CP violation beyond SM

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(on behalf of the BaBar Collaboration)

Outlook:

- **Introduction**
- **B sector**
  - **$b \to s\bar{q}q$ (q=d,s):**
    $B^0 \to K^0_s K^0_s K^0_s$ (BaBar)
  - **$b \to s\gamma$:**
    $B \to \Phi K \gamma$ (Belle)
  - **B^0 mixing (Summary)**
- **Charm Sector**
  $D^+_{(s)} \to K^+ K^0_s \pi^+ \pi^-$ T-odd correlation (BaBar)
  $D^+ \to \Phi \pi^+$ (Belle)
- **Tau Sector**
  $\tau^- \to \pi^- K^0_s \nu$ (BaBar, Belle)
- **Conclusions**

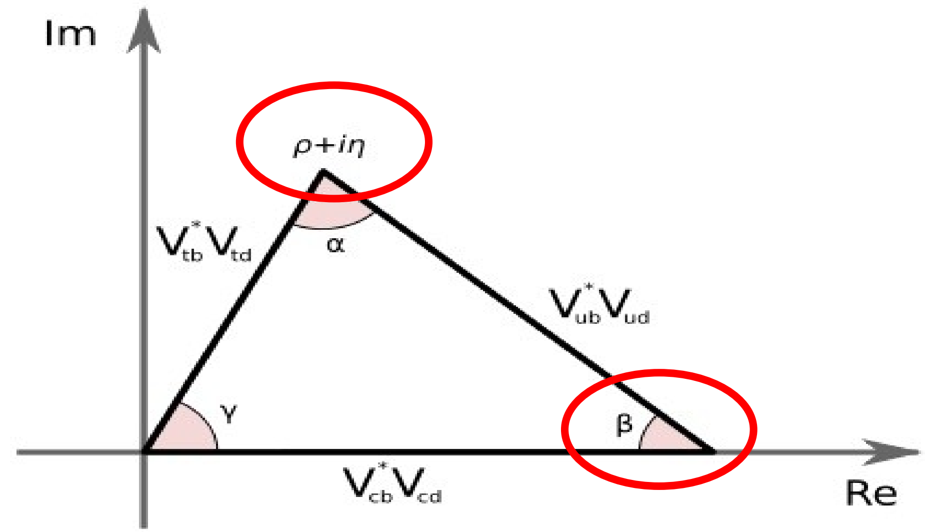
Introduction

Standard Model:

•CP violation in the quark sector described by a single weak phase iη in the CKM mixing matrix

•Time-dependent analyses of "golden" $b \to c\bar{c}s$ transitions give: $\sin(2\beta_{ccs})=0.679 \pm 0.020$

(HFAG, http://www.slac.stanford.edu/xorg/hfag/)



New Physics contributions may induce CPV effects which modify the SM expectations:

→ **Look for possible CPV induced by New Physics in systems where:**

SM CPV is expected to be approximately the same as in the "golden" transitions:

• **$b \to s\bar{q}q$ (q=d,s)**

SM CPV is predicted to be suppressed:

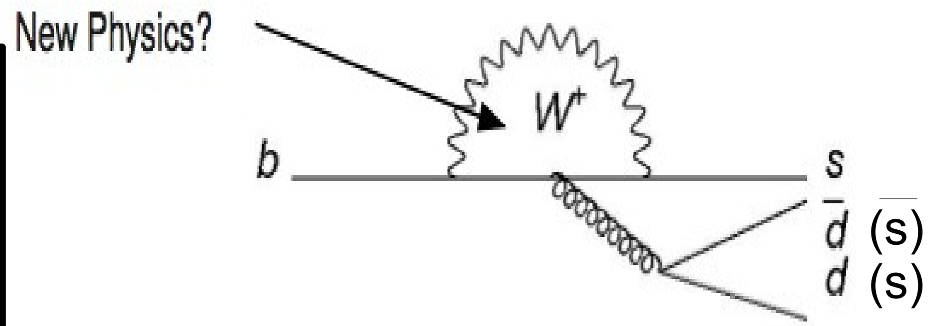
•**$b \to s\gamma$: CPV ~ $O(10^{-2})$**

•**B^0 mixing: CPV ~ $O(10^{-5} - 10^{-4})$**

•**Charm sector: CPV ~ $O(10^{-4} - 10^{-3})$**

•**Tau sector: CPV ~ $O(10^{-3})$**

$b \rightarrow s\bar{q}q$ (q=d,s): Motivations



Standard Model:

$$\frac{Br(\bar{B}^0(t) \to f) - Br(B^0(t) \to f)}{Br(\bar{B}^0(t) \to f) + Br(B^0(t) \to f)} \equiv S_f \sin(\Delta m_B t) - C_f \cos(\Delta m_B t)$$

- Time-dependent CP asymmetry of B^0 decays into CP eigenstate *f* described in terms of **mixing-induced CPV (S_f) and direct CPV (C_f) parameters**
- Amplitude dominated by a single weak-phase term as in $b \rightarrow c\bar{c}s$:
  $S_f \sim -\eta_f \sin(2\beta)$, $C_f \sim 0$;
  (η_f=+1(-1) for CP-even(odd) states)
- "Effective" $\sin(2\beta_{eff})$ could differ from $\sin(2\beta_{ccs})$ due to Final State Interactions & additional $b \rightarrow u$ tree diagrams depending on decay mode
  (Beneke, Phys, Lett. B620, 143;
  Cheng et al., Phys. Rev. D72, 014006;
  Li et al., Phys. Rev. D74, 094020)

Beyond Standard Model:

- Amplitude dominated by diagrams sensitive to new heavy particles in the loop which can give large correction to β_{eff} or $C_f \neq 0$.

- **Today:**
  $B^0 \rightarrow K^0_s K^0_s K^0_s$ (New BaBar result)
- Pure CP-even eigenstate, theoretically & experimentally clean:
  - $\sin(2\beta_{eff})-\sin(2\beta_{ccs})=0.06$ with negligible theory error;
  - Signal/Bkg~1.

(Cheng, Chua, Soni, Phys, Rev D 72, 094003;
Gershon, Hazumi, Phys. Lett. B 596, 163)

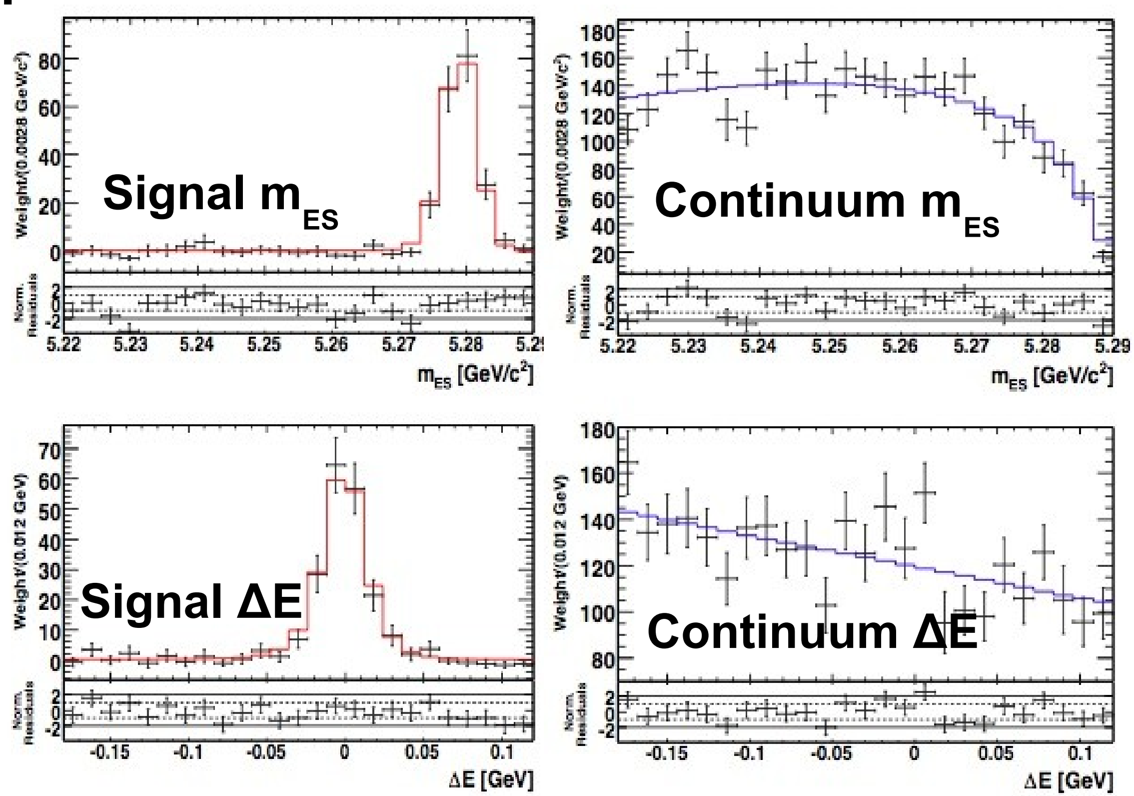
BaBar $B^0 \rightarrow K^0_s K^0_s K^0_s$ (426 fb^{-1})

arXiv:1111.3636

B^0 reconstruction:

- $3K^0_s(\pi^+\pi^-)$ & $2K^0_s(\pi^+\pi^-)K^0_s(\pi^0\pi^0)$ modes selected with cuts on vertex quality, $M(\pi^+\pi^-)$, K^0_s flight length, $E\gamma$, e.m. shower shape, $M(\gamma\gamma)$
- Combinatorial BKG suppressed exploiting the angle between K^0_s flight direction and momentum
- Signal selected by means of $\Delta E = E^*_B - E^*_{\rm beam}$ & $m_{\rm ES} = \sqrt{E^{*2}_{\rm beam} - \vec{p}^{\,*2}_B}$

(*=ϒ(4S) reference frame)



- Dominant BKG from Continuum suppressed by means of a Neural Network (event shape, θ_B, $\theta_{B\text{-}Thrust}$) trained using off-resonance data
- ε= 6.7% (3.1%) for $3K^0_s(\pi^+\pi^-)$ ($2K^0_s(\pi^+\pi^-)K^0_s(\pi^0\pi^0)$) from a MC generated using results of Dalitz-Plot amplitude analysis on data
- $B\bar{B}$ BKG (<2%) included in the fit

BaBar $B^0 \to K^0_S K^0_S K^0_S$ (426 fb^{-1})

arXiv:1111.3636

Proper-time difference PDF described in terms of:

- CP parameters ***S*** & ***C***
- Flavor q_{TAG} of the second B^0 (B_{TAG}) from charge, momentum & decay angle of the daughter tracks (6 different categories, with dilution D_c and difference ΔD_c between B^0 and $\overline{B}^0$)
- Δt resolution R_{sig} described by a sum of three Gaussians from MC

$$\Delta t = tB_{KsKsKs} - tB_{TAG} = \Delta z/\beta\gamma c$$

$$\mathcal{P}^i_{\rm sig}(\Delta t, \sigma_{\Delta t}; q_{\rm tag}, c) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ 1 + q_{\rm tag}\frac{\Delta D_c}{2} + q_{\rm tag}\langle D\rangle_c \left[S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t) \right] \right\} \otimes \mathcal{R}_{\rm sig}(\Delta t, \sigma_{\Delta t}),$$

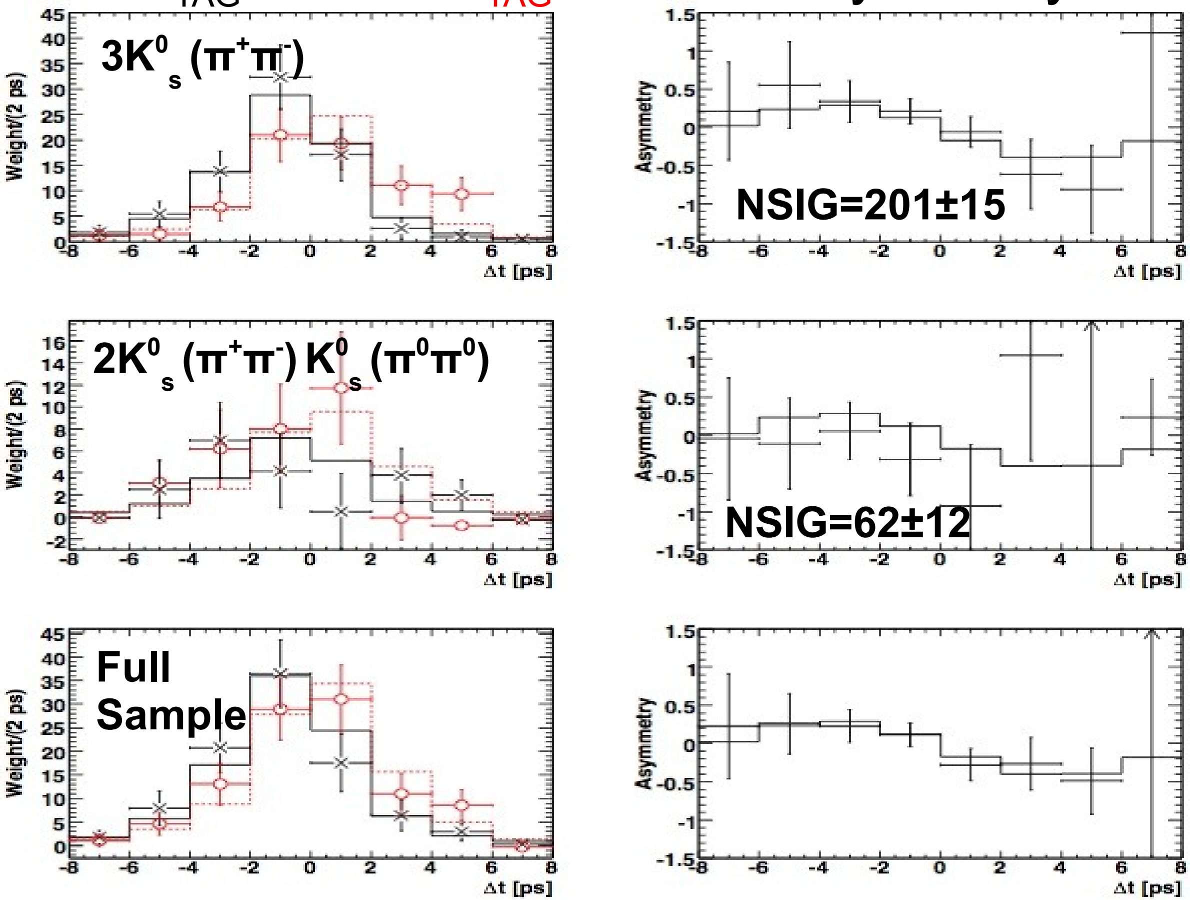
q_{TAG}=+1(-1) for $B_{TAG}=B^0(\overline{B}^0)$

