Belle / Belle II

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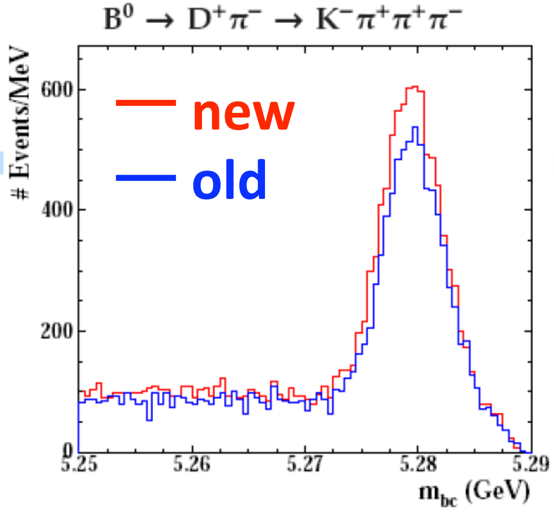
IPNS, KEK

Belle Collaboration

Topics on
the Belle Operation

Raw Data Grand Reprocess

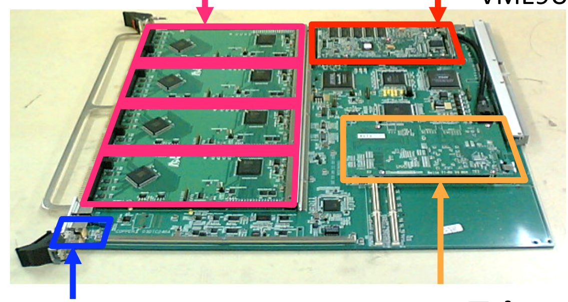


- **Grand reprocess of Belle raw data**
  - Track finding efficiency ↑
    - Track finding algorithm is switched from Conformal to Hough transformation method.
    - Reconst. efficiency: +7% for $J/\psi K_S(\pi^+\pi^-)$, +60% for $D^{*+}D^{*-}$ (no π^0).
  - γ/π^0 efficiency ↑
    - ECL *E* threshold is changed from constant to azimuth-angle dependent.
    - Reconst. efficiency: +10% for $J/\psi K_S(\pi^0\pi^0)$, +22% for $D^{*0}(D^0\pi^0)\pi^-$
  - Several minor modifications, corrections

- **All grand reprocess efforts have completely converged**
  - Exp#41-55 (372 fb^{-1}): released on Dec.24,2009.
  - Exp#31-39, 65, 69 (241 fb^{-1}): released on Feb.9,2010.

Additional COPPERs to Belle DAQ

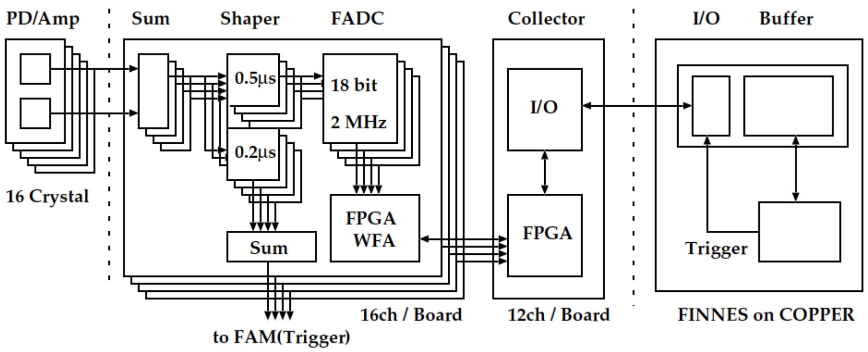
- **COPPER readout system consists of:**
  - Common R/O platform: COPPER
  - Signal digitizer unit
  - COPPER R/O PC, slow control, etc …



- **COPPER system test in Belle beam operation for Belle II**
  - KLM readout electronics changed from LeCroy FASTBUS TDCs to AMT-3 TDC + COPPER
    - Sequential timing signals from3264 input channels are digitized by AMT-3 TDC on COPPER.
    - 34 COPPERs are newly installed.
  - 179 COPPERs have been working for Belle DAQ so far.

New Readout System for Belle II ECL

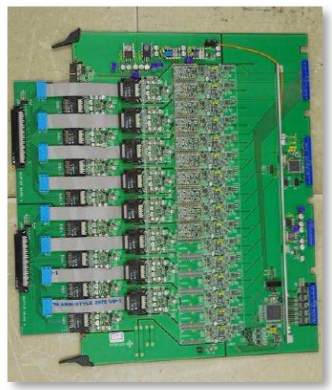
- **Readout system of Belle II ECL**



- Pre-amplifier
- Shaper (shaping-time 0.5μs … *E* measurement)
- Shaper (shaping-time 0.2μs … trigger)
- ADC (18-bit, 2MHz)
- FPGA for waveform analysis
- Data collector binding FE and COPPER

– Prototype system test in Belle
  - "Shaper + ADC" electronics
  - On-COPPER electronics with FPGA for data RX and WFA

TKO



Prototype system test in Belle beam operation started since Oct.15,2009.

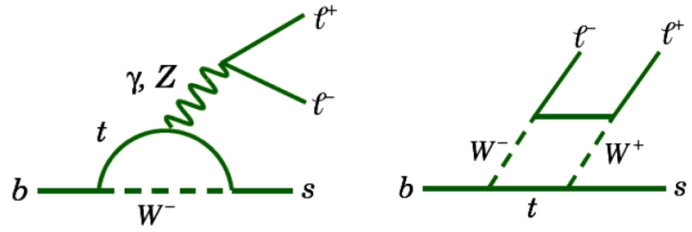
– New system under R&D
  - "Shaper + ADC + WFA FPGA" electronics

VME9U

Topics on
the Recent Physics Analyses

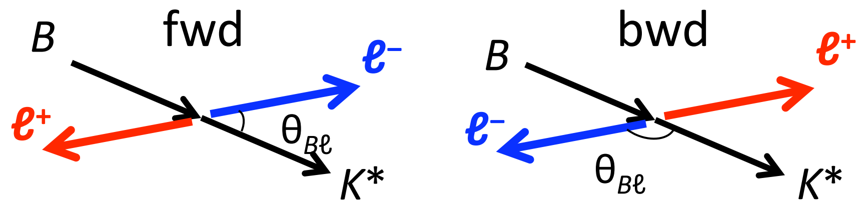
$b \to s\ell^+\ell^-$

- **Physics motivation**
  - In the SM, the decay is mediated by Z/γ penguin and W^+W^- box diagrams.



