Nagoya University
タウ・レプトン物理研究センター
Tau Lepton Physics Research Center

B崩壊の物理

飯嶋　徹
名古屋大学

2010年2月23日

特定領域「フレーバー物理の新展開」研究会

Bファクトリーの3大物理成果

高輝度電子･陽電子衝突実験で切り開く物理

- B崩壊におけるCP対称性の破れの発見と小林益川理論の検証
- b/ c /τ rare process における新物理探索
  - B稀崩壊 : B→ X_s γ, $K^{(*)}$ ll, τν
  - D中間子混合
  - τ LFV 高感度探索 ~$O(10^{-8})$
- 新しいハドロン共鳴の相次ぐ発見

Super-KEKB/Belle II 実験へ

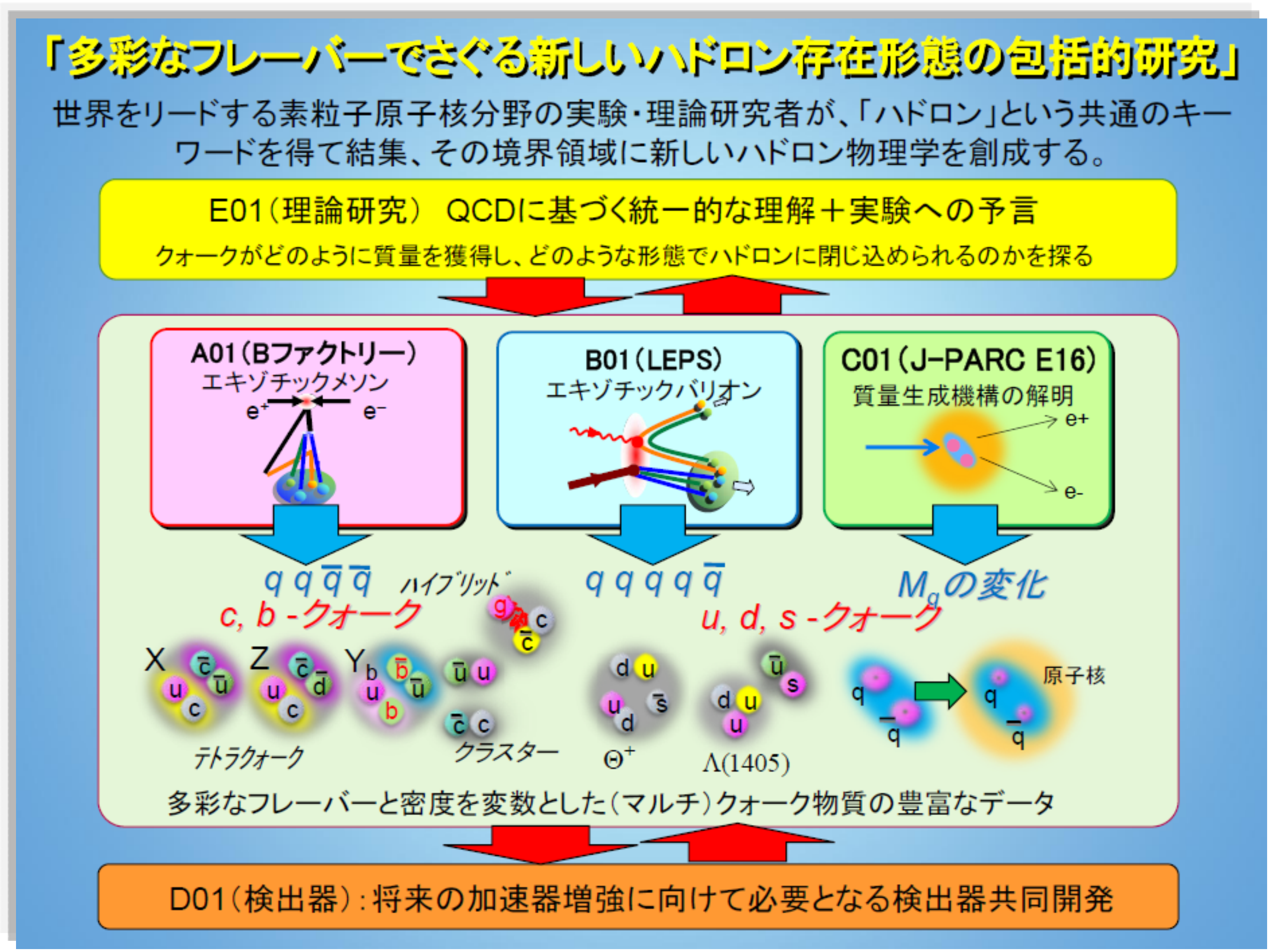
A02計画研究

居波

森、有田

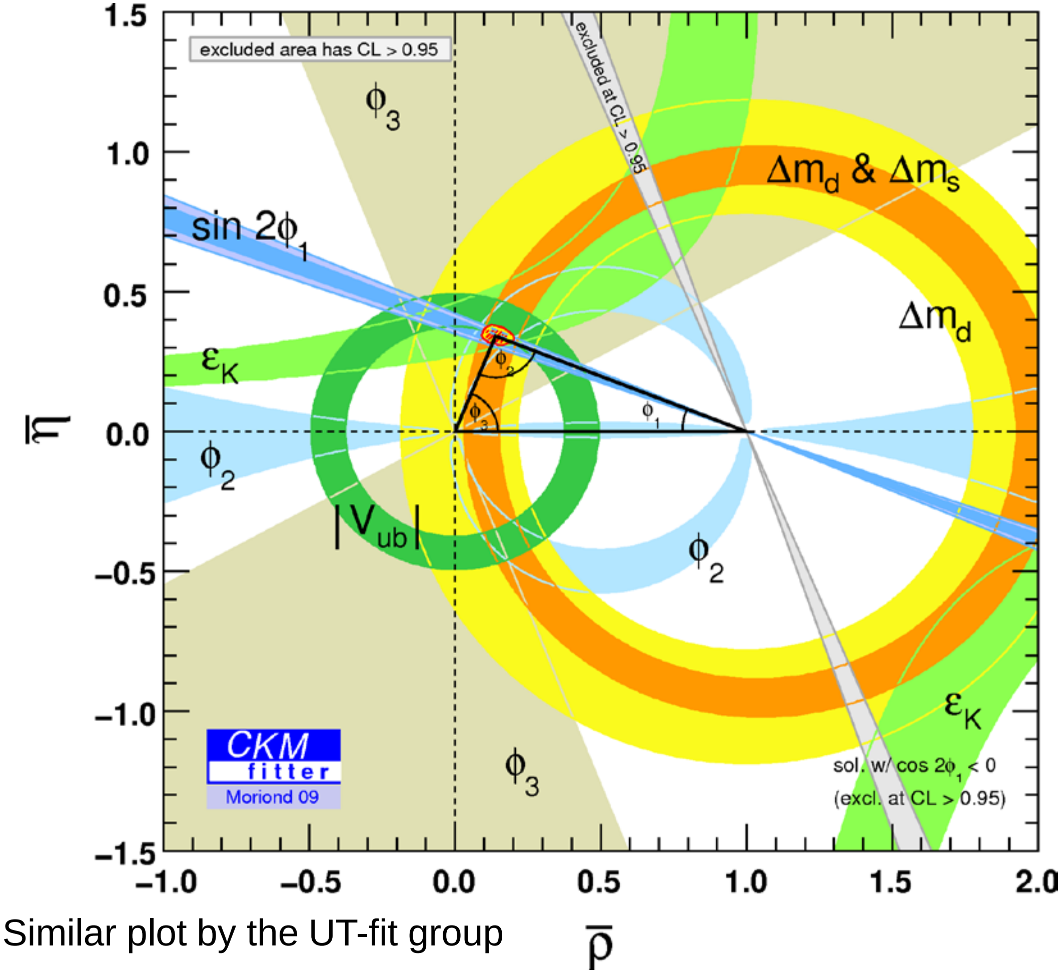
測定器開発

Bファクトリーの新たな可能性



We welcome your contribution
Visit our home page !
http://www.hepl.phys.nagoya-u.ac.jp/public/new_hadron/index.html

