Belle II:
Motivation, Status, and Prospects

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KEK

on behalf of Belle II collaboration

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Outline

1. Motivation of Belle II experiment
2. SuperKEKB and Belle II
3. Construction Status and Plan
4. Search for New Physics at Belle II
5. Collaboration with Theorists
6. Summary

1. Motivation of Belle II Experiment

- 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***, a new generation B-factory where there is no limit in the search energy, will be more important.

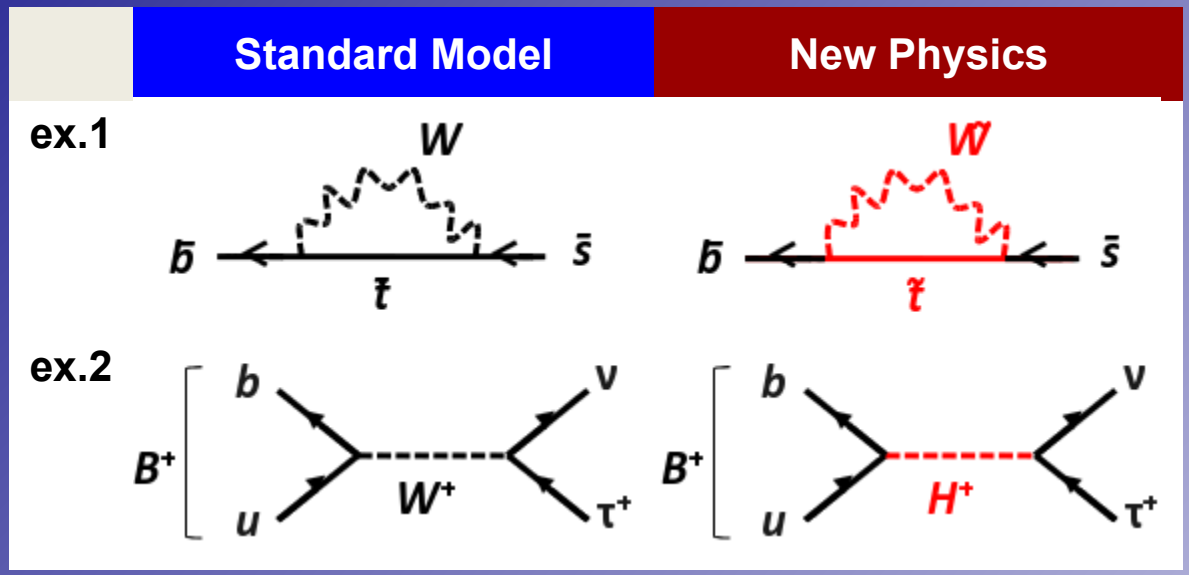
- However, the effect of NP in the indirect processes is expected to be tiny, and it has not been observed by Belle/BaBar so far, except for several "anomolous" measurements:
  * $A_{CP}(B^0 \to K^+\pi^-) \neq A_{CP}(B^+ \to K^+\pi^0)$ (5.6σ discrepancy),
  * Unexpectedly large D^0-$\overline{D}^0$ mixing (although SM pred. has large uncertainties)
  * $Br(B \to D^{(*)}\tau\nu)$: ~5σ discrepancy from SM pred.

- To go beyond, more precise measurements in much higher statistics of events is required.

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

How do we search for New Physics in Belle II?

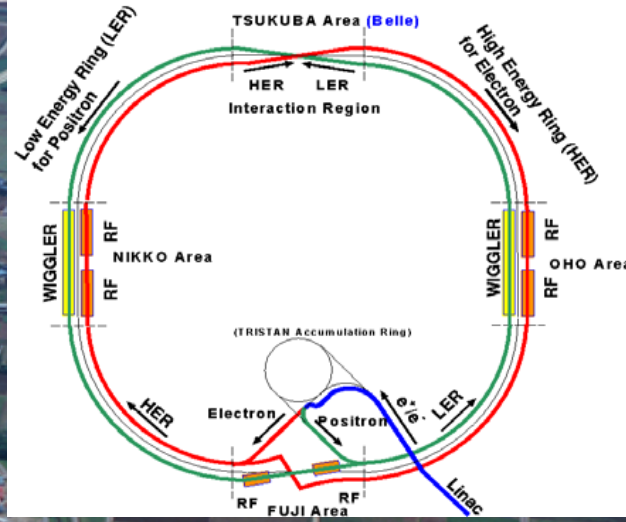
- Search for the “shift” from SM prediction caused by an existence of a new particle in quantum effect.

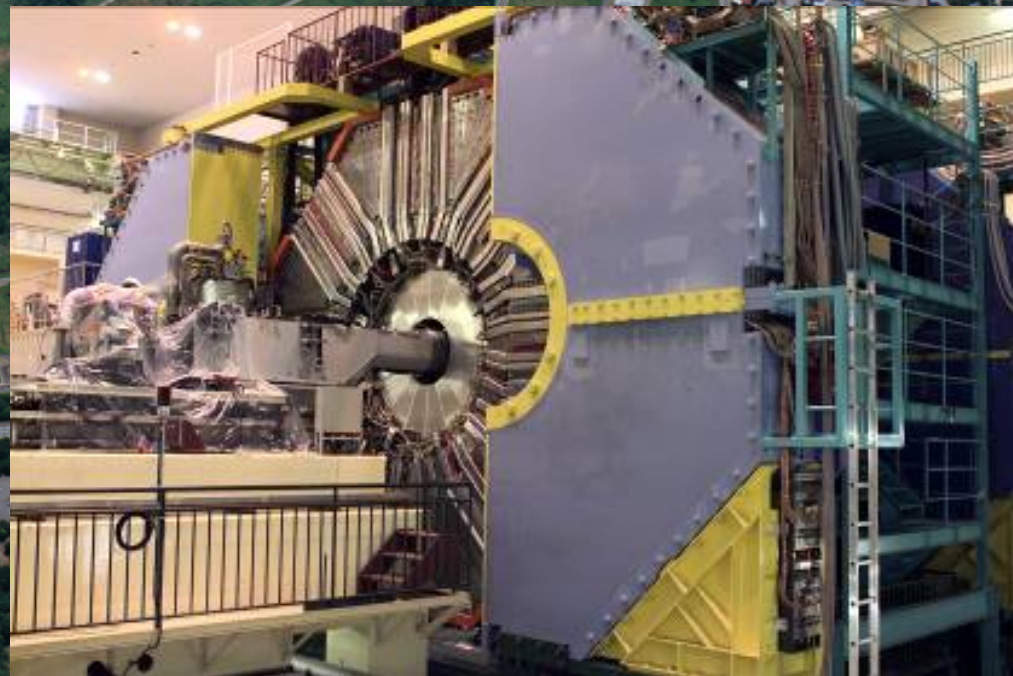


In order to search for NP, the measurement has to be compared with the Standard Model prediction in a high precision.

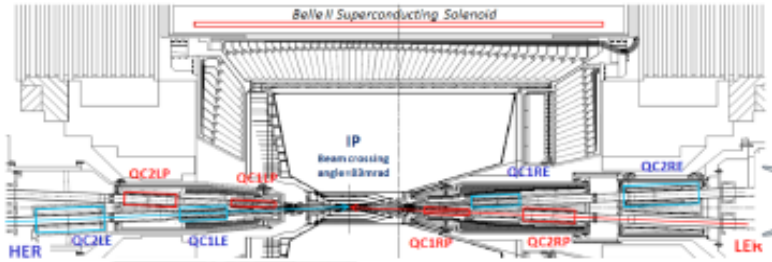
We need both of
* High precision experimental measurement
* High precision theory prediction of Standard Model

2. SuperKEKB and Belle II



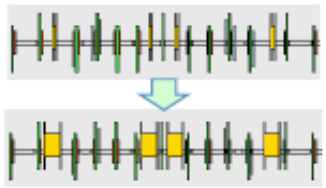


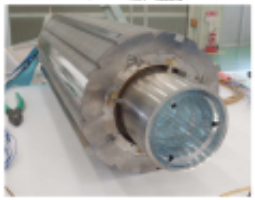
The SuperKEKB accelerator



Colliding bunches

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)





New superconducting final focusing magnets near the IP

e^+ 3.6A

e^- 2.6A

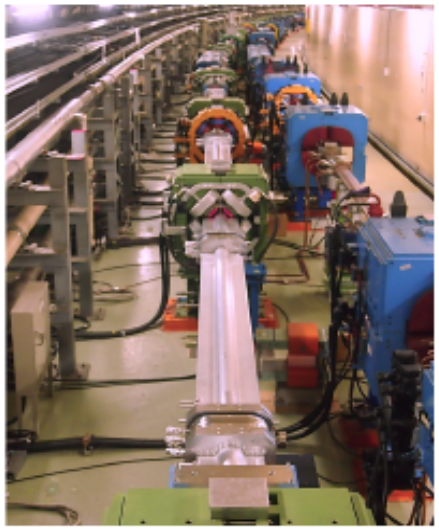
KEKB to SuperKEKB

- Nano-Beam scheme
  extremely small β_y^*
  low emittance
- Beam current double

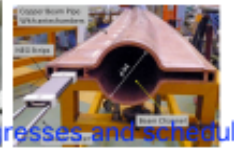
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

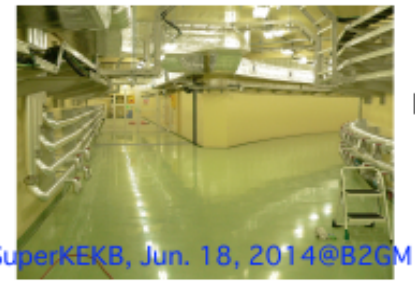
40 times higher luminosity
2.1×10^{34} --> 8×10^{35} $cm^{-2}s^{-1}$

