Search for New Physics at Belle II Experiment by Global Fit

Ryosuke Itoh
KEK
(Belle/Belle II/CKMfitter/NP-Japan)

Kavli IPMU Seminar, Apr.17, 2013

Outline

1. New Physics (NP) at Belle II

2. Search for New Physics by Global Fit

3. Examples of Global Fit Analysis
   1) Determination of Unitarity Triangle
   2) Search for NP in B-$\overline{B}$ mixing
   3) Search for Charged Higgs

4. Status and Plan of Belle II and Global Fit

5. Summary

1. New Physics(NP) at Belle II

- We had been studying B meson decays at the previous Belle experiment (B-factory exp.@KEK) for more than 10 years.

- The main purpose of the Belle experiment is to establish the CP violation in B meson decays within the framework of Standard Model, as predicted by Kobayashi-Maskawa.
  -> It was confirmed by us and brought Novel prize to them.

- The purpose of Belle II upgraded from Belle is the experimental search for the signature of New Physics in B-meson decays.
  <- Indirect search for NP in "quantum effect"
- No guiding theory for promising NP search. Need a careful study of "subtle" shift from Standard Model(SM) in various measurements.

New Physics Search at Belle II : Motivation

- Up to now, there is no symptom of New Physics(NP) observed in LHC experiments. There is a possibility that the scale of NP is even more than 10 TeV, which is out of reach by LHC.

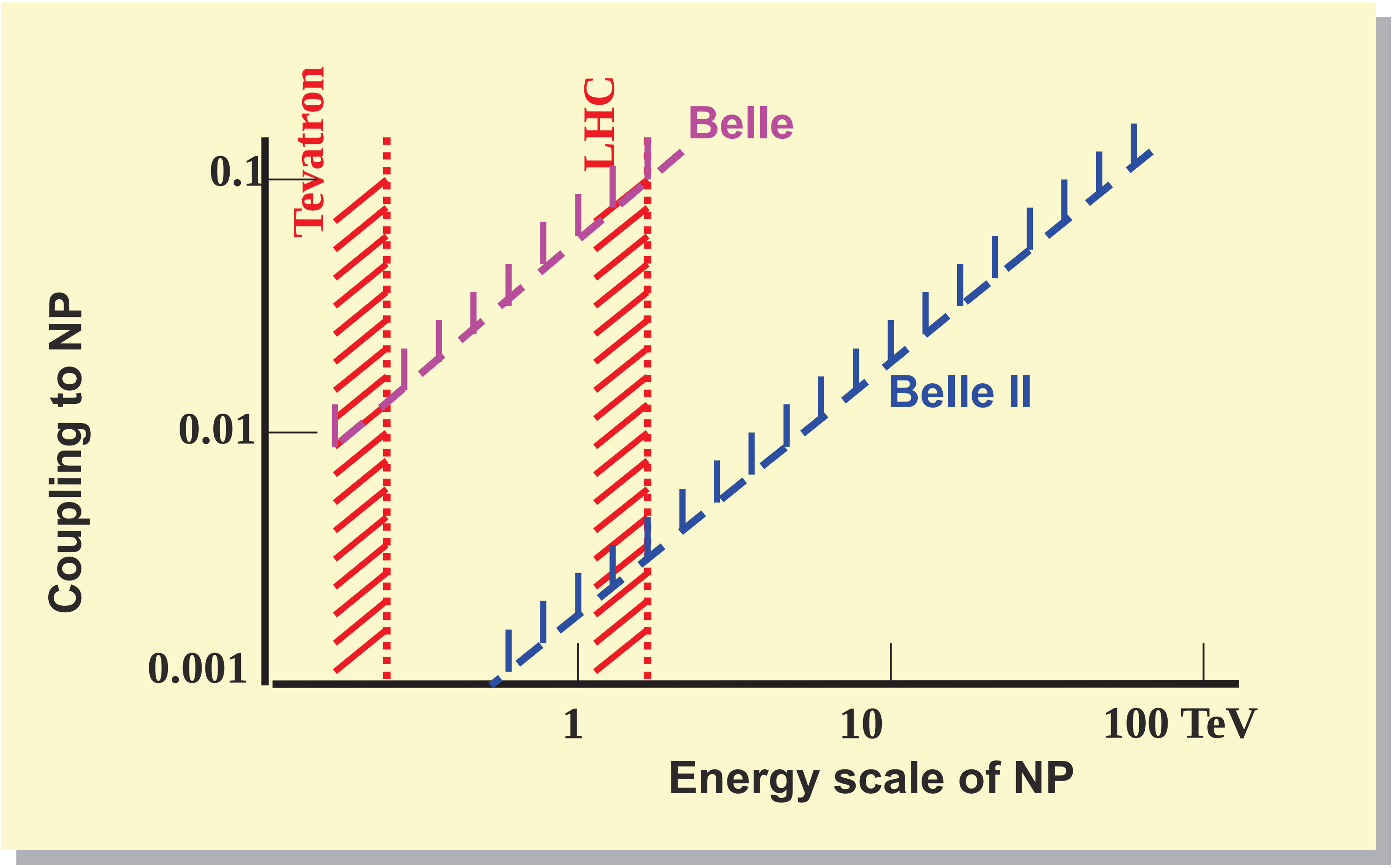
- The indirect search for NP at Belle II, where there is no limit in the search energy, will become more important.

- However, the effect of NP in the indirect processes is expected to be tiny, and it has not been observed by the Belle experiment except for several exceptions
  * $A_{CP}(B^0 \rightarrow K^+\pi^-) \neq A_{CP}(B^+ \rightarrow K^+\pi^0)$ (4σ discrepancy),
  * Large D^0-$\overline{D}^0$ mixing (although SM pred. has large uncertainties)

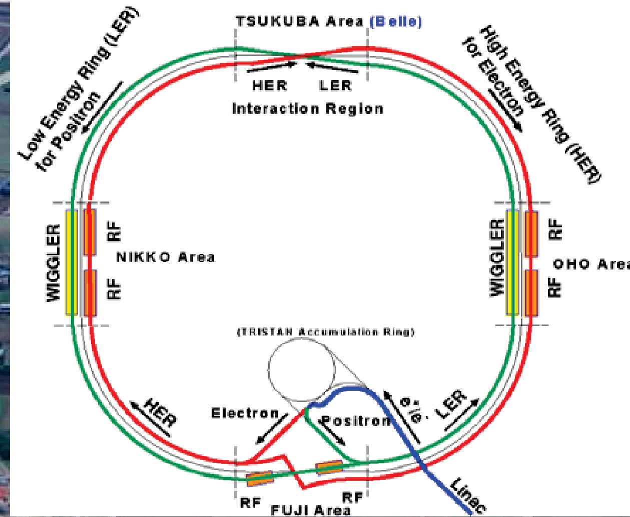
- To go beyond, an accumulation of very high statistics events is required.

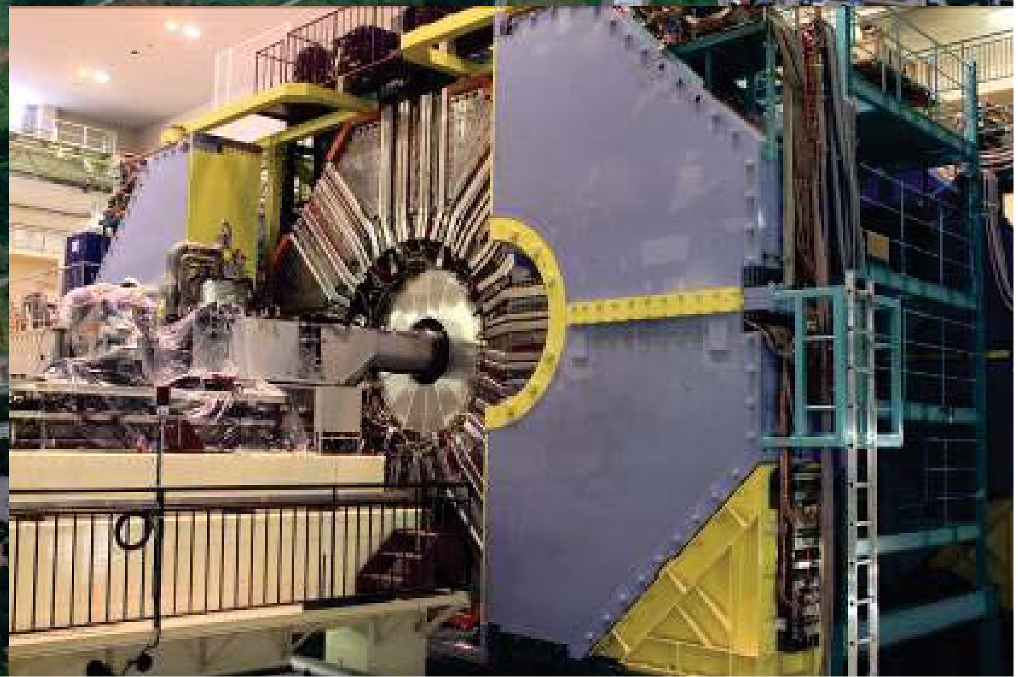
Accelerator upgrade to achieve > x40 larger luminosity. = **SuperKEKB/Belle II**

Comparison of NP sensitivity by LHC and Belle II experiments



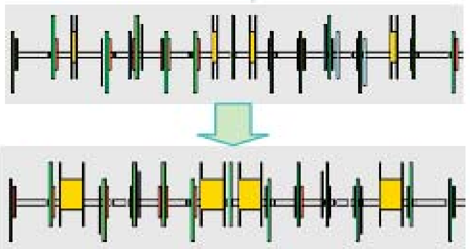
Upgrading KEKB/Belle to SuperKEKB/Belle II





The SuperKEKB accelerator

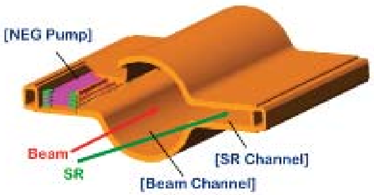
Replace short dipoles with longer ones (LER)



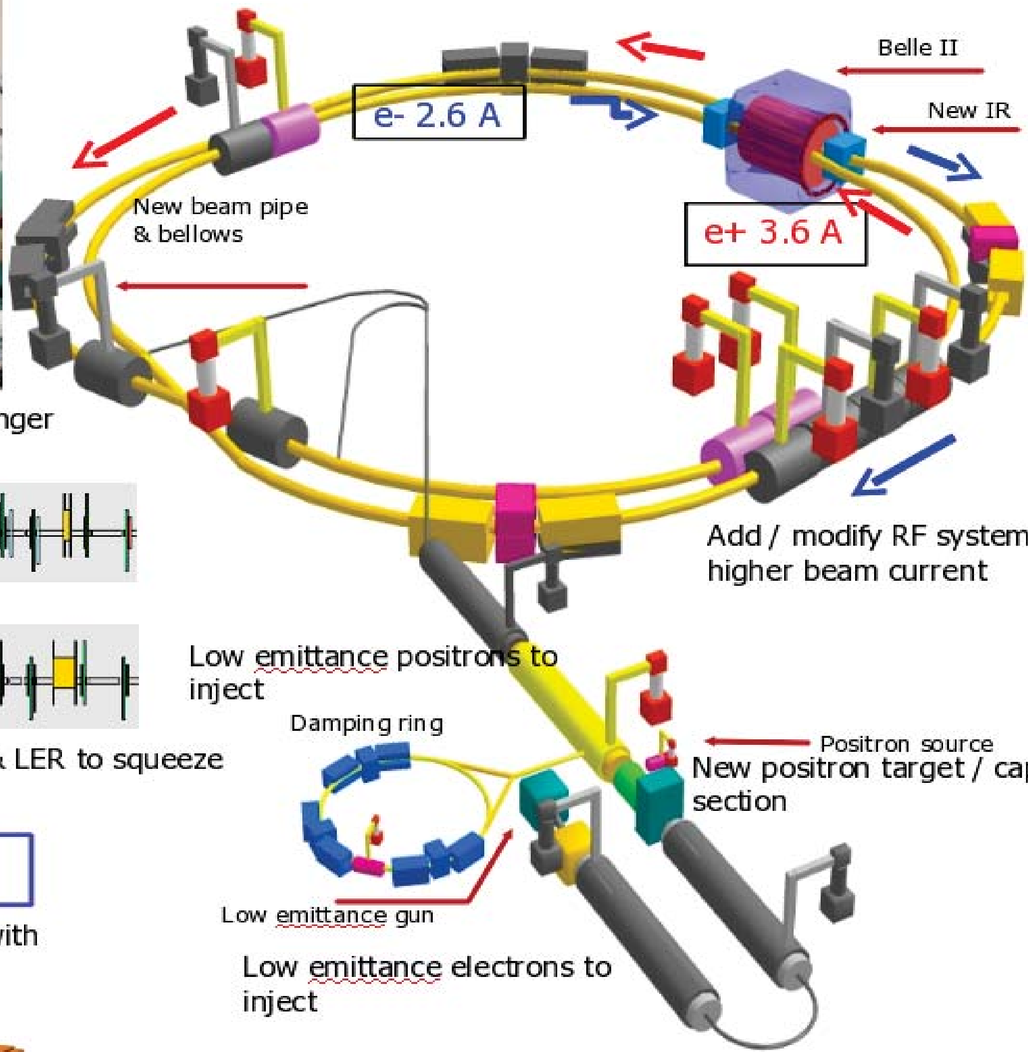
Redesign the lattices of HER & LER to squeeze the emittance

Nano-beams!

TiN-coated beam pipe with antechambers



SuperKEKB

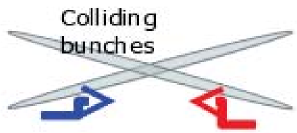


Low emittance positrons to inject

Low emittance electrons to inject

Add / modify RF systems for higher beam current

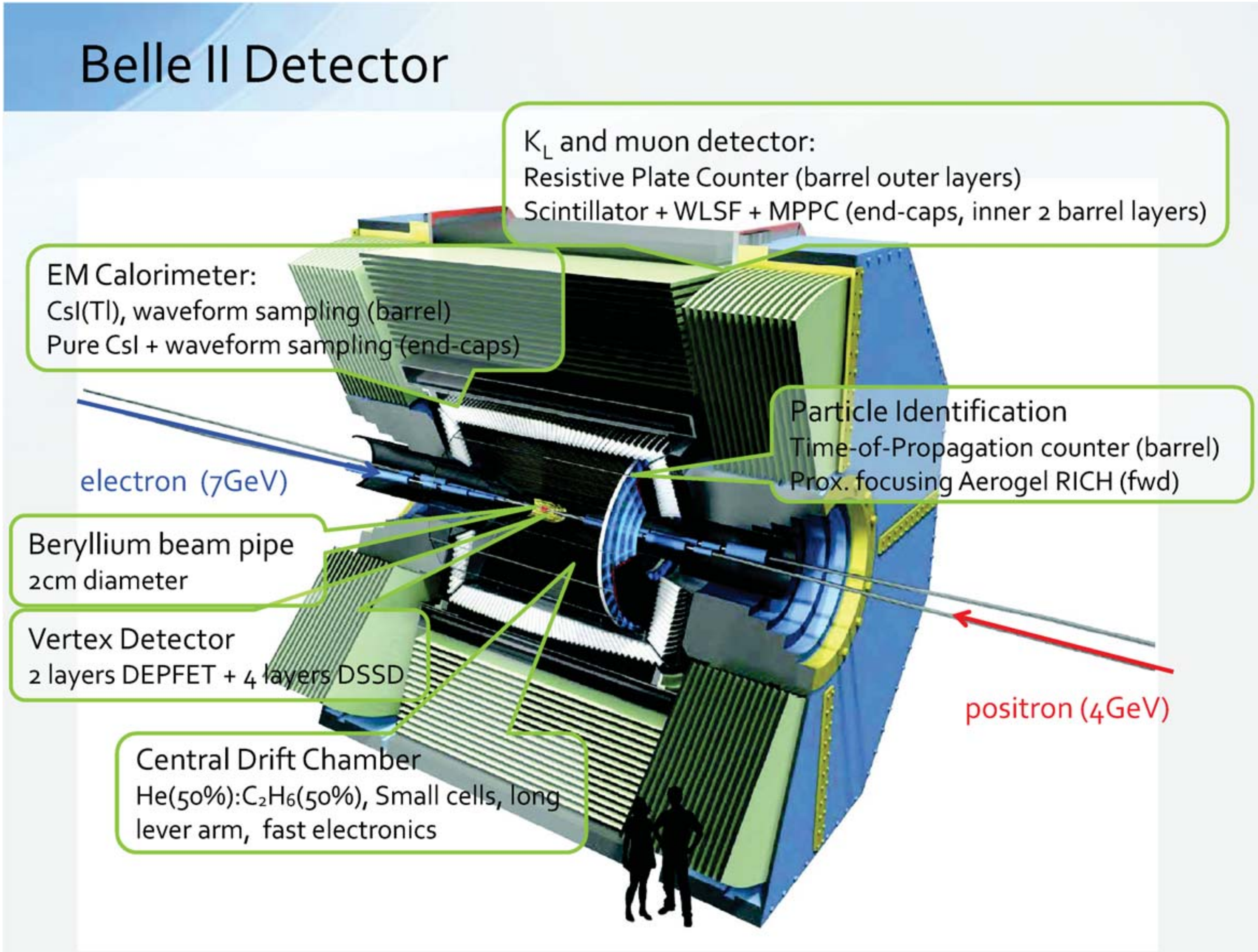
New positron target / capture section



New superconducting /permanent final focusing quads near the IP

To get x40 higher luminosity

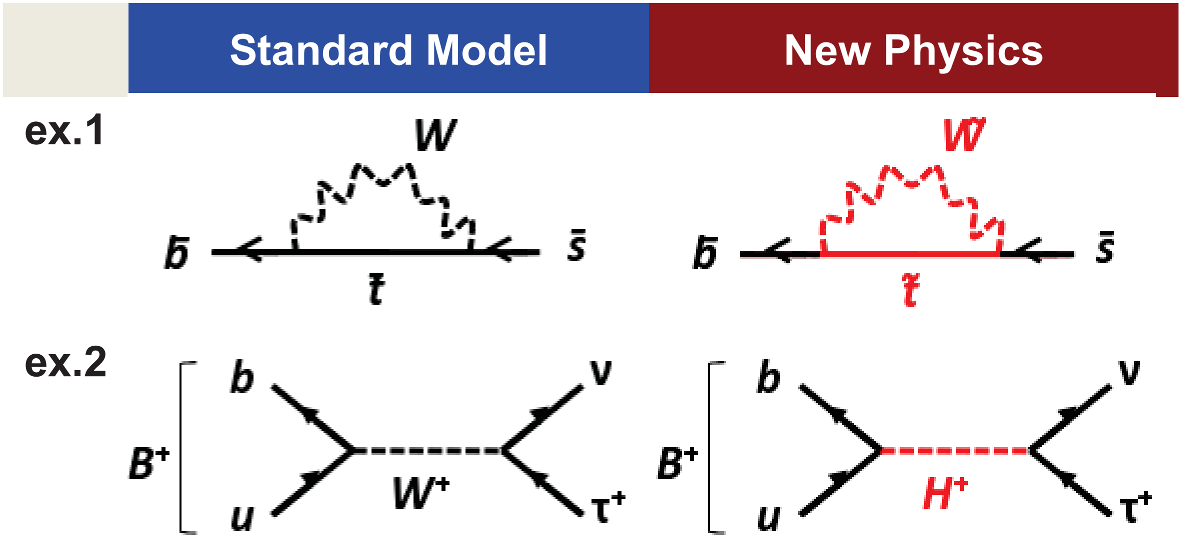
The Belle II detector



- High granularity “pixelized” sensors <- to be tolerable for high rate
    * Improved vertex detector with DEPFET Pixel sensors + DSSD
    * Improved particle ID devices (TOP, ARICH)
- High bandwidth DAQ (>30GB/sec data flow @30kHz, >1MB/event)

How do we search for New Physics at Belle II?

- Search for the “shift” from SM prediction caused by an existence of a new particle in quantum effect.



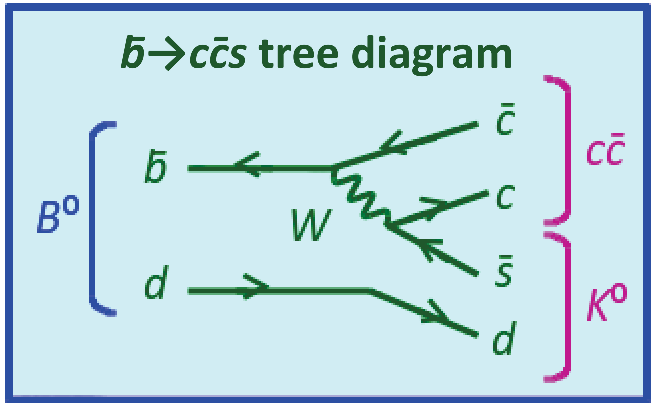
In order to search for NP, the measurement has to be compared with the Standard Model prediction in a high precision.

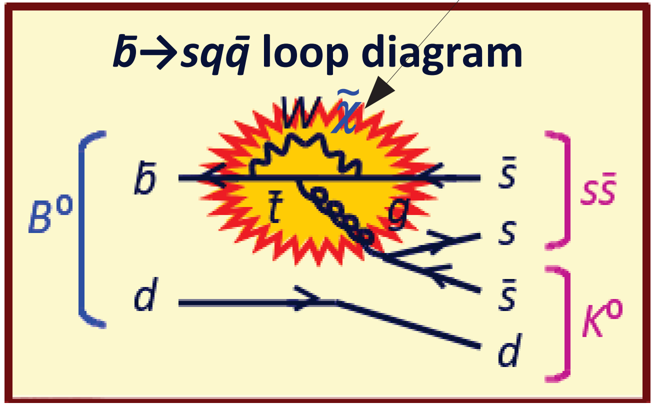
We need both of
* High precision experimental measurement
* High precision theory prediction of Standard Model

Examples of NP search at Belle II

1) CPV in b→s transition

possible contribution of
new particle





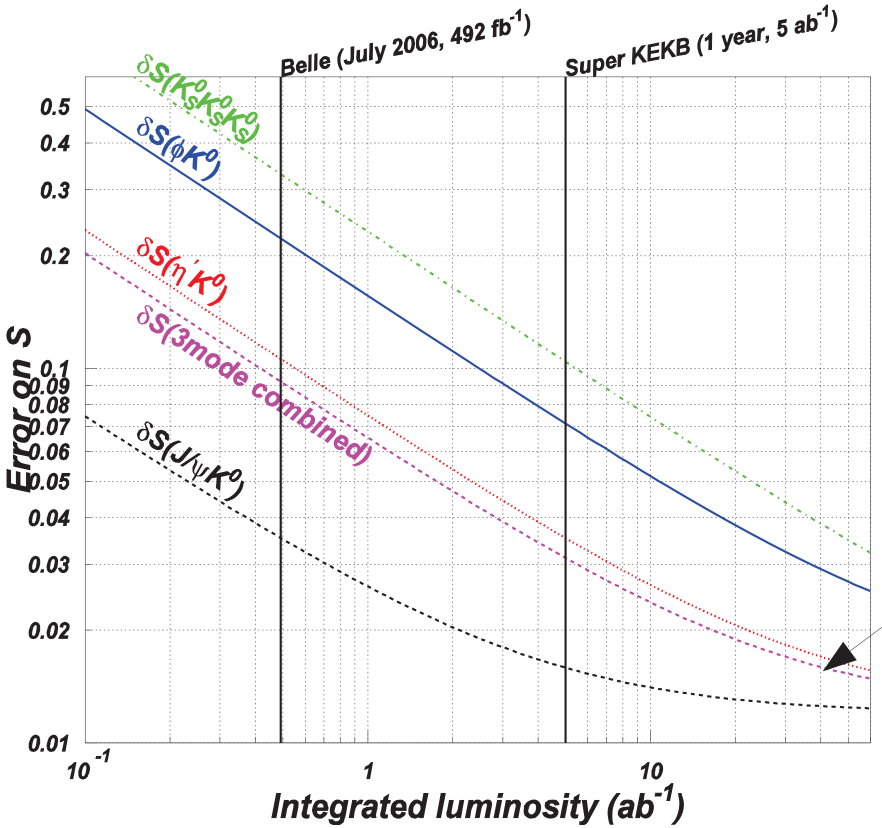
Current measurement

$\sin 2\phi_{1\ \mathrm{W.A}}^{sq\bar{q}} = +0.64 \pm 0.03$

$\sin 2\phi_{1\ \mathrm{W.A}}^{c\bar{c}s} = +0.682 \pm 0.019$

* Deviation ~0.8σ

SM predicts the same value at a precision of ~1%.