  - Interference by NP particles to SM diagram may detect the NP, especially for Wilson coefficients: C_7, C_9, C_{10}

- ***B* → *K*$^{(*)}\ell^+\ell^-$ (exclusive)**
  - Low-BG reconstruction
  - A_{FB}: fwd/bwd asymmetry



in K^* rest frame

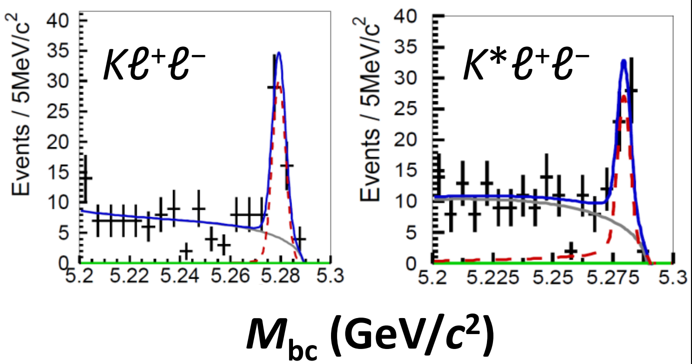
- ***B* → $X_s\ell^+\ell^-$ (inclusive)**
  - Low form-factor uncertainty in $B \to K$ decay
  - $d(Br)/d(q^2)$: differential branching fraction

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

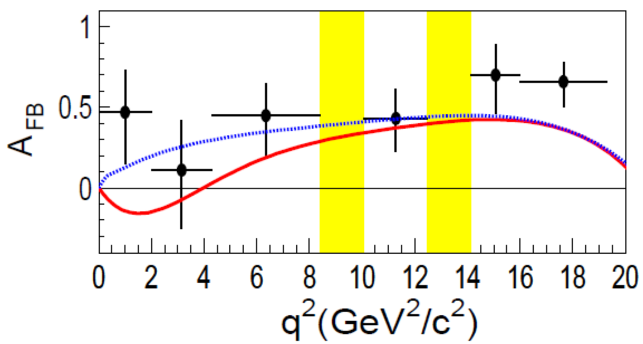
- **$K^{(*)}\ell^+\ell^-$ reconstruction**
  - $K^{(*)}$: $K^+\pi^-$, $K^+\pi^0$, $K_S\pi^+$, K^+, K_S
  - $\ell^+\ell^-$: excluding lepton pairs forming J/ψ and $\psi(2S)$ mass (yellow band).
  - BG suppression: (qq / semi-ℓ B decays):
    - Fisher-discriminant, cosθ, etc.

$$\begin{cases} \left|\delta(m_{\pi^0})\right| < 18.5\,\mathrm{MeV}/c^2, \quad \left|\delta(m_{K_S^0})\right| < 15\,\mathrm{MeV}/c^2 \\ \left|\delta(m_{K^*})\right| < 80\,\mathrm{MeV}/c^2 \end{cases}$$

657M *BB*



- **A_{FB} as a function of $q^2=M_{\ell\ell}^2c^2$ for $\to K^*\ell^+\ell^-$**



A_{FB} is determined for each of 6 q^2 regions by fitting $\theta_{B\ell}$ to distribution function including A_{FB}.

SM prediction (red line)

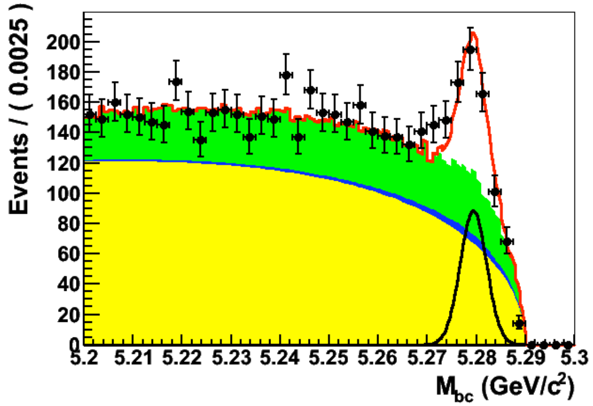
$C_7 = -C_7^{SM}$ case (blue line)

Hint of New Physics ?

Phys. Rev. Lett. **103**, 171801 (2009).

$B \to X_s \ell^+\ell^-$ (inclusive)

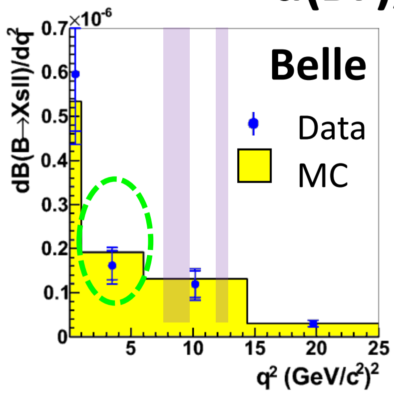
657M BB

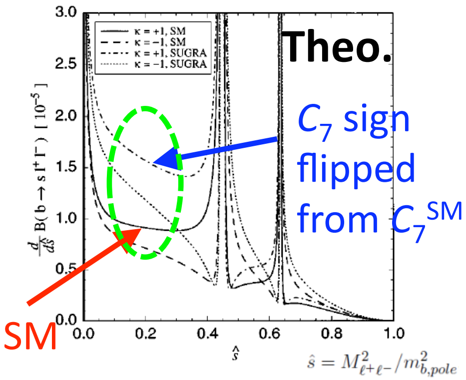


- $X_s\ell^+\ell^-$ **reconstruction**
  - Xs: $K^+ + n\pi^\pm + m\pi^0$ / $K_S + n\pi^\pm + m\pi^0$
    - $n+m = 0 \ldots 4$, $m = 0,1$
  - $\ell^+\ell^-$: excluding J/ψ and $\psi(2S)$
  - BG suppression as well.
  - Peaking BG ($X_s c\bar{c}$, $X_s hh$, $X_s h\ell\nu$) and self cross feed → sys.err.

d(Br)/d(q^2):

- **Total** ***Br*** **and differential** ***Br***
  - $Br(X_s\ell^+\ell^-)\times 10^6 = 3.22 \pm 0.79^{+0.28}_{-0.25}$
    - $Br(X_s\ell^+\ell^-)\big|_{SM} \times 10^6 = 4.4 \pm 0.7$
    - $Br(X_s\ell^+\ell^-)\big|_{C_7=-C_7^{SM}} \times 10^6 = 8.8 \pm 0.7$



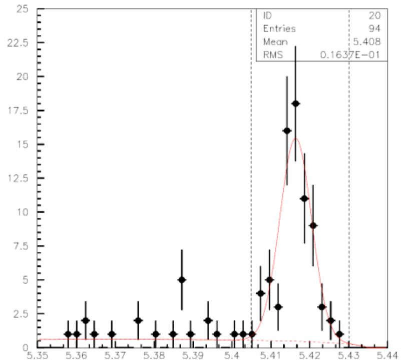


Results favor SM

H.Nakayama, Ph.D. thesis (2010).

Υ(5S), Υ(2S), Υ(1S) Physics Analyses

- **Υ(5S) … L=125 fb^{-1}: on-going analyses**
  - $Br(\Upsilon(5S) \to BB\pi(\pi))$: information to Υ(5S) resonance dynamics
  - $Br(B_s \to D_s^{(*)+} D_s^{(*)-})$: input to $\Delta\Gamma_s$ determination
  - $Br(B_s \to D_s^{*}\pi, D_s^{(*)}\rho)$: first meas. to be compared with B_d case
  - $Br(B_s \to J/\psi\eta^{(\prime)})$: input to the time-dependent CPV analysis
  - $B_s \to J/\psi\phi$: time-dependent analysis to get $\Delta\Gamma_s/\Gamma_s$



M_{bc} of $B_s \to J/\psi\phi$ @ 24 fb^{-1}

- **Υ(2S), Υ(1S) … L=24.1 fb^{-1}, L=5.7 fb^{-1}: on-going analyses, efforts**
  - $Br(\eta_{bJ} \to J/\psi J/\psi)$: judgment of 2 existing *Br* model; $(\Upsilon(2S) \to \gamma\eta_{bJ})$
  - Decay simulation tool of Υ(1S) is being developed/tuned.