- Signal yield and CP parameters obtained by means of simultaneous unbinned extended maximum likelihood fit to m_{ES}, ΔE, NN, Δt
- Total PDF is the sum of Signal, Continuum and $B\overline{B}$ BKG contributions
- Some m_{ES}, ΔE Signal and Continuum shape parameters fixed from MC
- $B\overline{B}$ BKG PDF described by fixed histograms from MC
- Dilutions (D_c, ΔD_c) fixed from $B \to c\overline{c}K^{(*)}$ analysis (Phys. Rev. D 79, 072009)

BaBar $B^0 \to K^0_S K^0_S K^0_S$ (426 fb^{-1})

arXiv:1111.3636

Δt: B^0_{TAG} $\overline{B}^0_{TAG}$ Asymmetry



RESULTS:

$S = -0.94^{+0.24}_{-0.21} \pm 0.06$

$C = -0.17 \pm 0.18 \pm 0.04$

In agreement with SM

- Systematics from Δt resolution, BKG BRs, fit bias, m_{ES} and ΔE shape parameters from MC

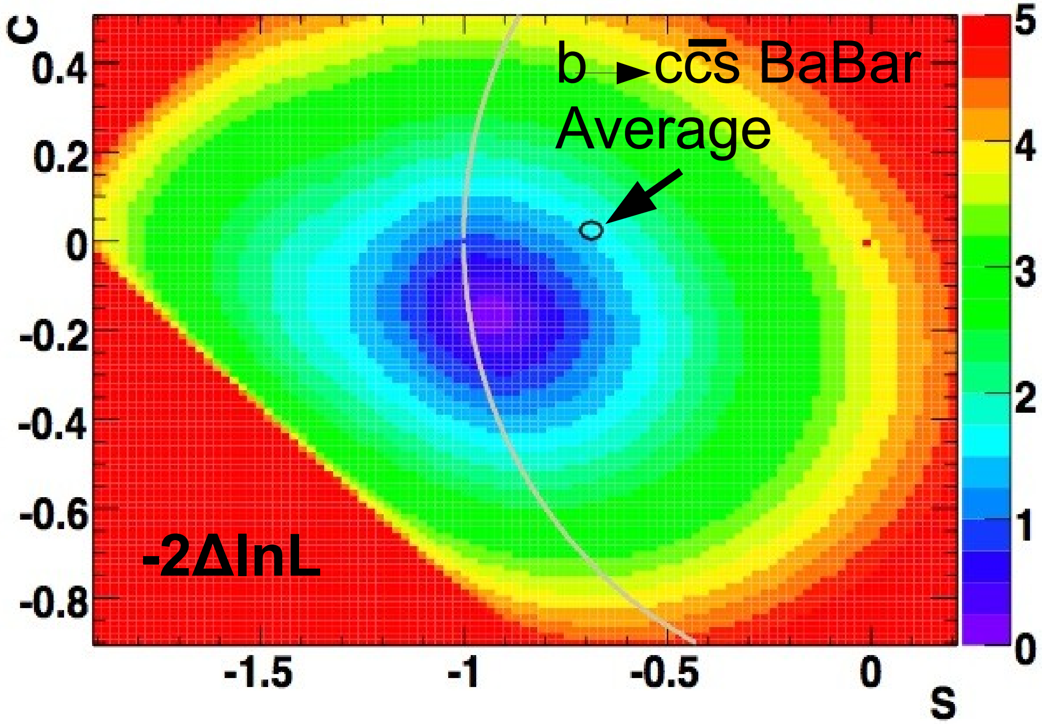
Mode	$\mathcal{B}$ [$\times 10^{-6}$]
Inclusive $B^0 \to K^0_S K^0_S K^0_S$	$6.19 \pm 0.48 \pm 0.15 \pm 0.12$
$f_0(980)K^0_S$, $f_0(980) \to K^0_S K^0_S$	$2.7^{+1.3}_{-1.2} \pm 0.4 \pm 1.2$
$f_0(1710)K^0_S$, $f_0(1710) \to K^0_S K^0_S$	$0.50^{+0.46}_{-0.24} \pm 0.04 \pm 0.10$
$f_2(2010)K^0_S$, $f_2(2010) \to K^0_S K^0_S$	$0.54^{+0.21}_{-0.20} \pm 0.03 \pm 0.52$
NR, $K^0_S K^0_S K^0_S$	$13.3^{+2.2}_{-2.3} \pm 0.6 \pm 2.1$
$\chi_{c0} K^0_S$, $\chi_{c0} \to K^0_S K^0_S$	$0.46^{+0.25}_{-0.17} \pm 0.02 \pm 0.21$

- Same data sample provides inclusive and intermediate resonance BRs from **first Amplitude Analysis** of $B^0 \to K^0_S K^0_S K^0_S$

Summary: $\sin(2\beta_{eff})$ from $b \to s\bar{q}q$

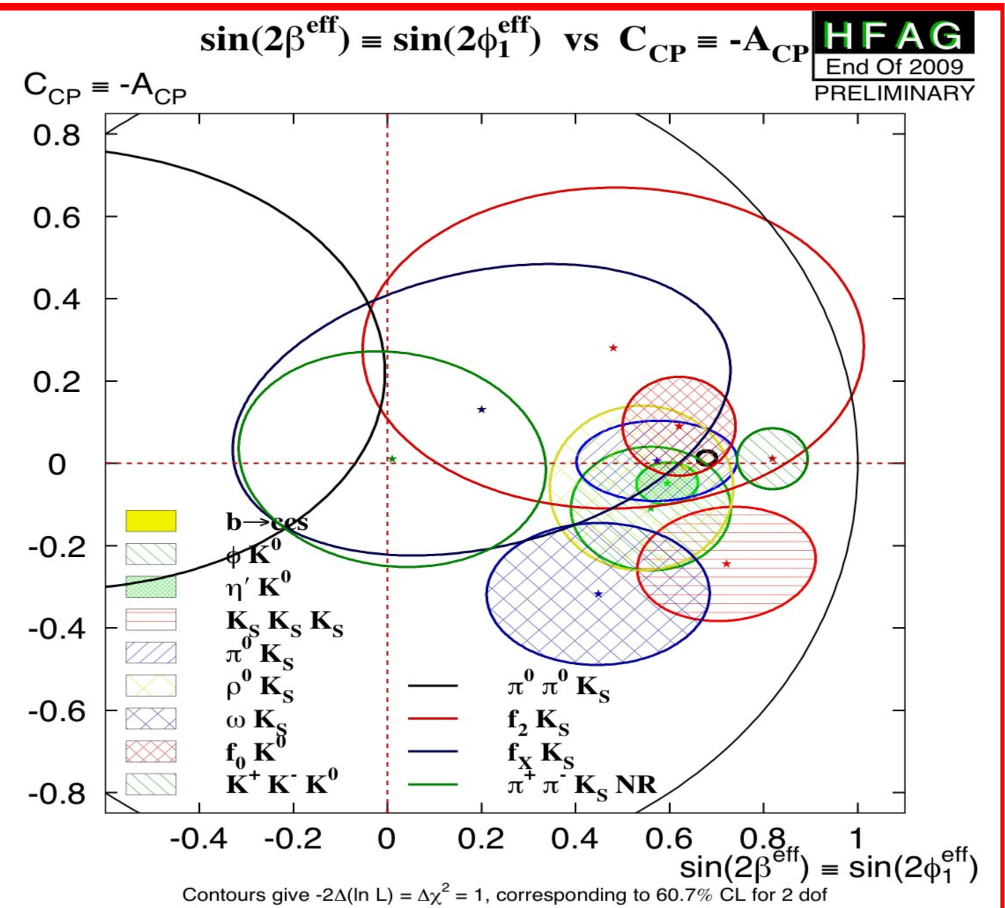
•BaBar $B^0 \to K^0_s K^0_s K^0_s$ (426 fb^{-1})

Likelihood scan in the (*C*, *S*) plane:



•Agreement with $b \to c\bar{c}s$ BaBar average better than 2 σ

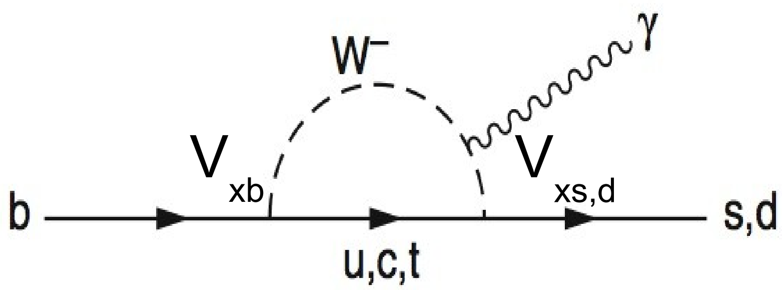
•Result close to the physical boundary $S^2+C^2 \leq 1$



•**HFAG:** **Direct comparison of charmonium and "Naive-s-penguin" averages gives 0.8 σ difference** (χ^2=0.7,CL=0.40)

(HFAG, http://www.slac.stanford.edu/xorg/hfag/)

$b \to s\gamma$: Motivations



FCNC process forbidden at tree level: Probe the SM!

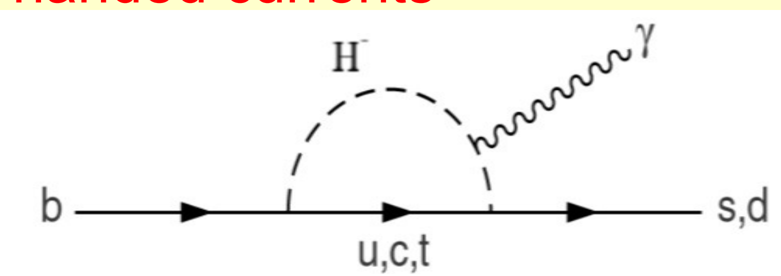
NNLL order $BR(b \to s\gamma)_{(E^*\gamma>1.6\ GeV)} = (3.15\pm0.23)*10^{-4}$ (Misiak et al. PRL 98 022002)

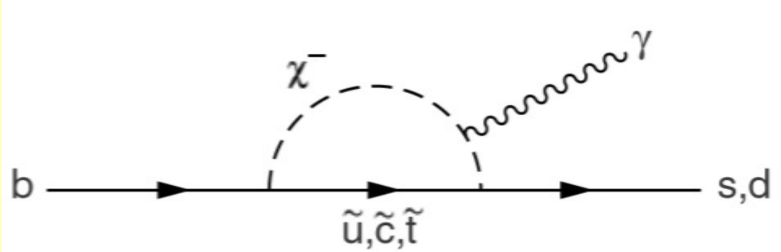
- Emitted photons in $b \to s\gamma$ ($\bar{b} \to \bar{s}\gamma$) predominantly left(right)-handed with the same weak-phase: Time-dependent CP asymmetry is suppressed by $2m_s/m_b$
- Expected mixing-induced parameter S ~ O(3%); direct CP asymmetry parameter C ~ -0.6% (Atwood et al., Phys. Rev. Lett. 79, 185; Atwood et al., Phys. Rev. D 71, 076003)

Beyond Standard Model:

New heavy particles in the loop could:

- Modify BR wrt SM prediction
- Modify CP parameters via right-handed currents





- **Today:**

$B^0 \to \Phi K^0_s\gamma$: **First observation** (Belle)

- At future High Luminosity B Factories will provide precise Time-dependent measurements & probe the photon polarization

Belle $B \to \Phi K\gamma$ (791 fb^{-1})

PRD 84, 071101(R)

B reconstruction:

- $B^+ \to \Phi(K^+K^-)K^+\gamma$, $B^0 \to \Phi(K^+K^-)K^0_s(\pi^+\pi^-)\gamma$ selected with cuts on $M(K^+K^-)$, $M(\pi^+\pi^-)$
- K identification based on a Likelihood Ratio (Cherenkov, Time of Flight & Drift Chamber informations): ε=90%, Purity 92%
- High energy prompt γ selected with 1.4 GeV<$E_\gamma(B_{CM})$<3.4 GeV
  - π^0/η BKG reduced exploiting M(γγ) & e.m. shower profile combined in a Likelihood Ratio
- B candidates identified by means of ΔE and m_{ES}

- Dominant BKG from Continuum suppressed by a Likelihood Ratio using event-shape variables (removed 91% of BKG retaining 76% of Signal)

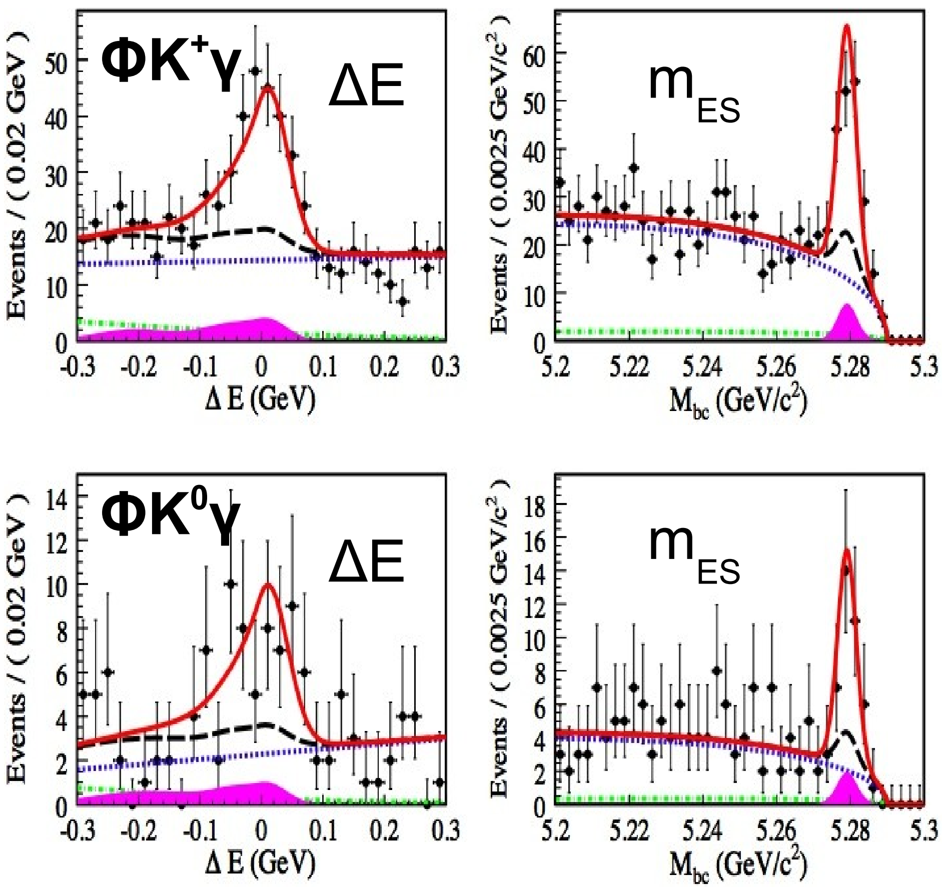
- $D^0\pi^0$, $D^0\eta$, $D^-\rho^+$ Peaking Background vetoed rejecting ΦK^0_s combination compatible with the D mass

- Non Resonant $K^+K^-K\gamma$ BKG estimated in the Φ side-band in data

Belle B→ΦKγ (791 fb^{-1})

PRD 84, 071101(R)

- Signal yield extracted from an extended unbinned maxmimum likelihood fit to the two-dimensional (ΔE, m_{ES}) distribution
- Continuum parameters floated in the fit; Peaking BKG shape fixed to the signal one; Other BKG shapes fixed to MC & adjusted using $K^{*0}(K^+\pi^-)\gamma$ control sample



Total
Total BKG
Continuum
b → c
NR

- **N($\Phi K^+\gamma$) = 144±17**
  BR = (2.48±0.30±0.24)10^{-6}
- **Direct CP Asymmetry:**
  $A_{CP}=(N_{B+}-N_{B-})/(N_{B+}+N_{B-})=$ -0.03±0.11±0.08

- **N($\Phi K^0\gamma$) = 37±8**
  First Observation (5.4 σ)
  BR = (2.74±0.60±0.32)10^{-6}

- BRs systematics dominated by Non-Resonant BKG yield, K^0_s reconstruction and γ efficiency

Belle $B \to \Phi K \gamma$ ($791\ fb^{-1}$)

PRD 84, 071101(R)

- CP parameters obtained by a likelihood fit to the $\Phi K^0_s \gamma$ Δt distribution for B^0 & $\bar{B}^0$ tags (7 different flavor tagging categories)
- Continuum shape from data side-band
- Non Resonant BKG CP parameters fixed to the signal ones, no CPV assumed for other $B\bar{B}$ BKG
- CP fitting technique checked on $\Phi K^0_s \gamma$ side-band, $\Phi K^+ \gamma$ and $K^{*0}(K^+\pi^-)\gamma$ samples

- Only CP parameters floated in the fit
- Statistical error from Toy MC

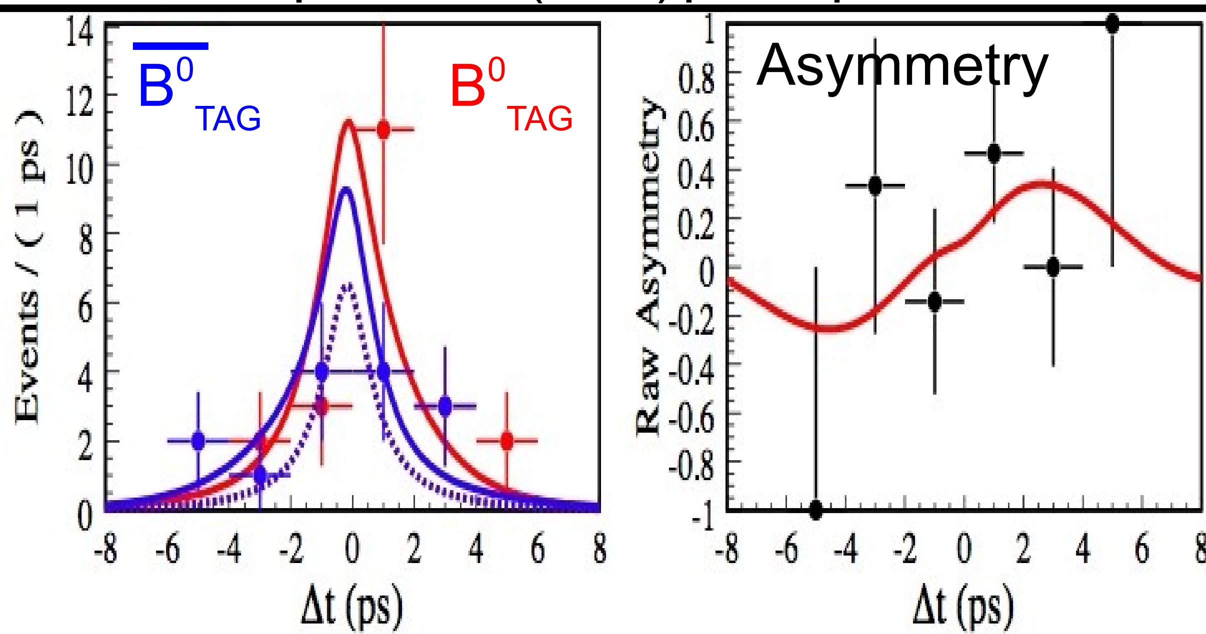
RESULTS:

$S = 0.74^{+0.72}_{-1.05}\,^{+0.10}_{-0.24}$

$C = -0.35 \pm 0.58\,^{+0.23}_{-0.10}$

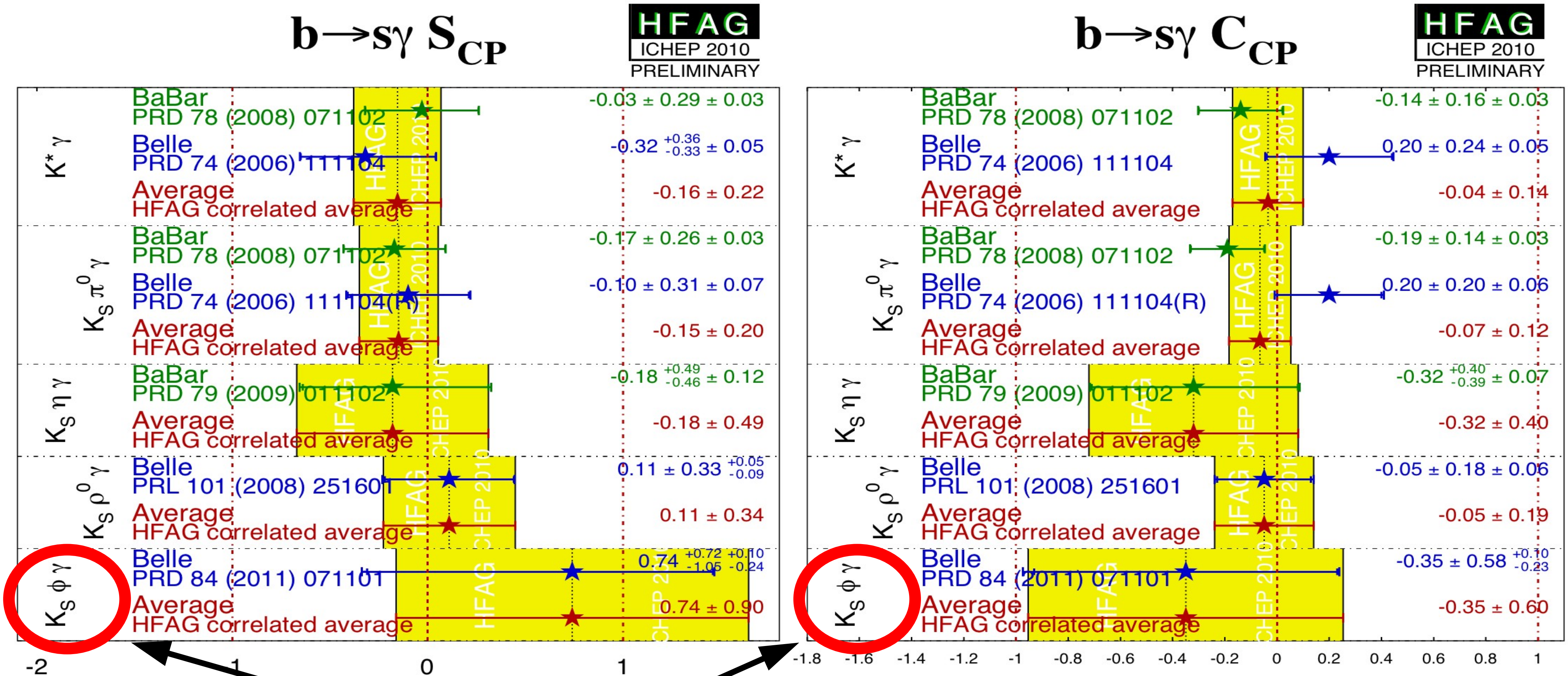
In agreement with SM

- Systematics from vertex reconstruction, fit bias, resolution function



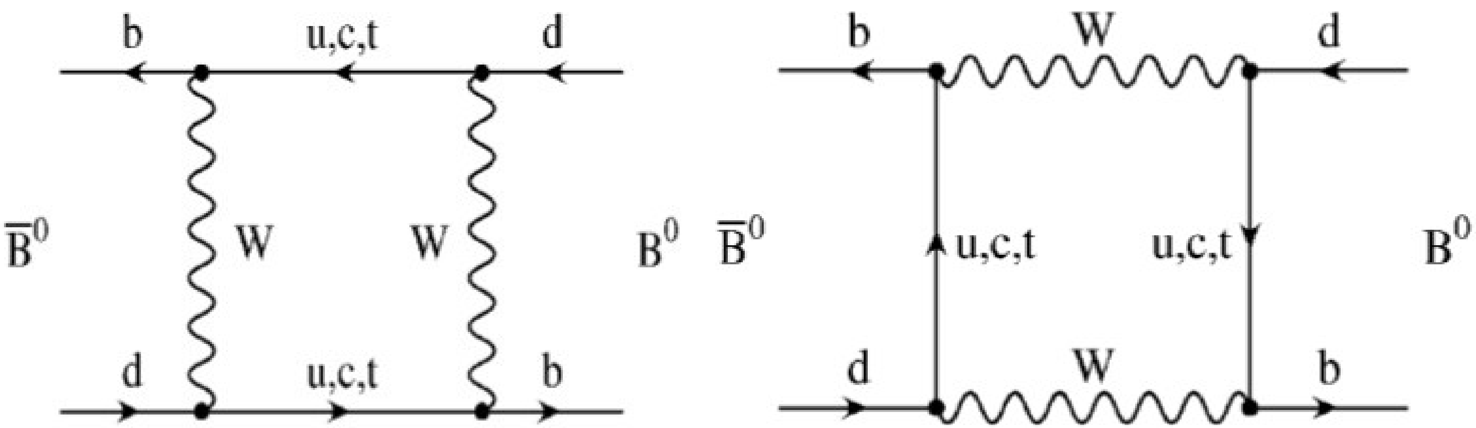
Summary: b→sγ

•**HFAG Compilation does not show any deviation from Standard Model expectations** (HFAG, http://www.slac.stanford.edu/xorg/hfag/)



