XL International Meeting on Fundamental Physics

Benasque, May '12

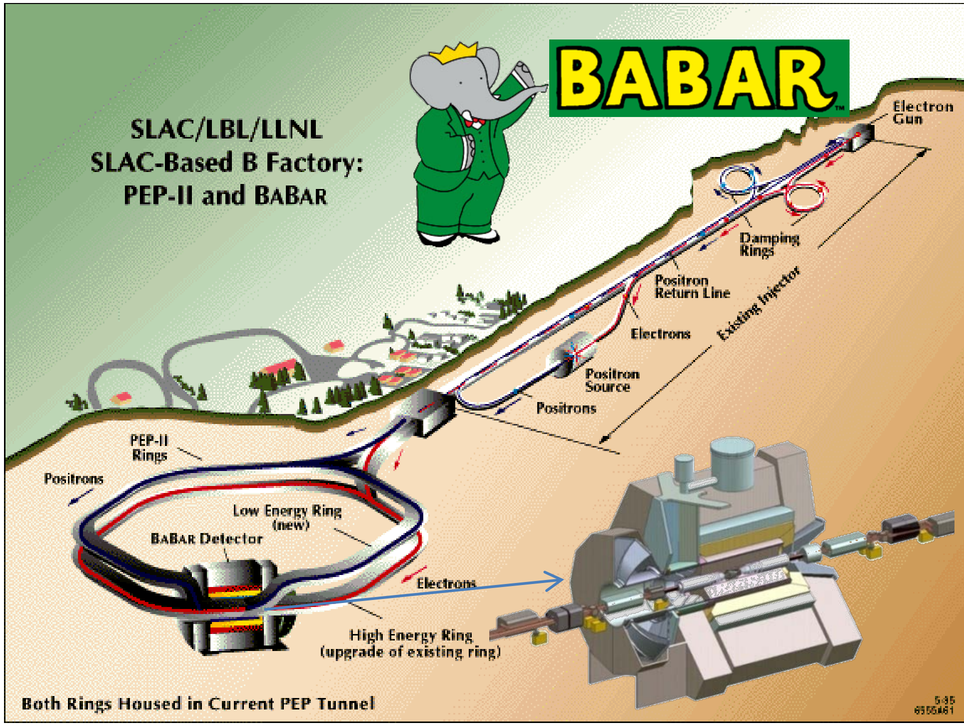
BABAR

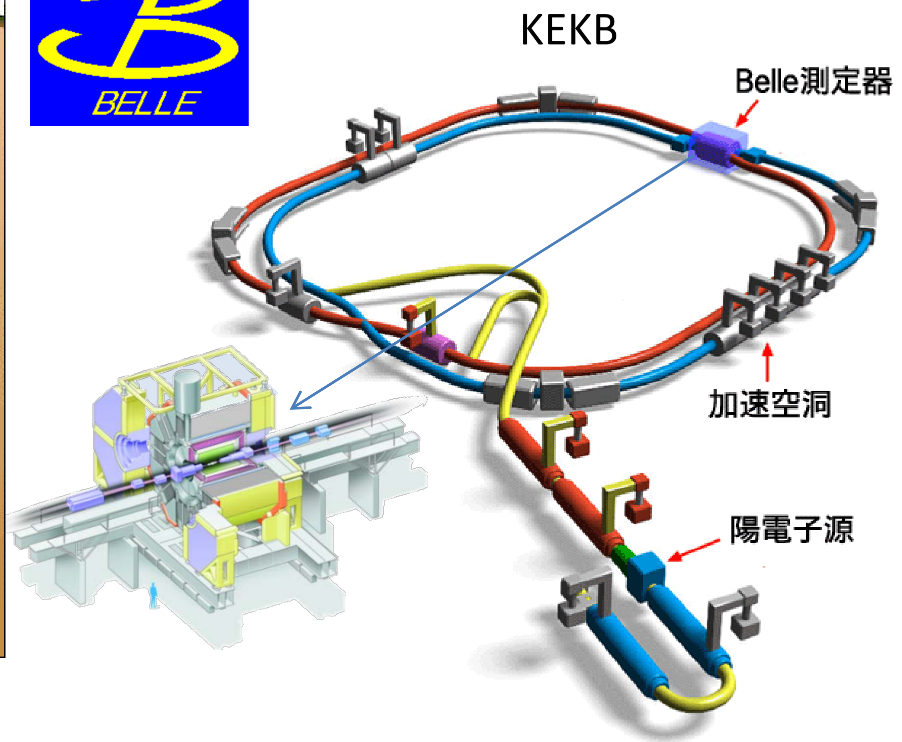
BELLE

RESULTS FROM B-FACTORIES

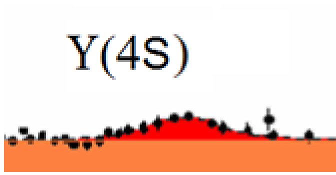
A. Oyanguren
(IFIC – Valencia)

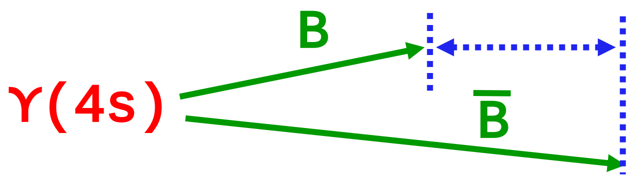
B factories





$\sqrt{s}$=10.58 GeV

e^+ →  ← e^-



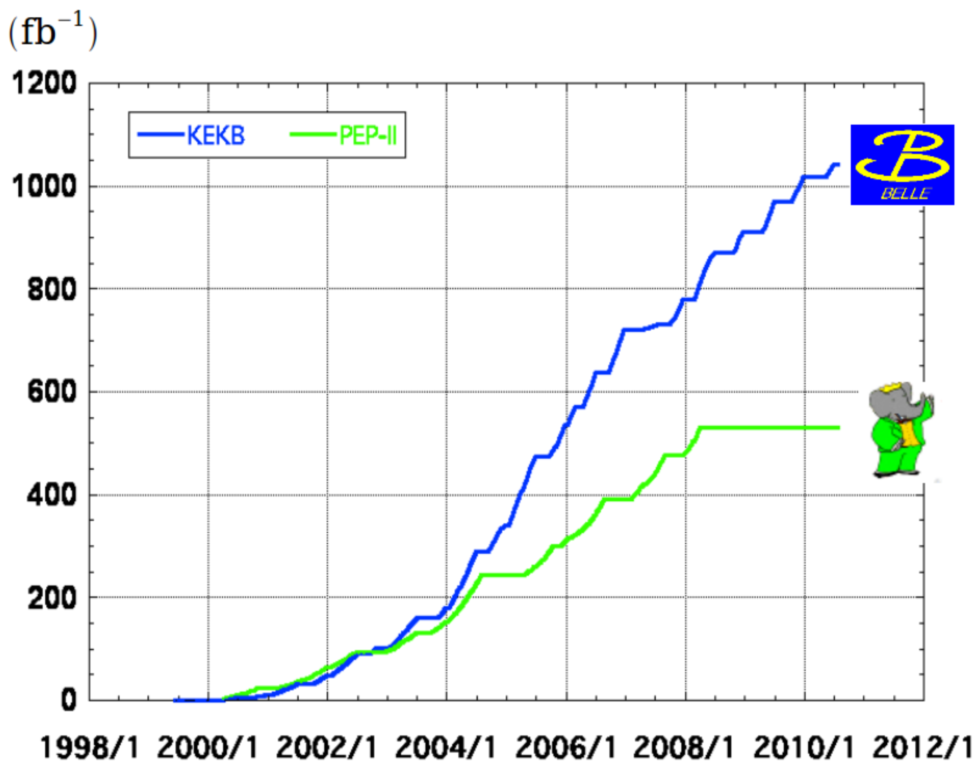
$\Delta z \sim c\,\beta\gamma\,\tau_B$

$\sim 200\mu m$

BaBar	$p(e^-)$=9 GeV $p(e^+)$=3.1 GeV	$\beta\gamma$=0.56
Belle	$p(e^-)$=8 GeV $p(e^+)$=3.5 GeV	$\beta\gamma$ =0.42

B factories

Integrated luminosity of B factories



> 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}

492 BaBar + 363 Belle publications !

Outline

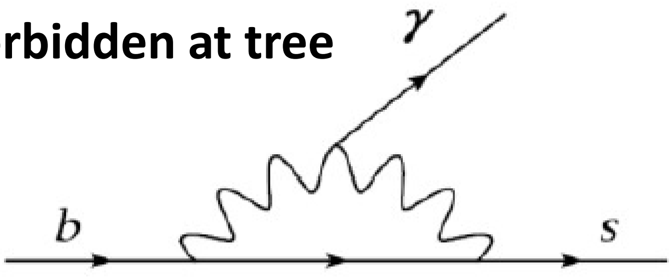
- B Physics:
  - Radiative $b \to s\gamma$ (NEW, Moriond '12)
  - Rare $B \to X\ell\ell$ (NEW, Moriond '12)
  - Semileptonic $B \to D^{(*)}\tau\nu$ (UPDATE, FPCP '12)
  - Time Reversal Violation (NEW, FPCP '12)
- Charm Physics:
  - Mixing and CPV (NEW, CHARM '12, FPCP '12)
- τ Physics:
  - CPV (RECENT, SUSY '11)
- Summary

B Physics

$B \to X_s\gamma$

Motivation:

Flavor-Changing Neutral-Current processes, forbidden at tree level in the Standard Model



- **LO radiative penguin diagram**

- **For photon energy Eγ>1.6 GeV** [Misiak et al. PRL 98 022002 (2007)]
  - **SM-based prediction:** $B(B\to X_s\gamma) = (3.15 \pm 0.23)\times10^{-4}$
  - **HFAG average:** $B(B\to X_s\gamma) = (3.55 \pm 0.25 \pm 0.09)\times10^{-4}$

    [HFAG arXiv:1010.1589v3 (2011)]

- **New physics may increase the rate significantly**

- **Photon energy spectrum important for understanding the *b* quark momentum distribution**

  → access to HQET parameters: m_b and μ_π^2 → $|V_{ub}|$

$B \rightarrow X_s\gamma$

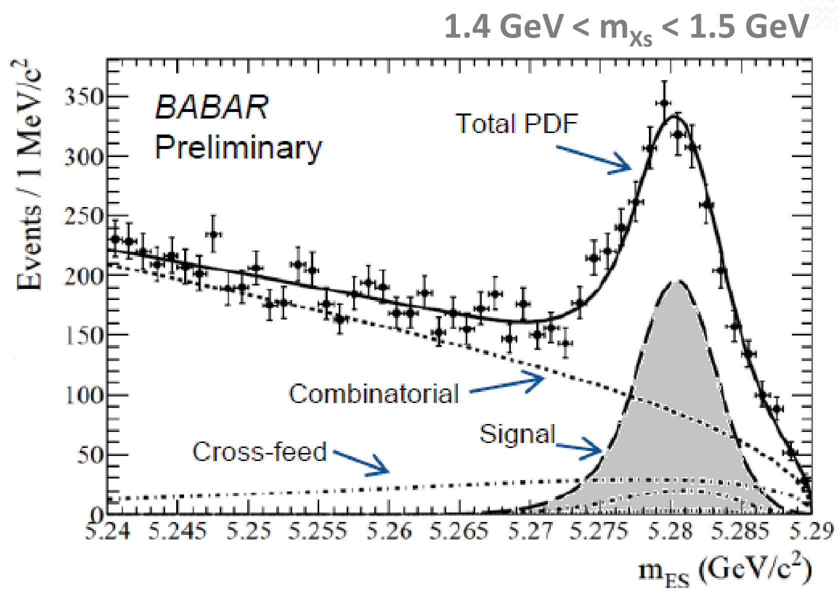
Experimental method: **429 fb^{-1}**

- **m_{ES} fits to a sum of 38 exclusive *X_s* final states to extract signal yields (X_s = 1 or 3 kaons (with ≤ 1 K_s ($\rightarrow\pi^+\pi^-$); ≤ 1 η; ≤ 4 π's (≤ 2 π^0's))**

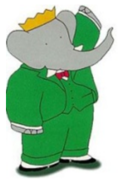
$$m_{ES} = \sqrt{(\sqrt{s}/2)^2 - (P_B^*)^2}$$

m_{Xs} range from 0.6 to 2.8 GeV in18 bins
E_γ range from 1.9 < E_γ < 2.61 GeV

$$E_\gamma^B = \frac{m_B^2 - m_{X_s}^2}{2m_B}$$



- **Signal and background separated using *random forest classifiers*:**
  Signal: **B energy and error, m_{Xs} , event shape**
  Background: **event shape, B direction, veto to photons from π^0…**