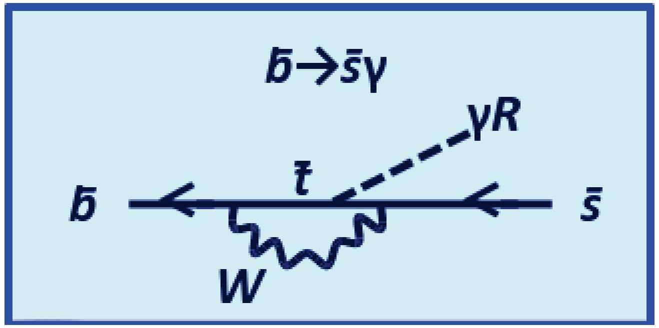


Prospect in Belle II

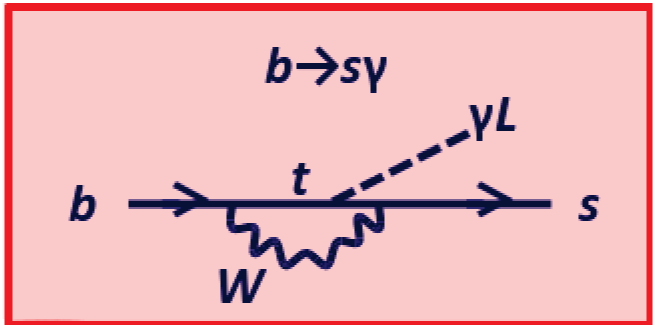
$\delta(\sin 2\phi_1 (sq\bar{q}))=$
$\sim 0.012 @ 50ab^{-1}$

* Some of systematics are cancelled by taking the difference between measurements for cc̄s and sqq̄.

2) CPV in $B^0 \to K^0_S \pi^0 \gamma$ ($b \to s\gamma$)



$\bar{b} \to \bar{s}\gamma_R$: **right handed photon**



$b \to s\gamma_L$: **left handed photon**

$$S^{\mathrm{SM}} \simeq (\sin 2\phi_1) \times \left(-\frac{2m_s}{m_b} \right)$$

$$S^{\mathrm{average}} = -0.15 \pm 0.20$$

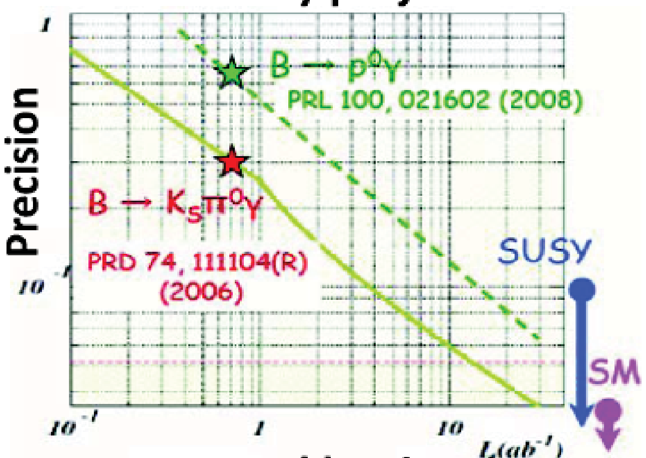
Average by Heavy Flavor Averaging Group (2009 winter).

$$S^{\mathrm{NP}} \simeq +0.67$$

A NP (left-right symmetric model) may enhance *CP* violation in this decay.

D. Atwood *et al.*, Phys. Rev. Lett. **79**, 185 (1997).

Luminosity projection

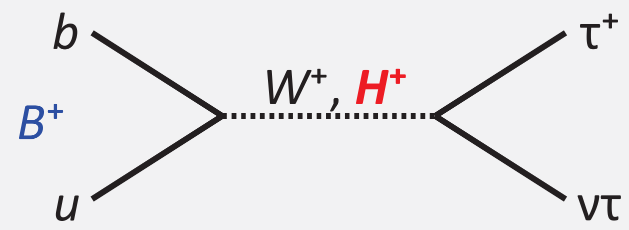


Integrated luminosity

Prospect in Belle II

$\delta(S_{b\to s\gamma}) \sim 0.09$ @ $5\mathrm{ab}^{-1}$
$\delta(S_{b\to s\gamma}) \sim 0.03$ @ $50\mathrm{ab}^{-1}$

3) Pure leptonic decay of B meson



$$r_H = \frac{Br(B \to \tau\nu)}{Br(B \to \tau\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

SM prediction

$$Br(B \to \tau\nu)_{SM} = \left(0.73^{+0.12}_{-0.07}\right) \times 10^{-4}$$

Belle Measurement

$$Br(B \to \tau\nu) = \left(0.72^{+0.27}_{-0.25} \pm 0.11\right) \times 10^{-4}$$

Prospect in Belle II

$\delta(Br) \sim 2\%$ @ $50ab^{-1}$

2. Search for New Physics by Global Fit

NP search in such “gold plated” modes might be promising.
But is this method optimized for NP search?

Pros:
* Each mode gives a clean NP signal.
* Well-defined systematic uncertainties both in measurement and theory prediction.

↕

Cons:
* It is difficult to acquire high statistics in each individual mode to conclude NP existence.
* The prediction of the single mode/measurement may depend on a specific theory (esp. hadronization) which has a possibility of some bias with a relatively large uncertainty.

-> This method may not be optimized for NP search.......

- A simple idea to improve the NP sensitivity is just to ask accelerator physicists to increase the luminosity so that we can have more statistics.

- But it is a difficult task. SuperKEKB, which is upgraded from KEKB aiming at 40 times higher luminosity, is still a challenging effort and the luminosity is not guaranteed...

- Question: How should we do to maximize the NP sensitivity with a minimal accumulation of luminosity (data)?

One Idea

- If NP exists in quantum effect, it can affect on many different measurements simultaneously.
- By combining multiple independent measurements sensitive to the same NP, we can improve the sensitivity.
- But How?

- In order to combine multiple measurements,

* Describe the NP effects in various measurements using the same parameter set in the theory and formulate the predictions using the parameters.
* Calculate sum of χ^2 between each measurement and prediction, and determine the parameter values by minimizing it.
* Study the shift in the parameter values from the standard model predictions to search for NP.

- This technique is called as the global fit.

- By using the technique, we can gain

  * An effective increase in event statistics usable for NP search,
  * To relax the dependence on a specific (hadronization) theory.

- To perform the global fit, a consistent theory model with the same parameterization to give predictions for measurements is the key.

Detail of global fit algorithm : Frequentist Approach

Experimental Likelihood

$$\mathcal{L}_{\rm exp}(x_{\rm exp} - x_{\rm theo}(y_{\rm mod})) = \prod_{i,j=1}^{N_{\rm exp}} \mathcal{L}_{\rm exp}(i,j) \ ,$$

The likelihood components $\mathcal{L}_{\rm exp}$(i) : independent Gaussians

$$\mathcal{L}_{\rm exp}(i) = \frac{1}{\sqrt{2\pi}\sigma_{\rm exp}(i)} \exp\left[-\frac{1}{2}\left(\frac{x_{\rm exp}(i) - x_{\rm theo}(i)}{\sigma_{\rm exp}(i)}\right)^2\right] \ ,$$

* Treatment of errors:

- Statistical error in measurement : Gaussian
- Experimental systematic error : Gaussian / Rfit
- Theoretical systematic error (<-$\mathcal{L}_{\rm theo}$) : Gaussian / Rfit

* Normalization of likelihood components

- Likelihood ratio

$$\lambda(\vec{x};\vec{\mu}) = \frac{\sup_{\vec{v}} \mathscr{L}(\vec{\mu},\vec{v};\vec{x})}{\sup_{\vec{\mu},\vec{v}} \mathscr{L}(\vec{\mu},\vec{v};\vec{x})},$$

- Equivalent to use "$\Delta\chi^2$" -> Use CL interval calculation

$$\Delta\chi^2(y_{\rm mod}) = \chi^2(y_{\rm mod}) - \chi^2_{{\rm min};y_{\rm mod}} \ ,$$

3. Examples of Global Fit Analysis

1) Determination of Unitarity Triangle

- In the standard model, the quark mixing is described by the Kobayashi-Maskawa matrix.

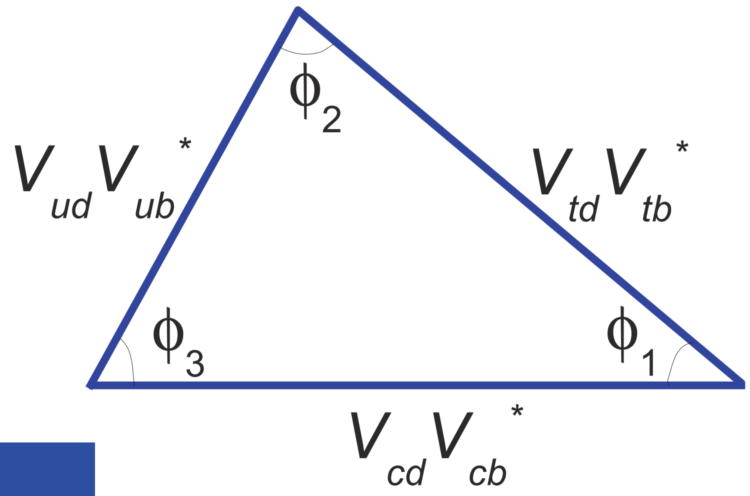
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$= \begin{pmatrix} 1-\lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

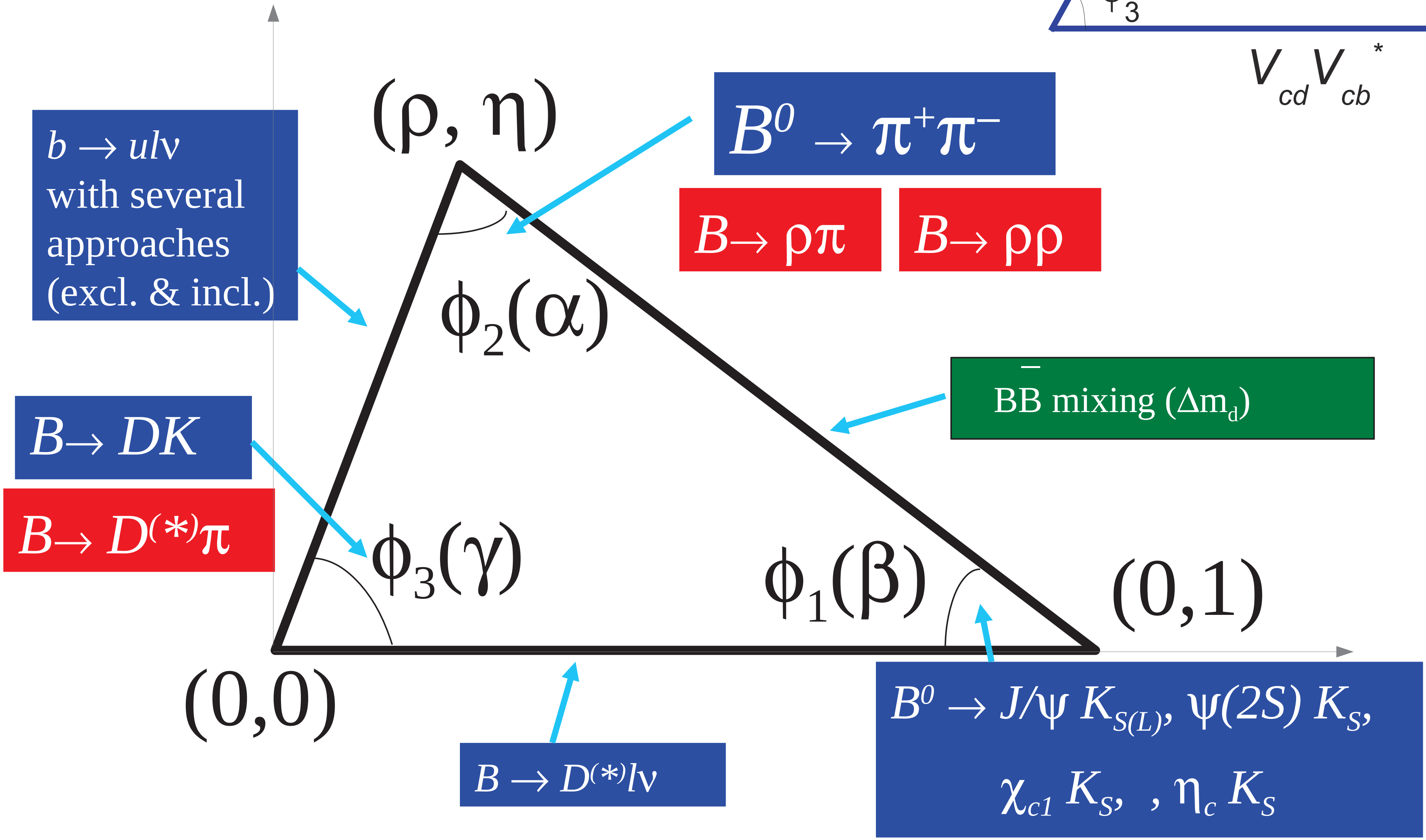
Wolfenstein Notation

- The unitarity condition $V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 1$ is expressed in a trianlge.

- In the standard mode, the origin of CP violation comes from the non-zero value of η.
- Experimental determination of apex (ρ,η) was the goal of the 1st generation B-factory experiments (Belle and BaBar).



$$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 1$$



Determination of Unitarity Triangle by CKMfitter

Parametrization

Phys. Rev. D85, 033005 (2011)

"rescaled" Unitarity Triangle

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$s_{12} \equiv \lambda$ $s_{23} \equiv A\lambda^2$ $s_{13}e^{-i\delta} \equiv A\lambda^3(\rho - i\eta)$

$$\rho + i\eta = \frac{\sqrt{1-A^2\lambda^4}(\bar{\rho} + i\bar{\eta})}{\sqrt{1-\lambda^2}\left[1 - A^2\lambda^4(\bar{\rho} + i\bar{\eta})\right]}$$

where: $\bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$

To define the triangle phase-convention independent up to all orders of λ .

➔ $A, \lambda, \bar{\rho}, \bar{\eta}$

Determine the values by the global fit
-> CKM fit

CKMfitter

Eur.Phys,J, C21,225 (2005)

* Frequentist statistics in the fit framework.
   <- conventional approach

* “Rfit (Range Fit)” treatment of systematic errors (esp. theory errors)

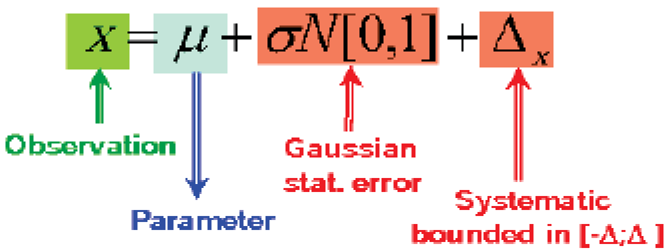
Rfit:
Uniform p-value
in the given range

■ ***RFit* scheme**

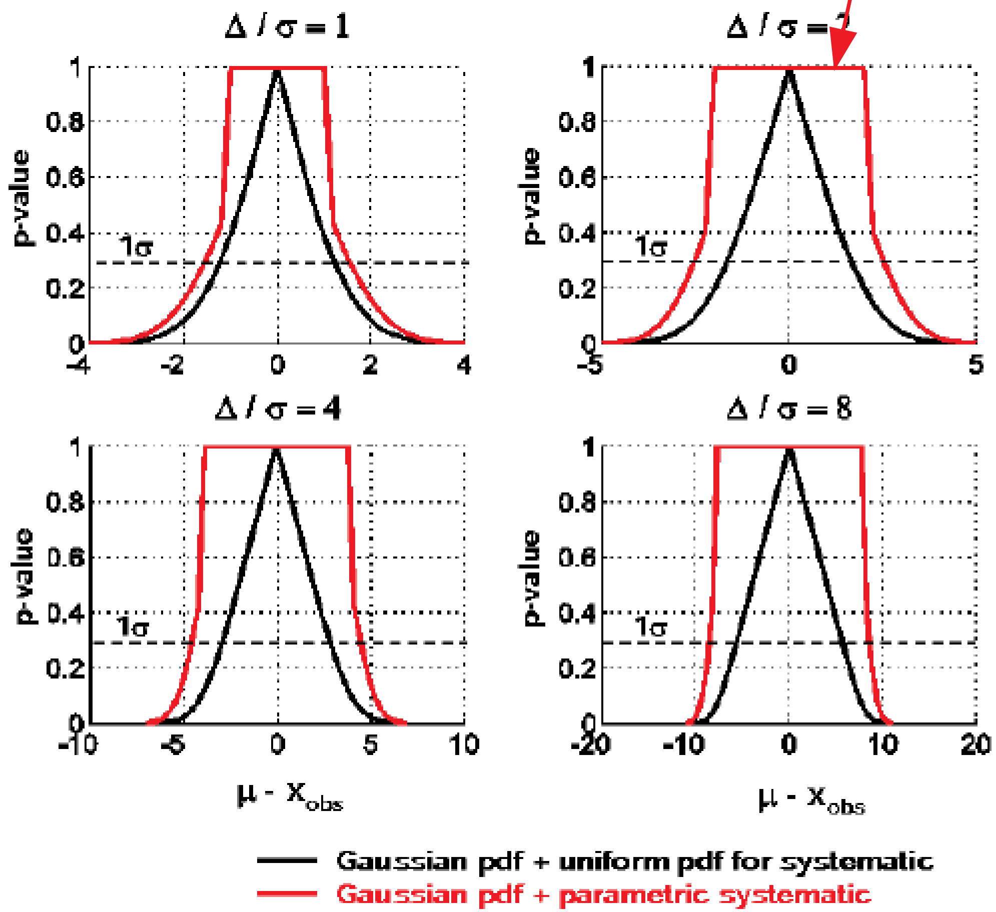
Theoretical systematics are considered as additional *nuisance parameters* bounded over a confident enough range. Considering the worst case –supremum-, on the latter interval the significance is flat.

Note that this result is very different from what one would get from a statistical modelling of the systematic (ex: uniform over the range)

Simple illustrative example allowing analytical resolution:

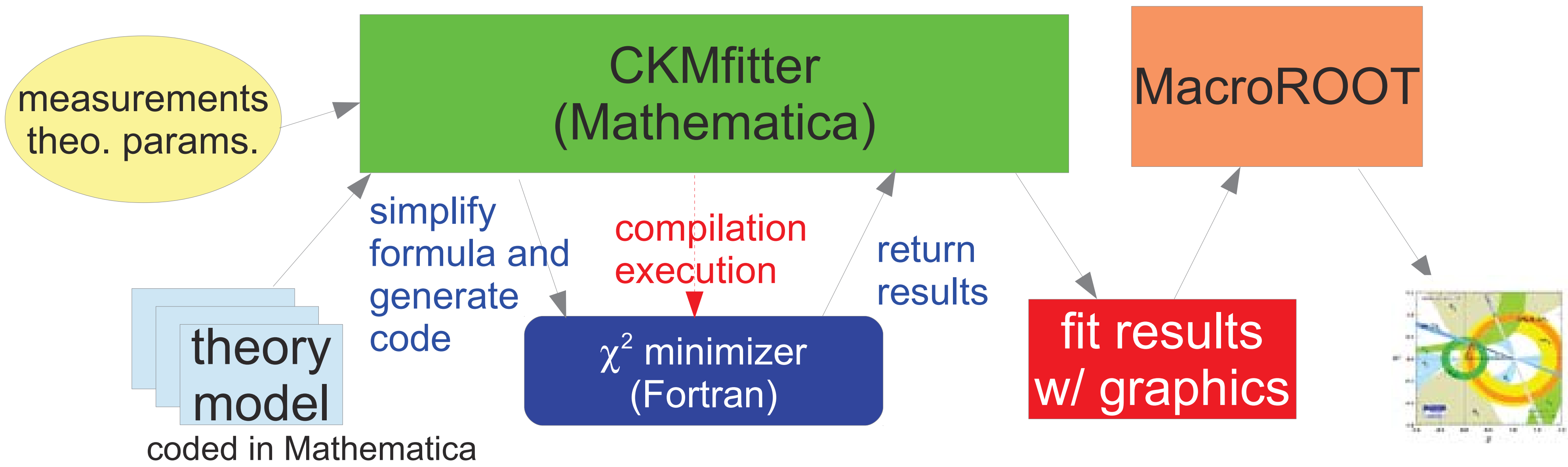


$$\text{p-value} = \begin{cases} 1 & \text{if} \quad x-\mu \in [-\Delta;\Delta] \\ \frac{1}{2}(\mathrm{erfc}[\frac{|x-\mu|+\Delta}{\sqrt{2}\sigma}] + \mathrm{erfc}[\frac{|x-\mu|-\Delta}{\sqrt{2}\sigma}]) & \text{elsewhere} \end{cases}$$



- Originally coded in Fortran and specialized in calculating unitarity triangle constraints. Minimizer : MINUIT in CERNLIB

- Rewritten in Mathematica in 2006 for speed up.
  * Analytic simplification of theoretical formula helps to reduce the calculation time. (>O(10) faster than Fortran version).
  * Generalized χ^2 minimizer



Inputs to CKM fit

- Various measurements including outside B-factory results are used for the fit.

a) B-factory measurements

* Angles :
$\sin(2\phi_1)$ (+$\cos(2\phi_1)$ for area constraint)
ϕ_2
ϕ_3

* Sides : absolute value of KM matrix elements
$|V_{ub}|$, $|V_{cb}|$

* B_d Mixing
Δm_d

* Leptonic/radiative decay
$Br(B\text{->}\tau\nu)$

B-factory measurements for CKMfit

1) $|V_{cb}|$ and $|V_{ub}|$

- We measure

$$\Gamma(B \to X_u \ell\nu) \times f_C = |V_{ub}|^2 \zeta_C$$

Total b → ulν rate

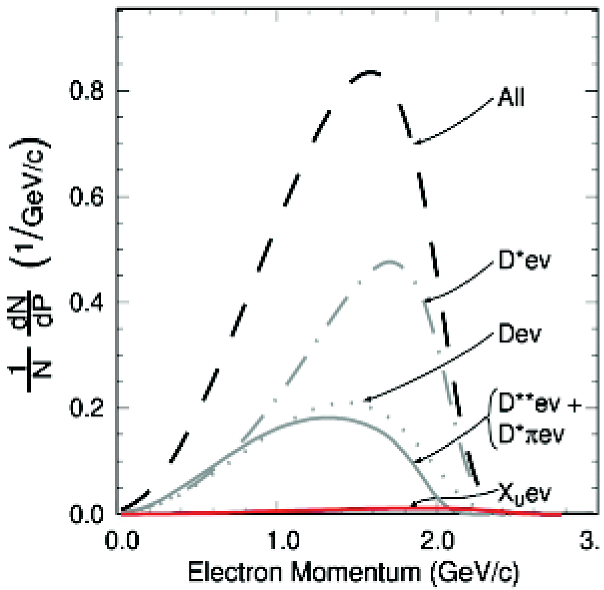
Fraction of the signal that pass the cut

