The Upcoming Grand Challenge by the Super *B*-Factory

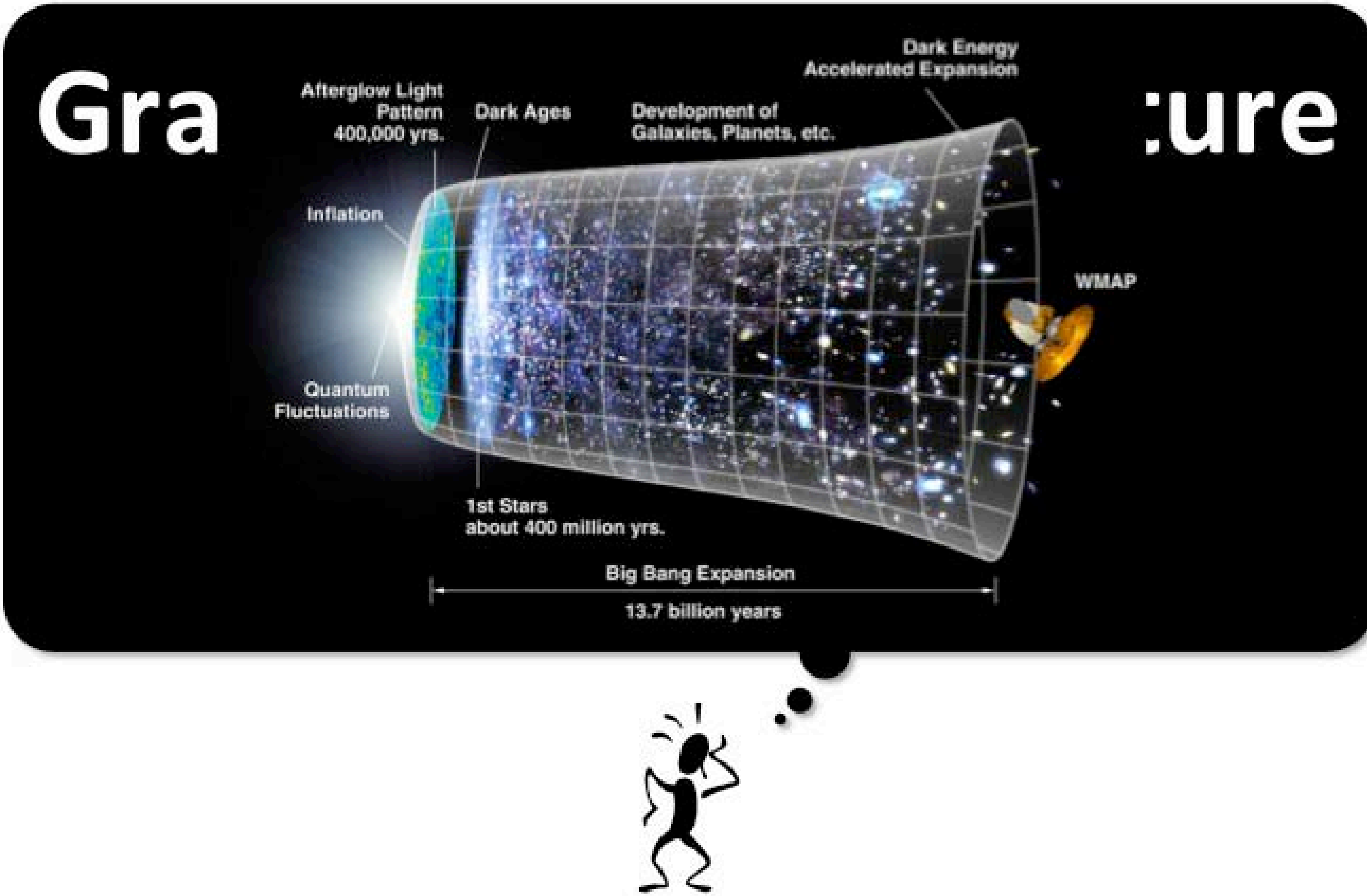
Takeo Higuchi (KEK)

Contents

1. KM Theory and *B*-Factories

1.1 Introduction

What Are Physicists Pursuing?



What Are Physicists Pursuing?

Particle ph ... ed
the Grand ... el

We started *B*-factory experiments to test the KM theory.

Standard Model of particle physics (SM)

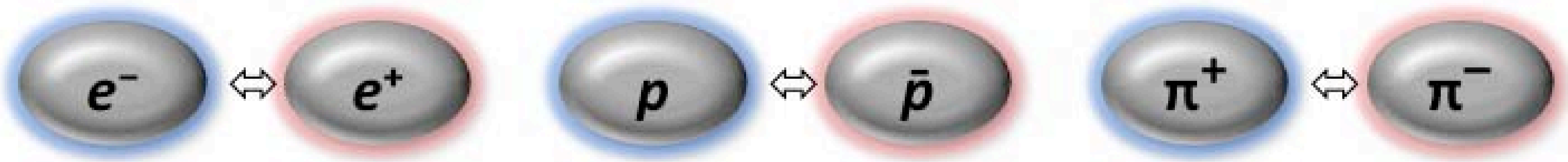
Electroweak interaction	QCD	KM theory	Higgs mechanism

1. KM Theory and *B*-Factories

1.2 The Kobayashi-Maskawa Theory

Antimatter

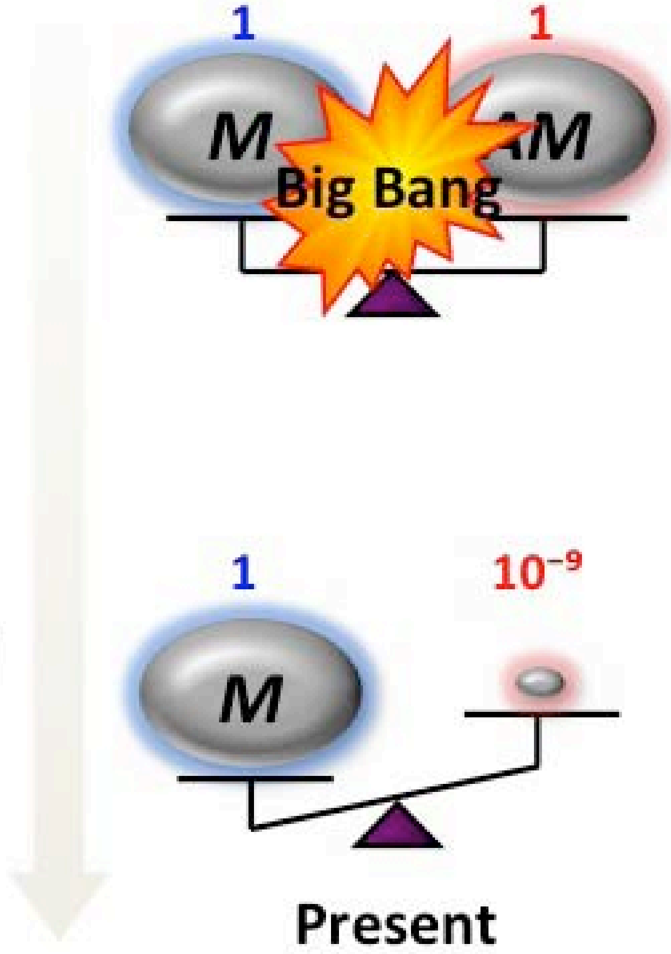
- **Antimatter = a material that has the same mass as the matter, while its quantum numbers flipped.**



- **Two basic rules: pair annihilation and pair creation**
  - When a matter meets with its counter antimatter, they just disappear with leaving $E=2mc^2$ energy.
  - When one produces $E=2mc^2$ energy in some way, he/she will get matter and antimatter pair with mass m.

Missing Antimatter

- The same amount of matter (*M*) and antimatter (*AM*) should be created in pair at the Big Bang,
- While that of the *AM* in the present Universe is so small that it had not been discovered until 1932.
  - C. D. Anderson discovered the e^+ in cosmic rays.



CP Violation: *M-AM* Difference

Only the *M* survived, while the *AM* did not. → **Physics governing the *M*** ≠ **Physics governing the *AM***

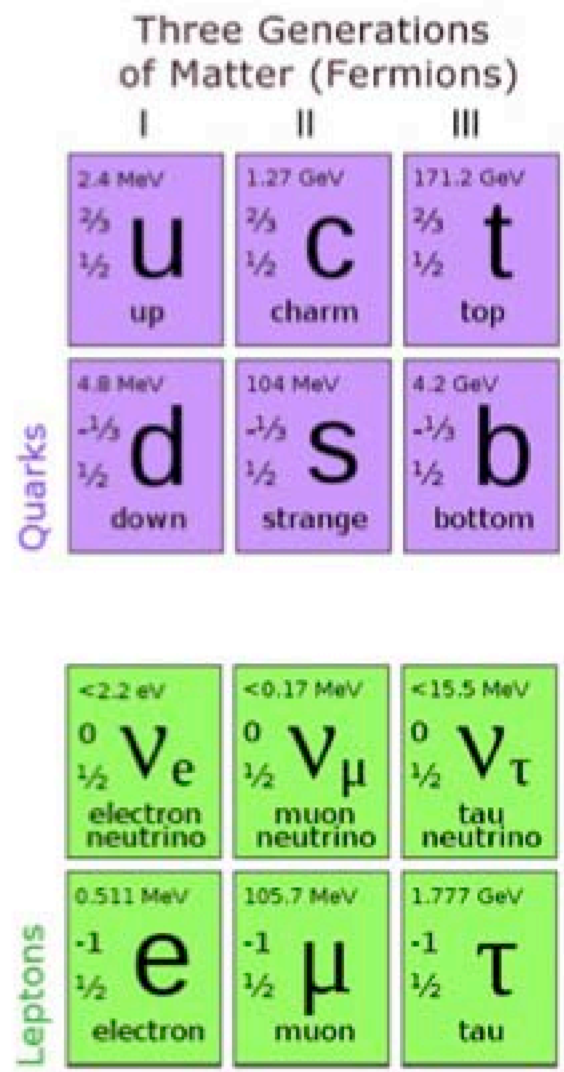
- **The first discovery of *M-AM* difference (1964)**
  - J. Cronin *et al*. discovered the difference between behaviors of K^0 and $\bar{K}^0$ mesons.

- **Kobayashi-Maskawa (KM) theory (1973)**
  - M. Kobayashi and T. Maskawa proposed a new theory about the weak interaction that can violate *M-AM* symmetry (*CP* violation) observed in the 1964 experiment.

Weak Interaction in a Nutshell

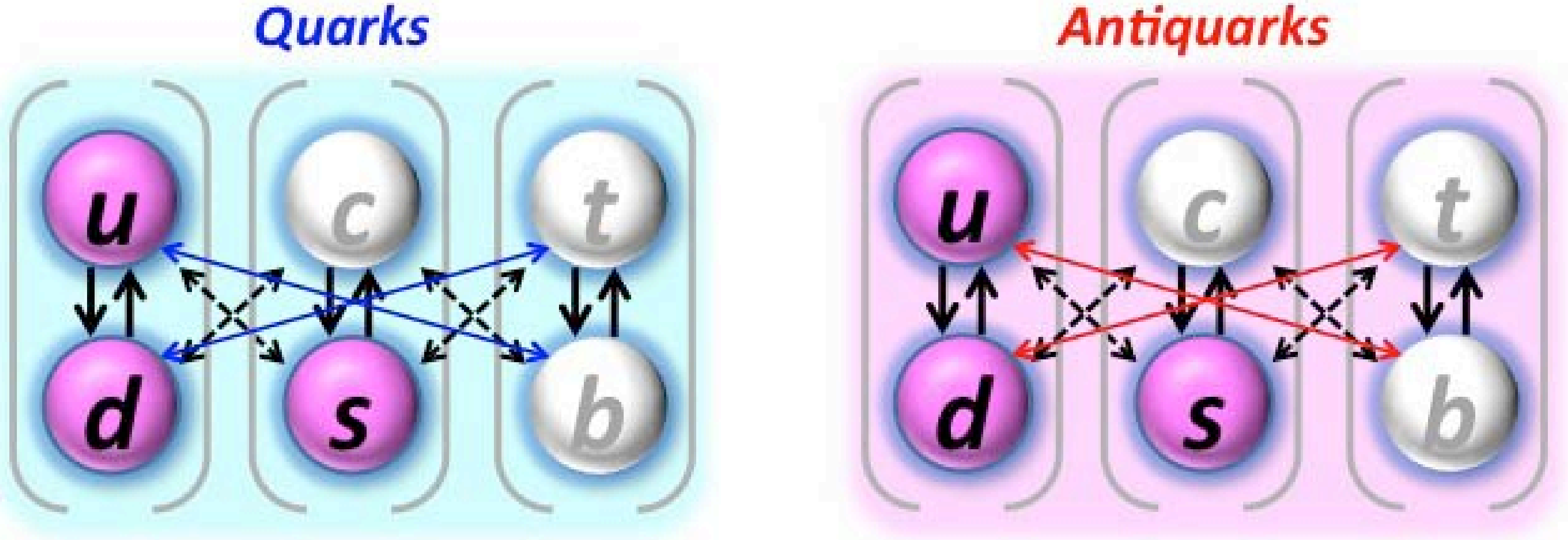
- **Four forces in the Universe**
  - Strong force
  - Electromagnetic force
  - **Weak force**
  - Gravity

- **Weak force (weak interaction)**
  - **Quark sector**: interchanges (*d*,*s*,*b*) to (*u*,*c*,*t*).
  - **Lepton sector**: interchanges (e^-,μ^-,τ^-) to (ν_e, ν_μ, ν_τ).



KM Theory in a Nutshell

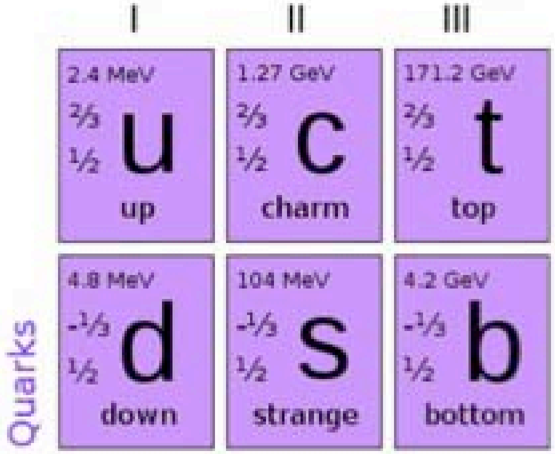
- **Weak interactions among *M***
  ≠ weak interactions among *AM*

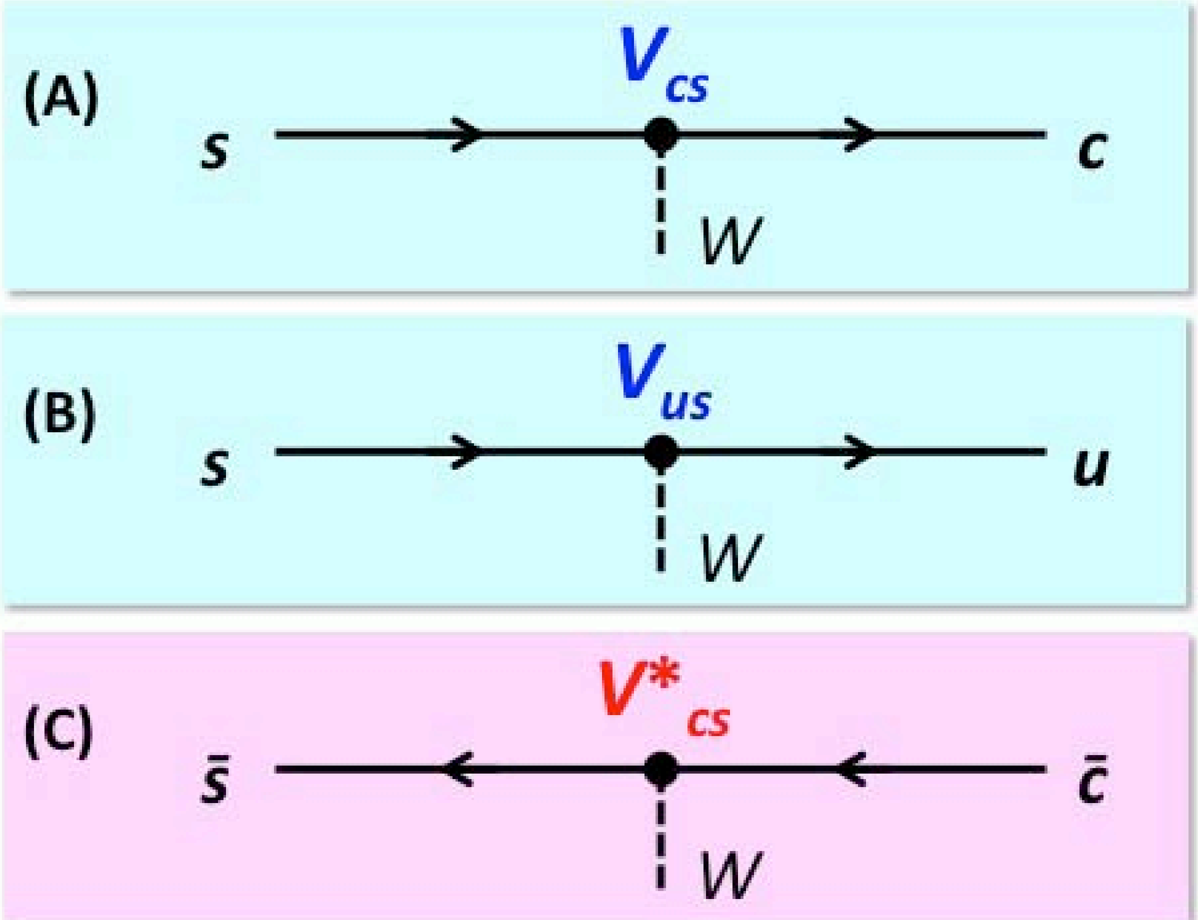


When more than three quark generations (a pair of most interacting quarks) exist, *M*-*AM* symmetry in the quark sector can be violated.

In 1973, the charm quark was not discovered yet, but its existence was somewhat believed; while the bottom and top quarks were out of people's mind.

Coupling Constants of Quarks





Kobayashi-Maskawa says coupling constant for *M* is different from that for *AM*; *i.e.*: $V_{xy} \neq V^*_{xy}$ → V_{xy} is a complex number.

KM Theory

- **Quark mixing matrix = an array of coupling constant V_{xy}.**
- **If # of quark generations ≥ 3, an irreducible phase remains in the matrix, which violates *CP* invariance.**

Quark mixing matrix for case of generation # = 3

$$V_{n=3} = \begin{pmatrix} V_{ud} & V_{us} & \underline{\underline{V_{ub}}} \\ V_{cd} & V_{cs} & V_{cb} \\ \underline{\underline{V_{td}}} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & \underline{\underline{A\lambda^3(\rho - i\eta)}} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ \underline{\underline{A\lambda^3(1-\rho-i\eta)}} & -A\lambda^2 & 1 \end{pmatrix}$$

Irreducible complex phase shows up that violates *CP* invariance.

Unitarity Triangle

Quark mixing matrix for case of generation # = 3

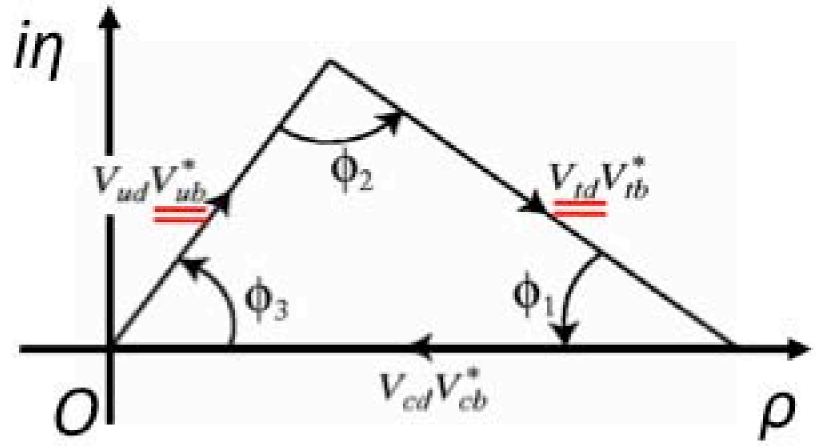
$$V_{n=3} = \begin{pmatrix} V_{ud} & V_{us} & \underline{\underline{V_{ub}}} \\ V_{cd} & V_{cs} & V_{cb} \\ \underline{\underline{V_{td}}} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & \underline{\underline{A\lambda^3(\rho - i\eta)}} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ \underline{\underline{A\lambda^3(1-\rho-i\eta)}} & -A\lambda^2 & 1 \end{pmatrix}$$

Unitarity condition: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

Unitarity triangle

Irreducible phase exists

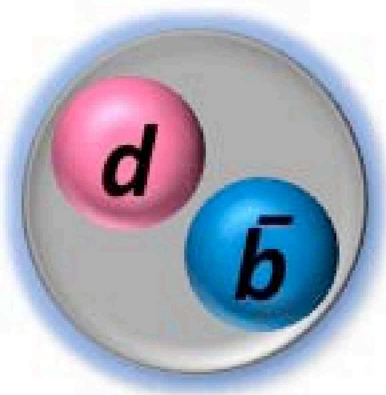
↔ $\phi_1 \neq 0$



1. KM Theory and *B*-Factories

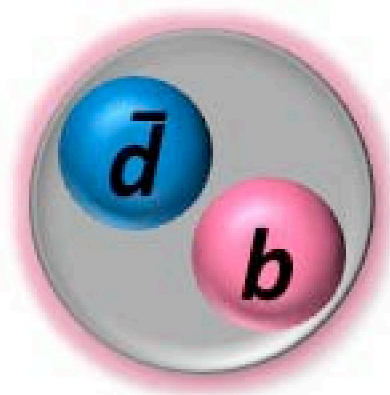
1.3 Phenomenology of the KM Theory

Neutral *B* Mesons



Neutral *B* meson

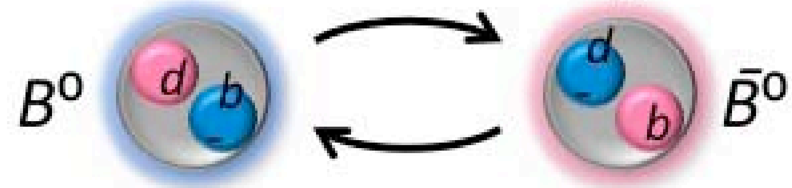
B^0



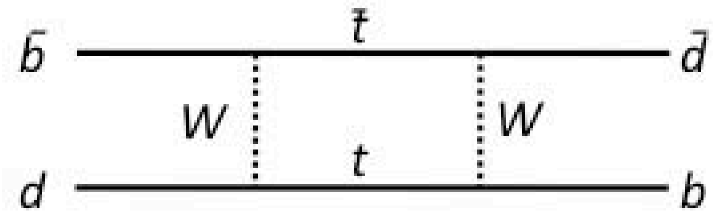
Anti neutral *B* meson

$\bar{B}^0$

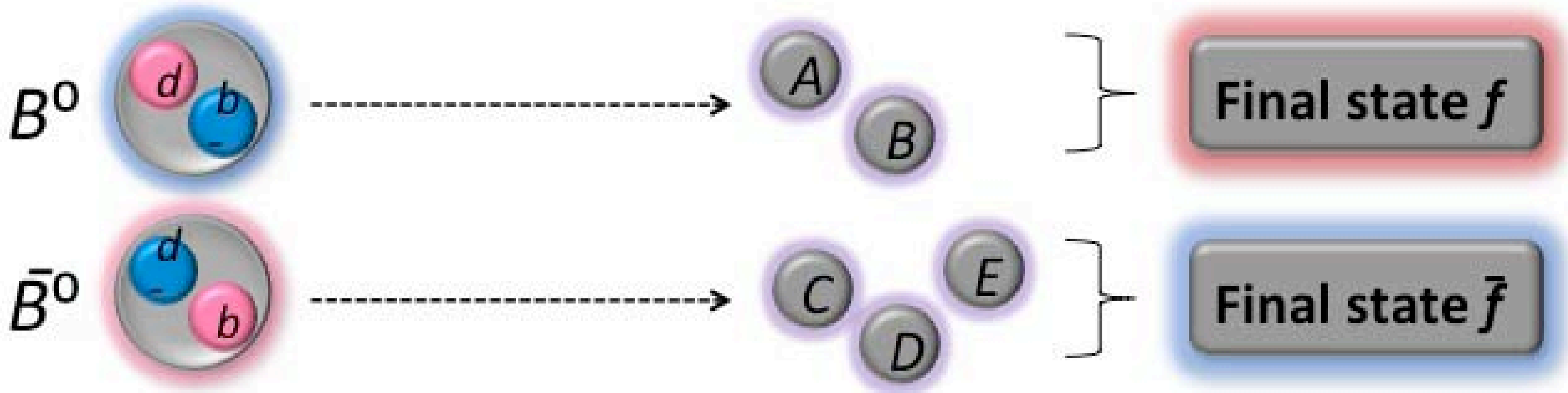
B^0-$\bar{B}^0$ Mixing and B Meson Decay



- B^0 and $\bar{B}^0$ change their flavors mutually through a box diagram (~twice/ps).

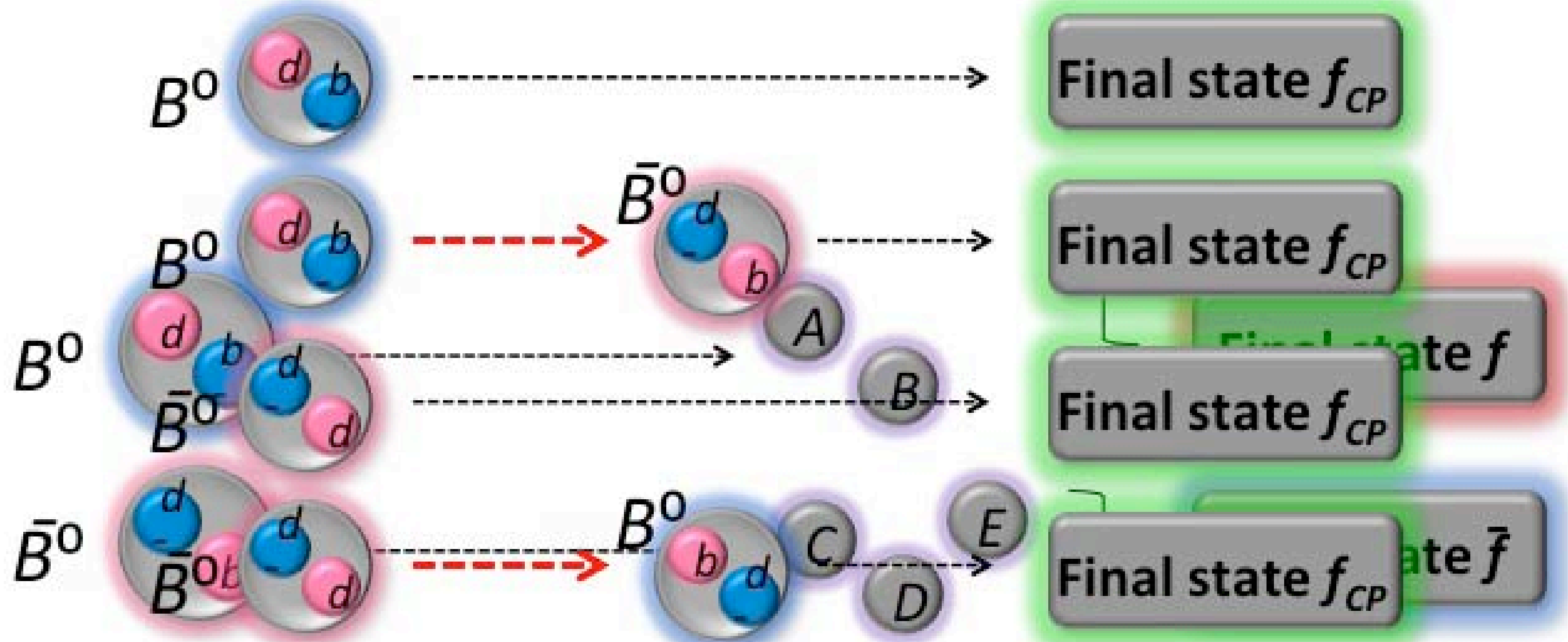


- While mixing, the B^0 and $\bar{B}^0$ mesons decay to other particles in ~1.5ps lifetime.



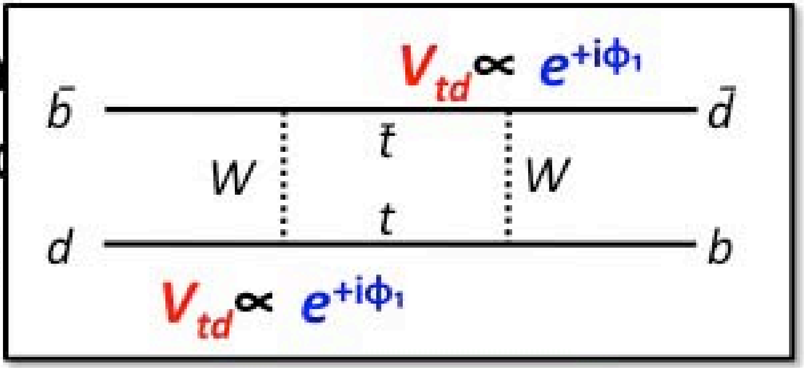
B Meson Decay to *CP* Eigenstate

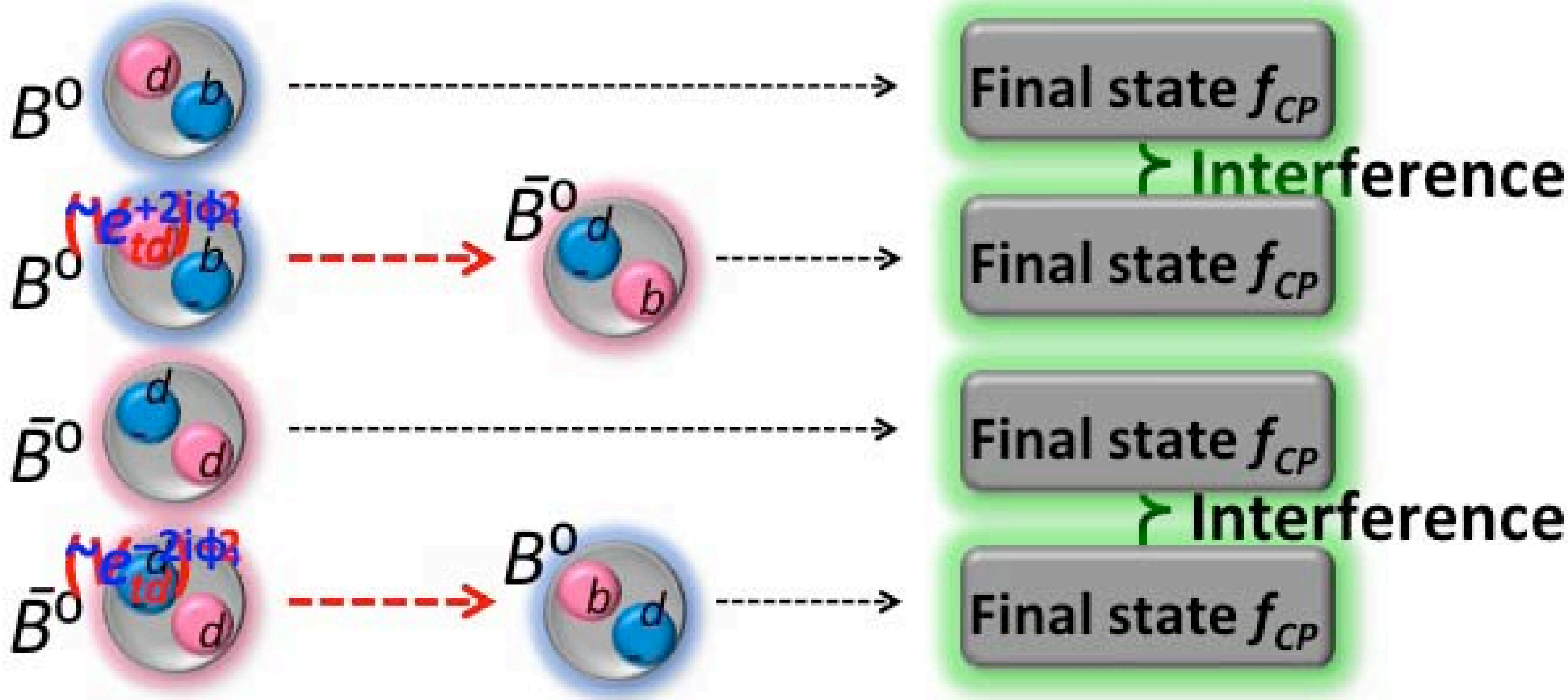
- There exists a special final state f_{CP}: $f = \bar{f}$.
- There are 4 possible paths from the neutral *B* mesons to f_{CP}, when the B^0-$\bar{B}^0$ mixing is considered.



Mixing-Induced *CP* Violation

- **Interference between “unm decay amplitudes enables to to the irreducible phase in t**





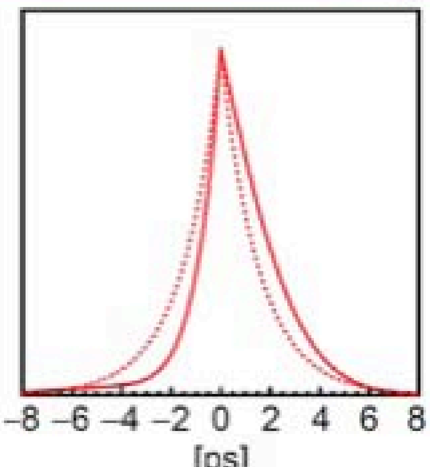
Manifestation of *CP* Violation

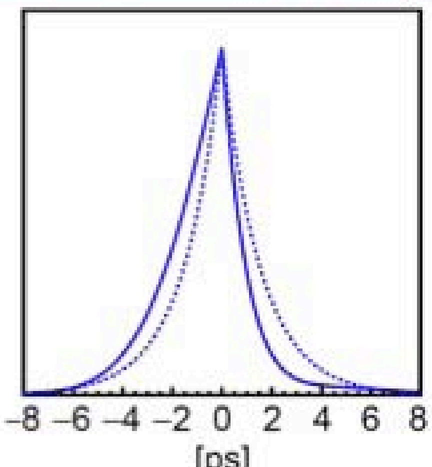
- **Suppose a pair of neutral *B* mesons created, and …**
  - One decays to a *CP* eigenstate f_{CP} at $t=t_{CP}$;
  - The other decays to a flavor specific state f_{B^0} or f_{B^0} at $t=t_{\mathrm{flv}}$.