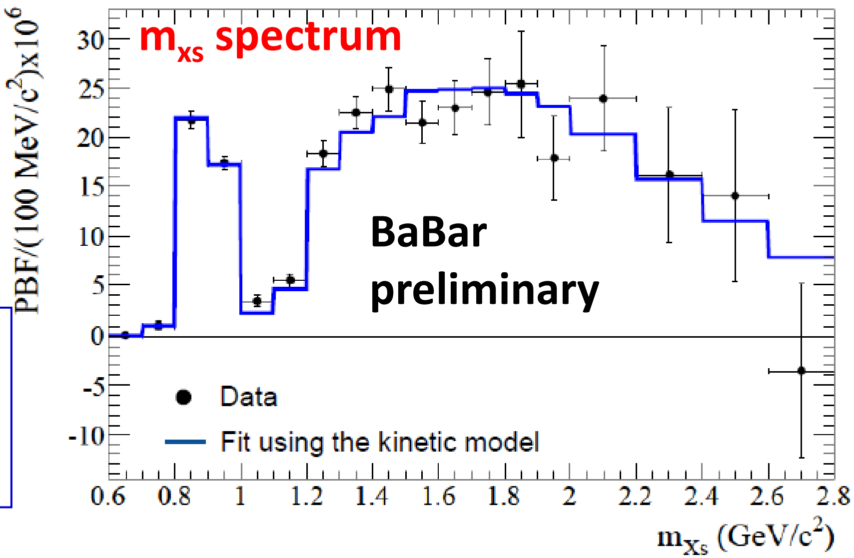


Systematics includes quark hadronization models

$B \to X_s\gamma$

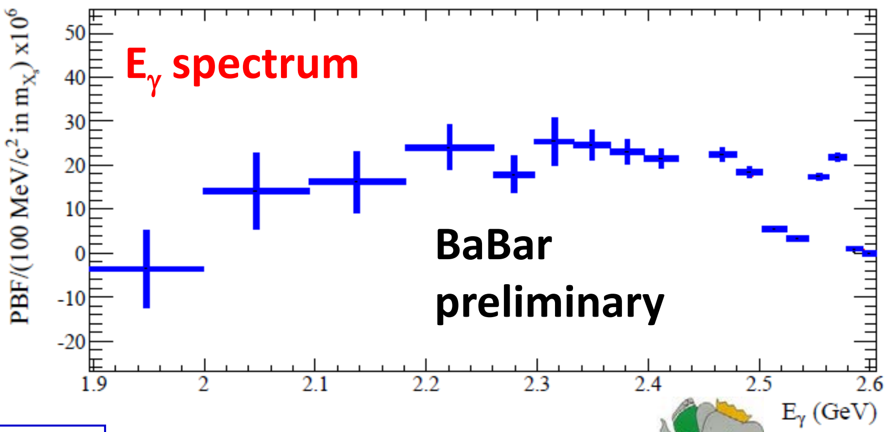
- **Fit to m_{Xs} spectrum (HQET parameters):**
  - ***Kinetic model***
    [Bensen et al. Nucl. Phys. B 710 371 (2005)]
  - ***Shape function model***
    [Lange et al. PRD 72 073006 (2005)]

	Kinetic Model	Shape Function Model
m_b	$4.568^{+0.038}_{-0.036}$ GeV/c^2	$4.579^{+0.032}_{-0.029}$ GeV/c^2
μ_π^2	$0.450^{+0.054}_{-0.054}$ GeV^2	$0.257^{+0.034}_{-0.039}$ GeV^2



Compared to HFAG:

	Kinetic model	Shape function
m_b (GeV/c^2)	4.591 ± 0.031	$4.620^{+0.039}_{-0.032}$
μ_π^2 (GeV^2)	0.454 ± 0.038	$0.288^{+0.054}_{-0.074}$



- **The total branching fraction (E_γ>1.9GeV):**

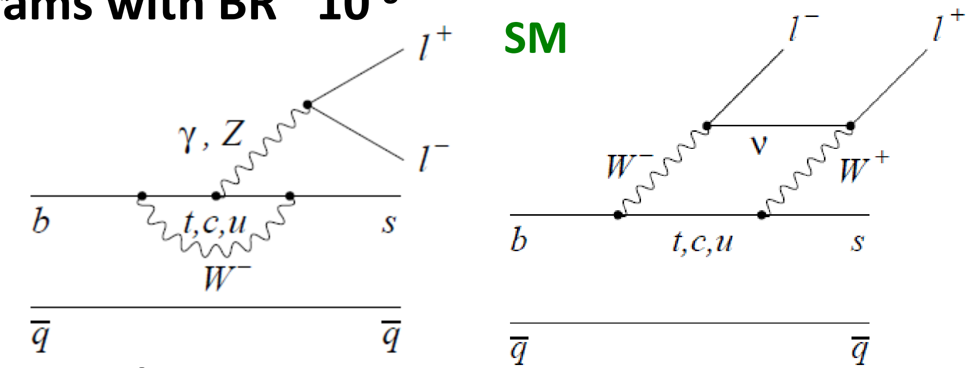
$$\mathcal{B}(\overline{B} \to X_s\gamma) = (3.29 \pm 0.19 \pm 0.48) \times 10^{-4}$$

In agreement with SM

$B \to K^{(*)}\ell^+\ell^-$

Motivation:

- $b \to s\ell^+\ell^-$ forbidden at tree level in the Standard Model
- It is allowed in loop and box diagrams with BR~ 10^{-6}

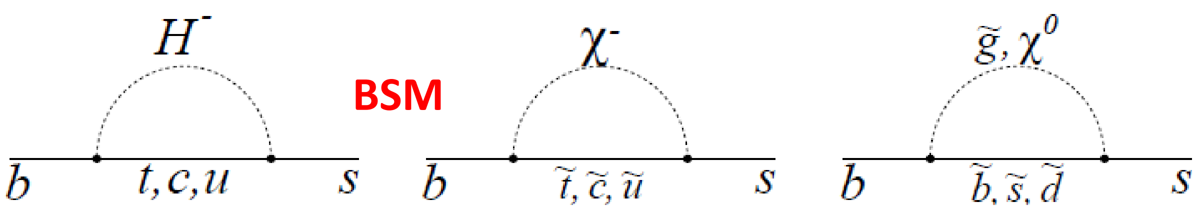


- H_{eff} factorizes short-distance C_i from long-distance effects

$$H_{Eff} \propto \sum_{i=1}^{10} C_i \mathcal{O}_i$$

Three effective Wilson coefficients contribute:
C_7^{eff} from γ penguin (also in b→sγ processes)
C_9^{eff}(C_{10}^{eff}) from vector (axial-vector) part of Z penguin & W box

- Contribution from New Physics may alter the C_{eff} values
→ Observables: decay rates, rate asymmetries, angular distributions



$B \to K^{(*)}\ell^+\ell^-$

Experimental method:

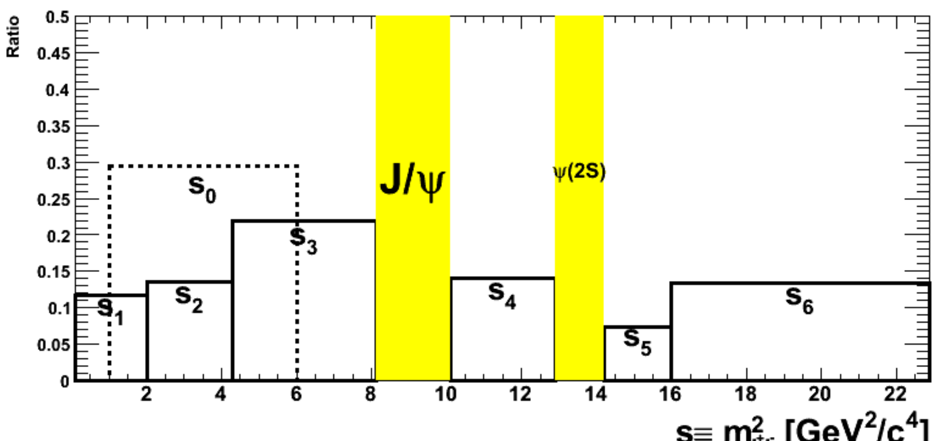
[BaBar, PRD, arXiv:1204.3933]

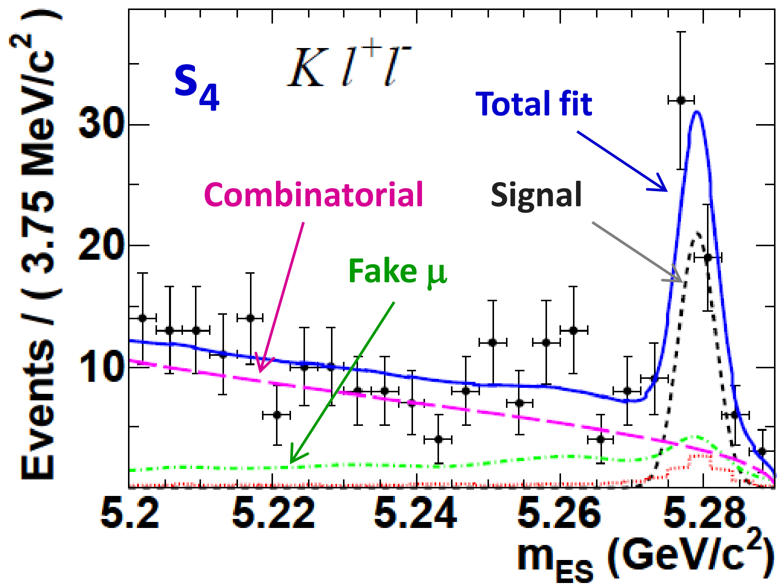
429 fb^{-1}

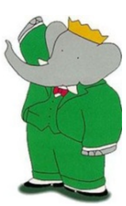
- Signal reconstructed in the decay channels:

$B^{0,+} \to K^{0}_{s}{}^{,+}\ell^+\ell$, $B^{0,+} \to K^{*0,*+} (\to K\pi)\, \ell^+\ell^-$ (μ and e)

- Fit to m_{ES} (and $m_{K\pi}$)
- Veto J/ψ and $\psi(2S)$ regions ($\to \ell^+\ell^-$)
- Background rejected using *Bagged Decision Trees (BDT's)*
  - $\Delta E = E^*_B - E_{CM}/2$, event shape, p_T of the event, decay vertex, angular info of the event
- Results in six bins (s_1-s_6) + one (s_0) of $s=m^2_{\ell\ell}$







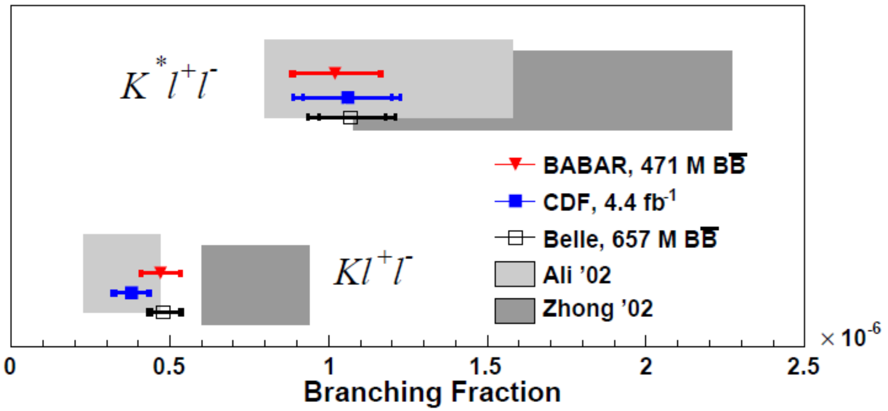
$B \to K^{(*)}\ell^+\ell^-$

[BABAR, arXiv:1204.3933]
[Belle, PRL 103, 171801 (2009)]
[CDF, PRL 107, 201802 (2011)]

