Physics prospects and plan of SuperKEKB/Belle II

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On behalf of the Belle II collaboration

IHEP ИФВЭ

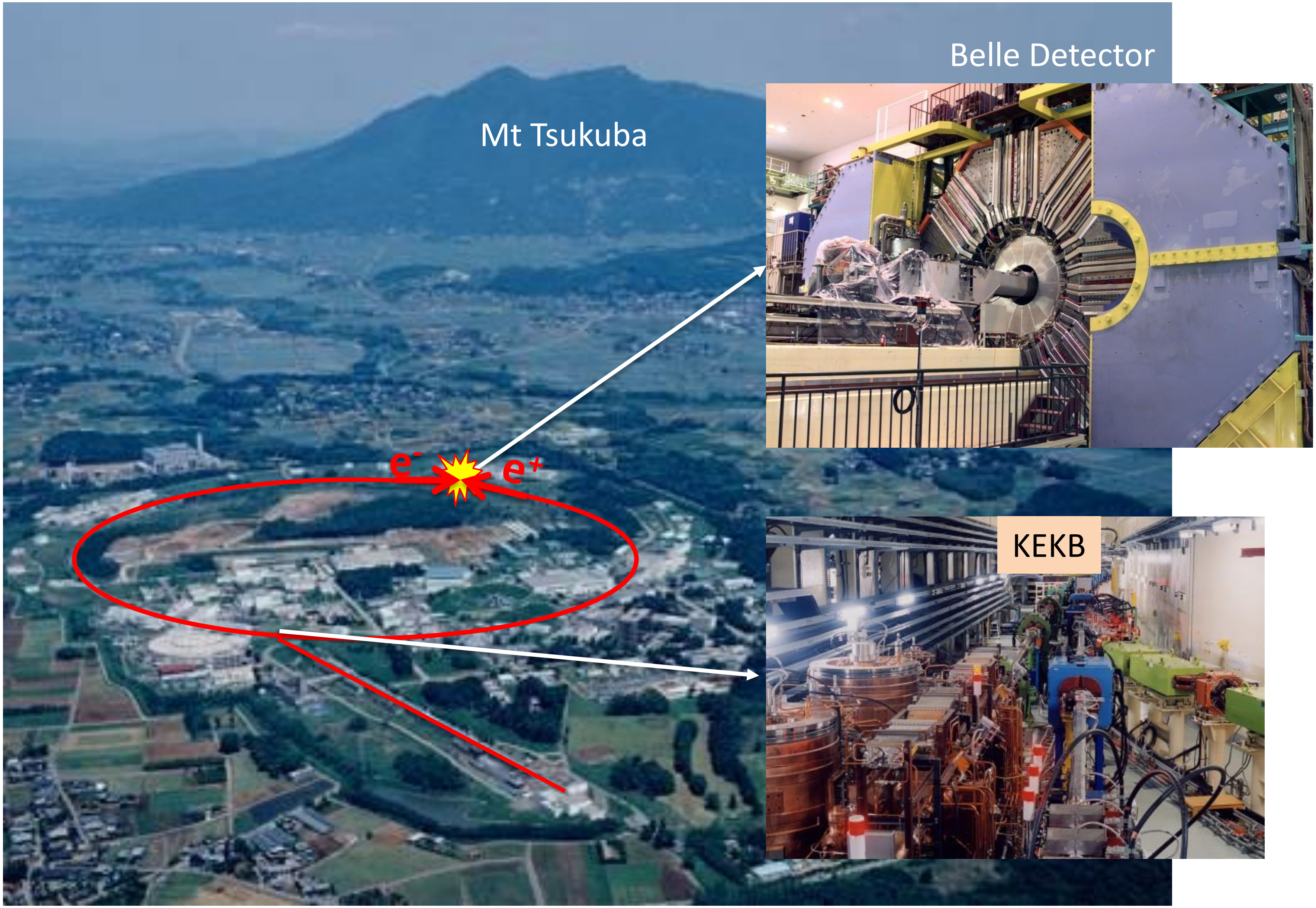
Super KEKB

Belle II

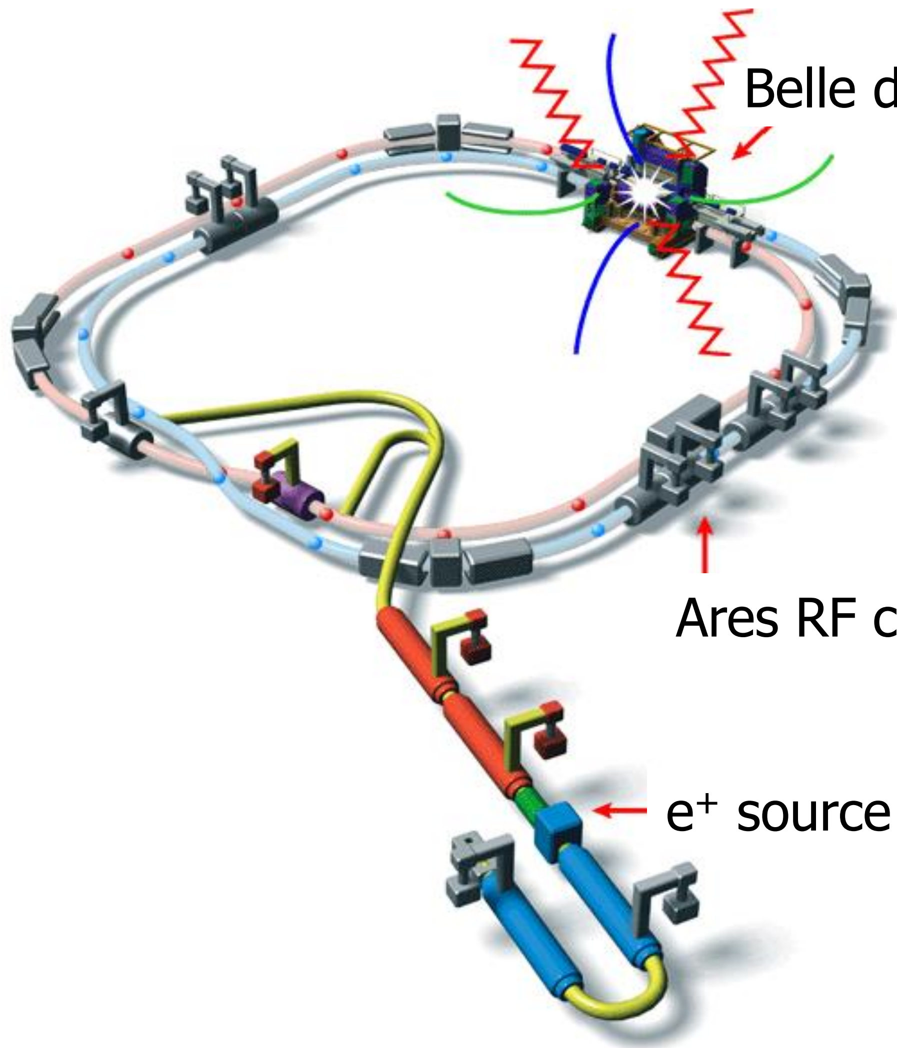
Outline

- KEKB and Belle
- Physics Achievement and Prospects
- SuperKEKB and Belle-II

KEK Laboratory, Tsukuba Japan



The KEKB Collider



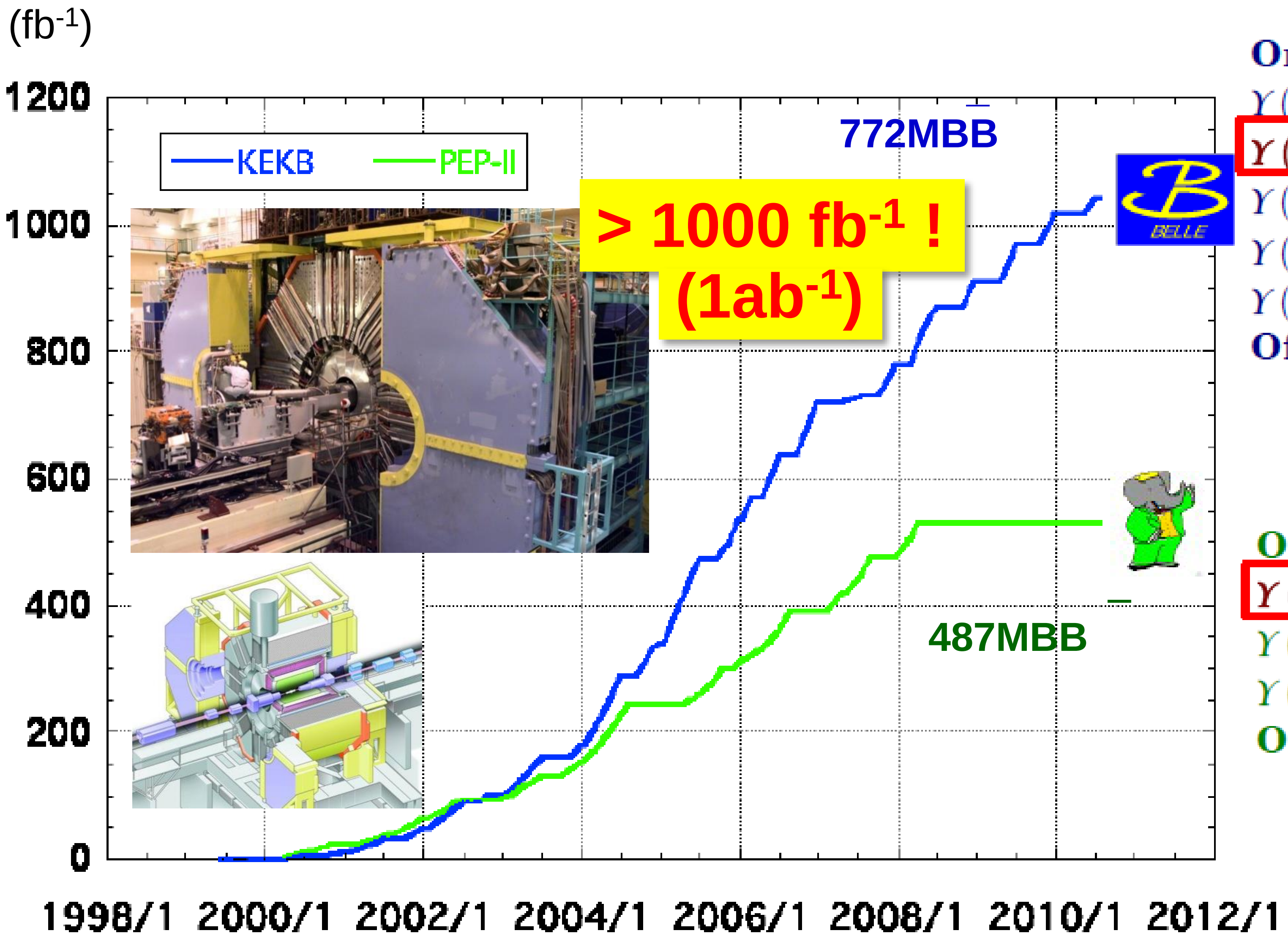
- Asymmetric energy collider (8 GeV e^- x 3.5 GeV e^+)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$ ($\Upsilon(nS)$, n=1,2,3,5)
  - Lorentz boost: $\beta\gamma = 0.425$
- Finite angle beam crossing (22mrad)

Peak luminosity (WR!) :
2.1×10^{34} cm^{-2}s^{-1}
=2x design value

First physics run on June 2, **1999**
Last physics run on June 30, **2010**
$L_{peak} = 2.1\times10^{34}/cm^2/s$

$\int \mathcal{L}\, dt = 1.04\ ab^{-1}$

Data at KEKB/Belle



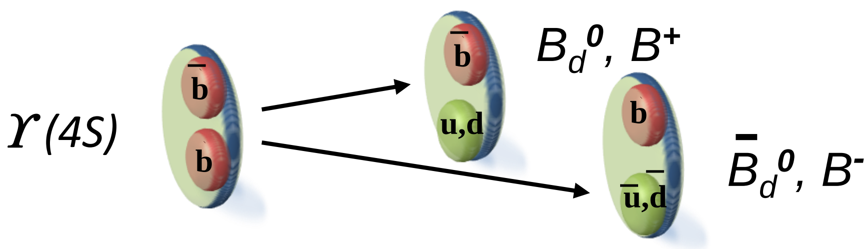
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 24 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Physics at B factory

Accelerator

"B-Factory", KEKB @, KEK



"on resonance" production

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_d^0\bar{B}_d^0, B^+B^-$

$\sigma(e^+e^- \rightarrow B\bar{B}) \approx$ 1.1 nb (~10^9 $B\bar{B}$ pairs)

"continuum" production

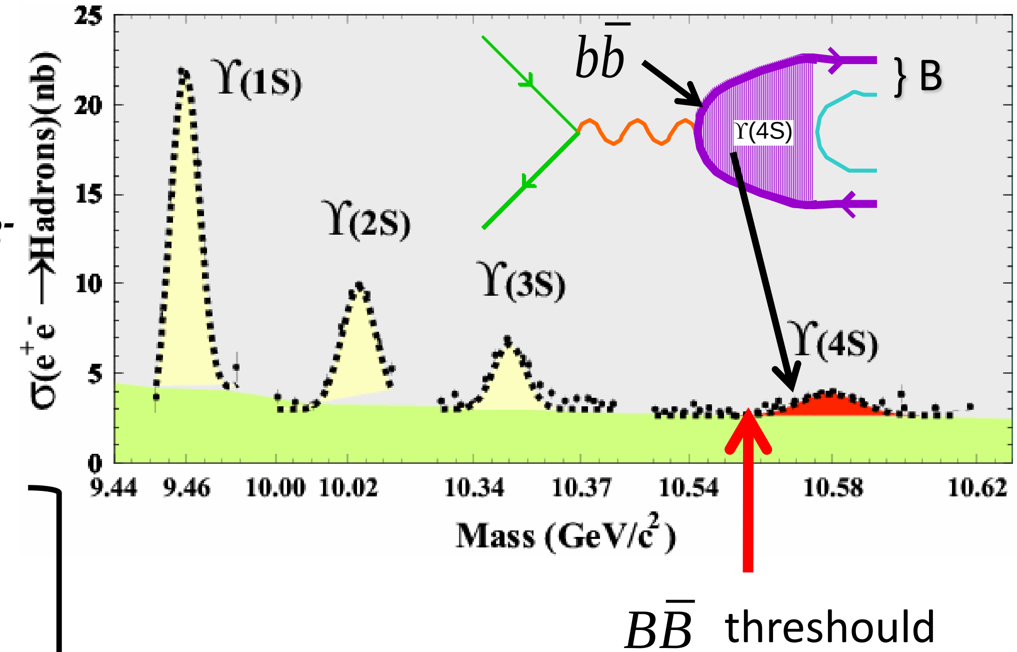
$\sigma(e^+e^- \rightarrow c\bar{c}) \approx$ 1.3 nb (~1.3×10^9 $X_c\bar{Y}_c$ pairs)

$\tau^+\tau^-$ production

$\sigma(e^+e^- \rightarrow \tau^+\tau^-) \approx$ 0.9 nb (~0.9×10^9 $\tau^+\tau^-$ pairs)

Running at $\Upsilon(nS)$, e.g. $\Upsilon(5S) \rightarrow (B_s\bar{B}_s)$

Belle $\int \mathcal{L}dt \approx 1020$ fb^{-1}



Variety of Physics

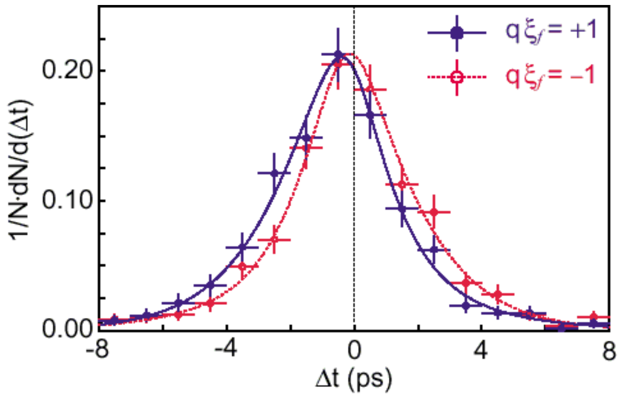
Primary goal: search for and study of CP violation in weak decays of B meson

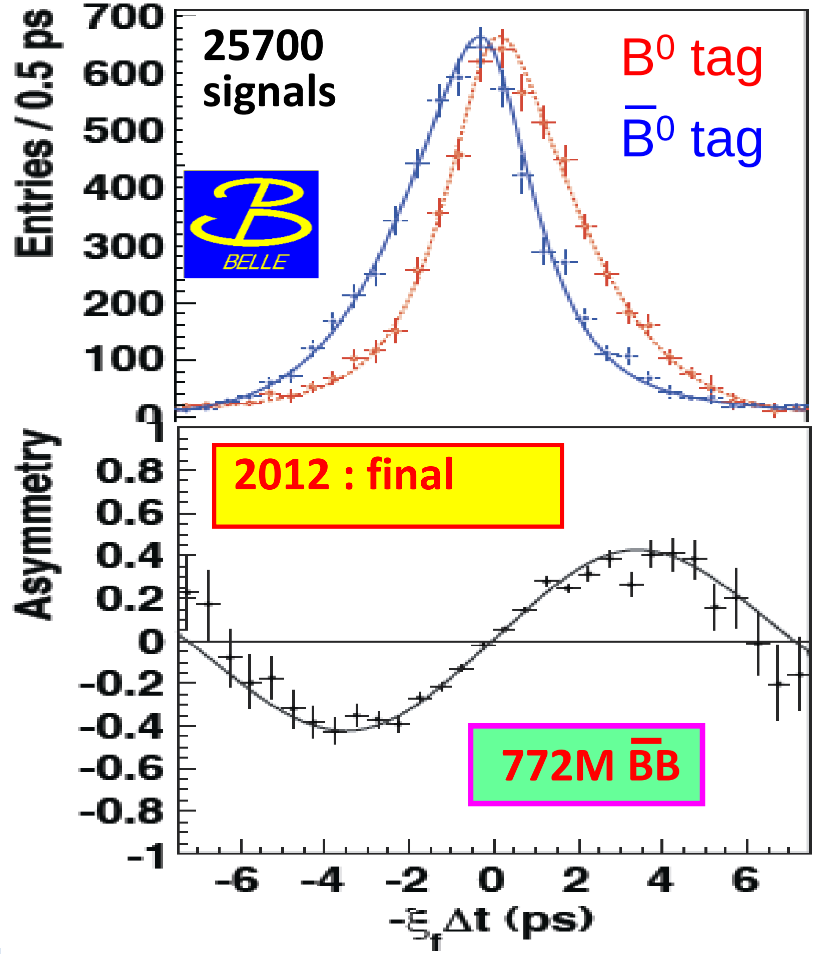
DONE !

