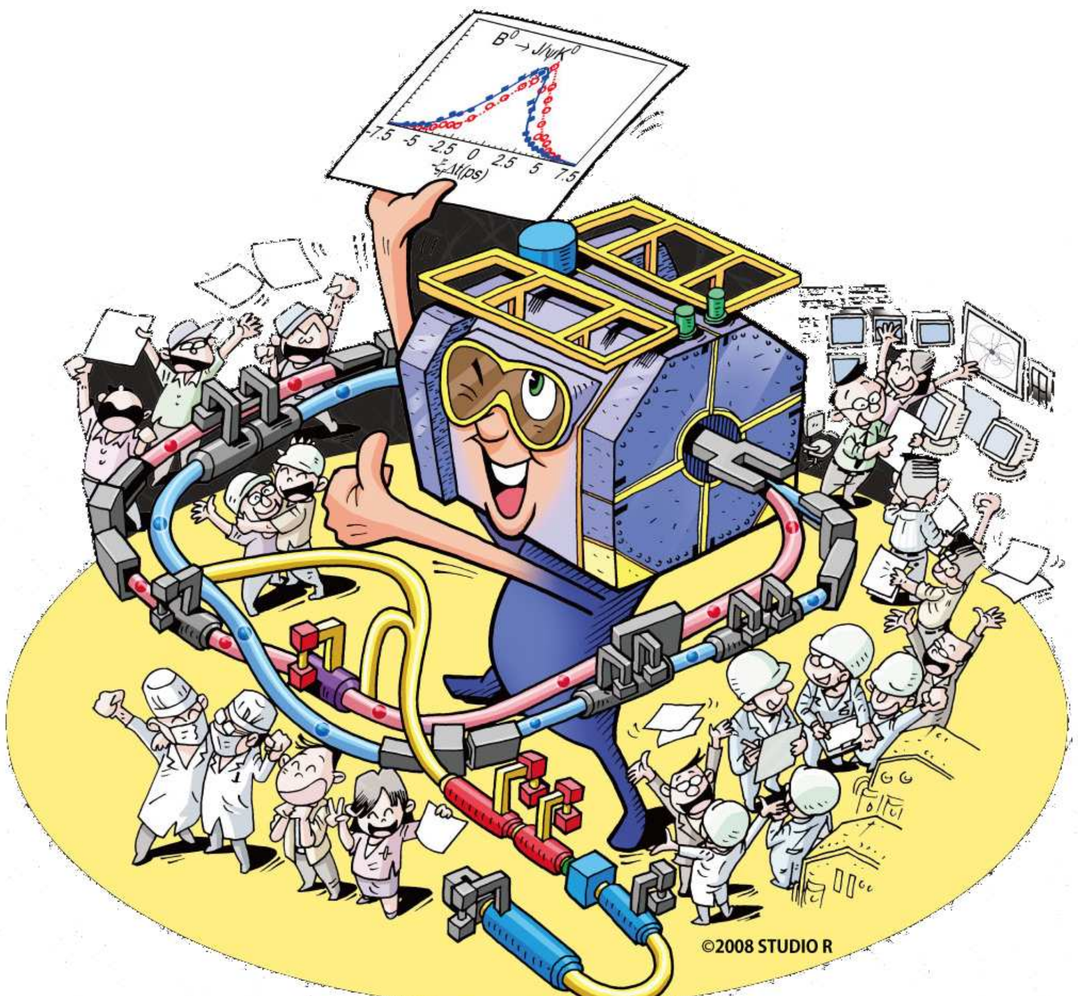
$A_{CP}(K\pi)$, $A_{FB}(K^{*}\ell^{+}\ell^{-})$ and D^{0} mixing as probe of 4th Generation

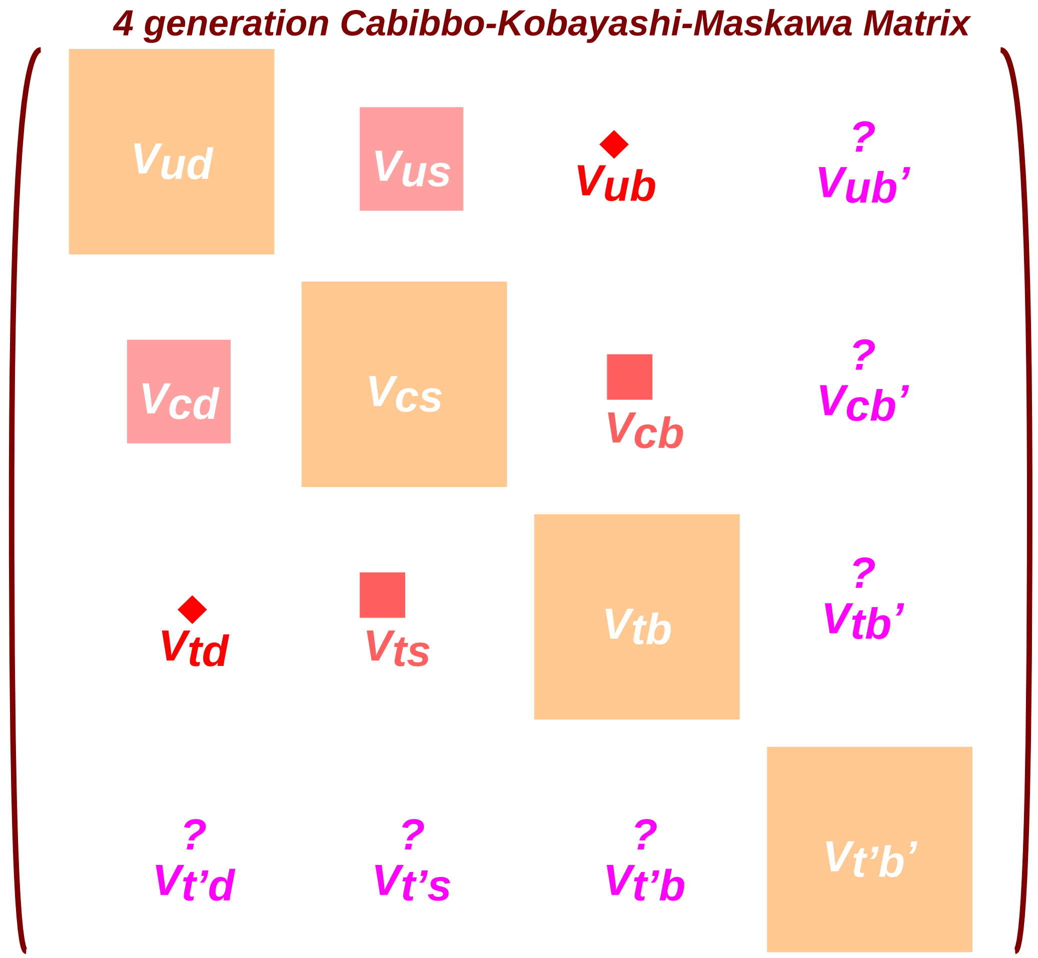


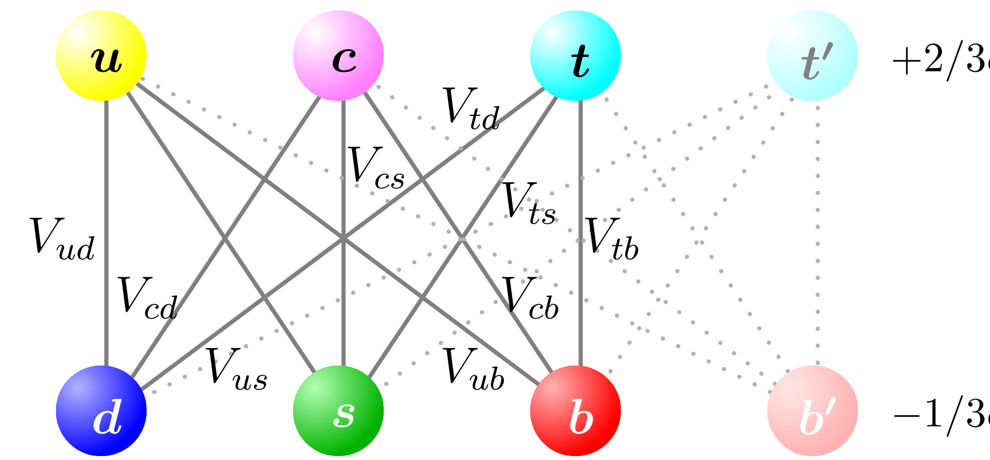
Mikihiko Nakao
for the Belle collaboration

KEK, IPNS
mikihiko.nakao@kek.jp

at the Second Workshop on Beyond 3 Generation SM
2009.1.15, Taipei

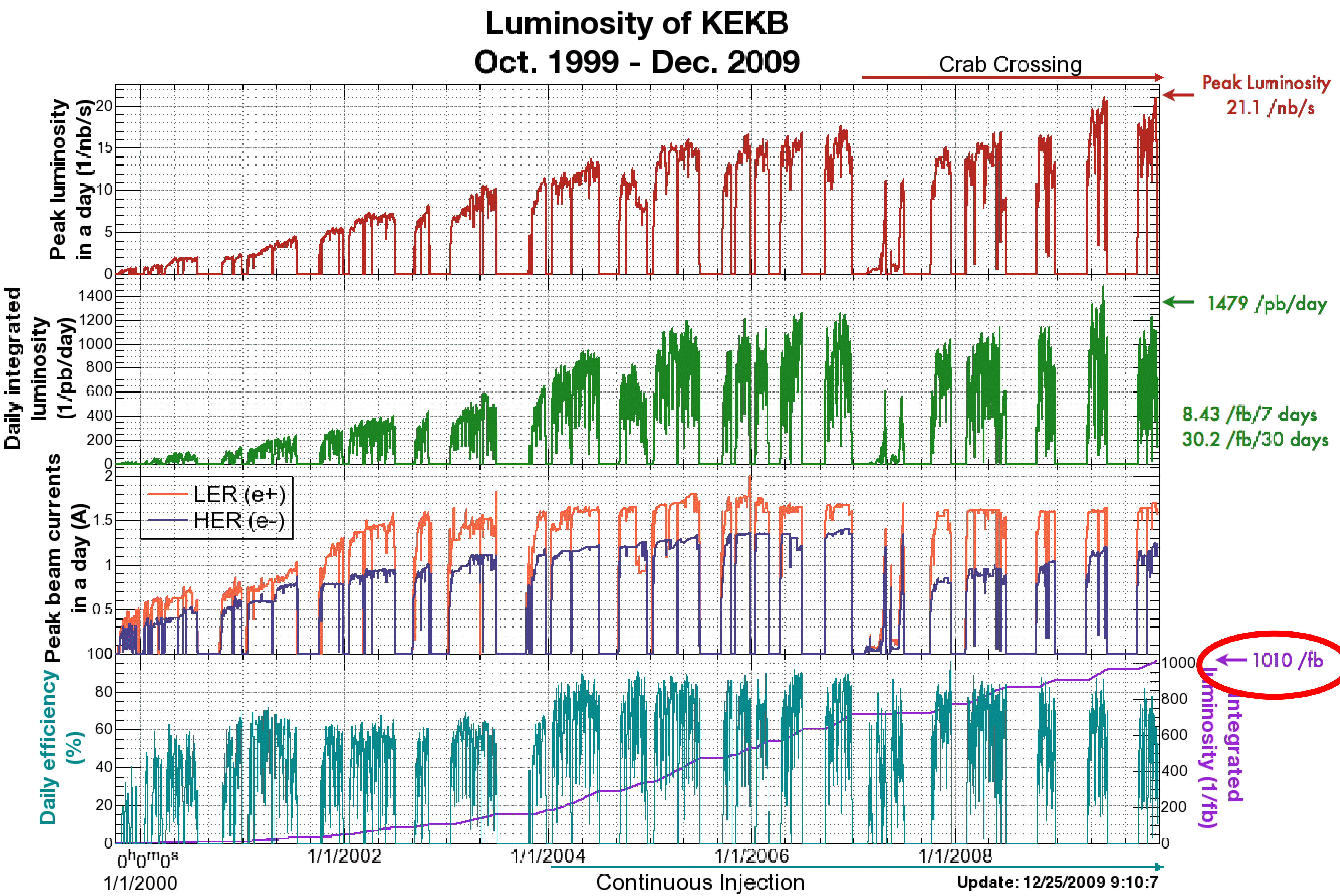
4th generation and Belle physics

$\mathbf{V} \sim$ 



- Unitarity triangle does not close
- Many effects on loop processes ($A_{CP}(K\pi)$, $A_{FB}(K^*\ell^+\ell^-)$, ...)
- Large contributions to charm decays (D^0 mixing, CPV)

