New physics searches at B-factories

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on behalf of the BaBar collaboration

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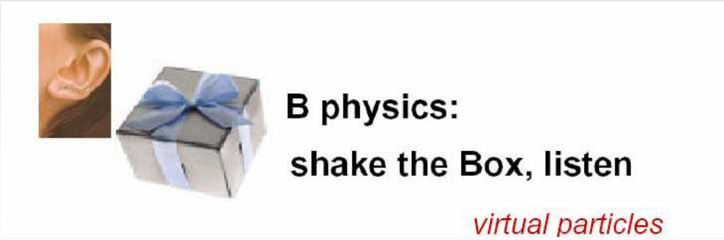
Outline

- ✓ New Physics searches: how to
- ✓ B-factories and datasets
- ✓ kinematics constraints and rare decay search
- ✓ Belle and BaBar results on
  - $B^+ \rightarrow \tau^+ \nu$
  - $B^{0(+)} \rightarrow K^{(*)0(+)} l^+ l^-$
  - $B^{0(+)} \rightarrow K^{*0(+)} \nu \bar{\nu}$
  - $B^0_s \rightarrow \varphi\gamma, \gamma\gamma$
- ✓ Conclusions

Rare decays and New Physics

- ✓ 2 complementary approaches to detect New Physics (NP) effects



- ✓ "shake the box" where..
  - NP effects are of the same order of SM contributions
  - physical quantities are predicted with small theoretical uncertainties in the SM

$\rightarrow$ RARE DECAY Branching Fractions, ASYMMETRIES (A_{CP}, A_{FB})

- ✓ what can be learnt :
  - claim evidence for NP or constraint NP parameters if measurements are inconsistent with the SM expectation

decay	$O(BR_{SM})$
$B^+ \rightarrow \tau^+ \nu$	10^{-4}
$B^{0(+)} \rightarrow K^{*0(+)} l^+ l^-$	10^{-6}
$B^{0(+)} \rightarrow K^{*0(+)} \nu \bar{\nu}$	10^{-6}
$B_s^0 \rightarrow \varphi \gamma$	10^{-5}

Belle and BaBar : detectors and datasets

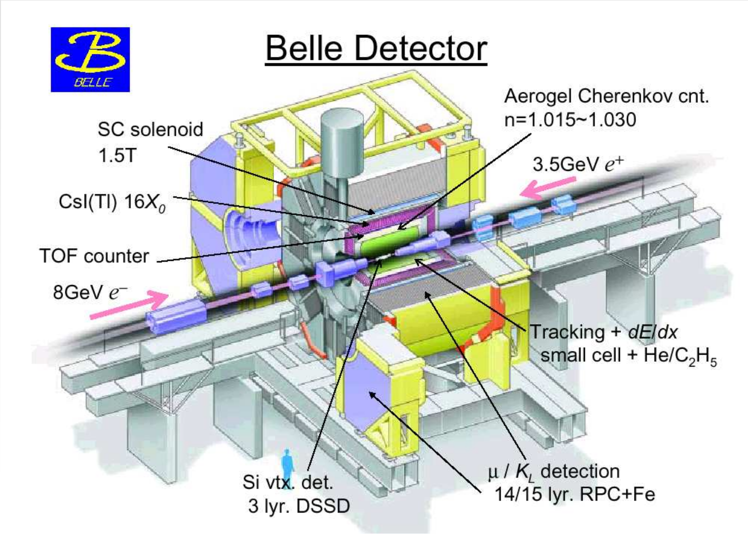
Belle @ KEK B-factory

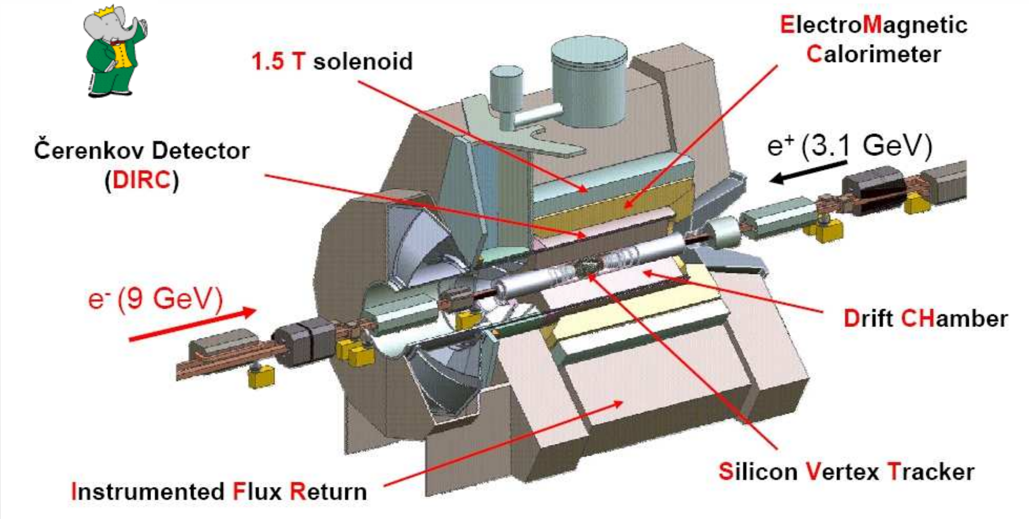
- ✓ E_{e+} = 3.5 GeV, E_{e-} = 8.0 GeV
- ✓ Y(4S) boost : $\beta\gamma$=0.425
- ✓ Data samples:

~ 900 fb^{-1} @ Y(4S)→ 980M $B\bar{B}$

~ 23.6 fb^{-1} @ Y(5S)→ 2.8M $B_s\bar{B}_s$

(data taking ongoin)





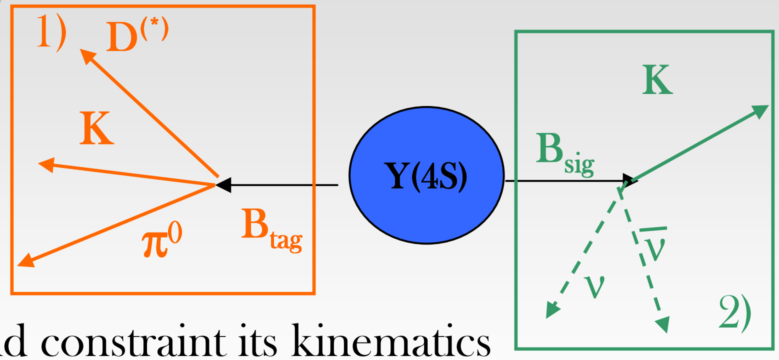
BaBar @ PEPII B-factory

- ✓ E_{e+} = 3.1 GeV,
  E_{e-} = 9.0 GeV
- ✓ Y(4S) boost : $\beta\gamma$=0.56
- ✓ Data sample @ Y(4S) :

~ 430 fb^{-1} → 471M $B\bar{B}$

Ingredients to rare decay searches

How to Exploit the kinematics



✓ RECOIL ANALYSIS:

- fully reconstruct one B in the event in semileptonic or hadronic modes (B_{tag}) and constraint its kinematics
- search in the rest of the event for the signal signature (B_{sig})

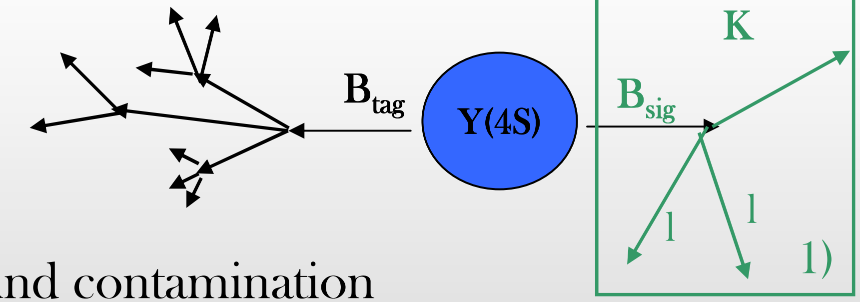
→ used when there are undetectable particles in the signal side; efficiency $O(10^{-2} \div 10^{-3})$, very clean sample

$$m_{ES} \equiv \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$

$$\Delta E \equiv E^{*}_{B} - \sqrt{s}/2$$

✓ EXCLUSIVE ANALYSIS:

- reconstruct the all the B_{sig} and decay products and constraint its kinematics



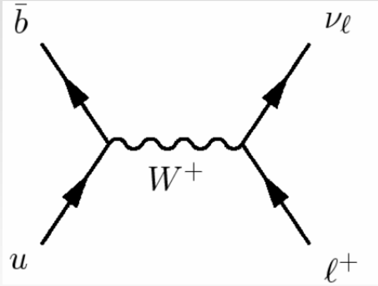
→ higher efficiency and background contamination

$B^+ \rightarrow \tau^+ \nu$

$B^+ \to \tau^+ \nu$ theoretical overview

- SM predictions:

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



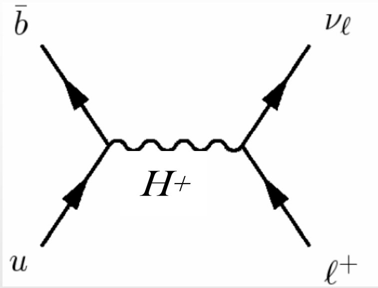
f_B = 216 ± 22 MeV (A. Gray et al. [HPQCD Collaboration], Phys.Rev.Lett. 95 212001 (2005))

$|V_{ub}|$ = (4.39 ± 0.33) x 10^{-3} (E. Barberio et al. (Heavy Flavor Averaging Group) (2006))

$$\to \mathcal{B}(B^+ \to \tau^+ \nu)_{SM} = (1.59 \pm 0.40) \times 10^{-4}$$

- NP models
  - SUSY : charged Higgs can mediate the annihilation

$$\frac{\mathcal{B}(B^+ \to \tau^+ \nu)_{exp}}{\mathcal{B}(B^+ \to \tau^+ \nu)_{SM}} \approx \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$



(W.S. Hou Phy.Lett. D 48, 2342 (1993))

$B^+ \to \tau^+\nu$ in the SL recoil

✓ $B^-_{tag} \to D^{(*)0} l^- \nu$, l=e,μ vs $B^+_{sig} \to \tau^+\nu$

$\tau^+\nu$:
- $e^+\nu\nu$, $\mu^+\nu\nu$
- $\pi^+\nu\nu$, $\rho^+(\pi^+\pi^0)\nu$ — BaBar only

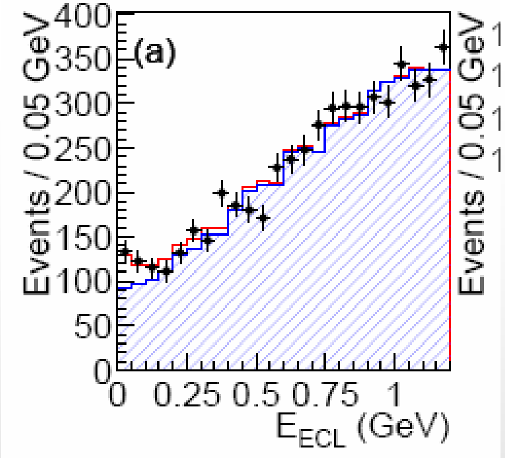
✓ background suppression by using event shape and kinematical variables

✓ most discriminat variable: extra neutral energy in the calorimeter neither associated to B_{sig} nor to B_{tag} (E_{extra})

✓ Results:

BELLE

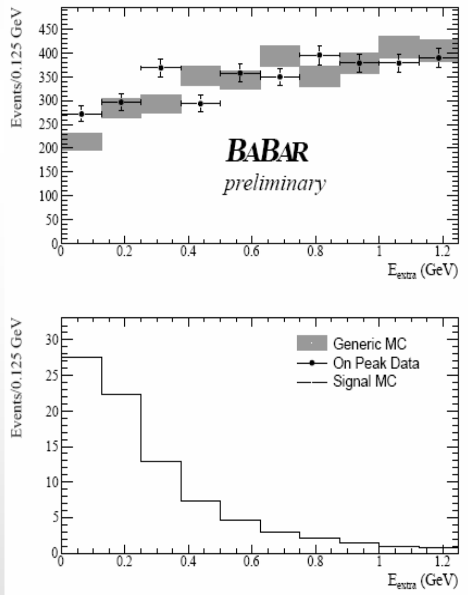
arXiv:0809.3834
605 fb^{-1}



$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$$

BABAR

arXiv:0809.4027
417.6 fb^{-1}



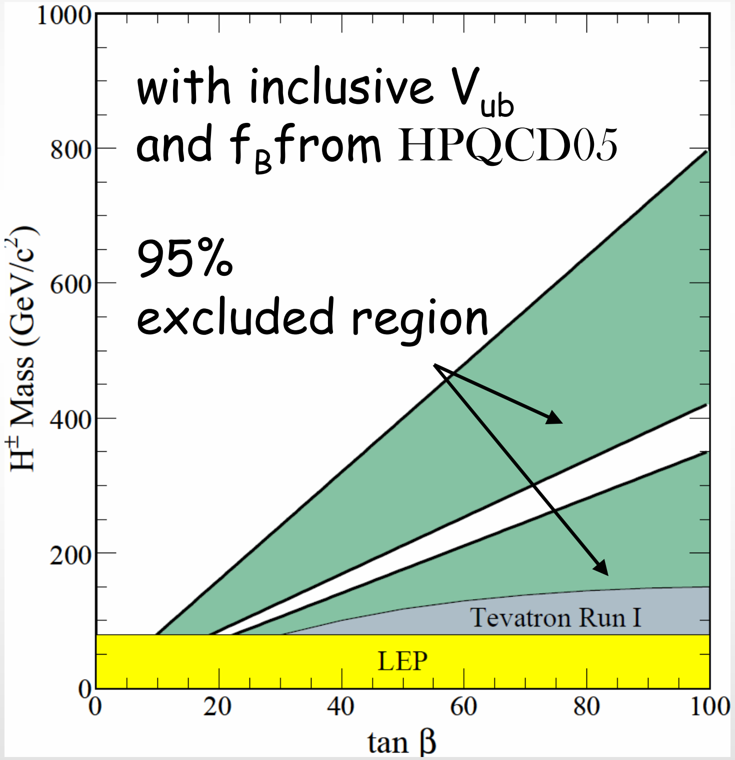
$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$$