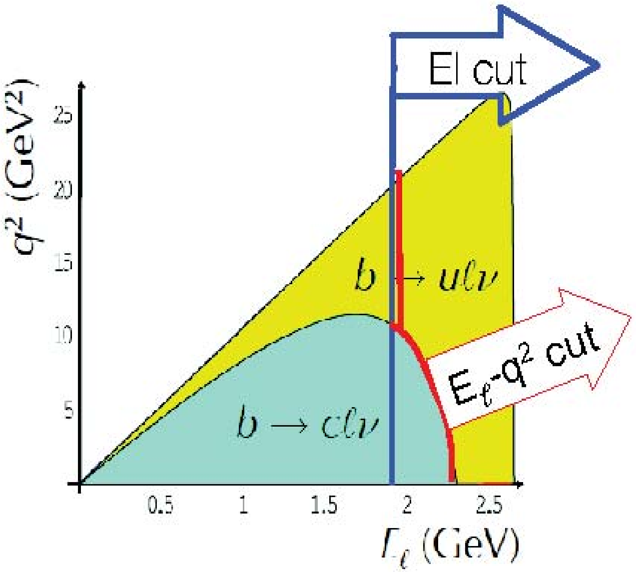
Requires the knowledge of the b quark's motion inside the B meson

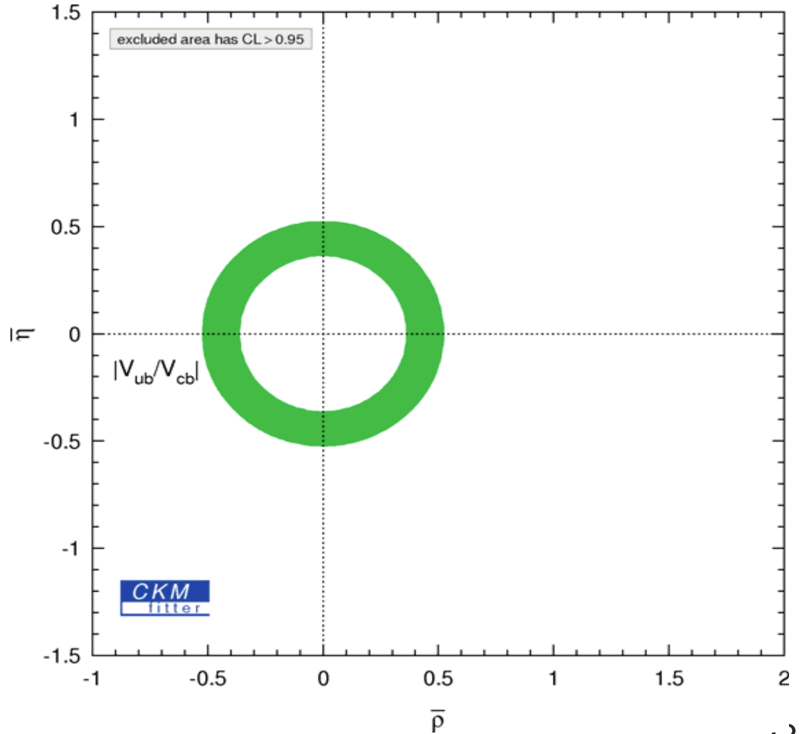
Cut-dependent constant predicted by theory

	exclusive	inclusive
$b \to u$	$B \to \pi \ell\nu$	$B \to X_u \ell\nu$
$b \to c$	$B \to D^* \ell\nu$	$B \to X_c \ell\nu$
dominant uncertainties	Form factor	OPE ($\lvert V_{cb,ub}\rvert$) and shape function ($\lvert V_{ub}\rvert$)

$$\frac{\Gamma(b \to u l\nu)}{\Gamma(b \to c l\nu)} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

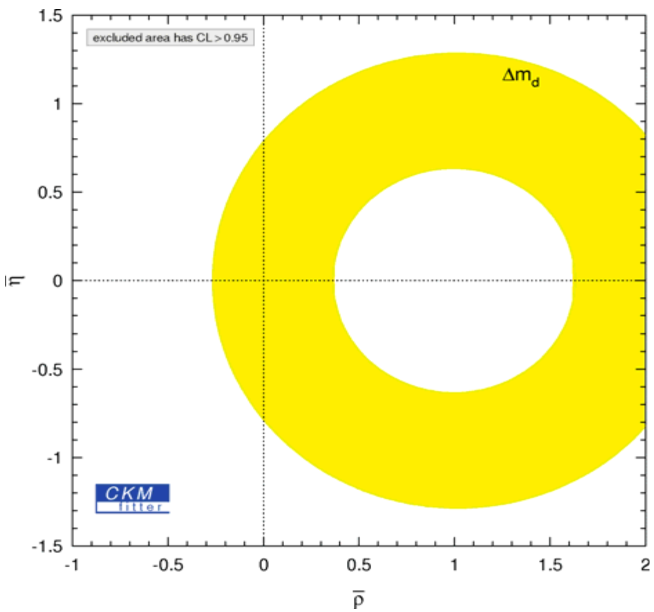


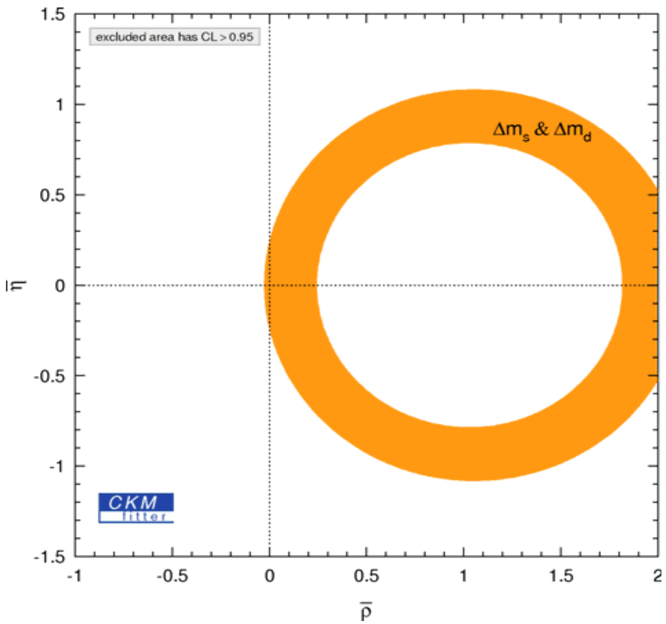




- $|V_{ub}|$ ($\to \rho^2+\eta^2$) is crucial for the SM prediction of $\sin(2\beta)$
- $|V_{cb}|$ ($\to A$) is important in the kaon system (ε_K, BR($K\to\pi\nu\nu$), …)

2) Δm_d and Δm_s





$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_W^2 \eta_B S_0(x_t) f_{B_d}^2 B_d \left|V_{td} V_{tb}^*\right|^2 \propto A^2 \lambda^6 \left[(1-\bar{\rho})^2 + \bar{\eta}^2\right]$$

$$\Delta m_s = \frac{G_F^2}{6\pi^2} m_{B_s} m_W^2 \eta_B S_0(x_t) f_{B_s}^2 B_s \left|V_{ts} V_{tb}^*\right|^2$$

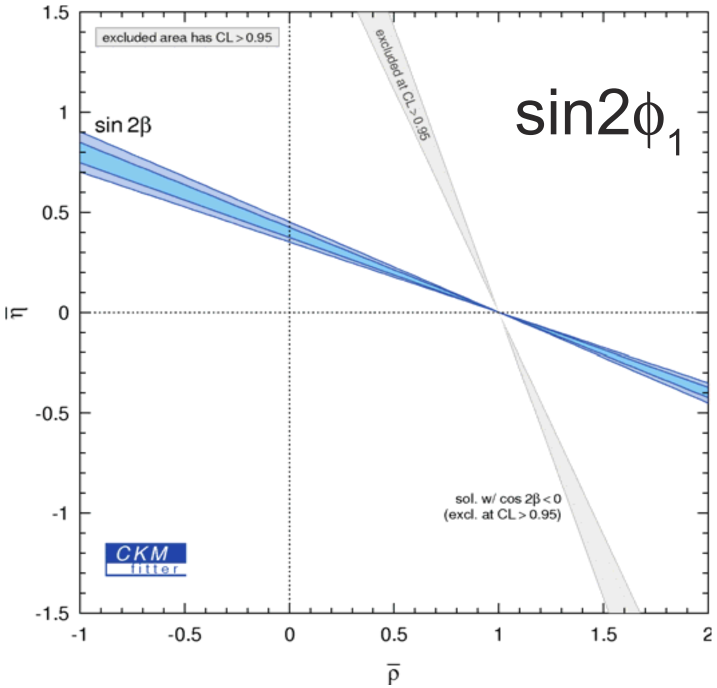
This does not give a strong constraint in (ρ,η) alone.

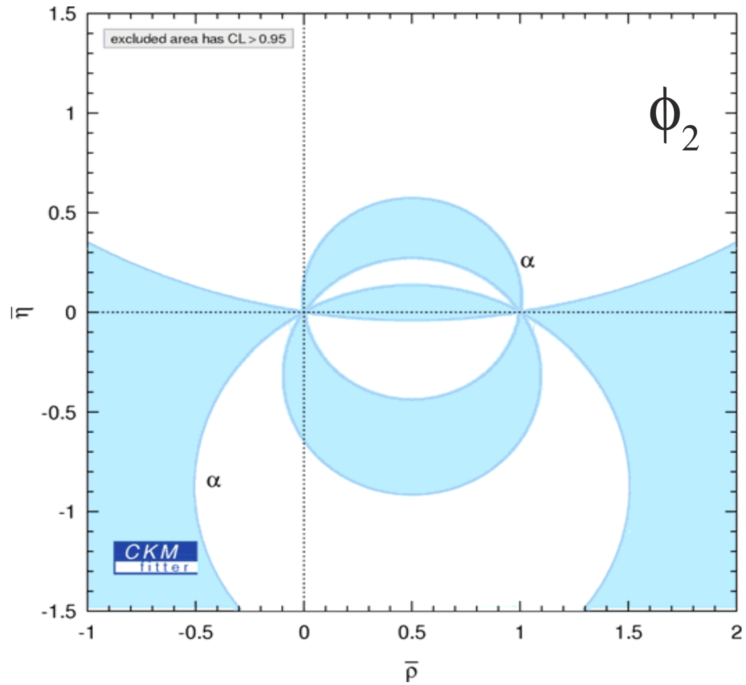
The point is:

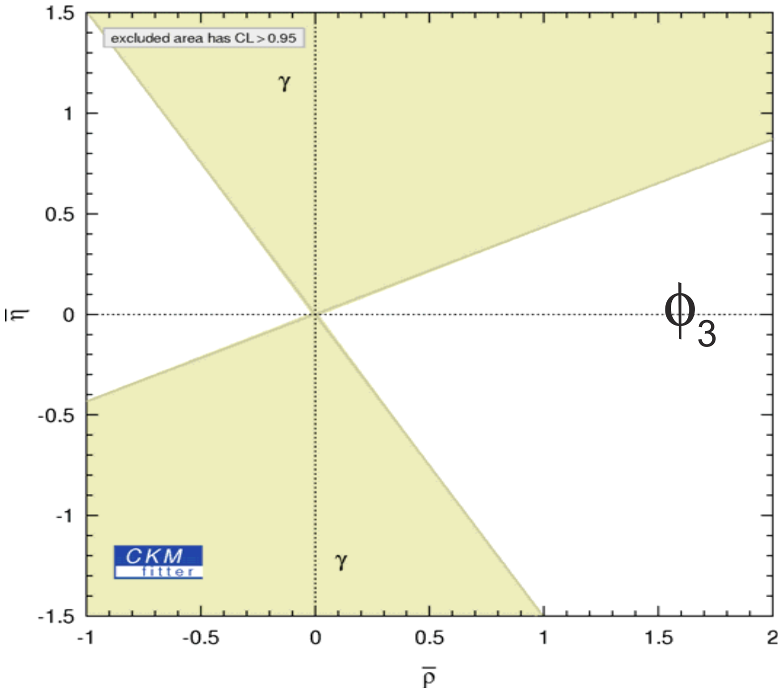
$$f_{B_s}^2 B_s = \frac{f_{B_s}^2 B_s}{f_{B_d}^2 B_d} f_{B_d}^2 B_d = \xi^2 f_{B_d}^2 B_d$$

$\sigma_{\rm rel}\left(f_{B_{d/s}}^2 B_{d/s}\right) = 36\%$ → $\sigma_{\rm rel}\left(\xi^2 = f_{B_s}^2 B_s / f_{B_d}^2 B_d\right) = 10\%$

3) Angles of UT







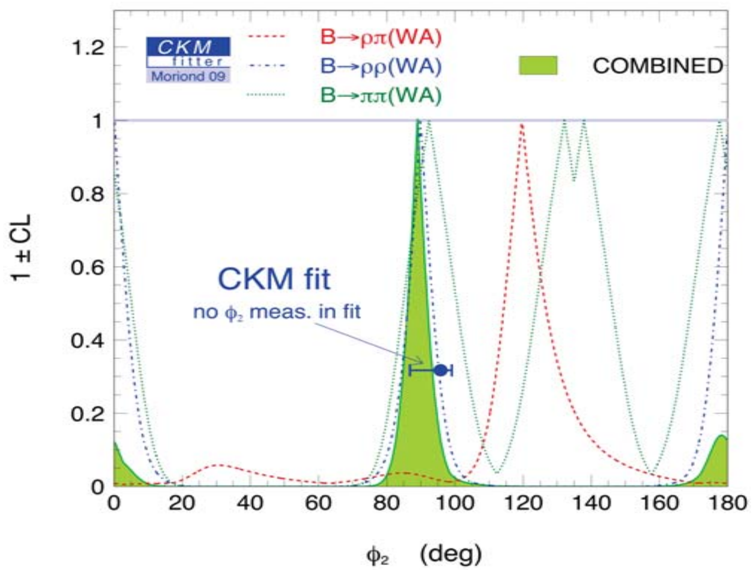
Averaging measurements

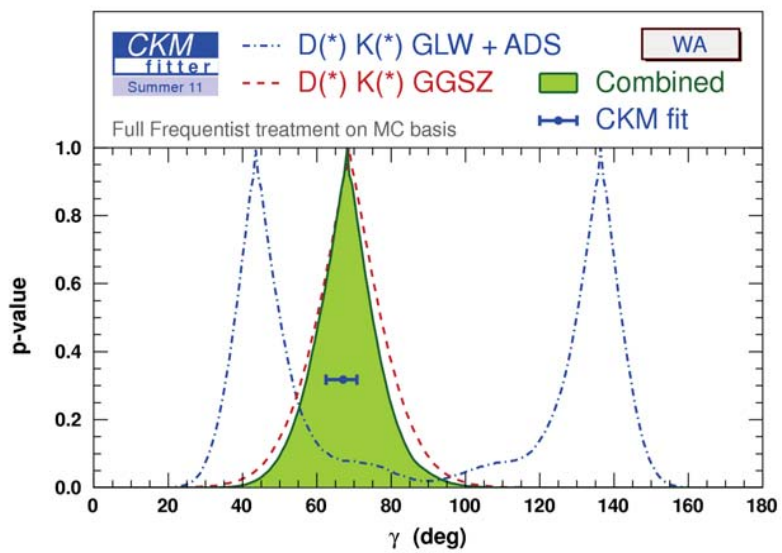
- To use measurements of a quantity by different experiments in the fit, the measurements have to be averaged.

- Many measurements are already averaged by HFAG group.

- However, the error treatment is not simple in some measurements and a simple averaging cannot be used for them.
  * ex. Measurements of CP angles ϕ_2 and ϕ_3 have multiple central values with non-gaussian errors. The likelihood function is provided by each experiment group for such a case.

-> A toy Monte Carlo simulation is performed and the average and error are estimated based from the result.





b) Non B-factory measurements:

* ε_K : Kaon CPV parameter from Kaon experiments
* Δm_s : Bs mixing parameter from Tevatron / LHCb
* $|V_{ud}|$
* $|V_{us}|$
* MSbar quark mass
* α_s

....

c) Theory parameters

- To obtain theory predictions, a variety of parameters in hadronization theories have to be provided and included in the global fit as input parameters.

Examples:

* f_B, B (structure constant and Bag parameter) for $\Delta m_{(d,s)}$
* Form factors to convert Br measurements into V_{ub}, V_{cb}
* B_K, η_{ct}, η_{tt} for ε_K

etc.

- Most of them are obtained by Lattce QCD calculaton, where the errors is supposed to be non-gaussian.
  -> Rfit treatment.

- They still have relatively large errors, and they can directly affect on the NP sensitivity in Belle II.

Estimated TH errors 2015

S. Sharpe, U.S. Lattice QCD executive committee
V. Lubicz, talk given at the IV SuperB workshop

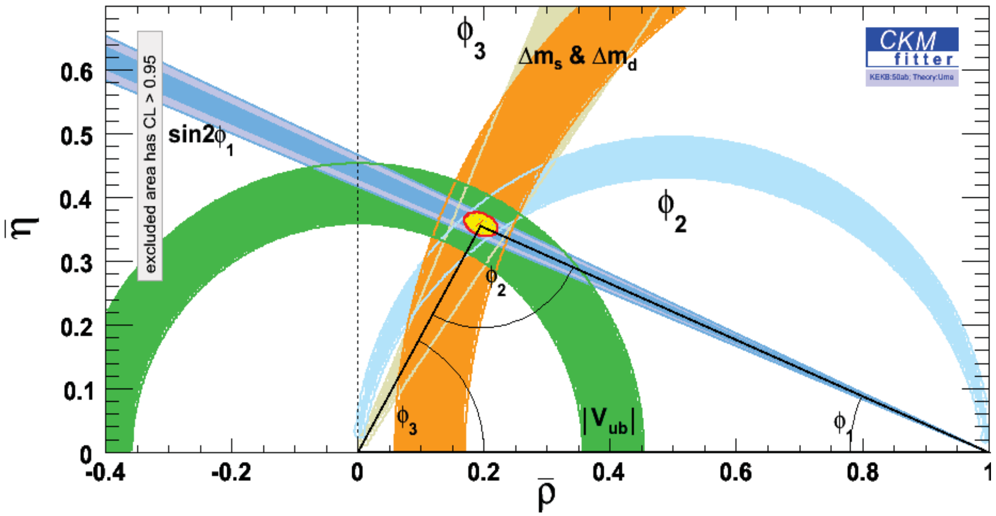
Hadronic matrix element	Current lattice error	6 TFlop Year	60 TFlop Year	1-10 PFlop Year
$f_+^{K\pi}(0)$	0.9% (22% on $1-f_+$)	0.7% (17% on $1-f_+$)	0.4% (10% on $1-f_+$)	**< 0.1% (2.4% on $1-f_+$)**
$\hat{B}_K$	11%	5%	3%	**1%**
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	13%	4 - 5%	3 - 4%	**1 – 1.5%**
ξ	5% (26% on ξ-1)	3% (18% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	**0.5 – 0.8 % (3-4% on ξ-1)**
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on $1-\mathcal{F}$)	2% (21% on $1-\mathcal{F}$)	1.2% (13% on $1-\mathcal{F}$)	**0.5% (5% on $1-\mathcal{F}$)**
$f_+^{B\pi}$,...	11%	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B\to K^*/\rho}$	13%	----	----	**3 – 4%**

CKM IV Nagoya 13

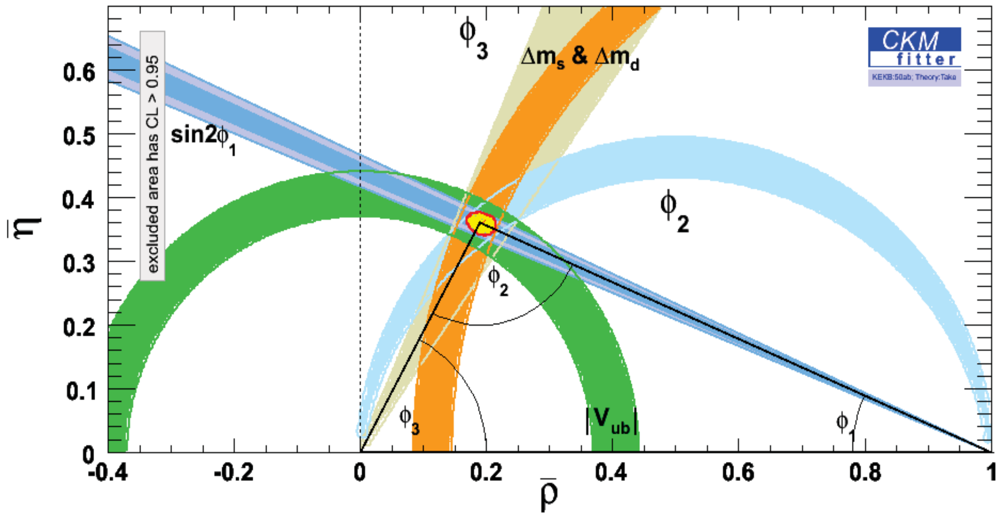
梅 (ume) | 竹 (take) | 松 (matsu)

Results of global CKM fit (SuperKEKB prediction w/ 50/fb)

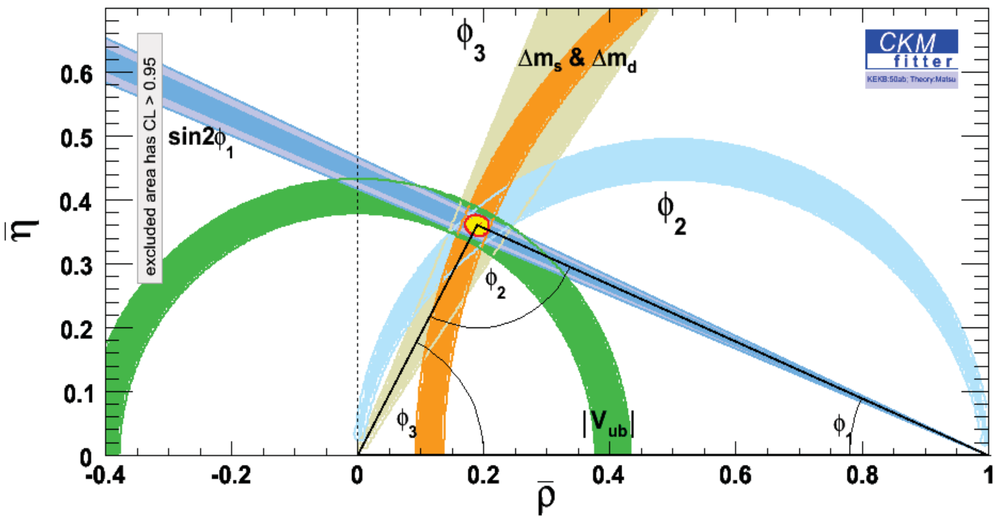
梅 (ume)



竹 (take)



松 (matsu)



	$\sigma(\bar{\rho})$	$\sigma(\bar{\eta})$
梅 Ume	5.1%	2.1%
竹 Take	4.6%	2.0%
松 Matsu	3.1%	1.8%