Belle/KEKB history — 1 ab^{-1} ☺



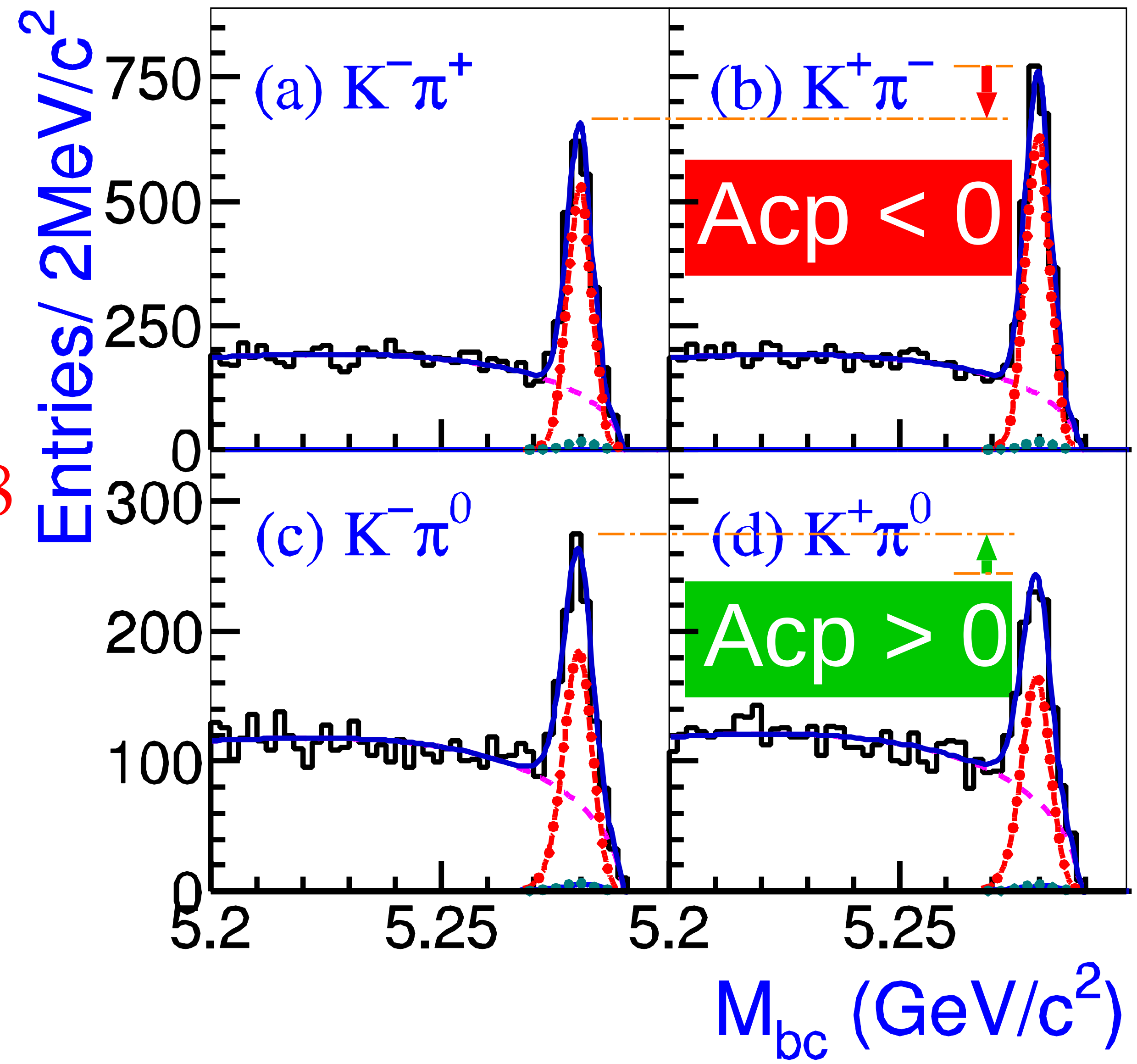
772M $B\overline{B}$ for B physics, all 1000 fb^{-1} for D mixing, grand reprocess in progress

$A_{CP}(K\pi)$ and $K\pi$ puzzle

(Belle S-W Lin *et al.*,
Nature452,332(2008) 535M$B\bar{B}$)

$$A_{CP} = \frac{N(\bar{B} \to \bar{f}) - N(B \to f)}{N(\bar{B} \to \bar{f}) + N(B \to f)}$$

$A_{CP}(K^+\pi^-) = -0.094 \pm 0.018 \pm 0.008$
$A_{CP}(K^+\pi^0) = +0.07 \pm 0.03 \pm 0.01$



Differences:

- Color suppressed diagram
- EW penguin diagram

Both are small in SM,
the latter could be large in NP

Sum rule

$\delta_{K\pi} =$
$A_{CP} \times \Gamma(K^+\pi^-) + A_{CP} \times \Gamma(K^0\pi^+) - 2A_{CP} \times \Gamma(K^+\pi^0) - 2A_{CP} \times \Gamma(K^0\pi^0)$

Branching fractions and $A_{CP}(B \to K^0\pi^0)$

Branching fraction measurements

(Belle PRL99,121601(2007) and
Belle PRL98,181804(2007) 535M$B\overline{B}$)

$A_{CP}(K^0\pi^+) = +0.03 \pm 0.03 \pm 0.01$

$\mathcal{B}(K^0\pi^+) = (8.7 \pm 0.5 \pm 0.6) \times 10^{-6}$

$\mathcal{B}(K^+\pi^-) = (19.9 \pm 0.4 \pm 0.8) \times 10^{-6}$

$\mathcal{B}(K^+\pi^0) = (12.4 \pm 0.5 \pm 0.6) \times 10^{-6}$

$K^0\pi^0$ mode requires time-dependent measurement

(Belle arxiv0809.4366(to appear in PRD), 657M$B\overline{B}$)

$A_{CP}(K^0\pi^0) = +0.14 \pm 0.13 \pm 0.06$

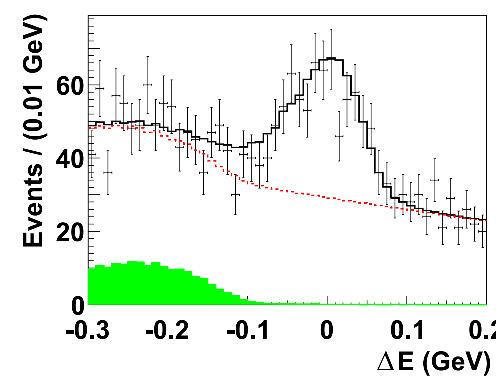
$\mathcal{B}(K^0\pi^0) = (8.7 \pm 0.5 \pm 0.6) \times 10^{-6}$

$\mathcal{S}(K^0\pi^0) = +0.67 \pm 0.31 \pm 0.08$

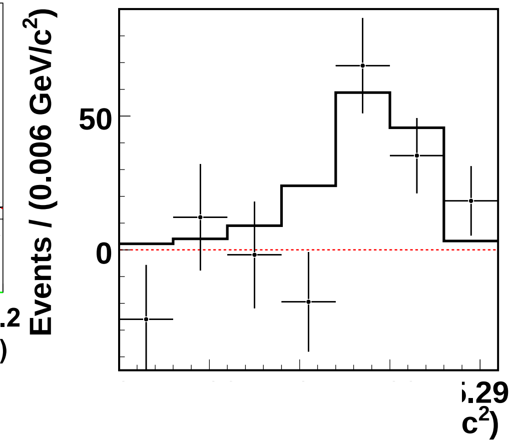
$A_{CP}(K^0\pi^0)$ violates the sum rule by 1.9 σ

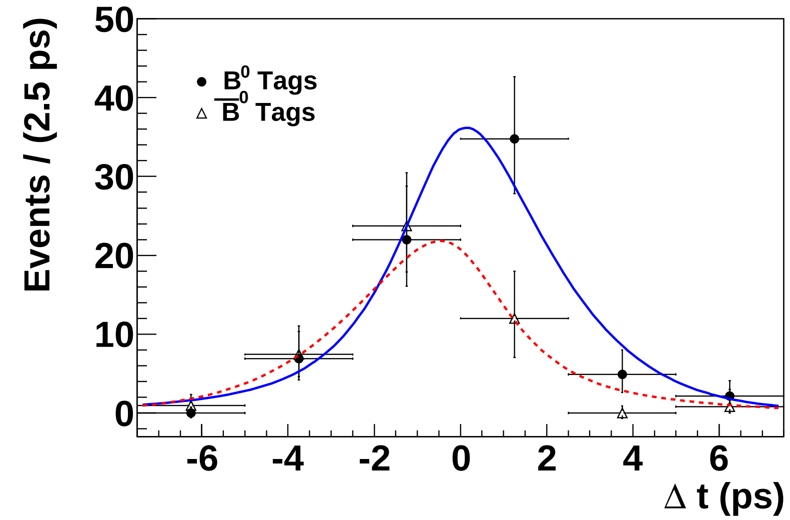
(but BaBar's result is in a opposite direction. . .)

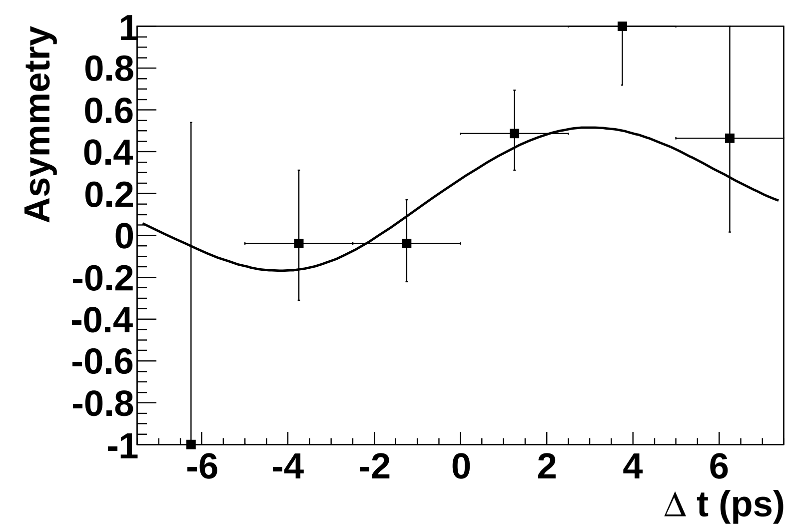
$K^0_S\pi^0$



$K^0_L\pi^0$

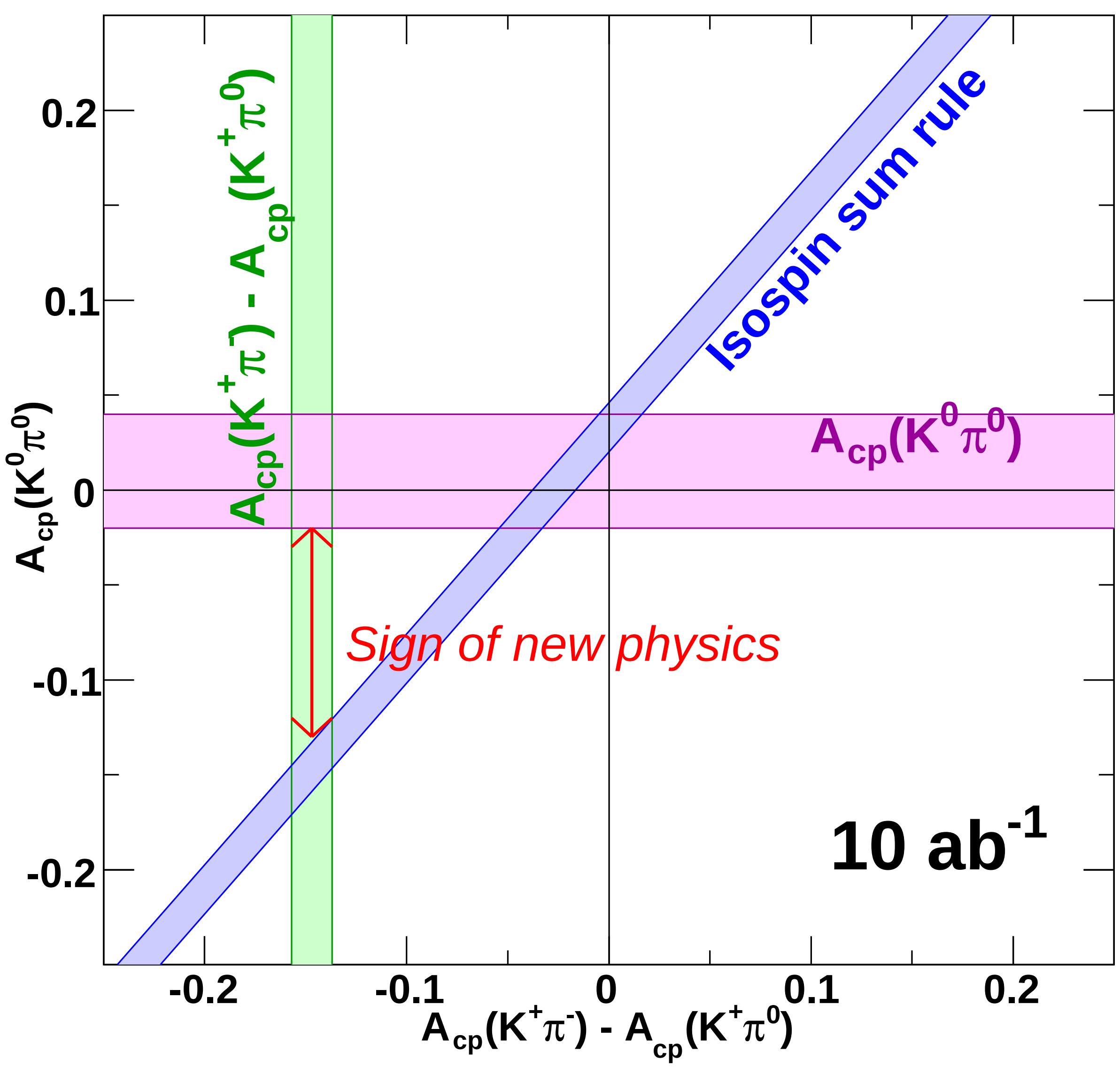






$B \to K\pi$ prospects

- BF measurements are already systematics dominated
- A_{CP} measurements will be systematics dominated with $\sim 10\ \text{ab}^{-1}$



