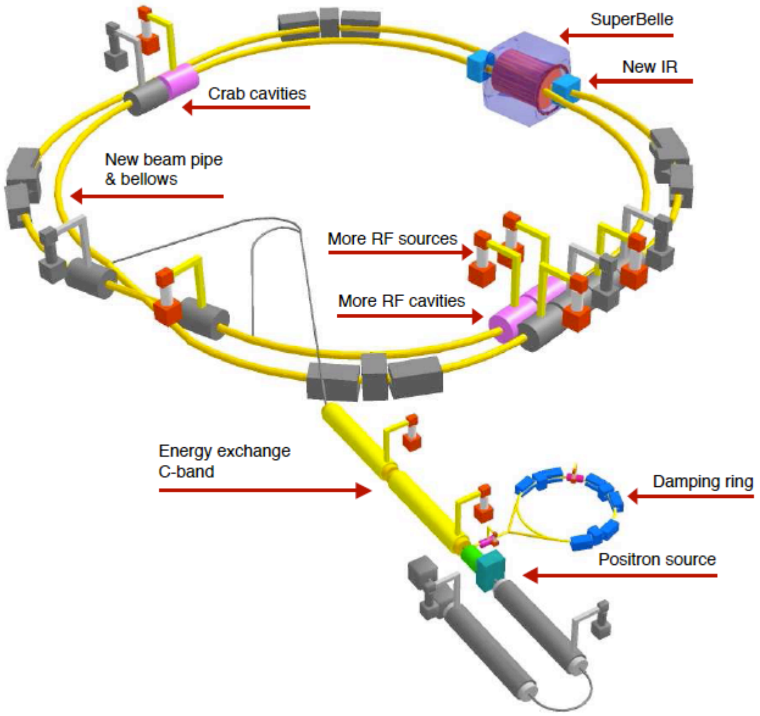
Why a super flavor factory

- Despite all valuable results from *B*-factories, many questions remain unanswered

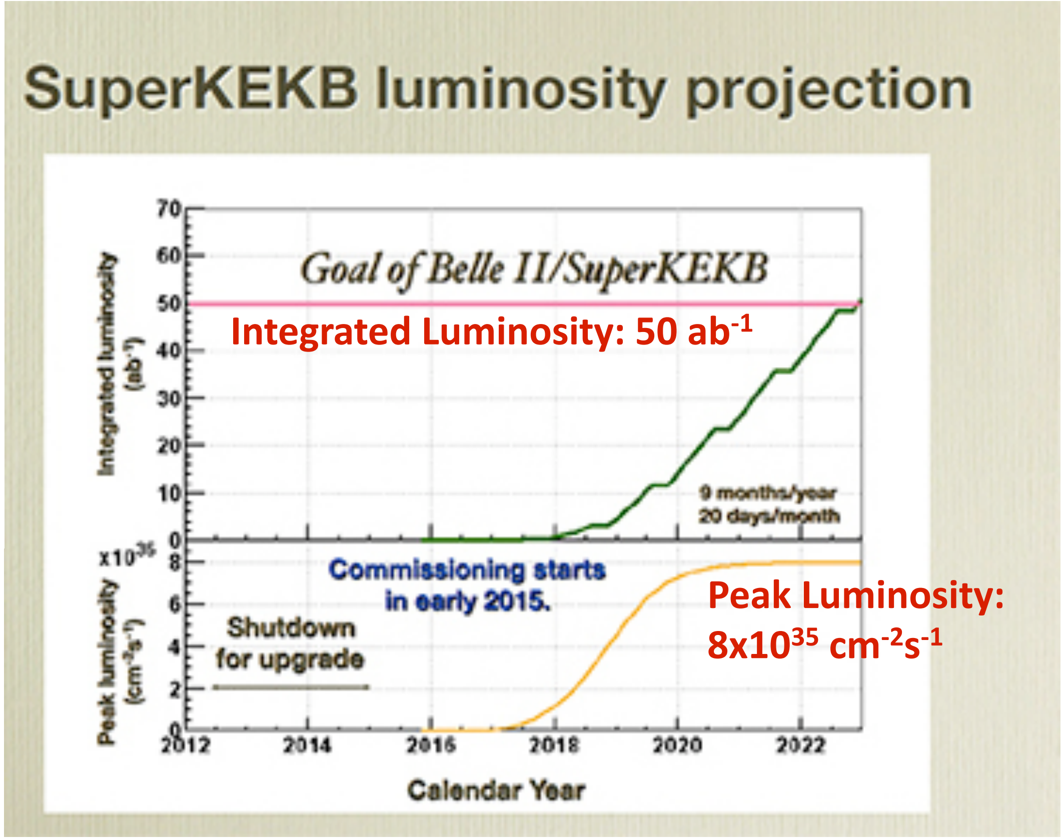
- We saw that processes that occur at one-loop level in the SM may be of *O*(1) in New Physics models: FCNC, neutral meson mixing, CP violation in B, D, τ decays. NP can be probed at energy scale not directly accessible at LHC.

- Physics motivations are complementary to LHC:
  - Search for direct production of New Physics particles at LHC can be effective for masses up to few TeV/c^2
  - If LHC finds NP, precision flavor physics is the main way to investigate its nature
  - If LHC does not find NP, high statistic B/D/τ decays would be a unique way to search for the *O*(1 TeV) (MFV scenario) up to *O*(100 TeV) scale physics
  - Complementarity between Flavor Physics program at LHC and at a super B factory

Nano-beam scheme originally proposed by P. Raimondi
for the Italian SuperB project => **x40 peak Luminosity**



Higher currents
Reduced boost: **4 GeV (e+) vs 7 GeV (e-)**
Larger crossing angle



Integrated Luminosity: 50 ab^{-1}

Peak Luminosity: 8x10^{35} cm^{-2}s^{-1}

Primary physics goals

- In three years from now LHCb and partly BESIII should have significantly improved the present *B* factory results in many processes
- Still e^+e^- colliders running at (or near) $\Upsilon(4S)$ will have considerable advantage in several classes of measurements, and will be complementary in many more

Main classes of measurements

- Missing Energy (E_{miss}):

  $\mathcal{B}(B \to \tau\nu), \mathcal{B}(B \to X_c\tau\nu), \mathcal{B}(B \to h\nu\nu),$

  invisible decays of bottom and charmed hadrons, ...
- Inclusive:

  $b \to (d,s)\gamma$ and $b \to (d,s)\ell^+\ell^-$ (rate, asymmetries,...) ...
- Neutrals:

  $S(B \to K_S\pi^0\gamma), S(B \to \eta' K_S), S(B \to K_S K_S K_S), \mathcal{B}(B \to K_S\pi^0\gamma), \mathcal{B}(B \to K_S\pi^0\gamma),$

  $\tau \to \mu\gamma$, Low mass CP – odd Higgs and Dark bosons searches,....