- **Total branching fractions:**

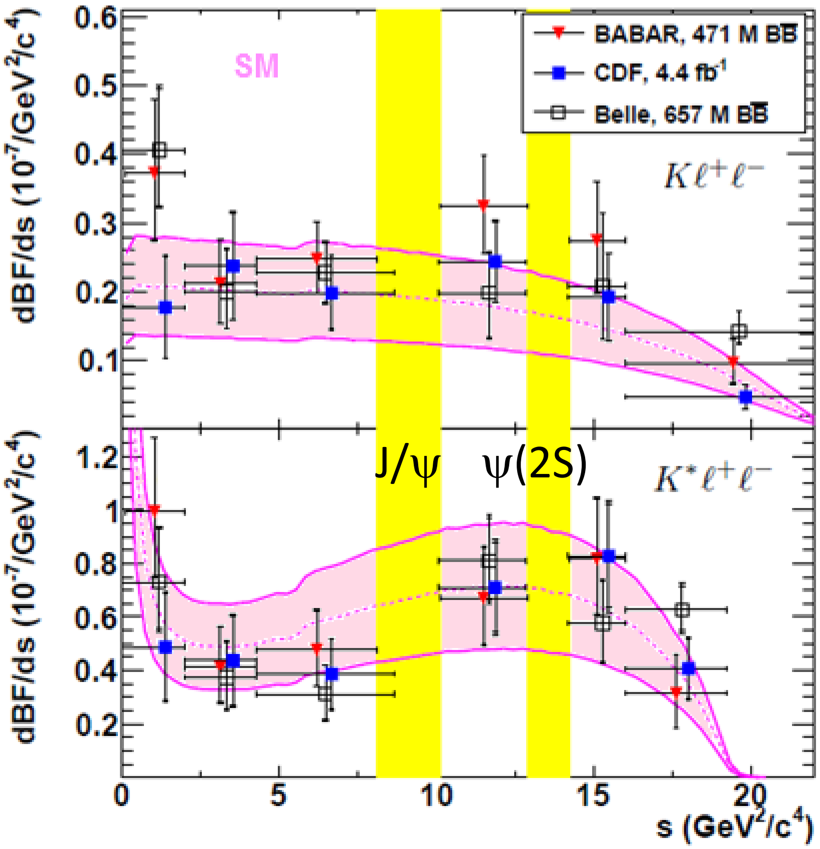
$$\mathcal{B}(B \to K\ell^+\ell^-) = (4.7 \pm 0.6 \pm 0.2) \times 10^{-7}$$

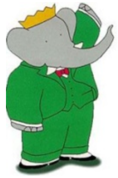
$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (10.2^{+1.4}_{-1.3} \pm 0.5) \times 10^{-7}$$



[Ball & Zwicky, PRD71, 014015(2005), PRD71, 014029(2005);
[Ali et al, PRD 66, 034002 (2002)]

- **Partial branching fractions:**





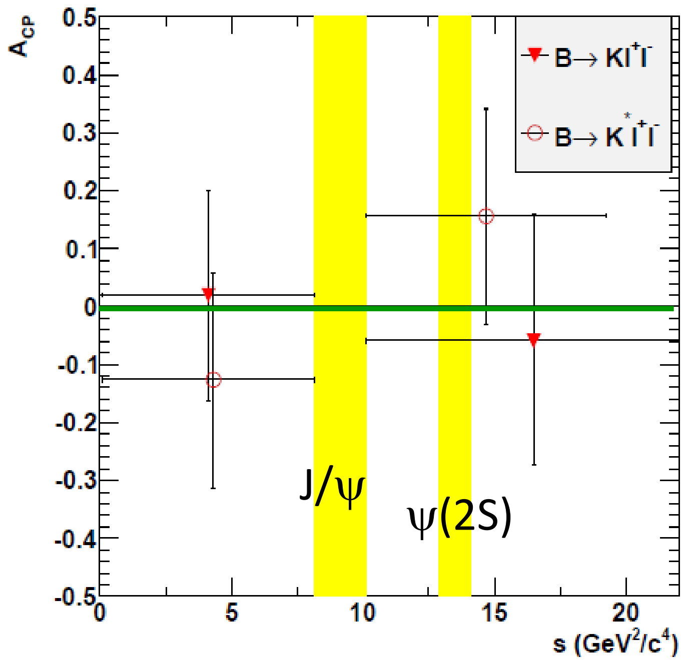
Good agreement between experiments (also with LHCb, arxiv:1112:3515) and with SM

$B \to K^{(*)}\ell^+\ell^-$

- **Rate asymmetry and dimuon/dielectron rate have less theo. uncertainties (more sensitive to New Physics effects)**

CP asymmetry:

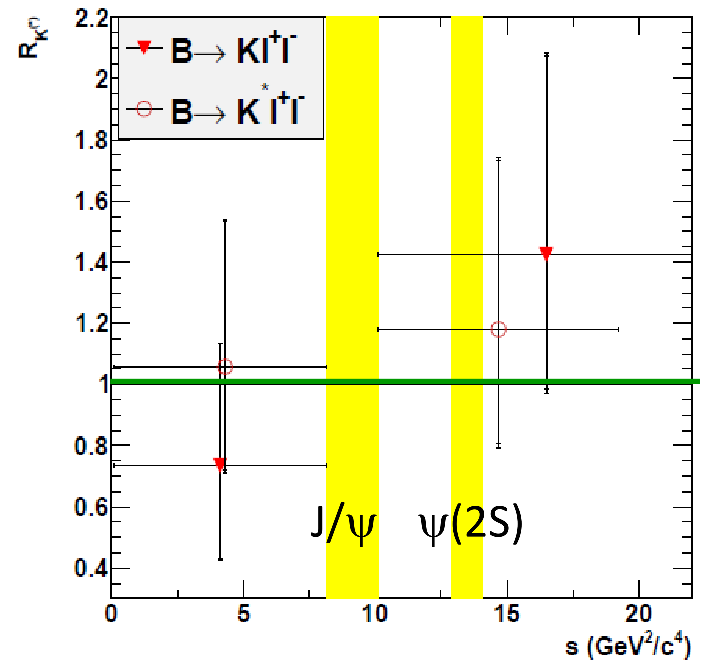
$$\mathcal{A}_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}$$



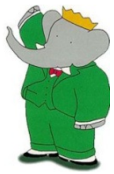
Consistent with null expectation (SM)

Lepton flavour ratio:

$$\mathcal{R}_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$



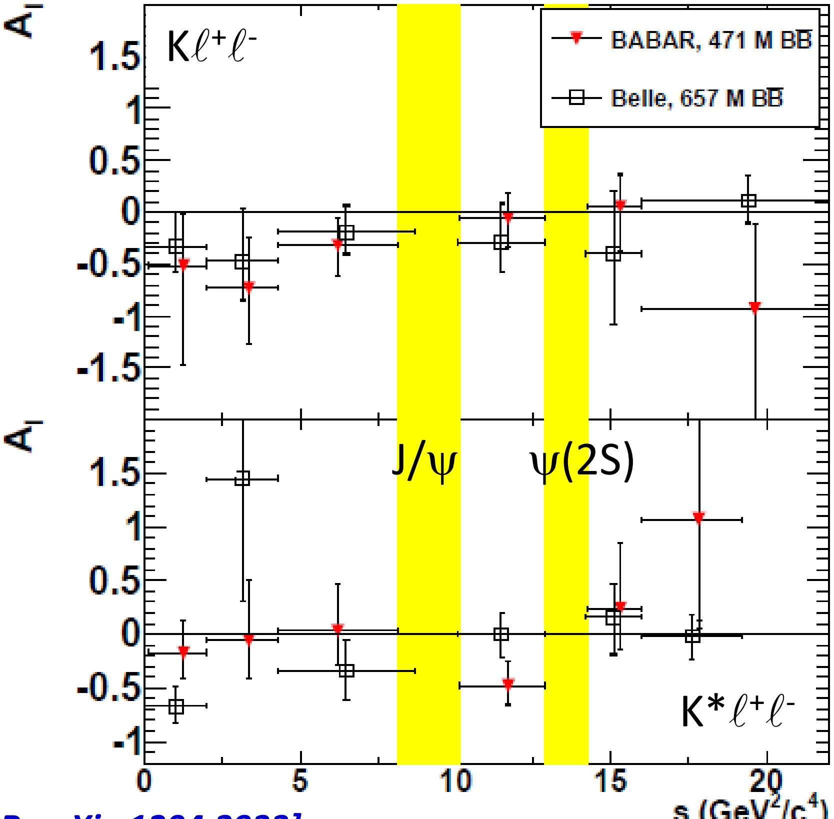
Consistent with unity (SM)



- **Isospin asymmetry:**

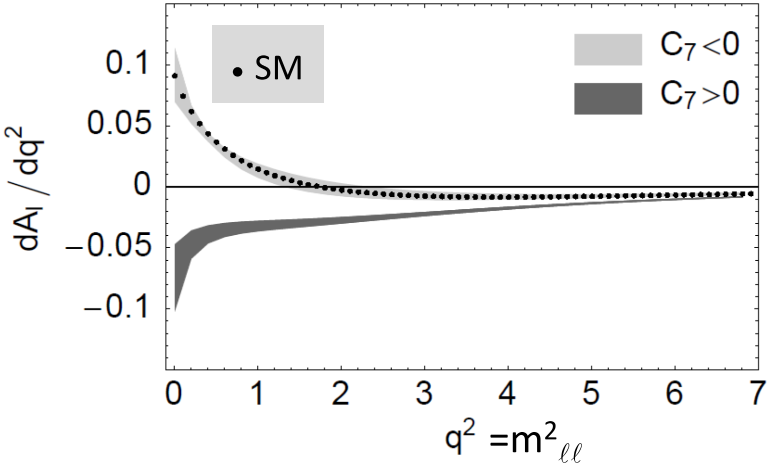
$$\mathcal{A}_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}$$

$$r_\tau \equiv \tau_{B^0}/\tau_{B^+} = 1/(1.071 \pm 0.009)$$



[BABAR, arXiv:1204.3933]
[Belle, PRL 103, 171801 (2009)]

- **In the SM, A_I at s=0 expected ~9% (→ 4%)**
[Feldmann & Matias, JHEP 0301, 074 (2003)]



- **For the low s region (0.1< s <8.12 GeV²):**

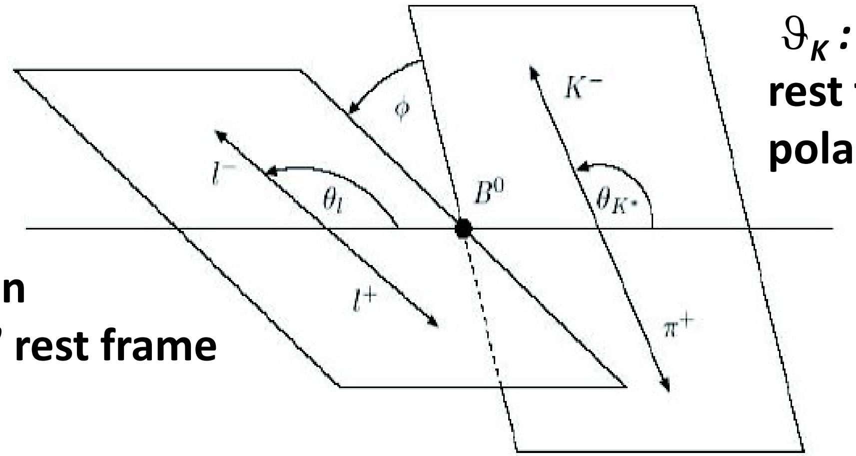
$$\mathcal{A}_I(B \to K\ell^+\ell^-) = -0.58^{+0.29}_{-0.37} \pm 0.02$$

$$\mathcal{A}_I(B \to K^*\ell^+\ell^-) = -0.25^{+0.20}_{-0.17} \pm 0.03$$

In agreement with SM predictions

$B \rightarrow K^{(*)}\ell^+\ell^-$

- **Angular observables:**



ϑ_K *: K angle in K** **rest frame, *K** polarization**

ϑ_ℓ**: angle between the lepton and the B in the $\ell\ell$ rest frame**

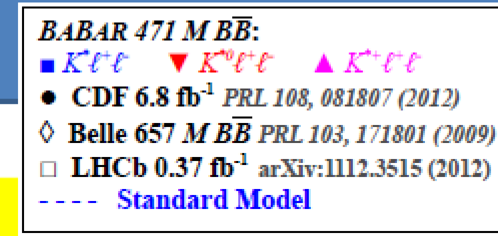
F_L: Fraction of longitudinal polarization of K^*

$$\frac{1}{\Gamma(s)}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L(s)\cos^2\theta_K + \frac{3}{4}(1-F_L(s))(1-\cos^2\theta_K)$$