Success of the B-factories



Similar plot by the UT-fit group

2008 Nobel Prize in Physics

M. Kobayashi

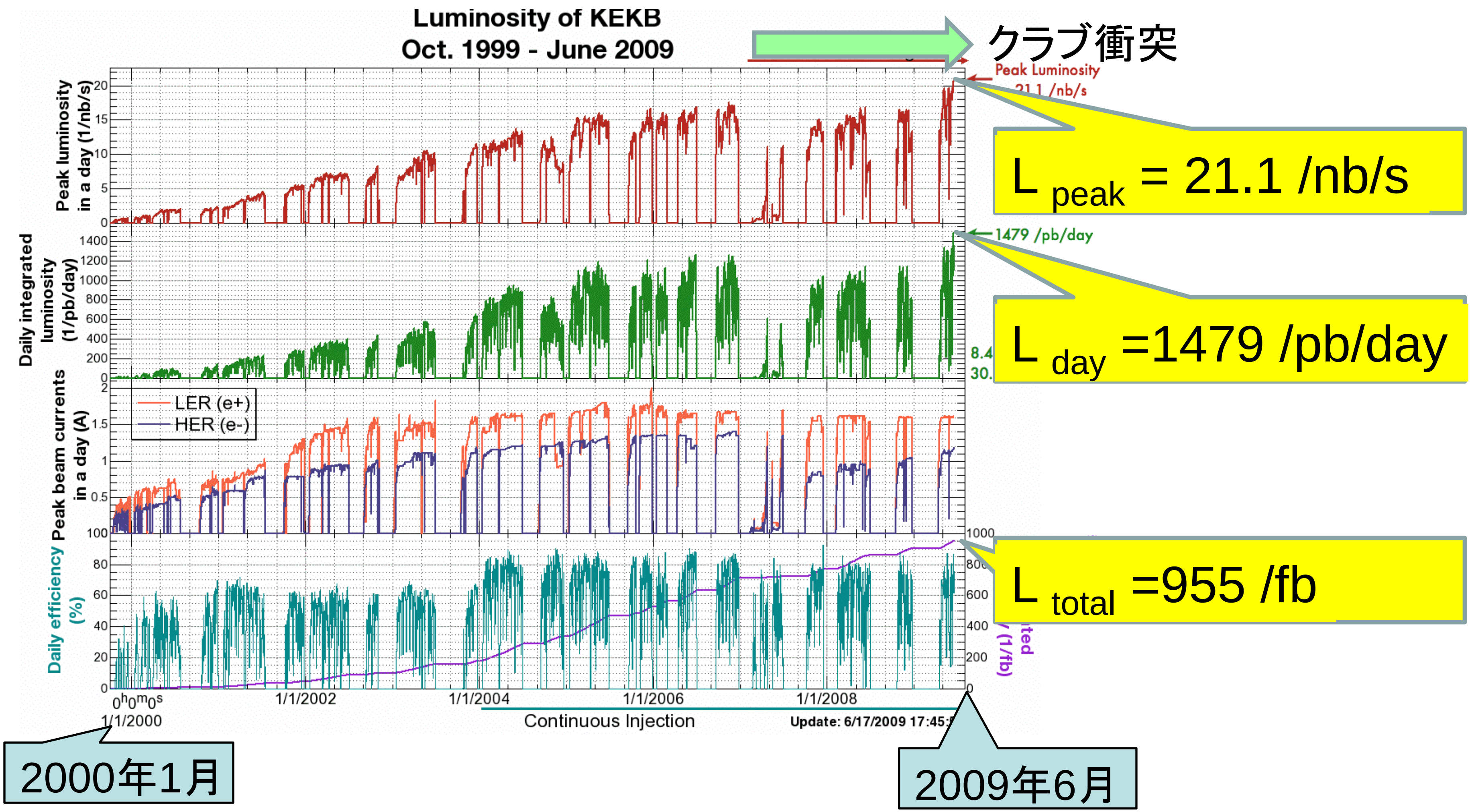
T. Maskawa

Still room for modifications by NP.

Rare B decays are powerful tools !

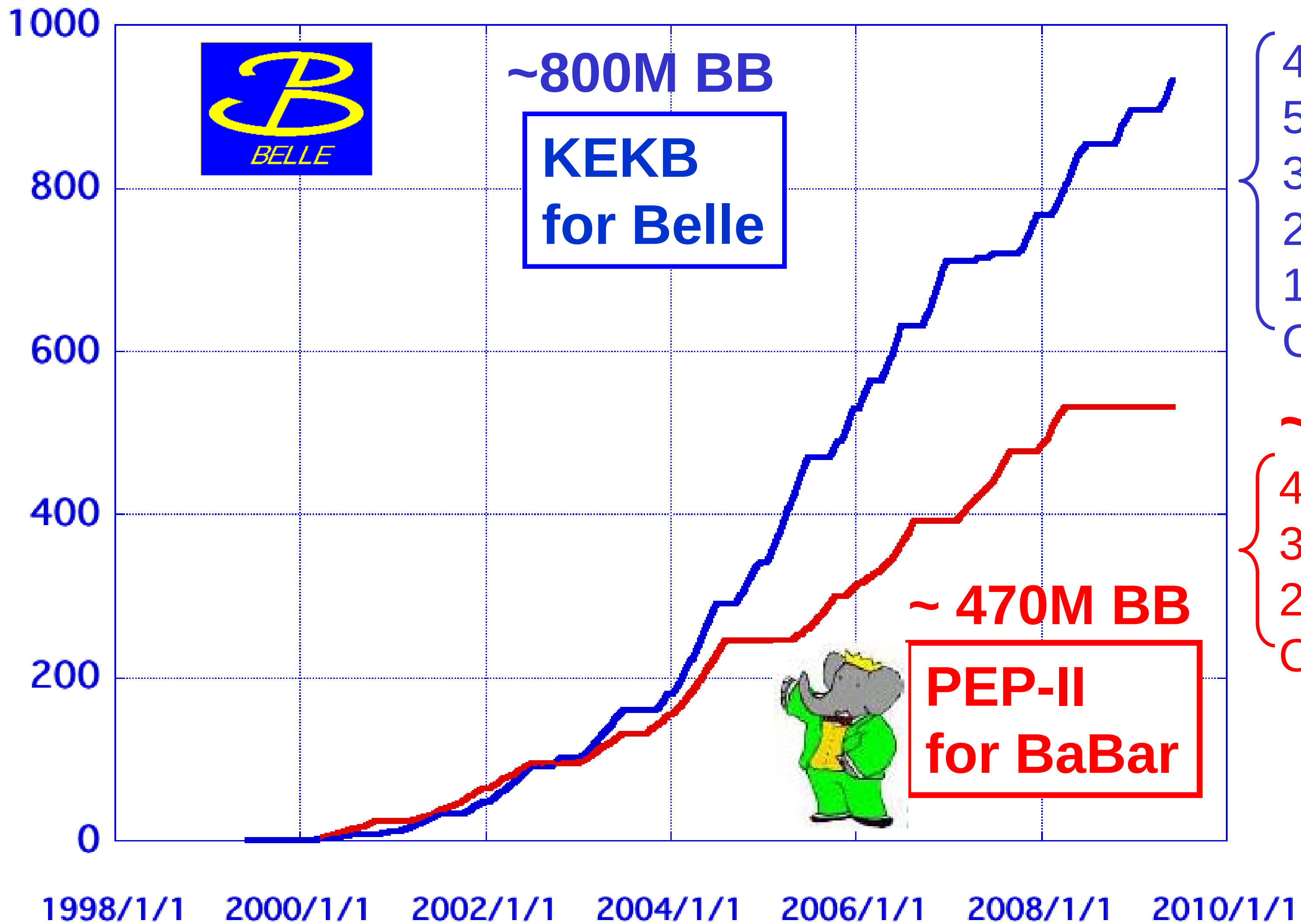
KEKB加速器の成果

世界最高のルミノシティーを達成



→ 2009年12月までに >1ab^{-1} を達成

Luminosity at the B-factories



~950 fb^{-1}

- 4S: 710fb^{-1}
- 5S: 86.fb^{-1}
- 3S: 3.3 fb^{-1}
- 2S: 6.7 fb^{-1}
- 1S: 7.6 fb^{-1}
- Off peak: 90 fb^{-1}

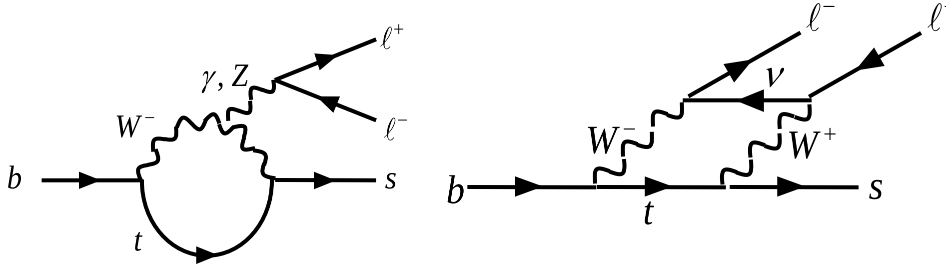
~553 fb^{-1}

- 4S: 433fb^{-1}
- 3S: 30fb^{-1}
- 2S: 14fb^{-1}
- Off peak: 54fb^{-1}

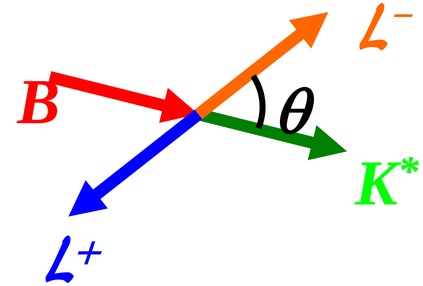
Stopped in April 2008

B→K*ll崩壊

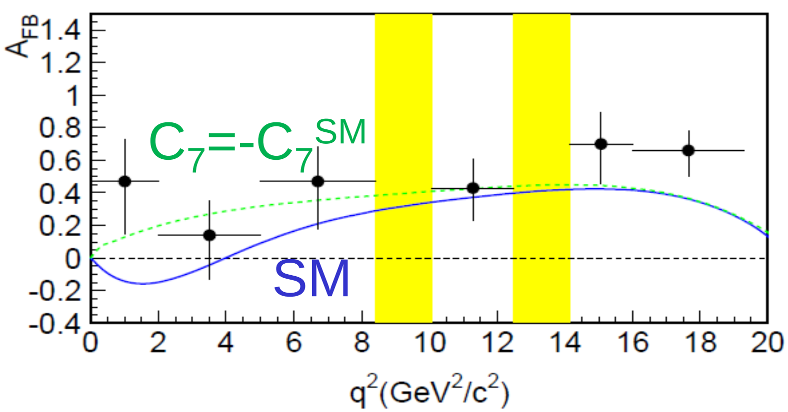
- FCNC 崩壊
- 極めてクリーンなプローブ
- 様々な測定量
  - q^2 分布
  - Forward-backward asymmetry
  - Isospin asymmetry etc.