New HER wiggler section



Replace beam pipes with TiN-coated beam pipes with antechambers





DR tunnel

Injector Linac upgrade

New e+ Damping Ring

Reinforce RF systems for higher beam currents 2

K. Akai, Other progresses and schedule of SuperKEKB, Jun. 18, 2014@B2GM

Beam-beam parameter

Lorentz factor

Beam current

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

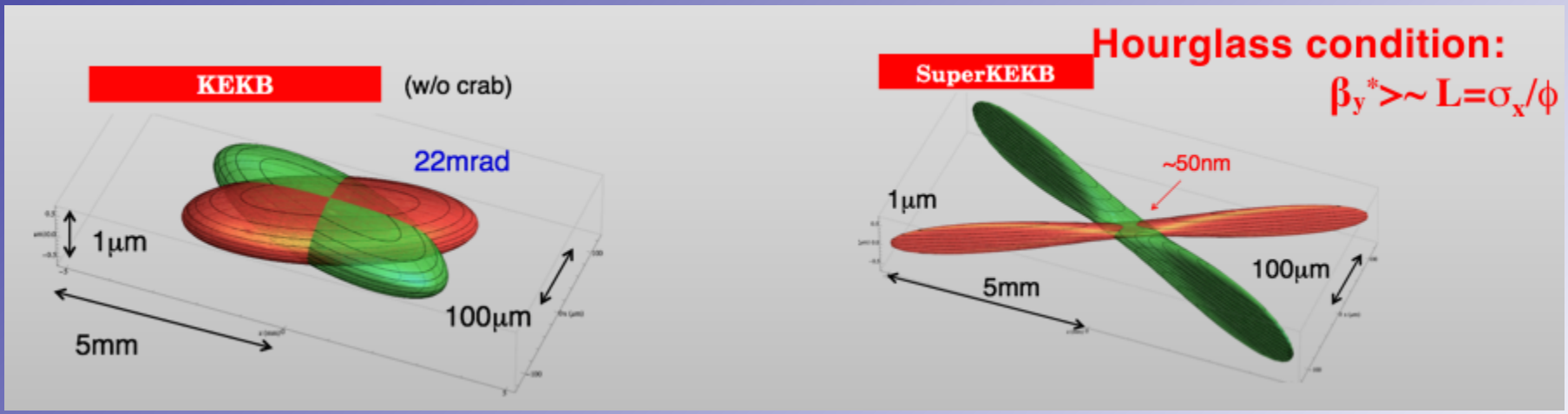
Lumi. reduction factor
(crossing angle)&
Tune shift reduction factor
(hour glass effect)
0.8 ~ 1
(short bunch)

Classical electron radius

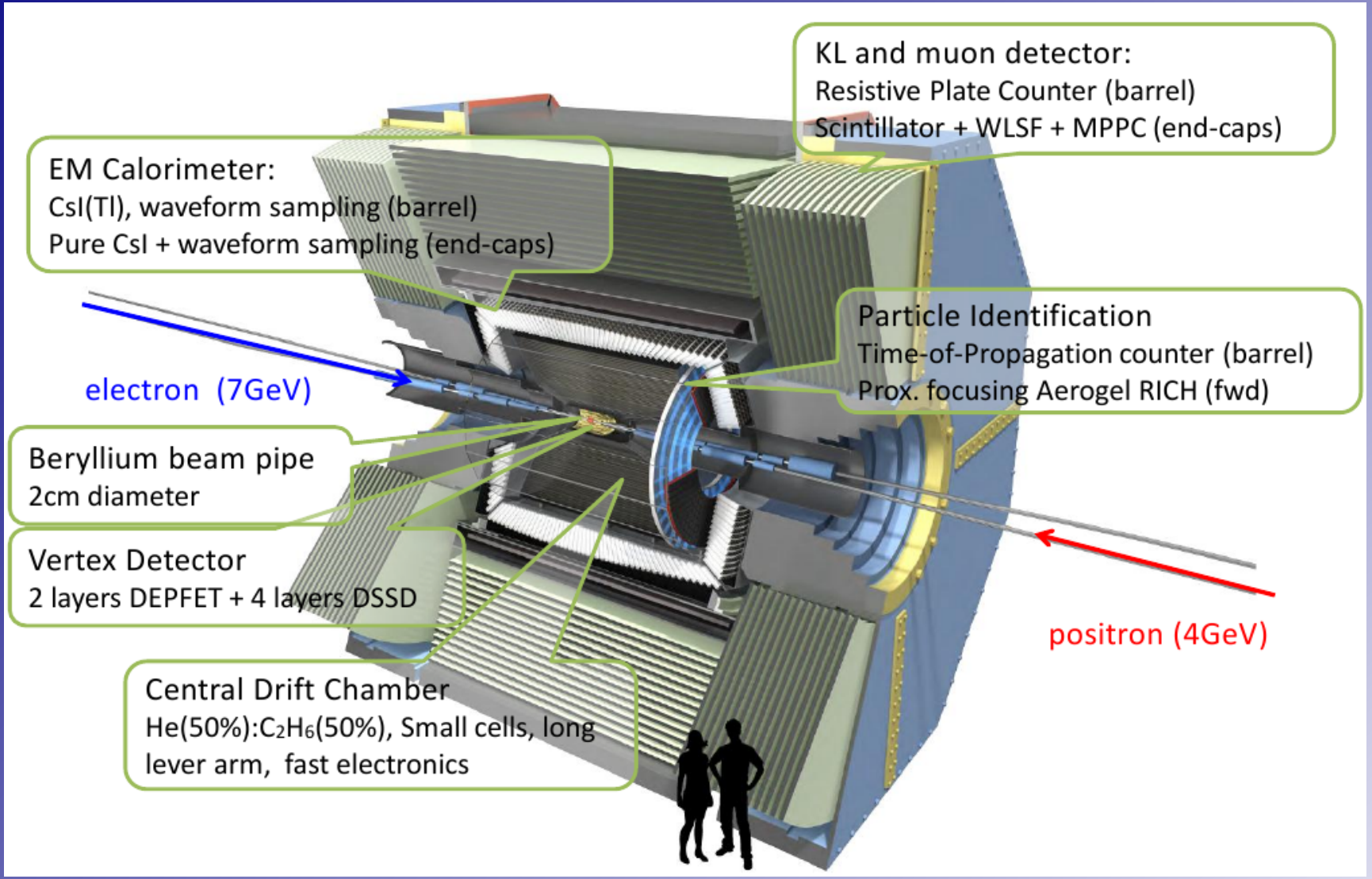
Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

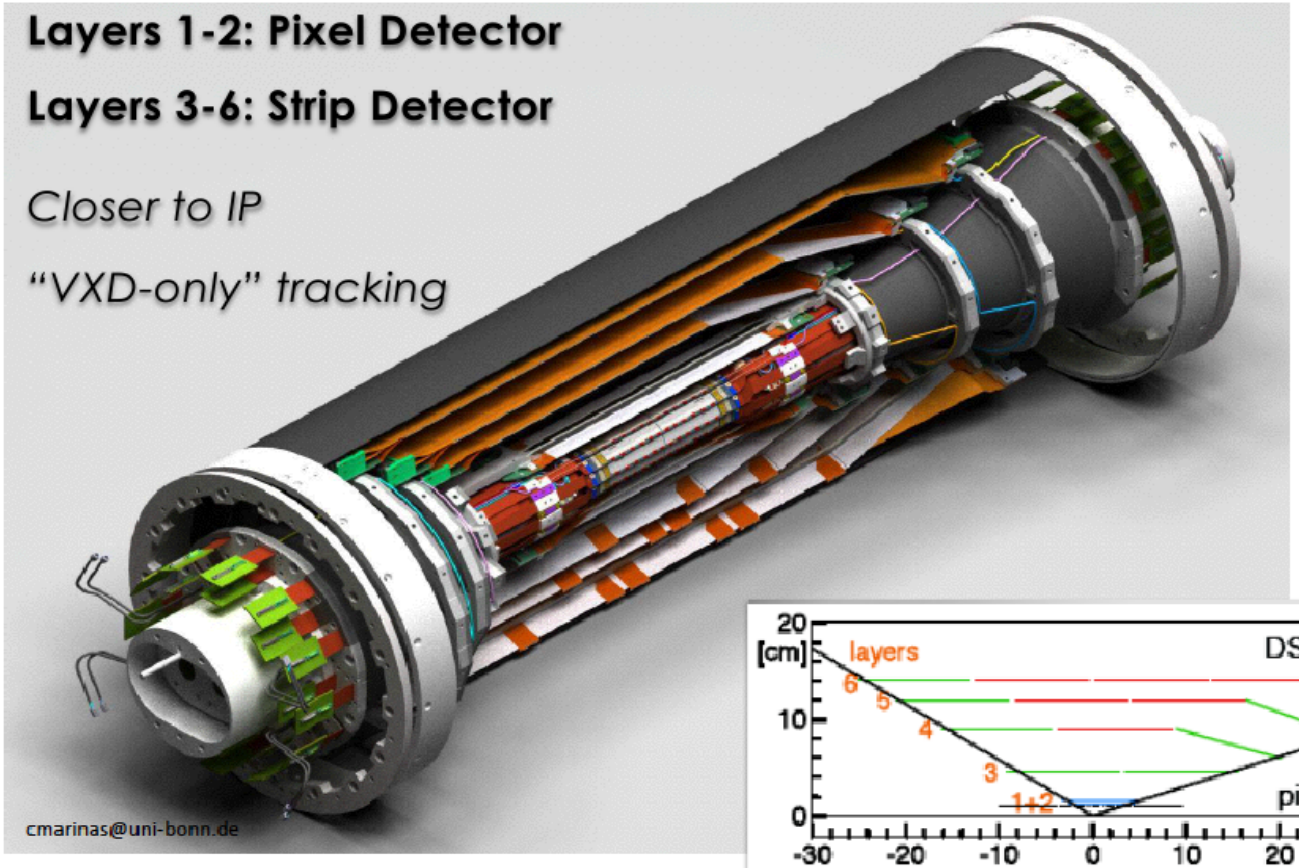


The Belle II detector

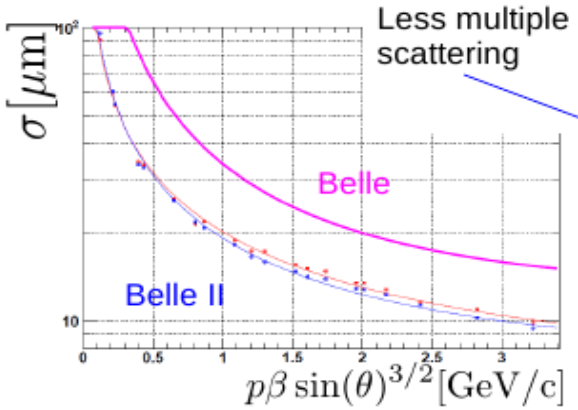


- High granularity "pixelized" sensors ← to be tolerable for high rate
  - * Improved vertex detector with DEPFET Pixel sensors + DSSD
  - * Improved particle ID devices (TOP, ARICH)
- High bandwidth DAQ (>30GB/sec data flow @30kHz, >1MB/event)

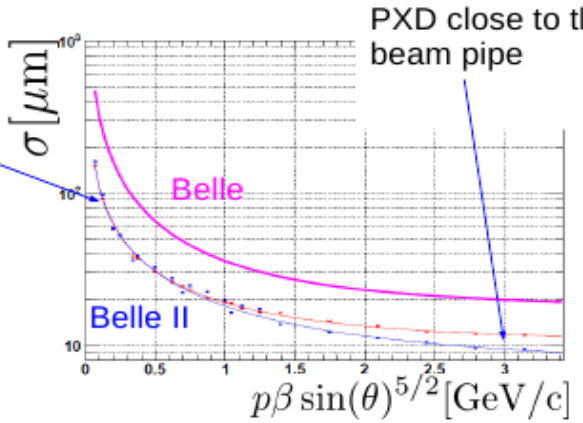
Vertex Detector : Pixel detector + Silicon strip detector