More and more are going on.

Υ(4S) Physics Analyses (780fb^{-1})

- **Time-dependent analyses**
  - Published: CPV in $B^0 \to D^{*+}D^{*-}$, CPV in $B^0 \to K^0\pi^0$ … Accepted by PRD
  - On-going: CPV in $B^0 \to K^+K^-K_S$, CPV in $B^0 \to \phi K_S \gamma$,
    CPTV in $B^0 \to J/\psi K^0$, $D^{(*)}h$, $D^*\ell\nu$
  - Prospects: The final CPV in $B^0 \to (c\bar{c})K^0$ with full Υ(4S) data for summer;
    ϕ_2 update, CPV in $b \to s$, CPV in DD for summer or later

- ***D^0-$\bar{D}^0$* mixing analyses**
  - Toward summer 2010: $D^0 \to \pi^+\pi^-K_S$, $D^0 \to K^+K^-K_S$
  - Toward early 2011: $D^0 \to K^+\pi^-\pi^0$, $D^0 \to KK/\pi\pi$

- **Rare-*B*-decay analyses**
  - $B \to D^+\ell^+\ell^-$, $B \to \rho^+\omega$, $B \to \pi^0\pi^0$, $B \to \nu\bar{\nu}$ …

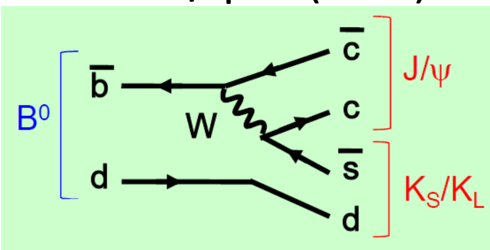
More and more are going on as well.

Hints of the New Physics

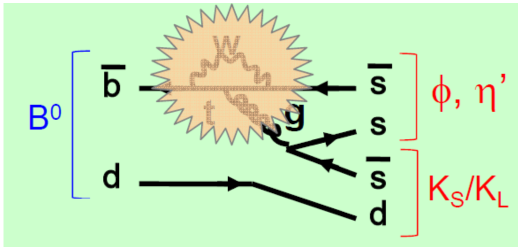
CP Violation in *b*→*s* Penguin

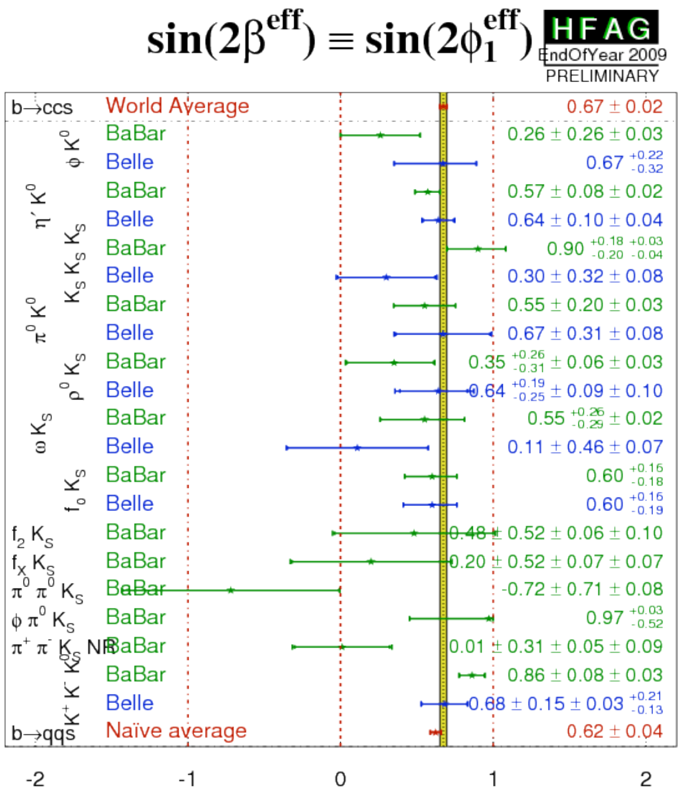
- **Deviation of *b*→*s* *CP*-violating parameter from *b*→*c* indicates NP in the penguin loop**

$B^0 \to J/\psi K^0$ ($b \to c$)



$B^0 \to \phi K^0, \eta' K^0$ ($b \to s$)



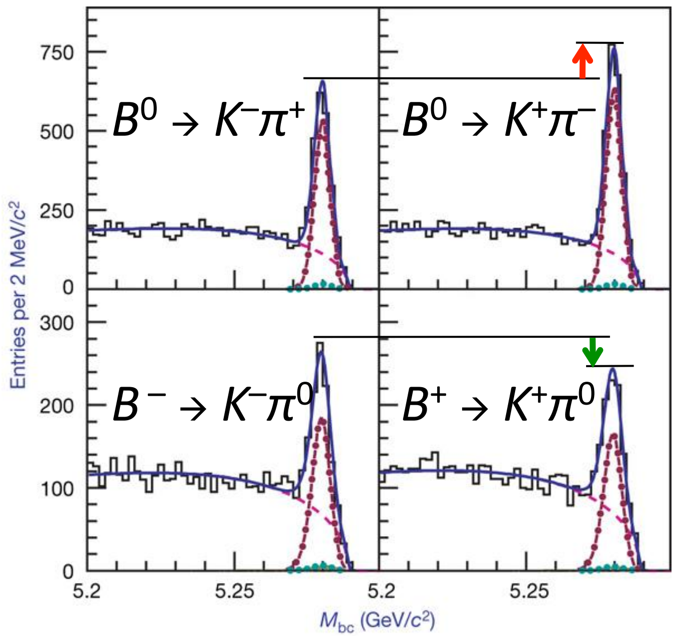


- $S_{b\to c} = S_{b\to s}^{SM}$
- W.A.: $S_{b\to s} = 0.62 \pm 0.04$
- W.A.: $S_{b\to c} = 0.673 \pm 0.023$

1.3σ deviation

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

$K\pi$ Puzzle in B^0/B^+ *CP* Violation



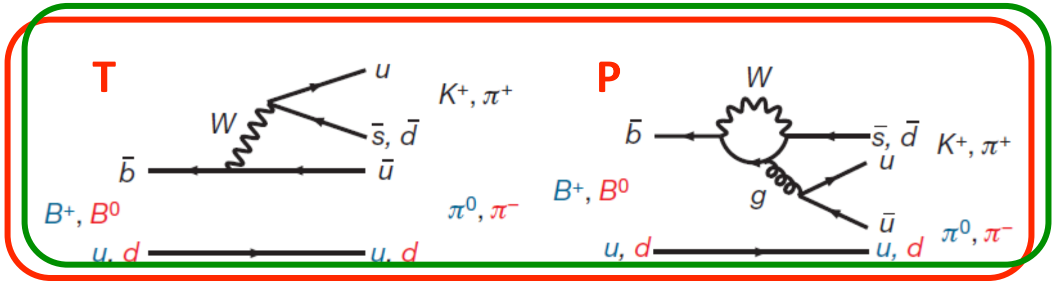
$$A_{CP}(K^+\pi^-) = -0.094 \pm 0.018 \pm 0.008$$

