

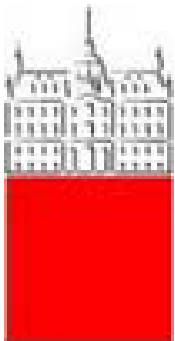


From Belle to Belle-II

Peter Križan

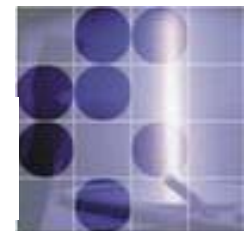
University of Ljubljana and J. Stefan Institute

**Seminar, Stefan-Meyer-Institut für subatomare Physik,
Wien, 15. Oktober 2010**



**University
of Ljubljana**

**"Jožef Stefan"
Institute**



Contents

- Highlights from Belle
- Physics case for a Super B factory
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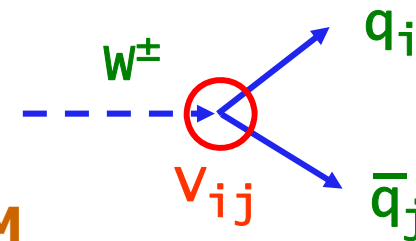
B factory physics program

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

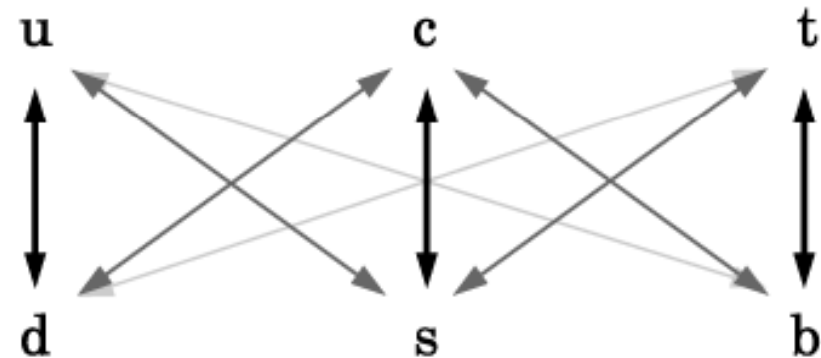
specifically: various measurements of complex elements of **Cabbibo-Kobayashi-Maskawa matrix**

CKM matrix is unitary

deviations could signal processes not included in SM



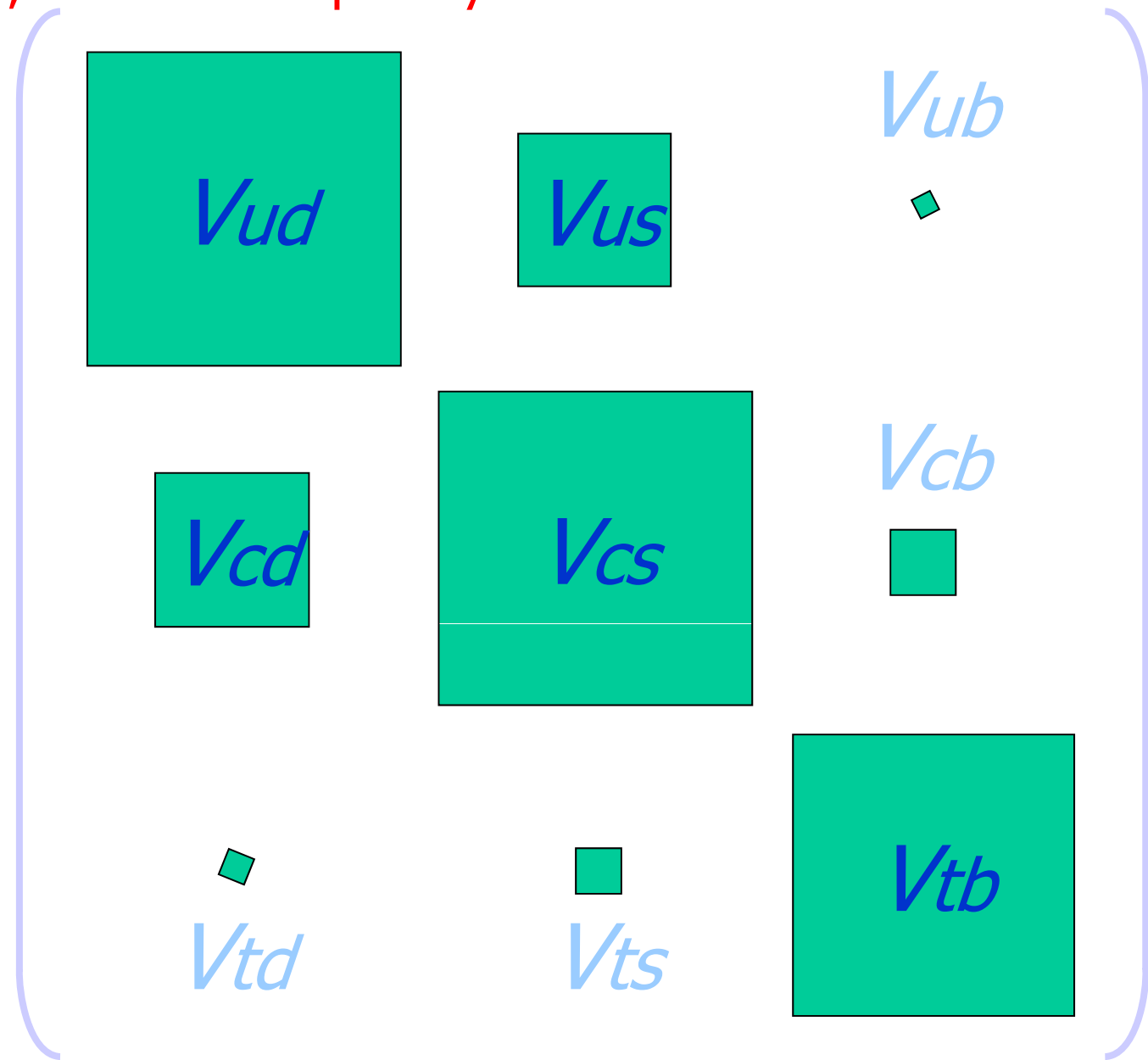
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



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

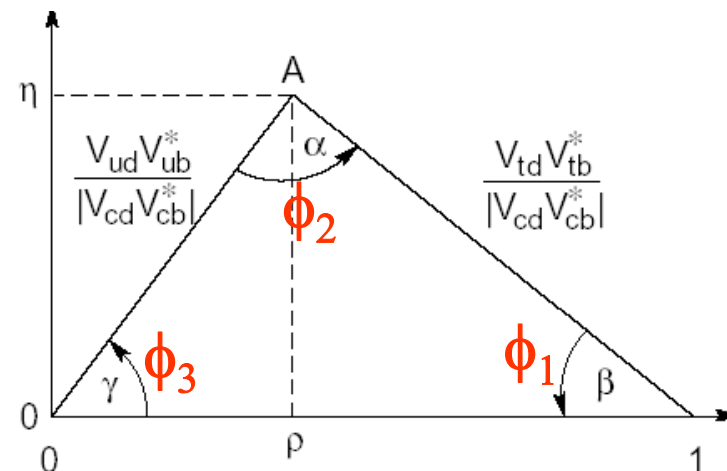
Wolfenstein parametrisation: expand in the parameter λ ($=\sin\theta_c=0.22$)

A , ρ and η : all of order one

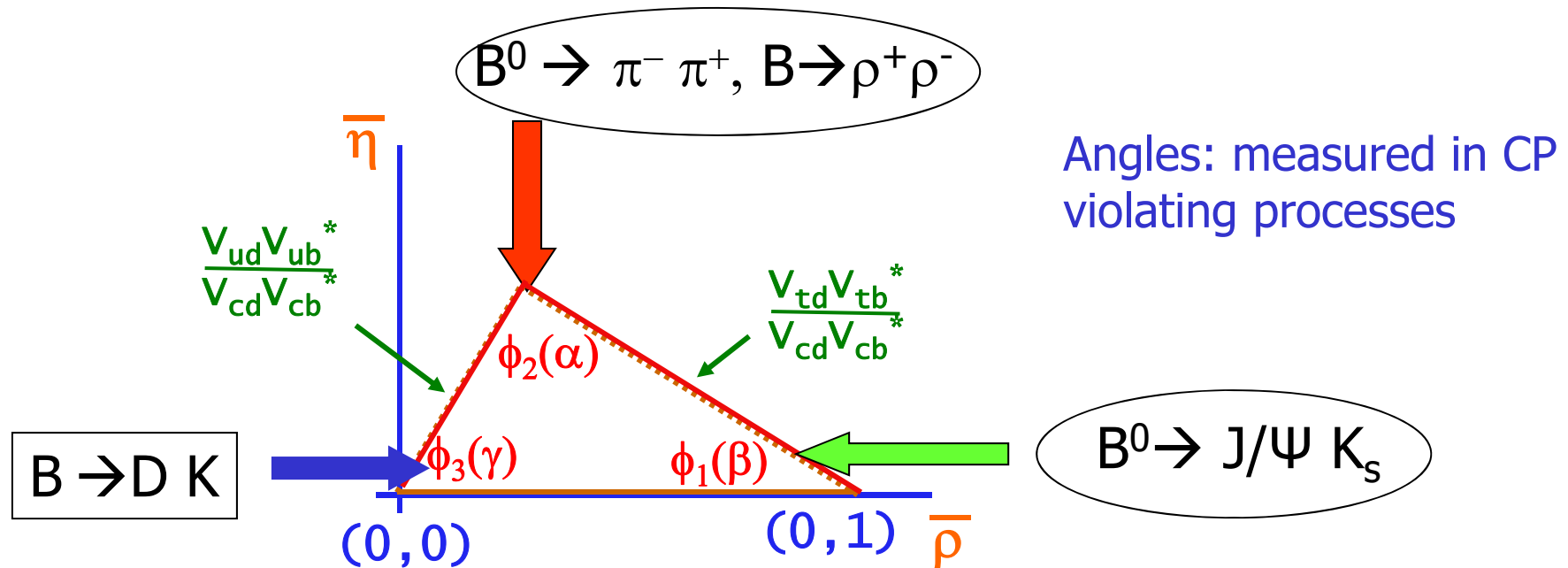
$$V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

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)



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

$$a|B^0\rangle + b|\bar{B}^0\rangle$$

is governed by a time-dependent Schroedinger equation

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

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

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

diagonalize \rightarrow

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

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

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

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

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

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

Time evolution of B's

Time evolution:

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

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

with

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

$$M = (M_H + M_L) / 2$$

Decay probability

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

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

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

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

Decay amplitude as a function of time:

$$\begin{aligned} \langle f | H | B_{phys}^0(t) \rangle &= g_+(t) \langle f | H | B^0 \rangle + (q/p) g_-(t) \langle f | H | \bar{B}^0 \rangle \\ &= g_+(t) A_f + (q/p) g_-(t) \bar{A}_f \end{aligned}$$

... and similarly for the anti-B

CP violation: decay rate asymmetry vs. time

$$\begin{aligned}
 a_{f_{CP}} &= \frac{P(\bar{B}^0 \rightarrow f_{CP}, t) - P(B^0 \rightarrow f_{CP}, t)}{P(\bar{B}^0 \rightarrow f_{CP}, t) + P(B^0 \rightarrow f_{CP}, t)} = && \text{Decay rate asymmetry} \\
 &= \frac{\left| (p/q)g_-(t)A_{f_{CP}} + g_+(t)\bar{A}_{f_{CP}} \right|^2 - \left| g_+(t)A_{f_{CP}} + (q/p)g_-(t)\bar{A}_{f_{CP}} \right|^2}{\left| (p/q)g_-(t)A_{f_{CP}} + g_+(t)\bar{A}_{f_{CP}} \right|^2 + \left| g_+(t)A_{f_{CP}} + (q/p)g_-(t)\bar{A}_{f_{CP}} \right|^2} = \\
 &= \frac{(1 - |\lambda_{f_{CP}}|^2) \cos(\Delta mt) - 2 \operatorname{Im}(\lambda_{f_{CP}}) \sin(\Delta mt)}{1 + |\lambda_{f_{CP}}|^2} \\
 &= C \cos(\Delta mt) + S \sin(\Delta mt)
 \end{aligned}$$

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

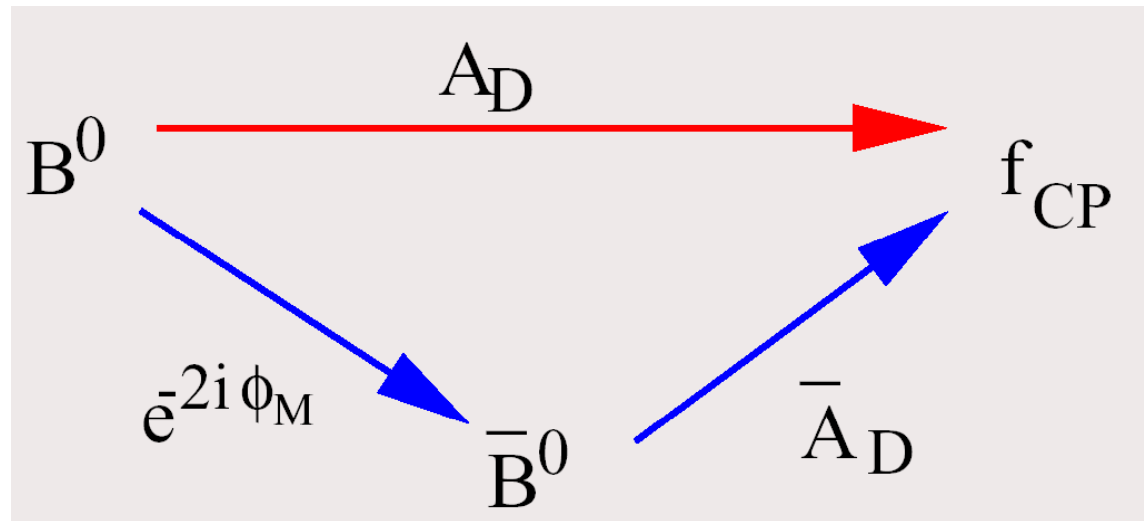
Non-zero effect if $\operatorname{Im}(\lambda) \neq 0$, even if $|\lambda| = 1$

$$\text{If } |\lambda| = 1 \rightarrow a_{f_{CP}} = -\operatorname{Im}(\lambda) \sin(\Delta mt)$$

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 $J/\psi K_S$



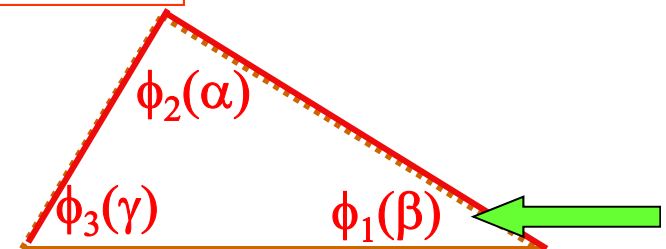
Decay rate asymmetry

$$a_{f_{CP}} = -\text{Im}(\lambda) \sin(\Delta mt)$$

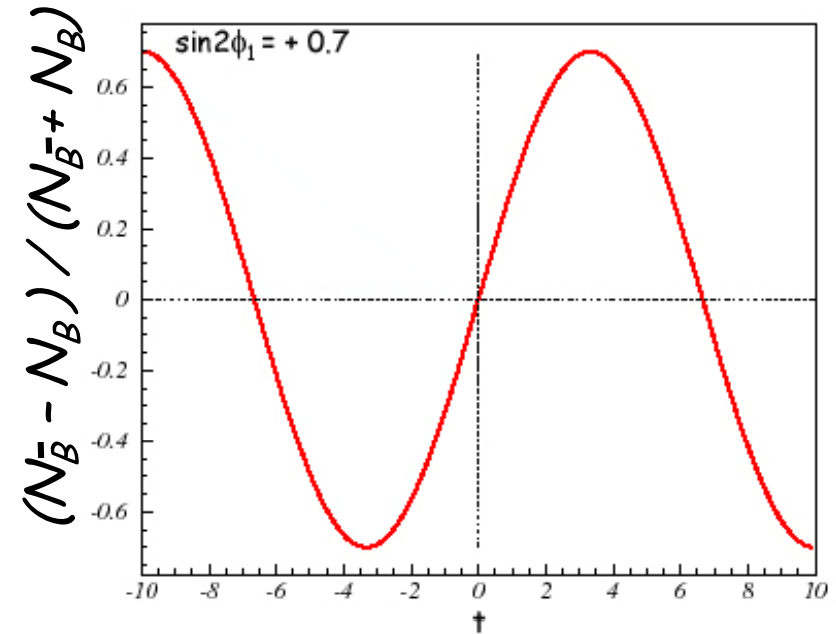
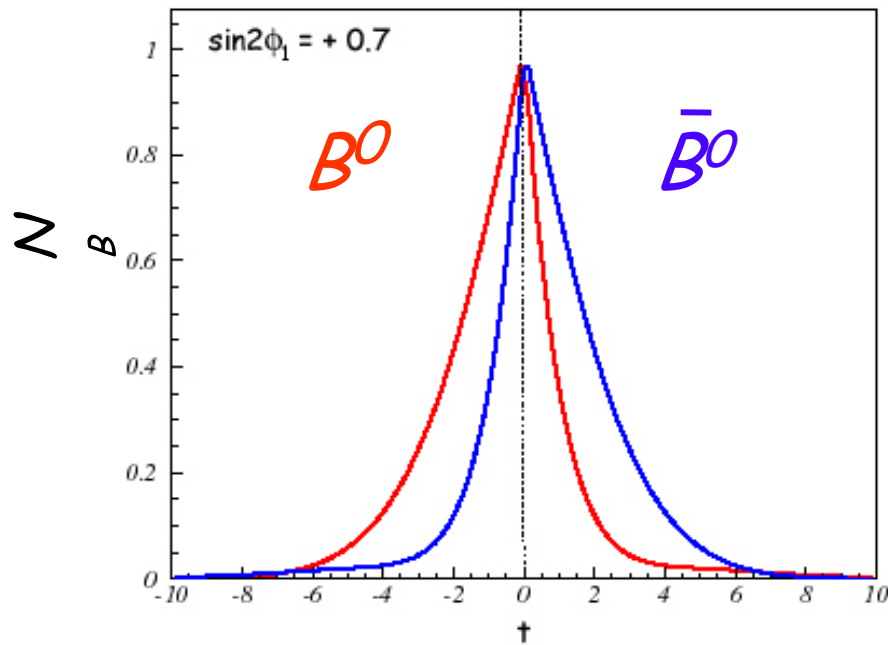
If $|\lambda| = 1$

For $J/\psi K_S$

$$\text{Im}(\lambda) = \sin 2\phi_1$$



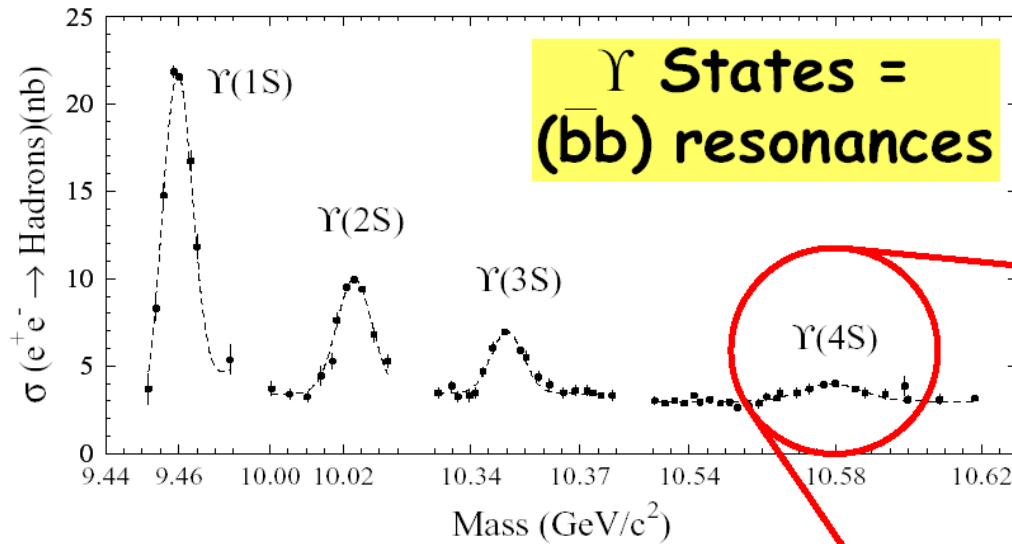
CP Violation in B decays to CP eigenstates f_{CP}



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

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

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



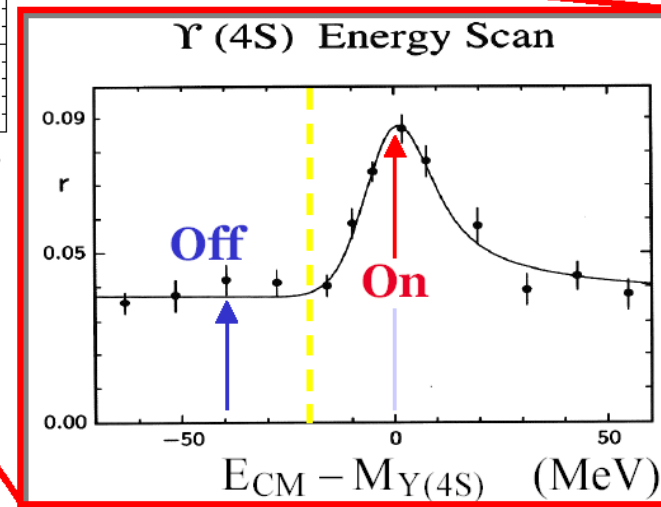
Cross Sections at $\Upsilon(4S)$:

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

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

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

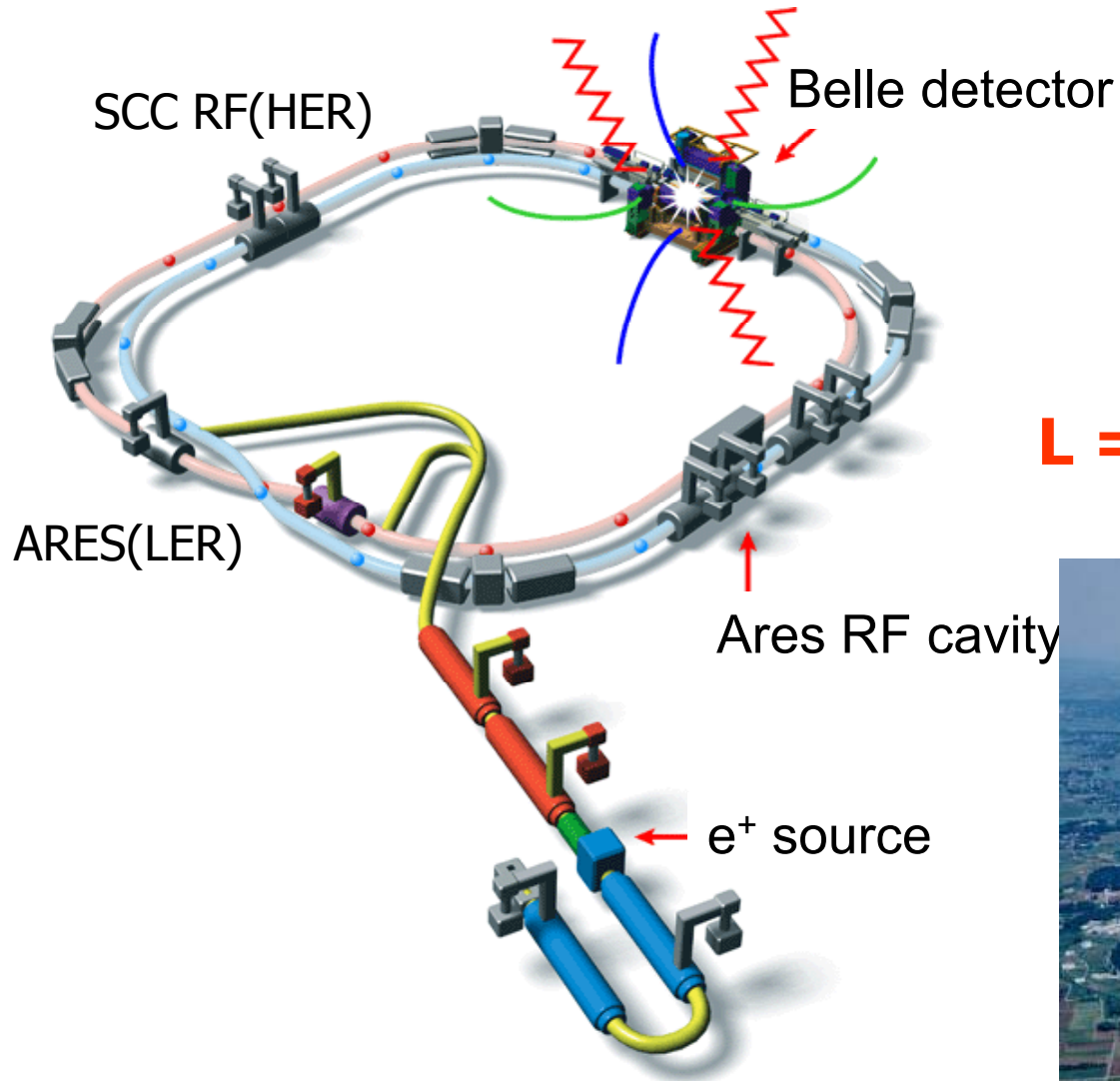
$u\bar{u} \sim 1.4 \text{ nb}$



$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
 $L=1$ state

Big advantage: low background

The KEKB Collider



8 x 3.5 GeV

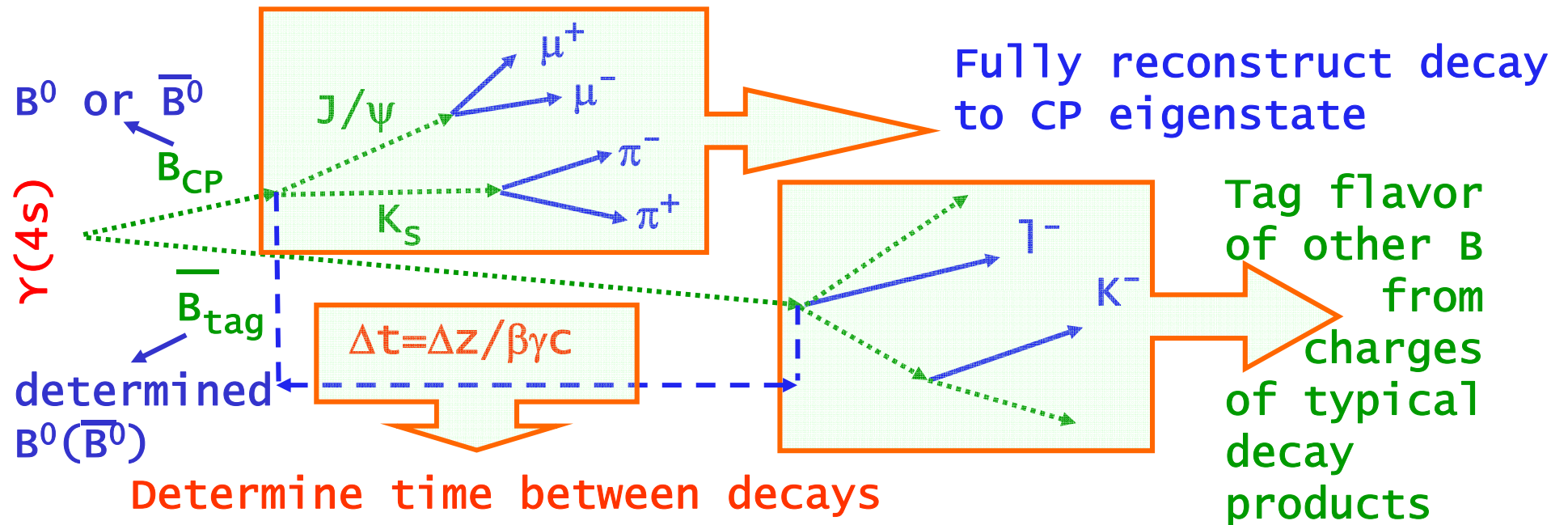
22mrad crossing angle

World record:

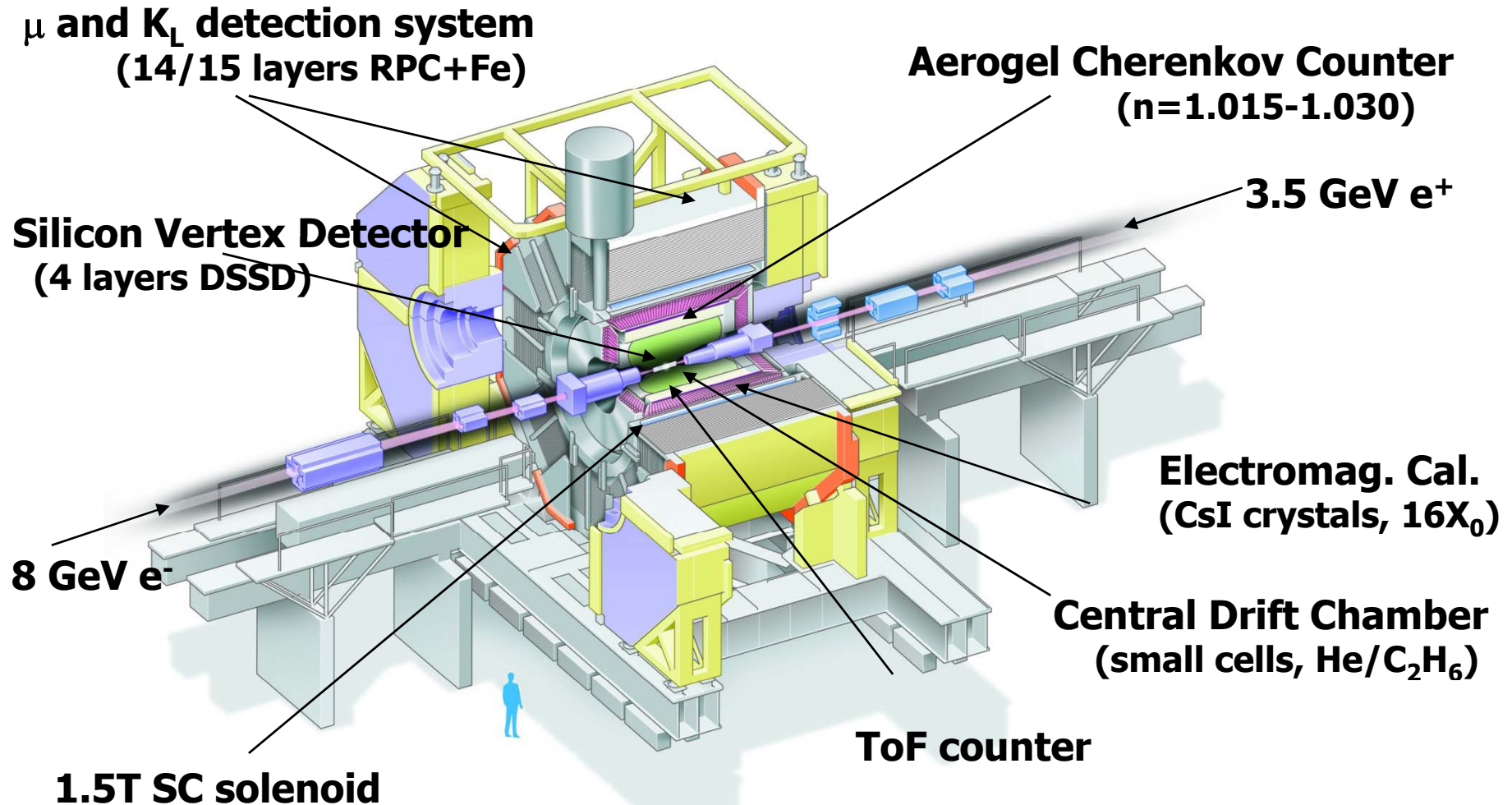
$$L = 2.1 \times 10^{34} / \text{cm}^2 / \text{sec}$$



Principle of measurement



Belle spectrometer at KEK-B



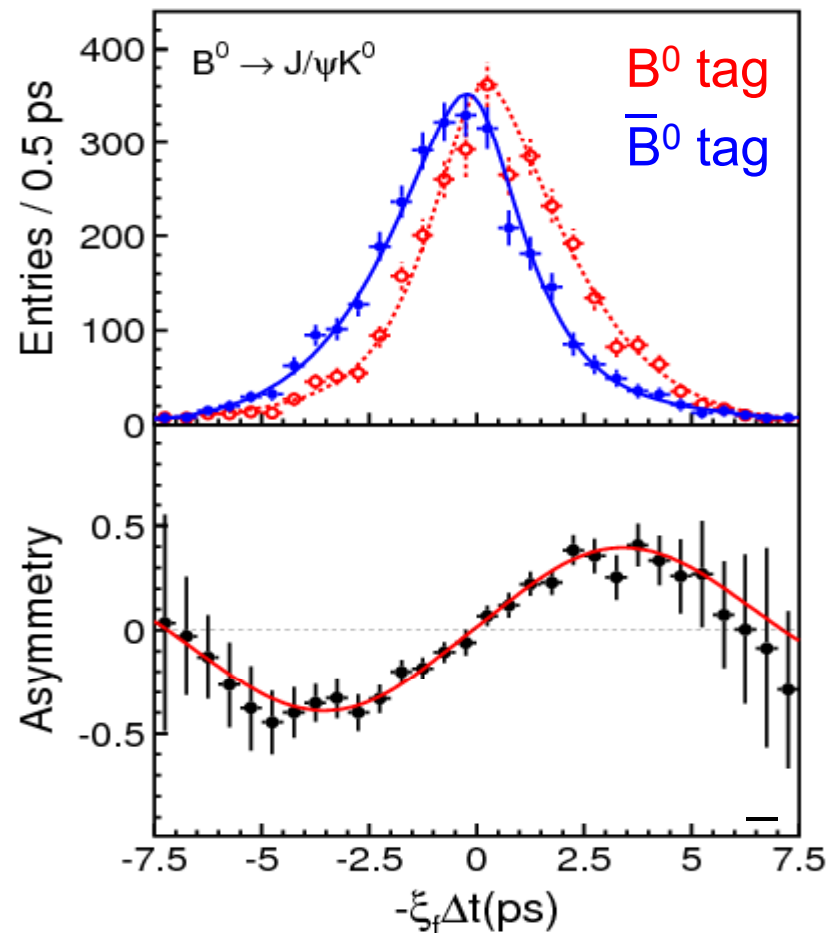
+ an extremely well operating KEK-B collider →

CP violation in the B system

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

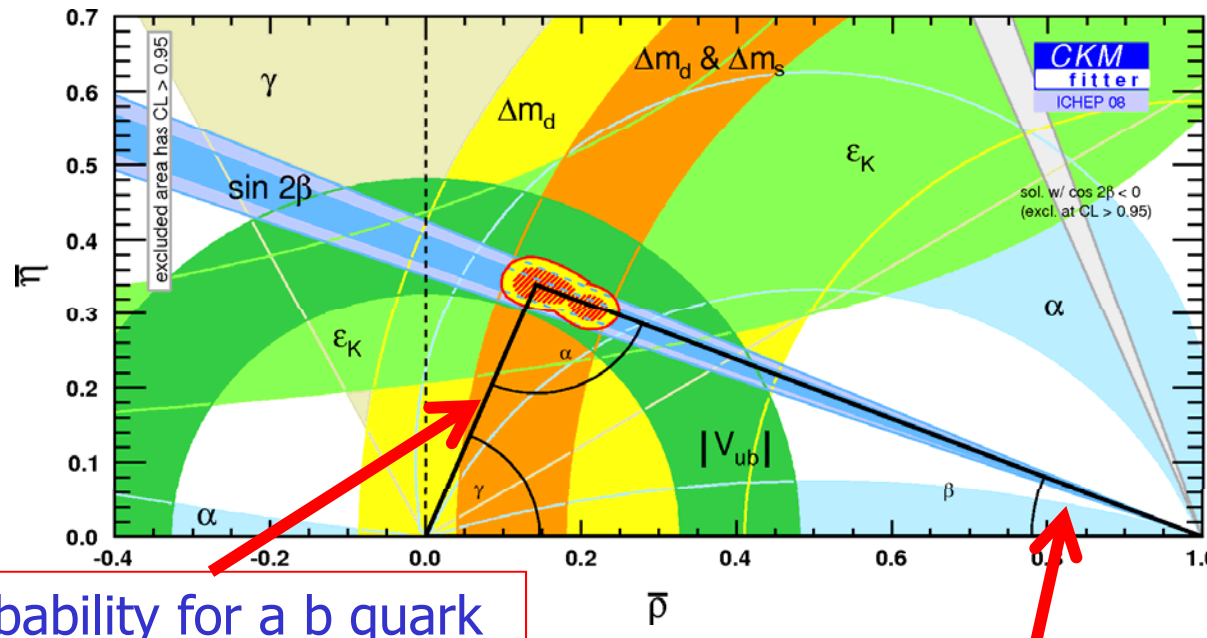
$\sin 2\phi_1 / \sin 2\beta$ from $b \rightarrow cc\bar{s}$

535 M $B\bar{B}$ pairs



$$\sin 2\phi_1 = 0.642 \pm 0.031 \text{ (stat)} \pm 0.017 \text{ (syst)}$$

All measurements combined...



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

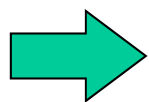
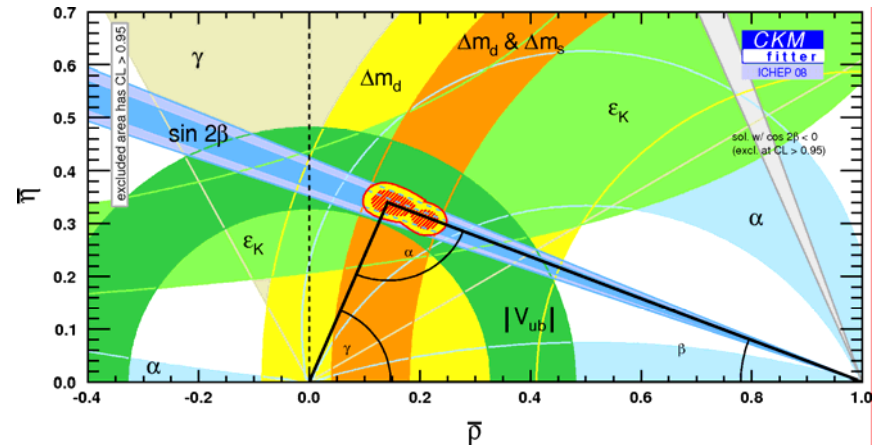
CP asymmetry oscillation amplitude \rightarrow angle $\phi_1 = \beta$

Constraints from measurements of angles and sides of the unitarity triangle

\rightarrow Remarkable agreement

Consistent picture

Relations between parameters as expected in the Standard model →



Nobel prize 2008!



Peter Križan, Ljubljana

Also for us a good reason to celebrate...

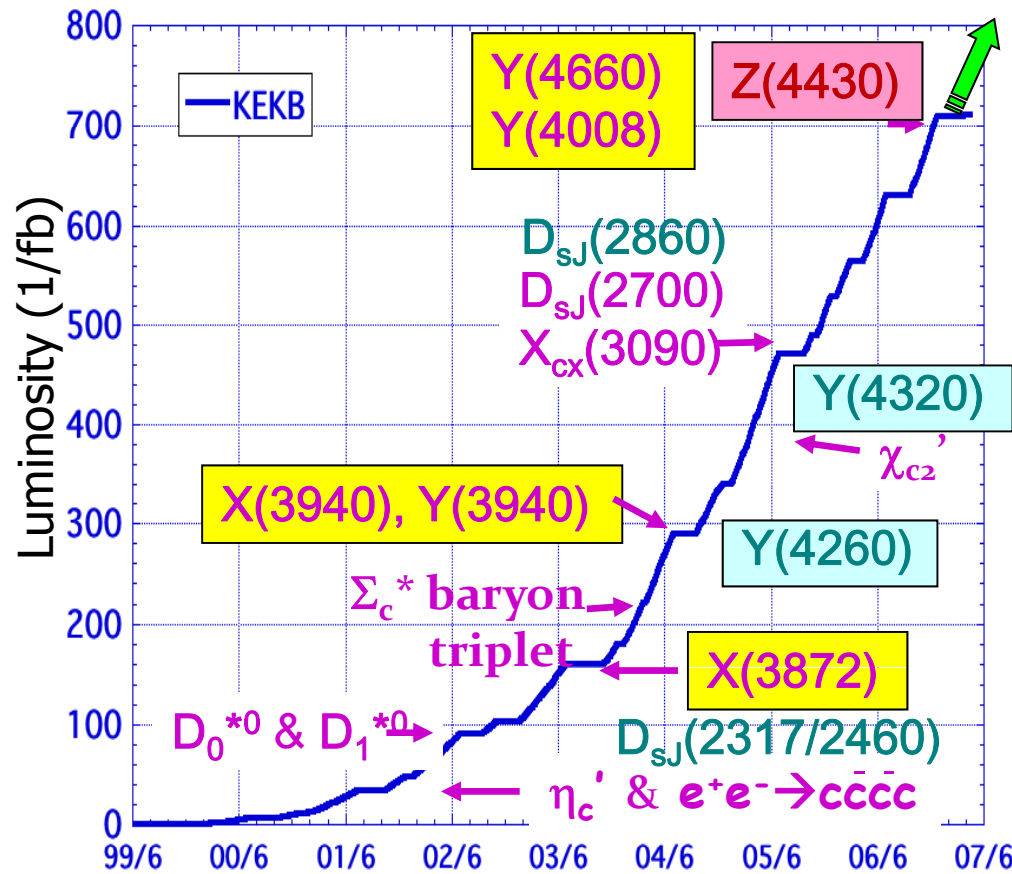


B factories: a success story

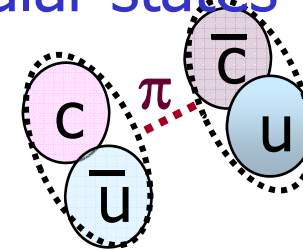
- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \rightarrow \tau \nu$, $D \tau \nu$)
- $b \rightarrow s$ transitions: probe for new sources of CPV and constraints from the $b \rightarrow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

New hadrons at B-factories

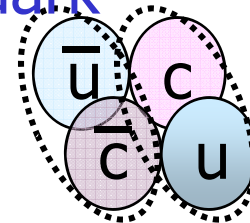
Discoveries of many new hadrons at B-factories have shed light on a new class of hadrons beyond the ordinary mesons.



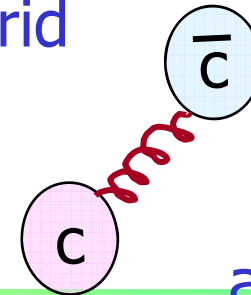
Molecular states



Tetra-quark

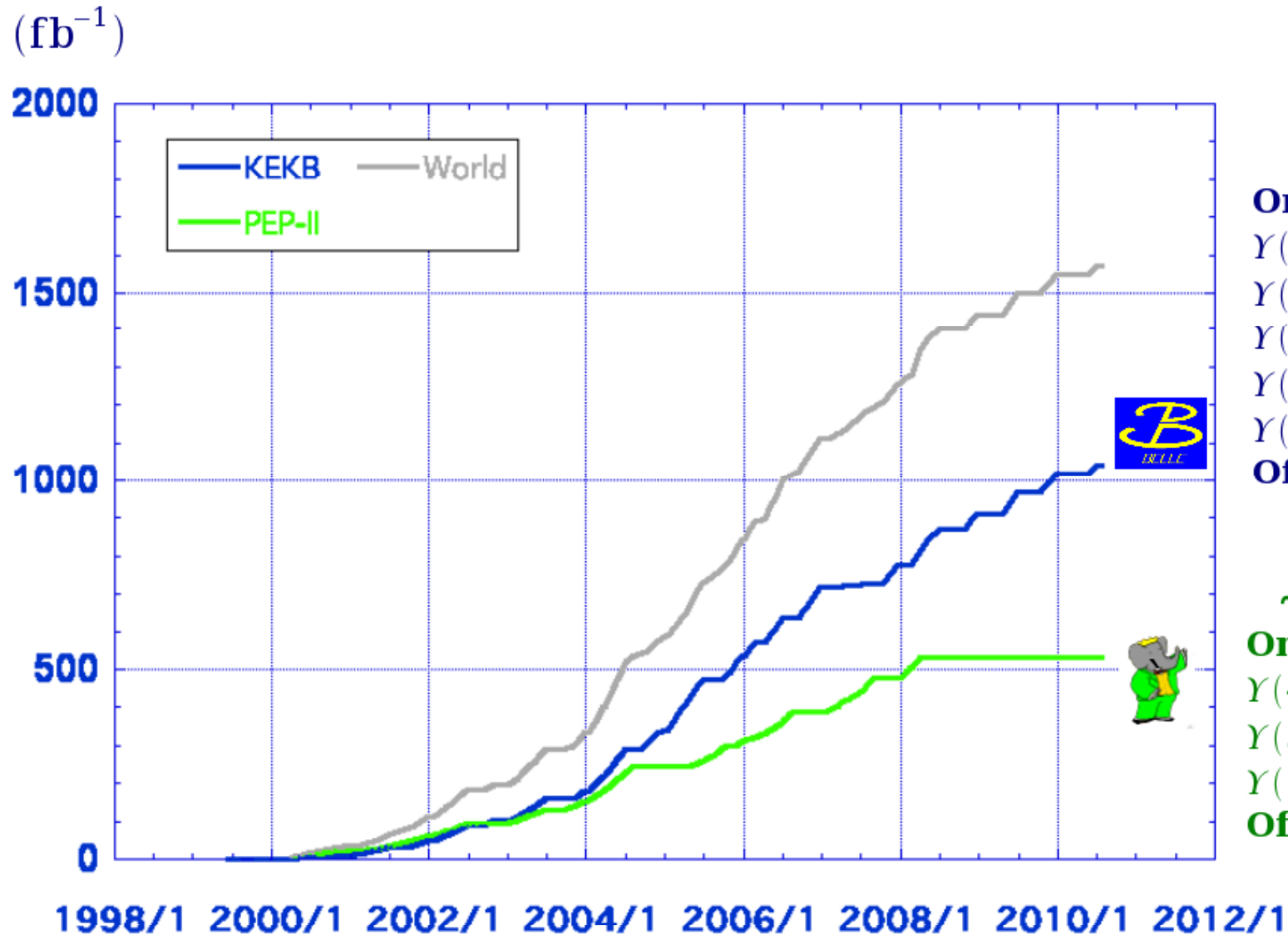


Hybrid



and more...

Luminosity at B factories



> 1 ab⁻¹
On resonance:
Y(5S): 121 fb⁻¹
Y(4S): 711 fb⁻¹
Y(3S): 3 fb⁻¹
Y(2S): 24 fb⁻¹
Y(1S): 6 fb⁻¹
Off reson./scan:
~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
Y(4S): 433 fb⁻¹
Y(3S): 30 fb⁻¹
Y(2S): 14 fb⁻¹
Off resonance:
~ 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?