$B^+ \to \tau^+\nu$ and phenomenological constraints

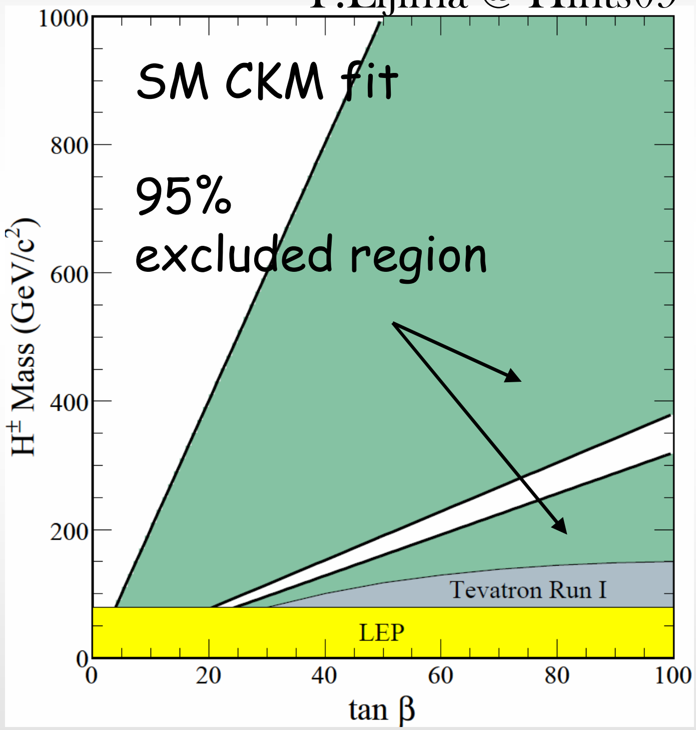
$\mathcal{B}(B^+ \to \tau^+\nu)_{EXP} = (1.51 \pm 0.34)\text{x}10^{-4}$ (HFAG BaBar + Belle average, Summer 2008)

$\mathcal{B}(B^+ \to \tau^+\nu)_{SM} = (1.59 \pm 0.40) \text{ x } 10^{-4}$

$\mathcal{B}(B^+ \to \tau^+\nu)_{SM-fit} = (0.79^{+0.18}_{-0.08}) \text{ x } 10^{-4}$



T.Lijima @ Hints09



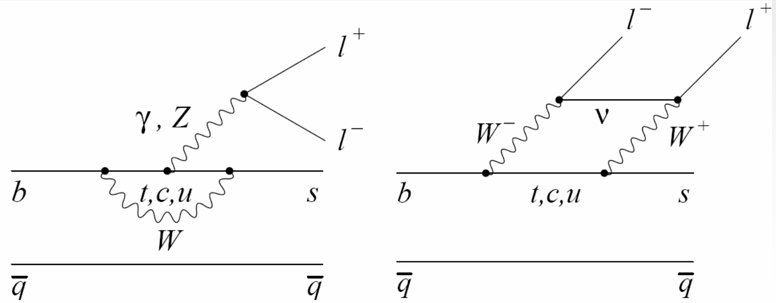
V_{ub} tension between measured result and fit estimate

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

$B \to K^{(*)}ll$ theoretical overview

- ✓ Operator Product Expansion framework: 3 effective Wilson coefficients govern the $b \to sll$ process

  - C_7 : electromagnetic penguin (modulus from $b \to s\gamma/sll$, sign from $b \to sll$)
  - C_9 : vector part of electroweak diagrams
  - C_{10} : axial-vector part of electroweak diagrams

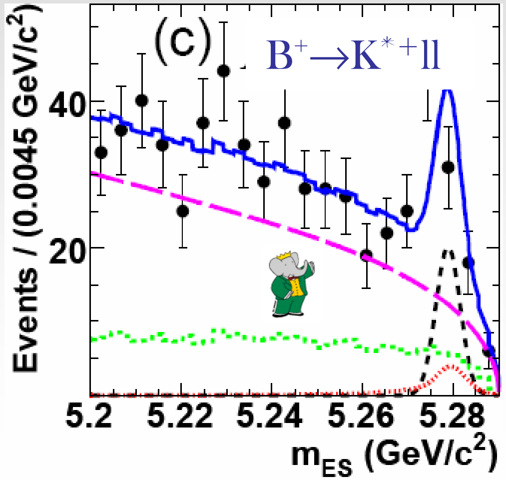


→ NP can change magnitude and relative sign of C_i wrt SM predictions

- ✓ All the following results from:
  - PRL 102, 091803 (2009), PRD 79, 031102 (2009) , $350 fb^{-1} \to 384M B\bar{B}$
  - arXiv:0810.0335 , $597 fb^{-1} \to 657M B\bar{B}$

$B\to K^{(*)}ll$: signal yield and branching fraction

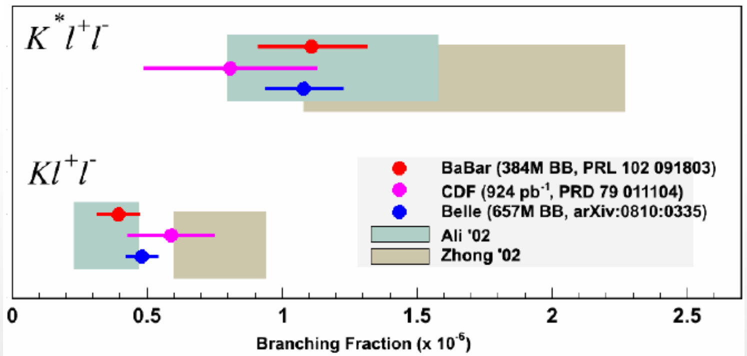
- ✓ $e^+e^-/\mu^+\mu^-$ pair + $\{K^+, K_s, K^+\pi, K^+\pi^0, K_s\pi^+\}$
- ✓ signal window defined by m_{ES}, ΔE and $m(K\pi)$ for K^*
- ✓ veto $B\to(c\bar{c})X_s$ by cutting on $q^2=m_{ll}$
  $\to$ Belle (BaBar) fits in 6 (2) q^2 bins
  half the bins in the low-q^2 region and the other half in the high-q^2 region



data (dots);
signal;
peaking;
hadronic;
combinatorial;
total

- ✓ agreement between the two experiments

	$B\to Kll$	$B\to K^*ll$
	$(0.48^{+0.05}_{-0.04}\pm0.03)\text{x}10^{-6}$	$(1.08^{+0.11}_{-0.10}\pm0.09)\text{x}10^{-6}$
	$(0.39\pm0.07\pm0.02)\text{x}10^{-6}$	$(1.11^{+0.19}_{-0.18}\pm0.07)\text{x}10^{-6}$



relative exp uncertainties:
~ 13% (Belle)
~ 18% (BaBar)

