Physics School 2010: B Physics

Lecture 1: UT angles I (Belle/BaBar)
Lecture 2: UT angles II (Belle/BaBar)
Lecture 3: UT sides (Belle/BaBar/CDF/D0)
Lecture 4: Future Super-b Factories

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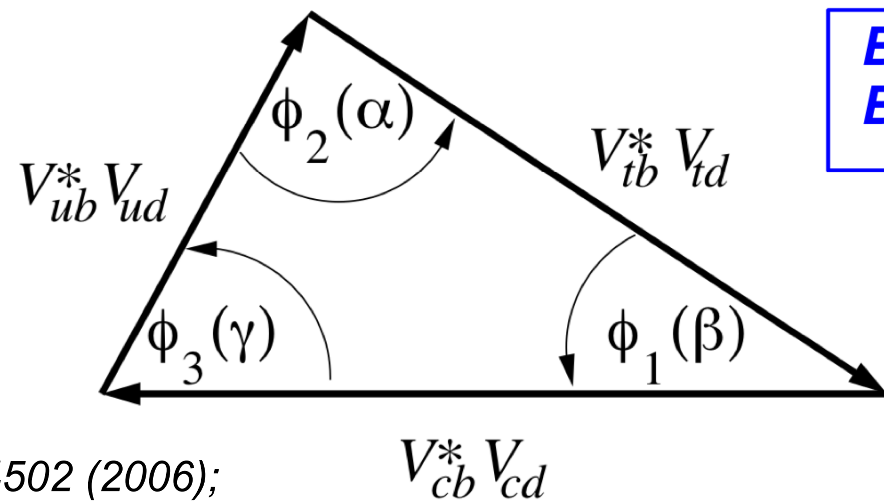
23-35 June 2010
University of Bern

Caveats:

- *will not talk much about theoretical technical details*
- *will not discuss D0's new like-sign dilepton result*
- *will probably run out of time*

Unitarity triangle - determining the sides



$B^0 \to \pi \ell^+ \nu$
$B^0 \to X_u \ell \nu$
$B^+ \to \tau^+ \nu$

HPQCD, PRD 73, 074502 (2006);
PRD75, 119906 (2007)
FNAL/MILC, Nucl. Phys. Proc. Suppl. 140, 461 (2005)

Lange et al. (BLNP), PRD 72, 073006 (2005)
Andersen, Gardi (DGE), JHEP 601, 97 (2006)
Gambino et al. (GGOU), JHEP 710, 58 (2007)
Aglietti et al. (ADFR), EPJ C59 (2009); Nucl. Phy. B768, 85 (2007)
Bauer et al. (BLL), PRD64, 113004 (2001)

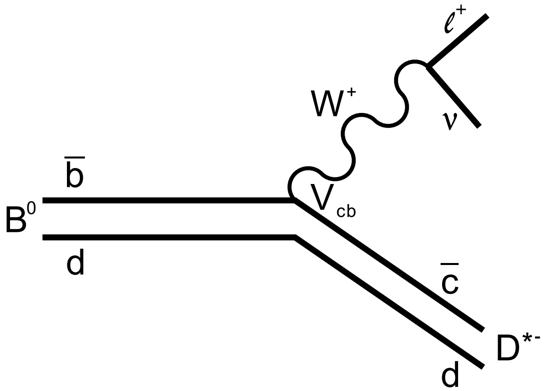
$B^0 \to \rho^0 \gamma$
B_s–$\underline{B}_s$ mixing (CDF/D0)

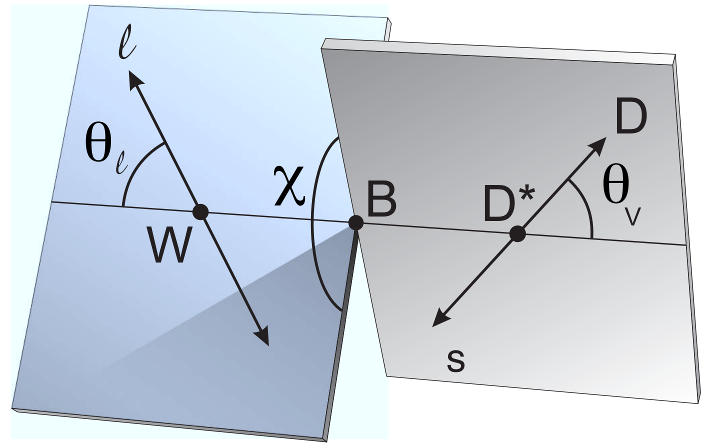
Ali et al., arXiv:hep-ph/0610149; PLB 595, 323 (2004)
Ball et al., JHEP 04, 046 (2006); PRD 75, 054004 (2007)
Bosch et al., JHEP 0501, 035 (2005)

$B^0 \to D^{(*)} \ell \nu$
$B^0 \to X_c \ell \nu$ (ℓ energy, hadron mass moments)
$B^0 \to X_s \gamma$ (γ energy moments)

Caprini, Lellouch, Neubert, Nucl. Phys. B530, 153 (1998)
Neubert, Phys. Rep. 245, 259 (1994)
Isgur, Wise, PLB 237, 527 (1990); PLB 232, 113 (1989)
Gambino, Uraltsev, EPJ C34, 181 (2004)
Benson, Bigi, Uraltsev, Nucl. Phys. B710, 371 (2005)
Benson et al., Nucl. Phys. B665, 367 (2003)

V_{cb} via $B^0 \to D^{(*)} \ell \nu$





Variables: $\theta_\ell,\ \theta_V,\ \chi,\ w$

where: $w = \frac{P_B \cdot P_{D^*}}{M_B M_{D^*}} = \frac{M_B^2 + M_{D^*}^2 - q^2}{2 M_B M_{D^*}}$ and $q^2 = (P_\ell + P_\nu)^2$

Note: $q^2 = 0 \Rightarrow w = w_{max} = 1.50$; $w_{min} = 1$ $q^2 = q^2_{max} = 10.69\ \mathrm{GeV}^2$

Decay rate:

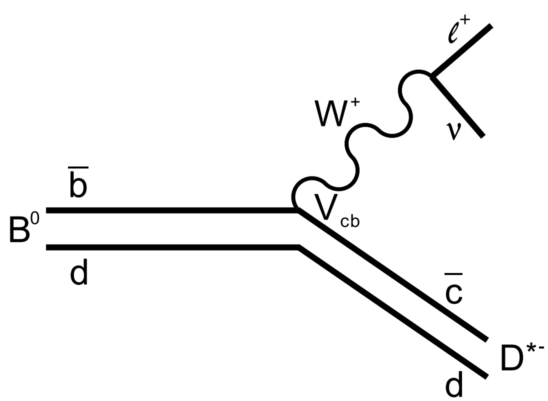
$$\frac{d^4\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\, d(\cos\theta_\ell)\, d(\cos\theta_V)\, d\chi} = \frac{6 m_B m_{D^*}^2}{8(4\pi)^4}\sqrt{w^2-1}(1-2wr+r^2)G_F^2|V_{cb}|^2 \times$$
$$\Big\{(1-\cos\theta_\ell)^2\sin^2\theta_V H_+^2(w) + (1+\cos\theta_\ell)^2\sin^2\theta_V H_-^2(w)$$
$$+ 4\sin^2\theta_\ell\cos^2\theta_V H_0^2(w) - 2\sin^2\theta_\ell\sin^2\theta_V\cos 2\chi H_+(w)H_-(w)$$
$$- 4\sin\theta_\ell(1-\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi H_+(w)H_0(w)$$
$$+ 4\sin\theta_\ell(1+\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi H_-(w)H_0(w)\Big\}$$

$$\left(r = \frac{M_{D^*}}{M_B}\right)$$

V_{cb} via $B^0 \to D^{(*)}\ell\nu$

Differential decay rate:

$$\frac{d^4\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\, d(\cos\theta_\ell)\, d(\cos\theta_V)\, d\chi} = \frac{6 m_B m_{D^*}^2}{8(4\pi)^4}\sqrt{w^2-1}(1-2wr+r^2)G_F^2|V_{cb}|^2 \times$$
$$\Big\{(1-\cos\theta_\ell)^2\sin^2\theta_V H_+^2(w) + (1+\cos\theta_\ell)^2\sin^2\theta_V H_-^2(w)$$
$$+ 4\sin^2\theta_\ell\cos^2\theta_V H_0^2(w) - 2\sin^2\theta_\ell\sin^2\theta_V\cos 2\chi H_+(w)H_-(w)$$
$$- 4\sin\theta_\ell(1-\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi H_+(w)H_0(w)$$
$$+ 4\sin\theta_\ell(1+\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi H_-(w)H_0(w)\Big\}$$

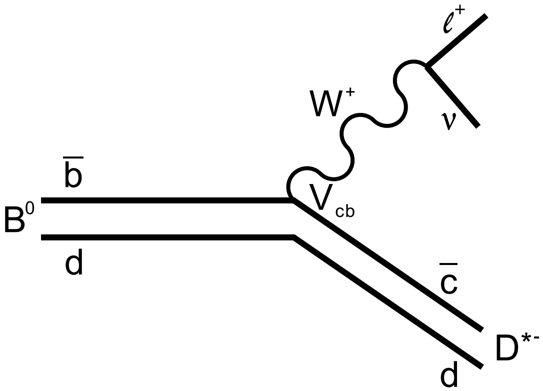


(H_+, H_-, H_0 are helicity amplitudes)

Procedure to extract $|V_{cb}|$:

1) Express helicity amplitudes in terms of functions $h_{A1}(w)$, $R_1(w)$, $R_2(w)$ [these can be related to form factors $A_1(w)$, $A_2(w)$, $A_3(w)$, $V(w)$]
2) Parameterize these functions with analytic forms
   [e.g., Caprini et al., Nucl.Phys. B530, 153 (1998)]
3) Integrate fully differential decay rate to get single differential distributions $d\Gamma/dw$, $d\Gamma/d\cos\theta_l$, $d\Gamma/d\cos\theta_V$, $d\Gamma/dx$ that depend on $h_{A1}(w)$, $R_1(w)$, $R_2(w)$
4) Fit data for $\mathcal{F}(w)|V_{cb}|$, extrapolate back to w=1
5) Use theory to calculate $\mathcal{F}(1)$, determine $|V_{cb}|$

V_{cb} via $B^0 \to D^{(*)} \ell \nu$



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$$H_\pm(w) = M_B \frac{R^*(r+1)(w+1)}{2} h_{A_1}(w) \left[1 \mp \sqrt{\frac{w-1}{w+1}} R_1(w)\right]$$

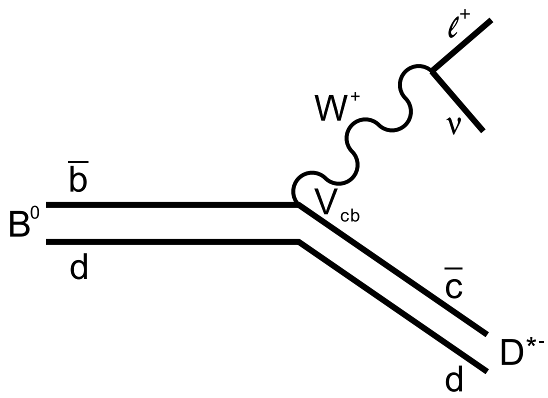
$$H_0(w) = M_B \frac{R^*(1-r^2)(w+1)}{2\sqrt{1-2wr+r^2}} h_{A_1}(w) \left[1 + \frac{(w-1)(1-R_2(w))}{1-r}\right]$$

$$\left(R^* = \frac{2\sqrt{M_B M_{D^*}}}{M_B + M_{D^*}}\right)$$

$$h_{A_1}(w) = h_{A_1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$
$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$

$$\left(z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}\right)$$

V_{cb} via $B^0 \to D^{(*)} \ell \nu$



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2) *Parameterize these functions with analytic forms*
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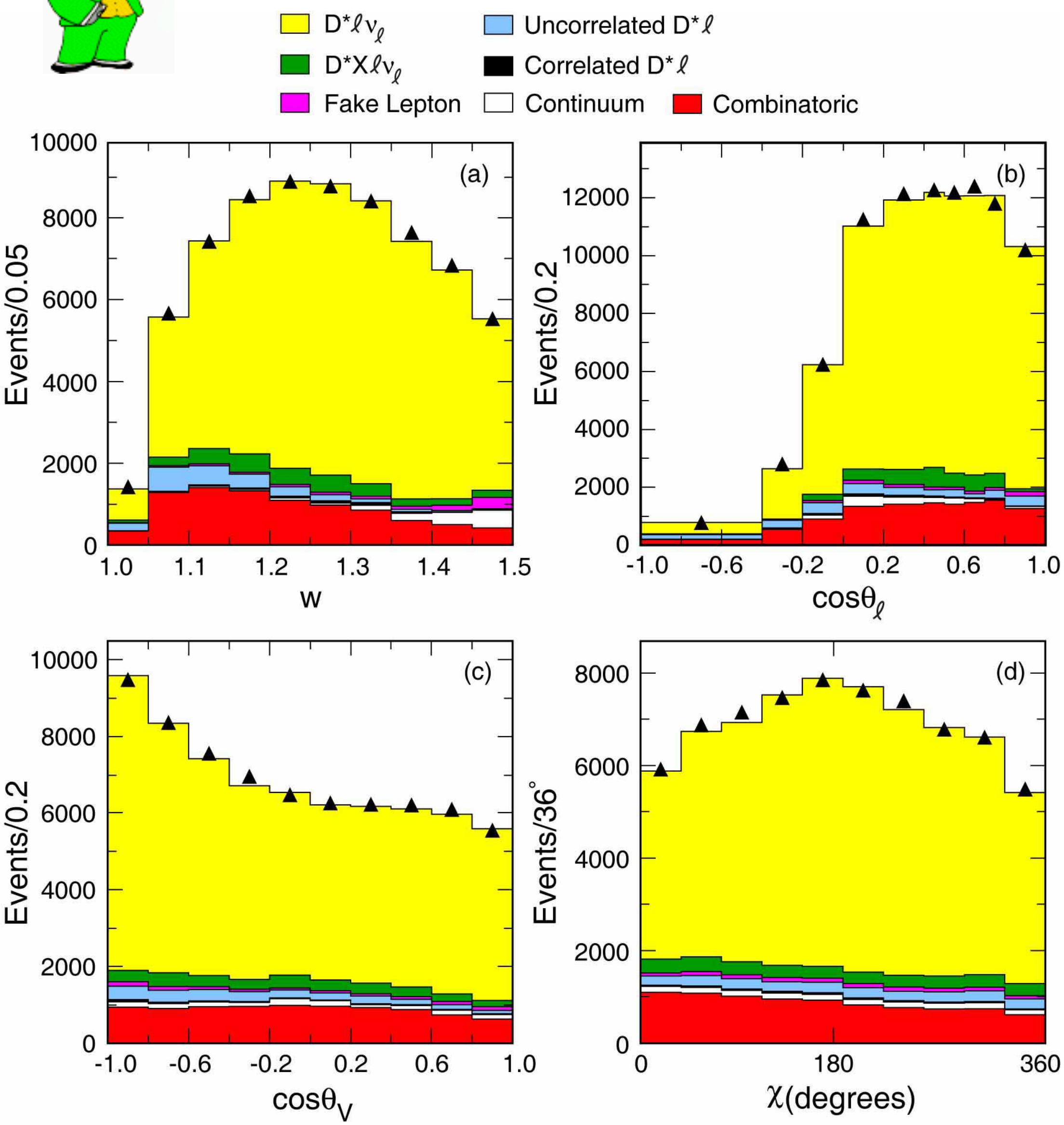
3) *Integrate fully differential decay rate to get single differential distributions $d\Gamma/dw$, $d\Gamma/d\cos\theta_l$, $d\Gamma/d\cos\theta_V$, $d\Gamma/dx$ that depend on $h_{A1}(w)$, $R_1(w)$, $R_2(w)$*
4) *Fit data for $\mathcal{F}(w)|V_{cb}|$, extrapolate back to w=1*
5) *Use theory to calculate $\mathcal{F}(1)$, determine $|V_{cb}|$*