For detail descriptions of the physics program at a SuperB factory, see:

- Physics at Super B Factory (Belle II) arXiv:1002.5012
- SuperB Progress Reports: Physics (SuperB) arXiv:1008.1541

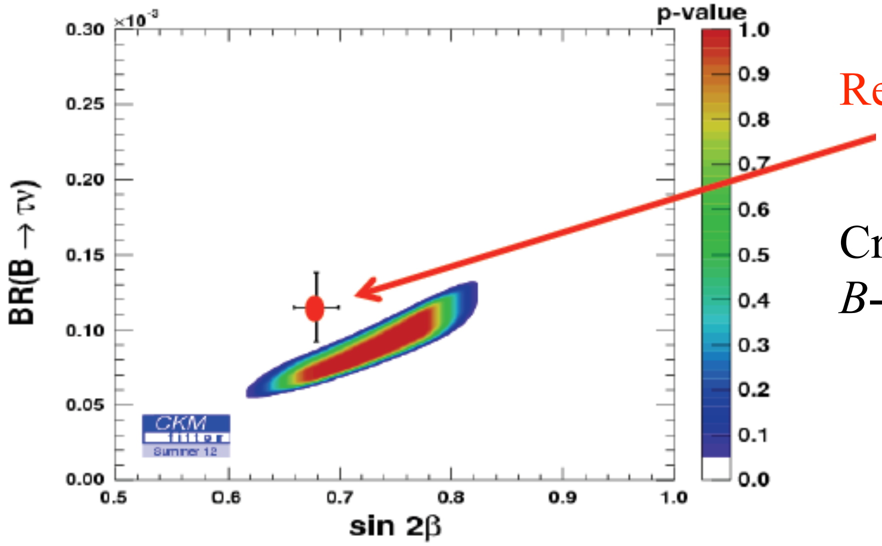
$B \to \tau\nu$

- Particularly sensitive to NP, because of helicity supression
- Small tension with sin2β and V_{ub} with present measurements

- Can be precisely (~3% error) measured at Belle II

- ECL (= extra energy in the calorimeter) is the the key variable for the measurement,
  - large machine background (environment significantly worse than in Belle)

  ==> crucial role of the EM calorimeter



Red contour: expectation on $\mathcal{B}(B \to \tau\nu)$ vs sin2β at $50ab^{-1}$

Cross: values at 1σ measured at present *B*-factories

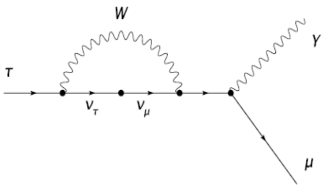
$\sigma_{\sin 2\beta} \approx 0.012$ @ 50ab-1 (now 0.02)

$\sigma_{\mathcal{B}(B \to \tau\nu)} \approx 0.03$ @ 50ab-1 (now 0.23)

LFV in τ decays

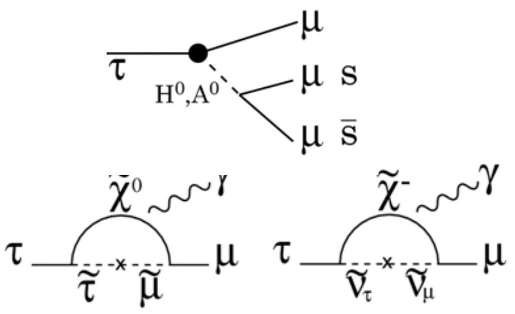
- LFV not forbidden by SM gauge symmetry
- SM extended to include ν mixing predicts LFV of $O(10^{-54})$
- Any observation of LFV in lepton decays would mean NP
- Most of NP models predicts τ LFV *BF* of $O(10^{-7}-10^{-10})$
- advantgae of using τ :
  - enhanced coupling to NP particles , many different decays ==> tests of different models
- Eventually ratio of *BF*'s can distinguish among models

LFV in SM



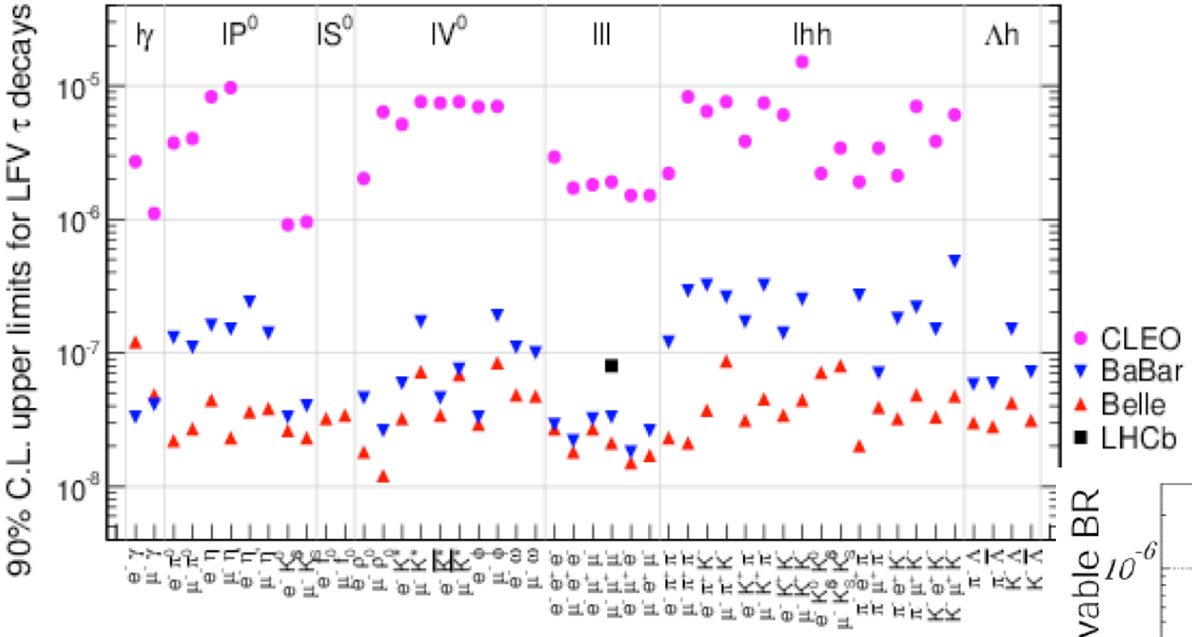
		$\tau\to\mu\gamma$	$\tau\to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	10^{-54} – 10^{-40}	10^{-40}
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

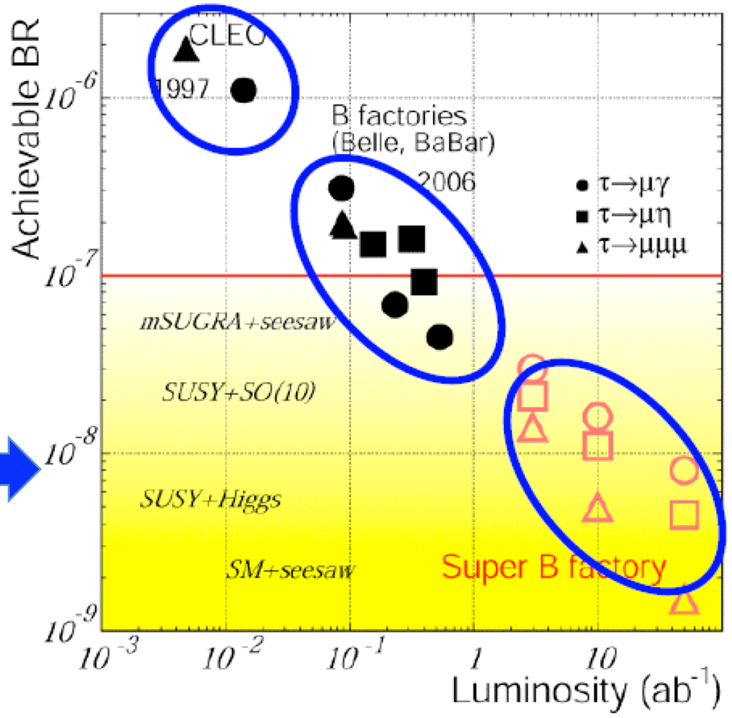
Examples of LFV beyond SM



LFV in τ decays

48 modes analysed by Belle and *BABAR*





Expect about one order improvement on sensitivity with 50 ab^{-1}:

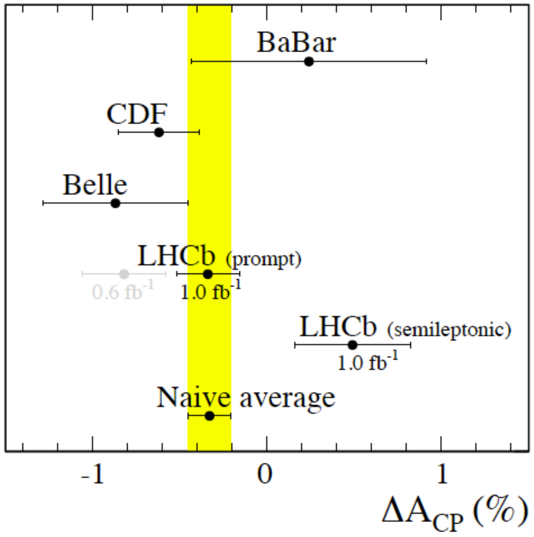
- $\mathcal{B}(\tau \to \mu\gamma) < 10^{-8}$
- $\mathcal{B}(\tau \to lll) \sim 10^{-9}$ or better

Examples of NP search in charm decays

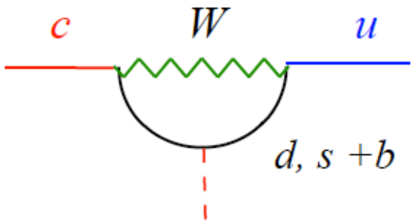
- CPV in D^0-$\overline{D}^0$ mixing.
  - New HFAG average [March '13]

$$\Delta a_{CP}^{\text{dir}} = (-0.33 \pm 0.12)\%$$

  - LHCb should set the best results, but a cross checks from the SuperB is mandatory



- Radiatve D decays (D→ $X_u\gamma$, D→ $X_u l^+ l^-$)
  - $c \to u$ transitions
  - FCNC in the up sector can be different from those in the down sector (b → s,d and s→ d)
  - in particular no top-enhancement in c → u
  - Belle II can study them, tagging the ccbar events by reconstruction of the other "D" (technique already used for measuring absolute Ds BFs)

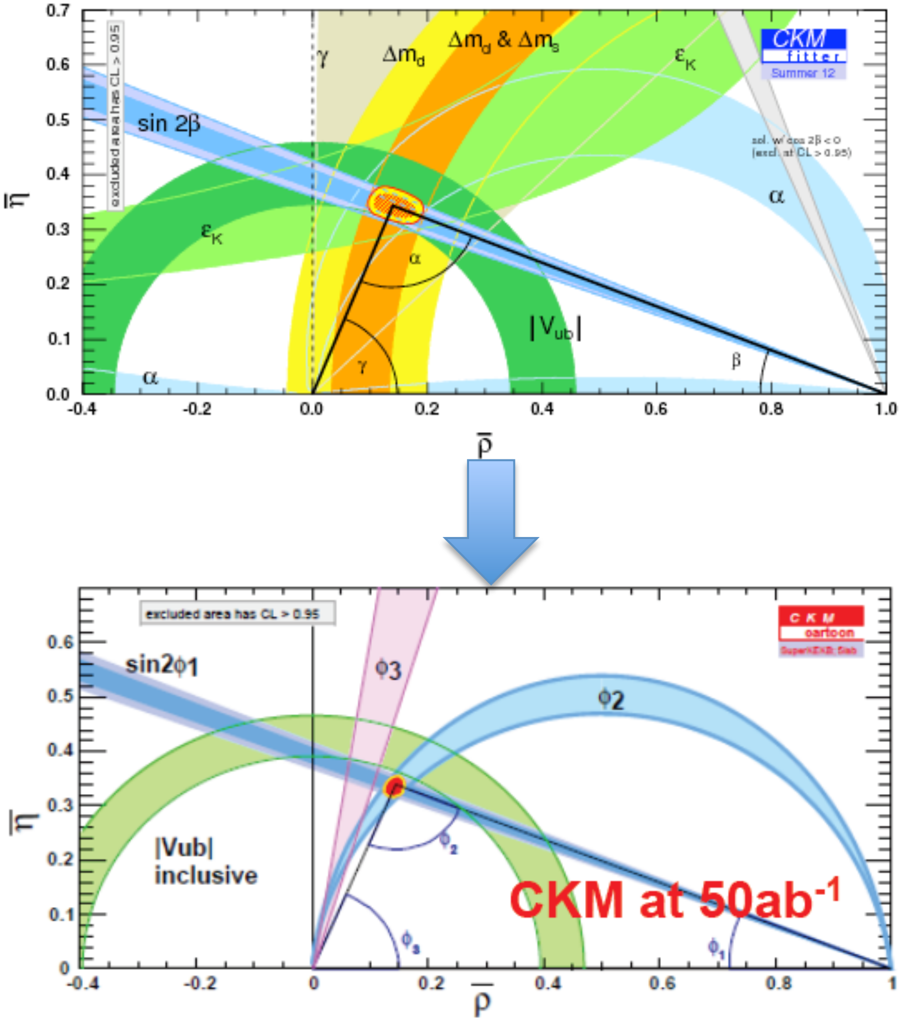


Belle II physics reach: a compact summary

	Belle' 06 (~0.5ab^{-1})	5ab^{-1}	50ab^{-1}
$\Delta S(\phi K^0)$	0.22	0.073	0.029
$\Delta S(\eta' K^0)$	0.11	0.038	0.020
$\Delta S(K_S K_S K_S)$	0.33	0.105	0.037
$\Delta S(K_S \pi^0 \gamma)$	0.32	0.10	0.03
$Br(X_s\gamma)$	13%		
$A_{CP}(X_s\gamma)$	0.058	0.01	0.005
C_9 [$A_{FB}(K^*ll)$]	---	11%	4%
C_{10} [$A_{FB}(K^*ll)$]	---	13%	4%
$Br(B^+ \to K^+\nu\nu)$	<9Br(SM)	33ab^{-1} for 5σ discovery	
$Br(B^+ \to \tau\nu)$	3.5σ	10%	3%
$Br(B^+ \to \mu\nu)$	<2.4Br(SM)	4.3ab^{-1} for 5σ discovery	
$Br(B^+ \to D\tau\nu)$	---	7.9%	2.5%
$Br(\tau \to \mu\gamma)$	<45	<30	<8
$Br(\tau \to \mu\eta)$	<65	<20	<4
$Br(\tau \to 3\mu)$	<209	<10	<1
$\Delta\sin 2\phi_1$	0.026	0.016	0.012
$\Delta\Phi_2$ ($\rho\pi$)	68°—95°	3°	1°
$\Delta\Phi_3$(Dalitz)	20°	7°	2.5°
ΔV_{ub} (incl.)	7.3%	6.6%	6.1%

$\left.\right\}$ X10^{-9}

Expected improvement in the determination of the CKM parameters



Conclusions

- The *B* factories continue to produce new and unique results
  - The *B*-factories Physics Book will summarize their achievements
- *BABAR* and Belle are completing the CKM related program
  - The CKM picture of CP violation describes generally well the data
- Rare decays and *B* decays to a τ are ideal places to look for NP effects
  - 3.4σ tension with SM in *BABAR* $B \rightarrow D^{(*)}\tau\nu$ decays. This result can be checked with additional measurements already at Belle and *BABAR*
- A significant part of physics programs are on exploring new areas, not in the originl *B*-factories' physics program, as :

==> *B* factories will continue to produce interesting results, until Belle II and SuperKEKB will be fully operational

- The unique features of SuperKEKB will allow Belle II to perform a physics program at the intensity frontier complementary to that of LHC