- ✓ agreement with SM expectation
  - theoretical error ~ 30%

$B \to K^{(*)}ll$: direct CP asymmetry

$$A_{CP} \equiv \frac{\Gamma(\overline{B} \to \overline{K}^{(*)} l^+ l^-) - \Gamma(B \to K^{(*)} l^+ l^-)}{\Gamma(\overline{B} \to \overline{K}^{(*)} l^+ l^-) + \Gamma(B \to K^{(*)} l^+ l^-)}$$

- ✓ predicted to be $O(10^{-3})$ both for K and K^* in the SM;
  enhancement up to 10% in generic NP scenarios (Bobethet al., JHEP0807, 106(2008))

- ✓ experimental results in the combined q^2 region:
  – consistent with null direct CP violation

	BaBar	Belle
$K^+l^+l^-$	$-0.18^{0.18}_{-0.18} \pm 0.01$	$-0.04^{0.10}_{-0.10} \pm 0.02$
$K^{*0}l^+l^-$	$0.02^{0.20}_{-0.20} \pm 0.02$	$-0.08^{0.12}_{-0.12} \pm 0.02$
$K^{*+}l^+l^-$	$0.01^{0.26}_{-0.24} \pm 0.02$	$-0.13^{0.17}_{-0.16} \pm 0.01$
$K^*l^+l^-$	$0.01^{0.16}_{-0.15} \pm 0.01$	$-0.10^{0.10}_{-0.10} \pm 0.01$

$B \to K^{(*)}ll$: Lepton Flavor Ratio

$$R_{K^{(*)}} \equiv \frac{\Gamma(B \to K^{(*)}\mu^+\mu^-)}{\Gamma(B \to K^{(*)}e^+e^-)}$$

- ✓ in the SM:

  $R_K \sim 1$,

  $R_{K^*} \sim 1$ (0.75 including the $q^2<2m_\mu$ region where the e channel is enhanced);
- ✓ SUSY with large tanβ : enhancement up to 10% (Higgs preferentially couples to μ)

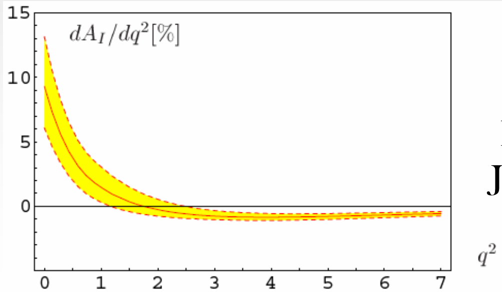
  (Yan al., Phys.Rev.D62, 094023(2000))
- ✓ experimental results:
  - consistency between the two experiment and agreement with the SM prediction

	BELLE	BABAR
R_K	1.03±0.19±0.06	$0.96^{+0.44}_{-0.34}\pm0.05$
R_{K^*}	0.82±0.17±0.01	$1.10^{+0.42}_{-0.32}\pm0.07$
R_{K^*} (including $q^2<(2m_\mu)$)		$0.56^{+0.29}_{-0.23}\pm0.04$

$B \to K^{(*)}ll$: Isospin Asymmetry

$$A_I^{K^{(*)}} \equiv \frac{\Gamma(B^0 \to K^{(*)0} l^+ l^-) - (\tau_0/\tau_+)\Gamma(B^\pm \to K^{(*)\pm} l^+ l^-)}{\Gamma(B^0 \to K^{(*)0} l^+ l^-) + (\tau_0/\tau_+)\Gamma(B^\pm \to K^{(*)\pm} l^+ l^-)}$$

- ✓ SM expectation: very small asymmetry, reaches O(%) at lowest q^2



Feldmann and Matias, JHEP 0301, 074 (2003)

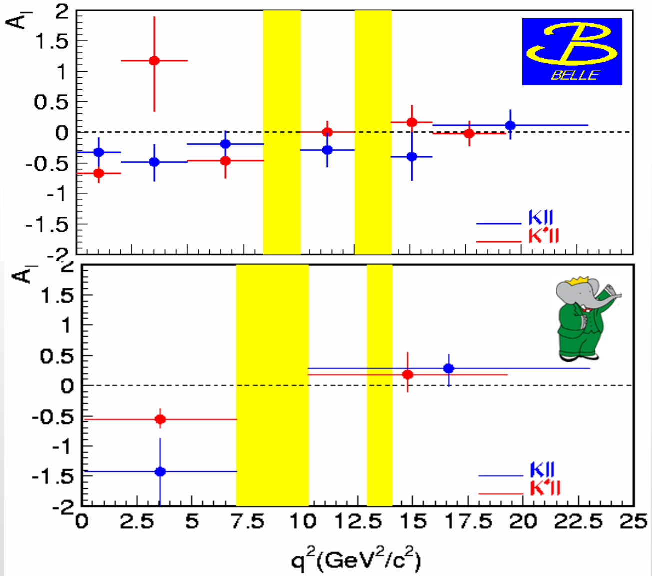
- ✓ experimental results:
  - no isospin violation at high q^2
  - at small q^2

BELLE

$A_I(B\to K^* ll)$	$-0.29 \pm 0.16 \pm 0.03$
$A_I(B\to K ll)$	$-0.31^{+0.17}_{-0.14} \pm 0.05$
$A_I(B\to K^{(*)} ll)$	$-0.30^{+0.12}_{-0.11} \pm 0.04$

BABAR

$A_I(B\to K^* ll)$	$-0.56^{+0.17}_{-0.15} \pm 0.03$
$A_I(B\to K ll)$	$-1.43^{+0.56}_{-0.85} \pm 0.05$



BELLE significance from null $A_I(B\to K^{(*)}ll)$: $\sigma = 2.24$

BABAR difference from null $A_I(B\to K^{(*)}ll)$: $3.9\sigma_{stat+syst}$

B→K*ll : angular fits(I)

✓ longitudinal K* polarization F_L :
sensitive to NP at low q^2

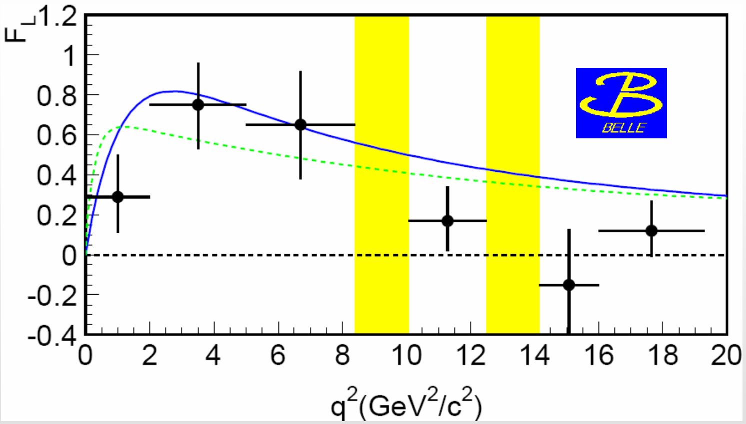
F_L	Low q^2	High q^2
BaBar	0.35 ± 0.16	$0.71^{+0.20}_{-0.22}$
Belle	0.53 ± 0.14	0.11 ± 0.09