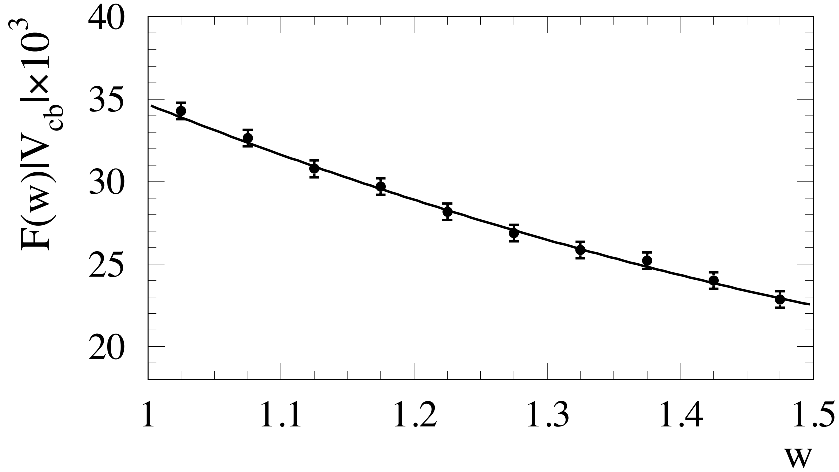
$$\frac{d\Gamma}{dw} = \frac{G_F^2}{48\pi^3} M_{D^*}^3 (M_B - m_{D^*})^2 |V_{cb}|^2 \times \sqrt{w^2-1}(w+1)^2 \left[1 + \frac{4w}{w+1}\left(\frac{1-2wr+r^2}{(1-r)^2}\right)\right] \mathcal{F}^2(w)$$

$$\left\{2\frac{1-2wr+r^2}{(1-r)^2}\left[1+\frac{w-1}{w+1}R_1^2(w)\right] + \left[1+\frac{w-1}{1-r}(1-R_2(w))\right]^2\right\}\frac{R^{*2}(w+1)^2}{4} h_{a_1}^2(w)$$

V_{cb} via $B^0 \to D^{(*)}\ell\nu$

Aubert et al. (Belle), PRD77, 032002 (2008) **[53k signal cand.]**





$$\rho^2 = 1.191 \pm 0.048 \pm 0.028$$
$$R_1(1) = 1.429 \pm 0.061 \pm 0.044$$
$$R_2(1) = 0.827 \pm 0.038 \pm 0.022$$
$$\mathcal{F}(1)|V_{cb}| = (34.4 \pm 0.3 \pm 1.1) \times 10^{-3}$$

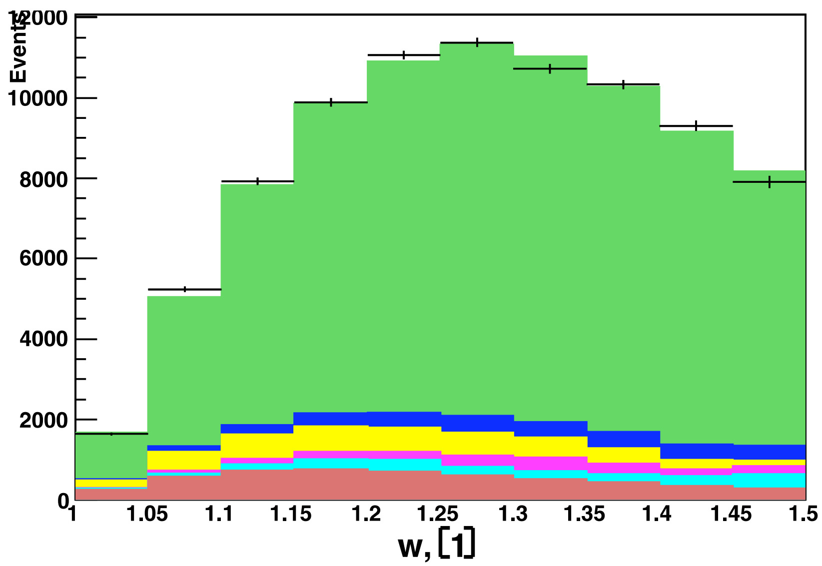
$$\Rightarrow |V_{cb}| = (37.4 \pm 0.3 \pm 1.2\,^{+1.2}_{-1.4}) \times 10^{-3}$$

Using lattice calculation Hashimoto et al., PRD66, 014503 (2002) for $\mathcal{F}(1)$

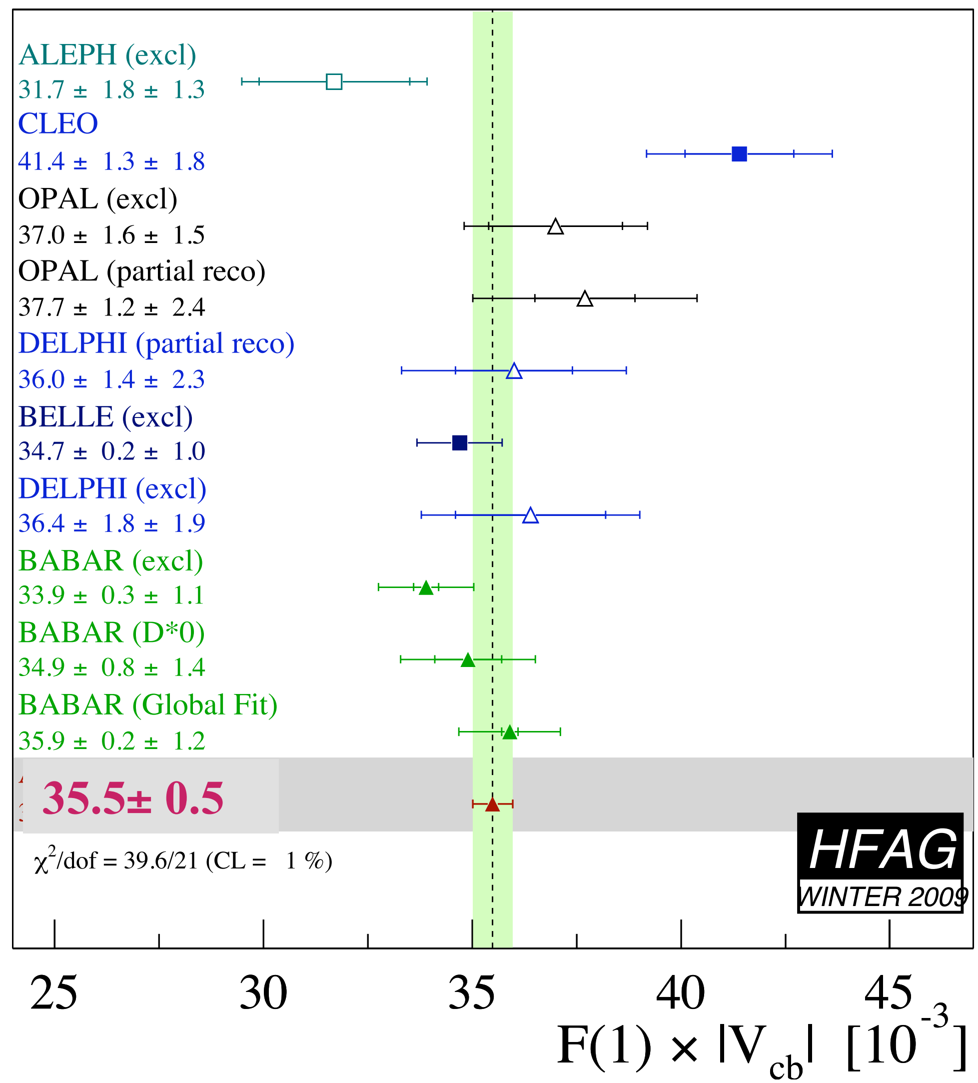
V_{cb} via $B^0 \to D^{(*)}\ell\nu$

BELLE

Adachi et al. (Belle), arXiv:0810.1657
[140 fb^{-1} , 69k signal cand.]



$$\rho^2 = 1.293 \pm 0.045 \pm 0.029$$
$$R_1(1) = 1.495 \pm 0.050 \pm 0.062$$
$$R_2(1) = 0.844 \pm 0.034 \pm 0.019$$
$$\mathcal{F}(1)|V_{cb}| = (34.4 \pm 0.2 \pm 1.0) \times 10^{-3}$$



V_{cb} via Global Fit to Moments

Schwanda et al. (Belle), PRD 78, 032016 (2008)
http://www.slac.stanford.edu/xorg/hfag/semi/fpcp2009/gbl_fits/kinetic/index.html

Operator product expansion (OPE) and Heavy Quark Effective theory (HQET) predict various moments of distributions as a function of $|V_{cb}|$, mb, and several non-perturbative HQ parameters $\Rightarrow$ fit the data for all these parameters, obtain $|V_{cb}|$

"1S Scheme" *[Bauer et al., PRD 70, 094017 (2004)]*
(can also use the "Kinetic Scheme," Gambino et al., EPJ C34, 181 (2004); Benson et al., Nucl. Phys. B710, 371 (2005)

Partial branching fraction:

$$\Delta\mathcal{B}_{E_{\min}} = \frac{G_F^2\, m^5}{192\pi^3}\,|V_{cb}|^2\,\eta_{\rm QED}\tau_B\,\langle X\rangle_{\Delta\mathcal{B},E_{\min}}$$

where:

$$\begin{aligned}\langle X\rangle_{E_{min}} = {} & X^{(1)} + X^{(2)}\Lambda + X^{(3)}\Lambda^2 + X^{(4)}\Lambda^3 + \\ & X^{(5)}\lambda_1 + X^{(6)}\Lambda\lambda_1 + X^{(7)}\lambda_2 + X^{(8)}\Lambda\lambda_1 + \\ & X^{(9)}\rho + X^{(10)}\rho_2 + X^{(11)}\tau_1 + X^{(12)}\tau_2 + X^{(13)}\tau_3 + X^{(14)}\tau_4 + \\ & X^{(15)}\epsilon + X^{(16)}\epsilon^2_{\rm BLM} + X^{(17)}\Lambda\epsilon\end{aligned}$$

$X^{(i)}$ are perturbatively calculated coefficients; HQ parameters are Λ (leading order), λ_1, λ_2 (order $1/m_b^2$), ρ_1, ρ_2, τ_1, τ_2, τ_3, τ_4 (order $1/m_b^3$).

V_{cb} via Global Fit to Moments

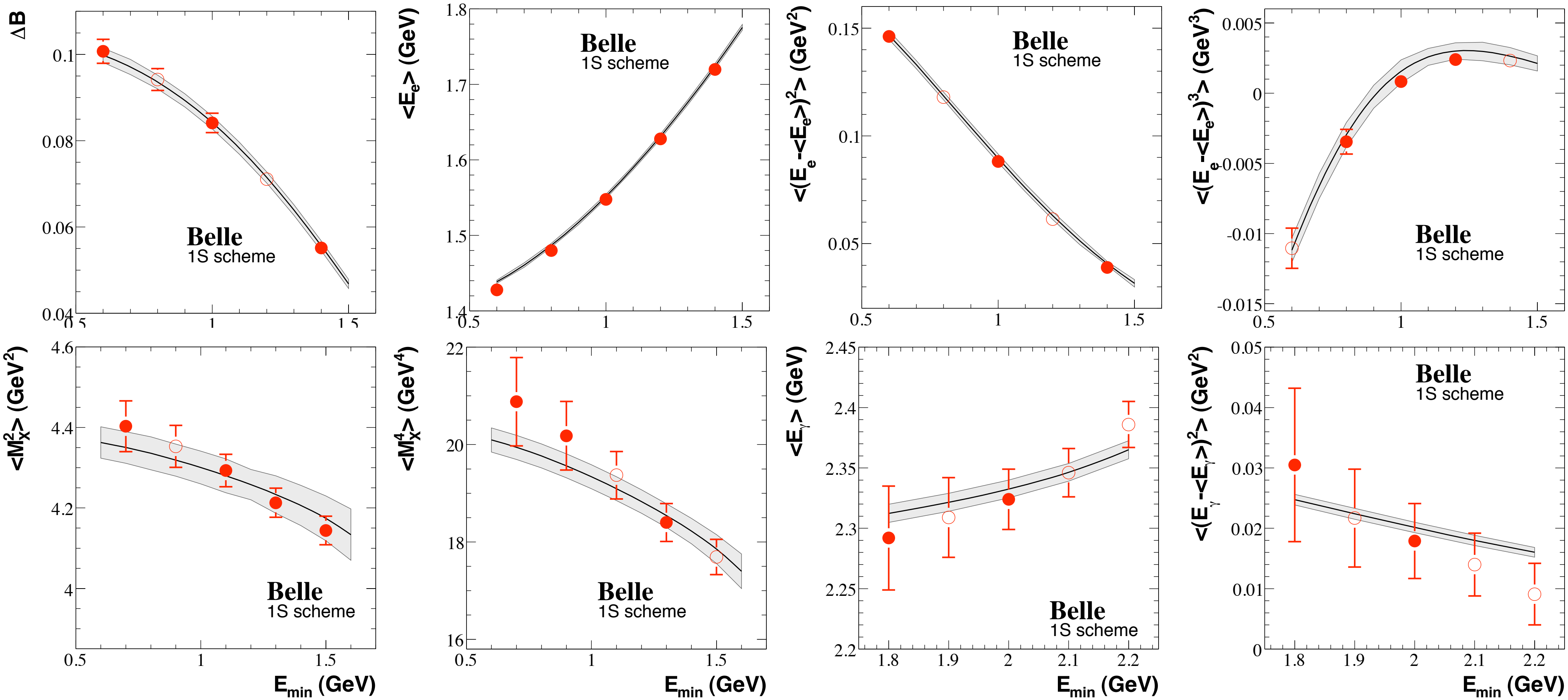
Analysis	Moments $\langle (E-\langle E\rangle)^n \rangle$
$B \to X_c \ell \nu$	E_ℓ, M_X^2
$B \to X_s \gamma$	E_γ

BaBar	n=2 c=0.9,1.1,1.3,1.5 n=4 c=0.9,1.0,1.2,1.4 [1]	n=0 c=0.6,1.2,1.5 n=1 c=0.6,0.8,1.0,1.2,1.5 n=2 c=0.6,1.0,1.5 n=3 c=0.8,1.2 [2]	n=1 c=1.9,2.0 n=2 c=1.9 [3,4]	[1] Phys.Rev. D69 (2004) 111103 [2] Phys.Rev. D69 (2004) 111104 [3] Phys.Rev. D72 (2005) 052004 [4] Phys. Rev. Lett. 97, 171803 (2006)
Belle	n=2 c=0.7,1.1,1.3,1.5 n=4 c=0.7,0.9,1.3 [5]	n=0 c=0.6,1.0,1.4 n=1 c=0.6,0.8,1.0,1.2,1.4 n=2 c=0.6,1.0,1.4 n=3 c=0.8,1.0, 1.2 [6]	n=1 c=1.8,1.9 n=2 c=1.8,2.0 [7]	[5] Phys.Rev. D75 (2007) 032005 [6] Phys.Rev. D75 (2007) 032001 [7] Phys.Rev. D78 (2008) 032016
CDF	n=2 c=0.7 n=4 c=0.7 [8]	.	.	[8] Phys.Rev. D71 (2005) 051103
CLEO	n=2 c=1.0,1.5 n=4 c=1.0,1.5 [9]	.	n=1 c=2.0 [10]	[9] Phys.Rev. D70 (2004) 032002 [10] Phys.Rev.Lett. 87 (2001) 251807
DELPHI	n=2 c=0.0 n=4 c=0.0 [11]	n=1 c=0.0 n=2 c=0.0 n=3 c=0.0 [11]	.	[11] Eur.Phys.J. C45 (2006) 35-59

V_{cb} via Global Fit to Moments

"1S Scheme" [Bauer et al., PRD 70, 094017 (2004)]