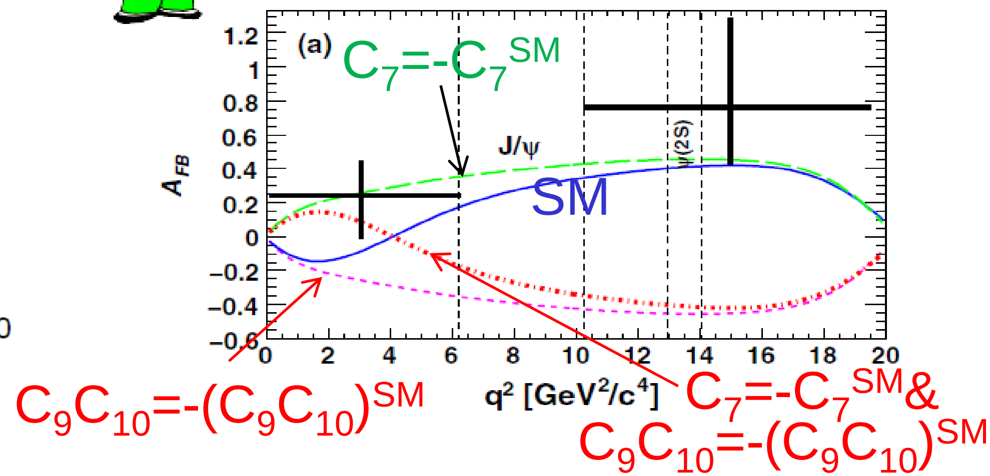
$$A_{FB} \propto \Re\left[C_{10}^{*}\left(sC_9^{eff}(s)+r(s)C_7\right)\right]$$



657 M BB,
submitted to PRL, arXiv: 0904.0770



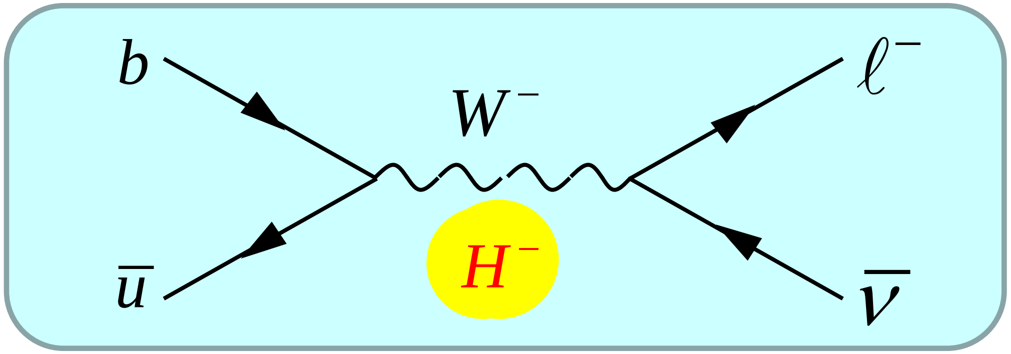
384M BB,
PRD79, 031102(R) (2009)



CDF → 三宅さんのトーク

A_{FB} exceeds SM ?

$B^- \to l^- \bar{\nu}$



- Within SM, proceed via W annihilation.

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

Helicity suppression

$$Br(B \to e\,\nu) \ll Br(B \to \mu\,\nu) \ll Br(B \to \tau\,\nu)$$

~10^{-11} ~10^{-7}

Determination of $f_B|V_{ub}|$

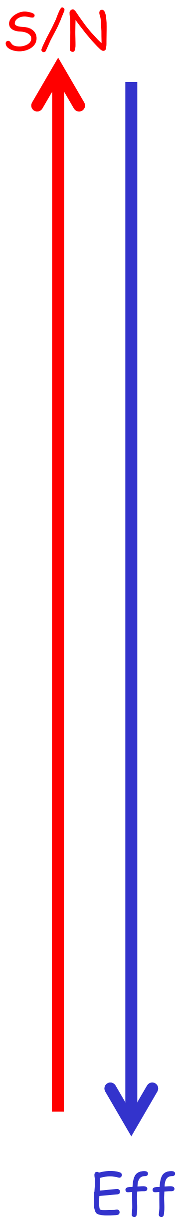
$f_B = 190 \pm 13\ MeV$ HPQCD, 0902.1815v2

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$ HFAG ICHEP08

$\Rightarrow$ $Br_{SM}(\tau\nu) = (1.20 \pm 0.25) \times 10^{-4}$

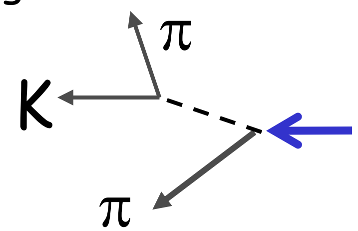
Sensitive also to NP (charged Higgs)

Analysis for $B \to l\nu$



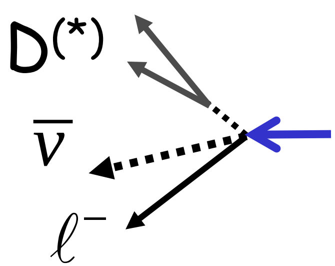
Hadronic tags

$B_{tag} \to D^{(*)}\pi/\rho$ etc.



Semileptonic tags

$B_{tag} \to D^{(*)} l\nu$ etc.



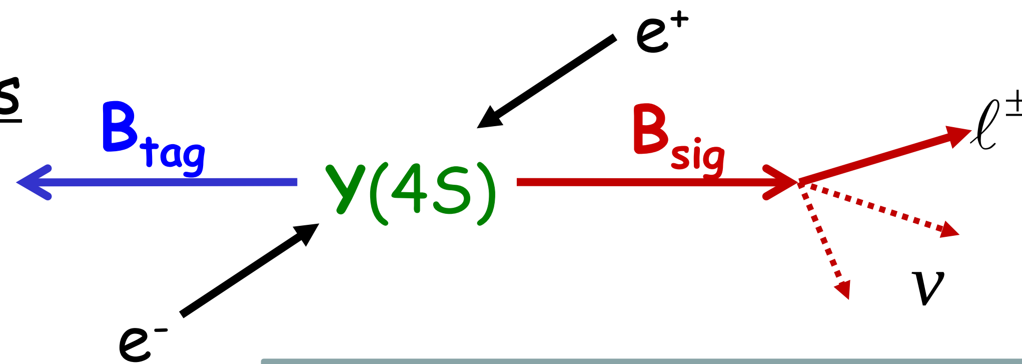
Inclusive tags

4-vector sum of PID tracks (except for signal tracks)

Tagging side

Reconstruct the recoil B to tag

- B production
- B flavor/charge
- B momentum



Signal side: $B_{sig} \to l\,\nu$

- Detect charged track(s)
- Missing energy (mass) due to ν's
- No extra activities in EM calorimeter ($E_{ECL(extra)}$)

