Time and Matter

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CP violation in the B and D meson system – present and future

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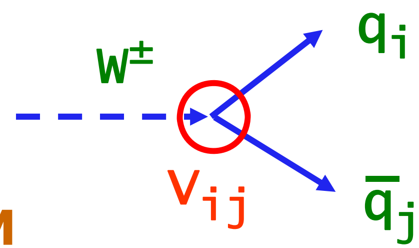
Contents

- Highlights from present B factories
- Physics case for a Super B factory
- Super B factory: accellerator + detector
- Status and prospects of the project

B factory physics program

B factory main task: **measure CP violation in the system of B mesons**

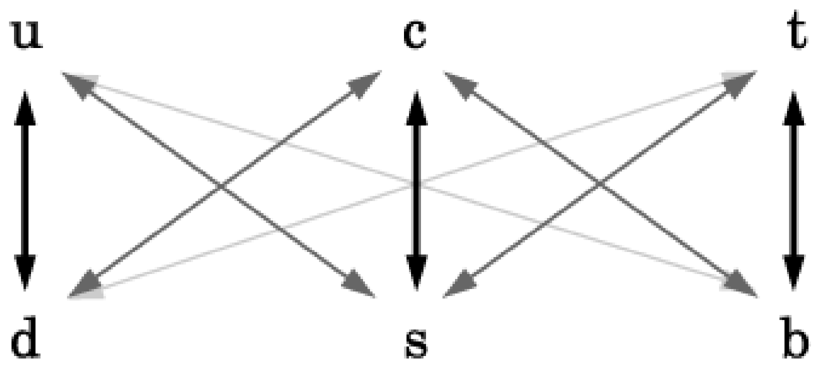
specifically: various measurements of complex elements of Cabbibo-Kobayashi-Maskawa matrix



CKM matrix is unitary

deviations could signal processes not included in SM

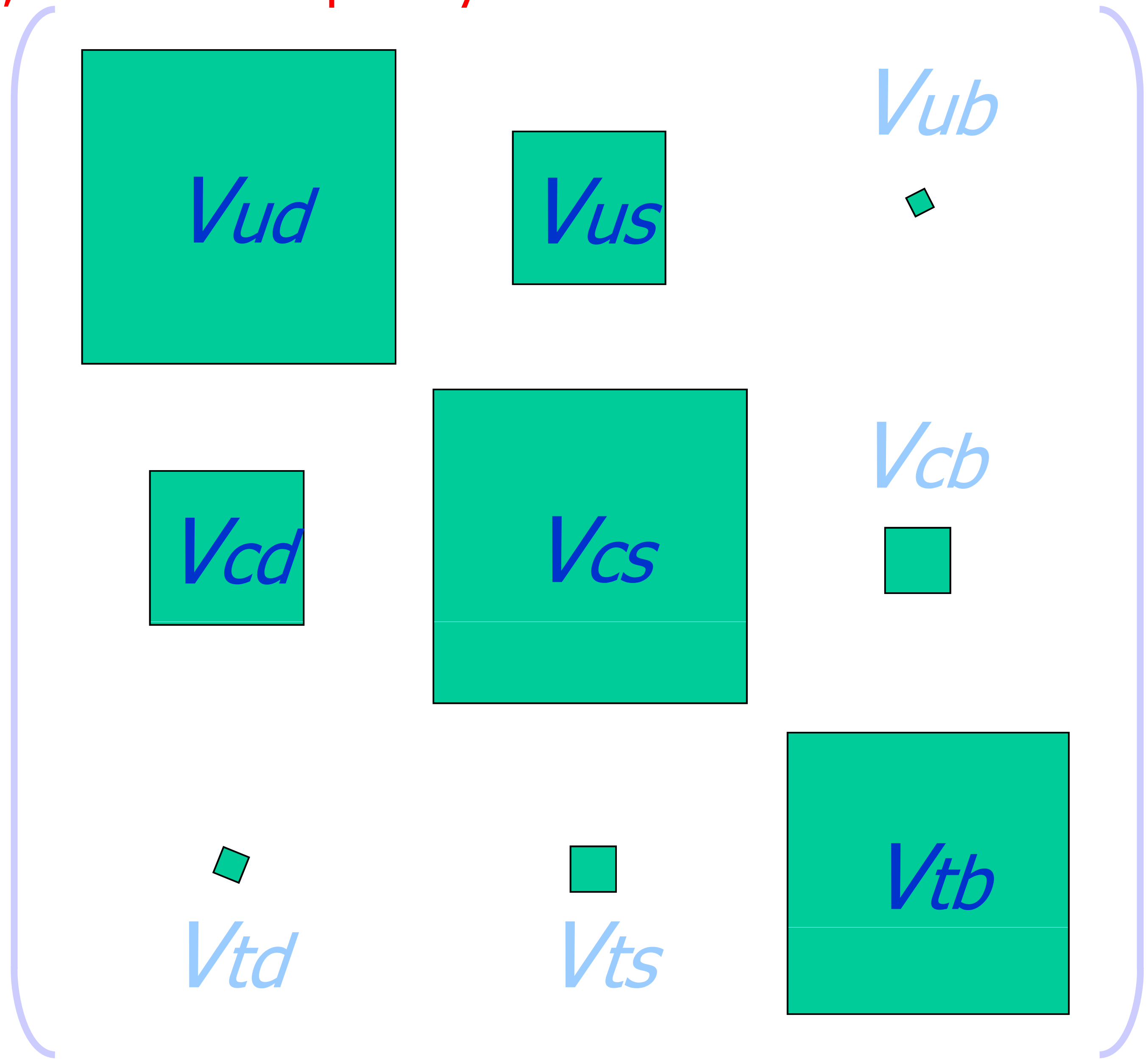
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



Transitions between members of the same family more probable (=thicker lines) than others

CKM: almost a diagonal matrix, but not completely

CKM: almost real, but not completely!



CKM matrix

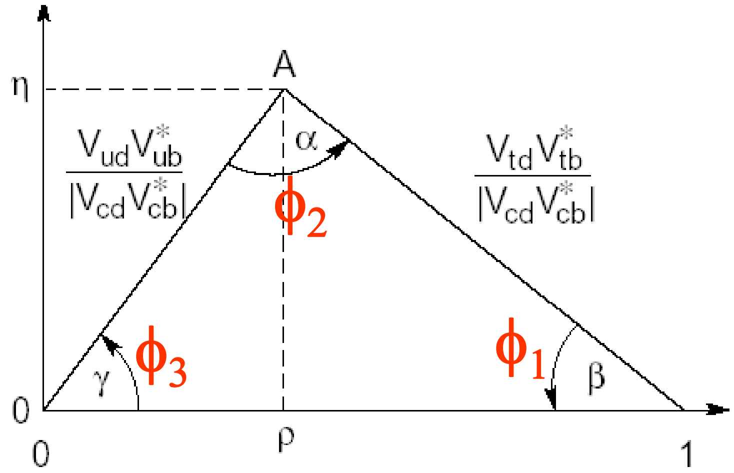
Wolfenstein parametrisation: expand in the parameter λ (=sinθ$_c$=0.22)

A, ρ and η: all of order one

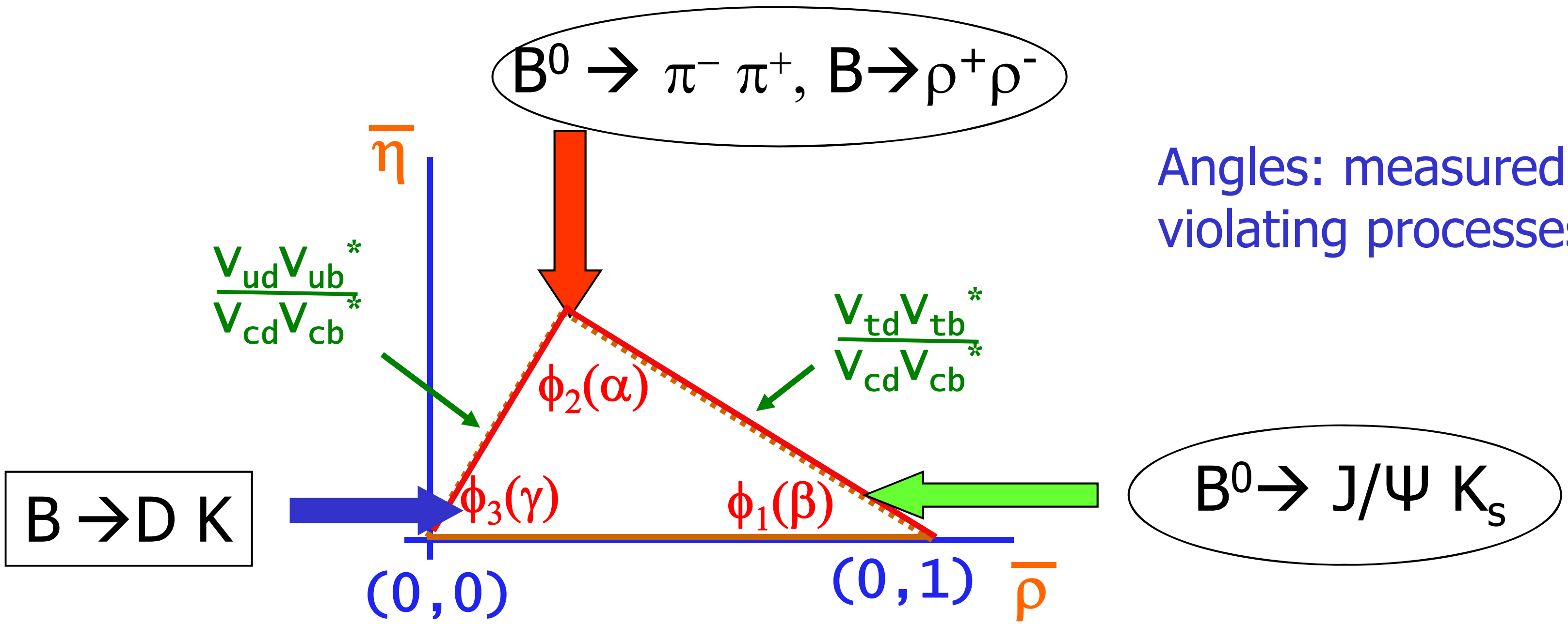
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity condition:

$$V_{ud}V_{ub}^{\ *} + V_{cd}V_{cb}^{\ *} + V_{td}V_{tb}^{\ *} = 0$$



Three Angles: (ϕ_1,ϕ_2,ϕ_3) or (β, α, γ)



Angles: measured in CP violating processes

Big Questions: *Are determinations of angles consistent with determinations of the sides of the triangle? Are angle determinations from loop and tree decays consistent?*

Time evolution in the B system

An arbitrary linear combination of the neutral B-meson flavor eigenstates

$$a\left|B^0\right\rangle + b\left|\overline{B}^0\right\rangle$$

is governed by a time-dependent Schroedinger equation

$$i\frac{d}{dt}\begin{pmatrix} a \\ b \end{pmatrix} = H\begin{pmatrix} a \\ b \end{pmatrix} = (M - \frac{i}{2}\Gamma)\begin{pmatrix} a \\ b \end{pmatrix}$$

M and Γ are 2x2 Hermitian matrices. CPT invariance → $H_{11}=H_{22}$

$$M = \begin{pmatrix} M & M_{12} \\ M_{12}^* & M \end{pmatrix}, \Gamma = \begin{pmatrix} \Gamma & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma \end{pmatrix}$$

diagonalize →

Time evolution in the B system

The light B_L and heavy B_H mass eigenstates with eigenvalues $m_H, \Gamma_H, m_L, \Gamma_L$ are given by

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

The eigenvalue differences

$$\Delta m_B = m_H - m_L, \Delta\Gamma_B = \Gamma_H - \Gamma_L$$

They are determined from the M and Γ matrix elements

$$(\Delta m_B)^2 - \frac{1}{4}(\Delta\Gamma_B)^2 = 4(|M_{12}|^2 - \frac{1}{4}|\Gamma_{12}|^2)$$

$$\Delta m_B \Delta\Gamma_B = 4\,\mathrm{Re}(M_{12}\Gamma_{12}^*)$$

Time evolution of B's

Time evolution:

$$\left| B^0_{phys}(t) \right\rangle = g_+(t) \left| B^0 \right\rangle + (q/p) g_-(t) \left| \overline{B}^0 \right\rangle$$

$$\left| \overline{B}^0_{phys}(t) \right\rangle = (p/q) g_-(t) \left| B^0 \right\rangle + g_+(t) \left| \overline{B}^0 \right\rangle$$

with

$$g_+(t) = e^{-iMt} e^{-\Gamma t/2} \cos(\Delta m t / 2)$$

$$g_-(t) = e^{-iMt} e^{-\Gamma t/2} i \sin(\Delta m t / 2)$$

$M = (M_H + M_L)/2$

Decay probability

Decay probability $$P(B^0 \to f, t) \propto \left| \langle f | H | B^0_{phys}(t) \rangle \right|^2$$

Decay amplitudes of B and anti-B to the same final state ***f***

$$A_f = \langle f | H | B^0 \rangle$$

$$\overline{A}_f = \langle f | H | \overline{B}^0 \rangle$$

Decay amplitude as a function of time:

$$\langle f | H | B^0_{phys}(t) \rangle = g_+(t) \langle f | H | B^0 \rangle + (q/p) g_-(t) \langle f | H | \overline{B}^0 \rangle$$

$$= g_+(t) A_f + (q/p) g_-(t) \overline{A}_f$$

... and similarly for the anti-B

CP violation: decay rate asymmetry vs. time

Decay rate asymmetry

$$a_{f_{CP}} = \frac{P(\overline{B}^0 \to f_{CP},t) - P(B^0 \to f_{CP},t)}{P(\overline{B}^0 \to f_{CP},t) + P(B^0 \to f_{CP},t)} =$$

$$= \frac{\left|(p/q)g_-(t)A_{f_{CP}} + g_+(t)\overline{A}_{f_{CP}}\right|^2 - \left|g_+(t)A_{f_{CP}} + (q/p)g_-(t)\overline{A}_{f_{CP}}\right|^2}{\left|(p/q)g_-(t)A_{f_{CP}} + g_+(t)\overline{A}_{f_{CP}}\right|^2 + \left|g_+(t)A_{f_{CP}} + (q/p)g_-(t)\overline{A}_{f_{CP}}\right|^2} =$$

$$= \frac{(1-|\lambda_{f_{CP}}|^2)\cos(\Delta m t) - 2\,\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t)}{1+|\lambda_{f_{CP}}|^2}$$

$$= C\cos(\Delta m t) + S\sin(\Delta m t)$$

$$\lambda = \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

Non-zero effect if Im(λ) ≠ 0, even if |λ| = 1

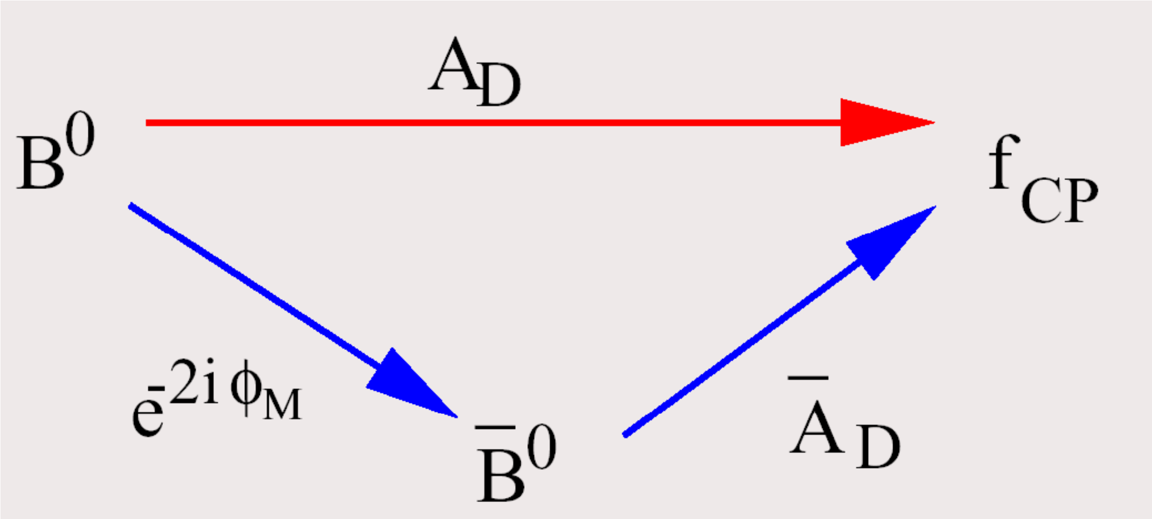
If |λ| = 1 →

$$a_{f_{CP}} = -\mathrm{Im}(\lambda)\sin(\Delta m t)$$

CP violation in the interference between decays with and without mixing

CP violation in the interference between mixing and decay to a state accessible in both B^0 and anti-B^0 decays

For example: a CP eigenstate f_{CP} like $\pi^+ \pi^-$ or $J/\psi K_S$

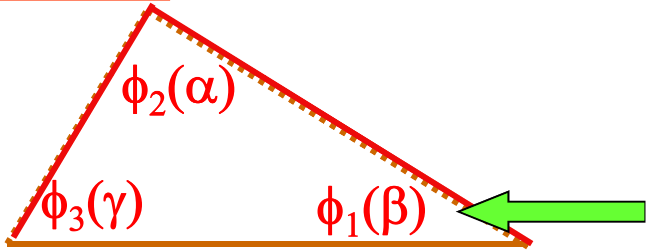


Decay rate asymmetry

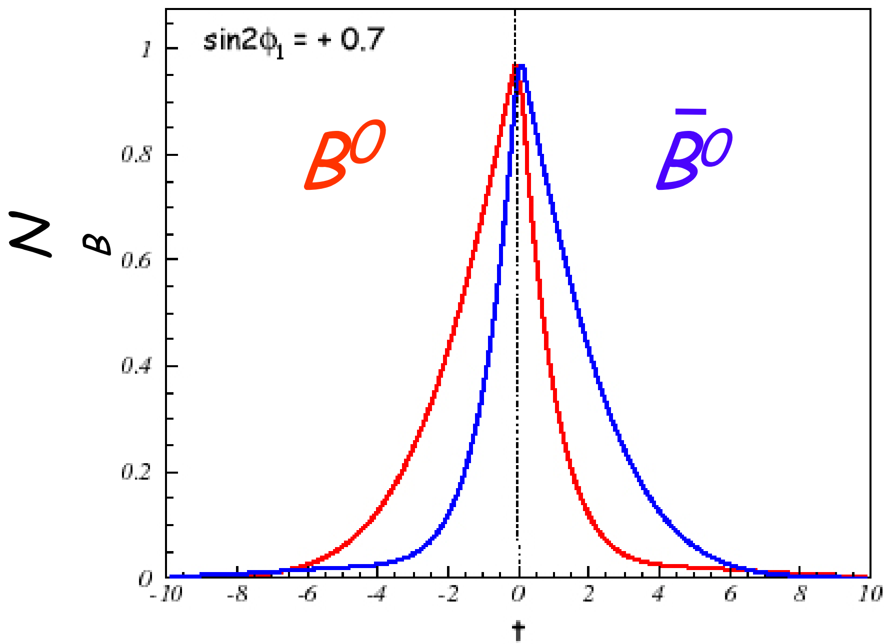
$$a_{f_{CP}} = -\mathrm{Im}(\lambda)\sin(\Delta m t)$$

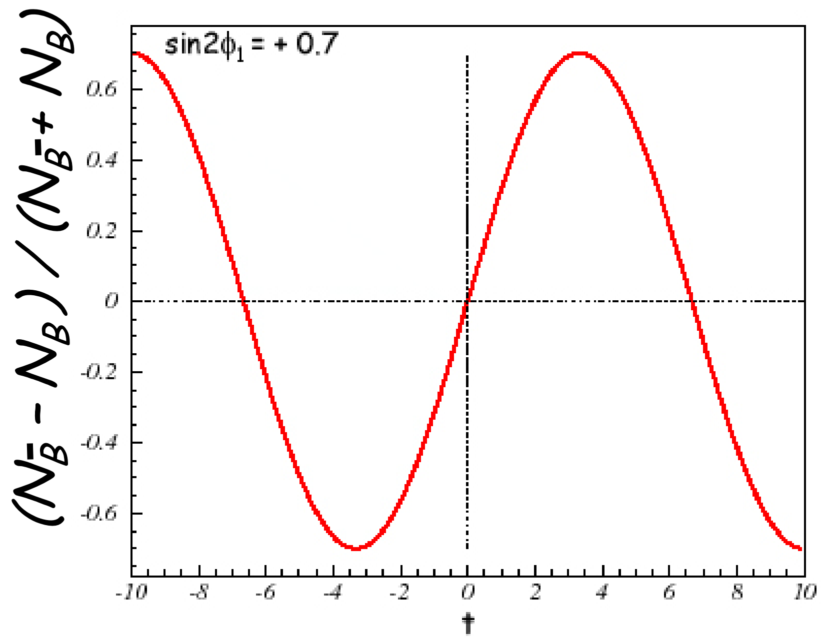
If $|\lambda| = 1$

For $J/\psi K_S$ $\quad \mathrm{Im}(\lambda) = \sin 2\phi_1$



CP Violation in B decays to CP eigenstates f_{CP}

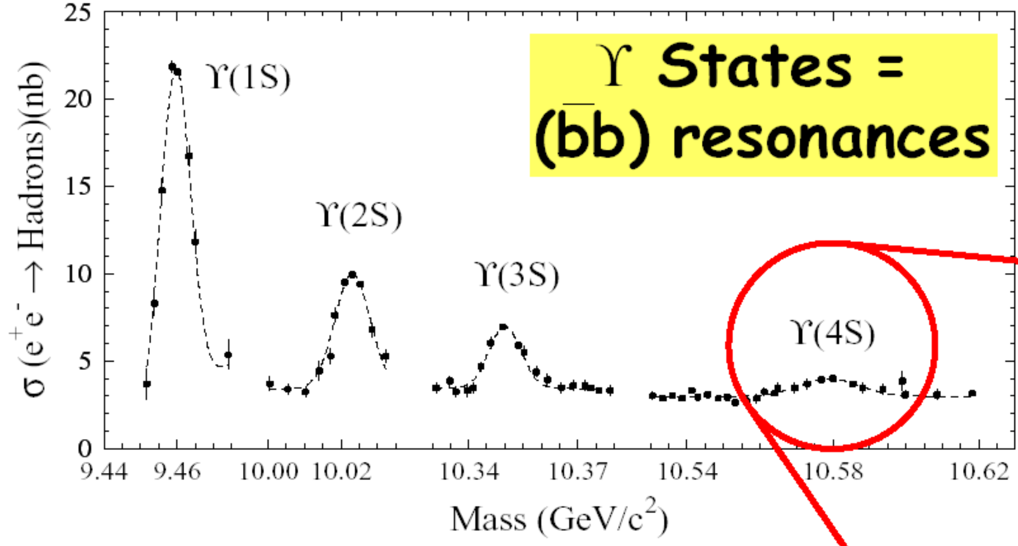


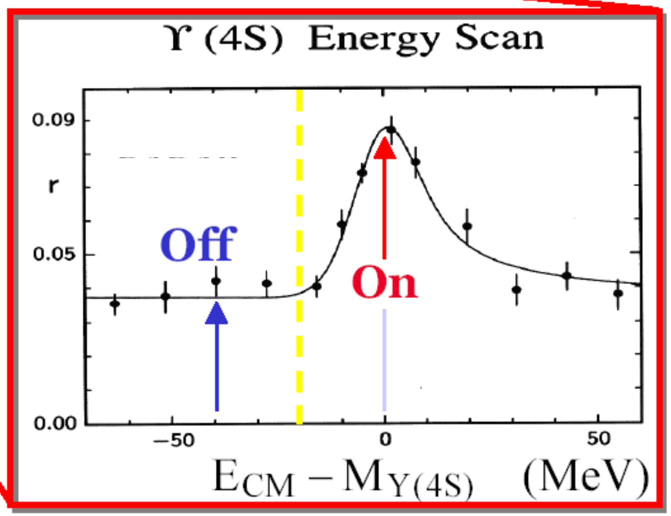


$$A_{CP}(t)=\frac{\Gamma(\overline{B}^0(t)\rightarrow f_{CP})-\Gamma(B^0(t)\rightarrow f_{CP})}{\Gamma(\overline{B}^0(t)\rightarrow f_{CP})+\Gamma(B^0(t)\rightarrow f_{CP})}=-\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