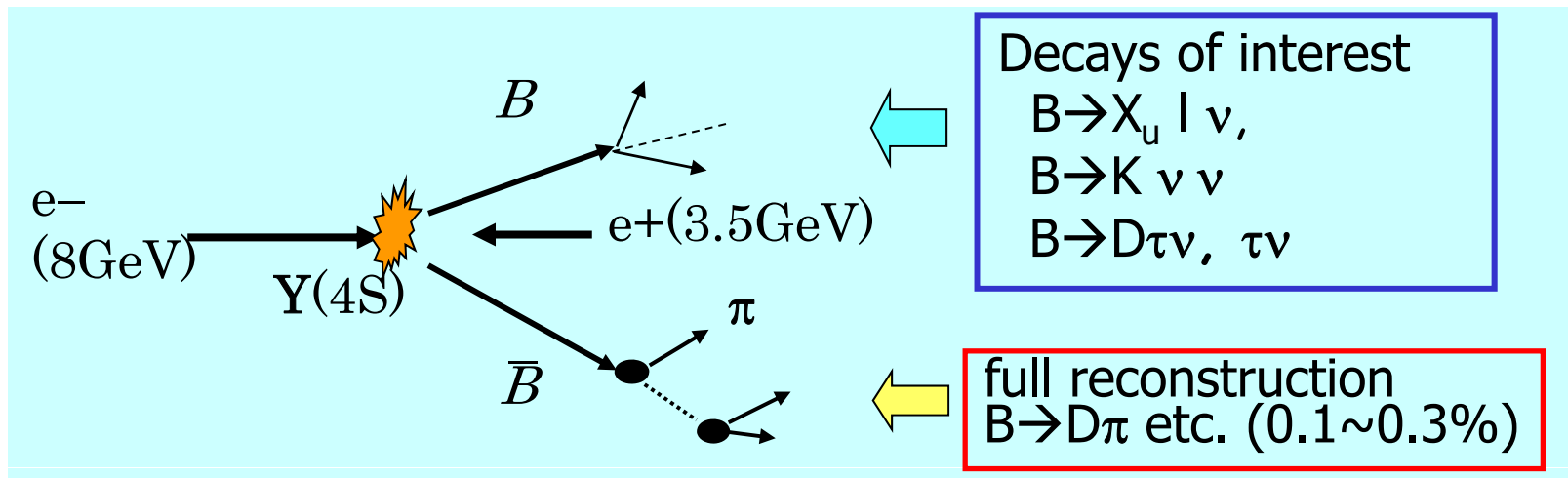
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

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) $\Upsilon(4s)$ will have considerable advantages in several classes of measurements, and will be complementary in many more

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

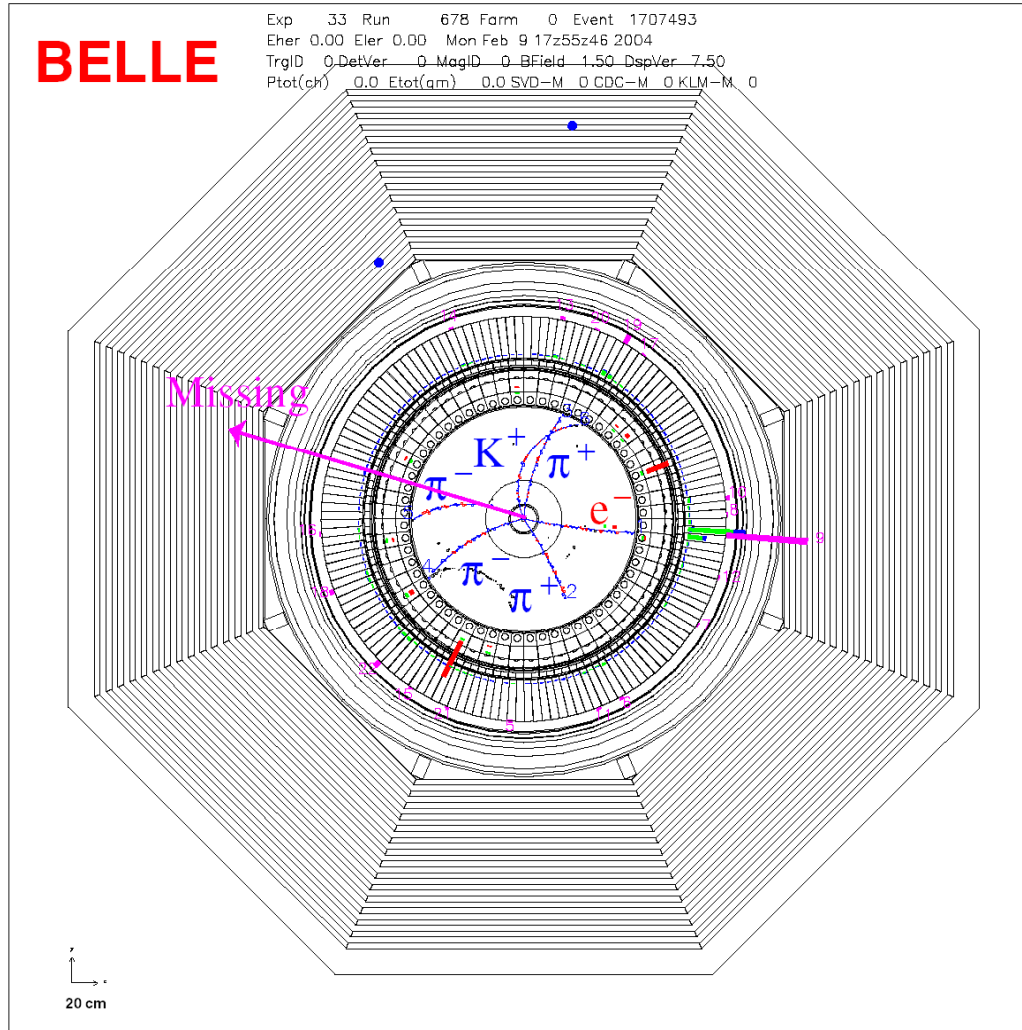


→ Offline B meson beam!

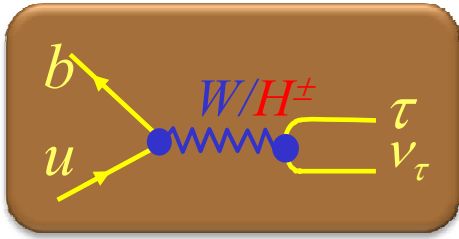
Powerful tool for B decays with neutrinos

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

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

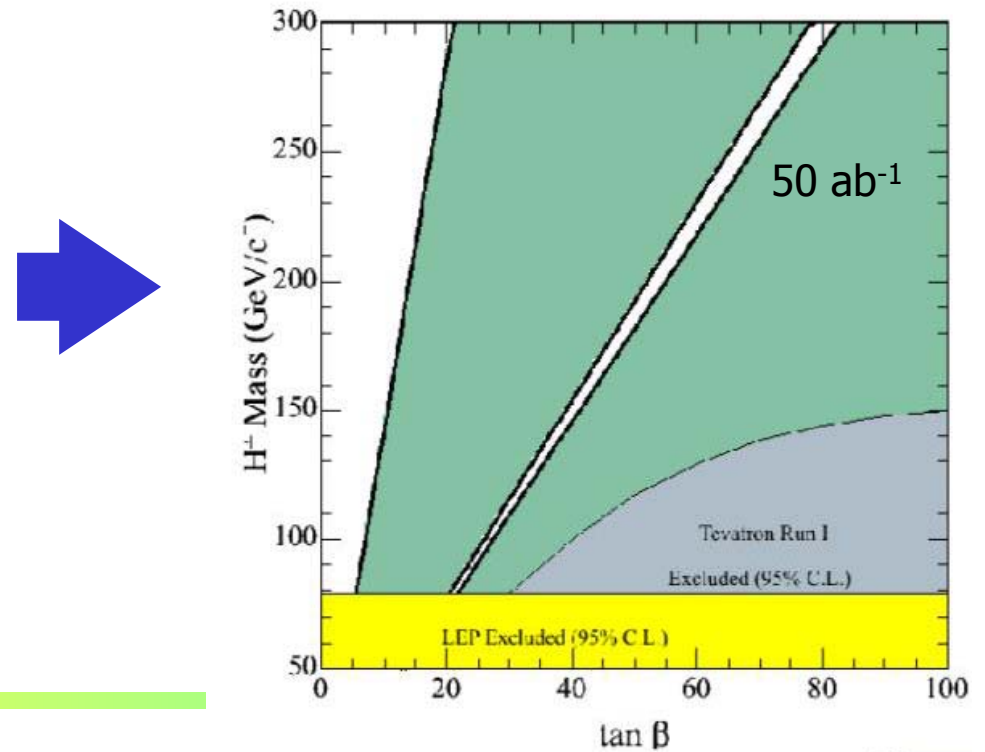
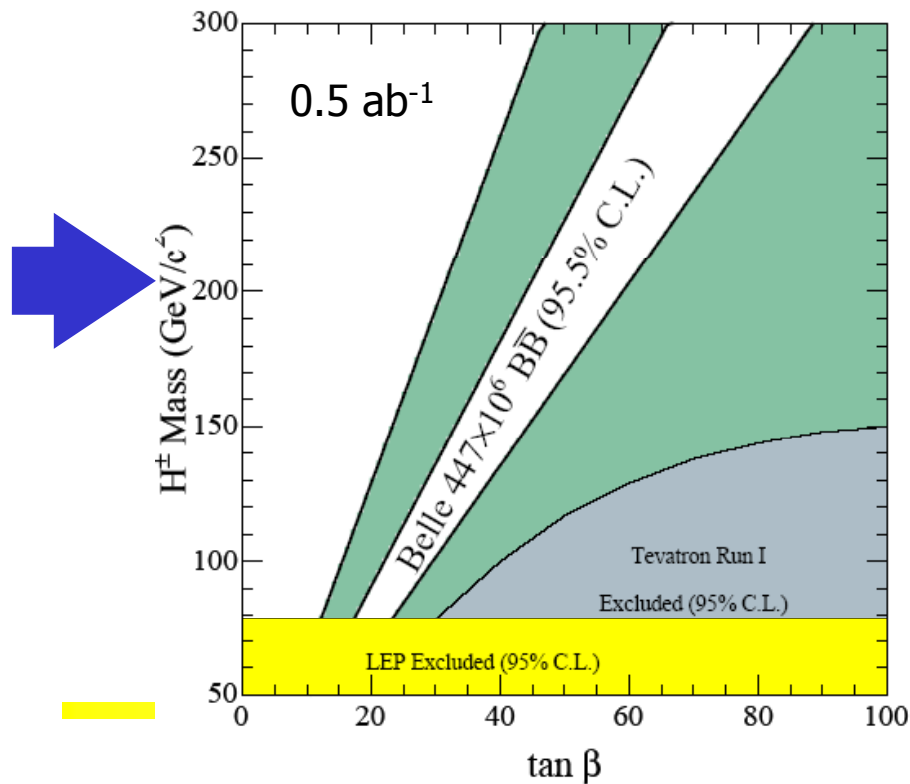


Charged Higgs limits from $B^- \rightarrow \tau^- \nu_\tau$



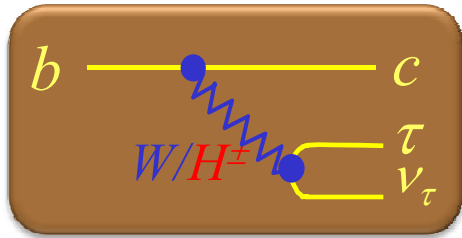
$$r_H = \frac{BF(B \rightarrow \tau \nu)}{BF(B \rightarrow \tau \nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2$$

→ limit on charged Higgs mass vs. $\tan \beta$



B → D^(*)τν

Semileptonic decay sensitive to charged Higgs



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

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

Compared to B → τν

1. Smaller theoretical uncertainty of R(D)

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

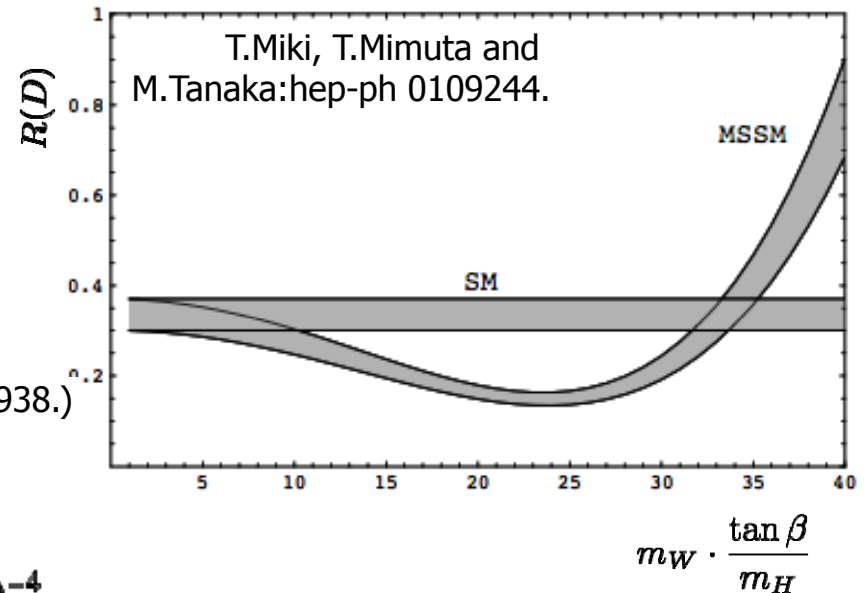
2. Large expected Br

(Ulrich Nierste arXiv:0801.4938.)

$$\mathcal{B}(B^- \rightarrow D^0 \tau^- \bar{\nu}_\tau)^{SM} = (0.71 \pm 0.09)\%$$

$$\mathcal{B}(\bar{B}^0 \rightarrow D^+ \tau^- \bar{\nu}_\tau)^{SM} = (0.66 \pm 0.08)\%$$

$$\mathcal{B}(B \rightarrow \tau\nu) = [1.65_{-0.37}^{+1.38} (stat)_{-0.37}^{+0.15} (syst)] \times 10^{-4}$$

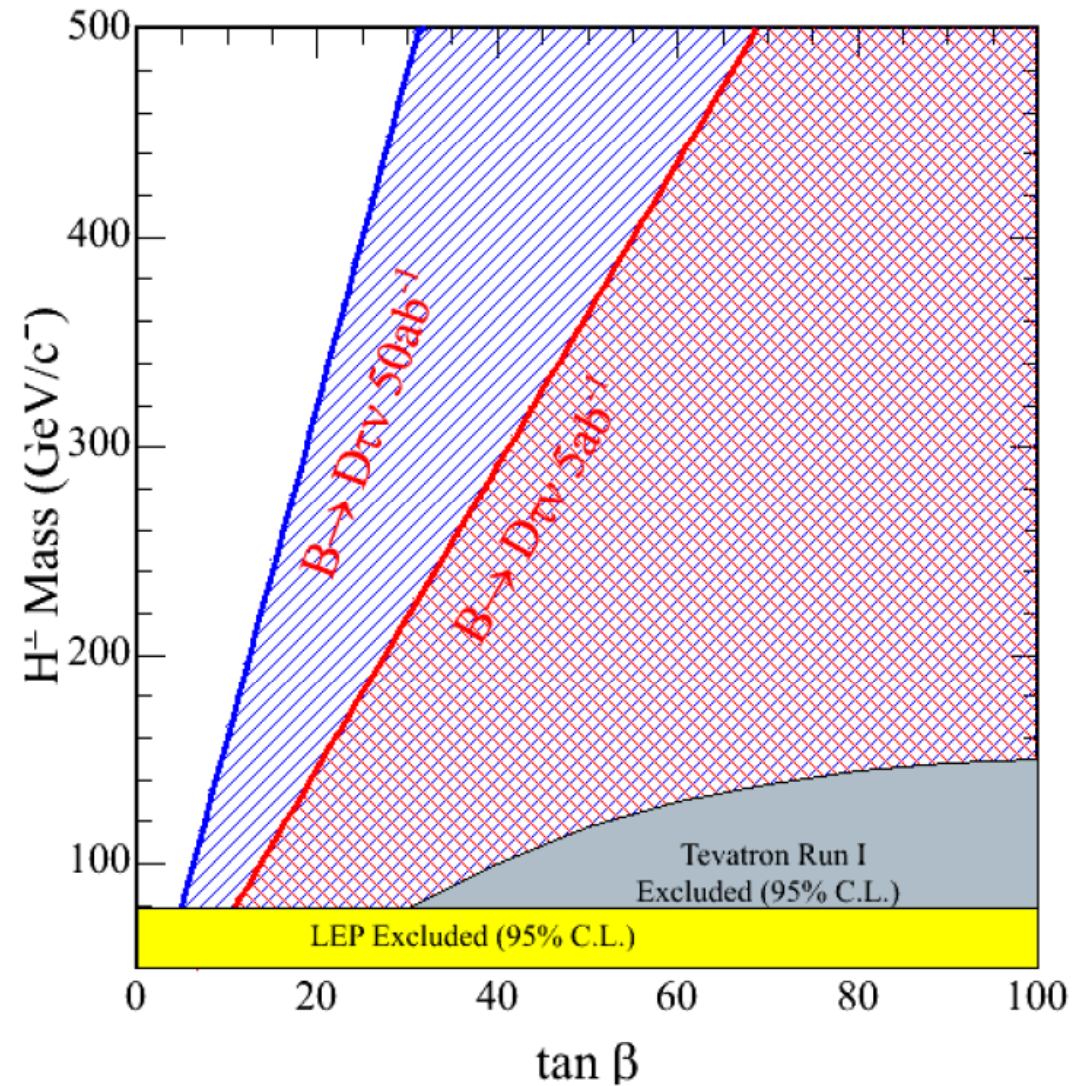


3. Differential distributions can be used to discriminate W⁺ and H⁺

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

$B \rightarrow D\tau\nu$

Exclusion plots for
 $\tan\beta$ and H^+ mass
for $5ab^{-1}$ and $50ab^{-1}$





$B \rightarrow D^* \tau \nu$ – similar constraints on H^+

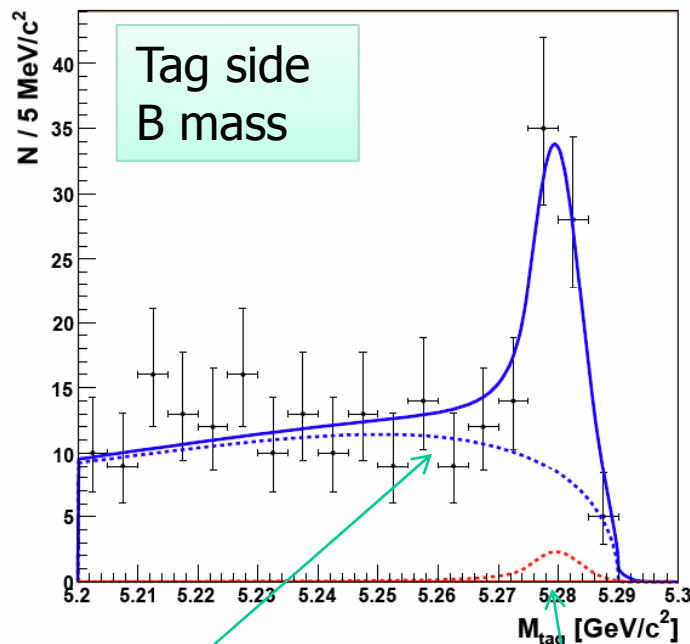
[PRL 99, 191807 (2007)]

FIRST OBSERVATION - 2007

535M $B\bar{B}$

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

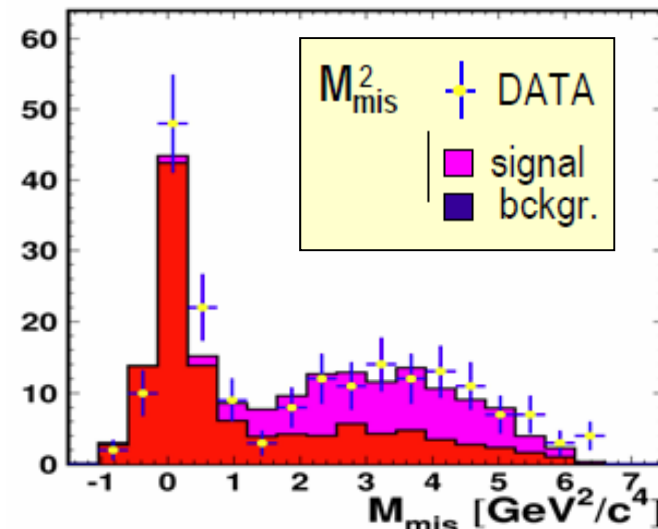
SIGNAL YIELD $N_s = 60^{+12}_{-11}$ 6.7σ (5.2σ with syst.)



combinatorial background

peaking background ($D^{*-}e\nu$)

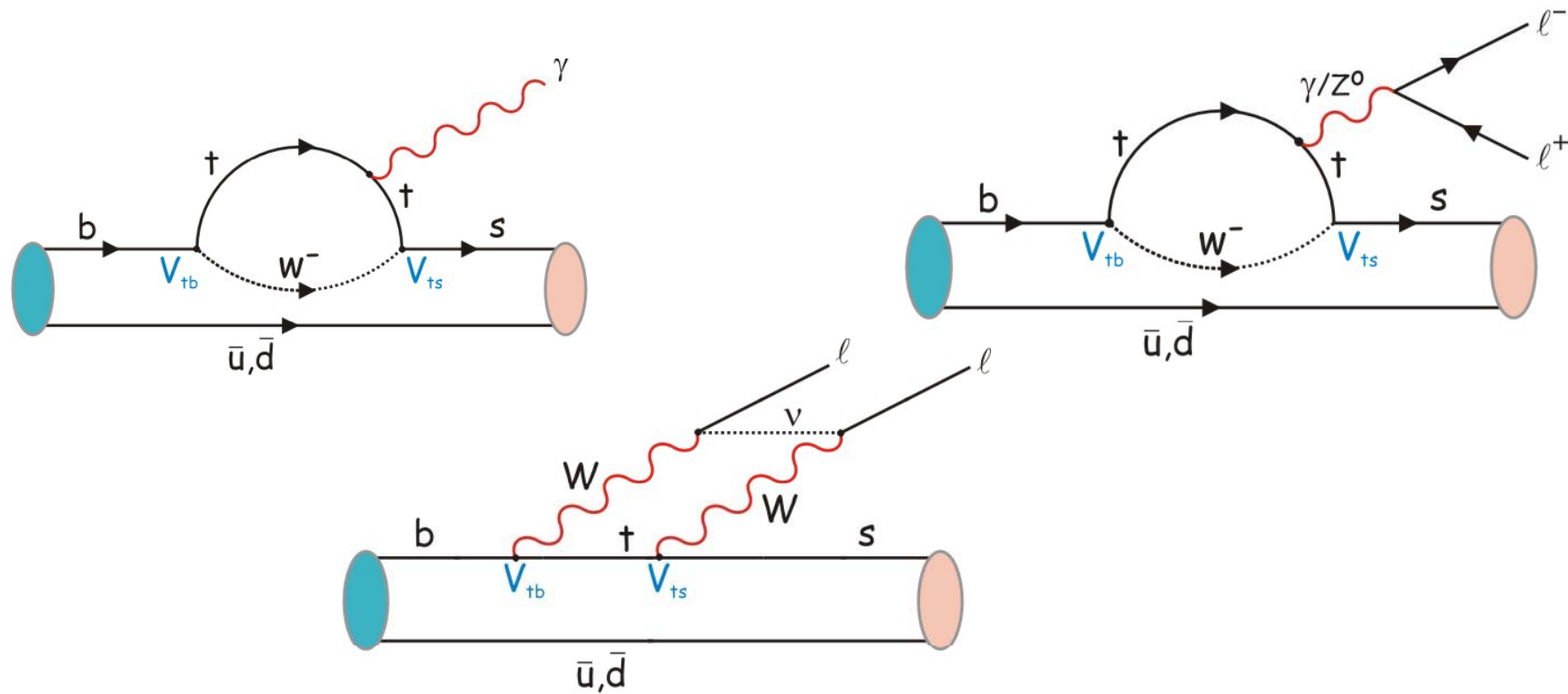
$$M_{mis}^2 = (E_b - E_{D^{(*)}} - E_{l/h})^2 - (-\vec{p}_{tag} - \vec{p}_{D^{(*)}} - \vec{p}_{l/h})^2$$



Update soon!