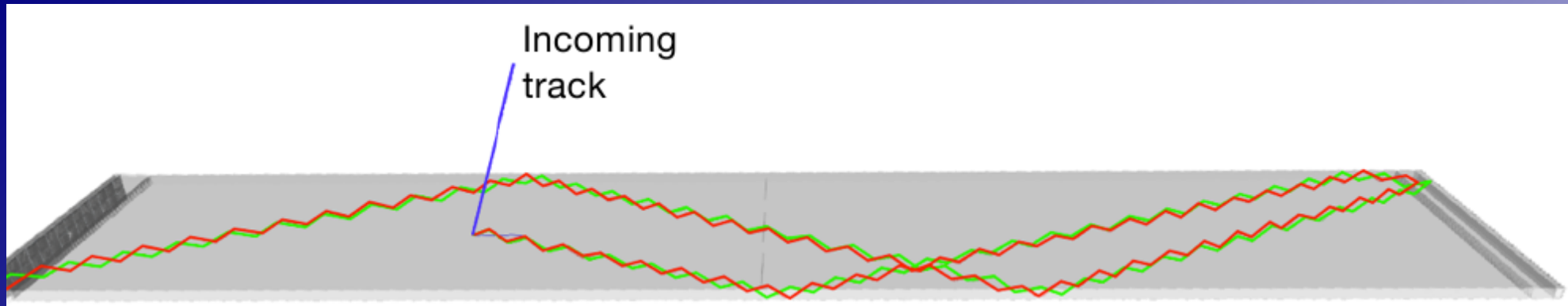


Closest approach resolution

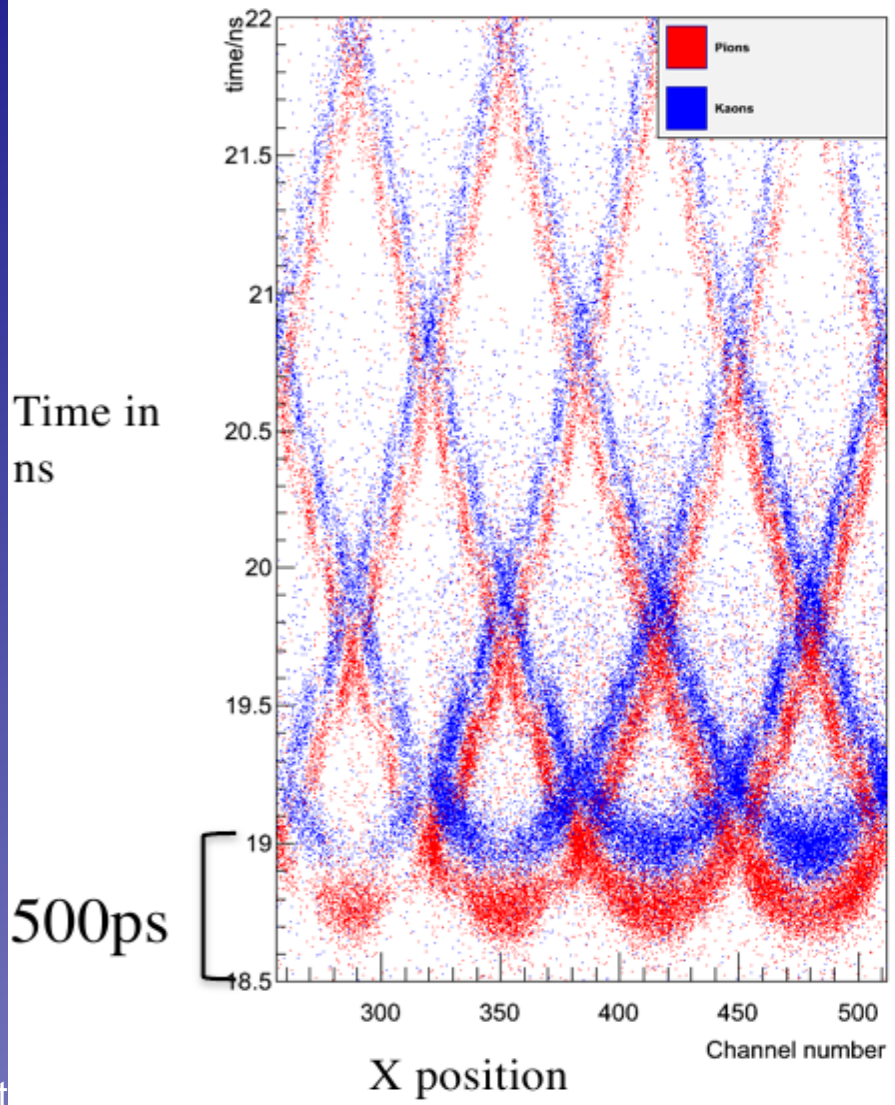


Z resolution





Channel Vs. time for 3GeV pions/kaons with beam test setup

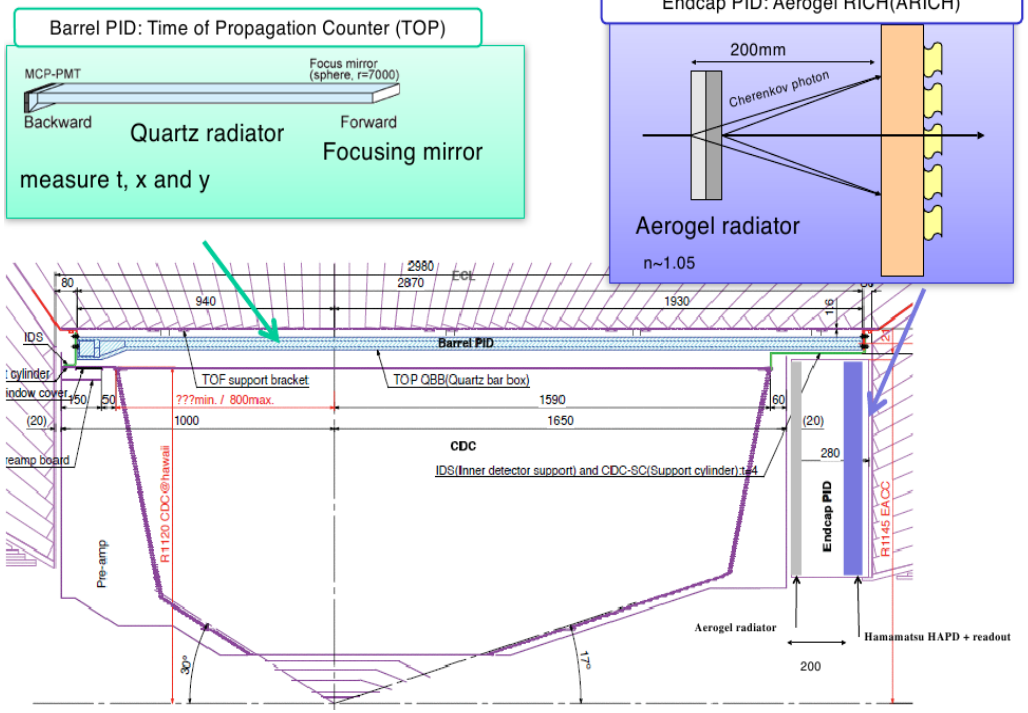


Time in ns

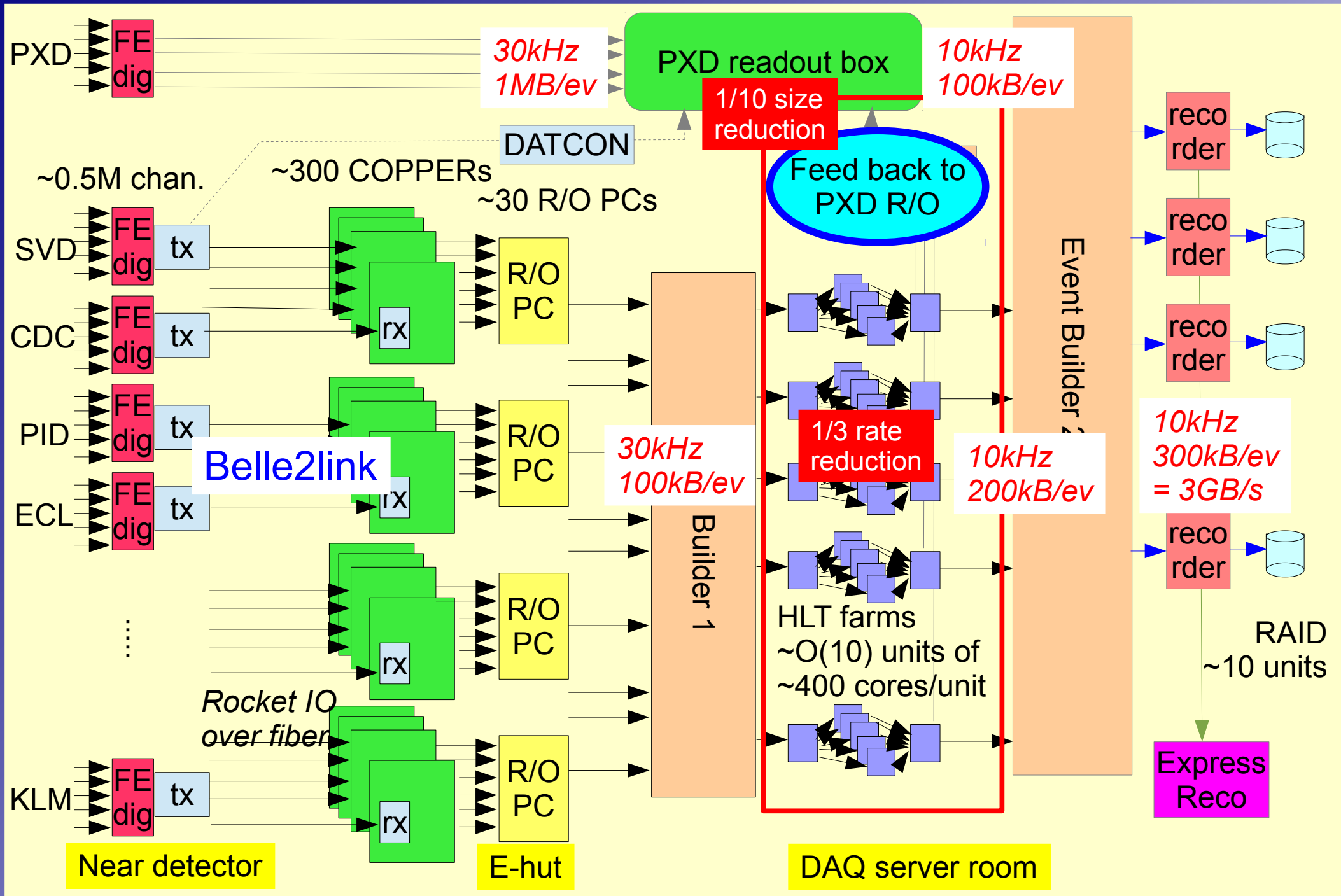
500ps

At 3 GeV *Timing at the ~100 ps level is needed to separate pion and Kaon*

Particle ID : TOP + ARICH

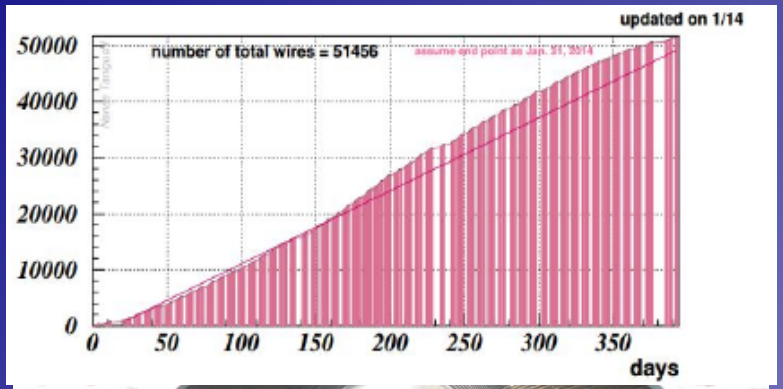


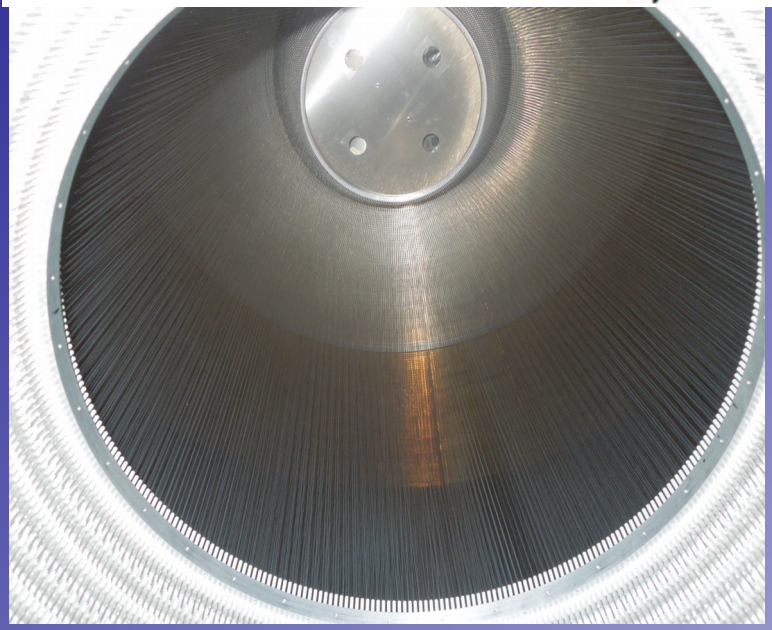
DAQ : PXD data reduction by HLT feed-back



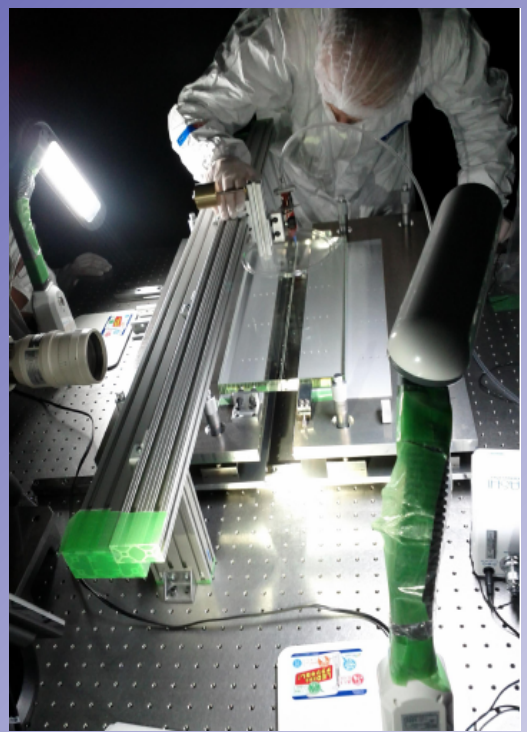
3. Construction Status and Plan

Wire-stringing of CDC completed





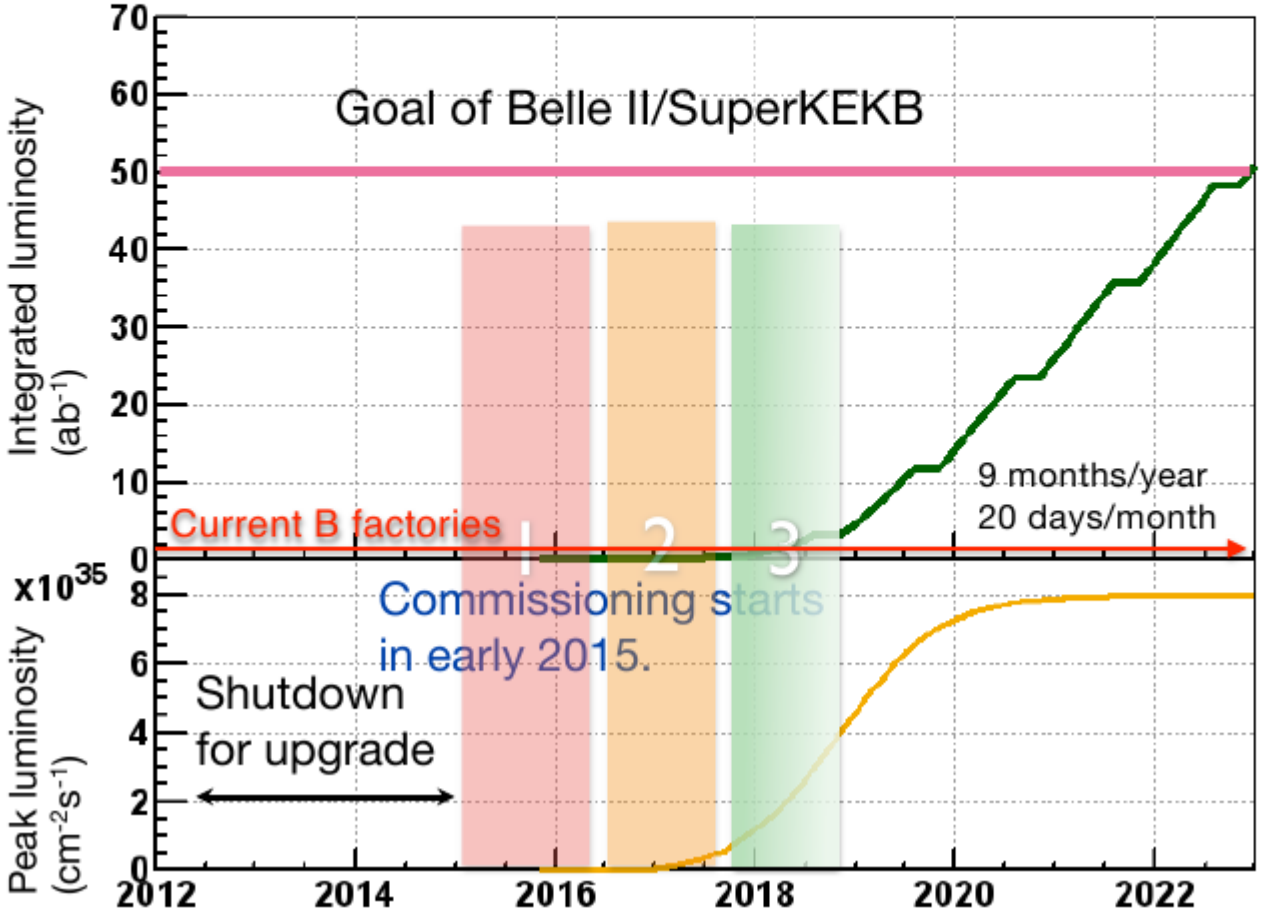