Schwanda et al. (Belle), PRD 78, 032016 (2008) **[140 fb^{-1}]**

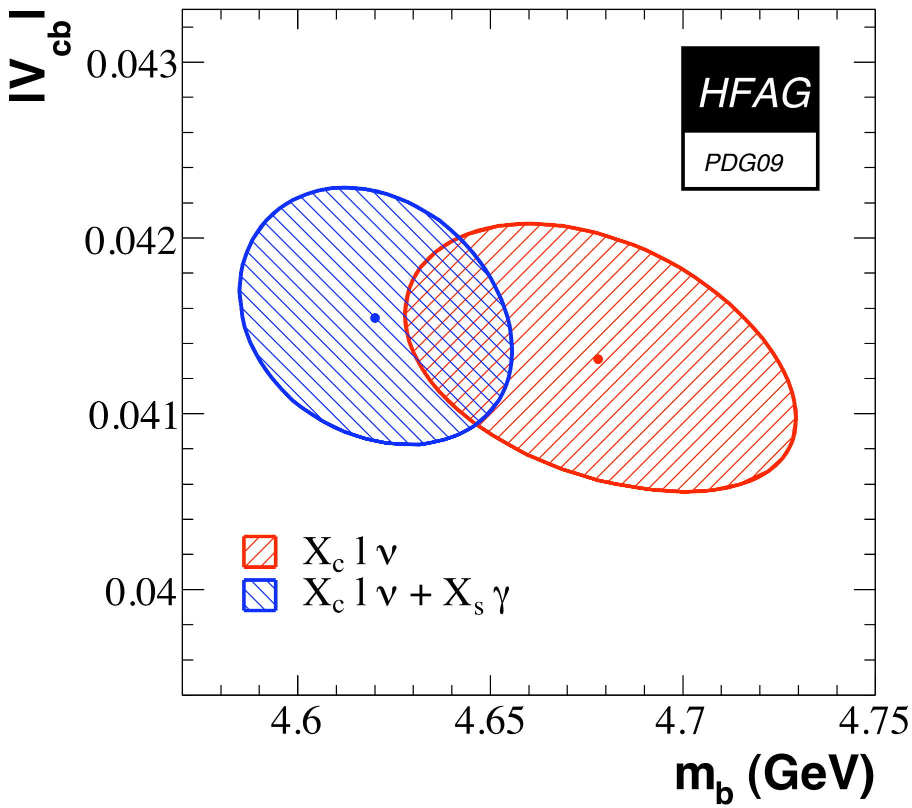


	$\lvert V_{cb}\rvert$ (10^{-3})	m_b (GeV)	λ_1 (GeV^2)	ρ_1 (GeV^3)	τ_1 (GeV^3)	τ_2 (GeV^3)	τ_3 (GeV^3)
value	41.56	4.723	−0.303	0.067	0.125	−0.101	0.125
σ(fit)	0.68	0.055	0.046	0.030	0.005	0.056	0.005
$\sigma(\tau_B)$	0.08						

V_{cb} via Global Fit to Moments

"Kinetic Scheme"

Gambino et al., EPJ C34, 181 (2004); Benson et al., Nucl. Phys. B710, 371 (2005)
http://www.slac.stanford.edu/xorg/hfag/semi/fpcp2009/gbl_fits/kinetic/index.html

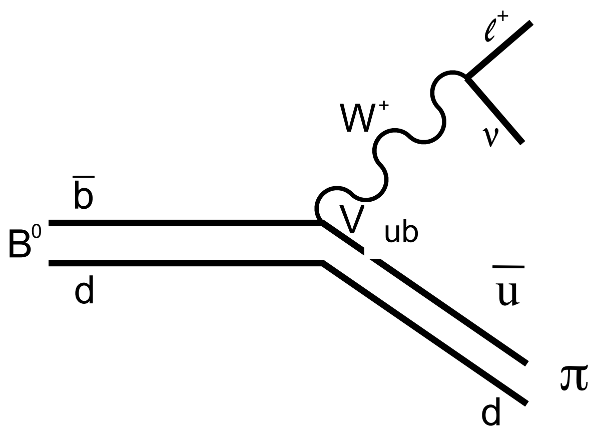


$$
\begin{aligned}
m_b &= 4.620 \pm 0.035 \quad \mathrm{GeV/c^2} \\
m_c &= 1.190 \pm 0.052 \quad \mathrm{GeV/c^2} \\
\mu_\pi^2 &= 0.424 \pm 0.042 \quad \mathrm{GeV^2}
\end{aligned}
\Bigg\} \text{ main non-pert. parameters}
$$

$$
|V_{cb}| = [41.54 \pm 0.43 \pm 0.08\,(\tau_B) \pm 0.58\ (\text{theory})] \times 10^{-3}
$$

(WA most precise result)

V_{ub} via $B^0 \to \pi^- \ell^+ \nu$



$\Gamma(\pi\ell\nu)$ proportional to $|V_{ub}|^2$ x (form factor)^2

⇒ ***need calculation of form factor to extract $|V_{ub}|$***

Two strategies:

light cone sum rules (low q^2, high hadron momentum)
lattice calculation (high q^2, low hadron momentum)

The labels "B_{reco}" and "SL" tags refer to the type of B decay tag used.

	$\mathcal{B}[10^{-4}]$	$\mathcal{B}(q^2 > 16\ \mathrm{GeV}^2/c^2)[10^{-4}]$	$\mathcal{B}(q^2 < 16\ \mathrm{GeV}^2/c^2)[10^{-4}]$
CLEO π^+, π^0	$1.38 \pm 0.15 \pm 0.11$	$0.41 \pm 0.08 \pm 0.04$	$0.97 \pm 0.13 \pm 0.09$
BABAR π^+	$1.45 \pm 0.07 \pm 0.11$	$0.38 \pm 0.04 \pm 0.05$	$1.08 \pm 0.06 \pm 0.09$
BELLE SL π^+	$1.38 \pm 0.19 \pm 0.15$	$0.36 \pm 0.10 \pm 0.04$	$1.02 \pm 0.16 \pm 0.11$
BELLE SL π^0	$1.43 \pm 0.26 \pm 0.15$	$0.37 \pm 0.15 \pm 0.04$	$1.05 \pm 0.23 \pm 0.11$
BABAR SL π^+	$1.39 \pm 0.21 \pm 0.08$	$0.46 \pm 0.13 \pm 0.03$	$0.92 \pm 0.16 \pm 0.05$
BABAR SL π^0	$1.80 \pm 0.28 \pm 0.15$	$0.45 \pm 0.17 \pm 0.06$	$1.38 \pm 0.23 \pm 0.11$
BABAR B_{reco} π^+	$1.07 \pm 0.27 \pm 0.19$	$0.65 \pm 0.20 \pm 0.13$	$0.42 \pm 0.18 \pm 0.06$
BABAR B_{reco} π^0	$1.54 \pm 0.41 \pm 0.30$	$0.49 \pm 0.23 \pm 0.12$	$1.05 \pm 0.36 \pm 0.19$
BELLE B_{reco} π^+	$1.12 \pm 0.18 \pm 0.05$	$0.26 \pm 0.08 \pm 0.01$	$0.85 \pm 0.16 \pm 0.04$
BELLE B_{reco} π^0	$1.24 \pm 0.23 \pm 0.05$	$0.41 \pm 0.11 \pm 0.02$	$0.85 \pm 0.16 \pm 0.04$
Average	$\mathbf{1.36 \pm 0.05 \pm 0.05}$	$\mathbf{0.37 \pm 0.02 \pm 0.02}$	$\mathbf{0.94 \pm 0.05 \pm 0.04}$

V_{ub} via $B^0 \to \pi \ell^+ \nu$

Using the average results from previous slide:

The first uncertainty is experimental, and the second is from theory.

Method	$V_{ub}[10^{-3}]$
LCSR, full q^2	$3.45 \pm 0.11^{+0.67}_{-0.42}$
LCSR, $q^2 < 16\ \mathrm{GeV}^2/c^2$	$3.34 \pm 0.12^{+0.55}_{-0.37}$
HPQCD, full q^2	$3.05 \pm 0.10^{+0.73}_{-0.43}$
HPQCD, $q^2 > 16\ \mathrm{GeV}^2/c^2$	$3.40 \pm 0.20^{+0.59}_{-0.39}$
FNAL, full q^2	$3.73 \pm 0.12^{+0.88}_{-0.52}$
FNAL, $q^2 > 16\ \mathrm{GeV}^2/c^2$	$3.62 \pm 0.22^{+0.63}_{-0.41}$
APE, full q^2	$3.59 \pm 0.11^{+1.11}_{-0.57}$
APE, $q^2 > 16\ \mathrm{GeV}^2/c^2$	$3.72 \pm 0.21^{+1.43}_{-0.66}$

*(for references see HFAG semileptonic web page:
http://www.slac.stanford.edu/xorg/hfag/semi/index.html)*

V_{ub} via $B^0 \to X_u \ell^+ \nu$

This is very challenging due to huge background from $B^0 \to X_c \ell^+ \nu$ decays.

To isolate signal, cuts are required that substantially reduce the acceptance. To calculate the partial rates for these restricted kinematic regions is complicated and requires much theoretical machinery. HFAG considers 5 theoretical frameworks:

Lange et al. (BLNP), PRD 72, 073006 (2005)
Andersen, Gardi (DGE), JHEP 601, 97 (2006)
Gambino et al. (GGOU), JHEP 710, 58 (2007)
Aglietti et al. (ADFR), EPJ C59 (2009); Nucl. Phy. B768, 85 (2007)
Bauer et al. (BLL), PRD64, 113004 (2001)

The Data:

Measurement	Accepted region	$\Delta\mathcal{B}[10^{-4}]$	Notes
CLEO **[1]**	$E_e > 2.1$ GeV	$3.3 \pm 0.2 \pm 0.7$	
BaBar **[2]**	$E_e > 2.0$ GeV, $s_{\rm h}^{\rm max} < 3.5\,{\rm GeV}^2$	$4.4 \pm 0.4 \pm 0.4$	
BaBar **[3]**	$E_e > 2.0$ GeV	$5.7 \pm 0.4 \pm 0.5$	
BELLE **[4]**	$E_e > 1.9$ GeV	$8.5 \pm 0.4 \pm 1.5$	
BaBar **[5]**	$M_X < 1.7\ {\rm GeV}/c^2, q^2 > 8\ {\rm GeV}^2/c^2$	$7.7 \pm 0.7 \pm 0.7$	65% correlation with BaBar M_X analysis
BELLE **[6]**	$M_X < 1.7\ {\rm GeV}/c^2, q^2 > 8\ {\rm GeV}^2/c^2$	$7.4 \pm 0.9 \pm 1.3$	
BaBar **[5]**	$P_+ < 0.66$ GeV	$9.4 \pm 0.9 \pm 0.8$	38% correlation with BaBar $(M_X - q^2)$ analysis
BaBar **[5]**	$M_X < 1.55\ {\rm GeV}/c^2$	$11.7 \pm 0.9 \pm 0.7$	67% correlation with BaBar P_+ analysis
BELLE **[7]**	$p_\ell^* > 1$ GeV/c	$19.6 \pm 1.7 \pm 1.6$	

V_{ub} via $B^0 \to X_u \ell^+ \nu$

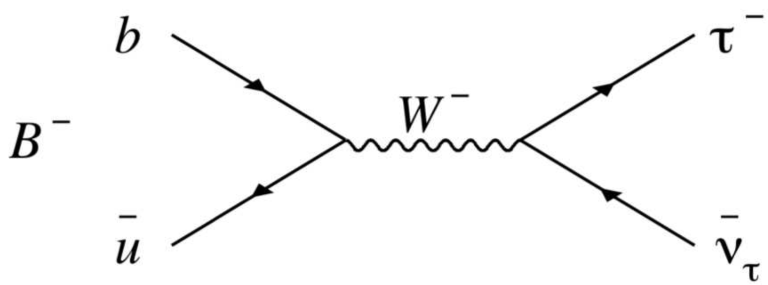
Data vs. Theoretical scheme *(references correspond to previous slide):*

(see also http://www.slac.stanford.edu/xorg/hfag/semi/index.html)

The errors quoted are experimental and theoretical, respectively.

	BLNP	DGE	GGOU	ADFR	BLL
			Input parameters		
scheme	SF	$\overline{MS}$	kinetic	$\overline{MS}$	$1S$
m_b (GeV)	$4.620\ ^{+0.039}_{-0.032}$	4.222 ± 0.051	4.591 ± 0.031	4.222 ± 0.051	4.70 ± 0.03
μ_π^2 (GeV^2)	$0.288\ ^{+0.054}_{-0.074}$	-	0.454 ± 0.038	-	-
Ref.			$\lvert V_{ub}\rvert$ values		
E_e **[1]**	$4.01 \pm 0.47^{+0.34}_{-0.34}$	$3.71 \pm 0.43^{+0.30}_{-0.26}$	$3.82 \pm 0.45^{+0.22}_{-0.39}$	$3.47 \pm 0.41^{+0.21}_{-0.22}$	-
M_X, q^2 **[6]**	$4.40 \pm 0.46^{+0.31}_{-0.19}$	$4.31 \pm 0.45^{+0.24}_{-0.23}$	$4.25 \pm 0.45^{+0.25}_{-0.33}$	$3.94 \pm 0.41^{+0.23}_{-0.24}$	$4.67 \pm 0.49^{+0.34}_{-0.34}$
E_e **[4]**	$4.82 \pm 0.45^{+0.32}_{-0.29}$	$4.67 \pm 0.43^{+0.26}_{-0.25}$	$4.66 \pm 0.43^{+0.19}_{-0.30}$	$4.53 \pm 0.42^{+0.27}_{-0.27}$	-
E_e **[3]**	$4.36 \pm 0.25^{+0.31}_{-0.30}$	$4.16 \pm 0.28^{+0.28}_{-0.25}$	$4.18 \pm 0.24^{+0.20}_{-0.33}$	$3.98 \pm 0.27^{+0.24}_{-0.25}$	-
$E_e, s_{\mathrm{h}}^{\mathrm{max}}$ **[2]**	$4.49 \pm 0.30^{+0.39}_{-0.37}$	$4.16 \pm 0.28^{+0.30}_{-0.30}$	-	$3.87 \pm 0.26^{+0.24}_{-0.24}$	
p_ℓ^* **[7]**	$4.46 \pm 0.27^{+0.24}_{-0.21}$	$4.54 \pm 0.27^{+0.15}_{-0.15}$	$4.48 \pm 0.27^{+0.11}_{-0.15}$	$4.55 \pm 0.30^{+0.27}_{-0.27}$	-
M_X **[5]**	$4.20 \pm 0.20^{+0.29}_{-0.27}$	$4.41 \pm 0.21^{+0.23}_{-0.20}$	$4.12 \pm 0.20^{+0.25}_{-0.28}$	$4.01 \pm 0.19^{+0.25}_{-0.26}$	-
M_X, q^2 **[5]**	$4.49 \pm 0.29^{+0.32}_{-0.29}$	$4.37 \pm 0.29^{+0.24}_{-0.23}$	$4.34 \pm 0.28^{+0.26}_{-0.34}$	$4.12 \pm 0.26^{+0.24}_{-0.25}$	$4.88 \pm 0.32^{+0.36}_{-0.36}$
P_+ **[5]**	$3.83 \pm 0.25^{+0.27}_{-0.25}$	$3.86 \pm 0.25^{+0.35}_{-0.28}$	$3.57 \pm 0.23^{+0.28}_{-0.27}$	$3.53 \pm 0.23^{+0.23}_{-0.23}$	-
M_X, q^2 **[8]**	-	-	-	-	$4.97 \pm 0.39^{+0.37}_{-0.37}$
Average	$4.32 \pm 0.16^{+0.22}_{-0.23}$	$4.46 \pm 0.16^{+0.18}_{-0.17}$	$4.34 \pm 0.16^{+0.15}_{-0.22}$	$4.16 \pm 0.14^{+0.25}_{-0.22}$	$4.87 \pm 0.24^{+0.38}_{-0.38}$

$|V_{ub}|$ via $B^+ \to \tau^+\nu$



Adachi et al., arXiv:0809.3834;
Ikado et al., PRL 97 251802 (1996)