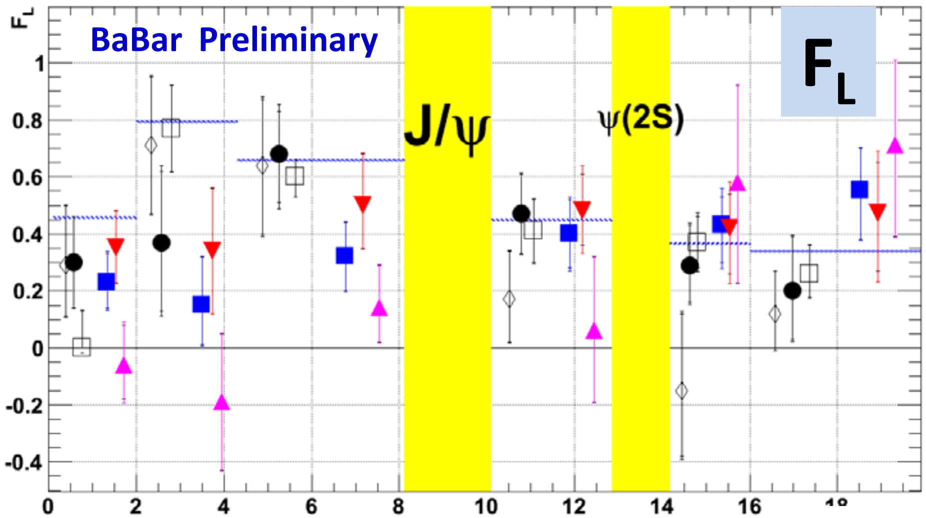
A_{FB}: Forward-Backward Asymmetry of $\ell^+\ell^-$

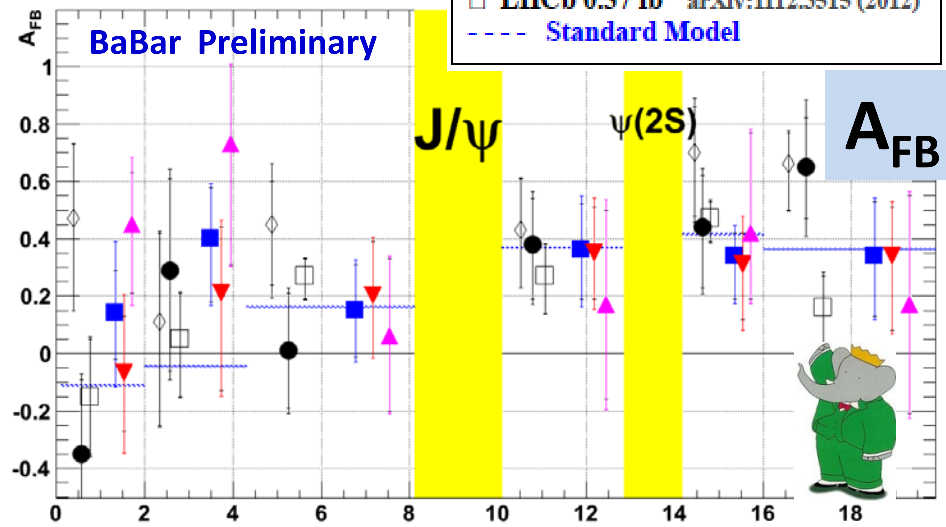
$$\frac{1}{\Gamma(s)}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_L(s)(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L(s))(1+\cos^2\theta_\ell) + \mathcal{A}_{FB}\cos\theta_\ell$$

$B \rightarrow K^{(*)}\ell^+\ell^-$



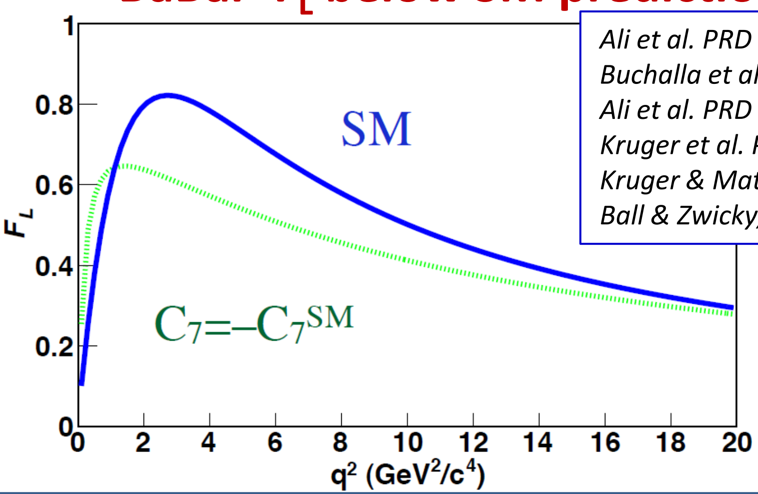
- Fit results:



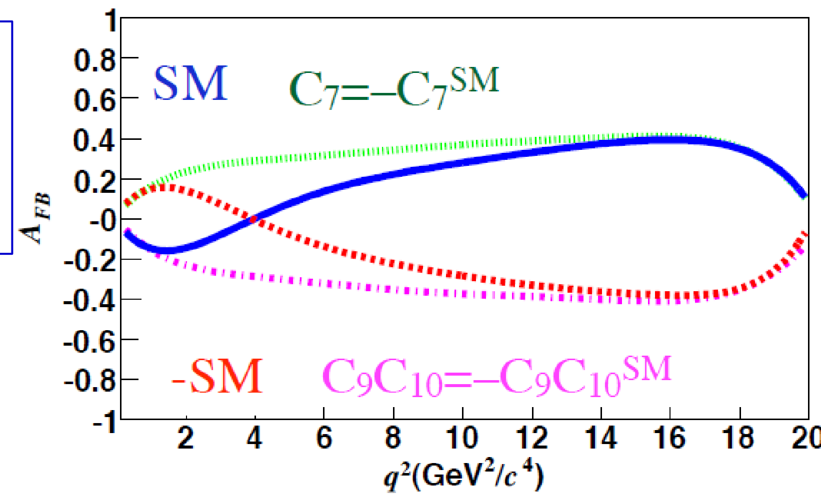


- Good agreement between experiments.

BaBar F_L below SM predictions at low s



Ali et al. PRD 61, 074024 (2000)
Buchalla et al. PRD 63, 014015 (2001)
Ali et al. PRD 66, 034002 (2002)
Kruger et al. PRD 61, 114028 (2002)
Kruger & Matias PRD71, 094009 (2005)
Ball & Zwicky, PRD71, 014029(2005)



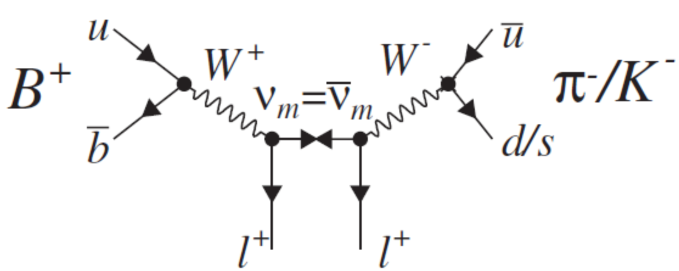
Lepton Number Violation

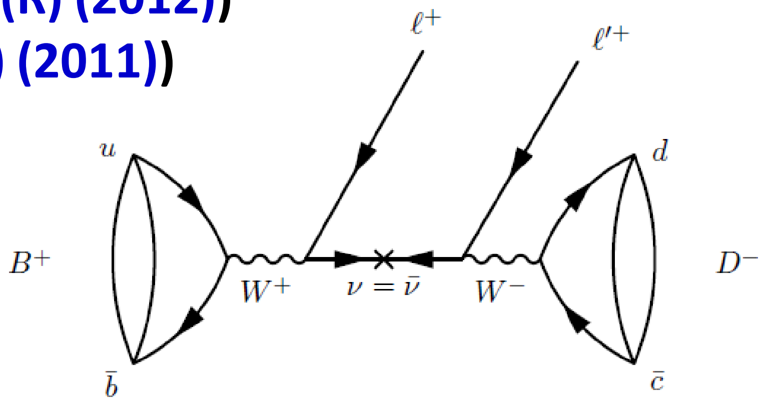
Motivation:

- Lepton Number Violation → understanding of quantum nature of neutrinos
  → test predictions in BSM models

- At B-factories LNV may be searched in $\Delta L=2$ B meson decays:

$B^+ \to K^-/\pi^- \ell^+ \ell^+$ (BaBar, PRD 85, 071103(R) (2012))
$B^+ \to D^- \ell^+ \ell^+$ (Belle, PRD 84, 071106(R) (2011))





→ Sensitive to heavy Majorana neutrinos ($m\nu_M$ 2-4 GeV) BR's being ~ 10^{-7}
→ Lepton-hadron mass enhancement by resonance production

[J.-M. Zhang and G.-L. Wang, Eur. Phys. J. C 71, 1715(2011);
A. Atre, T. Han, S. Pascali, and B. Zhang, J. High Energy Phys. 05 (2009) 030;
T. Han and B. Zhang, Phys. Rev. Lett. 97, 171804 (2006).]

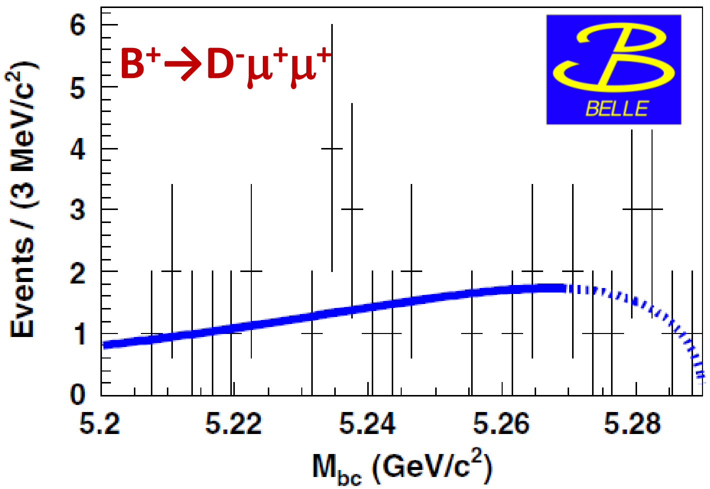
Lepton Number Violation

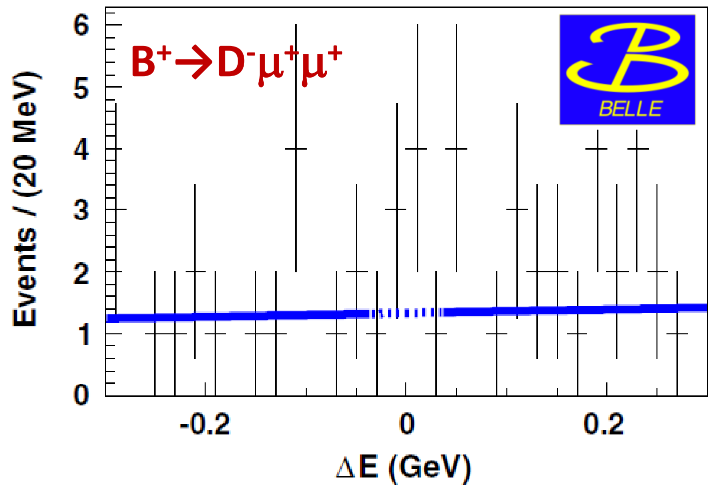
Experimental method:

[Belle, PRD 84, 071106(R) (2011)]

700 fb^{-1}

- Belle: $D^- \to K^- \pi^+ \pi^-$ + 2 leptons of same charge
- 2D fit to ΔE and m_{ES} distributions





90% CL Upper Limits:

Mode	ϵ [%]	N_{obs}	N^{bkg}_{exp}	U.L. [10^{-6}]
$B^+ \to D^- e^+ e^+$	1.2	0	0.18 ± 0.13	<2.6
$B^+ \to D^- e^+ \mu^+$	1.3	0	0.83 ± 0.29	<1.8
$B^+ \to D^- \mu^+ \mu^+$	1.9	0	1.10 ± 0.33	<1.1