$\xi_f = \pm 1$ ***for*** $CP = \pm 1$

B meson production at $\Upsilon(4s)$





Cross Sections at $\Upsilon(4S)$:

$b\bar{b} \sim 1.1$ nb

$c\bar{c} \sim 1.3$ nb

$d\bar{d}, s\bar{s} \sim 0.3$ nb

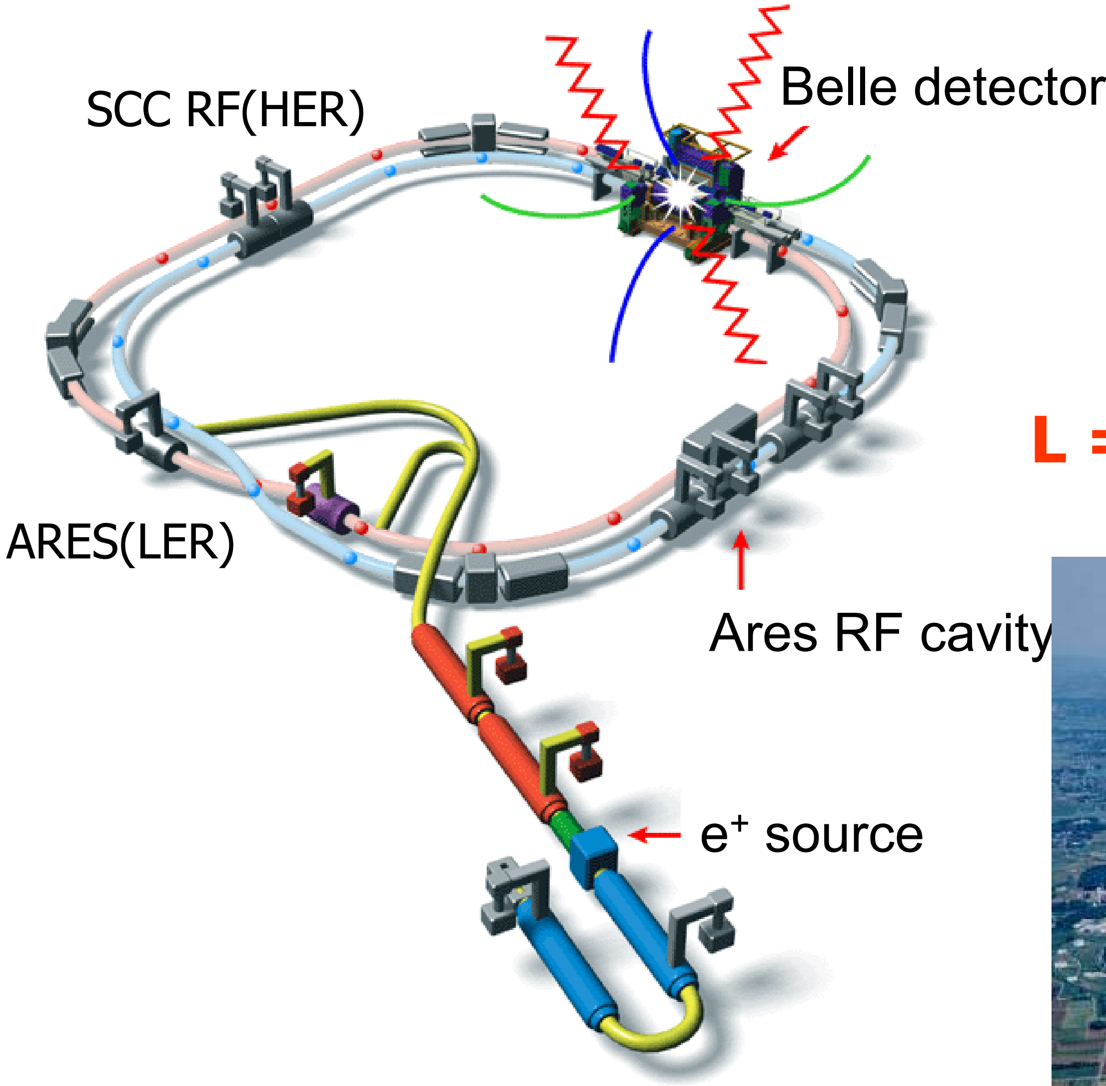
$u\bar{u} \sim 1.4$ nb

$$e^+e^- \to \Upsilon(4S) \to B\bar{B}$$

$L = 1$ state

Big advantage: low background

The KEKB Collider

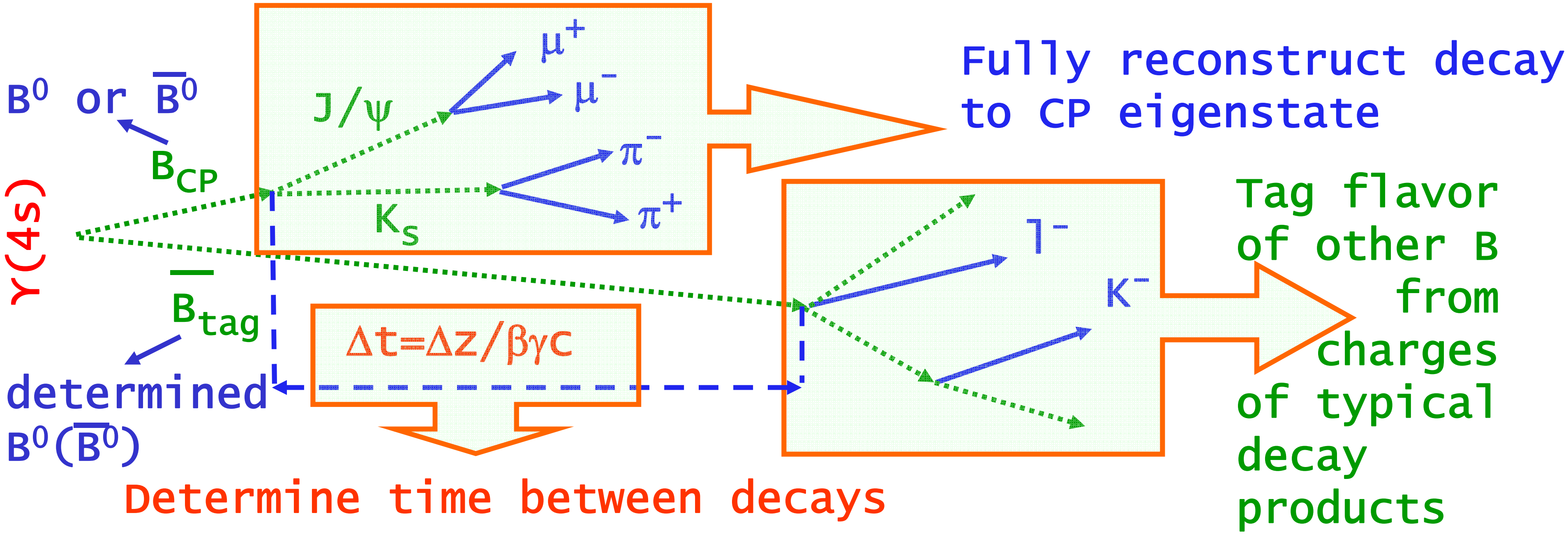


8 x 3.5 GeV
22mrad crossing angle

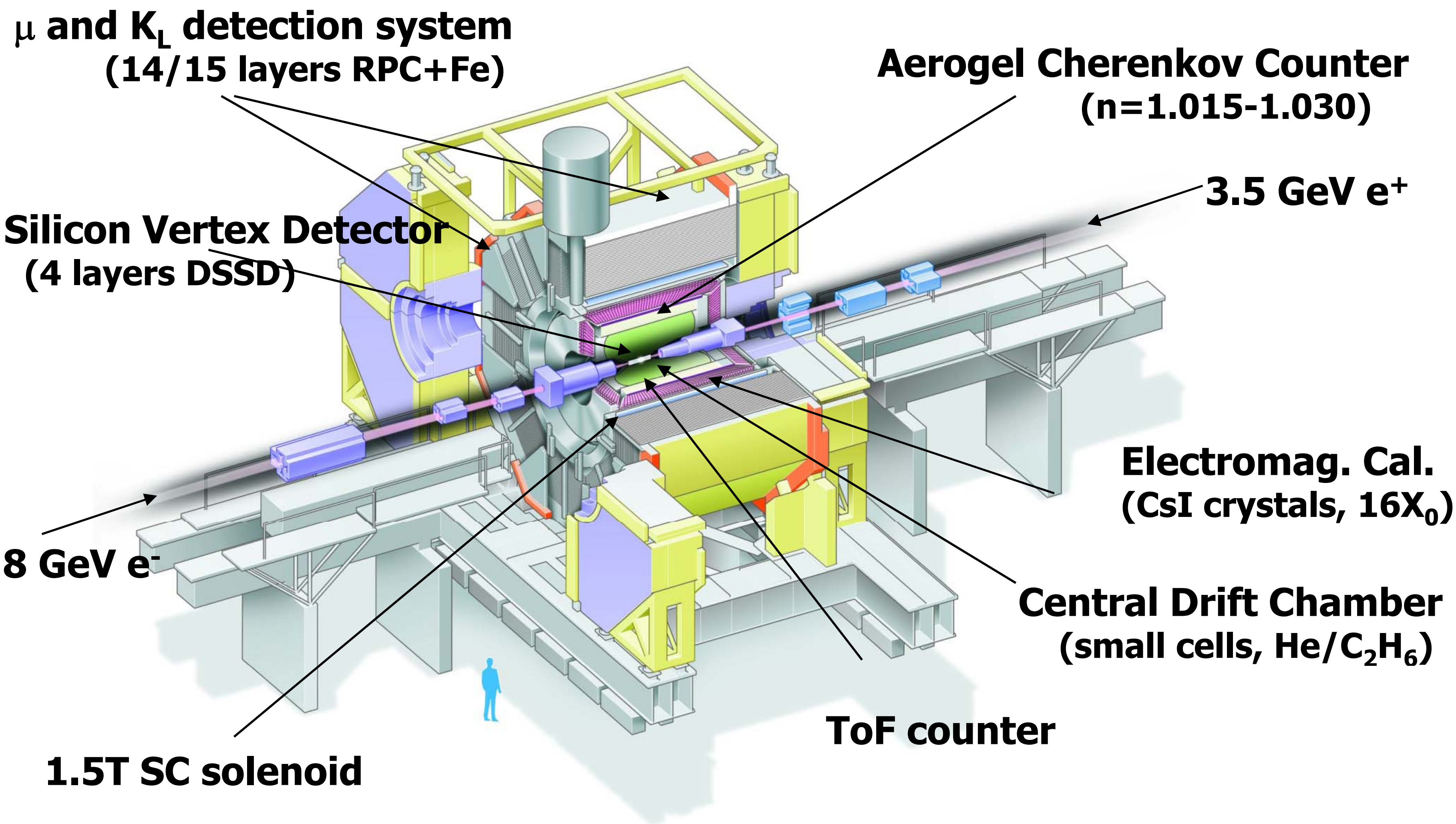
World record:

L = 2.1 x 10^{34}/cm^2/sec

Principle of measurement



Belle spectrometer at KEK-B



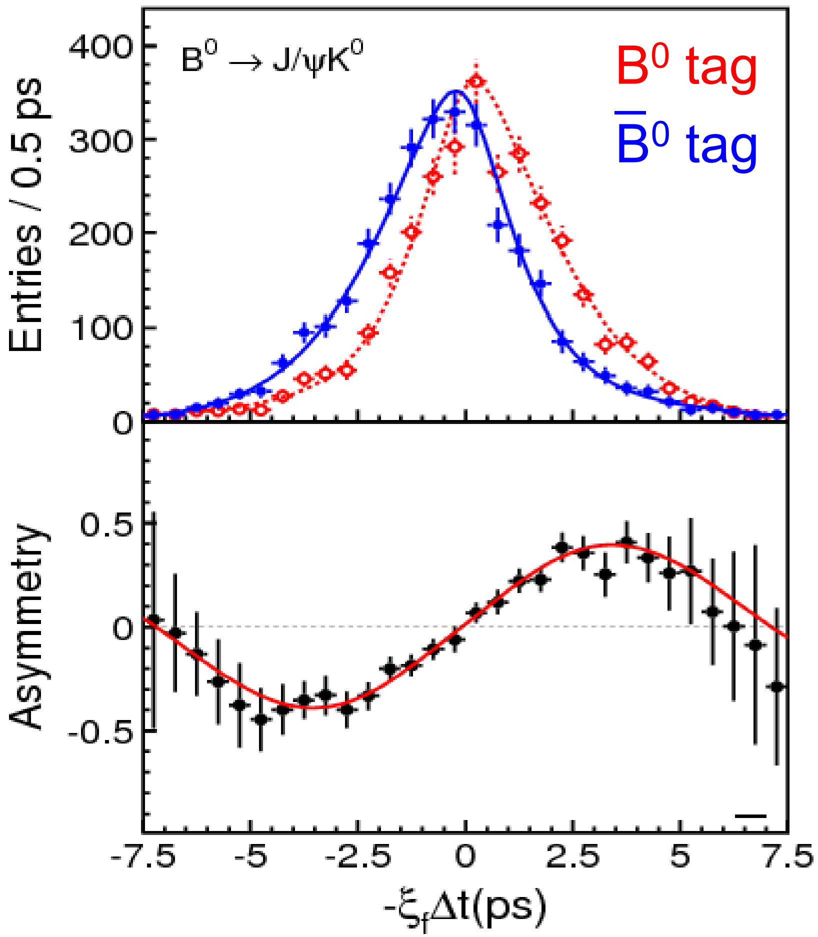
+ an extremely well operating KEK-B collider →

CP violation in the B system

CP violation in B system: from the discovery (2001) to a precision measurement (2006)

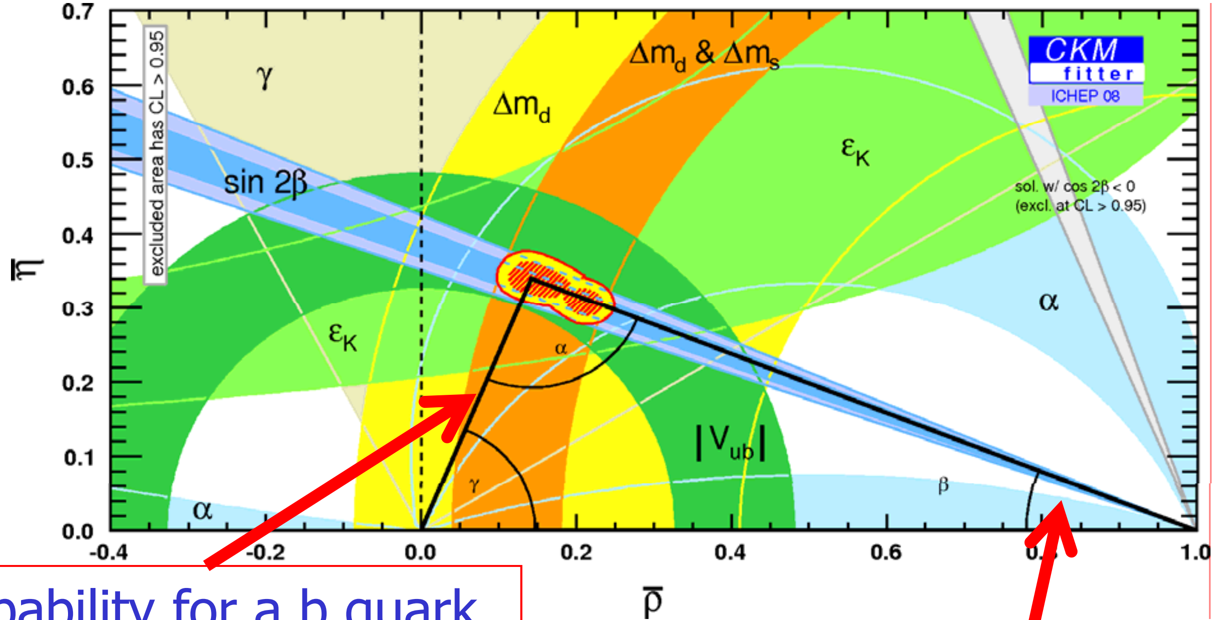
$\sin 2\phi_1/\sin 2\beta$ from $b \rightarrow ccs$ transitions

535 M $B\bar{B}$ pairs



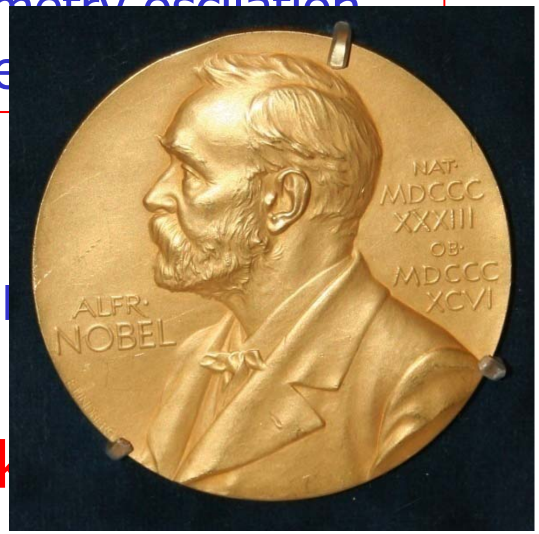
$\sin 2\phi_1$= 0.642 ±0.031 (stat) ±0.017 (syst)

All measurements combined...



Probability for a b quark to turn into a u quark → determines the length of the side **V_{ub}**

CP asymmetry oscilation amplitude



Constraints from measurements of angles a
unitarity triangle

Nobel prize 2008

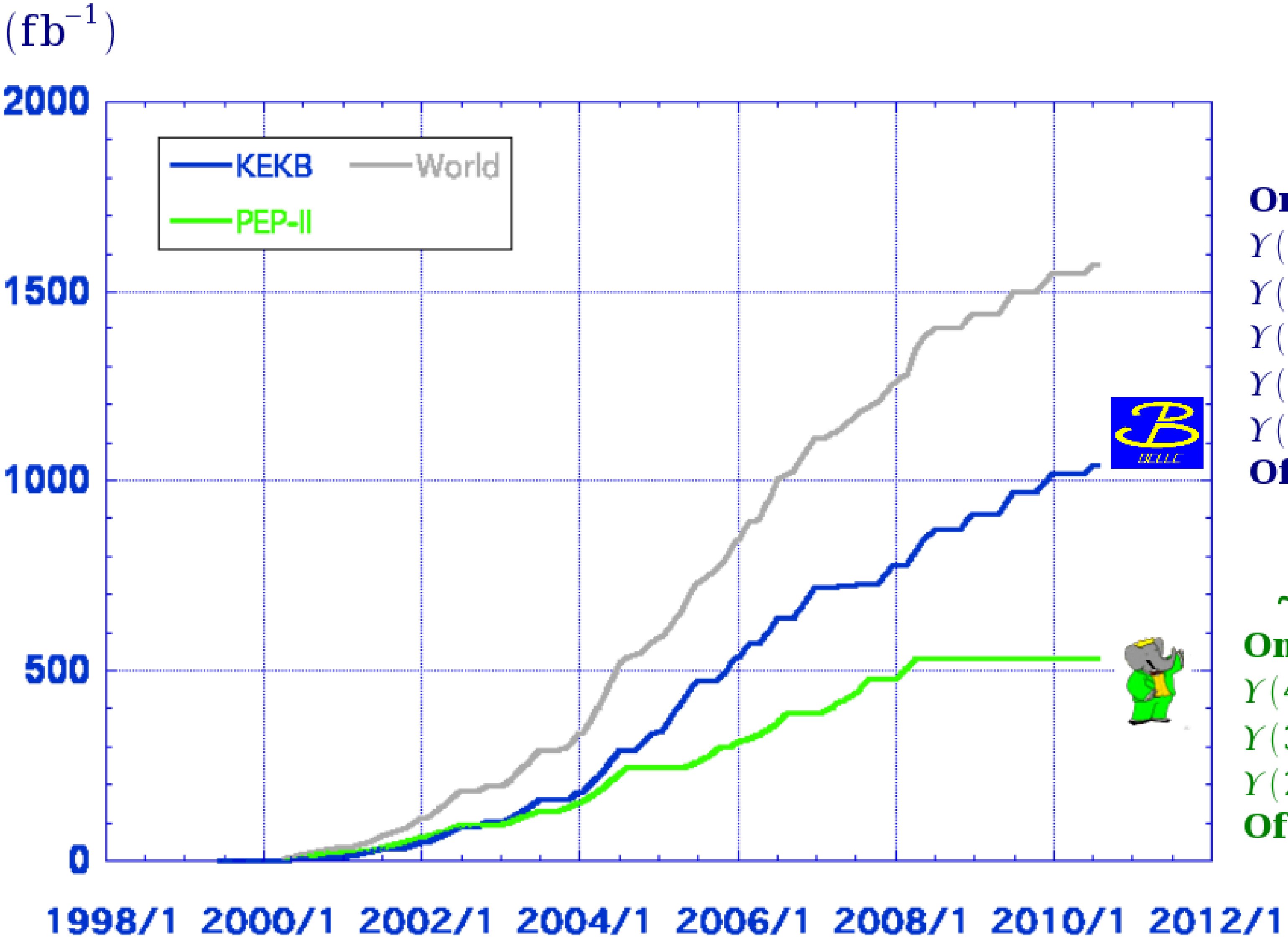
→ Remark

Also for us a good reason to celebrate...

B factories: a success story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$)
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

Luminosity at B factories



> 1 ab^{-1}

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:

$\sim$ 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:

$\sim$ 54 fb^{-1}

Fantastic performance much beyond design values!

What next?

B factories → is SM with CKM right?

Next generation: Super B factories → in which way is the SM wrong?