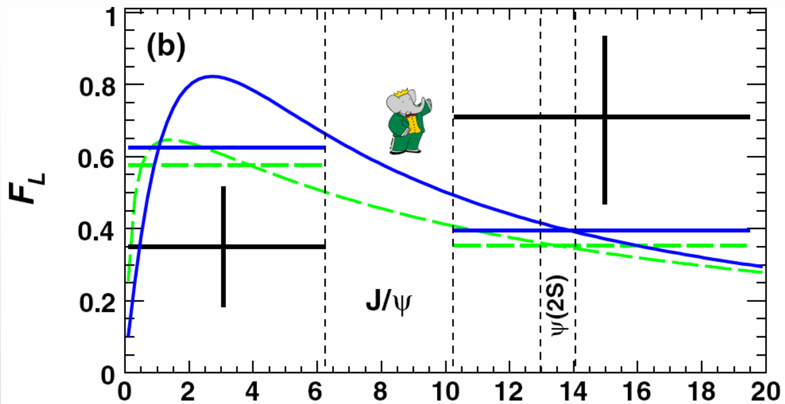
θ_K : angle between K and B in K* rest frame

fit to $\cos\theta_K$:

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

→ determination of F_L





SM C_7=-C^{SM}_7 (Krüger et al. PRD 71, 094009 (2005))

$B \to K^* ll$: angular fits (II)

✓ forward-backward asymmetry :

$$A_{FB}(s) = \frac{\int_{-1}^{1} d\cos\theta_l \frac{d^2\Gamma(B\to K^* l^+ l^-)}{d\cos\theta_l ds} \mathrm{Sign}(\cos\theta_l)}{d\Gamma(B\to K^* l^+ l^-)/ds}$$

($s \equiv q^2/m^2_B$, θ_l angle between $l^+(l^-)$ and B(B) in ll rest frame)

fit to $\cos\theta_l$:

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

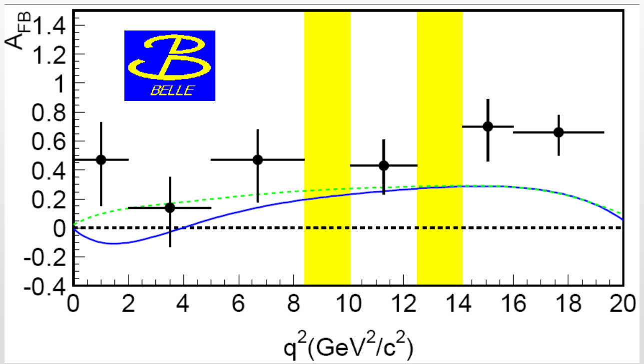
→ determination of A_{FB}

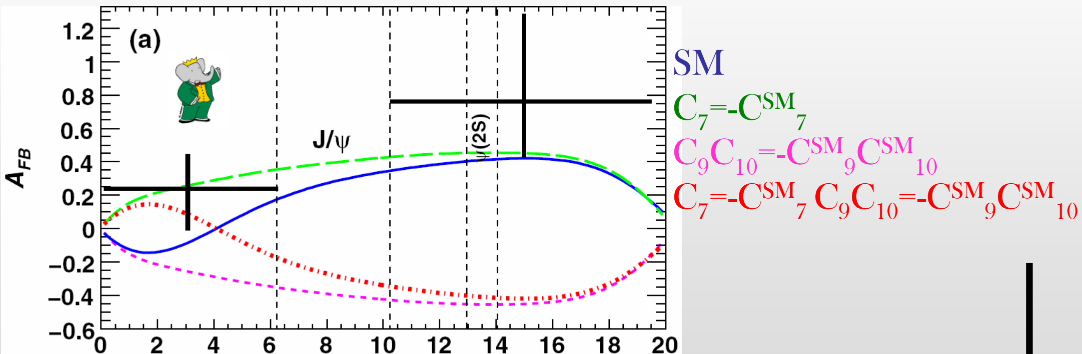
✓ experimental results :

A_{FB}	Low q^2	High q^2
BaBar	$0.24^{+0.18}_{-0.23}$	$0.76^{+0.52}_{-0.32}$
Belle	0.30 ± 0.15	0.58 ± 0.11

Ali et al. PRD 61, 074024 (2000)
Buchalla et al. PRD 63, 014015 (2001)
Ali et al. PRD 66, 034002 (2002)

Krüger et al. PRD 61, 114028 (2002)
Krüger et al. PRD 71, 094009 (2005)

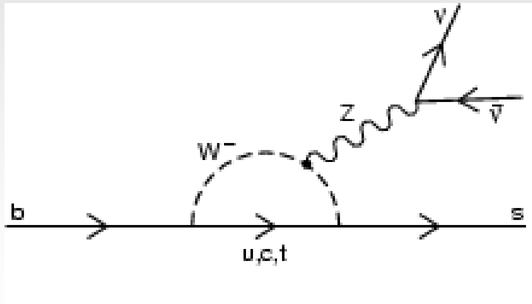


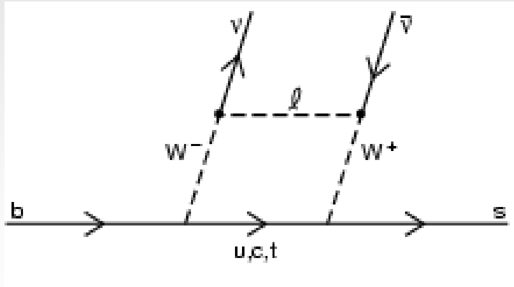


$B \to K^{*} \nu\nu$

B→K(*)νν: theoretical overview

✓ b→sνν diagrams in the SM model





✓ SM prediction:

$$BR_{SM}(B \to K^* \nu\nu) = (6.8^{+1.0}_{-1.1})x10^{-6}$$

$$BR_{SM}(B \to K \nu\nu) = (4.5 \pm 0.7)x10^{-6}$$

G.Altmannshofer et al., arXiv:0902.0160

✓ NP effects:

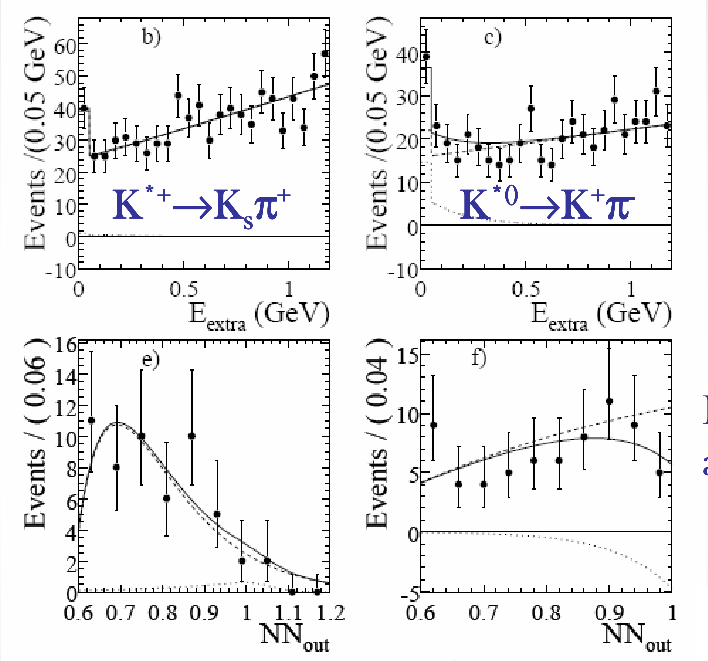
– Non-standard Z coupling: enhancement of a factor 10 G.Buchalla et al. Phys. Rev. D 63, 014015 (2000)

– New sources of missing energy: production of light dark matter via Higgs mediated vertex, BR_{NP} up $50xBR_{SM}$ C. Bird et al. Phys.Rev.Lett.93:201803 (2004)

$B \to K^{*} \nu\nu$ from Belle: analysis strategy

✓ Belle: inclusive reconstruction of B_{tag} in hadronic channels ($B \to D^{(*)} nK m\pi$)

BaBar: combined results from the semileptonic and hadronic recoil analyses



SL analysis

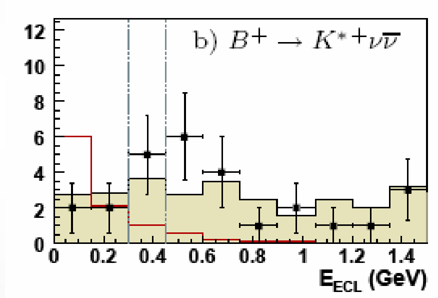
HAD analysis

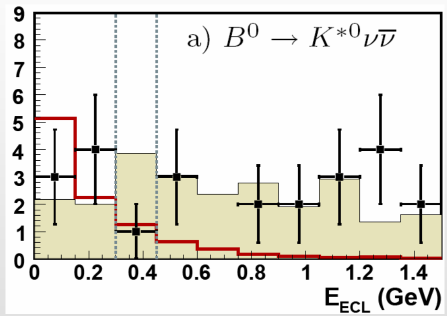
PRD 78, 072007 (2008), 413 fb^{-1}

UL @ 90%CL	$B^+ \to K^{*+} \nu\nu$	$B^0 \to K^{*0} \nu\nu$	$B \to K^{*} \nu\nu$
HAD	21×10^{-5}	11×10^{-5}	
SL	9×10^{-5}	18×10^{-5}	
Combined	8×10^{-5}	12×10^{-5}	8×10^{-5}

UL @ 90% CL

$B^+ \to K^{*+} \nu\nu$	$B^0 \to K^{*0} \nu\nu$
14×10^{-5}	34×10^{-5}

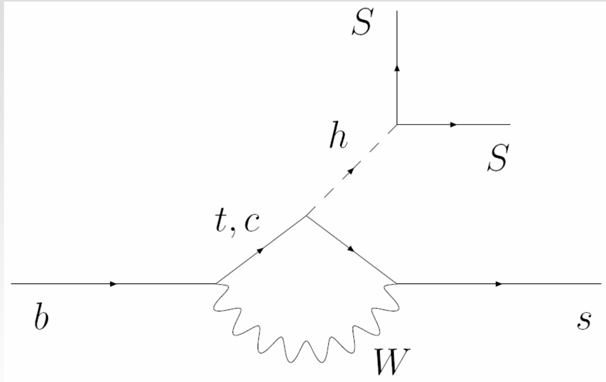




492 fb^{-1}

Phys.Rev.Lett.99:22180(2007)

$B \to K^* \nu\nu$ and light dark matter



- ✓ light scalar dark matter candidate S (m_S < 2.5GeV)
  - – $b \to s$ SS transition mediated by a Higgs boson (h) with coupling λ

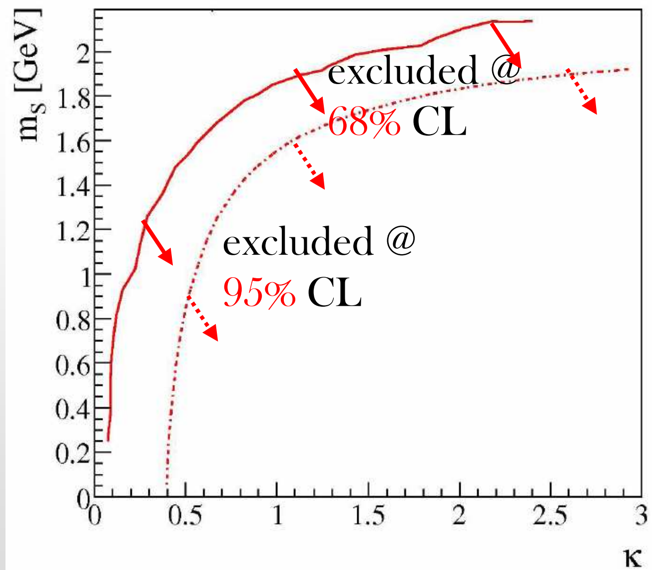
related to the dark matter abundance in the universe

$$\kappa^2 = \lambda^2 \left(\frac{100\text{GeV}}{m_h} \right)^4$$

m_h = Higgs mass

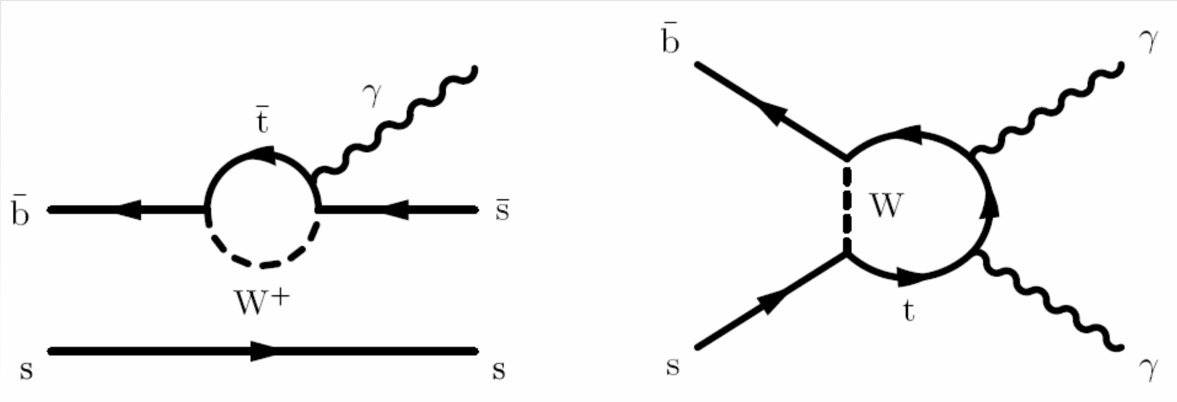
for low m_S, κ~O(1) (Burgess et al. Nucl.Phys. B619, 709 (2001))