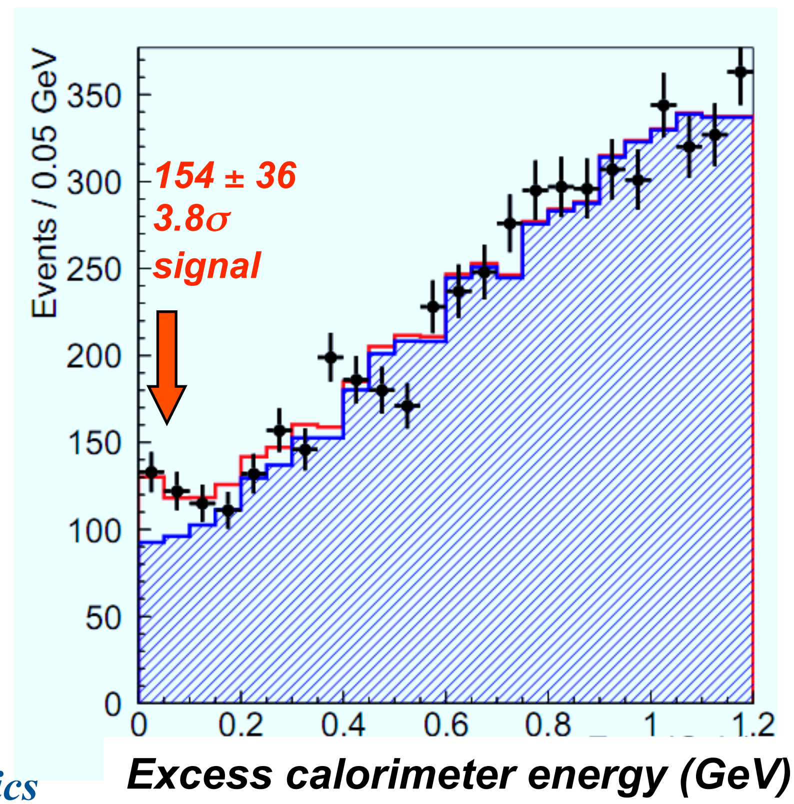
first evidence, 3.5σ

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

- ***Semileptonic tag:***

$B^+ \to D^{(*)0}\ell^+\nu$, $D^{*0} \to D^0\gamma$, $D^0\pi^0$ $D^0 \to K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$
$\tau \to \mu\nu\nu$, $e\nu\nu$, $\pi\nu$ (1 charged track) in signal hemisphere

- *Dominant backgrounds are b→ c ($B\bar{B}$) and continuum*
- *Signal is obtained by fitting the ECL (electromagnetic calorimeter energy) distribution: peak new zero indicates $\tau \to \ell\nu\nu$, $\pi\nu$ decay.*
- *ECL simulation is validated with identically tagged $B^+ \to D^{(*)0}\ell^+\nu$ control sample*



$|V_{ub}|$ via $B^+ \to \tau^+\nu$

Adachi et al., arXiv:0809.3834; Ikado et al., PRL 97 251802 (1996)

$$\mathcal{B}(B^+ \to \tau^+\nu) = \left(1.65\,^{+0.38}_{-0.37}\,^{+0.35}_{-0.37}\right) \times 10^{-4} \quad = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

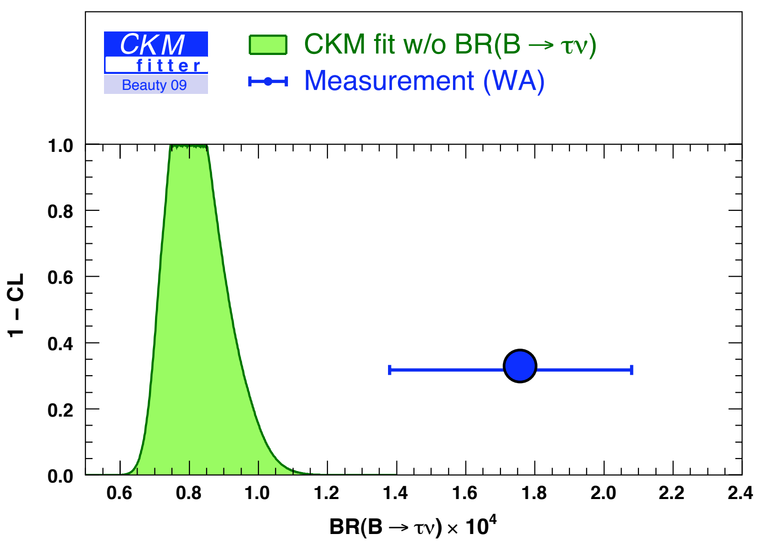
$$\Rightarrow \quad f_B|V_{ub}| = 0.97 \pm 0.11\,^{+0.10}_{-0.11} \text{ MeV}$$

$$\Rightarrow \quad |V_{ub}| = [0.51 \pm 0.08\,(\text{exp.}) \pm 0.06\,(\text{theor.})]\,\%$$

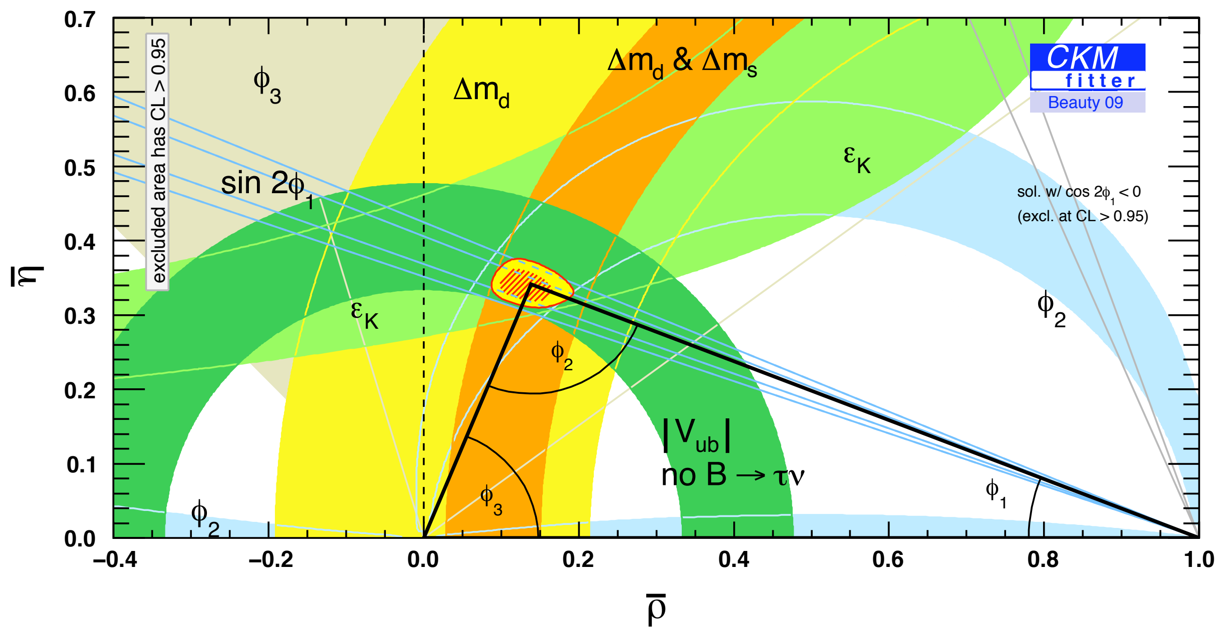
World average:

$\mathcal{B}(B^+ \to \tau^+\nu) = (1.67 \pm 0.39) \times 10^{-4}$

2.4σ discrepancy with the value predicted by the CKM fit:

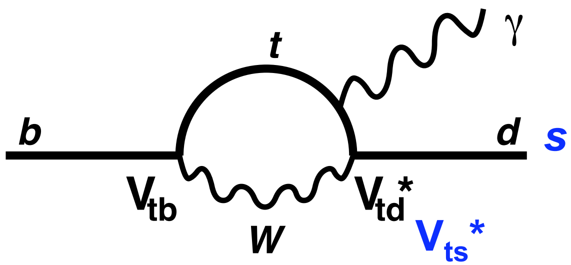


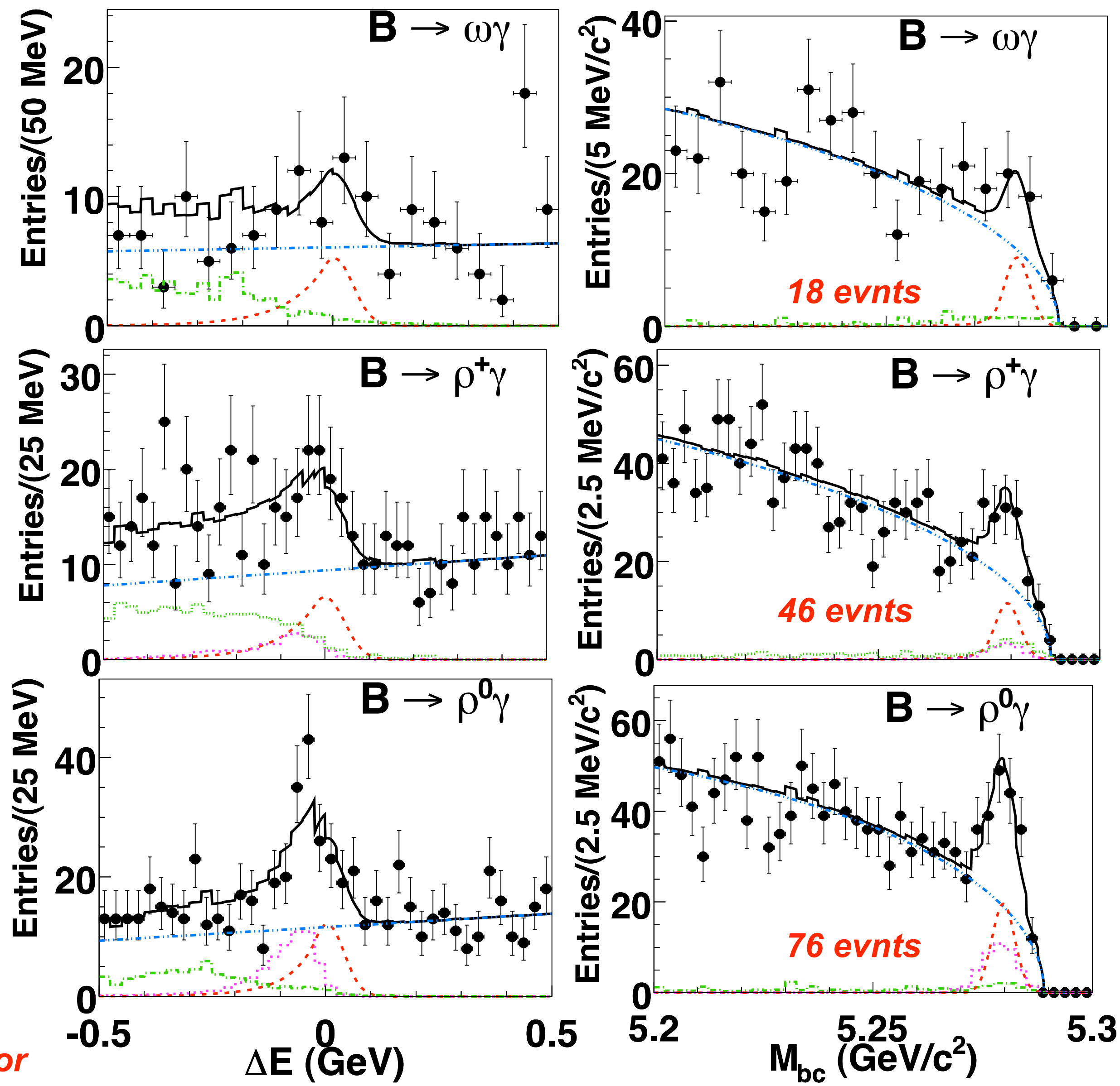
Tension is coming from $|V_{td}|$ measured in B^0-$\bar{B}^0$ mixing, ϕ_1 (β) and ϕ_2 (α):



$|V_{td}/V_{ts}|$ via $B \to \rho\,\gamma$

Taniguchi et al. (Belle), PRL 101, 111801 (2008)
[605 fb^{-1}]





Combined fit assuming

$$\mathcal{B}_{\rho^+\gamma} = 2\left(\frac{\tau_{B^+}}{\tau_{B^0}}\right)\mathcal{B}_{\rho^0\gamma} = 2\left(\frac{\tau_{B^+}}{\tau_{B^0}}\right)\mathcal{B}_{\omega\gamma}$$

gives

$$\mathcal{B}(B\to\rho\gamma) = (1.14 \pm 0.20\,^{+0.10}_{-0.12}) \times 10^{-6}$$

Taking ratio to $\mathcal{B}(B\to K^*\gamma)$ gives

$$|V_{td}/V_{ts}| = 0.195\,^{+0.020}_{-0.019} \pm 0.015$$

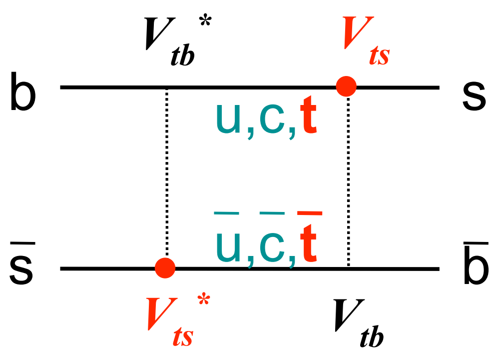
theory error

Ball et al., PRD 75, 054004 (2007)
Ali et al., PLB 595, 323 (2004)

V_{ts} via B_s–$\bar{B}_s$ mixing (CDF)

Most precise value of $|V_{td}/V_{ts}|$ is obtained from measurements of B_s-B_s mixing made by CDF.

Abulencia et al. (CDF), PRL 97, 242003 (2006) ***[1 fb⁻¹]***



$$\Delta m_s = \frac{G_F^2 M_W^2}{6\pi^2} \left|V_{ts}^* V_{tb}\right|^2 \eta_{\rm QCD} S_0(x_t) M_{B_s} f_{B_s}^2 \hat{B}_{B_s}$$

$$\left(\Delta m_d = \frac{G_F^2 M_W^2}{6\pi^2} \left|V_{td}^* V_{tb}\right|^2 \eta_{\rm QCD} S_0(x_t) M_{B_d} f_{B_d}^2 \hat{B}_{B_d}\right)$$

Inami-Lim kinematic function

decay constant

"Bag" parameter

Dalgic et al. (HPQCD), PRD 76, 011501 (2007)

But many differences between hadronic experimental measurements and e^+e^- measurements:

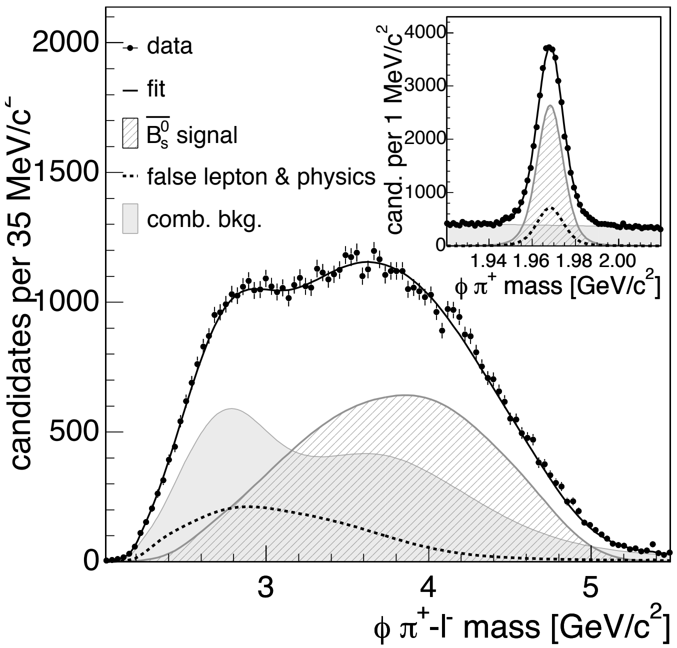
- *many more B's produced, but only a tiny fraction triggered on and reconstructed*
- *much higher background*
- *much poorer π/K discrimination*
- *much poorer flavor tagging*

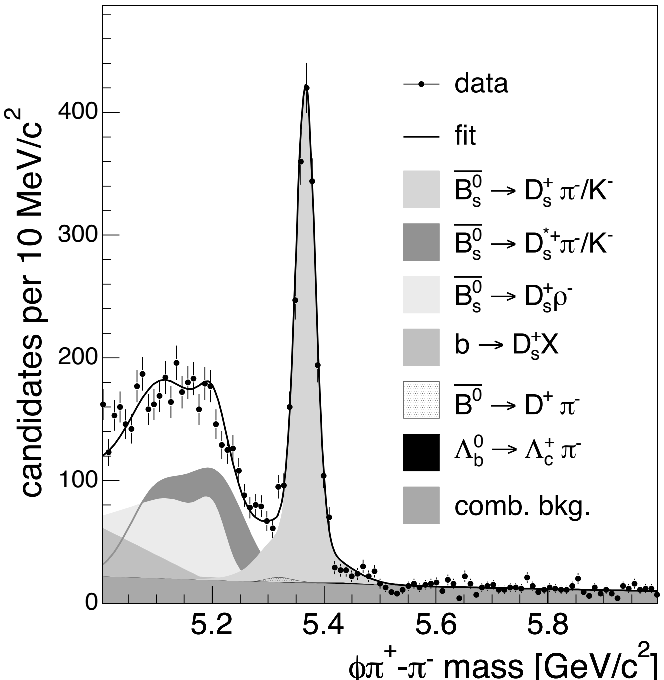
V_{ts} via B_s–$\bar{B}_s$ mixing (CDF)