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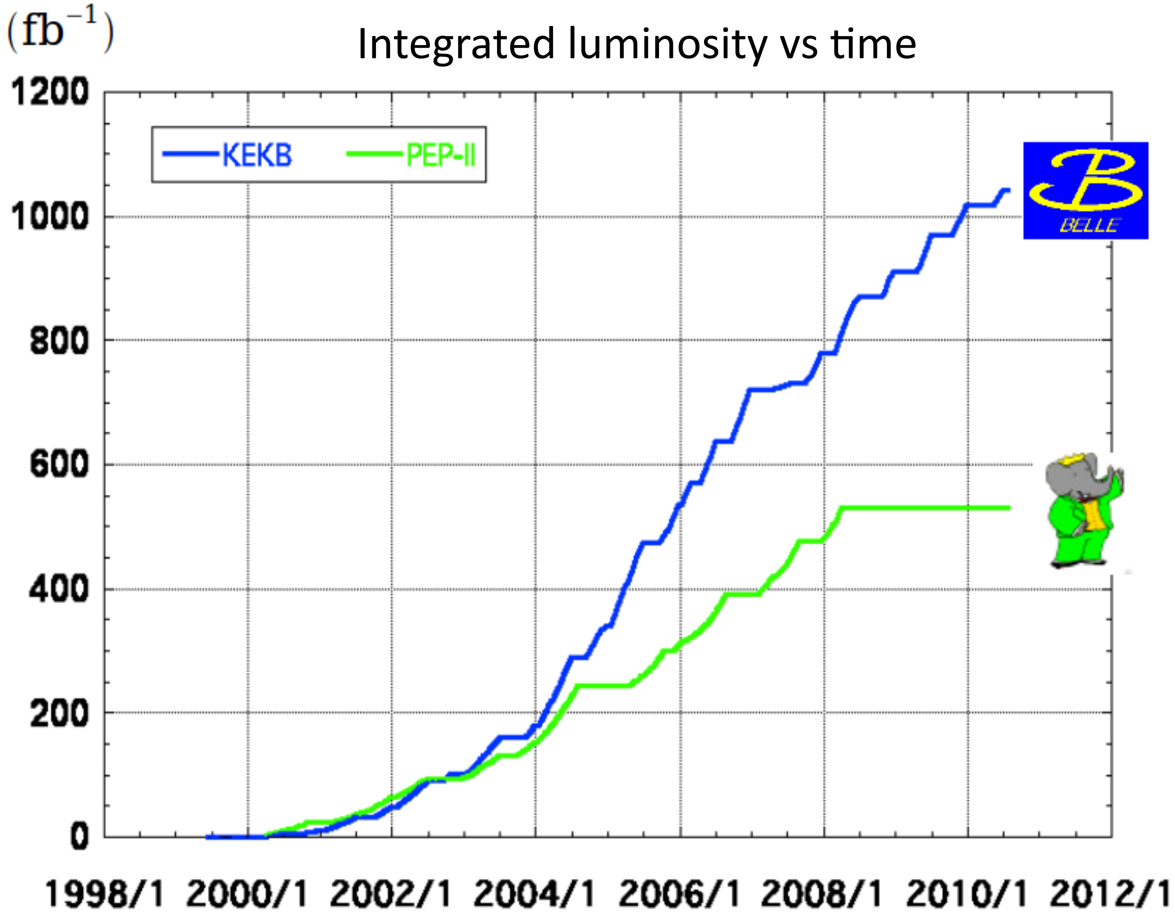
Thank you!

Backup Slides

Luminosity and data sets

- Performances far beyond design…

Integrated luminosity vs time



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

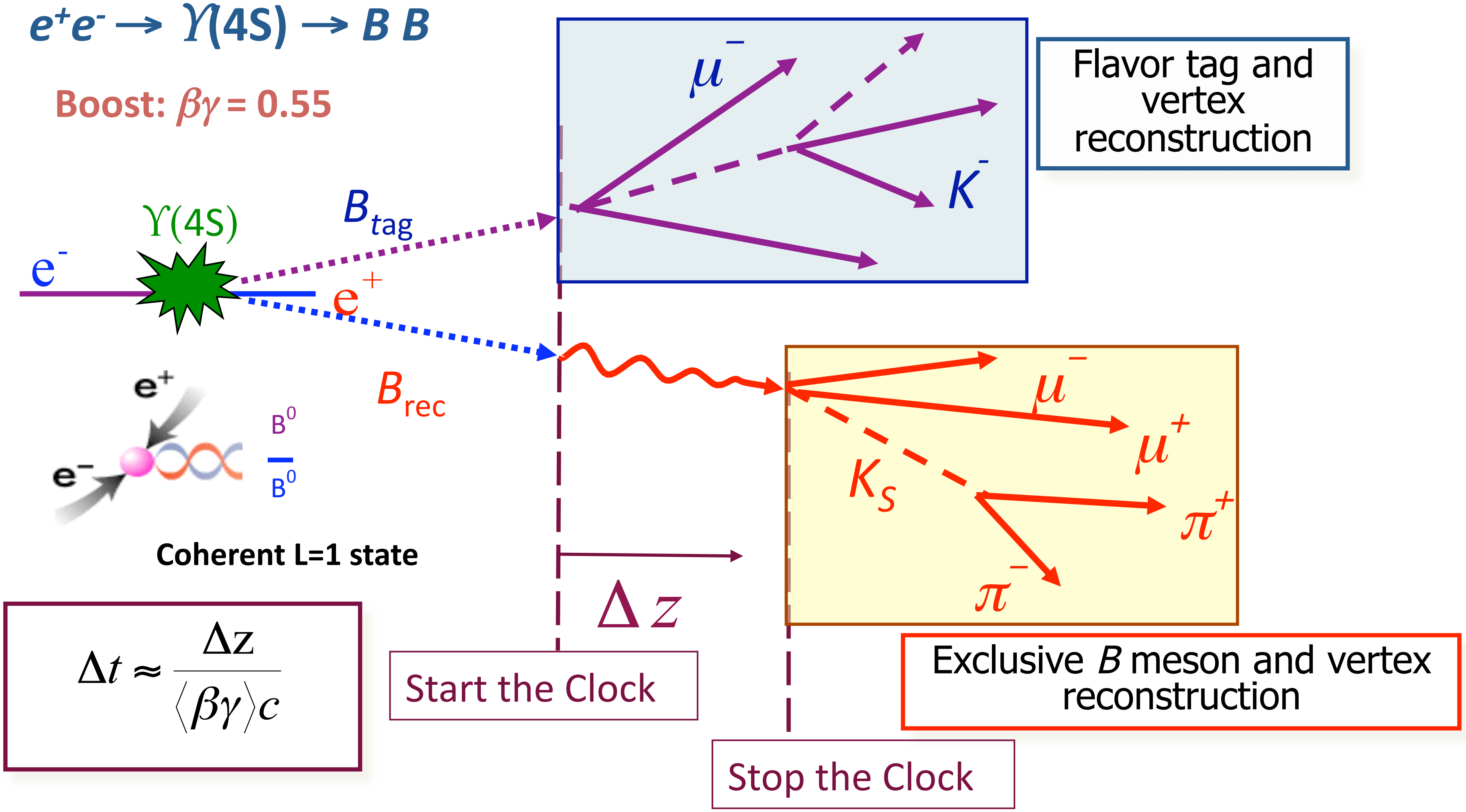
~ 54 fb^{-1}

- More than 96% of the delivered luminosity was recorded by the experiments

Experimental Techniques

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

Boost: $\beta\gamma = 0.55$



Coherent L=1 state

Flavor tag and vertex reconstruction

Exclusive *B* meson and vertex reconstruction

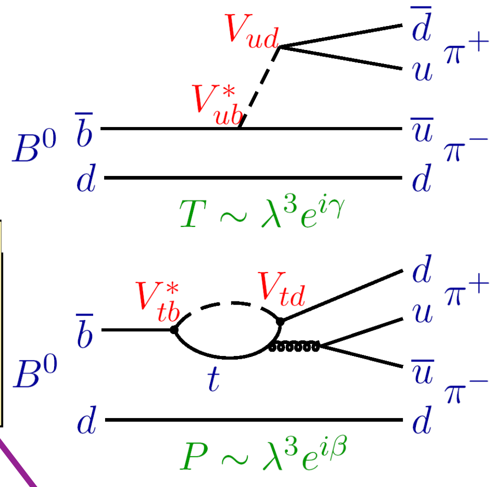
Start the Clock

Stop the Clock

$$\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle c}$$

Isospin relations for measuring α

- Penguin diagram (with weak phase β) sizable
- Non negligible shift on α measured from Time Dependent *CP* asymmetries