- **Comparison with LHCb:**

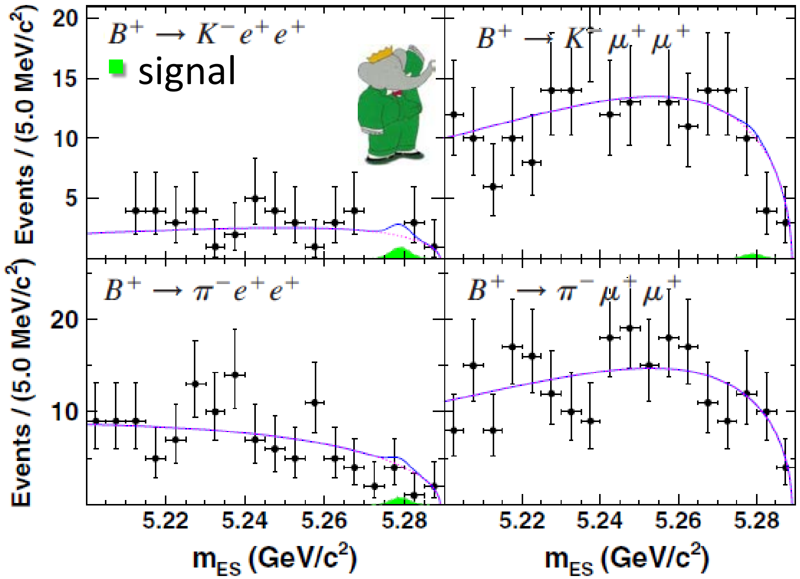
$$\mathcal{B}(B^- \to D^+ \mu^- \mu^-) < 6.9 \times 10^{-7}$$
$$\mathcal{B}(B^- \to D^{*+} \mu^- \mu^-) < 2.4 \times 10^{-6}$$

[LHCb, arXiv:1201.5600]

Lepton Number Violation

Experimental method: **429 fb^{-1}** **[BaBar, PRD 85, 071103(R) (2012)]**

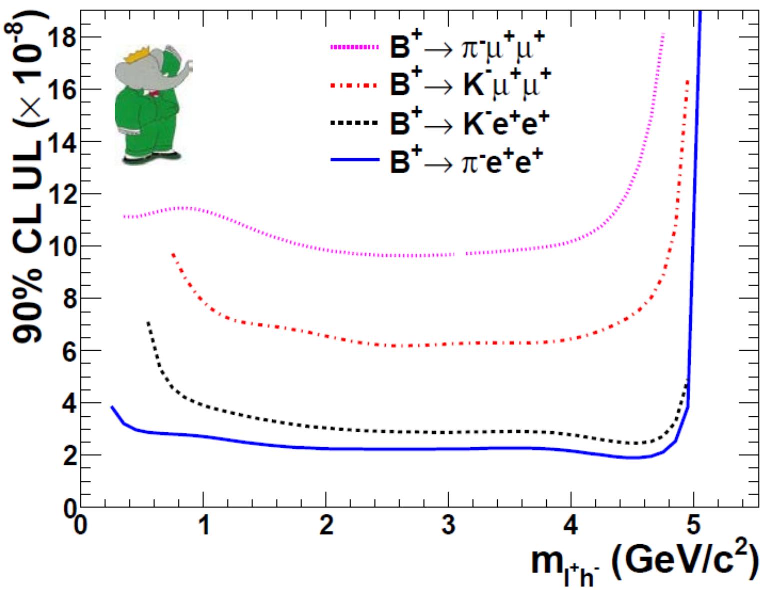
- **B$\rightarrow$ K or π + $\ell^+\ell^+$ (selection similar to B$\rightarrow$K$^{(*)}\ell^+\ell^-$)**



- **90 % CL Upper Limits:**

Mode	$\mathcal{B}$ $(\times 10^{-8})$	$\mathcal{B}_{UL}$ $(\times 10^{-8})$
$B^+ \rightarrow \pi^- e^+ e^+$	$0.27^{+1.1}_{-1.2} \pm 0.1$	2.3
$B^+ \rightarrow K^- e^+ e^+$	$0.49^{+1.3}_{-0.8} \pm 0.1$	3.0
$B^+ \rightarrow \pi^- \mu^+ \mu^+$	$0.03^{+5.1}_{-3.2} \pm 0.6$	10.7
$B^+ \rightarrow K^- \mu^+ \mu^+$	$0.45^{+3.2}_{-2.7} \pm 0.4$	6.7

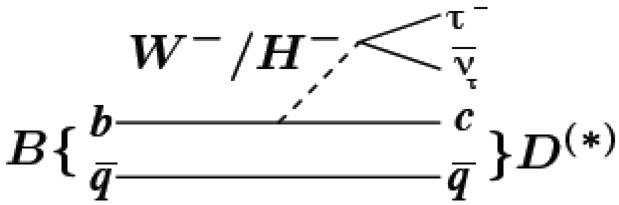
- **Limits on resonance production ($m_{\ell h}$), sensitive to $m_{\nu M}$**



- **Comparison with other experiments:**

CLEO *[PRD 65, 111102 (2002)]*
BF($B^+\rightarrow(\pi,K^{(*)},\rho)\ \ell^+\ell^+$) < (1.0 – 8.3)·10^{-6}
LHCb *[PRL 108, 101601 (2012); arXiv:1201.5600]*
BF($B^+\rightarrow(K^-,\pi^-)\mu^+\mu^+$) < (5.4 – 1.3)·10^{-8}

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



Motivation:

- **Sensitive to charged-Higgs effects**
- **Involve form factors which can be measured in $B \to D^{(*)} e/\mu\nu$ decays**
- **Observables: R(D) and R(D*) ratios**

$$R(D^{(*)}) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\tau\right)}$$

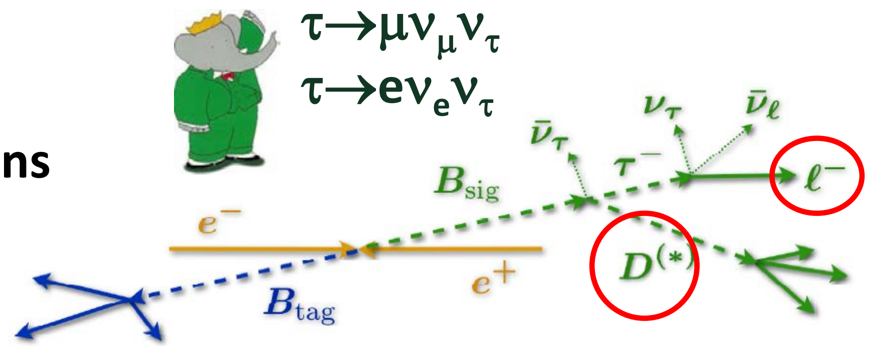
- can be enhanced by the charged-Higgs ($\tan\beta/m_H$)
- several syst. and theo. uncertainties cancel out

SM predictions:

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

[S. Fajfer, J. F. Kamenik, and I. Nisandzic, arXiv:1203.2654;
J. F. Kamenik and F. Mescia, Phys. Rev. D 78, 014003, (2008)]

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



Experimental method:

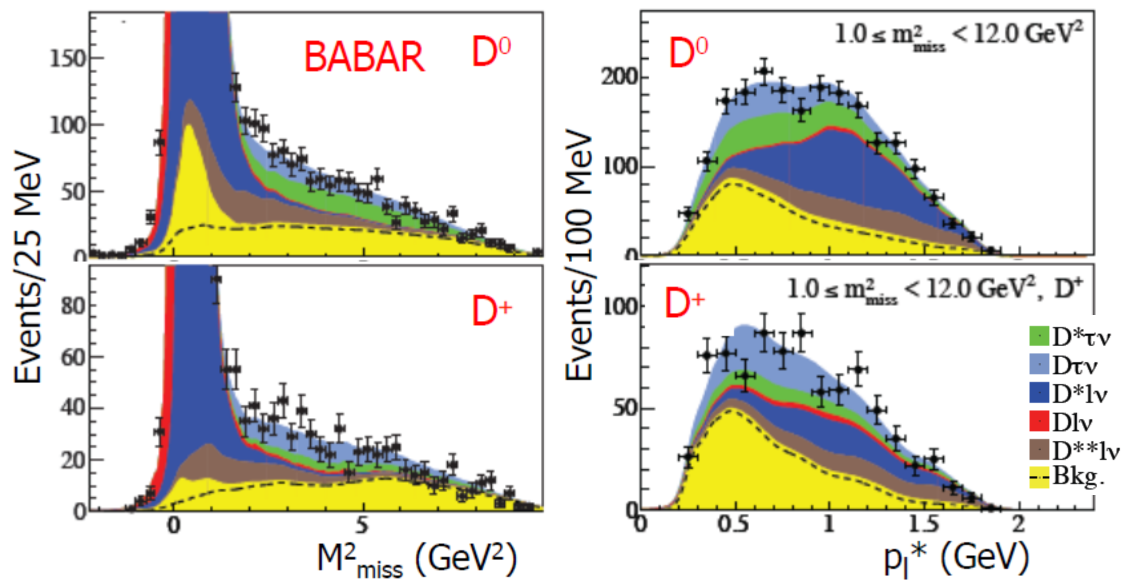
- BaBar: Btag fully reconstructed into hadrons (Improved efficiencies (lepton and Btag))
- Bsig: $D^{(*)}$ and lepton (μ, e)
  - 4 signal samples: $(D^0, D^+, D^{*0}, D^{*+})\ell\nu$ (to extract $B \rightarrow D^{(*)}\tau\nu$)
  - 4 control samples: $(D^0, D^+, D^{*0}, D^{*+})\pi^0\ell\nu$ (to derive $D^{**}\ell\nu$ bkg)

$$m_{miss}^2 = (p_{e+e-} - p_{Btag} - p_{D(*)} - p_\ell)^2$$

426 fb^{-1}

- 2D unbinned ML fit m_{miss}^2-p^*_ℓ
  Yields for:
  $B \rightarrow (D^0, D^+, D^{*0}, D^{*+})\tau\nu$
  $B \rightarrow (D^0, D^+, D^{*0}, D^{*+})\ell\nu$
  $B \rightarrow (D^0, D^+, D^{*0}, D^{*+})\pi^0\ell\nu$

$\longrightarrow$ R(D) and R(D*)



Large signal significance : 16σ (D*) and 8σ (D)

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

- **New Results (FPCP'12):**

to be submitted to PRL

Decay	N_{sig}	N_{norm}	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	Σ_{tot}
$B^- \to D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	4.7
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	$0.322 \pm 0.032 \pm 0.021$	$1.71 \pm 0.17 \pm 0.13$	9.6
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	$0.469 \pm 0.084 \pm 0.052$	$1.01 \pm 0.18 \pm 0.12$	5.3
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	$0.355 \pm 0.039 \pm 0.020$	$1.74 \pm 0.19 \pm 0.12$	10.5
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.10$	6.8
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.017$	$1.76 \pm 0.13 \pm 0.11$	13.4

- **Comparison with the SM:**

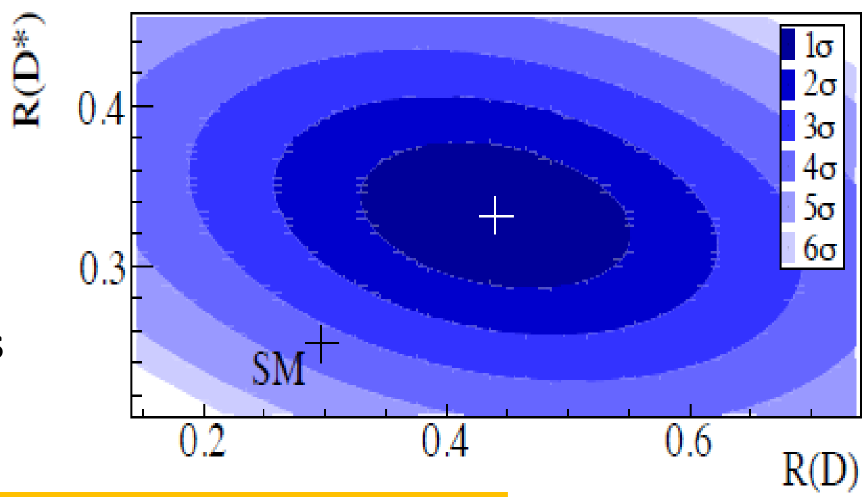
R(D) = 0.440 ± 0.071
SM = 0.297(17)

2.0σ

R(D*) = 0.332 ± 0. 029
SM = 0.252(3)