$b \to s\ell^+\ell^-$

$\mathcal{B}(B \to X_s\gamma)$, $A_{FB}(B \to K^*\ell^+\ell^-)$ and $\mathcal{B}(B \to X_s\ell^+\ell^-)$ are direct probes of Wilson coefficients C_7, C_9 and C_{10} as functions of $\hat{s}(= q^2/m_b^2)$

$$\mathcal{B}(B \to X_s\gamma) \propto |C_7|^2$$

$$A_{FB}(B \to K^*\ell^+\ell^-;\ \hat{s}) = -C_{10}\xi(\hat{s})\left[\mathrm{Re}(C_9)F_1 + \frac{1}{\hat{s}}C_7F_2\right]$$

$$\frac{d\Gamma(B \to X_s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{\mathrm{em}}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2$$
$$\times\left[(1+2\hat{s})\left(|C_9|^2 + |C_{10}|^2\right) + 4\left(1+\frac{2}{\hat{s}}\right)|C_7|^2 + 12\mathrm{Re}\left(C_7C_9\right)\right] + \text{corr.}$$

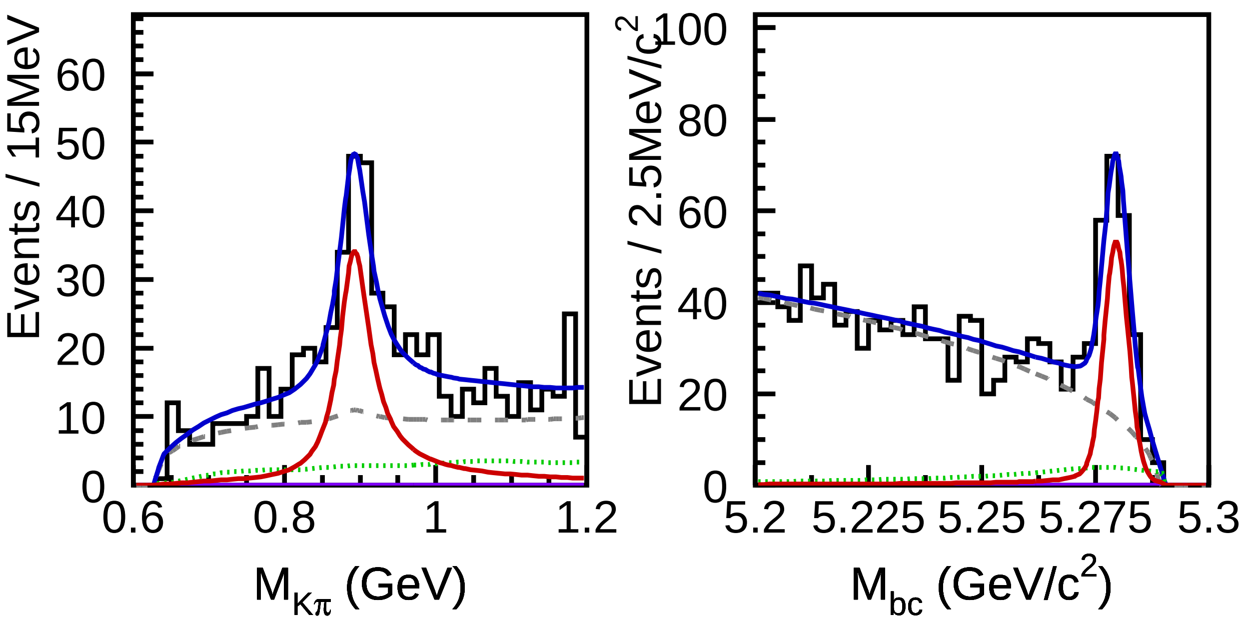
Key features:

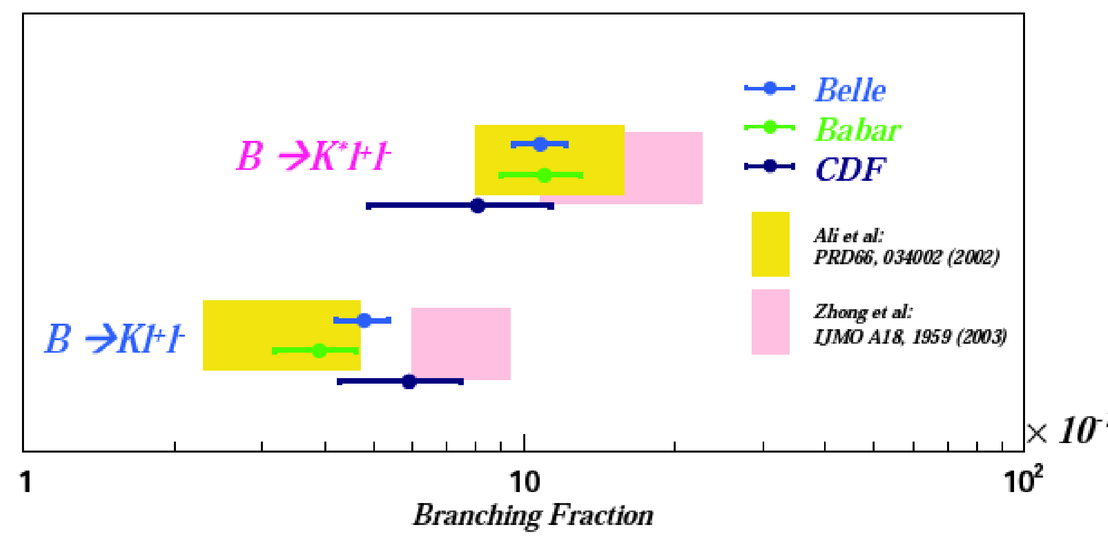
- Size of C_7 from $\mathcal{B}(B \to X_s\gamma)$
- Zero crossing of $A_{FB}(B \to K^*\ell^+\ell^-)$
- C_7C_9 term in $\mathcal{B}(B \to X_s\ell^+\ell^-)$

$B \to K^* \ell^+ \ell^-$

(Belle J-T Wei *et al.*, PRL103,171801(2009), 657M $B\overline{B}$)

- Very small branching fraction $\sim 10^{-6}$ or less
  But branching fraction is not very predictive





(SM suffers from form factor uncertainties)

- Various ratios (Forward-backward asymmetry, F_L,
  CPV, isospin, lepton flavor, etc)
- Three-body decay:
  ➡ Observables as functions of q^2 ($q^2 = m^2_{\ell^+\ell^-}$)

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

Angular distributions to extract FB asymmetries

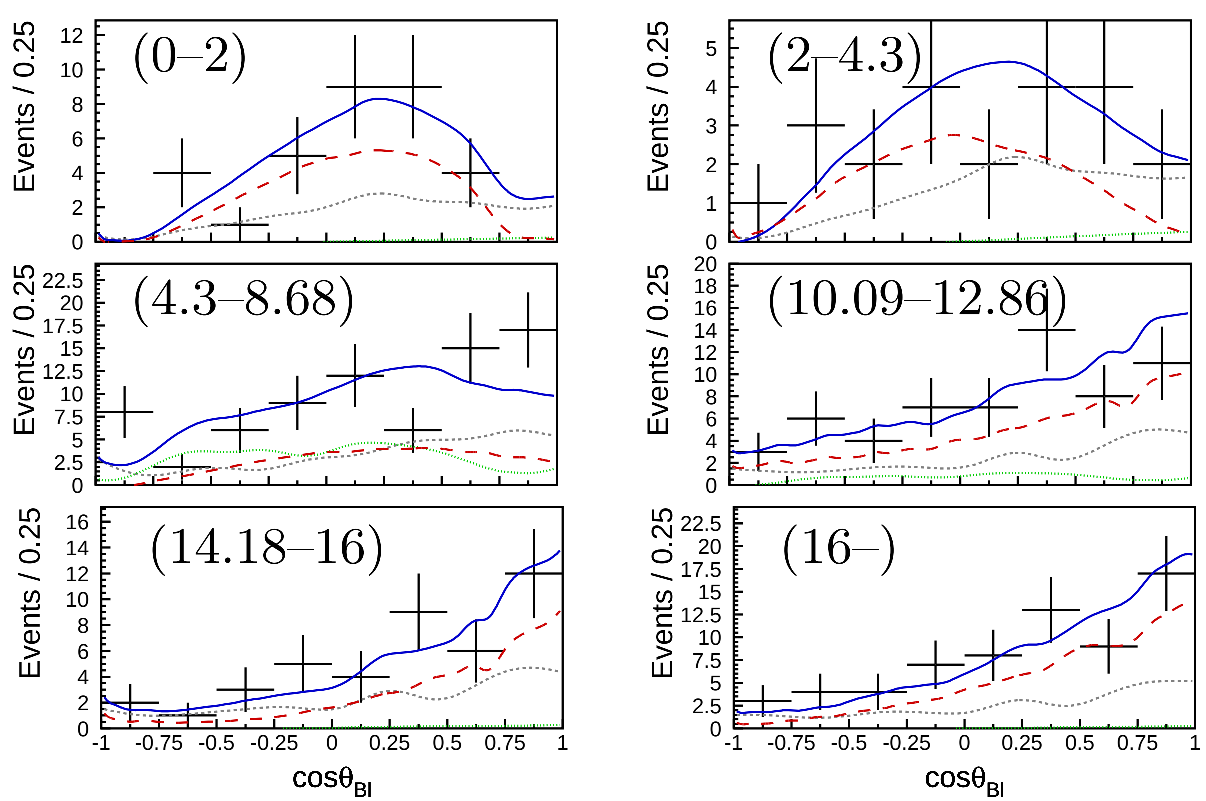
K^* longitudinal polarization F_L from kaon angle θ_K

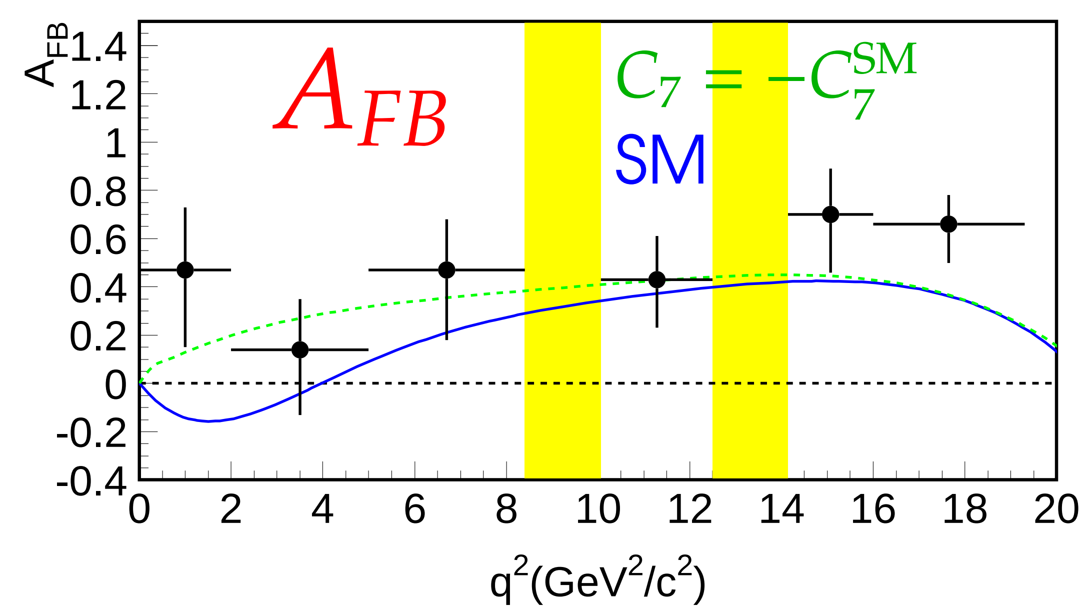
$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