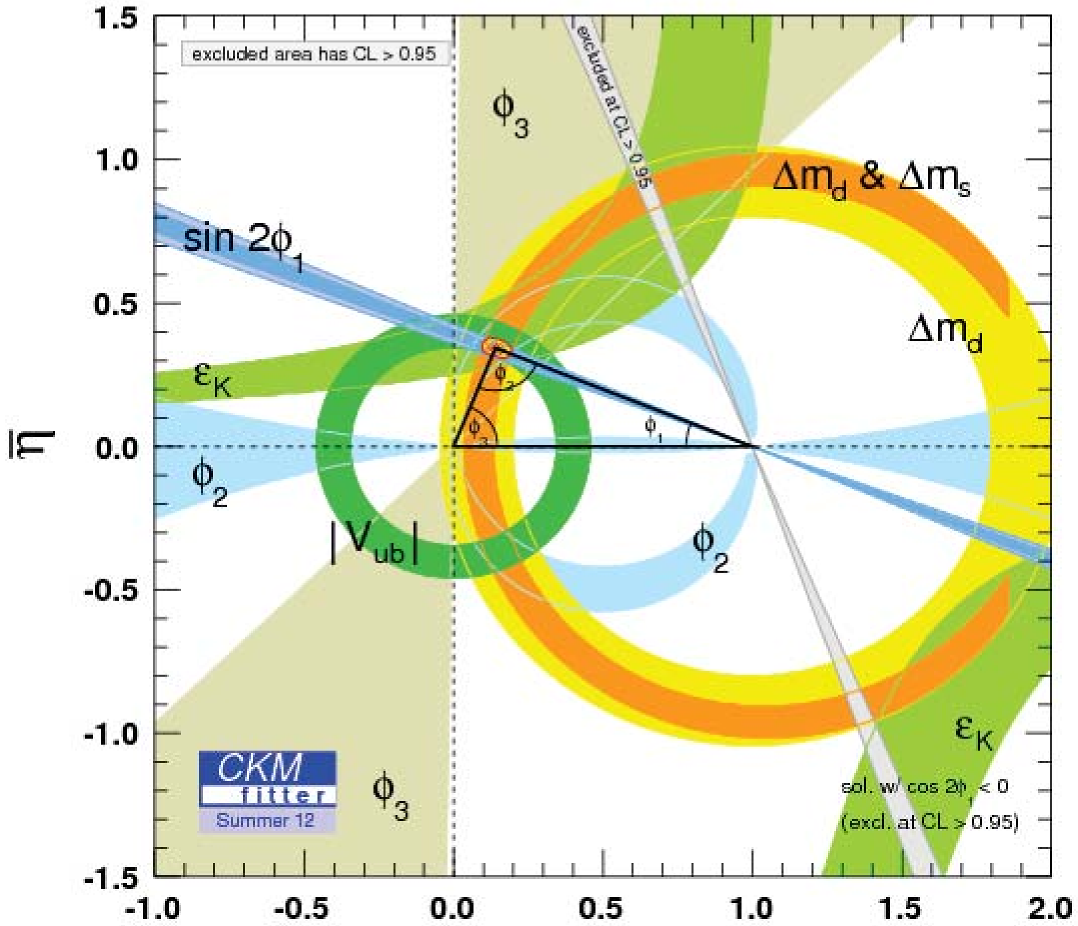
Experimental inputs to CKMfitter (ICHEP2012)

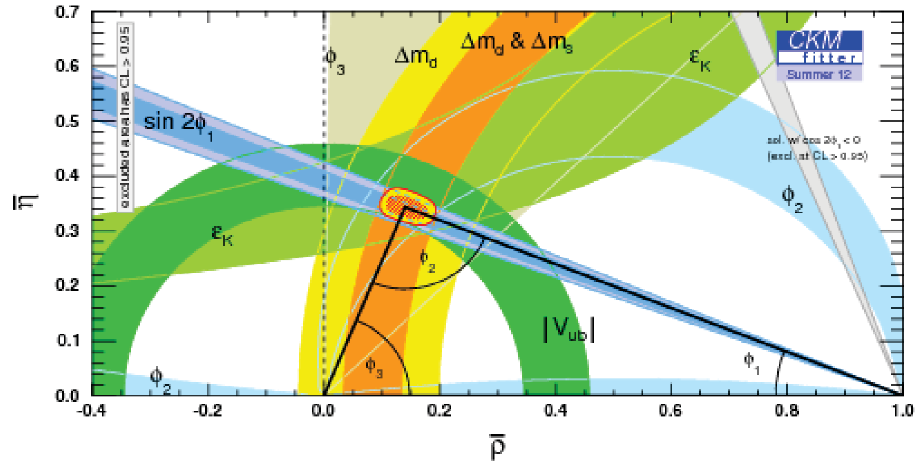
Parameter	Value ± Error(s)	Reference	Errors GS	Errors TH
$\|V_{ud}\|$ (nuclei)	0.97425 ± 0.00022	[1]	⋆	-
$\|V_{us}\|$ ($K_{\ell 3}$)	$0.2246 \pm 0.0009 \pm 0.0012$	[2, 3]	⋆	⋆
$\|V_{cd}\|$ (νN)	0.230 ± 0.011	[4]	⋆	-
$\|V_{cs}\|$ ($W \to c\bar{s}$)	$0.94^{+0.32}_{-0.26} \pm 0.13$	[4]	⋆	⋆
$\|V_{ub}\|$	$(3.75 \pm 0.14 \pm 0.25) \times 10^{-3}$	[5, 6]	⋆	⋆
$\|V_{cb}\|$	$(41.15 \pm 0.33 \pm 0.59) \times 10^{-3}$	[5]	⋆	⋆
$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau)$	$(1.15 \pm 0.23) \times 10^{-4}$	[7]	⋆	-
$\mathcal{B}(D_s^- \to \mu^- \overline{\nu}_\mu)$	$(5.90 \pm 0.33) \times 10^{-3}$	[5]	⋆	-
$\mathcal{B}(D_s^- \to \tau^- \overline{\nu}_\tau)$	$(5.29 \pm 0.28) \times 10^{-2}$	[5]	⋆	-
$\mathcal{B}(D^- \to \mu^- \overline{\nu}_\mu)$	$(3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$	[8]	⋆	⋆
$\mathcal{B}(K^- \to e^- \overline{\nu}_e)$	$(1.584 \pm 0.020) \times 10^{-5}$	[4]	⋆	-
$\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu)$	0.6347 ± 0.0018	[2]	⋆	-
$\mathcal{B}(\tau^- \to K^- \overline{\nu}_\tau)$	$(0.696 \pm 0.023) \times 10^{-3}$	[4]	⋆	-
$\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu)/\mathcal{B}(\pi^- \to \mu^- \overline{\nu}_\mu)$	1.344 ± 0.0041	[2]	⋆	-
$\mathcal{B}(\tau^- \to K^- \overline{\nu}_\tau)/\mathcal{B}(\tau^- \to \pi^- \overline{\nu}_\tau)$	$(6.53 \pm 0.11) \times 10^{-2}$	[9]	⋆	-
$\|V_{cd}\| f_+^{D\to\pi}(0)$	0.148 ± 0.004	[10]	⋆	-
$\|V_{cs}\| f_+^{D\to K}(0)$	0.712 ± 0.007	[10, 11]	⋆	-
$\|\varepsilon_K\|$	$(2.229 \pm 0.010) \times 10^{-3}$	[4]	⋆	-
Δm_d	(0.507 ± 0.005) ps^{-1}	[5]	⋆	-
Δm_s	(17.719 ± 0.043) ps^{-1}	[5]	⋆	-
$\sin(2\beta)_{[c\bar{c}]}$	0.679 ± 0.020	[5]	⋆	-
$(\beta_s)_{J/\psi\phi}$	Analysis of $B_s \to J/\psi\phi$	[12]	⋆	-
$S_{\pi\pi}^{+-}$, $C_{\pi\pi}^{+-}$, $C_{\pi\pi}^{00}$	Inputs to isospin analysis	[5]	⋆	-
$\mathcal{B}_{\pi\pi}$ all charges	Inputs to isospin analysis	[5]	⋆	-
$S_{\rho\rho,L}^{+-}$, $C_{\rho\rho,L}^{+-}$, $S_{\rho\rho}^{00}$, $C_{\rho\rho}^{00}$	Inputs to isospin analysis	[5]	⋆	-
$\mathcal{B}_{\rho\rho,L}$ all charges	Inputs to isospin analysis	[5]	⋆	-
$B^0 \to (\rho\pi)^0 \to 3\pi$	Time-dependent Dalitz analysis	[14, 15]	⋆	-
$B^- \to D^{(*)} K^{(*)-}$	Inputs to GLW analysis	[5]	⋆	-
$B^- \to D^{(*)} K^{(*)-}$	Inputs to ADS analysis	[5]	⋆	-
$B^- \to D^{(*)} K^{(*)-}$	GGSZ Dalitz analysis	[5]	⋆	-

Used Inputs: Theory parameters

Parameter	Value ± Error(s)	Reference	Errors GS	Errors TH
$\overline{m}_c(m_c)$	$(1.286 \pm 0.013 \pm 0.040)$ GeV	[16]	⋆	⋆
$\overline{m}_t(m_t)$	$(165.8 \pm 0.54 \pm 0.72)$ GeV	[20]	⋆	⋆
$\alpha_S(m_Z)$	$0.1184 \pm 0 \pm 0.0007$	[4]	-	⋆
B_K	$0.7615 \pm 0.0026 \pm 0.0137$	[3]	⋆	⋆
η_{cc}	Calculated from $\overline{m}_c(m_c)$ and α_S	[22]	-	⋆
η_{ct}	$0.47 \pm 0 \pm 0.04$	[23]	-	⋆
η_{tt}	$0.5765 \pm 0 \pm 0.0065$	[22, 23]	-	⋆
$\eta_B(\overline{\mathrm{MS}})$	$0.5510 \pm 0 \pm 0.0022$	[24, 25]	-	⋆
f_{B_s}	$(229 \pm 2 \pm 6)$ MeV	[3]	⋆	⋆
B_s	$1.322 \pm 0.026 \pm 0.035$	[3]	⋆	⋆
f_{B_s}/f_{B_d}	$1.221 \pm 0.010 \pm 0.033$	[3]	⋆	⋆
B_s/B_d	$1.024 \pm 0.013 \pm 0.015$	[3]	⋆	⋆
f_K	$(156.3 \pm 0.3 \pm 1.9)$ MeV	[3]	⋆	⋆
f_K/f_π	$1.1985 \pm 0.0013 \pm 0.0095$	[3]	⋆	⋆
f_{D_S}	$(249 \pm 2 \pm 5)$ MeV	[3]	⋆	⋆
f_{D_S}/f_D	$1.185 \pm 0.005 \pm 0.010$	[3]	⋆	⋆
$f_+^{D\to\pi}(0)$	$0.666 \pm 0.017 \pm 0.048$	[3]	⋆	⋆
$f_+^{D\to K}(0)$	$0.747 \pm 0.010 \pm 0.034$	[3]	⋆	⋆

2012 CKMfitter Result (ICHEP12)





Wolfenstein parameters and Jarlskog invariant:

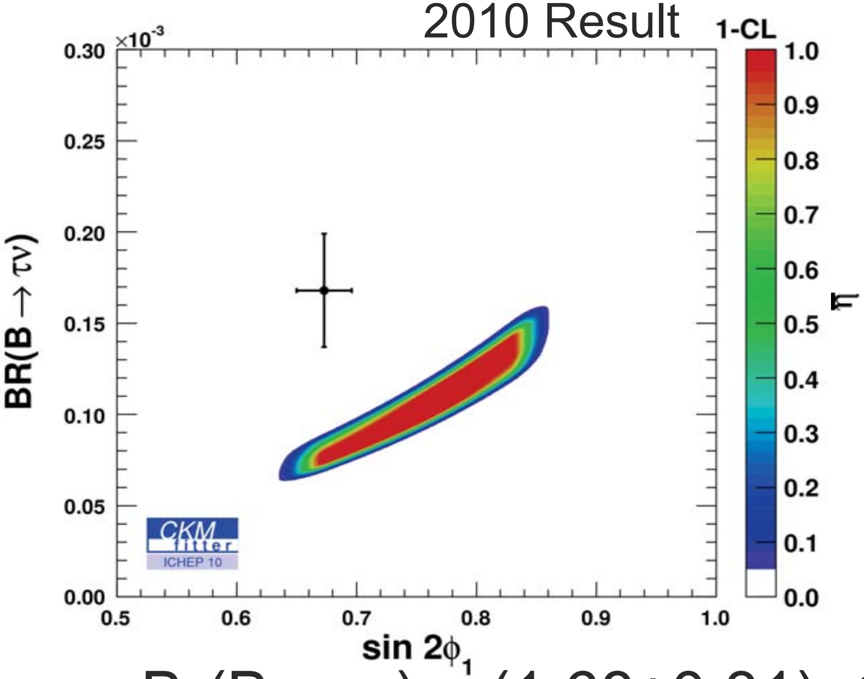
Observable	Central ± 1 σ	± 2 σ	± 3 σ
A	0.802 [+0.029 -0.011]	0.802 [+0.038 -0.018]	0.802 [+0.048 -0.025]
λ	0.22543 [+0.00059 -0.00094]	0.2254 [+0.0010 -0.0019]	0.2254 [+0.0013 -0.0027]
ρbar	0.140 [+0.027 -0.026]	0.140 [+0.047 -0.038]	0.140 [+0.059 -0.049]
ηbar	0.343 [+0.015 -0.014]	0.343 [+0.029 -0.027]	0.343 [+0.043 -0.037]
J [10^{-5}]	2.890 [+0.281 -0.085]	2.89 [+0.42 -0.13]	2.89 [+0.56 -0.18]

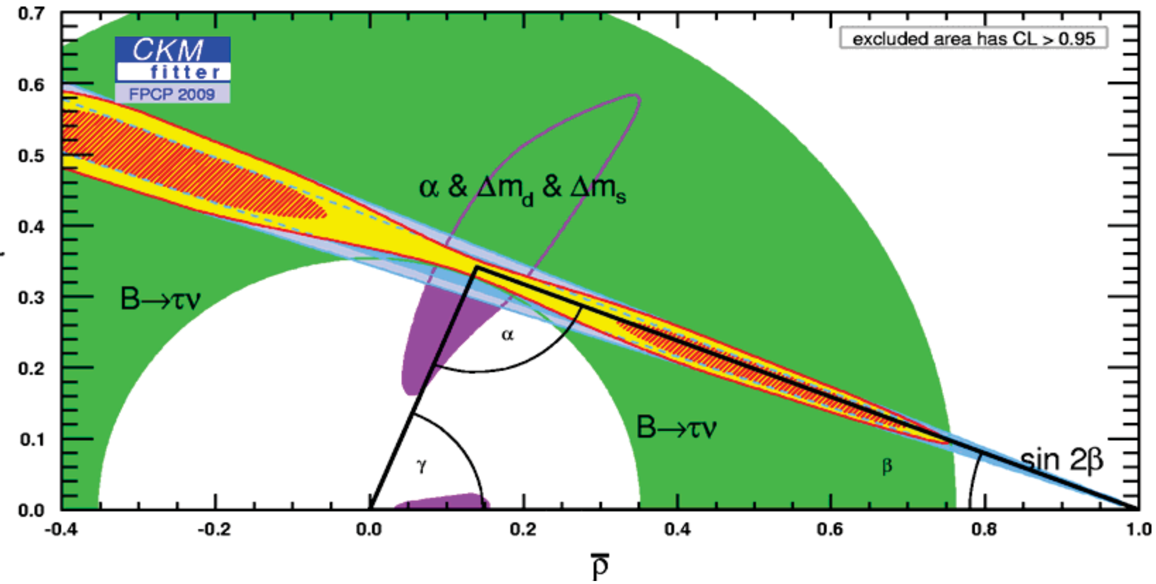
“Anomaly” in CKM fit

- Anomalous input value used for CKM fit is a possible signature of NP.
- An anomaly in one measurement can be compared with the value predicted by the CKM fit excluding that measurement.

- Example : “Tension” between B->$\tau\nu$ and $\sin 2\phi_1$

2010 Result





$Br(B\to\tau\nu) = (1.68\pm0.31)\times10^{-4}$ (CKMfitter ave. in 2010)

- 2.8σ discrepancy at that time.
- First reported by global fit groups (CKMfitter, UTfit)

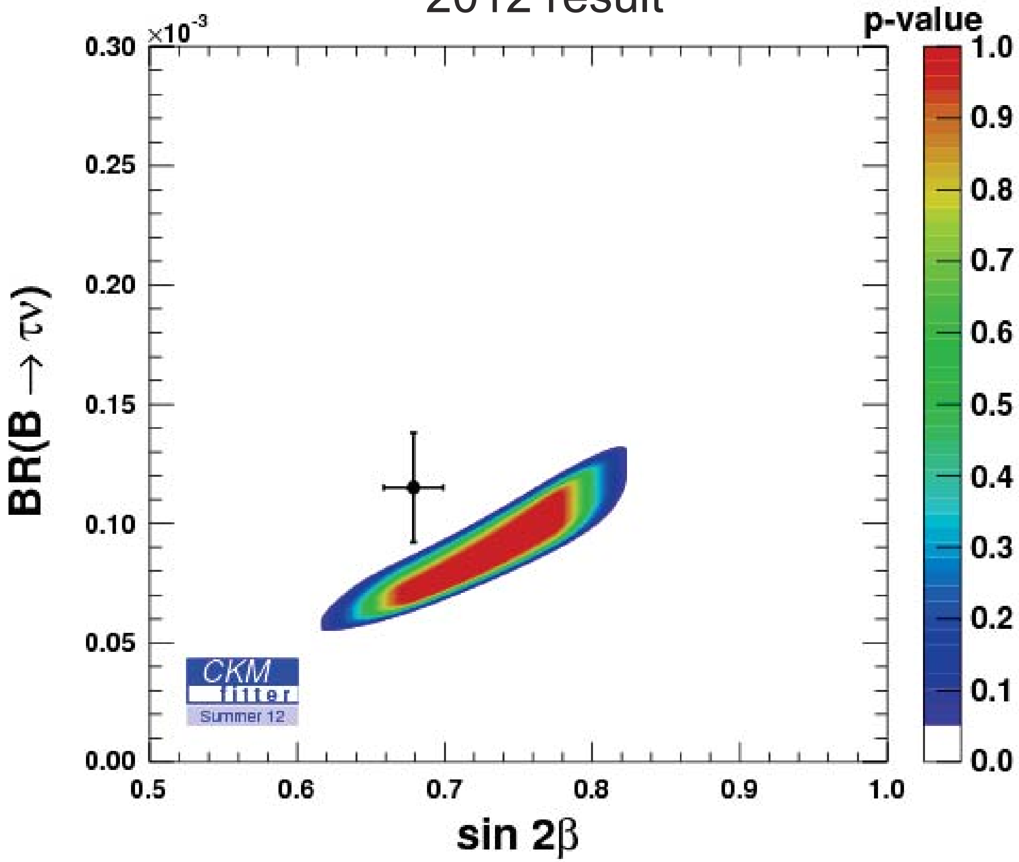
- Belle's new measurement in 2012 is significantly lower.

$Br(B \to \tau\nu) = (1.68 \pm 0.31) \times 10^{-4}$ (CKMfitter ave in 2010)

↓

$Br(B \to \tau\nu) = (1.15 \pm 0.23) \times 10^{-4}$ (CKMfitter ave in 2012)

2012 result



The latest (ICHEP12) fit with Belle's updated $Br(B \to \tau\nu)$ with hadronic tag.

↓

"Tension" is relaxed.....
1.6σ discrepancy

2) New Physics in B-$\overline{\text{B}}$ Mixing

CKMfitter: Phys.Rev.D83, 036004 (2011)

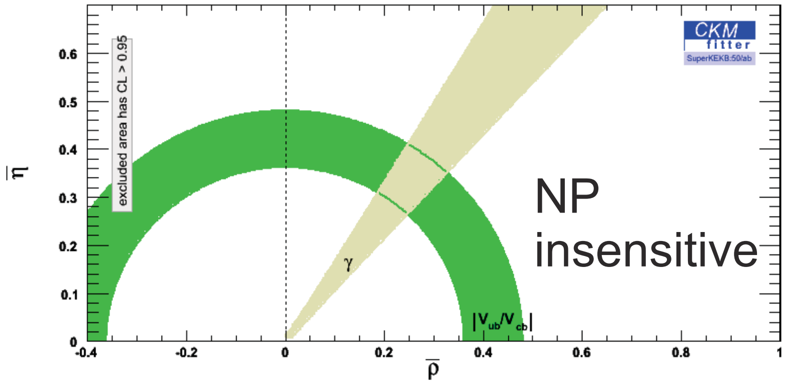
Model independent parameterization of New Physics in Mixing

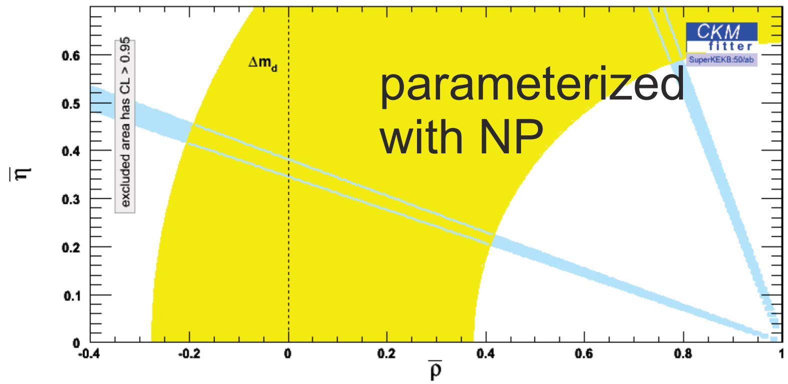
$$M_{12}^{q} \equiv M_{12}^{SM} \cdot \Delta_q$$
$$\Delta_q \equiv |\Delta_q| \exp(i\phi_q^{\Delta})$$

where CP phase is $\phi_q = \phi_q^{SM} + \phi_q^{\Delta}$

Principle:
NP parameters can be determined for by comparing
- measurements affected by NP parameters:
  Δm_d, Δm_s, Γ_d, Γ_s, $A_{SL}(t)$, a_{sl}
- measurements insensitive to NP
  * tree level measurements : $|V_{ub}|$, ϕ_3.......

For example:





Constraint in NP parameters is obtained by the global CKM fit to all inputs.

2 scenarios in NP modeling

I) Non-MFV(minimal flavor violation)

Conventional model-independent NP parameterization without assuming any flavor structure.

-> Δ_s and Δ_d can take different values.

II) With MFV ("generic" MFV with a large bottom Yukawa coupling)

$\Delta_s = \Delta_d = \Delta$

Minimal Flavor Violation (MFV)

Assumption that all FCNCs stem from the KM-like matrix element as in Standard Model.

Measurements sensitive to NP in mixing: Δm, $\Delta\Gamma/\Gamma$, a_{SL}

a_{SL}/A_{SL}

$$a^d_{SL} = \frac{N_{\ell^+\ell^+} - N_{\ell^-\ell^-}}{N_{\ell^+\ell^+} + N_{\ell^-\ell^-}} = 2(1 - |q/p|) \ .$$

$$A^q_{SL}(t) \equiv \frac{\Gamma(\bar{B}^0_q(t) \to l^+ X) - \Gamma(B^0_q(t) \to l^- X)}{\Gamma(\bar{B}^0_q(t) \to l^+ X) + \Gamma(B^0_q(t) \to l^- X)}$$
$$= \frac{1 - |q/p|^4}{1 + |q/p|^4} = 2(1 - |q/p|) + O\left((|q/p| - 1)^2\right),$$

- A_{SL} (B_d) : average of Belle/Babar/CLEO measurements.
- $A_{SL}(B_s)$: D0
- $a_{SL}(B_s)$: average of CDF/D0/LHCb measurements.