Discovery of CPV in B decays

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

2001（31M $B\bar{B}$） **Discovery!**





$$A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\bar{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}$$

$$= -\xi_f \sin 2\phi_1 \sin \Delta m \Delta t$$

Precise Measurement [PRL 108, 171802 (2012)]

$\sin 2\phi_1 = 0.667 \pm 0.023$ (stat) ± 0.012 (syst)

Complete Test of KM & SM

Measurements of CKM

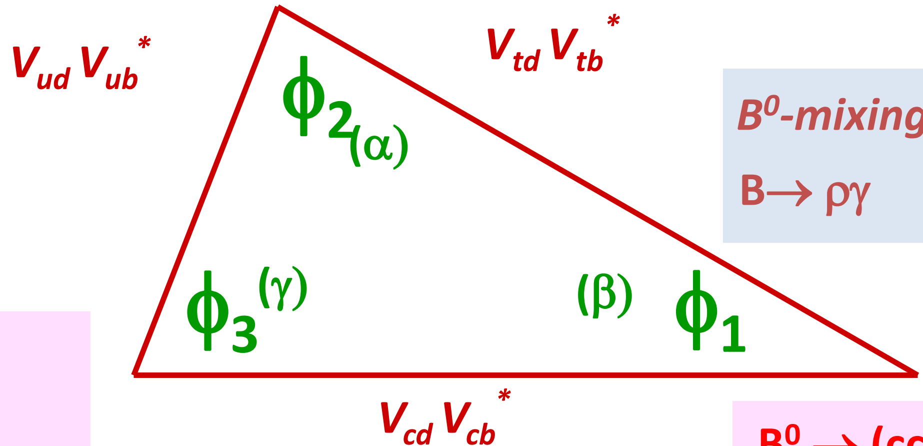
Determination of UT

LQCD: important roles

$B \to \pi\pi$, $\rho\pi$, $\rho\rho$

$b \to u\, l^- \nu$

$B \to \pi/\rho\ l\ \nu$



B^0-mixing (Δm_d)

$B \to \rho\gamma$

$B^- \to D_{com}K^-$

$B^0 \to D^{(*)+}\pi^-$

$b \to c\ l^- \nu$

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

$B^0 \to (cc)K^{(*)0}$

$B^0 \to D^{*+}D^{(*)-}(K)$

Over constraint !

B experiments can provide all measurements !

B - Factories (KEKB&PEP-II): A Success Story

Quantitative confirmation of the KM model in the SM

The Nobel Prize in Physics 2008

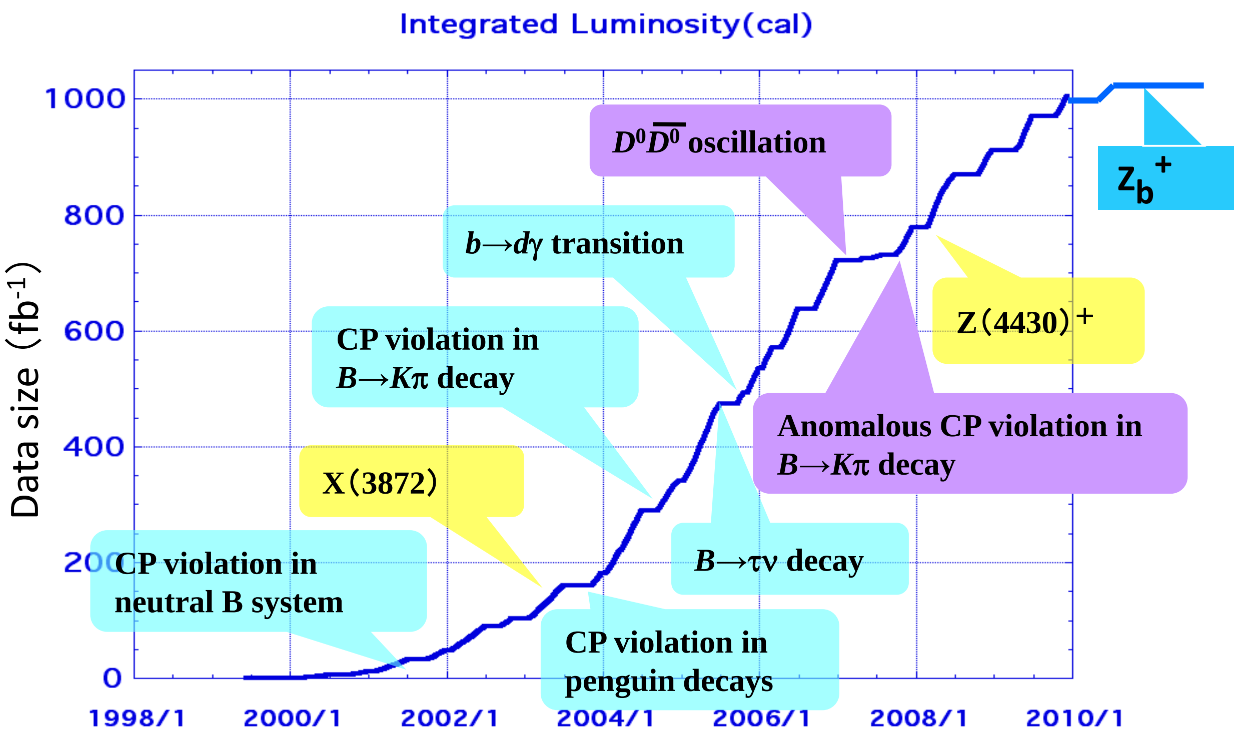
KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Press Release

7 October 2008

**"… As late as 2001, the two particle detectors
BaBar at Stanford, USA and Belle at Tsukuba, Japan,
both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa
had predicted almost three decades earlier."**

KEKB/Belle results



Excellent KEKB performance allowed BELLE experiment to obtain many exciting results

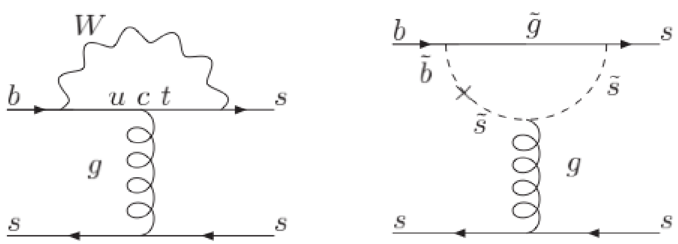
Variety of Successes from B Factories

Belle II physics: Searching physics beyond the SM using indirect probes

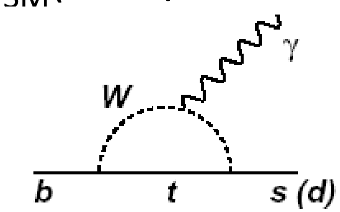
SM is a valid effective theory at the current E-scale

LHC - New Physics beyond SM at **High Energy scale**
B-, charm-, τ-factories – search for NP using **indirect probes**
(like *c*-quark prediction from the $K_L \to \mu^+\mu^-$ suppression; m_c estimation from Δm_K)

Precision test of CKM unitarity
- CKM verified to ~$\mathcal{O}$(10%)
(search for new CP violating phases - $b \to sqq$tCPV)



Rare B decays - FCNC
(virtual contributions of new heavy particles in loops-
$b \to s(d)\gamma$, $b \to s(d)\ell^+\ell^-$, …)
A_{NP}~ A_{SM}(small/forbidden)



???

Rare B decays - search for the charged Higgs boson in $B \to \tau\nu$ and $B \to D(*)\tau\nu$ decays ($\tau \leftrightarrow H^{\pm}$)

Search for lepton flavor violation in τ decays (SUSY breaking mechanism, right-handed neutrino couplings)
(Lepton Flavor Violation = NP)
B-factory = τ-factory

LHC vs SuperKEKB

In order for the flavor physics to be useful in the coming LHC era, the precision of various flavor measurements must be significantly improved, both in terms of experimental reach and understanding of theoretical uncertainty

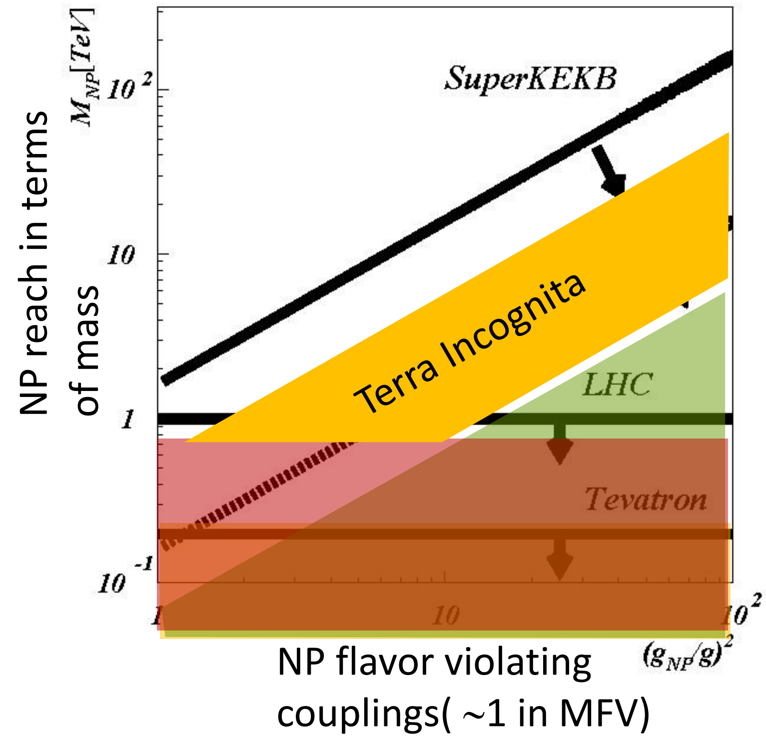
B Factories (**BF**) $\rightarrow$ Super B Factory (**SBF**)

•$\sigma \propto 1/\sqrt{N} \Rightarrow \mathcal{O}(10^2)$ higher luminosity

•complementarity to other intensity frontiers experiments (LHCb, BES III, ...);

•accurate theoretical predictions to compare to

Illustrative reach of NP searches



$\int \mathcal{L}\, dt \approx$ **1 ab^{-1}**

$\int \mathcal{L}\, dt \approx$ **50ab^{-1}**

Complementary to LHC Searches

- Study of modes with missing energy

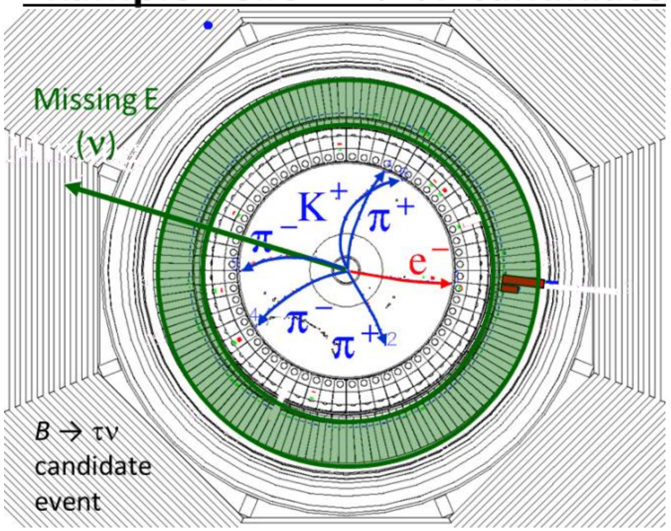
  $B \rightarrow \tau\nu$, $B \rightarrow D^{(*)}\tau\nu$, $B \rightarrow K^{(*)}\nu\nu$

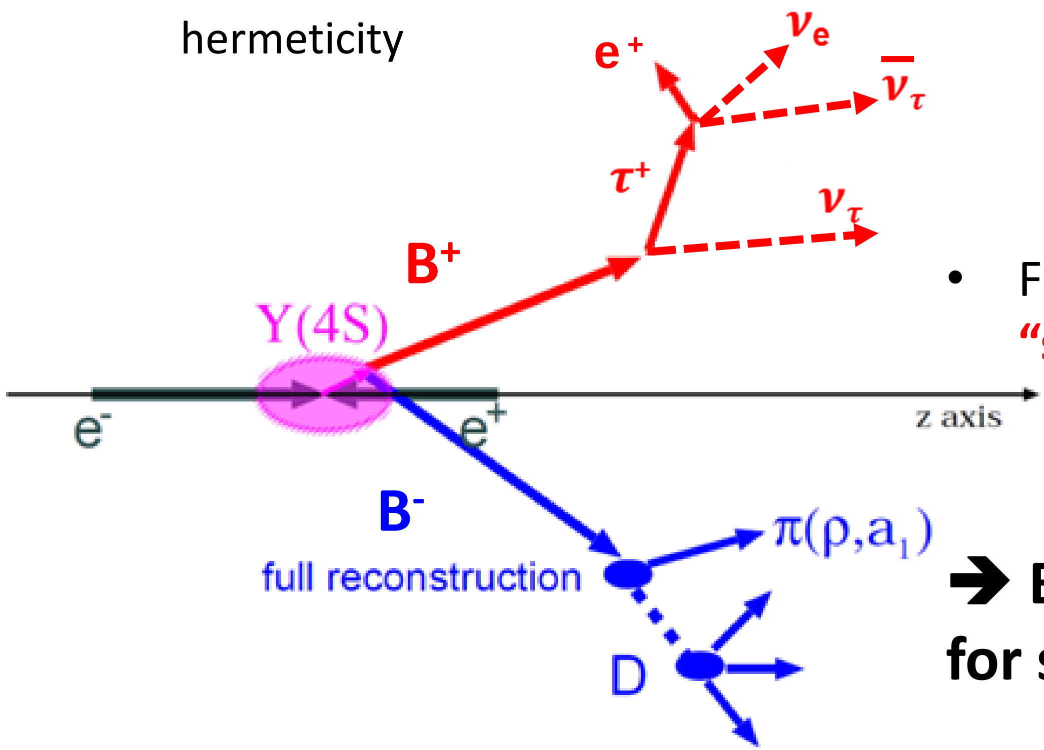
  – Multiple neutrinos! Significant missing energy.

- These are very challenging experimentally…

  – Rely on clean e+e- environment and detector hermeticity

Example Belle B → τν candidate

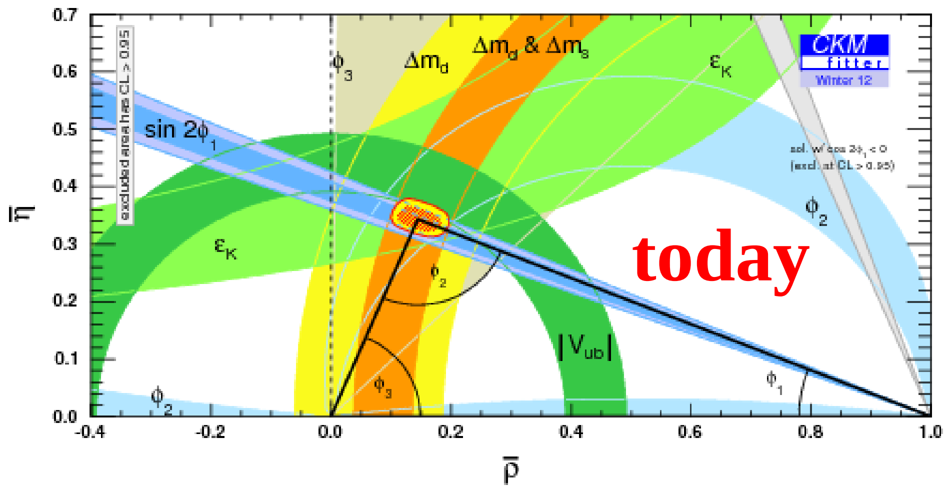


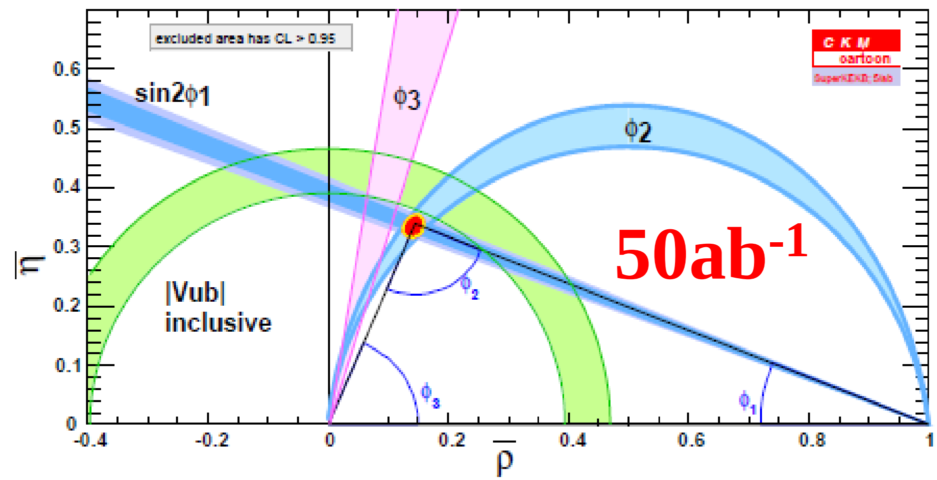


- Fully reconstruct **"tag"** ***B*** to determine **"signal"** ***B*** flavor, charge, momentum.