- **Distribution of $\Delta t \overset{\mathrm{def}}{=} t_{CP} - t_{\mathrm{flv}}$**

$$(B\ \mathrm{pair}) \to (f_{CP}, f_{B^0}) \qquad (B\ \mathrm{pair}) \to (f_{CP}, f_{\overline{B}^0})$$

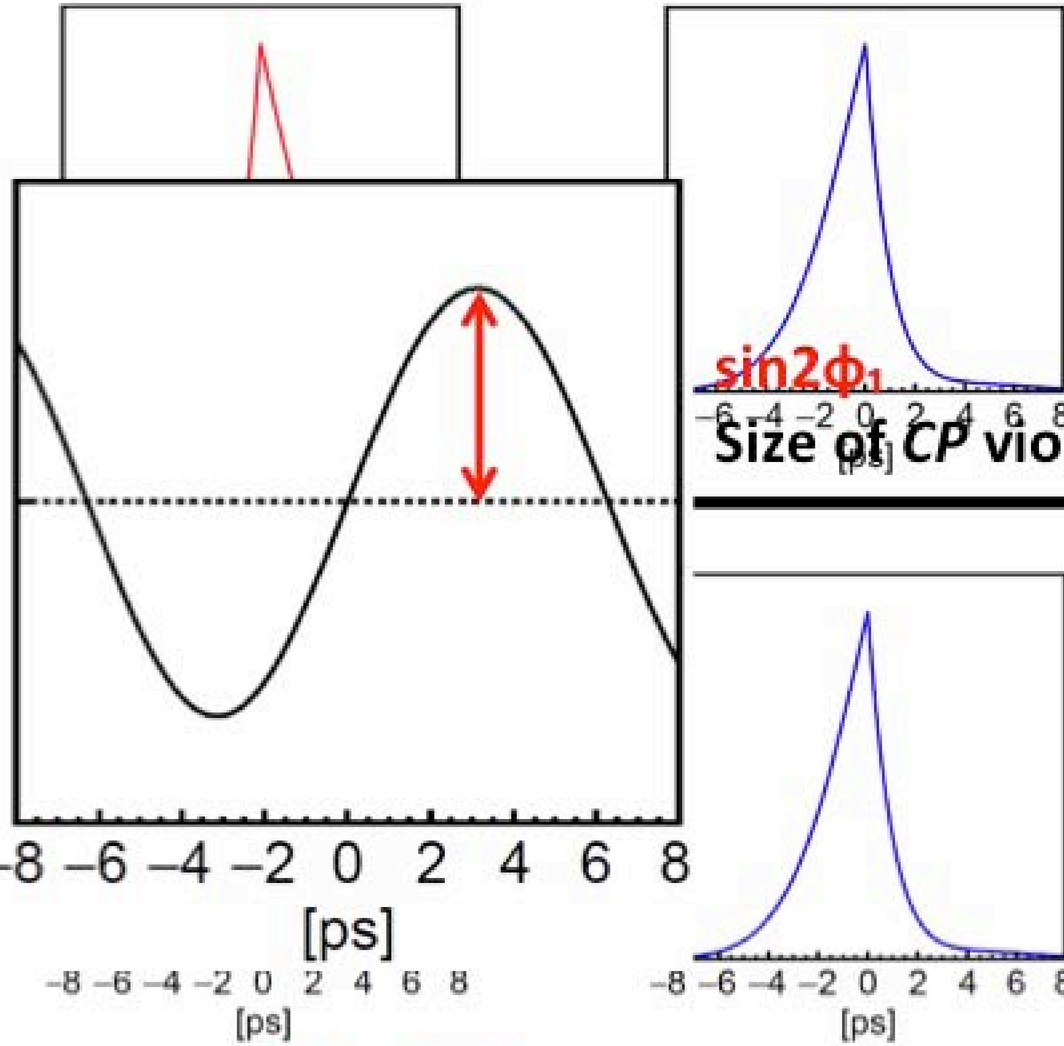
If *CP* invariance is violated





Manifestation of *CP* Violation

$$A_{CP}(\Delta t) \stackrel{\text{def}}{=} -$$

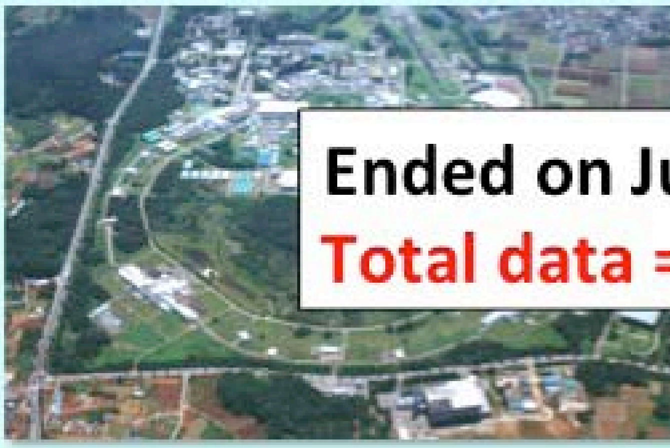
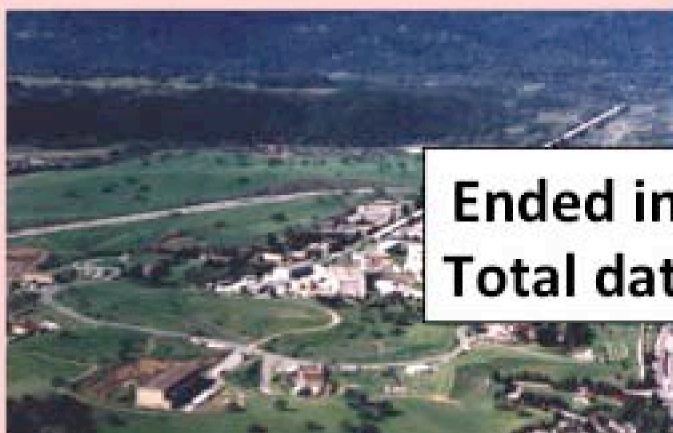
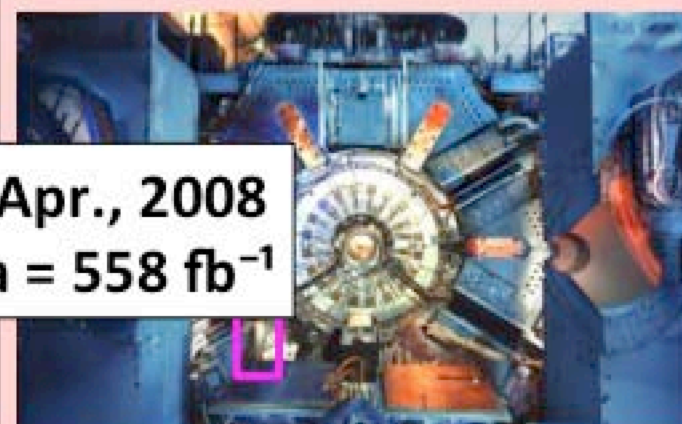


$$= -\eta_{CP} \times \sin 2\phi_1 \times \sin(\Delta m_d \Delta t)$$

1. KM Theory and *B*-Factories

1.4 Experimental Test of the KM Theory

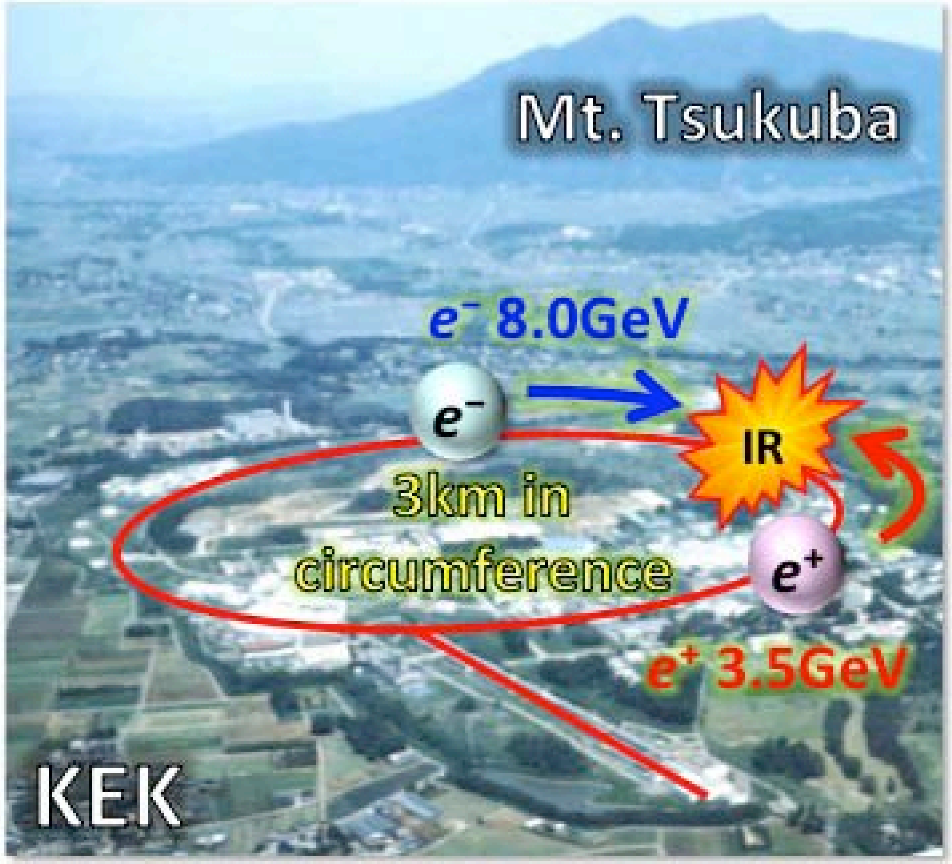
B-Factories in the World

	Accelerator	Detector
Belle (Japan)		
BaBar (US)		

Ended on Jun. 30th, 2010
Total data = 1052.79 fb^{-1}

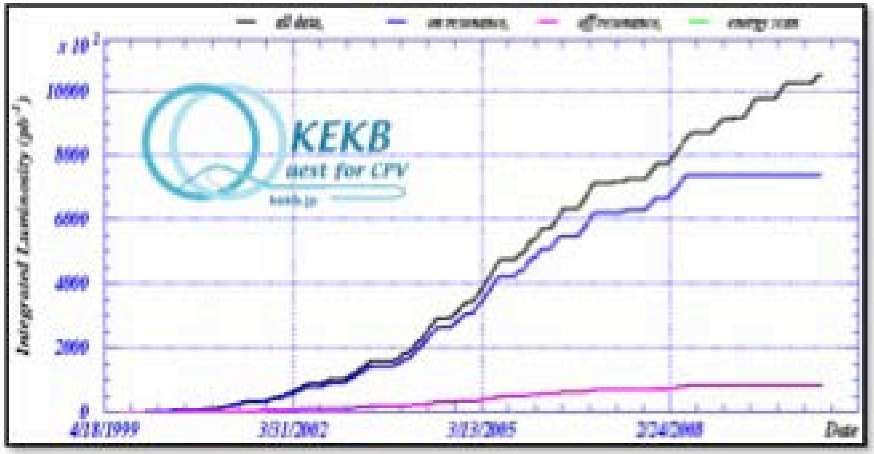
Ended in Apr., 2008
Total data = 558 fb^{-1}

KEKB Accelerator



World highest luminosity
$2.1 \times 10^{34} cm^{-2}s^{-1}$

World highest integrated luminosity
$1052.79\ fb^{-1}$



History of the integrated luminosity

Luminosity

- **Luminosity: accelerator performance**

$$\text{Event Rate}\,[\mathrm{s}^{-1}] = \sigma\,[\mathrm{cm}^{2}] \times L\,[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$$

Reaction cross-section σ is a physics parameter governed by the Nature

Luminosity *L* is a accelerator parameter that depends on its design

- **Integrated luminosity: amount of delivered data**

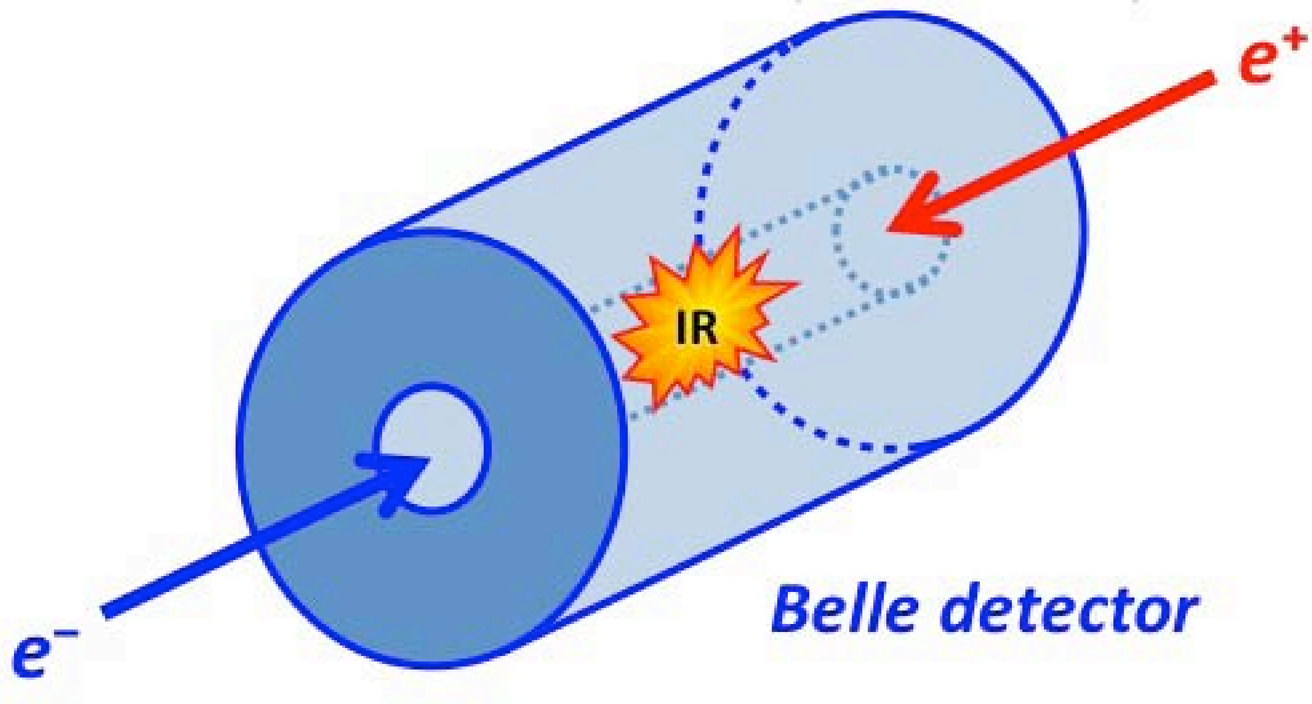
$$I\,[\mathrm{cm}^{-2}] = \int dt\,[\mathrm{s}] \times L\,[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$$

$1\mathrm{fb}^{-1} \overset{\mathrm{def}}{=} 10^{39}\mathrm{cm}^{-2}$, $1000\mathrm{fb}^{-1} = 1\mathrm{ab}^{-1} = 10^{42}\mathrm{cm}^{-2}$

$10\mathrm{fb}^{-1} \sim 10\times10^{6}\ B\bar{B}$, $100\mathrm{fb}^{-1} \sim 100\times10^{6}\ B\bar{B}$, $1\mathrm{ab}^{-1} \sim 1000\times10^{6}\ B\bar{B}$

Belle Detector

- **The Belle detector was located at an e^{+}-e^{-} interaction region (IR) to record subsequent particle behaviors to the interaction.**
  - The Belle detector had a semi-cylindrical shape.



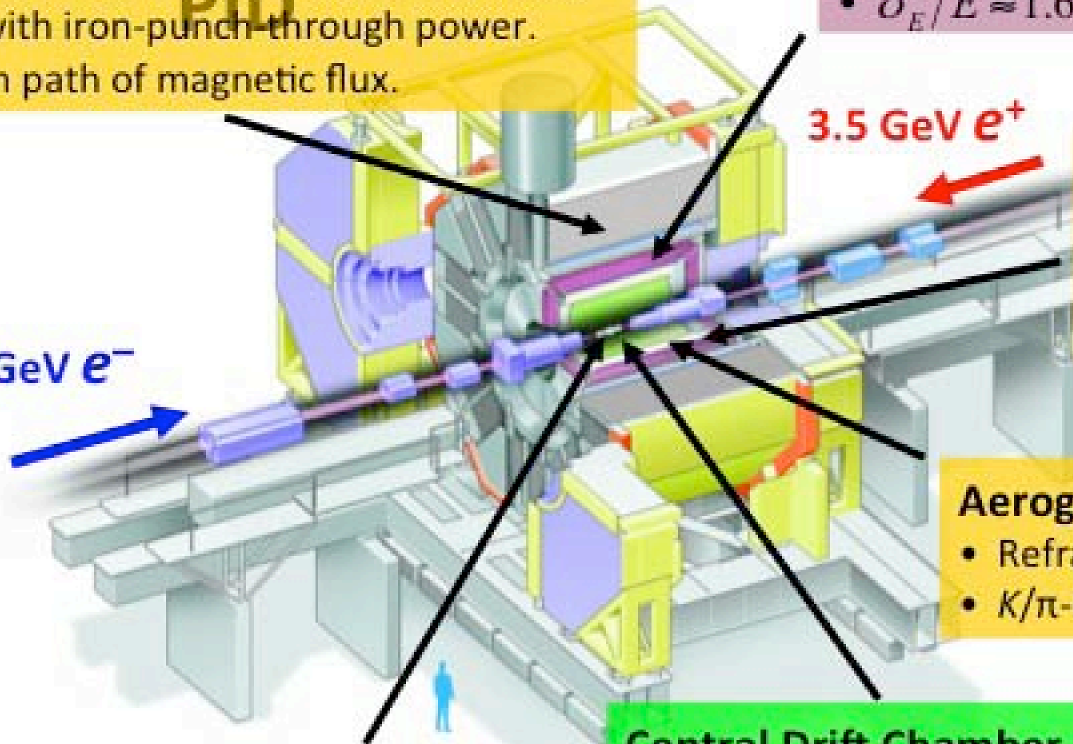
Belle Detector

Electromagnetic Calorimeters
- CsI ($T\ell$) crystal.
- Energy measurements of γ and $e^{\pm}$.
- $\sigma_E/E \approx 1.6\%$ @ 1 GeV.

γ and e^- energy

$K_L\mu$ Detector
- Sandwich of 14 RPCs and 15 iron plates.
- μ-ID with iron-punch-through power.
- Return path of magnetic flux.

PID



Time-of-Flight Counters
- Plastic scintillation counter.
- K/π-ID of high range p.
- Time resolution ~100 ps.

PID

Aerogel Čerenkov Counters
- Refractive index n=1.01-1.03.
- K/π-ID of middle range p.

PID

Silicon Vertex Detector
- Four detection layers.
- Vertex resolution ~ 100 μm.

B-decay vertex

Central Drift Chamber
- 8,400 sense wires along the beam direction.
- Momentum resolution $\sigma_{p_t}/p_t \approx 0.28\, p_t\,(\mathrm{GeV}/c) \oplus 0.3\%$
- PID with dE/dx measurement.
- 1.5 T magnetic field.

Charged particle momentum

Factory of *B* Mesons

$$e^+e^- \rightarrow b\bar{b}_{(4S)} \rightarrow B\bar{B}$$

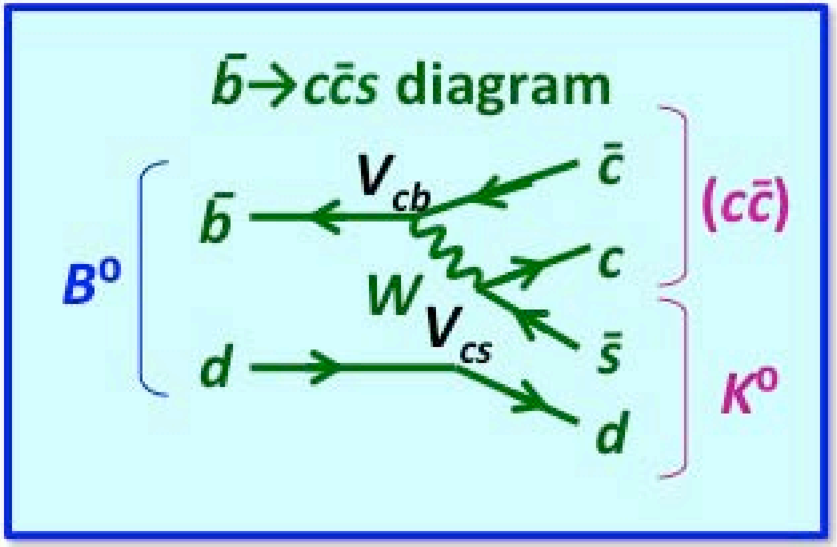
We created *B*-meson pairs from a collision of e^+e^- thorough Υ(4*S*).

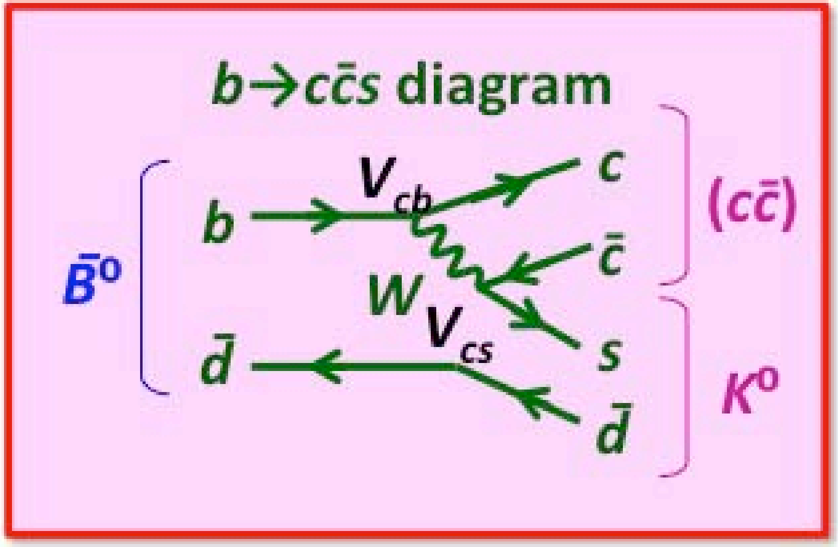
√s = 11.5 GeV

Like a factory
we created the enormous number
of *b* and $\bar{b}$ quark pairs
as *B* mesons.

in the e^+e^- cms.

Access to ϕ_1: $B^0 \to (c\bar{c})K^0$ Decay





V_{xy} … coupling constant of the two relevant quarks x and y.

Decay diagrams contain neither V_{td} nor V_{ub}.

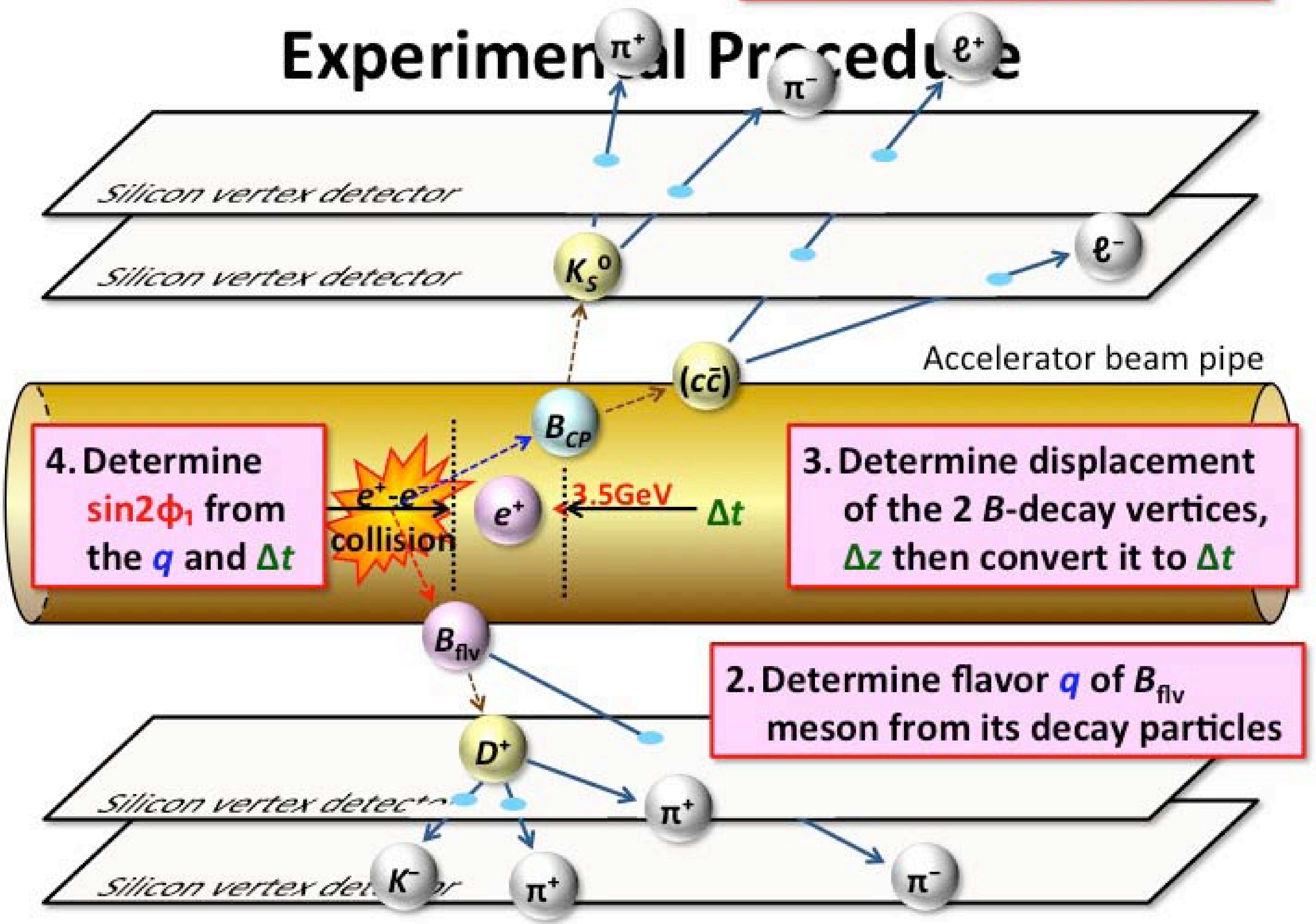
↓

No extra phase in the $b \to c\bar{c}s$ transition diagrams.

↓

Pure ϕ_1 is accessible through this decay.

Experimental Procedure



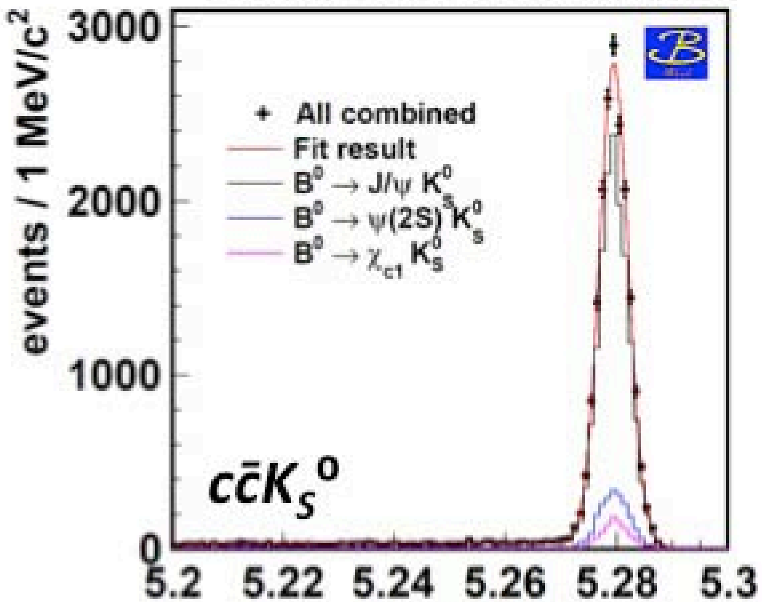
$B^0 \to (c\bar{c})K^0$ Reconstruction

from 772 x 10^6 $B\bar{B}$ pairs
final Belle data sample

- We identified B_{CP} meson from its reconstructed invariant mass.

$$m_{B_{CP}} = \sqrt{\left(\sum_k E_k\right)^2 - \left|\sum_k \vec{p}_k\right|^2}$$

k runs over all decay particles of B_{CP}.



Invariant mass of B_{CP} [GeV/c^2]

Belle preliminary (Belle final)

	$J/\psi K_S^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	$J/\psi K_L^0$
Signal yield	12727±115	1981±46	943±33	10087±154
Purity [%]	97	93	89	63

Δt Measurement

Determine B_{flv} decay position using particle's trajectory information.

Determine B_{CP} decay position using particle's trajectory information.

B_{CP} speed is fixed because of the fixed e^+ and e^- energies.

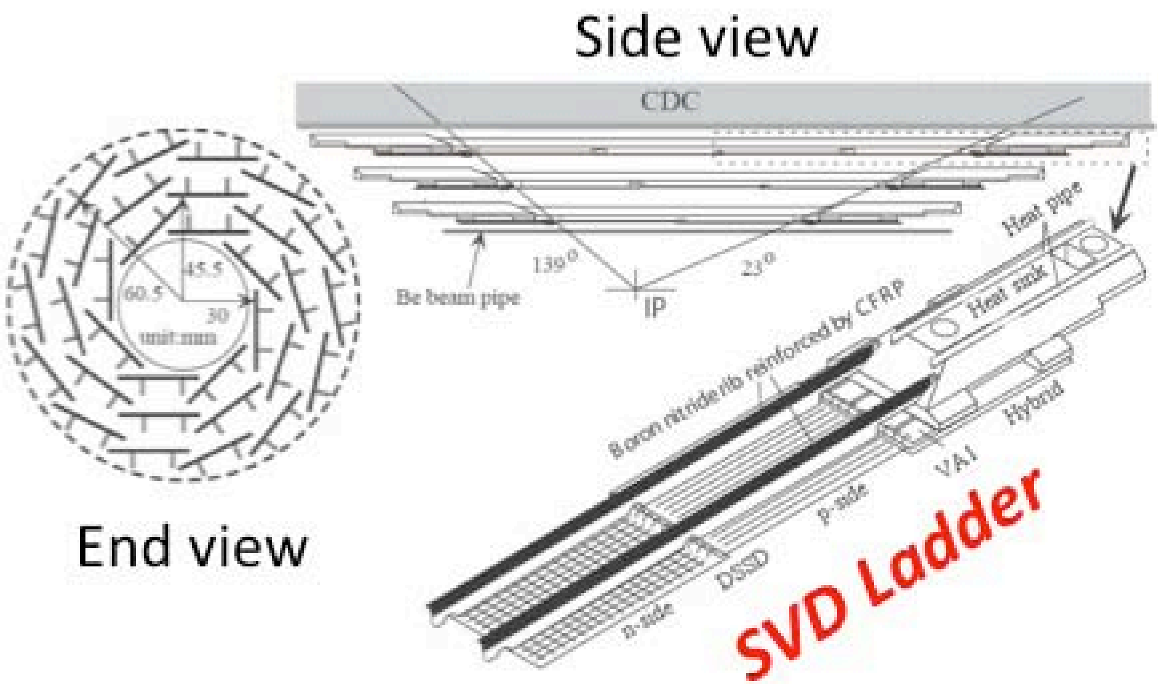
$\Delta t = \Delta z / B_{CP}$-speed

The typical value of Δz~200μm, while Δz resolution is ~100-150μm.
We carried out very intensive investigations on detector resolution.

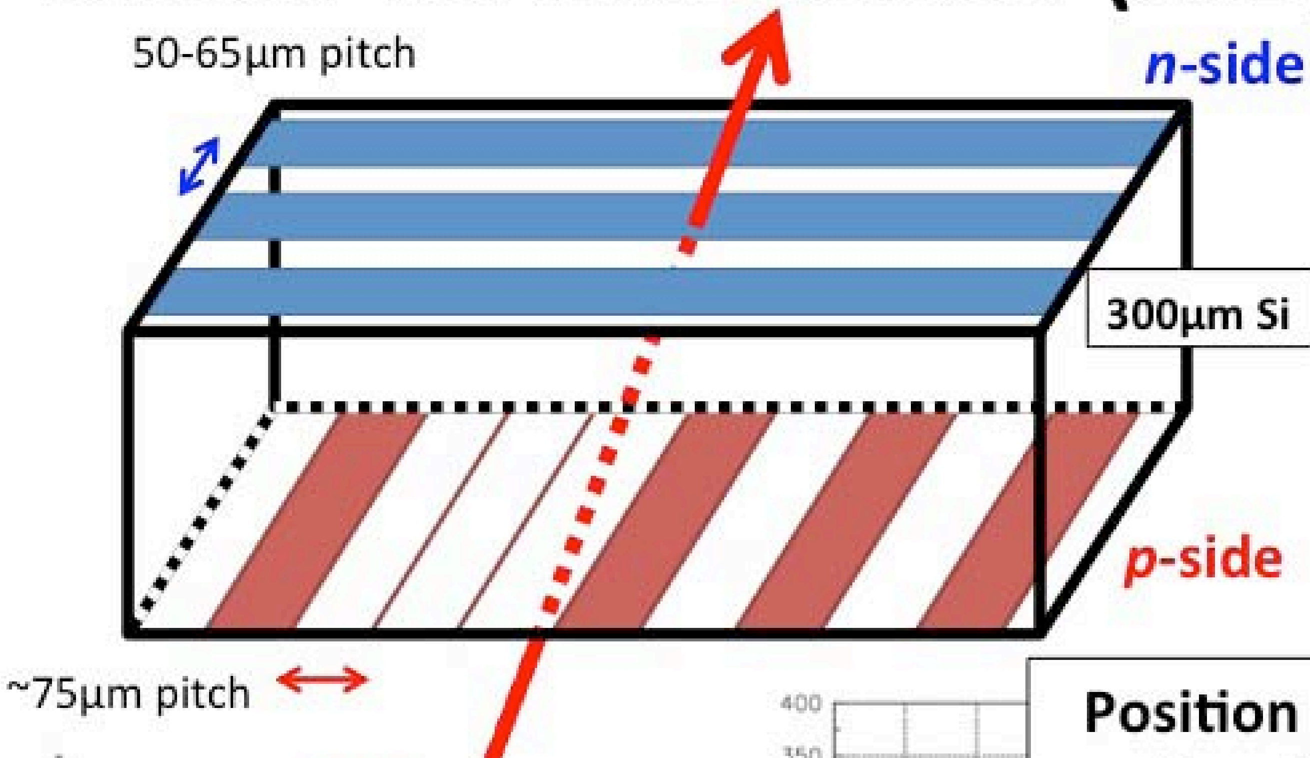
H. Tajima, H. Aihara, T. Higuchi *et al.*, Nucl. Instrum. Meth. A **533**, 370 (2004).