$$\lambda_{h^+h^-} = e^{i2\alpha}\frac{T + Pe^{+i\gamma}e^{i\delta}}{T + Pe^{-i\gamma}e^{i\delta}}$$

$$C_{hh} \propto \sin\delta$$

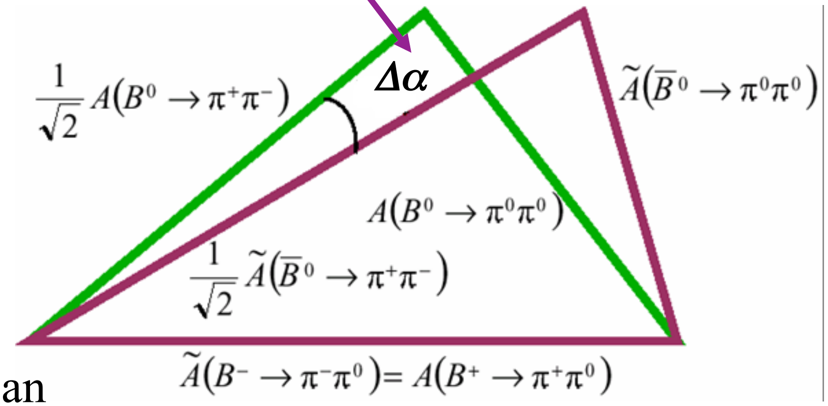
$$S_{hh} = \sqrt{1-C_{hh}^2}\,\sin 2\alpha_{eff} = \sin(2\alpha + 2\Delta\alpha)$$

- Δα from Isospin Analysis (Gronau & London, PRL 65 3381 (1990)
- Assuming SU2:

$$\boldsymbol{B\ decays} \Rightarrow A^{+-} = \sqrt{2}A^{+0} - \sqrt{2}A^{00}$$

$$\boldsymbol{\bar{B}\ decays} \Rightarrow \bar{A}^{+-} = \sqrt{2}\bar{A}^{+0} - \sqrt{2}\bar{A}^{00}$$

- Need to measure all isospin related decays
  - B/Bbar → $\pi^+\pi^-,\pi^+\pi^0,\pi^0\pi^0$
  - B/Bbar → $\rho^+\rho^-,\rho^+\rho^0,\rho^0\rho^0$
  - B/Bbar → $\rho^+\pi^-,\rho^+\pi^0,\rho^0\pi^0$
  - ...
- Alternative flavour SU(3) based approach can be used to constrain penguin pollution, i.e. Δα



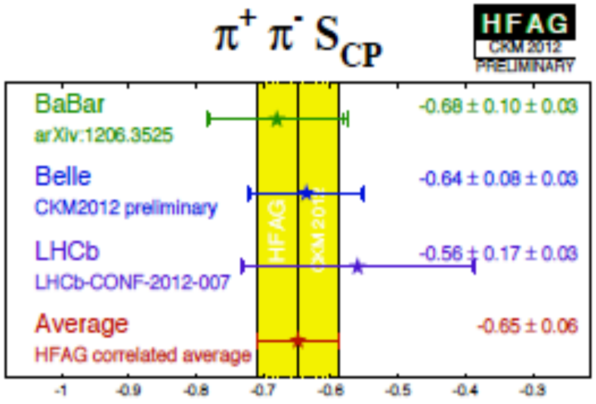
$\sin2\alpha$ ($\alpha \equiv \phi_2$)

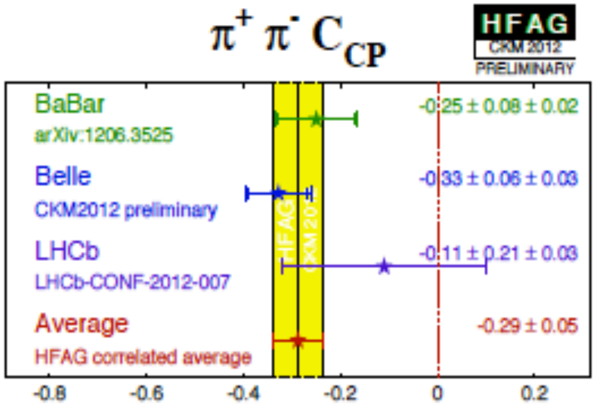
- The study of the three main systems to extract α, that is $\pi\pi$, $\rho\rho$, and $\rho\pi$, is almost completed by both experiments, using the full data sets:
- $B \rightarrow \pi\pi$:
  - Recently published result on $B \rightarrow \pi^+\pi^-$ from BABAR and Belle
  - BABAR published also $B \rightarrow \pi^0\pi^0$ on full dataset
- $B \rightarrow \rho\rho$:
  - VV final state, not pure CP eigenstate, => helicity analysis to measure CP
  - $B \rightarrow \rho^+\rho^-$: old BABAR ($384\text{x}10^6$ BB pairs) and Belle ($535\text{x}10^6$ BB pairs)
  - $B \rightarrow \rho^0\rho^0$: full dataset from BABAR (2008) and Belle (NEW arXiv: 1212.4015)
- $B \rightarrow (\rho\pi)^0$:
  - requires a Dalitz plot analysis
  - old Belle results (2007) on $\sim 450\text{x}10^6$ BB pairs
  - NEW result from BABAR (ref.) ==> warning about lack of robustness in extracting a with current statistics!

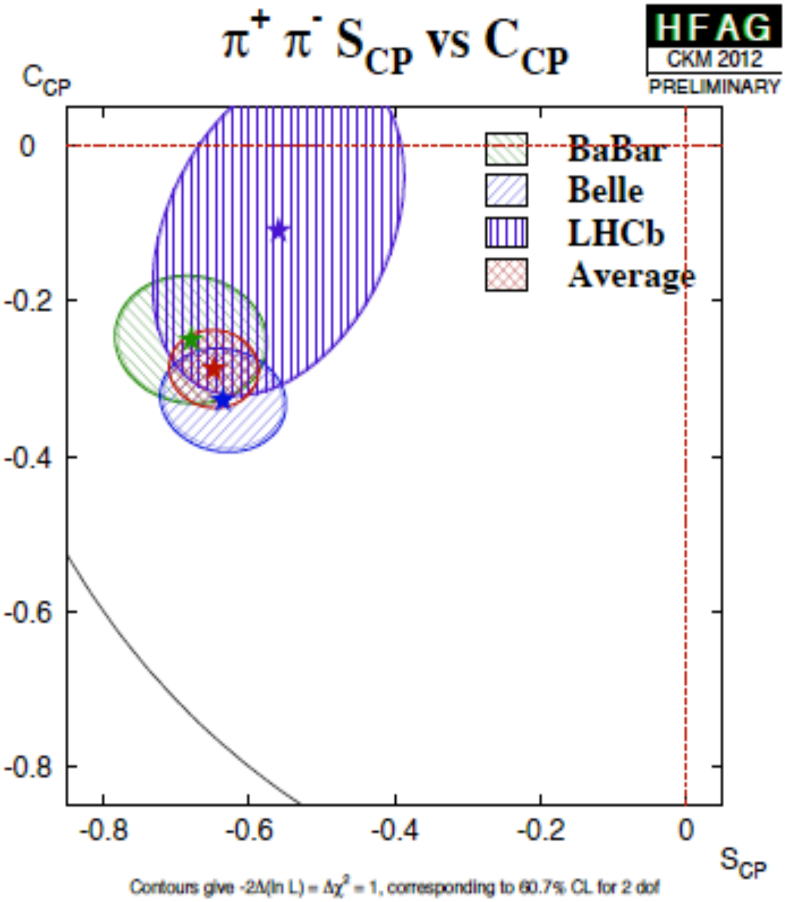
$B \to \pi^+\pi^-$

World averages

$$\boxed{\mathcal{C}_{CP} = -\mathcal{A}_{CP}}$$







⇒ good agreements between experiments (prev. tension removed)