Abulencia et al. (CDF), PRL 97, 242003 (2006) ***[1 fb^{-1}]***

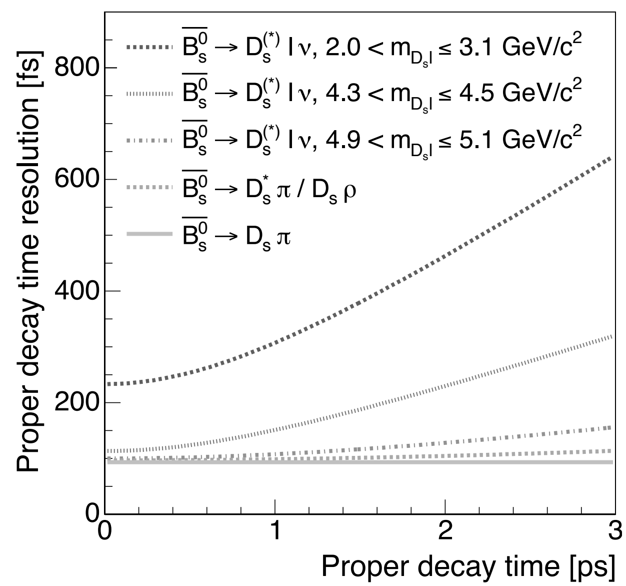
To increase statistics, many modes used:

$B_s \rightarrow D_s^{(*)-}\ell^+\nu$, $B_s \rightarrow D_s^{(*)-}\pi^+$,
$B_s \rightarrow D_s^- \pi^+ \pi^- \pi^+$, $B_s \rightarrow D_s^- \rho^+$,
also $D_s \rightarrow \pi^+ \pi^- \pi^+$





To account for missing π^0's, ν's, scale decay time by MC-determined κ factor. Resulting resolution is nonetheless pretty good:

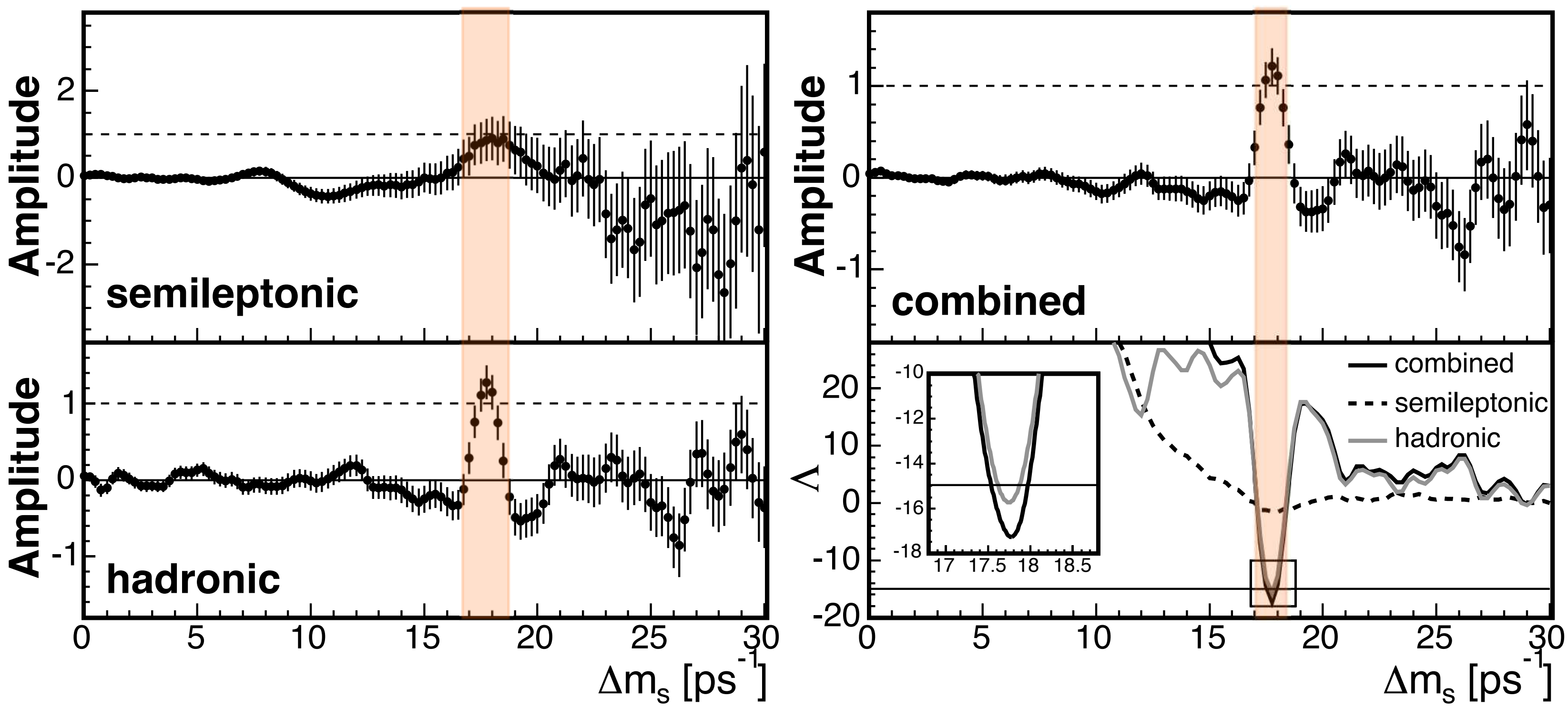


(e^+e^- : $\sigma \sim 1$ ps)

V_{ts} via B_s–$\bar{B}_s$ mixing (CDF)

Abulencia et al. (CDF), PRL 97, 242003 (2006) **[1 fb^{-1}]**

Three methods to measure mixing: ***amplitude scan, likelihood scan, likelihood fit***



From likelihood fit: $\Delta m = (17.77 \pm 0.10 \pm 0.07)\ \mathrm{ps}^{-1}$

$$\Rightarrow \quad \left|\frac{V_{td}}{V_{ts}}\right| = \xi\sqrt{\frac{\Delta m_d\, m_{B_s}}{\Delta m_s\, m_{B^0}}} = 0.2060 \pm 0.0007\,(\mathrm{exp.})\,^{+0.0081}_{-0.0060}(\mathrm{theor.})$$

CDF/D0 also measures $\Delta\Gamma_s$ (mixing) and β_s (CPV)

Abulencia et al. (CDF), PRL 100, 161802 (2008) ***[1.3 fb^{-1}]***
CDF Public Note 9458 (2009) ***[2.8 fb^{-1}]***
CDF Public Note 9787 (2009) ***[2.8 fb^{-1} (CDF) + 2.8 fb^{-1} (D0)]***

METHOD:

Select $B^0 \to J/\psi\phi$ decays. This state can decay to both CP-even and CP-odd eigenstates – it depends on L (orbital angular momentum of J/ψ, ϕ pair). If you could separate the final states into these two categories, and measure the lifetime ($1/\Gamma$) for each category, you would determine $\Delta\Gamma$. But one CAN do this statistically (i.e., not event-by-event): do an unbinned ML fit to the angular distribution (to determine the CP) and decay time (to determine $1/\Gamma$ and $\Delta\Gamma$). Finally: add flavor-tagging information (a probability density function) into the likelihood function; this allows one to also fit for the CPV parameter $\beta_s = \mathrm{Arg}[-V_{tb}V_{ts}/(V_{cb}V_{cs})]$.

Fit parameters:

$$\beta_s, \quad \Delta\Gamma_s = \Gamma_1 - \Gamma_2, \quad \Gamma = (\Gamma_1 + \Gamma_2)/2 = 1/\tau, \quad \Delta m_s,$$

$$f_s, \quad |A_0|^2, \quad |A_\perp|^2, \quad |A_\parallel|^2,$$

$$\delta_\parallel = \mathrm{Arg}[A_\parallel^* A_0], \quad \delta_\perp = \mathrm{Arg}[A_\perp^* A_0]$$

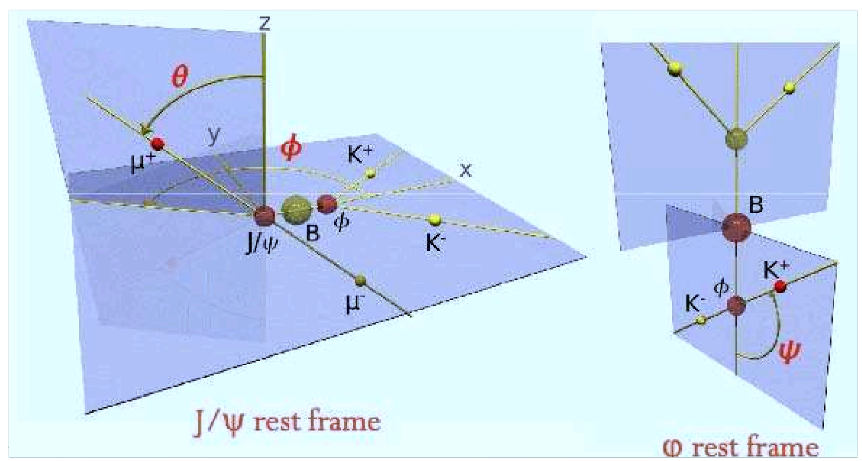
Fit variables:

$$M_{\mathrm{recon}}, \quad \sigma_M, \quad t_{\mathrm{recon}}, \quad \sigma_t,$$

$$\cos\theta_T, \quad \cos\psi_T, \quad \phi_T,$$

$$\xi = \{-1, 0, +1\} \text{ (flavor tag)},$$

$$\mathcal{D} = \text{dilution factor}$$



CDF measurement of $\Delta\Gamma_s$, β_s

Probability density function (PDF) for angles, decay time:

$$\begin{aligned}
P(t,\theta_T,\psi_T,\phi_T) = {} & |A_0|^2\; 2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T) \times \mathcal{T}_+ \\
& + |A_\parallel|^2\; \sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T) \times \mathcal{T}_+ \\
& + |A_\perp|^2\; \sin^2\psi_T\sin^2\theta_T \times \mathcal{T}_- \\
& - |A_\parallel||A_\perp|\sin^2\psi_T\sin(2\theta_T)\sin\phi_T \times \mathcal{U} \\
& + |A_\parallel||A_0|\cos\delta_\parallel\left(\frac{1}{\sqrt{2}}\right)\sin(2\psi_T)\sin^2\theta_T\sin(2\phi_T) \times \mathcal{T}_+ \\
& + |A_\perp||A_0|\left(\frac{1}{\sqrt{2}}\right)\sin(2\psi_T)\sin(2\theta_T)\cos\phi_T \times \mathcal{V}
\end{aligned}$$

$$\begin{aligned}
\mathcal{T}_+ &= e^{-\Gamma t} \times \left[\cosh(\Delta\Gamma t/2) - \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \sin(2\beta_s)\sin(\Delta m_s t)\right] \\
\mathcal{T}_- &= e^{-\Gamma t} \times \left[\cosh(\Delta\Gamma t/2) + \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \pm \sin(2\beta_s)\sin(\Delta m_s t)\right] \\
\mathcal{U} &= \pm e^{-\Gamma t} \times \left[\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t)\right. \\
&\qquad \left. \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma_s t/2)\right] \\
\mathcal{V} &= \pm e^{-\Gamma t} \times \left[\sin\delta_\perp\cos(\Delta m_s t) - \cos\delta_\perp\cos(2\beta_s)\sin(\Delta m_s t)\right. \\
&\qquad \left. \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma_s t/2)\right]
\end{aligned}$$

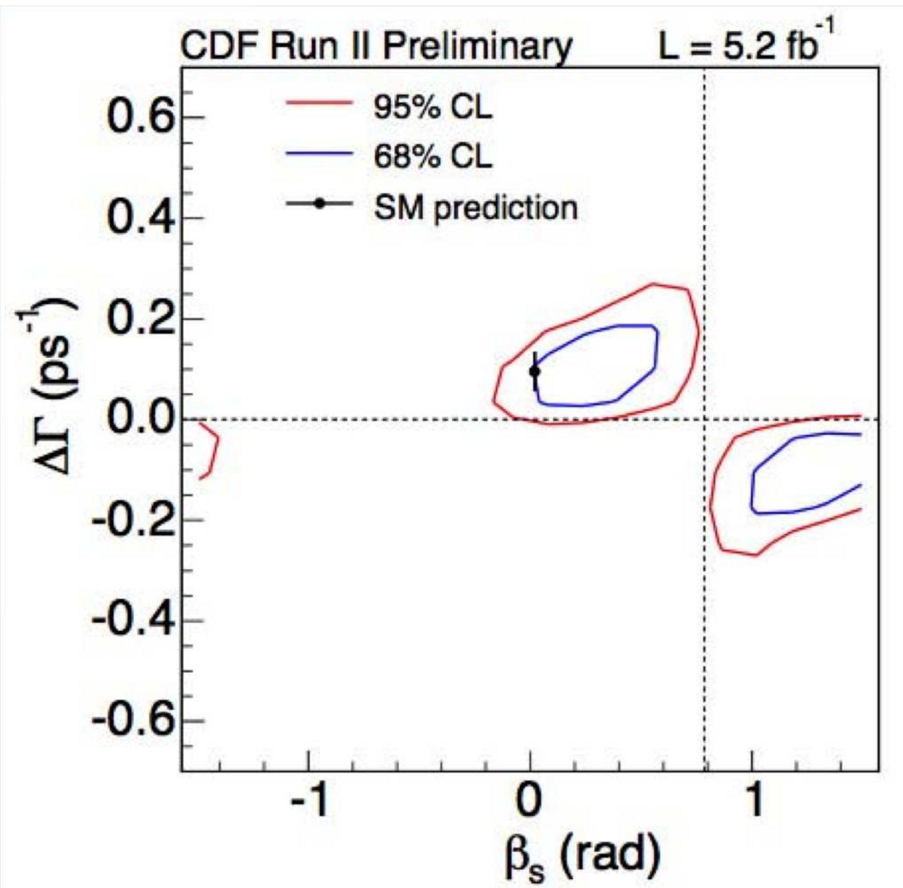
changes for $B^0/\bar{B}^0$ tags

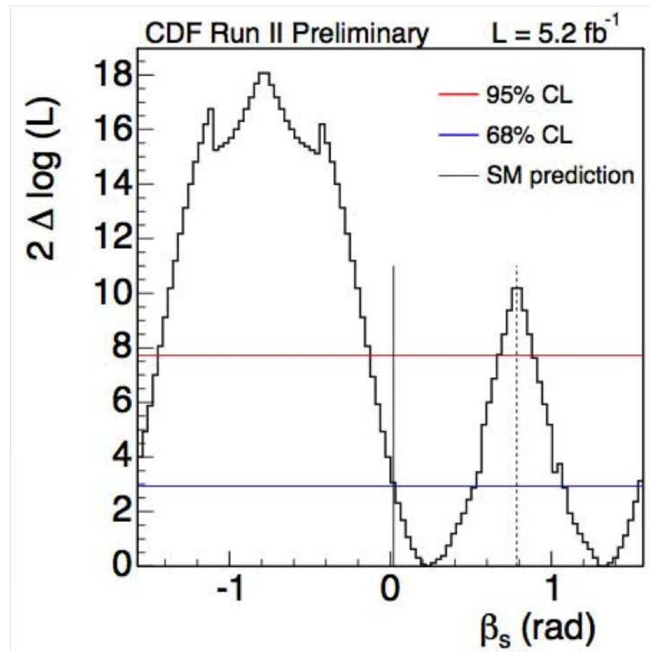
CDF measurement of $\Delta\Gamma_s$, β_s