$$A_{CP}(K^+\pi^0) = +0.07 \pm 0.03 \pm 0.01$$

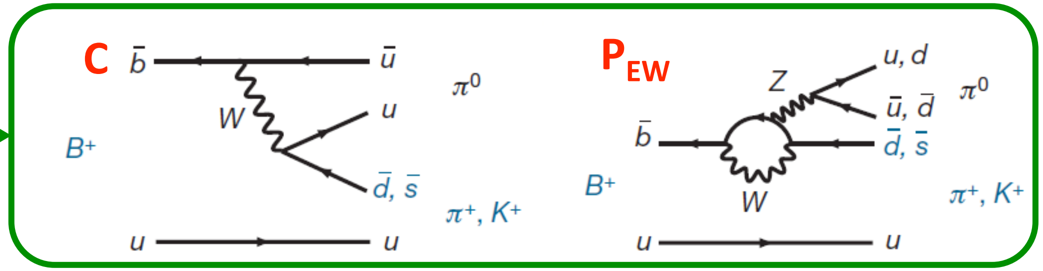
B^0

B^+

5.3σ deviation → Hint of NP



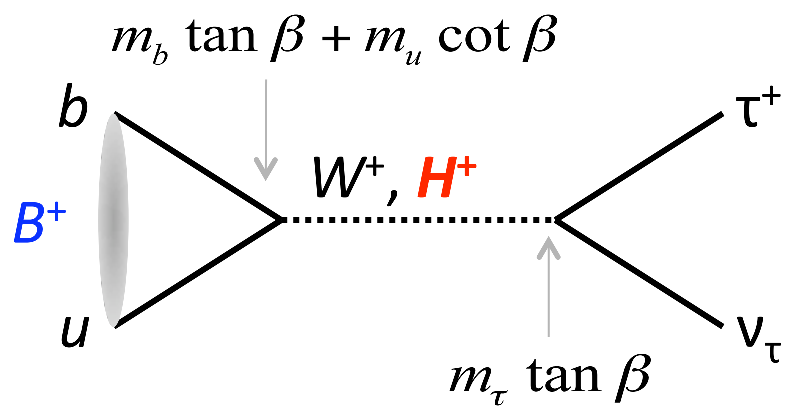
P_{EW} contribution to CPV (only to B^+ mode) may be large due to NP…?

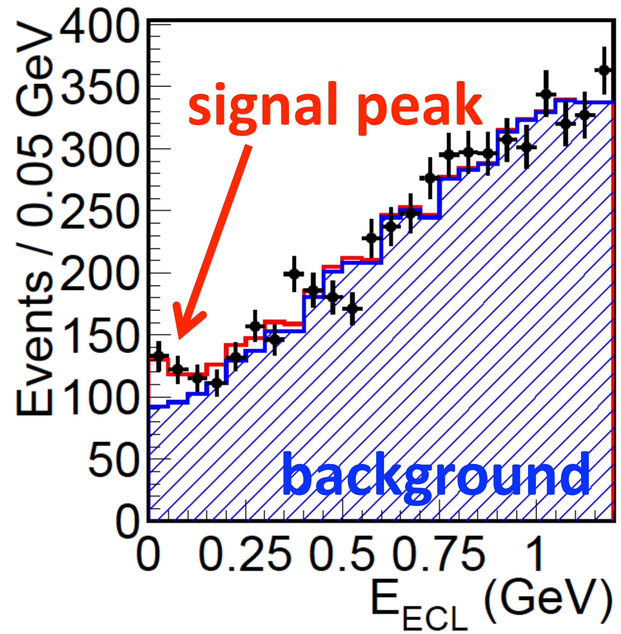


$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

NP will violate above equation → Measurements of 4 A_{CP}'s answer.

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





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

$$Br\big|_{\text{meas.}} = (1.73 \pm 0.35) \times 10^{-4}$$

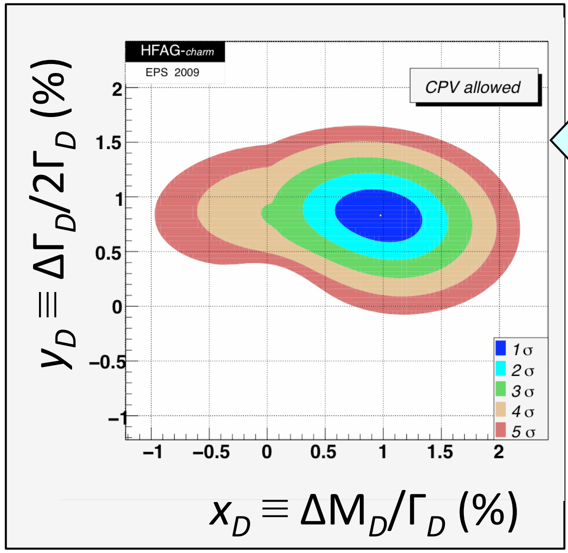
$$Br\big|^{\text{CKMfit}}_{\text{w/o } B\to\tau\nu} = \left(0.786^{+0.179}_{-0.083}\right) \times 10^{-4}$$

2.4σ deviation

Constraint on tanβ and m_{H+} relation is imposed.

δ(*Br*) ~2% @50 ab^{-1}

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



$$x_D = (0.98^{+0.24}_{-0.26})\%$$

$$y_D = (0.83 \pm 0.16)\%$$

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)

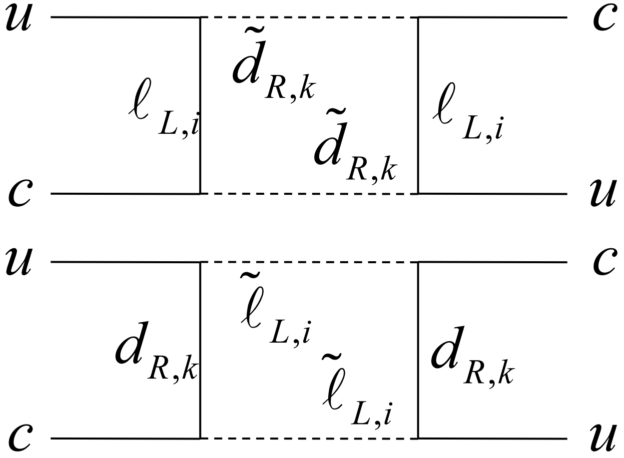
Larger D^0-$\bar{D}^0$ mixing than the SM prediction (x_D).

Hint of NP

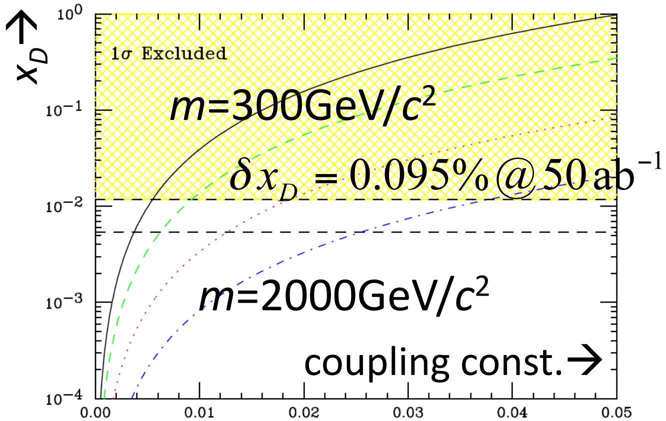
Possible scenario to have large D^0-$\bar{D}^0$ mixing

R-parity-violating SUSY particle in the box-diagram

E. Golowich *et al.*, PRD**76** 095009 (2007)



R-parity-violating coupling constant can be determined by precise meas. of x_D and SUSY particle masses ($m_{\tilde{d}}=m_{\tilde{\ell}}$).