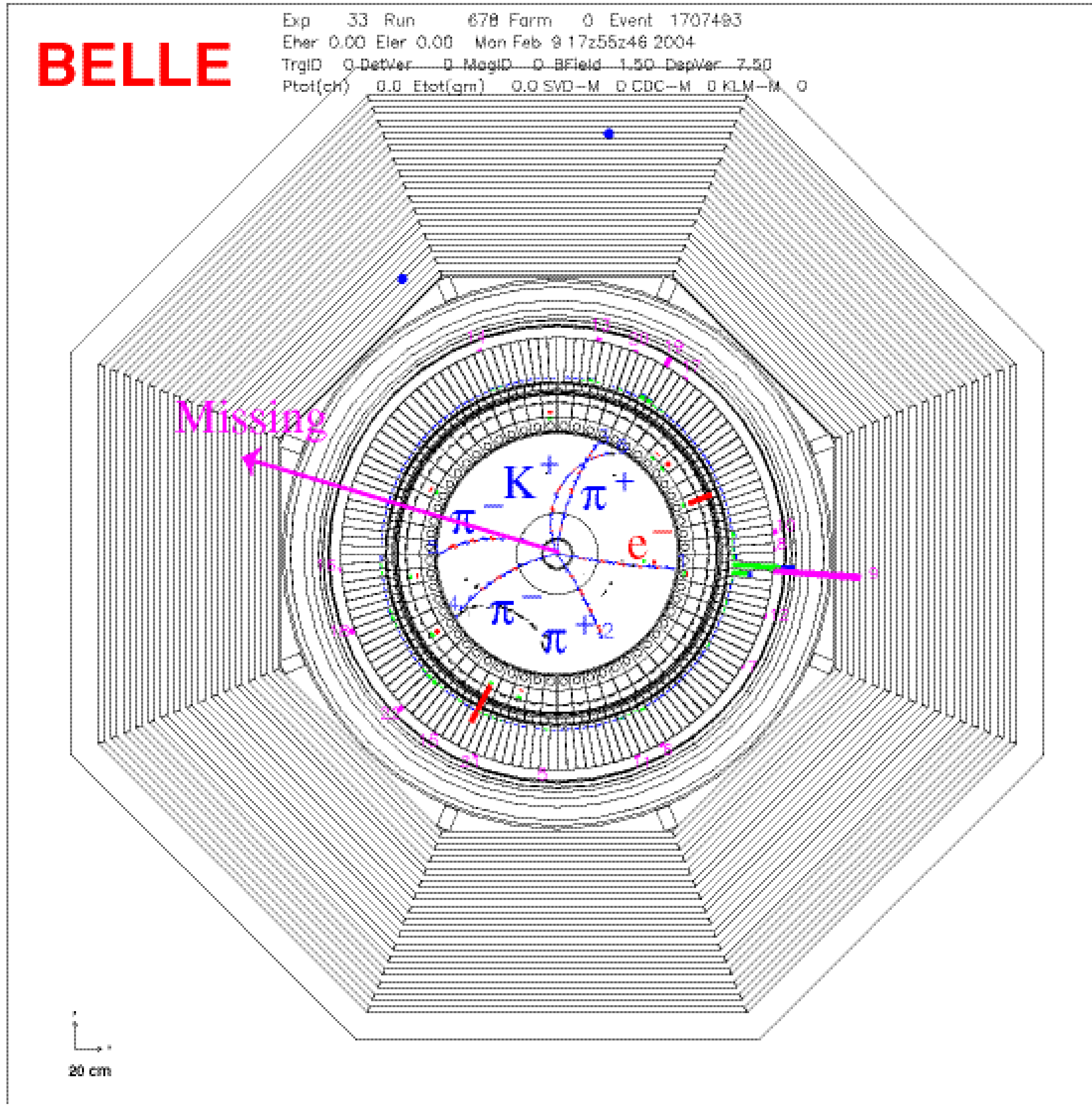
$B \rightarrow \tau\nu$ Candidate Event

$B^+ \rightarrow \overline{D^0} \pi^+$

$\quad \hookrightarrow K^+ \pi^- \pi^+ \pi^-$

$B^- \rightarrow \tau^- \nu$

$\quad \hookrightarrow e^- \nu\nu$



Belle Results

Signal shape : Gauss + exponential
Background shape : second-order polynomial

- Hadronic Tag (449M $B\bar{B}$)

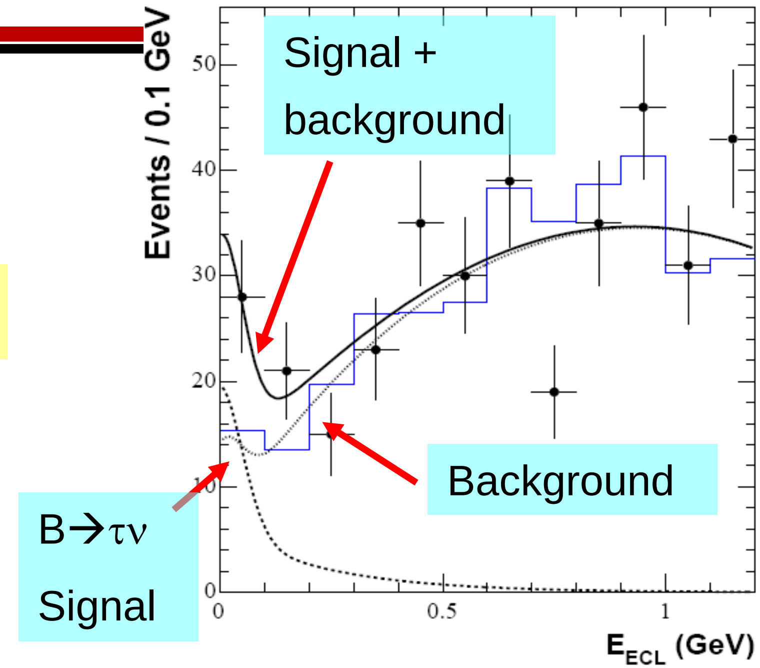
PRL 97, 251802 (2006)

$$Br(\tau\nu) = [1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)]\times 10^{-4}$$

$$N_S = 24.1^{+7.6}_{-6.6}(stat)^{+5.5}_{-6.3}(syst)$$

in all EECL region.

3.5σ (incl. syst.)



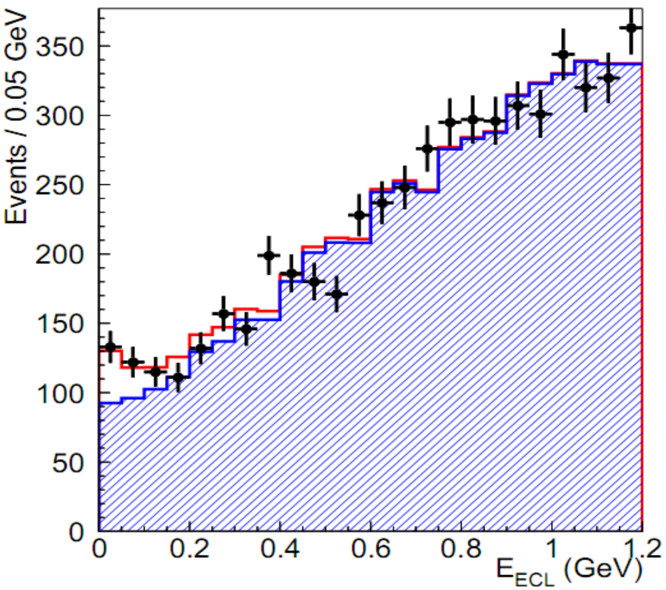
- Semileptonic Tag (657M $B\bar{B}$)

BELLE-CONF-0840, arXiv:0809.3834

$$Br(\tau\nu) = [1.65^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)]\times 10^{-4}$$

$$N_S = 154^{+36}_{-35}(stat)^{+21}_{-22}(syst)$$

3.8σ (incl. syst.)



Constraint on Charged Higgs

Naïve world average

$Br(\tau\nu) = [1.73 \pm 0.35] \times 10^{-4}$ ⟺ $Br_{SM}(\tau\nu) = [1.20 \pm 0.25] \times 10^{-4}$

Based on fB from HPQCD and $|V_{ub}|$ from HFAG (BLNP, ICHEP08)

Effect of Charged Higgs

W. Hou, Phys. Rev. D48, 2342 (1993)

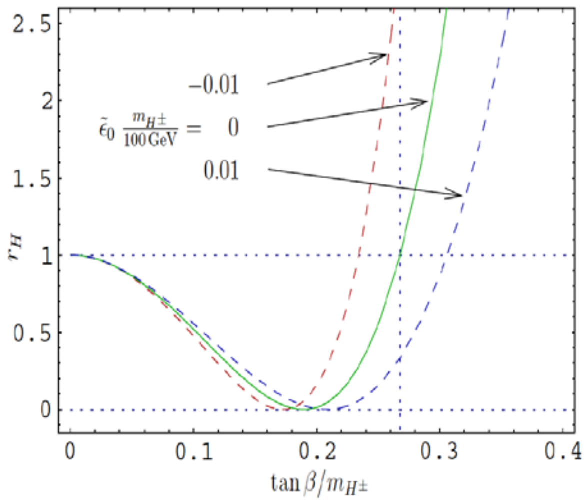
$$Br = Br_{SM} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2 \tan\beta^2}{m_H^2} \frac{1}{1+\varepsilon_0 \tan\beta}\right)^2$$