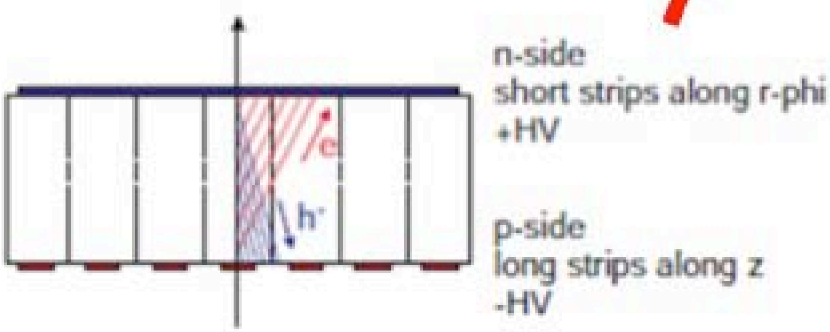
Measurement of *B*-Decay Position

- **Silicon vertex detector (SVD)**
  = a key detector to locate *B*-decay position
- **Detector layout**
  - Ladders are cylindrically arranged around the beam pipe.

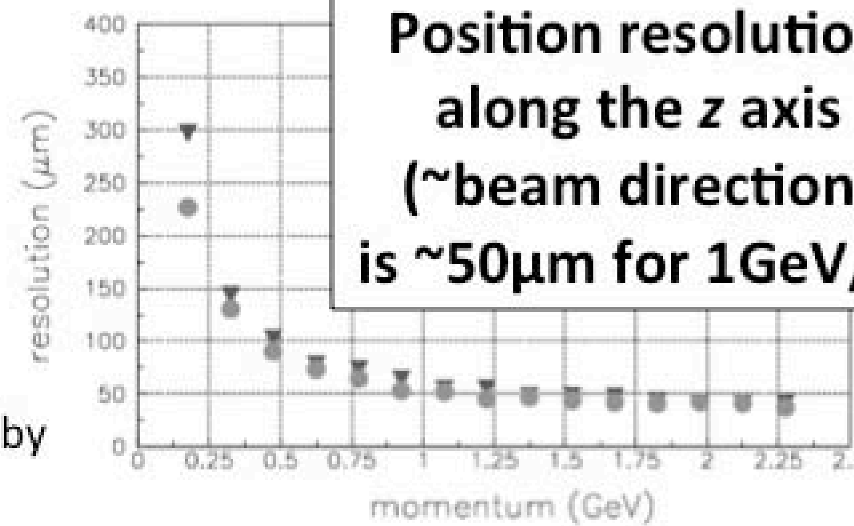


Silicon Vertex Detector (SVD)





Generated electrons and holes in the silicon by the traversing particle drifts to electrodes.



Position resolution along the *z* axis (~beam direction) is ~50µm for 1GeV/*c*.

$\sin 2\phi_1$ in $B^0 \to (c\bar{c})K^0$

Belle preliminary (Belle final)

$$\sin 2\phi_1 = +0.668 \pm 0.023 \pm 0.013$$

772 x 10^6 $B\bar{B}$ pairs

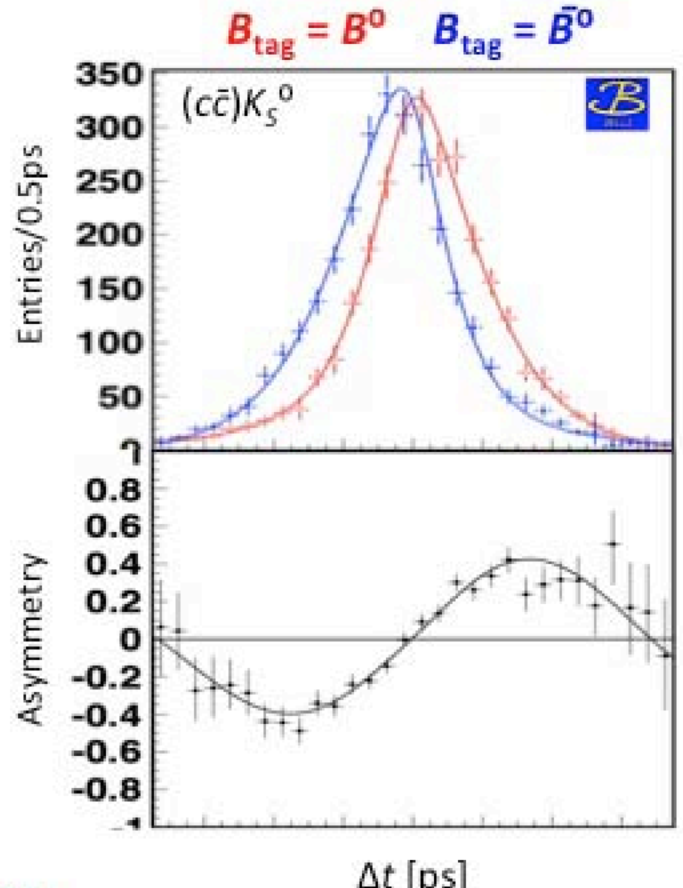
$B^0 \to (cc)K_S^0 + B^0 \to J/\psi K_L^0$ combined

History of $\sin 2\phi_1$ by Belle

Year	Data size	$\sin 2\phi_1$
2001	11.2M $B\bar{B}$	$+0.58^{+0.32+0.09}_{-0.34-0.10}$
2001	31.3M $B\bar{B}$	$+0.99 \pm 0.14 \pm 0.06$
2002	85M $B\bar{B}$	$+0.719 \pm 0.074 \pm 0.035$
2005	152M $B\bar{B}$	$+0.728 \pm 0.056 \pm 0.023$
2005	386M $B\bar{B}$	$+0.652 \pm 0.039 \pm 0.020$
2007	535M $B\bar{B}$	$+0.642 \pm 0.031 \pm 0.017$
2011	772M $B\bar{B}$	$+0.668 \pm 0.023 \pm 0.013$

← My Ph.D thesis ($B^0 \to J/\psi K_S^0$)

Belle preliminary ← (Belle final)



772 x 10^6 $B\bar{B}$ pairs

I. Adachi *et al.*, arXiv:1201.4643 [hep-ex] (2012).

Latest sin2ϕ_1 with Belle + BaBar

$$\sin 2\phi_1^{\mathrm{Belle}} = +0.668 \pm 0.023 \pm 0.013$$

(Belle preliminary)

$$\sin 2\phi_1^{\mathrm{BaBar}} = +0.691 \pm 0.031$$

$$\sin 2\phi_1^{\mathrm{average}} = +0.678 \pm 0.020$$

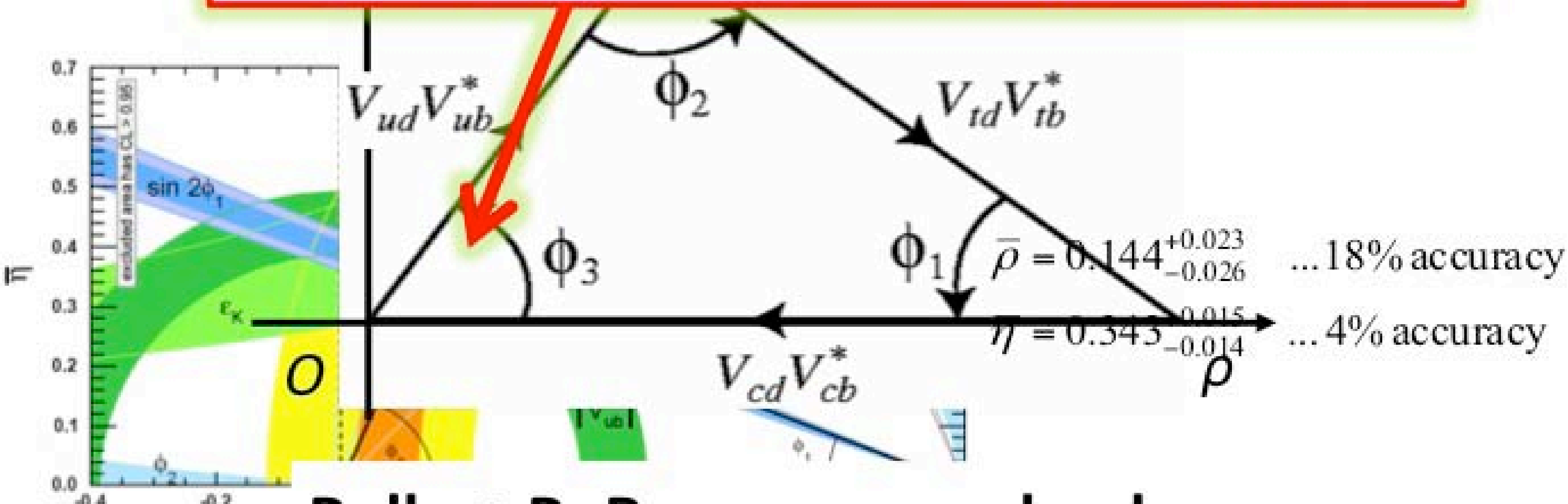
$$\phi_1^{\mathrm{average}} = (21.4 \pm 0.8)^\circ$$

(HFAG preliminary)

Belle: 772 x 10[6] $B\bar{B}$ pairs; I. Adachi *et al.*, arXiv:1201.4643 [hep-ex] (2012).
BaBar: 465 x 10[6] $B\bar{B}$ pairs; B. Aubert *et. al.*, arXiv:0808.1903 [hep-ex] (2008).
Average: Average by Heavy Flavor Averaging Group.

Determination of Unitarity Triangle

Nearly all measurements consistently converge to the unitarity triangle.



Belle + BaBar measure ϕ_2, ϕ_3,

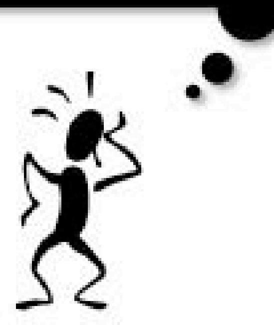
***B*-factory experiments have established the KM theory and, as its consequence, the SM.**

What Are Physicists Pursuing?

Particle physicists had considered the Grand Law = Standard Model

Standard Model of particle physics

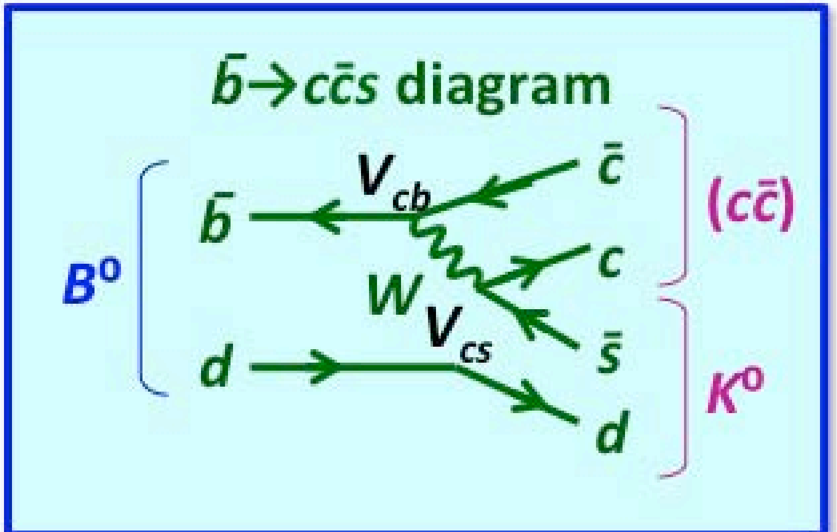
Electroweak interaction	QCD	KM theory	Higgs mechanism

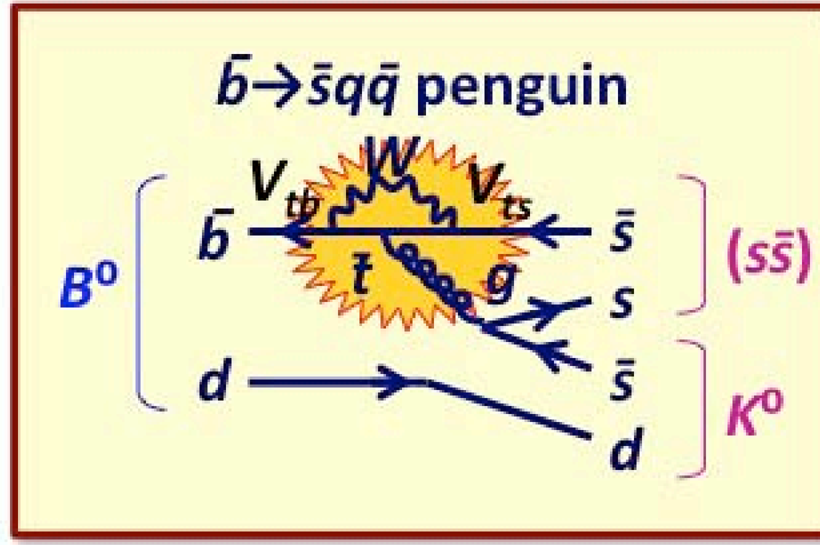


1. KM Theory and *B*-Factories

1.5 Example of Analysis Using 'Δt'

CP Violation in $b \to sq\bar{q}$ Transition





V_{xy} … coupling constant of the two relevant quarks x and y.

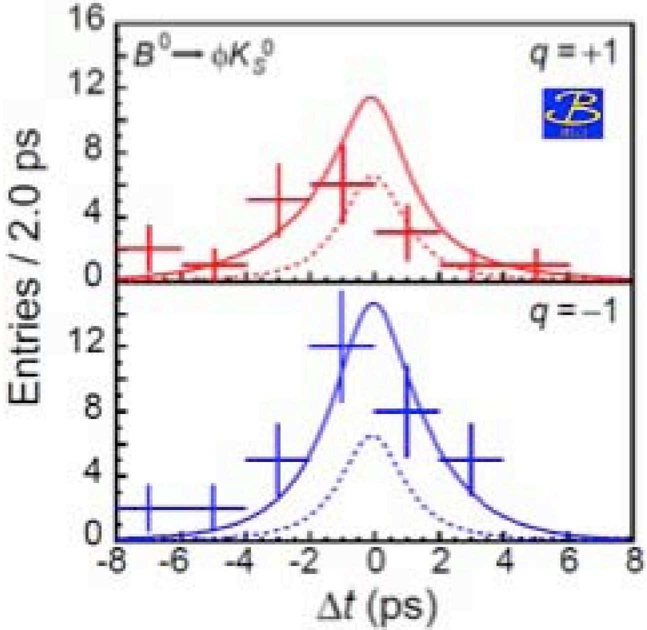
As well as $b \to c\bar{c}s$, no extra phase in $b \to sq\bar{q}$.

↓

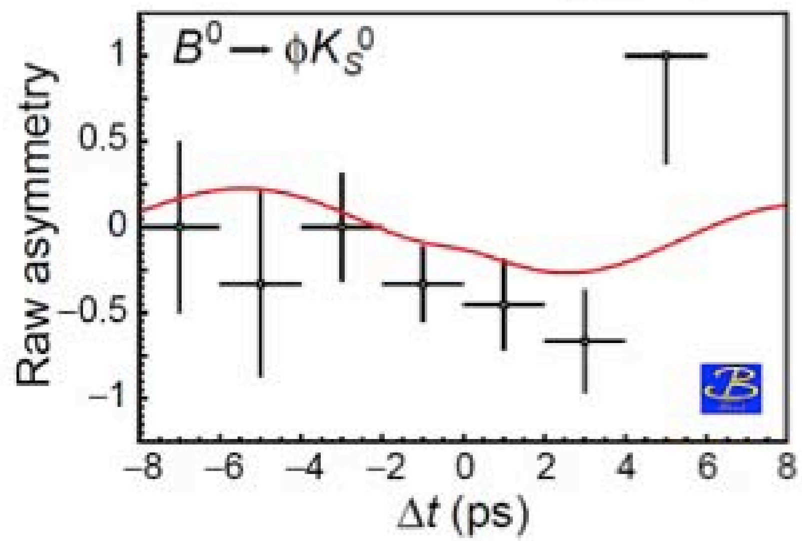
The ϕ_1 is accessible through the $b \to sq\bar{q}$ as well.

In a case when a heavy new particle with a phase virtually appears in the $b \to sq\bar{q}$ () loop → $\phi_1^{c\bar{c}s} \neq \phi_1^{sq\bar{q}}$?

CP Violation in $b \rightarrow sq\bar{q}$ (First Result)



85 x 10[6] $B\bar{B}$ pairs



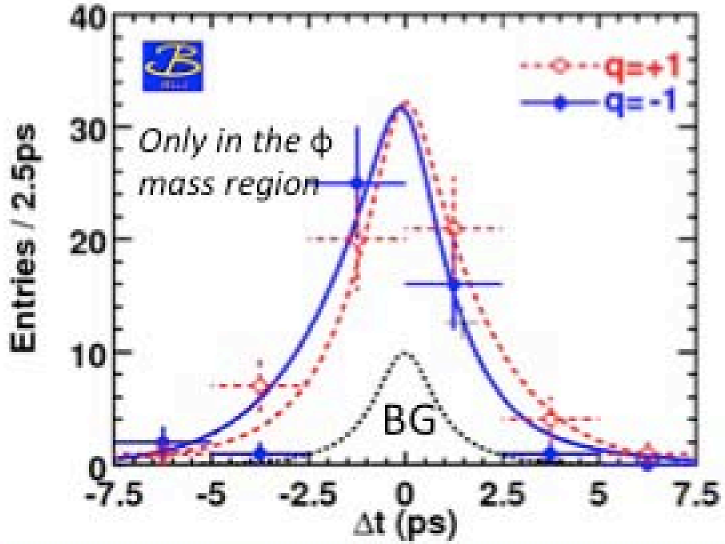
ϕK_S^0	$\sin 2\phi_1^{sq\bar{q}} = -0.73 \pm 0.64 \pm 0.22$

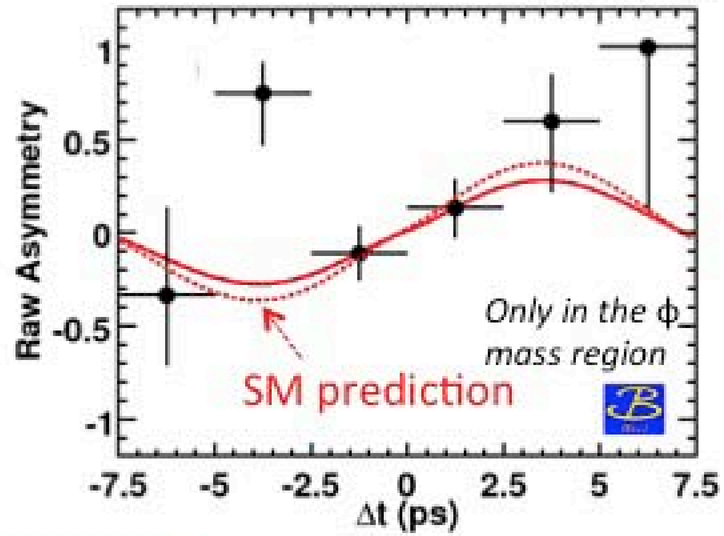
Sign of the observed $\sin 2\phi_1^{sq\bar{q}}$ was flipped from the $\sin 2\phi_1^{c\bar{c}s}$.
New physics!?

K. Abe *et al.*, Phys. Rev. D **67**, 031102 (2003).

CP Violation in $b \to sq\bar{q}$ (Latest)

657 x 10^6 $B\bar{B}$ pairs





ϕK_S^0	$\phi_1^{sq\bar{q}} = (32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$
$f_0(980)K_S^0$	$\phi_1^{sq\bar{q}} = (31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$

The third error accounts for an uncertainty arises from Dalitz model.

With more statistics, $\phi_1^{c\bar{c}s}$ and $\phi_1^{sq\bar{q}}$ get consistent, and the initially observed flipped-sign is concluded from the statistical fluctuation.

Y. Nakahama *et al.*, Phys. Rev. D **82**, 073011 (2010).

1. KM Theory and *B*-Factories

1.6 Another Example

Measurement of *CPT* Violation

- ***CPT* violation**
  - A new physics that violates *CPT* invariance will necessarily violates Lorentz invariance, as well.
  - *CPT* violation will have a serious impact on general physics, not only in the SM, but also in most of its extensions.

- ***CPT*-violating complex parameter: *z***
  - The Δt distribution with *CPT* violation

$$P(\Delta t, q; z) = \frac{\Gamma_d}{2} e^{-\Gamma_d |\Delta t|} \left[\frac{|\eta_+|^2 + |\eta_-|^2}{2} \cosh \frac{\Delta\Gamma_d}{2}\Delta t - \mathrm{Re}(\eta_+ \eta_-^*) \sinh \frac{\Delta\Gamma_d}{2}\Delta t + \frac{|\eta_+|^2 - |\eta_-|^2}{2} \cos \Delta m_d \Delta t - \mathrm{Im}(\eta_+ \eta_-^*) \sin \Delta m_d \Delta t \right]$$

Re(z) ≠ 0 or Im(z) ≠ 0
⇔ The *CPT* is violated.

$$\eta_+ \equiv A_1 \bar{A}_2 - \bar{A}_1 A_2,$$

$$\eta_- \equiv \sqrt{1 - z^2} \left(\frac{p}{q} A_1 A_2 - \frac{q}{p} \bar{A}_1 \bar{A}_2 \right)$$

$$A_1 = \langle f_1 | H_d | B^0 \rangle, \quad \bar{A}_1 = \langle f_1 | H_d | \bar{B}^0 \rangle,$$
$$A_2 = \langle f_2 | H_d | B^0 \rangle, \quad \bar{A}_2 = \langle f_2 | H_d | \bar{B}^0 \rangle.$$

The q =±1 is taken into account of the A.

CPT Violation in B^0 Decays

Belle preliminary

$$\mathrm{Re}(z) = (+1.9 \pm 3.7 \pm 3.2) \times 10^{-2}$$

$$\mathrm{Im}(z) = (-5.7 \pm 3.3 \pm 6.0) \times 10^{-3}$$

Consistent to *CPT* conservation

535 x 10^6 $B\bar{B}$ pairs

Used decay modes	Main sensitivity
$J/\psi K_S^0$, $J/\psi K_L^0$	Re(z) and $\Delta\Gamma_d/\Gamma_d$
$D^-\pi^+$, $D^{*-}\pi^+$, $D^{*-}\rho^+$	Im(z) and Δt resolution
$D^{*-}\ell^+\nu_\ell$	
$D^0\pi^+$, $J/\psi K^+$	Δt resolution

Other parameters

$$\Delta\Gamma_d/\Gamma_d = (-1.7 \pm 1.8 \pm 1.1) \times 10^{-2}$$

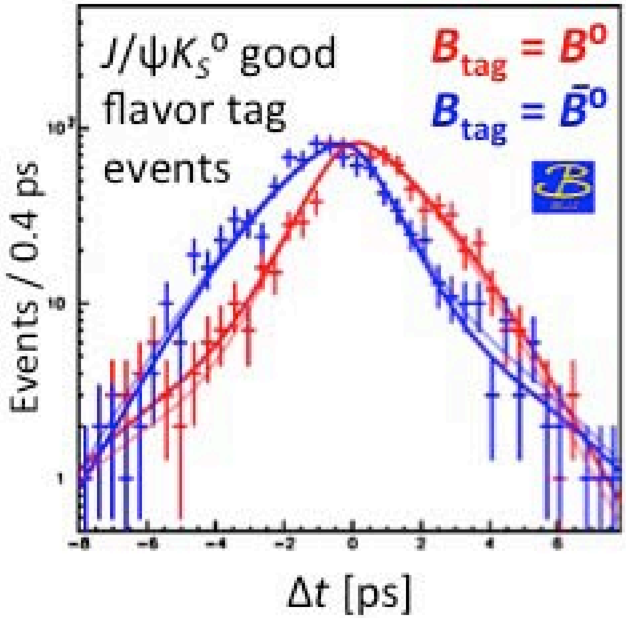
$$\tau_{B^0} = 1.531 \pm 0.004 \quad \text{(ps)}$$

$$\tau_{B^+} = 1.639 \pm 0.006 \quad \text{(ps)}$$

$$\Delta m_d = 0.506 \pm 0.003 \quad (\text{ps}^{-1})$$

$$|\lambda_{CP}| = 0.999 \pm 0.004$$

$$\arg(\eta_{CP}\lambda_{CP}) = -0.70 \pm 0.04$$



Light lines indicate Re(z) = +0.2 Im(z) = +0.0 case.

T. Higuchi (Belle Collaboration), talk at EPS2011 (2011).

2. Implications of Imperfectness of the SM

2.1 Introduction

Standard Model ≠ a Silver Bullet

- **Many yet-unanswered questions in the Universe:**
  - Why matter dominates the Universe?
  - How can we unify the electroweak and strong interactions?
  - What is the dark matter?
  - What is the dark energy?
  - …

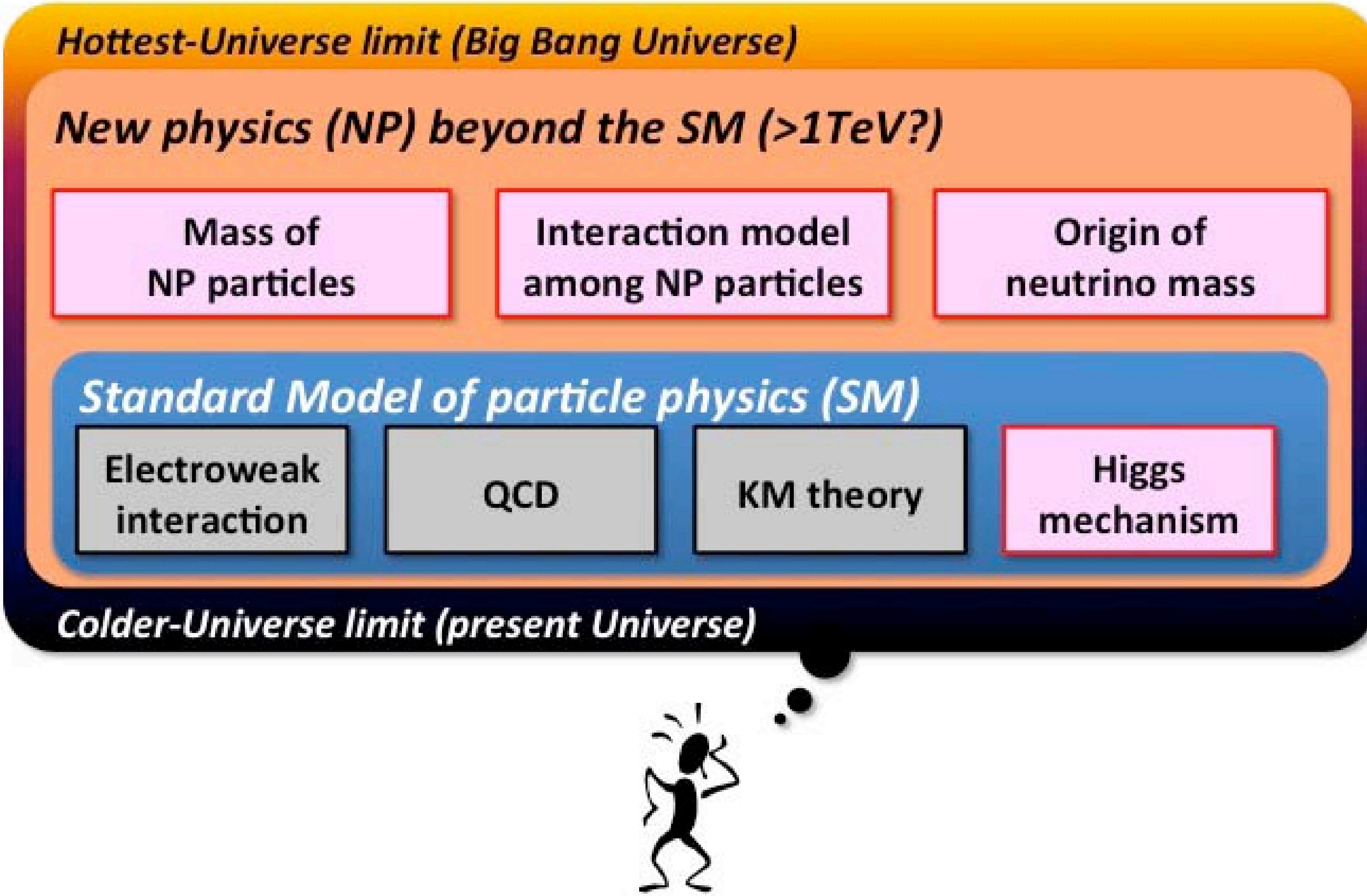
What Are Physicists Pursuing?

Particle physicists had considered the Grand Law = Standard Model

Standard Model of particle physics (SM)

- Electroweak interaction
- QCD
- KM theory
- Higgs mechanism

What Are Physicists Pursuing?

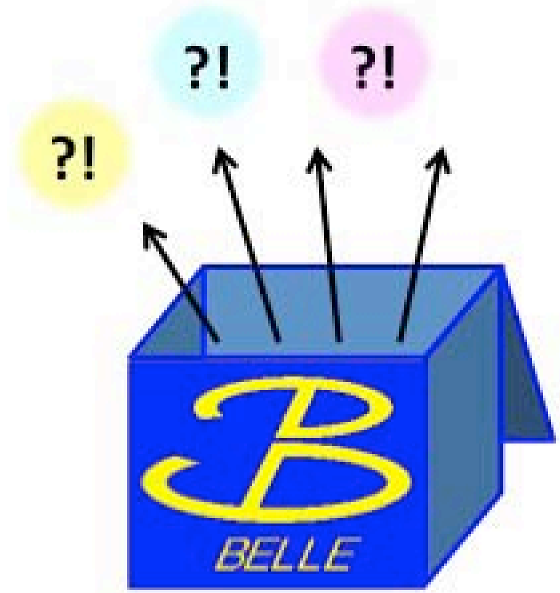


2. Implications of Imperfectness of the SM

2.2 Observed Anomalies[?]

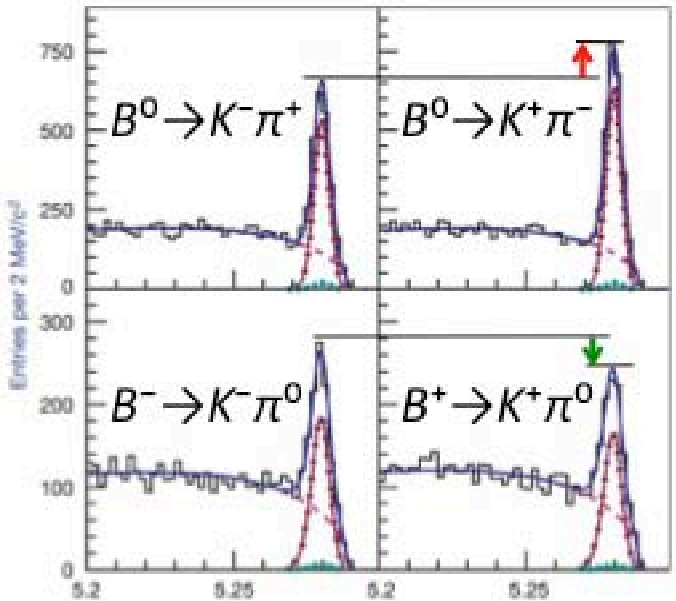
Observed Anomalies[?]

- **Several phenomenological implications of a NP beyond the SM have already been reported by Belle.**
  - Difference in *CP* violation between B^0 and B^+
  - Larger $Br(B^+ \to \tau^+ \nu_\tau)$ than expectation
  - Anomaly in forward-backward asymmetry in $B \to K^{(*)} \ell^+ \ell^-$
  - Unexpectedly large D^0-$\bar{D}^0$ mixing
  - …



Anomaly[?] in B^0/B^+ *CP* Violation

Figures are taken from 535 x 10^6 $B\bar{B}$



B^0

B^+

Reconstructed *B*-meson candidates' invariant mass [GeV/c^2]

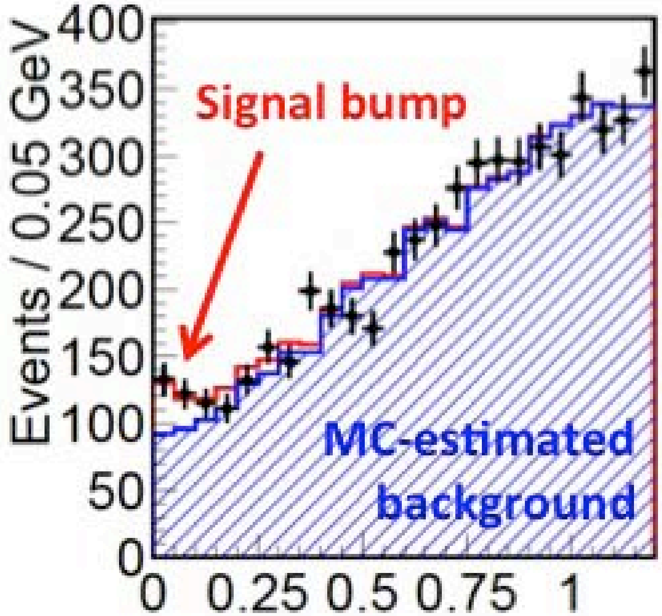
Belle preliminary **772 x 10^6 $B\bar{B}$**

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

$$A_{CP}(K^+\pi^0) = +0.043 \pm 0.024 \pm 0.002$$

4.0σ deviation → **Hint of NP?**

Anomaly[?] in $Br(B^+ \to \tau^+ \nu_\tau)$



Remaining energy in the calorimeter unassociated to charged particle and π^0 [GeV/c^2]

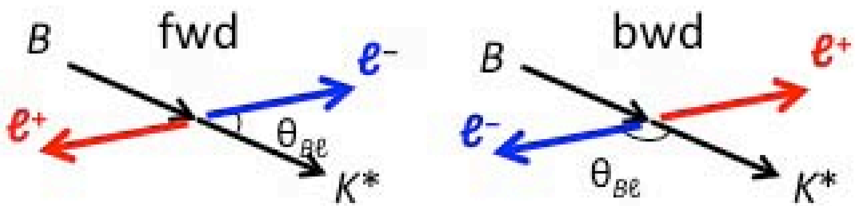
$$Br\Big|^{\text{average}} = (1.68 \pm 0.31) \times 10^{-4}$$

$$Br\Big|^{\text{SM w/o}}_{B\to\tau\nu} = (0.76^{+0.11}_{-0.06}) \times 10^{-4}$$

2.8σ deviation ➡ **Hint of NP?**

Anomaly[?] in $B \to K^{(*)}\ell^+\ell^-$

- $B \to K^{(*)}\ell^+\ell^-$ **forward-backward asymmetry** A_{FB}

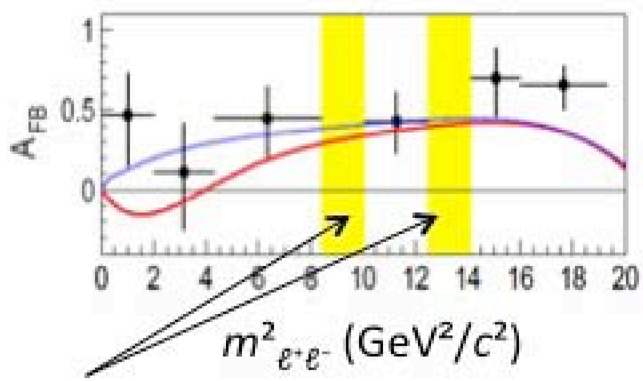


in K^* rest frame

$$A_{FB}(m^2_{\ell^+\ell^-}) = \frac{\int_{-1}^{1} \mathrm{sgn}(\cos\theta_{B\ell})\, g(m^2_{\ell^+\ell^-}, \theta_{B\ell})\, d(\cos\theta_{B\ell})}{\int_{-1}^{1} g(m^2_{\ell^+\ell^-}, \theta_{B\ell})\, d(\cos\theta_{B\ell})}$$

- **Possible inconsistency with SM prediction**

657 x 10⁶ $B\bar{B}$



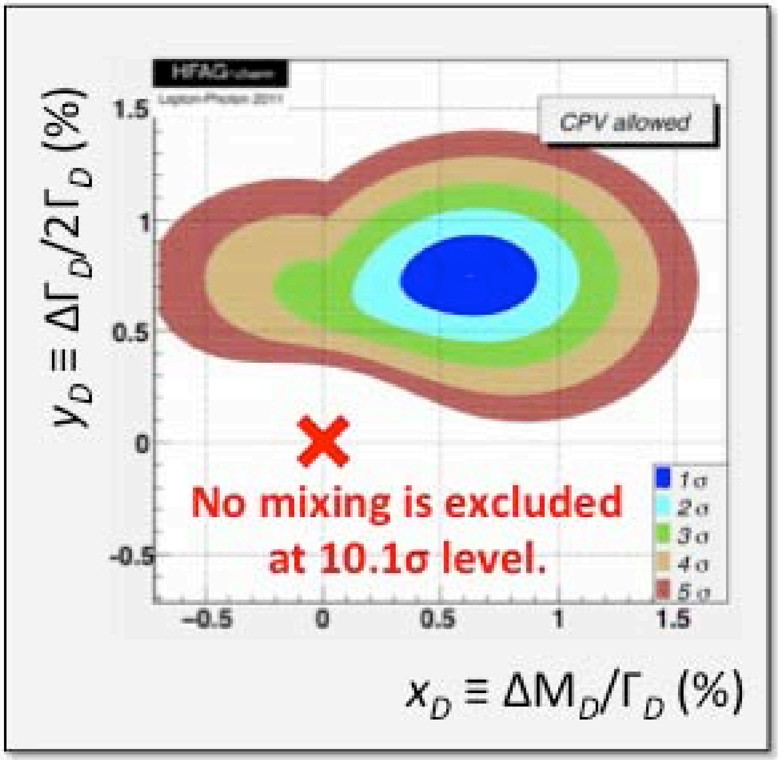
J/ψ and $\psi(2S)$ mass regions are excluded.