Why FCNC decays?

Flavour changing neutral current (FCNC) processes (like $b \rightarrow s$, $b \rightarrow d$) are forbidden 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 $b \rightarrow s$?

For example in the process:

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

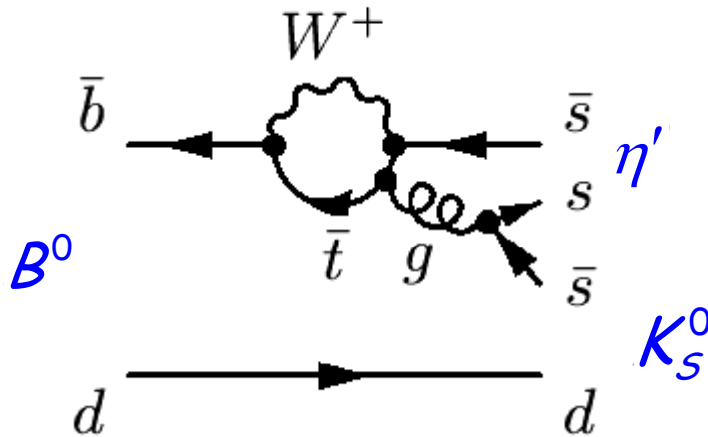
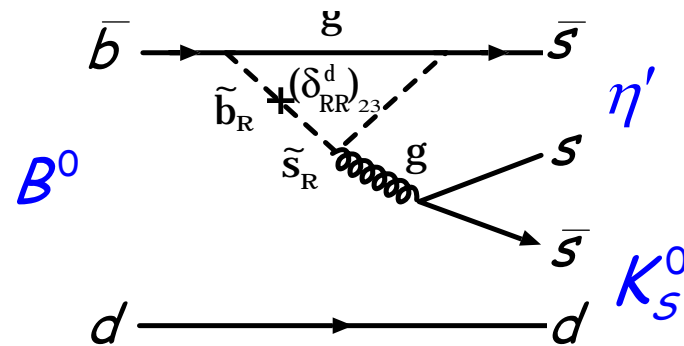


Diagram with supersymmetric particles

Ordinary penguin diagram with a t quark in the loop



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

arXiv:1002.5012

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

SM: penguin+box

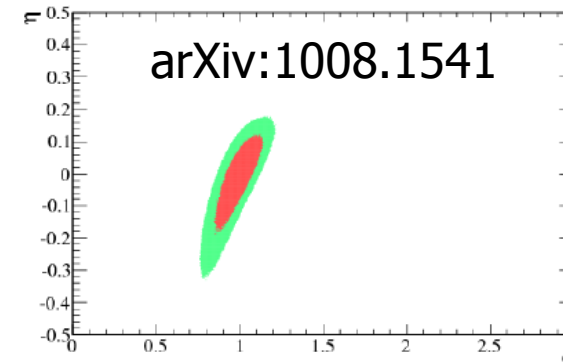
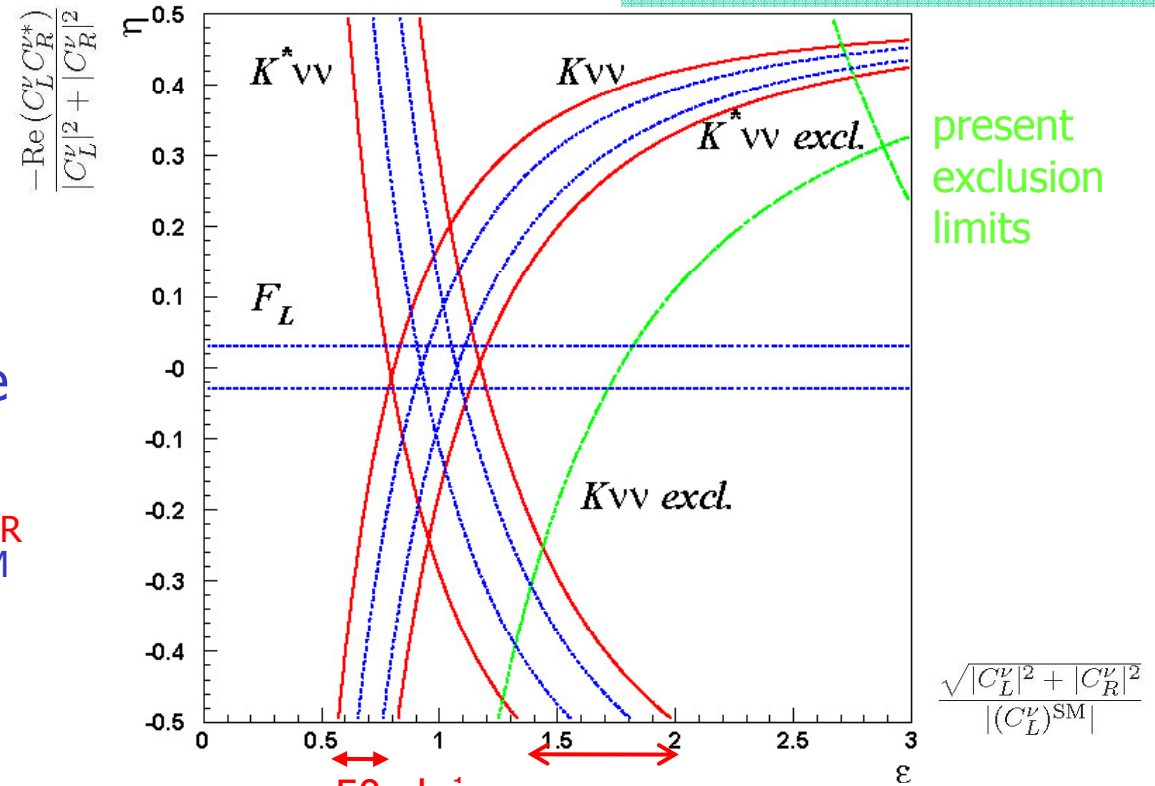
Look for departure from the expected value \rightarrow information on couplings C_R^{ν} and C_L^{ν} compared to $(C_L^{\nu})^{SM}$

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

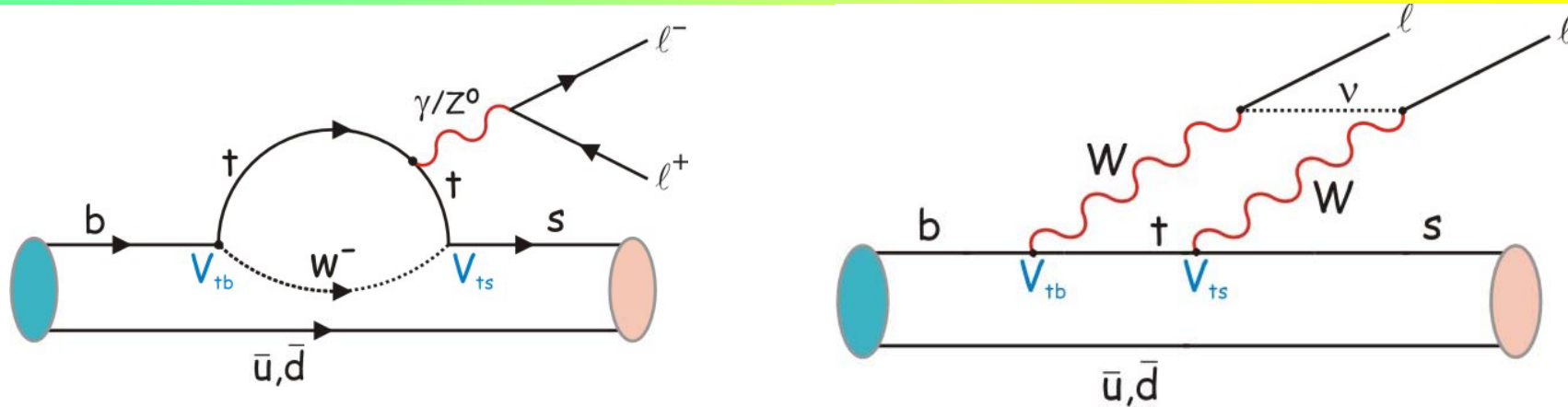
not possible @ LHCb

\leftrightarrow Theory

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



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).

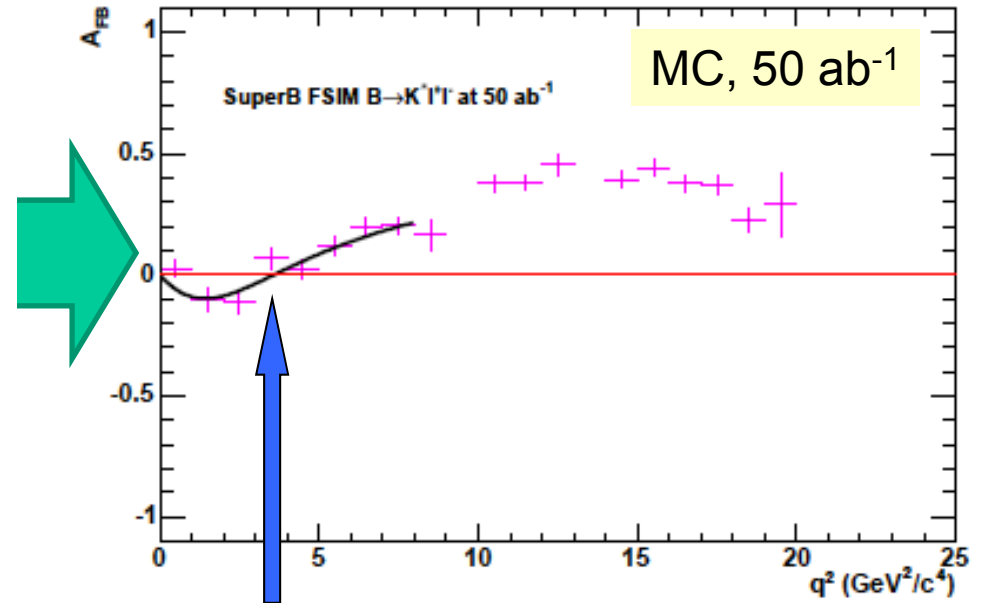
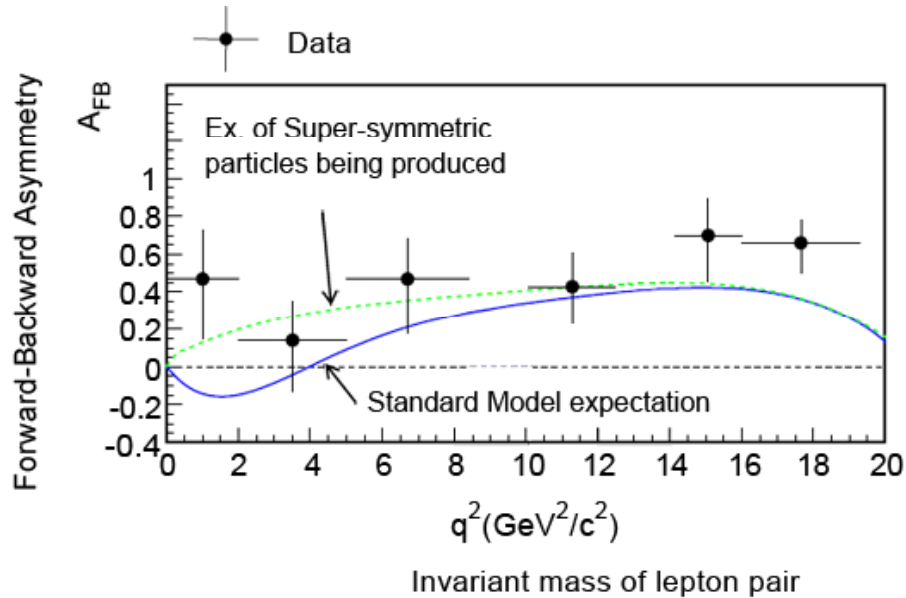
Important for further searches for the physics beyond SM

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

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

C_i : Wilson coefficients, abs. value of C_7 from $b \rightarrow s \gamma$
 $s = \text{lepton pair mass squared}$

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



Data: very interesting!

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

Strong competition from LHCb and ATLAS/CMS

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

CP asymmetry

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

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)

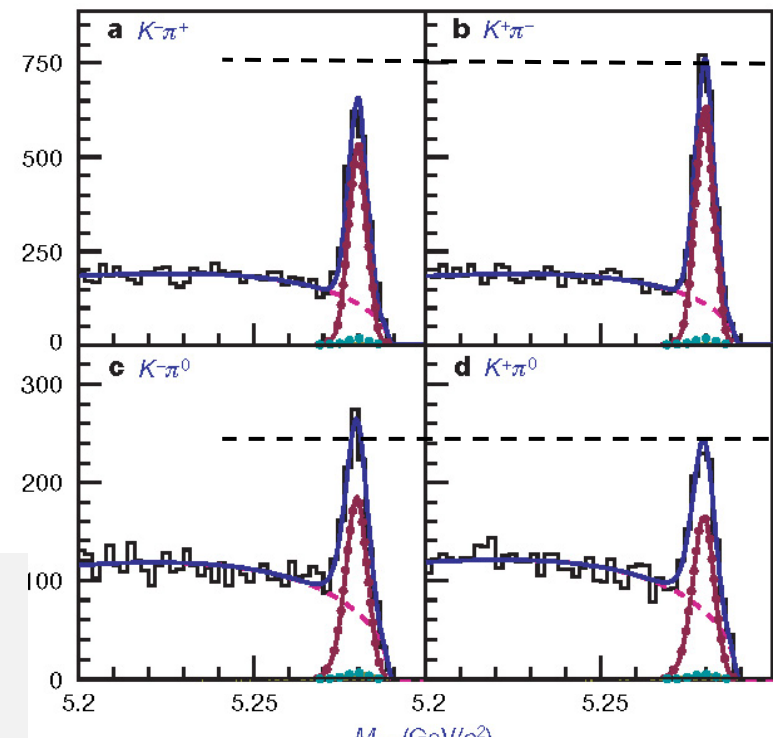
A hint for new sources of CP violation?



LETTERS

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

The Belle Collaboration*

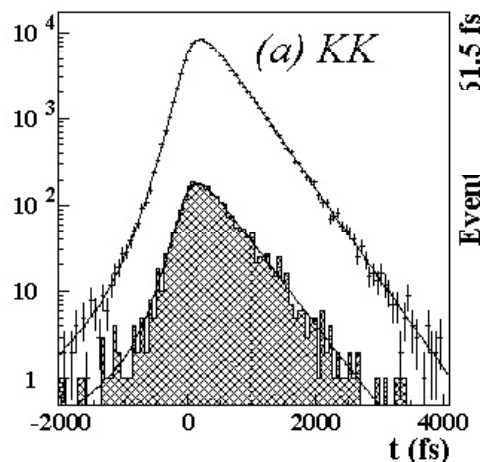


~ 1 in 10^5 B mesons decays in this decay mode

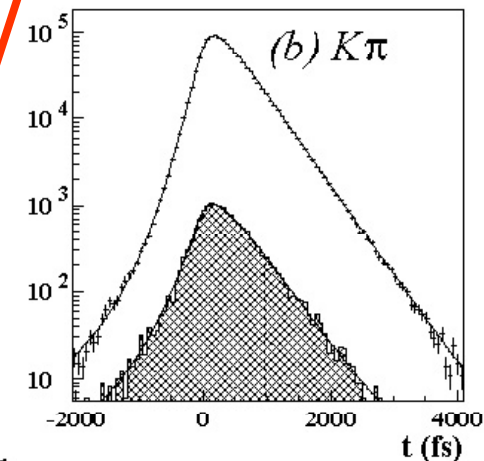
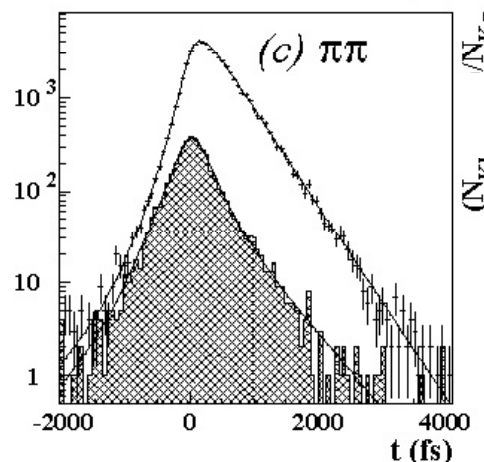
Belle, Nature 452, 332 (2008)

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

Decay time distributions for KK , $\pi\pi$, $K\pi$



+



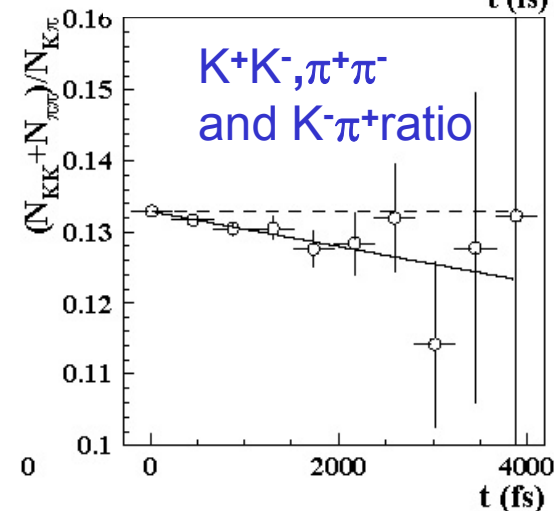
Difference of lifetimes visually observable in the ratio of the distributions \rightarrow

Real fit:

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

\rightarrow Observation of D mixing!

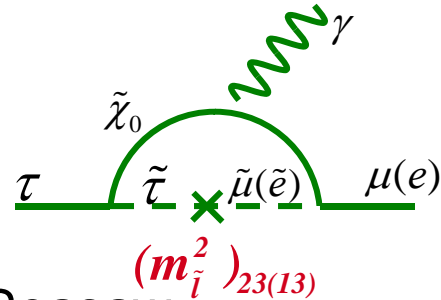
\rightarrow on a high side of SM predictions



CP violation in the D system would be a clear sign of new physics

LFV and New Physics

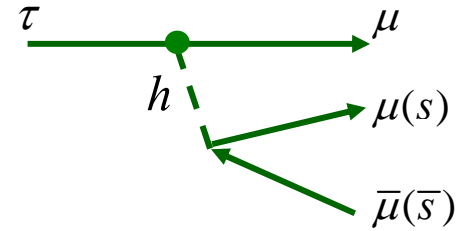
$\tau \rightarrow l \gamma$



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

$$Br(\tau \rightarrow \mu \gamma) \approx 10^{-6} \times \left(\frac{(m_L^2)_{32}}{\bar{m}_L^2} \right) \left(\frac{1 \text{ TeV}}{m_{\text{SUSY}}} \right)^4 \tan^2 \beta$$

$\tau \rightarrow 3l, l \eta$



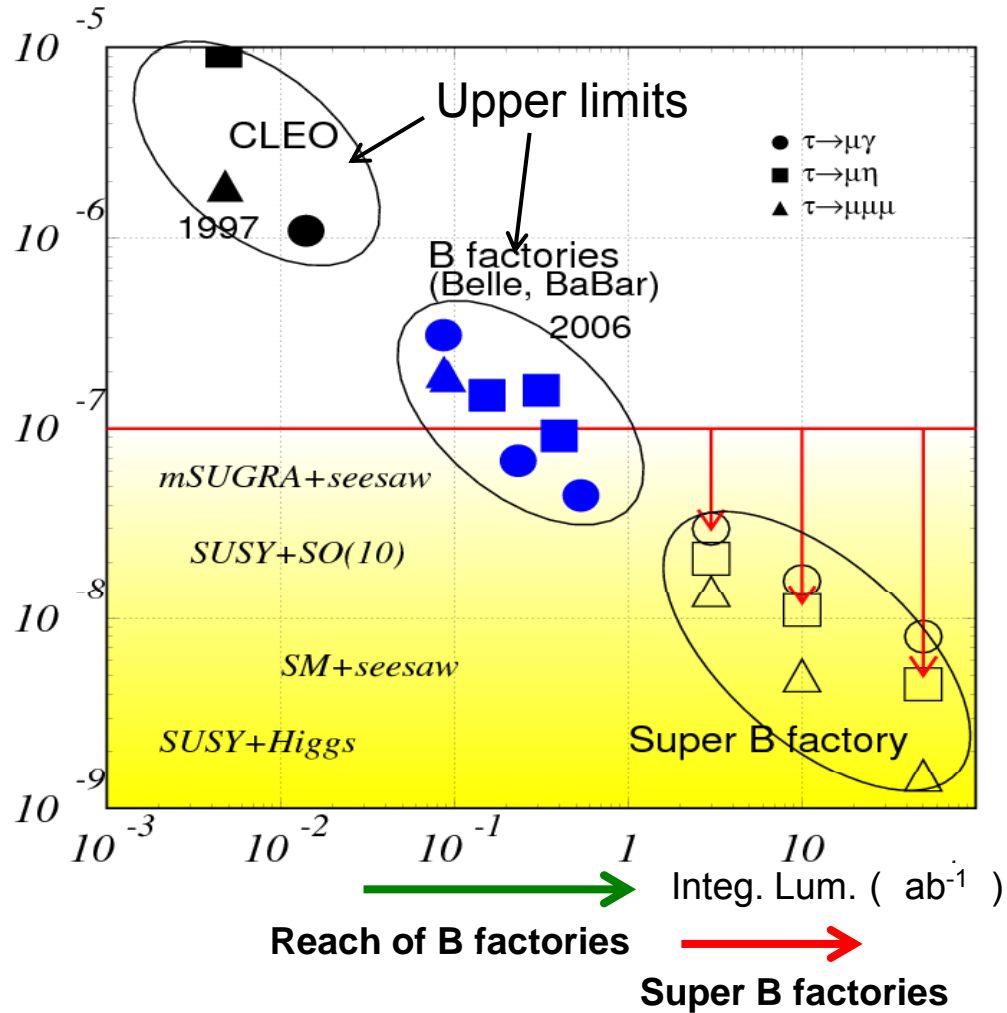
- Neutral Higgs mediated decay.
- Important when $M_{\text{SUSY}} \gg \text{EW scale}$.