➔ **B factories are uniquely suited for such measurements!**

Precise CKM



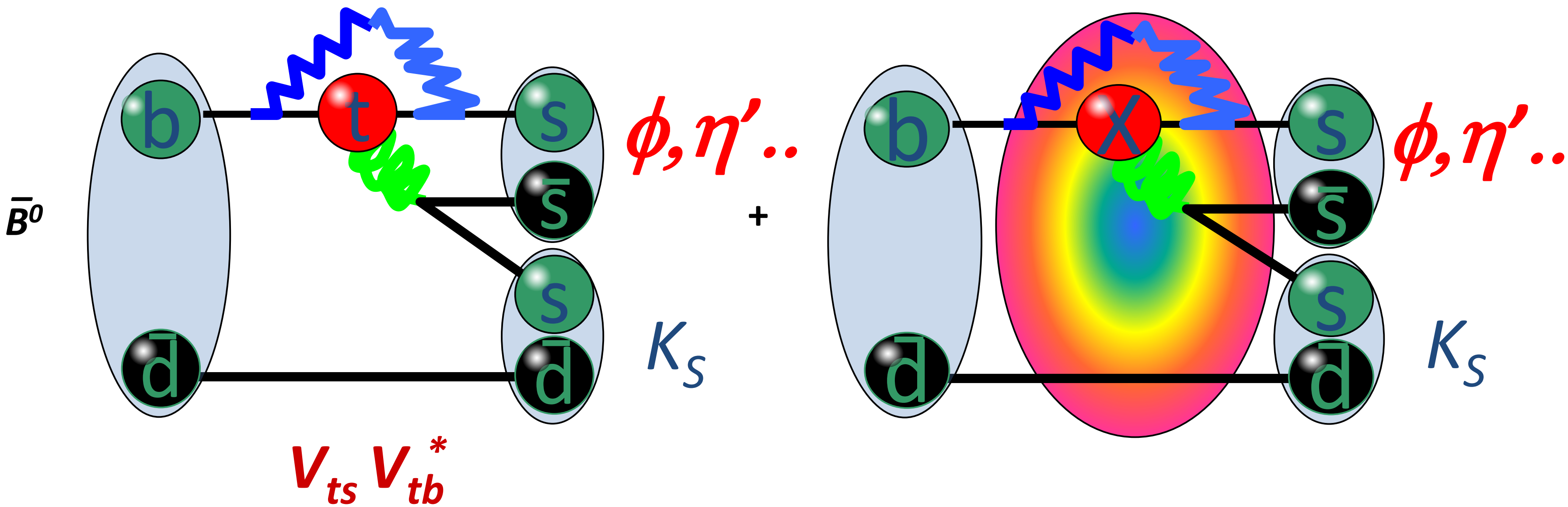


Observable	Belle 2006 ($\sim$0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	†LHCb (2 fb^{-1})	†LHCb (10 fb^{-1})
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	$\sim$0.02	$\sim$0.01
ϕ_2 $(\pi\pi)$	11°	10°	3°	-	-
ϕ_2 $(\rho\pi)$	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 $(\rho\rho)$	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 $(D^{(*)}K^{(*)})$ (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 $(DK^{(*)})$ (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 $(D^{(*)}\pi)$	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\lvert V_{ub}\rvert$ (inclusive)	6%	5%	3%		
$\lvert V_{ub}\rvert$ (exclusive)	15%	12% (LQCD)	5% (LQCD)		
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

BELLEII in many cases is more sensitive to UT parameters than LHCb

Physics at Super B factory: arXiv:1102.5012v1

New Source of CPV: $b \to sq\bar{q}$



$B^0 \to \phi K^0$ ~ $B^0 \to J/\psi K^0$ $\quad$ $B^0 \leftrightarrow \bar{B}^0$ is the same

Decay

SM: b→s Penguin	**+ New Physics**
phase = ($c\bar{c}$) K^0 (tree)	**with New Phase**
$S_{bs} = S_{bc}$, $A_{DCP} = 0$	$S_{bs} \neq S_{bc}$, A_{DCP} can $\neq 0$

"$b \to c\bar{c}s$: $\sin 2\phi_1$" (SM reference) ⟹ **deviation**

Summary of New CPV search

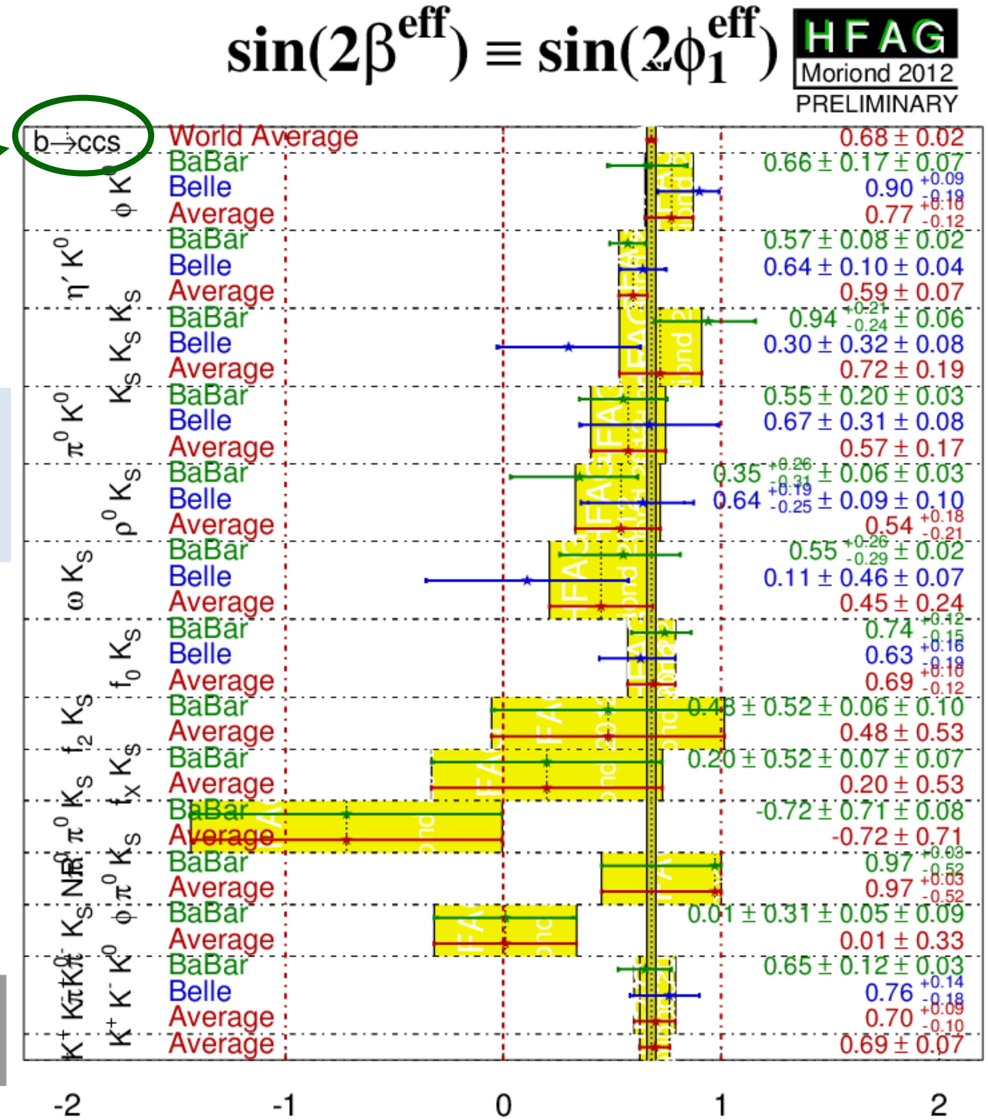
$B^0 \to J/\psi K^0$

Reference point of SM

No clear deviation seen in all modes (1~2σ)

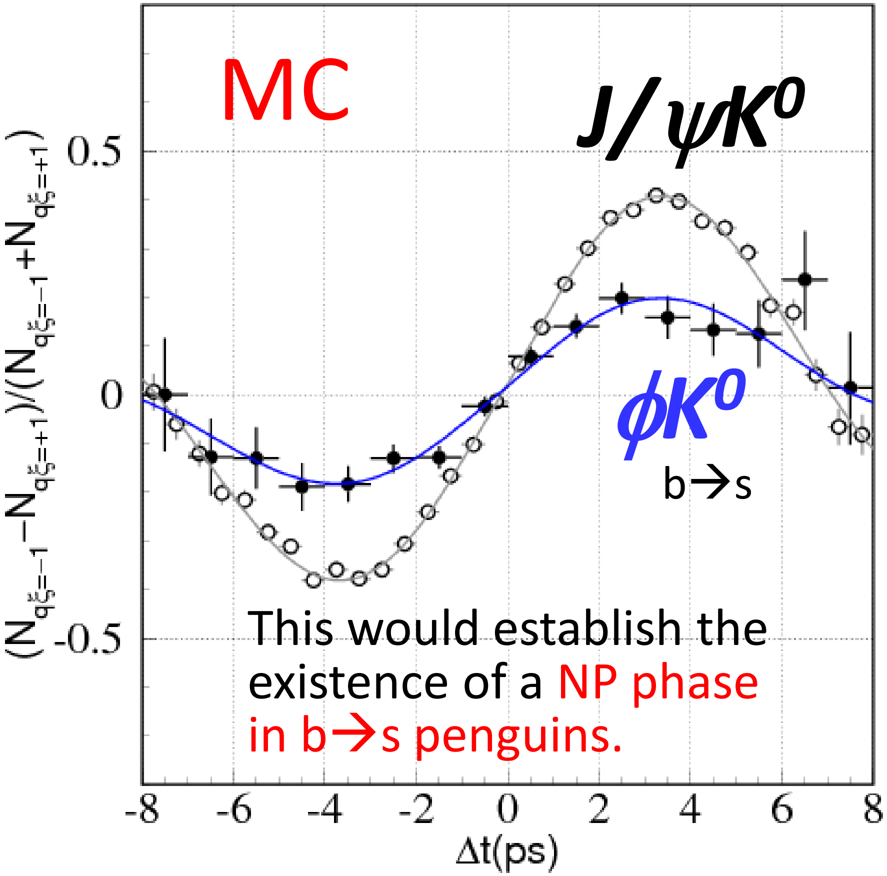
New CPV effect can be seen with much larger data

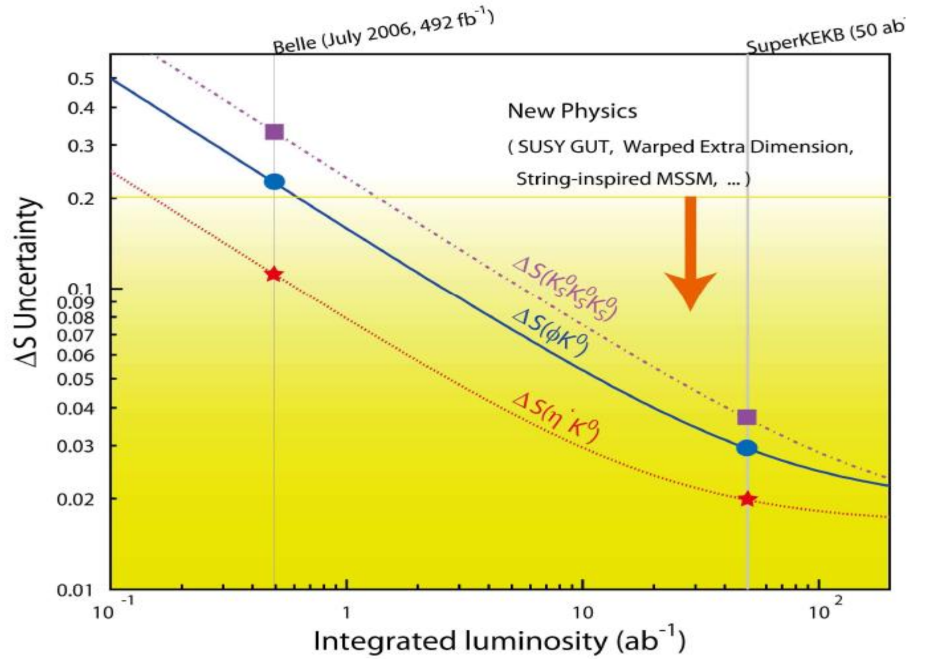
Super B-factory



SuperKEKB prospect

$B \to \phi K^0$ at 50/ab with ~2010 WA values

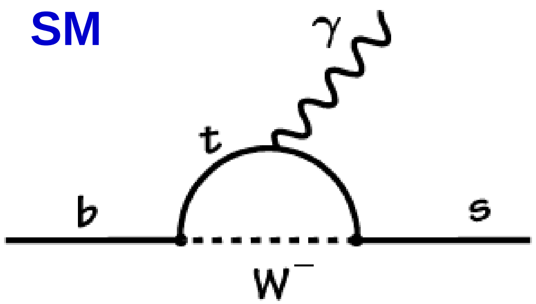


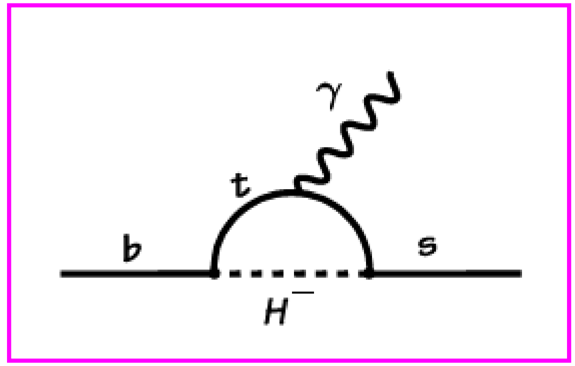


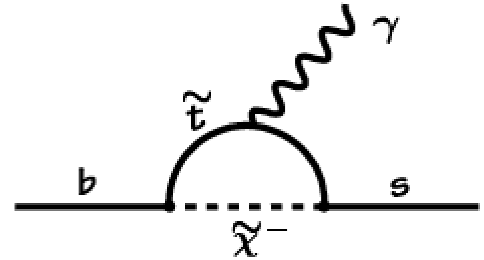
Prospect $\delta(S_{b\to s}) \sim 0.02$ @ $50ab^{-1}$

$b \to s(d)\,\gamma$

SM







- precise measurement of inclusive $B \to X_s\gamma$ branching fraction
- measurement of inclusive $B \to X_d\gamma$ branching fraction
- direct CP violation: $B \to X_s\gamma$, $B \to K^*\gamma$, $B \to X_s l^+l^-$ and so on
- time-dependent CP violation in $B \to K^*\gamma$, $B \to \rho\gamma$ and related modes
- measurement of photon polarization with photon-conversion
- measurement of the forward-backward asymmetry and q^2 distribution of $B \to K^* l^+l^-$ and $B \to X_s l^+l^-$
- lepton flavor dependence of $B \to s l^+l^-$

Time-dependent CPV in $B \to K^{*}\gamma$ decay

$B \to K^* (\to K_S \pi^0)\gamma$
t-dependent CPV

SM:
$S_{CP}^{K^*\gamma} \sim -(2m_s/m_b)\sin 2\phi_1 \sim -0.04$

Left-Right Symmetric Models:
$S_{CP}^{K^*\gamma} \sim 0.67 \cos 2\phi_1 \sim 0.5$

D. Atwood et al., PRL79, 185 (1997)
B. Grinstein et al., PRD71, 011504 (2005)

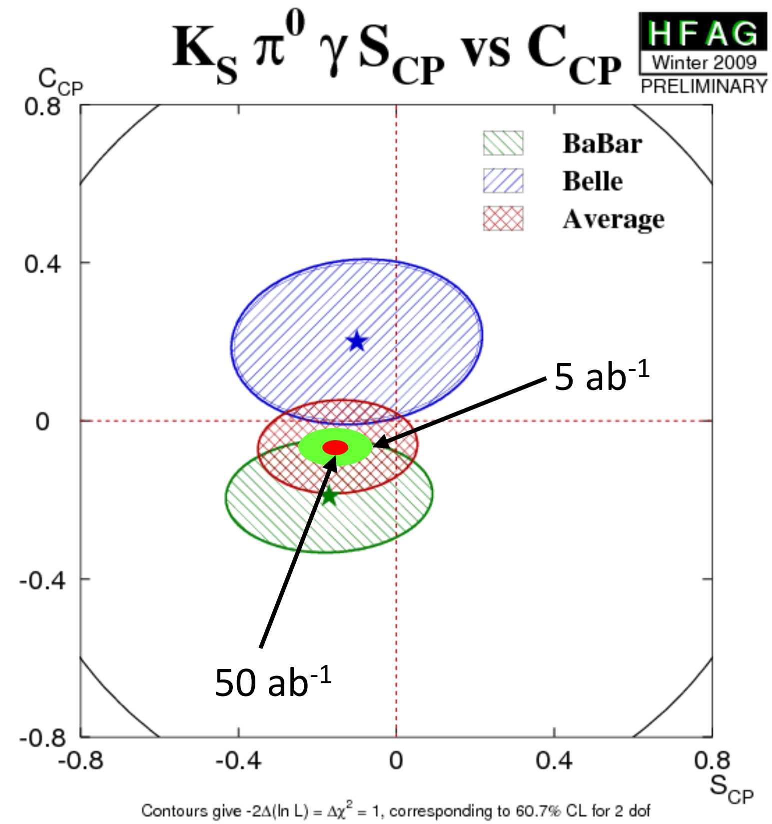
$S_{CP}^{K_S\pi^0\gamma} = -0.15 \pm 0.20$
$A_{CP}^{K_S\pi^0\gamma} = -0.07 \pm 0.12$

HFAG, Summer'11

$\sigma(S_{CP}^{K_S\pi^0\gamma}) =$ 0.09 @ 5 ab^{-1}
0.03 @ 50 ab^{-1}
(~SM prediction)

t-dependent decays rate of $B \to f_{CP}$;
S and A: CP violating parameters

$$P(B^0 \to f;\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 + S_{CP}^f \sin(\Delta m \Delta t) + A_{CP}^f \cos(\Delta m \Delta t)]$$



Example of complementarity: MSSM searches

$$m_{\tilde{q}} = m_{\tilde{g}} = 1TeV$$

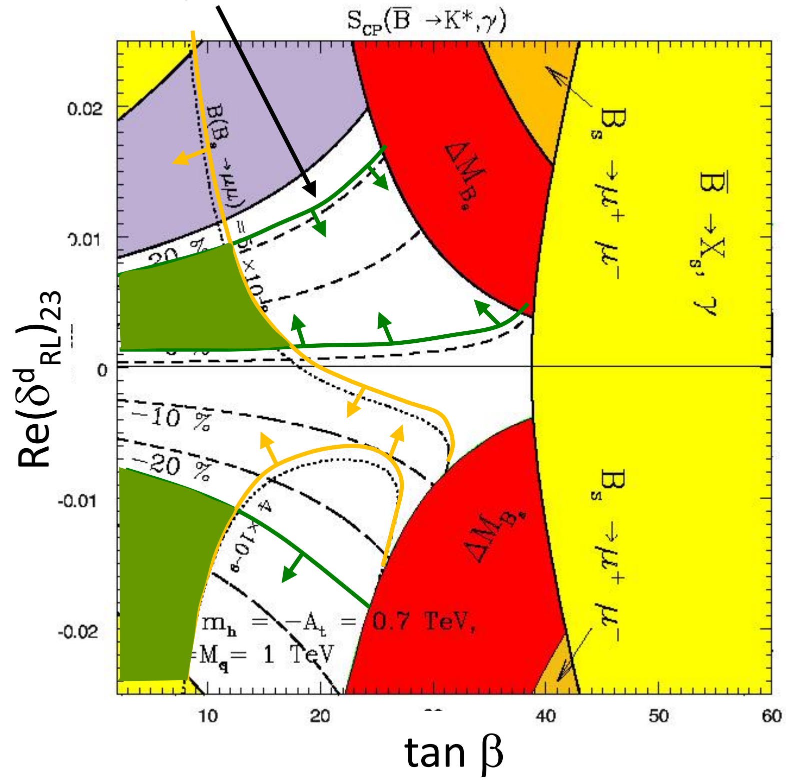
$S(K_S\pi^0\gamma) \sim -0.4\pm0.1$
$S(K_S\pi^0\gamma) \sim 0.1\pm0.1$

Belle II constraints shown @ 5 ab^{-1}

LHCb: $Br(B_s \to \mu^+\mu^-) \sim (4\text{-}5)\times10^{-9}$ (@ 3 fb^{-1})

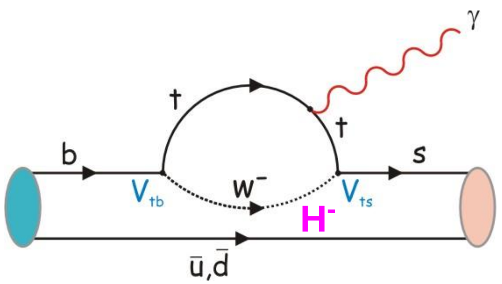
Belle II/LHCb combination: stringent limits on $Re(\delta^d_{RL})_{23}$, $\tan\beta$

contours of $S(K_S\pi^0\gamma)$



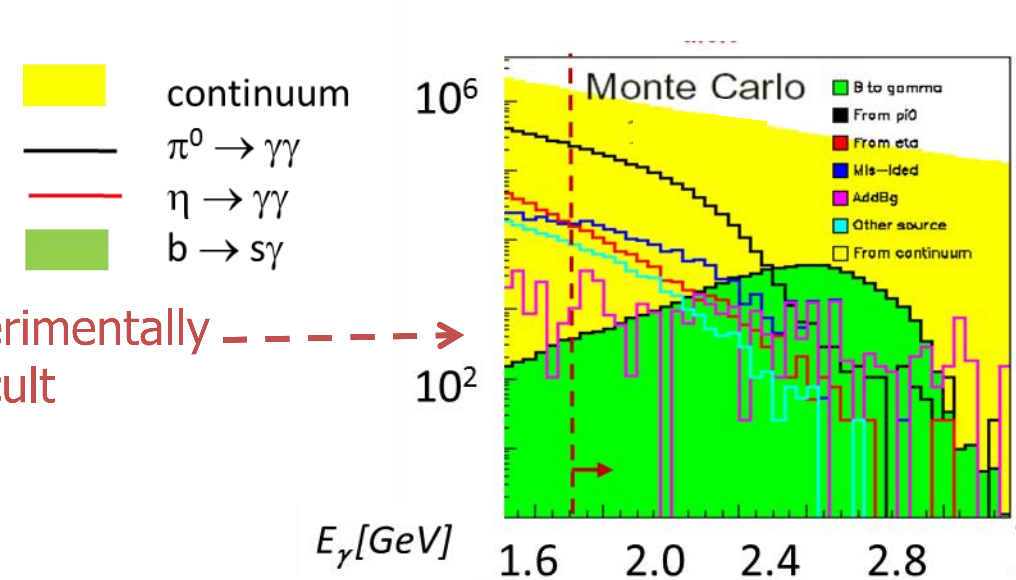
A.G. Akeroyd et al., arXiv:1002.5012

$B \to X_s\gamma$ inclusive



Radiative decay sensitive to charged Higgs

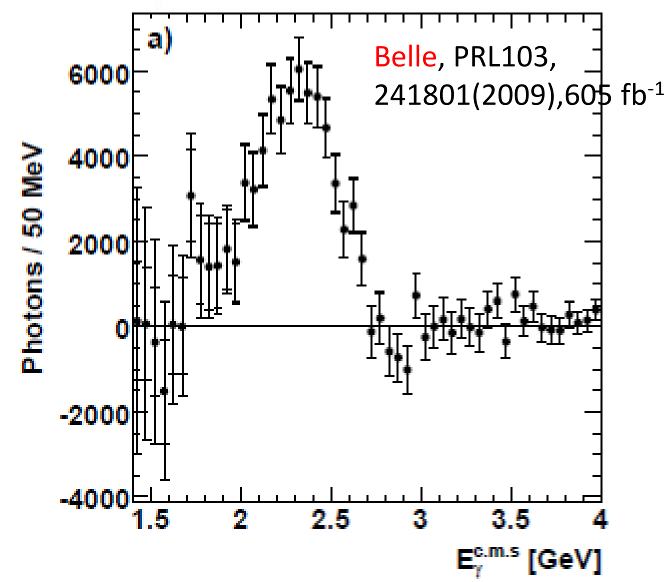
Experimentally difficult



Experiment: measure low E_γ
$\Rightarrow$ huge bkg. $\Rightarrow$ $E_\gamma > E_{cut}$

Advantage of B factories!