$B^0 \to \Phi K^0_s \gamma$ Belle First Observation

Summary: CPV in B^0 mixing



- New Particles in the boxes could modify SM expectations

- B^0_q - $\overline{B^0_q}$ oscillations & decay governed by an Effective Hamiltonian:

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

$[M_{ij}]$= mass matrix
$[\Gamma_{ij}]$= decay matrix

- Physical Eigenstates with defined masses and widths:

$$|B_q^{L,H}\rangle = \frac{1}{\sqrt{1+|(q/p)_q|^2}}\left(|B_q\rangle \pm (q/p)_q\,|\overline{B}_q\rangle\right)$$

→If $|(q/p)_q|=1$ they would be also CP Eigenstates

- Neglecting $O(m^2_b/M^2_W)$:

$$\Delta m_q = m_H - m_L = 2\left|M_{12}^q\right|; \Delta\Gamma_q = \Gamma_L - \Gamma_H = 2\left|\Gamma_{12}^q\right|\cos\phi$$

$\phi = arg\left(-M_{12}^q / \Gamma_{12}^q\right)$ CP violating phase

Summary: CPV in B^0 mixing

- $\Upsilon(4S)$ machines & Hadron Colliders: b quarks produced mainly in $b\bar{b}$ pairs
  - → CP Asymmetry (time-independent):

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

- Experimentally: measure charge asymmetry in **mixed** semileptonic B^0 events:

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

→CPV in mixing if:
$A_{SL}\neq0 \leftrightarrow |q/p|\neq1 \leftrightarrow \Phi\neq0$

Standard Model predicts
(Lenz, Nierste, J. High Energy Phys. 0706, 072):

- B_d: $A^d_{SL}=(-4.8^{+1.0}_{-1.2})10^{-4}$

  $\Phi_d=-5.2^{o}{}^{+1.5^o}_{-2.1^o}$

- B_s: $A^s_{SL}=(2.06\pm0.57)10^{-5}$

  $\Phi_s=0.24^o\pm0.08^o$

Beyond Standard Model

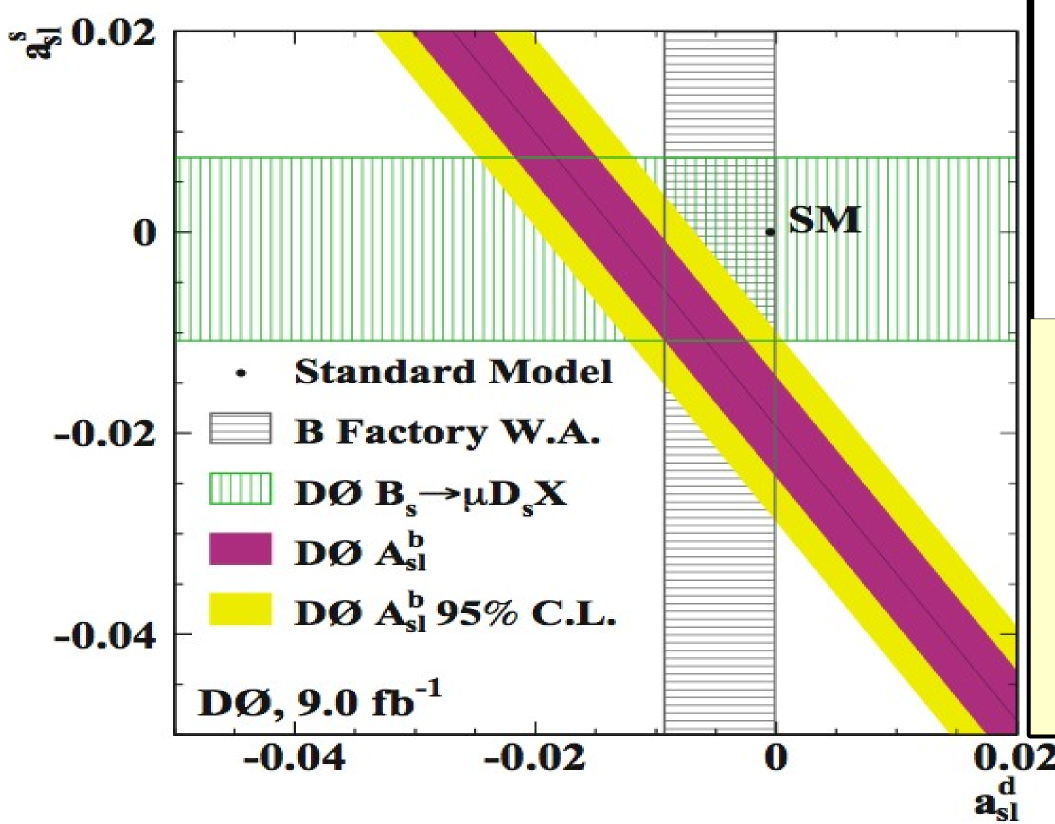
- New Physics could modify M_{12}^q and A_{SL} leaving Γ_{12}^q unchanged :

$$M_{12}^{NP,q}=M_{12}^{SM,q}\Delta_q;\ \Delta_q=|\Delta_q|e^{i\phi_q^\Delta}$$

$$A_{SL}^{NP}=\frac{|\Gamma_{12}^q|}{|M_{12}^{SM,q}|}\frac{\sin(\phi_q^{SM}+\phi_q^\Delta)}{|\Delta_q|}$$

Summary: CPV in B^0 mixing

- HFAG average of Υ(4S) measurements gives (arXiv:1010.1589v3):
  $|q/p|_d$=1.0024±0.0023
  ***A^d_{SL}* = -0.0047±0.0046**
  In agreement with SM



- Hadronic Colliders measure a combination of B^0_d & B^0_s CP parameters:
  $A^b_{SL}=C_d A^d_{SL}+C_s A^s_{SL}$
  → $C_{d,s}$ depend on $B^0_{d,s}$ production rates & mean mixing probability
- SM predicts:

$$A^b_{SL}=(-0.028\,^{+0.005}_{-0.006})\%$$

- New D0 result on charge Asymmetry of like-sign dimuons differs by 3.9 σ from SM expectation (Phys. Rev. D 84, 052007):
  A^b_{SL}=(-0.787±0.172±0.093)%

- New results from Beauty-Factories & LHCb will be available soon

CP violation in D decays: Motivations

Standard Model:

•Charm physics is ~CP conserving:

$$[\mathrm{CKM}]=\begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta+\frac{i}{2}\eta\lambda^2) \\ -\lambda & 1-\frac{\lambda^2}{2}-i\eta A^2\lambda^4 & A\lambda^2(1+i\eta\lambda^2) \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

•Indirect CPV predicted to be $a_{CP}^{ind} < O(10^{-3})$ and **universal** for CP eigenstates

•Direct CPV a_{CP}^{dir}:

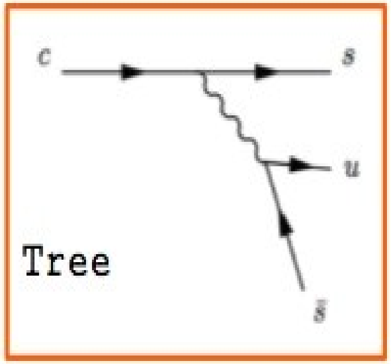
- ➔ Negligible in Cabibbo-Favoured & Doubly-Cabibbo-Suppressed decays (Bergman et al. JHEP 09, 031)
- ➔ Largest in Singly-Cabibbo-Suppressed decays $O(10^{-4} - 10^{-3})$ (Buccella et al. Phys. Rev. D 51, 3478)

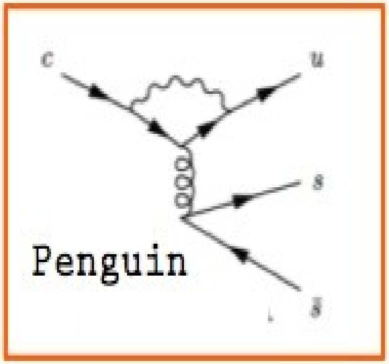
•Recent evidence in Time-integrated D^0 asymmetry from LHCb (see Ukleja talk):
$A_{CP}(K^+K^-)-A_{CP}(\pi^+\pi^-)=(-8.2\pm2.1\pm1.1)10^{-3}$
(arXiv:1112.0938v1)

Beyond Standard Model:

•New Physics could enhance direct & indirect CPV up to $\sim O(10^{-2})$ through loop diagrams
(Grossman et al. Phys. Rev. D 75, 036008; Bigi, arXiv:0907.2950)

•**Today:**
SCS modes with gluonic penguin very promising to search for direct CPV from interference between Tree and Penguin amplitudes



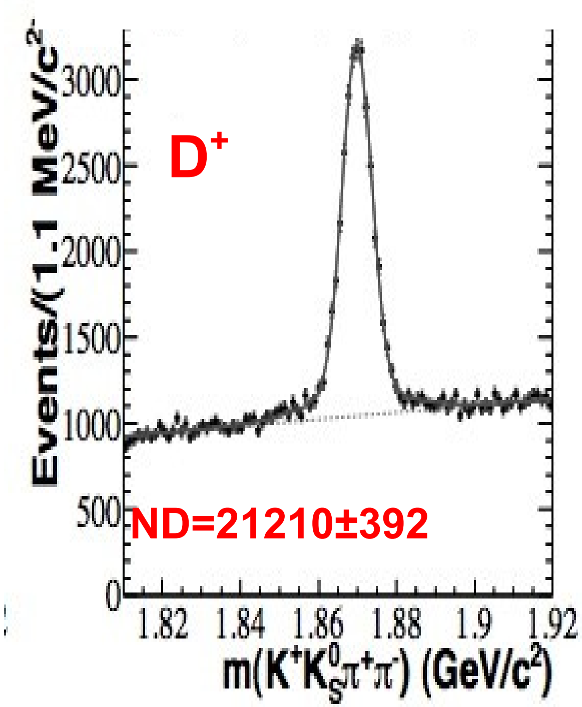


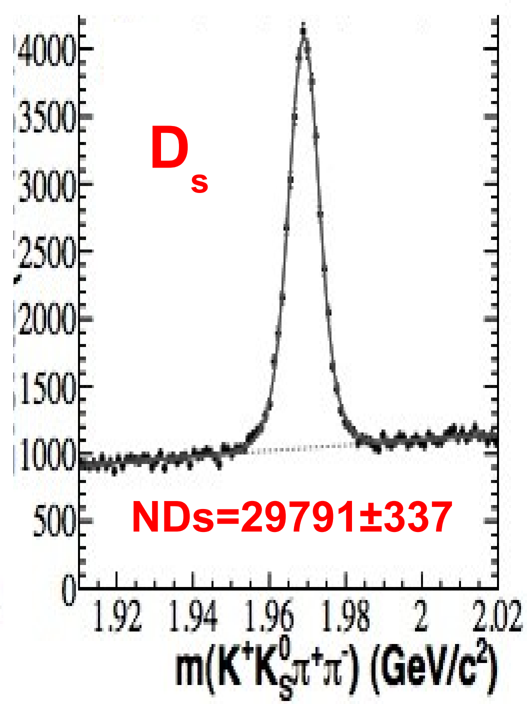
BaBar $D^+_{(s)} \to K^+K^0_s\pi^+\pi^-$ (520 fb^{-1})

PRD 84, 031103

D reconstruction:

- Singly-Cabibbo-Suppressed & Cabibbo-favoured $D^+_{(s)} \to K^+K^0_s(\pi^+\pi^-)\pi^+\pi^-$ selected with cuts on $M(\pi^+\pi^-)$, $\pi^+\pi^-$ vertex quality, K^0_s decay lenght
- K^0_s combined with $K^+\pi^+\pi^-$ with common vertex detached from interaction region (ε_K=90%, $\varepsilon_{\pi \to K}$=1.5%)
- Signal selected by means of a Likelihood Ratio ($p_{CM}(D)$, D transverse decay length, vertex probability)