Toward Belle II

Access to the New Physics by Belle II

Typical SUSY models → …

Measurements by Belle II and others ↓

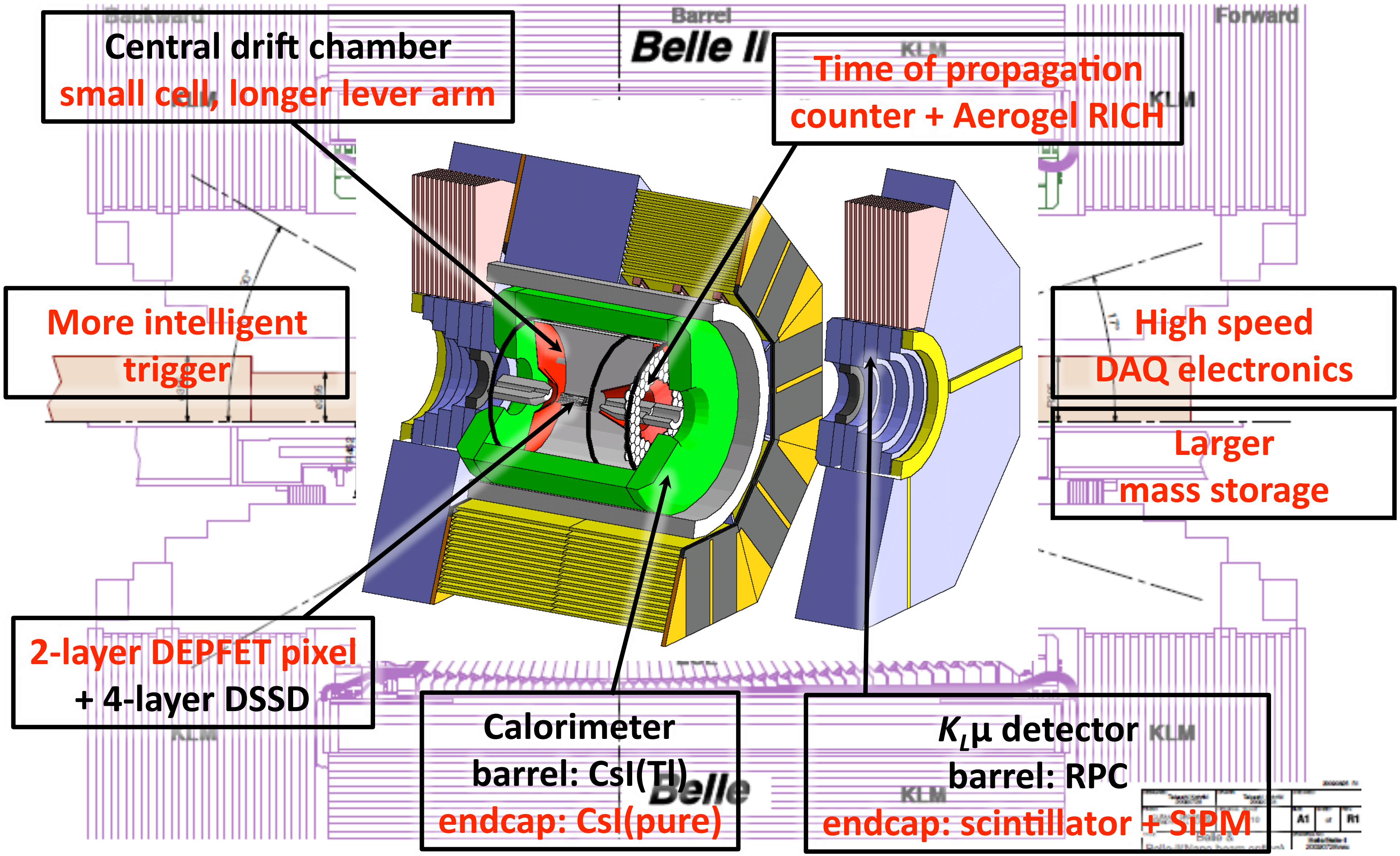
	mSUGRA	MSSM+ν_R		SU(5)+ν_R		U(2) FS
		degenerate	non-degenerate	degenerate	non-degenerate	
$A_{CP}(s\gamma)$						✓
$S(K^*\gamma)$				✓	✓	✓
$S(\rho\gamma)$				✓	✓	✓
$S(\phi K_S)$				✓	✓	✓
$S(B_s \to J/\psi\phi)$				✓	✓	✓
$\mu \to e\gamma$		✓		✓	✓	?
$\tau \to \mu\gamma$		✓	✓	✓	✓	?
$\tau \to e\gamma$	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

✓: possible deviation from SM

T.Goto *et al.*, Phys. Rev. D**77**, 095010 (2008).

Survey as much modes as possible and figure out the nature of NP (e.g.: SUSY) hidden above TeV.