2.7σ

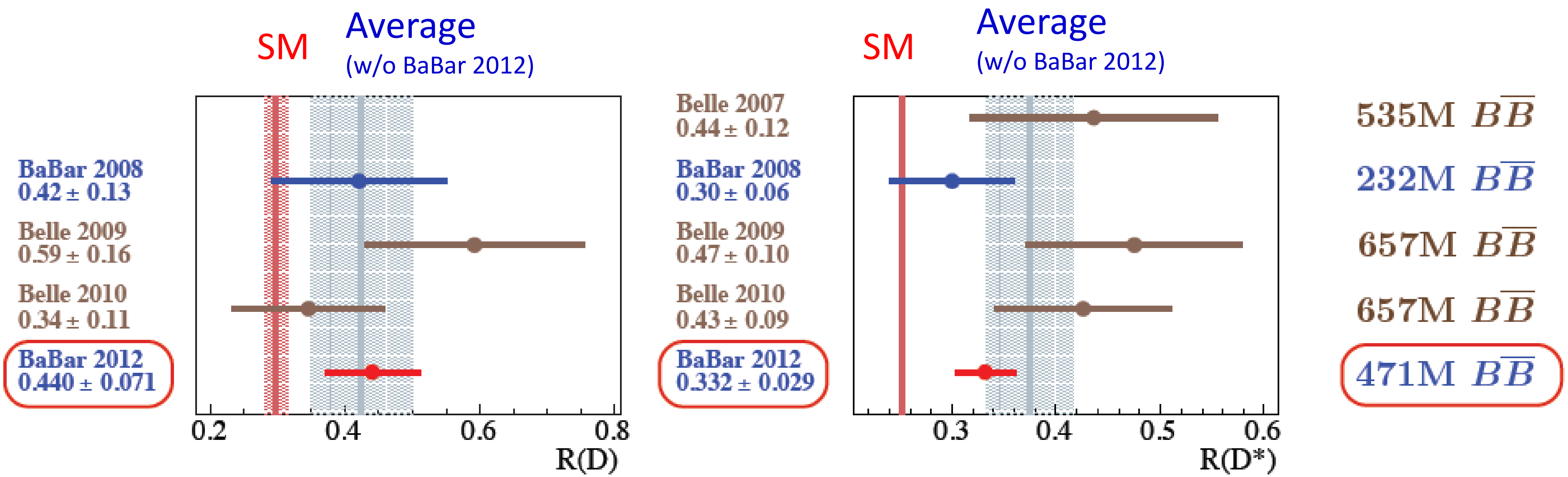
The combination of the two measurements (-0.27 correlation) yields χ^2/NDF=14.6/2 (i.e. Prob. = 6.9 x10^{-4})→



The SM prediction is excluded at 3.4 σ

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

- **Comparison with previous measurements:**



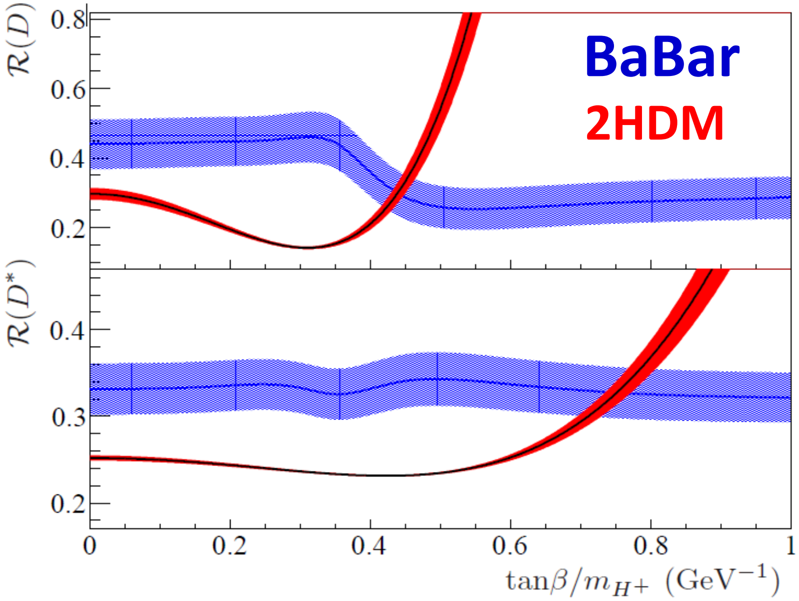
Good agreement between experimental results

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

- **Interpretation Beyond the Standard Model:**

A charged Higgs (2HDM type II) could enhance or decrease the R(D) and R(D*) ratios depending on tanβ/mH

$$R(D^{(*)}) = R(D^{(*)})_{SM} + A^{(*)}\frac{\tan^2\beta}{m_{H+}^2} + B^{(*)}\frac{\tan^4\beta}{m_{H+}^4}$$



Effect of 2DHM (accounting for difference in efficiency):

$\tan\beta/m_H$= 0.44 ± 0.02 for R(D)
$\tan\beta/m_H$= 0.75 ± 0.04 for R(D*)

↓

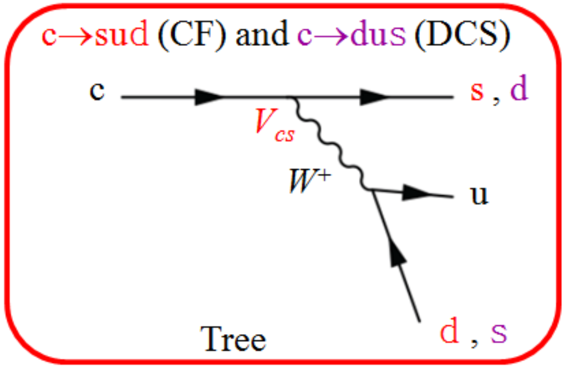
The combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space with a probability of >99.8% (M_H>10GeV)

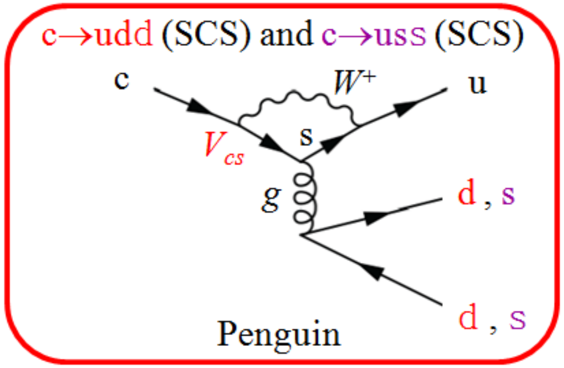
Charm Physics

CPV in charm

Motivation:

- **Direct CP violation in D decays arises through interference between:**





- **In the SM is CKM suppressed O(10^{-3}) or less:** $V_{cs} \rightarrow 1 - \frac{1}{2}\lambda^2 - i\eta A^2\lambda^4$
- **New Physics can increase or reduce the effect:**
  - **e.g. additional CP phase from charged Higgs boson**

[PRD 75, 036008 (2007)]
[hep-ph/0104008 (2001)]
[PRD 51, 003478 (1995)]

- **SCS decays are more likely to show the effect if present**
- **Current experimental sensitivity O(10^{-3})**
- **LHCb results at 3.5σ, CDF at 2.7σ:**

$\Delta A_{CP} = A_{K^+K^-} - A_{\pi^+\pi^-} = -(0.82 \pm 0.21 \pm 0.11)\%$, (LHC$_b$) 3.5σ Phys. Rev.lett.108,111602 (2012)

$\Delta A_{CP} = A_{K^+K^-} - A_{\pi^+\pi^-} = -(0.62 \pm 0.21 \pm 0.10)\%$, (CDF) 2.7σ arxiv: 1205.3899

CPV in charm

- **CP violation in various SCS modes has been searched by B-factories**

Ex. of recent result:

$$A_{cp}(D^+ \to \phi\pi^+) = \frac{\Gamma(D^+ \to \phi\pi^+) - \Gamma(D^+ \to \phi\pi^+)}{\Gamma(D^+ \to \phi\pi^+) + \Gamma(D^+ \to \phi\pi^+)}$$

(Corrected by A_{FB} and A_{π}^{ε})

Mode	Data (fb^{-1})	Process type	CP eigen state	Acp (%)	Ref
$D^0 \to K^+K^-$	540	SCS	Yes	$-0.43 \pm 0.30 \pm 0.11$	PL B670,190(2008)
$D^0 \to \pi^+\pi^-$	540	SCS	Yes	$+0.43 \pm 0.52 \pm 0.11$	PL B670,190(2008)
$D_s^+ \to K_S^0\pi^+$	673	SCS		$+5.45 \pm 2.50 \pm 0.33$	PRL 104,181602(2010)
$D^+ \to K_S^0K^+$	673	SCS		$-0.16 \pm 0.58 \pm 0.25$	PRL 104,181602(2010)
$D^+ \to \phi\pi^+$	955	SCS		$+0.51 \pm 0.28 \pm 0.05$	PRL 108,071801(2012)
$D^+ \to \eta\pi^+$	791	SCS		$+1.74 \pm 1.13 \pm 0.19$	PRL 107,221801(2010)
$D^+ \to \eta'\pi^+$	791	SCS		$-0.12 \pm 1.12 \pm 0.17$	PRL 107,221801(2010)

→ **No CP violation**

CPV in charm

- **Due to CPV in mixing in the kaon sector, the direct CP asymmetry for $D^+ \to K_s \pi^+$**

$$A_{CP} = \frac{\Gamma(D^+ \to \pi^+ K_s^0) - \Gamma(D^- \to \pi^- K_s^0)}{\Gamma(D^+ \to \pi^+ K_s^0) + \Gamma(D^- \to \pi^- K_s^0)}$$

is expected to be [hep-ph/0104008 (2001)]

$A_{CP} = -(0.332 \pm 0.006)\%$

Mode	Data (fb^{-1})	Process type	CP eigen state	Acp (%)	Ref BELLE
$D^+ \to K_S^0 \pi^+$	977	CF/DCS		$-0.36 \pm 0.09 \pm 0.07$	arxiv. 1203.6409
$D_S^+ \to K_S^0 K^+$	673	CF/DCS		$+0.12 \pm 0.36 \pm 0.22$	PRL 104,181602(2010)
$D^0 \to K_S^0 \pi^0$	791	CF/DCS	Yes	$-0.28 \pm 0.19 \pm 0.10$	PRL 106,211801(2011)
$D^0 \to K_S^0 \eta$ *	791	CF/DCS	Yes	$-0.54 \pm 0.51 \pm 0.16$	PRL 106,211801(2011)
$D^0 \to K_S^0 \eta'$ *	791	CF/DCS	Yes	$-0.98 \pm 0.67 \pm 0.14$	PRL 106,211801(2011)

Belle results consistent with SM expectation (CPV in the K sector)

CPV in charm

Time dependent analyses

- Measurement of lifetime difference between $D^0 \rightarrow K\pi$ and $D^0 \rightarrow KK,\pi\pi$ allow to determine the D^0-$\overline{D}^0$ mixing parameter y_{CP}

$$\tau_{hh}^{+} = \tau(D^0 \rightarrow h^+h^-) = \frac{1}{\Gamma^+}$$

$$\overline{\tau}_{hh}^{+} = \tau(\overline{D}^0 \rightarrow h^+h^-) = \frac{1}{\Gamma^-}$$

$$\tau_{K\pi} = \tau(D^0 \rightarrow K^-\pi^+) = \frac{1}{\Gamma_D}$$

$$y_{CP} = \frac{\tau_{K\pi}}{2}\left(\frac{1}{\tau_{hh}^{+}} + \frac{1}{\overline{\tau}_{hh}^{+}}\right) - 1$$

$$y_{CP} = \frac{\Gamma^+ + \Gamma^-}{2\Gamma_D} - 1$$

$y_{CP} \neq 0 \rightarrow$ Mixing

If CP is conserved y_{CP} =y

- Differences in D^0 and $\overline{D}^0$ lifetimes are sensitive to contributions from CPV in mixing and decay

$$\Delta Y = \frac{\Gamma^+ + \Gamma^-}{2\Gamma_D}\frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}$$