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

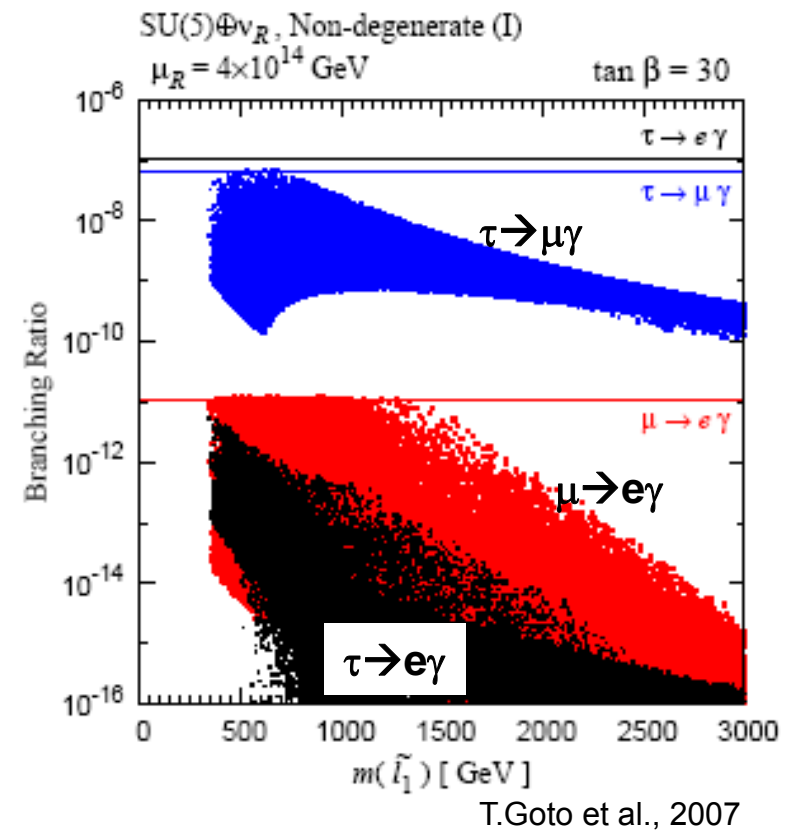
model	$Br(\tau \rightarrow \mu \gamma)$	$Br(\tau \rightarrow 3l)$
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Rare τ decays

LF violating τ decay?



Theoretical predictions compared to **present** experimental limits



B Physics @ Y(4S)

Observable	B Factories (2 ab ⁻¹)	SuperB (75 ab ⁻¹)	Observable	B Factories (2 ab ⁻¹)	SuperB (75 ab ⁻¹)
$\sin(2\beta) (J/\psi K^0)$	0.018	0.005 (†)	$ V_{cb} $ (exclusive)	4% (*)	1.0% (*)
$\cos(2\beta) (J/\psi K^{*0})$	0.30	0.05	$ V_{cb} $ (inclusive)	1% (*)	0.5% (*)
$\sin(2\beta) (Dh^0)$	0.10	0.02	$ V_{ub} $ (exclusive)	8% (*)	3.0% (*)
$\cos(2\beta) (Dh^0)$	0.20	0.04	$ V_{ub} $ (inclusive)	8% (*)	2.0% (*)
$S(J/\psi \pi^0)$	0.10	0.02	$\mathcal{B}(B \rightarrow \tau \nu)$	20%	4% (†)
$S(D^+ D^-)$	0.20	0.03	$\mathcal{B}(B \rightarrow \mu \nu)$	visible	5%
$S(\phi K^0)$	0.13	0.02 (*)	$\mathcal{B}(B \rightarrow D \tau \nu)$	10%	2%
$S(\eta' K^0)$	0.05	0.01 (*)	$\mathcal{B}(B \rightarrow \rho \gamma)$	15%	3% (†)
$S(K_s^0 K_s^0 K_s^0)$	0.15	0.02 (*)	$\mathcal{B}(B \rightarrow \omega \gamma)$	30%	5%
$S(K_s^0 \pi^0)$	0.15	0.02 (*)	$A_{CP}(B \rightarrow K^* \gamma)$	0.007 (†)	0.004 († *)
$S(\omega K_s^0)$	0.17	0.03 (*)	$A_{CP}(B \rightarrow \rho \gamma)$	~ 0.20	0.05
$S(f_0 K_s^0)$	0.12	0.02 (*)	$A_{CP}(b \rightarrow s \gamma)$	0.012 (†)	0.004 (†)
$\gamma (B \rightarrow DK, D \rightarrow CP \text{ eigenstates})$	~ 15°	2.5°	$A_{CP}(b \rightarrow (s+d)\gamma)$	0.03	0.006 (†)
$\gamma (B \rightarrow DK, D \rightarrow \text{suppressed states})$	~ 12°	2.0°	$S(K_s^0 \pi^0 \gamma)$	0.15	0.02 (*)
$\gamma (B \rightarrow DK, D \rightarrow \text{multibody states})$	~ 9°	1.5°	$S(\rho^0 \gamma)$	possible	0.10
$\gamma (B \rightarrow DK, \text{combined})$	~ 6°	1-2°	$A_{CP}(B \rightarrow K^* \ell \ell)$	7%	1%
$\alpha (B \rightarrow \pi \pi)$	~ 16°	3°	$A^{FB}(B \rightarrow K^* \ell \ell)_{s_0}$	25%	9%
$\alpha (B \rightarrow \rho \rho)$	~ 7°	1-2° (*)	$A^{FB}(B \rightarrow X_s \ell \ell)_{s_0}$	35%	5%
$\alpha (B \rightarrow \rho \pi)$	~ 12°	2°	$\mathcal{B}(B \rightarrow K \nu \bar{\nu})$	visible	20%
$\alpha (\text{combined})$	~ 6°	1-2° (*)	$\mathcal{B}(B \rightarrow \pi \nu \bar{\nu})$	-	possible
$2\beta + \gamma (D^{(*)\pm} \pi^\mp, D^\pm K_s^0 \pi^\mp)$	20°	5°			

Charm mixing and CP

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

Charm FCNC

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

τ Physics

Sensitivity

$\mathcal{B}(\tau \rightarrow \mu \gamma)$	2×10^{-9}
$\mathcal{B}(\tau \rightarrow e \gamma)$	2×10^{-9}
$\mathcal{B}(\tau \rightarrow \mu \mu \mu)$	2×10^{-10}
$\mathcal{B}(\tau \rightarrow e e e)$	2×10^{-10}
$\mathcal{B}(\tau \rightarrow \mu \eta)$	4×10^{-10}
$\mathcal{B}(\tau \rightarrow e \eta)$	6×10^{-10}
$\mathcal{B}(\tau \rightarrow \ell K_s^0)$	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_{SL}^*	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$	-	$< 8 \times 10^{-9}$
$ V_{td}/V_{ts} $	0.08	0.017
$\mathcal{B}(B_s \rightarrow \gamma \gamma)$	38%	7%
β_s from $J/\psi \phi$	10°	3°
β_s from $B_s \rightarrow K^0 \bar{K}^0$	24°	11°

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 $> \text{TeV}$ scale physics (=TeV scale in case of MFV).

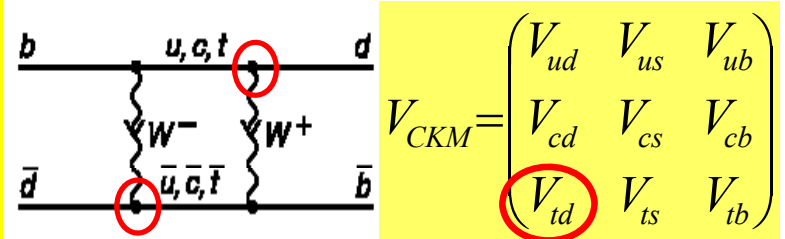
There are many more topics: CPV in charm, new hadrons, ...

Super B Factory Motivation 2

- Lessons from history: the top quark

Physics of top quark

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



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

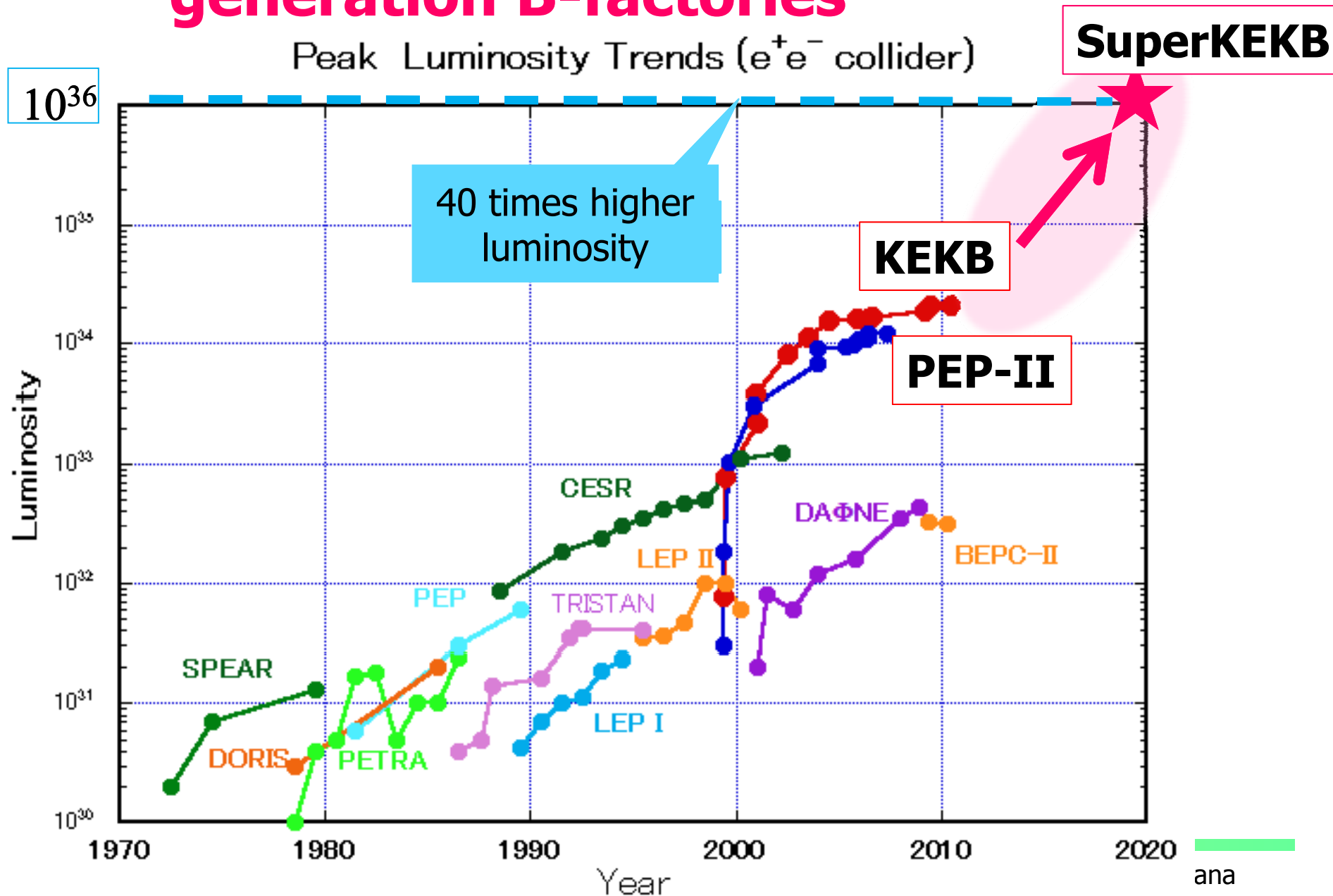
Recent update of the physics reach with 50 ab^{-1} :

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

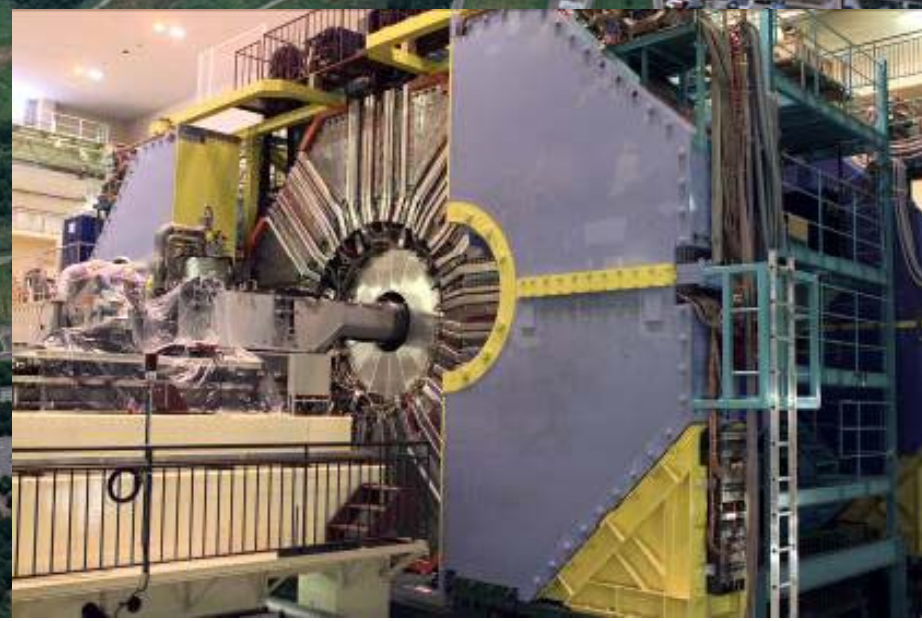
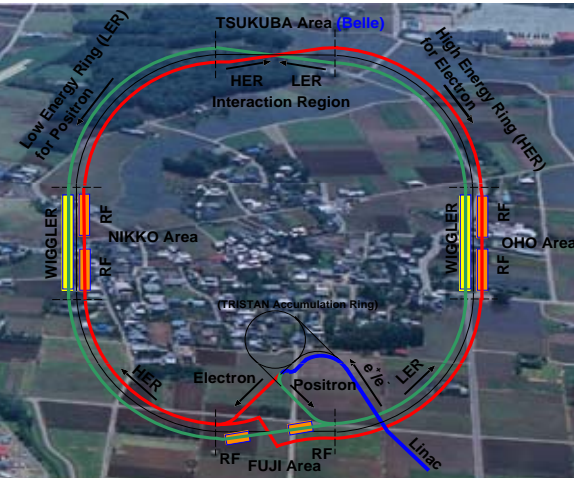
[hep-ex](https://arxiv.org/abs/1002.5012) > arXiv:1002.5012

Accelerator

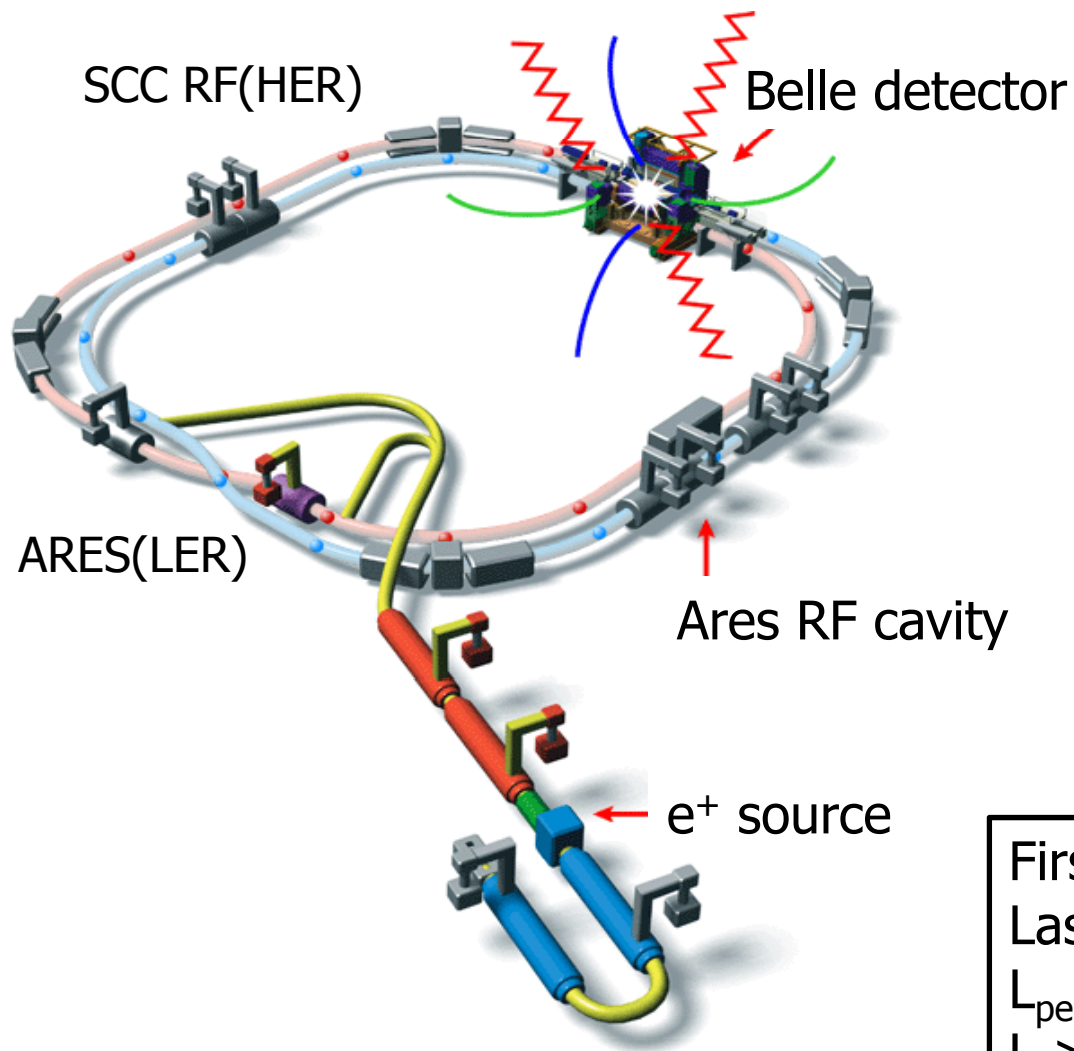
Need O(100x) more data → Next generation B-factories



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!) :
 $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
=2x design value

First physics run on June 2, 1999
Last physics run on June 30, 2010
 $L_{\text{peak}} = 2.1 \times 10^{34} / \text{cm}^2 / \text{s}$
 $L > 1 \text{ ab}^{-1}$

The last beam abort of KEKB on June 30, 2010



→ Can start construction of SuperKEKB and Belle II

Strategies for increasing luminosity



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

Lorentz factor γ_{e^\pm}
 Beam current I_{e^\pm}
 Beam-beam parameter $\xi_{\zeta_y}^{e^\pm}$
 Classical electron radius r_e
 Beam size ratio@IP $\frac{\sigma_y^*}{\sigma_x^*}$
 1 - 2 % (flat beam)
 Vertical beta function@IP β_y^*
 Lumi. reduction factor (crossing angle) & Tune shift reduction factor (hour glass effect) $\frac{R_L}{R_{\xi_y}}$
 0.8 - 1 (short bunch)

"Nano-Beam" scheme

(1) Smaller β_y^*
 (2) Increase beam currents
 (3) Increase ξ_{ζ_y}

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

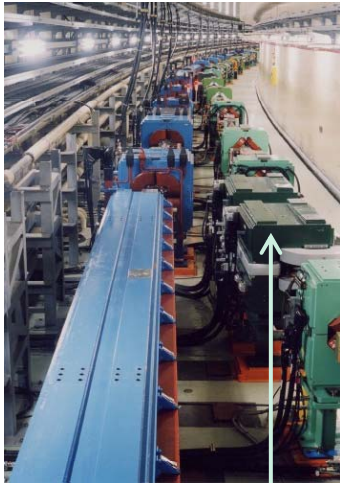
Machine design parameters



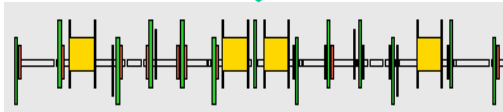
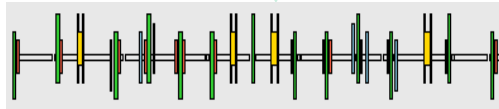
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ϵ_x	18	24	3.2	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60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

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

KEKB to SuperKEKB

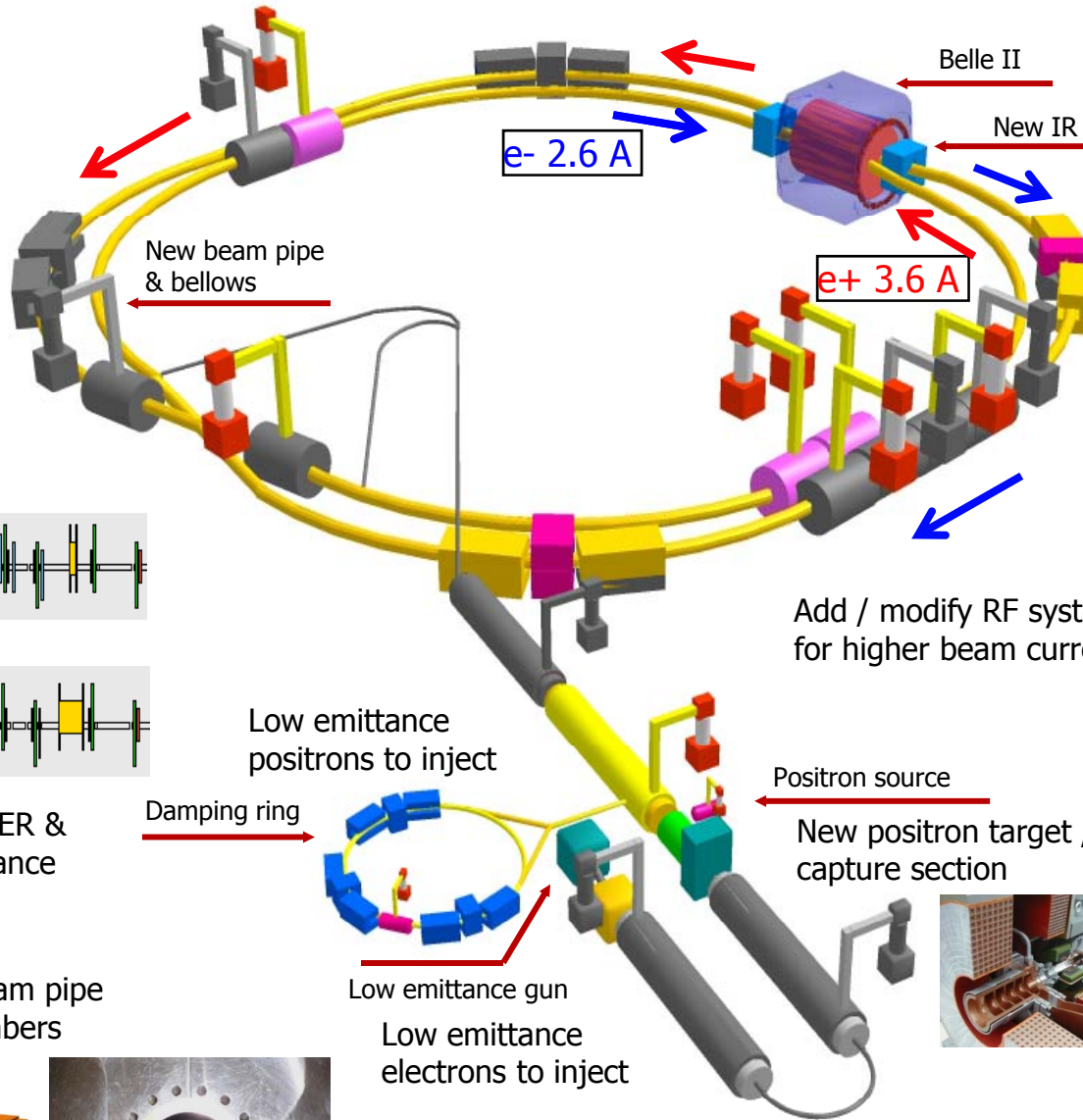
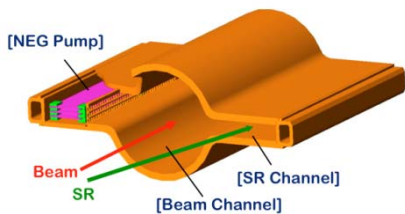