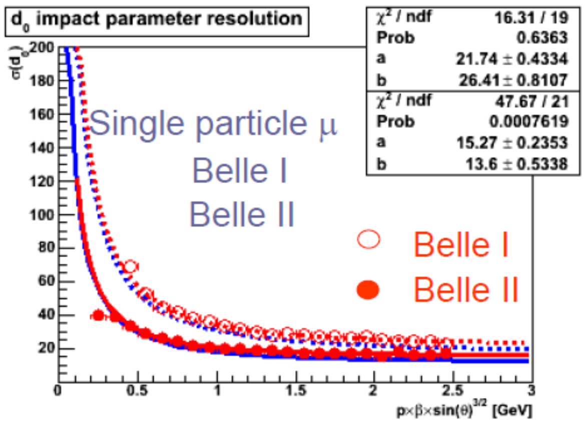
Belle II Detector



Vertex Detectors

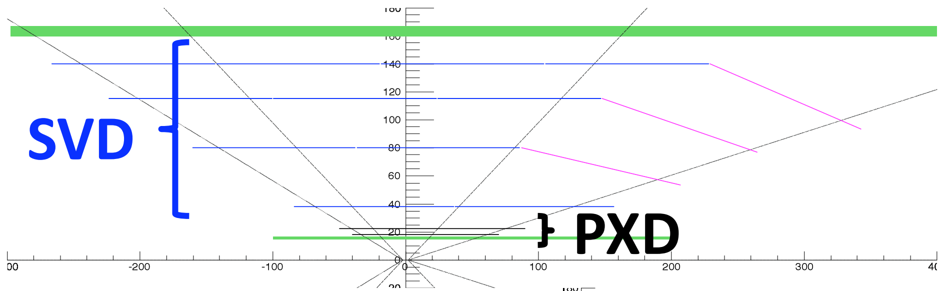
2-layer DEPFET pixel
4-layer DSSD

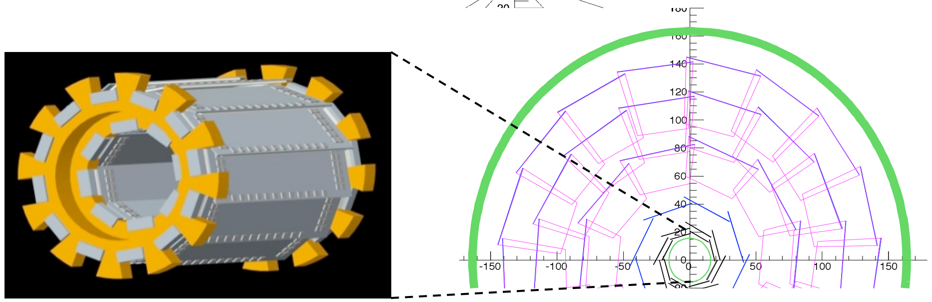
Track impact parameter resolution



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

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





B-meson efficiency ↑ by acceptance increase

If PXD/SVD coverage increases from 92 to 94%

eff._B = 34.5 → 37.5%

IR design

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

Central Drift Chamber

Longer lever arm
Smaller cell

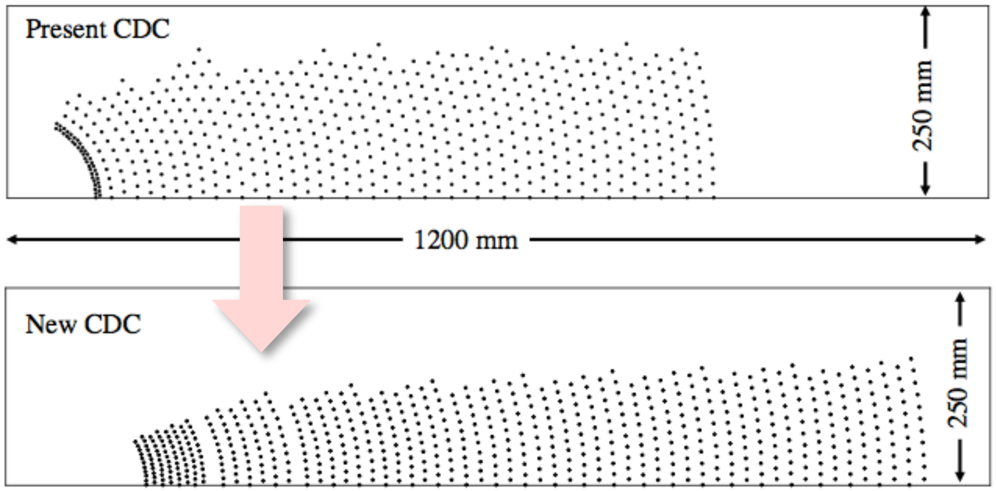
Geometrical parameters (preliminary)

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

B-meson efficiency vs. background (MC)

$B^0 \to J/\psi K_S$ 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

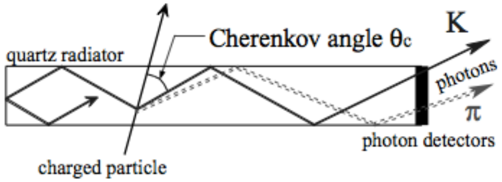
Deadtime is to be suppressed by smaller cell, new R/O electronics, and software updates to maintain the present tracking efficiency under the higher BG.

Particle Identification

Barrel: TOP counter
Endcap: Aerogel RICH

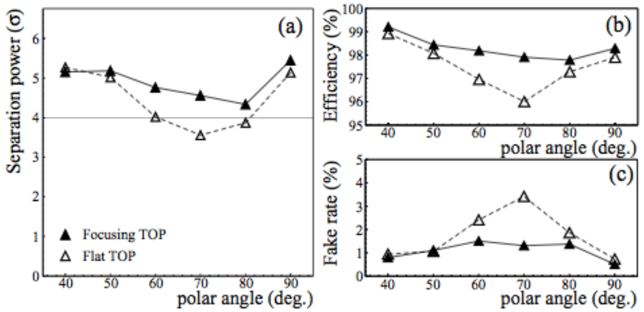
Theory of TOP operation

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



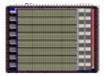
R/O by photo-cathode

TOP performance (MC)



Detector configuration and cylindrical layout are being studied to tune the performance.

TOP readout



Frontend ASIC

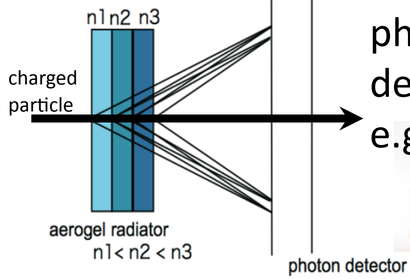
- 4GSa/s, 9bit
- FADC: 32MHz 10bit

DSP FINESSE on COPPER

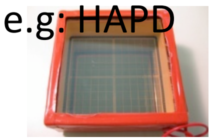
- 60 waveform Sa/s
- Optical fiber I/F

Theory of Aerogel RICH operation

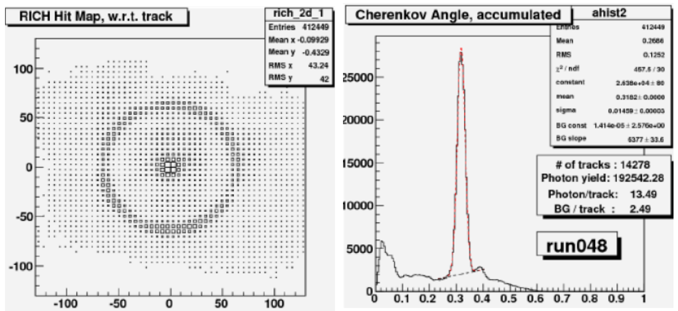
Identify particles by detecting Cherenkov ring photon from aerogel radiator.



photon det.
e.g: HAPD



ARICH performance from beam test



resol. = 4mrad/trk

5.8σ K/π @ 4GeV/c

Calorimetry and K_L/μ Detection

Calorimeter: B=CsI(Tℓ),
E=CsI,BSO,$PbWO_4$
K_L/μ: B=RPC, E=Scintillator

ECL endcap baseline option: CsI(pure)

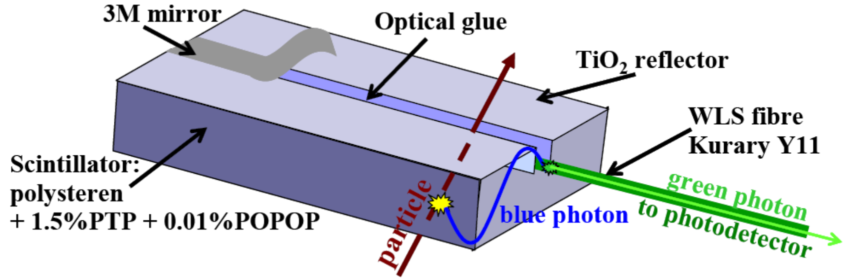
- CsI(pure) has shorter decay time than CsI(Tℓ).
- Pipeline readout w/ waveform analysis.
  → Combined effect of shorter decay time and timing information suppresses fake clusters by factor 30;
  Pileup noise will be reduced by factor 5.