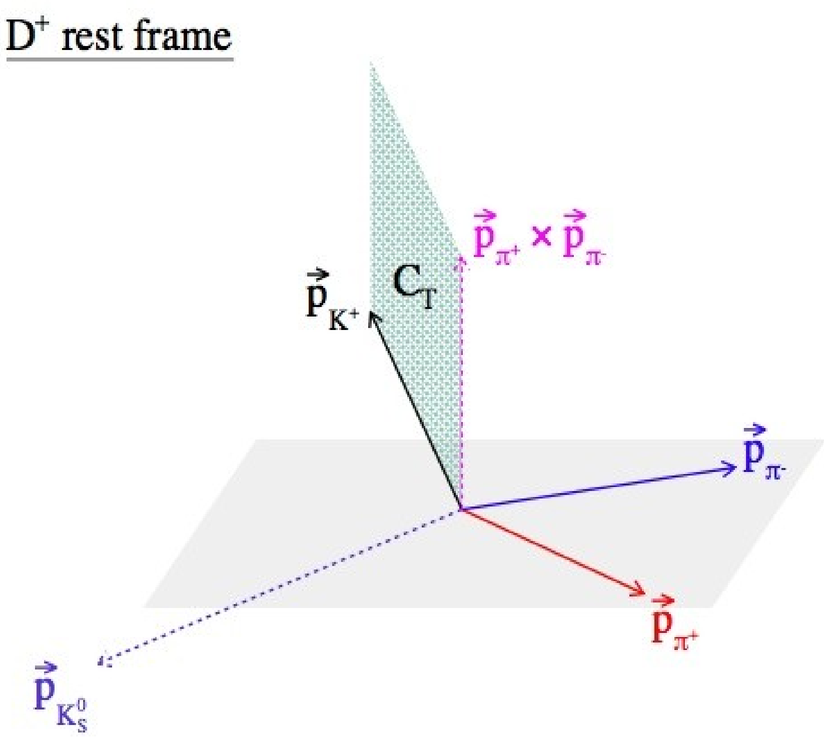
- Combinatorial BKG from B decays suppressed by $p_{CM}(D)$>2.5GeV/c
- Charm BKG with the same topology: $D^{*+} \to \pi^+D^0(K^0_sK^+\pi^-)$, $D^+ \to K^+K^0_sK^0_s(\pi^+\pi^-)$ removed by means of $M(D^*)-M(D^0)$ & $M(\pi^+\pi^-)$ requirements
- BKG from $D^+ \to K^0_s\pi^+\pi^+\pi^-$, $\Lambda^+_c \to pK^0_s\pi^+\pi^-$ does not bias the signal yield extraction

BaBar $D^+_{(s)} \to K^+ K^0_s \pi^+ \pi^-$ (520 fb^{-1})

PRD 84, 031103

•T-odd correlation observable built from final state momenta:

$$C_T \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$$



•CPT theorem:
Asymmetry in T-odd observable indicates CPV

$$A_T \equiv \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)}$$

•Final State Interactions could produce $A_T \neq 0$ due to strong phases
(Bigi et al. Int. J. Mod. Phys. A 24S1, 657)

- Effects removed by using

$$\mathcal{A}_T \equiv \frac{1}{2}\left(A_T - \bar{A}_T\right)$$

- $\bar{A}_T$ defined on CP-conjugate process
(Bensalem et al. Phys. Rev. D 66, 094004; Phys. Lett. B 538, 309; Phys. Rev. D 64, 116003))

BaBar $D^+_{(s)} \to K^+ K^0_s \pi^+ \pi^-$ (520 fb^{-1})

PRD 84, 031103

- Sample divided according to $D_{(s)}$ charge and C_T sign
- Signal yields & asymmetries obtained from simultaneous fit to mass spectra sharing same parameters among different subsamples

$$A_T(D^+) = (+11.2 \pm 14.1_{\rm stat} \pm 5.7_{\rm syst}) \times 10^{-3}$$

$$\bar{A}_T(D^-) = (+35.1 \pm 14.3_{\rm stat} \pm 7.2_{\rm syst}) \times 10^{-3}$$

$$A_T(D_s^+) = (-99.2 \pm 10.7_{\rm stat} \pm 8.3_{\rm syst}) \times 10^{-3},$$

$$\bar{A}_T(D_s^-) = (-72.1 \pm 10.9_{\rm stat} \pm 10.7_{\rm syst}) \times 10^{-3}$$

- Final State Interaction produces CPV effects only in D_s decays due to different resonance substructure between D and D_s (e.g. $K^{*0}K^{*+}$)

RESULTS

$\mathcal{A}_T(D^+)=(-12.0\pm10.0\pm4.6)10^{-3}$

$\mathcal{A}_T(D_s)=(-13.6\pm7.7\pm3.4)10^{-3}$

In agreement with SM

To be compared with FOCUS previous results (Phys. Lett. B 622, 239):

$\mathcal{A}_T(D^+)=(23\pm62\pm22)10^{-3}$

$\mathcal{A}_T(D_s)=(-36\pm67\pm23)10^{-3}$

- Systematics dominated by reconstruction asymmetries, Likelihood Ratio selection and particle identification

Belle $D^+ \rightarrow \Phi\pi^+$ (955 fb^{-1})

arXiv:1110.0694

- SCS and CF decays $D^+_{(s)} \rightarrow \Phi(K^+K^-)\pi^+$ reconstructed using K, π candidates surviving proton & lepton vetos (ε~90%, Misid. Prob. ~5%)
- D^+ candidates constrained to originate from interaction region
- Dominant Combinatorial BKG from B decays reduced exploiting $M(K^+K^-)$, $p_{CM}(D)$>2.5GeV/c, p_π and helicity angle between K^- and D^+ directions in the Φ rest frame

- Reconstructed asymmetry depends on several contributions:

$$A_{CP}^{D^+_{(s)}\to\phi\pi^+} = \frac{\Gamma(D^+_{(s)}\to\phi\pi^+) - \Gamma(D^-_{(s)}\to\phi\pi^-)}{\Gamma(D^+_{(s)}\to\phi\pi^+) + \Gamma(D^-_{(s)}\to\phi\pi^-)} = A_{CP} + A_{FB}(\cos\theta^*) + A_\epsilon^{KK} + A_\epsilon^\pi(p_\pi, \cos\theta_\pi)$$

- A_{CP}: Physics
- A_{FB}: Forward-Backward $c\bar{c}$ production asymmetry in terms of $D_{(s)}$ polar angle in CM frame, θ*
- A^{KK}_ε , A^π_ε : charge asymmetries due to detector K, π efficiencies

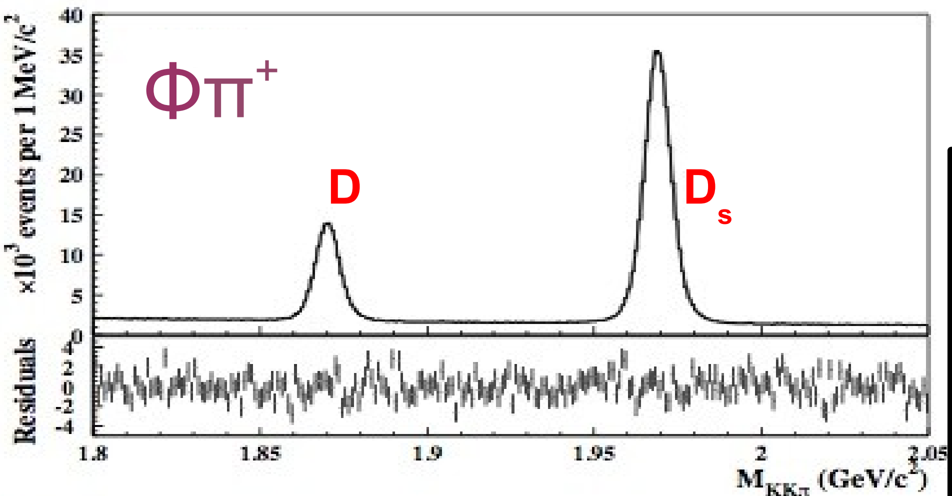
- CF D_s decays expected to have negligible A_{CP}: non-CP contributions reduced in the difference

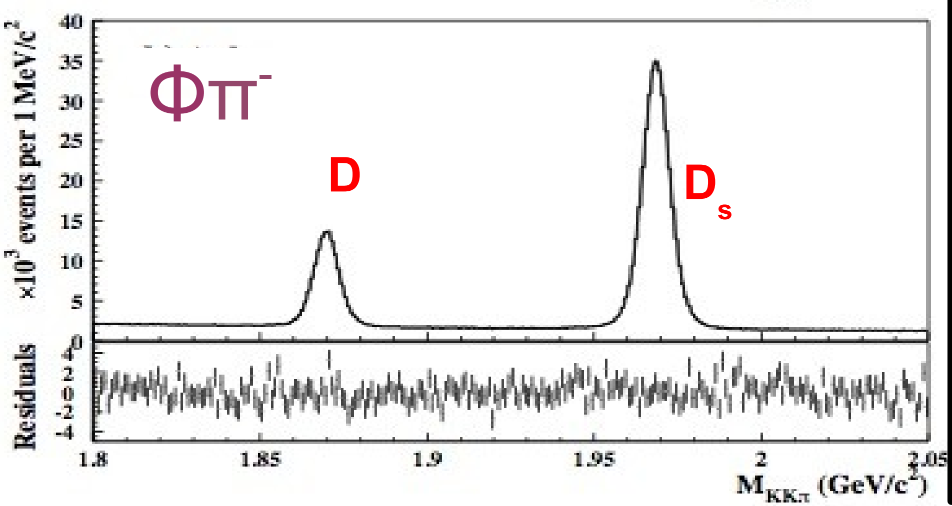
$\Delta A_{rec} = A_{CP}(D) - A_{CP}(D_s)$

Belle $D^+ \rightarrow \Phi\pi^+$ (955 fb^{-1})

arXiv:1110.0694

- Signal yields obtained from Binned Likelihood Fit to M(KKπ) in 3D phase-space ($\cos\theta^*$, p_π, $\cos\theta_\pi$) bins
- Peak positions, D^+ width and BKG parameters floated





$N_D = 237525 \pm 577$

$N_{D_s} = 722871 \pm 931$

- ΔA_{rec} corrected to take into account difference in K efficiency charge-asymmetry between D and D_s subsamples due to different $p_{K\pm}$ spectra: $\Delta A_\varepsilon^{KK} = (0.111 \pm 0.025)\%$
- Difference in π efficiency charge asymmetry avoided by fitting the D, D_s yields in ($\cos\theta^*$, p_π, $\cos\theta_\pi$) bins

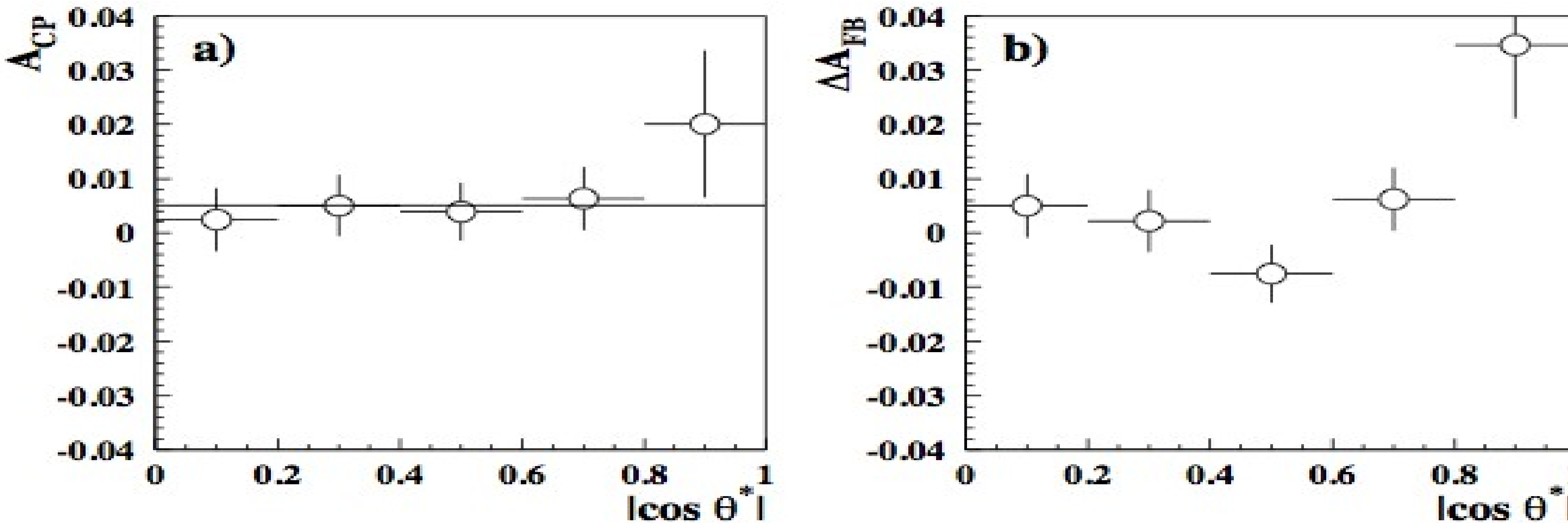
$$\Delta A_{rec}^{cor} = \Delta A_{rec} - \Delta A_\epsilon^{KK}$$

Belle $D^+ \rightarrow \phi\pi^+$ (955 fb^{-1})

arXiv:1110.0694

- A_{CP} & A_{FB} asymmetries computed in bins of cos(θ*):

$$A_{CP}^{D^+\to\phi\pi^+} = \frac{\Delta A_{\rm rec}^{\rm cor}(\cos\theta^*) + \Delta A_{\rm rec}^{\rm cor}(-\cos\theta^*)}{2} \qquad \Delta A_{FB} = \frac{\Delta A_{\rm rec}^{\rm cor}(\cos\theta^*) - \Delta A_{\rm rec}^{\rm cor}(-\cos\theta^*)}{2}$$