SM prediction

$C_7 = -C_7^{SM}$ case

Hint of NP?

Anomaly[?] in D^0-$\bar{D}^0$ Mixing



Averaged measurements

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

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

Average of Belle, BaBar, CDF, CLEOc

SM prediction

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

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

Unexpectedly large D^0-$\bar{D}^0$ mixing (x_D) was observed from a lifetime difference between $D^0 \to K^+K^-$ and $D^0 \to K^+\pi^-$ decays.

Hint of NP?

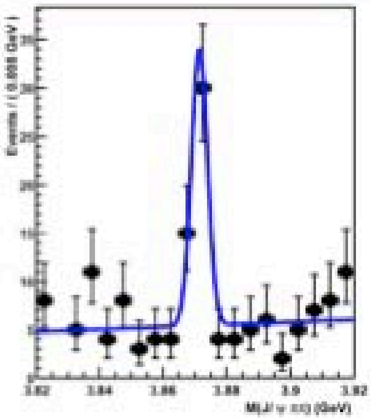
Discoveries of New Resonances

$X(3872)$

$B^+ \to X(3872)\, K^+$

$X(3872) \to J/\psi \pi^+\pi^-$

A new particle, which can never be $c\bar{c}$ resonances.

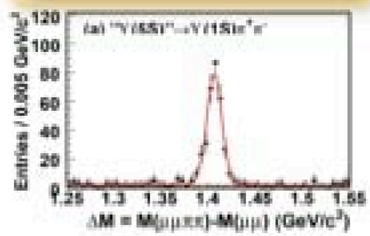


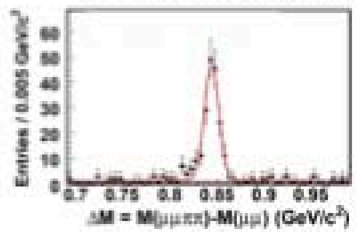
Y_b

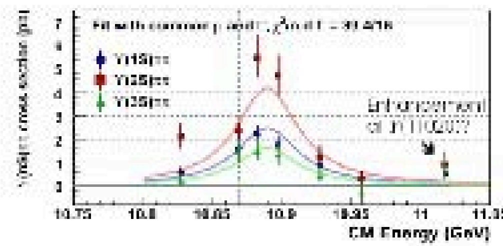
$Y_b \to \Upsilon(1S)\, \pi^+\pi^-$

$Y_b \to \Upsilon(2S)\, \pi^+\pi^-$

A new $b\bar{b}$ resonance beside the $\Upsilon(5S)$?







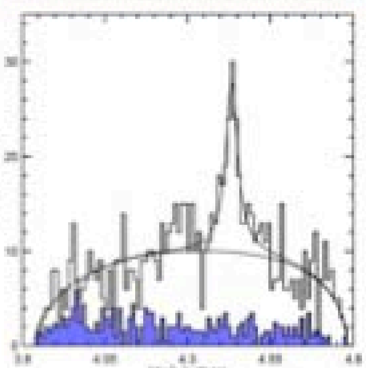
$Z(4430)^+$

$B^0 \to Z(4430)\, K^-$

$Z(4430)^+ \to \psi(2S)\pi^+$

A new particle with charge, which can never be $c\bar{c}$ resonance

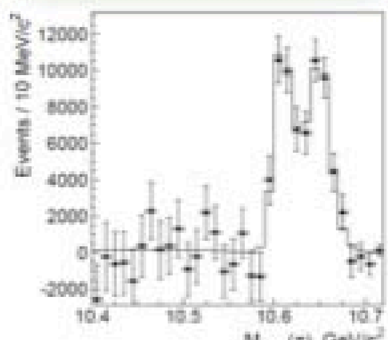
Bound state of 4 quark resonance?

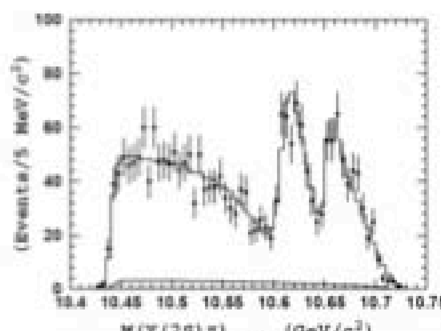


Z_b

$Z_b \to \Upsilon(2S)\, \pi^+$

$Z_b \to h_b(1P)\, \pi^+$





Observed Anomalies[?]

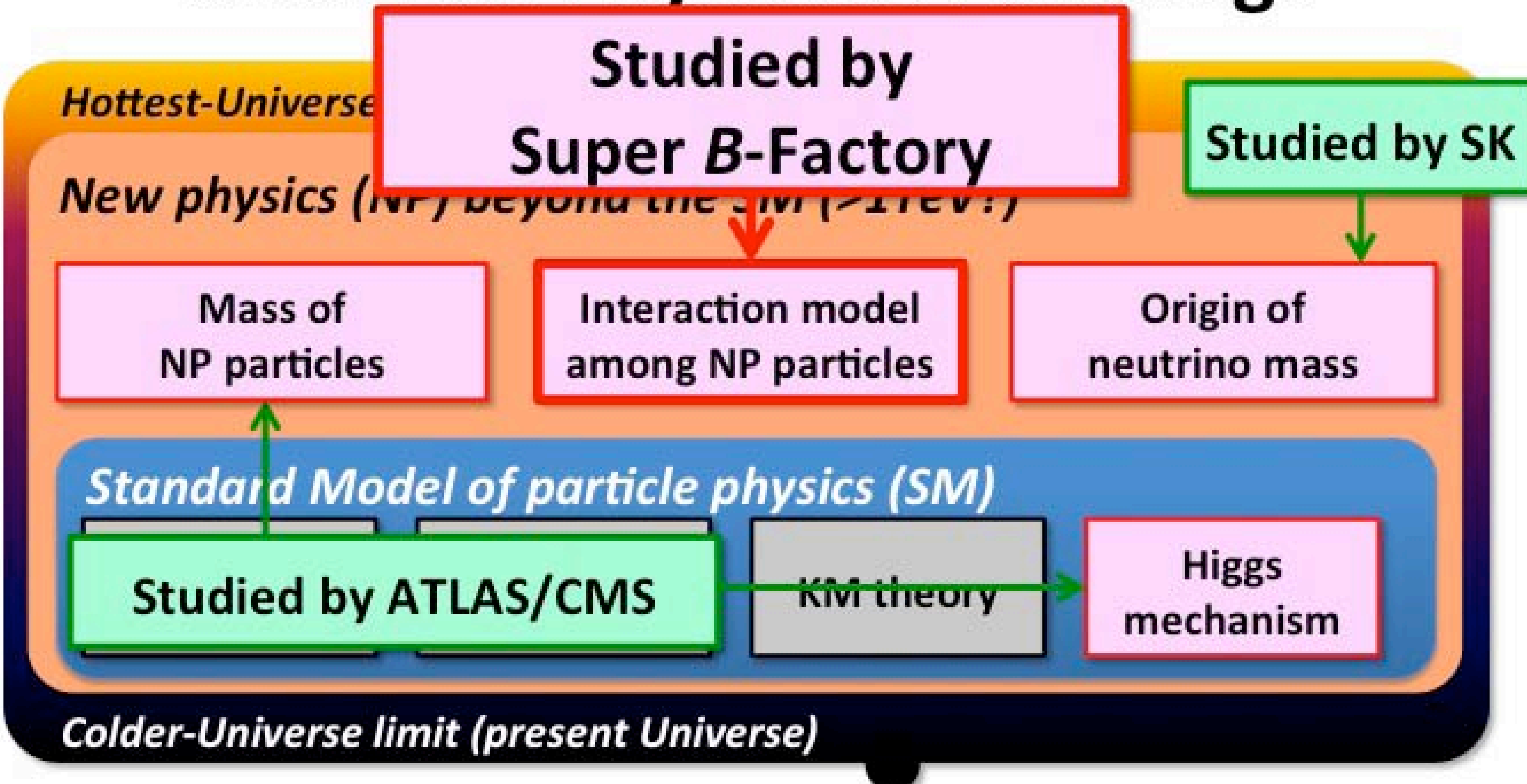
Why have I focused on these anomalies?
Because we can explained these anomalies[?] if NP contribution is considered.

We are sufficiently excited to make action toward an experimental search for a NP.

3. New Physics Search by Super *B*-Factory

3.1 Introduction

What Are Physicists Pursuing?



Super *B*-Factory (and LHCb) and ATLAS/CMS will complementarily elucidate a NP.

Method of Super *B*-Factory

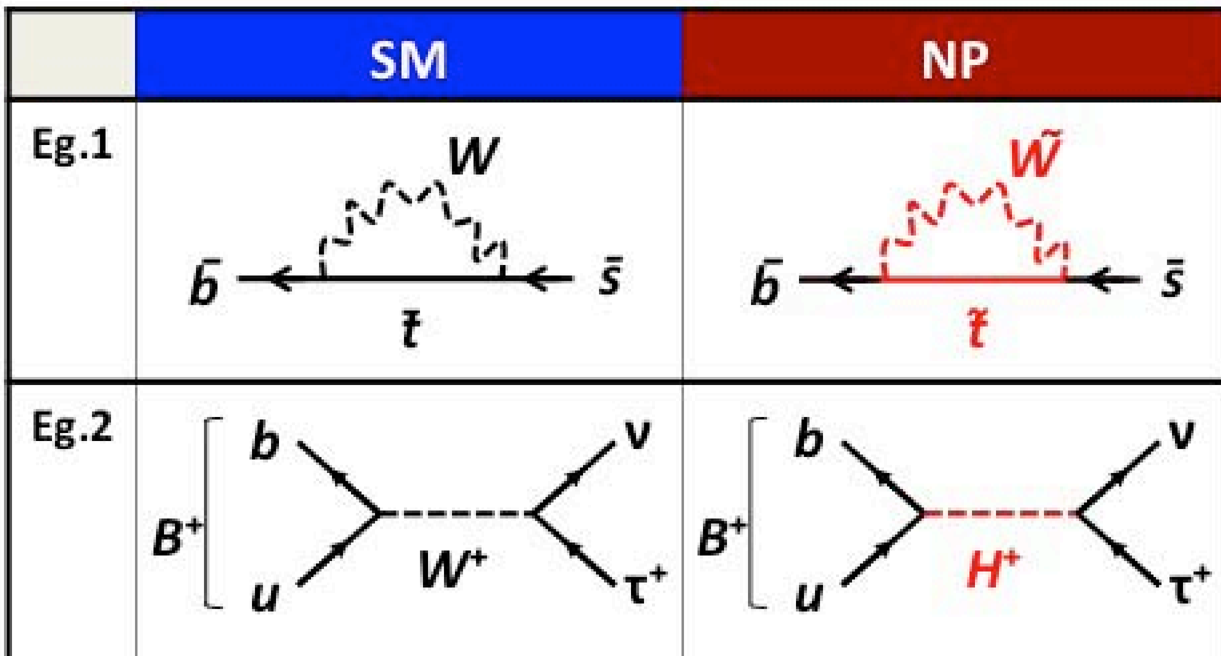
The maximum $\sqrt{\bar{s}}$ of the LHC is 14TeV.

Expected mass of NP particle	Collision energy of SB accelerator	Direct detection of a NP particle	Determination of a NP interaction model
$O(1\mathrm{TeV}/c^2)$	$\sqrt{\bar{s}}$ = 11GeV	*Impossible* ☹	*Tunnel effect* ☺

Method of Super *B*-Factory

The maximum $\sqrt{\bar{s}}$ of the LHC is 14TeV.

Expected mass of NP particle	Collision energy of SB accelerator	Direct detection of a NP particle	Determination of a NP interaction model
$O(1\text{TeV}/c^2)$	$\sqrt{\bar{s}}$ = 11GeV	*Impossible* ☹	*Tunnel effect* ☺



A virtual NP particle may deviate physics observables from SM expectations.

We measure the deviation.

‘Matrix Approach’ by Super *B*-Factory

- Characteristic deviation patterns per NP hypothesis.
- Several deviation measurements will identify the true NP model among many NP hypotheses.

Typical SUSY models → …

Measurements by Super B-factory and other experiments. ↓ …

	mSUGRA	MSSM+ν_R		SU(5)+ν_R		U(2) FS
		degenerate	non-degenerate	degenerate	non-degenerate	
$A_{CP}(s\gamma)$						✓
$S(K^*\gamma)$				✓	✓	✓
$S(\rho\gamma)$				✓	✓	✓
$S(\phi K_S)$				✓	✓	✓
$S(B_s \to J/\psi\phi)$				✓	✓	✓
$\mu \to e\gamma$		✓		✓	✓	?
$\tau \to \mu\gamma$		✓	✓	✓	✓	?
$\tau \to e\gamma$			✓		✓	?

✓: Possible deviation from the SM prediction. T. Goto *et al.*, Phys. Rev. D**77**, 095010 (2008).

Super *B*-Factory = Luminosity Frontier

- **As a NP signature (deviation from the SM prediction) is expected to be so faint at $\sqrt{s}$=11GeV that we need enormous number of collision data.**

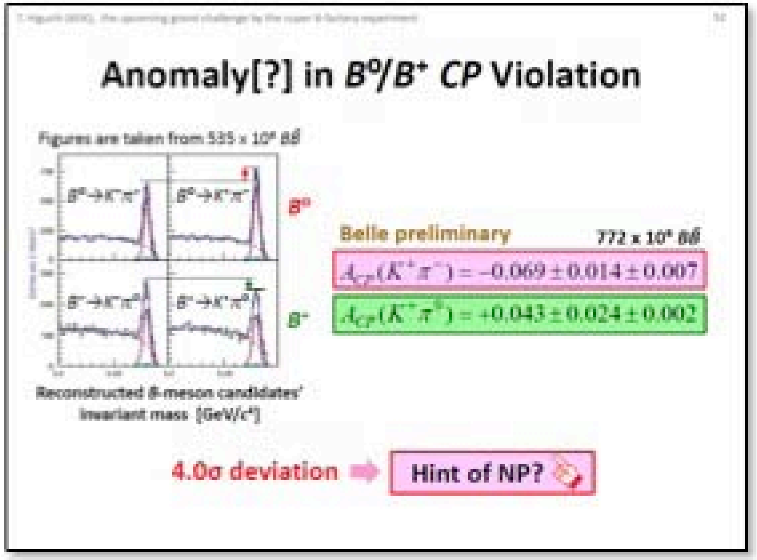
KEKB → SuperKEKB: **x40 luminosity**
$L = 8.0 \times 10^{35}/\mathrm{cm}^2\mathrm{s}$

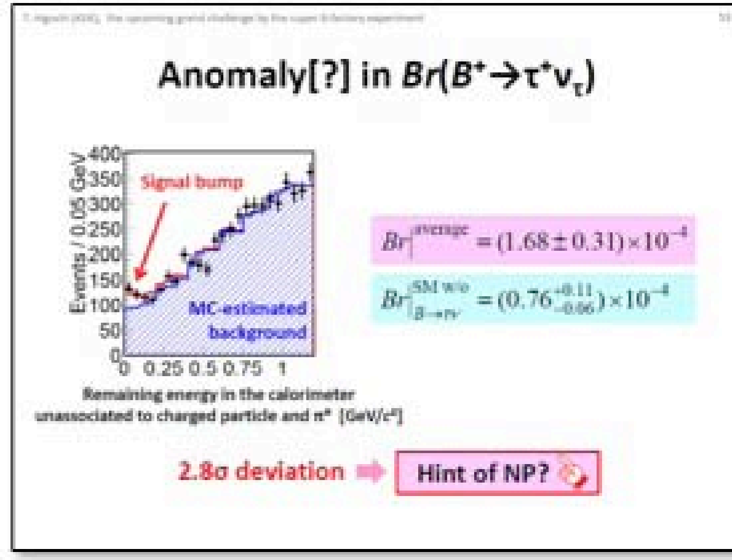
BELLE → Belle II:
Larger solid-angle coverage
More granular resolution
Faster signal output
Lower noise level

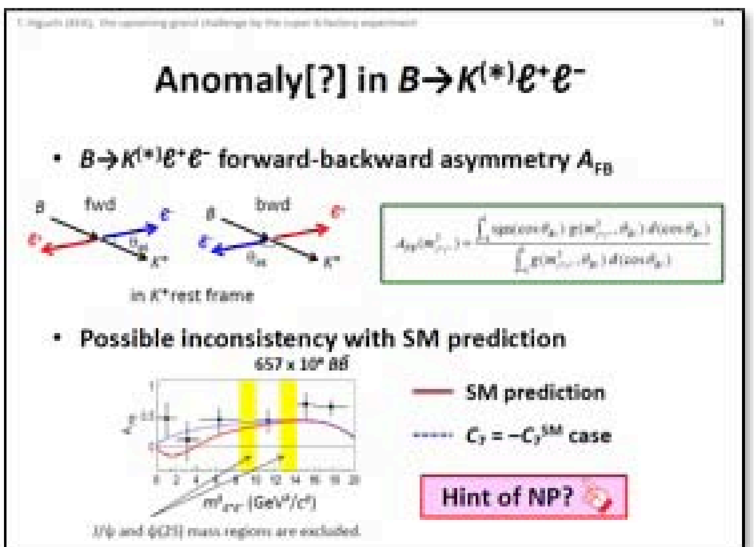
3. New Physics Search by Super *B*-Factory

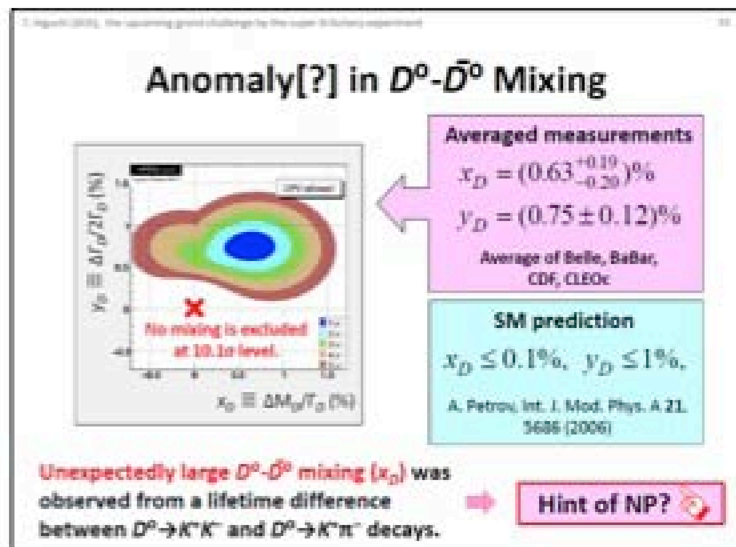
3.2 Prospects of the Observed Anomalies[?]

Observed Anomalies[?]





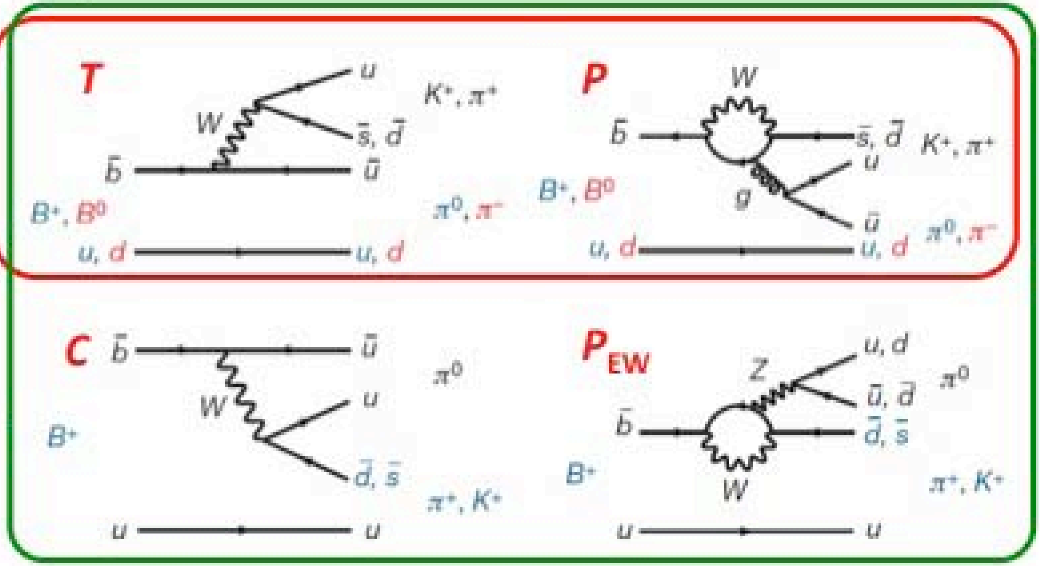




Prospect of B^0/B^+ *CP* Violation

B^0, B^+

- **NP contribution**



Contribution from P_{EW} to the B^+ *CP* violation may be large due to a NP…?

- **NP contribution is probed via the isospin sum rule.**

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

Measurements of four *CP*-violating parameters in $K\pi$ are needed.
That in $K^0\pi^0$ is only possible with Super *B*-factory statistics.

$0.14 \pm 0.13 \pm 0.06$ @ 600 fb^{-1} (Belle)

If sum rule is violated → **NP!**

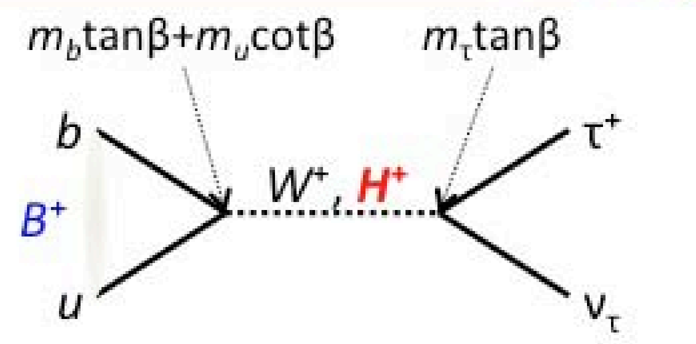
Prospect | **Sum rule test @ 10ab^{-1}**

Prospect of $Br(B^+ \to \tau^+ \nu_\tau)$

- **NP contribution**

  If the decay is also mediated by H^+ as well as W^+, the Br will be deviated from the SM prediction.

$B^+ \to \tau^+ \nu_\tau$

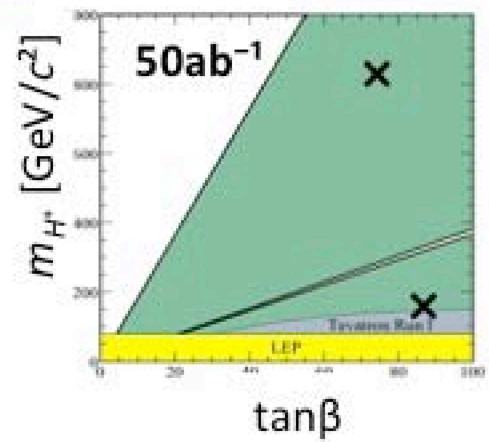


tanβ: free parameter of MSSM (NP).

$$Br^{\mathrm{obs}} = Br^{\mathrm{SM}} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2\beta\right)^2$$ ... two Higgs doublet model

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

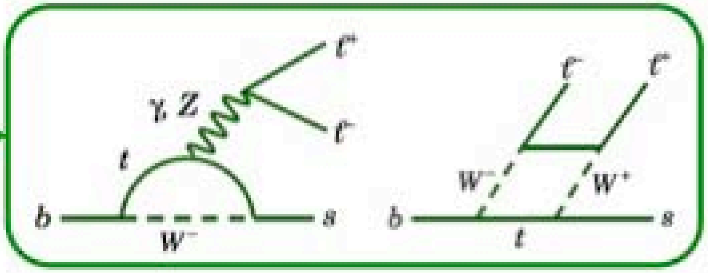
- **Precise measurement of $Br(B^+ \to \tau^+ \nu_\tau)$ will exclude more tanβ-m_{H^+} region.**



Prospect of $B\to K^{(*)}\ell^+\ell^-$

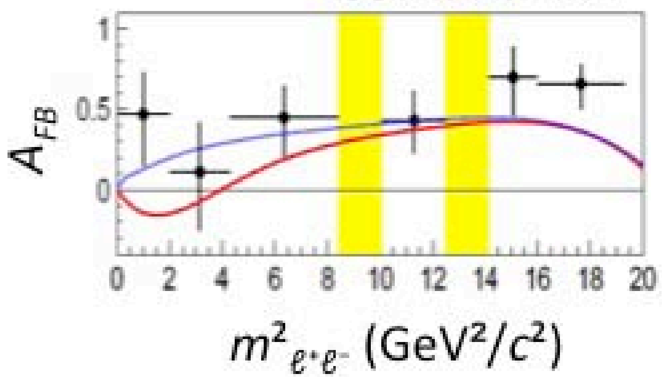
$b\to s\ell^+\ell^-$

- **NP contribution** NP particle shows up in the loop…?

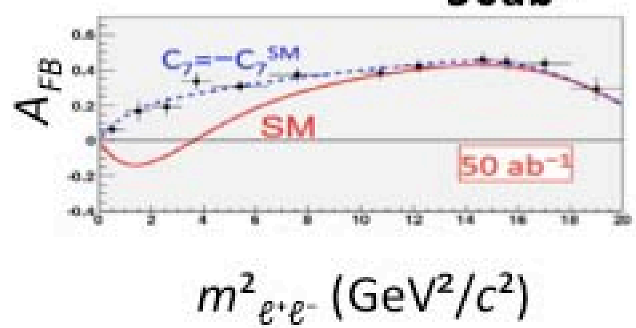


- **Prospect**

657 x 10^6 $B\bar{B}$



50ab⁻¹



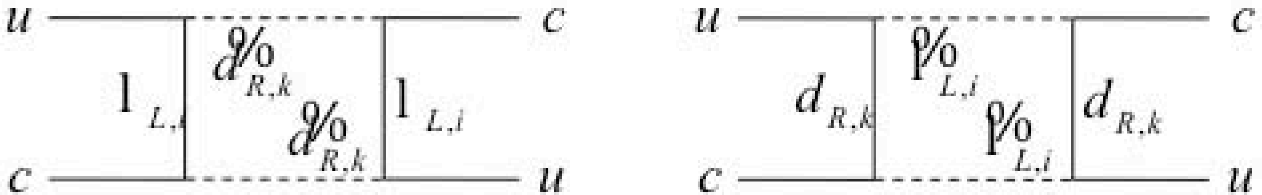
- **More observables**
  - *CP* violation in $B\to K^{(*)}\ell^+\ell^-$
  - Lepton universality between $B\to K^{(*)}e^+e^-$ and $B\to K^{(*)}\mu^+\mu^-$

Prospect of D^0-$\bar{D}^0$ Mixing

- **NP contribution**

E. Golowich *et al.*, Phys. Rev. D **76** 095009 (2007).

  - R-parity-violating SUSY particles in box diagrams enhance the mixing parameter x_D. The R-parity-violating coupling constant can be determined by a precise measurement of x_D and SUSY particle masses ($m_{\tilde{d}}$, $m_{\tilde{\ell}}$).



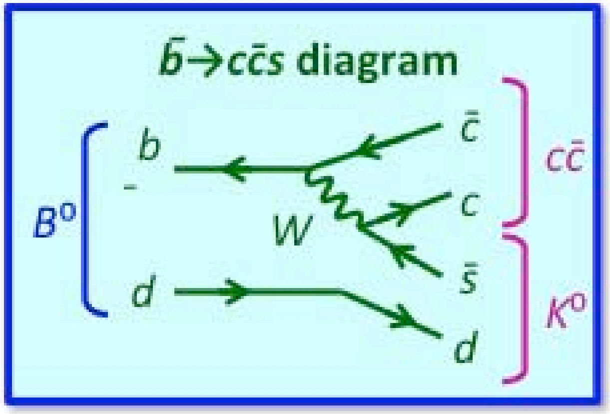
Prospect	$\delta(x_D)$ ~ 0.1% @ 50ab^{-1}

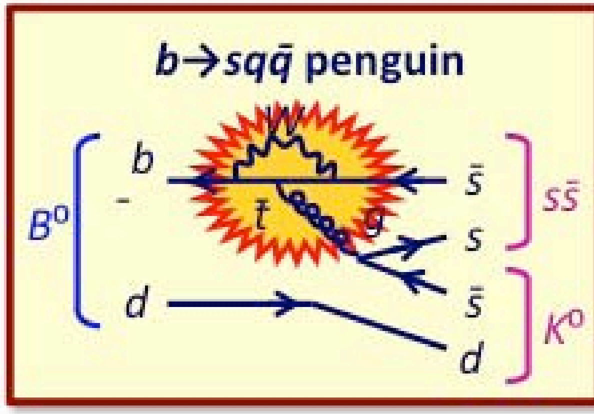
- **Measurement of the mixing-induced *CP* violation in the neutral *D* meson system becomes possible.**

3. New Physics Search by Super *B*-Factory

3.3 More Physics Cases

CP Violation in $b\to s q\bar{q}$





$$\sin 2\phi_1^{sq\bar{q}}{}_{\rm W.A} = +0.64 \pm 0.04$$

$$\sin 2\phi_1^{c\bar{c}s}{}_{\rm W.A} = +0.678 \pm 0.020$$

0.8σ deviation

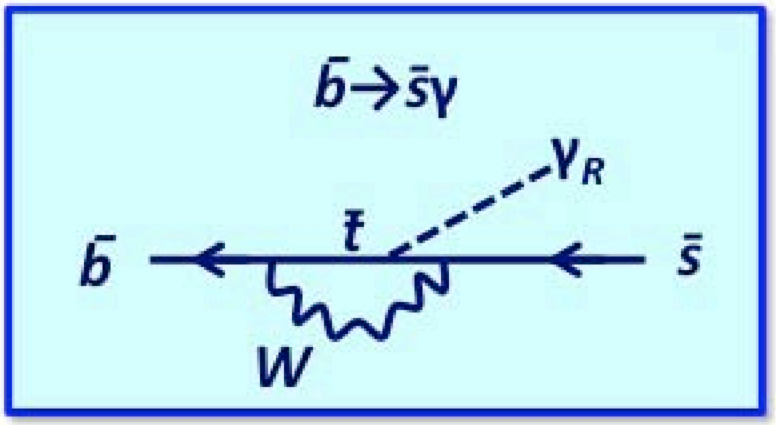
Measurement of the *CP*-violating parameter in $b\to sq\bar{q}$ is not expected to be systematic dominant until 50ab^{-1} data with elaborated tunings of vertex detectors.

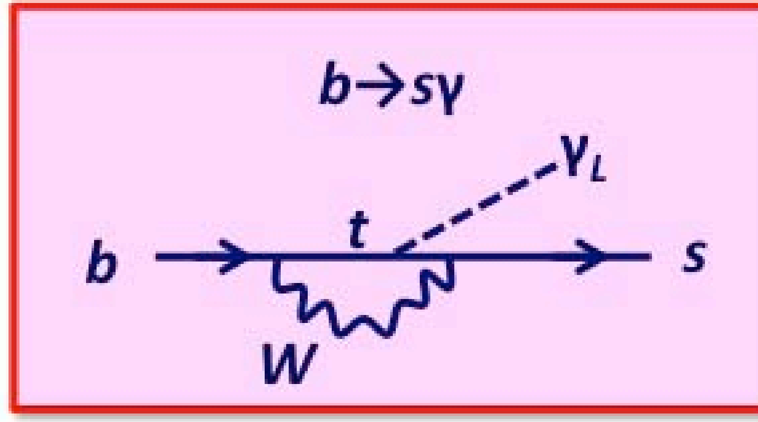
We may find a NP effect in the $b\to sq\bar{q}$ with 50ab^{-1} data assuming the present discrepancy holds.

Prospect $\delta(S_{b\to s}) \sim 0.012$ @ 50ab^{-1}

Super-precise determination of *B*-decay vertices with SVD and PXD is a very crucial issue in Belle II.

CP Violation in $B^0 \to K^0_S \pi^0 \gamma$ ($b \to s\gamma$)





$\bar{b} \to \bar{s}\gamma_R$
photon helicity is right-handed

$b \to s\gamma_L$
photon helicity is left-handed

As a consequence, $B^0 \to K^0_S \pi^0 \gamma$ behaves like an effective flavor eigenstate, and mixing-induced *CP* violation is expected to be small:

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

Analysis procedure is similar to that of $B^0 \to (c\bar{c})K^0$.