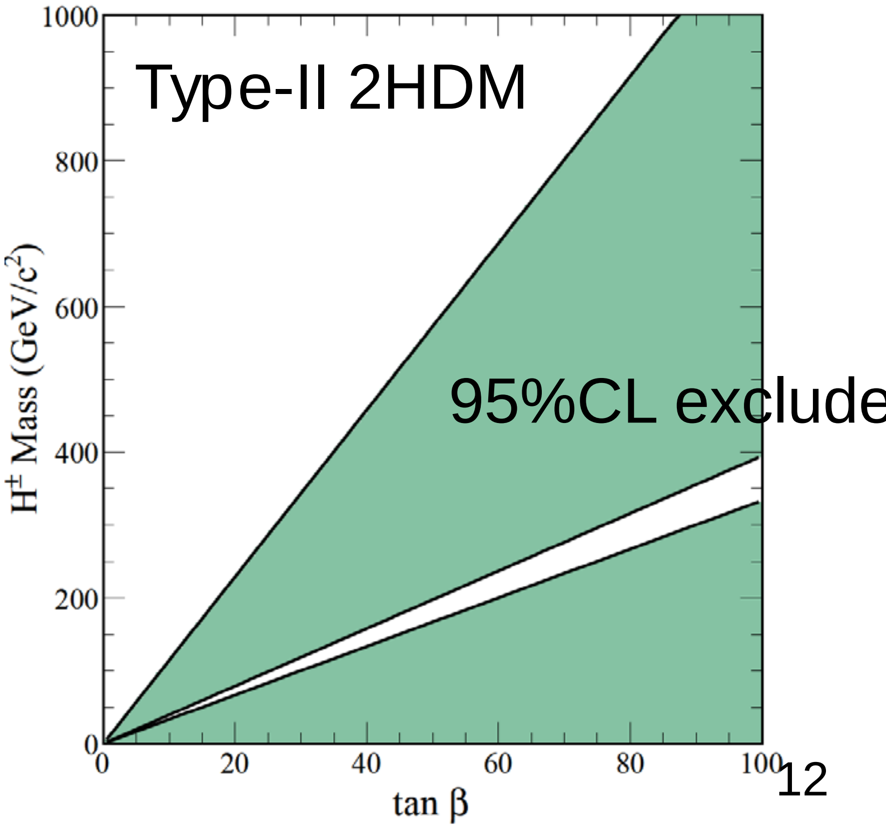
$$\tan\beta = \frac{v_u}{v_d}$$

SUSY Loop correction

$\varepsilon_0=0$ for Type-II 2HDM

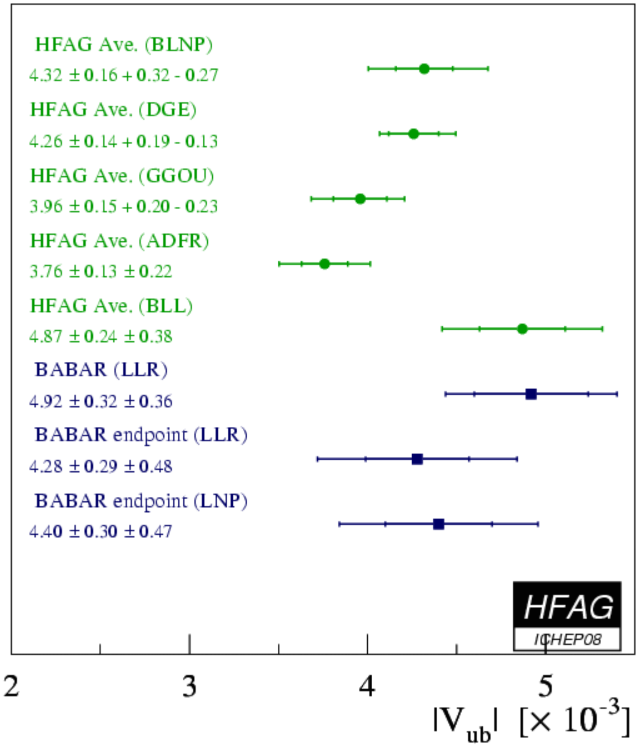


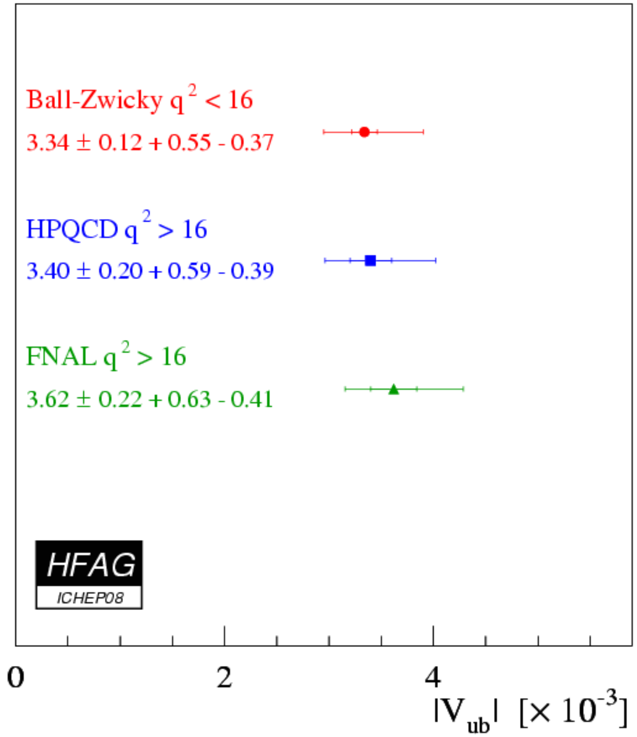
Constraint on charged Higgs



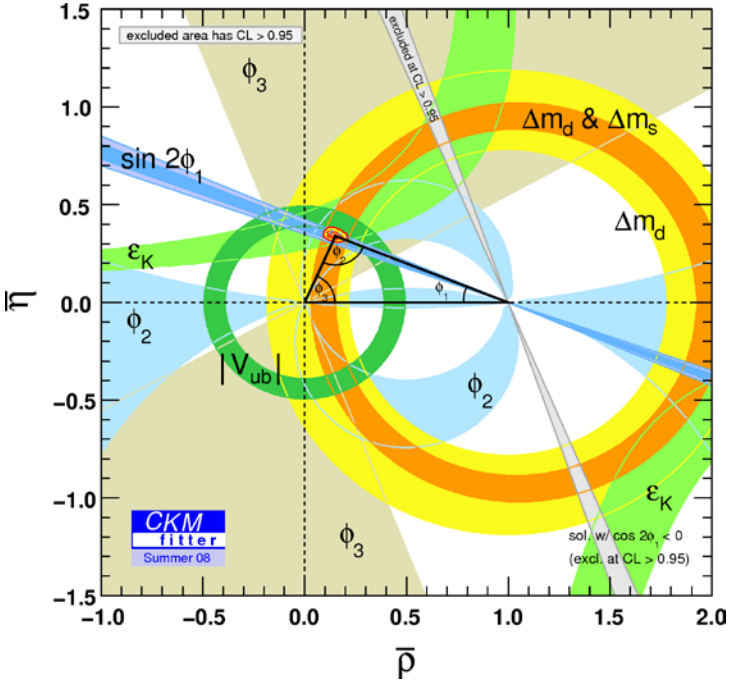
However….

- Can we rely on lattice for f_B ?
- Can we rely on $|V_{ub}|$?





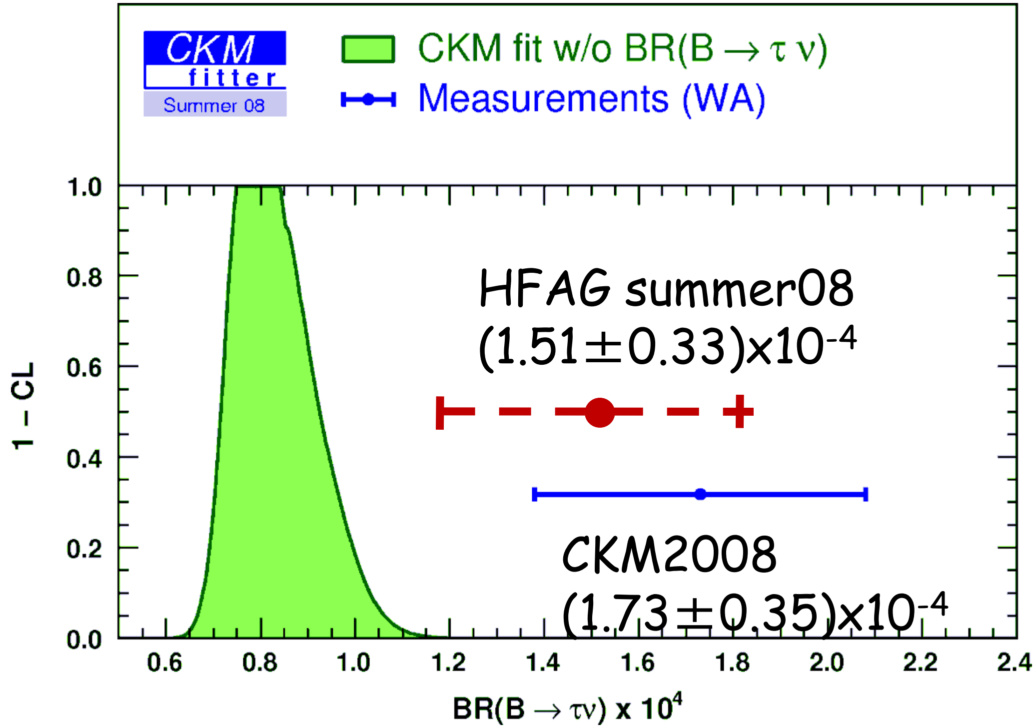
If we use CKM fit…



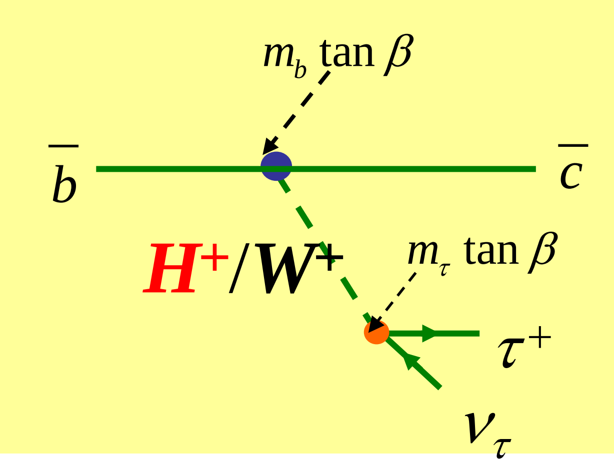
$$Br(\tau\nu)_{fit} = (0.937^{+0.096}_{-0.015}) \times 10^{-4}$$

$$Br(\tau\nu)_{fit} = (0.786^{+0.179}_{-0.083}) \times 10^{-4}$$

$\tau\nu$ is not included in the fit



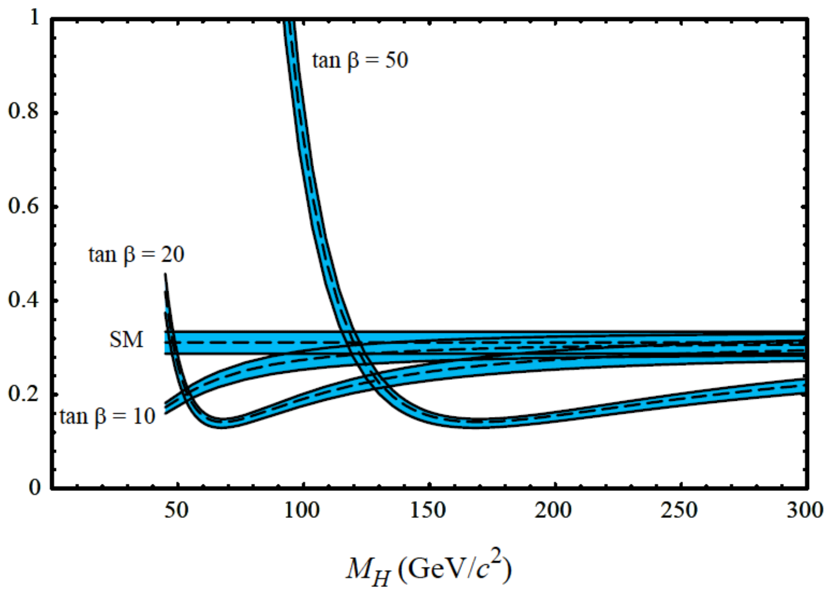
$B \to D\, \tau\, \nu$



B→D τ ν is also sensitive to H⁺, and complementary to B→τν.