Forward-backward asymmetry A_{FB} from lepton angle θ_ℓ

$$\frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

$\cos\theta_\ell$

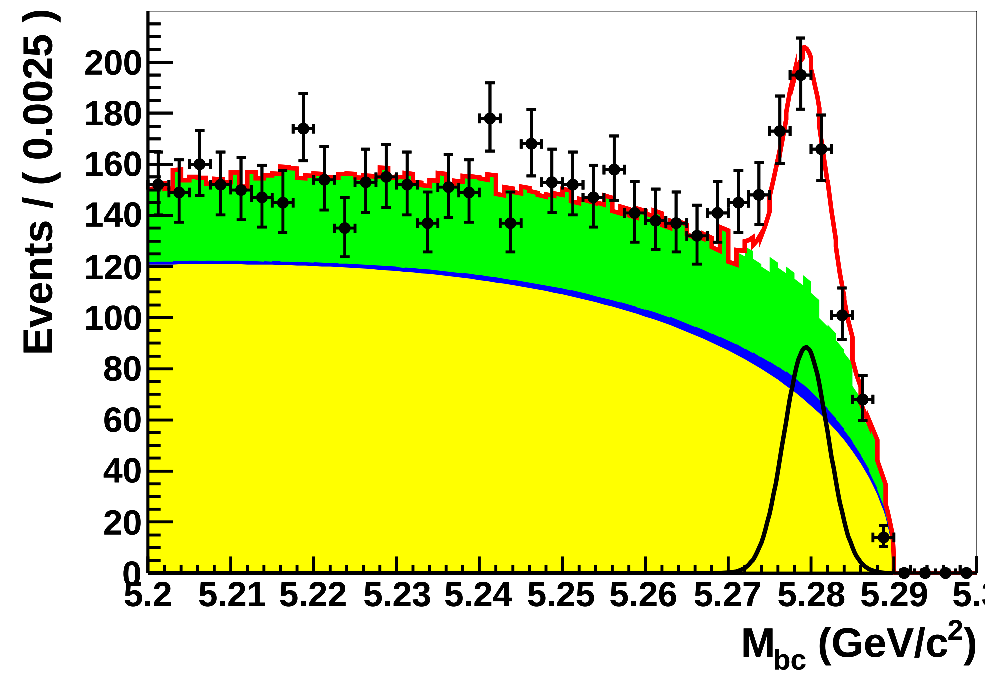




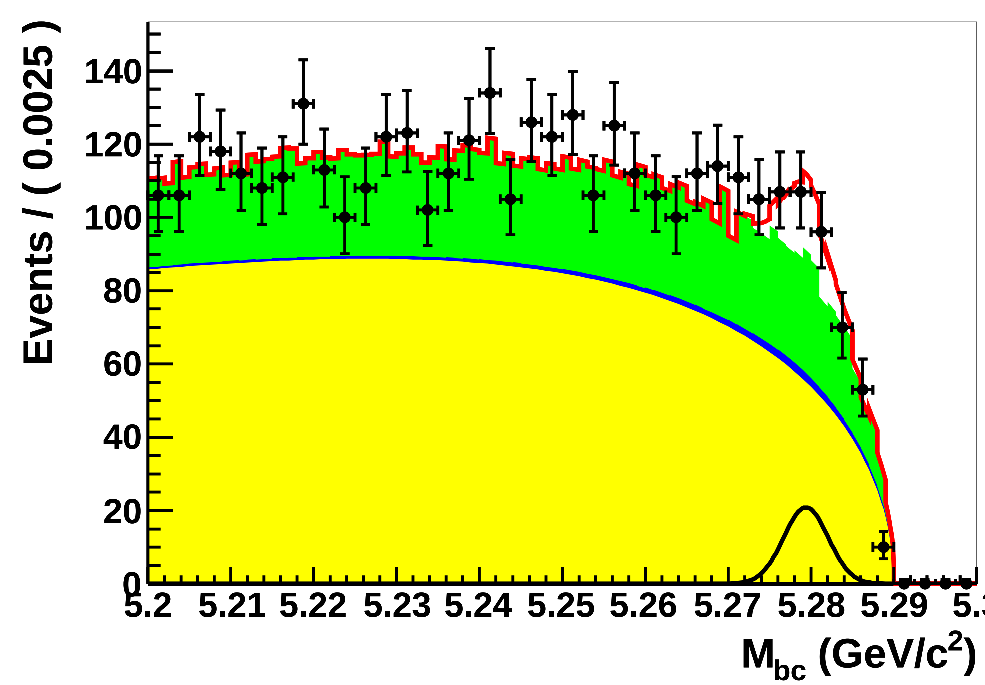
- Opposite sign C_7 is favored
- 2.7 σ deviation from the SM

$B \to X_s \ell^+ \ell^-$ (Belle 657M $B\overline{B}$, preliminary)

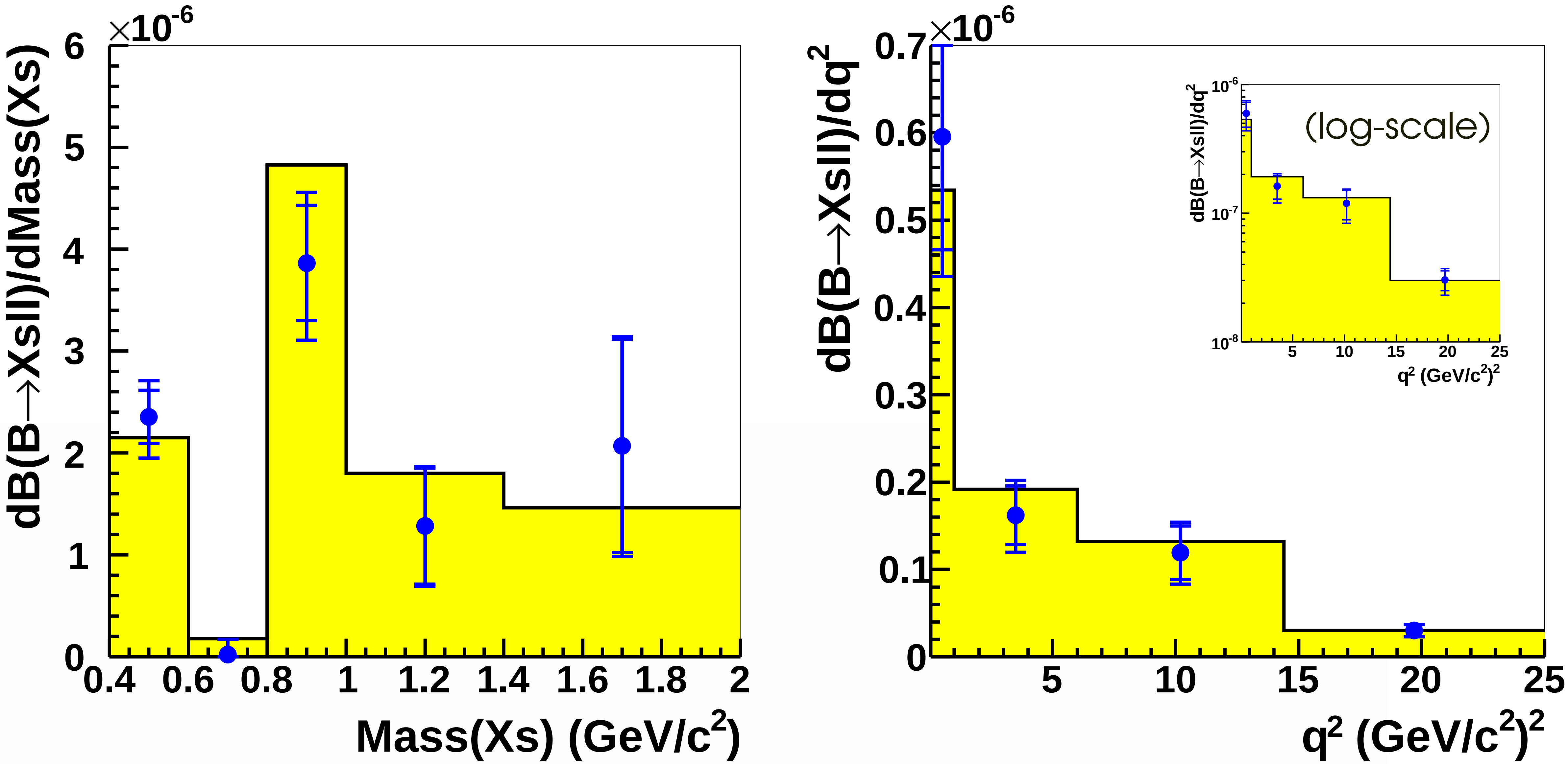
- Sum-of-exclusive analysis
  $X_s = K + n\pi$ $(n = 0..4)$
  (sum of $K\ell^+\ell^-$, $K^*\ell^+\ell^-$, high-mass $X_s\ell^+\ell^-$)
  Updated with 4.5 times data and analysis improvements
- Backgrounds
  - Semileptonic B decays, continuum $q\overline{q}$
  - Leakage from J/ψ and ψ' veto
  - $B \to X_s \pi^+\pi^-$ (double mis-id)
  - $\psi(3770)$, $\psi(4040)$, $\psi(4160) \to \ell^+\ell^-$
  - $B \to X_c(l\nu) \to X_s \ell \nu$ (single mis-id + random slow π replacing ν)



10σ signal for entire $M(X_s)$



3.0σ signal for $M(X_s) > 1.0$ GeV



$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = (3.33 \pm 0.80\,^{+0.19}_{-0.24}) \times 10^{-6}$$

[$q^2 > 0.2$ GeV$^2/c^2$, extrapolated for J/ψ, ψ', and $M(X_s) > 2.0$ GeV]

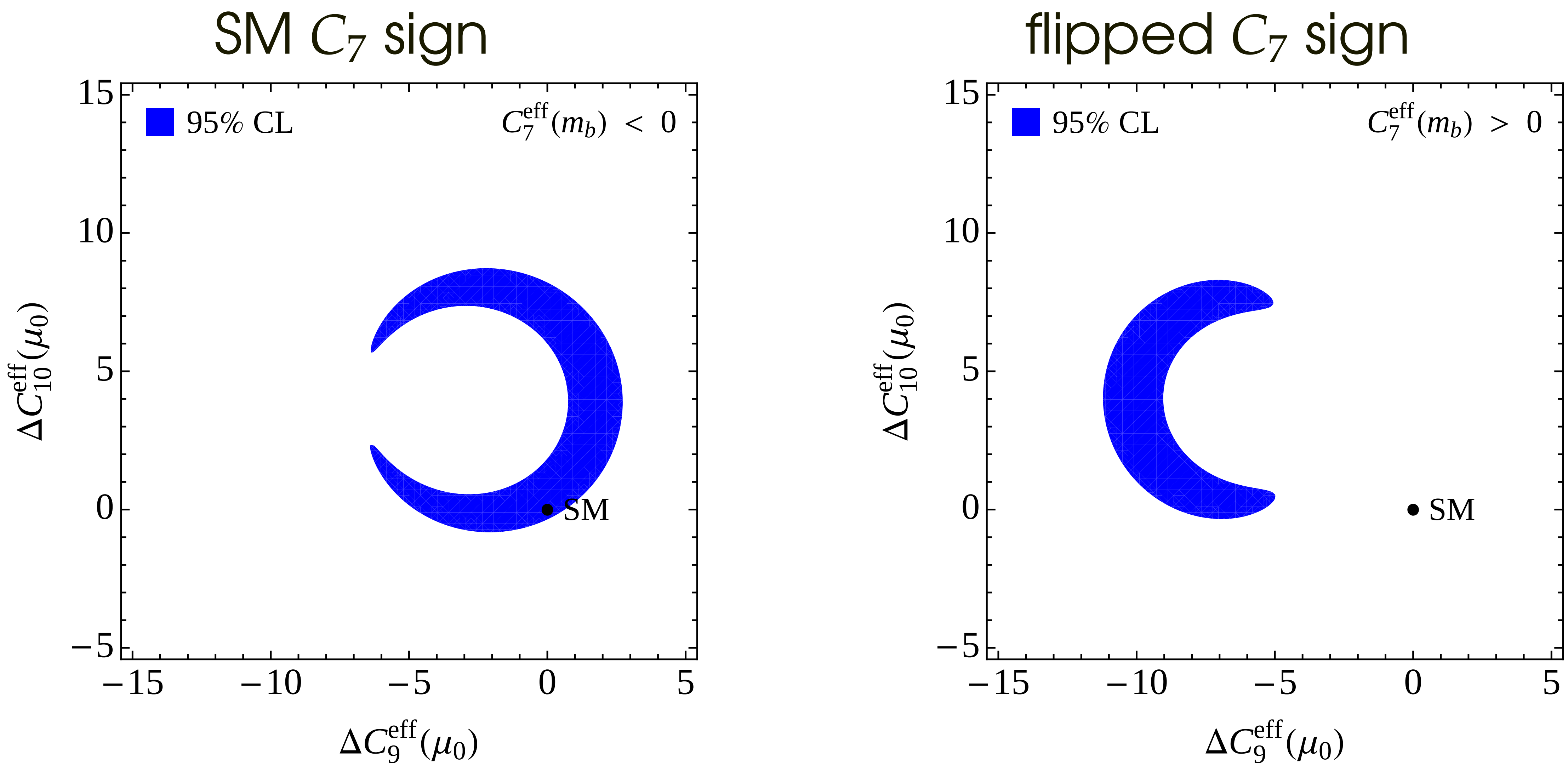
HFAG average: $\mathcal{B} = (3.66\,^{+0.76}_{-0.77}) \times 10^{-6}$

SM (Ali et al): $\mathcal{B}_{\rm SM} = (4.2 \pm 0.7) \times 10^{-6}$

C_7 sign-flip (Gambino et al): $\mathcal{B}_{C_7>0} = (8.8 \pm 1.0) \times 10^{-6}$

➡ Flipped-sign C_7 is disfavored...