$\Delta\Gamma_d/\Gamma_d$: Belle/Babar, but exp. error is still large -> no constraint

$\Delta\Gamma_s/\Gamma_s$, ϕ_s : CDF+D0+LHCb

Δm_d : HFAG 2012

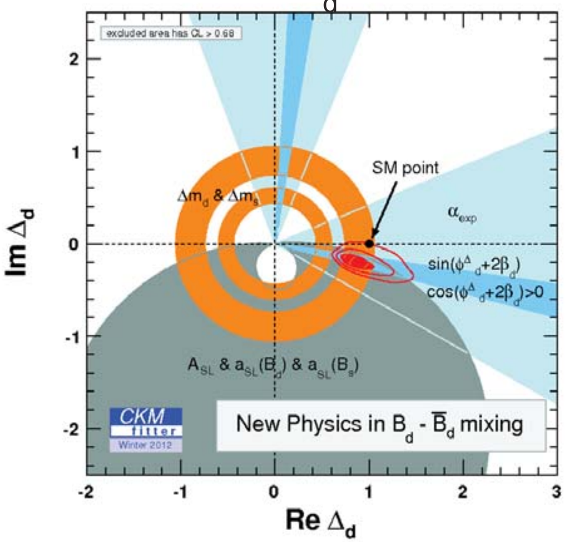
Δm_s : CDF + LHCb

2012 CKMfitter results

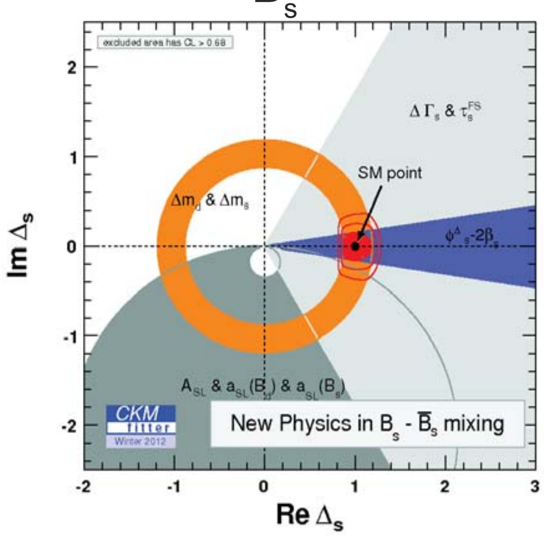
non-MFV scenario

generic-MFV scenario

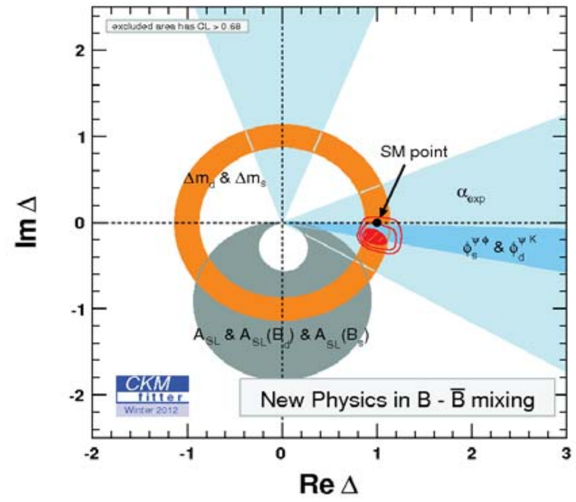
B_d



B_s



$\Delta = \Delta m_d = \Delta m_s$



Quantity	1σ	3σ
$\mathrm{Re}(\Delta_d)$	$0.823^{+0.143}_{-0.095}$	$0.82^{+0.54}_{-0.20}$
$\mathrm{Im}(\Delta_d)$	$-0.199^{+0.062}_{-0.048}$	$-0.20^{+0.18}_{-0.19}$
$\lvert\Delta_d\rvert$	$0.86^{+0.14}_{-0.11}$	$0.86^{+0.55}_{-0.22}$
ϕ_d^Δ [deg]	$-13.4^{+3.3}_{-2.0}$	$-13.4^{+12.1}_{-6.0}$
$\mathrm{Re}(\Delta_s)$	$0.965^{+0.133}_{-0.078}$	$0.97^{+0.30}_{-0.13}$
$\mathrm{Im}(\Delta_s)$	$-0.00^{+0.10}_{-0.10}$	$-0.00^{+0.32}_{-0.32}$
$\lvert\Delta_s\rvert$	$0.977^{+0.121}_{-0.090}$	$0.98^{+0.29}_{-0.15}$
ϕ_s^Δ [deg]	$-0.1^{+6.1}_{-6.1}$	$-0^{+18.}_{-18.}$
$\phi_d^\Delta + 2\beta$ [deg] (!)	$17^{+12.}_{-13.}$	$17^{+40.}_{-55.}$
$\phi_s^\Delta - 2\beta_s$ [deg] (!)	$-56.8^{+10.9}_{-7.0}$	$-57.^{+66.}_{-20.}$

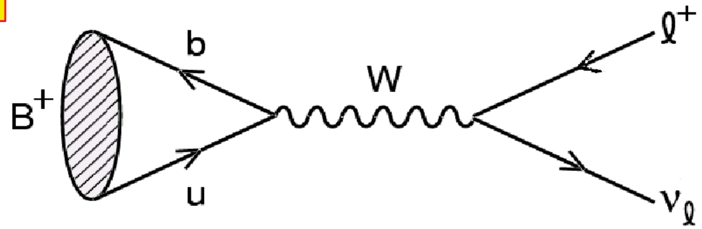
	non MFV		gen. MFV
Hypothesis	Sc. I	Sc. II	Sc. III
$\mathrm{Im}\Delta_d = 0$	3.2σ		2.6σ
$\mathrm{Im}\Delta_s = 0$	0.0σ		
$\Delta_d = 1$	3.0σ	0.6σ	2.1σ
$\Delta_s = 1$	0.0σ		
$\mathrm{Im}\Delta_d = \mathrm{Im}\Delta_s = 0$	2.8σ		
$\Delta_d = \Delta_s = 1$	2.4σ		

3) Search for Charged Higgs

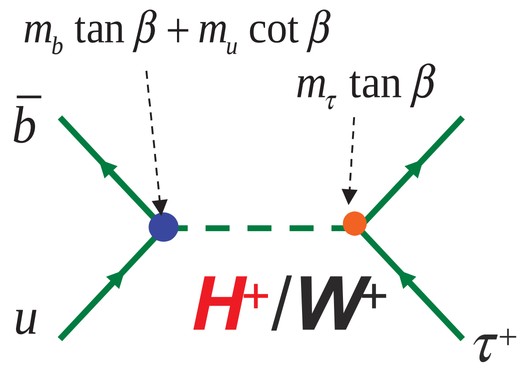
by NP-Japan group (2013), Preliminary

- The search for charged Higgs at B factory experiment has been performed in B->τν decays.

SM



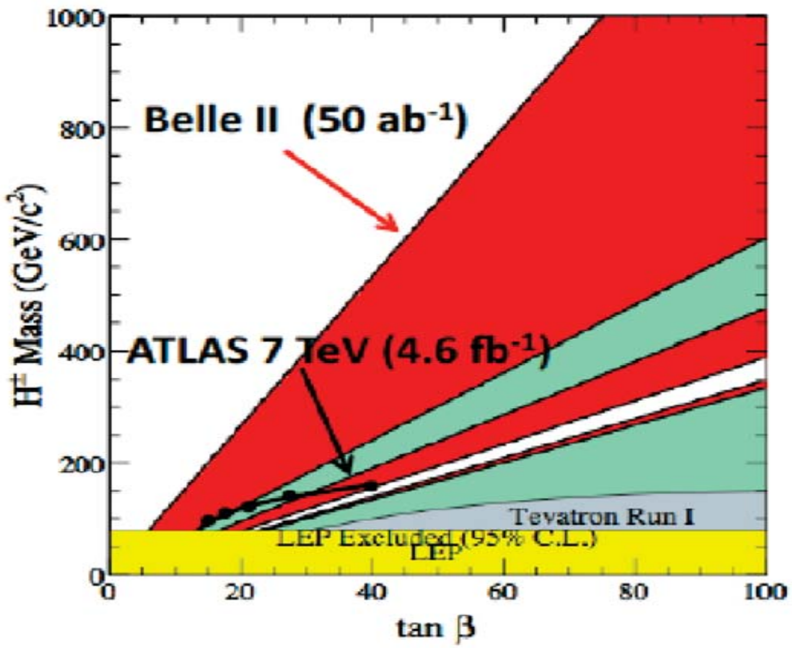
NP



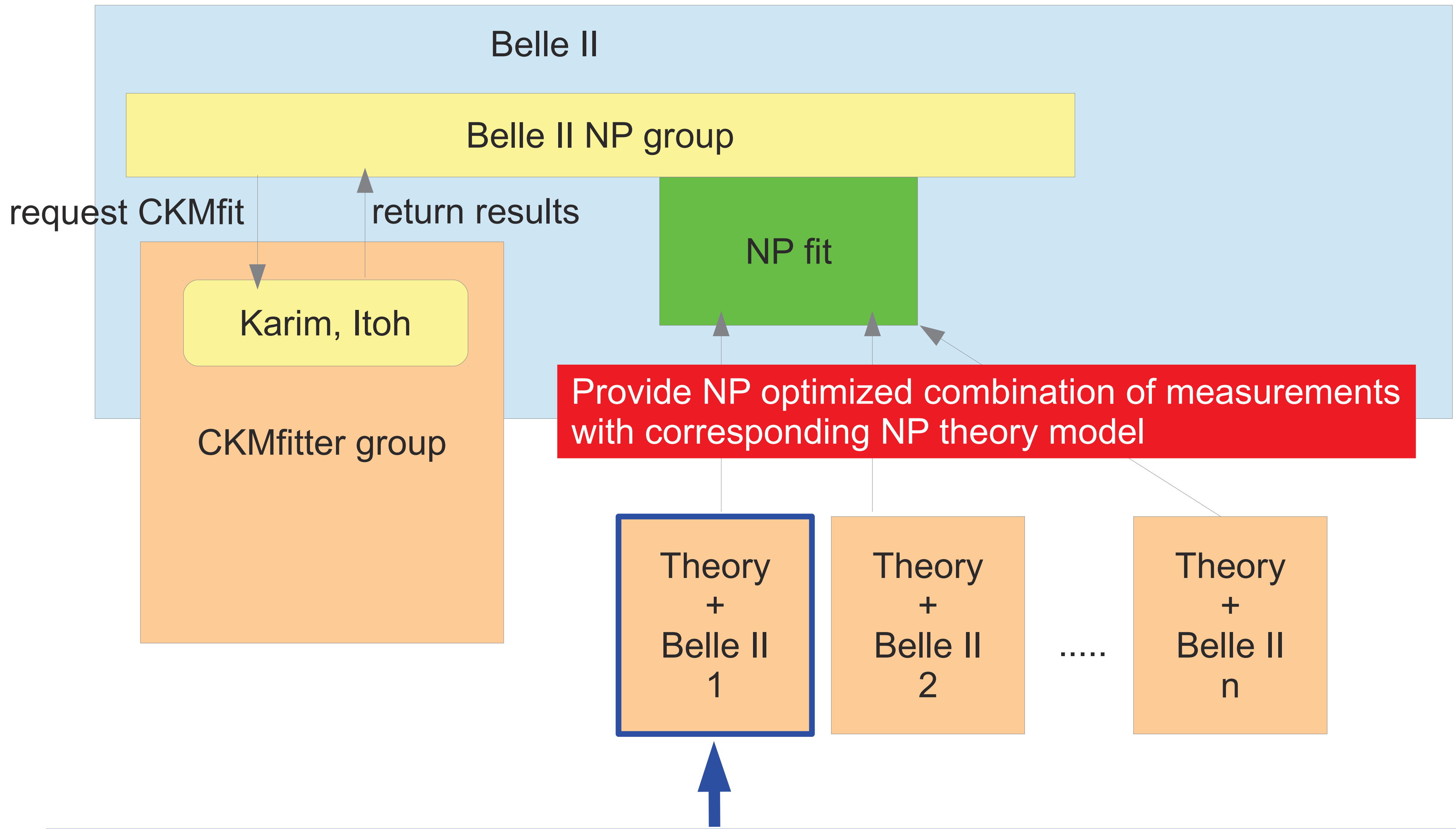
$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

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

$Br = Br_{SM} \times r_H$

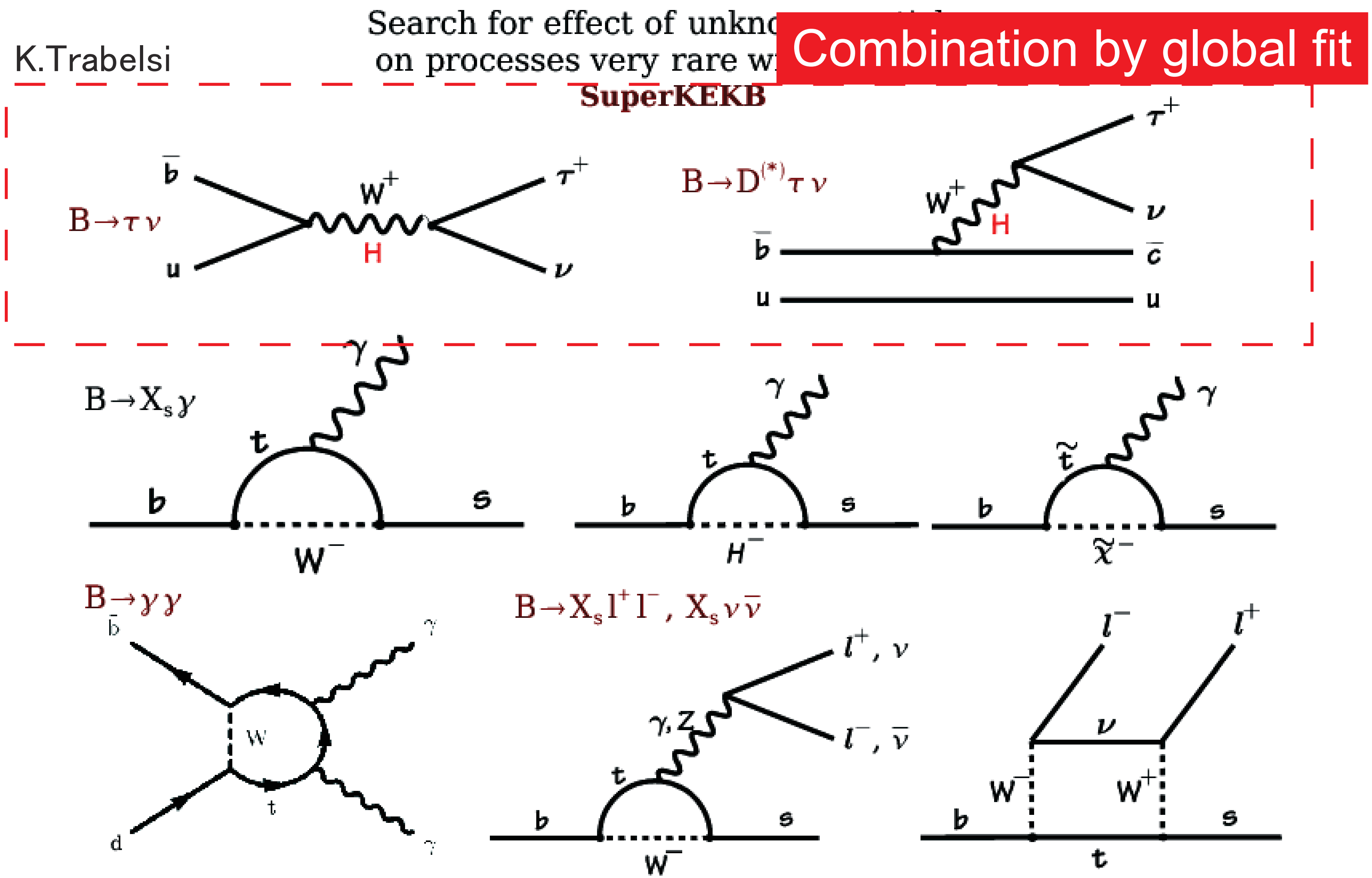


NP-Japan and Belle II



- We will start one of the groups as a Japanese-initiated group consisting of Japanese theorists + Belle II members (not limited to Japanese, of course!) = NP-Japan group : NPJ.

- If charged Higgs is there, it can affect in various B meson decay modes.



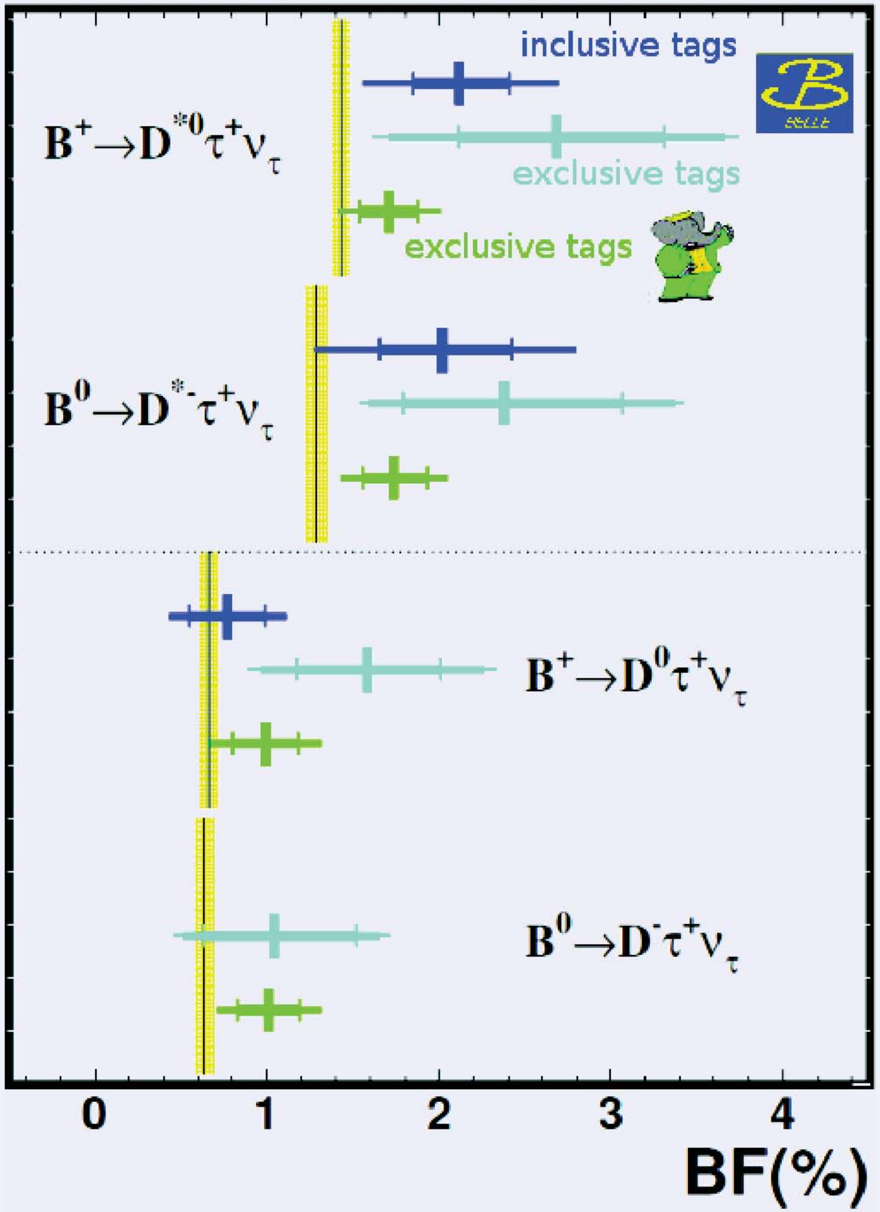
Measurements

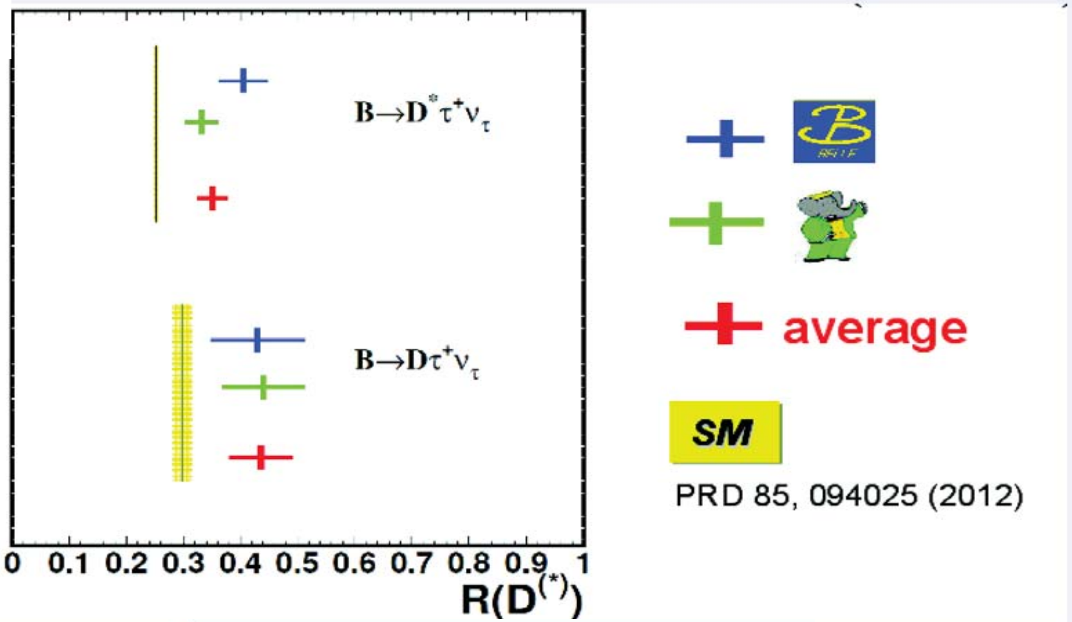
PRL 99 (2007) (535×10^6)

PRD 82 (2010) (657×10^6)

hep-ex/0910.4301 (657×10^6)

PRL 109 (2012) (471×10^6)





R - BF ratios

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B \to \bar{D}^{(*)} \tau^+ \bar{\nu}_\tau)}{\mathcal{B}(B \to \bar{D}^{(*)} \ell^+ \bar{\nu}_\ell)}$$

Belle and *BABAR* average deviation from **SM**

- $R(\overline{D}^*)$ 3.8σ
- $R(\overline{D})$ 2.4σ
- $R(\overline{D}^{(*)})$ 4.8σ

Note: Belle's measurements with a full luminosity are not available yet. Need confirmation by Belle!

Theory Model : 2HDM (2 Higgs Doublet Model)

- Minimal "model-independent" extension of Standard Model with two additional Higgs doublet.
  ex. Minimal SUSY(MSSM)

$$|\langle 0|\phi_1|0\rangle| = \begin{pmatrix} 0 \\ v_1/\sqrt{2} \end{pmatrix}, \qquad |\langle 0|\phi_2|0\rangle| = \begin{pmatrix} v_2/\sqrt{2} \\ 0 \end{pmatrix},$$

- 8DoFs are inside. 5 out of 8 are real fields : $H^{\pm}$, A, and (h^0,H^0).