- Relatively large Br ~0.8%
- Different theory systematics:
  - free from V_{ub} and f_B uncertainties.
  - depends on the B→D form factors,

$$R(D) = \frac{Br(B \to D\tau\nu)}{Br(B \to D\ell\nu)}$$



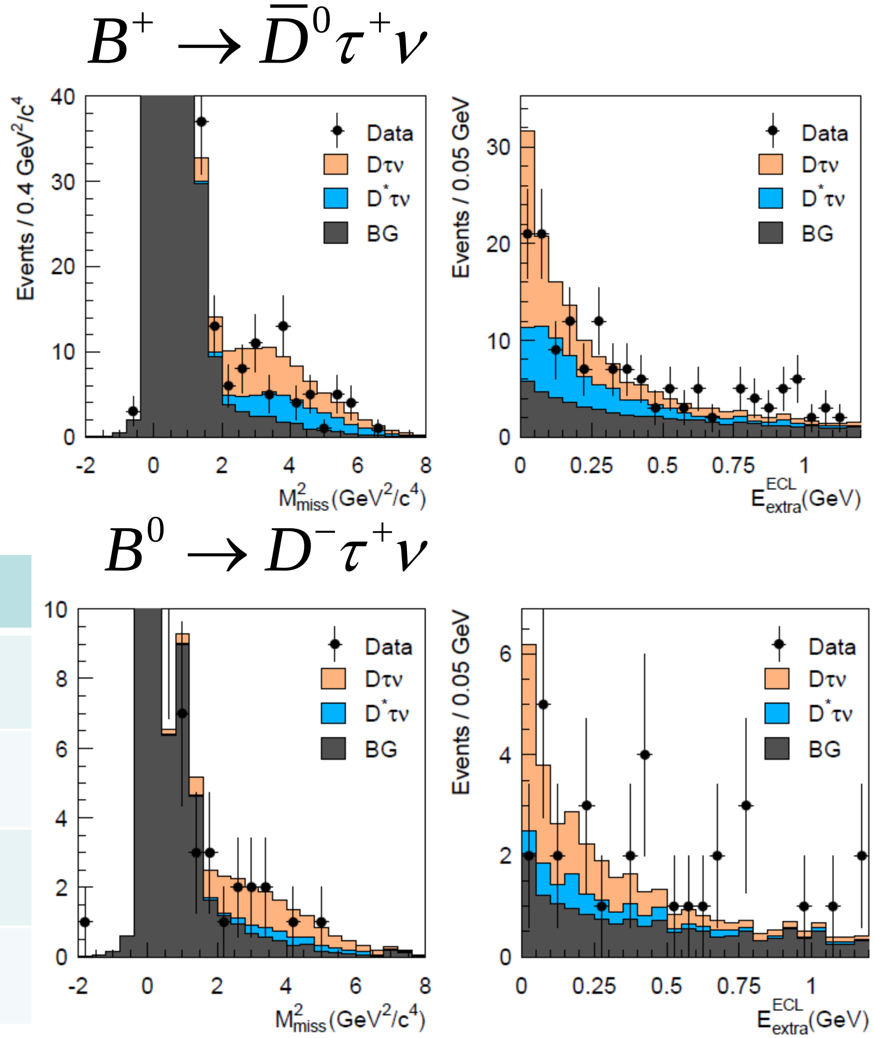
- Three-body decay permits the study of decay distributions which discriminate between W^+ and H^+ exchange. U. Nierste, S. Trine, S.Westhoff PRD78, 015006 (2008).
- Universality between H-b-c, (Dτν), H-b-u (τν), H-b-t (LHC) can be tested.

arXiv:0906.1652 (hep-ph/)
A. Cornell, A. Deandrea, N. Gaur, H. Itoh, M. Klasen, Y. Okada

$B \to D \tau \nu$ w/ by Belle

First observation of $B \to D^* \tau \nu$
w/ inclusive tag
PRL99, 191807 (2007),

- 657M BB
- Hadronic tags.
- Extract signals in (MM^2, E_{ECL}) distribution.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.



	R(%)	Ns	Signif.
$D^0 \tau \nu$	$70.2^{+18.9\ +11.0}_{-18.0\ -9.1}$	$98.6^{+26.3}_{-25.0}$	3.8(4.4)
$D^+ \tau \nu$	$47.6^{+21.6\ +6.3}_{-19.3\ -5.4}$	$17.2^{+7.7}_{-6.9}$	2.6(2.8)
$D^{*0} \tau \nu$	$46.8^{+10.6\ +6.2}_{-10.2\ -7.2}$	$99.8^{+22.2}_{-22.3}$	3.9(5.2)
$D^{*+} \tau \nu$	$48.1^{+14.0\ +5.8}_{-12.3\ -4.1}$	$25.0^{+7.2}_{-6.3}$	4.7(5.9)

$D\tau\nu$ signal

$D^*\tau\nu$ cross talk

B→Dτν: BaBar+Belle

My Naïve Average

- Belle $R(D) = [60 \pm 14(stat) \pm 8(syst)]\%$
- BaBar $R(D) = [41.6 \pm 11.7(stat) \pm 5.2(syst)]\%$
- Belle+BaBar $R(D) = [49 \pm 10]\%$

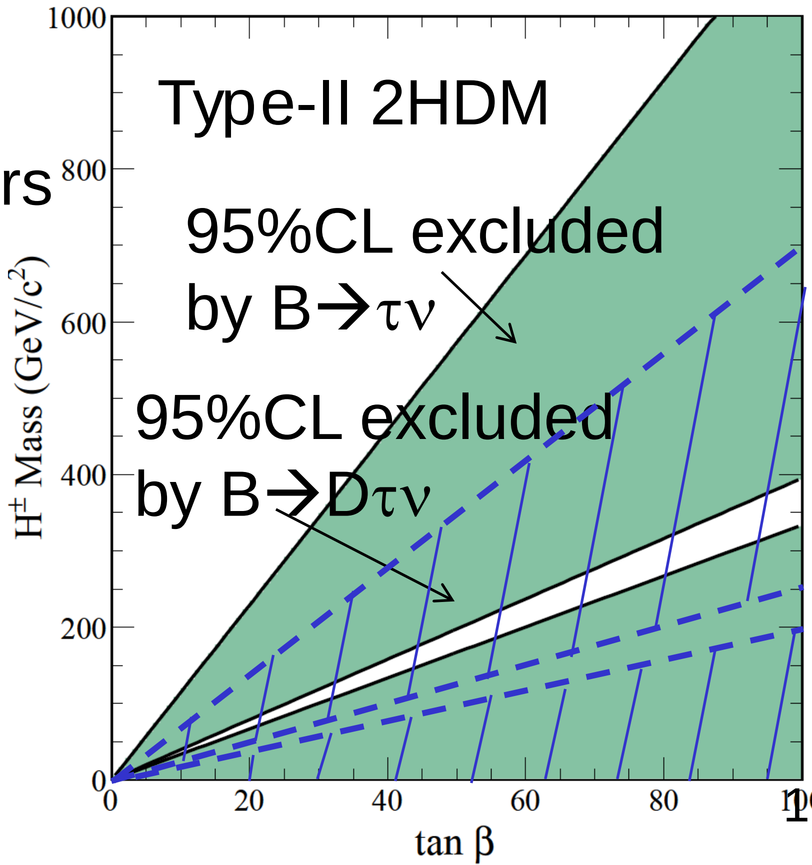
$$R(D) = \frac{Br(B \to D\tau\nu)}{Br(B \to D\ell\nu)}$$

Constraint on Charged Higgs

form factors

$$Br(B \to D\tau\nu) = G_F^2 \tau_B |V_{cb}|^2 \, f(F_V, F_S, g_S)$$

$$g_S = \frac{m_B^2}{m_H^2} \tan^2\beta \quad \text{(Type-II 2HDM)}$$



H. Itoh, S. Komine and Y. Okada, PTP 114, 179 (2005), hep-ph/0503124.
D l ν form factor reported by BaBar; arXiv: 0807.4978, 0809.0828

Sensitivity to charged Higgs

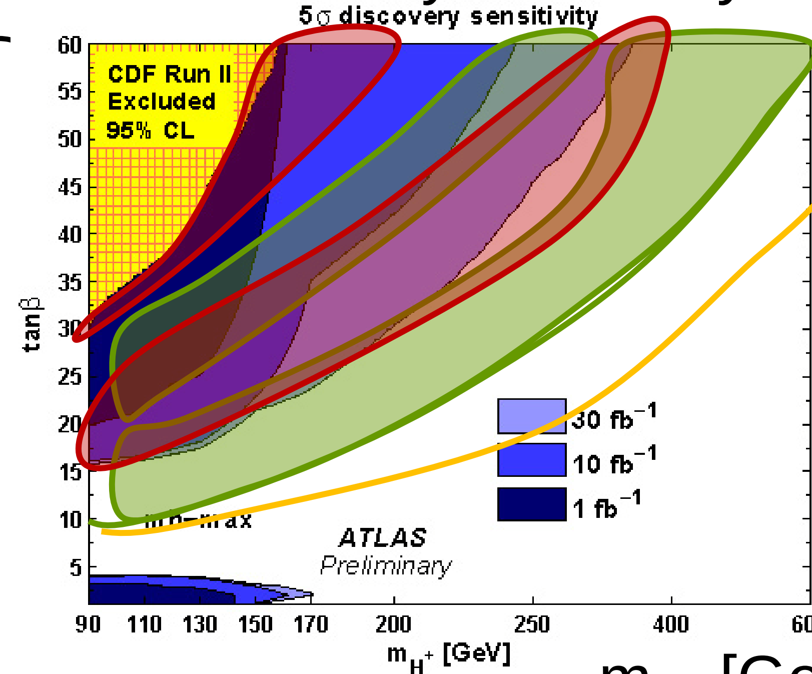
Charged Higgs boson

Atlas
Belle II, 5 ab^{-1}
Belle II, 50 ab^{-1}

- excluded currently ($Br(B \to \tau\nu)$) @ 95.5%
- 5σ discovery, Belle II, 5 ab^{-1}
- 5σ discovery, Belle II, 50 ab^{-1}