RESULT
A_{CP} = (0.51±0.28±0.05)%
In agreement with SM

$\langle\Delta A_{FB}\rangle$=(0.25±0.28)%
No significant difference between D and D_s

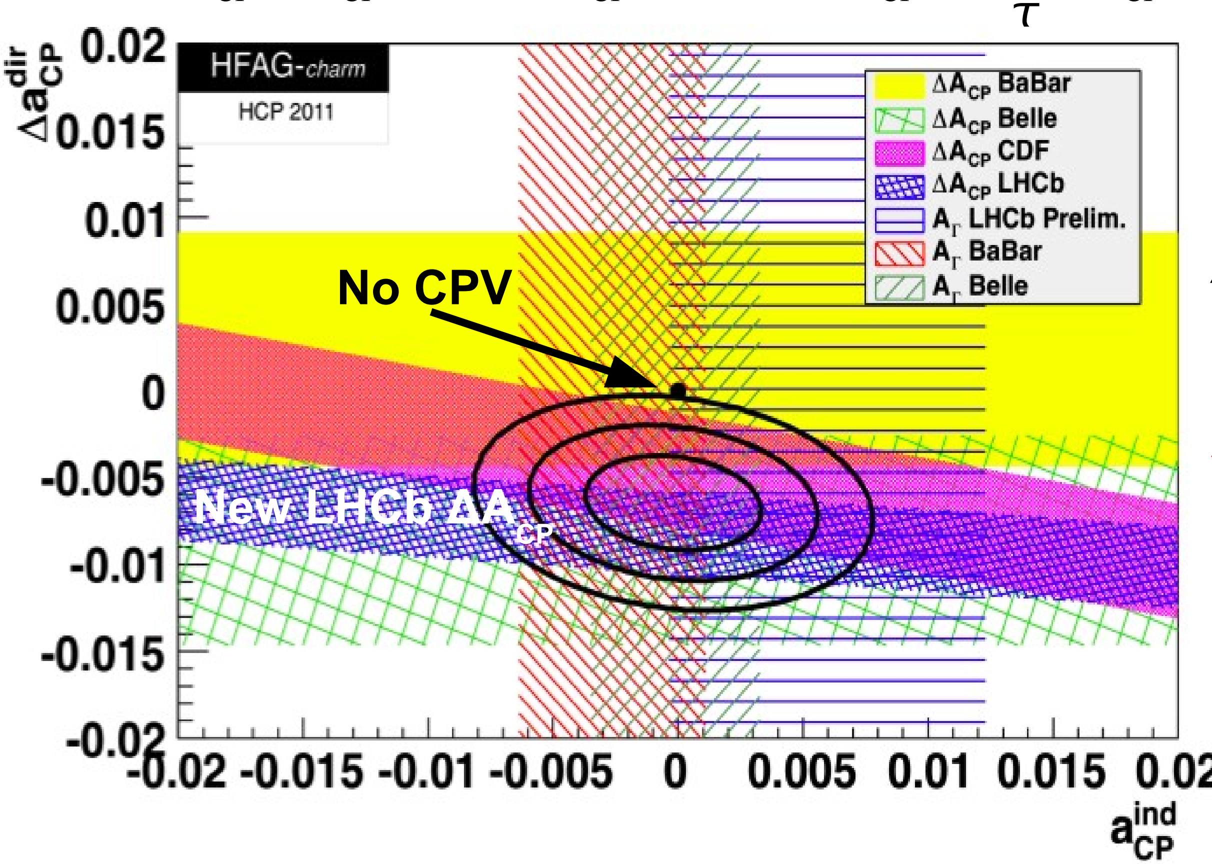
- Dominant systematics from K charge asymmetry correction, (cosθ*, p_π, $\cos\theta_\pi$) & M(KKπ) binning, signal & BKG parameterization

Summary: D^0 decays

- $A_{CP}(D^0 \rightarrow f_{CP}) = a_{CP}^{dir}(f_{CP}) + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}, \langle t \rangle$ average decay time
- Combination of direct & indirect CPV obtained in terms of observables:

$$\rightarrow A_\Gamma = \frac{\tau(\overline{D^0} \rightarrow KK) - \tau(D^0 \rightarrow KK)}{\tau(\overline{D^0} \rightarrow KK) + \tau(D^0 \rightarrow KK)} = -a_{CP}^{ind}$$ constrains universal indirect CPV

$$\rightarrow \Delta A_{CP} = A_{CP}(KK) - A_{CP}(\pi\pi) = \Delta a_{CP}^{dir} + \frac{\Delta \langle t \rangle}{\tau} a_{CP}^{ind}$$ constrains direct CPV



- From a 2D fit to all the available measurements of A_Γ, $A_{CP}(KK)$, $A_{CP}(\pi\pi)$ & ΔA_{CP}:

a_{CP}^{ind}=(-0.019±0.232)%

Δa_{CP}^{dir}=(-0.645±0.180)%

Data "consistent" with no CPV at 0.128% CL

(HFAG, http://www.slac.stanford.edu/xorg/hfag/)

CP violation in τ decays: Motivations

Standard Model:

- Negligible Direct CPV expected
- Small $O(10^{-3})$ A_{CP} into final states with K^0_s due to CPV in the kaon sector

(Bigi, Sanda, Phys. Lett. B 625, 47; Calderon et al., Phys. Rev D 75, 076001)

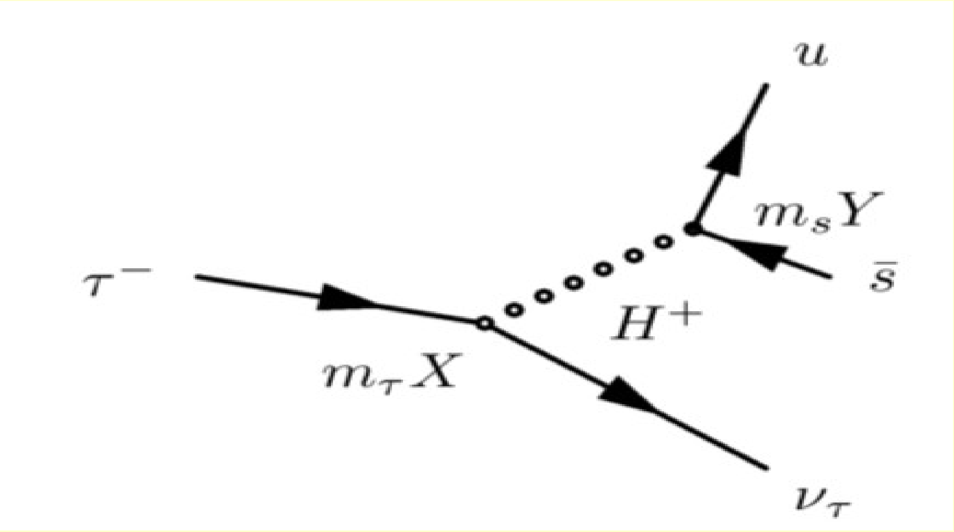
- **Today:** $\tau^- \to \pi^- K^0_s \nu$
- Interference between K^0_s & K^0_L intermediate amplitudes plays an important role. Assuming a $K^0_s \to \pi^+\pi^-$ fully efficient selection for decay times long compared to the K^0_s lifetime:

$$A_Q = \frac{\Gamma\left(\tau^+ \to \pi^+ K^0_S\, \bar{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K^0_S\, \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K^0_S\, \bar{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K^0_S\, \nu_\tau\right)}$$

$=(0.33\pm0.01)\%$ for decay times $\sim\tau_{K0s}$

(Grossman, Nir, arXiv:1110.3790)

Beyond Standard Model:



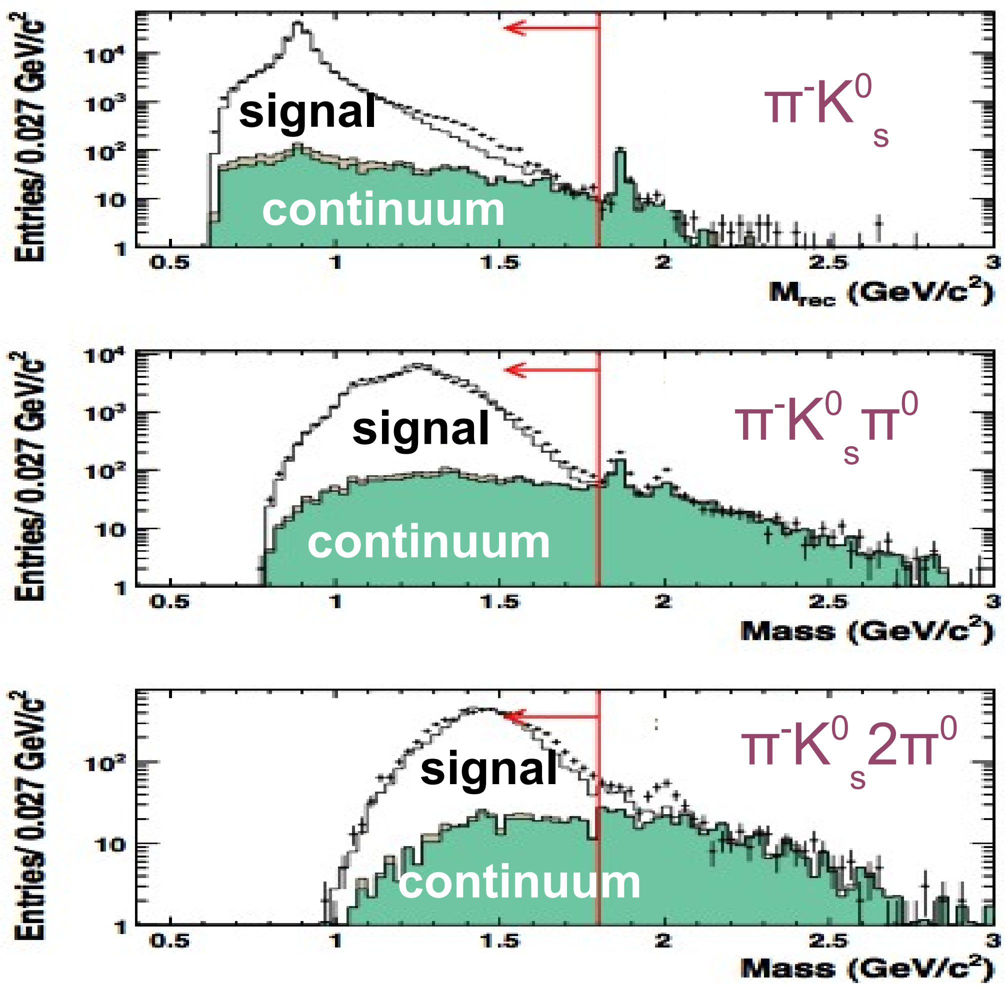
- New Physics could significantly modify the measured $\tau^- \to \pi^- K^0_s \nu$ decay-rate charge asymmetry from the SM expectations
- Charged scalar boson exchange could reflect in differences between the τ^+ & τ^- decay angular distributions

(Kuhn, Mirkes, Phys. Lett. B 398, 407)

BaBar $\tau^- \to \pi^- K^0_s (\geq 0\pi^0)\nu$ (476 fb^{-1})

arXiv:1109.1527

- Events divided in two hemispeheres according to Thrust axis
- $\tau^+\tau^-$ events selected with a single prompt track + $K^0_s \to \pi^+\pi^-$ candidate in one hemisphere and one prompt Tag-lepton (e/μ) with opposite charge in the other
- Additional $\pi^0 \to \gamma\gamma$ candidates permitted (do not affect A_Q)



- Signal selected by means of two Likelihood Ratios (topological & kinematical quantities) to distinguish τ from $q\bar{q}$ and to reduce K^0_s BKG
- Bhabha, $\mu^+\mu^-$, and Continuum BKG suppressed exploiting p_{Prompt}, Thrust-value, $M(\pi^- K^0_s (\leq 3\pi^0))$
- Residual BKG from $\tau \to K K^0_s (\geq 0\pi^0)\nu$ & $\tau \to \pi K^0 \bar{K}^0 \nu$ estimated from MC & corrected using L.R. data side-band $f_{BKG}=(20.0\pm3.7)\%$

$N_{signal}(\tau^-)=170211$
$N_{signal}(\tau^+)=169455$

BaBar $\tau^- \to \pi^- K^0_s (\geq 0\pi^0)\nu$ (476 fb^{-1})

arXiv:1109.1527

- After Continuum & non-K^0_s τ decays subtraction, raw charge asymmetry:

A_Q(e-Tag)=(-0.32±0.23)%

A_Q(μ-Tag)=(-0.05±0.27)%

- No significant decay-rate asymmetries from selection criteria and detector response found in real & simulated $\tau \to h^+ h^- h^+ (\geq 0\pi^0)\nu$, BKG events rejected from the data sample and MC signal sample

- Decay-rate asymmetry modified by the different $K^0/\bar{K}^0$ nuclear interaction cross-sections with the material, related to $K^\pm$-nucleon one via isospin symmetry (Ko et al., arXiv:1006.1938v1)
  - → Corrections computed on event-by-event basis in terms of (p, θ) of K^0_s :