Only γ on signal side reconstructed
Improve S/B by tagging the other B



Theory:
parameter extraction from partial Br($E_\gamma > E_{cut}$) $\Rightarrow$ extrapolation needed;

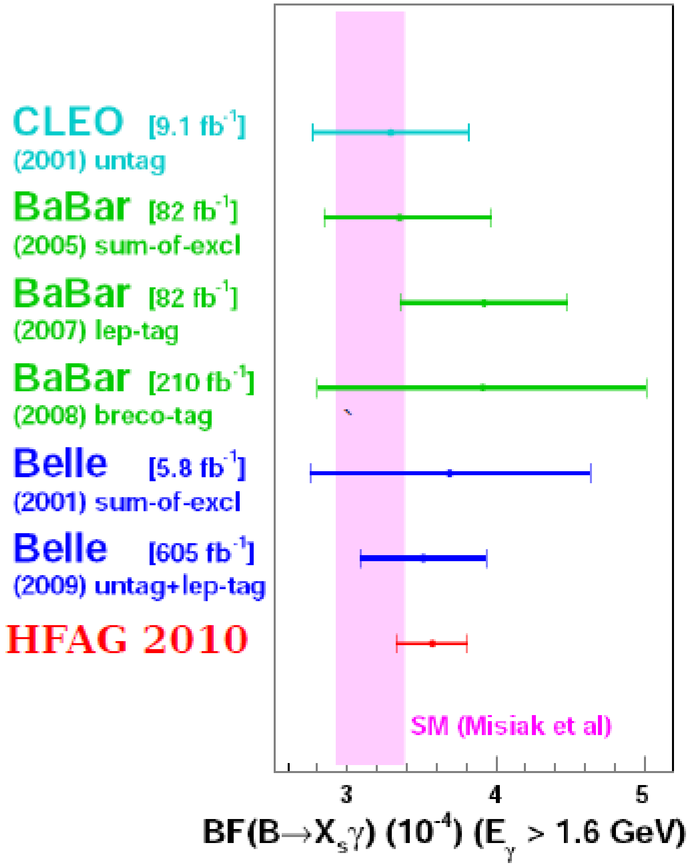
$$\mathcal{B}(B \to X_s\gamma; 1.7\,GeV < E_\gamma < 2.8\,GeV) = (3.47 \pm 0.15 \pm 0.40)\cdot 10^{-4}$$

$B \to X_s\gamma$ summary

$$\text{HFAG 2010: } \mathcal{B}(B \to X_s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \text{ (for } E_\gamma > 1.6 \text{ GeV)}$$

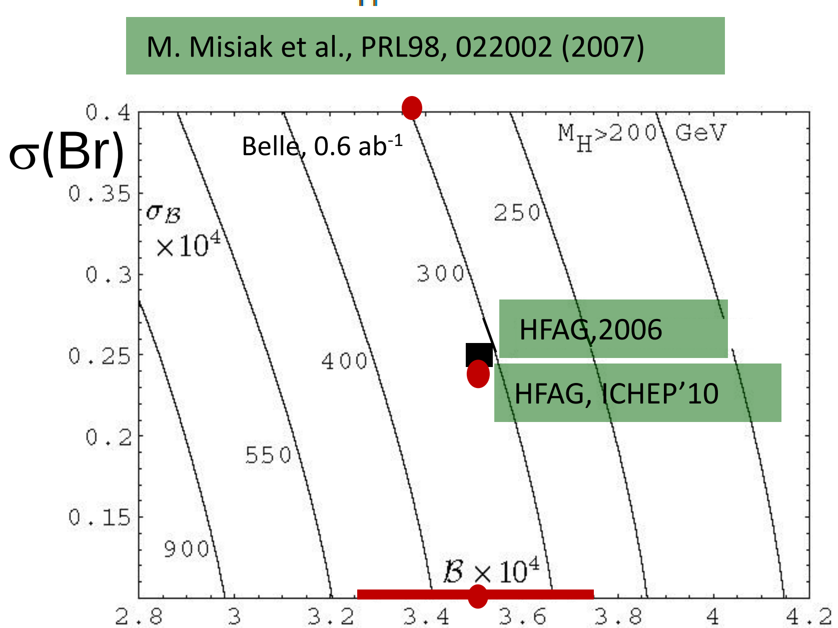
vs

$$\text{SM: } \mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4} \text{ (for } E_\gamma > 1.6 \text{ GeV)}$$



Charged Higss bound (2HDM TypeII)

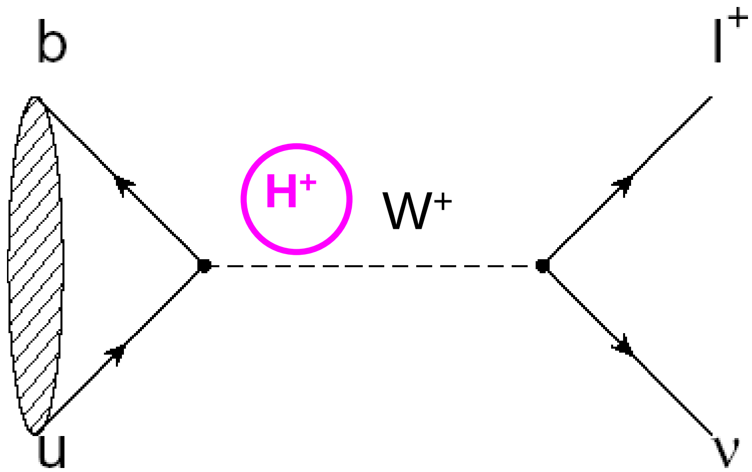
$M_{H^+} > 300$ GeV



H^+ Search: $B^+ \rightarrow \tau^+ \nu_\tau$

(Decays with *Large* Missing Energy)

Sensitivity to new physics from charged Higgs



SM:

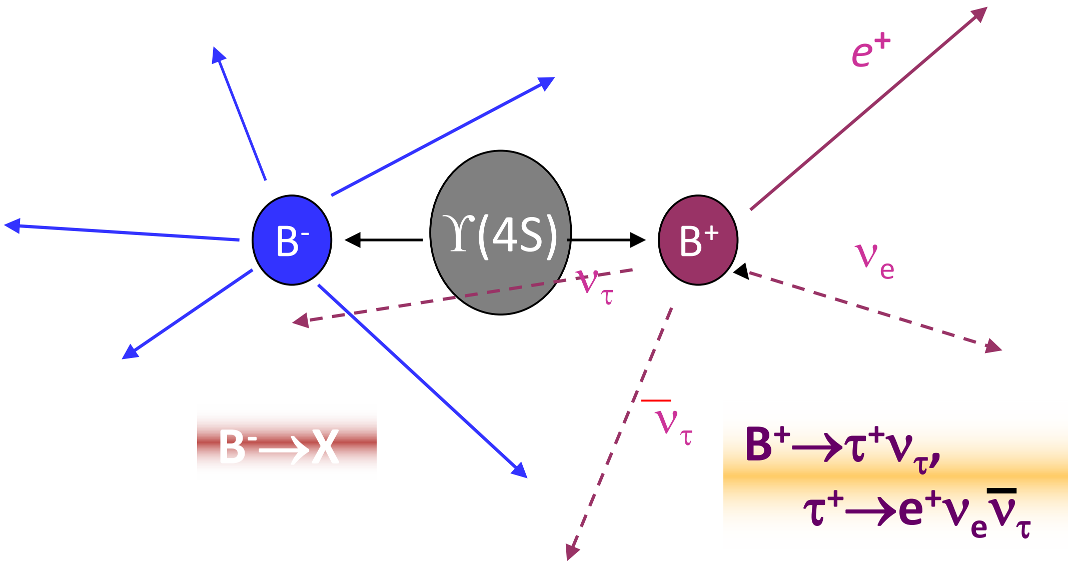
$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

The B meson decay constant

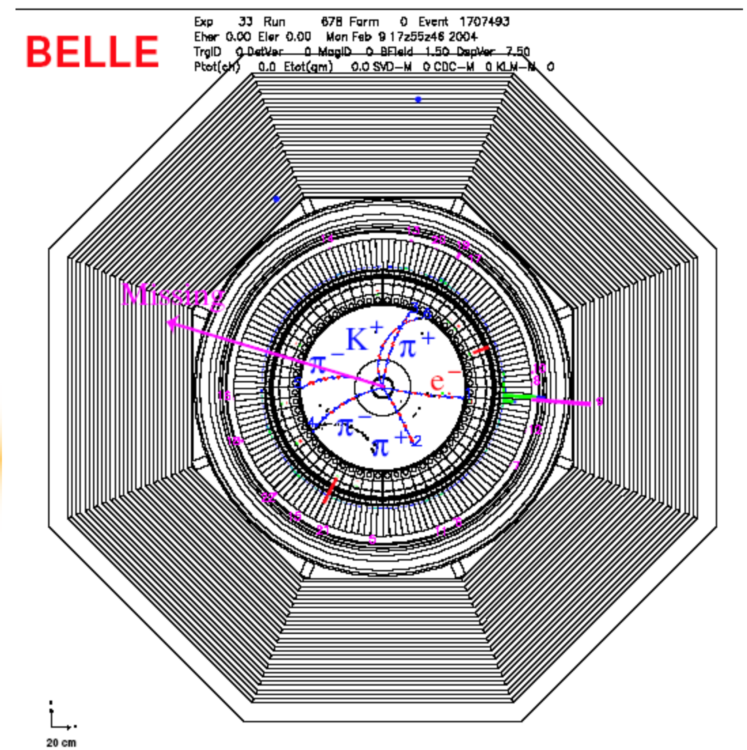
LQCD

$|V_{ub}|$: from indep. measurements.

B–>τν : Experimental Challenge



$B^+ \to \tau^+ \nu_\tau$,
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$

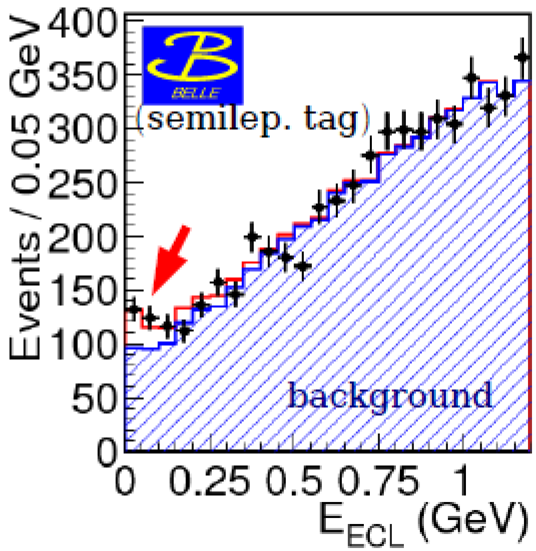


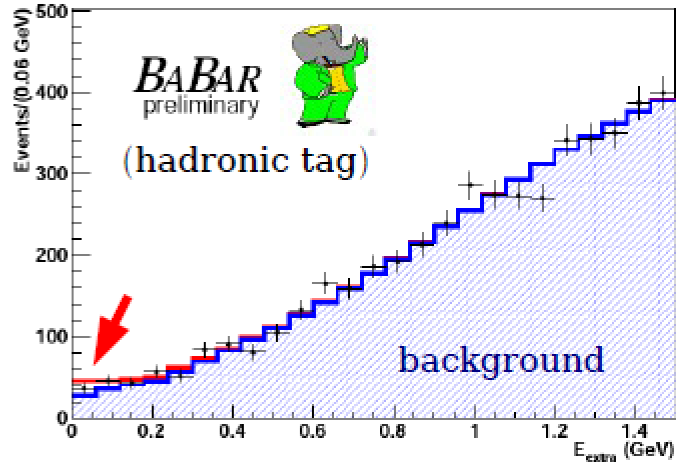
Always ≥ 2 neutrinos appear in B → τ ν decay

Signature : 1 track +invisible

Experimental Challenge !

B–>τν results

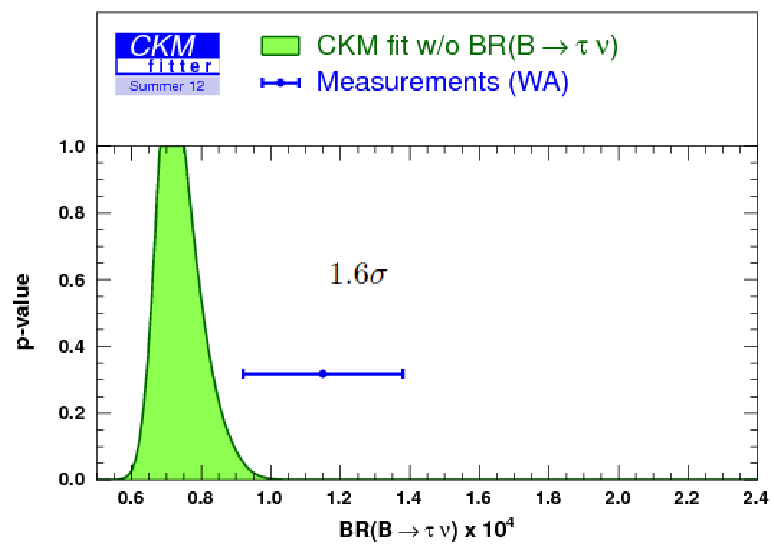




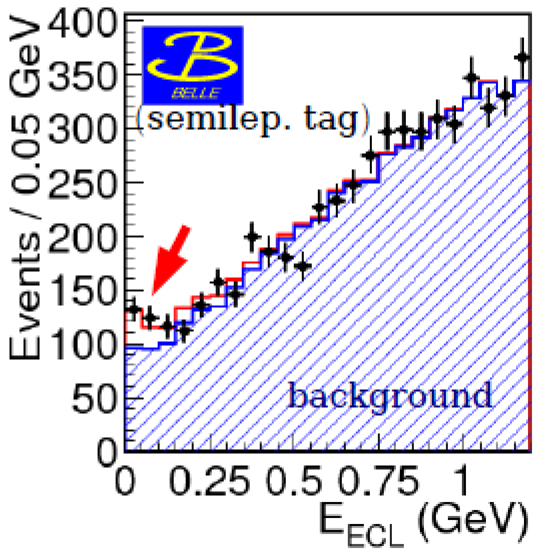
Extra calorimeter energy : $E_{ECL/extra}$ (GeV)

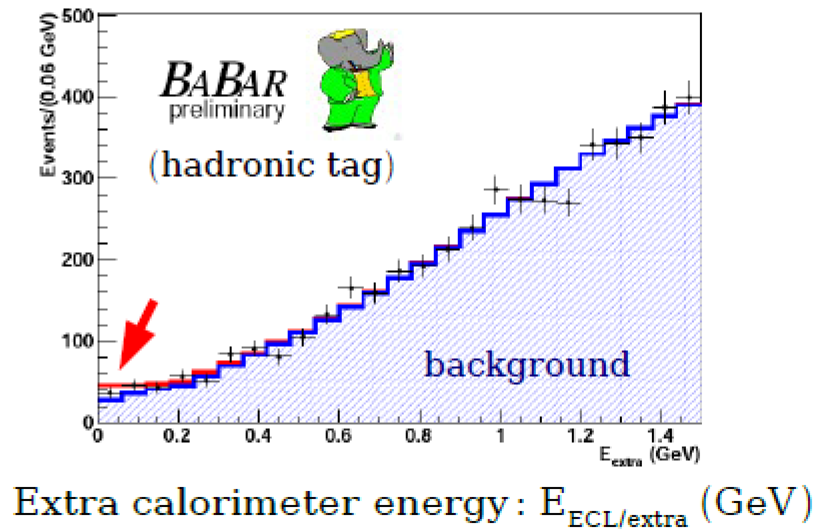
$$Br(B^{+} \rightarrow \tau\nu) = (1.15 \pm 23) \cdot 10^{-4}$$ **World av.**

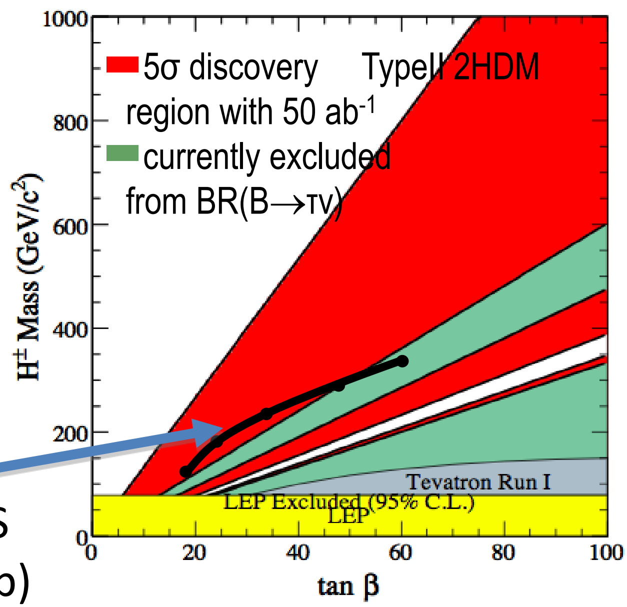
$$0.76^{+0.11}_{-0.06} \times 10^{-4}$$ **CKM fit**