- ✓ Use the measured UL to constraint m_S vs κ
  - – use BaBar UL and Buchalla et al PRD 63, 014015 for SM prediction
  - – for high κ: light higgs with strong coupling to SS $\to$ h$\to$SS can saturate the higgs decay rate making impossible the Higgs discovery at LHC



$B^0_s \to \varphi\gamma, \gamma\gamma$

$B_s \rightarrow \varphi\gamma$, $\gamma\gamma$: theoretical overview



$B^0_s \rightarrow \varphi\gamma$

- ✓ SM prediction : BR($B_s \rightarrow \phi\gamma$) ~ 40 x 10^{-6} with 30% theoretical uncertainty

  (Ball et al Phys.Rev.D75, 054004

  Ali et al Eur.Phys.J.C55:577-595)

- ✓ is it consistent with the theoretical prediction for $b \rightarrow s\gamma$ transition, as in the B_d sector is ?

$B^0_s \rightarrow \gamma\gamma$

- ✓ SM prediction : BR($B_s \rightarrow \gamma\gamma$)~(0.5-1.0)x$10^{-6}$

  (Chang et al Phys.Lett.B 451,395

  Reina et al Phys.Rev.D56,5805

  Bosch et al J. High Energy Phys.08,054)

- ✓ several NP models can enhance BR wrt SM up to 1 order of magnitude

$B^0_s \to \phi\gamma, \gamma\gamma$: results

23.6 fb^{-1}

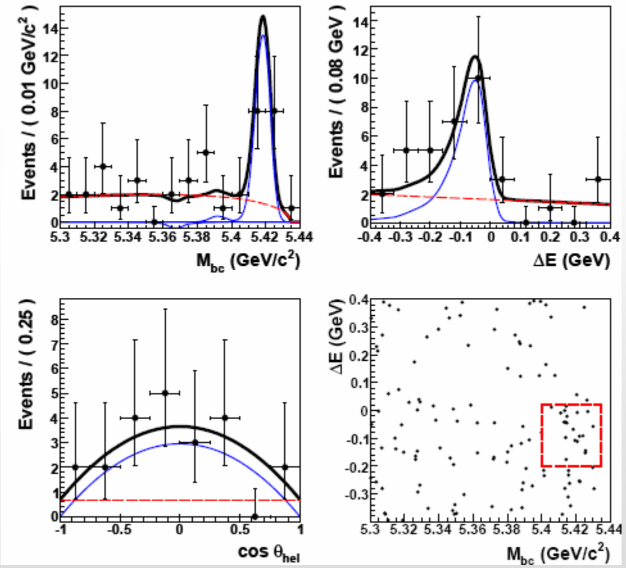
Phys.Rev.Lett.100:121801(2008)

Experimental searches performed using Belle Y(5S) data sample

$B^0_s \to \varphi\gamma$

- ✓ $N_{sig} = 18^{+6}_{-5}$
- ✓ $\mathcal{B}(B_s \to \varphi\gamma) = (57^{+18+12}_{-15-11})\text{x}10^{-6}$

  → first observation of radiative B_s decay
- ✓ Compatible with SM expectation

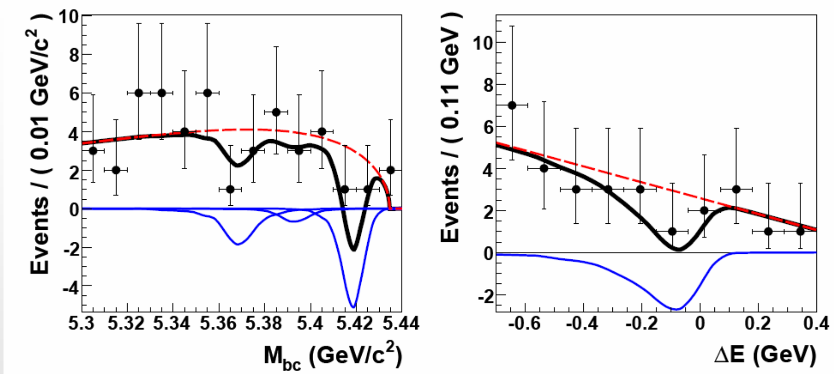


$B^0_s \to \gamma\gamma$

- ✓ No evidence for signal
- ✓ UL @ 90%CL:

$$\mathcal{B}(B_s \to \gamma\gamma) < 8.7\text{x}10^{-6}$$

- ✓ ~ 10 x SM expectation



Both limited by statistics

Conclusions

Conclusions

- ✓ Search for rare decays: test for the Standard Model and probe for New Physics

- ✓ High statistics and clean data samples provided by B-factories
  - indirect search for NP
  - complementary to direct search @ high energy machines
  - reached sensitivity $O(10^{-7})$

- ✓ Experimental measurements allow to constraint parameters defining NP

- ✓ Much more can be done at LHCb and at a Super Flavor Factory

  only place where further searches for rare decays with undetectable particles are feasible

back-up slides

V_{ub} tension (2007)

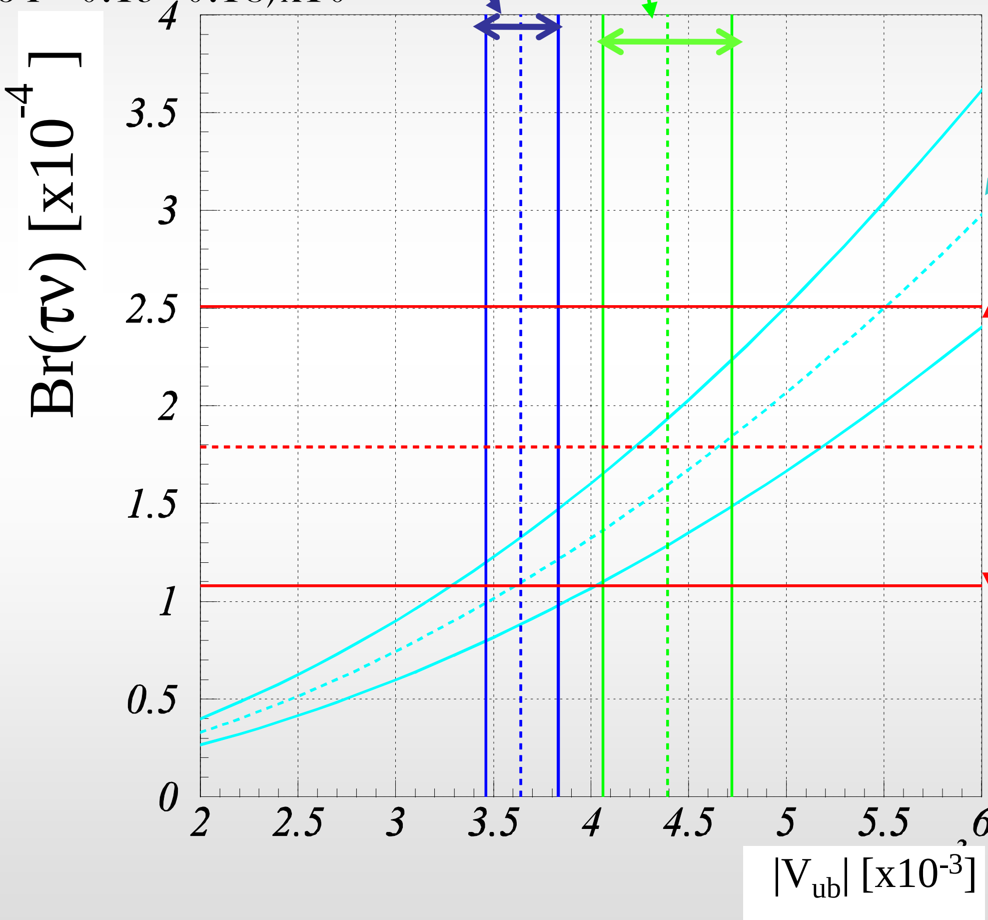
$|V_{ub}|$ from CKM fit
(meas. not in fit)
Br=(3.64 +0.19 -0.18)x10^{-3}