Replace short dipoles with longer ones (LER)

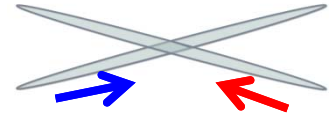


Redesign the lattices of HER & LER to squeeze the emittance

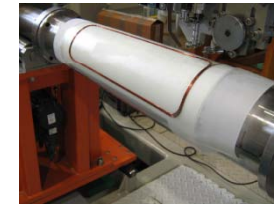
TiN-coated beam pipe with antechambers



Colliding bunches



New superconducting / permanent final focusing quads near the IP



Add / modify RF systems for higher beam current



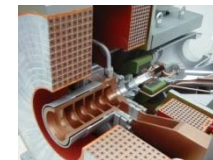
Low emittance positrons to inject

Damping ring



Positron source

New positron target / capture section



Low emittance gun

Low emittance electrons to inject

To get x40 higher luminosity

Detector



Requirements for the Belle II detector

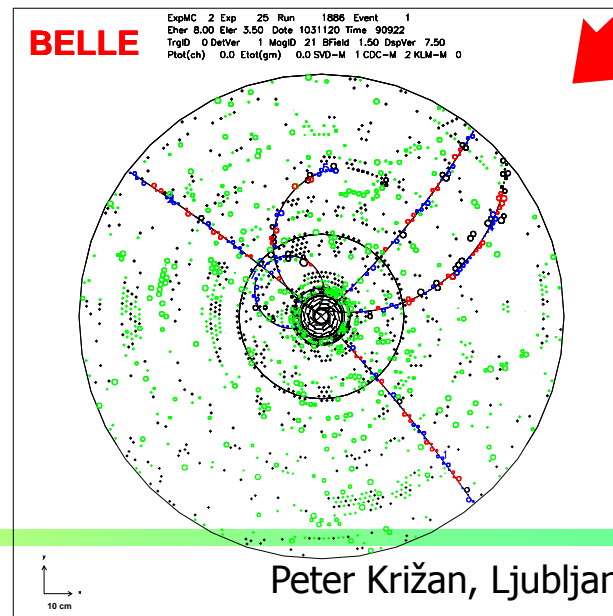
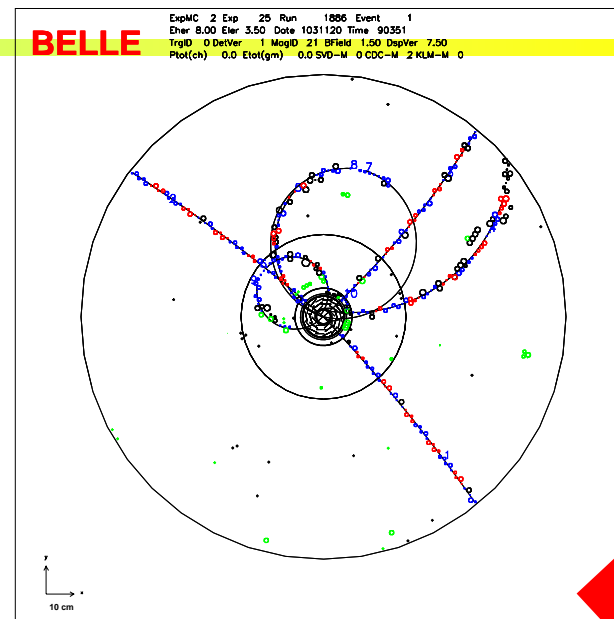
Critical issues at $L = 8 \times 10^{35}/\text{cm}^2/\text{sec}$

- ▶ **Higher background ($\times 10\text{-}20$)**
 - radiation damage and occupancy
 - fake hits and pile-up noise in the EM
- ▶ **Higher event rate ($\times 10$)**
 - higher rate trigger, DAQ and computing
- ▶ **Require special features**
 - low $p \mu$ identification $\leftarrow s_{\mu\mu}$ recon. eff.
 - hermeticity $\leftarrow \nu$ "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.

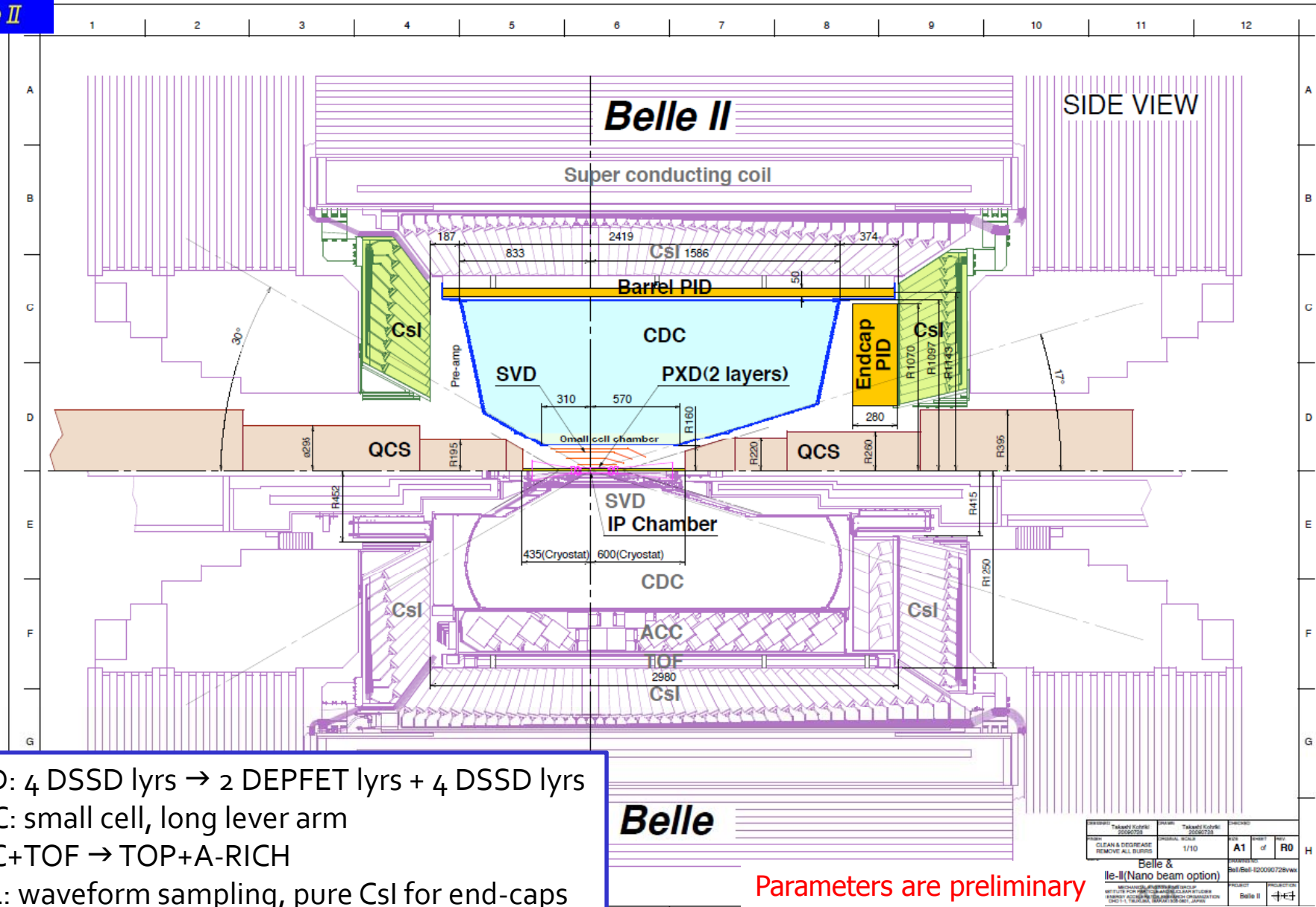
Very similar reasoning also for SuperB



Peter Križan, Ljubljana



Belle II in comparison with Belle



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)

Belle

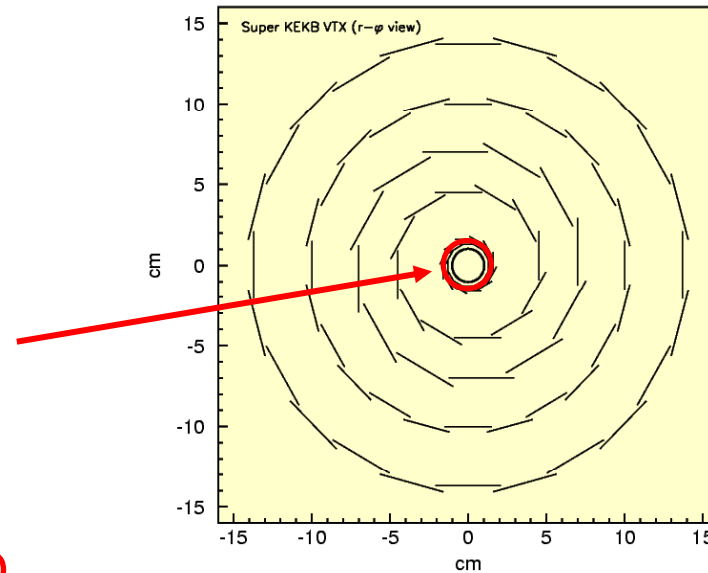
Parameters are preliminary

DESIGNED BY Takashi Kubota 20060728	DESIGNED BY Takashi Kubota 20060728	REV A1	SHEET of	REV R0
CLEAN & DECREASE REMOVE ALL BURRS		1/10		
Belle & Belle-II (Nano beam option)				
PROJECTED BY Takashi Kubota		PROJECTED BY Takashi Kubota		
Belle II		Belle II		

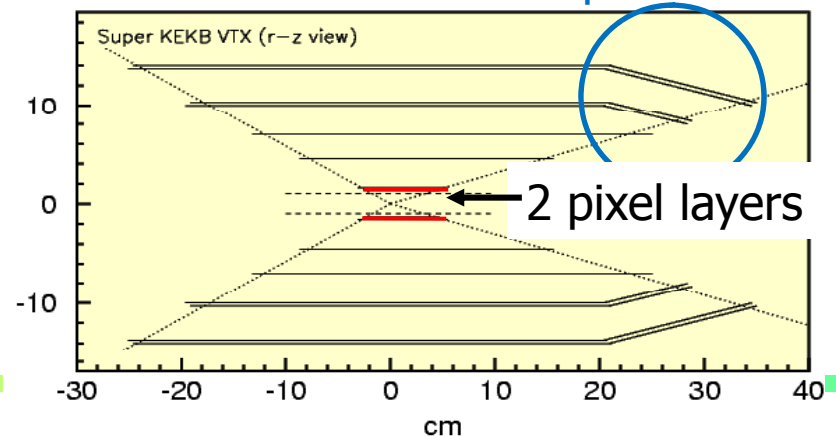
Y. Ushiroda, ICHEP2010

Vertex detector upgrade: PXD+SVD

- Configuration: 4 layers \rightarrow 6 layers (outer radius = 8cm \rightarrow 14cm)
 - More robust tracking
 - Higher Ks vertex reconstr. efficiency
- Inner radius: 1.5cm \rightarrow 1.3cm
 - Better vertex resolution
- Sensors of the two innermost layers L1+L2: **DEPFET Pixel sensors \rightarrow PXD**
- Layers 3-6: **normal double sided Si detector (DSSD) \rightarrow SVD**
- Strip readout chip: **VA1TA \rightarrow APV25**
 - Reduction of occupancy coming from beam background.
 - Pipeline readout to reduce dead time.



Slanted layers to keep the acceptance





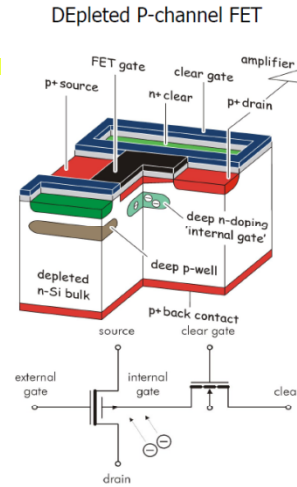
Vertex Detector

DEPFET:

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



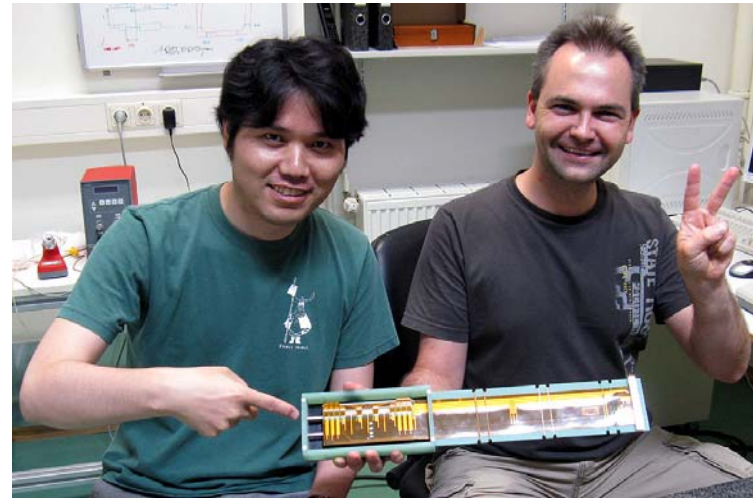
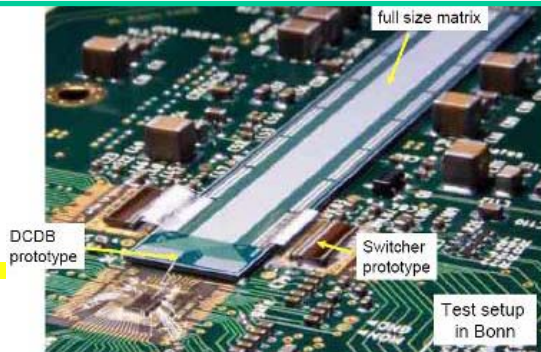
Beam Pipe	r = 10mm
DEPFET	
Layer 1	r = 14mm
Layer 2	r = 22mm
DSSD	
Layer 3	r = 38mm
Layer 4	r = 80mm
Layer 5	r = 115mm
Layer 6	r = 140mm



Mechanical mockup of pixel detector



Prototype DEPFET pixel sensor and readout



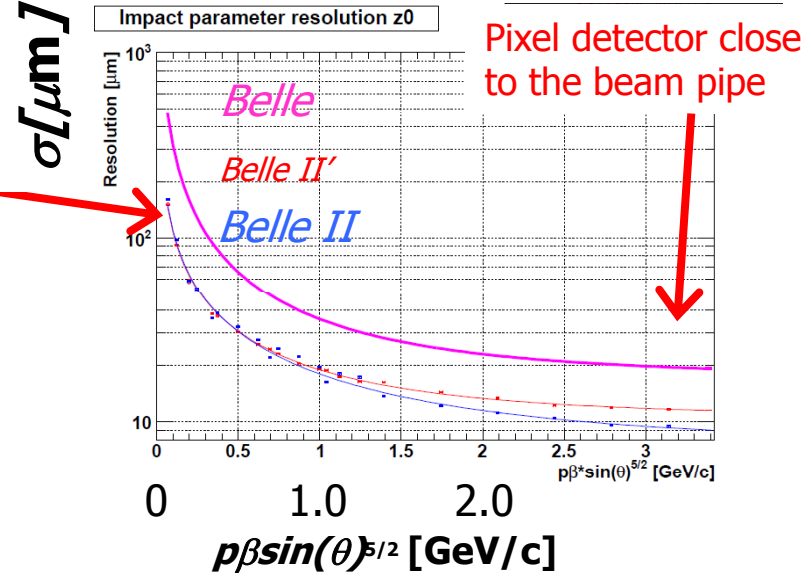
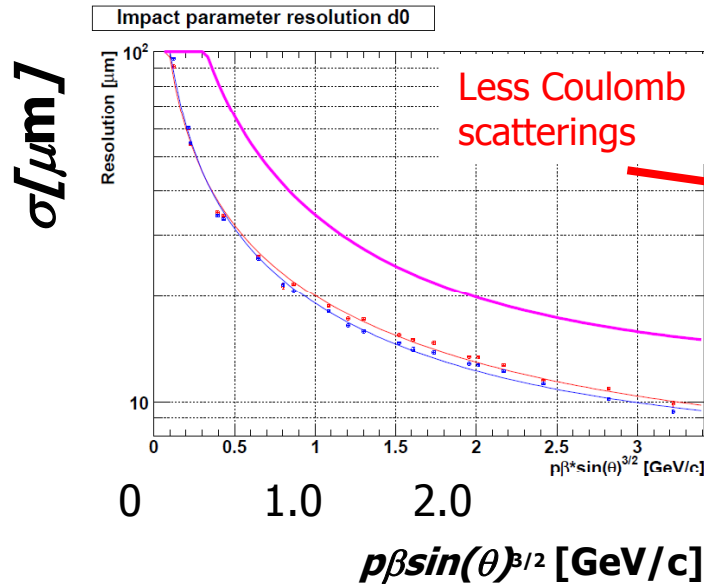
A prototype ladder using the first 6 inch DSSD from Hamamatsu has been assembled and tested.



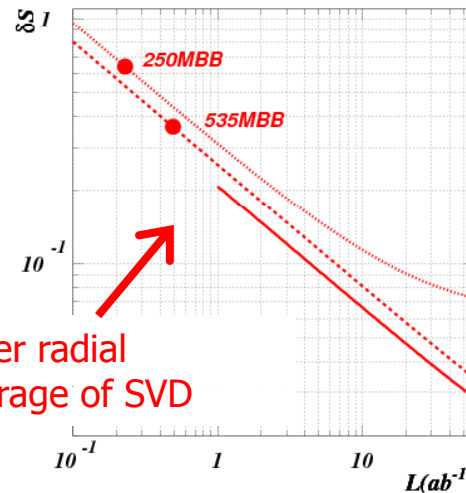
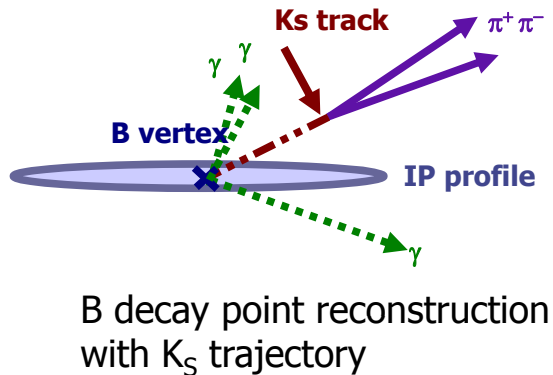
Expected performance

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

Significant improvement in IP resolution!



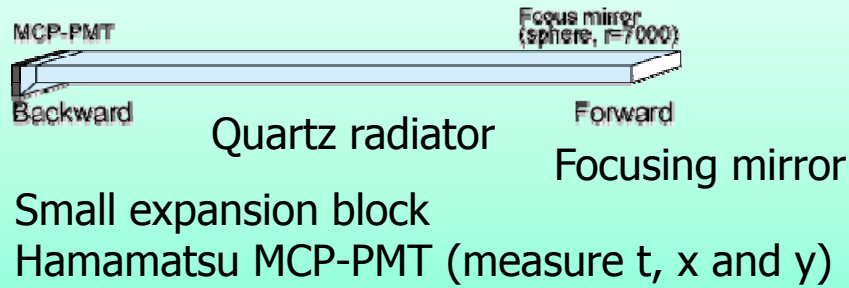
Significant improvement in $\delta S(K_S \pi^0 \gamma)$



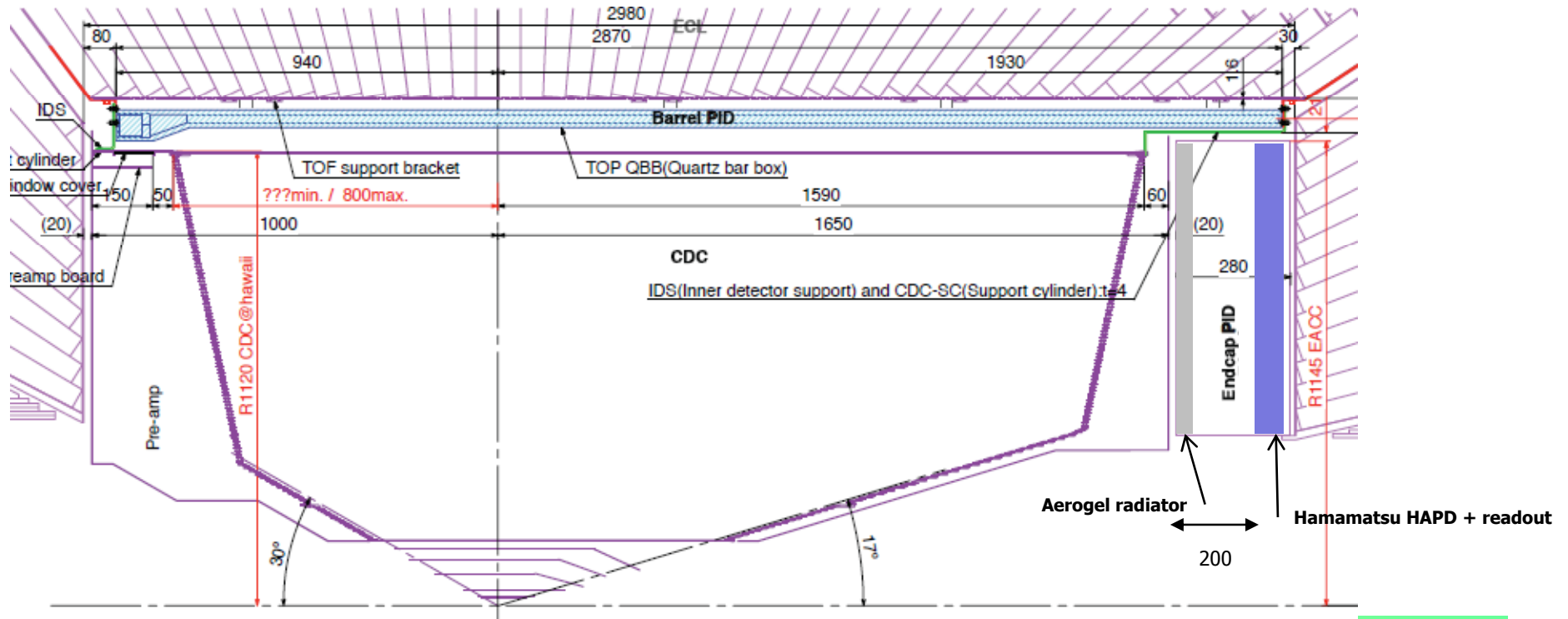
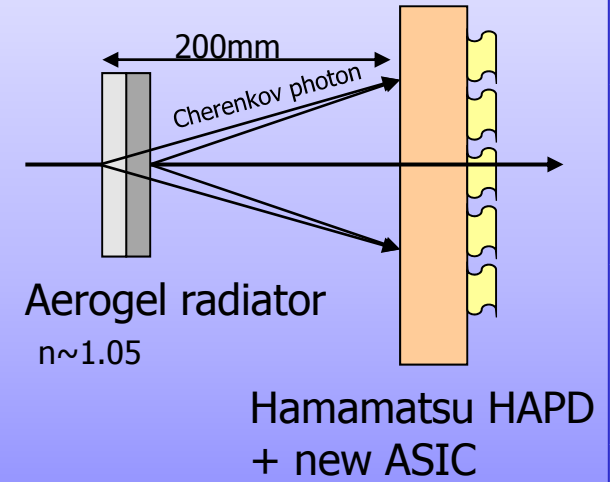


Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)

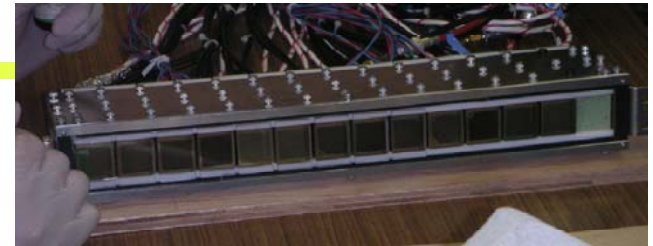
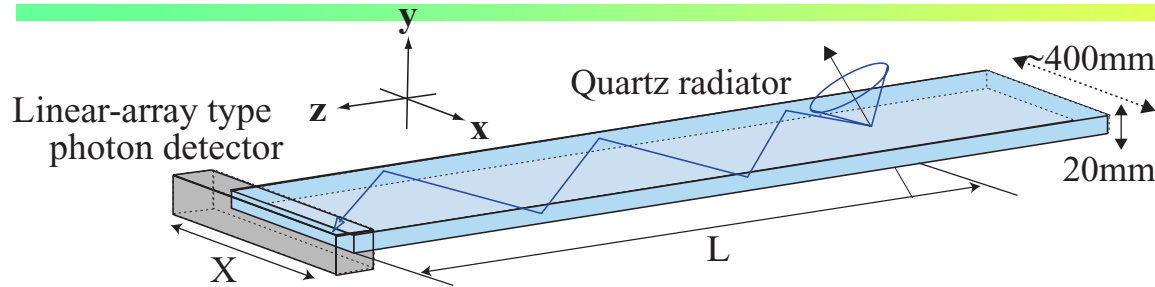


Endcap PID: Aerogel RICH (ARICH)

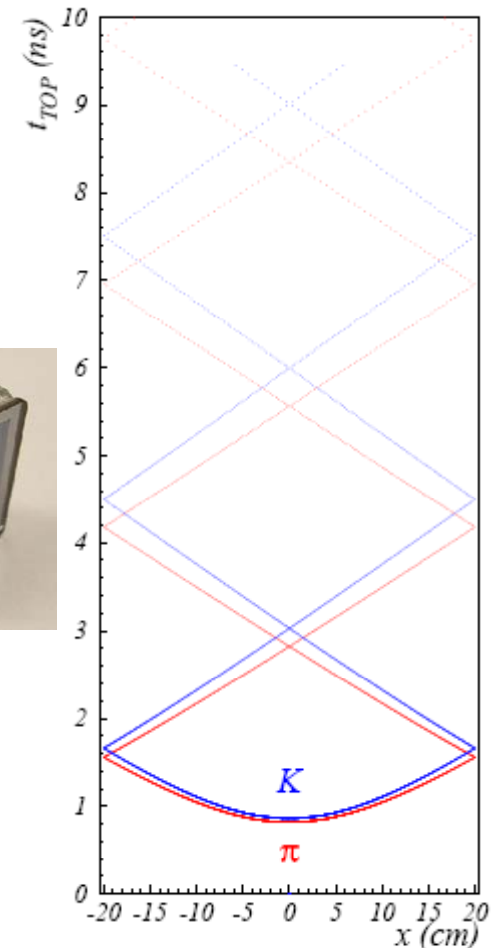
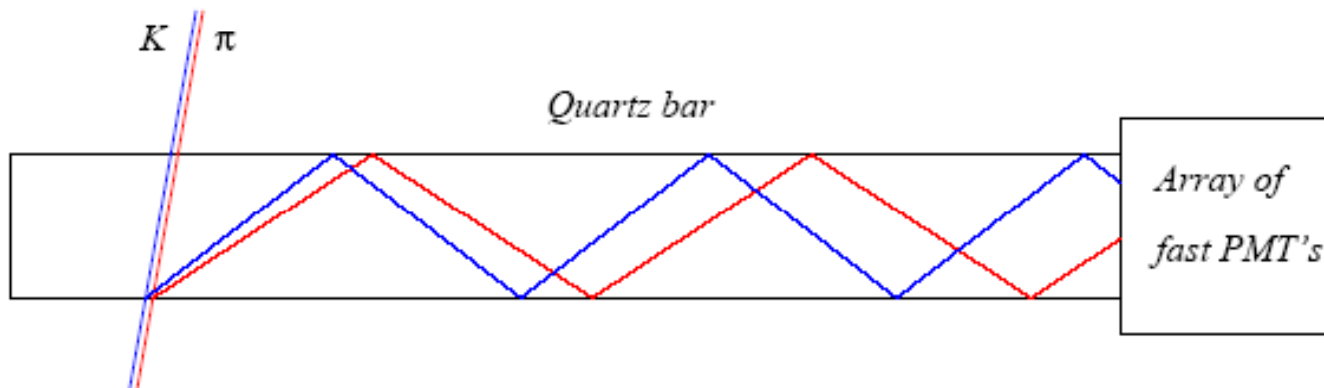
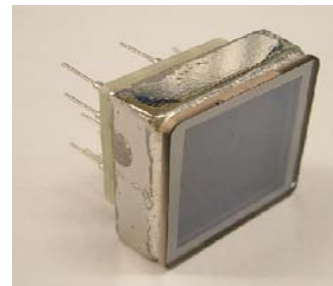


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Barrel PID: Time of propagation (TOP) counter



- 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

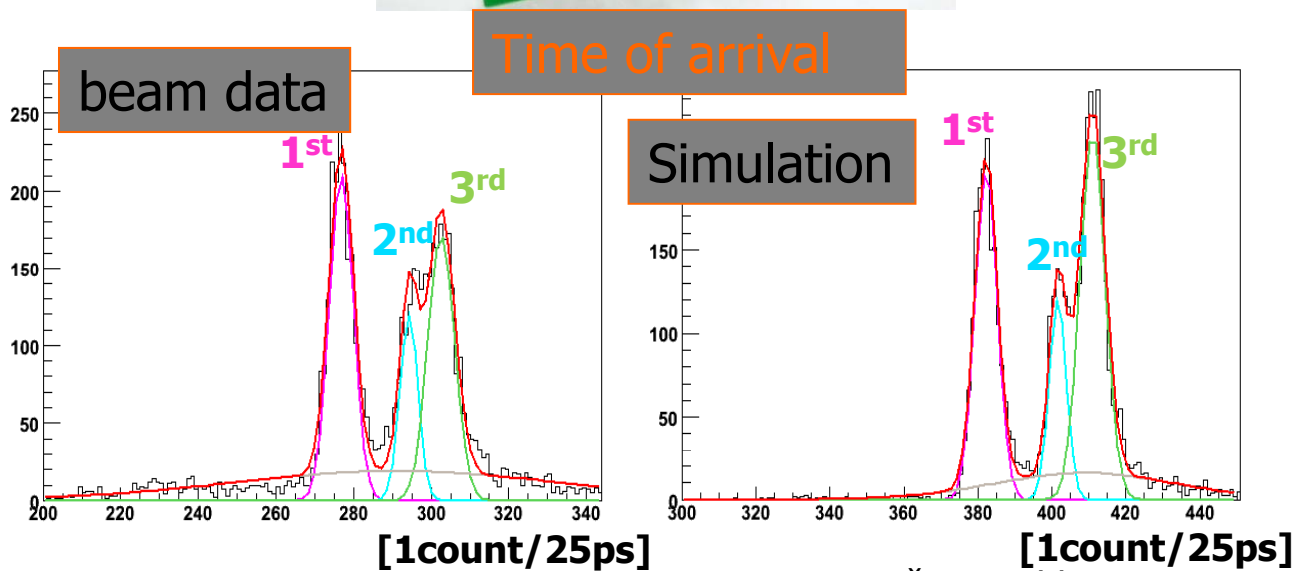
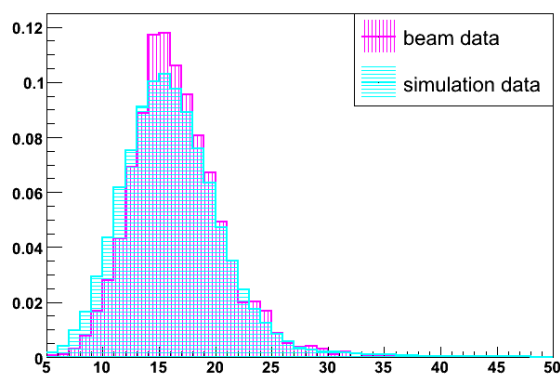
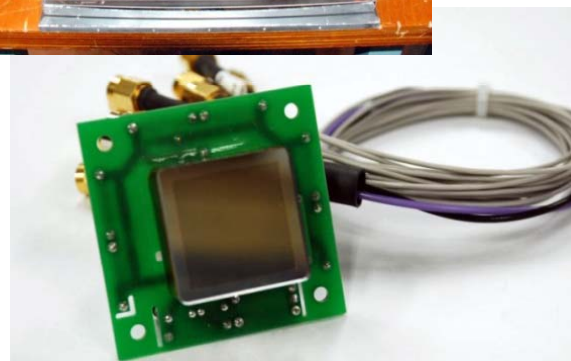
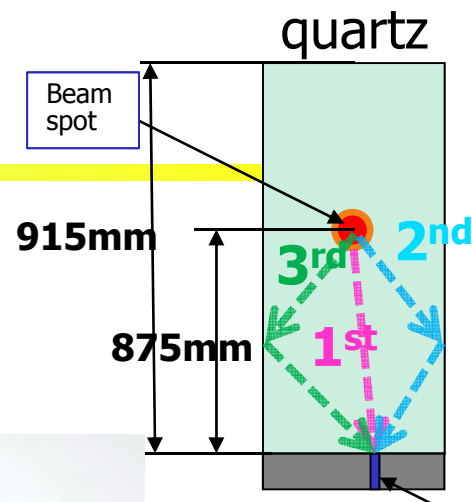


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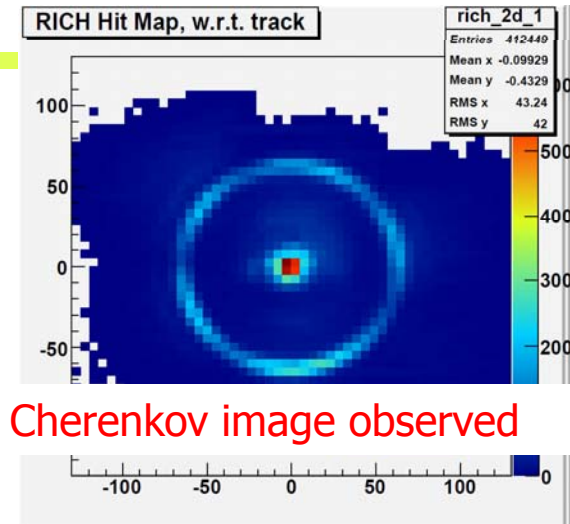
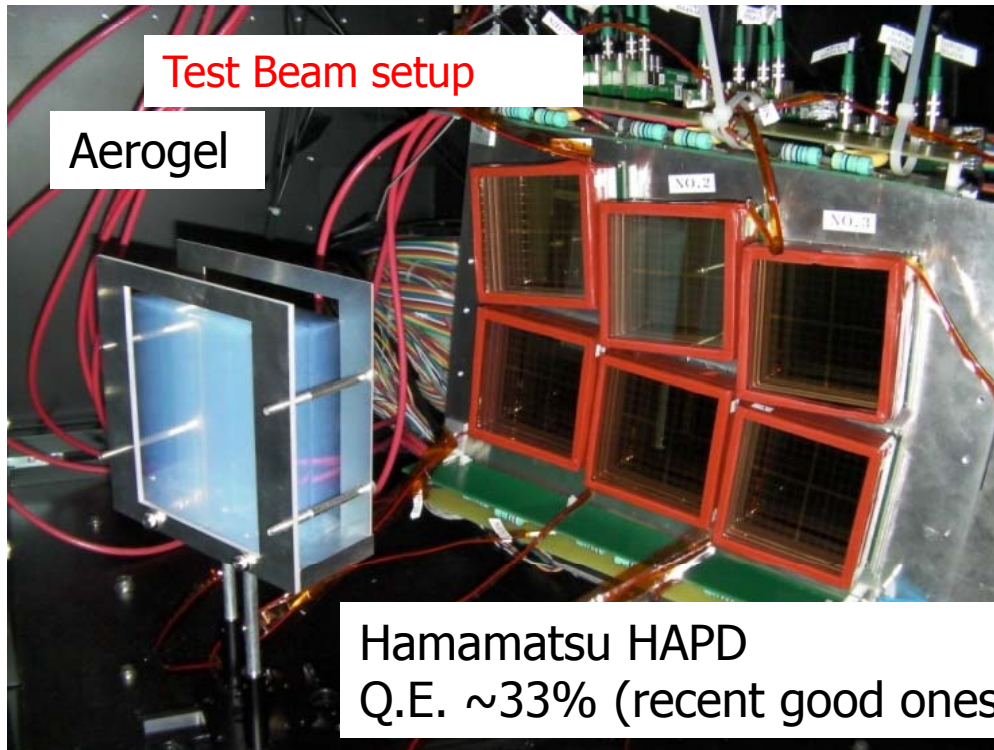
TOP (Barrel PID)

- 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



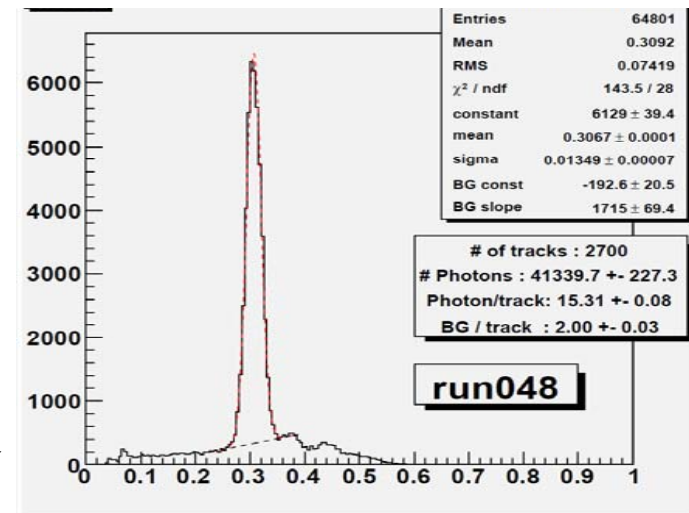
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Aerogel RICH (endcap PID)



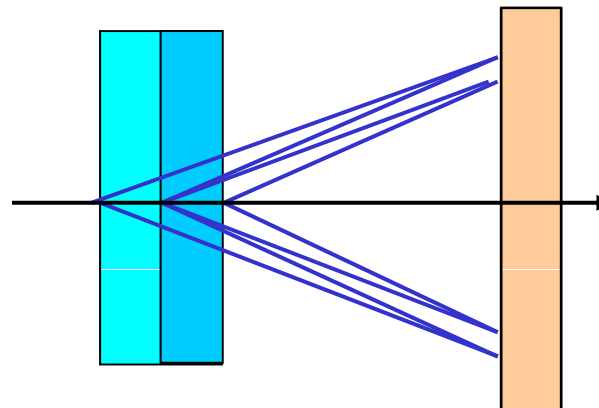
Clear Cherenkov image observed

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.



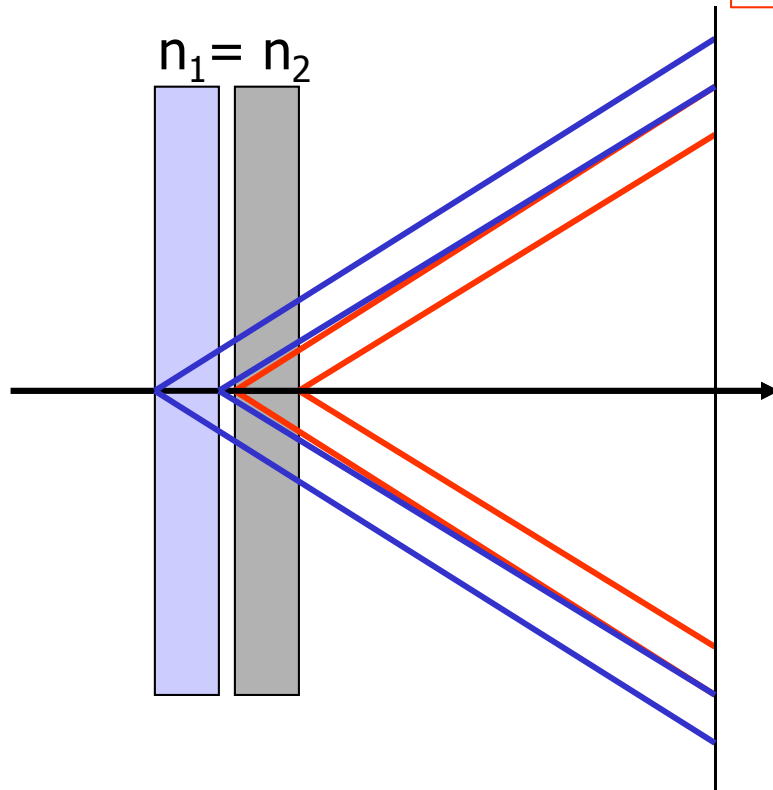
6.6 σ π/K at 4GeV/c!

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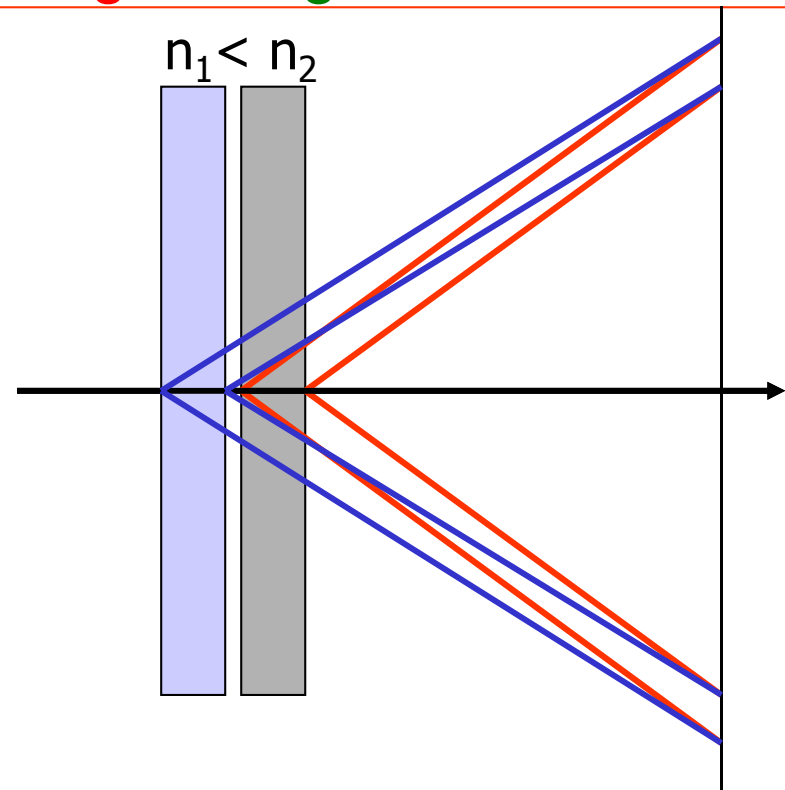
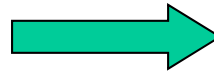
Radiator with multiple refractive indices

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

normal

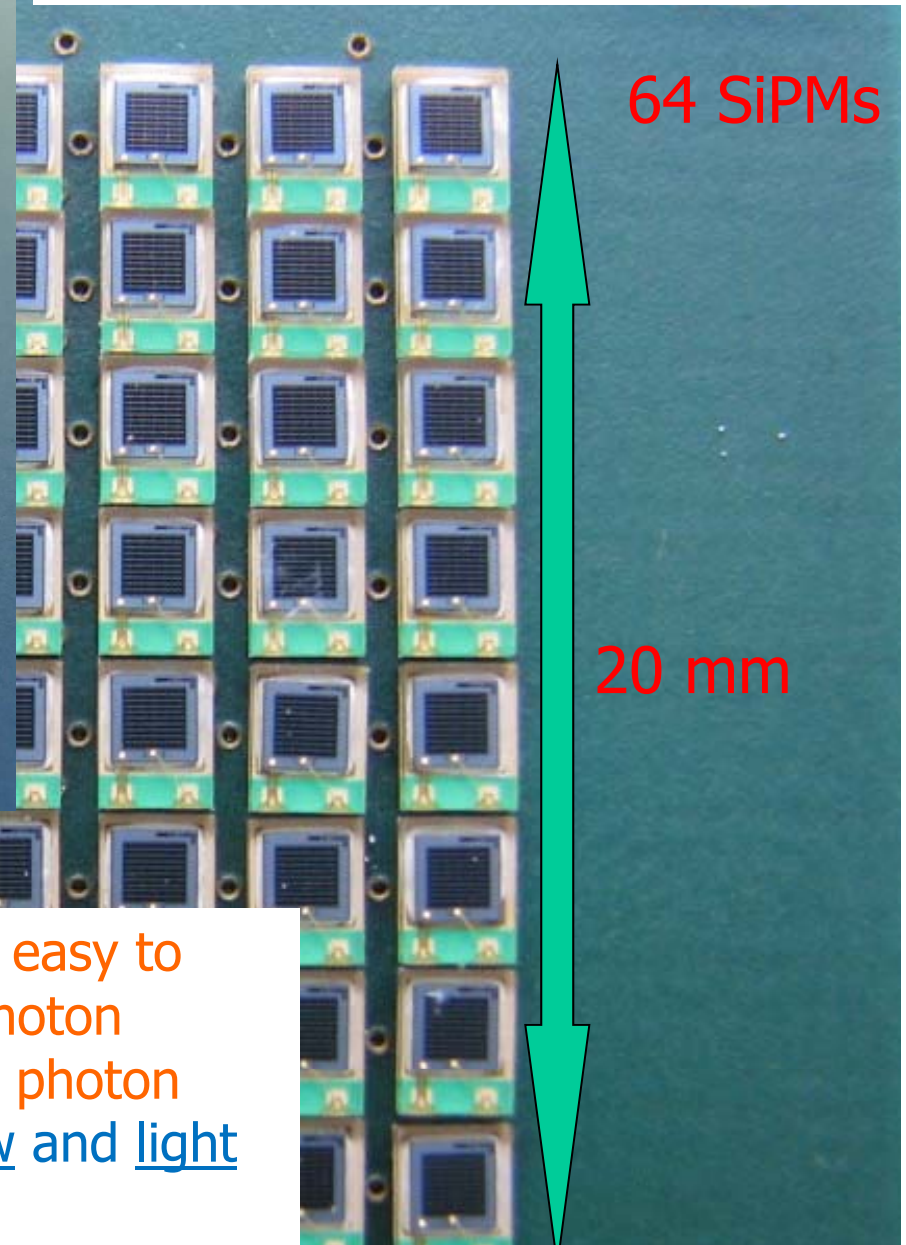
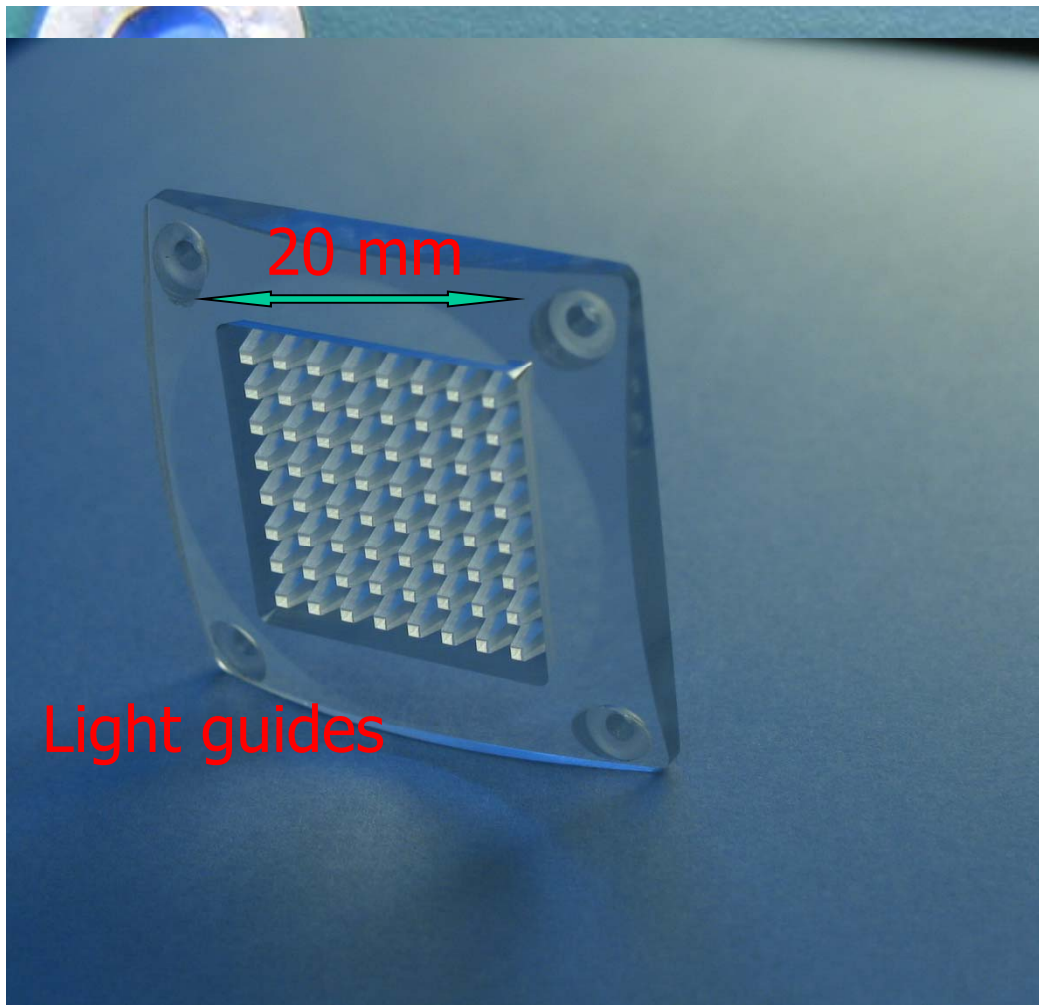