$b \to s\ell^+\ell^-$ puzzle?



by U. Haisch for new HFAG results, based on PRL94,061803(2005)

- $B \to X_s\ell^+\ell^-$ results prefers SM-like signs ($C_7C_9 < 0$)
- $A_{FB}(B \to K^*\ell^+\ell^-)$ prefers opposite signs? ($C_7C_9 > 0$)

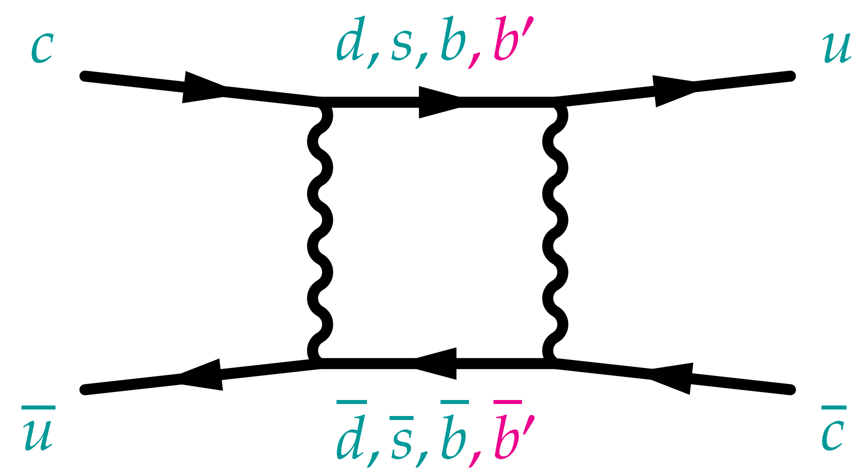
D^0 mixing and CPV

Mixing ($D^0 \Leftrightarrow \overline{D}^0$) occurs if $x \neq 0$ or $y \neq 0$

$$\left[x = \frac{m_1 - m_2}{\Gamma}, y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}, m = \frac{m_1 + m_2}{2}\right]$$

mass eigenstate $\neq$ flavor eigenstate

$D_{1,2} = pD^0 \pm q\overline{D}^0$ $\neq$ $D^0(c\overline{u})$, $\overline{D}^0(\overline{c}u)$



- SM short distance — x, y are extremely small ($O(10^{-5})$)
- SM long distance — could be $O(10^{-2})$
- Non SM effects — could be $O(10^{-2})$

CPV — both in mixing and decay

- SM Mixing — $A_M \leq O(\arg(V^*_{cd}V_{ud})) \sim O(10^{-3})$
- SM Decay — $A_D \leq O(\arg(V^*_{cs}V_{us})) \sim O(10^{-3})$ (in e.g. $D^0 \to K^+K^-$)
- Interference between mixing and decay — ϕ

D^0 mixing methods

Observable are combinations of x, y, A_M, A_D and ϕ

- Decays to CP eigenstate (e.g. K^+K^-) ☺
  Lifetime: $y_{CP} = \dfrac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1 = y\cos\phi - \dfrac{A_M}{2} x \sin\phi$
- Wrong sign semileptonic decays
  Any mixing, sensitive to $R_M = \dfrac{P(D^0 \to K^{(*)+}\ell^-\overline{\nu})}{P(D^0 \to K^{(*)-}\ell^+\nu)} = \dfrac{x^2+y^2}{2}$
- Wrong sign hadronic decays ($D^0 \to K^+\pi^-$)
  Complication due to doubly Cabibbo-suppressed decays,
  Sensitive to $x'^2 = (x\cos\delta + y\sin\delta)^2$ and $y' = y\cos\delta - x\sin\delta$
- Time-dependent Dalitz analysis ☺
  $D \to K^0_S\pi^+\pi^-$ — many involved modes $K^{*\pm}\pi^{\mp}$, $K^0_S\rho^0$, ...
  Direct extraction of x, y (and p/q)

D^0 mixing — y_{CP}

(Belle PRL98,211803(2007) 540 fb^{-1})

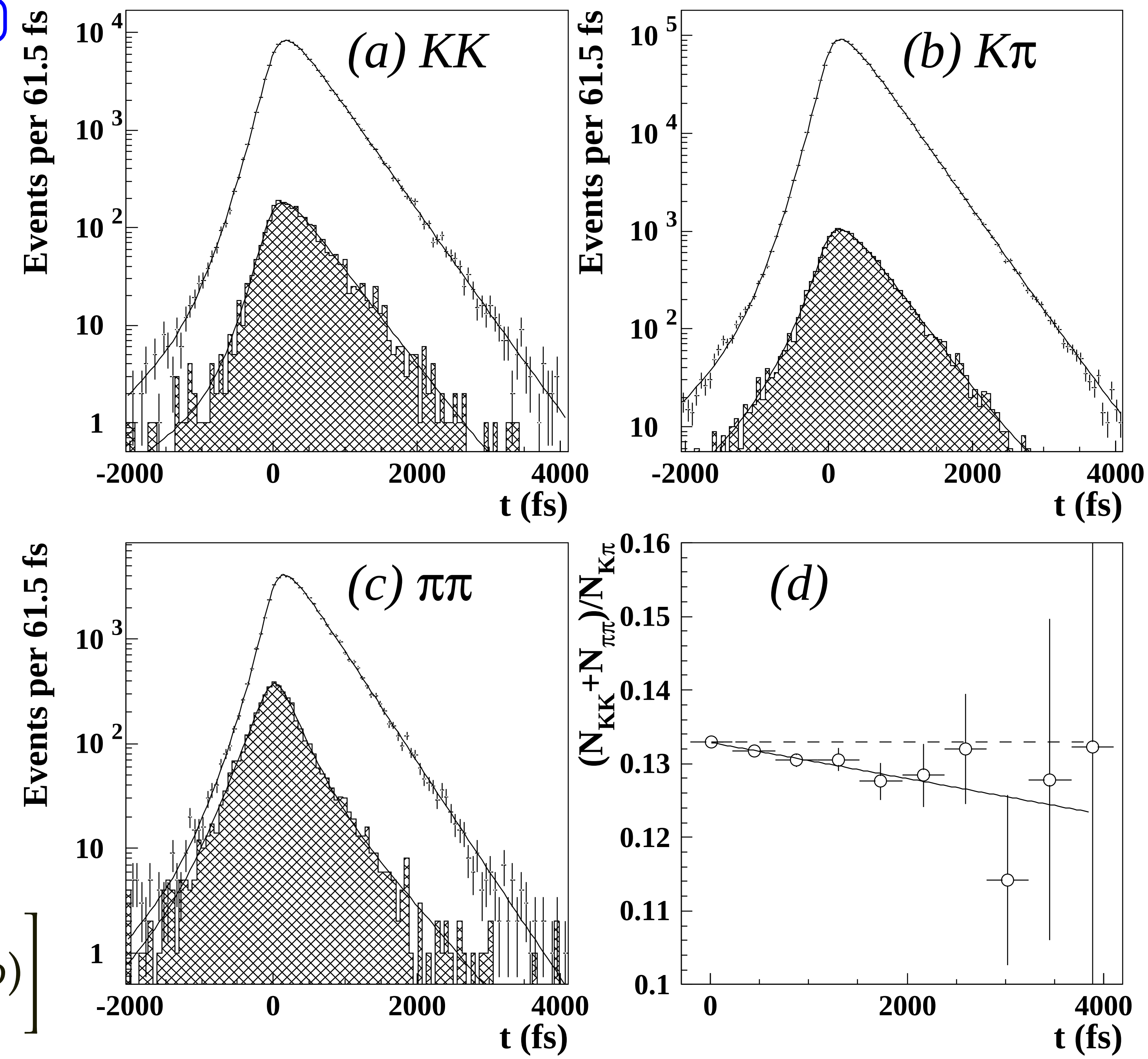
Lifetime measured in $D^0 \to K^-\pi^+, K^+K^-, \pi^+\pi^-$

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

Lifetime difference:
Tag $D^0/\overline{D}^0$ from $D^{*\pm} \to D\pi_s^\pm$

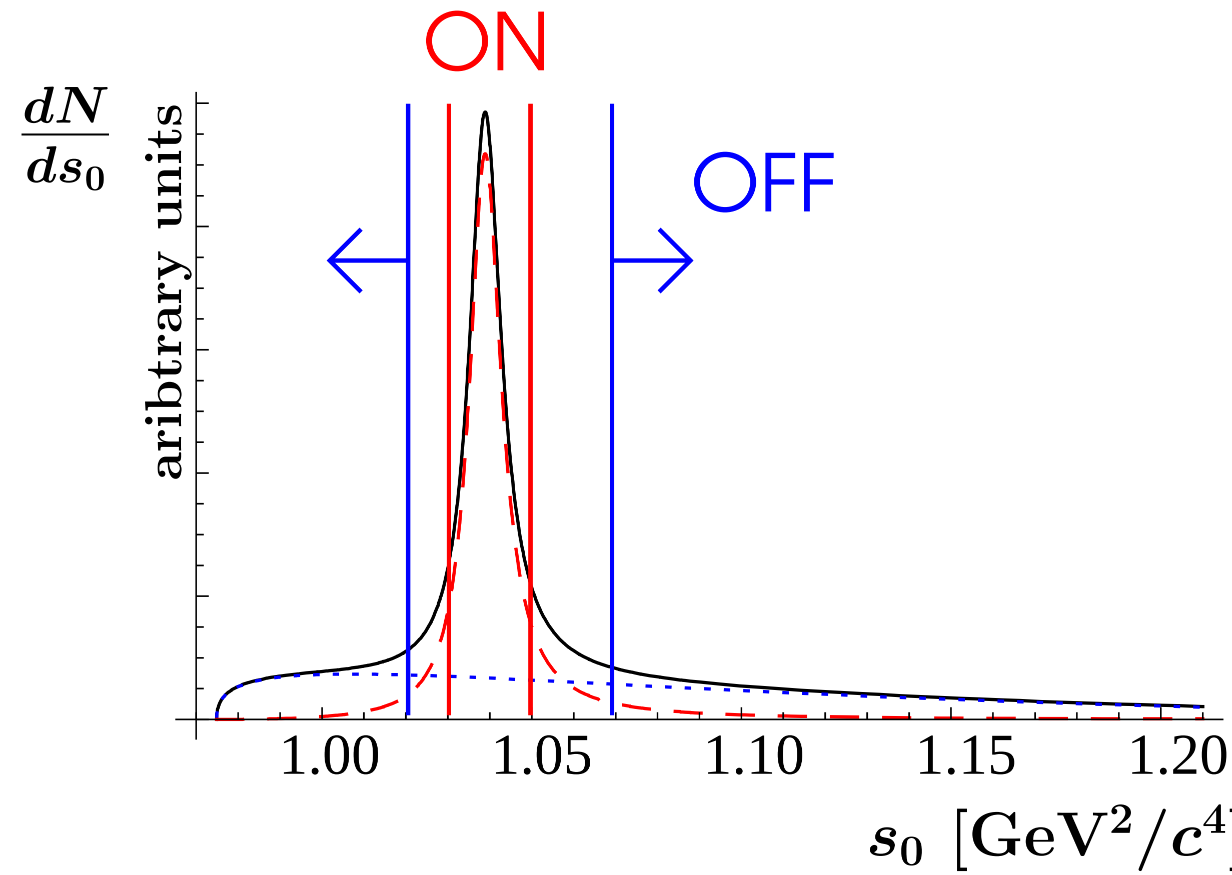
$$A_\Gamma = (0.01 \pm 0.30 \pm 0.15)\%$$

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^+K^-) - \tau(\overline{D}^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^+K^-) + \tau(\overline{D}^0 \to K^+K^-)}$$
$$= \frac{1}{2}\left[\left(\left|\frac{p}{q}\right| - \left|\frac{q}{p}\right|\right) y\cos\phi - \left(\left|\frac{p}{q}\right| + \left|\frac{q}{p}\right|\right) x\sin\phi\right)\right]$$