B–>τν results

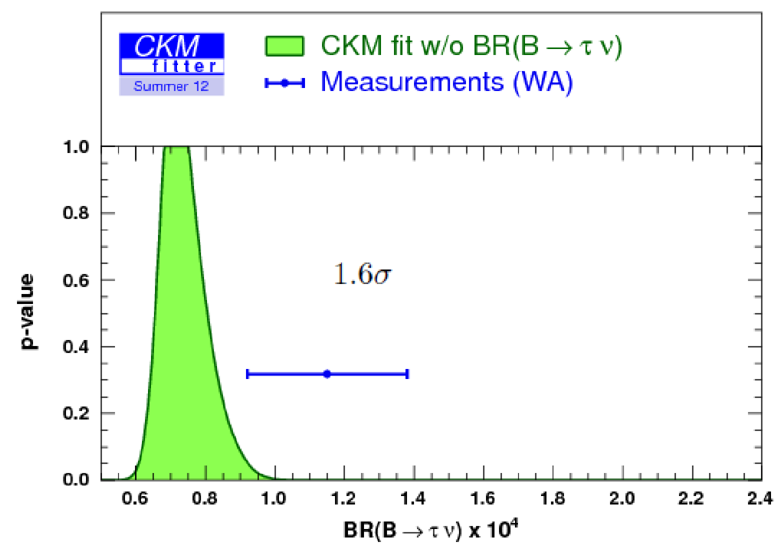






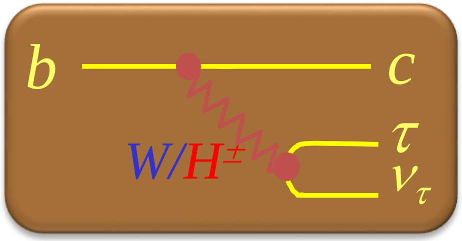
14 TeV ATLAS

5σ H^+ (4.6/fb)



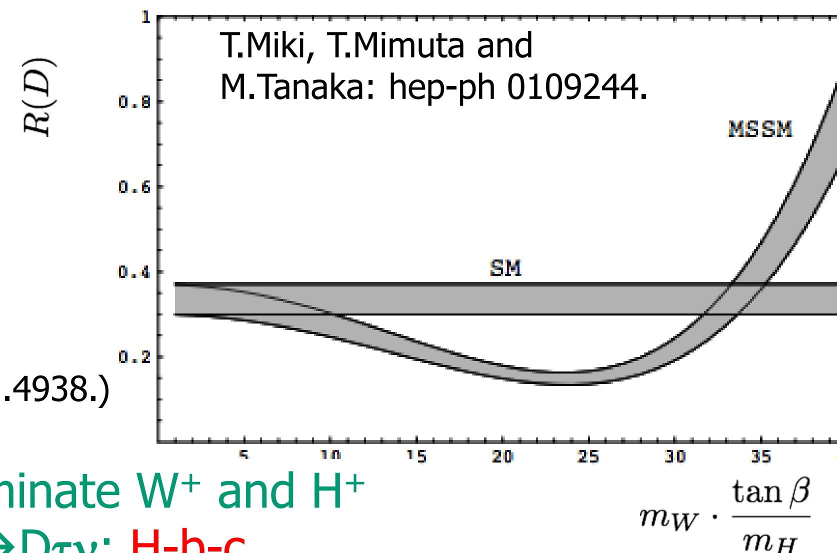
B→D$^{(*)}$τν

Semileptonic decay sensitive to charged Higgs



Ratio of τ to μ,e could be reduced/enhanced significantly

$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$



Complementary and competitive with B→τν

1.Smaller theoretical uncertainty of R(D)

(For B→τν,
There is O(10%) f_B uncertainty from lattice QCD)

2.Large Brs (~1%) in SM (Ulrich Nierste arXiv:0801.4938.)

3. Differential distributions can be used to discriminate W^+ and H^+

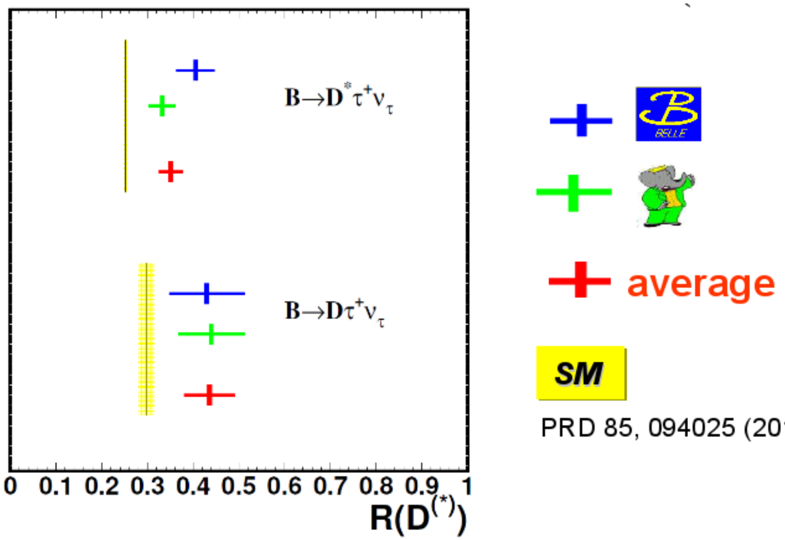
4. Sensitive to different vertex B→τ ν: H-b-u, B→Dτν: H-b-c
(LHC experiments sensitive to H-b-t)

Always ≥ 2ν
B meson tagging

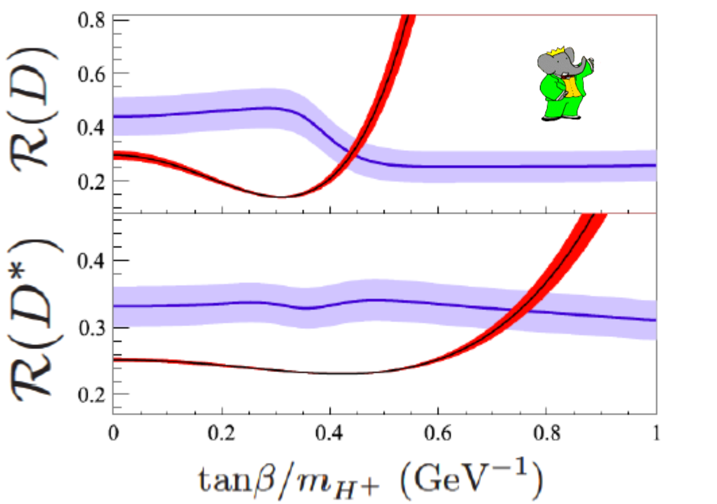
Advantage of B factories!

First observation of B → D^{*-}τν by Belle (2007) → PRL 99, 191807 (2007)

$B \rightarrow D^{(*)}\tau\nu$ decays



PRD 85, 094025 (2012)



Blue: this result, red: Type-II 2HDM.

exp. - acceptance variation with $tan\beta/m_{H+}$

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

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

$R(r_H)$ in $B \rightarrow \tau\nu$, $B \rightarrow D\tau\nu$ and $B \rightarrow D^{*}\tau\nu$ suggest different values of $tan\beta/m_{H\pm}$

- $r_H \rightarrow tan\beta/m_H \approx 0 - 0.1$ or ≈ 0.25 GeV^{-1}
- $R_D \rightarrow tan\beta/m_H \approx 0.4 - 0.5$ GeV^{-1}
- $R_{D^*} \rightarrow tan\beta/m_H \approx 0.7 - 0.9$ GeV^{-1}

The *BABAR* collaborations excludes 2HDM-II charged Higgs at 99.8%

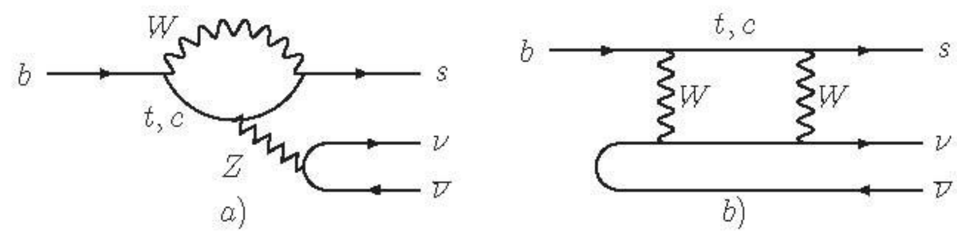
J. P. Lees *et al.* [BABAR Collaboration], arXiv:1303.0571 [hep-ex], submitted to Phys. Rev. D.

$B \to K^{(*)}\nu\nu$ decays

$B \to K^{(*)}\nu\nu$ SM: penguin + box diagrams

$B \to K\nu\nu$, $Br \sim 4 \cdot 10^{-6}$

$B \to K^{*}\nu\nu$, $Br \sim 6.8 \cdot 10^{-6}$

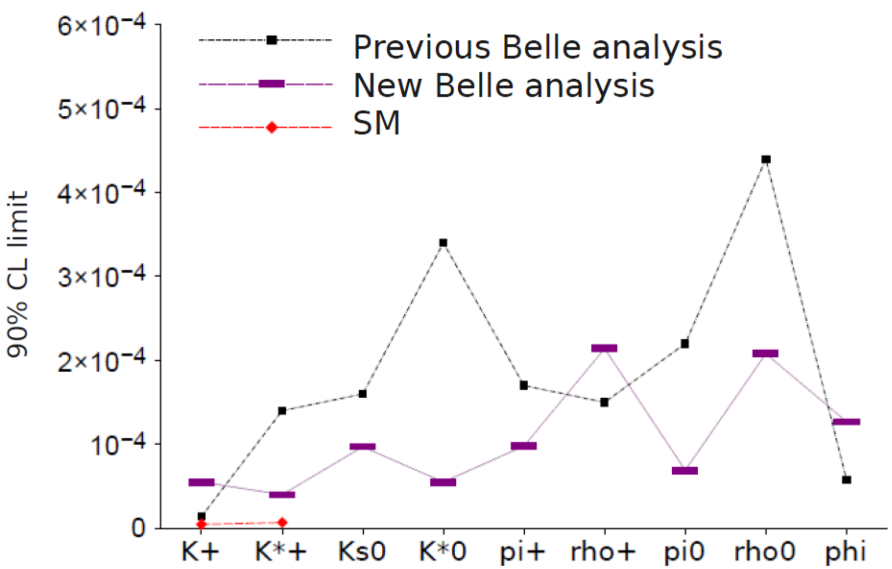


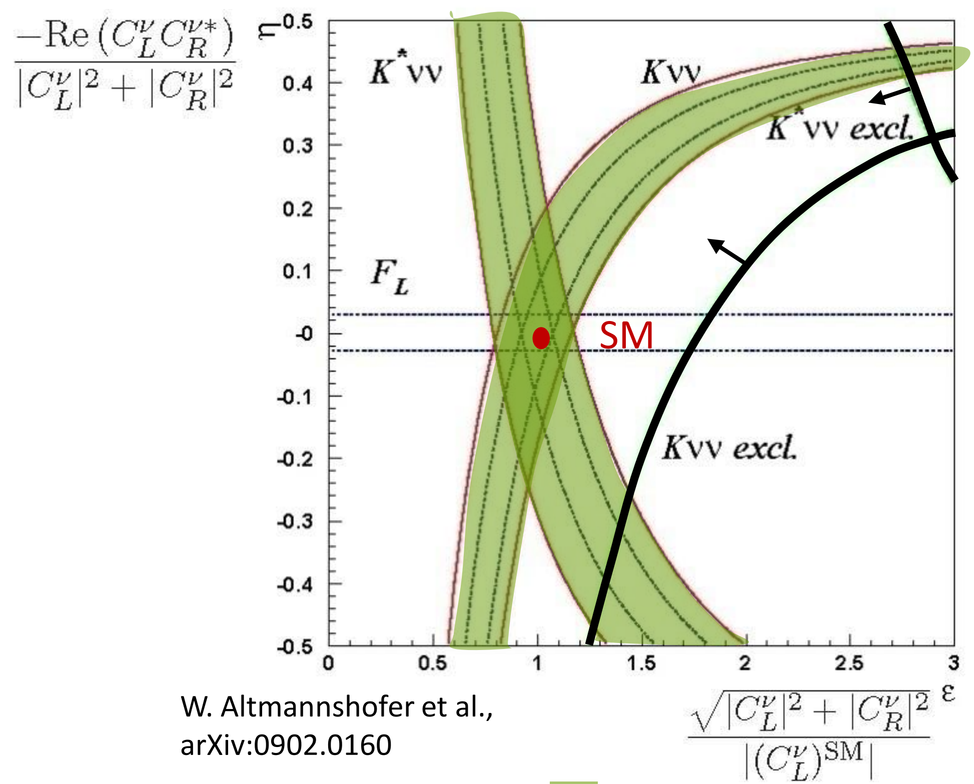
$\mathcal{B}(B^+ \to K^{(*)+}\nu\nu)$ can be measured to ±30% with 50 ab^{-1};

limits on right-handed currents

$B_{sig}B_{tag} \to (K^{(*)}\nu\nu)(X\ell\nu)$ semil. tag

$\to (K^{(*)}\nu\nu)(X)$ hadr. Tag



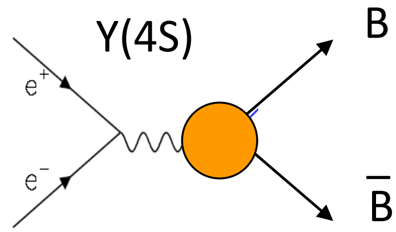


W. Altmannshofer et al., arXiv:0902.0160

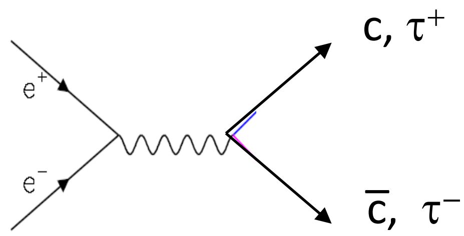
approx. expected precision @ 50 ab^{-1}

Charm and τ physics

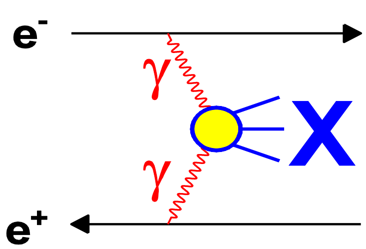
- **B physics** **(~1.1nb)**
  - CP violation & CKM
  - Rare decays



- **Charm physics** **(~1.3 nb)**
- **τ physics** **(~0.9nb)**

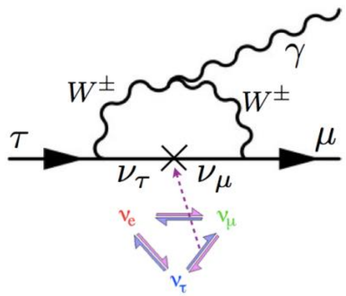


- **two-photon processes**
- **New Resonance**
  - ordinary & exotics



Complement/Cooperative with τ/Charm factory

LFV in τ decays



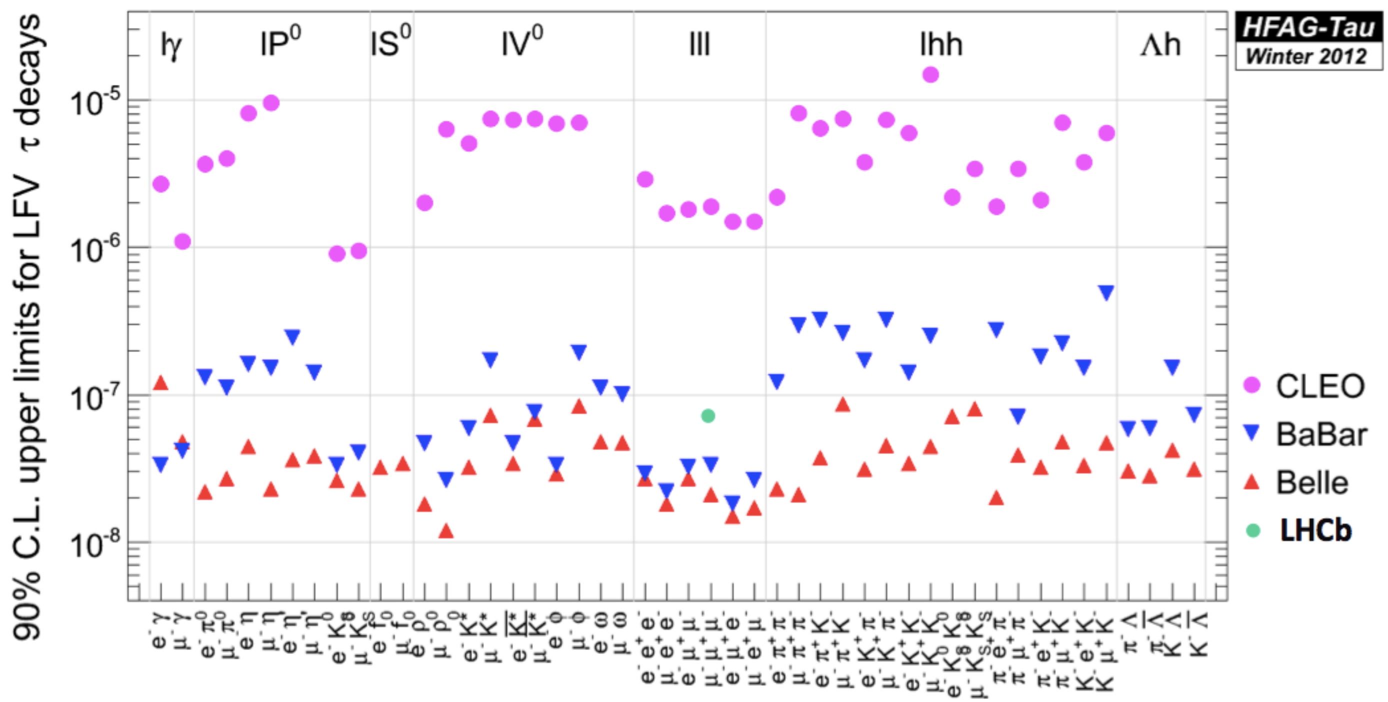
Strongly suppressed in SM
$Br(\tau \to \mu\gamma)$ ~ 10^{-49} -10^{-53}

Beyond experimental sensitivity

Lepton flavour violation (LFV) in tau decays:

would be a clear sign of new physics

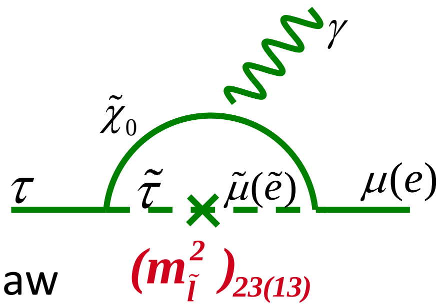
Present status



48 modes searched for, U.L.s around ~10^{-8}

LFV and New Physics

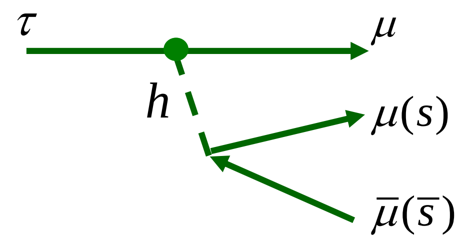
$\tau \rightarrow \ell\gamma$



- SUSY + seesaw
- Large LFV

Br($\tau \rightarrow \mu\gamma$) = O (10^{-7} - 10^{-9})