A_{K0}(e-Tag)=(0.14±0.03)%; A_{K0}(μ-Tag)=(0.14±0.02)%

Have to be subtracted from the raw asymmetry result

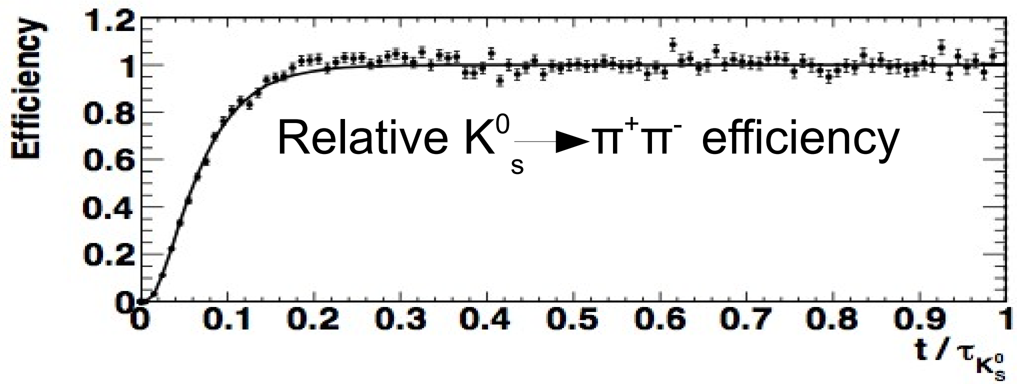
BaBar $\tau^- \to \pi^- K^0_s (\geq 0\pi^0)\nu$ (476 fb^{-1})

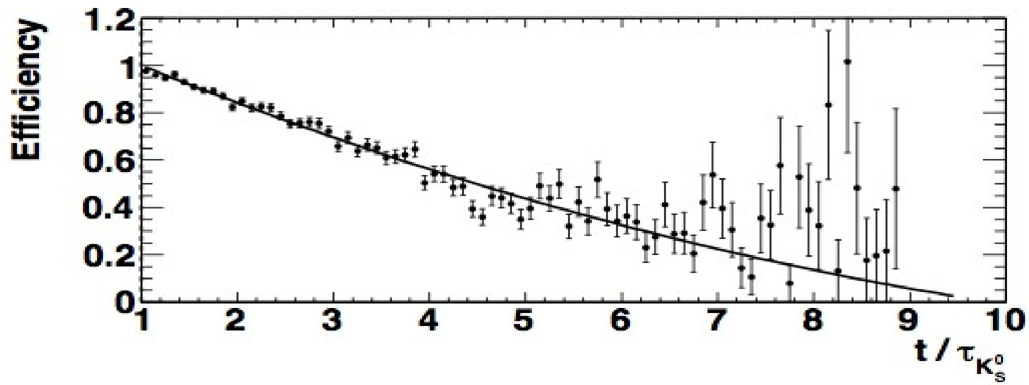
arXiv:1109.1527

- After correction and taking into account the residual $\tau \to K^0_s$ BKG charge asymmetries:

A_Q=(-0.45±0.24±0.11)%   FIRST MEASUREMENT

- Systematics from detector & selection bias, BKG subtraction and $K^0/\overline{K^0}$ nuclear interaction





- K^0_s - K^0_L interference affects the predicted A_Q =(0.33±0.01)%
  - ➔ Correction to be applied in terms of the $K^0_s \to \pi^+\pi^-$ decay time dependence of the selection efficiency (Grossman, Nir, arXiv:1110.3790):

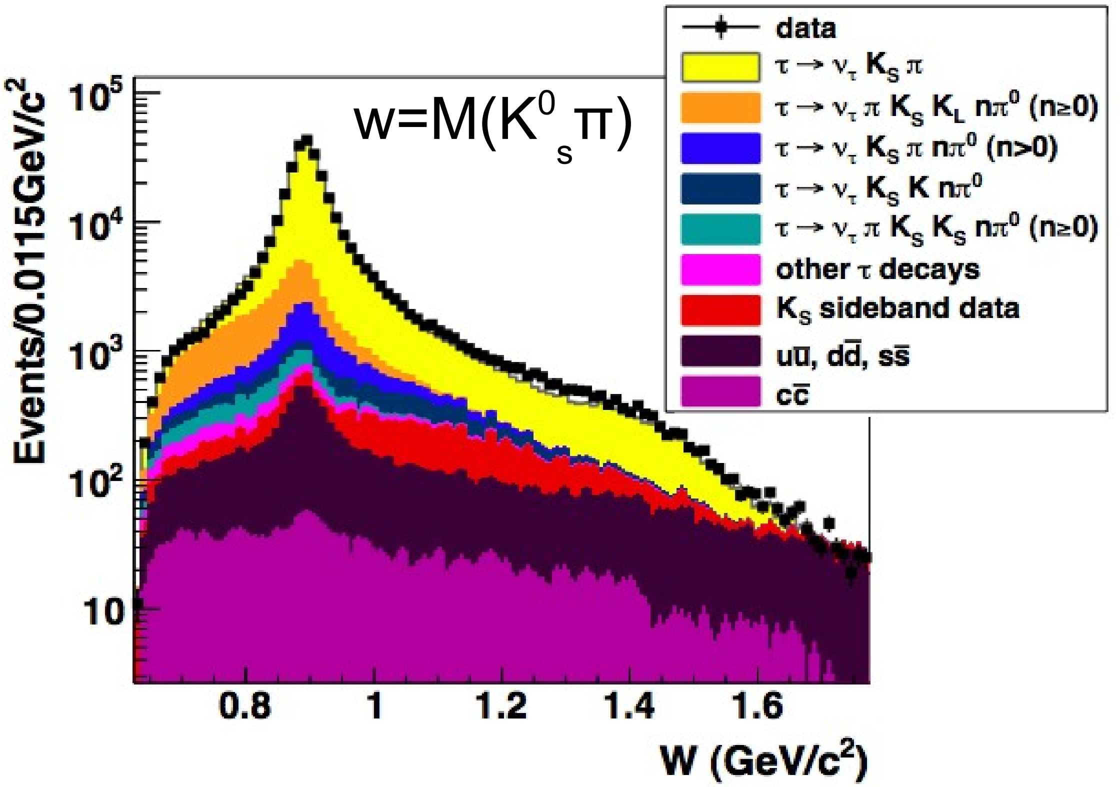
- $A_Q^{COR}=A_Q$*(1.08±0.01)=(0.36±0.01)%

Measurement is 3.1 standard deviations from the SM predictions

Belle $\tau^- \to \pi^- K^0_s \nu$ (699 fb^{-1})

PRL 107, 131801

- Events divided in two hemispeheres according to Thrust axis
- $\tau^+\tau^-$ events selected with a single prompt track + $K^0_s \to \pi^+\pi^-$ candidate in one hemisphere and one prompt Tag-lepton or π with opposite charge in the other
- π^0 BKG suppressed by rejecting events with photons in the signal side
- Continuum BKG reduced exploiting thrust value & number of γ in tag side



- $\tau^- \to \pi^-\pi^+\pi^-\nu$ BKG estimated on data K^0_s side bands
- Residual BKG dominated by $\tau^- \to K^0_L K^0_s \pi^- \nu$, $\tau^- \to K^0_s \pi^- \pi^0 \nu$ and Continuum estimated on MC $f_{BKG}=(22.1\pm3.6)\%$

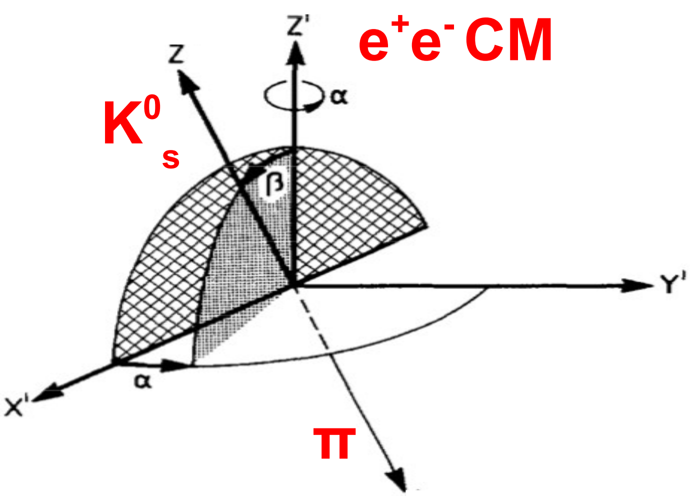
$N_{signal}(\tau^-)=162200\pm400$
$N_{signal}(\tau^+)=162000\pm400$

Belle $\tau^- \to \pi^- K^0_S \nu$ (699 fb^{-1})

PRL 107, 131801

$K^0_S \pi$ reference frame:

- β= angle between e^+e^- CM and K^0_S dir.
- Ψ= angle between e^+e^- CM and τ dir. computed from the hadronic energy in the CM system



- Exchange of charged scalar Higgs boson in Multi Higgs Doublet Models:
  - Parameterized by a modified scalar Form Factor and dimensionless complex coupling constant η_s

    (Choi et al., Phys. Rev. D 52, 1614)
  - Reflects in difference between the mean values of $\cos\beta \cos\Psi$ for τ^+ and τ^- decays in bins of $M^2(K^0_S\pi)$:

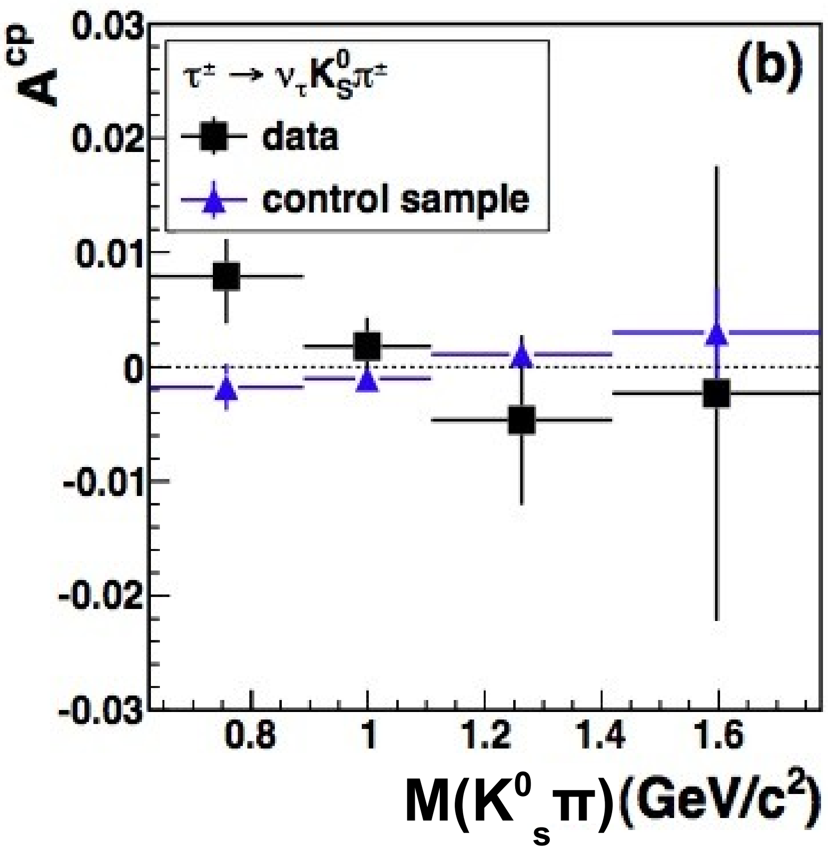
$$A^i_{CP} = \langle \cos\beta \cos\Psi \rangle^i_{\tau-} - \langle \cos\beta \cos\Psi \rangle^i_{\tau+} = c_i \, \mathrm{Im}(\eta_s)$$

- Decay-rate asymmetry due to $\tau^+\tau^-$ production A_{FB} and detector response determined on real data $\tau^- \to \pi^-\pi^+\pi^-\nu$ control sample in terms of the 3π momentum and polar angle:
  - $\Delta A_{CP}(A_{FB}) \sim O(10^{-4})$, $\Delta A_{CP}(\mathrm{Detector}) \sim O(10^{-3})$

Belle $\tau^- \to \pi^- K^0_s \nu$ (699 fb^{-1})

PRL 107, 131801

• A_{CP} computed in bins of $M(K^0_s\pi)$:
  → No significant CPV observed



• Limits for the charged Higgs couplings obtained using different scalar Form Factor parameterizations:

→ **$|Im(\eta_s)|<(0.012\text{-}0.026)$ @90%CL**

• Which reflects in:

→ $|Im(XZ^*)|<0.15\ M^2_{H\pm}/(1\ GeV^2/c^4)$

• Z, X: couplings of the charged Higgs boson to (τ, ν) and (u, s)

• Systematics from detector asymmetry, BKG subtraction, limited MC statistics

Conclusions

CP violation is an excellent laboratory for the search for physics beyond the Standard Model in systems where:

- It is expected to be suppressed (radiative penguins, B^0 mixing, charm decays, tau decays)
- It is expected to be the same as in the "golden" $b \to c\bar{c}s$ transitions (charmless hadronic B decays $b \to s\bar{q}q$)