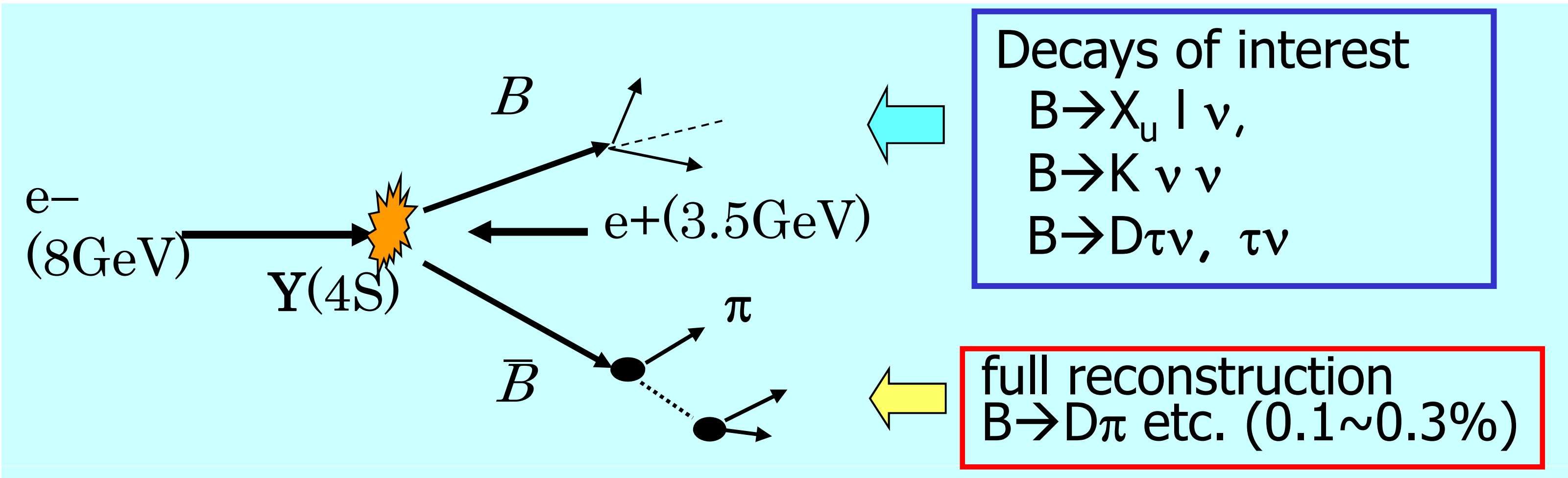
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

However: it will be a different world in four years, there will be serious competition from LHCb and BESIII

Still, e^+e^- machines running at (or near) Υ(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

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

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

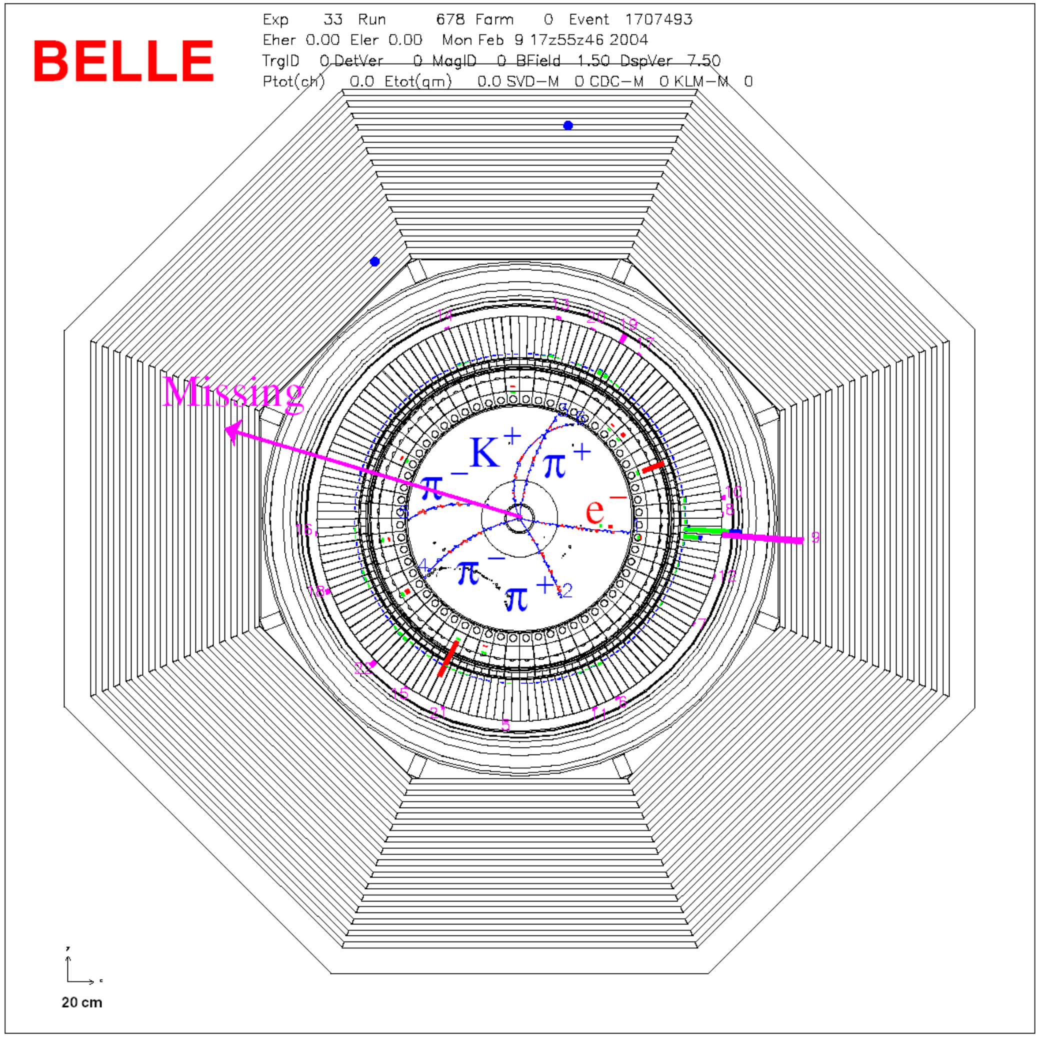


→ Offline B meson beam!

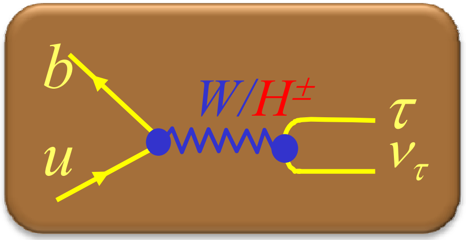
Powerful tool for B decays with neutrinos

Event candidate $B^- \rightarrow \tau^- \nu_\tau$

$$B^+ \rightarrow D^0\pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$

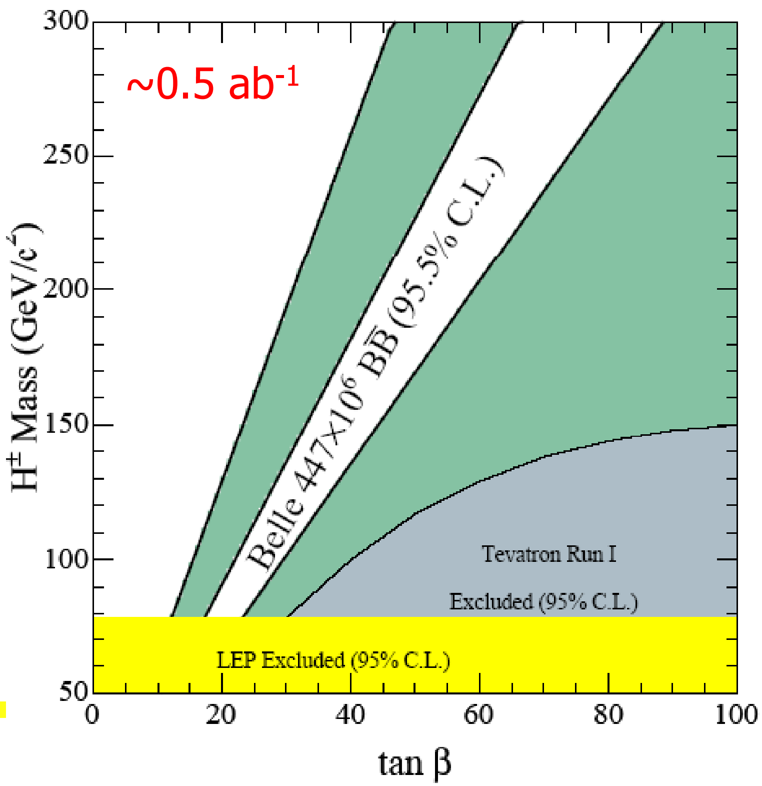


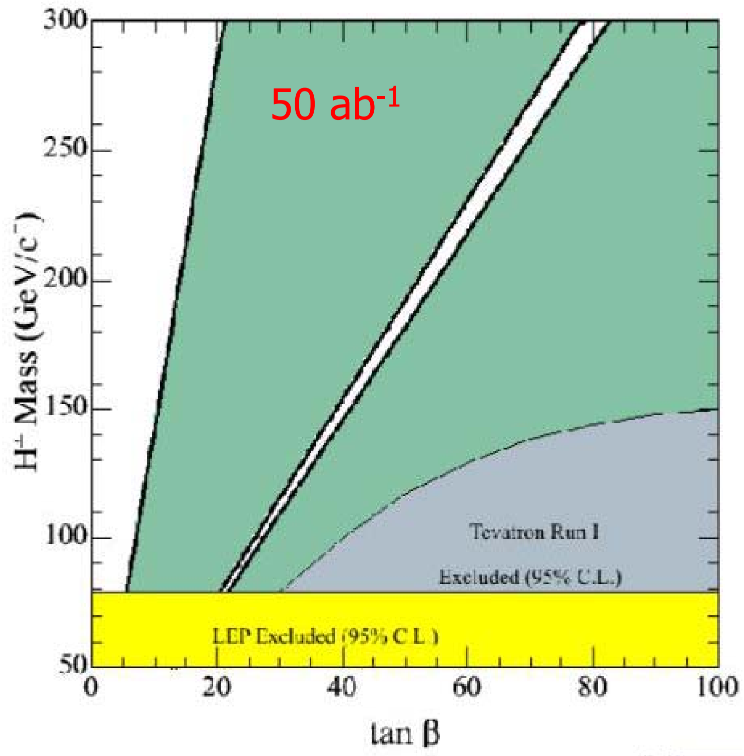
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$



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

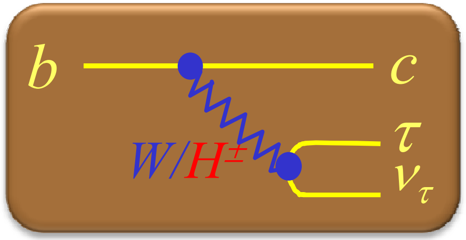
→ limit on charged Higgs mass vs. tanβ





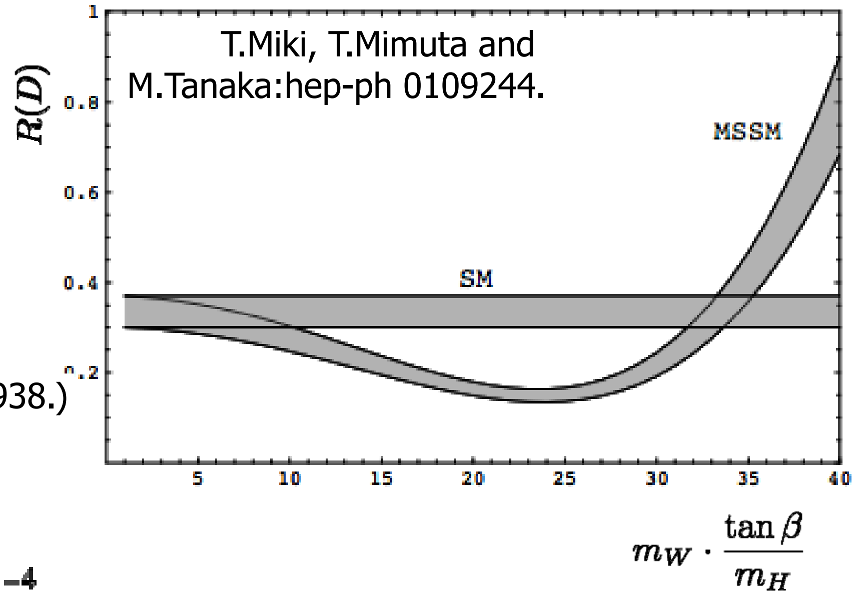
B→D$^{(*)}$τν

Semileptonic decay sensitive to charged Higgs



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

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



Compared to B→τν

1.Smaller theoretical uncertainty of R(D)

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

2.Large expected Br (Ulrich Nierste arXiv:0801.4938.)

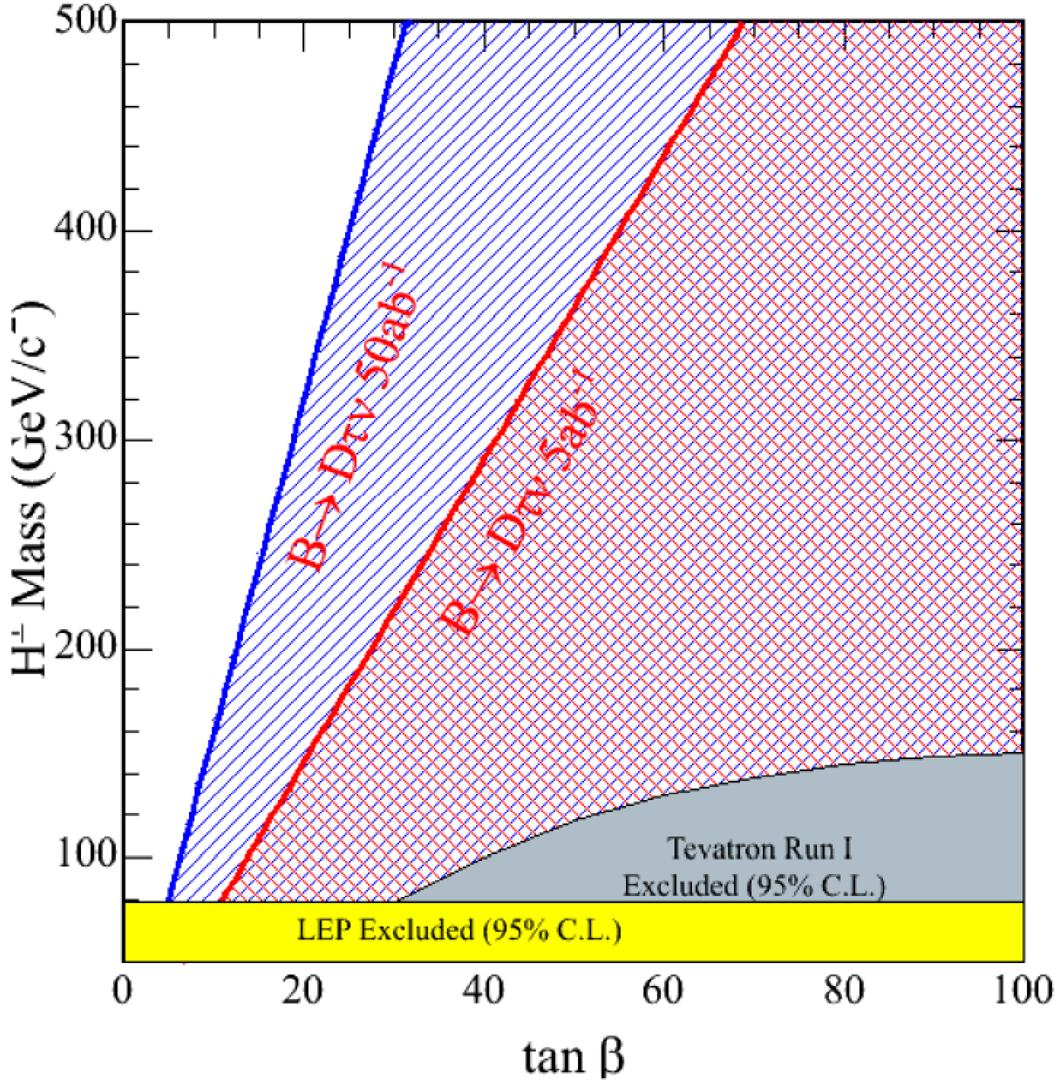
$$\mathcal{B}(B^-\to D^0\tau^-\bar{\nu}_\tau)^{SM} = (0.71\pm0.09)\%$$
$$\mathcal{B}(\bar{B}^0\to D^+\tau^-\bar{\nu}_\tau)^{SM} = (0.66\pm0.08)\%$$
$$\mathcal{B}(B\to\tau\nu) = [1.65^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)]\times10^{-4}$$

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)

B→Dτν

Exclusion plots for
tanβ and H⁺ mass
for 5ab⁻¹ and 50ab⁻¹



B→D*τν – similar constraints on H+

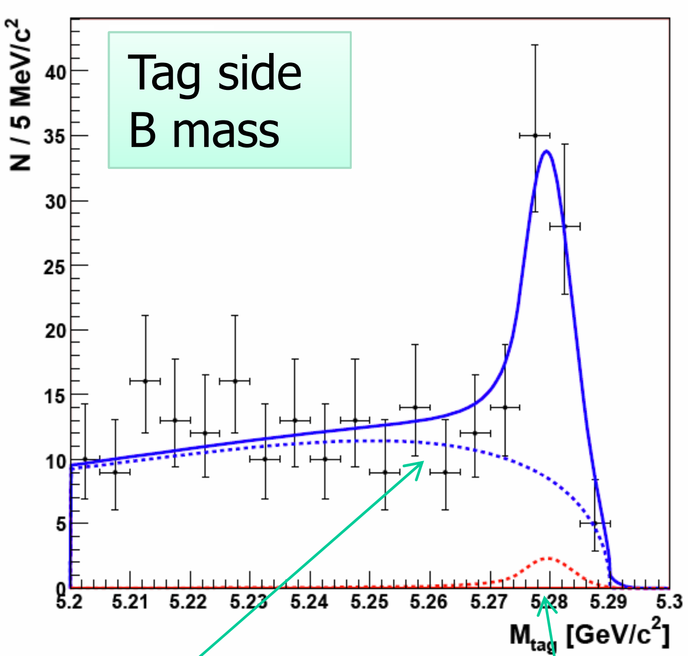
[PRL 99, 191807 (2007)]

FIRST OBSERVATION - 2007

$BF(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.02\,^{+0.40}_{-0.37}(stat) \pm 0.37(syst)) \times 10^{-2}$

535M $B\bar{B}$

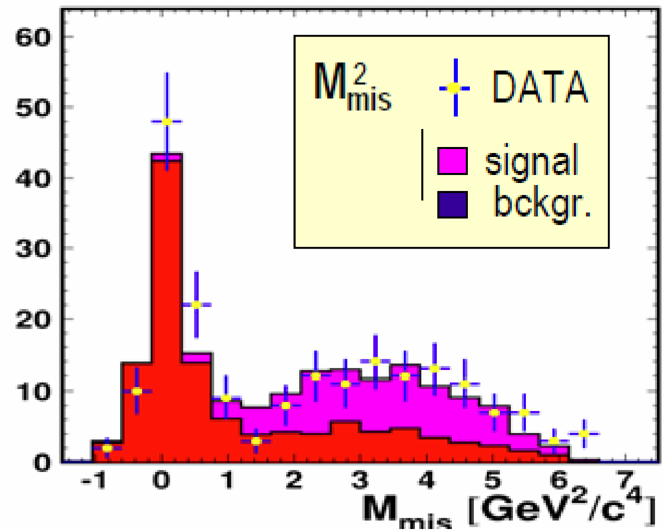
SIGNAL YIELD $N_s = 60\,^{+12}_{-11}$ **6.7σ (5.2σ with syst.)**



combinatorial background

peaking background (D*-eν)

$M^2_{mis} = (E_b - E_{D^{(*)}} - E_{l/h})^2 - (-\vec{p}_{tag} - \vec{p}_{D^{(*)}} - \vec{p}_{l/h})^2$



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

arXiv:1002.5012

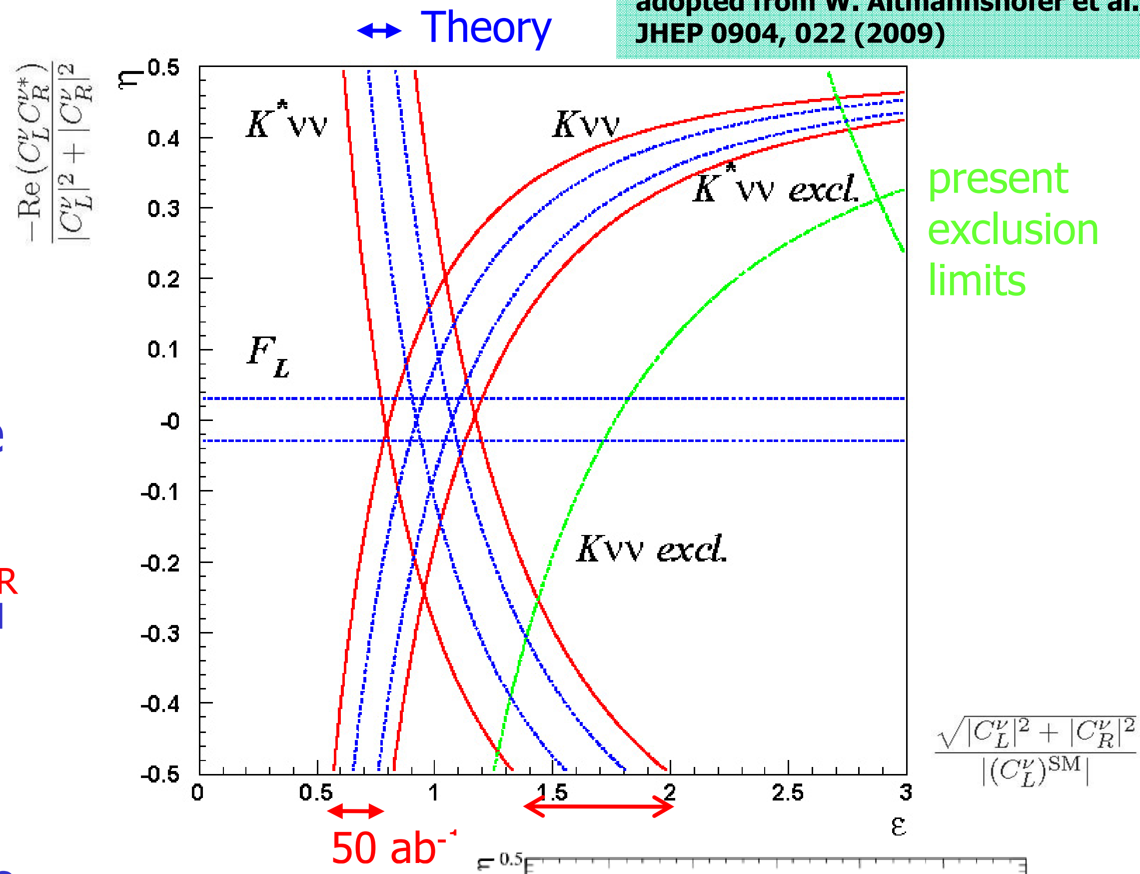
adopted from W. Altmannshofer et al., JHEP 0904, 022 (2009)

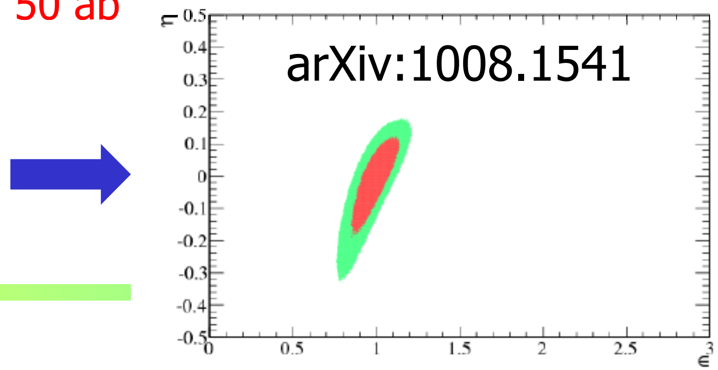
$B \to K\nu\nu$, $\mathcal{B} \sim 4{\cdot}10^{-6}$
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8{\cdot}10^{-6}$

SM: penguin+box

Look for departure from the expected value → information on couplings C^{ν}_R and C^{ν}_L compared to $(C^{\nu}_L)^{SM}$

Again: fully reconstruct one of the B mesons, look for signal (+nothing else) in the rest of the event.