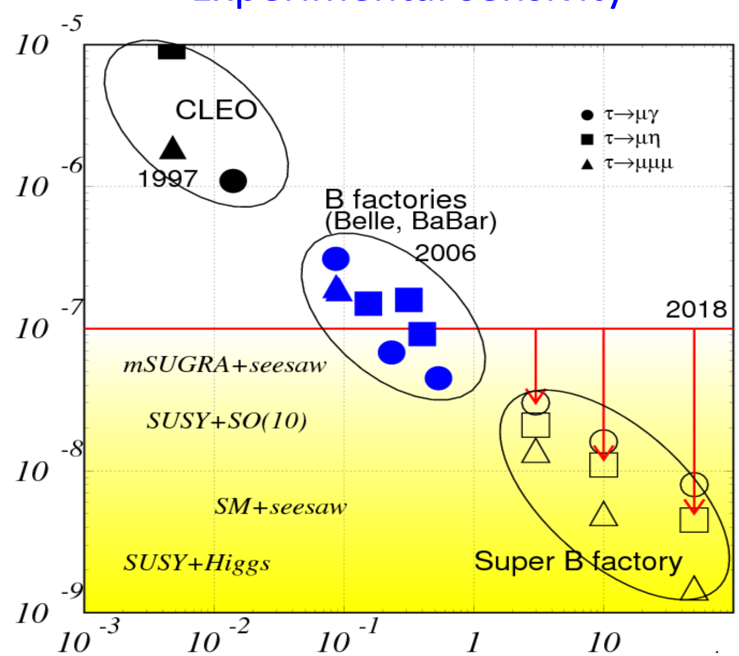
$\tau \rightarrow 3\ell,\ \ell\eta$



- Neutral Higgs mediated decay
- Important when M_{SUSY} >> EW scale

mode	Br($\tau \rightarrow \mu\gamma$)	Br($\tau \rightarrow$ 3l)
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

Experimental sensivity



Belle II sensitivity for LFV covers predictions of many models

Physics sensitivity at Belle II

Observable	Belle 2006	SuperKEKB		†LHCb	
	($\sim$0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Hadronic $b \to s$ transitions					
$\Delta\mathcal{S}_{\phi K^0}$	0.22	0.073	0.029		0.14
$\Delta\mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta\mathcal{S}_{K_S^0 K_S^0 K_S^0}$	0.33	0.105	0.037	-	-
$\Delta\mathcal{A}_{\pi^0 K_S^0}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
$\phi_1^{eff}(\phi K_S)$ Dalitz		3.3°	1.5°		
Radiative/electroweak $b \to s$ transitions					
$\mathcal{S}_{K_S^0 \pi^0 \gamma}$	0.32	0.10	0.03	-	-
$\mathcal{B}(B \to X_s\gamma)$	13%	7%	6%	-	-
$A_{CP}(B \to X_s\gamma)$	0.058	0.01	0.005	-	-
C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	-	11%	4%		
C_{10} from $A_{FB}(B \to K^*\ell^+\ell^-)$	-	13%	4%		
C_7/C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	-		5%		7%
R_K		0.07	0.02		0.043
$\mathcal{B}(B^+ \to K^+\nu\nu)$	†† $< 3\ \mathcal{B}_{\rm SM}$		30%	-	-
$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$	†† $< 40\ \mathcal{B}_{\rm SM}$		35%	-	-
Radiative/electroweak $b \to d$ transitions					
$\mathcal{S}_{\rho\gamma}$	-	0.3	0.15		
$\mathcal{B}(B \to X_d\gamma)$	-	24% (syst.)		-	-

Physics sensitivity at Belle II

Observable	Belle 2006 (~0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	†LHCb (2 fb^{-1})	†LHCb (10 fb^{-1})
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+\nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+\nu)$	†† $< 2.4\mathcal{B}_{SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ $[10^{-9}]$	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ $[10^{-9}]$	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ $[10^{-9}]$	21	3	1	-	-

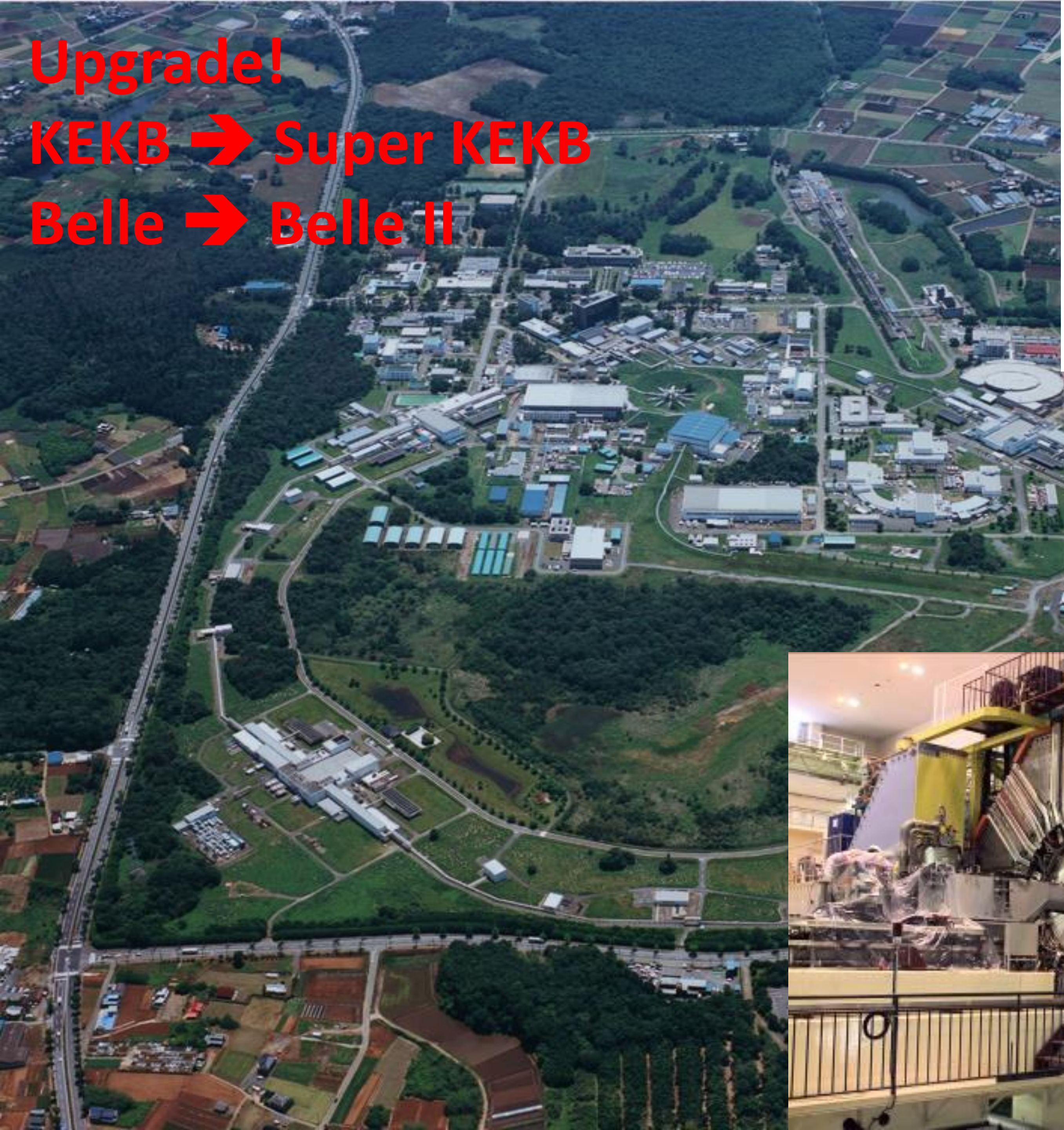
Very broad physics program.
For more, see the following article

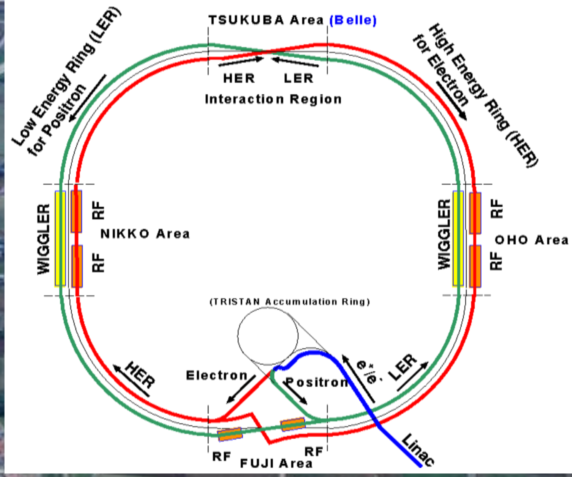
Physics at Super B factory: arXiv:1002.5012v1

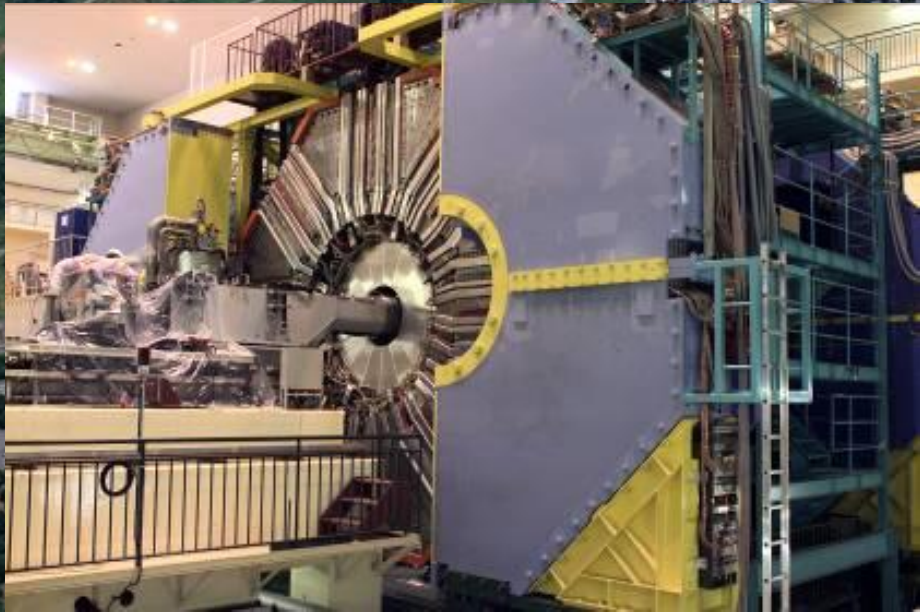
Upgrade!

KEKB → Super KEKB

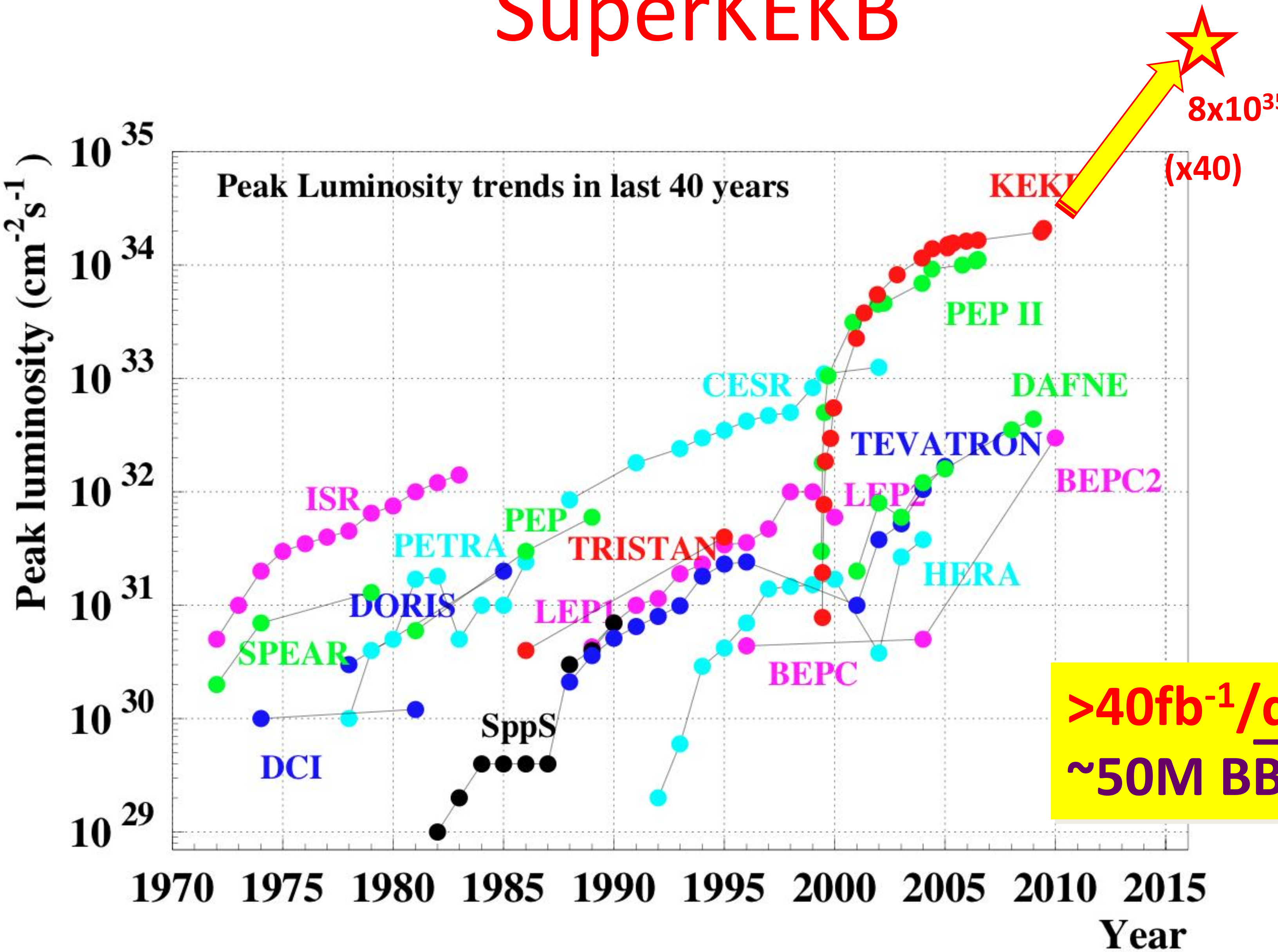
Belle → Belle II







SuperKEKB



>40fb^{-1}/day
~50M $B\bar{B}$/day

Super KEKB in nano-beam scheme

- To increase luminosity:

→ squeeze beams to nanometer scale and enlarge crossing angle (minimize β^*_y)

→ decrease beam emittance (keep current ξ_y)

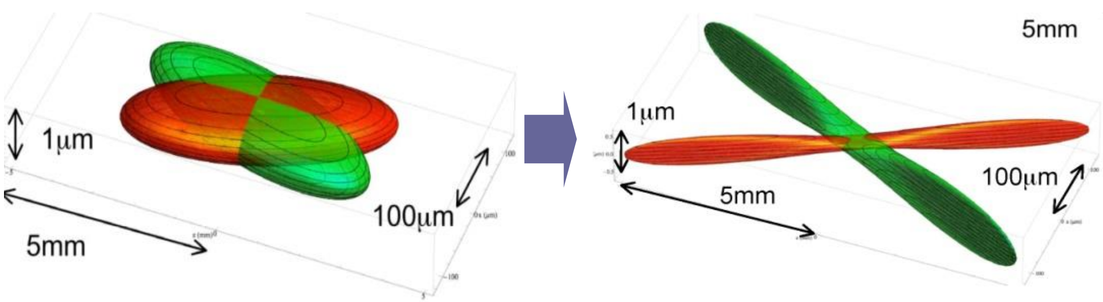
- Squeezing beams in stronger magnetic field saturated by hourglass effect

→ intersect bunches at highly focused region

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\frac{I_\pm \xi_{y\pm}}{\beta^*_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

I: beam current
β^*: envelope around trajectories at IP
$\xi_y \propto \sqrt{(\beta^*_y / \varepsilon_y)}$ beam-beam parameter
ε: beam emittance
σ^*: beam size $\propto \sqrt{(\beta^* \varepsilon)}$
$R_L, R_{\xi y}$: geometrical reduction factors (crossing angle, hourglass effect)

σ_x~100µm, σ_y~2µm **σ_x~10µm, σ_y~60nm**

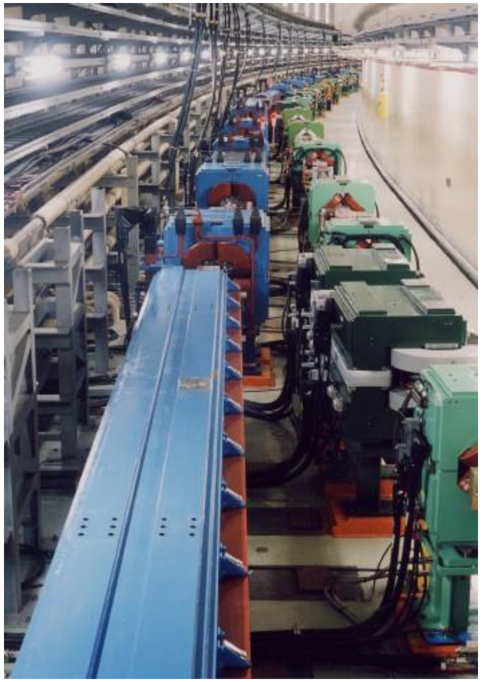


- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of short lifetime for LER

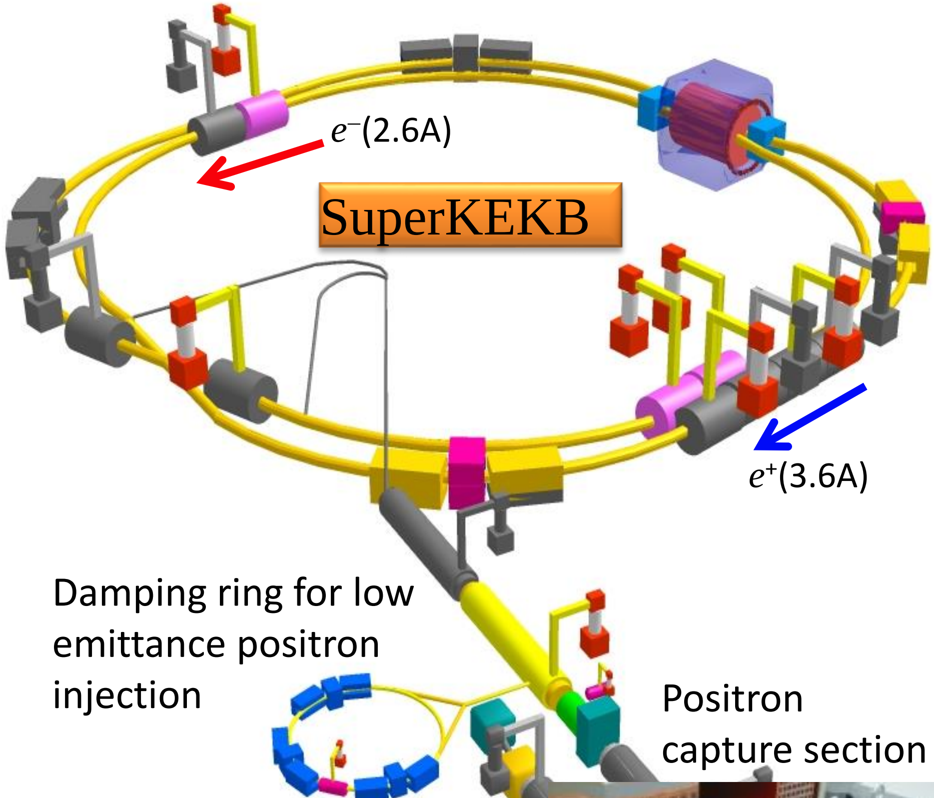
	E (GeV) e+/e-	β^*_y (mm) e+/e-	β^*_x (cm) e+/e-	ε_x (nm) e+/e-	$\varepsilon_y/\varepsilon_x$ e+/e-	φ (mrad)	I (A) e+/e-	L ($cm^{-2}s^{-1}$)
KEKB	**3.5/8.0**	**5.9/5.9**	**120/120**	**18/24**	**0.88/0.66**	**11**	**1.6/1.2**	**2.1 x 10^{34}**
Super KEKB	**4.0/7.0**	**0.27/0.31**	**3.2/2.5**	**3.2/5.3**	**0.27/0.24**	**41.5**	**3.6/2.6**	**80x10^{34}**