KLM installation almost completed



TOP optics assembly in progress

HLT 1st unit ready

1	2015	Accelerator commissioning
2	2016	Belle II “Beast” and partial detector commissioning
3	2017	First runs with full detector



4. Search for New Physics at Belle II

- Examples of “Golden modes”

a) CPV in tree level and penguin decays
   - sin $2\phi_1$(charm) vs. sin $2\phi_1$(strange)

b) CPV in radiative decays
   - sin $2\phi_1$ in $B \to K_s \pi^0 \gamma$

c) Missing Energy
   - pure leptonic decay of B : $B \to l\nu$ ($l=e,\mu,\tau$)
   - $B \to D^{(*)} \tau\nu$

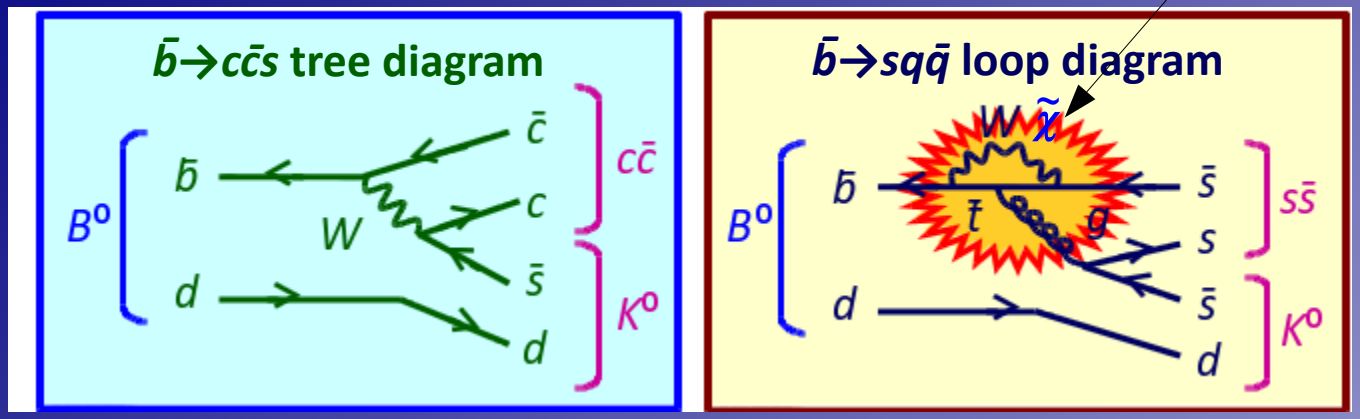
d) Lepton Flavor Violation(LFV)
   - $\tau \to \mu\gamma$, $\tau \to \mu\mu\mu$