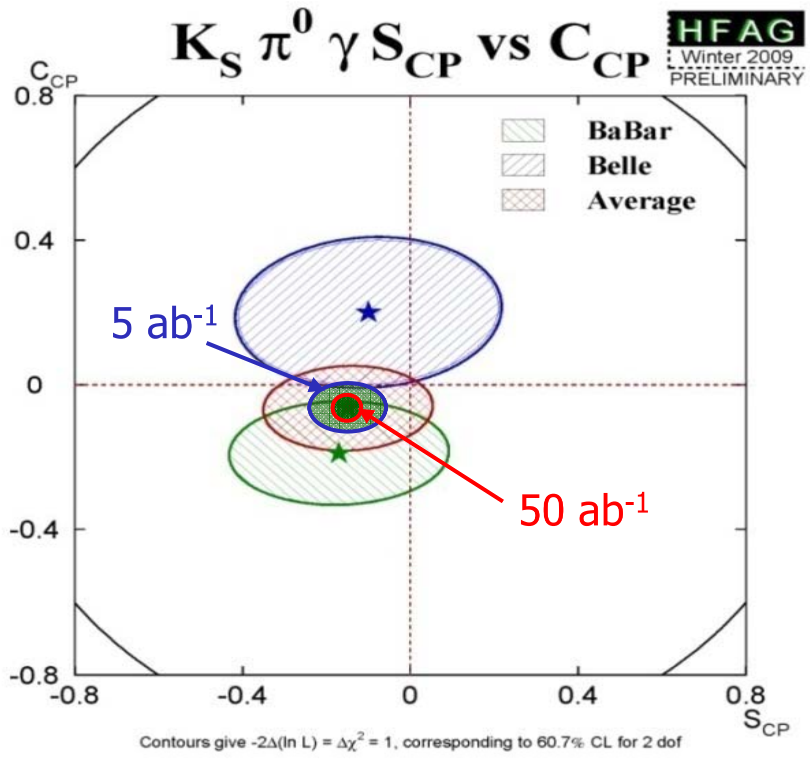
not possible @ LHCb

CP violation in $B \rightarrow K_S \pi^0 \gamma$

CP violation in $B \rightarrow K_S \pi^0 \gamma$ decays:
Search for right-handed currents

$B \rightarrow K^* \gamma$, $\mathcal{B} \sim 4.0 \cdot 10^{-5}$

$\delta S \sim 0.2$ (present)
→ ~a few % at 50 ab^{-1}

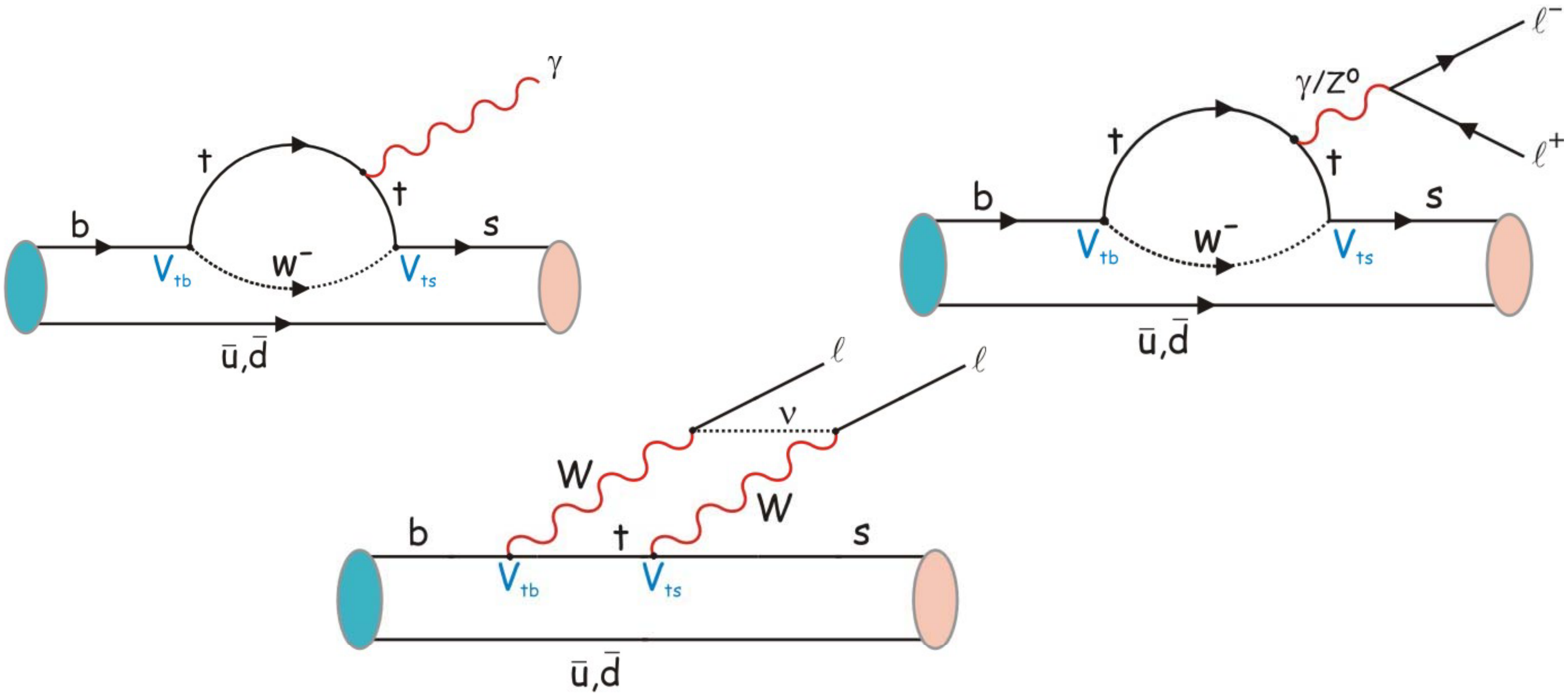


adopted from HFAG

not possible @ LHCb

Search for new physics in FCNC decays

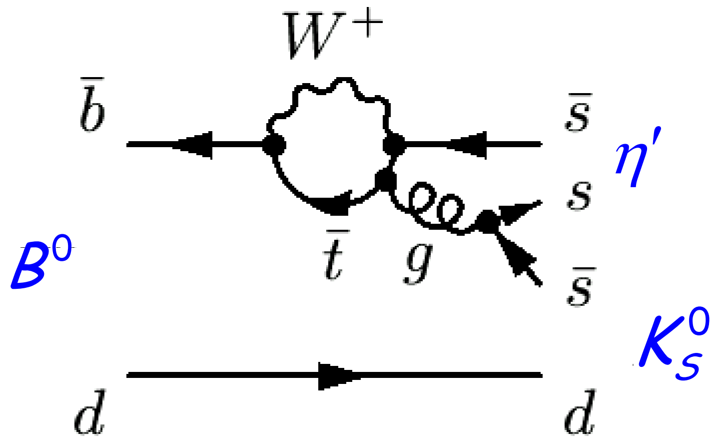
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



How can New Physics contribute to b→s?

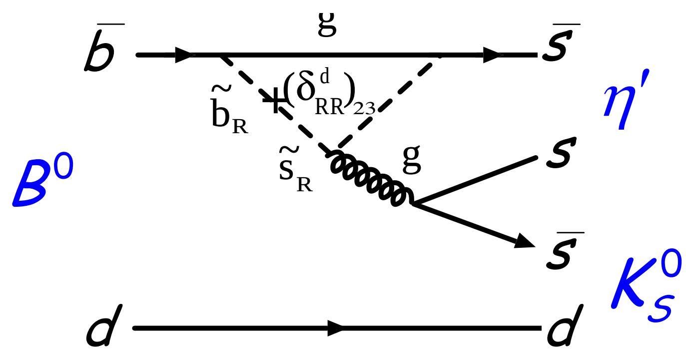
For example in the process:

$B^0 \to \eta' K^0$



Ordinary penguin diagram with a t quark in the loop

Diagram with supersymmetric particles

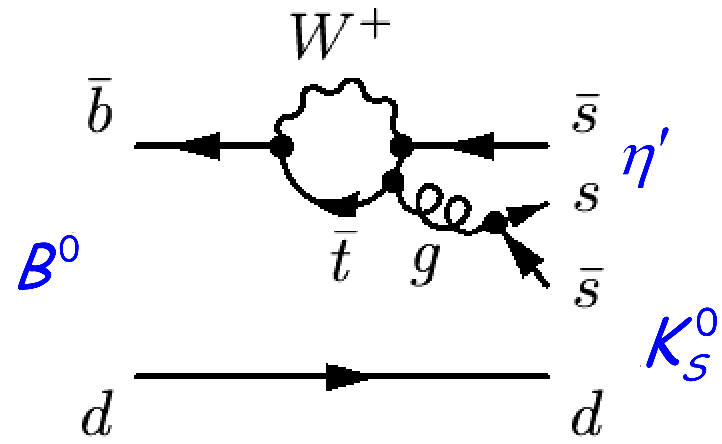


Searching for new physics phases in CP violation measurements in b→s decays

Prediction in SM: CP violation parameter

$B^0 \to \eta' K^0$

$$a_f = -\mathrm{Im}(\lambda_f)\sin(\Delta m t)$$

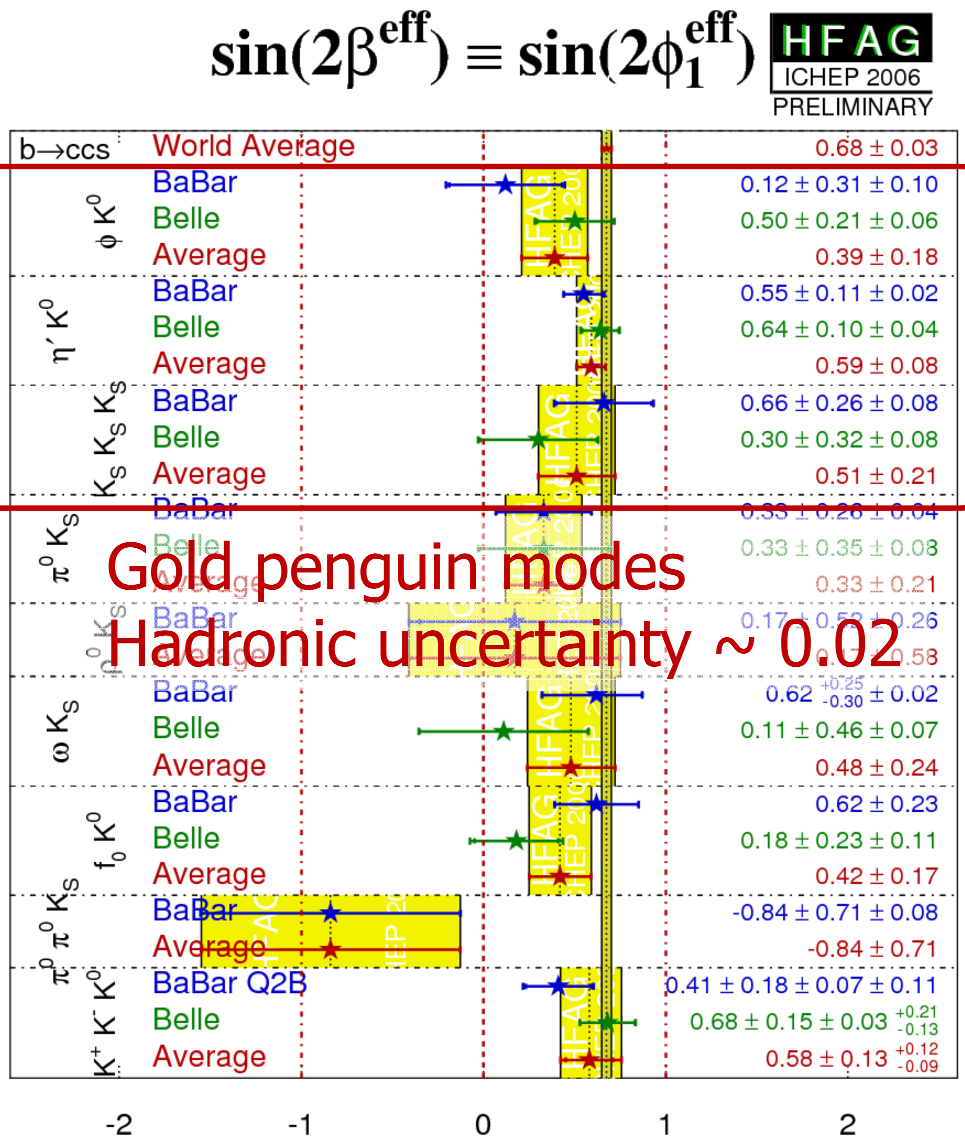


$$\mathrm{Im}(\lambda_f) = \xi_f \sin 2\phi_1$$

The same value as in the decay $B^0 \to J/\psi\ K_S$!

This is only true if there are no other particles in the loop! In general the parameter can assume a different value $\sin 2\phi_1^{eff}$

Search for NP: $b \to s\bar{q}q$



Gold penguin modes

Hadronic uncertainty ~ 0.02

ICHEP08

BaBar
Belle
Naïve average

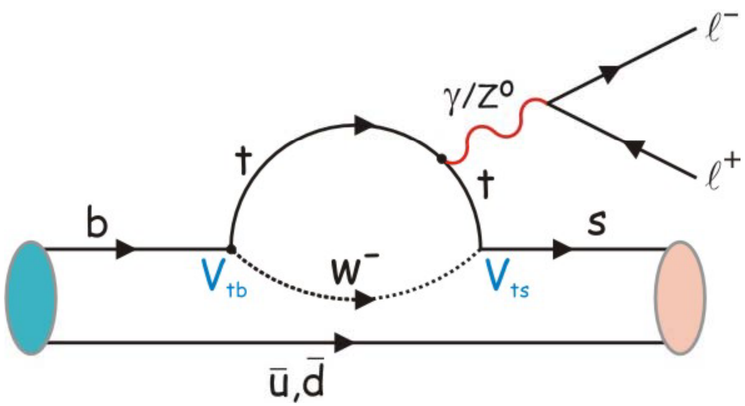
ϕK^0:
- 0.26±0.25±0.04
- $0.67\pm^{0.25}_{0.27}\pm0.07$
- 0.45±0.18

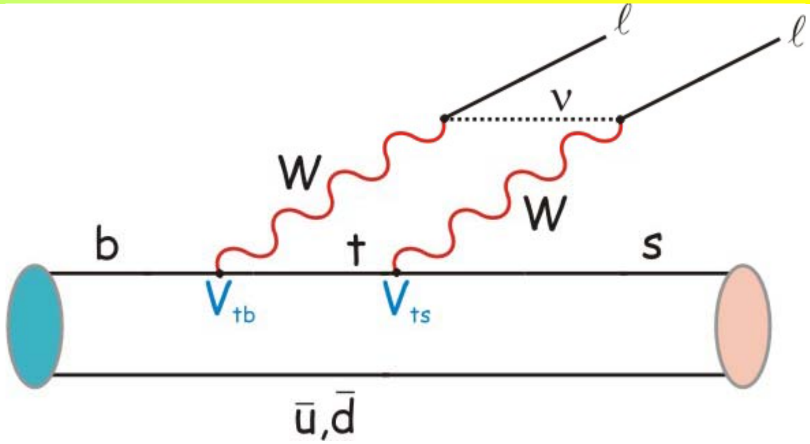
$\eta' K^0$:
- 0.57±0.08±0.02
- 0.64±0.10±0.04
- 0.60±0.07

$K_S K_S K_S$:
- 0.71±0.24±0.04
- 0.30±0.32±0.08
- 0.57±0.20

Need much more data to clarify the issue
→Super B factory

Another FCNC decay: $B \rightarrow K^* l^+ l^-$





$b \rightarrow s\, l^+ l^-$ was first measured in $B \rightarrow K\, l^+ l^-$ by Belle (2001).

Important for further searches for the physics beyond SM

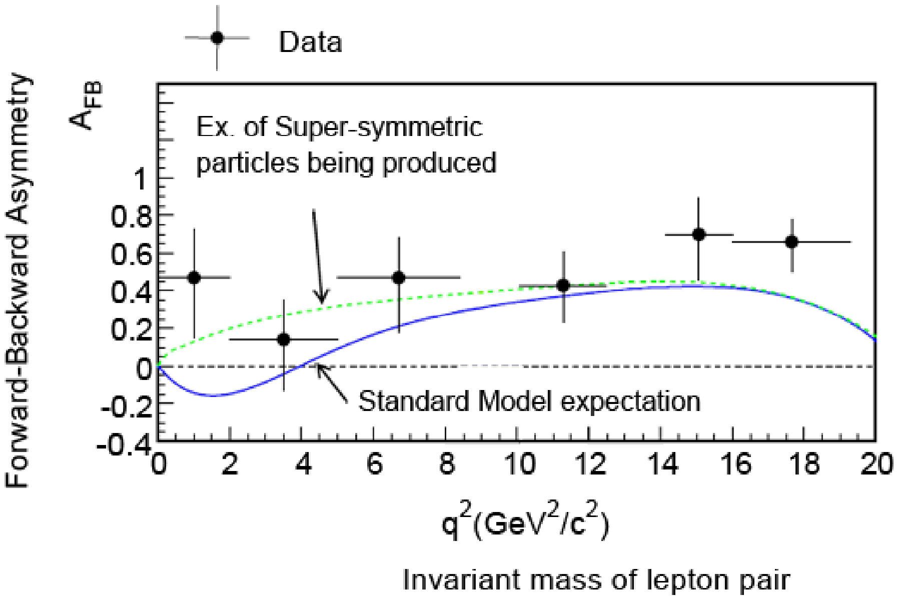
Particularly sensitive: backward-forward asymmetry in $K^* l^+ l$

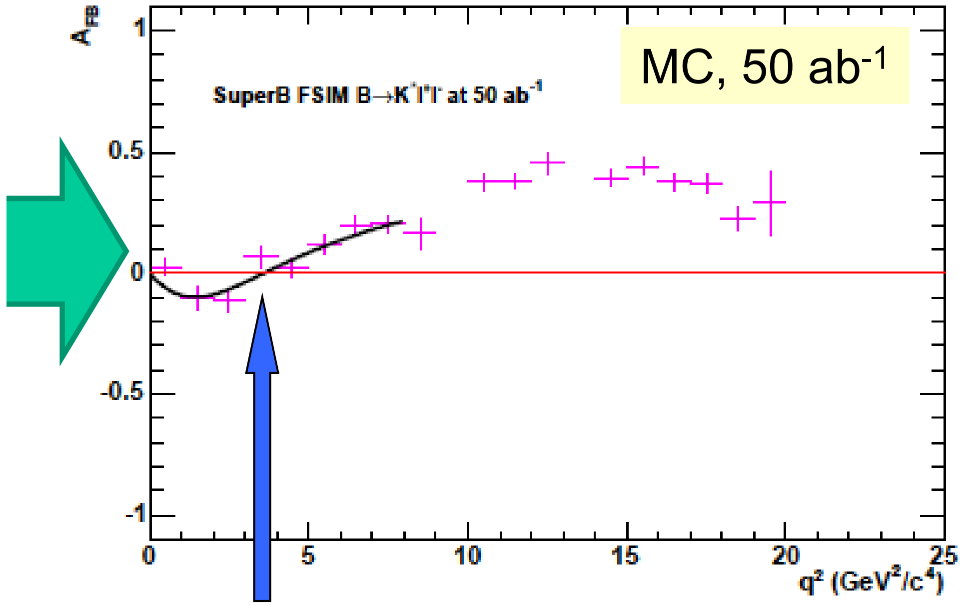
$$A_{FB} \propto \Re\left[C_{10}^{*} \left(s C_9^{eff}(s) + r(s) C_7 \right) \right]$$

C_i : Wilson coefficients, abs. value of C_7 from $b \rightarrow s\gamma$

s=lepton pair mass squared

$A_{FB}(B \to K^* l^+ l^-)[q^2]$





Data: very interesting!

Zero-crossing q^2 for A_{FB} will be determined with a 5% error with $50ab^{-1}$.

Strong competition from LHCb and ATLAS/CMS

A difference in the direct violation of CP symmetry in B^+ and B^0 decays


nature International weekly journal of science

nature Vol 452 | 20 March 2008 | doi:10.1038/nature06827

LETTERS

Difference in direct charge-parity violation between charged and neutral *B* meson decays

The Belle Collaboration*

CP asymmetry

$$\mathcal{A}_f = \frac{N(\overline{B} \to \bar{f}) - N(B \to f)}{N(\overline{B} \to \bar{f}) + N(B \to f)}$$

Difference between B^+ and B^0 decays

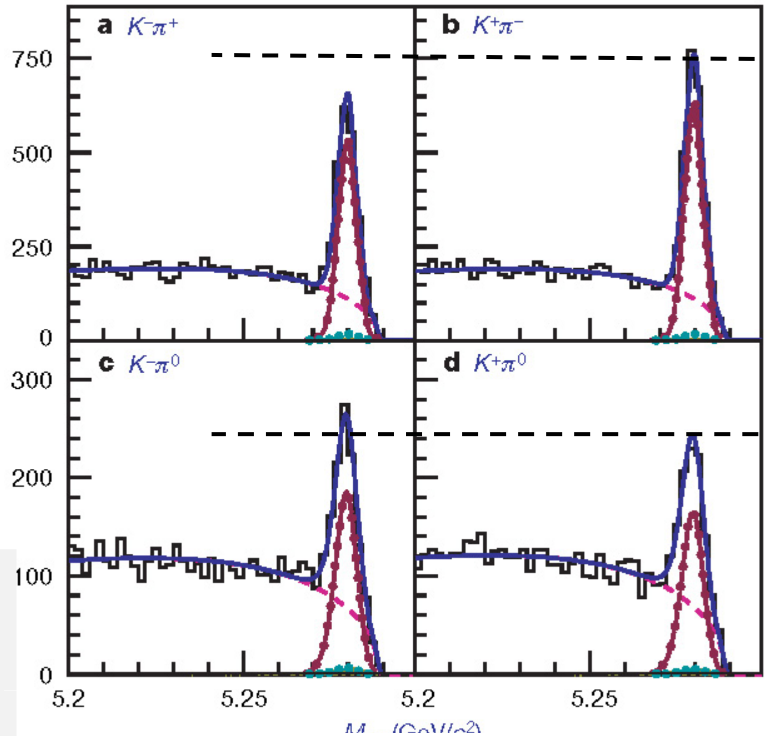
In SM expect $\mathcal{A}_{K^\pm\pi^\mp} \approx \mathcal{A}_{K^\pm\pi^0}$

Measure:

$$\mathcal{A}_{K^\pm\pi^\mp} = -0.094 \pm 0.018 \pm 0.008$$

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

$$\Delta\mathcal{A} = +0.164 \pm 0.037$$



A problem for a SM explanation
(in particular when combined with other measurements)
A hint for new sources of CP violation?

~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

D^0 mixing in K^+K^-, $\pi^+\pi^-$

$D^0 \rightarrow K^+K^- / \pi^+\pi^-$

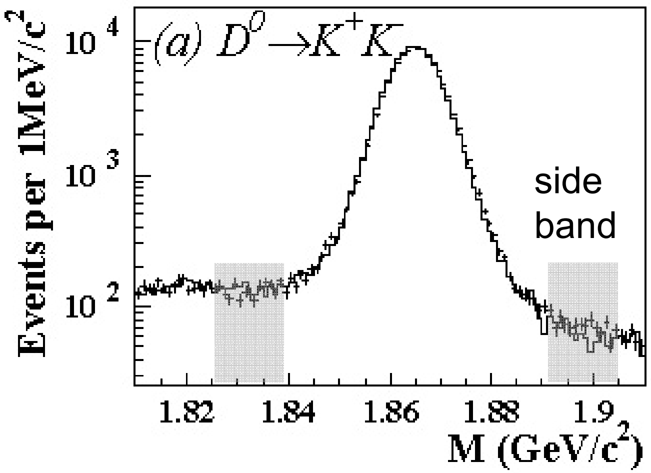
CP even final state;
in the limit of no CPV: CP|D_1> = |D_1>
$\Rightarrow$ measure $1/\Gamma_1$

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

$$y_{CP} \equiv \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 = y\cos\varphi - \frac{1}{2}A_M x \sin\varphi = \underset{no\,CPV}{=} y$$

S. Bergman et al., PLB486, 418 (2000)

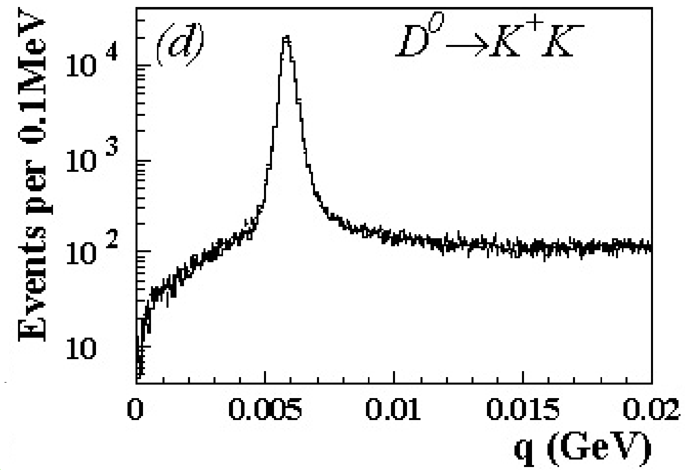
A_M, ϕ: CPV in mixing and interference



Signal: $D^0 \rightarrow K^+K^- / \pi^+\pi^-$ from D^*

M, Q, σ_t selection optimized in MC

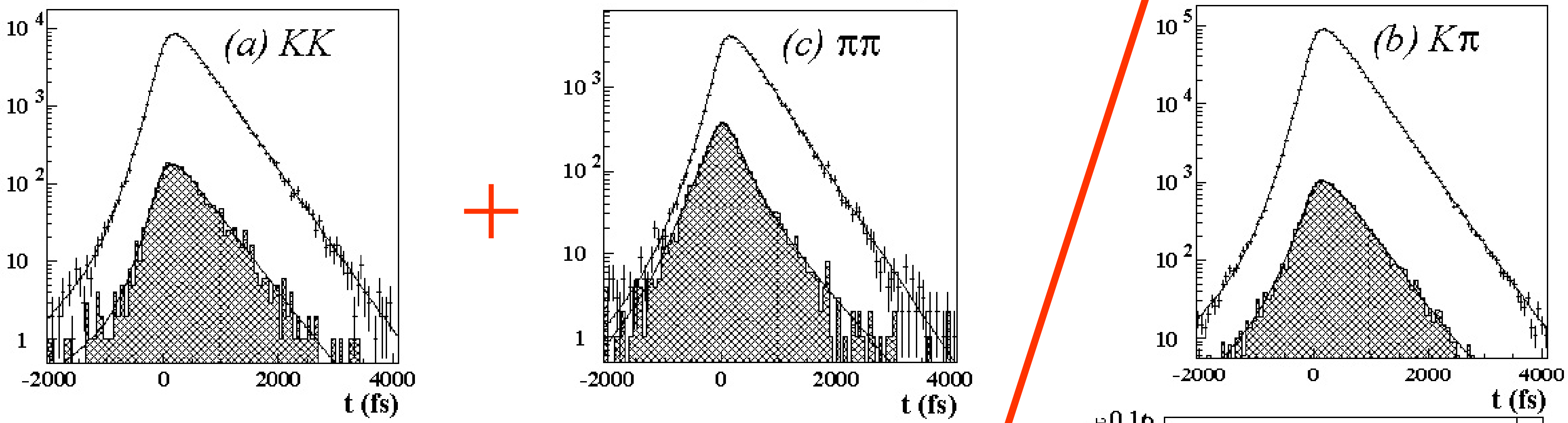
	K^+K^-	$K^-\pi^+$	$\pi^+\pi^-$
N_{sig}	111×10^3	1.22×10^6	49×10^3
purity	98%	99%	92%