Accelerator upgrade

Low emittance lattice



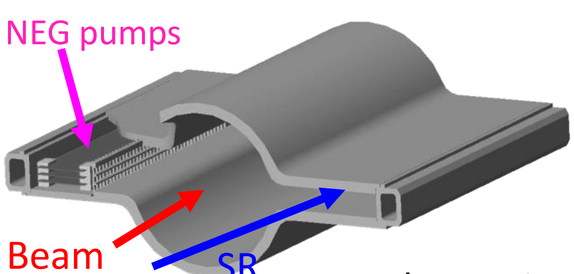
IR with β_y*=0.3mm
SC final focus system



Add RF systems for higher beam current

Damping ring for low emittance positron injection

Positron capture section

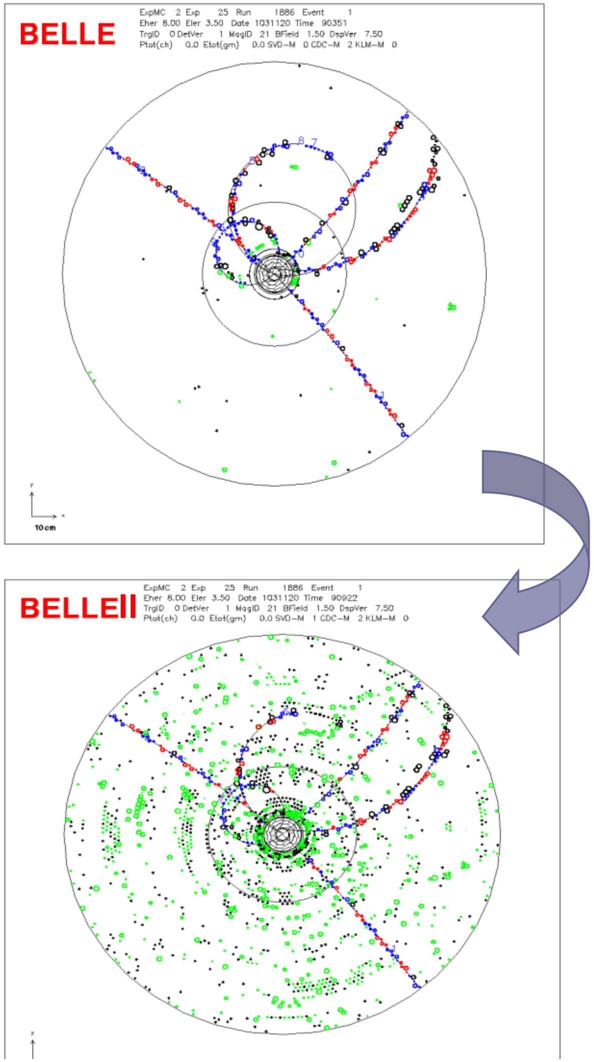


LER beampipe to suppress photoelectron instability

Detector upgrade

Critical issues at L= 8 $\times$ 10^{35}/cm^2/s:

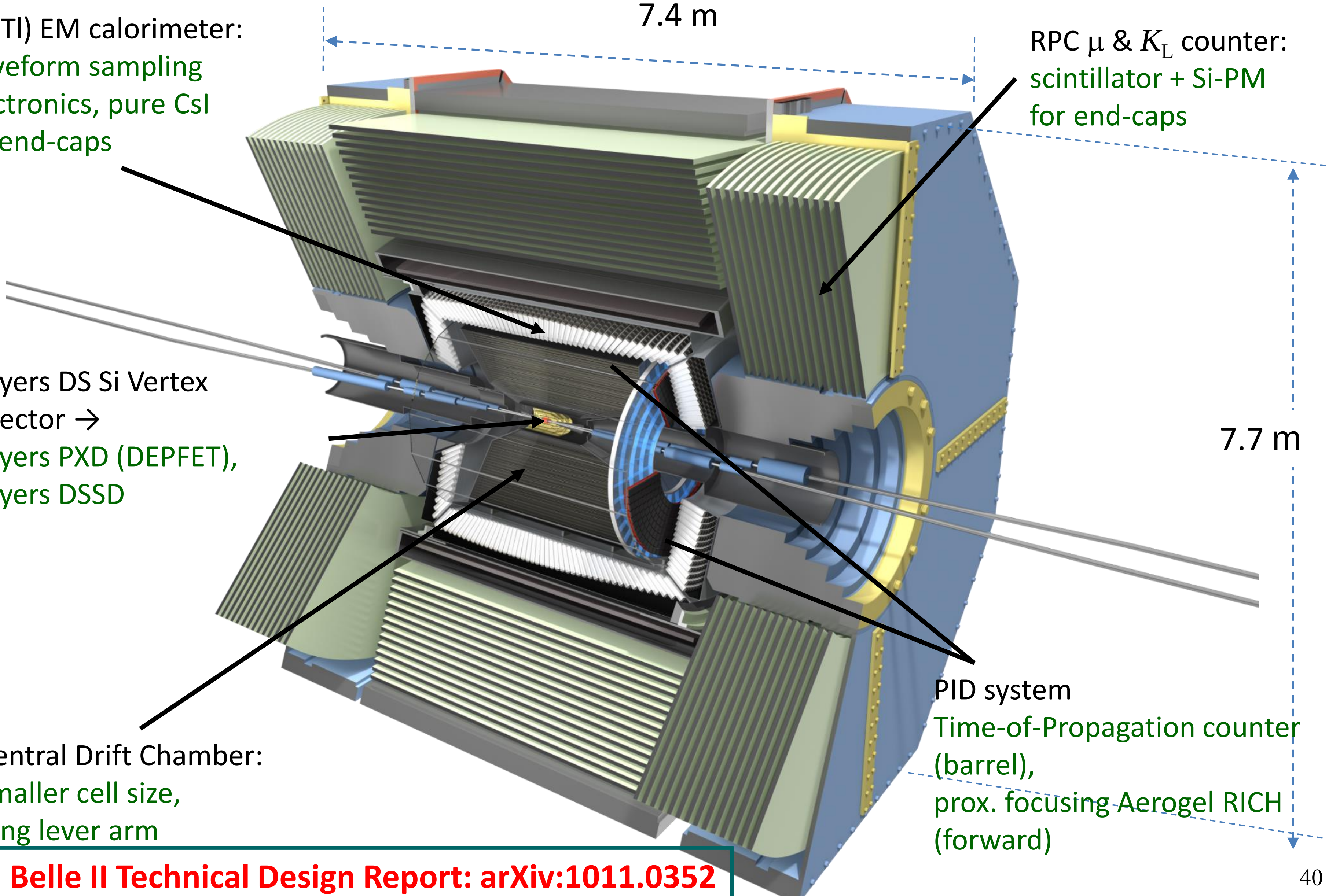
- **Higher background ($\times$10-20)**
  - **radiative Bhabha dominate**
  - **synchrotron radiation**
  - **beam-gas interactions**
  - **beam size (intrabeam scattering effects)**
- **Higher event rates ($\times$10)**
  - **higher rate trigger (L1 trigg. 0.5→30 kHz)**
  - **DAQ, computing**
- **Targeted improvements:**
  - **increase hermeticity**
  - **improve IP and secondary vertex resolution**
  - **improve K_s and π^0 efficiency**
  - **improve K/π separation**
  - **add μ-ID and PID in end-caps**



Higher luminosity → higher background → the **Belle** detector has to be upgraded

Belle becomes **Belle II**

Belle II Detector Upgrade



CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for end-caps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps

4 layers DS Si Vertex Detector →
2 layers PXD (DEPFET),
4 layers DSSD

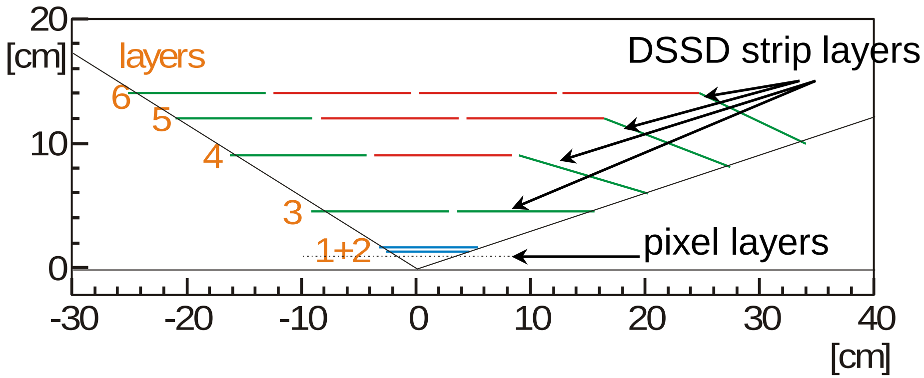
Central Drift Chamber:
smaller cell size,
long lever arm

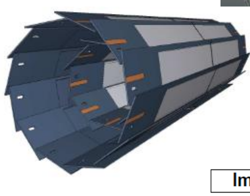
PID system
Time-of-Propagation counter (barrel),
prox. focusing Aerogel RICH (forward)

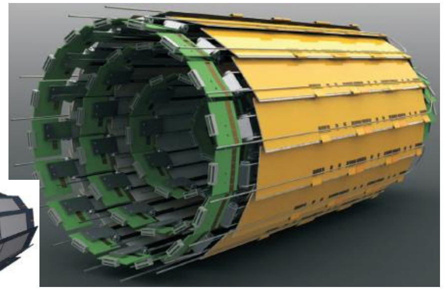
Belle II Technical Design Report: arXiv:1011.0352

Vertexing with silicon pixels and strips

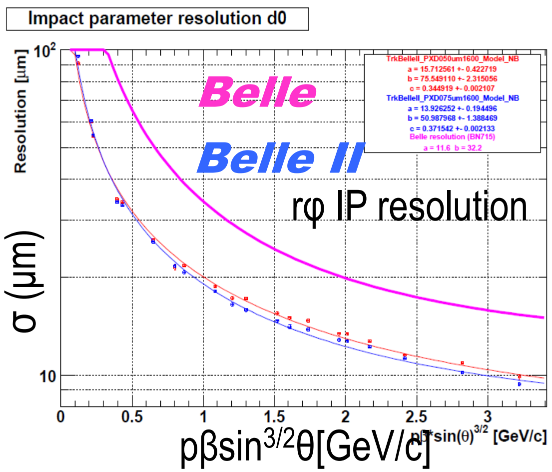
- PXD + SVD in Belle II (in Belle only strip layers)

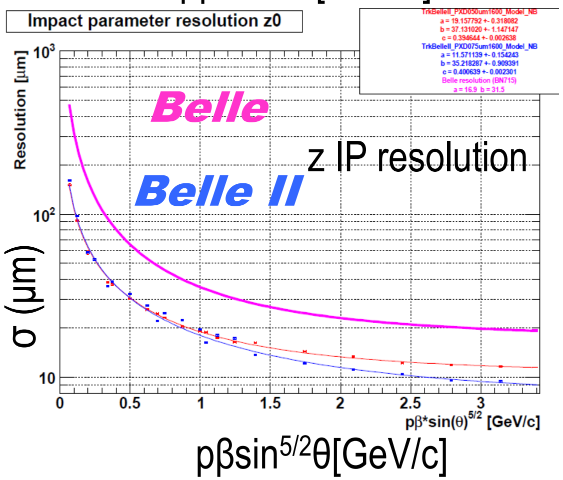






- Pixels in DEPFET technology: thin (75μm) sensors give little multiple scattering, deal with high occupancy close to the IR, fast readout
- Strips deal with 10% occupancy, reduce bckgd. in PXD
- Improved IP resolution and p_T<100MeV tracks reconstr., 30% larger eff. of $K_S \to \pi^+\pi^-$ with vertex info

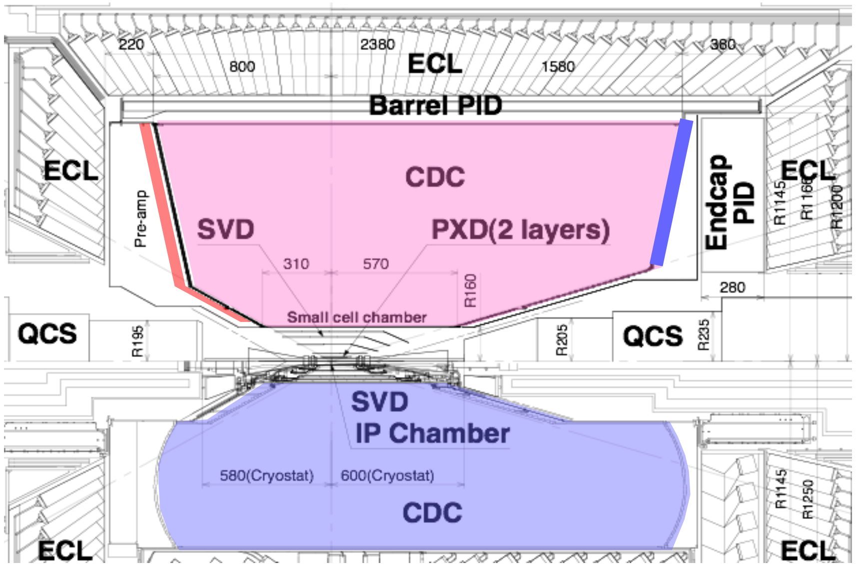




Mechanical mockup of pixel detector

DEPFET sensor

Tracking with Central Drift Chamber



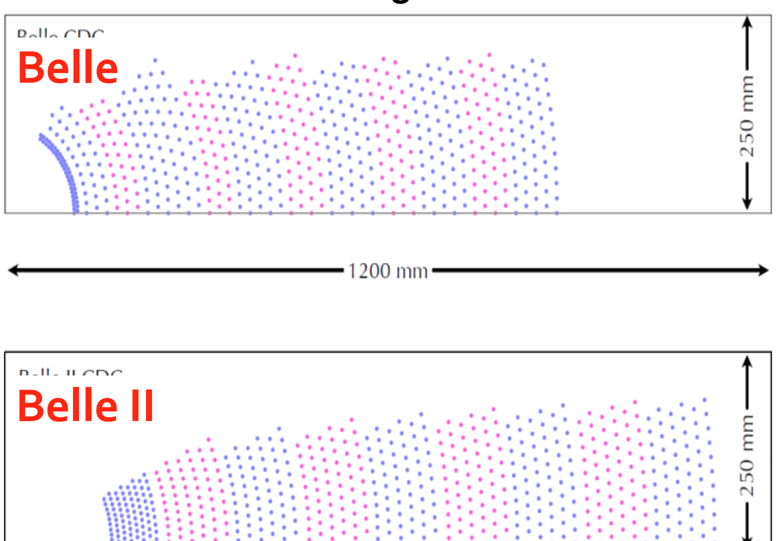
- ❑ Extended outer radius, longer lever arm, smaller cells near beampipe, faster readout electronics (1-2 μs → 200 ns)
- ❑ Improved momentum and dE/dx resolution

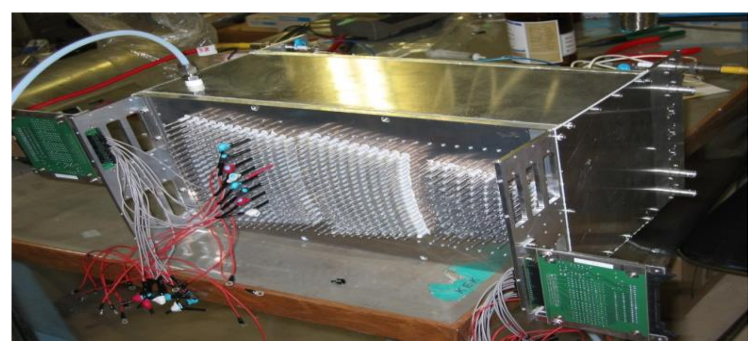
$$\sigma_{Pt} / P_t = 0.19 P_t \oplus 0.30 / \beta$$

$$\sigma_{Pt} / P_t = 0.11 P_t \oplus 0.30 / \beta \quad \text{with SVD}$$

	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C_2H_6	He:C_2H_6
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

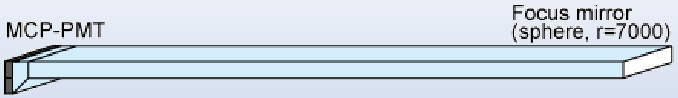
wire configuration





Particle identification

Barrel PID: Time of Propagation Counter



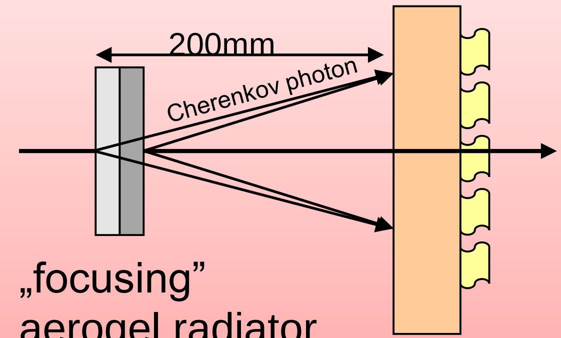
Quartz radiator

Focusing mirror

Small expansion block

Hamamatsu MCP-PMT (measure t, x and y)