→ stack two tiles with different refractive indices: “focusing” configuration



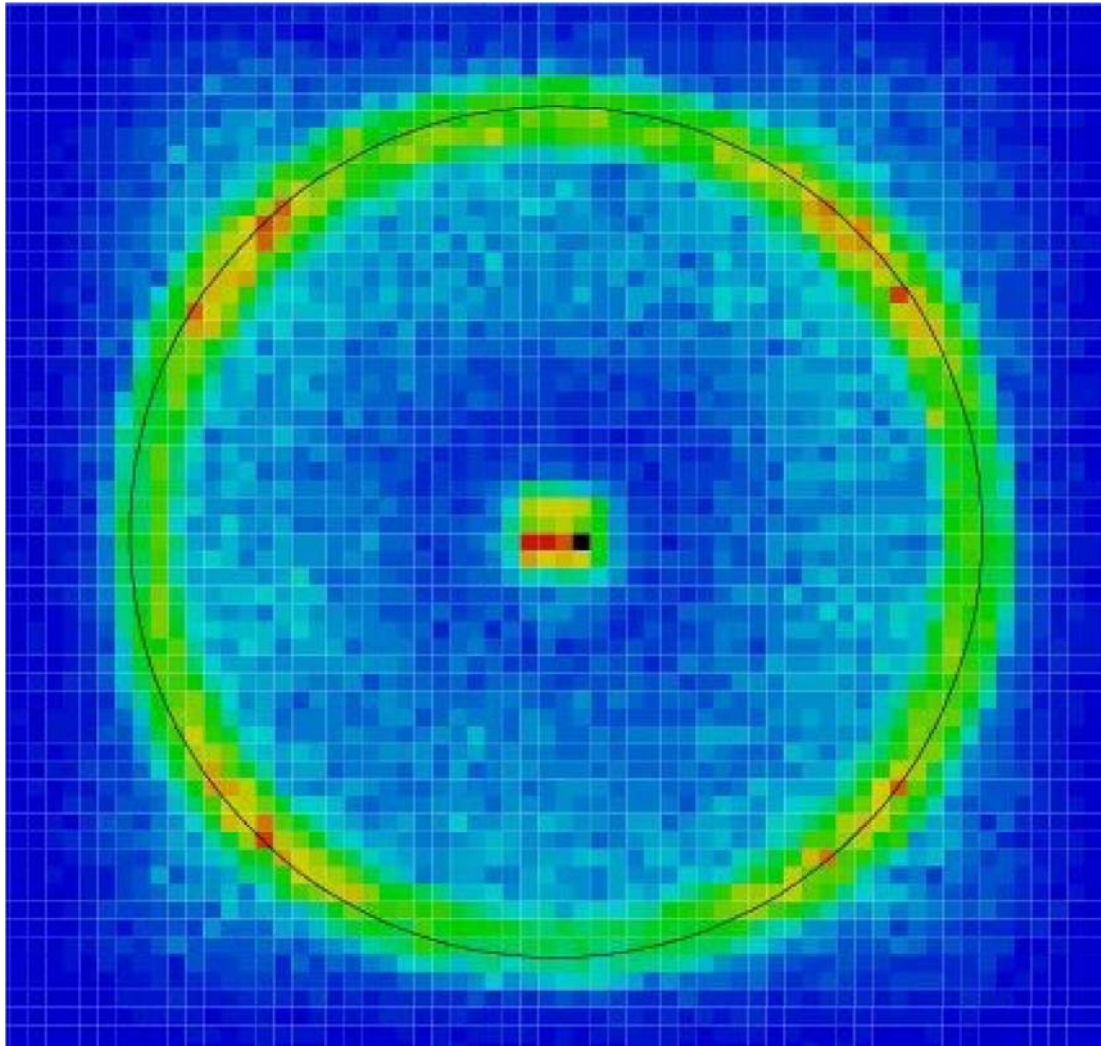
→ focusing radiator

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



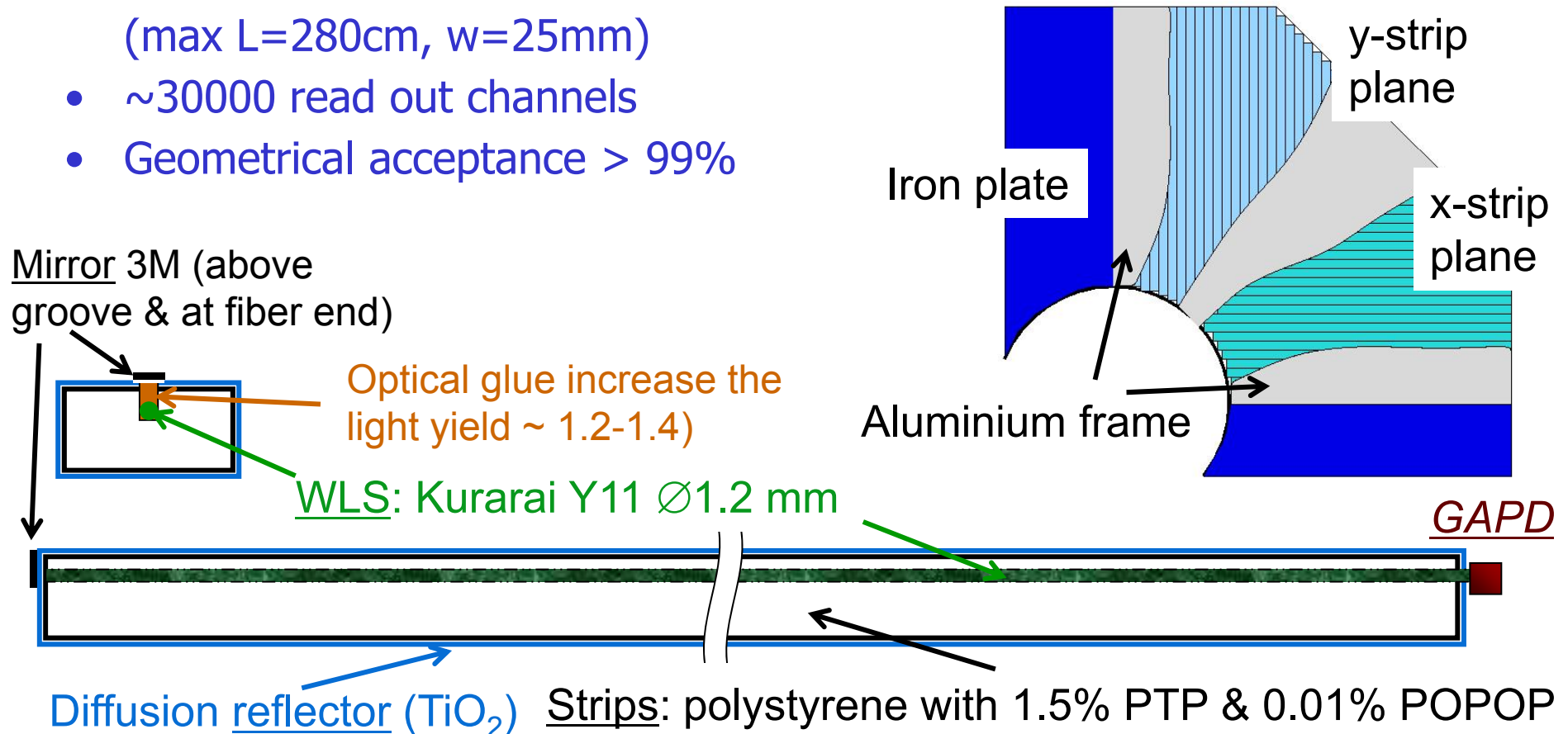
First successful use of SiPMs as single photon detectors in a RICH counter!

NIM A594 (2008) 13

KLM upgrade in the endcaps

Scintillator-based KLM (endcap)

- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- ~ 120 strips in one 90° sector (max $L=280\text{cm}$, $w=25\text{mm}$)
- ~ 30000 read out channels
- Geometrical acceptance $> 99\%$

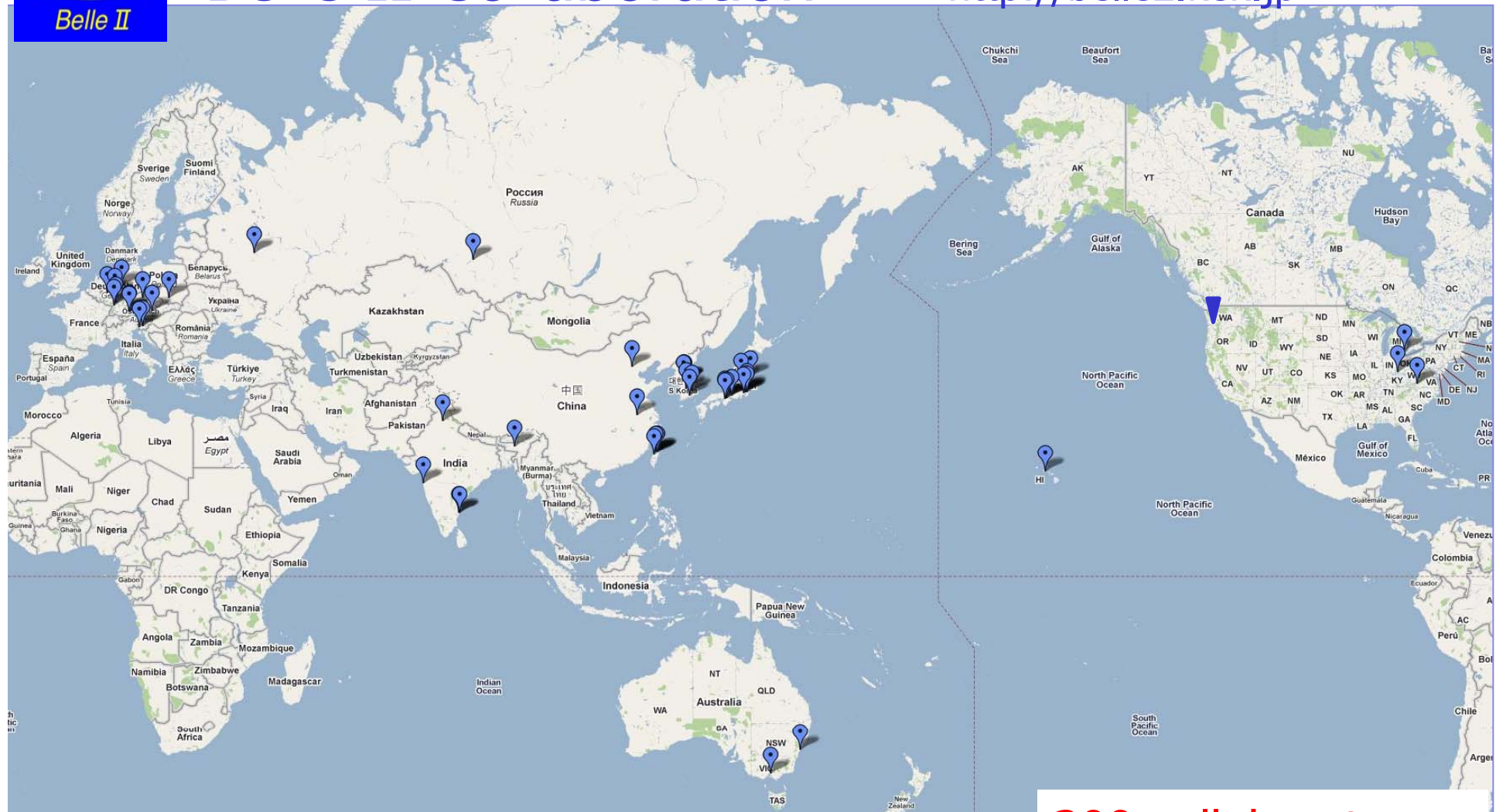


Status of the project



Belle II Collaboration

<http://belle2.kek.jp>



13 countries/regions, 54 institutes

300 collaborators,
>100 from Europe



European groups of Belle-II

- Austria: HEPHY (Vienna)
- Czech republic: Charles University in Prague
- Germany: U. Bonn, U. Giessen, U. Goettingen, U. Heidelberg, KIT Karlsruhe, LMU Munich, MPI Munich, TU Munich
- Poland: INP Krakow
- Russia: ITEP (Moscow), BINP (Novosibirsk),
- Slovenia: J. Stefan Institute (Ljubljana)

A sizeable fraction of the collaboration: in total >100 collaborators out of ~300!

Vienna in Belle and Belle-II

Vienna@Belle:

- Large impact in hardware (SVD, silicon vertex detector)
- Coordination of a very important analysis group (CKM, C. Schwanda)
- Important analyses (including measurements of the hot $D \rightarrow \mu \nu$ decay channel, measurements of V_{cb})

The Vienna group is contributing significantly to the Belle-II project:

- SVD, silicon vertex detector, much bigger than in Belle, subsystem leader M. Friedl
- Project management: C. Schwanda, member of the Executive board
- Software: reconstruction, calibration and analysis

Belle II is looking forward to a continuation of the excellent collaboration with Vienna



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!



KEKB upgrade plan has been approved

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

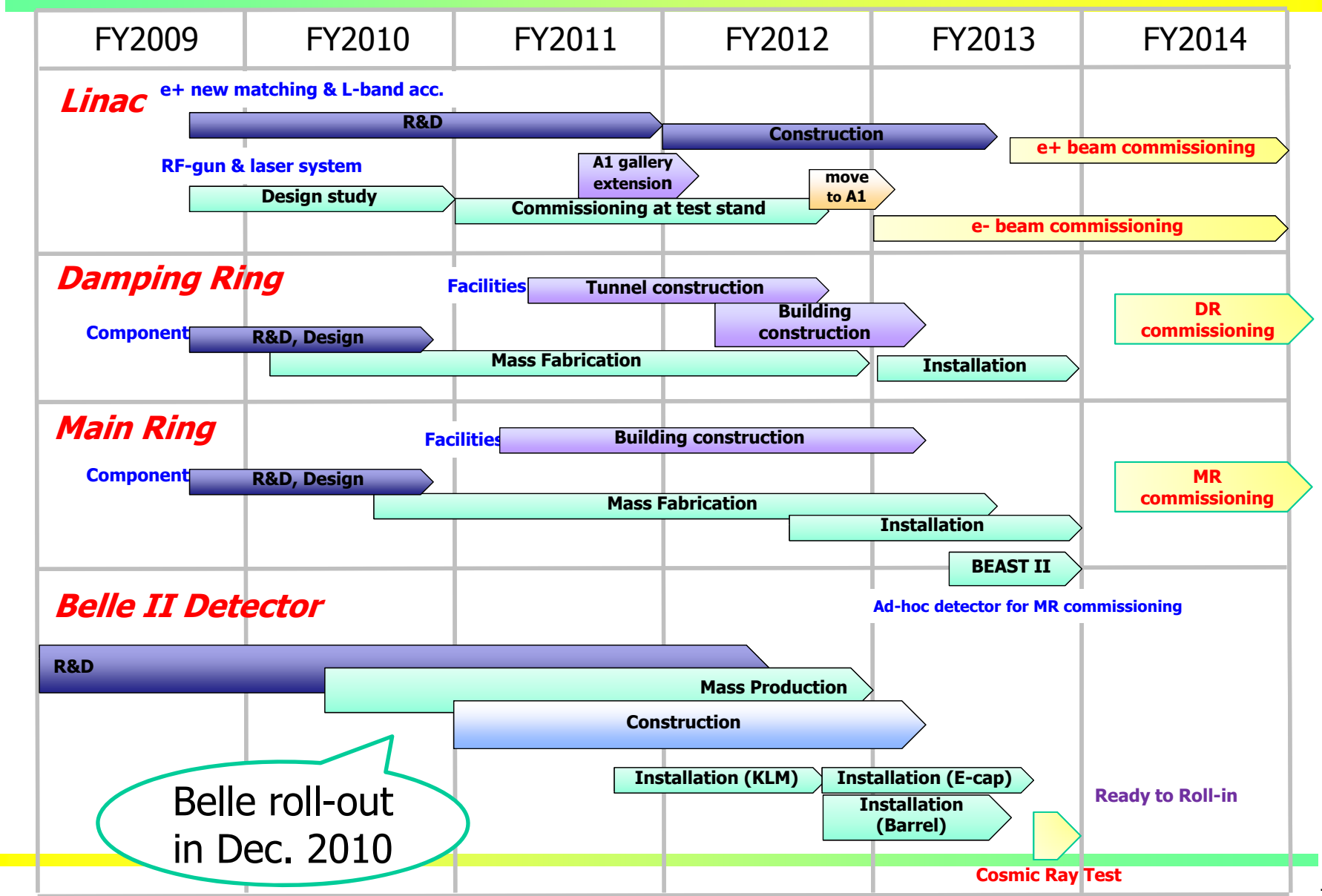
The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx \$110M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new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

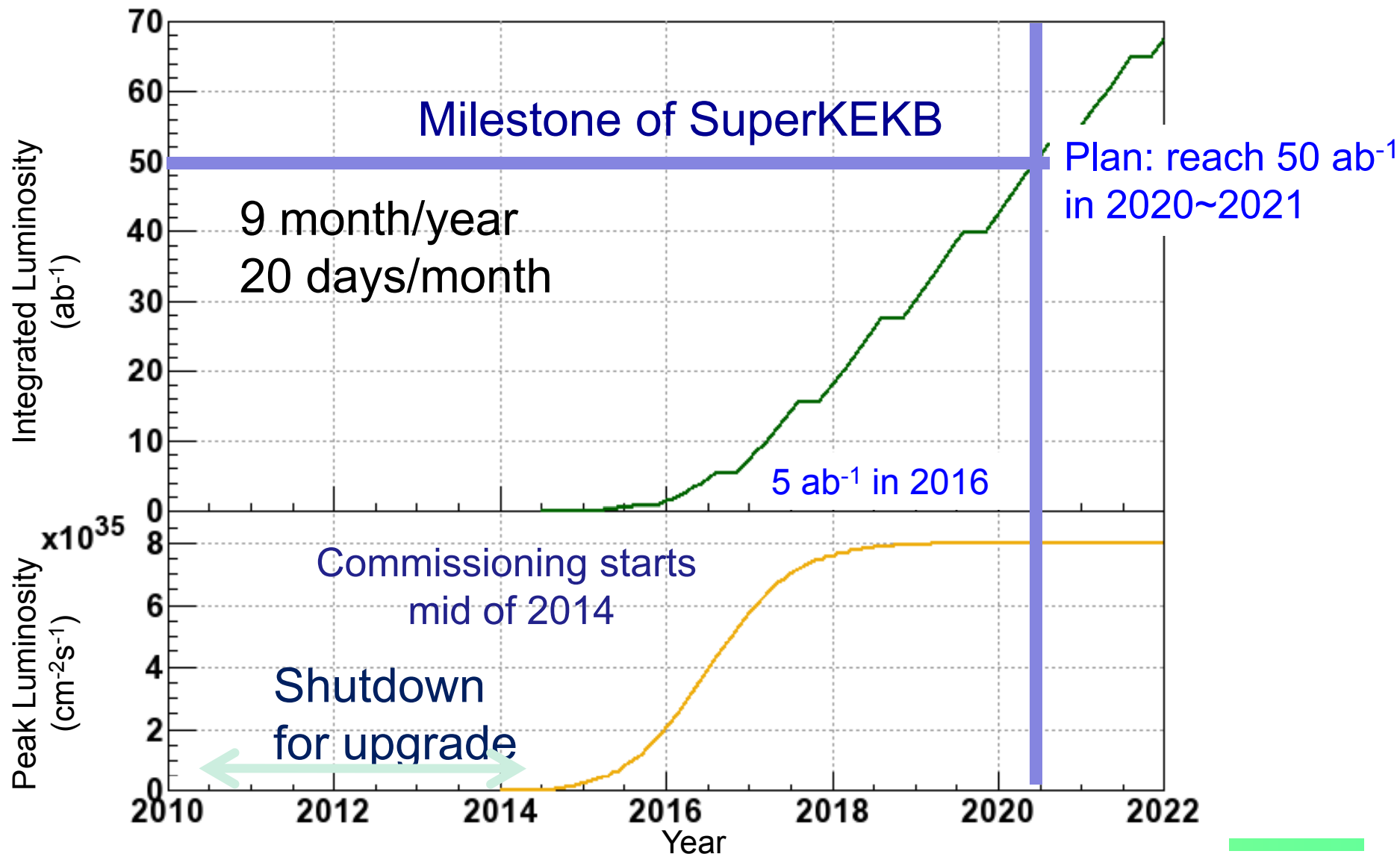
Jun. 24, 2010



Belle roll-out in Dec. 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 surpassing** design performance
- Major upgrade at KEK in 2010-14 → SuperKEKB+Belle II, **L x40, construction started**
- Physics reach updates available
- Expect a new, exciting era of discoveries, complementary to the LHC