Other ECL endcap options: BSO or $PbWO_4$

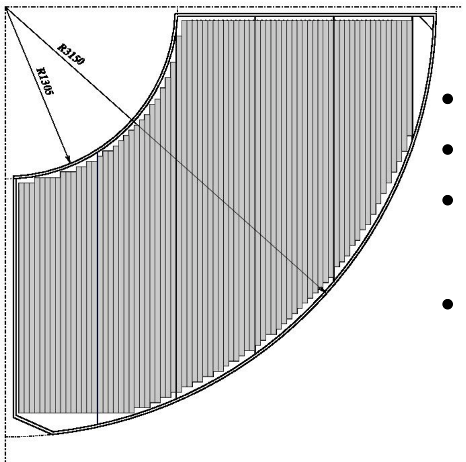
- Pro: better 2 shower resolution …
- Con: mechanical strength …

KLM endcap upgrade

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



KLM endcap general layout



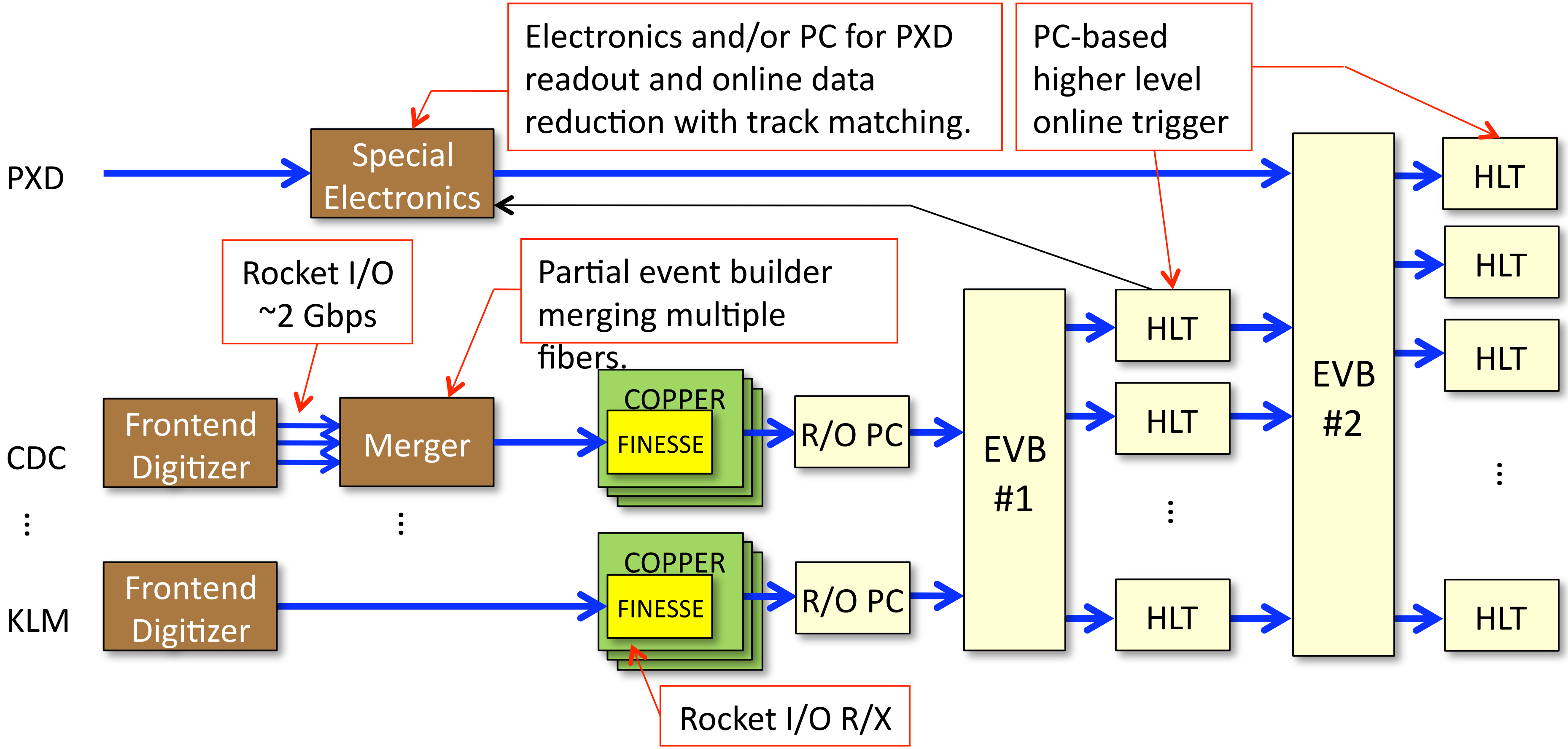
- 4cm width / strip.
- 75 strips / sector.
- 2-superlayer structure; orthogonal each other
- 4% dead zone in total due to cables, supports, etc.

Readout System

Anticipated data size [kB/ev]

PXD	100	ARICH	4
SVD	≲120	ECL	12
CDC	6	KLM	–
TOP	4	TRG	–

Design max L1 rate: 30kHz
L1 latency: 5μs



Belle II Short-Term Schedule

- **Technical design report**
  - The preliminary version of TDR will be released around the end of February (or beginning of March).

- **The 5th open meeting of the Belle II collaboration**
  - The Belle II group meeting is held from March 31st to April 2nd to make an important step toward finalizing the detector design.

Belle II and LHCb

	Belle	Belle II	Belle II	LHCb
	~ 0.5 ab^{-1}	5 ab^{-1}	50 ab^{-1}	10 fb^{-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	---
ϕ_s 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%	–
$B_s\to\mu\mu$	?	?	?	5σ @ 6 fb^{-1}
$\tau\to\mu\mu$ [$\times 10^{-9}$]	<45	<30	<8	---
$\tau\to\mu\mu\mu$ [$\times 10^{-9}$]	<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 would co-reveal the New Physics**
  - Belle II has advantages in modes with γ, π^0; modes with ν; modes with K_S vertex reconstruction; … ($B\to\tau\nu$, $b\to sq\bar{q}$, τ LFV…)

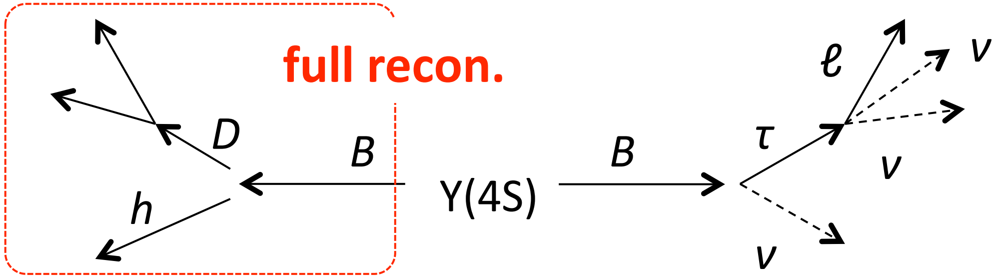
Summary

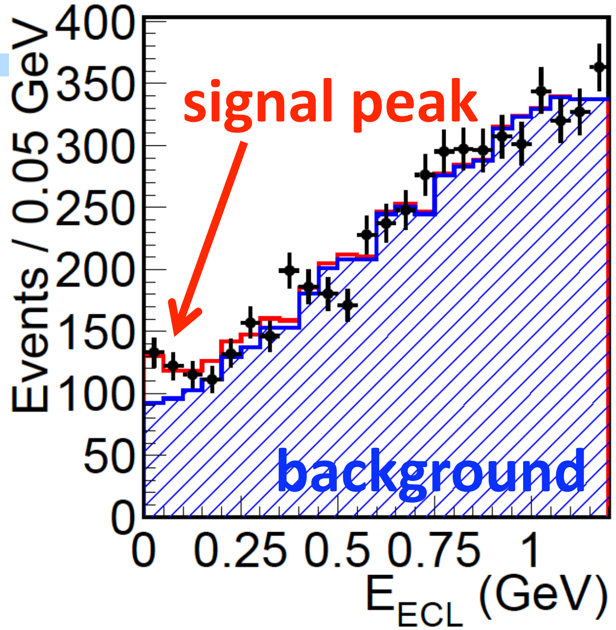
- Grand reprocess has been finished.
- Readout components of Belle II are tested in Belle.
- NP searches with $b \to s\ell^+\ell^-$ are recently published.
- Belle has observed several hints of the NP
  to be revealed by Belle II.