CKM summary: the angles

Average of *B* factories results

$\beta = \phi_1 = (21.4 \pm 0.8)^o$

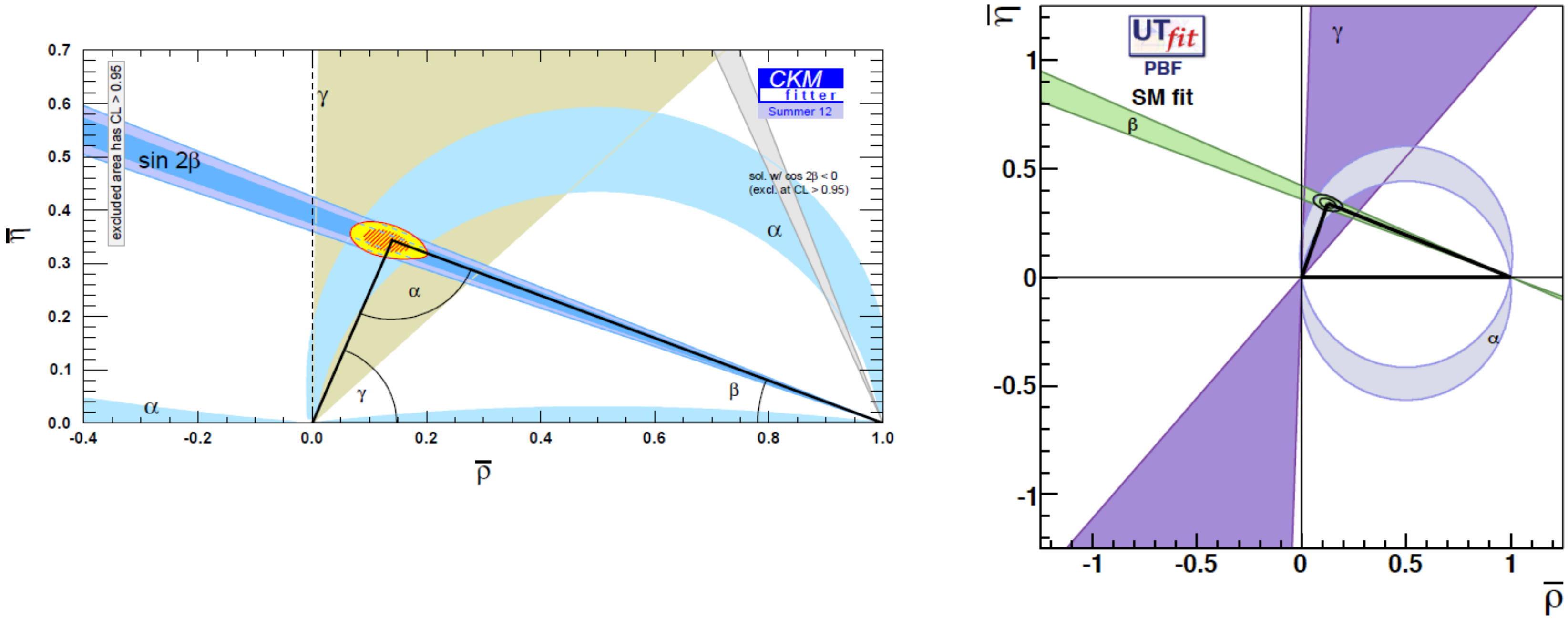
$\alpha = \phi_2 = (88.5 \pm 4.5)^o$

$\gamma = \phi_3 = (67 \pm 11)^o$

$\alpha + \beta + \gamma = (177 \pm 12)^o$

- Good agreement with SM
- Need to improve precision on γ (and α) to better overconstrain the CKM with angles only

$(\bar{\rho},\bar{\eta})$ constraints from fit to angles only



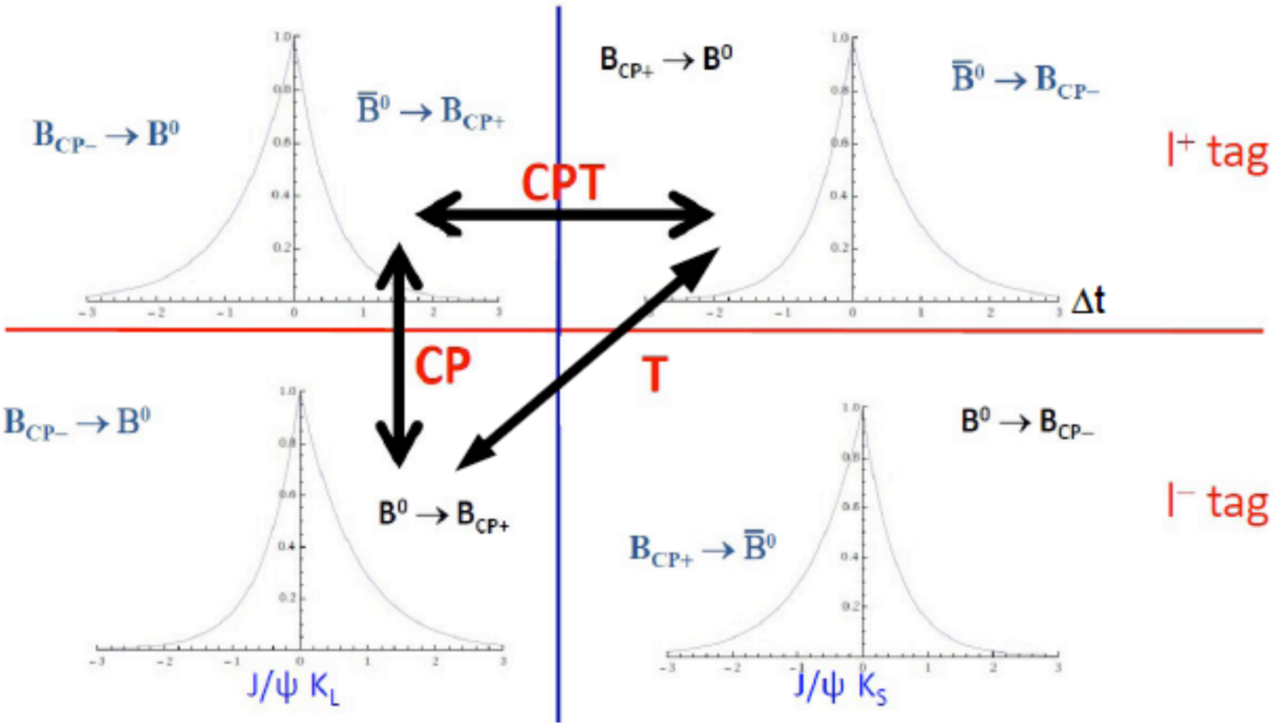
Transformed processes

JHEP08 (2012) 064

- Define processes of interest and their T-transformed counterparts
- In total we can build 4 independent T comparisons (and 4 CP, and 4 CPT)