Endcap PID: Aerogel RICH

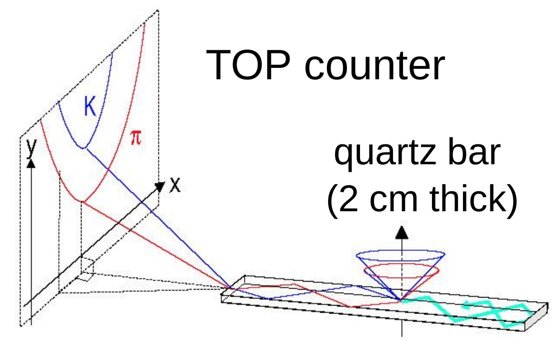


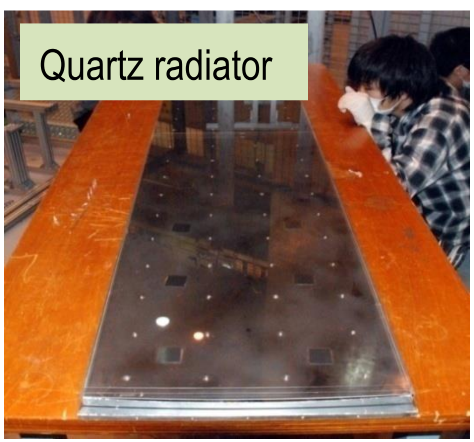
„focusing" aerogel radiator

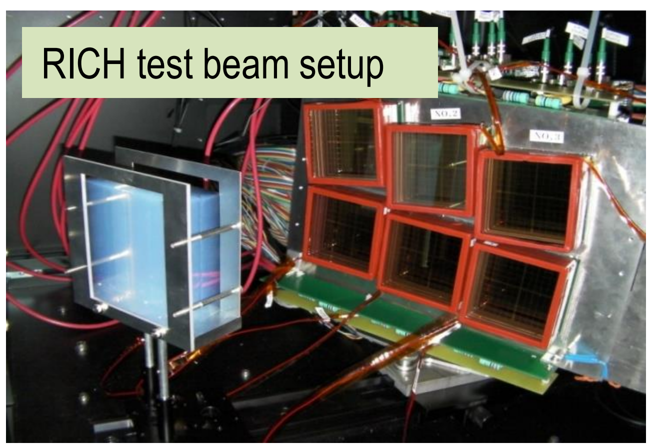
n~1.05

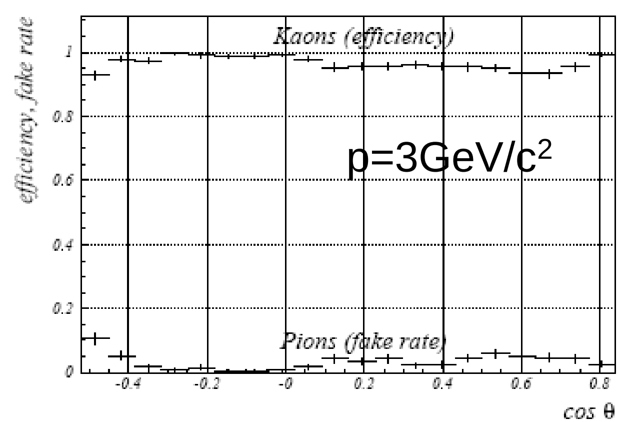
Hamamatsu HAPD + new ASIC

- TOP: reconstructs Cherenkov rings from 3D info from PMTs: x,y and time of photon propagation (40 ps resolution)
- ARICH: measures Cherenkov angle.Inhomogeneous aerogel radiator to improve photon resolution
- Improved K/πseparation in wide momentum range (>4σ for $p$up to 4 GeV/c)



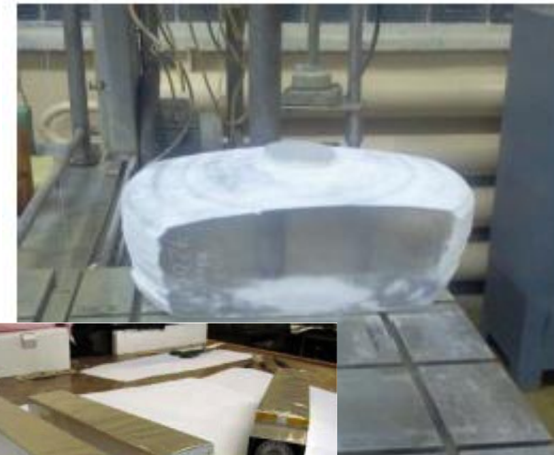




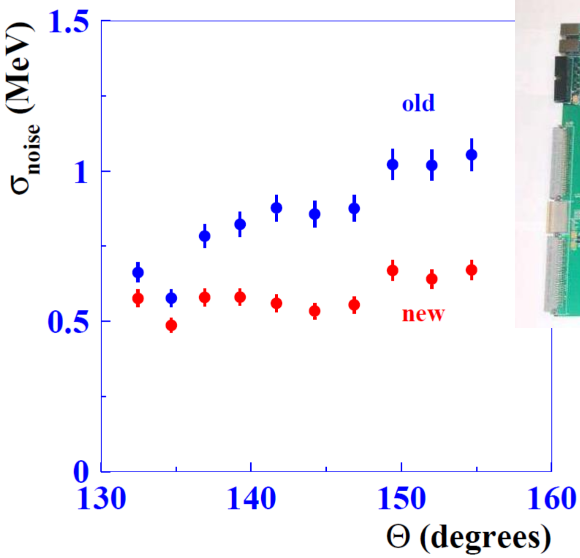


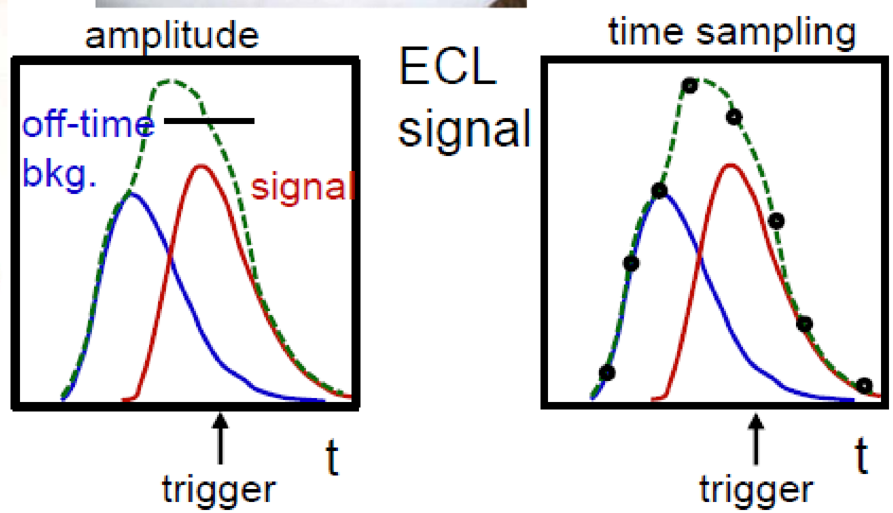
Electromagnetic Calorimeter

- Crystals:
  - Barrel: reuse existing CsI(Tl).
  - Endcaps: (possibly staged) upgrade to pure CsI.
    - ➔ Better performance & radiation hardness.



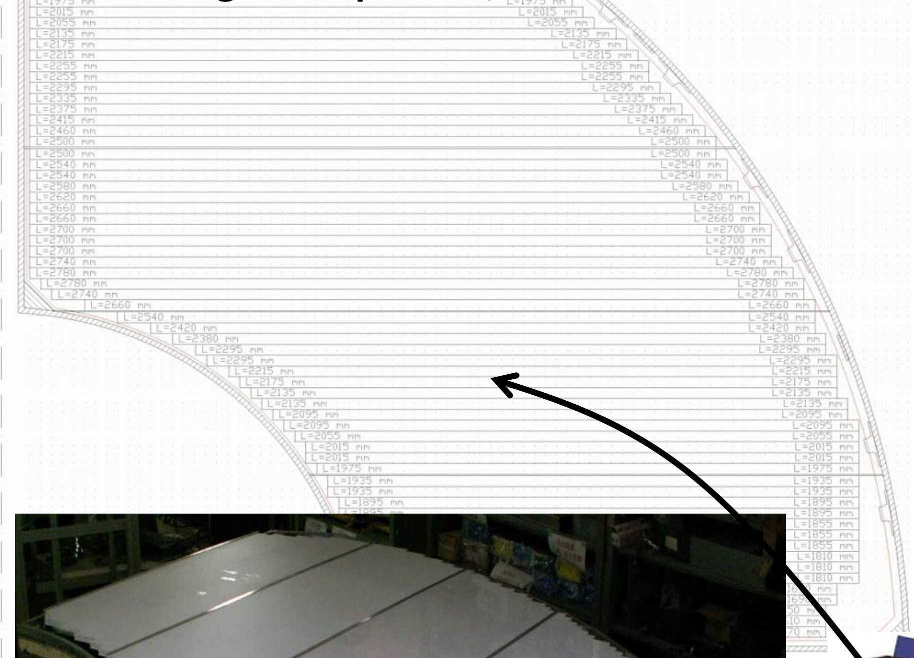
- Readout electronics:
  - Upgrade to 2 MHz waveform sampling.
  - Online signal processing.
  - ➔ Improved energy resolution.



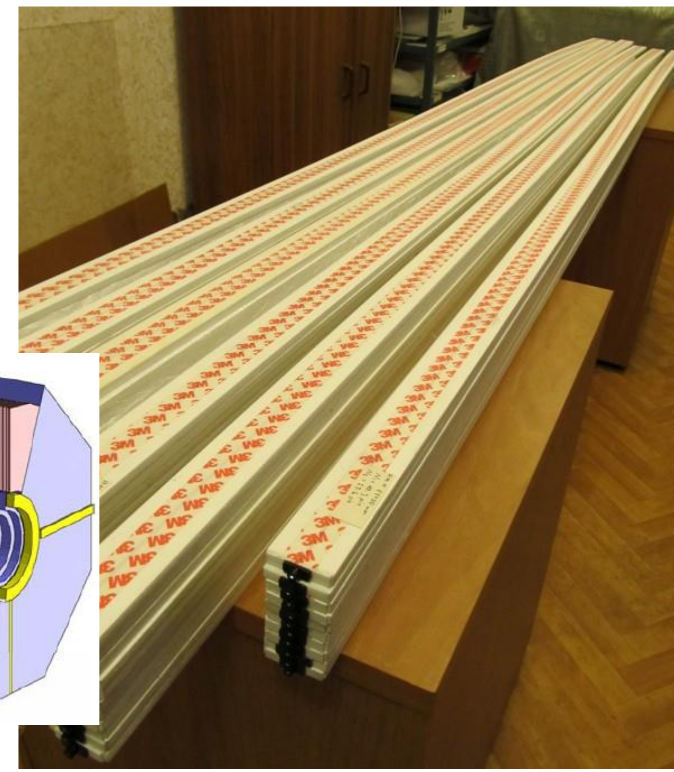


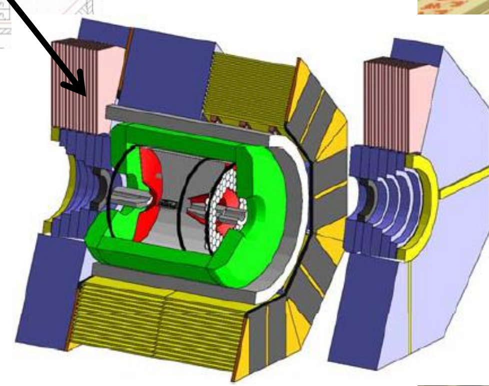
Endcap $K_{\mathrm{L}}\mu$ Detector

- **RPCs → scintillator to tolerate high BG**
- **75 strips (4 cm width)/1 layer/sector = 150 strips/superlayer**
- **16800 strips for F&B endcap KLM w/ waveform sampling readout**
- **the longest strip 2.8 m; the shortest 0.6 m**

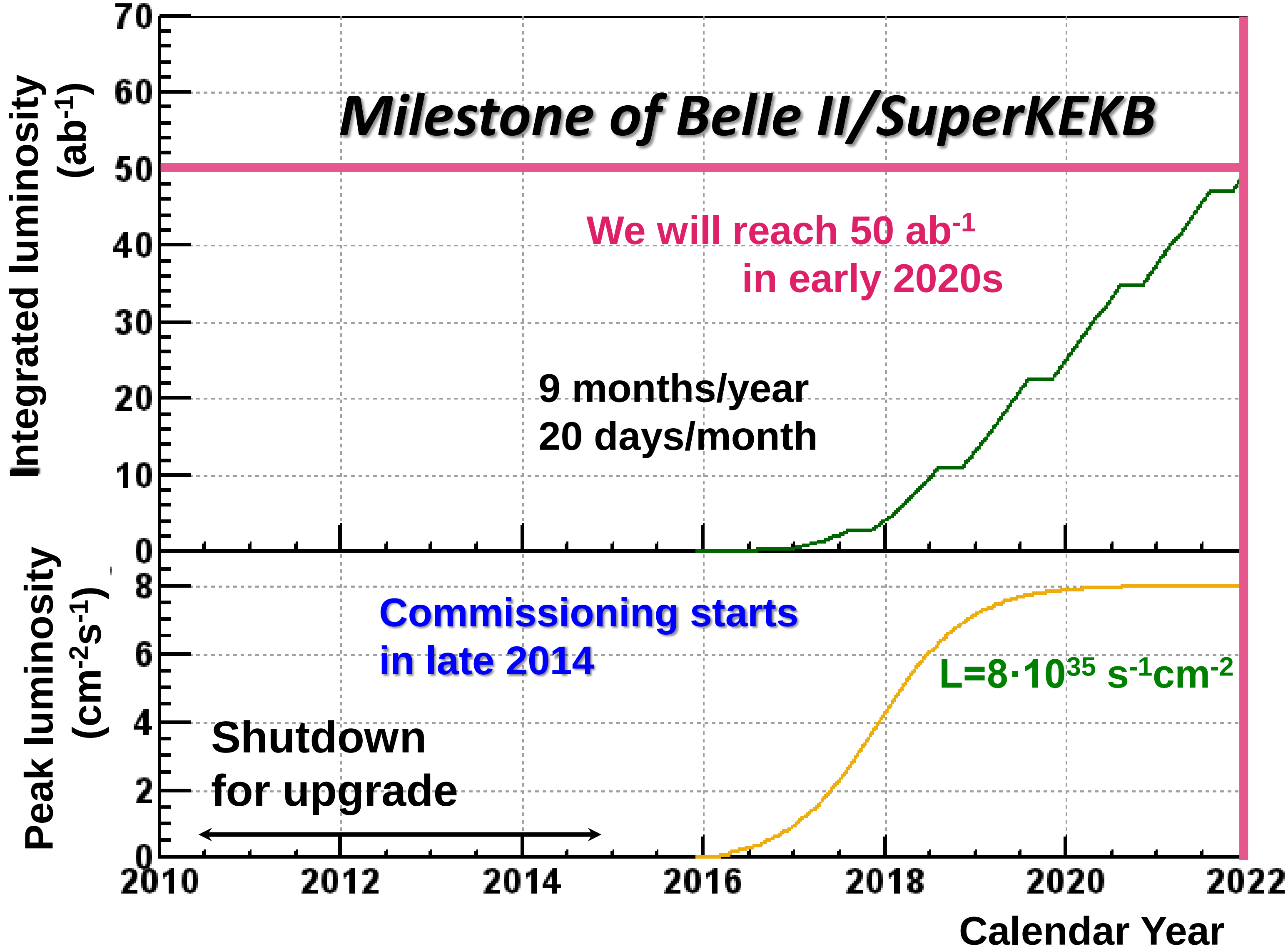


- WLS (blue → green) fiber in each strip (Y11 MC D=1.2mm)
- SiPM at one fiber end (at outer sector radius)
- mirrored far fiber end

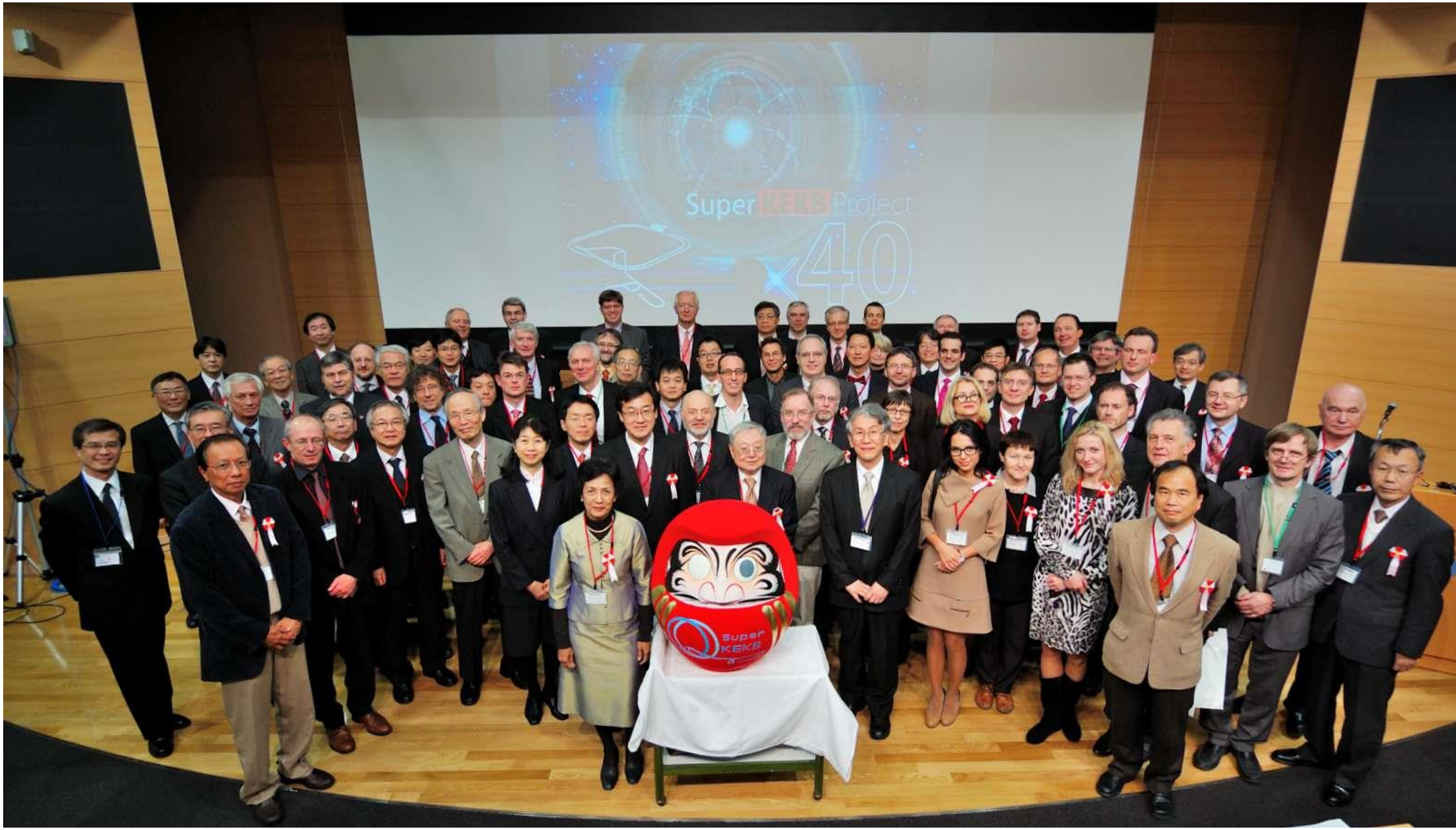




SuperKEKB luminosity



Nov 18, 2011: SuperKEKB groundbreaking



The formal start of the project…

Belle-II Collaboration

~420 collaborators
from 70 institutions
in 20 countries

Summary

- Belle/KEKB is a very successful e+e- B Factory
  - ✓ Discovery of CPV in B decays
  - ✓ Precise test of KM and SM
  - ✓ Search for NP
- Major upgrade: SuperKEKB and Belle II, with 40x larger event rates
- Belle II at SuperKEKB will enable a new generation of precision studies in flavor physics.
- Belle II and LHC experiments will be complimentary.
- Upgrade of KEKB and Belle progressing well
- Start of data taking: October 2016
- Goal: Collect 50 ab^{-1} by end of 2022