e) CPV in D^0-$\overline{D^0}$ mixing

- Ultra-precise measurement of unitarity triangle

1) CPV in b→s transition

possible contribution of new particle



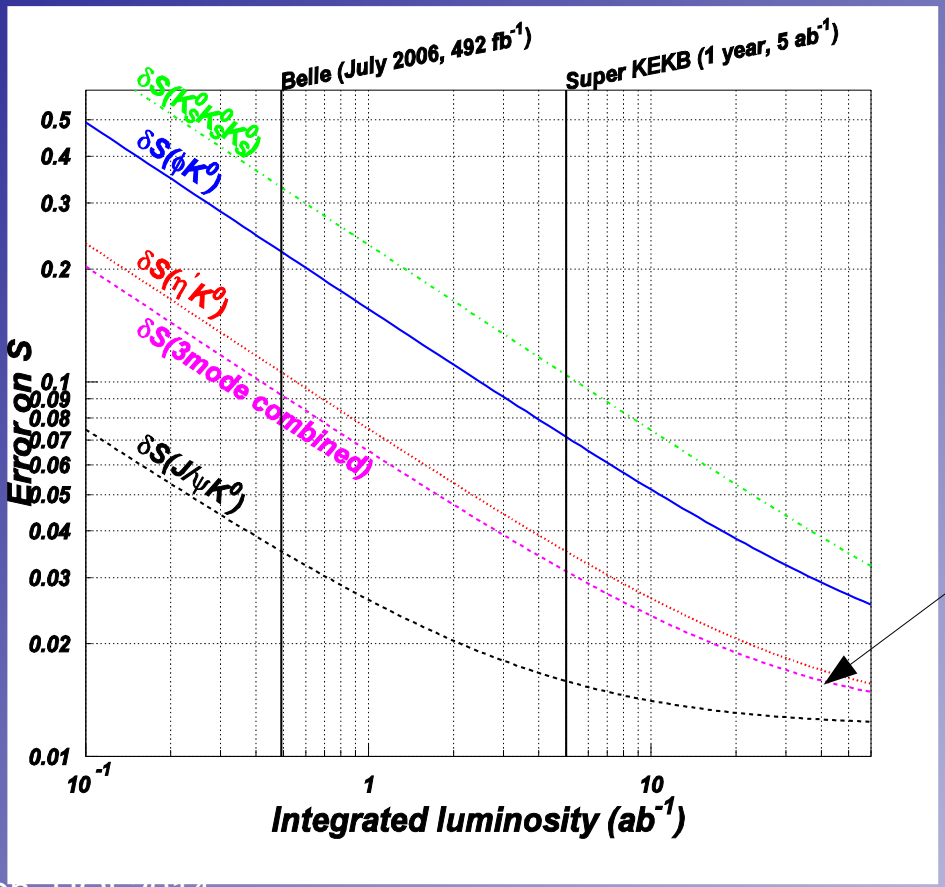
Current measurement

$$\sin 2\phi_1^{sq\bar{q}}{}_{\text{W.A}} = +0.64 \pm 0.03$$

$$\sin 2\phi_1^{c\bar{c}s}{}_{\text{W.A}} = +0.682 \pm 0.019$$

* Deviation ~0.8σ

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

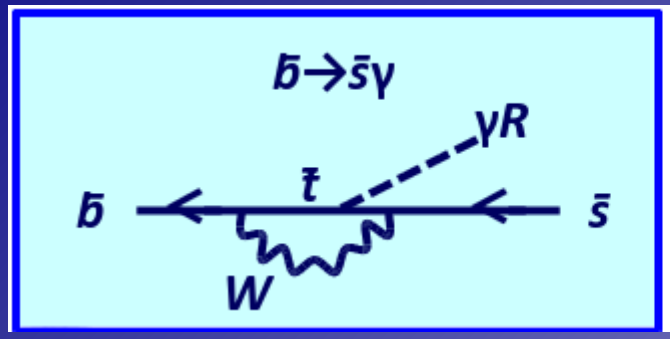


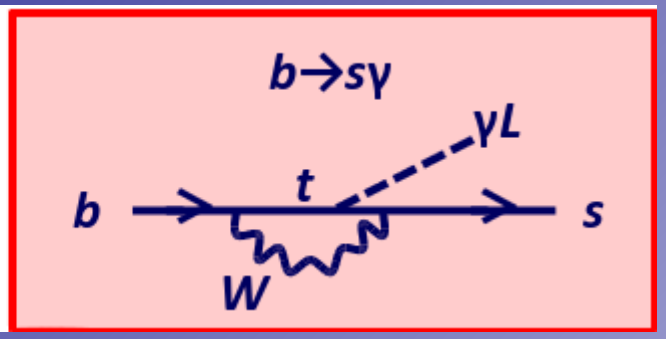
Prospect in Belle II

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

* Some of systematics are cancelled by taking the difference between measurements for $c\bar{c}s$ and $sq\bar{q}$.

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

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

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

Average by Heavy Flavor Averaging Group (2009 winter).

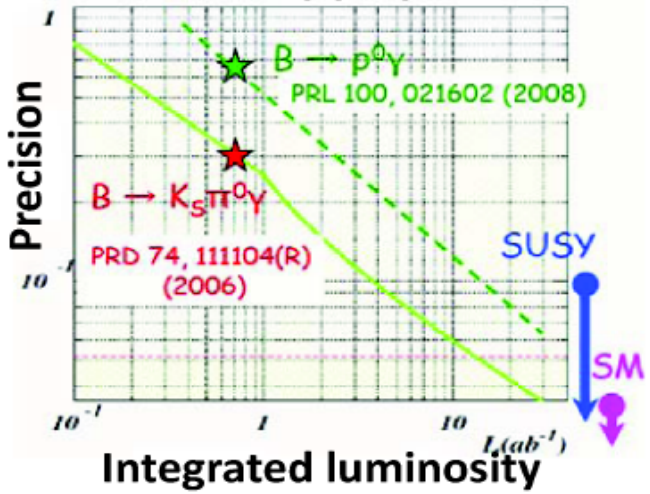
$$S^{\mathrm{NP}} \cong +0.67$$

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

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

SM: $\mathbf{S = -2(m_s/m_b)\sin(2\phi_1) \sim -0.03}$

Luminosity projection



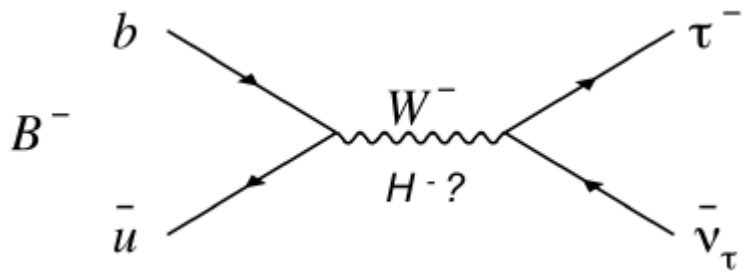
Prospect in Belle II

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

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

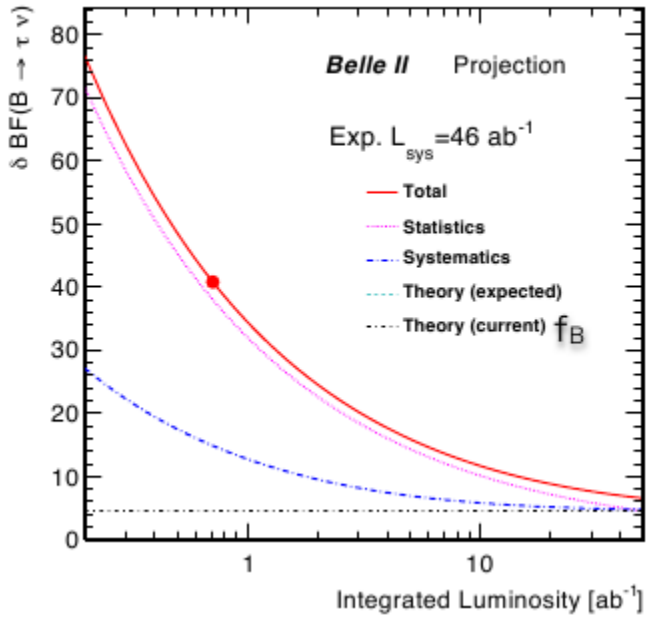
3) Missing Energy

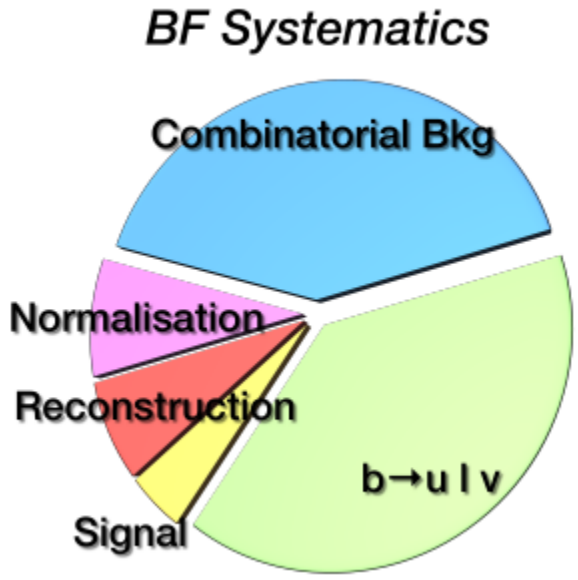
a) Pure leptonic decay of B meson



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

$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \cdot \left(1 - m_B^2 \frac{\tan^2 \beta}{m_H^2}\right) \quad \text{(2HDM)}$$





SM : $Br(B \to \tau\nu)_{SM} = (1.11 \pm 0.28) \times 10^{-4}$

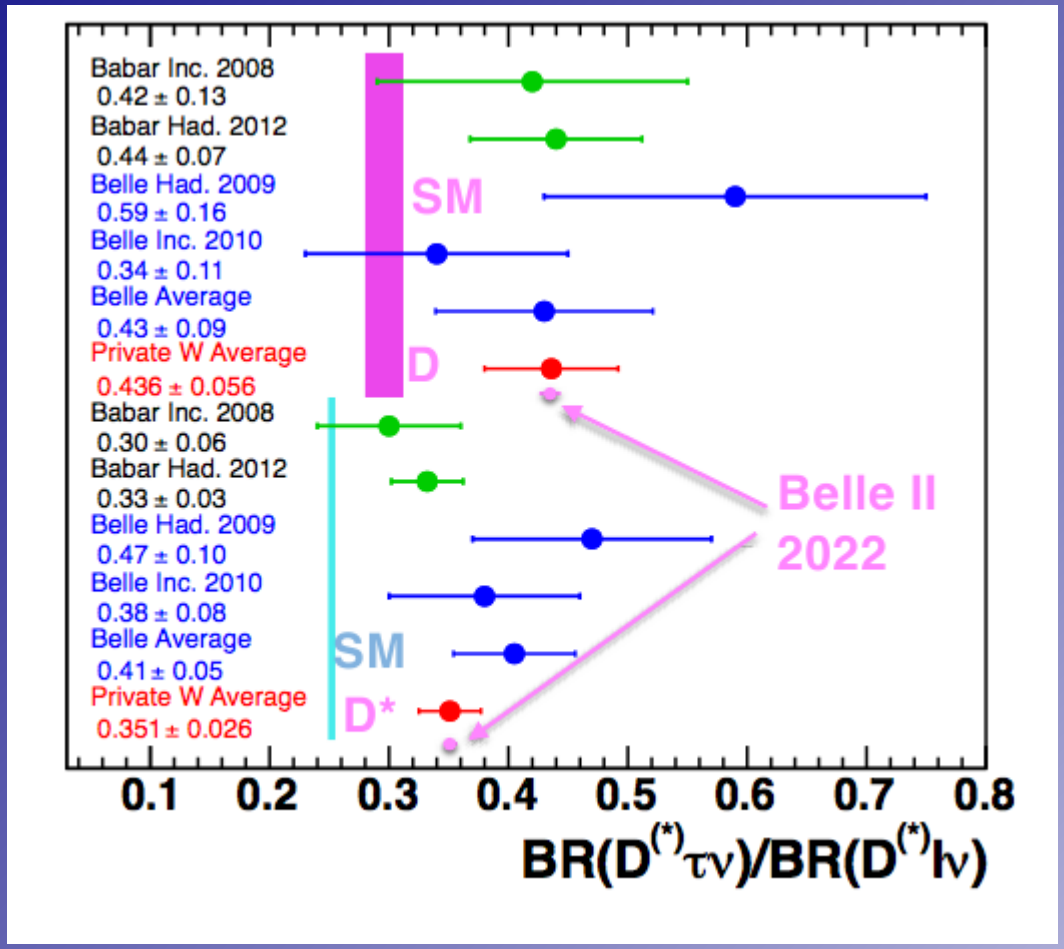
HFAG13 $Br(B \to \tau\nu)_{SM} = (1.14 \pm 0.22) \times 10^{-4}$