- Coupling model : "Type II"
  * ϕ_1 couples to down type quarks
  * ϕ_2 couples to up type quarks.

$$\mathcal{L}_{II,Y} = -\bar{Q}_L\phi_1 y^d D_R - \bar{Q}_L\phi_2 y^u U_R - \bar{L}_L\phi_2 y^e E_R + h.c.,$$

$$\mathcal{L}_{II,H^+} = -\frac{g}{\sqrt{2}}\sum_{ij}\left[\tan\beta\frac{m_{dj}}{M_W}\bar{u}_{Li}V_{ij}d_{Rj} + \cot\beta\frac{m_{ui}}{M_W}\bar{u}_{Rj}V_{ij}d_{Lj} + \tan\beta\frac{m_{ei}}{M_W}\bar{\nu}_{Lj}\ell_{Rj}\right]H^+ + h.c.$$

Modification to SM prediction of Br(B->τν)

$$r_H = \left(\frac{m_{q_u} - m_{q_d}\tan^2\beta}{m_{q_u} + m_{q_d}}\right)\left(\frac{m_M}{m_{H^+}}\right)^2.$$

Br prediction by 2HDM consistent for both Dτν and D*τν

BR(B→Dτν) and BR(B→Dlν) from Y. Sakaki, R. Watanabe, and M. Tanaka

New!

$$\mathrm{Br}(\bar{B}\to D\tau\bar{\nu}_\tau) = \tau_B \Gamma(\bar{B}\to D\tau\bar{\nu}_\tau)$$

$$\equiv \tau_B G_F^2 |V_{cb}|^2 V_1(1)^2 \times \Big[\Gamma_1 + \Gamma_2\rho_1^2 + \Gamma_3\rho_1^4$$

$$+ (\Gamma_4 + \Gamma_5\rho_1^2 + \Gamma_6\rho_1^4)\left(\frac{4.91\mathrm{GeV} - 1.77\mathrm{GeV}}{m_b - m_c}\right)\mathrm{Re}(C_{S_1} + C_{S_2})$$

$$+ (\Gamma_7 + \Gamma_8\rho_1^2 + \Gamma_9\rho_1^4)\left(\frac{4.91\mathrm{GeV} - 1.77\mathrm{GeV}}{m_b - m_c}\right)^2 |C_{S_1} + C_{S_2}|^2\Big]$$

$$\Gamma_1 = +(1.868 \; - 2.321\times 10^{-2}a \; + 1.373\times 10^{-4}a^2)\,10^{-2}$$
$$\Gamma_2 = -(6.829 \; - 7.181\times 10^{-2}a \; + 3.708\times 10^{-4}a^2)\,10^{-3}$$
$$\Gamma_3 = +(7.005 \; - 6.645\times 10^{-2}a \; + 3.121\times 10^{-4}a^2)\,10^{-4}$$

$$\Gamma_4 = +(2.804 \; - 6.543\times 10^{-2}a \; + 4.140\times 10^{-4}a^2)\,10^{-2}$$
$$\Gamma_5 = -(8.864 \; - 18.08\times 10^{-2}a \; + 9.985\times 10^{-4}a^2)\,10^{-3}$$
$$\Gamma_6 = +(8.317 \; - 15.45\times 10^{-2}a \; + 7.735\times 10^{-4}a^2)\,10^{-4}$$

$$\Gamma_7 = +(1.953 \; - 4.881\times 10^{-2}a \; + 3.265\times 10^{-4}a^2)\,10^{-2}$$
$$\Gamma_8 = -(5.518 \; - 12.05\times 10^{-2}a \; + 7.065\times 10^{-4}a^2)\,10^{-3}$$
$$\Gamma_9 = +(4.787 \; - 9.484\times 10^{-2}a \; + 5.039\times 10^{-4}a^2)\,10^{-4}$$

$$\mathrm{Br}(\bar{B}\to D\ell\bar{\nu}_\ell) = \tau_B \Gamma(\bar{B}\to D\ell\bar{\nu}_\ell)$$
$$\equiv \tau_B G_F^2 |V_{cb}|^2 V_1(1)^2 \times [\Gamma_1 + \Gamma_2\rho_1^2 + \Gamma_3\rho_1^4]$$

$$\Gamma_1 = +8.788\times 10^{-2}$$
$$\Gamma_2 = -5.230\times 10^{-2}$$
$$\Gamma_3 = +0.8190\times 10^{-2}$$

Assume Type II 2HDM.

ρ_1^2 = 1.186±0.036±0.041 (HFAG).

a = 1±1
(M. Tanaka and R. Watanabe).

m_b = 4.20±0.07 GeV and
$m_c = 0.901^{+0.111}_{-0.113}$ GeV
(MSbar, PRD77, 113016 (2008)).

Gaussian assumption for the errors.

$$C_{S_1} = -\frac{m_\tau m_b}{m_{H^2_\pm}}\tan^2\beta$$

$$C_{S_2} = -\frac{m_\tau m_c}{m_{H^2_\pm}}$$

BR(B→D*τν) and BR(B→D*lν) from Y. Sakaki, R. Watanabe, and M. Tanaka

New!

$$
\begin{aligned}
\mathrm{Br}(\bar{B} \to D^* \tau \bar{\nu}_\tau) &= \tau_B \Gamma(\bar{B} \to D^* \tau \bar{\nu}_\tau) \\
&= \tau_B G_F^2 |V_{cb}|^2 A_1(1)^2 \times \Big[\Gamma_1 + \Gamma_2 \rho_{A_1}^2 + \Gamma_3 \rho_{A_1}^4 \\
&\quad + (\Gamma_4 + \Gamma_5 \rho_{A_1}^2 + \Gamma_6 \rho_{A_1}^4) \left(\frac{4.91\mathrm{GeV} + 1.77\mathrm{GeV}}{m_b + m_c}\right) \mathrm{Re}(C_{S_1} - C_{S_2}) \\
&\quad + (\Gamma_7 + \Gamma_8 \rho_{A_1}^2 + \Gamma_9 \rho_{A_1}^4) \left(\frac{4.91\mathrm{GeV} + 1.77\mathrm{GeV}}{m_b + m_c}\right)^2 |C_{S_1} - C_{S_2}|^2 \Big]
\end{aligned}
$$

$$\Gamma_1 = +\left(5.538 - 0.005388 R_1(1) + 0.1344 R_1(1)^2 - 2.027 R_2(1) + 0.3519 R_2(1)^2 + 5.400 \times 10^{-2} a_3 + 7.117 \times 10^{-4} a_3^2 - 2.444 \times 10^{-2} R_2(1) a_3\right) 10^{-2}$$

$$\Gamma_2 = -\left(15.64 - 0.01815 R_1(1) + 0.4034 R_1(1)^2 - 6.847 R_2(1) + 1.226 R_2(1)^2 + 17.11 \times 10^{-2} a_3 + 20.83 \times 10^{-4} a_3^2 - 7.749 \times 10^{-2} R_2(1) a_3\right) 10^{-3}$$

$$\Gamma_3 = +\left(12.97 - 0.01635 R_1(1) + 0.3373 R_1(1)^2 - 6.254 R_2(1) + 1.144 R_2(1)^2 + 14.90 \times 10^{-2} a_3 + 17.09 \times 10^{-4} a_3^2 - 6.756 \times 10^{-2} R_2(1) a_3\right) 10^{-4}$$

$$\Gamma_4 = +\left(1.136 - 1.028 R_2(1) + 0.2327 R_2(1)^2 + 5.972 \times 10^{-2} a_3 + 8.307 \times 10^{-4} a_3^2 - 2.701 \times 10^{-2} R_2(1) a_3\right) 10^{-2}$$

$$\Gamma_5 = -\left(3.611 - 3.272 R_2(1) + 0.7412 R_2(1)^2 + 17.55 \times 10^{-2} a_3 + 22.48 \times 10^{-4} a_3^2 - 7.946 \times 10^{-2} R_2(1) a_3\right) 10^{-3}$$

$$\Gamma_6 = +\left(3.154 - 2.859 R_2(1) + 0.6481 R_2(1)^2 + 14.44 \times 10^{-2} a_3 + 17.35 \times 10^{-4} a_3^2 - 6.541 \times 10^{-2} R_2(1) a_3\right) 10^{-4}$$

$$\Gamma_7 = +\left(0.3132 - 0.2834 R_2(1) + 0.06409 R_2(1)^2 + 1.738 \times 10^{-2} a_3 + 2.538 \times 10^{-4} a_3^2 - 0.7857 \times 10^{-2} R_2(1) a_3\right) 10^{-2}$$

$$\Gamma_8 = -\left(0.9240 - 0.8368 R_2(1) + 0.1895 R_2(1)^2 + 4.724 \times 10^{-2} a_3 + 6.346 \times 10^{-4} a_3^2 - 2.138 \times 10^{-2} R_2(1) a_3\right) 10^{-3}$$

$$\Gamma_9 = +\left(0.7623 - 0.6908 R_2(1) + 0.1565 R_2(1)^2 + 3.658 \times 10^{-2} a_3 + 4.600 \times 10^{-4} a_3^2 - 1.657 \times 10^{-2} R_2(1) a_3\right) 10^{-4}$$

$$
\begin{aligned}
\mathrm{Br}(\bar{B} \to D^* \ell \bar{\nu}_\ell) &= \tau_B \Gamma(\bar{B} \to D^* \ell \bar{\nu}_\ell) \\
&\equiv \tau_B G_F^2 |V_{cb}|^2 A_1(1)^2 \times [\Gamma_1 + \Gamma_2 \rho_{A_1}^2 + \Gamma_3 \rho_{A_1}^4]
\end{aligned}
$$

$$\Gamma_1 = +\left(32.87 - 0.04784 R_1(1) + 0.8060 R_1(1)^2 - 17.68 R_2(1) + 3.351 R_2(1)^2\right) \times 10^{-2}$$

$$\Gamma_2 = -\left(15.34 - 0.02262 R_1(1) + 0.3460 R_1(1)^2 - 9.521 R_2(1) + 1.875 R_2(1)^2\right) \times 10^{-2}$$

$$\Gamma_3 = +\left(1.993 - 0.002827 R_1(1) + 0.04062 R_1(1)^2 - 1.337 R_2(1) + 0.2699 R_2(1)^2\right) \times 10^{-2}$$

Assume Type II 2HDM.

ρ_{A1}^2 = 1.207±0.015±0.021 (HFAG).

$R_1(1)$ = 1.403±0.033 (HFAG).

$R_2(1)$ = 0.854±0.020 (HFAG).

a_3 = 1±1
(M. Tanaka and R. Watanabe).

m_b = 4.20±0.07 GeV and
$m_c = 0.901^{+0.111}_{-0.113}$ GeV
(MSbar, PRD77, 113016 (2008)).

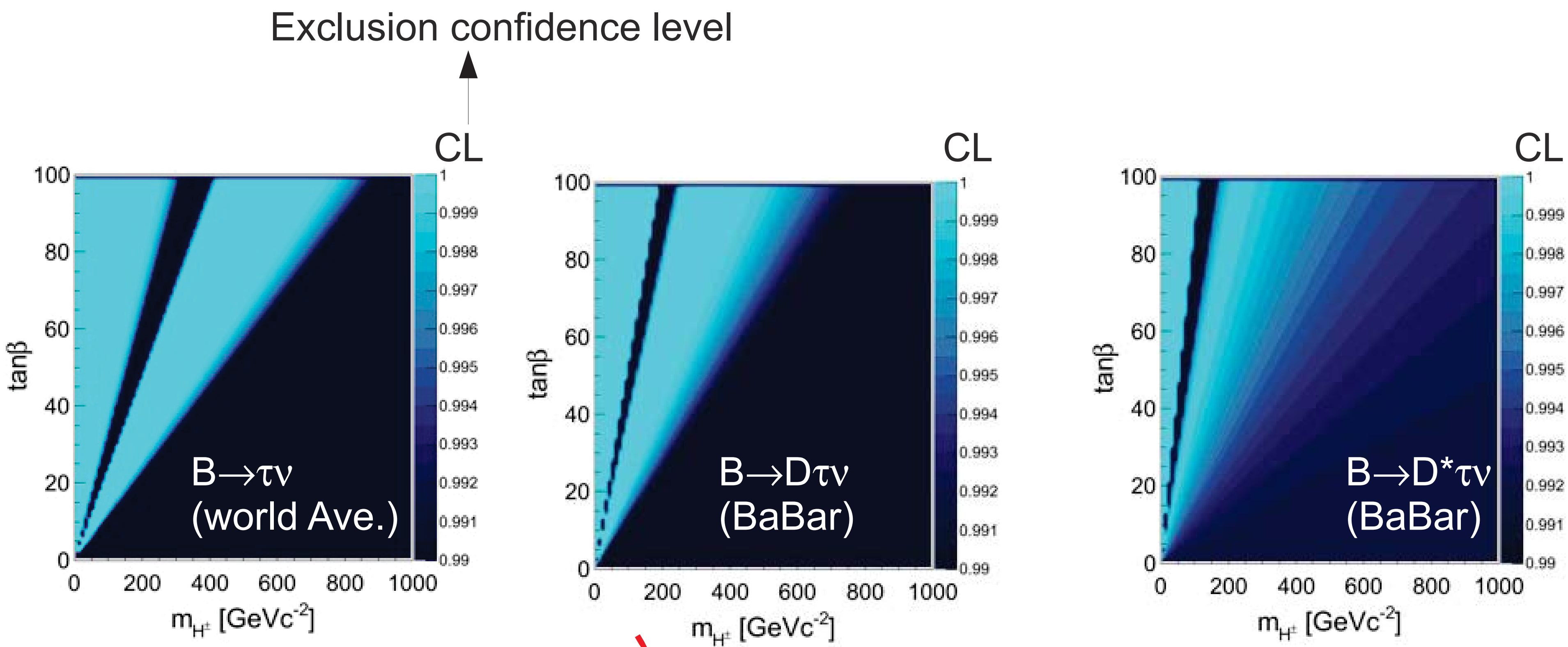
Gaussian assumption for the errors.

$$C_{S_1} = -\frac{m_\tau m_b}{m_{H_\pm^2}} \tan^2 \beta$$

$$C_{S_2} = -\frac{m_\tau m_c}{m_{H_\pm^2}}$$

Excluded region in (tanβ,m_H) for individual modes

* Excluded region in tanβ and m_H plane for each input before combining them.



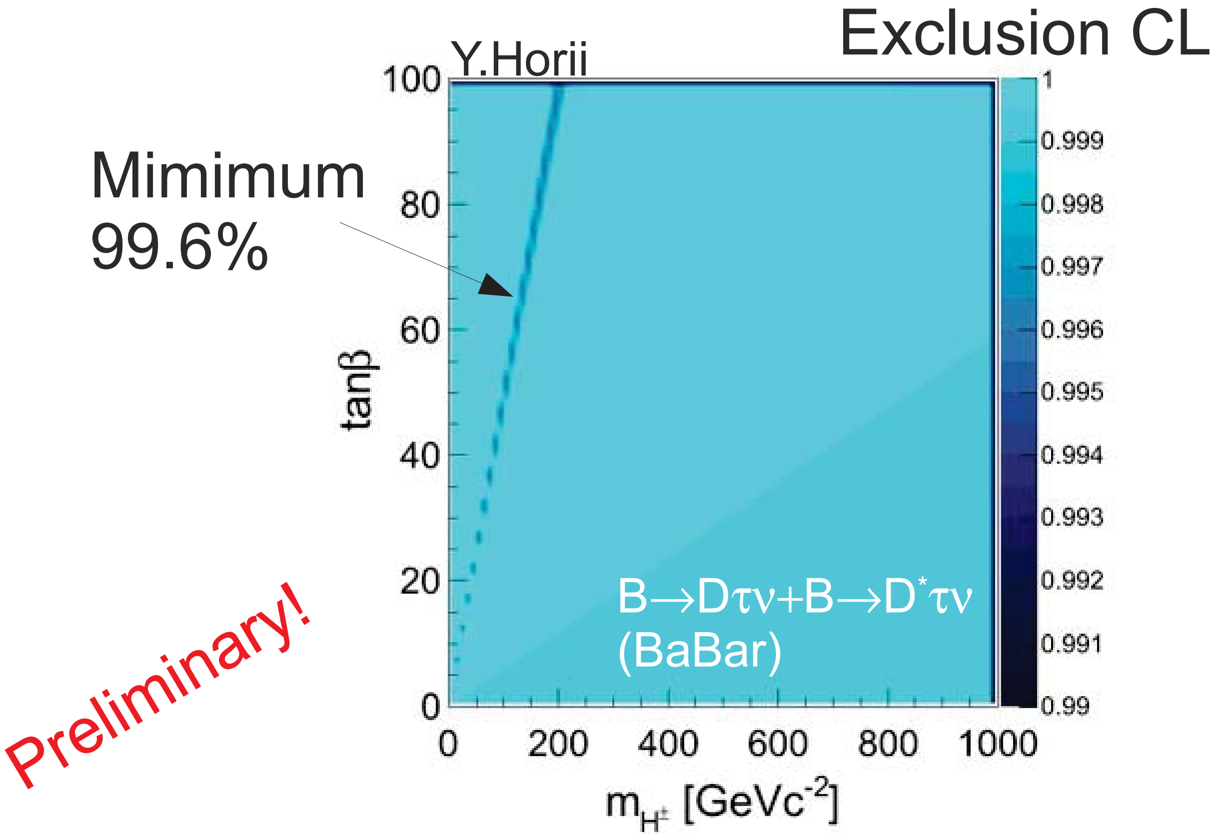
Preliminary!

Analysis by Y.Horii (Nagoya/NP-Japan)

Combining $B \to D\tau\nu$ and $D^*\tau\nu$

- Need to consider correlation between two measurements of Br since they are obtained by the similar analysis.

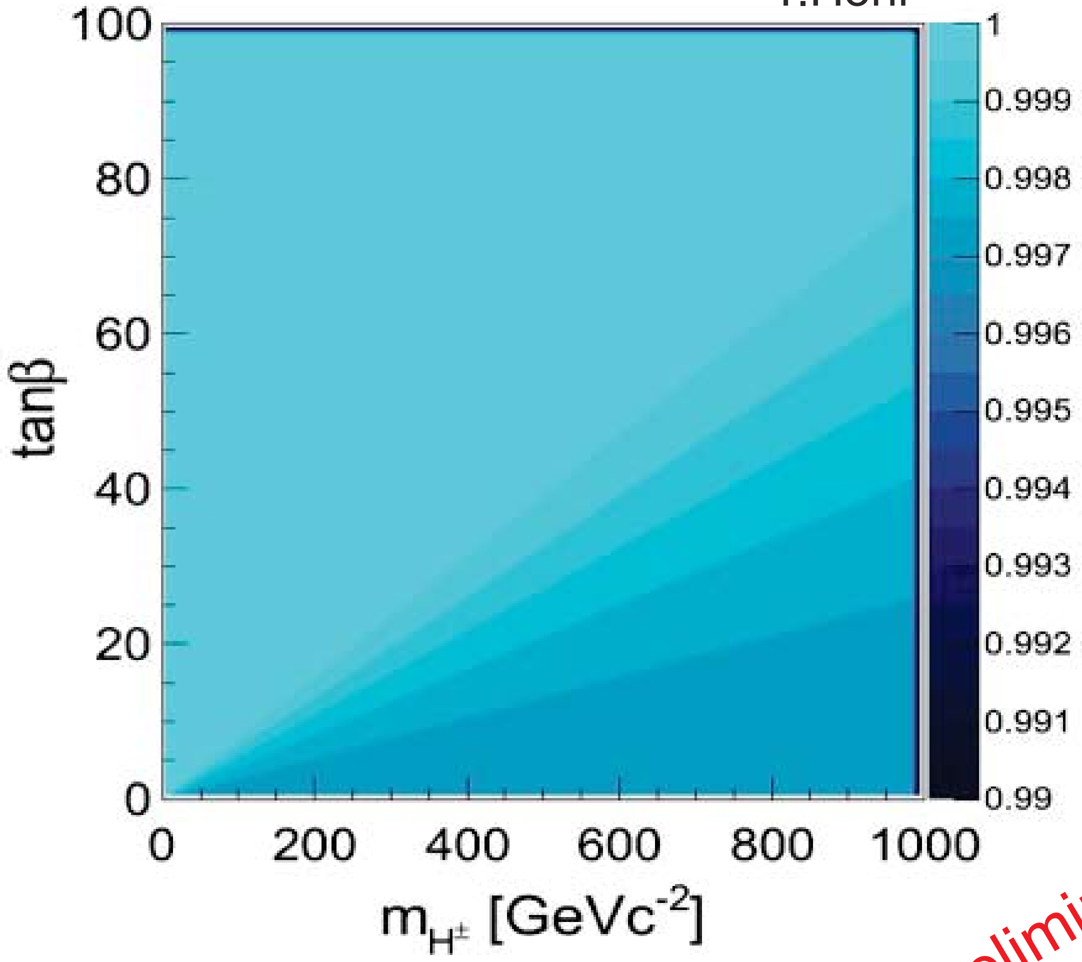
- The correlation factor : -0.27 (stat.+syst.)



Constraint with all modes combined

B→τν (world Ave.) + B→Dτν (BaBar) + B→D*τν (BaBar)

Y.Horii



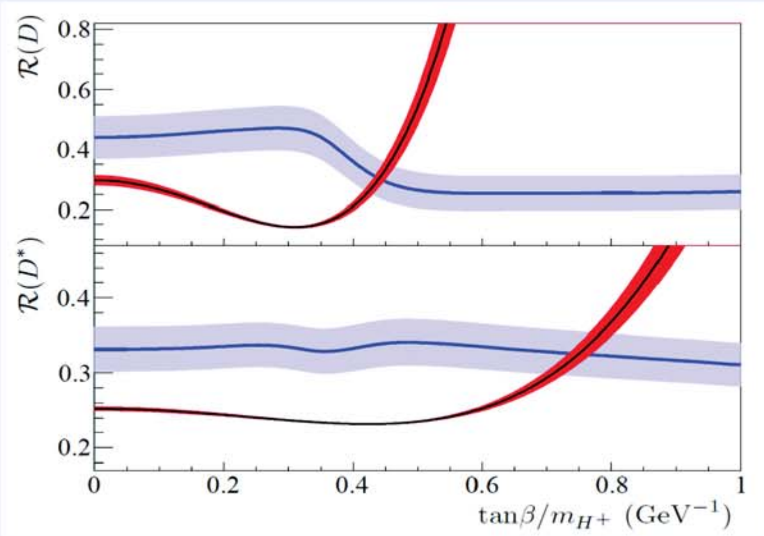
Preliminary!

- 2HDM Type II is rejected at more than 99.7%.

- Belle results of B→Dτν and B→D*τν measurements will be added soon.

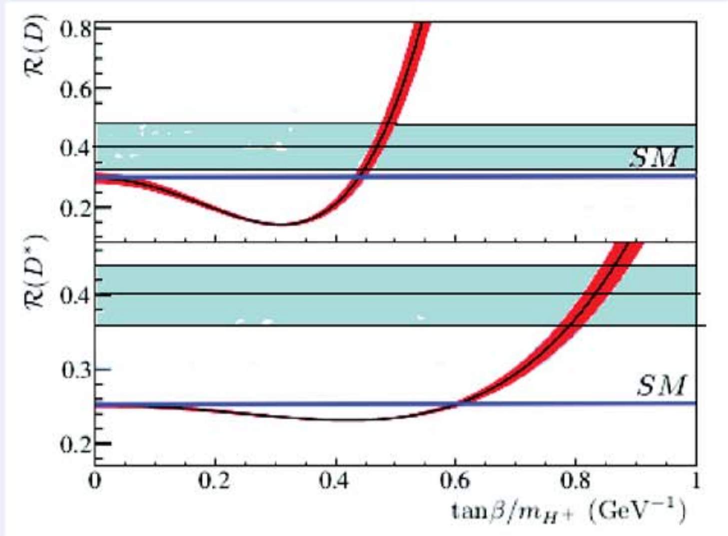
Comparison with 2HDM-II

BABAR

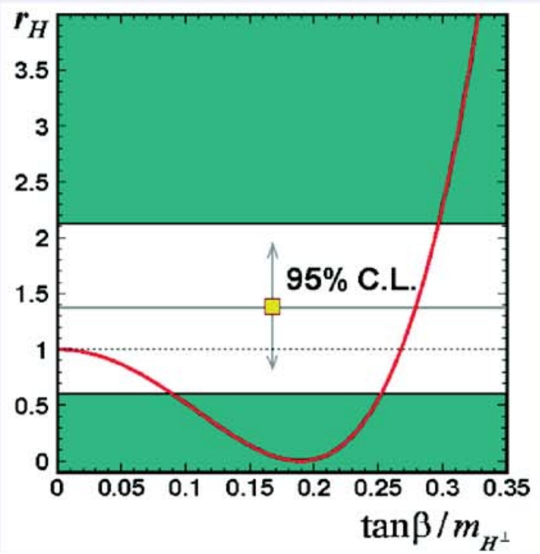


experimental band → acceptance variation with $\tan\beta/m_H^+$

Belle results

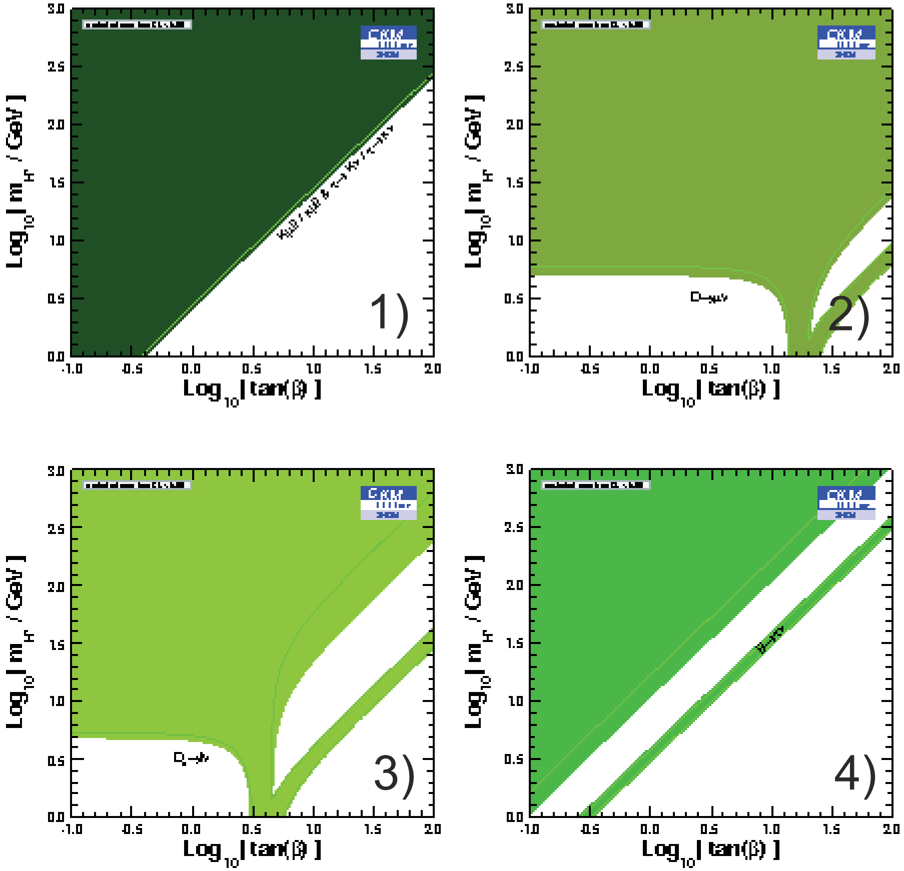


Acceptance variation with $\tan\beta/m_H^+$ was not included in that plot. Small for *exclusive* analysis.