D^0 mixing y_{CP} in $K^+K^-K^0_S$

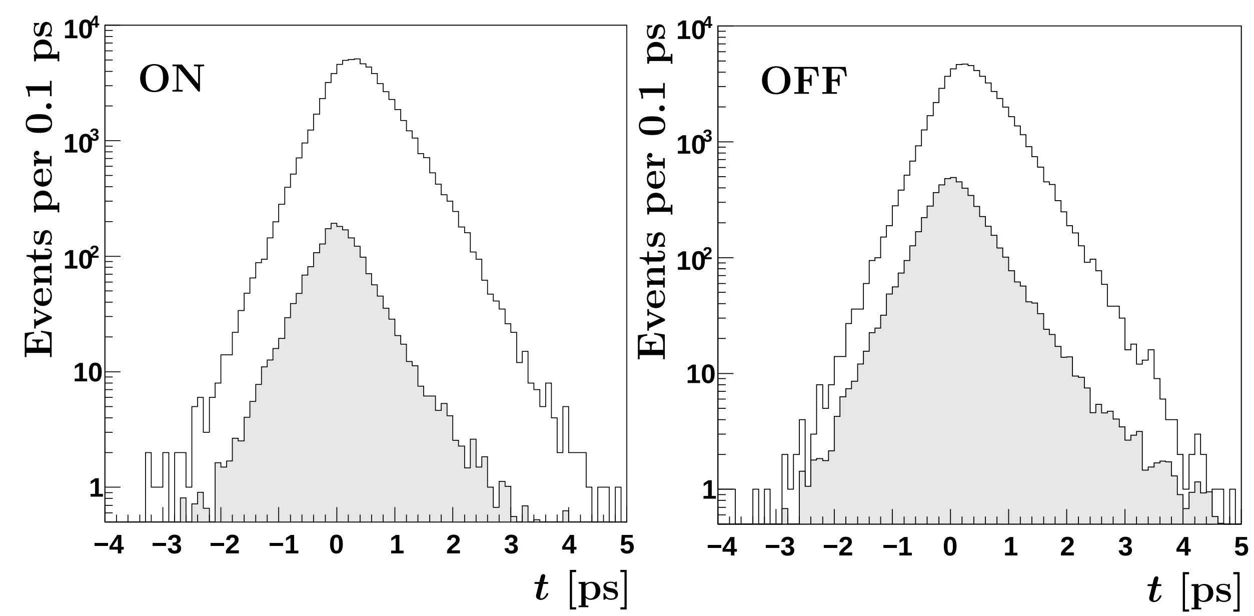
Lifetime difference:
$D^0 \to \phi K^0_S$ vs $D^0 \to [a^0_0, f^0_0, f^0_2]K^0_S$
(CP−) (CP+)
(Belle PRD80,052006(2009) 673 fb^{-1})



Dalitz analysis of $K^+K^-K^0_S$
(with flavor specific $[a^+_0, f^+_0, f^+_2]K^-$)

$$y_{CP} = \frac{1}{f_{ON} - f_{OFF}}\left(\frac{\tau_{OFF} - \tau_{ON}}{\tau_{OFF} + \tau_{ON}}\right)$$

$$= (0.11 \pm 0.61 \pm 0.52)\%$$



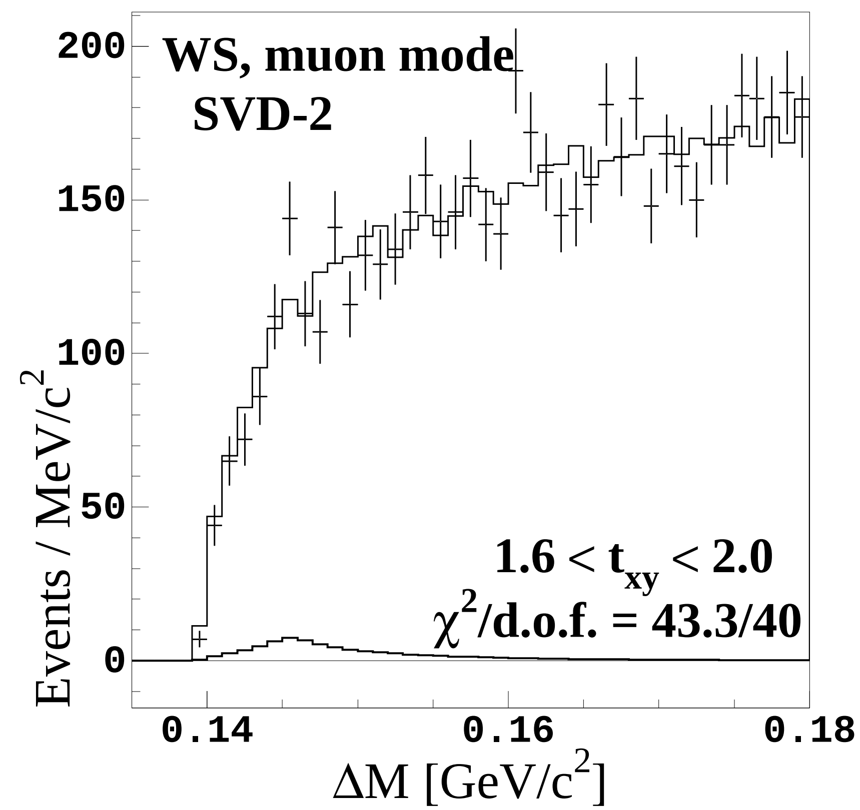
Wrong sign measurements

Leptonic ($D^0 \to K^+\ell^-\overline{\nu}$)

(Belle PRD77,112003(2008) 492 fb^{-1})

- $\Delta M = M(D^0\pi^+_{\rm slow}) - M(D^0)$
- Missing neutrino — kinematic constraints $p_{\rm miss}$, $M_{\rm miss}$, M_{D^0}

$$R_M(\sim \frac{x^2+y^2}{2}) < 6.1\times 10^{-4}$$

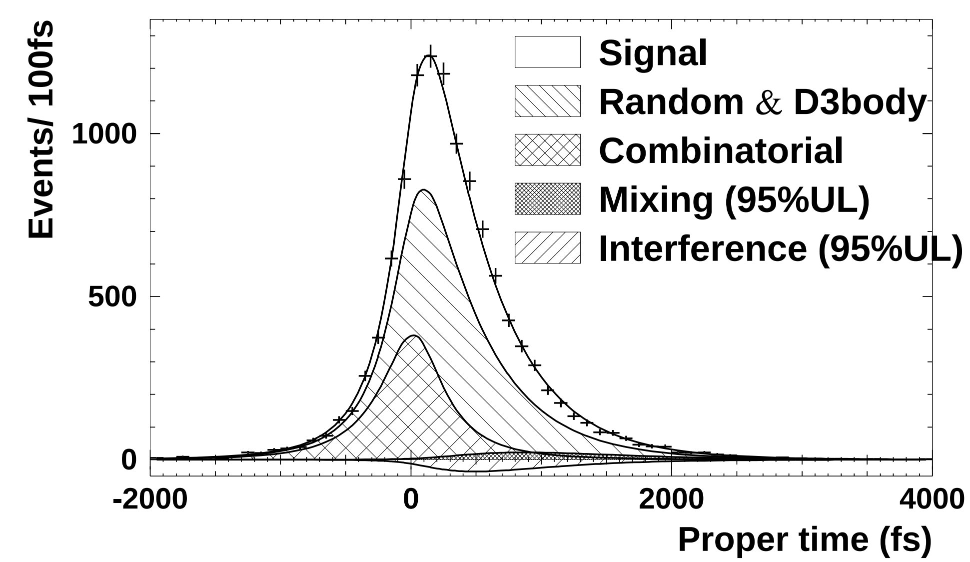


Hadronic ($D^0 \to K^+\pi^-$)

(Belle PRL96,151801(2006) 400 fb^{-1})

- Large DCS component, precision time measurement

$$x'^2 < 7.2\times 10^{-4},\ y' \in [-9.9, 6.8]\times 10^{-3}$$



Belle sees no D mixing in $D^0 \to K^+\pi^-$ although BaBar saw 3.9σ evidence

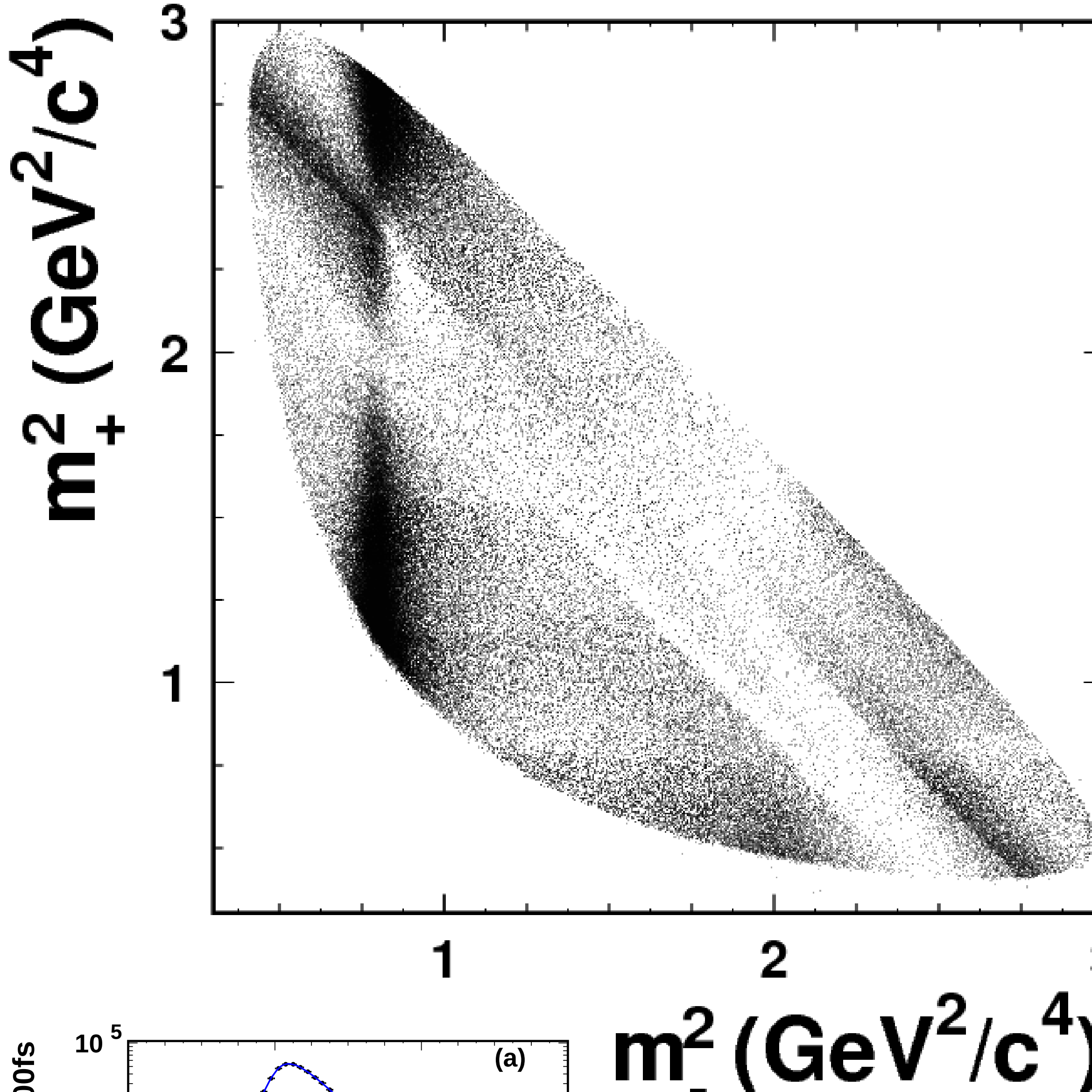
D^0 mixing — time-dependent Dalitz

(Belle PRL99,131803(2007) 540 fb^{-1})

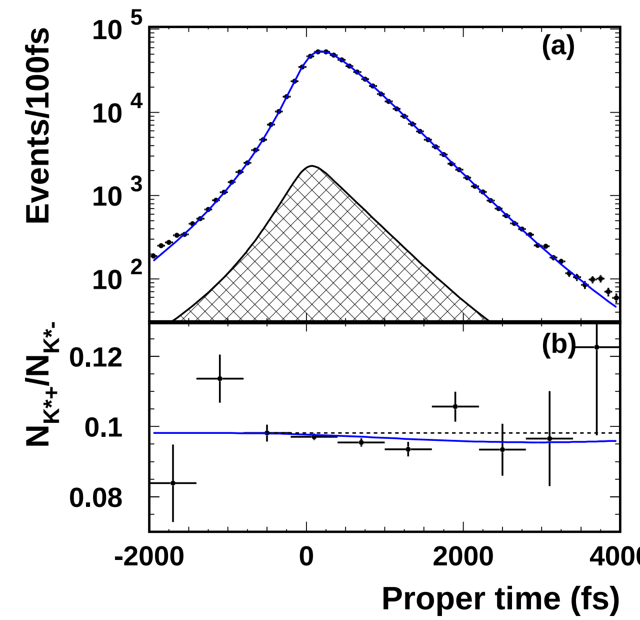
$$\mathcal{M}(m_-^2, m_+^2, t)$$
$$= \tfrac{1}{2}\mathcal{A}(m_-^2, m_+^2)[e^{-i\lambda_1 t} + e^{-i\lambda_1 t}]$$
$$+\tfrac{1}{2}\tfrac{q}{p}\overline{\mathcal{A}}(m_-^2, m_+^2)[e^{-i\lambda_1 t} - e^{-i\lambda_1 t}]$$
$$(\lambda_{1,2} = m_{1,2} - i\Gamma_{1,2}/2)$$