5 σ discovery sensitivity

tan β



m_{H+} [GeV]

Belle II $Br(B \to \tau\nu)$ sensitive to H^+ at large m_{H+} and tan β

at low tan β $B \to X_s \gamma$ constraints the parameters

Belle II reach @ **L** can be parametrized:

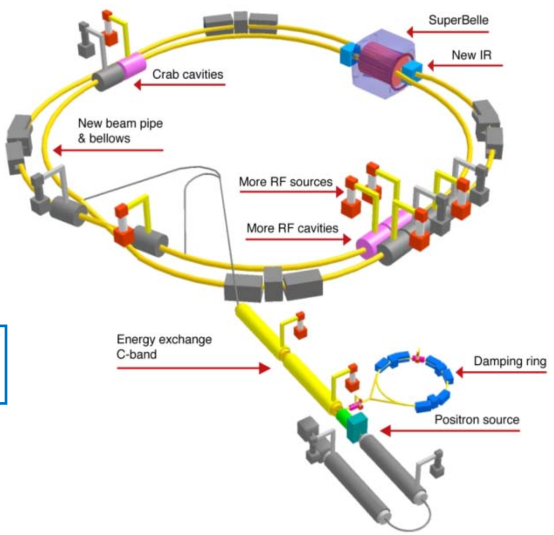
$$\tan\beta \geq 5 \cdot \sqrt{(0.5\ ab^{-1}/L)} \cdot [1 \cdot 10^{-4} GeV^{-2} \cdot (m - 90\ GeV)^2 + 12.2]$$

B.Golob

Bファクトリーのアップグレード

目標ルミノシティー = $8 \times 10^{35} cm^{-2}s^{-1}$

- RFの増強　　より高いビーム電流
- 衝突点の改良　より小さいビームサイズ



Super-KEKB

$L = 8 \times 10^{34} cm^{-2}s^{-1}$

$I_{LER/HER} = 2.96/1.70A$

$\beta_y^* = 0.22mm$

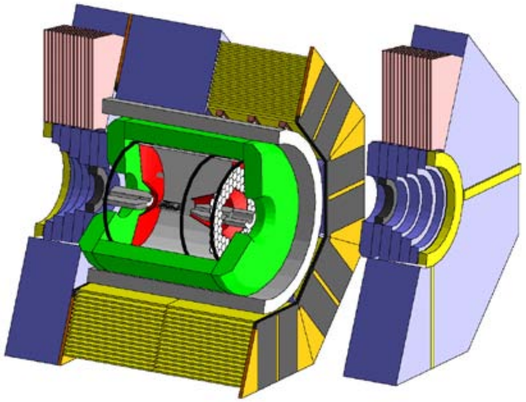
$\int Ldt = 50ab^{-1}$

$\int Ldt = 10ab^{-1}$

Three year shutdown to:

- install new beam pipe
- increase RF
- modify IR

+ Belle upgrade



Present KEKB

$L = 2 \times 10^{34} cm^{-2}s^{-1}$

$I_{LER/HER} = 1.62/0.95A$

$\beta_y^* = 5.9mm$

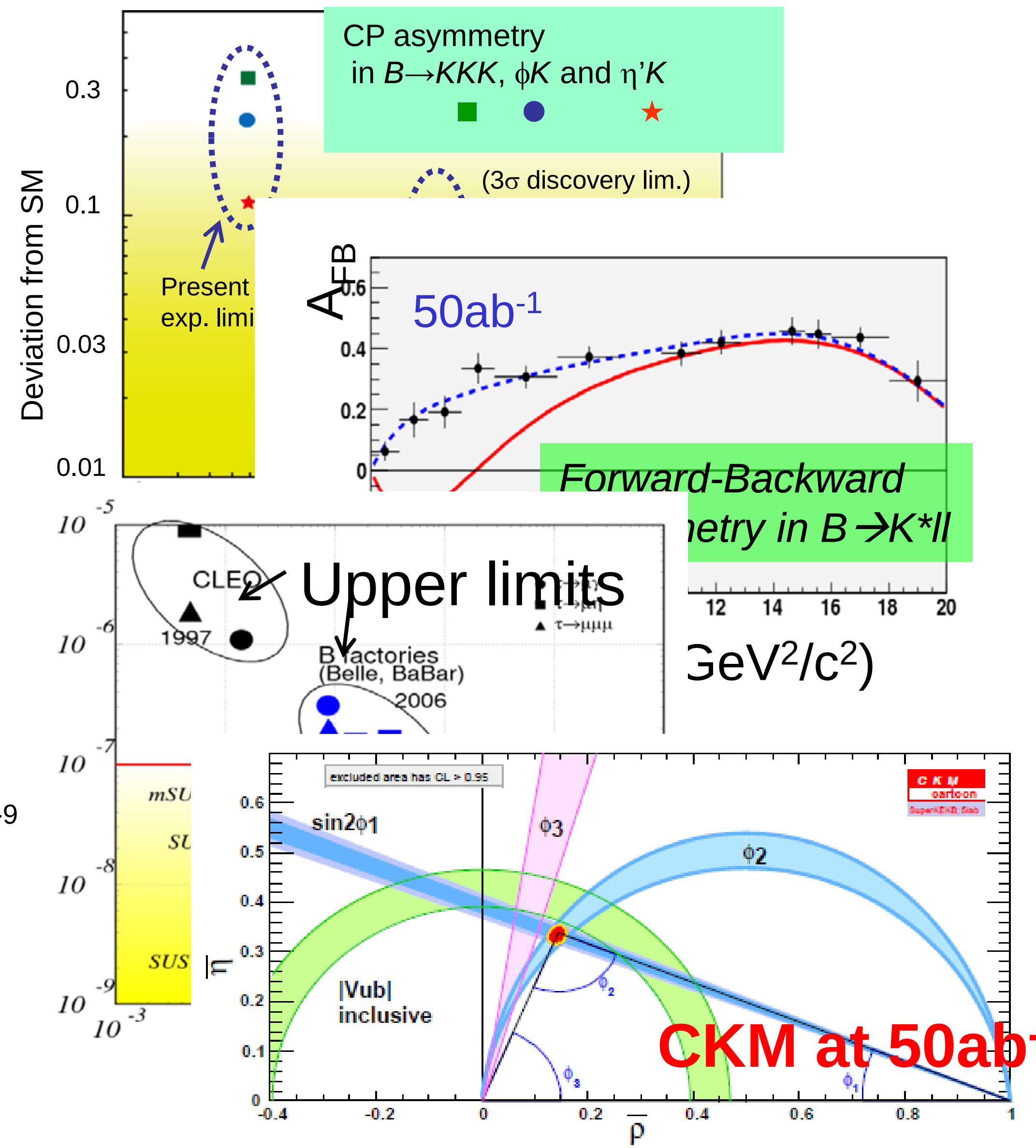
$\int Ldt = 1ab^{-}$

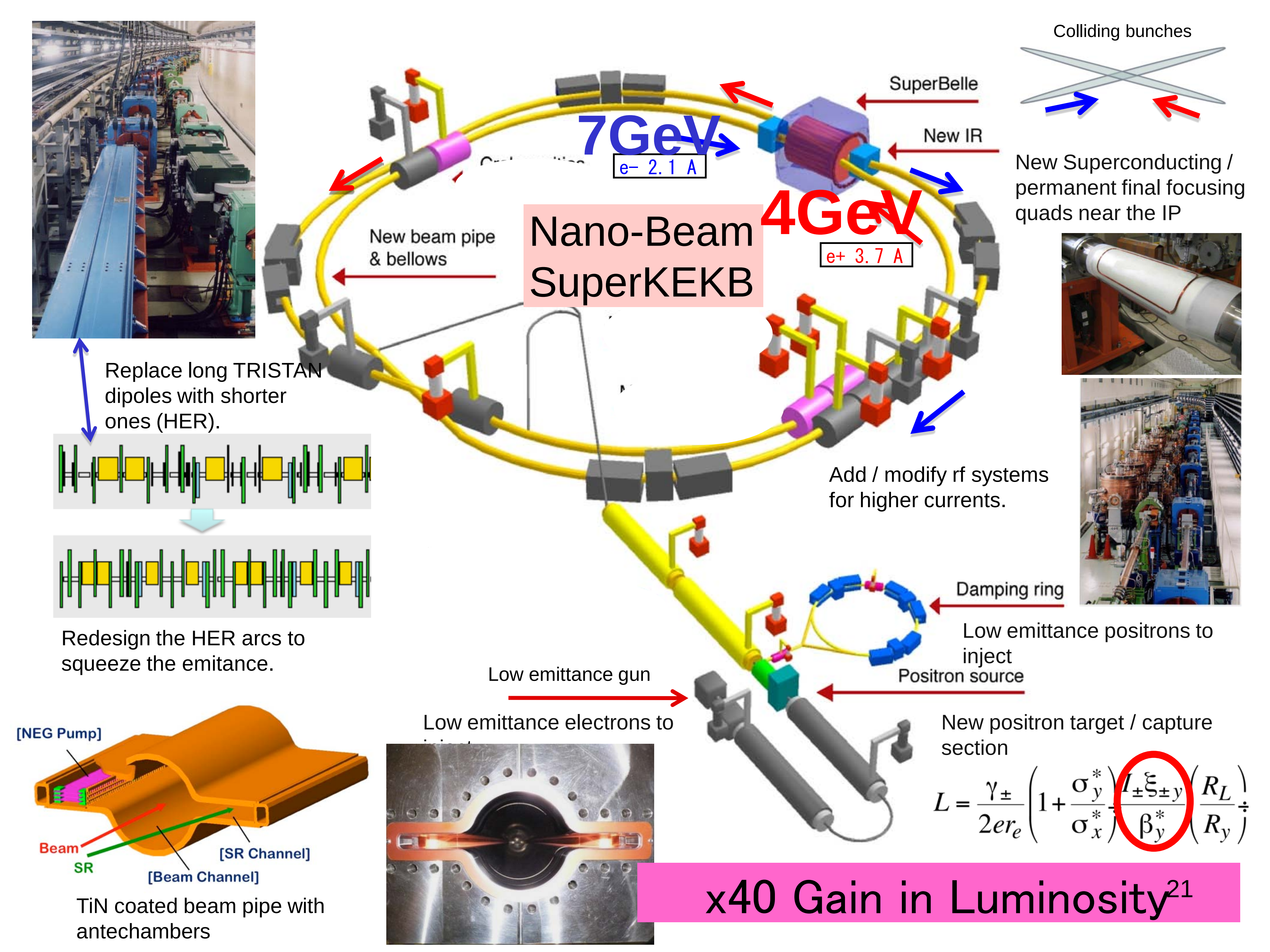
2010　2015　2020

Physics with $O(10^{10})$ B, τ, charm

Physics Reach at Super-KEKB/Belle

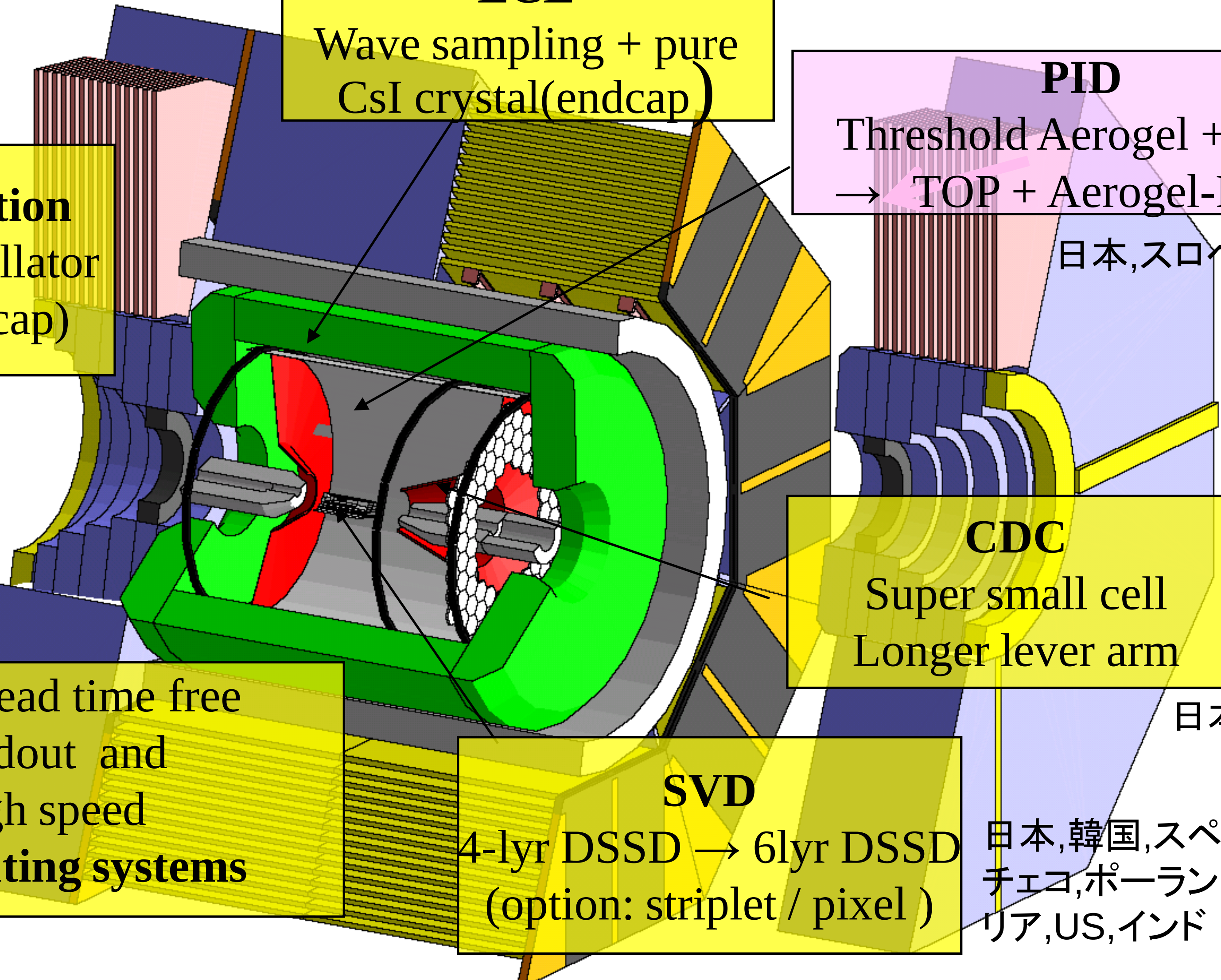
	Belle'06 (~0.5ab^{-1})	5ab^{-1}	50ab^{-1}	
$\Delta S(\phi K^0)$	0.22	0.073	0.029	
$\Delta S(\eta' K^0)$	0.11	0.038	0.020	
$\Delta S(K_S K_S K_S)$	0.33	0.105	0.037	
$\Delta S(K_S \pi^0 \gamma)$	0.32	0.10	0.03	
$Br(X_s \gamma)$	13%			
$A_{CP}(X_s \gamma)$	0.058	0.01	0.005	
C_9 [$A_{FB}(K^*ll)$]	---	11%	4%	
C_{10} [$A_{FB}(K^*ll)$]	---	13%	4%	
$Br(B^+ \to K^+ \nu\nu)$	<9Br(SM)	33ab^{-1} for 5σ discovery		
$Br(B^+ \to \tau\nu)$	3.5σ	10%	3%	
$Br(B^+ \to \mu\nu)$	<2.4Br(SM)	4.3ab^{-1} for 5σ discovery		
$Br(B^+ \to D\tau\nu)$	---	7.9%	2.5%	
$Br(\tau \to \mu\gamma)$	<45	<30	<8	
$Br(\tau \to \mu\eta)$	<65	<20	<4	$\times 10^{-9}$
$Br(\tau \to 3\mu)$	<209	<10	<1	
$\Delta \sin 2\phi_1$	0.026	0.016	0.012	
$\Delta\Phi_2$ ($\rho\pi$)	68° —95°	3°	1°	
$\Delta\Phi_3$(Dalitz)	20°	7°	2.5°	
ΔV_{ub} (incl.)	7.3%	6.6%	6.1%	




Colliding bunches
SuperBelle
New IR
7GeV
e− 2.1 A
4GeV
e+ 3.7 A
Nano-Beam SuperKEKB
New beam pipe & bellows
New Superconducting / permanent final focusing quads near the IP
Replace long TRISTAN dipoles with shorter ones (HER).
Redesign the HER arcs to squeeze the emitance.
Add / modify rf systems for higher currents.
Damping ring
Low emittance positrons to inject
Positron source
Low emittance gun
Low emittance electrons to
New positron target / capture section
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN coated beam pipe with antechambers
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$
x40 Gain in Luminosity

Belle Upgrade

Better background tolerance
Better performance



Technical Design Report　作成中

New Collaboration

2004.06: **SuperKEKB LoI**

2008.01: **KEK ロードマップ**

2008.03 **1sr プロトコラボレーションミーティング**

2008.10 **Detector design study report**

2008.12: **新実験コラボレーションキックオフ(1st. meeting)**

13 ヶ国, 43 研究機関 、スポークスマン選考中

ドイツ、チェコ、インド、US などから新たな参加

Belle II

2010.3.31-4.2 **第5回コラボレーションーティング**

まとめ

- KEKB/Belle 実験→　世界最高ルミノシティーによる成果総括へ
  - CPV, 小林益川理論の検証
  - B稀崩壊
  - τ 物理

- Super-KEKB/Belle II 実験
  - 目標ルミノシティー: **$8x10^{35}cm^{-2}s^{-1}$**
  - **B物理**
  - **タウ物理**

Heavy flavor による
新物理の探索と解明

  - **ハドロン物理（QCD）**

新しい物質の存在形態

物理は豊富。新たな価値観も。

世界最高ルミノシティー加速器の増強と、ユニークな最先端測定器によって、
電子・陽電子衝突加速器実験のフロンティアを切り開く。

若手の参加を歓迎しています。