CP Violation in $B^0 \to K^0_S \pi^0 \gamma$ ($b \to s\gamma$)

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

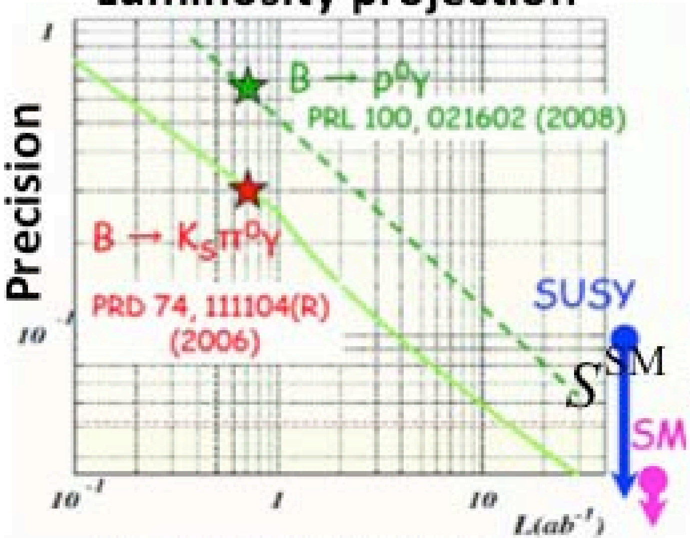
Average by Heavy Flavor Averaging Group (2009 winter).

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

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

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

Luminosity projection



Integrated luminosity

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

$S^{\rm SM} \cong$

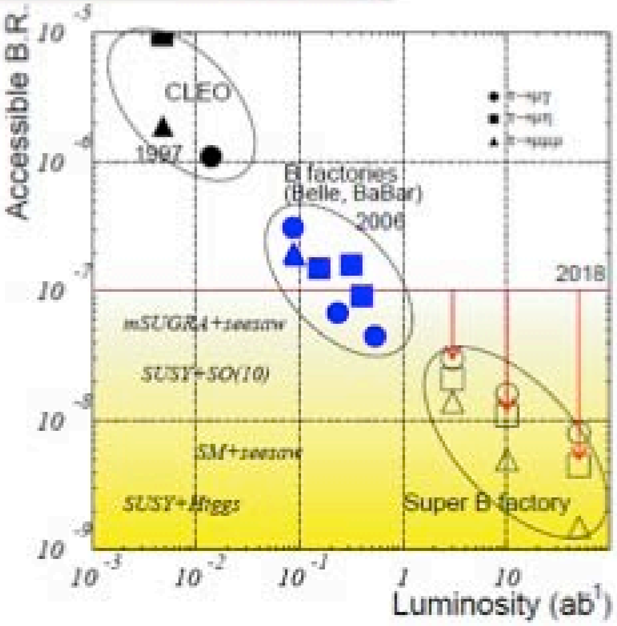
SVD and PXD will play again an important role in this analysis.

Lepton Flavor Violation

- ***B*-factory = τ-factory**
  - A NP may enhance the forbidden lepton-flavor violating decay within the SM to a feasible level by Belle II.

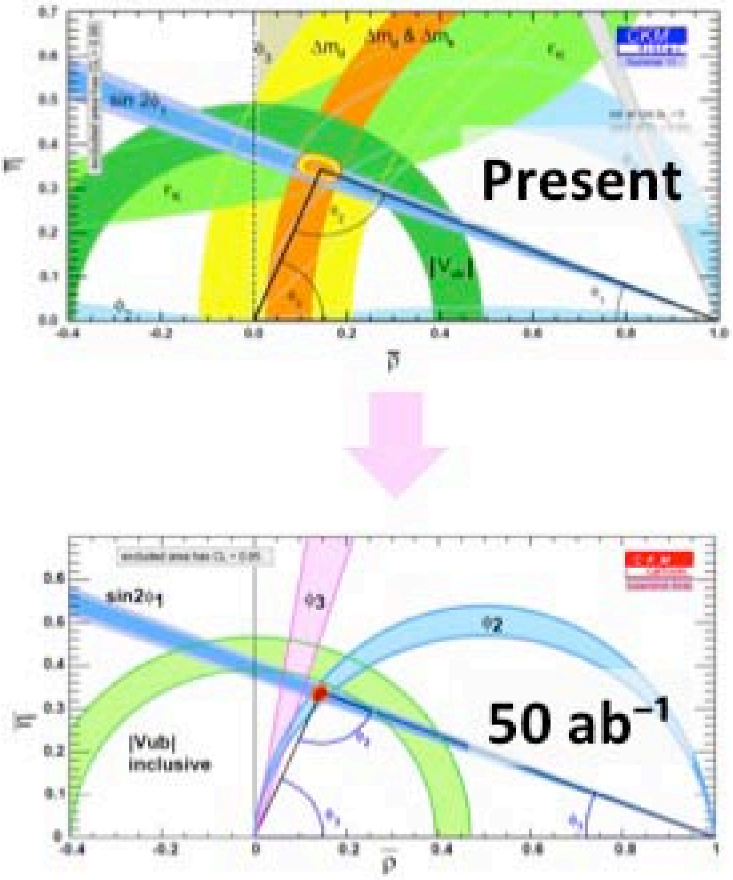
SM prediction	Possible NP enhancement
$Br(\tau^- \to \mu^- \gamma) \sim O(10^{-40})$	$Br(\tau^- \to \mu^- \gamma) \sim O(10^{-8})$[?]

Prospect	$Br(\tau^- \to \mu^- \gamma) < 7\times10^{-9}$ @ $50b^{-1}$ $Br(\tau^- \to \mu^- e^+ e^-) < 10^{-9}$ @ $50ab^{-1}$



Kobayashi-Maskawa Unitarity

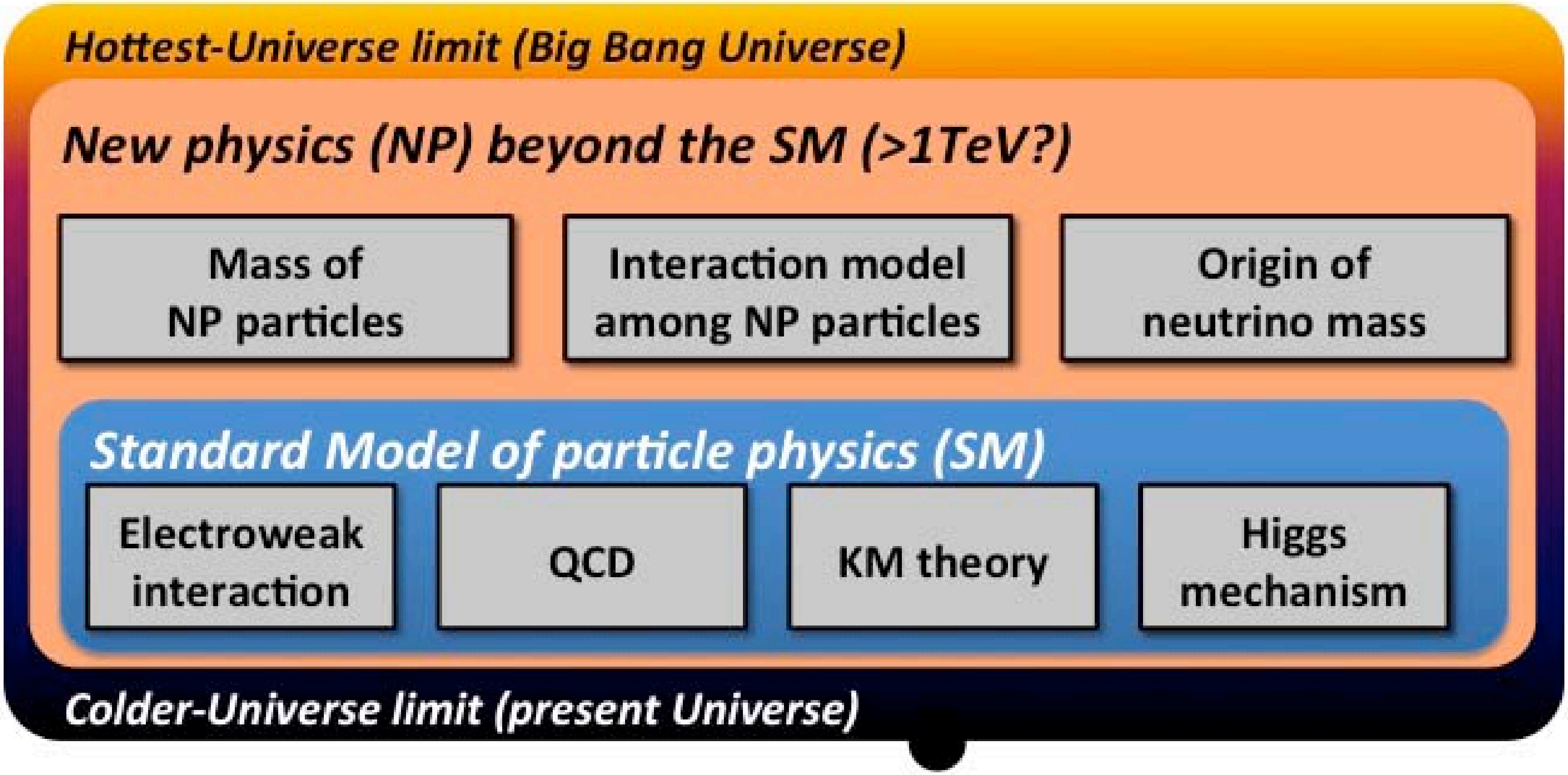
- **Precise test of the Kobayashi-Maskawa unitarity**



Combination of precise measurements on angles and sides of the unitarity triangle will test the unitarity of the Kobayashi-Maskawa matrix.

If the unitarity is violated, **50ab^{-1}** data will reveal the violation, assuming the present values of the angles and sides.

What Are Physicists Pursuing?



In the next decade, we will significantly extend our knowledge on the Law governing the Universe.

3. New Physics Search by Super *B*-Factory

3.4 Experimental Apparatus – General Issues

Super *B*-Factory = Luminosity Frontier

- **As a NP signature (deviation from the SM prediction) is expected to be so faint at $\sqrt{s}$=11GeV that we need enormous number of collision data.**

KEKB → SuperKEKB

x40 luminosity
$L = 8.0 \times 10^{35} cm^{-2}s^{-1}$

BELLE → Belle II

Larger solid-angle coverage
More granular resolution
Faster signal output
Lower noise level

SuperKEKB Accelerator in a Nutshell

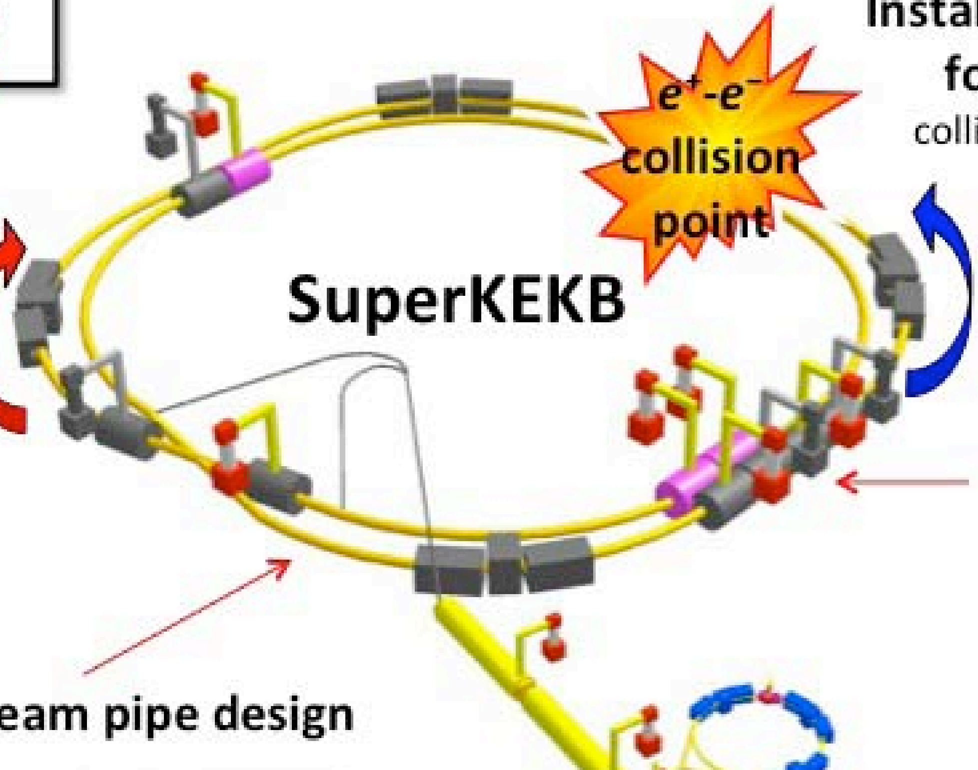
$L = 80 \times 10^{34}$/cm^{2}s

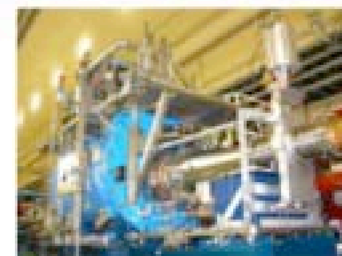
Installation of new final focusing magnet

collision point resolution = 3mm

7.0GeV e^-

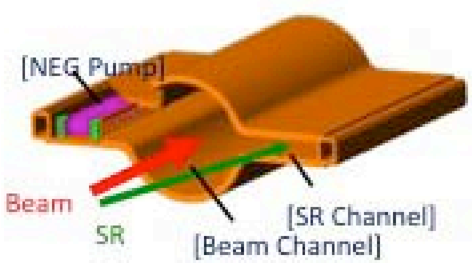
4.0GeV e^+

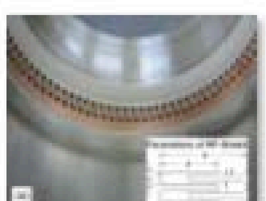




More RF cavities

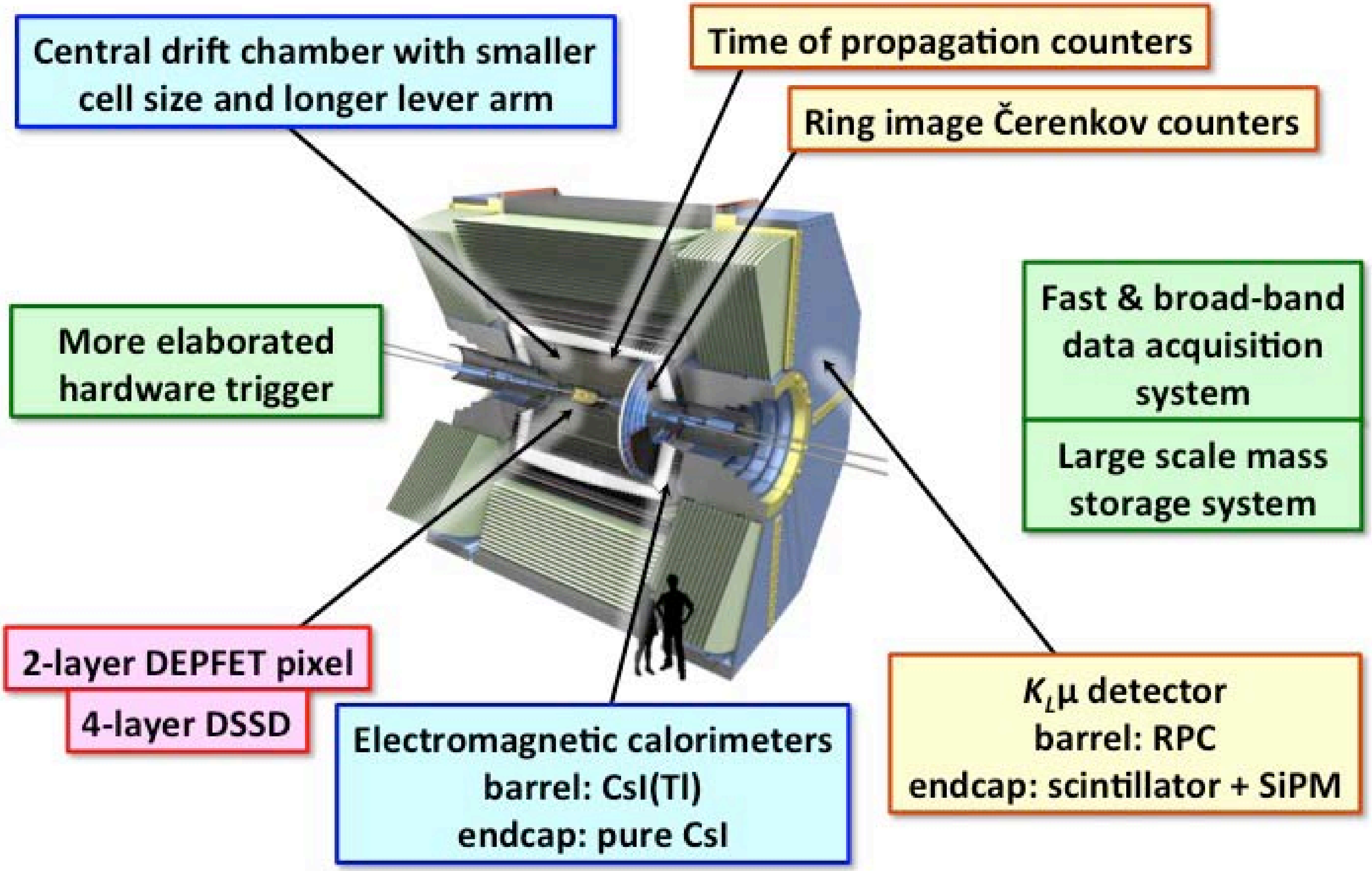
Improvements in beam pipe design





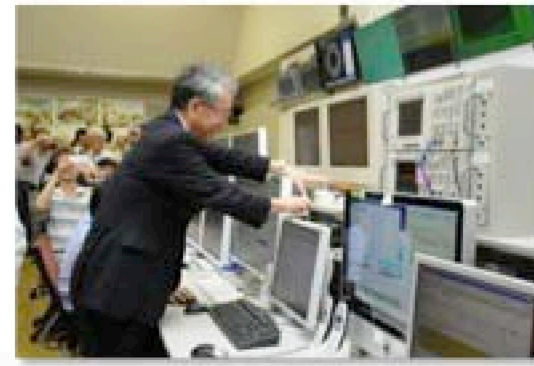
Construction of damping ring for low emittance e^+ beam

Belle II Detector in a Nutshell



Break toward SuperKEKB/Belle II

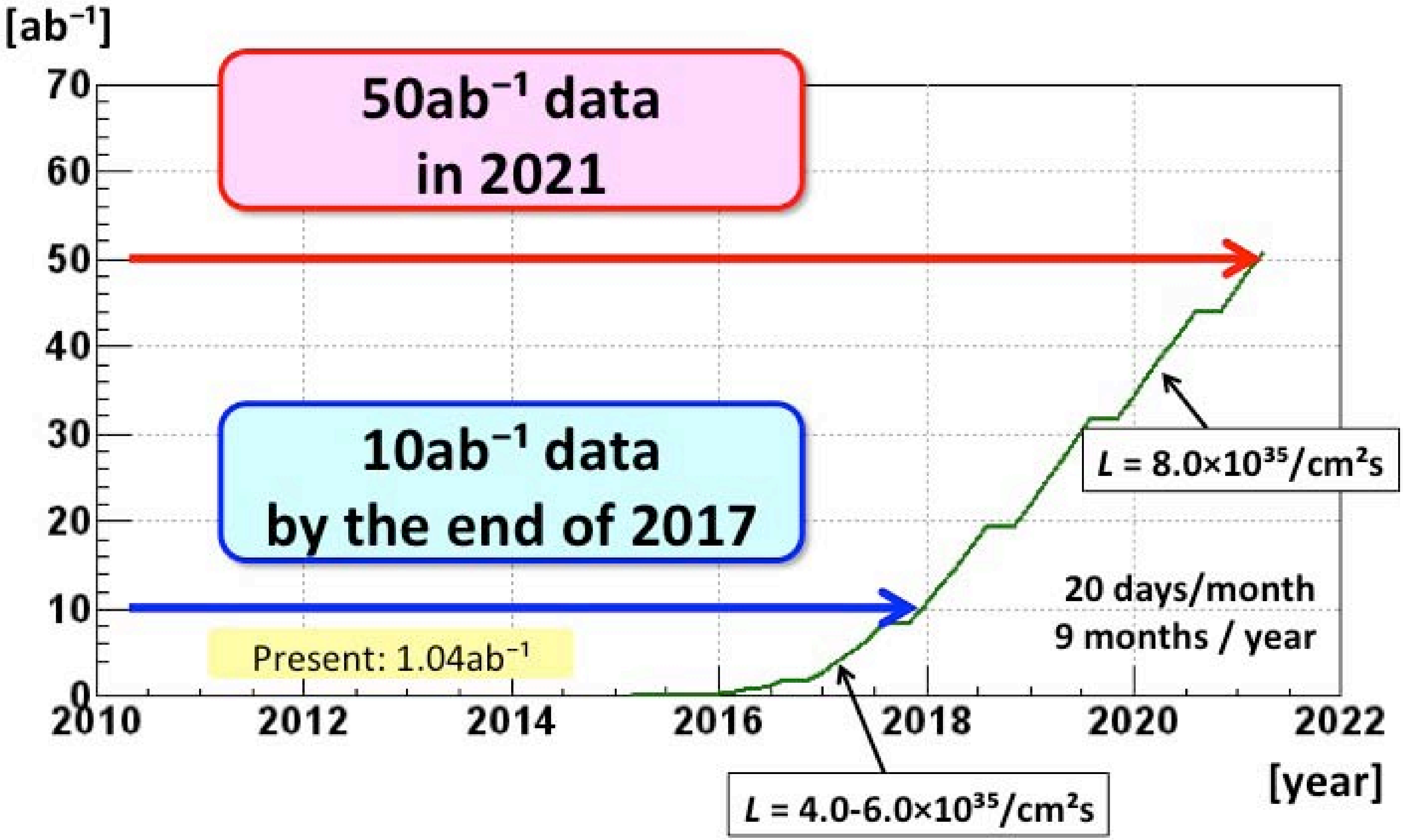
- **End-run ceremony (Jun.30th,2010)**
  - A. Suzuki, the director general of KEK stopped the KEKB operation at 9am.



- **End-run snapshot in KEKB control room**

I'm here

Integrated Luminosity Prospect



3. New Physics Search by Super *B*-Factory

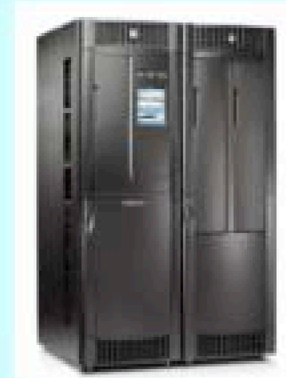
3.4 Experimental Apparatus – DAQ

What is DAQ?

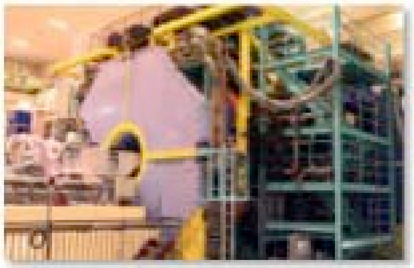
DAQ = Data AcQuisition (System)

DAQ coverage

Mass storage system



Belle/Belle II detector



Analog raw data

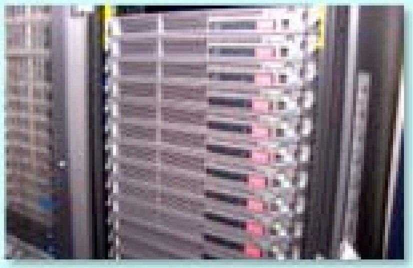
Convert analog data to digital

Write down

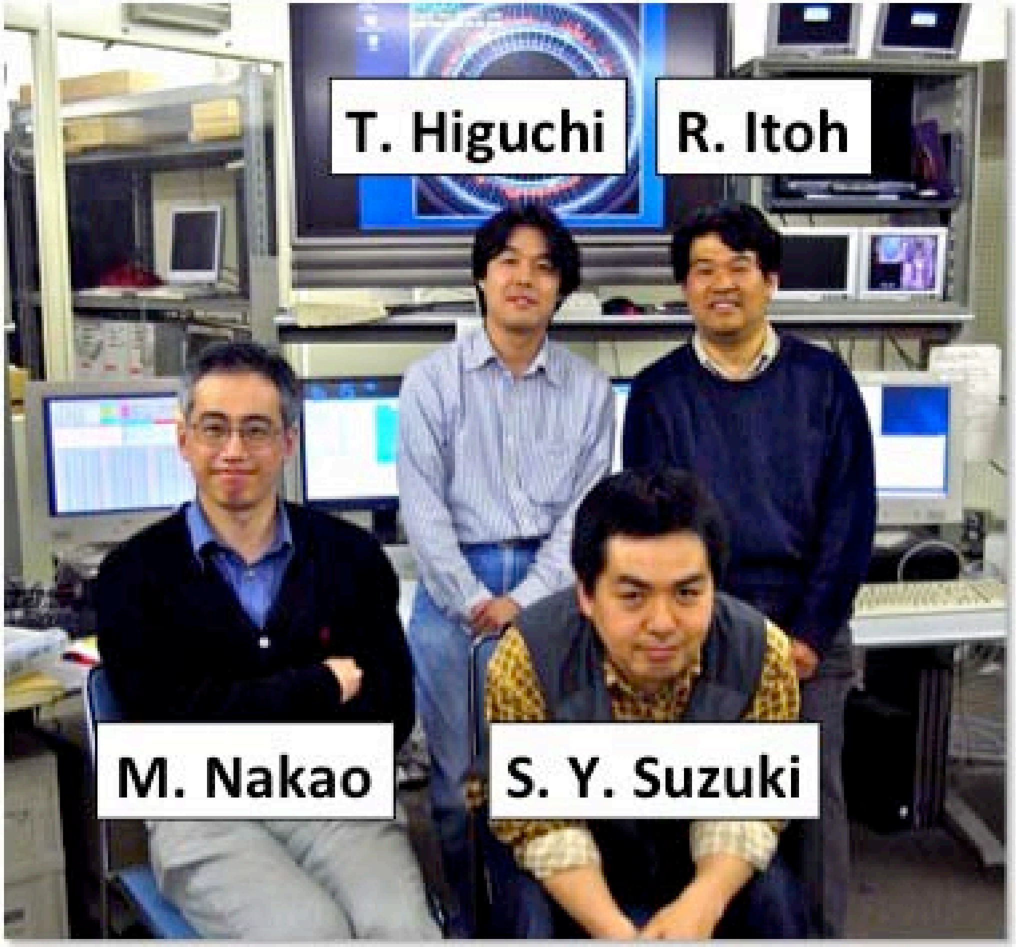
Digitized data

Readout

Readout computers



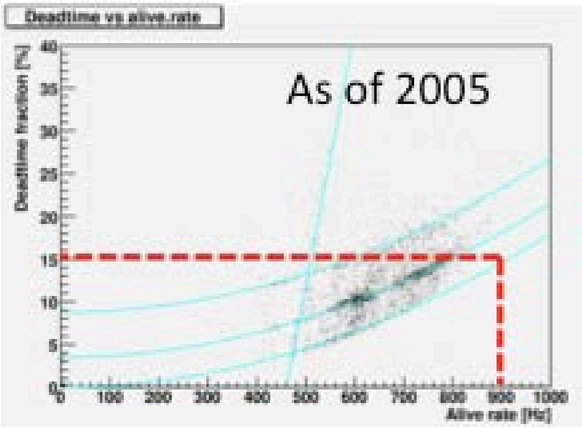
Belle/Belle II DAQ Team (KEK)



R&D of Belle II DAQ

	KEKB/Belle ($L = 2.1 \times 10^{34}/\mathrm{cm}^2\mathrm{s}$)	SuperKEKB/Belle II ($L = 80 \times 10^{34}/\mathrm{cm}^2\mathrm{s}$)
Physics rate	140 Hz	8 kHz
Average event rate including BG	500 Hz	30 kHz ?
Data size per event	40 kB	1MB + 80kB

- **Limit in the Belle DAQ design**
  - In general, a DAQ system has an intrinsic "dead time", in which the system cannot respond to a trigger.
  - In case of the Belle DAQ, >15% data will be lost by the dead time if >900Hz event rate.



New DAQ that can handle 30kHz event rate is needed.

R&D of Belle II DAQ

New DAQ that can handle 30kHz event rate is needed.

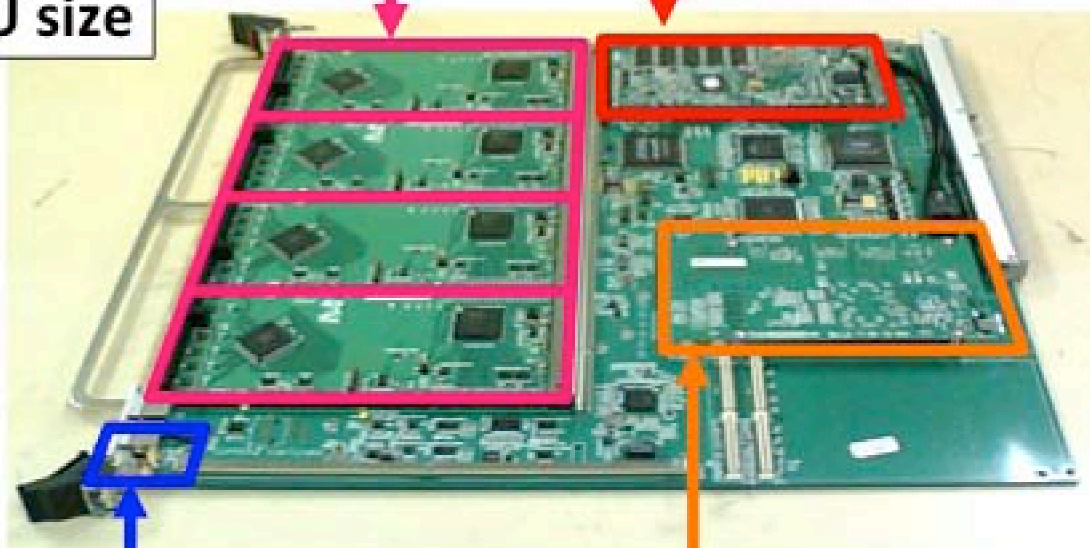
COPPER

COPPER = COmmon Pipelined Platform for Electronics Readout

x4 data receiver/DSP
add-on cards of the COPPER module.

Online CPU

VME-9U size



Pipeline FIFO
4MB FIFO in total on the back side of the board.

x2 GbE port
one for the data transfer,
and the other for system control.

Timing distribution module

COPPER System Test in Belle

- After intensive checks on the COPPER board, we decided to evaluate COPPER performance using the running Belle DAQ system.