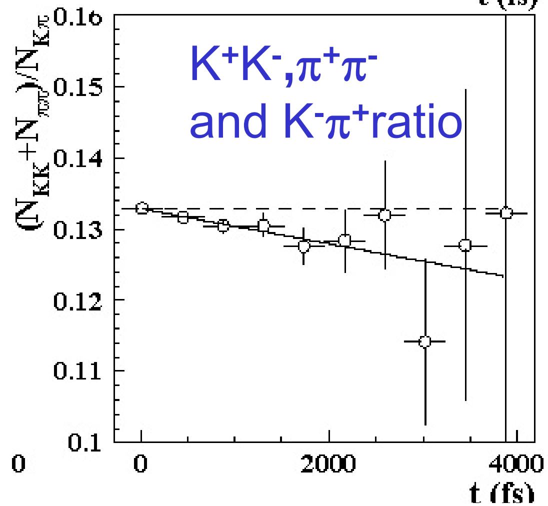
PRL 98, 211803 (2007), 540fb^{-1}

D^0 mixing in K^+K^-, $\pi^+\pi^-$

Decay time distributions for KK, ππ, Kπ



Difference of lifetimes visually observable in the ratio of the distributions →



Real fit:

$y_{CP} = (1.31 \pm 0.32 \pm 0.25)$ **%**

evidence for D^0 mixing

(regardless of possible CPV)

→y_{CP} is on the high side of SM expectations

CPV in D^0 system

example $D^0 \to K^+K^-$

t-dependent method

Belle, PRL 98, 211803 (2007), $540 fb^{-1}$

$$A_\Gamma \equiv \frac{\bar{\tau}_{KK} - \tau_{KK}}{\bar{\tau}_{KK} + \tau_{KK}} = \frac{A_M}{2} y \cos\varphi - (1 - \frac{A_D}{2}) x \sin\varphi \approx \frac{A_M}{2} y \cos\varphi - x \sin\varphi$$

$$\sigma^2_{A\Gamma} = \left[\frac{0.33\%}{\sqrt{\mathfrak{L}/\mathfrak{L}_0}}\right]^2 + [0.06\%]^2$$

$\mathfrak{L}_0 = 540\ fb^{-1}$

t-integrated method

Belle, PLB670, 190 (2008), $540 fb^{-1}$

$$A_{CP}^{KK} = \frac{\Gamma(D^0 \to KK) - \Gamma(\overline{D}^0 \to KK)}{\Gamma(D^0 \to KK) + \Gamma(\overline{D}^0 \to KK)} \approx \frac{A_D}{2} + x \sin\varphi - \frac{A_M}{2} y \cos\varphi$$

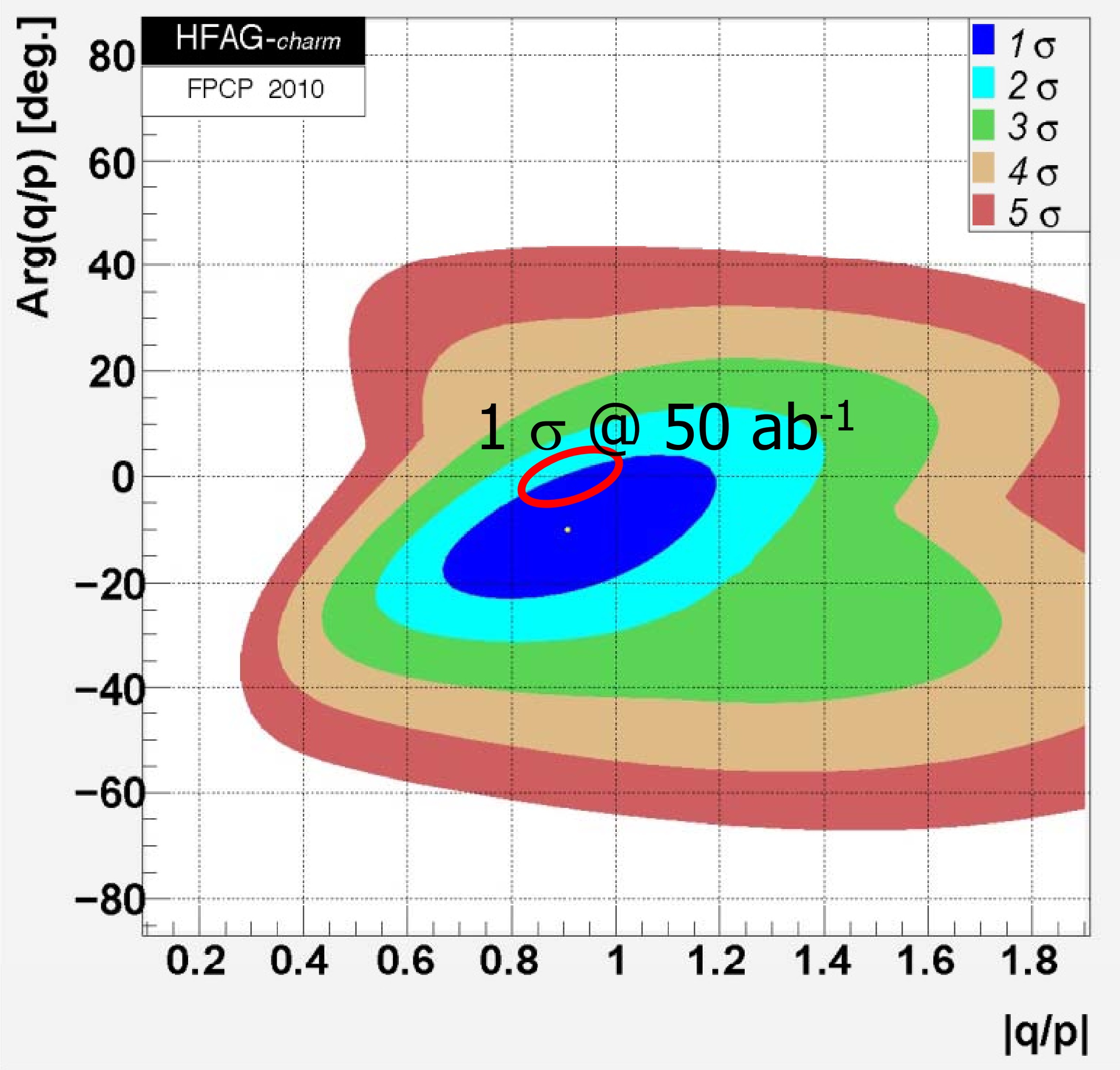
$$\sigma^2_{ACP} = \left[\frac{0.32\%}{\sqrt{\mathfrak{L}/\mathfrak{L}_0}}\right]^2 + [0.06\%]^2$$

Illustrative expected sensitivities
CPV parameters

Belle II, 50 ab^{-1}

$$x = (0.832 \pm 0.095)\%$$
$$y = (0.813 \pm 0.064)\%$$
$$\delta_{K\pi} = 24.6° \pm 4.9°$$
$$R_D = (0.336 \pm 0.003)\%$$
$$\frac{|q|}{|p|} = 0.894 \pm 0.054$$
$$\varphi = -0.004 \pm 0.049\ rad$$
$$A_D = (-0.1 \pm 0.8)\%$$

only KK/ππ, Kπ and $K_s\pi\pi$ projected sensitivities are included



B Physics @ Y(4S)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\, \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_s K^0_s K^0_s)$	0.15	0.02 (∗)
$S(K^0_s \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_s)$	0.17	0.03 (∗)
$S(f_0 K^0_s)$	0.12	0.02 (∗)
γ $(B \to DK,\, D \to CP$ eigenstates$)$	$\sim 15°$	2.5°
γ $(B \to DK,\, D \to$ suppressed states$)$	$\sim 12°$	2.0°
γ $(B \to DK,\, D \to$ multibody states$)$	$\sim 9°$	1.5°
γ $(B \to DK$, combined$)$	$\sim 6°$	1–2°
α $(B \to \pi\pi)$	$\sim 16°$	3°
α $(B \to \rho\rho)$	$\sim 7°$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12°$	2°
α (combined)	$\sim 6°$	1–2° (∗)
$2\beta + \gamma$ $(D^{(*)\pm}\pi^{\mp},\, D^{\pm}K^0_s\pi^{\mp})$	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_s\pi^0\gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Charm mixing and CP

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\lvert q/p\rvert$	3×10^{-2}	
	ϕ	$2°$	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

Charm FCNC

	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_s e^+e^-$, $D^0 \to K^0_s\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^{\pm}\mu^{\mp}$	1×10^{-8}
$D^+ \to \pi^+ e^{\pm}\mu^{\mp}$	1×10^{-8}
$D^0 \to \pi^0 e^{\pm}\mu^{\mp}$	2×10^{-8}
$D^0 \to \eta e^{\pm}\mu^{\mp}$	3×10^{-8}
$D^0 \to K^0_s e^{\pm}\mu^{\mp}$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^{\pm}\mu^{\mp}$, $D^+ \to K^- e^{\pm}\mu^{\mp}$	1×10^{-8}

τ Physics

	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_S)$	2×10^{-10}

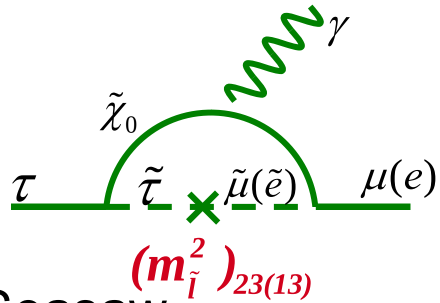
B_s Physics @ Y(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
A^s_{SL}	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

M. Giorgi, ICHEP2010

LFV and New Physics

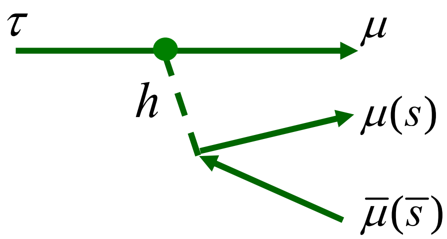
$\tau \to l\gamma$



- SUSY + Seasaw
- Large LFV $Br(\tau \to \mu\gamma) = O(10^{-7\sim 9})$

$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{1\,TeV}{m_{SUSY}} \right)^4 \tan^2\beta$$

$\tau \to 3l, l\eta$



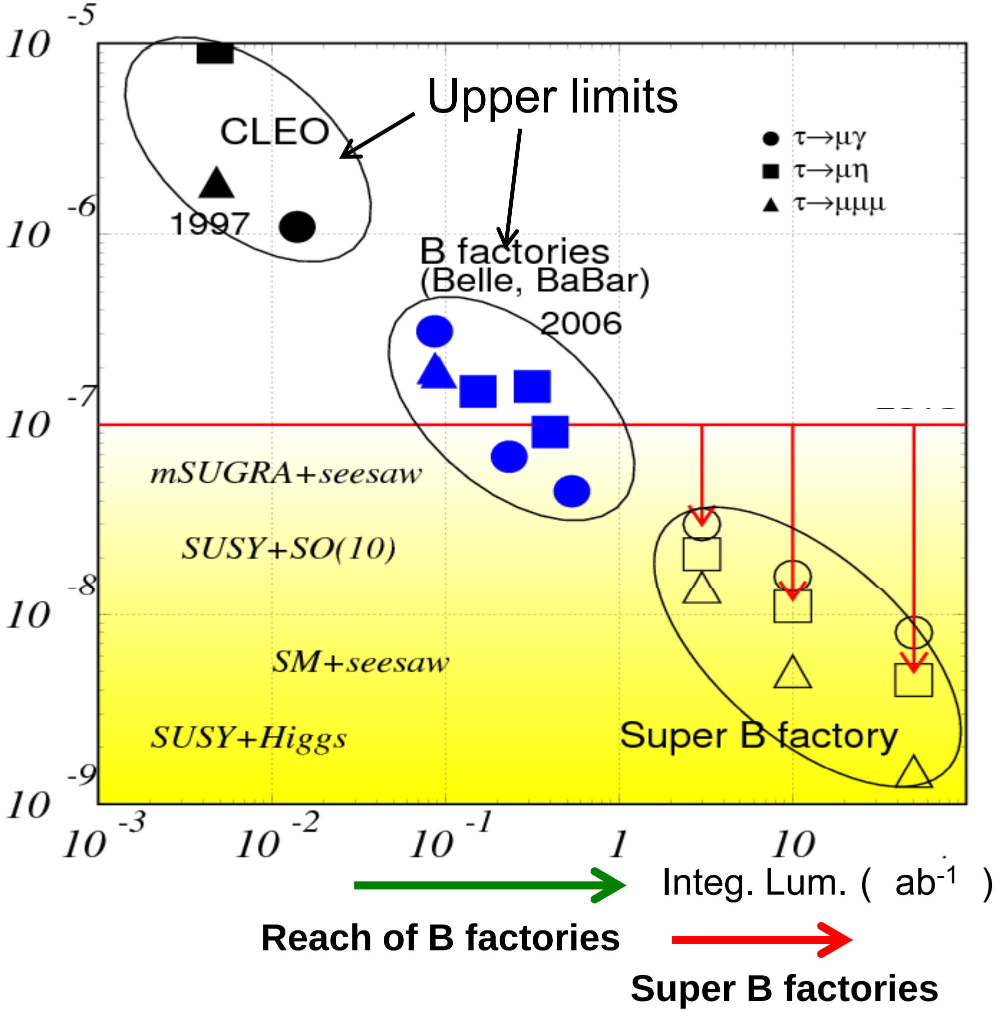
- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

$$Br(\tau \to 3\mu) = 4 \times 10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{\tan\beta}{60} \right)^6 \left(\frac{100\,GeV}{m_A} \right)^4$$

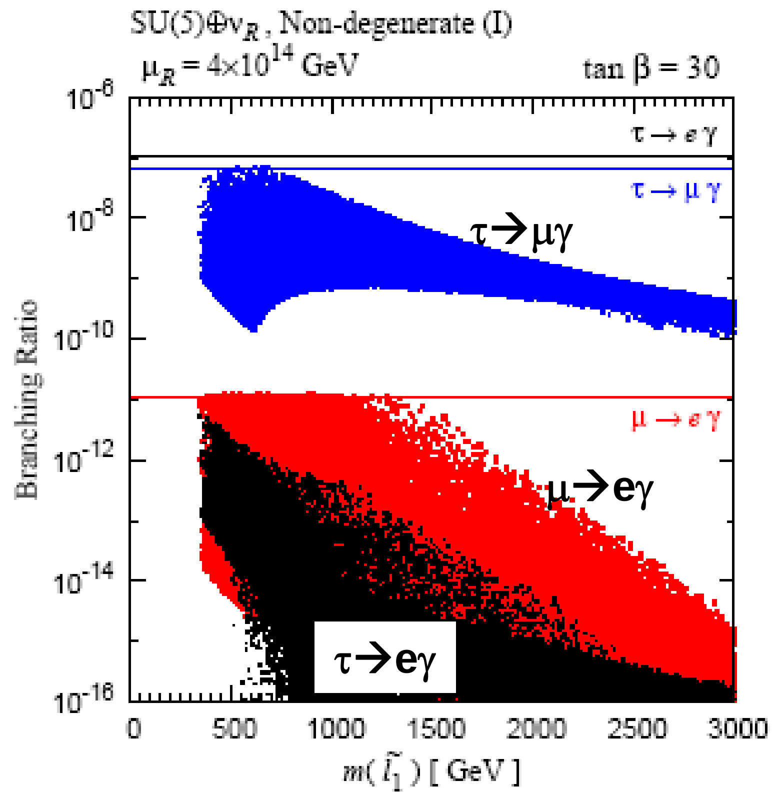
model	$Br(\tau \to \mu\gamma)$	$Br(\tau \to lll)$
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Rare τ decays

LF violating τ decay?



Theoretical predictions compared to present experimental limits



T.Goto et al., 2007

Physics with 50ab^{-1} / 75ab^{-1}

→Two recent publications:

- Physics at Super B Factory (Belle II authors + guests)

hep-ex > arXiv:1002.5012

- SuperB Progress Reports: Physics (SuperB authors + guests)

hep-ex > arXiv:1008.1541

Physics at a Super B Factory

- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large $\tan\beta$ region.
- **Physics motivation is independent of LHC.**
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the >TeV scale physics (=TeV scale in case of MFV).

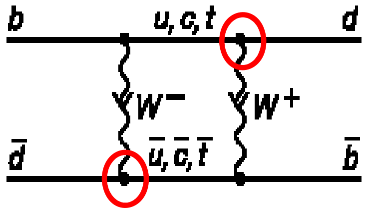
There are many more topics: CPV in charm, new hadrons, …

Super B Factory Motivation 2

- Lessons from history: the top quark

<u>Physics of top quark</u>

First estimate of mass: BB mixing	→ ARGUS
Direct production, Mass, width etc.	→ CDF/D0
Off-diagonal couplings, phase	→ BaBar/Belle

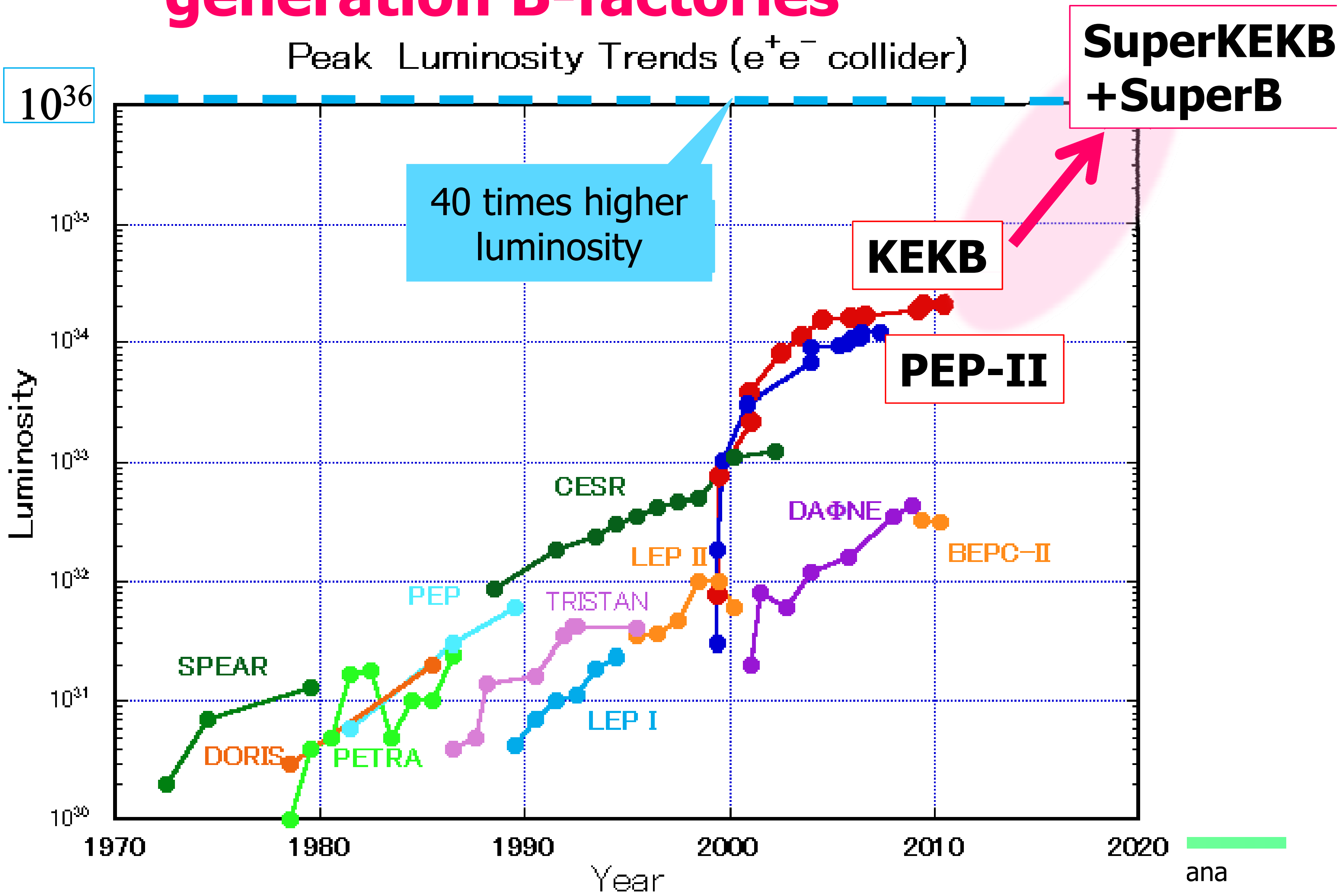


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

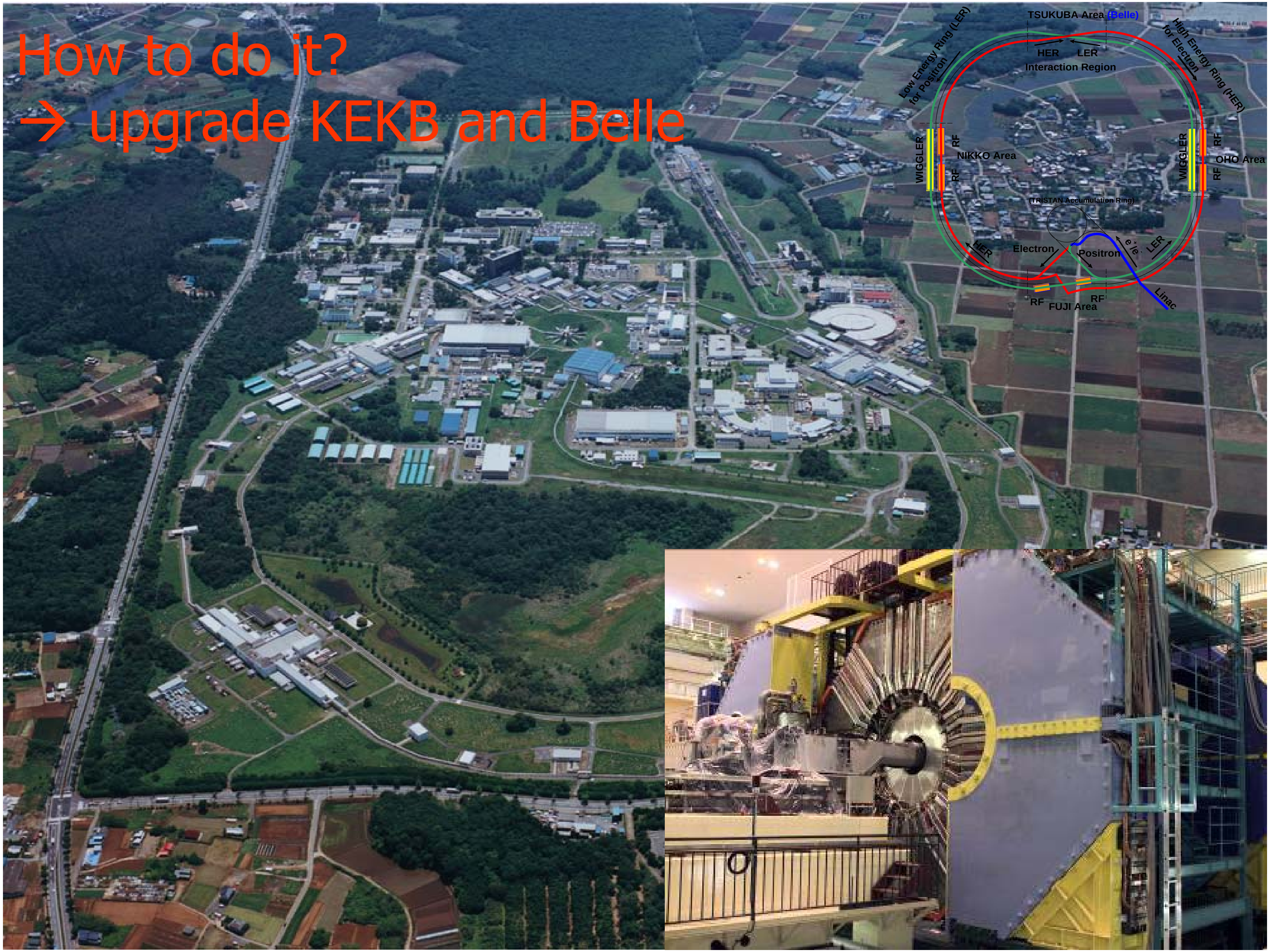
- Even before that: prediction of charm quark from the GIM mechanism, and its mass from K^0 mixing