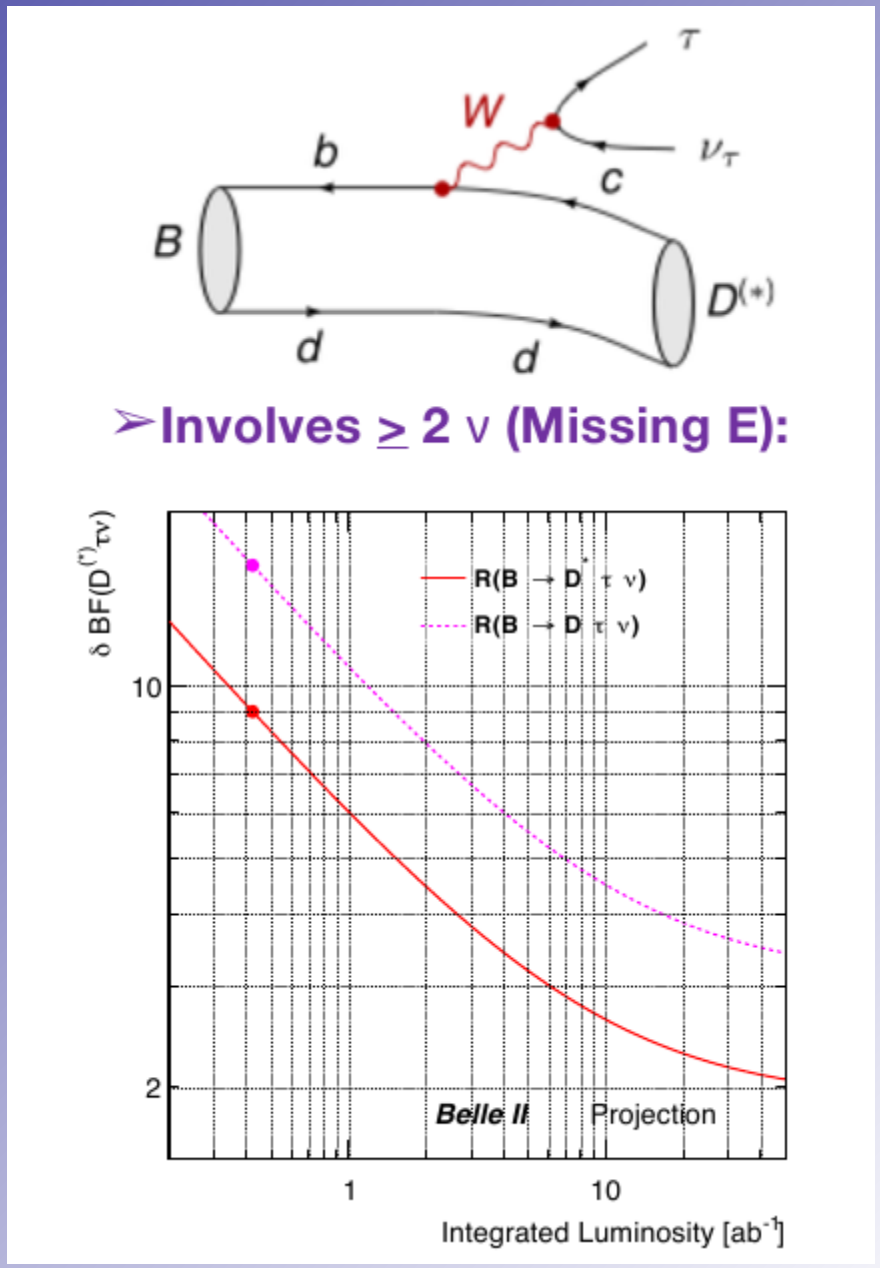
Prospect in Belle II

$\delta(Br) \sim 5\%$ @ $50 ab^{-1}$

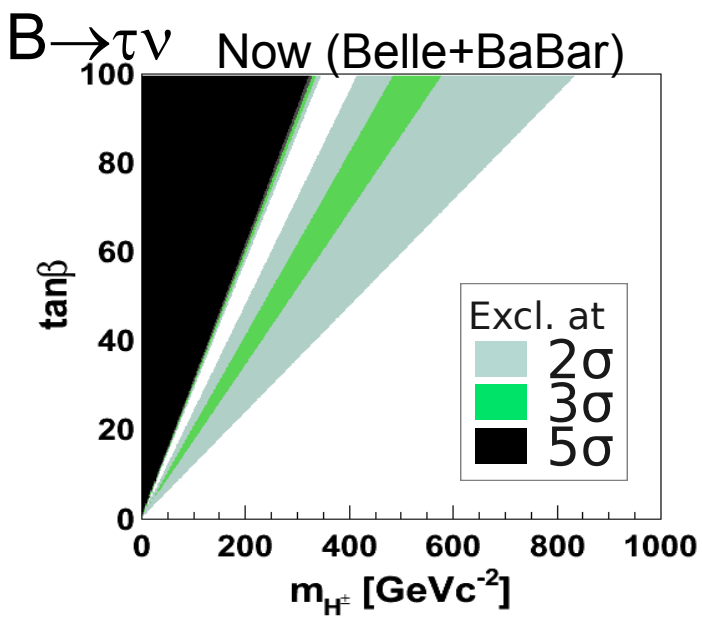
b) $B \to D^{(*)}\tau\nu$

- World Average is shifted
  ~ 5σ from SM prediction!

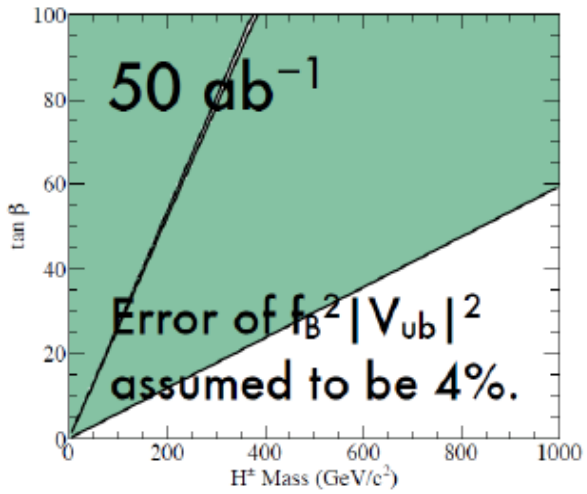




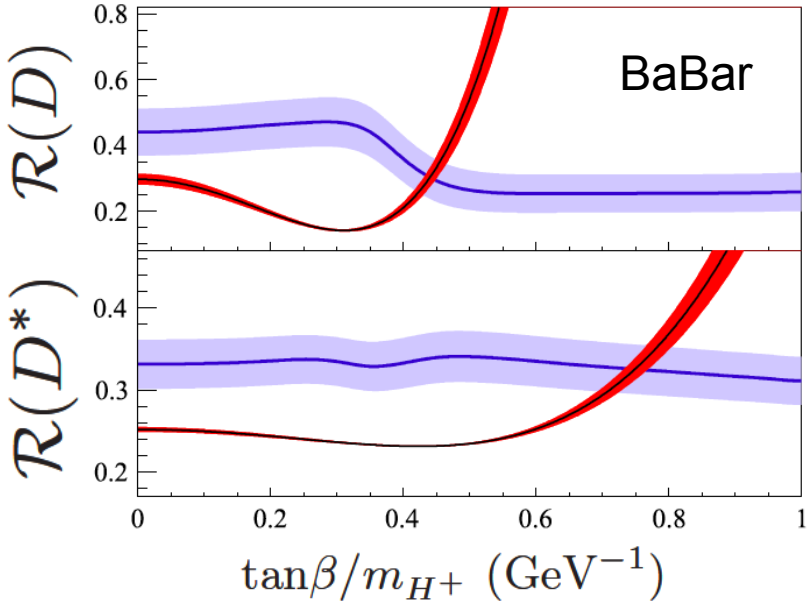
Constraint on Charged Higgs mass by B→τν



2HDM (Type II)



* 2HDM (Type II) cannot explain the difference between Dτν and D*τν in BaBar data.....

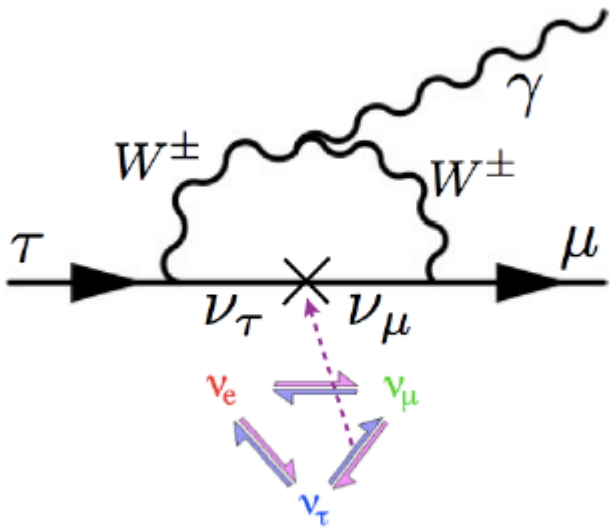


* Detailed study with precise measurements at Belle II is required.