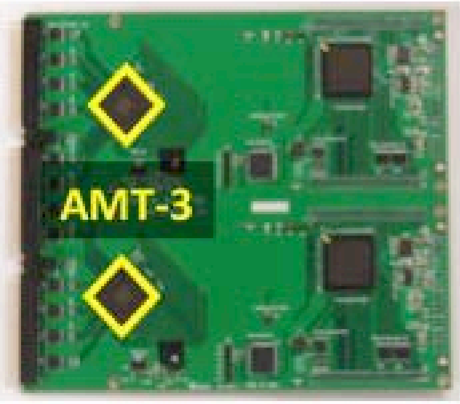
Special TDC Card for COPPER

- **Belle DAQ was based on TDC**

TDC = Time to Digital Converter

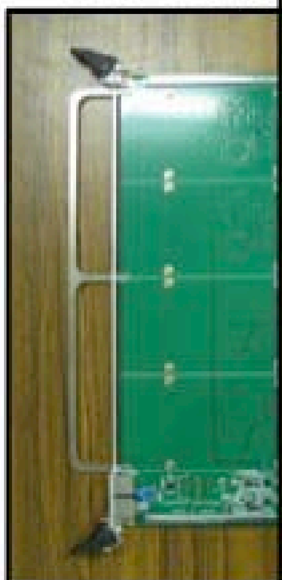
Analog signal (amount of charge) → [Q-to-T conversion] → Analog signal (length of time) → [TDC] → Digital signal (edge timings)

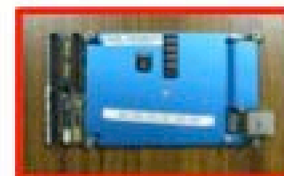
- **TDC card for COPPER**
  - To test the compatibility of the COPPER system with the Belle DAQ, we developed a special TDC card for the COPPER module. As a TDC chip, we adopted AMT-3, which has compatible performance with the Belle TDC.
  - The AMT-3 chip was originally for ATLAS, while we were the first user of the chip in the real operation; we had to perform several debugs…

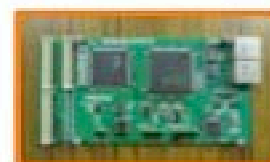


System Assembly

- COPPER
  - x2 AMT-3 TDC modules
  - COPPER m
  - g redistributor

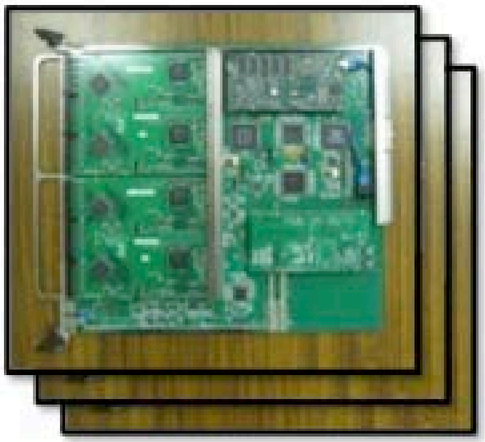




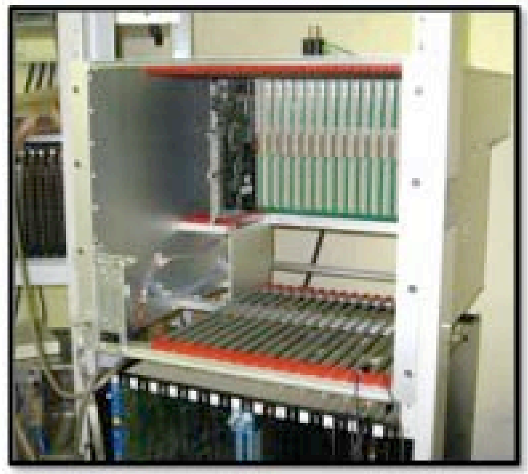


System Assembly

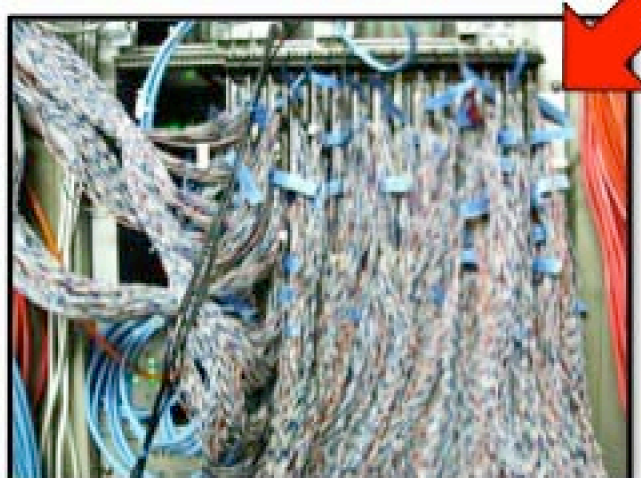
- **COPPER crate**



+



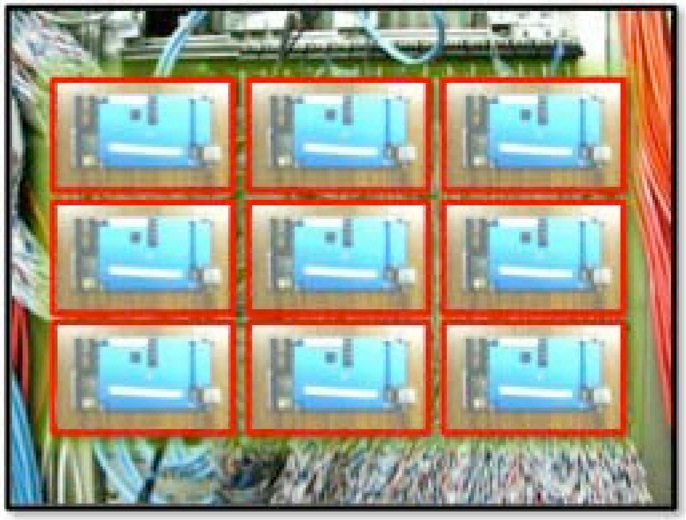
=



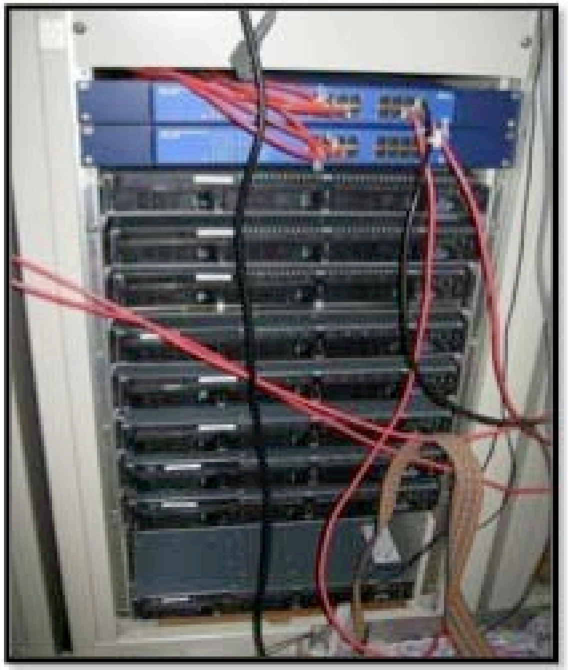
← **After cabling of input signals**

System Assembly

- Crate readout

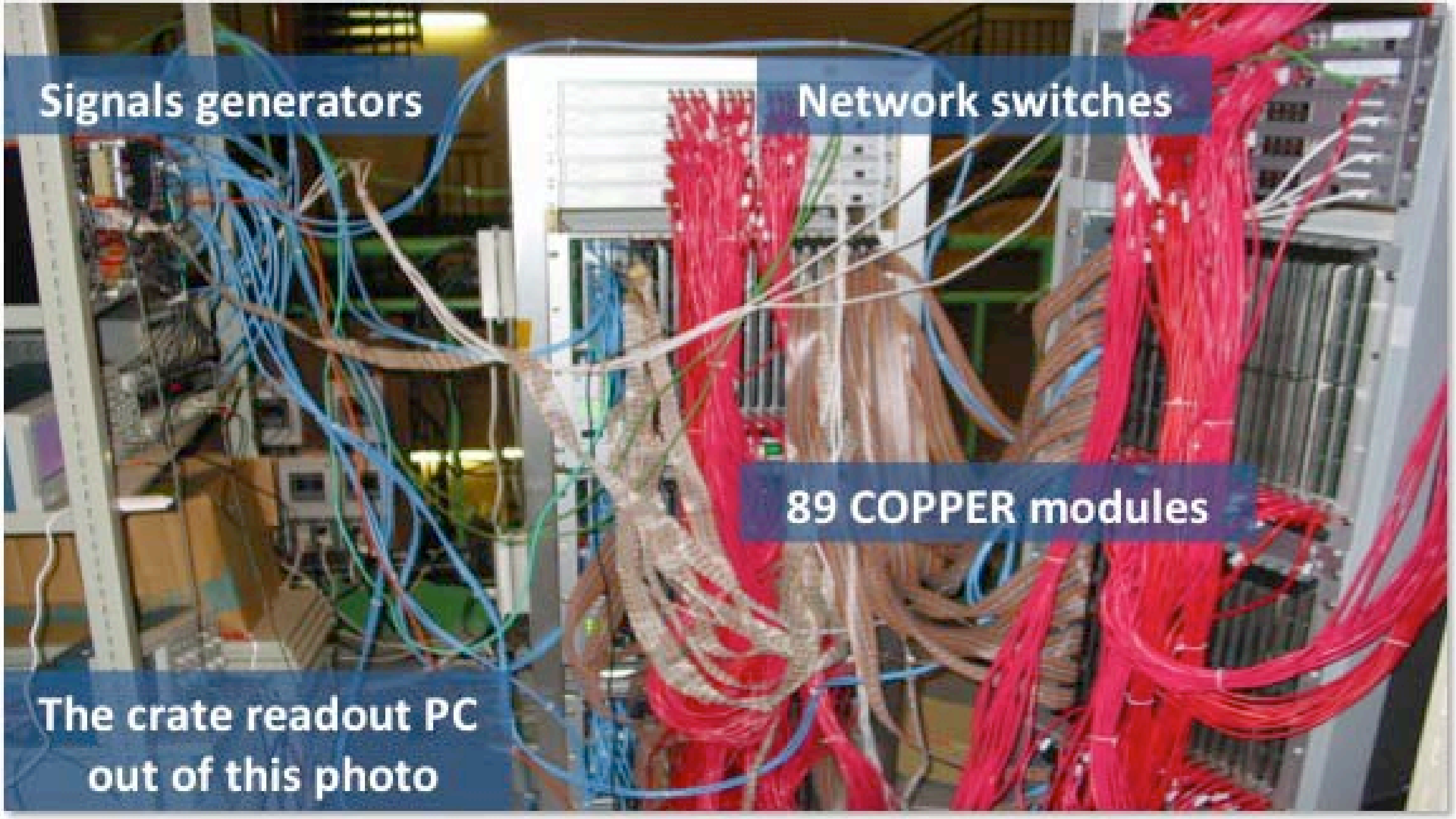


Readout data by the online CPUs are sent to crate readout PCs over a network.



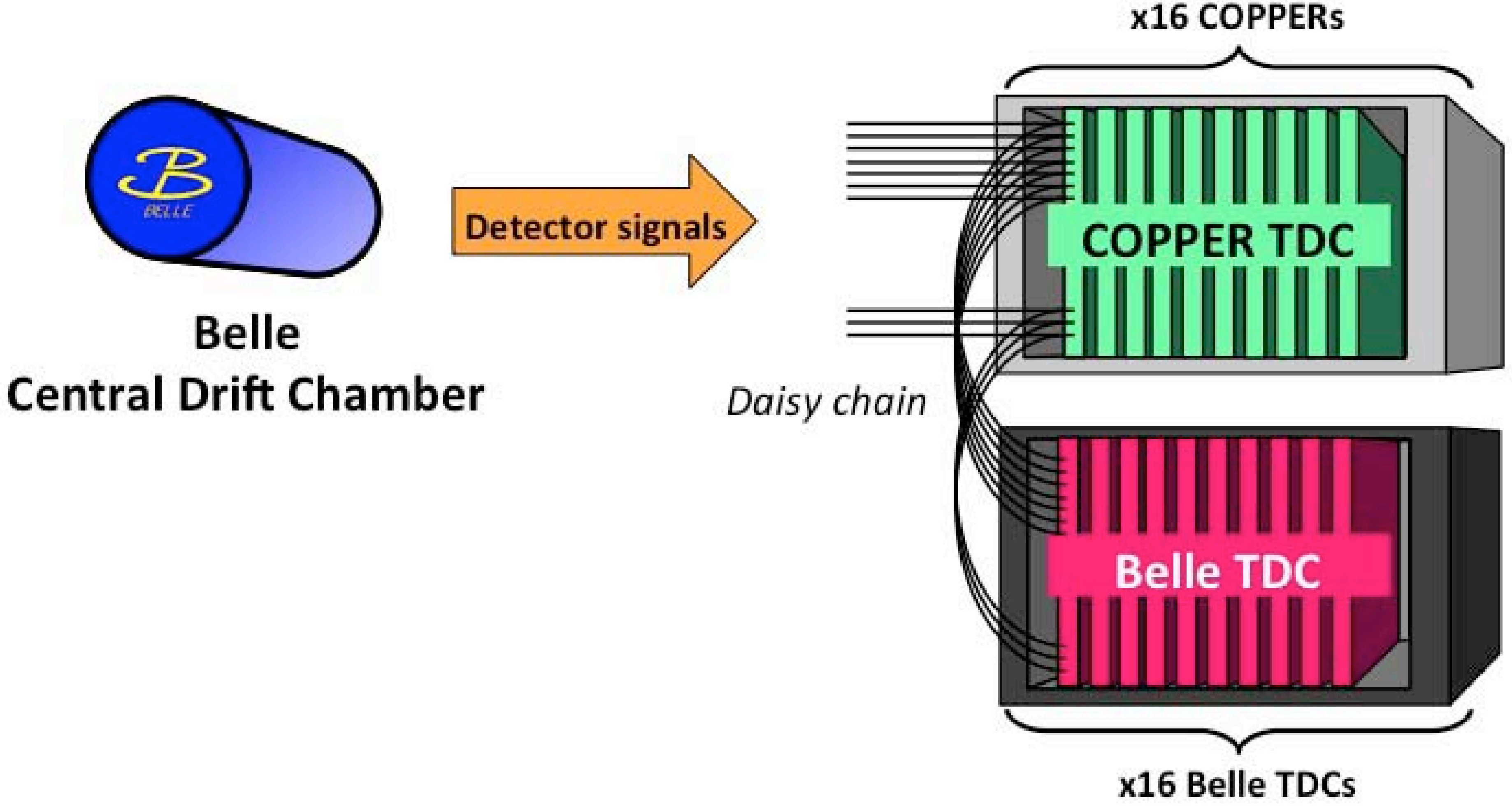
The PC is also responsible for housekeeping of the COPPER CPUs.

Full-Scale Pre-installation Test Bench



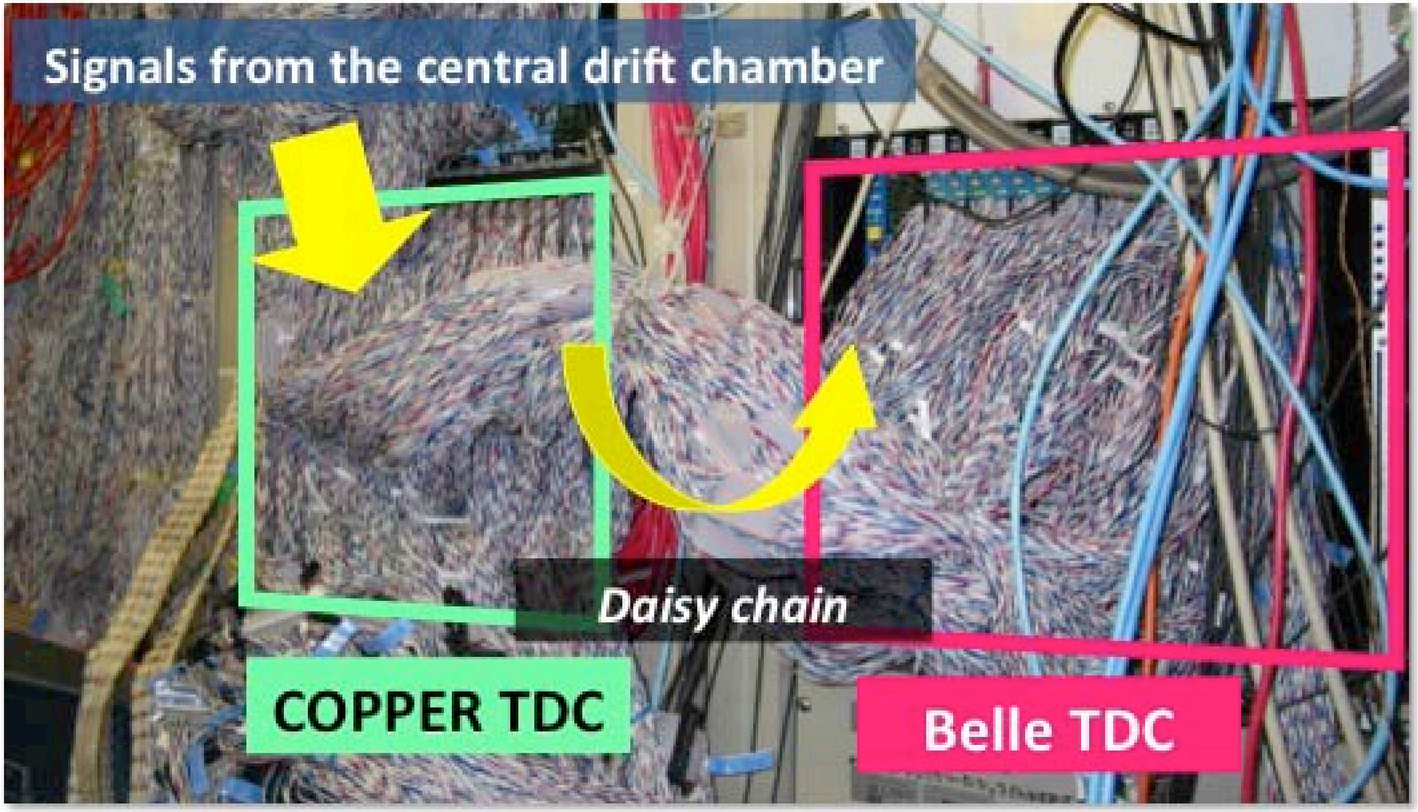
Compatibility Check

- Compatibility check: COPPER TDC ⇔ Belle TDC



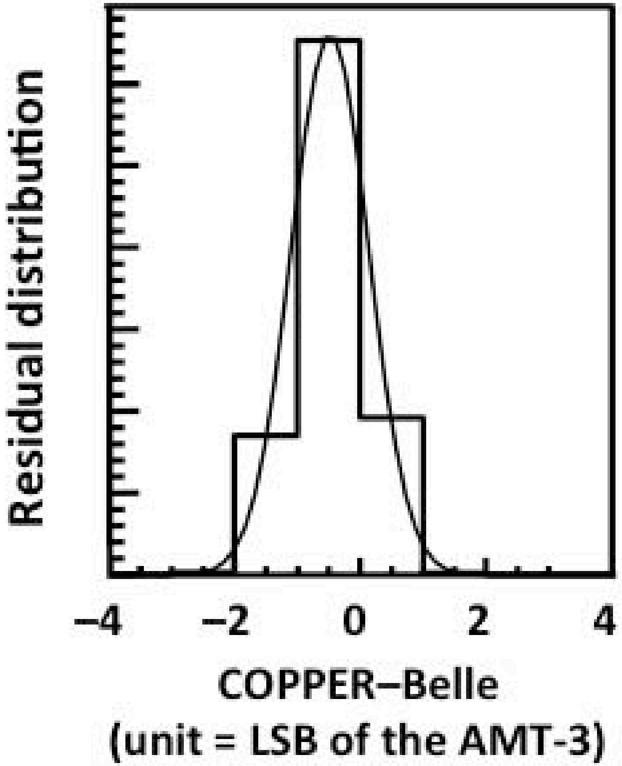
Compatibility Check

- Compatibility check: COPPER TDC ⇔ Belle TDC



Compatibility Check

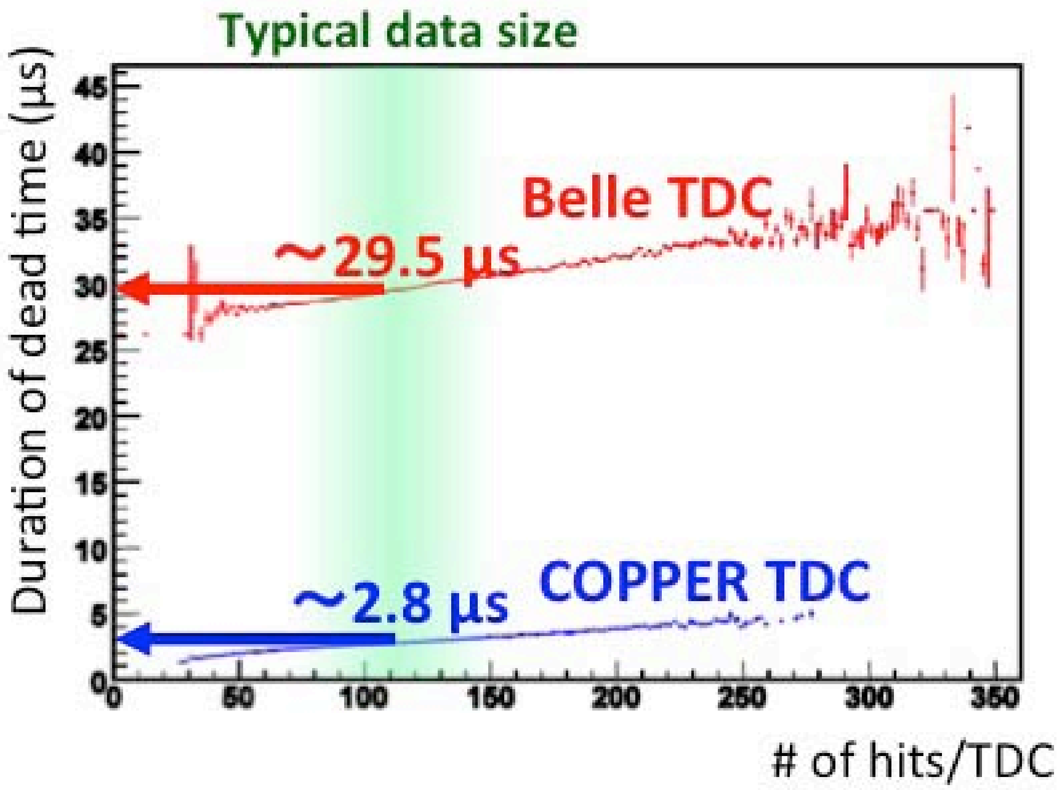
- Compatibility check: COPPER TDC ⇔ Belle TDC



Resolution (RMS)
= 0.61 LSB

Good compatibility was demonstrated.

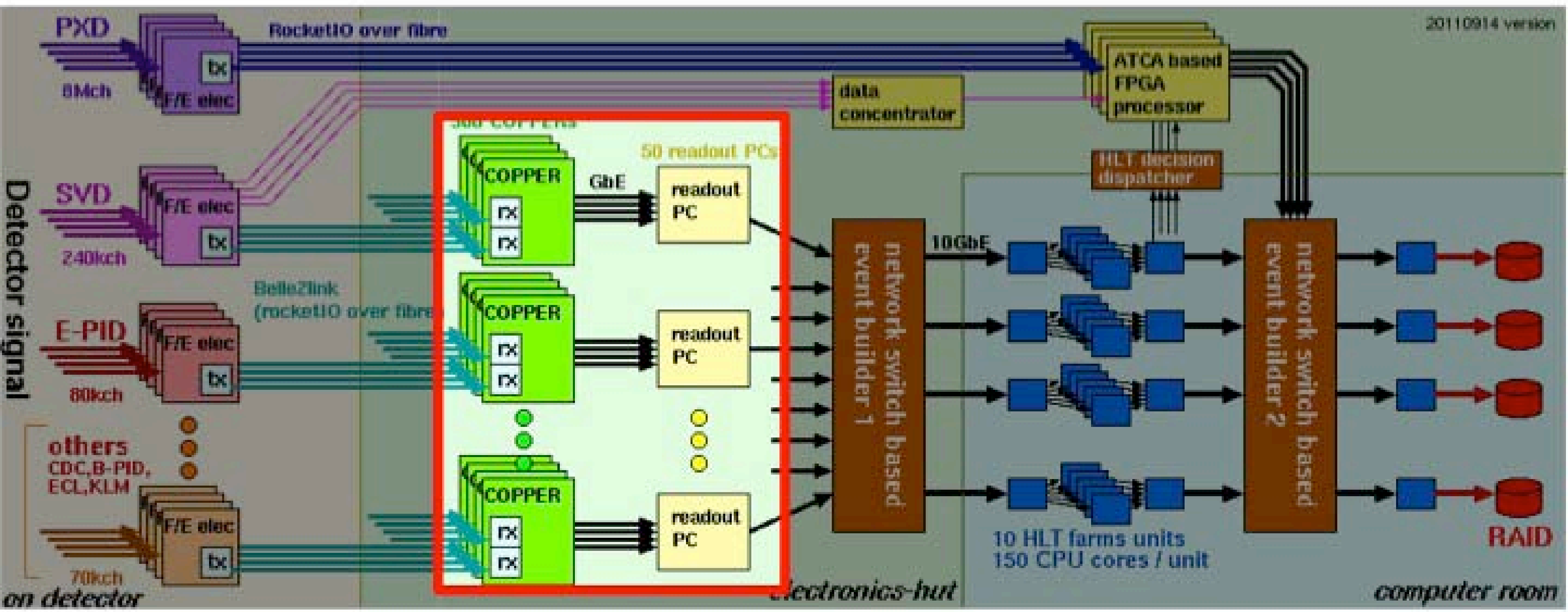
Dead-Time Improvement by COPPER



We successfully reduced the DAQ dead time by a factor 10 by the COPPER system.

Global Picture of Belle II DAQ

- Based on the success of the COPPER system, we decided to employ the COPPER system in Belle II.

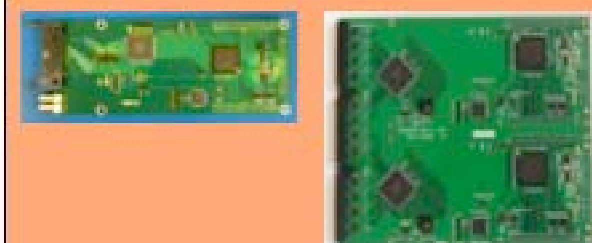


M. Nakao, T. Higuchi, R. Itoh, and S. Y. Suzuki, JINST **5**, C12004 (2010).

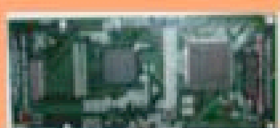
COPPER Add-on Card: FINESSE

FINESSE = **F**rontend **IN**strumentation for **S**ub-detector **S**pecific **E**lectronics

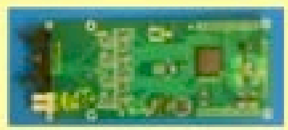
- **Variations of FINESSE cards**
  - COPPER usage is not limited to Belle II.
  - Several variations of FINESSE cards are provided to meet several boundary conditions of each (HEP) experiment.



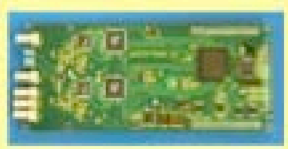
AMT-3 TDC FINESSE



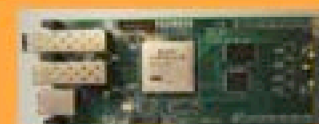
HPTDC FINESSE



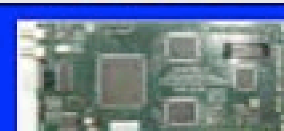
65 MHz 8ch FADC FINESSE



500 MHz 2ch FADC FINESSE

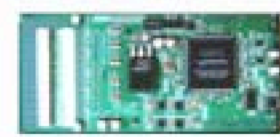


Optical link I/F FINESSE



USB I/F FINESSE

Digital signal receiver FINESSE



Dry run FINESSE

COPPER Systems in HEP Experiments

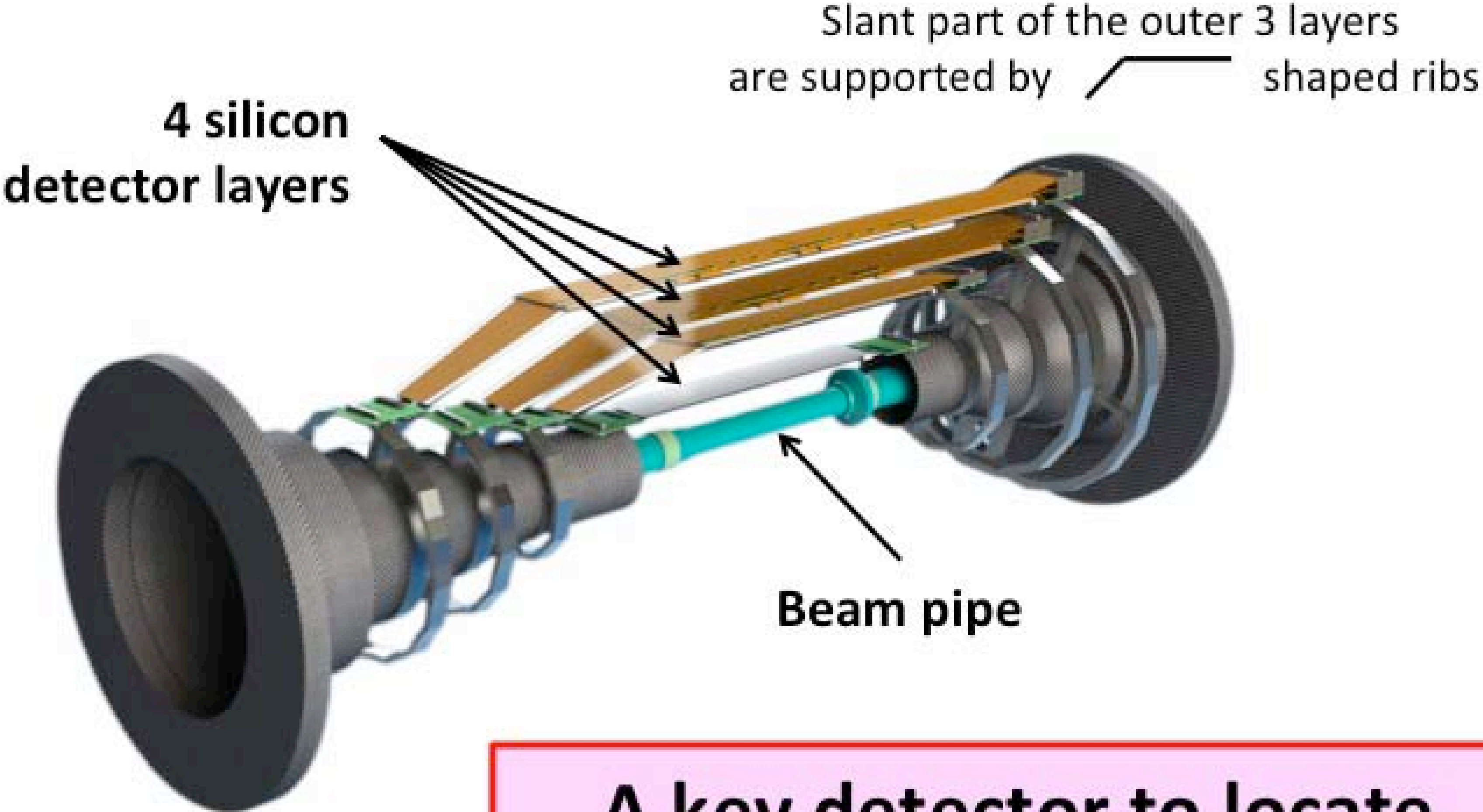
- **Belle**
  - **After we confirmed the COPPER's good performance, we replaced most of Belle TDCs with COPPER modules:**
    → 173 COPPER modules.
  - AMT-3 TDC FINESSE cards.
- **Belle II**
  - ~300 COPPER modules.
  - Optical link I/F FINESSE card.
- **T2K beam line monitor**
  - 49 COPPER modules.
  - 65MHz 12-bit ADC FINESSE cards.
- **J-PARC K1.8**
  - 12 COPPER modules.
  - MWPC encoder FINESSE cards.
- **J-PARC BL05**
  - 65MHz 12-bit ADC FINESSE card.
- **μSR**
  - FPGA TDC FINESSE card.

The COPPER system is now employed in many HEP experiments beyond Belle/Belle II.

3. New Physics Search by Super *B*-Factory

3.4 Experimental Apparatus – SVD

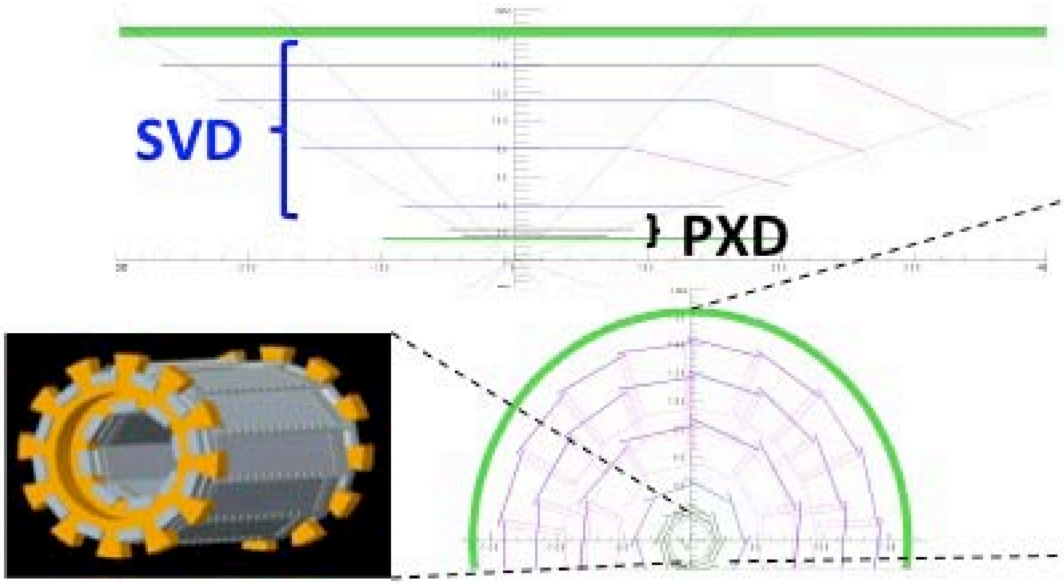
Belle II Silicon Vertex Detector



A key detector to locate
***B*-decay vertices (Δz,Δt)**

Belle II Vertex Detectors (SVD+PXD)

PXD = **P**i**X**el to **D**etctor



PXD

SVD

Self tracking performance in very fwd/bwd region @ 1GeV/*c*

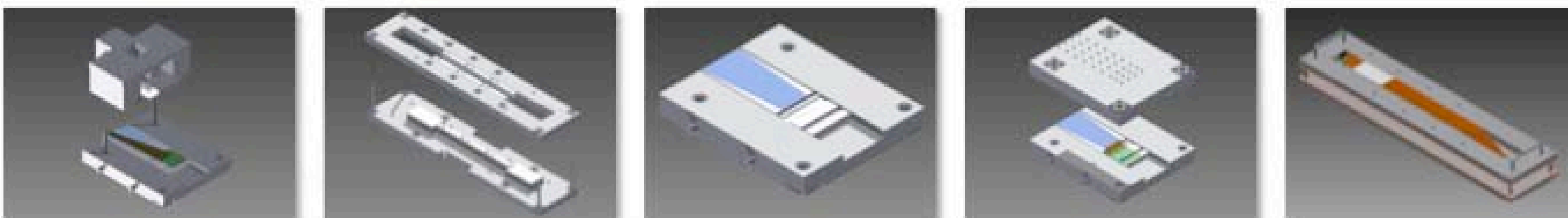
	PXD/SVD	PXD/SVD/CDC
FWD	69μm	54μm
BWD	38μm	30μm

B-meson reconstruction efficiency ↑ by acceptance ↑

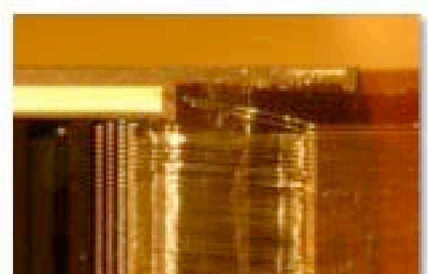
$$\mathrm{eff.}_B = 34.5\% \rightarrow 37.5\%$$

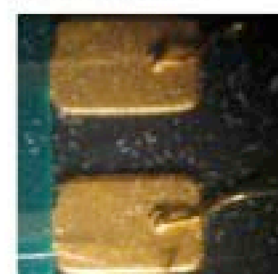
Key Missions [1]: Ladder Assembly

- **Immediate action items**
  - To achieve high assembly precision (~10μm), we are developing dedicated assembly jigs (some examples are shown below) and assembly procedure.

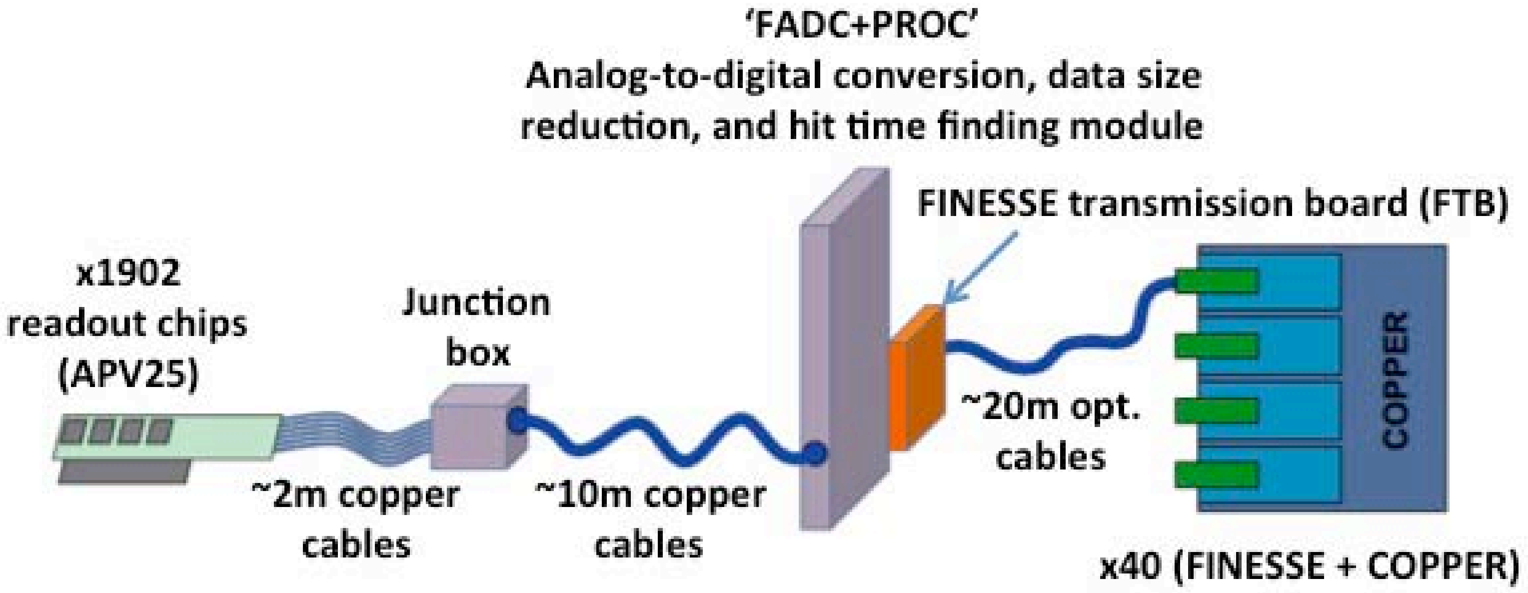


  - Connections between sensors and readout chips *etc* are made by 'wire bonds'; we need to be well skilled in the wire bonding technique.