Accellerator

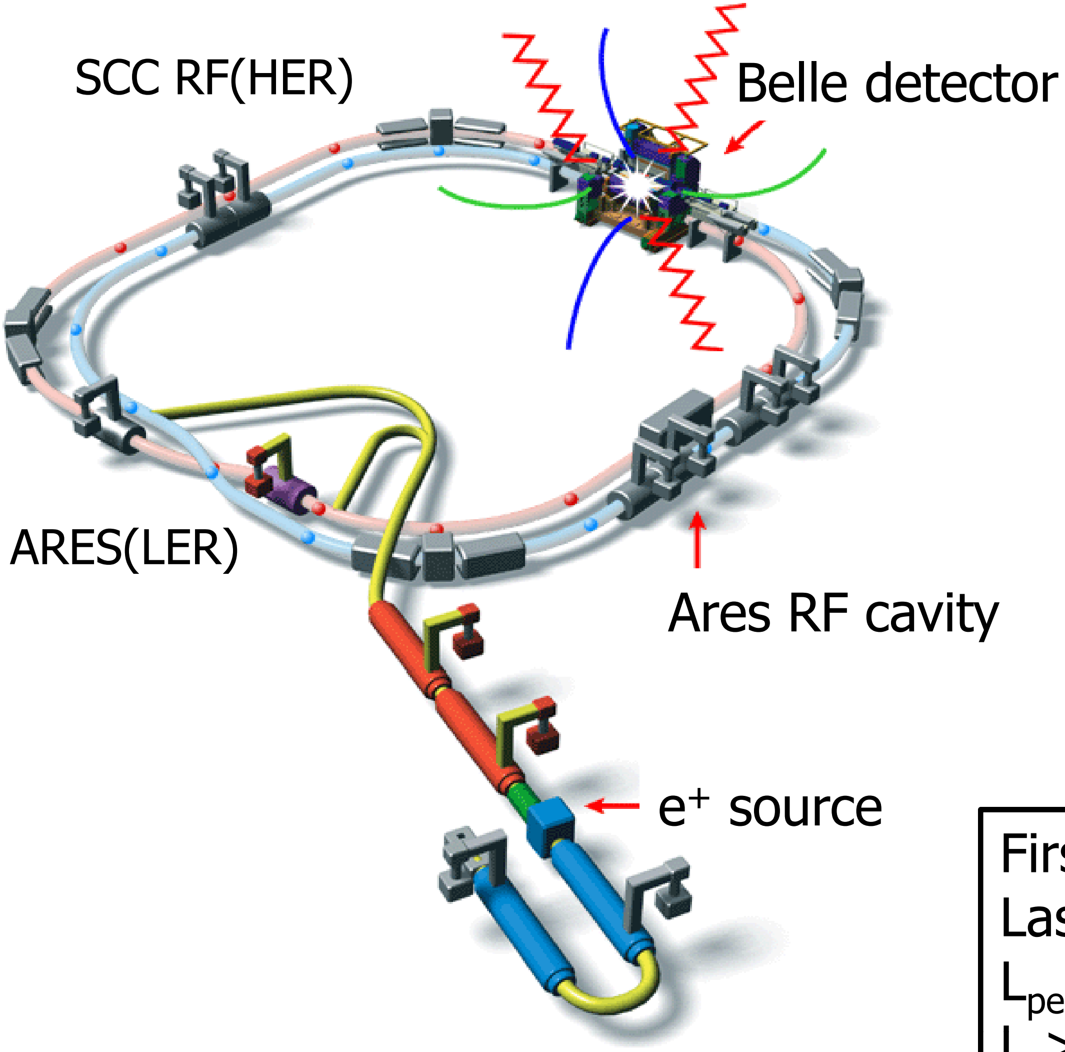
Need O(100x) more data →Next generation B-factories



How to do it?
→ upgrade KEKB and Belle



The KEKB Collider & Belle Detector



- e^- (8 GeV) on e^+(3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma$=0.425
- 22 mrad crossing angle
- Operating since 1999

Peak luminosity (WR!) :

2. 1 x 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} = 2.1x10^{34}/cm^2/s
L > 1ab^{-1}

The last beam abort of KEKB on June 30, 2010

→ Can start construction of SuperKEKB and Belle II

Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

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

Vertical beta function@IP

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

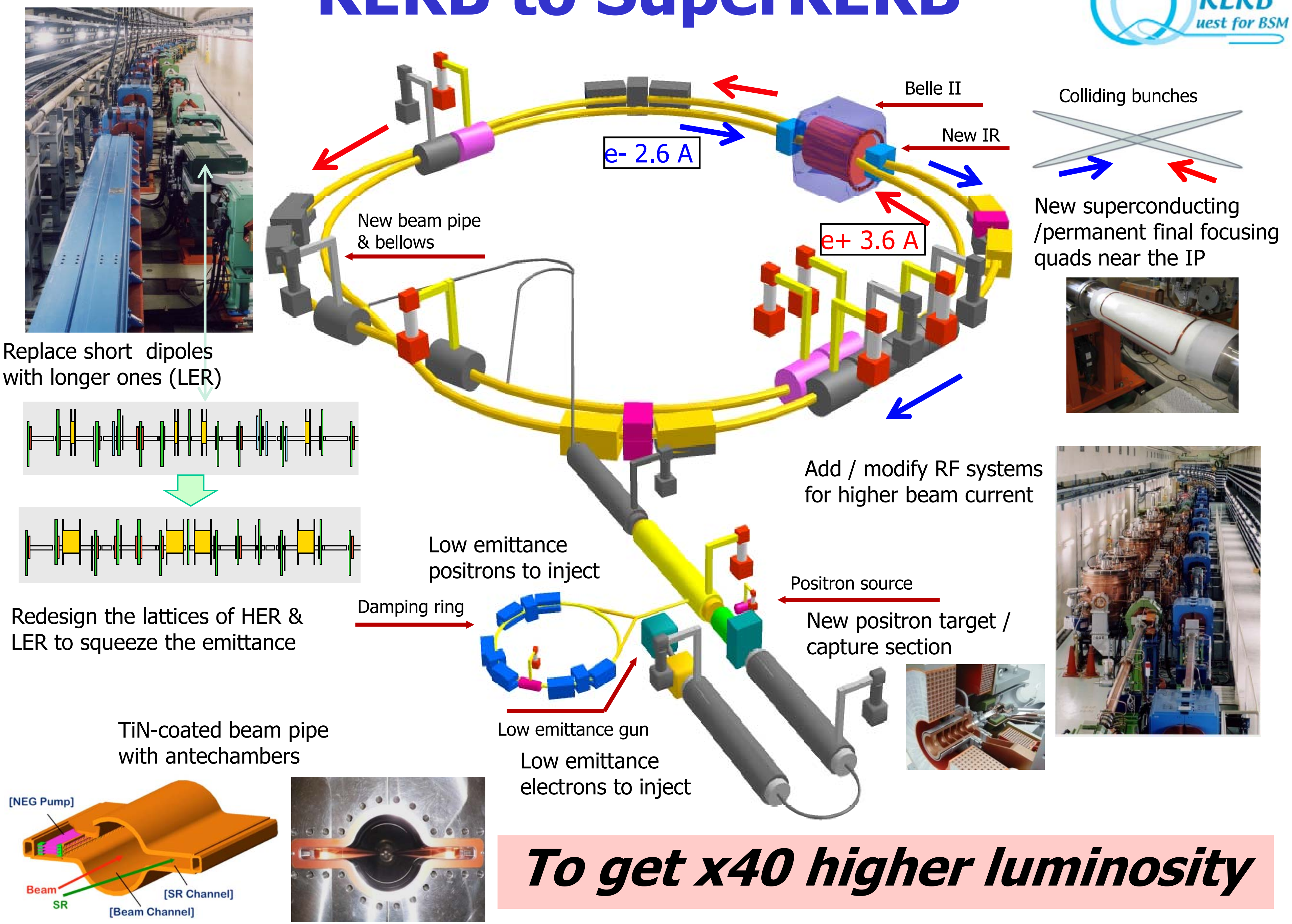
Machine design parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

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

M. Iwasaki, ICHEP2010

KEKB to SuperKEKB



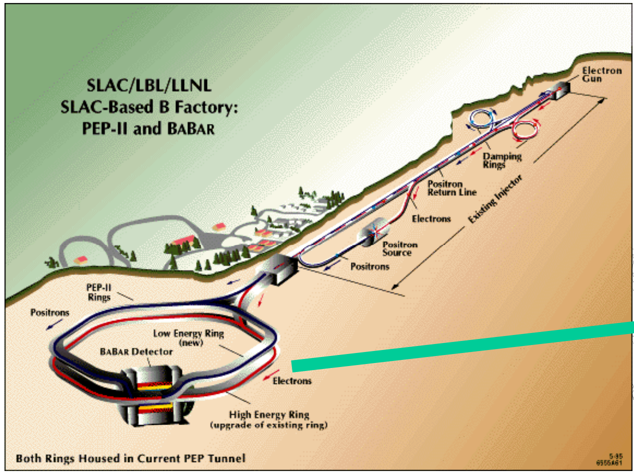
To get x40 higher luminosity

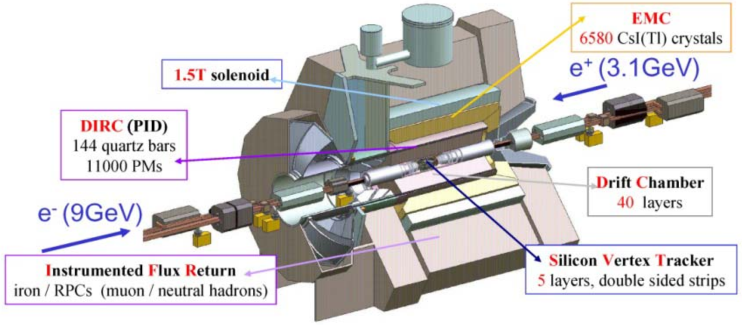
How to do it? (2)

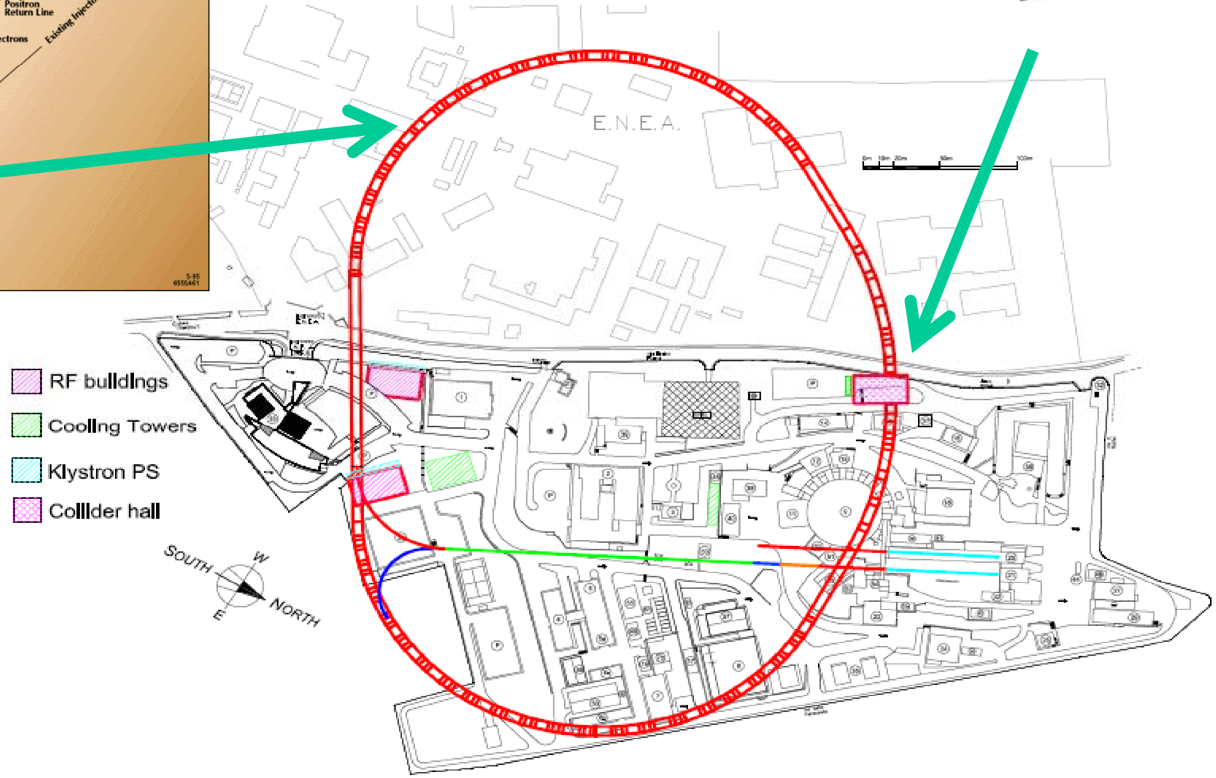
→Construct a new tunnel at LNF Frascati

→Move magnets from PEP-II

→Move BaBar, upgrade





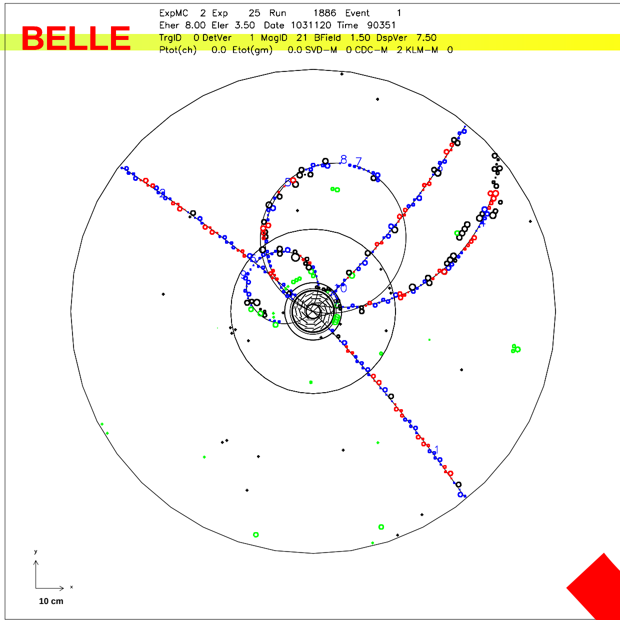


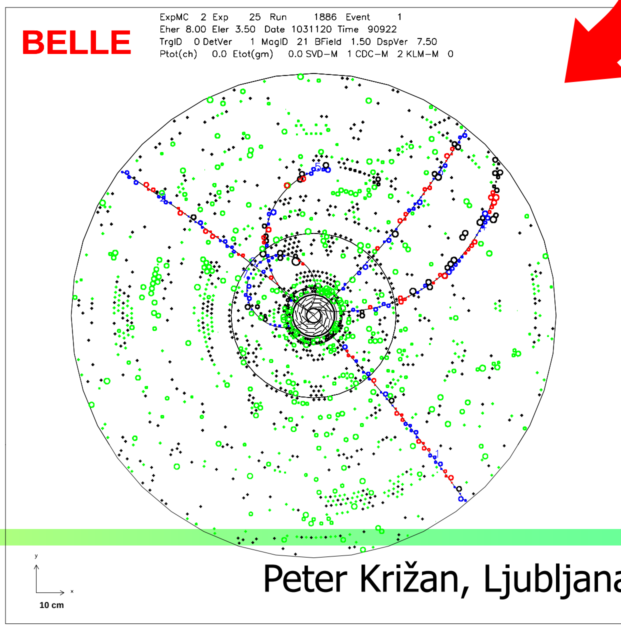
Detector

Requirements for the Belle II detector

Critical issues at L= 8 x 10^{35}/cm^2/sec

- **Higher background (×10-20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate (×10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low p μ identification ← $s\mu\mu$ recon. eff.
  - hermeticity ← ν "reconstruction"

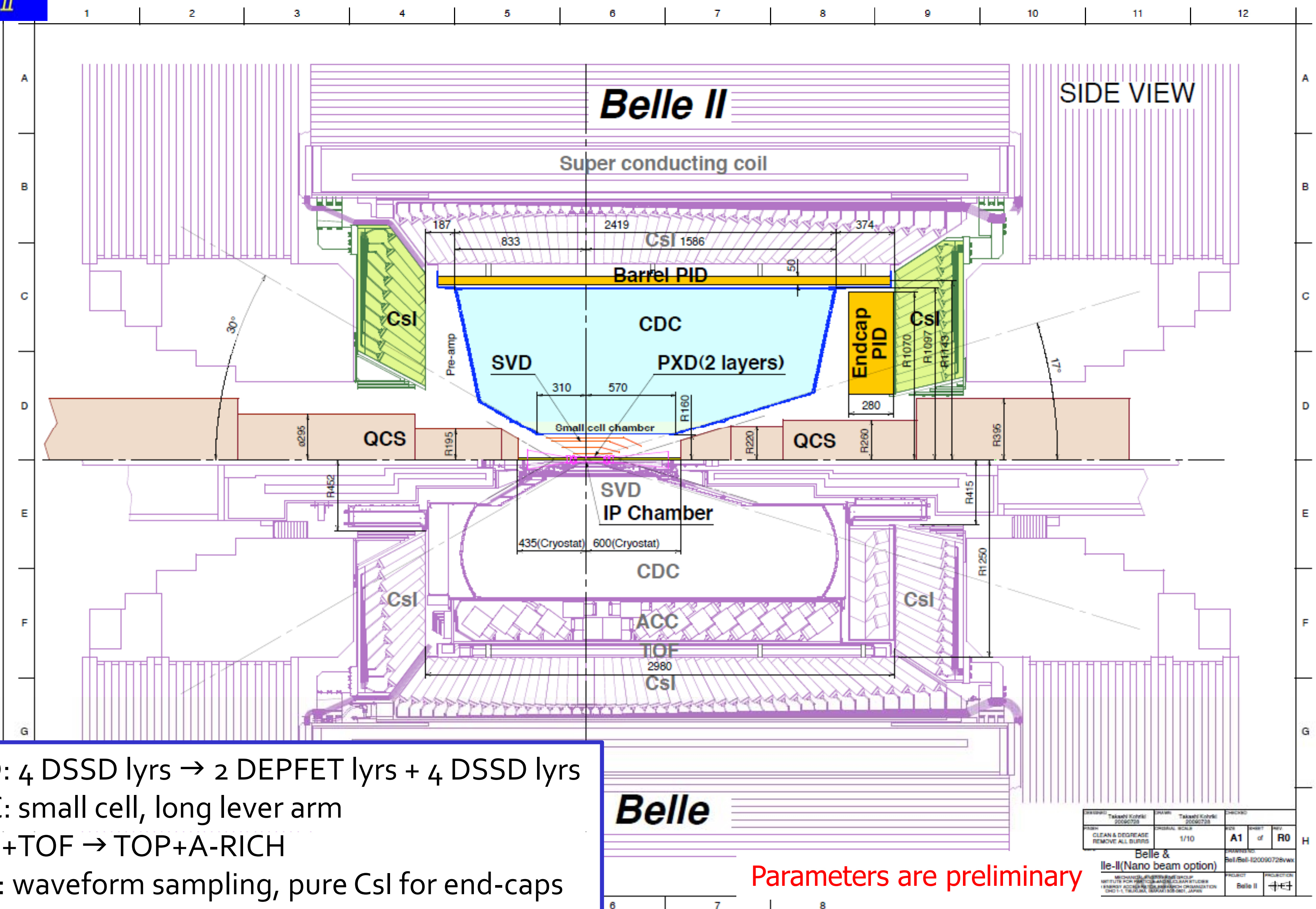




Solutions:

- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

Belle II in comparison with Belle



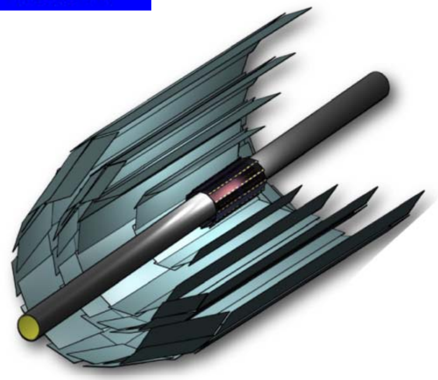
Parameters are preliminary

SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Y. Ushiroda, ICHEP2010

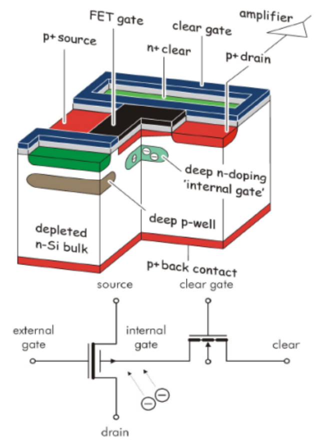
Vertex Detector

DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

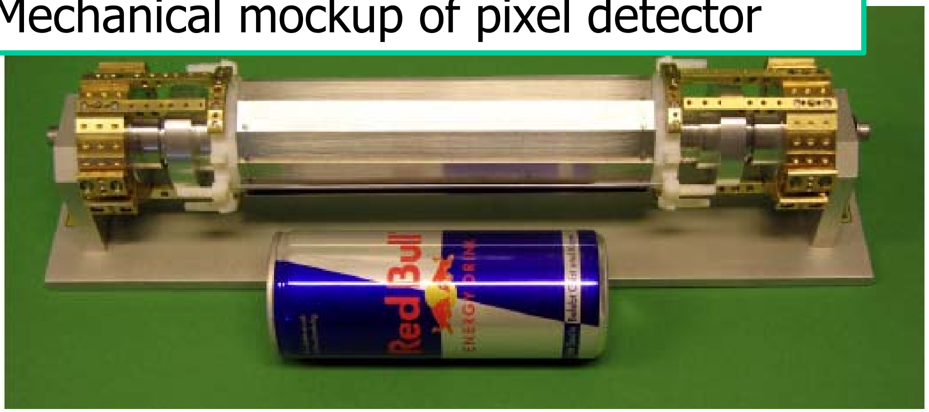


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

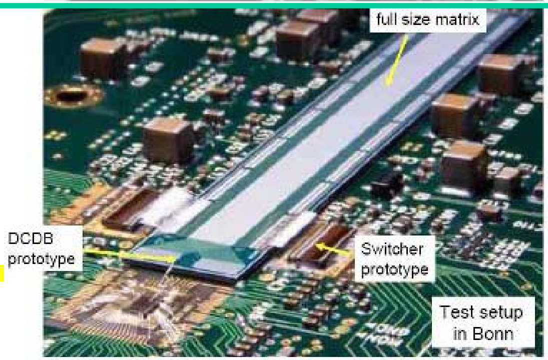
DEpleted P-channel FET

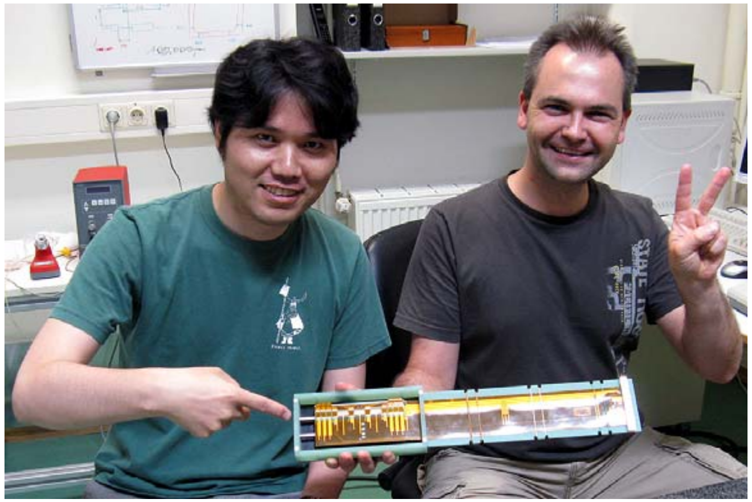


Mechanical mockup of pixel detector



Prototype DEPFET pixel sensor and readout



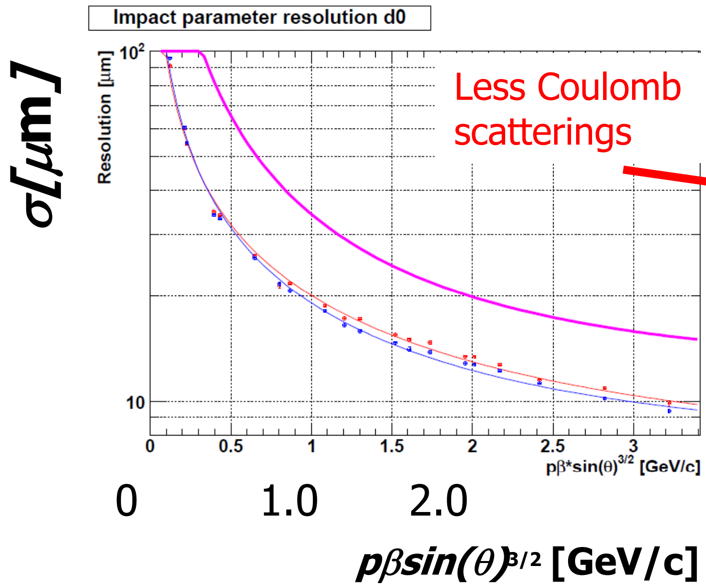


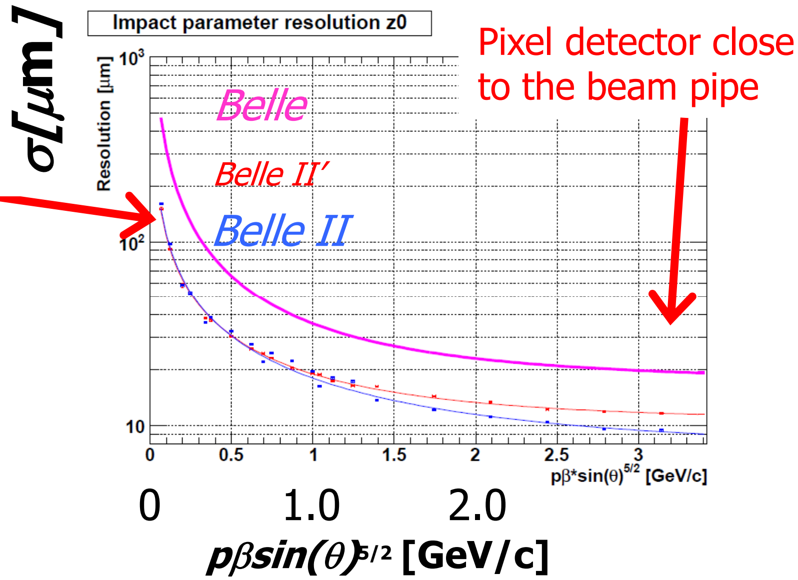
A prototype ladder using the first 6 inch DSSD from Hamamatsu has been assembled and tested.