2007/03/24 02.34

$|V_{ub}|$ from SL
Br=(4.39 +/- 0.33)x10^{-3}

SM formula w/
f_B = 0.216 +/- 0.022 GeV

Belle result:
Br=(1.79 +0.72 -0.71)x10^{-4}



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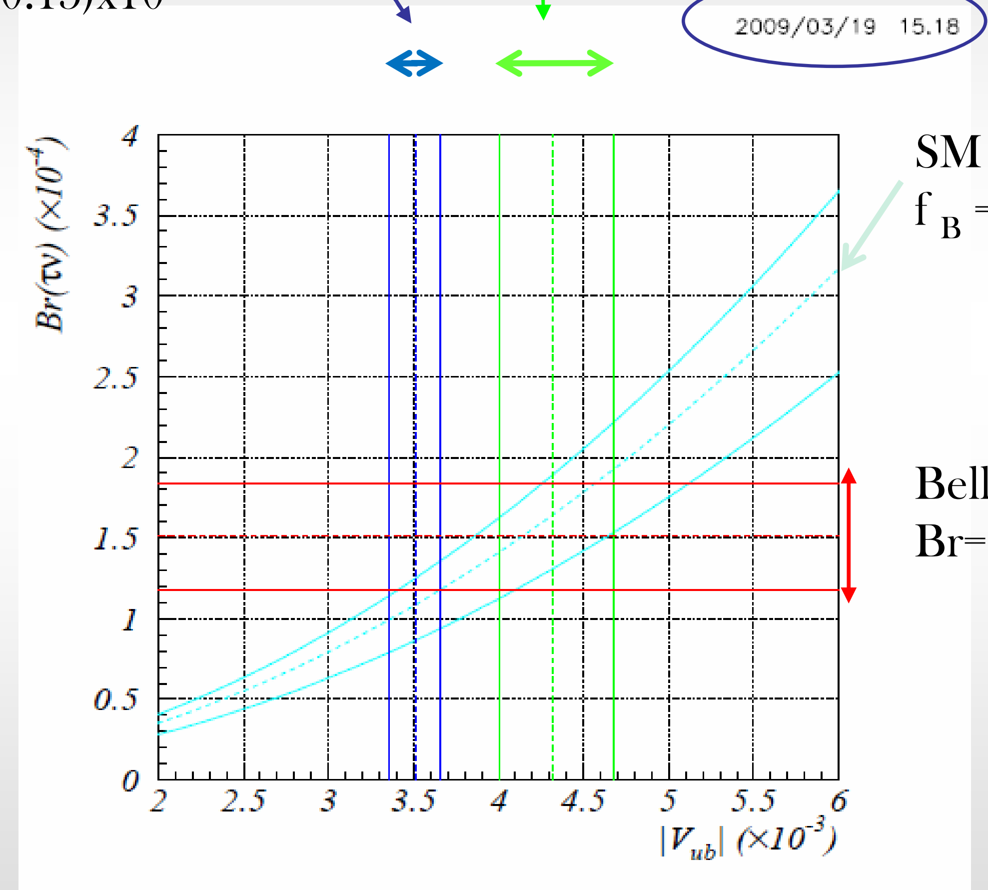
V_{ub} tension (2009)

|Vub| from CKM fit
(meas. not in fit)
Br=(3.51+/-0.15)x10^{-3}

|V_{ub}| from SL
Br=(4.32 +0.36 -0.31)x10^{-3}



SM formula w/
f_B = 0.223 +/- 0.024 GeV

Belle/BaBar average:
Br=(1.51 +/-0.33)x10^{-4}

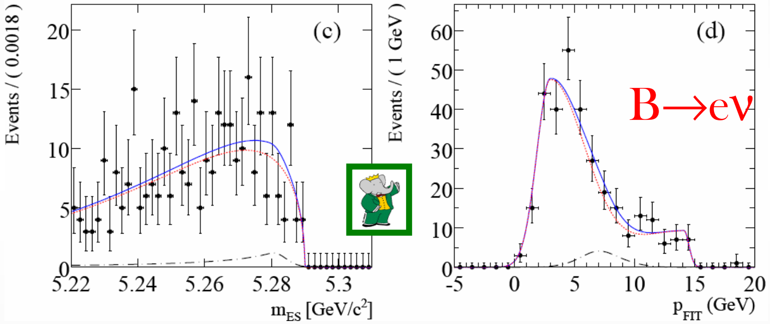
Good progres
in experiments!

Toru Iijima @ Hints09

Inclusive search for $B^+ \to l^+ \nu$

- B_{sig} = 1 with highest momentum lepton (tight particle ID) + B_{tag} =extra tracks and neutral
- background suppression:
  - B_{tag} ΔE and p_T (Belle olny), Fisher discriminat to suppress qq background, direction and module of the transverse missing 3-momentum (BaBar only)

  → main background left: qq, $B \to X_u l\nu$, Xh with misidentified h, two-γ events for the electron ch.



- yield extraction:
  - fit to B_{tag} m_{ES} (Belle) or 2-dim fit

  to B_{tag} m_{ES} and $p_{FIT} = a_0 + a_1 p_l^{CM} + a_2\, p_l^{REST}$ (BaBar)

	Belle		BaBar	
	B→eν	B→μν	B→eν	B→μν
ε_{sig}	(2.4±0.1)%	(2.2±0.1)%	(4.7±0.3)%	(6.1±0.2)%
N_{sig}	-1.8±3.3	4.1±3.3	17.9±17.6	1.4±17.2
$UL_{90\%}$	1.7×10^{-6}	9.8×10^{-6}	1.9×10^{-6}	1.0×10^{-6}
(Lumi & Ref)	253 fb^{-1} Phys.Lett.B,647,67(2007)		426 fb^{-1} arXiv:0903.1220