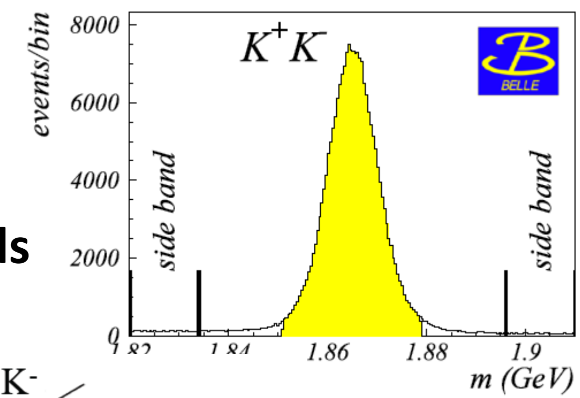
$$\Delta Y = (1 + y_{CP})A_\Gamma$$

$$A_\Gamma = \frac{\overline{\tau}_{hh}^{+} - \tau_{hh}^{+}}{\overline{\tau}_{hh}^{+} + \tau_{hh}^{+}}$$

$$\Delta Y = \frac{\tau_{K\pi}}{2}\left(\frac{1}{\tau_{hh}^{+}} - \frac{1}{\overline{\tau}_{hh}^{+}}\right) \neq 0 \Rightarrow CPV$$

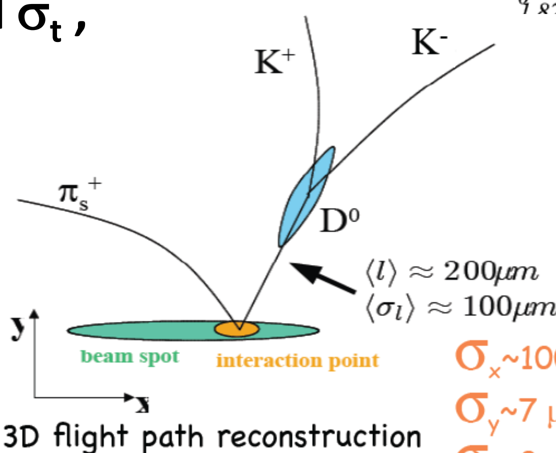
CPV in charm

- Similar techniques at BaBar (468 fb^{-1}) and Belle (976 fb^{-1})
- Tagged analysis:
  Use $D^{*+} \rightarrow \pi^+ D^0$ to tag the D^0 flavour and suppress the background, and reconstruct the D^0 into $K\pi$, KK and $\pi\pi$ modes
  (BaBar uses for Y_{CP} measurement an additional untagged $D^0 \rightarrow K\pi$, KK sample (stat. X 4, less pure))



- Reject D* from B decays (p_{D^*} > 2.5GeV)
- Signal yield from mass distributions, bkg from sidebands
- Measure D^0 proper decay time: t and σ_t, by reconstructing the D momentum and flight length L:

$$t = \frac{L}{\beta\gamma c} = \vec{L} \cdot \frac{\vec{p}}{p} \frac{m_{D^0}}{p}$$

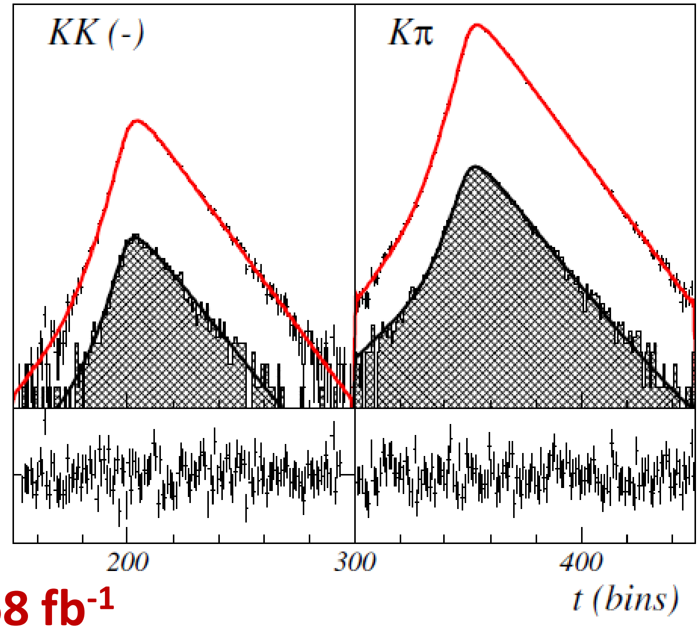


σ_x~100 μm
σ_y~7 μm
σ_z~8 mm

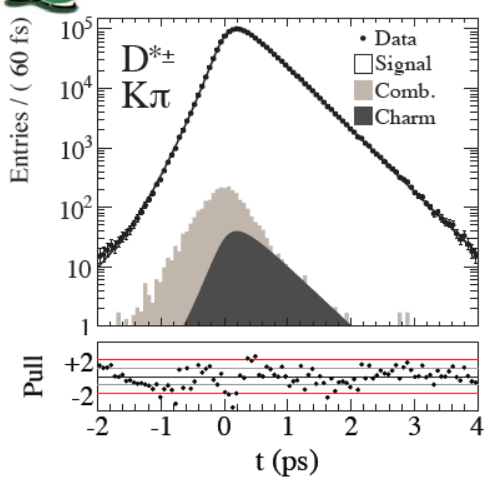
- Fit the proper decay time distribution

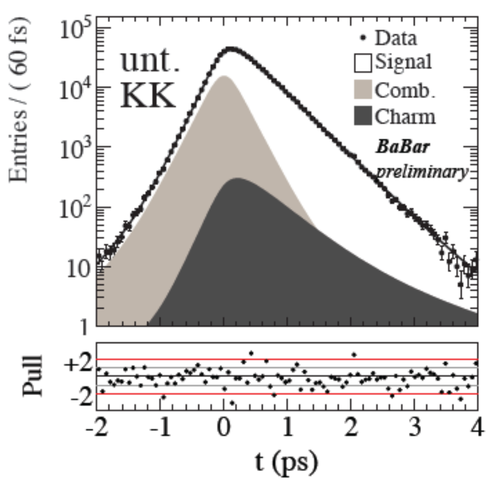
CPV in charm

976 fb^{-1}



468 fb^{-1}





NEW @ CHARM '12

Preliminary

y_{CP} = (+1.11 ± 0.22 ± 0.11)%
A_Γ = (-0.03 ± 0.20 ± 0.08)%

No mixing excluded at 4.5σ
A_Γ consistent with no indirect CPV

Preliminary

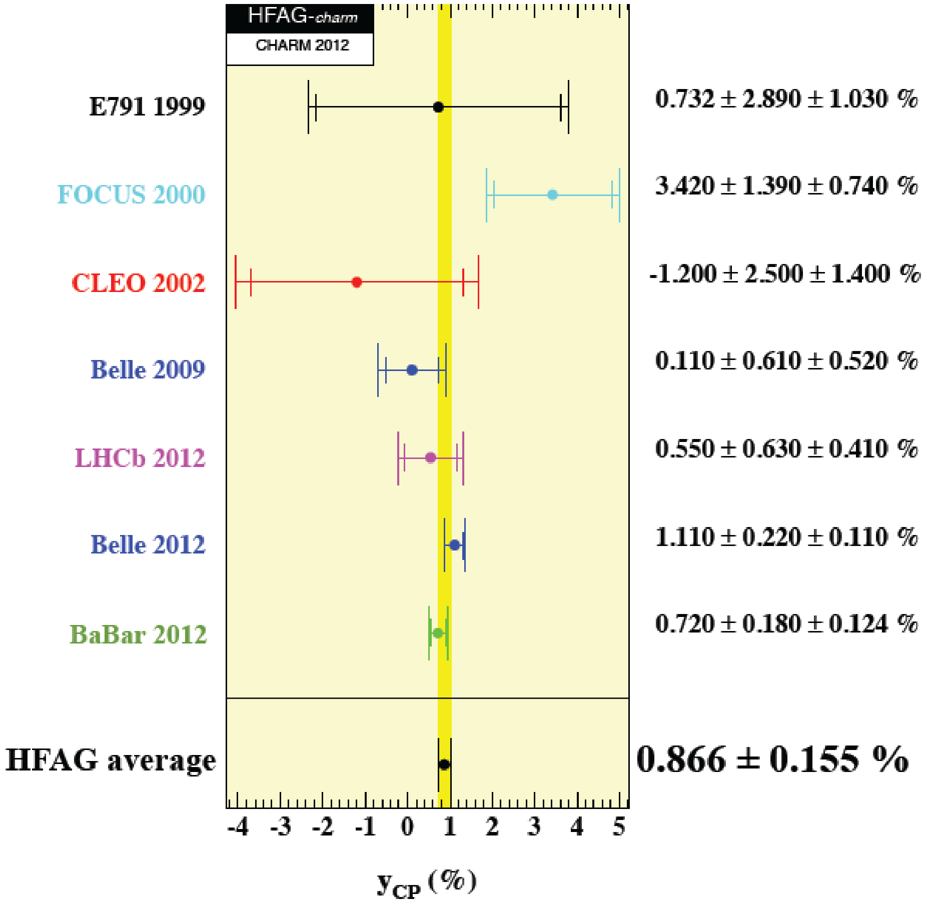
y_{CP} = (+0.72 ± 0.18 ± 0.12)%
ΔY = (0.09 ± 0.26 ± 0.06)%

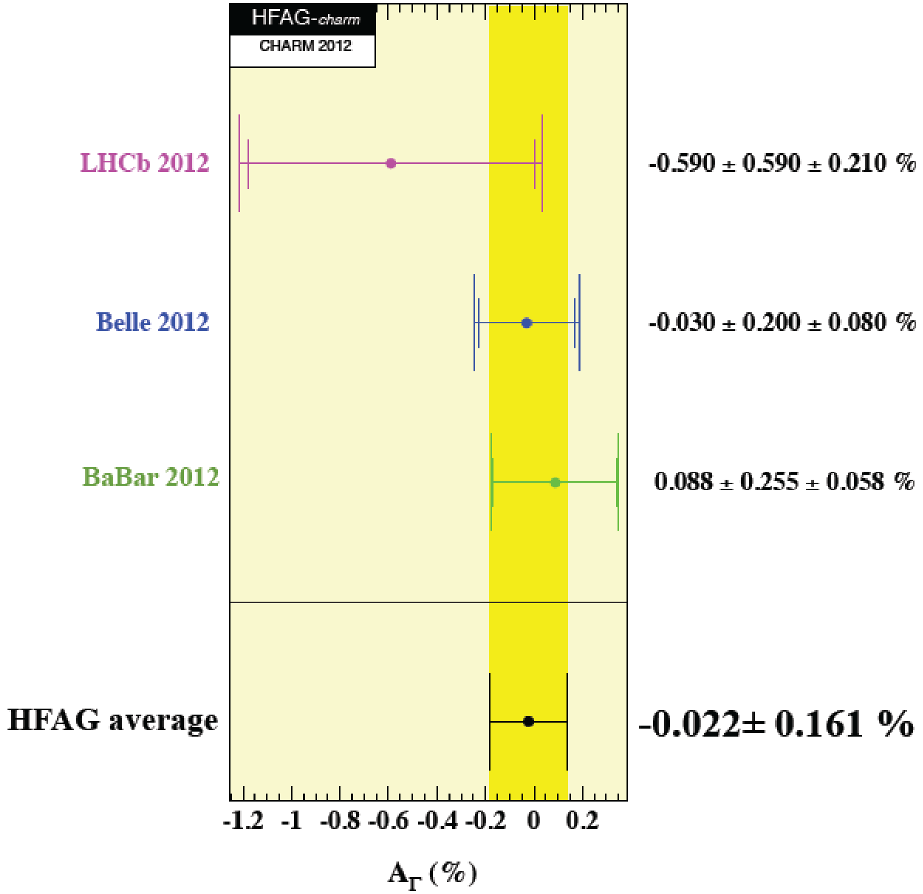
$\Delta Y = (1+y_{CP})A_\Gamma$

No mixing excluded at 3.3σ
No indirect CPV

CPV in charm

- **HFAG updated values:**

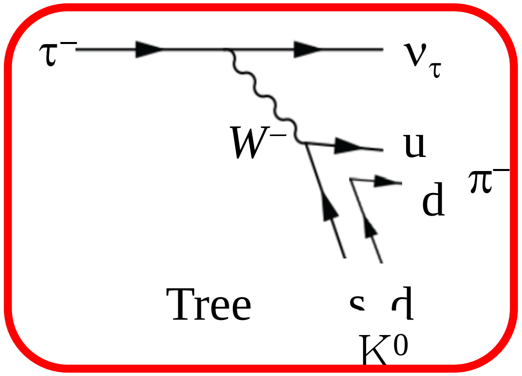




Good agreement between experiments, BaBar and Belle increase precision

τ Physics

CPV in τ decays



Motivation:

- **CP violation not yet observed in the lepton sector**
- **Search for direct CP violation in tau decays: $\tau^- \to \pi^- K_s \nu_\tau$**

$\to$ **within the SM, due to the K_s presence, the decay rate asymmetry:**

$$A_{CP} = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \overline{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \overline{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}$$

is expected to be $A^{SM}_{CP} = (0.332 \pm 0.006)\%$ [Bigi and Sanda, PLB 625, 47 (2005)]

(same argument than for $D \to K_s \pi$ decays)

$\to$ **A deviation of the measured A_{CP} from A_{CP}^{SM} would be a hint of New Physics**

- **e.g. an additional CP violating phase from an exotic charged Higgs boson**

[PLB 398, 407 (1997)]

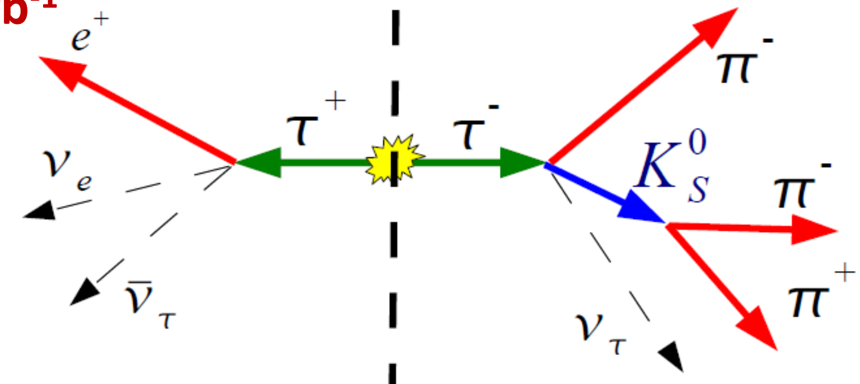
Can consider $\tau^- \to \pi^- K_s (>=0\pi^0) \nu_\tau$ since π^0s are not expected to change the asymmetry

CPV in τ decays

Experimental method:

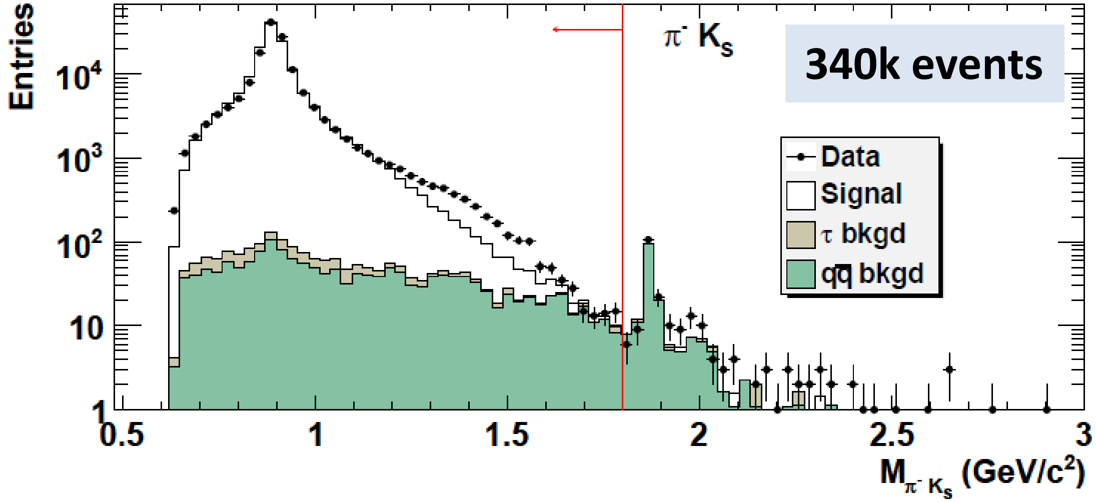
476 fb^{-1}

[PRD85, 031102 (2012)]



- Reconstruct from continuum $\tau^- \to \pi^- K_s (>=0\pi^0)\nu_\tau$ (up to $3\pi^0_s$)
- Electron and muon tags with $p_\ell^* > 4$ GeV (reduce bkg from non-τ-pairs)
- Reconstructed hadronic mass < 1.8 GeV (rejects qq bkg)
- Remaining background further reduced using information of:
  - → $q\bar{q}$ events: visible energy, number of neutral clusters, thrust, total transverse momentum
  - → Fake K^0_s: displaced vertex, invariant mass, momentum and polar angle of the K^0_s candidate

Invariant mass of the hadronic final state ($0\pi^0_s$)



CPV in τ decays

- Measured raw A_{CP} value (after subtraction of qq background and non-$K^0_s\tau$ decays) has to be corrected by:
  - Different nuclear reaction cross-section of $\overline{K^0}$ and K^0 with material detector
    - (0.14±0.03)% for e-tag, (0.14±0.02)% for μ-tag
    - Uncertainties from kaon-nucleon cross-sections and isospin
  - Dilution from background modes including K^0_s

Source	Fraction e-tag (%)	Fraction μ-tag (%)	SM expected A_{CP}
$\tau^- \to \pi^- K^0_S (\geq 0\pi^0)\nu_\tau$	78.7 ± 4.0	78.4 ± 4.0	(0.33±0.01)%
$\tau^- \to K^- K^0_S (\geq 0\pi^0)\nu_\tau$	4.2 ± 0.3	4.1 ± 0.3	(–0.33±0.01)%
$\tau^- \to \pi^- K^0 K^0 (\geq 0\pi^0)\nu_\tau$	15.7 ± 3.7	15.9 ± 3.7	0

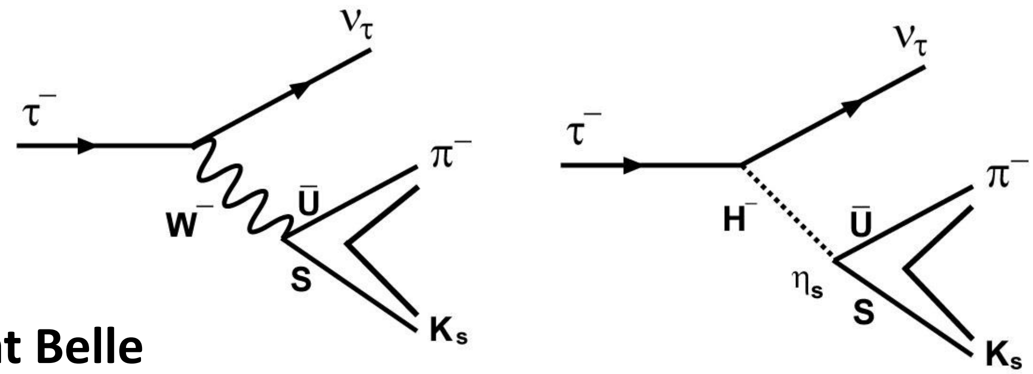
- Result:

$$A_{CP} = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8σ from the SM prediction

CPV in τ decays

- CP violation in τ decay is possible generally if there is an interference between the SM diagram and the CP violating scalar boson exchange diagrams. (Kuhn, Mirkes 1993）



- Search for a CPV decay angle asymmetry at Belle

$$A^{cp} = \frac{\int \cos\beta \cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega} \right) d\omega}{\int \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega} \right) d\omega}$$

$$(d\omega = dQ^2 d\cos\theta d\cos\beta)$$

$$\simeq \langle \cos\beta \cos\psi \rangle_{\tau^-} - \langle \cos\beta \cos\psi \rangle_{\tau^+}$$

ϑ = K^- direction

ψ = τ^- direction in Kπ rest frame

CPV in τ decays

Experimental method:

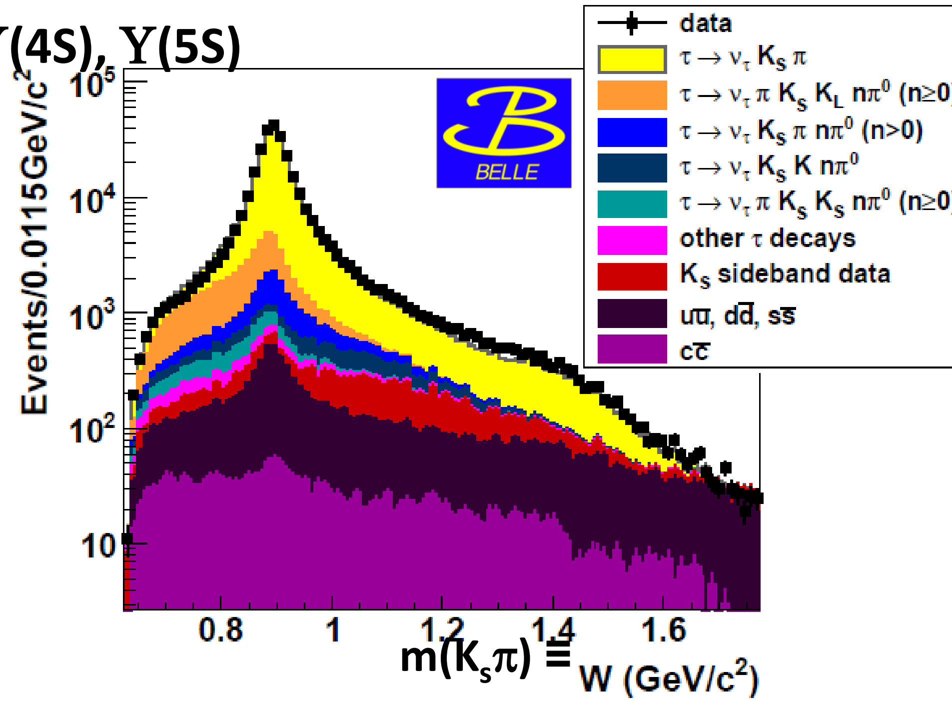
- 699 fb^{-1} of Belle data at the $\Upsilon(3S)$, $\Upsilon(4S)$, $\Upsilon(5S)$
- Reconstruct $\tau \to \nu K_s \pi$

  $\to$ Signal events:

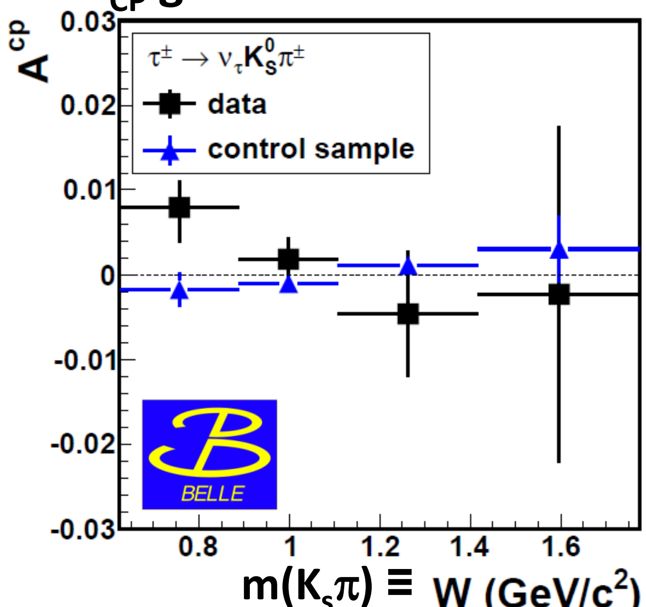
  $(162.2 \pm 0.4) \times 10^3$ events for $\tau^+ \to \nu K_s \pi^+$

  $(162.2 \pm 0.4) \times 10^3$ events for $\tau^- \to \nu K_s \pi^-$

  $\to$ Background: 23%



- After applying small corrections for A_{FB} and A_ε^π (measured in $\tau \to \nu\pi\pi\pi$), the A_{CP} gives:



- **No significant A^{CP} asymmetry**
- Limits for the CP violating parameter (depending on the hadronic form factors param.)

$$|\Im(\eta_S)| < 0.026$$ at 90%CL

Summary

- **Flavour Physics is a very active field, as you have already seen in this meeting (look for additional info at CHARM'12, FPCP'12…)**
- **B factories are still providing high precision results in B, c and τ sectors**
- **In general, good agreement with the SM predictions**
- **~3σ effects involving τ leptons: $B \rightarrow D^{(*)} \tau \nu$, CPV in $\tau \rightarrow \nu K_s \pi$ (BaBar)**
- **No CPV in charm (contrary to LHCb, CDF)**
- **Now that we have huge data samples and sophisticated analysis techniques it would be nice to have feedback from theorists…**
- **And be prepared for the near future…**