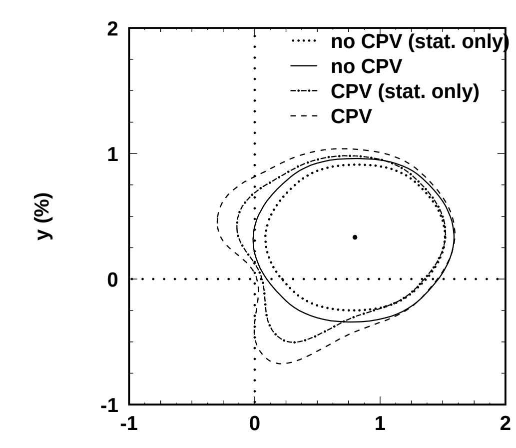
$\mathcal{A} = \sum(5\times\text{CF}, 8\times\text{CP}, 5\times\text{DCS}, \text{NR})$

Fit $|\mathcal{M}|^2$ and $|\overline{\mathcal{M}}|^2$ with m_-^2, m_+^2, t



$$x = (0.80 \pm 0.29\,^{+0.13}_{-0.16})\%$$
$$y = (0.33 \pm 0.24\,^{+0.10}_{-0.14})\%$$
$$|p/q| = 1 + \frac{A_M}{2} = 0.86\,^{+0.30}_{-0.29}\,^{+0.10}_{-0.09}$$
$$\phi = (-0.24\,^{+0.28}_{-0.30} \pm 0.09)\ \text{rad}$$





D mixing/CPV status and prospects

B. Golob at FPCP09

expected sensitivity

only KK/ππ, Kπ and $K_s\pi\pi$ projected sensitivities included

HFAG χ^2 fit

50 ab^{-1}

$$x = (0.793 \pm 0.087)\%$$

$$y = (0.798 \pm 0.062)\%$$

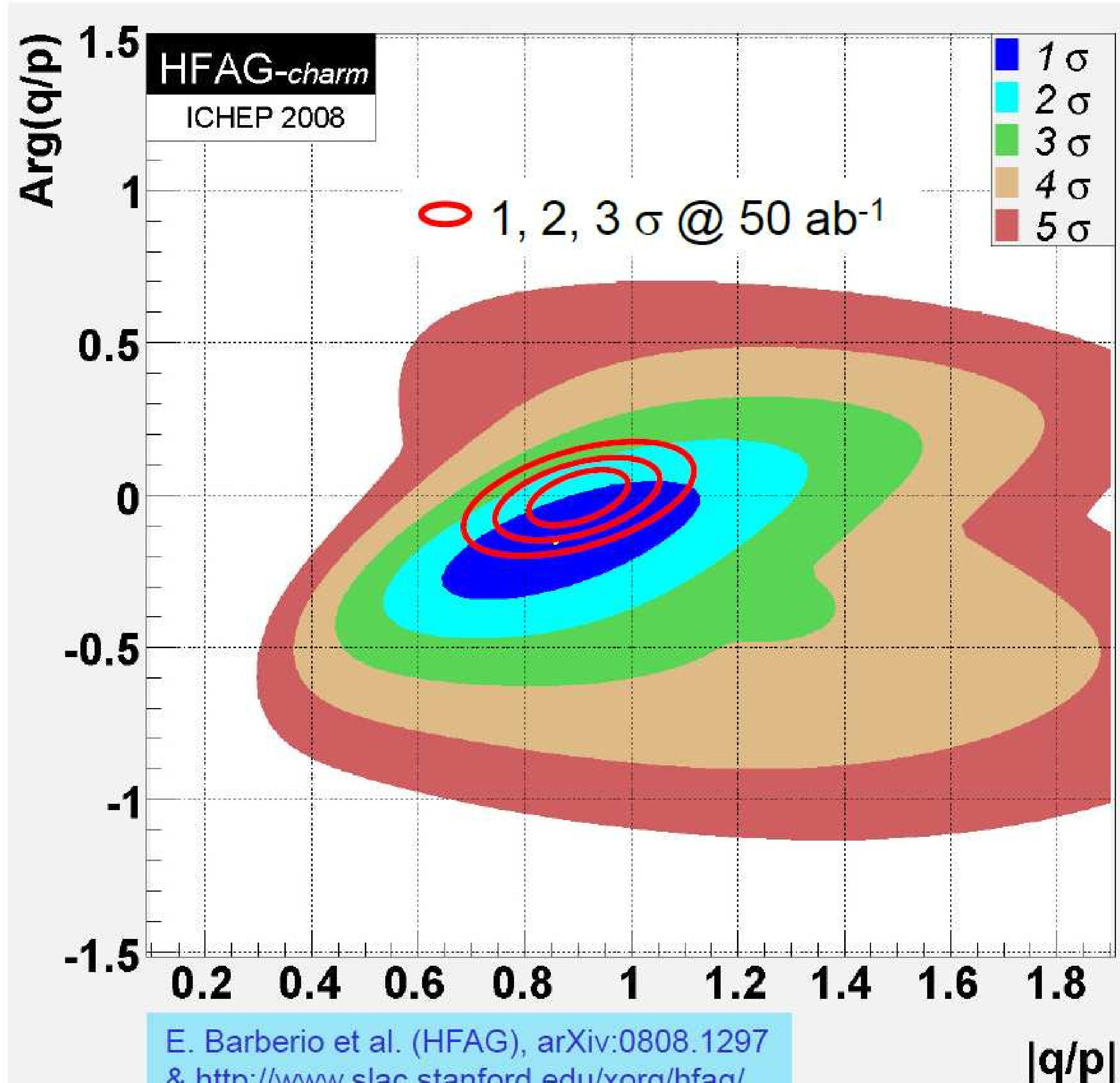
$$\delta_{K\pi} = 24.5° \pm 4.6°$$

$$R_D = (0.336 \pm 0.001)\%$$

$$\frac{|q|}{|p|} = 0.919 \pm 0.055$$

$$\varphi = -0.01 \pm 0.049 \; rad$$

$$A_D = (-0.1 \pm 0.3)\%$$



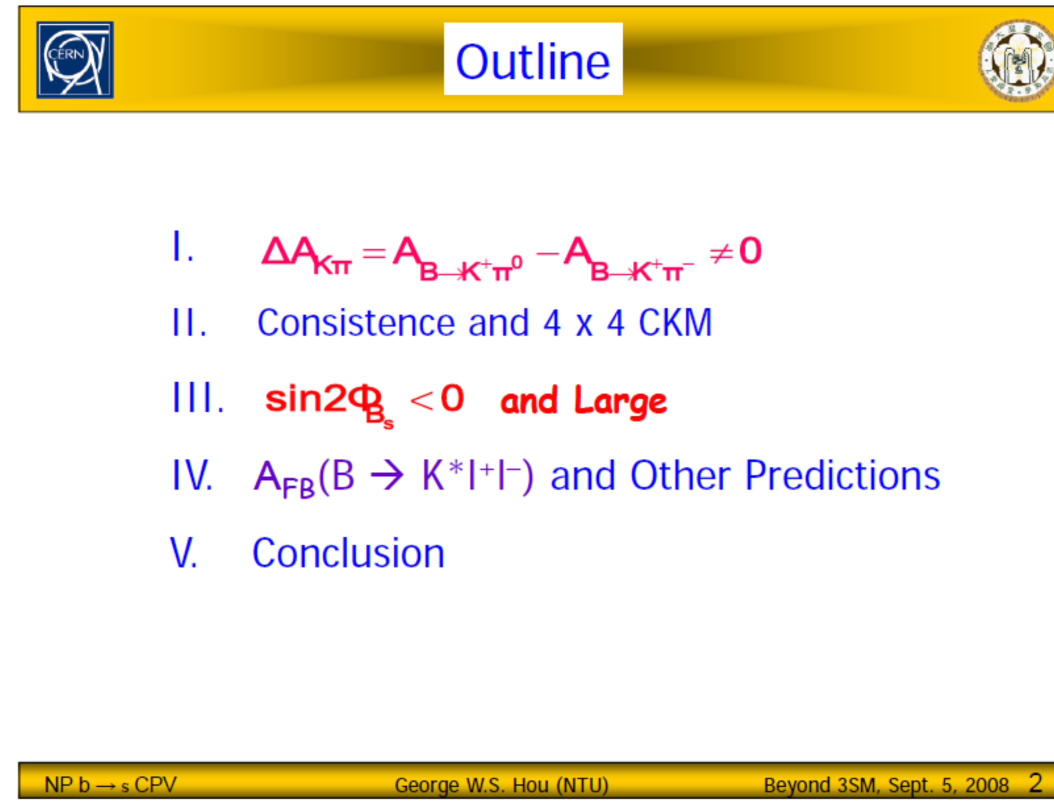
E. Barberio et al. (HFAG), arXiv:0808.1297
& http://www.slac.stanford.edu/xorg/hfag/

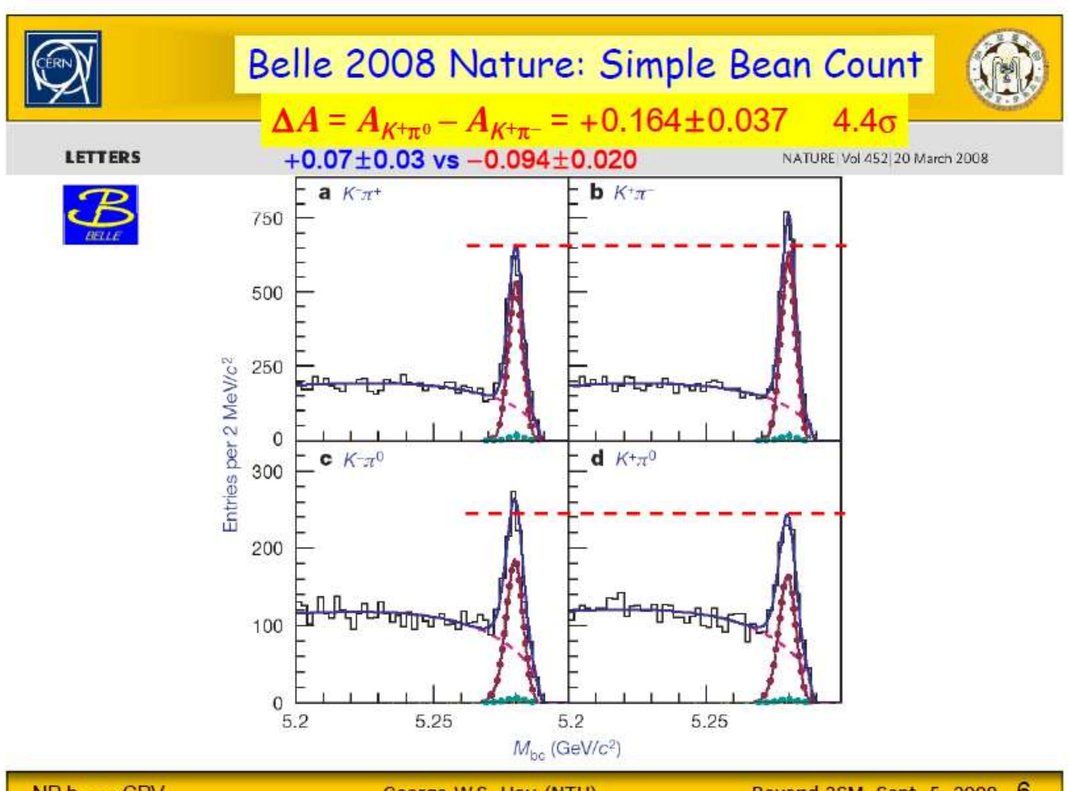
Summary

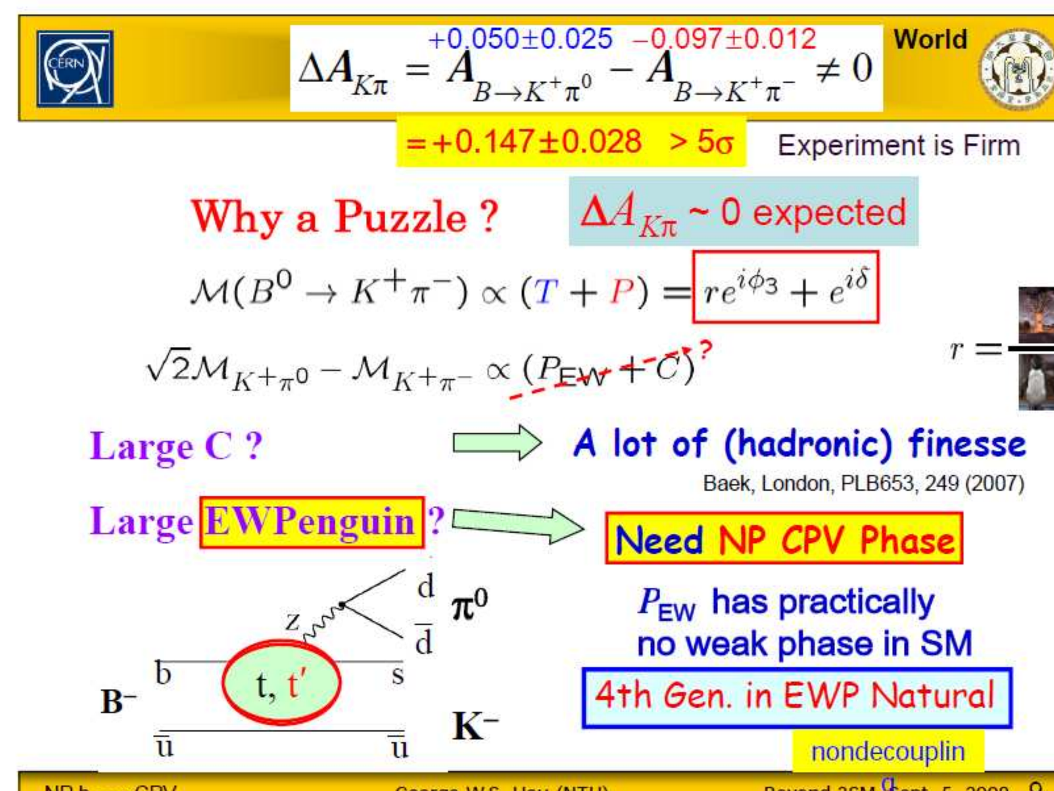
- Many intriguing results from Belle, hopefully useful hints for new physics, including 4th generation quarks
- Still some more data to be analyzed by Belle
- Belle II future seems to be bright