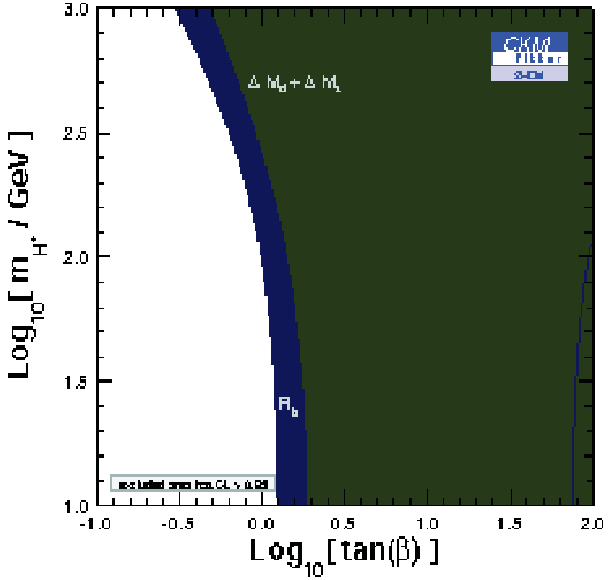
- R probes in $B^+ \to \tau^+\nu$, $B \to \bar{D}\tau^+\nu$ and $B \to \bar{D}^*\tau^+\nu$ different values for $tan\beta/m_{H^\pm}$
  - $R_D \to tan\beta \approx 0.4 - 0.5$ GeV^{-1}
  - $R_{D*} \to tan\beta \approx 0.7 - 0.9$ GeV^{-1}
- The *BABAR* collaborations excludes 2HDM-II charged Higgs at 99.8% confidence level for any value of $tan\beta/m_{H^\pm}$.

Further constraints

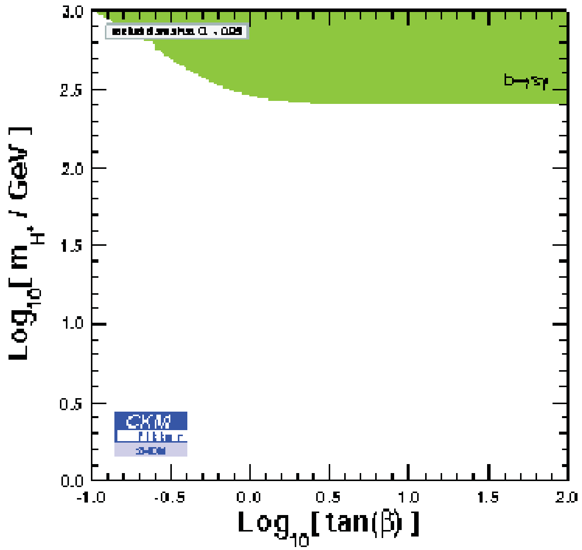


1) K->μν, τ->Kν
2) D->μν
3) D_s->μν
4) B_d->τν

Mixing + Z->bb



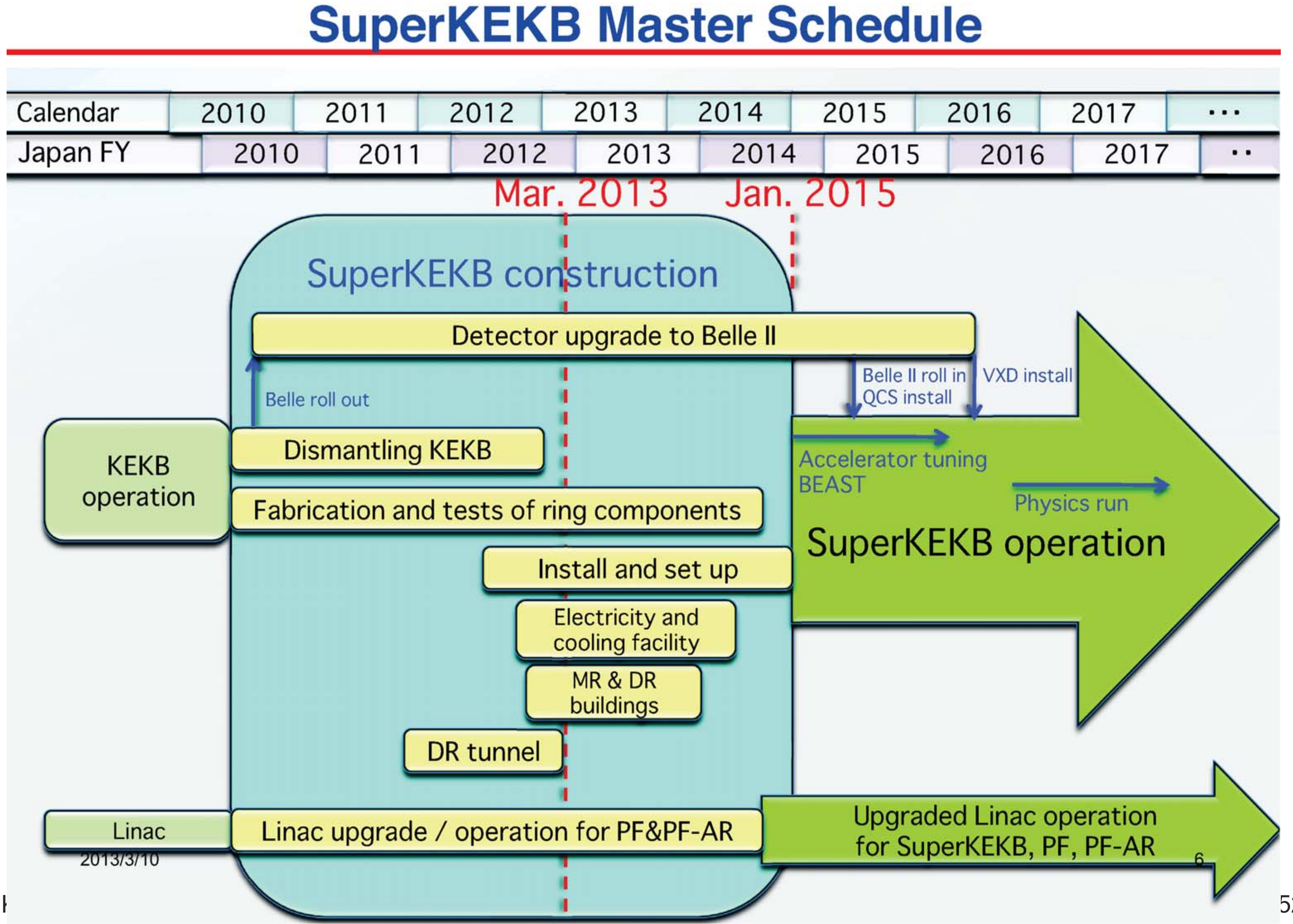
b->sγ



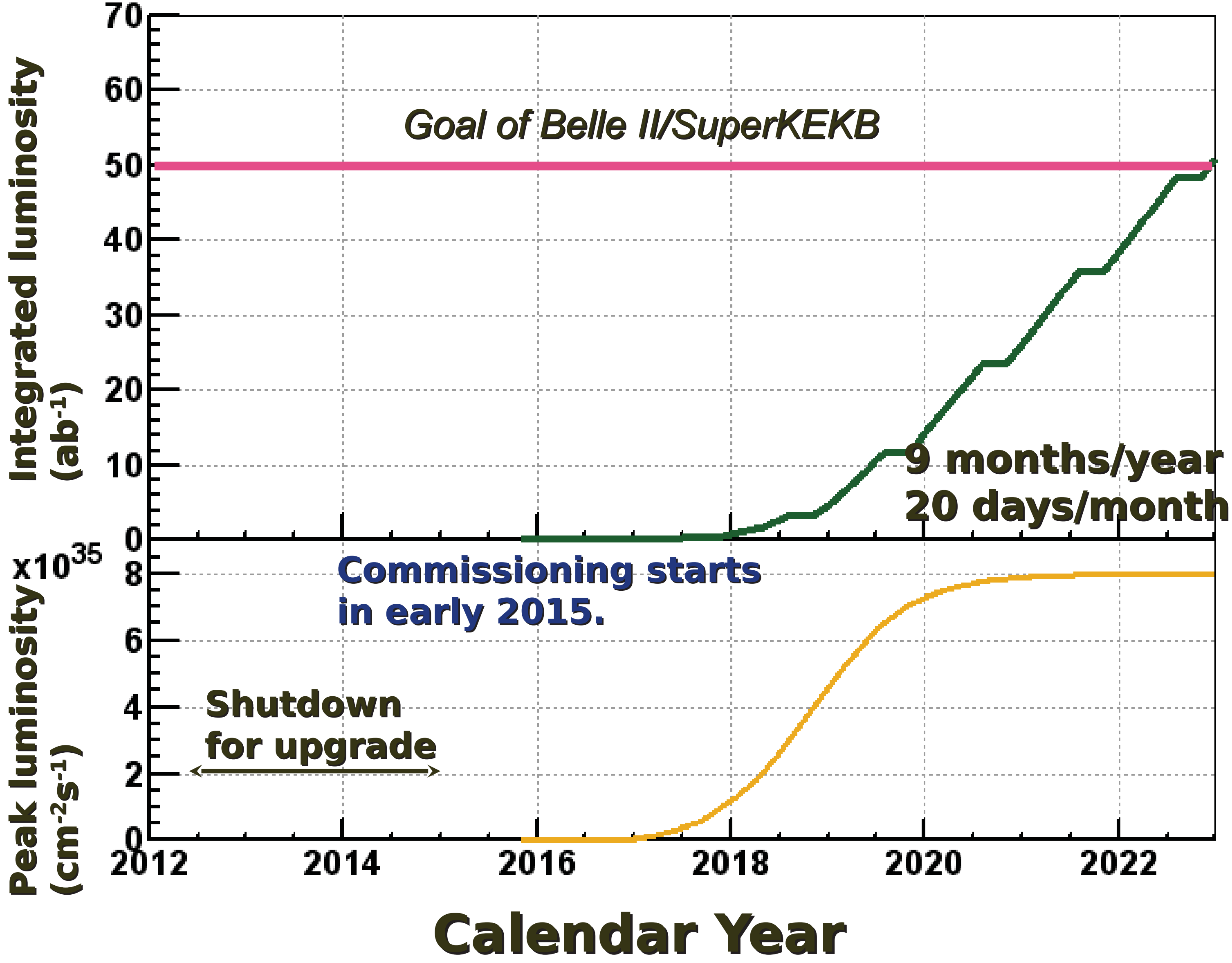
But 2HDM Type II is almost gone.... New NP model needed.

5. Status and Plan of Belle II and Global Fit

1) Belle II/SuperKEKB schedule



SuperKEKB luminosity projection



The Belle II Collaboration

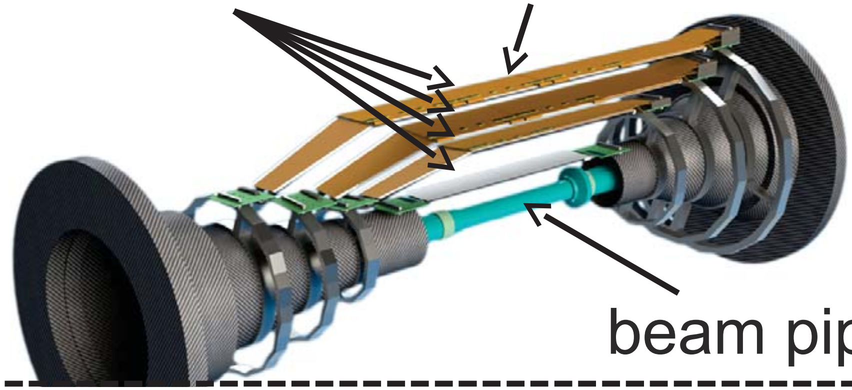
A very strong group of ~480 highly motivated scientists!

Status of detector construction: example = SVD

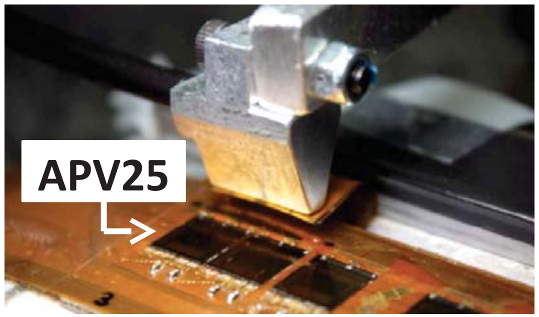
- SVD is one of the key components in Belle II detector for the precise reconstruction of the decay point of B mesons.
- Its assembly is partially taken care by Kavli IPMU lead by T.Higuchi, and being in progress.

4 layers of DSSD sensors

Ladder: set of DSSDs

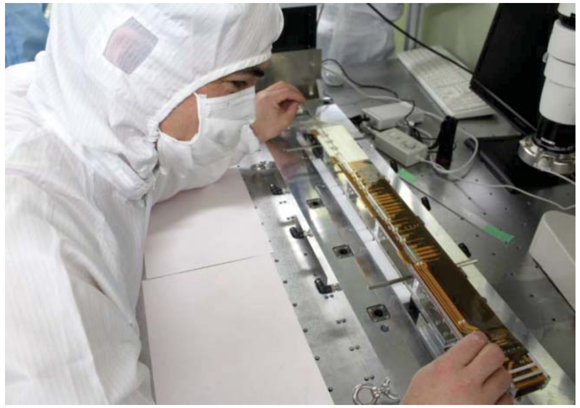


beam pipe



Readout chip: APV25 is placed on the sensor. Both side of sensors are read out by the chip.

Work at KIPMU



TH

Assembled Ladder for mock-up test (3/28/2013)

2) Further improvement of Global Fit approach

- If NP exists, its effect will be seen not only in B-factory measurements, but also in various experiments.
- Global fit combining measurements at various flavor factories (tau/charm factory + B factory + Kaon + LFV + EDM + g-2) can drastically improve the NP sensitivity.

A.Buras (arXiv:1012.1447)

Belle II + J-PARC(Kaon,COMET, g-2/EDM) + LHCb.....

	AC	RVV2	AKM	δLL	FBMSSM	$SSU(5)_{\rm RN}$
$D^0-\bar{D}^0$	★★★	★	★	★	★	★
ϵ_K	★	★★★	★★★	★	★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★★
$A_{\rm CP}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★
$A_{7,8}(K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★★★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★★★
d_e	★★★	★★★	★★	★	★★★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★★★

	LHT	RSc	4G	2HDM	RHMFV
$D^0-\bar{D}^0$ (CPV)	★★★	★★★	★★	★★	
ϵ_K	★★	★★★	★★	★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★★★	★★★
$S_{\phi K_S}$	★	★	★★		
$A_{\rm CP}(B\to X_s\gamma)$	★		★		
$A_{7,8}(K^*\mu^+\mu^-)$	★★	★	★★		
$B_s\to\mu^+\mu^-$	★	★	★★★	★★★	★★
$K^+\to\pi^+\nu\bar{\nu}$	★★★	★★★	★★★		★★
$K_L\to\pi^0\nu\bar{\nu}$	★★★	★★★	★★★		★★
$\mu\to e\gamma$	★★★	★★★	★★★		
$\tau\to\mu\gamma$	★★★	★★★	★★★		
$\mu+N\to e+N$	★★★	★★★	★★★		
d_n	★	★★★	★	★★★	
d_e	★	★★★	★	★★★	
$(g-2)_\mu$	★	★★	★		

Theory for global fit

- Currently, the theory models applicable for the global fit are limited to "model-independent" models:
  SM(Kobayashi-Maskawa model), MFV, 2HDM....
  <- Specific models (like SUSY) have a huge parameter space whose number is much more than the number of observables.

- To apply global fit approach for NP search in wider range, it is necessary to have a well-defined interface between theories and experimental measurements.

- Once the theory can be expanded in a unified "effective theory" with a limited number of parameters, it can be used for the global fit. Prediction of each measurement is parameterized using them.

- Global fit determines the coefficients in the effective theory while each theory gives the predictions for the coefficients.

- "DNA identification" of NP models can be done by comparing the determined coefficients with theory predictions.

Parameterization using Wilson Coefficients: (T.Goto, KEK)

$$\mathcal{L}_{\text{eff}} = \mathcal{L}(\text{QCD} + \text{QED}) + \sum_i C_i \mathcal{O}_i.$$

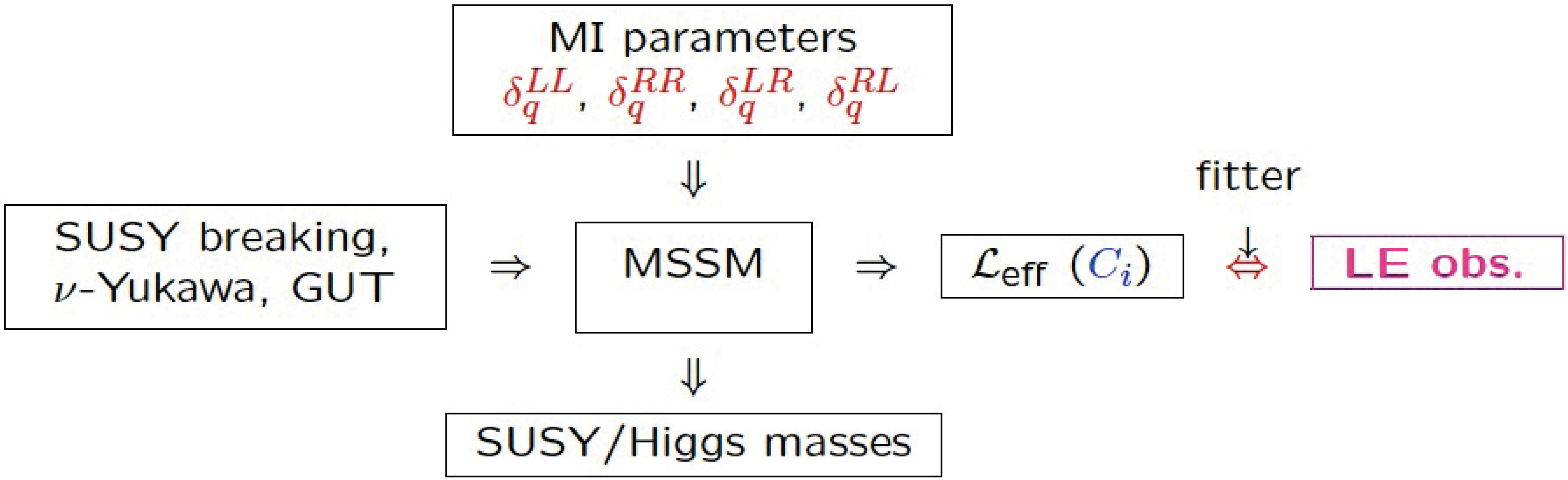
$\mathcal{O}_i$: 次元 > 4 の effective operators

- 4-fermi interaction (dim-6): $(\overline{\psi}_1 \gamma^\mu \psi_2)(\overline{\psi}_3 \gamma_\mu \psi_4)$,
- dipole moment (dim-5): $\overline{\psi}_1 \sigma^{\mu\nu} \psi_2 F_{\mu\nu}$,

etc..

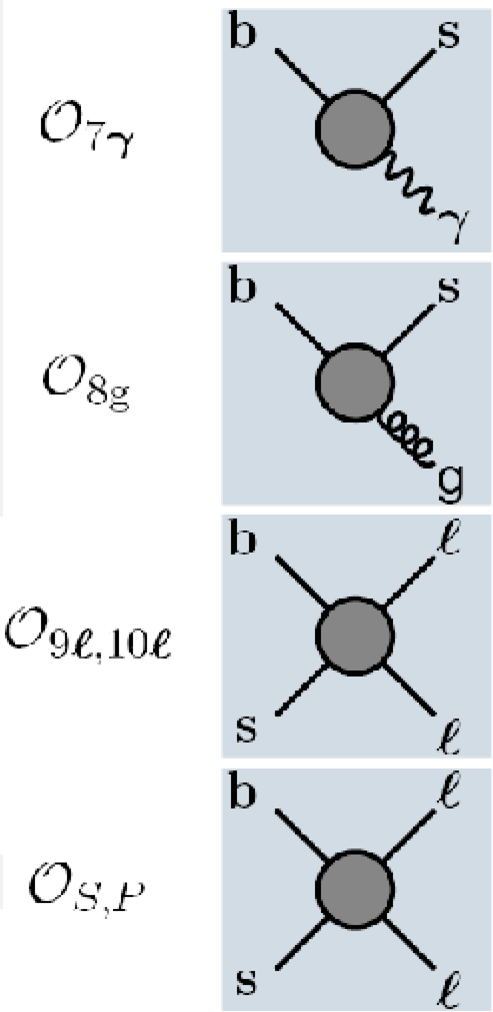
C_i: Wilson 係数 ← Determined by Global Fit

Example: expansion of MSSM to Effective Theory



ΔF=1 FCNC: b→s transitions and OPE

G. Hiller - hep-ph/0308180



Describe $b \to s$ transitions by an effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu) \mathcal{O}_i(\mu)$$

- Long Distance:
  - Operators O_i
- Short Distance:
  - Wilson coef. C_i

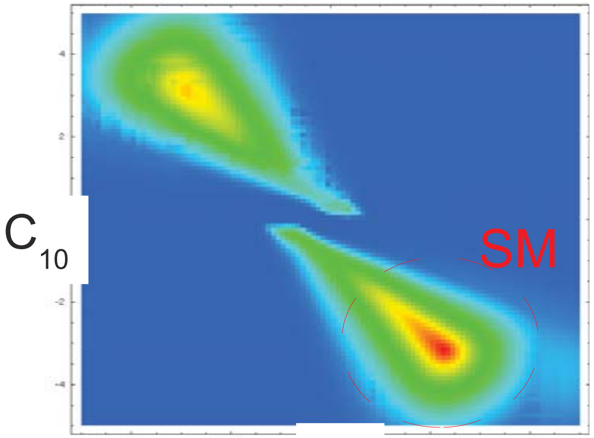
New physics shows up as modified C_i,

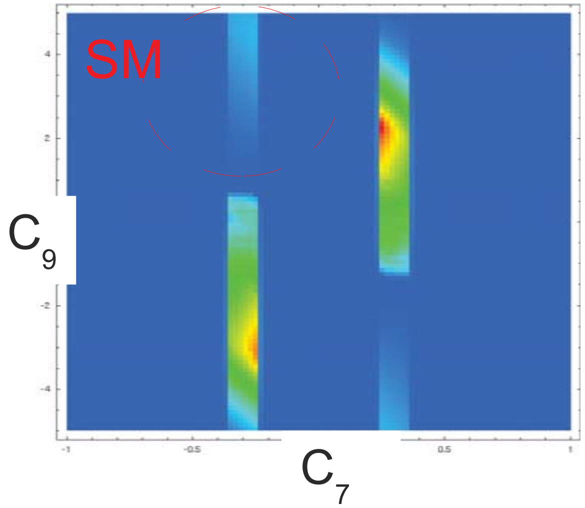
(or as new operators)

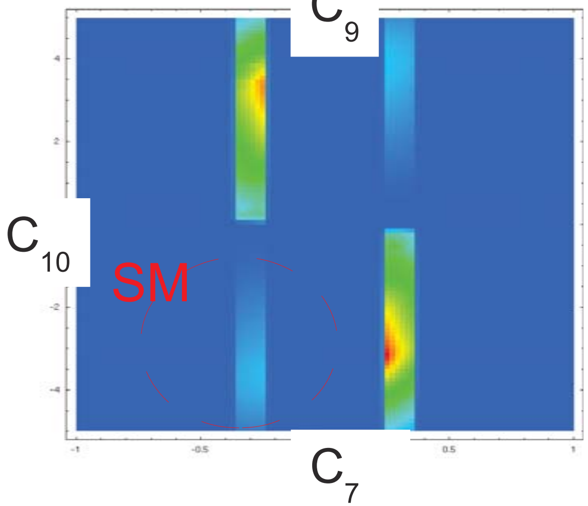
"Pilot effort" of the determination of Wilson Coeff.