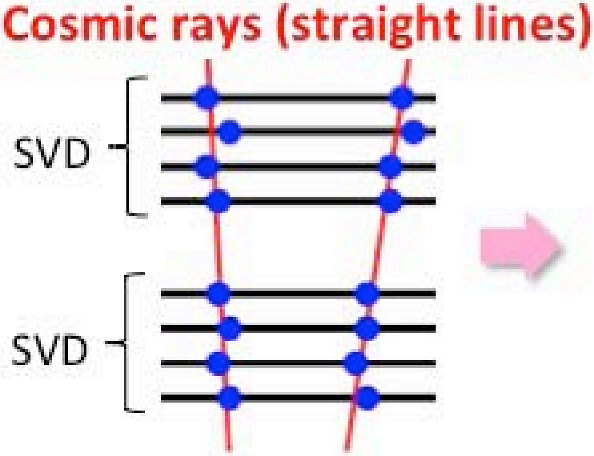
Key Missions [2]: Readout Electronics



- **Immediate action items**
  - Finalization of FADC and FTB designs.
  - Establishment of data flow especially from the FADC +PROC to the FINESSE/COPPER system including online-software development to run on the COPPER CPUs.
  - Development of system control and monitoring software.

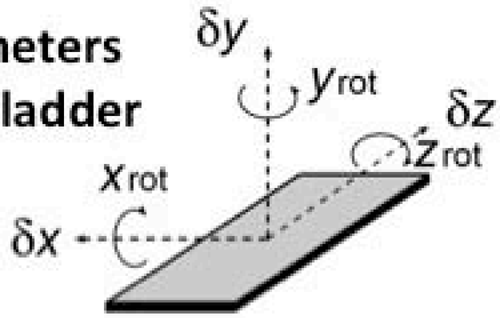
Key Missions [3]: Software

- **Immediate action item**
  - Software to quantify misalignment of SVD-ladders.
  - Alignment procedure:



Find out the set of misalignment parameters that minimizes the residuals.

6 parameters for each ladder

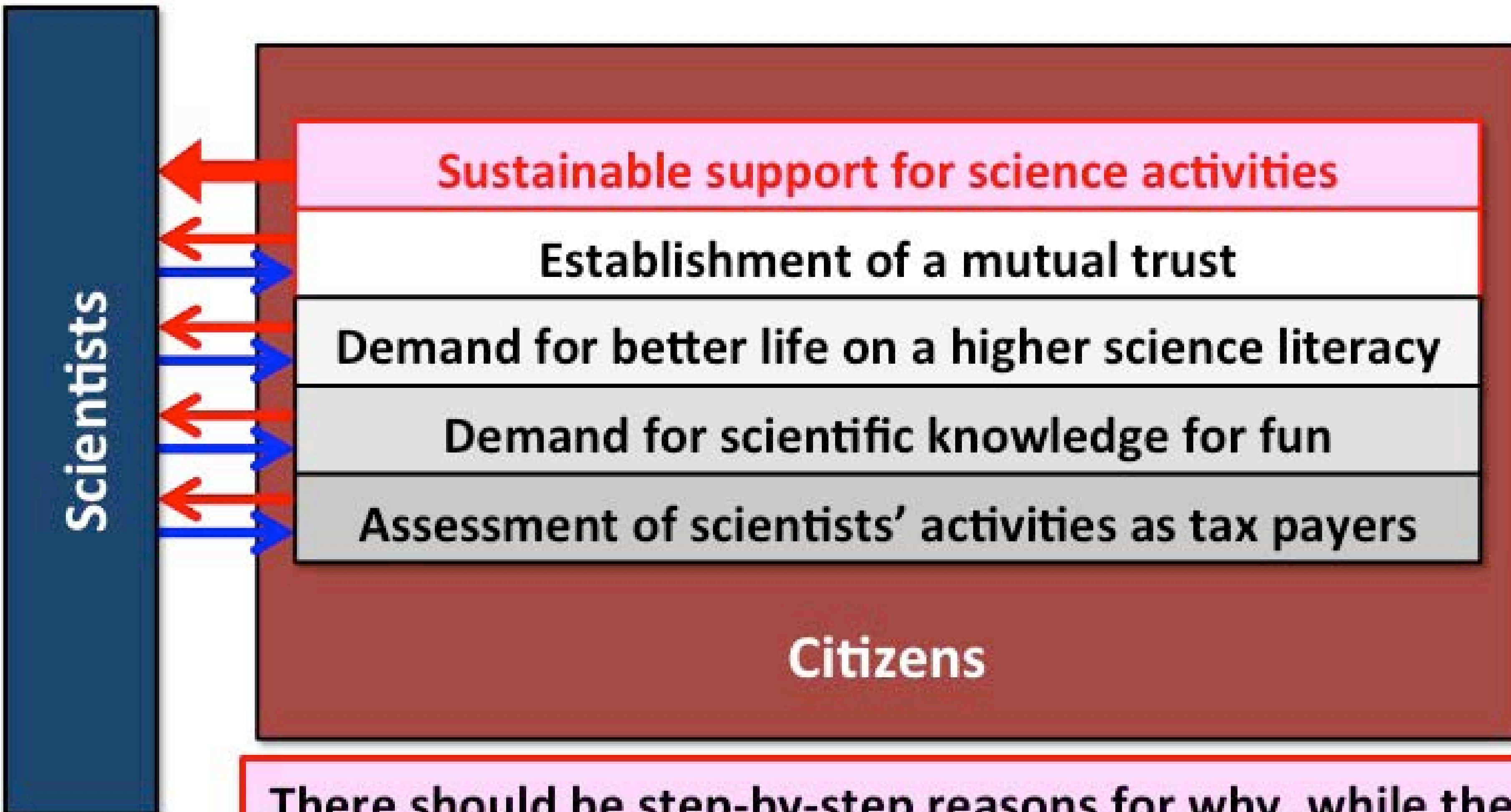


+

6 parameters for PXD-SVD-CDC global alignment

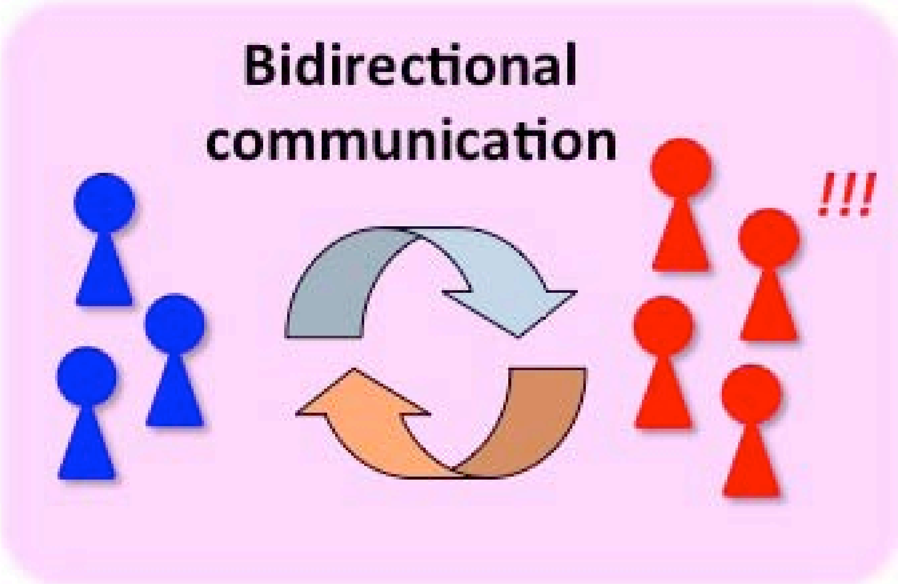
4. Communications with Citizens

Why Communications with Citizens?



There should be step-by-step reasons for why, while the final goal is an establishment of a mutual trust and acquisition of a sustainable support for science activities.

Science Communication



**Bidirectional communication, so called science communication, between scientists and citizens under the same atmosphere is very effective to perform successful outreach programs.
We employ the science communication technique in most of our outreach programs.**

Belle Science School

We are keen to provide attractive programs for students.

- **Experience of the real science**
  - With ***the real Belle data*** and ***the real Belle detector***,
  - Under education by ***the real Belle researchers***,
  - Students can experience ***the real process of science***: experiment, study, presentation, and discussion.

S. U. Kataoka and T. Higuchi, J. Phys. Soc. Jpn. **65,7**, 364 (2010).

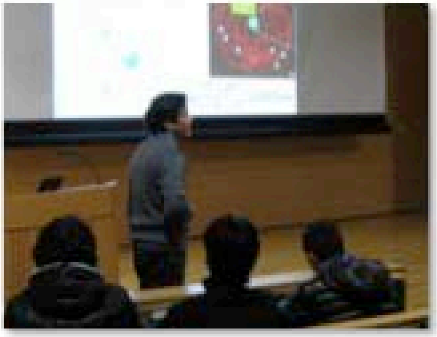
- **Belle Plus: science school for high-school students**

Venue	Dates	# of students
KEK	Dec.26th-Dec.28th, 2011	22
	Sep.20th-Sep.23rd, 2009	23
	Aug.10th-Aug.13th, 2008	24
	Aug.30th-Sep.2nd, 2007	23
	Sep.16th-Sep.19th, 2006	22

Free of charge.
Support for travel and lodging.

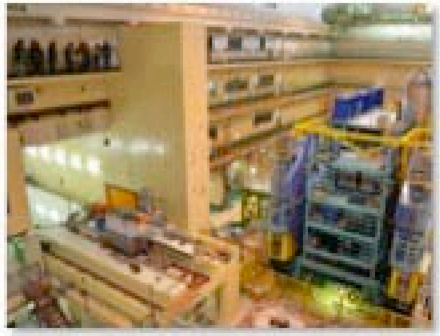
Belle Plus 2011 (Dec.26th-28th, 2011)

- Lecture by Prof. Haba (KEK)



- Party (with no beer, no wine)

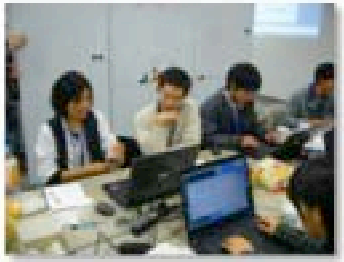
- KEKB/Belle visit



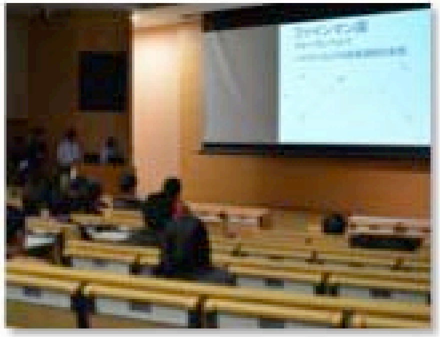
- Science café about radiological protection

Belle Plus 2011 (Dec.26th-28th, 2011)

- **The main work of the school**
  1. Particle search in the real Belle data
  2. Study on *B*-decay diagrams
  3. Study on wire chamber
  4. Study on cosmic ray with spark chamber




- **Discussions / presentations**

- **How did they like the school?**
  - "It was very good that I could make friends to talk on physics."
  - "I learned the particle physics is connected to the cosmology.
  - "I want to be a researcher."

Rating by students = 4.8/5.0

Many Other Programs …

Communication with
elementary-school pupils

Science café
on microscope and volvox

Talk show with
magician (T. Maeda) and
Prof. Murayama

Science café
on the Kobayashi-Maskawa
theory

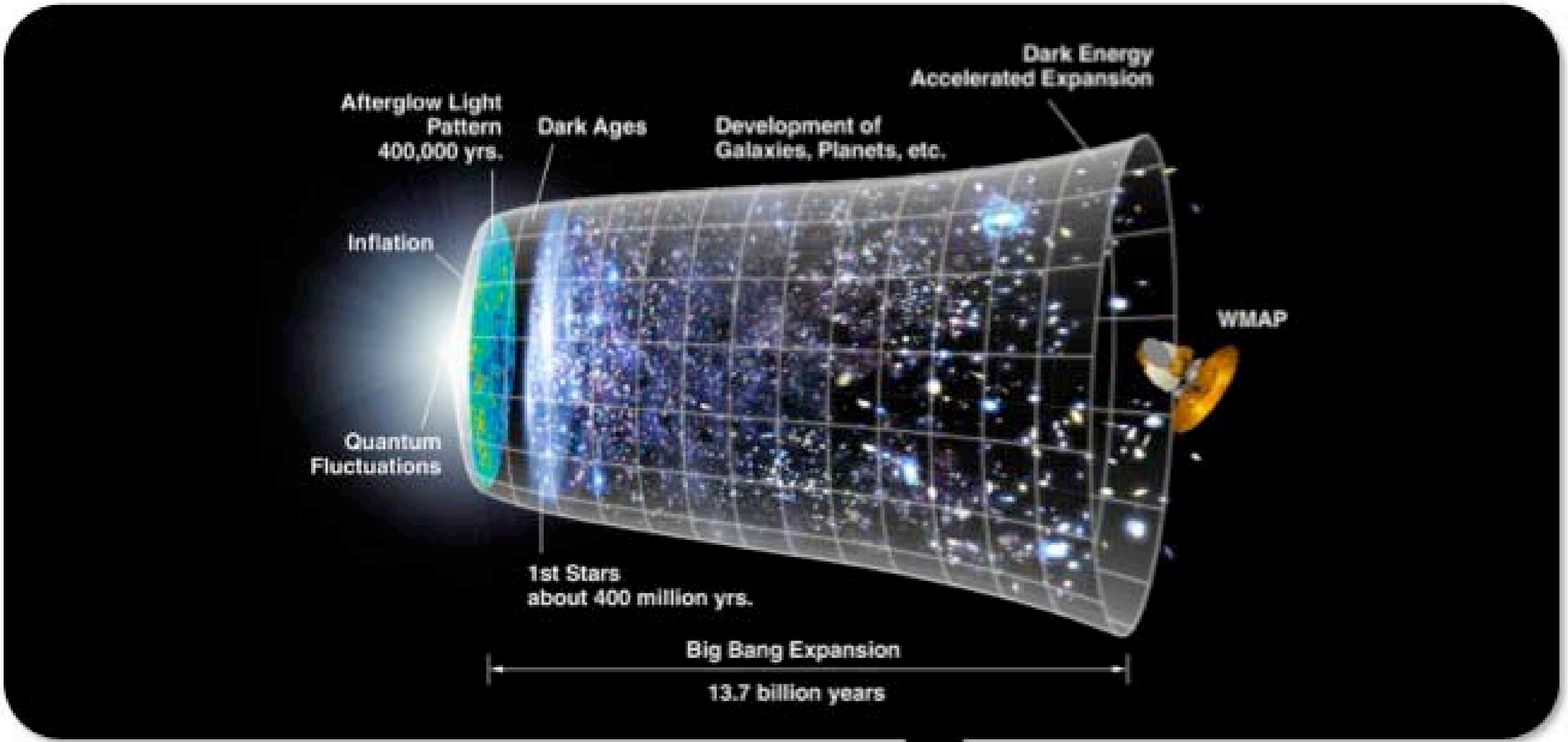
- **But I need more time to cover all…**

5. Summary

Summary

- The *B*-factory experiments have established the Kobayashi-Maskawa theory.
- Several phenomenological implications of a new physics beyond the Standard Model have been observed.
- To access to the new physics, we have been upgrading our *B*-factory to Super *B*-factory, and we will continue our effort.
- The nature of the new physics will be complementarily elucidated in the coming decade by Super *B*-factory/LHCb and ATLAS/CMS.

Summary


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

6. Backup Slides

After the KM Theory

KM theory
(1973)

A. I. Sanda and I. Bigi proposed an experiment to prove the KM theory
(1981)

TRISTAN experiment put large value for lower mass limit for the top quark

$$\Delta m_d \simeq 2\frac{m_t^2}{m_W^2}$$

ARGUS measured a large B^0-$\bar{B}^0$ mixing parameter (Δm_d)
(1987)

It eventually turned out that a test of the KM-theory with a *B*-factory is well feasible.

Establishment of "Belle"

Agenda of the 48th Belle General Meeting

December 8 (Mon)

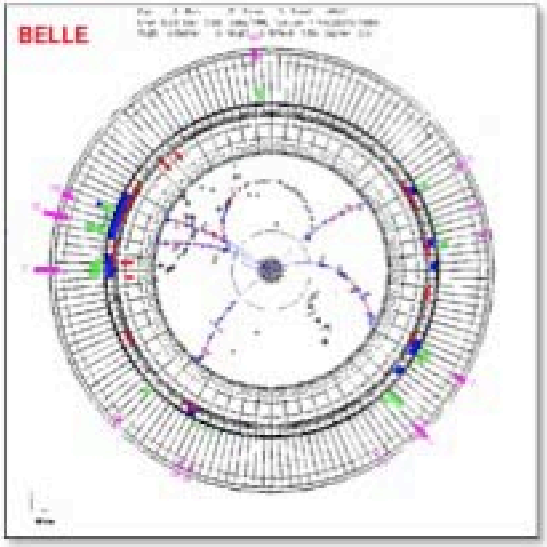
09:00 - 09:20	Belle detector status and operations [PPT]	S. Uno (KEK)
09:20 - 09:40	Belle luminosity measurements [PDF]	V. Zhilich (BINP)
09:40 - 10:00	KEKB, Crab Commissioning, Plans [PPT]	Y. Funakoshi (KEK)
	10:00 - 10:20 Coffee break	
10:20 - 10:40	Discussion (including 2S run plan, crabs)	
10:40 - 11:00	Obs of 5S->B Bbar pi pi [PDF]	A. Drutskoy (Cincinnati)
11:00 - 11:20	B_s ->J/psi eta [PDF]	J. Li (Hawaii)
11:20 - 11:40	Bs absolute BF's and f_s [PDF]	R. Louvot (Lausanne)
11:40 - 12:00	Other Upsilon(5S) activities [PDF]	A. Schwartz (Cincinnati)
	12:00 - 13:40 Lunch	
13:40 - 14:00	Computing/Reprocess/MC/GRID [PDF1][PDF2]	S. Nishida (KEK)
14:00 - 14:20	Belle radiation safety [PPT]	S. Uehara (KEK)
14:20 - 14:40	B->pi l nu untagged (cancelled)	H. Ha (Korea U)
14:40 - 15:00	B->D^(*)0 tau^+ nu [PPT]	M. Rozanska (Krakow)
KEK Seminars by BaBar collaborators		
15:00 - 16:00	Discovery of the eta_b	Peter Kim
16:00 - 17:00	R_b scan measurements near the 5S	Francesco Renga
	15:00 - 15:20 Coffee break	
15:20 - 15:40	Summary of other CKM [PDF]	C. Schwanda (Vienna)
15:40 - 16:00	Full B recon swan song [PDF]	J. Schuemann (IPMU/KEK)
16:00 - 16:20	New B recon [PDF]	T. Kuhr (Karlsruhe)
16:20 - 16:40	CPV in tau->K pi nu (strategy) [PDF]	M. Bischofberger (Nara)
19:00 - 20:00	Institutional Board meeting	L. Piilonen (VPI)
20:00 - 21:30	Executive Board meeting [PDF]	A. Bondar (BINP)/T.Browder (Hawaii)

December 9 (Tue)

09:00 - 09:20	B -> phi pi [PDF]	J.-H. Kim (Sungkyunkwan)
09:20 - 09:40	X(214) search [PPT]	H.-J. Hyun (Kyungpook)
09:40 - 10:00	B^0->K+K-KS time-dep. Dalitz [PDF]	Y. Nakahama (Tokyo)/K. Sumisawa (KEK)
	10:00 - 10:20 Coffee break	
10:20 - 10:40	B->D K, D->K_S K+K- dalitz [PDF]	M. Iwabuchi (Sokendai)
10:40 - 11:00	Other phi_3 summary [PDF]	K. Trabelsi (KEK)
11:00 - 11:20	Other ICPV summary [PPT1][PDF2]	T. Aushev (Lausanne)
11:20 - 11:40	Flavor tagging w/ Neurobayes [PDF]	T. Kuhr (Karlsruhe)
11:40 - 12:00	DCPV in B->J/psi K+ [PPT][PDF]	K. Sakai (Niigata)
	12:00 - 13:40 Lunch	
13:40 - 14:00	B->X_s l+ l- [PDF]	H. Nakayama (Tokyo)
14:00 - 14:20	B -> X_s eta [PDF]	K. Nishimura (Hawaii)
14:20 - 14:40	e+e- -> (ccbar)^2 [PDF]	J. Yoo (Korea)
14:40 - 15:00	X(3872)->psi gamma in B->X(3872)K [PDF]	V. Bhardwaj (Panjab)
	15:00 - 15:20 Coffee break	
15:20 - 15:40	e+e- ->D D^** pi via ISR [PPT]	G. Pakhlova (ITEP)
15:40 - 16:00	Charm summary [PPT]	J. Brodzicka (Cracow)
16:00 - 16:20	Upsilon(1S) status [PDF]	R. Mussa (Torino)
16:20 - 16:40	IB report [PPT1][PDF2]	L. Piilonen (VPI)
16:40 - 17:00	EB report [PPT]	A. Bondar (BINP)/T.Browder (Hawaii)
17:00 - 17:20	Winter conference wrap-up/closeout [PPT][PDF]	Y. Sakai (KEK) / P. Chang (NTU)

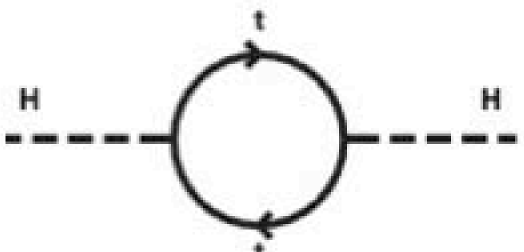
Start of Belle

- **1993** **Letter of intent**
- **1995** **Technical design report**
- **Dec., 1998** **Completion of detector construction**
- **Jan., 1999** **Cosmic ray data taking using Belle detector**
- **Feb., 1999** **First e^+e^- collision**
- **May, 1999** **Enroll Belle detector to collision point**
- **Jun. 4, 1999** **First physics event**



Why Do Expect NP in TeV Scale?

- **Hierarchy problem**
  - Standard-Model Higgs mass m_H is expected to have mass of $O(100\mathrm{GeV}/c^2)$, while because of a diagram shown below, the it will receive correction as $m_H^2 = (m_H^0)^2 + O(\Lambda^2)$ where Λ is a scale of new physics.



  - If no new physics until the Planck scale $O(10^{18}\mathrm{GeV}/c^2)$, Λ and consequently m_H will be ~ $O(10^{18}\mathrm{GeV}/c^2)$ as well.
  - We expect $O(100\mathrm{GeV}/c^2) < \Lambda < O(1\mathrm{TeV}/c^2)$
  - In SUSY words, the upper diagram is canceled by the lower one.

The “Big Two”

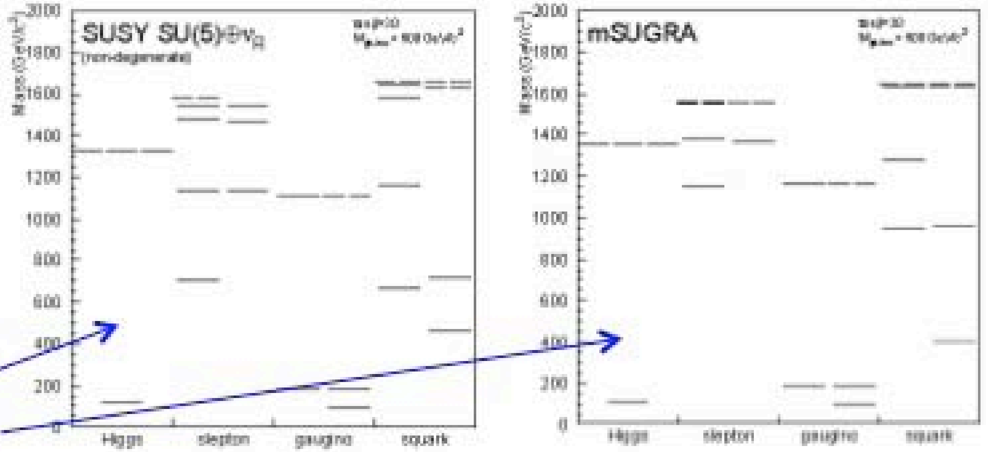
Energy frontier

Direct detection of SUSY particles

Mass spectra are insufficient to figure out the SUSY model.

SU(5)+vR (non-degenerate)

mSUGRA

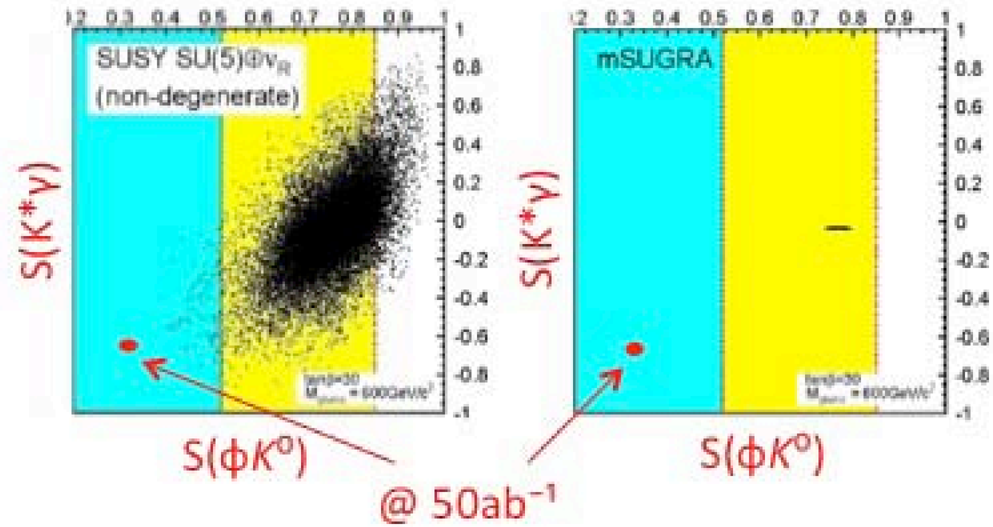


Similar mass spectra show up across different SUSY models.

Luminosity frontier

Measurements between SUSY-SUSY and/or SUSY-SM interactions

Various analyses on B,τ,charm etc. decays enable to reveal the SUSY model.



Complementarity to LHCb and Others

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\lvert V_{ub}\rvert$ $[B \to \pi \ell \nu]$	input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi\phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi\phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^*\gamma}$	few $\times$ 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi\gamma}$	few $\times$ 0.01	0.01	—	0.05	LHCb
A^d_{SL}	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
A^s_{SL}	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau\nu)$	1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$	4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$	3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$	1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{FB}(B \to K^*\mu^+\mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar\nu$	4×10^{-6}	$20\% \to 10\%_{\rm Latt}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\lvert q/p\rvert_{D\text{-mixing}}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+\nu\bar\nu)$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0\nu\bar\nu)$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi\ell\nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to cZ, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})

Belle II has advantages to LHCb in modes with γ, π^0, ν, K_S^0, *etc* … (*B*→τν, τ LFV…).

G. Isidori , Y. Nir , G. Perez, arXiv:1002.0900 [hep-ph] (2010).

Belle II and LHCb

	Belle	Belle II	Belle II	LHCb
	~0.5ab^{-1}	5ab^{-1}	50ab^{-1}	10fb^{-1} [5yrs]
$\Delta S(\phi K_S)$	0.22	0.073	0.029	0.14
$\Delta S(\eta' K_S)$	0.11	0.038	0.020	–
ϕs from $S(J/\psi\phi)$	–	–	–	0.01
$S(K^*\gamma)$	0.36	0.12	0.03	–
$S(\rho\gamma)$	0.68	0.22	0.08	–
$\Delta Br/Br(B\to\tau\nu)$	3.5σ	10%	3%	–
$Bs\to\mu\mu$	?	?	?	5σ @ 6 fb^{-1}
$\tau\to\mu\mu$ [x10^{-9}]	<45	<30	<8	–
$\tau\to\mu\mu\mu$ [x10^{-9}]	<209	<10	<1	–
ϕ_2	11^o	2^o	1^o	4.5^o
ϕ_3	16^o	6^o	2^o	2.4^o

- **Belle II and LHCb complementarily elucidate a NP.**
  - Belle II has advantages in modes with γ, π^0, ν, $K_S{}^0$, *etc* … ($B\to\tau\nu$, $b\to sq\bar{q}$, τ LFV…).

Comment on $Br(B^+ \to \tau^+ \nu_\tau)$

A. Lenz *et al*. (CKMfitter group), arXiv:1008.1593 [hep-ph] (2010).

- **Comment on the *Br* anomaly from CKMfitter group**
  - Form factor f_B, which has a significant contribution to the theoretical uncertainty of the $Br(B^+ \to \tau^+ \nu_\tau)$, can be canceled out by taking a ratio:

$$\frac{Br(B^+ \to \tau^+ \nu_\tau)}{\Delta m_d} = \frac{3\pi}{4} \frac{m_\tau^2}{m_W^2 S(x_t)} \left(1 - \frac{m_\tau^2}{m_{B^+}^2}\right)^2 \tau_{B^+} \frac{1}{B_{B_d} \eta_B} \frac{1}{|V_{ud}|^2} \left(\frac{\sin \phi_1}{\sin \phi_3}\right)^2$$

  - The anomaly can be reduced to a discrepancy between the observed and predicted fudge factors B_{Bd} (called a bag parameter) in the ratio.
  - Precise investigation on the B_{Bd} may answer the origin of the anomaly.

Requirements on Belle II DAQ

- Maximum average of level-1 trigger rate = 30kHz.
- Minimum time interval btw triggers = 190ns.
- Level-1 trigger pipeline = 5-trigger depth.
- Level-1 trigger processing time < 30μs.
- Dead-time fraction at 30kHz < 3.5%.
- System clock = 127 MHz (RF clock divided by 4).
- Maximum event size per FINESSE card = 128 kB.
- No event data reordering until event builder.

R&D of Belle II DAQ

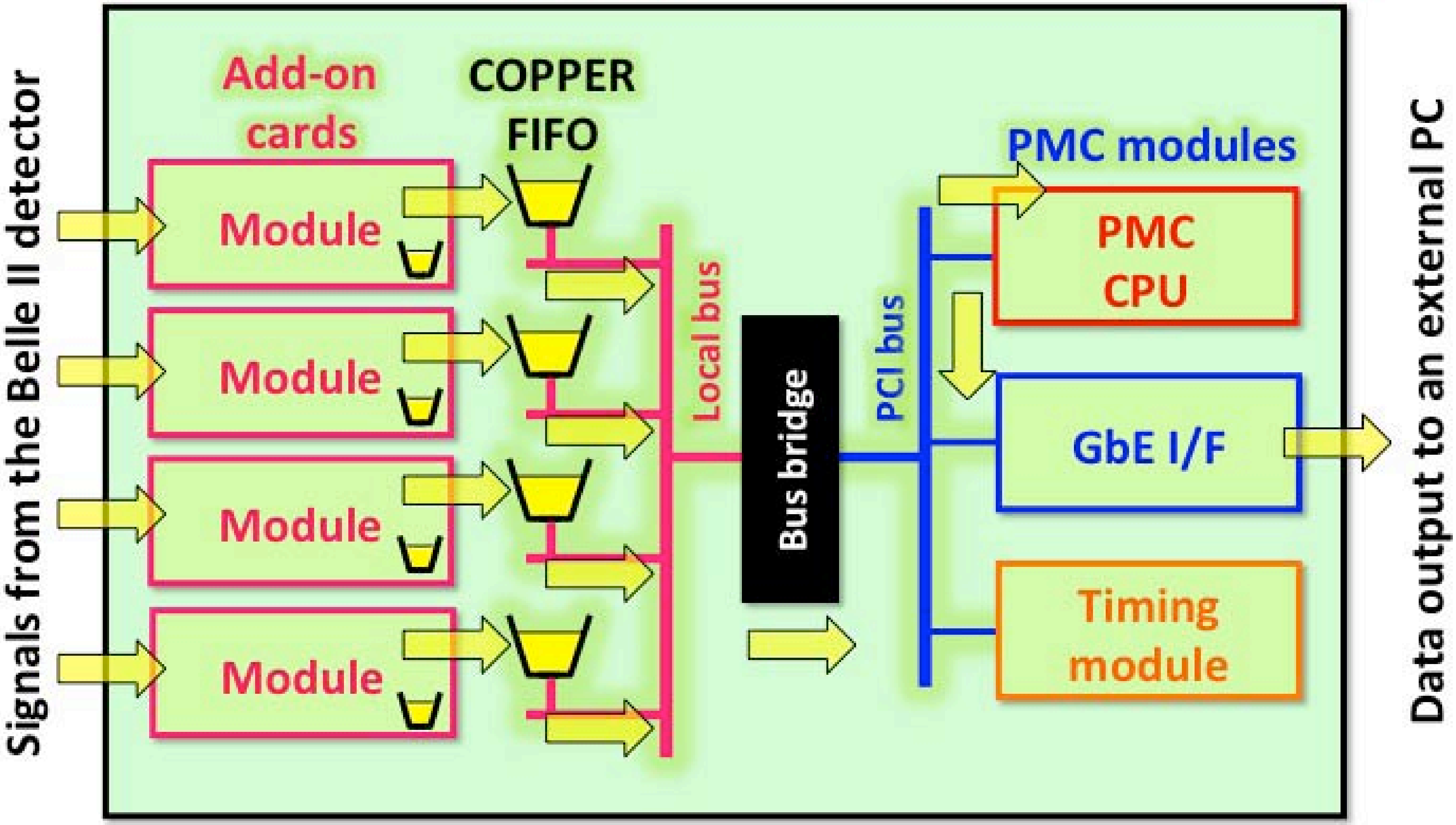
New DAQ that can handle 30kHz event rate is needed.