Expected performance

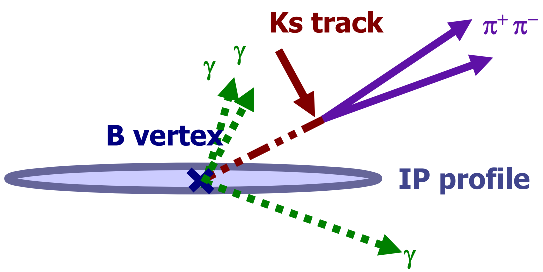
$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

Significant improvement in IP resolution!

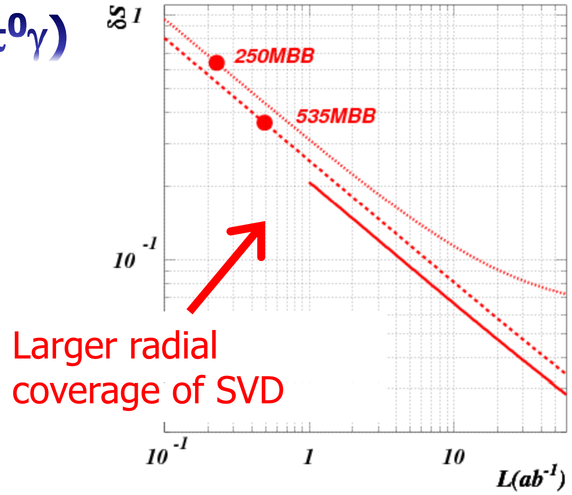




Significant improvement in $\delta S(K_S\pi^0\gamma)$

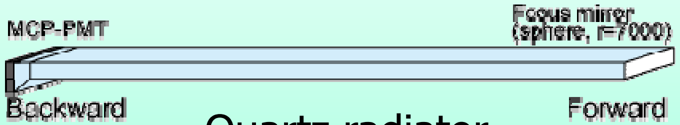


B decay point reconstruction with K_S trajectory



Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



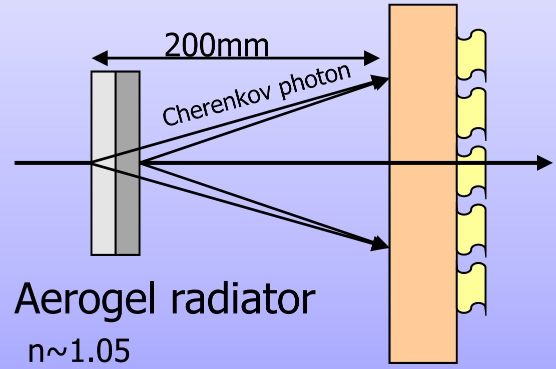
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

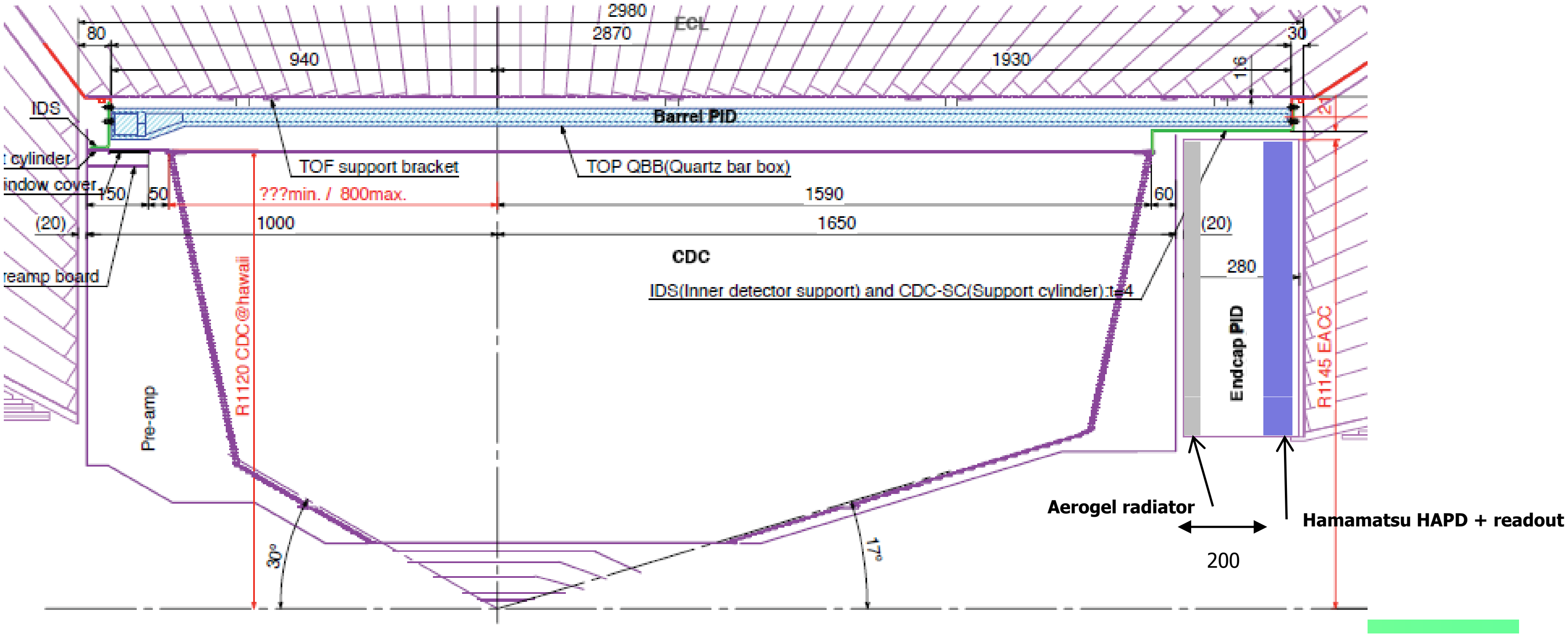


Aerogel radiator

n~1.05

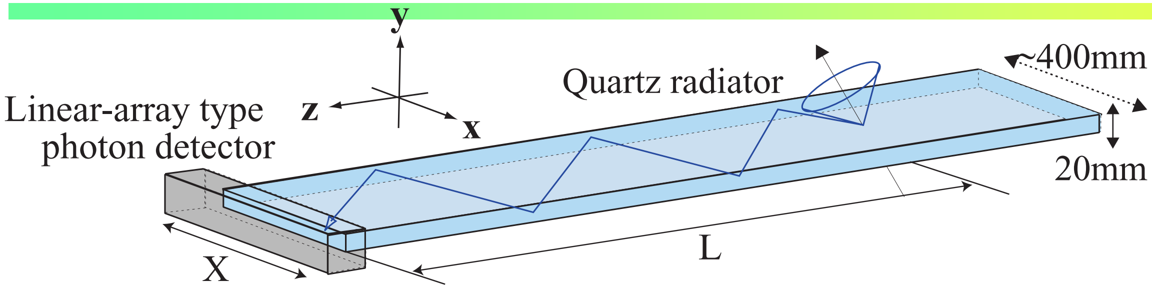
Hamamatsu HAPD

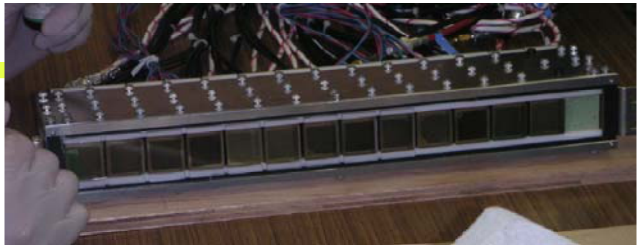
+ new ASIC



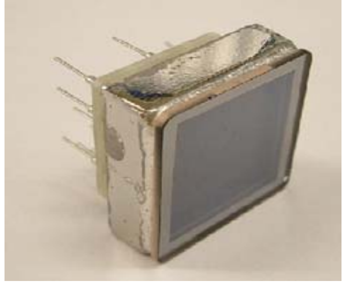
Peter Križan, Ljubljana

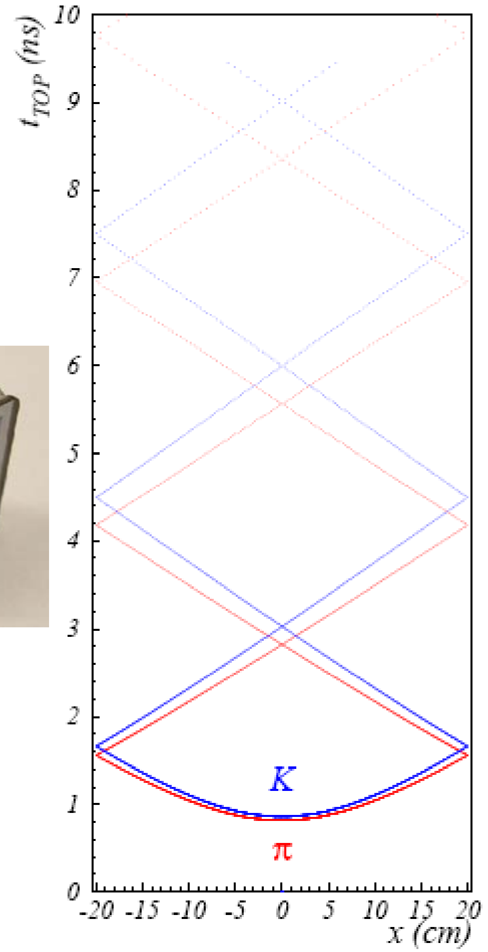
Barrel PID: Time of propagation (TOP) counter

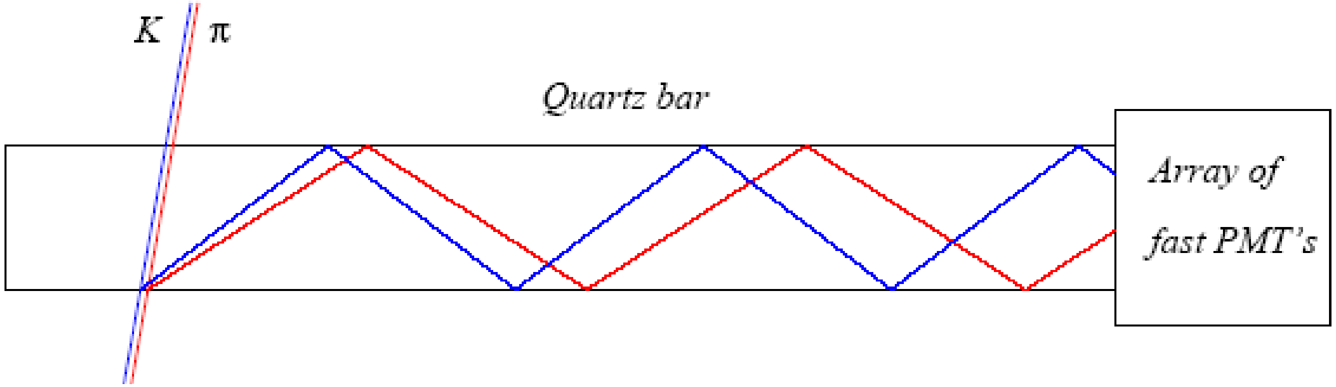




- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from two coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40 ps
    - Single photon sensitivity in 1.5 T



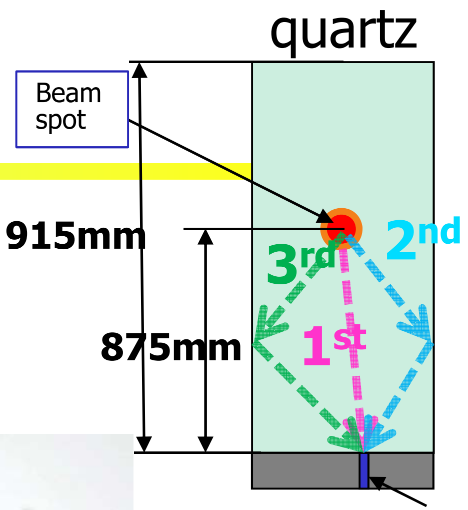


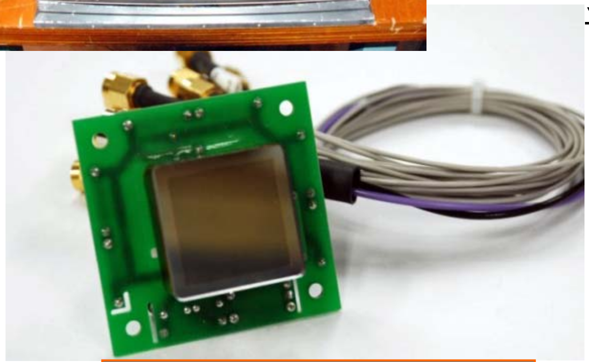


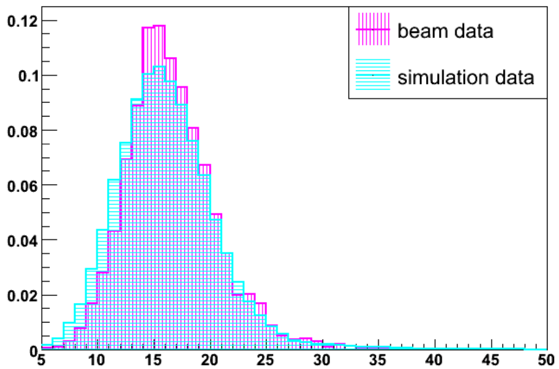
Peter Križan, Ljubljana

TOP (Barrel PID)

- Quartz radiator
  - 2.6m^L x 45cm^W x 2cm^T
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA
- Beam test in 2009
  - # of photons consistent
  - Time resolution OK

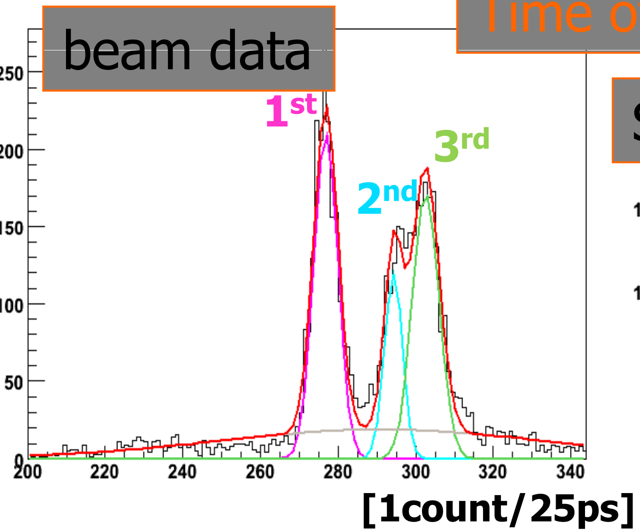


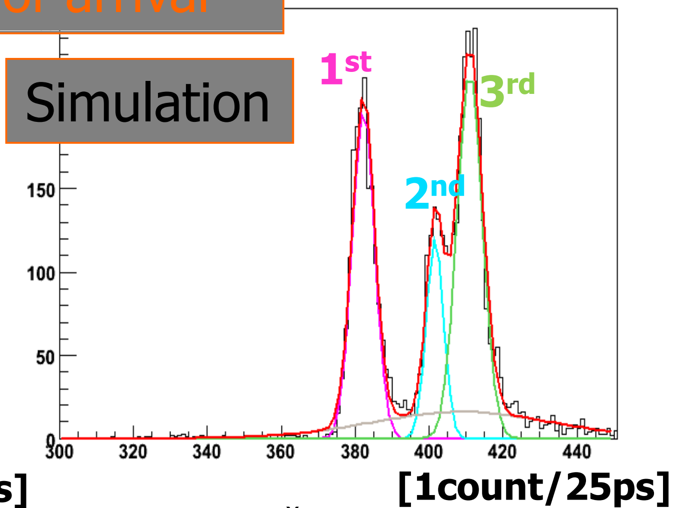




# of photons

Time of arrival





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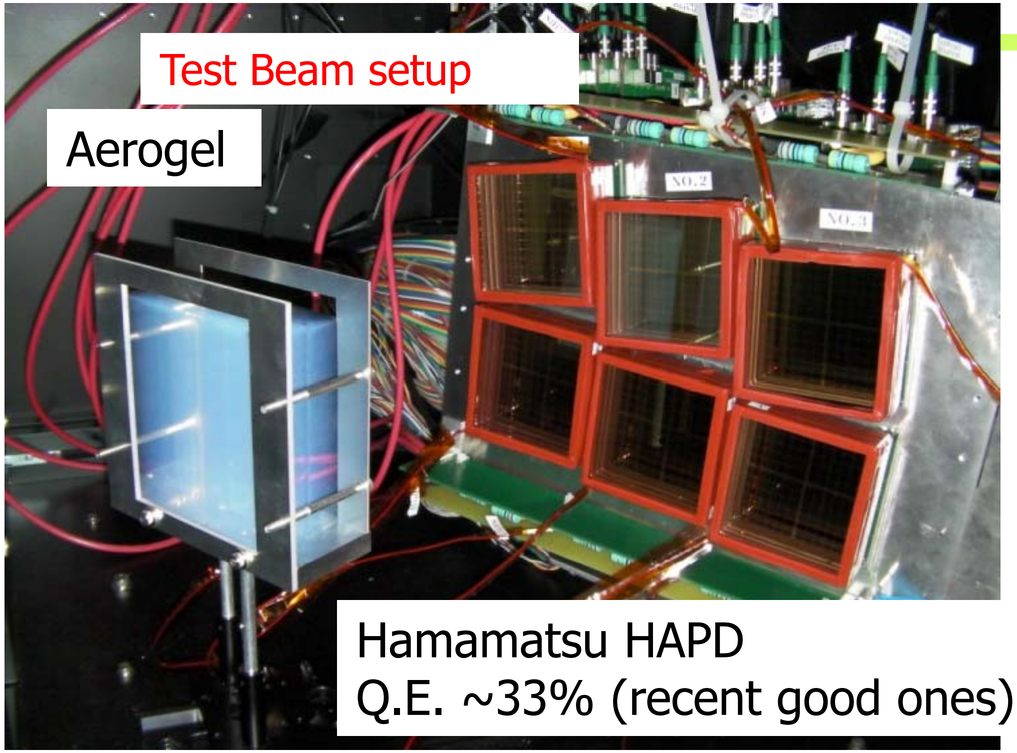
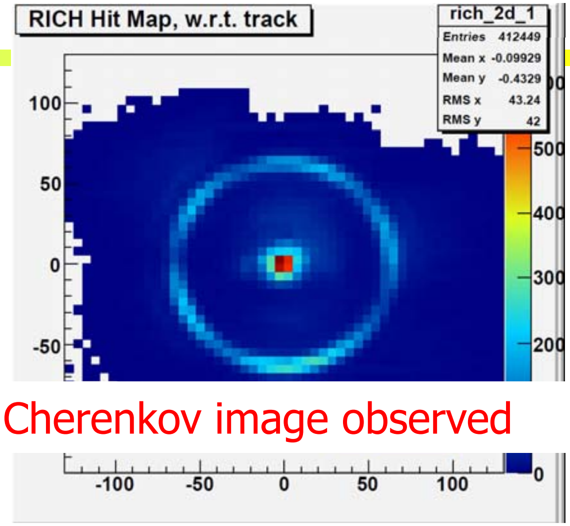
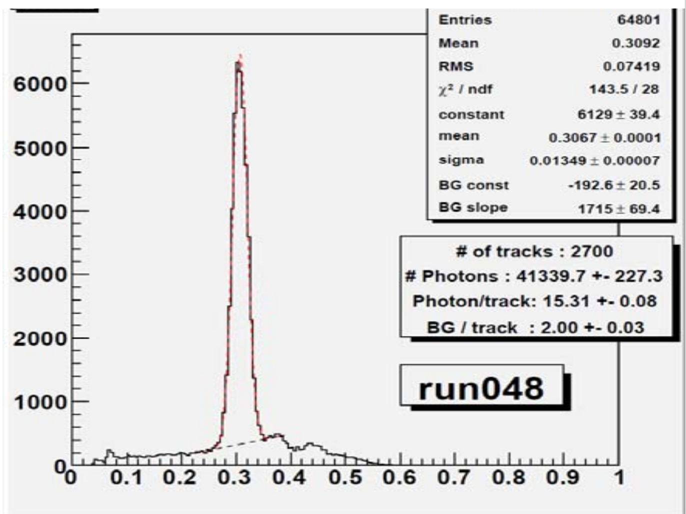
Aerogel RICH (endcap PID)

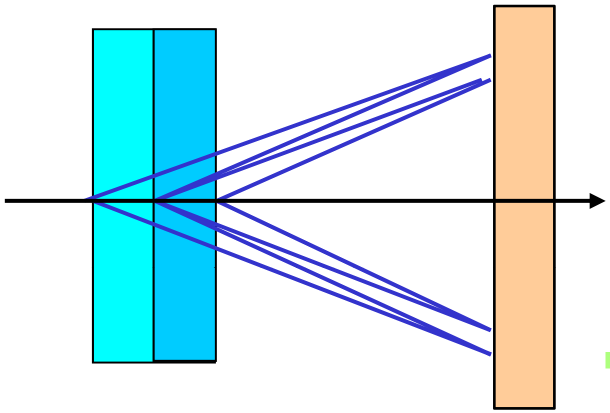




Cherenkov angle distribution



RICH with a novel "focusing" radiator – a two layer radiator



Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.