R.Itoh

- Inputs
  - * Br(B→K*γ) (HFAG 2008)
  - * Br(B→K*$\mu^+\mu^-$) (HFAG 2008)
  - * A_{FB}(B→K*l^+l^-) as a function of q^2 (Belle 2008)
- Free parameters : Wilson Coefficients C_7, C_9 and C_{10}.





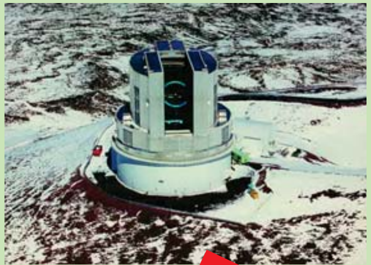


2-D scan favors
- * Positive C_9
- * Negative C_{10}
- * Positive C_7

Synergy with cosmology

High-statistics cosmological survey

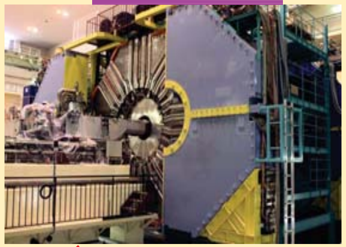
Subaru Telescope



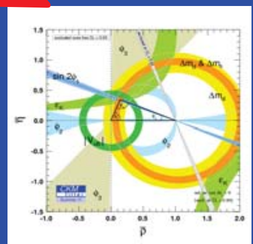
Fermi Satelite

High-statistics particle experiment

Belle II



J-PARC



Global Fit

Study of “Dark” sector

New theory framework

* Combined Dark Matter search by satellite and particle experiments
* Study of dark energy in a framework of particle theory.

5. Summary

- The key for the success of Belle II experiment is to establish "the method to optimize the sensitivity to NP with a minimal accumulation of data".

- The global fit technique, which combines various observables originated from the same NP source, can be a "killer application" in Belle II analysis.

- Various global fit activities are already going on until now and its usefulness has well been established by "CKM fit".

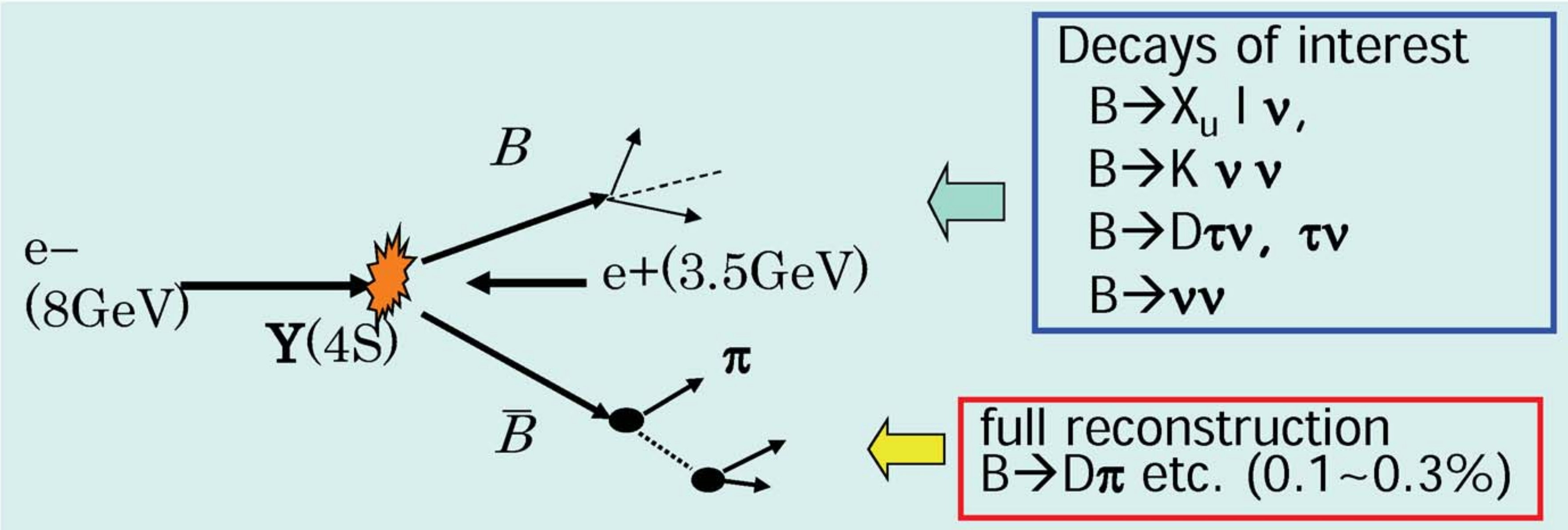
- The extension of global fit to combine wide range of observables including not only high energy experiments but also cosmological survey could be the ultimate tool for NP search.

- To function global fit effectively, a very close collaboration of both experimentalists and theorists is essential.
  Theory meets Experiment "in the same framework".

Backup Slides

Power of e^+e^-, example: Full Reconstruction Method

- Fully reconstruct one of the B mesons to
  - Tag B flavor/charge
  - Determine B momentum
  - Exclude decay products of one B from further analysis



→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Complementary to LHCb

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c\ell\nu]$	**	1%	Belle II
$\lvert V_{ub}\rvert$ $[B_d \to \pi\ell\nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K^0_S]$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

→Need both LHCb and super B factories to cover all aspects of precision flavour physics

- B. Golob, KEK FF Workshop, Feb. 2012

Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 - 1 (short bunch)

Classical electron radius

Beam size ratio@IP 1 - 2 % (flat beam)

Vertical beta function@IP

(1) Smaller β_y^*

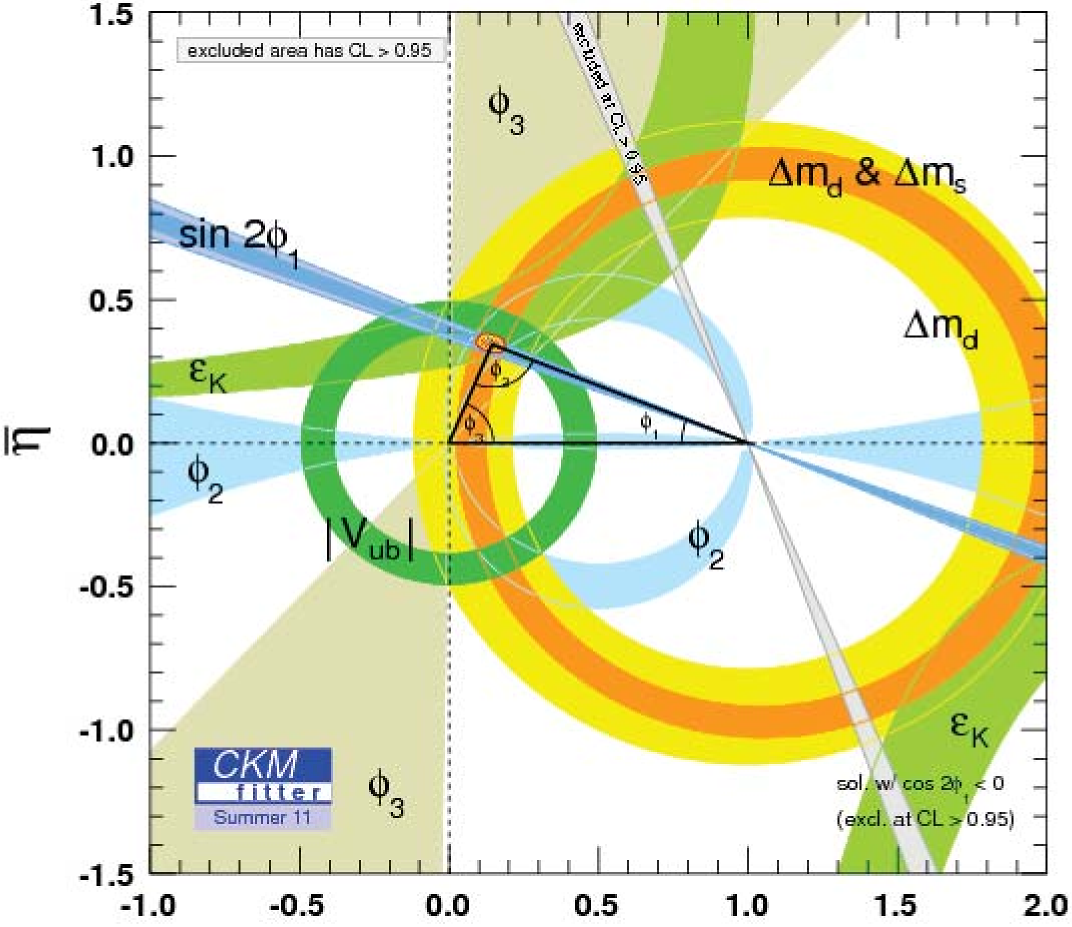
(2) Increase beam currents

(3) Increase ξ_y

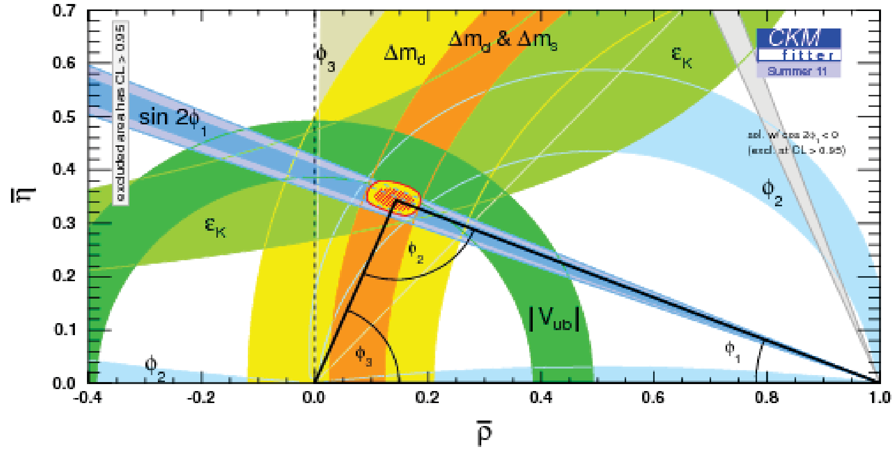
"Nano-Beam" scheme

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB



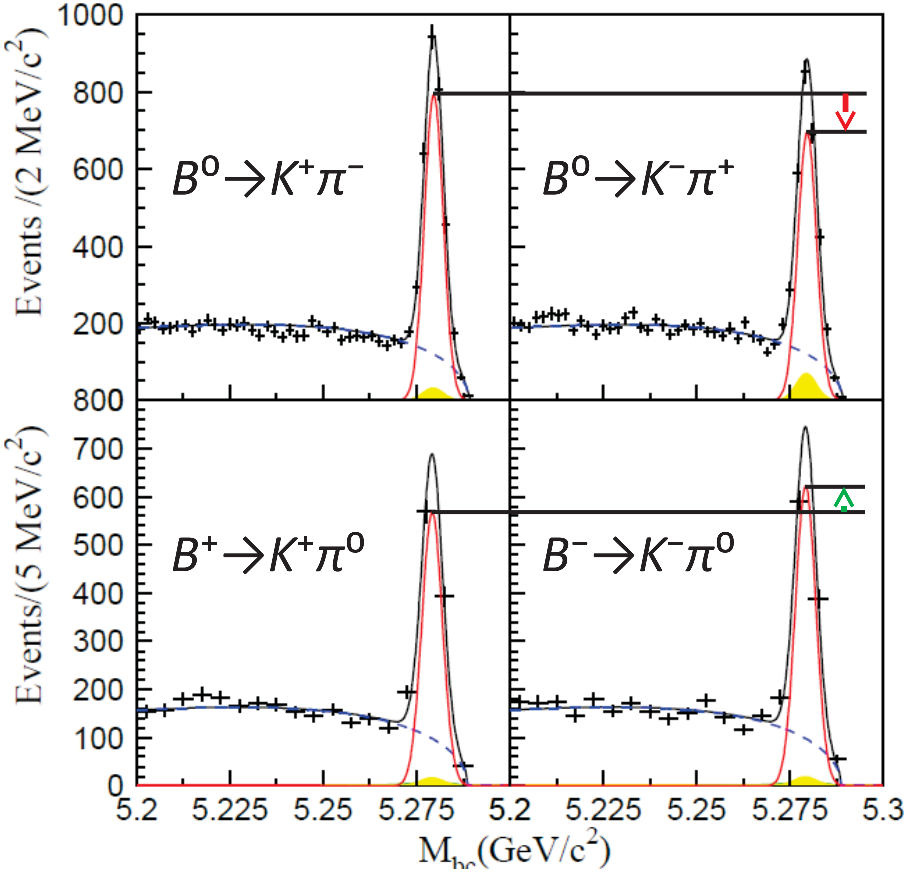
2011 CKMFitter Result



Wolfenstein parameters and Jarlskog invariant:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
A	0.801 [+0.026 -0.014]	0.801 [+0.036 -0.022]	0.801 [+0.046 -0.029]
λ	0.22539 [+0.00062 -0.00095]	0.2254 [+0.0010 -0.0019]	0.2254 [+0.0014 -0.0027]
ρbar	0.144 [+0.023 -0.026]	0.144 [+0.038 -0.046]	0.144 [+0.048 -0.057]
ηbar	0.343 [+0.015 -0.014]	0.343 [+0.030 -0.025]	0.343 [+0.045 -0.033]
J [10^{-5}]	2.884 [+0.253 -0.053]	2.884 [+0.400 -0.098]	2.88 [+0.55 -0.14]

- ***The direct CP violation "flips" between B^0 and B^+***



772 x 10⁶ $B\bar{B}$

B^0

$A_{CP}(K^+\pi^-) = -0.069 \pm 0.014 \pm 0.007$

$A_{CP}(K^+\pi^0) = +0.043 \pm 0.024 \pm 0.007$

B^+

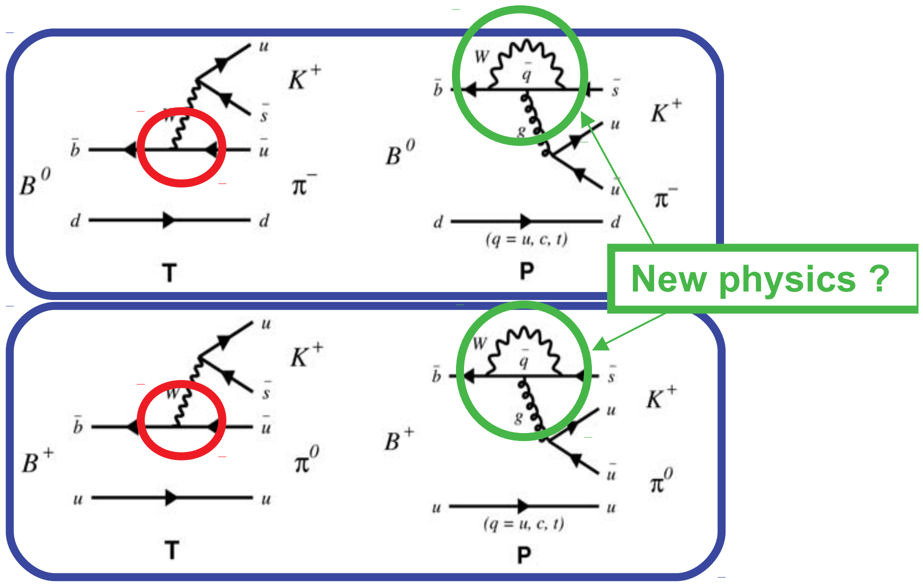
Y.-T. Duh *et al.* (Belle Collab.),
Phys. Rev. D **87**, 031103(R) (2013).

4.0σ discprepancy.......

Quark level diagram is the same for both decays.....

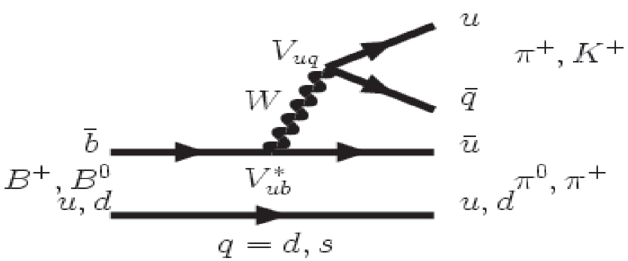
$B^0 \rightarrow K^+\pi^-$

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

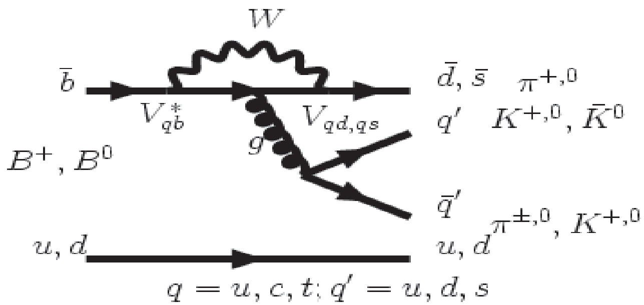


Possible explanation of $\Delta A_{CP}(K\pi)$ puzzle

T



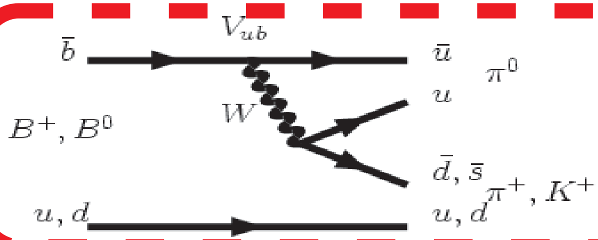
P

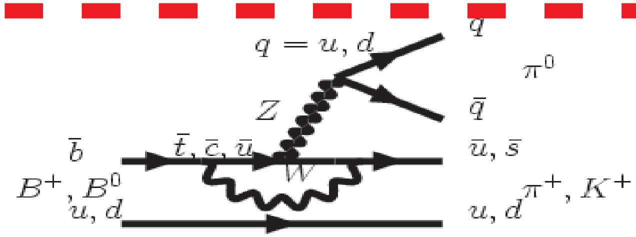


+

Color Suppressed Tree

C





EW Penguin

P_{EW}

Expected to be negligible in SM

- C.-W.Chaing, et al., PRD 70, 034020
- Y.-Y.Charng, et al., PRD 71, 014036
- W.-S.Hou, et al., PRL 95, 141601
- S.Baek, et al., PRD 71, 057502
- S.Baek, et al., PLB 653, 249
- H.-n.Li,et al., PRD 72, 114005
- etc…

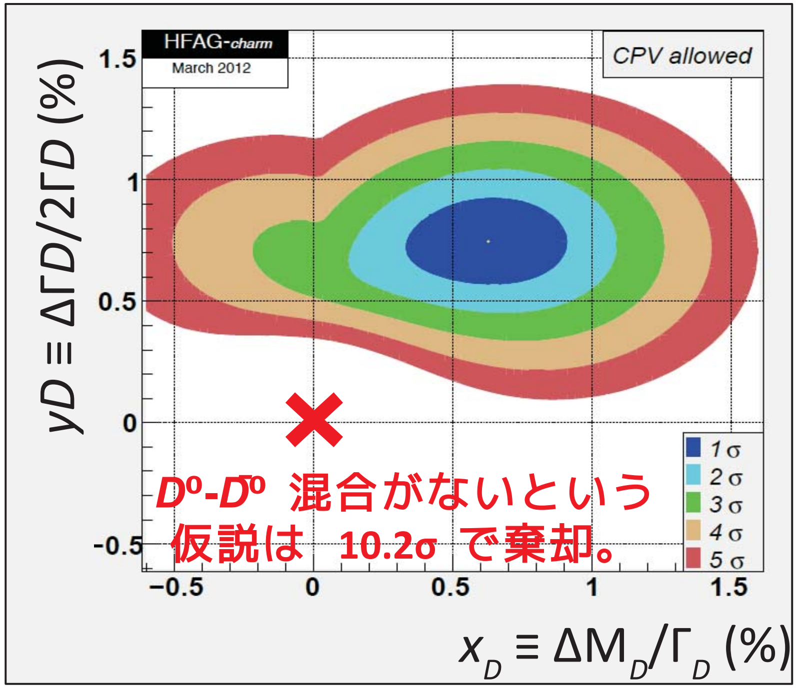
- Enhancement of **C** ?
  - → C > T is needed (C/T = 0.3–0.6 in SM)
  - → breakdown of theoretical understanding
- Enhancement of **P_{EW}** ?
  - → Would indicate new physics.
- Due to poor understanding of strong int.?

Sum Rule : M. Gronau, PLB 627, 82 (2005); D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998)

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

Sum Rule tells $A_{CP}(K^0\pi^0)$ to be -0.15±0.06 ← Belle meas. +0.14±0.13±0.06 → more statistics!

- **Unexpectedly large D-D mixing**



SM prediction

$$x_D \leq 0.1\%, \;\; y_D \leq 1\%,$$

A. Petrov, Int. J. Mod. Phys. A **21**, 5686 (2006)

Measurement Ave.

$$x_D = (0.63^{+0.19}_{-0.20})\%$$

$$y_D = (0.75 \pm 0.12)\%$$

Average of Belle,BaBar,CDF,CLEOc

L. M. Zhang *et al*. (Belle Collab.), Phys. Rev. Lett. **96**, 151801 (2006) *etc*.

- However, still SM predictions vary largely depending on the model/calculartion .....

Digression: Statistics

D.R. Cox, Principles of Statistical Inference, CUP (2006)

W.T. Eadie et al., Statistical Methods in Experimental Physics, NHP (1971)

www.phystat.org

Statistics tries answering a wide variety of questions ➔ two main different! frameworks:

Frequentist: probability **about the data** (randomness of measurements), given the model

P(data|model)

[only repeatable events (Sampling Theory)]

Hypothesis testing: given a model, assess the **consistency** of the data with a particular parameter value ➔ 1-CL curve (by varying the parameter value)

Bayesian: probability **about the model** (degree of belief), given the data

$$P(\text{model}|\text{data}) \equiv \text{Likelihood}(\text{data},\text{model}) \times \textbf{Prior(model)}$$

P(data|model) ≠ P(model|data):

model: Male or Female

data: pregnant or not pregnant

P (pregnant | female) ~ 3%

but

P (female | pregnant) >>>3%

Lyons – CDF Stat Committee

Although the graphical displays appear similar: the meaning of the “Confidence level” is not the same. It is especially important to understand the difference in a time where one seeks deviation of the SM.