4) Lepton Flavor Violation (LFV) : $\tau \to \mu\gamma$, $\tau \to \mu\mu\mu$

Theoretically very clean test of Standard Model

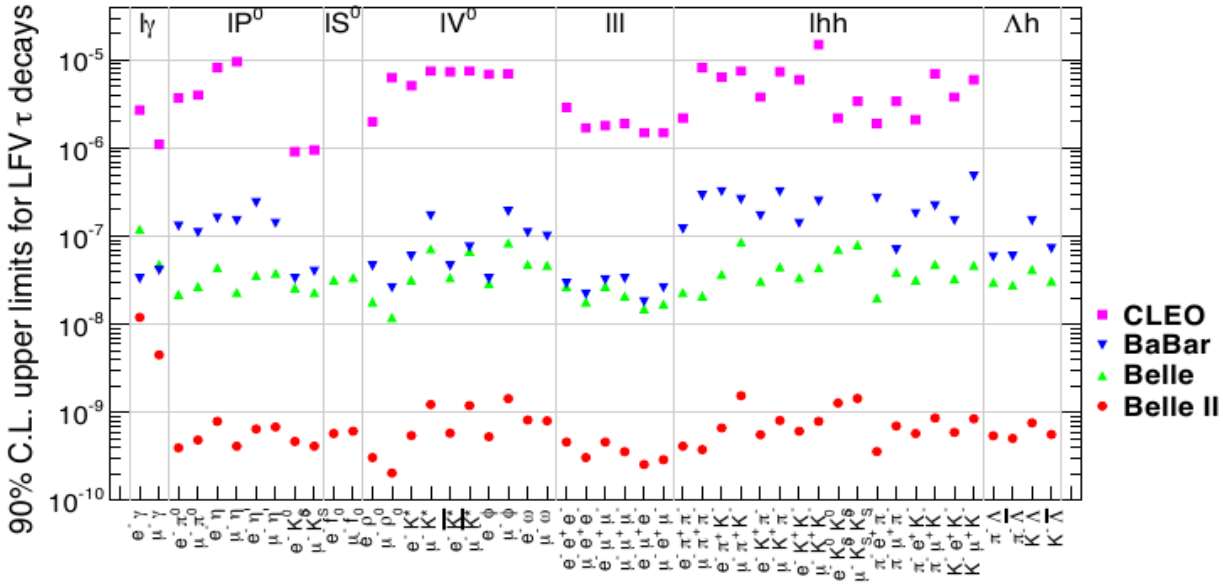
SM:



Br ~ 10^{-25}

NP:

	reference	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}



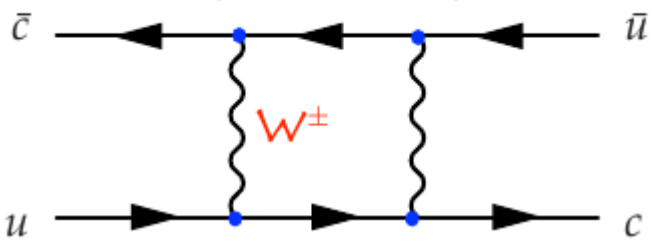
Prospect in Belle II

$< \sim 10^{-9}$ ($B \to \mu\gamma$)

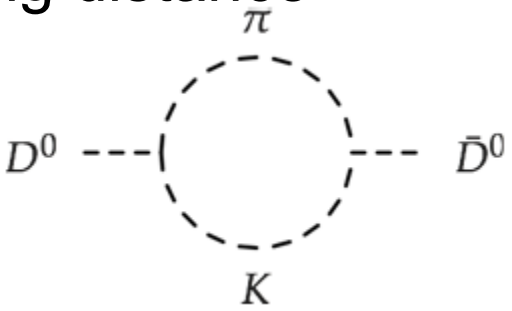
$< \sim 10^{-10}$ ($B \to \mu\mu\mu$)

5) CP Violation in D^0-$\overline{D}^0$ mixing

SM (+NP): V_{qc} V_{qu}



Long distance

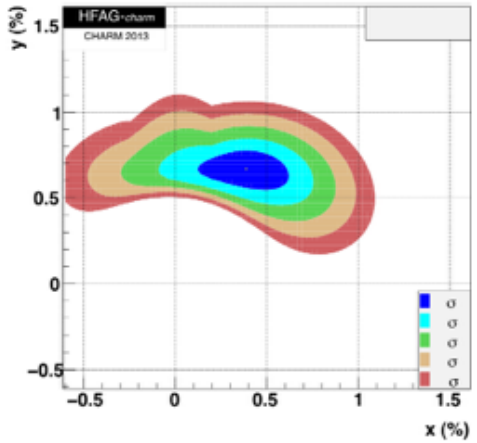


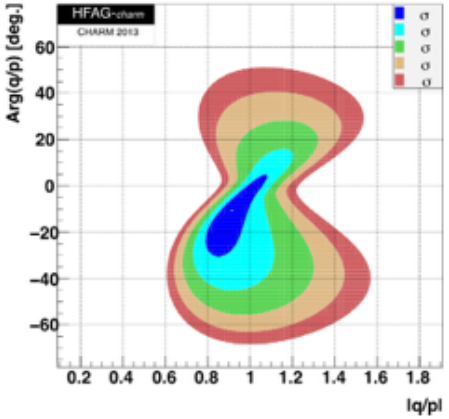
$$x = \frac{m_1 - m_2}{\Gamma}$$

$$y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

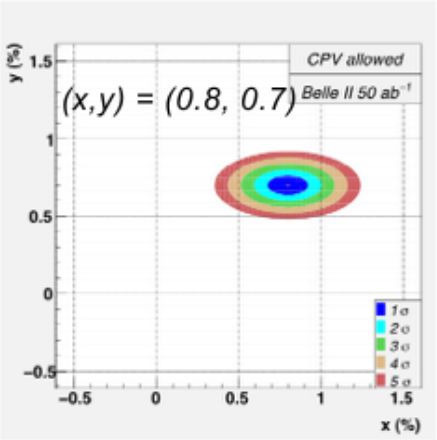
$$\phi = \arg\left(\frac{q}{p}\right)$$

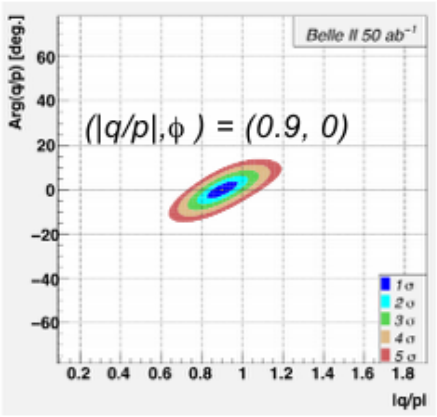
HFAG2013





Belle II 50ab^{-1}

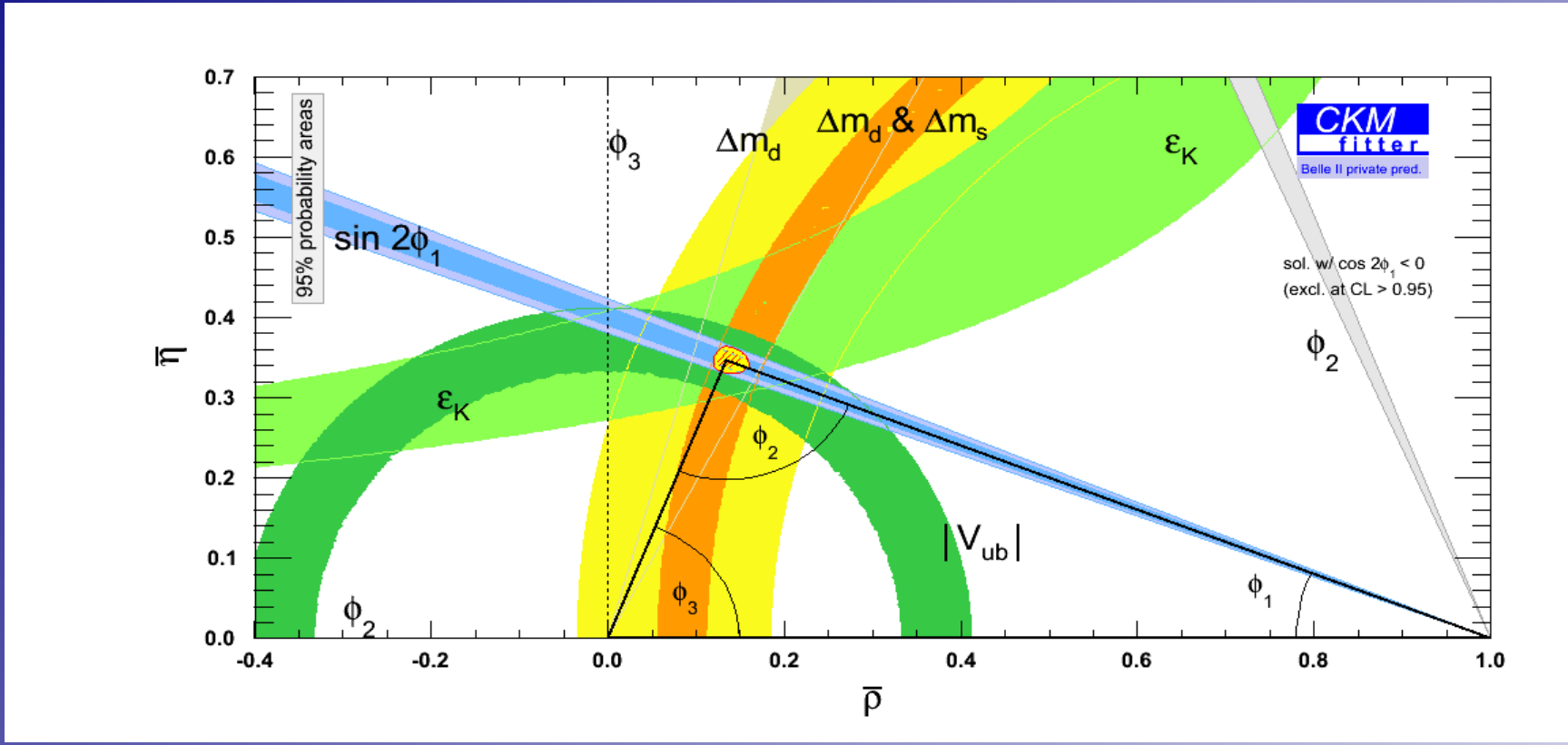




Physics Reach of Belle II and the LHCb upgrade

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi\ell\nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c\ell\nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi\ell\nu]$	*	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
$\|q/p\|_D$	***	0.03	Belle II/LHCb
$arg(q/p)_D$	***	1.5°	

Expected CKM constraint with 50/ab



* Adjusted central values used. (except Δm_d, Δm_s, and ε_K)
* Measurement errors with 50/ab : arXiv1002.5012
* Lattice parameters : PBF numbers

$\sigma(\bar{\rho}) = 3.4\ \%$

$\sigma(\bar{\eta}) = 1.7\%$

5. Collaboration with Theorists

- Since there is no clear scenario of NP discovery in Belle II, we need to seek for every possible way for NP search.

- A closer collaboration with theorists is essential to have an optimized strategy of NP search.

  * "NP-Japan group" was formed in 2012.
  * "Belle II Theory interface Platform (B2TiP)" has been initiated in 2014.

- The purpose of these groups is to provide a framework to work both theorists and Belle II experimentalists together closely.

- The strategy includes the global fit activity to combine multiple NP-sensitive measurements in order to maximize the sensitivity to NP.