6.6 σ π/K at 4GeV/c !

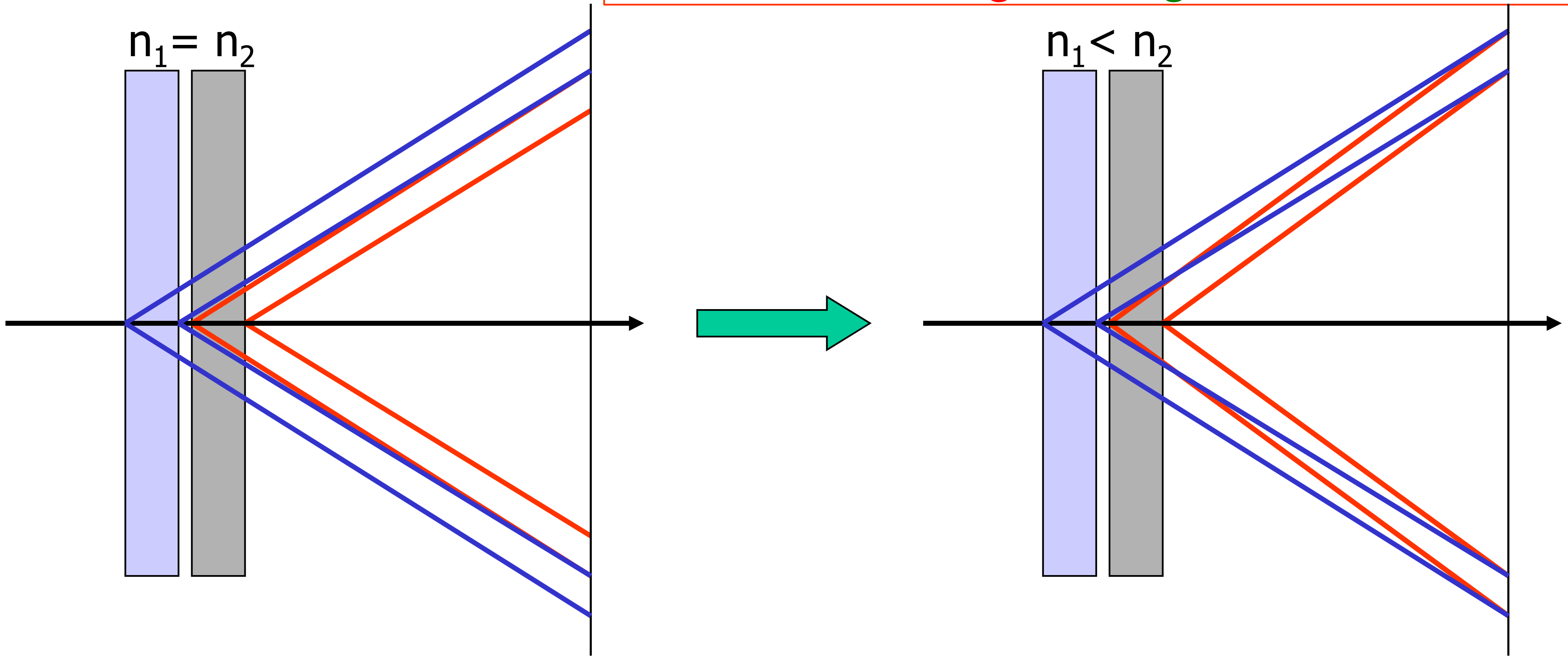
Peter Križan, Ljubljana

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

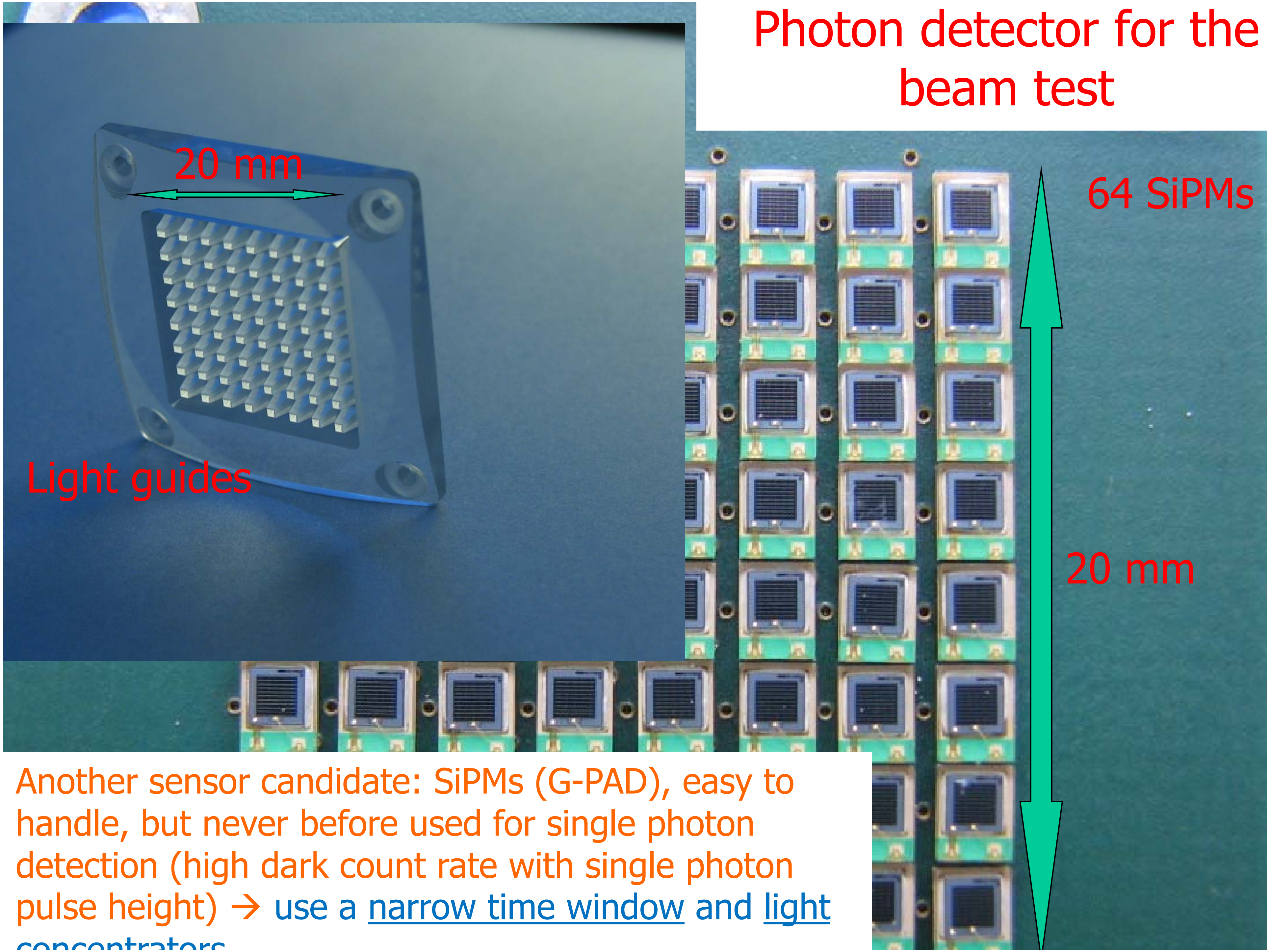
normal

→ stack two tiles with different refractive indices: “focusing” configuration



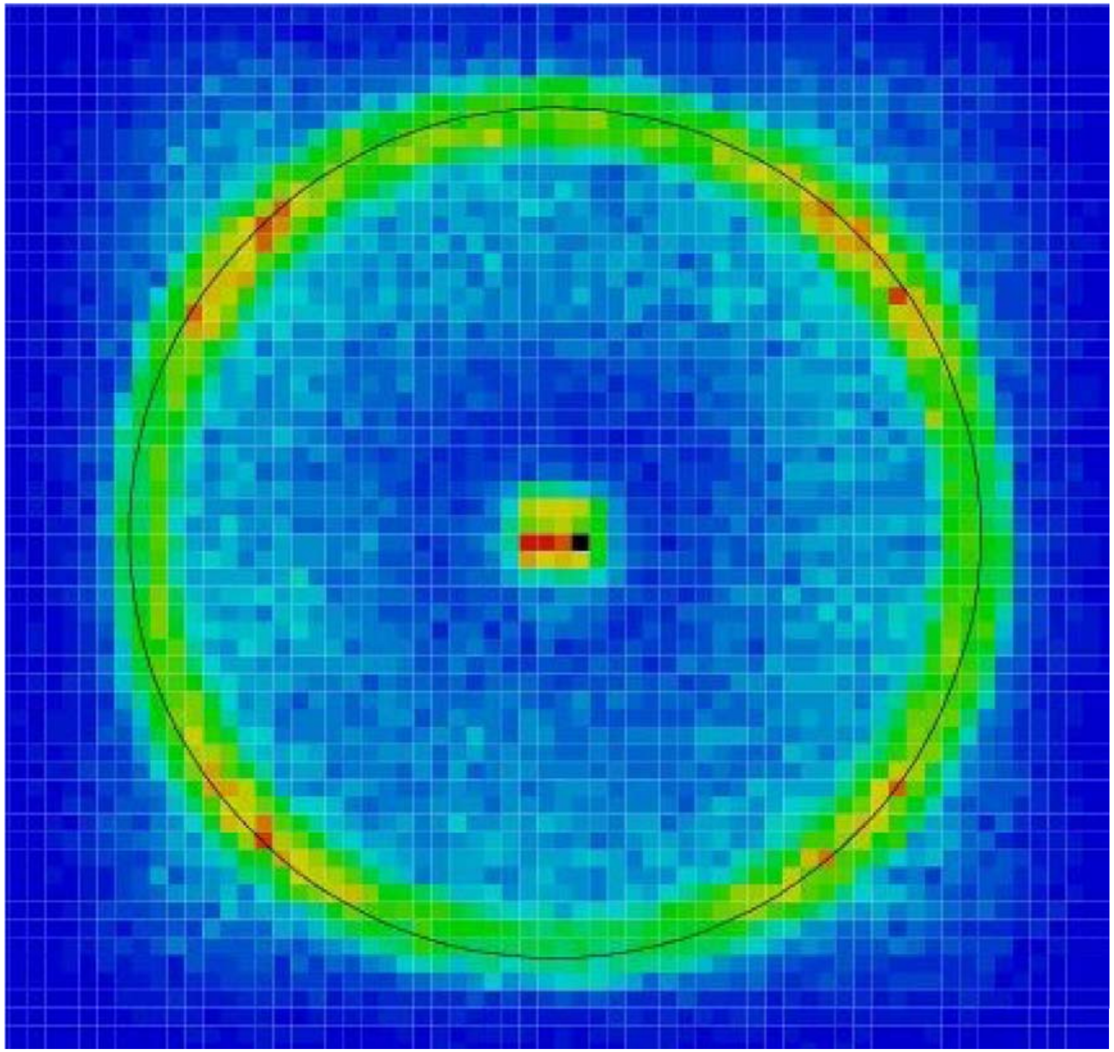
→ focusing radiator

Photon detector for the beam test



Another sensor candidate: SiPMs (G-PAD), easy to handle, but never before used for single photon detection (high dark count rate with single photon pulse height) → use a narrow time window and light concentrators

Cherenkov ring with SiPMs



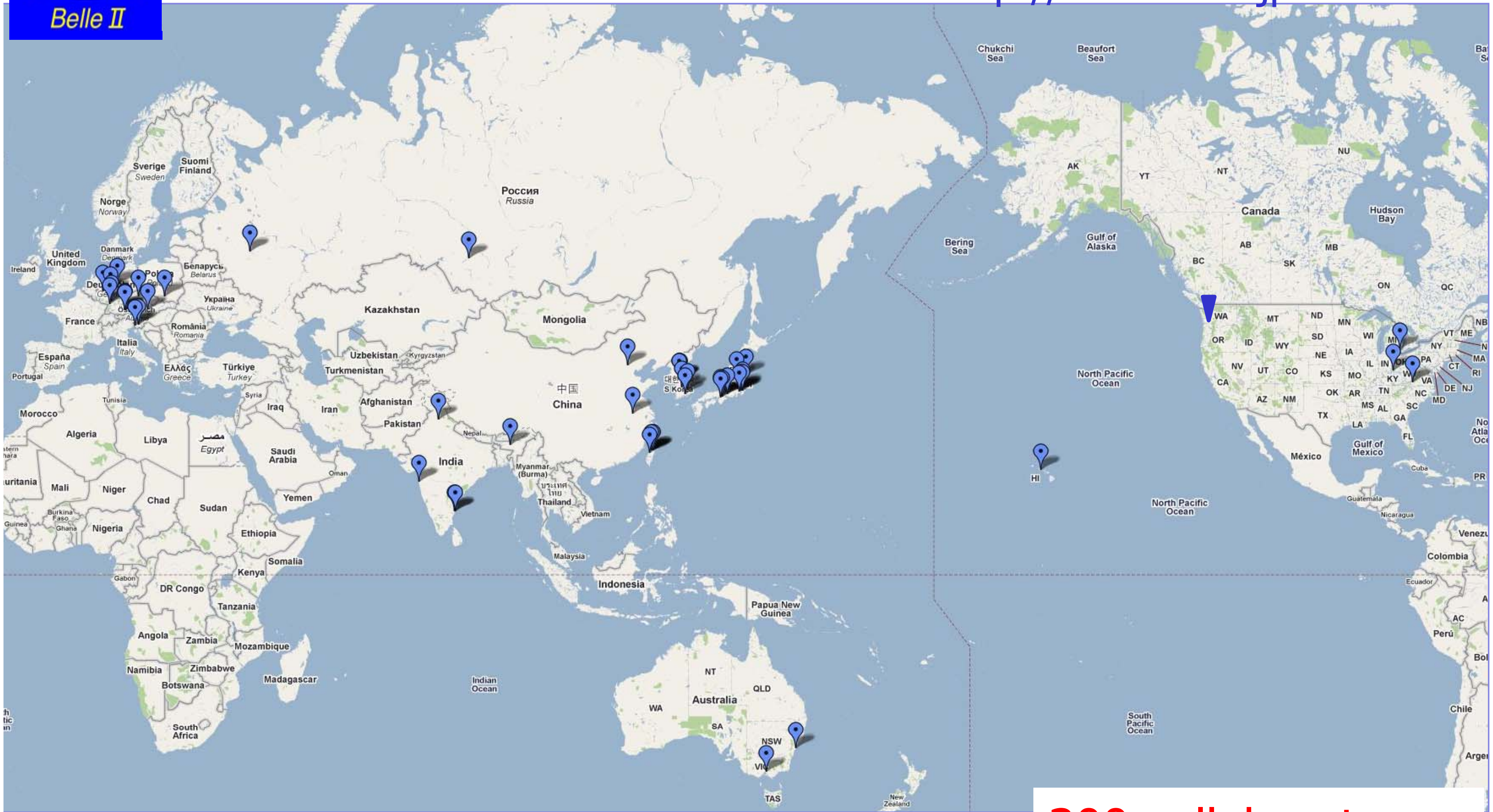
First successful use of SiPMs as single photon detectors in a RICH counter!

NIM A594 (2008) 13

Status of the project

Belle II Collaboration

http://belle2.kek.jp



13 countries/regions, 54 institutes

300 collaborators,
>100 from Europe

SuperKEKB/Belle II funding Status

KEKB upgrade has been approved

- 5.8 oku yen (~MUSD) for Damping Ring (FY2010)
- **100 oku yen** for machine -- Very Advanced Research Support Program (FY2010-2012)

Continue efforts to obtain additional funds to complete construction as scheduled.

Several non-Japanese funding agencies have already allocated sizable funds for the upgrade.

→construction started!

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大学共同利用機関法人 KEK 高エネルギー加速器研究機構

Press Release

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>Top >PressRelease >this page — last update: 10/06/23

Press Release

KEKB upgrade plan has been approved

June 23, 2010
High Energy Accelerator Research Organization (KEK)

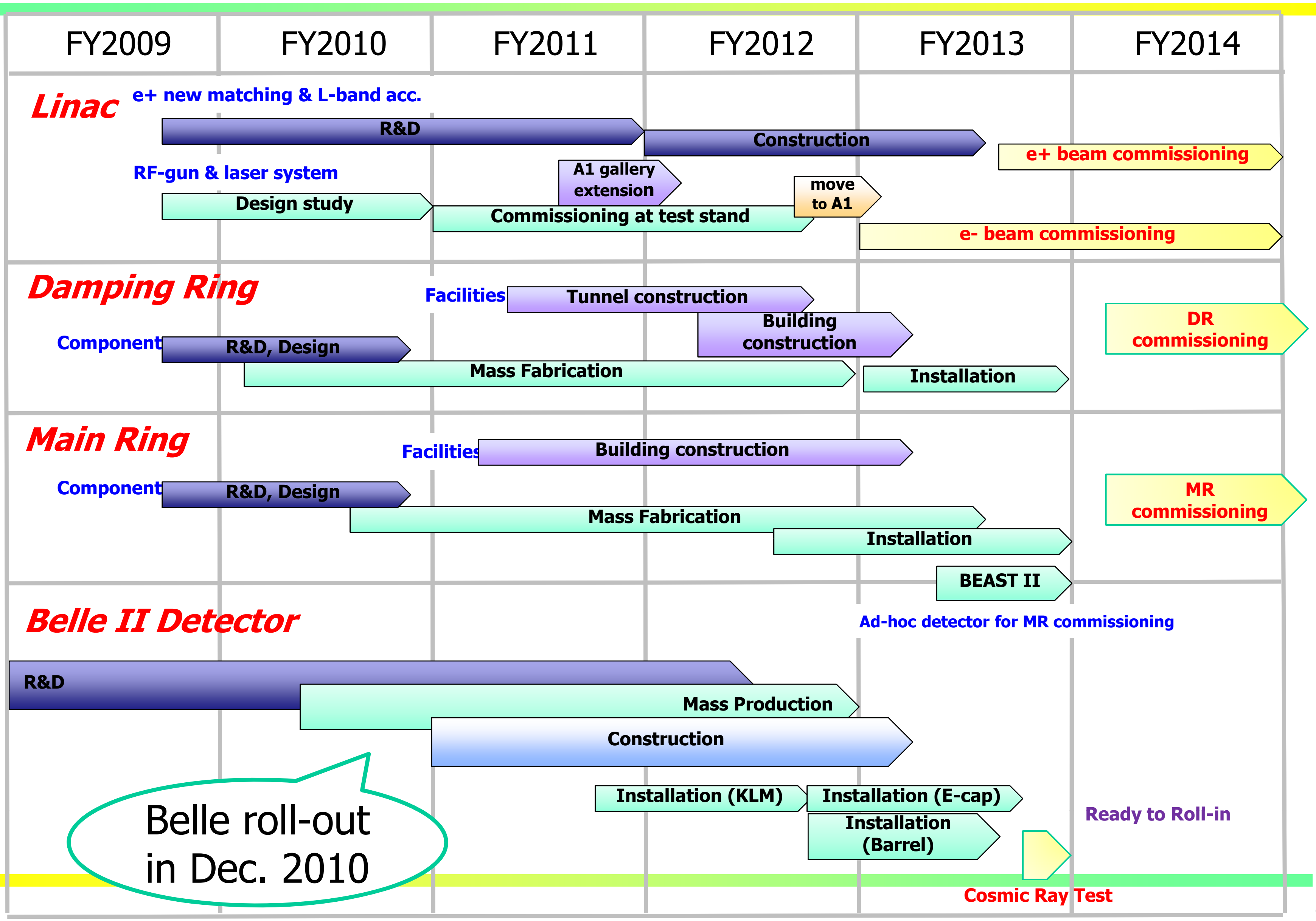
The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx $110M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new "Very Advanced Research Support Program" of the Japanese government.

"We are delighted to hear this news," says Masanori Yamauchi, former spokesperson for the Belle experiment and currently a deputy director of the Institute of Particle and Nuclear Studies of KEK. "This three- year upgrade plan allows the Belle experiment to study the physics from decays of heavy flavor particles with an unprecedented precision. It means that KEK in Japan is launching a renewed research program in search for new physics by using a technique which is complementary to what is employed at LHC at CERN."

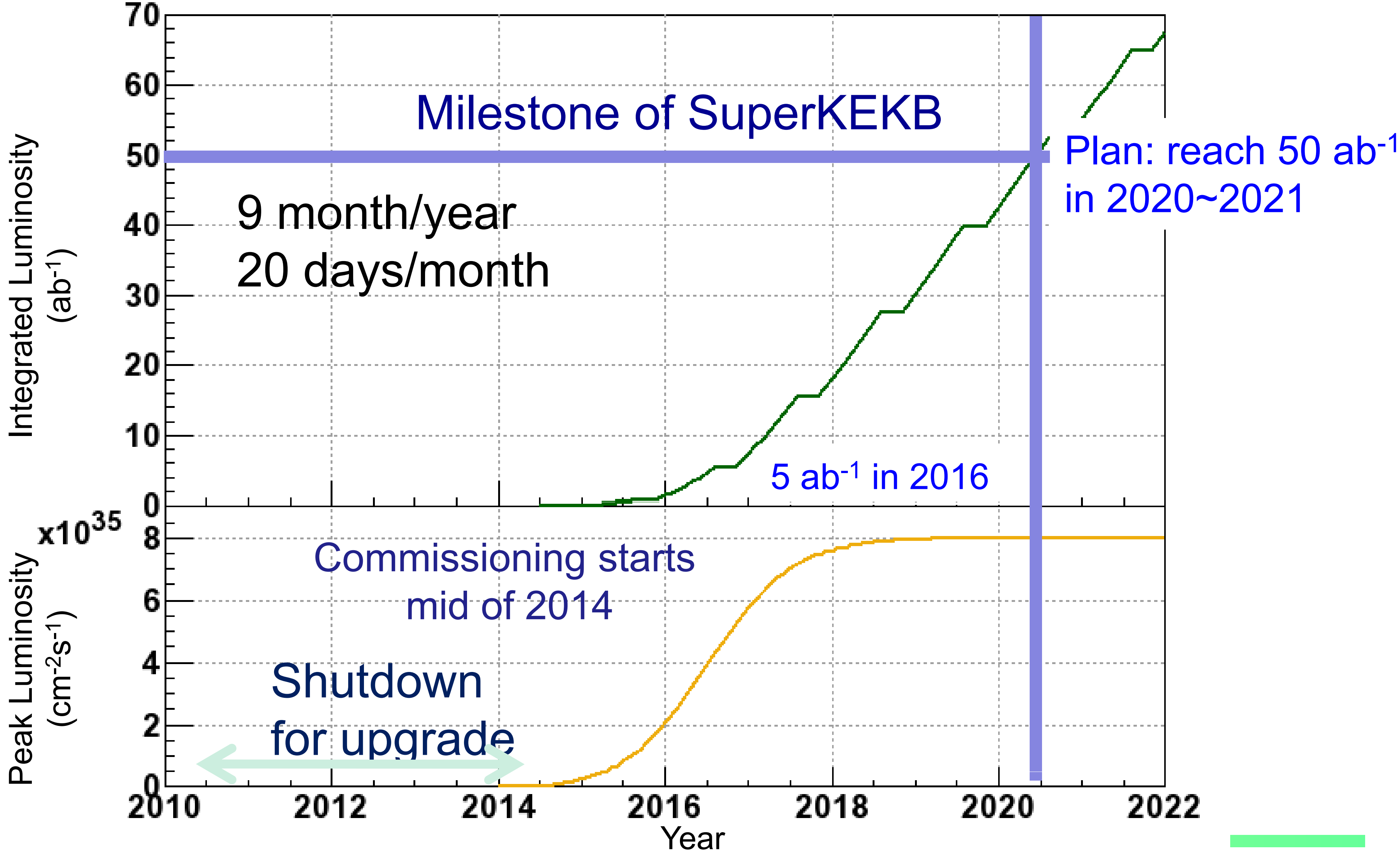
[Media Contact] Youhei Morita,
Head of Public Relations Office, KEK
tel. +81-29-879-6047

Construction Schedule of SuperKEKB/Belle II

Jun. 24, 2010



Luminosity upgrade projection



Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance, achieving and surpasing design perfomance
- Major upgrade at KEK in 2010-14 → SuperKEKB+Belle II, L x40, construction started
- SuperB in Frascati: build a new tunnel, reuse (+ugrade) PEP-II and BaBar, waiting for approval
- Physics reach updates available
- Expect a new, exciting era of discoveries, complementary to the LHC