Expected "signed" decay time distributions

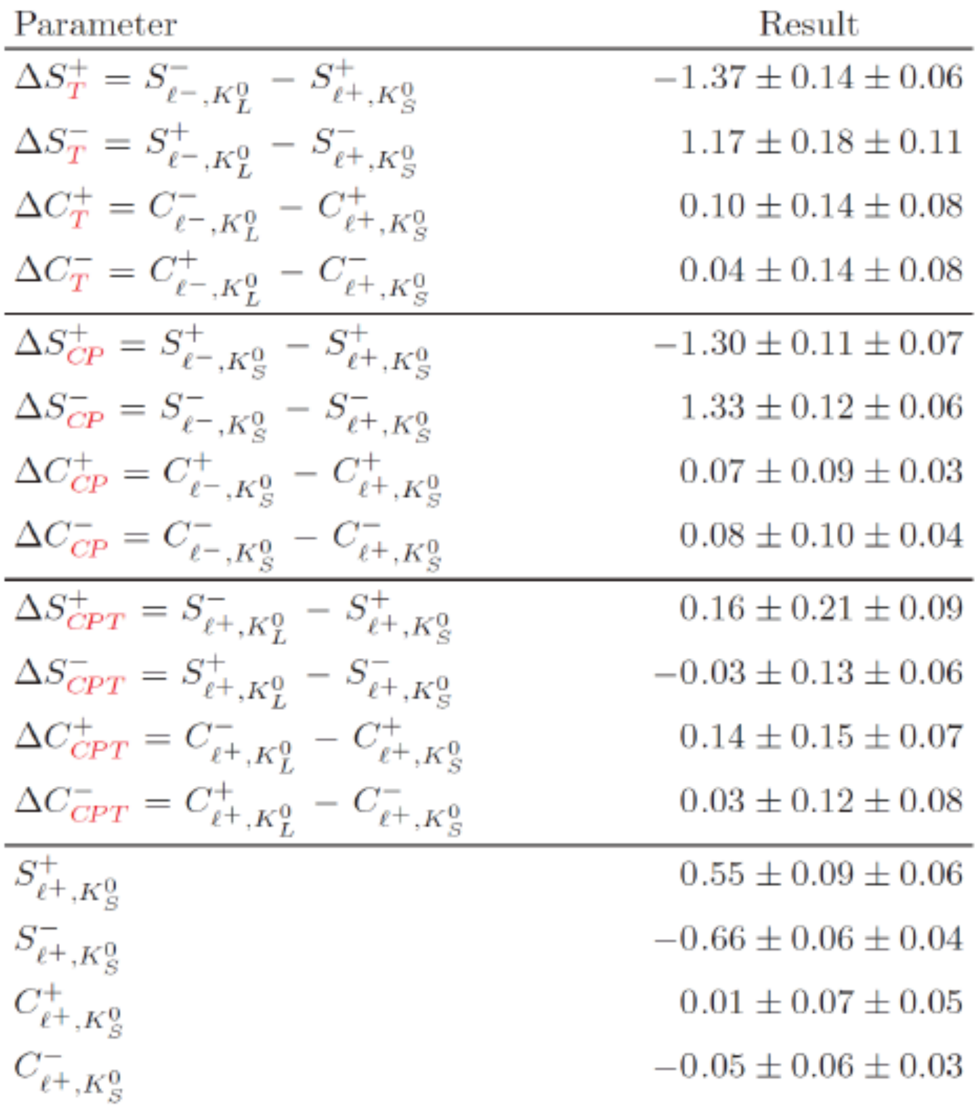
$$\Delta t = t_{CP} - t_{flav} = \Delta z/\beta\gamma c$$



T implies comparison of:
- ✓ Opposite Δt sign
- ✓ Opposite CP states
- ✓ Opposite flavor states

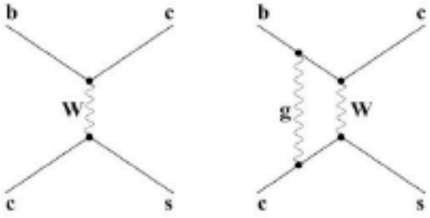
$B^0 \to B_{CP+}\ (l^-, J/\psi\ K_L)$	$\xrightarrow{T}$	$B_{CP+} \to B^0\ (J/\psi\ K_S, l^+)$
$B^0 \to B_{CP-}\ (l^-, J/\psi\ K_S)$		$B_{CP-} \to B^0\ (J/\psi\ K_L, l^+)$
$\bar{B}^0 \to B_{CP+}\ (l^+, J/\psi\ K_L)$		$B_{CP+} \to \bar{B}^0\ (J/\psi\ K_S, l^-)$
$\bar{B}^0 \to B_{CP-}\ (l^+, J/\psi\ K_S)$		$B_{CP-} \to \bar{B}^0\ (J/\psi\ K_L, l^-)$

TRV: results



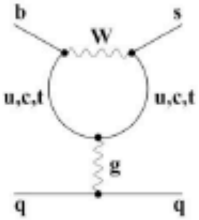
	Parameter	Result	Expected value (given CPV)
TV	$\Delta S_T^+ = S^-_{\ell^-,K_L^0} - S^+_{\ell^+,K_S^0}$	$-1.37 \pm 0.14 \pm 0.06$	-1.4
	$\Delta S_T^- = S^+_{\ell^-,K_L^0} - S^-_{\ell^+,K_S^0}$	$1.17 \pm 0.18 \pm 0.11$	1.4
	$\Delta C_T^+ = C^-_{\ell^-,K_L^0} - C^+_{\ell^+,K_S^0}$	$0.10 \pm 0.14 \pm 0.08$	0.0
	$\Delta C_T^- = C^+_{\ell^-,K_L^0} - C^-_{\ell^+,K_S^0}$	$0.04 \pm 0.14 \pm 0.08$	0.0
CPV	$\Delta S_{CP}^+ = S^+_{\ell^-,K_S^0} - S^+_{\ell^+,K_S^0}$	$-1.30 \pm 0.11 \pm 0.07$	-1.4
	$\Delta S_{CP}^- = S^-_{\ell^-,K_S^0} - S^-_{\ell^+,K_S^0}$	$1.33 \pm 0.12 \pm 0.06$	1.4
	$\Delta C_{CP}^+ = C^+_{\ell^-,K_S^0} - C^+_{\ell^+,K_S^0}$	$0.07 \pm 0.09 \pm 0.03$	0.0
	$\Delta C_{CP}^- = C^-_{\ell^-,K_S^0} - C^-_{\ell^+,K_S^0}$	$0.08 \pm 0.10 \pm 0.04$	0.0
CPTV	$\Delta S_{CPT}^+ = S^-_{\ell^+,K_L^0} - S^+_{\ell^+,K_S^0}$	$0.16 \pm 0.21 \pm 0.09$	0.0
	$\Delta S_{CPT}^- = S^+_{\ell^+,K_L^0} - S^-_{\ell^+,K_S^0}$	$-0.03 \pm 0.13 \pm 0.06$	0.0
	$\Delta C_{CPT}^+ = C^-_{\ell^+,K_L^0} - C^+_{\ell^+,K_S^0}$	$0.14 \pm 0.15 \pm 0.07$	0.0
	$\Delta C_{CPT}^- = C^+_{\ell^+,K_L^0} - C^-_{\ell^+,K_S^0}$	$0.03 \pm 0.12 \pm 0.08$	0.0
Reference	$S^+_{\ell^+,K_S^0}$	$0.55 \pm 0.09 \pm 0.06$	0.7
	$S^-_{\ell^+,K_S^0}$	$-0.66 \pm 0.06 \pm 0.04$	-0.7
	$C^+_{\ell^+,K_S^0}$	$0.01 \pm 0.07 \pm 0.05$	0.0
	$C^-_{\ell^+,K_S^0}$	$-0.05 \pm 0.06 \pm 0.03$	0.0

Operator Product Expansion (OPE)



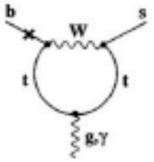
Current-current

$$\begin{cases} \mathcal{O}_1 = (\bar{s}_L \gamma_\mu T^a c_L)\,(\bar{c}_L \gamma^\mu T^a b_L)\,, \\ \mathcal{O}_2 = (\bar{s}_L \gamma_\mu c_L)\,(\bar{c}_L \gamma^\mu b_L)\,, \end{cases}$$