- Significant efforts on Belle II upgrade are carried out.
- In a coming few weeks, we publish Belle II TDR.
- Belle II and LHCb would co-reveal the nature of the NP.

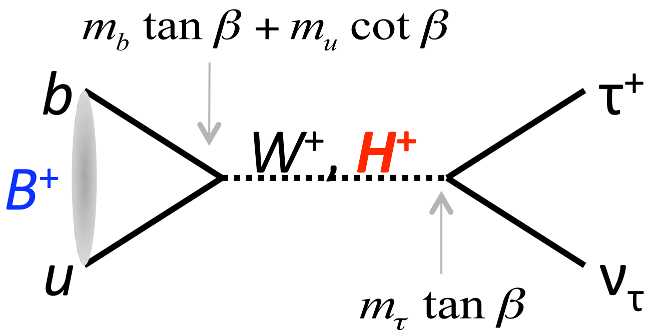
Backup

$B^+ \rightarrow \tau^+ \nu_\tau$





As $B \rightarrow \tau\nu$ includes 2 or more neutrinos in decay, opposite side B needs fully reconstructed.



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

$$Br\big|_{\text{meas.}} = (1.73 \pm 0.35)\times 10^{-4}$$

$$Br\big|^{\text{CKMfit}}_{\text{w/o } B\rightarrow\tau\nu} = \left(0.786^{+0.179}_{-0.083}\right)\times 10^{-4}$$

2.4σ deviation

Constraint on tanβ and m_{H+} relation is imposed.

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

The “Big Two”

Energy frontier

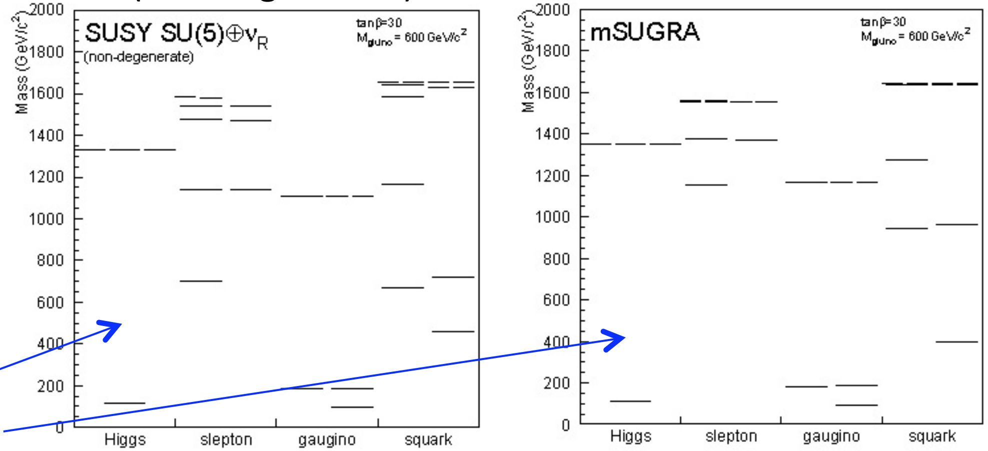
Direct detection of SUSY particles

Mass spectra are insufficient to figure out the SUSY model.

Similar mass spectra show up across different SUSY models.

SU(5)+ν_R (non-degenerate)

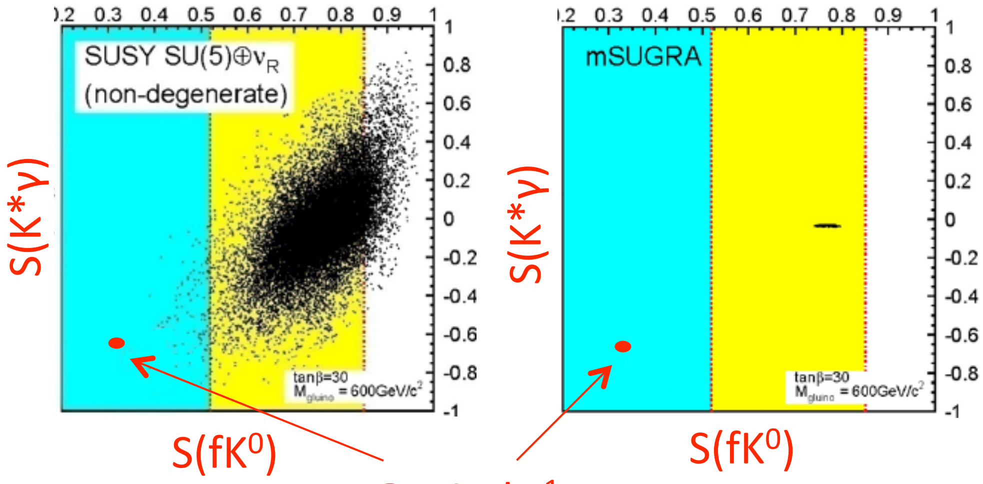
mSUGRA



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.



OPE and Wilson Coefficient

- **Effective Hamiltonian is expressed in term of Operator Product Expansion.**

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

  - $O_{1,2}$: current current operator
  - $O_{3\text{-}6}$: QCD penguin operator
  - O_7: electro- magnetic operator
  - O_8: chromo-magnetic operator
  - O_9 : semileptonic vector operator
  - O_{10} : semileptonic axial vector operator
  - C_i : Wilson coefficient
- **Wilson coefficient is a strength of corresponding short distance operator.**
- **Precise measurement of Wilson coefficients is one of the goals for B physics.**
- **For $b \to s\gamma$ and $b \to \ell\ell$ case, only O_7, O_9 and O_{10} appear in the Hamiltonian.**

$$\begin{aligned}
\mathcal{O}_1 &= (\bar{s}_\alpha \gamma_\mu L c_\beta)(\bar{c}_\beta \gamma^\mu L b_\alpha), \\
\mathcal{O}_2 &= (\bar{s}_\alpha \gamma_\mu L c_\alpha)(\bar{c}_\beta \gamma^\mu L b_\beta), \\
\mathcal{O}_3 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu L q_\beta), \\
\mathcal{O}_4 &= (\bar{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu L q_\alpha), \\
\mathcal{O}_5 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\beta), \\
\mathcal{O}_6 &= (\bar{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\alpha), \\
\mathcal{O}_7 &= \frac{e}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) b_\alpha F^{\mu\nu}, \\
\mathcal{O}_8 &= \frac{g}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) T^a_{\alpha\beta} b_\beta G^{a\mu\nu}, \\
\mathcal{O}_9 &= \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{\ell} \gamma_\mu \ell, \\
\mathcal{O}_{10} &= \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{\ell} \gamma_\mu \gamma_5 \ell,
\end{aligned}$$

New Physics may change Wilson coefficients.