Result of fit:
(FPCP 2010, 5.2 fb^{-1})

$$\begin{aligned} \tau_s &= 1.53 \pm 0.025\ (\text{stat.})\ \pm 0.012\ (\text{syst.})\ \text{ps} \\ \Delta\Gamma &= 0.075 \pm 0.035\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ ps^{-1} \\ |A_{\parallel}(0)|^2 &= 0.231 \pm 0.014\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\ |A_0(0)|^2 &= 0.524 \pm 0.013\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\ \phi_{\perp} &= 2.95 \pm 0.64\ (\text{stat}) \pm 0.07\ (\text{syst.}) \end{aligned}$$

2σ above PDG value: 1.47 ± 0.027

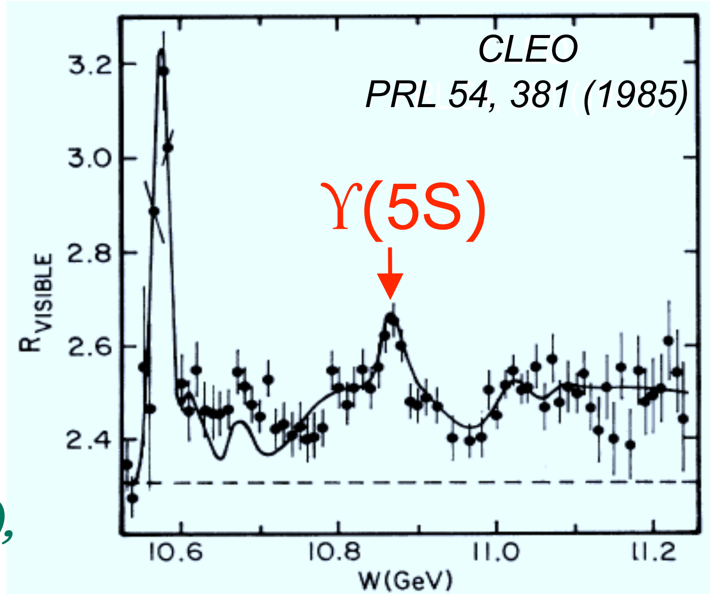




Nicely consistent with SM! (0.8-1.0σ)

Belle has also studied B_s decays with Υ(5S) data

$e^+e^- \to \Upsilon(5S) \to B^0B^0,\ B^{0*}B^0,\ B^0B^{0*}, B^{0*}B^{0*},$
$B^+B^-,\ B^{+*}B^-,\ B^+B^{-*},\ B^{+*}B^{-*},$
$B^0B^0\pi,\ B^{0*}B^0\pi,\ B^0B^{0*}\pi, B^{0*}B^{0*}\pi,$
$B^+B^-\pi,\ B^{+*}B^-\pi,\ B^+B^{-*}\pi,\ B^{+*}B^{-*}\pi,$
$B^0B^0\pi\pi,\ B^+B^-\pi\pi,$
(19 ± 3)% → $B_sB_s,\ B_s^*B_s,\ B_sB_s^*,\ B_s^*B_s^*$
$\Upsilon(1S)\pi\pi,\ \Upsilon(2S)\pi\pi,\ \Upsilon(3S)\pi\pi$



To move from Υ(4S)→Υ(5S) (√s=10579 → √s=10870), increase beam energies by 2.7%

Belle Υ(5S) data:

June 2005:	1.86 fb^{-1}	fall 2008:	28.2 fb^{-1}
June 2006:	21.7 fb^{-1}	spring 2009:	53.2 fb^{-1}
Dec. 2007:	7.9 fb^{-1}	fall 2009:	23.7 fb^{-1}

TOTAL: 129 fb^{-1}

Other (world) Υ(5S) data:

1985: CLEO,CUSB:	0.1 fb^{-1}
2003: CLEO III:	0.42 fb^{-1}
2008: BaBar:	0.7 fb^{-1}

$N = (129\ fb^{-1}) \times (0.302\ nb) \times (0.193) \times 2 =$ **15 x 10^6 B_s decays**

Belle sample — $\sigma[e^+e^- \to \Upsilon(5S)]$ — $\mathcal{B}[\Upsilon(5S) \to B_s^{(*)}B_s^{(*)}]$

Belle B_s results

$\Upsilon(5S) \to D_s^+ X, D^0 X$ (inclusive) $J/\psi X$ (inclusive)	1.86 fb^{-1}	*Drutskoy et al., PRL 98, 052001 (2007)*
$B_s \to D_s^{(*)} \pi^+, D_s^{(*)} \rho^+$ $J/\psi\, \phi, J/\psi\, \eta$	1.86 fb^{-1}	*Drutskoy et al., PRD 76, 012002 (2007)*
$B_s \to \phi\, \gamma,\ \gamma\gamma$ (upper limit)	23.6 fb^{-1}	*Wicht et al., PRL 100, 121801 (2008)*
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-, \Upsilon(1S)K^+K^-,$ $\Upsilon(2S)\pi^+\pi^-, \Upsilon(3S)\pi^+\pi^-$	21.7 fb^{-1}	*Chen et al., PRL 100, 112001 (2008)*
$B_s \to D_s \pi^+, D_s K^+$	23.6 fb^{-1}	*Louvot et al., PRL 102, 021801 (2009)*
$B_s \to D_s^{*}\pi^+,$ $D_s^{(*)}\rho^+$ (with polarization)	23.6 fb^{-1}	*Louvot (EPF-Lausanne), submitted to PRD*
$B_s \to K^+K^-, K_S K_S, K^-\pi^+, \pi^+\pi^-$	23.6 fb^{-1}	*Peng (NTU-Taiwan), ~submitted to PRL*
$B_s \to J/\psi\eta, J/\psi\eta'$	23.6 fb^{-1}	*Li (Hawaii), presented at BEAUTY'09*
$B_s \to D_s^{(*)} D_s^{(*)}$	23.6 fb^{-1}	*Esen (Cincinnati), submitted to PRL*
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-, \Upsilon(2/3S)\pi^+\pi^-$	8.2 fb^{-1}	*Chen (NTU-Taiwan), presented at ICHEP'08*
$\Upsilon(5S) \to BB\pi, BB\pi\pi$	23.6 fb^{-1}	*Drutskoy (Cincinnati), submitted to PRD*

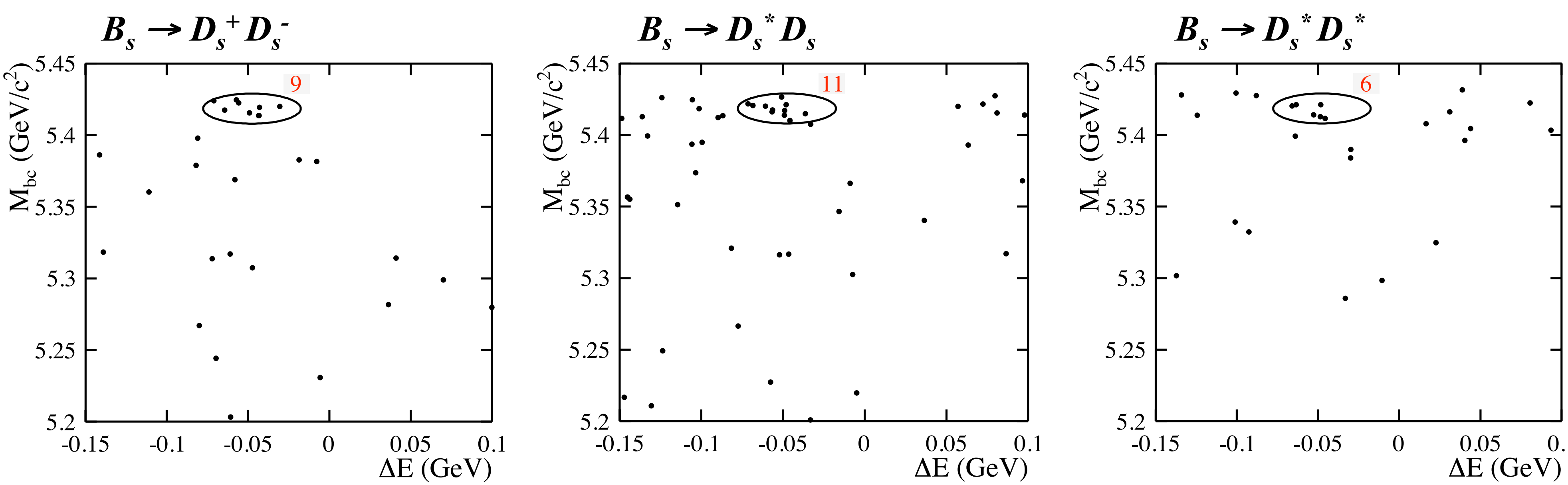
Measuring $\Delta\Gamma_s$ with $B_s \to D_s^{(*)} D_s^{(*)}$

Esen, Schwartz et al. (Belle), arXiv:1005.5177, submitted to PRL ***[23 fb^{-1}]***

The partial width of (Cabibbo-favored) $B_s \to D_s^{*+} D_s^{*-}$ is expected to dominate the decay width difference between B_s-B_s mass eigenstates. *Aleksan et al., PLB 316, 567 (1993)*

⇒ ***Measuring the branching fraction constrains $\Delta\Gamma_s / \Gamma_s$, which is an important mixing parameter in the B_s system. Our results are competitive with CDF/D0.***

23.6 fb^{-1}: *We reconstruct $D_s^{*+} \to D_s^+ \gamma$. To maximize sensitivity, reconstruct 6 D_s final states:* ***$\phi\pi^+$, $K^{*0} K^+$, $K_S K^+$, $\phi\rho^+$, $K_S K^{*+}$, $K^{*0} K^{*+}$***



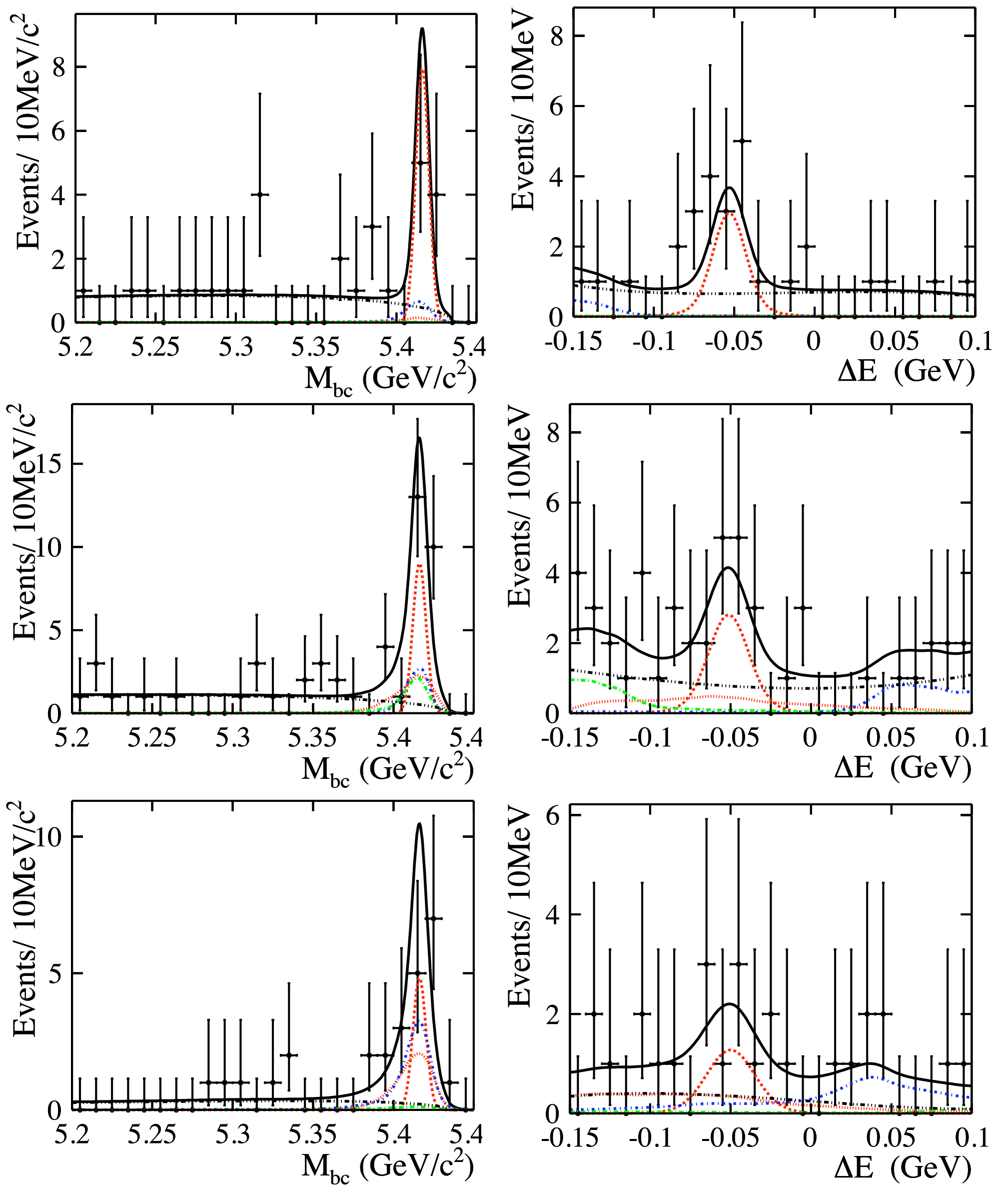
Measuring $\Delta\Gamma_s$ with $B_s \to D_s^{(*)} D_s^{(*)}$

Two-dimensional fit for event yields:

$B_s \to D_s^+ D_s^-$

$B_s \to D_s^* D_s$

$B_s \to D_s^* D_s^*$



$N_{signal} = 22.5 ^{+4.7}_{-3.9}$

$\mathcal{B} = (\, 6.9 \pm 1.5 \pm 1.9)\%$

$\Delta\Gamma_s / \Gamma_s = 2\mathcal{B}/(1-\mathcal{B})$

$= 0.147 ^{+0.04}_{-0.03} \pm 0.04$

Compare to 2010 PDG:

$\Delta\Gamma_s / \Gamma_s = 0.092 ^{+0.051}_{-0.054}$

The Future: KEKB+Belle → SuperKEKB+Belle II

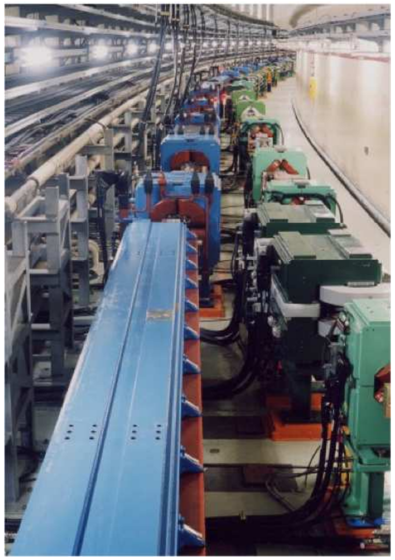
Why do this? Why is a flavor factory so important?