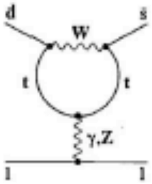
QCD penguin

$$\begin{cases} \mathcal{O}_3 = (\bar{s}_L \gamma_\mu b_L) \sum_q (\bar{q}\gamma^\mu q)\,, \\ \mathcal{O}_4 = (\bar{s}_L \gamma_\mu T^a b_L) \sum_q (\bar{q}\gamma^\mu T^a q)\,, \\ \mathcal{O}_5 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q)\,, \\ \mathcal{O}_6 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q)\,, \end{cases}$$



Magnetic operator

$$\begin{cases} \mathcal{O}_7 = \frac{e}{g_s^2} m_b\,(\bar{s}_L \sigma^{\mu\nu} b_R)\,F_{\mu\nu}, \\ \mathcal{O}_8 = \frac{1}{g_s} m_b\,(\bar{s}_L \sigma^{\mu\nu} T^a b_R)\,G^a_{\mu\nu}, \end{cases}$$



Vector electroweak penguin

Axial-vector electroweak penguin

$$\begin{cases} \mathcal{O}_9 = \frac{e^2}{g_s^2} (\bar{s}_L \gamma_\mu b_L) \sum_\ell (\bar{\ell}\gamma^\mu \ell)\,, \\ \mathcal{O}_{10} = \frac{e^2}{g_s^2} (\bar{s}_L \gamma_\mu b_L) \sum_\ell (\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \end{cases}$$

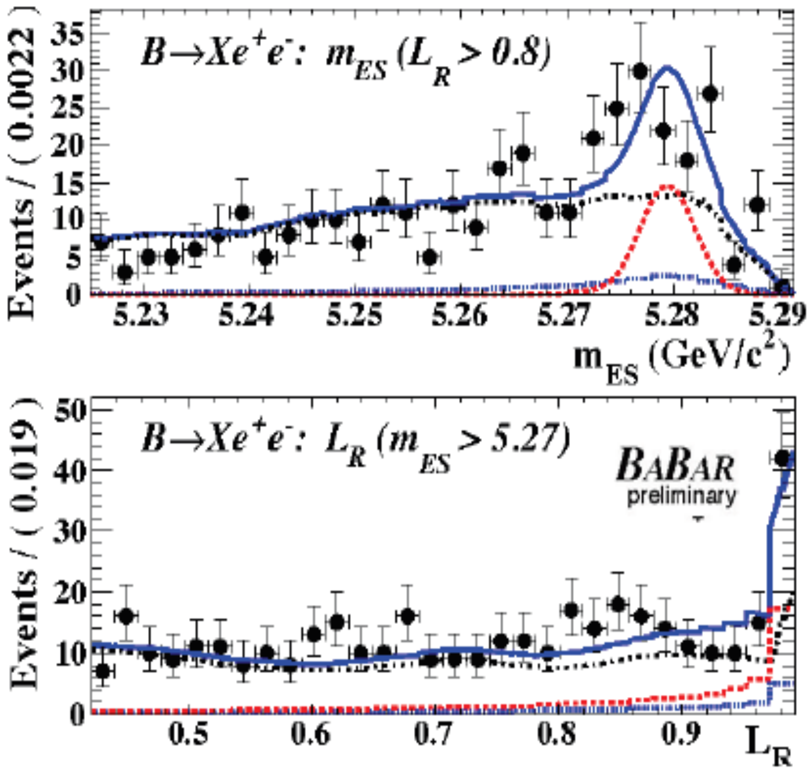
$B \rightarrow X_s l^+ l^-$

- BABAR analysis uses ~470x10^6 BBbar events
- Measure the total BF and partial BFs in 5 bins of $q^2 = m_{ll}^2$ and 4 bins of m_{Xs}
- Exclusive final state reconstruction separately in each mode using kinematic variables

$$m_{ES} = \sqrt{\left(\tfrac{1}{4}E^2_{CM} - p^{*2}_B\right)} \qquad \Delta E = E^*_B - \tfrac{1}{2}E_{CM}$$

- Extract signal yield with 2D Maximum Likelihood fit to m_{ES} and likelihood ratio (based on signal/(signal+bckgd))

mES and Likelihood ratio distributions



Belle ➡ Belle II upgrade

Higher background (x10÷20)

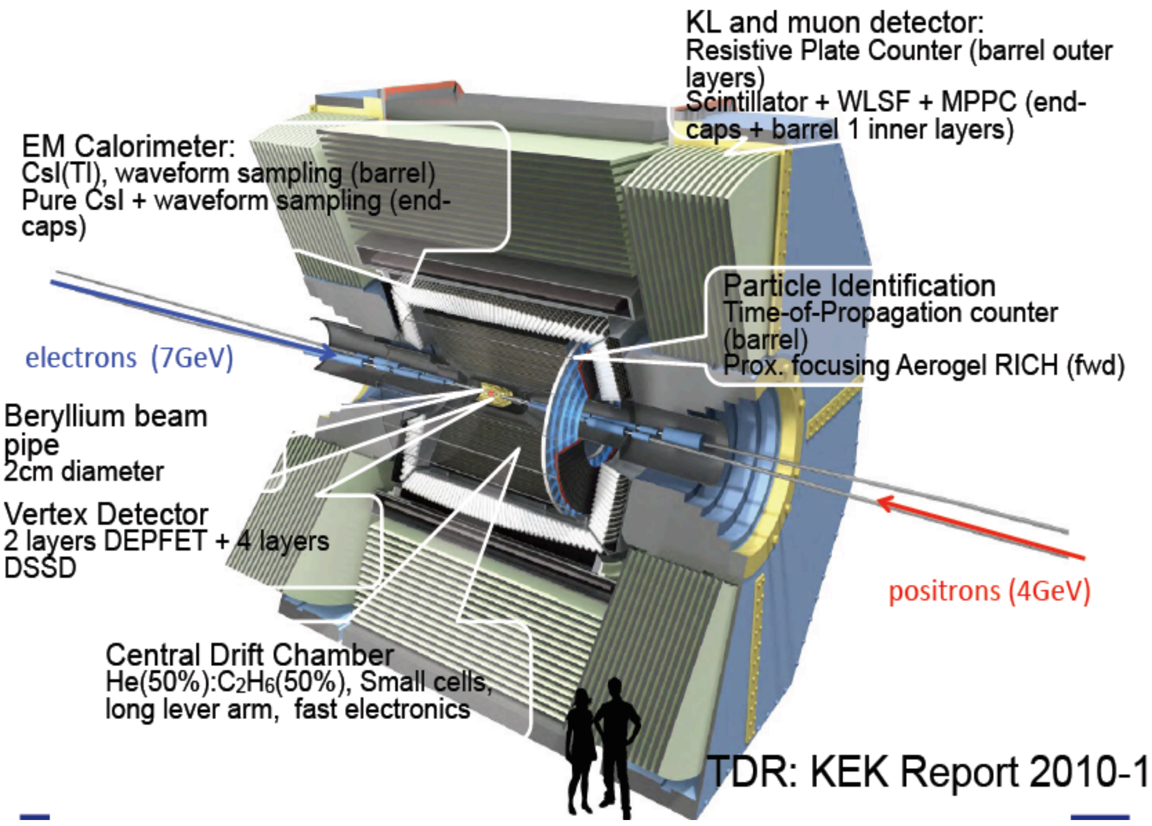
- **Radiative Bhabha events dominate**
- **Fake hits and pileup noise in EM calorimeter**
- **Radiation damage and higher occupancy**

Higher trigger rates (x40)

- **Level1 trigger (0.5→20 KHz)**
- **High performance DAQ, computing**

Important improvements

- **Hermeticity of the detector**
- **IP and secondary vertex resolution**
- **K_s and π^0 reconstruction efficiency**
- **$K^\pm/\pi^\pm$ separation**
- **PID in the end-cap parts**



KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps + barrel 1 inner layers)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

electrons (7GeV)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

positrons (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

TDR: KEK Report 2010-1