- Boundary conditions of Belle II DAQ and solutions

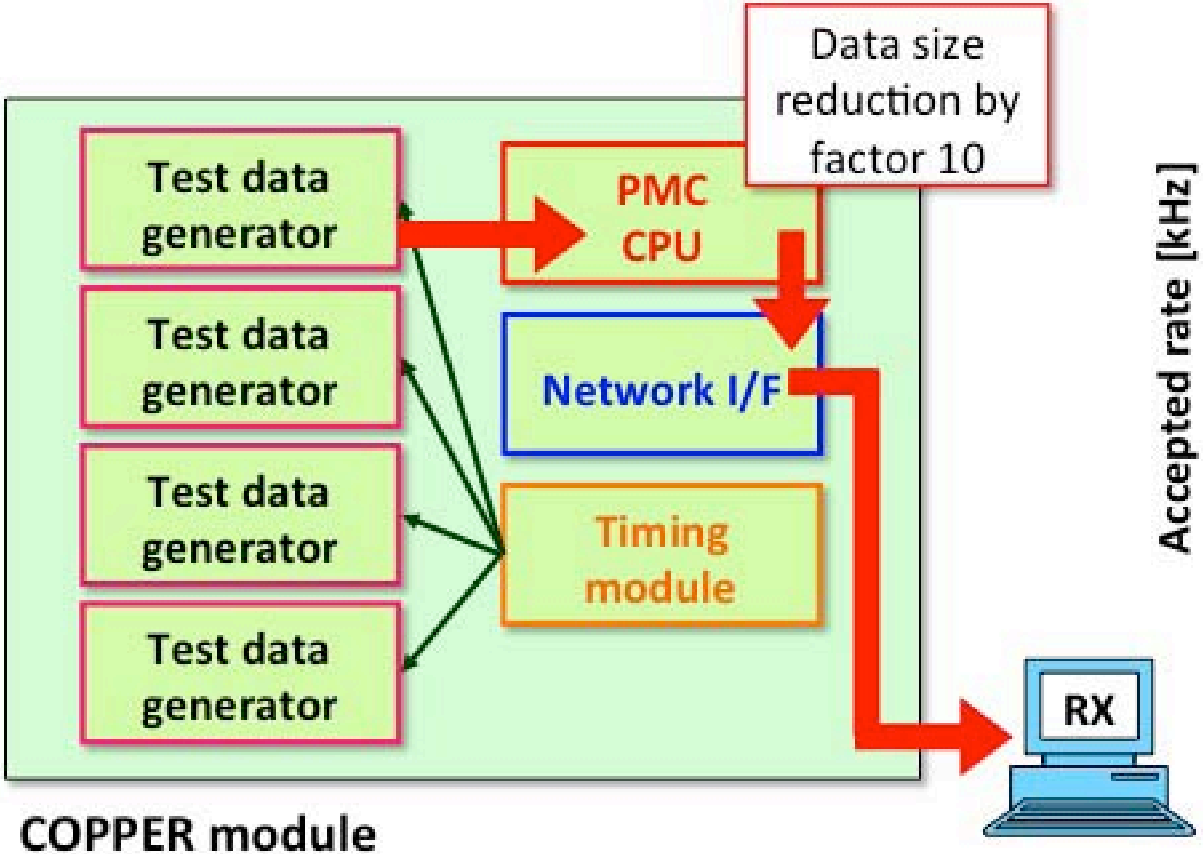
Less DAQ dead time	→	Online storage (pipeline)
Less demand for bandwidth	→	Data size reduction by online CPU
Less R&D and maintenance cost	→	Use of commodity modules
Possibility of system test in Belle	→	Compatible design with Belle DAQ

COPPER

COPPER = COmmon Pipelined Platform for Electronics Readout

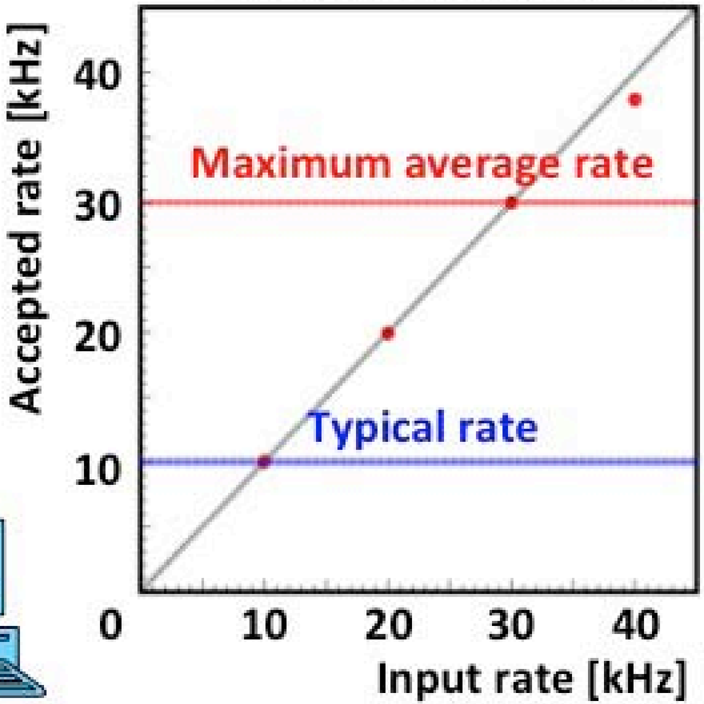


COPPER Basic Performance



COPPER module

@ 1.6kB / event
corresponding to a typical
data size of Belle II CDC



The COPPER system can handle >30kHz event rate.

T. Higuchi *et al.*, IEEE Trans. Nucl. Sci. **52**, 1912 (2005).

COPPER System Test in Belle

- **R&D items for the COPPER system test**

TDC = Time to Digital Converter

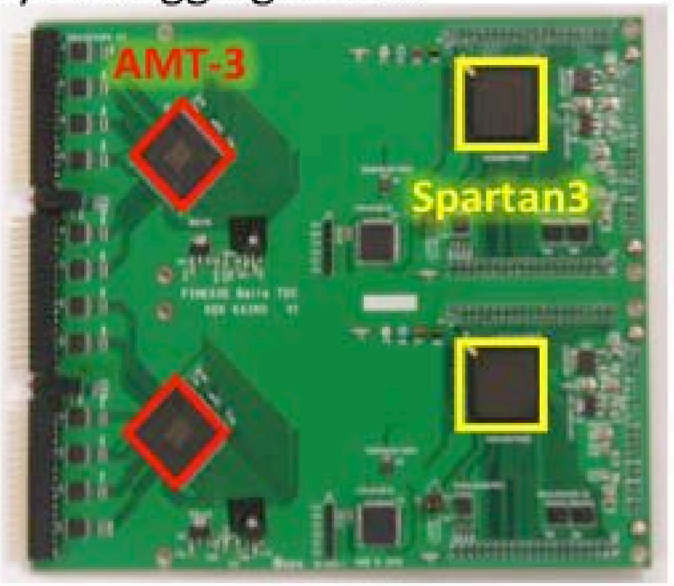
  - Add-on TDC card for the COPPER module that is compatible with the Belle TDC.
    - Belle TDC = LeCroy TDC 1877S.
  - Clock and timing distribution system.
  - Device drivers and software for COPPER readout.
  - Software for COPPER-data processing.
  - Event record builder from multiple COPPER boards.
  - Software for COPPER-system control.

COPPER TDC Module

- **x2 AMT-3 TDC Chip** (AMT = ATLAS Muon TDC)
  - The chip has compatible performance with the Belle TDC:

Time resolution ≤ 750 ps	Linearity = 0.49%	Dynamic range = 17bit
Timing buffer depth = 256	Inputs per chip = 24	

- As we were the first users of the chip (in the real operation) prior to ATLAS themselves, we performed many debugging works.



- x2 Spartan3 FPGA
  - I/F with the AMT-3: data readout, preprocessing, and parameter set.
  - I/F with the COPPER: data output, communication with the local bus.

of COPPER Boards in Belle II

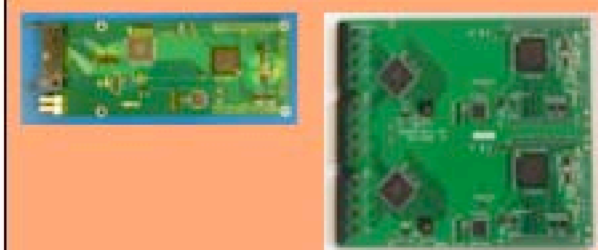
Data rate corresponds to 30kHz L1 rate

	#ch	occ [%]	#link	/link [B/s]	FNS	#CPR	ch sz [B]	ev sz [B]	total [B/s]	/CPR [B/s]
PXD	8M	2	40	455M	—	—	4	800k	18.2G	—
SVD	243456	1.9	40	13.8M	HSLB	40	4	18.5k	555M	13.8M
CDC	14336	10	302	0.6M	HSLB	75	4	6k	175M	2.3M
BPID	8192	2.5	128	7.5M	DSP	16	16	4k	120M	8M
EPID	65664	1.5	78	1.1M	HSLB	20	2.8	2.8k	84M	4.2M
ECL	8736	33	52	7.7M	HSLB	26	4	12k	360M	15M
BKLM	19008	1	16	9.7M	HSLB	6	8	2K	60M	10M
EKLM	16800	2	66	19.5M	HSLB	5	4	1.4k	42M	5.3M
TRG					HSLB	10				

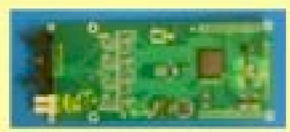
COPPER Add-on Card: FINESSE

FINESSE = **F**rontend **IN**strumentation for **S**ub-detector **S**pecific **E**lectronics

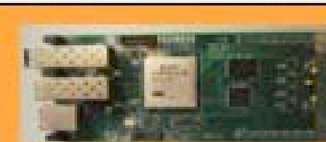
- **Variations of FINESSE cards**
  - COPPER usage is not limited to Belle II.
  - Several variations of FINESSE cards are provided to meet several boundary conditions of each experiment group.



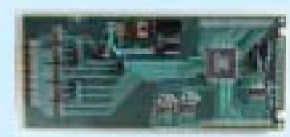
AMT-3 TDC FINESSE



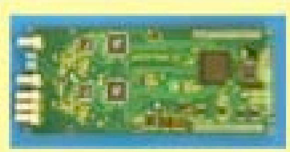
65 MHz 8ch FADC FINESSE



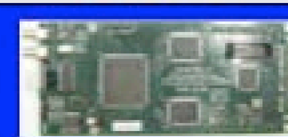
Optical link I/F FINESSE



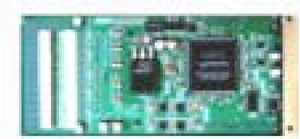
Digital signal receiver FINESSE



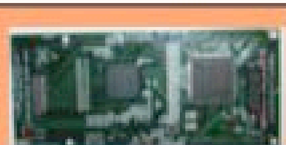
500 MHz 2ch FADC FINESSE



USB I/F FINESSE



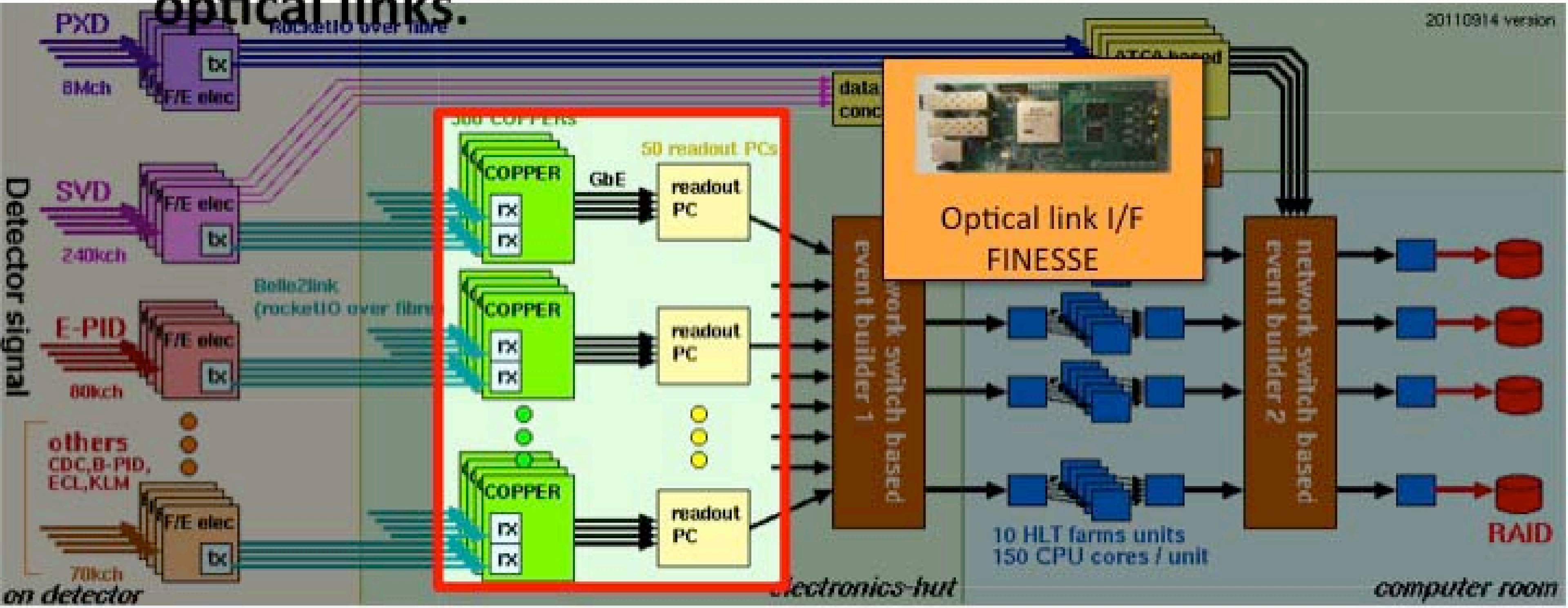
Dry run FINESSE



HPTDC FINESSE

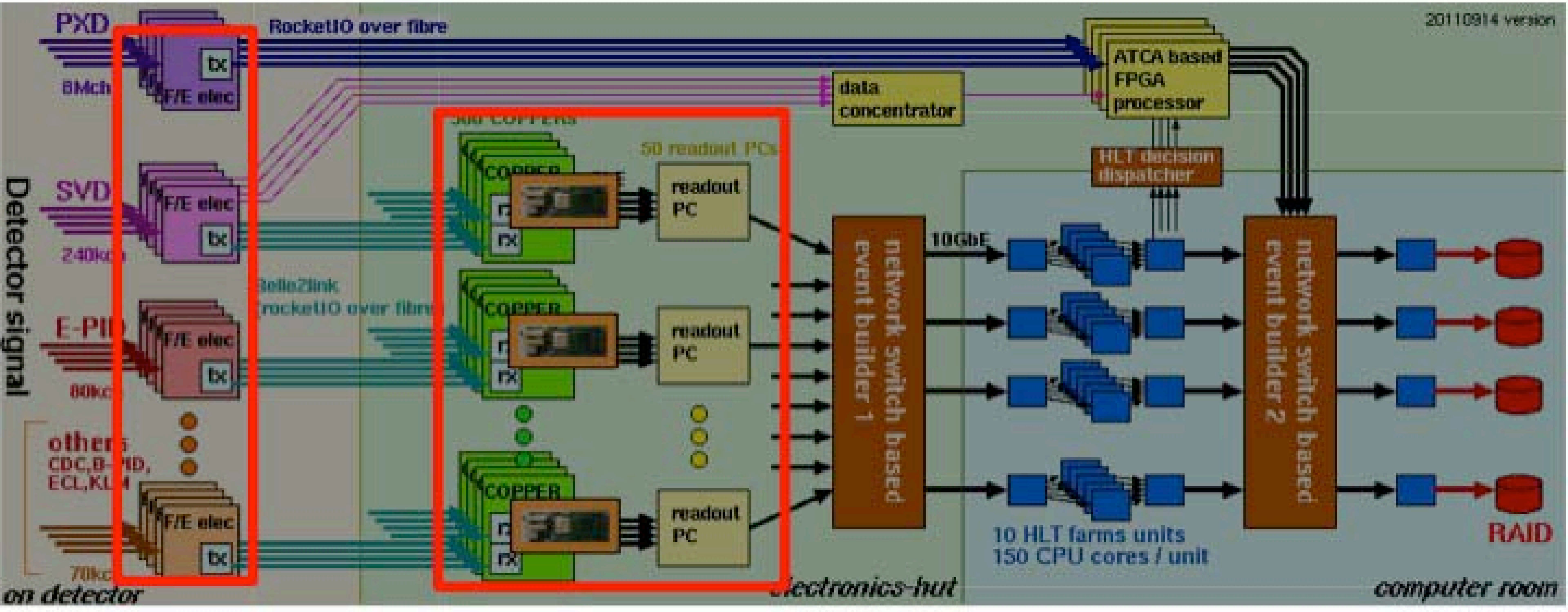
Design of Belle II DAQ

- In Belle II, detector hit signals are digitized in/on the detector, and the digitized signals are transmitted to the FINESSE/COPPER system over optical links.



Design of Belle II DAQ

- In Belle II, detector hit signals are digitized in/on the detec



Radiation Effect to DAQ Components

- We bombarded our in/on-detector DAQ electronics with neutrons and γ rays at exposure facilities.

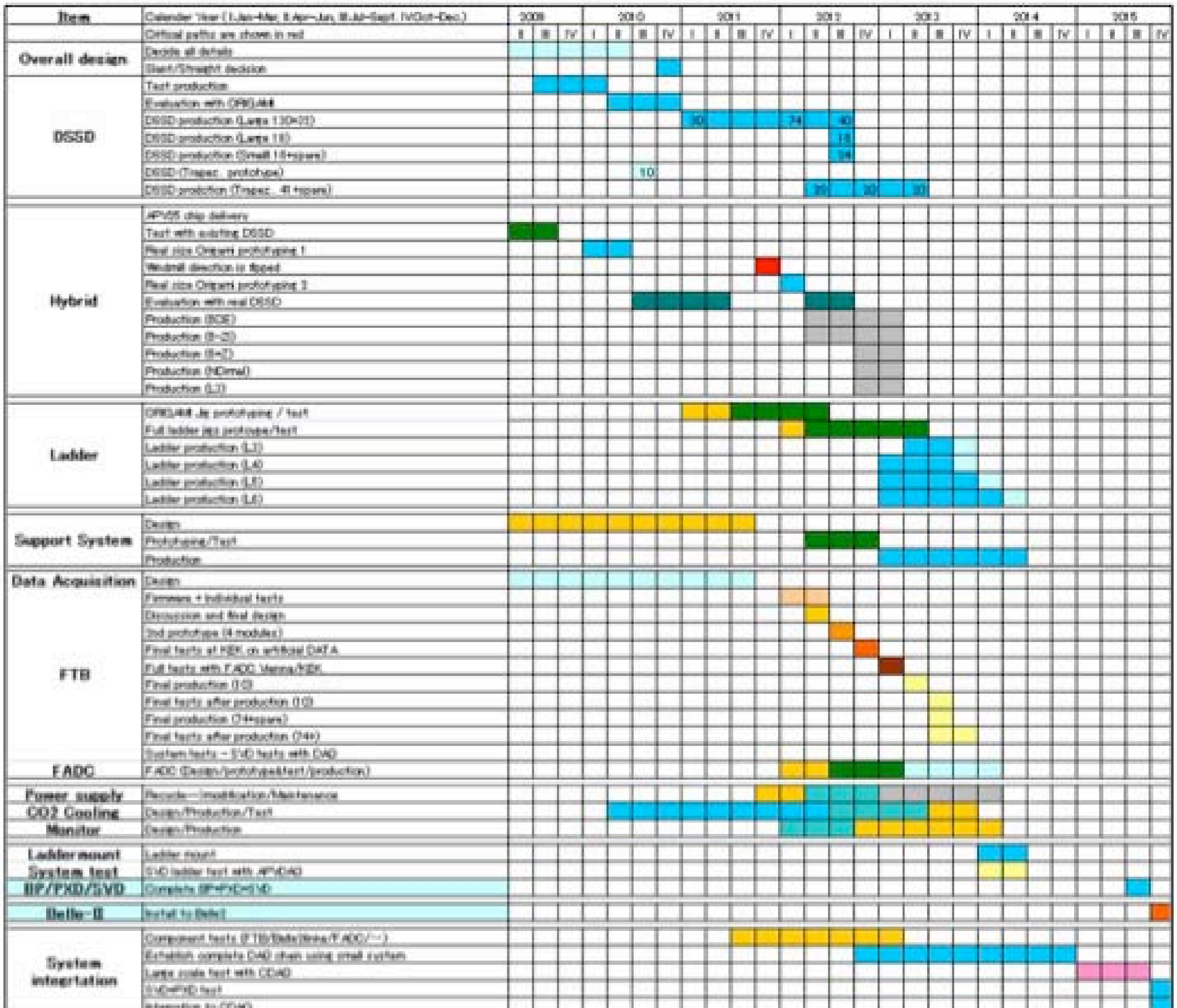
- Radiation hardness of DAQ components (lifetime)

Device	Neutron	γ ray
Virtex5 FPGA	>20 year Belle II run	>88 year Belle II run
Optical transceivers	>12 year Belle II run	3 year Belle II run ☹
Voltage regulators	N/A	>25 year Belle II run

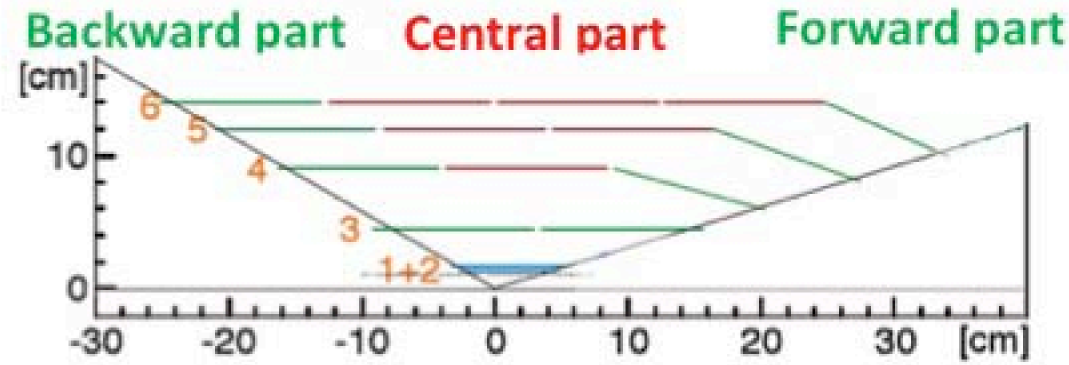
- Data-error rates in FPGA (entire Belle II CDC)
  - One recoverable error without penalty per ~ 4 minutes.
  - One unrecoverable error per ~11.5 hours.

T. Higuchi, M. Nakao, and E. Nakano, JINST **7**, C02022 (2012).

Milestones of Belle II SVD



Key Missions [1’]: Ladder Assembly



Assembly procedure

Placing all DSSDs on the assembly bench

↓

Central part assembly | **Backward part assembly** | **Forward part assembly**

Backward part assembly + Forward part assembly ↓

Gluing edge DSSD on the ribs

Central part assembly + Gluing edge DSSD on the ribs ↓

Gluing the central part on the ribs

Key Missions [2']: Readout Electronics

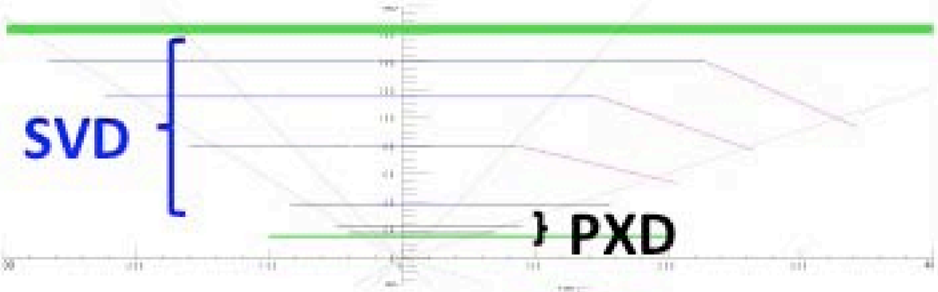
- **FADC system**
  - Suggestion of higher density FADCs.
- **Zero suppression with APVDAQ**
  - Firmware extension to APVDAQ (small-scale test system) for experiment at J-PARC.
- **Online software**
  - C++ software for control / readout of existing FADC prototype.

Sensors of Belle II SVD

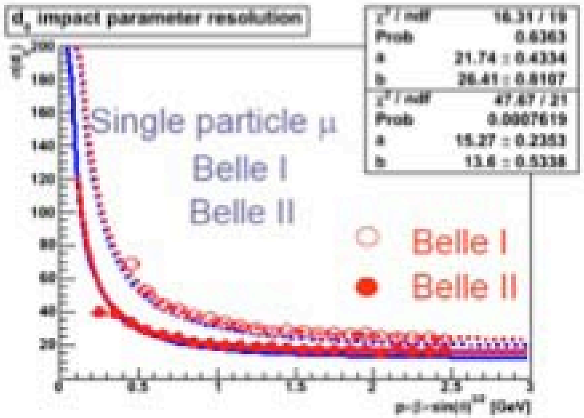
- **HPK status**
  - Large delivery expected in late 2012.
- **Micron status**
  - Sensors with improved *p*-stop design now in production.

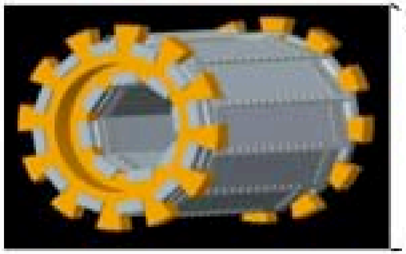
Belle II Vertex Detectors (SVD+PXD)

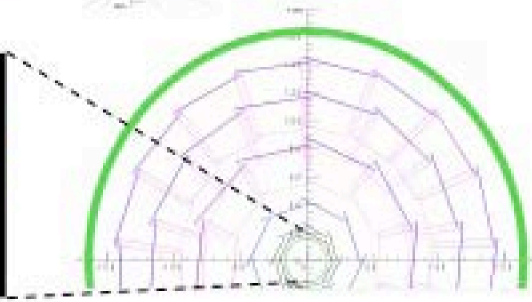
2-layer PXD
4-layer SVD



Track impact parameter resolution







B-meson efficiency ↑ by acceptance increase

If PXD/SVD coverage increases from 92 to 94%.

eff.$_B$ = 34.5 → 37.5%

Self tracking performance in very fwd/bwd region @ 1GeV/*c*

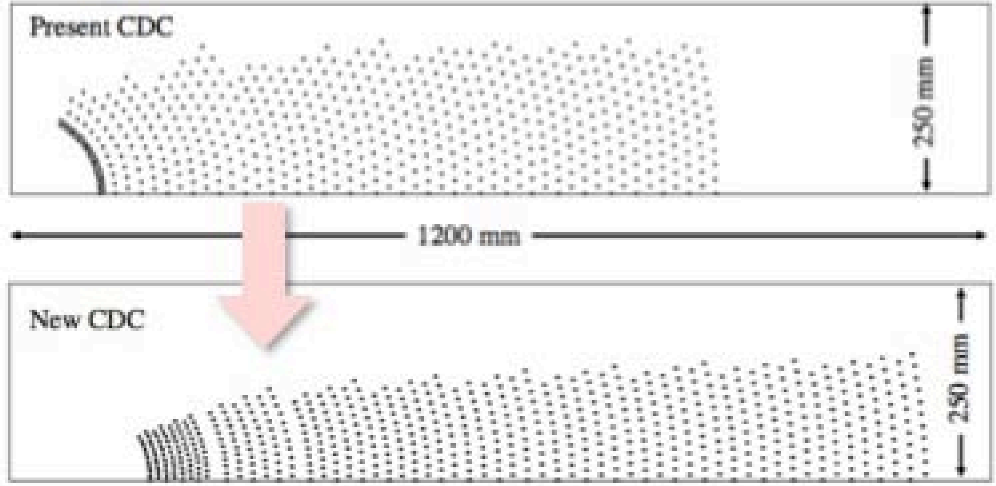
	PXD/SVD	PXD/SVD/CDC
FWD	69μm	54μm
BWD	38μm	30μm

IR design

Be pipe with 20mm/30mm diameter and with beam crossing angle 83mrad.

Belle II Central Drift Chamber

Longer lever arm
Smaller cell



Geometrical parameters (preliminary)

Radius (mm)	160-1096
Number of layers	58
Number of sense wires	15104

B-meson efficiency vs. background (MC)

$B^0 \to J/\psi K^0_S$ reconstruction efficiency is not very degraded even in higher background.

bkg level	eff. (%)	eff. ratio - 1 wrt 1× bkg (%)	eff. ratio - 1 wrt Belle (%)
1× bkg	58.7	≡ 0	+11.3
5× bkg	57.7	−1.7	+ 9.4
20× bkg	53.6	−8.8	+ 1.5
1× bkg (Belle)	52.7	-	≡ 0

Prototype of CDC frontend readout

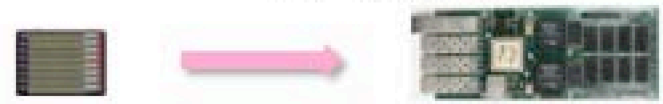
- Installed inside Belle II
- Preamplifier & shaper
- FADC: 32MHz, 10bit
- TDC: 1ns counting
- Tracking performance was studied with beam test

Deadtime is to be suppressed by smaller cell, new R/O electronics, and software updates to maintain the present tracking efficiency under the higher BG.

Belle II Particle Identification

Barrel: TOP counter
Endcap: Aerogel RICH

TOP readout

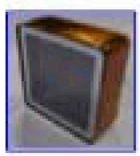


Frontend ASIC
- 4GSa/s, 9bit
- FADC: 32MHz 10bit

DSP FINESSE on COPPER
- 60 waveform Sa/s
- Optical fiber I/F

Theory of TOP operation

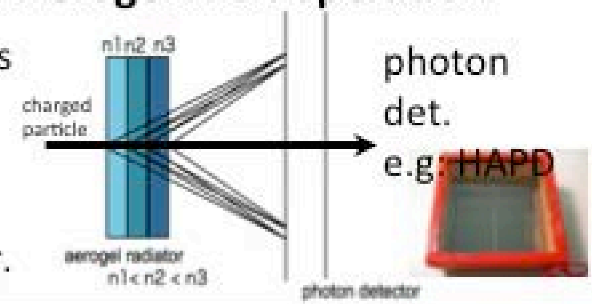
Identify particles by measuring propagation time of Cherenkov light in quartz bar.



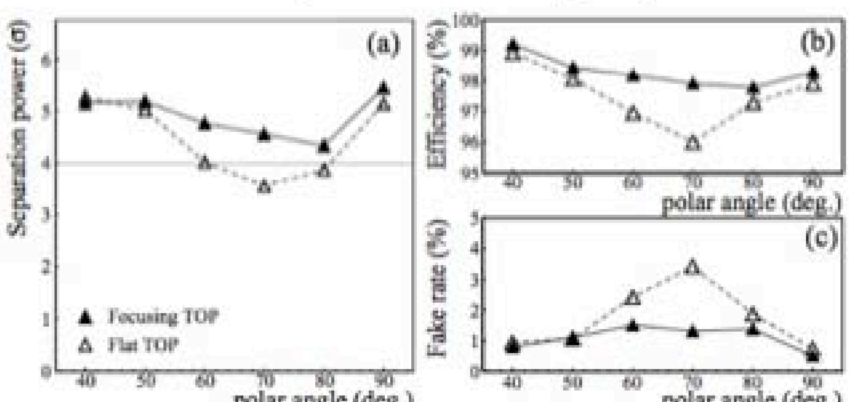
R/O by photo-cathode

Theory of Aerogel RICH operation

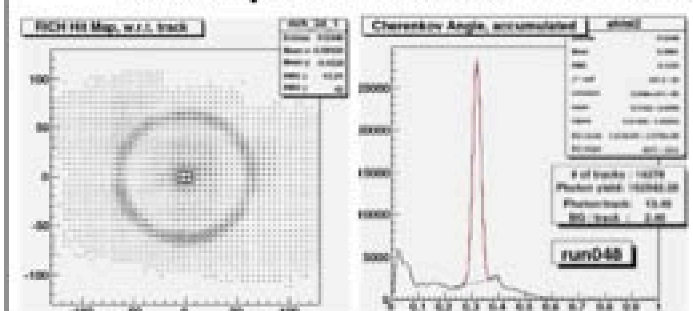
Identify particles by detecting Cherenkov ring photon from aerogel radiator.



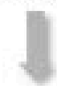
TOP performance (MC)



ARICH performance from beam test



resol. = 4mrad/trk



5.8σ K/π @ 4GeV/c

Belle II Calorimetry and K^0_L/μ Detection

Calorimeter: B=CsI(Tℓ),
E=CsI,BSO,$PbWO_4$

K^0_L/μ: B=RPC, E=Scintillator

ECL endcap baseline option: CsI(pure)

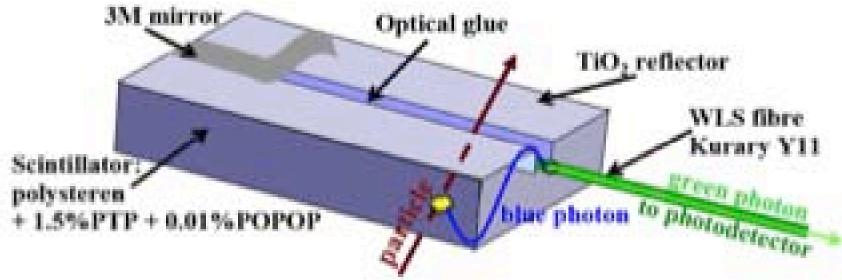
- CsI(pure) has shorter decay time than CsI(Tℓ).
- Pipeline readout w/ waveform analysis.
  → Combined effect of shorter decay time and timing information suppresses fake clusters by factor 30;
  Pileup noise will be reduced by factor 5.

Other ECL endcap options: BSO or $PbWO_4$

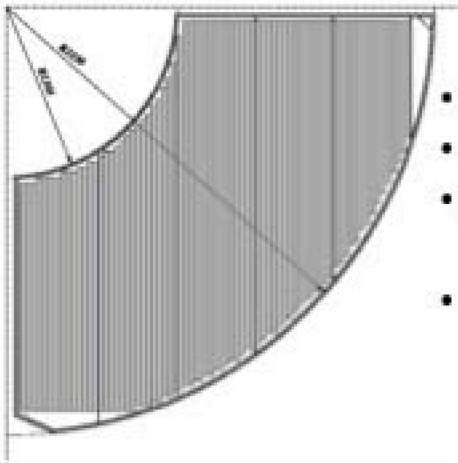
- Pro: better 2 shower resolution …
- Con: mechanical strength …

KLM endcap upgrade

RPC is replaced with scintillator strip + WLS + SiPM against higher background in endcap part.



KLM endcap general layout



- 4cm width / strip.
- 75 strips / sector.
- 2-superlayer structure; orthogonal each other
- 4% dead zone in total due to cables, supports, etc.

Kids' Program by Belle

We are also keen to provide attractive programs for kids.

- **A journey to the smallest world**
  - *Start* = children's height (10^{0}m)

    ⋮

    18 stages to the goal

    ⋮

  - *Goal* = size of quarks and leptons ($<10^{-18}$m)

Stage # 10^{-5}m
A cell nucleus

- **Stage guard = quiz**
  - 18 quizzes to the last stage.
  - Pupils can *feel* the difficulty to get to and to explore the quark and lepton world.