Backup


New Physics CP Violation in
b → s & bs ↔ sb Transitions
George W.S. Hou (侯維恕)
National Taiwan University
September 5, 2008, Beyond 3SM @ CERN
National Taiwan University
NP b → s CPV
George W.S. Hou (NTU)
Beyond 3SM, Sept. 5, 2008 1


Outline
I. $\Delta A_{K\pi} = A_{B\to K^+\pi^0} - A_{B\to K^+\pi^-} \neq 0$
II. Consistence and 4 x 4 CKM
III. $\sin 2\Phi_{B_s} < 0$ and Large
IV. $A_{FB}(B \to K^* l^+ l^-)$ and Other Predictions
V. Conclusion
NP b → s CPV
George W.S. Hou (NTU)
Beyond 3SM, Sept. 5, 2008 2

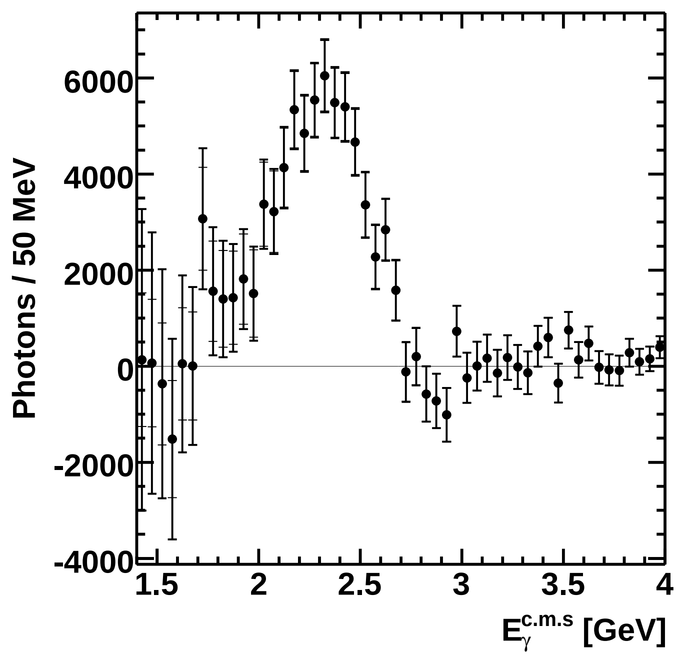

Belle 2008 Nature: Simple Bean Count
$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} = +0.164 \pm 0.037$ 4.4σ
+0.07±0.03 vs −0.094±0.020
LETTERS
NATURE | Vol 452 | 20 March 2008
BELLE
a $K^-\pi^+$
b $K^+\pi^-$
c $K^-\pi^0$
d $K^+\pi^0$
Entries per 2 MeV/c²
M_{bc} (GeV/c²)
NP b → s CPV
George W.S. Hou (NTU)
Beyond 3SM, Sept. 5, 2008 6


$\Delta A_{K\pi} = A_{B\to K^+\pi^0} - A_{B\to K^+\pi^-} \neq 0$
+0.050±0.025 −0.097±0.012
World
= +0.147±0.028 > 5σ
Experiment is Firm
Why a Puzzle ?
$\Delta A_{K\pi}$ ~ 0 expected
$\mathcal{M}(B^0 \to K^+\pi^-) \propto (T + P) = r e^{i\phi_3} + e^{i\delta}$
$\sqrt{2}\mathcal{M}_{K^+\pi^0} - \mathcal{M}_{K^+\pi^-} \propto (P_{EW} + C)$?
r =
Large C ?
A lot of (hadronic) finesse
Baek, London, PLB653, 249 (2007)
Large EWPenguin ?
Need NP CPV Phase
P_{EW} has practically
no weak phase in SM
4th Gen. in EWP Natural
nondecouplin
g
B⁻
K⁻
π⁰
t, t′
NP b → s CPV
George W.S. Hou (NTU)
Beyond 3SM, Sept. 5, 2008 9

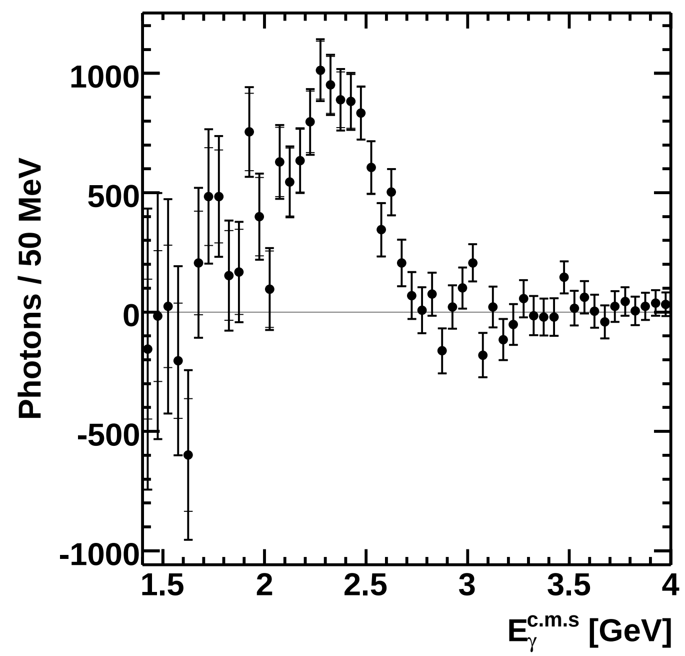
$\mathcal{B}(B \to X_s\gamma)$

Background subtracted

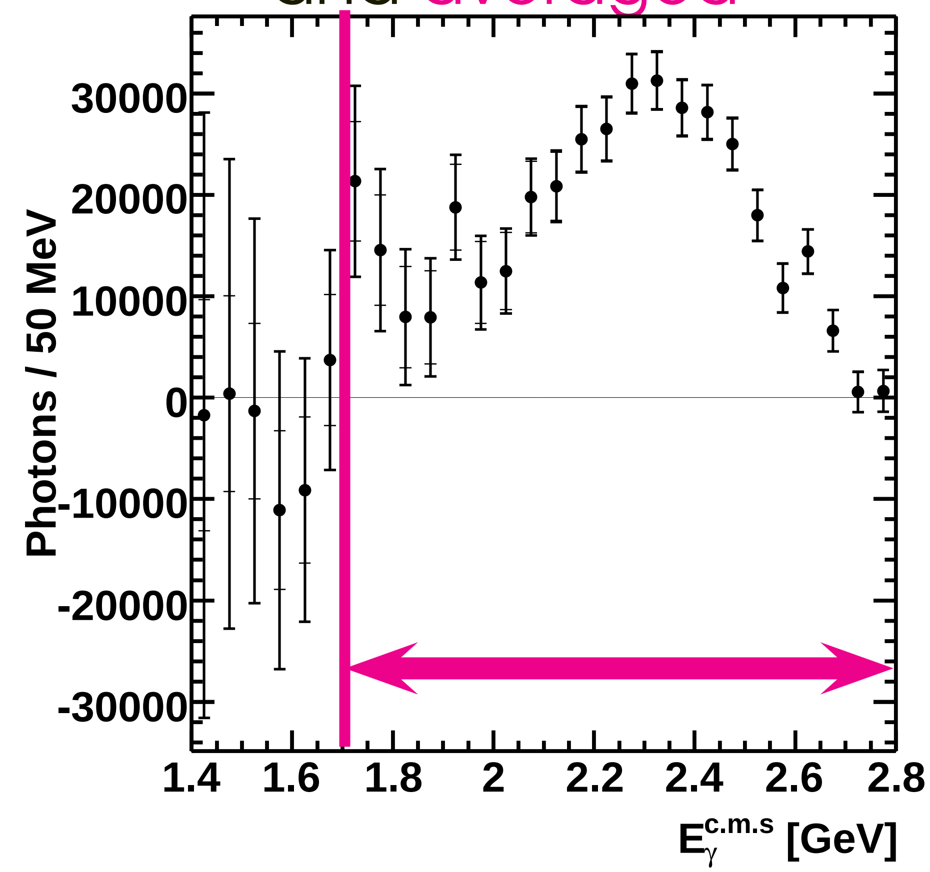
untagged sample



lepton-tag



Efficiency corrected and averaged



(Belle PRL103,241801(2009) 657M $B\overline{B}$)

$$\mathcal{B}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4} \quad \text{(for } E_\gamma > 1.7 \text{ GeV)}$$

- The most precise $B \to X_s\gamma$ measurement
- HFAG: $(3.57 \pm 0.24) \times 10^{-4}$ vs SM $(3.15 \pm 0.23) \times 10^{-4}$ ($E_\gamma > 1.6$ GeV)
- Systematic error is dominated by off-resonance subtraction and B backgrounds other than $B \to \pi^0/\eta$ (syst≃stat for $E_\gamma > 2$ GeV)

$B \to X_s \ell^+ \ell^-$ by Belle — table

bin	N_{sig}	eff.(%)	$\mathcal{B}$ (10^{-7})
$M(X_s)$ (GeV/c^2)			
(0.4, 0.6)	$104.4 \pm 11.5 \pm 1.8$	$8.44^{+0.86}_{-1.09}$	$4.7 \pm 0.5^{+0.5}_{-0.6}$
(0.6, 0.8)	$0.4 \pm 3.0 \pm 0.2$	$3.86^{+0.39}_{-0.50}$	$0.0 \pm 0.3^{+0.6}_{-0.0}$
(0.8, 1.0)	$79.0 \pm 11.6 \pm 0.5$	$3.89^{+0.40}_{-0.50}$	$7.7 \pm 1.1^{+0.8}_{-1.0}$
(1.0, 1.4)	$23.7 \pm 10.5 \pm 0.3$	$1.68^{+0.17}_{-0.22}$	$5.4 \pm 2.4^{+0.6}_{-0.7}$
(1.4, 2.0)	$32.5 \pm 16.5 \pm 0.9$	$0.99^{+0.10}_{-0.13}$	$12.5 \pm 6.3^{+1.3}_{-1.7}$
Sum (0.4, 2.0) for $X_s \ell^+ \ell^-$			$30.3 \pm 6.9^{+1.7}_{-2.1}$
(Sum (0.4, 2.0) for $X_s e^+ e^-$			$40.4 \pm 9.8^{+2.8}_{-3.4}$)
(Sum (0.4, 2.0) for $X_s \mu^+ \mu^-$			$18.4 \pm 8.8^{+1.5}_{-1.7}$)
q^2 (GeV^2/c^2)			
(0.04, 1.0)	$36.1 \pm 7.8 \pm 0.1$	$2.40^{+0.33}_{-0.38}$	$5.7 \pm 1.2^{+0.8}_{-0.9}$
(1.0, 6.0)	$74.0 \pm 15.3 \pm 0.4$	$3.48^{+0.47}_{-0.55}$	$8.1 \pm 1.7^{+1.1}_{-1.3}$
(6.0, 14.4)	$64.9 \pm 16.6 \pm 0.3$	$2.20^{+0.30}_{-0.35}$	$11.2 \pm 2.9^{+1.5}_{-1.8}$
(14.4, 25.0)	$62.8 \pm 11.0 \pm 2.3$	$7.44^{+1.01}_{-1.17}$	$3.2 \pm 0.6 \pm 0.5$

sum up