Belle II Theory Interface Platform (B2TIP)

Overview

The "Belle II-Theory Interface Platform" is an initiative to coordinate a joint theory-experiment effort to study the potential impacts of the Belle II program.

We plan to organize meetings twice a year gathering theory experts and Belle II members, starting from June 2014 until the end of 2016.

One of the expected outcomes of the project is a "KEK Report", summarizing all the important observables which will be measured at Belle II, their experimentally achievable precision and their impact on our understanding of the theory (Standard Model and New Physics). This report should also include a "milestones table" clarifying the targets for the first 5 to 10 ab-1 of data as well as for the final goal at 50 ab-1.

This project is an official activity of Belle II, approved by the executive board of the Belle II Collaboration, in February 2014.

Workshop Dates

The 2014 meetings will be held at KEK in June and November, as a satellite meeting of the Belle and Belle II General meetings. There is a possibility of holding one workshop in 2015 at an external location. Individual working groups may choose to hold additional meetings. Please register for the meetings on the linked indico pages.

B2TIP Meeting	Meeting Agenda	Belle (II) associated meetings
2014 June 16-17 at KEK	workshop indico	B2GM June 18-21, BGM June 22-23
2014 November/December		B2GM November 3-6, BGM November 7-8
2015 June (External Workshop)		
2015 November (KEK)		
2016 June (External Workshop)		

Committees

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Karim Trabelsi	KEK / Lausanne
Phillip Urquijo (B2 Physics Coord.)	Melbourne

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Matthias Neubert	Mainz
Yoshihide Sakai	KEK
Junko Shigemitsu	Ohio

8 working groups + New physics working group

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

6. Summary

- Belle II is a new generation B-factory experiment for the hunt of New Physics in rare B/D/τ decays.

- The construction of SuperKEKB and Belle II is on-going aiming at the start of physics run in 2017.

- A wide variety of physics program is there utilizing an enormous event statistics obtained with a 40 times higher luminosity. It is complementary to the one of LHCb.

- A close collaboration with theorists has been initiated to optimize the strategy for the New Physics search at Belle II.

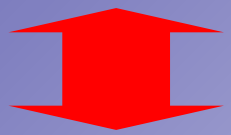
Stay Tuned!

Backup Slides

From Belle to Belle II

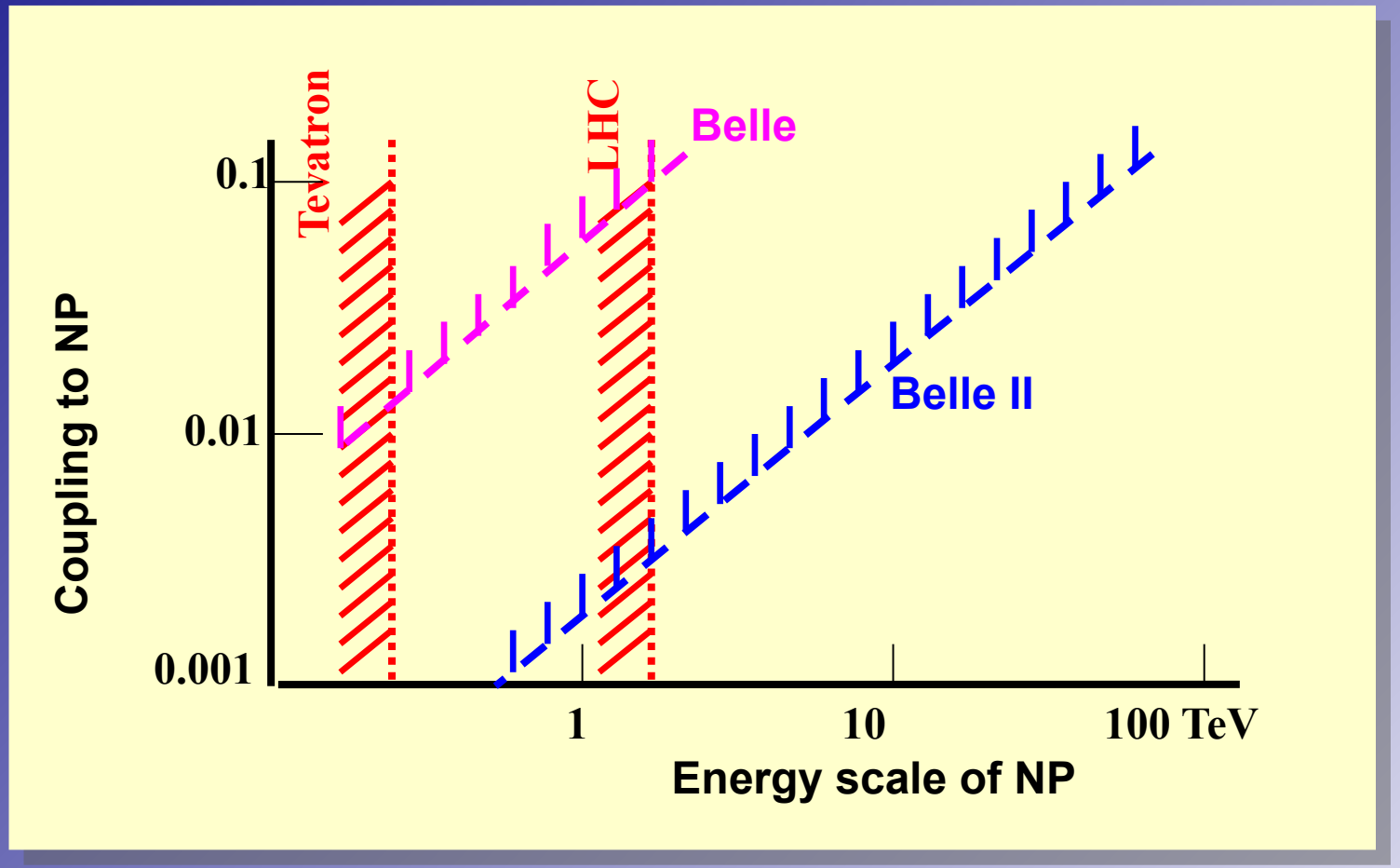
- We had been studying B meson decays in the previous Belle experiment (B-factory exp.@KEK) for more than 10 years.

- 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 Belle + BaBar and brought Novel prize to them.



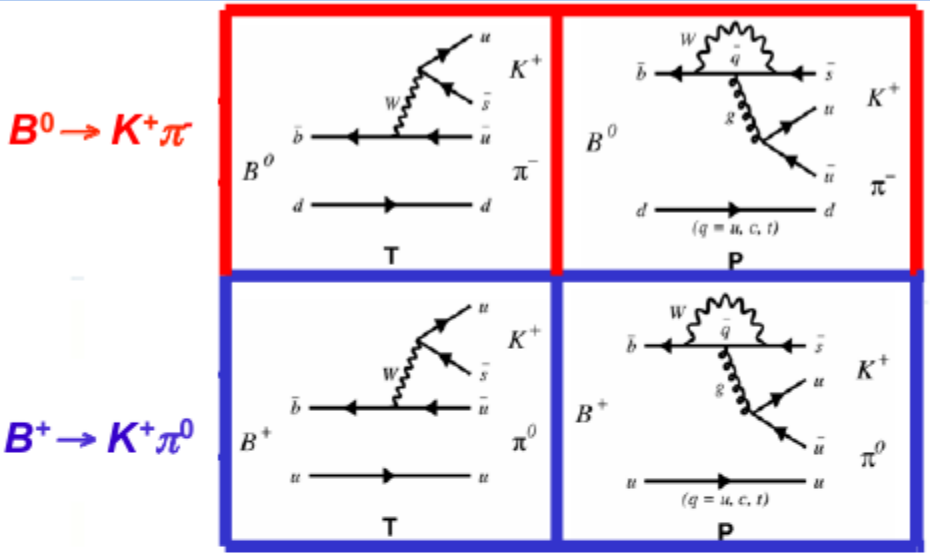
- The purpose of Belle II upgraded from Belle is the experimental search for the signature of New Physics in B, D and τ decays.
  <- Indirect search for NP in “quantum effect”
- No guiding theory for promising NP search. Need a careful study of “subtle” shift from Standard Model(SM) in various measurements.

Comparison of NP sensitivity by LHC and Belle II experiments

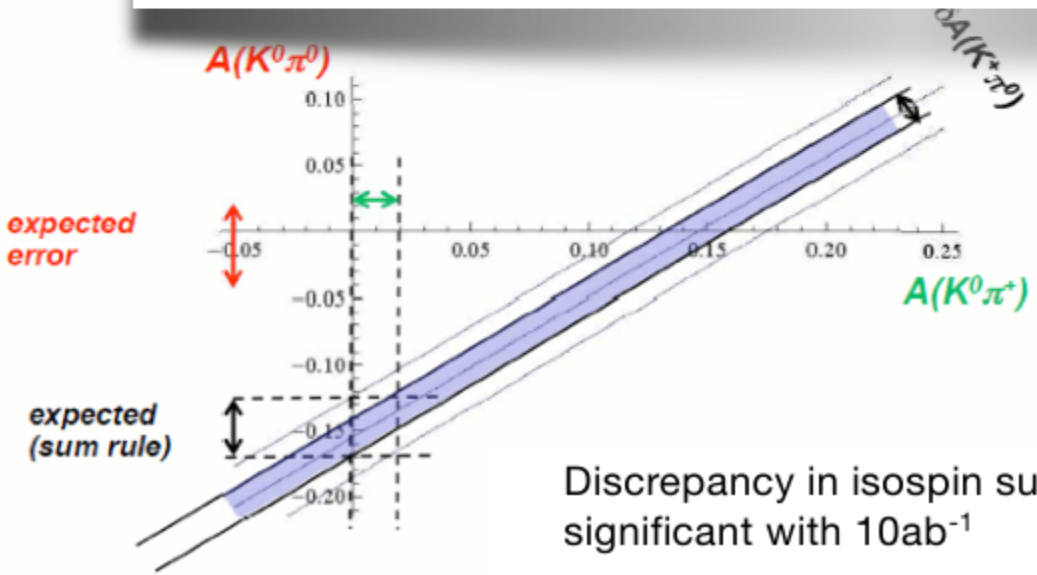


Direct CPV in B→Kπ ($K^{(0)}\pi^0$)

- A_{CP} in hadronic modes cannot be understood without complete isospin analyses.
- Sum rule approach needs neutrals



$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{Br(K^0\pi^+)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2\,Br(K^+\pi^0)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\,Br(K^0\pi^0)}{Br(K^+\pi^-)}$$



$A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0) = -0.122 \pm 0.022$

(5.6σ difference from zero)

$A(K^0\pi^0) = 0.006 \pm 0.06$ (stat limited

$A(K^0\pi^+) = -0.015 \pm 0.019$

$A(K^+\pi^0) = 0.040 \pm 0.021$

$A(K^+\pi^-) = -0.082 \pm 0.006$

Discrepancy in isospin sum rule may be significant with $10ab^{-1}$