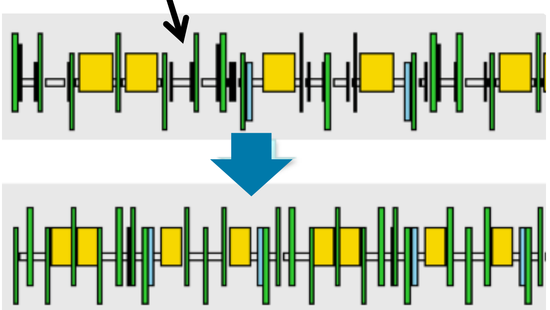
- *A flavor factory studies processes that occur at 1-loop in the SM but may be O(1) in NP: FCNC, neutral meson mixing, CP violation. These loops probe energy scales that cannot be accessed directly (even at the LHC).*
- *Current experimental bounds NP scale is 10-100 TeV; thus, if the LHC finds NP at O(1) TeV, it must have a nontrivial flavor/phase structure*
- *Even if no new sources of CPV or flavor violation, current SM couplings are sufficient to provide sensitivity to new particles at a super flavor factory*
- *SM CP violation is insufficient to account for baryogenesis of matter-dominated universe; must be other sources of CPV*
- *If supersymmetry is found at the LHC, a crucial question will be: how is it broken. By studying flavor couplings, a flavor factory can address this.*

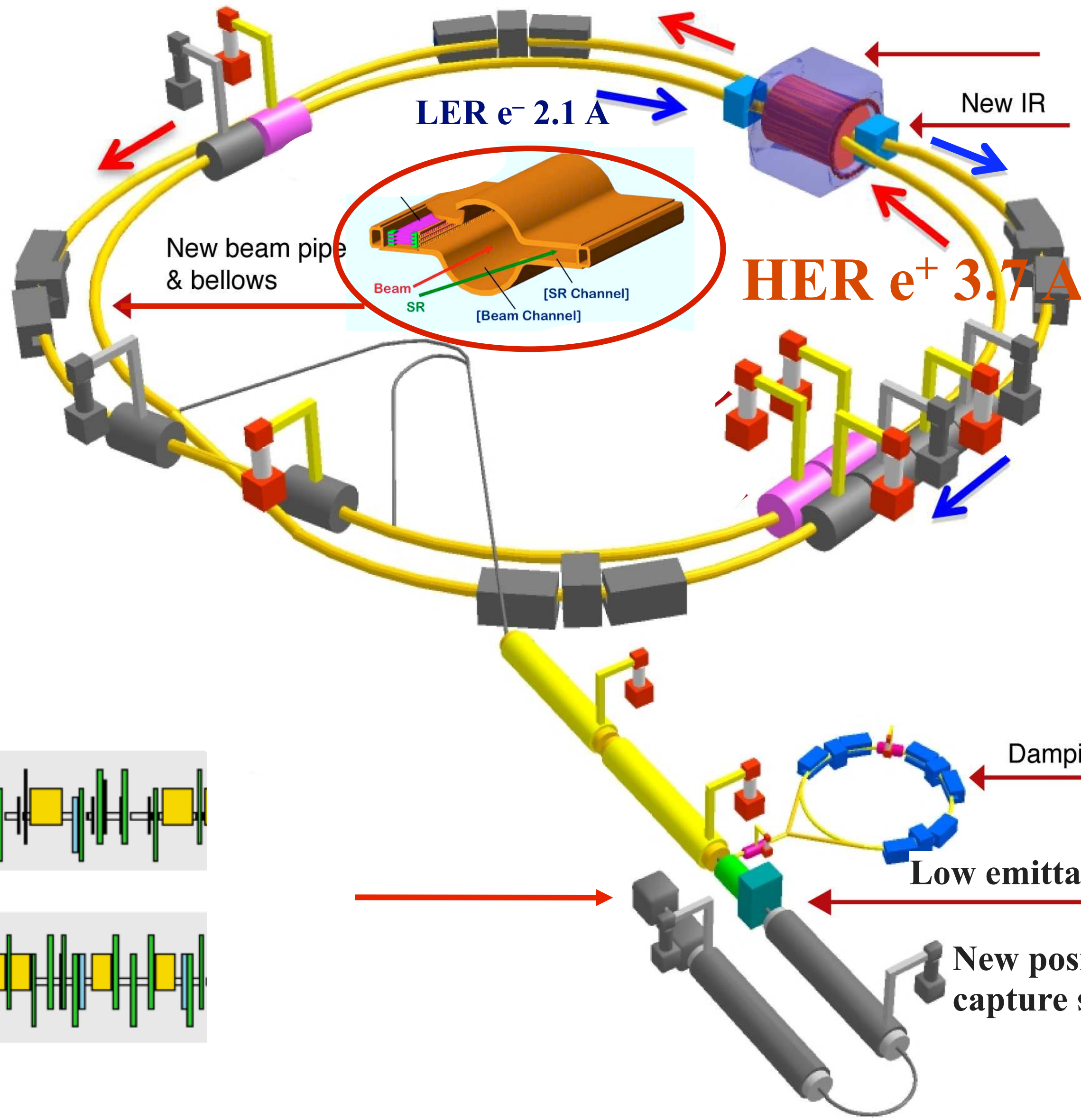
A (super) flavor factory searches for NP by phases, CP asymmetries, inclusive decay processes, rare leptonic decays, absolute branching fractions. There is a wide range of observables. These are complementary to the LHC Atlas and CMS experiments, which will search for NP via direct new particle production at high-p_T.

Project was just approved!
http://kek.jp/intra-e/press/2010/KEKBupgrade.html

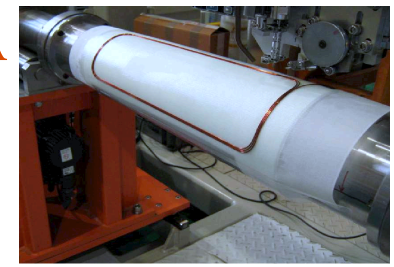
KEKB → SuperKEKB (nano-beam)







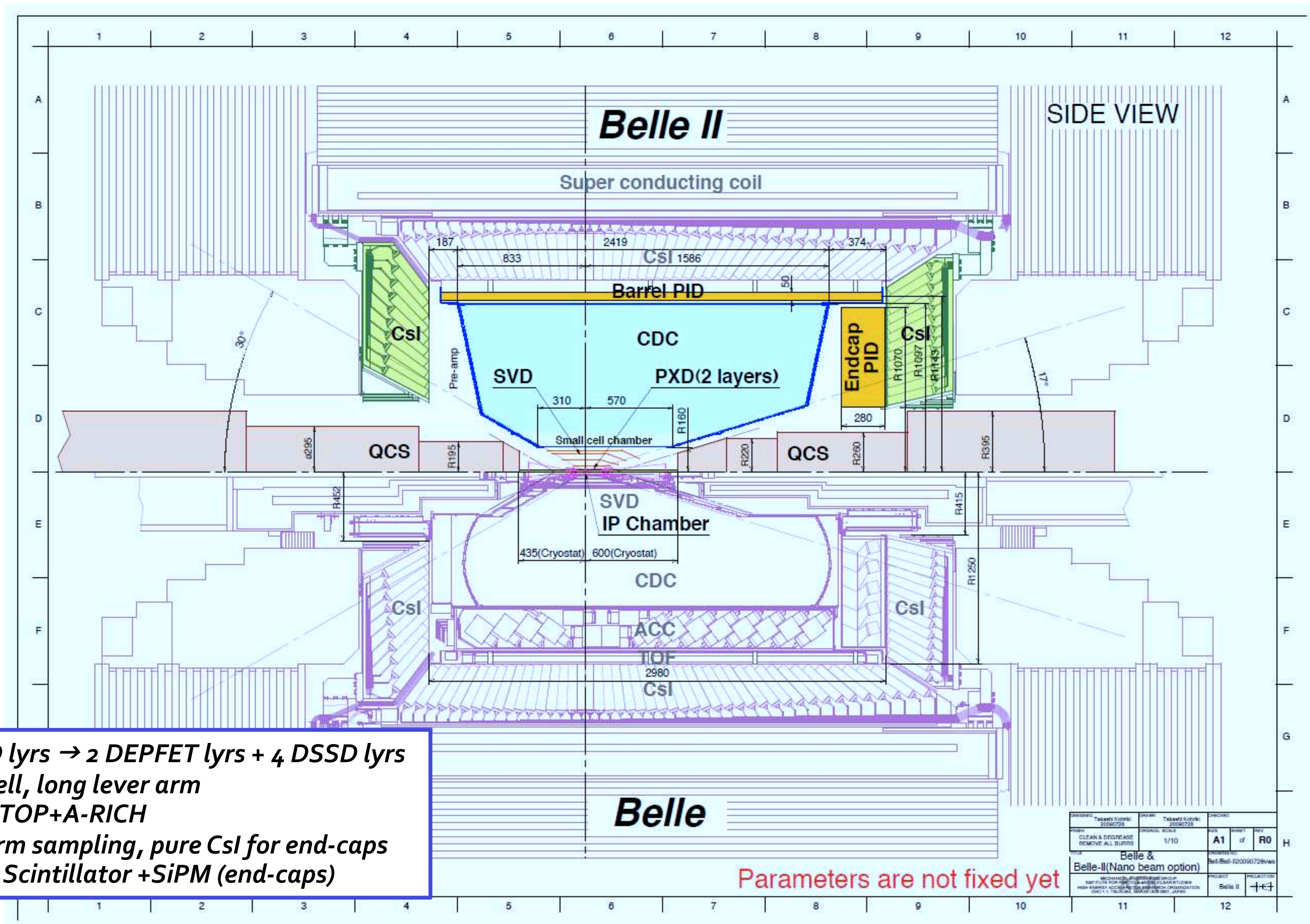
Two separate focusing quads/each 2 beams closer to IP; Superconducting / permanent magnets



Low emittance positrons

New positron target / capture section

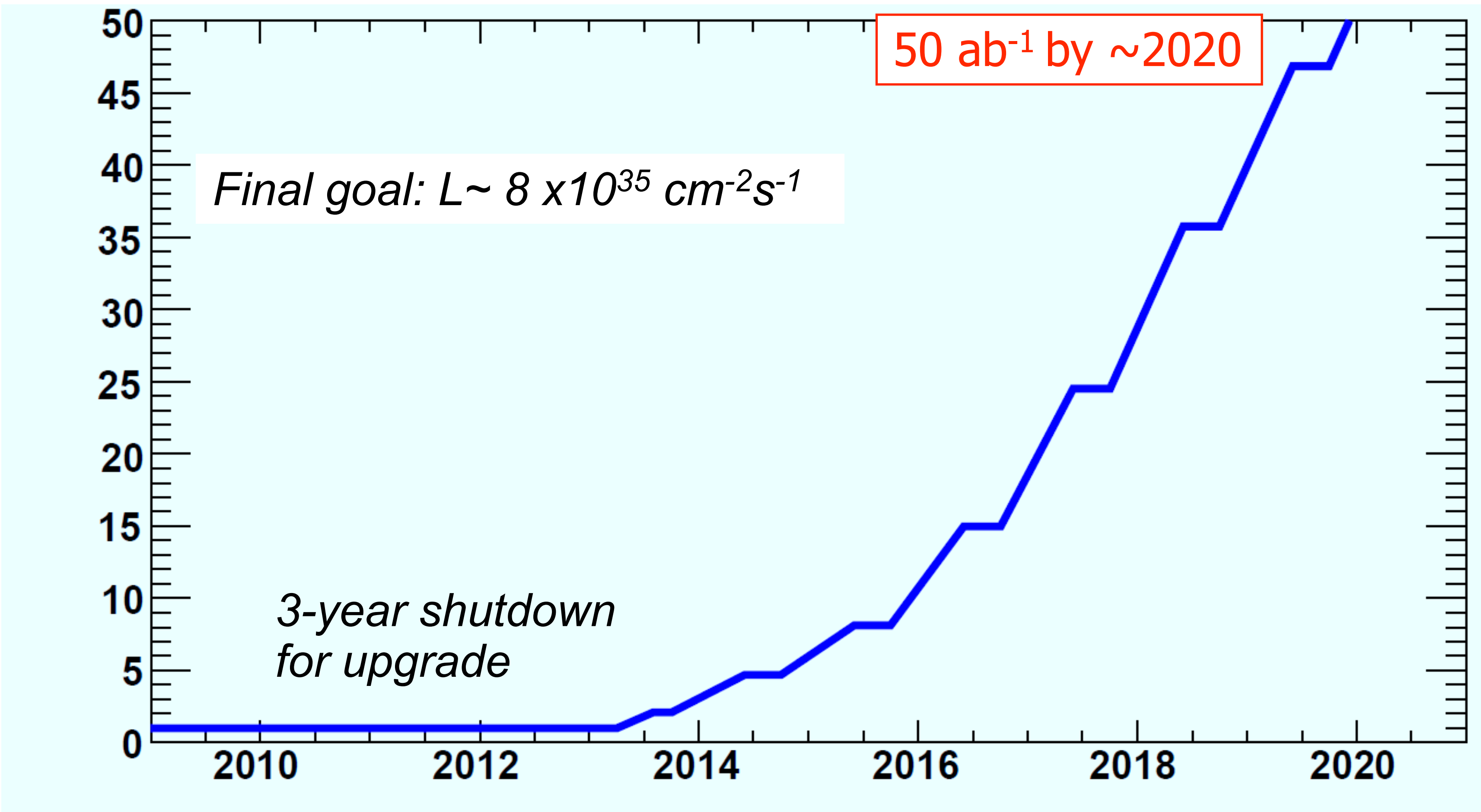
Belle II compared to Belle:



SVD: *4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs*
CDC: *small cell, long lever arm*
ACC+TOF → *TOP+A-RICH*
ECL: *waveform sampling, pure CsI for end-caps*
KLM: **RPC** → *Scintillator +SiPM (end-caps)*

Long-term plan:

- *3 year shut-down for upgrade of the accelerator and detector*
- *Start machine operation in 2014*



Direct CP Violation

$$
\begin{aligned}
\mathcal{A}_t &= |A_t|\, e^{i\phi_t}\, e^{i\delta_t} \\
\mathcal{A}_p &= |A_p|\, e^{i\phi_p}\, e^{i\delta_p}
\end{aligned}
$$

$$
\begin{aligned}
\Gamma(B \to f) &= |\mathcal{A}_t + \mathcal{A}_p|^2 \\
&= |A_t|^2 + |A_p|^2 + 4|A_t||A_p| \cos(\Delta\phi + \Delta\delta),
\end{aligned}
$$

$$
\begin{pmatrix}
\Delta\phi & = & \phi_t - \phi_p \\
\Delta\delta & = & \delta_t - \delta_p
\end{pmatrix}
$$

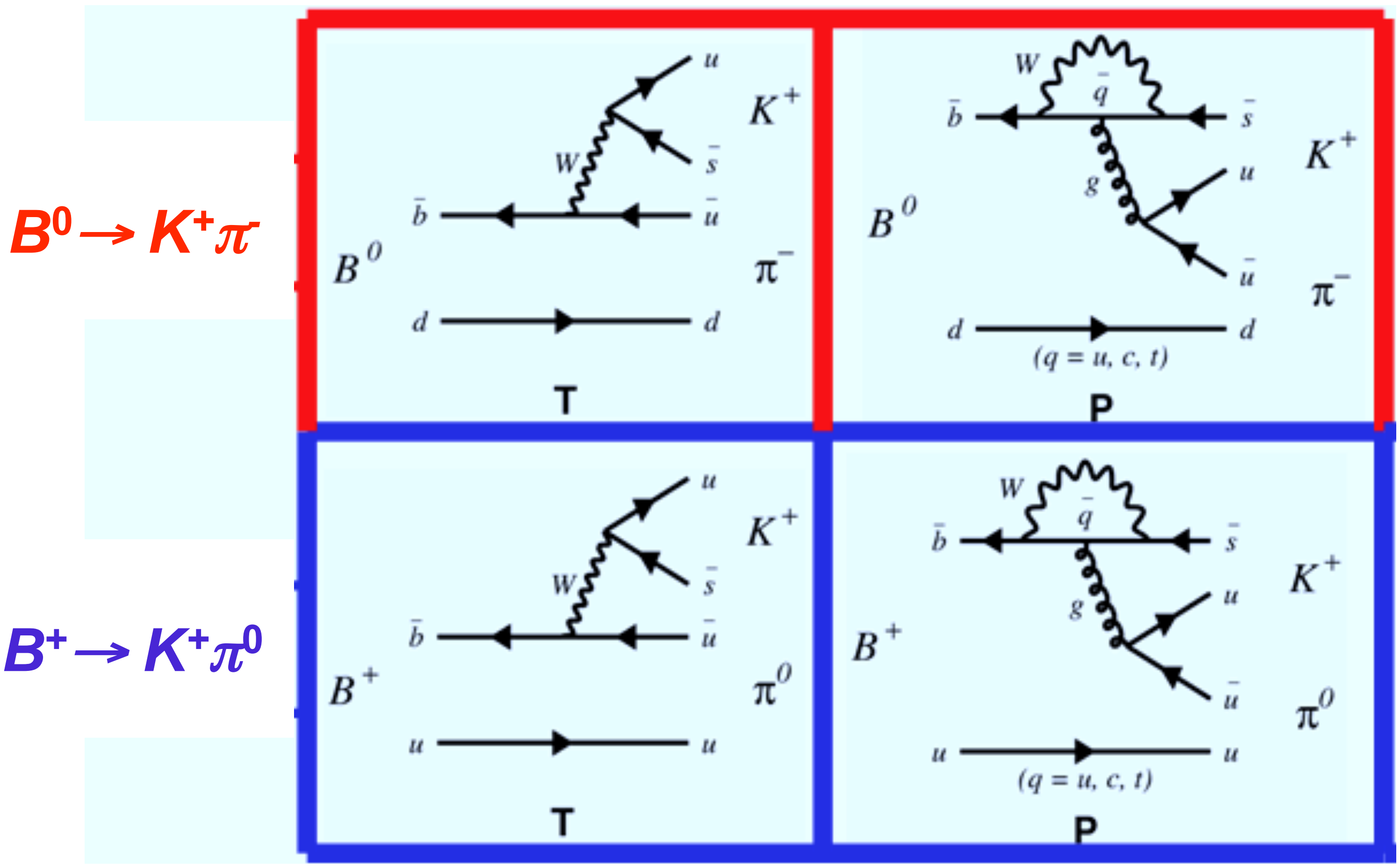
$$
\begin{aligned}
\bar{\mathcal{A}}_t &= |A_t|\, e^{-i\phi_t}\, e^{i\delta_t} \\
\bar{\mathcal{A}}_p &= |A_p|\, e^{-i\phi_p}\, e^{i\delta_p}
\end{aligned}
$$

$$
\begin{aligned}
\Gamma(\bar{B} \to \bar{f}) &= \left|\bar{\mathcal{A}}_t + \bar{\mathcal{A}}_p\right|^2 \\
&= |A_t|^2 + |A_p|^2 + 4|A_t||A_p| \cos(-\Delta\phi + \Delta\delta),
\end{aligned}
$$

$$
\Rightarrow \boxed{A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} \propto \sin\Delta\phi \, \sin\Delta\delta}
$$