Almost all results in agreement with expectations

In the Near Future LHCb & High Intensity B Factories will offer the Opportunity to:

•Improve Experimental Techniques

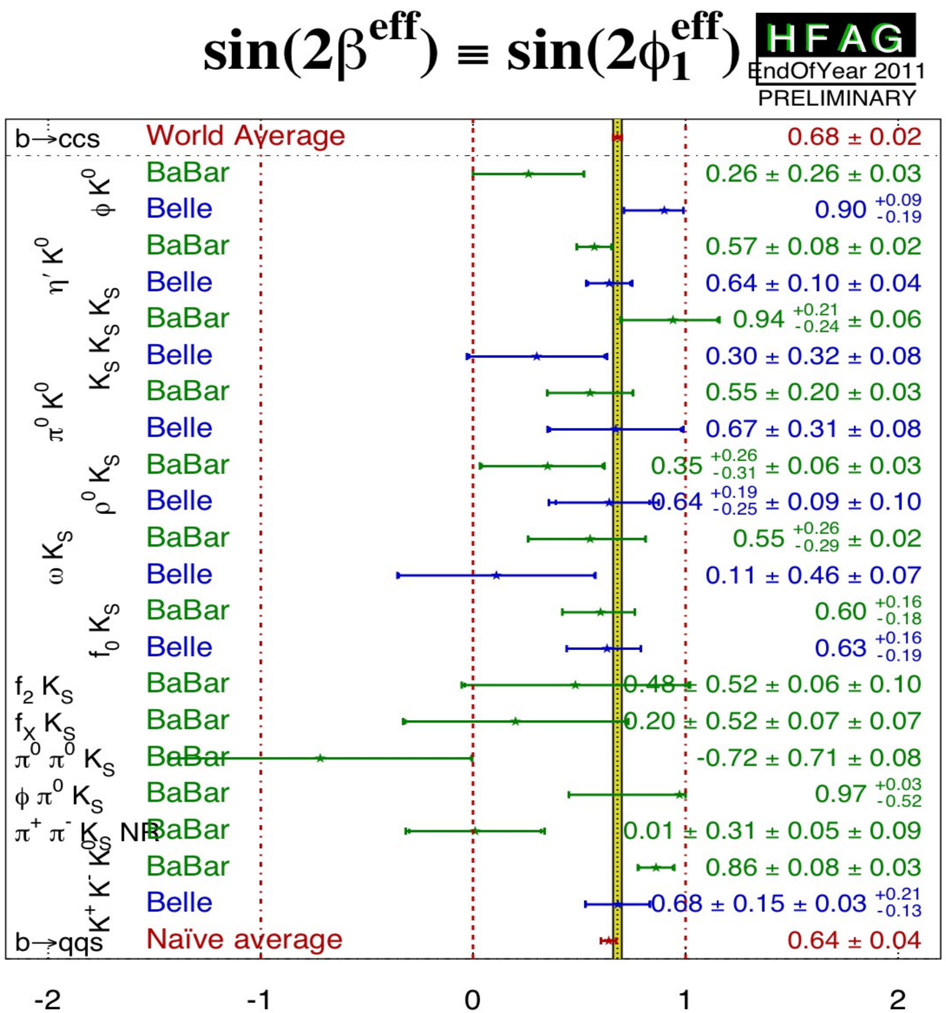
•Provide very stringent SM tests

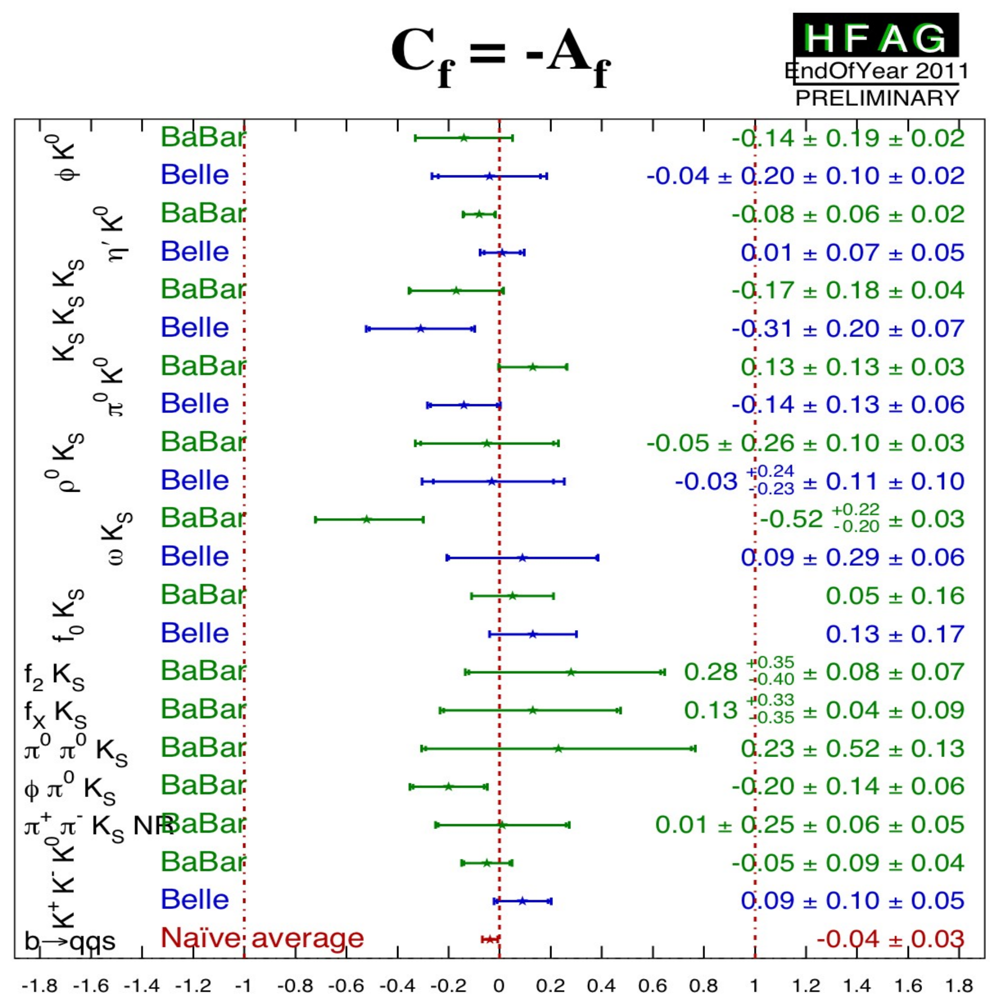
•**Hopefully discover/understand New Physics**

Backup

Summary: $\sin(2\beta_{eff})$ from $b \to s\bar{q}q$

- HFAG (end of 2011): Direct comparison of charmonium and s-penguin averages gives χ^2=0.7 (CL=0.40, 0.8σ)





Belle $D^0 \to K^0_s P^0$ (791 fb^{-1})

arXiv:1101.3365v2

- $K^0_s P^0$ neutral pseudoscalar meson ($\pi^0/\eta/\eta'$), mixture of CF $\bar{K}^0 P^0$ and DCS $K^0 P^0$:
  - ➔ No Direct A_{CP}, Indirect $A_{CP} \sim O(10^{-4})$
  - ➔ K^0 mixing in the final state leads to $A_{CP}(D^0 \to K^0_s P^0) \sim A_{CP}(K^0) = (-0.332 \pm 0.006)\%$ (PDG, J.Phys. G 37, 075021)

- Flavor of the D^0 obtained from the slow pion π_s^+ charge in the decay $D^{*+} \to D^0 \pi_s^+$
- $D^0 \to K^0_s(\pi^+\pi^-)P^0(\gamma\gamma)$ reconstructed with cuts on $M(\pi^+\pi^-)$, $E\gamma$, $M(\gamma\gamma)$
- $B\bar{B}$ BKG removed by $p_{CM}(D^*) > 2.5$ GeV/c
- $A_{CP}(D^0 \to K^0_s P^0)$ measured from D^* charge asymmetry:

$$A_{\rm rec}^{D^{*+}\to D^0\pi_s^+} = \frac{N_{\rm rec}^{D^{*+}\to D^0\pi_s^+} - N_{\rm rec}^{D^{*-}\to \bar{D}^0\pi_s^-}}{N_{\rm rec}^{D^{*+}\to D^0\pi_s^+} + N_{\rm rec}^{D^{*-}\to \bar{D}^0\pi_s^-}} = A_{CP}^{D^0\to K_S^0 P^0} + A_{FB}^{D^{*+}}(\cos\theta_{D^{*+}}^{\rm CMS}) + A_\epsilon^{\pi_s^+}(p_{T\pi_s^+}^{\rm lab}, \cos\theta_{\pi_s^+}^{\rm lab})$$

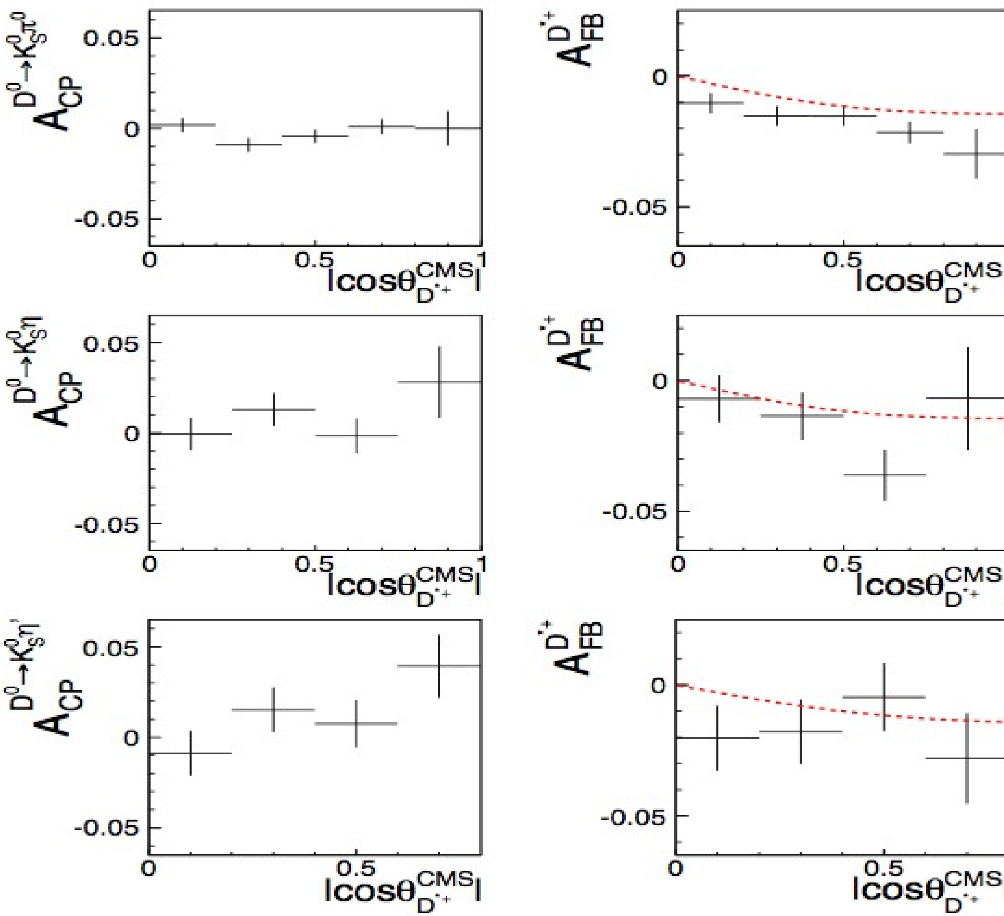
- A_{CP}: Physics
- A_{FB}: Forward-Backward $c\bar{c}$ production asymmetry
- A^{π}_{ε} :Slow π efficiency asymmetry computed from the comparison of untagged $D^0 \to K^-\pi^+$ and tagged $D^{*+} \to D^0\pi^+_s \to K^-\pi^+\pi^+_s$ charge asymmetries

Belle $D^0 \rightarrow K^0_s P^0$ (791 fb^{-1})

arXiv:1101.3365v2

- Signal yields obtained from a fit to D^{*+} & D^{*-} $\Delta M = M(D^*) - M(D^0)$ distribution
- A_{CP} & $A_{FB}(D^{*+})$ computed in bins of $\cos(\theta_{D^{*+}})$:

$N(K^0_s \pi^0) = 326303 \pm 679$
$N(K^0_s \eta) = 45831 \pm 283$
$N(K^0_s \eta') = 26899 \pm 211$



RESULTS:

$A_{CP}(K^0_s \pi^0) = (-0.28 \pm 0.19 \pm 0.10)\%$

[CLEO previous result $A_{CP} = +0.1 \pm 1.3\%$]

$A_{CP}(K^0_s \eta) = (0.54 \pm 0.51 \pm 0.16)\%$ FIRST

$A_{CP}(K^0_s \eta') = (0.98 \pm 0.67 \pm 0.14)\%$ FIRST

In agreement with SM

- A_{FB} results compared with LO predictions: deviations due to higher order corrections
- Systematics from slow pion efficiency asymmetry, difference in interaction of K^0 and $\overline{K}^0$ with the material, fitting method and binning