Measuring direct CPV with $B \to K\pi$

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} \propto \sin\Delta\phi \sin\Delta\delta$$

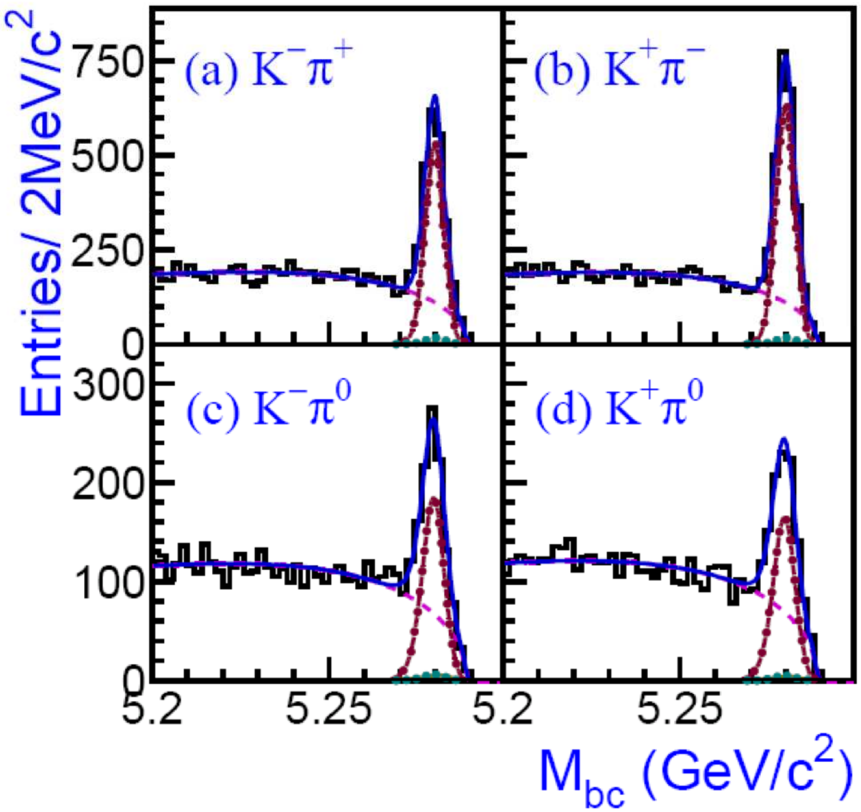


diagrams identical except for "spectator" quark

⇒ strong and weak phases are the same, A_{CP} should be the same…

Measuring direct CPV with $B \to K\pi$

But they are not (?!) ***(Belle, Nature 452, p332, 2008):***



$B^0 \to K^+\pi^-$

$A_{CP}(K^+\pi^-)$ =

-0.094 ± 0.020 (Belle)

-0.107 ± 0.017 (Babar)

-0.086 ± 0.025 (CDF) → LHCb

$B^+ \to K^+\pi^0$

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

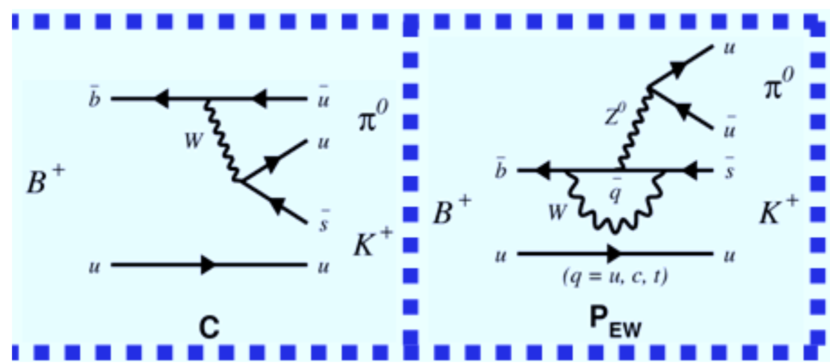
+0.07 ± 0.03 (Belle)

+0.030 ± 0.040 (Babar)

$A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$ = -0.147 ± 0.028

(5.3σ difference from zero)

Supersymmetry?



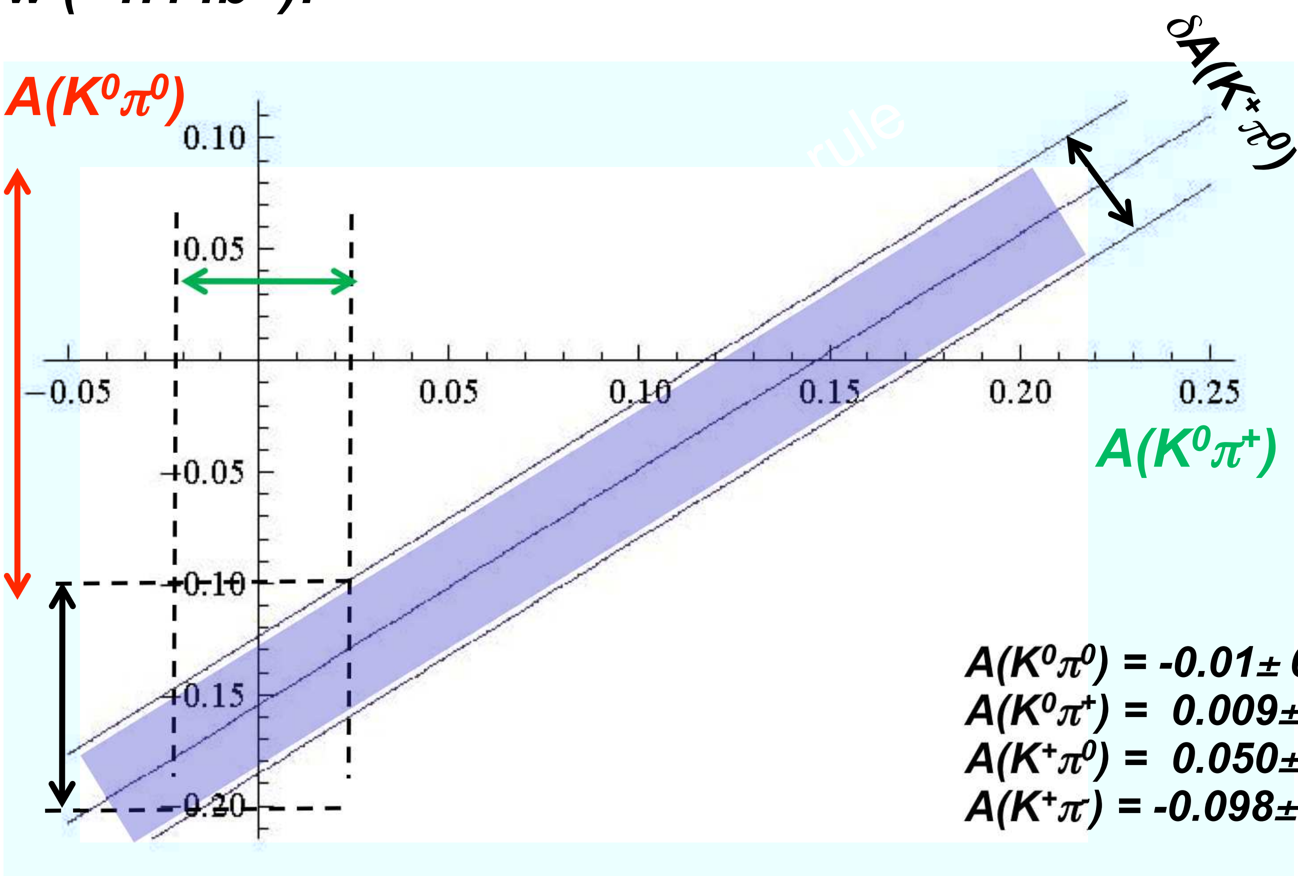
Measuring direct CPV at Belle

``Model independent" sum rule for all four modes:

Gronau, PLB 627, 82 (2005); Atwood & Soni, PRD 58, 036005 (1998):

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

B factories now (~1.4 fb^{-1}):

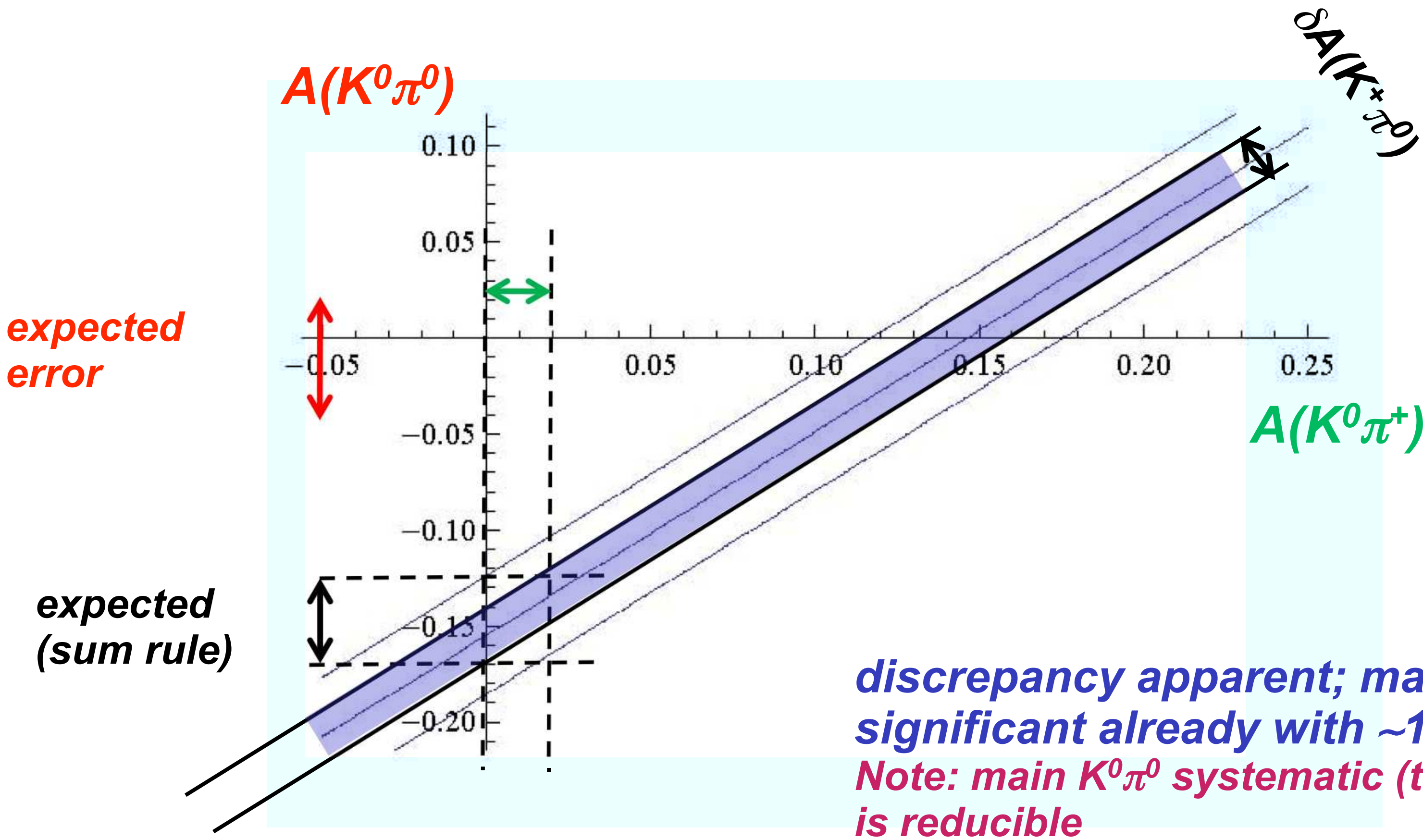


$A(K^0\pi^0)$ = -0.01± 0.10
$A(K^0\pi^+)$ = 0.009± 0.025
$A(K^+\pi^0)$ = 0.050± 0.025
$A(K^+\pi^-)$ = -0.098± 0.012

Measuring direct CPV at Belle II

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

B factory at 50 fb^{-1}, with today's central values:

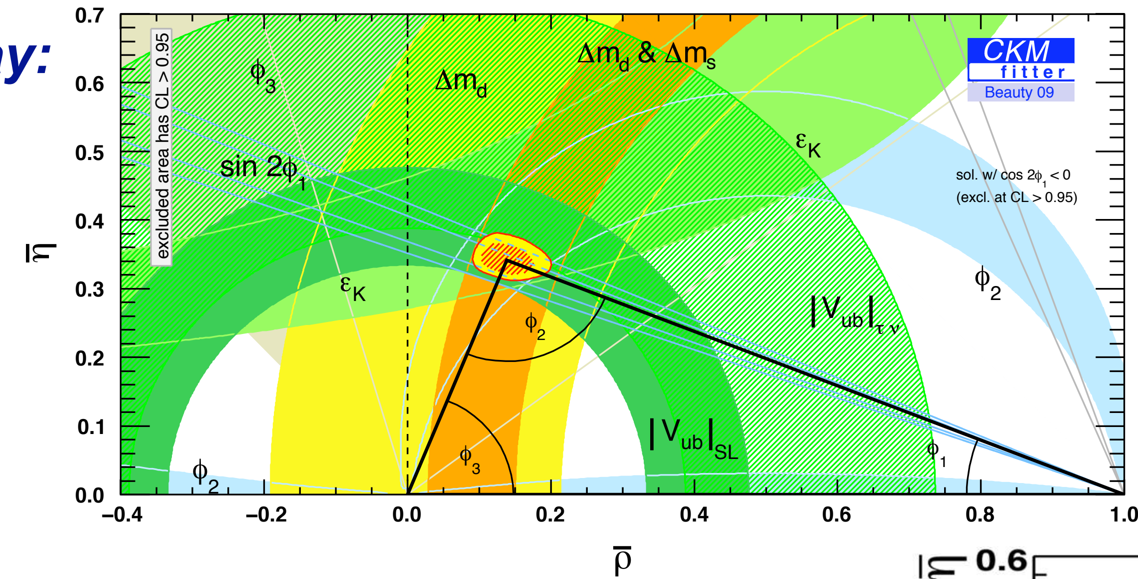


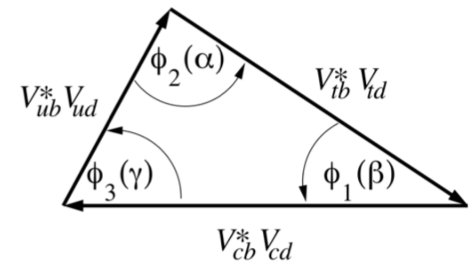
discrepancy apparent; may be significant already with ~10 ab^{-1}

Note: main $K^0\pi^0$ systematic (tag-side interference) is reducible

Summary of Belle II/Super-B (Italy)

Today:





Future flavor factory (75 fb^{-1}):